ATLAS in RG application 2/2009

ATLAS Experiment [CERN LHC]

Current Activities

Introduction

The period from 2006 to the present marks the successful culmination of the construction phase of the Semiconductor Tracker (SCT) EndCap-C. The commissioning and installation of EndCap-C into ATLAS at CERN is a major milestone after some 16 years of planning, R&D and construction in which the Liverpool group has played a leading role from the outset. The group is again playing a major role in commissioning the SCT and the necessary online and offline monitoring of its performance.

On the computing front, Liverpool has successfully developed its Tier 2 centre which was the first in the UK to achieve 10^6 CPU hours in the 2008-09 audit. A great deal of software has been developed for monitoring the SCT as well as for studying techniques for the calibration of the ATLAS detector and performing simulation studies for various physics channels.

The group has been actively preparing for physics analysis with strong involvement in software development, performance studies and Higgs, SUSY and SM related studies.

Over this grant period, the group has grown significantly with the addition of 4 academics, an STFC Fellow, 2 PDRAs transferring from H1 and CDF, 1 responsive RA, and 6 new postgraduate students. We have lost Scott Lindsay, a PDRA, and Neil Thresher, a technician.

Installation and Commissioning of the SCT

Following the post-shipment acceptance tests in spring 2006 (**T. Jones**, **Greenall**), subsequent activity centred on the completion of the EndCap before the rear wing, outer thermal enclosure and the front wing were mounted. The foil grounding and shielding structures next to disks 1 and 9 were mounted (**T. Jones**, **Greenall**) and the integrity of the cooling connections at the edge of the disks verified (**T. Jones**, **Muskett**). The temporary interconnect cables were removed from patch panel PPF1 (**Greenall**, **Lindsay**, **Vossebeld**, **Dervan**) and temporary fluid connections were made and tested (**T. Jones**). The services thermal feed-through was completed (**Thresher**, **Lindsay**) and the outer thermal enclosure was finally fitted over the EndCap in late August 2006 (**Thresher**, **Lindsay**, **T. Jones**) and tested for leak tightness (**T. Jones**, **Burdin**). Final sealing of the services was completed in September (**Lindsay**, **Thresher**), the Transition Radiation Tracker (TRT) was slid over the EndCap and the front wing attached. Following the connection of the services, a total of over 200 modules were tested (**Burdin**, **Dervan**, **Greenall**, **Lindsay**, **Vossebeld**). This included power and optical readout connection and testing, mapping and setting up the ATLAS DAQ configuration files and the tuning of the optical settings and calibration (experts only) of the individual silicon modules in preparation for data taking. A cosmic trigger was set up (**Burdin**, **Lindsay**) and EndCap SCT monitoring code was tested (**Hayward**, **student**: Austin).

The assembly of the heat exchanger (Hex) to the heaters and their qualification was followed by their installation. Due to problems associated with the heaters, they were dismounted and returned to the supplier for modification (**T. Jones**, **Lindsay**). The lack of the Hex/heater assemblies

necessitated the testing of the electrical and optical services using systems developed by Liverpool (**Dervan**, **Greenall**, **Lindsay**, **Vossebeld**). Due to time pressure, a multi-way Hex/heater test box was developed (**T. Jones**, **Muskett**, **Workshop**) to qualify all the Hex/heater assemblies (**T. Jones**, **Lindsay**) before mounting in the pit. Making the fibre and electrical connections to the Data Control System (DCS) sensors on the cylinder and thermal enclosure and the subsequent testing was a major task (**Lindsay**, **Thresher**).

During the commissioning in the cavern (**Greenall**, **Vossebeld**, **Dervan**), it was discovered that the PIN currents from the detector dropped as the VCSEL (laser diode) voltage was increased from 0 to 6 volts. This effect was traced to the presence of capacitors on patch panel 3. In addition, **Greenall** found that the power supplies could not monitor low PIN currents accurately, which necessitated a change in the firmware. A standalone test kit was developed (**Greenall**) to facilitate this investigation. During the run-up to beams and during cosmic data taking a significant effort was spent in calibrating the SCT (**Vossebeld**, **Dervan**, **Kluge**). **Vossebeld** was elected UK SCT project leader in January 2009.

Offline Monitoring

Offline code has been developed to monitor the efficiencies of the SCT modules (**Hayward**, **student**: Austin). This has been used in detailed studies of the hit efficiency of the SCT detector, during commissioning tests on the surface and after installation in the cavern. The software has been used to test various alignment algorithms and to verify the timing of the SCT with respect to the other sub-detectors. **Hayward** is a key person for the SCT and has taken the role of managing the SCT offline monitoring group, chairing fortnightly meetings to co-ordinate the different SCT monitoring activities. She is responsible for ensuring that trained personnel are available to man the daily SCT data quality shifts and the required software tools are available. She is currently developing the strategy and procedure to assign data quality flags to the SCT for different runs to be used by all physics groups who require good tracking capabilities.

Additional monitoring code has been developed (**Dervan**) to access the DCS information for each of the modules (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.

Dervan has developed a method for deriving the radiation doses received by SCT modules based on their monitored temperatures and leakage currents, obtained from the monitoring code described above, together with the data accumulated during irradiation tests of silicon wafers. The radiation parameter α can be derived from the data as this is accumulated. Another initiative has been to make use of the sensor noise at different biases to track the full depletion voltage and hence the radiation damage in the silicon detectors (**Burdin**).

Online Monitoring

The fastest method of online monitoring is to analyze data directly from the byte stream. A programme, "SCT Com Tool", was developed to monitor occupancies at the strip, chip and module levels (**Burdin**). Occupancies and the number of double hits can be studied in time bins and the number of readout errors displayed.

A second initiative was to develop a Detector Quality Status Calculator (DQSC) which combines information from the DCS, detector configuration and monitoring information into one status word for each sub-detector (**Burdin**). This work has been carried forward and extended to form part of the overall ATLAS Data Quality Monitoring framework (**student**: Leney).

A scheme known as "SCT CAF processing" (CAF – CERN Analysis Facility) has been developed to identify noisy/dead channels offline, as a part of the 24-hour SCT calibration cycle (**Vankov**). This is now partially implemented and has been used to extract the noisy/dead channel information for the ATLAS single-beam and cosmic runs in September to November 2008.

Databases

The ATLAS post of Conditions Database Tag Manager is now filled by **Laycock** who is responsible for creating the global COOL conditions DB tags used to determine the conditions data necessary for processing data and Monte Carlo. Every subsystem provides conditions data for different purposes (cosmic data/single beam/colliding beam etc.) for their system. Using tools which create tag hierarchies for all of the subsystems, these are linked to produce one global tag. In the reprocessing of cosmic data, four global tags, corresponding to four sets of t_0 measurements from the Monitored Drift-tube Chambers (MDTs), have been made for use in the processing of different data streams. There have also been significant contributions to several SCT online databases (**Kluge**). These cover data from calibration runs, the run book-keeping and a silicon module problem history database. The work done includes the development of the system from scratch, the installation at point 1 and the integration into the DCS and DAQ.

Software Development

King has developed a full suite of b-tagging algorithms based on secondary vertex reconstruction and lifetime signed impact parameters. This code has been used to cross-check existing algorithms and parts of it are now being implemented in official ATLAS releases. The effect of using various b-fragmentation models and lifetimes on the tagging efficiency obtained with existing ATLAS code has been studied, as has the determination of track parameter errors from the data (**Gwilliam**, **Mehta**, **King**). This work was part of the studies for the b-tagging CSC note.

Gwilliam plays a leading role in the implementation and development of offline software for the ATLAS SCT. He is responsible for the clustering algorithm, which groups the binary hit information from the individual strips in an SCT module into cluster objects that are subsequently used in the formation of space-points for the track finding. He also jointly manages the implementation of conditions data, which provides information on the status of the detector, within the SCT software. He has designed code to provide information on modules and channels within the SCT which are dead or noisy. Installing and validating the ATLAS software (ATHENA) releases on the Grid sites around the world is a major task to which **Gwilliam** contributes. He is also responsible for installing and maintaining the ATHENA distribution kits and the ATLAS grid tools in Liverpool and contributed strongly to the development and testing of the Liverpool Tier 2 grid site and possible Tier 3 options in the context of ATLAS analysis performance and throughput.

Cosmic Studies

A large amount of cosmic ray data has been taken and used to calculate module efficiencies and generally tune, align and commission the SCT as described above. Since the cosmic rays traverse the whole detector, it is possible to split each track into two, one above the beam line and one below. By fitting these track elements independently, a first impact parameter resolution of 38 μm has been determined by comparing the tracks at the beam plane (**Burdin**). Cosmic muons are being used to study the linking of the ID to the muon spectrometer (**student**: Wiglesworth).

Shift Work

Group members have made significant contributions to the shift work involved in running the experiment and monitoring its performance including: SCT shifts (**Kluge**), SCT DAQ shifts (**Dervan**, **Vossebeld**, **Burdin**, **Kluge**), DCS shifts (**Vankov**), Inner Detector (ID) general shifts (**students**: Wrona, Migas), ATLAS Shift Leader (**Kluge**), offline shifts (**Hayward**, **Vankov**, **Burdin**, **student**: Wiglesworth), ATLAS Grid production shifts (**Gwilliam**), Data Quality shifts (**student**: Leney). **Kluge** and **Hayward** are responsible for training newcomers to the shift system.

General Service Tasks

M. Klein was the Chair of the ATLAS Publications Committee (1/3/2008 – 1/3/2009) following one year as Deputy Chair. As such, he was editor of the 2000 page ATLAS Computing Systems Commissioning (CSC) Book "Expected Performance of the ATLAS Experiment: Detector, Trigger and Physics". He was also referee of the ATLAS detector paper. **Kluge** performed the (technical) editing of the CSC Book and was a webmaster for the ATLAS Publication Committee. Group members have acted as referees of the comprehensive CSC Book chapters on b-tagging (**King**, **Mehta**) and the SM (**U. Klein**). **Kretzschmar** has played an active role in ATLAS Physics Validation for the SM group. His contribution is to evaluate the performance for electrons using simulated $Z \rightarrow ee$ events. This involves running, maintaining, and extending a software package which is used to monitor several electron efficiencies, e.g. at all levels of the trigger and after electron identification (so called "is EM") cuts. **U. Klein** is the SM group contact person for the

Luminosity Coordination and Working groups. **Laycock** is Conditions DB tag manager as described above.

Physics Studies

The LHC is built to reach beyond the SM by accessing the multi-TeV energy scale. Considerations of unitarity and the limitations of the SM suggest that, at these energies, the Higgs mechanism and further new physics should be observed, manifest perhaps as new symmetries, extra dimensions or new particles. The LHC is therefore the most exciting endeavour in particle physics today and is thus the major focus of the Liverpool particle physics group's analysis activities.

The current and future studies of the Liverpool ATLAS group are guided by three considerations: Firstly, there is a hierarchy of estimated cross-sections, which implies that the data will be dominated by QCD events. For example, for 10 pb^{-1} of data, one expects 10^4 Z bosons compared to 10^9 di-jet events. The cross-section for gluon-initiated Higgs production, at $M_H = 150$ GeV, is 3 to 4 orders of magnitude below the Z production cross-section, but still about 50 times the cross-section for gluon induced pair production of squarks or gluinos of TeV mass. Secondly, ATLAS is a new apparatus of unprecedented complexity, which needs to be calibrated and aligned with beam data and which requires computing resources, software and simulation tools more advanced and more challenging than ever before. Thirdly, it is presently unclear which final states (charged leptons, missing energy, photons, b and other jets) are most likely to reveal new physics.

These three considerations define the strategy being pursued at Liverpool. Analysis techniques and software are being developed to understand in detail the identification and reconstruction of leptons, photons, jets and missing energy in ATLAS. These must be tested and calibrated through the measurement and understanding of SM processes like Z and W production with decays to various modes. While pursuing this programme, we will be continually alert to the possibility that there are early surprising signals of new physics (Higgs, SUSY, Z') and we will perform first searches for such phenomena in the 10 TeV run in 2009-10.

The Liverpool ATLAS analysis activities may broadly be categorised into the following related items: software development, SM measurements, Higgs physics and searches for supersymmetry.

Software Development: Liverpool software development is both detector and analysis related. Detector related studies are described above, as are some general studies directly relevant to our physics analyses, such as those of **King** on b-tagging. Development of a joint analysis framework (**Dervan**, **Gwilliam**, **Vankov**, **students**: Flowerdew, Wiglesworth) is being performed within ATHENA, as is our regular work on data quality checking (**Burdin**, **Laycock**, **student**: Leney). The analysis related computing capability includes the Liverpool farm (**Gwilliam**, **Houlden**, **King**) which ran in excess of 3 billion jobs in 2008, 2nd of the Tier 2 centres in the UK.

Higgs physics: SM and BSM Higgs physics is a prime interest of the group. The work on e, μ, τ and b measurements will bear fruit in the planned early search for Higgs to ZZ in the first run data (**Burdin**, **Gwilliam**, **Mehta**, **Vankov**, **Vossebeld**). At low mass, to which the electroweak indirect fits point, the Higgs particle may best be discovered through its $\tau\bar{\tau}$ decay. Strong analysis efforts (**Burdin**, **Gwilliam**, **student**: Leney) are therefore directed towards the understanding of this channel, with $Z \rightarrow \tau\bar{\tau}$ analyses being used to understand τ signatures in ATLAS. Studies of $t\bar{t}$ production are also underway as this constitutes the largest background to $H \rightarrow \tau\bar{\tau}$. These studies are also examining the measurement of anomalous top couplings (**Dervan**). At masses which are not too high, the Higgs decays predominantly into $b\bar{b}$ pairs. This channel may possibly be observed in association with W and Z production, under study at Liverpool using neural network techniques (**Mehta**). The SM work on W and Z production is thus related to the b-tagging software work (**King**) and with earlier work on CDF data.

Searches for Supersymmetry: SUSY searches are another prime analysis interest of the Liverpool group. Experimentally, many signatures for SUSY involve large missing (transverse) energy and jet production which we are studying using Monte Carlo data (**Jackson**, **Kluge**, **Laycock**, **student**: Prichard). Further studies we are pursuing are in the context of gauge mediated SUSY breaking (GMSB) scenarios, in which the gravitino is the lightest supersymmetric particle (**Hayward**, **King**,

Maxfield). Here, a characteristic signature is the decay of pair-produced gluinos or squarks to give jets, leptons, photons and gravitinos. In these scenarios, the heavy SUSY particles can have significant lifetimes, so the decay to photon-gravitino at the end of the chain can be significantly displaced from the primary vertex. Detecting these displaced photons is a challenge for the reconstruction and calorimeter timing on which work is ongoing. In this context, we are also pursuing studies of QCD di-photon production.

Standard Model Measurements: SM studies are mainly directed towards early physics, in particular the measurement of $Z \to ee$ (**U. Klein**, **student**: Migas, **Vossebeld, student**: Flowerdew) and $W \to \nu e$ (**M. Klein**, **Kretzschmar**, **Kluge**, **student** Wrona). These processes are of prime importance for understanding not only electron and missing energy signals in ATLAS, but also those of jets, as these form the main background and contribute to the underlying event. Understanding missing energy is of particular importance as it is a signature of physics beyond the SM such as dark matter and SUSY. The group has made particularly strong contributions (**student**: Flowerdew) to "tag and probe" studies of electron reconstruction. We have initiated and lead (**U. Klein**) an international ATLAS W and Z analysis group, as a platform for efficient first data analyses.

The Liverpool group's involvement in the fields described above is strong and growing. We have formed UK and international links with other ATLAS groups pursuing similar studies. Because of the focus of the Liverpool ATLAS group's work, we have been able to make leading contributions to the ATLAS analysis preparations and to pursue a truly challenging programme which has both a wide range and yet clear focus: the discoveries of the Higgs and SUSY, which we consider to be the most promising new directions for particle physics at the TeV scale.

Leadership:

Helen Hayward	SCT Offline Monitoring Group Leader.
Max Klein	Chair of the ATLAS Publications Committee (1/3/2008 – 1/3/2009)
Uta Klein	Leader of W and Z Analysis Group
Paul Laycock	Conditions Database Tag Manager
Joost Vossebeld	UK SCT Project Leader and UK SM Working Group Convenor

Proposed Programme

Our future programme is geared towards the production of leading physics analyses from the LHC. The first requisite is to obtain good quality data from ATLAS. To this end, the group will continue its efforts in the commissioning, running and monitoring of the SCT, contributing to SCT reconstruction, general tracking software and to other service tasks. Understanding and calibrating the ATLAS detector will be crucial to successful analysis of the data and our programme of physics studies encompasses work on SM processes which will make this possible as well as searches for new physics. The primary tasks identified for the first run are searches for new physics, specifically a high mass Higgs decaying via ZZ into 4 leptons or into 2 leptons and 2 b-jets, supersymmetry via multi-jets with missing energy, and initial measurements of Z and W production in the electron channel. These will be followed by searches for rarer processes, such as $H \to \tau\bar{\tau}$, and more precise analyses as luminosity increases.

Service Tasks

The group will continue to play a leading role in SCT commissioning, online and offline monitoring, developing databases, software development, Monte Carlo production, cosmic studies and physics validation as outlined above and in the cases for the individual group members. The manning of both expert and non-expert shifts will continue to be a major obligation.

Physics Studies

The strategy for future ATLAS physics studies at Liverpool will continue to be that outlined above, namely, developing our analysis techniques and software and our understanding of the detector through the study of SM processes, enabling us to produce early publications and make the most sensitive possible searches for BSM processes. In this regard, strong efforts in the 10 TeV run will be directed to searches and W and Z physics. These may result in the discovery of new physics such

as low mass SUSY, or high mass Higgs production. Our strategy will change in response to these early results.

Higgs Physics: First studies of the Higgs mechanism will involve a search for a Higgs particle of mass larger than $2M_Z$ in the channels $H \to 4$ leptons (**Burdin**, **Gwilliam**, **Vankov**, **Vossebeld**, **student**: Wiglesworth) and $H \to 2$ leptons and 2 b-jets (**U. Klein**, **King**, **Mehta**). This will immediately link the work on SM physics, on lepton and b identification, to new physics. Muon identification software will be refined (**Vankov**, **student**: Wiglesworth) and the efficiency and purity of muon selection studied using first data. Searches for the Higgs in the 4 lepton channel will continue. The $Z \to \tau\bar{\tau}$ analysis and studies of $t\bar{t}$ production will start with first data (**Burdin**, **Gwilliam**, **student** Leney). The expected significance for the observation of $H \to \tau\bar{\tau}$, for low Higgs masses, is about 3σ with an integrated luminosity of 10 fb^{-1}. This channel therefore becomes more important as higher luminosities are achieved in a few year's time. Similarly, early data will be used to improve and understand b-tagging routines (**King**) and then associated production of the Higgs and W and Z bosons studied (**Mehta**, **King**, **RA-1**). The thorough investigation of the Higgs mechanism is of prime importance for the LHC and the group. Cross sections are not large and final state characteristics are extremely demanding. **RA-1** is therefore requested to strengthen the analysis activity on associated boson-Higgs production with subsequent decay into $l\nu b\bar{b}$.

Searches for Supersymmetry: New physics, for which SUSY is a prime candidate, is expected to have spectacular signatures involving missing energy and photons. First data will be used to develop a quantitative understanding of the measurement of missing energy, mainly using W production (**Jackson**, **M. Klein**, **Kluge**, **Kretzschmar**, **Laycock**, **student**: Wrona), ensuring that early publications in this area can be produced and the group takes an active part in the initial 10 TeV run searches for SUSY. Data will also be used to develop an understanding of di-photon production for which we have initiated a dedicated, international analysis group. Photons are key to several processes of exotic nature: GMSB signatures involve a gravitino (a dark matter candidate) and a displaced photon. The graviton and especially the low mass Higgs decay into $\gamma\gamma$ have a high chance for discovery at the LHC. The key importance and particular challenges of photon physics at ATLAS require stronger support in order to enable us to maintain the leadership in this field we have established through our GMSB photon studies, exploiting our expertise from CDF and H1 (**Hayward**, **King**, **Maxfield**). We request **RA-2** to strengthen our work in this area. The missing energy, the jet based and the photon based analyses will naturally develop into a programme of more sensitive searches for new physics as luminosity increases.

Standard Model Measurements: Studies of $Z \to e^+e^-$ (**U. Klein**, **Vossebeld**, **student**: Migas) and $W \to \nu e$ (**M. Klein**, **Kretzschmar**, **Kluge**, **student**: Wrona) will be made with first data and brought to publication with the international ATLAS group we have established. These measurements will reveal whether higher order QCD provides an accurate link between the HERA proton structure information, to which Liverpool has been making leading contributions, and the W and Z cross sections at the LHC. Subsequent precise LHC measurements will also allow a determination of the pp luminosity and the constraining of the parton distributions at the edges of phase space, likely to be particularly important for searches for new physics.

To summarise, success in the areas described here requires that we maintain our analysis team and continue to exploit the expertise it has developed through links with CDF, H1 and ZEUS. Rapid development of a good understanding of the ATLAS detector, through studies of SM physics, is also essential. As luminosity grows, increasing demands will be made on the detector and its reconstruction software and problems such as pile-up will become more significant. Further strengthening our analysis team will ensure we are able to meet these challenges and can continue to make a leading contribution to ATLAS physics.