The International Linear Collider

- Next in the line of $e^+e^-$ colliders at the high energy frontier of particle physics
e^+e^- colliders at the frontier

- Centre-of-mass energy (GeV)
- Year

- PETRA
- PEP
- TRISTAN
- SLC
- LEP - I
- LEP - II
- ILC
- ILC - II

- dark matter threshold?
- tt threshold
- HZ^0 threshold?
- W^+W^- threshold
- Z^0 threshold
Why Linear?

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

\[ R \propto E^2 \]

\[ L \propto E \]
“Energy Frontier” Particle Physics

- Increasing the collision energy allows for new fundamental processes to be observed and probes matter and space at smaller distance scales
  - precision measurements sensitive to mass scales well above $\sqrt{s}$
- The two main energy frontier tools in the past three decades: proton colliders and electron colliders
  - protons are more easily accelerated to high energies because they radiate less synchrotron radiation in a circular accelerator
  - electron interactions are more easily studied because the initial state is simpler
  - both tools have been essential to advance our knowledge of fundamental physics:
    - discoveries of new phenomena
    - testing models that account for these phenomena
Interplay of proton and electron colliders

- **Proton Colliders**
  - 1980’s: SppS
    - Discovery of the $Z^0$, $W^+$, $W^-$
  - 1990’s: Tevatron
    - Discovery of the top quark
  - 2000’s: LHC
    - Discovery of the Higgs boson?
    - Discovery of the dark matter particle?

- **Electron Colliders**
  - 1990’s: LEP/SLC
    - Detailed investigation of $Z^0$, $W^+$, $W^-$ production
    - Indirect influence of top quark – definitive prediction of its mass
    - Indirect influence of Higgs boson – mass estimated
  - 2010’s: ILC
    - Detailed study of the Higgs
    - Detailed study of dark matter
Linear Collider Physics: I

- The electromagnetic and weak forces are now known to arise from a unifying symmetry in nature
  - most precisely demonstrated by the LEP/SLC experiments
- The symmetry between the electromagnetic and weak forces is broken (weak bosons are heavy)
  - The Higgs model is an ad hoc component of the Standard Model that accounts for the broken symmetry – does not explain why
    - it works for low energy processes but falls apart at high energies
    - the model predicts that a new particle exists (the Higgs boson) with definite properties
    - the ILC will be able to make a large variety of precision measurements that will provide critical data to understand the real nature of electroweak symmetry breaking
At LEP, the golden processes for studying the electroweak sector were:
\[ e^+ e^- \rightarrow Z^0 \quad e^+ e^- \rightarrow W^+ W^- \]

At the ILC, the golden processes for studying the Higgs sector are:
\[ e^+ e^- \rightarrow Z^0 H \quad e^+ e^- \rightarrow H \nu \bar{\nu} \]

- LEP beam energies were not sufficiently high enough for these process to occur
Higgs production at a LC
From astrophysical observations, it appears that 
~25% of the Universe is “Dark Matter”
- neutral, stable, cold (massive), non-baryonic
- new physics – a new (conserved) quantum number?
- production and detection of dark matter particles at future colliders would be very exciting!

One possible explanation: supersymmetry
- not developed specifically to solve the DM problem!
- the LSP is an excellent candidate for DM
Dark Matter at the ILC?

- There are strong hints that dark matter could be produced at the ILC
  - SUSY favours sparticle masses below \( \sim 1 \text{ TeV} \)
  - The dark matter density is consistent with a neutral particle having “weak” strength couplings
- The LHC has the best chance to discover strongly interacting sparticles (gluinos, squarks)
  - Challenging study at LHC: initial state is not well known, final state involves a cascade of sparticle decays, with at least two massive invisible particles
- ILC can study the weakly interacting sparticles
- LHC+ILC data can “predict” DM relic density
ILC/LHC complementarity

- Well documented study underway:
  - LHC/ILC Study Group:
    - [http://www.ippp.dur.ac.uk/~georg/lhclc/](http://www.ippp.dur.ac.uk/~georg/lhclc/)
  - Recent document:
    - “Physics Interplay of the LHC and the ILC”
      - hep-ph / 0410364
      - 470 pages:
        - Higgs Physics
        - Strong Electroweak Symmetry Breaking
        - Supersymmetric Models
        - Electroweak and QCD Precision Physics
        - New Gauge Theories
        - Models with Extra Dimensions
- all cases: ILC + LHC data complementary
Consensus in the HEP community

- Given the broad range of fundamental physics questions that it addresses, the HEP community sees the ILC to be the next step that is needed to advance the field.
  - Over 2700 particle physicists have signed a document supporting the physics potential of the ILC.
  - The US DOE places the ILC as the top priority for mid-term new facilities.
  - Committees for future accelerators (ICFA, ACFA, ECFA) also put the ILC as their first priority.
Building the ILC

- Over the past decade, significant effort has gone into the necessary R&D to design a linear collider to reach the required specifications:
  - Centre of mass energy: 500 GeV – 1000 GeV
    - requires RF cavities with a large accelerating gradient (>30 MeV/m)
  - Luminosity: > 10^{34} \text{ cm}^{-2} \text{s}^{-1}
    - requires large numbers of electrons (> 10^{10}) packed into very small bunches (< 500 \times 5 \text{ nm}^2) brought into collision at high rate (> 10^4 \text{s}^{-1})
Building the ILC

- Two complete designs were prepared that met these requirements:
  - the key feature distinguishing them was the nature of the RF accelerating cavities:
    - US + Japan – high frequency, room temperature
    - Germany – lower frequency, superconducting
  - international technical review found both suitable

- In 2004, the International Technical Recommendation Panel selected the superconducting option:
  - the world’s labs now working towards a single design
Superconducting accelerator cavities
Possible Tunnel Layout

- Need a 30 km tunnel to reach energy goal
Damping ring R&D

- ATF facility in Japan has demonstrated necessary reduction in emittance
Final focus R&D

Final Focus Test Beam Collaboration

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

Vertical beam size of 60-70 nm … the needed demagnification.
Linear collider detector concepts

LDC: start from TESLA design
Coordinators:
- Ties Benke: Germany
- Henri Videau: France
- Marco Battaglia: USA
- Dean Karlen: Canada
- Bob Hsiung: Taiwan
- Yasuhiro Sugimoto: Japan
See: www.ilcldc.org
Linear collider detector challenges

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

- Precise Si pixel detectors near the collision point
  - to detect the displaced vertex of particles coming from the decay of a particle with a very short lifetime (less than $10^{-12}$ s)
  - examples: charm, bottom quarks, tau leptons
Tracking detector
Tracking challenge

- Example: Higgs recoil mass

\[ e^+e^- \rightarrow ZH, \quad Z \rightarrow \ell^+\ell^- \]

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

- Two technologies considered: Si (few precise measuring layers) or gas (continuous)
- Gas tracker: Time projection chamber
  - to achieve resolution goal requires an advance in TPC technology
- Canadian groups have made big advances towards this goal
LC TPC R&D in Canada

- Prototype TPCs built to use MPGD readout:
  - Carleton/Montreal group has pioneered the method of charge dispersion with a resistive anode for GEM and Micromegas TPC readout
  - Victoria group has operated a GEM-TPC in magnetic fields up to 5 T
  - both prototypes have demonstrated significantly better resolution as compared to traditional TPCs
  - see presentations on Wednesday at CAP congress
Future plans for LC TPC R&D in Canada

- The Canadian group plans to:
  - participate in test beam studies at KEK and DESY
  - participate in the design and construction of a large scale prototype in collaboration with other groups from around the world
    - how to segment and tile MPGDs on a large endplate?
  - perform simulation studies to answer questions arising in the detector concepts
    - pattern recognition in jets
    - how well can non-uniform magnetic fields be determined and corrected for?
Calorimeter
Jet Energy Resolution Requirements

- Goal: distinguish W and Z when they decay into quarks
  - requires excellent jet energy resolution, $\sigma_E \sim 30\% \sqrt{E}$

  example: $e^+ e^- \rightarrow WW \nu \bar{\nu}$, $e^+ e^- \rightarrow ZZ \nu \bar{\nu}$
Calorimeter technology

- To reach goal requires narrow showers and fine segmentation: ECAL: Si+W  HCAL: SS+Scint?

![Image of particle showers for Iron and Tungsten]
LC Calorimetry R&D in Canada

- Canadian group is just starting to join existing LC calorimeter efforts:
  - Regina group has experience with SiPM readout – very attractive option for HCAL readout
  - McGill group to participate in test beam studies of prototype calorimeter systems (CALICE collaboration)
Bringing the ILC into reality

- An international structure has been set up to complete the global design of the ILC
- Leader of the Global Design Effort: Barry Barish
ILC timescale

- **2005:**
  - GDE put together
  - Detector concept groups in formation

- **2006:**
  - GDE to prepare the ILC Conceptual Design
  - Detector concept groups to prepare “detector outlines”

- **2007/8:**
  - GDE to complete the ILC Technical Design
  - Detector concepts complete Conceptual Designs

- **2008/9:**
  - Site selection, government approvals, begin construction
  - Detector collaborations form

- **2015?:**
  - earliest start of experimental program
Next steps

- Later this summer, a two-week workshop is being held at Snowmass
- finalize baseline accelerator parameters for CDR
- strong focus on detector concept studies
- 450 registered already
- a good opportunity for newcomers to join the effort

2005 International Linear Collider Physics and Detector Workshop
and Second ILC Accelerator Workshop
Snowmass, Colorado, August 14-27, 2005
Canadian planning

- Canadian ILC R&D funded through NSERC discovery grants
  - eg. 5 grantees on last TPC request (2004)

- Travel to ILC workshops have been supported through IOF grants
  - 14 grantees on last request (2002)

- Nucleus of Canadian group is meeting to plan for future ILC activity:
  - Montreal / McGill / Carleton / Toronto / Regina / UBC / Victoria

- Next meeting: June 6, 5:15pm, room: CEME 1202
  (follows PPD session) All are welcome
Summary

- The physics case for a Linear Collider is very compelling
- The technologies for the machine and the experiments are in hand
- The international HEP community is solidly behind the project and is working together to bring it to reality
- To ensure a strong future for particle physics in Canada, it is important for us to participate in this project

Please join us. For more information see:

www.linearcollider.org  www.linearcollider.ca