DEPFET Pixel Sensors Simulation in Marlin

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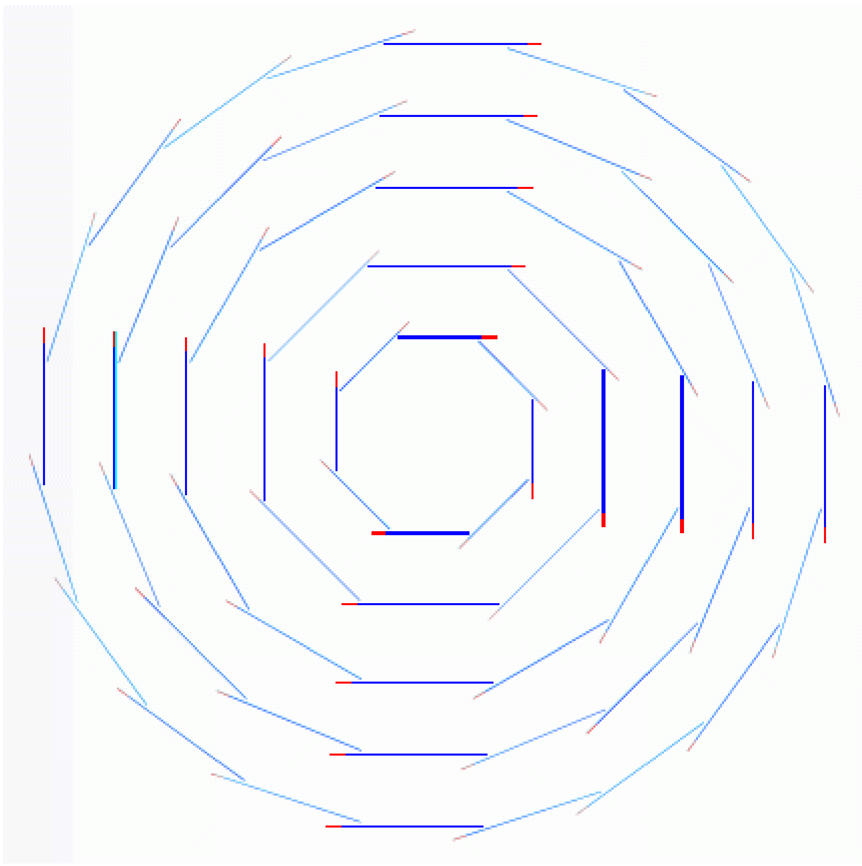
Introduction : Scope of Studies

- **Implementation of DEPFET based VXD in Mokka (Geant4 ILC Detector Simulation package)**
- **Development of detailed digitization code (Marlin Processor) for DEPFET-based VXD, including following effects**
  - Landau fluctuations of specific energy loss along track path
  - charge transport and sharing between neighboring pixels; diffusion
  - Lorentz shift in magnetic field
  - electronic noise effects ... *etc*
- **Verification of simulation with testbeam data**
- **Evaluation of point resolution using digitization code**
- **Development stand-alone pattern recognition for VXD**
- **Evaluation of pattern recognition in the presence of beam induced backgrounds**

Implementation of VXD Geometry in Mokka



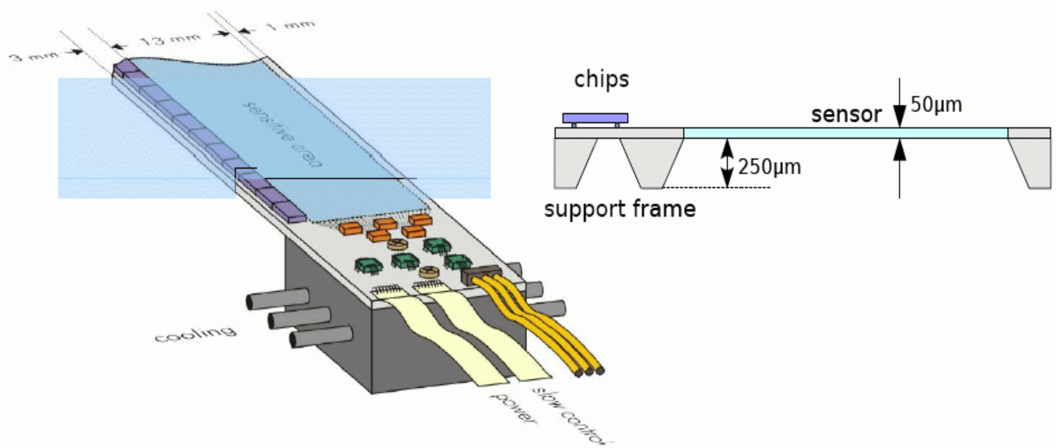
Si layer thickness = 50μm
Pixel size = 25$\times$25μm^2
(other pixel sizes also studied)

	Radius (cm)	Ladders	Length (cm)
1	1.5	8	10.0
2	2.6	8	2×12.5
3	3.8	12	2×12.5
4	4.9	16	2×12.5
5	6.0	20	2×12.5

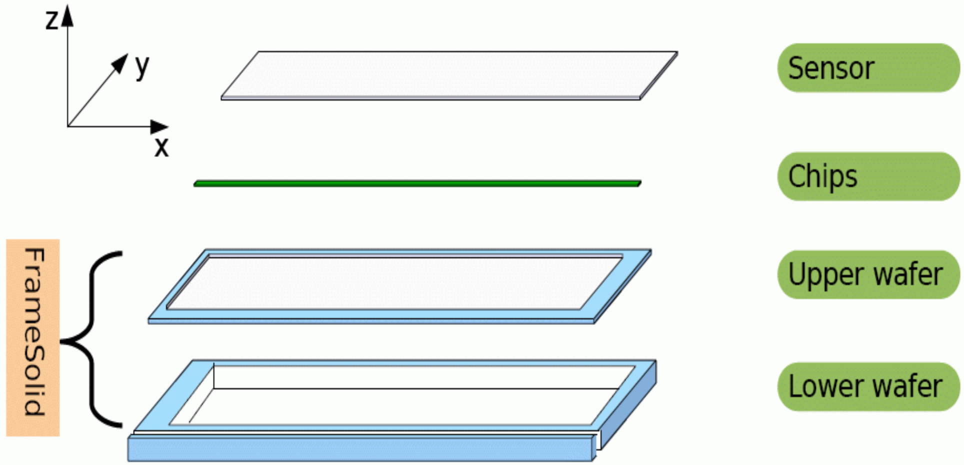
Material up to first layer : **beam pipe (500 μm beryllium)**

Implementation of VXD Geometry in Mokka

Layout of Ladders



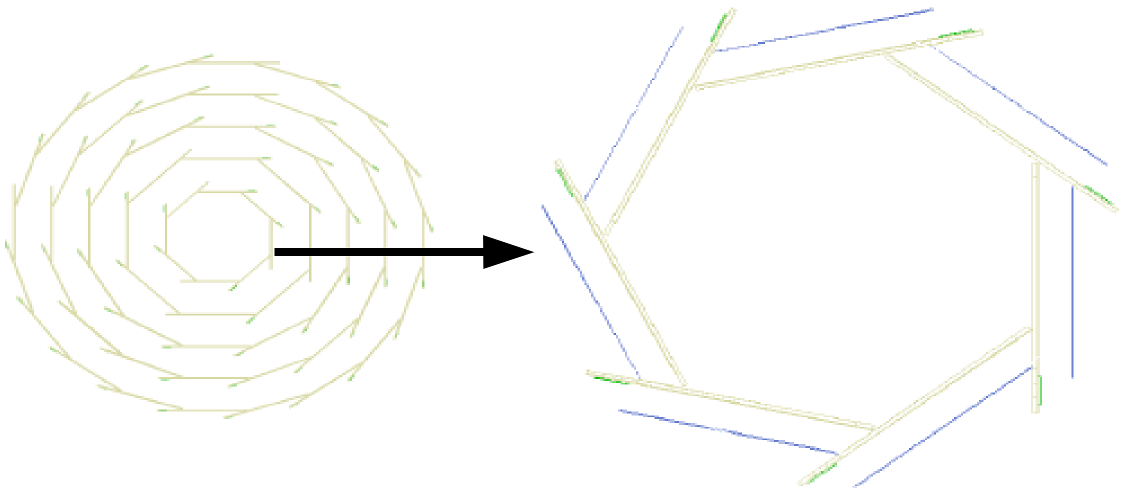
Build a Ladder



- Dedicated Mokka driver (VXD03.cc) is implemented by Xun Chen
- Geometry parameters are stored in mySQL DB (vxd03)

Test Mokka Setup

Idea proposed by Marc Winter: put 2 layers few mm apart instead of one @ 12-14 mm distance from beam axis to support efficient pattern recognition in the region of severe background environment



Standard setup

	radius	ladders	length	ladder gap
1	15.5	8	100	0

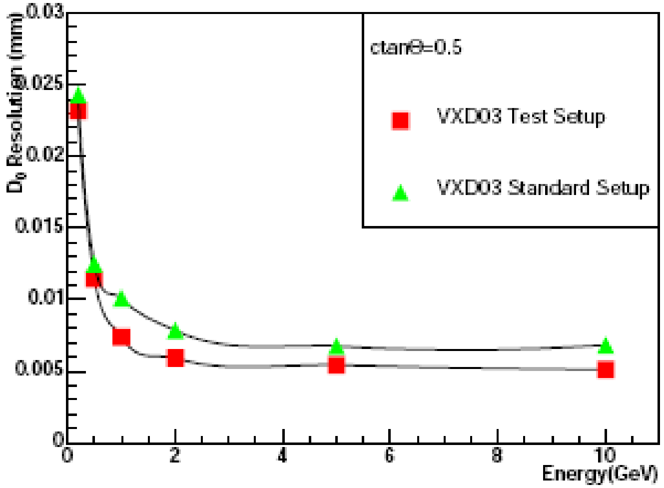
Test setup

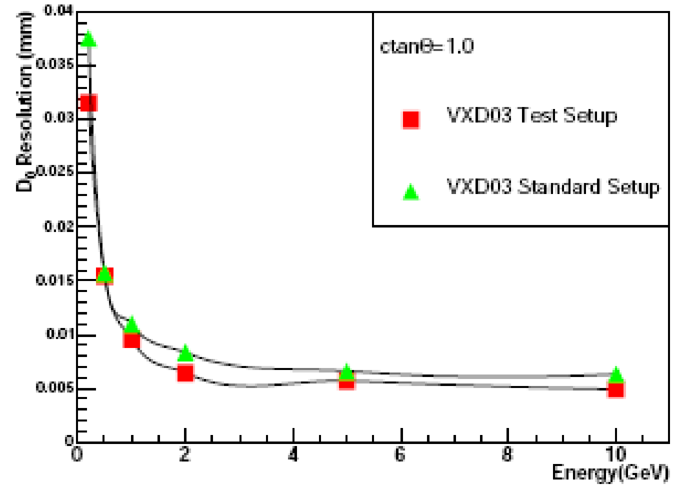
	radius	ladders	length	ladder gap
1	12	7	100	0
a	14	7	100	0

Implemented in Mokka by Xun Chen. Geometry of two innermost layers is steered via mySQL DB parameters

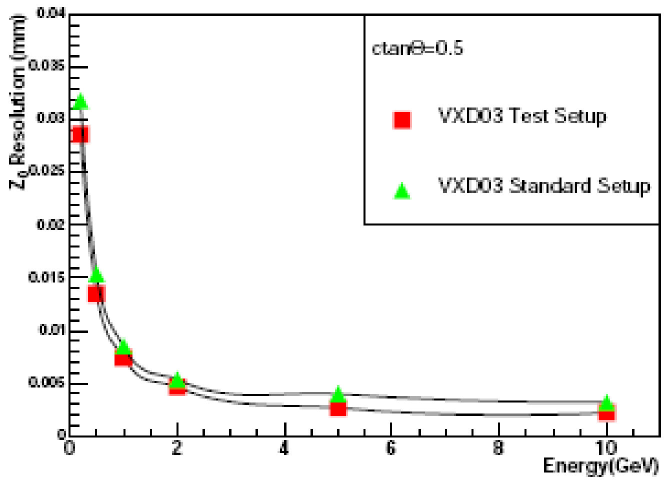
Initial Studies of Test Setup

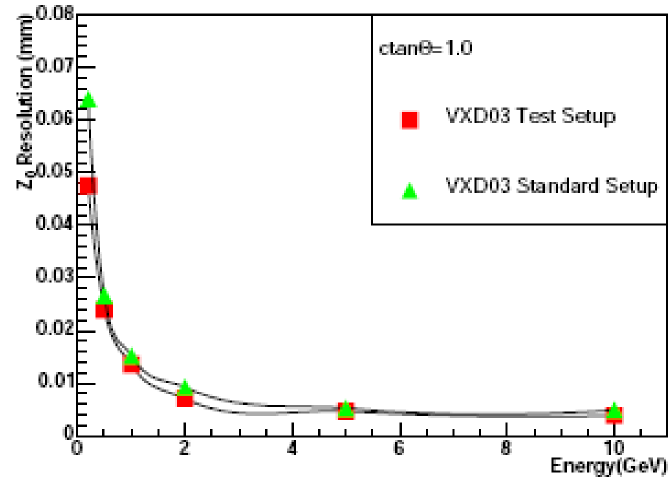
D0 Resolution for single tracks





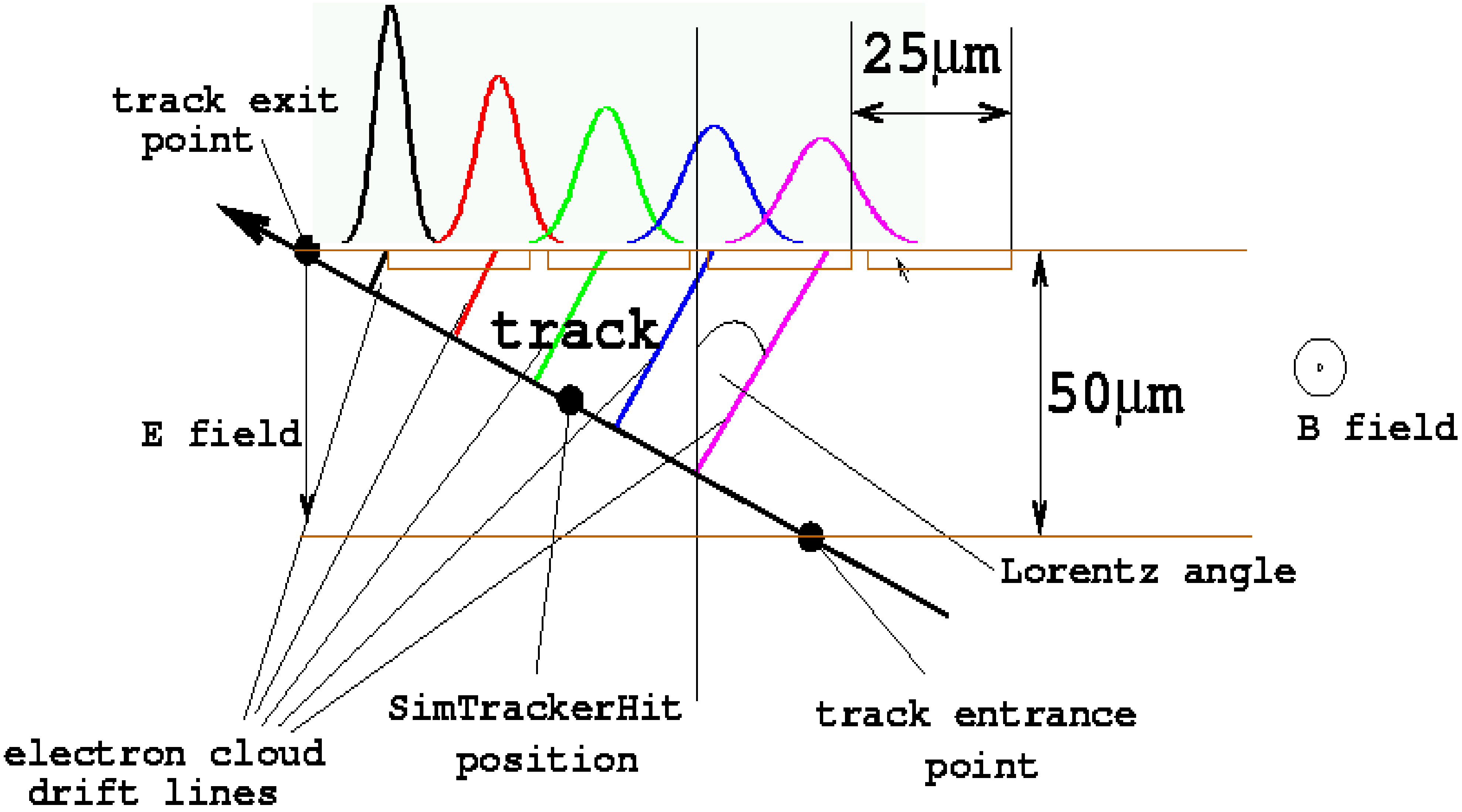
Z0 Resolution for single tracks





Impact on pattern recognition performance is under study

Hit Digitization Procedure

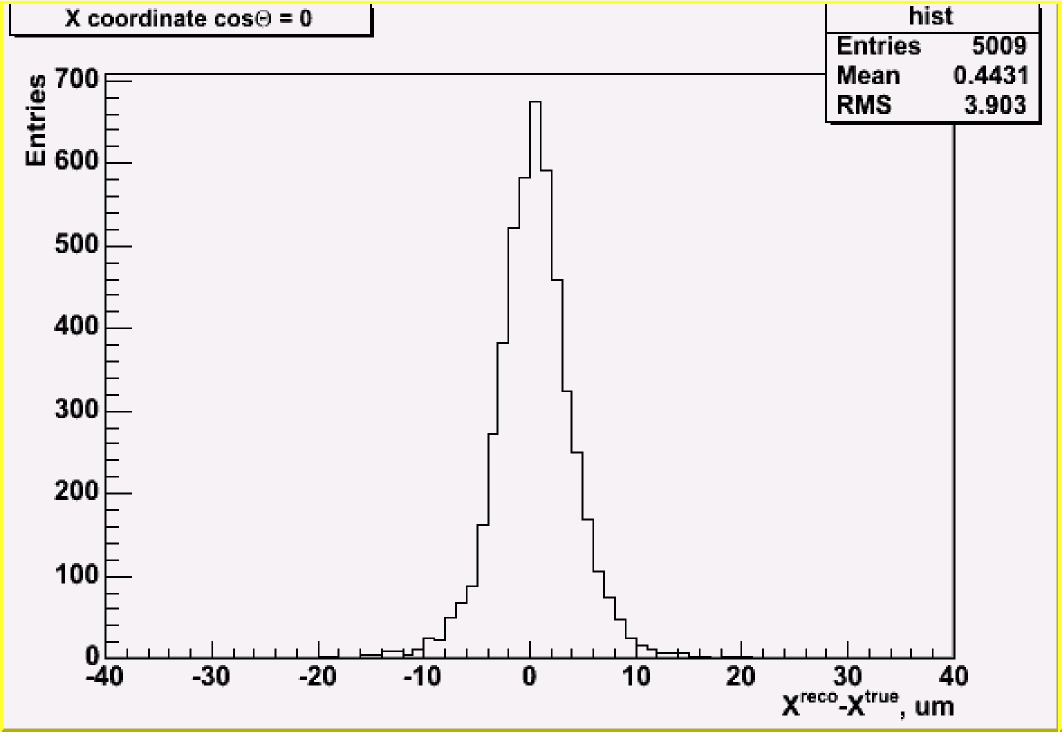


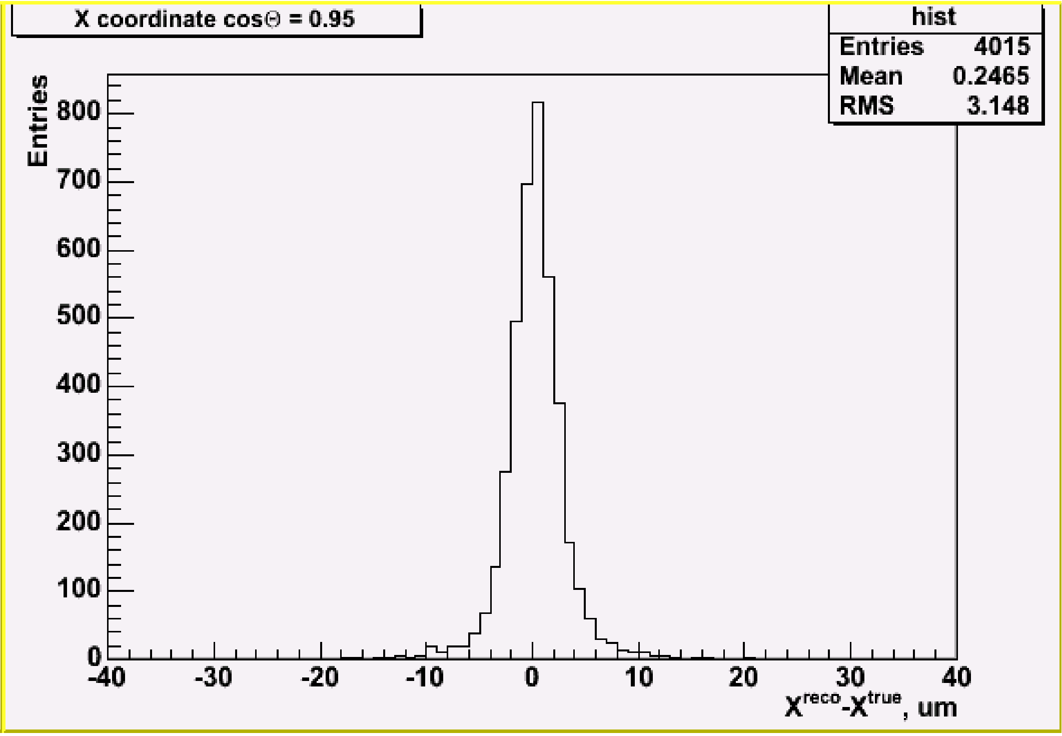
Parameters Steering Digitization

- Calculated diffusion normalised to layer thickness (50 μm) : 2.4 μm
- Tan Lorentz angle : 33° at 4 T field [V. Bartsch *etal.*, LC-Note LC-Det-2001]
- Electronic noise : 100e-
- Coefficient converting deposited energy into e-h pairs : 270.3 e / keV
- Hit amplitude threshold : $2\sigma_{noise}$

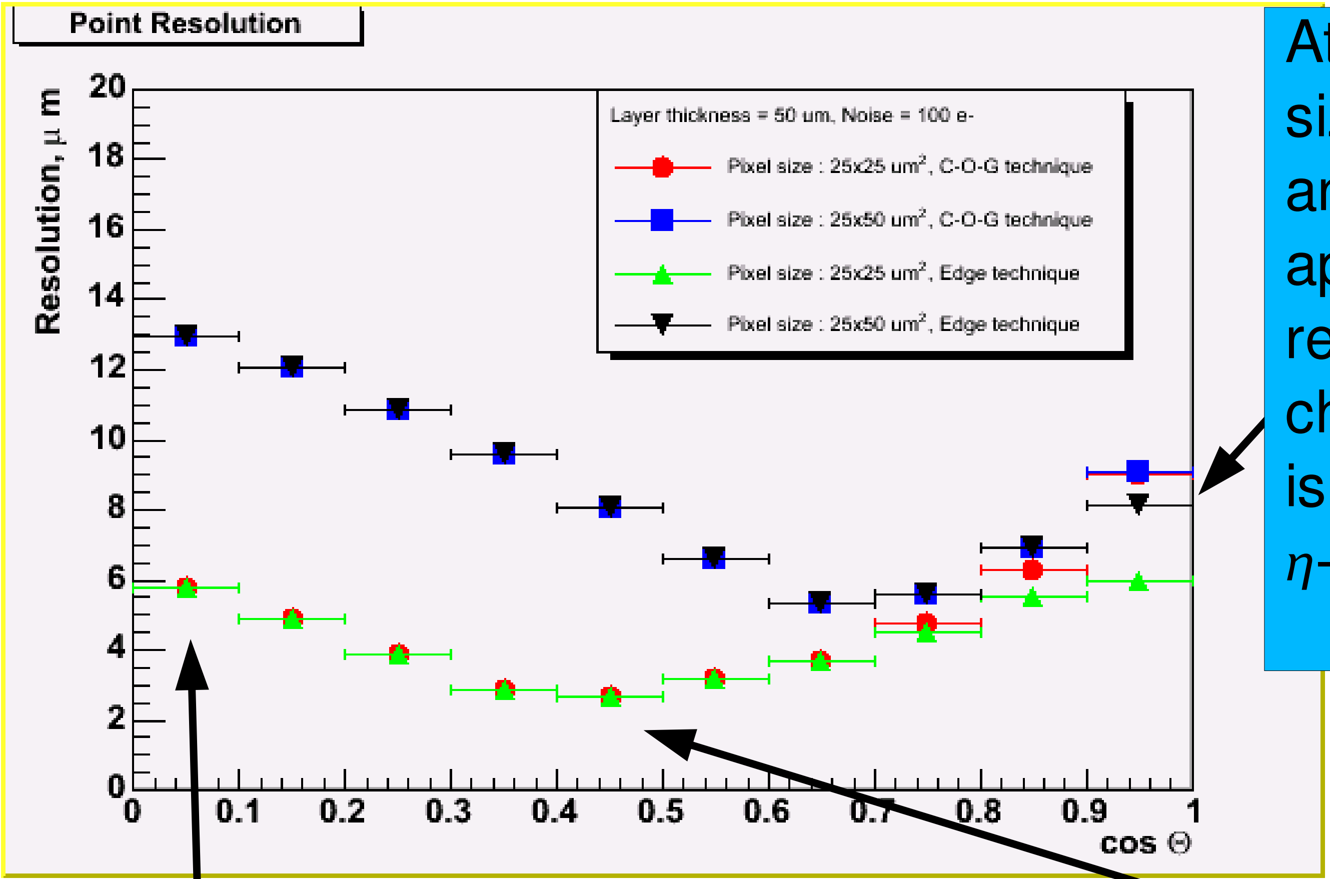
R-ϕ Point Resolution

$\cos\Theta=0$	$\cos\Theta=0.95$





Point Resolution in Z



At shallow angles cluster size gets extremely large and simple centre-of-gravity approach yeilds poor resolution due to inter-pixel charge fluctuations. Resolution is improved by means of η-algorithm (edge-technique)

In many cases at normal incidence only one row is fired : resolution is limited by pixel size

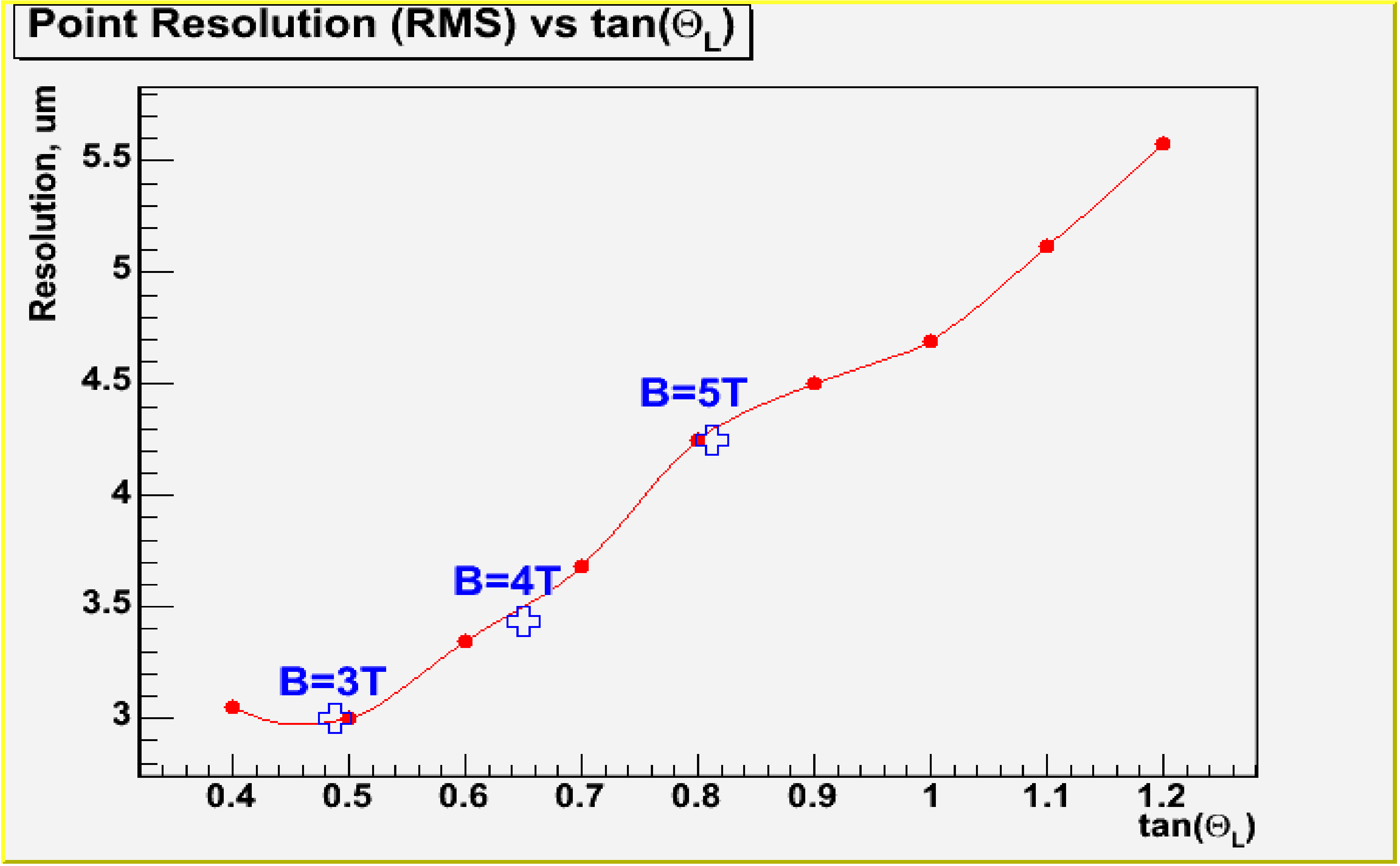
When track is inclined more than one row is fired -> resolution gets better

Effect of Magnetic Field

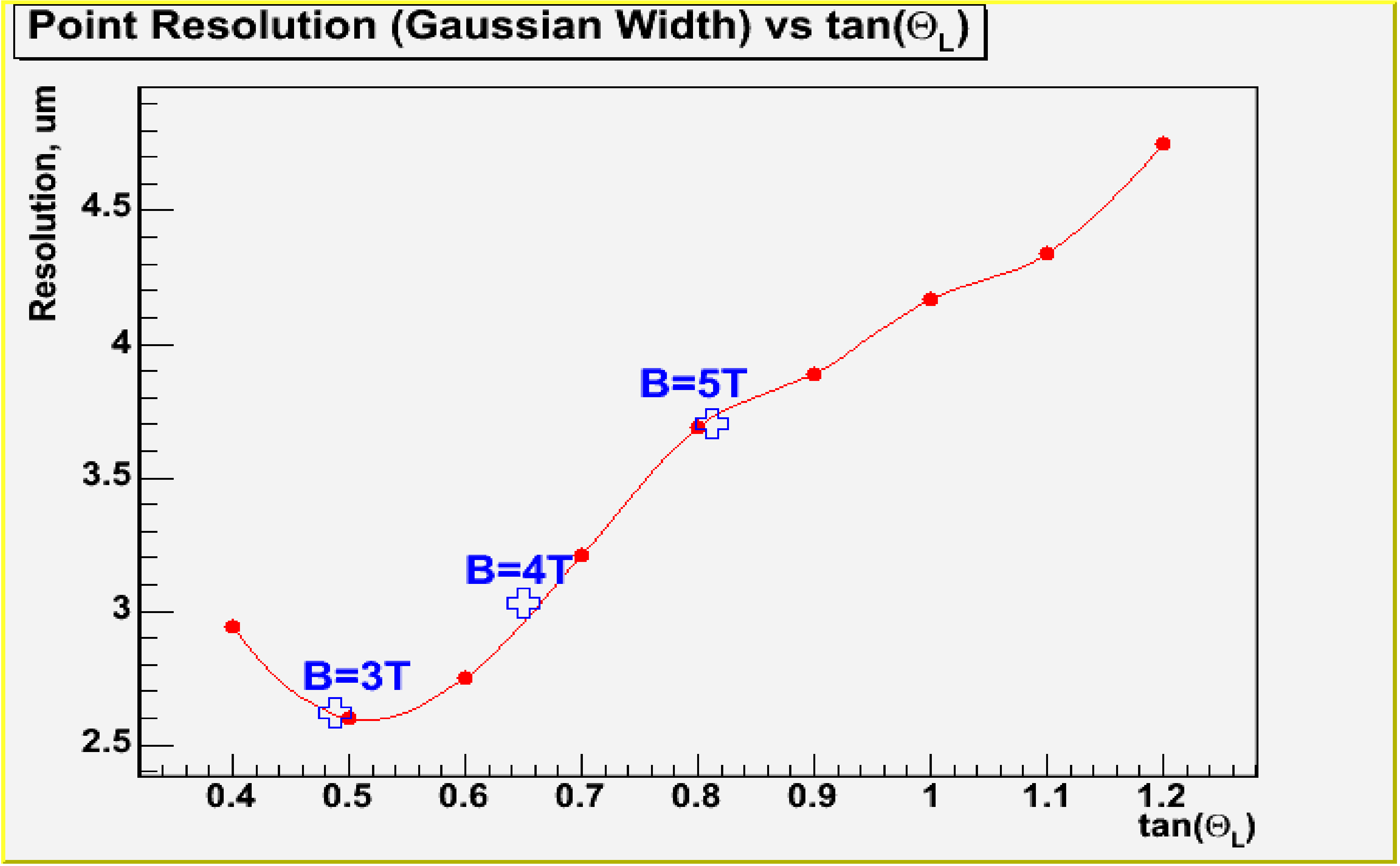
$$\tan\theta_L = \mu r_H \mathbf{B}$$

- θ_L has been measured @ 4T field: $\theta_L(4T) = 33°$
  [W.Boer *etal.* NIM A461 (2001) 200]
- Experimental data and theory : $r_H(B) \approx 1$ ⇨
- $\tan\theta_L(B) = \tan\theta_L(B_0) \times B/B_0$: $B_0 = 4T$ ⇨
  - ✗ $\tan\theta_L(3T) \approx 0.49$ (GLD);
  - ✗ $\tan\theta_L(4T) \approx 0.65$ (LDC);
  - ✗ $\tan\theta_L(5T) \approx 0.81$ (SiD);

R-Φ Resolution

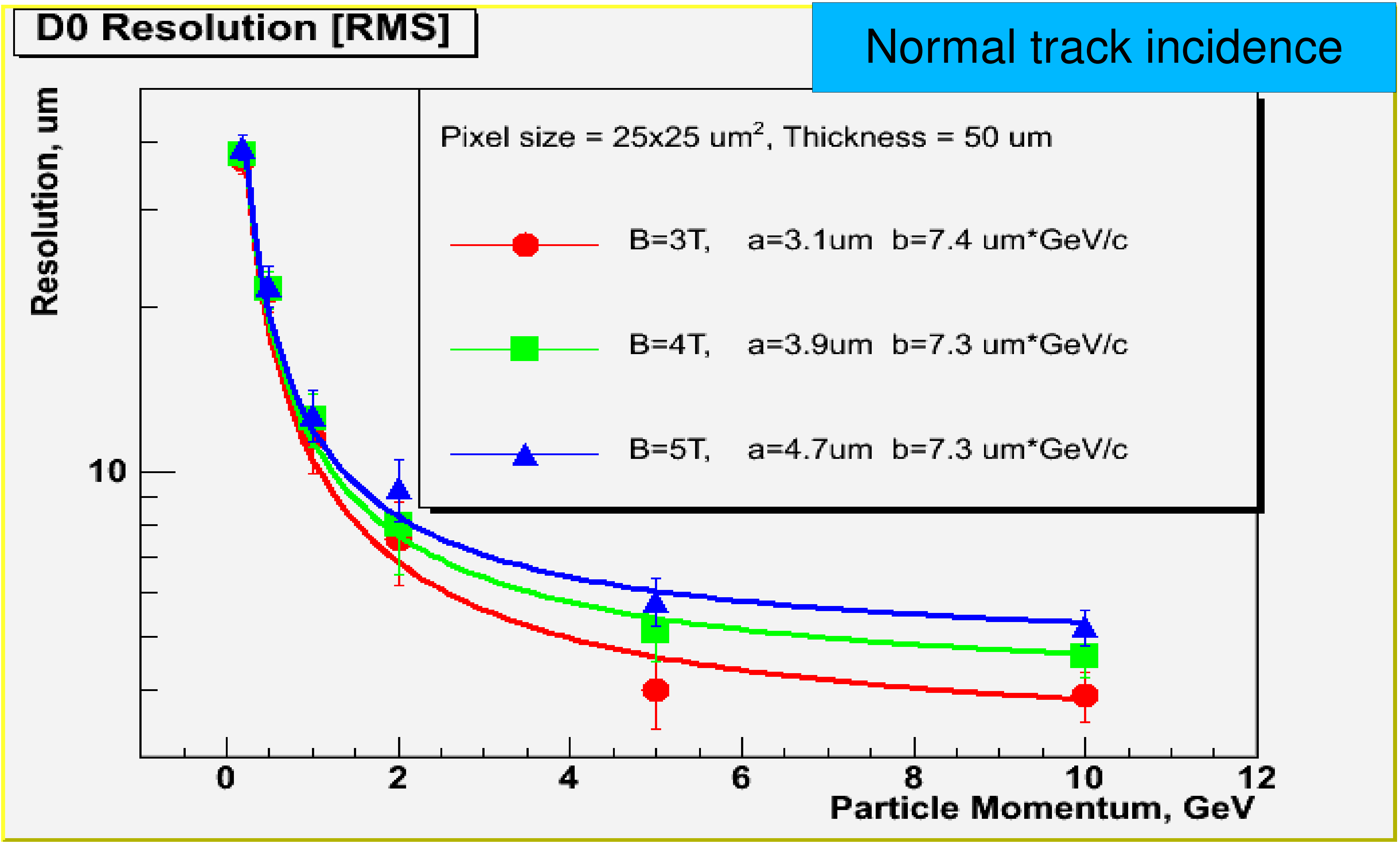


R-Φ Resolution



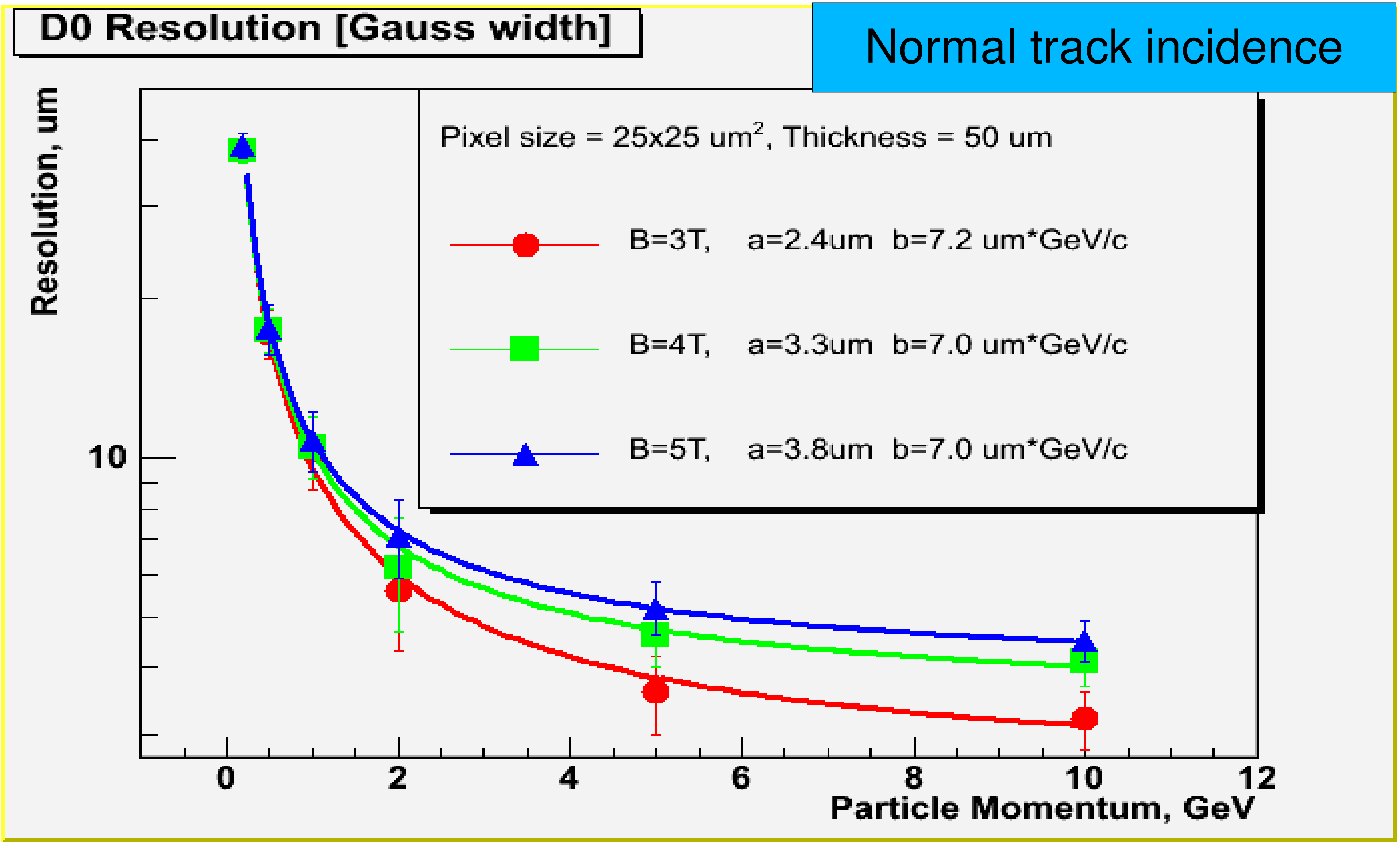
IP Resolution [RMS]

Normal track incidence



IP Resolution [Gauss Width]

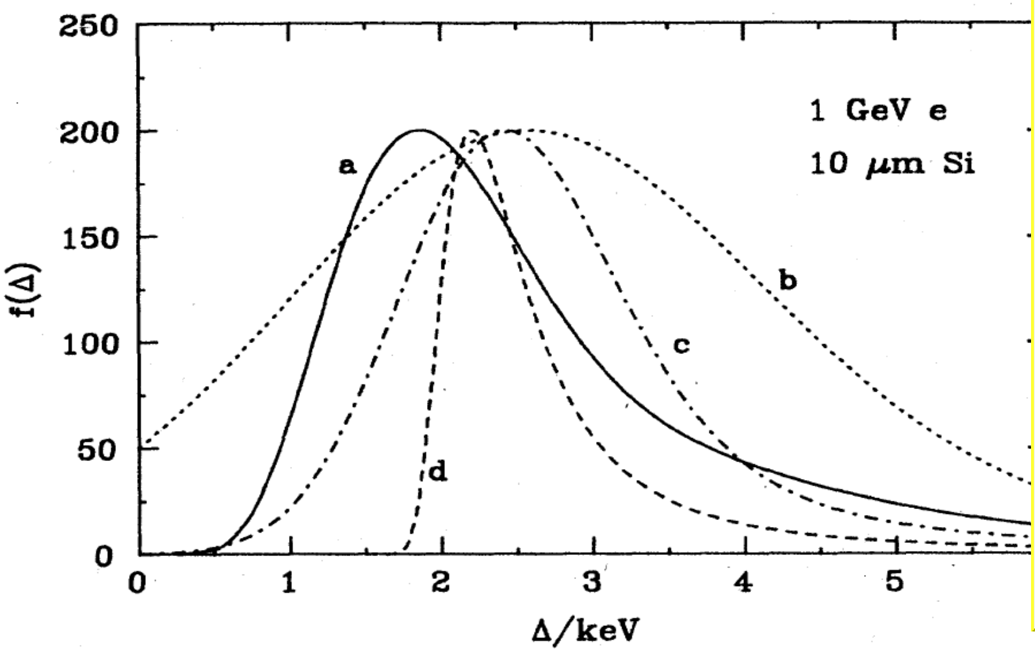
Normal track incidence

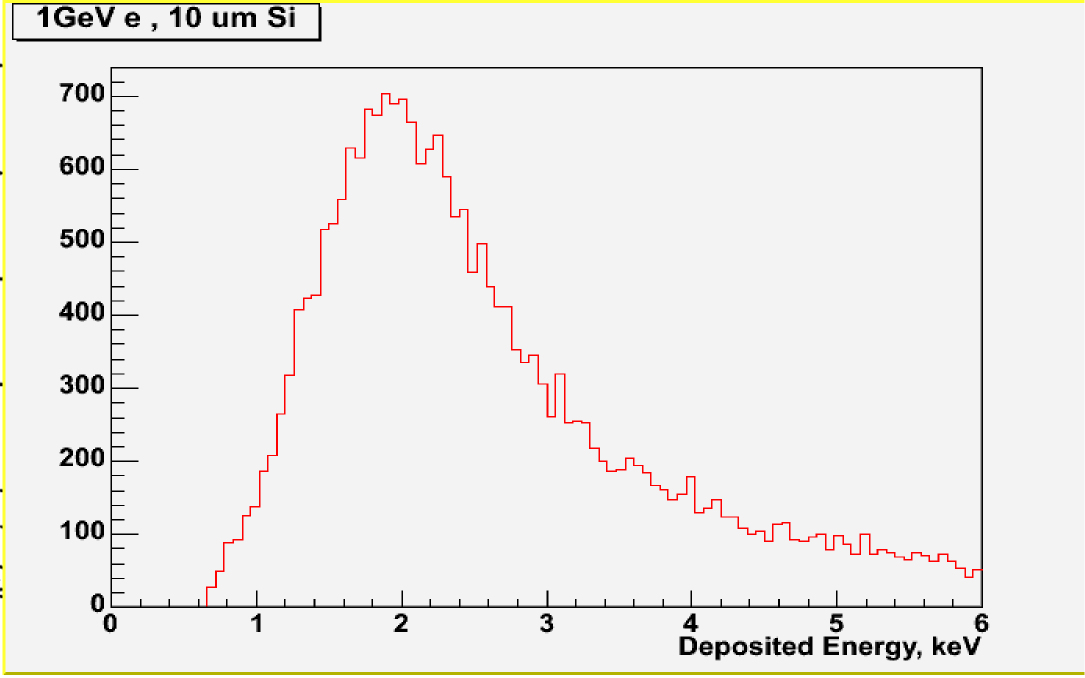


Is G4 Simulation of E_{loss} Fluctuations @ Short Flight Distances reliable?

H.Bichsel
Rev. Modern Physics 60-3 (1998)
plot a)

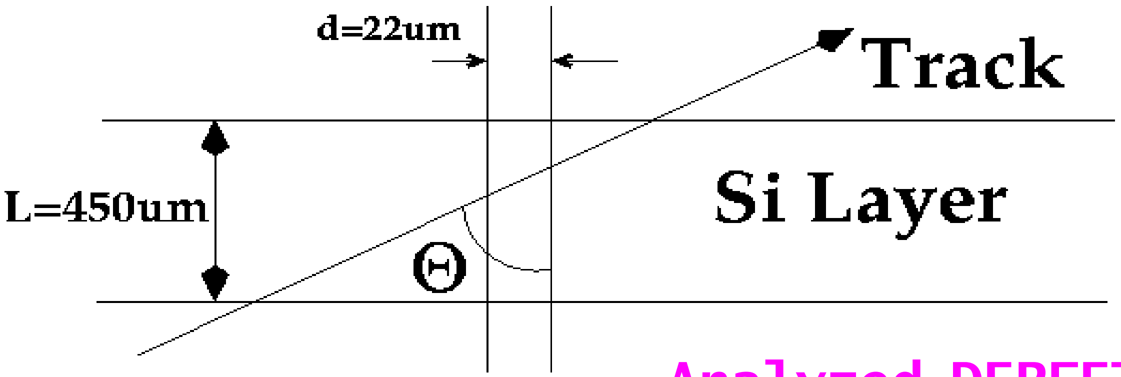
G4 Simulations





DEPFET Sensor Response to Inclined Tracks (Simulations vs. Testbeam Data)

- **Particularly interesting data**
  - Allow to check simulation of straggling functions at short flight distance / thin Si sensors

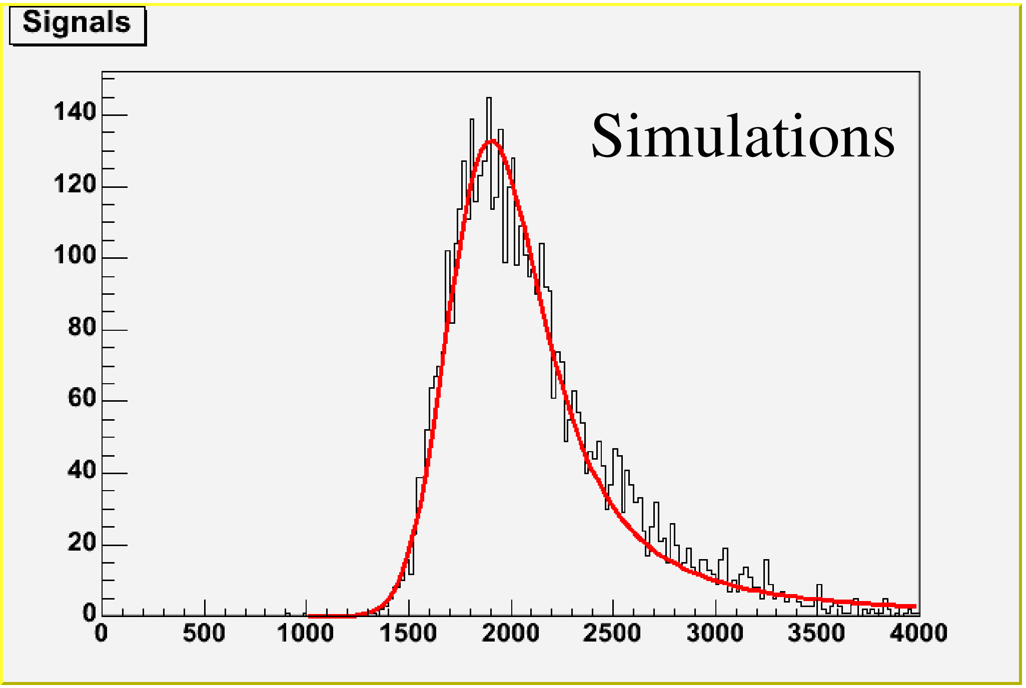


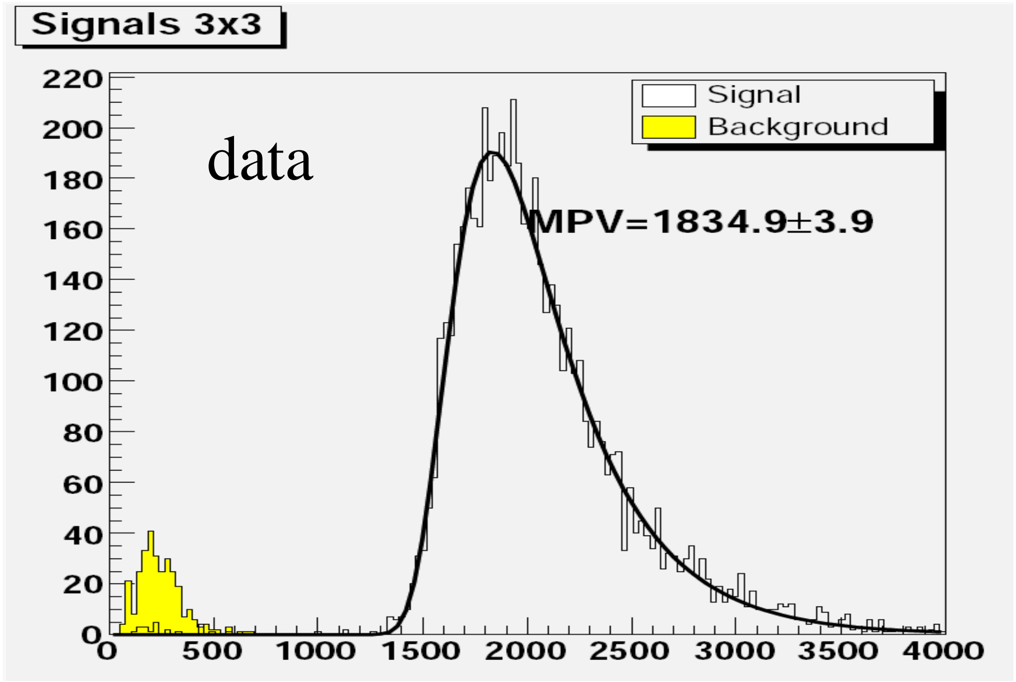
G4 Simulations can be probed @ a scale ≈ d/sinθ;
d – pixel size;
θ - track incidence angle

Analyzed DEPFET Matrix (Hyb2A):

- Pixel dimensions : D_x = 36 um, D_y = 22 um;
- Layer thickness = 450 um ; electronic noise = 300 e^-
- Rotations up to 40° around X axis [θ-rotations] and Y axis [ϕ-rotations] are performed

Total Cluster Amplitude (Normal Track Incidence)



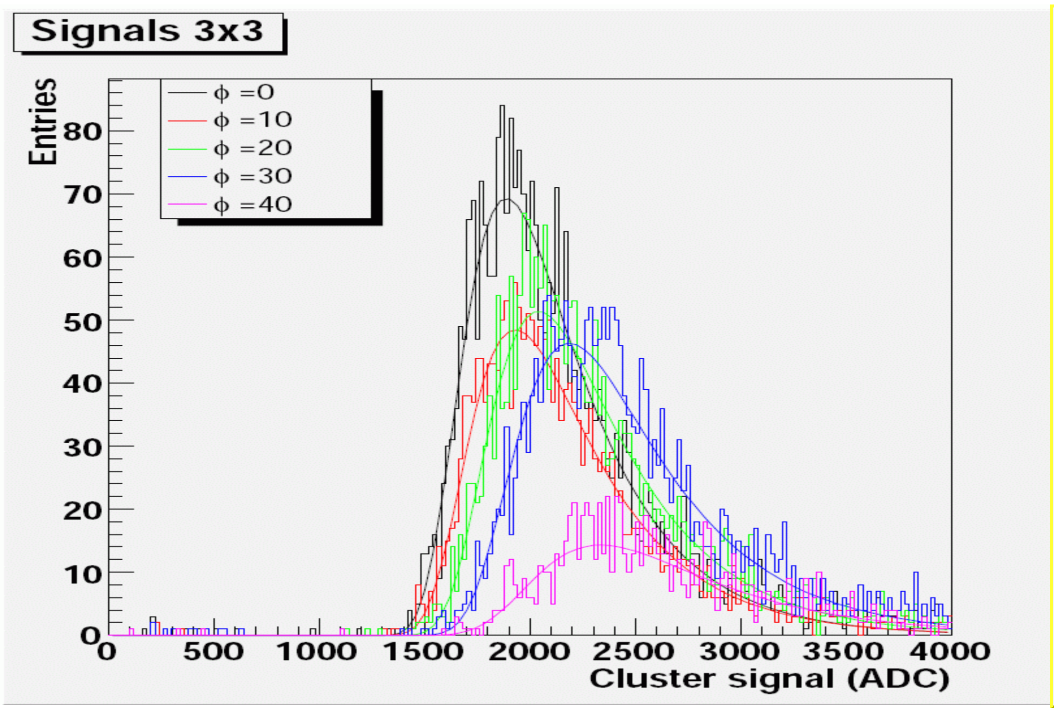


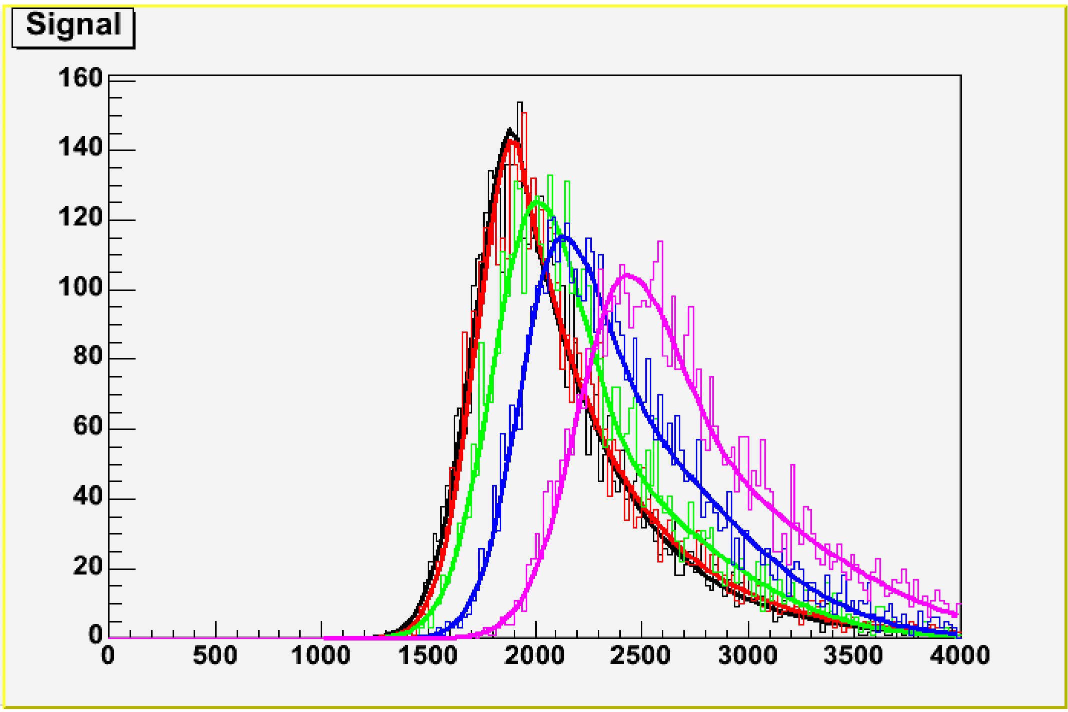
Data collected at normal track incidence is used to derive coefficient converting E_{loss} into ADC counts

Amplitude Distribution vs Incidence Angle

Testbeam data

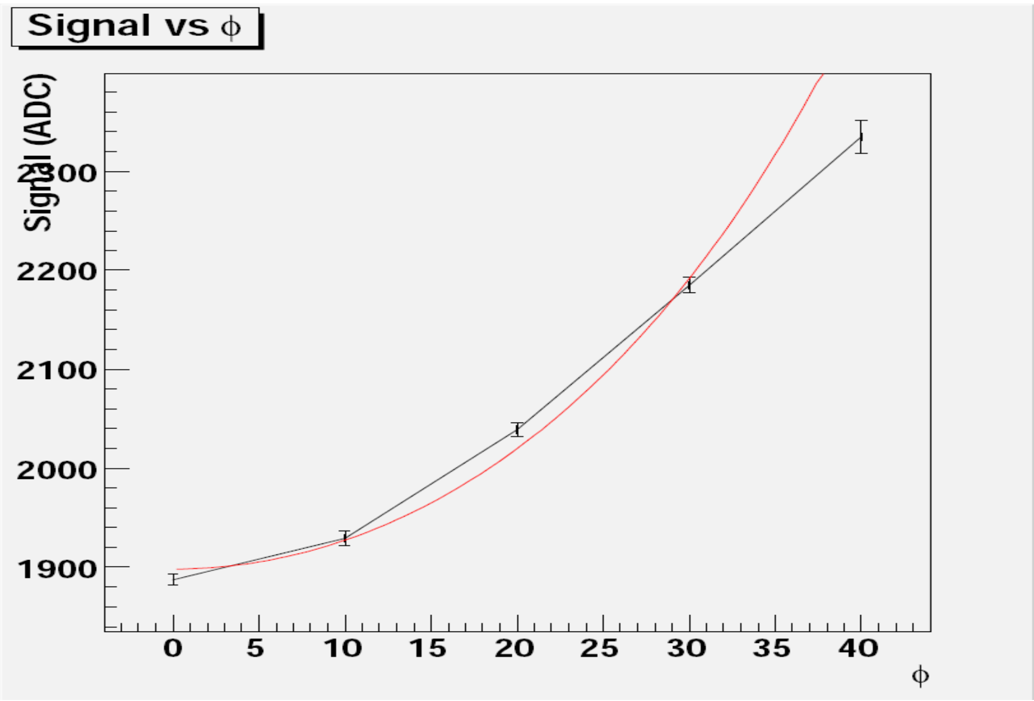
Simulations

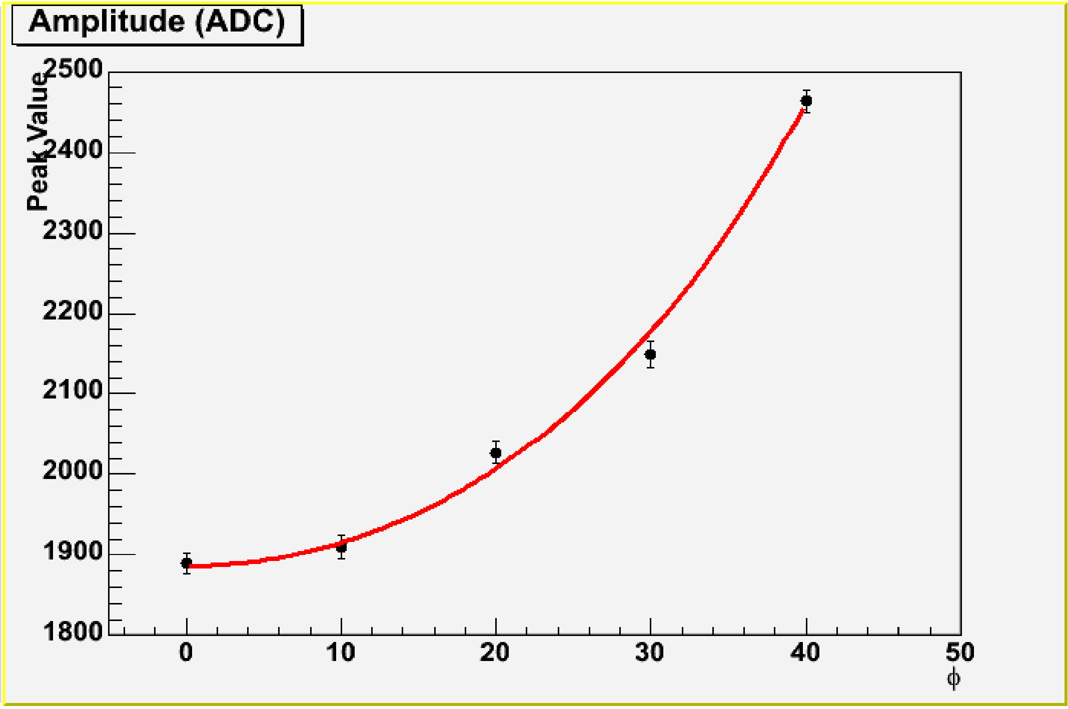




Peak Value vs Incidence Angle

Testbeam data	Simulations

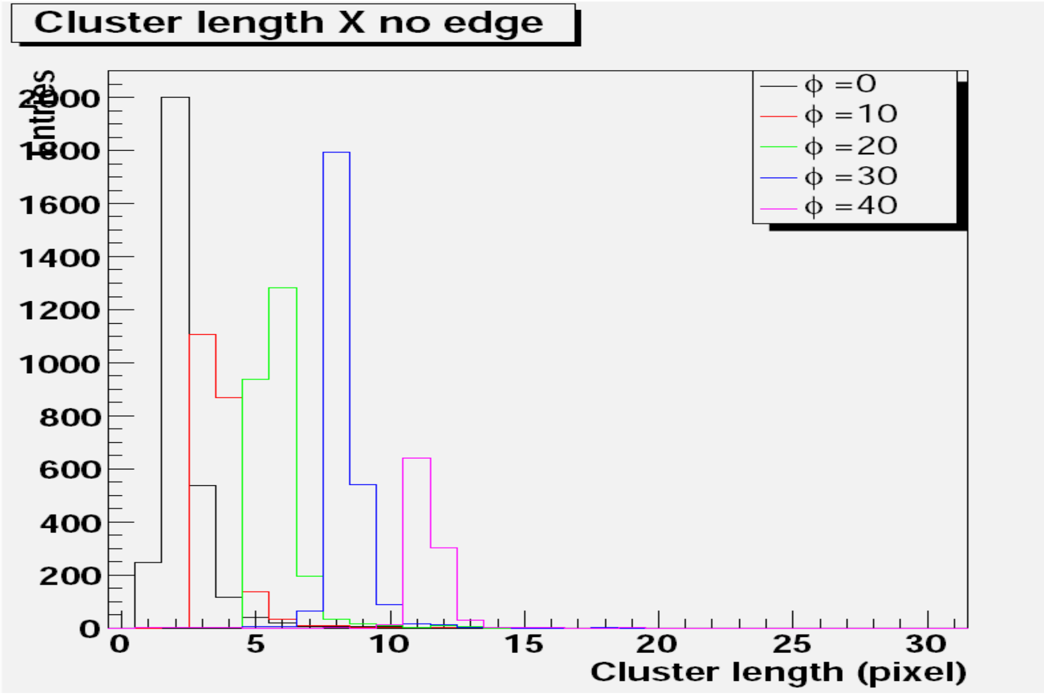


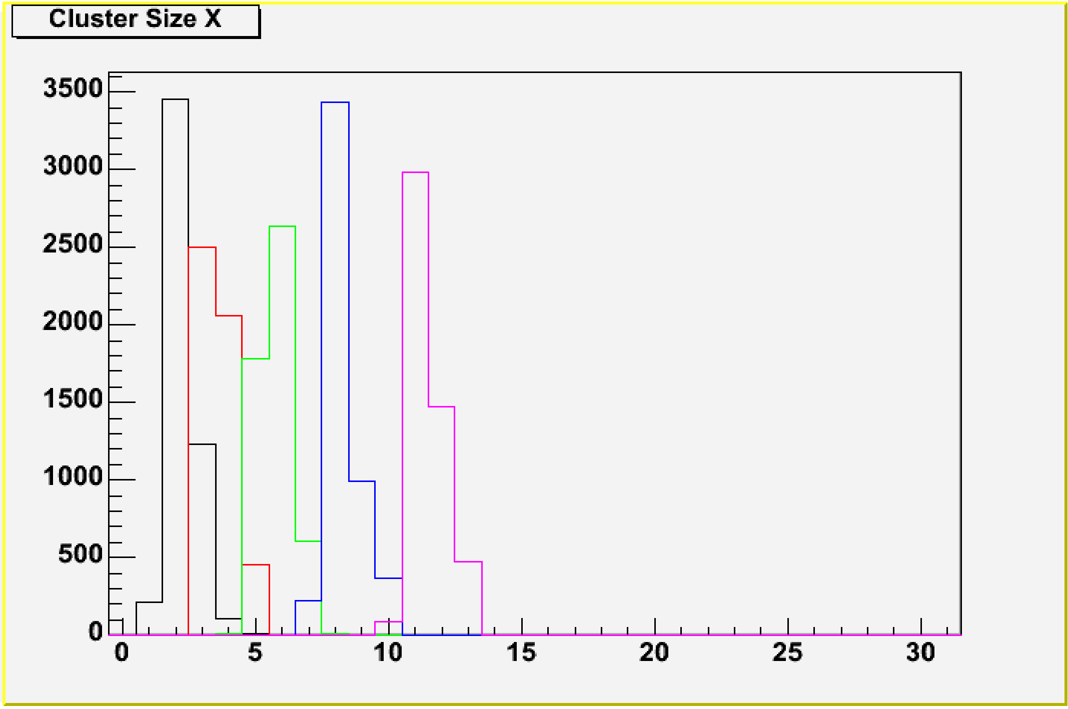


Cluster Length X vs Incidence Angle

Testbeam data

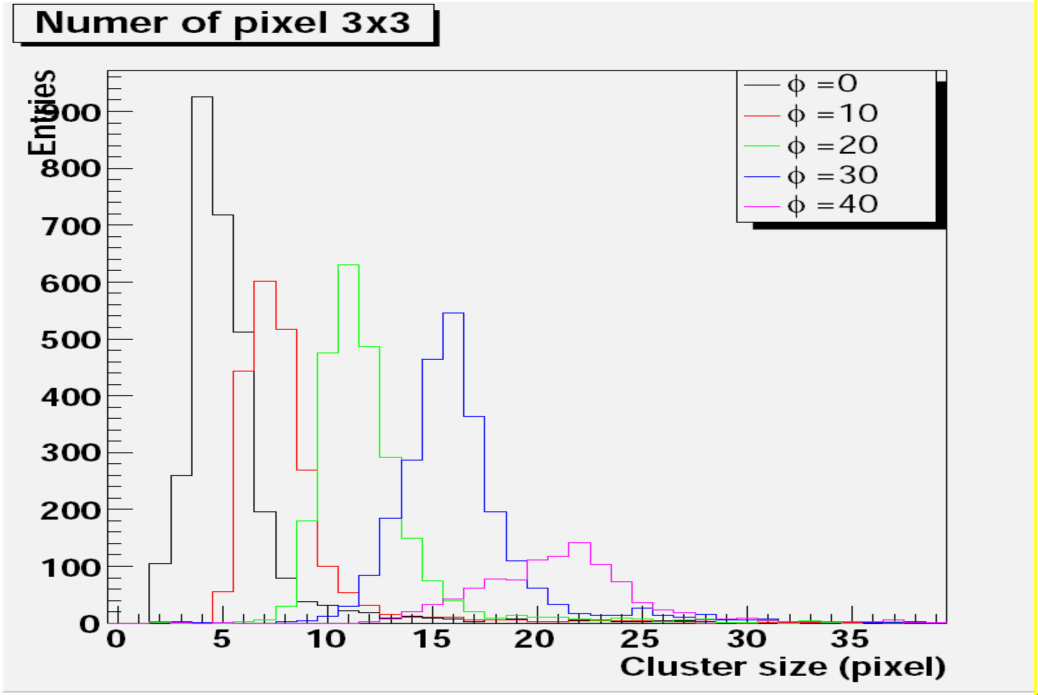
Simulations

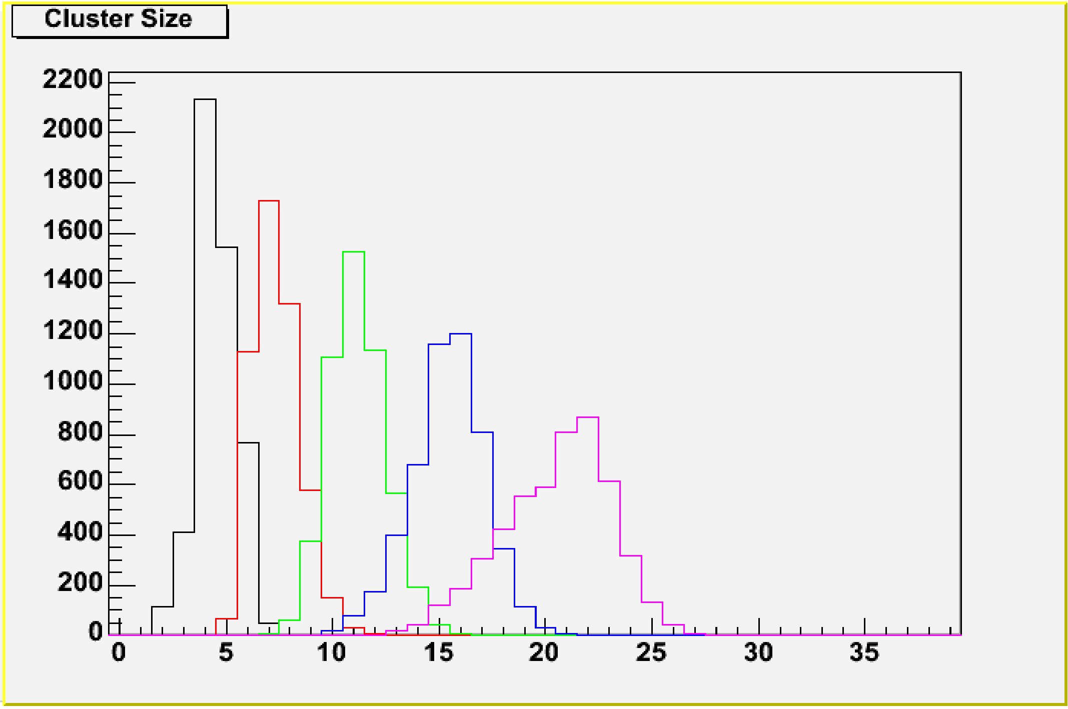




Cluster Size vs Incidence Angle

Testbeam data	Simulations





Probing Straggling Functions @ short flight distance

- Validity of G4 simulation of energy loss fluctuations @ short flight distances can be probed by investigating distributions of signal projection on pixel rows (columns) perpendicular to the inclined track momentum

- Probed scale :

  $$D_{x,y}/\sin(\theta,\phi),\ D_{x,y}$$ being pixel dimensions

- Expected mean signal on central rows (excluding edges) :

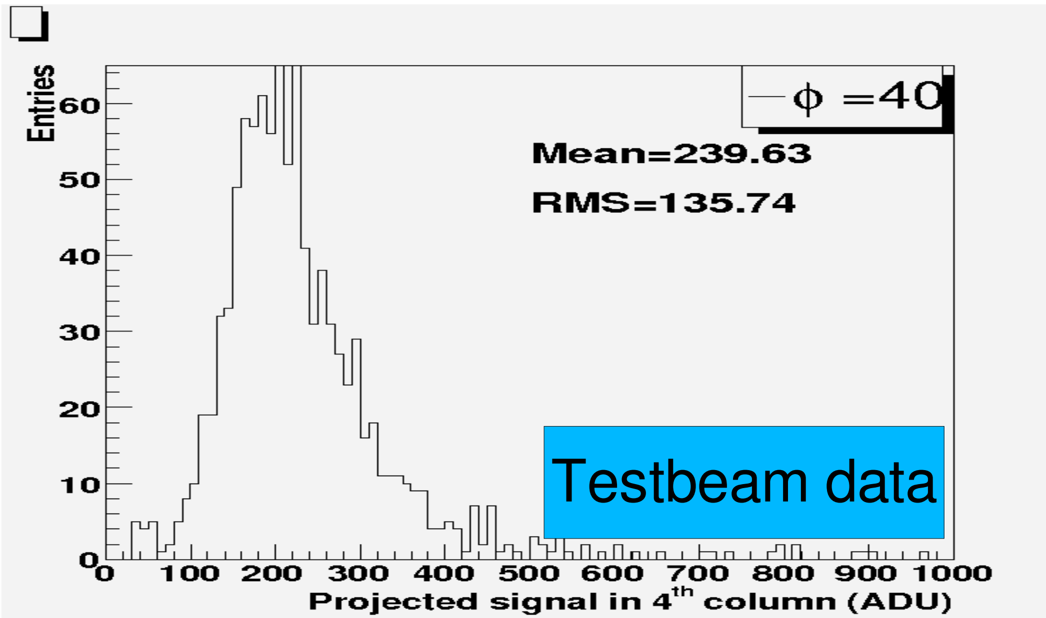
  $$A_{row,column} \approx A_0 D_{x,y}/(L \cdot \sin(\theta,\phi)),$$

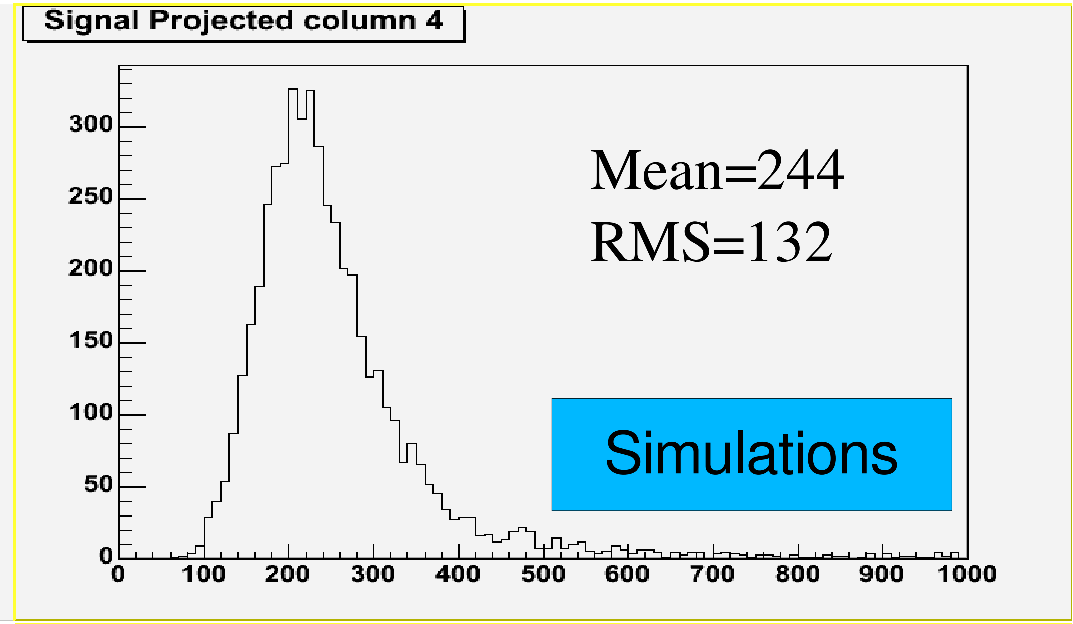
  L is layer thickness,

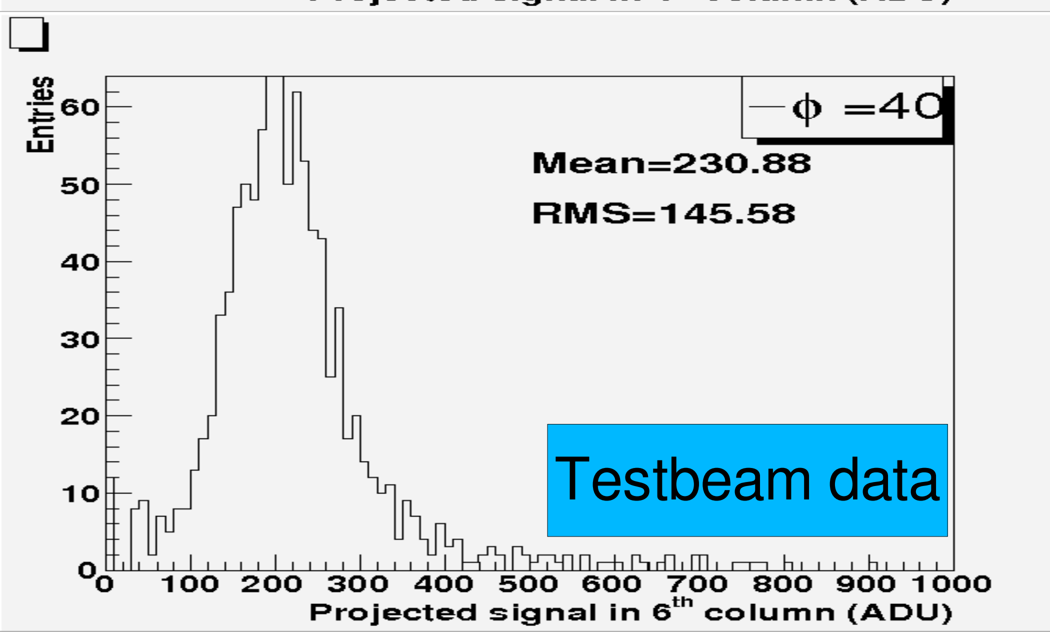
  A_0 is total cluster amplitude for normally incident track

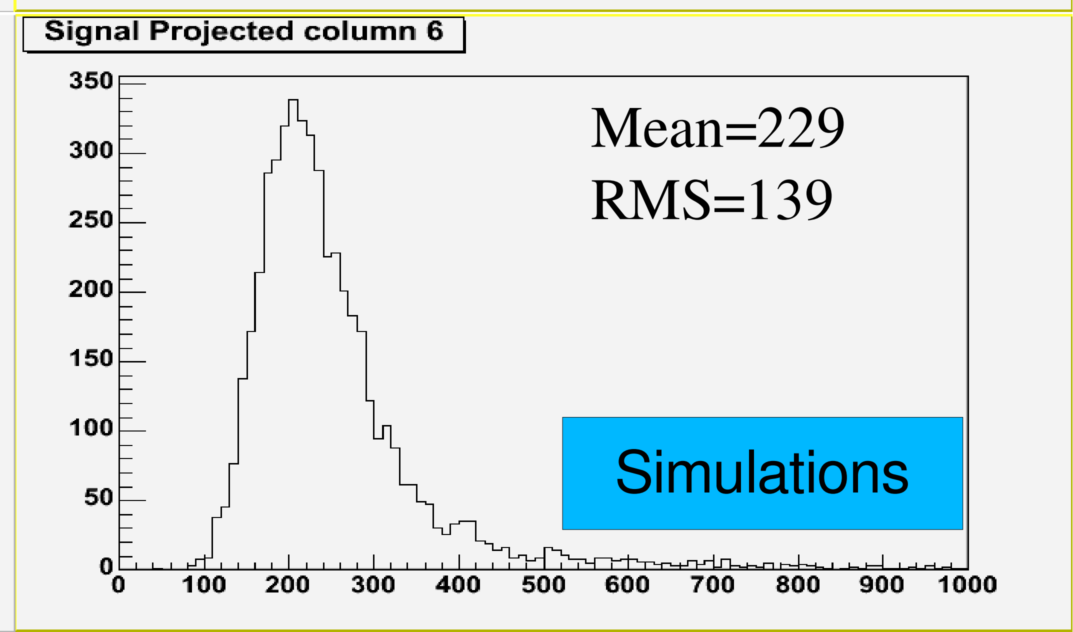
- In the following only few representative columns(rows) are shown

Signal projected on pixel columns; ϕ-rotations [ϕ=40°]

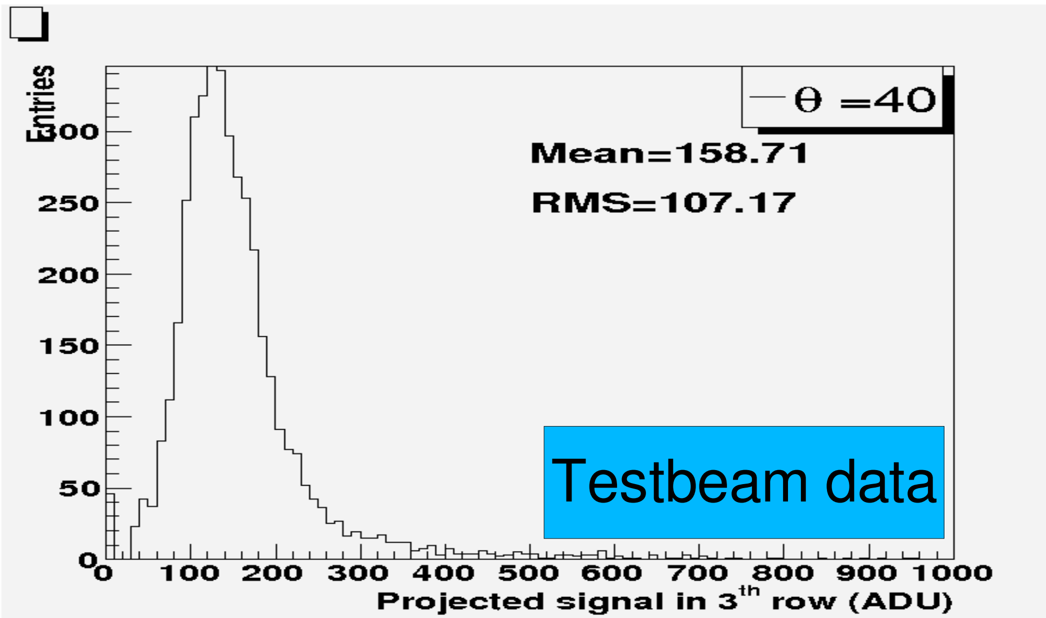


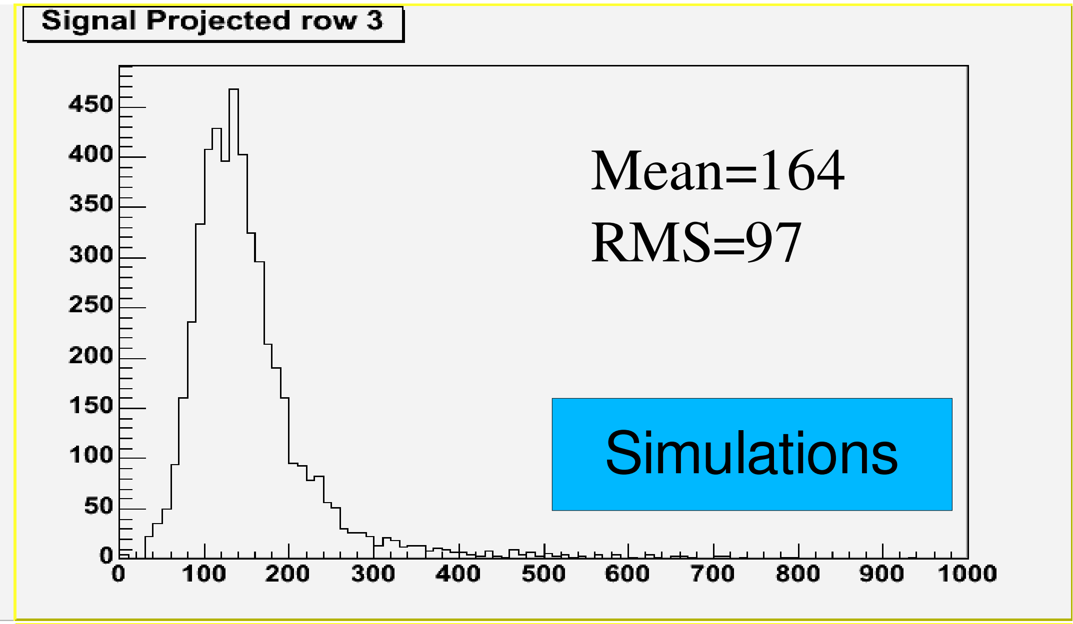


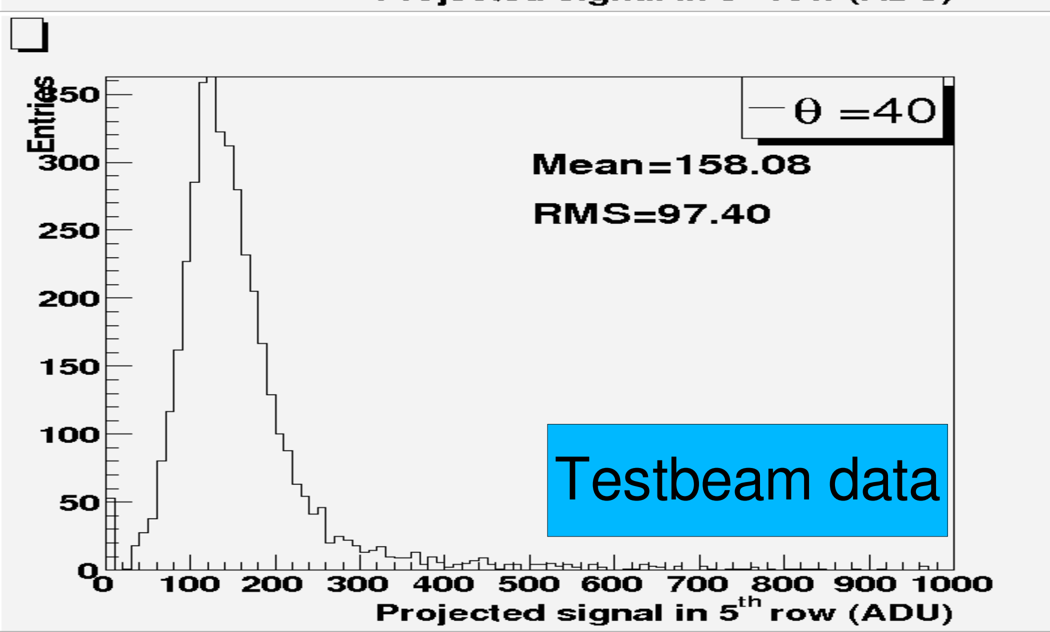


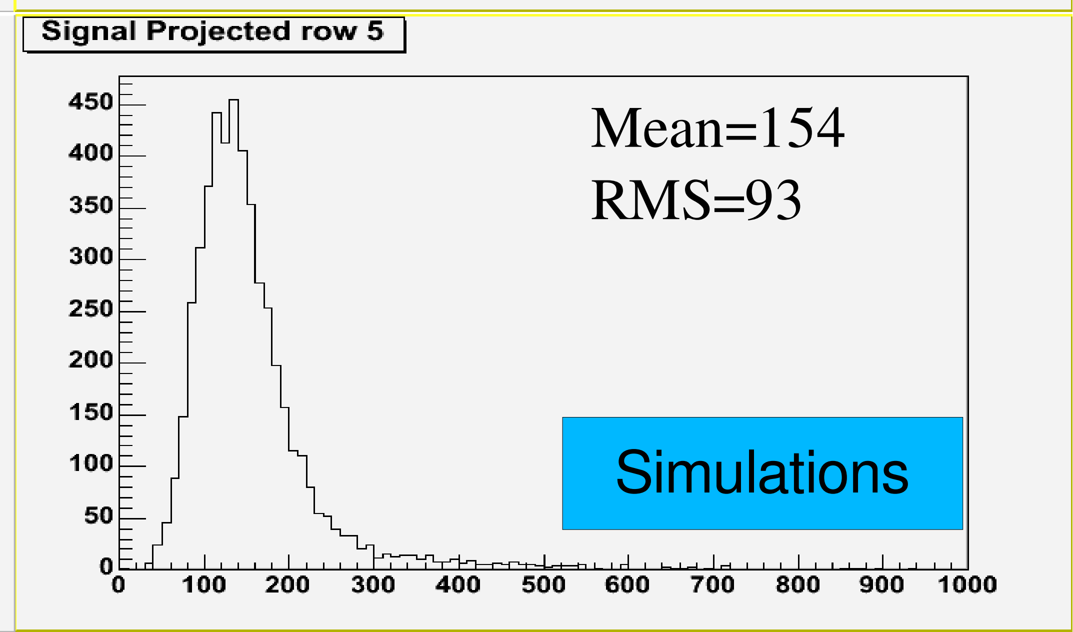


Signal projected on pixel rows; θ-rotations $[\theta=40^\circ]$







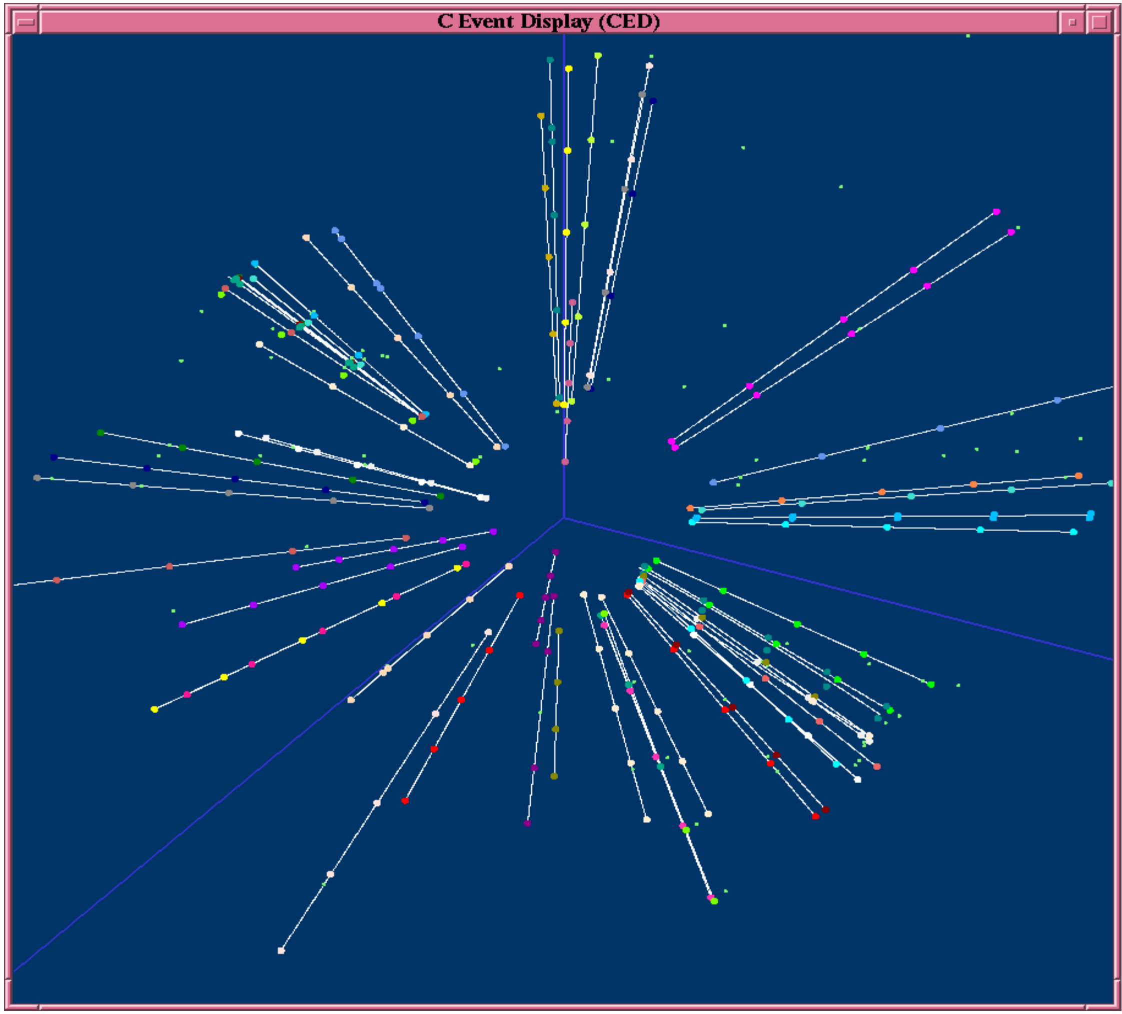


Stand-alone Pattern Recognition in VXD

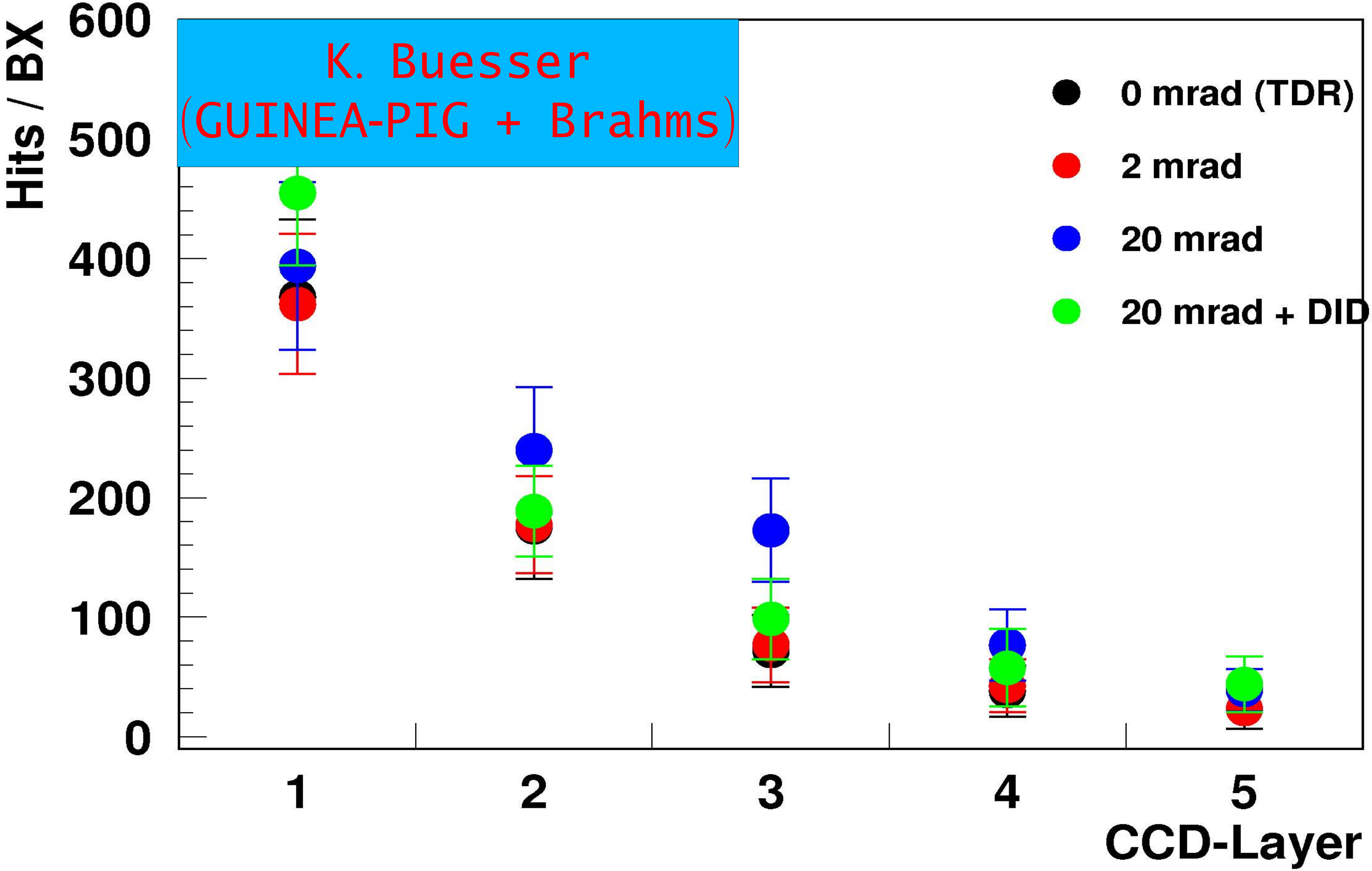
Algorithm features:

- **Starts with finding triplets in the outer layers**
- **Inward search for additional hits**
- **Good χ^2 of helix fit – main criterion to accept track candidates**
- **Additional loose cuts against fake tracks composed of background hits:**
  - D_0, Z_0 < 10mm
  - P_T > 100 MeV
  - # hits in track candidate > 3

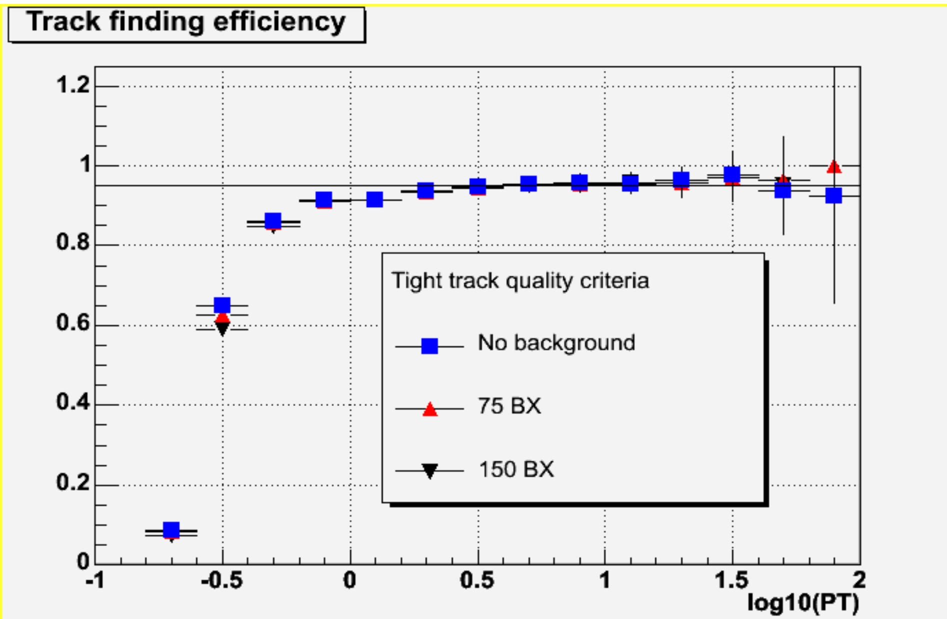
$t\bar{t} \Rightarrow$ 6jet event @ $\sqrt{s}$ = 500 GeV

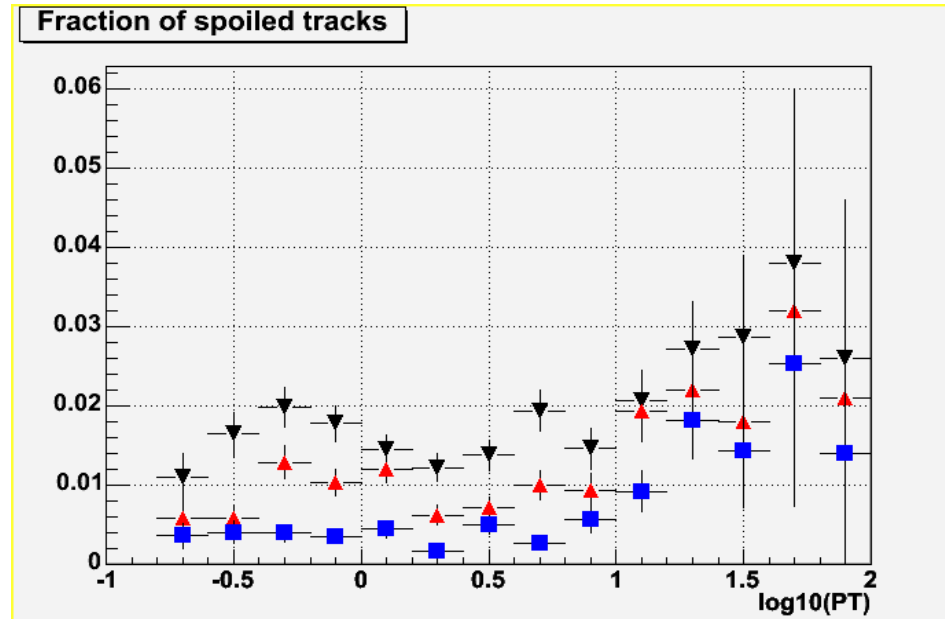


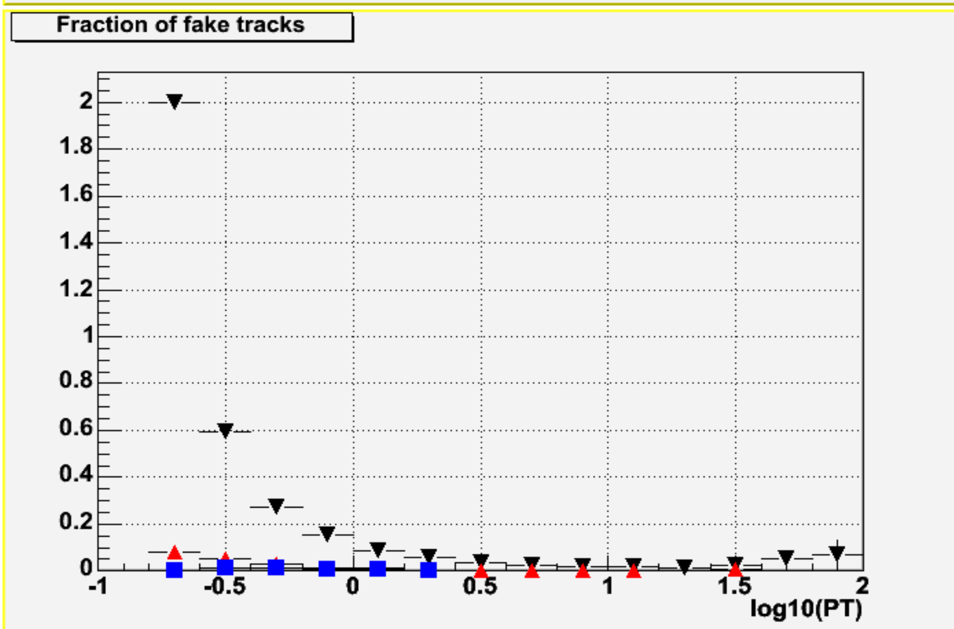
Expected Beam Backgrounds

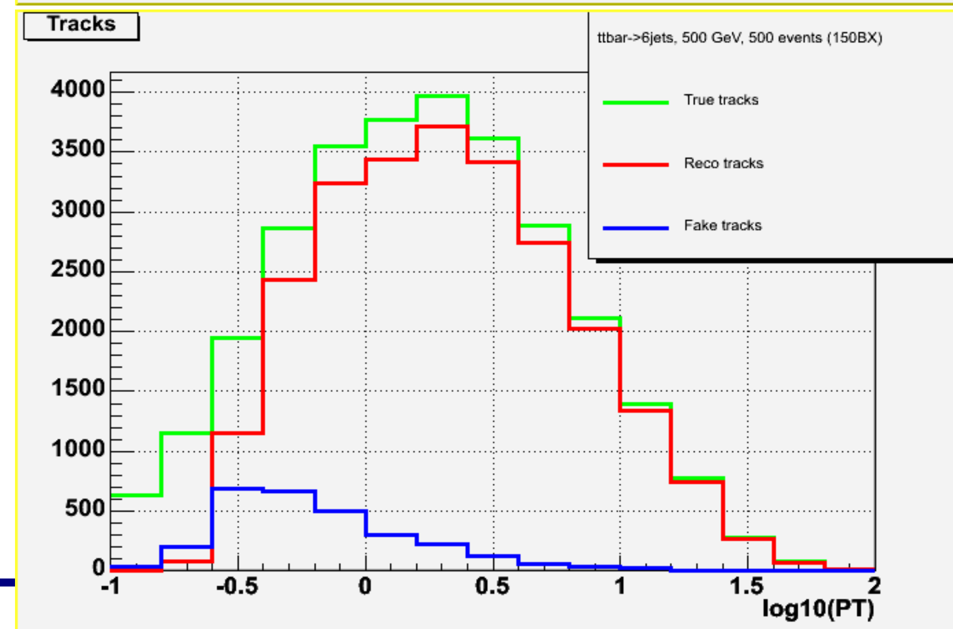


Pattern Recognition Performance in Presence of Backgrounds









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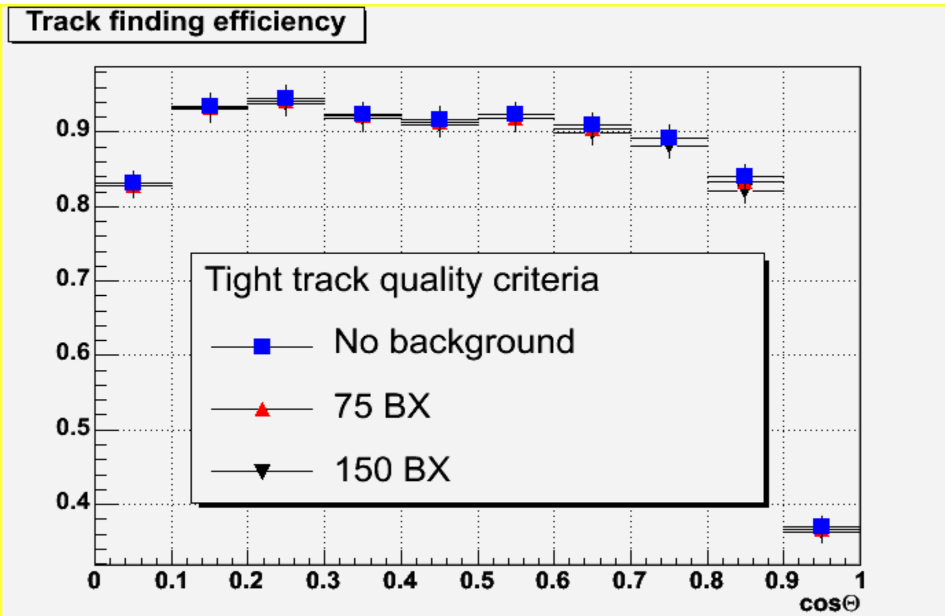

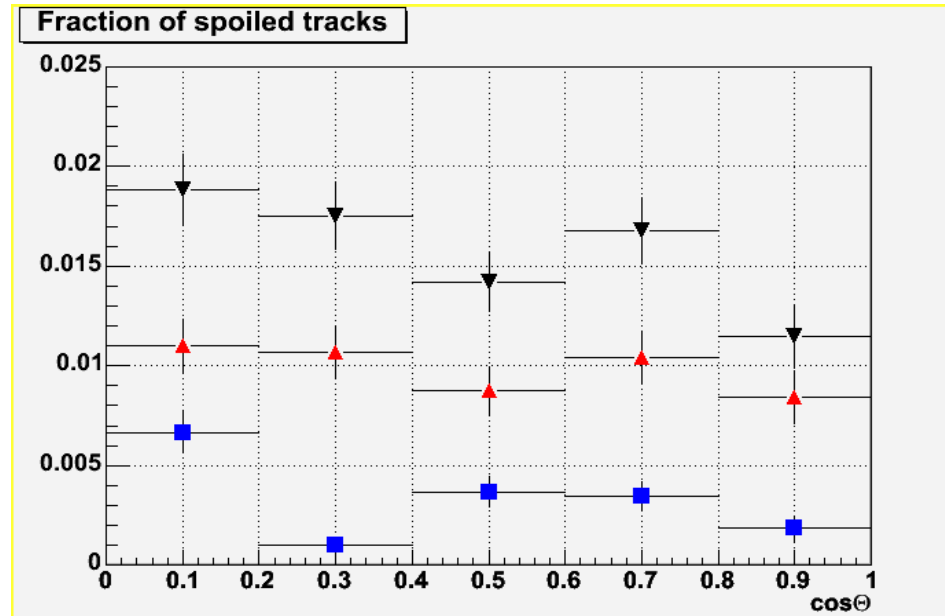

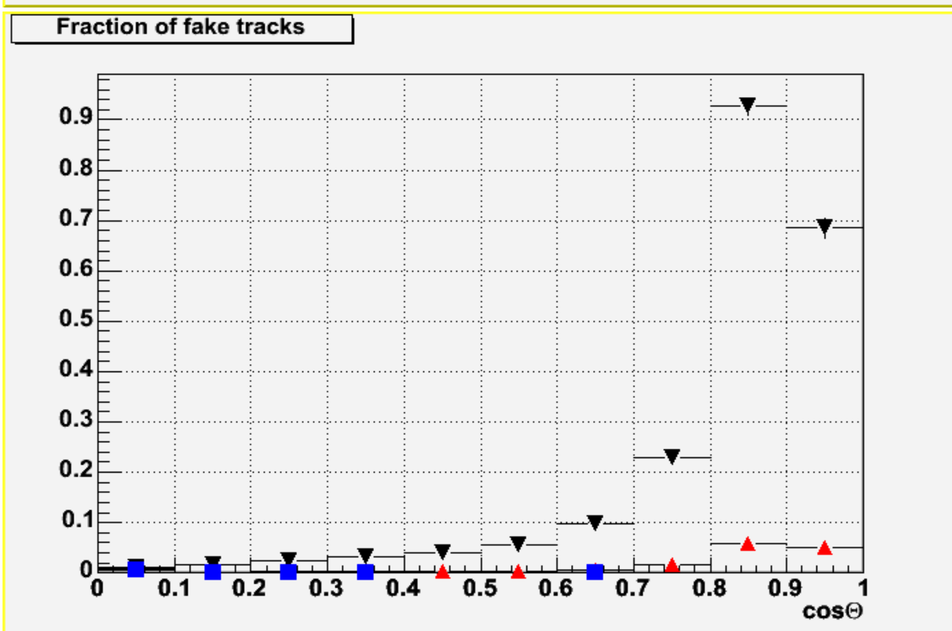

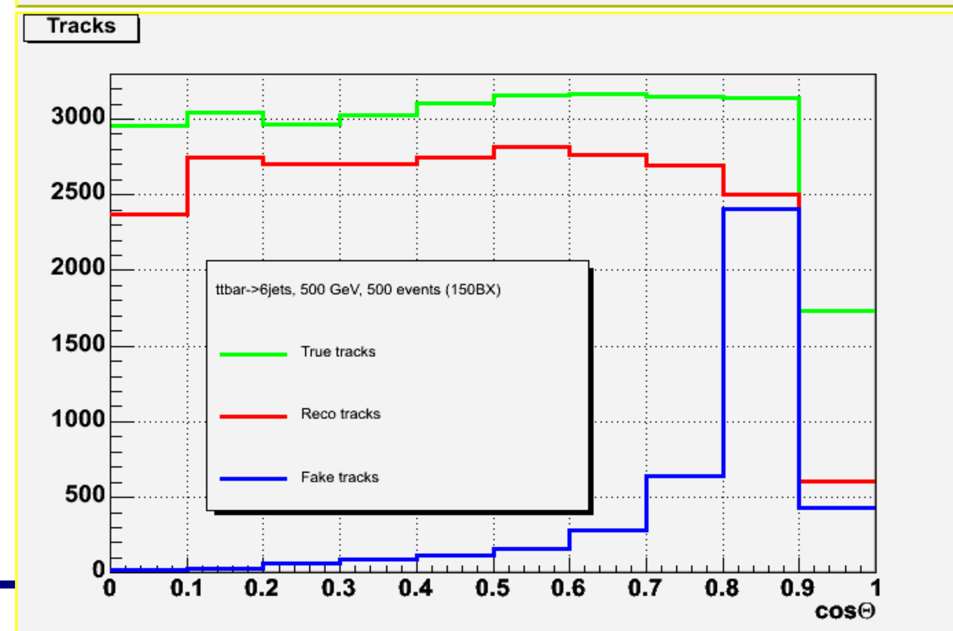

Summary (1)

- Geometry of DEPFET-based VXD is implemented in Mokka
- Detailed digitization of detector hits is implemented in Marlin
- Anticipated point resolution ranges from 3 to 6 μm depending on coordinate and angle of incidence
- Effect of magnetic field studied. No dramatic deterioration of detector performance with increasing magnetic field is found; at 5T field VXD performance still meets ILC physics requirements
- Good agreement between simulations and testbeam data is found, giving confidence in simulation
- Simulation of E_{loss} fluctuations in Geant4 is validated for MIP flight distances in the range down to ~30 μm

Summary (2)

- Stand-alone pattern recognition in VXD is developed
- Performance of tracking is evaluated in the presence of beam induced backgrounds in terms of track finding efficiency and fake track rates
- Stand-alone VXD pattern recognition algorithm is capable of finding tracks with efficiency > 92% for p_T>0.5GeV and cosθ<0.8 while keeping fake track rate at few percent level in this range of track parameters; fake track rate blows up at lower p_T and θ
- However significant improvement in performance is expected when additional information from forward tracking disks (FTD) and intermediate silicon tracker (SIT) is exploited

Current Developments

- ◆ Since recently pattern recognition includes also tracking in FTD

$t\bar{t} \Rightarrow$ 6-jet event with forward tracks