Vertex Detectors for the Linear Collider

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ALCPG Workshop
UT Arlington
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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

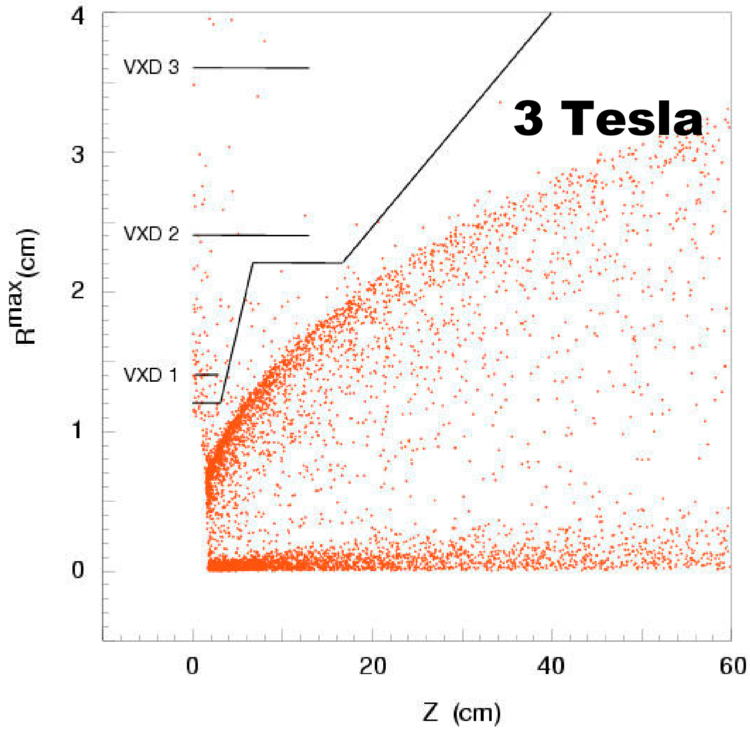
- Accelerator-related requirements, such as
  - Beam-pipe radius, thickness, machine stayclear
  - Radiation levels & background rates
  - Event rate and time structure of collisions
  - etc.
- Physics requirements, eg vertex flavor tagging, driven by:
  - Impact parameter resolution
  - Two-track/two-hit separation
  - Efficiency, fake track rate
  - Solid angle coverage
  - etc.

Physics Requirements

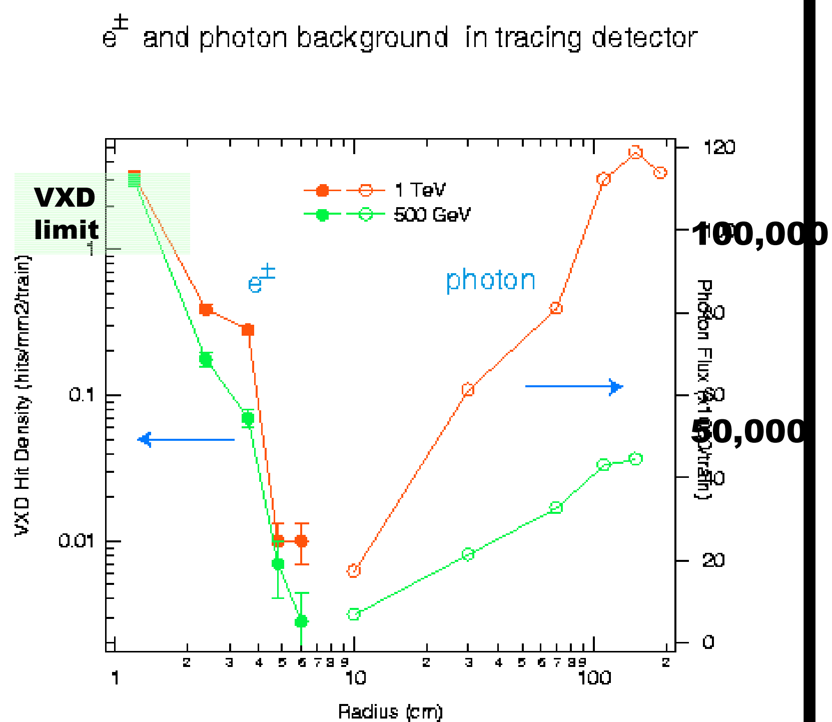
- Higgs branching ratios
- W and Z reconstruction and tagging
- SUSY
- top physics

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

IR Issues

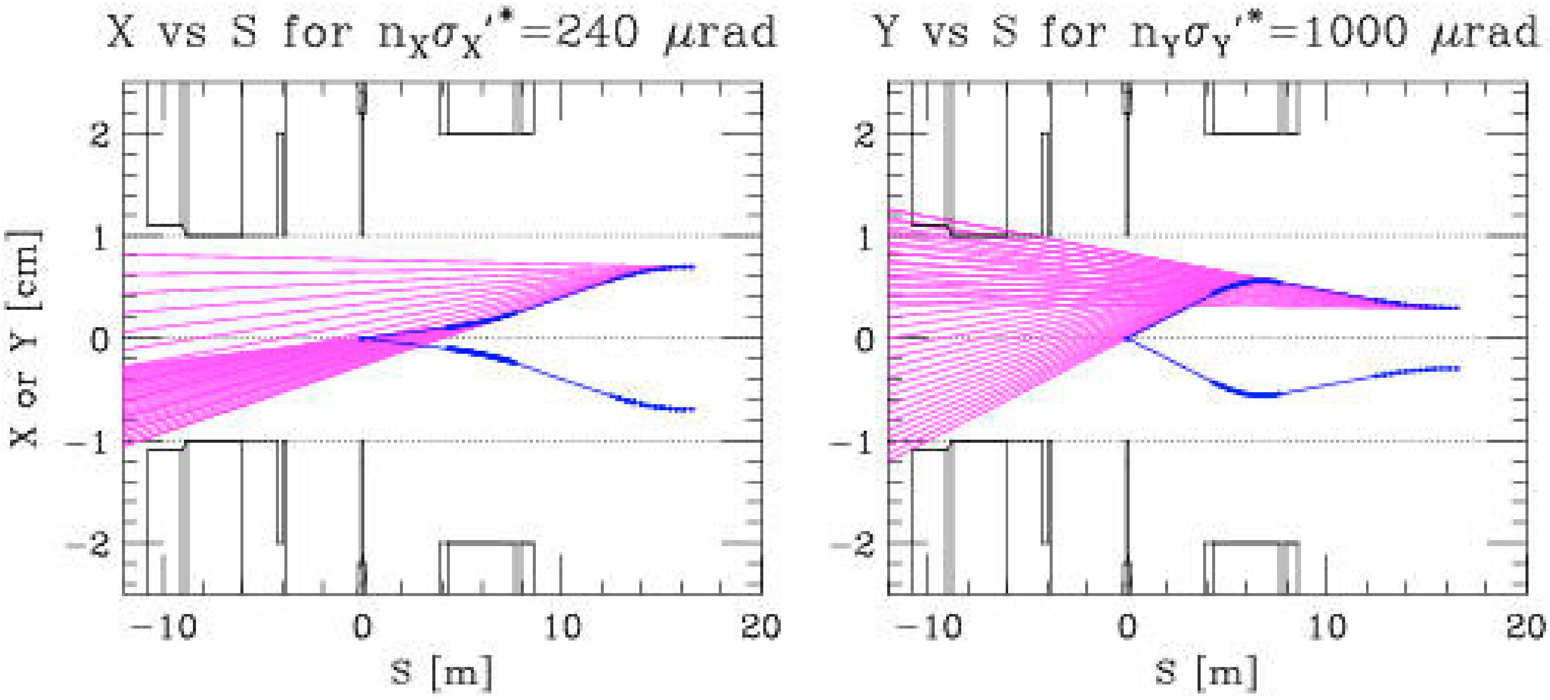


e^+e^- pairs



Hits/bunch train/mm² 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

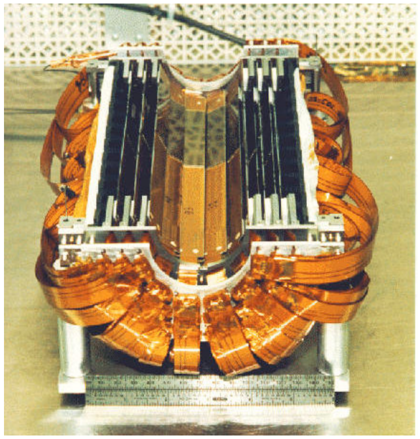
→ large solenoidal field (≥ 3 Tesla)

pixelated detector [(20 μm)^2 → 2500 pixels/mm^2]

min. inner radius (< 1.5 cm), ~5 barrels, < 4 μm 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
  - $\sigma_{r\varphi}$ (μm)= $7.8 \oplus 33/p \sin^{3/2}\theta$
  - σ_{rz} (μm)= $9.7 \oplus 33/p \sin^{3/2}\theta$
- pure and efficient flavor tagging at the Z-pole
  - ~ 60% b eff with 98% purity
  - > 20% c eff with ~ 60% purity
- decay vertex charge measurement (Q = -1, 0, 1)

SLD Collab., NIM A400, 287-343 (1997)

Vertex Detector

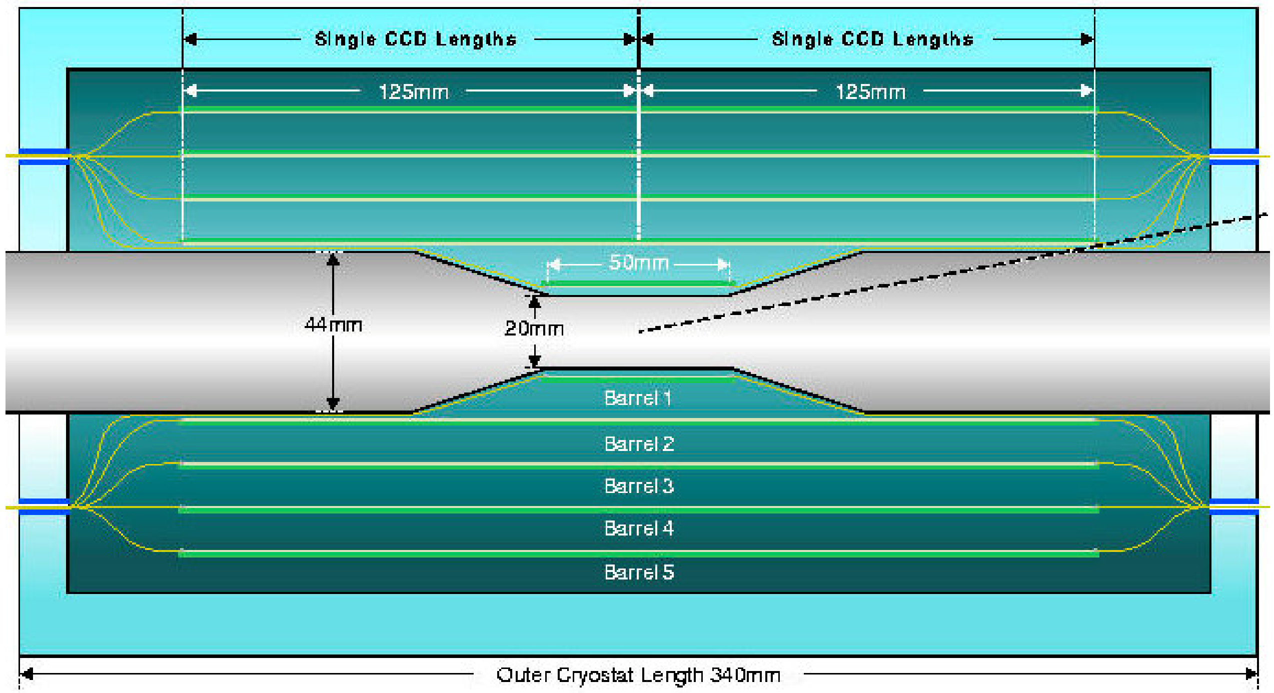
American L, SD, and P detectors all assume the same CCD VXD

~700,000,000 pixels [20x20x20 $(\mu m)^3$]

3 μm hit resolution

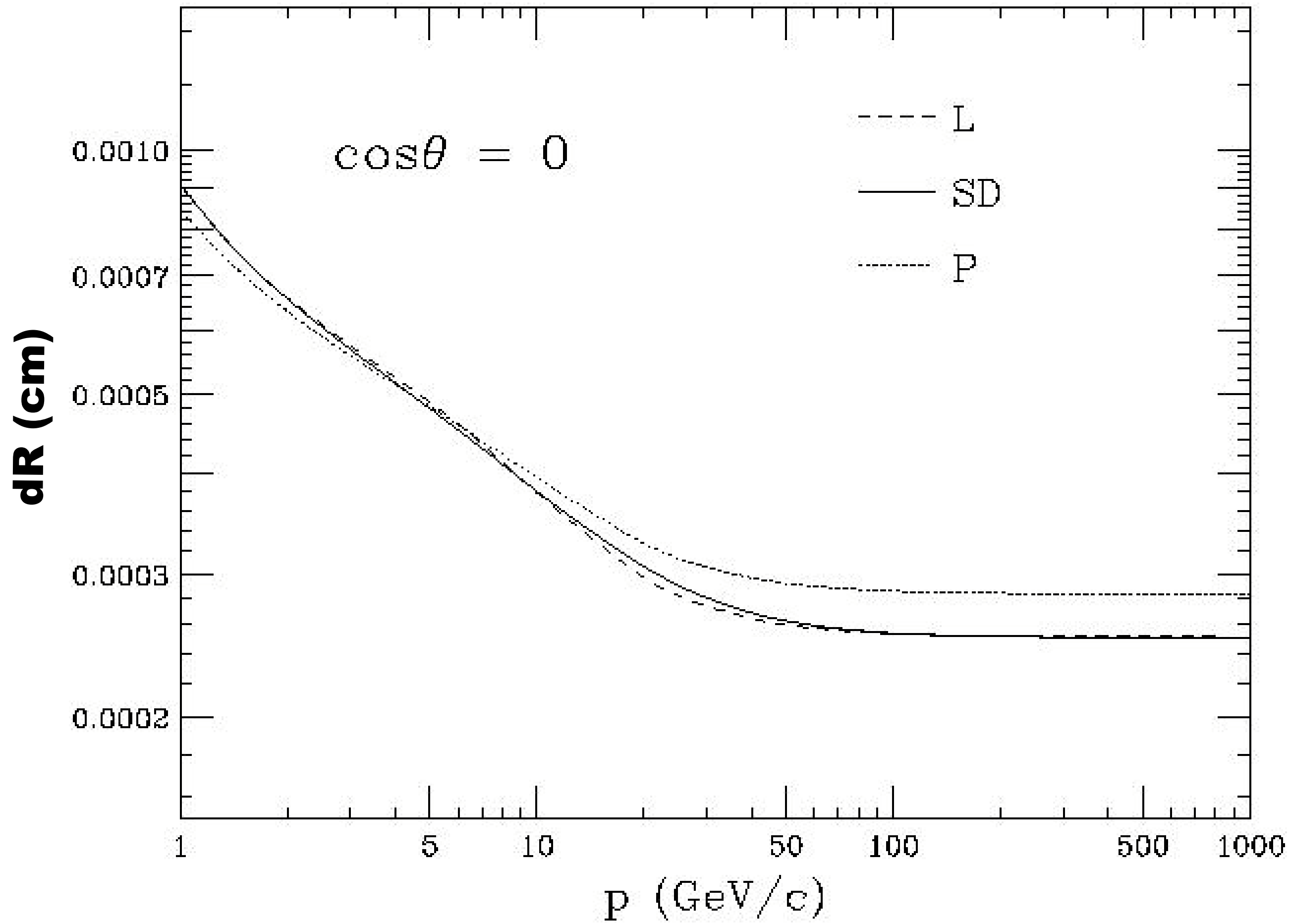
inner radius = 1.2 cm

5 layer stand-alone tracking



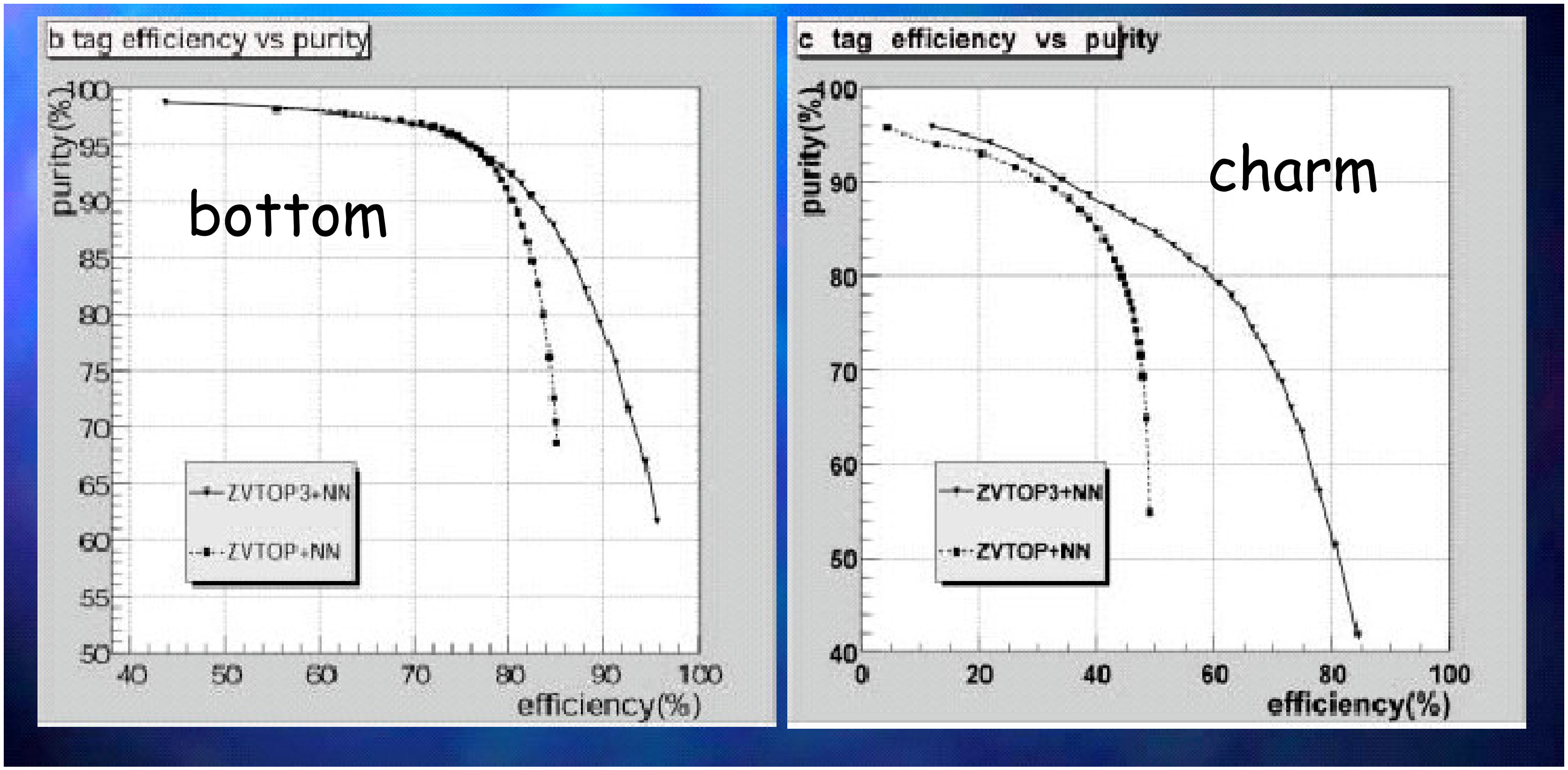
Cos θ = 0.98

Impact Parameter Resolution



B. Schumm

Flavor Tagging



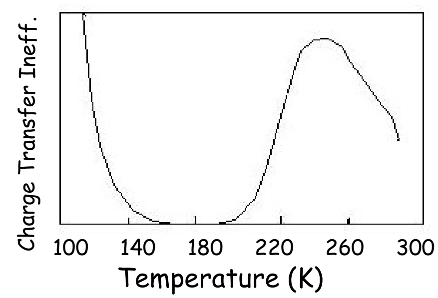
T. Abe

Radiation Hardness, CCDs

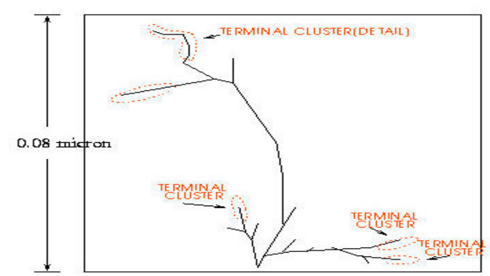
<u>Surface Damage</u> from ionizing radiation
hard to > 1 Mrad (acceptable for LC)

<u>Bulk Damage</u>
results in loss of charge-transfer efficiency (CTE)

<u>ionizing radiation</u>
damage suppressed by reducing the operating temperature



<u>hadronic radiation (neutrons)</u>
damage clusters → complexes
cooling much less effective

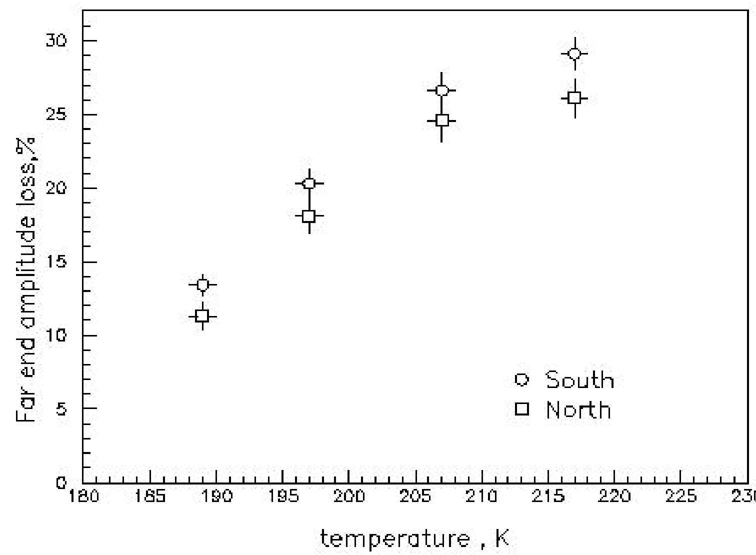


VXD3 Experience on Radiation Damage

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 (≈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

- 2.3×10^9 n/cm^2/year (Maruyama-Berkeley2000)

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

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 ~ 2×10^9 n/cm^2, T_{room}, Pu(Be), ≈ 4 MeV
@SLAC Annealing study 100° C for 35 days
@Reactor (I) ~ 2×10^9 n/cm^2, T_{room}, reactor*, ≈ 1 MeV
@Reactor (II) ~ 1.2×10^9 n/cm^2, T~190K, reactor*, ≈ 1 MeV

Total exposure ~ 5.2×10^9 n/cm^2

IEEE Trans. Nucl. Sci. 47, 1898 (2000)

Neutron Damage and Amelioration Study

Image of damaged sites

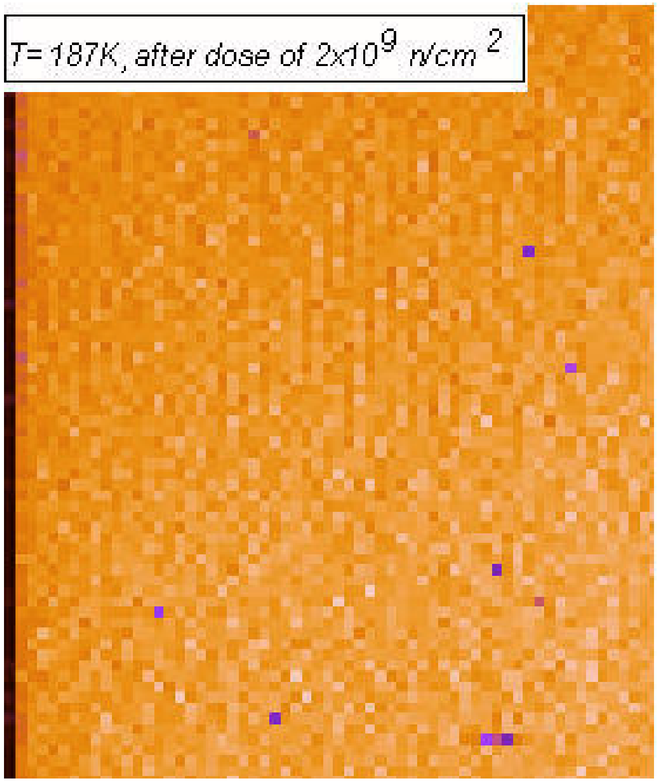
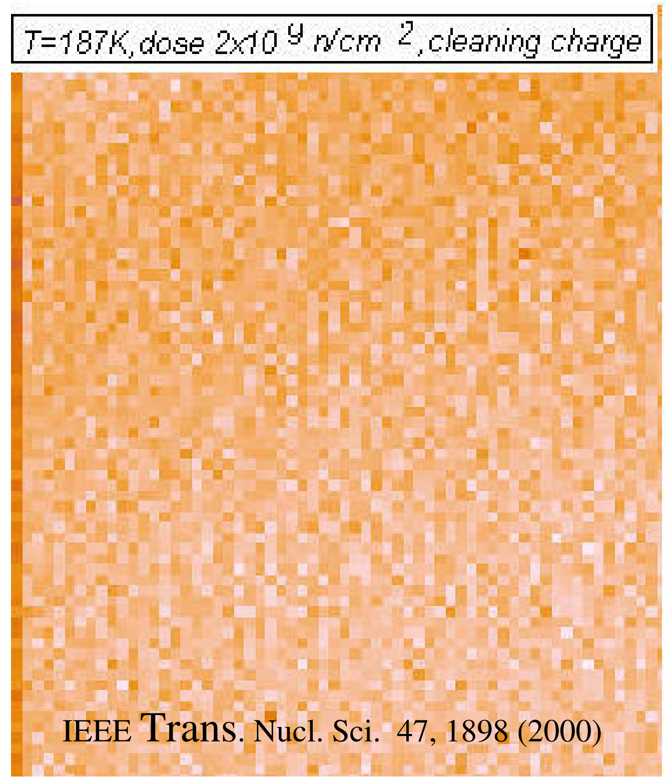


Image of damaged sites after flushing



Basic concept demonstrated; future work will involve charge injection to keep traps filled.

The R&D Program

Vertex Detector

The R&D program must include the following

develop hardened CCDs
develop CCD readout, with increased bandwidth
develop very thin CCD layers (eg. 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**

ECFA DESY Linear Collider Workshop | American Linear Collider Physics Group | ACFA Joint Linear Collider Physics and Detector Working Group

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 Damerell, Akiya Miyamota, Natalie Roe, Yasuhiro Sugimoto
  All talks are 20 minutes + 5 minutes for discussion

TIME (US Central)	TITLE OF TALK	SPEAKER
15:00	Monolithic Active Pixel option pdf	Marc Winter
15:25	Monolithic Active Pixel option pdf	Renato Turchetto
15:50	CCD option pdf	Konstantin Stefanov
16:15	DEPFET option pdf	Marcel Trimpl
16:40-17:00	Break	
17:00	Physics Simulations pdf	Nicolo de Groot
17:25	Oregon/Yale CCD R&D and Radiation Damage Studies pdf	Nikolai Sinev
17:50	GEANT4 simulation of vertex detector beam background pdf	Tsukasa Aso
18:15	CCD radiation damage test with 150 MeV electrons pdf	Yasuhiro Sugimoto