# Vertex Detector Studies for the Linear Collider

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Higgs Branching Ratio measurements

Vertex Detector Parameter dependences

Neutron Radiation Damage Studies
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# Higgs Branching Ratio Measurements and Vertex Detection

**The physics opportunities of a future Linear Collider motivates a detector with the best possible vertex detector:**

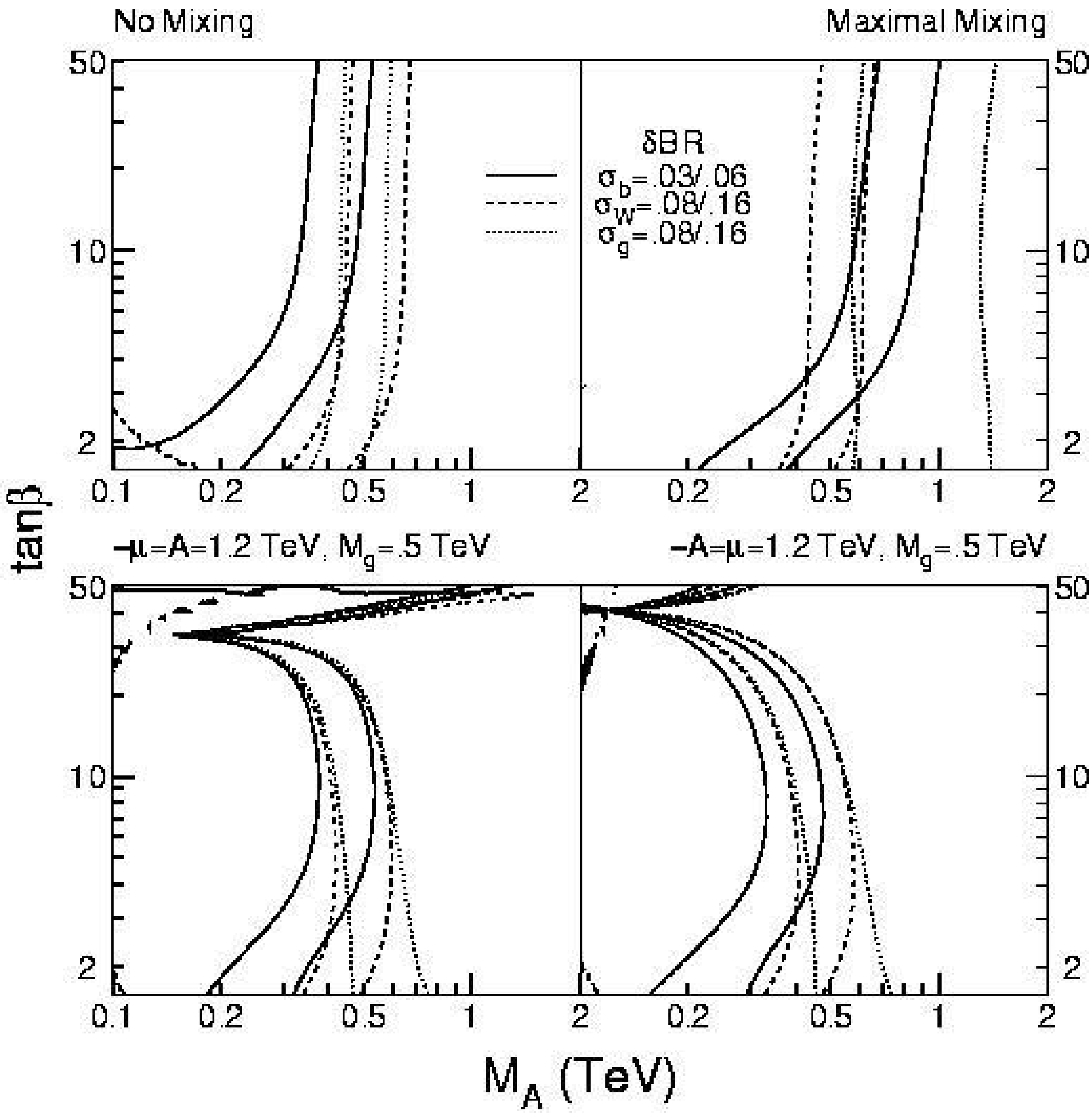
**Higgs branching ratios**
**Higgs self coupling**
**SUSY physics, eg. staus**
**Top physics**
**W/Z reconstruction**
**Z pole physics**

**We really want to optimize performance, to extract maximal use from every event.**

**The measurement of Higgs decay modes is a particularly good benchmark physics process for the vertex detector design:**

**Significant physics goal**
**Rich in secondary vertexing**
**Contains mixture of common and weaker channels**
**eg. bb vs. cc**

# MSSM Higgs Branching Ratios

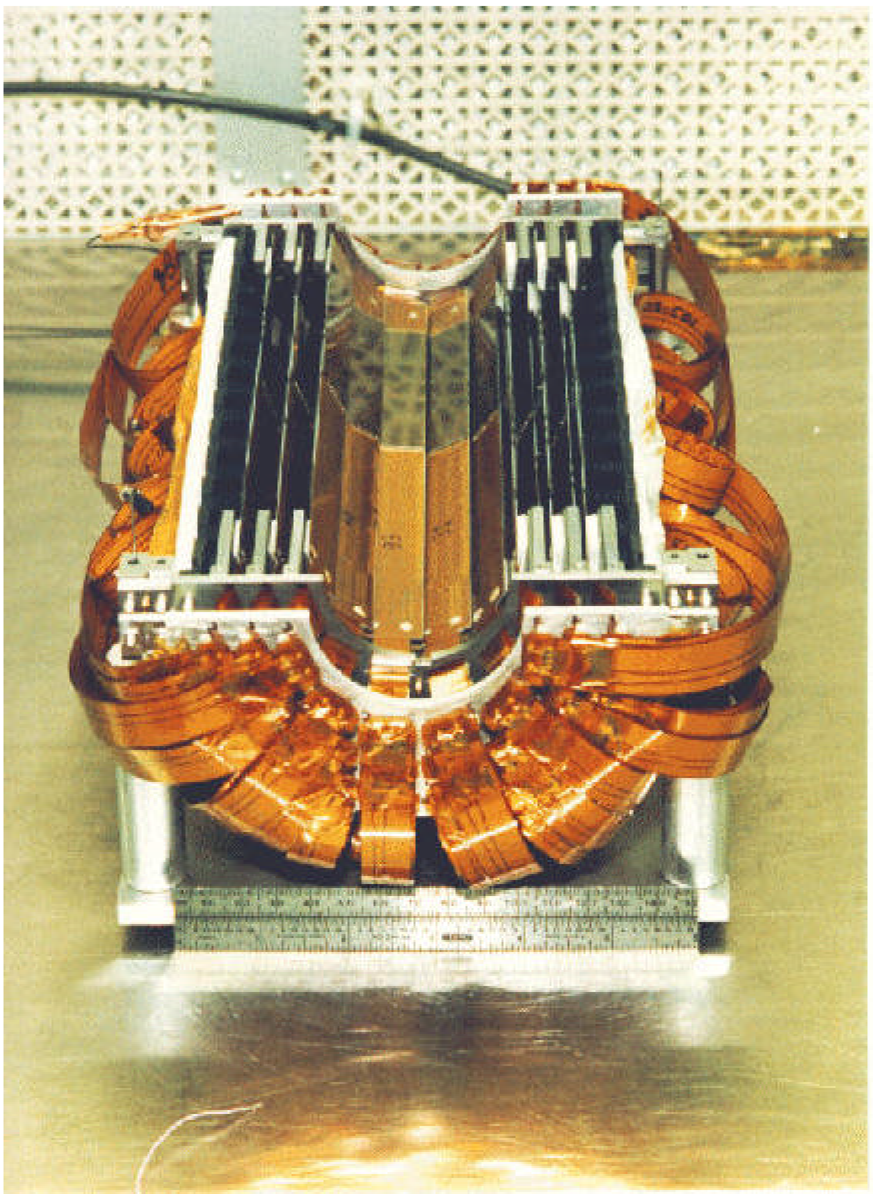



M. Carena, H.E. Haber, H.E. Logan, and S. Mrenna, FERMILAB-Pub-00/334-T

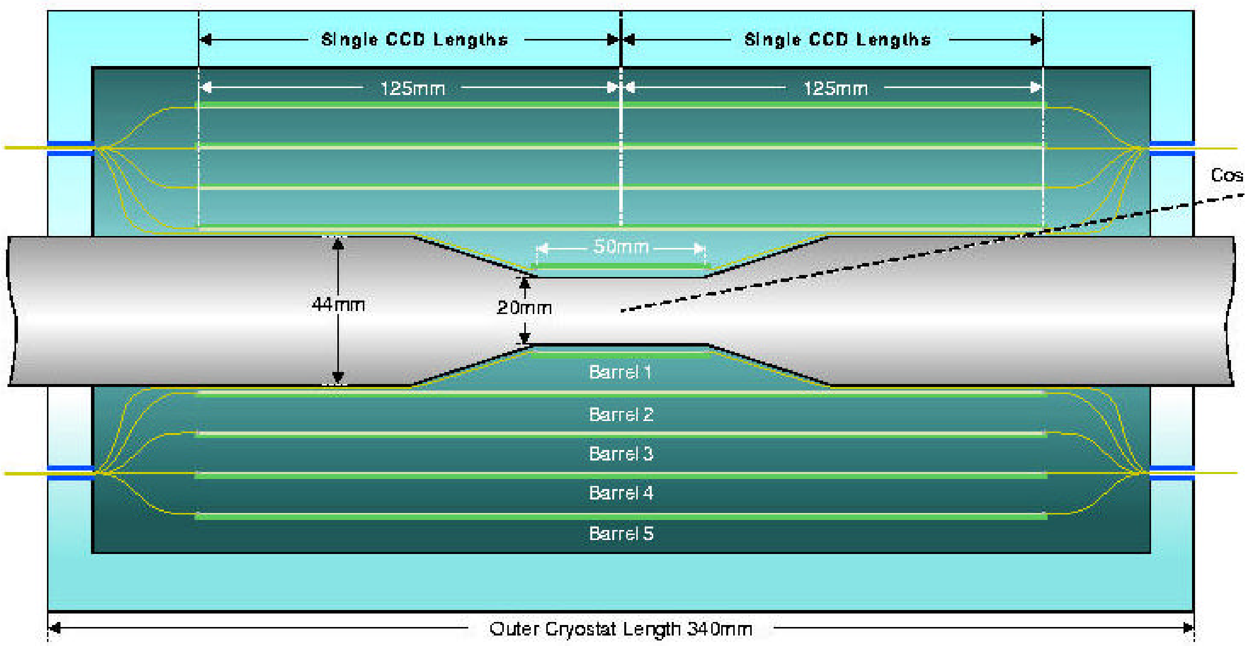
# SLD's VXD3

**307,000,000 pixels**
**3.8 μm point resolution**
**Excellent b/c tagging**

} **We can do even better**



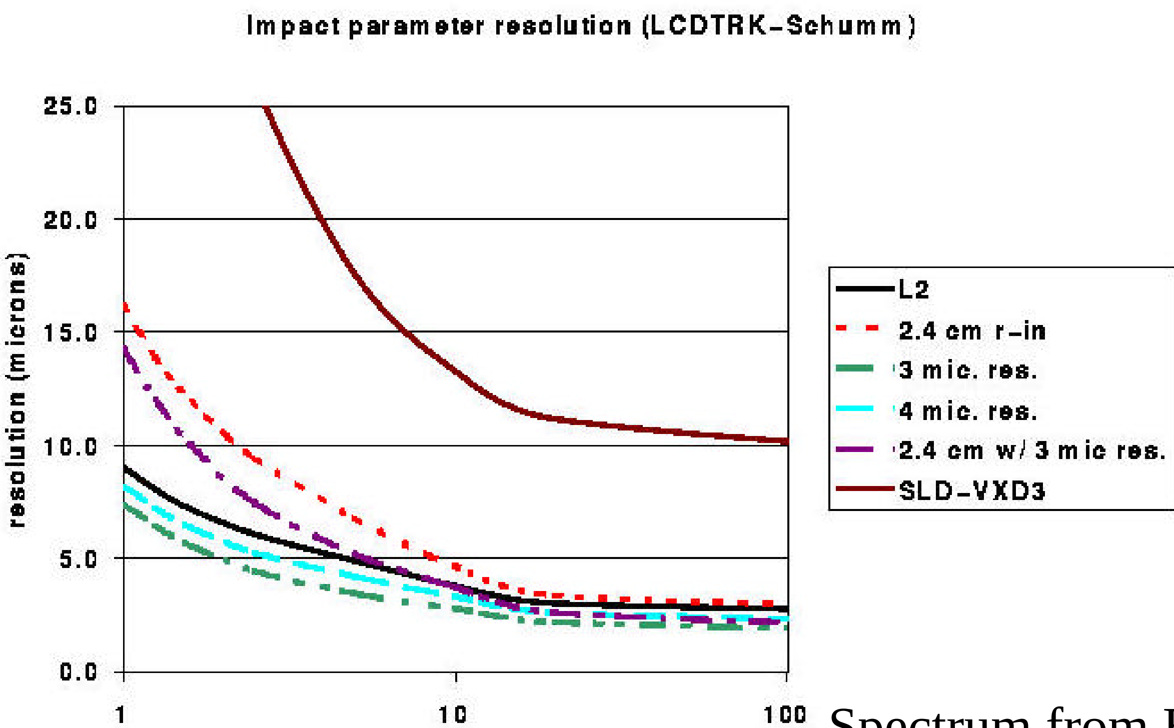
# CCD Vertex Detector for the Future Linear Collider

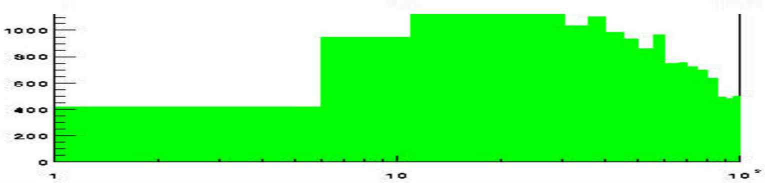



**~700,000,000 pixels**
**standalone tracking**
**w/ 5 barrels**

# Vertex Detector Parameters

**Hit resolution**
**Number of barrels**
**Thickness of barrels (rad. lengths)**
**Angular coverage**
**Readout speed**
**Material inside vertex detector (beampipe, etc.)**
**Radiation hardness**



Spectrum from B decays in ZH events

# Vertex Detector Design for Future Linear Collider

- Maximum Precision ( < 4 μm)
- Minimal Layer Thickness

  (1.2% $X_0$ → 0.4% $X_0$ → 0.12% $X_0$ → 0.06% $X_0$)
  SLD-VXD2 SLD-VXD3 Linear Collider stretched
- Minimal Layer 1 Radius

  (28 → 12 mm → 5mm)
  SLD-VXD3 LC Schumm challenge
- Polar Angle Coverage ($\cos\theta \sim 0.9$)
- Standalone Track Finding (perfect linking)
- Layer 1 Readout Between Bunch Trains
- Deadtime-less Readout

# Event simulation

- **Pandora-pythia and Pythia v5.7**
  - **beamstrahlung included and important**
- **Detector model : NLC L**

$e^+e^- \to ZH$
$H \to bb$
$H \to \tau\tau$
$H \to cc$
$H \to gg$
$H \to WW$
$H \to ZZ$
$e^+e^- \to WW$
$e^+e^- \to ZZ$
$e^+e^- \to qq$
$e^+e^- \to tt$

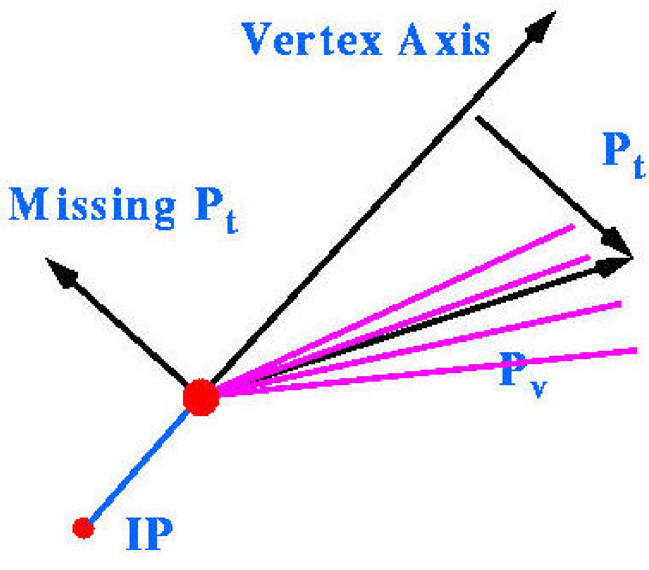
$\sqrt{s} = 500$ GeV
$M_H = 140$ GeV/$c^2$
$\int L = 500$ fb$^{-1}$
Analysis with $Z \to l^+l^-$ evts, scaled to $Z \to qq$ (x 4)
(OPAL LEP 2, D. Strom)

**Previous studies:**

**Hildreth, Barklow, Burke, PRD49, 3441 (1994)**
**I. Nakamura, K. Kawagoe, LCWS (1996)**
**M. Battaglia, HU-P-264 (1999)**
**G. Borisov, F. Richard, LAL-99-26 (1999)**

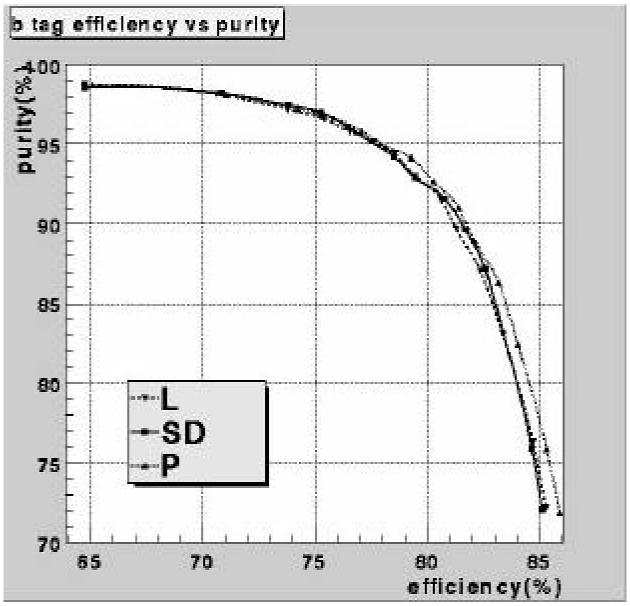
# ZVTOP

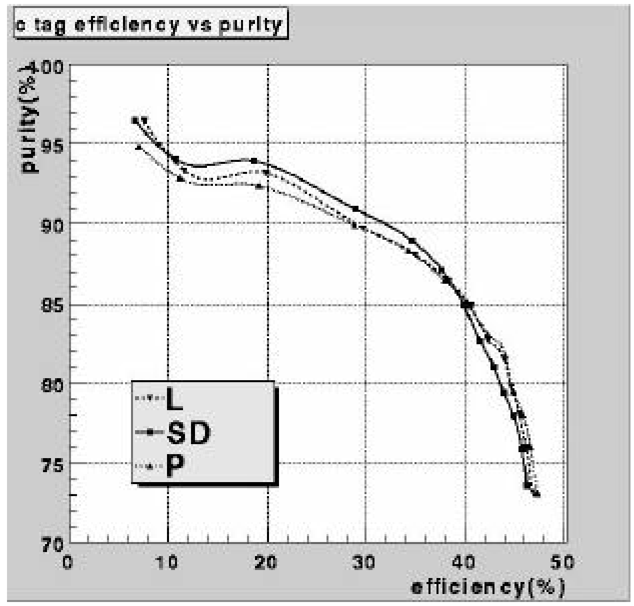
- Vertex reconstruction is based on the SLD algorithm ZVTOP
  - D. Jackson, NIM A388, 247 (1997)
- Implemented in the ROOT based NLC software by T. Abe
- Provides secondary vertex reconstruction, and pt-corrected mass




$$M = p_T + \sqrt{M_V^2 + p_T^2}$$

# Flavor Tagging




**T. Abe,**
**(one prongs in progress,**
**will do better)**

**These are the efficiency/purity curves for Z-pole decays.**

**Higgs decays have much different bottom/charm ratios, with charm greatly outnumbered by bottom.**

# Event Selection

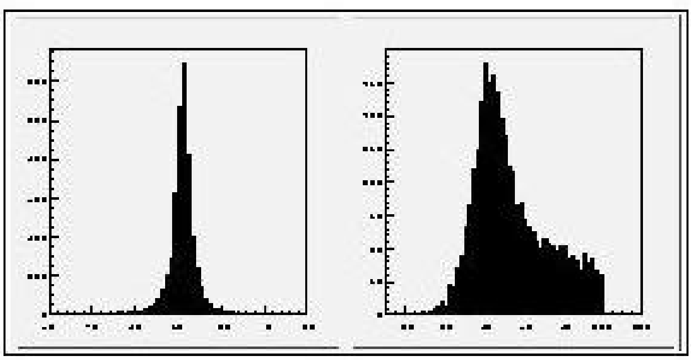
We select for $e^+e^- \to HZ \to l^+l^-$ $(l = e, \mu)$

- Reconstruct all lepton pair masses in an event
- Select pair with mass closest to $m_Z$
- Calculate recoil mass
- Apply cuts on masses:

$$|m_Z - m_{l^+l^-}| < 10 \text{ GeV}$$

$$m_H - 10 \text{ GeV} < m_{recoil} < m_H + 20 \text{ GeV}$$

- Include hadronic Z decays by scaling signal up by a factor of 4 (D. Strom, LEP experience)



**Signal event reconstructed Z and recoil mass distributions.**

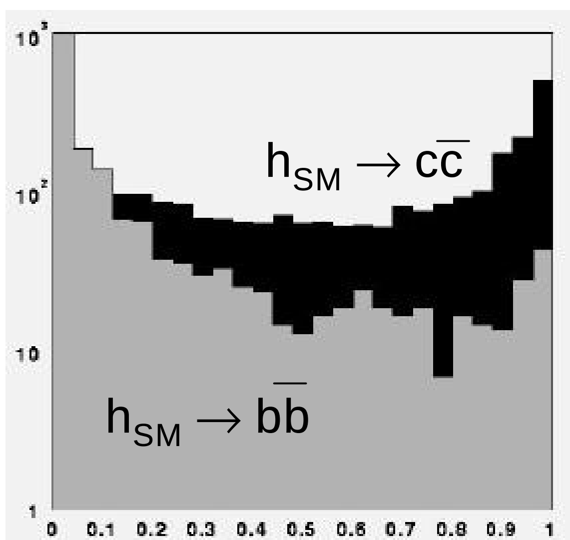
# Neural Net Analysis

14 parameters have been defined to distinguish decay modes of the Higgs Boson, and the backgrounds.

See C. Potter talk in P1-WG2 for details.

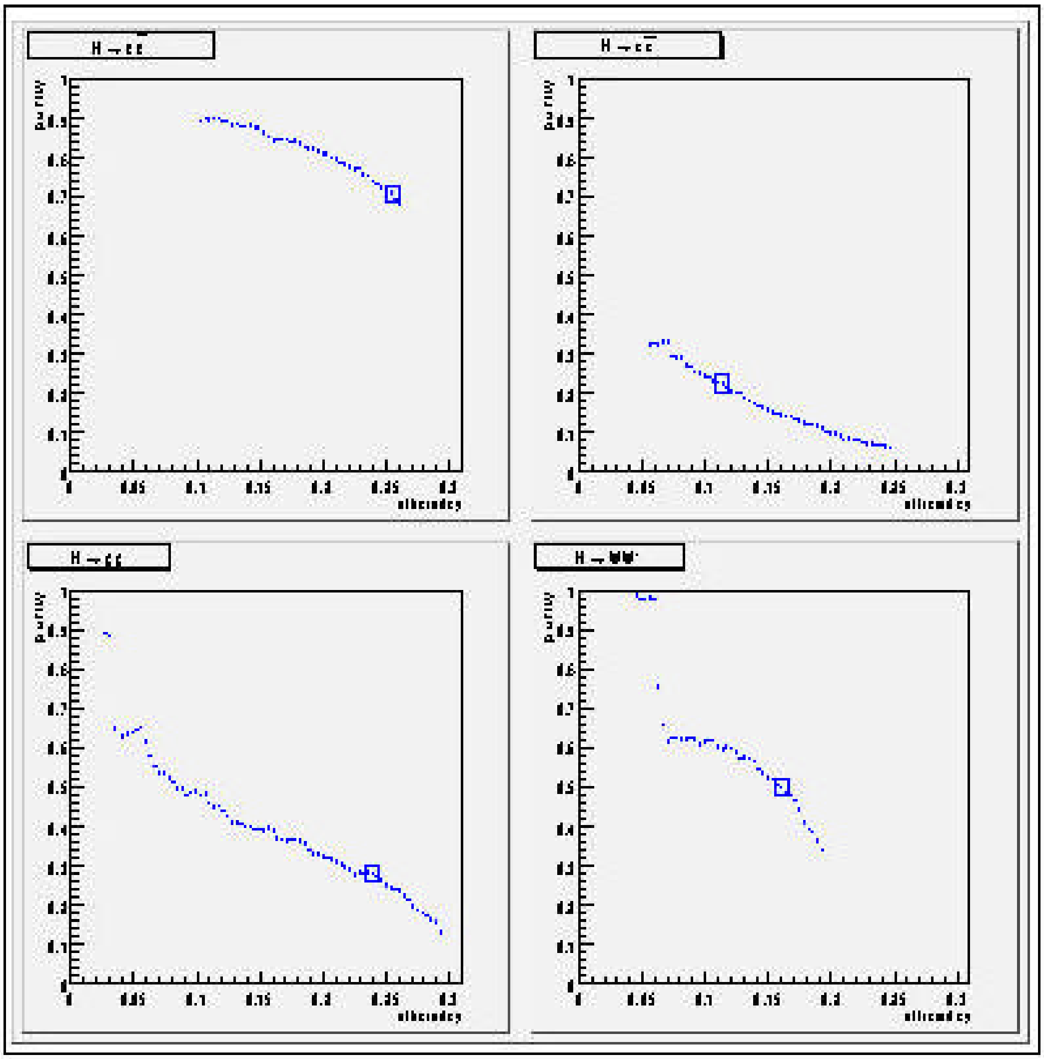
A neural net with 15 hidden units and 6 output units (one for each decay mode) was trained.

Cuts on each of the 6 output units was determined for each decay mode to maximize $S/\sqrt{S+B}$.




$h_{SM} \to c\bar{c}$ output

# Efficiency/Purity Curves from Neural Net



Purity vs. efficiency for the case $m_H = 120$ GeV. The maximum possible efficiency is 0.31 due to mass cuts.

# Branching Ratio Errors

$M_H = 140$ GeV/$c^2$ ,  $\sqrt{s} = 500$ GeV,

$\int L = 500$ fb$^{-1}$

| | | |
|---|---|---|
| $H \rightarrow bb$ | $0.34 \pm 0.013$ | (3.8%) |
| $H \rightarrow \tau\tau$ | $0.036 \pm 0.0038$ | (10%) |
| $H \rightarrow cc$ | $0.014 \pm 0.0064$ | (46%) |
| $H \rightarrow gg$ | $0.035 \pm 0.0079$ | (23%) |
| $H \rightarrow WW^*$ | $0.51 \pm 0.018$ | (3.5%) |

# Impact of Detector Parameters on BR Errors

$M_H = 140$ GeV/$c^2$ ,  $\sqrt{s} = 500$ GeV,

$\int L = 500$ $fb^{-1}$

| $R_{INNER}$(cm) | 1.2 | 2.4 | 1.2 | 2.4 | 1.2 |
|---|---|---|---|---|---|
| hit res (μm) | 5.0 | 5.0 | 3.0 | 3.0 | 4.0 |
| $H \to bb$ | 3.8% | 3.8% | 3.8% | 3,8% | 3.8% |
| $H \to \tau\tau$ | 10% | 10% | 10% | 10% | 10% |
| $H \to cc$ | 46% | 47% | 42% | 46% | 42% |
| $H \to gg$ | 23% | 22% | 22% | 22% | 22% |
| $H \to WW^*$ | 3.5% | 3.5% | 3.5% | 3.5% | 3.5% |

Mild dependence of charm to $r_{INNER}$ and hit resolution.

In this analysis, we are essentially tagging on one of the two possible jets. In an analysis in which one needs to tag multiple jets, the dependence will be stronger.

# Neutron Damage at the Linear Collider

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 x $10^9$ n/cm$^2$/year
  (Maruyama-Berkeley2000)

Expected tolerance for CCDs about $10^{9-10}$

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

Total exposure ~ $5.2 \times 10^9$ n/cm$^2$

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# Neutron Damage and Amelioration Study

Image of damaged sites

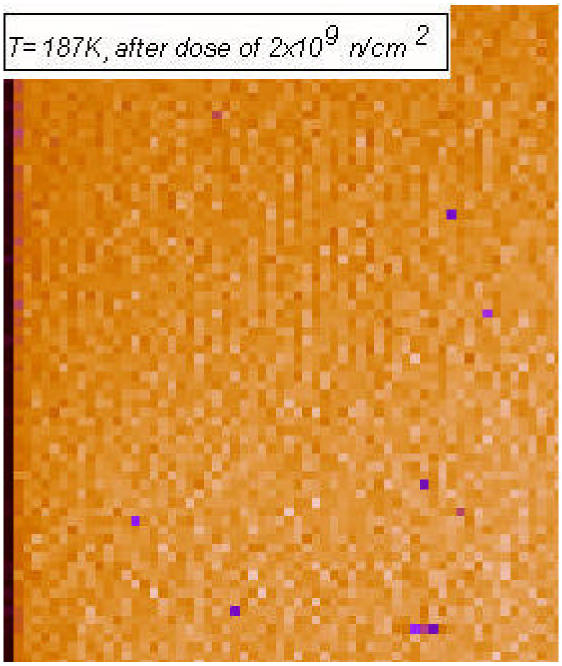
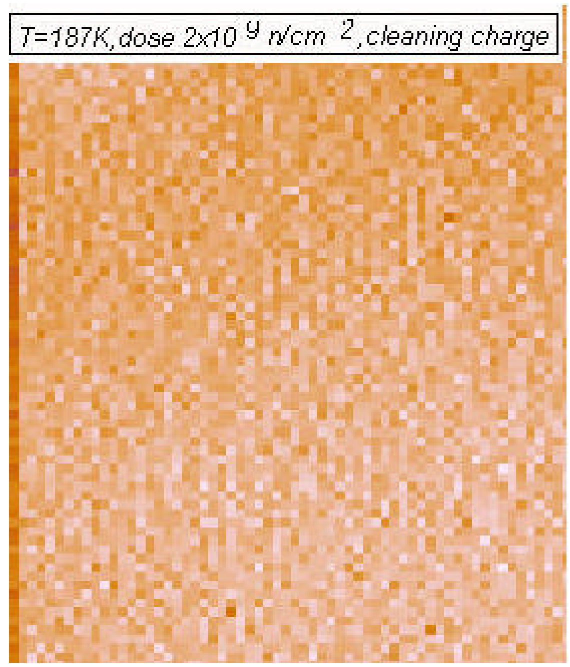



Image of damaged sites after flushing

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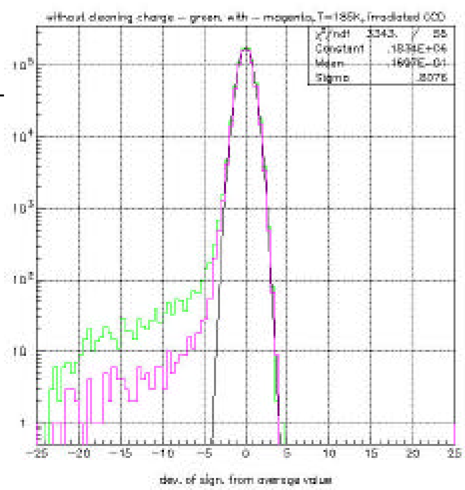
Basic concept demonstrated; traps are filled by flash, permitting charge to pass without loss.

# Signal Loss Results from Exposure

| | ~ $2 \times 10^9$ n/cm$^2$ | ~ $5.2 \times 10^9$ n/cm$^2$ |
|---|---|---|
| T = 185K, cluster sum<br>no flushing light | 4.05% | 29.1% |
| T = 185K, cluster sum<br>with flushing light | 1.5% | 18.0% * |
| T = 178K | | 11.0% * |

**Note (*) - flush is only partially effective in test set-up due to required delay between flash and readout (1 second)**

**In LC detector – much reduced loss with flushing**




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

# Summary

- We have studied the sensitivity of the Higgs branching ratio measurements to the vertex detector parameters

- Very weak dependence of HBR's for
  - $R_{INNER}$ = 1.2 cm - 2.4 cm
  - hit res. = 3 $\mu$m - 5 $\mu$m

- The neutron levels at the NLC are expected to reach the limits for CCD survival
  - Flushing techniques can keep traps filled
  - We need to improve rad hardness of CCDs