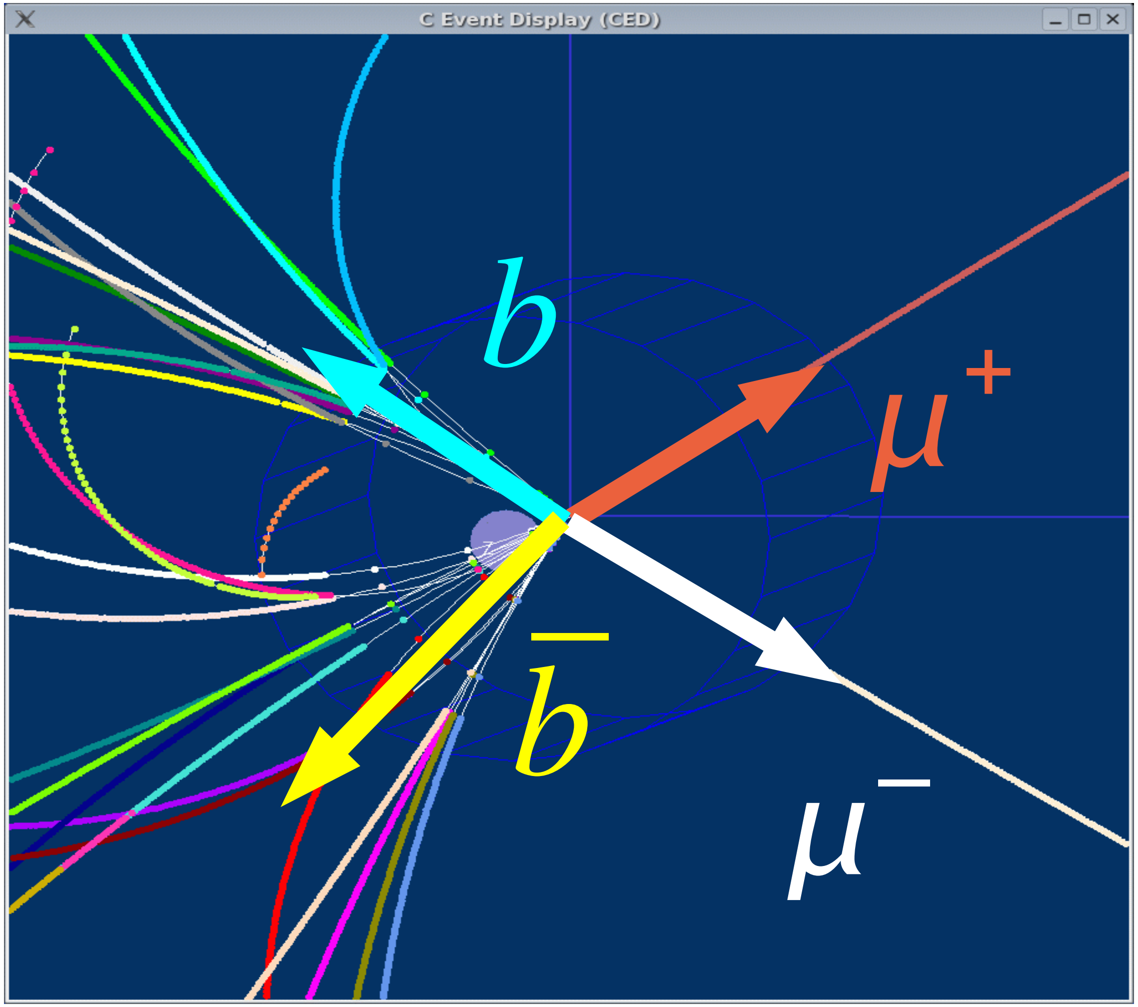
LDC Tracking Software

H^0

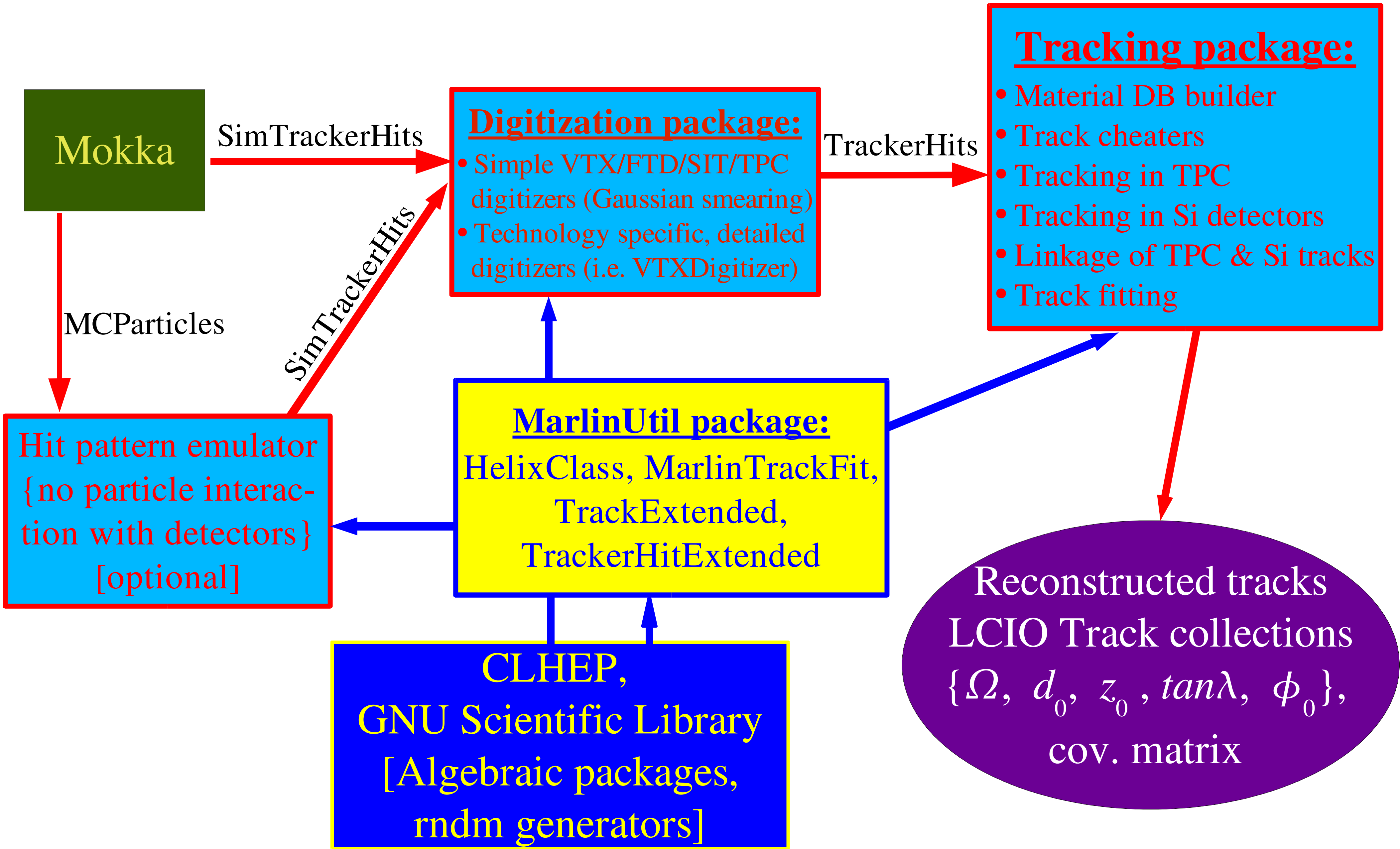


Z^0

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

LCWS07, Hamburg 31/05/2007

Structure of LDC Tracking Package

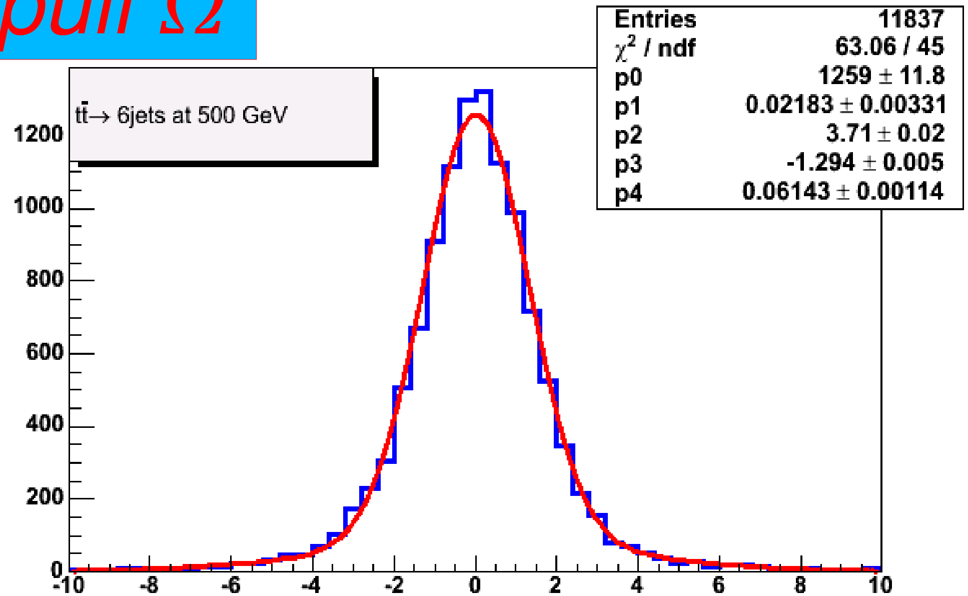


Tracking Package

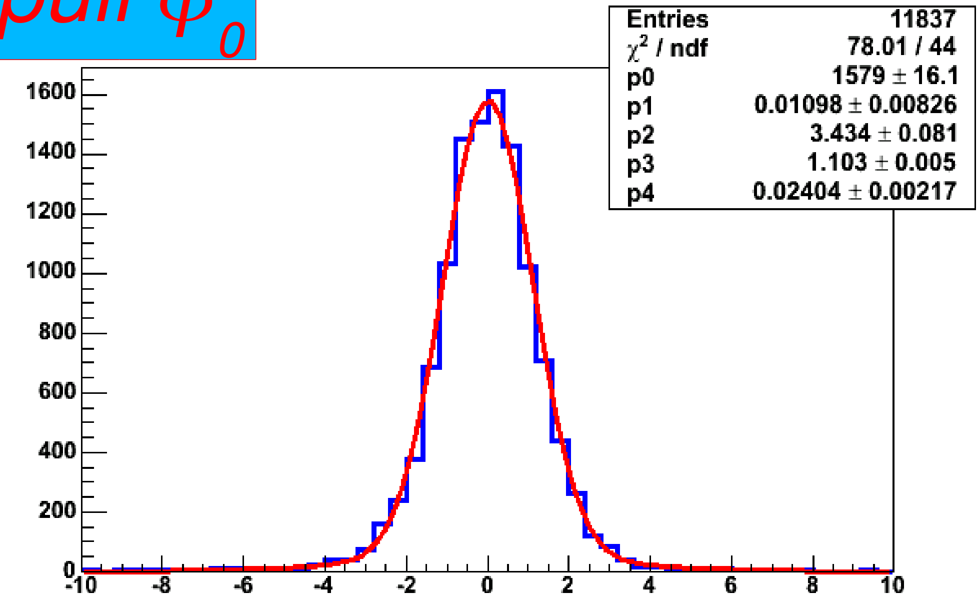
- **Tracking in TPC : LEPTrackingProcessor (C++ wrappers of DELPHI code , author : S. Aplin)**
  - Inward search for continuous track segments. Kalman track fit
  - Input : collection of TPC hits. Output : collection of TPC tracks
- **Tracking in Si detectors : SiTracking processor**
  - Search for hit patterns compatible with the helix model. Kalman track fit
  - Input : collection of VTX, FTD & SIT hits. Output : collection of Si tracks
- **FullLDCTracking processor**
  - Association of Si & TPC track segments. Assignment of left-over hits to found tracks ⇒ full track recovery (loopers). Kalman track fit. Extrapolation of tracks to ECAL
  - Input : collections of VTX, FTD, SIT & TPC hits + Si & TPC tracks. Output : Full LDC tracks + cov. matricies

$t\bar{t}\rightarrow$6jets @ 500 GeV. Pull Distributions

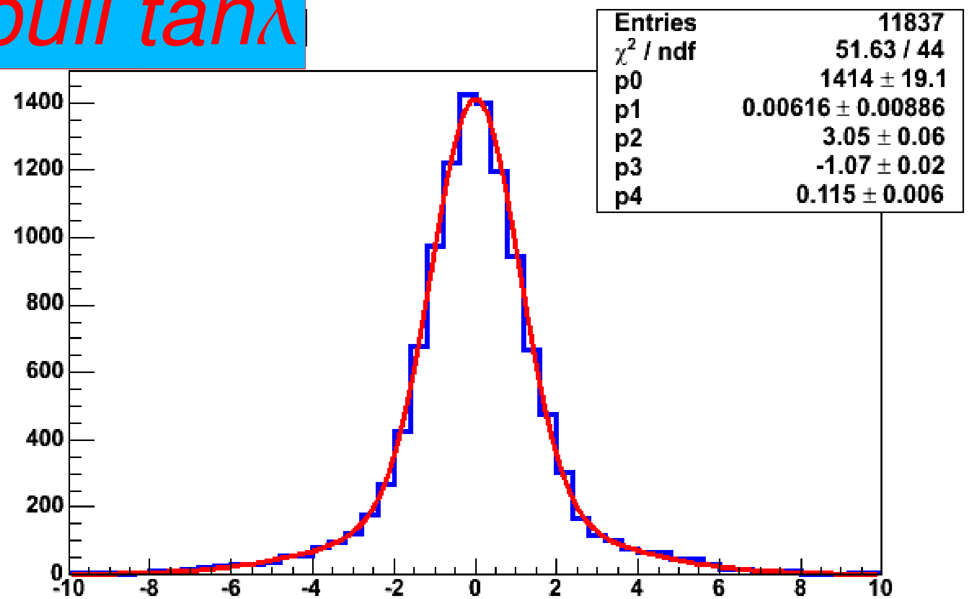
pull Ω



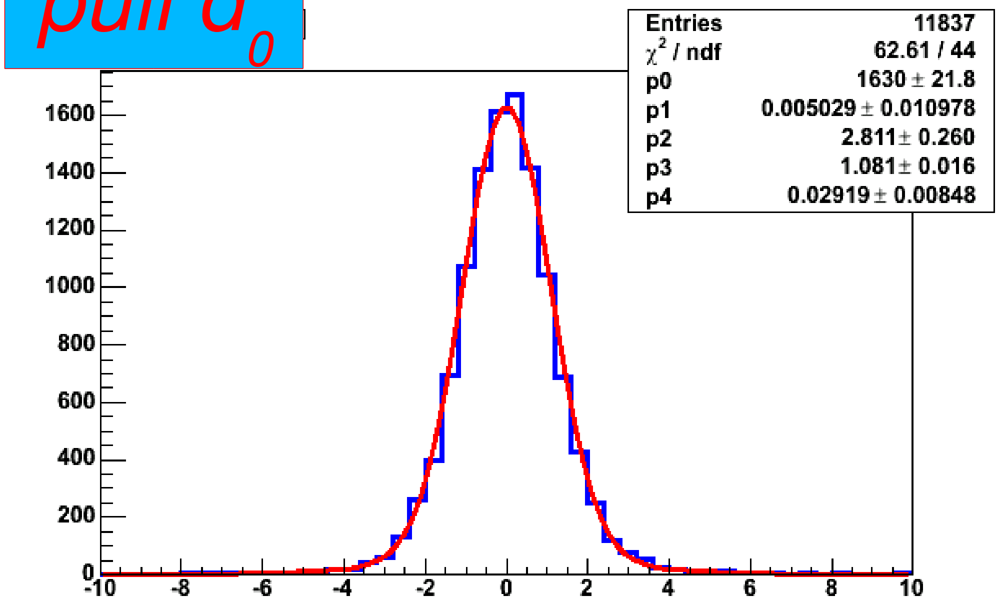
pull ϕ_0



pull tanλ

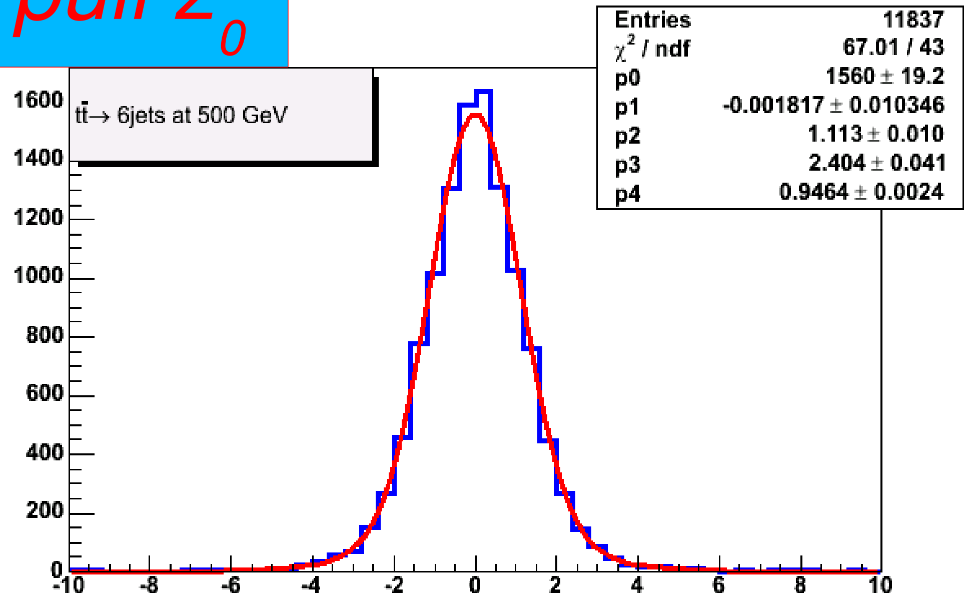


pull d_0

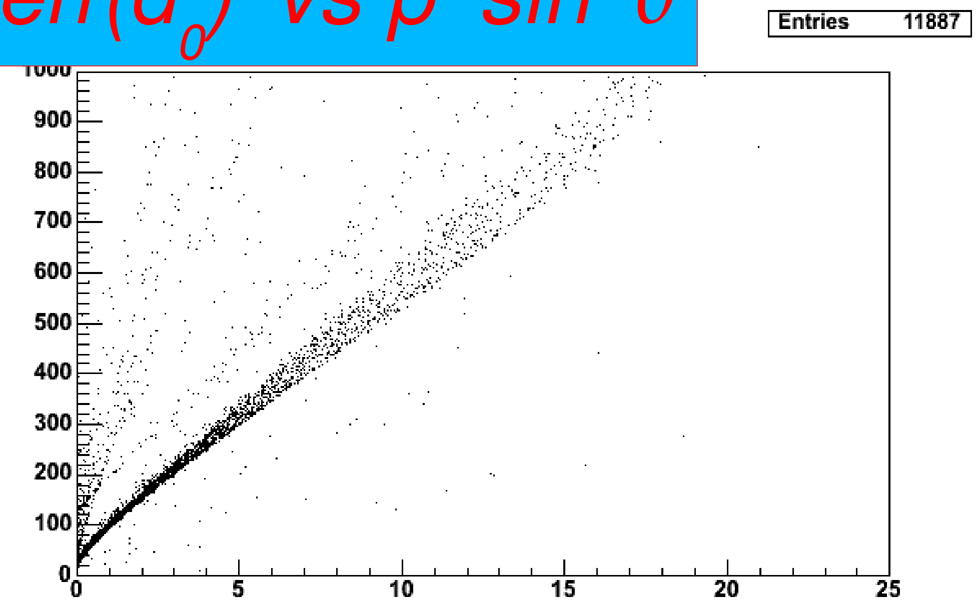


$t\bar{t}\rightarrow$6jets @ 500 GeV. d_0 & z_0 Errors. χ^2

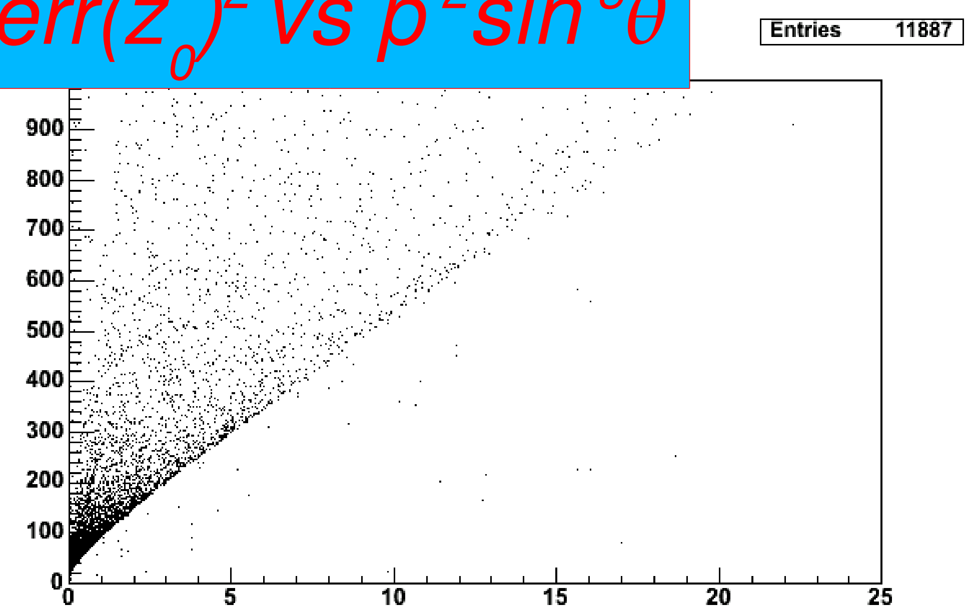
pull z_0



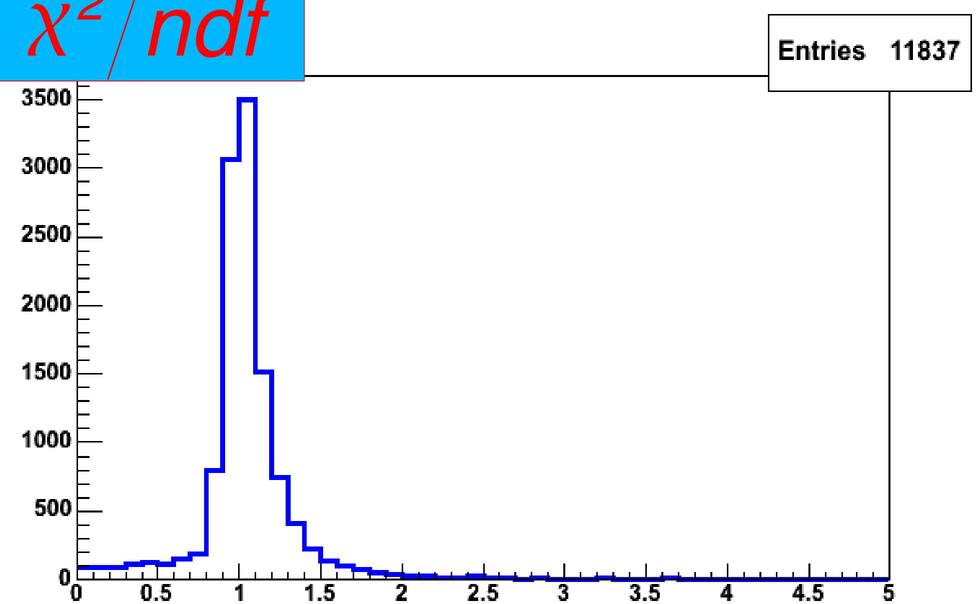
$err(d_0)^2$ vs $p^{-2}sin^{-3}\theta$



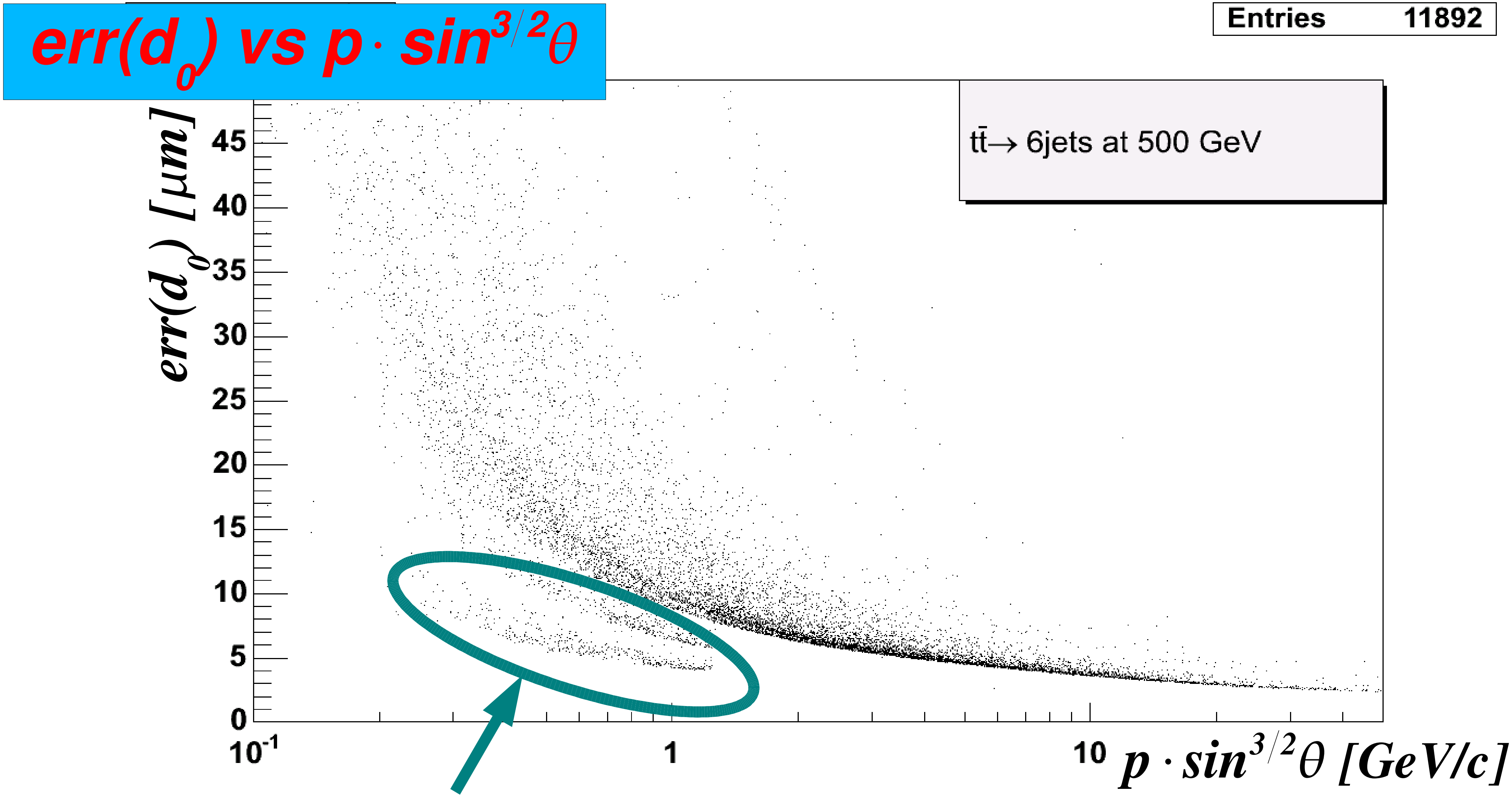
$err(z_0)^2$ vs $p^{-2}sin^{-3}\theta$



χ^2 / ndf

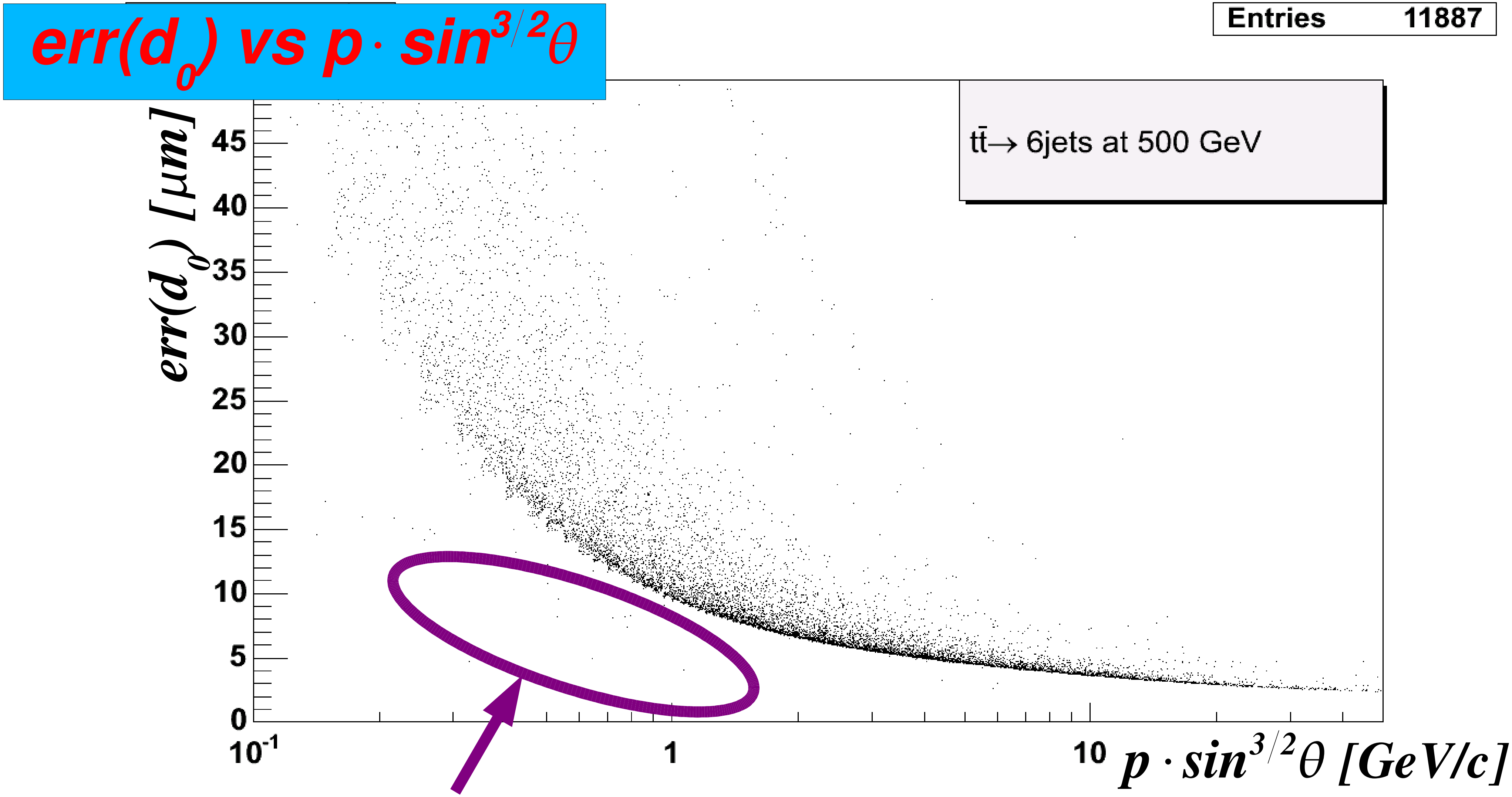


Problem in previous version of code...



Sizable fraction of low p tracks with anomalously small d_0 & z_0 errors ⇒ screws up flavor-tagging

... is solved in new version

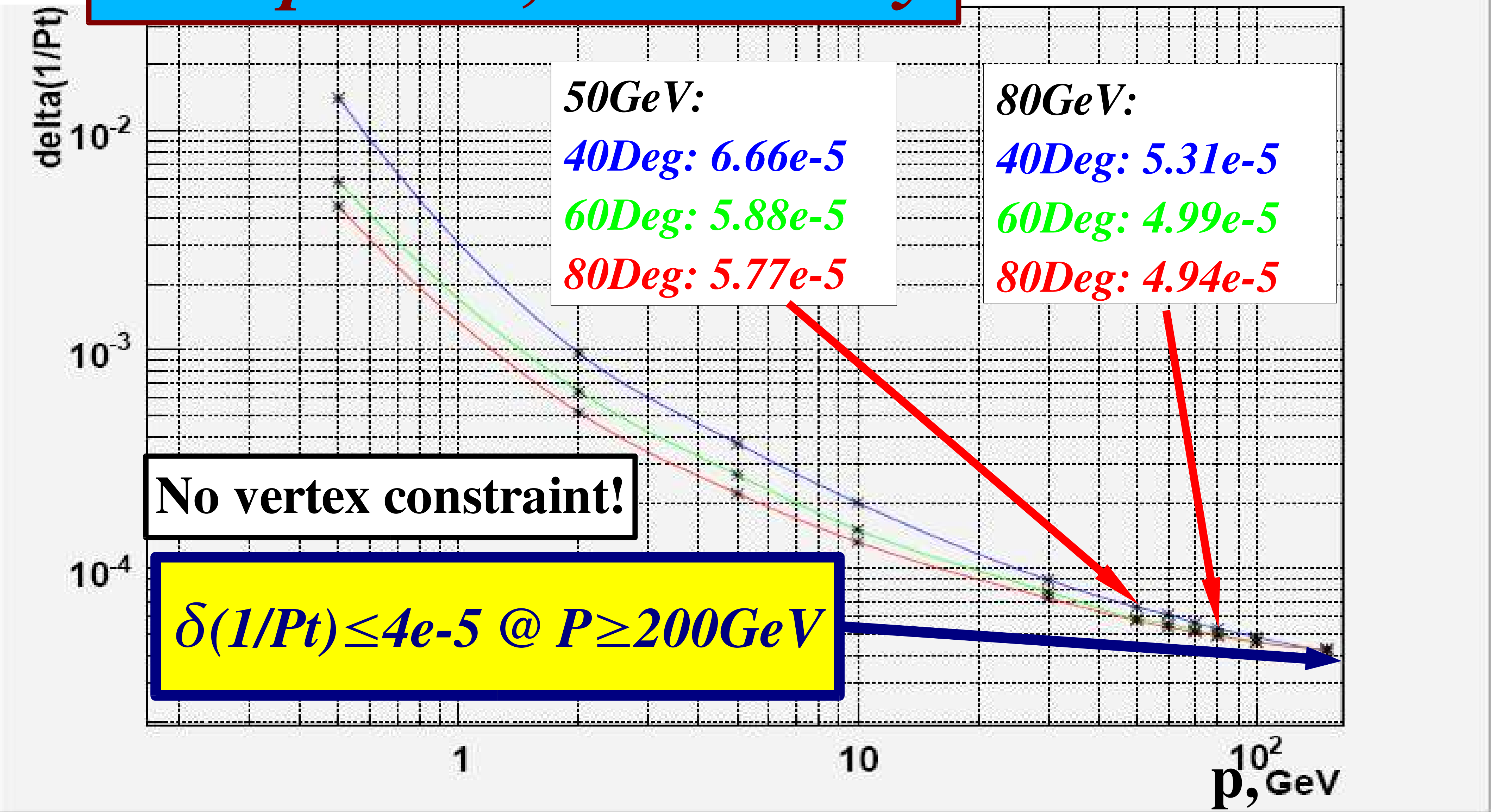


A more accurate track prefit ensures stability of DELPHI Kalman filter and reliable evaluation of covariance matrix

Transverse Momentum Resolution

Central Region. Single Muons. LDC01 Mokka Model

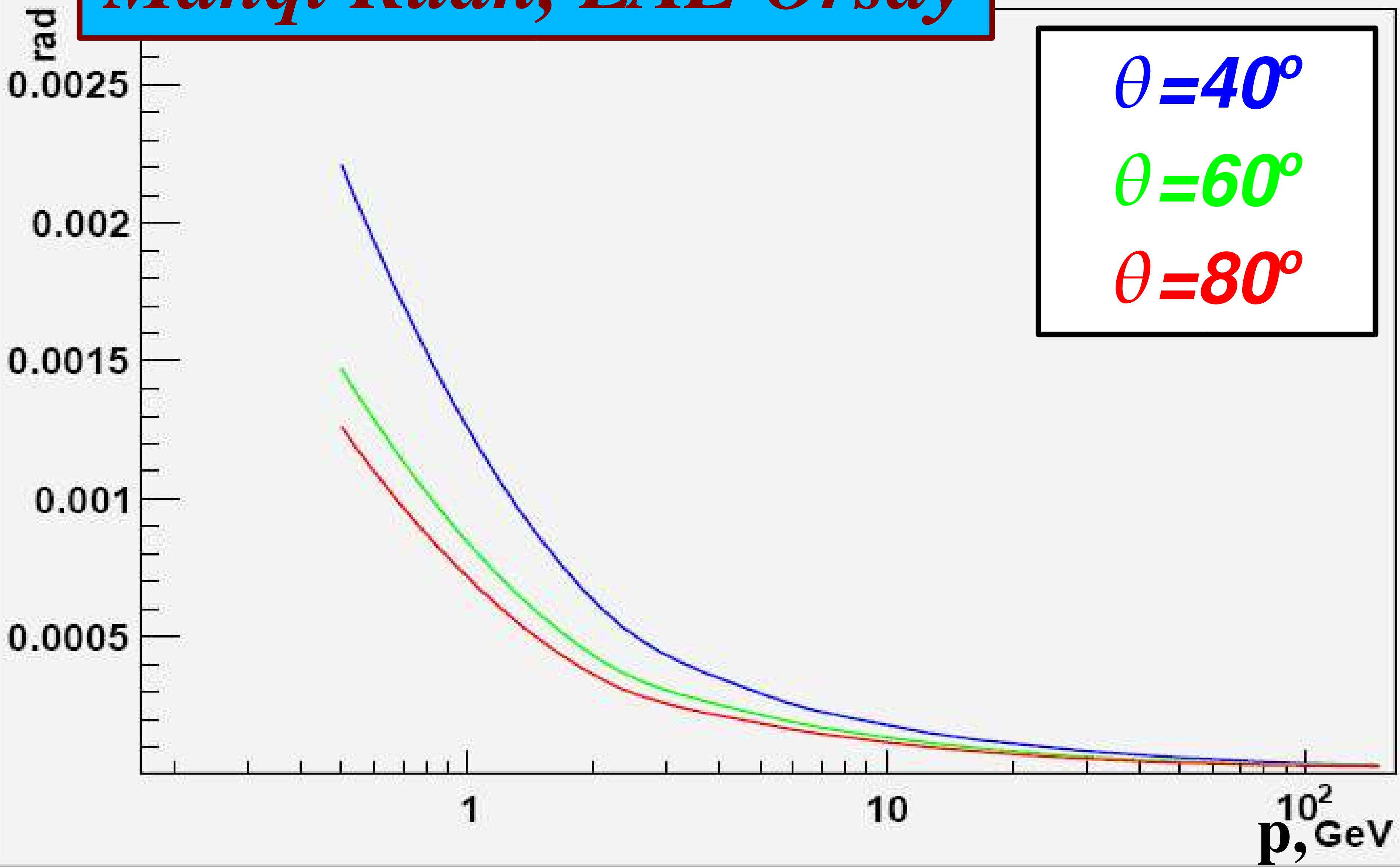
Manqi Ruan, LAL-Orsay



Azimuthal Angle Resolution

Central Region. Single Muons. LDC01 Mokka Model

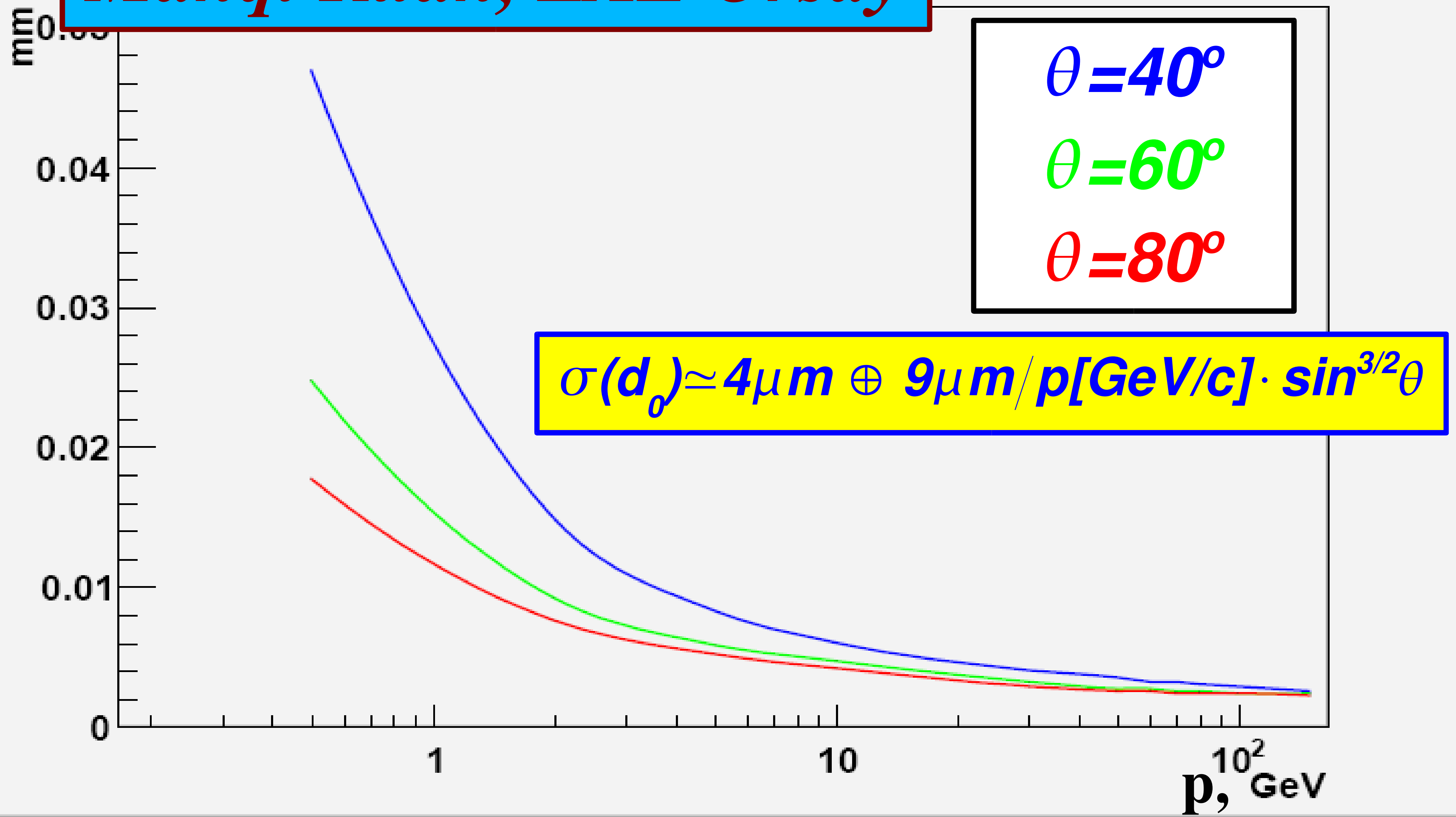
Manqi Ruan, LAL-Orsay



Impact Parameter Resolution

Central Region. Single Muons. LDC01 Mokka Model

Manqi Ruan, LAL-Orsay

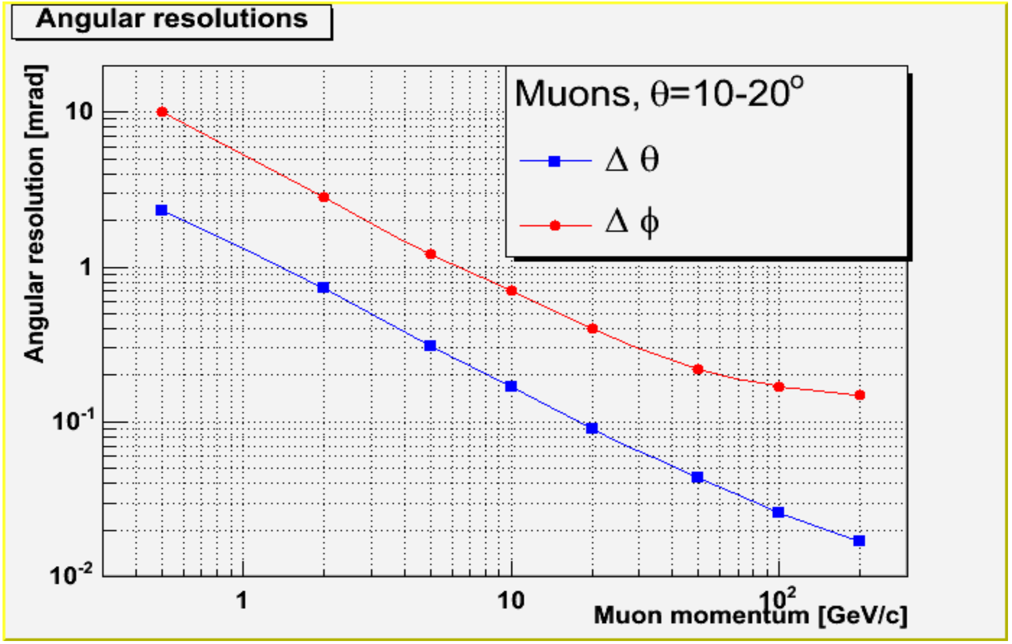


Track Parameter Resolutions

Forward Region. Single Muons. LDC01 Mokka Model

Forward region [$10^o \le \theta \le 20^o$] ⇒

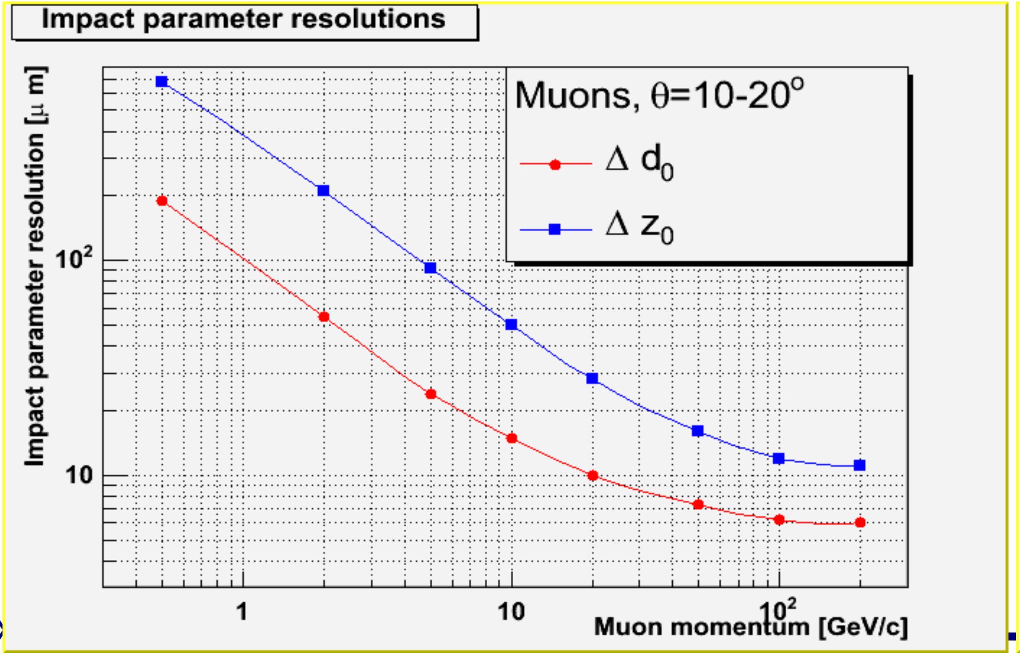
Tracks reconstructed with FTD

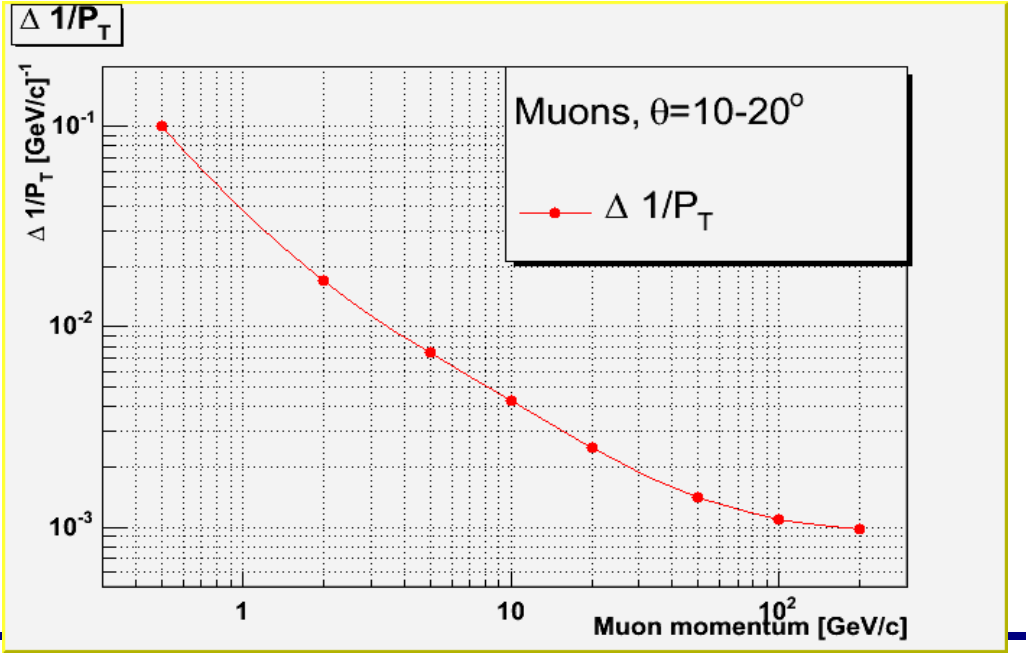


Planar z-Discs ⇒

$$\sigma_{\phi} \propto \sigma_{\theta} / \sin\theta$$

$$\sigma_{z0} \propto \sigma_{d0} / \tan\theta$$

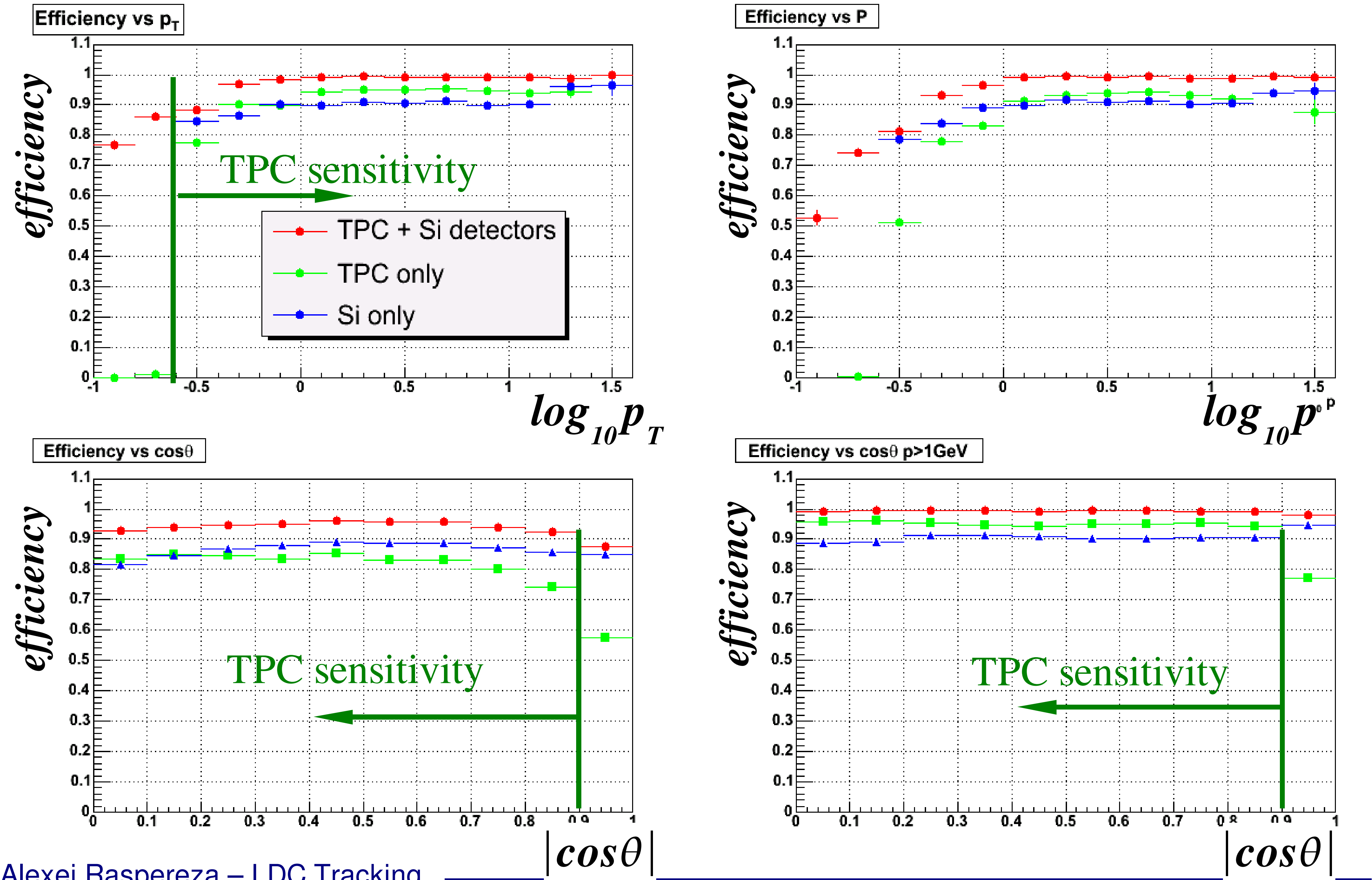




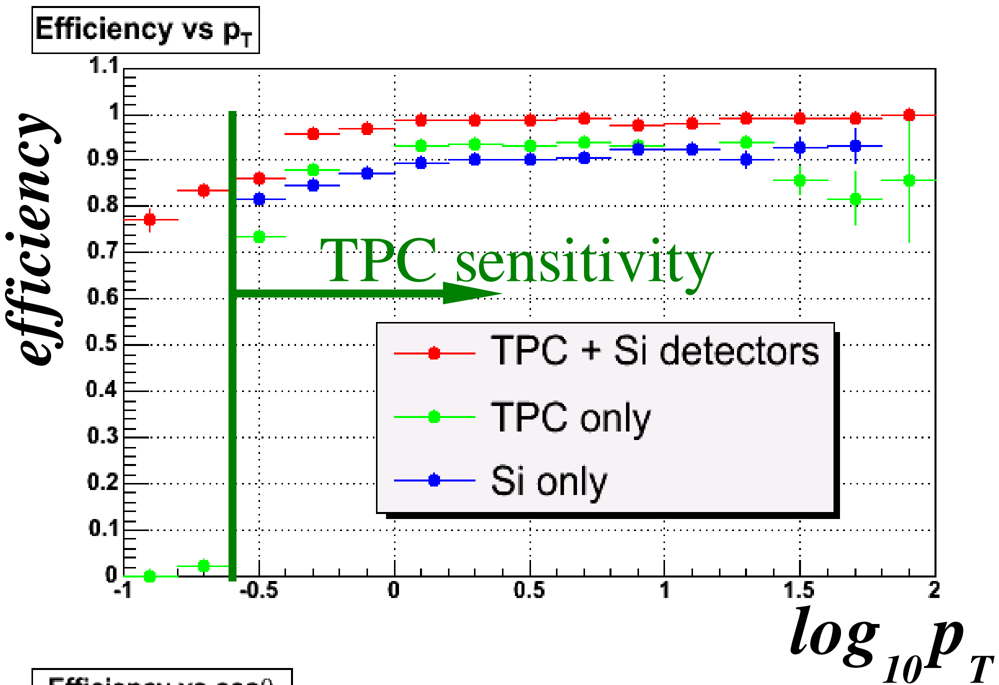
Overall Tracking Performance

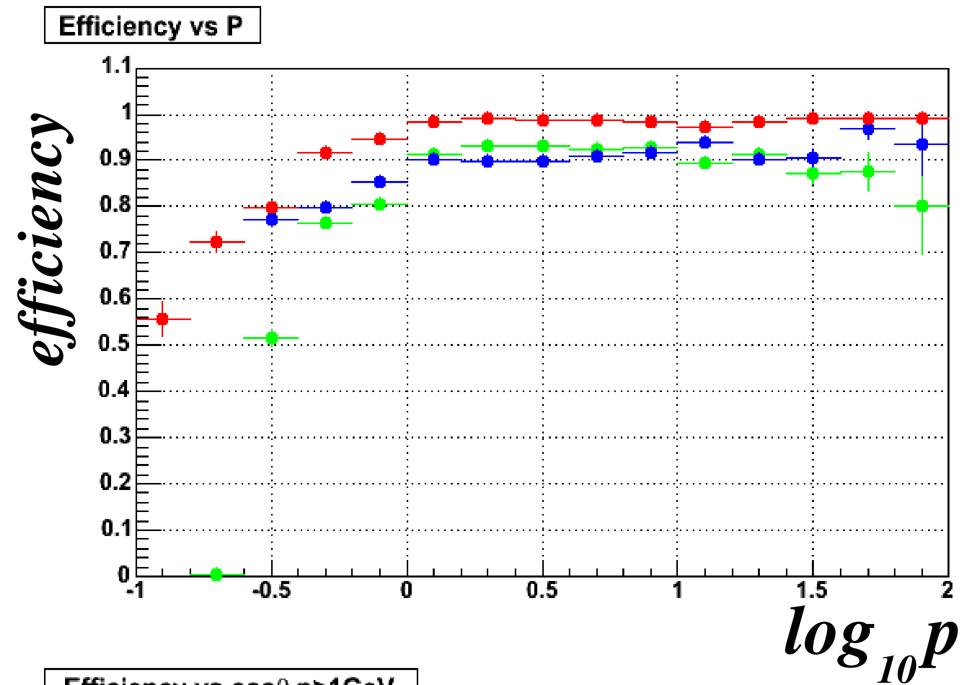
- **Overall quality of code is evaluated in terms of**
  - Track finding efficiency
  - PFA Performance
- **Used benchmark processes**
  - Hadronic events at Z pole ($\sqrt{s}$ = 91.2 GeV)
  - $e^+e^- \to W^+W^-\nu\bar{\nu} \to H\nu\bar{\nu} \to 2jets + \not{E}$ @ $\sqrt{s}$ = 800 GeV
  - $t\bar{t} \to W^+W^- b\bar{b} \to 6jets$ @ $\sqrt{s}$ = 500 GeV

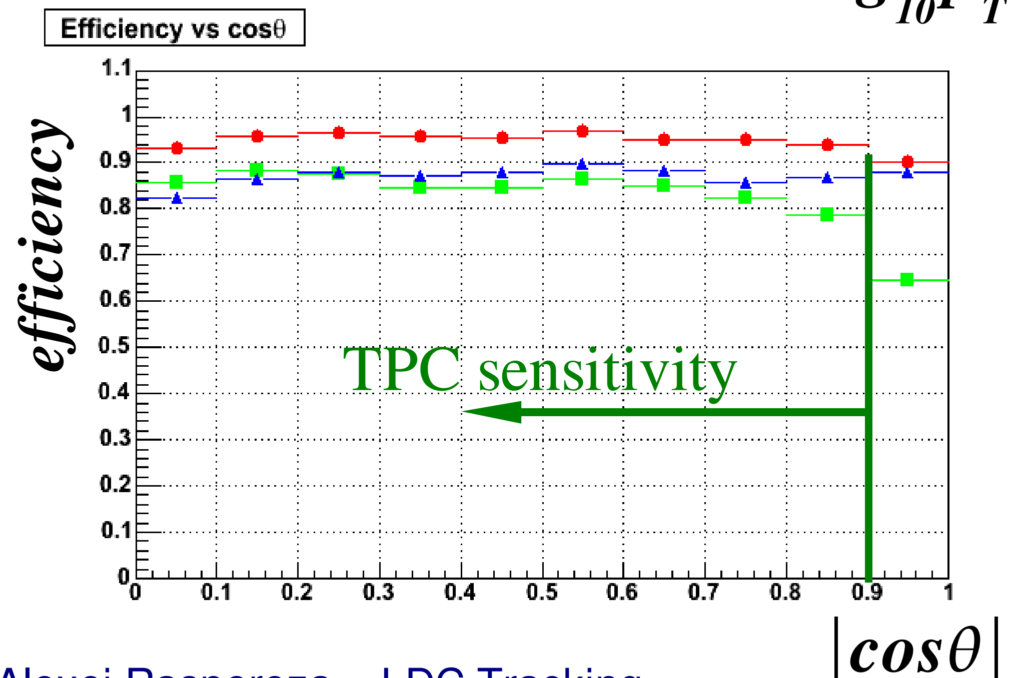
Tracking Efficiency. Z Pole Events

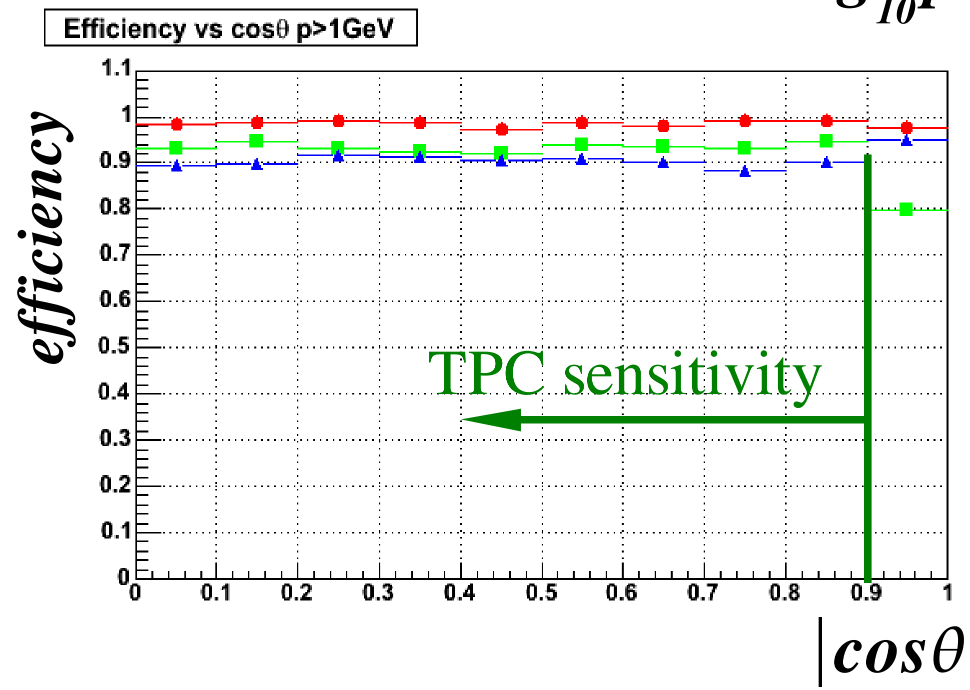


Tracking Efficiency. tt→6jets @ 500 GeV









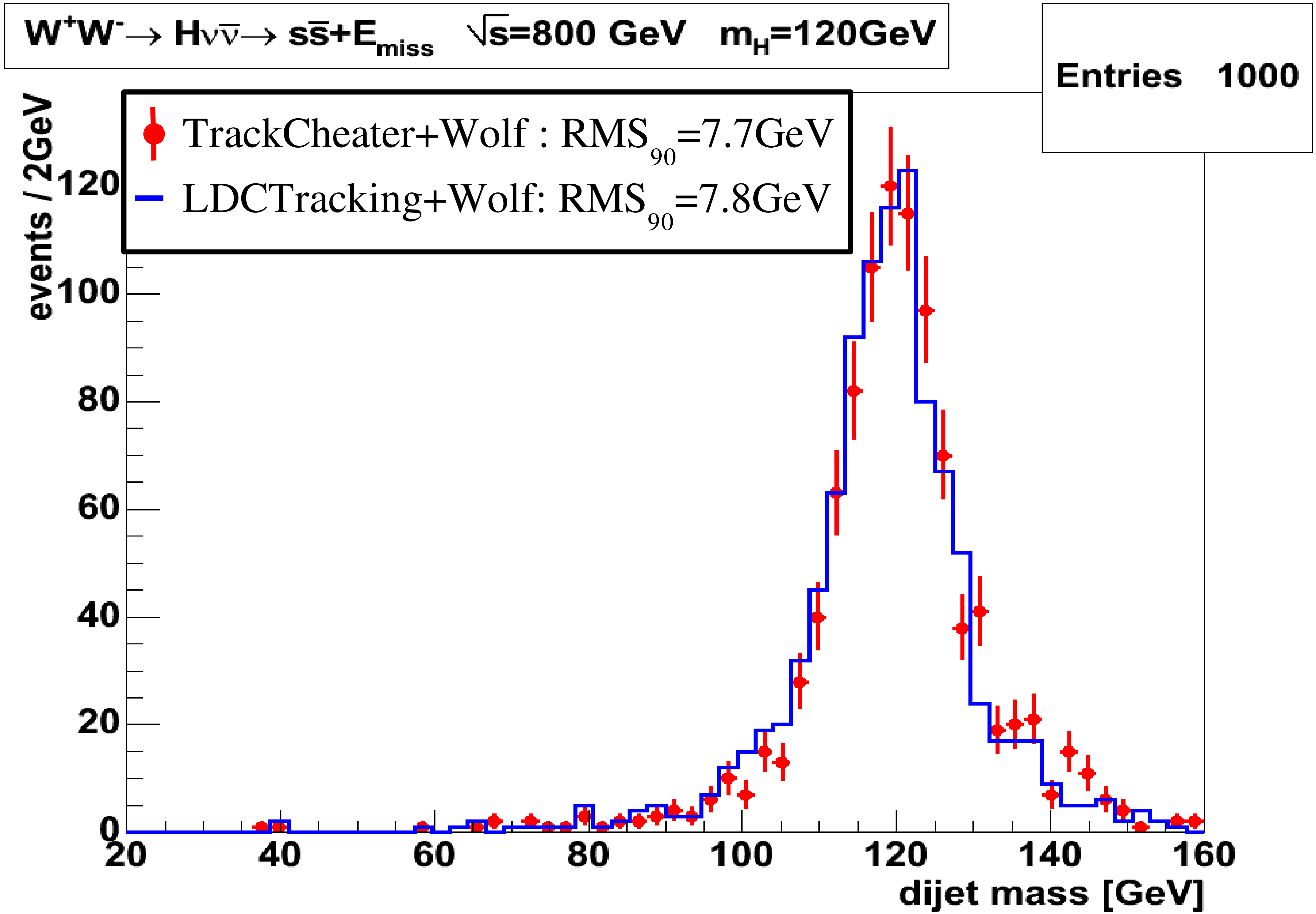
PFA Performance Studies

- ***LDC tracking is tried with PFA-cheater and Wolf-PFA***

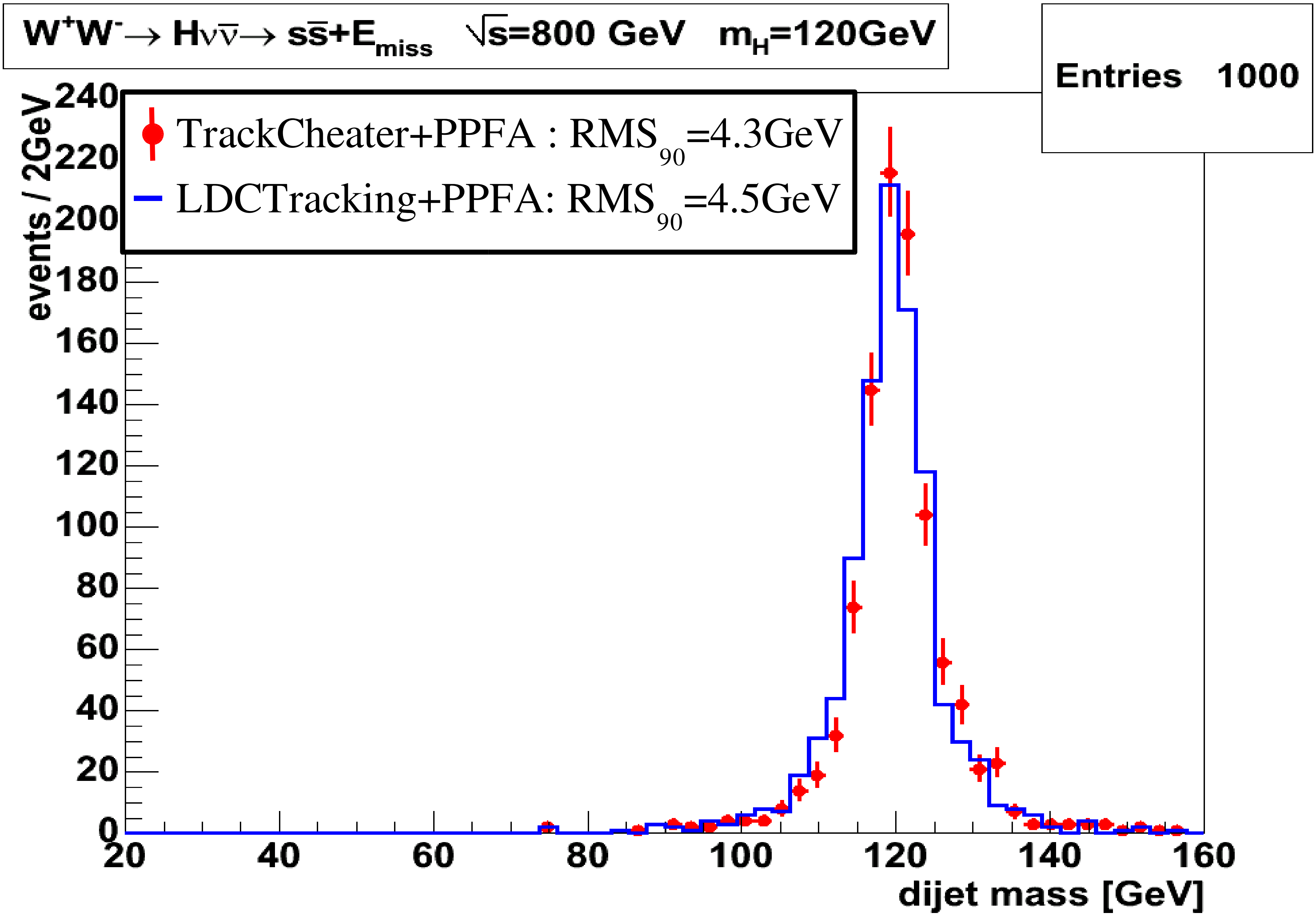
LDCTracking+Wolf ⇒ first publicly available full reconstruction chain!

- *DEPFET-based detailed digitization of VTX hits; gaussian smearing of FTD/TPC/SIT hits according to a-priori known spatial resolutions*
- *TPC Tracking + Si Tracking ⇒ Full LDC Tracking*
- *Wolf-PFA : not perfect and not the best algorithm available on the market, but yields sensible performance for topologies of moderate complexity, e.g.*
  - $ZH \to \nu\bar{\nu}jj,\ l^+l^-jj \ @ \sqrt{s} \le m_H + m_Z + 50\,\mathrm{GeV}$
  - $e^+e^- \to W^+W^-\nu\bar{\nu} \to H\nu\bar{\nu} \to 2\mathrm{jets} + \not{E} \ @ \sqrt{s} \le 800\,\mathrm{GeV}$

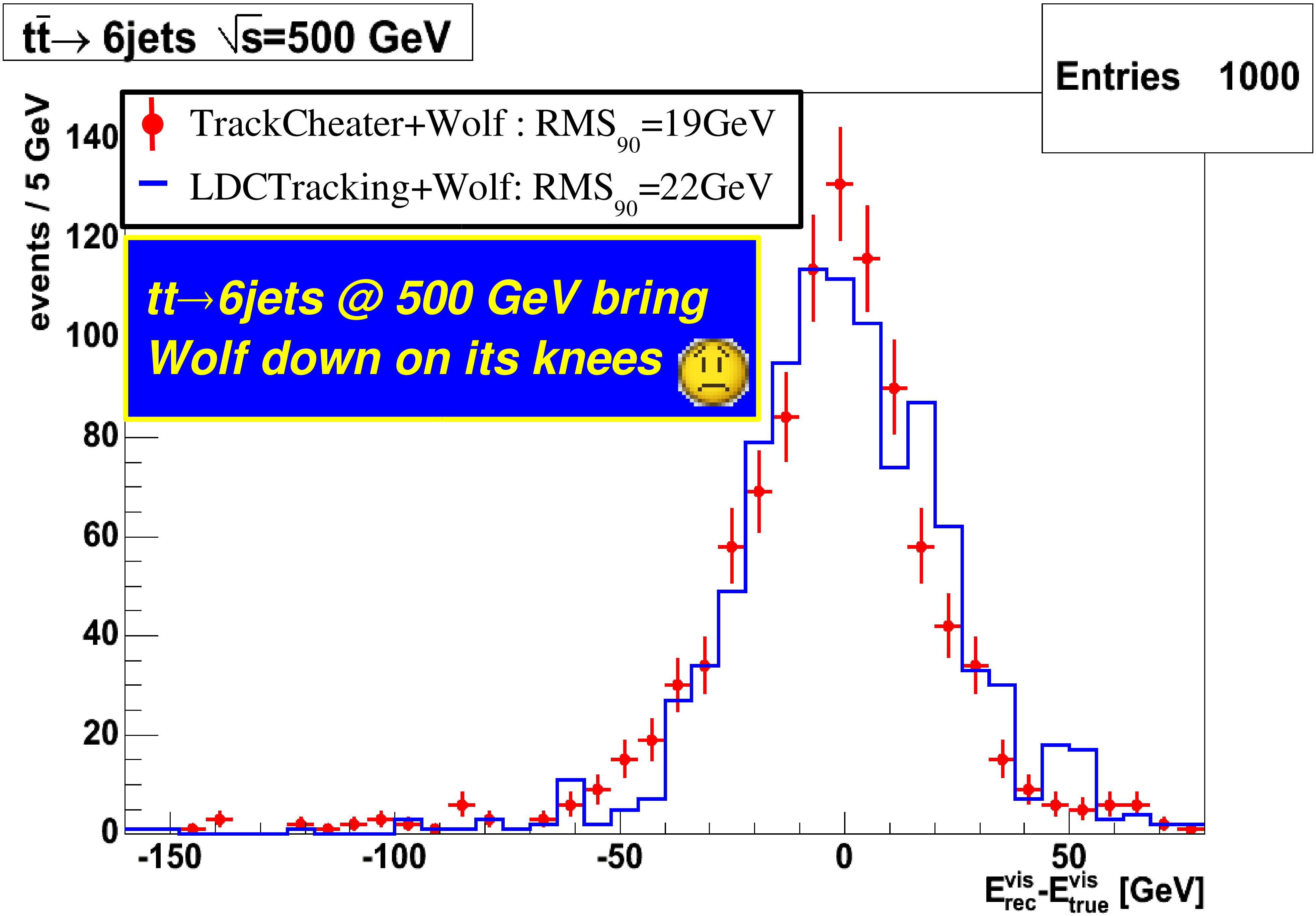
LDCTracking+Wolf



LDCTracking+PFA-cheater

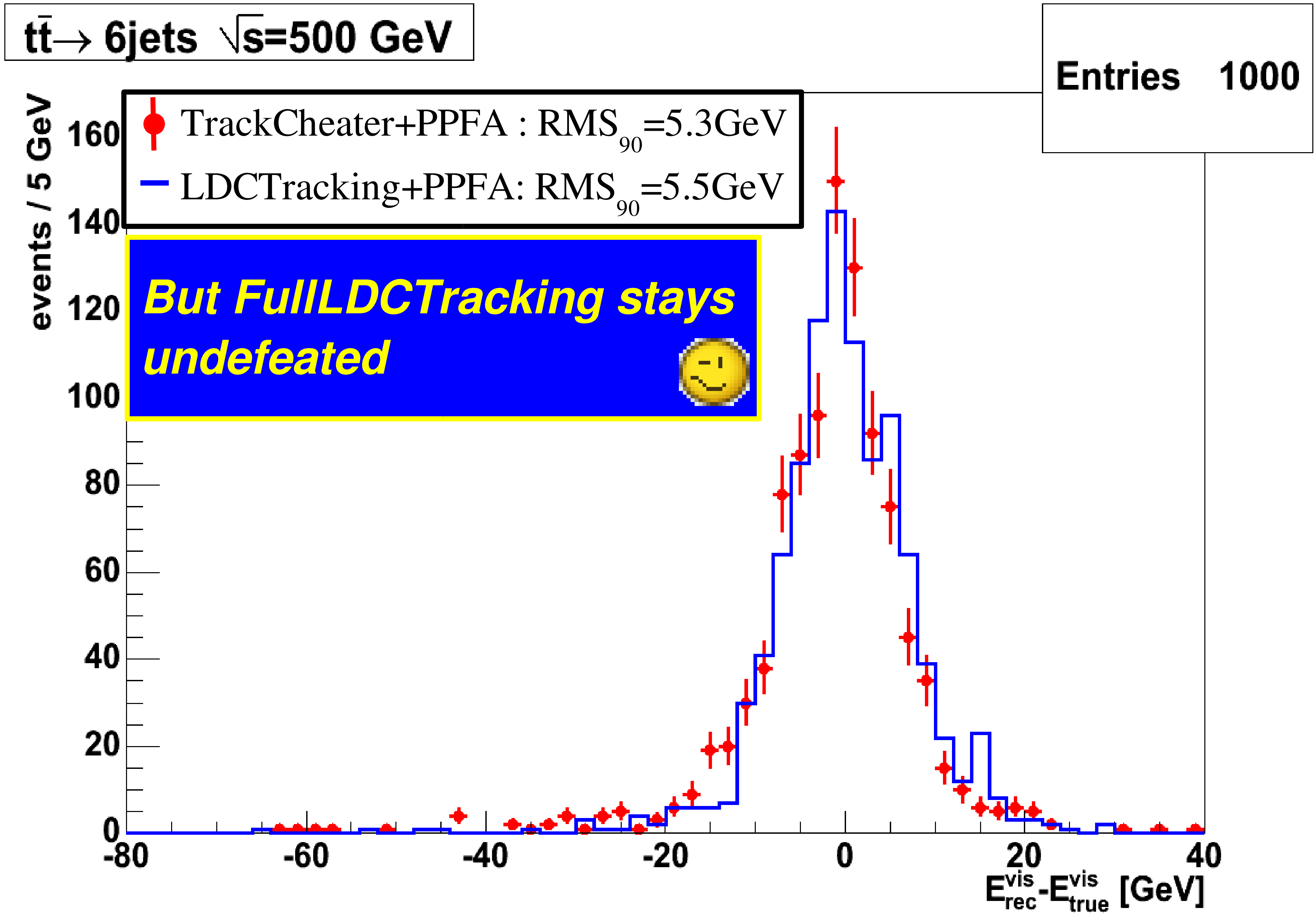


LDCTracking+Wolf



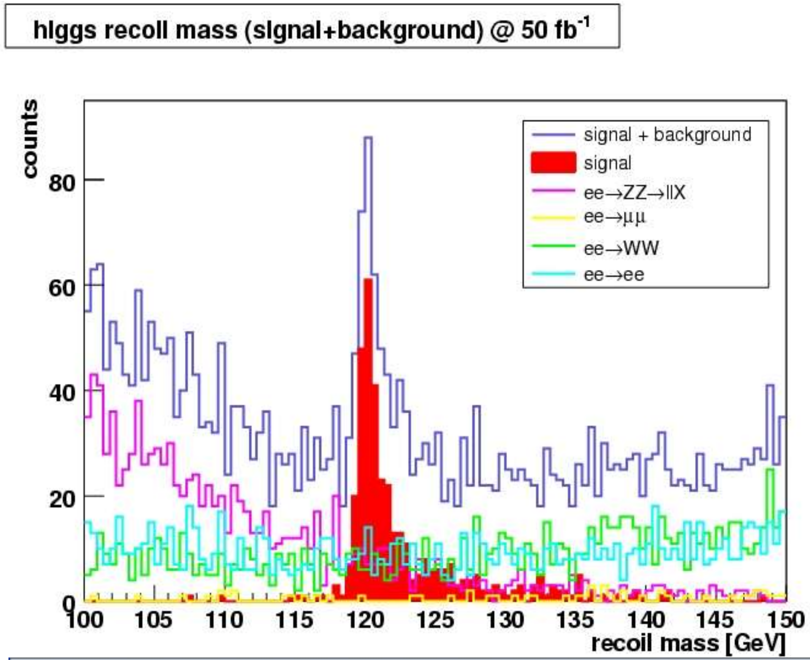
tt→6jets @ 500 GeV bring Wolf down on its knees

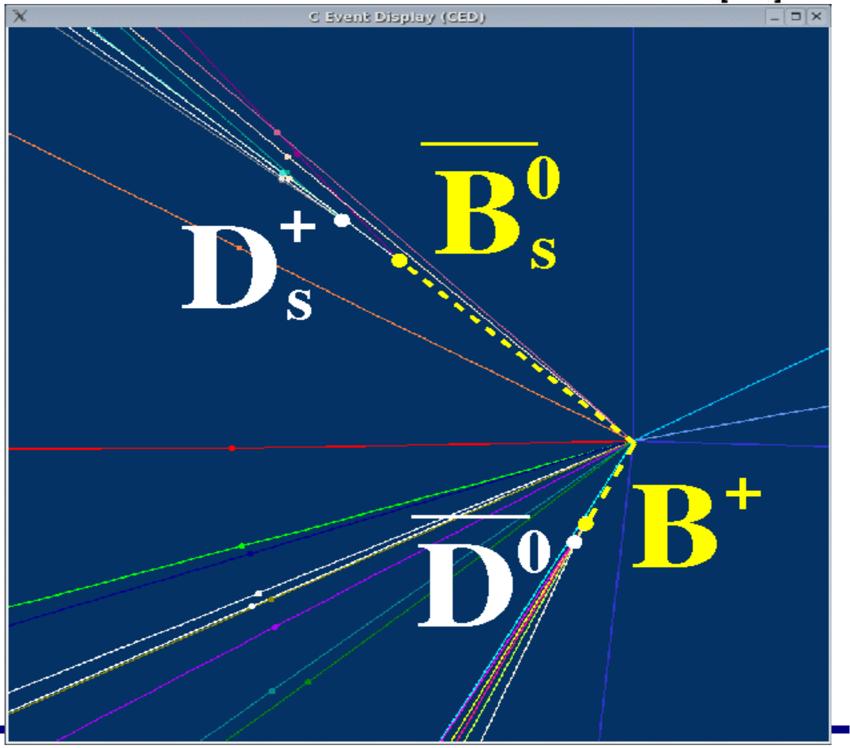
LDCTracking+PFA-Cheater



Fields of Application

- Detector performance studies (LAL, DESY)
- Optimization of DEPFET based VTX (MPI)
- Physics analysis (LAL, DESY, MPI)
- FullLDCTracking is successfully interfaced to LCFI package (Oxford U). **But...** LCFI code, combined with FullLDCTracking, is found to be more performant than with FullLDCTrackCheater ⇒ **WE ARE BETTER THAN PERFECT** but worse than with Si-only TrackCheater ⇒ **WHO TOLD YOU THAT WE NEED TPC?**





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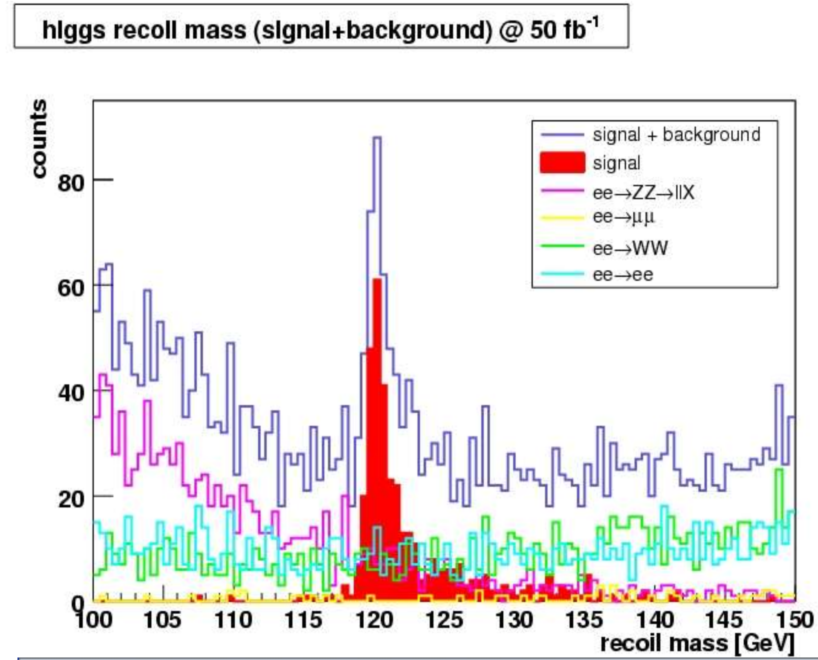
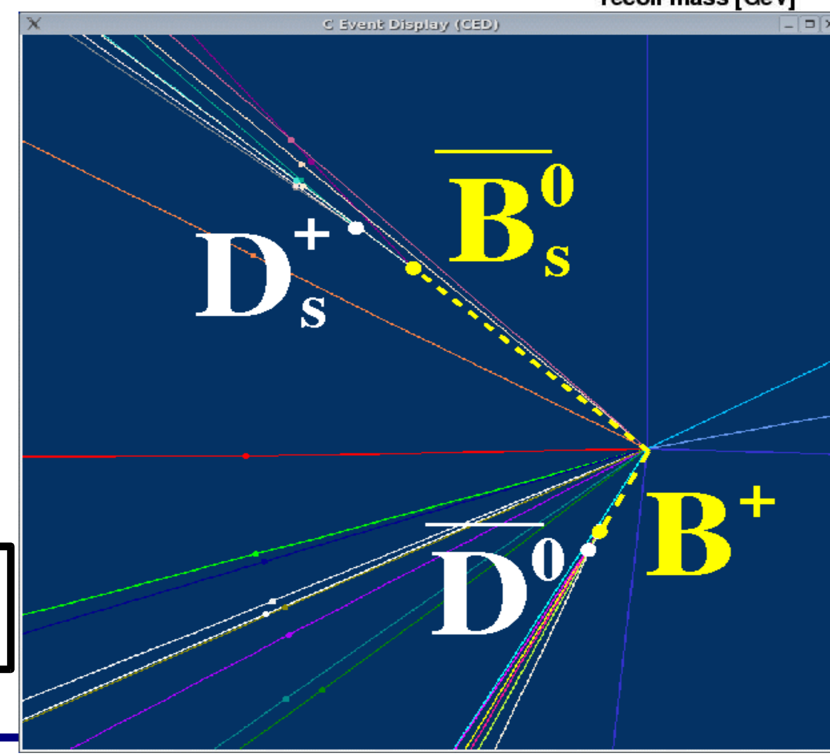




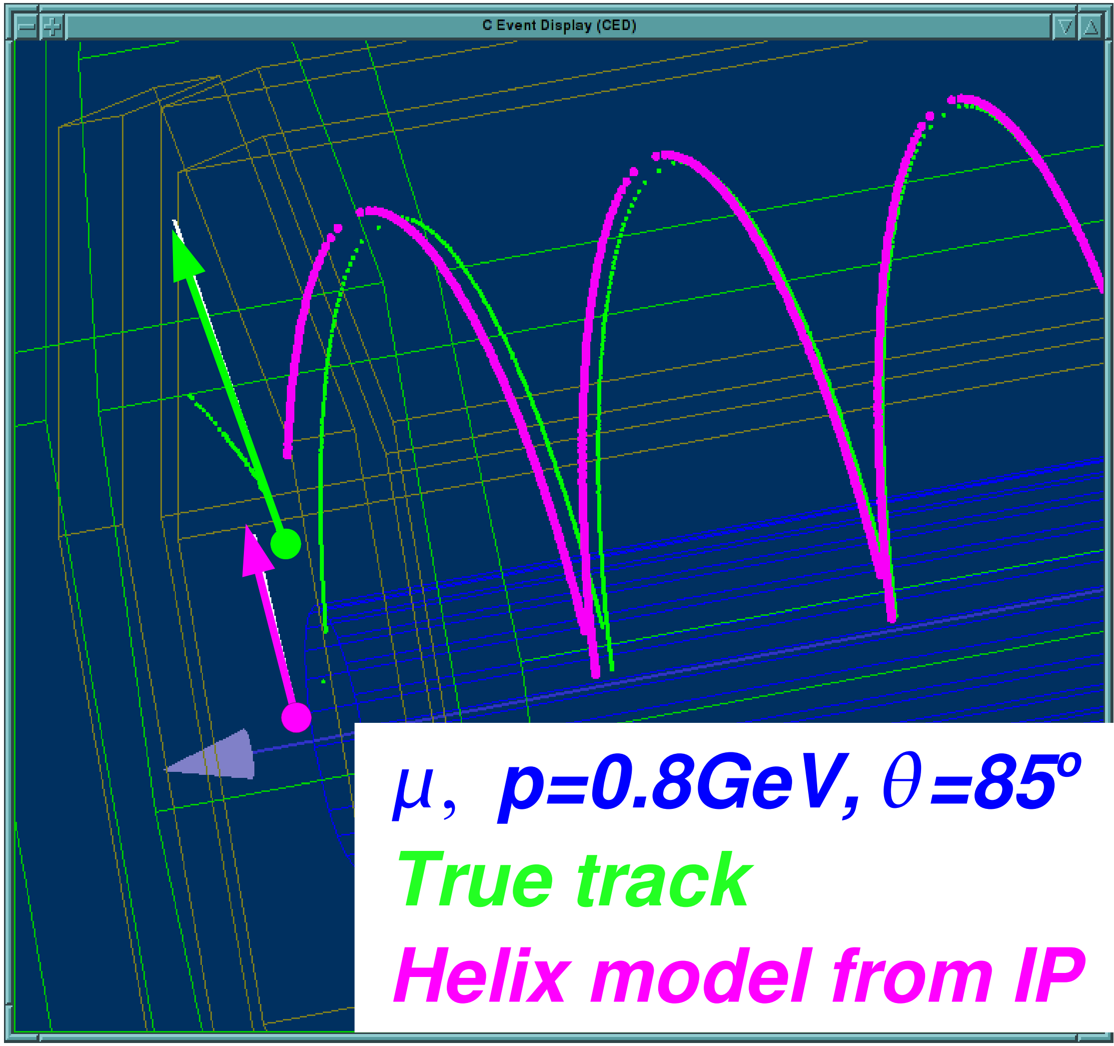
These funny effects are being investigated

- **Updated/improved Tracking Package available in Zeuthen CVS [Caveat: not tagged as an official release!] Well documented**
- **New features ⇒**
  - ✗ Dedicated procedures, recovering splitted loopes in TPC; extrapolation of curling tracks to endcap ECAL; few bugs fixes
- **Performance ⇒**
  - ✗ Benchmark goals in terms of ***p_T*, *angular & IP*** resolutions are reached
  - ✗ Track finding efficiency ***>99(97.5)%*** for track momenta ***>1(0.4)GeV***
  - ✗ In good shape regarding PFA performance ⇒ ready to support any PFA
- **Release of the first official, fully operational/verified version is planned for mid of June [few bugs still need to be fixed]**
- **Please, make use of the code. Only by using the LDC Tracking software you can help us to improve it.**
  Nice examples : Oxford U., LAL-Orsay & DESY groups!

Backup Slides

Track Extrapolation to ECAL Endcap

1. Full looper recovery including FCH hits
2. Fitting last ***N*** hits before ECAL (***N*** steered by user) [Kalman fit]
3. Extrapolating track to ECAL using result of Kalman fit and taking into account extrapolation errors due to MS and energy loss in TPC endplate
4. Finding intersection point with ECAL front-face
5. Determination of particle mometum @ intersection point



Stand-alone Pattern Recognition in VTX in the Presence of Beam Induced Backgrounds

- *Two scenarios considered for the most favorable ILC design*

  1) 25 μs integration time (75 bx) in 1st layer; 50 μs integration time (150bx) in layers 2-4

  2) 50 μs integration time (150 bx) in 1st layer; 100 μs integration time (300bx) in layers 2-4

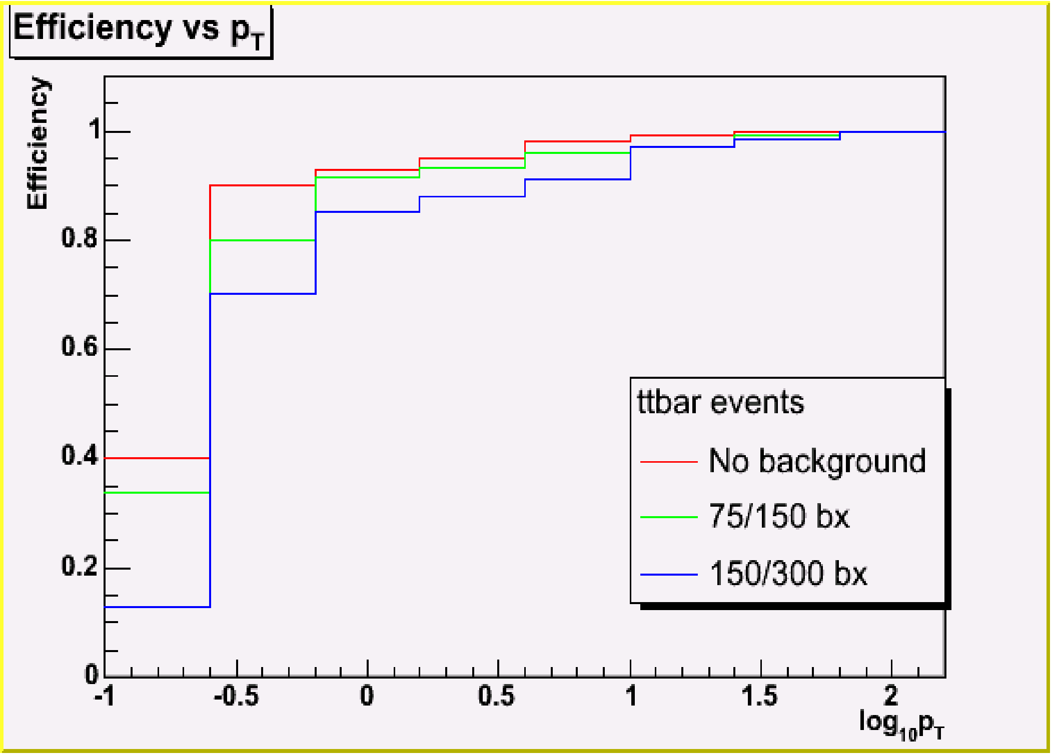
# of background hits in VTX

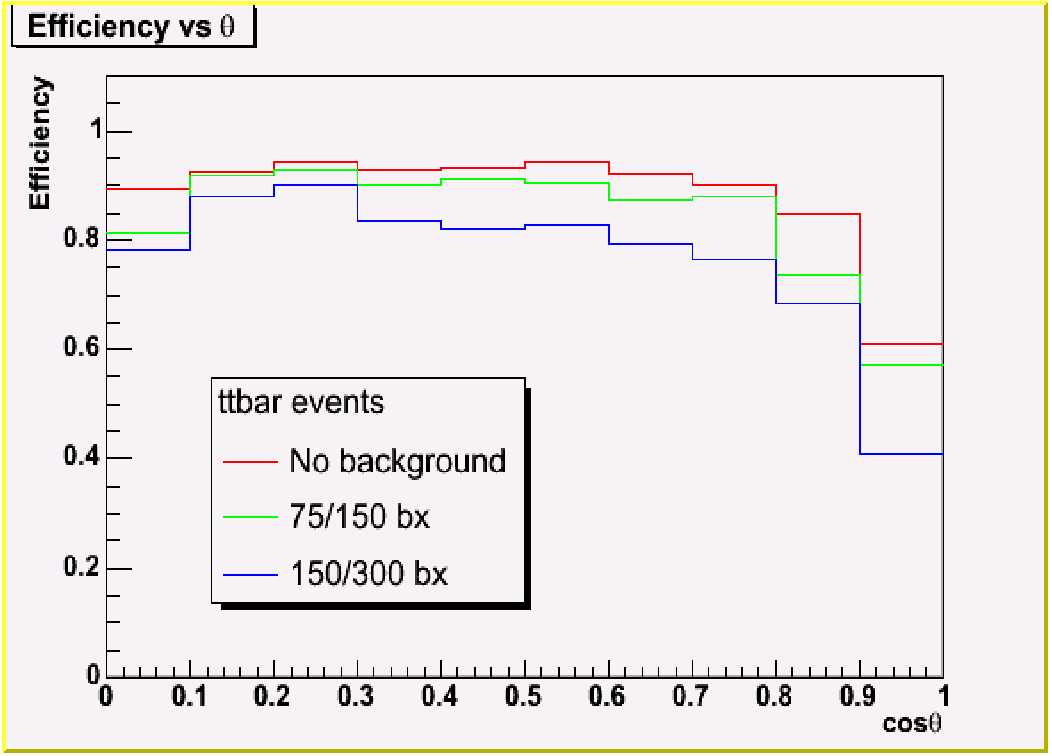
VTX Layer	1BX	Scenario1	Scenario2
1	400	30000	60000
2	200	30000	60000
3	100	15000	30000
4	50	7500	15000
5	20	3000	6000

Evaluation of Tracking Performance

- Tracking performance is evaluated in terms of track finding efficiency and fake track rate
- χ^2 of track fit and number of hits in track are used as main criteria to accept track candidate found in silicon tracking devices
- default requirements (no background) : χ^2/ndf $<$ 20, # hits ≥4
- With default track qulity criteria pattern recognition gets CPU intensive and produces enormous number of fakes in the presence of background → track quality criteria are tightened when studying impact of background
  - No backg : χ^2/ndf $<$30, # hits ≥3
  - Scenario 1 : χ^2/ndf $<$15, # hits ≥4
  - Scenario 2 : χ^2/ndf $<$10, # hits ≥5

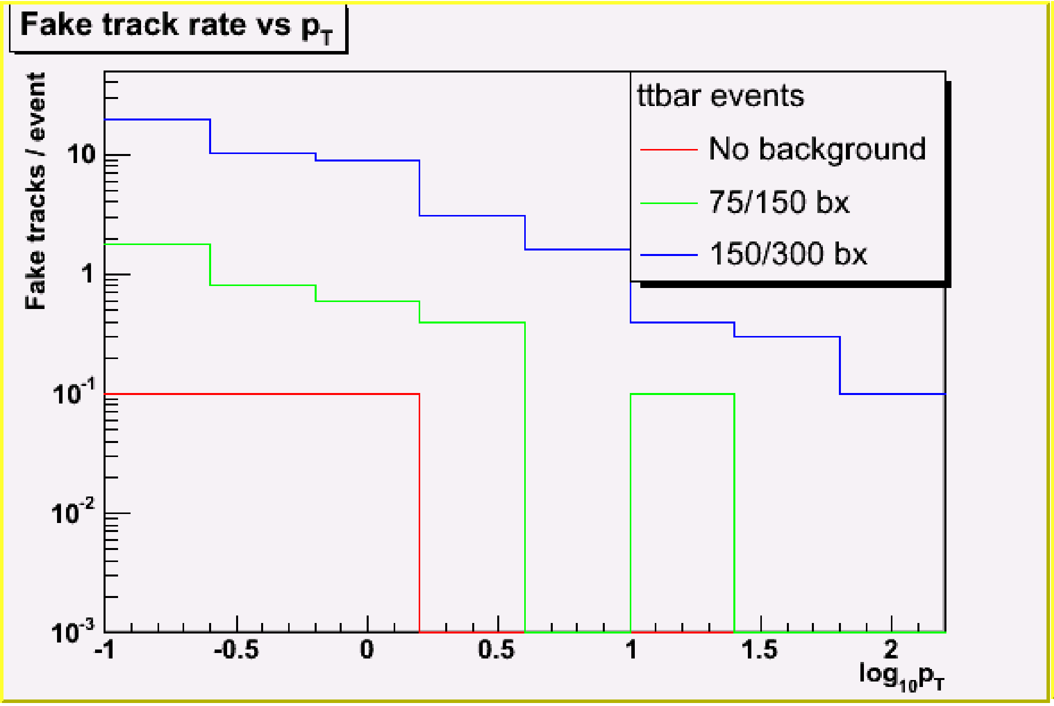
Track Finding Efficiency (10 *tt* events)

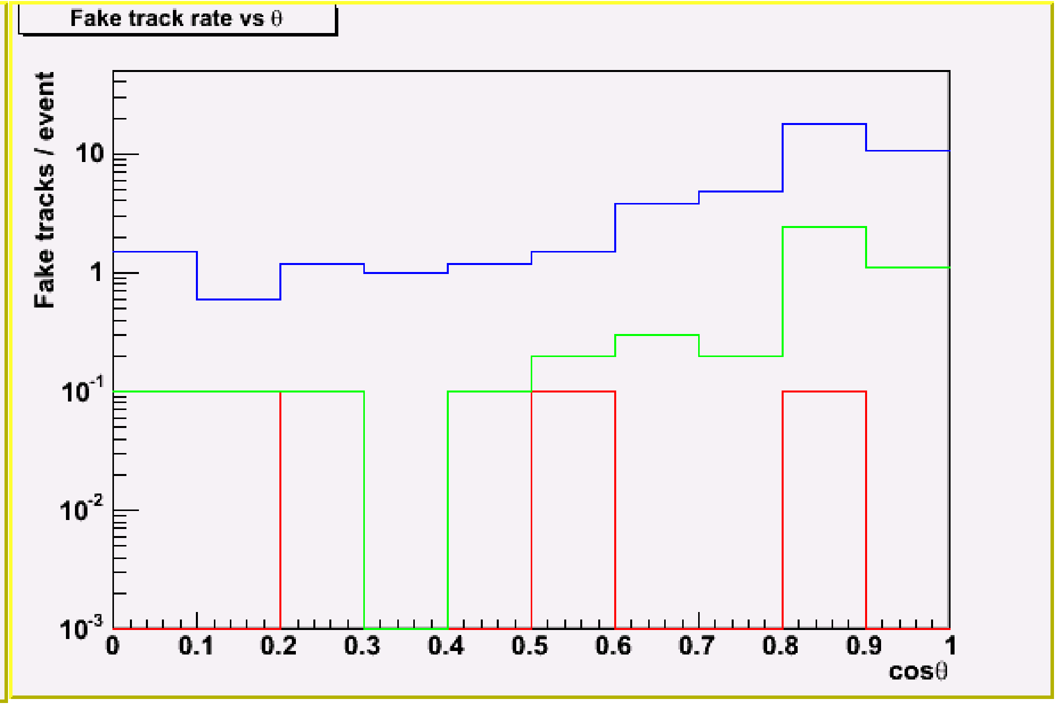




- **Track finding efficiency degrades with increasing background as track quality requirements get tighter**
  - ε **= 88% (94)% for p_T> 0.1GeV (>0.5GeV) : no background**
  - ε **= 84% (91)% for p_T> 0.1GeV (>0.5GeV) : 75/150 bx**
  - ε **= 79% (86)% for p_T> 0.1GeV (>0.5GeV) : 150/300 bx**

Fake Track Rate (10 *tt* events)





- **Despite tighter track quality requirements, the fake track rate in the case of 50/100 μs integration time is still high due to extremely large combinatorics.**

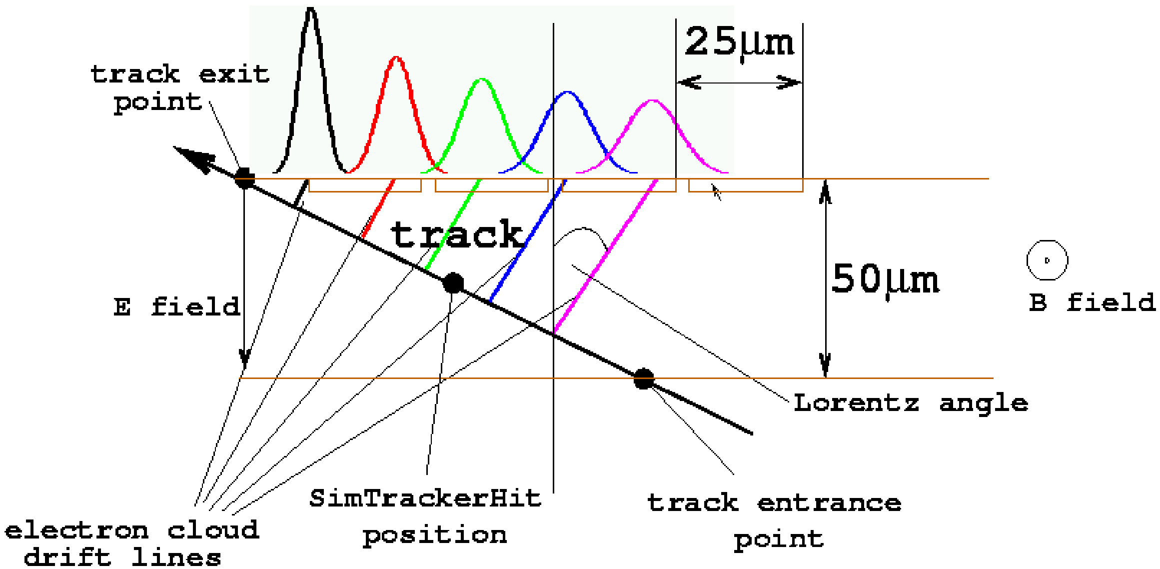
- **Fake tracks per event**
  - **0.3 : no background**
  - **4.2 : 25/50 μs integration time**
  - **45 : 50/100 μs integration time**
  - **Average number of tracks in *tt→6jets* events @ 500 GeV : 77**

High Readout Speed of Si sensors is vital for patrec in VTX!

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

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 previous version (VTX cryostat added)
- **GEAR v00-03 or higher is needed to describe VTX !**

Simple Digitization: New Features

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

$$\sigma_{r\text{-}\varphi}^2 = \sigma_0^2 + D \cdot L_{drift}$$

  - σ_0^2 & σ_D^2 are specified for via GEAR steering : $\sigma_0 = 55\mu$m , $D = 3\mu\text{m}^{1/2}$
  - σ_z is assumed to be constant along z : $\sigma_z = 0.5$mm [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) $\Rightarrow$ they are specified once and forever at the digitization step and used later on by fitting routine (no duplication in Tracking code)