ILC Accelerator Design: Status and Politics

Loopfest V
SLAC
June 19th, 2006
The ILC Accelerator

• 2nd generation electron-positron Linear Collider

• Parameter specification
  – $E_{\text{cms}}$ 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%
  – Options for electron-electron and $\gamma-\gamma$ collisions
  – The machine must be upgradeable to 1 TeV

• Three big challenges: energy, luminosity, and cost
Experimental Basis for the ILC Design

SLC, FFTB, ASSET, E-158

ε Preservation

Bunch Compression

SLC and FEL’s

SLC and (ATF2 in the future)

BDS & IR

Linac rf system

ATF, 3rd Gen Light Sources, SLC

Damping Rings

e+ / e- Sources

SLC, E-158

ε Preservation
International Linear Collider – Americas

ILC Schematic and Tunnels

Schematic Layout of the 500 GeV Machine

Tunnels:
- e- Linac
- 11.4 Km + ~1.2 Km
- Service Tunnel
- Beam Line e- ML
- 138 m
- 2 mrad
- 5 mrad
- 20 mrad
- Beam Line e+ ML
- 11.4 Km + ~1.2 Km
- Service Tunnel
- 27 m
- 27 m
- D=6.6 Km
- DR ~6.6 Km
- 5 GeV

Section A
Global Design Effort Schedule

2005       2006        2007       2008        2009       2010

Global Design Effort

- Baseline configuration
- Reference Design
- Technical Design
- Regrion coord
- Globally coordinated
- Sample sites
- Expression of interest
- ICFA / ILCSC
- FALC

Project

- Funding
- ILC R&D Program
- Hosting
- International Mgmt
International Linear Collider – Americas

Global Design Effort

http://www.linearcollider.org/

Current News

From TRIUMF | 17 May 2006

TRIUMF successfully commissions Canada's first superconducting linear particle accelerator:

"The TRIUMF national laboratory has achieved a new milestone by successfully commissioning a superconducting linear accelerator (linac) at its subatomic physics complex situated on the UBC campus in Vancouver. The superconducting linac will accelerate rare isotopes created by the TRIUMF cyclotron beam. This development positions TRIUMF as the world’s premier facility for the study of nuclear physics and astrophysics, addressing fundamental questions of the universe’s existence."

From nature | 8 June 2006

Features

ILC NewsLine | 15 June 2006

A Marriage Made in TTF

Discovering the Quantum Universe

Website Launched
<table>
<thead>
<tr>
<th>R&amp;D Board</th>
<th>Design Board</th>
<th>Config Board</th>
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<tr>
<td>Chris Damerell</td>
<td>W. Bialowons</td>
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<td>Eckhard Elsen</td>
<td>J.P. Delahaye</td>
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<td>Andy Wolski</td>
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</table>
ILC GDE Program

• The present GDE ILC program has two portions:
  – Reference Design Report (RDR)
    • A conceptual design based on sample sites with a cost estimate
    • Accelerator physics and engineering efforts are being developed
  – R&D Program
    • Presently administered through the different regions
    • ILC Global Design Effort will coordinate effort more globally

• ILC design timeline
  – RDR at end of CY2006
  – TDR based on supporting R&D in ~2009

• ILC Americas
  – Effort spread between RDR and R&D programs
  – Coordinated by Gerry Dugan – MOUs between GDE and labs

http://www.lns.cornell.edu/~dugan/LC/Labs/
• What exactly is the RDR?
  – A 1st attempt at an international cost estimate for the ILC using 'reasonable' extrapolations from present technology
    • Baseline design mostly established at Snowmass, Aug. 2005
    • Not TESLA and not USTOS
  – Must document sufficiently to estimate cost
  – Cost estimate based on sample sites from different regions
  – Goal of completing the estimate in CY2006
    • Need to use existing information: TESLA TDR, USTOS, Japanese ITRP estimate
    • New information from US industrial estimates, DESY XFEL estimates, Japanese industrial estimates but most of these will be late → provide calibration but not a basis
    • Need to make laboratory estimates for cost drivers

• Highest priority for the GDE in 2006
Sample Sites

- Sample sites located in US, Japan, Germany, and CERN.

- Site located in northeast Illinois.

- Tunnel placed in a north-south alignment, in the top half of the Galina/Platteville dolomite, limestone stratum. This rock stratum is structurally stable and relatively dry.

- Potential sites under consideration range from being centered on Fermilab to a site 30 KM to the west of Fermilab.
RDR Working Groups

- Established working groups to complete RDR effort
  - Organized by Area around regional sections of LC
    - Sources; damping rings; main linac; beam delivery; …
  - Technical design provide by technical groups that reach across Areas
    - Coordinates technical resources but makes communication harder
    - Uniform technical standards applied across collider
    - Similar to style used for NLC Lehman design and TESLA TDR
  - Some groups provide technical support for Areas but also have system-wide responsibility → Global groups
    - Conventional Facilities and Siting (CF&S)
    - Control systems; Operations; Installation; …
  - Costs get rolled up to the Area groups so that they can study cost versus performance trades
  - Costs get output to Cost Engineers so they can study cost basis across systems
RDR Matrix
(Organization to complete Design)

- Matrix of Area Systems and Technical Systems to develop cost estimate
  - International representation in all working groups

<table>
<thead>
<tr>
<th>Area Systems</th>
<th>e- source</th>
<th>e+ source</th>
<th>Damping Rings</th>
<th>RTML</th>
<th>Main Linac</th>
<th>BDS</th>
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RDR Management group:
Nick Walker, Tor Raubenheimer,
Kaoru Yokoya, Ewan Paterson,
Wilhelm Bialowons, Peter Garbincius, Tetsuo Shidara
• Use the spirit of ITER “Value” methodology
  – Doesn’t include labor costs, but estimates of institutional labor effort in person-hours
  – Doesn’t include contingency – need to subtract this cleanly from regional estimates
  – Will need a risk assessment for costs
  – Costs for raw materials will be standardized across project

• Use TESLA TDR, DESY XFEL, and USTOS costing
  – Get additional industrial estimates to support laboratory #s

• Insufficient time to develop a loaded schedule
  – Assume a 7 year construction period
    • Construction starts with the 1st contracts and finishing with the installation of the final components
RDR Schedule

- **RDR Matrix – established @ Frascati (12/05)**
  - Area Systems meeting @ KEK (1/06)
  - Area & Technical Systems meeting @ FNAL (2/06)

- **GDE Meeting @ Bangalore (3/06)**
  - Weekly review of different Area Systems
  - Linac Systems meeting @ DESY (5/06)
  - Weekly review of different Technical Systems
  - First pass at cost estimates to AS and DCB by June 25th

- **GDE Meeting @ Vancouver (7/06)**
  - Iterate on main cost drivers and estimates
  - Complete written drafts of RDR
  - Probable RDR meetings in early fall

- **GDE Meeting @ Valencia (11/06)**
  - First draft of RDR and cost estimate → complete in early 2007
Parameter Plane

- Parameter plane established
  - TESLA designed for $3.4 \times 10^{34}$ but had a very narrow operating range
    - Designed for single operating point
  - ILC luminosity of $2 \times 10^{34}$ over a wide range of operating parameters
    - Bunch length between 500 and 150 μm
    - Bunch charge between $2 \times 10^{10}$ and $1 \times 10^{10}$
    - Number of bunches between $\sim 1000$ and $\sim 6000$
      - Significant flexibility in damping ring fill patterns
      - Vary rf pulse length
      - Change linac currents
    - Beam power between $\sim 5$ and $11$ MW
      - Thought to have small cost impact – to be checked
<table>
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<tr>
<th>Parameter</th>
<th>nom</th>
<th>low N</th>
<th>lrg Y</th>
<th>low P</th>
<th>High L</th>
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<td>$N \times 10^{10}$</td>
<td>2</td>
<td>1</td>
<td>2</td>
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<td>$n_b$</td>
<td>2820</td>
<td>5640</td>
<td>2820</td>
<td>1330</td>
<td>2820</td>
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<td>$\varepsilon_{x,y}$</td>
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<td>10, 30</td>
<td>12, 80</td>
<td>10,35</td>
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<td>$\sigma_{x,y}$</td>
<td>nm</td>
<td>543, 5.7</td>
<td>495, 3.5</td>
<td>495, 8</td>
<td>452, 3.8</td>
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<tr>
<td>$D_y$</td>
<td>18.5</td>
<td>10</td>
<td>28.6</td>
<td>27</td>
<td>22</td>
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<tr>
<td>$\delta_{BS}$</td>
<td>%</td>
<td>2.2</td>
<td>1.8</td>
<td>2.4</td>
<td>5.7</td>
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<td>$\sigma_z$</td>
<td>μm</td>
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<td>150</td>
<td>500</td>
<td>200</td>
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<td>$P_{beam}$</td>
<td>MW</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>5.3</td>
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Parameter range established to allow operating optimization
Energy Upgrade Path

- Linac energy upgrade path based on empty tunnels hard to ‘sell’
  - Empty tunnels obvious cost reduction
- Lower initial gradient increases capital costs

- Baseline has tunnels for 500 GeV cms with a linac gradient of 31.5 MV/m
- Geometry of beam delivery system adequate for 1 TeV cms
  - Require extending linac tunnels past damping rings, adding transport lines, and moving turn-around \(\rightarrow\) \(~50\) km site
RF System

Modulator (120 kV, 140 A)

1.3 GHz

10 MW Klystron (1.4 ms, 5 Hz)

RF Transmission Line

Circulator

Phase Tuner

Coaxial Coupler

Beamline

1 m

Cryomodule 1 of 3
(8 Cavities per Cryomodule)
Gradient Choice

• Balance between cost per unit length of linac, the available technology, and the cryogenic costs

• Optimum is fairly flat and depends on details of technology

<table>
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<tr>
<th></th>
<th>Cavity type</th>
<th>Qualified gradient MV/m</th>
<th>Operational gradient MV/m</th>
<th>Length Km</th>
<th>Energy GeV</th>
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<td>initial</td>
<td>TESLA</td>
<td>35</td>
<td>31.5</td>
<td>10.6</td>
<td>250</td>
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<td>upgrade</td>
<td>LL</td>
<td>40</td>
<td>36.0</td>
<td>+9.3</td>
<td>500</td>
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</table>
Superconducting Cavities

Gradients of Accelerator Modules

Goal → 35

< \( E_{acc} \) [MV/m] vs. Time (10/97 to 05/03)

- Assembly problems with the old accelerator module (type II)
- Installed in 2/2004:
  - 4 old cavities with intentionally low gradient,
  - 1 electro-polished cavity,
  - 3 standard cavities

- 1 cold option
Positron Source Choice

- Snowmass debate between conventional, undulator, and Compton sources
  - Snowmass recommendation of undulator source with Compton source as ACD
- Conventional source
  - Reduces operational coupling
- Undulator-based positron source
  - Much lower radiation environment
  - Smaller e+ emittance for given yield
  - Similar target and capture system to conventional
  - Easy path to polarized positrons Photon production at 150 GeV electron energy
- Compton source
  - Requires large laser system and/or capture ring
• **Positron source**
  – SLAC is coordinating the positron source development
  – Undulator-based positron source is a large system
  – Focused on systems design and capture structure R&D
    • Working with LLNL on target design
    • Working with ANL on AMD and capture simulations
    • Working with UK and ANL/LBNL on undulator design
• Compress 1 ms linac bunch train in to a “reasonable size” ring
  – Fast kicker (ns)
• Damping of $\gamma \varepsilon_{x,y} = 10^{-2}$ m-rad positron beams to
  $(\gamma \varepsilon_x, \gamma \varepsilon_y) = (8 \times 10^{-6}, 2 \times 10^{-8})$ m-rad
  – Low emittance, diagnostics
• Cycle time 0.2 sec (5 Hz rep rate) $\Rightarrow \tau = 25$ ms
  – Damping wiggler
• 2820 bunches, $2 \times 10^{10}$ electrons or positrons per bunch, bunch length= 6 mm
  – Instabilities (classical, electron cloud, fast ion)
• Beam power $> 220$ kW
  – Injection efficiency, dynamic aperture
Damping Ring Issues

- Damping rings have most accelerator physics in ILC
- Required to:
  1. Damp beam emittances and incoming transients
  2. Provide a stable platform for downstream systems
  3. Have excellent availability ~99% (best of 3rd generation SRS)
- Mixed experience with SLC damping rings:
  - Referred to as the “The source of all Evil”
  - Collective instabilities, dynamic aperture and stability were all hard
- ILC damping rings have lower current than B-factories
  - More difficult systems feedback because of very small extracted beam sizes in constant re-injection (operate with small S/N)
  - More sensitive to instabilities – effects amplified downstream
Damping Rings – BCD Choice

- Compared multiple lattice styles
  - Optics tuning and dynamic aperture
  - Collective instabilities (ECI, Ions, Space charge)
  - Cost

![Diagram with different lattice styles and costs](image-url)
• **Baseline**
  – Two BDSs, 20/2mrad, 2 detectors, 2 longitudinally separated IR halls

• **Alternative 1**
  – Two BDSs, 20/2mrad, 2 detectors in single IR hall @ Z=0

• **Alternative 2**
  – Single IR/BDS, collider hall long enough for two push-pull detectors
• Design of IR for both small and large crossing angles
• Pairs induced background similar in both cases
• Losses in extraction & background harder in 2mrad
• ATF-2 would be the BDS test facility
  – Follow-on to FFTB
  – New FFS optics
  – Operational issues
  – Train next generation

ILC like optics at ATF-2

ILC Technology Status

• Very High R&D priorities (categorized by Global Board):
  – Superconducting cavities and gradient
    • Gradient of 25 versus 35 MV/m
    • Cavity tuners
  – Rf sources
    • Klystrons do not meet spec
    • New modulator designs, eg Marx Generator
  – High availability hardware
    • Power supplies and magnets
  – Positron target
  – Instrumentation (BPMs, laser wires, and energy spectrometers)
  – Damping ring (collective effects, kickers and emittance)
  – Beam delivery system (crab cavity, feedback and tuning)

The ILC will be an order of magnitude more complex than any accelerator ever built

- If it is built like present HEP accelerators, it will be down an order of magnitude more (essentially always down)
- For reasonable uptime, component availability must be much better than ever before \(\rightarrow\) requires serious R&D

<table>
<thead>
<tr>
<th>Device</th>
<th>Required MTBF Improvement Factor</th>
<th>MTBF from Present Experience (khours)</th>
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<tbody>
<tr>
<td>magnets - water cooled</td>
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<td>1,000</td>
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<td>power supply controllers</td>
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<td>flow switches</td>
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<td>250</td>
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<td>water instrumentation near pump</td>
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<td>30</td>
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<td>power supplies</td>
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<td>kicker pulser</td>
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<td>collimators and beam stoppers</td>
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Summary

• ILC baseline configuration is well thought out
  – Based on decades of R&D
  – Technology reasonable extrapolation of the R&D status
  – Inclusion of availability and operational considerations
  – Conservative choices (for the most part) to facilitate rapid cost evaluation

• International team will complete RDR by end of CY2006
  – Unknown review process afterwards

• Active R&D program to address technical and cost risks
  – Global R&D Board is working to coordinate the program