International $e^+ e^-$ Linear Collider Detector

R&D and Fermilab

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World LC Detector Activities

North American R&D Projects

LC Detector R&D at Fermilab

Interaction Region

Vertexing and Tracking

Calorimetry

Muons

Solenoid

Test Beams

Summary and Outlook
Studies of Physics and Detectors for LC

- Understanding of EWSB requires precision measurements.
- Large group of physicists worldwide wants to build a TeV class Linear Collider starting at 0.5 TeV as the next international accelerator facility.
- ITRP recommended the International Linear Collider to be based on SuperConducting RF technology.
- Global Design Initiative is being formed to lead and coordinate ILC activities.
- World Wide Study asked to organize Global Experimental Program, parallel to GDI for the ILC.
The World Wide Study fosters working relations between participants of the regional studies by organizing regularly the International Linear Collider Workshops.

Expanded roles of the WWS after the technology decision:

- Coordinate studies on regional detector concepts, and work toward inter-regional detector TDRs;
- Interface closely with GDI, especially to address the most important Machine-Detector Interface issues;
- Identify R&D efforts relevant to the ILC experimental program, catalog existing work, encourage activities on the important but still missing aspects, establish peer review process of the proposals;
- Panels set up on: Costing, Detector R&D and MDI.
GDI Proposed Milestones

- 2004 - ITRP Technology Recommendation (√)
- 2005 - Accelerator CDR
- 2005 - Detector CDRs (preliminary)
- 2007 - Accelerator TDR/Detector CDR
- 2008 - ILC Site Selection
Physics and Detector Requirements

- Provide precision measurements in the energy range from $M_Z$ to 1 TeV of small signals in the presence of backgrounds.
  - EWSB - Higgs, Susy, Strong WW scattering
  - Top physics
  - New or Unknown Physics

Contributions from M. Carena, B. Dobrescu, A. Freitas, J. Lykken.

- Two-jet mass resolution adequate to distinguish $W$ from $Z$
- High efficiency and purity heavy flavor $b$ and $c$ tagging
- Momentum resolution for precision reconstruction of the recoil mass in Higgs-strahlung events (better than beam energy spread)
- Precise determination of the missing energy $-\tau$
ILC Detector R&D

- Define performance of individual detector subsystems necessary to implement all elements of the physics program at LC, and when needed explore new technologies in a R&D program.

- R&D programs launched in Asia, Europe and America, coordinated internationally (J.Brau, Ch.Damerell, H.E.Fisk, Y.Fujii, R.Heuer, H.Park, K.Riles, R.Settles, H.Yamamoto - members of the panel)

  http://blueox.uoregon.edu/~lc/randd.html

- Studies of essential physics benchmarks of concept detectors;

- Many open issues for LC detectors;

- Detector R&D devoted to the LHC helpful, but not sufficient.
Detector Performance Goals

- ILC detector studies aim at development and optimizations in the following areas:
  - finely segmented calorimetry for particle flow measurement
  - very thin pixel vertex detector
  - integrated, low power readout
  - development of cost reduction strategies

- Understand beamline-detector interaction
  - IR layout - masks, Final Focus
  - beam-beam interactions, Lumi spectrum, polarization, backgrounds, bunch structure
Physicists at universities and national labs prepared a number of proposals describing a nation-wide program of R&D activities leading to the design and construction of the LC.

University Program of Accelerator and Detector Research for the Linear Collider - a proposal written by Linear Collider R&D Working Group (DOE) and University Consortium for the LC (NSF). (Coordination by physicists at FNAL, SLAC, Cornell and Universities)

The proposal covered both accelerator and detector projects and was prepared in coordination with other efforts world-wide to avoid unnecessary duplication of efforts.

The groups represent a broad cross section of institutions: 71 projects, 47 universities in 22 states, 5 national labs, 11 foreign institutions.

Lumi (9), VTX&Tracking (14), Calo (13), Muon (3).

Fermilab involved in both accelerator (7) and detector proposals: (4).
Object Oriented Detector Design

Physics Objects:
- b, c quarks
- t quarks
- W and Z
- τ leptons

Detected Objects:
- Hadrons - in Jets
- Electrons, Photons
- Muons
- \( E_T \)
Beam Time Structure

- 200 ms
- Bunch trains at 5 Hz
- Bunch crossings at 337 ns
- 0.950 ms

... 2820 ...

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Luminosity Spectrum

- Lumi spectrum essential for many precision measurements: $m_H$, $m_t < 100$ MeV, $m_W$, new physics.
- Combination of acollinearity of Bhabhas and beamline spectroscopy to get the full spectrum;
- Masks shield from direct and backscattered beam induced bkg;
- Provide instrumentation for luminosity spectrum measurement, hermeticity;
Detector Conceptual Designs

Silicon Detector

Large Detector

Quadrant View

- Beam Pipe
- ECAL
- HCAL
- Coil
- Yoke
- Track Angle
- Endcap
- Endcap_ECAL
- Endcap_HCAL
- VXD

5 Tesla coil

4 Tesla coil

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Momentum Resolution

CDF

CMS

LC
Momentum Resolution

\( e^+e^- \rightarrow ZH/ZZ \rightarrow \ell\ell X \)

\( \sqrt{s} = 300 \text{ GeV} \)

\[ \int L \, dt = 500 \text{ fb}^{-1} \]

\[ \Delta E/E \sim 0.1\% \]

\[ \Delta P_T/P_T^2 = 5 \times 10^{-5} \]

\[ \Delta P_T/P_T^2 = 20 \times 10^{-5} \]
Vertex Detection

Performance issues to be studied:

- Optimization of the detector geometry and pixel sizes;
- 5-layer device for excellent pattern recognition;
- Importance of the radius of the Inner Layer (1cm?) and its impact on the b,c tagging efficiency/purity, and instrumentation of the interaction region;
- Higgs BR studies with more realistic simulation in the presence of backgrounds;

\[ E_{CM} = 91 \text{ GeV} \]
**Vertex Detector Technologies**

- **CCD based VTX detector**
  - R&D to improve the limitations: readout speed, radiation tolerance, material budget;
  - development of fast column parallel CCD with readout electronics, 50 MHz;
  - thin ladder - unsupported version - 0.06% $X_0$ problematic; or semi/fully supported versions 0.1% $X_0$ under study;

- **Monolithic Active Pixel Sensor (CMOS)** - small prototypes (MIMOSA-n) with column parallel readout and zero suppression fabricated and under tests;

- **DEPFET** - first structures under tests

- **Rich experience in construction of vertex detectors at FNAL**...

- **Interest in development of MAPS and study of new DSM processes by W. Wester, R. Yarema’s group.**
Vertex Detection

- Material distribution in a typical vertex system.
Layout and Support Structure design by W.Cooper, M.Demarteau, M.Hrycyk

Ladder configuration under study

Minimal electronics and power pulsing make gas cooling possible for mass reduction

Double carbon fibre support cylinders for each barrel

5 layers at radii 20-125cm
Calorimeter Performance Goal

Precision measurement of jet energy to separate Ws and Zs in hadronic decays on an event by event basis:

\[ e^+e^- \rightarrow HZ, \ e^+e^- \rightarrow \nu \bar{\nu}WW(ZZ), \ e^+e^- \rightarrow HHZ \]
Particle Flow Concept

**Combination of two methods of particle energy measurement**

- charged particles in jets more precisely measured in a tracking detector;
- for a typical multijet event: 60% charged energy; 20% photons, 10% neutral hadrons;
- photons and electrons measured in calorimeter (ECAL).

Particle Flow Algorithm requires separating charged from neutral energies in Imaging Calorimeter system.

The main lines of design of the calorimeter system:

- high 3D granularity and hermeticity;
- minimal re-interactions, separate particles in the tracker;
- dense material for compact showers;
- Active interplay between simulation and detector designs to identify and measure each jet energy component as well as possible.
Calorimeter Technology Options

**Electromagnetic - ECAL**
- Silicon-Tungsten;
- Crystal PbWO$_4$;
- Silicon-Scintillator

**Hadronic - HCAL**
- Analog Readout:
  - Tiles
- Digital Readout:
  - Gas Electron Multipliers - GEM
  - Resistive Plate Chamber - RPC
  - Scintillator
  - Short Drift Tubes - SDT

Recent summary by A. White at Jan’04 ALCPG at SLAC
Many CALO options discussed: traditional, particle flow, digital HCAL.

Demonstration of full particle flow algorithm with pattern recognition underway.

Extensive tests of high granularity calorimeters (data, simulations) necessary to precede any technology recommendations.

1 m$^3$ prototype: 400,000 channels

CALO structures in the test beam by FY06.
Experience in the FNAL ASIC group in calorimeter electronics: KTeV, CDF, BTeV, CMS and overlap with new initiatives (LC, NOνA)

- Large channel counts require the low cost and power designs.
- Avalanche Photodiodes (APD) readout using FNAL ASICs.
- Prototype board for LC DCAL R&D using scintillator (U.Colorado proposal)
- Silicon Photomultipliers new readout for scintillator based tail-catcher (NIU proposal).
New ASIC development effort under way for the Digital Calo chip (submission planned for FY05)

64-channel chip designed for two gains, time stamping and triggering capabilities

Readout for:
- RPC (ANL proposal)
- GEM (UTArlington proposal)
Muon Detector Work @FNAL

- **Gaseous Electron Multiplication - UTA**
  - 3M foil
  - 50 µm holes

- **Resistive Plate Chambers - INFN Frascatti**
  - Screen printed resistive coating

- **Scintillator based - Davis/NIU/Notre Dame/Wayne St./FNAL H.E.Fisk**
  - 1.2 mm fibre thermally fused

MAPMT 16/64ch
Muon Detector Work @FNAL

- 1/16 plane from Notre Dame
- Testing to begin now

Simulation studies of single muons in the detector.
MIP tracks reconstructed in 5T magnetic field.

C. Milstene

EMCAL -2 RED Rings
HDCAL -2 BLACK Rings
COIL -2 GREEN Rings
MUDET -2 BLUE Rings

Mn-Detector 300 Phi Bins- 32 Layers

Before
Track
Hits
Now
Layer_Number

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The Resonant Mode Controller Chip (RMCC) is a long standing FNAL circuit design now implemented in an ASIC.

High Voltage/Low current applications such as phototubes, bias voltage supplies are ideal place for use.

Detectors with many HV channels will benefit from this low cost HV sources with the RMCC ASIC.

Chip used for PM supply.

Plan to build a demonstrator PCB for bias voltage.

LC Proposals: RPC (ANL) and Scintillator Calorimeter (U.Colorado) plan to use this device.
5 Tesla Solenoid Studies @FNAL

SiD: w/5T; technical feasibility?

FNAL expertise: R.P. Smith, R.Wands, K.Krempetz

Collaboration with Saclay

Use 4T CMS solenoid as a starting point

First results shown, stress analysis to follow
ILC groups are designing and building prototype detectors to be tested in electron and hadron test beams.

Specific proposals to laboratories are being created.

Needs of calorimeter R&D groups are most demanding and FNAL TB coordinator E. Ramberg is developing a plan how to address them at Fermilab.
- Vertex Detector Pixel and Silicon Front End Readout;
- Tracker layout and design;
- Calorimetry FE Electronics and readout ASIC;
- Scintillator studies applied to Calorimeter and Muon subsystems;
- Superconducting solenoid - 5 T;
- Prototype Detector tests in the beam;
- Physics and Detector simulation studies;
Fermilab assists WWS in managing the LC physics and detector studies:

- A. Kronfeld member of the International Organizing Committee WWS;
- D. Finley, G. Gollin, S. Tkaczyk R&D Proposal Coordinators;
- H. Weerts (FNAL) and J. Jaros (SLAC) leaders of the SiDetector concept study;
- M. Carena, H. Fisk, A. Juste, S. Tkaczyk WG leaders;
- E. Ramberg coordinates the Test Beam Facility at FNAL;
- E. Fisk and S. Tkaczyk lead the LC Physics and Detector work in EPP-PPD; G.P. Yeh liaison in CD for LC simulation support.
R&D on Front-End electronics for LC detectors is a very important element of this program.

Big unknown with longest lead times (as experience of present detectors shows)

Requires concentrated efforts and continuous attention

Embedded with active detectors

Impacts the designs in earliest stages:
  - power dissipation and cooling requirements;
  - material budget;
  - evaluation of production risks and cost;

Large laboratories usually lead those efforts! (e.g. CERN, DESY, RAL)
Summary

- FNAL involved in many aspects of the ILC detector R&D.
- FNAL efforts are increasing.
- FNAL well prepared to lead front-end electronics R&D activities.
- Collaboration with Universities and other labs essential element of concept detectors studies.
Outlook

- More Fermilab staff need to get involved at any level in the LC physics and detector studies.
- Eventually the ILC detector activities have to become an approved R&D project.
- It is not too early to start thinking about how to get there and when it should be.