REPORT to the PPC

A UK Leading Involvement in the Future Linear Collider

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1 Executive Summary

`Coordinator: JMB/ALL` **0.5 page?**

`include UK context/funding etc.` [1]

`previous statements of intereste` [2]

The UK particle physics community is engaged is a broad programme of research at high energy colliders around the world. The current energy frontier is at the Tevatron, a rich programme of strong interaction physics is being pursued at HERA, and the investigation of CP violation at Babar is benefitting from the outstanding performance of PEP II. Construction of the LHC detectors is well underway, with excitement heightened by the tantalising final results from LEP.

The LHC promises a wealth of data, after 2005, on the electroweak symmetry-breaking sector (around 1 TeV) of the standard model, and UK physicists will be leaders in analysing this data and understanding its implications. There is, however, a firm consensus that the LHC alone will not be sufficient to fully explore physics at this critical energy scale. A lepton collider will be essential to complete the picture and make precision measurements.

The machine closest to realisation in this context is a linear electron-positron collider. Several proposals exist around the world, and UK physicists have already been important contributors to the various design studies for accelerator and detectors. Over the next few years, key decisions on the shape of this project will be taken, and now is the time for the UK community to come together and form a substantial collaboration to ensure our continued international leadership at the forefront of particle physics. Many of the challenges lie in the accelerator design and for the UK to play a full part, a revitalising of the UK acclerator physics program and close coupling between this and detector design will be required. This document proposes a strategy for this process.

to be added:

Quantitive discussion of present financial commitments to ongoing experimental activities - and place the proposed LC activity in that context **JMB to provide**

LTSR:

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12. R&D is needed to select and develop the most suitable detector
technologies for experiments at new accelerators. The UK can make maximum
impact by carrying out R&D in areas where it is strong. There is also an
important need for 'blue-skies' detector research for the UK to remain
at the cutting edge. Furthermore due to stretched resources many small
scale alpha rated experiments cannot be properly funded, if at all.
Additional funding in the next SR for detector R&D and
new inititatives: 7.2M.
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                             1st Priority
  1. Prototype of Computational Grid for LHC (8.4M)
  2. LHC Exploitation: Presence of key teams/individuals at CERN
     to prepare detectors and take leadership in physics extraction (3.8M)
  3. Human Resources - Experiments: Maximise scientific return from
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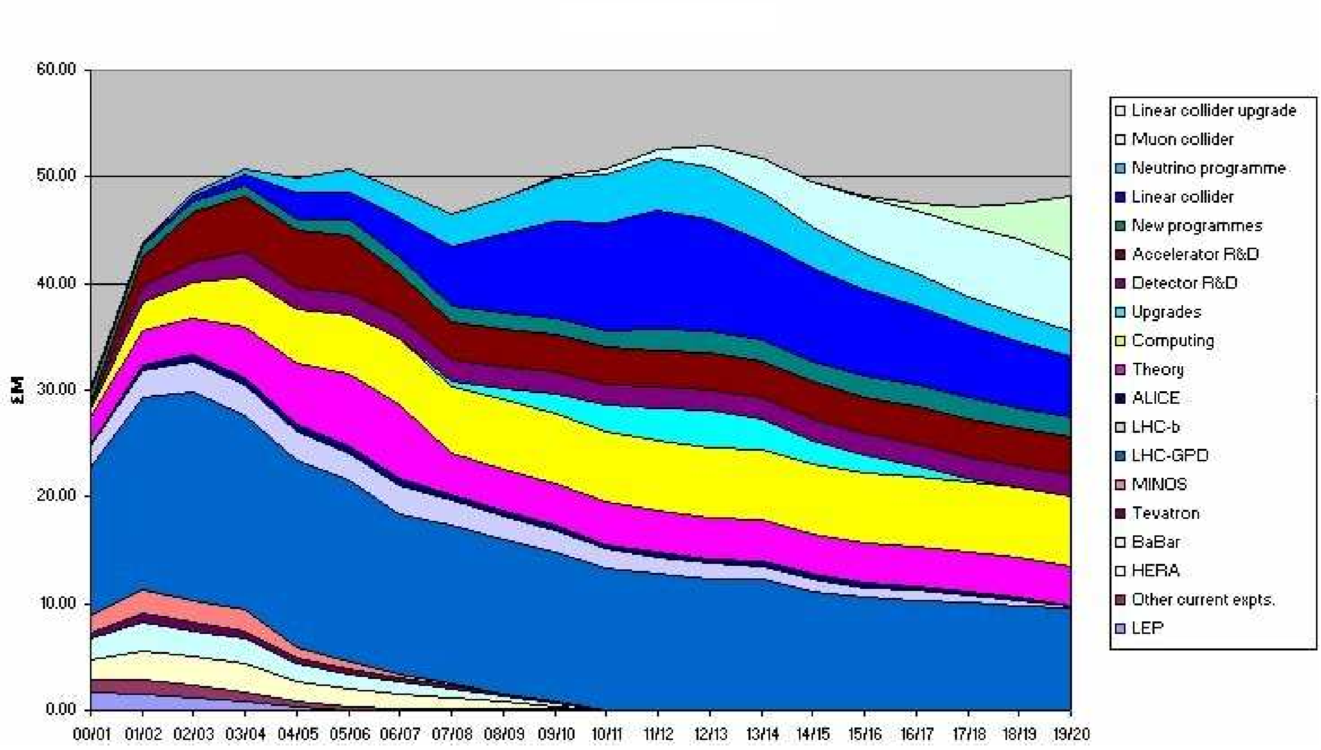
current and LHC programme - PDRAs and technicians/engineers (8.4M)

4. Human Resources - Theory: Increase PDRA support e.g. set up world-class presence in ‘Beyond the SM’ phenomenology (2.4M)
5. Feasibility studies for linear collider and neutrino factory experiments: (costs are not expected to be large during this SR period)
6. Accelerator R&D : neutrino factory (6.7M)

2nd Priority

Accelerator R&D : linear collider (5.0M)
Detector R&D (4.2M)
New Initiatives (3M)
Institute Infrastructure (4.2M)
Lattice Computing (1.6M)

The additional resources required during the period of the next Spending Review (SR) are given in Table 1. To be noted are the resources required for a linear collider and a neutrino factory experiment, peaking at around 2012.



2 Introduction

`Primary Authors: GB/ALL` **0.5 page?**

The physics case for a Linear Collider (LC) in the TeV centre of mass energy range has been well documented [3] and worldwide workshops [4] have been addressing detailed proposals for realising such a facility. The UK has been playing an active and significant rôle in these workshops by providing convenors for several working groups as well as key physics studies and detailed detector simulations.

The ECFA/DESY study has culminated in the submission of the TESLA Technical Design Report [5] to the German Government in March 2001 and both the US and Japanese studies are also well advanced. In addition CLIC technology, such as being pioneered at CERN, provides a longer term route to multi-TeV energy scales. Given a favourable reception to these proposals, it seems likely that a LC will be built in one of the regions, starting in a few years. Having recognised this challenging timescale, the UK has been building its strength in LC-related activities and in a short time has initiated new R&D programmes related to participation in the design and construction of the LC beam delivery system, damping rings and generic technologies, described in more detail below.

to be continued/rewritten!

3 Physics Case

`Coordinator: MS` **2 pages?**

Input from MS:

I have been looking at the US document and I think they have done all the work for us - I believe that my job is basically to come up with a punchy two-page summary of their case.

I would be very keen to get some kind of statement on the support for phenomenological preparations for the linear collider. It seems to me that if a meagre 1was diverted into physics studies it would really have a significant impact on the UK's (already strong) involvement. Of course to have this impact it would need to be genuinely new money that could be bid for by theorists or experimenters alike - simply directing the theory committee to spend Xits existing budget on a given experimental area would never work I think.

LTSR:

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Whatever the nature of the new physics revealed at the LHC, detailed
measurements of the masses, couplings and decays of the particles involved
will be essential for a deeper understanding of nature. A linear e+e-
collider operating at energies up to and beyond 1 TeV will be an
essential instrument for making these precision measurements.

The colliding particles at e+e- machines are simpler than at proton
machines, and hence the experimental signatures are expected to be
clearer and to be well calibrated against measurements at LEP, SLC and HERA.
Crucially, one or more of the beams can be polarized, a powerful tool
for unravelling the structure of the interactions involved.

As an example, if supersymmetry is discovered at the LHC, the number of
fundamental particles is doubled and they will be pair produced at e+e-
colliders. The operating centre-of-mass energy can be set at
successively increasing values, isolating the individual processes
for detailed study. Measurements such as these would elucidate the nature
of supersymmetry breaking and point the way towards a Theory of
Everything (TOE).
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4 Detector

`Coordinators: NDeG,JN` **2 pages?**

Input from TG/Rolf H:

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Vertex detector (covered by LCFI/Renato Turchetta's CMOS pixels)
Si/W calorimeter
Radiation tolerant v. forward calorimeter (Dave Miller?)
Alternative technology for hadron calorimeter
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Muon chambers (I suggested this one, perhaps Manchester interest Graham?)

gamma-gamma interaction region;

people we should be approaching on the above? I've asked Chris Damerell to think about possible RAL involvement in these areas

Refer to TDR etc. for costs

LTSR:

The traditional UK strengths are in silicon detectors, triggering, data acquisition, software and software engineering, the design and development of high density and high speed front-end electronics, scintillation detectors, (glass and crystal electromagnetic calorimetry), photodetectors (photomultiplier tubes, vacuum photodiodes and phototriodes), design and construction of experiment superconducting magnets, and particle identification using Ring Imaging Cherenkov (RICH) detectors.

It is likely that large area solid-state hybrid detector arrays will continue to increase in importance. One need is to decrease significantly detector cost in order to match the expected improvements in cost per channel of the associated micro-electronics, while also addressing the issues of radiation hardness. Charge Coupled Devices (CCDs) on very qthin substrates and with very fast clocking speeds will be required for future applications.

...

Resources are required for new initiatives involving relatively small scale experiments and for conceptual design and feasibility studies of experiments at the linear collider and the neutrino factory. In today's large experiments many positions of influence were secured as a result of leadership established in these early phases.

The additional resources needed during the period of the next SR are shown in the table below. Current spend on generic detector R&D is 0.5M p.a.

	01/02	02/03	03/04	Total M
Detector R&D	1.0	1.4	1.8	4.2
New Initiatives	1.0	1.0	1.0	3.0

We should discuss whether we want a table like that below, maybe for each section:

5 Machine Overview

Coodinator: SS **1 page?**

LTSR:

Physics beyond the LHC requires new accelerators. Experience over the past thirty years shows that a new machine takes at least ten years to design and build, and occupies a position as a leading edge machine, with upgrades, for at least ten years. There is a considerable period of research and development before the design phase. Significant investment in accelerator R&D worldwide is therefore required to meet the optimum timescale for the construction of the new accelerators.

Institute	FTE	Activity	Funding	Until
Bristol				
Brunel				
DL				
Liverpool				
Manchester				
Oxford				
RAL				
RHUL	1	Laserwire/Simulation	PPARC Resp.RA	Aug. 2003
...				

Table 1: *Publicly-funded UK-based contract personnel presently active in the linear collider field*

The machines under consideration worldwide are:

a linear e+e- collider at an energy per beam between 0.3 and 2.5 TeV,
a muon-derived neutrino beam between ~7 and 50 GeV,
a muon collider at an energy per beam between 50 GeV and 2 TeV,
a very large hadron collider at an energy per beam around 50 TeV.

The scientific case for the first three of these machines is well developed. The R&D for the linear collider is under way with first stage machines (˜250 GeV/beam) being designed in DESY (TESLA), and Japan and the US (NLC). A technically more advanced design (CLIC) at CERN would eventually enable higher energies up to 2.5 TeV to be reached. For the two muon machines R&D on a high current proton source is needed.

Future accelerators will be built by international consortia. It is essential for the UK to participate fully in these international projects as it becomes increasingly difficult to separate accelerator design from experiment design. However, since the closure of NIMROD in 1978 there has been no substantial research effort in accelerators for particle physics in the UK.

Despite this the UK could make significant contributions in three areas. These are the linear collider, the high-power proton source and generic technologies. There is a core of expertise upon which to build in the design of :

- the final focus, interaction region, damping rings, beam monitoring and spent beam systems, and high brightness electron sources for the linear collider;
- the pion production target and the muon collection systems for a muon-derived neutrino facility or a muon collider.

Generic technologies include superconducting magnets and r/f power sources, as well as developing expertise in superconducting r/f.

current effort and expertise to at least 25 people working on each of the linear collider, muon derived neutrino facility and generic accelerator technologies. Build-up to this level will take time. As a guide the cost of developing a preliminary design study for the proton source of a muon derived factory at RAL is estimated to be 20-30 staff years of effort. Over the period of the SR R&D into all three areas is a sound investment, which will lead to a better understanding of where UK skills should be most effectively developed. In the longer term it may make more sense to concentrate on one or two of these areas rather than all three.

Particle accelerators will continue to be an important component of the science and technology base. For example, synchrotron radiation and neutron sources are used for research in a wide range of scientific disciplines from the life sciences to condensed matter physics, and accelerators are used in the semiconductor industry, medical diagnosis and therapy, radioactive isotope production and food sterilization. Advanced technology is required to design, build and operate leading edge particle accelerators including precision engineering, vacuum engineering, thermal engineering, superconducting magnets and r/f cavities, power supplies and power converters, advanced electronics and control systems.

The additional resources, required during the period of the next SR, are shown in the table below. It is assumed that staff costs are about one-half of the total costs during the SR. The other half is for the construction of prototypes and tests. The cost of construction of these machines is not included. Current spend on accelerator R&D is 0.3M p.a.

Accelerator R&D	01/02	02/03	03/04	Total M
Linear Collider	1.0	2.0	2.0	5.0
Neutrino Factory	1.3	2.4	3.0	6.7

5.1 Beam Delivery System

Coodinator: PB **2 pages?**

5.1.1 Introduction

The 'beam delivery' section of the collider is the region between the ends of the accelerating linacs and the interaction point (IP). In this section the beams are focussed by quadrupole magnets to the nanometre-scale vertical sizes required to produce high luminosity. The beams are also collimated to remove halo particles, and hence minimise the beam-related backgrounds seen by the detector.

5.1.2 Current Activity

Both functions are vital elements of the design of any future linear collider, independent of the choice of linac accelerating technology. For this reason several UK groups involved in the 'seed round' of accelerator funding have started to develop expertise in beam delivery, and are attacking some of the most challenging aspects in a coordinated programme of R&D:

- **Brunel University**, via a PPARC Opportunity award, is collaborating with SLAC and DESY on the Collimator Wakefield Experiment, located in sector 2 of the SLAC linac. The design of collimators able to survive the extreme power density (5 MW) in the beams is extremely challenging. The Wakefield Experiment involves testing novel collimator structures and materials in the SLC beam, as well as performing advanced finite-element-analysis simulations in an attempt to understand the data. This is well suited to Brunel's skills in advanced materials and engineering.
- **Daresbury Laboratory** and **Manchester University** are collaborating with DESY on beam dynamics simulations. A sophisticated code has been developed which tracks the disturbance to

the beam in the linac caused by misalignment of the magnets, due to ground or other motions. This allows calculation of the subsequent luminosity degradation due to beam-size blowup, as well as the beam-orbit displacement. In the collider such orbit information needs to be measured and fed forward to the IP feedback system in order to preserve the luminosity on timescales greater than minutes.

- **Oxford University** is collaborating with SLAC, DESY, CERN and KEK on optimisation of the luminosity with an ultra-fast intra-bunch feedback system. In order to maintain the design luminosity of the collider the beams must be made to collide head-on to within 5 nm. Ground-motion effects near the IP at the relevent bunch-train-repetition frequency (10-100 Hz) are substantial on the nanometre 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. In order to regain as much luminosity as possible the feedback must respond within 100ns (TESLA) or within 10ns (NLC,JLC,CLIC). Measurement of beam misalignment, calculation of the required correction, and application of the correcting kick within 10ns is exceptionally challenging. The Oxford group has implemented the beam-beam interaction code GUINEA PIG into GEANT models of the NLC and TESLA interaction regions, and simulated the performance of the FB system. The group is now leading an effort to design a prototype system and test it in sector 2 of the SLAC linac: the FONT (Feedback on Nanosecond Timescale) Experiment.

- **Royal Holloway** has been working on detailed GEANT simulation of the detector and beam delivery system at TESLA. The RHUL group provided the original GEANT3 model (BRAHMS) for the detector and physics studies of the TDR and the beam delivery system collimation region was simulated for the machine studies. As part of the wider UK GEANT4 collaboration, RHUL is initiating the use of accelerator tracking techniques within GEANT4. A new experimental activity, in collaboration with DESY, SLAC, CERN and KEK, centres on laser-based beam diagnostics for the linear collider BDS. Traditionally, solid wire scanners have been used to measure beamspot sizes of several microns, however they will not withstand the intensities of bunches at the linear collider. 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. A new optical laboratory is being assembled at RHUL in order to develop novel laser-wire scanning techniques and to test them at existing machines; PETRA at DESY or the ATF at KEK are possible host facilities. Future extentions of this initiative could include the measurement of nm-scale beamspots using interferometric techniques, or a wider class of laser-based beam diagnostics such as the design of a Compton polarimeter.

5.2 Opportunity for Major Contributions

Give us the dosh, and we'll do the job.

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To include:     Present RA's, pgrads etc. in post
                Current Activities
                Spending profile into 2002-4
                Projected UK role (2004-2007 and beyond) given support
                'Flagship' element
                ???}
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Refer to TDR etc. for costs

5.3 Damping Rings

`Coodinator:` `SS` **2 pages?**

5.3.1 Introduction

The damping rings are placed between the particle sources and the start of the main linac. High luminosities at the interaction point depend on very small beam sizes. Since the beam size is a function of the emittance of the beam, it is necessary to achieve as small an emittance as possible to reach the required luminosity. The equilibrium emittance is a balance between quantum excitation and radiation damping, processes that take place at a relatively low level in the main linac and beam delivery system. A damping ring is therefore used before the main linac to reduce the emittance by many orders of magnitude, by radiation damping. In order to minimise the delay between bunch trains, the damping time must be short, which is normally achieved by long insertion devices producing powerful beams of synchrotron radiation. A design for a damping ring for CLIC, for example, uses 10 wiggler magnets for producing radiation, and specifies a damping time of 37 μs. A large circumference allows several bunch trains to circulate simultaneously, but adds considerably to the cost of the ring.

A good design for a damping ring would include very low emittance, short damping time, and minimum circumference. Therefore, there are many features common between damping rings and synchrotron light sources, on which there is considerable expertise at Daresbury Laboratory. The damping rings could be one part of the machine for which the UK could take primary technical responsibility. The design and construction of damping rings for a 1-3 TeV collider would be a challenging project, and there would be considerable spin-offs in areas such as RF and control system technology. Although the damping ring study would initially be motivated by the need for a design for a particular collider, much of the technological development would be generically applicable to any of the collider projects proposed.

Bunch trains are carried to and from the damping rings along transfer lines that must preserve beam quality. The particular challenges here are that some of the transfer lines are of considerable length. In TESLA, for example, positrons would be produced in pair creation from photons generated by a wiggler magnet at the end of the main electron linac. Carrying the positrons to the damping ring requires a transfer line of several kilometres. The transfer lines are not always straightforward lattices of bending and focusing magnets, but usually include other systems, such as bunch compressors and spin rotators, and will be important locations for a wide range of diagnostics.

A significant benefit of damping ring research will be an improvement in the understanding of, and design techniques for, accelerator storage rings and insertion devices in general. Applying the new skills and knowledge to synchrotron light sources, for example, would enable these machines to achieve still higher performance than is currently possible, and will benefit a wide range of subjects from structural biology to surface science.

5.3.2 Current Manpower

CLRC 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 damping ring design issues. Present resources have allowed around 0.5 s-y /year for two years to be directed specifically to the study of physics design issues for damping rings. The estimated resources required to fully complete these studies outlined immediately below is another 1 s-y.

5.3.3 Current activities

Although technically feasible designs have been produced for some of the options for NLC/JLC, TESLA and CLIC (1TeV) good understanding of how to optimise these designs is lacking as yet and a technical solution for 3TeV CLIC requirements has yet to be demonstrated in detail. Some work at CERN has been carried out to analytically analyse the optimisation of such rings using computer algebra codes, but further work is required to generalise this and to examine higher-order effects on the optimisation, such as the effects of multipole wigglers, intra-beam scattering and lifetime. Present simulation tools (such as MAD) allow local optimisation from a given starting point, but do not give a global optimum. In addition, they do not include all of the effects which are relevant to a damping ring design.

5.3.4 Project Objective

To produce a computer algebra toolkit that will allow analytic optimisation of a circular accelerator. This toolkit will then be used to derive the optimum base parameters for a damping ring satisfying a given set of target performances; there is a distinct need for this in linear collider designs, where the required incoming and outgoing beam properties can frequently change as part of the overall design evolution.

5.3.5 Physics Output

models showing properly how damping ring properties scale with different parameters, such as energy, bunch train length, and circumference;

derivation of optimum parameters for a given damping ring performance;

translation of optimum parameters for CLIC 3TeV damping rings into accelerator physics design of the rings.

5.3.6 Opportunities for Collaboration

Collaboration between Daresbury Laboratory and the CERN CLIC project is the most fruitful direction to pursue at present, and the development of the base design into a UK project to construct the final damping rings could involve designers and engineers from many laboratories. Several UK universities are interested in providing students to work on accelerator projects, and the UK expertise in circular accelerators of this type means that appropriate training can be provided and good progress be made.

5.3.7 Spending Profile 2002-2004

A much more major damping ring activity can be envisaged, translating physics studies into a comprehensive Technical Design Report, complete with cost. Based on similar light source study experience a detailed estimate of associated resource needs can be made and has been attached as an appendix in the form of effort. In practice most of this will need to be drawn from the CLRC skill base that is uniquely qualified (in the UK) to perform these functions. As can be seen, the bid is for a total of 40.5 s-y and at standard staff rates this is equivalent to sums of approximately £0.3/£0.6M/ £1.2M in each of the SR years. Most of this will be engineering/technical effort involved in the design of the many specialist systems, with accelerator physics maintained at £0.1-0.2K commitment throughout the period. During the design phase there would be the requirement to initiate the development of prototype systems to test and check some of the challenging engineering and physics issues. A damping ring design project bid must also include appropriate allowance for travel costs, perhaps at a level of £50k annually for this team. It would be important to fully involve universities and industry in this research and design to ensure that the UK accelerator base both academically and industrially can exploit the opportunities available from participation in such a project. By the end of the SR it is likely that a core group of 20-25 accelerator experts will have been formed and will be available for future activities.

5.3.8 Projected UK ROLE (2004-2007)

Taking leadership in the detailed design of say the CLIC 3TeV damping rings will have placed the UK in a strong position to take on the responsibility for the technical build and installation of any linear collider damping ring complex planned for construction. Such a damping ring complex forms a significant part of the accelerator with an estimated cost in the region of £200M. The level of responsibility could range from control and leadership of whole complex to responsibility for major component parts such as injection/extraction system, damping wiggers, magnet system, RF, vacuum, diagnostics etc. and would need to be negotiated with the other partners in the consortium. The involvement could be expected to continue throughout the lifetime of the collider with UK teams providing the support for development, upgrades and improvements in the defined areas. It has already been proposed that a future linear collider built with the collaboration of many national labs could be operated through a system of virtual control room at each of the laboratories. Accelerator scientists and engineers could be expected to share in the commissioning and operation and development of the facilities. This would allow UK teams to fully participate in frontier accelerator studies and developments which impact directly on the delivery of beams for physics. As with all large accelerators the component systems would have to be built in partnership with industry, this could be through collaborative R&D projects or by direct contracts for specified system or components.

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To include:       Present RA's etc. in post
                  Current Activities
                  Spending profile into 2002-4
                  Projected UK role (2004-2007 and beyond) given support
                  'Flagship' element
                  ???}
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Refer to TDR etc. for costs

6 Generic Technologies and Interaction with Industry

`Coodinator: TG` **2 pages?**

LSTR:

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There will be opportunities for UK companies to participate in the
design and building of new accelerators e.g. a linear collider.
High accelerating gradients (from 40MV/m up to a final possible 150MV/m)
are required to construct an electron-positron linear collider with an
energy of 0.25 to 0.5 TeV per beam, with possible upgrading to 2.5 TeV
per beam. One system (for the NLC) will require 7000 high power klystrons
and efficient industrial production is vital. One of the three companies
world-wide which has been awarded contracts to participate in this work is
Marconi Applied Technologies in the UK. Another proposal (for TESLA at DESY)
requires approximately 20km of high purity niobium superconducting cavities.
The most speculative proposal (CLIC) requires a completely new kind of
klystron (a multi-beam klystron), of even higher power and long pulse
duration, which will require extensive development work in industry.
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7 Response of International Labs (?)

`Coodinators: GW/PB/TG` **0.5 pages?**

Can we include "concrete" statements of support/collaboration for our flagship proposals (maybe more for the September report)?

8 Summary of Requested Resources

`Coordinator :(all)` **0.5 pages?**

9 Summary and Outlook

`Coodinator: (all)` **0.5 pages?**

10 Acknowledgements

References

[1] Report of the Particle Physics Long Term Science Review, PPARC, March 2000.

[2] **Statement of Interest in a High-Energy Linear e^+e^- Collider** The UK Linear Collider Consortium, 2000.

`http://www-pnp.physics.ox.ac.uk/~burrows/accelerators/soi_2000.ps`

[3] See eg. **The Case for a 500 GeV e^+e^- Linear Collider**, J Bagger *et al.*, http://xxx.lanl.gov/abs/hep-ex/0007022

[4] The various worldwide LC workshop proceedings and documentation of ongoing activities can be accessed from the central website: `http://lcwws.physics.yale.edu/lc/`

[5] The ECFA/DESY Technical Design Report