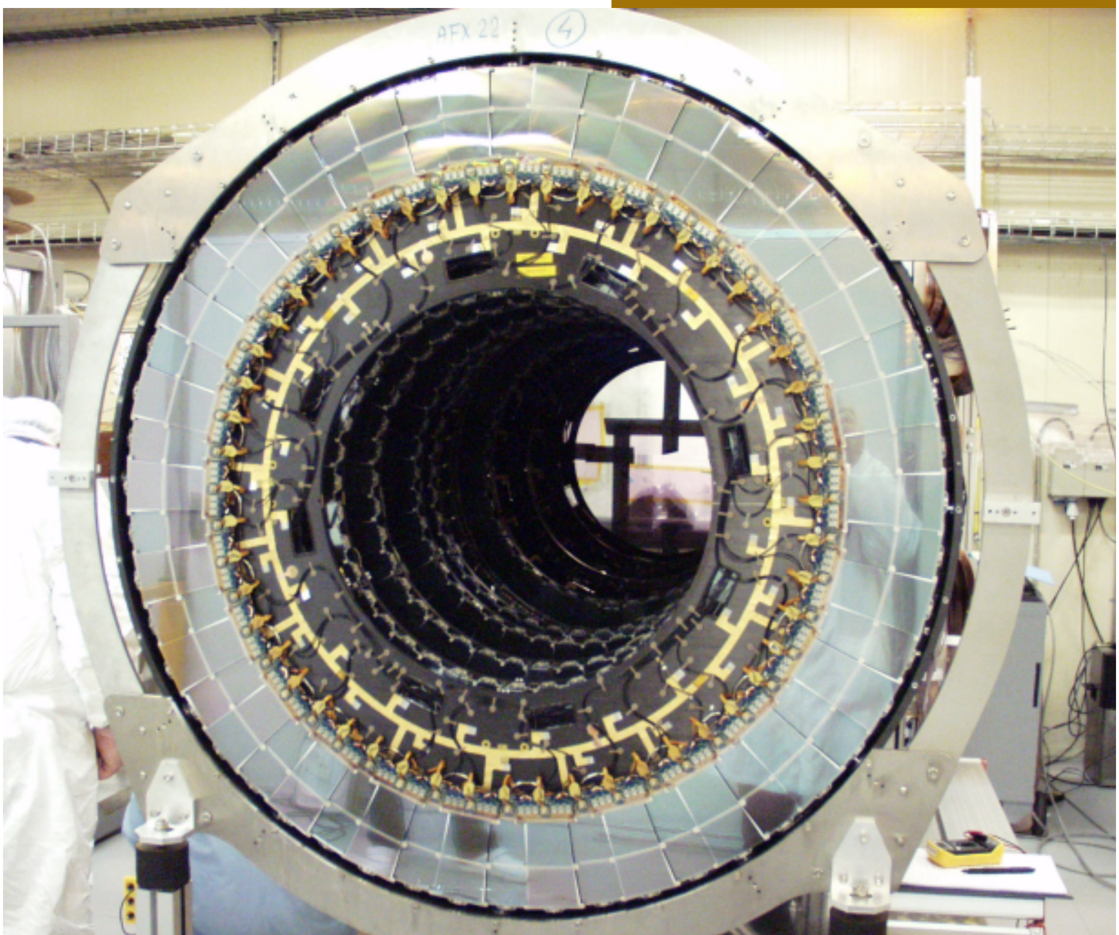
UNIVERSITY OF LIVERPOOL

2012

PARTICLE PHYSICS GRANT APPLICATION



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STFC
2/16/2012

APPENDIX 1 Research Programme

Liverpool Particle Physics Group Strategy

Introduction

The experimental particle physics programme at the University of Liverpool is dedicated to answering the most fundamental and highest priority questions in physics. Following years of anticipation and preparation, first data was delivered in 2010 from the LHC at CERN and from T2K in Japan. By early 2012, results with a significance of around 3σ for a light Higgs discovery and for a non-zero value of θ_{13} were already shaping discussions on the future of the field. Liverpool has had central roles in obtaining these results, and is ready to lead the detailed studies and new facilities that will go ahead if these are confirmed. Below we describe our physics strategy, our roles in experiments world-wide, and how we deliver our programme through a core team of physicists, engineers and technical staff.

The group is studying the origins of mass, searches for new symmetries, matter-anti-matter asymmetry in the universe and the nature of neutrinos. Using a range of techniques and facilities worldwide, we are searching for evidence of key, theoretically motivated, new physics (NP) phenomena. Our programme includes searching for signals of NP, both directly and indirectly, over-constraining the Standard Model (SM) and making the high precision measurements of the structure of matter. We are driving new experiments and accelerators, and expanding the breadth of our programme, to allow us to make world leading measurements. Our portfolio of activities is well aligned with established national and international priorities and the strategic objectives of STFC. The group strives for scientific excellence at the highest international level and our success is marked by our track record. We play prominent role, over a broad range of our activities, and promote UK science through leadership and outreach. A key enabler for our science is the detector R&D group. This is supported by the Liverpool Semiconductor Detector Centre (**LSDC**), which provides a world class facility for R&D, together with assembly and construction facilities, and our mechanical **workshop**. The Cockcroft Institute (CI) for accelerator science provides a substantial boost to our capabilities for future new experimental activities. The group benefits from collaboration with the Liverpool particle physics theory group through its lattice, supersymmetry and string phenomenology work.

Since our last report three academic members of staff have retired (**Fry**, **Houlden**, **Jackson**). The University has replaced one of these positions (**Kretzschmar**) and has offered long term support for two fellows on Royal Society and STFC fellowships (**Coleman**, **d'Onofrio**). We are actively seeking to expand the academic complement of the group to strengthen our core activities.

The group has contributed to national committees: STFC(Fellowships, PPGP, CERN UK Fellowships, IPS and CMS oversight), IoP(HEPP Group Chair and Treasurer/Secretary), and the Royal Society(Fellowships). Internationally we are represented at: CERN(SPSC, LHeC Steering Group, ECFA, CERN LHC M&O Scrutiny Group), Spain(CSIC Particle Physics Panel) and France (GDR Neutrino Scientific Council). The group has continued to act on the advisory and organizing committees of international conferences and has played key roles in the management of international collaborations including being elected to lead the upgrade of the ATLAS experiment.

Our longstanding programme of Knowledge Transfer/Industrial Engagement has continued to pay rewards back to UK plc. LHCb VELO technology partners, Hawk Electronics and Stevenage Circuits, are now in leading positions to supply the ATLAS Tracker upgrade with components and production services. The STFC PRD programme with e2v has placed the company in a position to compete internationally for large area silicon devices for ATLAS and LHCb. Our close relationship with silicon fabrication facilities includes continued joint development, with Micron Semiconductor, of novel detectors for health and security. We have secured funding (Royal Society, STFC) for developing neutrino detection associated with reactor activity – a programme that has been endorsed by the IAEA, and from the EU for neutron detection (FW7 Special Nuclear Materials call) We collaborate closely with the Liverpool nuclear physics group on medical physics applications of our sensor technologies.

Liverpool has lobbied hard for, and has been central to, the creation of a UK hybrid pixel programme. This has important implications not only for UK particle physics (ATLAS, LHCb) but also the UK's capability to deliver these devices for commercial benefit. Our composite materials programme, developed with UK companies, has provided state of the art structures for experiments on three continents and the only advanced composites currently installed at the LHC.

We communicate our programme through the press, radio and television. Short films, including one shortlisted for the 2011 NHK film festival (Japan), have also featured the Liverpool group. Importantly we continue to give lectures to the public and schools as well as arranging visits to CERN. The group has continued to run, and expand, its School CERN Summer Programme to introduce promising young scientists to Particle Physics.

ACHIEVEMENTS

COMPLETED PROGRAMMES 2009-2011

The group has brought to a conclusion its BABAR, CDF, H1 and LCFI programmes. These covered the searches for NP at the Fermi scale, Standard Model, Unitarity Triangle, *B* and *D* mixing, hadronic *B*-production, proton structure and future detector technologies. The major achievements for these programmes since October 2009 are listed below.

BABAR: We completed our programme with analysis of *D* decays and made measurements of charm mixing through lifetime measurements. We studied *D* decays to two light mesons (KK, $\pi\pi$, $K\pi$). Liverpool remains in the BABAR Speakers Bureau and convenes the HFAG charm group. Since Oct. 2009 we have 83 publications on the experiment.

CDF: Liverpool continued its involvement in the CDF experiment up to and beyond the end of data taking in 2010. Our work tested the predictions of QCD heavy quark production with publications on $Z+b$ jets and photon+b and c-jets. In addition we have reported results on a search for scalar bottom production. Since Oct. 2009 we have 104 publications on CDF.

H1: Since 2009 Liverpool has led the extraction of the structure functions (F_2, F_L, F_L^D, F_2^b) and a world known set of parton distributions (HERAPDF). The H1 data represent a basis for the development of QCD, for interpreting LHC data and physics with the LHeC. Approximately 40 papers have been published since Oct. 2009 on H1 (and ZEUS) by Liverpool authors.

LCFI: The Linear Collider Flavour Identification group, led by Liverpool, was brought to a conclusion with development of Column Parallel Readout CCDs. This technology remains a key part of the technical resource available to the UK, and will position the group well to contribute to a Linear Collider programme in the future.

ONGOING PROGRAMMES 2009-2011

Current activities are balanced between the exploitation of the LHC (ATLAS, LHCb), our neutrino programme at T2K, detector upgrades (ATLAS) and generic detector R&D. The R&D prepares the ground for our involvement in possible future experiments (LHCb upgrade, Laguna, LHeC) and underpins our application development. New activities include NA62 (quark flavour) and SNO+ (neutrinos). Our leadership and recent achievements include:

1. Major contributions and leadership in the search for the Higgs and SUSY in ATLAS.
2. Leadership roles in testing the SM through Electro-Weak (EW) physics at the LHC on the ATLAS and LHCb experiments.
3. Leadership in commissioning, maintenance and operation (M&O) of the LHCb VELO and construction of VELO2.
4. Establishing and securing funding for a UK hybrid pixel programme for ATLAS/LHCb.

5. Delivery, commissioning and recommissioning post-earthquake, of the T2K ND280 ECAL detector.
6. Leadership in the extraction of the first neutrino mixing results from T2K.
7. Leadership of the national and international ATLAS upgrade programme.
8. Securing substantial European (ERC) funding for the UK NA62 project.
9. International leadership in Silicon Detector R&D recognized by a group member becoming co-spokesperson of the RD50 collaboration.
10. Delivering one of the highest efficiency GRIDPP sites in Europe.
11. Continued leadership of the Large Hadron Electron Collider (LHeC) programme.

Physics Goals

The group aims to be a world leader in fundamental discovery, precision measurements and the development of technology for experiments that open new avenues for particle physics research.

Discovery

Our discovery programme focuses on the understanding of the origin of mass of elementary particles and for searching for new symmetries and particles.

If the existence of a Higgs in the 125 GeV region is confirmed, the measurement of its properties including spin and couplings will be a major undertaking. If not confirmed, we will need to understand what is responsible for regularizing the *WW* cross-section at high energies. Independently there is strong motivation to search for NP. Liverpool is dedicated to the long term exploitation of data from the LHC and extending its discovery potential through detector upgrades.

LHCb and NA62 provide indirect searches for NP through rare *B* and *K* decays, which have potentially higher reach than direct searches. Studying the differences between matter and anti-matter has been a long-standing priority for Liverpool, from CPLEAR through to LHCb, and we are committed to this for the short and medium term future.

A new TeV scale *ep* collider, LHeC, offers remarkable discovery potential for singly produced new states as occur in RPV SUSY. It enables the search for excited leptons and could provide important information on the CP properties of a low mass Higgs.

With the understanding that the quark sector cannot supply the mechanism for the observed matter dominance in the Universe the group has expanded its horizons towards a detailed understanding of the neutrino sector. Observation and measurement of neutrino mixing (T2K), elucidating the origin of neutrino mass through the search for neutrinoless double beta decay (SNO+), and the search for CP violation (LAGUNA-LBNO) are the short and long term objectives of the group. We are committed to expanding our neutrino activities.

Precision Measurements

The group has a detailed programme of measurements of the SM. We are involved in a major programme of understanding EW physics at the highest possible energies and we maximize our phase space coverage by exploiting both the ATLAS and LHCb detectors. The measurements from both experiments will contribute to a detailed understanding of the proton structure. In the longer term the group is driving the LHeC programme which is set to discover new, non-linear laws of parton evolution related to ultra high-energy neutrino scattering. It also aims to study quarks and gluons in the highest mass region of the LHC. where new particles and phenomena would be expected to reside.

Detector R&D

The major enabler for our medium and long term physics is our R&D programme. This is focussed on developing the technologies that permit new generations of experiments to be built at lower cost, and with greater physics potential than currently available. We highlight three major areas aligned with our physics goals: radiation tolerant planar silicon sensors, advanced materials for thermo-mechanical structures and the development of liquid argon (LAr) tracking detectors for neutrino detection. The group has seeded additional activities which have the potential to make a major impact on its science programme in the short to intermediate term: the utilisation of GPU processing and the development of new experimental techniques to detect Dark Energy (DE). Our R&D programmes drive application developments in medical physics and homeland security.

Core Group

We present to the PPGP a strong and balanced core group. The team is composed of academic members with international standing and highly qualified and expert core staff complemented by our exceptional facilities(**LSDC**, **workshop**). We aim for continuing growth and leadership building on our international reputation. The core group's deployment is summarized in Table 1.

	Experiment	**Activity**	Acad & Fellows	Phycicists	Programmers	Eng. & techs	Support	**CORE GROUP 2012**
LHC	**ATLAS**	Energy Frontier: Higgs, Direct Searches for NP and Precision tests of the SM	8					**Allport, Burdin, Kretzschmar, M. Klein, U. Klein, Mehta, D'Onofrio, Vossebeld**
				4				**Dervan, Hayward, King, Maxfield**
	LHCb	Indirect Searches for NP Precision tests of the SM	3					**Bowcock, Hutchcroft, Shears**
				2				**Patel, Rinnert**
SPS	**NA62**		2					**Dainton, Fry**
J-PARC	**T2K**	ν physics and LAr R&D	3					**Coleman, McCauley, Touramanis**
SNOLAB	**SNO+**			1				**Payne**
	RD50 Si R&D	future LHC detectors		3				**Affolder, Casse, Jones**
	CTA	Astro-Particle	1					**Greenshaw**
All projects		Computing			2			**Bland, Fay**
		Design & engineering				8		**Carroll, Greenall, Muskett, Smith, Sutcliffe, Tsurin, Whitley, Wormald**
		Administrative					**1**	**Fielding**
TOTAL EFFORT			17	10	2	8	**1**	

Table 1: Staff deployment within the Core Group that totals 38 people. Staff members share their research time on more than one project; they have been grouped here according to their main proposed activity for simplicity. Computing, design and engineering effort is shared across all projects and is indicated by the hatched shading above. See Form-X for details.

The spread of STFC supported core effort requested in the grant is summarized in Figure 1. The largest fractions proposed are for ATLAS and its upgrade (47%), which is supported by our world leading Si detector R&D (9%). The LHCb and upgrade (19%) and our neutrino activities and associated R&D (11%) together account for about 1/3 of the total requested core effort. We propose to invest a modest effort (~4%) in new future activities including NA62, LHeC and CTA. The remaining effort (9%) is for the computer support that underpins all our activities (6%) and for the general administration of finances(3%) required to maintain this group.

In Figure 1 we present the current and proposed complement of core staff. The continuity and evolution of our programme can be seen (Figure 2). Our first priority is the exploitation of ATLAS and preparation for the ATLAS upgrade. The dip in projected LHCb core funding reflects the drop in engineering and technical effort, although effort for maintenance and replacement of the VELO is still requested. The LHCb upgrade, although endorsed by the LHCC, has not yet been fully approved by STFC and we expect to bid for more effort from the PPRP. Our neutrino programme remains constrained by the available manpower. The LHeC initiative, led by Liverpool, will pass through decisive review during this grant period. We state our intention to play major role in leadership of the programme and its detector R&D. If approved at CERN we will seek further resources from our University and STFC. We reemphasize that our ability to contribute and lead major experimental initiatives (ATLAS upgrades, LHCb Upgrades, Future Neutrino experiments and LHeC) is contingent on having a world class core team.

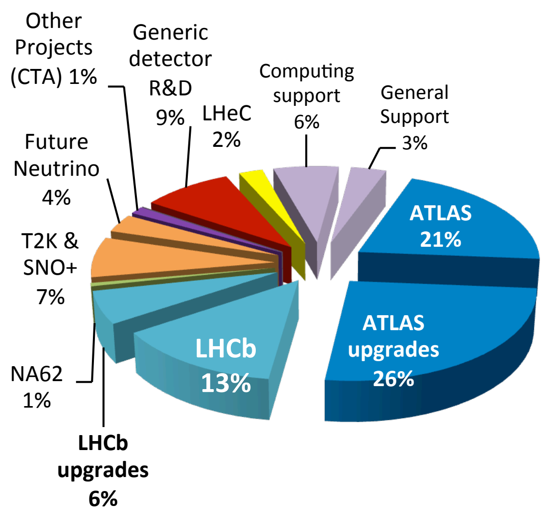

Figure 1: Fraction of STFC funded Core effort requested against activity for 2012-2016. Data from Form-X.

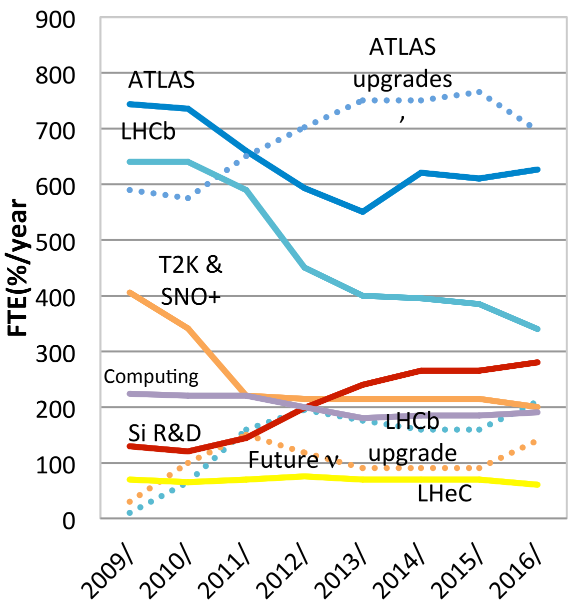

Figure 2: Core STFC funded effort from 2009 to 2012 and request from 2012 to 2016. For clarity smaller activities have been removed. See Form-X for details

The STFC core is complemented by responsive mode posts that are shorter term and project based. These are important for the training of the younger generation of physicists as well as for the delivery of our science programme. We are bidding to continue all the responsive posts but wish to convert one of these (**Huse**) to a core position. We also request six new responsive posts. See Form-X and the experimental and personal cases in Appendix 1 and Appendix 2, respectively, for more details.

Programme Management

The group is run by a management team that includes the PI, a deputy, and representatives from the staff and group members responsible for: operations, R&D, communications, training and finance. Its goal is to ensure maximum efficiency in the deployment of STFC resources and to meet STFC agreed milestones. At the same time it aims to enhance transparency and widen ownership of the programme. We constantly strive to provide support, training and opportunities for the core group as well as students and younger members of staff. An Operations Team oversees the day to day allocation of computing, **LSDC** and **workshop** resources. An oversight committee of the senior Particle Physics academics provides strategic guidance and receives financial reports.

Programme Summary

Physics at the LHC

ATLAS: In the previous grant period ATLAS made a huge and successful step from the preparation for beam operation to more than 100 journal publications. The allowed mass range of the Standard Model Higgs particle has been narrowed from several hundreds of GeV to a 15 GeV range, with tantalising hints at about 125 GeV. Improved search limits of around 1 TeV have been set on SUSY particles masses and other exotic particles as sequential vector bosons or monopoles. Tests of the SM have been performed on *W*,*Z*, jet and top production in an extended kinematic range with high precision. The group plays a major role in all these physics areas. The detector, including the SCT Endcap built at Liverpool, has functioned at efficiencies close to 100%. The LHC promises to triple its luminosity at higher energy in 2012 and to restart at nominal beam energy in 2014. At the end of the new grant period, the LHC will have reached its design energy and delivered nearly 50 fb^{-1} of luminosity. We are proposing to consolidate our analyses on Higgs, SUSY and the SM from 2012-2016. We request two new RAs to strengthen our physics programme.

LHCb: The VELO was the key Liverpool deliverable to LHCb and is central to the whole LHCb physics programme. The group fulfilled its objectives of making the transition from heavy construction to commissioning the detector with data and making its first physics studies with leptons. The group is now bidding to allow it to exploit the potential of the detector in two major areas. First it will continue to drive the programme of EW physics it initiated and leads and which provides important input to the LHC EW working group. These studies will be extended to top production using *b*-jet algorithms being pioneered by the group. Secondly we wish expand, and strengthen, our existing B_s studies to permit the group to make contributions to CP measurements at LHCb. We are requesting one new RA on LHCb for this activity. The group retains an important ongoing responsibility for operation of the VELO and is bidding to continue this role. Furthermore it has built the replacement VELO. We ask for resources to prepare for the insertion of this detector and to allow its rapid deployment in case of VELO becoming damaged. The major thrust of our activities will remain firmly fixed on exploitation and expansion of our physics programme on the existing detector.

Quark Flavour Physics beyond the LHC

NA62: This experiment extends our involvement in quark flavour physics. Its aim is to search for NP through the study of extremely rare kaon decays. This activity is funded by the ERC. The group will join the analysis effort measuring the rare decay $K^+ \to \pi^+ \nu\nu$. Our technical efforts will focus on upgrading the CEDAR Čerenkov detector to provide enhanced kaon tagging. We are requesting one senior RA on NA62.

Neutrino Physics

T2K: In 2010 the group delivered and commissioned the six largest modules of the T2K ND280 calorimeter (ECAL) which represent 75% of the full detector. Since then it has concentrated on data reconstruction and analysis. It had leadership roles in the extraction of the T2K first indication for a non-zero θ_{13} and the ν_μ disappearance result in 2011. The group is bidding to continue and expand its physics programme in the following key areas: the measurement of the ν_e flux, measurement of the neutrino interaction cross-sections in the near detector and the global fitting of neutrino oscillations. The group will analyse the full T2K data sample, expected to reach 10^{21} protons on target by 2013, yielding a 5σ result for θ_{13} at the current fit best value. We will also focus on preparations for anti-neutrino running starting in 2014, aiming to improve precision on anti-neutrino oscillations and to seek possible evidence for CP violation in the lepton sector. We are bidding to

SNO+: Some of the most important questions in the SM hinge around the nature and mass of neutrinos. With SNO+ the group aims to search for neutrinoless double beta decays. The experiment aims to determine if there is evidence for neutrinos being Majorana particles (i.e. their own antiparticles) and shed light on what determines the mass scale for neutrinos. This activity complements the Liverpool T2K programme and secures the group's presence on all frontline neutrino experiment areas. Currently carried out by one academic, we are bidding for one RA to support and extend this activity.

LAGUNA-LBNO: Whilst T2K and SNO+ cover measurements of the PMNS neutrino mixing matrix parameters and the search for the origin of neutrino masses respectively, the next big questions to be answered in neutrino physics are the determination of the Mass Hierarchy (MH) and the search for CP violation. LAGUNA-LBNO is a design study for a large European underground laboratory for proton decay and neutrino astrophysics. It proposes to use a CERN neutrino beam to study MH and search for CP violation. It is one of the ASPERA Roadmap "magnificent seven" infrastructures for Europe and is funded through a €4.9M EU FP7 grant. Excluding CERN, the UK is the largest beneficiary country, with €1.2M of which €724k goes to British engineering companies. The Liverpool neutrino group plays an important role in the ~50 institutes consortium with leadership roles and responsibilities in the conceptual design and optimisation of the near detector, as well as the long-term operation of the giant LAr far detector option. The immediate aims are to provide input to the European Strategy process and to continue with a Conceptual Design Report towards a facility that could be in construction in the second half of this decade.

Detector Upgrades and Development

ATLAS Upgrade: To be able to operate with the very high track multiplicities and to withstand the associated radiation levels, this programme requires ATLAS to build a completely new tracker. This must be available for complete testing and commissioning on the surface in 2020 for installation during the 2021-22 long shutdown to install the accelerator upgrades required to deliver the HL-LHC.

LHCb Upgrade: The group has supported and contributed to the LoI for the LHCb upgrade due to be installed in 2018. The group is collaborating on the development of strip and pixel detectors for the VELO upgrade. The UK hybrid pixel programme (ATLAS, LHCb) is of strategic importance to the UK. We request limited resources, about 20% of the total group effort on LHCb, to continue to develop cooling and contribute to the construction of LHCb prototype modules. The group will request further resources, with the other UK groups, from STFC for the LHCb upgrade for the construction and testing of upgrade modules and to prepare for physics with the new detector.

Neutrino Detectors: The next round of long-baseline neutrino experiments will require extremely powerful neutrino beams and huge underground detectors. In the US Liquid Argon (LAr) is the technology of the MicroBooNe detector under construction at FNAL and has been selected as the technology for the LBNE far detector. LAr is one the main technology considered in Europe (LAGUNA-LBNO) and one of the options in Japan (Tokai-to-Okinoshima). As early as 2008 Liverpool decided to invest in LAr R&D with University funds. We have designed, constructed in-house and commissioned a large 250 l Argon bath with an inner 40 l chamber and our own novel liquid recirculation and filtering system which allowed us to present and publish first results in 2011. We are partners with established leaders in the field (ETH Zurich) and other strong collaborators (Saclay), working with them at CERN and in house. Combined with our LAGUNA-LBNO participation, we aim to be major contributors to the construction of a very large detector in Europe or elsewhere. In the short term the group will demonstrate ionisation charge drift and detection in our chamber and perform the characterisation of new types of micromegas detectors working with Saclay, followed by exploration of novel ideas for charge-through-imaging readout in collaboration with RAL-PPD. The group is a member of the RE18 LAr programme at CERN. We are involved in high-level discussions for a European LAr R&D facility at CERN as a basis for the CERN-to-Pyhasalmi project and/or possible European participation in LBNE or a smaller LAr project linked to the NOVA experiment which is currently under discussion.

Future Accelerators at the Energy Frontier

LHeC: The LHeC is a Liverpool led project at CERN for complementing the LHC physics programme. Recently, a comprehensive design report has been delivered, which was commissioned by CERN, ECFA and NuPECC from 2008-2011. The report covers the physics programme, a detector design and the accelerator concept and system. As presented by the CERN accelerator director (S. Myers) at EPS2011, LHeC could be installed in the 2020 shutdown of the LHC. The LHeC is designed to perform Deep Inelastic *ep* and *eA* Scattering (DIS) experiments at 1.3 TeV c.m.s. energy. It uses a new 60 GeV electron beam providing a 100 times higher luminosity compared to HERA, based on a design luminosity of $10^{33}cm^{-2}s^{-1}$ and synchronous *pp* and *ep* operation. The physics programme is for NP at the TeV scale including: the Higgs, unique precision

QCD and electroweak measurements, the first full mapping of the quark and gluon contents of the proton, the measurement of nuclear parton distributions over a hugely extended range and for the discovery of the saturation of the rise of the gluon density at small momentum fractions of the nucleon. The detector is designed for high precision, full acceptance DIS physics, and it requires a collaboration of about 500 physicists to build and operate. The accelerator is most likely to be an energy recovery linac of racetrack configuration, using ILC type cavity techniques in continuous wave mode, as used by the XFEL at DESY and the SPL at CERN. The LHeC report will be submitted for publication in spring 2012. The LHeC is part of the road map of NuPECC and is under review by ECFA. The next steps include the development of dipoles at BINP Novosibirsk and at CERN and the development program of the other components at CERN. The physics case, the detector and accelerator concepts have been developed and coordinated by Liverpool with important contributions to the accelerator optics by the Cockcroft Institute.

Astroparticle Physics & Dark Energy

CTA The Čerenkov Telescope Array (CTA) is a global £185M effort (>25 nations, >700 scientists) to deliver northern and southern observatories for photon astronomy at the highest energies (~10 GeV to ~300 TeV) using the atmospheric Čerenkov technique. CTA will dramatically improve on all aspects of performance with respect to the highly successful current generation of Čerenkov telescopes (HESS, MAGIC, VERITAS). CTA will survey the sky ~200 times faster than any current instrument, have the best energy flux sensitivity and angular resolution of any instrument operating above the X-ray band and will outperform the Fermi satellite by 4-5 orders of magnitude in sensitivity for sub-minute-timescale transient phenomena such as gamma-ray bursts. The project combines guaranteed scientific return, in the form of precision very high-energy astrophysics, with considerable potential for major particle astrophysics discoveries. The breadth and depth of the CTA science case has made it a key project in the field of particle astrophysics: it is included on the ASPERA, ASTRONET and ESFRI roadmaps and has been recommended by the STFC Particle Astrophysics Advisory Panel. CTA is currently in an EU supported preparatory phase with construction envisaged from 2014 to 2020. UK groups have made major intellectual contributions to CTA and hold several senior roles within the consortium despite the modest UK financial investment in the project so far. The technical and scientific focus of the UK is on the high energy (1 to 300 TeV) component of the array, the Small Size Telescopes (SSTs), which will cover an area of about 10 km^2. The favoured SST design, proposed by the UK, with the first optical calculations being performed at Liverpool, uses dual mirror Schwarzschild-Couder (SC) optics. Liverpool leads international efforts to design and prototype the SSTs, the global funding for which is currently about €9M.

Dark Energy Search Liverpool are working on a unique terrestrial experiment using atom-interferometry to search for Dark Energy density and other unknown contents of the vacuum. The 2011 Nobel Prize in Physics was awarded for "the discovery of the accelerating expansion of the universe". This acceleration is thought to be driven by Dark Energy. The nature of Dark Energy has been a fundamental question in cosmology and particle physics for the past decade. Significant resources are going into continuing high-precision measurements of the expansion of the universe. However, there are limits to the new information these experiments can provide. Hence the possibility for Dark Energy detection on Earth should be explored.

Computing for Particle Physics

The strategy of the group is to ensure that the GRIDPP and University resources are fully exploited for the delivery of physics. With academic leadership we aim to continue to be a highly performing grid site benefiting the entire community. Further to this the staff are deployed in ensuring access to high-performance high-availability clusters for immediate turn-around of local physics analyses. As well as providing and maintaining the Particle Physics IT systems, including support for the LSDC, the group is looking to contribute to the design of the next generation of online and offline farms. It will designing and test, with collaborating computer science teams and industrial partners, innovative computer architectures aimed at reducing cost/CPU cycle by a factor of 100 over the next three years; potentially an important development for Particle Physics.

COCKCROFT INSTITUTE

The Cockcroft Institute is a collaboration amongst the accelerator scientists and engineers in the Universities of Liverpool, Manchester and Lancaster and the STFC's expertise and skills base in ASTeC at Daresbury and Rutherford Appleton Laboratories. The University of Liverpool accelerator group, working at Cockcroft, consists of three academics, four PDRAs and ten PhD students. This group has leading expertise in beam dynamics (including polarisation), instrumentation, beam cooling, antiproton facilities, atomic physics and ultra-fast photonics, together with strong international links, providing opportunities to make leading contributions to a range of different accelerator projects. The Liverpool Cockcroft group is particularly involved in the operation, conception, design and associated beam dynamics and instrumentation of present and future colliders such as ILC, CLIC, LHC, LHeC and Super-B factory; the low energy FLAIR and ELENA antiproton facilities; test facilities such as ALICE/EMMA on Daresbury campus, CESR-TA at Cornell University and ATF at KEK, Japan.

DETAILS OF EXPERIMENTAL PROGRAMME

ATLAS EXPERIMENT

CURRENT ACTIVITIES

LHC and ATLAS: The first important data set for physics, at a proton beam energy of 3.5 TeV, was delivered by the LHC in 2010. With a maximum instantaneous luminosity of $L_{imax} = 2 \times 10^{32} cm^{-2}s^{-1}$ a total of about $49pb^{-1}$ of integrated luminosity was delivered, of which ATLAS recorded $45pb^{-1}$. The performance of the LHC was dramatically improved in 2011: with $L_{imax} = 3.5 \times 10^{33} cm^{-2}s^{-1}$, about L=5.6 fb^{-1} was delivered of which ATLAS again registered essentially all (5.3 fb^{-1}). The efficiency of the data taking had continuously been very high, despite the unprecedented complexity of the apparatus. The data taking efficiency of the inner Silicon detector (SCT), of which Liverpool had built a large part (Endcap C), was 99.6%, in stable beam conditions outside warm starts of the DAQ system, with only 0.97% of the SCT modules disabled. The grant period 2009-2012 has been full of extraordinary successes.

Liverpool ATLAS Group: The group is one of the major groups in the ATLAS Collaboration, which currently has ~180 institutes from all over the world and approximately 3000 physicists. The Liverpool group makes major and highly recognised contributions to all aspects of the experiment: to the detector, its operation and upgrade (see p. 37) and in three major areas of physics, precision SM measurements, searches for the Higgs and for NP, primarily for SUSY. These are the three physics areas the LHC is built for: investigations of the SM in the much expanded kinematic range, the exploration of the electroweak symmetry breaking mechanism and the search for new phenomena at the energy frontier. A group rooting deep in its hardware contributions and as large as ours naturally needs to engage in all these main areas, even when the whole physics field of ATLAS is too vast to be covered by one group alone.

At the beginning of the grant period, 1.10.2009, the Liverpool ATLAS group was composed of 12 academics, seven technical core, six RAs and seven PhD students. A severe loss of two RA positions was imposed on the group during 2009: **Kluge**, **Vankov** left, who had been working on the SCT while at CERN on LTA. They had also worked on SM and Higgs physics and have not been replaced. This is increasingly problematic for the group and two new RAs are requested to ensure further leadership and analysis competence in these two areas. At this time the group has 12 academics, seven core, four RAs and nine PhD students. Although this means that Liverpool is the largest of the 14 UK ATLAS groups, it represents only a fraction of about 1% of all the ATLAS physicists. The group resides at Liverpool where its hardware and software basis is, but it makes every effort to also be present at CERN, with three academics (**Allport**, **Klein M.**, **Klein U.**), three RAs (**D'Onofrio**, **Hayward**, **Laycock**) and five PhDs on LTA, supported by STFC and CERN. In

2010 **D'Onofrio** decided to join the Liverpool group after she was awarded a Halliday fellowship. In 2010, the former leader of the group, **Jackson**, retired and since then the group has been led by **Klein M.**. Senior members of the group have simultaneously been involved in the finalisation of data analyses in previous experiments at the Tevatron (D0 – **Burdin**; CDF – **D'Onofrio**, **Hayward**, **Mehta**) and HERA (H1 – **Klein M.**, **Mehta**, **Laycock**; ZEUS – **Klein U.**), leading to major publications. The techniques and many results obtained in these former experiments have had an important impact on how the Liverpool group could engage in the ATLAS physics analysis.

SCT: The period from 2009 to the present marks the very successful start of the exploitation phase of the SCT detector, with an overall channel efficiency in excess of 99% as well as an excellent operational stability. Liverpool has been one of the UK's leading institutes on the SCT during the construction, installation and commissioning phase. It has maintained a strong role in the operation of the detector throughout the grant period, as with the development of the offline SCT monitoring systems and software (**Hayward**, **Burdin**), the SCT data quality coordination by **Hayward** (2007-2010) and with **Vossebeld** as the UK project leader for the SCT, who since 2009 has been coordinating the UK effort related to this detector and acting as the budget holder for SCT travel and M&O. Liverpool developed the strategy and procedures to assign the data quality flags set for the SCT during ATLAS luminosity periods, used to define ATLAS "good-run" lists. Liverpool was also responsible for the implementation of SCT data-quality information in the ATLAS DQ Web-browser (**Hayward**, **Burdin**). Additional monitoring code was developed and used by **Dervan** to access the DCS information for SCT modules, to monitor the long term behaviour of detector parameters (bias current and detector temperature) which is important for predicting the detector performance after irradiation. In 2010 **Dervan**, **Jones** and **Vossebeld** contributed to an extensive review of anticipated radiation damage effects in the SCT and the cooling requirements that derive from it. This used models of the running and intervention schedule for the SCT. These studies confirmed the SCT can be operated successfully until its expected replacement in the LHC phase-II upgrade. The study also established that the cooling capacity of the current SCT cooling plant is insufficient for operation after the detector has received the full anticipated integrated radiation level. The cooling plant is foreseen to be replaced in the long LHC shutdown in 2013-2014.

Burdin and **Dervan** led a study on the feasibility of extracting depletion voltage information from either the noise or the leakage currents observed in SCT modules as a function of the applied bias voltage. Increased noise levels recently observed in the SCT are seemingly correlated with the received radiation doses. This was studied at Liverpool using SCT modules which were re-irradiated in the PS. The irradiation program at CERN was led by **Dervan**, while **Greenall** at Liverpool performed measurements on irradiated and non-irradiated modules excluding early onset radiation damage to the front-end electronics as the suspected cause. As the likely cause, weaknesses in the SCT timing calibration were identified. Additional monitoring code has been developed (**Dervan**) to access the DCS information for SCT modules and to monitor the long term behaviour of parameters (detector HV voltage, HV bias, LV voltage, LV current, hybrid temperatures, environmental conditions and DAQ configuration). This now runs automatically, updating a web page that displays the information on a run by run basis and a time history of all SCT running. **Gwilliam** played a leading role in the implementation and development of offline software for the ATLAS SCT and jointly managed the implementation of conditions data, which provides information on the status of the detector, within the SCT software. He remains responsible for the clustering algorithm, which groups the binary hit information from the individual strips in an SCT module into cluster objects and account for missing that are subsequently used in the formation of space-points for the track finding.

Detector Operation: Liverpool is making major contributions to the operation of the ATLAS experiment beyond the SCT. It has a central role in the data quality team at ATLAS holding a crucial leadership role (**Hayward)** as ATLAS Data Quality Co-ordinator 2011-2012. Moreover, major infrastructure tools were developed, such as the Data Quality Status Calculator (combining information from the DCS, detector configuration and monitoring information into one status word for each sub-detector (**Burdin**)) and a new system for recording information on detector status and data quality and for transmitting this information to the users performing physics analysis. This latter system evolves (**Hayward**) around the concept of "defects," which are well defined, fine-grained, unambiguous occurrences affecting the quality of recorded data. Introduction of this system had been a major improvement in the efficiency of the ATLAS data taking and control. Liverpool maintains its expertise in the monitoring of the data quality of the ATLAS detector by continuing to be involved in the monitoring software of the SCT (**Hayward**) and developing the monitoring of the electron and photon reconstruction and trigger software packages. **Laycock** filled the role of tag data base Conditions Coordinator from 2008-2010 continuing on request from ATLAS as Deputy Conditions Coordinator from 2010-2011. As part of the Data Preparation Coordination group, the role involves coordinating the conditions (calibration, alignment, etc.) for the whole of ATLAS, for the trigger, the prompt data reconstruction, the reprocessing of data and all Monte Carlo simulation samples. In 2011 he designed and contributed to the implementation of a new model for managing conditions, which stream-lined the procedures used during conditions data transitions, simplifying their use and management. Liverpool played a leading role in the determination of the luminous region (beam-spot), which is an essential component of the ATLAS data preparation coordination.

The determination of the luminous region provides fast feedback to the LHC on the beam orbit, is a key component of the *b*-jet trigger and provides input to the offline primary vertex reconstruction. **Gwilliam** was convenor of the ATLAS beam-spot group 2010/11. A further essential contribution to the experiment was the successful participation in the extended ATLAS shift system. The members of the Liverpool group took responsibility for 576 shifts during 2011 and thus could fulfil their quota to 95(106)% in category 1(2) shifts taking place in the control room (offline). This was a major effort and improved performance as compared to 2010 (with 397 shifts in total), largely due to the efficient organisation by **Hayward**.

Computing and Grid: The Liverpool Particle Physics group have access to local and grid computing resources. These comprise a Tier2 compute cluster of 624 64bit cores, a high performance storage cluster of 545TB, with a large scale 1 Gigabit research network. Some of these CPU and disk resources are dedicated to local Liverpool physicists. Many of the group's CPU and storage resources are dedicated to ATLAS with many local configurations and tuning to obtain high performance and efficiency with ATLAS data analysis. Local researchers can take advantage of the high performance systems and tools used for the grid. Much use was made of the ATLAS grid. In terms of the success efficiency of jobs, our facility* came out 4th out of about 100 sites. Extremely time consuming NNLO QCD calculations could be run at Liverpool by combining about 200 desktop CPUs for jobs which ran 1-2 days for achieving per mille accuracy as required by the actual *W,Z* data precision. Many of the analyses run by the Liverpool ATLAS group have employed a common software platform and common N-tuple formats developed by us during the grant period (**Bland**, **Fay**).

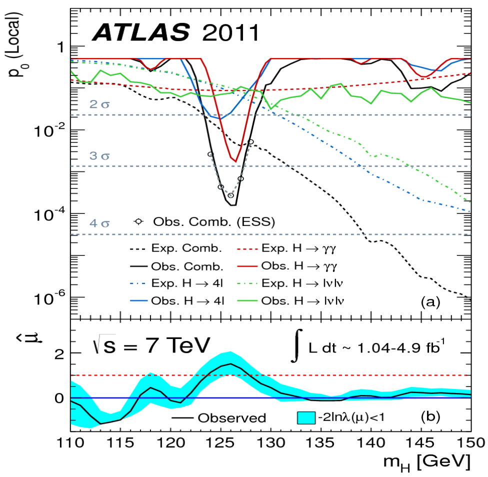

Figure 3: Combined Higgs exclusion plot for all channels

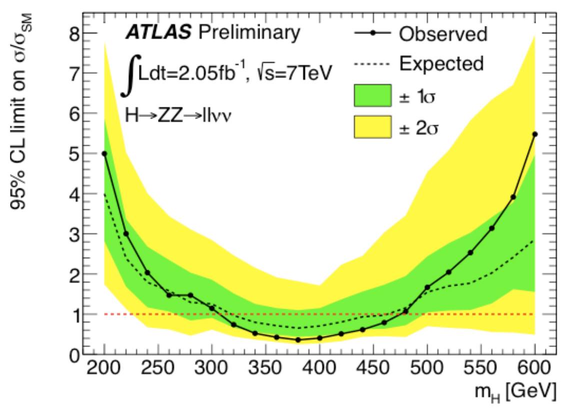

Figure 4: Higgs exclusion for the decay H→ZZ→llνν

Searches for the Standard Model Higgs Boson: The search for the Higgs is one of the major objectives of the LHC programme. Recent combination papers[1] show excesses with local significance of 3.5σ ATLAS and 3.1σ CMS in the 125 GeV region. The group invested heavily in preparing for first data. We pioneered the searches for $H\rightarrow ZZ\rightarrow ll\nu\nu$ and *llqq*. Our analyses using these channels now dominate the sensitivity for high mass Higgs, m_H>300 GeV. We also performed feasibility studies demonstrating the usefulness of the associated production, *ZH* and *WH*, which will be essential to measure the couplings of the Higgs. We now lead these analyses. Liverpool (**Gwilliam**, **Mehta**, **Vossebeld**) are lead authors on three journal publications, six public notes and have given four presentations at international conferences. A member of the group (**Gwilliam**) is a UK Higgs convenor.

High Mass Higgs Search: Prior to LHC data taking we significantly extended the anticipated sensitivity of high mass searches by including two new channels: $H\rightarrow ZZ\rightarrow ll\nu\nu$ *and llqq.* We demonstrated the feasibility of excluding Higgs, based on a combination of the *llνν, llqq* and *llll* channels*,* at the 95% c.l. within one year of nominal operation (~1fb^{-1}), much better than previous studies had indicated.

During the first two of years of data taking we have led the *llνν* and *llqq* searches and contributed to the *llll* channel[2]. We also undertook the understanding of *b*-tagging and the measurement of E_{Tmiss}, both essential to these channels. In 2011 we published preliminary and final results in both channels[3-5], and updates are being prepared for Spring 2012. These papers contribute to the combined Higgs search results of the LHC experiments; our channels helped rule out a high Higgs up to $m_H \sim$ 500 GeV. Above 300 GeV the *llνν* results provide the strongest limits (see Figure 4).

Low Mass Higgs Search: Constraints from EW measurements have favoured a low mass Higgs above the 114 GeV LEP limit. This is a difficult region to search for the Higgs boson as the largest production and decay modes are difficult to distinguish from background processes with higher cross-sections. Based on the first LHC data Liverpool has led the searches in the $ZH\rightarrow llbb$ (**Mehta**, **Gwilliam**) and $WH\rightarrow l\nu bb$ (**Mehta**) channels. Preliminary results for both analyses were published in 2011 and a journal publication is expected in 2012. The paper will also include results from a new Liverpool initiated $ZH\rightarrow \nu\nu bb$ analysis (**Gwilliam**, **Mehta**, **Vossebeld**).

With a small team of two academic staff and one responsive RA we have made a major impact on the ATLAS Higgs programme. We request, in this proposal, an additional PDRA (**RA-1**) to support this effort. The RA will extend our analyses in two key areas. In the High Mass region, where we have already excluded the SM Higgs, a search will be made for additional Higgs particles as predicted in some SUSY models. In the low mass region the RA will develop the *ZH* analysis to measure the Yukawa coupling of the Higgs to b-quarks. For the UK to be a major player in these critical measurements it is essential that this post be funded.

Standard Model Measurements: Our Standard Model (SM) work has focussed on the inclusive *W* and *Z* production cross sections and the partonic structure of the proton. It also included measurements of *Z*+*b* jets as a test of the *b* density. A quantitative understanding of these processes and necessary experimental and MC techniques is important also for searches for NP. The group (**Klein M.** , **Klein U.**, **Kretzschmar**) has played a leading role in the inclusive measurements using *W* and *Z* bosons produced in high energy *pp* collisions, starting from their first observation and early cross section measurements in summer 2010[6] and continuing with precision measurements in late 2010 and early 2011[7]. The first differential *W* asymmetry analysis[8], published early 2011, revealed some limited sensitivity to the proton structure. This was followed by *Z*[9] and *W* [10]cross section measurements differential in the boson transverse momentum. Finally, precise integrated and rapidity differential *W* and *Z* cross sections were published[11]. The potential of these measurements for improving the knowledge on the proton structure was demonstrated[12], where it was shown, that the data is able to provide completely novel constraints on the strange quark content of the proton. The high precision of the *W,Z* measurement and the latter QCD analysis result have given rise to the formation of a new PDF fit working group which opens a new direction of

ATLAS physics and is co-convened by **Klein U.** Our contributions to the various publications were in the experimental data analysis with special emphasis on the electron decay channels; in the theoretical calculations and in the editorial and analysis steering processes. One key aspect in the experimental analysis is a detailed understanding of the electron performance, which was also separately published with significant contributions, with **Kretzschmar** being convenor of the corresponding electron efficiency ATLAS study group. The precision of the results, the exploitation of latest and demanding theory calculations and the careful treatment of correlations among all channels have set new standards for such measurements at hadron colliders. This is largely the fruit of a three years preparatory work by an international ATLAS study group initiated by Liverpool and convened by **Klein U.**. As the luminosity and beam energy increase, work has begun to apply the *W,Z* electron channel techniques to the search for high mass resonances as are predicted in extra dimension theories or the sequential SM (**Klein U.**, **Kretzschmar**) which will lead to a measurement of the high mass Drell-Yan di-lepton cross section too. Our further success in this area, the complete lack of postdocs in the light of the increasing involvement in coordination (**Klein U.** PDF forum coordination (**Kretzschmar**) *W,Z* analysis coordinator of also the 2011 data, **Klein M.** team leader) and even stronger future demands, in precision and direction to BSM phenomena, make strengthening this area a necessity. We include in this grant application a corresponding request for an additional (**RA-2**) post.

Besides the inclusive precision measurements, the group (**Mehta**) successfully performed the first analysis of the *Z+b* cross section[12] which has opened this process to further investigations as are very important for SUSY searches and for heavy quark pdfs. The paper was also one of the first applications of *b*-vertexing techniques to which the group made strong contributions, both with the SCT and *b*-software developments. Liverpool (**Gwilliam**, **Mehta**) studied the effects of multiple scattering and alignment on the impact parameter resolution of tracks entering into the *b*-tagging algorithms in the first collision data (published in two conference notes). They were made responsible for estimating the uncertainty on the *b* and *c*-tagging efficiency and light quark mis-tagging rates and for obtaining Monte-Carlo correction factors from data analyses.

Searches for New Physics The search for Supersymmetry (SUSY) is one of the primary analysis interests of the Liverpool ATLAS group. SUSY is among the most compelling theories providing an extension of the Standard Model (SM) and naturally resolves the hierarchy problem by

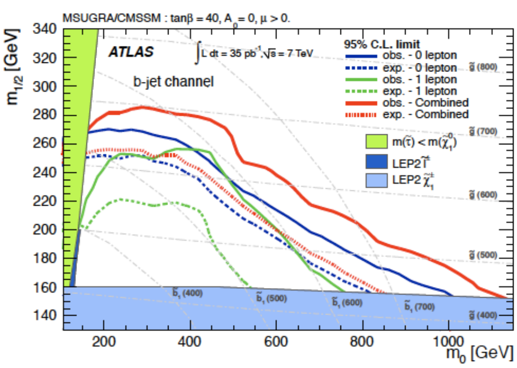

Figure 5: Exclusion in the $m_0/m_{1/2}$ plane

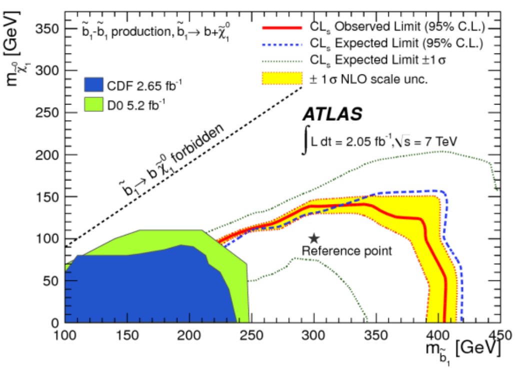

Figure 6: Exclusion plot showing sbottom v LSP phase space

introducing supersymmetric partners of the known bosons and fermions. In the framework of a generic R-parity conserving minimal supersymmetric extension of the SM, the MSSM, SUSY particles are produced in pairs and the lightest supersymmetric particle (LSP) is stable, providing a possible candidate for dark matter. In a large variety of models, the LSP is the lightest neutralino while third generation squarks (sbottom and stops, super-partners of the bottom and top quarks) can be significantly lighter than other sparticles. They may be copiously produced at the LHC. The characteristic signatures for sbottom and stop decays involve multiple jets, large missing transverse momentum and possibly leptons.

We are searching in several channels (**D'Onofrio**, **Laycock**), exploring a large variety of production processes (direct pair or gluino-mediated) and decay modes (multiple *b*-jets and no lepton for sbottom, multiple *b*-jets and 1 or 2 leptons for stop searches). First results have been reported in Winter 2011, which significantly extend exclusion limits obtained by LEP and Tevatron experiments[13]. Updates of these searches[14] with larger datasets and improved analyses techniques have been presented at HEP Summer Conferences, among them the prestigious EPS and Lepton&Photon conferences. The results have been extensively used by theorists to exclude several SUSY scenarios. Lately we have completed the first dedicated search at the LHC for direct production of sbottom: results have been presented in the HCP conference and have been submitted recently to PRL, see Figure 5 and Figure 6. Dedicated searches for stop pair production in several final states are in preparation, aiming to use the full 2011 dataset (5 fb^{-1}). A scalar top is expected to be the lightest squark. It possibly is the only accessible SUSY particle at the LHC, given the elusiveness of SUSY at and below a TeV, and the search for stop by ATLAS is coordinated by **D'Onofrio**. In scenarios were stop is lighter than the top mass, the expected signatures might be hardly distinguishable from an overwhelming SM background. Searches for stop are therefore extremely challenging, and will require using sophisticated analysis techniques and extensive work to reduce systematic uncertainties. Large datasets, 15 fb^{-1} and more, and possibly higher LHC center of mass energy will be necessary to discover or exclude the existence of a super-partner of the top quark in almost the whole SUSY phase-space. Another key scenario we are pursuing is where the breaking of SUSY is gauge mediated (GMSB), and the gravitino is the lightest supersymmetric particle (**Hayward**, **Maxfield**, **Burdin**). Here, a characteristic signature is the decay of pair-produced gluinos or squarks to give jets, leptons, photons and gravitinos. We have obtained the first results in this channel[15] and largely improved on the constraints from obtained from the Tevatron. In these scenarios, the SUSY particles can have a significant lifetime, so the decay to the photon-gravitino at the end of the SUSY decay chain can be significantly displaced from the primary vertex. The ATLAS Calorimeter was designed specifically to measure also the direction of the photons. We are studying the directional resolution, reconstruction and timing of the LAr calorimeter in order to detect such events. Besides searching for SUSY, a leading contribution has been made to searches for highly ionizing particles like Q-balls or magnetic monopoles (**Burdin**). The first paper[16] based on 3.1pb^{-1} was published in April 2011. Limits on the production cross section for electric charges $6e \leq |q| \leq 17e$ and masses $0.2 \leq M \leq 1$ TeV have been set in the cross section range of $1 - 12$ pb for different hypotheses on the production mechanism. Searching for magnetic monopoles requires a very good understanding of the detector response and in particular the electromagnetic calorimeter. A study of the calorimeter response to highly ionizing particles was initiated and led by Burdin[17]. This article provides the basis for the magnetic monopole search paper which is being prepared for publication in early 2012.

ATLAS Leadership

D'Onofrio	Convenor of SUSY stop group	2011-
	SUSY *b*-jet group	2010-2011
Gwillliam	Coordinator ID software release	2009-2010
	Convenor beam spot group	2010-2011
	Convenor UK Higgs group	2011-
Hayward	Convenor Data Quality Group	2011-2012
Klein M.	Member ATLAS CB	2010-
Klein U.	Convenor ATLAS PDF fit forum	2011-
	Member Speakers committee	2011-
Kretzschmar	Convenor *WZ* Inclusive group	2010-
	Convenor electron efficiency	2011-
Laycock	Coordinator tag data base & Deputy	2008-2011
Mehta	Member publications committee	2009-2011
Vossebeld	Project leader UK SCT	2009-
	Convenor UK SM group	2007-2009
	Member ID steering committee	2010-

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[3] G. Aad, *et al.*, Search for a Standard Model Higgs boson in the H → ZZ → $l^+l^-\nu\nu$ decay channel with the ATLAS detector, Phys.Rev.Lett. **107**, 221802 (2011).

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[15] G. Aad, *et al.*, Search for Diphoton Events with Large Missing Transverse Momentum in 1 fb^{-1} of 7 TeV Proton-Proton Collision Data with the ATLAS Detector, arXiv:1111.4116 (2011).

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ATLAS Proposed Programme

LHC and ATLAS The proposed programme of the Liverpool ATLAS group is determined by the machine schedule and its performance. It relies on the major results hitherto achieved by us in searching for the Higgs particle, testing the Standard Model and for NP, supersymmetry in particular. It is based, as in previous years, on the operation of the detector, the SCT built partially by Liverpool, and on its upgrade with mid and long term plans as are described elsewhere. This year (2012), the LHC is scheduled to restart operation in April, most likely at 4 TeV per beam and 50 ns bunch crossing, and to run until the end of 2012. The expected instantaneous luminosity is $L_{imax} = 6\times10^{33}cm^{-2}s^{-1}$ with an estimated integrated luminosity of about L=16 fb^{-1}. This data set will essentially replace the 2011 data (5 fb^{-1} at 3.5 TeV) when its high statistics analyses will be published. The data will lead to further enhanced sensitivity for NP and are expected to decide about the existence of the SM Higgs particle. Given the large amount of data, their complexity (as with a mean pileup of 30) and high precision demands, the year 2013 will be characterised by intense data analysis efforts and preparations for the restart in June 2014 at the increased energy of 6.5TeV. The reduced beam focus, with β* diminished from 1.5 to 0.5m, is predicted to boost the instantaneous luminosity to 10^{34} $cm^{-2}s^{-1}$ and above. The run in 2015 has been estimated to deliver an integrated luminosity of 30 fb^{-1}. Towards the end of the grant period, the LHC can thus be expected to have reached the design performance of its first phase of operation.

Group development: The Liverpool group makes all effort to maintain and strengthen its leading role in ATLAS. Its hardware base is of unique quality, in the UK and outstanding worldwide. The operation in 2012, the shutdown work and an efficient restart in 2014 are crucial to our success. The main analysis goals of the previous grant period remain valid but have been much substantiated by the analysis of the 2010/11 first ATLAS data. We have worked to leading positions in the precision tests of the SM and the Higgs and SUSY search areas. The group is ready for regaining its strength as of 2009 and has unique offers for two new RAs as are detailed below. The group will continue to be represented at CERN with about 3-4 PhD students out in parallel and 3-5 LTAs. Though the shutdown period is long, the analysis of the 2012 data and the preparation for the higher energy operation will not lead to major changes of the mode of doing analyses during 2013/14.

SCT Our current involvement with the SCT focuses on two main areas, which are both essential to the successful operation of the detector now and in the future. These are, firstly, the data-quality monitoring of the detector which needs continued coordination as well as further development and, secondly, a programme to prepare for and manage the successful long-term operation of the SCT in the light of increasing radiation damage to the sensors, the first effects of which are already observed. We intend to maintain our strong involvement with the data-quality monitoring of the SCT for which we developed much of the software (**Hayward**, **Burdin**). Following her role as the overall ATLAS DQ coordinator, **Hayward** will come back to coordinate the offline monitoring of the SCT and aim to coordinate the implementation of a planned merger of the monitoring shifts between the three sub-detectors of the ATLAS inner detector, thus helping to reduce the shift requirements in ATLAS. The impact of radiation damage on the sensors over the coming grant period and beyond is expected to be significant. To keep taking high quality data will require the development and implementation of new procedures to monitor the various indicators of radiation damage and to optimize module bias voltage and ASIC settings appropriately. Liverpool staff will continue to lead a programme of monitoring and analyzing detector temperatures, leakage currents and strip noise, verify these against radiation damage models and develop means to optimize detector setting accordingly (**Dervan**, **Burdin** and **Vossebeld**). We will also retain the expertise and necessary equipment to test irradiated and non-irradiated module if needed (**Greenall**, **Dervan**). Several staff will contribute to control room and monitoring shifts on the SCT/ID shifts (**Hayward**, **Vossebeld**, **Jones**, **Burdin** and **Dervan**). **Gwilliam** will retain an involvement with the offline software, in particular remaining responsible for the clusterisation code. **Vossebeld** will remain in post as the UK project leader for the SCT, coordinating UK effort related to the detector and acting as the budget holder related to SCT travel and M&O expenditure. **Greenall** and **Jones** will remain available for technical support. During the coming 18 month shutdown, we expect technical effort on the SCT and the work preparing for operation after radiation damage to be kept at a constant level. For work more directly related to physics data taking (**Hayward**, **Gwilliam**), a 50% reduction in the required effort is expected during these 18 months.

Detector Operation: Liverpool will continue to make major contributions to the detector operation of the ATLAS experiment, beyond involvement in the SCT. We will continue to lead improvements in the DQ infrastructure, developing and maintaining vital tools such as the defect database and new web tools for the DQ shift team working remote to CERN (**Hayward**). **Laycock** continues to be an important expert in the tag data base development, and he has been approached by the spokesperson to be candidate for the ATLAS data preparation coordinator role. We will continue to encourage our current and new students to take expert roles in system specific DQ activities such as the monitoring of the electron and photon reconstruction and trigger, jet and M_{ET} reconstruction, *b* tagging and the online global monitoring. A long term goal for detector operation is a reduction in size of the ATLAS control room shift crew, and the role of the online DQ shifter is being redesigned (**D'Onofrio**) to help achieve this. Finally, we intend to maintain our strong involvement in the daily running of the detector, taking more Run Control and eventually Shift Leader shifts (**Laycock**).

Software and Computing: At Liverpool we are currently purchasing hardware to boost our CPU resources to 816 64bit cores. The core network will be upgraded to a 40G backbone with 10G networking for storage and racks. We are also bidding for a GPU cluster for extreme parallel computing. The extensive upgrades to networking infrastructure, both within the cluster and on the desktops researchers use, should provide a solid base for increasing the scale of computer resources and speeding up analysis work. We are also working on modifying software and libraries to make best use of the GPU supercomputing technologies (**Bland, King**). While these developments are for the HEP group at Liverpool, the ATLAS demands are highest and with these upgrades we intend to ensure a further solid basis for computing and analysis needs of the ATLAS group.

Higgs Searches: During the next grant period the expected wealth of new results from the LHC will profoundly impact on our understanding of particle physics. The SM Higgs data in 2015 are expected to be enlarged by a factor of six for luminosity times three for energy, i.e. an about twenty fold increase in statistics is expected. If the recent indications for a Higgs around 125 GeV are confirmed, an extensive program will follow: measuring its couplings through various decay and production modes, its mass and spin as well as further searches to confirm whether it is the SM Higgs or, for example, one member of an extended Higgs sector. The Liverpool Higgs group (**Gwilliam**, **Mehta**, **Vossebeld**) have established their leadership in a wide range of search channels and are poised to consolidate and enhance this leadership during the period of the next grant. The Liverpool search in the $ZZ \rightarrow ll\nu\nu$ channel will remain one of the leading search channels allowing ATLAS to push the search for a possible high mass neutral Higgs boson up to the TeV scale, aided by further channels, such as, for example, the $bb\nu\nu$ channel currently being introduced by us. Our continued searches in the $ZH \rightarrow llbb$ and $WH \rightarrow l\nu bb$ channels and a new search in the $ZH \rightarrow \nu\nu bb$ channel will help establish whether the currently observed excess presents indeed the discovery of a Higgs candidate. The *ZH/WH* channels offer the best possibility to measure the dominant coupling of the Higgs to b-bbar. As a low mass Higgs is expected to be very narrow, this channel offers the best means of determining its width, indirectly from the branching fractions. In this context we also see the further analysis of the *Z+b* final states, where further analysis will build on our first publication and new data (**D'Onofrio**, **Laycock**, **Mehta**).

The Higgs sector is an excellent place to look for physics beyond the standard model. Any new particle coupling to the Higgs would be expected to significantly affect its production rate through loop diagrams. Other models would predict further higher mass neutral and charged Higgs bosons, which could be observed through their decays to SM particles including a lower mass neutral Higgs boson. We intend to extend the search in the *ZZ* final state to look for a high mass neutral Higgs boson and we will also look for the possibility of a high mass neutral Higgs boson decaying to a *Z* and a lighter neutral Higgs boson. We aim to exploit our leading position in the *ZZ* and *ZH* search channels to pursue these searches and thus retain our leadership in the high mass Higgs searches. Studying the diboson production (**Vossebeld**) is of high importance as it gives insight into the regularization of the diboson scattering cross section. To maintain our leading role, and discovery potential, a responsive post (**RA-1**) is requested as described below.

Standard Model Precision Measurements and Extra Dimensions: The LHC explores new kinematic regions which makes tests of the SM a subject of prime interest. Establishing unexpected new signals as real is impossible without controlling the measurement, energy scales, jets or missing energy for example, and neither without a deep understanding of proton structure, QCD and electroweak physics at the LHC. Our deep involvement in the experimental and theoretical analysis of the properties of the electroweak vector bosons gives as an excellent basis to build on and further develop our leadership within ATLAS for this subject (**Klein M.**, **Klein U.**, **Kretzschmar**). The analysis of the 4.9 fb^{-1} data taken in 2011 is now imminent and will be in the focus for 2012. Based on the rich statistics, increased by 100, we will map detector efficiencies to a new level of understanding, as electron identification, reconstruction and trigger. The new inclusive *W,Z* measurements will be performed in two dimensions, rapidity and transverse momentum p_T, also the di-lepton mass up to a few TeV. Understanding p_T effects is crucial for MC models, QCD and leads to the eventual measurement of the W mass. The experimental analysis will be accompanied by further theoretical developments at high order perturbation theory. Our group is specifically suited for such kind of investigations due to our close international collaborations with theorists e.g. from Dubna and Freiburg, and our leading role in the Standard Model "PDF Fit Forum" which is concerned with a whole variety of data interpretation work. An example is the determination of the amount of strange quark in the proton, a novel type of ATLAS analysis, which has only begun and is lead by us, in collaboration with DESY and Oxford. The work will be directed towards an analysis of the ultimate 13 TeV data in this grant period. This work will naturally extend to the exploration of the high di-lepton mass region in which signals for new *Z*-like resonances are predicted to occur, as in extra dimension theory (**Klein U.**, **Kretzschmar**). An addition responsive post (**RA-2**) is important to the delivery of this physics programme.

Searches for Super Symmetry**:** Dedicated searches for stop pair production in several final states are in preparation, aiming to use the full 2011 dataset (5 fb^{-1}). The corresponding work on ATLAS is coordinated by **D'Onofrio**, collaboration with **Laycock** and students. A scalar top is expected to be the lightest squark and may possibly be the only accessible SUSY particle at the LHC. Especially in scenarios were stop is lighter than the top mass, expected signatures might be hardly distinguishable from an overwhelming SM background. Searches for stop are therefore extremely challenging, and will require using sophisticated analyses techniques and extensive work to reduce systematic uncertainties. Large datasets (15 fb^{-1} and more) and possibly the highest LHC center of mass energy will be necessary to discover or exclude the existence of a super-partner of the top quark in almost whole SUSY phase-space. One of the other key SUSY scenarios, we are further pursuing, is Gauge Mediated SUSY breaking (GMSB), where the gravitino is the lightest supersymmetric particle (**Hayward**, **Maxfield**, **Burdin**). Here, a characteristic signature is the decay of pair-produced gluinos or squarks to give jets, leptons photons and gravitinos. First limits obtained by us will be improved with the 16 fb^{-1} at 8 TeV collision energy and 30 fb^{-1} at 13 TeV. In these scenarios, the SUSY particles can have a significant lifetime, so the decay to the photon-gravitino at the end of the SUSY decay chain can be significantly displaced from the primary vertex. A dedicated analysis is required for sensitivity for this situation. The ATLAS Calorimeter was designed specifically to measure the direction of the photons specifically for such a signature. We are studying the directional resolution, reconstruction and timing of the LAr calorimeter in order to detect such events. The searches for SUSY will develop much further, requiring refined analysis techniques for complex final states and no doubt the highest energy of the LHC and maximum luminosity.

LHCb Experiment

Current Activities

Introduction: Liverpool's key contributions to the LHCb experiment have been: the commissioning and maintenance of the VELO detector, the building of a replacement VELO(**Bowcock**) and the development of the LHCb EW physics programme(**Shears**). The VELO is of crucial importance to the experiment as it provides the vertex information vital to the separation of signal B-events from background. The VELO operates 8 mm from the colliding beams and is a unique device providing the highest spatial resolution of any LHC detector. The VELO is also the primary tracking device of the experiment providing up to about seven space points before the spectrometer magnet and is an important input to the trigger. The VELO modules were fully designed (except for the ASICS) and built in the **LSDC** and **workshop** by the Liverpool Group. The LHCb experiment funded the construction of a VELO replacement (VELO2) with manpower at Liverpool. VELO2, an agreed UK deliverable to LHCb, mitigates the risk to the LHCb programme should the existing VELO be unintentionally damaged due to a beam related incident; it also permits LHCb to function beyond the VELO design limitation of 6 fb^{-1} should this prove necessary. VELO2 fully utilises the n^+p technology developed at Liverpool (currently the baseline for the ATLAS and CMS upgrades) and which was first deployed in an LHC detector in the most upstream station of VELO(1). Liverpool (**Bowcock**) led the VELO project during the LHCb commissioning phase (2010) and from 2012 Liverpool will hold the VELO Deputy Project Leadership (**Hennessy**). Liverpool led the VELO2 construction and testing (**Bowcock**). The LHCb detector provides measurements are of unique precision in the forward region. The forward region facilitates precise tests of the electroweak sector (A_{FB}, the ttbar asymmetry), and yields production cross-section measurements which can constrain the underlying parton density functions. Liverpool (**Shears**) established the programme within LHCb and leads the physics working group.

VELO Commissioning and Maintenance: From 2010 to present the Liverpool group have played the central role in the latter stages of commissioning[1, 2], to effect the smooth transition from first physics to "standard" operation. in the maintenance and monitoring of the VELO in its final configuration. The success of the LHCb Physics programme has depended on the group's ability to successfully deliver a fully working detector which has, barring known dead strips, 99.9% efficiency. Early operation of the VELO (until 2011) required 7×24 hr supervision which was provided (together with other institutes) by members of the Group (**Bowcock**, **Hutchcroft**, **Shears**, **Affolder**, **Casse**, **Patel**, **Hennessy**, **Rinnert**). During the first half of 2010 expert VELO run coordination was provided by the Group (**Bowcock**, **Affolder**, **Patel**, **Hennessy**, **Rinnert**). From mid 2010 an expert piquet system has been in place with (**Hennessy**, **Patel**, **Rinnert**) all serving in this capacity. The group now provides both of the two experts who are the most required to operate the VELO (**Hennessy**, **Rinnert**) and who are capable of solving complex DAQ and Monitoring problems as they arise. The group is responsible for the VELO DAQ (**Hennessy**) and all aspects of the online monitoring and data-basing (**Rinnert). **For the VELO to operate it requires complex processing of the data in the TELL1 FPGAs. The 180,000 channels of the VELO each require several parameters (e.g. pedestals, timings) which much be determined and loaded into the TELL1s for the operation of the VELO. Maintenance and development for the system for determining, storing and uploading these millions of parameters is provided by Liverpool (**Rinnert**). Maintenance of the geometry description and the VELO raw data decoding is **Rinnert's** responsibility. An offline database that links production parameters, dead strips, every detail of the hardware and registers replacements and problems was designed and is maintained by **Patel**. The VELO depends for its safe operation on a complex, but failsafe, piece of equipment called the interlock box designed and

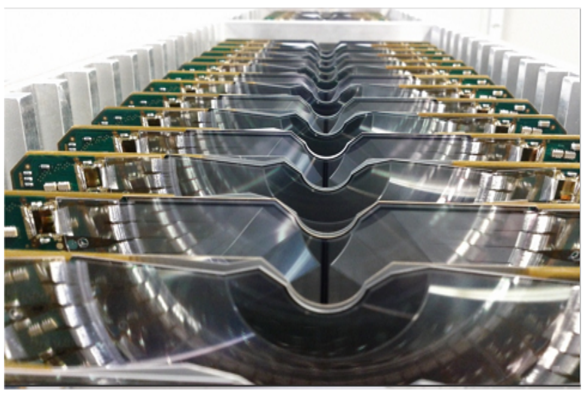

Figure 7 One half of new VELO2

maintained by Liverpool (**Smith**). The interface of the critical motion control system (the VELO must be retracted away from the beam during beam injection) to the DAQ is maintained by Liverpool (**Hennessy**). **Hennessy** was responsible developing the slow controls system that allowed the experiment to move from manual to automatic closing of the VELO. The time used for safety checks, due to powering and closing the VELO after declaration of stable beams, was 2.4% in 2010 and following the automation process this has been reduced below 1.0% in 2011. Liverpool is responsible for maintaining and developing the DAQ "recipes" used by the experiment for different modes of VELO running (**Hennessy**).

Radiation damage to the VELO sensors is one of the key factors that limit the lifetime, and performance of the VELO. Expert oversight and understanding of the radiation monitoring is provided by Liverpool (**Casse**, **Affolder**). Extract of radiation damage information from the VELO enables the Group to optimise strategy for the running of the detectors and to devise the optimal annealing strategy for the sensors. Detailed understanding of the impact of the radiation damage to the tracking efficiency of the experiment is provided by the Group (**Hutchcroft**).

Offline Software and Tracking**:** Liverpool remains responsible for a major component of the experimental software. We are one of the four authors of the overall LHCb tracking (**Rinnert**) and are responsible for the VELO tracking maintenance and development (**Hutchcroft**). The Group has acquired, through University of Liverpool funds, a NVIDIA Tesla system. **Rinnert** is investigating advantages of utilizing GPU for offline processing. Initial tests show that for LHCb VELO tracking and jet-clustering substantial (factors of 10 or greater) gains in "time-to-completion" are achievable

***VELO Replacement**:* From 2009 the Liverpool group has been involved in a major programme of work – delivering a replacement VELO detector known as VELO2. VELO2 modules were, as VELO1[3], fully designed and built at Liverpool. The VELO2 sensor technology was developed at Liverpool (**Casse**). Module production at Liverpool was managed by **Huse**. **Affolder**, **Huse**, **Patel** and **Smith** refined the methodology to use about 50% less effort than the original VELO build. The extensive quality assurance required infrastructure that has been developed and is maintained by **Patel**. All modules mechanics, testing and assembly equipment originally developed for VELO1 were refined, overhauled and maintained by **Carroll** (VELO module project engineer). The advanced composite substrates used for the VELO2 were designed by **Smith** and built by the **workshop.** The detailed electrical QA of cables and hybrids was performed by **Smith**. Over 500,000 wirebonds were required by VELO2. This was performed by **Wormald**. Since VELO1 production new wire-bonders were installed in the **LSDC**; this required a substantial re-programming and re-qualification exercise (**Wormald**). Gluing of components (ASICS, pitch adaptors) to the hybrids was performed by **Wormald. Huse** and **Carroll** performed all the sensor, hybrid and pedestal gluing. Improvements on the original build allowed final tolerances to be improved by over 20% yielding a sensor to sensor alignment of 5 μm and silicon to base alignment 10 μm. Metrology, using the Smartscope and CMM, was performed by **Huse** and **Carroll**. As opposed to the VELO1 construction, for VELO2 modules Liverpool had the responsibility for "burn-in". Hybrids pass a 24 hour burn-in conducted by **Huse**. The final assembled modules are operated (**Hutchcroft**) in our vacuum tank maintained by **Carroll**. Noise data is collected whilst the modules are operated for several hours under vacuum. This data is analysed, using software re-developed for VELO2 by **Rinnert** and any bad strips identified by **Patel**. Thermographs of the modules are taken during operation and analysed by **Hutchcroft** for evidence of "hot spots" which could indicate a thermo-mechanical failure of the hybrid or an electrical problem. **Smith** performed the final cable attachment. Final inspection of the modules was performed by **Patel**. Analysis of all the module metrology by **Patel** resulted in alignment constants for later use in the experiment. Transport to CERN was substantially modified. Liverpool now uses a specially developed 10 module transport box designed (**Carroll**) and built (**workshop)** at Liverpool. We emphasise all of the above is performed within the **LSDC**, using its unique suite of equipment. (LSDC is qualified **ISO-5** and **ISO-7** for silicon assembly and testing). The VELO2 production was critically dependent on the infrastructure of the **LSDC**. The Physics **workshop** is vital for providing the high precision module mechanics and assembly tooling.

The Liverpool Group also took responsibility (**Bowcock**) for the assembly of the VELO2 modules onto the experimental bases, and the testing of the system at CERN. The CERN assembly area was refurbished for the new production and **Hennessy** and **Rinnert** set up DAQ and software. The DAQ "slice" of the entire experimental control system (**Hennessy**, **Rinnert**) enables VELO2 to be tested but also acts as a test bed for new VELO software and firmware before deployment in the main experiment. Modules are protected by an interlock box produced and maintained by **Smith**. Installation of VELO2 modules is being performed by Liverpool Staff (**Carroll**, **Hennessy**, **Huse**, **Rinnert, Smith, Wormald, workshop**). Module and system tests are being performed by **Hennessy**, **Huse**, **Patel**, **Rinnert** and results compared with data taken at Liverpool. The database/QA system developed for production at Liverpool was extended to include the assembly data at CERN (**Patel**). Metrology of the VELO2 at CERN will be overseen, and the data interpreted, by **Patel**.

Physics: The group strategy was to test the performance of the VELO using muon data which would, at the same time, be a key ingredient to our analysis. Liverpool concentrated, in the first instance, on E-W physics. The LHCb EW programme was created and is led by Liverpool (**Shears**). The key analyses were the measurement of the *W,Z*[4, 5]differential cross-sections in LHCb and the reconstruction of *Z* bosons decays into all three leptonic channels. The W reconstruction methodology, for a non-hermetic detector, was developed by Liverpool and is a original contribution to the field. Expertise on reconstruction of vertices in the VELO (vital for background rejection) in *W, Z* events was provided by the group (**Bowcock**, **Hennessy**, **Rinnert**) whilst the muon samples that were used (in early running) to help debug the tracking code (**Bowcock**, **Hennessy**, **Hutchcroft**, **Rinnert).** The triggers used for *Z* sample were also used to provide a clean sample of low mass, down to 5GeV, Drell-Yan events for analysis (**Hennessy**). The non-resonant QED dimuon cross-section, a promising channel for a precise luminosity measurement, has also been measured by the group (**Shears**). The ratio of the W^+, W^- and the *Z* cross-sections provide important and unique input into the parton distribution functions providing tight constraints on the models. This is due to the rapidity range covered by LHCb which is complementary to that of the GPDs and allows access to very low-*x* ($<10^{-6}$). Liverpool is the convener (**Shears**) of the LHC E-W working group. Studies of the *Z* decays to muons A_{FB} are expected to yield precision comparable to one LEP experiment by the end of 2012(**Shears**). Extensions of the *Z* to tau decay analysis are being used to measure the top-cross section at LHCb (**Bowcock, Hennessy, Rinnert**); an analysis that Liverpool was one of the first to start on LHCb. Refinement of the top analysis requires the development of *b*-jet identification code. Currently this is of limited functionality on LHCb. Liverpool (**Rinnert**) are using expertise gained from CDF and DELPHI to deploy neural networks to increase the efficiency-purity of *b*-jet identification and expect a 30-40% improvement on the *b*-jet reconstruction. The group has a long term strategy of making measurements of *B*-decays. **Hutchcroft** leads this activity at Liverpool and has investigated the $B_s \rightarrow D_s D_s$ decays. Given the existing hardware commitments of the group we are bidding for an additional responsive post, **RA-3,** to allow us to exploit the B-physics potential of this experiment.

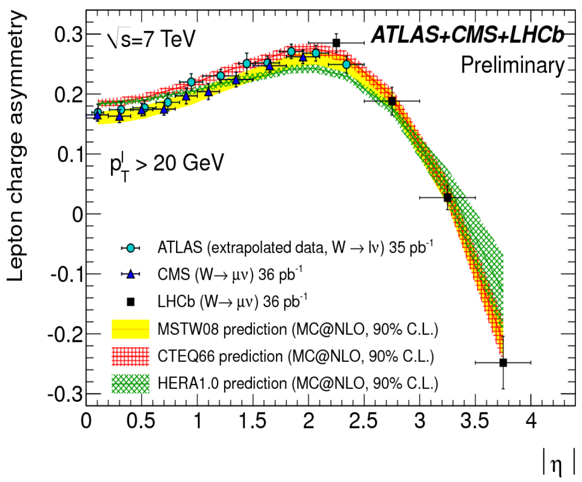

Figure 8: Combined lepton charge asymmetry in W production at LHC. This plot shpws the unique contribution at high rapidity by LHCb.

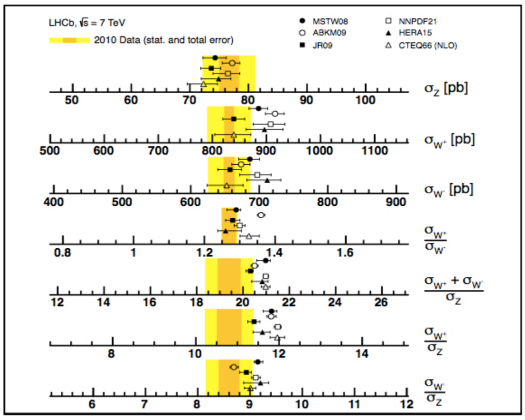

Figure 9: Cross section and ratios for different pdfs as measured by LHCb. Plot is preliminary.

LHCb Leadership

Bowcock	VELO Project Leader	2009-2010
	LHCb Collaboration Board	1997-
	LHCb Technical Board	2009-2019
	UK VELO Project Leader	2010-
Carroll	VELO Module Project Engineer	1997-
Hennessy	VELO Deputy Project Leader	2008-
Huse	VELO2 Module Production Manager	2008-
Hutchcroft	VELO Tracking Coordinator	2005-
Patel	Deputy UK Project Leader	2009-2010
	VELO2 Metrology Coordinator	2012-
Rinnert	VELO Online Monitoring Manager	2007-
Shears	LHCb Electroweak group convenor	2008-
	LHCb Leptonic group convenor	2010-2011
	LHC electroweak working group	2010-

[1] K. Hennessy, Data Readiness of the LHCb Vertex Locator (VELO), PoS **VERTEX2009**, 006 (2009).
[2] K. Hennessy, LHCb early running experience, JINST **5**, C12022 (2010).
[3] A. Affolder, *et al.*, Production of the LHCb VELO Modules, Nucl.Instrum.Meth. **Submitted** (2012).
[4] T. Shears, Studies of W and Z production with the LHCb experiment, PoS **EPS-HEP2009**, 306 (2009).
[5] D. Hutchcroft, Measurements of the W+- and Z0 boson production by LHCb, PoS **KRUGER2010**, 047 (2011).

LHCb Proposed Programme

Introduction: The group proposes to underpin the activities of LHCb by providing the crucial support for the running of the VELO during 2012 and, after the long shutdown, from 2014 onwards. The software and DAQ infrastructure is expected to undergo major revisions in 2013 for running in after the shutdown. During the shutdown detailed studies of the existing detector and the contingency of the replacement of VELO1 with VELO2 prepared. Our Physics topics will be expanded based on the EW, b-tagging and B-reconstruction already performed to include Higgs searches, exotics, B-lifetimes and CP-violation studies.

Operation and Maintenance of VELO[†]***:*** The core of the software expertise on the VELO (**Hennessy**, **Hutchcroft**, **Rinnert**) will be focused on ensuring the smooth and efficient operation of the detector. Monitoring will be extended to include a substantial AI component ensuring a further minimisation of Data Quality and expert oversight. The AI monitoring system[L6.20] will be developed and implemented by **Huse (**who designed the VELO monitoring GUI) **Rinnert** and **Patel**. Liverpool will also extend its responsibility for the semi-automated uploading of parameters into the VELO (pedestals etc.) and develop a fully automated system [L6.11](**Rinnert**). These expert systems will be made to fully integrate the online VELO monitoring[L6.14](**Rinnert**). **Hennessy** will be responsible for modifying and revising the VELO DAQ[L6.6,L6.8] to be compatible with the foreseen updates in 2013. The Liverpool group will continue to provide the two critical VELO software/DAQ experts (**Hennessy**, **Rinnert**) as on-call experts[L9.1] to solve problems the piquets cannot. Expertise on the radiation damage[L7.3] to the VELO sensors will be provided through our close ties with RD50 (**Affolder**, **Casse**) who will determine the correct running parameters for the silicon. Monitoring of the radiation damage and its consequential physics implications will be provided by **Patel**[L7.1], and **Huse** [L7.4]. The group will continue to study the performance of the detector and closely correlate this with the data gathered during production (**Patel**[L6.13]). The group will continue to be responsible for the VELO LV[L6.4], sensor electronics and the Interlock System[L6.5] (**Smith**). A programme of testbeam work, requested by the collaboration, will be performed to understand the impact of heavy ion and beam gas fragments on the detectors and electronics (**Casse**[L8.16], **Huse** [L8.18], **Patel** [L8.19], **Smith** [L8.15]). Mechanics [L8.13] for the testbeam will be designed (**Carroll**) and manufactured (**Whitley**) by the group. These will inform the choice of operating conditions[L7.3] during ion runs. Further testbeam studies (**Hennessy**, **Huse**) on heavily irradiated sensors will be performed to understand the end-of-life performance of the detectors in the experiment.

Offline Software and Tracking: The group will continue to be responsible for maintaining and supporting all development of the VELO tracking (**Hutchcroft**[**L7.11**], **Rinnert**[L6.15]). **Hutchcroft** will remain responsible for the simulation[L7.5] of energy deposition in the detector. Assuming that results achieved in late 2011 are verified then **Rinnert** will build (in 2012-2013) a demonstrator version for LHCb utilizing the GPU for all tracking and clustering in the experiment. This holds the promise of enormous cost savings to the experiment and STFC.

VELO Replacement: By the end of 2012 VELO2 will have been assembled and tested[L8.2] (**Hennessy**, **Huse**, **Rinnert**, **Smith**). **Huse**, currently the VELO2 module production manager[L8.1], will take responsibility for the preparation of VELO2 for insertion[L9.5]. Although the precise point at which VELO2 will need to be inserted has yet to be determined, substantial work has to be done to prepare for extraction of VELO1 and installation of VELO2 (**Huse**)[L8.6]. Plans for long term system monitoring[L8.3] of VELO2 need to be made (**Huse, Patel, Smith**) and designs for long term storage (**Carroll**) systems drawn up and fabricated (**Whitley**, **workshop**). Testing equipment for VELO2 must be maintained at the **LSDC**(**Carroll**, **Wormald**) to allow for repairs of modules[L8.10] should faults arise with the VELO2 modules during long term testing. Design and jigging of insertion equipment[L8.8,L8.11] will be made (**Carroll**) and fabricated (**Whitley**, **workshop**). The Liverpool group will be trained[L8.7], with the help NIKHEF group who performed the original VELO insertion, on the techniques required for the insertion of the VELO(**Carroll**, **Wormald**, **Whitley**). Metrology[L8.4] of VELO2 will be a Liverpool responsibility (**Patel**). Given the severe irradiation of the VELO1 substantial effort will be invested in developing safe handling techniques and radioprotection[L8.9] for the de-installation/installation process (**Patel**).

Physics: The LHCb experiment will expect to record over 5 fb^{-1} of data during the period 2012-2016. This data sample will quintuple the data recorded in 2011 and present the group with exciting opportunities. The first phase of the *W, Z* programme will be brought to a completion with a definitive measurement of the production cross-sections in the forward direction (**Hennessy**, **Shears**). These

[†] In this section cross-references to the LHCb experimental submission are done by superscript e.g. task[L6.9] refers to LHCb M&O task **L6.9**

measurements will need to be repeated, as the energy of the machine is increased, and compared with theory. The IVB cross-sections in the acceptance of LHCb, and extrapolated to a total cross-section, are expected to be world leading given the LHCb knowledge of its Luminosity. The *Z* to muons A_{FB} measurement (**Rinnert**, **Shears)** will be extended expected to match (at least) the LEP average. We note that this measurement is much harder at the GPDs. The larger data sample and increased cross-section (at higher energy) will increase the number of reconstructed top events. The group (**Bowcock**, **Hennessy**, **Rinnert**) will measure the *t*-*t*bar and single top production in the forward direction at LHC with unprecedented accuracy. The *b*-jet reconstruction (**Rinnert**) will be extended and made fully efficient. This will be extended to a Higgs search (**Bowcock**, **Hennessy**, **Rinnert**). Coupled to the identification of *b*-jets the code will be extended to select *c*-jets to enable a detailed measurement of W-*c*-jet production which will make world leading measurements (**Patel**, **Rinnert**, **Shears**) of the s-quark content of the proton. Building on our responsibilities for the VELO performance and software the group will perform a study of particle energy deposit in the VELO (**Bowcock**, **Huse**, **Hutchcroft**). This will aim to understand heavy, charged, nuclear fragments in the sensors (in data) as well as place limits on the production of fractionally and anomalously ionizing particles. The decays of the $B_s \rightarrow D_s D_s$ will be used to measure the mass differences between the two B_s mass states (**Hutchcroft**), leading to a program of detailed measurement of the CP violation in the charm decays of the heavy B states. We are asking for a responsive RA-3 to support our B-programme

NA62 Experiment

Proposed Programme

Introduction: The NA62 experiment at the CERN SPS7 was approved by the CERN Research Board in Dec. 2008 for a wide-ranging programme, including measurements of rare kaon decays and lepton flavour violation through the ratio $R_K = \Gamma(K \rightarrow e\nu)/\Gamma(K \rightarrow \mu\nu)$. Good energy resolution for photons also allows radiative kaon decays to be studied with unprecedented precision, enabling comparisons to be made with rare *B* meson decays and offering important inputs to the extraction of Chiral Perturbation Theory parameters. The apparatus already in place at CERN for experiment NA48 is optimised to make a decisive test of the SM by precisely measuring the branching ratio (BR) of the rare decay $K^+ \rightarrow \pi^+\nu\nu$, currently observed at the 10^{-10} level based on three events. The experiment will have a technical run in autumn 2012 and take data in 2013-14 to achieve a signal to background ratio of about 10:1. This physics is complementary to the LHC direct searches programme, with different variants of extensions beyond the SM giving different branching fractions for the rare K^+ decay. Greater sensitivity than is currently possible with stopping kaons is achieved by using a 75 GeV charged-particle beam obtained from a 400 GeV proton beam at the CERN SPS. A crucial requirement is the tagging of charged kaons, which make up 6% of the beam. This will be done using a modified version of the CERN West Čerenkov Differential Counter with Achromatic Ring Focus (CEDAR) filled with hydrogen at 4 bar instead of nitrogen. The UK will take responsibility for all hardware modifications to the CEDAR and for slow control, readout and monitoring. Liverpool (**Fry**, **workshop**[‡]), will take responsibility for the mechanics, optics, cooling of the photo-detection system, and safety. **Fry** and **Dainton** will lead the design and analysis effort in Liverpool. UK participation in NA62 has been assured by funding from the ERC over the 5-year period commencing on 1st Sept. 2011. Payment of the CERN Common Fund over the initial 2-year period is being provided by STFC and we request a continuation of this support. The UK participants will wish to assure the full exploitation of the physics from this experiment and hence will be seeking STFC support a PDRA (**RA-4**) post to allow Liverpool to establish a physics presence on this experiment.

CEDAR Upgrade: The entire upstream "nose" of the current CEDAR will be replaced. Figure illustrates Liverpool's conceptual design for the support structure, which is cantilevered off a steel support tube encircling the beam pipe and bolted to the existing flange. The beam pipe will be shortened and fitted with new, thinner windows to reduce the impact of multiple Coulomb

[‡] ERC funding for this activity has provided **workshop** resources. No STFC resources are requested for this..

scattering upon downstream detectors. The structure consists of seven sections making up a disc, each comprising a lightguide to channel light onto the group of photomultiplier tubes (PMTs), readout electronics and a cooling plate. The entire structure will be enclosed in a thermally-insulated, light-tight chamber flushed with dry nitrogen. Light emerging from each of the seven quartz windows will be focused onto a spherical mirror and reflected radially outwards onto the lightguide, which comprises highly-polished cones to direct the light onto the sensitive surface of the PMTs. We envisage using 32 PMTs in each of four sections for the technical run in Sept. 2012, and 64 PMTs in each of seven sections for the physics runs in 2014-15. Provision will be made for stabilizing the temperature of the PMTs and readout electronics. Monitoring, connected to an emergency system, is necessary for the pressure of hydrogen in the CEDAR and to test for leakage of hydrogen from the window seals into the cylindrical enclosure. A supply of gaseous nitrogen is required to flow through the compartments boxing in the electronics and high voltage to ensure an atmosphere free of oxygen to eliminate any risk of explosion associated with a potential hydrogen leak. A system of blue LEDs will be flashed to enable the optical performance of the lenses, mirrors and lightguides to be monitored and to give advance notice of any degradation. It will be necessary to design installation tooling (**workshop**) appropriate to the CERN beamline and this will be tested in Liverpool within a spatially-similar environment.

T2K Experiment

Current Activities

Introduction: Liverpool in T2K has contributed to detector construction and commissioning, preparation of the organisation and software for reconstruction and analysis, Monte Carlo studies, and data analysis. **Touramanis** had major roles during construction as T2K-UK Project Manager, ND280 ECAL convener, and member of the ND280 Technical Board. He supported the T2K-UK PI (D. Wark) at all stages of the project: proposal, planning, negotiations and approval, execution, and reporting. The £14M project was delivered on budget and on time in spite of very tight financial and time constraints. He personally led key parts of the project (Major procurements, ECAL design, Barrel ECAL module construction, full detector transportation and installation, UK contributions to the mechanics of ND280).

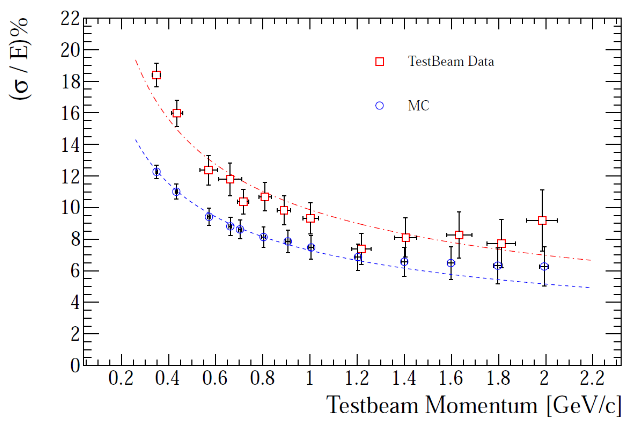

Figure 10: Resolution of the T2K ND280 ECAL from testbeam,

Liverpool physicists (**Payne**, **Chavez**, **Mavrokoridis**, **Coleman**) led a large number of technical staff and students in the construction of the ECAL Barrel modules at Liverpool and Daresbury and that was their full-time occupation in 2009/10. **workshop** and **LSDC** facilities and staff were instrumental in the timely construction of the ECAL modules. Liverpool proposed and set up the full T2K MC production system (**Touramanis** as Global Analysis Group deputy chair) and carried out the two Mock Data Challenges, MDC0 and MDC1 (**McCauley**) on the Liverpool cluster. The group set up and is still responsible for the ND280 software release system (**McCauley**). Liverpool (**McCauley**, **Payne** and **Mavrokoridis**) together with postgraduate students made major contributions to ECAL reconstruction, simulation, calibration, and analysis of the DS-ECAL CERN testbeam data. **McCauley** is the original developer and responsible for the ECAL electromagnetic energy measurement. They extended the development of ECAL reconstruction and neutrino event analysis using the ECAL on real data in the area of ν_e flux measurement. Liverpool provides leadership in the analysis at ND280 (**Touramanis**, Analysis coordinator; **McCauley** ν_e group convener) and T2K level (**Touramanis**, **McCauley** members of the ASGC group). **Touramanis** will be the T2K Speakers Board chair starting in April 2012.

Construction, installation and commissioning: The lead-scintillator sandwich sampling electro-magnetic calorimeter (ECAL) comprises 13 modules which cover five of the six sides of the ND280 inner detector volume (approx. 7×2.5×2.5 m3) and contain approx. 45 km of specially extruded scintillator bars with wavelength-shifting fibres running inside the bars and read out by 22,336 MPPCs (silicon photon detectors). With a volume of around 55m3 and a weight of 75 tonnes it is the largest particle physics detector ever constructed in Europe for an experiment in the Far East. Touramanis is the T2K ECAL convener, responsible for the all aspects of the detector from design to operation in the experiment.

The six largest modules for the Barrel section, amounting to more than 75% of the active volume, weight and readout channels were constructed between summer 2009 and October 2010 at Liverpool in the **LSDC** and at the nearby Daresbury Laboratory. Liverpool physicist **Payne** led the team of students (up to six at any time) and Daresbury engineers daily during the entire period, plus an extra month at the end for the orderly decommissioning of the Daresbury construction facility. At Liverpool this role was carried out by **Chavez**. When he took up a CERN Fellowship in 03/2010 the role was taken over by **Coleman**. **Mavrokoridis** has worked closely with them throughout construction and ensured continuity at the changeover point. Critical jobs fully carried out by Liverpool physicists (**Payne**, **Chavez**, **Mavrokoridis**, **Coleman**) and students at both Liverpool and Daresbury were the fibre routing in the bars of each layer, gluing of optical connectors at the end of each fibre to 0.3mm precision, full testing of each layer by source scanning, replacement of damaged fibres and retesting, installation of MPPCs and front end cards (TFBs), cabling, installation of cooling, dry air and light injection systems, final tests of the completed modules and the associated book-keeping. **Payne** was responsible for providing that information to the appropriate ND280 databases.

Figure 11: N2280 ECAL being installed into its final position

Expert **workshop** staff produced the code for the large automatic milling machine and carried out the production and finishing of the module bulkheads, each having 2,000 holes for fibre routing and photosensor location, made to sub-mm precision, constructed a large number of custom fixtures and fittings, and also performed repairs to elements procured from industry which often did not meet the specification (e.g. module cooling plates). Sending these back to the manufacturers for corrections was not an option as it would completely derail the very tight completion schedule. **Sutcliffe** and **Carroll**, who carried out much of the ECAL design, supervised the **workshop** operations and also provided hands-on guidance and assistance to the construction teams. **Cooke**, head of the workshop, provided support in the planning and coordination of the construction, he was the main advisor in the specification and procurement of the carbon-fibre sandwich skins for the modules of the complete ECAL, and he organized the laboratory preparation and decommissioning and module packing for shipping. **Whitley** was responsible for the facility, including setting up and removing the partition of the LSDC clean rooms used for construction, consumables, storage. His participation was crucial in the critical face of module completion and testing, often working very late and weekends.

The 12 ECAL modules (Barrel and P0D-ECAL) were installed at J-PARC in two periods, July and October 2010. **Touramanis** led the UK team comprising STFC staff A. Grant, A. Muir, R. Preece, T. Durkin and Japanese contractors who did the final testing, small repairs, installation, and first tests of the detector during those two months. An overview of the ECAL design and construction has been reported[1] while a more detailed, dedicated publication is being prepared under the coordination of **Coleman**. Commissioning with pedestal, cosmics, and beam interactions was led from November 2010 by Liverpool student Murdoch with guidance from **Mavrokoridis** and support from other UK physicists at J-PARC. This task includes the development of monitoring and HV-setting software and scripts which are being continuously upgraded. Tests and recommissioning after the March 2011 earthquake was performed by Murdoch with support from other UK physicists. Liverpool students Thorley and Calland will share the ECAL commissioning tasks with another UK student during 2012.

The full ECAL had 42/22,336 bad channels (0.19%) in November 2010 and a total of 182 bad channels (0.81%) today. Most of the extra bad channels correspond to two readout boards (TFBs) which are not communicating, probably due to data cable connections inside the modules which became loose during the magnitude 9.1 earthquake. The robustness and minimal damage suffered by the ECAL, as well as the rest of ND280 subsystems which are carried by the UK-designed and built basket, demonstrate the high standards of design and testing by our engineers and physicists. Particular mention should go to **Sutcliffe** who designed the basket and performed earthquake calculations for ND280, and **Carroll** who designed the structures carrying all the subdetectors' cables and services in the detector pit.

Software, reconstruction, analysis: Liverpool provides leadership and key contributions at all levels in ND280 and in the T2K collaboration as a whole. **Touramanis** has been ND280 Analysis Coordinator (2009-11) and **McCauley** was re-appointed recently for a second 2-year term as ND280 ν_e group convener, coordinating the measurement of the intrinsic ν_e flux in the T2K beam which is one of the two major backgrounds for the ν_e appearance measurement in SuperK, the main physics objective of the experiment. During those terms both of them serve as Analysis Steering Group Conveners for T2K. **Touramanis** is now member of the T2K Speakers Board and will become chair from April 2012. **McCauley** has continued to be fully responsible for the ND280 release code management that he has developed and he is the release manager responsible for validation and announcement of the official software releases used for physics analysis throughout the collaboration and the production of official physics results and publications. Together with **Payne** they carried out the complete MDC1 MC production in 2009/10 on the Liverpool cluster.

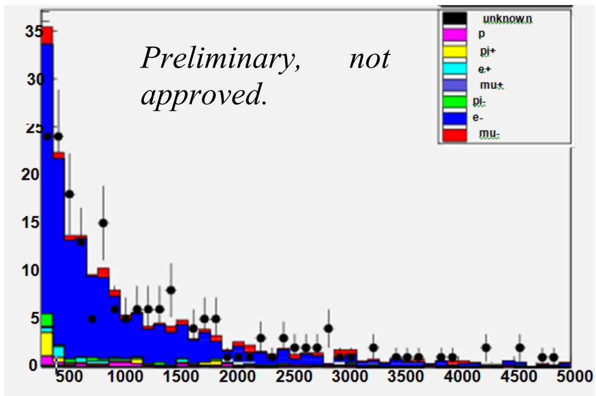

Figure 12: Momentum spectrum ν_e

McCauley is responsible for the electromagnetic energy measurement in the ECAL and he oversees the development of ECAL reconstruction software in the UK. **McCauley** together with **Mavrokoridis** guide Liverpool students in new and further developments of core ECAL reconstruction software, many of which are already incorporated to the official releases used since 2011 (new 3-dimension clustering, use of Kalman filter for tracking of charged particles in the ECAL, matching of ECAL objects to tracks in the TPCs, cluster reconstruction with seeding from incoming tracks etc). Calland (PhD student) is member of the global reconstruction task force, working on improvements for the official 2012 analysis. **McCauley** led a detailed study of CERN testbeam data and MC-data comparisons leading to the development of improved electron identification in the ECAL and the first ν_e interaction reconstruction and selection using the ECAL in data from RUN1. Further integration of the ECAL in the physics analysis is being pursued as are CC1pi (muon neutrino charged current interactions producing a muon and a charged pion).

Payne, has been developing a global fit for neutrino oscillations based on his extensive experience on complicated simultaneous likelihood fits from BABAR. He developed and presented the first 2d fit in T2K as early as in 2008, using the lepton momentum and angle with respect to the incoming neutrino beam to optimize sensitivity. He had put this effort on hold during 2009/10 as he spent

100% of his time on detector construction, and now he is continuing this work as a member of the core T2K Fitting Group, preparing the official analysis tools for 2012 which include the 2D fit, also leading the work of Calland in this area. **Coleman** and **Mavrokoridis** are starting T2K analysis in the area of cross-section measurements with ND280 data. **Touramanis** and **McCauley** had direct input to the first two physics publications from T2K, the first indication for ν_e appearance[2] and the first measurement of the parameters of ν_μ disappearance.[3]

			T2K Leadership
Touramanis	ND280 ECAL convener	2006-	
	T2K-UK Project Manager	2006-2011	
	ND280 Analysis Coordinator	2009-2011	
	Speakers Board Chair	2012-	
	T2K Analysis Steering Group Convener	2009-2011	
McCauley	ND280 nu_e group convener	2209-	
	T2K Analysis Steering Group Convener	2009-	
	ND280 Software Release Manager	2007-	

[1] K. Abe*, et al.*, The T2K Experiment, Nucl.Instrum.Meth. **A659**, 106-135 (2011).

[2] K. Abe*, et al.*, Indication of Electron Neutrino Appearance from an Accelerator-produced Off-axis Muon Neutrino Beam, Phys.Rev.Lett. **107**, 041801 (2011).

[3] K. Abe*, et al.*, First Muon-Neutrino Disappearance Study with an Off-Axis Beam, arXiv:1201.1386 (2012).

T2K Proposed Programme

Introduction: The Liverpool group will continue to support the ECAL operations at J-PARC, the further development of the relevant reconstruction software, the full inclusion of the ECAL in the physics analysis, and developments of core software. The central focus of the group is always leadership in physics analysis, where we will pursue the measurement of the intrinsic ν_e content of the beam, the measurement of neutrino cross-sections in ND280, and the development of optimal fitting techniques and tools for the main oscillation results of the experiment. The group will also utilize the available expertise to perform simulation studies in preparation for the possible antineutrino running from 2014.

ECAL operations: The group will continue to provide ECAL commissioners on site. Students Thorley and Calland will cover that role in 2012. **Payne, Coleman** will go to J-PARC for a year on LTA in 2013-14. This role will continue to cover both hardware status and operations and monitoring software utilities maintenance and development.

Leadership: **Touramanis** will continue to be the ND280 ECAL convener and serve for a year as SB chair. **McCauley** will continue to be ND280 Software Release Manager and after his second term as ν_e convener will move to another leadership role in the physics organisation of the collaboration. **Payne** and **Coleman** will aim to obtain positions of responsibility corresponding to their analysis contributions in the fitting and cross-section areas respectively.

ECAL reconstruction and analysis integration: The group will continue its further development and optimisation of the basic ECAL reconstruction software, focusing on clustering, charged track reconstruction, electromagnetic cluster energy measurement, hadronic/electromagnetic shower separation. This will expand on current work and utilize large statistics of real data and detailed MC/data comparisons and MC tuning. **Touramanis, Payne** and **McCauley** will utilize their experience of constant iterative improvement of reconstruction quality as the detector gets better understood, as in their previous projects (BABAR, SNO) to guide the activity of current and future students in this area. McCauley will continue to maintain and improve the electromagnetic energy measurement. **Mavrokoridis** will make crucial contributions based on his considerable detector understanding and experience. We will maximize contributions and impact of this work by combining with our physics analysis (e.g. electromagnetic shower reconstruction with ν_e flux measurements, pion/electron separation with charged current pion production). It is natural that with increased data statistics the detector understanding improves and that benefits the physics as it reduces systematic errors. The group will contribute in this effort throughout the next grant period.

Physics program: The group strives to be positioned centrally in the measurement of neutrino oscillation parameters and it will pursue a three-prong approach to that end: **McCauley** will continue to lead the ν_e measurements developing event selections of increased sophistication along the yearly analysis improvement cycle in T2K. **Mavrokoridis** and **Coleman** will concentrate on cross-section measurements, initially pion production in charged current events. At a later stage they will study neutral current events. This measurement in the Near Detector is important as it can be compared to the same measurement in SuperK to put limits on possible oscillations to sterile neutrinos. **Payne** will continue work within the T2K fitting group for the 2012 and 2013 analysis cycles where the fits utilized will use both the momentum and direction of the charged lepton in the near and far detectors and also allow a number of systematic errors to float in the fit. The group's aim is that the T2K neutrino mixing fits in 2012 and beyond will have substantial direct Liverpool input. **Touramanis** will be coordinating these efforts and determining the detailed group strategy to achieve the group's goals, and he will directly contribute to the global fitting work. All group members will also devote some of their time to evaluate and adapt their analyses for antineutrino running which is tentatively planned from 2014 onwards.

SNO+ Experiment

Current Activities

As the experiment progresses towards first data taking in 2012, **McCauley** has taken on the role of co-chair of the data flow group which responsible for the safe passage of data from the DAQ system to the surface and to external storage sites for permanent archive. He is responsible for all SNO+ data and Monte Carlo processing which will be carried out at multiple international sites. In 2011 **McCauley** designed and wrote the data system and scripts for the safe and reliable transport of data. SNO+ is proceeding well, the refurbishment of the SNO detector hardware is coming to its completion and the first SNO+ data taken with water fill is expected in the first half of 2012, with scintillator fill occurring later in the year.

SNO+ Leadership		
McCauley	Co-Chair Data Flow group	2012-

SNO+ Proposed Programme

Introduction: The group, consisting of **McCauley**, the proposed **PDRA**, and at least one student from the Liverpool STFC quota, will spend approximately half its effort on their core software obligations to the collaboration and the other half on the search for neutrinoless double-beta decay.

Core Software: When the first data is collected the data transport and archiving scripts that have been written must be running and fully operational. These first data will provide the final test of the dataflow system and this will require careful monitoring and support. In addition to the data transport scripts the data processing machinery will also start to be used at this time. The data flow group is adapting the SNO data processing code and infrastructure, which was designed and led by **McCauley** for several years, to SNO+. This infrastructure is being updated to improve upon issues discovered in its use on SNO and to support the new computing infrastructure that we now have access to such as the grid in the EU. The proposed Liverpool SNO+ PDRA working with **McCauley** will work on these improvements to the system and on the day to day maintenance and running of data processing for SNO+.

Physics: SNO+ will search for the neutrinoless double beta decay of ^{150}Nd. This can tell us about the absolute neutrino mass scale and can answer the question are neutrinos their own anti particle. The decay manifests itself by an energy deposit of 3.4 MeV in the liquid scintillator from the two electrons. To discover this decay background must minimised in this region and measured as accurately as possible. The expected distribution of signal and background in this region is shown in Figure 13. The background from two neutrino double beta decay can only be reduced by minimizing the energy resolution and the energy scale and resolution across the detector must be understood as accurately as possible. The proposed Liverpool PDRA (**RA-5**) will work with **McCauley** who has extensive experience with the SNO detector to improve the reconstruction in the region of the ^{150}Nd end point. This would lead to a reduced and better understood background in the search for ^{150}Nd double beta decay.

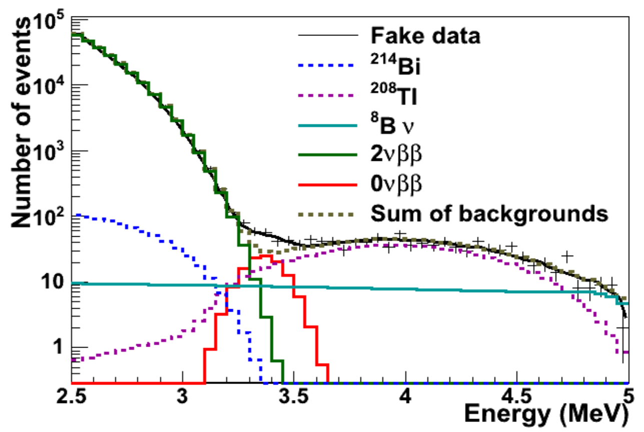

Figure 13 Distribution of signal(red) and backgrounds.

Neutrino Detector R&D

Current Activities

Liquid Argon: **Touramanis** initiated and is leading this activity since 2009. **Mavrokoridis**, on University funding for one year, with support from **Carroll** and the **workshop** staff designed, constructed, and commissioned a 250 lt Argon bath with an inner chamber volume of 40 lt. The system utilizes a novel, simple, cost-efficient liquid recirculation system and active copper / molecular sieves purification cartridge, all constructed in-house. After commissioning the chamber was operated with LAr, using a cryogenic PMT and alpha and gamma sources. The group demonstrated the effectiveness of their recirculation-purification system, and obtained results on the timing characteristics of the scintillation light emitted from alpha and gamma particles in liquid and gaseous Argon (Pulse Shape Discrimination) which were presented by **Mavrokoridis** in GLA2011 and published[1]. A high voltage field cage for ionisation charge drift has been constructed and is being commissioned.

Figure 14: The Liverpool LAr Chamber

The group is collaborating with ETH and CERN. Our group provided an Argon purity measuring system using PMTs and alpha sources, fully designed and constructed in house, which was used in a 6 m^3 vessel at CERN to demonstrate that Argon purification to the extreme levels (ppb) required for LAr TPC operation can be achieved without evacuation before filling. The results[2] were presented for the first time at GLA2010. This demonstration resolved years of debates between experts worldwide on the necessity of evacuation before filling to achieve high purity, something that is impossible in most giant LAr TPC designs. The purity measurement system was designed by **Mavrokoridis** with engineering drawings by **Carroll**. The special cryogenic PMT voltage divider was designed and produced by **Smith**, and the mechanical structures were made by the **workshop**. **Mavrokoridis** and **Coleman** have commissioned and operated the system at CERN.

The group has expertise in all aspects of detection of Argon scintillation light (128nm) using TPB as wavelength shifter, and the handling and evaporative deposition of this directly onto PMTs and on reflective surfaces, as presented by **Mavrokoridis** in GLA2010. Together with collaborators including ETH, Saclay and KEK the group has proposed a 10 ton prototype to be constructed at CERN and tested with charged particles in an SPS Testbeam.

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[1] K. Mavrokoridis, *et al.*, Argon purification studies and a novel argon re-circulation system, JINST **6**, P08003 (2011).

[2] A. Curioni, *et al.*, Towards a liquid Argon TPC without evacuation: filling of a 6 m^3 vessel with argon gas from air to ppm impurities concentration through flushing, J.Phys.Conf.Ser. **308**, 012024 (2011).

Neutrino Detector R&D Proposed Programme

LAr-TPC: The group is now preparing for full TPC double phase (liquid-gas) mode operation of the 40 l chamber. **Mavrokoridis** and **Touramanis** are driving this activity. The **workshop** has completed the field cage for ionisation charge drift using a 22 kV potential based on the detailed mechanical design done by **Carroll** and electrical design by **Smith**. Double phase operation with charge drift and extraction to the gas phase is being commissioned and validated using the S1/S2 scintillation light detection.

The next step will be the installation of micromegas charge readout devices of a new type (microbulk) which, together with their associated electronics and readout, will be provided at Liverpool by our Saclay collaborators, and the characterisation of these detectors.

Large Scale Prototypes: In the longer term the group is pushing the construction of a ton-scale chamber for tests with low energy beams at the SPS at CERN as a test bed for all the relevant techniques (Argon recirculation and purification, charge drift and readout, triggering). Between that and a full-size device (GLACIER in Pyhasalmi) there has to be an intermediate step of a (one to few) ktonne device as a demonstrator and for physics. Options for this, preferably at CERN but maybe at FNAL, are being developed and discussed with partners and with the laboratories at high level.

A proposal to STFC, together with other UK groups interested in LAr, will be submitted when a concrete international plan has been established.

Future Neutrino Experiment – LAGUNA

Current Activities

LAGUNA was an EU-funded design study for a large European underground facility for Grand Unification (proton decay) and neutrino astrophysics in 2008-11. Liverpool collaborates closely with the consortium since 2009 on initiatives towards forming and promoting a neutrino programme for Europe, where **Touramanis** had a prominent role at CERN (organizer of the CERN "Beyond the LHC landscape workshop" neutrino session and the "Future neutrino programme workshop" in 2009, member of the CERN SPSC). This Liverpool activity is based on the local LAr programme described under "Neutrino Detectors R&D" in this submission.

Liverpool joined the enlarged consortium LAGUNA-LBNO and played a big role in preparing the successful EU FP7 proposal, specially in the area of Long Baseline Neutrino Oscillations. **Touramanis**, **McCauley**, **Coleman**, **Mavrokoridis** attended the kick-off meeting at CERN in October 2011, and **Touramanis** gave the LAGUNA-LBNO talk at the NNN workshop in Zurich in November.

Future Neutrino Proposed Programme

Design Studies: According to their obligations agreed under the project work plan the group will concentrate on two aspects of the design study: **McCauley**, **Coleman** will perform studies on simulation for the near detector which is not specified at this point in time, using experience and tools from T2K. **Mavrokoridis** will contribute to the study of all aspects of the long-term operation and maintenance of the underground facility in the case of a giant LAr (GLACIER) detector. **Touramanis** will participate in the near detector studies and oversee both activities.

GENERIC SI R&D

CURRENT ACTIVITIES

Liverpool is maintaining a leadership position, nationally and internationally, in the investigation of silicon sensors for a range of applications. This position at the frontier of research in silicon sensors has been a strong feature of the group for many years.

n^+p technology: In particular the radiation hardening studies of n^+p sensors, that were proposed by Liverpool, are continuing with significant success. The group has established the accepted figures for the degradation of the charge collection of segmented silicon sensors as a function of hadron fluence that is driving the sensor choices for the upgraded experiments at the HL-LHC. Our systematic measurements of doses exceeding 2×10^{16} 1 MeV equivalent neutrons (n_{eq}) cm^{-2} include sensors from different manufacturers and show a coherent picture of the charge collection degradation. Figure 15 shows a compilation of our measurements with detectors supplied by Micron Semiconductor (UK), HPK(Japan), Centro Nacional De Microelectronica (CNM, Barcelona) and e2v(UK). This detailed investigation was conducted using devices designed in Liverpool and fabricated as part of the RD50 programme by Micron, CNM, e2v and sensors produced by HPK. Liverpool physicists (**Affolder**, **Allport**, **Casse**, **Dervan**, **Greenall**, **Huse**, **Tsurin**) have performed this campaign of measurements using the **LSDC**. [1-6]

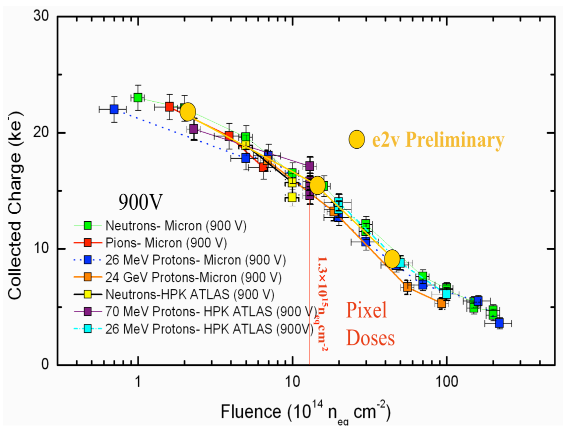

Figure 15: Liverpool results on charge collected from irradiated planar

Our studies revealed a radiation tolerance superior to expectation. The measured collected charge is well above the signal estimated by taking into account the charge trapping at radiation induced defect centres.[7] This higher signal has been documented to be due to charge multiplication[8] through impact ionisation from hot electrons drifting in the high, non-linear electric field near the n^+ electrodes of heavily irradiated silicon sensors. A convincing proof of this effect is shown in Figure 18, where the expected signal calculated including the trapping, the total ionised charge in a 140 µm thick sensor and the signal measured with irradiated 140 and 300 µm thick sensors are compared.[9, 10] The charge measured with the 140 µm thick sensor after irradiation with reactor neutrons to 5×10^{16} n_{eq} cm^{-2} exceeds by a factor of two, at high voltage, the charge produced by the minimum ionising particle indicating that impact ionisation is taking place. We have pioneered the studies of this effect and have designed the mask that has been used by Micron Semiconductor to produce miniature sensors that will be used by the institutes participating in RD50 for the future studies of this effect which seminal to the performance of the sensors chosen for the HL-LHC.[11]

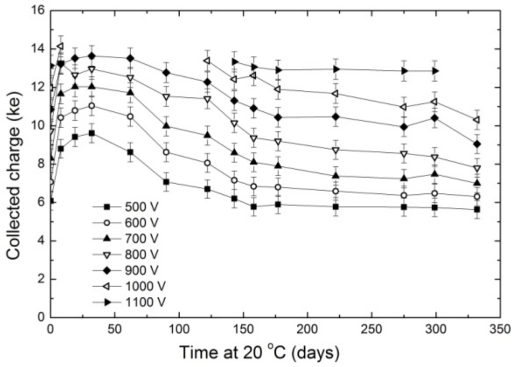

Figure 16: Signal as a function of time at RT (20°C) of an n-in-p Si microstrip detector irradiated with 26 MeV protons to 2×10^{15} neq cm^{-2}.

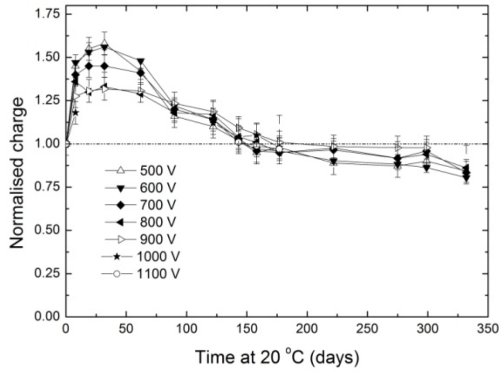

Figure 17:the changes of the collected charge relative to its value at the end of the irradiation.

Charge Multiplication: In collaboration with CNM (**Casse**) we have designed sensors for enhanced charge multiplication. The idea was to modify the geometry of the junction to shape the electric field to increase the impact ionisation. We explored two technologies: a trenched junction and a deep p-doping diffusion under the implanted strips. The trench is etched (with various depths from 5 to 50 µm) at the centre of the n^+ implant of every strip to increase the gradient of the electric field. The preliminary results from measurements performed at Liverpool (**Huse, Tsurin**) after irradiation show that the manipulation of the electric field by shaping the collecting electrode has an effect on the impact ionisation and therefore on the collected charge. This is the first time that measurements have demonstrated the charge multiplication effect in irradiated silicon detectors can be manipulated. Figure 19 shows that irradiated trenched devices exhibit a substantial improvement over reference sensors. Further studies are planned to improve the control of charge multiplication effect.

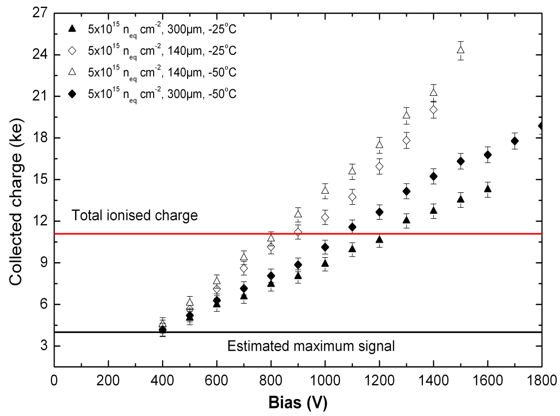

Figure 18: Charge collection as a function of the bias voltage (CC(V)) of proton irradiated n-in-p microstrip detectors (140 and 300 µm thick) after 5×10^{15} neq cm^{-2}.

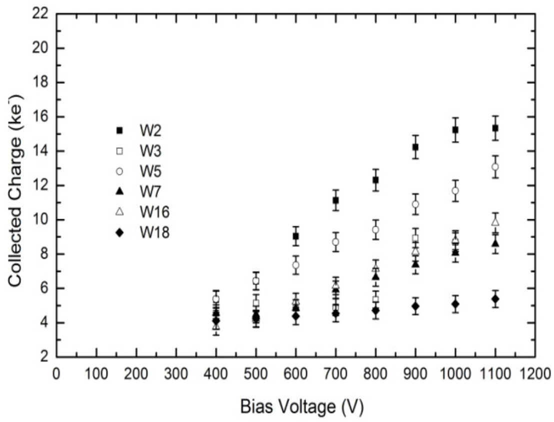

Figure 19: CC(V) characteristics measured at -25°C for standard (W7), 5 µm (W2) and 50 µm (W5) trenched and deep diffused (W16, W18) detectors, after 20×10^{15} n_{eq} cm^{-2}

Annealing: We were the first to measure and report that the long-term annealing in n-side readout segmented silicon sensors does not lead to catastrophic loss in signal, as might be expected from lower dose studies of depletion voltage degradation. We have established that, depending on the dose, a recovery of up to 150% of the signal is possible (Figure 16and Figure 17) with 30-50 days of room temperature annealing, with a simultaneous reduction of about 40% of the reverse current. We have performed studies using the accelerated annealing at elevated temperatures and actual room temperature

(R_T=20°C) annealing. Our results, obtained at R_T, are already informing the operation of experiments concerning the sensor temperature during the shut-down periods of the LHC (LHCb VELO, CMS and ATLAS pixels)[12-14].

Pixels: We have been studying radiation tolerant pixel sensors having previously obtained STFC PRD funding (**Casse**). The results have contributed to driving the international pixel community choice of n-in-p pixels. We were the first to accurately study the charge sharing between pixels at very high doses (2×10^{16} n_{eq} cm^{-2}) thanks to unique specially designed devices capable of full analogue readout (**Casse, Tsurin**). Our specially designed sensors allowed the study of charge collection and charge sharing with pixel detectors connected to analogue electronics, developed for microstrip sensor readout, to assess the properties of pixel sensors after irradiation decoupled from the effects on the readout chip. The ability of decoupling the post-irradiation performances of the detector and the ASICS has been a problem for many years. This technique has put us into a prominent position for the pixel studies for detector upgrades in the UK (**Casse** is the task leader for the planar pixel sensor upgrade of the ATLAS SCT, and leads the LHCb planar silicon technology).

Medical Applications: The group has utilized STFC developed detectors for medical physics. The first involvement was the successful use of a LHCb VELO module for measuring the beam intensity cross section and position in the opthalmic cancer treatment facility at Clatterbridge. The Clatterbridge Centre for Oncology (CCO) is the only facility in the UK using an MeV energy proton beam from a cyclotron for hadron therapy. Accurate, real time monitoring of the beam intensity and position is a major challenge for this type of facility and the use of high precision, high radiation tolerant and high speed silicon detector modules made for LHC experiments are suitable for this application. On the basis of the success of these measurement a beam monitor has been commissioned being assisting the accelerator operations (**Casse** and **Smith**).

Generic Si R&D Leadership		
Casse	RD50 Detector Systems Coordinator	2012-

[1] A. Affolder, *et al.*, Collected charge of planar silicon detectors after pion and proton irradiations up to 2.2 x 10^{16} n_{eq} cm^{-2}, Nucl.Instrum.Meth. **A623**, 177-179 (2010).

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[13] G. Casse, *et al.*, Annealing at different temperatures of silicon microstrip detectors after severe hadron irradiation, IEEE Trans.Nucl.Sci. (2012).

[14] G. Casse, *et al.*, Changes of the particle detection properties of irradiated silicon microstrip sensors after room temperature annealing, JINST **6**, C11022 (2011).

GENERIC SI R&D PROPOSED PROGRAMME

UK Large Area Devices: Liverpool will bring to completion the study of the large area micro-strip sensors (10×10 cm2) developed in collaboration with e2v Technologies to prove the capability of a large capacity manufacturer to produce world quality radiation hard silicon detectors for future collider (HL-LHC) applications. This enables UK PLC to bid for future CERN contracts for 100 m2 detectors, a market previously dominated by HPK. This programme is critical to the long term strategic entry of the UK into this domain. The activity will be carried out by comparing the quality of the large area sensors made by e2v Technologies with the current standard represented by HPK sensors. The irradiation campaign will take place at the CERN-PS facility for irradiation of large area silicon sensors (10x10 cm2) using the system made by Liverpool (**Dervan**) and collaborators. The measurements (**Casse**, **Dervan**) will be performed using the LSDC facilities using the techniques established for the detector studies and that are used for testing the large area HPK sensors.

Charge Multiplication: We will continue, in our leadership position, to study the charge multiplication in irradiated segmented silicon sensors to find the optimal implant geometry for the design of radiation tolerant silicon sensors. This is one of the main line of investigation towards ultra-radiation hard sensors and it involves many institutes worldwide. Many of these groups will use detectors produced by Micron Semiconductor according to a Liverpool (**Casse**, **Tsurin**) design. We will coordinate the irradiation and measurement campaign and lead the data collection and analysis (**Casse**, **Dervan**, **Tsurin**). On another front, we obtained the first evidence that charge multiplication can be engineered by modifying the junction geometry of segmented silicon sensors with the trenched and deep diffused strip designed by Liverpool and produced by CNM Barcelona. We will continue to develop these technologies with CNM with a new production of sensors with ampler design variations (**Casse**). Our investigations for the optimisation of the charge multiplication effect will provide the definitive data for the design of detectors for future super-colliders for high energy physics.

Pixels: This technology underpins the developments for the upgrades to ATLAS and LHCb. Experimental specific developments and are discussed later. As part of our generic R&D in this area we will develop large pixel sensors (Dervan) with special connectivity (Casse, Huse, Tsurin) to decouple the size of the sensing element from the size of the readout electronics ASIC. This development targets particular geometry needs (like the forward pixel disks anticipated in application like the LHCbVELO and ATLAS forward etector upgrades). Besides these application, it will allow using pixel sensor for a wide range of application where relatively large 2d detectors are needed (e.g. medical or industrial imaging). We will investigate four side buttable devices through reduction of the inactive area next to the detector edge and edge electrical passivation . We will develop, with industry, the through silicon via technology and exploit our results for producing sensor capable of large area coverage with almost full efficiency on a single layer.

Hadron Therapy: We will develop sensors for hadron therapy applications: beam monitors and micro-dosimeters for tissue equivalent phantoms. In particular the proton therapy beam monitor activity (Casse, Huse) and the development of the novel, high energy and position resolution tissue equivalent will continue with tests in the CCO. We (**Casse**, **Huse**, **Smith**) will study sensors with different thicknesses (from 50 to 2000 micron) for optimised performance whether the sensors are used as microdosimeters, proton counters or end of range energy measurement.

Neutron Detectors: We will explore the use of Si as neutron detectors (**Casse**, **Smith**, **Tsurin**) with a view to replacing 3He devices as neutron counters and for neutron crystallography. This development will be important in view of covering large areas for various applications including: medical physics, homeland security, and experimental physics.

ATLAS UPGRADE

CURRENT ACTIVITIES

The current ATLAS Semiconductor Tracker (SCT) is an array of microstrips with area 61 m^2, providing the main momentum measurement and much of the pattern recognition for charged particle tracks in the experiment. The SCT Endcap engineering was led from Liverpool and Endcap-C construction was based there. Liverpool personnel led the SCT sensor R&D, the forward module programme and Endcap-C assembly, engineering and commissioning at CERN. Of the total of 2 200 forward modules, 400 were wire-bonded at Liverpool and over 1 000 were tested here. Liverpool continues to play a prominent role in many aspects of the SCT operations, including many aspects of the understanding of the changes in tracker characteristics after irradiation which has been theoretically modelled by **Dervan** and compared by him with increases in detector leakage current. The agreement with predictions here is remarkable and **Dervan** represents ATLAS SCT on the inter-experiment (ATLAS, CMS, LHCb) task force, to monitor radiation effects. He is also responsible for coordinating the UK irradiation programme for the tracker upgrade and overseeing the facilities at CERN which have now been used to understand the changes in the current SCT modules as a function of relatively low doses. The interstrip capacitance and noise as a function of fluence have now been measured on SCT forward modules in an irradiation PCB frame designed by **Greenall** (ATLAS UK Hybrids Task Coordinator) and results are being evaluated by **Dervan** and **Casse**. The understanding of the changes in noise seen on the tracker in the current experiment depend critically on these studies.

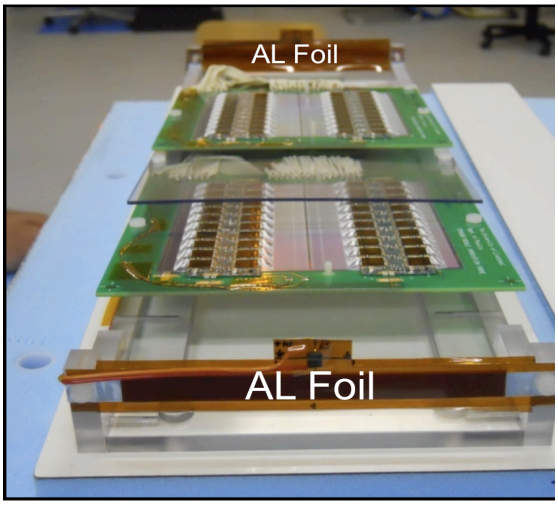

Figure 20: Liverpool ATLAS upgrade prototypes

The ATLAS UK Tracker Upgrade programme : this was initiated by **Allport**, who also led the UK upgrade programme from 2007 to 2010 and has been Upgrade Coordinator for the entire ATLAS Experiment at CERN since early 2011. Key to this role has been the work on design and testing for extreme radiation of planar silicon detectors with **Casse** (now Co-spokesperson of the CERN RD50 Collaboration and leader of ATLAS UK Upgrade Strip Sensor Development Task), **Dervan**, **Greenall, Tsurin**, and **Wormald**, and the contributions by **Affolder**, **Carroll, Greenall**, **Jones**, **Wormald** and **Whitley** to the development and testing of the world's first prototype ATLAS upgrade stave modules and corresponding support structures and cooling. This work has relied heavily on the unique facilities of the **LSDC** and **workshop** at Liverpool, as well as the design and thermal simulation activities of **Carroll** and **Sutcliffe**.

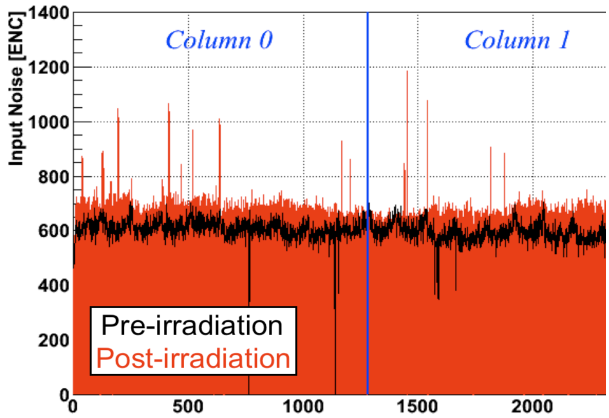

Figure 21 Noise pre and post irradiation on ATLAS prototype hybrids.

p-type Silicon: Liverpool have initiated and led the studies which have established p-type silicon[1] as the baseline for the replacement ATLAS Tracker (**Allport**, and **Casse**) and much of the work on both pixel and micro-strip planar sensor irradiation has been carried out at Liverpool.[2] Detectors designed by us with Micron Semiconductor (UK) Ltd and e2v technologies plc (**Tsurin**), as well as sensors from Hamamatsu Photonics and other international suppliers have been evaluated for charge collection (with 25ns 128 channel LHC ASICs) and IV characteristics, both before and after a wide range of doses, using the ALiBaVa read-out system we designed with Barcelona and Valencia. A compilation of results from Liverpool spanning the doses expect for strips and pixels at High Luminosity LHC for up to 3000 fb^{-1} and pixel radii down to 3cm, is presented in Figure 15. First results after irradiation of miniature micro-strip detectors processed with the new potential UK supplier, e2v technologies plc, are superimposed on those from other, more established suppliers (**Affolder**, **Allport**, **Casse, Tsurin**).

Modules: The Liverpool group has both designed the low-mass module in use for the ATLAS Stave and designed and produced all the low mass kapton hybrids with Stevenage Circuits UK (**Greenall**) using mass production techniques with a view to final assembly requirements. The hybrid circuits, each carrying 20 FE ASICs (ABCN250) and support electronics, are a multilayer low-mass flex circuit produced and tested in panels of seven hybrids, which have the full routing to electrically test all the circuits with the ASICs and surface mount components all glued and bonded with a stiff fibre-glass substrate. The flex tapes are then detached, lifted by the vacuum jigs contacting the passivated ASIC surfaces, glue applied through a stencil to carefully design thickness and pattern, and finally precision placed in pairs on the sensors which have four rows of 2.46 cm long 74.5 µm pitch read-out strips. The entire precision assembly tooling was designed by **Carroll** and constructed in the **workshop** with close iteration with **Wormald** to define all the bonding jigs and supports[3]. The precision module assembly is carried out in the Class-100 area of the **LSDC** under the supervision of **Affolder**, who coordinates the international ATLAS module programme and is deputy coordinator of UK Upgrade Workpackage 2. All the current stave modules in use for serial powering, DC-DC testing and the different stavelets have been produced at Liverpool.[4, 5] Copies of all the Liverpool tooling have been provided by us to Cambridge, Glasgow, Freiburg, DESY, LBNL, UC Santa Cruz and Valencia. Other module sites are starting to also produce high quality single-sided modules for stave assemblies and those sites targeting the forward region are learning module production with barrel modules prior to assembly of forward specific prototypes.

Irradiation: In addition to the module irradiation programme for current ATLAS, and a vast number of irradiated miniature sensors and several large area sensors, all scanned in the CERN PS test-beam using mechanics designed by Liverpool, we have now irradiated a fully equipped prototype ATLAS module (**Dervan**, **Casse**, **Greenall**). The two fully functional electrical modules shown, with the flex circuits glued the sensors as in the final proposed configuration, were irradiated well beyond the design specification of $1.3\times10^{15}\ n_{eq}cm^{-2}$, to $1.9\times10^{15}\ n_{eq}cm^{-2}$. Even though the detectors were tilted to allow more efficient use of the 24 GeV/c PS beam, several weeks were needed to achieve the required doses. Since results with neutrons from the Ljubljana research reactor, and lower energy protons at Karlsruhe give very consistent results when corrected for non-ionising energy loss, we (**Dervan**, **workshop**) have also, with Sheffield, been establishing a UK irradiation facility for faster turn-around based on the University of Birmingham synchrotron.

The results (Figure 21) show for the 2560 strips of a complete hybrids (2 rows of chips) noise increase at a low level, compatible with just the shot noise increase due to the much greater leakage current after irradiation. Even at this operating temperature of about -18ºC, the signal/noise anticipated with the observed signal at 500V after $1.3\times10^{15}\ n_{eq}cm^{-2}$ of 10,000 electrons, is 14 (this at end of life and with an additional factor of 2 safety applied to the anticipated dose). Lower temperature operation will only further improve this.

Staves: During the period of this grant, the Liverpool group (in particular **Carroll**, **Jones**, **Sutcliffe**, **LSDC** and **workshop**) have played a major role in the development of low mass local support structures (staves) for the strip tracker upgrade. In general a stave consists of two carbon-fibre face sheets separated by a core composed of thermally conducting foam and low density honeycomb.

The group have been responsible for the documentation of the UK stave core design, the procurement of carbon-fibre pre-impregnated fibre, thermally conducting foam and low density honeycomb materials from the vendors (and the distribution to other UK groups) and have been instrumental in driving forward the stave core thermo-mechanical design. Members of the group have contributed to the materials properties knowledge base through mechanical measurements of carbon-fibre test coupons and have applied the transient hot-wire technique to measure the thermal conductivities of glues before and after irradiation. During summer 2011 the group irradiated several CFRP sandwich structures which will be used to verify the properties of the construction materials, in particular the adhesives, after irradiation.

Several prototype short staves (stavelets) have been manufactured to support the international electrical module programme and to provide a vehicle for general stave core thermo-mechanical development. These structures have been fully evaluated in thermal and mechanical test systems developed at Liverpool. In conjunction with this work an extensive programme of thermal FEA has been undertaken to establish the robustness of the design with respect to thermal runaway. This work has been crucial in understanding how the mass of staves can be reduced to exploit the lower power 130nm ASICs promised for the future. In addition computational techniques have been developed to extract the face sheet and core shear moduli from 3-point bending data and to apply Classical Laminate Theory to understand the design and properties of co-cured face sheets in which the electrical bus tape is laminated to the un-cured carbon fibre pre-preg at high temperature to reduce the amount of adhesive needed in stave assembly. Currently the group are working on the development of improved tooling to manufacture staves (due December 2011) and a prototype carbon-fibre sector onto which several staves can be mounted to evaluate the stave mounting mechanisms and installation procedures (early 2012).

Pixels: Liverpool are also contributing to the design of the Phase-II tracker layout (**Burdin**, **King**). On the pixel upgrade side **Burdin** implemented the conical layout in `PixelGeoModel`. This provided a basis for the forward pixel layout studies which is starting now within the scope of his responsibilities as task manager for the Forward Pixel layout, Mechanics task of UK workpackage 5. The imminent plans include setting a system which would be flexible enough to compare different layouts. We also plan to participate in building and testing of a simple stave prototype (**Burdin**, **Jones**) and in preparation of the UK Pixel Upgrade Project proposal. ATLAS read-out for pixel detectors (FE-I3 and FE-I4) read-out systems have been established and commissioned by **Tsurin** and both unirradiated and irradiated pixel sensors with masks designed by him to ATLAS specifications and for both ASIC layouts, have been fabricated with Micron Semiconductor Ltd and e2v Technologies plc and evaluated at Liverpool. These include the first quad detectors for the Phase-II pixel replacement to be fabricated anywhere in the collaboration (with Micron)

ATLAS UPGRADE Leadership

Affolder	ATLAS Inner Tracker Upgrade Strip Modules Coordinator	2011 -
	Member ATLAS Upgrade Inner Tracker Sub-Committee	2011-
	UK ATLAS Upgrade Work-package-2 Deputy Manager	2010 –
	UK ATLAS Upgrade Modules Task Coordinator	2009-2011
	UK ATLAS Upgrade Work-package 4 Co - Manager	2007-2010
Allport	ATLAS Upgrade Coordinator	2011-
	Member ATLAS Executive Board	
	Member ATLAS Upgrade Inner Tracker Sub-Committee	
	Chair ATLAS Upgrade Steering Committee	
Burdin	UK ATLAS Upgrade Forward Pixel Layout and Mechanics Task Co-coordinator	
Casse	UK ATLAS Upgrade Strip Sensor Development Task Coordinator	2008-
Dervan	UK ATLAS Upgrade Device Irradiation Task Coordinator	
Greenall	UK ATLAS Upgrade Hybrids Task Coordinator	
Jones	UK ATLAS Upgrade Work-package 4 Manager	

[1] P. Dervan, *et al.*, Update of the annealing scenario for irradiated silicon p-in-n microstrip sensors, Nucl.Instrum.Meth. **658**, 2 (2011).

[2] A. Affolder, Latest Developments in planar n-on-p- sensor, Proceedings of Science (Vertex 2011), 031 (2011).

[3] A. Affolder, *et al.*, Design and performance of serial powered single-sided modules within an integrated stave assembly for the ATLAS tracker barrel upgrade, JINST **5**, C12013 (2010).
[4] A. Affolder, *et al.*, DC-DC converters with reduced mass for trackers at the HL-LHC, JINST **6**, C11035 (2011).
[5] P. P. Allport, *et al.*, Progress with the single-sided module prototypes for the ATLAS tracker upgrade stave, Nucl.Instrum.Meth. **A636**, S90-S96 (2011).

ATLAS Upgrade Proposed Programme

Through our leadership in RD50, ATLAS and in the UK planar sensor programme (both pixels and strips) we anticipate playing a major role in the development of sensors suitable for use in the forward pixel system of the ATLAS Tracker Upgrade. We have already designed and prototyped the relevant four chip sensors for this with Micron (all mask layouts designed by **Tsurin**) and have single-chip prototypes produced with Micron and e2v (**Casse**, **Dervan**, **Tsurin**). Other concepts under development at Liverpool (**Casse**, **Tsurin**) are to use routing on-detector or interposer technologies to allow better geometries for the forward region sensor to be used but made compatible with FE-I4 or equivalent pixel ASIC layout.

Modules: The module work will develop increasingly towards establishing production capabilities, but with the important changes that will be required to accommodate the new 256 channel ABCN130 ASIC, with a radically different hybrid layout needed (**Greenall**). This new chip should allow simplifications and greater material reduction within the module (**Affolder**, **Greenall**, **Jones**, **Sutcliffe**) but it will be a major rework of our current designs. Extensive new tooling will need to be designed (**Affolder**, **Carroll**) and it is expected that, as at present, Liverpool will provide the tooling to all ATLAS module production sites to ensure uniformity of quality(**Carroll**, **Whitley**, **Wormald**, **workshop** and **LSDC**). Both current and future module concepts and all the ancillary electronics and mechanics will require exhaustive radiation qualification (**Dervan, workshop** and **LSDC**) with a view to establishing and inventory of radiation properties of key components and materials.

Staves: As the first staves are assembled with the ABCN250 based ASICs, we will both be extremely busy on both the module production and quality assurance for this and in terms of contributions to the tapes (which cannot be designed independently of the flexes) and the stave itself (**Affolder**, **Carroll**, **Greenall**, **Jones**, **Wormald**, **Whitley**, **workshop** and **LSDC**). It is anticipated that we will prototype both further stavelets and staves (**Jones**, **Whitley**, **workshop** and **LSDC**). We have been central through the module work to prototyping both Serial Powering and DC-DC conversion schemes (**Affolder**, **Greenall, Wormald**) and we will be expected to play a central role in the final decision. ABCN130 allows both scheme and since the noise is both ASIC and system dependent (even with the final geometries needing to be faithfully reproduced) these studies will continue well into the new grant period.

Liverpool has the capacity to be a hybrid, module and stave production centre with the unique and closely integrated infrastructure of the **LSDC** and **workshop**, particularly lending itself to the modular construction implicit in the stave concept. Involvement in all three activities gives good use of resources and the possibility of fast turn-around in the case of repairs being needed at any stage in the process. To be able play this role, further infrastructure will be needed to allow stave assembly to proceed at Liverpool. Unlike the SCT case, we do not then envisage currently to be involved in the final integration of a large array but would anticipate providing fully tested staves to other centres.

Pixels: Given that Liverpool really initiated the consideration of planar pixel technology as a candidate for the extreme doses of the HL-LHC, we fully expect to continue to play a central role in the development of disc mechanics for future pixel systems and prototyping of the quad modules which are the current baseline for tiling the pixel forward region (**Affolder**, **Burdin**, **Carroll**, **Casse**, **Greenall**, **Jones**, **Tsurin, workshop** and **LSDC**). Our expertise with low mass electrical circuit (hybrid) design (ATLAS, LHCb, ATLAS Upgrade modules) and fabrication with UK industry makes us uniquely placed to prototype the hybrids and electrical service tapes needed for the pixel discs (**Tsurin**). We will also develop thermo-mechanical modeling of the disc structures to understand stresses and possible deformations with imbedded cooling tubes and different carbon-fibre lay-ups and study global pixel disc supports, along with alternatives technologies which may offer further reductions in material or greater ease of construction (**Burdin**, **Casse**, **Jones**, **Sutcliffe**, **Tsurin**). We will further develop simulation tools to both underpin the layout choices in ATLAS, particularly for the forward pixel region (**Burdin**, **King**), and aim to increasing contribute toward the physics studies which ultimately will help to define the optimal layout and which will play an essential role in the documentation needed for the Phase-II Upgrade work (**Allport**, **Burdin**, **King,** new **RA-n**).

Build and Tracking: It is intended that Liverpool be not only an R&D leader but a major build site internationally for both the hybrids, modules and staves for the barrel tracker (**Affolder**, **Allport**, **Carroll**, **Greenall**, **Jones**, **Whitley, Wormald, workshop** and **LSDC**) and as one of the lead UK institutions in the pixel forward disc production (**Burdin**, **Casse**, **Carroll**, **Jones**, **Tsurin, Whitley, Wormald, workshop** and **LSDC**). Both of these require the continued STFC support of the unique **LSDC** and **workshop** infrastructure at Liverpool and the internationally leading expertise in the group. The current size of the group and anticipated schedule of particle physics programmes for this decade, make such a contribution to both areas natural for Liverpool where much of the prototyping expertise for both resides.

The strip stave build activity will start first and the small pixel programme is expected to start after strip module production is completed. This matches well with our experience of building the ATLAS SCT Endcap-C at Liverpool where module production completed just as LHCb VELO production was starting. The track record of delivering a fully tested and commissioned 988 module 1.5 million channel silicon tracker array and all the LHCb vertex locator modules and much of their support structure (all to time and on budget) for the current LHC (along with ECAL module production for T2K and a number of smaller programmes) is testament to the Liverpool reputation for delivery which is a vital part of the UK's ambitions for continuing to play a central role in the future upgrades of the ATLAS tracking.

Similarly, the UK's vast experience in the current SCT is vital to the upgrade plans at CERN, since without replacement of the tracker, ATLAS cannot operate at anything close to the integrated doses implied by the 3000 fb^{-1} of the current Phase-II LHC Upgrade planning. We are requesting an PDRA (**RA-6**) to support the software for tracking and the build.

LHCb Upgrade

Current Activities

Introduction: An Upgrade to LHCb VELO had been proposed as early as 2005 (**Bowcock**). In 2011 a Letter of Intent (LoI) was presented to LHCC that contained a detailed description of physics case and an outline of the experimental consideration. The Liverpool group has taken a role in developing the technology for a future LHCb VELO. During 2012/2013 LHCb-UK will re-submit to STFC its SOI for the upgrade together with an updated delivery plan for the vertex detector

Upgrade Strategy: In the LHCb LOI two possible scenarios were presented for an LHCb VELO upgrade. First was a small-pixel design, utilizing the VELOPIX ASIC and the second was a enhanced strip design. The three largest UK VELO groups (Glasgow, Liverpool, Manchester) have proposed that the safest route to an upgrade is (mirroring the GPDs) a Phase I upgrade to 40 MHz followed by a Phase II upgrade (2021+) to a full pixel system. Phase I is intended to be a conservative, readily (and cheaply using VELO2 technology) buildable strip solution whose radiation tolerance is limited by existing cooling technology. This will need replacement when the integrated dose at the tips of the VELO reaches ~$3x10^{15}pcm^{-2}$ at the time of the ATLAS Phase II upgrade. VELO Phase II builds, synergistically, with ATLAS pixel developments and our pixel development programme. It will deliver a full pixel detector capable of operating at up to the highest radiation doses at the rates required with a capability of operating at even higher luminosity that a strip detector.

Phase I: The group is developing a viable strip module. In essence this is a development of the original design and will use similar technologies. **Smith**, who designed the original 2 hybrids for VELO (SCT and Beetle ASIC versions) is designing a 40 MHz VELO hybrid (VELO3). He is working with Krakow group, who are designing the replacement ASIC for LHCb to ensure the footprint and power requirements of the new chip match VELO3 requirements, as well as those for the rest of LHCb,. He is acting as a consultant to LHCb on the design of Inner Tracker (IT) hybrids which also utilize the same chip. Prototype testing on the new ASIC will be conducted by **Smith** in tandem with the IT. **Carroll** is designing, and the **workshop** will make modification to jigging to permit VELO3 prototypes to be built. This plan will be presented to STFC in our updated SOI as we are already on the critical time path for Phase I with production readiness being required at the lastest in 2015.

Phase II: The long term future (beyond Phase I) for the LHCb lies in the deployment of a pixel detector. The Group has been active in hybrid-pixels recognizing the strategic importance to the UK of the development of this technology for the LHC. This has been recognised through the award of a PRD Grant for pixel-tiles. The group (**Bowcock**, **Casse**, **Smith**) proposed the development of a generic pixel-tile whose architecture was applicable across a number of LHC experiments and disciplines. Within the VELO Upgrade Pixel Programme (currently led by CERN) Liverpool (**Casse**) is responsible for the Planar Silicon Technologies and for determining the required operating conditions for any silicon device. **Smith** is responsible for the pixel hybrid and is investigating cooling strategies based around TPG and novel engineering techniques. The group (**Cooke**, **workshop**) has investigated the possibility of using CF as a replacement foil – a critical component for the upgrade. They were able to exclude this option in 2011. Early mechanical design for a pixel tile and the pixel layout has been performed by **Carroll**. Layout for VELOPIX compatible pixels have been made by **Tsurin**, and fabricated by Micron Semiconductor. Tests on these pixels using the unique Liverpool analog readout technology are being performed by **Huse**. Simulation of the performance of both the pixel and strip options is being performed by **Hutchcroft**. Studies of heavily irradiated detectors have been performed by the group (**Casse**, **Hennessy**, **Huse**). These are being extended to measure the charge sharing, efficiencies and resolution of LHCb strips and pixels at fluencies of up to 2×10^{16} p/cm^2. A novel readout (for pixels and strips), requiring a third metal layer is being been designed (**Huse**) and is being fabricated by Micron Semiconductor.

GPU Processing:The group (**Rinnert**) is also studying the impact of utilizing GPUs instead of conventional CPUs to reconstruct events much more quickly than with traditional CPUs. A study, including a report on potential architectural changes for processing farms is being prepared.

LHCb Upgrade Leadership

Casse	VELO Upgrade Planar Silicon Coordinator	2011-
Smith	VELO Upgrade Module Coordinator	2011-

VELO Upgrade Proposed Programme

An important step for LHCb-UK will be to obtain recognition as a funded upgrade programme for the LHC. To this end a second SOI will be submitted in 2012. The group expects to be heavily involved in the preparation of the case for the LHCb VELO upgrade. Assuming the programme is approved along the lines described above and limited funding forthcoming, the group will undertake the following up to 2013.

Phase I (Strips): **Smith** with continue to refine the VELO3 hybrid. We will also design and test and qualify the VELO cooling system that can be used for any planar silicon device (**Bowcock**, **Carroll**, **Smith**). Device technology will be improved through designs developed at Liverpool to be more radiation tolerant and have a higher "packing factor" (**Casse**, **Huse**, **Tsurin**). The Liverpool readout system will be used to fully typify sensor technology (**Patel**, **Smith**). Both laboratory and testbeam studies of the sensors and readout systems will be made to qualify technologies for operation in the upgrade (**Hennessy**, **Huse**, **Patel**, **Smith**). The **workshop** and **LSDC** will be used for the building and testing of 2012-2013 prototypes with jigging and assembly effort provided by **Carroll**, **Whitley**, **Wormald**. Simulations of material and tracking reconstruction, based on prototypes, will be performed by **Rinnert** and **Hutchcroft**. **Huse** will be responsible the building of five prototype modules and, as for VELO1 and VELO2, **Patel** will oversee the quality assurance. A final choice of technology is currently expected in 2013 allowing a "fall forwards" to a full pixel solution for 2018. From that point onwards the group will focus on the development of a pre-production prototype module (**Bowcock**, **Carroll**, **Patel**, **Smith**, **Whitley**, **Wormald**) which we expect to be fabricated in the **LSDC** and **workshop** in 2014 with a Production Readiness Review in 2015. Liverpool aims to be a production site for VELO upgrade modules. For deployment/installation in 2018 production would have to start in the **LSDC** and **workshop** in 2016. Contingent to funding by STFC we would expect the group to make a significant contribution to this effort (**Bowcock**, **Casse**, **Carroll**, **Huse**, **Hutchcroft**, **Patel**, **Shears**, **Smith, Whitley,** and **Wormald**)

Phase II (Pixels): Assuming the choice has been made to continue strip development for 2022, or indeed for a 2018 installation the group will continue its programme of pixel development. **Smith** will continue to develop a pixel hybrid. **Carroll** and **Sutcliffe** will mechanically design and thermally model this hybrid. The existing VELO team (**Huse**, **Whitley**, **Wormald**) will build prototype pixel models to establish itself as a site for pixels (as well as strip) building for LHCb. The **LSDC** and **workshop** will construct the pixel module supports based on the expertise gained from VELO1 and VELO2 construction.

Simulation and Software: The physics impact of different designs will be studied by **Bowcock** and **Shears. Hutchcroft** and **Rinnert** will develop tracking and reconstruction algorithms for these upgraded detectors. If our GPD studies in 2012 are successful then further development work GPUs will be performed. Together with an existing consortium, which includes UCD Computer Science Dept and industrial partners, **Bowcock** and **Rinnert** will build and a prototype processing farm to demonstrate the feasibility of a GPU based online/offline system.

FUTURE ENERGY FRONTIER EXPERIMENT – LHEC

CURRENT ACTIVITIES

The Large Hadron electron Collider is new facility proposed at CERN by Liverpool. It is envisaged to be operational within the next decade with 60 GeV electron/positrons hitting the one of the LHC proton beams. It will operate synchronously with LHC operation. Within this grant we are asking for very limited support for (**Klein M.**, **Klein U.**, **Laycock** and **Maxfield**) to complete the initial programme of study including updates on the impact on LHeC on CERN's Higgs programme. Should the LHeC become and approved CERN project the UK will request funding from STFC to prototype a vertex detector/tracker which would part of the detector project Liverpool would expect to lead.

LHeC Leadership		
Klein M.	Project Leader	2009-

LHEC PROPOSED PROGRAMME

No major consolidate grant funding is requested during this period although we ask for sufficient academic time to ensure the continued UK leadership of the project and its physics.

AstroParticle Physics – CTA

Current Activities

SST Camera: The scientific and technical focus of the UK groups in CTA is on the high energy (1...300 TeV) component of the array, that is, the Small-Size Telescopes (SSTs). The SST design proposed by the UK uses dual mirror Schwarzschild-Couder (SC) optics, with the first optical calculations being performed by **Greenshaw**. The greater sophistication of SC designs compared to current single mirror Davies-Cotton (DC) telescopes allows better correction of optical aberrations and hence a smaller focal ratio (f = F/D, where F is the focal length and D the diameter of the primary mirror). This means that, for a given D, driven by triggering requirements, the focal length of the telescope can be smaller and hence a smaller camera can be used to cover the required field of view of 9...10°, allowing implementations with silicon photomultipliers (SiPMs) or multi-anode photomultipliers (MAPMs). Figure 22 shows Point Spread Functions (PSFs) for the UK SC design, from which it can be seen that the telescope performance will allow use of pixels as small as ~6 × 6 mm^2, typical for MAPMs. The use of MAPMs or SiPMs significantly increases the performance per unit cost of the SST array compared to that achievable using DC telescopes with the conventional photomultiplier (PM) cameras these require.

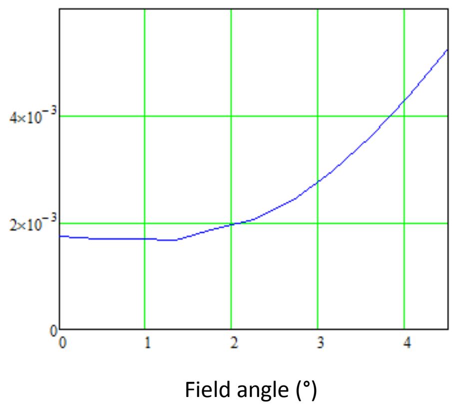

Figure 22 Point Spread Functions (80% containment diameter) for the UK designed Schwarzschild-Couder Small Size Telescope shown as a

The CTA groups in Durham, Leicester and Liverpool are designing and prototyping a camera for the SST. This, a first design of which is illustrated in Figure 23 will be based around MAPMs, but the front-end electronics and mechanics will be designed to allow the use of SiPMs if the price of these continues to fall. A Liverpool engineer (**Sutcliffe**) is responsible for the design of the lid of this camera, which must both protect the sensors it covers from the elements and provide an outer surface which is precisely located (to a few 100 μm over tens of thousands of operations) so that images projected onto it can be used to aid telescope alignment and additional optical instrumentation attached to it is correctly located.A Liverpool funded PhD student is currently extending optical calculations of the SC telescope performance to include the effects of polarisation and measuring the polarising properties of mirrors like those that will be used for the SST to feed into these calculations. The rationale for this programme is that the Čerenkov light liberated in air showers is polarised, and hence these effects must be understood and, if significant, taken into account in the design and operation of the SST.

CTA Proposed Programme

The goal of the CTA-UK collaboration is to ensure that UK physicists obtain complete and early access to CTA data, requiring that we contribute to the design, prototyping, construction and commissioning of the CTA observatory. Future activities in Liverpool and the UK must build on current successes to ensure this is achieved. Furthermore, preparations for physics analysis must now begin to ensure UK physicists are well placed to exploit CTA data as and when it arrives.

UK SST camera: This will be designed under the assumption that the sensors of choice are MAPMs rather than SiPMs, reflecting the current prices of these two sensor types. However, SiPMs could offer significant advantages in terms of performance and robustness and the current trend is that SIPM prices are decreasing. It is therefore important to characterize a range of SiPMs that could be used in the camera, and design also the modifications that must be made to the pre-amplifier and shaper in the FEE to accommodate SiPMs. The Liverpool CTA group propose to study a range of suitable SiPMs and request funding for a Research Associate to support this activity. The information gained will be passed on to the electronics engineers at Leicester so appropriate modifications can be made to the camera electronics. These studies will take about half of the RA's time over the grant period.

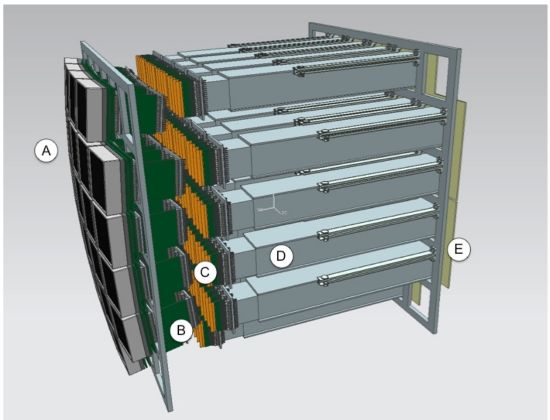

Figure 23: Conceptual design of the SC SST

Preparation for physics analysis: This will be coupled with Monte Carlo studies of the performance of the SSTs within the CTA. These studies will involve assessing the sensitivity of CTA to various astrophysical and fundamental physics phenomena and investigating how this is influenced by the configuration of the array. They will be carried out by a CTA Research Associate who will be funded by Liverpool University for three years from early 2012, Joanna Darling (PhD student) and the above-mentioned RA. Phenomena to be investigated include searches for axion-like particles and study of the Extragalactic Background Light (EBL). This work will be led by **Greenshaw**.

Very high energy (VHE) cosmic gamma rays travelling through the cosmos can convert to electron-positron pairs via scattering off the EBL, limiting their range. If photons are observed to reach the Earth from high red-shift objects, this suggests these photons are converting to axion-like particles (ALPs) in the galactic or inter galactic magnetic fields close to their production points, travelling towards the Earth, and then converting back to photons in the magnetic fields closer to or in our galaxy, a cosmological version of the "light shining through a wall" experiment.

Even if no axion-like particles are observed, studying VHE photons from remote sources is of great interest as it provides a measurement of the density of the EBL. This is the integrated flux from all light sources that have been present in the universe, including for example the first stars, and can thus provide unique insight into aspects of the history of the universe. Studying the EBL directly, particularly in the UV to IR range, is difficult because of the strong foreground emission, so studies using VHE photons as a probe are of particular interest.

Dark Energy

Proposed Programme

The initiation of apparatus construction began in mid 2010. The overall program calls for the construction, testing and use of the single interferometer system within two years, with publication of initial results, the measurement of "*g*".. Construction and commissioning of a double arm system (**Coleman**) will occur in the third and fourth year. The fifth year will see a mature experiment with increased sensitivity, and with an eye on the future horizon for bigger and more sensitive equipment for precision studies. Thus our research program has three parts. The first two years will build our collaboration into an experienced atom interferometry group. Then with the knowledge and experience gained we will begin to build and use our double interferometer apparatus, at the same time looking towards a next generation experiment with more than an order of magnitude increase in size. Each year will see the publication (as a measure of milestones achieved) in the relevant physics or instrumentation journals as well the presentation of results at major conferences.


Figure 24: Atom trap under construction at Liverpool

Computing and Grid

Current Activities

GRIDPP: The group has invested substantially in IT resources to allow the Physics exploitation of the data. The majority of the processing is done on the Grid as part of the GridPP project, Liverpool is a Tier 2 site with a very high efficiency for completing jobs (one of the highest in UK(, of which around 80% are for the ATLAS collaboration.

Hammer: Last year, led by **Hutchcroft**, a University initiative funded the replacement of MAP2, a cluster of 1500 3GHz Xeon processors, with our new cluster dubbed Hammer. Hammer has greater performance than MAP2, using eight chassis each with 64 cores on four motherboards. The reduction in power usage which we were able to demonstrate meant the upgrade paid for itself within seven months in reduced power bills. Hammer is largely dedicated to GRIDPP.

HEP Clusters: We also have set of computers dedicated to interactive and batch processing for departmental staff, these are based in the computer room, but also the queues run on the 40 quad core desktop computers installed for all staff increasing the resources available to staff for Physics processing. The batch nodes, totalling 72 cores, when not fully loaded by the Liverpool staff also process grid jobs. All computers are running SL5 64bit (with a handful of legacy nodes running SL5 32bit) to maximise the compatibility also they all have the request 4GiB of memory required for the current generation of ATLAS jobs. There is 540TB of disk space for GridPP data storage and further 2TB for the software installations, an additional 60TB is available for the local users. All of the services are protected with 6 uninterruptable power supplies each rated at 6000VA. These systems are operated and maintained by **Bland**, **Fay**, **Jones**, with **Muskett** providing technical effort.

GPU Development: There is also a dedicated system for GPU software development with a multi-GPU Tesla installation that is used as a test-bed for the technology. Both LHCb (**Rinnert**) and ATLAS (**King**) have developed code for the GPU system and benchmarked it against standard CPU.

Computing and GRID Proposed Programme

System management: This will performed by **Bland** and **Fay** funded on the HEP grant and **Jones, S.** who is be joined by **Norman** funded on the GridPP. The system has extensive monitoring installed by the local team, with Ganglia and Nagios monitoring available for each node which are also published though the central UK grid monitoring sites to the world. Many of the systems providing specific services, for example email and web hosting, are now consolidated into a few machines and run as virtual machines. This minimises the number of physical system while still providing the ability to reconfigure specific hosts as required. The network topology is based around an E600 Force10 switch which uses bonded 1Gb links to the racks for CPU nodes and specific bonded links to the disk server nodes. The University is completing a complete network rewire of the Oliver Lodge Laboratory which will provide 1Gb links to all offices and in the near term will provide a 40Gb campus wide network mesh that cluster room will be part of.

We have been very successful as a GridPP site going from 0.75 to 1.8 posts in the last grants round and we have expanded the CPU and disk provision with each funding round.

General Tasks: There are around 150 computers used by the HEP users most are desktops and laptops for general purpose use, others controlling DAQ systems and the equipment in the LSDC. A small number of pool laptops are also maintained as temporary spares and to borrow for travelling, a few desktop systems are also kept to replace faulty systems. Tasks performed by **Bland** and **Fay** include:

1. Maintain, support and purchase the heterogeneous mix of Windows, Mac and Linux machines used by HEP personnel.

2. Replace every system not directly controlling hardware every four years. For the Linux desktops we have a standard system to maximise the availability of spares and the ability to have a single disc image suitable for every system.
3. Provide the backup and archival services to both the local users and the Grid.
4. The network both in the cluster room and in the building topologies will continue to be evolved to optimise the through put of the high IO intensive jobs. The recent building network rewiring will provide 1 Gb links to each office, the University has agreed to provide dedicated switches for the machines acting as part of the computing cluster.
5. Integration of the University and our local systems into common VLAN topologies.
6. Updating and extending the UPS system protecting the hardware from damage and data loss in the event of power loss.

R&D: The core of our R&D for computing is focused on GPU systems. Supporting developments on LHCb and ATLAS, **Bland** and **Fay** will continue to test new configurations of GPU clusters. The aim is integrate custom made GPU cards (designed in Dublin, and produced by an industrial partner) within a high performance switch chassis to attempt to increase data flow to and from the GPUs.

Other Current Liverpool Grant Support

Current support for the Particle Physics Programme is summarized below Table 2. The total current grant support totals £,12,044,974,55 (@ 100%)

	Grant Title	Start Date	End Date	Funding Body	Reference	Amount	% Total
Core Programme	Search for Quarks	01/11/2009	31/10/2014	STFC	ST/G006717/1	£531.644.38	86%
	Measurement of ν	01/12/2009	30/11/2014	R S	UFO80825	£591,889.64	
	Rolling Grant*2010	01/10/2010	30/09/2102	STFC	ST/H001069/2	£6,630,295.54	
	Grant "top up"	01/02/2012	31/03/2012	STFC	ST/H001069/2	£30,701.25	
	Pan Euro Infrastr.	01/07/2011	30/06/2014	EC	LAGUNA/LBNO	£325,395.12	
	Universal Lepto	01/09/2011	31/08/2016	ERC	268062	£2,068,662.00	
	European Infrastr.	01/02/2011	31/01/2015	EC		£32,465.00	
	Reactor Monitoring	09/01/2012	31/12/2012	STFC	ST/J002909/1	£109,844.38	
Comput.	GridPP: The UK Grid	01/04/2011	31/03/2013	STFC	ST/1003576/1	£349,007.29	6%
	GridPP4 Tranche 1*	01/10/2011	30/03/2012	STFC	ST/J005855/1	£40,500.00	
	GridPP Networking	01/12/2011	31/12/2012	STFC	ST/J005495/1	£118,000.00	
Si R&D	Junction Engineering	01/07/2010	31/12/2013	MICRON	ST/H003924/1	£15,085.00	4%
	High Radiation*	01/01/2009	31/03/2012	STFC	ST/F01157/1	£326,583.00	
	Common Pixel Tile	1/03/2012	28/02/2014	STFC	ST/k000195/1	**£176,093.89**	
Apps	Reactor ν	01/04/2011	31/05/2013	RS		£50,000.00	4%
	MODES SNM	01/01/2012	30/06/2014	EU	EU FP7	**£249,312.00**	
	Tissue Equiv Phanto	01/01/2012	31/12/2012	STFC	ST/J000698/1	£149,496.06	
	Gravitometer	01/03/2013	28/02/2016	AWE		£250,000.00	
Total Support						£12,044,974.55	**100%**

Table 2: Support being received for Particle Physics as of 01/03/2012.Projects marked with an asterix will terminate before the beginning of this request; this is indicated by the lightly shaded boxes above. We also show the fractions of funding received for the core programme, computing, Si R&D and applications (last column). All figures representative of 100%.*

The group is active in pursuing all possible avenues for support for its core programme. Currently we hold ~£200K of support for activities related to STFC technology (Tissue phantom for hadron therapy and Nuclear Reactor Monitoring). A substantial ERC grant has enabled the group to participate in the NA62 experiment at CERN.

Concordat For Career Development

The University of Liverpool fully subscribes to the Concordat Support the Career Development of Researchers. The University has a single spine 56 point salary scale, a copy of which can be found on the University web pages§. The STFC Office and the PPGP should note that the University has decided that all its employees with a PhD or equivalent should be appointed at point 31 or above on this scale.

§ http://www.liv.ac.uk/hr/salary_scales/index.htm

The Liverpool University Human Resources Department[**] has embedded the Concordat on Contract Research Staff Career Management within its employment policies. Contract Research Staff (along with all other staff) participate in an Annual Review with trained senior staff in the Department to review their career development

Projected Spend in the Current Grant Period

The current was two year grant following on from a one year initial grant and runs from 1 Oct 2010 to 30 Sept 2012. Due to financial constraints imposed by STFC on FTE Liverpool was faced by a salary shortfall of £256,000. With the agreement of STFC Liverpool were allowed to spend fund from the one year (2009/2010) award in 2010/2012 grant period providing it was used by March 2011. This permitted us, along with virement from other budget headings, to employ all funded positions at 100% FTE, hence ensuring continuity of core and retained the talent that would otherwise have been lost. The total STFC award, including overheads, 2010/2012 to Liverpool was £6,630.295 (FEC and indexed) - The STFC contribution being £5,357,268 with the indicative spend being set at 30/09/2012 not to exceed £,3,621,813 (including overheads). To ensure that the indicative spend is not exceeded the University of Liverpool set budgets based on the two year expected roll date for the grant therefore the total salary budget we received from STFC £1,818,195 (@80%); with the remaining 20% the total for salaries was £2,272,745. STFCs non-salary award was £249,011. We have set monthly expenditure targets for travel, R&D, equipment and consumables. These are monitored through bi-weekly management meetings and reconciliation. The grant is projected to complete within £500 of the set indicative spend (allocated budget). Expenditure and projection set at 31/01/2012.

	100% Spend to 31/1/12	Allocated Budget	*Committed to to 30/9/12*	Projected to 30/09/12
Salaries	£1,524,276	£2,272,745	£841,852	£2,366,128
Consumables	£69,822	£129,312	£0	£69,822
Equipment	£31,200	£50,000	£0	£31,200
Equipment - Capital	£0	£52,802	£29,400	£29,400
Travel - UK	£23,171	£21,763	£0	£23,171
Travel - EU	£26,564	£44,187	£10,000	£36,654
Travel - Non EU	£14,076	£0	£0	£14,076
F010 - Inv Time	£302,439	£302,439	£0	£302,439
F051 - Clean Rooms	£434,148	£434,148	£0	£434,148
F701 - Laboratory	£184,990	£184,990	£0	£184,990
F800 - Indirect Costs	£1,021,680	£1,021,680	£0	£1,021,680
University Contribution	£892,253	-£892,253	£0	£0
Total	**£2,740,113**	**£3,621,813**	**£881,252**	**£3,621,366**

Table 3: Projected spend for University of Liverpool. The University contribution (£892,253) is included in the amount we spend but subtracted from the allocated (100%) budget.

[**] http://www.liv.ac.uk/hr/organisational-development/

APPENDIX 2 FUNDS REQUESTED

To aid review an index of staff names is provided. Names are cross referenced with all entries in the Appendices. The references to the staff cases are in bold face.

Academic Posts

Prof. Phil P. Allport, Ac/C

Project	
ATLAS	45
ATLAS upgrades	155
Generic Det R&D	40

ATLAS: Upgrade Coordinator, Executive Board

Phil initiated and led the ATLAS tracker upgrade programme within the UK, as well as leading the ATLAS Module Integration Working Group and was a founder member of the ATLAS Upgrade Project Office. Since 2011 he has been the ATLAS Upgrade Coordinator and Chair of the ATLAS Upgrade Steering Committee at CERN. He has presented to the LHCC as well as regularly updating the ATLAS collaboration and chairing upgrade related meetings. He has given many presentations at international instrumentation conferences and now organises the ATLAS Upgrade Weeks of over 200 participants. Until 2011, he chaired the IoP HEPP Committee and led the Liverpool Particle Physics Group. He gave evidence in 2011 to the Innovation, Universities, Science and Skills Select Committee, and has organised trips to CERN with local MPs. He presents on particle physics to local schools and is a member of the University Civic Engagement Action Group and is a member of the forum legati, Conference Ambassador Network of The Mersey Partnership. He remains active in silicon detector development and is one of the originators of the n^+p technology. He will continue to drive forwards innovations in silicon technology at Liverpool with particular emphasis on the new, generic, pixel programme. Phil's future work will be focussed on the international and national coordination of the ATLAS upgrade and leading the ATLAS upgrade effort at Liverpool.

Prof. Themistocles J.V. Bowcock, Ac/C

Project	
LHCb	175
LHCb upgrades	40
Generic Det R&D	25

LHCb: UK VELO Project Leader

Themis originated and led the LHCb VELO project in the UK, and was overall VELO project leader during the commissioning phase at CERN where he also served on the LHCb Technical Board. Since 2011 he has resumed responsibility for leading the UK VELO group. He has made presentation to the LHCC on LHCb and at several conferences on LHCb, LHCb VELO, LHCb Upgrade and detector developments for the LHC upgrades including at EPS. He has presented an overview of first *B*-physics results in US in 2010. From 2010 he has been overall responsible for the delivery of the LHCb VELO2 replacement at CERN, with the first half having been completed in 2012. He is currently leading the Liverpool group to build a strip VELO replacement (VELO3) for a Phase I 40 MHz upgrade and a pixel detector for a phase II upgrade. He leads the Liverpool activity on pixel tiles, a project aimed at delivering a generic technology solution for the LHC upgrades. Themis is currently working to identify top decays at LHCs where the group has just published a note on its first observation at LHCb. These studies will be extended to studying single top production at LHCb and di-boson production. He runs a summer school for pre-university students at CERN (funded by Liverpool). On top of his LHCb driven silicon activities his R&D interests include the development of new computer architectures for next generation processing and online farms utilizing GPUs, a project he is collaborating closely with computer scientists and physicist at University College Dublin on. From mid-2011 he has led the Particle Physics Group at Liverpool.

Dr. Sergey Burdin, Ac/C

Project	
ATLAS	160
ATLAS upgrades	80

ATLAS: ACR Shift Leader, Forward Pixel Layout Coordinator

Sergey has worked on searches for highly ionizing particles like Q-balls or magnetic monopoles. The first paper based on $3.1pb^{-1}$ was published in PLB in April 2011. Limits on the production cross section for charges $6e \leq |q| \leq 17e$ and masses $200\ GeV \leq M \leq 1000\ GeV$ have been set for different hypotheses on the production mechanism. The search for magnetic monopoles requires an excellent understanding of the detector response, in particular the electromagnetic calorimeter. Thus he initiated and led a study of the calorimeter response to highly ionizing particles published in NIM. Sergey also worked on the Higgs search in the di-tau channel and contributed to the data quality monitoring of ATLAS, specifically Detector Control System Status Calculator and the Semiconductor Tracker (SCT) Data Quality Web-page. He regularly took the SCT Data Quality and ACR shifts also contributing as SCT Data Quality on-call expert. His duties now include taking ACR shifts as a Shift Leader. Sergey also participates in the work of the D0 Editorial Board, and was invited to present D0 results at the EPS HEP 2011 conference. Sergey has taken the responsibility for the Forward Pixel layout, for the ATLAS UK Upgrade proposal. He has implemented the conical pixel designs in `GeoModel` and will participate in the detailed tracking studies needed to decide the detailed layout of the pixel forward system for the Phase-II upgrade. As well as task managing this team he will further develop the Pixel layout and be responsible for taking the design to a mechanical prototype stage. Sergey will continue searches for NP using existing data. During the period of this grant he will work on the non-pointing photon signatures as possible in GMSB SUSY.

Dr. Jonathon Coleman,Ac/C

Project	
T2K exploitation	160
Future Neutrino	80
Other Projects	160

Jon came to Liverpool and joined the neutrino group at the end of 2009 with a Royal Society University Research Fellowship. He has been charm group convener in BABAR a member of HFAG and an advisor to PDG 2010 on $f(D_S)$. In 2010 he dedicated most of his time in the coordination of the ND280 ECAL construction at Liverpool. In parallel he has initiated a project for the development of an anti-neutrino detector based on the ECAL technology for reactor monitoring, an effort endorsed by IAEA and funded so far through RS and STFC Follow-up funds. Jon has also initiated a feasibility study on an idea of Martin Perl for the search for a laboratory search Dark Energy using ultra-cold atoms. The detector technology, a cold atom interferometer, will also act as a precision gravitometer, and is proposed as novel technology for remote sensing. Jon has recently joined the T2K ND280 cross-sections group where he will study charged-current pion production using ND280 data, and then he will use his prior experience to incorporate these measurements and their systematic uncertainties in the global T2K neutrino oscillation fits. He is also participating in the LAGUNA-LBNO design study in the definition and conceptual design of the near detector for the proposed long baseline facility. Jon will also work on the MODES-SNM EU funded programme for the development of neutron detectors for security applications. We are not requesting any funds for Jon during the next grant round.

PROF. JOHN B. DAINTON FRS, AC/C

Project	
NA62	70
LHeC	55

NA62: PI ERC funded project UNIVERSALEPTO

John has been a member of the Liverpool group since 1986. Throughout this time he has primarily made contributions to the physics of lepton-quark interactions and to the chromodynamic structure of the hadronic interaction. He founded the Cockcroft Institute (CI) of accelerator science and technology which is now established as a unique research centre in its field with Director and staff of international distinction. He also followed closely the definitive analysis of deep-inelastic structure on H1, following the original pioneering work by the Liverpool group over a decade ago, and worked with Max Klein on preparation of the LHeC CDR, securing the support and endorsement of the CERN management, ECFA, NuPECC. This LHeC activity has been underpinned by the technological expertise available both in the Particle Physics group at Liverpool and in the CI. The LHeC work will continue with a view to its approval as a CERN project and then into a TDR phase. Recently John was awarded ERC funding for fixed-target experiment NA62 which is aimed at the measurement of the decay with unique sensitivity to NP, possibly to a scale of 10 TeV. NA62 will continue throughout the next three year grant period. He has chaired the SPSC at CERN, has served on the CERN Scientific Policy Committee, and chairs or has chaired a number of scientific oversight, advisory and review panels worldwide (STFC, Royal Society, INFN, NIKHEF) and is an assessor for US, Israeli and European funding agencies.

DR. JOHN FRY, AC/C

Project	
NA62	0

Dr John Fry is a part-time Reader in the Department of Physics. Together with Prof John Dainton he bid successfully for an ERC grant of €2.3M to enable the UK to lead the physics effort to test lepton-flavour universality in the CERN experiment NA62. This requires the UK to design and build KTAG, an upgrade to the CERN CEDAR detector that will enable charged kaons to be tagged and time-stamped to better than 100 ps in the charged particle beam of 800 MHz, more than two orders of magnitude higher than the original design. Dr Fry's responsibility in Liverpool is for the design of the mechanical support structure and the optical system that will channel the Cerenkov light produced exclusively by the K+ particles onto a system of 512 PMTs, as well as for safety and monitoring systems. A prototype detector will be built in Liverpool before the end of September 2012, with sufficient data to be taken during the technical run during October – December to enable the final detector to be designed and built in Liverpool during the CERN shutdown of 2013. Dr Fry will spend a significant period of time in CERN during 2014 to ensure installation and commissioning of the detector, returning to take part in physics analysis over the following two years. We are not requesting any STFC resources for John.

PROF. TIM J. GREENSHAW, AC/C

CTA: SST Prototype Coordinator

Project	
Generic Det R&D	80
CTA	160

The Liverpool Particle Physics group has had a long-standing interest in astrophysics and, in 2009, took the decision to join the Čerenkov Telescope Array (CTA) Collaboration. To this end, Tim started working with UK members of CTA, who developed a novel proposal for the design of the Small Size Telescopes (SSTs), which measure the atmospheric Cherenkov showers produced by the highest energy photons that CTA will detect, in the range 1...300 TeV. Tim's calculations showed that the dual mirror Schwarzschild-Couder telescope proposed by the UK would allow the use of multi-anode or silicon photomultipliers (MAPMs or SiPMs, respectively) rather than the more expensive conventional photomultipliers (PMs) required by the Davies-Cotton single mirror telescope designs considered for the SST up to that point. This results in an increase in the number of telescopes that can be built per unit cost by a factor approaching 2 and results in improved performance of CTA at the highest energies. These ideas were further developed and studied in the UK and presented to the Collaboration on several occasions by Tim. They now form a major plank of the three year EU funded "preparatory phase" of CTA, which is entering its second year. Tim has been asked by CTA to lead the prototyping of the SST, the total funding for which is €9M. Liverpool has applied for STFC funding for CTA with groups from Durham, Leeds and Leicester. This consortium aims to produce a prototype camera for the SST, part of which will be constructed in Liverpool.

In addition to the above, Tim led Liverpool studies of the layout and mechanics for the forward pixels of the ATLAS upgrade until 2011 when he took over as Head of the Liverpool Physics Department. This commitment, plus his role at CTA, have make it impossible for him to continue to contribute significantly to ATLAS at this time, so he is withdrawing from this activity. Tim has also reluctantly given up his post on the STFC "Small Awards" committee, but his other outreach activities will continue. He has given talks at schools and in pubs in Liverpool in the last three years, as well as at the Association for Science Educators conference. He provides work placements for local students and organises the Particle Physics Master Class with other Liverpool staff.

DR. DAVID HUTCHCROFT, AC/C

LHCb VELO Tracking Coordinator

Project	
LHCb	175
LHCb upgrades	40
Comp. support	25

David has played a key role in studying the VELO data and developing the simulation and reconstruction for the detector. He has developed the simulation and digitisation of the detector and has been leading the tuning of both to match the operational VELO. He has substantial experience having written much of the underlying code for the VELO simulation, digitisation and reconstruction and is leading the campaign to optimise the timing and accuracy of every component. He has lead the measurement and implementation in the simulation of the effects of radiation damage on the VELO performance. He has also been optimising the track fitting code leading to the best possible physics from LHCb by improving the track reconstruction. The reconstruction of the VELO both offline and in the trigger are evolving with the changing beam conditions, David leads the Liverpool effort to optimise the use of the VELO information for LHCb. This will continue to be a vital part of the LHCb program as the instantaneous luminosity is planned to increase and further optimisations for timing and occupancy are anticipated. He is leading the groups work on the hadronic decays of the B mesons, including using $B_S \rightarrow D_s^+ D_s^-$ which will provide the most precise measurement of the lifetime difference between the heavy and light B_s states. This and other decays will be used to measure the B(s) lifetime and make oscillation measurements of the B systems. His experience with the LHCb code will be used to write and optimise the simulation, digitisation and reconstruction of the planned upgrades to the VELO, for both the strip and pixel upgrades.

PROF. MAX KLEIN, AC/C

Project	
ATLAS	200
LHeC	40

LHeC: Project Leader

Max has led the Liverpool ATLAS group since September 2010. He has organized the analyses into three major topic: precision tests of the Standard Model, searches for the Higgs and for searches NP, primarily for SUSY. His own research is related to the inclusive production of *W* and *Z* bosons and the interpretation of these measurements. He initiated an international collaboration with DESY, Mainz and Dubna, which for three years prepared for a 1% *W, Z* measurement and its theoretical analysis, which culminated in the PRD paper of ATLAS last year of which Max was an editor. He was chair of the ATLAS Publications Committee until 2/2009 and reshaped the publication policy, which is still functioning. Max has chaired Editorial Boards on ATLAS publications on *J/φ* production on *W′* searches. Max was editor of the H1 publication on the measurement of F_L, which he had proposed while still H1 spokesperson, a new test of QCD at low Björken-*x* using the Silicon detector his Zeuthen group had built. He is a member of the H1-ZEUS team producing joint data and the HERAPDF sets. Since November 2007 Max has led the CERN-ECFA-NuPECC development of the LHeC. He organised three large workshops on the LHeC in 2008/09/10. With a team of 150 colleagues, Max has wrote, in 2011, a 550 page design report on this new *ep/eA* collider. He coordinated the physics, the detector and the accelerator design which he reported on at IPAC11. He was elected to ECFA as a UK member in 2011. He is a member of advisory committees for the DIS and Hadron Structure Series of Conferences.

DR. UTA KLEIN, AC/C

Project	
ATLAS	200
LHeC	40

ATLAS: Co-convener of the PDF fit forum; LHeC: Coordinator of the Higgs Study Group. Uta is a leading physicist on ATLAS. The key paper to which she has made a major contribution was the first precision measurement of the *W,Z* cross sections. Preceeding that paper was a three year international collaboration led by Uta, as documented in a 190 pages ATLAS approved note. Uta has successfully filled a number of leading roles: MC and theory contact of the SM group, electroweak physics contact to LPCC for ATLAS, co-editor of the P_T^Z paper. Uta has organised ATLAS and IoP workshops at CERN, Dubna, and Liverpool. She has been involved in further ATLAS papers: on P_T^W, and the NNLO QCD analysis of the *W,Z* cross sections, for which she pioneered the theory calculations in contact with theorists and challenged the computing resources at Liverpool. Recently she was awarded support for a joint Russian-CERN (ATLAS) analysis project, for which she is the CERN based PI. Recently Uta has been asked to co-chair new PDF forum of ATLAS. She has chaired seven editorial boards including the fundamental, 100 pages summary paper on the jet energy scale. In 2011 Uta was elected as a member of the ATLAS speakers committee, which distributes and rehearses ~700 talks annually. Uta is working on the 2011 *W,Z* data, and is developing the Drell-Yan physics analysis, an phenomenology, into the region of higher di-electron mass to search for exotic *Z′* resonances and to obtain the first precision measurement of that cross section. She has also been active on the LHeC project. In particular leads the study of Higgs physics at the LHeC. She has been selected as speaker for ATLAS and for LHeC at various conferences and workshop. She is referee for PRD, PRL and PLB.

DR. JAN KRETZSCHMAR, AC/C

Project	
ATLAS	200

ATLAS: Electron Efficiency Working Group Coordinator

LHeC	40

Jan joined the Liverpool group as an STFC research fellow in 2008 and was promoted to a lecturer position in 2011. In the he was finished a publication on inclusive electron-proton cross section measurement from H1, which as of today provides the strongest constraints on the proton structure in the covered kinematic region. This led to three talks at international conferences in 2009 and has been the basis for the HERAPDF set of parton distributions. Jan joined ATLAS in 2008 where he started to work towards a precision cross section measurement of W and Z bosons in the electron decay channels. Before the start of LHC, Jan contributed to an internally reviewed note on the prospects for precision W, Z measurements, and he worked to regularly validate changes and improvements of the ATLAS simulation and reconstruction software. Jan has contributed to four publications and two conference notes on the precision measurement of W, Z boson cross sections and ratios, which enable further precision studies of the proton structure. For two of these, Jan co-coordinated the analysis and paper writing. Since 2011 has Jan coordinated the working group that provides the electron efficiency measurements for ATLAS, which is an ingredient used in essentially every ATLAS publication. He has been invited to present three talks at international conferences and workshops, including was the first presentation of ATLAS W,Z measurements ICHEP 2010. Currently Jan is searching for high mass neutral gauge bosons (Z). In the coming grant period Jan will focus his ATLAS activities on the high precision measurement of differential W and Z cross sections. Exploiting this and the increasing luminosity he will measure the Drell Yan Z cross section at highest masses which is related to a search for extra dimensions. Based on his deep knowledge of DIS and ATLAS physics analysis, Jan will spend a small fraction of his time on preparations for the LHeC.

DR. NEIL MCCAULEY, AC/C

T2K: N280 and Physics Software; SNO+: Co-Convenor Dataflow

Project	
T2K	135
SNO+	80
Future Neutrino	25

Neil is a very productive and well recognized leader in T2K physics and analysis. He developed and manages the ND280 software release system and tools and has full responsibility for producing the official releases used for physics in T2K. He leads the efforts of the group in developing and improving ECAL reconstruction and he is personally responsible for calibrating the Electromagnetic Energy Scale of the detector. Following a very successful term as ND280 ν_e convener and T2K Analysis Steering Group convener, he was one of the few conveners that got re-appointed for a second term in the recent rotation of analysis management in T2K. His main physics analysis will continue to be the measurement of the intrinsic ν_e fraction and energy spectrum in the T2K beam, one of the two major sources of systematic errors in the measurement of θ_{13}. Neil was one of the founding members of the UK participation to SNO+. His intimate knowledge of the SNO computing system and reputation allowed him to be appointed co-convener of the Dataflow Group and he will continue in this role throughout the grant period. He will use his SNO expertise to optimize the reconstruction in the region of the ^{150}Nd end point in the search for neutrinoless double beta decay which is his main interest and the experiment's primary science objective. Neil will also play a leading role in LAGUNA-LBNO where he will use his deep understanding of neutrino physics and related experimental techniques, and his experience in simulation and reconstruction from ND280, to lead the studies for the definition and design of the near detector for the envisaged European long-baseline facility which will have the sensitivity to search for CP violation and elucidate the neutrino mass hierarchy and will come as a natural continuation to his physics in T2K.

Dr. Andrew Mehta, Ac/C

Project	
ATLAS	200
ATLAS upgrades	40

Andrew has made significant contributions to Higgs searches and QCD measurements on H1, CDF and ATLAS. On H1 he made an innovative measurement of the *b* and *c* structure functions based on the full HERA data, using an impact parameter technique. On CDF he made a measurement of *Z*+*b* jets. This measurement was the first in this channel to include differential distributions and showed that the pQCD predictions using the HERA data could be used to describe bottom production at a hadron collider. On ATLAS Andy made a first measurement of the tracking resolution using early 2009 /10 data. His main physics interest on ATLAS is in Higgs, with major contributions to searches where the Higgs has jets in its decay products. He pioneered the $H \rightarrow ZZ \rightarrow llqq$ and $H \rightarrow ZZ \rightarrow llbb$ channels and showed that this and related channels could substantially improve the sensitivity at high Higgs masses. Additionally, he introduced the analyses of the associated *H*+*W* and *H*+Z channels to ATLAS. These were previously thought to not to be promising at the LHC. He showed the large backgrounds could be reasonably suppressed to enable these channels to provide sensitivity the Higgs. The work on the Higgs will remain in the focus of Andy's work in the coming grant period and, should the light Higgs be confirmed, lead into the HL LHC physics, which Andy is going to be contributing to within the upgrade simulation studies. Andy also made a first measurement of *Z* + *b*-jets and a significant contribution to the first publication on this process. Andrew has served as a member of the ATLAS publications committee (2009/11). He has been the proceedings monitor and he served on and chaired several editorial boards for ATLAS papers.

Dr. Monica D'Onofrio, Ac/C

Project	
ATLAS	160

ATLAS: Convenor SUSY *b*-jet Group, Convenor stop search

Monica joined Liverpool with a Halliday Fellowship to work on searches for Supersymmetry (SUSY) . In summer 2010, she was appointed to be one of the two ATLAS coordinators for SUSY searches in events with missing transverse momentum and b-jets. This effort led to the release of initial results presented at the SUSY10 Conference. Monica became one of the conveners of the 'SUSY b-jet' group, comprising ~25 physicists from several universities, which focused its activities on searches for third generation squarks via gluino-mediated or direct pair production. Under her leadership the ATLAS SUSY b-jet group has published two papers and several public ATLAS notes. In September 2011, ATLAS created a new dedicated task force (~40 physicists) to search for stop; Monica leads this group which is working on six analyses designed to cover different mass ranges and final states. In addition to these major activities, Monica acts as internal reviewer of several ATLAS analyses (so far in Editorial boards for four papers and six CONF notes on top pair production cross section and searches for sbottom particles in different final states). The 3rd generation SUSY particles are subject to long term exploratory research, in which Monica will remain to be engaged. She has taken a task to reorganise the ATLAS DQ shift organisation, and she begins to contribute to SUSY physics with ATLAS in the twenties. Monica has been a member of the CDF collaboration since 2000. Recently she brought to conclusion her previous analysis work in CDF (Search for sbottom pair production, published in PRL) and ended serving as Exotic and SUSY CDF convener (2008-2010). Monica is still acting as senior reviewer of CDF analyses prior to publication in physics journals (6 papers published so far, one on-going). Monica has been invited to present at workshop and conferences on SM and SUSY-related topics for both ATLAS and CDF. She was chosen to represent the ATLAS collaboration to report its first results on SUSY searches, at the open CERN Seminar in March 2011.

Dr. Tara G. Shears, Ac/C

Project	
LHCb	200
LHCb upgrades	40

LHCb: Co-Convenor: EW, Exotics and QCD Group

Due to its unique acceptance, measurements made by LHCb can provide precision probes of the Standard Model in the electroweak sector, in a different kinematic region to ATLAS and CMS. The electroweak physics programme was established by Tara, who has convened the working group from 2008. She was co-convenor of the LHCb leptonic group (2012-2012). She is one of two LHCb representatives to the LHC electroweak working group (2010 onwards). Her work focuses on high transverse momentum muon identification, *W* and *Z* reconstruction (submitted for publication), and measuring the forward backward asymmetry of *Z* bosons. Besides testing Standard Model predictions, these measurements provide valuable constraints to parton density functions, and provide some sensitivity to NP in tau decay modes. She collaborates with theorists from IPPP, UCL, Cambridge and Milan, and has presented results in international conferences, seminars, and specialist workshop. She is a referee for JHEP and serves on three STFC committees: Fellowships, Education and Training and the Science and Society panel. She has an extensive portfolio of outreach in all the media and sits on the IoP public engagement grant panel. Over the next five years, her work will provide further tests of the Standard Model by measuring *W* and *Z* production at all centre-of-mass energies, extending measurements down in dimuon invariant mass to measure low invariant mass Drell-Yan production, and testing QCD predictions of *W/Z* + jet production. The strange quark content of the parton will be probed in *W*+charm production, and facilitate the study of top quark production by others in the group. Tara will devote a limited amount of time to understanding and developing the EW analysis techniques (and triggers) for the high upgrade luminosity.

Prof. Christos Touramanis, Ac/C

Project	
T2K Exploitation	165
Future Neutrino	75

T2K: ND280 ECAL, Speakers Board

Christos is the PI of the Liverpool neutrino group and the T2K ND280 ECAL convener. He was ND280 Analysis coordinator and member of the T2K Analysis Steering Group and he is now member of the T2K Speakers Board. He served as the £14M T2K-UK construction project in 2006-11. He just completed his 3-year term on the CERN SPS Committee where he was reviewer for DIRAC, NA62, and the European long baseline neutrino programme (CNGS). He organized workshop sessions at CERN on the future of the European neutrino programme and he has given keynote talks at national and international conferences and workshop and an invited presentation to the CERN SPC. He is member of the CERN LHC M&O Scrutiny Group and member of the French GDR Neutrino Scientific Council. He will continue to lead the Liverpool T2K group and he will work directly on the improvement of ECAL reconstruction and its further integration in the analysis, and guide the development of global fitting strategies and tools. He will chair the T2K SB. He will continue to lead and work on the LAr R&D programme. In LAGUNA-LBNO he will lead the group and work on MC studies for the definition and design of the Near Detector. He will continue high-level initiatives to promote the future European long baseline programme. He also leads the Liverpool group in MODES-SNM, an EU-funded project with Swiss and Italian universities and commercial partners for the development of neutron detectors for control of special nuclear materials at ports of entry, where he is leader of the Integration work package.

DR. JOOST VOSSEBELD, AC/C

Project	
ATLAS	185
ATLAS upgrades	55

ATLAS: UK SCT Project Leader

Joost has played a major role in the construction, testing and commissioning of the ATLAS SCT detector in Liverpool and at CERN. He is an expert on the calibration of SCT detectors and contributes to establish their performance after irradiation. Since 2009 Joost has been the UK project leader of the SCT and representing ATLAS-UK on the SCT and ID steering committees. He was UK Standard Model Convener until 2009 and contributed to an extensive study, laying the foundations for the first ATLAS Z and W measurements. He also contributed to the $H \rightarrow 4l$ search. Joost is a key member of the Liverpool effort opening up new $H \rightarrow ZZ$ decay modes allowing ATLAS to set the first exclusion limits on the SM Higgs in the very high mass region. He has been the lead analyser in the $H \rightarrow ZZ \rightarrow ll\nu\nu$ search channel. He was editor of a PRL publication searching for a SM Higgs boson with a mass above 200 GeV, and of subsequent publication, in preparation. Joost will push this search to higher masses, and set limits on both SM and BSM neutral Higgs bosons using, in addition, the $H \rightarrow ZZ \rightarrow bb\nu\nu$ channel. Joost has contributed to the first search results in the $H \rightarrow$ ZZ $\rightarrow 4l$ channel and to the search for a low mass Higgs in the $ZH \rightarrow \nu\nu bb$ channel. In 2011 Joost presented an overview of all ATLAS SM Higgs search results at the PANIC11. Over the coming grant period he will keep an active involvement in the SCT coordination and operation. For the upgrade he will study $H \rightarrow \gamma\gamma$ prospects and will be involved in the tracker upgrade.

Core Posts

Dr. Anthony A. Affolder, AP/C

Project	
ATLAS upgrades	360
Generic R&D	40

ATLAS Upgrade: Co-convener Strip Module Working Group

Tony is a world-leading expert in the design, quality assurance and commissioning of silicon systems for high energy physics experiments. Tony came to Liverpool from UCSB, where he was head of strip module electrical quality assurance for US CMS which built over 8000 modules. On LHCb at Liverpool, he played a key role in ensuring the VELO module construction achieved its delivery goals and was a VELO commissioning coordinator (2009). On the first UK ATLAS phase II strip upgrade grant, he was co-coordinator of Work Package 4 (ASICs and Interconnect Technologies) and deputy coordinator of Work Package 6 (Powering). Tony is an acknowledged world expert in the testing of irradiated silicon detectors. His measurements have become the benchmark for the predicted evolution of *n*-strip readout devices for the current LHCb VELO and the HL-LHC upgrades for LHCb and ATLAS. Since 2009, he has presented his results at nine international detector conferences and workshop. Over this period, he has 22 papers (15 as a primary author) in refereed journals on detector R&D and strip module design/quality assurance. Currently, he is the co-convener of the international Strip Module Working Group (SMWG) responsible prototyping of the on-detector electronics for the ATLAS Phase II strip upgrade and a member of the Inner Tracker Sub-Committee. He will continue these activities during the next grant period. Furthermore he initiated, and leads, seven international stave and module production sites. He will direct the prototyping of the on-detector using the latest ATLAS ASICs to meet the aggressive schedule to production readiness in 2016. His R&D will focus on the development of radiation hard silicon strip devices.

Dr. John Bland, PR/C

Project	
ATLAS	40
T2K	40
Generic detector	40
Computing	280

John is jointly responsible for both the Grid computing and the local HEP computing cluster and desktops. He provides the support for the desktops, laptops and central resources. The Liverpool Grid site has the highest efficiency for processing jobs of any UK site; the ongoing updating of both the hardware and software has been driven by the work of John. He has led the rationalisation of the hosted services as virtual machines onto a few servers also updating and upgrading the networking hardware infrastructure. The reorganisation of the cluster room networking from the over 1000 nodes of MAP2 to a eight chassis of Hammer required a substantial reorganisation of the infrastructure and this will continue with the ongoing investment from the GridPP project, including a complete refresh of the network switches and cabling in the HEP cluster room being designed and planned by John using the GridPP grants. His expertise is also valued by the central university cluster project where he provides advice to the Computer Service Department about their new clusters. John has been working to make GPU computing available to HEP to optimise the throughputs for LHC reconstruction and to provide an affordable trigger model for upgrades to LHC experiments. John has developed a comprehensive monitoring suite for the systems in Liverpool which is a vital component of the excellent reliability of the local and Grid computing systems. In summary, John supports the computing for many of the group's activities, helping to maintain a wide range of platforms and operating systems, and is an essential member of staff for Liverpool to be able to continue to exploit the vast data sets created by in our physics programme.

MR. JOHN L. CARROLL, E/C

Project	
ATLAS upgrades	190
LHCb	40
LHCb upgrades	65
Future Neutrino	70
Generic detector	35

LHCb: Module Project Engineer

John's expertise in the mechanical design of low-mass high precision structures is vital for the future programme of the group. John is the Project Engineer for the LHCb VELO1/2 module programme, modelling and designing all the assembly equipment and jigging, as well as the modules themselves. John designed, modelled and commissioned all of the hybrid and module tooling used so far in the ATLAS phase II strip upgrade and modelled the hybrids and module. He is central to the development of the strip stave core. John has modelled and designed Liverpool's assembly tools of the 1/3rd length stave cores (stavelets). On T2K, John designed the routing of all subsystem services in the Near Detector pit and also the ECAL module support and installation frames. On the Liverpool LAr R&D programme, he designed mechanical elements of the prototype chamber and the charge drift system. His leadership of the mechanical module design and tooling will continue for the ATLAS HL-LHC upgrade. For ATLAS upgrade, he will modify the existing tooling and mechanical module designs to be compliant to the 130 nm ASIC prototypes. He will then prototype the mechanical systems needed for the barrel strip module assembly and QA of the Phase II detector. For ATLAS he will continue to develop our full length ultra low mass designs which can take advantage of the lower heat load of the readout ASICs. John will also have a central role in the design of the disc mechanics in the ATLAS phase II pixel upgrade. On LHCb he will be responsible for mechanical aspects of VELO2 preparations for installation and will design the upgrade modules and tooling. He will provide the mechanical designs for the LAr R&D programme as it is evolves into a full double phase (liquid-gas) TPC system.

DR. GIANLUIGI CASSE, AP/C

Project	
ATLAS upgrades	200
LHCb	15
LHCb upgrades	40
Generic detector	145

RD50:Co-Spokesperson ;

Gianluigi Casse is an internationally recognized scientist in radiation tolerant silicon detectors. He is in charge of the R&D activities of the HEP group at Liverpool. He is the currently task leader for the planar pixel sensor development for the ATLAS Upgrade UK, and is the work package leader for the development for the silicon sensors for the upgrade of the LHCb-VELO detectors. He is the co-spokesperson of the CERN-RD50 collaboration. Detector concepts that he has are now the baseline for the sensors for the upgrade of the major CERN experiments (ATLAS, CMS and LHCb). Gianluigi has given a large numbers of talks at international conferences and workshops. He has been the PI and the Co-I in several successful research proposals. His main commitment during the period of this grant request will be to the ATLAS and LHCb upgrades and our vigorous Si R&D programme. For the LHC upgrades he will drive the pixel sensor developments. Within the R&D activity he will develop large area strip devices with UK companies enabling the UK to compete with Hamamatsu for large area Si contracts. He will also work on our new pixel programmes and applications of our Si technology including medical applications (hadron therapy) and neutron sensors.

DR. PAUL DERVAN, AP/C

Project	
ATLAS	200
ATLAS upgrades	200

ATLAS: Irradiation Facility Organiser

One of the strengths of the Liverpool Silicon Program is its world leading expertise in radiation tolerant detectors. As leaders in this field we are able to contribute to the design and building of the current upgrades and lead designs of future detectors. Paul is an expert on the understanding radiation damage in silicon. On ATLAS he is leading the monitoring of the current SCT for radiation damage by measuring sensor leakage currents. His data have been compared to predictions, and agree well. He is now the ATLAS representative on an inter-experiment (ATLAS, CMS, LHCb) task force, to monitor this the performance of silicon in the current experiments. He is also preparing a joint ATLAS Pixel and SCT paper on radiation damage. To supplement his SCT measurements Paul Dervan is carrying out an annealing study on mini SCT sensors to predict the evolution of sensor currents over the lifetime of the ATLAS experiment. His work was presented and published at various conferences (Radiation Effects on semiconductor materials and devices, Florence, IOP and RD50. Paul organises UK access to the irradiation facility at the PS CERN. The facility has successfully been used to irradiate sensors to evaluate the radiation tolerance and performance of the silicon and modules. The facility will be used to irradiate ATLAS pixel modules in the future and also continue to be used for studying irradiated upgrade strip modules. Paul is also involved in setting up a new irradiation facility in Birmingham. This will be vital in the years 2013-14 when the beams at CERN are turned off.). He is also developing a usbpix readout system for the ATLAS Pixel upgrade. He will use this system to test pixel modules in the laboratory in testbeams at DESY and CERN.

MR. ROBERT FAY, PR/C

Project	
LHCb	40
T2K	40
Generic Detector	40
Computing	280

Robert is jointly responsible for both the Grid computing and the local HEP computing cluster and desktops. He is a key member of the team that support the computing activity of the group, including the local North-Grid site, the local batch cluster and the desktop systems. Robert is a key figure in delivering the highest efficiency Grid site in the UK, he has developed the program to upgrade the hardware of the Grid site and lead the case to get a complete replacement of our existing MAP2 cluster with a replacement after demonstrating it would save the cost of the new systems in reduced electricity bills in seven months. He has centralised the monitoring and configuration of the computer system using the Nagios, Puppet and Ganglia. The computer security of the HEP computers has been continuously upgraded and monitored lead by Robert. He has been working with ATLAS on their HAMMERCLOUD tests which has lead to the optimisation of many grid sites and his configuration of the Liverpool cluster and storage node maximise the throughput of jobs. He is advising other department and the University's Computer Service Department on purchasing and deploying central computer clusters.

Robert is a central part of the excellent position Liverpool is in to use the very large data sets provided by the LHC based and T2K experiments and the smaller datasets produced locally by the detector production activities and local detector developments, including the liquid argon test stands.

Mr. Ashley Greenall, E/C	**Project**	
	ATLAS Upgrade	**400**

The UK's programme in module design and testing for the Upgrade Tracker depends crucially on Ashley. He has designed the only working readout (hybrid) circuit for the hybrid modules. This 20 chip multi-layer kapton circuit was available as soon as new upgrade ASICs arrived from CERN and worked immediately, giving the design noise values. Over 200 of his hybrids have now been produced and distributed round the world to collaborating institutes. He enjoys a huge international reputation, having presented at five out of six international ATLAS Upgrade Weeks and at TWEPP09 and TWEPP10 workshop. He was a member of the ABCn25 final design review committee in 2008, and has been asked to be a member of the ABCn13/HCC design review committees for 2012. He has given over 60 presentations to ATLAS in a variety of meetings on both current and upgrade programmes and is author of seven publications since 2009. Next he will design a further series of hybrids to reduce mass and improve hybrid and module yield and production. Ashley has also been key to specifying and electrically evaluating the ABCn25 design, the stave bus-tapes for linking the 24 hybrid chain along each side of the stave and the overall electronics design of the ATLAS Tracker. He is one of ATLAS's leading experts in powering and has designed the module testing frames for both serial powering and DC-DC conversion. He is collaborating with CERN on the design, production, and evaluation of lower mass DC-DC convertor units for use in HEP experiments. He will design the barrel hybrid and module concepts using the first prototype ASIC set (ABCn13 and Hybrid Controller Chip (HCC)) in the final 130 nm technology. He will design the final barrel hybrid and module and the test equipment necessary for electrical QA for detector construction.

Dr. Helen S. Hayward, PP/C	**Project**	
ATLAS: DQ Group Co-coordinator	**ATLAS**	**400**

From 2005 until Dec. 2010, Helen was responsible for the assessment of the quality of the data collected by the ATLAS silicon tracker (SCT), and coordinated the different SCT monitoring and data quality (DQ) activities, both in terms of software and personnel. In January 2011, she became one of two coordinators of the DQ group and managed the DQ activities of the entire collaboration. During this time she managed the implementation of a new framework for recording information on detector status and data quality, and for transmitting this information to users performing physics analysis. This system revolves around the concept of "defects," which are well defined, fine-grained, unambiguous occurrences affecting the quality of recorded data. She is leading the search for the discovery of Gauge Mediated Supersymmetry Breaking (GMSB) in the scenario where the next-to-lightest supersymmetric particle is a neutralino that decays in to a photon and a gravitino. The first related analysis was published, using data collected in 2010, was published. An updated analysis using 2011 data has been submitted to PLB. She presented these and other ATLAS SUSY results using lepton and *b*-jet signatures to the EPS11 conference. Helen is currently extending the analysis to scenarios where the neutralino can be long-lived. As well as the core activities in Data Quality and SUSY, Helen has taken an active role in supervising post graduate students. It is thanks to her efficient organisation and dedication that the ATLAS Liverpool group fulfilled its shift responsibilities in 2011. Helen has also been actively involved in outreach at CERN giving seminars to pupils from visiting UK schools and discussing the UK involvement in ATLAS to representatives from the Royal Academy of Engineering.

DR. TIM J. JONES, AP/C

Project	
ATLAS	25
ATLAS Upgrades	356
Generic Detector	25

ATLAS Upgrade: WP4 Manager

Tim is currently the manager of WP4 - the largest workpackage of the ATLAS-UK tracker upgrade programme. In this role Tim has guided a group of physicists, engineers and technicians in the task of developing low mass mechanical structures upon which the silicon detector modules will be mounted for the innermost short-strip layers of the barrel part of the ATLAS tracker upgrade. Tim coordinates the work through a combination of weekly and monthly meetings and provides written reports to the ATLAS-UK tracker upgrade PI for submission to the Oversight Committee on a six monthly basis. Currently, WP4 is on track to meet all its milestones and deliverables. Tim has designed and manufactured the tooling and developed the procedures to manufacture stavelets. Currently, six stavelets have been manufactured and three have been delivered to the international stave electrical programme. He has also been instrumental in developing an understanding of the thermo-mechanical robustness of staves through theoretical analysis and prototype manufacture and testing and has reported the only measurements of the thermal conductivity of irradiated adhesives and the post-irradiation robustness of carbon-fibre/honeycomb sandwich structures. Recently he has designed, manufactured, tested and reported the results of the first UK-built ATLAS pixel stave prototype.

Tim will continue to lead WP4 as it makes the transition from an R&D task into the pre-production phase contributing to both the proposal for the future scope of UK participation and the technical planning for the pre-production phase. At part of this programme we anticipate that Liverpool will participate in the manufacture and acceptance testing of stave cores, the subsequent mounting of modules upon them and the final stave electrical testing. With this in mind, Tim will lead the group's efforts in establishing the facilities needed to undertake stave core assembly based on the experience gained during prototyping Another major area will be the development of designs for the forward pixel region where Tim will help coordinate the disc support design and thermo-mechanical deformation studies..

DR. BARRY T. KING, PP/C

Project	
ATLAS	60
ATLAS upgrades	60

His ATLAS research activities are Supersymmetry searches and upgrade studies. On SUSY, Barry has been looking at gluino mediated sbottom production. Using both frequentist and Bayesian confidence level calculation tools, developed by Barry, exclusion limits have been placed on this SUSY process using 2 fb^{-1} of ATLAS data. This leads to a lower mass limit of ~880 GeV for mSUGRA gluinos. Barry is currently developing multivariate techniques for future use in the direct sbottom and direct stop searches with a view to producing limits using the full 2011 data sample. FUTURE PHYSICS. On the Upgrade, Barry has investigated and presented the hit occupancy, the number of hits on the tracks, and track momentum and impact parameter resolutions in various layouts of the proposed ATLAS Track Detector for HL-LHC. Leading on from this, he has developed vertex finding software and was the first person to investigate the feasibility of vertex finding in the anticipated extremely high pile-up expected during Phase-II operation (μ=140-200). The efficiency of vertex reconstruction and the probability of associating tracks to the correct vertex have been studied as a function of the pile-up environment. The possibility of speeding up the vertex reconstruction using GPU/CUDA is under investigation. FUTURE WORK on UPGRADES. Each July Barry supervises and provides lectures for groups of 12 sixth form students who come to spend four weeks in the Physics Department under the Nuffield scheme. As part of the programme, the students look at ATLAS data and search for hidden simulated Graviton and Higgs signals. In March 2012, Barry is organising a Particle Physics Masterclass for 120 school children. Barry has given outreach talks on ATLAS in both the UK and Mexico. We are seeking support for 50% of his research time.

DR. STEPHEN J. MAXFIELD, PP/C

Project	
ATLAS	320
LHeC	80

Steve has been looking at di-photon final states focusing on the search for, and setting limits on, the production of exotic high mass resonances as predicted in extensions to the Standard Model with extra space dimensions. In particular, limits have been set on Randall-Sundrum models, which predict high mass gravitons that can decay to $\gamma\gamma$ final states. The experimental signature of these events overlaps with that for GMSB SUSY models, in which a pair of neutralinos decays into gravitinos and photons leading to a diphoton final state with missing E_t. Initial published studies, lead by Liverpool, have set limits on those regions of the GMSB parameter space where the neutralino decays promptly. Steve is also working on the next developments of this analysis, extending it to the case where the neutralino is long-lived leading to experimentally challenging configurations where the photons do not point back to the primary event vertex. ADD LHeC PHOTONS. 10 lines on what he is going to do. List of explicit topics, photons, etc. Monte Carlo, HL versions. Text upgrade. Extra dimensions.

MR. DAVID MUSKETT, T/C

Project	
ATLAS upgrades	50
Future Neutrino	80
Generic Detector	120
Computing	150

Line of experiment responsibilities

Dave has been a group technician with Particle Physics for over 15 years. He has supported all the major builds and R&D activities in a tireless and professional manner. He maintains much of the Particle Physics the hardware installed in the department, and LSDC and has special expertise in vacuum systems (including UHV). He has developed evaporative cooling systems for ATLAS and has been responsible for all thermography equipment and vacuum systems for LHCb at Liverpool. His has expertise in building having made a major contribution to T2K ECAL construction, where he had responsibility for overseeing the production of components for the downstream module and worked full time on the assembly of the four ECAL modules. He also held responsibility for the design and maintenance of components of LSDC which needed modification (LHCb, T2K) for particular construction projects. He will be responsible for the preparation of the facilities for the ATLAS Upgrade. He is also an expert in cryogenic systems and is required for future development, and construction, of the next generation of LAr neutrino detectors. From 2009 Dave has maintained the software and IT infrastructure in the cleanrooms and workshop ensuring that the hardware is operational, licenses and software are kept up to date and been the main trouble shooter for IT system failures. His work was so successful in the LSDC that his responsibilities have been extended more widely for providing technical support for desktops, laptons and peripherals for the Particle Physics Group. He has also provided support for cabling and other laborious IT related activities in LSDC, and our Particle Physics Cluster room. Dave's role in providing a highly competent level technician effort over a broad range of our activities allows post-doctoral staff, engineers and physicists to devote themselves efficiently, without distraction, to the delivery of our research programme. This is an important core role within the group.

Dr. Girish D. Patel, PP/C

Project	
LHCb	360
LHCb upgrades	40

LHCb: L6.13, L6.20, L7.1, L8.3, L8.9, L8.19, L9.1

As Deputy Group Leader Girish plays a critical role in the smooth operation of the Liverpool group. For the VELO2 rebuild he has responsibility for all aspects of quality assurance from all the individual components to the completed modules, his software has been used extensively for all database interactions and provides immediate online analysis of test data and process control. This software is being extended to incorporate and log the installation and test stages of the modules at CERN. Upon completion of installation and testing of each half of the VELO2 replacement Girish will be responsible for organising a full metrology of all the installed sensors in their final positions and for the analysis to provide key inputs to the initial alignment of the detector. After the completion of the VELO2 rebuild, Girish will plan for the decommissioning of the installed VELO to allow for the rapid deployment of the replacement if and when that becomes necessary. He has overall responsibility for another database system that stores all aspects of the VELO hardware and DAQ chain at CERN and this information is vital for understanding the performance of each module and the system as a whole during data taking. As Deputy Group Leader at Liverpool his responsibilities include regular co-ordination meetings, budget administration and logistics for the VELO2 completion. He will lead the team developing software to automate the online monitoring and the production of detailed "corrections" for the radiation damaged VELO sensors. This is a critical task for the Liverpool group. Unlike other experiments, these corrections (thresholds, noise and cluster position corrections) are expected to change on an up to weekly basis. The code for the identification of *b*-jets will be extended to select *c*-jets to enable a detailed measurement of W-***c***-jet production which will allow for the measurement of the s-quark content of the proton. Girish will participate in test-beam studies of current and prototype VELO modules for the LHCb upgrade. Building on his experience from the original VELO project, he will be responsible for optimizing the layout of the upgrade modules, for the simulation of the module material and will work on production of the prototype modules.

Dr. David Payne, AP/C

Project	
T2K	350
Future Neutrino	50

David's time on T2K includes central tasks as described in the T2K-UK submission at 10% software support, 20% ECAL reconstruction and 30% central data production. David is an experienced physicist who spent more than one year full-time on construction of the T2K ECAL. He worked daily at Daresbury Laboratory leading the team who constructed and tested three of the six Barrel modules. He set up the DAQ test stands for QA at Daresbury and Liverpool. He has a strong background, form BABAR, in the development, validation, and use of complex, powerful multi-variate likelihood fits for measurements of small signals in large backgrounds. He is currently member of the core T2K fitting group where, working closely with Japanese collaborators. He is are preparing the fits for the T2K 2012 neutrino oscillation results. He is also responsible for validating the global fit that he designed for T2K before the ECAL construction period, and is working to ensure his fit is established as the official code. David's work will be the kingpin of the Liverpool analysis strategy in T2K. His direct contributions to the official fitting tools will ensure the integration of the group's results into the determination of the intrinsic ν_e flux and help validate our cross section measurements. In 2012/13 he will spend a long period on LTA at J-PARC contributing to ECAL operations and run coordination. He is an expert in large volume data handling and he will be supporting computing for the neutrino group on the local clusters, as he has done earlier for the T2K MDC0, MDC1 large scale MC productions. David will drive simulation studies for the antineutrino running planned from 2014. David will be responsible for the central T2K data reprocessing as member of the T2K computing group which will take up 40% of his time in the first two years of the new grant period. He will use his fitting tools in our sensitivity estimates for future neutrino detectors.

DR. KURT RINNERT, AP/C

Project	
LHCb	375
LHCb upgrades	25

LHCb: VELO Online Monitoring

Since joining LHCb from CDF, Kurt has been one of the key software programmers. His was one of the four people that wrote the core tracking code and then moved to dealing with writing the crucial online monitoring for the VELO. Using his highly technical and methodical approach to the development of software he has built a very reliable and powerful system that monitors the online performance of the VELO and which, ultimately, one of the ingredients to its safe and successful operation. He is updating and extending his system to deal with the challenges of LHCb running up to the Phase I (2018) upgrade. Kurt is also one of the two key experts on overall VELO online software i.e. someone who can be called on to solve critical issues if an when they arise and is indispensible to the running of the VELO. Using his experience of Neural Network Algorithms he is leading the LHCb development of these for the identification of b-jets with high efficiency and purity, part of an analysis to search for top at LHCb. For the upgrade he is studying the effectiveness of deploying LHCb code on GPUs and has already demonstrated substantial benefits in processing time.

MR. N. ANTHONY SMITH, E/C

Project	
ATLAS upgrades	60
LHCb	95
LHCb upgrades	115
Future Neutrino	45
Generic detector	85

LHCb Upgrade: Strip/Pixel Hybrid Coordinator

Tony is an experienced detector electronics engineer with a wide knowledge of materials and processes related to detector module design and assembly. Tony was responsible for the overall electrical design, prototyping and development of the highly successful VELO (& VELO2) modules and continues to play a key role in the final stages of the build of VELO2. In particular he developed relationships with UK suppliers for lamination and population of these novel substrates which has paved the way for industrial production of the ATLAS upgrade hybrids. He also has ongoing responsibilities for the maintenance of the VELO LV system as well as having, designed and built the VELO Interlock Controller (and its spare). The Interlock Controller is a failsafe hardware device that protects the VELO from damage in a number of different potential scenarios e.g.: voltage ramps 24 under operation in Neon, temperature overloads and cooling failures, motion, current and voltage deviations, etc. He is responsible for key activities in the replacement and provides the modules for our VELO testbeam activities. In the LHCb Upgrade he is coordinating the module development, which involves the integration and optimisation for radiation length of high thermal conductivity substrates, liquid CO_2 evaporative cooling using novel materials and high frequency (gigahertz) readout electronics in a high vacuum and severe radiation environment. Tony has also been responsible for design and production of a number of 50 channel beam profile monitors for CERN PS irradiations and a controller for irradiation platforms at the PS. As part of our Silicon detector research he is currently developing a method to coat silicon with Lithium for use in neutron detectors.

Mr. Peter Sutcliffe, E/C

Project	
ATLAS upgrades	150
LHCb upgrades	85
T2K	40
Future Neutrino	40
Generic detector	75
NA62	10

Line of experiment responsibilities

Peter continues to make major contributions to the engineering design of detector sub-systems to support the research goals of the group through 3D CAD, thermo-mechanical FEA modelling and metrology. The international ATLAS tracker program relies on Peter to maintain the 3D models of the emerging stave design from which the various staves and stavelets required by the international programmes are manufactured. He is also the UK's ANSYS thermal modelling expert applying the procedures developed for the ATLAS SCT Endcap module thermal runaway analysis to the more challenging task of evaluating the thermo-mechanical robustness of the inner-most short-strip staves for the ATLAS tracker upgrade. Peter has worked in collaboration with physicists at Liverpool and within the ATLAS-UK community to successfully validate the results of various FEA codes with experimental data from stave and stavelet prototyping. As the stave design moves forward to incorporate changes necessary for the exploitation of the lower power 130nn ASIC technology, Peter will play a vital role in establishing the final stave geometry and thermo-mechanical design. Subsequently, we anticipate Peter will take a leading role within the stave-building community in exploiting the recently acquired Smartscope CNC 624 to establish a programme of non-contact metrology for fully populated staves. Peter will take charge of thermo-mechanical modelling of the pixel discs for the Phase-II upgrade, looking at the effects of deformation with curved pipes and different carbon fibre lay-ups. He will implement detailed modelling of the disc electrical services and low mass kapton hybrid into these models as well as working with **Jones** on optimising the global disc supports. Peter will use his FEA expertise in advanced thermal modelling of the LHCb VELO upgrade to establish the robustness of the design against thermal runaway

Dr. Ilya Tsurin, E/C

Project	
ATLAS Upgrades	200
LHCb Upgrades	80
Generic Det. R&D	100

Line of experiment responsibilities

Ilya is am expert in the Cadence macro-language and is able to layout complicated geometries while respecting all fabrication design rules, giving Liverpool a unique silicon micro-strip detector design capability internationally. Without this capability, the contributions to numerous RD50 masks and mask sets for ATLAS miniature detector irradiation campaigns, along with the layout of ATLAS large area micro-strip detectors with e2v Technologies plc, and all the layout for the UK ATLAS planar pixel programmes (FE-3, FE-I4 single chip and FE-I4 quad sensors) with Micron Semiconductor Ltd would not have been possible. He is the key electronics expert in the Liverpool ATLAS pixel activity, leading the establishment of FE-I3 and FE-I4 pixel readout systems at Liverpool, and taking many of the measurements to extreme doses on pixel prototypes targeting HL-LHC operation.. Ilya brings to the programme not only an intimate knowledge of silicon design but also extensive ISE-TCAD modelling capability that enables the "in-silico" modelling of silicon detectors prior to fabrication. This allows interpretation of the device performance and he provides detailed advice to the silicon fabrication companies with whom we work in the UK on process optimisation. This capability underpins a number of generic silicon R&D areas where Liverpool is particularly involved and the design of interposers to match different pixel chip geometries to better optimised sensors for forward tracking, as well as further iterations of ATLAS strip and pixel mask sets will be vital to the future UK activity in this area. The uniquely complicated LHCb VELO sensors were produced by Micron with masks designed at Liverpool and future upgrades of LHCb will also rely on this key capability being maintained within the UK. On the pixel system, the final low mass pixel module kapton hybrids and electrical service tapes will need to be designed taking advantage of the Liverpool expertise in these areas demonstrated on the LHCb VELO and ATLAS strip upgrade modules. Ilya's electronics skills mean he is ideally placed to carry out this work exploiting the know-how and UK industrial links already in the group.

MR. MARK WHITLEY, T/C

Project	
ATLAS Upgrades	200
LHCb	35
LHCb upgrades	80
Generic Det. R&D	85

Line of experiment responsibilities, L8.8, L8.8,L8.13

Mark provides a key interface to the Physics workshop, where he is among the most experienced operators of the modern computer controlled equipment. He has used the Vertical Milling Centre (VMC) to produce numerous moulds for complex lightweight carbon fibre structures fabricated using the autoclave and carbon fibre CNC cutting equipment at Liverpool. The UK's contribution to the HL-LHC stave programme in ATLAS has relied heavily on these skills. He is able to carry out detailed metrology and run test equipment and has helped build test stands for the LHCb and ATLAS Upgrade programmes and worked on assembly of prototype modules. He has been to the jigging needed for the ATLAS irradiation programme and his skills are vital to future ALTAS single-sided module construction, where Liverpool lead internationally and for manufacture of numerous cool boxes, tooling and supports required for this programme. As someone who had responsibility for performing all the front-end bonding on the VELO rebuild modules, he has vital skills to help back-up the wire-bonding programme, which is key to most of our proposed future R&D.

More on LHCb and overall endorsement here

MR. MIKE WORMALD, T/C

Project	
ATLAS Upgrades	225
LHCb	45
LHCb upgrades	40
Generic Det. R&D	90

LSDC: Chief Wire Bonder

Mike is the chief wire-bonder at Liverpool. He has written the wire bonding programmes for all the different automatic bonding jobs at Liverpool. He is also skilled in module gluing and machining using hand tools. He wire bonded most of the 365 modules made at Liverpool for the ATLAS Endcap and has carried out all the wire-bonding on the 20 ASIC ATLAS HL-LHC 26 module prototypes built at Liverpool (out of 32 built internationally with seven institutes now producing modules with Liverpool designed jigs). He has carried out wire-bonding trials which set specifications for the module and new ASIC designs internationally and carries out the extensive wire-bonding for the irradiation programme, where the procedure is to connect all 128/256 channels through a re-bondable fan-in, measure with ^{90}Sr β-source, irradiate at an international facility, then re-measure giving an unambiguous figure for the reduction in signal and any changes in noise with dose. He w

Mike carries out all training for the bonding machines, writes the training and process documents for bonding machines and automated glue robot. Mike has wire bonded most of the VELO1 modules and VELO2 replacement modules. Mike, as chief bonder. acts as advisor regarding bonding issues to other institutes. Mike formulates the glue procedure for populating ASICS , pitch adaptors and sensors to enable planarity for wire bonding. Mike builds, bonds and helps with transportation and installation of equipment at CERN

Mike is also a key staff member for installing, testing and commissioning new equipment such as the new Bondjet 820 Hesse and Knipps wire-bonder. Mike is a recognised expert in the programming and use of many of the high technology items in the LSDC, often providing code to other institutes and his skills are vital to the long term programme of the particle physics group.

RESPONSIVE MODE POSTS

DR. CARL GWILLIAM, PH/R

Project	
ATLAS	300

ATLAS: UK Higgs Co-convenor

Carl has worked very successfully on ATLAS data, the SCT software, computing and supervision of students and his work has been key to Liverpool's strong contributions in the ATLAS search for the Higgs. He managed the implementation of the SCT conditions data in the reconstruction and remains responsible for the clustering algorithm. Carl was appointed Inner Detector Software Release Coordinator (2009 – 2010). With the first collision data, Carl studied the effects of multiple scattering and alignment on the impact parameter and resolution of tracks. He worked on the *b*- and *c*-tagging efficiency and light quark mistag rate from Monte Carlo simulation and data. In Oct 2010, Carl was appointed convenor of the ATLAS beamspot group for a year. Carl will continue his involvement in SCT software and maintain an active role in the ATLAS data preparation group. Carl's physics interests are focused on the search for the Higgs boson. In the high mass range ($M_H >$ 200 GeV) Carl used previously unexplored $H \to ZZ \to llqq/llbb$ channels, and was editor of a PLB on this result. He has also contributed to the related $H \to ZZ \to ll\nu\nu$ search channel. These channels have allowed to exclude a large region of Higgs boson phase space. At low Higgs mass, he made a major contribution to the search for a $ZH \to llbb$, working also on extending this to $ZH \to \nu\nu bb$. In 2011, he was appointed convenor of the UK Higgs working group. In addition to Higgs searches, Carl contributed significantly to the published measurement of the cross section for Z+ b-jets providing an insight into the proton b-quark density and also a major background to two of the above Higgs searches. Over the coming grant period, Carl will play a lead role in the ZH, $H \to bb$ and $H \to ZZ \to llqq$ searches and expects to contribute significantly to the measurement of the Hbb coupling.

DR. KAROL HENNESSY, PH/R

Project	
LHCb	400

LHCb: VELO Deputy Project Leader

As his recent appointment as VELO deputy project leader at CERN testifies Karol is a key member of the VELO group and is based at CERN. He is overall responsible for the VELO DAQ and he is only one of the two people on the experiment that can solve serious VELO DAQ problems. As the DAQ/Run Control expert he delivers all the software that allow the VELO to take data. This includes the PVSS system for subcomponents of the VELO including chips, control boards, TELL1, LV, HV etc. In addition to these duties he is playing an important role in the module installation assembly and testing of VELO2. He set up the new VELO assembly laboratory including its DAQ. As opposed to the original VELO assembly the new laboratory is a true "slice" of the LHCb online system. Karol's development this facility will enable new firmware to be tested during the lifetime of LHCb whilst the experiment is running, He will be expected to continue this to prepare VELO2 for, installation and commissioning. His other

duties will include the testing of the critical TELL1 boards and ensuring that we are able to "hot-swap" components as they fail. In addition to his VELO2 responsibilities he will take on the responsibility for analyzing data from 2012 and 2014 testbeam runs in order to understand(and reproduce) important effects such as the charge sharing in the VELO as it becomes radiation damaged. Although the VELO and VELO2 responsibilities will continue to be a major part of Karol's duties it is important that he is given has the opportunity to perform analysis on the data collected. Building on his EW background he will help perform the definitive LHCb differential cross-section analyses with his particular responsibility being the VELO part of the tracking and IP systematic. He will working on the top programme measuring with higher accuracy the cross section for t-tbar and single top using the 2012 and 2014/15 data samples.

DR. TORKJELL HUSE, PH/R

Project	
LHCb	295
LHCb Upgrades	105

LHCb: VELO2 Module Coordinator

Torkjell is a highly experienced detector physicist with experience of ATLAS and LHCb module production. For the initial module production he developed the mechanics, and programmed both the assembly systems, DAQ and metrology system. After the successful commissioning of VELO1 he became responsible for streamlining the production of the VELO2 for which he is responsible. He will continue oversight of all VELO2 module based activities at CERN and become involved in the final stages of testing of VELO2 and preparation for its. At CERN he will take co-responsibility for the testing and qualification of all the TELL1s and, at the same time, participate in designing the new AI monitoring system (Torkjell designed the original VELO Monitoring GUI). As an expert on radiation hard silicon he will analyse the VELO data (2012-2016) and, with the aid of simulation, determine the impact of radiation damage on the trigger and offline reconstruction efficiency. Having developed, analysed, the original charge sharing studies on VELO detectors with lasers and participated in early testbeams he will study the charge sharing effects in the double-metal sensors, using collision data and testbeam studies. This will be an important comparative study because (with ISE-TCAD skills) Torkjell will also insert the results into a full Si simulation of the sensors and develop the necessary understanding of any new underlying processing influencing this sensor technology. As an expert on the VELO system, he will contribute to the day to day running of the detector through his role as a piquet. His detector and software skills will be required for the next stage of VELO development. Torjkell is designing a prototype VELO strip detector, with improved and novel routing developed by LHCb group, for use at 40 MHz. He will participate in the design and prototyping and building of the Phase I upgrade, and as for VELO2, will lead the module build. As one of the top Silicon module builders in the world it is critical to the group, and the UK, to retain his skills.

DR. PAUL LAYCOCK, PH/R

Project	
ATLAS	270
LHeC	30

ATLAS: Co-convener W/Z Heavy Flavour Group

Paul has made major contributions to ATLAS operations and physics and performed important work on deep inelastic scattering on H1, and the LHeC. As ATLAS Calibrations Conditions Coordinator 2008-2010 and deputy until 2011, Paul was responsible for the management of all collision and simulated data. He contributed to the implementation of the prompt calibration loop, coordinated the conditions deliverables for reprocessing, and he led the design of a new model for managing conditions, implemented in 2011. For analysis, Paul has contributed to third generation searches for SUSY, primarily studying the b-tagging performance. He gave the ATLAS overview talk at ATLASUK 2010. Paul is the analysis contact of the $Z+b$-jet analysis using the 2011 data. As new co-convenor of the W/Z with heavy flavour group, he coordinates the analyses of 2011 data which drive the b-tagging performance of ATLAS. Paul has served three times as the chair of ATLAS Editorial Boards. He intends to measure WW scattering as a sign for the electroweak symmetry breaking mechanism during the next grant period. In the previous grant period, Paul successfully completed his term as diffractive working group convenor of H1. With H1 he published the only measurement of the diffractive longitudinal structure function, F_L^D. He has been convenor and summary speaker at conferences and workshops. As a member of the LHeC Steering Group, Paul contributed to the conceptual design report. He worked on the detector design and as the technical editor of the CDR.

DR. KOSTAS MAVROKORIDIS, PH/R

Project	
T2K	240
Future Neutrino	60

Kostas' time on T2K includes central tasks as described in the T2K-UK submission at 10% ECAL hardware support and 20% ECAL reconstruction. Kostas is a seasoned detector expert who came to Liverpool in 2009 in a University-funded position to work on the start-up liquid argon (LAr) R&D programme. He joins our Consolidated Grant to replace **Chavez** who accepted a CERN fellowship. He has designed, constructed, and commissioned a 250 l Argon bath with an inner 40 l LAr chamber with a novel liquid recirculation system and a purification system, both made in-house. His work led to a journal publication and material that he presented at international conferences. He also led the design and construction of a source-PMT Argon purity measurement device used in the first demonstration of purification through the "piston effect" in a 6 m^3 vessel at CERN. In parallel he contributed to the T2K ECAL modules construction and testing at Liverpool. Utilizing his detector expertise, in particular in scintillation detectors and energy measurement, he is working on ECAL reconstruction software and detector monitoring developments. Kostas will continue to work on and support ECAL reconstruction and monitoring software development. His main physics analysis will be the measurement of exclusive neutrino cross sections (single and double pion production) with ND280 data and specially the study of charged and neutral currents interaction. These will be the first measurements of exclusive ν_μ induced final states beloe 1 GeV. He will use these measurements as an input to the ν_e oscillation measurement (the main objective of T2K) as they directly influence the background and flux estimates. In parallel he will continue to oversee student work on the LAr system and the micromegas characterisation programme to be carried out at Liverpool in collaboration with Saclay. He will also participate with a small fraction of his time in LAGUNA-LBNO as an expert in LAr operations in the appropriate work package.

New Responsive Mode Posts

RESPONSIVE RA-1, PH/R

Project	
ATLAS	300

Liverpool has led the way in the search for a SM Higgs boson at high masses. Liverpool has also led the low mass associated *Z+H* and *W+H* searches, where the Higgs decays to *b*-quarks. We request a new responsive RA post to measure the coupling to *b*-quarks of the Higgs candidate and to search for additional non-SM Higgs candidates. For both measurements the *llbb* and the *vvbb* final states will be studied exploiting the techniques developed by Liverpool. The couplings of the Higgs are sensitive test of the SM. The *Z+H* channel will be the main channel in which to measure the coupling to *b*-quarks. Further searches for higher mass neutral and charged Higgs are also required to establish whether we have a single Higgs or an extended Higgs sector as predicted in many NP models (as in SUSY). The *llbb* and *vvbb* final states offer an excellent opportunity to look for a heavy neutral non-SM Higgs decaying either to a *Z* in association with the lower mass Higgs (*h* in this case) or to a pair of *Z* bosons. This will require the development of the framework needed to set limits on a high mass Higgs boson in different BSM models. The RA will be required to develop a generic framework in which one can present limits on BSM Higgs candidates. This will require close collaboration with phenomenology colleagues. They would also be expected to develop and contribute to the calibration of b-tagging software in ATLAS. The reconstruction of the E_{Tmiss} is vital for these channels and the RA will be expected to develop more robust reconstruction algorithms for use at higher energy and pile-up. They would also contribute to the preparation of physics techniques for use after the 2018 upgrade. In summary the appointee will make major contributions to the following publications: search for a SM Higgs in ZH, WH channels (2011/2012 data), search for a high mass A/H^0 decaying to ZZ, Zh (2011/2012), and a first measurement of the H-b quark coupling. Updates of these studies will be performed on the higher energy data samples after the 2013 shutdown . They will contribute to the preparation of the physics TDR for the upgrade.

RESPONSIVE RA-2, PH/R

ATLAS	300

Despite many of predictions the LHC has so far not observed any sign for a new, heavy resonance in the di-lepton channel, up to masses of about 2 TeV for SM couplings. In extra dimension theories, a sequence of Z^0-like resonances is predicted to exist. This will be explored further with the 2011/12 data with integrated luminosities of 5/15 fb^{-1} luminosity at c.m.s. energies of 7/8 TeV. The data of 2015 (30 fb^{-1} at 13 TeV anticipated) will extend such direct searches up to about 3 TeV. If a new state appears between 2-3 TeV, it is most likely only a lowest lying resonance state. In the absence of a direct resonance observation below 3 TeV, a precision DY cross section measurement may reveal the existence of higher mass *Z′* bosons via Z^0-Z' interference effects. Observation of such effects and their interpretation is only possible with mastering the substantial experimental and theoretical problems of measuring and interpreting the DY invariant mass spectrum. These include, for example, the need for a per cent accurate electron energy calibration or for a precision control of higher order electroweak and QCD effects. The Liverpool ATLAS group is uniquely suited to pursue this program, with **Kretzschmar** being the coordinator of the *W,Z* analysis and "Egamma" electron efficiency responsible, and with **Klein U**. being the convenor of the PDF ATLAS forum. They have lead the ATLAS precision measurement of the W,Z DY cross sections. This group is now pursuing a *W, Z* precision analysis of the 2011 data and has also moved into the search for $Z' \rightarrow$ ee. With the experimental and theoretical tasks becoming ever more demanding, and the two academics in coordinating roles for ATLAS at larger and for that specific physics programme, such an innovative search and measurement programme can only be pursued with an RA added to this effort. The RA tasks are: for 2012/13: precision measurement of the high mass DY cross section based on the 8 TeV data; 2013/14: theoretical and simulation work to prepare for the 13 TeV data and 2014/15: Search for 3-6 TeV mass new resonances, by direct and interference measurements of the high mass Drell-Yan spectrum and correlated information.

RESPONSIVE RA-3, PH/R

Project	
LHCb	300

The group has invested a large fraction of its effort in building and operating the VELO and its replacement and carry a heavy load of responsibility for the experiments operation. We are now asking for resources to allow us to exploit the B physics potential of the experiment. This RA would work on the decays of the B states to charm to hadronic final states to measure the CKM angle γ and the properties of the heavier B meson resonances. Initially they would join the work on the decays of $B_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-}$, let by Hutchcroft, separately measuring the branching ratio to each final state. This analysis will be the world's most sensitive measurements of the mass differences of the B_s meson states from the branching ratios, it will also provide a very sensitive measurement of the B_s lifetime. The research associate would extend this to a time dependent measurement of the decay providing a sensitive measurement of the oscillation frequency for the B_s mesons. This will be used to set the most sensitive limits on NP occurring in the box diagrams of the B_s oscillations. The RA would then extend the analysis to the time dependent measurements of other B_s oscillations and also to the reconstruction of the $B_c^+ \rightarrow D_S^+ D_S^- h^+$ [h = π or K]. The three body decays will be used to search for new heavy $c\bar{s}$ and $c\bar{c}$ states, measurements of their masses, spins and parity. These states will be used to test the lattice QCD and HQET predictions for heavy quark states. Leading the study of heavy quark states in this and other decays will be bolstered by the ties to the strong lattice QCD group in Liverpool. This effort will balance and complement the groups effort on standard model measurements and enable us to fulfil our mission of both designing, building and analysing data from LHCb.

The research associate would also lead the program to evaluate the sensitivity to NP of the *B*-decays using the higher luminosities of an upgraded LHC and specifically how to use an upgraded VELO to maximize the physics reach. This will require studying the potential trigger strategies and the expected signal and background retention rates. Also the sensitivity of the B decay measurements to the effects of NP in the properties of the decays. The requirement for resolution and alignment for any proposed strip and later pixel upgrades and how those impact on the data retention rates will be critical inputs to the future physics program of LHCb.

RESPONSIVE RA-4, PH/R

Project	
LHeC	300

The LHeC is due to become reality largely because of the leadership of Liverpool physicists, most of them are engaged in ATLAS. For the further development of this innovative project, full time person power at Liverpool becomes a necessity. Herewith a first RA is requested for work on physics, the detector design and its development. The time of the RAE will broadly be shared between three, joint tasks: First, the two salient processes, top production and WW fusion in ep, have to be studied in much more detail as these largely determine the design of the LHeC detector. Top production at the LHeC is copious allowing novel investigations of t quark properties, top and anti-top quark distinction and to develop a six quark variable flavour theory as a novel way to view proton structure at extreme momentum transfers. At the LHeC, WW scattering in charged current ep processes allows to explore the CP nature of the coupling of a scalar Higgs field to vector bosons, if a light SM Higgs is discovered at LHC. This reaction is also crucial for studying the unitarity conservation mechanism in WW scattering, which will be of special interest if the Higgs boson remains elusive. In a recent paper of Randall et al, top and W are considered to be composite. Secondly, professional work is required to simulate and optimise the detector configuration. It is for Liverpool most natural to lead the design of the LHeC silicon detector further, for which the in-house ATLAS and LHCb detector work represents an ideal basis. Thus, thirdly, prototype design and tests are to be performed of the pixel detector for the LHeC apparatus. The RA will work in intimate collaboration with world experts, as from DESY and CERN and will collaborate at Liverpool with **U.Klein** on DIS top and Higgs physics and simulation and **Tsurin** et al. on the detector development. The successful RA will be in the heart of the LHeC project and rise to become a core physicist in the new Collaboration being built.

RESPONSIVE RA-5, PH/R

Project	
SNO+	300

We request a responsive post to work on the SNO+ experiment. This post would allow Liverpool to fully participate in the exploitation phase of this experiment searching for neutrinoless double beta decay. The person filling this post would spend 60% of their time constructing, running and supporting the data processing and data flow scheme for SNO+. Data flow and data processing are key UK responsibilities for SNO+. This PDRA would work to adapt the SNO data processing infrastructure to the new challenges presented by the current computing environment in high energy physics. They would update the structure to make full use of available resources for SNO+, including the grid in the EU and various large computing farms in the Canada and the US. In the first year this PDRA would spend 70% of their time getting the data processing system up and running and supporting the overall SNO+ data processing. This fraction of time would drop in subsequent years to 40% of their time. In addition they would spend 20% of their time supporting the SNO+ data flow system ensuring that raw data is moved and archived efficiently and safely. In addition to the data processing tasks this PDRA would also contribute to the physics analysis. The search for the neutrinoless double beta decay of ^{150}Nd is a key physics goal for SNO. Working to with Neil McCauley who has extensive knowledge of the SNO detector this PDRA would join this group working to improve the reconstruction of SNO+ data in the region of the ^{150}Nd double beta decay end point, and to understand the background in this region. This would allow SNO+ to make the best possible measurement of the rate of neutrinoless double beta decay of ^{150}Nd and in doing so the PDRA would be able to make a substantial contribution to this analysis. We would expect this PDRA to spend a significant amount of time working at the detector site in Sudbury. This time would include collaboration meetings of which there are three a year, shift taking and the statutory experimental requirement for all PDRAs to spend one term (4 months) on site. This time on site would also allow the PDRA to work closely with member of the collaboration from other institutions both on physics analysis and on integrating external sites into the data processing infrastructure. The addition of this PDRA would prove invaluable to strengthen the Liverpool neutrino group and to the SNO+ collaboration

RESPONSIVE RA-6, PH/R

Project	
ATLAS Upgrade	300

The Liverpool ATLAS group has been extensively involved in the design, build and commissioning of the ATLAS SCT tracking detector and now plays a leading role in many key physics analyses. We are now playing an internationally leading role in the preparation of the upgrade of this detector for the HL-LHC. However, our ability to capitalise fully on both aspects is frustrated by the lack of dedicated upgrade simulation effort at Liverpool, reflecting the difficulties for the UK in general to take advantage of its technical leadership in helping shape the future layout of the experiment. We therefore request a PDRA to work specifically on the tracker upgrade and more generally on physics simulation under the conditions of the HL-LHC. This work will initially involve the development of a detailed simulation of various proposed detector designs, with UK colleagues, to establish the optimum design for HL-LHC physics. Using detailed simulations of various detector geometries, the PDRA will study the track reconstruction performance and become involved in the development of improved reconstruction algorithms to cope with the extremely high multiplicity environment of the HL-LHC. A key element work to on secondary vertexing code, better suited to the very large (140-200) primary vertices. The performance of the various detector designs combined with enhanced track reconstruction will then be evaluated in several important physics channels.

The proposal also overlaps with the period when the TDR will be being prepared for the ATLAS Tracker Upgrade project. An important role of will also be to study the physics channels expected to benefit most from the luminosity upgrade and to incorporate into this the perspectives gained from ongoing analyses with current data and to channel the analysis know-how at Liverpool into HL-LHC simulation studies.

Support Posts (1 page per post)

Ms. Linda Fielding, O/C

Liverpool Group: Finance Officer General Support 400

Linda joined the Department in 2007 and has taken particular responsibility for monitoring all aspects of the Rolling Grant expenditure and providing oversight of all the other STFC grants held within the Department. She provides the main interface to the University Human Resources (HR), Research and Business Services (RBS) and Facilities Management (FM) Departments, thus providing an invaluable service to the PI and Co-Is in the group. Linda prepares and maintains the spreadsheets which keep track of staff, equipment, consumables and travel spend. She also verifies costings for grants generated by RBS with whom she works closely. Linda provides regular reports to the PIs holding STFC grants and helps organise secretarial support and travel for the particle physics group. She is an integral part of the team and, as Finance Officer, for the Group audits and monitors all expenditures providing weekly feedback on all expenditure and projections. By managing cashflow through the grant period this permits the group to make careful to investment throughout year and to maximize the impact of STFC resources. She also interacts with STFC staff in Swindon directly, providing updates on grant and staffing related issues and ensuring appropriate paperwork is provided punctually by group members when required. This would only be possible with an intimate working knowledge of the functioning of the Particle Physics Group and from day to day experience as part of the management team. Linda makes a huge contribution to the operation and professionalism of the group and greatly reduces the burden on staff relating to University bureaucracy. As well as improving the efficiency of cost control within the group and she works tirelessly to help staff effectively and efficiently carry out their research without undue distractions. Liverpool has a major UK particle physics group with many diverse grants to administer in an environment of ever tighter regulation and ever greater reporting requirements. Linda is an extraordinarily hardworking member of staff, who makes a big difference to everyone by taking care of a wide range of mandatory, but highly time-consuming, administration responsibilities.

The STFC currently fund the cleanrooms and workshop facility through various grants, but mainly through the current HEP rolling grant. This is a major facility and investment and therefore requires efficient and effective financial management and monitoring. To ensure this, Linda is responsible for these accounts and works with the group and managers to set budgets and to report on actual as against set profiles, ensuring that all funds are maxinised and that all of the group are aware of the availability of expenditure in relation to running costs, staffing and equipment

Non Staff Costs (2 pages max)

Travel and Subsistence

The travel request is based on our emphasis on disseminating exciting physics results from our experiments and the large number demands to attend instrumentation conferences due to our leadership in this area. All members of staff are encouraged to travel on non-STFC funding, if possible, and to request travel money with new grants. In previous years a pro-forma costing was applied to travel. Here we have used our current travel budgets (2010/2012) to inform the request for 2012/2016. We have assumed that, on average, all academics, fellows, physicists and responsive RAs will present at 1 conference per year. Our engineers are leaders in the field and we estimate at least three attends a conference every year. With the data flowing in from LHC and with the leadership positions in our experiments these estimate are "light" but represents our commitment to minimizing the cost to STFC. The average cost for EU and non-EU overseas conferences is estimated at £1600 whereas UK conferences are estimated at £600 per conference. We have asked for four years travel for core staff and three years for responsive staff.

	UK / Cost	Number / Year	Non-UK / Cost	Number / Year	Cost / Year	Total
Core (48 months)						
Conferences	£600	6	£1,600	24	£42,000	£168,000
RD50	0	0	£1,000	3	£3,000	£12,000
IOP	£500	8	0	0	£4,000	£12,000
New Projects	£150	20	0	0	£3,000	£16,000
Resp. (36 months)						
Conferences	£600	1	£1,600	3	£5,400	£16,200
IOP	£500	2	0	0	£1,000	£3,000
Other						
Interviews	£200	6	£500	2	£2,200	£8,800
Hospitality					£2,000	£8,000
Visiting/ Profs			£2,000	2	£4,000	£16,000
Seminar Speakers	£120	20	£500	1	£2,900	£11,600
SNO+						
(1 Core + RA5)	£600	2	£2000	6	£12000	£46,200
LTA (RA-5)			£1260	3	£3780	£11,340
Total Request						£329,140

Table 4: Travel and subsistence costs for Liverpool. Included in this table is a request for travel for SNO+ (see text) which we will administrate but is not part of the group travel. Travel and Subsistence costs for core, responsive and other personnel. Note responsive staff are costed for 36 months whereas the core staff are costed at 48 months

We also request funding for out visiting fellows and professors who are conducting experiments at Liverpool. It is important that, as innovators and leaders, we are able to attend meetings on new projects. For this we request travel funds of approximately £16K per year. Finally we request £3K per year for speakers and collaborators visiting Liverpool.

SNO+: the absence of a centrally held SNO+ travel budget, and in line the agreement between the collaboration[††] and STFC we will administrate the travel budget for the Liverpool SNO+ locally.

[††] Contact S. Biller, Oxford: s.biller1@physics.ox.ac.uk

Their budget request is for £57,540 over 48 months of which assume three trips to the experiment per year. LTA costs, for **RA-5**, amount to £11,340 over three years.

The total sum requested is approximately £330,000 of which approximately £270,000 is for travel and subsistence for the group. This information is summarized in the Je-S tables.

CONSUMABLES

The group requests approximately £450,000 for consumables. An itemized list is provided in the accompanying Je-S form. The largest category is for our hardware IT requirements (£158,500), which includes a large expansion in our GPU processing capability. Electronic supplies are crucial to support our equipment building (£75,200) and communications (£75,200) are important to our continued operation. The remainder of the request is made up of requests for software, supplies and small equipment (value < £10,000).

Consumables	Cost
Advertising	£13,500
Communications	£66,400
VC & Data	£14,550
UPS	£12000
IT	£158,500
Printers	£13,850
Software	£41,111
Electronics	£72,200
General Supplies	£10,000
Office Supplies	£14,000
Small Equipment	£34,000
Total	£450,111

Table 5:Summary of consumables

EQUIPMENT

In this bid we also make the request for several items of equipment crucial to building individual items of instrumentation, and for R&D to support the next generation of particle physics experiments. First is an IR microscope required for our pixel building programme (£41,000). This would enable us to identify in detail the temperature profile of pixel modules and important, look at temperature profile of individual pixel structure post-irradiation. This will allow us to build ATLAS pixel sensors and be confident in their high fluence performance, in particular locating the position of any HV breakdown around the sensor structure. Electronics for the ATLAS upgrade also requires us to purchase one new high end Tektronix Oscilloscope(£55,000) with the capabilities (buffer lengths, sensitivity) required to test the DAQ chain. We also propose to upgrade our vacuum system for the ATLAS build as the current system is inadequate to support the number of bonders, probe stations and metrology systems required for this build. This will be a (£70,000) upgrade to the LSDC for which we are requesting £35,000 from STFC – the remainder of the cost being borne by the Department of Physics. Currently the ATLAS programme is using a one-pass CO_2 cooling system, developed by LHCb, that is difficult to use and stabilise. A major upgrade to our liquid, bi-phase, CO_2 system is needed. We propose to buy a £40,000 recirculating system from CERN. This will be a crucial piece of equipment for the ATLAS upgrade which matches the technologies to be use in the experiment. It is important for Liverpool to possess this if it is to bid to be a major build centre in the UK. We request two further items: an DAQ and control system for our Dark Energy search (£40,000) and a DELL Z9000 switch ....

Major Equipment	Cost
iR Microscope (Olympus)	£41,000
Tektronix Scope	£55,000
Vacuum System	£70,000
CO2 Cooling System	£40,000
DAQ/Control DE	£40,000
Dell Z9000 Switch	£81,000
Total	£327,000

Table 6: Major Equipment costs.

Research Facilities (2 pages each)

The success of the group is predicated on access to world class facilities. These enable the UK to compete internationally at the highest level and ensure the data returned for analysis from the experiments is of the highest quality. These facilities enable the both construction and maintenance of experiments. Our ability to innovate and contribute to new areas of physics, through development of state of the instrumentation, depends on the skills which embeded in our facilities: the **workshop** and the **LSDC**.

Workshop

The Liverpool Particle Physics group enjoys access a workshop which is one of the best equipped in the country. Updated at the same time as LSDC was constructed just over a decade ago it is equipped with computer controlled, large bed 4 axis milling machines, a CNC lathe as well as a sophisticated wire eroder capable of machining complex shapes that in fraction of time they could be milled conventionally. Our trained technicians (die and toolmakers) are experts in their owm fields and regularly work to the most demanding specifications. From 1 Oct 2009 to 1 January 2012 Particle Physics used about 62% of the work shop resources (we had requested ~60%) which was distributed as follows: ATLAS Upgrade (21%), LHCb VELO2 (11%), T2K Construction (7%), Future Neutrinos (8%), Detector R&D (9%) and NA2 (6%). A large fraction of work was done for the new ATLAS upgrade programme, where the workshop provided state of the art jigging for wire bonding, module assembly and composite prototype strip and pixel staves with embedded cooling for module support. Copies of the ATLAS Upgrade tooling have now been provided to UK, German and US colleagues who are all now producing working modules. The workshop has successfully delivered all the complex composites for the LHCb which is designed to operate in vacuum and to have minimal thermal and hygroscopic creep. The pedestals (built and designed at Liverpool) have compound CTE of ~1ppm/ ºC. Furthermore, the technique of sandwiching thermo-pyrolytic-graphite (TPG) with CF facings was developed at Liverpool and along with the other complex composite work underpins the future ATLAS and LHCb upgrade programmes. The workshop has provided substantial machining and effort to construct the T2K ND280 ECAL which was been successfully commissioned in 2011.

Over the last 10 years Liverpool have moved from working largely in traditional materials to being one of the leading centres for producing CF composite structures in Particle Physics. We have produced high precision supports for CDF, ATLAS as well as the LHCb VELO. Complex shapes have been manufactured for MICE. Substantial investment has been made in the equipment needed to fabricate high quality composites. Over the period of the last grant we invested in a pattern cutter that has increased the throughput (by decreasing the production time for complex cutting) of CF pieces. Staff have attended courses on the development of composites and regularly use the latest materials CF, C composites, TPG, C-foams to produce low mass stable structures.

During the period of the next grant the group will utilize the workshop in six major areas. The ATLAS Upgrade will move from its current R&D phase towards production readiness. Establishing that a green light may be given for production to proceed will involve a large amount of building of prototypes as well as finalizing the jigging and tooling for all production sites. Both staves and stavelets will produced in prototype quantities. Full electrical assemblies will need to be built at Liverpool as preparation for our final construction role, requiring extensive tooling development. The workshop will also play an important role in producing viable prototypes for the ATLAS pixel forward region; these are expected to be composite lightweight high thermal conductivity structures with embedded cooling and electrical services.

For the current LHCb VELO (including VELO2 replacement) the workshop will be involved in building equipment for the storage and installation/de-installation of VELO including designs required for handling heavily irradiated sensor. For the VELO upgrade (Phase I) the highly sophisticated jigging and tooling will have to be modified and tested for the new hybrid design.

Additional pedestals and bases will need to be fabricated, together with the precision hybrid machining, to produce full working VELO3 prototypes. The workshop will also drive the construction of Phase II VELO pixel sensors and build the structures required to mount these. Sophisticated cooling techniques will be used for the pixel upgrade and work will be performed on the bending and embedding of narrow wall tubes into composite structures.

Financial Yr	Oct 2012 to Mar 2013	April 2013 to Mar 2014	April 2014 to Mar 2015	April 2015 to Mar 2016	April 2016 to Sept 2016
ATLAS Upgrade	18	47	58	64	30
LHCb	8	18	6	2	1
LHCb Upgrades	9	11	19	17	8
Future Neutrino	10	12	12	12	8
NA62	6	11	0	0	0
Generic R&D	6	11	15	15	9
Total Days (Workshop)	55	110	110	110	55
Cost to STFC (80%)	**£83,556**	**£167,112**	**£167,112**	**£167,112**	**£83,556**

Table 7: Estimated cost for the use of the workshop. The table lists the number of days required for each project. The cost to STFC is calculated from at 80% × cost/day[7] (£1899)

We are committed to ensuring the workshop is able to keep up with high standards of mechanical and composite construction and fabrication techniques required by today's experiments. As such we are bidding, from University funds, for an additional 5-axis milling machine which enables complex shapes like the LHCb VELO foil to be fabricated. In addition we have recently purchased a 3D printer for the rapid production of small, low tolerance, objects that are would otherwise tie up valuable workshop time. The total we request from STFC for the workshop is £668,448.

Liverpool Semiconductor Detector Centre

The Liverpool cleanrooms and workshop refurbishment were established thanks to a PPARC Joint Infrastructure (JIF) grant of £3.1M. The cleanroom suite is a unique facility in particle physics internationally, with 210 m^2 dedicated to and designed for particle physics use. In late 2011, the cleanroom classifications were revalidated with the large area probing, wire-bonding, module assembly and metrology suite confirmed as ISO[8] Class 7 with the surrounding R&D, macro-assembly, testing and Coordinate Measuring Machine areas all confirmed as Class ISO 5. We have been nominated for a University Green Award having saved over 186MW/hrs. The cleanrooms have temperature control to 1ºC and humidity control to better than 5%. The environmental chamber for testing large arrays (such as the seven disc ATLAS Endcap-C which was fully assembled integrated and commissioned at Liverpool prior to shipment to CERN) can operate with dewpoint down to -30ºC and temperatures down to -15ºC.

The LSDC is central to the long-term plans of Liverpool and for many aspects of the UK in particle physics. On the ATLAS Upgrade, 26 of the 32 single-sided upgrade modules constructed internationally were built at Liverpool and the tooling for all the other sites was designed and prototyped there. The international lead on the Phase-II strip module programme is provided by **Affolder**, while the low mass multi-layer kapton hybrids used for this programme internationally are designed by **Greenall** and fabricated with UK industry and wire bonded at Liverpool. The

7 Costs of facilities are centrally calculated by the University of Liverpool. Details available on demand.
8 http://www.iso.org/iso/home.html . See 14644-1:1999.

LSDC has the capability to reception test the 5120 strip sensors with high speed probe-stations, wire-bond hybrids and modules, assemble modules to staves and ship assemblies in secure support structures to CERN. The high quality clean-rooms ensure excellent yields at all these steps and the reputation for delivery on ATLAS, LHCb and T2K helps attract future high quality programmes to the UK. The high skill level of technical staff (**Carroll**, **Whitley**, **Wormald**) working in the clean-rooms is similarly vital and they are engaged fully in designs for future projects, advising on assembly and testing issues with impact on ASIC and sensor final designs. The involvement from ASIC specifications and sensor design to macro-assembly allows a complete overview of the proposed programme which is vital to successful and on budget planning (**Affoder**, **Jones**). This is equally true for the pixel programme, where Liverpool has designed the first “Quad sensors” fabricated with UK industry and being tested by a CASE student using the probe station facilities at Liverpool. The irradiation programme requires extensive use of the facility for wire-bonding and testing (both strip and pixel miniature detectors) and the establishment of planar p-type sensor fabrication at Micron and e2v would not have been possible without the support of the centre for both pre- and post-irradiation characterisation, including charge collection, with temperature and voltage (Casse). This capability has underpinned our international leadership roles in ATLAS Upgrade and RD50 (**Affolder**, **Allport**, **Casse**). The metrology and macor-assembly high ceiling cleam-room area with built-in crane will be essential for future large scale assembly work for ATLAS. The testing of the low-mass complex composite assemblies with integrated read-out and cooling relies on the large suite of metrology equipment (two CMMs and two Smartscopes) both for prototyping and for final QA (**Jones**).

The LSDC has also been identified as the major build site for the LHCb VELO upgrade. No LHCb collaborator has equivalent facilities or expertise. Building on the successful delivery of VELO1 and VELO2 the unique LSDC facilities provides the key infrastructure and expertise for the delivery of the next generation of detectors. Careful management of the facilities and resources guarantees our ability to deliver multiple STFC projects at the same time.

Financial Yr	Oct 2012 to Mar 2013	April 2013 to Mar 2014	April 2014 to Mar 2015	April 2015 to Mar 2016	April 2016 to Sept 2016
ATLAS Upgrade	42	91	99	99	49
LHCb	8	8	3	3	0
LHCb Upgrades	14	28	28	25	14
Generic R&D	14	28	25	28	14
Total (days LSDC)	77	154	154	154	77
Cost to STFC (80%)	**£80,511**	**£161,022**	**£161,022**	**£161,022**	**£80,511**

Table 8: Estimated cost for the use of the LSDC. The table lists the number of days required for each project. The cost to STFC is calculated from at 80% × cost/day (£1307)

The total requested from STFC is £644,090.

APPENDIX 3 PUBLICATIONS AND CONFERENCES

The following data have been compiled for papers published since 1 September 2009 to 7 Feb 2012

	Number of refereed publications[9]	Number of lead researcher refereed publications	Number of technical reports	Number of first author technical reports	Number of conference proceedings
Allport, P.P.	150				
Bowcock, T. J. V.	44	2	3	0	0
Burdin, S.	181				
Coleman, J.	124				
Dainton, J. B.	40				
Fry, R.	119	0	0	0	0
Gamet, R.	92				
Greenshaw, T.	163				
Hutchcroft, D.	155	0	2	0	2
Klein, M.	165				
Klein, U.	128	4	10	8	0
Kretzschmar, J.	157	2	0	0	2
McCauley, N.	6				
Mehta, A.	279				
D'Onofrio, M	243				
Shears, T.	157	2	8	1	4
Touramanis, C.	124				
Vossebeld, J.	125				
Affolder, A.	63	22	0	0	0
Bland, J.	0				
Carroll, J.	4				
Casse, G.	61				
Dervan, P.	123				
Fay, R.	0				
Greenall, A.	12				
Hayward, H.	63				
Jones, T.	71				
King, B.	70				
Maxfield, S.	93				
Muskett, D.	0				

[9] This includes papers submitted to a refereed journal but currently in arXiv

Patel, G.	68	0	2	1	0
Rinnert, K.	33	0	1	0	0
Smith, N.A.	25	0	0	0	0
Sutcliffe, P.	3				
Tsurin, I.	7				
Whitley, M.	1				
Wormald, M.	11				
Gwilliam, C.	63				
Hennessy, K.	37	0	2	0	3
Huse, T.	38	0	0	0	0
Laycock P.	100				
Mavrokoridis, C.	8	0	0	0	0
Total Publications	578				

GLOSSARY: LIST OF ACRONYMS

To help the reviewers we include a list of acronyms and a glossary

A

ABCN130 ..ATLAS chip using 130nm technology
ACR..........ATLAS control room
ALICE ....Accelerators and Lasers In Combined Experiments (Daresbury)
ASIC..........Application Specific Integrated Chip
ASPERA.....Astropartícl ERANet
ASTRONET .... Comprehensive Long Term Planning for European Astronomy
ATF ....Accelerator Test Facility (Japan)
ATLAS ....Experiment: //atlas.web.cern.ch
ATLAS DQ .ATLAS Data Quality

B

BABAR ......Experiment: //www.slac.stanford.edu
BINP ....Institute: //www.inp.nsk.su
BSM..........beyond the standard model

C

CCD ....charge coupled device
CDF..........Experiment://www-cdf.fnal.gov/
CEDAR ......NA62 Čerenkov counter CERN
CERN ....Laboratory://cern.ch
CESR-TA....CESR Damping Ring Test Accelerator
CF ....carbon fibre
CFRP ....carbon fibre reinforced polymer
CI ....Institute: //www.cockcroft.ac.uk
CLIC ....Compact Linear Collider
CMS..........Experiment: //cms.cern.ch
CNM ....Institite://*www.cnm.es*
Co-I..........co-investigator (STFC term)
CP ....charge -parity
CPLEAR .....Experiment://cplear.web.cern.ch
CPU ....central processing unit
CSIC ....Institute://www.csic.es
CTA...........Experiment:// www.cta-observatory.org
CTE ....coefficient of thermal expansion
CUDA........compute unified device architecture

D

DAQ..........data acquisition
DC-DC.......direct current to direct current
DCS...........detector control system
DE ....dark energy
DIRAC ....Experiment://dirac.web.cern.ch

E

e2v Company://www.e2v.com
ECAL ....electromagnetic calorimeter
ECFA ....European Committee for Future Accelerators
ELENA.......Extra Low Energy Antiproton Ring (CERN)
EMMA ......Electron Machine with Many Applications
EPS........... European Physical Society
ERC .... European Resarch Council
ESFRI........ European Strategy Forum on Research Infrastructures
ETH .... Institute://www.ethz.ch
EU .... European Union
EW .... electro-weak

F

FEA .... finite element analysis
FEC........... full economic costing
FEE........... front end electronics
FE-I3......... ATLAS pixel ASIC
Fermi .... Fermi Gamma-Ray Space Telescope
FLAIR........ Facility for Low-energy **Antiproton** and Ion Research
FM .... Liverpool Facilities Management
FNAL .... Laboratory: //www.fnal.gov
FTE........... full time equivalent

G

GDR .... Groupement De Recherche Neutrino (France)
GLA2011 .. Giant Liquid Argon Conference
GLACIER ...
GMSB....... GaugeMediated Supersymmetry Breaking
GPD.......... general purpose detector
GPU .... graphics processor unit
GRIDPP .... Grid for Particle Physics

H

H1 .... Experiment://h1.desy.de
Hammer .. Liverpool computer cluster
HCP .... hadron collider physics (conference)
HEP .... high energy physics
HERAPDF . HERA parton distribution group
HESS .... Experiment://www.mpi-hd.mpg.de
HFAG .... Heavy Flavor Averaging Group
HL-LHC..... High Luminosity LHC
HPK .... Company://www.hamamatsu.com/
HQET........ heavy quark effective theory
HR .... Liverpool Human Resources
HV............ high voltage

I

IAEA .... International Atomic Energy Authority
ID .... identification
INFN......... Institut*e://*www.**infn**.it
IoP .... Institute of Physics
IoP HEPP .. IoP High Energy Physics Group
IPPP .... Institute://www.ippp.dur.ac.uk/
IPS............ Innovations Partnerships Schemes (STFC)
ISE-TCAD .. solid state simulation package

IT ....LHCb inner tracker

J

J-PARC ......Laboratory://j-parc.jp

K

KEK ....Laboratory://www.kek.jp

L

LAGUNA-LBNO
LAr...........liquid argon
LBNL ....Laboratory://www.lbl.gov
LCFI...........Linear Collider Flavour Identification
LEP ....Large Electron Positron Collider (CERN)
LHC...........Large Hadron Collider (CERN)
LHCb.........Experiment://lhcb.cern.ch
LHeC.........Large Hadron electron Collider
LSDC.........Liverpool Semiconductor Detector Centre
LSP...........lightest supersymmetric particle
LV ....low voltage

M

M&O ....maintenance and operation
MAGIC...... experiment:// magic.mppmu.mpg.de/
MC...........Monte Carlo
MDC0 ....T2K Monte Carlo Production
MH ....mass heirarchy
MPPC........multipixel photon counter

N

ND280 ......T2K Near Detector
NHK ....Japanese Film Festival
NIKHEF .....Laboratory://nikhef.nl
NIM ....Nuclear Instruments and Methods
NNLO........next to next to leading order
NuPECC ....Nuclear Physics European Collaboration Committee

P

P0D-ECAL .
pdf .... parton distribution function
PDRA........ post-doctoral research associate
PI .... principal investigator
PMT .... photo-multiplier tube
PPARC...... Particle Physics and Astronomy Research Council (replaced by STFC)
PPGP........ Particle Physics Grants Panel (STFC)
PRD.......... Project Research and Development Scheme (STFC)

Q

QA........... quality assurance
QCD .... quantum chromodynamics

R

R&D .... research and development
RA .... research associate (PDRA)
RBS ....
RD50........ Collaboration:// rd50.web.cern.ch
RE18 ....
RG2009.... Rolling Grant (2009)
RPV .... R-parity Violating
RS .... Royal Society

S

SC ....
SCT........... ATLAS Semiconductor Tracker
SiPM .... silicon photo- multiplier
SM .... Standard Model
SMWG ..... Standard Model Working Group
SNO+........ Experiment://snoplus.phy.queensu.ca
SPSC......... SPS and PS experiments Committee (CERN)
SST ....
STFC......... Science and Technology Facilities Council
Super-B.... Super Flavour factory
Super-K.... Experiment://www-sk.icrr.u-tokyo.ac.jp
SUSY .... supersymmtry