Technology Breakthroughs and International Linear Collider

Barry Barish
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Why a TeV Scale $e^+e^-$ Accelerator?

- Two parallel developments over the past few years (the science & the technology)
  - The precision information $e^+e^-$ and $\nu$ data at present energies have pointed to a low mass Higgs; Understanding electroweak symmetry breaking, whether supersymmetry or an alternative, will require precision measurements.
  - There are strong arguments for the complementarity between a $\sim 0.5$-1.0 TeV ILC and the LHC science.
Electroweak Precision Measurements

Winter 2003

\[ \Delta \alpha_{\text{had}}^{(5)} = \begin{cases} 0.02761 \pm 0.00036 \\ 0.02747 \pm 0.00012 \\ \text{Without NuTeV} \end{cases} \]

\( m_H [\text{GeV}] \)

Excluded

Preliminary

\( \chi^2 \)

\( 0 \)

\( 2 \)

\( 4 \)

\( 6 \)

\( 20 \)

\( 100 \)

\( 400 \)

\( e^+e^+ \) and neutrino scattering results at present energies strongly point to a low mass Higgs and an energy scale for new physics < 1TeV.
Why a TeV Scale e\textsuperscript{+}e\textsuperscript{-} Accelerator?

- Two parallel developments over the past few years (the science & the technology)

  - The precision information from LEP and other data have pointed to a low mass Higgs; Understanding electroweak symmetry breaking, whether supersymmetry or an alternative, will require precision measurements.

  - There are strong arguments for the complementarity between a ~0.5-1.0 TeV LC and the LHC science.
LHC/ILC Complementarity

Linear Collider Spin Measurement

The Higgs must be spin zero

LHC should discover the Higgs

The linear collider should measure its spin

The process $e^+e^- \rightarrow HZ$ can be used to measure the spin of a 120 GeV Higgs particle.
Map extra dimensions: study the emission of gravitons into the extra dimensions, together with a photon or jets emitted into the normal dimensions.
Why a TeV Scale $e^+e^-$ Accelerator?

• Two parallel developments over the past few years (the science & the technology)

  – Designs and technology demonstrations have matured on two technical approaches for an $e^+e^-$ collider that are well matched to our present understanding of the physics.
Parameters for the ILC

- $E_{cm}$ adjustable from 200 – 500 GeV
- Luminosity $\Rightarrow \int L \, dt = 500 \text{ fb}^{-1}$ in 4 years
- Ability to scan between 200 and 500 GeV
- Energy stability and precision below 0.1%
- Electron polarization of at least 80%

- The machine must be upgradeable to 1 TeV
Linear Collider Concept

- Pre-accelerator
- Source
- Few GeV
- Damping ring
- Few GeV
- Bunch compressor
- Main linac
- Few GeV
- 250-500 GeV
- Collimation
- Final focus
- Extraction & dump
- KeV
### Specific Machine Realizations

**rf bands:**

<table>
<thead>
<tr>
<th>Band</th>
<th>Frequency</th>
<th>Wavelength (λ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-band (TESLA)</td>
<td>1.3 GHz</td>
<td>3.7 cm</td>
</tr>
<tr>
<td>S-band (SLAC linac)</td>
<td>2.856 GHz</td>
<td>1.7 cm</td>
</tr>
<tr>
<td>C-band (JLC-C)</td>
<td>5.7 GHz</td>
<td>0.95 cm</td>
</tr>
<tr>
<td>X-band (NLC/GLC)</td>
<td>11.4 GHz</td>
<td>0.42 cm</td>
</tr>
<tr>
<td>(CLIC)</td>
<td>25-30 GHz</td>
<td>0.2 cm</td>
</tr>
</tbody>
</table>

Accelerating structure size is dictated by wavelength of the rf accelerating wave. Wakefields related to structure size; thus so is the difficulty in controlling emittance growth and final luminosity.

- Bunch spacing, train length related to rf frequency
- Damping ring design depends on bunch length, hence frequency

**Frequency dictates many of the design issues for LC**
The main linacs based on 1.3 GHz superconducting technology operating at 2 K.

The cryoplant, is of a size comparable to that of the LHC, consisting of seven subsystems strung along the machines every 5 km.
TESLA Cavity

- RF accelerator structures consist of close to 21,000 9-cell niobium cavities operating at gradients of 23.8 MV/m (unloaded as well as beam loaded) for 500 GeV c.m. operation.

- The rf pulse length is 1370 µs and the repetition rate is 5 Hz. At a later stage, the machine energy may be upgraded to 800 GeV c.m. by raising the gradient to 35 MV/m.
The TESLA cavities are supplied with rf power in groups of 36 by 572 10 MW klystrons and modulators.
The JLC-X and NLC are essentially a unified single design with common parameters.

The main linacs are based on 11.4 GHz, room temperature copper technology.
The main linacs operate at an unloaded gradient of 65 MV/m, beam-loaded to 50 MV/m.

The rf systems for 500 GeV c.m. consist of 4064 75 MW Periodic Permanent Magnet (PPM) klystrons arranged in groups of 8, followed by 2032 SLED-II rf pulse compression systems.
GLC / NLC Concept

- Two parallel tunnels for each linac.
- For 500 GeV c.m. energy, rf systems only installed in the first 7 km of each linac.
- Upgrade to 1 TeV by filling the rest of each linac, for a total two-linac length of 28 km.
Which Technology to Choose?

- Two alternate designs -- "warm" and "cold" had come to the stage where the show stoppers had been eliminated and the concepts were well understood.

- A major step toward a new international machine requires uniting behind one technology, and then make a unified global design based on the recommended technology.
ITRP Schedule of Events

- **Six Meetings**
  - RAL (Jan 27, 28 2004) → Tutorial & Planning
  - DESY (April 5, 6 2004)
  - SLAC (April 26, 27 2004)
  - KEK (May 25, 26 2004)
  - Caltech (June 28, 29, 30 2004)
  - Korea (August 11, 12, 13)
  - ILCSC / ICFA (Aug 19) → Exec. Summary
  - ILCSC (Sept 20) → Final Report

- Site Visits
- Deliberations
- Recommendation
Evaluate a Criteria Matrix

• The panel analyzed the technology choice through studying a matrix having six general categories with specific items under each:
  – the scope and parameters specified by the ILCSC;
  – technical issues;
  – cost issues;
  – schedule issues;
  – physics operation issues;
  – and more general considerations that reflect the impact of the LC on science, technology and society
Experimental Test Facility - KEK

• Prototype Damping Ring for X-band Linear Collider

• Development of Beam Instrumentation and Control

<table>
<thead>
<tr>
<th></th>
<th>ATF</th>
<th>GLC/NLC-DR</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_b$</td>
<td>$1.28$ (1.54 max)</td>
<td>$1.98$ GeV</td>
</tr>
<tr>
<td>$N_e$</td>
<td>$~10^{10}$</td>
<td>$0.75$ $10^{10}$ e-/bunch</td>
</tr>
<tr>
<td>$S_b$</td>
<td>$2.8$</td>
<td>$1.4$ ns</td>
</tr>
<tr>
<td>$N_b$</td>
<td>$20$</td>
<td>$192$ /pulse</td>
</tr>
<tr>
<td>$\gamma\varepsilon_x$</td>
<td>$~4$</td>
<td>$3$ $\mu$m.rad</td>
</tr>
<tr>
<td>$\gamma\varepsilon_y$</td>
<td>$~0.015$</td>
<td>$0.02$ $\mu$m.rad</td>
</tr>
</tbody>
</table>
Final Focus Test Facility - SLAC

Final Focus Test Beam Collaboration

BINP (Novosibirsk)
DESY
Fermilab
IBM
Kawasaki
KEK
LAL (Orsay)
MPI (Munich)
Rochester
SLAC

Vertical beam size of 60-70 nm
... the needed demagnification.
TESLA Test Facility Linac - DESY

- Laser driven electron gun
- Photon beam diagnostics
- Undulator
- Superconducting accelerator modules
- Bunch compressor
- Pre-accelerator
- E-beam diagnostics

Electron Beam Energies:
- 240 MeV
- 120 MeV
- 16 MeV
- 4 MeV

Diagram shows the layout of the TESLA Test Facility Linac with various components and energy levels.
Technology Recommendation

- The Panel recommended that the linear collider be based on superconducting rf technology.

  - The superconducting technology has several very nice features for application to a linear collider. They follow in part from the low rf frequency.
Some Features of SC Technology

• The large cavity aperture and long bunch interval reduce the complexity of operations, reduce the sensitivity to ground motion, permit inter-bunch feedback and may enable increased beam current.

• The main linac rf systems, the single largest technical cost elements, are of comparatively lower risk.

• The construction of the superconducting XFEL free electron laser will provide prototypes and test many aspects of the linac.

• The industrialization of most major components of the linac is underway.

• The use of superconducting cavities significantly reduces power consumption.
Technology Recommendation

- The recommendation was presented to ILCSC & ICFA on August 19 in a joint meeting in Beijing.

- ICFA unanimously endorsed the ITRP’s recommendation on August 20
What’s Next

- Organize the ILC effort globally (Wagner)
  - Coordinate worldwide R & D efforts, in order to demonstrate and improve the performance, reduce the costs, attain the required reliability, etc.
  - Undertake making a “global design” over the next few years for a machine that can be jointly implemented internationally.
  - These goals are within reach and we fully expect to have an optimized design within a few years, so that we can undertake building the next great particle accelerator.