Parameters for the Linear Collider

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1. Introduction

Over the past decade, studies in Asia, Europe and North America have described the scientific case for a future electron-positron linear collider [1,2,3,4]. A world-wide consensus has formed for a baseline LC project with centre-of-mass energies up to 500 GeV and with luminosity above 10^{34} $cm^{-2}s^{-1}$ [5]. Beyond this firm baseline machine, several upgrades and options are envisaged whose weight, priority and realisation will depend upon the results obtained at the LHC and the baseline LC. This document, prepared by the Parameters Subcommittee of the International Linear Collider Steering Committee, provides a set of parameters for the future Linear Collider and the corresponding values needed to achieve the anticipated physics program. The membership and the charge in 2003 and in 2006 to the subcommittee are appended
In the following, we define an equivalent integrated luminosity, $\mathcal{L}_{eq}T$, as that which would be obtained if the LC were operated at its maximum available energy. For LC operation at less than maximum energy, we assume that the luminosity scales as $\mathcal{L} \sim \sqrt{s}$. For example, in the 500 GeV baseline machine described below, the actual $\int \mathcal{L}\, dt$ collected at $\sqrt{s} = 250$ GeV would be $0.5 \times \mathcal{L}_{eq}T$.

It should be noted that the overall time of running quoted in this document by no means exhausts the full physics program expected. The numbers given should only indicate a first pass of physics running, needed in order to capitalize on the LHC and the LC operating simultaneously.

The document first discusses the parameters and their approximate values for a world-wide agreed baseline machine [5], listed according to priority. The physics results obtained in the first few years of running with this machine, together with the results from LHC will then define the schedule for upgrades or other modes of operation (options) of the baseline machine and their respective priorities. We consider the timely realisation of the baseline machine as very important particularly in view of the expected synergy with the LHC.

We expect shutdowns to install the upgrades or options discussed in sections 3 and 4 to take not more than two years after an initial physics running time of at least four years, including the commissioning of the upgrades or options.

This document does not aim at making the physics case for the Linear Collider and therefore does not repeat detailed physics arguments found in the documents referenced above.

2. Baseline Machine

- The maximum centre-of-mass energy should be 500 GeV. Removing safety margins in the energy reach is acceptable but should be recoverable without extra construction. The maximum luminosity is not needed at the top energy (500 GeV), however, 500 GeV should be reachable assuming nominal gradient. The machine should allow for an energy range for physics between 200 GeV and 500 GeV, with operation at any energy value as dictated by the physics (e.g. at the maximum of the Higgs production cross section).

- Luminosity and reliability of the machine should allow the collection of approximately $\mathcal{L}_{eq} = 500\ fb^{-1}$ in the first four years of running, not counting year zero which is assumed to mainly serve for machine commissioning and short pilot physics run(s).[1] Full luminosity at the highest baseline energy is not required in the first few years of the physics program. If absolutely necessary, it would be acceptable to run in the first year with fewer than the full number of klystrons and ramp up to the full complement by approximately year 4 of physics running. If new physics results dictate that the full luminosity of $2x10^{34}\ cm^{-2}s^{-1}$ at 500 GeV is essential for exploring those phenomena, operating time should be traded off against increased klystron procurement to permit highest energy running at full luminosity in a reasonable time.

- The collider has to allow for energy scans at all centre-of-mass energy values between 200 GeV and 500 GeV. The time needed for the change of energy values should not exceed about 10% of the actual data-taking time. Therefore, the down-time for switching between energy values should not exceed a few shifts within a particular scan, and should not take more than a few weeks when changing between different energy scans.[2]

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[1] It is assumed here that the design luminosity and the efficiency/reliability of the machine will only be reached gradually within the first years of operation (10, 30 and 60% in years 1,2 and 3, resp.) and that the design luminosity and reliability will be reached in year four (i.e. 100% in year 4) of physics running, not counting year 0.

[2] Collection of 10 fb^{-1} at one energy value requires 1-2 weeks of data-taking at design luminosity (1/25 of the year); a full scan of 100 fb^{-1} may take half a year.

Energy scans might include the top quark pair threshold, Higgs production threshold and the thresholds of various supersymmetric particle reactions.

- Beam energy stability and precision should be below the tenth of percent level at any energy. The experiments and machine interface must allow measurements of the beam energy and of the differential luminosity spectrum with a similar accuracy. For example, precision measurements of the Higgs boson and top quark masses call for this precision.

- The machine should be capable of producing electron beams with polarisation of at least 80% within the whole energy range used for physics running.

- The interaction region (IR) should allow for two experiments. Two experiments are desired to allow independent and complementary measurements of critical parameters and to provide better use of the beams thereby maximizing the physics output. Switching between experiments should be accomplished with less than a few percent loss of integrated luminosity. If necessary for design and cost considerations, the two experiments could share a common IR, provided that the detector changeover can be accomplished in approximately 1 week. In this “push-pull” scenario, it would be expected that detector changeovers would occur at predetermined values of luminosity accumulated.

- The machine should allow for an energy range for calibration that extends down to 90 GeV. For calibration, large emittance and consequently low luminosity are tolerable. The amount of calibration data and the frequency of such calibration runs at the Z^0 might depend on the detector technologies. However, it is assumed that a similar strategy as at LEP-2 will be appropriate for all technologies, where calibration runs were taken after long shutdowns. The machine design should allow such calibration runs without additional investment.

- Many measurements suffer from effects caused by beamstrahlung. In most of these cases increased beamstrahlung requires more integrated luminosity to reach the desired level of accuracy, in some cases background reduction becomes very difficult. Modes of running the accelerator with high beamstrahlung are not desirable, however, more quantitative studies by the experimental community are required here.

3. Energy Upgrade beyond the Baseline machine

Independent of the results from the first few years of running there are several reasons for an energy upgrade. Examples include higher sensitivities for anomalous gauge boson couplings, measurement of the Higgs boson self coupling, the coupling of the Higgs to the top quark, production thresholds for new massive particles or exploration of extra spatial dimensions. Consequently, the energy of the machine has to be upgradeable.

The strong likelihood that there will be new physics in the 500 – 1000 GeV range means that the upgradeability of the LC to about 1 TeV is the highest priority step beyond the baseline.

- The energy of the machine should be upgradeable to approximately 1 TeV.

- The luminosity and reliability of the machine should allow the collection of order of 1 ab^{-1} (equivalent at 1 TeV) in about 3 to 4 years.

- The machine should have the capability for running at any energy value for continuum measurements and for threshold scans up to the maximum energy with the design luminosity ($\sqrt{s}$ scaling assumed).

- Beam energy stability and accuracy should be as stated for the baseline machine.

4. Options beyond the Baseline machine

Timing and priorities of the options will depend on the results obtained at the LC baseline 500 GeV machine and possibly at the energy upgraded machine, together with the results from the LHC. An important issue here will be LC/LHC synergy and the time budget for the different options. Therefore, this list of options is not priority ordered.

- Luminosity and reliability of the baseline 500 GeV machine should allow doubling the integrated luminosity to a total of 1 ab^{-1} within two additional years of running, without requiring an additional shutdown. This extension could become a high priority if there is rich new physics discovered at $\leq$ 500 GeV.

- Running as an e^-e^- collider at any energy value up to the e^+e^- maximum energy may be important for some physics measurements, albeit with reduced luminosity. This option is also highly desirable if $\gamma\gamma$ collisions are to be provided.

- Positron polarisation at or above 50% is desirable in the whole energy range from 90 GeV to the maximum energy without significant loss of luminosity. Specific studies of the Higgs boson, electroweak parameters, QCD, supersymmetric particles and new non-supersymmetric physics require or would benefit from positron polarisation ($\mathcal{P}_+$); the exact gain differs for different measurements. Some studies are enabled by transverse polarisation of both beams and the ability to provide this should be retained. Reversal of the polarization state should be possible in the interval between bunch crossings.

- Running at the Z^0 with a luminosity of several 10^{33} $cm^{-2}s^{-1}$ (GigaZ running) would allow high precision tests of the Standard Model, within a year of data taking. Positron polarisation and frequent flips of polarisation states are essential for GigaZ, as is energy stability and calibration accuracy below the tenth of percent level.

- Running at the WW threshold with a luminosity of several 10^{33} $cm^{-2}s^{-1}$ will allow the most precise determination of the W-mass, within a year of data taking. Positron polarisation is not required. Beam energy calibration is required with an accuracy of a few 10^{-5} (still to be demonstrated by the experimental community).

- Several physics measurements are uniquely enabled through collisions of (polarized) photons, or electrons and photons, from backscattered laser beams. High polarization of both electron beams is required. This option will require transformation of one interaction region to run as a γγ or eγ collider at any energy up to 80% of the e^+e^- maximum energy, with reduced luminosity (some 30-50%) with respect to the e^+e^- luminosity. It is desired to keep the option of providing a second beam delivery system without major interruption. More studies on the technical aspects of a γγ or eγ collider are required by the experimental community.

5 References

[1] GLC Report 2003
[2] TESLA Technical Design Report 2001
[3] Linear Collider Physics: Resource Book for Snowmass 2001
[4] World-wide Study of Physics and Detectors for Future Linear e^+e^- Colliders, http://blueox.uoregon.edu/~lc/wwstudy
[5] "Understanding Matter, Energy, Space and Time: The Case for the e^+e^- Linear Collider", http://physics.uoregon.edu/~lc/wwstudy/lc_consensus.html

6 Appendices

6.1 List of subcommittee members

Asia: Sachio Komamiya, Dongchul Son
Europe : Rolf Heuer (chair), Francois Richard
North America: Paul Grannis, Mark Oreglia

6.2 Charge to the subcommittee in 2003

The Parameters Subcommittee has been set up by the ILCSC and will report to it, the first report being expected at the meeting in August during the 2003 Lepton Photon Conference.

The group comprises two members each from Asia, Europe and North America. It shall produce a set of parameters for the future Linear Collider and their corresponding values needed to achieve the anticipated physics program. This list and the values have to be specific enough to form the basis of an eventual cost estimate and a design for the collider and to serve as a standard of comparison in the technology recommendation process. The parameters should be derived on the basis of the world consensus document "Understanding Matter, Energy, Space and Time: The case for the e+e- Linear Collider" using additional input from the regional studies. The final report will be forwarded to the ILCSC for its acceptance or modification by end of September, 2003.

The parameter set should describe the desired baseline (*phase 1*) collider as well as possible subsequent phases that introduce new options and/or upgrades.

For all phases and options/upgrades priorities should be discussed wherever possible and appropriate, and the description should include at least the following parameters:

- Operational energy range
- Minimum top energy
- Integrated luminosity and desired time spent to accumulate it, for selected energy values
  (e.g. at the top energy, at the Z-pole, at various energy thresholds…)
- Polarisation and particle type for each beam
- Number and type of interaction regions

The committee may include any other parameter that it considers important for reaching the physics goals of a particular phase, or useful for the comparison of technologies, subject to the approval of the ILCSC.

6.3 Charge to the subcommittee in 2006

The ILCSC sub-group on parameters is asked to

- Revisit the Baseline Machine performance and Energy Upgrade parameters it had established three years ago, taking into account possible new insights and developments
- Discuss, together with the GDE and WWS, all areas of the RDR design optimisation affecting the performance parameters
- Revisit the Options Beyond the Baseline Machine it had established three years ago, and provide clear cost versus performance guidance as its effects the initial machine configuration
- Make report (and interim report if necessary) well in phase of the development of RDR