The Future Linear Collider Project

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CAP 2004
Winnipeg, June 14, 2004
What is a linear collider?

- Next in the line of high energy $e^+e^-$ colliders

SLAC/SLC  CERN/LEP
e^+e^- colliders at the frontier
why linear?

A circular 500 GeV machine would be 170 km around and consume 45 GW.

$circumference / length (km)$

$R \propto E^2$

$L \propto E$

$E_R \propto E_L$
Physics of a Linear Collider

• Just as LEP/SLC studied *electroweak symmetry* to high precision, the LC will study *electroweak symmetry breaking* to high precision:

  • LEP/SLC firmly established the electroweak theory
    • likewise, LEP/SLC could have shown the Standard Model to be incorrect
    • the large variety of measurements would have pointed to the new theory

• The LC will either firmly establish the mechanism of EWSB & mass generation,
  • or it will provide critical data to point to the new theory
Legacy of LEP/ SLC/ Tevatron:

- A large number of precise measurements testing the SM at the level of quantum fluctuations…
Higgs appears to be within grasp

- From these precision measurements:
  \( m_H < 240 \text{ GeV} \)
  @ 95% CL

- Direct searches at LEP:
  \( m_H > 114.4 \text{ GeV} \)
  @ 95% CL
The golden processes

• At LEP the golden processes for studying the electroweak sector were:

\[ e^+ e^- \rightarrow Z^0 \quad e^+ e^- \rightarrow W^+ W^- \]

• At the LC the golden processes for studying the Higgs sector are:

\[ e^+ e^- \rightarrow Z^0 H \quad e^+ e^- \rightarrow H \nu \overline{\nu} \]

• LEP beam energies were not sufficiently high enough for these process to occur
The golden processes

- Cross section vs. Higgs mass
Higgs production at a LC
Recoil mass

$E_{cm} = 350$ GeV
$L = 500$ fb$^{-1}$

$e^+e^- \rightarrow Z^0 H^0 \rightarrow \mu^+\mu^- X$

$e^+e^- \rightarrow Z^0 H^0 \rightarrow q\bar{q}b\bar{b}$

with $5C$ fit
$\delta m_H \sim 50$ MeV

$m_H = 140$ GeV
Higgs couplings

- Branching fractions to fermions & bosons:
  - confirm(?) its role in mass generation
  - distinguish SM from SUSY Higgs (?)
Other Higgs properties

• Confirm (?) fundamental properties:
  • spin & parity
  • total width

\[ \Gamma_H^{Total} = \frac{\Gamma(H \rightarrow WW)}{BR(H \rightarrow WW)} \]

• its couplings to Gauge bosons and to itself
  • confirm its role in EWSB
Other precision measurements

- Fermion pair production
  - sensitive to $Z'$, $W'$, R-parity violation, leptoquarks
  - sensitivity reaches beyond $\sqrt{s}$
    - for example, LC is sensitive to $Z'$ if $m_{Z'} < 5 - 10 \sqrt{s}$
- Top mass measurement: $\delta m_{top} \approx 100$ MeV
- W pair production
  - a gain by 2 orders in magnitude in the sensitivity to anomalous couplings in the gauge sector
- Return to the $Z^0$ peak and $W W$ threshold
  - 30 fb$^{-1}$ at $Z^0$ peak $\rightarrow 10^9 Z^0$ in a few months
  - with 80% (60%) $e^-$ ($e^+$) pol. $\rightarrow \delta \sin^2 \theta_{\text{eff}} \approx 0.00001$
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The Future Linear Collider Project
Consensus of our leaders

• (2000-2002) ACFA, ECFA, HEPAP:
  • The next large accelerator-based project of particle physics should be a linear collider

• (Late 2003) US DOE Office of Science:
  • Future Facilities Plan: LC is first priority mid-term new facility for all US Office of Science

• (Jan. 2004) ACFA, ECFA, HEPAP:
  • The chairs reaffirmed their community’s priorities for a 500 GeV linear collider operated in parallel with the LHC
Consensus amongst ourselves

- (Paris announcement): “Over 2600 physicists from around the world have signed a document supporting a high-energy electron-positron linear collider as the next major experimental facility for frontier particle physics research.”

- “Understanding Matter, Energy, Space and Time: the Case for the Linear Collider”
• Two design concepts for a linear collider:
  • TESLA: led by DESY (Germany)
    • lower frequency (1.3 GHz) superconducting cavities
    • Initially: \( E_{cm} = 500 \text{ GeV} \quad L = 3 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1} \)
    • Later: \( E_{cm} = 800 \text{ GeV} \quad L = 5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1} \)
    • Lower wakefields, looser tolerances, higher luminosity
  • NLC/GLC: led by SLAC & KEK (US & Japan)
    • higher frequency (11.4 and 5.7 GHz) warm cavities
    • Initially: \( E_{cm} = 500 \text{ GeV} \quad L = 2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1} \)
    • Later: \( E_{cm} = 1 - 1.5 \text{ TeV} \quad L = 4 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1} \)
    • highest gradients
Accelerator structures

• The heart of the linear collider:

TESLA

NLC
Accelerator physics challenges

- technical challenges for a linear collider:
  - high gradients
    - TESLA: TTF has performed according to design gradient
      - higher gradient cavities now routinely constructed
    - NLC: gradients achieved in NLCTA, but damage observed
      - redesign completed, problem solved
  - low emittance
    - damping ring test facility (ATF at KEK) successful
  - small beam spot size (high luminosity)
    - final focus test facility shows required demagnification
Beam spot sizes:

- SLC (500 nm)
- FFTB (50 nm)
- TESLA/NLC (2-5 nm)
The small vertical beam sizes (few nm) necessitate an accurate vibration control system for the linear collider magnets near the interaction point.

Tom Mattison (UBC) is studying the feasibility of a 10 m baseline laser interferometer to monitor and control the vibration of heavy objects at the nanometer scale.
Linear collider detector concepts
Linear collider detector challenges

- Compared to LHC, the LC environment is much less severe, but the performance requirements are much more demanding:
  - Vertexing: $\sigma \sim 5 \mu m \oplus 10 \mu m/(p \sin^{3/2} \theta)$
    - 1/5 $r_{\text{beampipe}}$, 1/30 pixel area, 1/30 thickness c.f. LHC
  - Tracking: $\sigma(1/p_t) \sim 5 \times 10^{-5} \text{ GeV}^{-1}$
    - 1/10 of LHC. 1/6 material in tracking volume
  - Jet energy: $\sigma_E \sim 0.3 \sqrt{E}$
    - 1/200 granularity of calorimeter c.f. LHC
Linear collider detector challenges

- Example: Higgs recoil mass

\[ \sigma(1/p_t) \sim 5 \times 10^{-5} \text{ GeV}^{-1} \] is necessary!
Vertex detector

- charm tagging (light Higgs, W) is a challenge
- prime motivator for bringing in vertex detector as close as possible
- leading candidate: CCDs (success at SLD)
Central tracker
Central tracking designs

- Leading candidate: Time projection chamber
TPC readout technology choices

- Gas Electron Multiplier (GEM)
  - negligible E x B distortions: improved resolution
  - narrower and faster signals: improved 2 particle separation
  - reduced ion feedback

30 cm drift
2mm × 7 mm pads
Magnetic field tests

TRIUMF

DESY

\[ B=0T \quad B=0.9T \quad B=2.5T \quad B=4.5T \]
Transverse resolution

- For fields above 1.5 T achieve 100 µm
Calorimeter concepts
Jet Energy Resolution Requirements

- Goal: distinguish W and Z in their hadronic modes
- requires: jet energy resolution,

\[ \sigma_E \approx 30\% \sqrt{E} \]

example: \( e^+ e^- \rightarrow WW \nu\overline{\nu} \), \( e^+ e^- \rightarrow ZZ \nu\overline{\nu} \)
Moliere radius (Iron vs. Tungsten)

(many images courtesy H. Videau)
Status of Linear Collider Planning

• A global review of accelerator technologies (2003) concluded that both LC technologies are feasible

• ICFA has set up process to move forward:
  • Technology recommendation panel to report before end of 2004
  • Global design effort to begin once report released
  • Full detector costings to be prepared next year Lols/CDRs to follow in 2007
  • Site selection possibly as early as 2008, construction begins before end of decade
  • First beams possibly by 2015
Victoria Linear Collider Workshop

• Part of a series of N. American regional meetings held twice a year
• Sign up! www.linearcollider.ca/victoria04
• Over 100 registered so far…
• Thanks to our sponsors: TRIUMF, IPP, UVic, NSERC
TRIUMF bid to host Central Team

- Canada is neutral territory, Vancouver well situated geographically
  - ILCSC asking labs for EOIs to host 15 – 30 accelerator physicists over the next 4 years
  - would add expertise and recognition to TRIUMF
  - EOI in preparation, due July 1
Summary

• The physics case for a Linear Collider is very strong
• The technology for the machine and experiments is in hand…
• Movement towards a single global proposal and experimental collaborations
• Canada may be playing an important role in the accelerator design

• To follow the developments, visit:

   http://www.linearcollider.ca