4th Concept Detector Performance Studies

Corrado Gatto
INFN Lecce
On behalf of Software Groups

INFN+BINP

V. Di Benedetto
F. Ignatov
A Mazzacane
M. Rucco
G. Tassielli
G. Terracciano

and Fermilab

L. Garren
H. Wenzel

Outline

- Status of the studies
- New DCH performance
- Calorimeter performance
- Plans for the future

Status of Current Performance Studies

- Use delayed LoI to consolidate simulation and upgrade packages
- Faster geometries for background studies
- Start comparing detector performance with and without beam background
- Use full digitization or fast recpoints depending on the study
- Compare Fluka with Geant for tracking

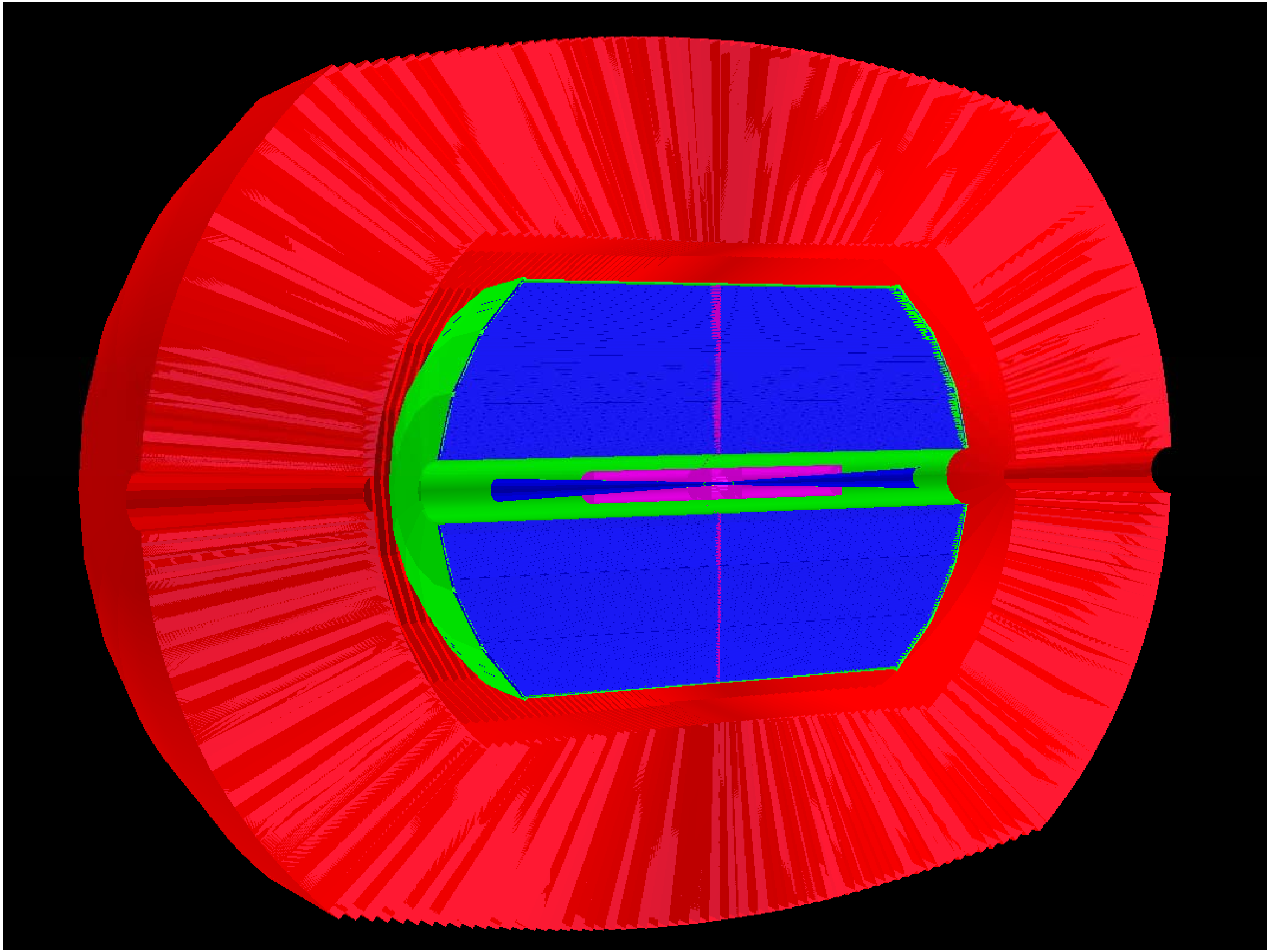
New DCH Layout

- Vessel: 23-150 cm with **spherical Endcaps**
- Active volume: 23-147 cm
- Individual wires simulated
  - 60000 20 μm W sense wires
  - 120.000 80 μm Al field wires
- Gas: 90% He + 10% iC4H10
- Layers: 133
- Cells size and shape:
  - 6-7 mm x 6-7 mm axial exagonal for reconstruction studies
  - Exagonal all-stereo superlayers, r-dependent size, for occupancy studies

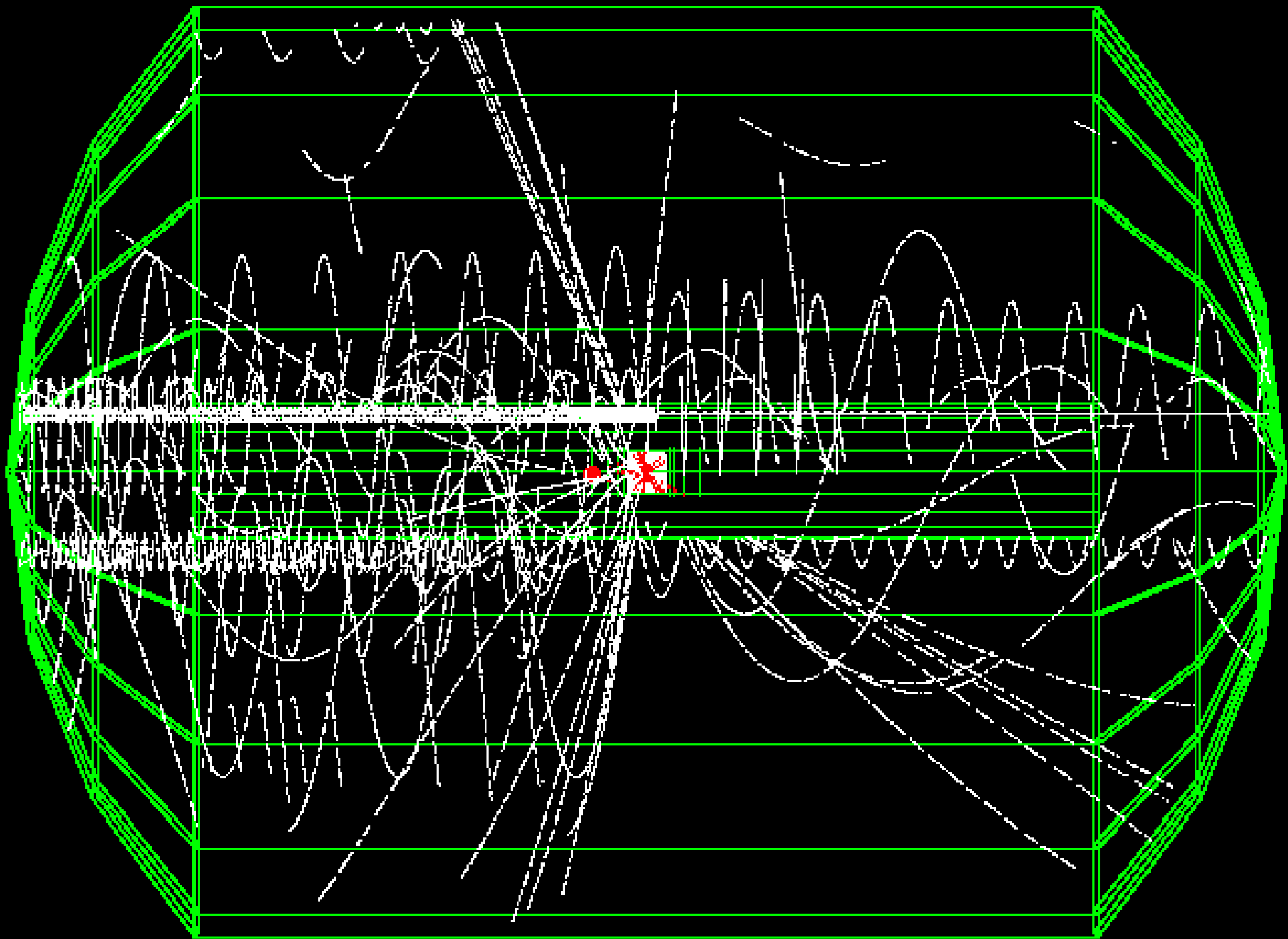
Material Budget

- Gas [He-C4H10/90-10]: 0.15%
- Wires: 0.4%
- Vessel:
  - Inner wall: 0.1% X/Xo
  - Outer wall: 2% X/Xo
  - Endcaps (wires, pads,electronics & services included): 8% X/Xo

See F. Grancagnolo talk for PET wires and Boron fiber endplates

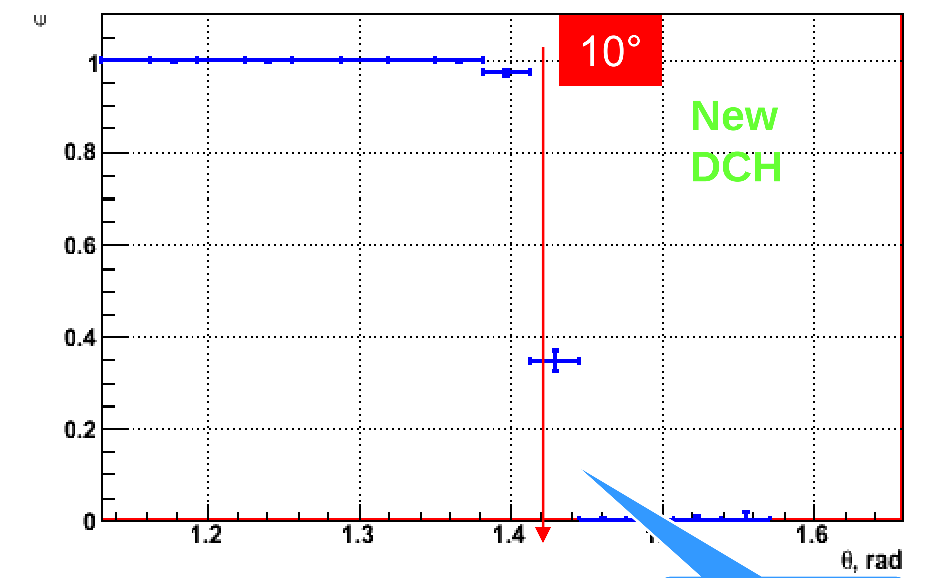


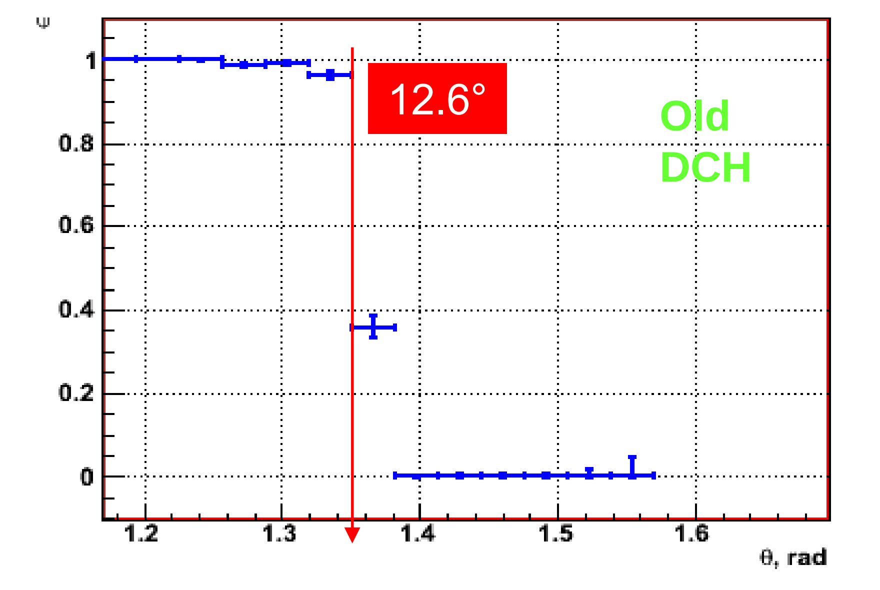
ttbar->6 jets event in 5 T field



Good Tracks (Reconstructable)

10 muons





Spherical EndPlates

Defining "Good Tracks" (reconstructable)

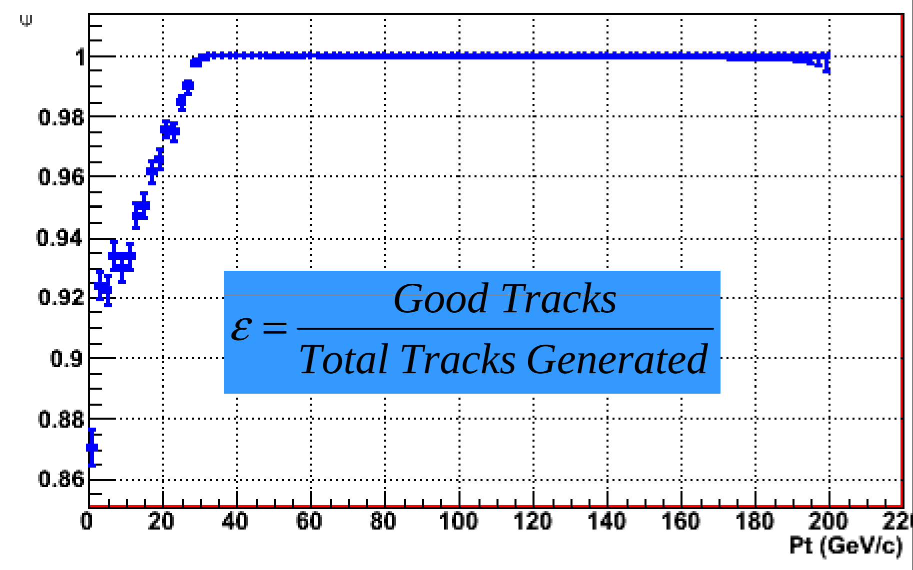
I. DCA(true) < 3.5 cm

AND

II. (At least 10 hits in DCH

OR

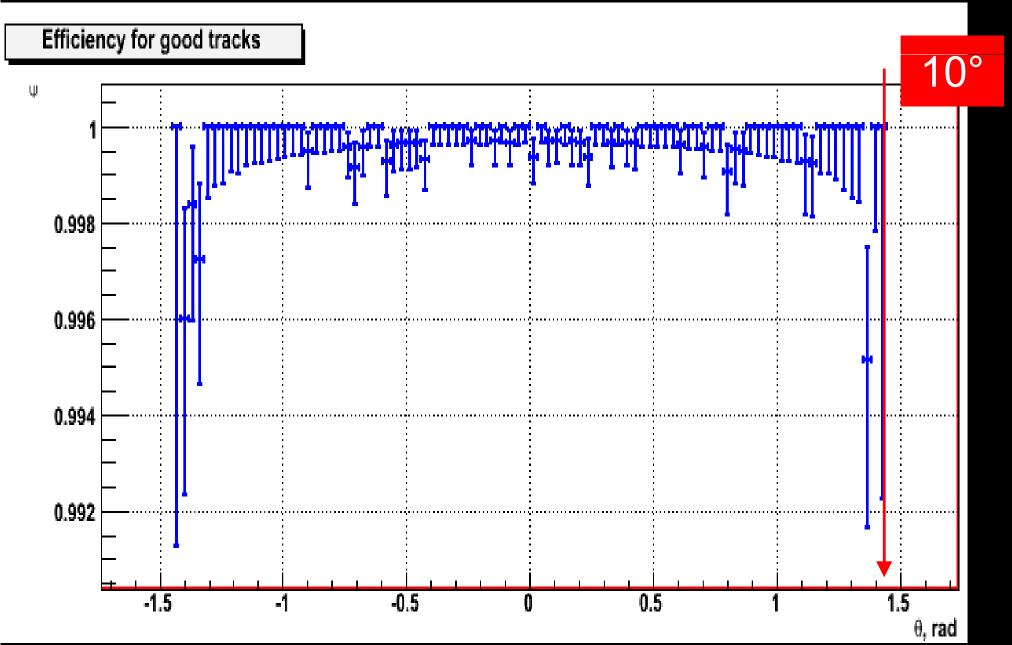
III. At least 4 hits in VTX)



$$\varepsilon = \frac{Good\ Tracks}{Total\ Tracks\ Generated}$$

Reconstruction Efficiency

10 muons

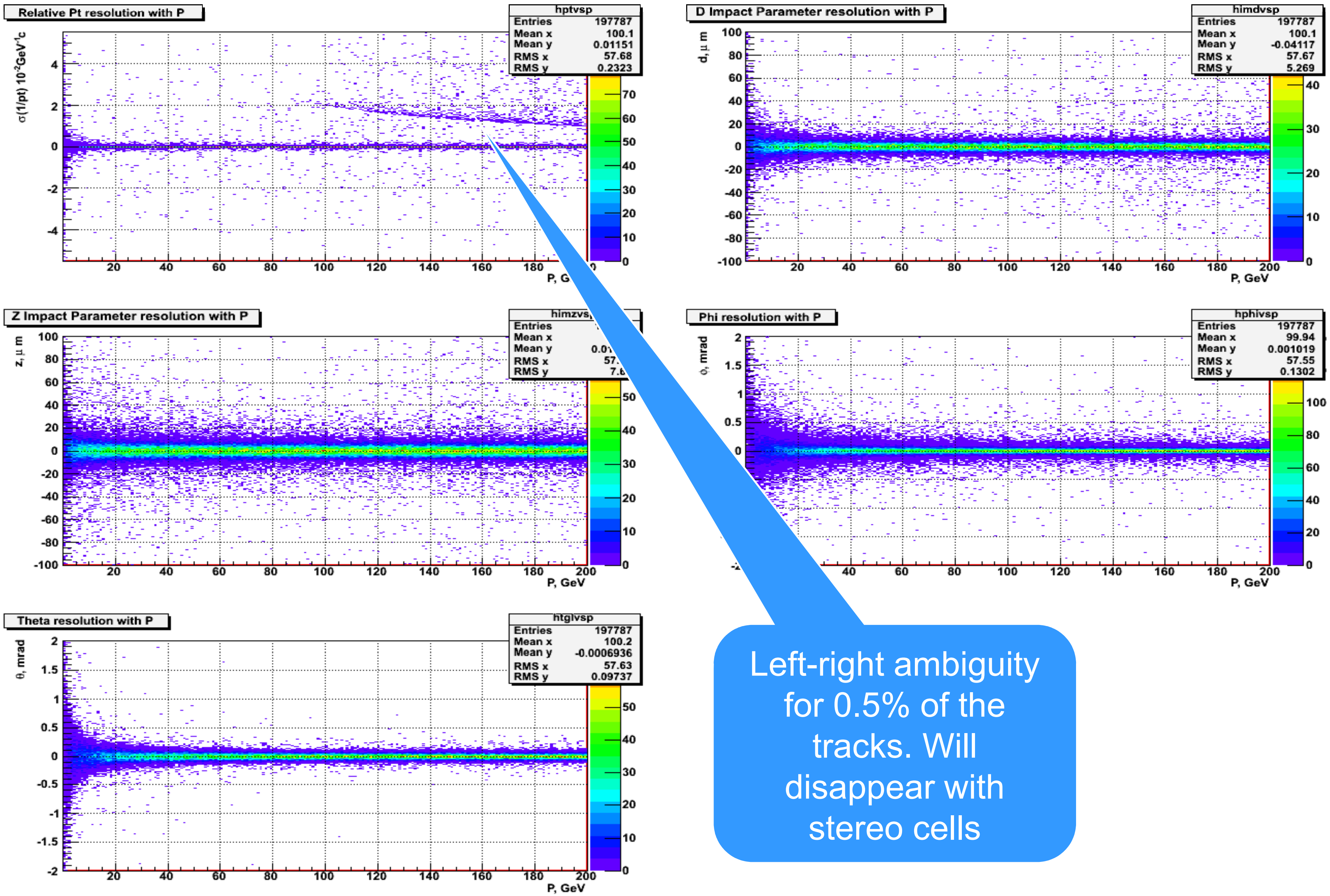


Axial DCH used for reconstructing tracks.

$$\varepsilon = \frac{reconstructed\ tracks}{good\ tracks}$$

DCH Resolution vs P

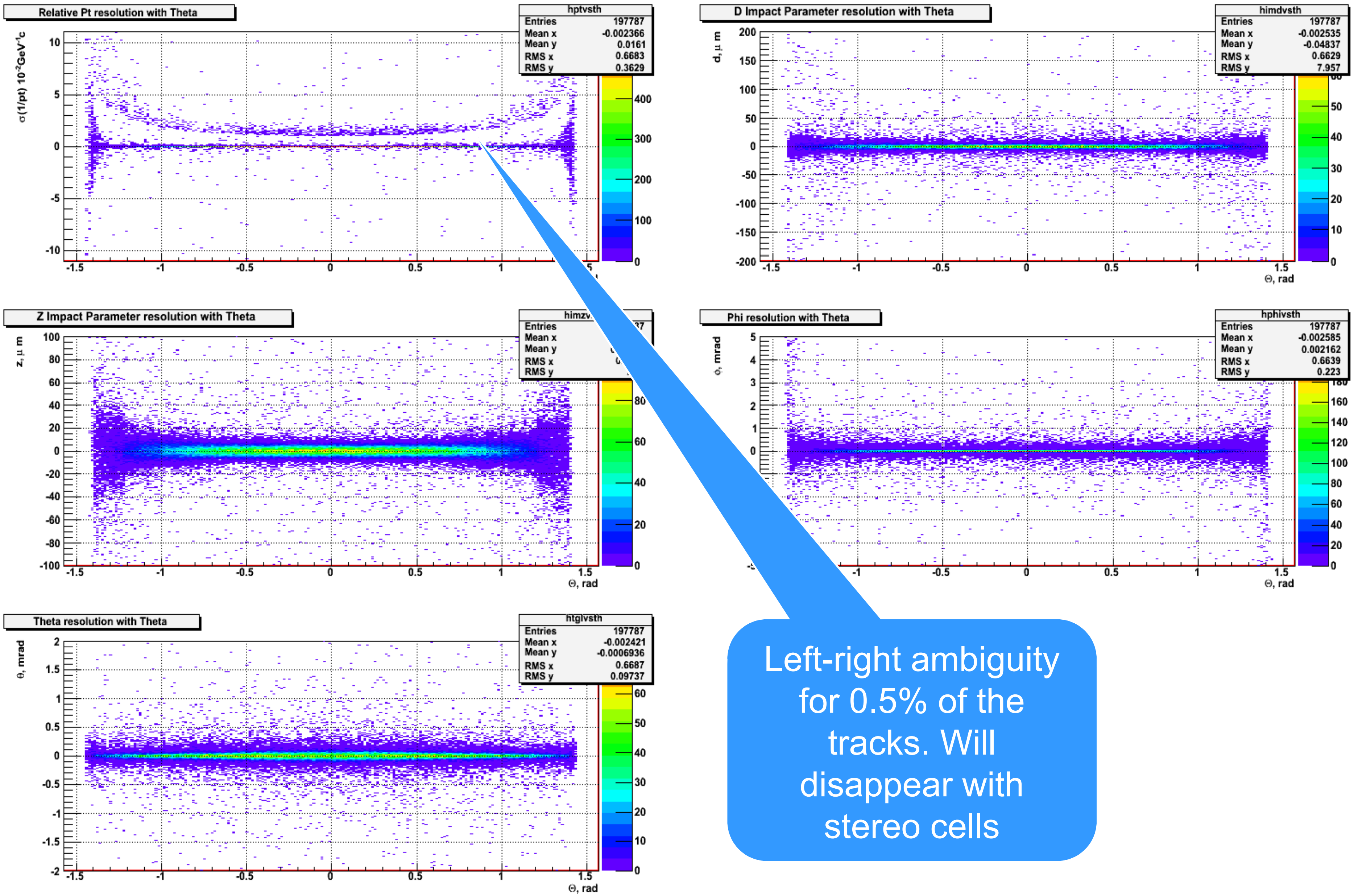
10 muons

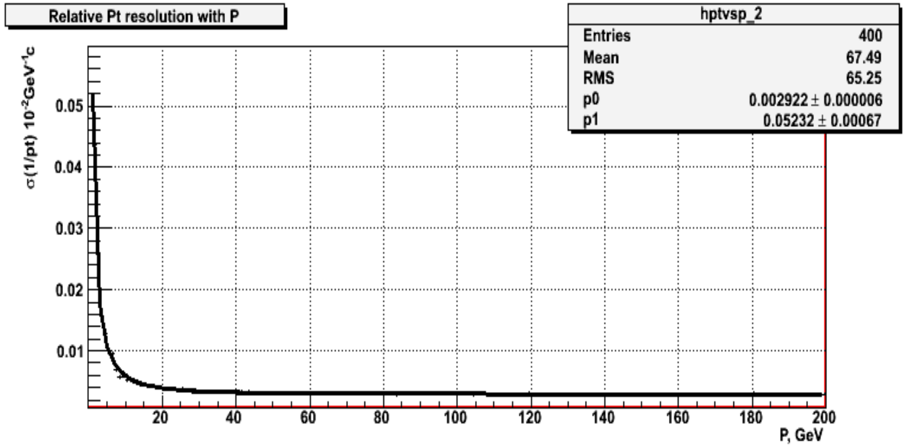


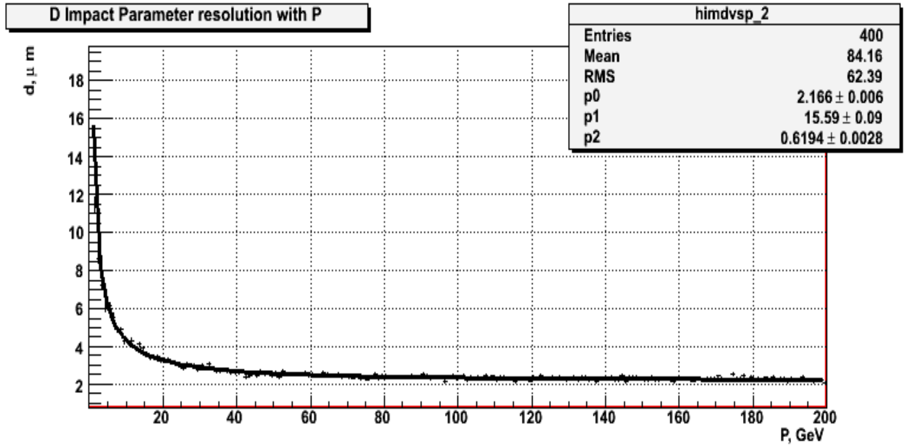
Left-right ambiguity for 0.5% of the tracks. Will disappear with stereo cells

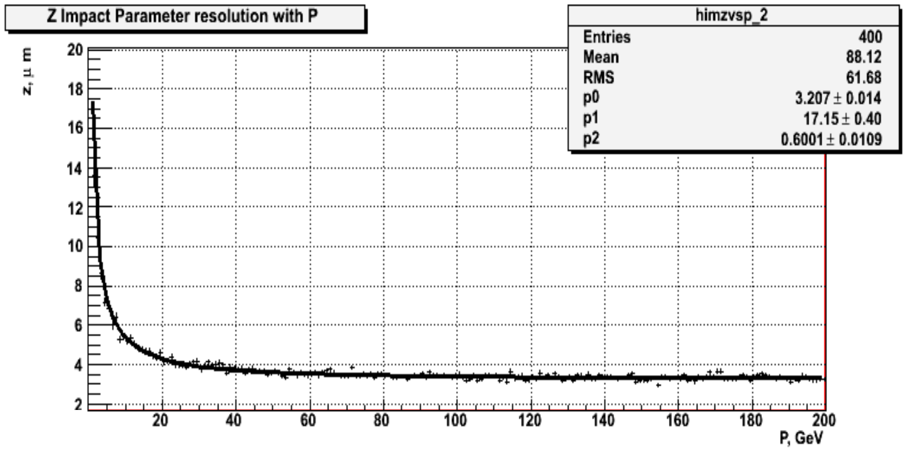
DCH Resolution vs θ

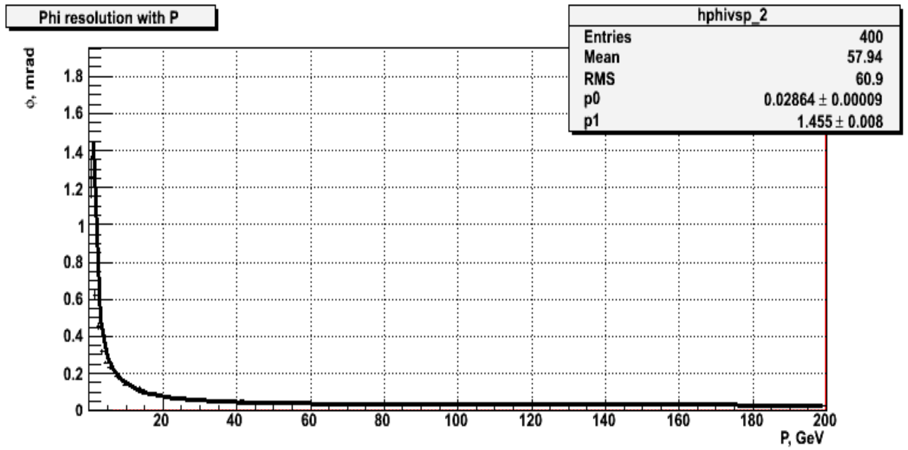
10 muons

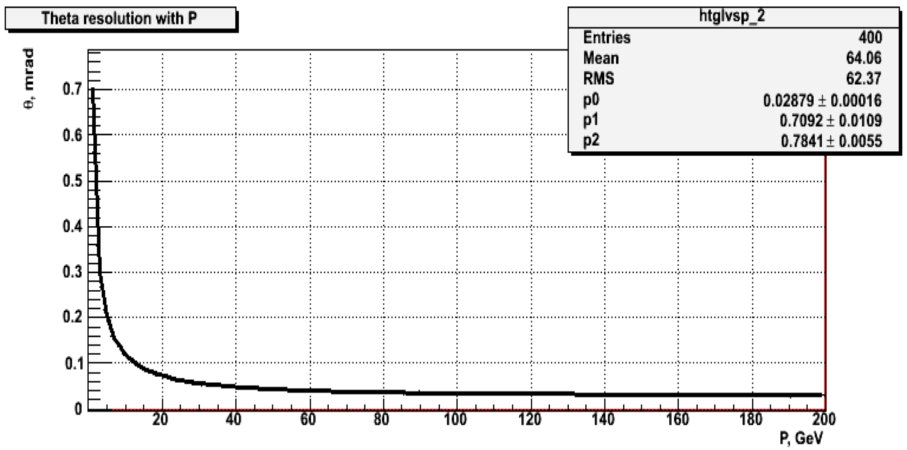












$$\sigma(P_t^{-1}) = 2.9/P \oplus 0.52\times10^{-4}\,GeV^{-1}c$$

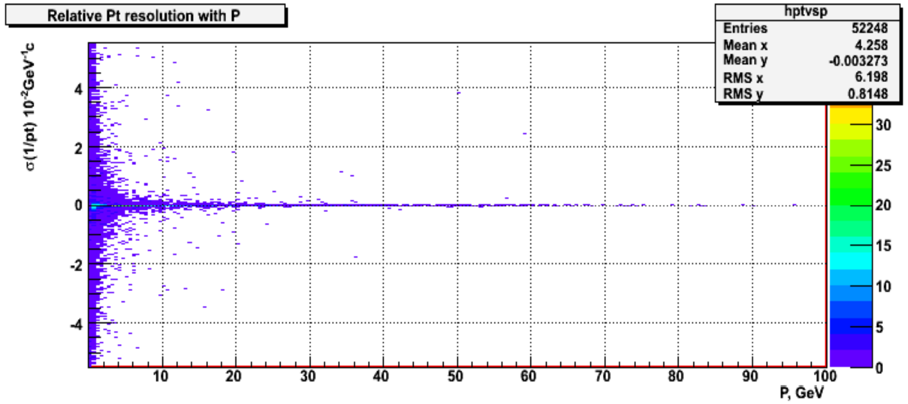
$$\sigma(\vartheta) = 0.71/P^{0.78} \oplus 0.029\ mrad$$

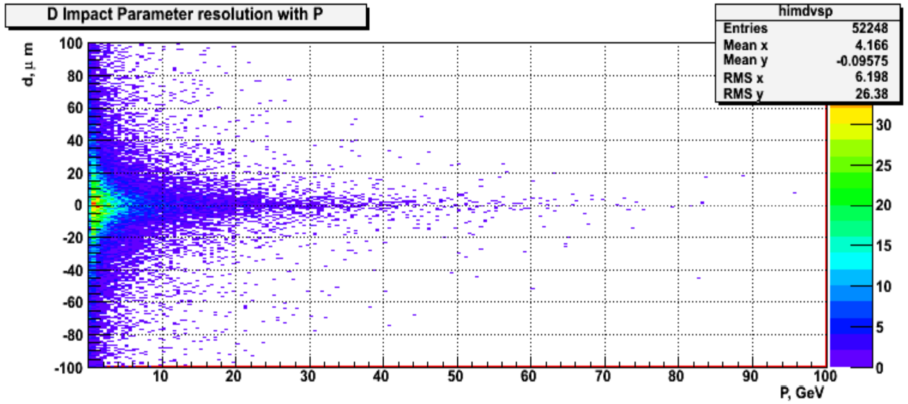
$$\sigma(\varphi) = 1.46/P \oplus 0.029\ mrad$$

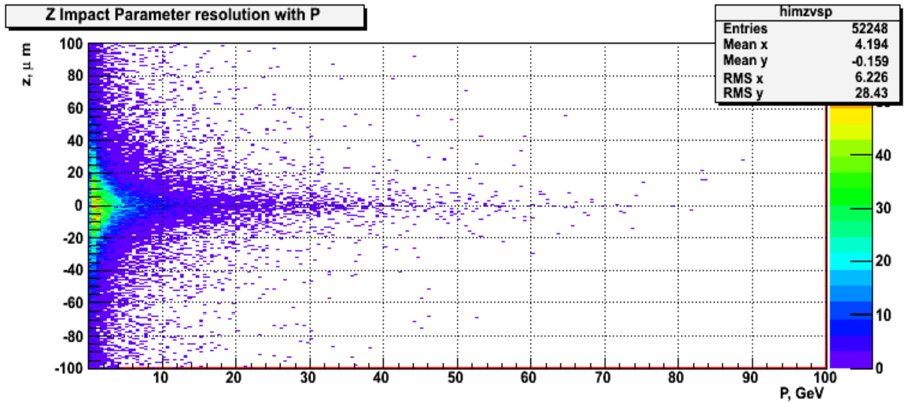
$$\sigma(D_o) = 15.6/P^{0.62} \oplus 2.2\ \mu m$$

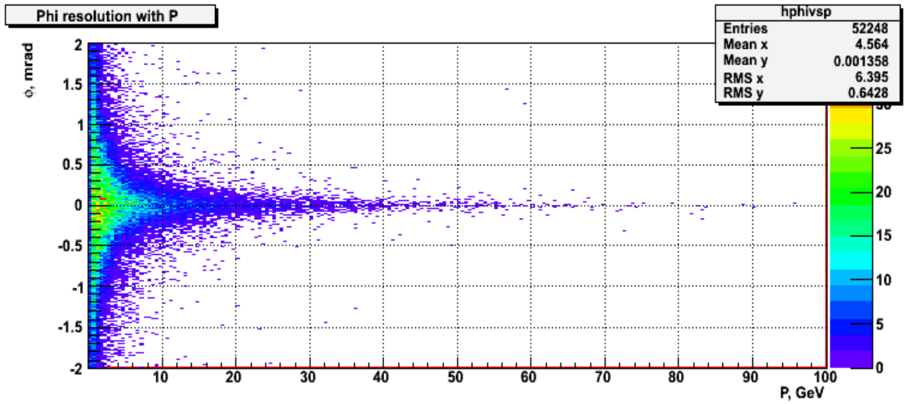
$$\sigma(Z_o) = 17.2/P^{0.60} \oplus 3.2\ \mu m$$

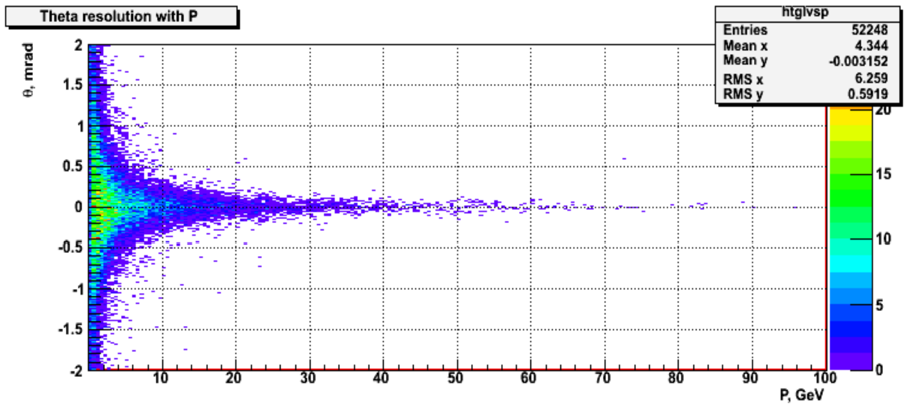
Performance with ttbar->6jets (I)



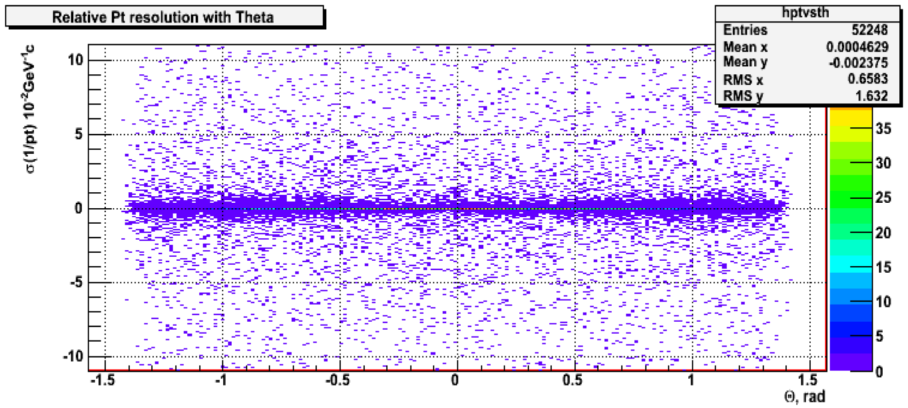


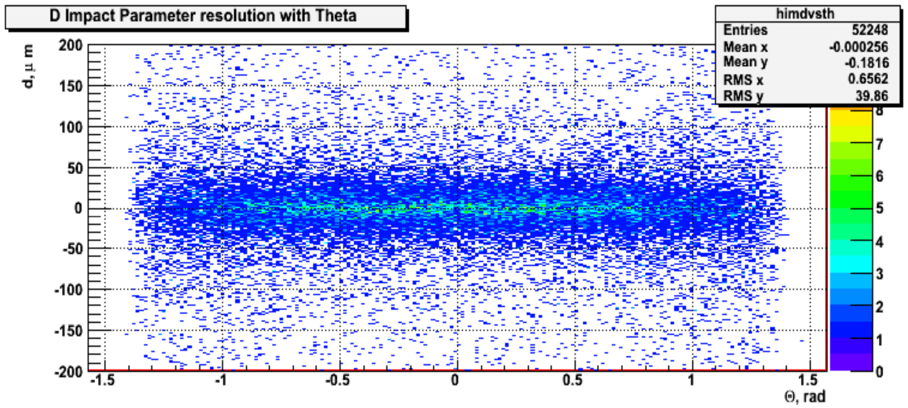


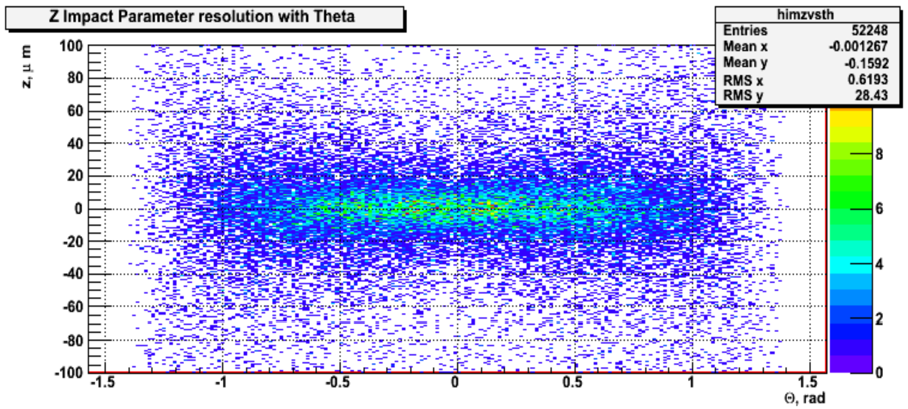


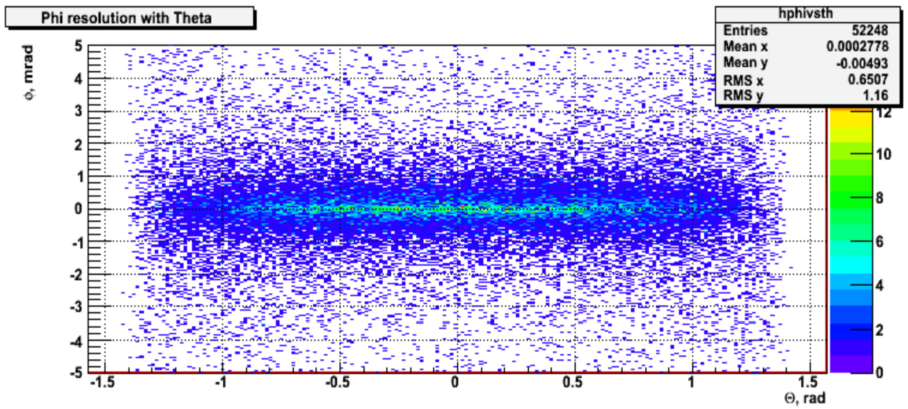


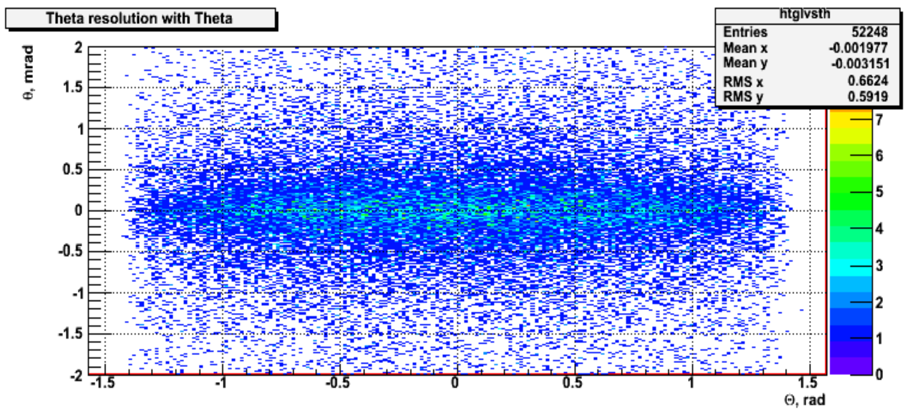
Performance with ttbar->6jets (II)





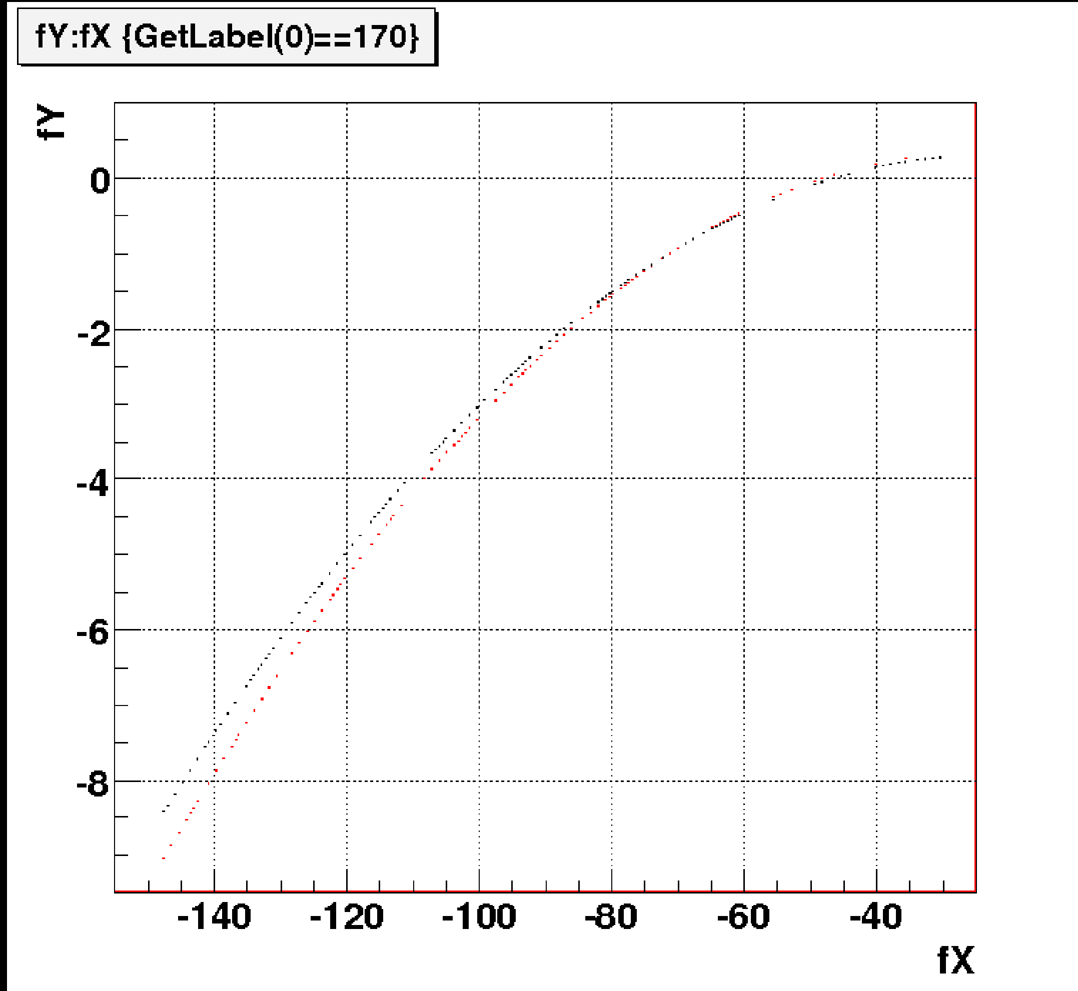




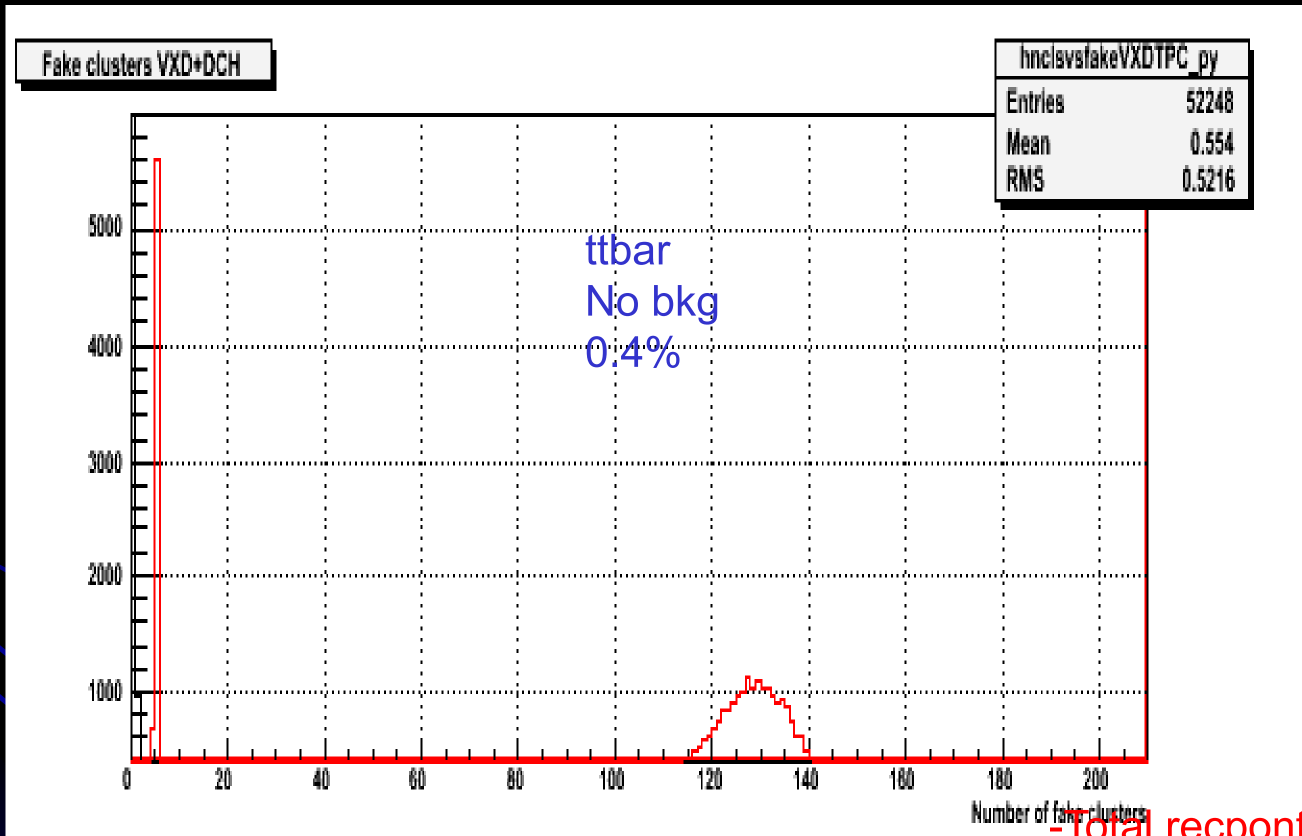


The Fake Clusters Problem

- to accept a new recpoint in Kalman track we require $\chi^2<16$
- for correct assignment this translate into a minimum distance between clusters greater than 4 sigmas of resolution.



Pattern Recognition Performance



-Total recponts

-Misassigned recpoints

Performance Studies for the Hadronic Calorimeter

- New HCAL layout (3rd version)
- Still improving simulation algorithms
- Waveform analysis -> disentangling the neutron component

The 4th Concept Hadronic Calorimeter (third version)

Cu + scintillating fibers + Ĉerenkov fibers

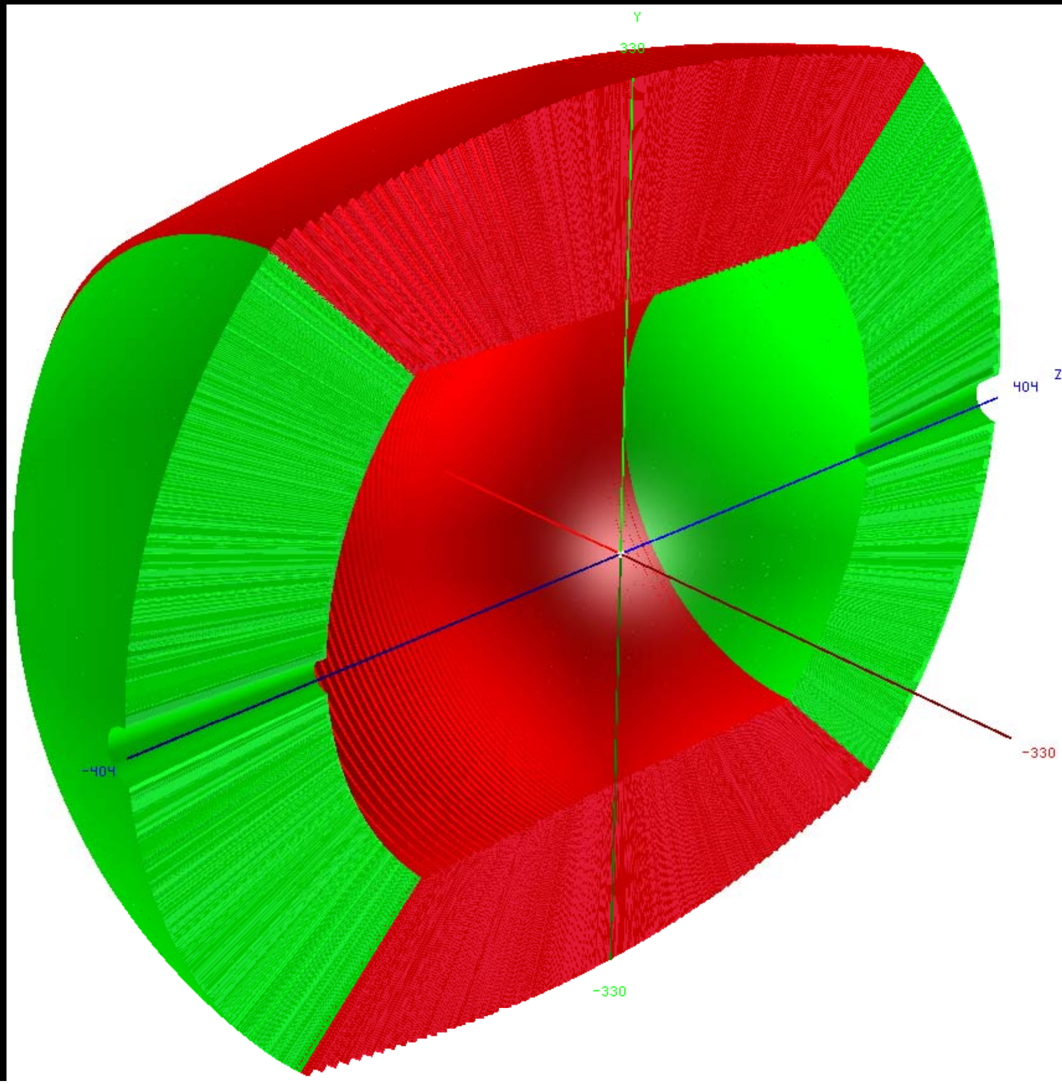
~1.4° aperture angle

~ 10 λ_{int} depth

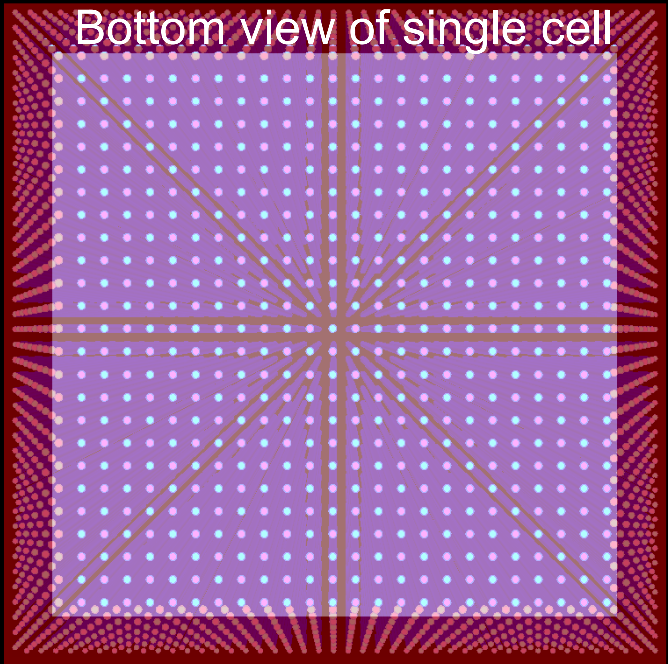
Azimuth coverage

down to 2.8°

- Barrel: 16384 cells
- Endcaps: 7450 cells



Hadronic Calorimeter Cells



Prospective view of clipped cell

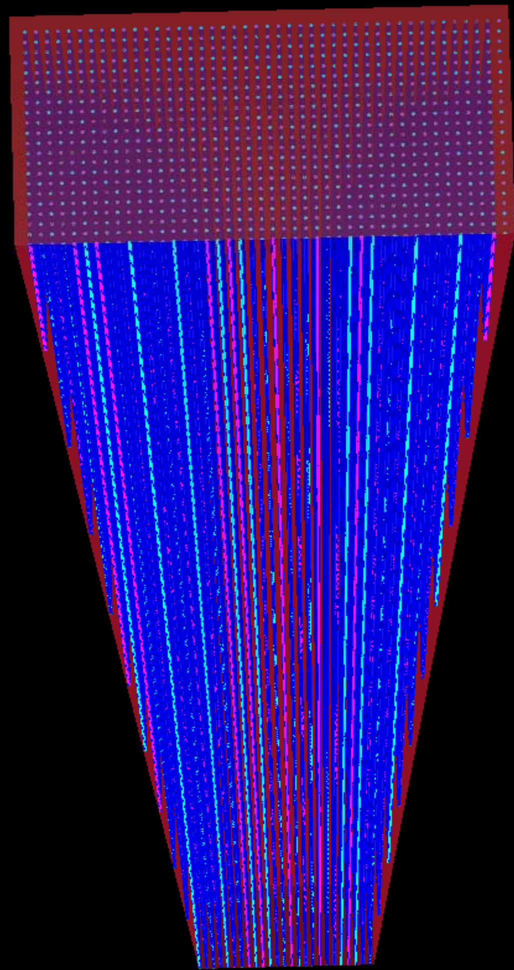
300 μm radius

Plastic/Quartz fibers

Aperture Number=0.50

(C fibers)

Top cell size:~ 8.1 × 8.1 cm^2



Bottom cell size: ~ 4.4 × 4.4 cm^2

Number of fibers inside each cell: ~1600

equally subdivided between Scintillating and Cerenkov

Fiber stepping ~2 mm

Cell length: 150 cm

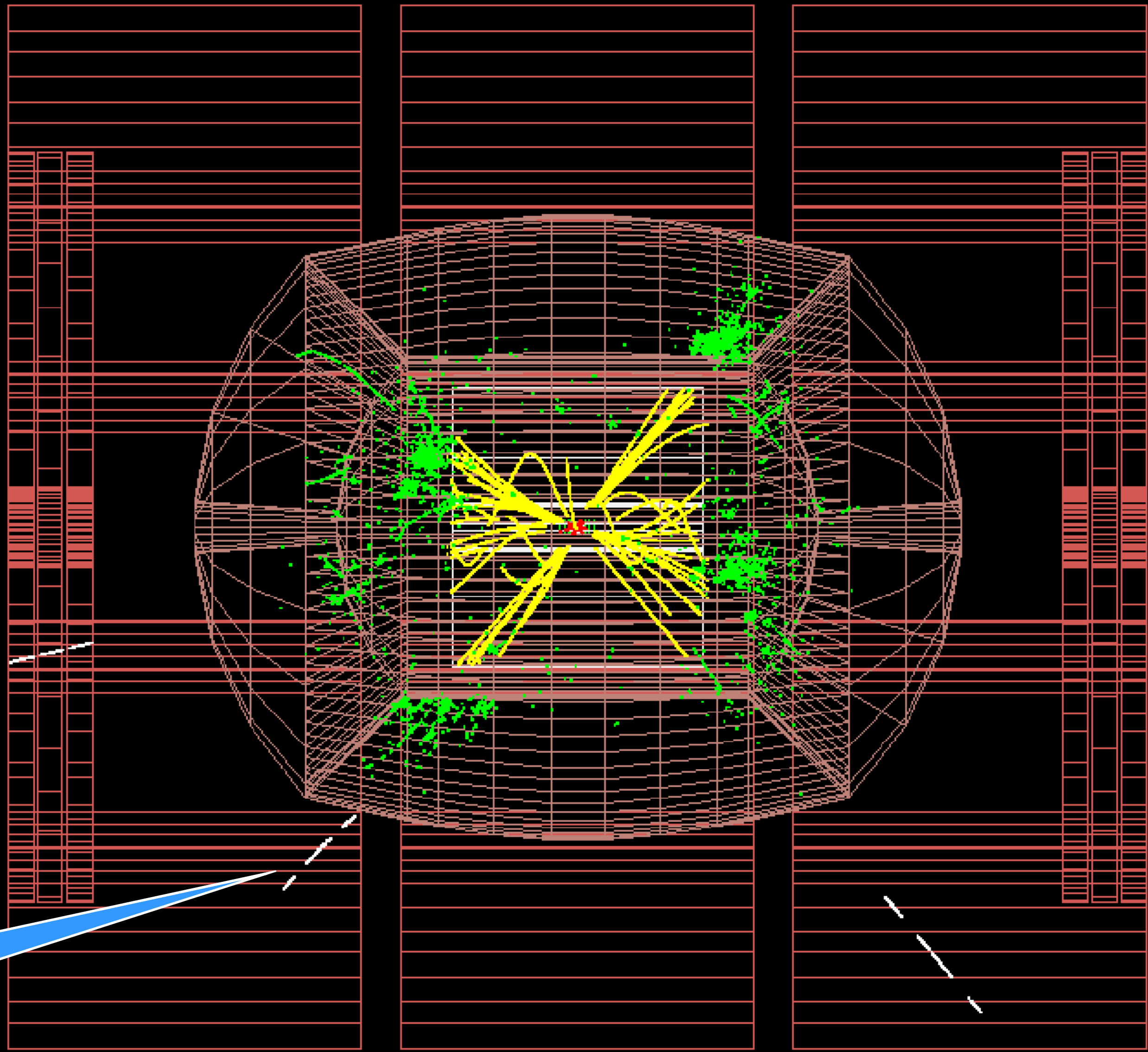
Each tower works as two independent towers in the same volume

Simulation Details

- ILCroot framework
- Pandora-Pythia,Whizard, Sherpa, CompHEP, GuineaPig to generate events
- Fluka to track particles across the detectors
- Scintillation and Cerenkov light handled with appropriate algorithms
- Full digitization/clusterization (noise, thresholds, etc.)
- Full pattern recognition
  - Clusterization = collection of nearby “digits”
  - Unfolding of overlapping showers through Minuit fit to shower shape
  - Durham for jet-finding/reconstruction

Event Display in ILCroot

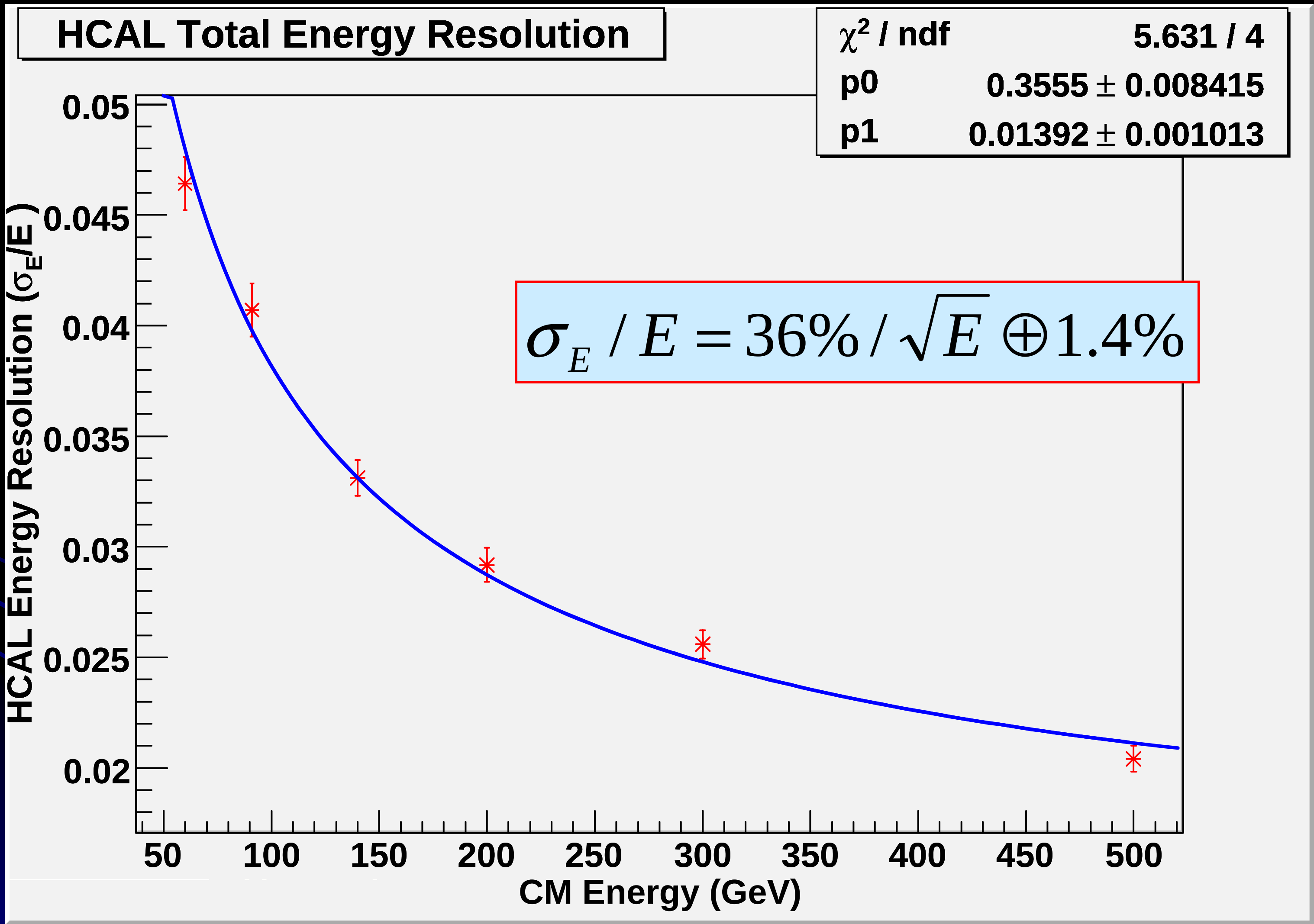
$e^+e^- \rightarrow H^oH^oZ^o$
$\rightarrow$ 4 jets 2 muons
ECM = 500 GeV



Low pt secondary muon

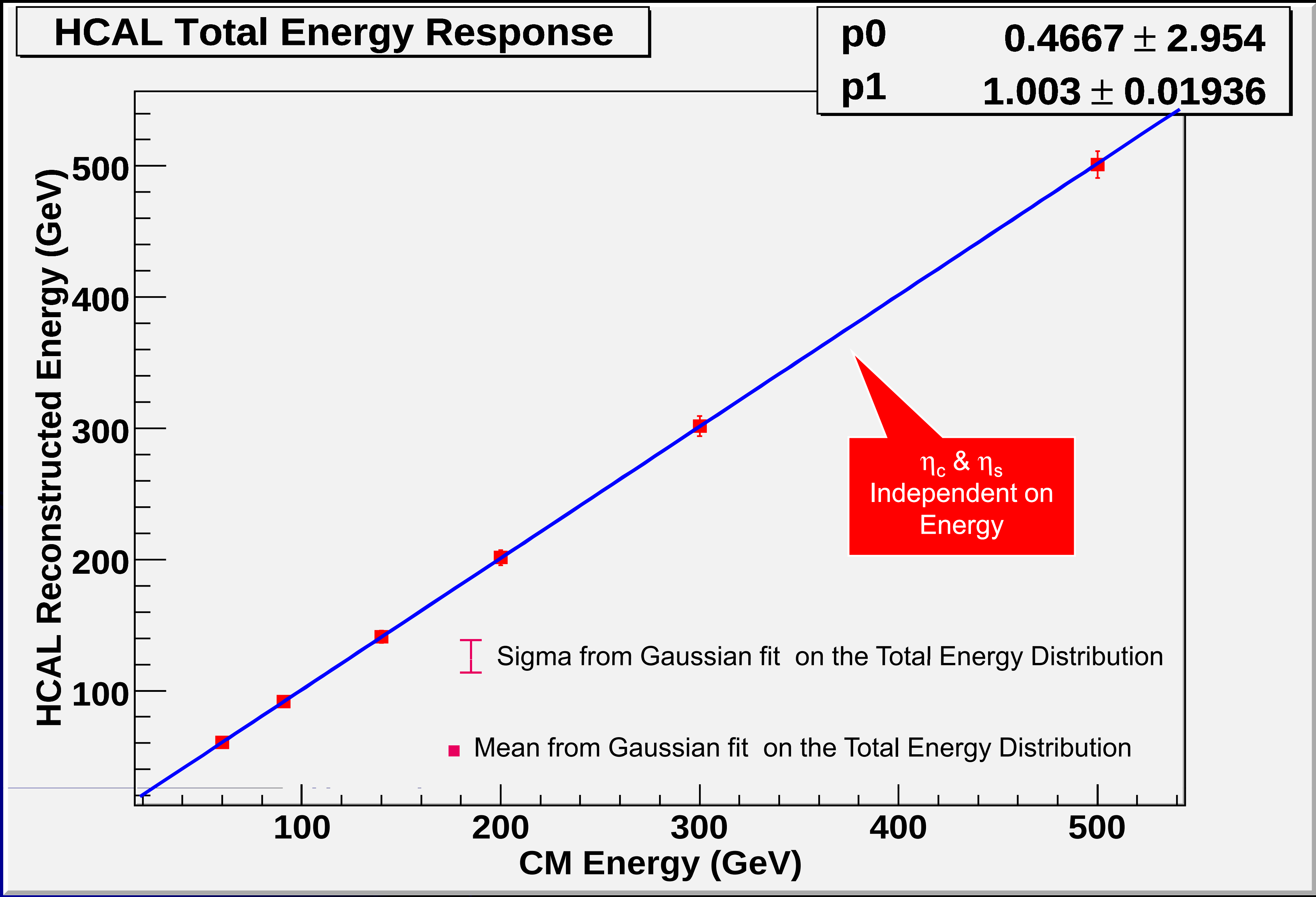
Total Energy Resolution for di-jets (gaussian fit)

Di-jets events

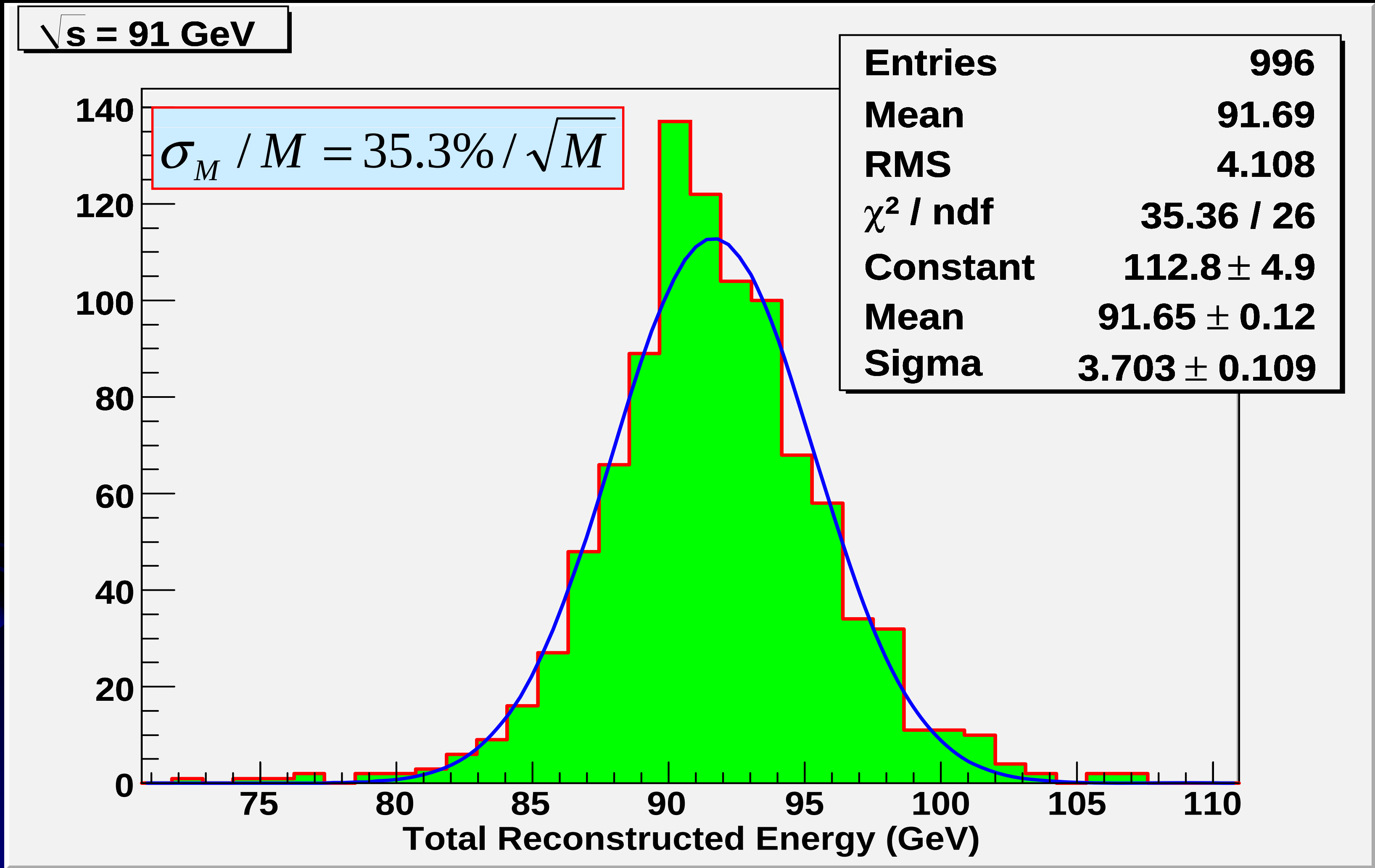


Energy Response

Di-jets events



Z_o Mass (with Gaussian fit)



All events, no cuts

Summary of Performace Studies

- Resolutions with multi-jets are dominated by multiple scattering
- Redundancy of measurements and seeding in central tracker is fundamental for good performance
- Small drift cell (drift time <= time between BXs) relax the requirements on the VTX
- Energy resolution in Dual Readout calorimeter is unaffected by smaller tower

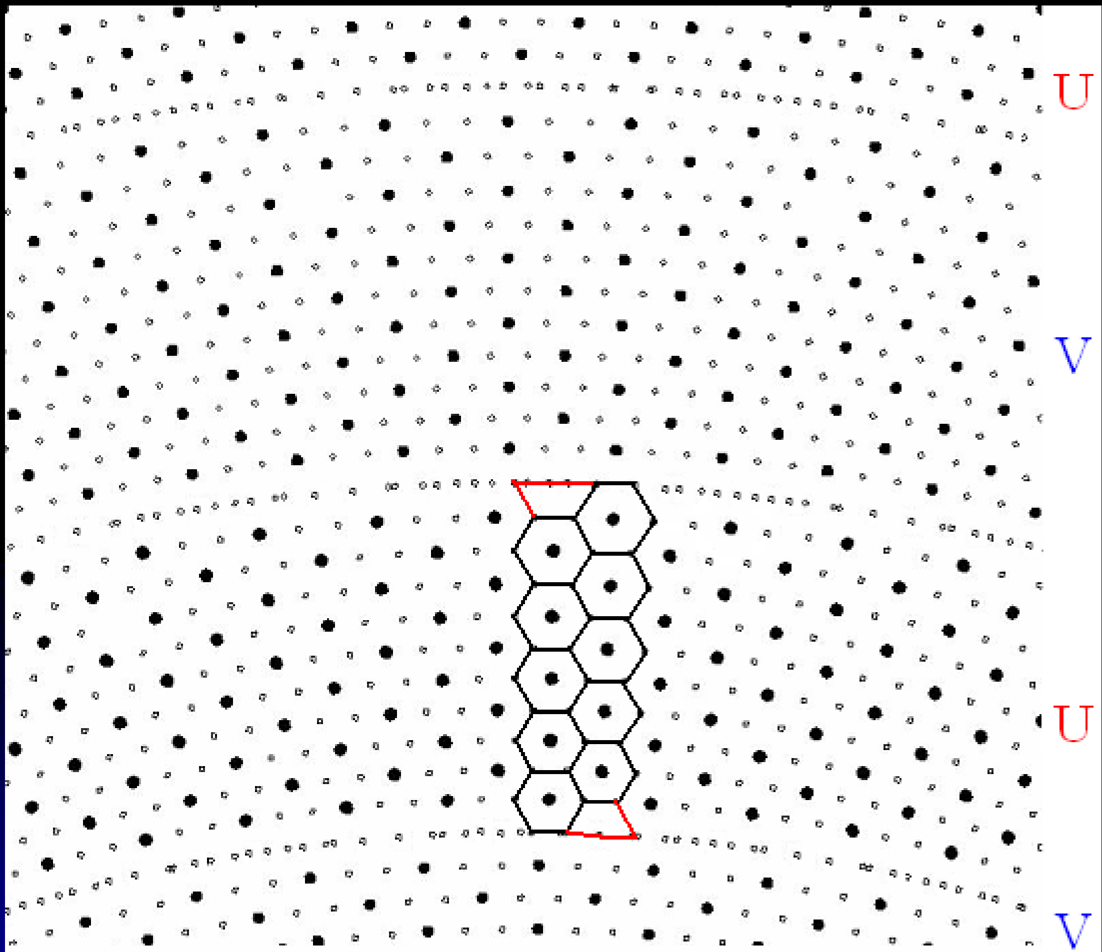
Conclusions

- Performance studies are well under way
- Critical issues have been pinpointed
- ILCroot is being continuously upgraded, with newer versions of the subdetectors
- Simulation consolidation phase is mostly concluded
- Physics benchmark studies will start shortly
- We just learnt that Fluka must be used for shower simulation and G4 for tracking (not a problem in ILCroot)
- Muon detector studies have been deferred

Backup slides

4thConcept ILC Drift Chamber

Layout



Hexagonal cells f.w./s.w.=2:1

cell height: 1.00 ÷ 1.20 cm
cell radius: 6.00 ÷ 7.00 mm

(max. drift time < 300 ns !)

20 superlayers, in 200 rings
10 cells each (7.5 in average)
at alternating stereo angles
±72 ÷ ±180 mrad
(constant stereo drop = 2 cm)

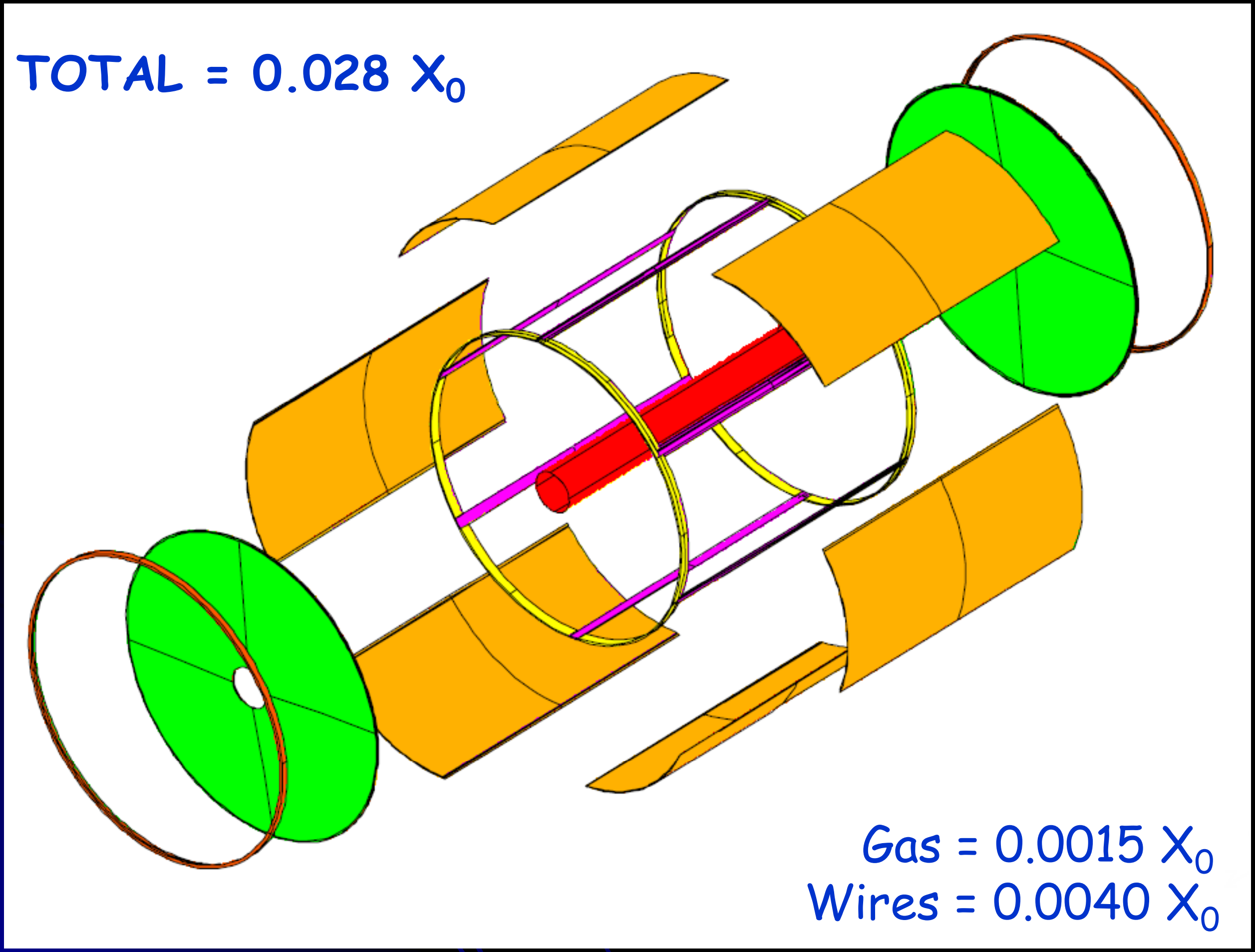
60000 sense w. 20 μm W
120000 field w. 80 μm Al

"easy" t-to-d r(t) (few param.)

>90% sampled volume

4thConcept ILC Drift Chamber

Layout and assembly technique



Length:
3.4 m at r = 22.5 cm
3.0 m at r = 147.0 cm

Spherical end plates:
C-f. 12 mm + 30 μm Cu
(0.047 X_0)

Inner cylindrical wall:
C-f. 0.2 mm + 30 μm Al
(0.001 X_0)

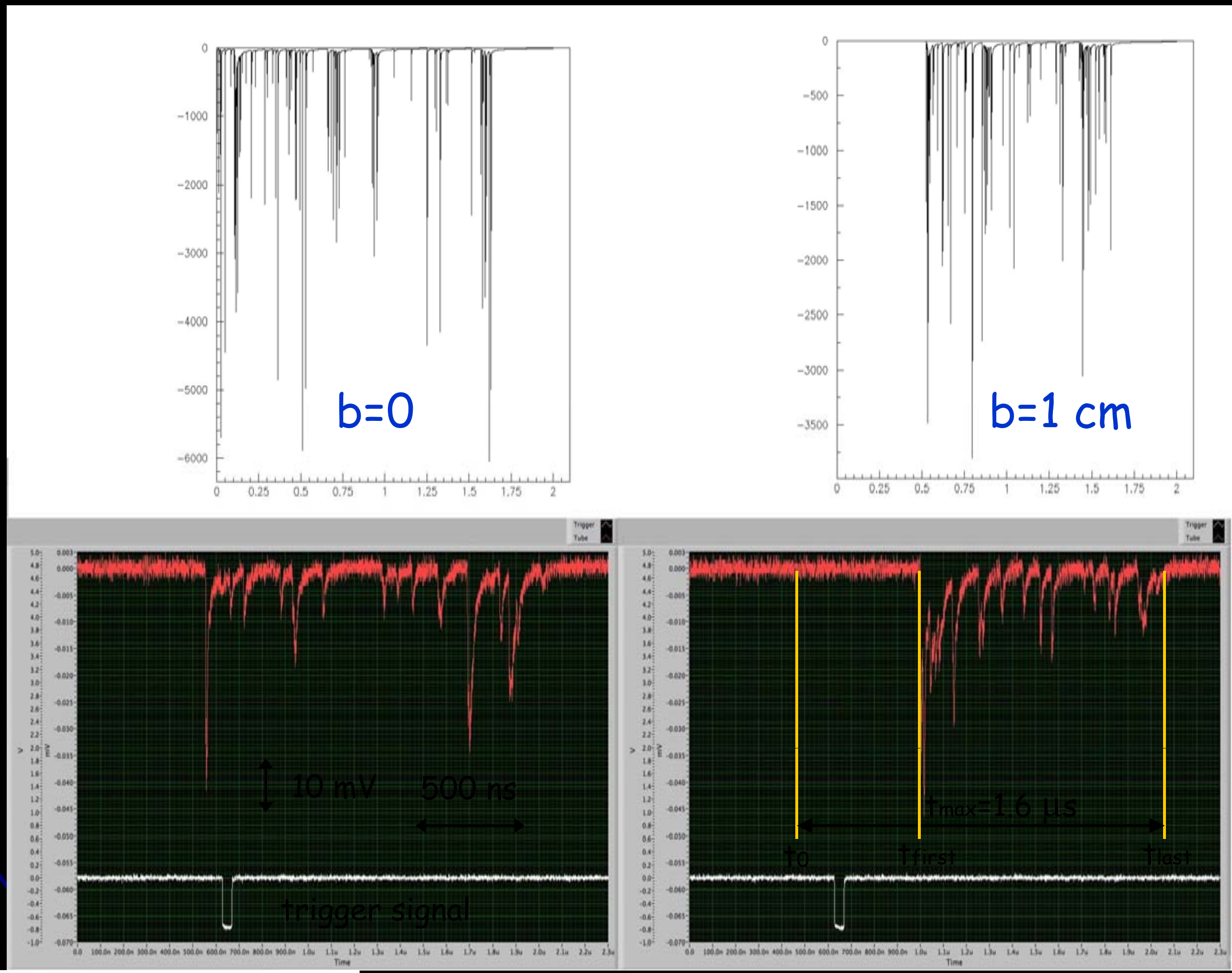
Outer cylindrical wall:
C-f./hex.cell. sandwich
held by 6 unidir. struts
0.020 X_0)

Retaining ring

Stiffening ring

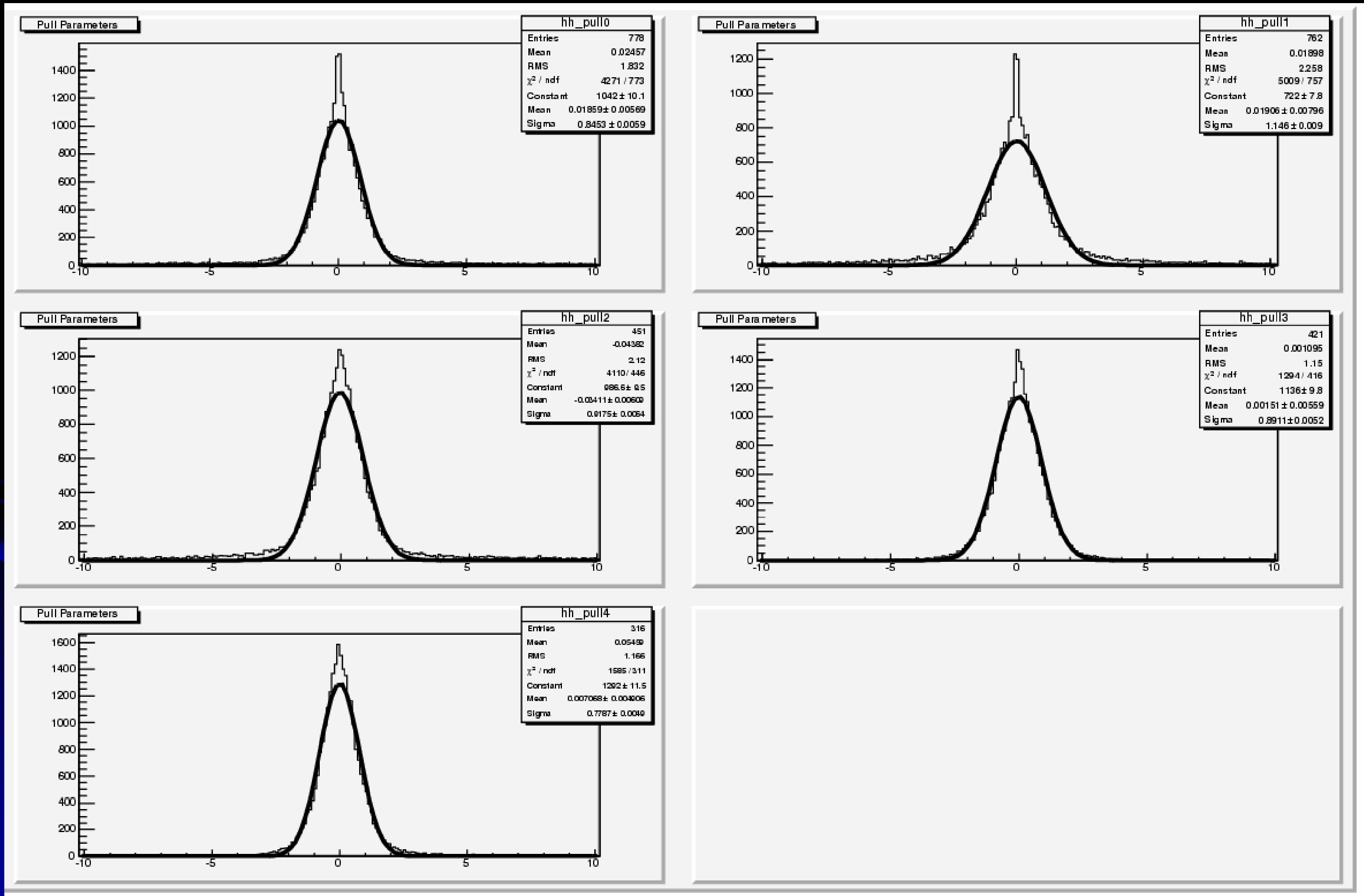
CLUster COUnting

MC generated events:
2cm diam. drift tube
gain = few x 10
gas: 90%He-10%iC_4H_{10}
no electronics simulated
vertical arbitrary units

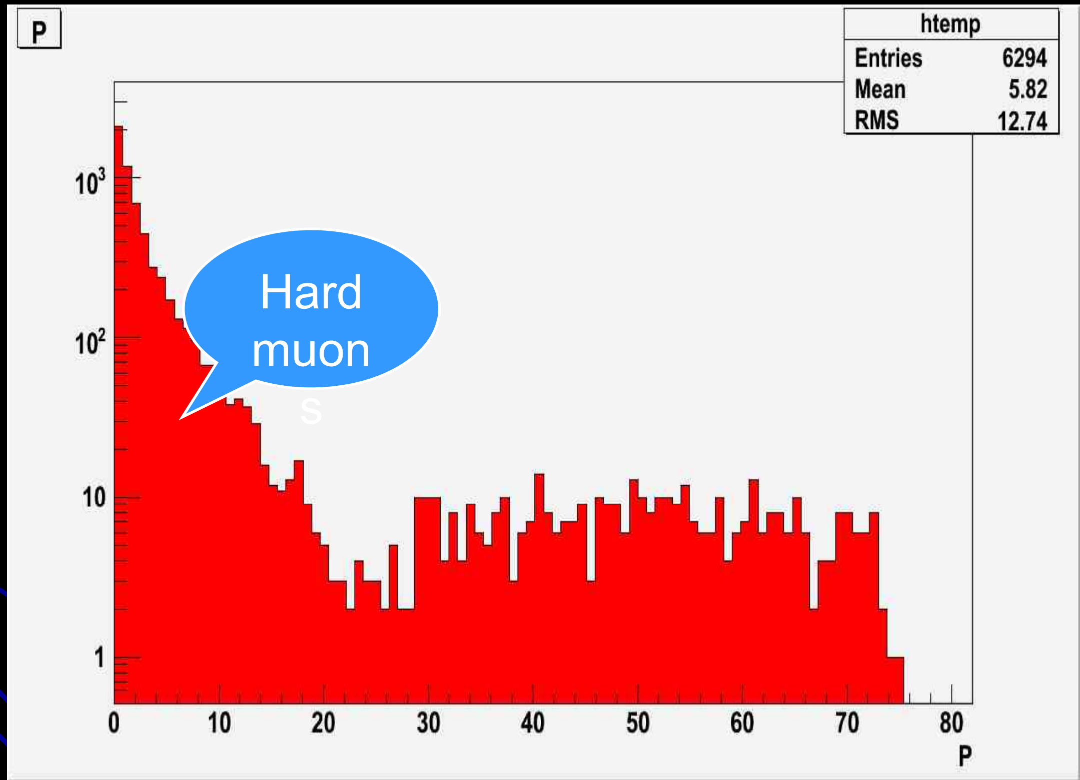


cosmic rays triggered
by scintillator telescope
and readout by:
8 bit, 4 GHz, 2.5 Gsa/s
digital sampling scope
through a 1.8 GHz, x10
preamplifier

Pulls (full digitization)

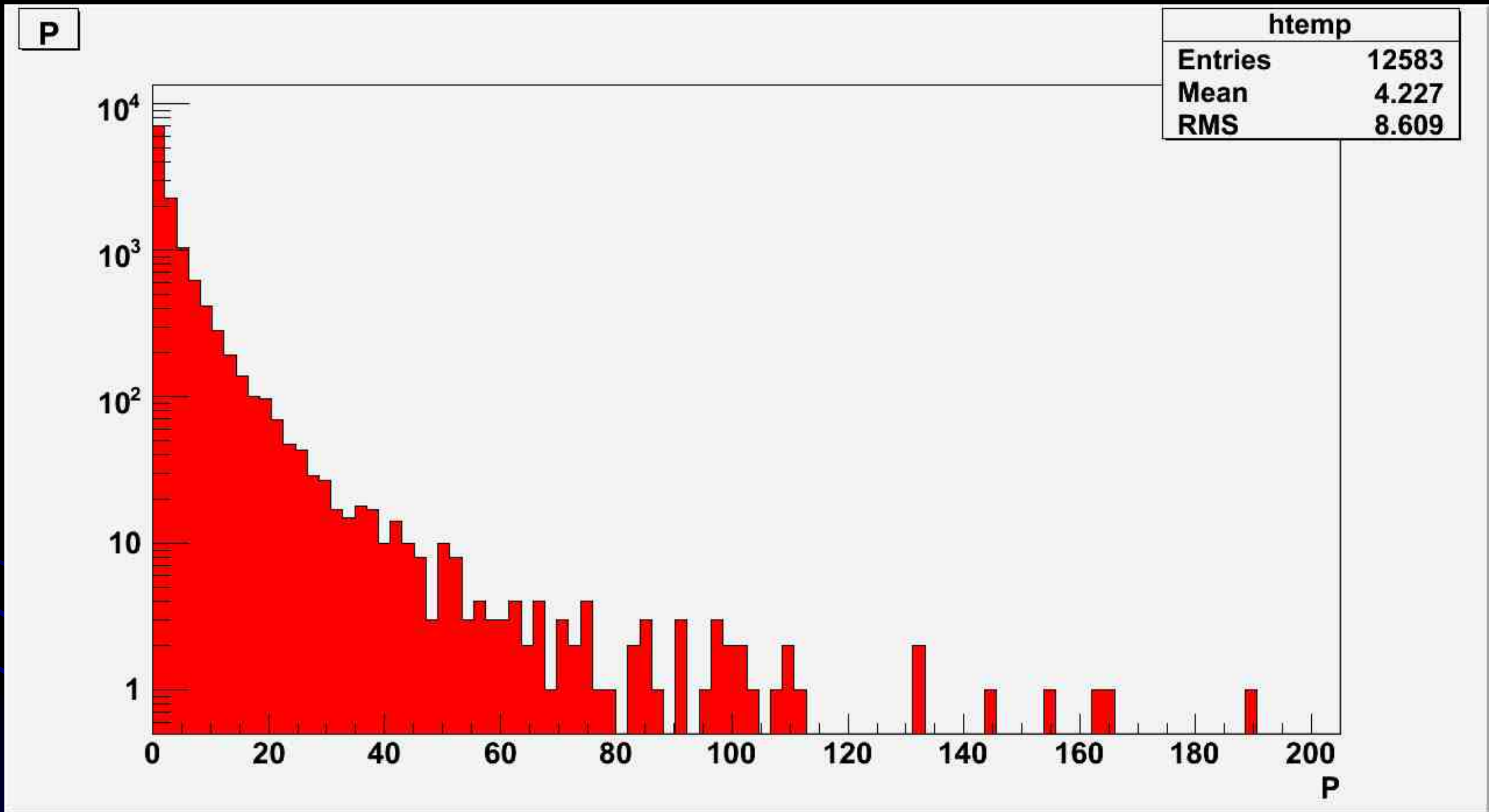


$e^+e^- \to Z_oH_o \to \mu^+\mu^- X$ + $e^+e^- \to Z_oZ_o \to \mu^+\mu^- X$ background [E_{cm}=230]



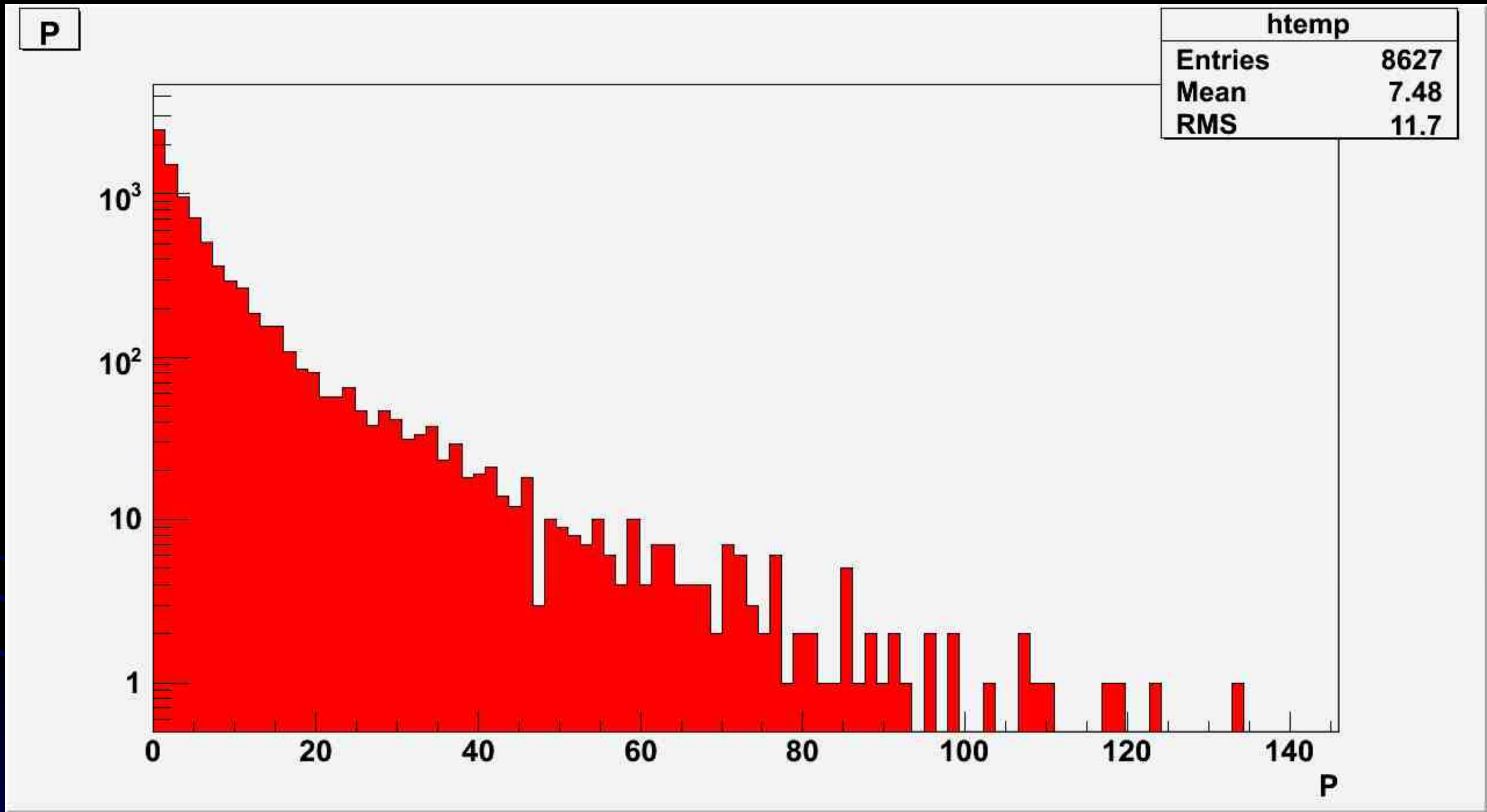
- Momentum spectrum for generated tracks entering the central tracker region
- Standard benchmarck channel
- Used as reference with existing analyses

e^+e^- -> ttbar->6jets E_{cm}=350



- Momentum spectrum for generated tracks entering the central tracker region
- One of channels with softest charged tracks

e^+e^- -> W^+W^- ->4jets Ecm=350



- W^+ and W^- generated mostly in the forwar/backward direction
- Channels with soft charged tracks emitted in the forward direction

The Framework: ILCroot

- Integrated framework for generation, simulation, reconstruction and analysis
- CERN architecture (Aliroot)
- Uses ROOT as infrastructure
  - All ROOT tools are available (I/O, graphics, PROOF, data structure, etc)
  - Extremely large community of users/developers
- TGenerator for events generation
- Virtual Geometry Modeler (VGM) for geometry
- Virtual Montecarlo (VMC) for simulation
- Six MDC have proven robustness, reliability and portability
- Available via cvs repository at Fermilab:
  cvs -d :pserver:anonymous@cdcvs.fnal.gov:/cvs/ilcroot co
- For the installation, see:
  http://www.fisica.unile.it/~danieleb/IlcRoot

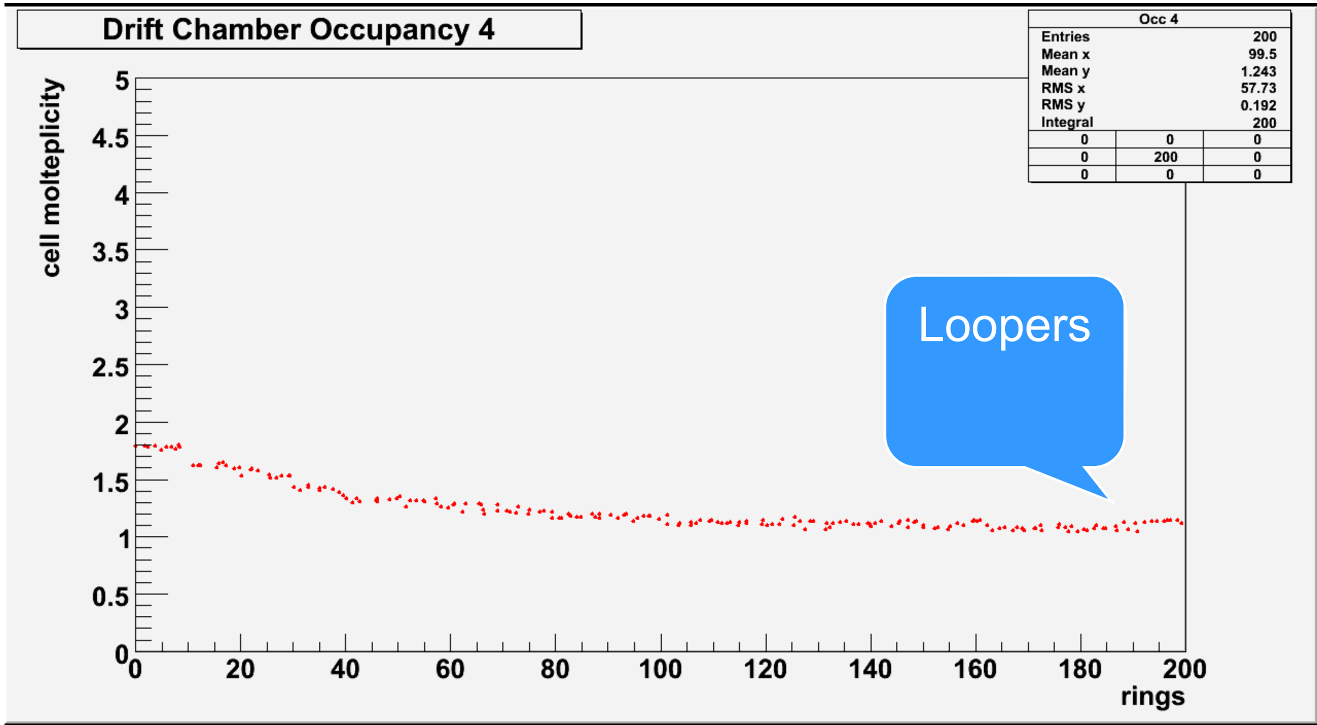
The Virtual Montecarlo Concept

- Virtual MC provides a virtual interface to Monte Carlo
- It decouples the dependence of a user code on a concrete MC
- It allows to run the same user application with all supported Monte Carlo programs
- The concrete Monte Carlo (Geant3, Geant4, Fluka) is selected and loaded at run time
- Choose the optimal Montecarlo for the study

A Modular Approach: The Detector Class

- **Both sensitive modules (detectors) and non-sensitive ones are described by this base class.**
- **This class must support:**
  - **Geometry description**
  - **Event display**
  - **Simulation by the MC**
  - **Digitization**
  - **Pattern recognition**
  - **Local reconstruction**
  - **Local PiD**
  - **Calibration**
  - **QA**
  - **Data from the above tasks**
- **Several versions of the same detector are possible (choose at run time)**

- The geometry can be specified using:
  - ***Root (TGeo)***
  - Geant3
  - Geant4
  - Fluka
  - GDML
  - XML
  - Oracle
  - CAD (semi-automatic)

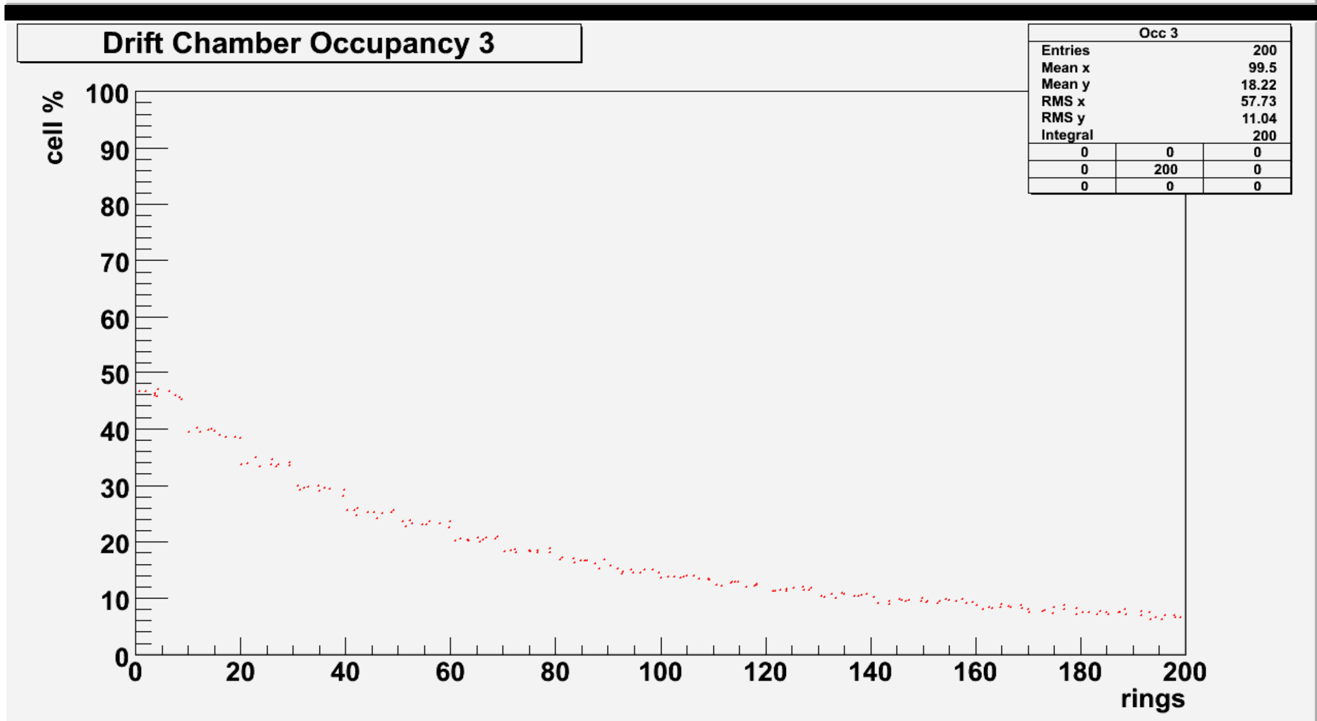


DCH

e^+e^- -> HHZ -> 4 jets+2muons with DCH

E_{CM}=500 GeV

- Hits per cell vs layer



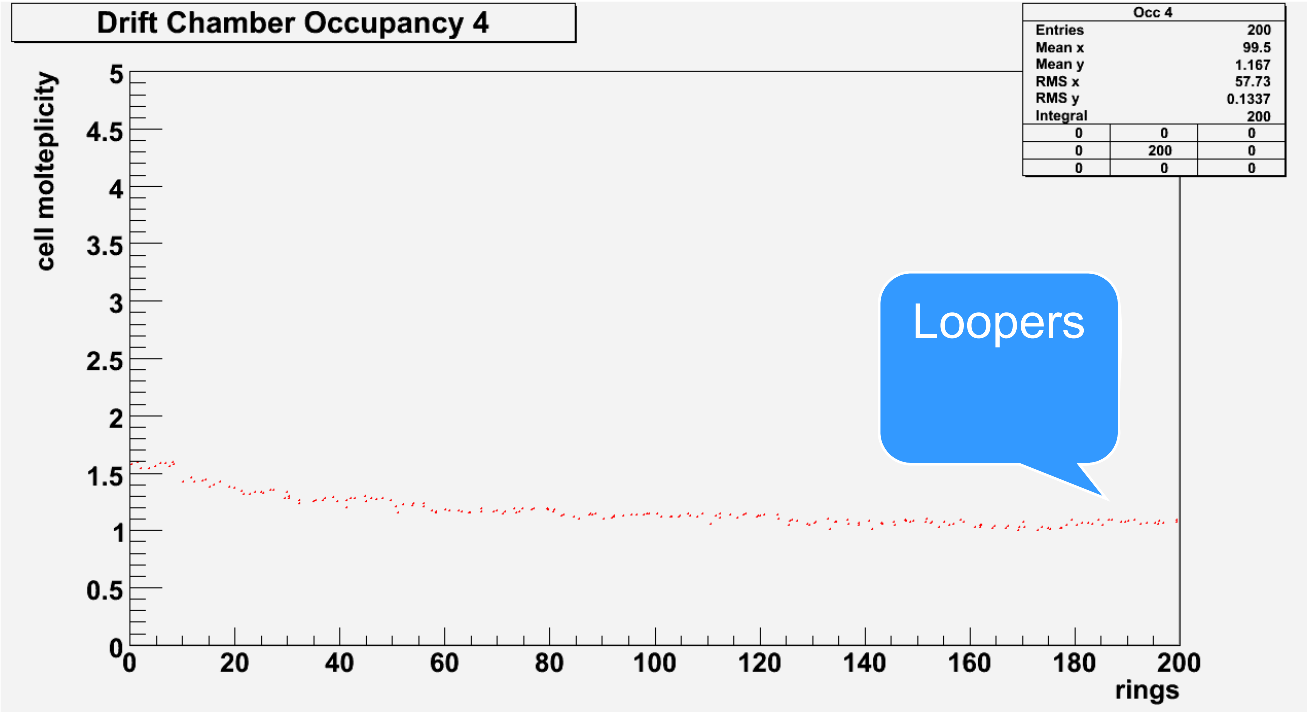
- Occupancy vs layer

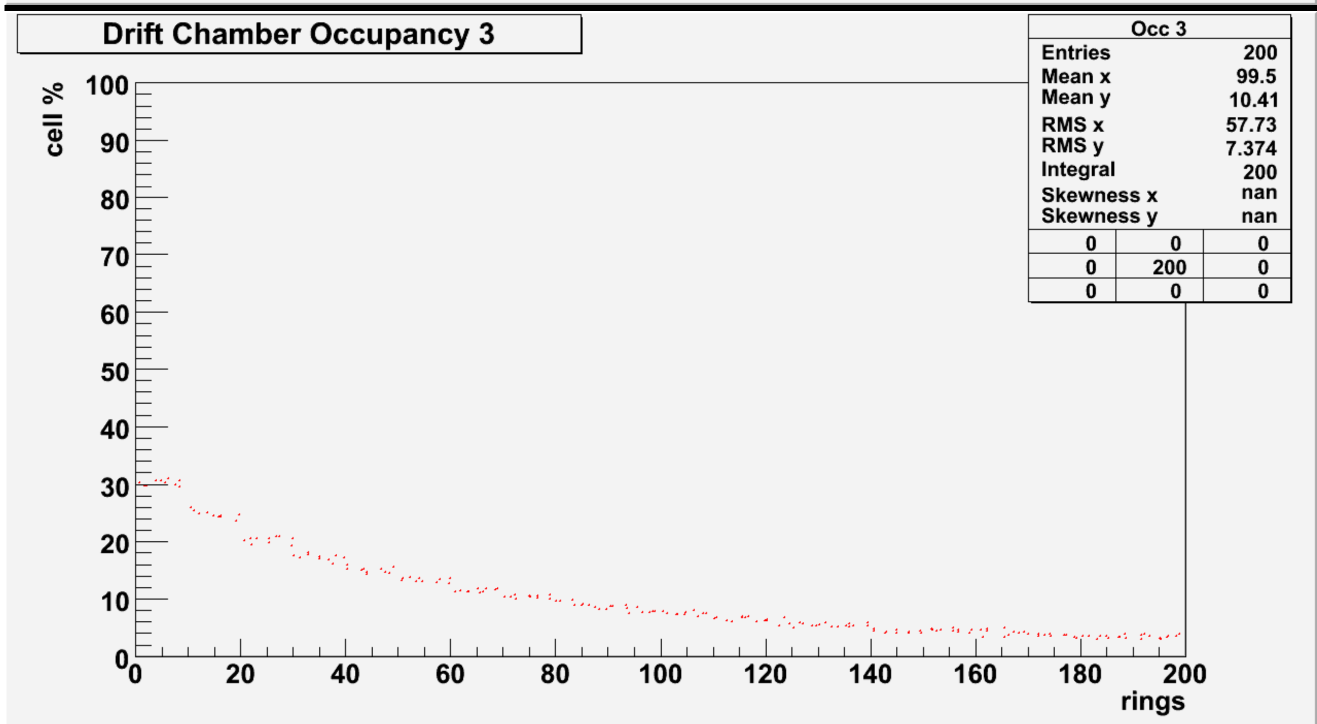
DCH

$e^+e^- \to H^oZ^o \to$ 2 jets+2muons with DCH

E_{CM}=230 GeV

- Hits per cell vs layer





- Occupancy vs layer

VXD SDigitization

- Follow the path of the track inside the silicon in steps of 1 μm
- Per each step:
  - convert the energy deposited into charge
  - spreads the charge asymmetrically across several pixels:

$$f(x,z) = Errf(x_{step}, z_{step}, \sigma_x, \sigma_z)$$

$$\sigma_x = \sqrt{T \cdot k / e \cdot \Delta l / \Delta V \cdot step}$$

$$\Delta l = Si\, tickness, \quad \Delta V = bias\, voltage, \quad \sigma_x = \sigma_x \cdot fda$$

- Simulate capacitive pixel coupling by switching on nearby pixels
- Add random noise
- Simulate electronic threshold

Clusterization For VXD

- Create a initial cluster from adjacent pixels (sidewise only)
- subdivide the initial cluster in smaller NxN clusters (to be optimized)
- Kalman filter picks up the best clusters

SDigitization Parameters

- Size Pixel X = 20 μm
- Size Pixel Z = 20 μm
- Eccentricity = 0.85 (fda)
- Bias voltage = 18 V volts
- cr = 0% (coupling probability for row)
- cc = 4.7% (coupling probability for column)
- threshold = 3000 Electrons
- electronics = 0 (elettronic noise)

SDigitization in Strips Detector

- Get the Segmentation Model for each detector module (allows for different segmentations)
- Load background hits from file (if any)
- Loop on the hits and create a segment in Si in 3D
  - Step inside the Si in equal size increments
    - Compute Drift time to p-side and n-side:

```
tdrift[0] = (y+(seg->Dy()*1.0E-4)/2)/GetDriftVelocity(0);
tdrift[1] = ((seg->Dy()*1.0E-4)/2-y)/GetDriftVelocity(1);
```

    - Compute diffusion constant:

```
sigma[k] = TMath::Sqrt(2*GetDiffConst(k)*tdrift[k]);
```

    - integrate the diffusion gaussian from -3σ to 3σ
  - Charge pile-up is automatically taken into account

SDigitization in Strips (cont'd)

- Add gaussian electronic noise per each side separately: s/n = 20

- Add coupling effect between nearby strips
  - different contribution from left and right neighbours
  - Proportional to nearby signals (B-field effect)

- Threshold = 3 x noise

Clusterization in Strip Detector

- Create an initial cluster from adjacent strips
- Separate into Overlapped Clusters
  - Look for through in the analog signal shape
  - Split signal of parent clusters among daugheter clusters
- Intersect stereo strips to get Recpoints from CoG of signals (and error matrix)
- Kalman filter picks up the best Recpoints

The Parameters fot the Strips

- Strip size (p, n): 50 mm
- Stereo angle (p-> 17.5 mrad, n->17.5 mrad)
- Ionization Energy in Si = 3.62E-09
- Hole diffusion constant (= 11 cm^2/sec)
- Electron diffusion constant (= 30 cm^2/sec)
- v^P_{drift}(=0.86E+06 cm/sec) , v^N_{drift}(=2.28E+06 cm/sec)
- Calibration constants
  - Gain
  - ADC conversion (1 ADC unit = 2.16 KeV)
- Coupling probabilities between strips (p and n)
- σ of gaussian noise (p AND n)
- threshold

DCH SDigitization (in progress)

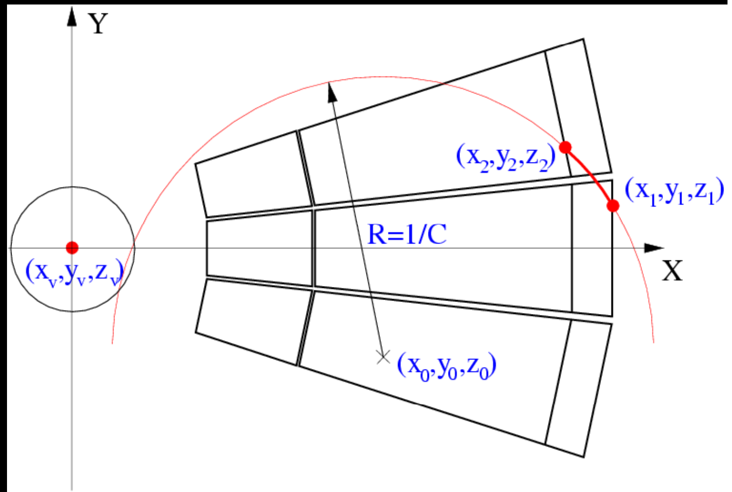
- Follow the path of the tracks inside the cell
- Per each deposited energy step:
  - convert the energy deposited into charge
  - Drift charge toward sense wire using Magboltz parameters
  - Add charge to FADC corresponding channel
- Add random noise
- Simulate electronic threshold

Clusterization For DCH (Cluster Counting)

- Clusterization is done per cell
- Shape analisys od FADC count
- Returns as many recpoints as the number of recognized clusters (max 2)

Tracking Algorithm (for TPC and DCH)

- Primary TPC/DCH seeding: looks for tracks with 20 hits (pads and/or μmegas) apart + beam constraint
- Secondary TPC/DCH seeding: looks for tracks with hits in layer 1, 4 and 7 (no beam constraint)
- **Parallel Kalman Filter** then initiated:
  - 1st step: start from TPC/DCH fit + prolongation to VXD (add clusters there)
  - 2st step: start from VXD, refit trough TPC/DCH + prolongation to MUD
  - 3st step: start from MUD and refit inword with TPC + VXD
- Final step: isolated tracks in VXD (see next slide) and in MUD*
- **Kinks and V0** fitted during the Kalman filtering
- All passive materials taken into account for MS and dEdx corrections



*not yet implemented

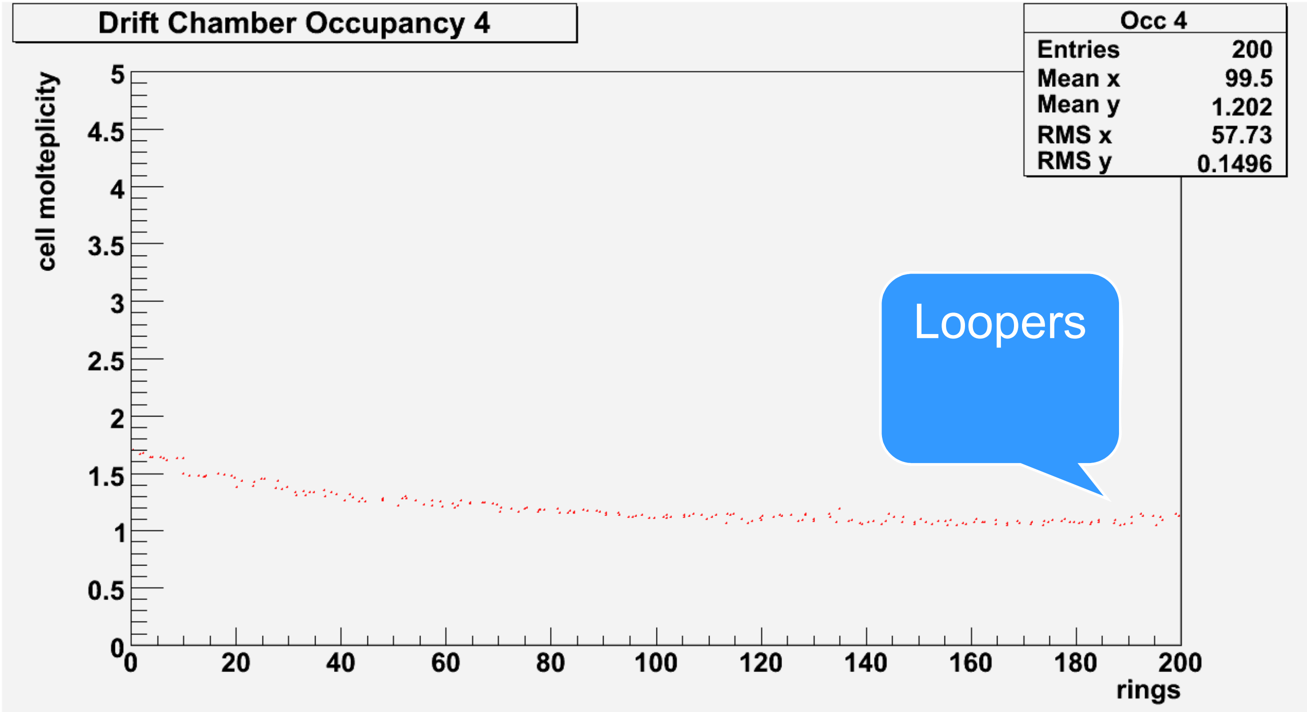
VXD Standalone Tracker

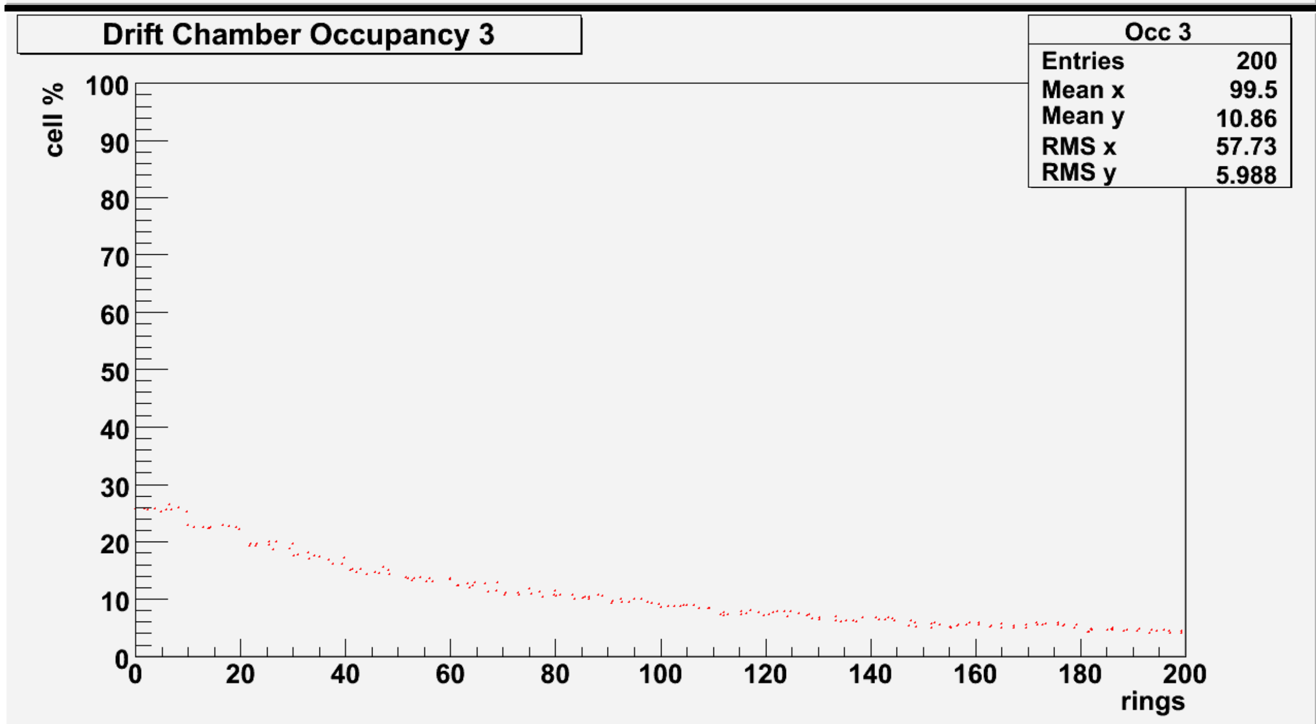
- Uses Clusters leftover from Parallel Kalman Filter
- **Requires at least 4 hits to build a track**
- Cluster finding in VXD in two steps
  - Step 1: look for 3 RecPoints in a narrow row or 2 + the beampoint.
  - Step 2: prolongate to next layers each helix constructed from a seed.
- After finding clusters, all different combination of clusters are refitted with the Kalman Filter and the tracks with lowest χ^2 are selected.
- Finally, the process is repeated attempting to find tracks on an enlarged road constructed looping on the first point on different layers and all the subsequent layers.
- In 3.5 Tesla B-field -> P_t > 20 MeV

DCH

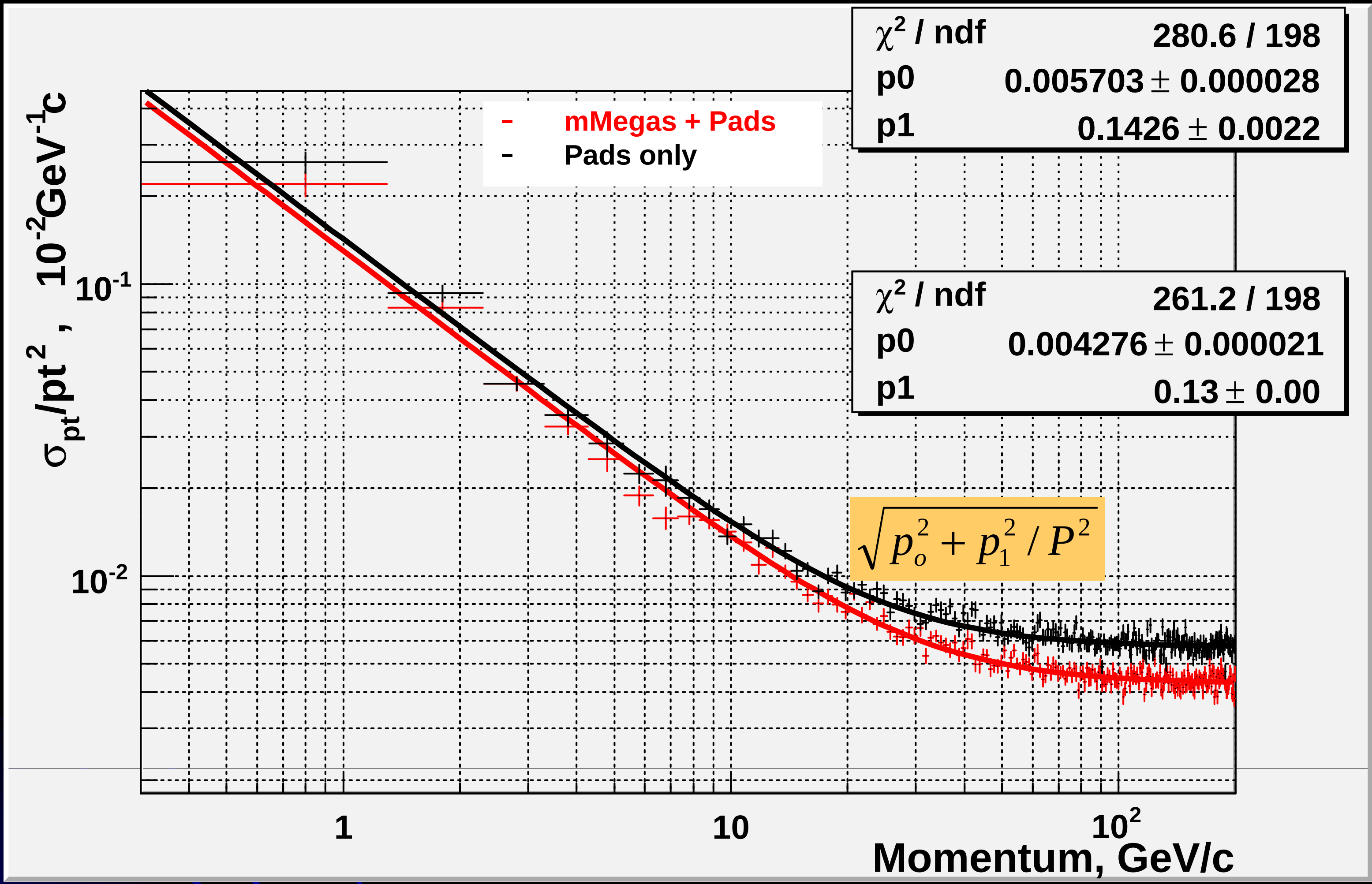
$e^+e^- \to W^+W^-$
$\to$ 4 jets
with DCH
E_{CM}=500 GeV

- Hits per cell vs layer





- Occupancy vs layer



- VXD + TPC

Expected

$$(\delta\kappa)^2 = \left(\frac{\varepsilon_\perp}{L_\perp^{\,2}}\sqrt{\frac{320}{N+4}}\right)^2 + \left(\frac{0.016\,(GeV/c)}{L\beta p_\perp \sin\theta}\sqrt{\frac{L}{X_0}}\right)^2$$

$$\kappa = 1/\rho \qquad \rho = p_\perp / 0.3B$$

Multi-jets

$H^+ \to \tau\nu \to \pi\nu$

HoZo