Performance of FPCCD vertex detector

T. Nagamine
Tohoku University
Feb 6, 2007
ACFA 9, IHEP, Beijing
Outline

- FPCCD and Vertex Detector Structure
- Impact Parameter Resolution
- Pair Background in Vertex Detector
- Track finding / fitting in Vertex Detector
- Cluster Shape Analysis
- Energy Loss in Thin Material
FPCCD features

- Large area device fabrication can be made
  - small dead area between sensors on ladders
- Fully depleted  -> Less smearing
- Very small pixel size
  - good hit position resolution (~ 2 μm)
  - Less occupancy
- No charge transfer during a bunch train
  - Avoid EM noise from beam
- Very thin (a few 10 μm)
  - Less Multiple scattering, but small signals
- High back ground hit rate accumulated (~ 40 hits / mm² / train)
  - Need good background rejection and tracking method
Structure of Vertex Detector

- 3 doublets structure
- Silicon thickness : 50 µm \((0.53 \times 10^{-3} X_0)\)
- Depletion layer thickness : 15 µm
- Pixel size : 5x5 µm

CCD Cross Section
Structure of Vertex Detector

- 3 doublets structure
- Silicon thickness: 50μm (0.53x10^{-3}X_0)
- Depletion layer thickness: 15μm
- Pixel size: 5x5μm

CCD Cross Section
Structure of Vertex Detector

- 3 doublets structure
- Silicon thickness: 50 $\mu$m ($0.53 \times 10^{-3} X_0$)
- Depletion layer thickness: 15 $\mu$m
- Pixel size: 5x5 $\mu$m

CCD Cross Section
Geometry for Simulation Study

- Tube shape used as each layer
- Layer thickness: 80µm
- 50µm for CCD, 30µm for Support Material, Air used for gaps
- 2 mm separation for each doublet
- 3 configurations are studied
- Doublet 1: R = 20 mm
- Doublet 2: R = 32 mm
- Doublet 3: R = 48 mm
- Hit position resolution: 2µm
- Beam Pipe: Be, t = 250µm, R = 18mm
Impact Parameter Study
and Helix Parameter
Impact Parameter Resolution $\sigma_{r-\phi}$

Momentum Dependence

\[
\sigma^2 = \sigma_0^2 + \frac{\sigma_1^2}{p} + \frac{\sigma_2^2}{p^2}
\]

Impact Parameter res. at $\cos \theta = 0$

<table>
<thead>
<tr>
<th></th>
<th>$\chi^2 / \text{ndf}$</th>
<th>31.55 / 14</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_0$</td>
<td>$1.221 \pm 0.03998$</td>
<td></td>
</tr>
<tr>
<td>$p_1$</td>
<td>$6.855 \pm 0.1985$</td>
<td></td>
</tr>
<tr>
<td>$p_2$</td>
<td>$7.68 \pm 0.1931$</td>
<td></td>
</tr>
</tbody>
</table>

Momentum (GeV/c)

1

$\mu$m

res. ($\mu$m)
Impact Parameter Resolution

$\cos\theta$ dependence at 1, 3, 10 and 30 GeV/c

$\sigma_{r-\phi} = \frac{\sigma_{r-z}}{\sin \theta}$
Pair Background Trajectory

- Pair Background($e^+ / e^-$) have low-Pt
- Their Radii are small
- They hit the vertex detector many times
Distribution of Pair Background in Vertex Region

By Sugimoto

B=3T
Background rate
Plain vs. anti-DID in VTX

By Fujishima, Saga Univ.

- 50 hits/mm²
- 20 hits/mm²

- CAIN/Jupiter/Geant4 results
- Beam Parameter: nominal 500GeV, 14mrad
- Background rate is reduced to 1/2 with ANTI-DID Field
Z distribution of VTX hits

Layer 1
Small Z dependence

Layer 2
By Fujishima
Track Finding

- Track Finder is under development in SimTools!
- Efficiency depends on hit probability in track finding window.
- Track finding window (area) from impact parameter resolution at the layer
- Area depends on polar angle of track as $1 / \sin^4 \theta$
Effect of Background on Track Finding

- Estimate track-hit matching efficiency using Toy MC
- Generate a true hit around a track with distribution functions obtained by Full MC
- Generate Background hits randomly around the track; 50, 100 and 200 hits/mm$^2$
- Accept the true hit closer to the track than background hits
- Ignoring finite pixel and cluster sizes
Track-Hit Matching Efficiency

Track is Fitted using TPC, SIT and Outer Layers of Vertex

Layer 1 & 2 Hits is not used

Doublet 1

Doublet 2

True hits
Extrapolated points
Track-Hit differences distributions

- **VTX l0 l1 hit diff**
  - Entries: 4997
  - Mean: 1.466
  - RMS: 1.03 µm

- **VTX DRphiZ at layer1**
  - Entries: 4997
  - Mean: 6.784
  - RMS: 4.579 µm

- **VTX l0 l1 hit diff**
  - Entries: 4997
  - Mean x: 1.453
  - Mean y: 6.722
  - RMS x: 0.9889
  - RMS y: 4.312 µm

Muon

1 GeV/c

COSθ = 0.05
$|R2|$ resolution v.s. Momentum

~ 1/3 of Impact Parameter Resolution at IP
Efficiencies for different hit rates

**Track-Hit Eff**

- **(1)** Background Rate=100 hits/mm²
- **(2)** Background Rate=200 hits/mm²
- **(3)** Background Rate= 50 hits/mm²

Condition: $|TR-TH| < |TR-BH|$

**Legend:**
- TR: track hit
- TH: true hit
- BH: background hit
FPCCD based Vertex Detector can work under hit rate up to 50 \( / \text{mm}^2 \)

The reasons:

- Good Outer Tracking detector - SIT and TPC
- Vertex has 6 Layer - 4 layer can use for extrapolate to inner most layer
- Vertex detector layers are very thin
- Small pixel size which matches to the resolution
Impact Parameter Resolution (R dependence (OLD Geometry))

- Impact Parameter Resolution (R-phi plane) v.s. Momentum
- $\mu^-$ at $\cos(\theta)=0.05$
- Impact Parameter Resolution increases as radius increases
Cluster Shapes for Low-Pt and High-Pt tracks

RED:  Low-Pt Track (Pair Background)
BLUE: High-Pt Track

wider cluster
narrow cluster
wider cluster

R-Phi Plain  R-Z Plain
Distributions of Cluster Width v.s. Z for Muon Tracks

- 1 GeV/c \( \mu^- \)
- Left: R-Phi, Right: R-Z
- Clear Z dependence of Cluster Width in R-Z
Distributions of Cluster width v.s. Z for Pair Background

- Pair background
- Left: R-Phi, Right: R-Z
- No Z dependence in both R-Phi and R-Z
Efficiency for Muon track

- 1GeV/c µ⁻
Efficiency for Pair Background

Rejection factor is $1/2 \sim 1/20$ depend on Z
Energy Deposit in Thin material

- Effect of statistical fluctuation of collision
- Effect of Plasmon Excitation

Differential collision cross section in Silicon

H. Bichsel, Rev. Mod. Phys. 60, p663
Plasmon Spectrum Measurement by Electron Spectrometer

J. Perez, et al, PR A16, p1061
Electron Energy Loss
0.76 and 3 µm Al, T=1.0 MeV

- Plasmon Peaks: 15 eV separation

J. Perez, et al, PR A16, p1061
Energy deposit of $t=1,3,5\mu m$ Si

Geant4 Simulation

1µm

1KeV

3µm

3KeV

5µm

5KeV

1 GeV/c Muon
No Plasmon Peaks seen
MPV and $E_{\text{low}(>99\%)}$
Summary

- Current design of FPCCD base Vertex detector has good Impact Parameter Resolution.
- Good tracking efficiency can be expected under high background rate (100 hits/mm$^2$) for higher momentum region, and up to 50 hits/mm$^2$ for lower momentum region.
- Good Pair Background rejection can be expected by Cluster shape (rejection factor = 1/2~1/20).
- Need more study for Energy deposit in thin Si.
- Need to study b,c and tau tagging in physics events(Z, ZH, etc).