Simulation Study of FPCCD vertex detector at ILC

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May 30-Jun 2, 2007
LCWS 2007, DESY

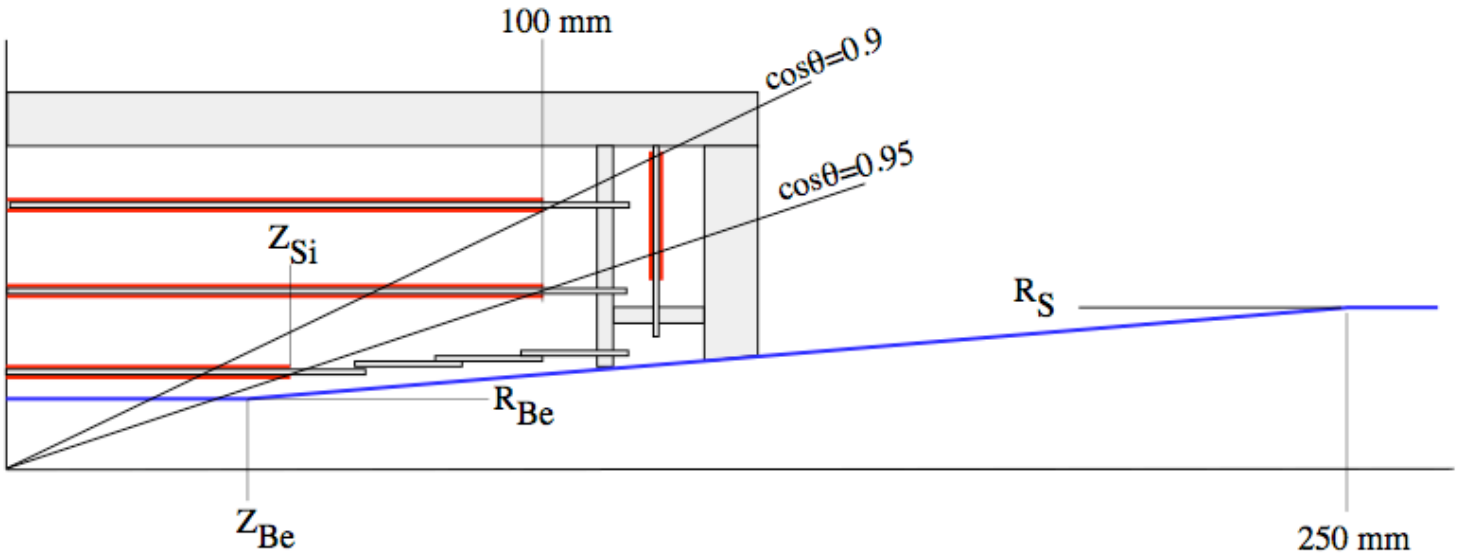
Outline

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

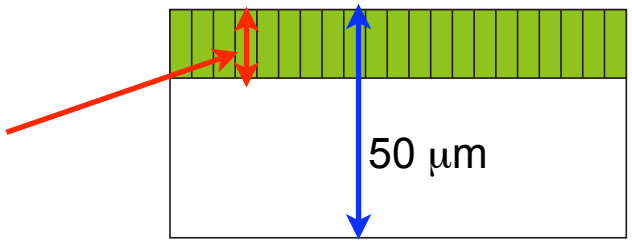
FPCCD features

- Large area device can be made
  -> small dead area between sensors
- Fully depleted epitaxial layers -> Less diffusion/smearing
- Very small pixel size
  -> good hit position resolution (<2 μm)
  -> Lower occupancy
- No charge transfer during a bunch train
  -> Avoid EM noise from beam
- Very thin sensors (50 μm or less)
  -> Less Multiple scattering, small signals
- High back ground hit rate accumulated
  -> Need good background rejection and tracking method

Structure of Vertex Detector

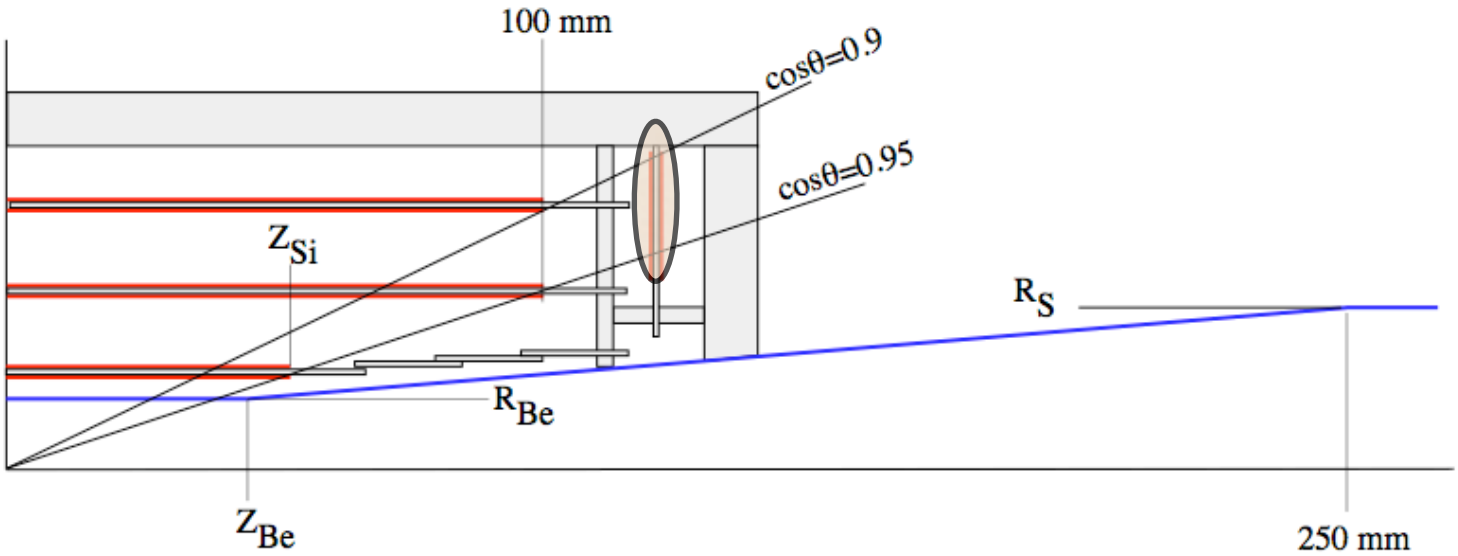


- 3 doublets - 2 mm gaps
- Silicon thickness : 50 μm ($0.53 \times 10^{-3} X_0$)
- Epitaxial layer thickness : 15 μm
- Pixel size : 5x5 μm



CCD Cross Section

Structure of Vertex Detector



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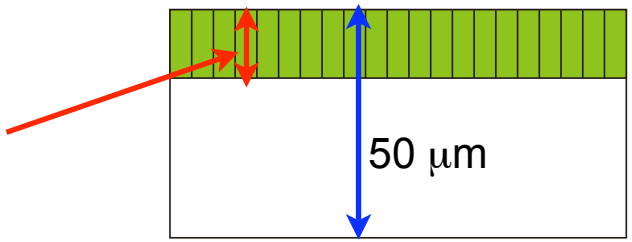

CCD Cross Section

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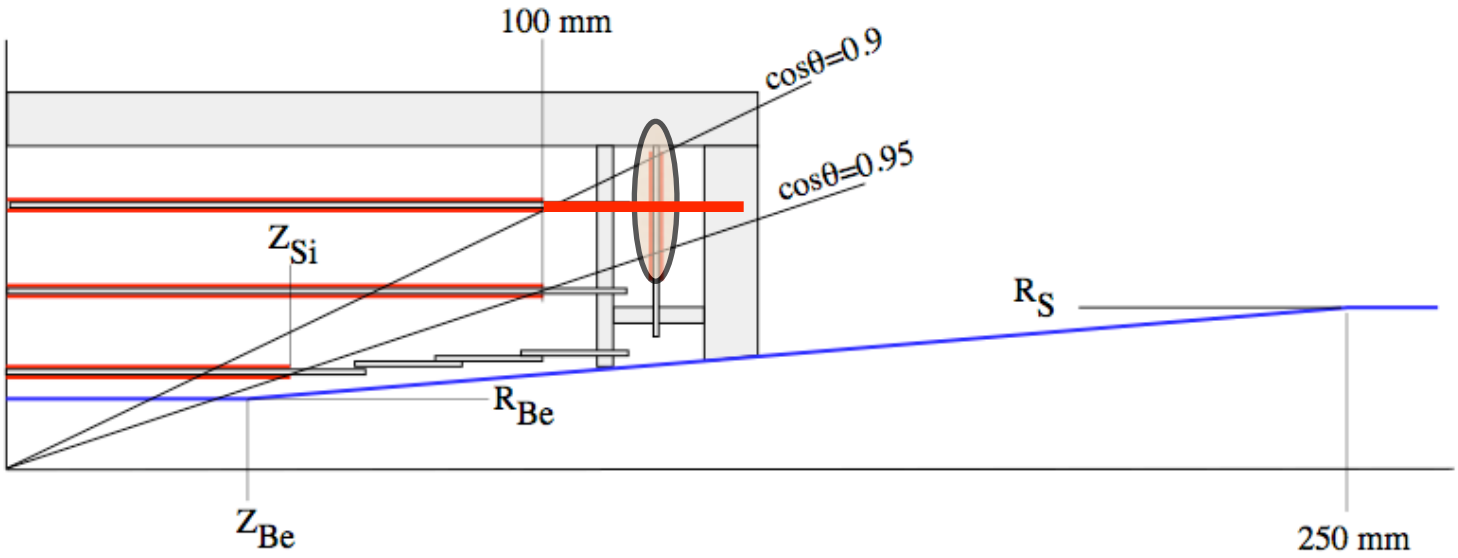

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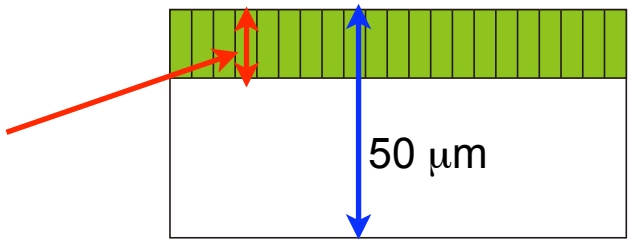
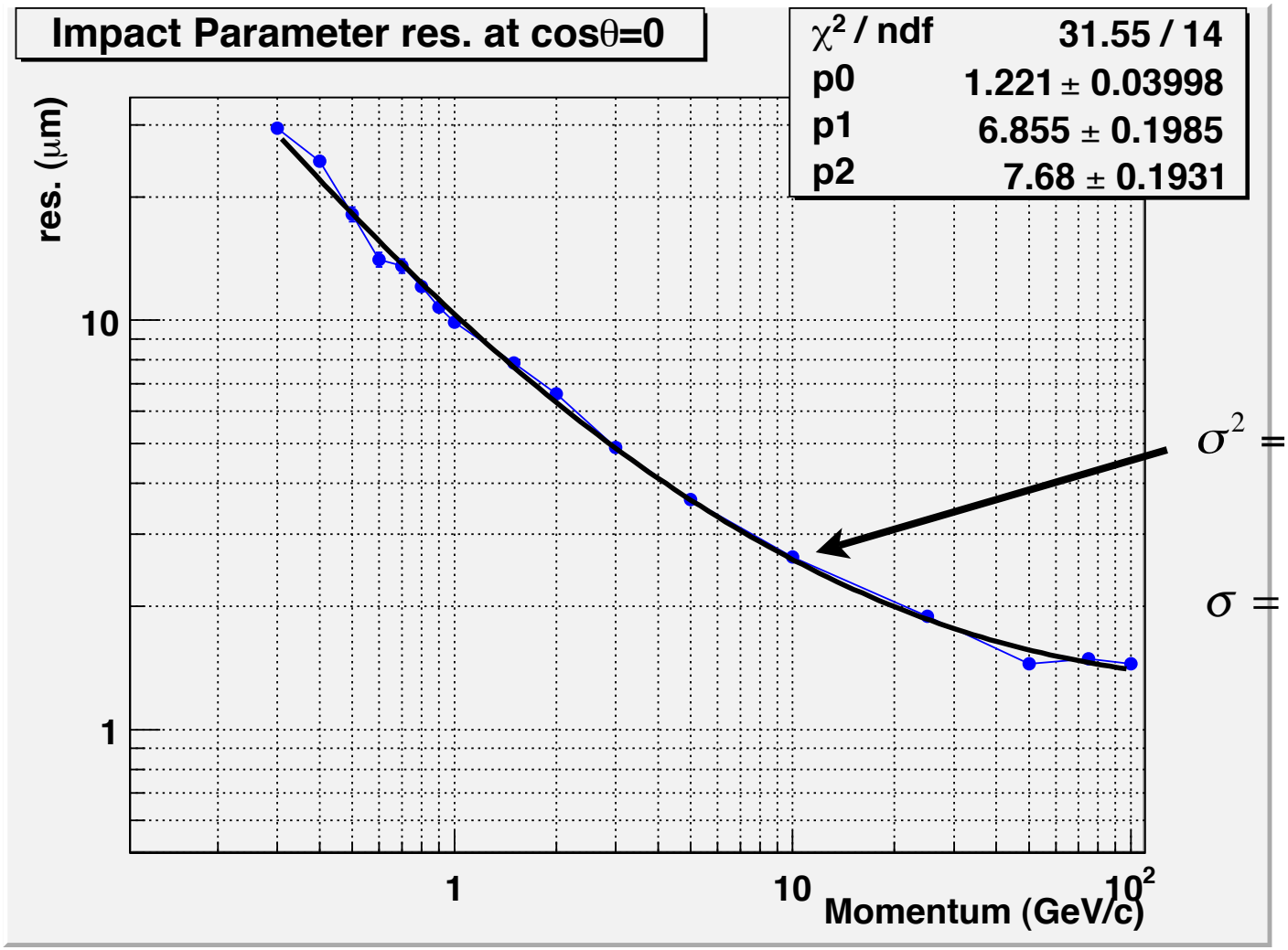


CCD Cross Section

Geometry for Simulation Study

- Cylinder 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 and 22 mm
- Doublet 2 : R= 32 and 34 mm
- Doublet 3 : R= 48 and 50 mm
- Hit position resolution: 2μm
- Beam Pipe : Be, t=250μm, R=18mm

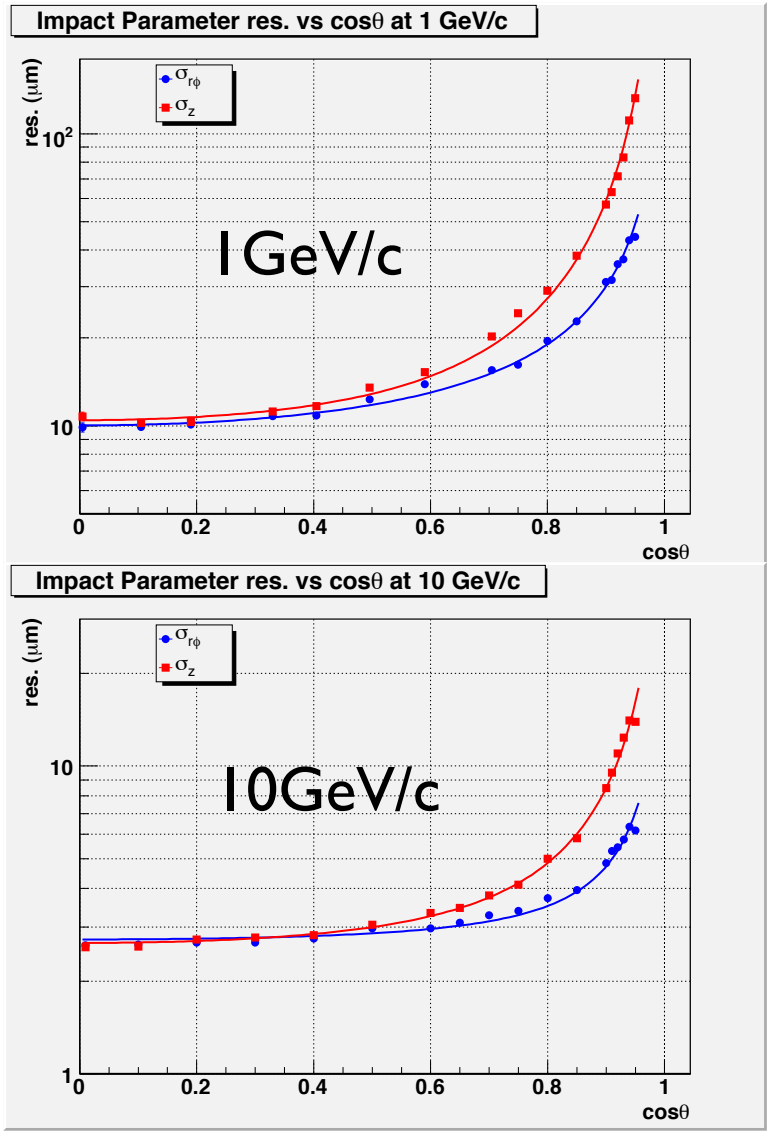
Impact Parameter Resolution σ_r Momentum Dependence

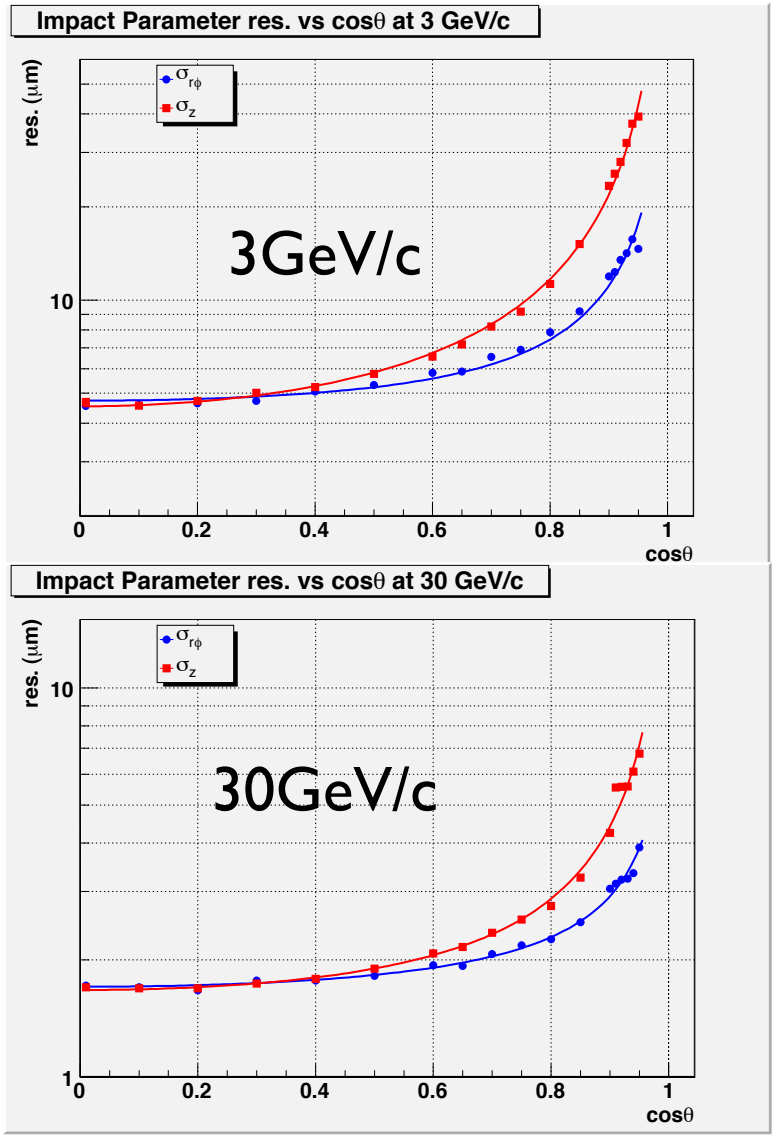


$$\sigma^2 = \sigma_0^2 + \frac{\sigma_1^2}{p} + \frac{\sigma_2^2}{p^2}$$

$$\sigma = 5 \oplus \frac{10}{P \sin^{3/2}\theta}\,(\mu m)$$

Impact Parameter Resolution
cosθ dependence at 1, 3, 10 and 30 GeV/c





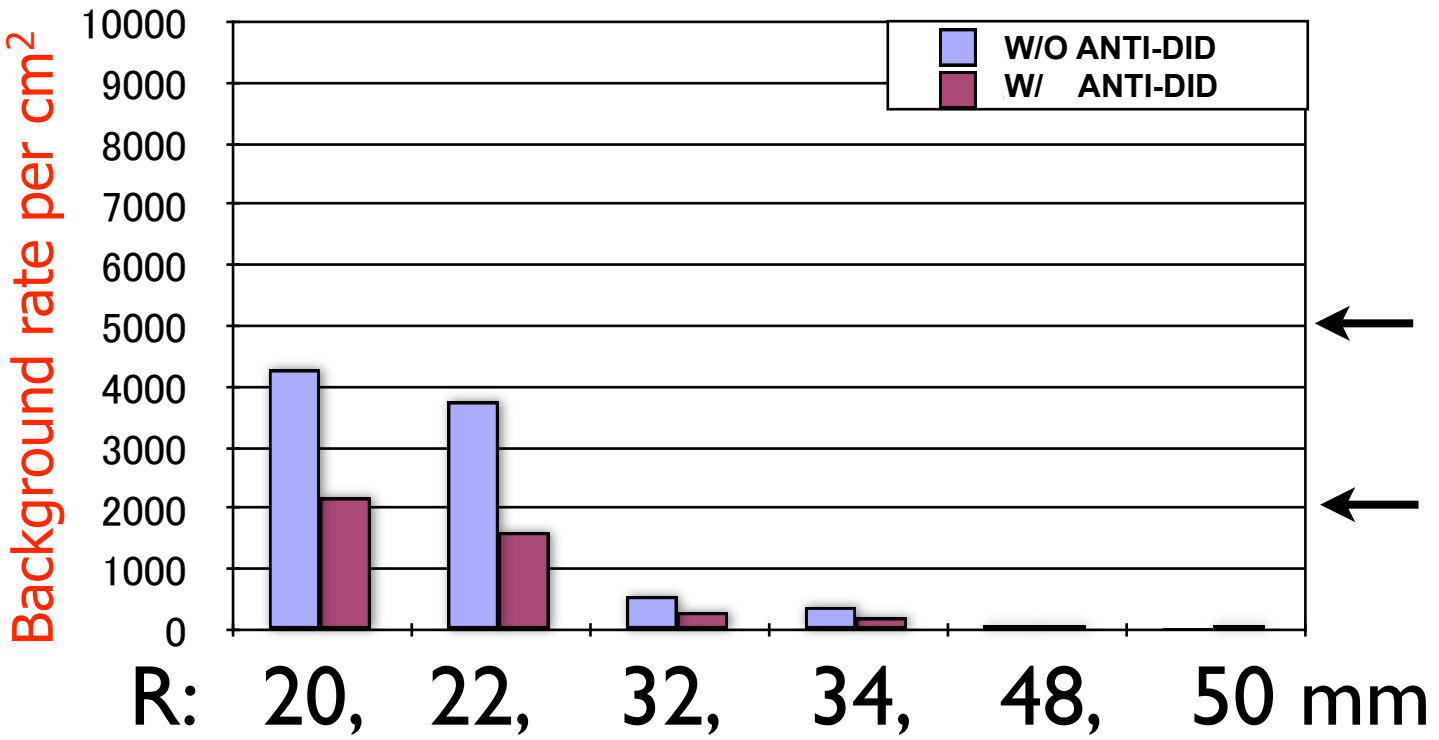
σ_r

σ_z

Effect of Pair Background to 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 when the true hit closer to the track than background hits
- Sizes of pixel and cluster are ignored

Background rates in VTX With and Without anti-DID



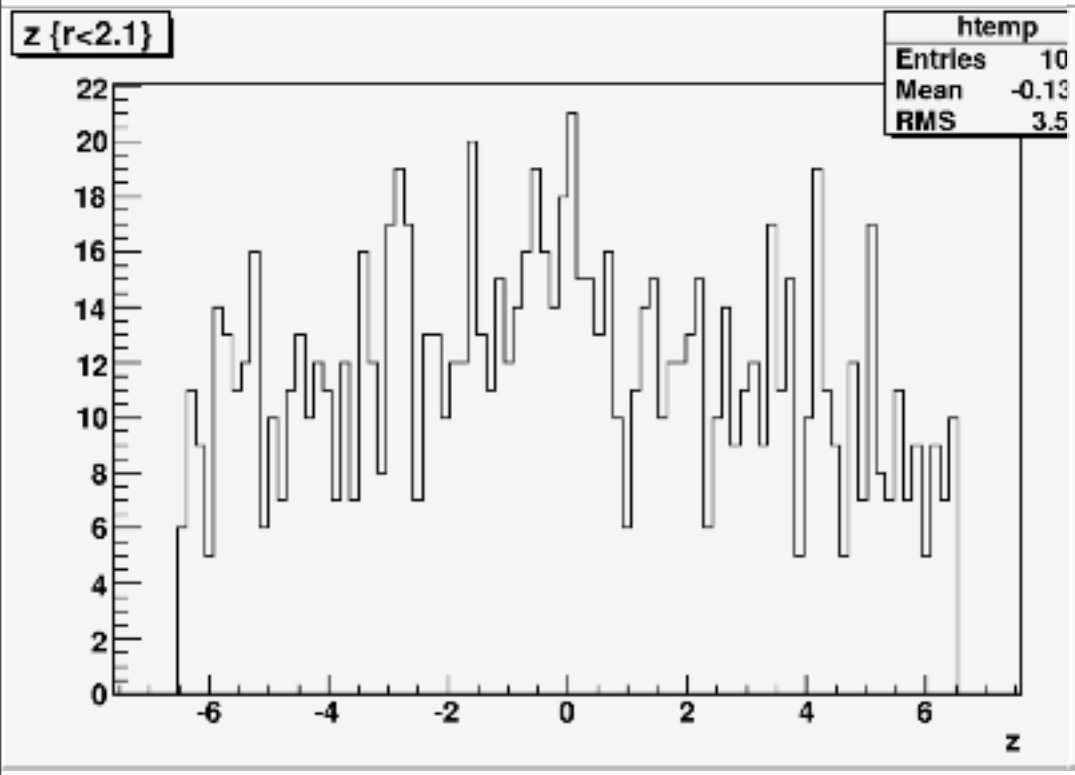
By Fujishima, Saga Univ.

← 50 hits/mm^2

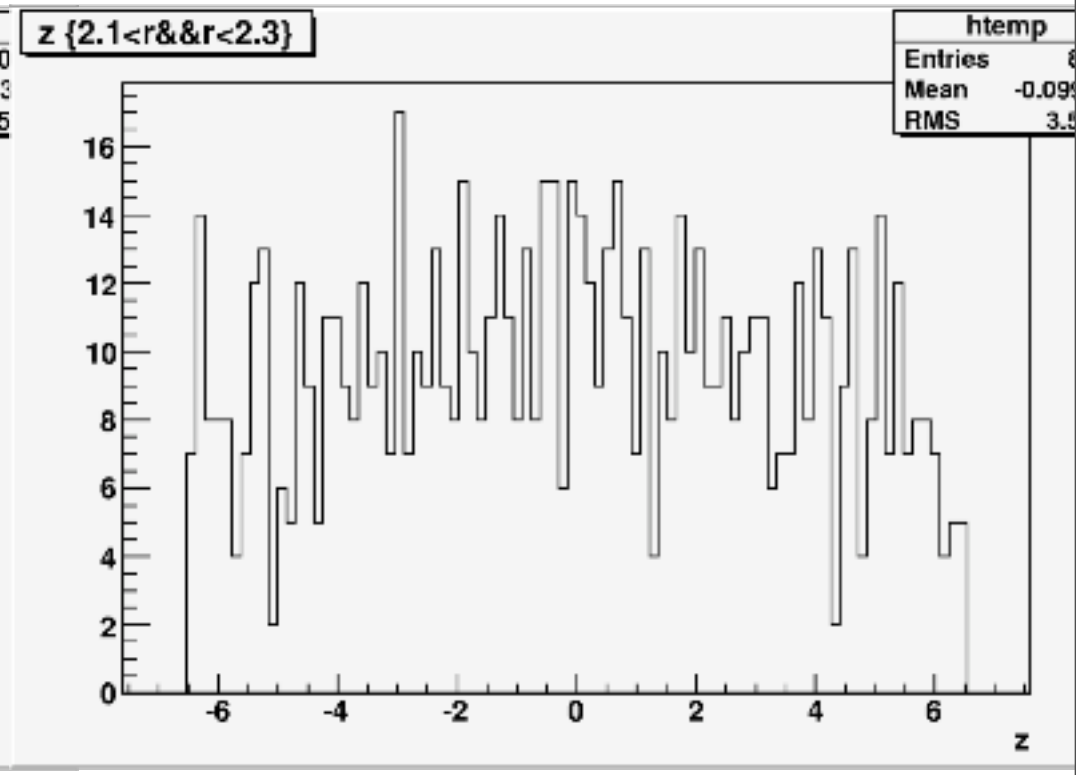
← 20 hits/mm^2

- CAIN + Jupiter(Geat4) results
- Beam Parameter: nominal 500GeV, 14 mrad
- Background rate is reduced to 1/2 with ANTI-DID Field

Z-distribution of Pair Background hits



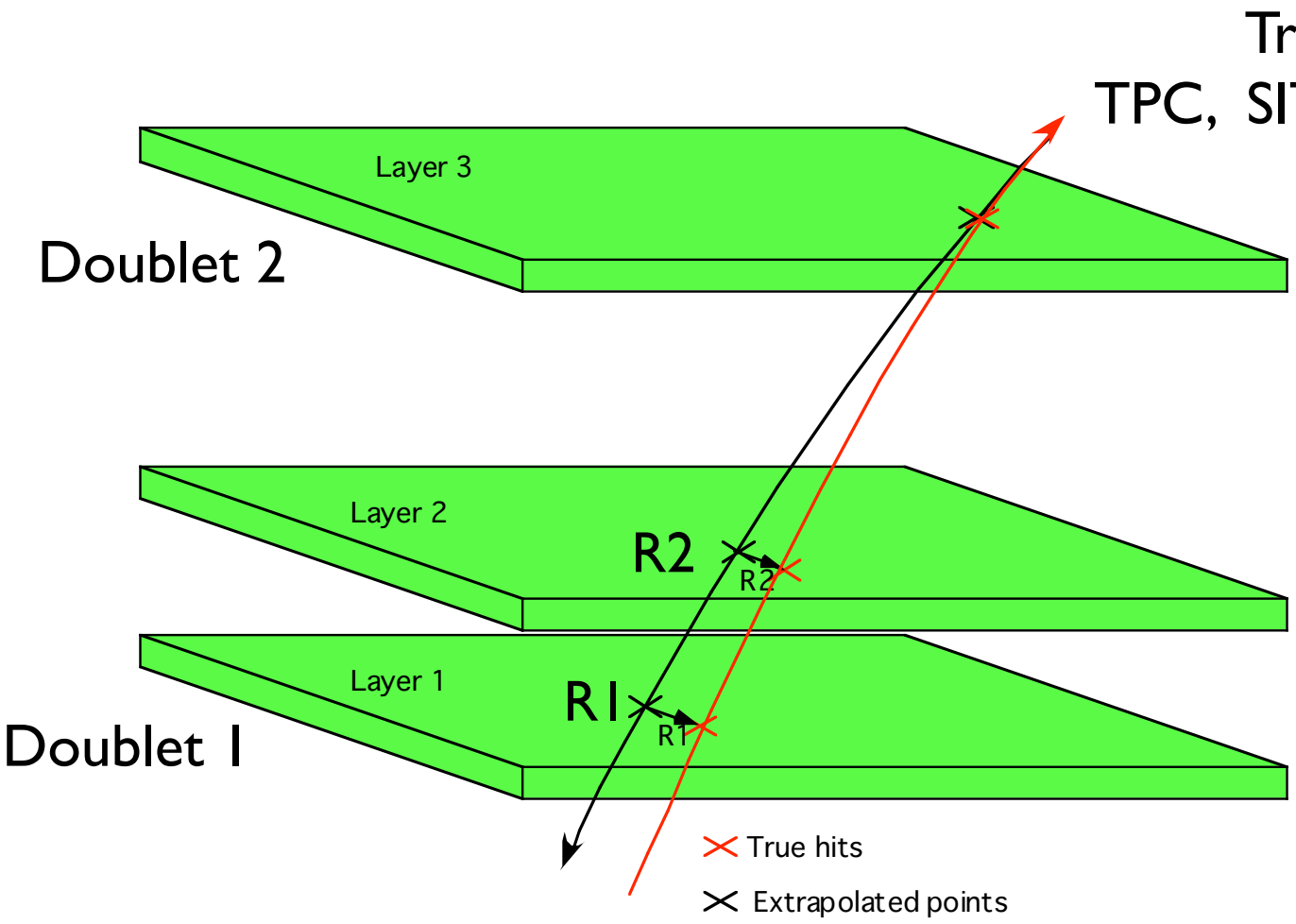
Layer 1



Layer 2

By Fujishima

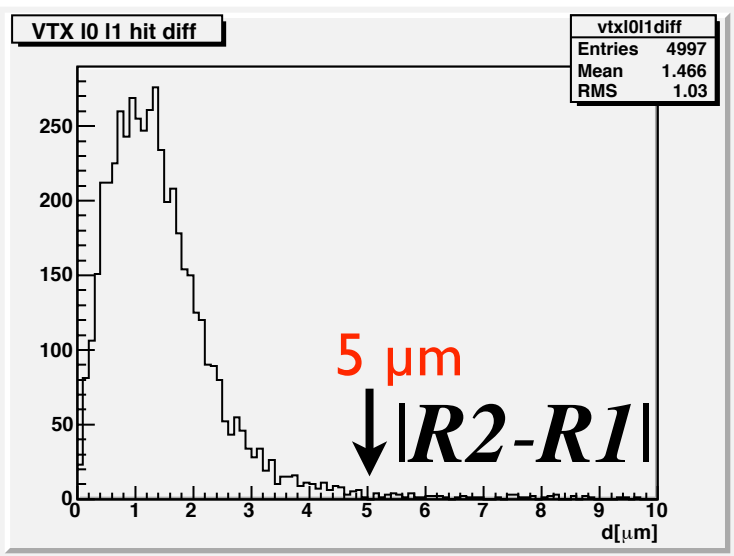
Track Hit displacement at layers of the inner Doublet

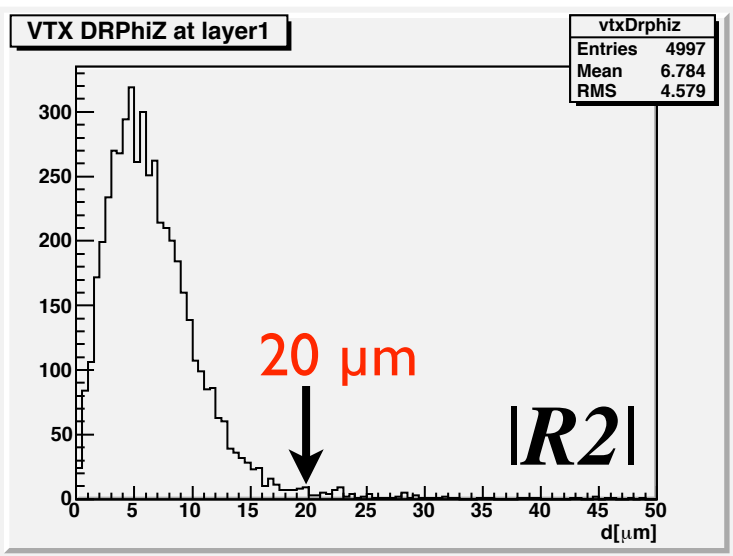


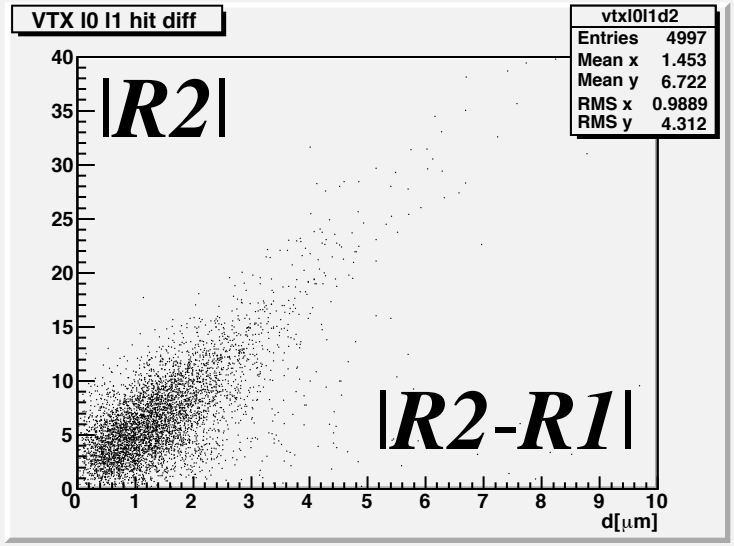
Layer 1&2 Hits is not used to fit tracks

R1,R2 : Distance/Displacement between extrapolated point to true hit

Track-Hit distance distributions

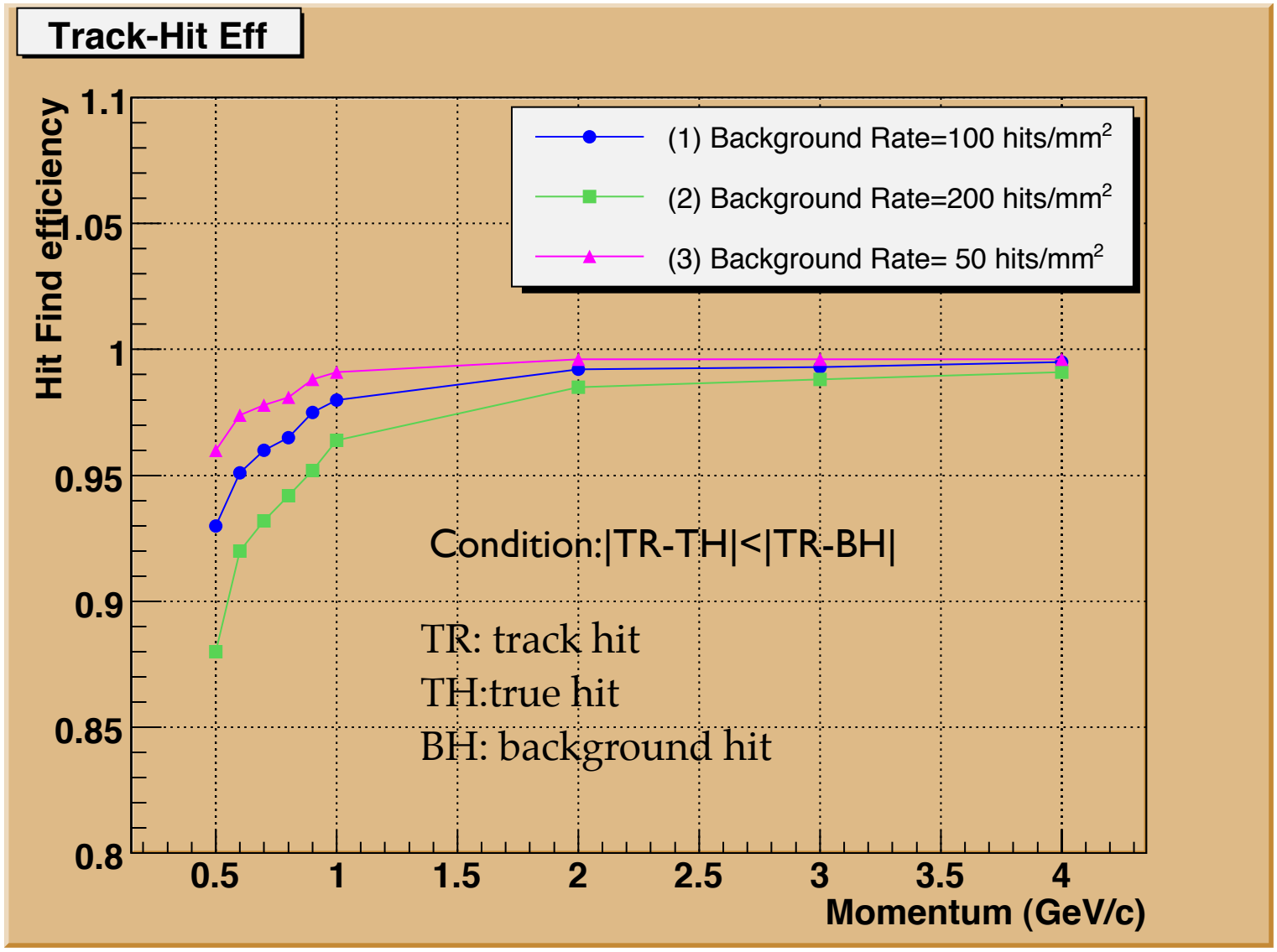






Muon
1 GeV/c
COSθ=0.05

Hit Finding Efficiencies on Layer 2

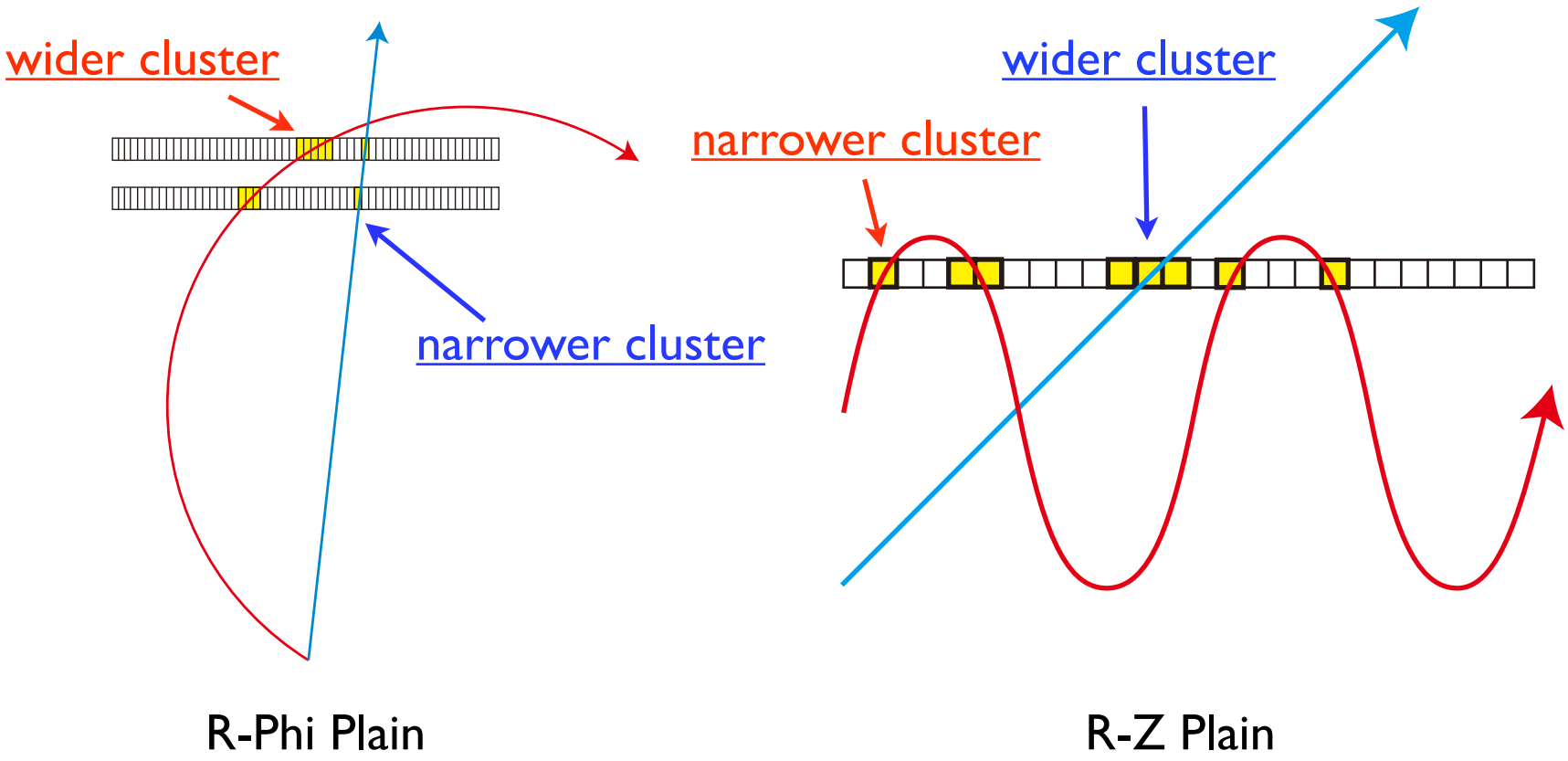


- Efficiency loss due to background in **one** of the layers of Doublet is small or tolerable.
- FPCCD based Vertex Detector with doublet structure can work under hight hit rates.

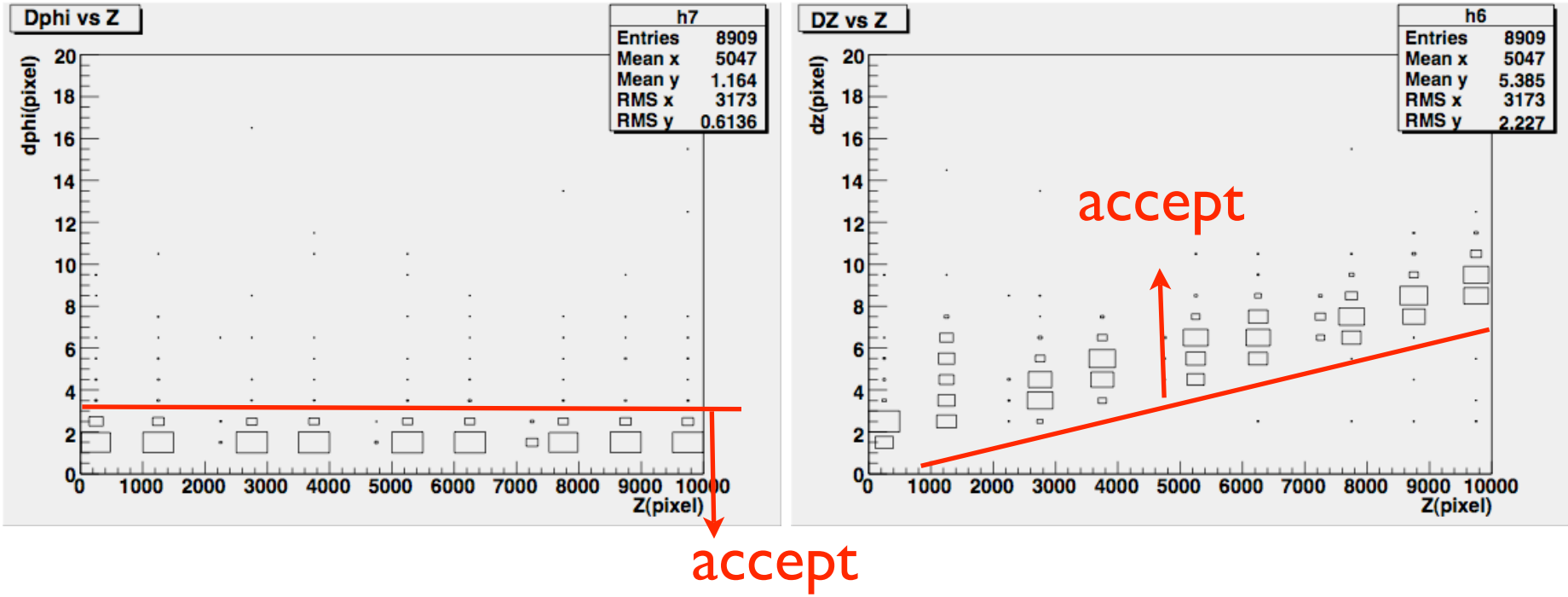
  - Good outer tracking detector - SIT and TPC
  - With outer 4 layers, precise extrapolation to inner layers is possible.
  - Very thin layers reduce track errors.
  - Small pixel size matches the small track errors.

Cluster Shapes of Low- and High-Pt tracks

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

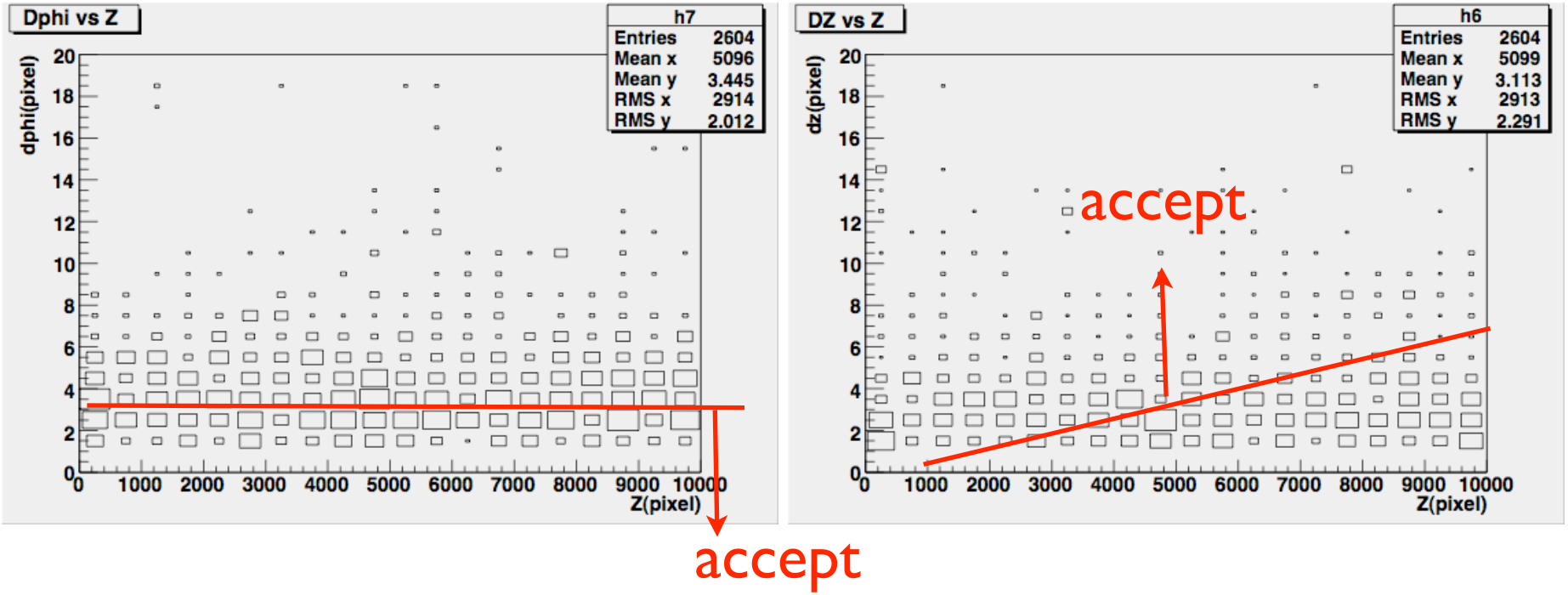


Distributions of Cluster Width v.s. Z for 1 GeV/c μ^- Tracks



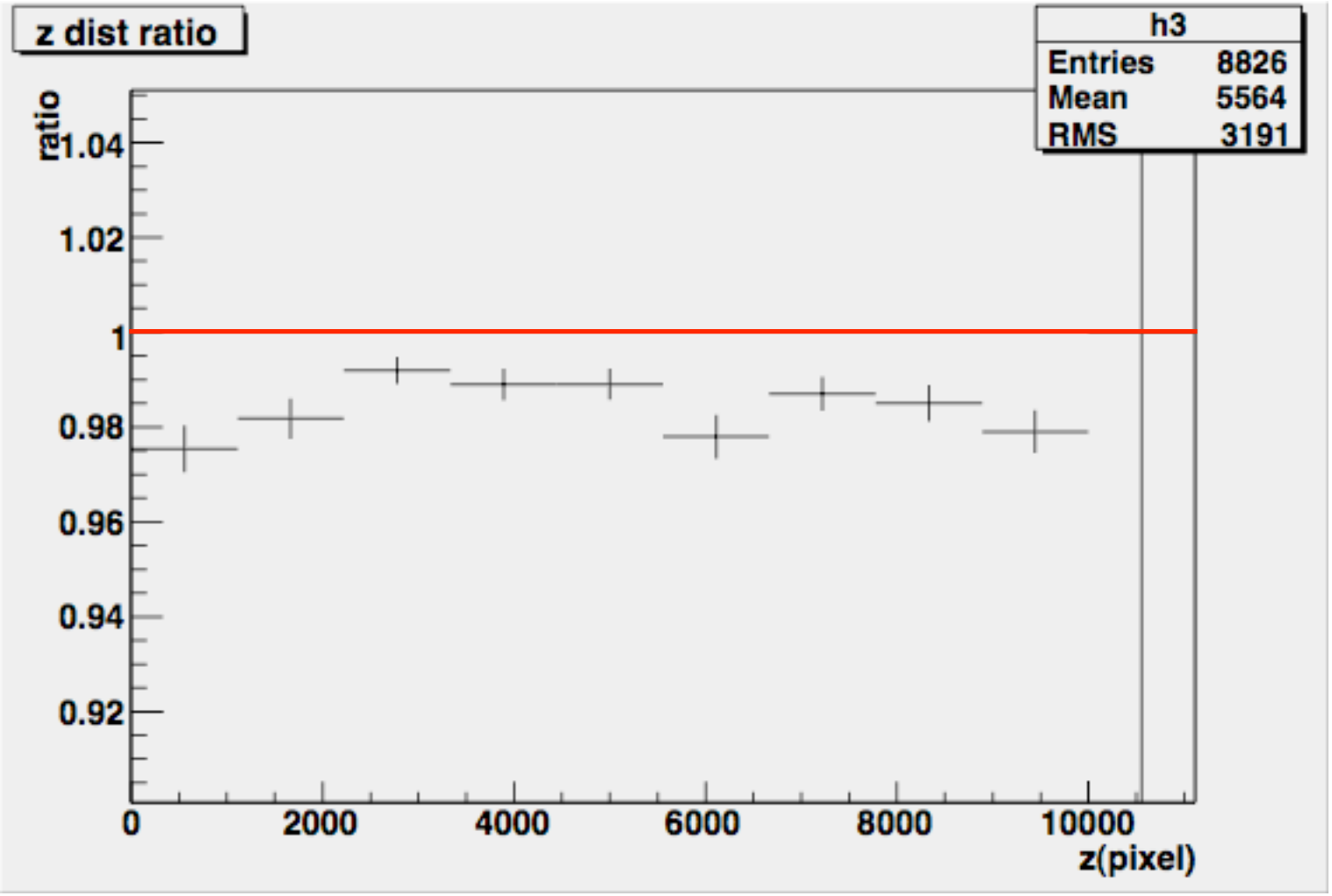
- Left: Phi, Right: Z
- Clear Z dependence of Cluster Width in Z

Distributions of Cluster width v.s. Z for Pair Background

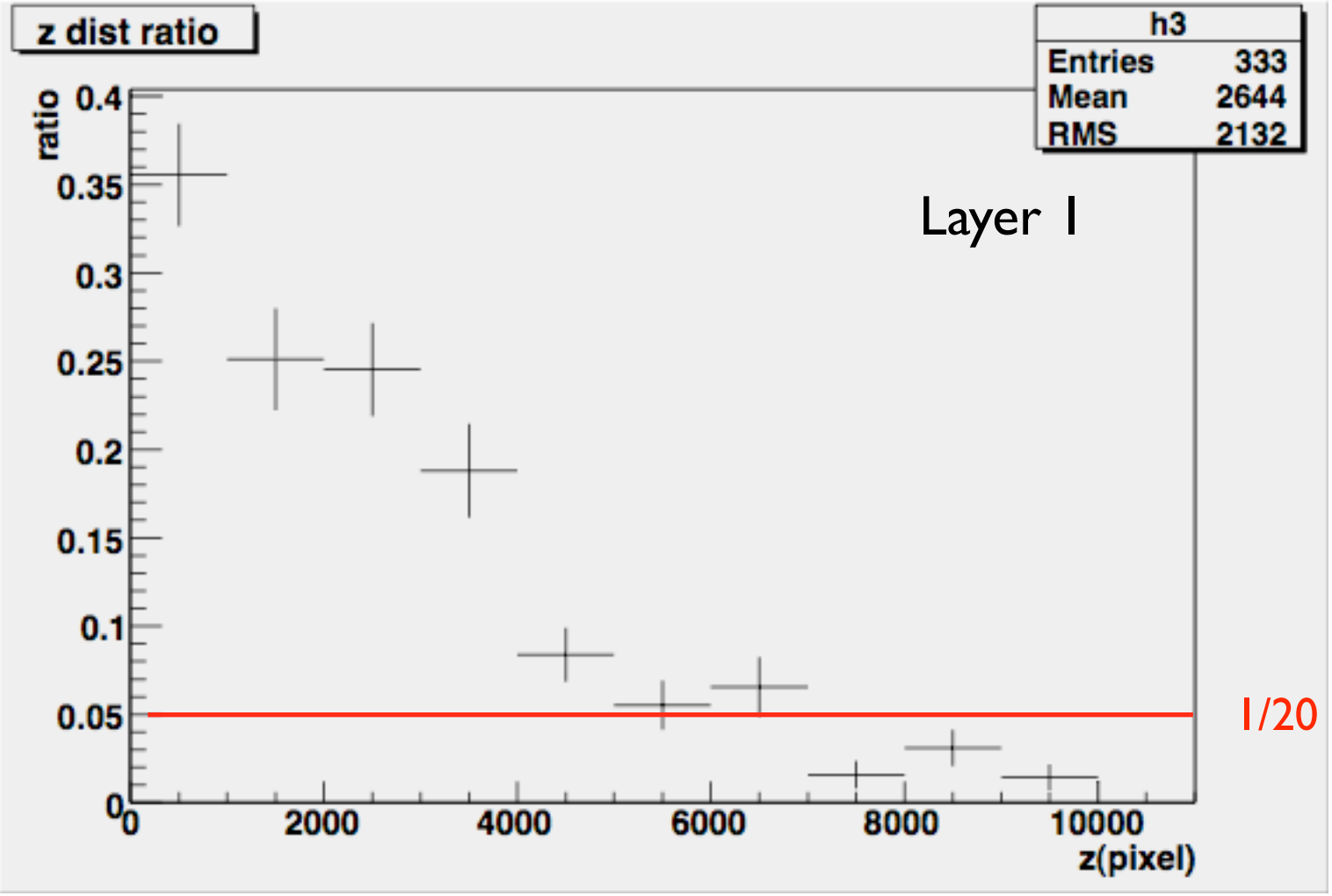


- Left: Phi, Right: Z
- No Z dependence in both Phi and Z

Efficiencies for 1 GeV/c μ^- Tracks

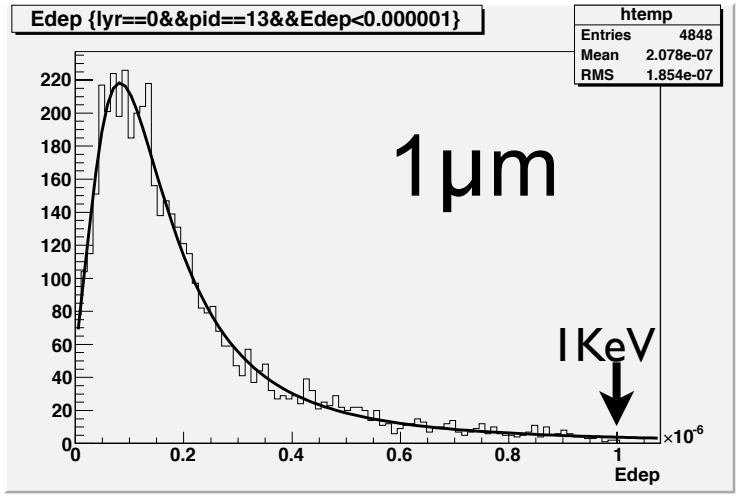


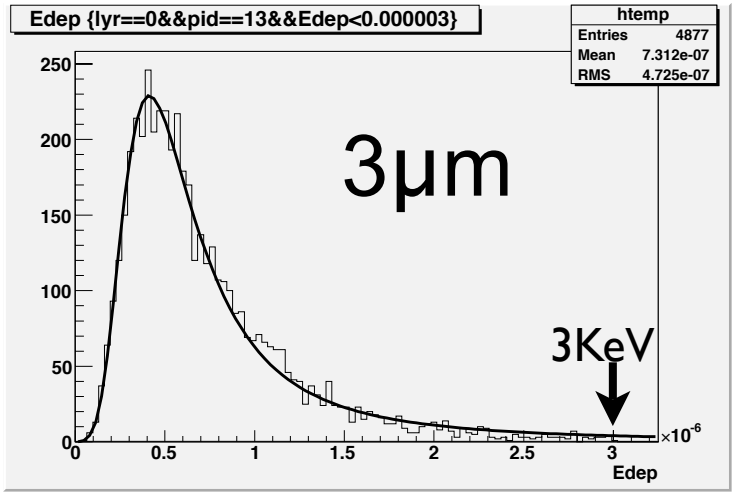
Cluster Shape Rejection for Pair Background

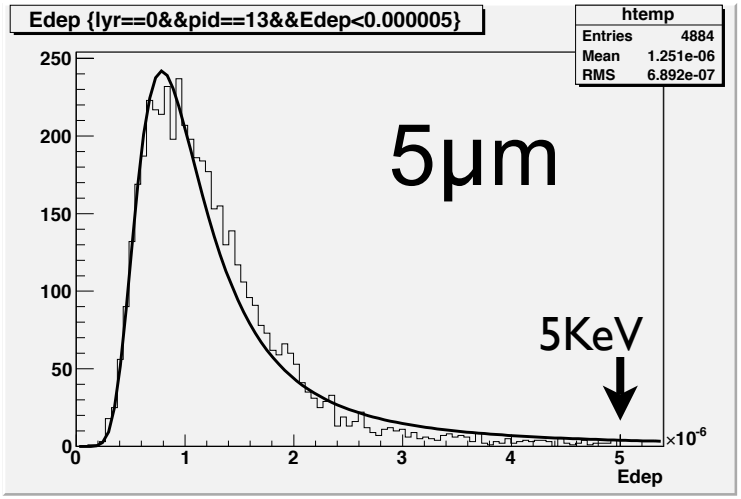


- Pair BackGround Rejection : 1/2 ~ 1/20 depend on Z

Energy Deposit Study in Very Thin Silicon Layer





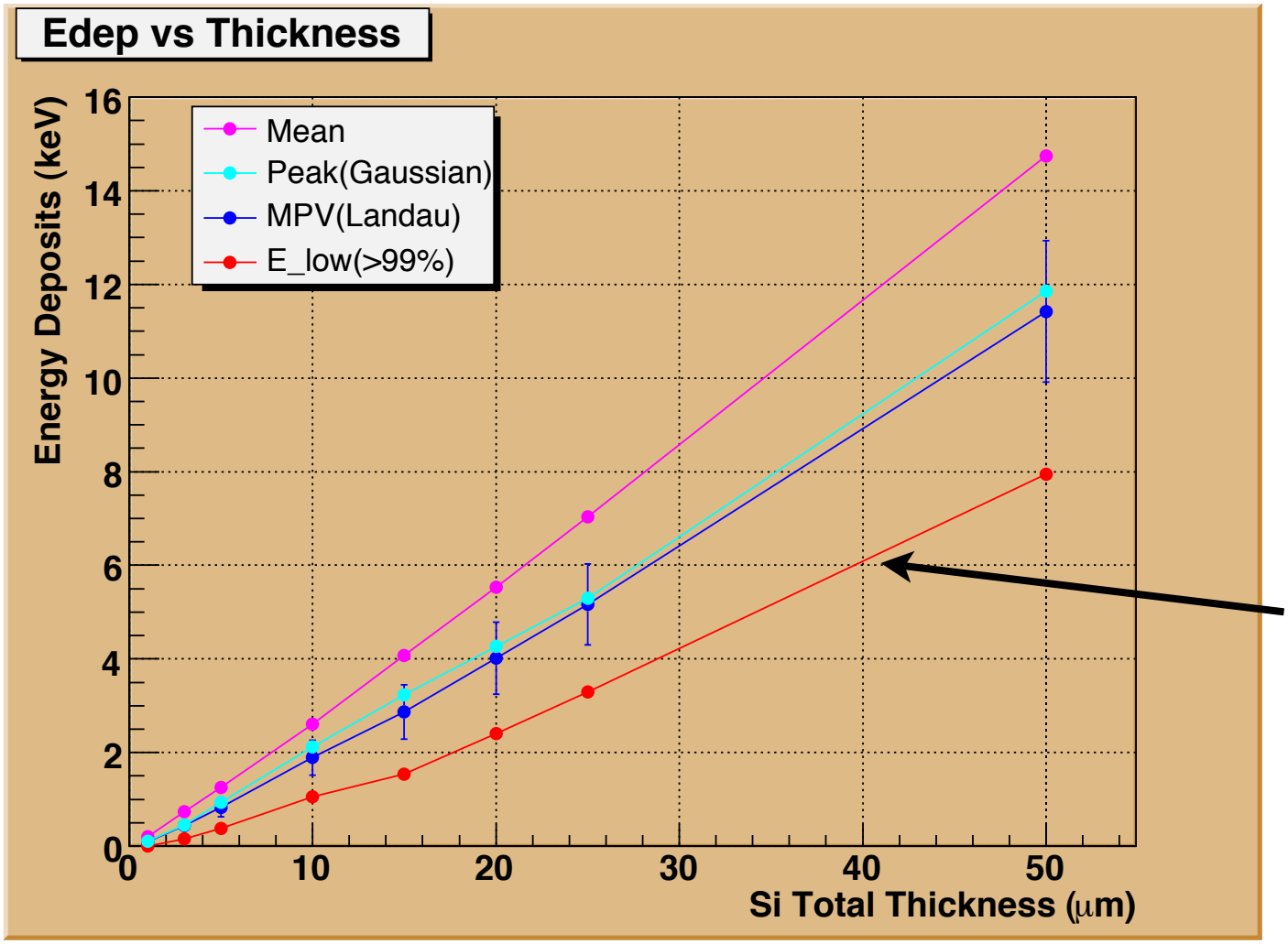


Geant4 Simulation

T = 1, 3 and 5 μm

1 GeV/c Muon

MPV and E_{low}(>99%)



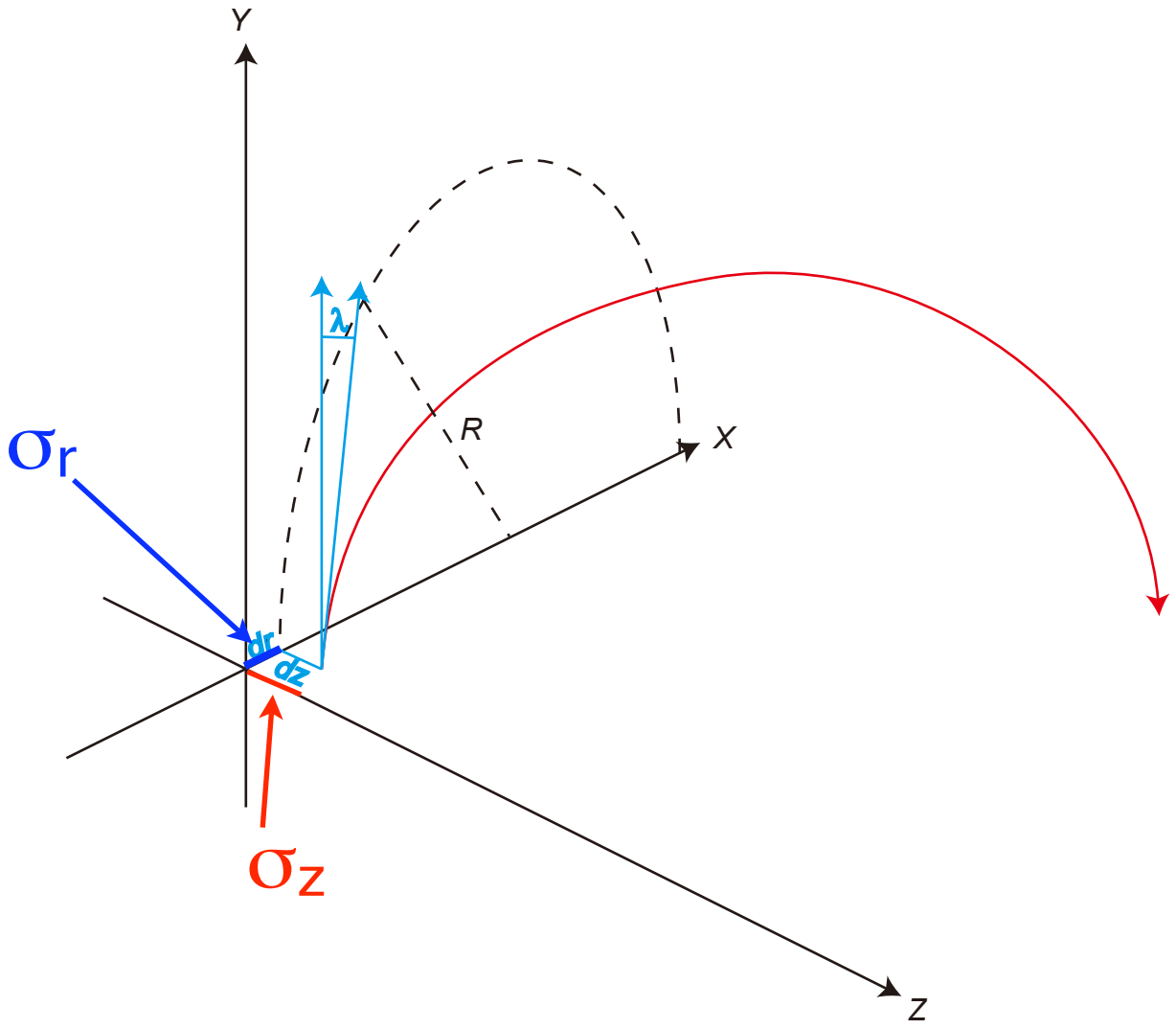
E_{low}(>99%)

Summary

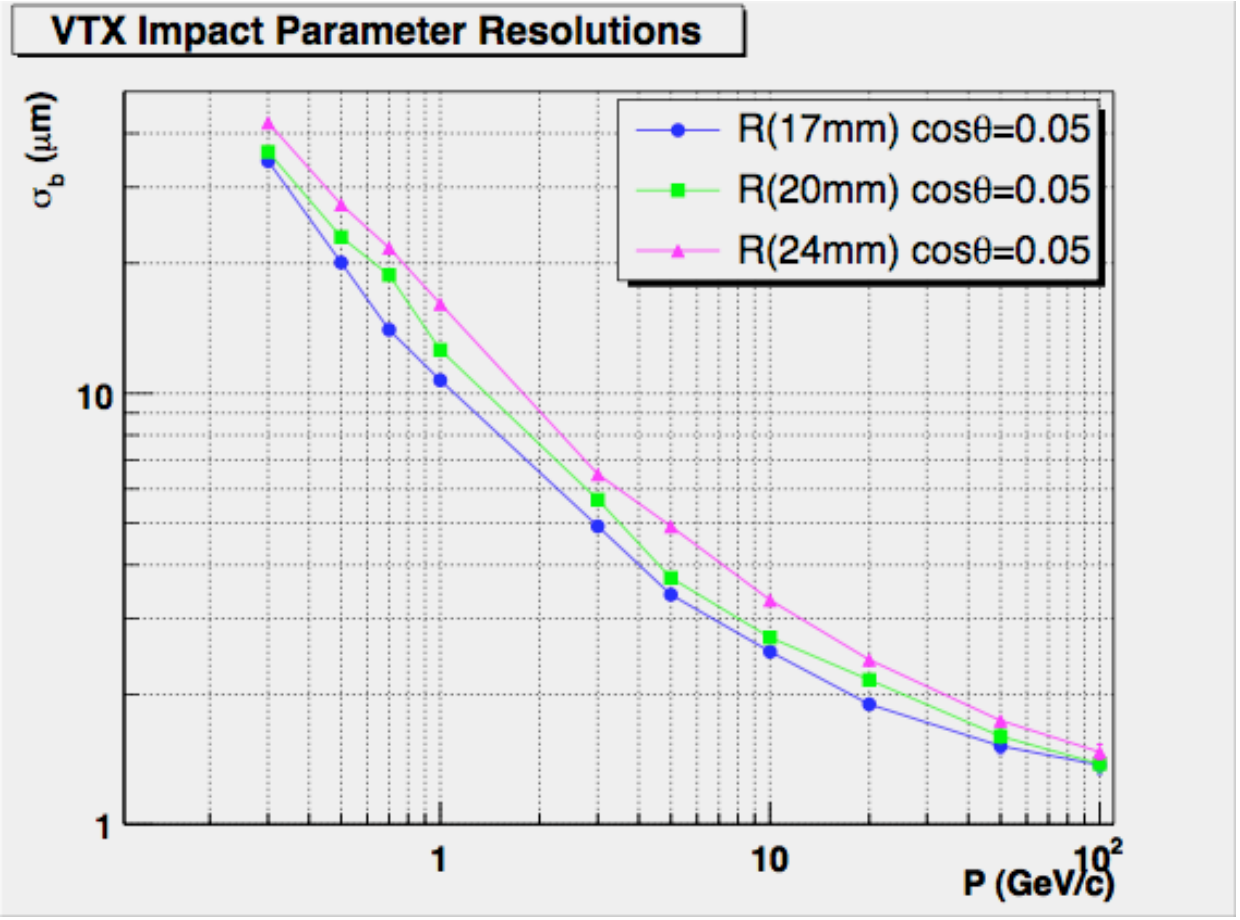
- Good Impact Parameter Resolution can be achieved with FPCCD base Vertex detector.
- Good tracking efficiency can be expected under high background rate (100 hits/mm^2) for higher momentum region, and up to 50 hits/mm^2 for lower momentum region
- Pair Background rejection/discrimination is possible by Cluster shape (rejection factor : 1/2~1/20)
- Need more study for energy deposit in thin Si layers

BackUp

Impact Parameter Study and Helix Parameter



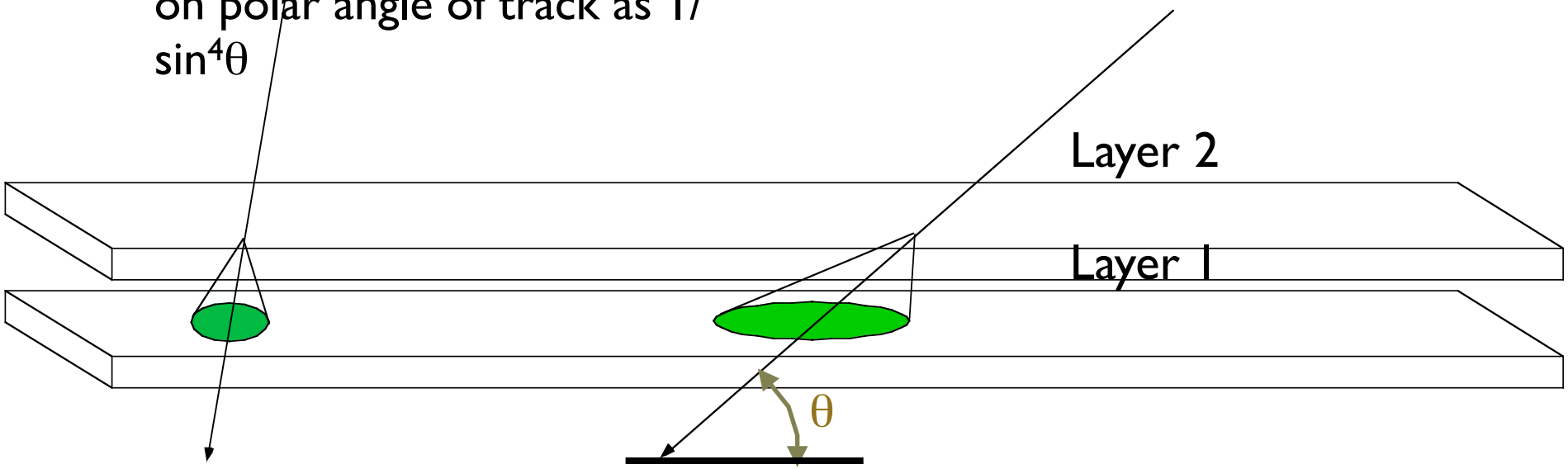
Impact Parameter Resolution
R dependence (OLD Geometry)



- Impact Parameter Resolution(R-phi plane) v.s. Momentum
- μ^- at cos(θ)=0.05
- Impact Parameter Resolution increases as radius increases

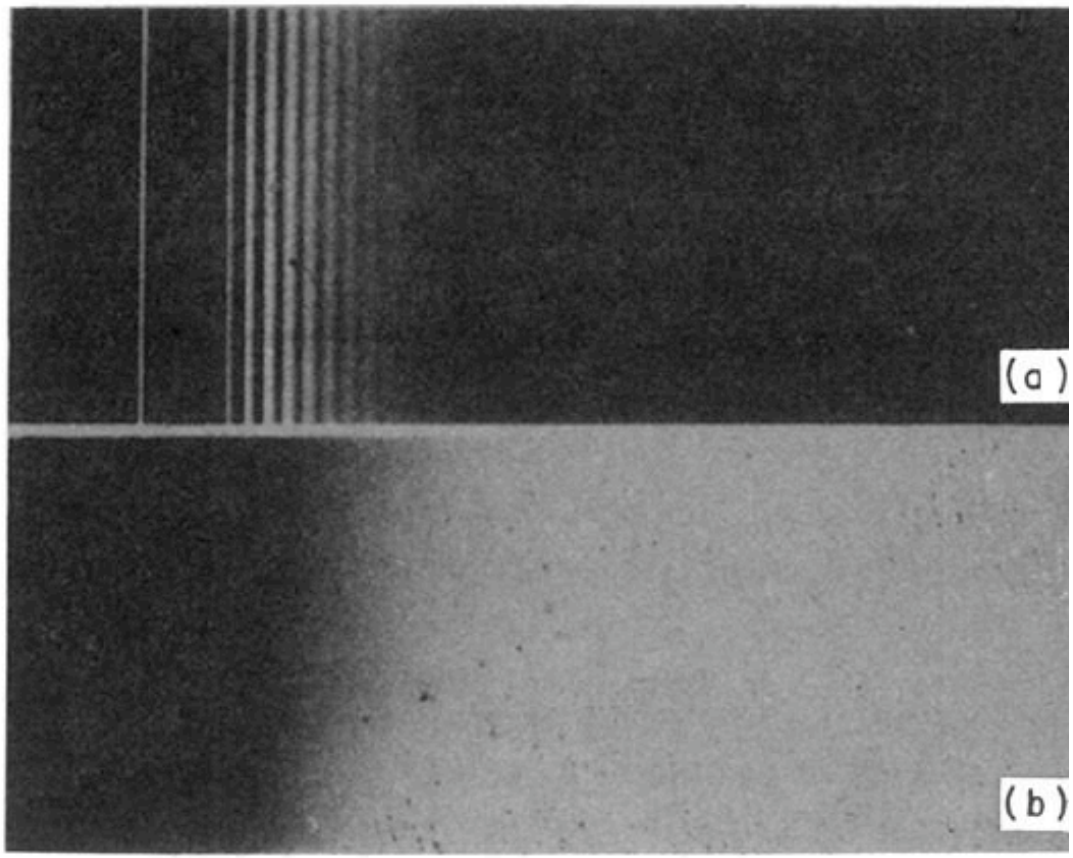
Track Finding in Pair Background

- Track Finder is under development in GLD SimTools!
- Efficiency depends on probability to pick up a right hit.
- Area of the window depends on polar angle of track as $1/\sin^4\theta$



Plasmon Spectrum Measurement by Electron Spectrometer

J. Perez, et al, PR A16, p1061



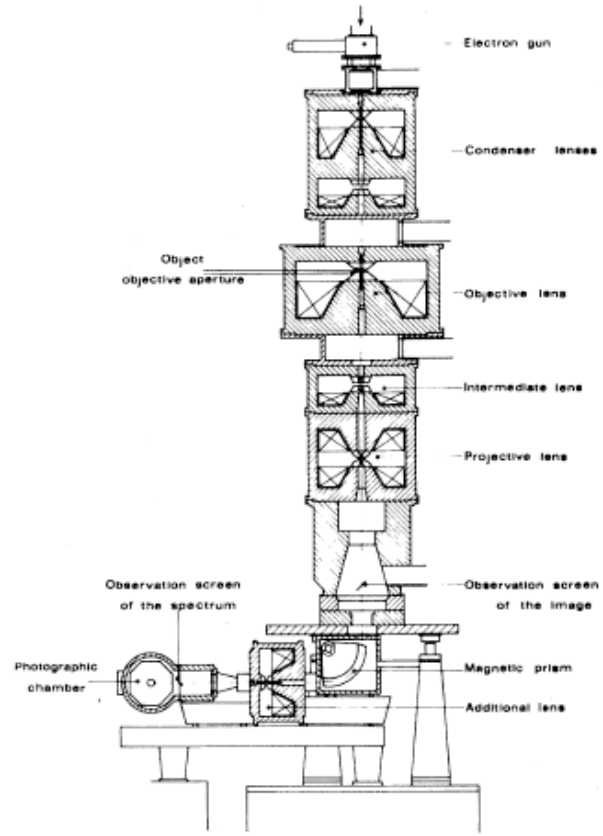
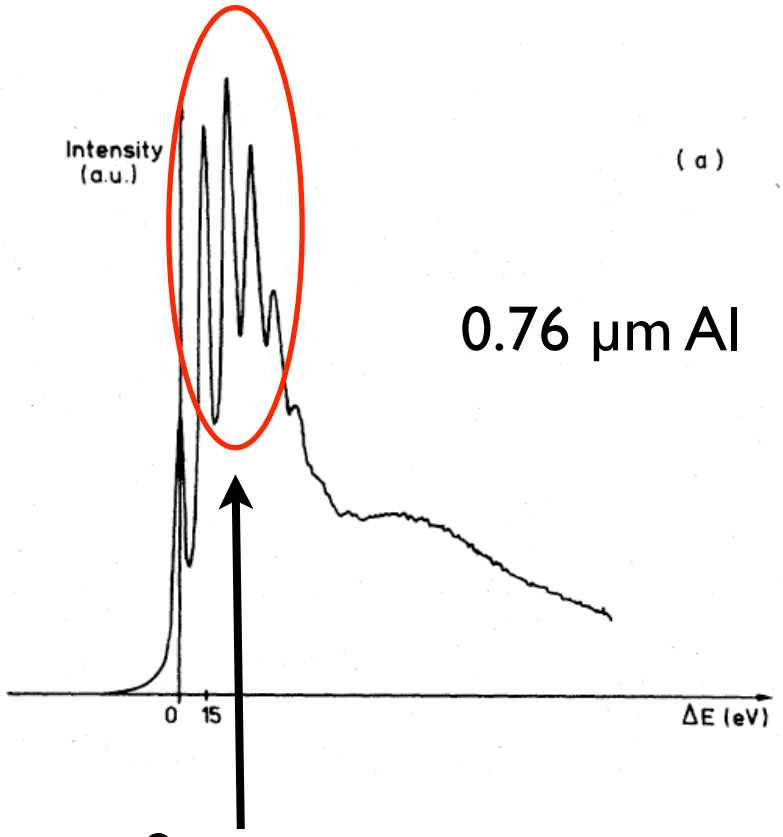
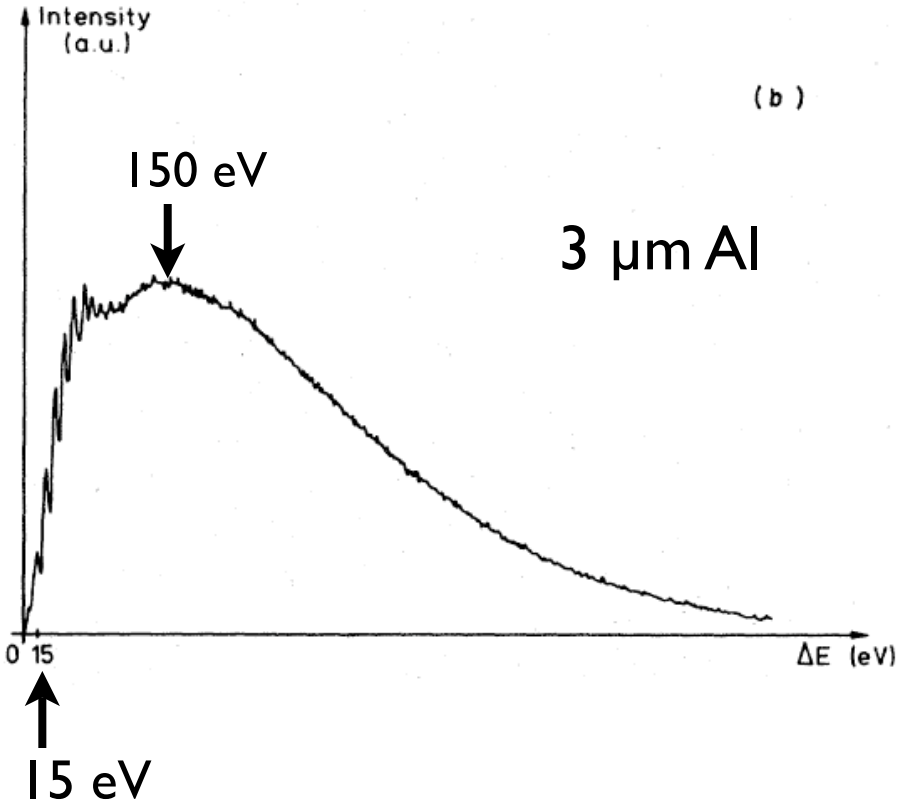


FIG. 1. Cross section of the high-voltage electron analyzer.

Electron Energy Loss
0.76 and 3 μm Al, T=1.0 MeV

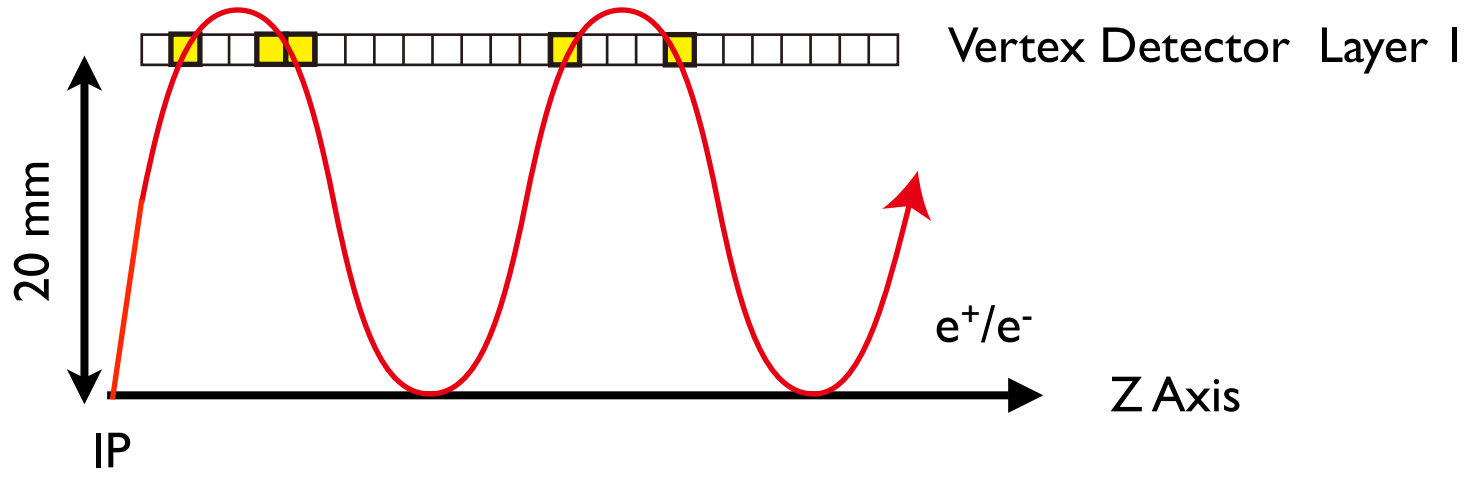




- Plasmon Peaks: 15eV separation

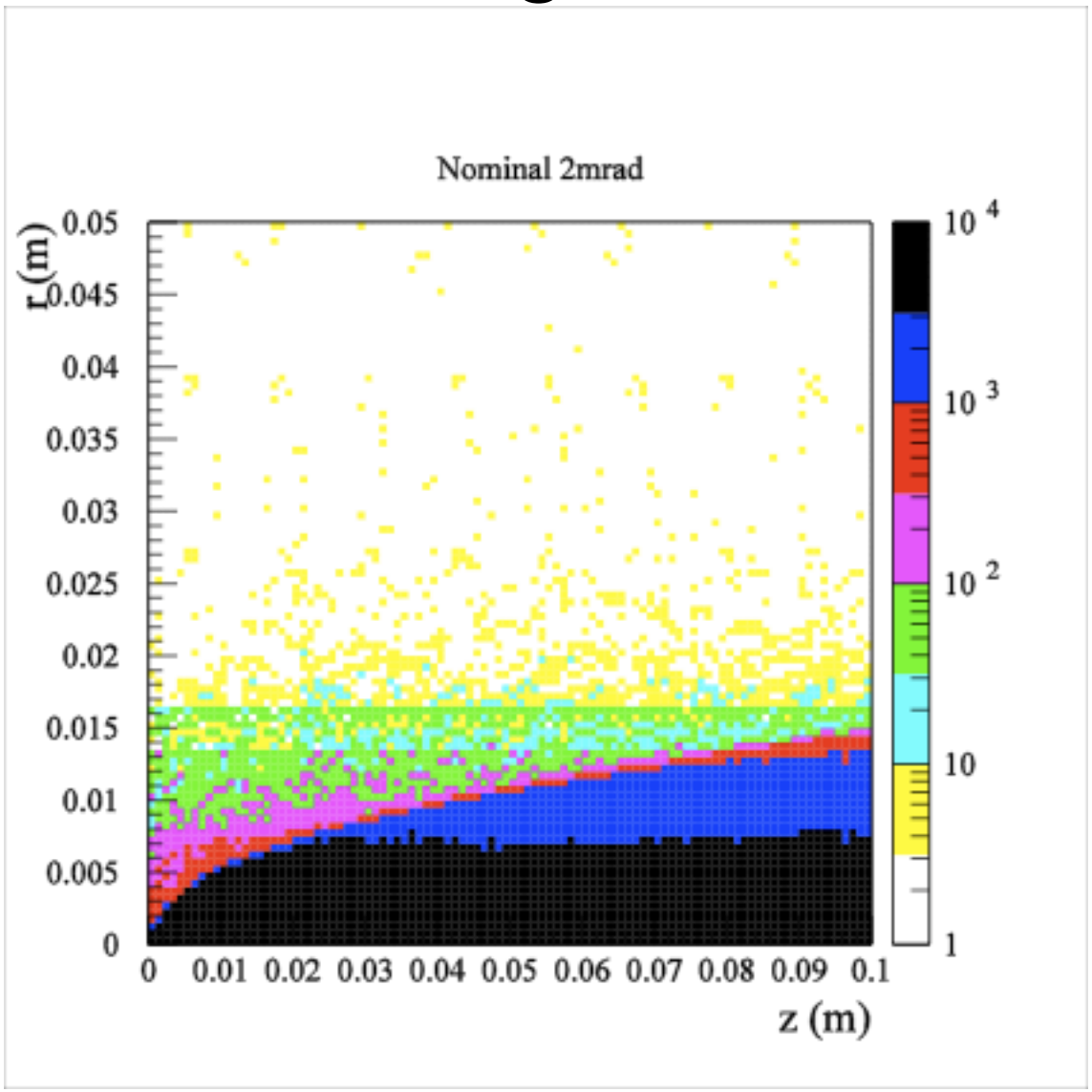
J. Perez, et al, PR A16, p1061

Pair BackGround Trajectory



- Pair Background(e+/e-) have low-Pt
- Their Radii are small
- They hit the vertex detector many times

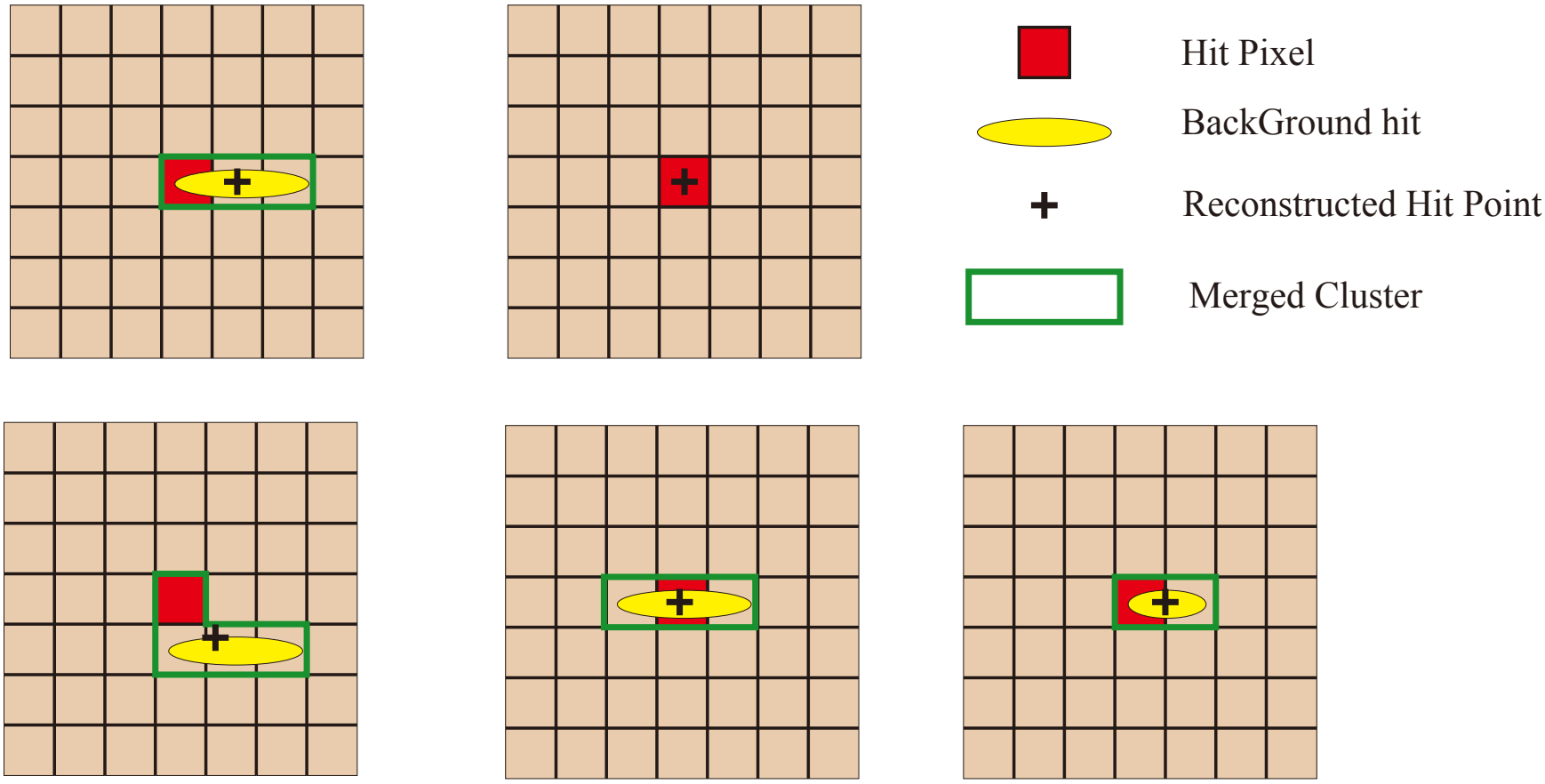
Distribution of Pair Background in Vertex Region



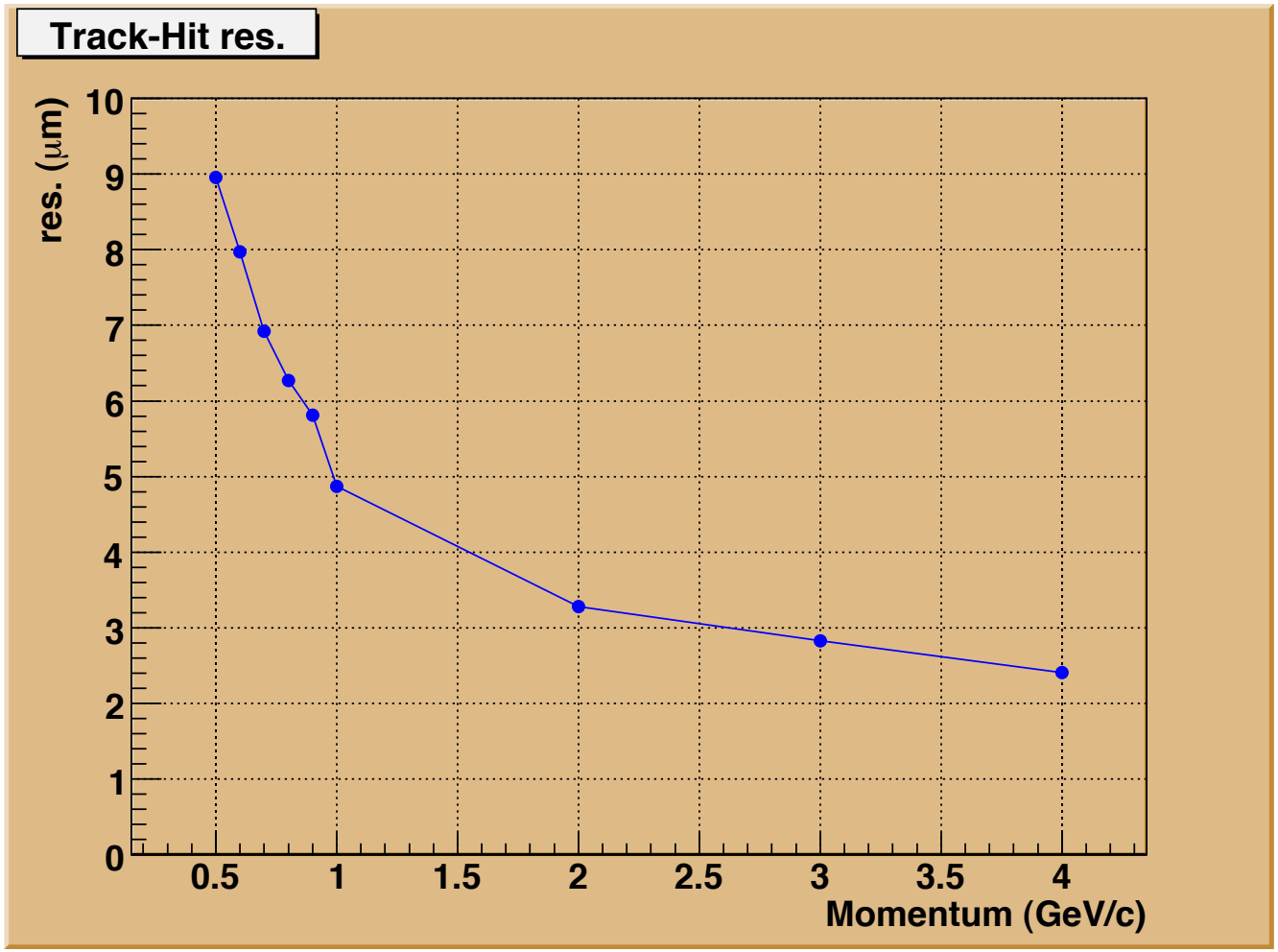
B=3T

By Sugimoto

Cluster Overlap Pattern

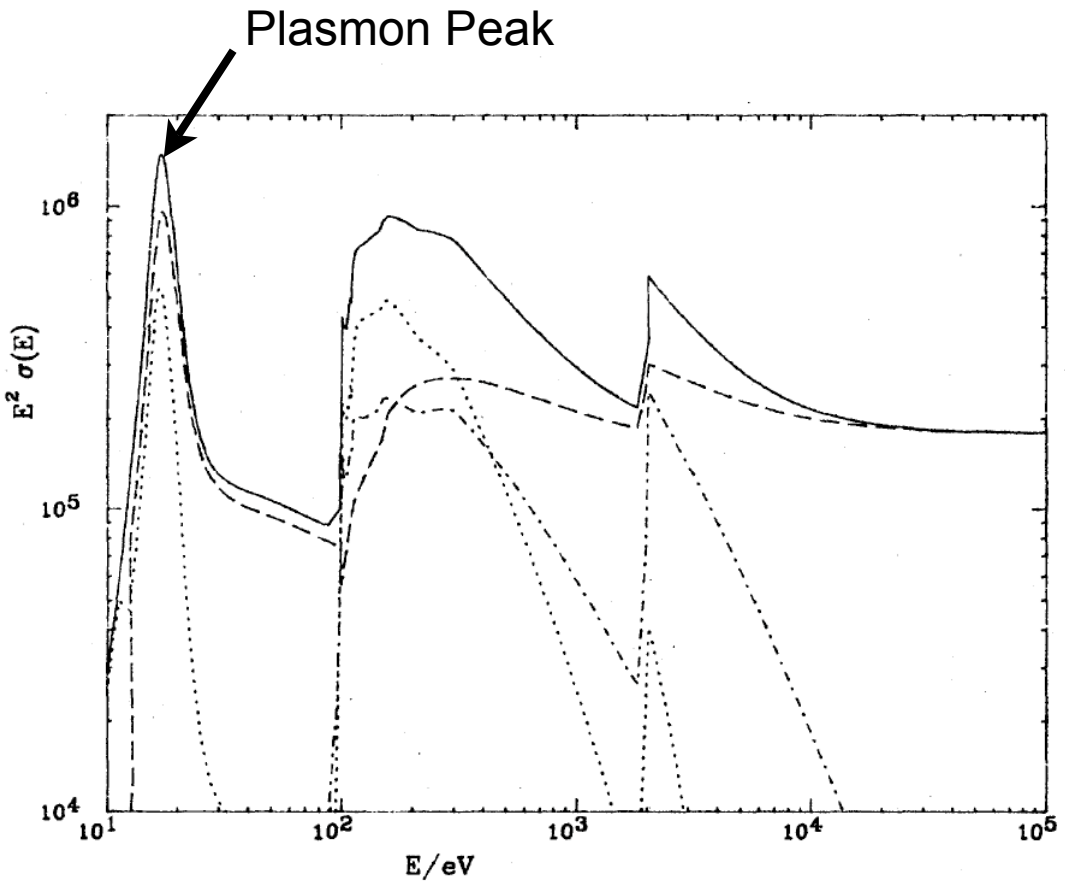


|*R2*| resolution v.s. Momentum



~ 1/3 of Impact Parameter Resolution at IP

Energy Deposit in Thin material



differential collision cross section in Silicon

H. Bichsel, Rev. Mod. Phys. 60, p663

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