WHY SiD FOR AN ILC DETECTOR?

J. Brau
March 11, 2006
Bangalore - LCWS 2006
Physics Goals

○ SiD has been designed to address questions of fundamental importance to progress in particle physics:
  ✉ The mechanism responsible for electroweak symmetry breaking and the generation of mass
  ✉ The unification of the forces
  ✉ The structure of space-time at small distances
  ✉ The connections of the nature of the fundamental particles and forces to cosmology

○ These are addressed through precision measurements by SiD at the International Linear Collider (ILC) of the following:
  ✉ Higgs boson properties
  ✉ Strong coupling effects
  ✉ Effects resulting from the existence of extra dimensions
  ✉ Studies of supersymmetric particles
  ✉ Top quark studies

○ Cost Constraint important concern from start.
ILC Detector Requirements

- **Two-jet mass resolution** comparable to the natural widths of W and Z for an unambiguous identification of the final states.

- Excellent **flavor-tagging** efficiency and purity (for both b- and c-quarks, and hopefully also for s-quarks).

- Momentum resolution capable of reconstructing the **recoil-mass** to di-muons in Higgs-strahlung with resolution better than beam-energy spread.

- Hermeticity (both crack-less and coverage to very forward angles) to precisely determine the **missing momentum**.

- **Timing** resolution capable of separating bunch-crossings to suppress overlapping of events.
SiD (the Silicon Detector)

CALORIMETRY IS THE STARTING POINT IN THE SiD DESIGN

assumptions
- Particle Flow Calorimetry will result in the best possible performance
- Silicon/tungsten is the best approach for the EM calorimeter
- Silicon tracking delivers excellent resolution in smaller volume
- Large B field desirable to contain electron-positron pairs in beamline
- Cost is constrained
SiD has been designed to operate optimally in the ILC environment. Limiting sensitivity to particles generated in a selected, single bunch crossing is a critical goal, and central to the SiD philosophy.

- Collisions of bunches at the IP occur every 308 nsec (or less).

- Bunch trains consisting of 2820 bunches in each beam pass through the IP five times per second.

- Consequently, the bunch trains are 868 msec long, separated by 199 msec.

- The design luminosity is $2 \times 10^{34}$ cm$^{-2}$ sec$^{-1}$.
Backgrounds

- Backgrounds generated by stray beam particles upstream, and collisions of the bunches themselves (beamstrahlung and beam-beam interactions), consist of large numbers of low energy (~MeV) photons, and electron-positron pairs.

- Additionally, the hadronic collision rate itself, including the two-photon events, is about 200 events per bunch train.

- Other than the two-photon events, high energy interactions comprise only one event in about every ten bunch trains.

- Therefore, the pile up of the two-photon events could significantly confuse detection of the principal signal of interest unless the detector can cleanly select single bunch crossings, which SiD is designed to do.

- For example, only a few Higgstrahlung events per hour, or less, might be produced, motivating clean separation of the overriding two-photon events, and the lower energy backgrounds.
Background Sources

IP Backgrounds

- Beam-beam Interactions
  - Disrupted primary beam
    - Extraction line losses
  - Beamstrahlung photons
  - e+e- pairs
- Radiative Bhabhas
- $\gamma \gamma \rightarrow \text{hadrons/}\mu^+\mu^-$

Somewhat manageable -
- Scale with luminosity
- Transport them away from IP
- Shield sensitive detectors
- Exploit detector timing
- Reliable simulations.

Machine backgrounds

- Muon production at collimators
- Collimator edge scattering
- Beam-gas
- Synchrotron radiations
- Neutrons from dumps/extr. line

Harder to handle -
- Don’t make them
- Keep them from IP if you do
- Dominated by beam halo
- Dependent on assumptions
Backgrounds

- The electron-positron pairs, largely produced in beam-beam interactions, while soft, are a particularly major problem for the most inner layers of the detector.
- SiD’s high solenoidal field is an effective protection from the bulk of these pairs, and allows the smallest possible beam pipe radius, optimizing vertexing resolution.
Event Rates and Backgrounds

- **Event rates (Luminosity = 2 x 10^{34})**
  - $e^+e^- \rightarrow qq, WW, tt, HX$
  - $\sim 0.1$ event / train
  - $e^+e^- \rightarrow e^+e^- \gamma\gamma \rightarrow e^+e^- X$
  - $\sim 200$ /train

- **Background**
  - $6 \times 10^{10} \gamma / BX$ (from synchrotron radiation, scatters into central detector)
  - 40,000-250,000 $e^+e^- / BX$ (90-1000 TeV) @ 500 GeV
  - Muons: $< 1$ Hz/cm$^2$ (w/ beamline spoilers)
  - Neutrons: $\sim 3 \times 10^8 /cm^2/ yr @ 500 GeV$

Ref: Maruyama, Snowmass 2005
At SLC, bunch-to-bunch variations in the beam parameters were large, and hard to predict, model, and control.

Individual bunches with anomalous backgrounds were problematic to operation of the SLD detector.

Significant precautions are being taken at ILC to deal with this, but experience suggests the need for robust detectors.

SiD’s reliance on silicon sensors for vertexing, tracking, and electromagnetic calorimetry promises the needed robustness.

Sensitivity to single bunch crossings, made possible by silicon detectors, is the key to immunity.
SiD is a detector concept based on silicon tracking and a silicon-tungsten sampling calorimeter, complemented by a powerful silicon pixel vertex detector, and outer hadronic calorimeter and muon system. Optimized forward detectors are deployed.

In order to meet the ILC physics goals, SiD is designed as a general purpose detector taking full advantage of the silicon technology.

Silicon detectors are fast, robust against machine-induced background, fine in segmentation and, by now, a mature technology.
Detector Performance

- The detector performance required for the ILC physics goals includes:
  - i) unprecedented jet energy resolution of $\sigma_E/E = 30\%/\sqrt{E}$, where $E$ is the jet energy in GeV,
  - ii) a superb momentum resolution $\sigma(1/p_T) = 5 \times 10^{-5}$, where $p_T$ is the momentum perpendicular to the beam axis measured in GeV/c and
  - iii) the impact parameter resolution of $\sigma_{r\phi} \approx \sigma_{z} \approx 5 \oplus 10/(p \sin^{3/2} \theta) \ \mu m$, where $p$ is the momentum of the charged track in GeV/c and $\theta$ is the polar angle with respect to the beam axis.

- The jet energy resolution, a factor of 2 better than SLC/LEP calorimeters, and comparable to ZEUS uranium-plastic scintillator calorimeter, for multi-jet final states.

- The momentum resolution required is a factor of 10 better than LEP experiments and a factor of 3 better than CMS at LHC.

- The impact parameter resolution, which is a factor of 3 better than what SLD achieved, for flavor (b or c origin) tagging of jets.
SiD (the Silicon Detector)

CALORIMETRY IS THE STARTING POINT IN THE SiD DESIGN

assumptions

- Particle Flow Calorimetry will result in the best possible performance
- Silicon/tungsten is the best approach for the EM calorimeter
- Silicon tracking delivers excellent resolution in smaller volume
- Large B field desirable to contain electron-positron pairs in beamline
- Cost is constrained
SiD Configuration

5 Tesla

Scale of EMCal & Vertex Detector
Parametric Cost Model

Cost = f (B-field, $R_{TRK}$, ....)
Summary

- The ILC detector must have the capability to identify the bunch crossing, in which the recorded collision event has occurred.
- ILC bunches are separated by 308 ns, or less (150 ns).
- SiD identifies the ILC bunches separated by as little as 150 ns.
- SiD is a state-of-the-art detector meeting all physics requirements:
  - built-in robustness against machine-induced backgrounds
  - large field coil located outside calorimeter for optimal PFA
  - finely granular calorimeter to achieve optimal particle flow calorimetry,
    - silicon-tungsten electromagnetic calorimeter.
    - compact geometry since Si-W expensive
    - tracking in compact configuration with large magnetic field and silicon
    - ancillary benefit of the large magnetic field is small beampipe/very close vxd
- Designed with Cost Constraint from Start