Vertex Detectors for the Linear Collider

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- Physics goals of the LC involve low event rates with relatively low backgrounds
  - opportunity for very efficient and precise vertex detection
Requirements for an LC Vertex Detector

- Accelerator-related requirements, such as
  - Beam-pipe radius, thickness, machine stayclear
  - Radiation levels & background rates
  - Event rate and time structure of collisions
  - etc.

- Physics requirements, eg vertex flavor tagging, driven by:
  - Impact parameter resolution
  - Two-track/two-hit separation
  - Efficiency, fake track rate
  - Solid angle coverage
  - etc.
Physics Requirements

- Higgs branching ratios
- $W$ and $Z$ reconstruction and tagging
- SUSY
- top physics

- heavy quark tagging will play a central role in most physics goals of the Linear Collider
IR Issues

$e^+e^-$ pairs

Hits/bunch train/mm$^2$ in VXD, and photons/train in TPC
IR Issues

Synchrotron radiation photons from beam halo in the final doublet
halo limited by collimation system
Detector Requirements

**Vertex Detector**

- Physics motivates excellent efficiency and purity
- Large pair background from beamstrahlung
  - Large solenoidal field ($\geq 3$ Tesla)
- Pixelated detector $[(20 \, \mu m)^2 \rightarrow 2500\, \text{pixels/mm}^2]$}
- Min. inner radius ($< 1.5\, \text{cm}$), $\sim 5$ barrels, $< 4\, \mu m$ resol,
  - Thickness $< 0.2\%\, X_0$
SLD VXD3

- SLD has demonstrated the power of a **PIXEL** detector in the LC environment
  
  - 307,000,000 pixels
  - 3.8 μm point resolution
  
  - Excellent impact parameter resolution
    - $\sigma_{r\phi} (\mu m) = 7.8 \oplus \frac{33}{p} \sin^{3/2}\theta$
    - $\sigma_{rz} (\mu m) = 9.7 \oplus \frac{33}{p} \sin^{3/2}\theta$
  
  - pure and efficient flavor tagging at the Z-pole
    - $\sim 60\%$ b eff with 98% purity
    - $> 20\%$ c eff with $\sim 60\%$ purity
  
  - decay vertex charge measurement ($Q = -1, 0, 1$)

SLD Collab., NIM A400, 287-343 (1997)
American L, SD, and P detectors all assume the same CCD VXD
~700,000,000 pixels  [20x20x20 (μm)^3]
3 μm hit resolution
inner radius = 1.2 cm
5 layer stand-alone tracking
Impact Parameter Resolution

\[ \cos \theta = 0 \]

- \( L \)
- \( SD \)
- \( P \)

B. Schumm

LC Vtx Detectors, Jim Brau, UTA, Jan 9, 2003
Flavor Tagging

T. Abe
Radiation Hardness, CCDs

Surface Damage from ionizing radiation
hard to > 1 Mrad (acceptable for LC)

Bulk Damage
results in loss of charge-transfer efficiency (CTE)
ionizing radiation
damage suppressed by reducing the operating temperature

hadronic radiation (neutrons)
damage clusters → complexes
cooling much less effective
VXD3 Experience on Radiation Damage

SLD experience during VXD3 commissioning,

An undamped beam was run through the detector, causing radiation damage in the innermost barrel. The damage was observed as the detector was operating at an elevated temperature ($\approx 220$ K). Reducing to 190 K ameliorated the damage.

There is a strong temperature dependence to the effect of exposure.
Neutron Damage

Background estimates for the next Linear Collider have varied from $10^7$ n/cm$^2$/year to $10^{11}$ n/cm$^2$/year

- $2.3 \times 10^9$ n/cm$^2$/year (Maruyama-Berkeley2000)

Expected tolerance for CCDs in the range of $10^9$ - $10^{10}$

Increase tolerance to neutrons can be achieved through:
- improve understanding of issues and sensitivity
- engineering advances
  - flushing techniques
  - supplementary channels
  - bunch compression & clock signal optimization
  - others
Neutron Damage and Amelioration Study

Radiation Hardness Tests of CCDs - N. Sinev

This study investigated flushing techniques on spare VXD3 CCD

Flash light to fill traps, then read out

@SLAC \( \sim 2 \times 10^9 \text{n/cm}^2 \), \( T_{\text{room}}, \text{Pu(Be)}, \sim 4 \text{ MeV} \)

@SLAC Annealing study 100\(^\circ\) C for 35 days

@Reactor (I) \( \sim 2 \times 10^9 \text{n/cm}^2 \), \( T_{\text{room}}, \text{reactor}^*, \sim 1 \text{ MeV} \)

@Reactor (II) \( \sim 1.2 \times 10^9 \text{n/cm}^2 \), \( T_{\sim 190K}, \text{reactor}^*, \sim 1 \text{ MeV} \)

Total exposure \( \sim 5.2 \times 10^9 \text{n/cm}^2 \)

Neutron Damage and Amelioration Study

Image of damaged sites

$T = 187 K, \text{ after dose of } 2 \times 10^9 \text{ n/cm}^2$


Image of damaged sites after flushing

$T = 187 K, \text{ dose } 2 \times 10^9 \text{ n/cm}^2, \text{ cleaning charge}$

Basic concept demonstrated; future work will involve charge injection to keep traps filled.
The R&D program must include the following:

- develop hardened CCDs
- develop CCD readout, with increased bandwidth
- develop very thin CCD layers (e.g., stretched)
- investigate alternatives to CCDs

- resolve discrepancy in Higgs BR studies
- understand degradation of flavor tagging with real physics events compared to monojets (as seen in past studies)
- understand requirements for inner radius, and other parameters
  - what impact on physics?
  - what impact on collider if minimize inner radius?
- segmentation requirements (two track resolution)
  - 500 GeV u,d,s jets
  - pixel size
Linear Collider Vertex Detector Workshop  
January 8, 2003  
University of Texas, Arlington

- Location: TBA  
Dial-in: 510-665-5437 Meeting ID: 7913  
Time: 15:00 - 19:00, US Central Time  
22:00 - 02:00, UK  
06:00 - 10:00 January 9, Japan  
Session Organizers: Chris Damereil, Akiya Miyamota, Natalie Reo, Yasuhiro Sugimoto  
All talks are 20 minutes + 5 minutes for discussion

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