REPORT OF THE PPARC LINEAR COLLIDER STEERING GROUP

THE UK LINEAR COLLIDER PROJECT

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1. EXECUTIVE SUMMARY

The international particle physics community has recommended an electron-positron linear collider (LC) operating in the energy range 0.5-~1 TeV LC as the next major particle physics facility [1]. This report presents the goal of UK leadership in the accelerator, detector and physics at the LC and shows how this can be accomplished within an encompassing UK Linear Collider project.

The UK LC community has recommended the build up of a vigorous accelerator programme in the field of the LC Beam Delivery System (BDS). The BDS project will be a long term commitment, starting now. By 2007 the UK should have produced a fully costed BDS design and be leading the emerging international LC collaboration in this area. To achieve this, the following requirements have been identified the three years starting in April 2004.

- A core team of fourteen full-time accelerator physicists should be built up (seven each within CCLRC and the universities) to provide expertise in the design of the BDS and the integration of its key subsystems.
- A wider team should prototype key sub-systems and perform essential design and simulation studies. This team will build to around 36 FTEs over three years. Within this team, sub-groups should build rapidly to about five FTEs each.
- A Linear Collider Test Facility (LCTF) should be established to support all the projects and integrate them into a coherent activity. This should include a prototype Global Accelerator Network (GAN) control room to form the basis of such a future LC facility situated in the UK. The LCTF should evolve into a centre for an international final focus collaboration.
- Collaboration with UK industry on prototype development is essential from the start and should be vigorously pursued.
- Five studentships per year should be allocated to LC accelerator R&D.

The UK is already gaining leadership in LC physics and detector R&D.

- The Linear Collider Flavour Identification (LCFI) collaboration is one of the UK flagship detector R&D projects and should be maintained at least at the current level into the foreseeable future and strengthened where possible.
- The UK calorimeter collaboration, CALICE-UK, must play a major role in the future test-beam work and design studies. The CALICE collaboration is dominating the international LC calorimeter studies and the UK must capitalize on this opportunity.
- The UK continues to lead in both theoretical and experimental physics studies. The UK travel budget necessary for essential participation in the emerging global LC collaboration is estimated to be £50k per year.

Total costs for this integrated 3-year start-up programme are estimated to be £13M.

2. INTRODUCTION

In 2001 a report [2] highlighted the urgency of a UK programme of R&D for both the accelerator and detector and it indicated key opportunities in these areas. The physics case for the LC has been well documented [3,4] and worldwide workshops [5] have been addressing detailed proposals for realising such a facility. The UK has continued to play an active and significant role in these workshops by convening several working groups and leading key physics studies and detailed detector simulations. In addition, ongoing and new R&D programmes for the detector [6,7] have been strengthened and the growing UK involvement in LC accelerator development and beam diagnostics [8] has gained favourable international recognition.

The construction of the LC will require international agreements both at the technical and political levels. The progress towards a technical design was furthered this year by the G. Loew Technical Review Committee (TRC) [9], which confirmed the viability of the competing designs for a 0.5-1 TeV LC and identified a number of outstanding R&D items for the LC projects. In February 2003 the German Federal Research Ministry announced 50% funding for a Free Electron Laser based on TESLA (superconducting) technology to be built in Hamburg and confirmed that Germany will actively participate in a future LC [10,11]. It was confirmed that DESY should continue LC R&D in the context of an international project. This includes in particular R&D for the superconducting cavities, which are also needed for the Free Electron Laser. The JLC Roadmap Report [3] was presented at the ACFA (Asian Committee for Future Accelerators) LC Symposium in February 2003 and the US NLC collaboration is preparing a study on hosting either the X-band or the superconducting technology machine, with a report to be presented in October 2003.

If there is to be significant overlap in the running schedules of the LC and LHC, highly desirable on physics grounds [13], the LC needs to be operational by 2015. It is expected that the LC will be constructed, starting within a few years, although the final site and technology are yet to be decided. ICFA (International Committee for Future Accelerators) recommends that the decision about the technology should be made within a year.

The Terms of Reference behind this report are given in Annex A. One of the main tasks is to identify current LC R&D effort and to recommend how to build up the programme within the universities, CCLRC and industry in a focussed and coherent manner, placing the UK in a position to deliver in kind a contribution at the level of 10% to an international LC project as part of a GAN.

The growing UK programme of LC R&D includes the detector, the accelerator and, more recently, RF-generation for HEP accelerators via a Faraday Partnership. In total (Annex B) there are currently 29.4 PPARC-funded FTEs and 18.6 funded from other sources (ASTeC, HEFC *etc.*) working on LC R&D. The relative weighting of the effort is 35% on the accelerator, 45% on the detector and 20% on the High Power RF Faraday Partnership. The UK has also been playing a very significant role in the international physics workshop series and is taking part in high profile physics studies and theoretical investigations.

A glossary of abbreviations is included at the end of this report.

3. UK LINEAR COLLIDER ACCELERATOR PROJECT

There is now the opportunity to expand substantially the support for the R&D and project preparation necessary to build a strong UK team with the resources capable of delivering a substantial component of the 0.5-~1 TeV LC. It is therefore recommended to focus now on one high-profile and prestigious sub-system under a coherent UK Linear Collider Accelerator (LCA) project. Careful consideration of the options has come out in favour of concentrating on the BDS, which has a number of strategic advantages:

1) both CCLRC and universities have successfully developed internationally-recognised expertise directed towards the design and simulation of the BDS, as well as in more generic systems such as alignment and diagnostics, which will be implemented in this area of the machine.
2) The TESLA and NLC/JLC BDS system designs have converged recently and present excellent opportunities for UK R&D and engineering design contributions, independent of the linac technology and site selection choices.
3) UK groups have had strong encouragement to contribute in this area from both the NLC/JLC and TESLA collaborations.
4) The BDS is close to the experience of the particle physics community, being the link between the accelerator and the detector.

This strategy maximises the involvement of particle physicists in the LCA project and will promote a rapid and vigorous collaboration between the universities and the CCLRC in the field of high energy accelerators. An organisational framework to achieve this is included in Annex C.

Areas of expertise necessary to design and build the BDS are presented here, together with proposals on the establishment of the teams necessary both to construct the BDS and to interface it appropriately with the other machine sub-systems. The LCA project will encompass collaboration with industry both in building components for the BDS and in identifying wider LC opportunities, such as RF provision for the main linac. UK industry has much wider interests in the LC than represented by the BDS alone and these interests must not be discouraged by a decision by the UK particle physics community to concentrate its effort on the BDS. Industrial issues are discussed further in Sec.4.

The first report [2] investigated how the UK could contribute to the LC machine and came up with a list of exciting possibilities in addition to the BDS: damping rings (DRs), RF systems, and particle sources such as laser photo-injectors. These possibilities still offer opportunities for UK involvement but are not discussed in detail here because they are not directly related to the BDS. It is recommended that focussed activity be maintained as appropriate for longer-term development of LC technology, for example for an eventual multi-TeV collider, possibly based on CLIC technology.

3.1 The LC Beam Delivery System

The BDS is the part of the machine that receives the high energy beam from the main linac and then collimates, optically corrects and finally focuses the beams down to the nm-scales required for physics collisions inside the detector. The beams are also collimated to remove halo particles and hence minimise the beam-related backgrounds seen by the detector. This part of the machine is thus of great significance for the detector design and the overlap of machine and detector issues is of central importance to the LC physics programme. After collision the beams must be extracted safely and then directed to purpose-built beam-dumps, involving safety, environmental and civil engineering issues. The BDS cannot be considered in isolation and must be interfaced with the wider LC design.

The UK has started to develop expertise in beam delivery (Sec.3.3**)** and is attacking some of the most challenging aspects in a programme of R&D. These specifically targeted projects should be encased within the framework of an integrated LCA project, which will plan and deliver a coherent programme of activities. This programme will be designed to ensure that the necessary skills, expertise and R&D activities are built up within CCLRC, universities and industry, thereby positioning the UK to take responsibility for the BDS within a globally funded LC project.

Considerable expertise in aspects of the BDS currently resides at CERN, DESY, KEK, Saclay and SLAC and continued close collaboration with these laboratories will be essential throughout this project. However each of these major labs has only limited effort devoted exclusively to BDS issues and it is clear that by concentrating in this area the UK will be able to build an extremely strong team and take a world lead in this field.

3.2 Immediate BDS Strategy

The details of the UK BDS project and in particular how and when individual items are designed, prototyped and tested, will depend on the expertise and interests of the team brought together to deliver the programme. However within these constraints a broad outline of the main themes of activities required by the BDS project can be identified.

- Plan, programme and deliver projects which, in collaboration with international LC groups, will produce a detailed design study for the BDS.
- Build up a core group of accelerator experts with an overview of the BDS status for both TESLA and NLC/JLC. Based initially on existing BDS concepts, this group should identify priorities for the design study programme.
- Develop innovative and challenging systems and build accelerator related expertise within CCLRC, universities and industry.
- Develop a road map of R&D activities, which exploits existing test facilities such as TTF, ATF, NLCTA *etc.* and establishes in detail the design of the LCTF.
- In partnership with the international laboratories develop the necessary training activities and education of CCLRC, university and industry partners.
- Prepare the business plan to deliver the LC BDS to a globally funded LC including an understanding of the contribution of international collaborators.
- Participate in global LC technical collaborations and lead the BDS component of an international LC EU Framework 6 (FP6) design study that is currently being planned.

3.3 Current and Future UK Accelerator Activities

The ongoing UK BDS-related projects are listed here as a concise summary of Annex B.1 and then a list of additional high-priority future projects is included. The UK is already active in the essential fields of BDS beam feedback diagnostics and control, simulation, alignment and machine-detector interface (MDI):

- FONT Feedback on Nanosecond Timescales.
- LiCAS Linear Collider Alignment and Survey.
- LBBD Laser Based Beam Diagnostics.
- BDSIM BDS SIMulation using Geant4.
- Simulation of halo, collimator wakefields and closed-loop DR to IP beam dynamics.
- MDI studies of low angle region, backgrounds and luminosity spectrum determination.

Expertise in the following areas will also be required in order to build a coherent team for delivery of the BDS project.

- Global BDS optics design.
- Collimation.
- Final focus stability.
- Integrated beam diagnostics + feedback.
- Reliability, quality control and environmental protection.

- Civil engineering issues.
- Core technologies (vacuum, RF engineering, magnets, lasers *etc.*).
- Critical interfaces to other LC sub-systems.
- Beam dump.
- Operation in the context of the GAN.

In order to deliver the BDS it will be essential to build teams to become expert within and across these areas. Project teams of 3-5 FTEs will need to be built up to enhance current activity and to address the additional issues. While some areas are more suited to CCLRC expertise and others are ideally suited for the universities, it is important that the teams cross both sectors so that experience is both exchanged and nurtured. The relative priorities and scheduling of these projects will depend on the funds available and will benefit from input from international accelerator experts, preferably through a structure such as a Machine Advisory Committee (MAC) introduced in Annex C.

The High Power Faraday RF partnership (Annex.B.2) includes the following projects with relevance to the wider LCA activity.

- Multipactoring studies.
- Magnetron simulation.
- Travelling wave amplifier design.
- Matrix converter-driven power supplies.
- Klystron modulators.

The BDS design study and subsequent engineering phase will require the design, prototyping and testing of detectors, components, technologies, algorithms and control systems in a central facility that could evolve into a fully engineered prototype of the final focus and machine detector interface for the collider. Such a Linear Collider Test Facility (LCTF) could include:

- a high quality electron beam for development of beam feedback and instrumentation technologies such as FONT, bunch-length monitors, position monitors *etc*.
- An engineering prototype of the interaction region, including the final-doublet quadrupole magnets, the low-angle calorimeters, masks, vertex detector, luminosity monitors *etc.*, for study of the mechanical, magnetic and electrical integration of these systems.
- A mechanical test system for study of ground vibrations and facilities noise (electrical feedthrough, coolant flows *etc*), and the development of active stabilisation schemes (inertial actuators and optical anchors) and alignment systems such as LiCAS.
- A prototype GAN control room for study of remote operation of the BDS, including the above systems.

The establishment of such a test facility as part of the BDS design and engineering projects would place the UK at the centre of the international collaboration that will emerge to realise the BDS and give us a tremendous strategic advantage to lead this effort.

3.4 BDS Milestones

The milestones for the BDS (which are also milestones for the entire LC) are illustrated in Fig.3.1. The UK’s responsibility for this system would be maintained throughout the design, delivery, commissioning and operation of the facility, in line with the concept of a GAN. The BDS project is thus a long term commitment, starting now.

The short-term focus of the UK BDS project should be to continue to lead in the fields of beam diagnostics, feedback, alignment and BDS simulation and to focus on the preparation, in coordination with our international partners, of a detailed design study. This will require the construction, testing and operation of prototypes of critical components and will position the UK, at the end of the SR02 funding period, to lead the next phase: the preparation of the BDS engineering design and start of construction, which would by necessity be funded from any SR04 settlement.

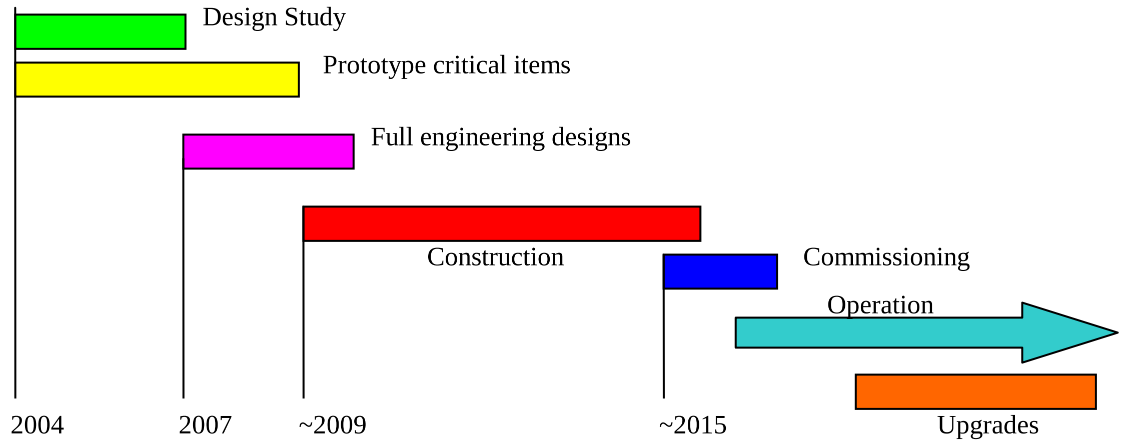

Fig. 3.1 Milestones for the BDS

4. INDUSTRIAL PARTICIPATION

Industrial participation will be essential to the LCA project and UK industry is well placed to play a significant role in the LC as a whole. The nature and scale of industrial involvement can be divided into those areas that are independent of the LC technology choice and those that are highly specific to it. The BDS alone is a €100M project with components largely supplied by industry. Many of these components are of very high specification, for example:

- FD quadrupoles
- hundreds of beamline magnets
- km of high quality vacuum
- advanced beam diagnostics
- alignment systems
- fast feedback electronics and devices
- lasers and optics
- control systems.

Collaboration between the universities, CCLRC and industry on the design and production of prototypes will be essential.

There are also excellent opportunities for UK industry in the wider LC programme. Taking RF provision for the linac as an example (detailed in Annex D) a klystron suitable for TESLA, which had been successfully designed for ease of manufacture and high yield, could be sold for around £130k each. Approximately 600 such klystrons will be needed for the 0.5 TeV TESLA (NLC will require approximately 4000 klystron tubes of a different type), together with many replacements throughout the life of the project, which represents an excellent opportunity for UK industry. However the production of a single klystron prototype will take three years and cost £1.6M and so requires a significant up front R&D investment. A similar analysis applies to the power supplies.

The LCA project plan will require high quality staff in CCLRC and the universities to carry it out. In the next sections the level of effort that needs to be built up over the next three years is identified in both sectors. A very important consideration is how to tap the enthusiasm of young blood entering this field and proposals for increased studentships in this area, together with appropriate training schemes, are addressed in Sec 5.3.

5.1 Effort for the BDS Design Study and Projects

It is recommended that, over the 3 years starting in April 2004, a core team of 7 accelerator scientists will be built up within CCLRC, together with 7 university-based scientists, focussed on the design and development of the BDS (Fig.5.1). A total of approximately 30 staff years will be required over this period. This core team will be supported by a wider team of around 60 staff years of effort from within the universities, ASTeC and CCLRC generally. In the university communities the increasing resources will be used to maintain the programme of development of highly challenging innovative systems whilst expanding the university contribution to the more general development of the BDS project as appropriate.

Such a UK based resource will be providing by far the major contribution to an international collaborative effort to develop the BDS. Groups from other laboratories and institutes abroad will continue to provide valuable expertise and effort throughout the whole of the project and it is expected that the developing international LC steering groups will coordinate the collaborative programmes. With this plan in mind, the UK has joined an EU FP6 Network proposal called “Co-ordination of Studies and Technical R&D for Electron Linear Accelerators and Colliders”, the outcome of which will be known later this year. The UK LC community also plans to lead the BDS design work within an international FP6 Design Study on the LC. This will further the process of integrating the UK BDS activity within a global LC project.

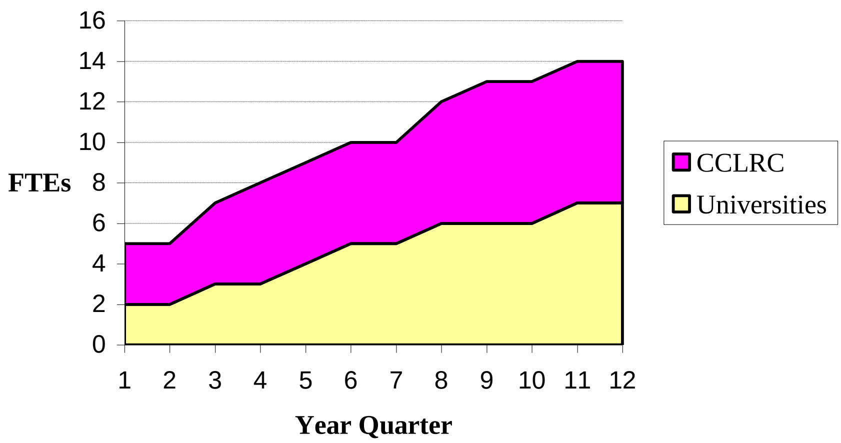

Fig 5.1. Proposed build up of staff numbers in the CCLRC and universities for the core BDS design study. A total of 30 staff years are required over the three year period starting in April 2004.

5.1.1 Finances

A similar build-up of staff effort will be required to deliver the essential project areas listed in Sec.3.3, involving a collaboration between CCLRC and the universities developing expertise across these sectors.

Adopting a project based approach, teams should be built up with about 3-5 FTEs in post by the end of the next three years. In Tab.1, a cost summary is presented that includes the design study and the projects + LCTF. Non-staff costs are estimated at somewhere between £50-100k per project per year. FTE staff costs are estimated at £70k per year.

After three years the UK will have approximately 50 staff in post across CCLRC and the universities working full-time on the BDS, its interfaces, and on a co-ordinated set of high-profile BDS projects.

	Staff Years	Staff (£M)	Non-Staff (£M)	Total (£M)		Final Posts
Core Team	30	2.1		2.1		14 dedicated
Wider Team	60	4.2		4.2		36 FTEs
BDS Design Study			1.0	1.0		
Projects + LCTF			5.0	5.0		
				Total:	£12.3M	50

Table 1. Staff levels and cost estimates summed over the first three years of LCA.

5.2 Travel Support for the Physics Programme

The high profile of UK physicists in the international LC workshops has been achieved using a modest travel budget, which has financed mainly the UK convenors of the European working groups to attend the workshop meetings. It is important to at least maintain this level of support and to widen the UK participation, both theoretical and experimental, in these meetings so that future convenors and leaders can emerge. The number of UK physicists taking part in these workshops will increase as some currently ongoing experimental programmes come to their natural end; the means should be provided to allow these physicists to transfer their expertise to the LC. Aiming at a UK presence at the ECFA (European Committee for Future Accelerators) workshops at the level of 10% of the number of international participants implies approximately 20 participants per workshop and, with three workshops per year and £500 per trip, will require support of £30k per year.

In addition it can be expected that the LC physics organisation will become rapidly more global in the coming three years, as must the organisation of the machine studies. An estimated support of £20k per year would allow UK physicists to maintain a presence at the US and Asian international laboratories and workshops. This will enable the essential participation of the UK in the emerging global collaboration. In summary, it is recommended that travel funds of £50k per year be provided to support the LCUK physics programme.

5.3 Studentships and Training

The LCFI and CALICE programmes will naturally provide opportunities for traditional particle physics Ph.D. students to be trained in physics, hardware and simulation skills. As a result, studentships in these areas should be supported implicitly via the usual quota system. The situation is somewhat different for the accelerator programme, since there has been almost zero university-based training for several decades. Clearly the UK's long-term future capability in accelerator technology will depend on the supply of trained individuals who are committed to a career in this area. Appropriate training and educational opportunities will need to be provided at both the undergraduate and graduate levels in a variety of accelerator physics and related technology disciplines. The universities, CCLRC and industry all have a role to play as both providers and customers.

5.3.1 Undergraduate training

Undergraduate level courses in the basics of particle acceleration have all but disappeared from UK universities. Interested universities should provide introductory sections or modules as part of their electromagnetism and/or particle physics courses. Since the overhead in creating courses from scratch is high, an attractive possibility is the creation of a central teaching resource that could be used by any university and CCLRC. This might include web-based material, lecture notes, and video connection to lectures delivered remotely, as well as recordings of lectures.

5.3.2 Postgraduate-level training

A master's course in accelerators has long been discussed within the UK community. Such a course could provide a more rigorous training for those wishing to pursue a career in accelerators and related technology. It could also provide a basis for specialist training of “traditional” particle physics Ph.D. students. Since the expertise for such a course resides primarily within CCLRC, a good way forward would be for PPARC and CCLRC, in partnership with the universities and industry, to develop a course that could be available to interested students from any UK university. This could naturally involve applied participation in UK national projects such as a LCTF, current projects such as DIAMOND and ISIS, and possible future projects such as 4GLS and MICE.

To date (Annex B) only a small number (approximately 3) of PPARC-supported particle physics students at a few universities have pursued a Ph.D. in the accelerator aspects of the LC (not including the High Power RF Faraday Partnership). They have not benefited from the formal training suggested above, but have learned by working side-by-side with experts at CCLRC, SLAC and DESY, including time spent at international accelerators under the PPARC LTA scheme. Such opportunities are immensely valuable and the hands-on experience gained is complementary to any formal training.

As part of the expanded LC effort via SR02 it would be desirable for each university group involved to have the opportunity to take Ph.D. students: they are the life-blood of our field, and are keys to balanced project teams comprising students, RAs, technical and faculty staff. Since the existing PPARC particle physics quota Ph.D. places are heavily subscribed, specific LC Ph.D. studentships should be provided for the accelerator initiative, to be part of the team structure discussed above. At least five such places per year should be created to join the peer-reviewed projects, starting in October 2004. Estimating the cost of a 3-year studentship at £50k, this will require £500k over the three year period, by which time there will be 15 students in the field.

Joint studentships between universities and CCLRC should be encouraged, as well as industrially-sponsored studentships for technology development. The studentships could be solicited and awarded by LCUK, in a similar manner to the award of the e-science studentships that were funded via SR00.

5.4 Total Funding Required

The proposed three-year programme will require £12.3M for the core BDS design study, the associated BDS projects and the LCTF. In addition, for the first three years the studentships will cost £500k and the travel for UK participation in the international LC workshops £150k. The total needed is thus £13M.

6. SUMMARY

The LC will be the next major particle physics facility. The LC technology choice will be made within the next one to two years and formal collaborations will form soon thereafter. The UK has identified where it can play a leading role, independent of site and technology considerations, in both the machine and the detector. In addition the UK is continuing to lead the physics studies and play influential roles in the LC decision making process.

A careful consideration of the issues has resulted in the recommendation of the LC BDS as the main focus of UK activity in the accelerator. This is a major step forward for the UK LC Accelerator project and an ambitious, but realistic, goal has been set of delivering a fully costed BDS design study by 2007. The projects and funds required to meet this goal have been described in this report and will result in 14 full-time LC accelerator physicists (seven each at CCLRC and the universities) working with 36 FTE LC staff across the universities and CCLRC, who work on critical LC projects and also contribute to global design issues. Including non-staff costs, this will require £12.3M over the next three years. In addition 5 studentships per year should be allocated to this field, which will require £500k over this period.

Collaboration with UK industry on the design and manufacture of prototypes is important from the start. There are many opportunities for UK industry in the construction of the BDS. Great opportunities also exist in the wider LC project, for instance in the field of RF provision. The risks can be high and UK industry may need help to tackle the substantial technological challenges.

The UK has positioned itself for leadership in the LC detector and physics programmes. The LCFI and CALICE collaborations are major players in worldwide R&D for vertexing and calorimetry respectively. These fields will be at the heart of the most exciting LC physics and the UK should continue to strengthen these groups as a high priority. Further experimental activity is also likely to emerge, especially in the area of machine-detector interface.

Both the IPPP and the UK universities are making world-class contributions to LC theoretical studies. UK experimental studies are prominent in the international workshops and there are UK physicists convening European and worldwide working groups. It is essential that this physics leadership should be underpinned with increased travel funds, which will allow more UK physicists to take part in the emerging international LC collaboration. A travel budget of £50k per year is recommended, which could be managed by the LCUK Collaboration Board.

The UK community is forming itself around a LCUK framework that encompasses the machine, the detector and the physics programmes. This broad structure is a real strength, providing crucial understanding across the fields and maximising the use of UK talent. The prospect of this wider UK community working towards precision LC physics, overlapping in timescale with the LHC programme, is an exciting one. This report indicates how this can be achieved while also re-building UK expertise in high-energy accelerator physics and at the same time contributing in kind to the international LC project. This opportunity is not to be missed.

Acknowledgements

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Annex A

Linear Collider Steering Committee - Terms of Reference

1) To identify and catalogue the research being carried out within the UK towards future linear colliders.

2) To identify options and set priorities for future research in this field to enable the UK to participate in the research programme at a linear collider

3) To identify the likely resources to be required, timescales for decisions on funding and for provision of the resources.

4) To report to the Director, Programmes, PPARC with an interim report by 1 April 2003

A.1 Membership

Grahame Blair – RHUL – chairman.
Mike Begg – Tesla Engineering.
Philip Burrows – QMUL.
Tim Greenshaw – Liverpool.
Mike Seymour – Manchester.
Susan Smith - CLRC.
Georg Weiglein – IPPP, Durham.
David Wilcox E2V.

Annex B
Current Effort

B.1 Accelerator

The UK is currently involved in a variety of accelerator R&D activities, all of which are expected to grow rapidly in the coming years. Most of the effort is in the area of the BDS [12], however some activities are related to damping ring (DR) or particle source development. The current distribution of effort is presented in Fig.B.1 and the individual projects are discussed below. In addition to the staff effort, non staff costs from the PPRP have been awarded to FONT (£60k), laser-wire (£55k) and LiCAS (£50k).

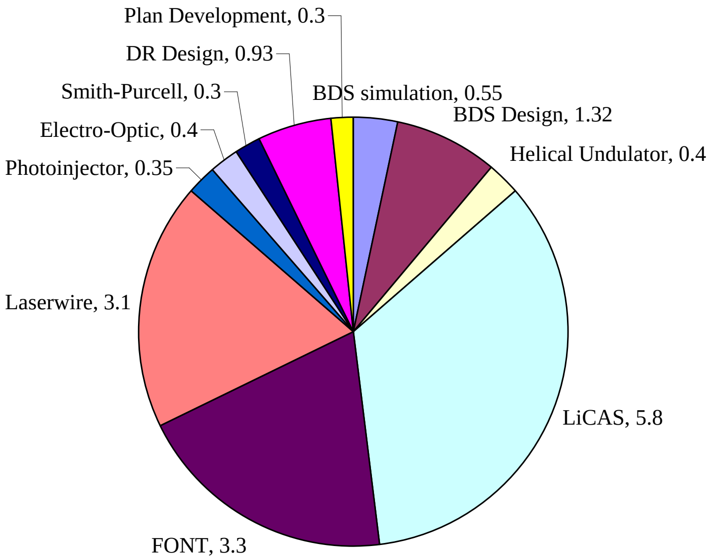

Fig B.1. The current distribution of UK FTEs involved in LC accelerator R&D.

B.1.1 FONT

FONT (Feedback On Nanosecond Timescales) is an intra-train beam-based feedback system for use at the interaction region (IR) of the LC. In order to maintain the design luminosity of the collider the beams must be made to collide head-on to within a few nm. Ground-motion effects near the interaction point (IP) at the relevant bunch-train-repetition frequency (10-100 Hz) are substantial on the nm scale, necessitating a fast-feedback system to correct beam misalignments, as well as active stabilisation of the final doublet magnets and the upstream linac components. The demonstration of such an intra-train beam-based feedback system was identified by the TRC [9] as an important issue for continuing LC R&D.

The FONT collaboration is led by the UK (QMUL, ASTeC, Oxford) and is working with SLAC, DESY, KEK and CERN to develop a prototype system. FONT has been peer-reviewed twice by the PPRP and was awarded two rounds of start-up funds, in 2002 and 2003. FONT is developing both hardware and simulations of the BDS. FONT has designed and built beam position monitors, fast kicker amplifiers, electronics and feedback circuits. These have been tested with beam at the NLC Test Accelerator (NLCTA) at SLAC.

The first beam test (September 2002) provided a zeroth-order demonstration of the feasibility of an intra-train feedback system with an electronics latency of 31ns. Further beam tests are planned in autumn 2003 with improved amplifiers and electronics, with the goal of a reduction in latency of at least 10ns. The FONT collaboration is in discussion with KEK, SLAC and LLNL concerning deployment of a feedback system in the extraction line of the Accelerator Test Facility at KEK in 2004. By integrating FONT with an active inertial system it may be possible to demonstrate beam stabilisation at the nanometre level, which would be a significant milestone in LC technology development, and essentially fulfil the TRC requirement.

B.1.2 Laser-Based Beam Diagnostics

Laser-based beam diagnostics (LBBD) is an experimental activity in the UK that started three years ago, as a collaboration with DESY, SLAC, CERN and KEK. Traditionally, solid wire scanners have been used to measure beam-spot sizes of several microns, however they will not withstand the bunch intensities at the LC. A different approach, pioneered several years ago for measuring the micron-size SLC beams at SLAC, employs precision laser optics to scan the electron bunches, the bunch size being determined by counting the resulting Compton-scattered photons. This is called a laser-wire and is one of the technologies identified by the TRC [9] where R&D is very important.

A new optical laboratory has been assembled at RHUL, in collaboration with the RAL Central Laser Facility (CLF), to develop novel laser-wire scanning techniques and to test them at existing machines. RHUL collaborated with CERN at the CTF2 test facility in the first tests of a laser-wire there. UCL joined the laser-wire project in 2002 and have contributed hardware to the CCD diagnostic system. PETRA at DESY is hosting the first major UK prototype, which was installed in March 2003 and first data-taking is planned for summer 2003. Future extensions of this initiative could include the measurement of sub-micron beam-spots using interferometric techniques, or a wider class of laser-based beam diagnostics such as the design of a Compton polarimeter or feasibility study for a Shintake monitor.

B.1.3 LiCAS

The LiCAS (Linear Collider Alignment and Survey) project aims to develop survey methods and technologies that are suitable for the alignment of any LC. The initial focus lies on the development of a survey system that can be used for automated construction survey, and diagnostics of collider misalignments during operation. The technology is based on frequency scanning interferometry (FSI) and laser straightness monitors (LSM). FSI is an interferometric technique for absolute distance measurement and an LSM measures straightness against a laser beam. Both systems will operate in an evacuated tube.

The LiCAS project has recently been approved by the PPRP and is now partially funded for the next 14 months. In the next two years the group at Oxford will develop a prototype survey train in collaboration with the DESY surveyors. This device will be tested at DESY in the second half of 2004 and a fully functional system should be developed by the time the DESY X-FEL tunnel is ready for surveying in 2005. LiCAS are collaborating with DESY on a re-evaluation of survey tolerances. This will involve providing co-ordinates of a typical accelerator after a simulated survey as input to the beam dynamics simulations. This is a significant step forward from the current situation in which the correlations between component co-ordinates from survey measurements are not systematically transferred into the beam dynamics simulations.

In the longer term, the group aims to make the instrument more suitable for diagnostics purposes during LC operation. This will involve a focus on auto-calibration and resolution enhancement. The main goal however remains to transfer the technology into an on-line position monitoring system that can be operated in an actuator feedback loop and be used to stabilise critical components in the BDS and the final focus. In this area they offer an alternative to the inertial stabilisation systems which can not easily extend their sensitivity into the sub-Hertz region, which would be accessible to LiCAS technology. An important step in this direction will be the inclusion of fixed frequency Michelson Interferometers into the FSI distance measurement systems. This will allow highly sensitive O(nm) displacement measurements at rates of O(Hz) to be performed in a network of FSI lines that have already determined the absolute geometry of the collider components to O(μm) accuracies.

B.1.4 Accelerator Simulation

Detailed simulations are vital to the design of the BDS and sophisticated codes exist to track particles along the BDS. These codes have already been used in the UK to explore how beam halo is either lost or transported between the linac and the IP. In addition, novel tracking code based on Geant4 has been developed in the UK to simulate secondary production in the collimation system and perform detailed studies of collimation efficiency including edge effects and the effects of the distribution of material along the beamline.

FONT has also developed a sophisticated beam dynamics software package. This allows full closed-loop simulation of the beam from the damping ring exits, through the linacs, BDS, IP and on into the extraction lines. The IR and MDI are explicitly simulated, including the production of both electromagnetic and hadronic background particles. Arbitrary ground motion, facilities noise and magnetic error models can be included. A database has been set up to allow LC design teams to access the data.

B.1.5 Helical Undulator

Positron polarisation is an essential tool for a detailed analysis of the underlying structure of any kind of new physics as well as for high-precision tests of the SM. Furthermore it increases the effective luminosity for some processes by significant factors and can therefore save running time [14]. The TESLA collaboration intend to create the polarised positrons with high energy (gamma ray) synchrotron radiation generated by the electron beam passing though a state of the art helical undulator. Daresbury Laboratory in collaboration with Liverpool University have started to specify and design a small prototype in advance of studying the extremely demanding LC undulator. The final design will either be made of permanent magnets or be a superconducting electromagnet. This magnet will have a very short period, high magnetic field and will be at least 100 m long. The advanced undulator design will also be of direct interest to the FEL and light source communities as well as to other LC laboratories.

B.1.6 Longitudinal Bunch Profile

Two universities are interested in measuring the longitudinal profile of electron bunches [12]. The Abertay group are studying the precision monitoring of electron beam bunch shape and timing through electromagnetic and electro-optic techniques. The group at Oxford have been investigating the use of Smith-Purcell radiation for the determination of the longitudinal profile of ps or sub-ps electron bunches. These projects will find a natural home within LCA and could install prototype devices in the LCTF, or at international test facilities.

B.1.7 Damping Rings

CCLRC has a number of accelerator physicists and accelerator engineers whose main activities are the support and design of synchrotron radiation sources but who take an active interest in DR design issues. Some work has been carried out for the CLIC DRs to study analytically the optimisation of such rings using computer algebra codes.

B.1.8 Photo-injector

The UK photo-injector R&D looks specifically to the longer-term CLIC project at CERN. The photo-injector uses short laser pulses to illuminate a photo-cathode in order to generate an electron beam with a momentum of several MeV. In this way the required sequence of bunches can then be directly injected into the drive-beam and low emittances obtained. The CLF at RAL has two collaborative projects in progress on the development of lasers for photo-injectors. These follow an earlier paper and experimental feasibility study carried out in collaboration with CERN and the RAL Particle Physics Division.

The first project is a contract from CERN to build a laser system for photo-injector tests at CERN in May 2003 on their CTF2 facility. These tests will determine whether the photo-injector route will be adopted for future development of the CLIC machine at CERN. The laser system under construction is expected to deliver to the photo-cathode sub-10 ps ultraviolet pulses in a 250 MHz pulse train at a repetition rate of 5 Hz, and with a long term stability better than 1%. Further development of the CERN photo-injector is currently proposed under FP6 with the CLF being the main contractor for the laser system.

The second project is a feasibility study to develop photo-injectors for the 4GLS programme, with funding from this programme at DL. Two varieties of photo-injectors are currently under design, both providing trains of short pulses, with one operating continuously and the other in repetitively pulsed mode.

B.2 High Power RF Engineering

Since the successful outcome of a Faraday bid, PPARC is taking part in a Faraday Partnership in High Power RF Engineering. At present the programme consists of five projects with approximately equal effort, as is clear from Fig. B.2. The individual projects are now described in turn.

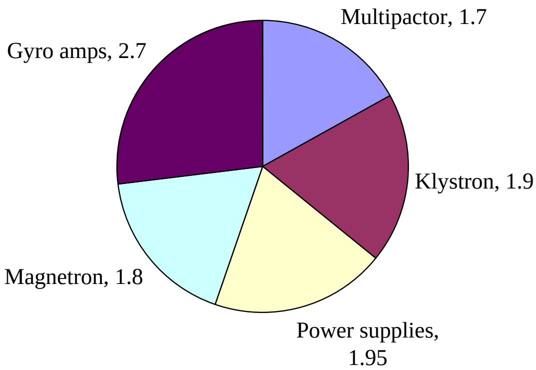

Figure B.2 Distribution of FTEs among the projects in the High Power RF Faraday Partnership

B.2.1 Multipactoring Studies

All vacuum devices that produce or conduct RF energy are prone to problems due to multipactoring. Multipactoring can result in the failure of the device to perform its proper function leading, in extreme cases, to the catastrophic failure of the device. These devices include RF generating tubes such as klystrons and magnetrons and passive devices such as accelerator cavities and RF windows. This work is being carried out at Lancaster University and is expected to impact on all vacuum devices through a better understanding of the mechanisms that lead to multipactoring, its suppression and its enhancement. The phenomenon is exploited in multipactor-tuned magnetrons whereas several methods are used in suppressing it. PPARC's interest is mainly to do with problem solving within accelerator cavities and waveguides.

B.2.2 Magnetron Simulation

Magnetron chains that can be phase locked using a small injection power could be used for driving long pulse accelerators. Phase, frequency and power stability are all of great importance. The modelling work being carried out at QMUL has so far produced some very accurate simulations of real-life situations concerning instability and mode development. An ability to exploit the efficiency of magnetrons having acceptable performance in these three respects could result in a very attractive, physically compact alternative to klystrons.

B.2.3 Travelling Wave Amplifier

The travelling wave amplifier (TWA) is a device invented at Strathclyde University and work is underway there to develop it further in a programme supported by Dstl, E2V Technologies and TMD. The PPARC project will draw from that programme to develop a version more suited to applications where efficiency, high power and narrower bandwidth are required. There is the potential to produce an RF power source for CLIC as an alternative to the drive accelerator. The TWA could also be developed into an RF energy source for industrial processing at frequencies in the range of 1 GHz to 50 GHz and at powers up to 1 MW continuous wave.

B.2.4 Matrix Converter-Driven Power Supplies

Matrix converters are used in sophisticated electric motor drives to produce highly stable power at any frequency from DC to several tens of kHz with very rapid power control. This is achieved with a very low reflection of noise back into the electrical supply. Many man-years of development have gone into developing this technology and the pace of development is still high. The techniques have not yet been applied to power supplies. A study at Nottingham University is addressing how this technology will transfer to power supplies, with the benefits of solving problems such as noise generation (covered by tight regulations), small physical size and high efficiency. The high frequency at which the power is transferred through such a power supply permits much more compact designs to be created that would be of benefit in a wide range of applications. One such application is the power supplies for the TESLA project.

B.2.5 Klystron Modulators

The NLC is most likely to be driven by X band (11.424 GHz) klystrons running at a peak power of 75MW. In the latest version it is proposed that there will be almost 4000 klystrons operating at 120Hz. Sets of eight klystrons will be driven from one modulator which must supply 3 µs pulses at around 500 kV at a peak current of 2000 A. The task of designing and building a modulator for this purpose is very challenging since the mean time between failure has also to be very long. The efficiency, reliability and cost of the modulators are major considerations in achieving a successful machine design. The project being undertaken at Oxford University, aims to identify new circuit techniques for power modulators that produce the very high quality rectangular pulses needed to drive klystrons or other high power RF sources demanded by particle accelerators such as NLC. Circuit techniques for such modulators will be developed to make them highly reliable for long periods of operation and able to withstand severe fault conditions. This project aims to demonstrate that these techniques are practical, viable and cost effective and to involve UK manufacturers of electrical components and systems relevant to the modulator circuits so that they can contribute to the research programme and exploit the results commercially.

B.3 Detector

The UK is pursuing a significant programme of LC detector R&D, currently in two main areas: vertexing and calorimetry. In addition, there remains interest in widening UK detector studies in the future to include other sub-detectors, such as those in the low angle region. The UK now also has a convenor in the working group on global detector performance issues in the ECFA series of LC workshops. These are all very positive developments and represent an excellent start in securing UK leadership in the LC physics programme.

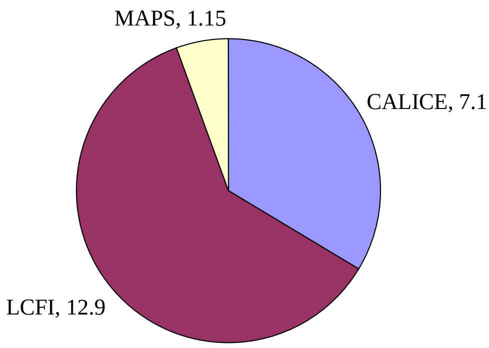

Fig. B.3. The distribution of UK FTEs currently employed in detector R&D.

The numbers of FTEs involved in the various detector R&D projects are illustrated in Fig B.3. The UK is currently contributing to the design of the vertex detector, both for CCDs and Monolithic Active Pixel Sensors (MAPS). Both physics and vertex detector design studies are taking place, described below. The other main current activity is the calorimeter, where the UK groups within the CALICE (Calorimeter for the Linear Collider with Electrons) collaboration are working on both design studies and electronics R&D; test beam work is planned in the near future.

Before including staff-effort on the rolling grant, the grants awarded via the PPRP to CALICE amount to £308k (with a provisional £110k for the third year following review). LCFI received £2.2M over three years, which includes the university PPARC funded staff on the rolling grants and the cost of RAL PPD effort. The main current UK sub-detector activities are now described in more detail.

B.3.1 CALICE UK

The CALICE-UK collaboration [6] comprises Birmingham, Cambridge, Imperial, Manchester, RAL and UCL and is investigating high performance calorimetry for the LC detector. CALICE is already a large international collaboration consisting of 160 people from 25 institutes in 8 countries (including Europe, US and Asia) and is still expanding. As a result, the CALICE collaboration dominates the international LC calorimeter studies.

CALICE embraces a number of R&D activities connected with high resolution calorimetry for a LC detector. It covers both electromagnetic and hadronic calorimeter studies, as an integrated device will be required. A key ingredient in this is the need to achieve high spatial resolution to aid pattern recognition as well as good energy resolution, in order to optimise the measurement of jet energies.

The main focus of the R&D programme is a beam test, anticipated in 2004/5, in which pre-prototypes of various detector technologies will be evaluated. The data thus obtained will be of great value in validating the Monte Carlo simulations upon which the design of full LC detector calorimeters will depend. The calorimeters will take around five years to construct so prototype studies for the final design will need to begin around 2007.

The UK responsibility in CALICE is the provision of the off-detector readout electronics, DAQ system and run control software for the calorimeter beam test. CALICE-UK was approved in 2002 and is currently employing engineering effort at RAL to design VME readout boards, based on a design made originally for the CMS tracker. These boards will be ready for summer 2004 and will then be used in the beam test studies for at least one year.

In addition CALICE-UK is participating strongly in the connected simulation studies, positioning them well to play a leading role in the design of a full detector in due course. These studies are currently under way at Cambridge (where an RA position has recently been awarded for this task by the PPRP) and Birmingham. Additional studies of how the calorimeter could contribute to the crucial measurement of the luminosity spectrum are being carried out at UCL.

B.3.2 LCFI

The Linear Collider Flavour Collaboration (LCFI) comprises Bristol, Lancaster, Liverpool, Oxford, QMUL and RAL [7]. Formed in 1998, this collaboration is engaged in physics studies to determine the requirements for a vertex detector at the LC and in detector R&D aimed at satisfying these requirements by extending the capability of a CCD-based system beyond that used successfully in the 307 Mpixel SLD vertex detector.

LCFI is one of about a dozen collaborations round the world developing vertex detectors for the LC. All of them envisage using silicon pixels, but the architectures are quite diverse (CCDs, MAPS, HAPS, DEPFET and SoI). The goal is to have prototype ladders made with some or all of these technologies by about 2010. Performance comparisons will then enable the LC Detector Collaboration(s) to choose the technology. It is hoped that participants in LCFI and all R&D programmes will then join forces to construct complete detectors designed to achieve the challenging performance goals. As happened at SLC, there may be one technology ready for start-up, with a superior option becoming available later.

The current phase of the LCFI R&D programme is described in a 3-year proposal [15] that was approved in 2002. The programme comprises physics studies, detector development, and minimising the material budget.

Physics studies have shown that for b-tagging the detector parameters could be relatively relaxed, but that more adventurous physics goals such as charm tagging and the measurement of vertex charge require minimal material and minimal inner-layer radius (hence good tolerance to background and radiation damage). These studies are still at an early stage. Many important questions which could influence the detector design still need to be explored, such as the importance of photon conversions in diluting rare signals, and the possibility of combining information from the vertex detector with data on neutral pions reconstructed in the extremely fine-grained calorimeter. There is clearly potential for combined studies with CALICE-UK in this field.

The relatively high bunch train frequency at NLC will require a much faster readout than for the SLD detector. The LCFI proposal is to achieve this by reading out each column of the CCD in parallel. TESLA has much more intense bunch trains, requiring multiple readout during the train. This implies considerably faster column parallel readout than is necessary for the NLC. The CCD design work is being guided from RAL by powerful device simulation software which has only recently become available. The first column parallel CCDs have just been delivered by E2V. They will initially be tested with conventional readout electronics, then bump-bonded on the column pitch of 20 μm to custom-designed readout chips from the RAL Microelectronics Group.

The goal for the material budget is around 0.1% of a radiation length per layer, about a quarter of the SLD value. Achieving this, while preserving micron-level mechanical stability and the ability to deal with the inevitable heat output from the detector, is challenging. As a result of extensive simulations with Finite Element Analysis programs, and experimental work in the lab, interesting ideas are emerging for solving these problems. This aspect of the R&D programme will be applicable at least in part to all the above mentioned sensor technologies.

LCFI is one of the UK flagship detector R&D projects and should be maintained at least at the current level into the foreseeable future and strengthened where possible. The UK must be careful not to lose any of its current lead in this field.

B.3.3 MAPS

In addition to the CCD R&D, work is also in progress at Glasgow, Liverpool and RAL on developing MAPS technology for future particle physics experiments, including the LC. Possible advantages over CCD technology include greater readout speed, increased radiation hardness, on-device intelligence and low power dissipation with consequently lower cooling requirements. Current work includes modelling the basic MAPS concept as a detector for minimum ionizing particles. Hardware is also being set up to characterize devices designed at RAL. Future plans are to address the issues of radiation hardness, read-out speed and device thickness.

B.3.4 Low Angle Region

The low angle region is central to LC physics; this region sets the scale of detector hermeticity and is crucial both for the determination of the luminosity spectrum and for the bunch-by-bunch luminosity information, vital for optimal machine operation. RHUL and UCL have been involved in studying this region, financed mainly by INTAS. The studies have concentrated on simulating the low angle region and how measurements in this area can be used, together with information from the ECAL, to extract the luminosity spectrum. This work could extend to an increased UK experimental activity including the design of the low angle calorimeters and mask region of the detector. Such work would fit in well with the home-based LCTF concept discussed in Sec.3.3. Simulation and related physics studies such as luminosity spectrum determination should be strengthened as part of the LCUK physics programme.

B.4 Theoretical and Experimental Physics Studies

The experimental programme of the LC, offering a high discovery potential for new physics and providing prospects for high-precision measurements of physics within and beyond the Standard Model (SM), needs to be accompanied by a strong theoretical programme in order to be able to exploit fully the experimental capabilities. Thorough investigations are required both of possible signals of new physics and of all accessible SM processes. Theoretical predictions whose accuracy matches the LC experimental precision require an enormous effort. A lot of progress has been made over the last few years, but an intense dedicated effort will be needed to reach this ambitious goal.

The UK has continued to play a central role in this context. It has been a driving force behind the ECFA-DESY workshop series. The Chair of the European study is a UK physicist, as are the conveners of the working groups on top and QCD physics, gamma-gamma and e-gamma physics, polarisation issues, the LHC-LC interface, global detector performance and machine-detector interface. In addition UK physicists are also actively involved in the US and Asian LC studies.

Within the UK, physics studies range from the highly theoretical to the highly experimental. The Institute for Particle Physics Phenomenology (IPPP) at Durham hosted nine LC-related workshops in 2002 and has typically 5 FTEs working on LC physics. The IPPP also co-ordinates two international working groups which play a central role in the world-wide LC activities. The POWER group [14] consists of machine physicists, experimentalists and theorists who investigate LC polarisation issues, with a particular emphasis on the physics potential and the technical feasibility of having both beams polarised. The LHC/LC Study Group [13] is a world-wide collaboration of experimentalists from both the LHC and the LC and of theorists who investigate to what extent the results obtained at one machine can directly impact the analyses carried out at the other. In this way the physics impact of concurrent running of the two machines is explored. Current plans foresee the expansion of both the LC related workshop activities and the number of FTEs working on LC physics. For instance, the IPPP plans to host an LC physics summer school in the near future.

The detailed LC activities of the IPPP are presented in Annex B.4.1. Theoretical work in other university phenomenology groups is equally intensive. Many of the headline physics measurements and searches at the LC will involve detecting and measuring final states of up to eight fermions (leptons and/or quark jets). Calculating the rates of these signal processes, and particularly the relevant backgrounds, is a daunting challenge. The Southampton group has done pioneering work on these complex calculations and are currently working on benchmarking comparisons of the several competing Monte Carlo implementations, an essential prerequisite to any physics study of these channels. They are also exploring the phenomenological implications for top quark, Higgs and supersymmetry studies. An alternative approach is parton shower simulation, as implemented in the HERWIG Monte Carlo event generator, which was used by almost every high energy physics experiment in the last ten years to simulate their data. The Cambridge and Manchester groups are currently working on its successor, which will bring massive improvements to the quality of the physics simulation, as well as to its scalability. Manchester physicists are also working on the capability of a LC to identify CP violating supersymmetry scenarios and on the physics potential of a gamma-gamma collider option. A Manchester physicist contributes to the Higgs and supersymmetry working groups of the ACFA LC study. The Edinburgh group are working on signal and background studies for Higgs and supersymmetry channels, the ability of a LC to measure Higgs boson self-couplings, and on top quark threshold studies. The effort on these projects currently totals around 5 FTEs.

Experimental studies have been performed within the LCFI collaboration of the sensitivity of the charm tag and the vertex charge measurement for b- and c-jets to the critical detector parameters. The response of the LC calorimeter to hadrons is under active study and simulation in the CALICE-UK group. Further phenomenological physics studies within UK experimental groups cover the fields of supersymmetry, gamma-gamma to hadron processes, and the effects of luminosity spectrum errors on precision measurements.

B.4.1 IPPP LC Activities

The LC related activities of IPPP members include Higgs physics, supersymmetry, electroweak precision physics, quantum chromodynamics, heavy quark physics and phenomenology of models with large extra dimensions. Investigating the Higgs sector will be one of the prime goals at the LC, and providing precise theoretical predictions will be mandatory in order to disentangle possible effects of physics beyond the SM. IPPP members work in particular on Higgs physics in supersymmetric theories. The program *FeynHiggs*, which is widely used for physics studies at present and future colliders, provides currently the most precise predictions of masses and couplings in the supersymmetric Higgs sector. It is planned that this will be steadily improved and extended over the next few years in preparation for the LC. Higgs production is also studied in gamma-gamma collisions, where the polarisability of the beams has been shown to lead to a significant improvement in the signal to background ratio. Concerning the search for supersymmetric particles, the clean experimental environment at the LC will be crucial for disentangling the underlying mechanism for supersymmetry breaking. IPPP members work on strategies to determine the supersymmetric parameters including CP-violating phases in a precise and model-independent way, making use of high-precision measurements and polarisation analyses, which will allow discrimination between different underlying theories.

Electroweak precision measurements at the Z pole and the WW threshold will form an integral part of the LC programme. The IPPP group is involved in investigating the determination of the W mass from a WW threshold scan, which avoids the systematic errors associated with the reconstruction of the W momenta from their decay products. The electroweak precision measurements have a high sensitivity for probing the indirect effects of new physics. This requires very precise predictions for these observables within the SM and beyond, in which the IPPP group is actively involved. The top pair threshold production cross-section will be measured with unprecedented precision at the LC and this makes it necessary to improve the theoretical prediction. In addition to higher order corrections the effects due to the instability of the top quark have to be taken into account. So far this has not been done in a satisfactory way and work at the IPPP is going on to improve this situation.

QCD effects at the LC are important, both in their own right and as a background to new physics. Studies at the IPPP include the strong interaction "interconnection" between the hadronic decay particles of heavy colour singlet states and the properties of heavy quark fragmentation. IPPP members have also prepared a Monte Carlo program which describes photoproduction at the LC and can serve as a tool to study the gluon distribution in the real photon using LC measurements. The latter is not very well known up to now, but is very important for precise predictions of signals and backgrounds for processes measured at the LC. Other QCD studies include the total hadronic cross section in the high-energy limit, where BFKL effects become important, as well as event shapes and multi-jet rates, where power corrections are further diminished, giving cleaner access to the perturbative structure of the strong interaction.

B.5 Student Effort

Student effort in LC R&D currently amounts to 11.3 student FTEs, of which 50% is funded by PPARC. The distribution of student effort is shown in Fig.B.4.

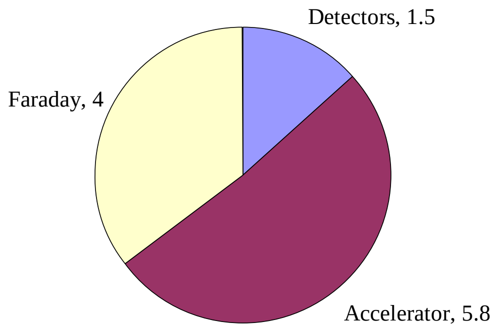

Fig B.4 Distribution of student FTEs among the UK LC R&D activity.

B.6 Detailed Effort Lists

B.6.1 Accelerator

		Other	PPARC
BDS Simulation	Glasgow	0.05	
	Manchester	0.1	
	RHUL		0.4
DR Design	ASTeC	0.93	
BDS Design	ASTeC	1.32	
Undulator	ASTeC	0.1	
	Liverpool	0.3	
LiCAS	Oxford	1.1	4.7
Smith-Purcell	Oxford	0.3	
Photoinjector	CLF	0.35	
Electro-Optics	Abertay	0.4	
FONT	ASTeC	0.2	0.9
	QMUL	0.6	1.2
	Oxford	0.1	0.3
Laserwire	RHUL		2.3
	UCL	0.3	0.5
Plan Development	ASTeC	0.1	
	CCLRC		0.2

B.6.2 High Power RF Faraday

		Other	PPARC
Multipactor	Lancaster	0.7	0.6
	Company	0.4	
Klystron	Oxford	0.3	0.4
	Company	0.3	
Power Supply	Nottingham	0.75	0.5
	Company+MOD	0.7	
Magnetron	QMUL	0.35	1
	Company	0.45	
Gyro Amps	Strathclyde	0.8	0.6
	Company	0.4	

B.6.3 Detector

		Other	PPARC
CALICE	Birmingham	0.5	
	Cambridge	0.9	0.9
	IC	0.7	0.7
	Manchester	1.5	0.5
	UCL	0.4	1
LCFI	Bristol	0.4	0.35
	Lancaster	0.5	0.4
	Liverpool	0.7	
	Oxford	0.7	2.25
	QMUL	0.4	
	RAL	0	7
MAPS	Glasgow	0.05	0.1
	Liverpool	0.4	0.6

B.6.4 Student Effort

	Other	PPARC
LCFI		1.5
Damping Ring Design	1	
Helical Undulator	1	
BDS Simulation	1	
LiCAS		0.8
FONT		1
Laser-wire	1	

The High Power RF Faraday student effort is currently distributed as follows:

	Other	PPARC
Multipactor	0.66	0.35
Power Supply	0.65	0.35
Gyro Amps	0.6	1.4

Annex C

UK Linear Collider Organisation

The LC activity in the UK has been built up over the last few years from small seed-corn funded projects into a growing LCUK collaboration, which spans accelerator work, detector R&D, theoretical studies, and physics simulations. It is recommended that these activities should now be organised into a co-ordinated activity with a clear structure that encourages the projects to grow, while maintaining both an appropriate balance among the activities and a clear reporting line back to PPARC. The newly formed Joint Coordinating Board on Accelerator R&D (JCBoARD) will coordinate UK accelerator activity between the universities, CCLRC and PPARC so any new LC structure must match well with this.

Following the first report [2] in 2001, the LCUK proto-collaboration was formed and nominated an *ad hoc* steering group to coordinate UK activities in the period until substantial longer-term funding became available. A sub-group of LCUK called LC Accelerator and Beam Delivery (LC-ABD) also formed to act as an umbrella organisation for individual university bids to PPARC. The LCUK collaboration, the steering group and the LC-ABD have met approximately twice a year since their formation. It is now appropriate to set up formally the LCUK grouping as a plenary body, with its own Collaboration Board made up of members from each of the participating institutes (*e.g.* group leaders) and a Chair elected by the LCUK collaboration. The Collaboration Board would meet in conjunction with LCUK meetings, in which open presentations and reports from the wider LCUK collaboration would be given, as is current practice. Those institutes with both an accelerator and a detector activity could send two members (one from each field) to the Collaboration Board.

The LCUK Steering Group should be set up as the body that makes decisions on the project, but is accountable to and receives guidance from the Collaboration Board. All substantive issues will also be discussed in plenary LCUK.

The LCUK activity naturally divides into two new sub-groups: “accelerator” (LCA) and “detector and physics” (LCP). These need to be closely linked because of the large amount of overlap, particularly in issues concerning the machine detector interface, in the areas of LC physics that the UK is already pursuing. LCA will coordinate the activities aimed towards UK leadership in the BDS. LCP will coordinate CALICE, LCFI, MAPS, physics studies and LC phenomenology – and any new LC detector projects. Both LCA and LCP will each set up their own meetings and each elect a Chair, who will sit on the Steering Group.

The following members should sit on the Steering Group.

- The LC representative on JCBoARD.
- The Chair of the LCUK Collaboration Board.
- A representative of ASTeC.
- The Chairs of LCA and LCP.
- One or two additional members with wide experience of UK particle physics and international LC developments should be co-opted.

The Chair of the Steering Group should be elected by plenary LCUK. The chair could be one of the above members, but the Chair of the Collaboration Board should not also hold the office of Chair of the Steering Group. All members would serve two-year terms, with terms being renewable.

An expert international Machine Advisory Committee (MAC) should give advice on the entire LCA programme. Such a committee would be a natural link to the international LC steering committees and place the LCA immediately in the emerging international LC project.

The relationship between the new organisational structures is presented in Fig. C.1 and a suggested management structure for the LCA project in Fig C.2.

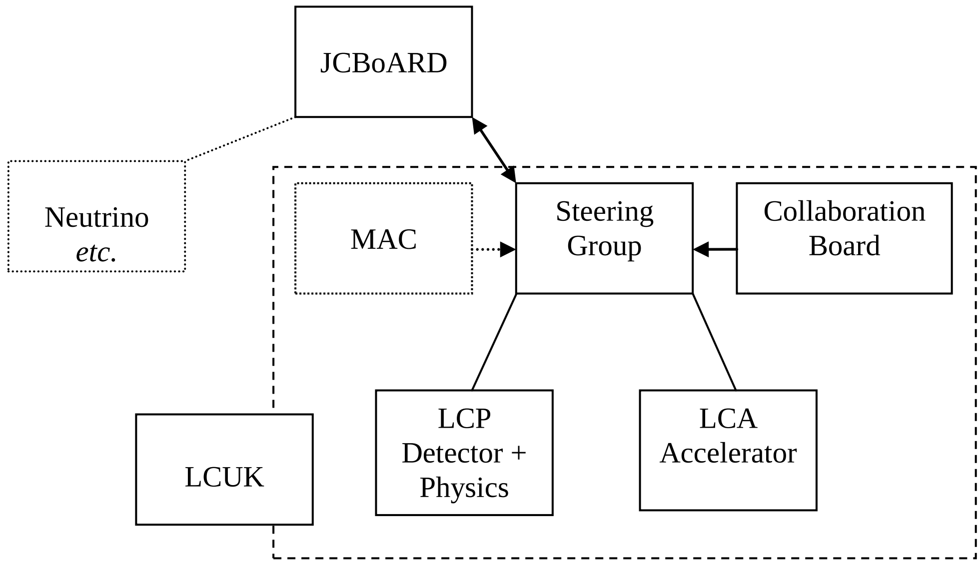

Fig C.1. The relationship between the organisational structures for LCUK

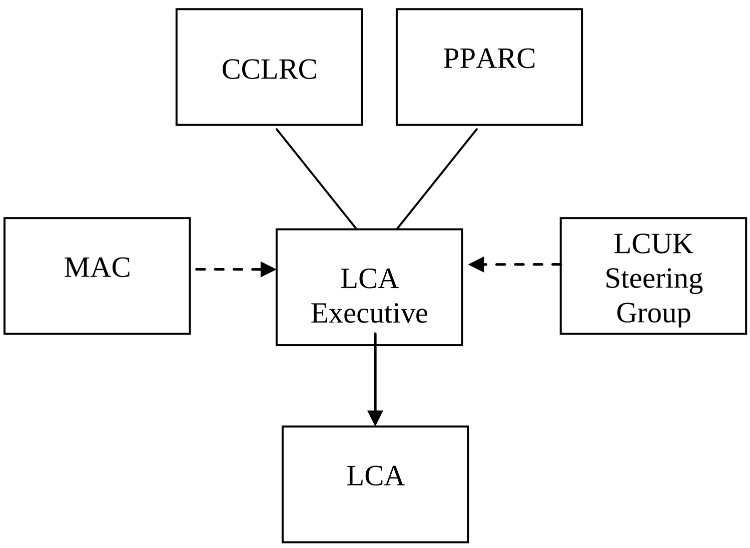

Fig C.2. Structure for management of the LCA project. A PPARC oversight committee would also be involved.

Annex D

Klystron R&D – An Industrial Example

An example of R&D that is linac-specific but which could have enormous payoffs to UK industry is the design of klystron tubes. If TESLA technology is chosen, then 600 (1200) 10 MW klystrons will be required for the 0.5 (0.8) TeV machine. If NLC technology is chosen, then 4000 (8000) 75 MW klystrons will be needed for the 0.5 (1) TeV machine [9]. In addition, a steady supply of tubes will be required as replacements throughout the life of the LC.

Each klystron for TESLA will be worth approximately £130k, so the payoffs to UK industry could be large. However, a correspondingly large investment is required to design a klystron to deliver a particular type of RF, which can only pay off if that specific RF is eventually chosen; a decision on the LC RF choice can be expected within the next two years. A minimum total of 146 weeks are required to develop a klystron for TESLA (Tab.D.1), assuming no major problems arise during that period. So there is an approximate minimum three-year up-front R&D programme required before a confident bid could be made towards substantial RF provision.

The mean requirement is for at least seven man years spread over three years, which can be costed at about £550k. A project such as this needs a broad range of expertise that includes some very specialised skills, which can generally be found only in a vacuum tube company. Any company will be very wary about committing so much valuable engineering resource to a project having uncertain business potential. Some form of positive business outcome that does not depend upon the progress of the greater project needs to be guaranteed.

In order to build a klystron, £800k is required to cover the purchase or construction of essential equipment needed to build and test the prototype. The choice of equipment would be suitable for serial manufacturing where economically possible. In addition, £275k is required to buy materials, including those used for risk reduction projects as well as for the prototype. This also includes electrical power used for testing the prototype.

The above analysis implies that to produce a single klystron prototype will take three years and cost £1.625M. A klystron that has been successfully designed for ease of manufacture and high yield could be sold for around £130k each when manufactured at a rate of about 5 per month using the equipment acquired for the prototype phase. If the UK were to produce 30% of the 600 klystrons for the TESLA 0.5 TeV machine, it would take three years at this rate and the business would be worth £23M (neglecting replacement tubes during running). A higher rate of production would need duplication of some expensive elements used in manufacturing and test. A power supply based on new technology would take approximately as long and cost as much to develop as the klystron example above although this will depend to some extent on its rating. A similar analysis could be applied to the klystrons for the NLC, where 4000 units will be required for the 0.5 TeV machine.

An important additional factor in considering timescales is that the specification for RF sources should never be frozen before potential suppliers are involved. This means that this front-end phase is likely to be much more drawn out than shown in Tab.D.1. In practice this can add years to the process during which a supplier has to hold a competent development team together, which is expensive. The corollary is that if a fixed specification can be agreed from the outset, time and cost can be minimized. These factors will make it very hard to start any serious R&D on klystrons before the LC technology choice has been made.

For the advanced products being considered for the LC, delays resulting from very technical problems are highly likely and close collaboration with subcontractors, for instance in materials development, may be necessary. It cannot be over-emphasised that these products push present technology in materials, processes and the present understanding of device physics to the limits and the best that the world can put on the task does not guarantee success. However, by pushing the limits, UK industry could benefit long term through the development of new processes and products. It is plain that the high risks inherent to such projects are unsuitable for commercial organisations even though they are probably the best places in which to carry out this type of development. The LC physics community must recognise that it has to bear a large proportion of the risk if a commercial organisation is going to place its capability at their disposal.

		Activity	Weeks	Comments
1		Specification analysis	12	Interaction between industrial designers, machine engineers and universities. Project team and Project Manager defined.
2		Mapping of specification onto chosen technology; first estimates made of overall cost and time.	8	Includes decision on technology to be used, definition of risk reduction projects and design of experiments to evaluate any new manufacturing processes. Key sub-contractors identified and consulted where appropriate
3		Risk reduction projects and process development	26	Funding required to complete these tasks. Timescale assumes successful outcome. Design concepts modified in accordance with project outputs
4		Interim project report and re-evaluation of risk. New cost estimate and timescale projections for tube development	4	Expectations are that the revised cost and timescale are both less than the original figures
5		Preparation of full prototype data pack and procurement plan.	16	Detailed discussion of parts design with potential suppliers and judicious redesign where prudent. Particular attention paid to major or unusual items.
6		Fully costed bill of materials with delivery times.	6	This task will be performed against an established budget derived from the original contract value.
7		Recalculate cost and rework the project plan to work round any potential time over-run. Review with Customer.	2	Any budgetary problems raised with customer and mutually acceptable resolution achieved. Decision to proceed or to stop.
8	A	Place orders and procure parts	16	Depends upon need for unusual items. Large ceramics can be a problem
	B	Procure or build test specialised equipment	26	Depends upon scale and nature of requirement relative to existing capability.
9		Manufacture prototype	8	
10		RF condition and initial test of prototype	4	Assumes no ‘glitches’
12		Detailed testing to characterise device.	12	Assumes no ‘glitches’
13		Customer demonstration	2	Assumes success

Table D.1. Tasks and timescales to design a klystron to deliver RF to the LC.

GLOSSARY

ASTeC	UK Accelerator Science and Technology Centre.
ATF	Accelerator Test Facility (KEK).
BDS	Beam Delivery System.
BPM	Beam Position Monitor.
CALICE	CAlorimeter for the LInear Collider with Electrons
CCD	Charge Coupled Device.
CERN	European Centre for Particle Physics
CLF	Central Laser Facility at RAL.
CLIC	Compact Linear Collider (CERN).
CCLRC	Council of the Central Laboratory for the Research Councils (RAL and DL).
CTF	CLIC Test Facility.
DL	Daresbury Laboratory.
DR	Damping Ring.
ECFA	European Committee for Future Accelerators
FD	Final Doublet of quadrupoles.
4GLS	Fourth Generation Light Source.
FTE	Full Time Equivalent.
FSI	Frequency Scanning Interferometry.
FONT	Feedback On Nano Second Timescales collaboration.
FP6	European Union Framework 6 Programme.
GAN	Global Accelerator Network
HEFC	Higher Education Funding Council.
IP	Interaction Point.
IPPP	Institute for Particle Physics Phenomenology at Durham.
INTAS	International Association for the promotion of cooperation with scientists from the New Independent States of the former Soviet Union.
IR	Interaction Region.
JCBoARD	UK Joint Coordinating Board on Accelerator R&D.
JLC	Japan Linear Collider.
LBBD	Laser Based Beam Diagnostics.
LC	Linear Collider.
LCA	UK Linear Collider Accelerator group.
LCFI	Linear Collider Flavour Identification.
LCP	UK Linear Collider Physics (and detector) group.
LCTF	UK Linear Collider Test Facility.
LCUK	Linear Collider UK collaboration.
LHC	Large Hadron Collider (CERN)
LiCAS	Linear Collider Alignment and Survey.

Linac	Linear Accelerator.
LSM	Laser Straightness Monitor
MAC	UK Machine Advisory Committee
MDI	Machine Detector Interface
MAPS	Monolithic Active Pixel Sensors.
MICE	Muon Ionisation Cooling Experiment
NLC	Next Linear Collider.
PPARC	UK Particle Physics and Astronomy Research Council.
PPRP	PPARC Projects Peer Review Panel.
QMUL	Queen Mary, University of London.
RA	Post Doctoral Researcher.
R&D	Research and Development.
RAL	Rutherford Appleton Laboratory.
RF	Radio Frequency.
RHUL	Royal Holloway, University of London.
SR	Synchrotron Radiation
SR02	UK Spending Review 2002.
TESLA	TeV Electron-positron Superconducting Linear Accelerator.
TRC	The G. Leow International Linear Collider Technical Review Committee.
TTF	TESLA Test Facility.
TWA	Travelling Wave Amplifier.
UCL	University College London.