The 4th Concept Detector for a Linear Collider

Corrado Gatto
INFN Lecce
On behalf of the 4th Concept Collaboration

Outline

- The 4^{th} Concept Detector
- The Software framework
- Performance studies (with an eye at 3 TeV)
- Status and Perspectives

The 4th Concept Collaboration

4th Letter of Intent

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Rapidly growing since EoI

Started @ Snowmass 8 / 2005

78 Members
19 Institutions
10 Countries

3 Spokepersons
J. Hauptman (America)
S. Park (Asia)
F. Grancagnolo (Europe)

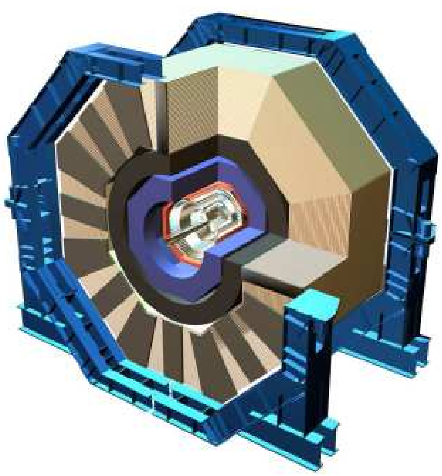
www.4thconcept.org

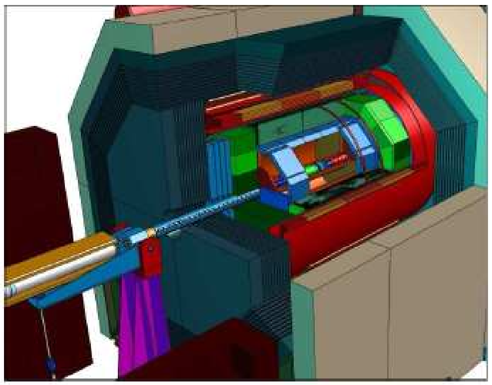
Design Guidelines

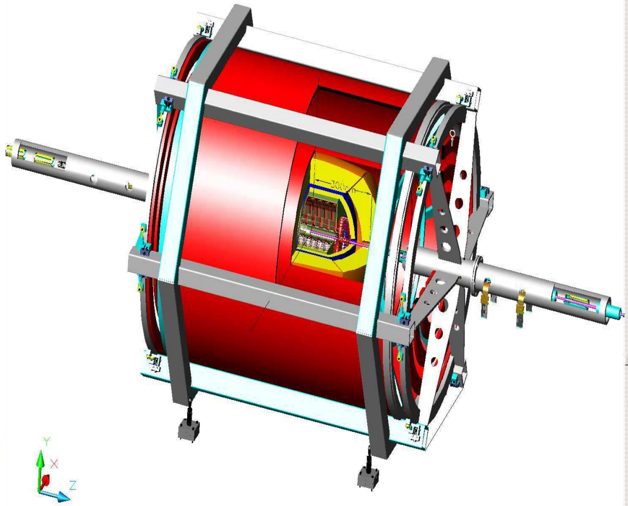
- Light -> no iron
- Alternative to other Concepts
  - No PFA for Calorimetry
  - No TPC for Central Tracking
  - No range-based Muon Detector
- Low material budget in front of the Calorimeter
- Open mind toward the choice of technology

Detectors Comparison

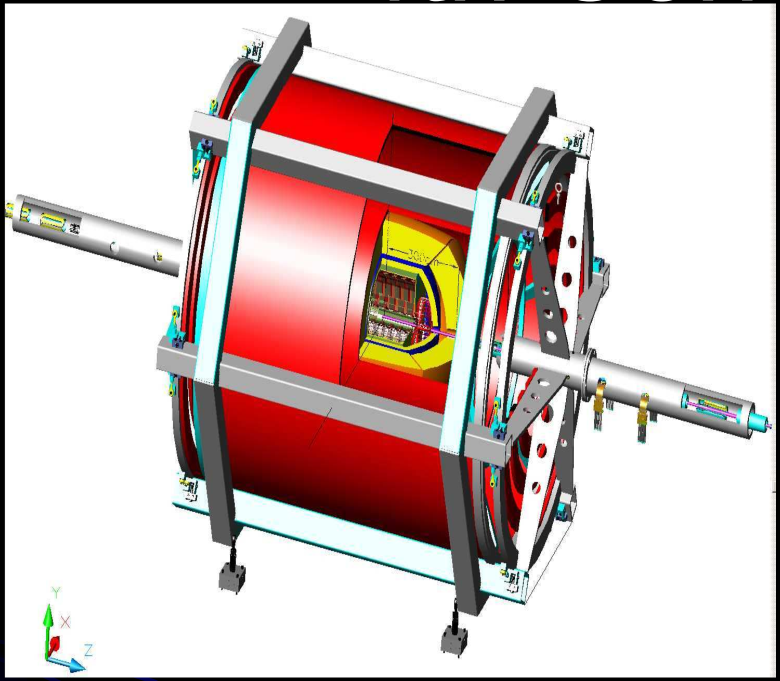
	ILD	SiD	4-th
VTX	Si-pixels	Si-pixels	Si-pixels
Tracker	TPC + Si-strip	Si-strip	DC with Clust. Counting
Calorimeter	PFA Rin=2.1m	PFA Rin=1.27m	Compensating Rin=1.5m
B	3-4T	5T	3.5T/-1.5T No return yoke
BR^2	10.2-13.2 Tm^2	8.1 Tm^2	(non-PFA)
E_{store}	1.6-1.6 GJ	1.4 GJ	2.7 GJ
Size	R=6.0-7.2m |Z|=5.6-7.5m	R=6.45m |Z|=6.45m	R=5.5m |Z|=6.4m

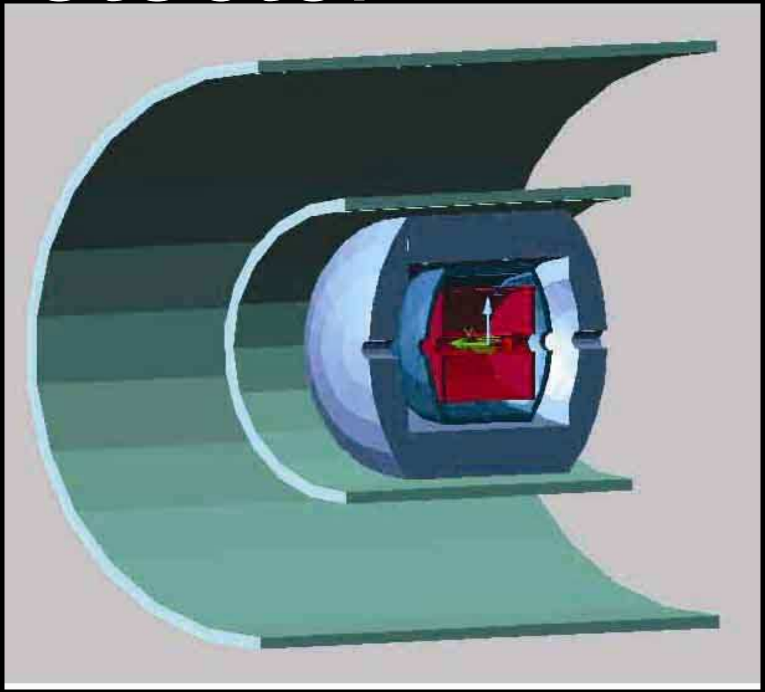






4th Concept Detector





1. Vertex Detector 20-micron pixels (based on SiD design)
2. Drift Chamber with He gas and Cluster Counting
3. Double-readout calorimeter as alternative to PFA
4. Muon dual-solenoid spectrometer

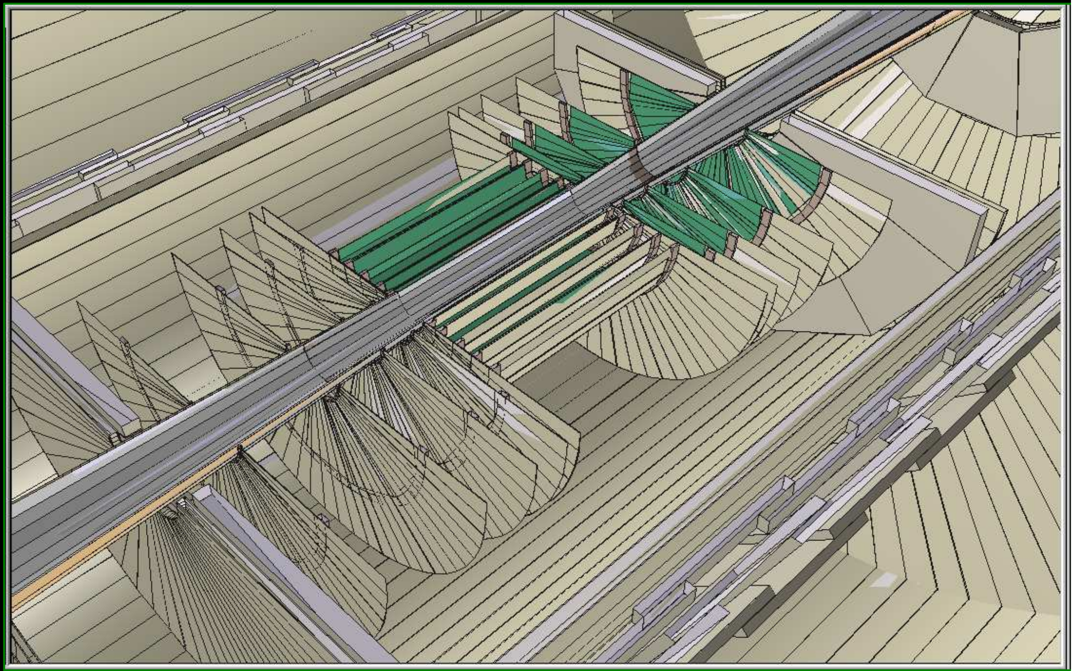
Motivations

- **He-based Drift Chamber with Cluster Counting**
  - Continuous tracking and seeding from Central Tracker
  - Lowest material budget
  - $\mathcal{O}(10^4)$ channels
  - Consolidated technology (i.e. Kloe)
  - Cost
- **Dual/Triple readout calorimeter**
  - Resolution daesnt depend on Energy
  - $\mathcal{O}(10^4)$ channels
  - Cost
- **Dual Solenoid Muon Spectrometer**
  - No iron
  - Precise determination of momentum
  - Tail catcher
  - Independent calibration for the calorimeter (i.e. via $\mu \to \mu\gamma$)

The 4th Concept Tracking Systems

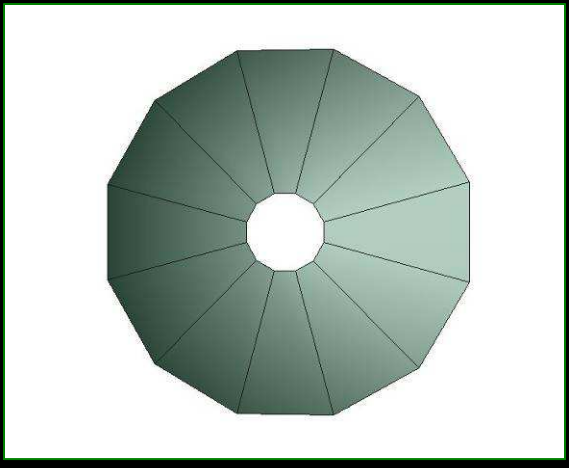
Beam Pipe and VXD layout

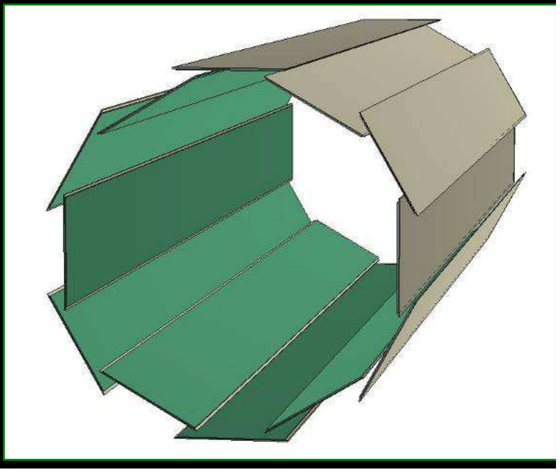
- Beam Pipe:
  - 400 µm Be
  - 25 µm Ti
- VXD: SiD/4th Concept
  - 5 barrel layers (96 ladders) x 4 endcaps (96 sectors)
  - 20 µm x 20 µm pixel size (10^9 pixels)
  - Detector support: 100 µm CarbonFiber
  - Si modules: 100 µm Si



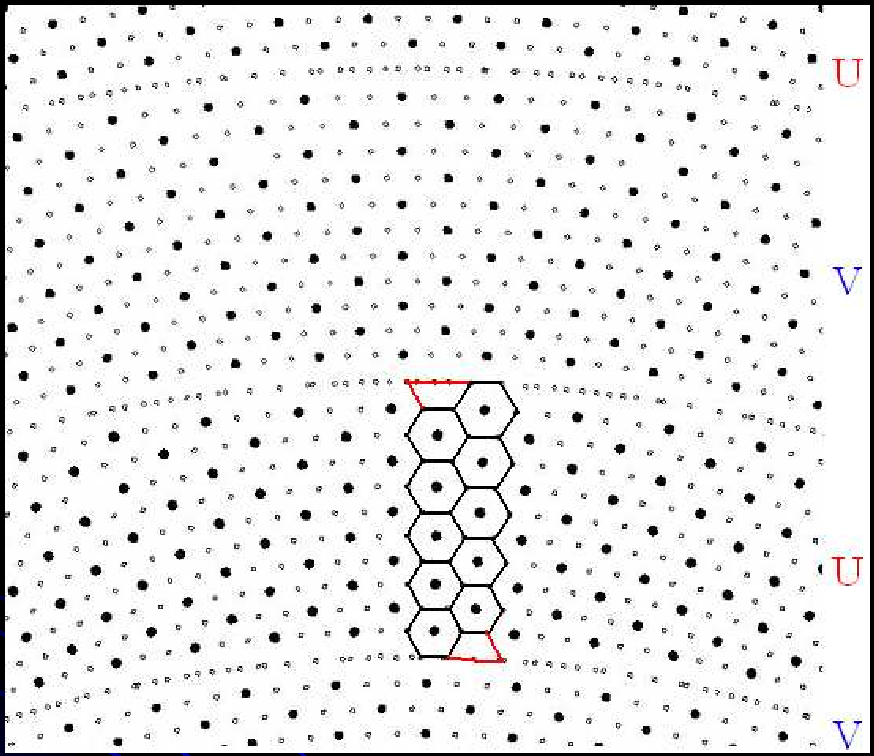
Material Budget

- Beam Pipe: 0.18% X/X_o
- VXD (including support & electr.): 0.8% X/X_o





Drift Chamber Layout



Under test
PET Filed wires 25 µm
Boron fiber Endplates

Vessel: 18-150 cm with **spherical Endcaps**
Active volume: 20-147 cm

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

cell height: 1.00 ÷ 1.20 cm
cell radius: 4.5 ÷ 6.00 mm

(max. drift time < 300 ns !)

27 superlayers, in 270 rings
10 cells each (7.5 in average)
at alternating stereo angles
±72 ÷ ±180 mrad
(constant stereo drop = 2 cm)

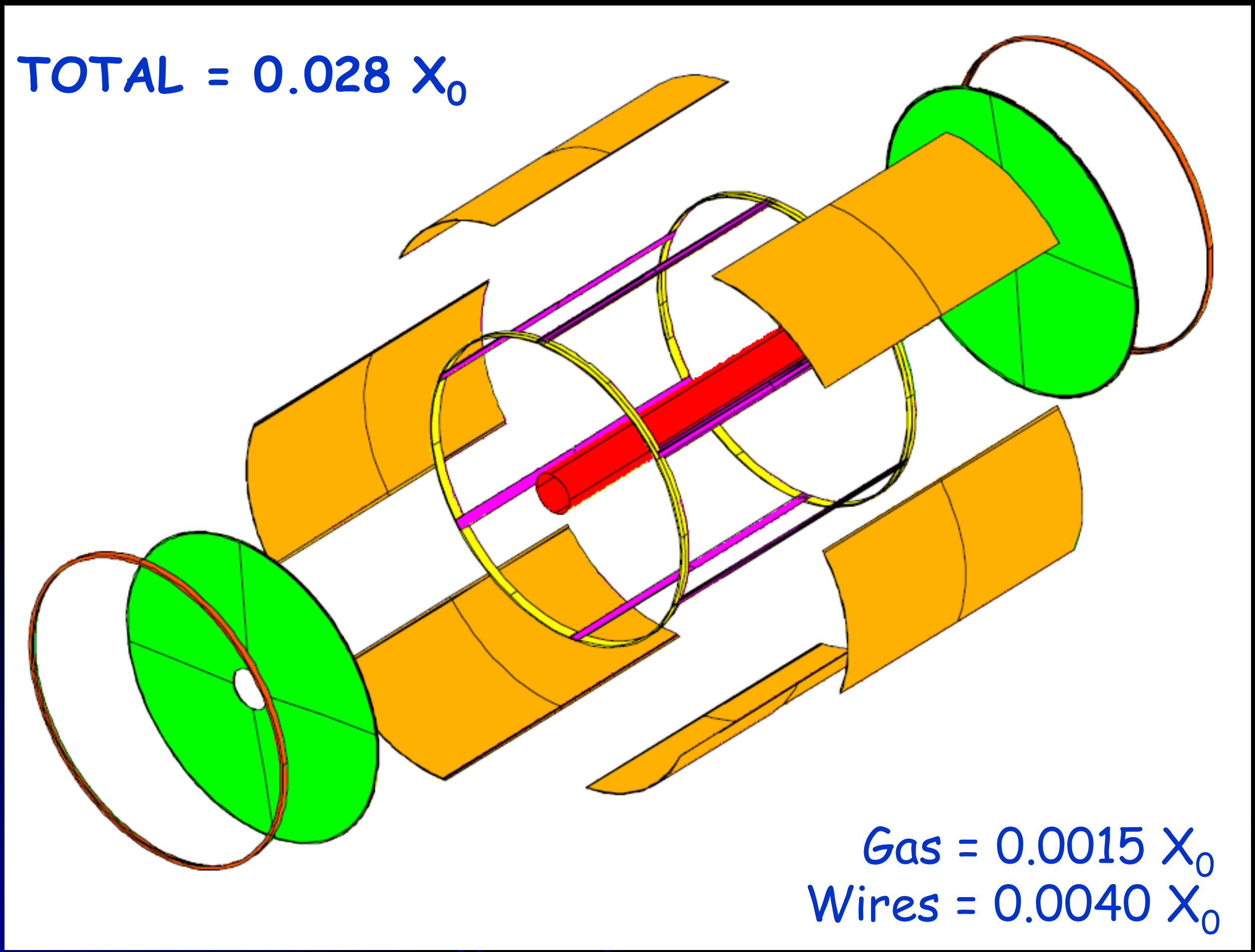
78000 sense w. 20 µm W
156000 field w. 80 µm Al

"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 = 20 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)

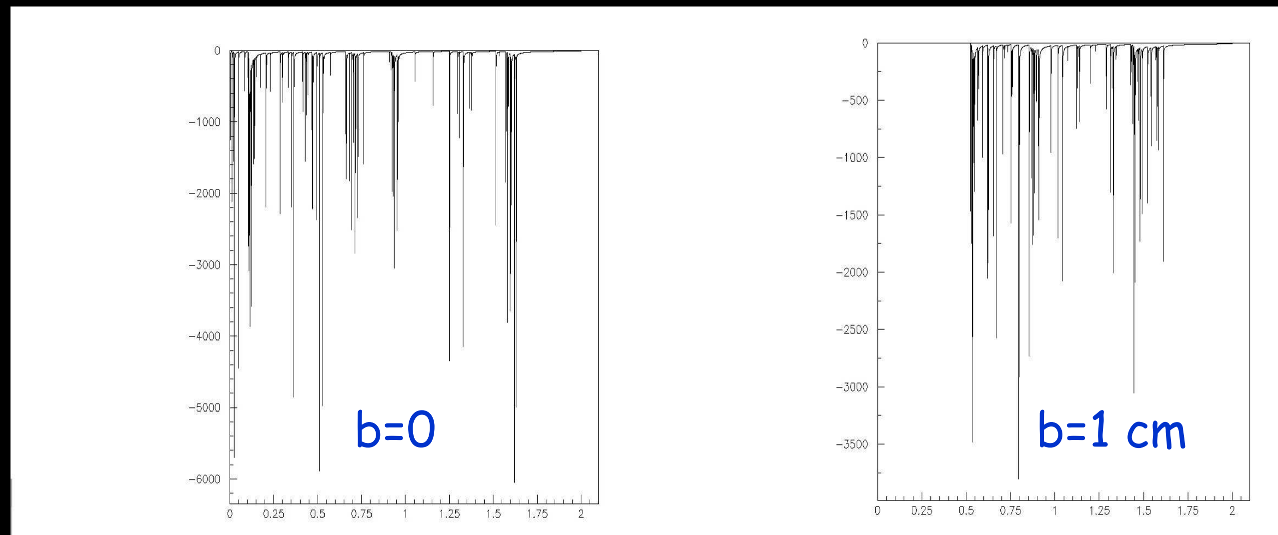
Outer cylindrical wall:
C-f./hex.cell. sandwich
held by 6 unidir. struts
0.020 X_0)

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

Material Budget at $\theta = 90^\circ$ ($\theta = 0^\circ$ for endcaps/endplates)

- Beam Pipe: 0.18% X/X_o
- VXD:
  - Detector & support: 0.8% X/X_o

Drift Chamber

- 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

The 4th Concept Dual/Triple Readout Calorimeter

Dual Readout Calorimetry

Total calorimeter energy: use two measured signals and two, energy-independent, calibration constants

$$E_{HCAL} = \frac{\eta_S \cdot E_S \cdot (\eta_C - 1) - \eta_C \cdot E_C \cdot (\eta_S - 1)}{\eta_C - \eta_S}$$

Dual Readout Calorimetry

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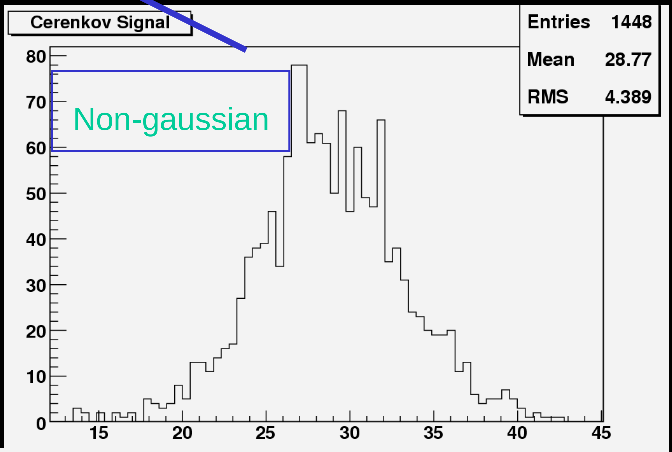

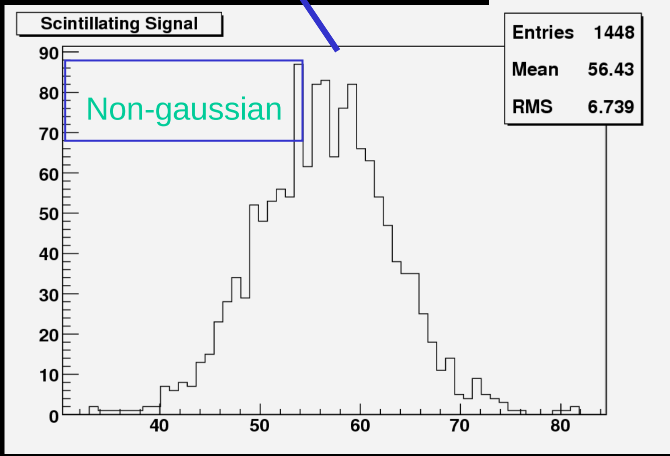

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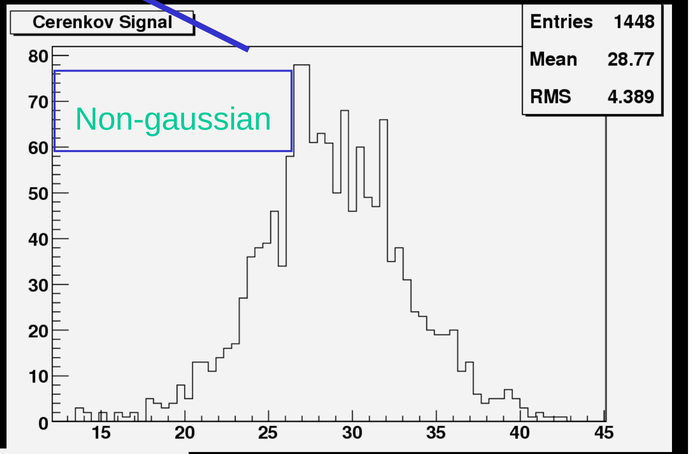
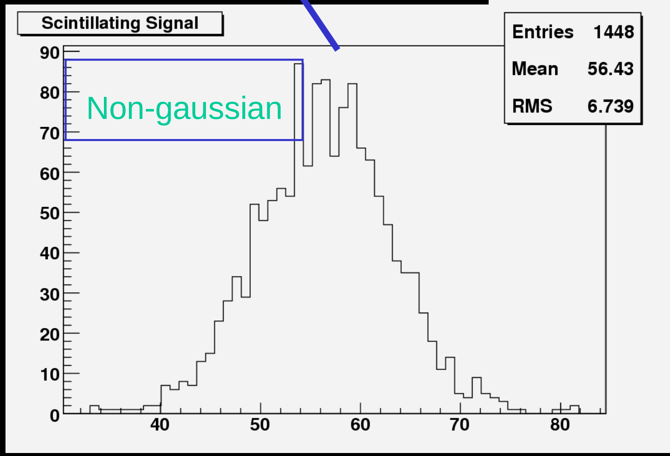




$$\eta_c = \left(\frac{e}{h}\right)_C \qquad \eta_S = \left(\frac{e}{h}\right)_S$$

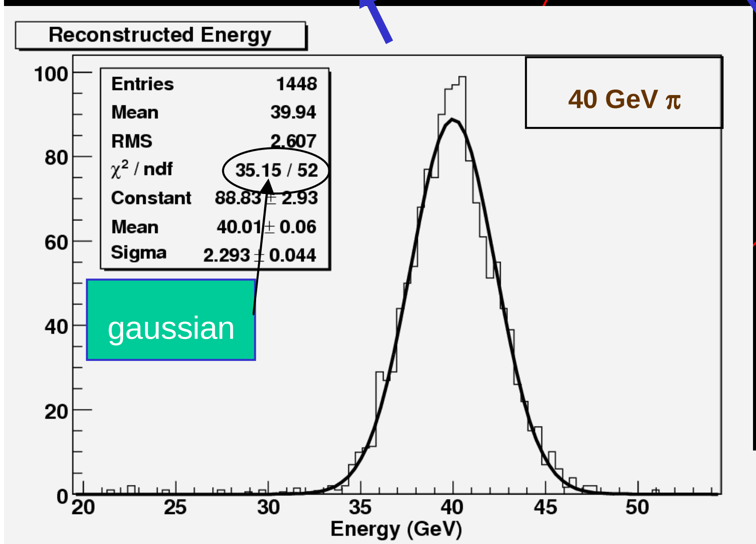
From calibration

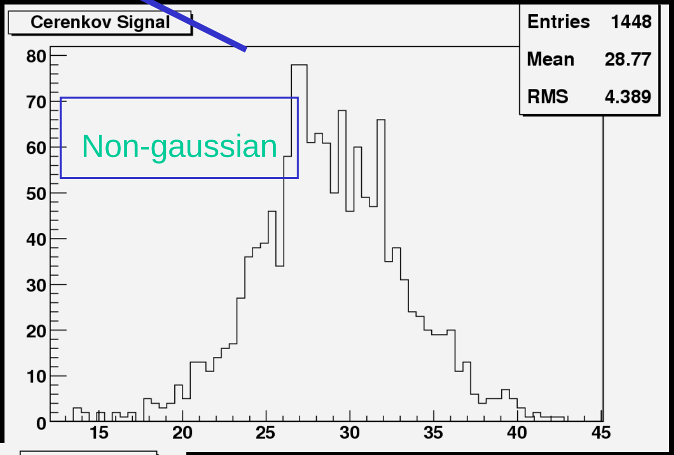
@ 1 Energy only

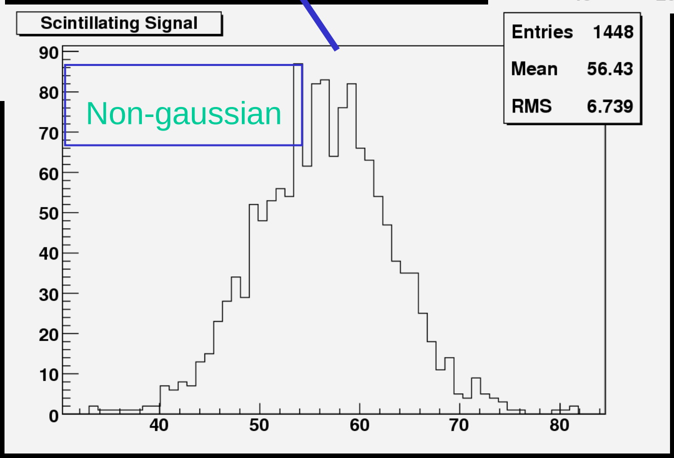
Dual Readout Calorimetry

Total calorimeter energy: use two measured signals and two, energy-independent, calibration constants

$$E_{HCAL} = \frac{\eta_S \cdot E_S \cdot (\eta_C - 1) - \eta_C \cdot E_C \cdot (\eta_S - 1)}{\eta_C - \eta_S}$$







$$\eta_c = \left(\frac{e}{h}\right)_C \qquad \eta_S = \left(\frac{e}{h}\right)_S$$

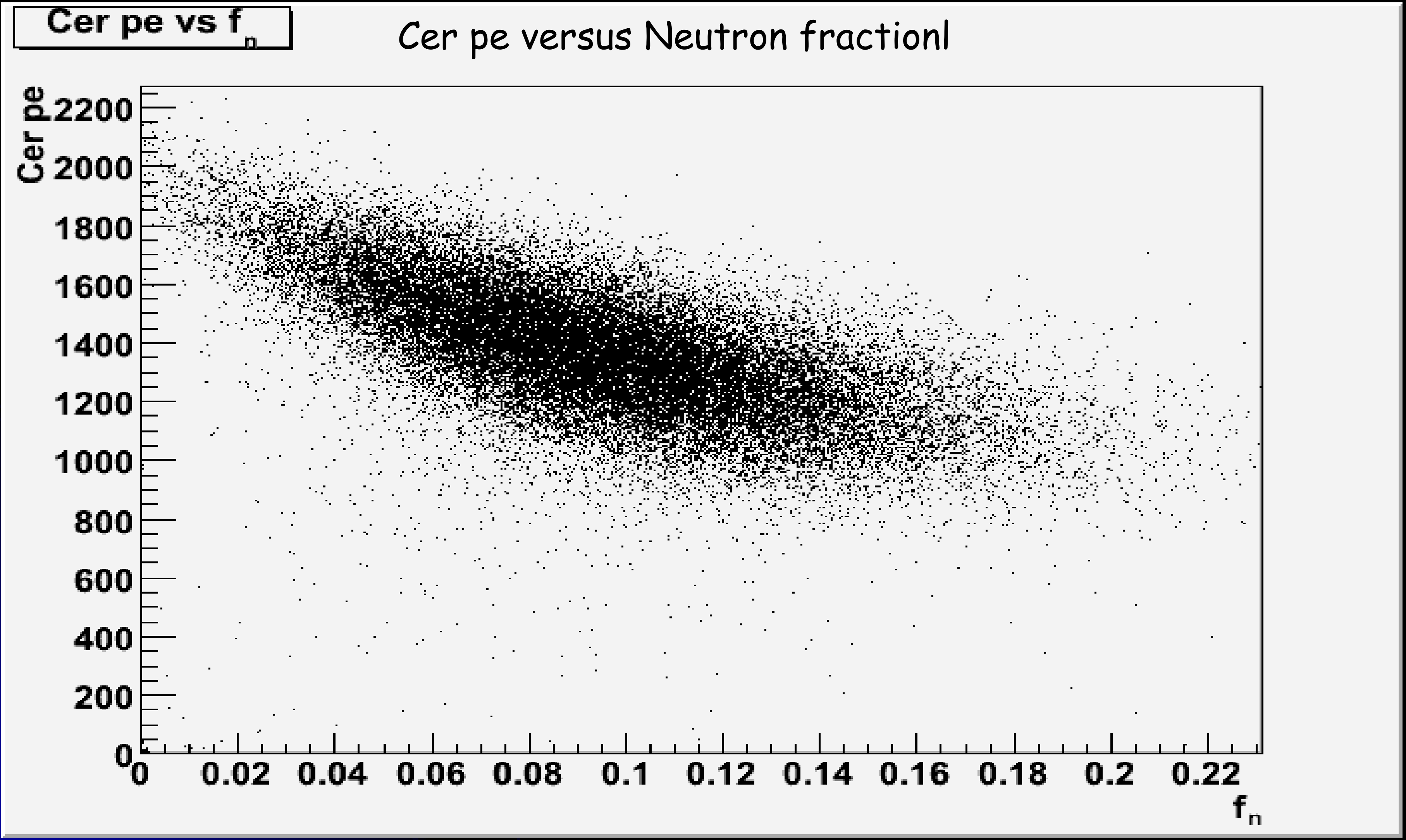
From calibration

@ 1 Energy only

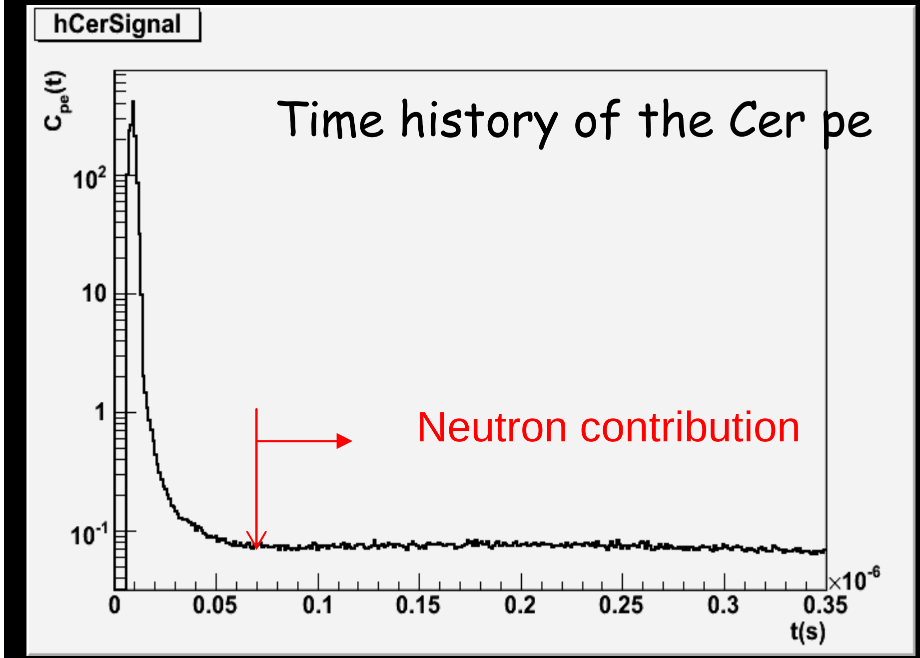
Improving the Energy Resolution: The Effect of Neutrons

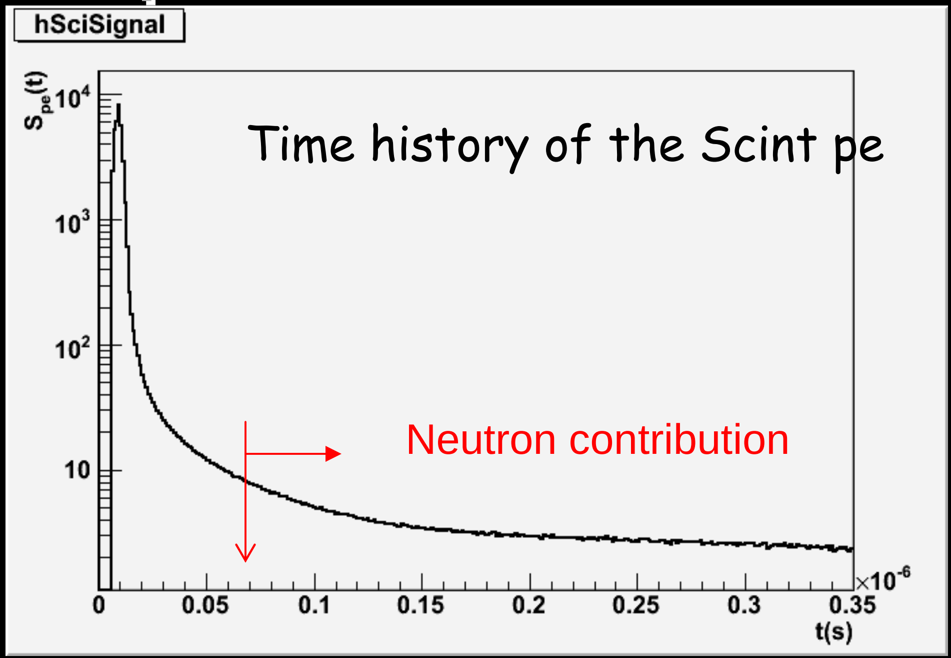
From V. Di Benedetto at Calor08

45 GeV π^-



From Dual to Triple Readout





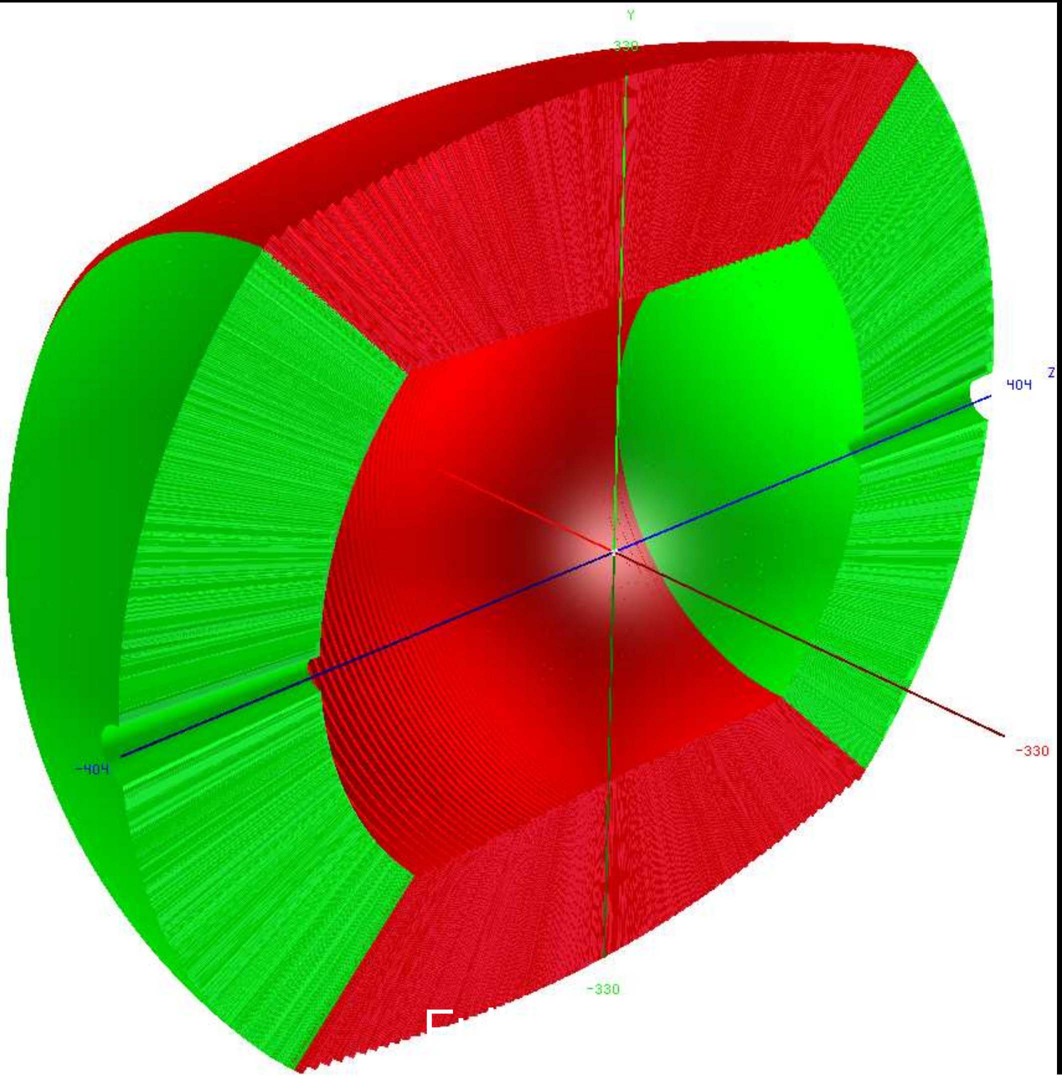
45 GeV π⁻

$$E_{HCAL} = \frac{\eta_S \cdot E_S \cdot (\eta_C - 1) - \eta_C \cdot E_C \cdot (\eta_S - 1)}{\eta_C - \eta_S} + \eta_n \cdot E_{neutrons}$$

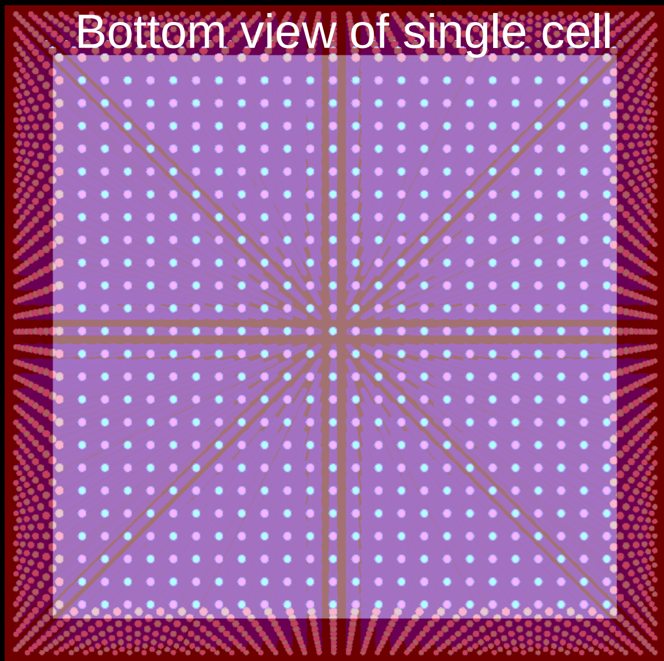
From V. Di Benedetto at Calor08

The 4th Concept Hadronic Calorimeter (third version)

- Cu + scintillating fibers + Ĉerenkov fibers
- Fully projective layout
- ~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

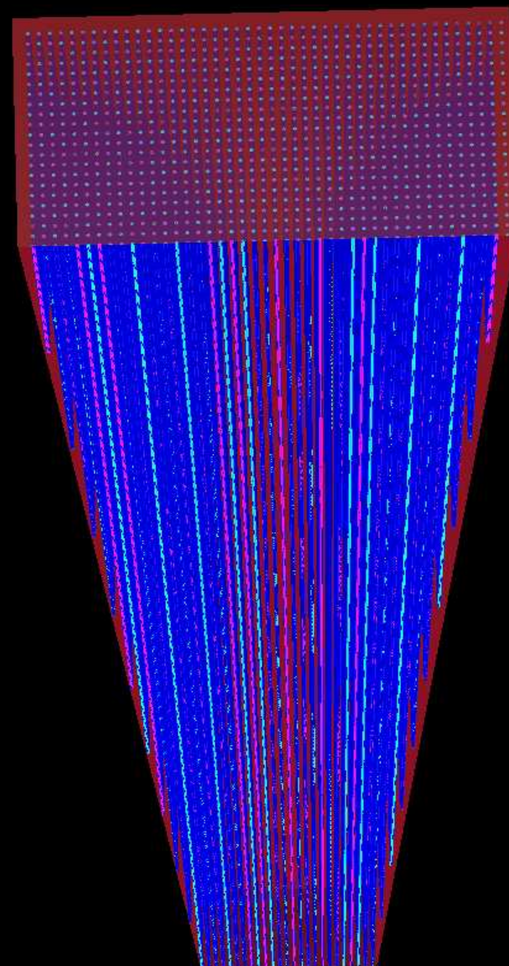
300 μm radius

Plastic/Quartz fibers

Aperture Number=0.50

(C fibers)

Top cell size:~ 8.1 × 8.1 cm^2



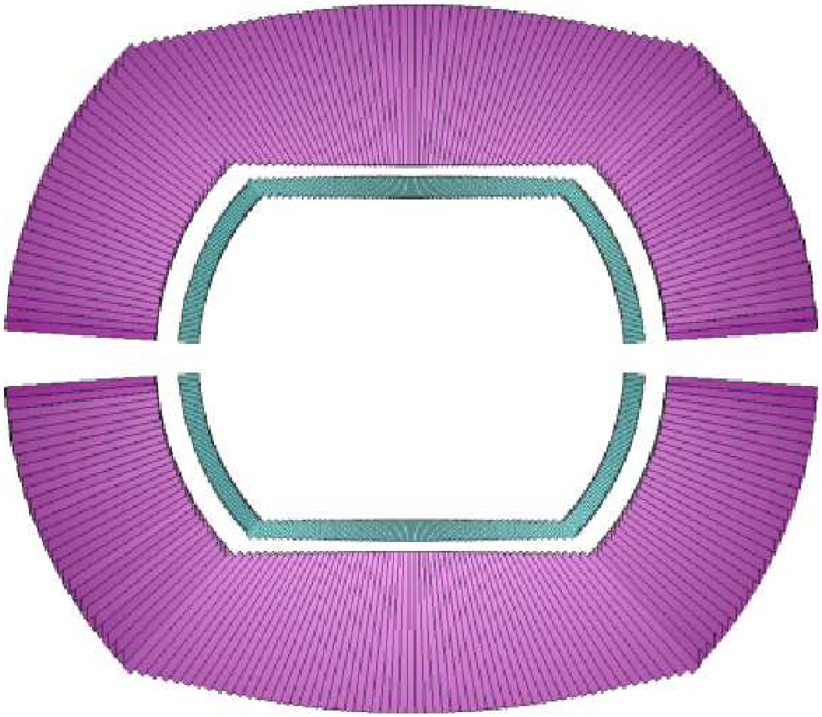
Bottom cell size: ~ 4.4 × 4.4 cm^2

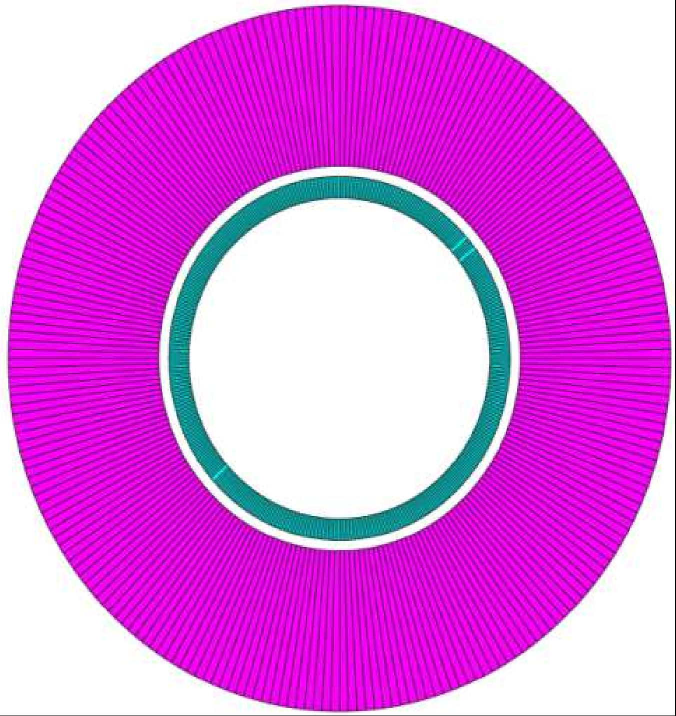
Number of fibers inside each cell: ~1600 equally subdivided between Scintillating and Cerenkov

Fiber stepping ~2 mm

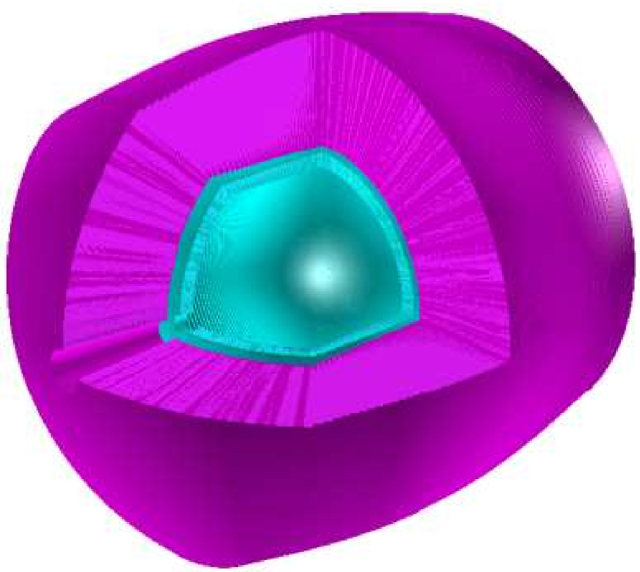
Cell length: 150 cm

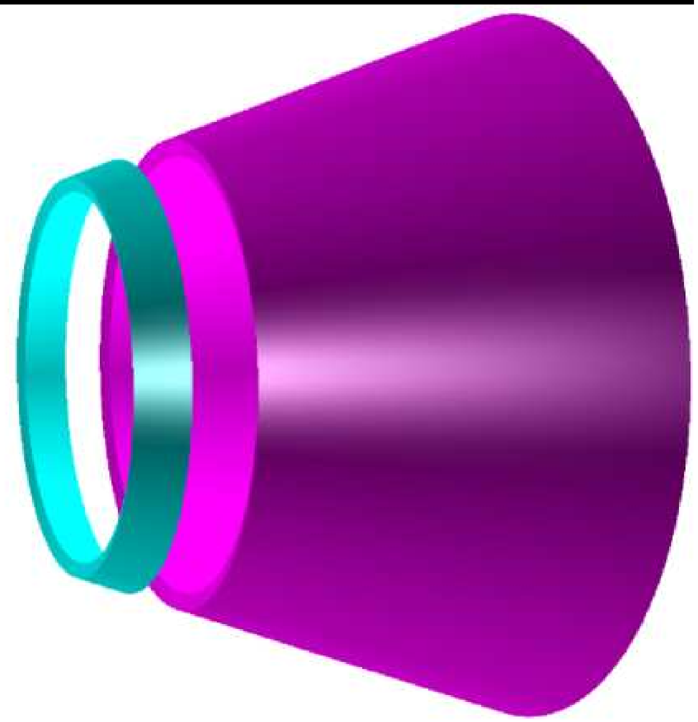
Each tower works as two independent towers in the same volume





ECAL + HCAL

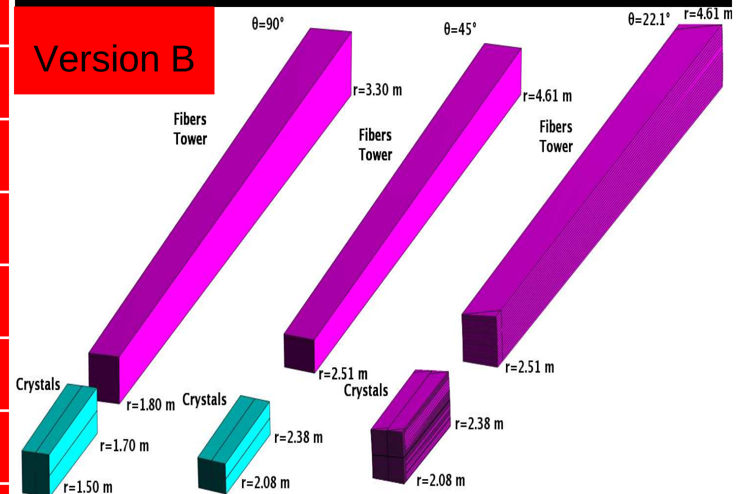




October 15th, 2008

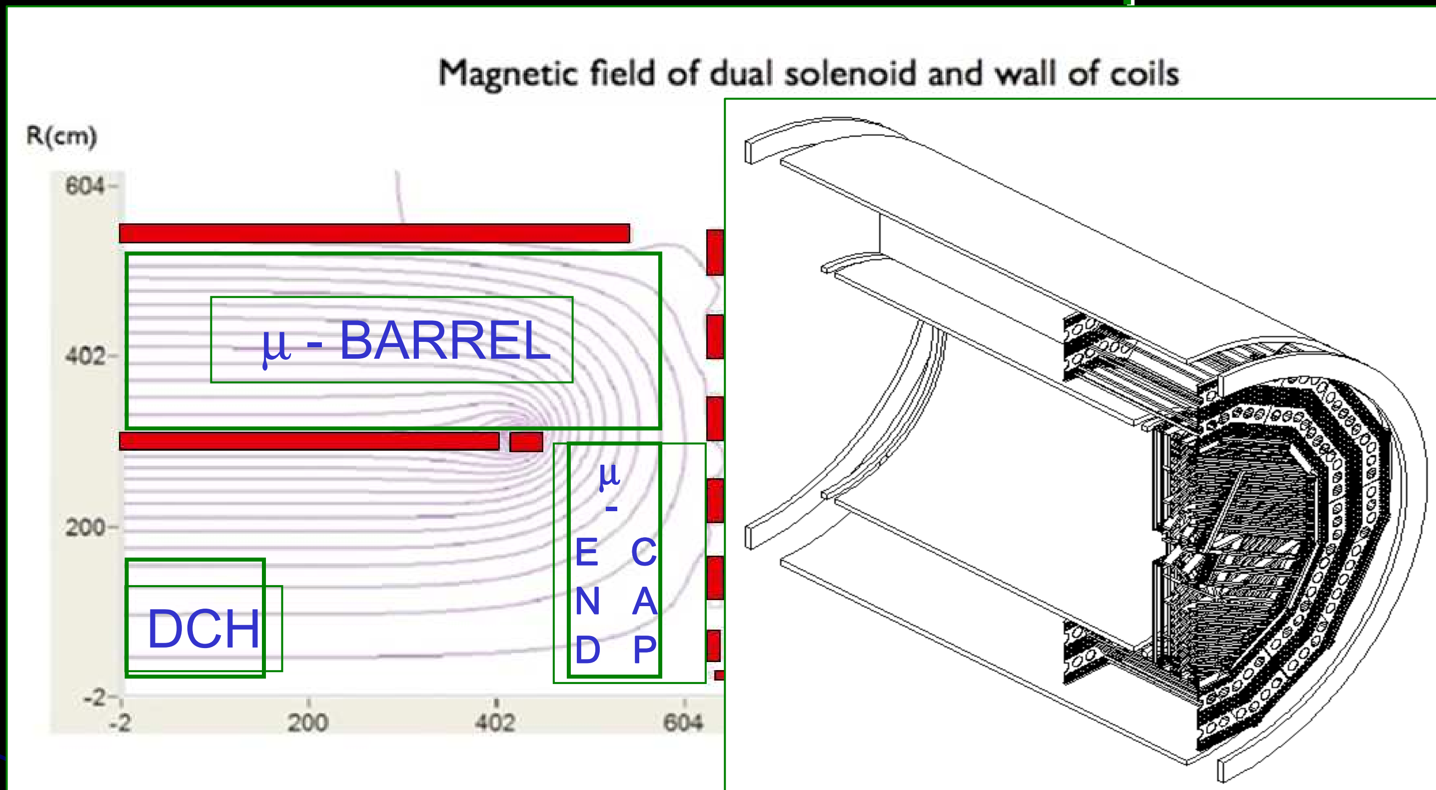
4^{th} Concept Crystal Calorimeter

	Version A	Version B
Crystals	BGO (20 cm)	PbF_2 with 0.15% Gd doping 25 cm
Scintillation yield	5 pe/MeV	4.5 pe/MeV
Cerenkov yield	0.6 pe/MeV	1.4 pe/MeV
Dimensions	1 x 1 x 20 cm	2 x 2 x 25 cm
Rin, Rout cm	155,175	155, 180
material in front	5% X/Xo + tracking	None + tracking
Depth (X/X_o)	~ 17.9 X/X_o	~ 27.7 X/X_o
Depth (λ)	~0.88 λ	~1.25 λ
Granularity	~0.38°	~0.76°
Coverage in θ	3.4 °	3.4°
Total cell barrel	222784	55696
Total cell endcaps	2*50624	2*25312



The 4th Concept Muon Spectrometer

Dual Solenoid B-field & Muon Spectrometer



radius 2.3 cm
filled with 90% He – 10% iC_4H_{10} @ NTP
gas gain few × 10^5
total drift time 2 μs
primary ionization 13 cluster/cm ⇒ ≈ 20 electrons/cm total
both ends instrumented with:

- > 1.5 GHz bandwith
- 8 bit fADC
- > 2 Gsa/s sampling rate
- free running memory

for a

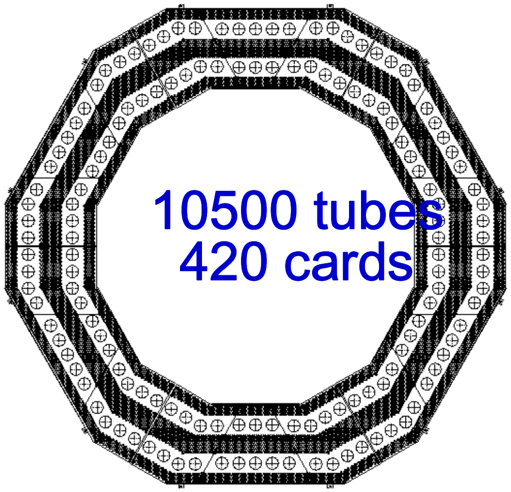
- fully efficient timing of primary ionization: cluster counting
- accurate measurement of longitudinal position with charge division
- particle identification with dN_{cl}/dx

Barel:
31500 tubes
21000 channels
840 cards

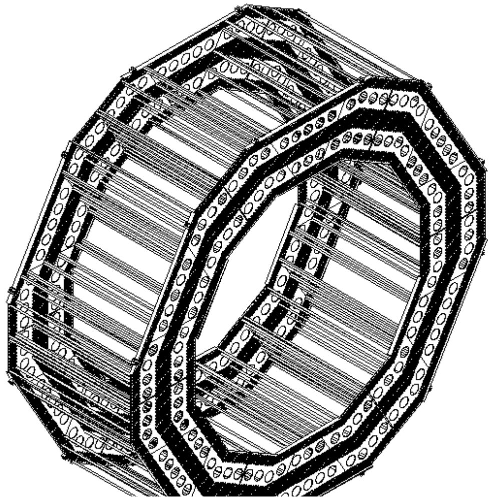
End caps:
8640 tubes
9792 channels
456 cards

Total:
40140 tubes
30792 channels
1296 cards

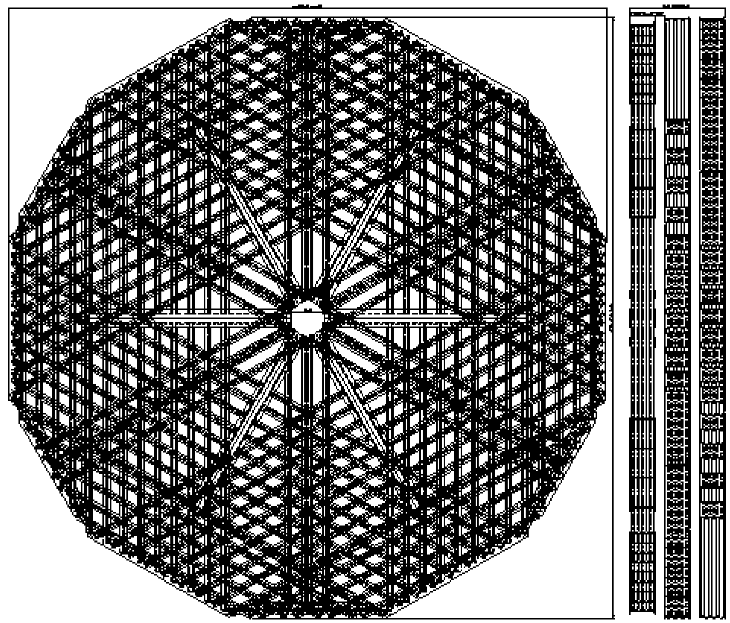
MUD Barrel (1/3)+Endcap

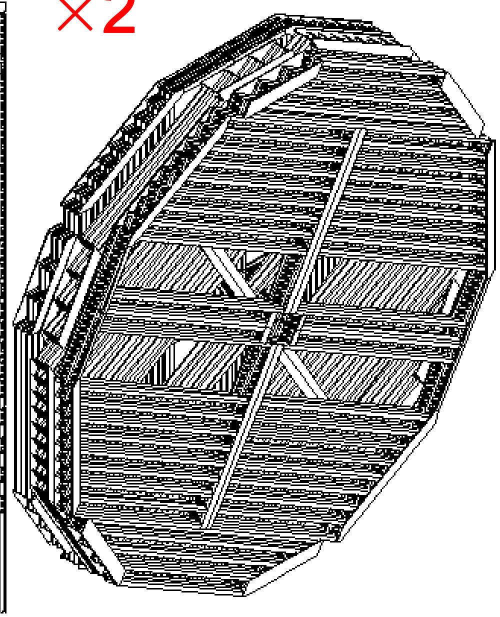


×3



×2





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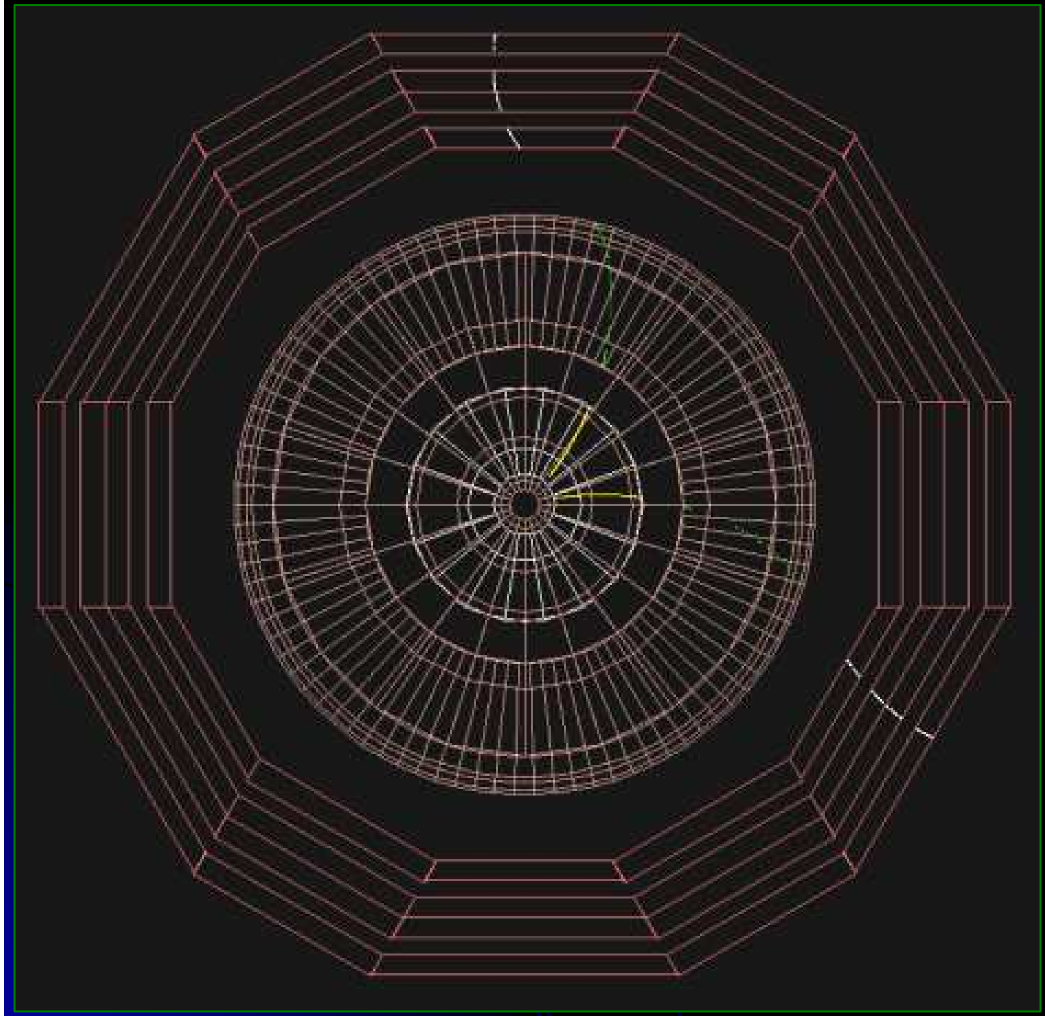
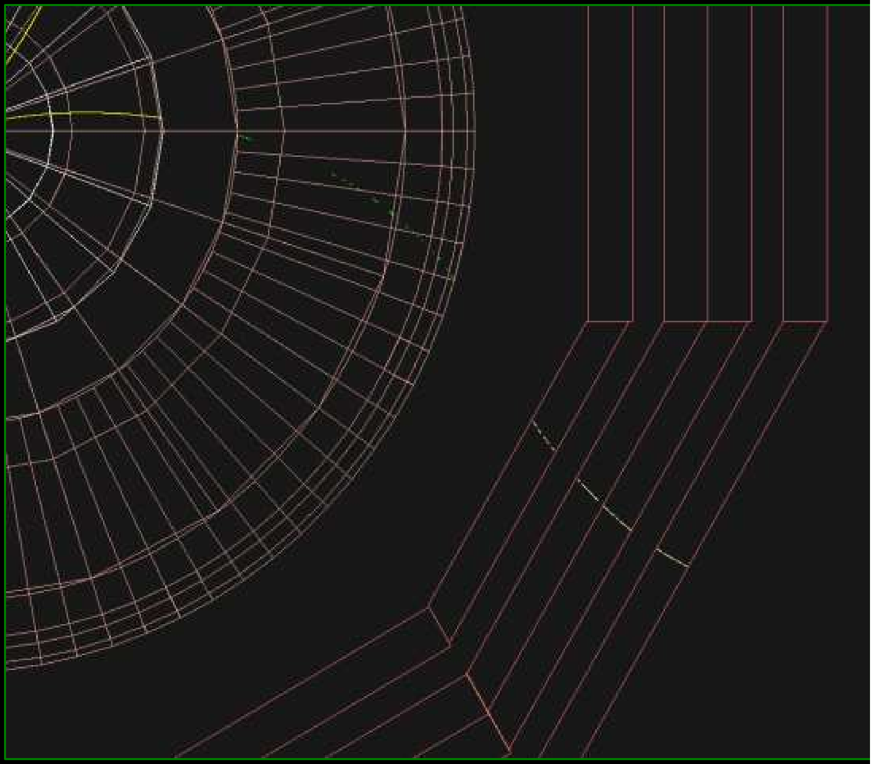
$\mu^+ \mu^-$ at 3.5 GeV/c





ILCRoot simulation

4^{th} Concept Detector Performance Studies

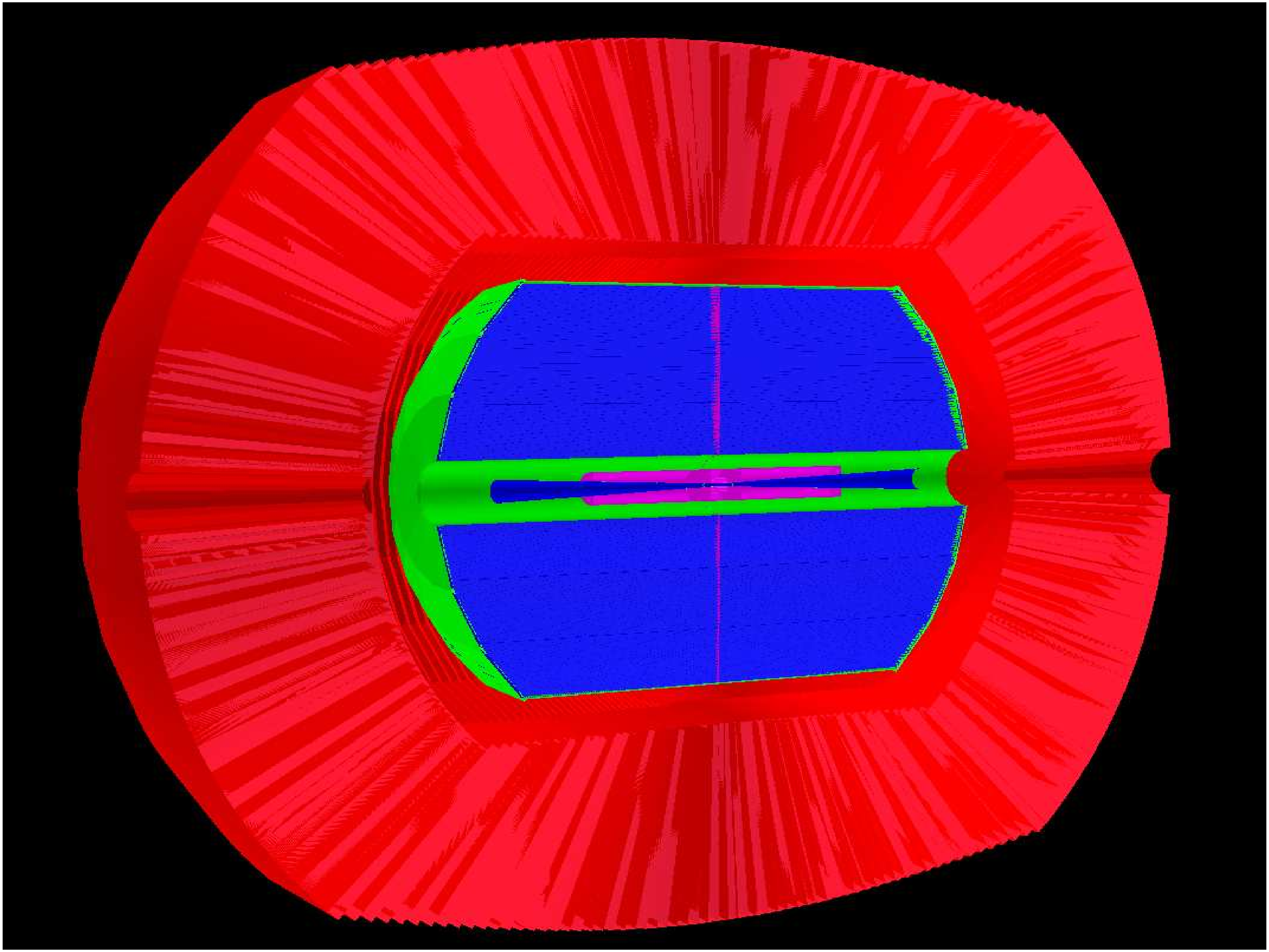
4^{th} Concept Software Strategy: ILCroot

- CERN architecture (based on Alice's Aliroot)
- Full support provided by Brun, Carminati, Ferrari, et al.
- 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
- Based on Virtual Montecarlo
  - Virtual MC provides a virtual interface to Monte Carlo
  - The concrete Monte Carlo (Geant3, Geant4, Fluka) is selected and loaded at run time
- Could it ever evolve into a general purpose entity for the HEP community (as ROOT)?
- Growing number of experiments have adopted it: Alice, Opera, CMB, (Meg), Panda, 4th Concept
- Six MDC have proven robustness, reliability and portability

Do not Reinvent the wheel
Concentrate on Detector studies and Physics

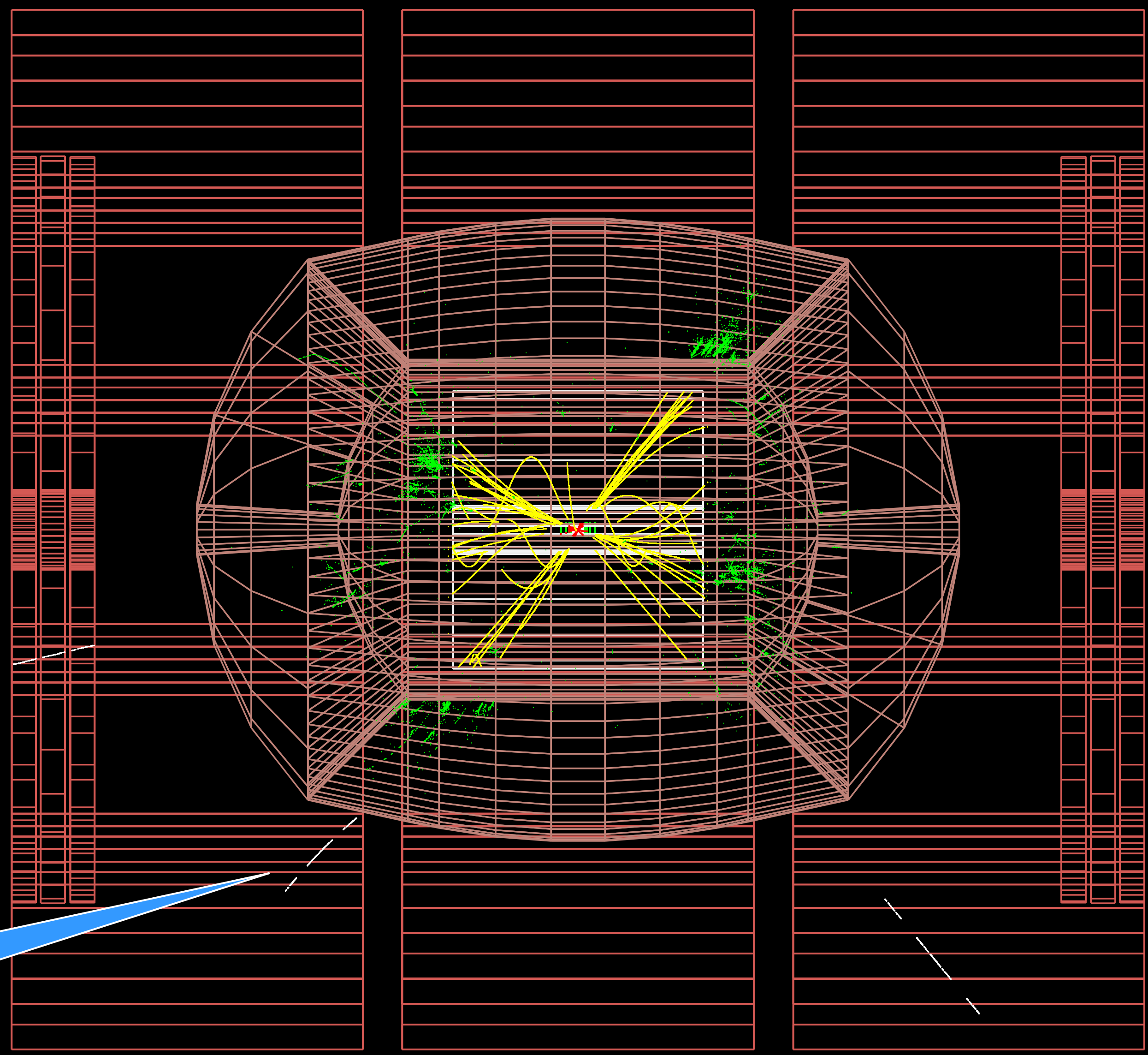
Detectors in ILCroot

- VTX Detectors: 4th Concept,SiD, FTD
- Central Trackers: TPC, Drift Chamber (3 versions), Si-Strips (SID01), SPT (Pixel Tracker)
- HCAL: DREAM (3 versions)
- ECAL: 4th Concept (2 versions)
- Muon Spectrometer: 4th Concept
- **Total: 10 subdetectors (15 versions), most of them with full simulation**

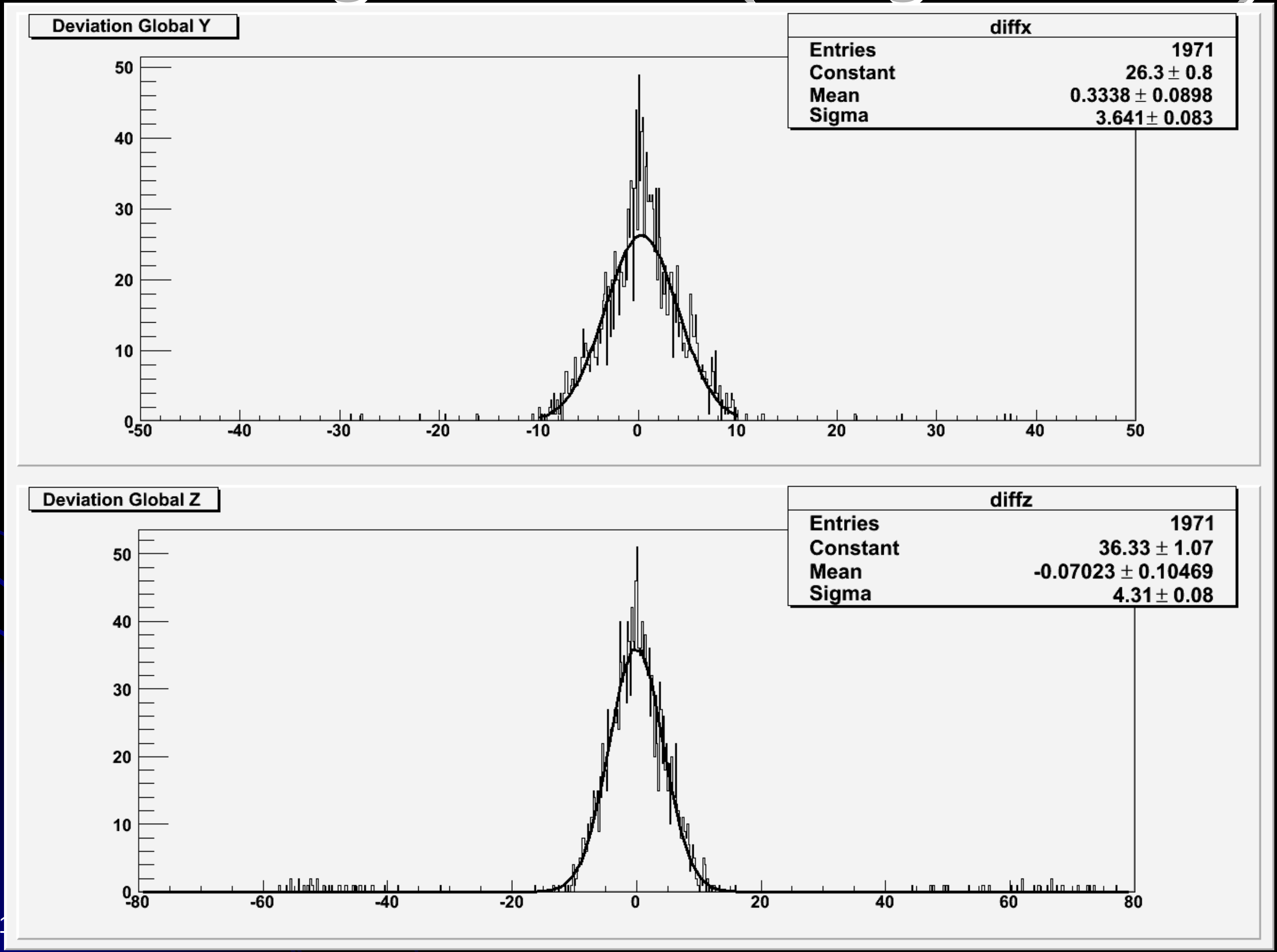


Event Display in ILCroot

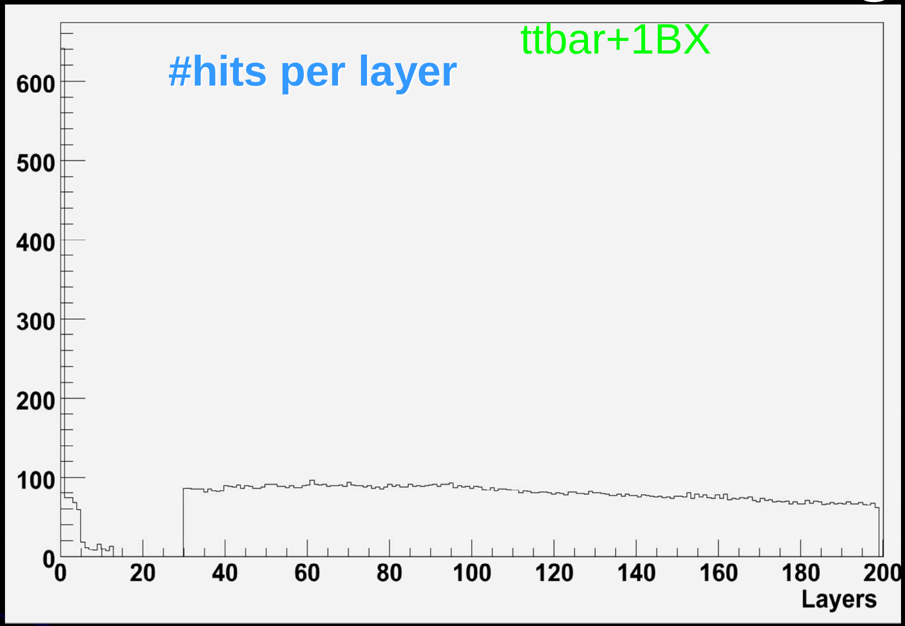
$e^+e^- \rightarrow H^oH^oZ^o$
$\rightarrow$ 4 jets 2 muons
ECM = 500 GeV



VXD Single Cluster Resolution with Full Digitization (single track)



Effects on Track Reconstruction of 1 BX Background



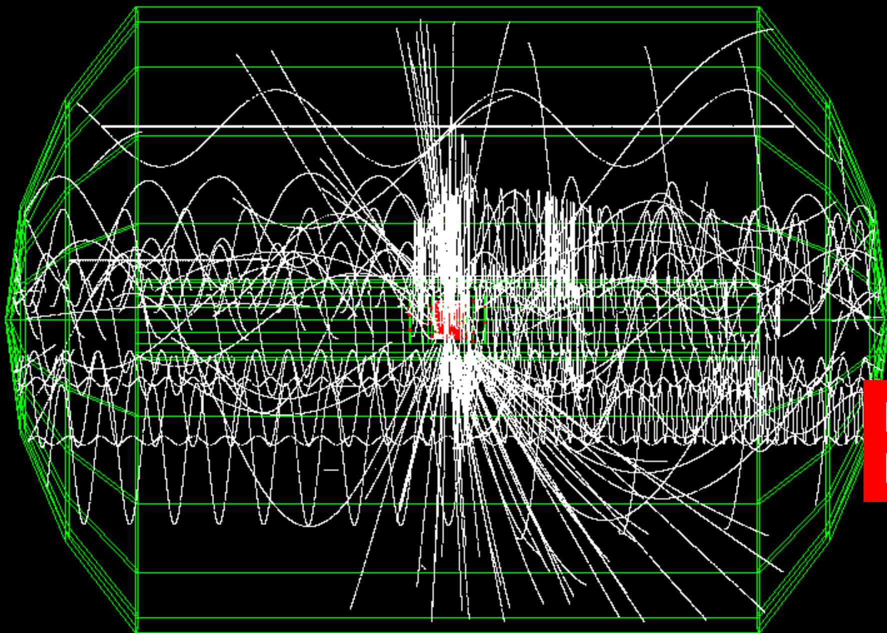
- Geant threshold: **10 keV**
- VTX threashold: **3000 e$^-$**

- Reconstruction efficiency for ttbar->6jets in VTX+DCH is mostly unaffected
- Fake clusters: 0.4% ->0.7%

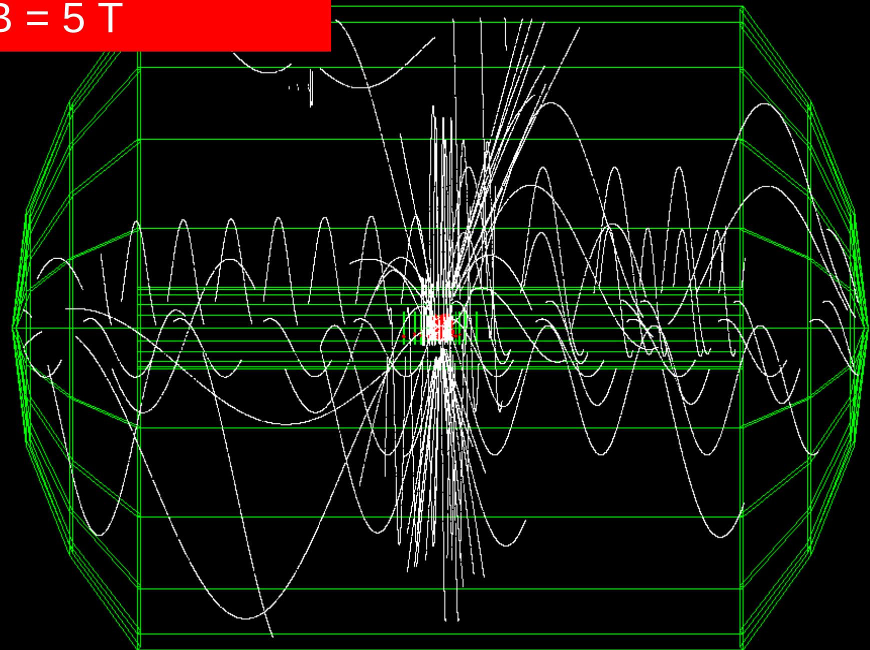
- VTX performance depends heavily on the technology chosen for the Central Tracker
- Careful studies with multiple BX's are required
- Geant3 and Fluka not adequate for such studies

ttbar->6 jets events

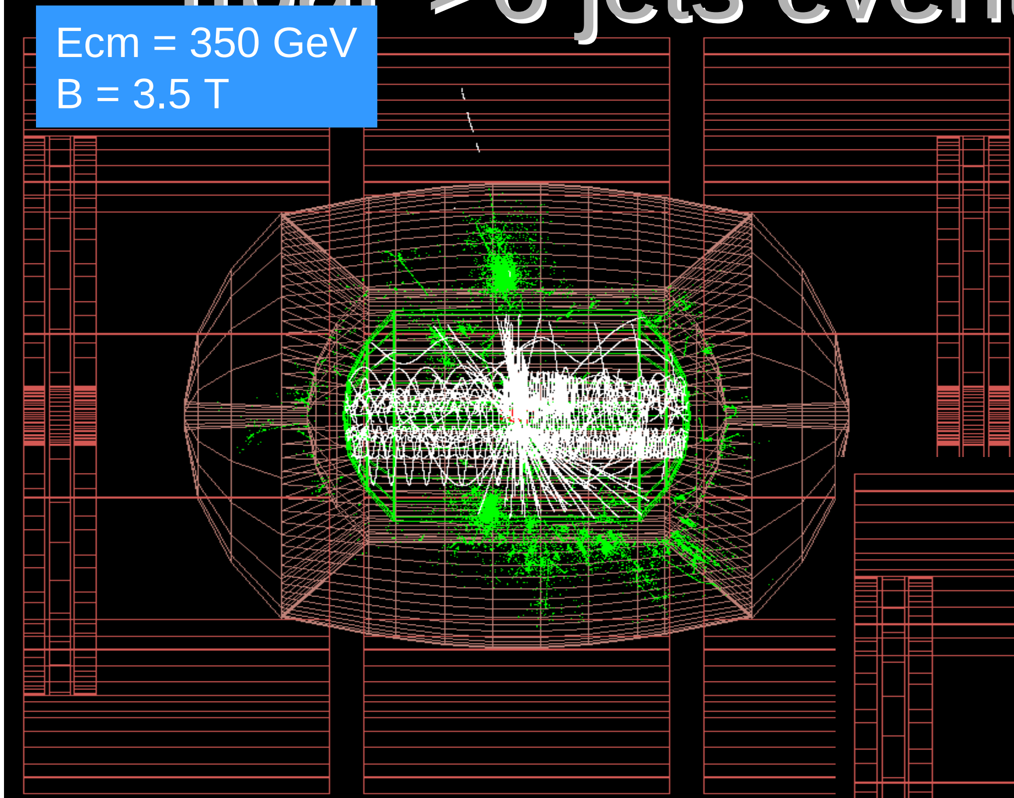
Ecm = 350 GeV
B = 3.5 T

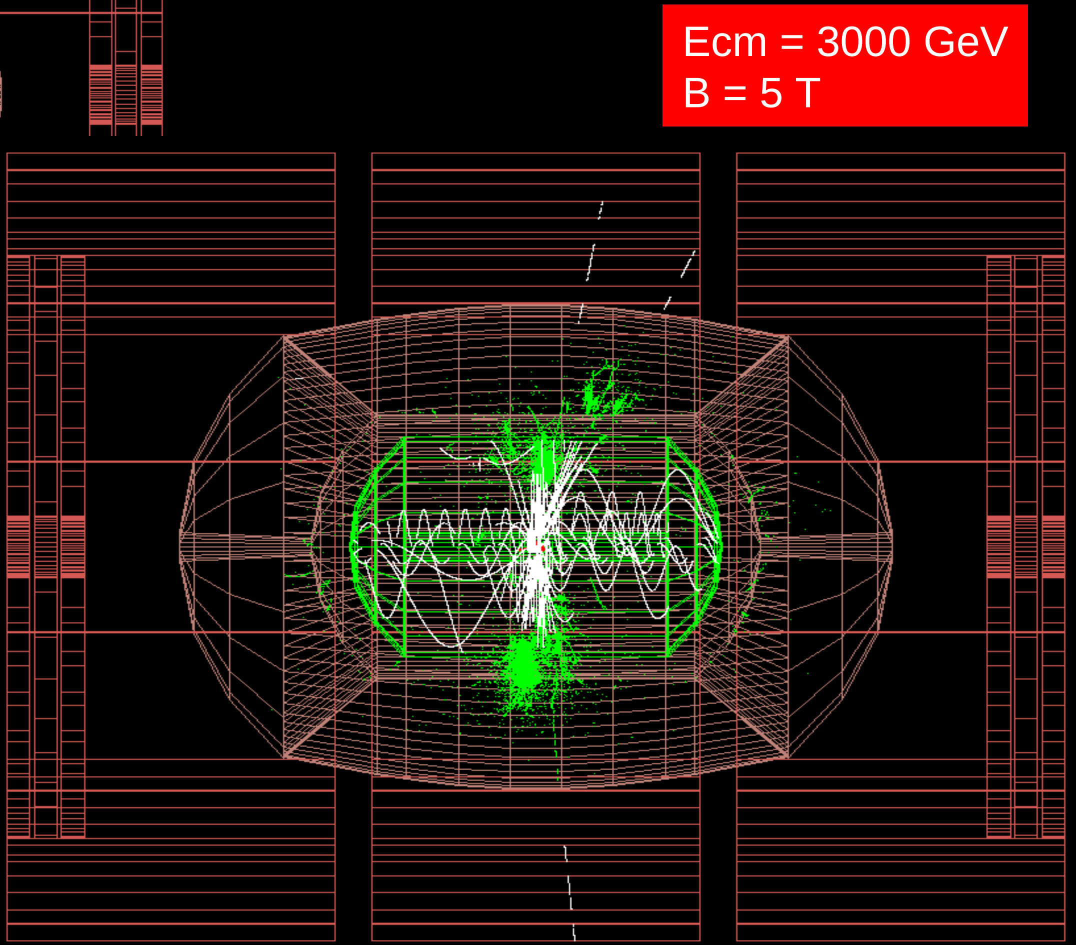


Ecm = 3000 GeV
B = 5 T



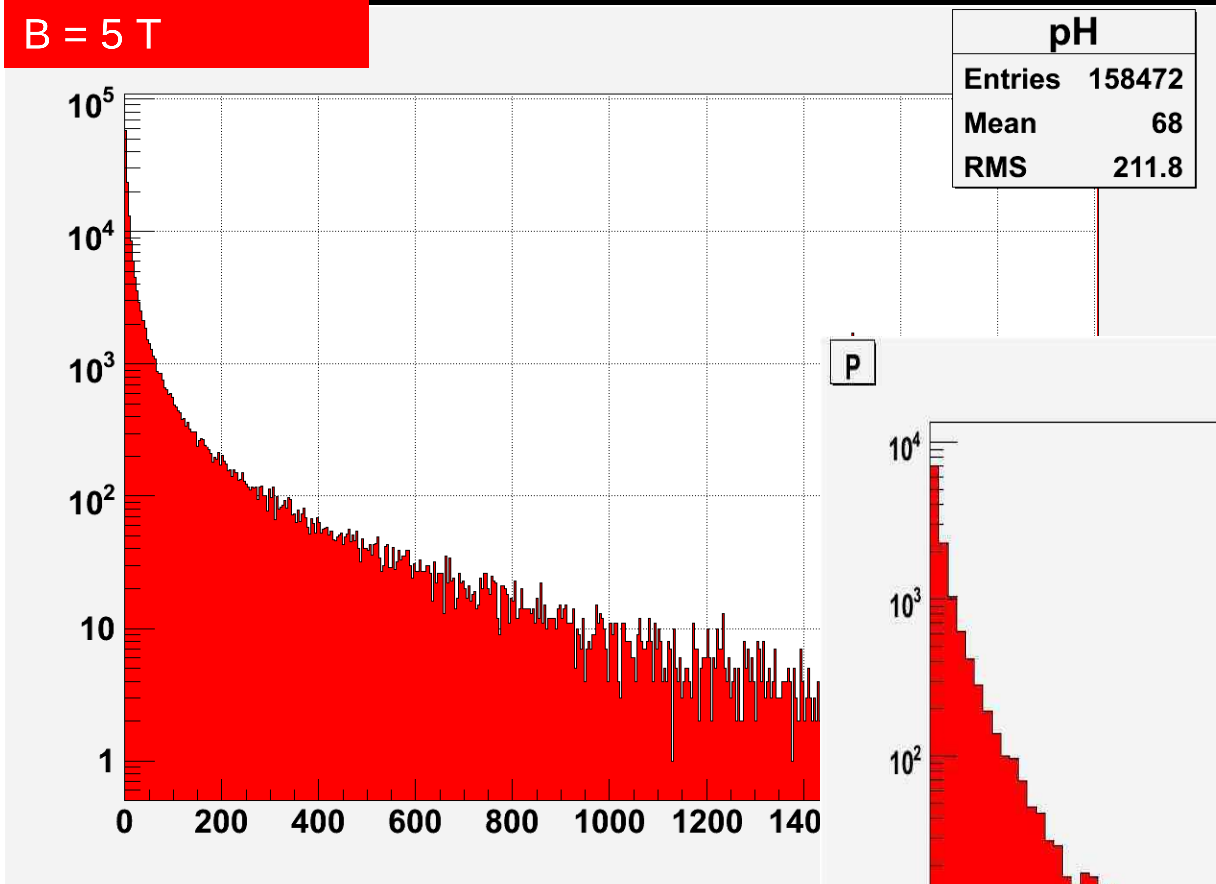
ttbar->6 jets events: Full Detector



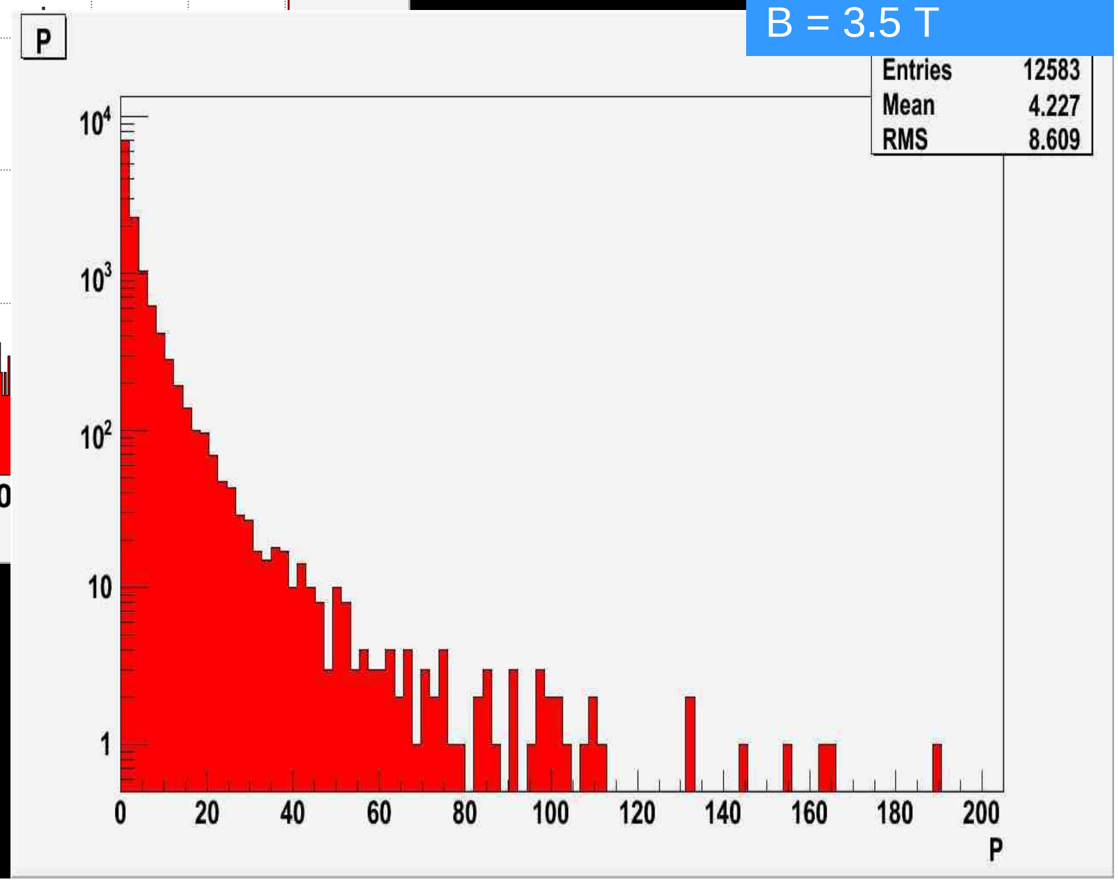


e^+e^- -> ttbar->6jets: Momentum Spectrum

Ecm = 3000 GeV
B = 5 T



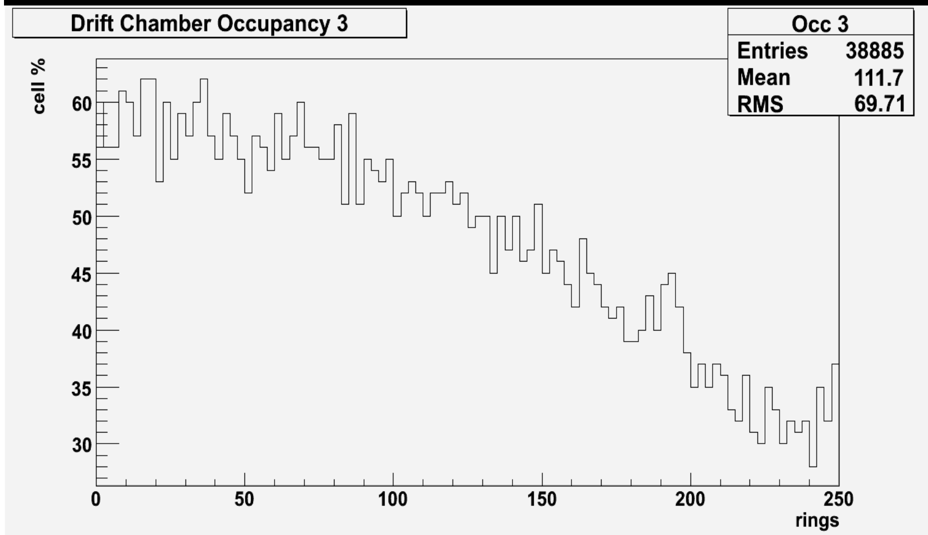
Ecm = 350 GeV
B = 3.5 T

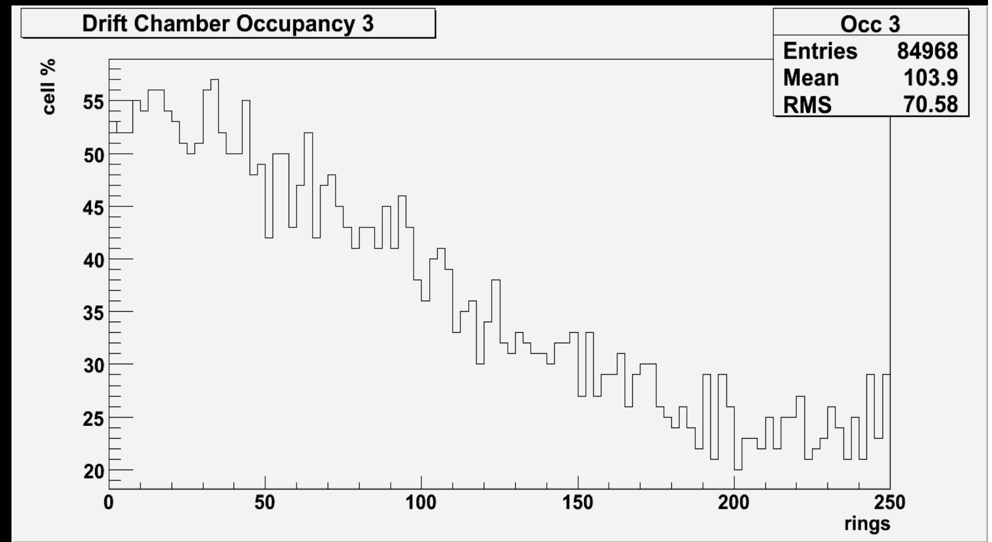


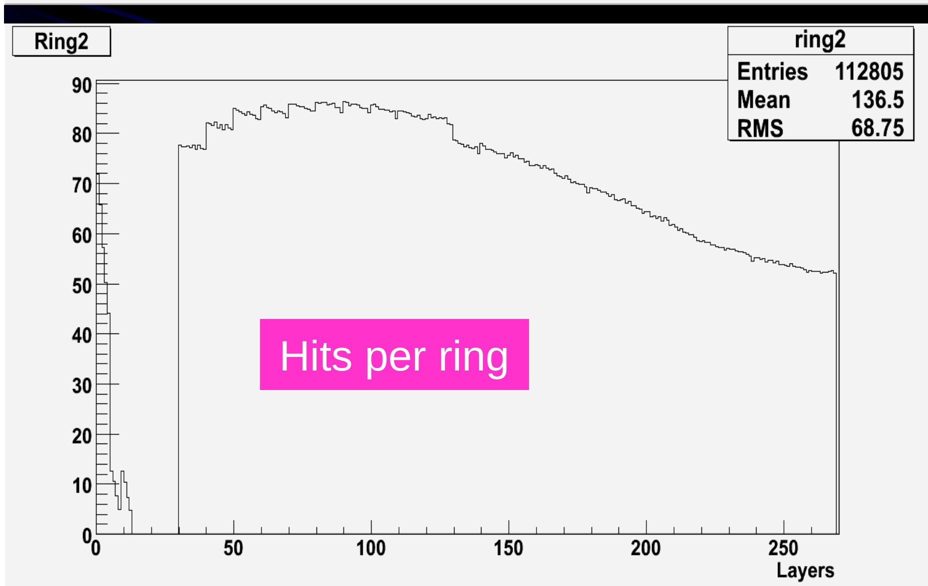
ttbar->6 jets events: Hits distributions

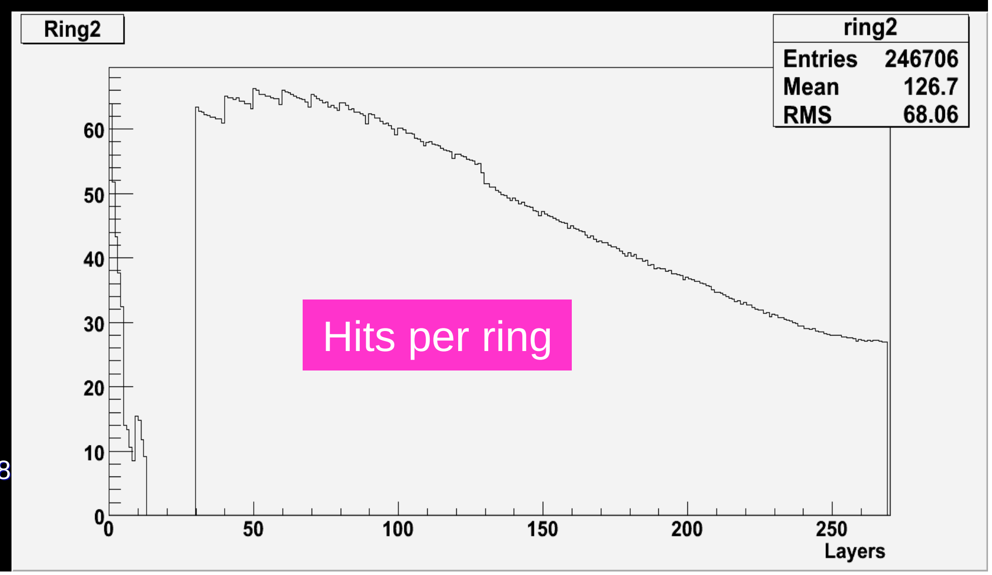
Ecm = 350 GeV
B = 3.5 T

Ecm = 3000 GeV
B = 5 T



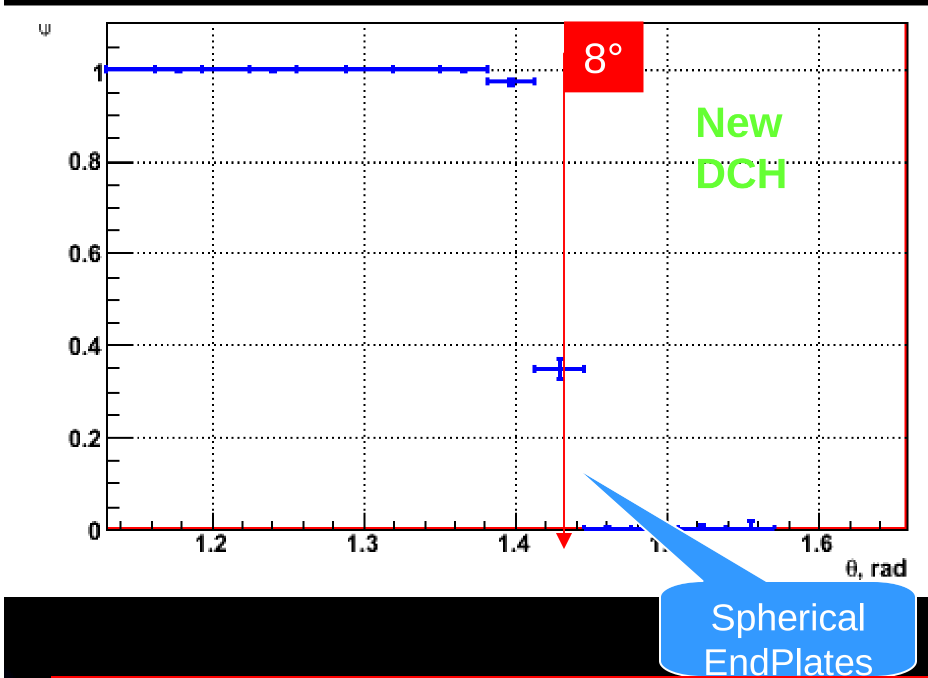


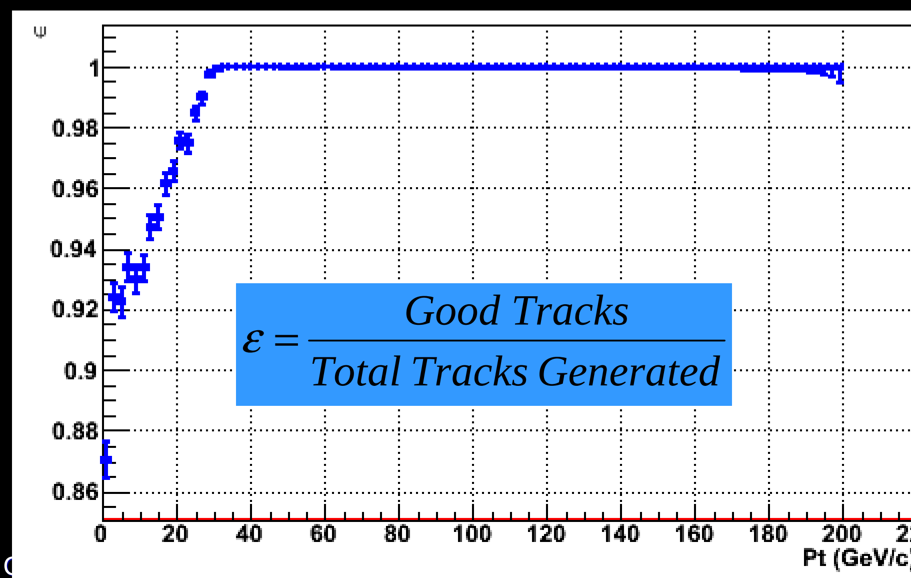




Geometrical Efficiency

10 muons





Defining “Good Tracks” (reconstructable)

I. DCA(true) < 3.5 cm

AND

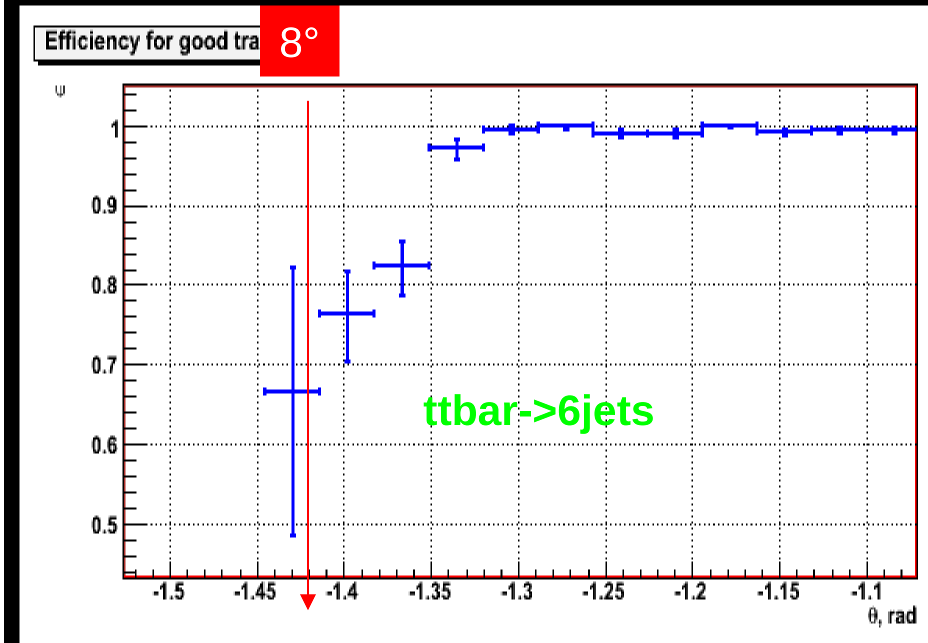
II. (At least 10 hits in DCH

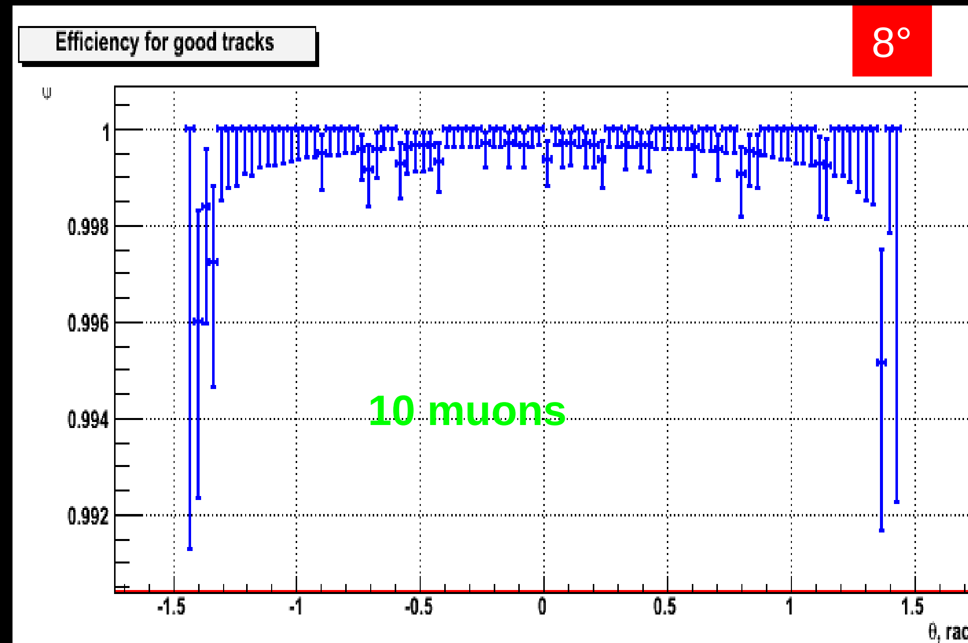
OR

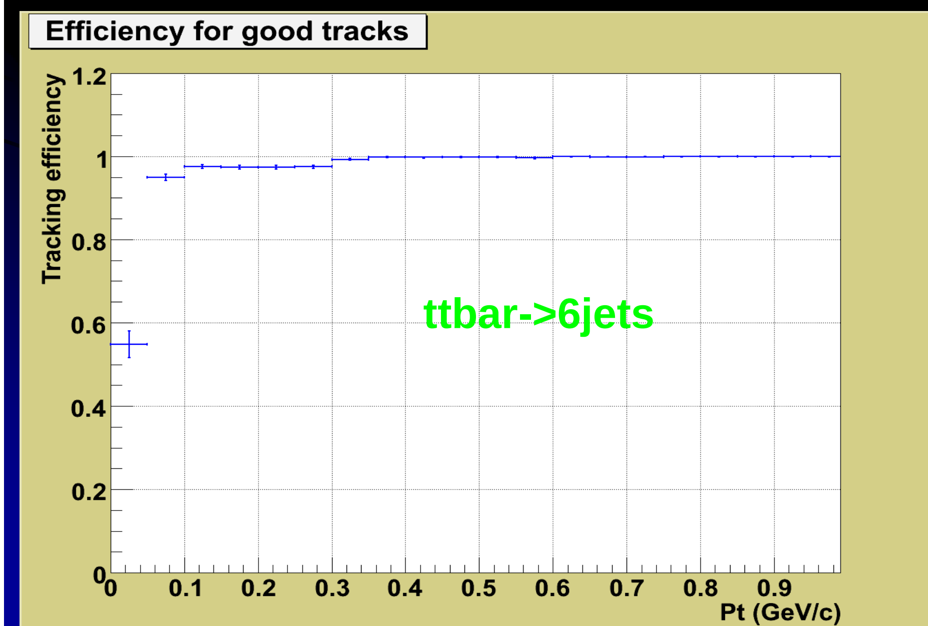
III. At least 4 hits in VTX)

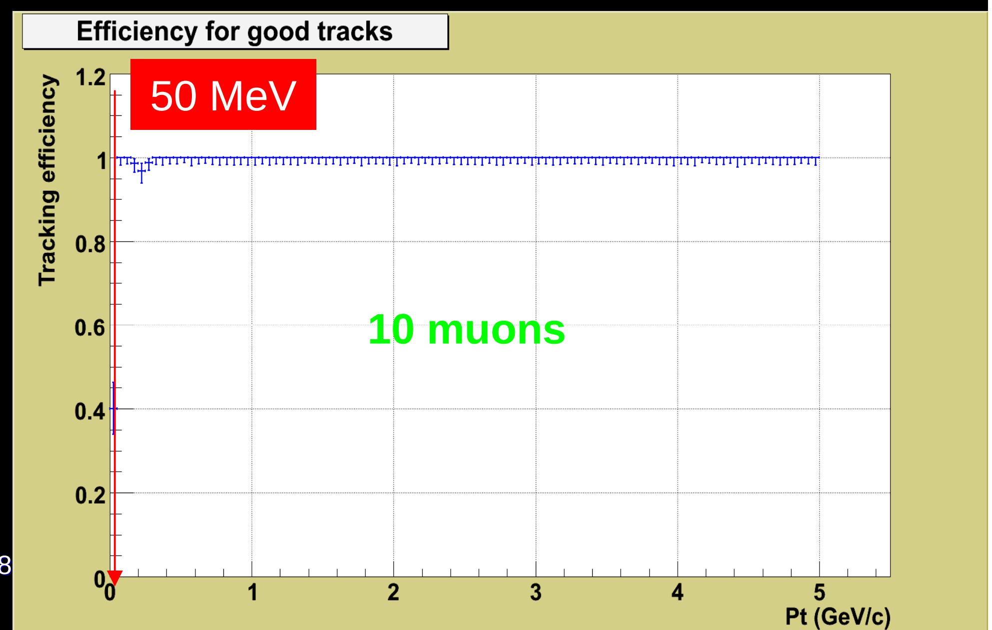
$$\varepsilon = \frac{\textit{reconstructed tracks}}{\textit{good tracks}}$$

Reconstruction Efficiency



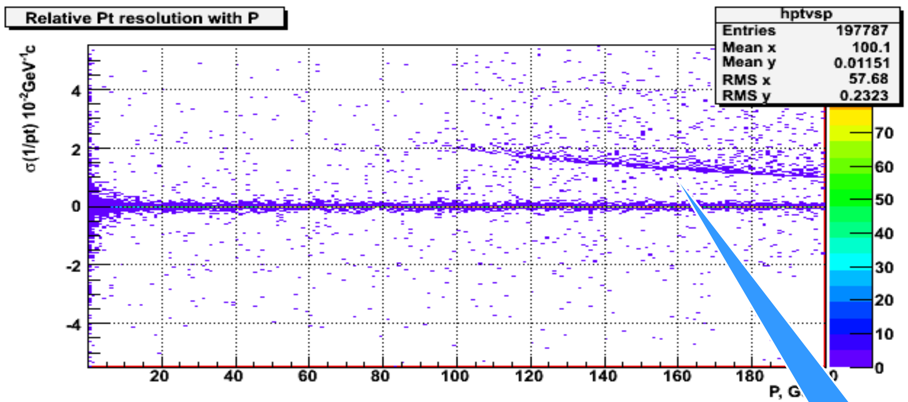


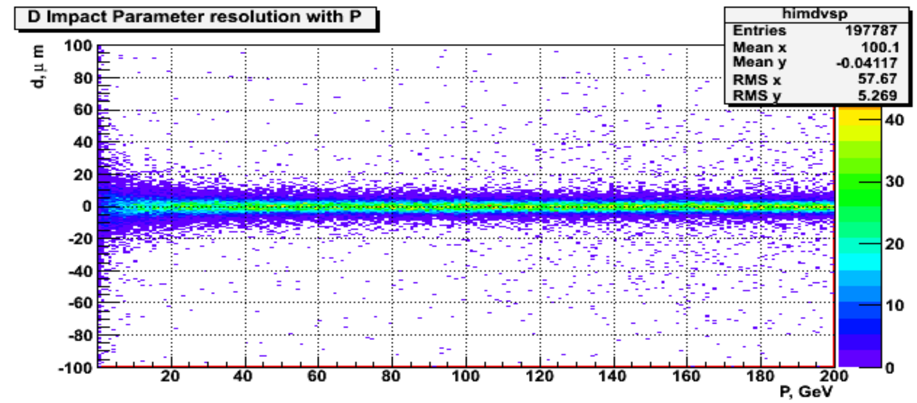


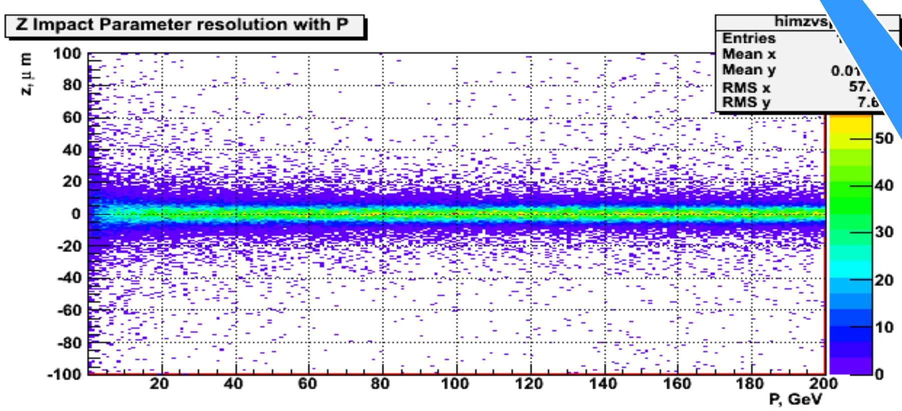


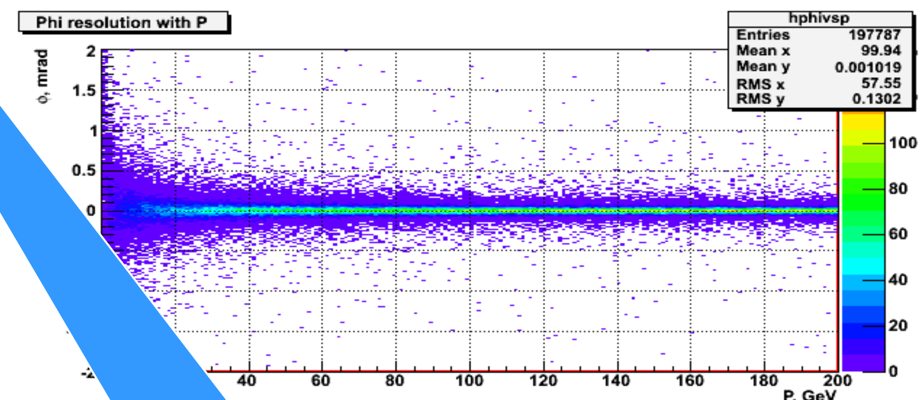
10 muons

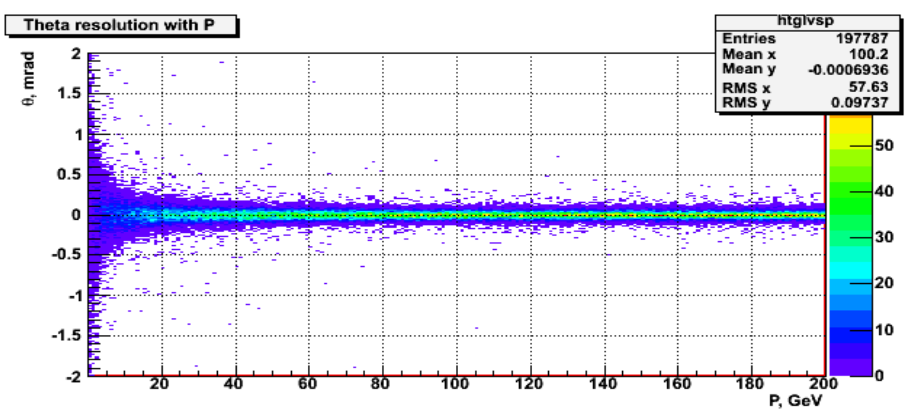
DCH Resolution vs P







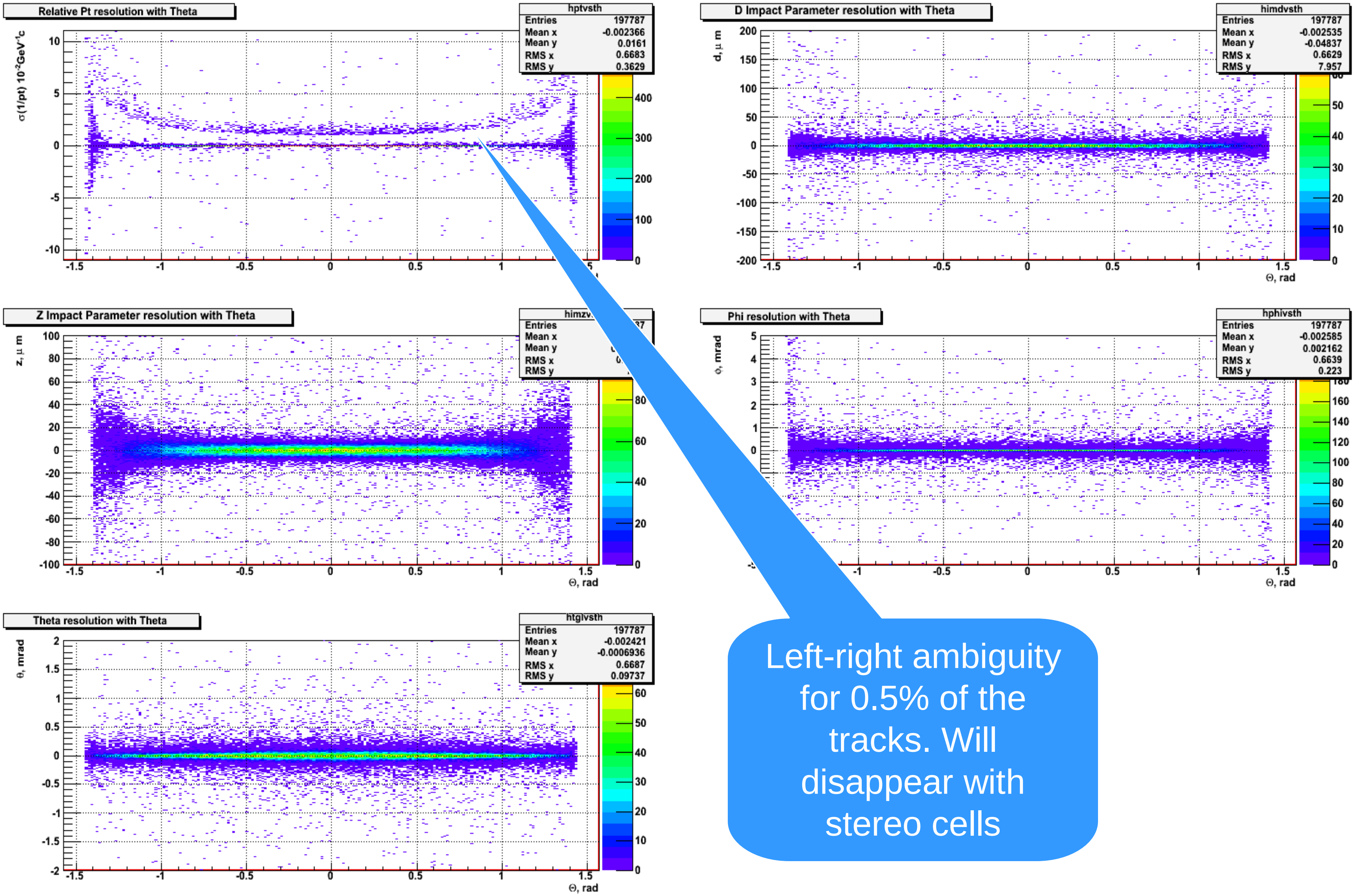




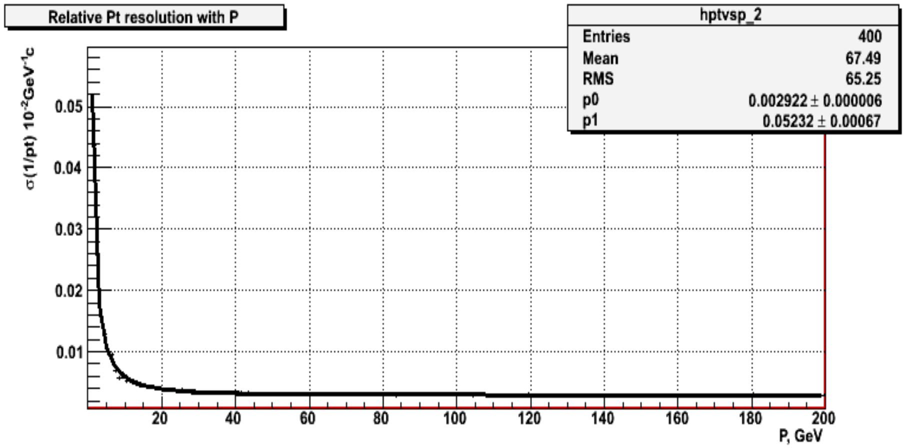
Left-right ambiguity for 0.5% of the tracks. Will disappear with stereo cells

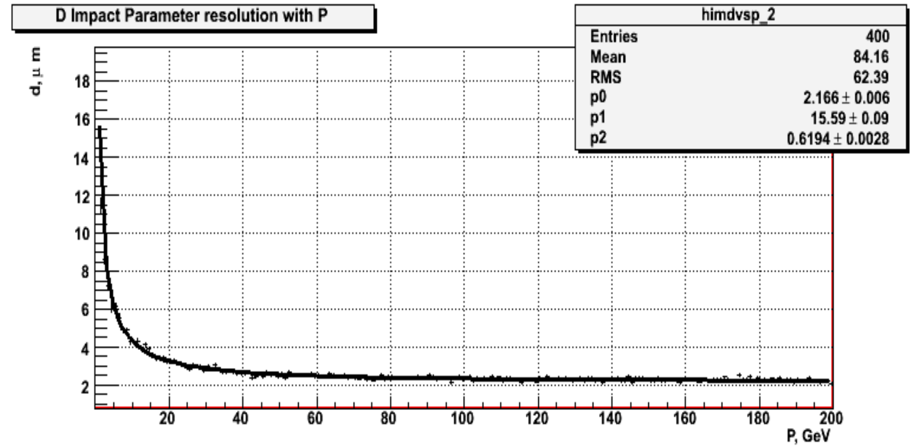
10 muons

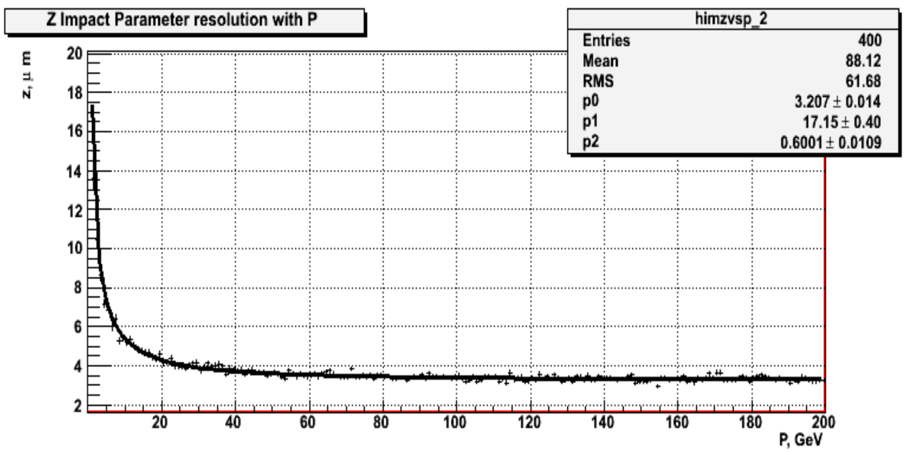
DCH Resolution vs θ

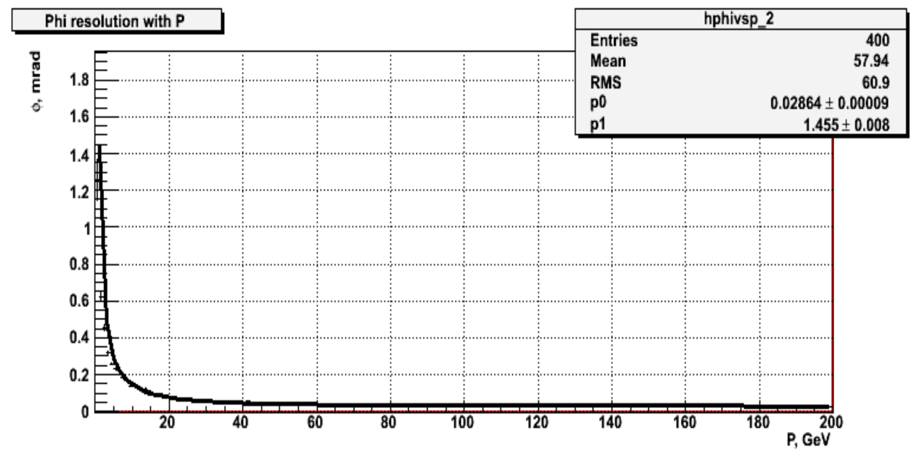


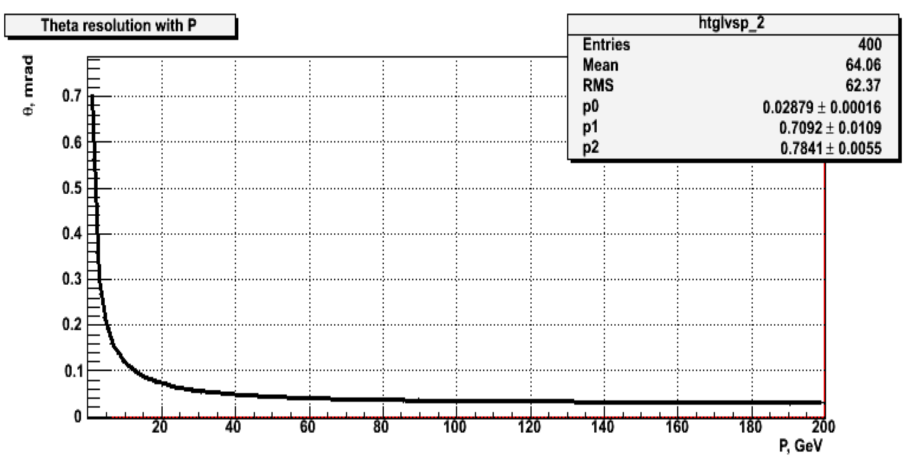
Left-right ambiguity for 0.5% of the tracks. Will disappear with stereo cells











$$\sigma(P_t^{-1}) = 5.2/P \oplus 0.3\times10^{-4}\,GeV^{-1}c$$

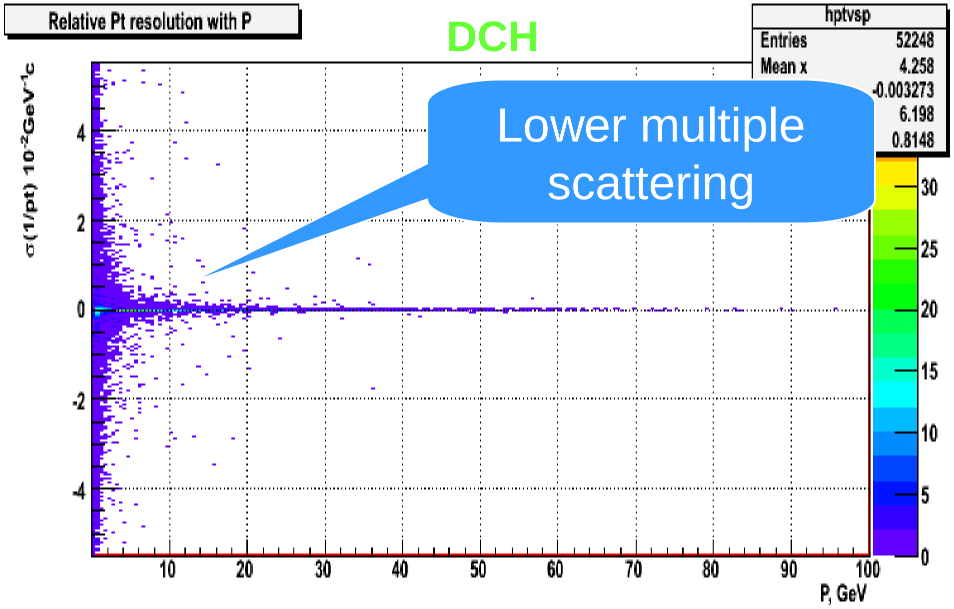
$$\sigma(\vartheta) = 0.71/P^{0.78} \oplus 0.029\ mrad$$

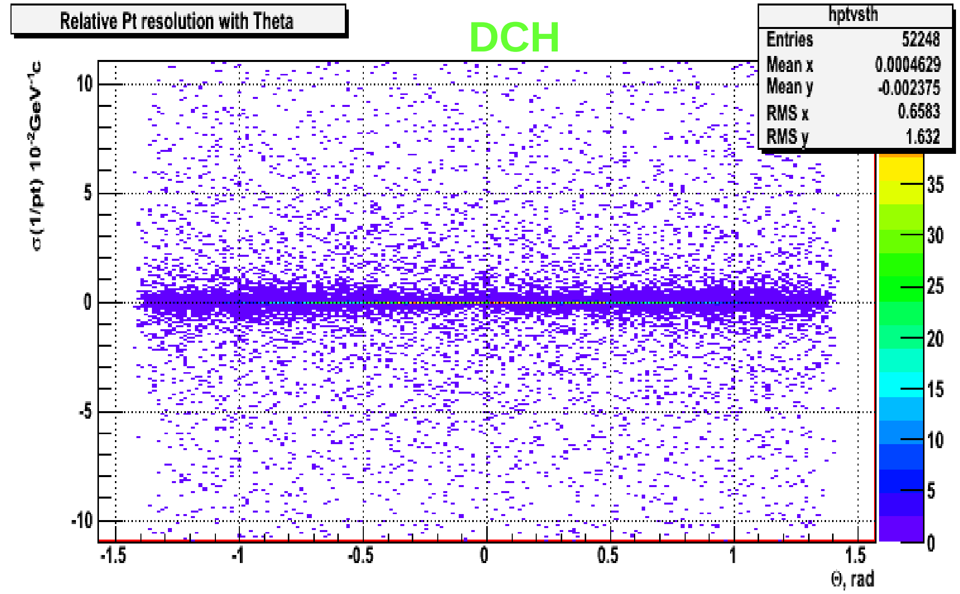
$$\sigma(\varphi) = 1.46/P \oplus 0.029\ mrad$$

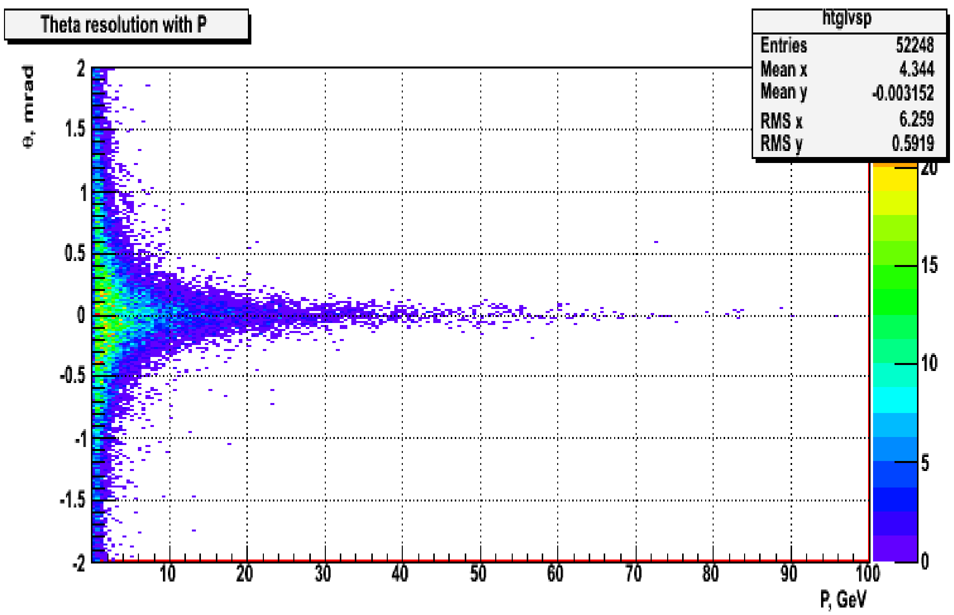
$$\sigma(D_o) = 15.6/P^{0.62} \oplus 2.2\ \mu m$$

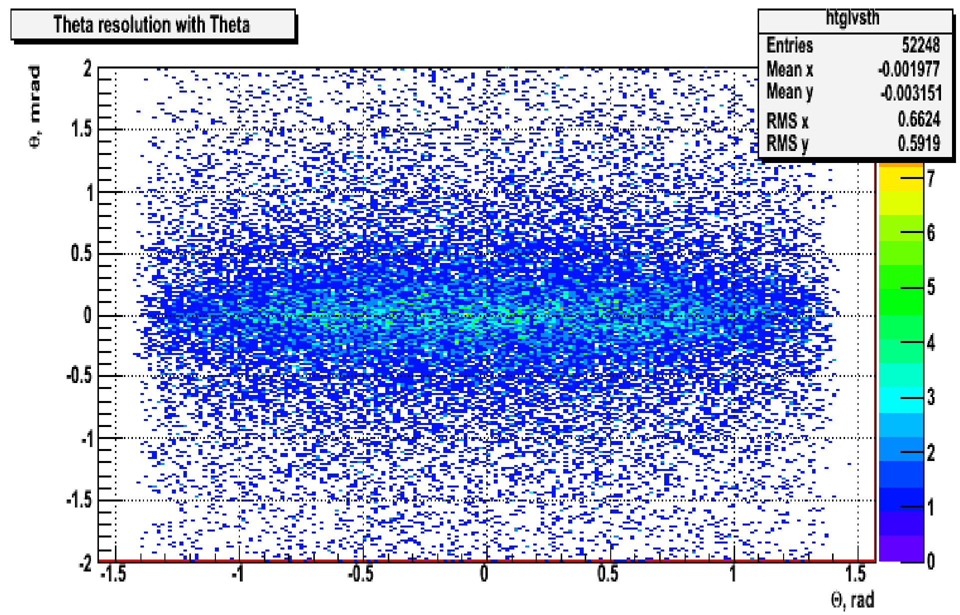
$$\sigma(Z_o) = 17.2/P^{0.60} \oplus 3.2\ \mu m$$

Resolution in ttbar->6jets

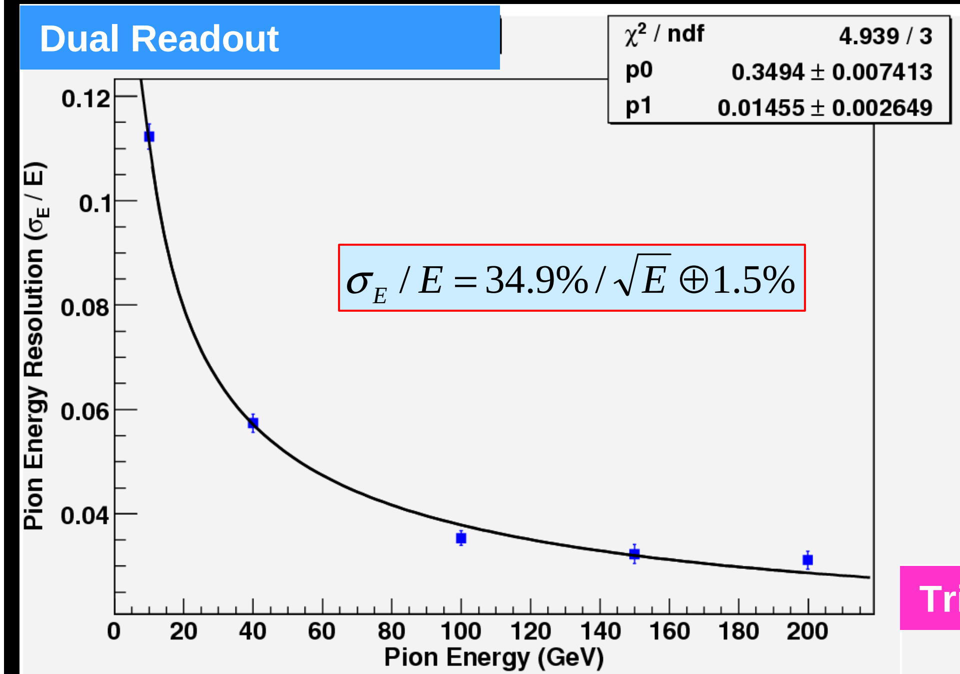


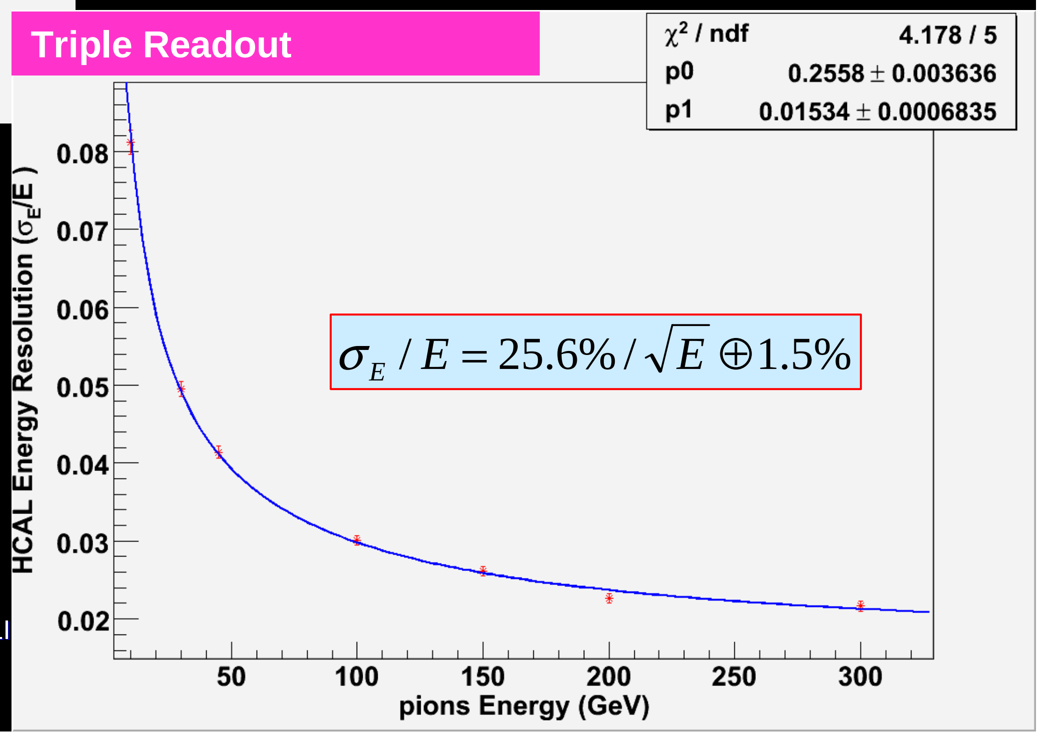




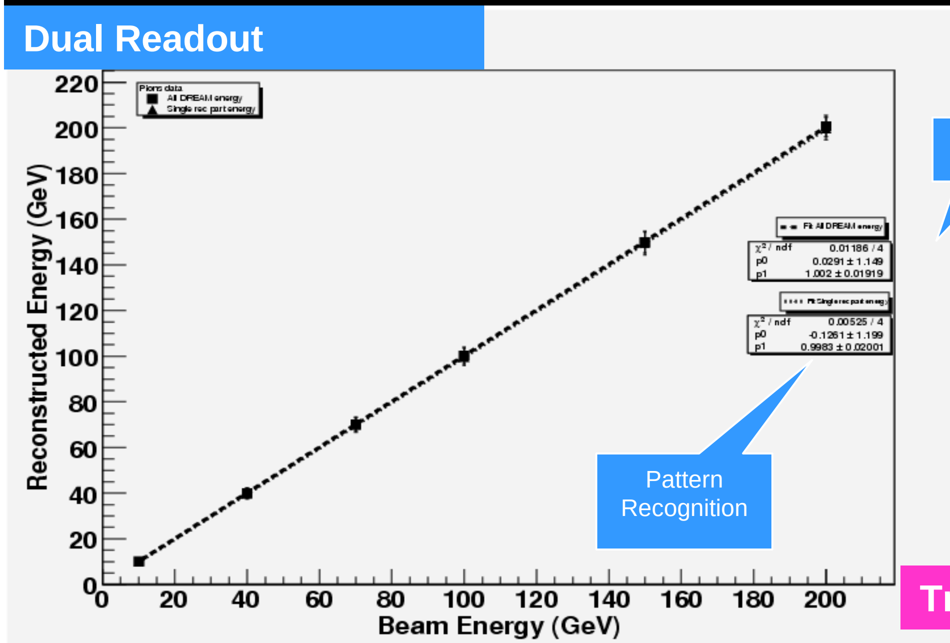


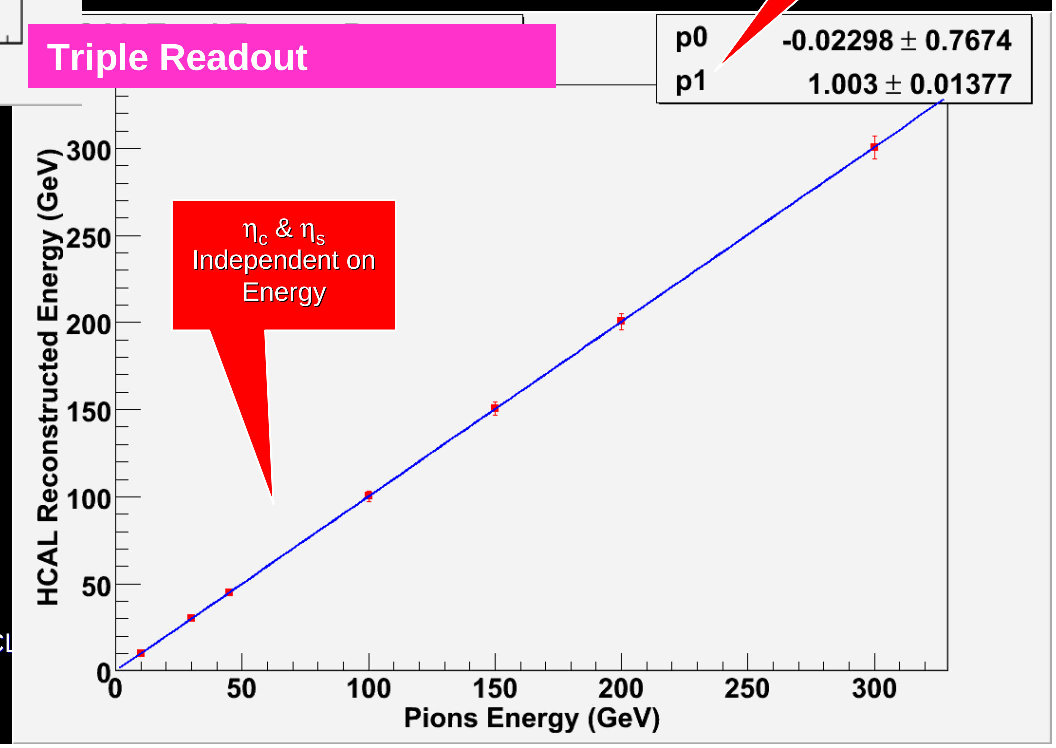
HCAL resolution with single π





Reconstructed vs Beam Energy

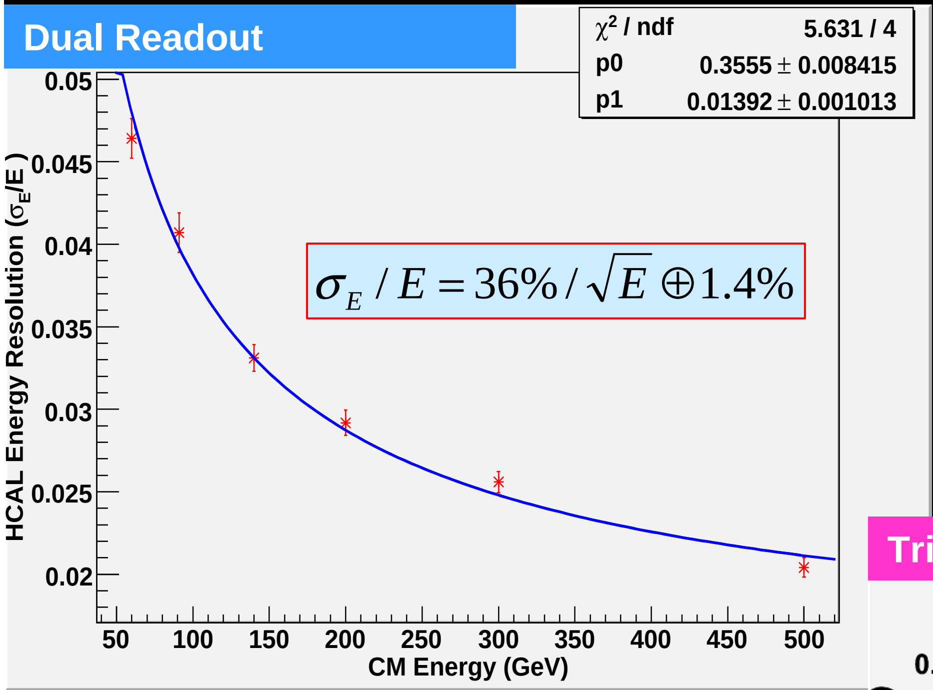




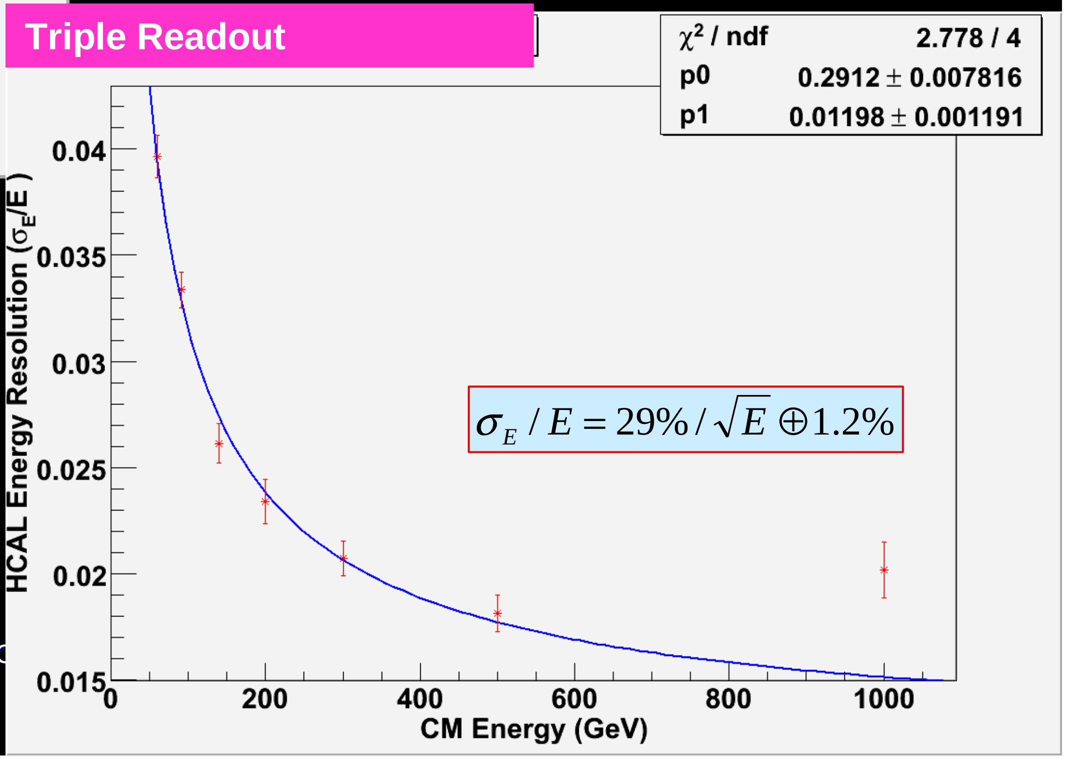
Di-jets events

Total Energy Resolution for di-jets

Dual Readout



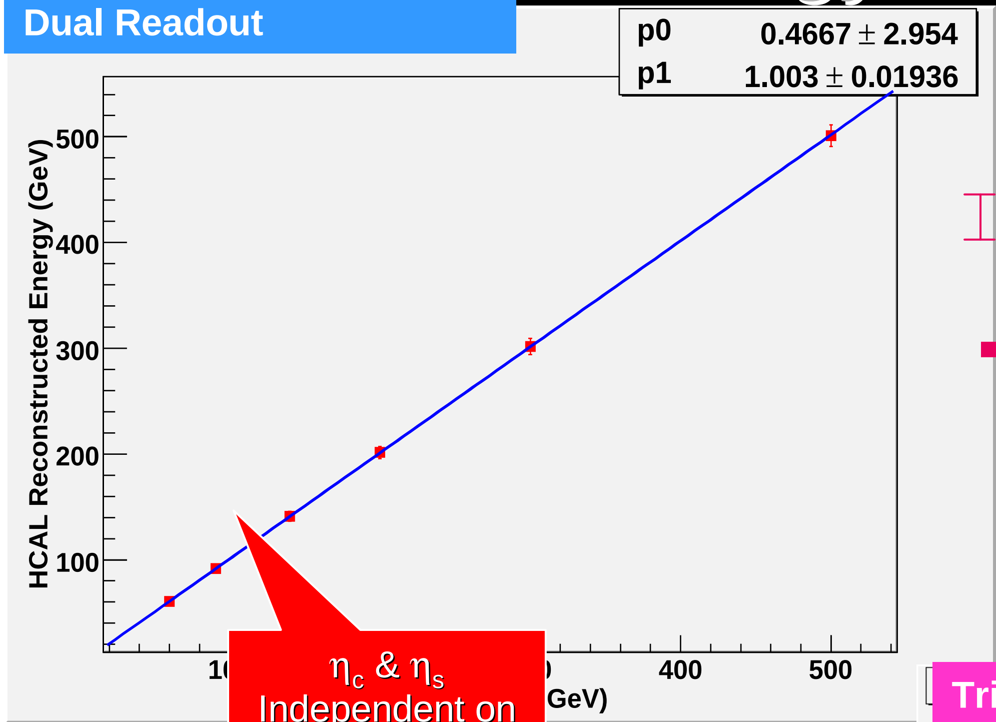
Triple Readout



Energy Response

Di-jets events

Dual Readout

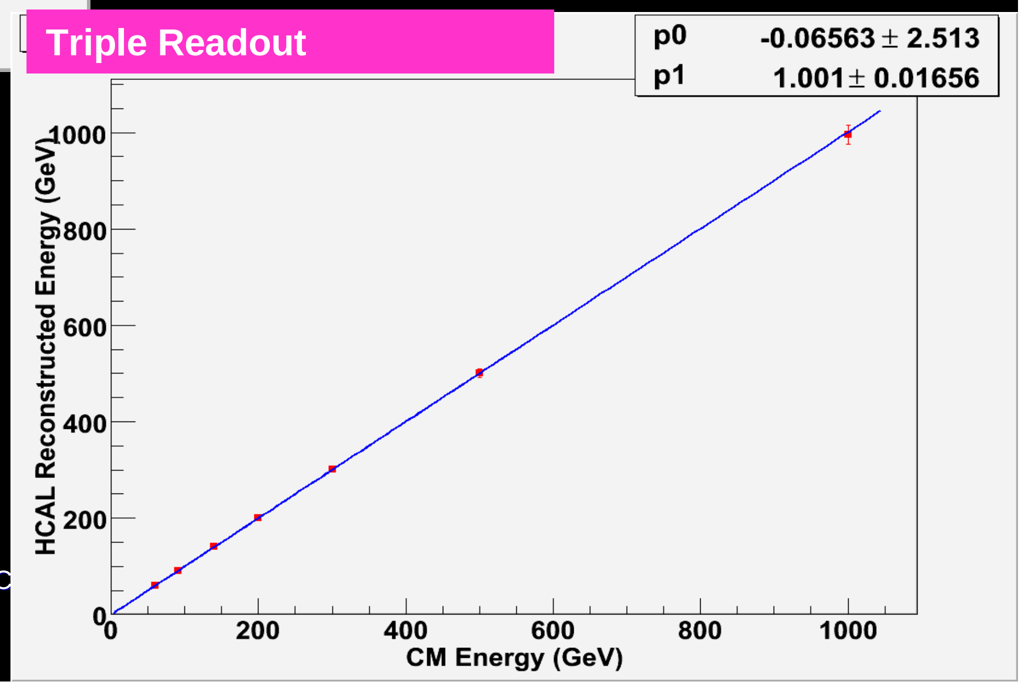


η_c & η_s Independent on Energy

Sigma from Gaussian fit on the Total Energy Distribution

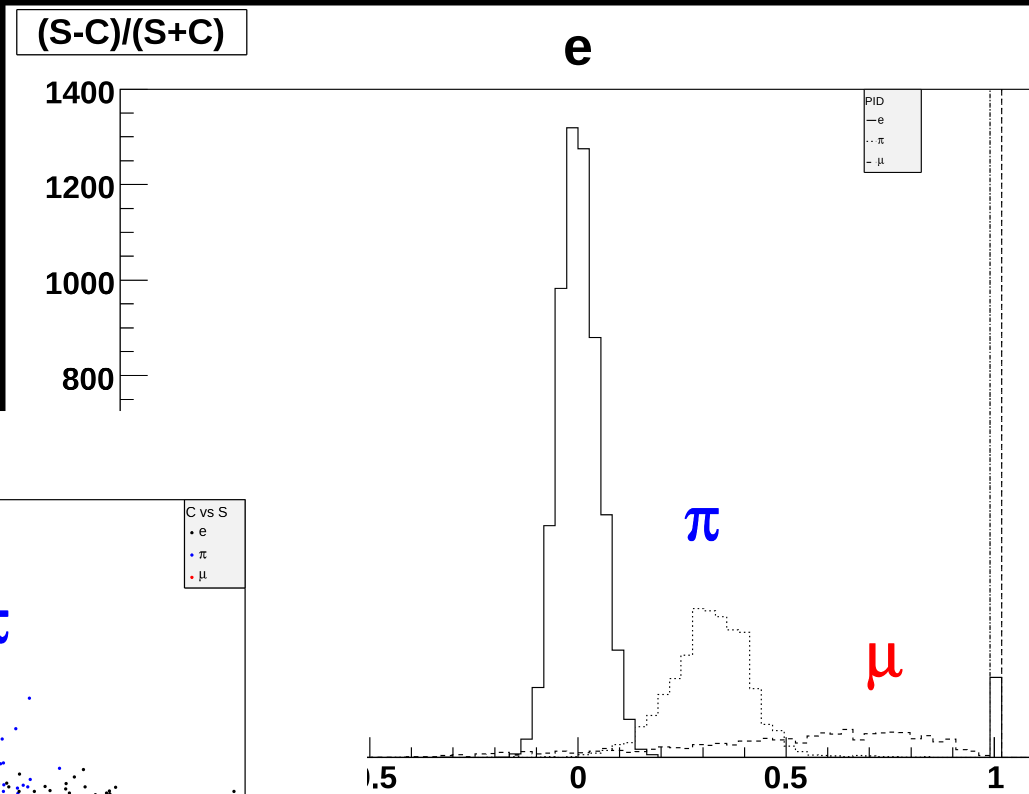
Mean from Gaussian fit on the Total Energy Distribution

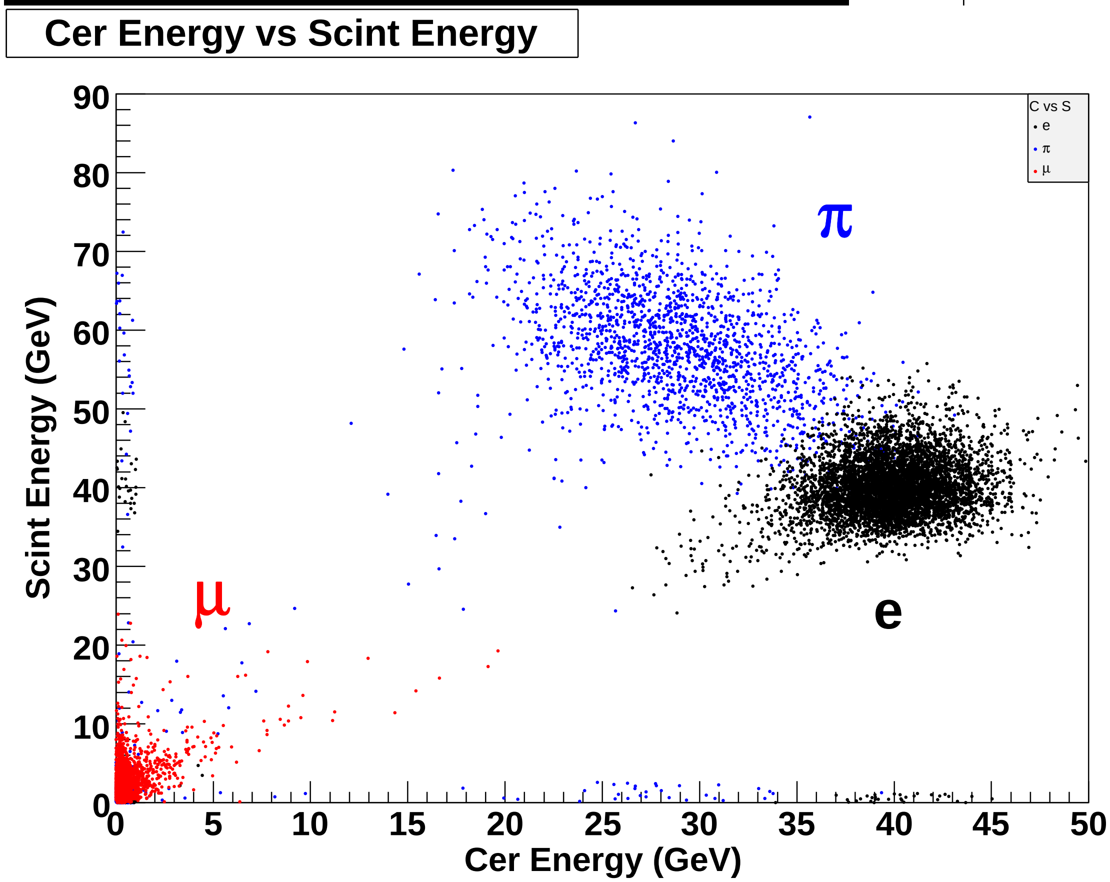
Triple Readout



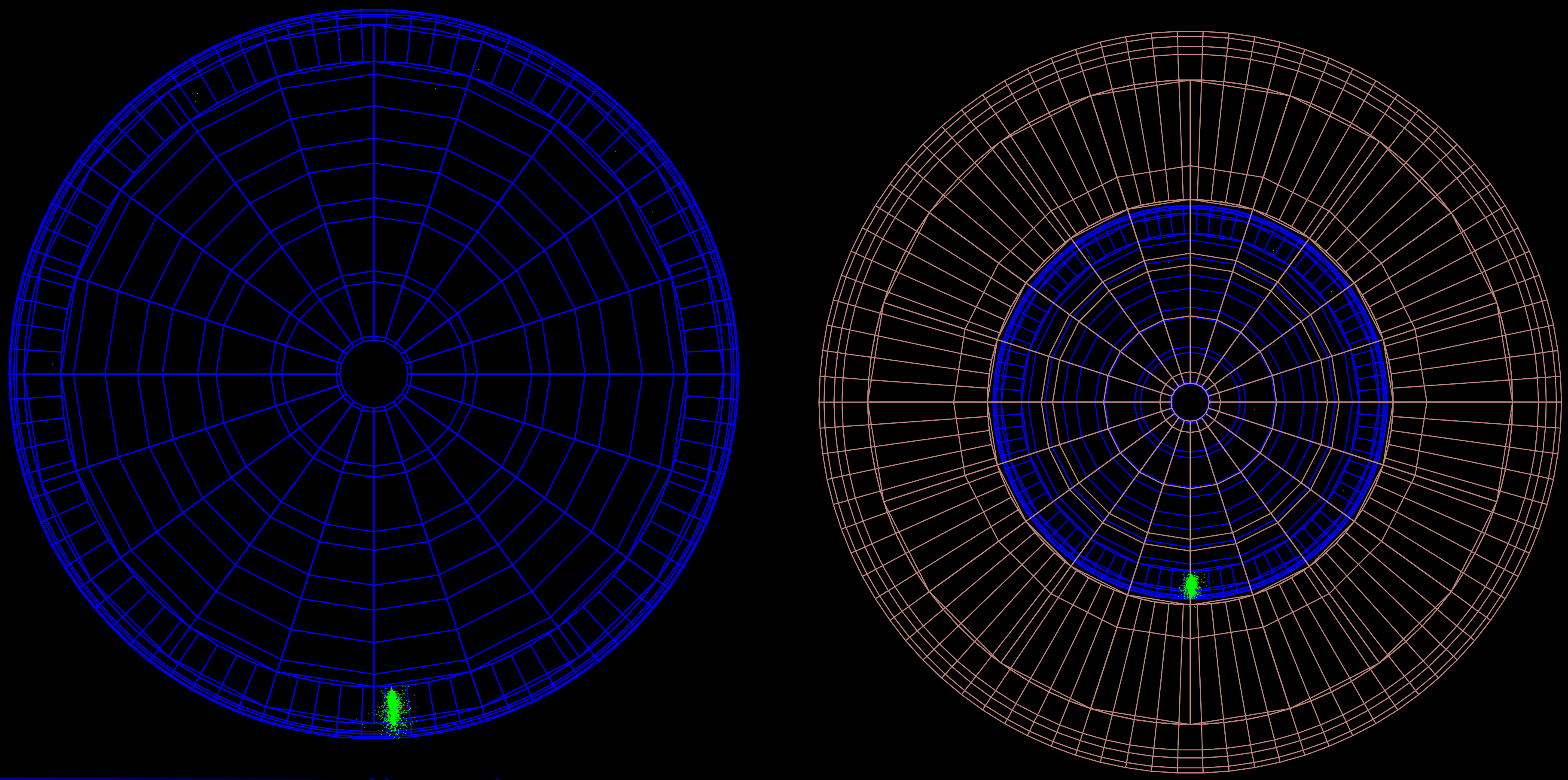
HCAL Particle Identification

- 40 GeV particles

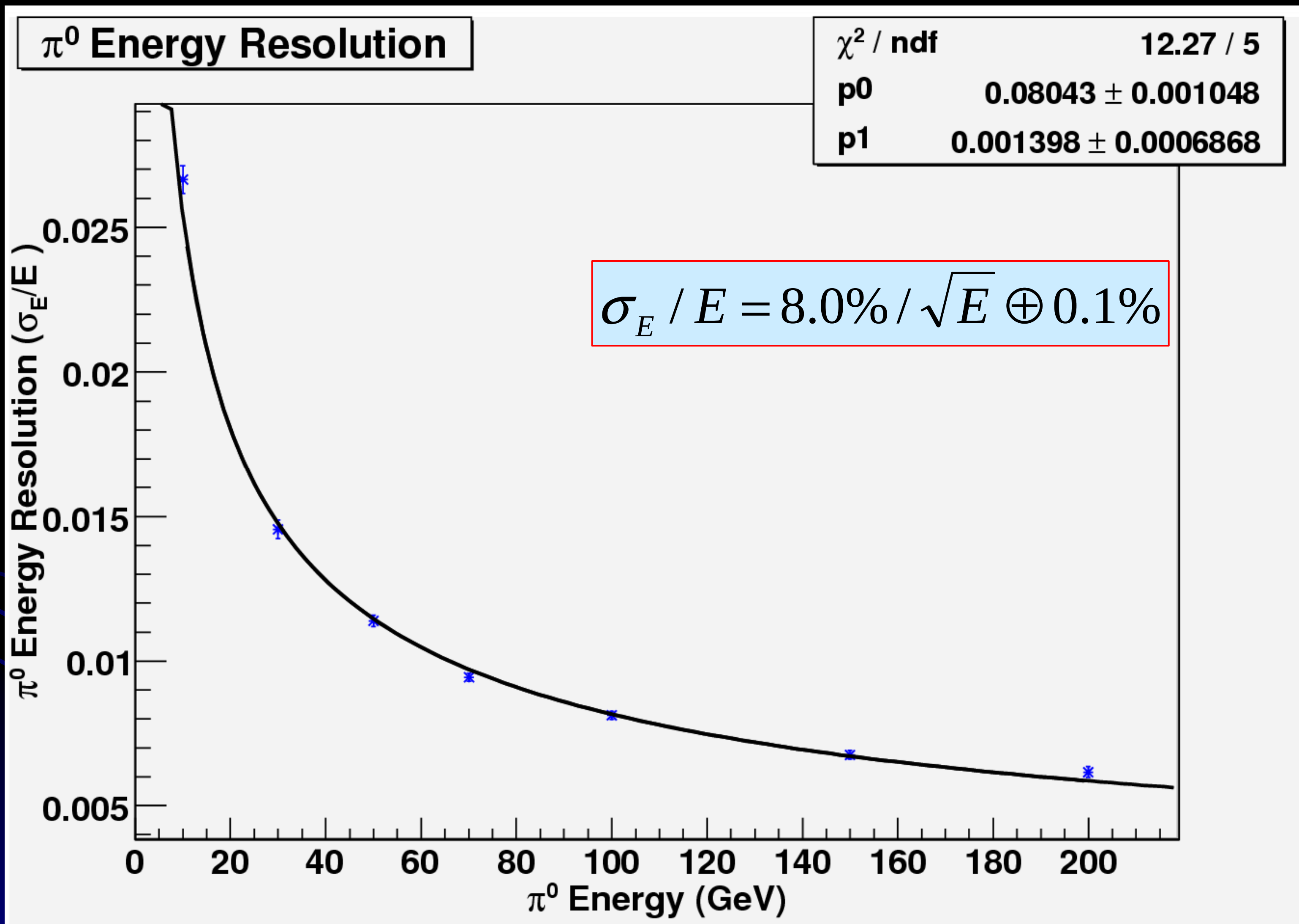




70 GeV π^o in ECAL+HCAL



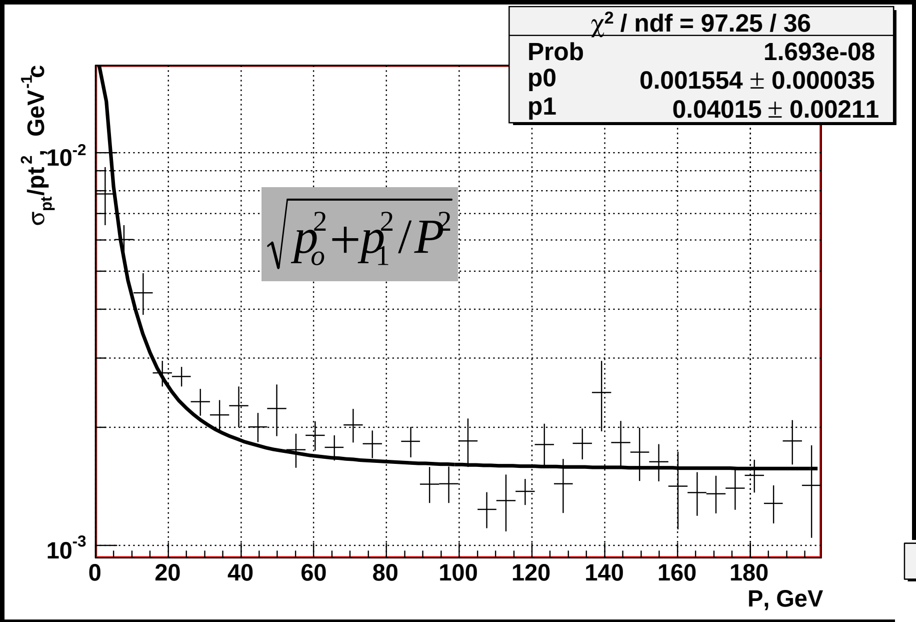
Resolution for π^o in ECAL+HCAL



ECAL+HCAL Issues

- Preliminary studies on ECAL+HACAL for hadronic showers and jets
- Making ECAL and HCAL working together is not trivial
- Simple merging of the two showers is not working
- Need a more involved calibration
- Otherwise need to give up the crystals or make a purely crystal calorimeter

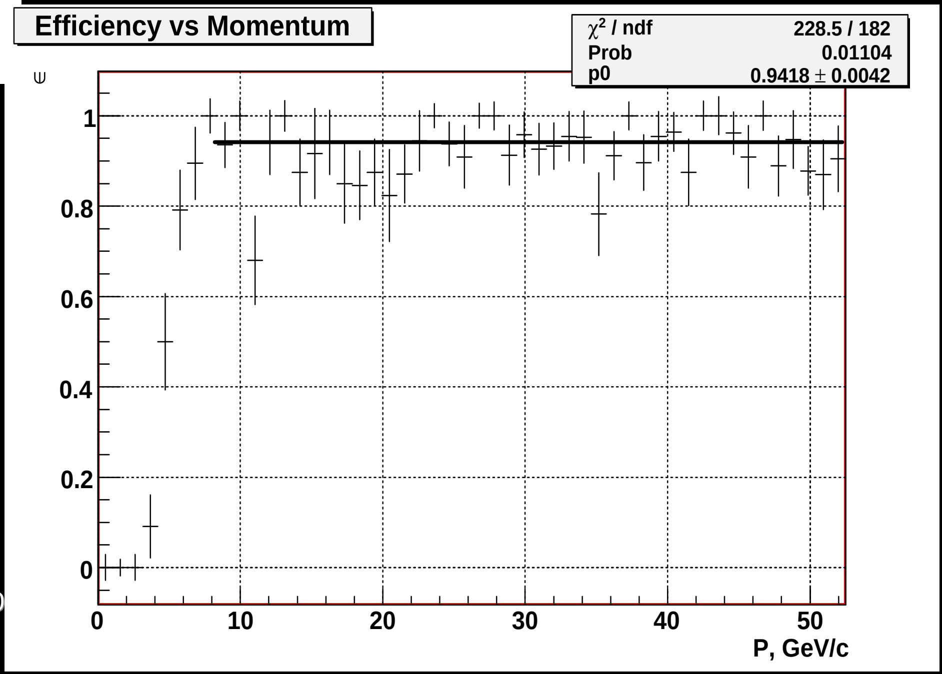
Muon Spectrometer Performance



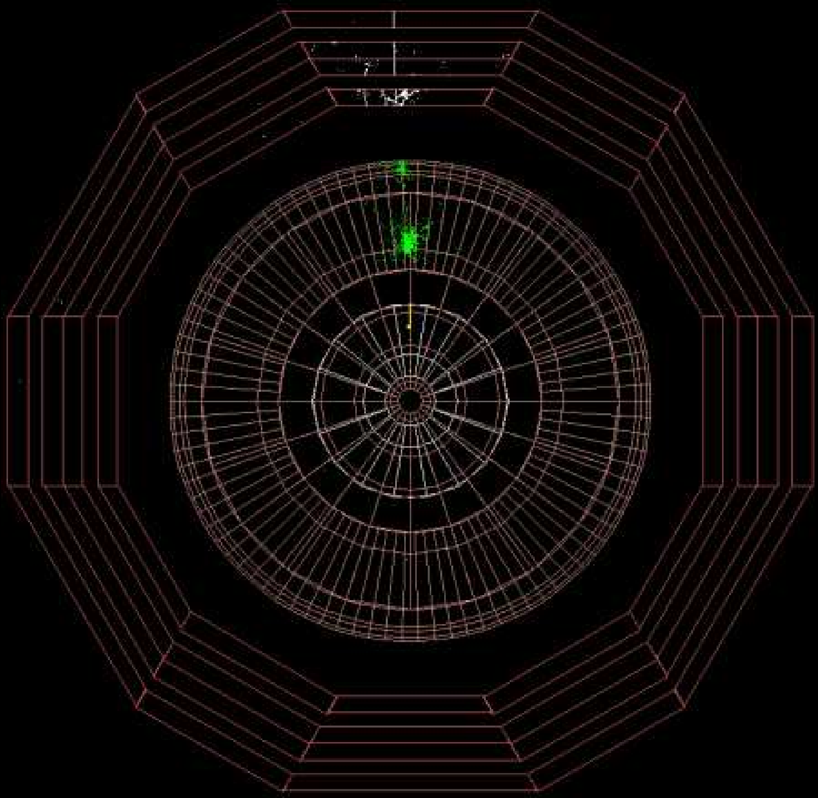
Cracks excluded

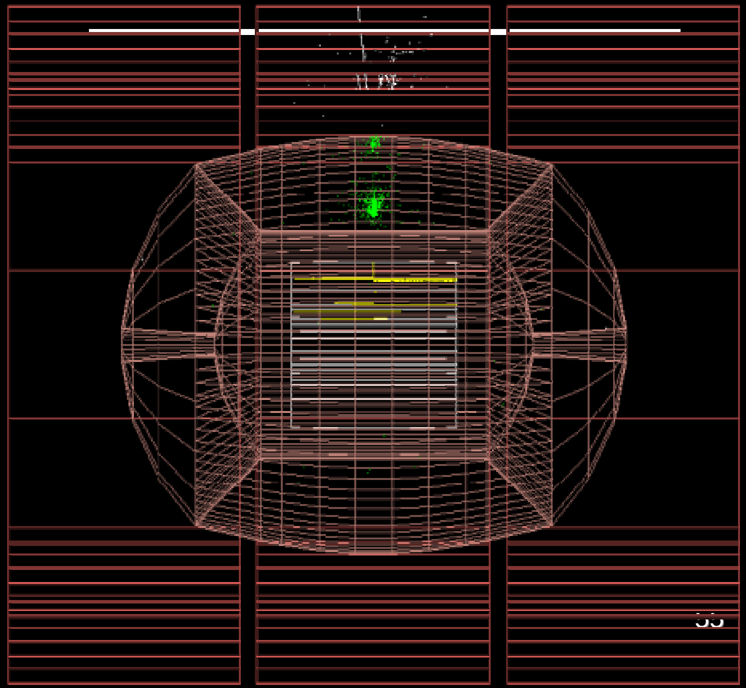
Tracks already reconstructed in DCH

Efficiency is for barrel only



80 GeV jet with escaping particles

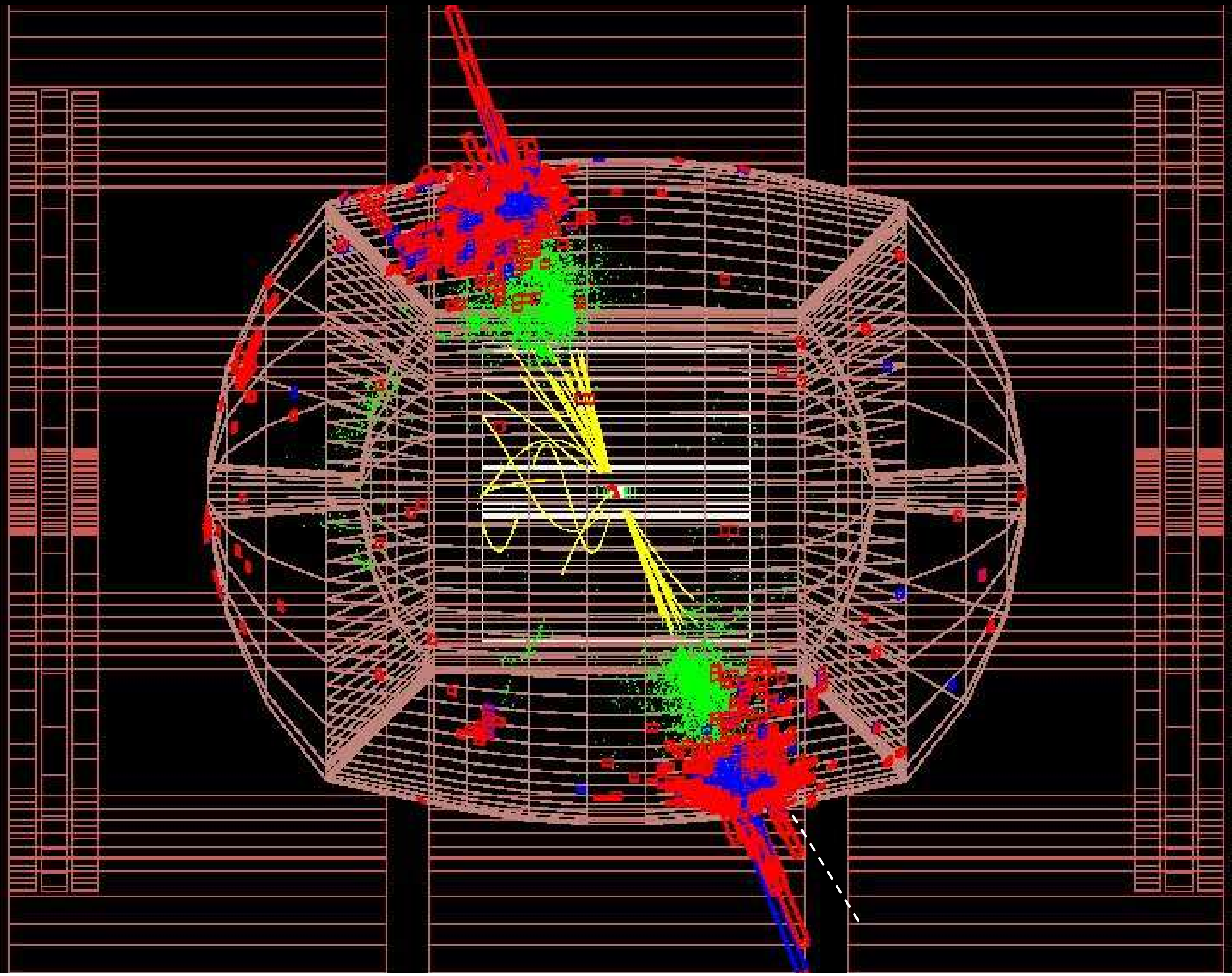




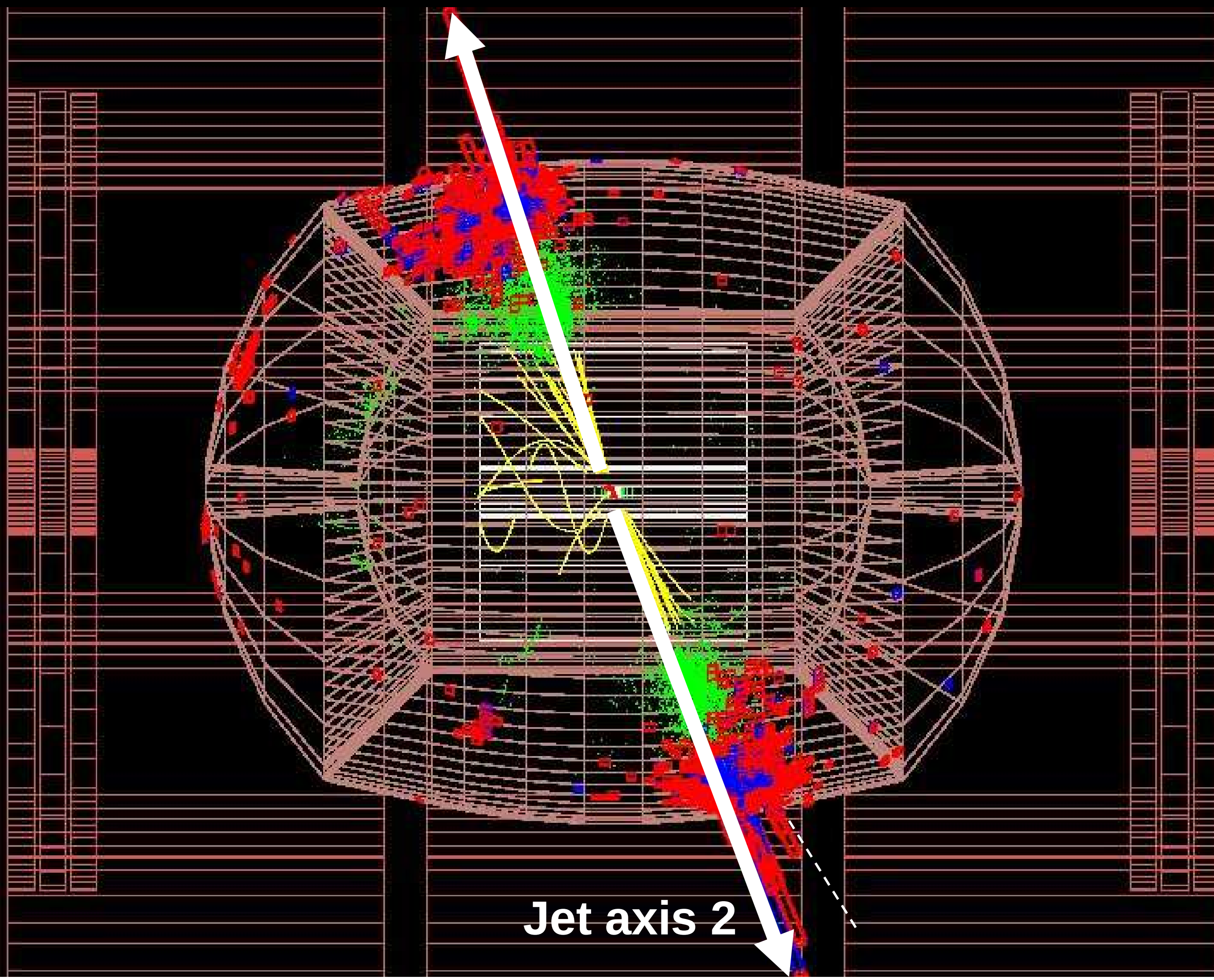
Jet reconstrucion:
combine calormetric and tracking informations

(work in progress)

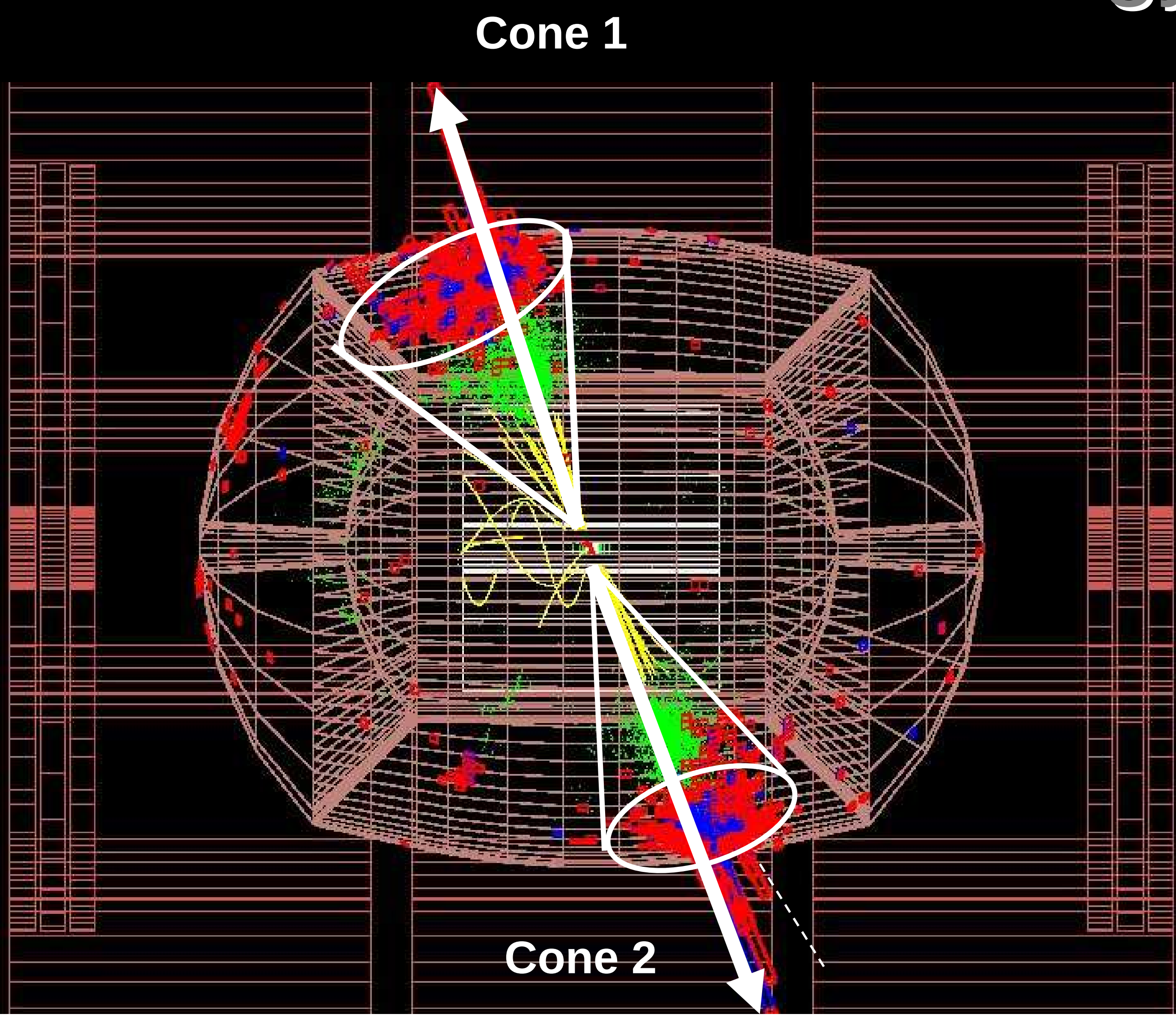
Jet Reconstruction Strategy



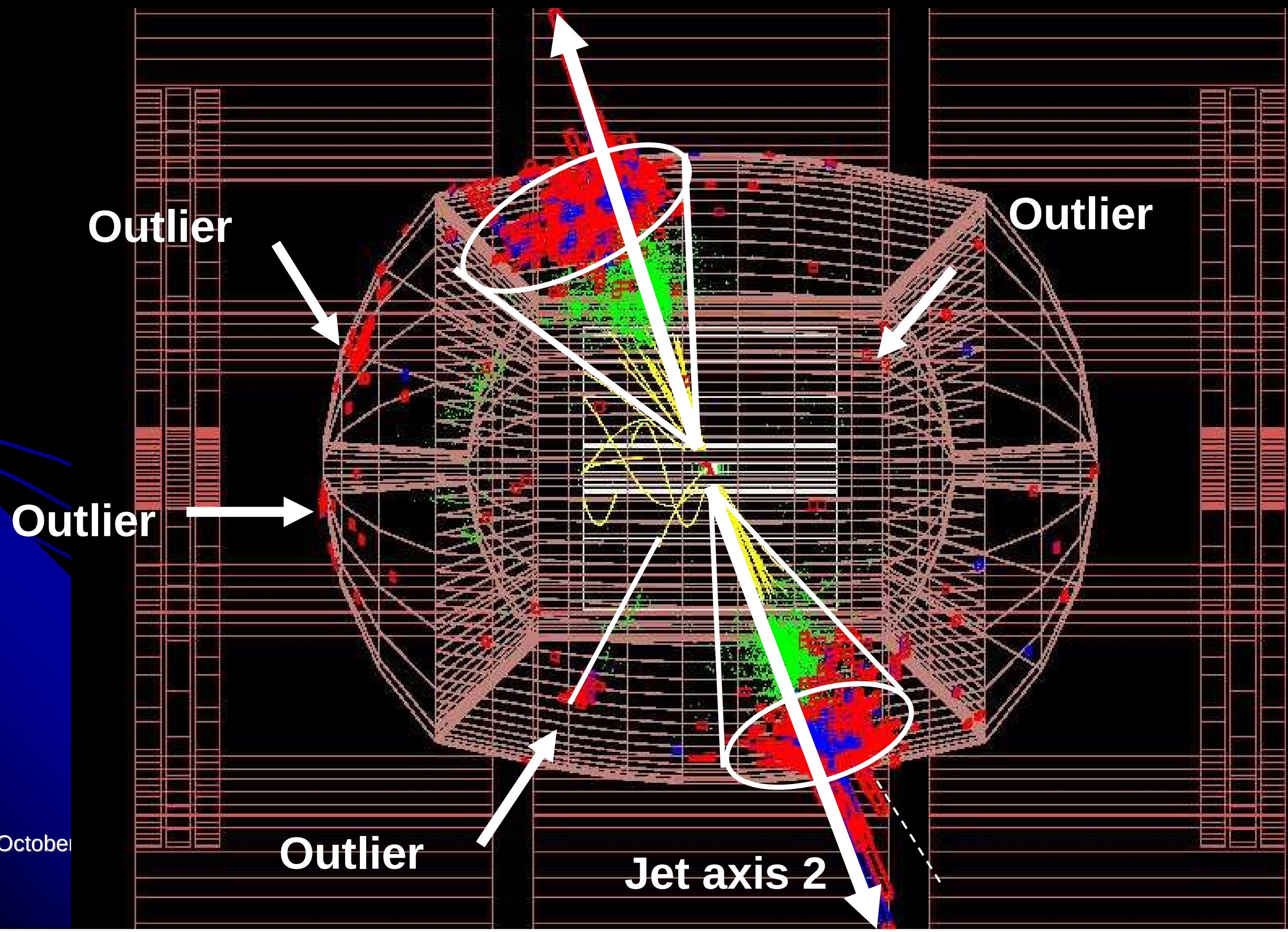
Jet Reconstruction Strategy



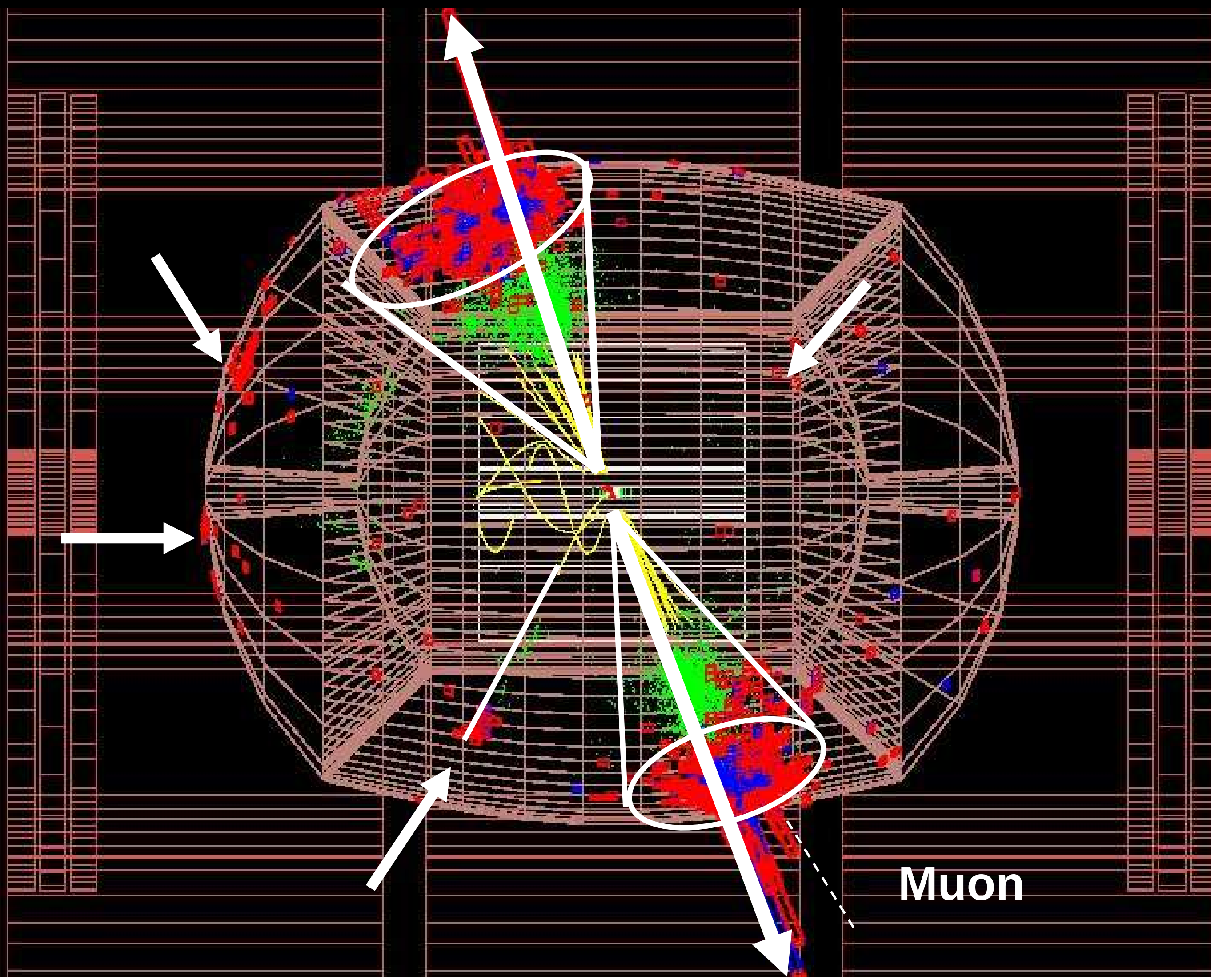
Jet Reconstruction Strategy



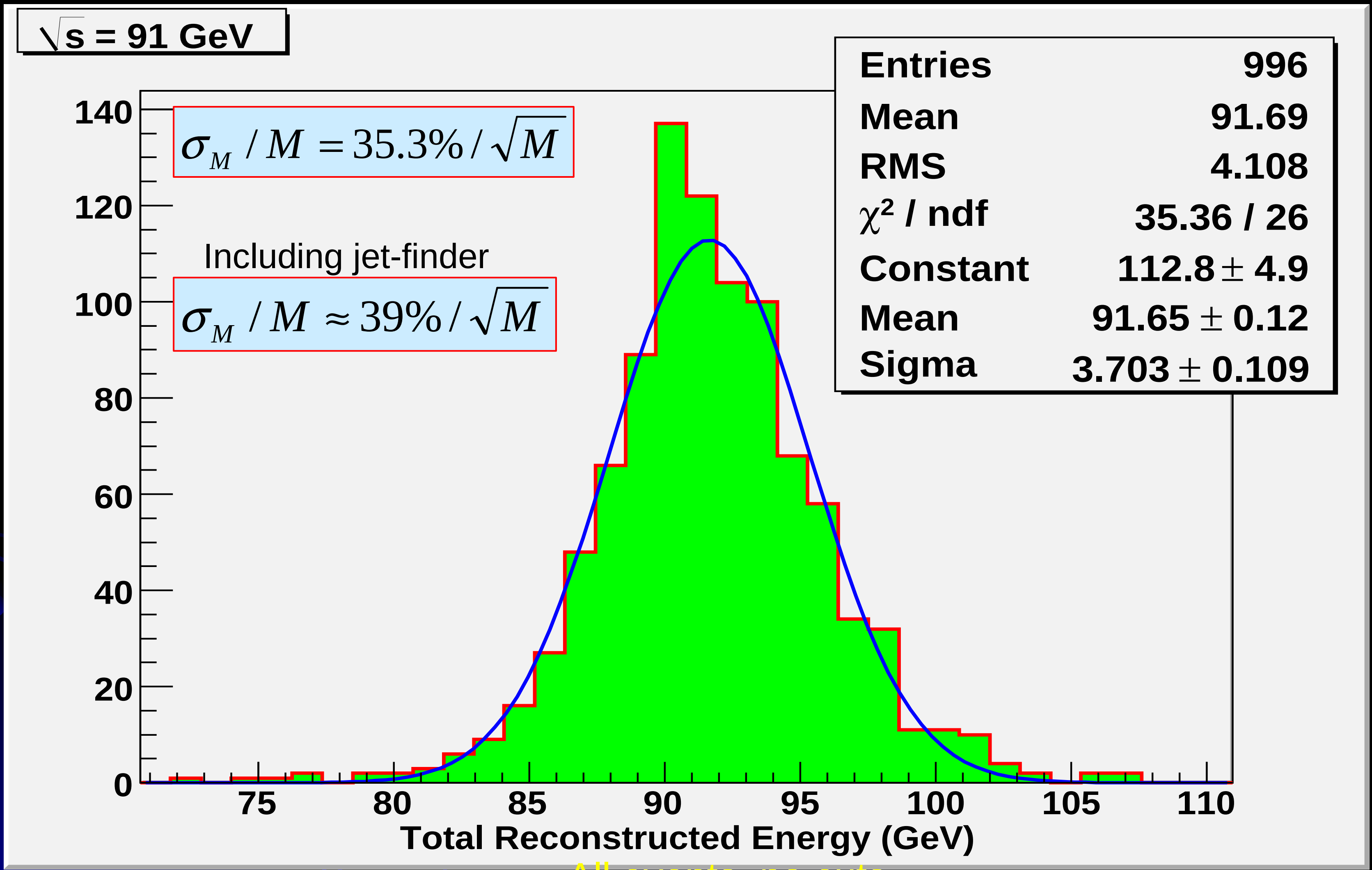
Jet Reconstruction Strategy



Jet Reconstruction Strategy



Z_o Mass with Dual Readout

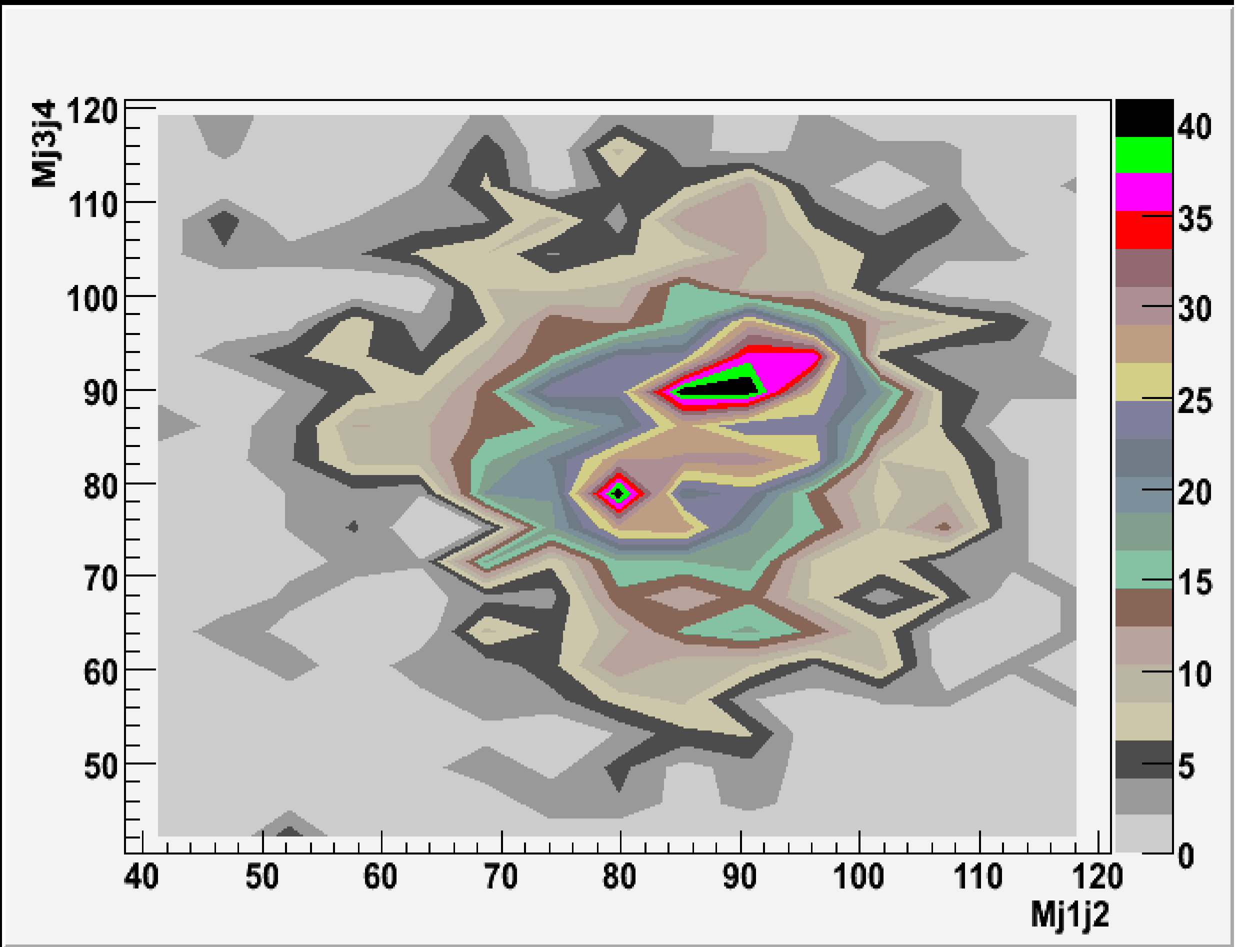


All events, no cuts

$$e^{+}e^{-} \rightarrow W^{+}W^{-}\nu\bar{\nu}, Z^{o}Z^{o}\nu\bar{\nu}$$

W/Z Mass Separation with Dual Readout

- Simple Durham jet-finder a la L3 (fixed/variable ycut) used for this analysis
- No combined information with tracking yet
- 4-jets finding efficiency: 95%



Study by A. Mazzacane

Summary of Detector Studies

- Resolutions with multi-jets are dominated by multiple scattering in VTX + Central Tracker
- Redundancy of measurements and **seeding in central tracker** is fundamental for good/safe performance
- Small drift cell (drift time<= time between BXs) relax the requirements on the VTX
- VTX resolution likely not an issue (for pixels about 20 μm x 20 μm)
- VTX material budget of 1% X/X_o is OK
- Energy resolution in Triple Readout Calorimeter is comparable with PFA
- Dual Solenoid Muon Spectrometer nice complement to Tracking + Calorimeter

Status and Perspectives

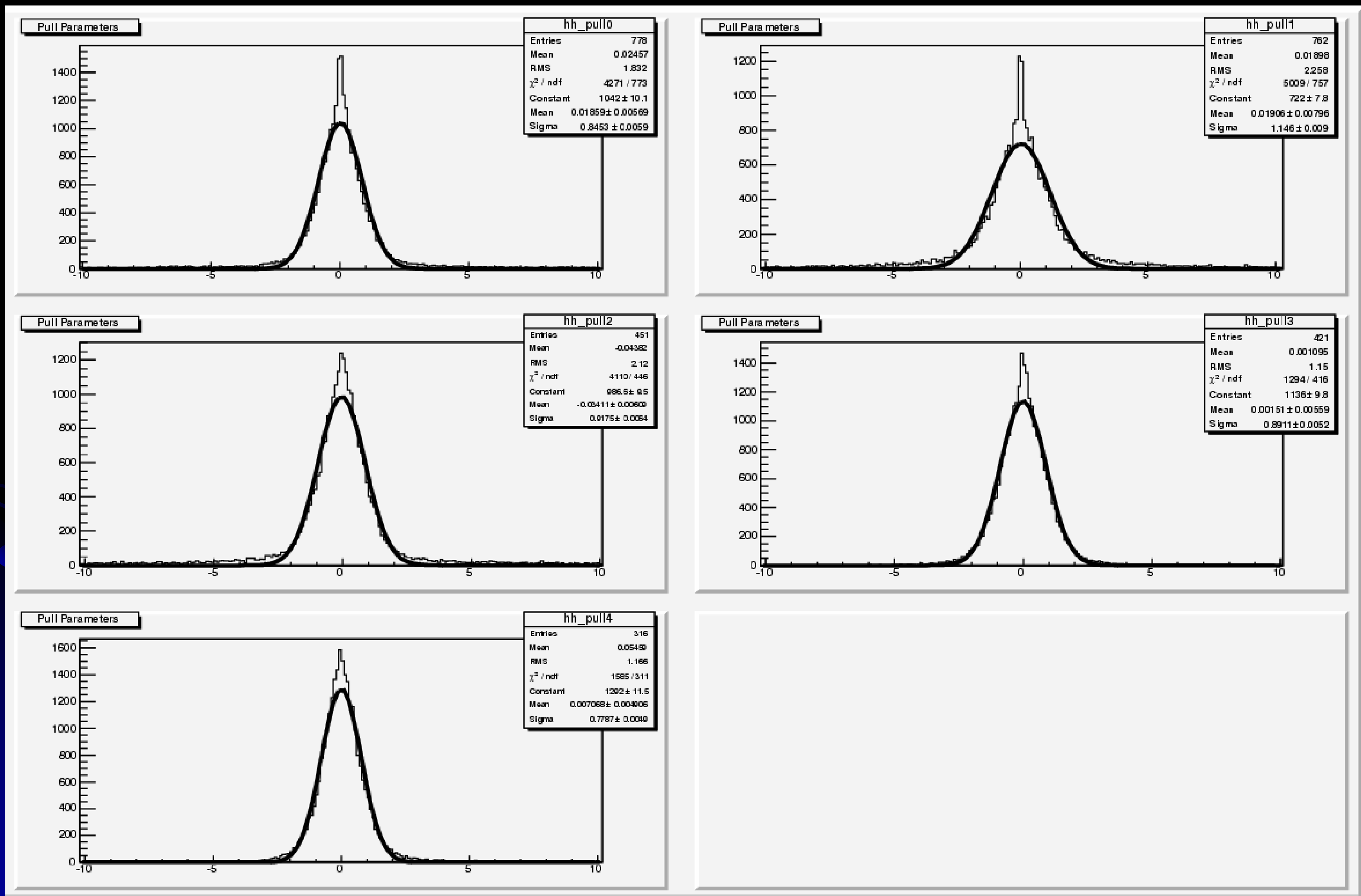
- Detector R&D is performed by independent collaborations (CLUCOU, DREAM, SiLC, etc)
- Most critical issues have been pinpointed:
  - DCH needs Si in fwd region: -> CLUCOU + SiLC
  - Crystal Calorimeter -> Collaboration with FNAL (A. Para)
- Software framework (ILCroot) runs smoothly at FNAL. It allows quick test of new ideas and efficient optimization work
- It is continuously upgraded, with newer versions of the subdetectors
- Present effort is for the Letter of Intent (March 2009)
- **We suffer from shortage of funding rather than human resources**

Backup slides

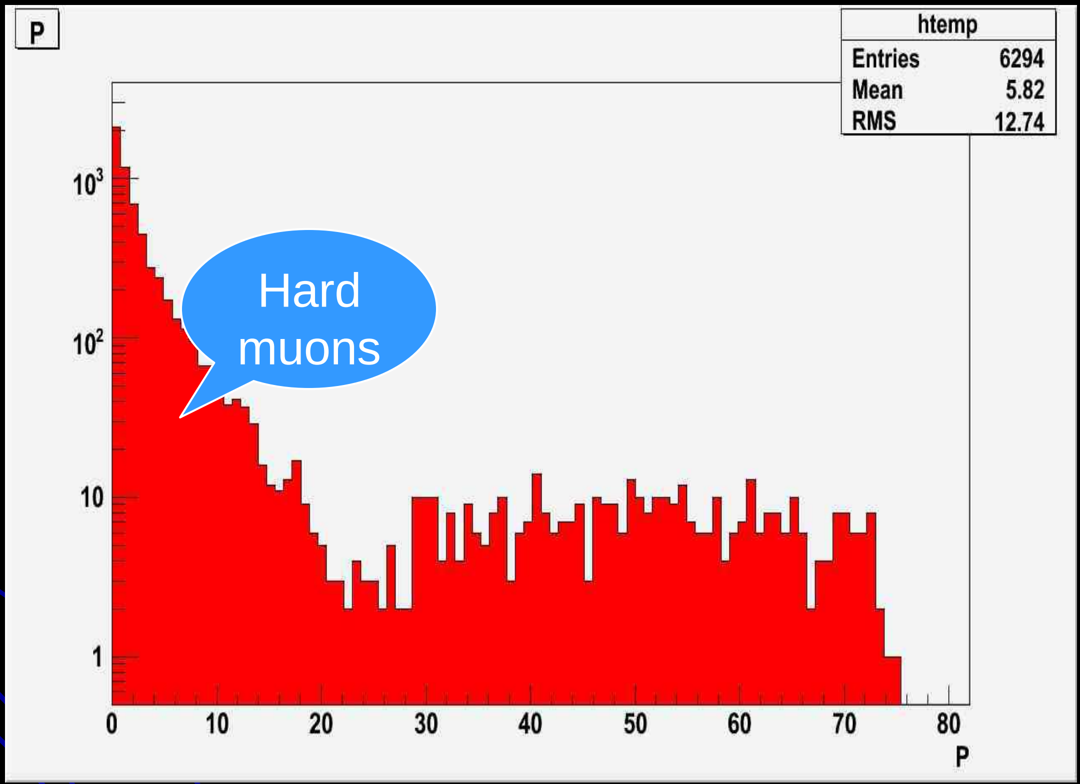
The Virtual Montecarlo Concept

- 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

Pulls (full digitization)

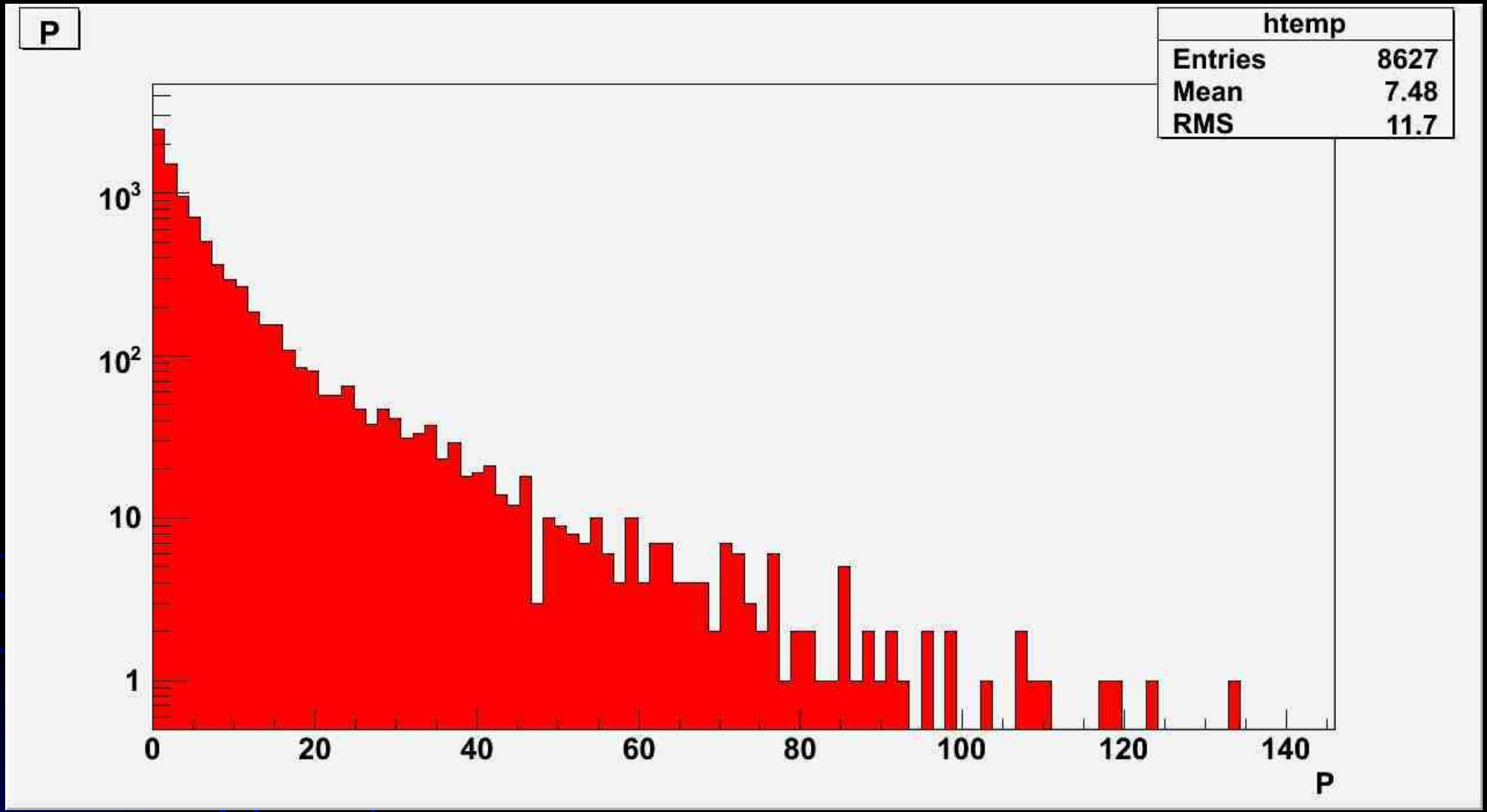


$e^+e^- \to Z_oH_o \to \mu^+\mu^- X$ + $e^+e^- \to Z_oZ_o \to \mu^+\mu^- X$ background [E_{cm}=230]



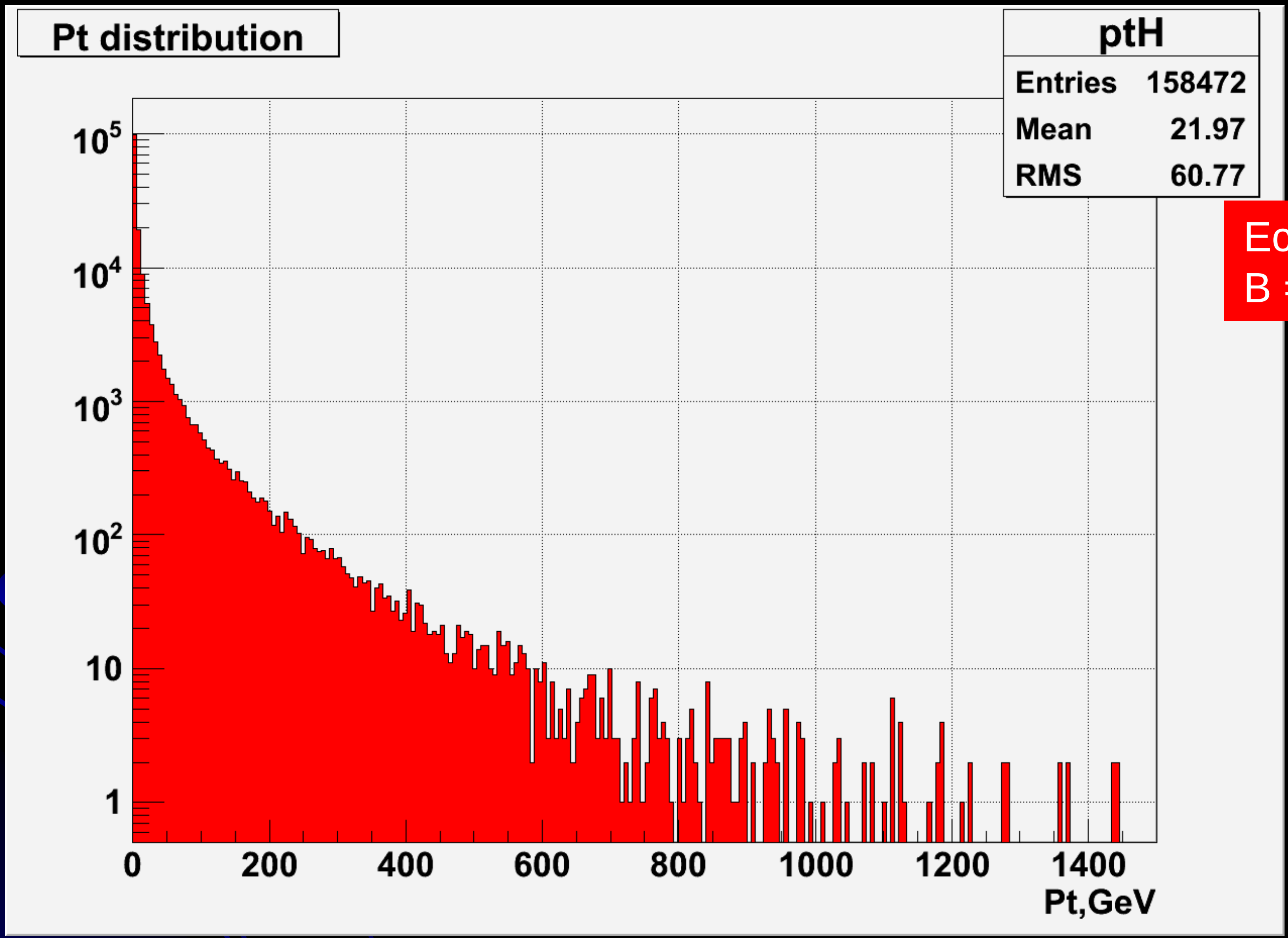
- Momentum spectrum for generated tracks entering the central tracker region
- Standard benchmarck channel
- Used as reference with existing analyses

e^+e^- -> 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

e^+e^- -> ttbar: Pt Spectrum

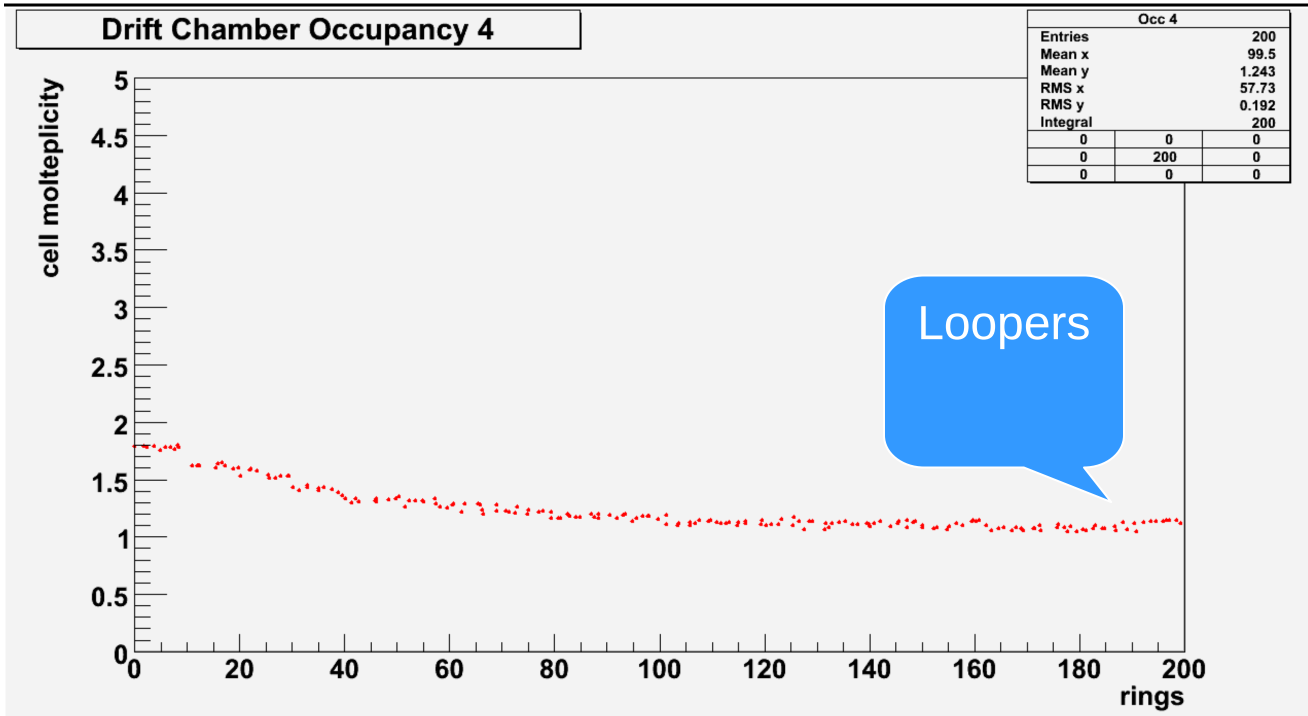


Ecm = 3000 GeV
B = 5 T

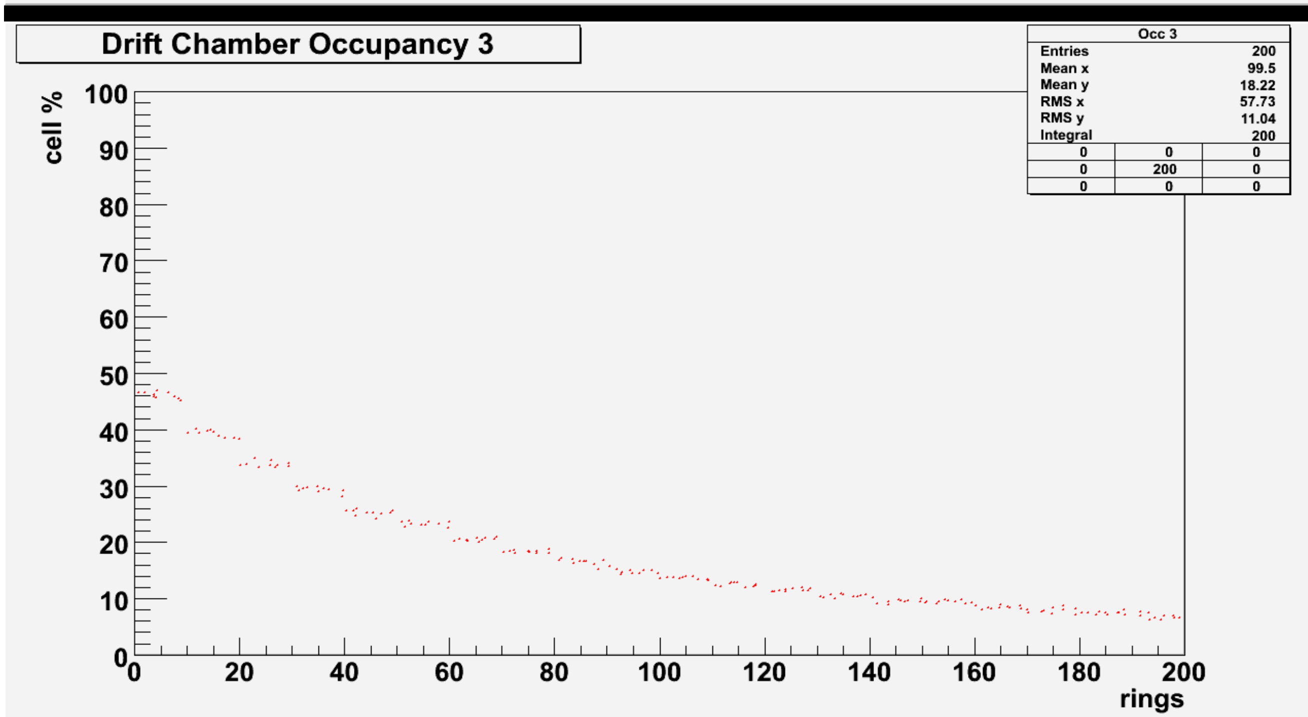
DCH

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

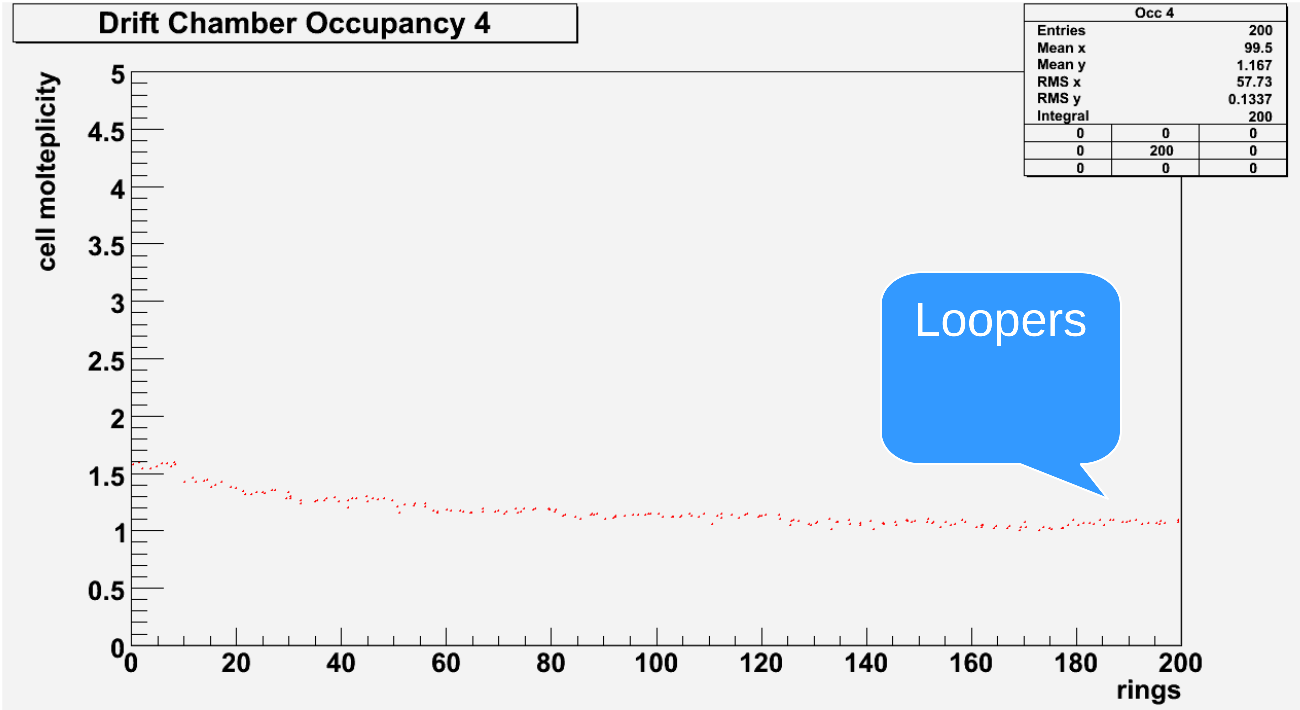
E_{CM}=500 GeV

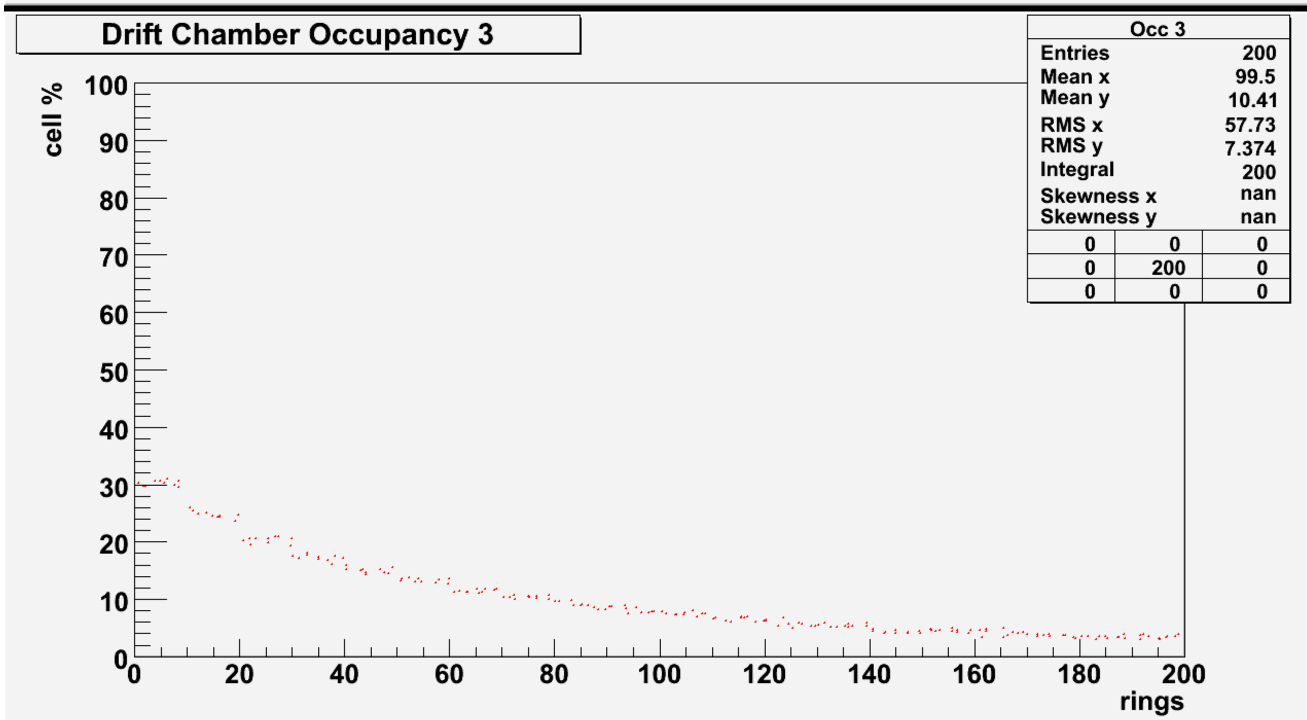


- Hits per cell vs layer



- Occupancy vs layer





DCH

$e^+e^- \to H^0Z^0 \to$ 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)

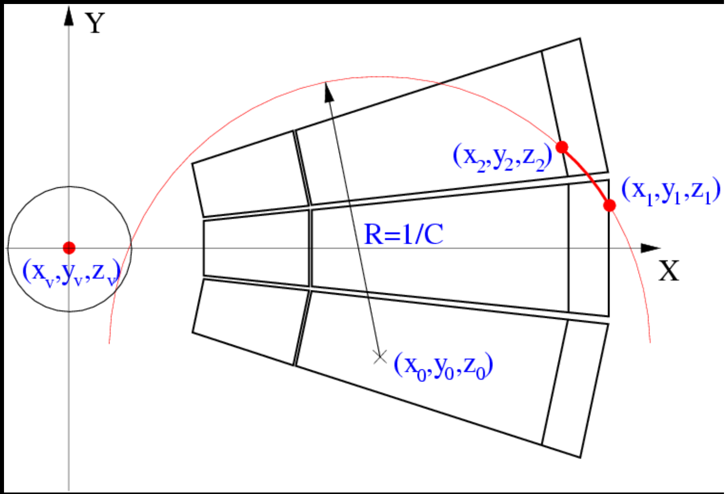
- Follow the path of the tracks inside the cell
- Per each deposited energy step:
  - convert the energy deposited into charge
  - Drift charge toward sense wire using Magboltz parameters
  - Add charge to FADC corresponding channel
- Add random noise
- Simulate electronic threshold

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)

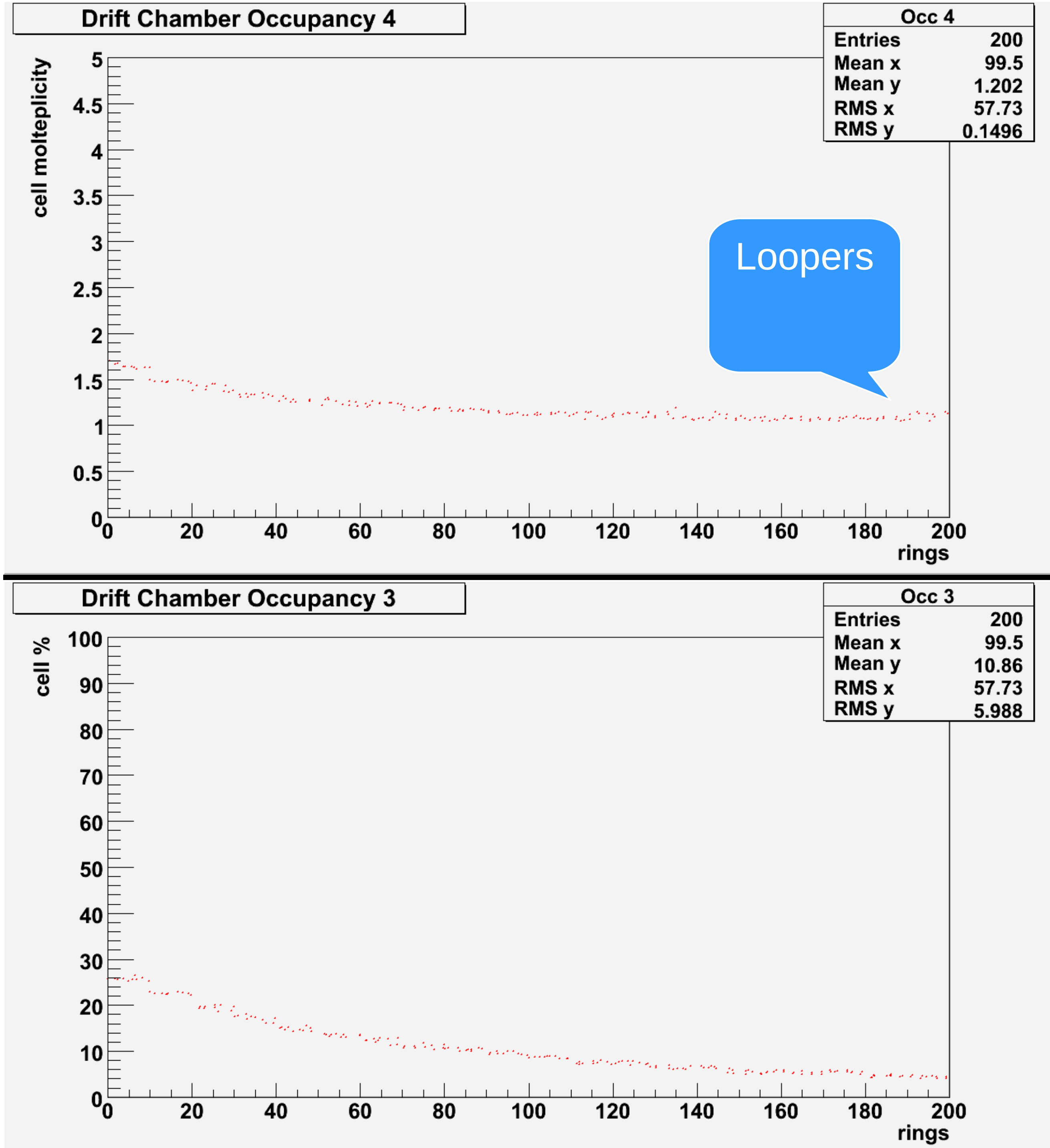
- Primary TPC/DCH seeding: looks for tracks with 20 hits (pads and/or µmegas) apart + <u>beam constraint</u>
- Secondary TPC/DCH seeding: looks for tracks with hits in layer 1, 4 and 7 (<u>no beam constraint</u>)
- **<u>Parallel Kalman Filter</u>** then initiated:
  - 1st step: start from TPC/DCH fit + 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

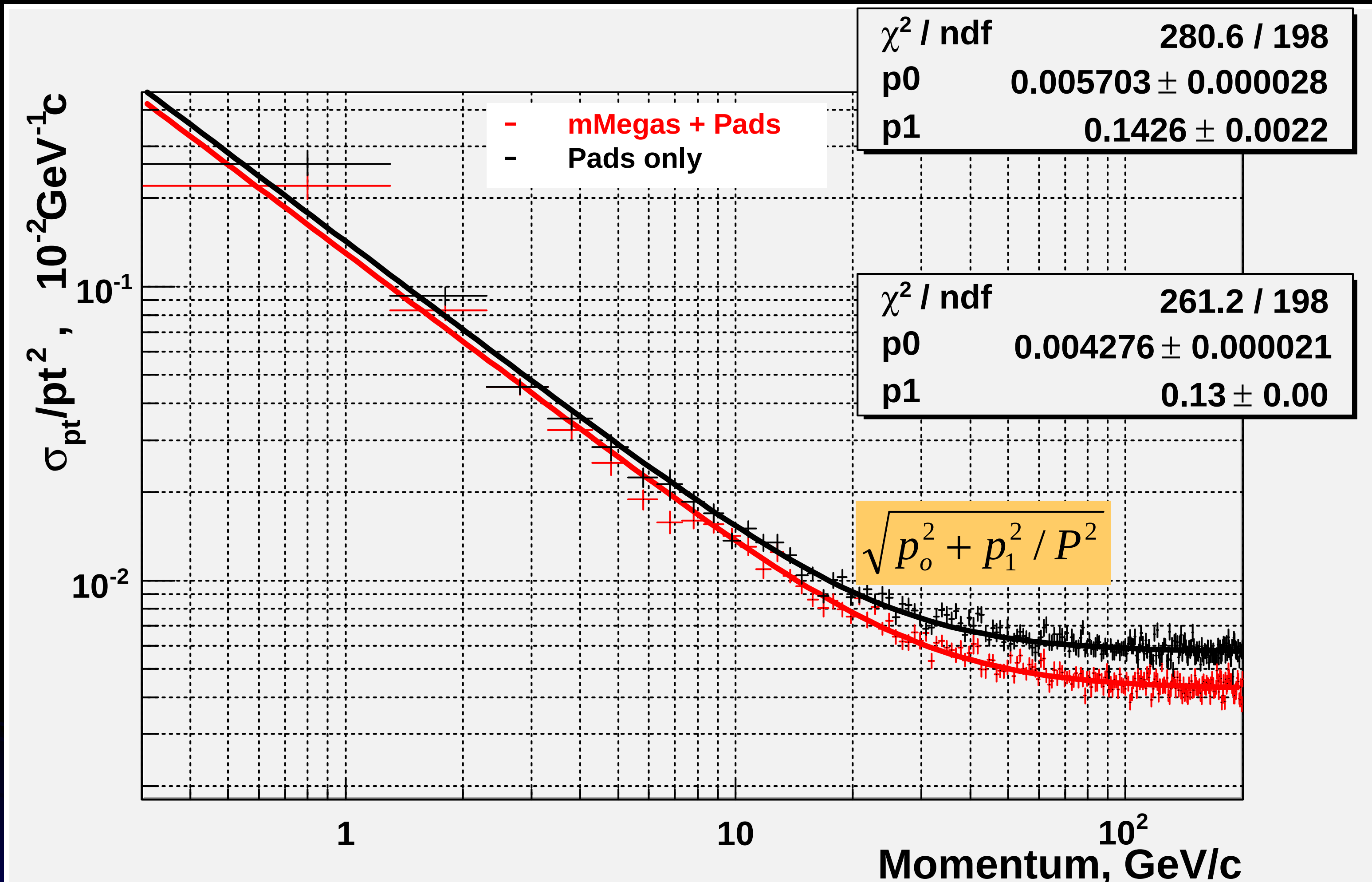


DCH

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

- Hits per cell vs layer

- Occupancy vs layer



- VXD + TPC

Expected

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

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

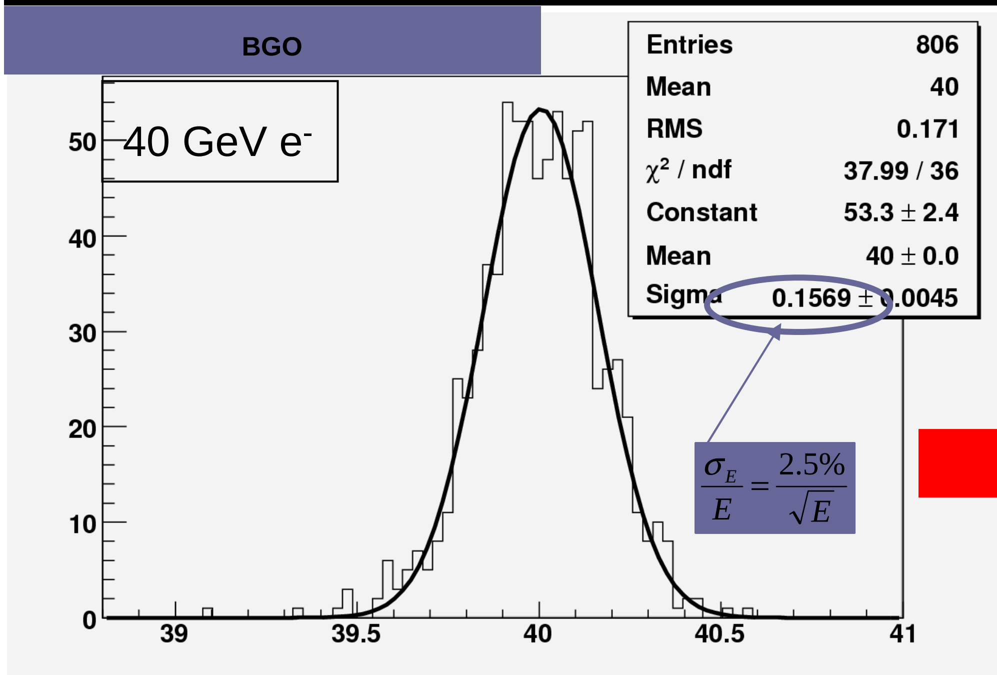
Multi-jets

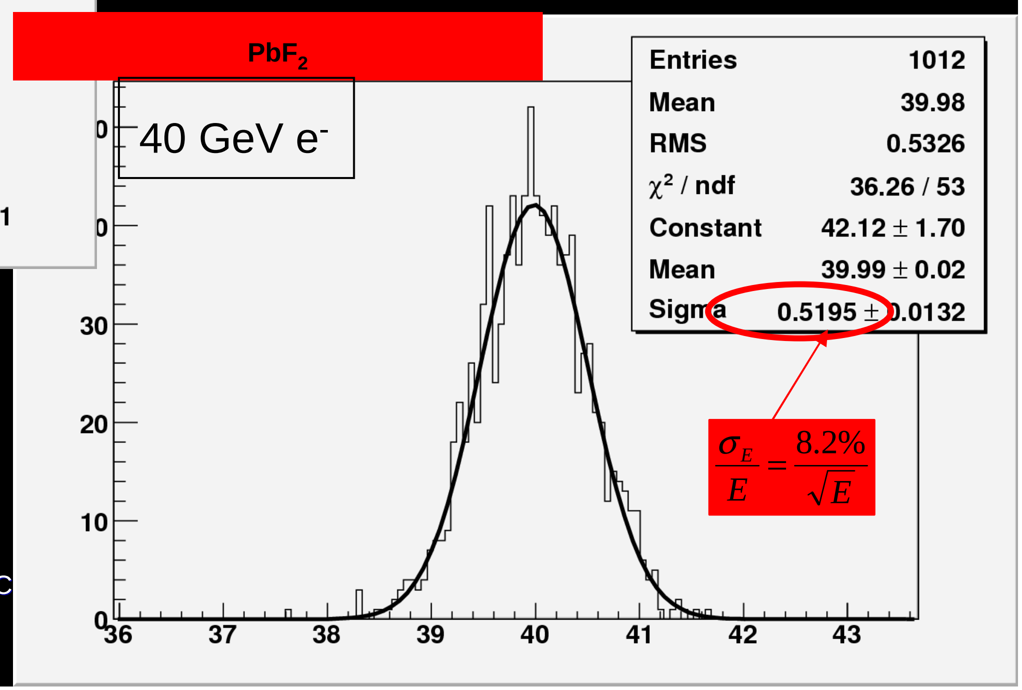
$H^+ \to \tau\nu \to \pi\nu$

HoZo

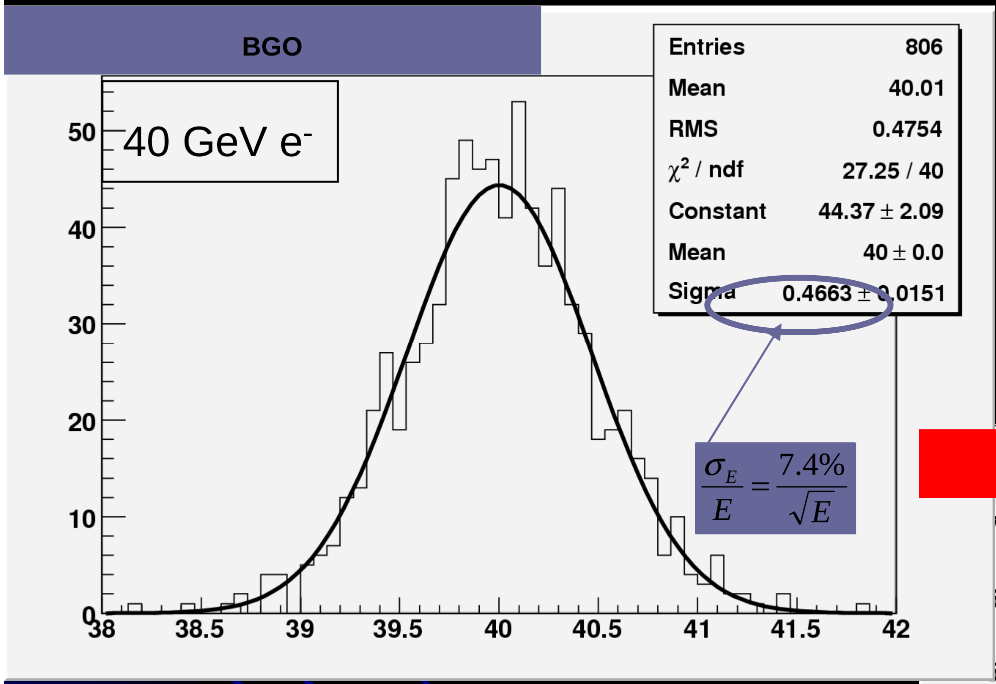
E_S Distribution

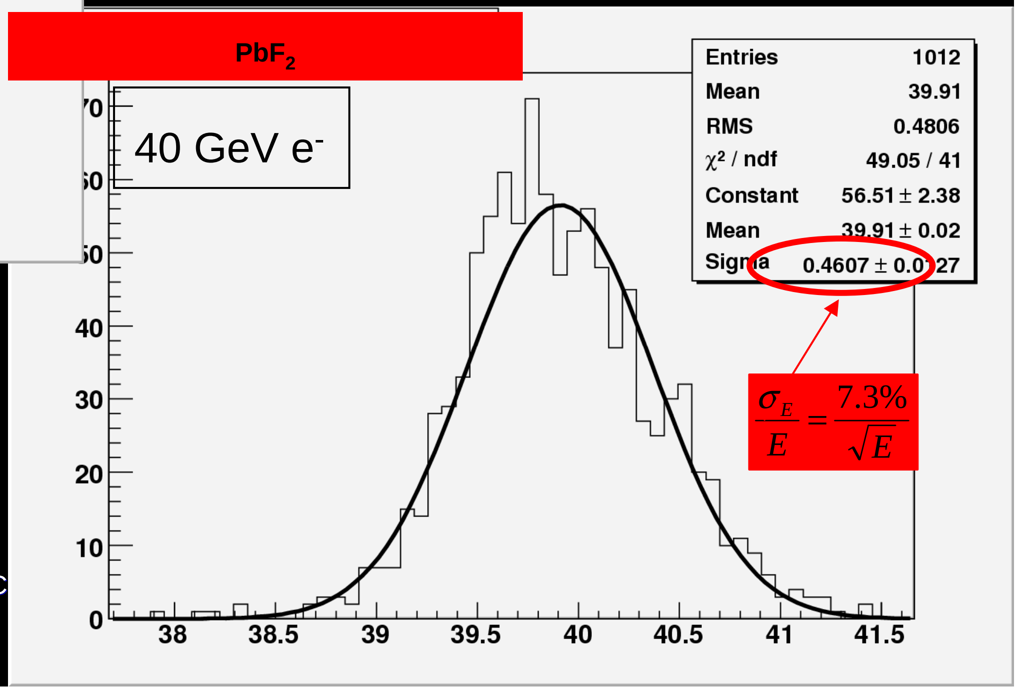
(for 50 cm long crystals)





E_C Distribution
(for 50 cm long crystals)





Combining E_S and E_C

(for 50 cm long crystals)