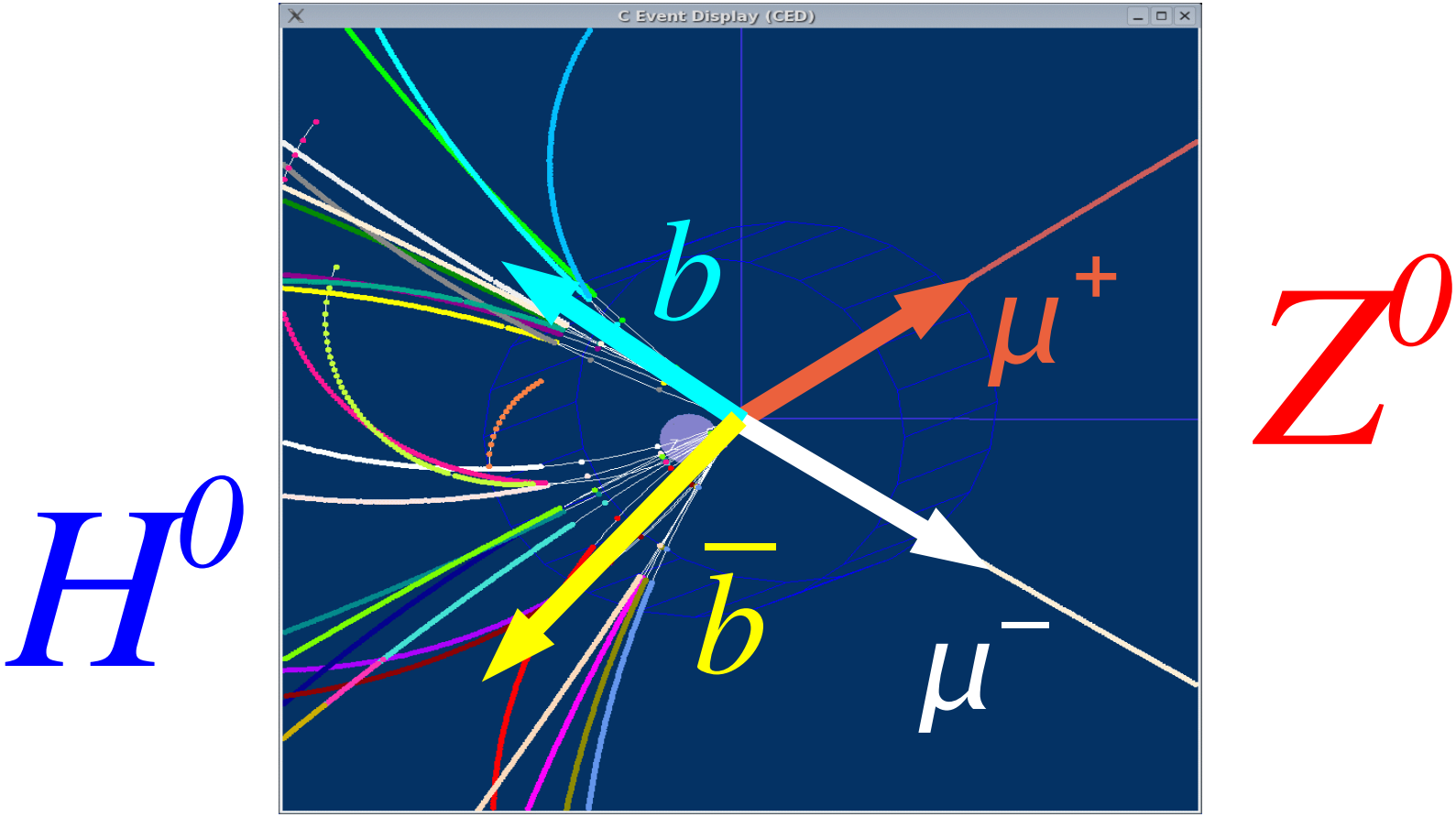
Status of LDC Tracking Software



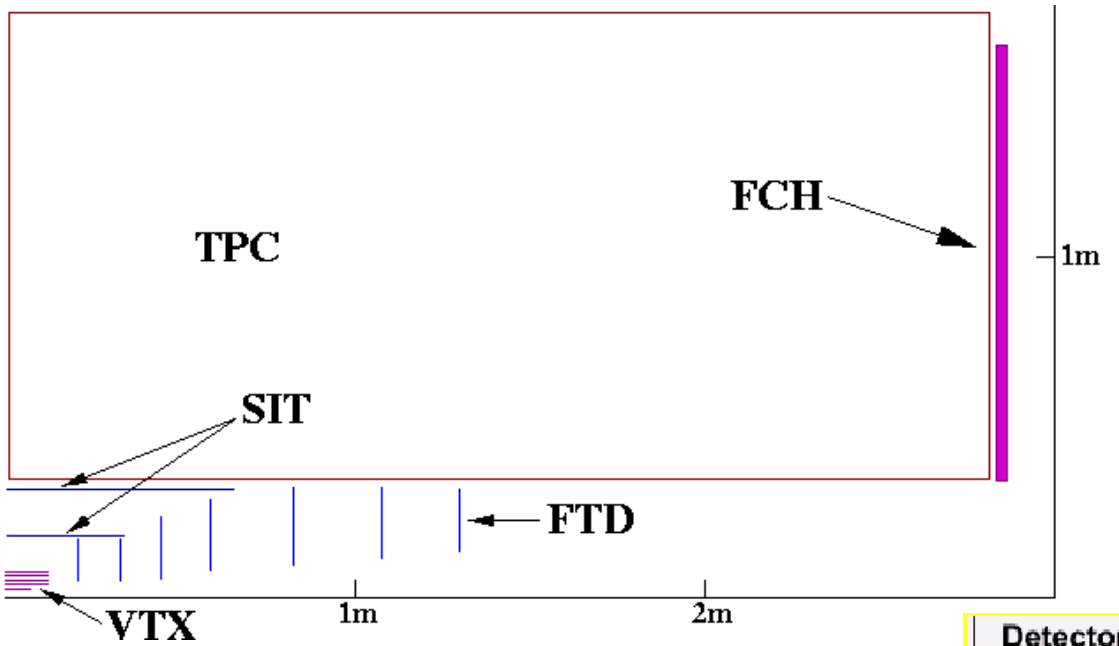
A. Raspereza, A. Frey, Xun Chen – MPI Munich

ILC Software Workshop, Orsay 2007

Outline

- *Overview of LDC Tracking System*
- *Review of LDC Tracking software*
  - *Digitization package*
  - *Hit pattern emulation in absence of particle interactions with detector materials*
  - *Pattern recognition and track fitting packages*
- *Tracking Performance*
  - *Track finding efficiency*
  - *PFA Performance*
- *Summary & Outlook*

LDC Tracking System (Mokka)



TPC : main device, measures $\vec{P}$ in central part

VTX : b/c tagging, refines measurement of $\vec{P}$

FTD : extends angular coverage

SIT : bridge between VTX & TPC, improves V^0 finding

FCH : track – ECAL-endcap cluster linker for PFA (behind TPC endplate)

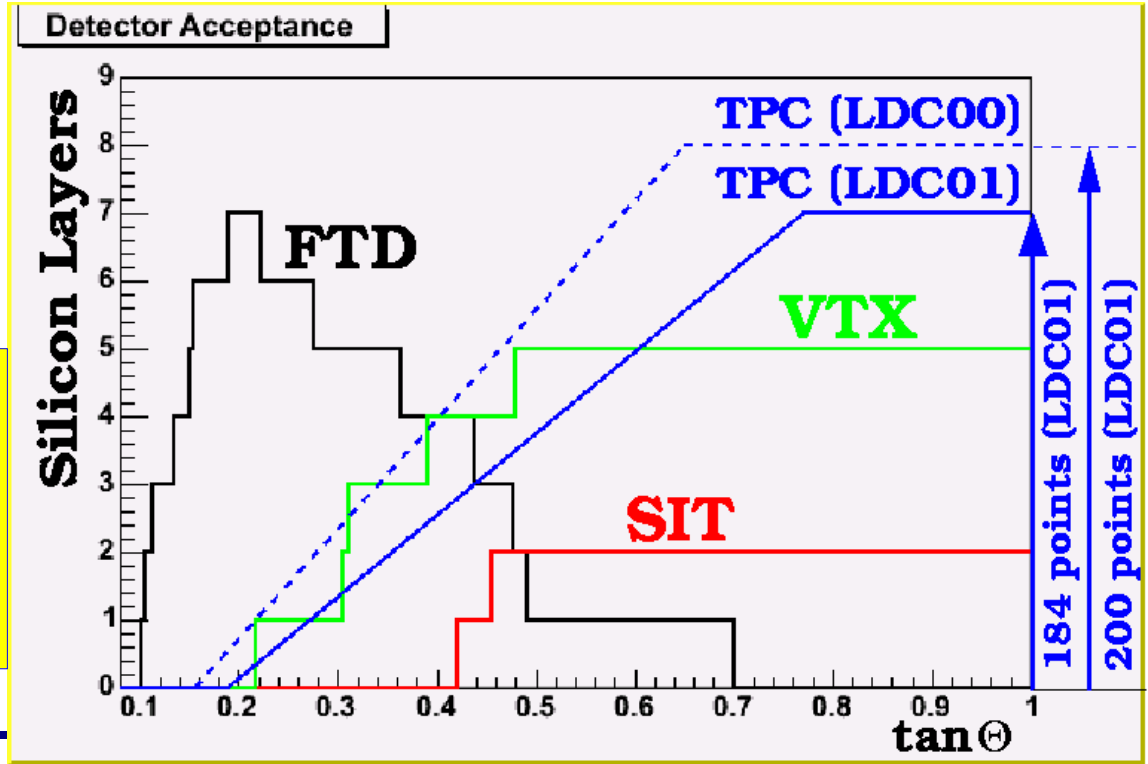
Mokka models

LDC00 & LDC01 :

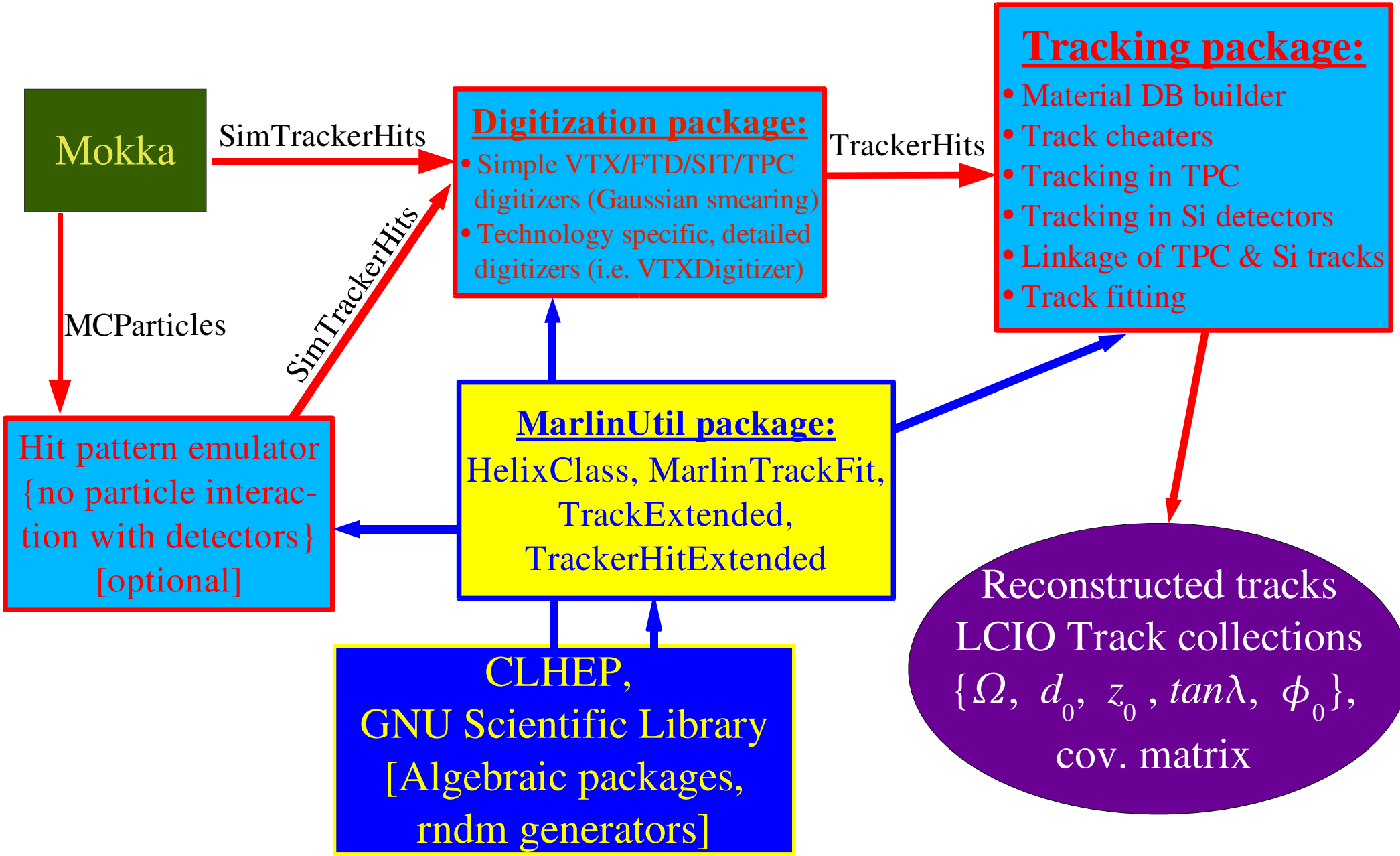
tracking system differs only by TPC

Default parameters of TPC

Model	R_{in}	R_{out}	L [mm]
LDC00	386	1626	2500
LDC01	371	1516	1970



Structure of LDC Tracking Package



Digitization Package

- Two approaches for Tracker Hit digitization

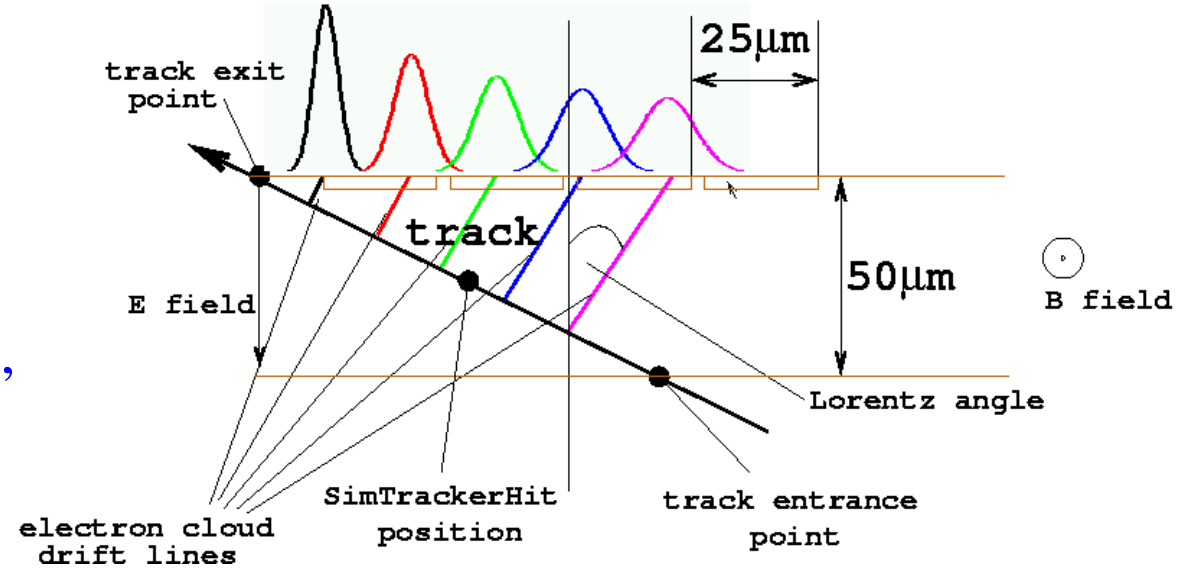
  1) Straightforward gaussian smearing of SimTrackerHit position (TPC/VTX/FTD/DigiProcessor in Marlin) based on specified (apriori-known) spatial point resolution (r-ϕ and Z resolutions)

  2) Detailed digitization based on features of VXD technology and readout

- Example : DEPFET

  ➔ VTXDigitizer accounts for:

  energy loss fluctuations, lorentz shift, electronic noise, diffusion, *etc*



- New digitizing package by S. Shulha ⇒ digitization of Silicon detectors (VTX, SIT, FTD) taking into account pixel/strip structure of sensitive layers

Simple Digitization: New Features

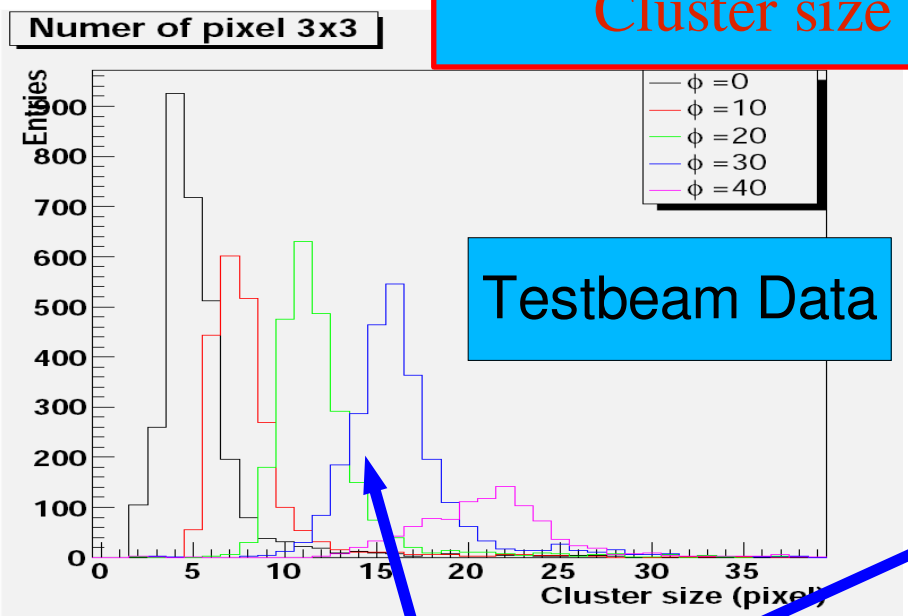
- Improved & flexible digitization procedure for TPC
  - Smearing of r-φ hit position according to correct resolution functions

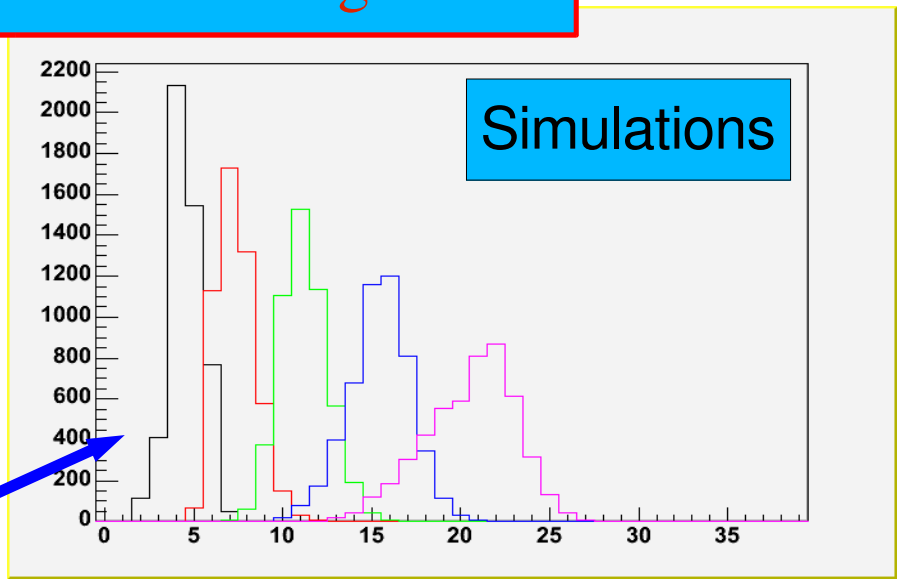
$$\sigma_{r\text{-}\varphi}^{2} = \sigma_{0}^{2} + \sigma_{D}^{2} \cdot L_{drift}$$

  - σ_0^2 & σ_D^2 are specified for via GEAR steering : $\sigma_0 = 55\mu m$, $\sigma_D = 3\mu m^{1/2}$
  - σ_z is assumed to be constant along z : $\sigma_z = 0.5mm$ [suggested by LC-TPC, R. Settles]
- Simple digitization is done by Gaussian smearing of SimTrackerHits
  - Cyllindrical detectors (VTX, SIT, TPC) : r-ϕ & z positions are smeared
    - VTX ------- : $\sigma_{r\text{-}\phi} = \sigma_z = 4\mu m$ [Brahms]
    - SIT --------- : $\sigma_{r\text{-}\phi} = \sigma_z = 10\mu m$ [Brahms]
  - Planar detectors (FTD) : (x,y) is smeared isotropically ($\sigma_x = \sigma_y = 10\mu m$) [Brahms]
- Spatial resolutions are stored in the vector of hit position covariance matrix (LCIO TrackerHit class) ⇒ they are specified once and forever at the digitization step and used later on by fitting routine (no duplication in Tracking code)

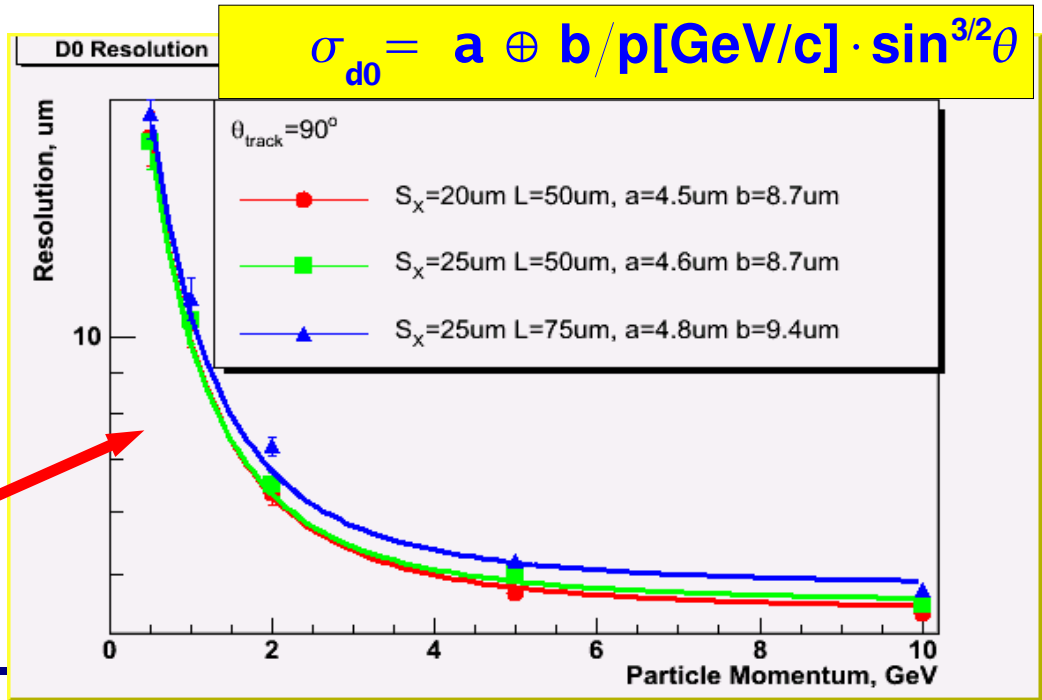
DEPFET Technology Specific Digitizer

Cluster size vs. incidence angle





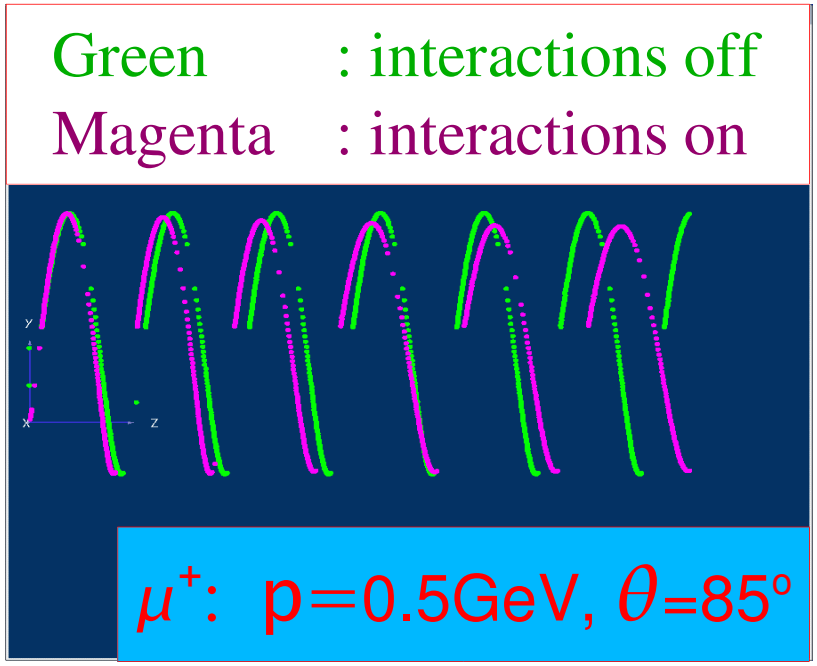
- Software is tuned & validated with testbeam data at DESY (e^+ beam with energy up to 6GeV) : good agreement between data & simulations
- Validated simulation is applied to study performance of DEPFET-based ILC VTX detector : IP resolution meets physics requirements

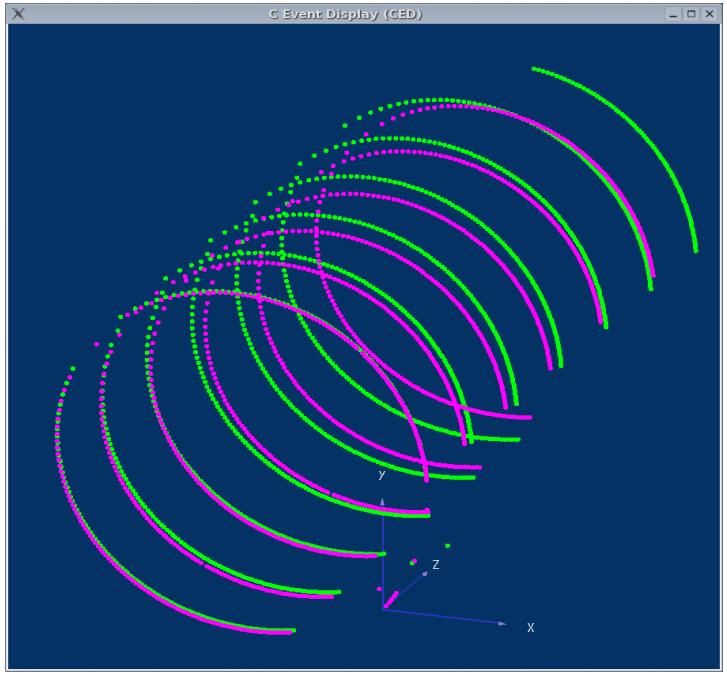


Hit Pattern Emulator Processor

- `TrackerHitEmulator` processor simulates hit pattern, excluding multiple scattering & energy loss effects

- Propagates particles in the uniform magnetic field and calculates track intersection points with tracker sensitive shapes (MCParticles ⇒ SimTrackerHits)





- **Errors in extrapolation of low momentum tracks to endcap ECAL possible**
  ⇒ potential deterioration of track-cluster association efficiency
  ⇒ drop in PFA performance
  Remedy : fit only late segment of track before ECAL, use track parameters defined at last track point (work in progress)

MaterialDB Processor

- Reads GEAR steering sections, describing tracking devices
- Stores in C++ structures/FORTRAN common's material shapes and properties, assumes infinitely small thickness of detector shapes
  - Cyllindrical detector shapes - z_{min} , z_{max} , R
  - Planar discs shapes ---------- R_{min} , R_{max} , z
  - Properties ---------- $[dE/dx] \cdot thickness$, $X_0/thickness$
  - TPC volume is approximated as sequence of 50 thin cyllinders
- Stores in C++ structures/FORTRAN common's extrapolation surfaces at which track parameters are evaluated
- Information about detectors shapes/properties and extrapolation surfaces is used by DELPHI Kalman track fitter
- **Don't forget to activate this proessor in your Marlin steering !**

GEAR Description of Tracking Detectors. Examples

TPC section of GEAR steering

```
<gear>

    <!-- XML file for GEAR describing the LDC01 detector -->

  <detectors>

    <detector id="0" name="TPC" geartype="TPCParameters"
                    type="UNKNOWN" insideTrackingVolume="yes">
        <maxDriftLength value="1970"/>
        <driftVelocity value="" />
        <readoutFrequency value="10" />
        <PadRowLayout2D  type="FixedPadSizeDiskLayout"
                         rMin="371" rMax="1516"
                         padHeight="6.2" padWidth="2.2"
                         maxRow="184" padGap="0.0" />
        <parameter name="tpcRPhiResConst" type="double"> 0.055  </parameter>
        <parameter name="tpcRPhiResDiff" type="double"> 0.003  </parameter>
        <parameter name="tpcZRes" type="double"> 1.0  </parameter>
        <parameter name="tpcPixRP" type="double"> 1.0  </parameter>
        <parameter name="tpcPixZ" type="double"> 1.4  </parameter>
        <parameter name="tpcIonPotential" type="double"> 0.00000003  </parameter>
        <parameter name="tpcInnerRadius" type="double"> 305.0 </parameter>
        <parameter name="tpcOuterRadius" type="double"> 1580.0 </parameter>
        <parameter name="tpcInnerWallThickness" type="double"> 1.16 </parameter>
        <parameter name="tpcOuterWallThickness" type="double"> 1.51 </parameter>
        <parameter name="TPCWallProperties_RadLen" type="double"> 88.9253 </parame
        <parameter name="TPCWallProperties_dEdx" type="double"> 4.374e-4 </paramet
        <parameter name="TPCGasProperties_RadLen" type="double"> 109831 </paramete
        <parameter name="TPCGasProperties_dEdx" type="double"> 2.736e-7 </paramete
        <parameter name="BField" type="double"> 4.0 </parameter>
    </detector>
```

SIT section of GEAR steering

```
<!-- Silicon Intermediate Tracker -->
<detector id="18" name="SIT" geartype="GearParameters"
            type="UNKNOWN" insideTrackingVolume="true">
 <parameter name="SITLayerRadius" type="DoubleVec">160.0 300.0</parameter>
 <parameter name="SITLayerHalfLength" type="DoubleVec"> 380. 660.0 </parameter>
 <parameter name="SITLayerThickness" type="double"> 0.3 </parameter>
 <parameter name="SITLayer_dEdx" type="double"> 0.00144752 </parameter>
 <parameter name="SITLayer_RadLen" type="double"> 25.0 </parameter>
</detector>
```

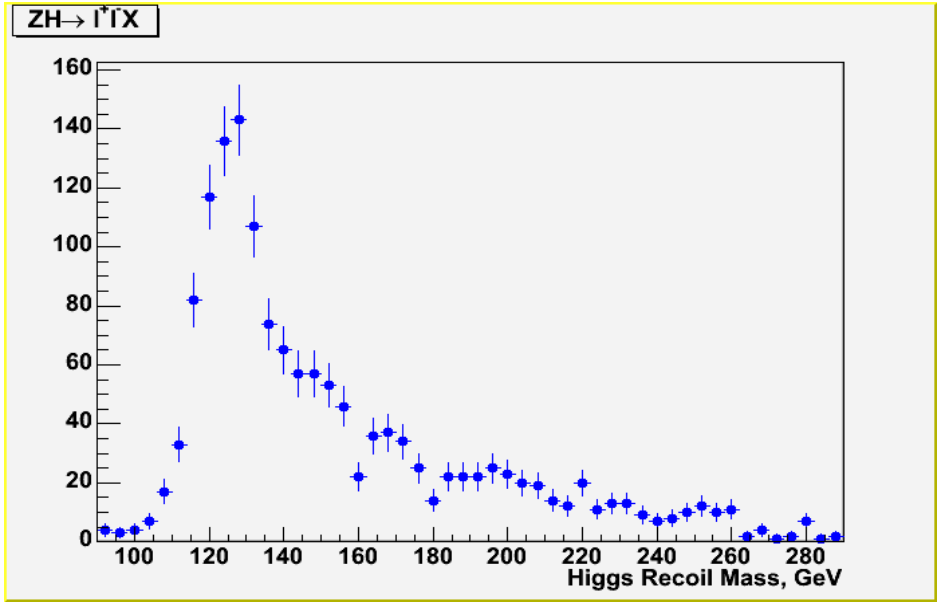
- GEAR steering provided for two Mokka models: LDC00 & LDC01
- More accurate description of materials compared to Valencia release (VTX cryostat added)
- **GEAR v00-03 or higher is needed to describe VTX !**

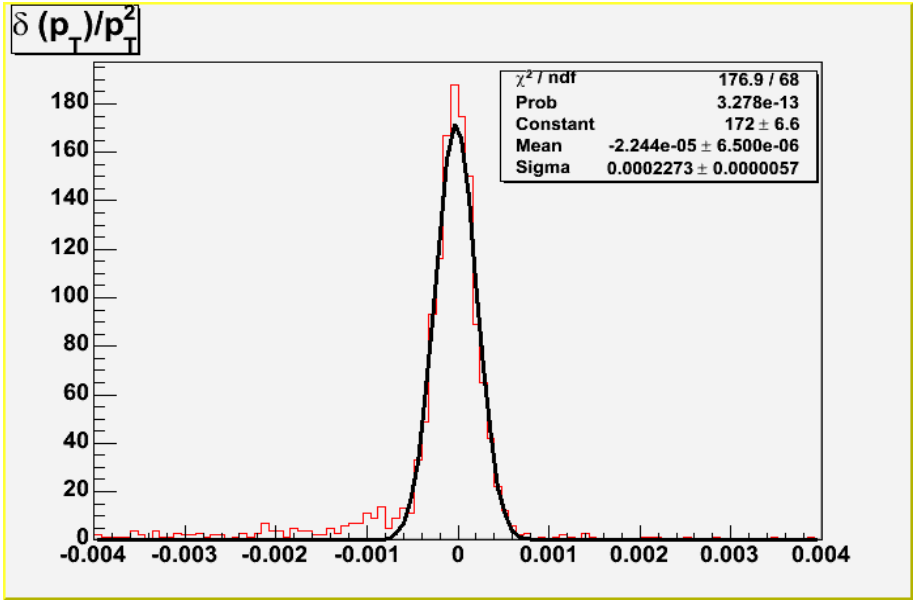
Tracking in TPC. LEPTrackingProcessor

- C++ wrappers of DELPHI code (S. Aplin)
  - Inward search for continuous track segments
  - Kalman track fitting (MS + energy loss is accounted for)
- Input : collection of TPC hits
- Output : collection of TPC tracks
- Achieved resolution

$\delta(1/p_T)=2.0\{2.2\}\cdot 10^{-4}$ *for LDC00{01}*

- Flaws :
  - Tends to split loopers
  - Significant efficiency drop for track segments with number of hits ⩽ 40





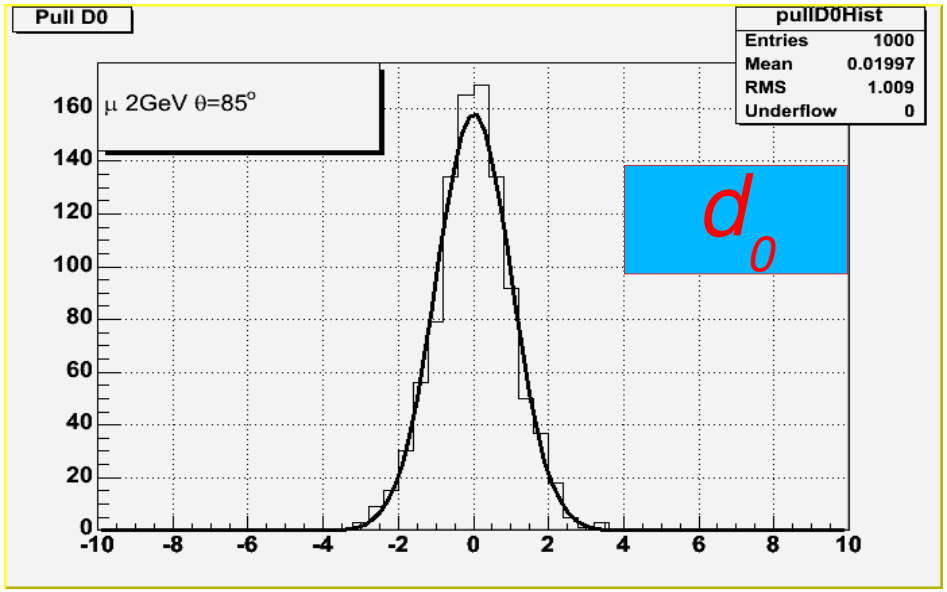
Tracking in Silicon Detectors. SiliconTracking Processor

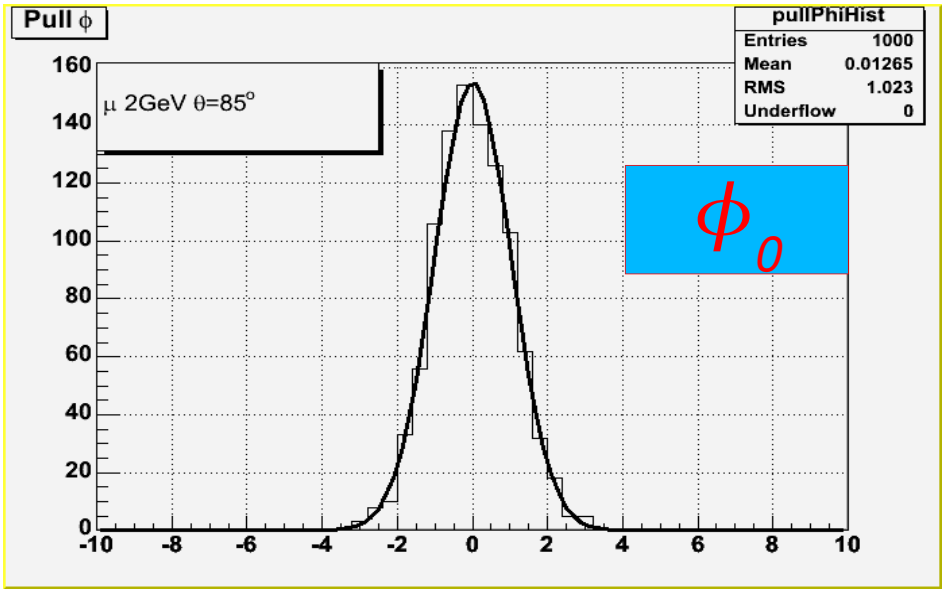
- Initial search for triplets in VTX+SIT or FTD starting from outermost layers
- Special treatment of VTX-FTD transition region in θ. Combined triplet search (2+1 or 1+2 pattern)
- Inward extrapolation of helicies defined by triplets. Picking up additional hits in inner layers on the road to IP
- Track fitting with DELPHI Kalman filter ⇒ track parameters @ PCA to IP
- Track fit χ^2 as the main track quality criterion ($\chi^2/\mathrm{ndf} \leqslant 10$)
- Input ----- : collection of Si TrackerHits (VTX+FTD+SIT)
- Output --- : collection of Si tracks
- Flaw ----- : drop of efficiency for low momentum tracks (multiple scattering), relaxing cut on χ^2 causes rise of fake track rate

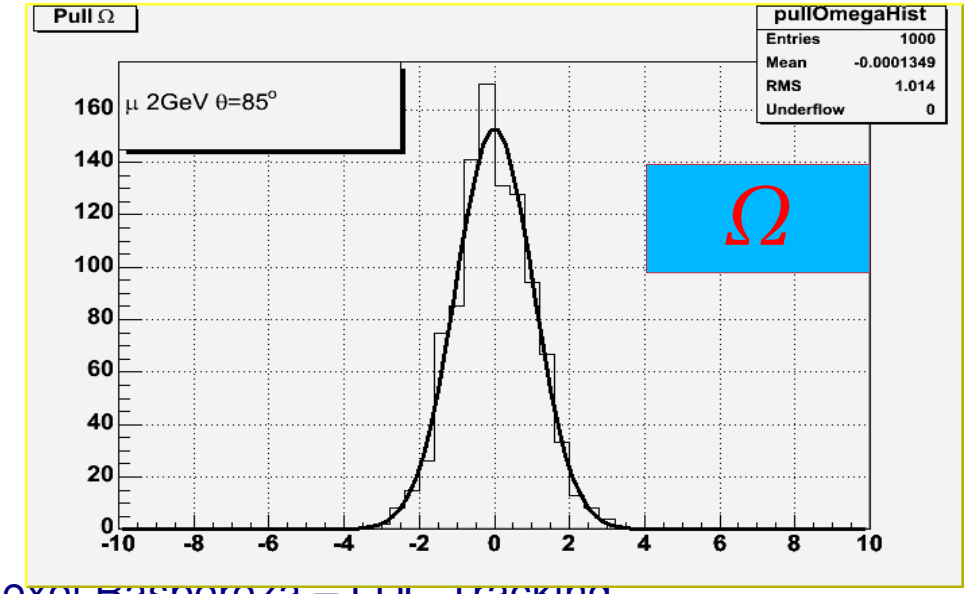
Association of TPC & Si Segments. FullLDCTracking Processor

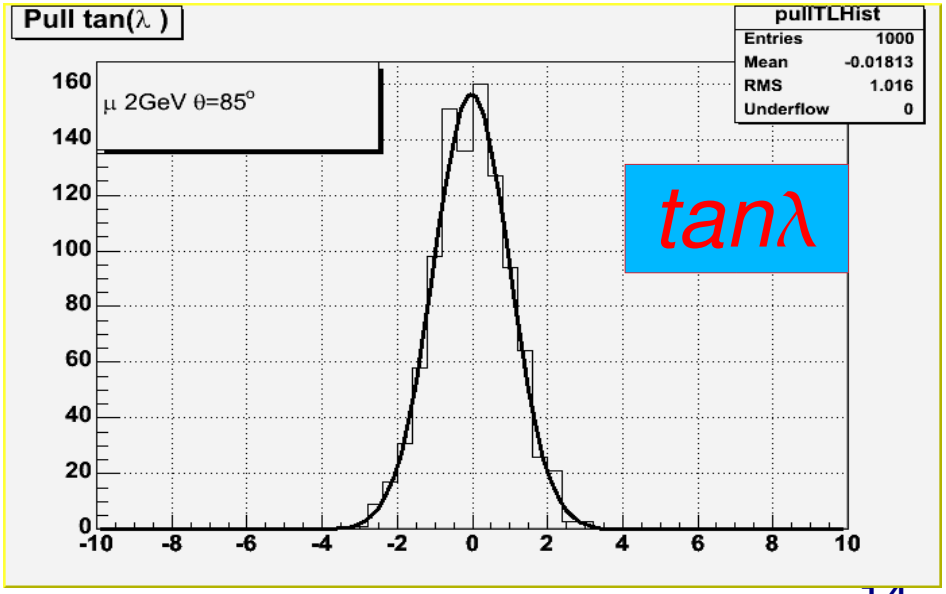
- **Procedure steps :**
  - Association of Si & TPC track segments
  - Identification and merging of splitted loopers in TPC
  - Search for non-assigned hits, potentially attributable to the found LDC tracks; full hit sequence recovery (crucial for accurate track extrapolation to ECAL, PFA demand for efficient track-cluster matching!)
  - Tracks refit with DELPHI Kalman filter ⇒ track parameters @ PCA to IP
- **Inputs ------ : collection of TPC & Si tracks, collections of TrackerHits (VTX+SIT+FTD+TPC)**
- **Outputs ---- : collection of LDC tracks & MCParticle-Track relations**

Track Fit Check. Pull Distributions. Interactions with Detector off



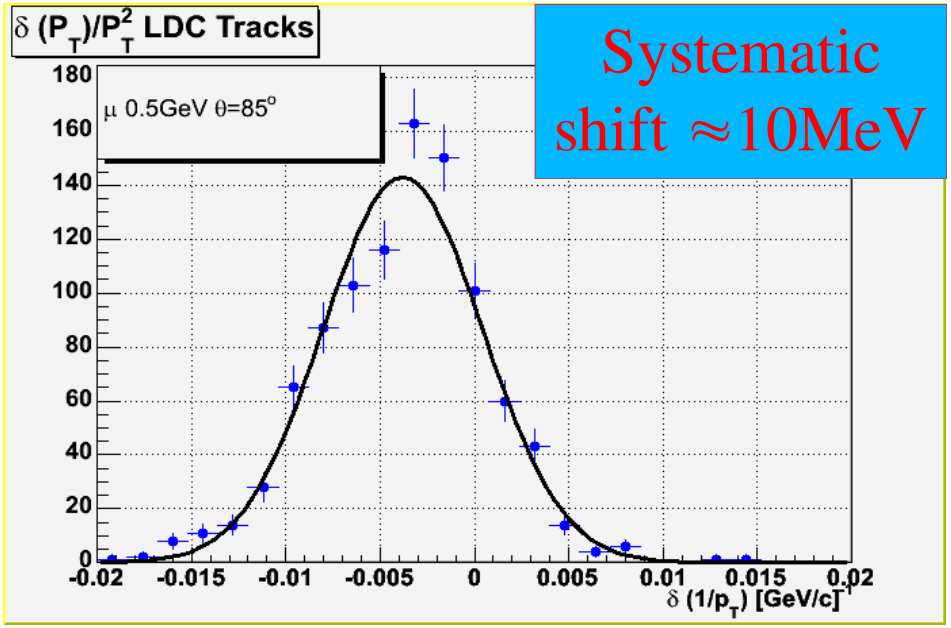


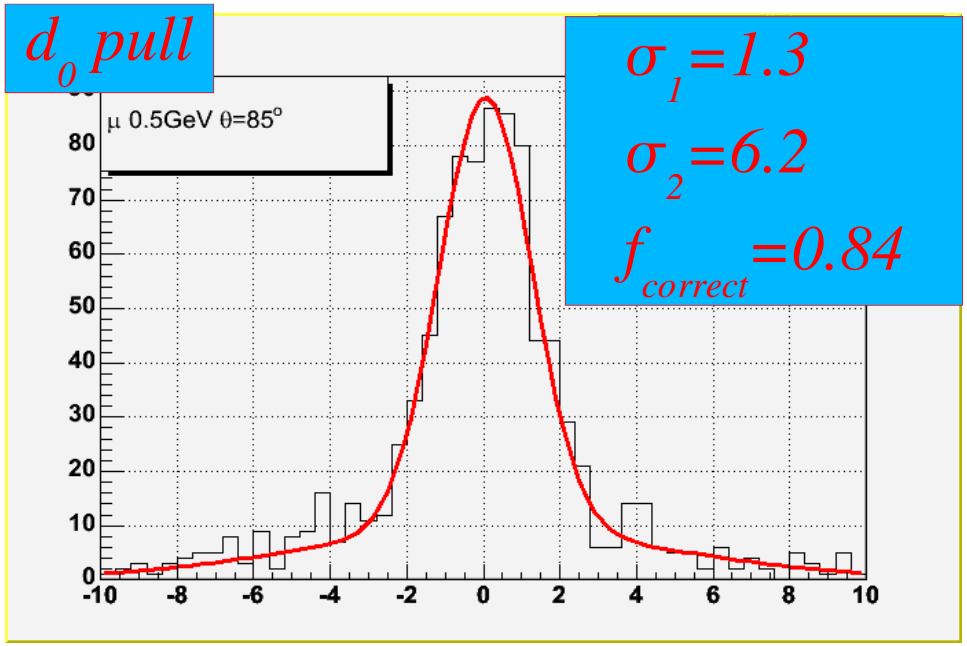


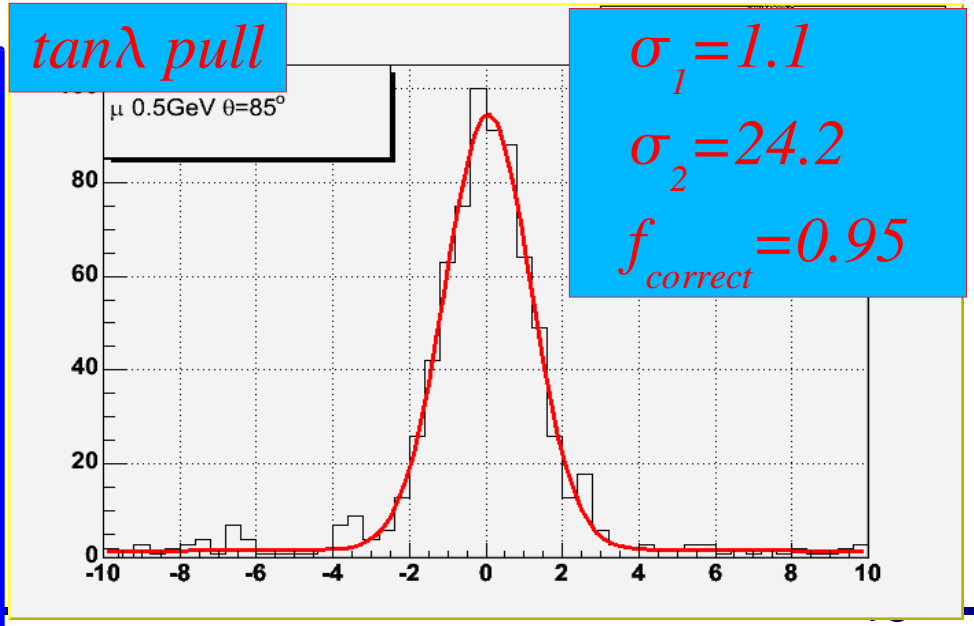


Track Fit Check.

Interactions with Detector on. Low P Tracks





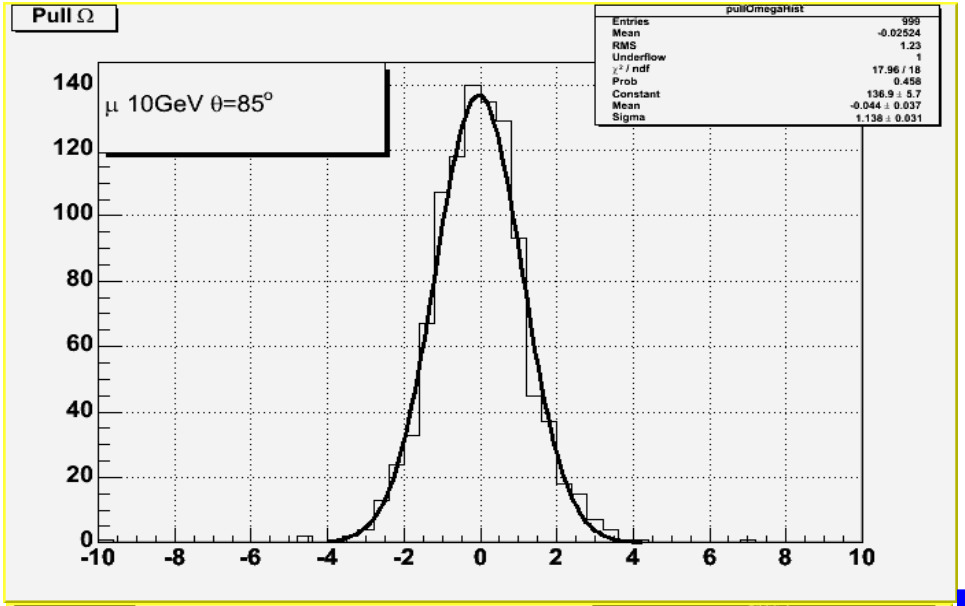


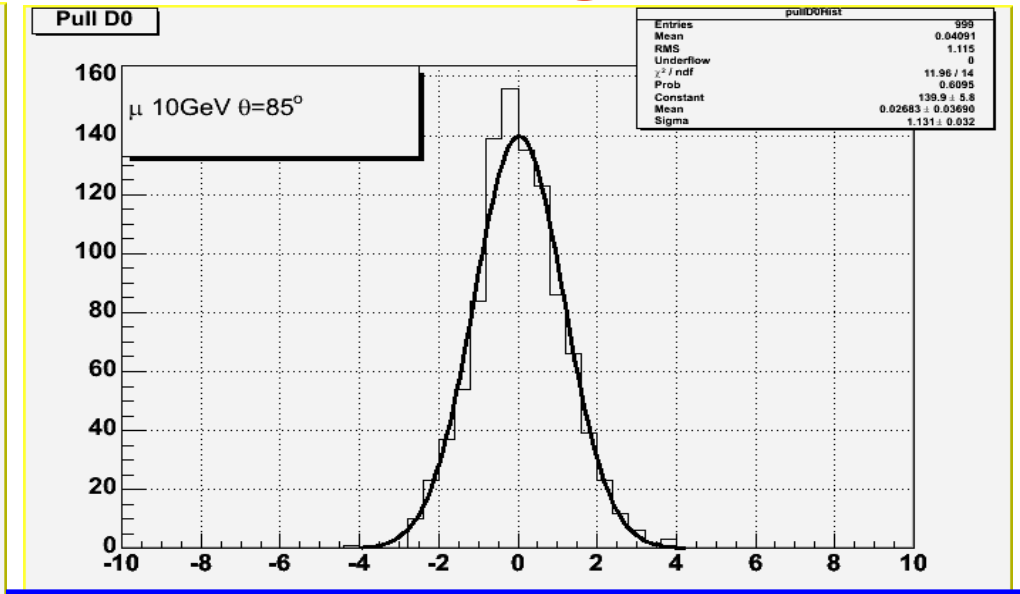
Problems with low p tracks:

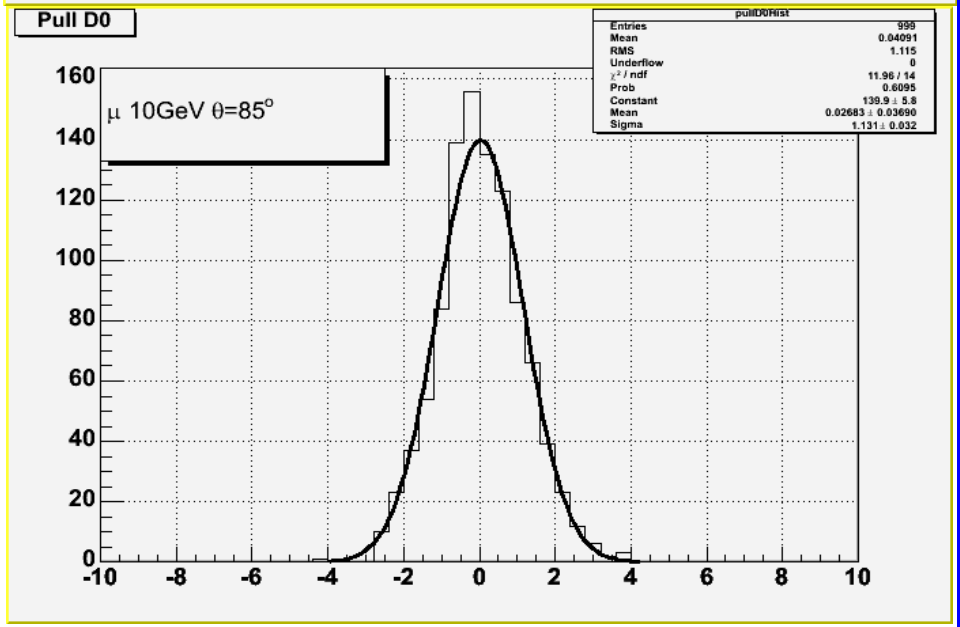
- Systematic bias in p_T (≈10 MeV) ⇒ underestimation of p_T
- Long tails in pull distributions ⇒ sizable fraction of events with underestimated errors

Track Fit Check.

Interactions wiht Detector on. High P Tracks







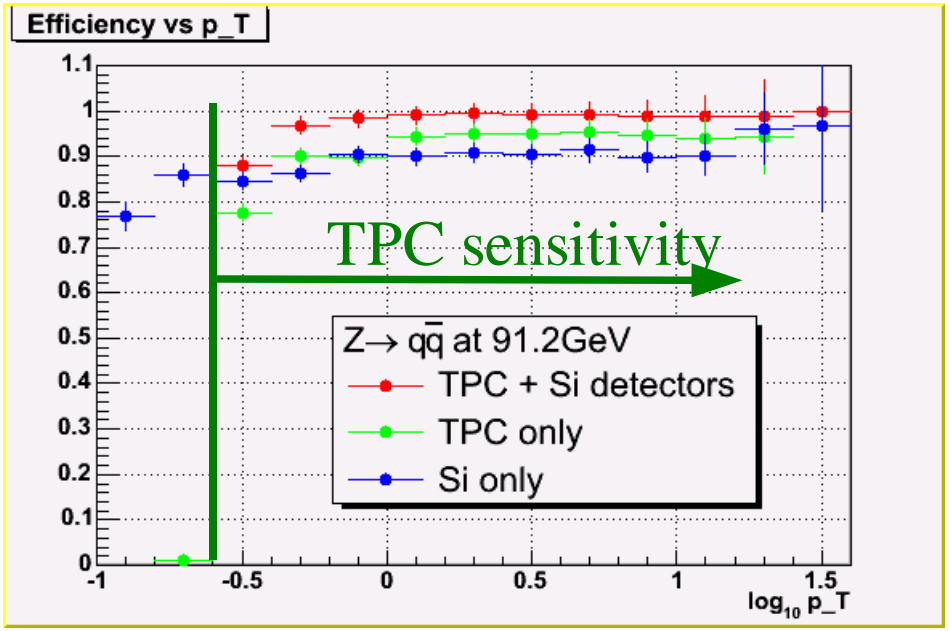
Situation improves with increasing P

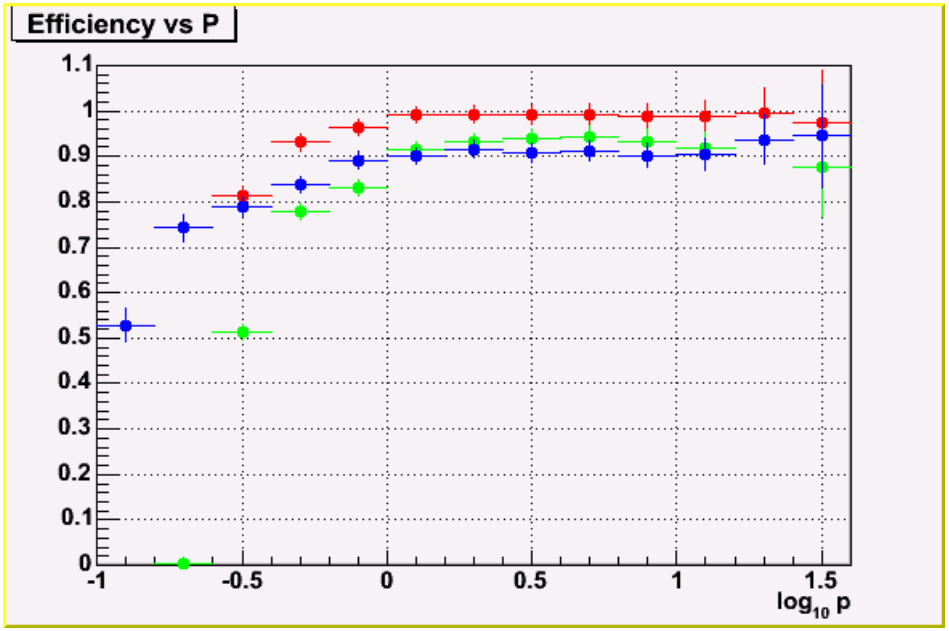
Educative guess : problem with low P tracks due to inaccurate/incomplete gear description of materials. Missing material ⇒ 10 MeV shift in p_T and tails in pull distributions for low P tracks

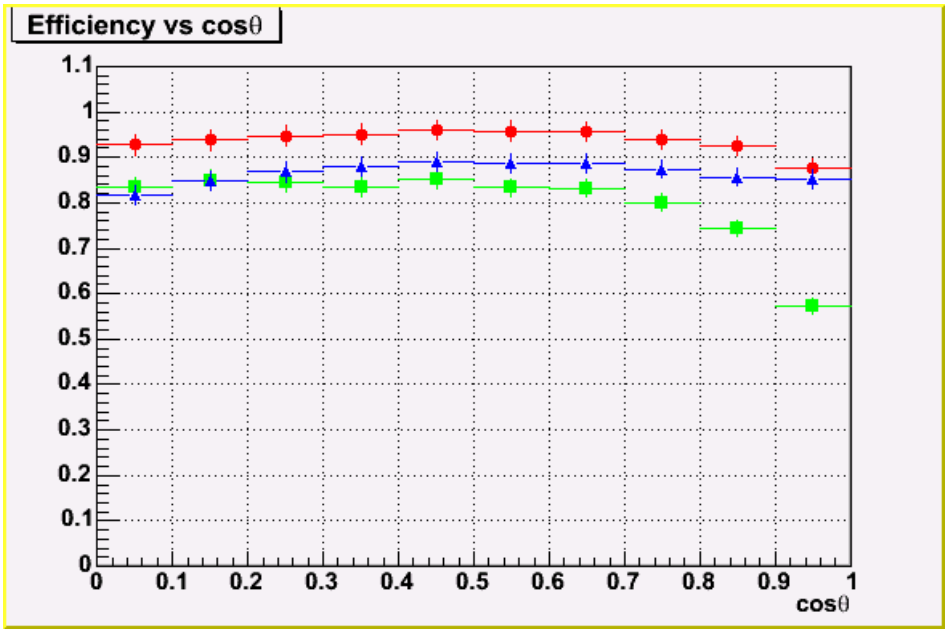
Tracking Performance

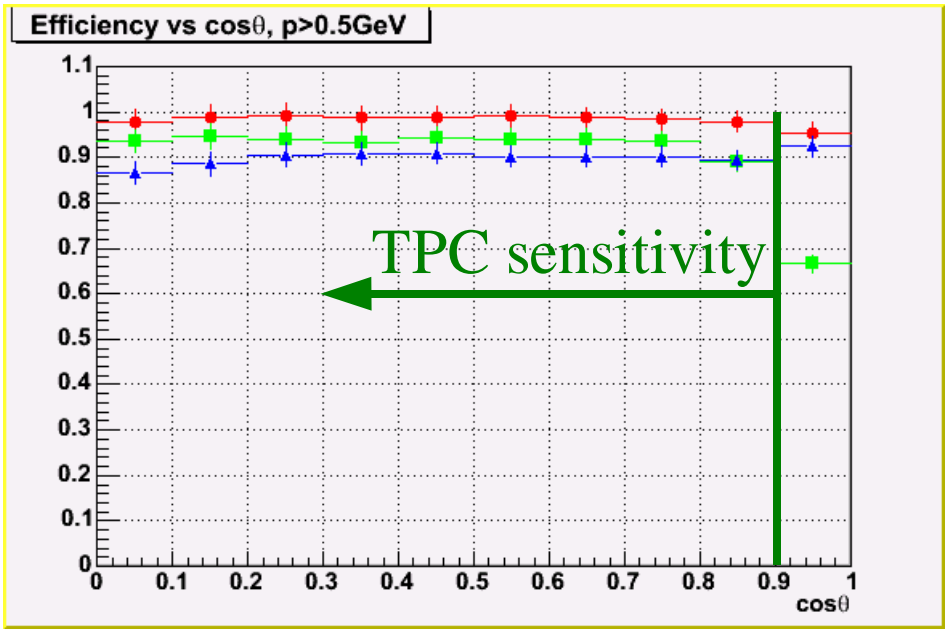
- Performance is evaluated using two benchmark reactions
  - $Z \rightarrow q\bar{q}$ events @ 91.2 GeV (1000 events)
  - $t\bar{t} \rightarrow 6jets$ events @ 500 GeV (200 events)
- A more conservative Mokka model LDC01 is used
- Two aspects of tracking performance are studied
  - track finding efficiency
  - accuracy in reconstruction of $(E, \vec{P})_{\text{charge particles}}$
- Track parameter resolutions studies with single particle events will be covered in separate talk by M. Ohlerich (Higgs analysis in the $ZH \rightarrow l^+l^-X$ channel)

Track Finding Efficiency. Z Pole

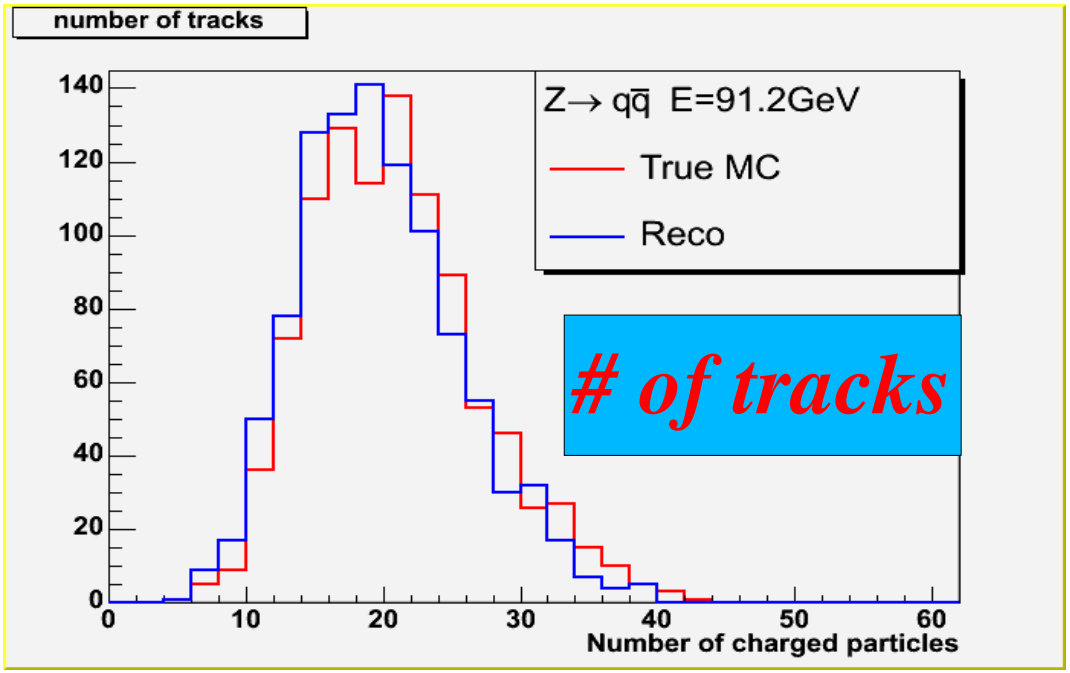


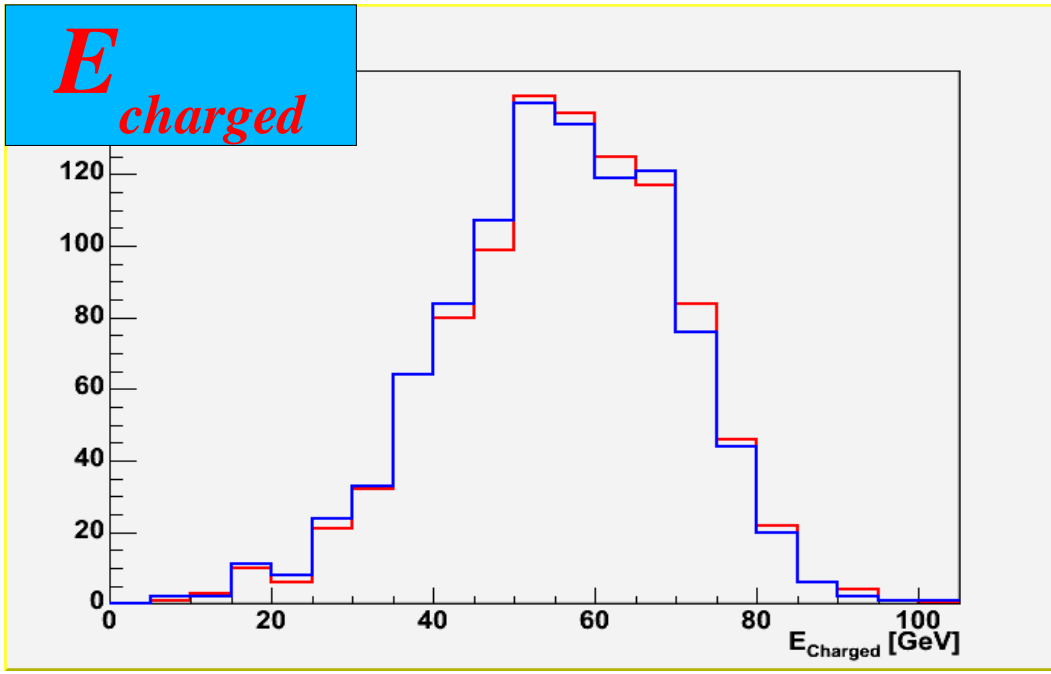






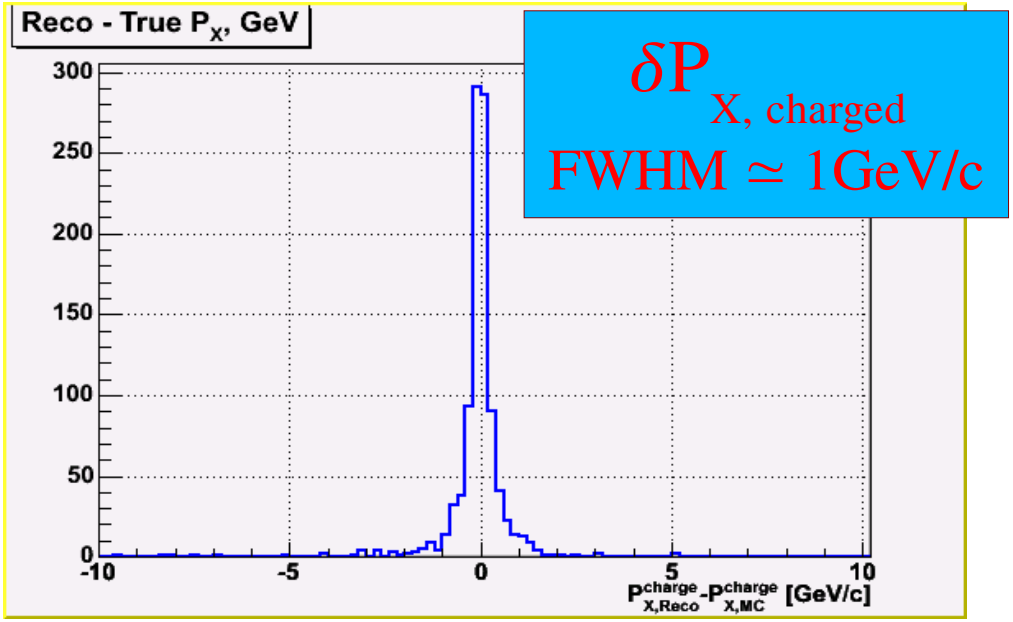
Charged Component of Event. Z Pole

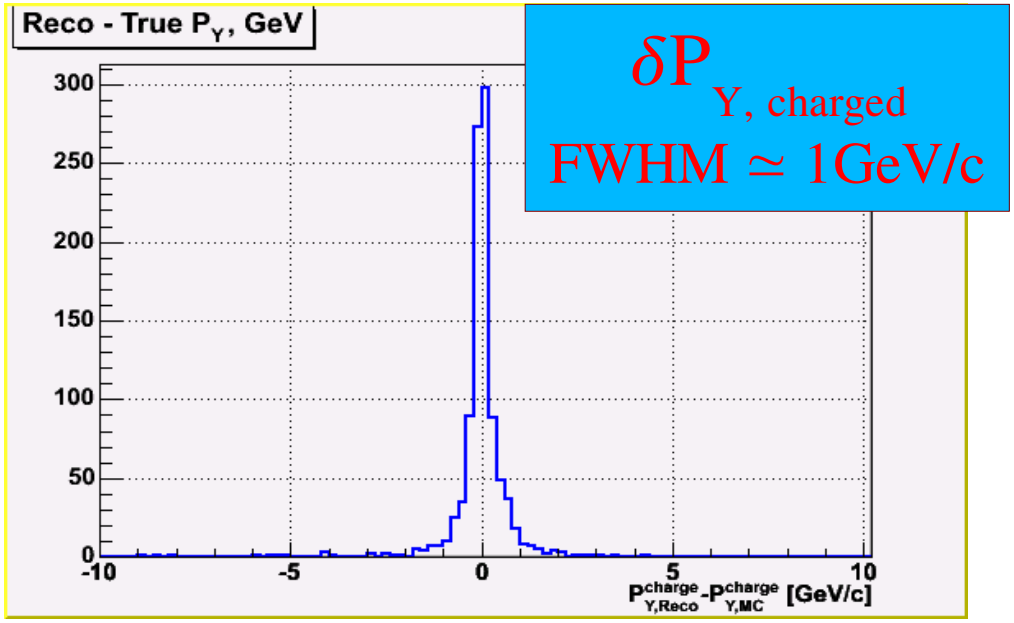


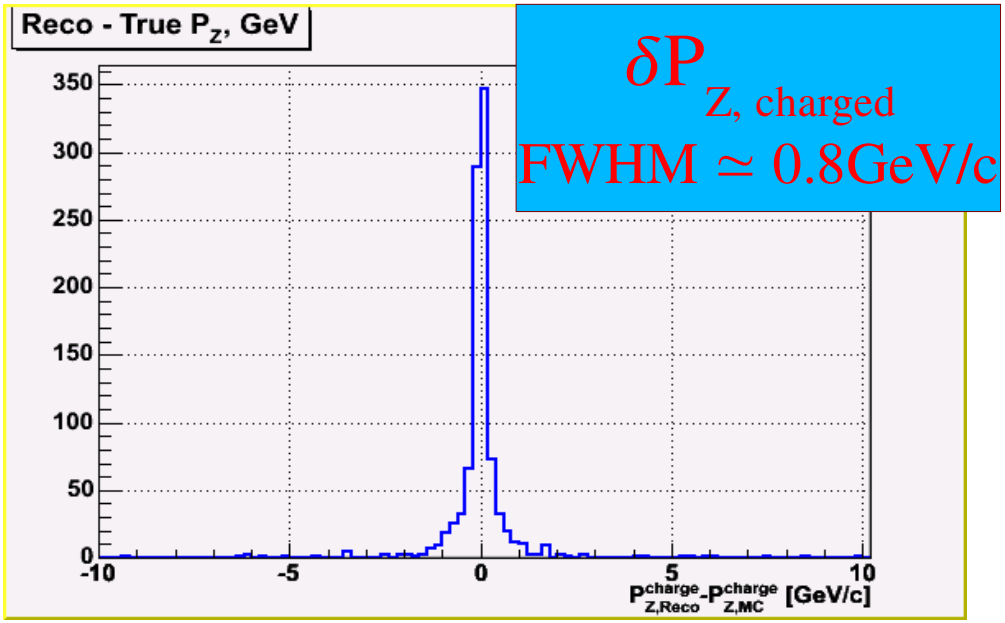


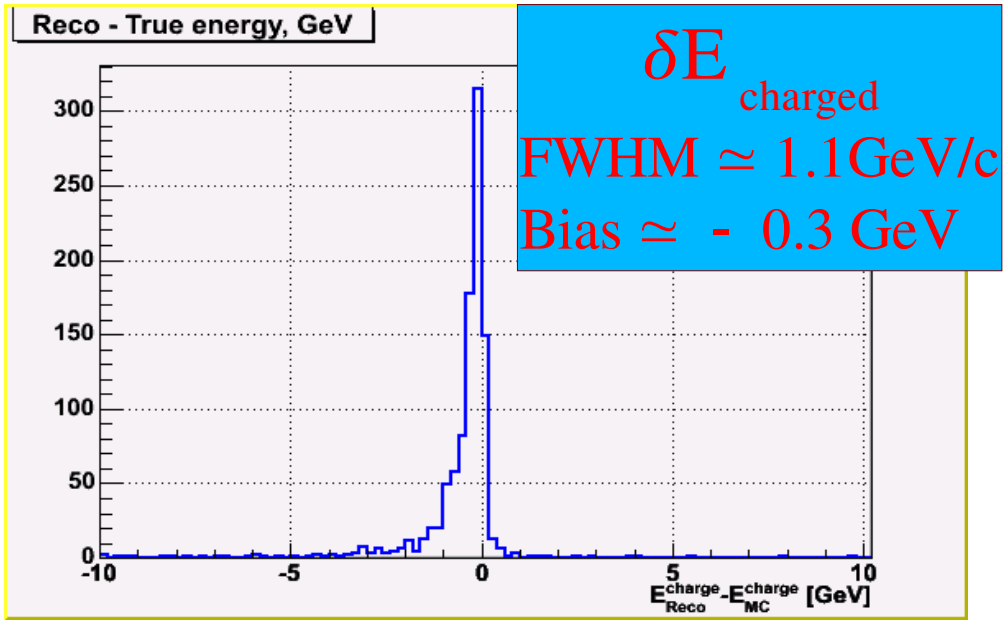
- On average smaller number of reconstructed tracks compared to MC (drop of efficiency @ low p)
- Reconstructed energy spectrum of charged component of an event is in a good agreement with MC expectation

PFA Performance. Z Pole

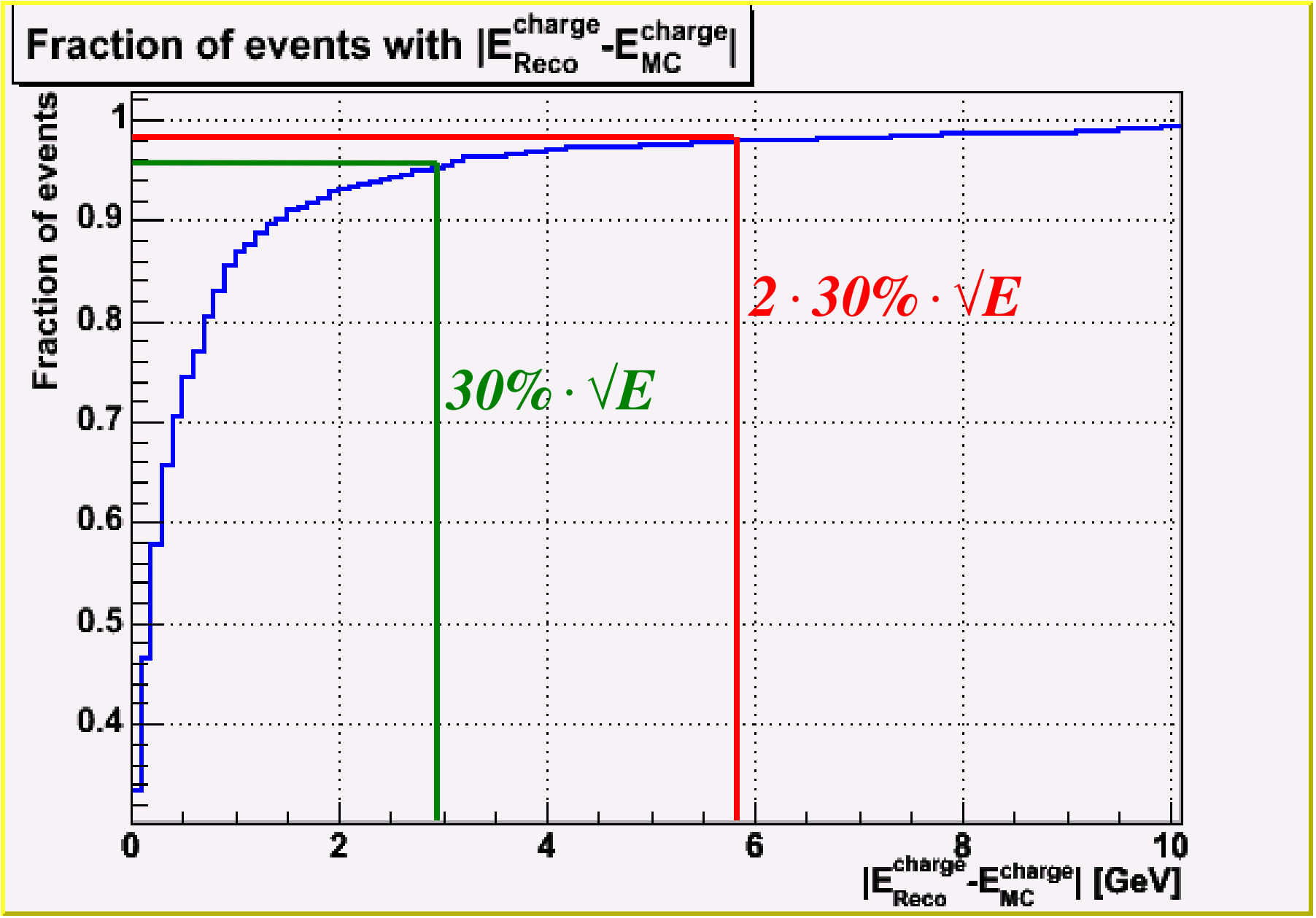




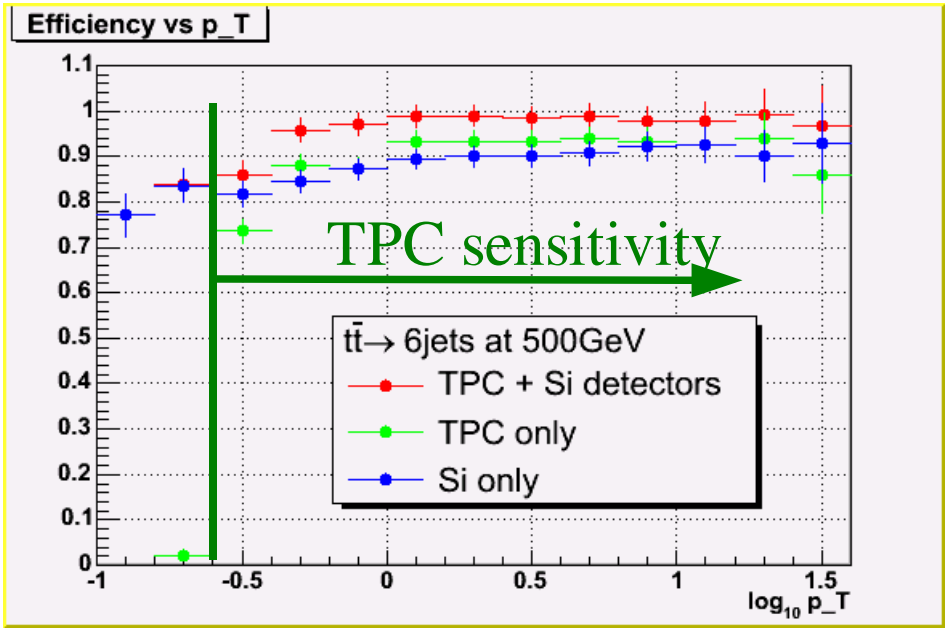


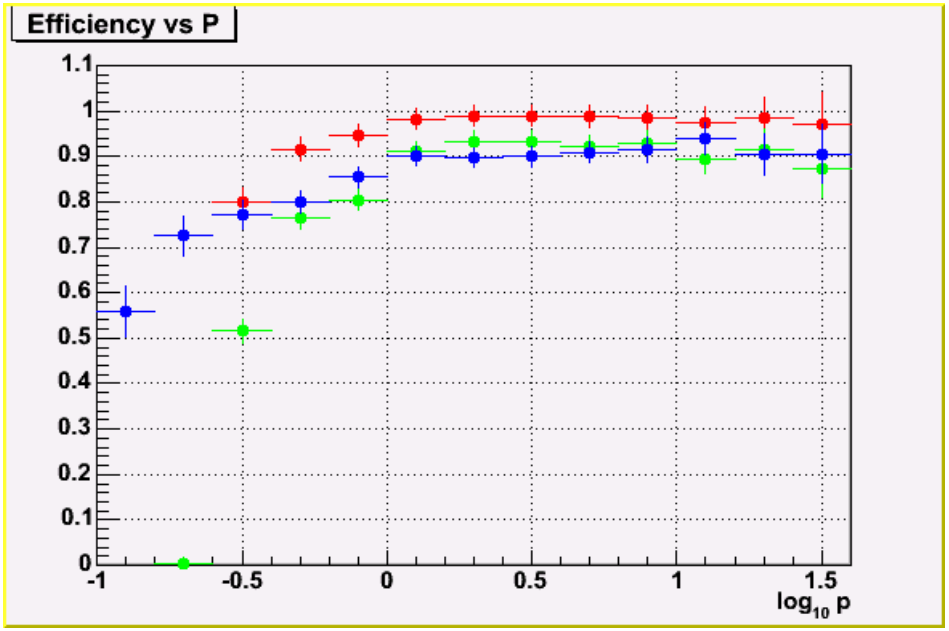


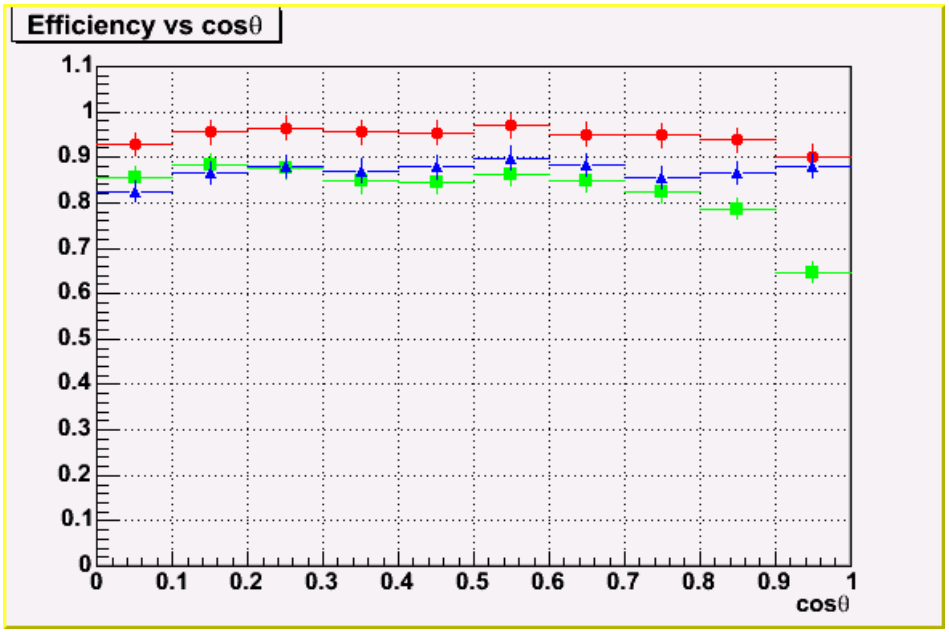
PFA Performance. Z Pole

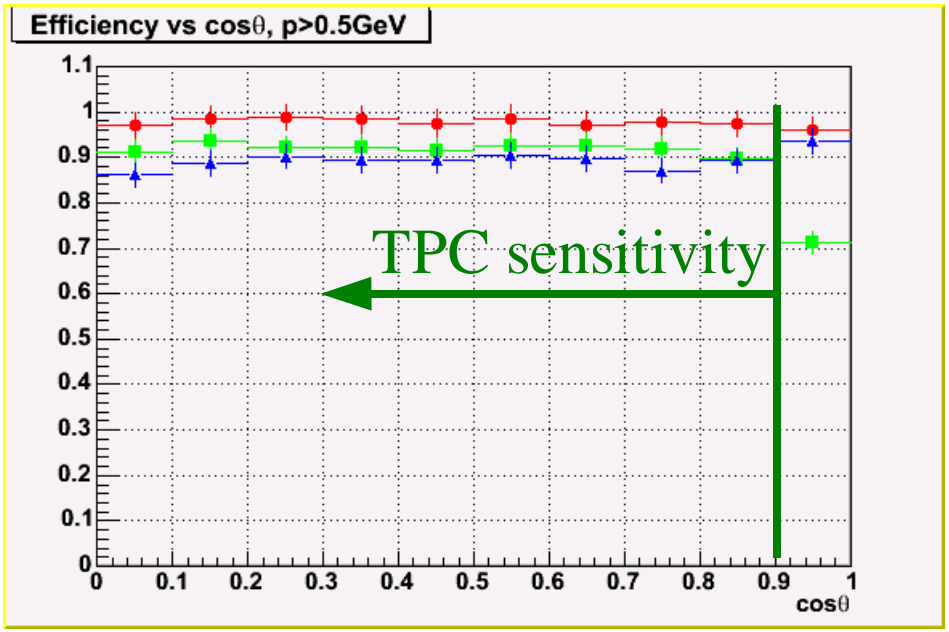


Track Finding Efficiency. $t\bar{t}$ events

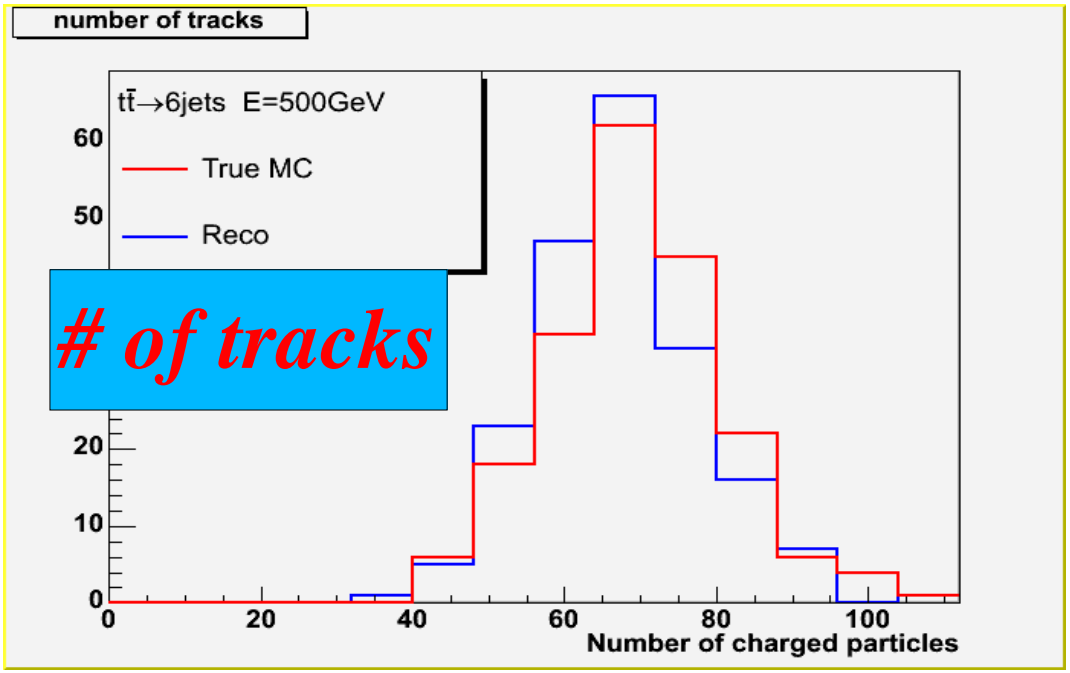


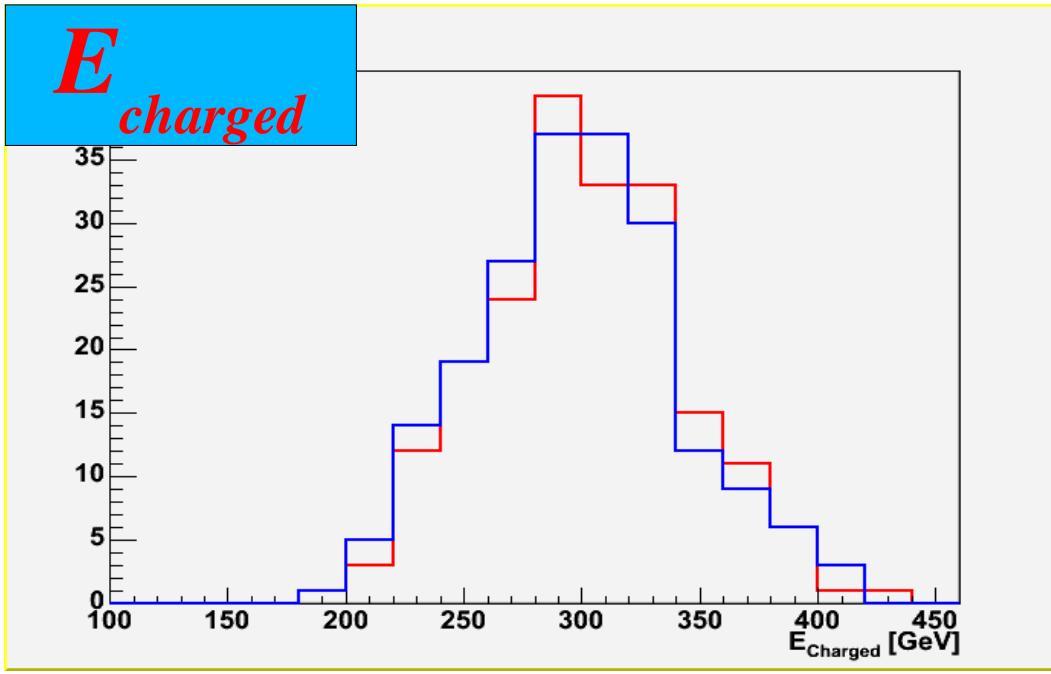






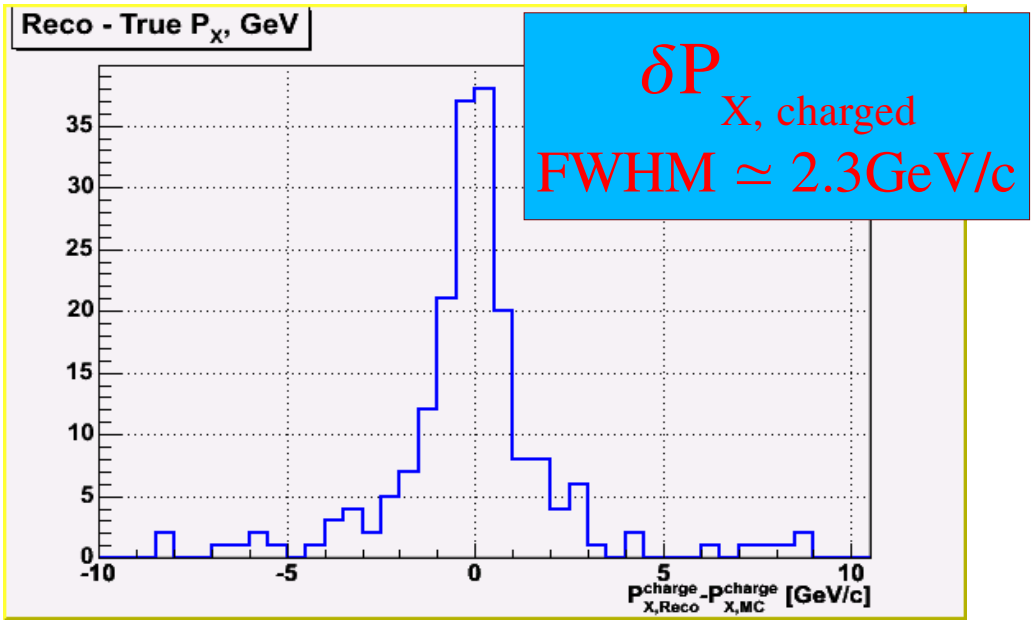
Charged Component of Event. $t\bar{t}\rightarrow 6jets$

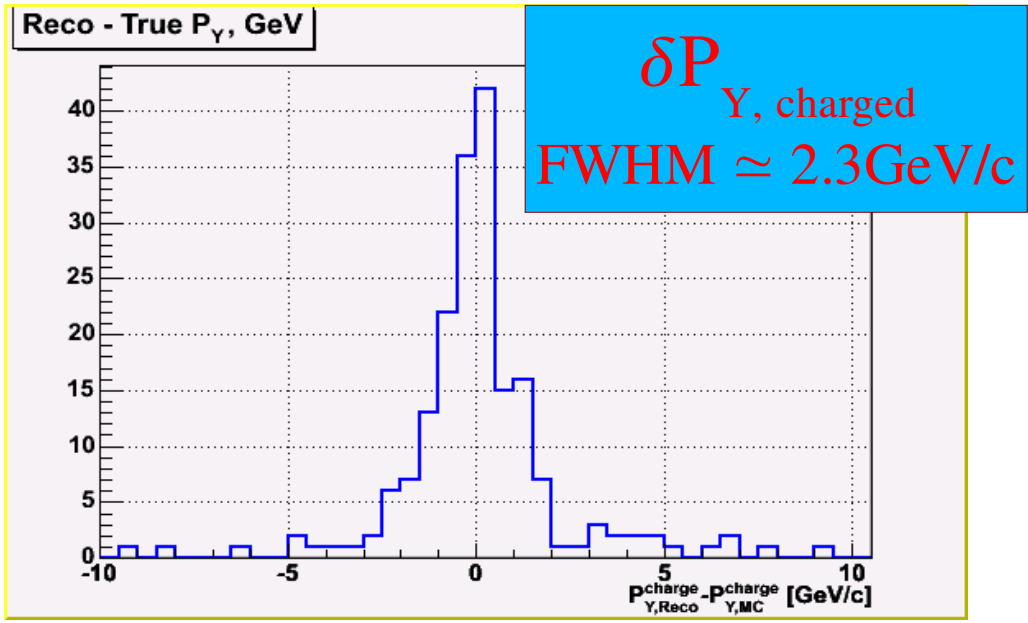


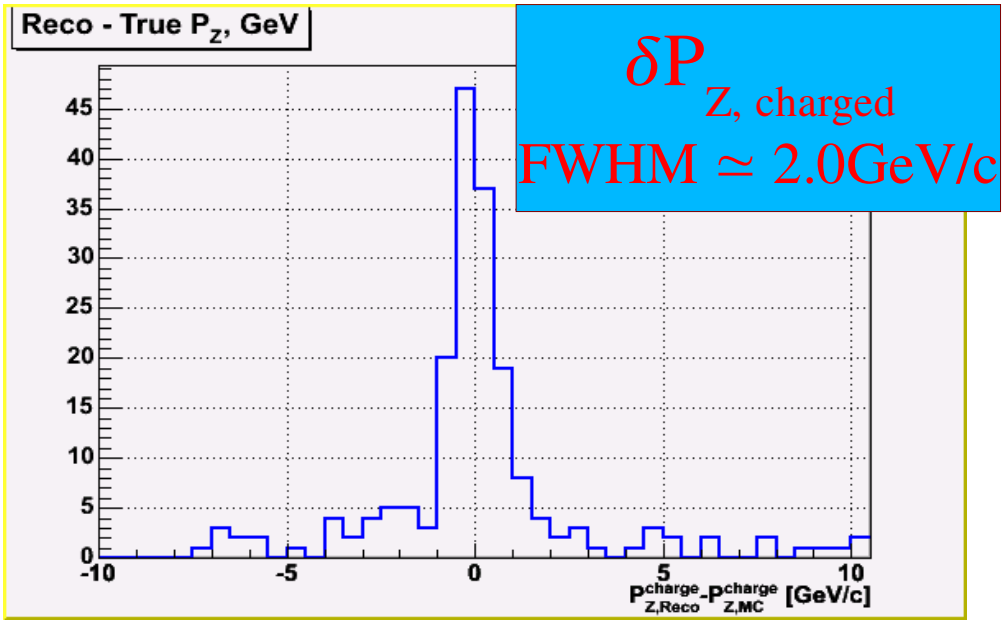


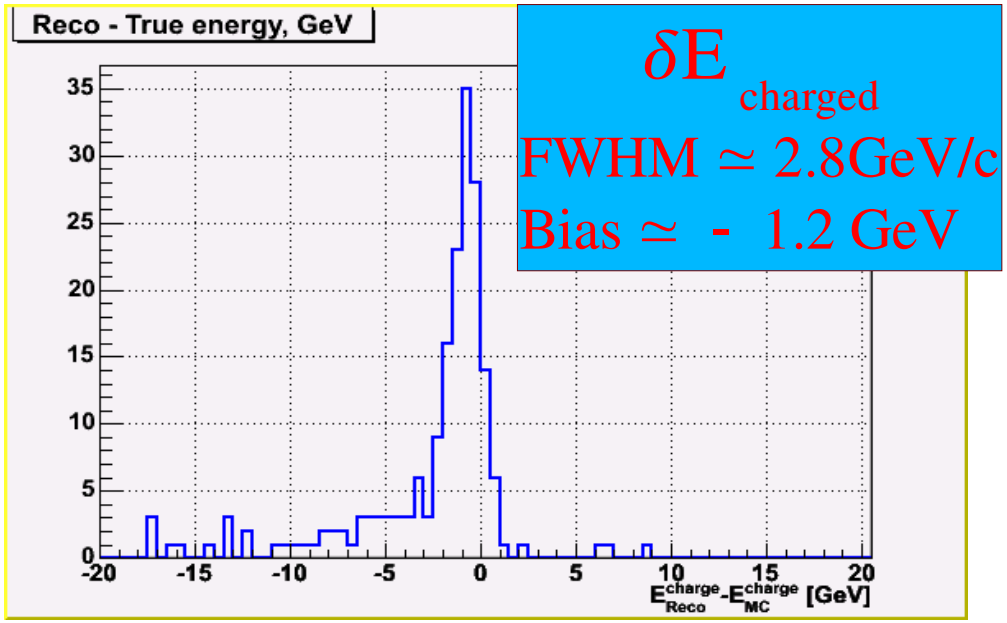
- **Averaged # of reconstructed tracks is smaller compared to MC (effect is more pronounced than in Z pole sample)**
- **Reconstructed energy spectrum is only slightly shifted towards lower values w.r.t MC true distribution**

PFA Performance. $t\bar{t}$ events

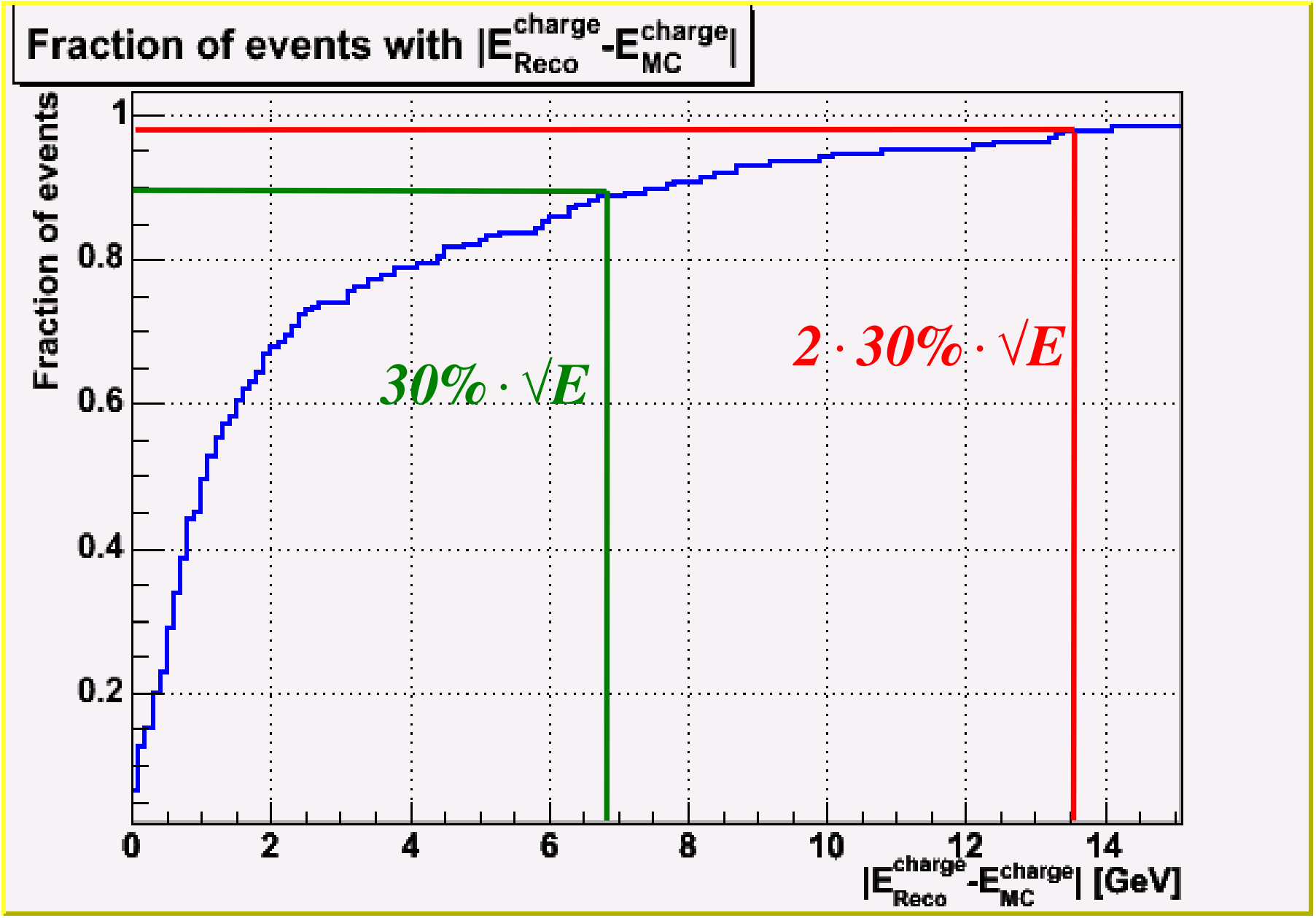






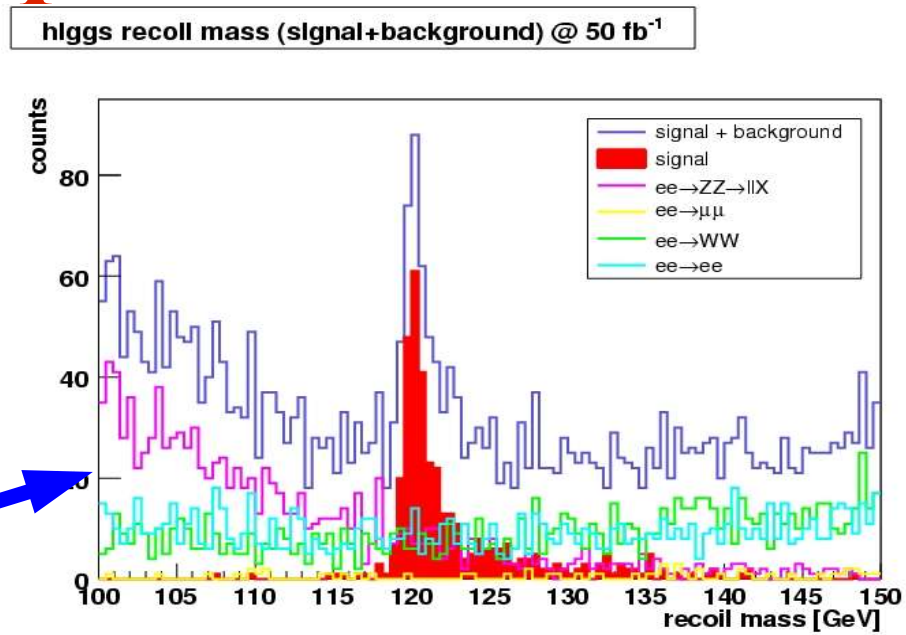


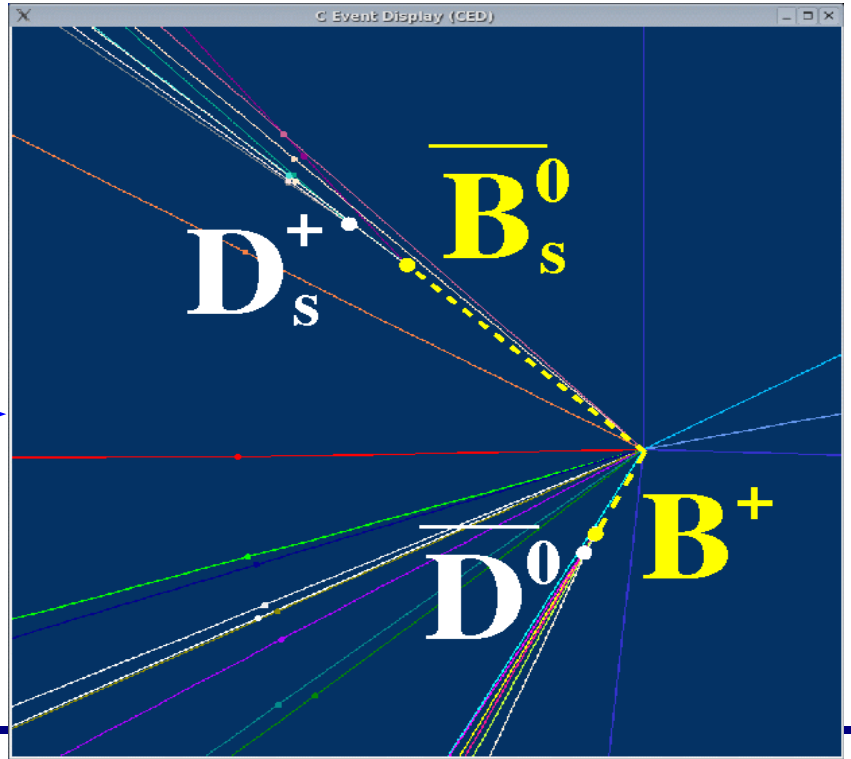
PFA Performance. $t\bar{t}$ events



Fields of Application

- Detector performance studies (LAL, DESY)
- Optimization of DEPFET based VTX (MPI Munich)
- Physics analysis. $ZH \rightarrow l^+ l^- X$ channel (LAL, DESY)
- Beam background studies (MPI Munich)
- Vertexing and flavour tagging (Oxford U.)





Summary

- **Updated/improved Tracking Package available. New features:**
  - Calculation of cov. matrix for track parameters
  - Dedicated procedure, recovering splitted loopes in TPC
  - A more accurate GEAR description of VTX (cryostat added)
  - Special treatment of VTX-FTD transition region in θ
- **Performance**
  - Track finding efficiency = $98.9(97.5)\%$ for track momenta $>1(0.4)GeV$
  - PFA : 90% of events with $\delta E_{charged} \leqslant 0.3 \cdot \sqrt{E_{total}}$ $[tt \rightarrow 6jets\ @\ 500GeV]$
- **Further developments**
  - Refinement of GEAR description of tracking system
  - Extension of functionality dictated by PFA demands (accurate track extrapolation to calorimeter)

Acknowledgements

- **The code has evolved as a result of close cooperation between developers (MPI Munich) and users (LAL, DESY, Oxford U.)**

- ***Thanks to Martin Ohlerich, Manqi Ruan, Henge Li, Sonja Hillert, Ben Jeffery for helping to improve the existing LDC Tracking Package***