International Linear Collider

Status i perspektywy po wyborze technologii

- Wprowadzenie
- Program fizyczny
- Projekty akceleratora
- Wybór technologii
- Koncepcje detektorów

A.F. Żarnecki
17.12.2004
Brief ILC History

• Late 1980s and 1990s:
  – Next Linear Collider:
    • SLAC/KEK warm RF designs
    • NLC detector group
  – TESLA:
    • European superconducting RF design
    • ECFA-DESY physics/detector studies

+ World-Wide Study of Physics & Detectors

  → International Linear Collider Workshops organized starting 1991

• 2000s:
  – Snowmass 2001
  – HEPAP recommendation 2002

  - "Understanding Matter, Energy, Space and Time: The Case for the e+e- Linear Collider" 2003

  TESLA TDR: 2001
  GLC Project Report: 2003
Physics programme for the ILC depends on what appears at LHC but interesting scenarios can be considered in each case.

- *top measurements*

- *light "Higgs" measurements*

- *new particles (SUSY ?)*

- *precision measurements*
1. **Definite job to be done. Measure $m_t$ to $< \pm 100 \text{ MeV}$**

**Why?** Because precision on $m_t$ limits current SM fit.

**Recent illustration; D0's new $m_t$ measurement**

2001; $m_t=174.3 \pm 5.1$; PDG

2004; $m_t=178.0 \pm 4.3$

**Moves best fit $m_h$ by $> 20 \text{ GeV}$. Very sensitive.**
what precise $m_t$ would do for MSSM

$\Delta m_h^{\text{exp}}$

$m_t = 175 \text{ GeV}, \tan\beta = 5$

theory prediction for $m_h$

$\delta m_t^{\text{exp}} = 2.0 \text{ GeV}$

$\delta m_t^{\text{exp}} = 1.0 \text{ GeV}$

$\delta m_t^{\text{exp}} = 0.1 \text{ GeV}$

(Heinemeyer et al)
If there is a light Higgs of any kind, seen or unseen at LHC, ILC will:

- see it,
- measure its precise mass,
- measure its total and partial widths (BRs),
  determine its couplings to other particles,
- measure its spin and parity,
- measure Higgs selfcoupling.

Many different scenarios have been investigated...
**LHC Higgs signal**

\[ H \rightarrow \gamma \gamma \]

**ILC Higgs signal**

**CMS, SM**

\[ M_{\gamma\gamma} \text{ GeV} \]

**Bkg.**

\[ ttH \rightarrow WbWbbb \rightarrow l\nu j j b b b b \]

**ATLAS**

30 fb\(^{-1}\)

**Bkg.**

**Typical numbers**

Tagging efficiency
~ 30-50 %

S/N > 1

Satoru Yamashita, ACFA LCWS 7
Nov. 9, 2004
Measurement of top Yukawa coupling

Dawson, Juste, Reina and Wackeroth, LHC/LC report.

Branching ratios and couplings from 500 GeV ILC + LHC rates

**LHC:**

![Diagram of top Yukawa coupling](image)

**Example of LHC-LC synergy:**

without precise BR measurements at ILC, LHC measurements are model dependent
**GAUGE AND HIGGS BOSONS**

| H | $J^{PC}=0^{++}$ [a] |
|   | Charge = 0 |
|   | Mass $m=120.0\pm0.040$ GeV [b] |
|   | Full Width $\Gamma =3.6\pm0.2$ MeV[a] |

**H DECAY MODES** [b]  

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>$bb$</td>
<td>$(67.8 \pm 1.6)$ %</td>
</tr>
<tr>
<td>$cc$</td>
<td>$(3.08 \pm 0.25)$%</td>
</tr>
<tr>
<td>$\tau\tau$</td>
<td>$(6.8 \pm 0.35)$%</td>
</tr>
<tr>
<td>$gg$</td>
<td>$(7.04 \pm 0.5)$%</td>
</tr>
<tr>
<td>$\gamma\gamma$</td>
<td>$(0.21 \pm 0.05)$%</td>
</tr>
<tr>
<td>$WW$</td>
<td>$(13.3 \pm 1.3)$%</td>
</tr>
</tbody>
</table>

[a] LC, [b] LC/LHC

**SUMMARY TABLES OF PARTICLE PROPERTIES**

Extracted from the Particle listings of the
**Review of Particle Physics**
Available at http://www.eilamgross.com

Like the Z boson measurements at LEP
Higher precision *can give discoveries.*

Cosmic Microwave Background

If *ILC* measures the *wrong* Higgs mass (using S.M. fits with *ILC* value of $m_t$), it *has discovered the new physics.* LHC precision on $m_h$ may not be enough to do this.

*WMAP* constrains $\Omega_\Lambda + \Omega_M$

Wouldn’t know it’s there from COBE

AND Planck is coming; more precise still
SUSY
E.g. the Minimal Supersymmetric Standard Model*, then LHC expects to see squarks and gluinos.

**ILC** good for sleptons and especially for Lightest Supersymmetric Particle (\(\tilde{\chi}_1^0\) LSP is favoured candidate for Dark Matter).

New studies at point SPS1a in LHC/LC report (Martyn).

\(\text{LC at } \sqrt{s}=400 \text{ GeV,}\)

\[\int \Lambda = 200 \text{ fb}^{-1}.\]

Clear endpoints give, for example,

\[\delta m_{\mu_R}^+ \approx \delta m_{\tilde{\chi}_1^0} \approx 200 \text{ MeV}\]

(some others come from threshold scans).

*(+ new work on NMSSM and others in LHC/LC report, at Victoria, here)*
LHC - LC synergy

Very precise LSP mass measurement at ILC
will improve precision of other measurements at LHC
Precision measurements
Summary of the case for the TeV ILC

1. Definite; $\delta m_t < 100$ MeV
   - Vital constraint.
     Increasingly sure it can be done.

2. If there is a light Higgs
   - LHC probably sees.
     ILC shows what it is.

3. and extra particles

4. If LHC sees nothing new below ~ 500 GeV mass
   - ILC looks beyond LHC's direct reach
     Then LHC + ILC point to CLIC, and maybe superLHC

LHC and ILC needed to pin down model, identify DM(?), extrapolate to GUT scale.
Accelerator designs

Parameters for the Linear Collider

– BASELINE MACHINE
  • $E_{\text{CM}}$ of operation 200-500 GeV
  • Luminosity and reliability for 500 fb$^{-1}$ in 4 years
  • Energy scan capability with <10% downtime
  • Beam energy precision and stability below about 0.1%
  • Electron polarization of > 80%
  • Two IRs with detectors
  • $E_{\text{CM}}$ down to 90 GeV for calibration

– UPGRADES
  • $E_{\text{CM}}$ about 1 TeV
  • Allow for $\sim 1$ ab$^{-1}$ in about 3-4 years

– OPTIONS
  • Extend to 1 ab$^{-1}$ at 500 GeV in $\sim$ 2 years
  • $e^-e^-$, $\gamma\gamma$, $e^-\gamma$, positron polarization
  • Giga-Z, WW threshold

http://www.fnal.gov/directorate/icfa/LC_parameters.pdf
The energy and luminosity challenges for a future e+e- linear collider:

Luminosity (cm²·s⁻¹)

E_{cm} (TeV)

LEP

SLC

Luminosity: four orders of magnitude from the SLC
High luminosity could be "easily" reached at the circular collider.

Ruled out by:
- construction costs
- power consumption

"LEP 1000"
2 TeV in Center-of-Mass
Diameter $\approx 900$ km
Linear Collider at 50 MeV/m
Length $= 40$ km $\rightarrow \leftarrow$

Why LEP 1000 gave way to the idea of linear colliders
Electron Gun
Deliver stable beam current

Damping Ring
Reduce transverse phase space (emittance) so smaller transverse IP size achievable

Bunch Compressor
Reduce $\sigma_z$ to eliminate hourglass effect at IP

Final Focus
Demagnify and collide beams

Positron Target
Use electrons to pair-produce positrons

Main Linac
Accelerate beam to IP energy without spoiling DR emittance

LC conceptual scheme
NLC design
X-band technology
(SLAC/KEK & coll. Inst.)

SLC-like 20MV/m, 3 GHz → 50MV/m (65 unloaded), 11.4GHz
Test Structure Run History
(T-Series 2003, not final version for linac)

NLC/JLC Goal:
Less than 1 trip per 10 Hrs at 65 MV/m

NLC/ JLC Goal:
Less than 1 trip per 10 Hrs at 65 MV/m

1 Trip per 25 Hrs

Unloaded Gradient (MV/m)

Time with RF On (hr)

400 ns Pulse Width
No Observed Change in Microwave Properties
500 (→ 800) GeV e+e- Linear Collider

Based on superconducting linac technology

TESLA

The Superconducting Electron-Positron Linear Collider
with an Integrated X-Ray Laser Laboratory

Technical Design Report

EPS-HEP Aachen 2003

R. Brinkmann, DESY
Why superconducting?

- High efficiency AC → beam (>20%, ~10% normal c.)

- **Low frequency:**
  - Long pulses with low RF peak power
  - Small beam perturbations from wakefields
  - Intra-train feedback on beam orbit, energy, luminosity...

- First proposed in 1960s (M. Tigner)... show stopper was too low acc. Gradient, too high cost
- Long Term (> 1000 h) Horizontal Test
- In Chechia the cavity has all its ancillaries
- Chechia behaves as 1/8th (1/12th) of a TESLA cryomodule

**Cavity AC73**
- Vertical tests of naked cavity
- Chechia tests of complete cavity

**TESLA 800 specs:**
35 MV/m @ $Q_0 = 5 \times 10^9$
CLIC two-beam accelerator approach
CERN & coll. Inst.

3 TeV CLIC LAYOUT WITH DRIVE-BEAM GENERATION

EPS-HEP Aachen 2003  R. Brinkmann, DESY
## Linear Collider Parameter Overview

<table>
<thead>
<tr>
<th></th>
<th>NLC/JLC</th>
<th>TESLA</th>
<th>CLIC</th>
<th>SLC</th>
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</thead>
<tbody>
<tr>
<td>f / GHz</td>
<td>11.4</td>
<td>1.3</td>
<td>30</td>
<td>2.9</td>
</tr>
<tr>
<td>E-cms / GeV</td>
<td>500 – 1000</td>
<td>500 – 800</td>
<td>3000 – 5000</td>
<td>100</td>
</tr>
<tr>
<td>g / MV/m</td>
<td>50</td>
<td>23 – 35</td>
<td>150</td>
<td>~20</td>
</tr>
<tr>
<td>Lumi / 10^{34}</td>
<td>2 – 3</td>
<td>3.4 – 5.8</td>
<td>~10</td>
<td>.0003</td>
</tr>
<tr>
<td>Power p. beam / MW</td>
<td>6.9 – 13.8</td>
<td>11.2 – 17</td>
<td>~15</td>
<td>0.04</td>
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<tr>
<td>σ_y at IP / nm</td>
<td>2.7 – 2.1</td>
<td>5 – 2.8</td>
<td>1</td>
<td>500</td>
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<tr>
<td>Beamstrahlung δB / %</td>
<td>3.2 – 4.3</td>
<td>3.4 – 7.5</td>
<td>21</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Site length / km</td>
<td>30</td>
<td>33</td>
<td>~35</td>
<td>3.5</td>
</tr>
<tr>
<td>Site power / MW</td>
<td>195 – 350</td>
<td>140 – 200</td>
<td>~400</td>
<td></td>
</tr>
<tr>
<td>Cost(^\S) (stage-I)</td>
<td>~3.5B$</td>
<td>3.14B€+7k p.y.</td>
<td>?</td>
<td></td>
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</tbody>
</table>

\(^\S\) numbers quoted at Snowmass 2001, no pre-operation, escalation and contingency included

EPS-HEP Aachen 2003 R. Brinkmann, DESY
Total for Baseline: 3.14 B€ + 7000 py
1 IR
COMPETING TECHNOLOGIES

1.3 GHz - Cold

30 GHz - Warm

11.4 GHz - Warm
Why Decide Technology Now?

- We have an embarrassment of riches !!!!
  
  - Two alternate designs -- “warm” and “cold” have come to the stage where the show stoppers have been eliminated and the concepts are well understood.
  
  - R & D is very expensive (especially D) and to move to the “next step” (being ready to construct such a machine within about 5 years) will require more money and a concentration of resources, organization and a worldwide effort.
  
  - It is too expensive and too wasteful to try to do this for both technologies.
  
  - A major step toward a decision to construct a new machine will be enabled by uniting behind one technology, followed by a making a final global design based on the recommended technology.
  
  - The final construction decision in ~5 years will be able to fully take into account early LHC and other physics developments.
The ITRP Members

Jean-Eudes Augustin (FRANCE)
Jonathan Bagger (USA)
Barry Barish (USA) - Chair
Giorgio Bellettini (ITALY)
Paul Grannis (USA)
Norbert Holtkamp (USA)
George Kalmus (UK)
Gyung-Su Lee (KOREA)
Akira Masaike (JAPAN)
Katsunobu Oide (JAPAN)
Volker Soergel (GERMANY)
Hirotaka Sugawara (JAPAN)
David Plane - Scientific Secretary
General Considerations

The International Technology Recommendation Panel (the Panel) should recommend a Linear Collider (LC) technology to the International Linear Collider Steering Committee (ILCSC).

On the assumption that a linear collider construction commences before 2010 and given the assessment by the ITRC that both TESLA and JLC-X/NLC have rather mature conceptual designs, the choice should be between these two designs. If necessary, a solution incorporating C-band technology should be evaluated.

Note -- We have interpreted our charge as being to recommend a technology, rather than choose a design.
Evaluating the Criteria Matrix

• We 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

• We evaluated each of these categories with the help of answers to our “questions to the proponents,” internal assignments and reviews, plus our own discussions
<table>
<thead>
<tr>
<th>Still missing</th>
<th>TESLA</th>
<th>JLC-C</th>
<th>JLC-X/NLC</th>
<th>CLIC</th>
<th>Common</th>
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<tbody>
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<td>feasibility</td>
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<td>1</td>
<td>2</td>
<td>2</td>
<td>0</td>
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<tr>
<td>design</td>
<td>7</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>prototype tests</td>
<td>10</td>
<td>3</td>
<td>3</td>
<td>11</td>
<td>5</td>
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<tr>
<td>final optimization</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>
Dog-bone and the ATF-cold is riskier.

High-power and precision-warm is riskier.

TRC R1s and R2s: warm is riskier.

Highest risks for both options: addressed only when high-power beams are available.

\[ L \propto n^+, \text{ or } n^2 \]
The Recommendation

• We recommend that the linear collider be based on superconducting rf technology *(from Exec. Summary)*
  
  – This recommendation is made with the understanding that we are recommending a technology, not a design. We expect the final design to be developed by a team drawn from the combined warm and cold linear collider communities, taking full advantage of the experience and expertise of both *(from the Executive Summary)*.
  
  – We submit the Executive Summary today to ILCSC & ICFA
  
  – Details of the assessment will be presented in the body of the ITRP report to be published around mid September
  
  – The superconducting technology has features that tipped the balance in its favor. They follow in part from the low rf frequency.
Some of the 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.

Both technologies have wider impact beyond particle physics. The superconducting rf technology has applications in other fields of accelerator-based research, while the X-band rf technology has applications in medicine and other areas.
Luminosity stability: “Start-to-end” simulations, including ground motion
Can **TESLA** be the baseline?

Still many alternatives remain after the SC/NC decision

- Accelerating gradient: 35MV/m or higher?
- Tunnel: **Single** or **double** (or triple)?
- Damping ring: **dogbone** or **small**?
- Positron production: **undulator** or **conventional**?
- Crossing angle: **zero** or **small** or **large**?

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Note -- "We have interpreted our charge as being to recommend a technology, rather than choose a design..."
• **It is imperative to establish a US-based capability in the fabrication of high gradient superconducting accelerating structures.**
  – Assume the fabrication of ~20,000 ILC accelerating structures will be shared among the three regions.
  – Significant U.S. SCRF expertise at: Argonne, Cornell, Fermilab, Jefferson Lab, Los Alamos, Michigan State
  – Experience extends to both development and fabrication (e.g. SNS), but at gradients significantly below 35 MV/m
  – JLab has made an SRF proposal to DOE for ILC cryomodule fabrication and technology transfer.

• **The vehicle is the SMTF (Superconducting Module and Test Facility).**
  – “The goal is to strengthen U.S. capabilities in high gradient and high Q superconducting accelerating structures in support of the International Linear Collider (ILC) and other accelerator projects of interest to U.S. laboratories.”
  – Collaboration of major DOE and NSF laboratories and universities, with international participation.
  – Incorporate ILC, $\beta<1$ (Proton Driver, RIA), and CW test areas.

G. Dugan, Cornell Univ.
• **Expression of Interest submitted to Fermilab Director.**
  – Based on commitment to play a leading role following the cold decision.
  – Provisional goal is fabrication and testing of three U.S. plus one European high gradient cryomodules by 2008. (in close coordination with the GDE).
  – Cryomodule test facility to be constructed at Fermilab

• **Interested partners:** ANL, BNL, Cornell, FNAL, JLab, LANL, LBNL, MIT, MSU, NIU, ORNL, Pennsylvania, SLAC (DESY, INFN, KEK)

• **Concept of a possible evolution (ILC portion):**

  1) A0 injector

  2a) Add Beam

  2b) One RF Unit

  3) ILCinjector

  Possible ILC test bed

  2005-06

  2008-…
Depressed? Honestly yes, for a while, but

Quickly reforming ourselves

- Forming SCRF group
  - Fortunately we have rich manpower and experience for SCRF (Tristan, KEKB, J-Parc)
  - Planning a test facility

- ATF continues
  - The only ring that can create low emittance beam
  - May even create TESLA format beam

- Strengthening Asian collaboration (⇒ Kurokawa)

- Even more enthusiastic participation of industries
3rd ACFA Statement on e⁺e⁻ Linear Collider in Nov. 2004 in Kolkata, India

• ACFA welcomes the truly international nature of the decision on technology for the ILC (...)

(...)

• ACFA reconfirms the importance of hosting ILC in Asia, which will make high energy physics and accelerator science truly global.

(...)

• ACFA reconfirms that KEK is the best suited institute for hosting the Central Team of GDI.
Asians Desperately Needs
A Major Energy-Frontier Machine
LC Detector Requirements

Any design must be guided by these goals:

- **a)** Two-jet mass resolution comparable to the natural widths of W and Z for an unambiguous identification of the final states.
- **b)** Excellent flavor-tagging efficiency and purity (for both b- and c-quarks, and hopefully also for s-quarks).
- **c)** Momentum resolution capable of reconstructing the recoil-mass to di-muons in Higgs-strahlung with resolution better than beam-energy spread.
- **d)** Hermeticity (both crack-less and coverage to very forward angles) to precisely determine the missing momentum.
- **e)** Timing resolution capable of separating bunch-crossings to suppress overlapping of events.
Challenge

In order to accomplish our physics goal at ILC

With respect to detectors at LHC:

- Inner VTX layer: 3--6 times closer to IP
- VTX pixel size: 1 / 30
- VTX materials: 1 / 30
- Materials in Tracker: 1 / 6
- Track mom. resolution: 1 / 10
- EM cal granularity: 1 / 200

Nov.9 2004
S. Yamashita, 7th ACFA WS
A Medium Size Detector for the ILC

... what used to be the TESLA or LD detector concept

A medium size detector for the linear collider:
- precision tracking
- particle flow based event reconstruction
- high precision VTX
- large volume gaseous tracker
- medium precision SI tracker
to join the two devices

advantages of a gaseous detector:
- many space points (200 for current design)
- good precision
- TPC is true 3D device: very robust against backgrounds
- long lived particles (new particles)
- Thin (little material)
SiD design study

SiD starting assumptions…

Particle flow calorimetry will deliver the best possible performance

Si/W is the right technology for the ECAL

Size of VXD outer cryostat and EMCAL

(EMCAL inner radius larger than Dzero EM cal radius)
Large Detector Concept

Basic design concept

- Performance goal (common to all det. concepts)
  - Vertex Detector: \[ \delta(IP) \leq 5 \oplus 10 / p \sin^{3/2} \theta \]
  - Tracking: \[ \delta p_t / p_t^2 \leq 5 \times 10^{-5} \]
  - Jet energy res.: \[ \delta E / E \leq 0.3 / \sqrt{ } \]

  ➔ Detector optimized for Particle Flow Algorithm (PFA)

- Figure of merit (ECAL):
  - Barrel: \[ B \left( R_{in}^2 / R_m^{\text{effective}} \right) \]
  - Endcap: \[ B Z^2 / R_m^{\text{effective}} \]

  \( R_{in} \): Inner radius of Barrel ECAL
  \( Z \): Z of EC ECAL front face

  ➔ Increase R and Z, keeping moderate B

Y. Sugimoto, ACFA LWS 7

- \[ B \left( R_{in}^2 \right) \]: TESLA
Detector size

- EM Calorimeter

- Area of EM CAL (Barrel + Endcap)
  - SiD: ~40 m² / layer
  - TESLA: ~80 m² / layer
  - GLD: ~100 m² / layer
  - (JLC: ~130 m² / layer)
Global geometry

SD

5 m

TESLA

GLD

GLD is smaller than CMS
“Large” is smaller than “Compact” 😊
Detector design timeline:

(2004) ITRP tech. recommendation
Set up 3 panels (costing, detector R&D, and MDI)

(2005) Accelerator CDR
Single preliminary-costing paper for >1 whole detector concepts

(2007) Accelerator TDR
WWS receives CDR from each detector concept team

(2008) LC site selection
Collaborations form and submit LOIs for proposal to the global lab (or GDO?)

Site selection + 1yr
Global lab selects experiments.