Contribution of LCUK Collaboration to the Council Symposium

Submission to the Open Symposium at Orsay; final submission to the Zeuthen meeting.

1 Introduction

The LCUK collaboration is a group of more than 150 physicists and engineers in the UK who are interested in building the ILC machine and its associated experiments. They are drawn from CCLRC (both Rutherford Appleton and Daresbury Laboratories) and the following universities: Birmingham, Bristol, Cambridge, Dundee, Durham, Edinburgh, Glasgow, Imperial College London, Lancaster, Liverpool, Manchester, Oxford, Queen Mary University of London, Royal Holloway University of London, Southampton, Strathclyde, University College London.

2 Strategy for HEP

Goals and impact of HEP
The research goal of particle physics is to get a deep understanding of all existing laws in nature and in the Universe. As shown in the past, a successful strategy is to have a few big experiments that have a broad physics potential and whose results are expected to provide the crucial input and to clearly push the overall picture. Further important information to complete the whole mosaic is expected from several smaller experiments with specific research goals. With the start of the LHC in 2007, extremely exciting times in particle physics are close ahead. The correct interpretation of the involved LHC data and reliable physics results may, however, require a rather long time. Due to the strong physics case, the high-energy physics (HEP) community decided in a world-wide consensus that the next large facility in HEP should be the planned 500 GeV–1 TeV International Linear Collider [1] operating in time to have a substantial overlap with LHC.

In addition to the physics case for experiments in HEP itself, important spin-off for further sciences exist: e.g. the development of forefront technologies for accelerator science, for material sciences and for the administration of huge amounts of data.

HEP structure in a global context
The maintenance of large HEP facilities as well as of a suitable number of smaller experiments is important to serve a broad range of research in particle physics as well as in other related sciences. Since, however, financial resources are scarce, future major HEP experiments can probably only be approved and funded in a global context. The activities of ICFA will become even more important in order to keep the flexibility in the HEP programme as well as a geographical

diversity of the projects. Forefront technology R&D as well as excellent education of students and scientists should be provided on a national basis. The collaboration of the large and small HEP institutes is essential and should be coordinated through ICFA at a world-wide level including a central role for the large international laboratories, in particular CERN. The HEP-strategy study under the *aegis* of CERN Council is welcome and opens up a promising path for the future of HEP.

Activities in UK

The UK is strongly involved in many major running experiments: BaBar, at HERA, at the Tevatron, several ν as well as astrophysics experiments and plays an important role in the LHC experiments. Many R&D projects and phenomenology studies are ongoing. The LC-UK group represents one of the strongest national linear collider groups. The UK is also active in future developments on HEP accelerators, as e.g. a possible multi-TeV linear collider CLIC or a ν factory. In this context, we recommend in this submission a strategy for HEP in the next decade including decisions on possible future accelerator options.

3 Recommended strategy

3.1 Short time scale

Results from recent and current experiments (SLC, LEP, Tevatron, flavour, astrophysics experiments) are essentially consistent with Standard Model (SM) physics extended to include neutrino mass terms. As shown in [2] a light SM Higgs is favoured: from a global fit of all data within the SM an upper bound below $m_H = 400$ GeV can be set with a confidence level above 99%. Also in Supersymmetry (SUSY), which is one of the most promising candidates for theories beyond the SM, a light SUSY Higgs below about 200 GeV is required. Precision measurements of the properties of the Higgs particle will be indispensable to verify experimentally the Higgs mechanism and for identifying the underlying physics that is responsible for electroweak symmetry breaking. Another sector which is very important is precision top physics. Even if the Higgs mechanism is not fulfilled in nature, precision measurements in the top and gauge boson sector will give insights about the possible underlying physics. The investigation of the nature of electroweak symmetry breaking, top physics and the promising discovery potential for light SUSY [3] are the main motivations for pursuing an e^+e^- linear collider with an energy of $\sqrt{s} = 500$ GeV as the main goal on a short time scale.

Physics Case for the ILC with $\sqrt{s} = 500$ GeV

- High-precision measurements of the properties of the top quark. As the top quark is by far the heaviest quark (and the heaviest fundamental particle observed so far), top quark physics provides a unique window to new physics. Knowing the properties of the top quark with high precision will be mandatory for identifying quantum effects of new physics. This physics programme can only be carried out at the ILC. No other machine can provide a comparable precision.

- If the Higgs mechanism is realised in nature, it is practically guaranteed that at least one Higgs boson will be detected at ILC(500). At the LHC, on the other hand, a Higgs boson with non-standard properties may be missed. Precision measurements of the mass, the couplings, the spin and the CP properties of the new particle will be indispensable to experimentally verify the Higgs mechanism and for identifying the underlying physics that is responsible for electroweak symmetry breaking.

- High precision measurements at GigaZ (high luminosity running at the Z pole and at the WW threshold). These measurements provide a unique opportunity for detecting effects of new physics at much higher scales. The results from GigaZ and the other measurements at ILC(500) will allow the detection of even tiny deviations from Standard Model expectations. The high-precision physics at ILC(500) will provide stringent constraints on any kind of new physics. It therefore sets the boundary conditions that models for physics at higher scales will have to obey. This information will be of utmost importance for constraining the scale of new physics and thus to outline future search strategies in HEP.

- ILC(500) has very good prospects for detecting the light states of various kinds of new physics in direct searches, for instance supersymmetric particles. The part of the spectrum accessible at ILC(500) is very likely to be complementary to the LHC. The precise measurements at ILC(500) will be crucial for revealing the underlying structure of the new physics, even if only a few new particles are accessible. Since the lightest SUSY particle is a promising candidate for cold dark matter in the Universe, studying its properties in detail is of particular importance. The results from the LHC and the ILC taken together will clearly outline which kind of energy upgrade will be really needed. Possible overlap in running time between both machines would strongly enhance the physics potential of both machines and maximize the physics output of the HEP experiments [4].

Physics case for linear collider options based on LHC results
The physics case for the ILC(500) and in particular possible high-energy upgrade options should be put into the context of possible LHC physics outcomes (see also discussion at the Townmeeting at Snowmass 2001 [3]):

a) LHC has not detected any kind of new physics;

b) LHC has only detected a SM-like Higgs but no physics beyond the Standard Model;

c) LHC has detected some new physics beyond the Standard Model;

One has to distinguish between early LHC results, based on about three years of LHC running, and results of the complete physics run. We concentrate first on early LHC results.

- In the worst case scenario that the LHC has not yet any indication for the Higgs or for physics beyond the SM, there would be a case for building the ILC in order to see whether signals of new TeV-scale physics had been missed, and/or to look for indirect signatures of new physics via precision measurements. Detailed studies have shown that the ILC(500) with polarized beams has the capability to observe even small deviations from expectations in the SM e.g. in the channels $e^+e^- \to b\bar{b}$, $c\bar{c}$, $\ell\bar{\ell}$ [3] using left–right asymmetries and specific azimuthal asymmetries. In this way new physics can be detected and different possible models can be distinguished. The results of both LHC and ILC(500) together will clearly indicate whether there is some new physics at a very high scale. The precise measurements at the ILC(500) could even constrain the new scale rather precisely, so that future collider options could be based on reliable results.

- In the scenario that only a SM-like Higgs has been found at the LHC, the ILC would clearly be best-suited for studying the details of the Higgs boson properties and to actually establish the mechanism of electroweak-symmetry breaking. The ILC could reveal whether the detected particle is really a SM Higgs boson or whether it is e.g. a SM-like Higgs state of SUSY, implying that further, not yet detected, heavier Higgs particles should also exist. Such measurements are important to base decisions about possible LHC and ILC or multi-TeV linear collider upgrades on a factual rather than speculative basis.

- If the LHC detects new light particles, the ILC with its tunable beam energy and polarized beams will be ideally suited to study the properties of the new particles with high precision. Even if the early LHC results indicate that only a few light particles are accessible, the precision measurements of the light particles at the ILC(500) would be sufficient to give crucial information on the underlying model and to provide excellent predictions for the heavier spectrum [3]. Models could already be tested and constrained without the knowledge of the full spectrum. Furthermore the ILC(500) results would provide input for the possible LHC and linear collider upgrade options. They would determine which of the LHC and linear collider upgrade options (see next section) would be most appropriate and which energy scale of a linear collider is best-suited to reveal the remainder of the expected spectrum. Even in case that the LHC results indicate that the new physics scale will be unreachable, the precise environment of the ILC(500) including polarized beams can reveal the underlying physics in indirect searches in a largely model-independent approach [3].

Recommended strategy
In our opinion, the physics case for a 500 GeV ILC is compelling irrespective

of the results that emerge from the LHC [5]. To wait with the linear collider until the complete LHC data have been analyzed is not reasonable on scientific grounds: the measurements in the top sector and the expected results on the electroweak symmetry breaking sector could only be obtained with the ILC(500). No other accelerator option would offer a comparable physics potential in that energy region. Not to exploit such an accelerator option as soon as it is practicable to build it would not only mean a loss in time, but also would sacrifice a reliable physics basis for the choice of upgrades of the LHC and ILC and to miss the opportunity of optimal interplay between the different HEP facilities.

We believe that the work of the ILC GDE will lead to an ILC design that is mature and feasible by around 2008. We therefore believe that it is vital:

- to build the ILC(500), ILC with $\sqrt{s} = 500$ GeV, as soon as possible thereafter;
- to optimize the possible interplay between LHC, ILC, flavour factories and astroparticle physics experiments.

R&D for the multi-TeV option, CLIC, should be maintained and the decision about construction of such a machine made after LHC and first ILC(500) results have been analysed in detail. The pros and cons of this choice should be compared with other options including LHC and ILC upgrades.

Possible upgrade scenarios and future strategy

As mentioned before, several LHC as well as linear collider upgrade scenarios are under discussion.

LHC upgrades

A luminosity upgrade by about a factor of ten is under discussion. R&D is still needed to get e.g. the electron cloud effect under control and to meet the vertexing/tracking challenges for such a luminosity upgrade. An energy upgrade of the LHC would require a major redesign of the LHC and the replacement of all the dipoles. Substantial R&D is still needed for this option since its feasibility has not yet been shown. While the necessary R&D for both machine and detectors must proceed with urgency, a decision about the final upgrade choice should be based on the physics results from the early LHC, the ILC(500), and results from smaller related experiments.

Linear collider upgrades

In the current Baseline Configuration Document (BCD) [6] of the ILC an energy upgrade up to 1 TeV is foreseen, while higher energies are not excluded. The final choice of the energy scale and further possible machine and detector upgrades should be based on reliable physics results from the LHC and ILC(500). On the basis of these experiments, one could clearly decide whether an ILC upgrade is sufficient or whether a multi-TeV collider is desirable. The completion of the CLIC R1 and R2 design requirements of the ITRP [7] is planned for earliest in the year 2010. However, even after reaching the ITRP goals, there is still a long way to go before a Technical Design for a multi-TeV machine could be produced. We therefore recommend maintaining the ongoing R&D activities. In the same time frame also feasibility studies of a ν factory and a μ collider should have been performed. On the basis of the LHC, ILC(500) and results of ongoing flavour and ν experiments, the optimal decision concerning possible multi-TeV options could be made.

Further strategy
As outlined above, it is also important to maintain diversity in HEP experiments. Neutrino facilities as well as flavour physics experiments, low-energy precision measurements and astroparticle facilities should be pursued. Therefore R&D for such facilities and further future accelerator designs should be supported. The basic input from LHC and ILC(500) are together with already ongoing flavour and ν experiments, however, absolutely crucial for outlining all further design and experiment considerations.

4 Concluding remarks

With the start of the LHC and the progress in the design of the ILC, so that first ILC data could be available at the middle of the next decade, exciting times are close ahead in HEP. Therefore the strongest effort should be made to optimize the interplay of the currently feasible two major facilities taking into account forthcoming results from the international neutrino programme and from smaller experiments in HEP, astroparticle physics and flavour physics. Furthermore, strong activities in accelerator R&D are needed to develop multi-TeV collider designs such as CLIC or a μ collider. Also new accelerator concepts should be studied. The coordination of all activities through ICFA and other international bodies as necessary will be essential.

References

[1] ICFA, *Parameters for the Linear Collider*, see webpage: `www.interactions.org/linearcollider/documents/index.htm`.

[2] see webpage of the LEP Electroweak Working Group: **http://lepewwg.web.cern.ch/LEPEWWG/**; *Precision Electroweak Measurements on the Z Resonance*, The ALEPH, DELPHI, L3, OPAL, SLD Collaborations, the LEP Electroweak Working Group, the SLD Electroweak and Heavy Flavour Groups, 2005, CERN-PH-EP/2005-041, hep-ex/0509008; *A Combination of Preliminary Electroweak Measurements and Constraints on the Standard Model*, The LEP Collaborations ALEPH, DELPHI, L3, OPAL and the LEP Electroweak Working Group, 2005, CERN-PH-EP/2005-051, hep-ex/0511027.

[3] J. A. Aguilar-Saavedra *et al.* [ECFA/DESY LC Physics Working Group Collaboration], arXiv:hep-ph/0106315; K. Abe *et al.* [ACFA Linear Collider Working Group Collaboration], arXiv:hep-ph/0109166; T. Abe *et al.* [American Linear Collider Working Group Collaboration], in *Proc. of the APS/DPF/DPB Summer Study on the Future of Particle Physics (Snowmass 2001)* ed. N. Graf, arXiv:hep-ex/0106056; G. Moortgat-Pick *et al.* [POWER Group], hep-ph/0507011; J. R. Ellis, S. Heinemeyer, K. A. Olive and G. Weiglein, JHEP **0502** (2005) 013 [arXiv:hep-ph/0411216]; see also contributions to the *Proc. of the 2005 International Linear Collider Physics and Detector Workshop and Second ILC Accelerator Workshop*, Snowmass, Colorado, 2005, webpage: `http://alcpg2005.colorado.edu/`.

[4] G. Weiglein *et al.* [LHC/LC Study Group], hep-ph/0410364.

[5] ICFA Statement on Linear Colliders, 2004, see webpage: **http://www.fnal.gov/directorate/icfa/icfa LCstatement0204.html**.

[6] International Linear Collider Baseline Configuration Design (BCD), webpage: **http://www.linearcollider.org/wiki/**.

[7] Executive Summary of the International Technical Recommendation Panel (ITRP), webpage: **http://www.interactions.org/pdf/ITRPexec.pdf**; International Linear Collider - Rechnical Review Report (ILC-TRC) (2003), webpage: **http://www.slac.stanford.edu/xorg/ilc-trc/2002/2002/report/03rep.htm**.