Name of Service/Facility/Programme	CALICE
Facility Manager /Principal Investigator	Paul Dauncey
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What are the key science objectives of this programme activity?

The LHC will make the first exploration of physics at the TeV scale, but the next stage will require a lepton collider for precision mapping and understanding, just as LEP established the precise properties of the Z and W bosons discovered at the CERN proton-antiproton collider. The physics to be done at such a machine places stringent requirements on the calorimetry. In order to achieve an energy resolution for jets that will permit the study of Higgs bosons and supersymmetric particles, the calorimeter must have excellent position resolution, with the ability to record and reconstruct an entire shower. Such calorimeters were built at LEP on a very small scale for luminosity monitoring; the challenge is to extend and update such detector technology to cover the entire experiment solid angle.

The ILC is the most advanced proposal for such a lepton collider, and the key scientific objective of the CALICE programme is R&D towards a detector for the ILC, although research into these calorimetric techniques will be necessary whatever proposal is finally implemented. Throughout this response our comments address the ILC generally and/or CALICE specifically as appropriate.

The ILC is a 500GeV e^+e^- linear collider which could be designed, built and delivering physics by 2019. The overall scientific objectives for the ILC are at the forefront of particle physics and involve the major questions in the field: the origin of mass, the nature of the fundamental particles and the structure of the forces between them. The ILC will excel in precision measurements of Standard Model (SM) particles and any others found by the LHC, as well as having a significant discovery potential in its own right. For example, the ILC will be able to compare properties of the Higgs in detail against the SM expectations, including branching fractions to many modes, spin, CP and its self-coupling, the latter being a critical component of the mechanism for mass generation. It will allow precise measurements of the top, W and SUSY masses (if they exist). It will also be able to discover non-strongly interacting new particles which might be unobservable at the LHC.

Although the ILC could be delayed beyond 2019 for political or financial reasons, over the next five years there are several major milestones. The call to the detector community for Letters Of Intent (LoI) has gone out and responses are required by Oct 2008. Following this, two LoIs will be chosen and detector collaborations will form around these. It is widely assumed that these will be based on the existing ILD and SiD detector concept groups. These two collaborations will produce initial Engineering Design Reports (EDR) by 2010 followed by final EDRs in 2012, at which point it would be technically possible to start building the detectors. It is very important that the UK particle physics community is well placed in these collaborations, and participation in R&D projects such as CALICE is necessary for this. First results from the LHC are expected to be reported in 2010 and hence there will be time to optimise the detector designs to take major discoveries into account before the final EDRs.

The main scientific objectives of the international CALICE programme are to understand the requirements of an ILC detector calorimeter and to evaluate the performance of several possible calorimeter technologies so that we know how to build a detector capable of delivering the broad

ILC physics programme. The actual technology choices will only be made at the time of the final EDRs but it is expected that there will be some reduction in the number of alternatives at both the LoI and initial EDR stages. Hence the more immediate scientific objectives of CALICE are to build and test prototypes of viable calorimeter technologies and analysis techniques, and hence make informed choices on the timescales required. The UK groups have been contributing strongly to the analysis of test beam data of various calorimeter prototypes as well as to studies of the physics performance of the detector concepts within the CALICE collaboration.

An important political objective of the UK groups is to play a leading role in the ILC detector collaborations and hence to exploit the eventual ILC data. The major steps towards this goal in the shorter term are to contribute significantly to the detector LoIs and EDRs such as to establish our expertise and leadership in the ILC community and potentially to lead the construction of a major detector component.

To this end we have a significant presence through the beam test and physics studies work already mentioned. We have a very high profile (but high risk) project, the Monolithic Active Pixel Sensors (MAPS) electromagnetic calorimeter (ECAL) concept, which is a purely UK project and would give the UK a central position if it proved viable. The scientific objective of this project is to provide an existence proof that such an ECAL is possible and to evaluate its performance. We are also leading the R&D for the DAQ system, which we know is essential, will be technically feasible, can be applied to more than the calorimetry, and where there is little competing work elsewhere in the ILC community. For this, the scientific objectives are to understand the main requirements and limitations of an ILC DAQ system and to produce a "pre-prototype" system which would meet the requirements using existing technology. This pre-prototype will be used for reading out the next generation of prototypes in beam tests. Once such a system is operating, then our DAQ design will evolve with time, becoming simpler and cheaper through advances in technology. To maintain a presence in calorimeter construction we have a somewhat smaller project, the thermal and mechanical studies workpackage, where we are making use of existing UK expertise in these areas from Atlas. Here the scientific objectives are to develop techniques for the reliable mechanical assembly and cooling of the EM calorimeter modules, given the extremely tight space requirements.

We view working on several projects at this stage as an essential requirement to ensure that whatever the outcome of our R&D, we can take a leading role by the time of the final EDR. UK groups are in a position to provide a major part of the calorimeter (and probably the overall detector) DAQ system. If the MAPS approach turns out to be workable and is accepted, then the UK would be leading the calorimeter sensor design.

What can you say about its likely scientific impact in the coming years?

- Identify 3 of the most scientifically important papers published in the last 3 years and describe their international impact.

- Using the past as a guide, publication supporting information could be provided such as: How many UK authored papers published in the last 3 years? How has publication rate changed over the years? What citation data are available?

The CALICE beam test programme is ongoing and first papers are in preparation. UK results have been presented at conferences, with the most significant being first results from the beam tests and from physics studies, showing that particle flow (PFA) techniques do indeed work. At the

main annual worldwide LCWS workshop at DESY in May 2007, 7 of the 23 CALICE talks were given by CALICE-UK members, along with 4 of the 10 CALICE talks at the associated review of ILC calorimetry. The DAQ work has been reported at the IEEE conference at FNAL in May 2007 and there have also been several EUDET reports. There will be a further presentation at the forthcoming IEEE symposium at Hawaii in Oct 2007. The first public presentation of MAPS results from the first sensor will be presented at the same IEEE meeting.

The beam test data will be published in a series of papers, the first two of which are currently in preparation and are expected to be published early in 2008. As well as providing the two overall Physics and Analysis coordinators for CALICE, a CALICE-UK member is primary author of the first one of these. Papers on the MAPS and DAQ projects will be produced towards the end of the grant period in 2008/9. The UK is positioning itself to play a major role in writing parts of the detector LoIs, which will be submitted towards the end of 2008.

The calorimeters, and the solenoid which must encompass them, are the main cost drivers for an ILC detector and they effectively define the whole detector concept. The results presented at LCWS this year and which are expected to come out over the next few years are crucial to the detector optimisation programme. CALICE completely dominates this field and the results we produce will have a major impact.

- For predicting future impact, outline information on planned scientific exploitation programmes should be provided.

- For R&D projects, describe how the project will position the UK for future scientific output. Highlight any opportunities for knowledge/technology transfer or exchange.

The scientific exploitation of this R&D project is mainly covered in the reply to the first question.

The DAQ work is using cutting-edge electronics and will continue to use technology at the forefront as it evolves, so as to understand the advantages to be gained. This has already meant a close relationship with the electronics companies supplying the existing equipment and this would be expected to grow with time.

The MAPS project is a wholly UK effort which is developing a unique microelectronic technology process (INMAPS) for pixel detectors. This technology would allow MAPS to have the same kind of processing complexity as Hybrid Pixel Sensors. As the cost of MAPS is likely to be significantly lower than the main alternative, this would open up new possibilities and have a dramatic impact on many scientific areas, including other particle physics experiments, and provide new commercial opportunities. This would set the UK in a unique position for knowledge exchange if the technology is developed to maturity over the next few years. This is also discussed in the answer to the last question below.

- Also, for international collaborations, what is the level of UK leadership/participation?

The UK has 44 members of CALICE, out of a total of around 210 collaborators. The UK has significant number of leadership roles within CALICE. On the Technical Board, UK members hold 3 posts, namely Physics Coordinator, Analysis Coordinator and DAQ/Online Coordinator, out of a total of 12 members. The Speakers Bureau chair is a UK member and we provided one of the two Run Coordinators for the 2007 beam test run. One of the four ex-officio members of the Collaboration Steering Board is from the UK, in addition to the member representing the UK

directly.

The DAQ groups are also members of the EUDET collaboration. The EUDET collaboration has around 150 members, of which 20 are from the UK. The UK groups provide the Task Manager for the calorimetry DAQ task and the convenor of the overall DAQ studies.

What are the options for future development?

- What future developments/investments would be required to maintain or improve the current scientific standing and productivity?

Clearly, future investment in the ILC accelerator itself is needed for this programme to come to fruition in the longer term. For CALICE, the current grant will support us until Mar 2009, which is through the LoI period. It should allow us to know whether the MAPS ECAL is viable and to have built a functional DAQ system. The next step will be to form the detector collaborations by the time of the initial EDRs in 2010 and then to produce the final EDRs in 2012. Through this period we need to expand from the R&D level work currently being done in the MAPS, DAQ and mechanics to a fully engineered, realistic and costed design for the detectors.

- What are the scientific and political consequences of a substantial reduction in support, or closure/withdrawal?

The consequences of not supporting the ILC would have a very major impact on the UK particle physics programme. The ILC will be the major international programme at the time it is operating, as the LHC is now, and for the UK not to be involved would be unthinkable if we consider ourselves to be participating in this area of science.

Assuming the UK participates in the ILC then it needs to contribute strongly to the detector collaborations to be able to exploit the scientific opportunities of this machine. CALICE is one of only two UK R&D programmes for the ILC detectors, the other being the vertex detector R&D within LCFI. To reduce or close the CALICE work would effectively force the UK to withdraw from participating in calorimetry and so would limit our involvement to one sub-detector. This would be risky given the large uncertainties in the process of choosing technologies for the detectors.

The political fallout of withdrawal from CALICE would also be severe. We have positioned ourselves to be able to lead several aspects of the detector design and construction. If we then did not produce the relevant work needed for the EDRs, it would badly tarnish the reputation of the UK groups and would make any re-entry into the ILC detectors at a later date very difficult, if not impossible.

- What is the projected (scientifically competitive) lifetime?

It is not possible to give a definite answer at this time. Technically the ILC could start in 2019, although this could be delayed for political or financial reasons. Whenever it starts, it is expected to run for ten to twenty years and will be scientifically competitive throughout its lifetime.

- Are there options for changing its operational arrangements that could extend competitiveness or reduce costs?

Current costs are relatively modest and our contribution is highly respected by our collaborators. The operational arrangements of the next phase of detector collaborations and optimisation for the ILC are not yet known. The costs of a potential UK contribution to a detector are not yet known.

One of the major issues we are addressing is reducing the cost of the calorimeters since these are the major cost component of the detectors. In particular, one major attraction of the MAPS ECAL is its potentially lower cost compared to current alternatives. Therefore our current R&D is already aimed towards cost reduction in the longer term.

What alternative facilities are available to UK researchers?

- In particular, what other facilities could provide UK researchers with similar scientific opportunities and how do they compare? What alternative facilities are planned to come on stream in the future? When?

There are no comparable facilities to the ILC on the same timescale. There is a higher energy e^+e^- linear collider concept (CLIC) which requires significantly more development before a realistic engineering design could be put forward. There are also discussions of a possible high energy muon collider but these are at a very preliminary stage. Even with significant delays to the current ILC schedule of physics by 2019, both these projects could only operate well after the ILC and indeed could be a natural project to follow the ILC.

Within the ILC community there are other calorimetry R&D groups apart from CALICE but these are smaller in size by at least an order of magnitude. Uniquely CALICE has strong ties to both the large ILC detector concepts and to all three main worldwide regions involved in the ILC. There is a strong push from the WWS R&D oversight group for the other groups to cooperate with, and preferably join, CALICE.

To what Extent does this activity provide the UK internationally leading science opportunities?

- How does it compare with competing activities overseas? For example, what and who are the main competitors and future threats?

There will only be one ILC and it will be organised on a global scale so there are no direct competitors.

There is a clear path from the UK work in CALICE to its application in an ILC detector. This will give us a major role in at least one, if not both, planned ILC detectors. We are currently positioning ourselves relative to our collaborators in the future detector groups so that the UK can take a major lead in the detector construction and subsequently in the data exploitation.

The UK DAQ work is far in advance of any other efforts in the ILC community and has no realistic competitors at present.

There are two major designs for the ECAL with which the MAPS concept will be competing. The most advanced is mechanically identical but uses silicon sensors with diode pads rather than MAPS sensors. The physics performance of this design is good and seems similar to MAPS.
The main issue with this concept is the cost; the diode pads must be fabricated from high resistivity silicon, which is not in widespread commercial use so that there is a restricted number

of manufacturers who can produce such sensors. In contrast, MAPS uses a standard CMOS process and could be sourced from a large number of vendors, with obvious cost advantages. The other competing ECAL design would use scintillator tiles as the sensitive components. This is substantially cheaper than either MAPS or diode pad silicon sensors, but suffers from poor granularity and has not been shown to meet the physics requirements of an ILC calorimeter.

What is the scientific user base for this facility?

- For example, how many UK scientists have used it in each of the last 3 years? What are their scientific interests? How is this expected to change?

CALICE is not a facility; the user base consists of the 44 members of CALICE-UK. Their scientific interests in CALICE are detector development, construction and testing, physics simulation and data analysis. Their primary motivation is ILC physics output. This will not change in the medium term, although the number of people involved will grow as the ILC timescale and funding are better defined.

In the longer term, the ILC will be a major facility and, like the LHC, a significant fraction (possibly half or more) of the UK particle physics community might participate in the experiments.

What is the influence of this activity on the training and development of young scientists?

- For example, in the last 3 years how many PhDs have been generated as a result of this facility?
- How many current PhD students?

There has been one UK PhD student at Imperial who completed in 2006 and who worked 50% on CALICE. Currently there are five PhD students, two at Imperial and one each at Birmingham, Cambridge and RHUL, who are due to finish over the next 1-3 years, and an M.Sc. student at Manchester.

What are the main threats to continuing success?

- For example, are there any potential "showstoppers" (technical, financial, political, competitive)?

For the ILC, most of the technical issues are thought to have been solved and an engineering design will be ready for funding approval by 2010. The main threats are therefore political and financial; this will be a huge and expensive project requiring global coordination and funding from many countries. It will therefore be necessary to convince national governments of the importance of particle physics in the cultural and educational life of the nation. There are no realistic competitors.

Most of the technical issues related to the detectors for the physics programme of the ILC are well understood. It is now important to be sure that the technical choices made are the right ones and that they are optimised for physics output and cost effectiveness. Compared with the ILC the financial and political risks to the detectors are small; the main risk would be a forced merger of two detector groups into one collaboration for financial reasons with a subsequent reduction in the scientific payoff.

The MAPS sensors are a new technological development and so there is some risk in terms of the required development time. There is little technical risk in the DAQ development.

How will this activity improve public engagement with science?

- What do you see as the likely impact on the public's perception of science and how would this impact be delivered?

The ILC will deliver a deeper and detailed understanding of anticipated discoveries at the LHC such as the Higgs mechanism, SUSY or some completely new phenomenon. It will be of significant interest to young people and the "science-inclined" public. It will certainly attract some young people towards a scientific or technical career. The whole ILC project will dominate particle physics when it is running and the public engagement will need to be delivered through a major effort similar to that currently in hand for the LHC.

What will be its economic impact?

- How do you see this activity benefiting others, outside this area of science? Are there any technology transfer benefits to industry or others?

The ILC will require a large amount of technical development in the fields of superconducting cavities and RF power sources. UK industry is already engaged in this development and they can capitalise on this interchange by bidding for major parts of the ILC construction.

Within the area of CALICE calorimetry, the DAQ system will use high-end communications technology, potentially including ATCA equipment which is becoming a telecommunications industry standard. This should bring mutual benefits to UK industry. The INMAPS process developed for the MAPS project could be used for many other scientific or commercial applications. Developing a detailed understanding of the properties of this process will set the UK in a unique, world-leading position. There was significant interest from several foundries to fabricate the first sensor earlier this year and, if the concept is accepted, the eventual production for a calorimeter would be a significant contract with industry.

Other Comments: