Simulation Studies of VXD Performance

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LCWS'06   Bangalore   March 2006

Introduction

- Ambitious physics program @ ILC $\Rightarrow$ stringent requirements on the detector performance

- VXD should be capable of efficient b/c tagging (Higgs hadronic branchings) in the presence of severe beam induced backgrounds

- Robust and reliable tools are needed to estimate VXD performance and optimize VXD design

Software Tools for Detector Optimization (Simulation)

- Detector optimization must be done with full simulation and realistic reconstruction
- Example : Mokka – Geant4 based detector simulator (LCD)
  - Almost complete description of the LDC detector : VXD + TPC + forward tracker + ECal + Hcal + forward calorimeters; the only missing ingridient : muon system
  - flexible definition of detector configuration via MySQL database: allows to change detector dimensions and material
- NB : Detector simulation is disentangled from digitization

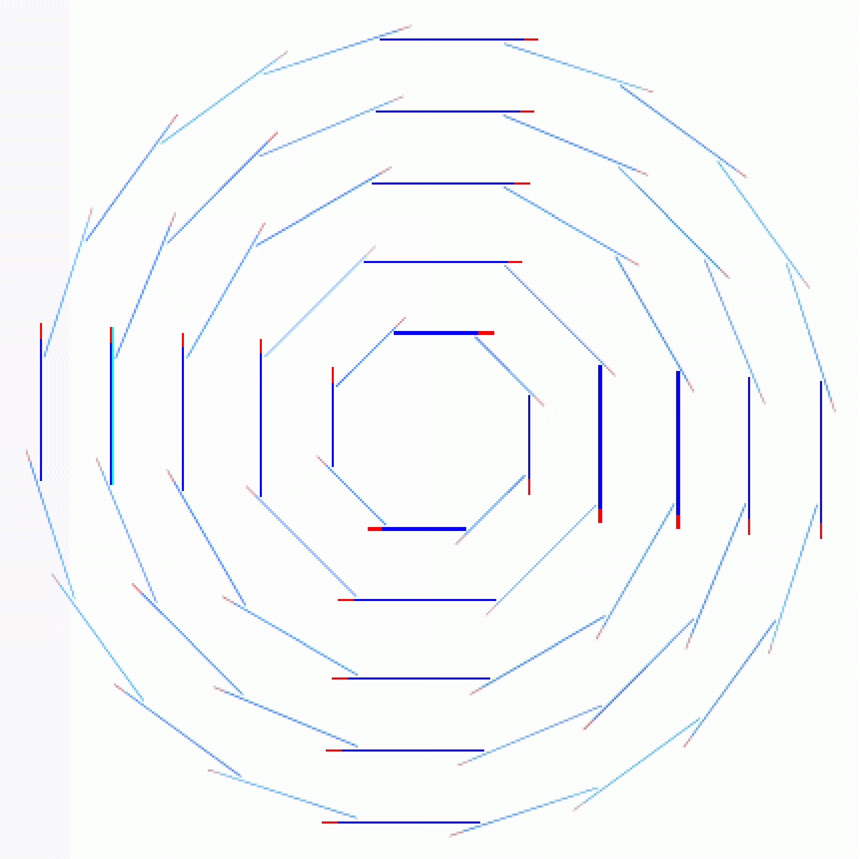
Software Tools for Detector Optimization (Reconstruction)

- MARLIN (Modular Analysis and Reconstruction framework for LINear collider) : digitization, reconstruction and analysis framework
- Currently includes
  - Digitization of TPC hits, track finding and fitting in TPC
  - Digitization of calorimeter hits, pattern recognition in calorimeters
  - PFA implementation
  - Some high level tools (jet clustering, event shape variable calculation)
- Missing
  - Realistic digitization of VXD, FTD and SIT hits
  - Pattern recognition in VXD, FTD and SIT

Goals of Present Study

- Develop digitization code for VXD hits taking into account
  - Landau fluctuations of specific energy loss along track path
  - charge transport and sharing between neighboring pixels
  - Lorentz shift in magnetic field
  - electronic noise effects ... *etc*
- Verify simulation with testbeam data
- Evaluate point resolution using digitization code
- Develop stand-alone pattern recognition for VXD
- Evaluate of pattern recognition in the presence of beam induced backgrounds

VXD Geometry under Study

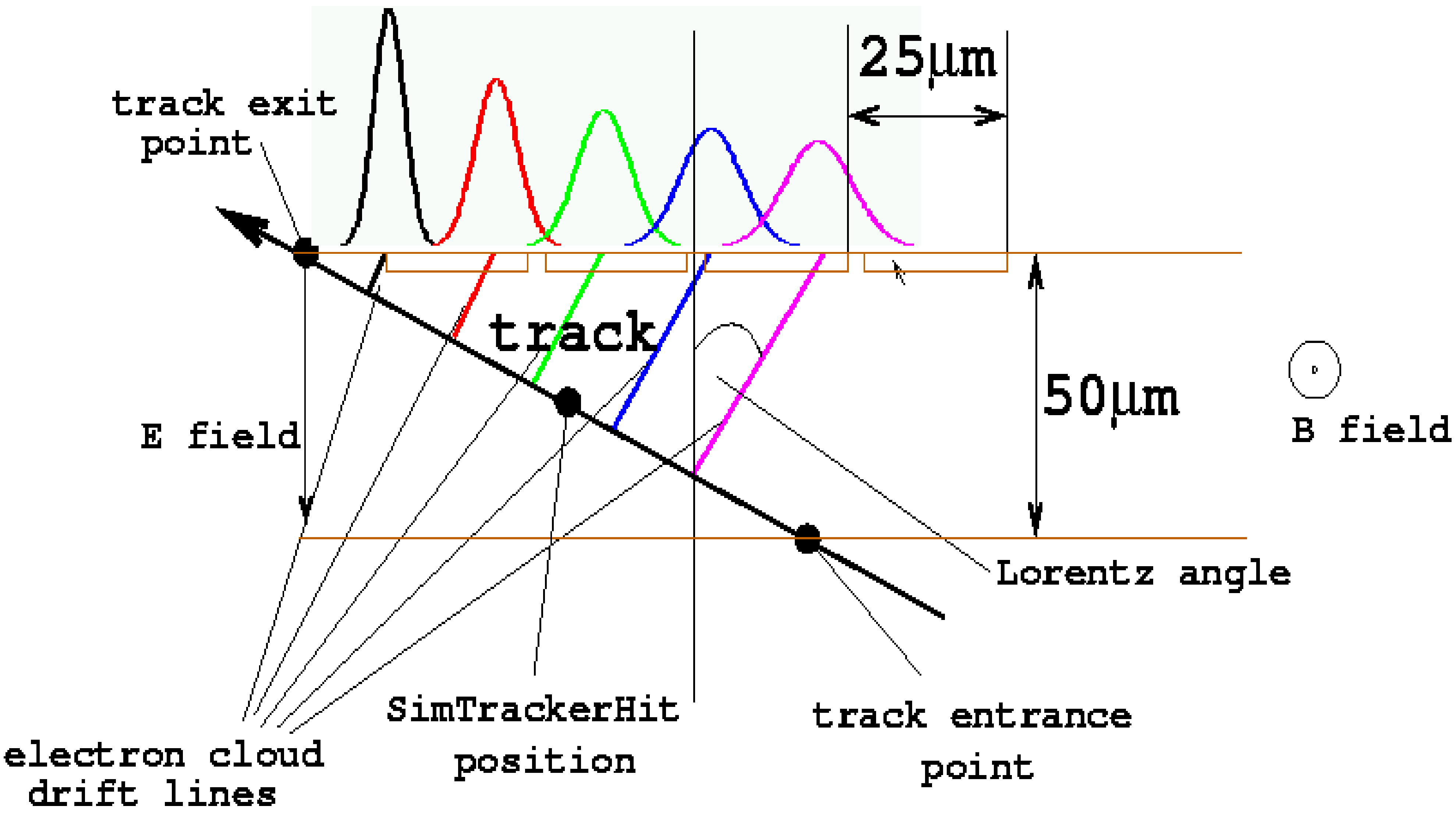


Si layer thickness = 50 μm
Pixel size = 25x25 μm^2
(other pixel sizes also studied)

	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)**

Hit Digitization Procedure



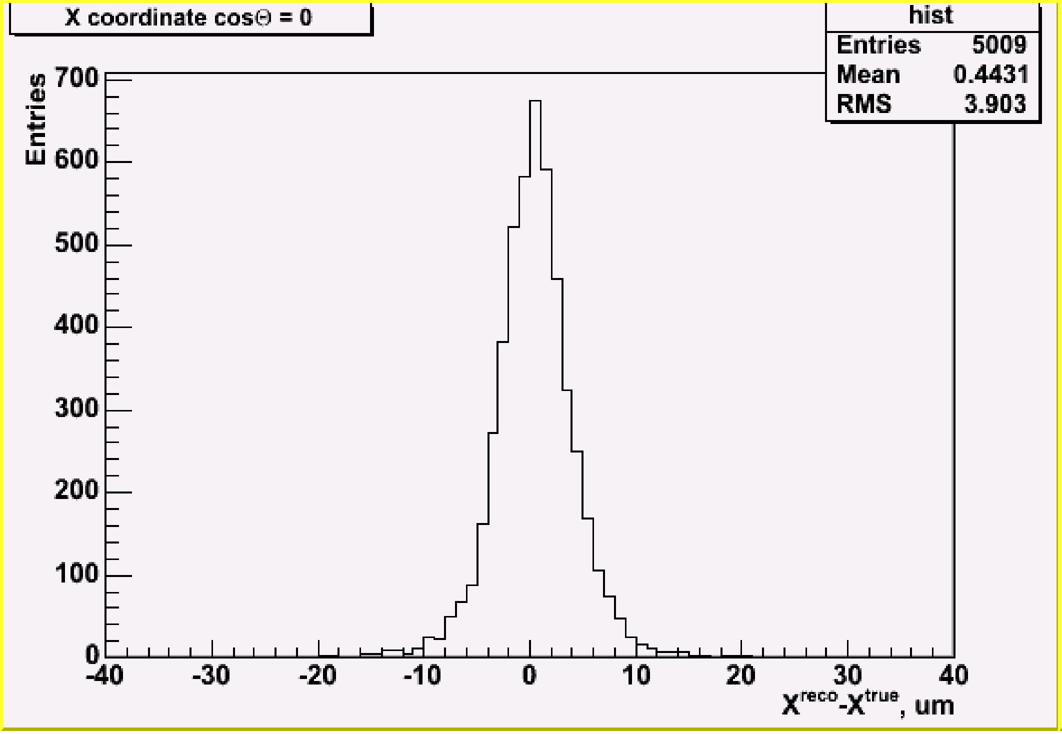
Parameters Steering Digitization

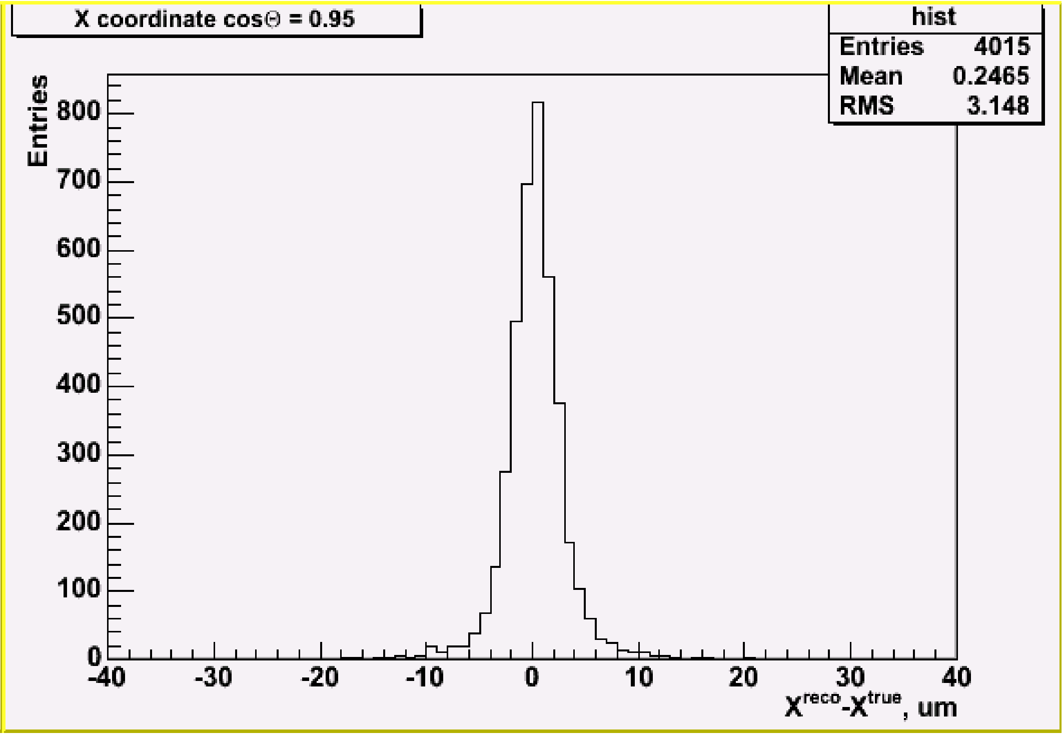
- Calculated diffusion normalised to layer thickness (50 μm) : 2.4 μm
- Tan Lorentz angle : 33^{o} at 4 T field (V. Bartsch etal LC-Note LC-Det-2001)
- Electronic noise : 100e-
- Coefficient converting deposited energy into e-h pairs : 270.3 e / keV
- Hit amplitude threshold : $2\sigma_{noise}$

Point Resolution in R-Phi

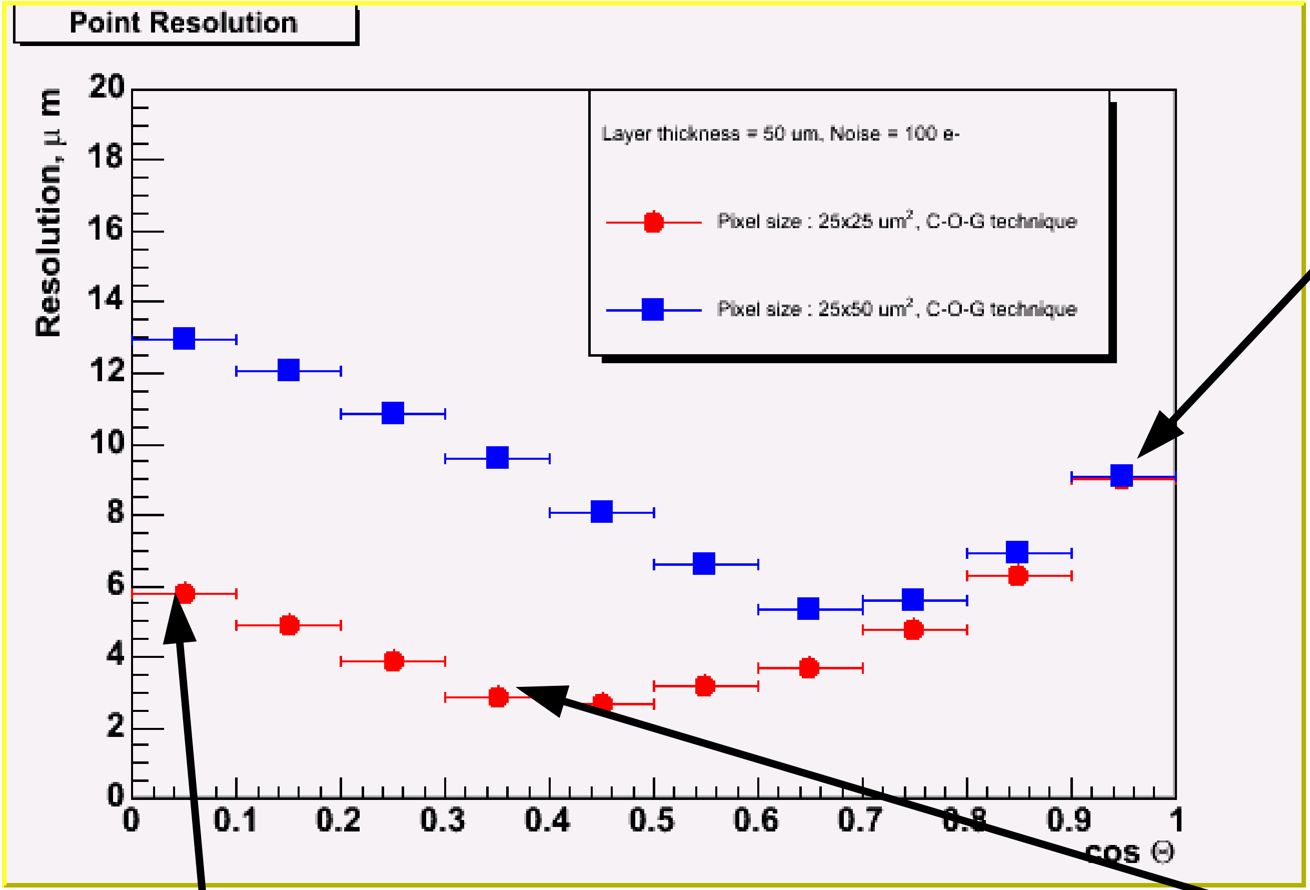
cosΘ= 0

cosΘ= 0.95





Point Resolution in Z



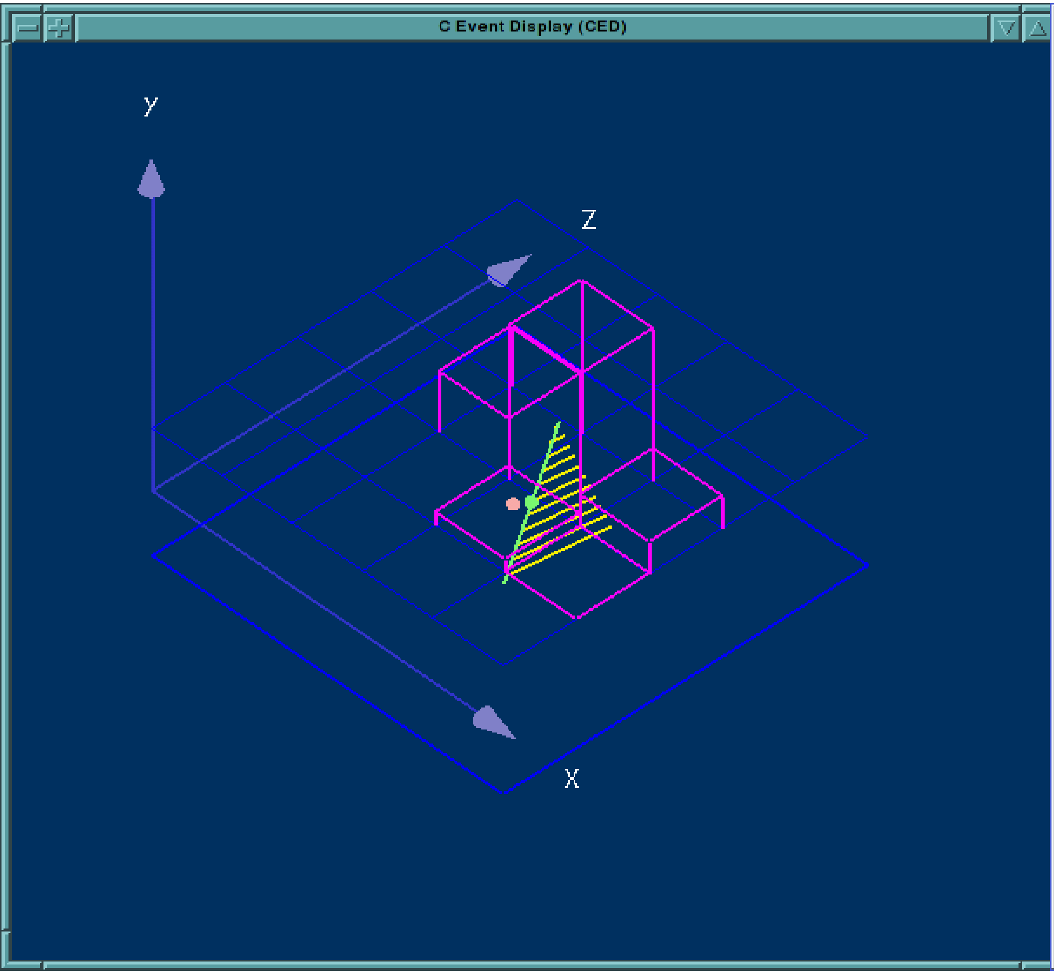
At shallow angles cluster size gets extremely large and simple centre-of-gravity approach yeilds poor resolution due to inter-pixel charge fluctuations

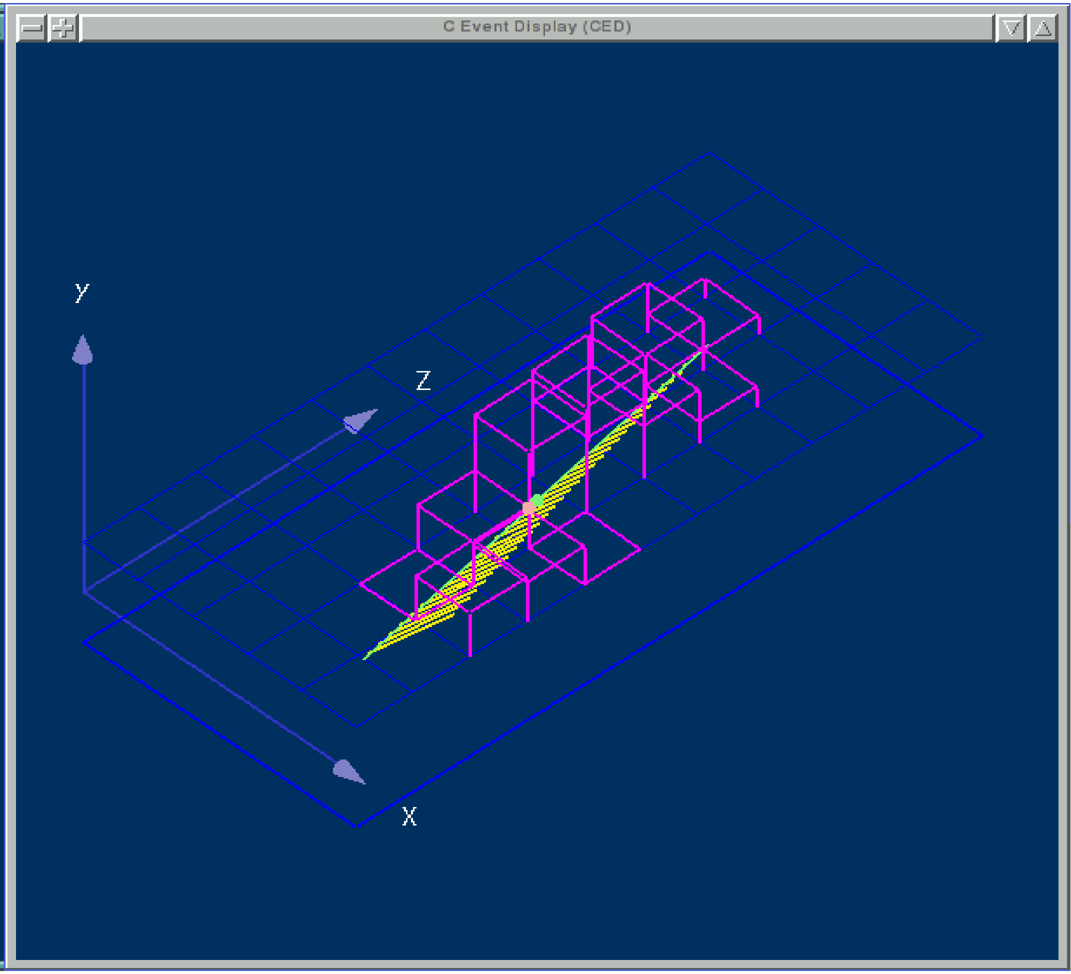
In many cases at normal incidence only one row is fired : resolution is limited by pixel size

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

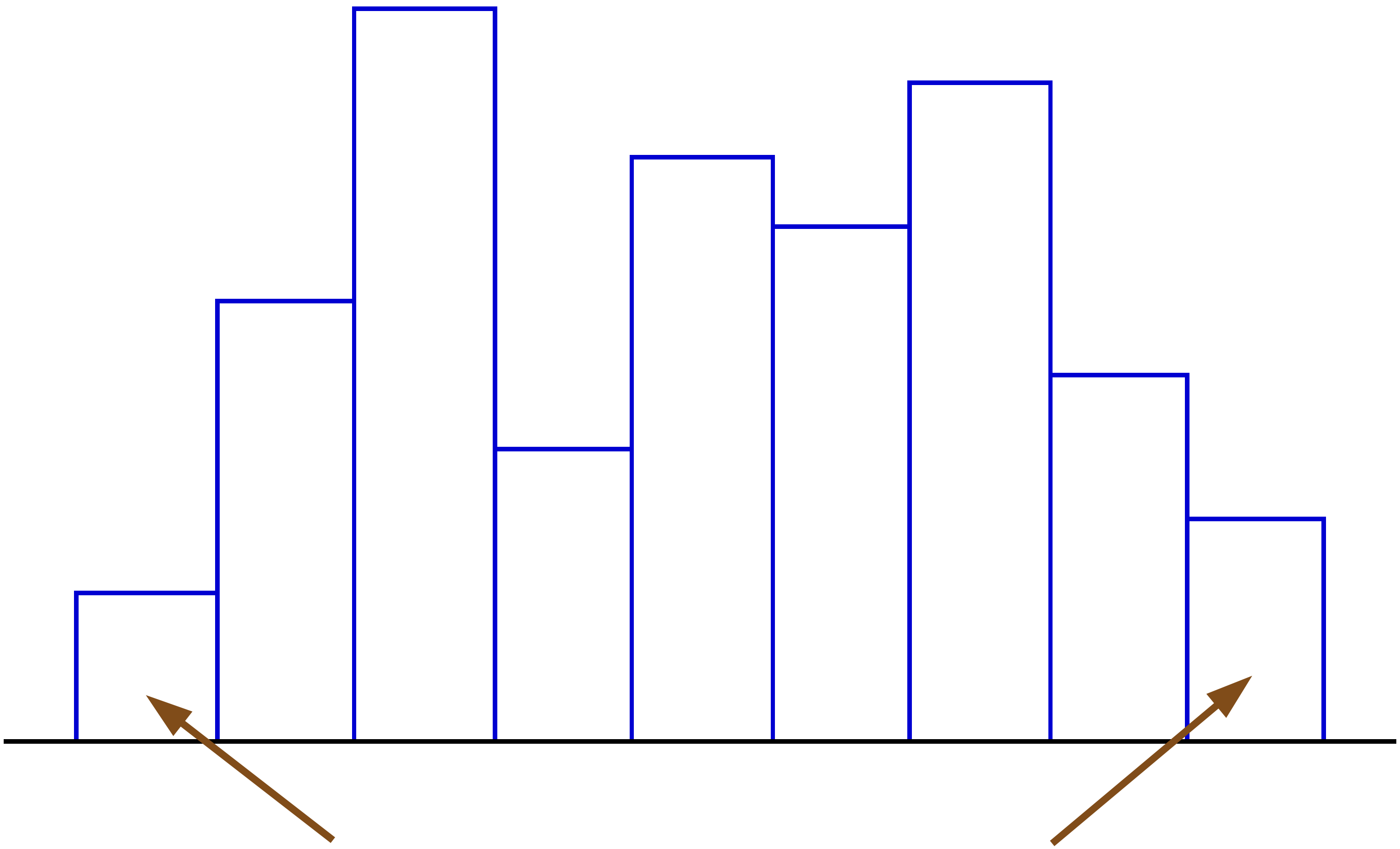
Graphical Illustration

moderate incidence angle	shallow incidence angle



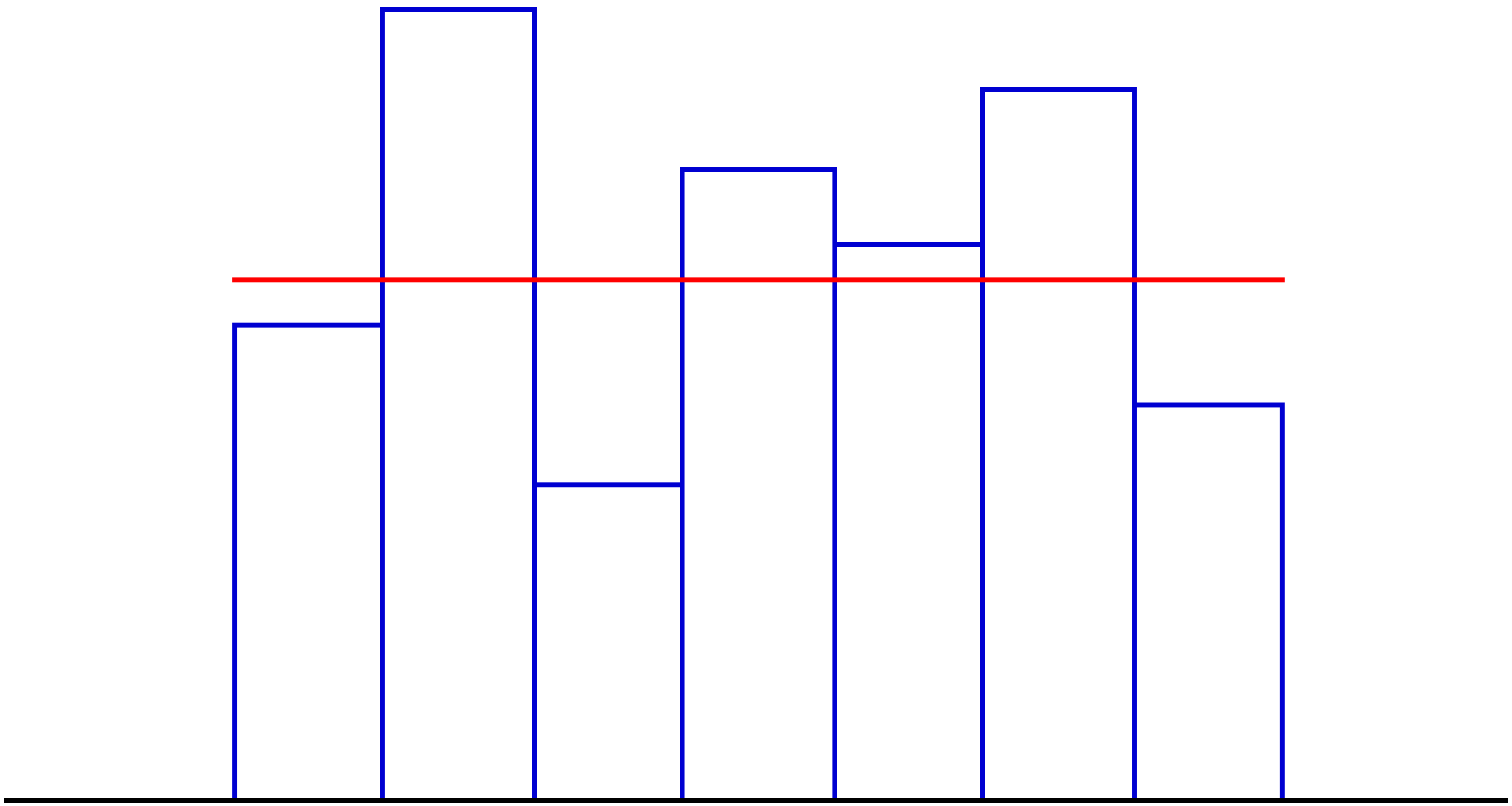


New Reconstruction Method



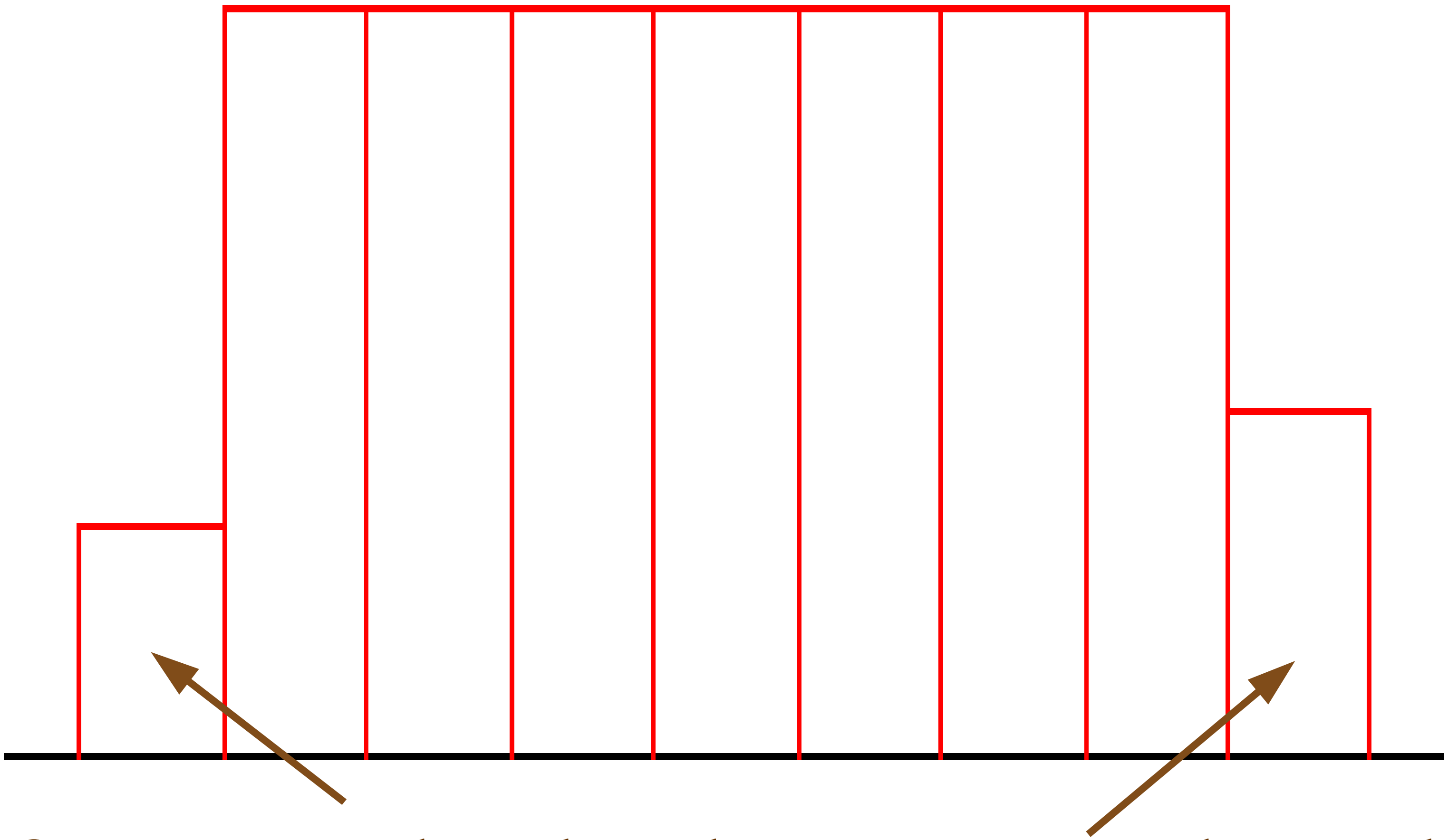
Step 1 : remove edge rows of pixels

New Reconstruction Method



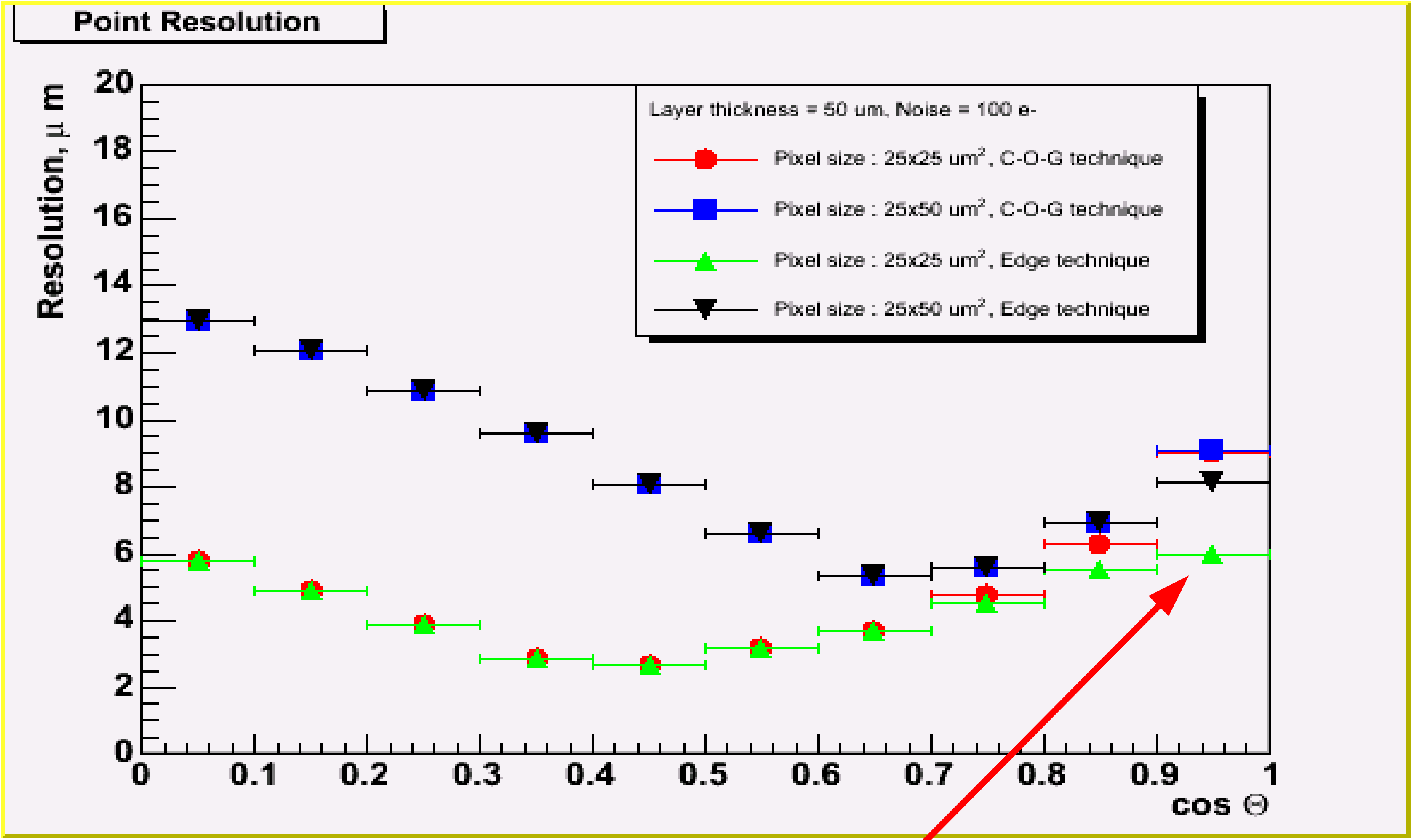
Step 2 : average signal over remaining rows and assign averaged value to each row

New Reconstruction Method



Step 3 : return back edge rows and recalculate centre-of-gravity

Z Resolution with New Method



With new technique resolution improves at shallow incident angles

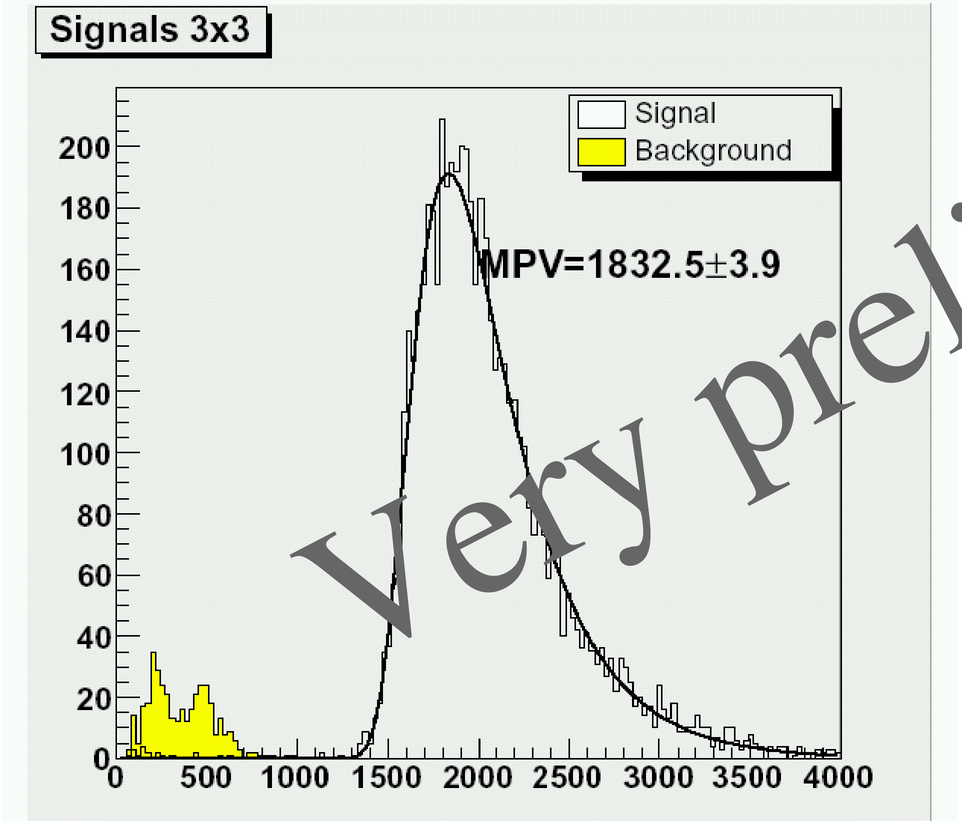
Comparison of Simulation with Testbeam Data

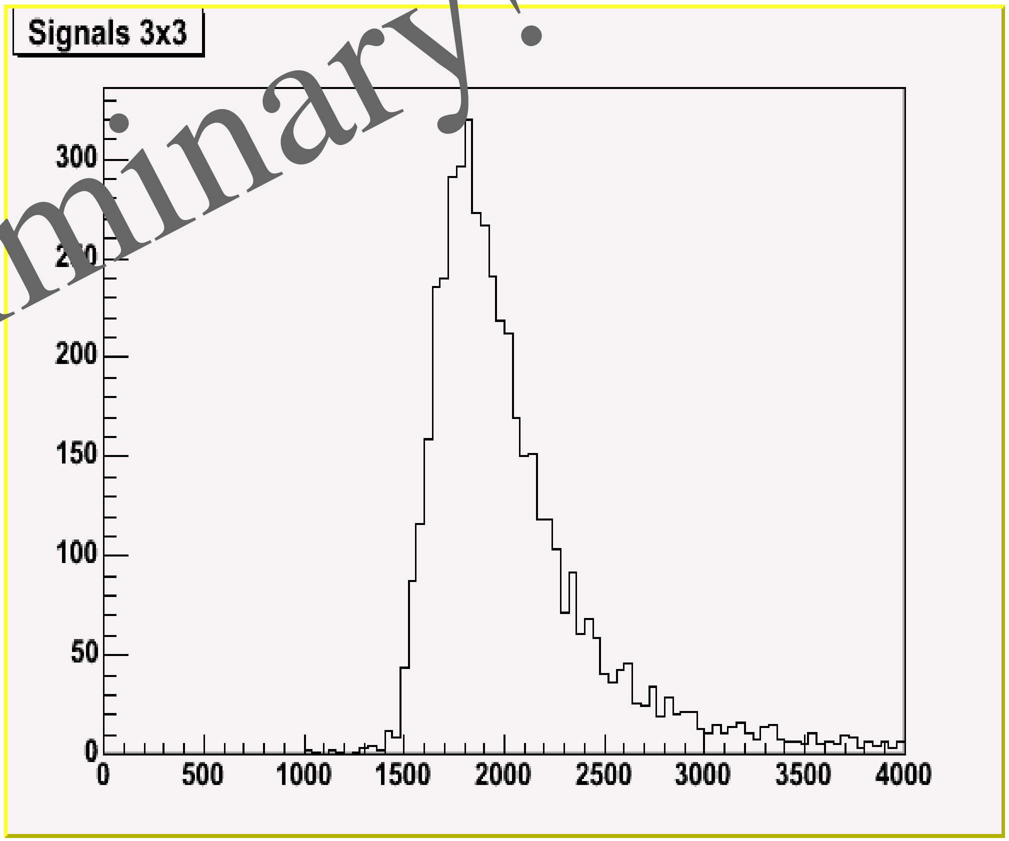
- DEPFET 450 μm thick sensors have been tested in e^+ beam (6 GeV) at DESY
- Pixel sizes are about 36x22 μm^2
- Noise is estimated to be ~ 300 e^-
- Preliminary results of testbeam data analysis are available and comparison with simulations is made

Total Cluster Amplitude

Testbeam data
Courtesy of J. Velthuis

Simulation

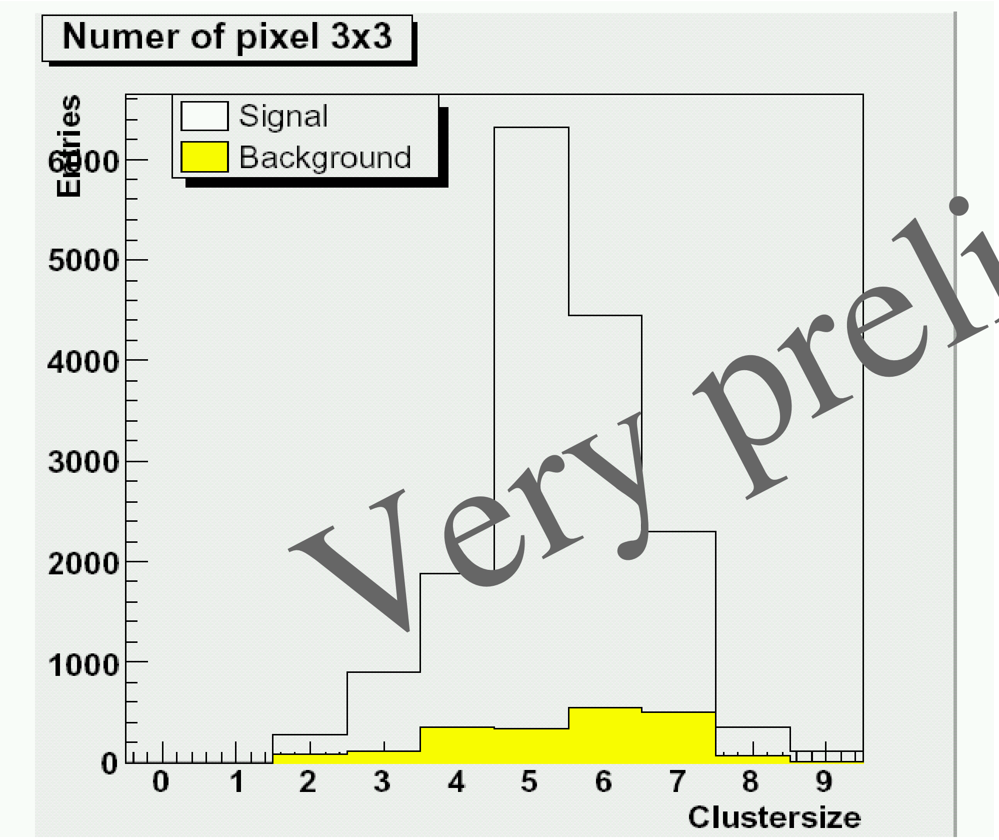


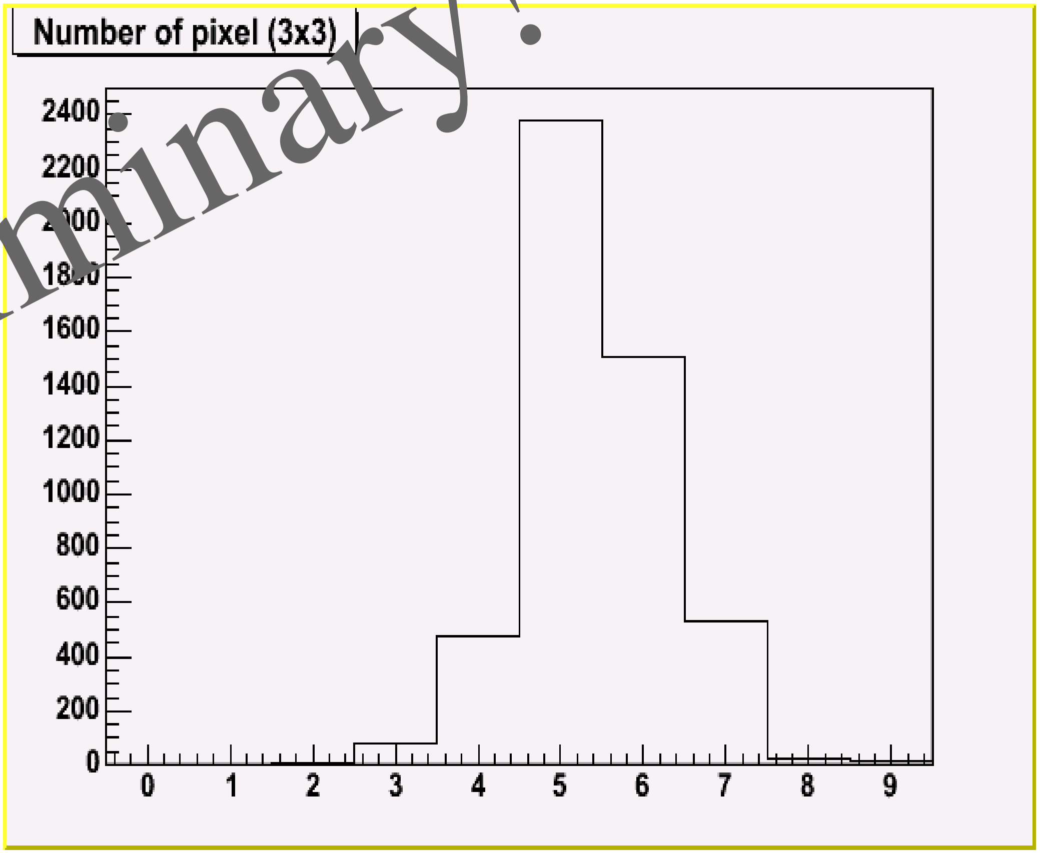


Cluster Size (# of pixels)

Testbeam data
Courtesy of J. Velthuis

Simulation



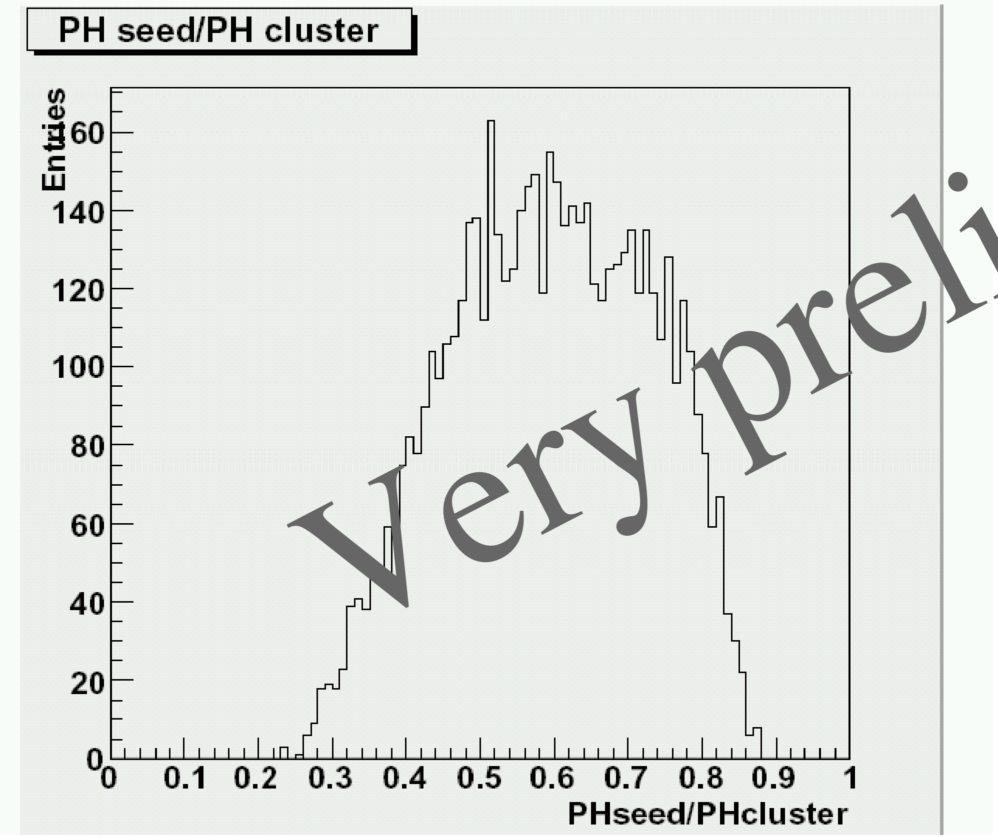


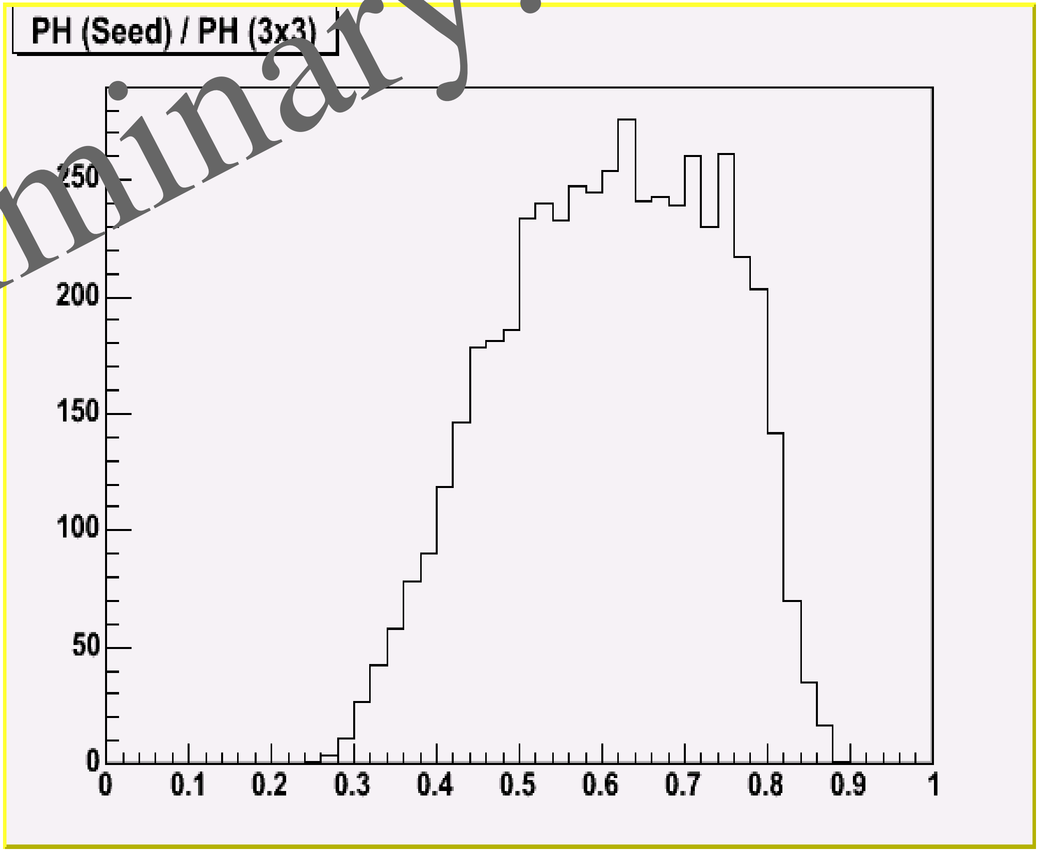
Very preliminary!

Ratio of Maximal Pixel amplitude to the Total Cluster Amlitude

Testbeam data
Courtesy of J. Velthuis

Simulation





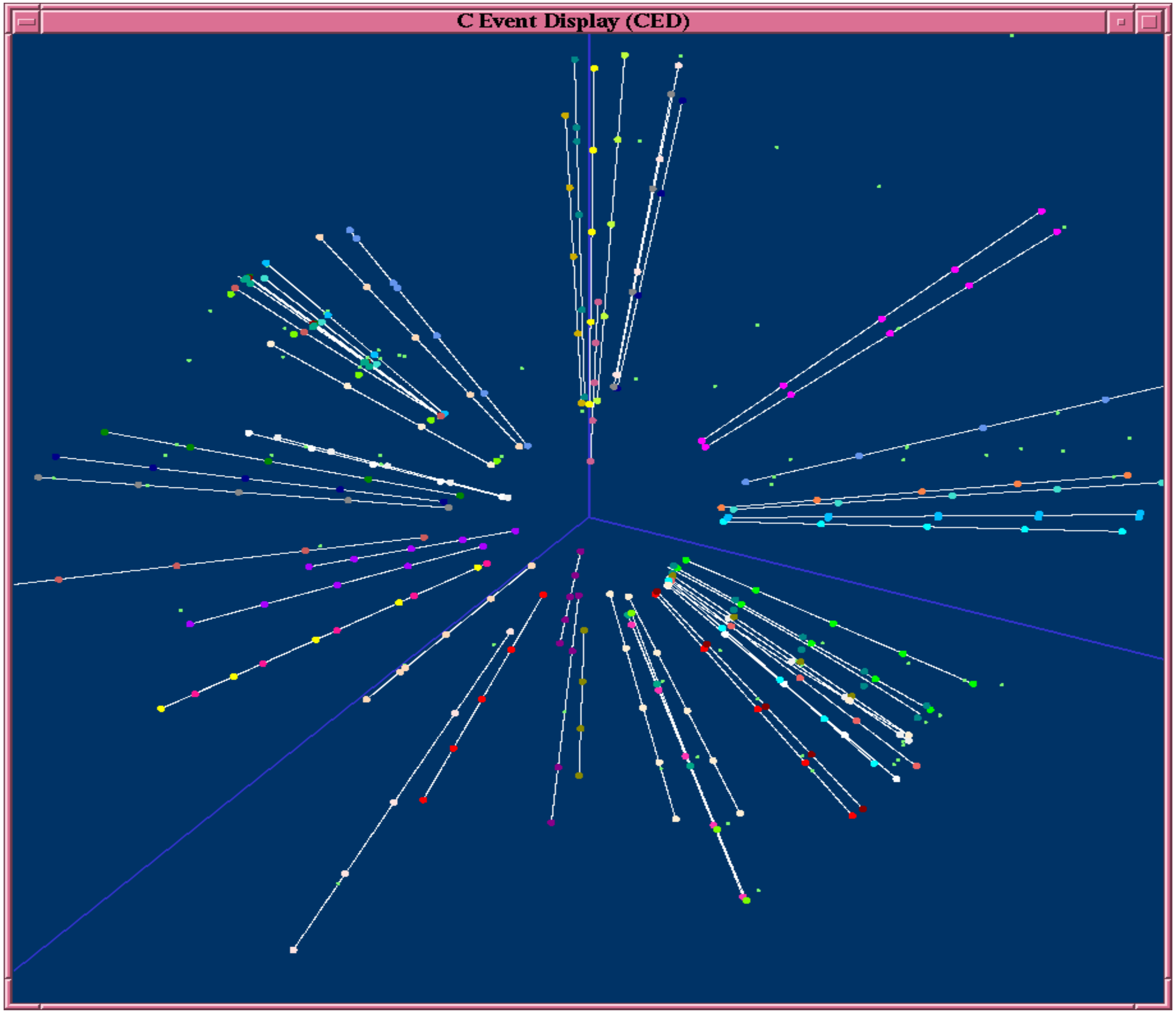
Pattern Recognition Algorithm

- Divide the whole (Φ ,cosΘ) plane into (40,40) sectors
- Find triplets of hits compatible with the helix hypotheis in the 2x2 window of adjacent sectors
  - Hits must belong to different layers
  - Look sequentially for triplets in different layer combinations
  - Accept triplet if $\chi^2 < 20$ and D0 < 5mm and Z0 < 5mm
  - Discard triplet if hits are already assigned to one track
- Extrapolate track inward, pickup hits in the inner layers if they are close to extraplated helix (< 100 um), only one closest hit is allowed to be attached to track in one layer

Pattern Recognition Algorithm

- 3 categories of tracks (more than 4 hits, 4 hits, 3 hits)
- Sort tracks in each category in ascending order of fit χ^2
- Analyse sequentially each category
- First track candidate is accepted; hits belonging to track are marked as used
- Go to next candidate; candidate is discarded if it contains more than 1 already used hits
- Process continues until all track candidate in the sector window have been output or discarded
- Move to the next sector window

Example of reconstructed tt->6jet Event @ 500 GeV c-o-m energy



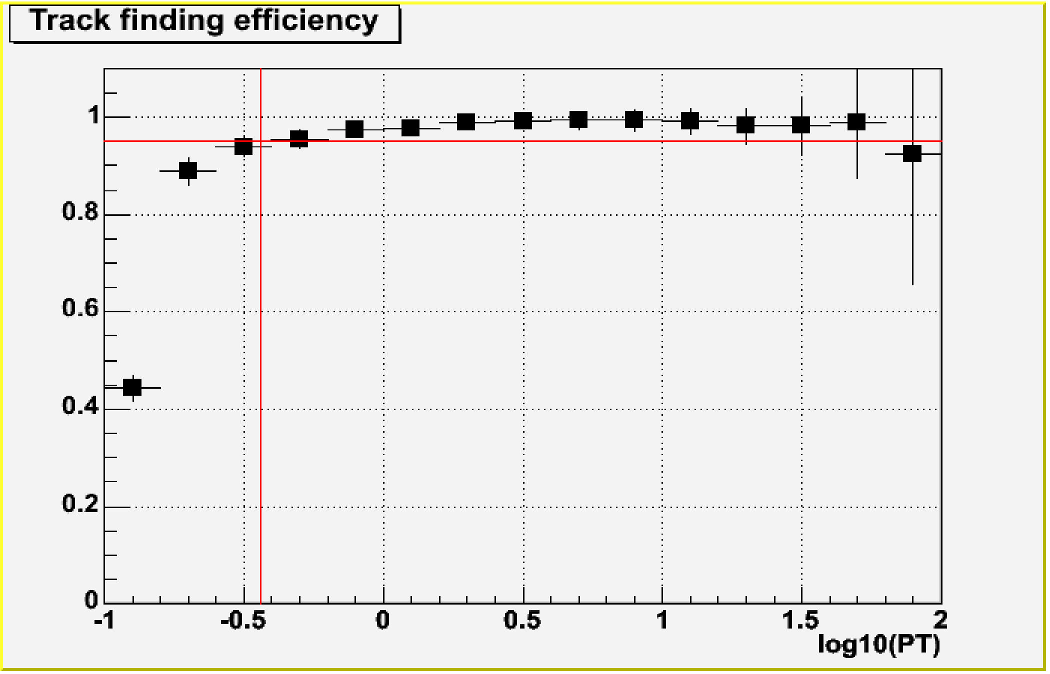
Evaluation of Algorithm Performance with G4 Detector Simulations

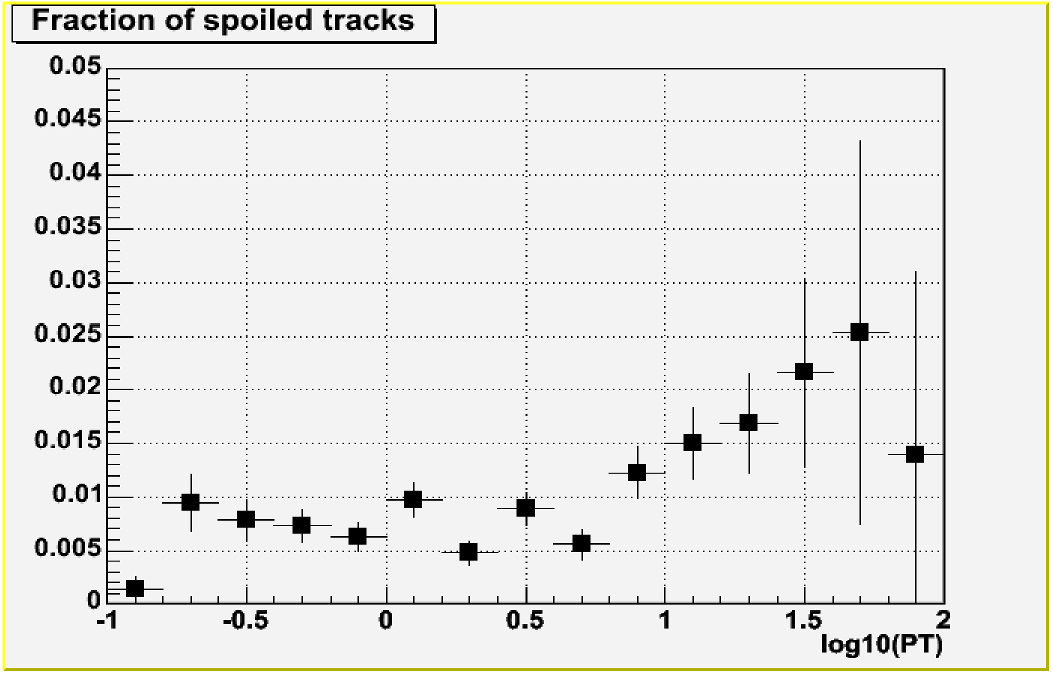
- Performance of algorithm is evaluated with tt->6jet events @ 500 GeV
- Detector simulation is done with Mokka. Particle interactions with detector material are included. Magnetic field = 4 T.
- Digitization of hits is done using procedure described before with noise taken into account. (Noisy pixels are also simulated)
- Cluster of pixels is accepted if it has more than 2 pixels with amplitude $> 2\sigma_{noise}$
- At least one pixel must have amplitude $> 5\sigma_{noise}$

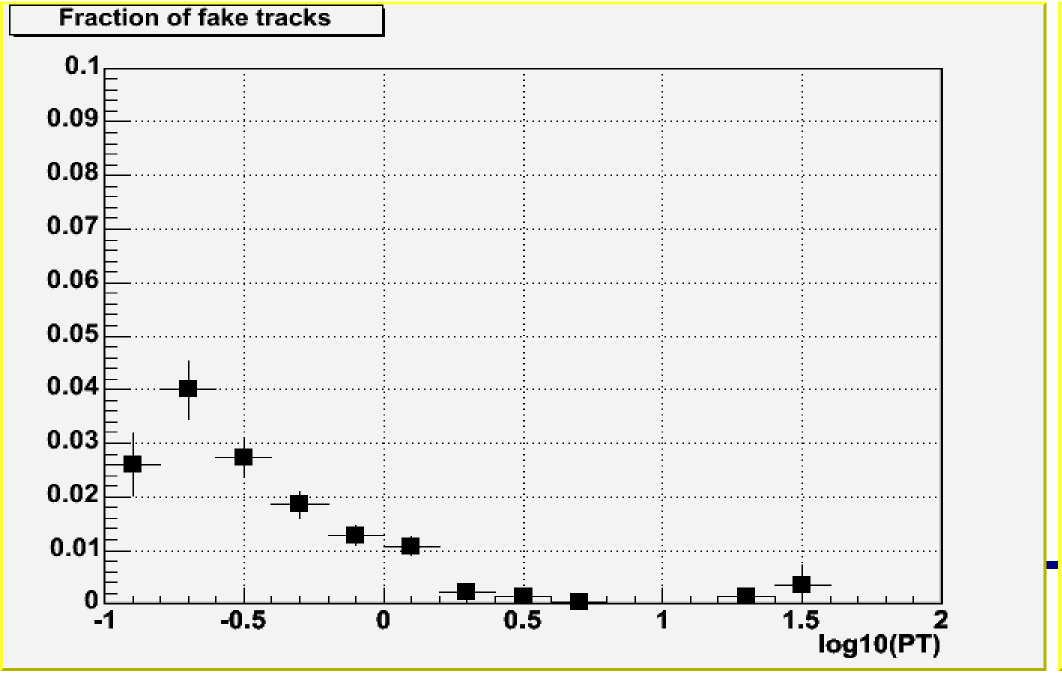
Algorithm Performance. Key Quantities

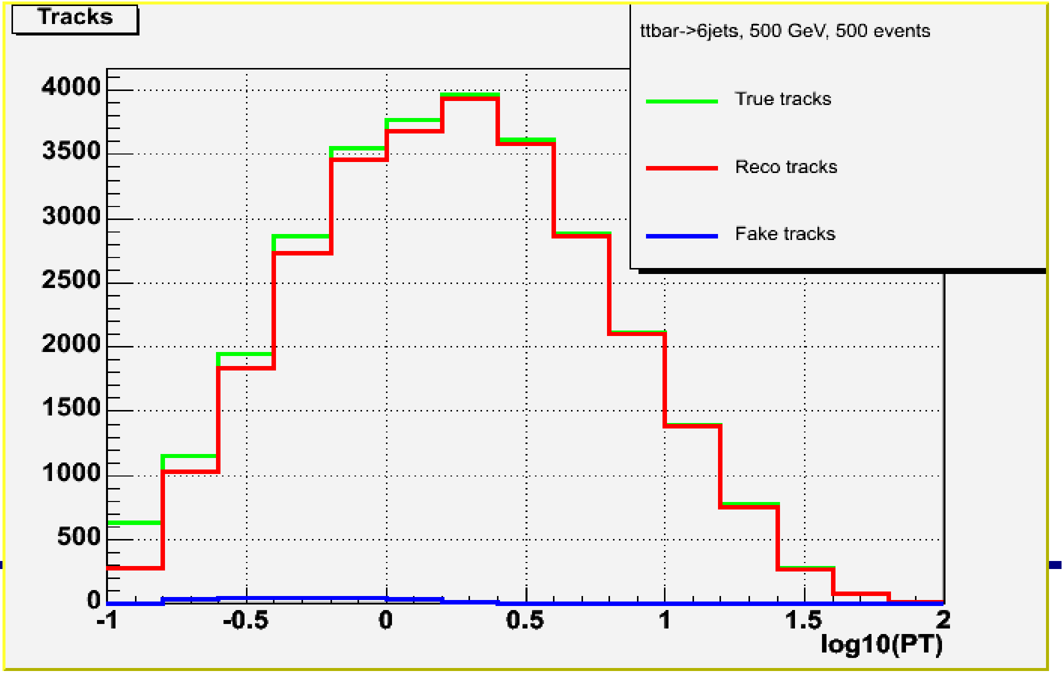
- Performance of algorithm is evaluated in terms of the following quantities
  - Track finding efficiency as a function of P_T and $\cos\Theta$
  - Fraction of spoiled tracks ; spoiled track is defined as track having one and only one wrongly assigned hit
  - Ratio of fake tracks to correctly reconstructed tracks; track is regarded as fake if it has more than one wrongly assigned hits

Algorithm Performance

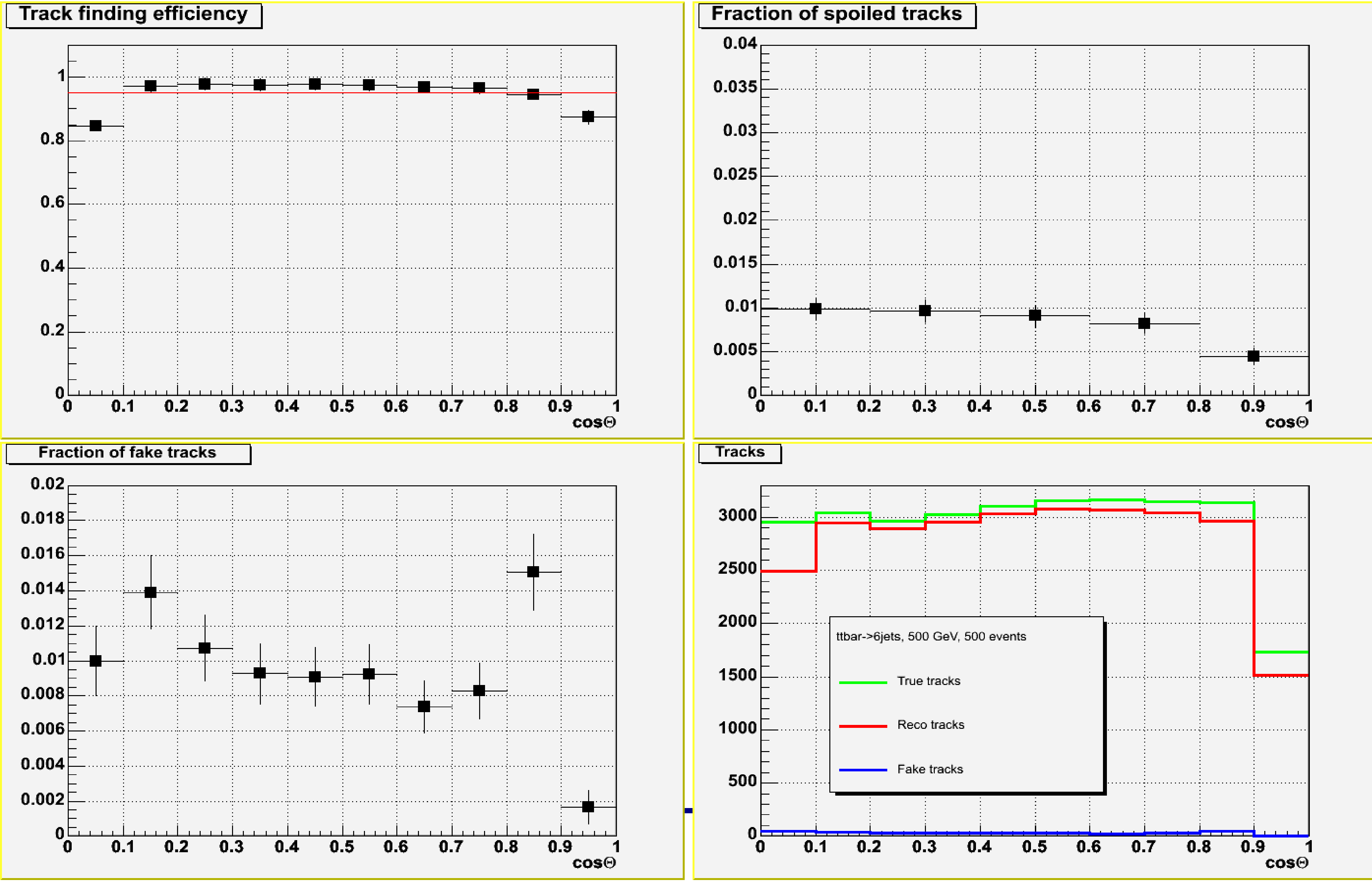








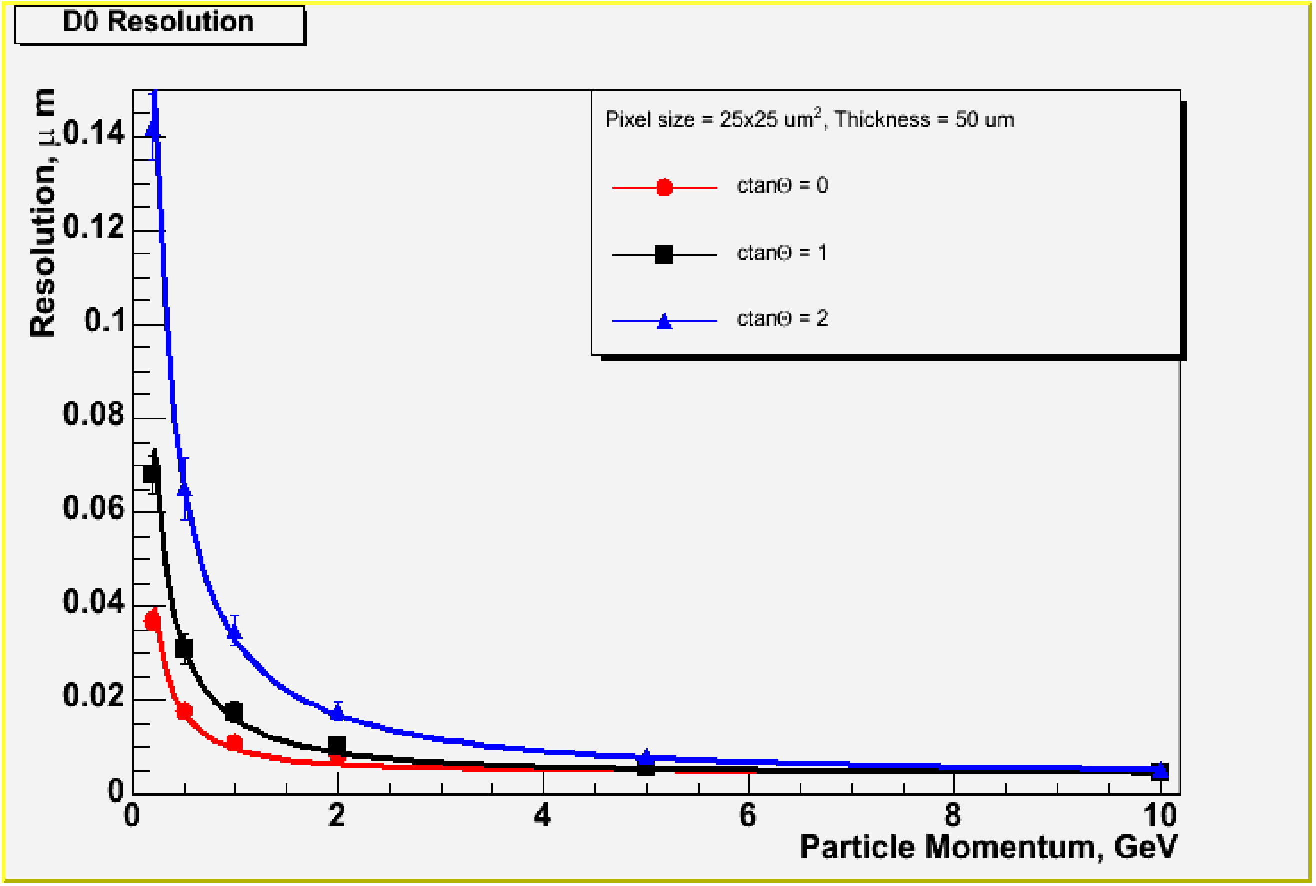
Algorithm Performance



Quality of Track Reconstruction in Dense Environment

- The following procedure has been employed to evaluate quality of track reconstruction in jet
  - Samples of single particles are generated with predefined energy and polar angle : m , E = 0.2 – 10 GeV, cosQ = 0,1,2
  - Single particles are overlaid with ttbar->6jet events; in order to correlate particle momentum vector with momentum of initial parton, the particle momenta in the ttbar->6jet event are rotated such that the momentum of reference particle coincides with momentum of one of the initial partons
  - Event is then passed to Mokka to simulate detector responce. Produced VXD hits are then digitized and pattern recognition is applied on the list of these hits
  - Reconstructed track parameters are compared between ideal pattern recognition (assuming that all hits belonging to the reference particle are found and attached to track) and realistic pattern recognition

Impact parameter resolution (D0)

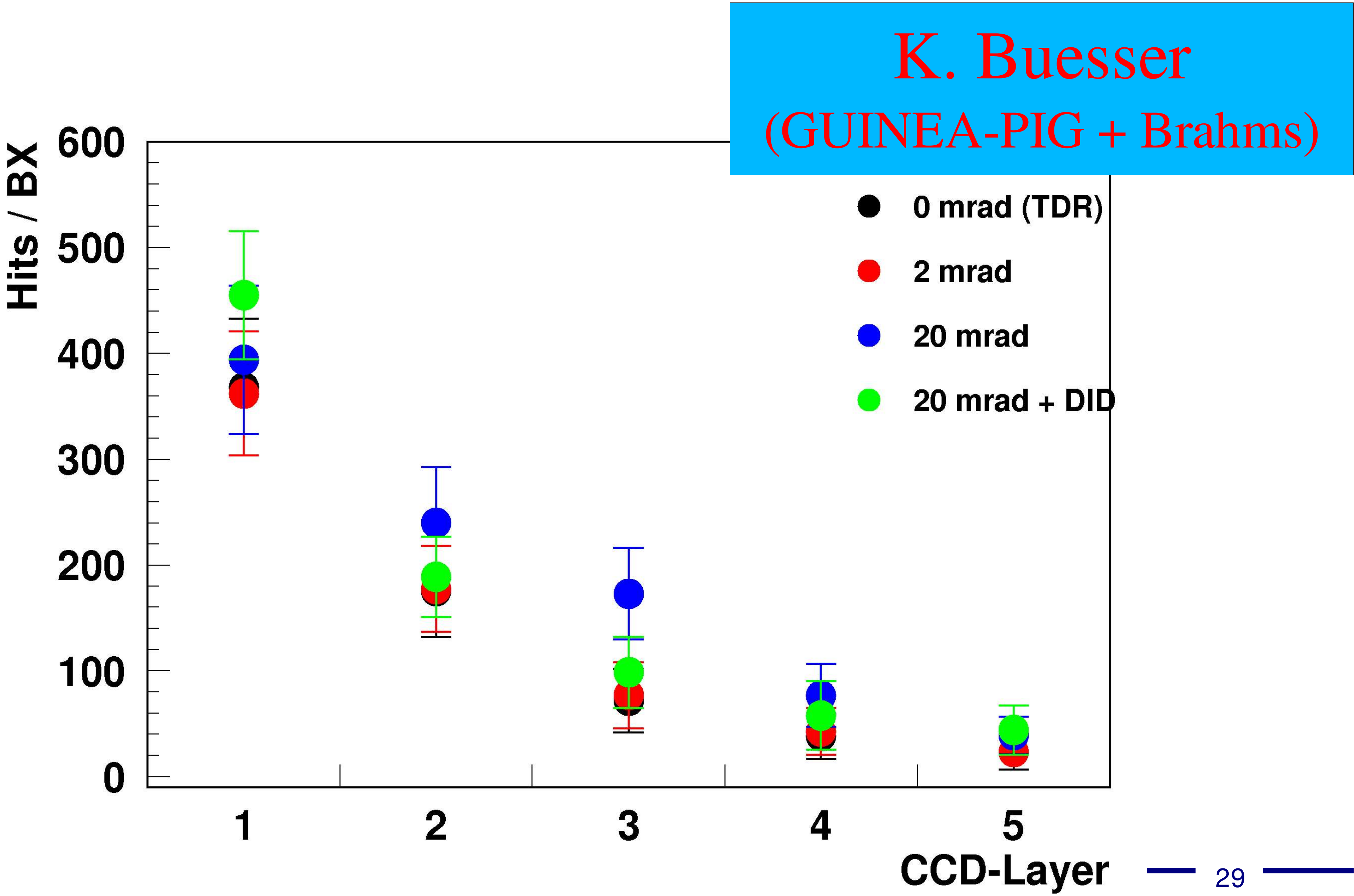


$$\sigma_{d0} = \sqrt{a^2 + b^2/p^2 \sin^3\Theta}$$

a = 4.7 um ; b = 8.9 um GeV with realistic patrec (track in jet)

a = 4.4 um ; b = 8.1 um GeV for ideal patrec

Expected Beam Backgrounds



Expected Beam Backgrounds. Simulation with GUINEA-PIG and Mokka

Number of background hits per layer

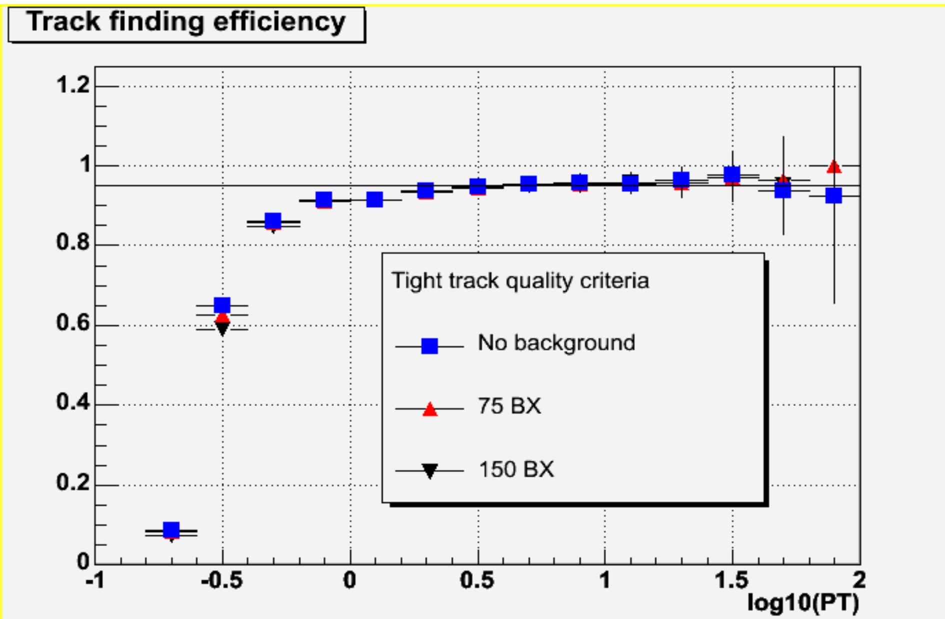
VXD Layer	1BX	75BX	150BX
1	344	25800	51600
2	240	18000	36000
3	96	7200	14400
4	55	4125	8250
5	31	2325	4650

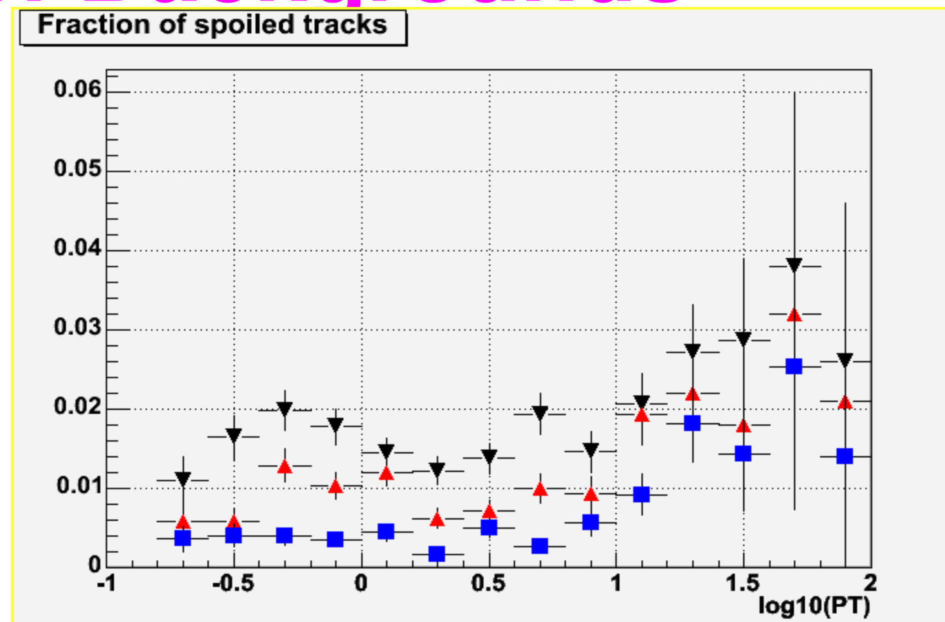
75 bunch crossings correspond to 25 µm of integration time (500 GeV, cold machine); 150 BX – 50 µm

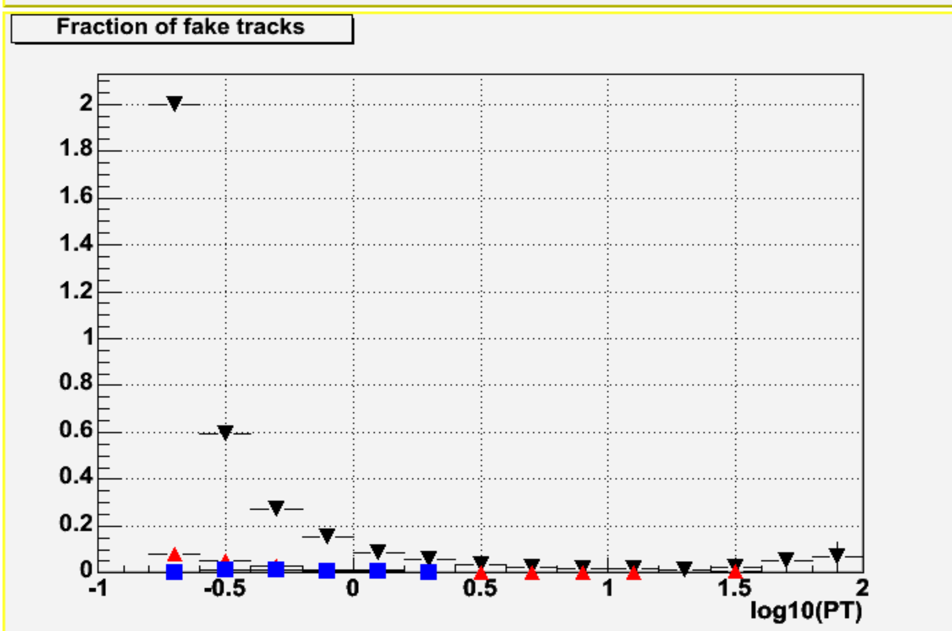
Pattern Recognition in the Presence of Backgrounds

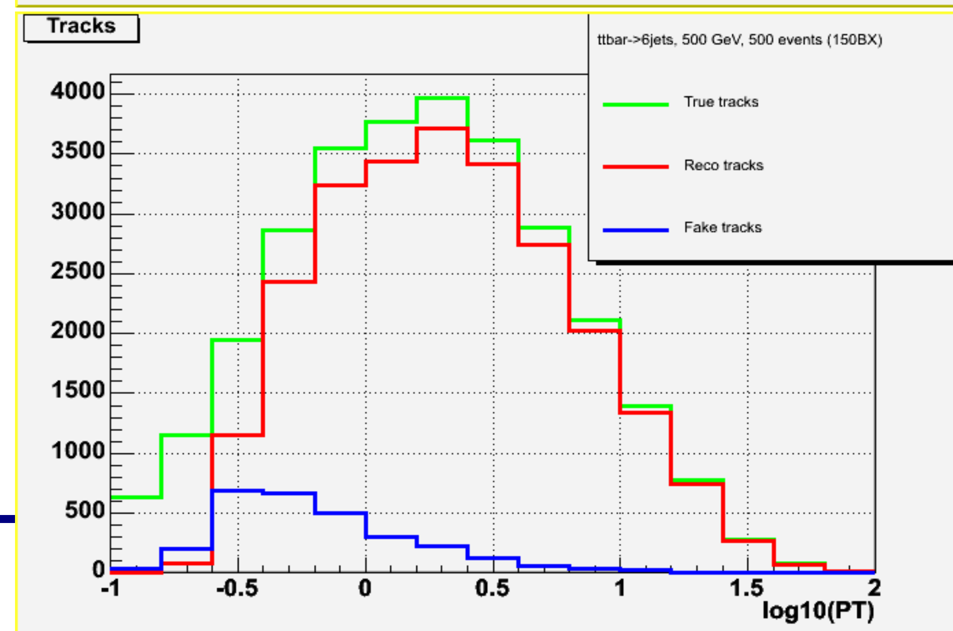
- To suppress fake track rate caused by background hits and accelerate the procedure of track finding, the algorithm has been slightly modified and the track quality criteria have been tightened:
  - Search for hit triplets is restricted to four outer layers (inner layer is excluded);
  - Cut on χ^2 of track fit is tightened from 20 to 5;
  - $(\Phi, \cos\Theta)$ plane is divided in 100x100 sectors;
  - Track is accepted if it has 4 or more hits

Pattern Recognition Performance in Presence of Backgrounds

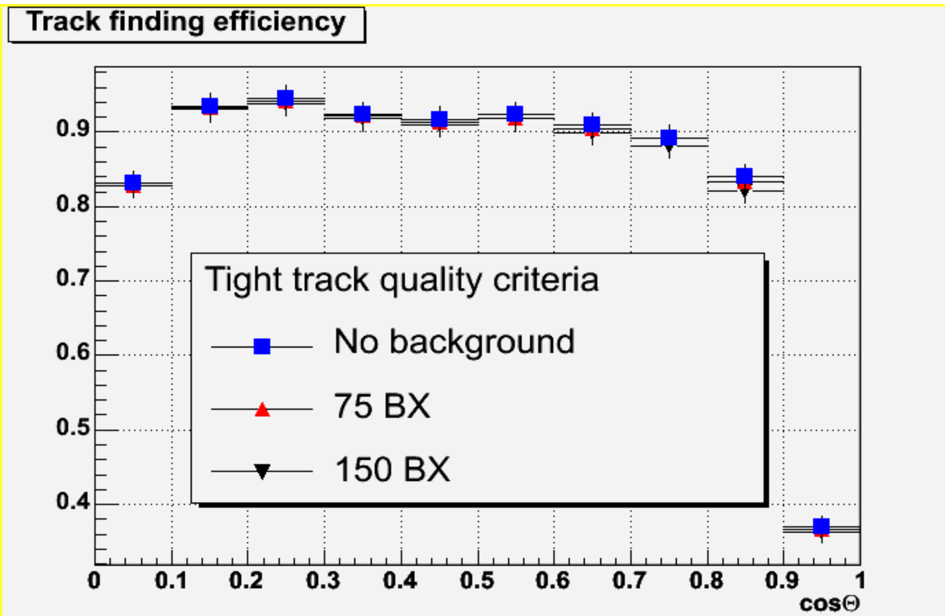


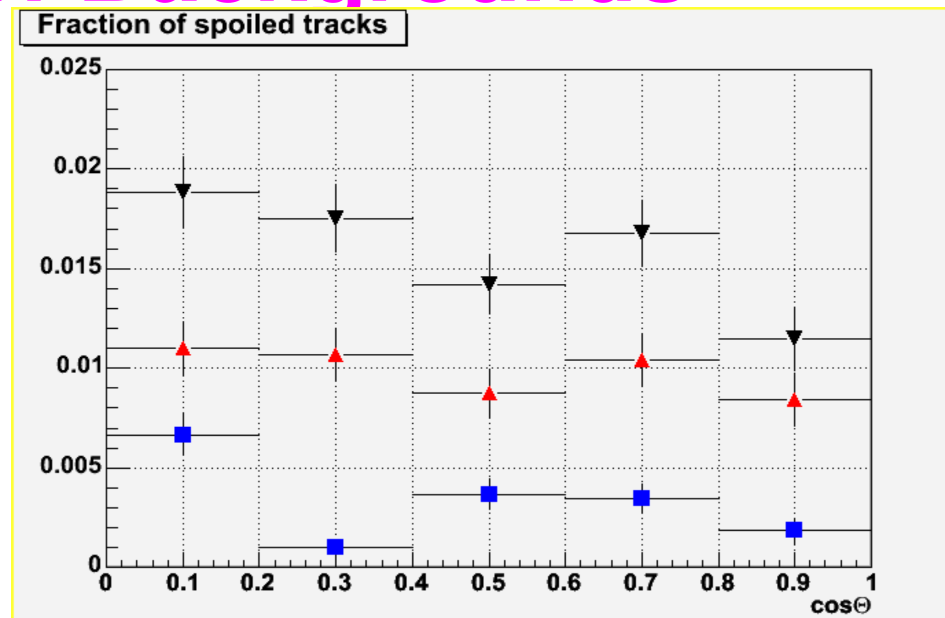


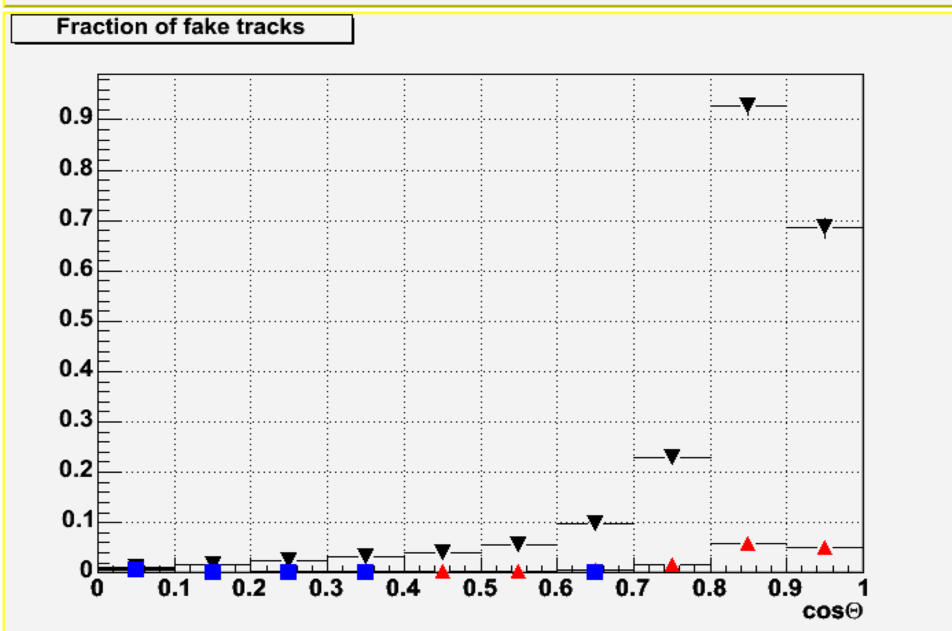


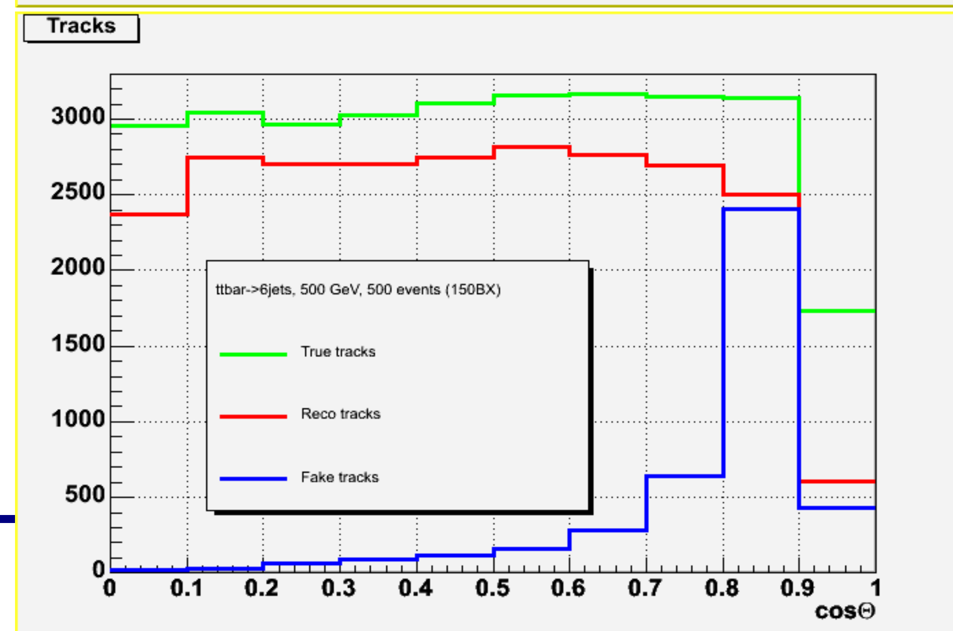


Pattern Recognition Performance in Presence of Backgrounds









Summary

- Digitization procedure of VXD hits and pattern recognition algorithm for VXD have been developed. The code is included in MarlinReco package and available @ http://www-zeuthen.desy.de/linear_collider
- Simulation studies showed that point resolution of 3-4 μm in R-Phi plane and 3-6 μm in Z plane, depending on incidence angle, can be achieved with pixelized detector (pixel size of 25x25 μm^2)
- Pattern recognition performance have been evaluated in presence of beam induced backgrounds. Initial studies showed that algorithm can handle backgrounds, maintaining efficiency above 90% for tracks with $p_T > 0.7$ GeV, while keeping fake track rate at few percent for $p_T > 0.7$ GeV. Algorithm has not been finally optimized yet, leaving room for further improvements
- Developed tools can be used for further detector optimization