The International Linear Collider

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Abe-Fest, Carmel Mission Inn
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1. Are there undiscovered principles of nature: New symmetries, new physical laws?
2. How can we solve the mystery of dark energy?
3. Are there extra dimensions of space?
4. Do all the forces become one?
5. Why are there so many kinds of particles?
6. What is dark matter? How can we make it in the laboratory?
7. What are neutrinos telling us?
8. How did the universe come to be?
9. What happened to the antimatter?

from the Quantum Universe
Answering the Questions

Three Complementary Probes

• Neutrinos as a Probe
  – Particle physics and astrophysics using a weakly interacting probe

• High Energy Proton Proton Colliders
  – Opening up a new energy frontier ( ~ 1 TeV scale)

• High Energy Electron Positron Colliders
  – Precision Physics at the new energy frontier
Accelerators and the Energy Frontier

Large Hadron Collider
CERN – Geneva Switzerland
Electroweak Precision Measurements

What causes mass??

The mechanism – Higgs or alternative appears around the corner
LHC and the Energy Frontier

Source of Particle Mass

Discover the Higgs

The Higgs Field

or variants or ???
LHC and the Energy Frontier

A New Force in Nature

Discover a new heavy particle, Z’

Can show by measuring the couplings with the ILC how it relates to other particles and forces
Why $e^+e^-$ Collisions?

- elementary particles
- well-defined
  - energy,
  - angular momentum
- uses full COM energy
- produces particles democratically
- can mostly fully reconstruct events
How do you know you have discovered the Higgs?

Measure the quantum numbers. The Higgs must have spin zero!

The linear collider will measure the spin of any Higgs it can produce by measuring the energy dependence from threshold.
The ILC measures coupling strength of the Higgs with other particles

Higgs Coupling-mass relation

\[ m_i = V \times \kappa_i \]
What can we learn from the Higgs?

Precision measurements of Higgs coupling can reveal extra dimensions in nature

- Straight blue line gives the standard model predictions.
- Range of predictions in models with extra dimensions -- yellow band, (at most 30% below the Standard Model)
- The red error bars indicate the level of precision attainable at the ILC for each particle
New space-time dimensions can be mapped by studying the emission of gravitons into the extra dimensions, together with a photon or jets emitted into the normal dimensions.
Supersymmetry

\[ \begin{align*}
&\begin{array}{c}
u_e \nu_\mu \nu_\tau \\
e \mu \tau
\end{array} \\
&\begin{array}{c}
u_e \nu_\mu \nu_\tau \\
e \mu \tau
\end{array}
\end{align*} \]

Spin
1/2

Spin
1

Spin
0

Supersymmetric Partner

\[ \begin{align*}
&\begin{array}{c}
\tilde{u} \tilde{c} \tilde{t} \\
\tilde{d} \tilde{s} \tilde{b}
\end{array} \\
&\begin{array}{c}
\tilde{e} \tilde{\mu} \tilde{\tau}
\end{array}
\end{align*} \]

Spin
0

Spin
1/2

Spin
1/2
Parameters for the ILC

• $E_{cm}$ adjustable from 200 – 500 GeV
• Luminosity $\Rightarrow \int Ldt = 500 \text{ fb}^{-1}$ 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
Circular or Linear Collider?

- **Circular Machine**
  - $\Delta E \sim (E^4/m^4 R)$
  - Cost $\sim aR + b \Delta E$
    $\sim aR + b (E^4/m^4 R)$
  - Optimization: $R \sim E^2 \Rightarrow$ Cost $\sim cE^2$

- Linear Collider
  - Cost (linear) $\sim a'L$
  - where $L \sim E$

- Synchrotron Radiation

- $R \sim 200$ GeV
Luminosity & Beam Size

\[ L = \frac{n_b N^2 f_{\text{rep}}}{2\pi \sum_x \sum_y} H_D \]

- \( f_{\text{rep}} \times n_b \) tends to be low in a linear collider

<table>
<thead>
<tr>
<th></th>
<th>( f_{\text{rep}} ) [Hz]</th>
<th>( n_b )</th>
<th>( N \times 10^{10} )</th>
<th>( \sigma_x ) [( \mu )m]</th>
<th>( \sigma_y ) [( \mu )m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILC</td>
<td>( 2 \times 10^{34} )</td>
<td>5</td>
<td>3000</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td>SLC</td>
<td>( 2 \times 10^{30} )</td>
<td>120</td>
<td>1</td>
<td>4</td>
<td>1.5</td>
</tr>
<tr>
<td>LEP2</td>
<td>( 5 \times 10^{31} )</td>
<td>10,000</td>
<td>8</td>
<td>30</td>
<td>240</td>
</tr>
<tr>
<td>PEP-II</td>
<td>( 1 \times 10^{34} )</td>
<td>140,000</td>
<td>1700</td>
<td>6</td>
<td>155</td>
</tr>
</tbody>
</table>

- The beam-beam tune shift limit is much looser in a linear collider than a storage ring to achieve luminosity with spot size and bunch charge
  - Small spots mean small emittances and small betas:
    \[ \sigma_x = \sqrt{\beta_x \varepsilon_x} \]
Achieving High Luminosity

• Low emittance machine optics
• Contain emittance growth
• Squeeze the beam as small as possible

~ 5 nm

Interaction Point (IP)
Designing a Linear Collider

Superconducting RF Main Linac
Parametric Approach

- A working space - optimize machine for cost/performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>min</th>
<th>nominal</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunch charge</td>
<td>1</td>
<td>2</td>
<td>$2 \times 10^{10}$</td>
</tr>
<tr>
<td>Number of bunches</td>
<td>1330</td>
<td>2820</td>
<td>5640</td>
</tr>
<tr>
<td>Linac bunch interval</td>
<td>154</td>
<td>308</td>
<td>461 ns</td>
</tr>
<tr>
<td>Bunch length</td>
<td>150</td>
<td>300</td>
<td>500 $\mu$m</td>
</tr>
<tr>
<td>Vert.emit.</td>
<td>0.03</td>
<td>0.04</td>
<td>0.08 mm-mrad</td>
</tr>
<tr>
<td>IP beta (500GeV)</td>
<td>10</td>
<td>21</td>
<td>21 mm</td>
</tr>
<tr>
<td>IP beta (1TeV)</td>
<td>0.2</td>
<td>0.4</td>
<td>0.4 mm</td>
</tr>
<tr>
<td>IP beta (1TeV)</td>
<td>10</td>
<td>30</td>
<td>30 mm</td>
</tr>
<tr>
<td>IP beta (1TeV)</td>
<td>0.2</td>
<td>0.3</td>
<td>0.6 mm</td>
</tr>
</tbody>
</table>
The Key Decisions

Critical choices: luminosity parameters & gradient

Luminosity Parameters
- one or two IRs
- Laser-straight or terrain following linac
- RF Gradient for 500 GeV for 1 TeV
- Cavity Shape
- Damping ring location
- Damping ring concept
  - 3 km ring
  - 6 km ring
  - 17 km 'dogbone'
- need for e+ pre-DR

Main linac tunnel configuration
- single tunnel
- two tunnel with access
- two tunnel no access

positron source
- conventional
  - undulator
  - compton

11-Sept-06 Abe-Fest
Making Choices – The Tradeoffs

Many decisions are interrelated and require input from several WG/GG groups
The Baseline Machine (500GeV)

RTML ~1.6km

ML ~10km (G = 31.5MV/m)

BDS 5km

e+ undulator @ 150 GeV (~1.2km)

R = 955m

E = 5 GeV

not to scale
~30 km long tunnel

Main Research Center

Particle Detector

Linear Collider Facility

Two tunnels
- accelerator units
- other for services - RF power
Superconducting RF Cavities

High Gradient Accelerator
35 MV/meter  -- 40 km linear collider
Gradient

Results from KEK-DESY collaboration

After Standard etch Average
28.9 +/- 1.1 MV/m

After EP Average
35.6 +/- 2.3 MV/m

must reduce spread (need more statistics)
Baseline Gradient

36.9 +/- 1.85 MV/m
42.3 +/- 2.12 MV/m

10%
5%
Baseline Features – Electron Source

- Electron Source – Conventional Source using a DC ----- Titanium-sapphire laser emits 2-ns pulses that knock out electrons; electric field focuses each bunch into a 250-meter-long linear accelerator that accelerates up to 5 GeV
Baseline Features – Positron Source

- **Positron Source – Helical Undulator with Polarized beams** – 150 Gev electron beam goes through a 200m undulator ing making photons that hit a 0.5 rl titanium alloy target to produce positrons. The positrons are accelerated to 5-GeV accelerator before injecting into positron damping ring.
The damping rings have more accelerator physics than the rest of the collider.
**Beam Delivery System**

- **Baseline**

![Diagram showing beam delivery system with Baseline and various components like tune-up dump, BSY, final focus, 2 mrad IR, 20 m rad IR, and 1000 m, 10 m scales.]

- **Requirements:**
  - Focus beams down to very small spot sizes
  - Collect out-going disrupted beam and transport to the dump
  - Collimate the incoming beams to limit beam halo
  - Provide diagnostics and optimize the system and determine the luminosity spectrum for the detector
  - Switch between IPs
• **Large Scale** $4\pi$ detectors with solenoidal magnetic fields.

• In order to take full advantage of the ILC ability to reconstruct, need to improve resolutions, tracking, etc by factor of two or three

• **New techniques in calorimetry, granularity of readout etc being developed**
Cost vs Performance

• We obtained our first ILC costing in July
• We are validating those costs and studying areas where different costing disagree
• We are studying areas where costs appear larger than expected for requirements, value engineering, etc.
• Our aim is to produce a reference design, which has taken into account major cost vs performance optimization – examples
  – 2mr x 20 mr compared to 14mr x 14 mr
  – One positron damping ring
  – Optimizing size of tunnels
  – Position of damping ring
Final Remarks

• Design Status and Plans
  – Baseline was determined and documented at end of 2005
  – Plan to complete reference design / cost by the end of 2006
  – Technical design by end of 2009

• R & D Program
  – Support baseline: demonstrations; optimize cost / performance; industrialization
  – Develop improvements to baseline – cavities; high power RF

• Overall Strategy
  – Be ready for an informed decision by 2010
  – Siting; International Management; LHC results; CLIC feasibility etc