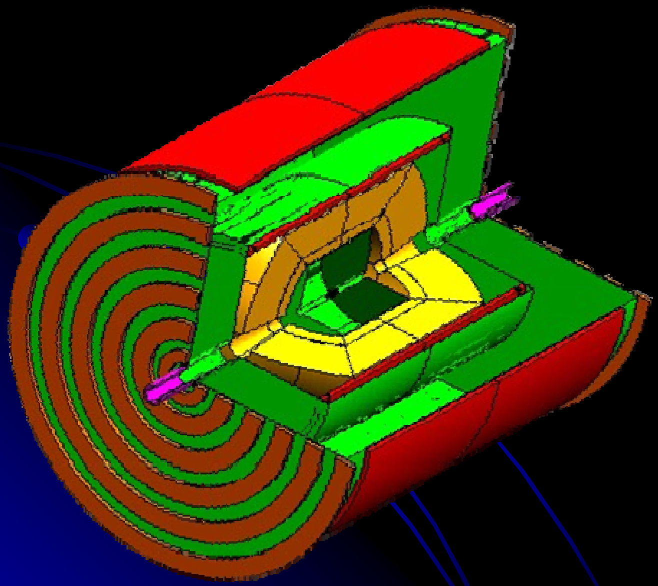
Tracking Studies in the 4^{th} Concept



On behalf of 4th Concept Software Group

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Central Tracker Studies

Central Tracker Issues

- Many interesting results (mostly simulations) at the Tracking Review in Beijing
- However, simulations were not on equal footing
- We decided to compare TPC vs DCH vs Si Tracker central trackers within the same framework and with comparable cheat
- Goal is to find the detector that best matches the Dual Readout Calorimeters and the Muon Spectrometer

TPC vs DCH Material Budget

- Beam Pipe: 0.18% X/X_o
- VXD:
  - Detector & support: 0.8% X/X_o
  - Outer shield: 0.16% X/X_o

Central Tracker:

- Vessel: 23-150 cm
- Active volume: 37-136 cm

Drift Chamber

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

TPC

- Gas[Ar-CF4/97-3]: 1.3%
- Vessel:
  - Inner wall + cage: 0.29% X/X_o
  - Outer wall: 1.2% X/X_o
  - Endcaps (wires, pads,electronics & services included): 35-54% X/X_o

DCH Studies Planner

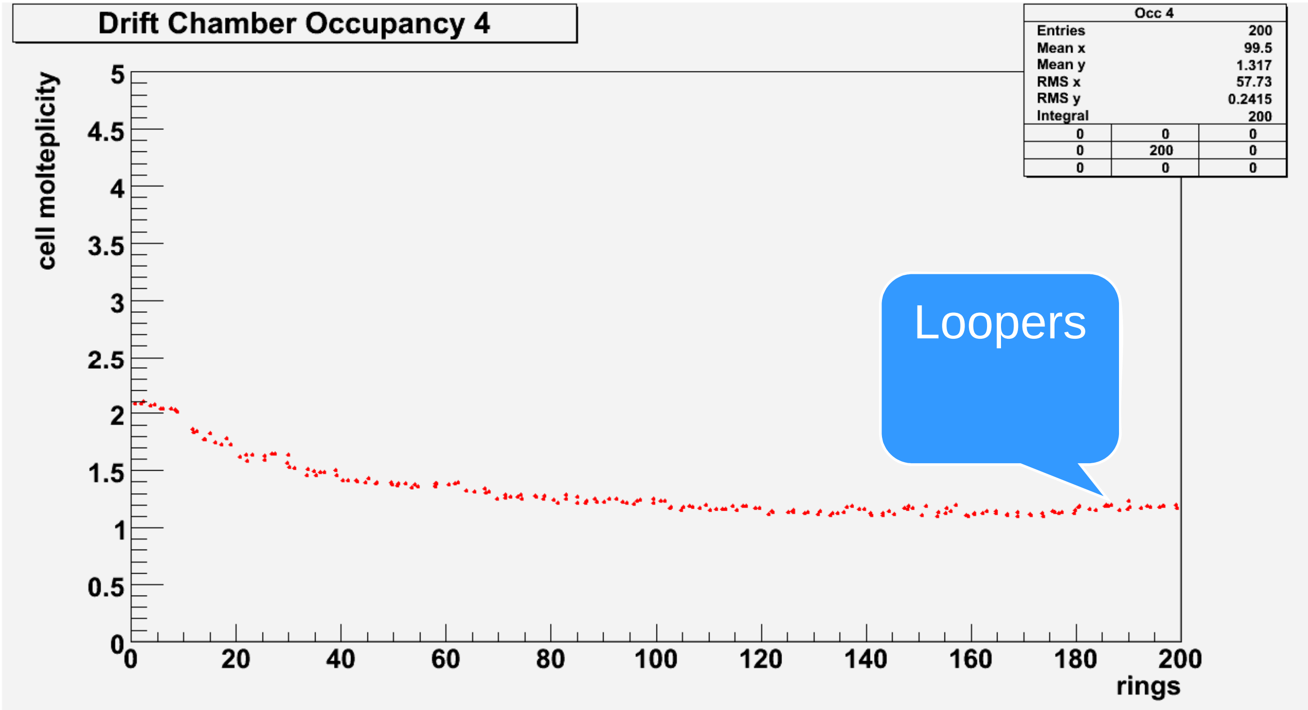
Short Term

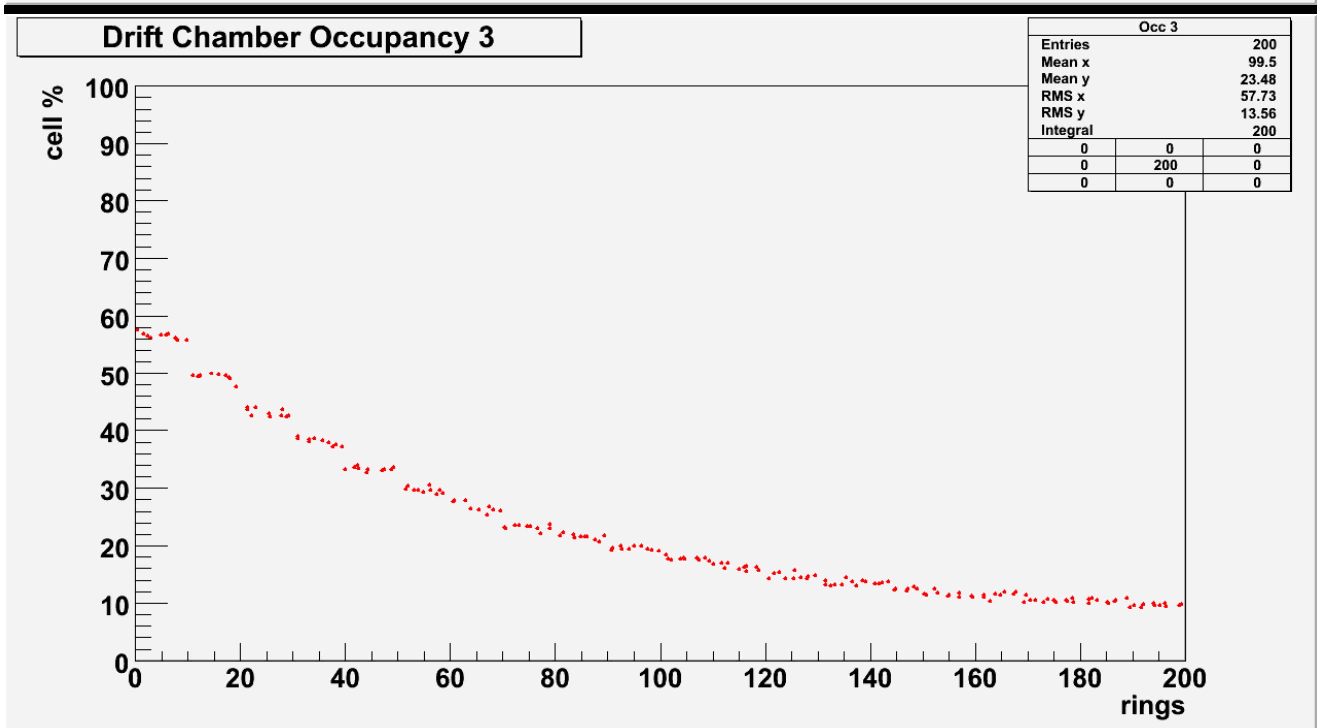
- Axial Cell DCH
- Intended for resolution studies only
- Easily interfaceable with existing Seed Finding and Parallel Kalman Filter

- Full Stereo DCH
- Intended for Occupancy related studies
- Cannot be easily adapted to existing reconstruction code

Long Term

- Dedicated Pattern recognition (exploiting the vectorial informations provided by the Cluster Counting)
- Dedicated Track Fitter (not necessarily Kalman Filter)

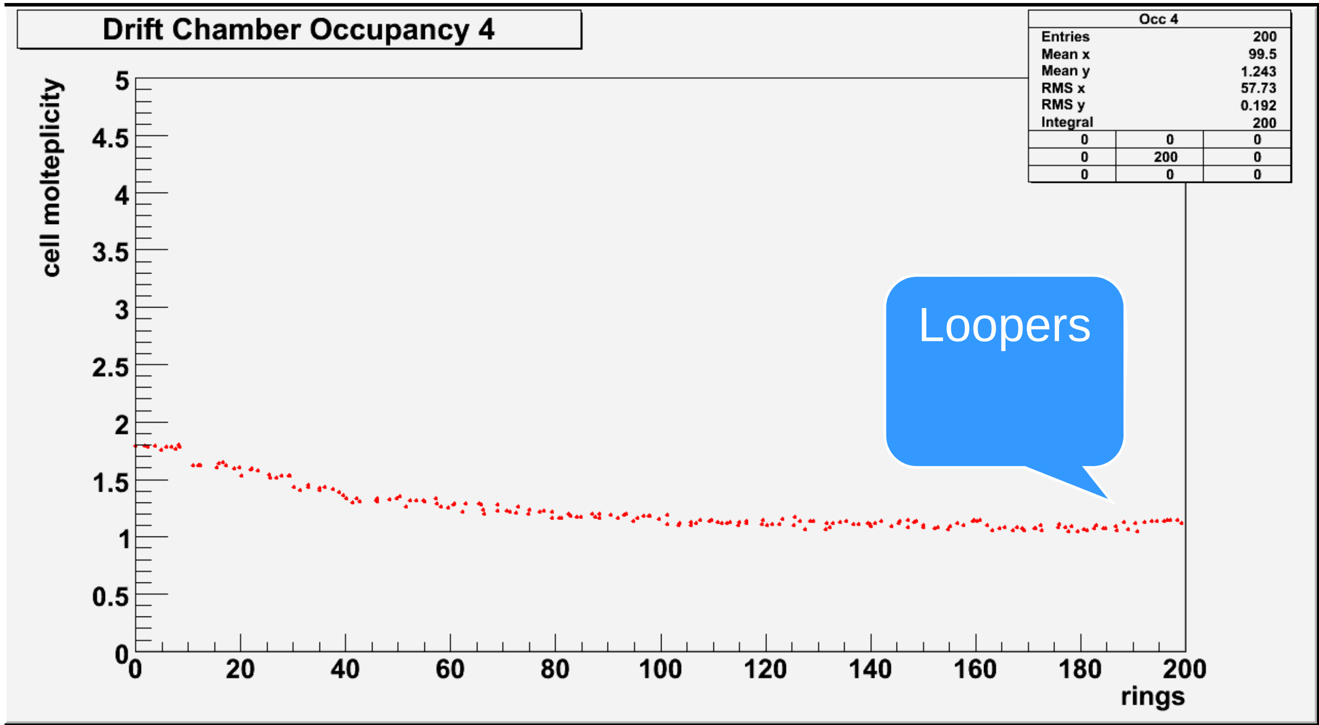


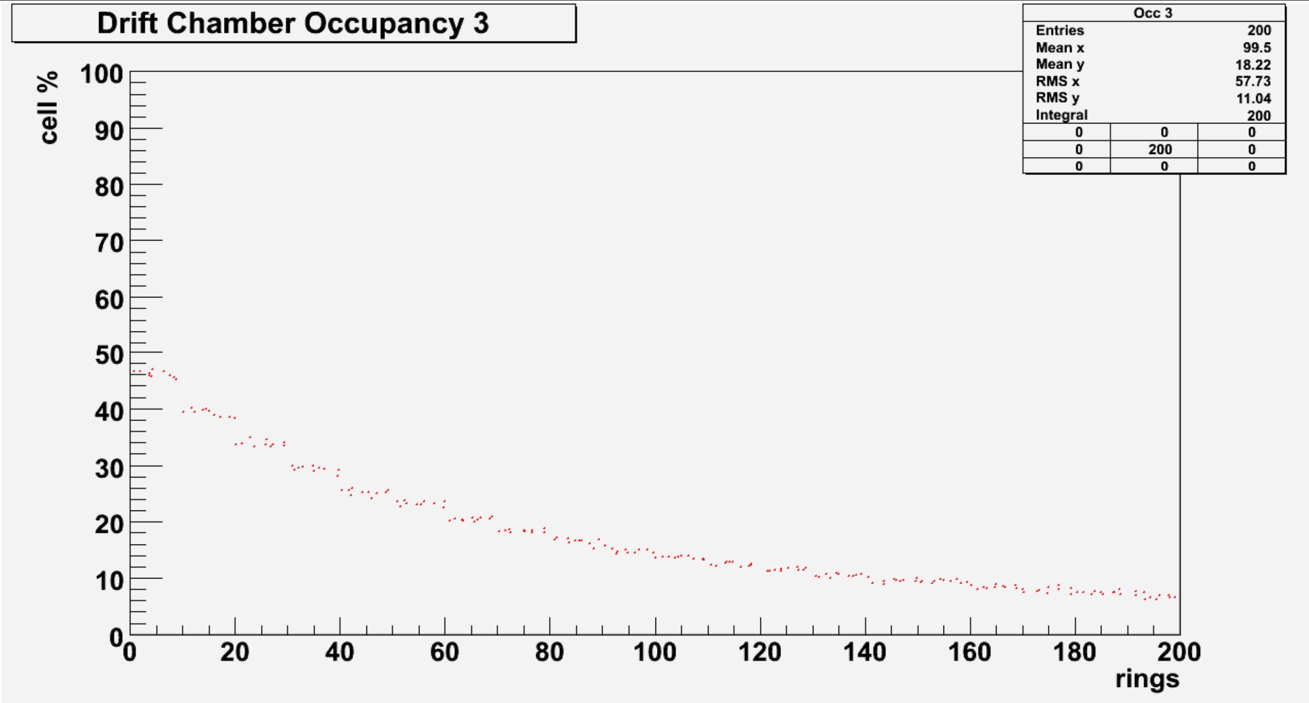


$e^+e^- \to t\bar{t} \to$ 6 jets with DCH

E_{CM}=500 GeV

- Hits per cell vs layer
- Occupancy vs layer





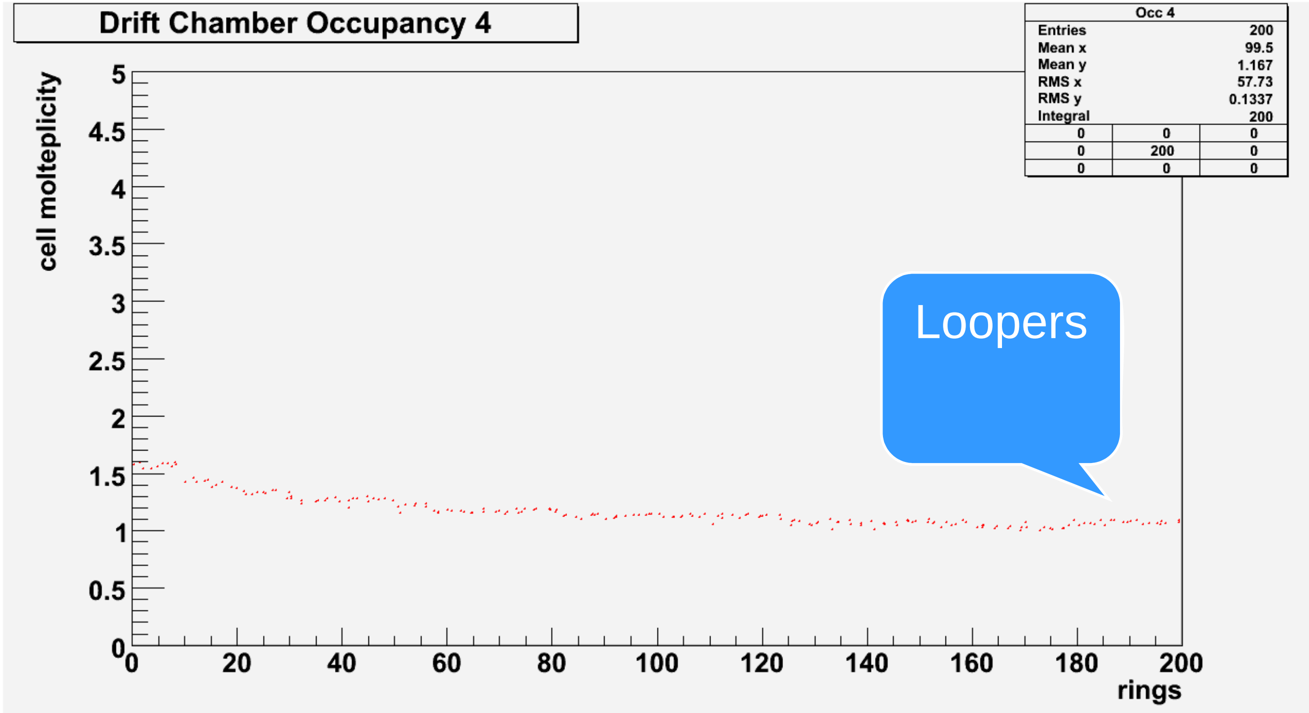
e^+e^- -> HHZ -> 4 jets+2muons with DCH

E_{CM}=500 GeV

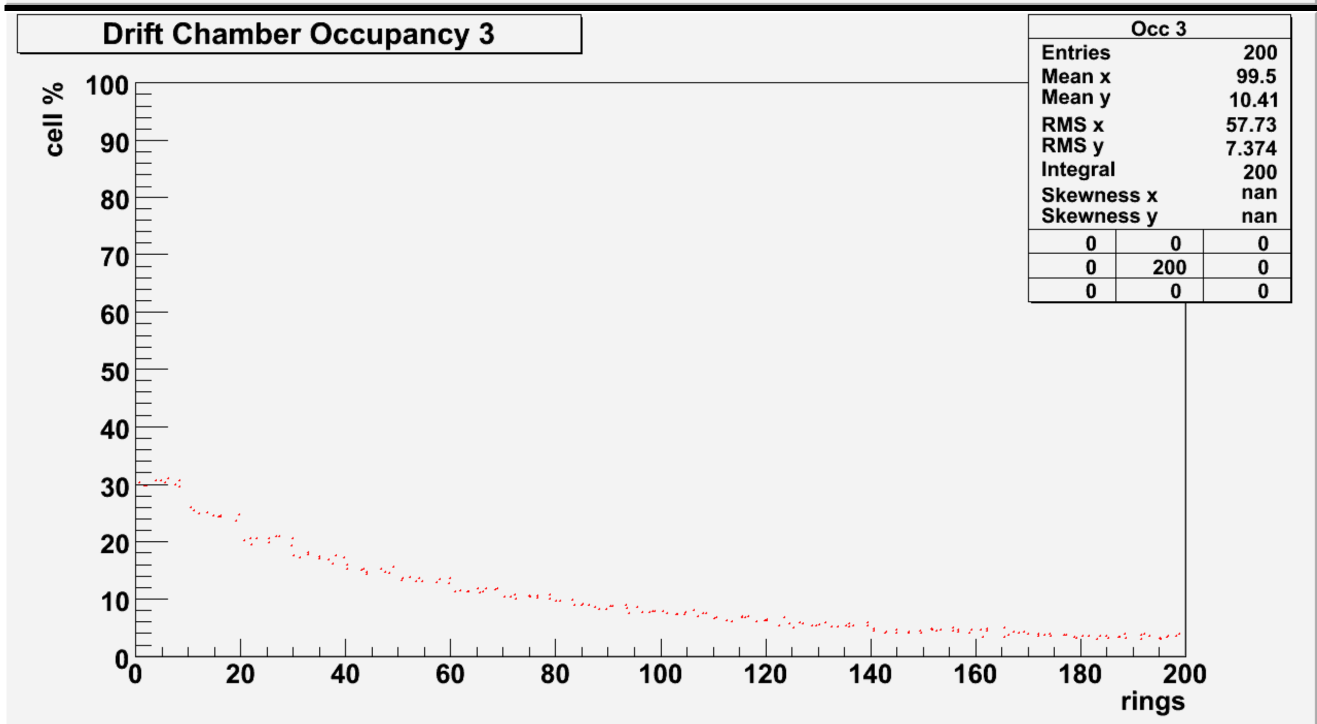
- Hits per cell vs layer
- Occupancy vs layer

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

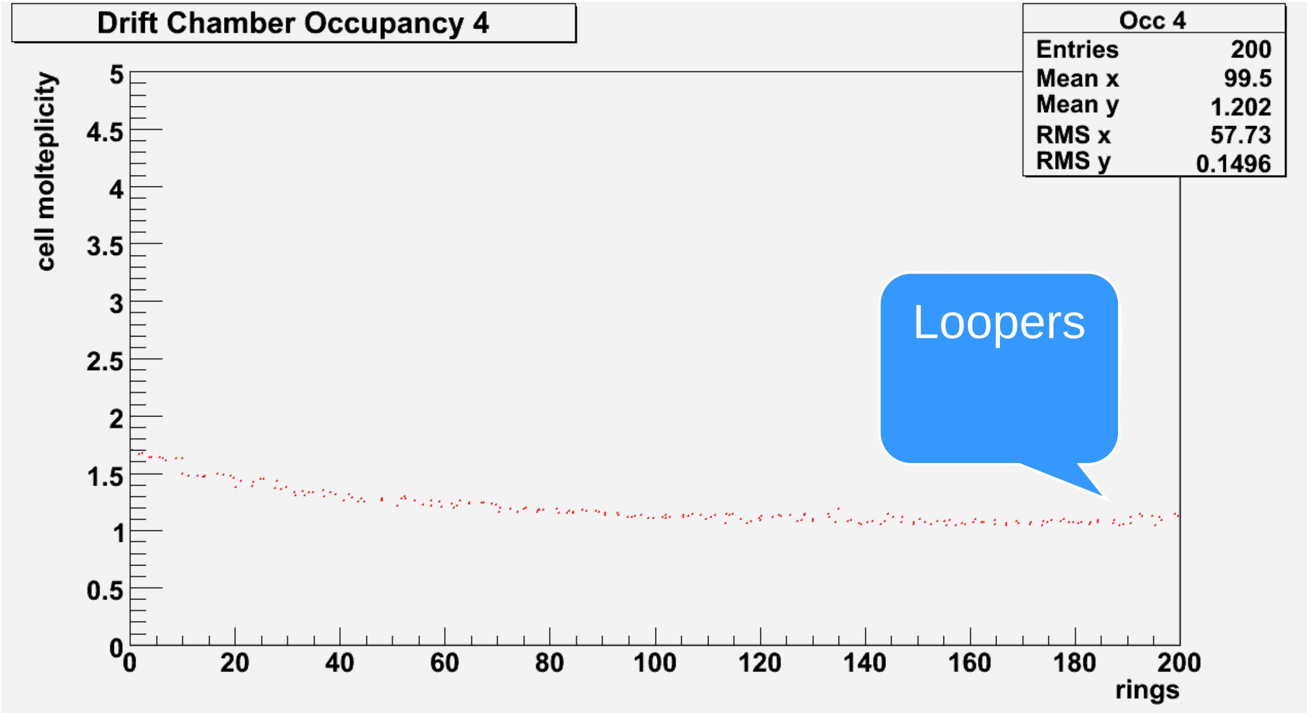
E_{CM}=230 GeV

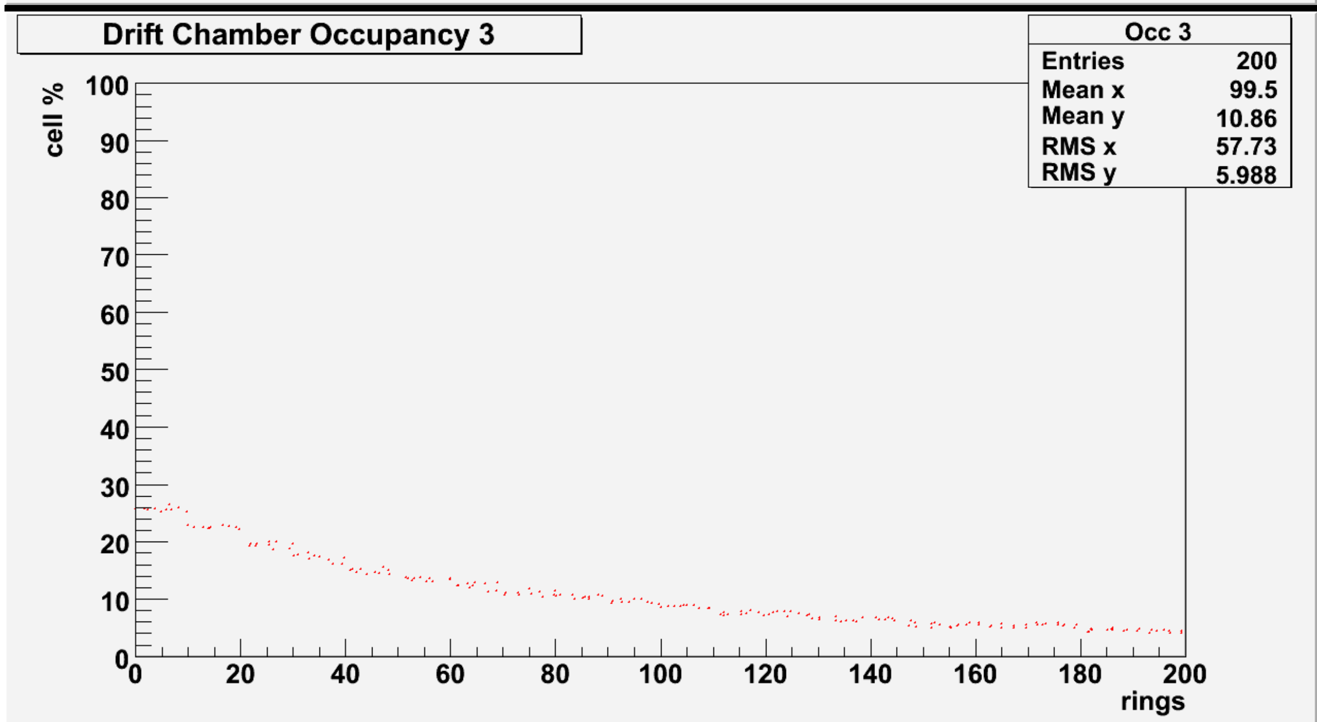


- Hits per cell vs layer



- Occupancy vs layer





$e^+e^- \to W^+W^-$
$\to$ 4 jets
with DCH

E_{CM}=500 GeV

- Hits per cell vs layer

- Occupancy vs layer

TPC vs DCH Simulation

VXD

- Full digitization (CCD assumed):
  - Pixel size: 20 μm x 20 mm

Drift Chamber

- Gaussian smearing:

  $\sigma(d) = 100\ \mu m$

  $\sigma(z) = 3000\ \mu m$

Very conservative

TPC

- Gaussian smearing:
  - Mumegas
    - $\sigma(d) = 55/\mathrm{sqrt}(12)\ \mu m$
  - Pads

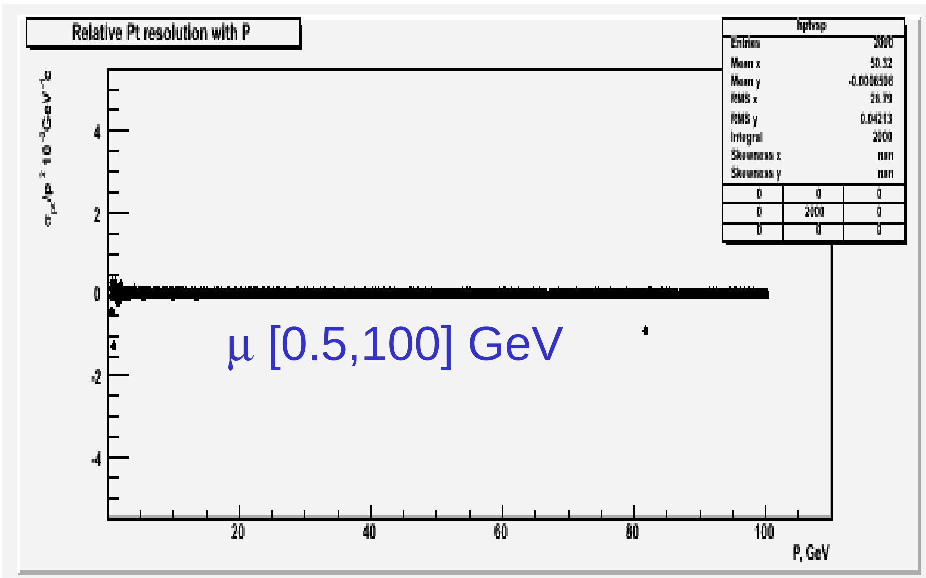
$$\sigma_{tCOG} = \sqrt{\frac{\sigma_L^2 (z_{max} - z)}{N_{ch}} G_g + \frac{tan(\alpha)^2 l_{pad}^2 G_{Landau}(N_{prim})}{12 N_{chprim}} + \sigma_{noise}^2}$$

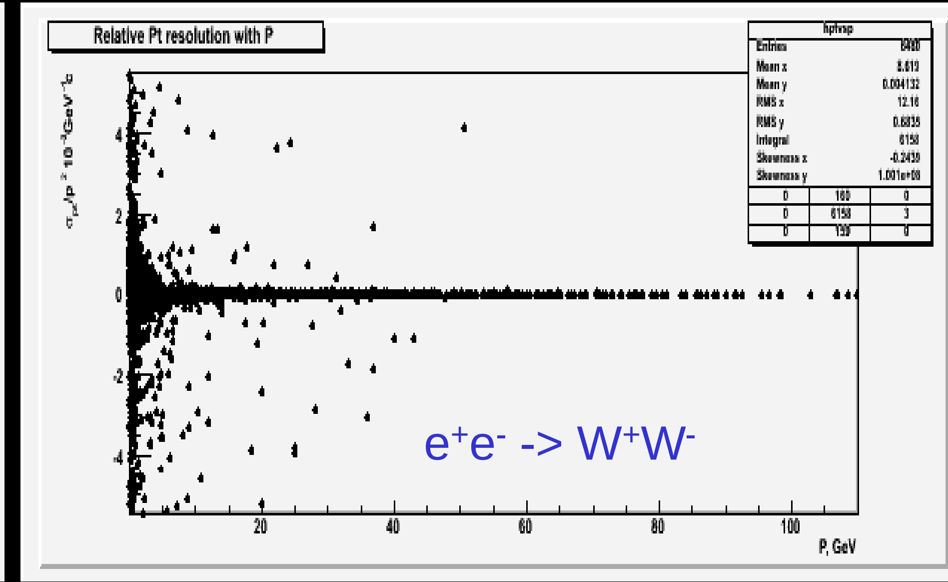
Performance with Physics

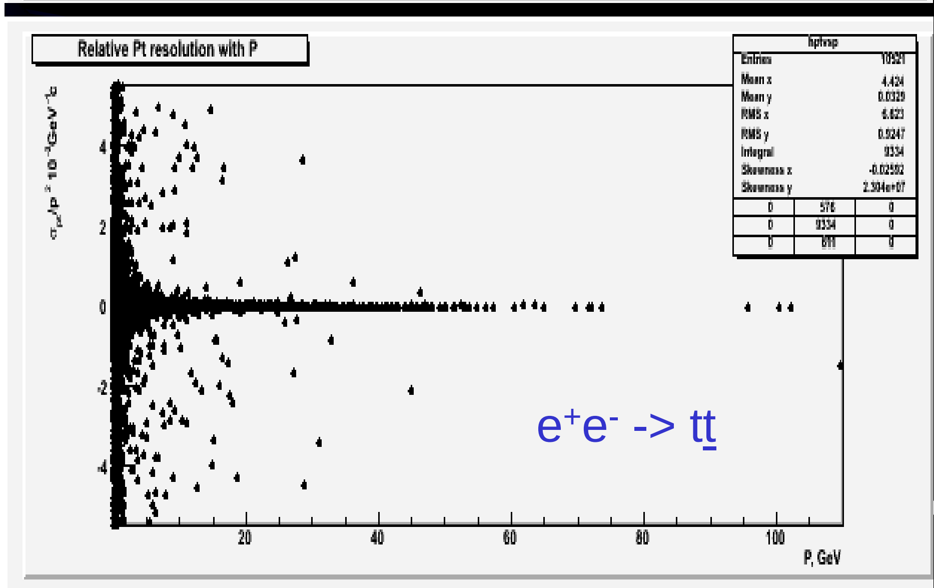
- Several channels simulated
  - 10 muons [0.5,100] GeV
  - e^+e^- -> W^+W^- -> 4 jets @ E_{cm} = 500 GeV
  - e^+e^- -> $t\underline{t}$ -> 6 jets @ E_{cm} = 500 GeV
  - e^+e^- -> H^oZ^o -> 2 jets 2 muons @ E_{cm} = 230 GeV
  - e^+e^- -> $H^oH^oZ^o$ -> 4 jets 2 muons @ E_{cm} = 500 GeV
- Results not available yet for the Drift Chamber

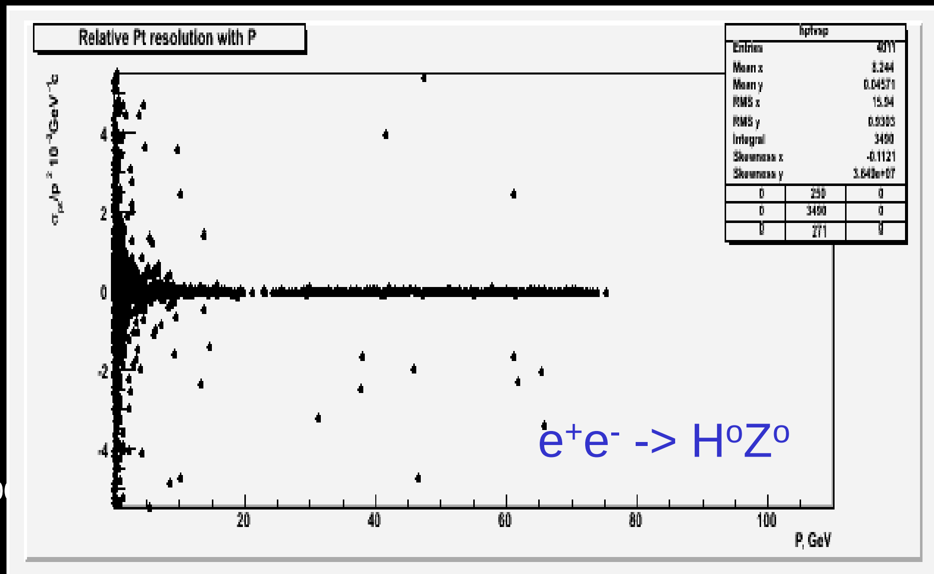
TPC

$\Delta(1/p_t)$ vs P

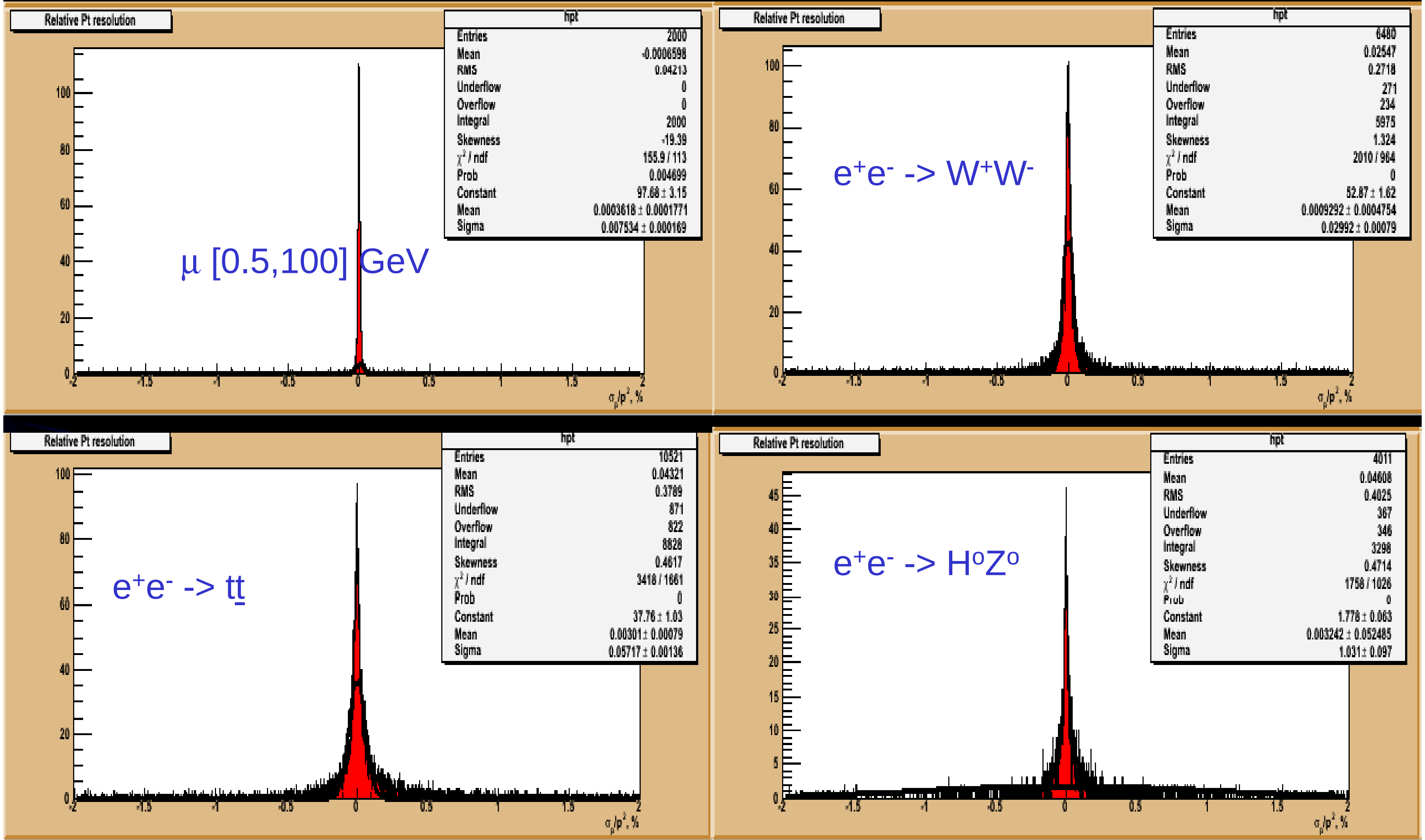






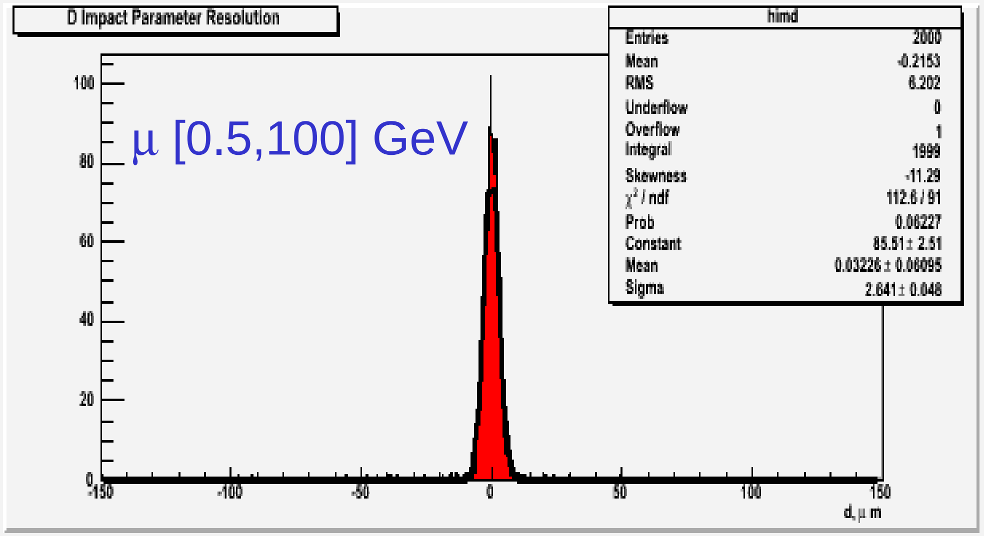


$\Delta(1/p_t)$

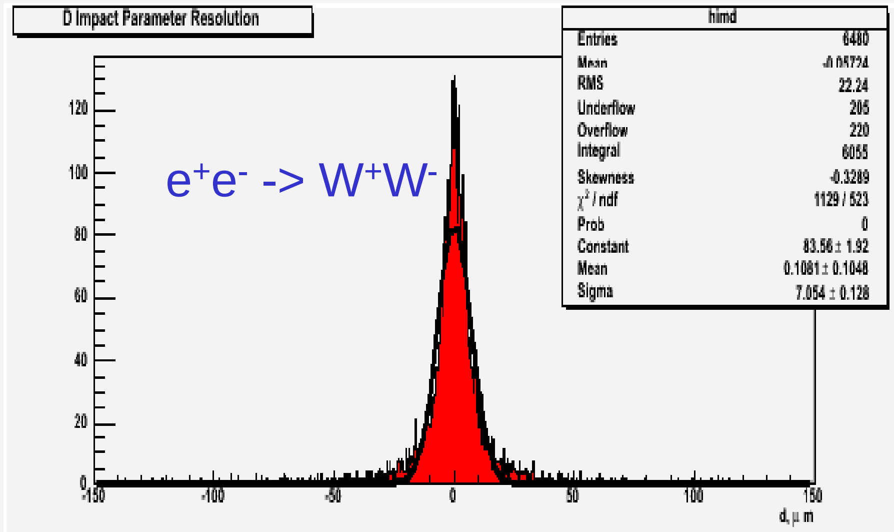

Relative Pt resolution
hpt
Entries 2000
Mean -0.0006598
RMS 0.04213
Underflow 0
Overflow 0
Integral 2000
Skewness -19.39
χ² / ndf 155.9 / 113
Prob 0.004699
Constant 97.68 ± 3.15
Mean 0.0003618 ± 0.0001771
Sigma 0.007534 ± 0.000169
μ [0.5,100] GeV
σ_p/p², %
Relative Pt resolution
hpt
Entries 6480
Mean 0.02547
RMS 0.2718
Underflow 271
Overflow 234
Integral 5975
Skewness 1.324
χ² / ndf 2010 / 964
Prob 0
Constant 52.87 ± 1.62
Mean 0.0009292 ± 0.0004754
Sigma 0.02992 ± 0.00079
e+e- -> W+W-
σ_p/p², %
Relative Pt resolution
hpt
Entries 10521
Mean 0.04321
RMS 0.3789
Underflow 871
Overflow 822
Integral 8828
Skewness 0.4617
χ² / ndf 3418 / 1661
Prob 0
Constant 37.76 ± 1.03
Mean 0.00301 ± 0.00079
Sigma 0.05717 ± 0.00136
e+e- -> tt
σ_p/p², %
Relative Pt resolution
hpt
Entries 4011
Mean 0.04608
RMS 0.4025
Underflow 367
Overflow 346
Integral 3298
Skewness 0.4714
χ² / ndf 1758 / 1026
Prob 0
Constant 1.778 ± 0.063
Mean 0.003242 ± 0.052485
Sigma 1.031 ± 0.097
e+e- -> HoZo
σ_p/p², %

ΔD_o

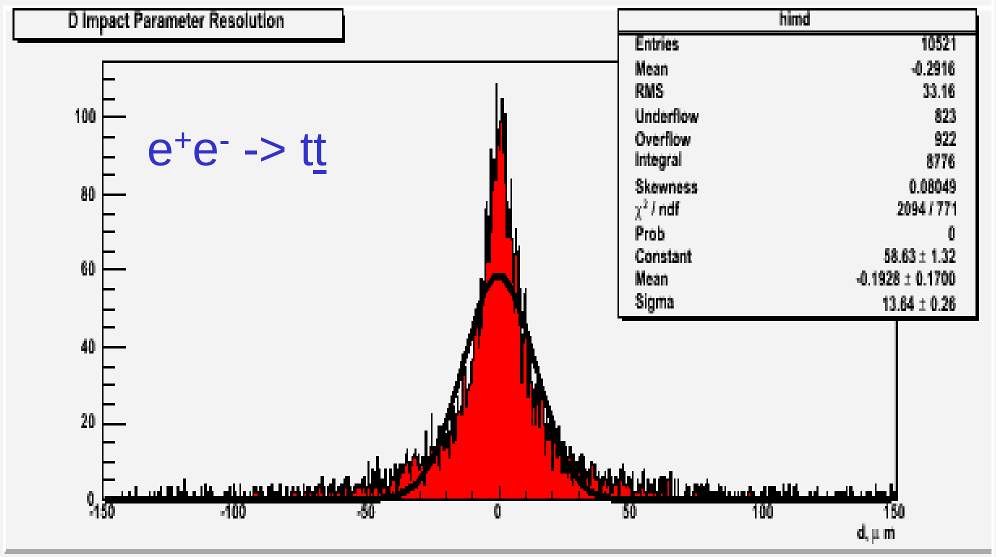
TPC



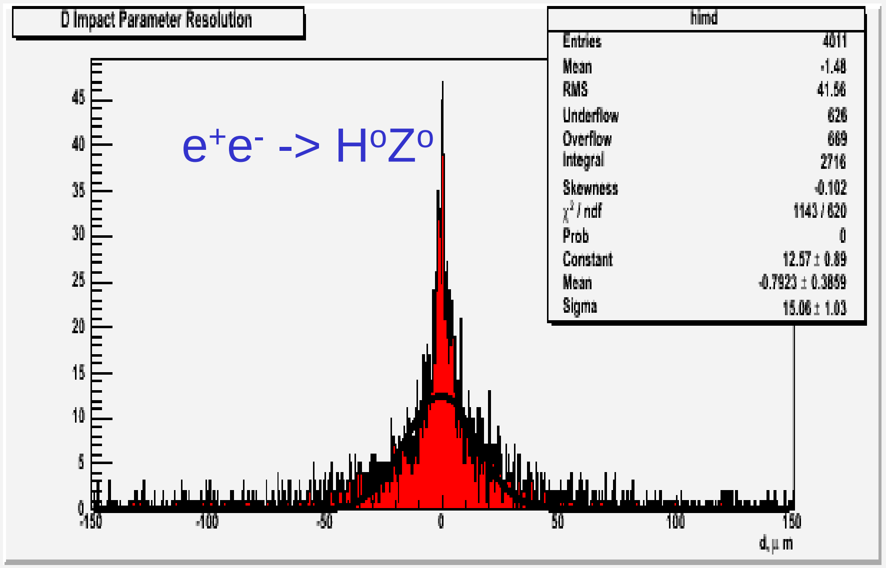
D Impact Parameter Resolution
μ [0.5,100] GeV
himd
Entries 2000
Mean -0.2153
RMS 6.202
Underflow 0
Overflow 1
Integral 1999
Skewness -11.29
χ² / ndf 112.6 / 91
Prob 0.06227
Constant 85.51 ± 2.51
Mean 0.03226 ± 0.06095
Sigma 2.641 ± 0.048
d, μ m



D Impact Parameter Resolution
e+e- -> W+W-
himd
Entries 6480
Mean -0.05724
RMS 22.24
Underflow 205
Overflow 220
Integral 6055
Skewness -0.3289
χ² / ndf 1129 / 523
Prob 0
Constant 83.56 ± 1.92
Mean 0.1081 ± 0.1048
Sigma 7.054 ± 0.128
d, μ m



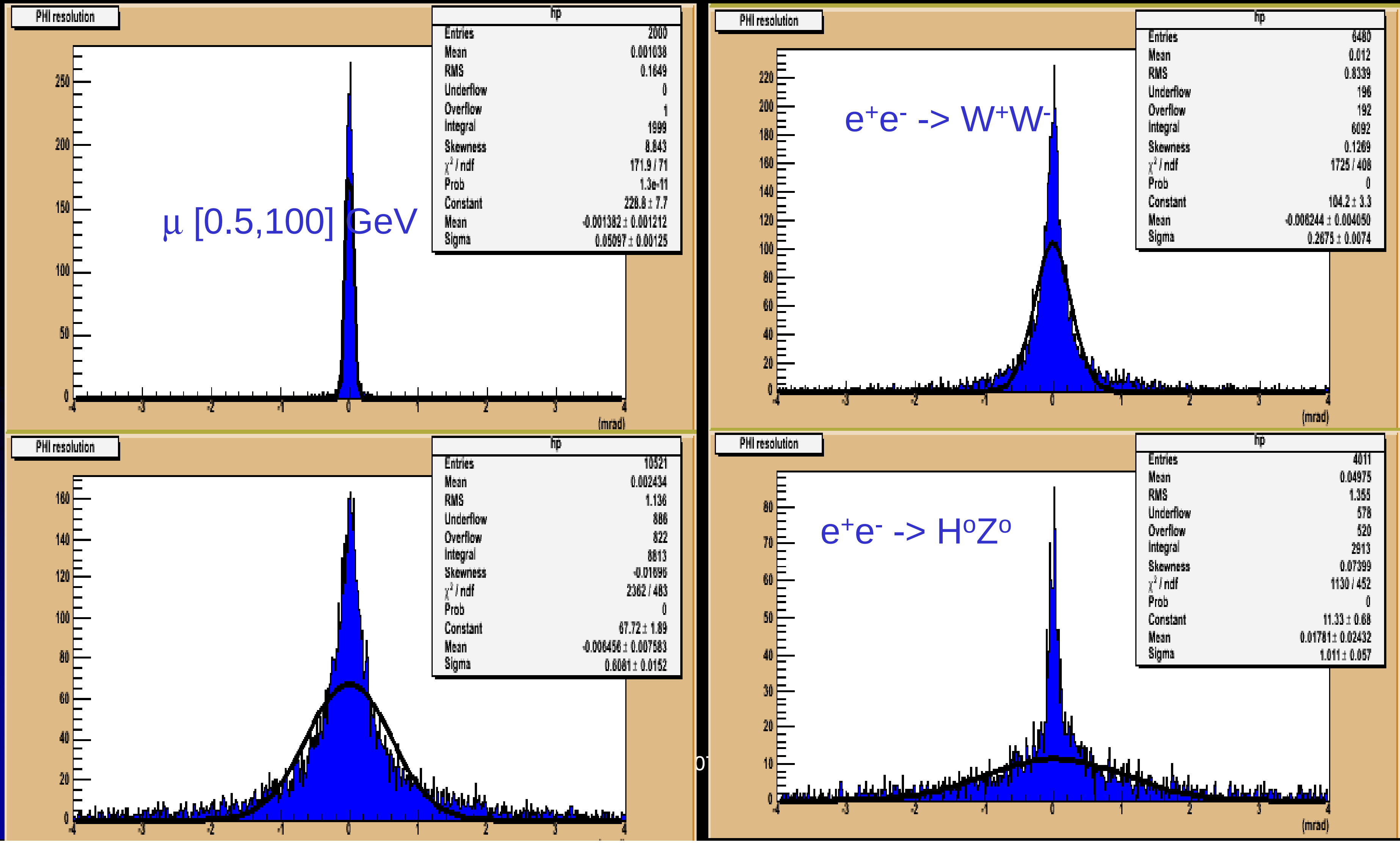
D Impact Parameter Resolution
e+e- -> tt
himd
Entries 10521
Mean -0.2916
RMS 33.16
Underflow 823
Overflow 922
Integral 8776
Skewness 0.08049
χ² / ndf 2094 / 771
Prob 0
Constant 58.63 ± 1.32
Mean -0.1928 ± 0.1700
Sigma 13.64 ± 0.26
d, μ m



D Impact Parameter Resolution
e+e- -> HoZo
himd
Entries 4011
Mean -1.48
RMS 41.56
Underflow 626
Overflow 669
Integral 2716
Skewness -0.102
χ² / ndf 1143 / 620
Prob 0
Constant 12.57 ± 0.89
Mean -0.7923 ± 0.3859
Sigma 15.06 ± 1.03
d, μ m

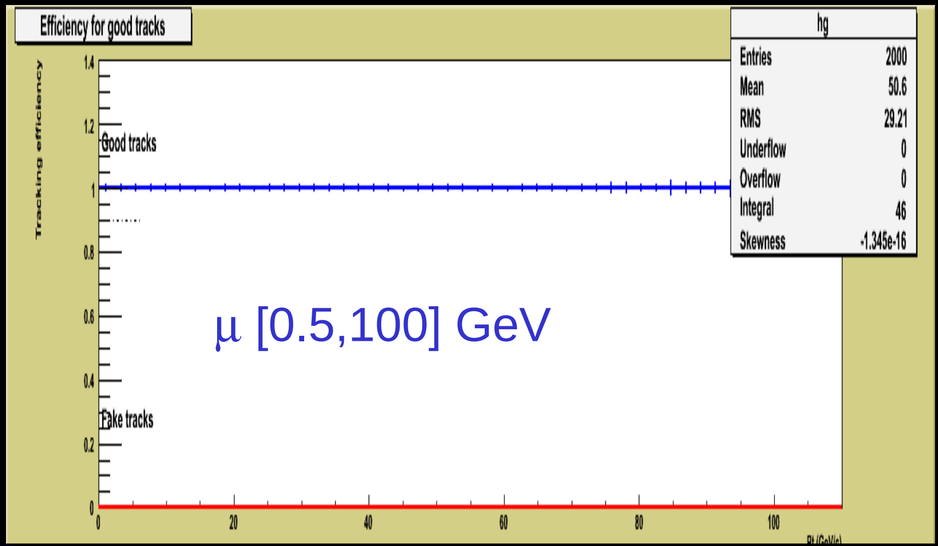
TPC

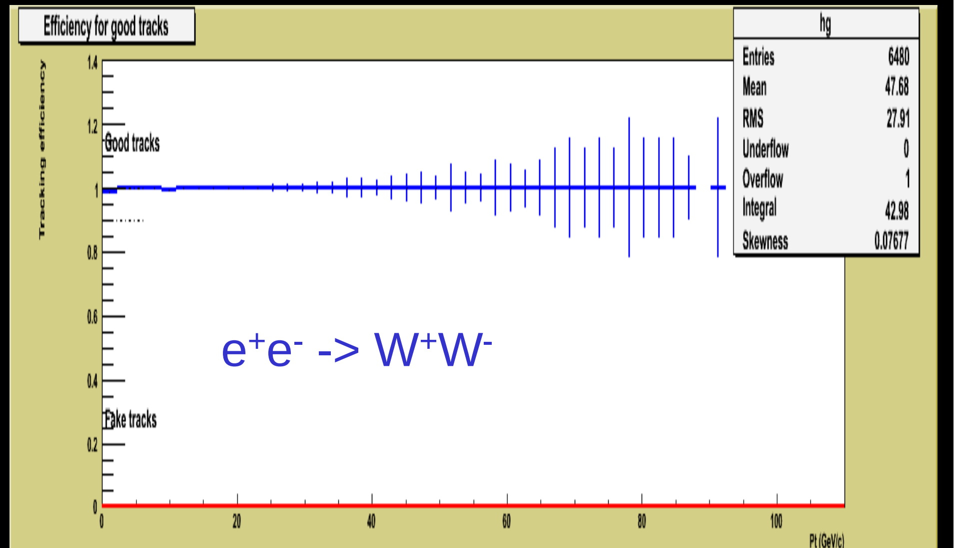
Δφ

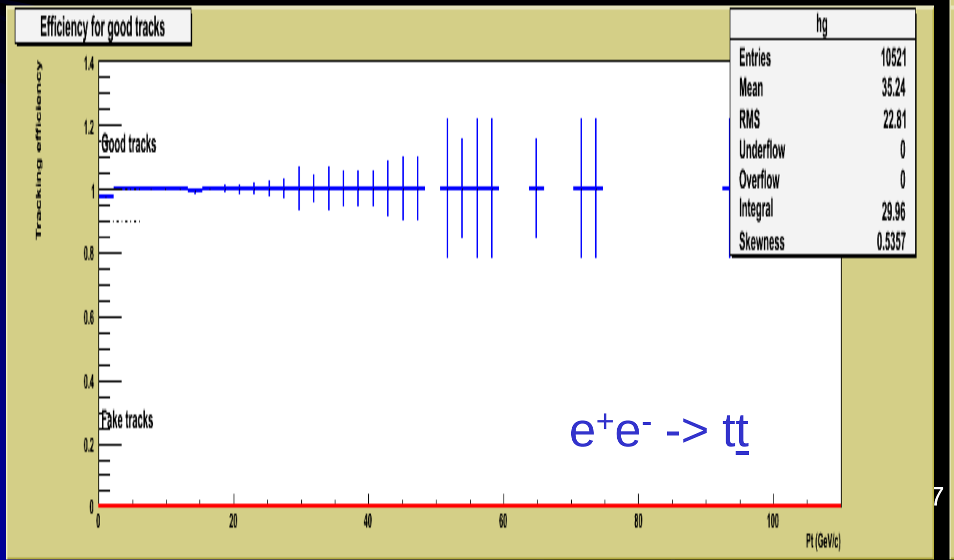


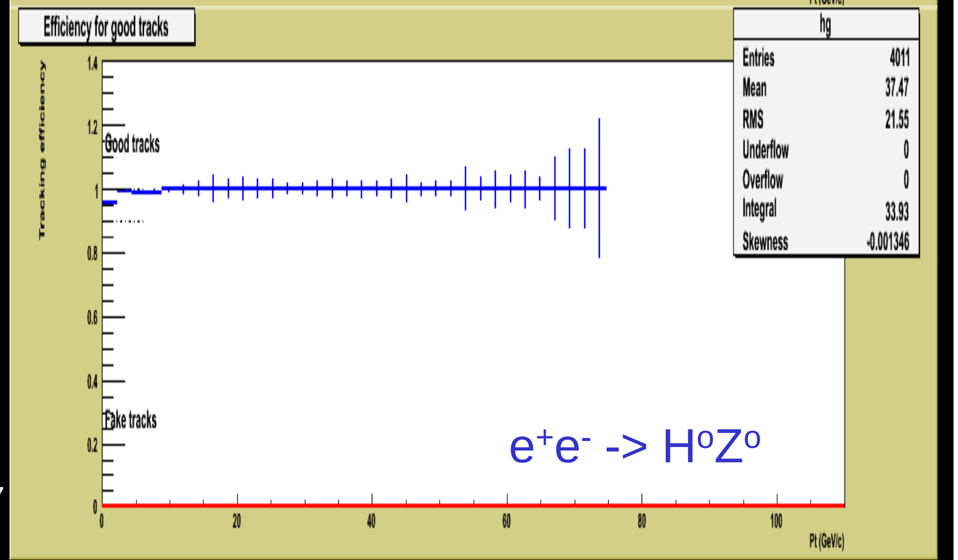
PHI resolution
hp
Entries 2000
Mean 0.001038
RMS 0.1649
Underflow 0
Overflow 1
Integral 1999
Skewness 8.843
χ² / ndf 171.9 / 71
Prob 1.3e-11
Constant 228.8 ± 7.7
Mean -0.001382 ± 0.001212
Sigma 0.05097 ± 0.00125
μ [0.5,100] GeV
(mrad)
PHI resolution
hp
Entries 6480
Mean 0.012
RMS 0.8339
Underflow 196
Overflow 192
Integral 6092
Skewness 0.1269
χ² / ndf 1725 / 408
Prob 0
Constant 104.2 ± 3.3
Mean -0.006244 ± 0.004050
Sigma 0.2675 ± 0.0074
e+e- -> W+W-
(mrad)
PHI resolution
hp
Entries 10521
Mean 0.002434
RMS 1.136
Underflow 886
Overflow 822
Integral 8813
Skewness -0.01696
χ² / ndf 2362 / 483
Prob 0
Constant 67.72 ± 1.89
Mean -0.006456 ± 0.007583
Sigma 0.6081 ± 0.0152
PHI resolution
hp
Entries 4011
Mean 0.04975
RMS 1.355
Underflow 578
Overflow 520
Integral 2913
Skewness 0.07399
χ² / ndf 1130 / 452
Prob 0
Constant 11.33 ± 0.68
Mean 0.01781 ± 0.02432
Sigma 1.011 ± 0.057
e+e- -> HoZo
(mrad)

Tracking Efficiency





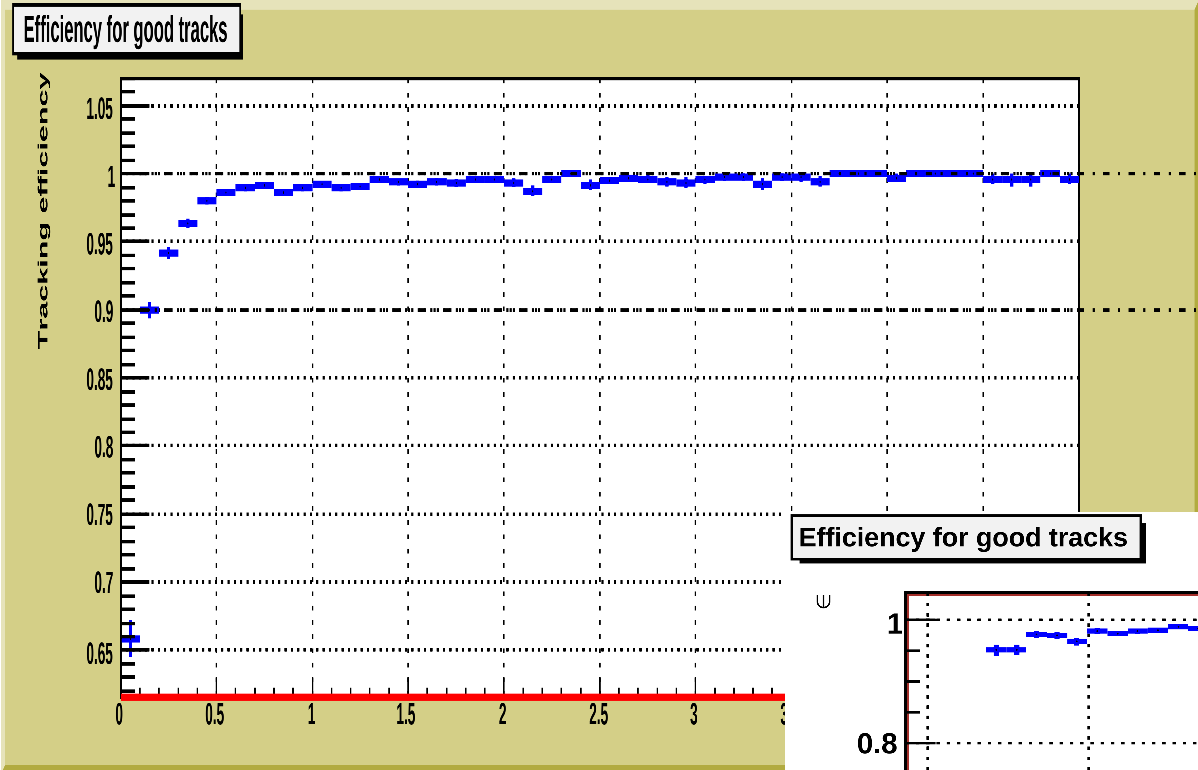


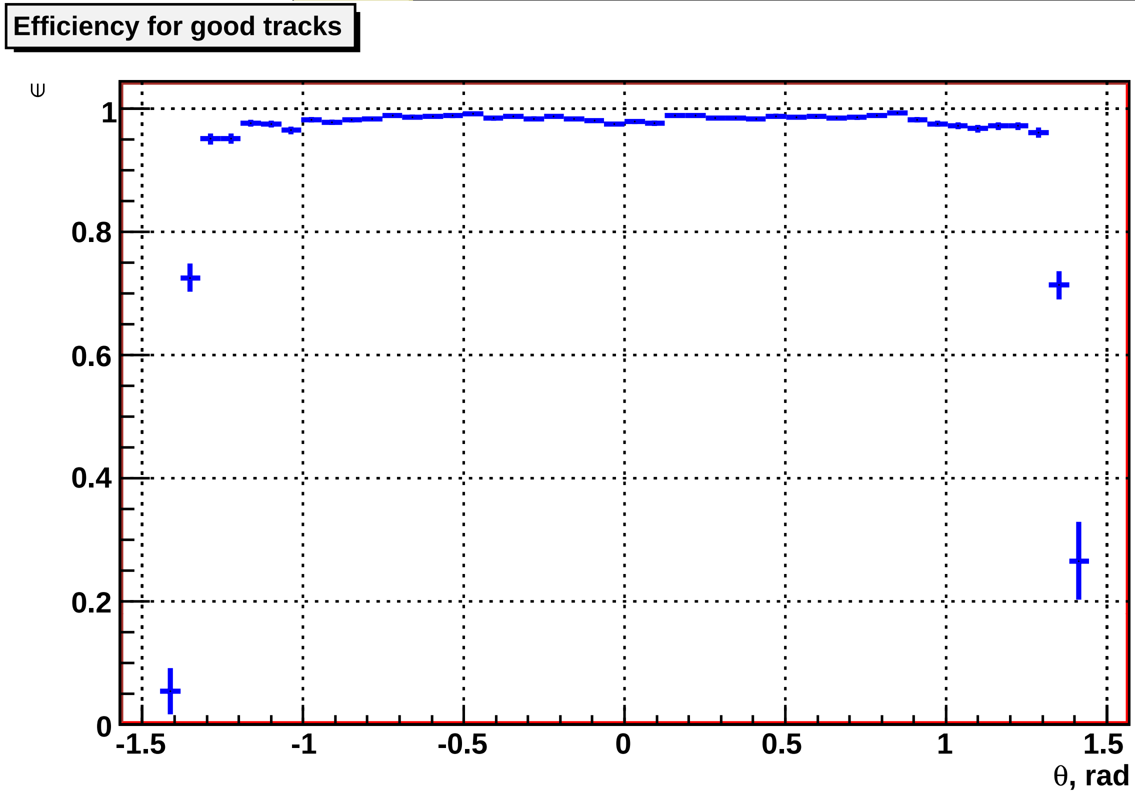


Tracking Efficiency

TPC

e+e- -> tt̲ -> 6 jets

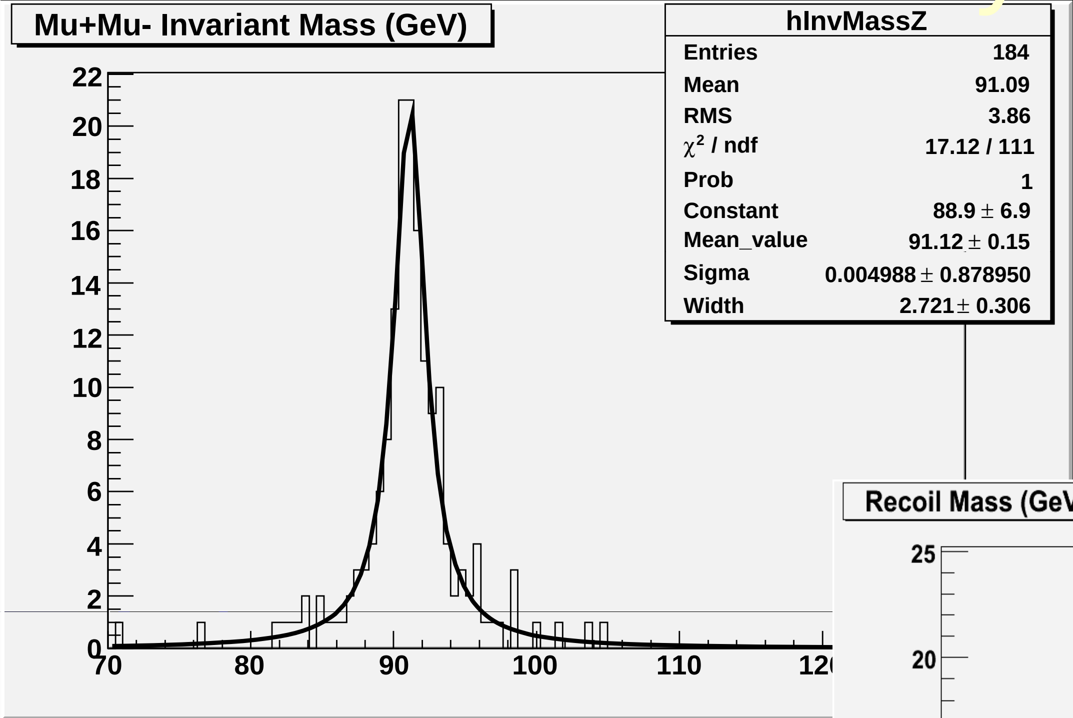




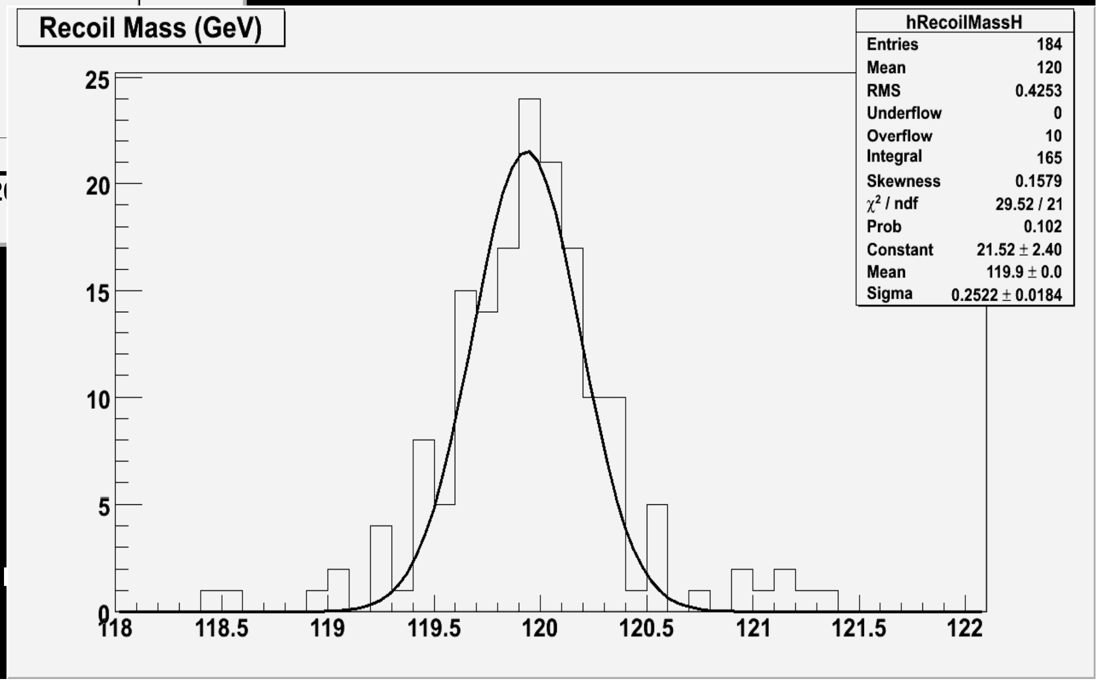
May 31th, 2007

TPC

$e^+e^- \rightarrow H^oZ^o$ @ E_{cm} = 230 GeV Analysis



- ΔM_{recoil} = 380 MeV (90% RMS)
- ΔM_{recoil} = 250 MeV (gauss fit)



Summary of Performance

- Tracking efficiency:
  - $\varepsilon_{reco} > 90\ \%$ above 100 MeV
  - $\varepsilon_{reco} = 99.7\ \%$ above 1.5 Gev
- TPC + VXD resolution:
  - $\sigma(1/p_t) = 6\ x10^{-5}$ up to $8\ x10^{-4}$
  - $\sigma(\varphi) = 0.05$ up to 1 mrad
  - $\sigma(d) = 2.6\ \mu m$ up to $15\ \mu m$
  - $\sigma(z) = 3.9\ \mu m$ up to $18\ \mu m$
- Totally dominated by MS
- e^+e^- -> H^oZ^o @ E_{cm} = 230 GeV is the worse case

Plans for Central Tracking Simulation

- TPC simulation frozen
- DCH
  - Gaussian smearing response: June 2007
  - Digitizaton: August 2007
- Si tracker
  - Will start mid June 2007
  - Expect first results in September 2007
  - Start with Gaussian smearing
  - Digitization by end of 2007

Vertex Detector Studies

Vertex Detector Studies

- Digitization and clusterization implemented for VXD
  - Very parametric implemetation
  - Several tecnologies can be represented
- FTD simulated in IlcRoot (help from Valencia's group)
  - Gaussian smearing only
  - Kalman filter needs to be optimized

New VXD Digitization & Clusterization

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

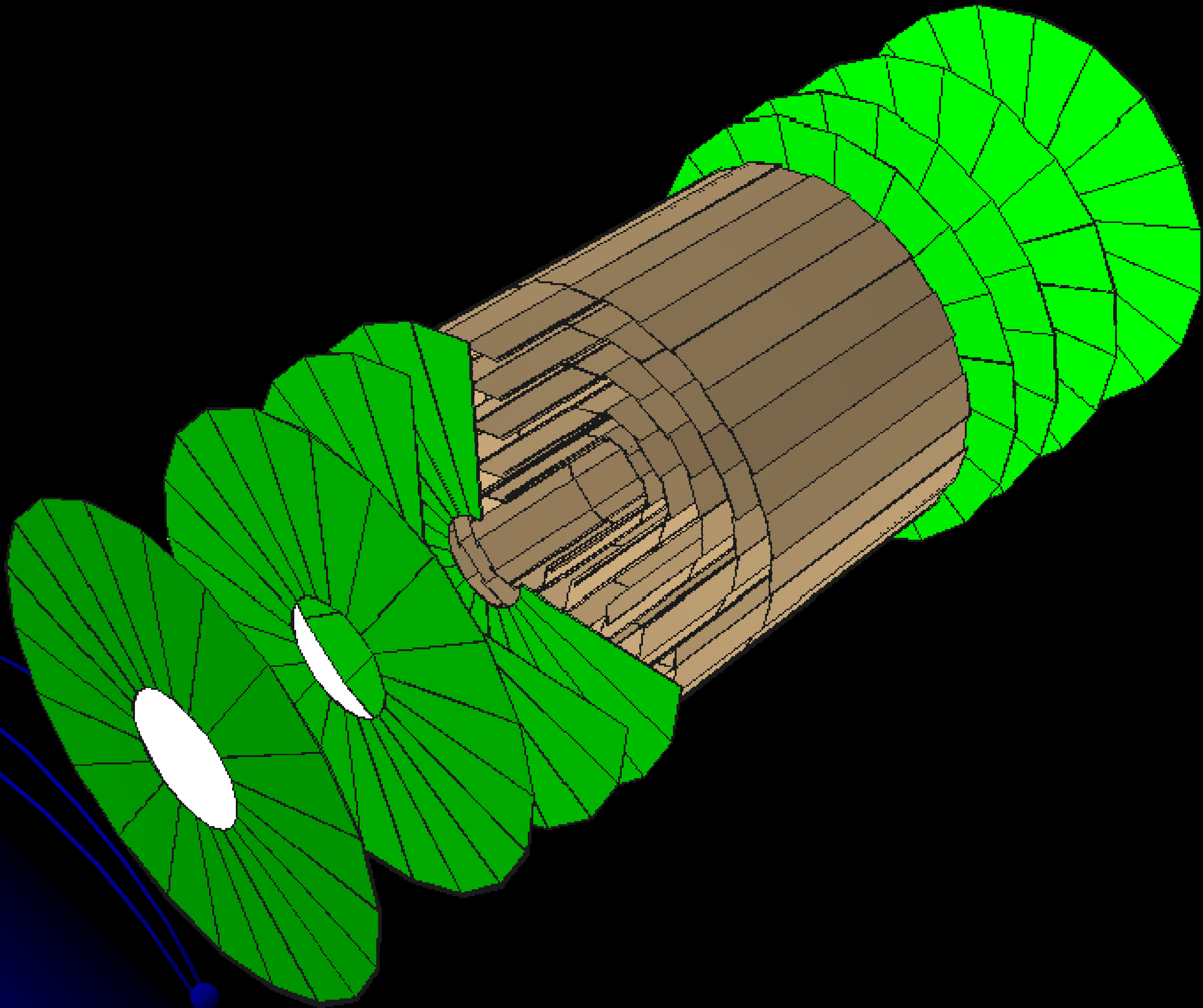
$$f(x,z) = Errf(x_{step}, z_{step}, \sigma_x, \sigma_z)$$

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

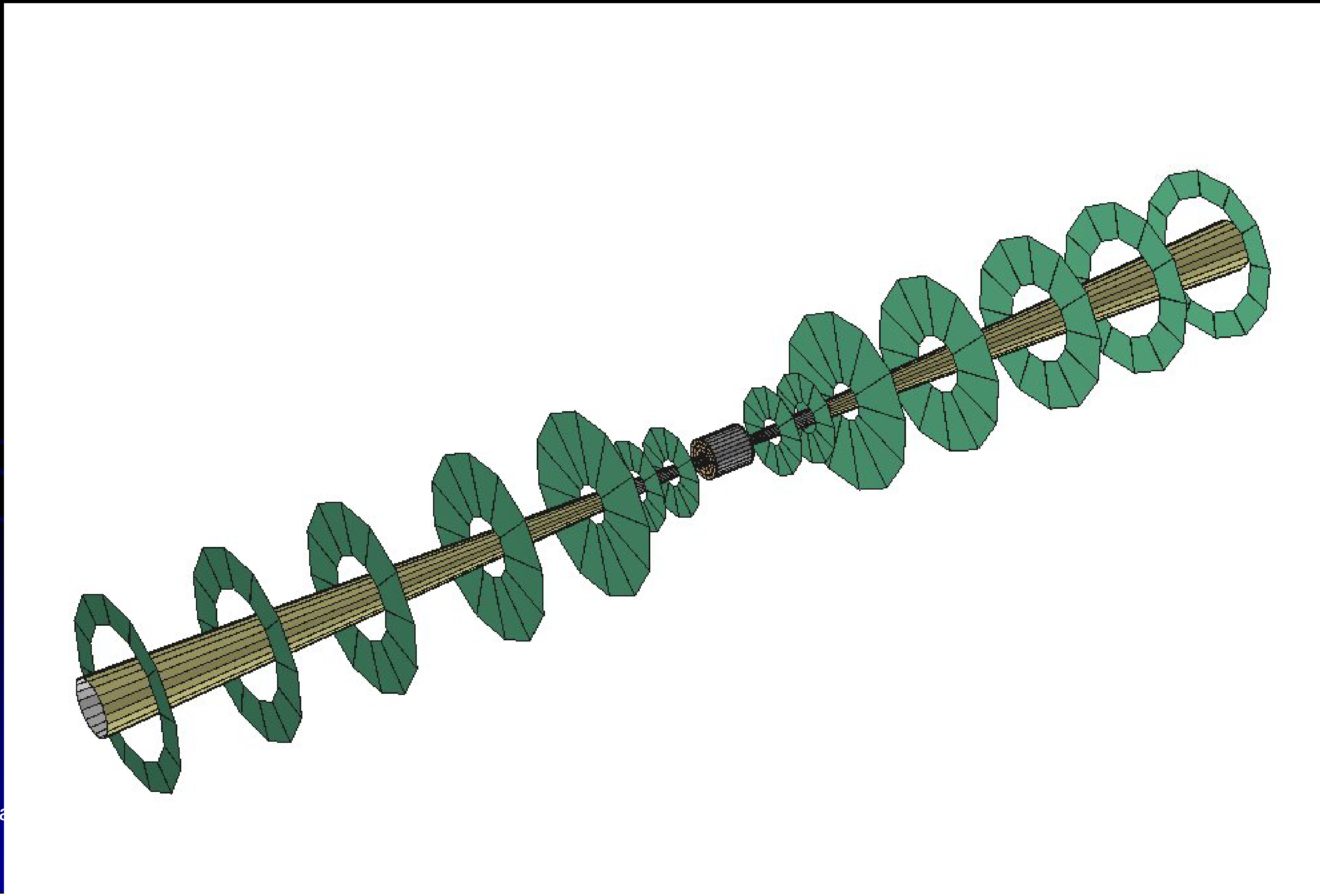
$$\Delta l = Si\,tickness, \quad \Delta V = bias\,voltage, \quad \sigma_x = \sigma_x \cdot fda$$

- Include also:
  - capacitive pixel coupling
  - random noise
  - electronic threshold
- Clusterization:
  - divide the initial cluster in smaller NxN clusters (to be optimized)
  - Kalman filter picks up the best clusters

SiD/4th VXD



FTD



VXD vs FTD Layout

VXD Barrel

- Δz=125 mm
- R=1.40-1.52, 2.20-2.31, 3.50-3.59, 4.76-4.84 and 6.00 6.08 cm
- Azimuth coverage: >11°
- Thickness: 100+100 μm

VXD Endcaps

- z=76, 95, 125, 180 mm
- Rin=16, 16, 20, 20mm
- Rout= 75, 75, 75, 75 mm
- Azimuth coverage: >6.5°
- Thickness: 100 +100 μm
- Thermal shield: r=12

FTD

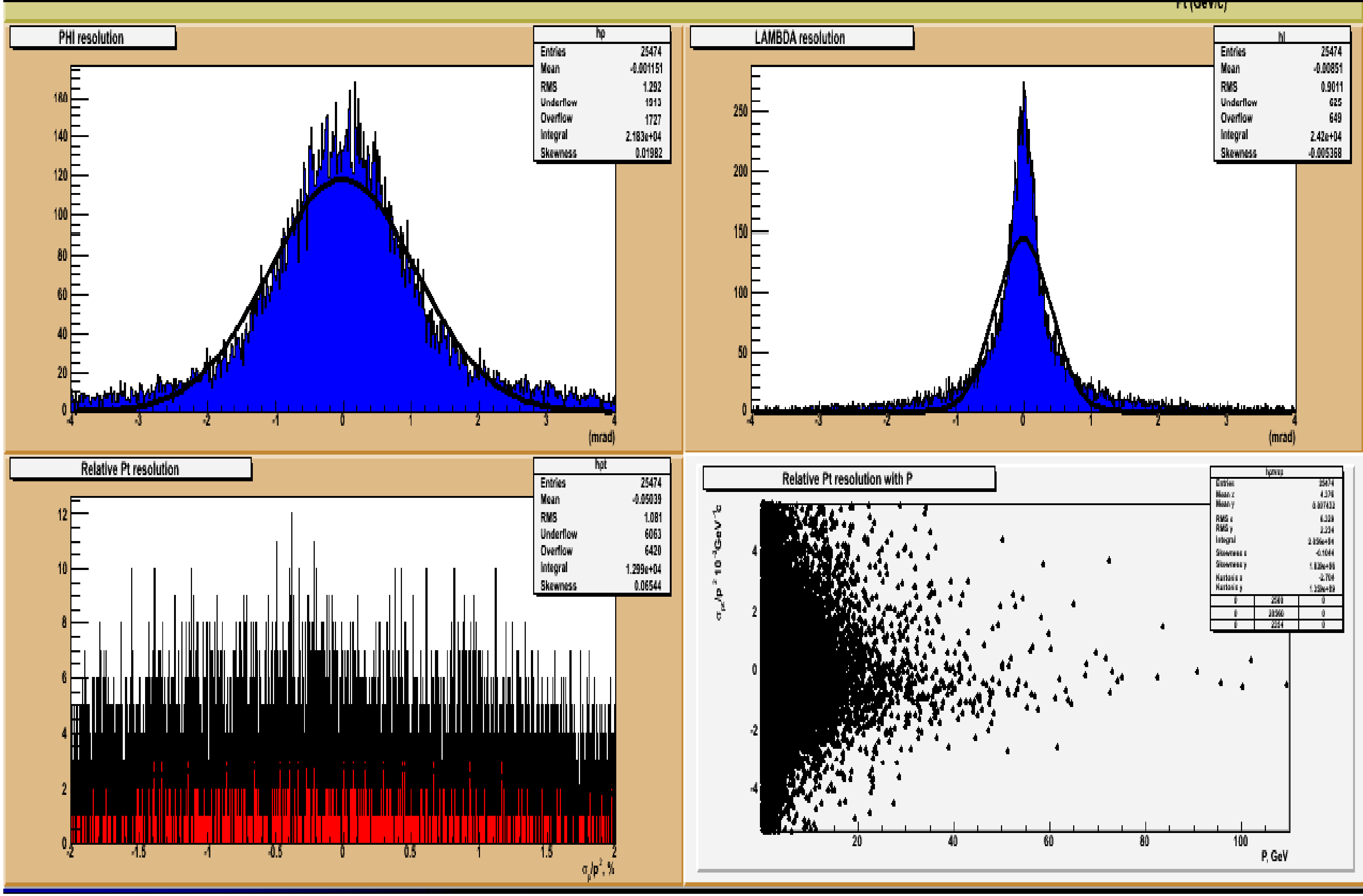
- Z=200, 320, 440, 550, 800, 1050, 1300 mm
- Rin=38, 48,59, 68, 90, 111, 132 mm
- Rout=140, 140, 210, 270 , 290 , 290 , 290 mm
- Azimuth coverage: >5.8°
- Thickness: 100 μm
- Thermal shield: r=29

VXD vs FTD Simulations

FTD (gaussian smearing):	**VXD (full digitization):**
• Barrel: $\sigma_{r\phi}$ = 5 μm σ_z = 6 μm • Pixel Endcaps $\sigma_{r\phi}$ = 14 μm σ_z = 60 μm • Strips Endcaps (±20mrad stereo angle) $\sigma_{r\phi}$ = 14 μm σ_z = 50 μm/sqrt(12)/tan(40 mrad)	Pixel size: 20 μm x 20 μm

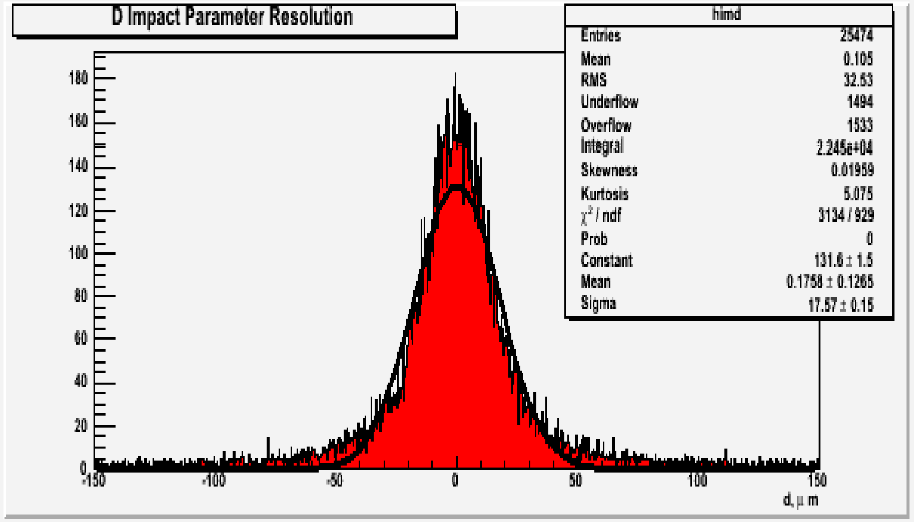
VXD

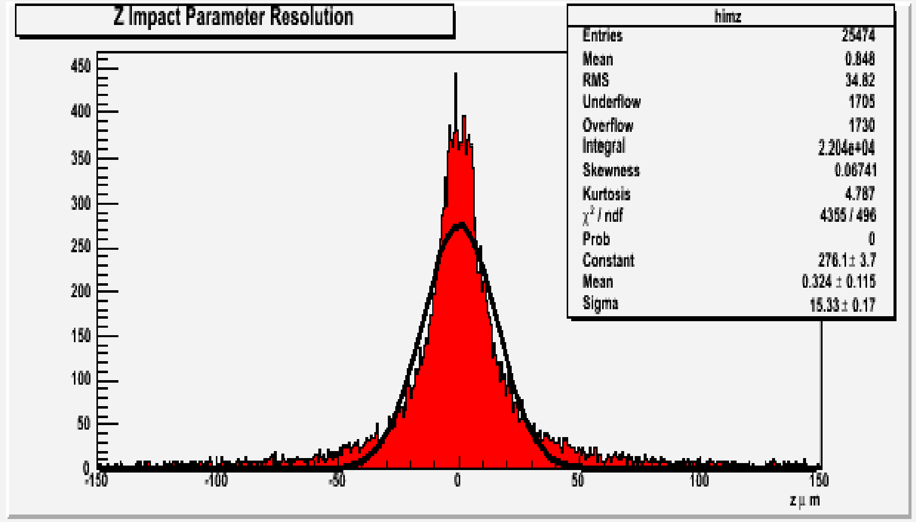
Track Resolutions

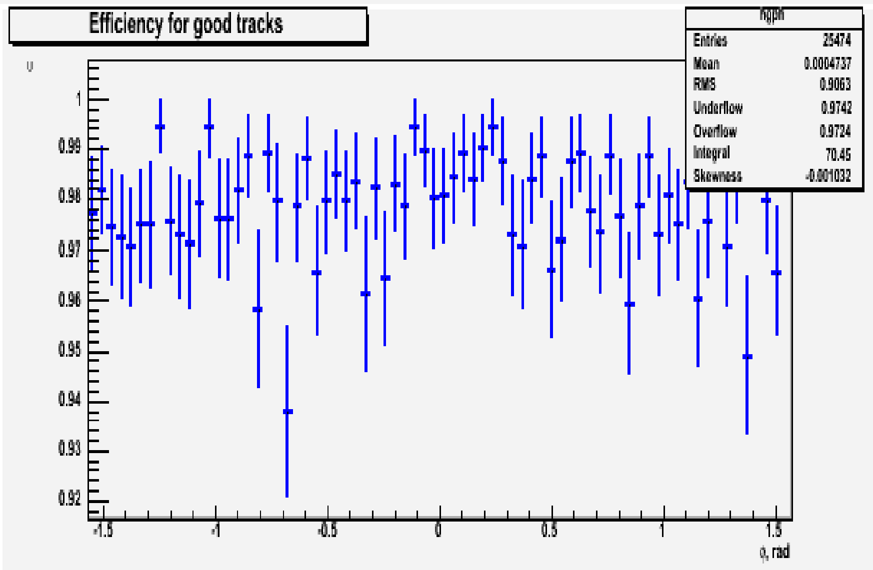


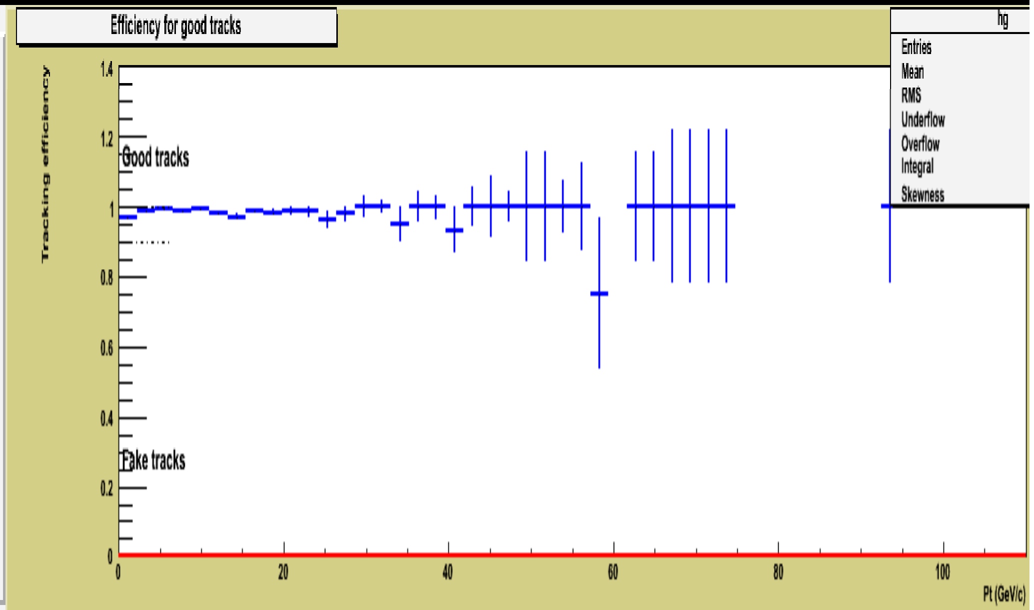
$e^+e^- \to t\bar{t} \to 6$ jets

VXD

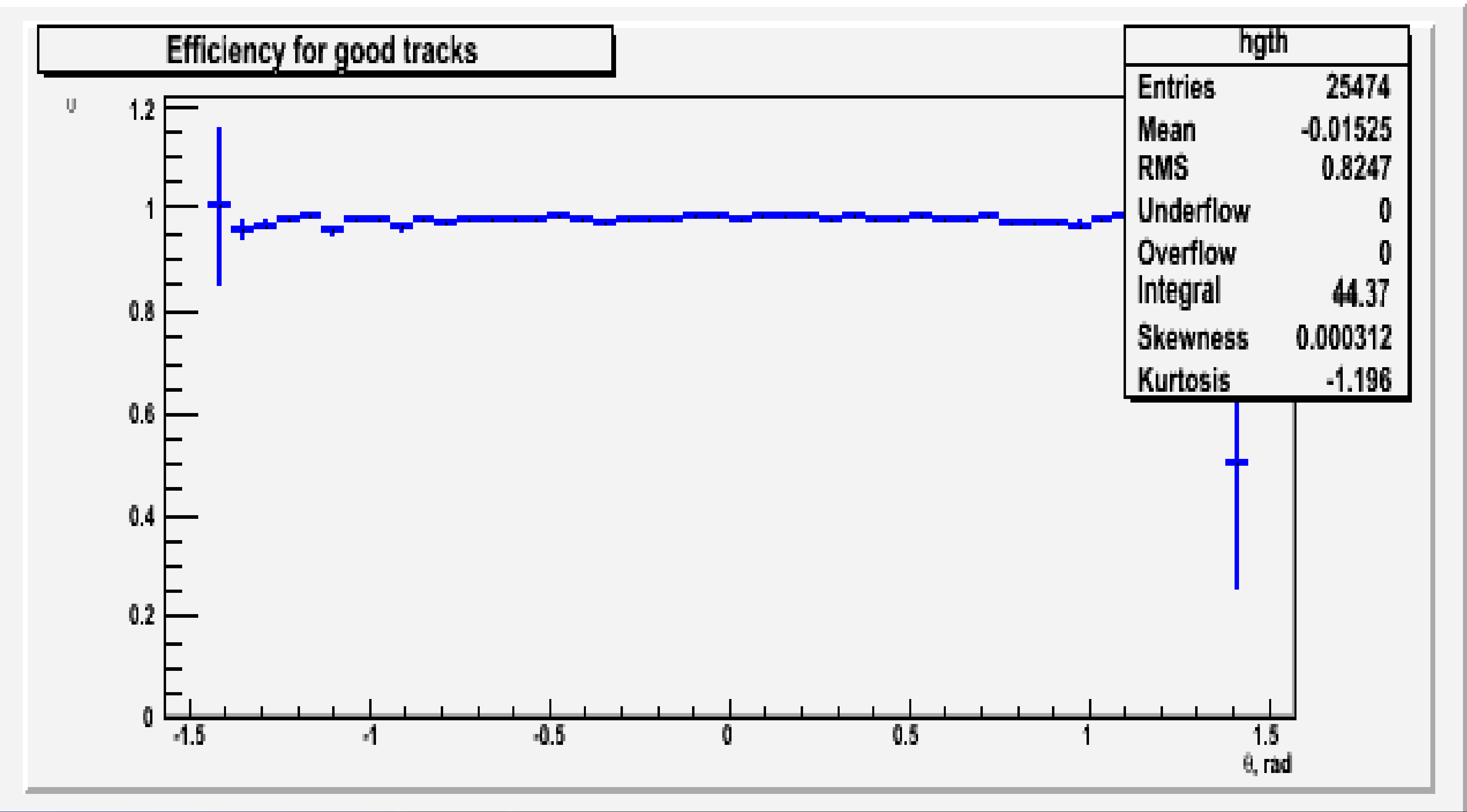








Efficiency vs θ



VXD vs FTD (tt-> 6 jets)

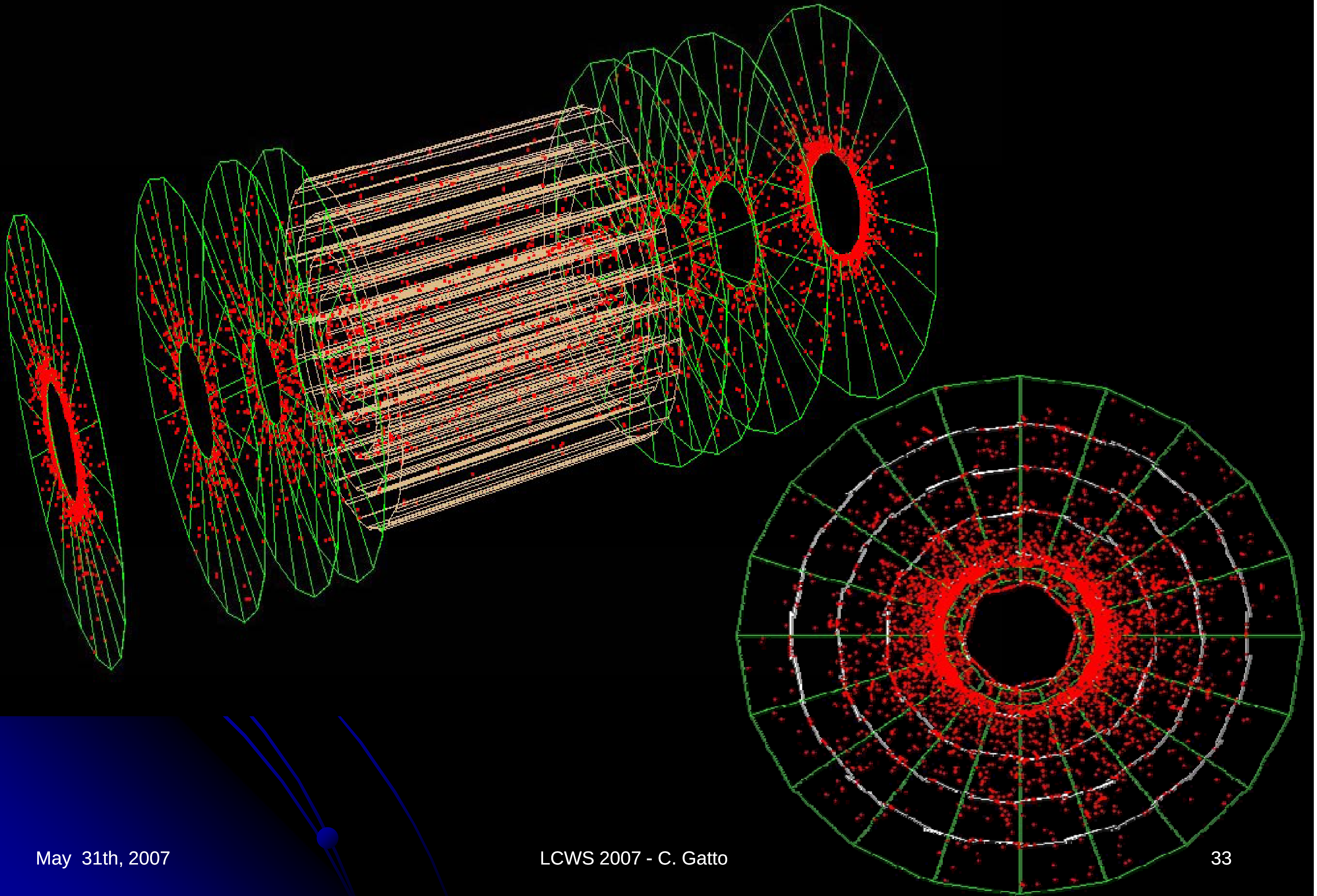
VXD	FTD
• Tracking efficiency: ε_{reco} = 98 % ε_{reco} = 99 % above 4 Gev	• Tracking efficiency: Need optimization
• Params resolution : • $\sigma(\varphi)$ = ~1.3 mrad • $\sigma(\lambda)$ = ~1 mrad • $\sigma(d) = 18\ \mu m$ • $\sigma(z) = 16\ \mu m$	• Params resolution • $\sigma(\varphi)$ = ~1.3 mrad • $\sigma(\lambda)$ = ~1 mrad • $\sigma(d) = 21\ \mu m$ • $\sigma(z) = 17\ \mu m$

Beam Pair Background Study with FTD , VXD and TPC

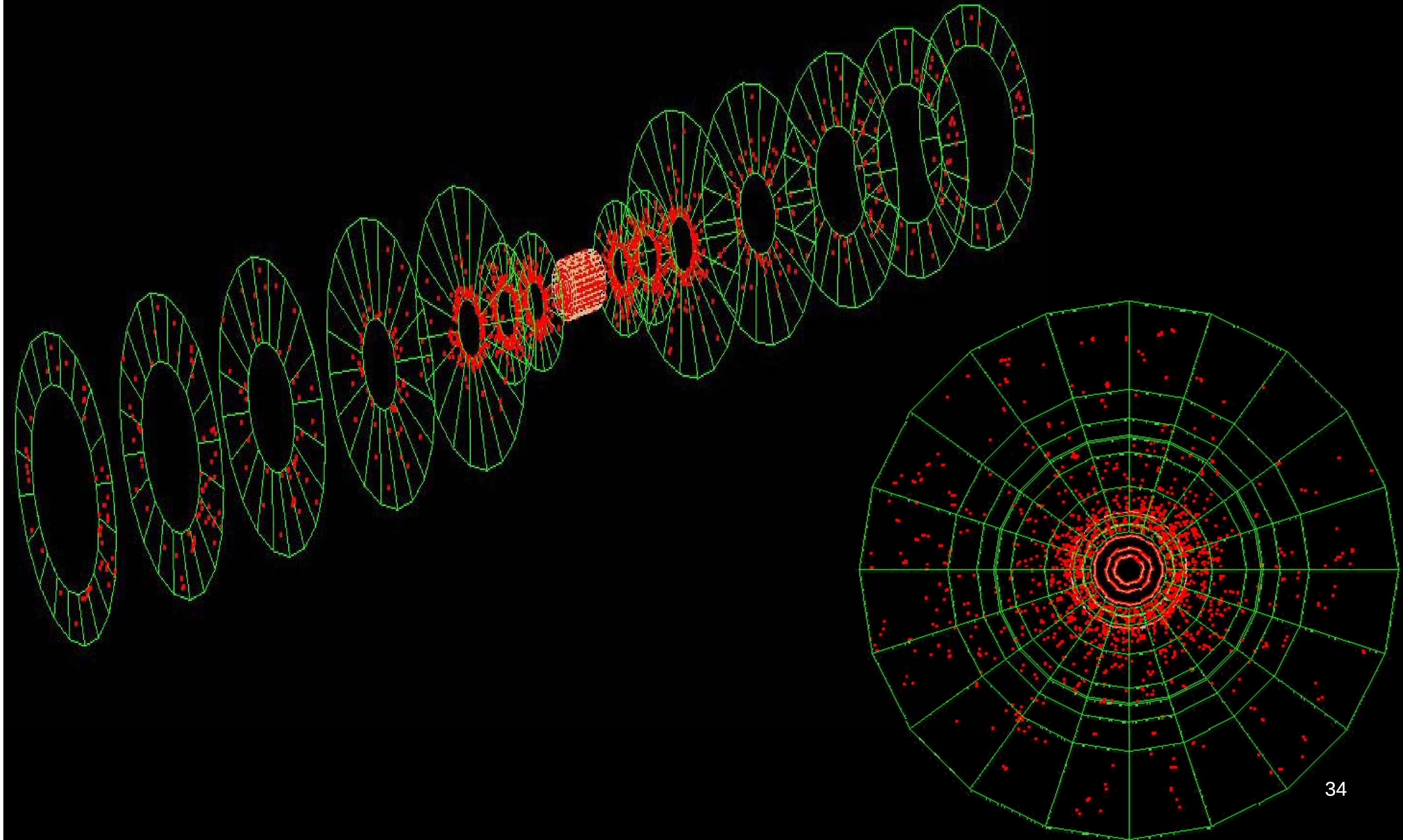
- New studies with Guinea Pig (in collaboration with M. Vos and C. Mariñas)

- Beam Parameters (Nominal Settings):
- E_{beam} = 250 GeV
- N_{beam} = 2.05 10^{10}
- Bunch Crossing = 140

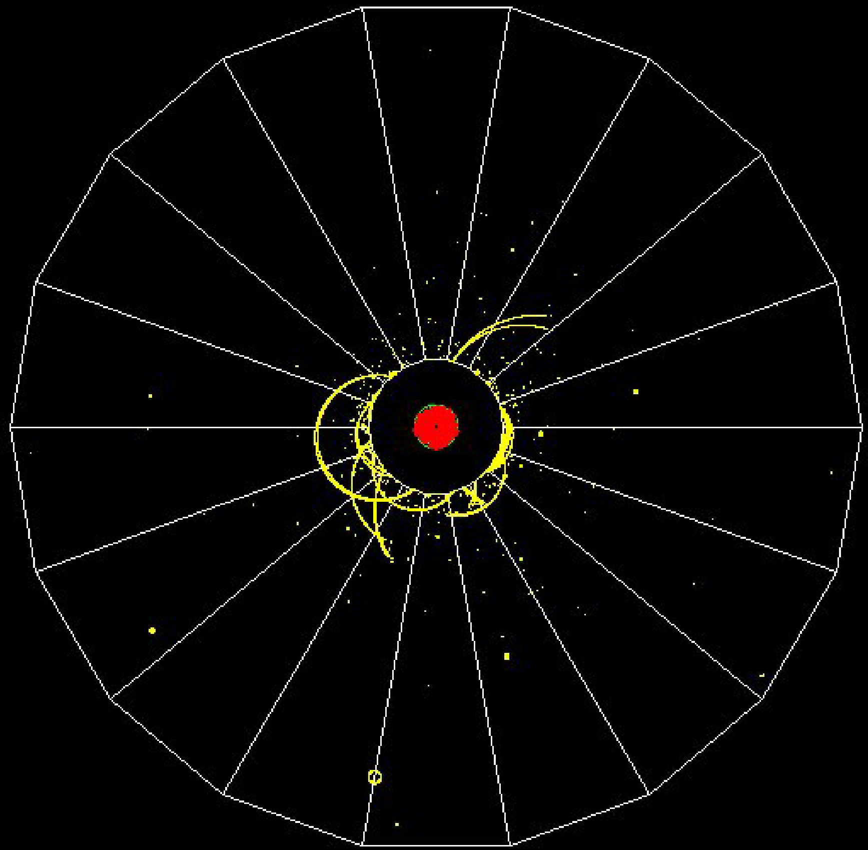
VXD Beam Background

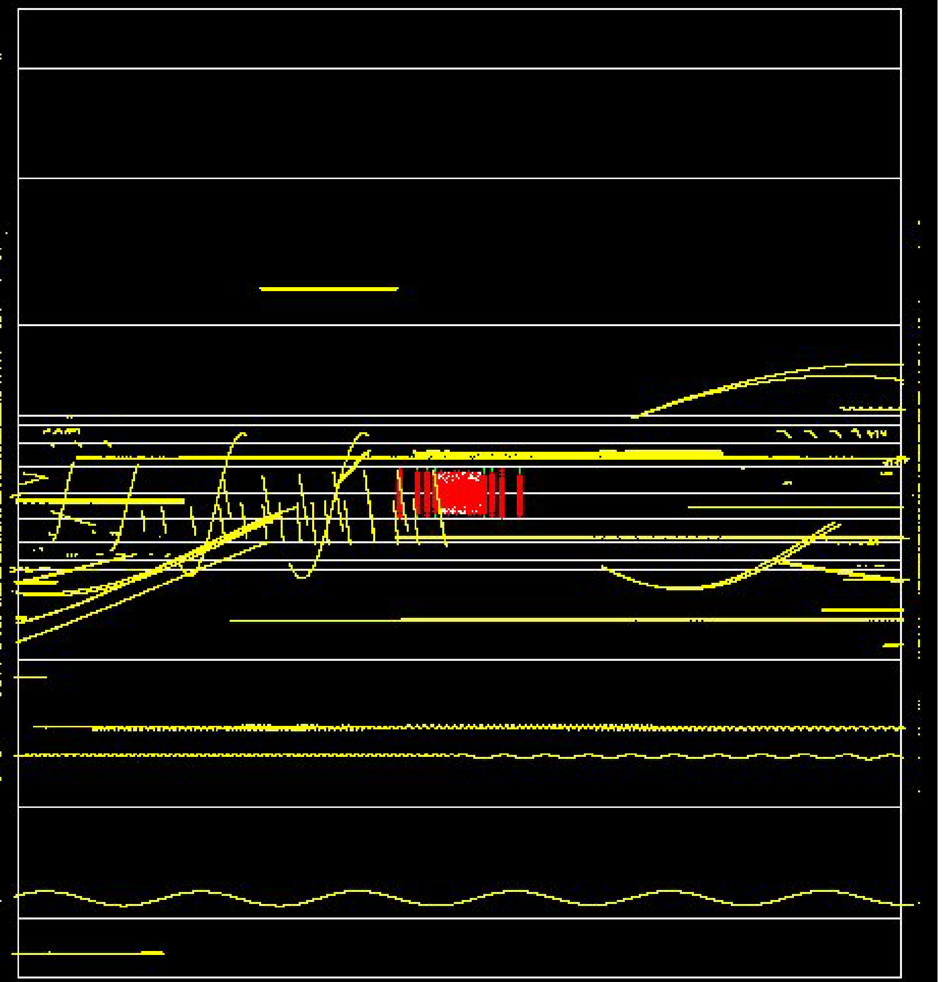


FTD Beam Background

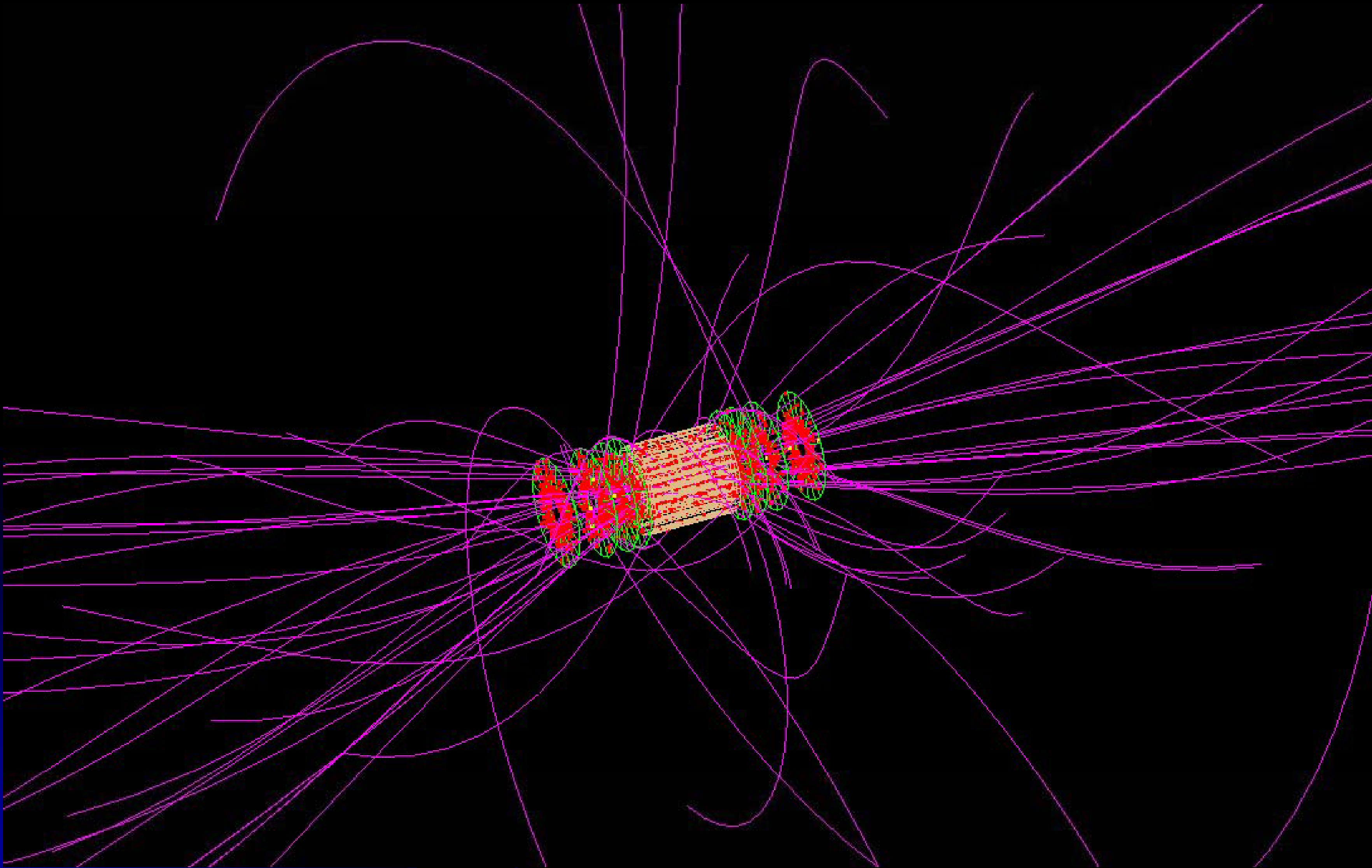


TPC Beam Background

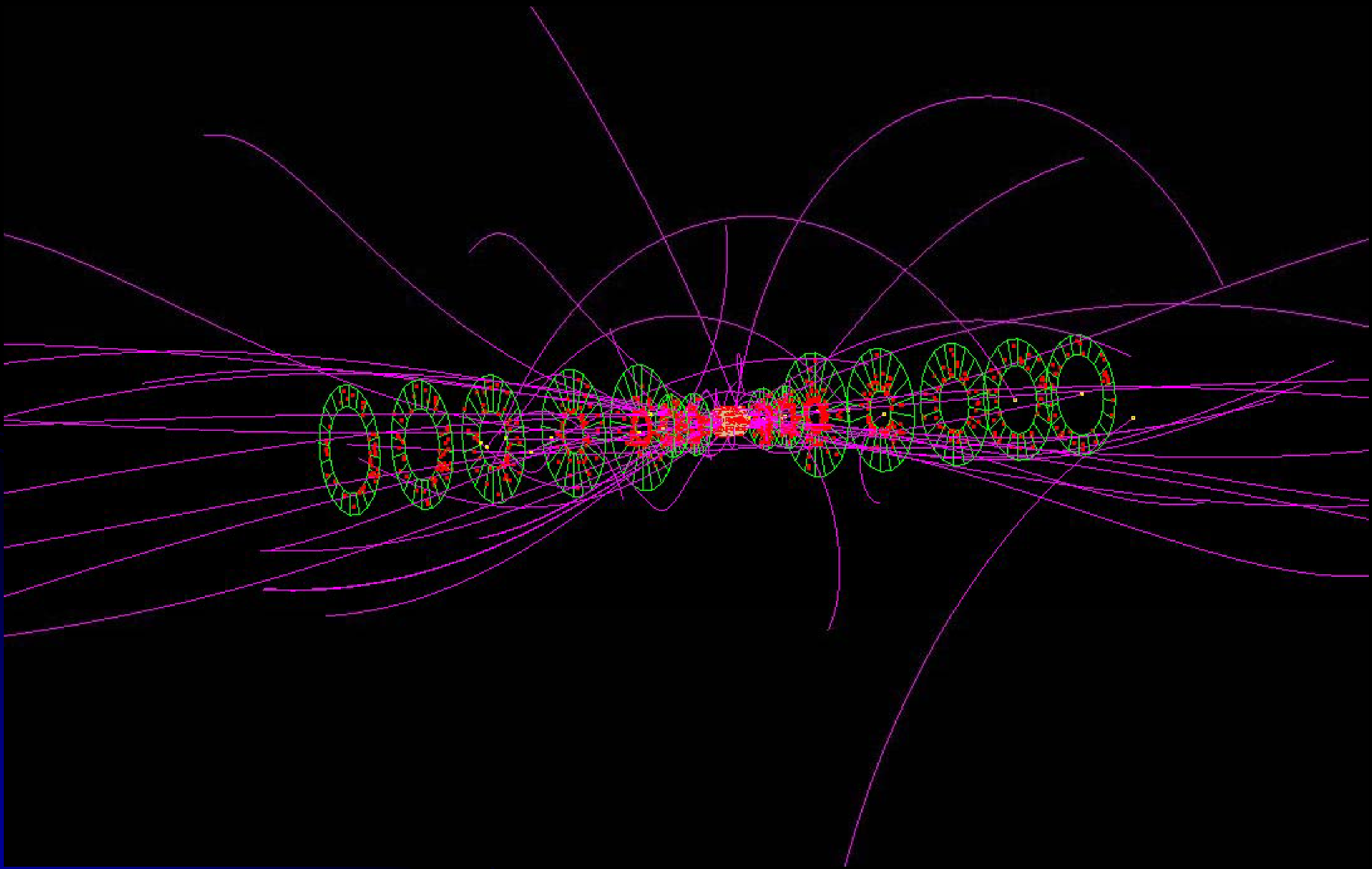




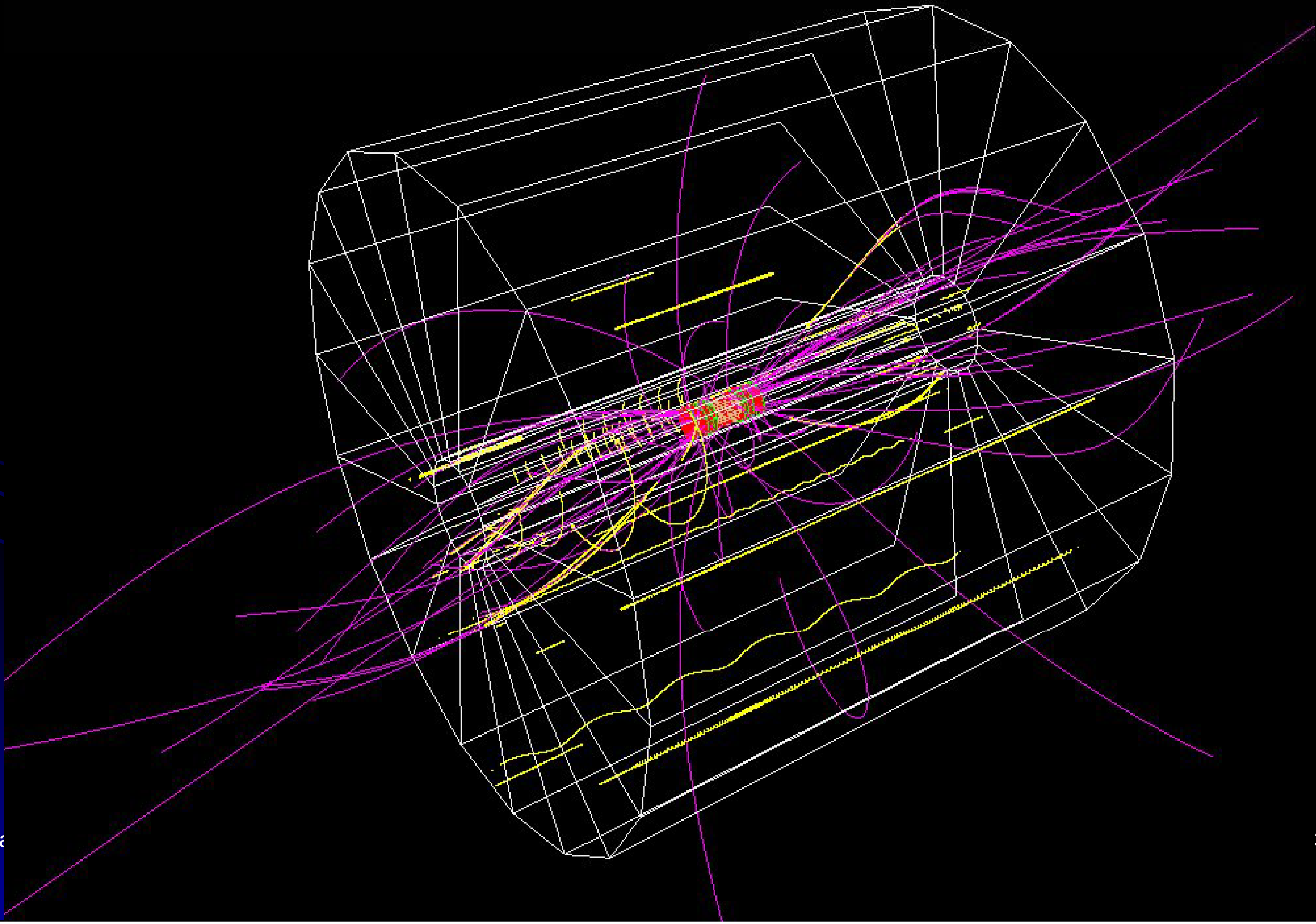
VXD Tracks Reconstruction



FTD Tracks Reconstruction



TPC Tracks Reconstruction



Summary

- About 13,000 hits found in the VXD (14,000 in FTD+Barrel VXD)
- About 278,000 hits in TPC alone
- About 163 reconstructed tracks (SA Vertex Tracker)
- VXD average clusters/track = 4.3
- About 176 reconstructed tracks in VXD +TPC
  - 443 particles entering the TPC
  - TPC average clusters/track = 19.6
- Very dangerous background when integrating many bunch crossings

Summary

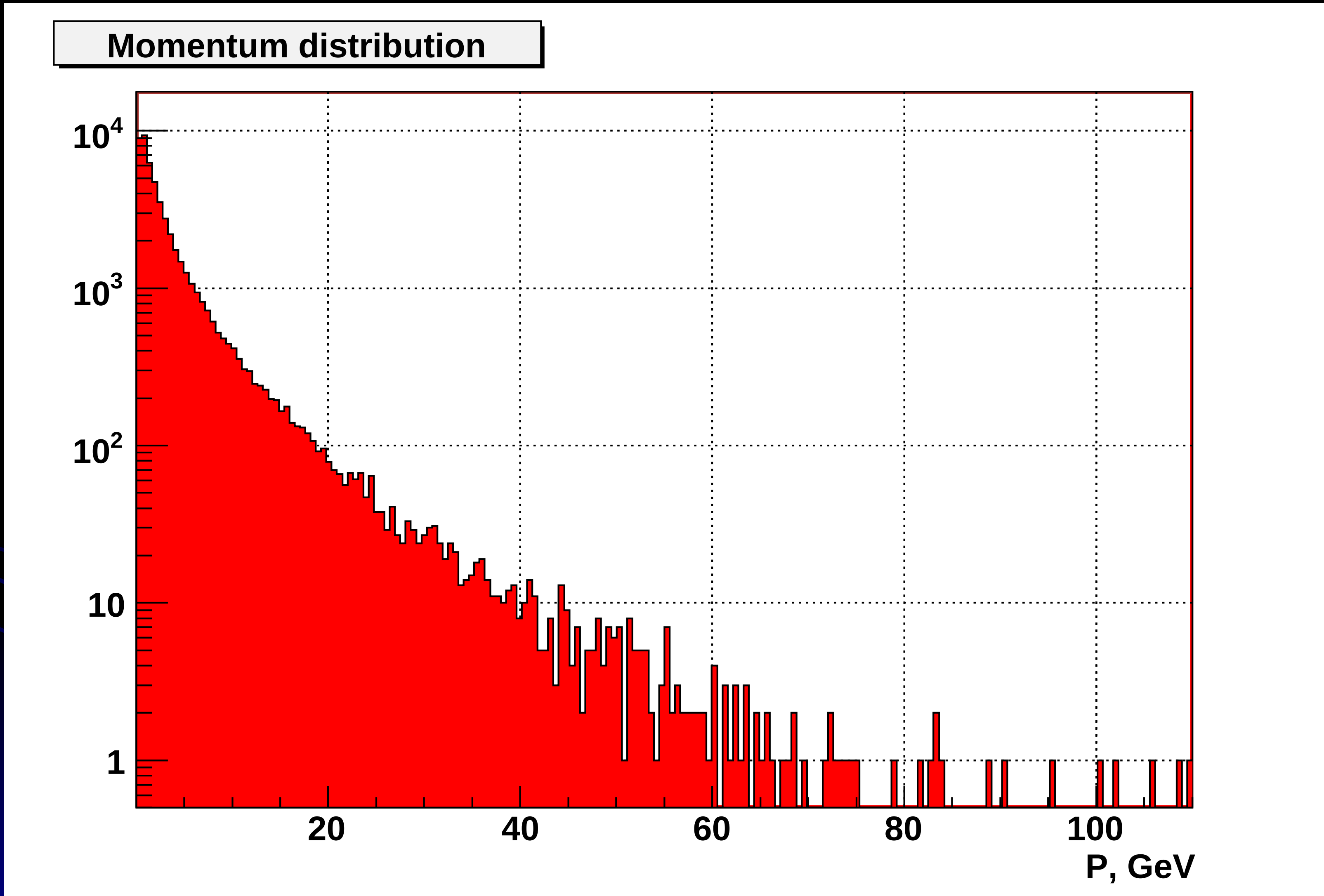
- First DCH occupancy studies presented
  - Occupancy is tolerable
  - Only 1 beam crossing is integrated with current cell design
- Preliminary resolution results in few weeks
- Expect improved performance vs TPC for slow momentum tracks in forward direction
  - Multiple scattering lower in He
  - Resolution is not dependent on z (no $\omega\tau$ effect)
- VXD and FTD studies are in progress
  - SA Kalman filter needs to be optimized for FTD
  - Strip digitization ready in the next 2-3 months
- Background studies: need more studies
  - Albedo neutrons
  - More beam generated background

Conclusions

- Large effort from the 4th Concept Simulation group to understand optimal tracking
- Other people are getting interested (Valencia, Paris VI (?))
- Growing interest at Fermilab on Tracking and Calorimetry simulation
  - ILCroot is also available at Fermilab
  - 4th Concept also uses Grid Computing at Fermilab
- Central Tracker studies and background will take center stage in the next few months (TPC vs Si vs DCH)

Backup Slides

$e^+e^- \rightarrow t\bar{t} \rightarrow$ 6 jets



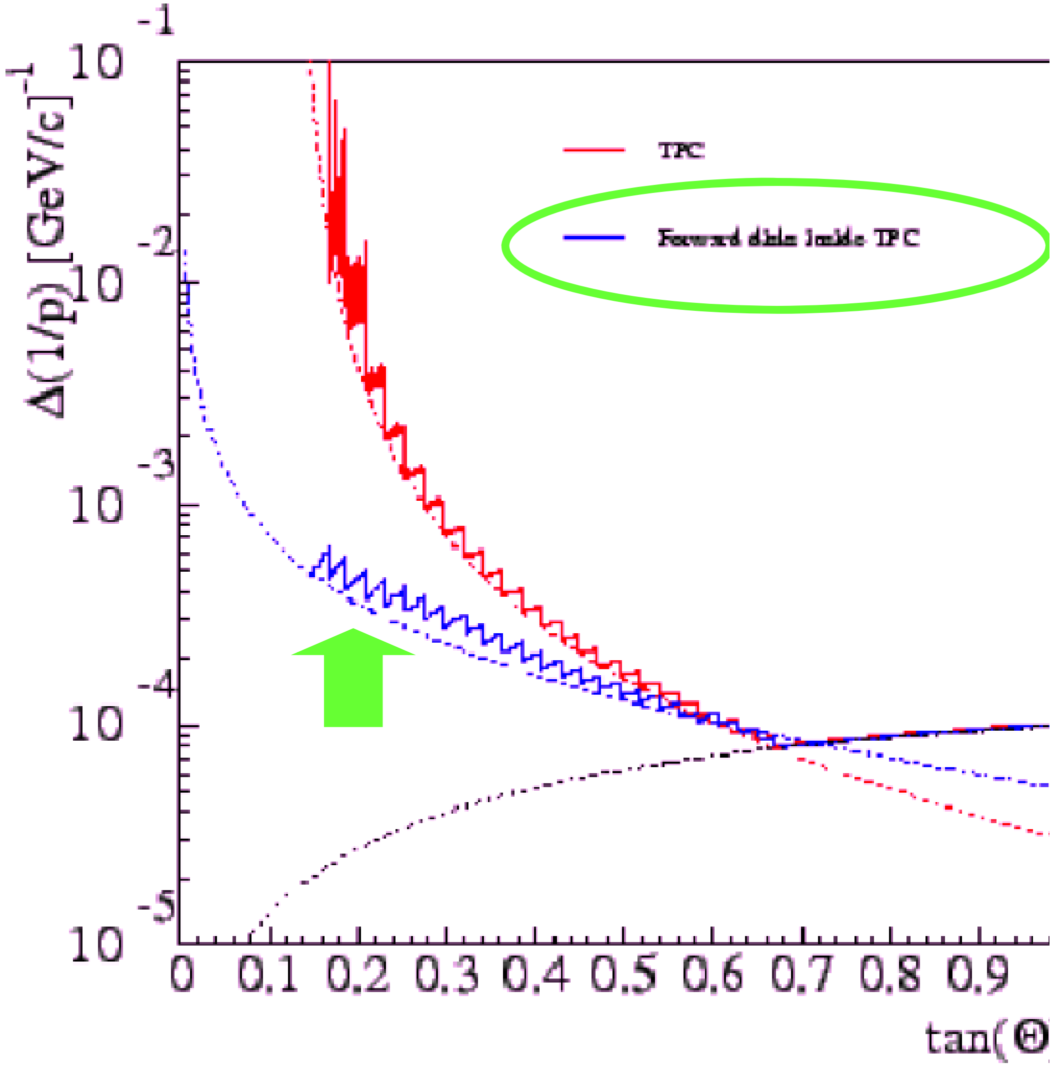
SiLC assets: fast simulation

SGV simulation (M. Berggren) of the LDC tracker central region

Impact of silicon (FTD) disks on momentum resolution on forward tracking.

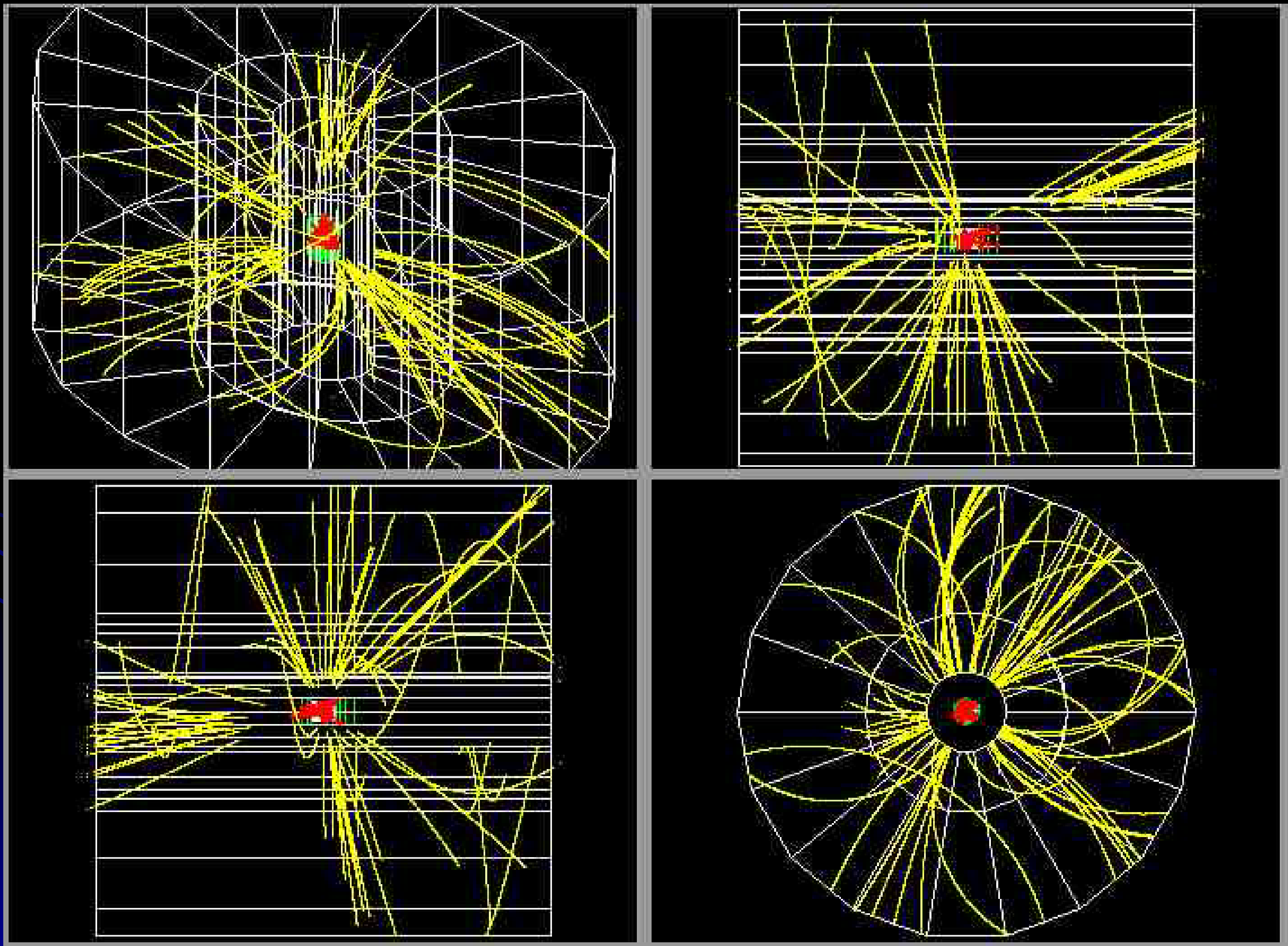
To maintain an adequate performance in the forward region, the TPC must be complemented by silicon.

Marcel Vos's Talk Orsay2007

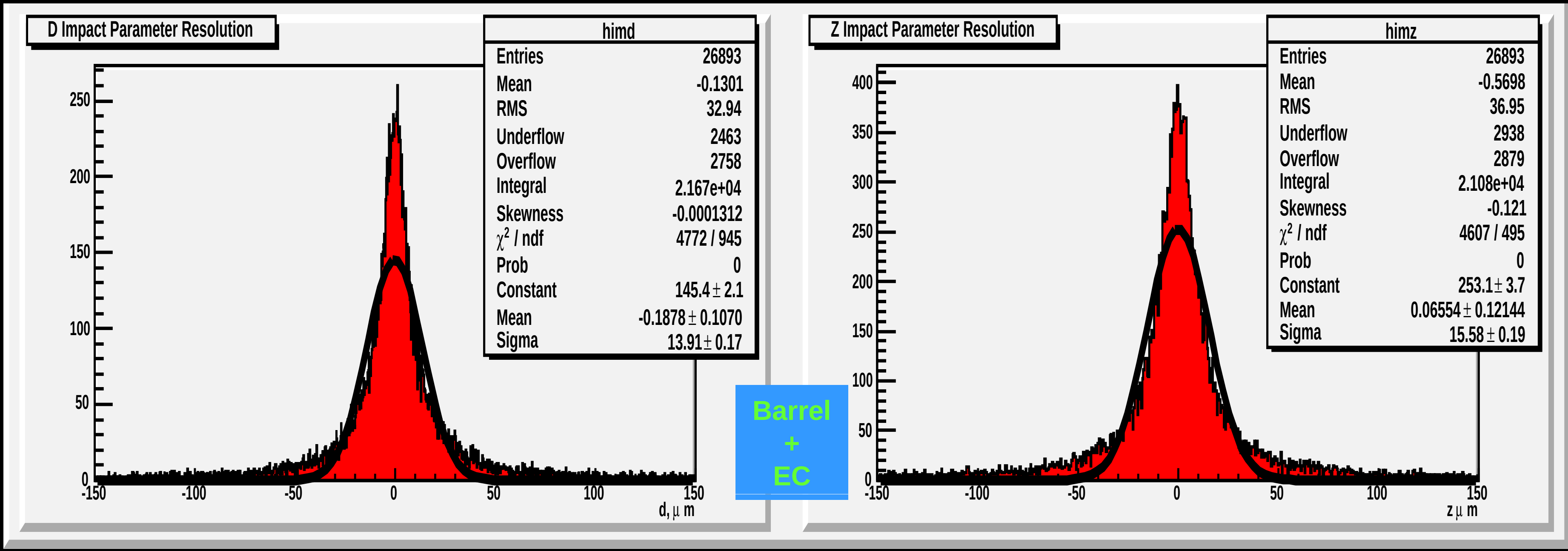


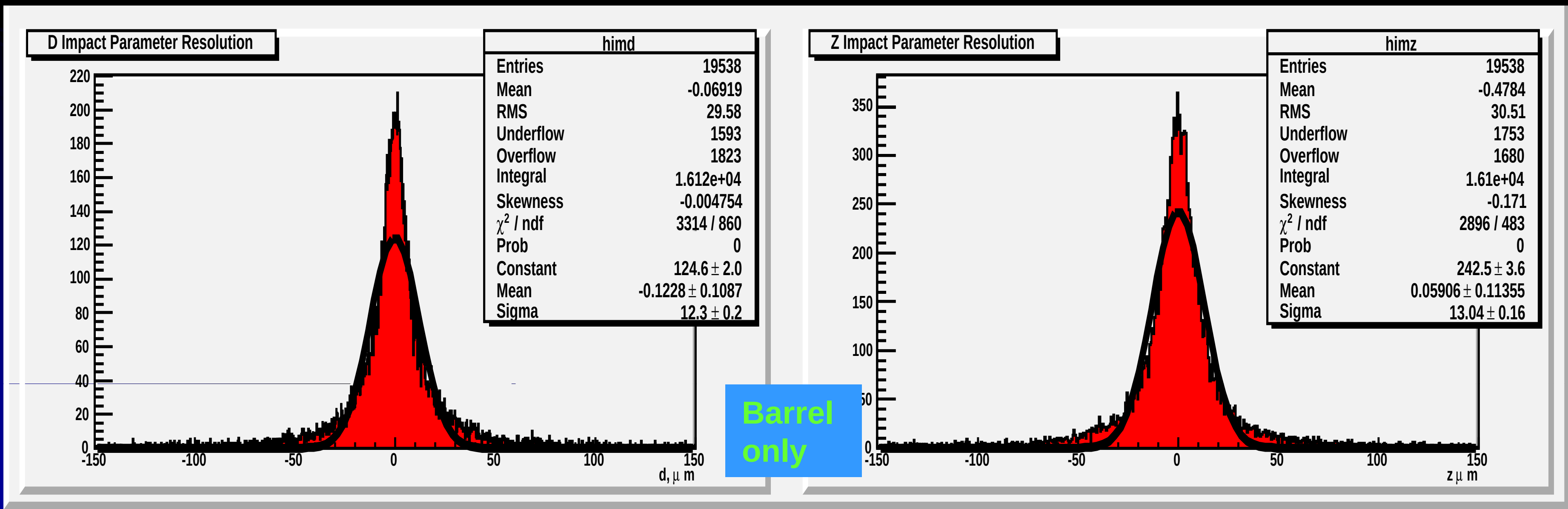
Marcel Vos, ILC-SW, Orsay, May 3rd 2007

$e^+e^- \rightarrow t\underline{t} \rightarrow$ 6 jets

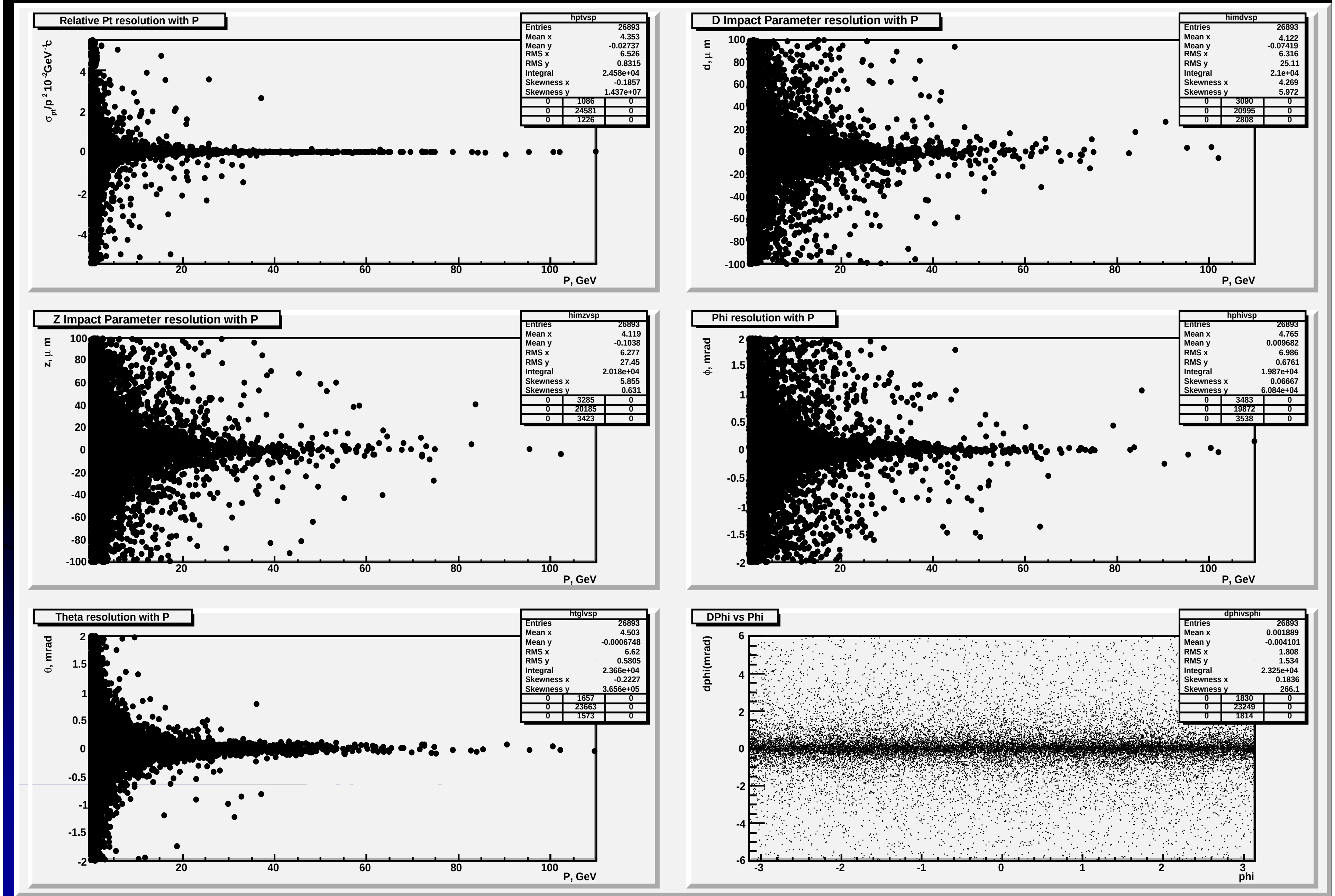


$e^+e^- \to t\bar{t} \to$ 6 jets (VXD+TPC)



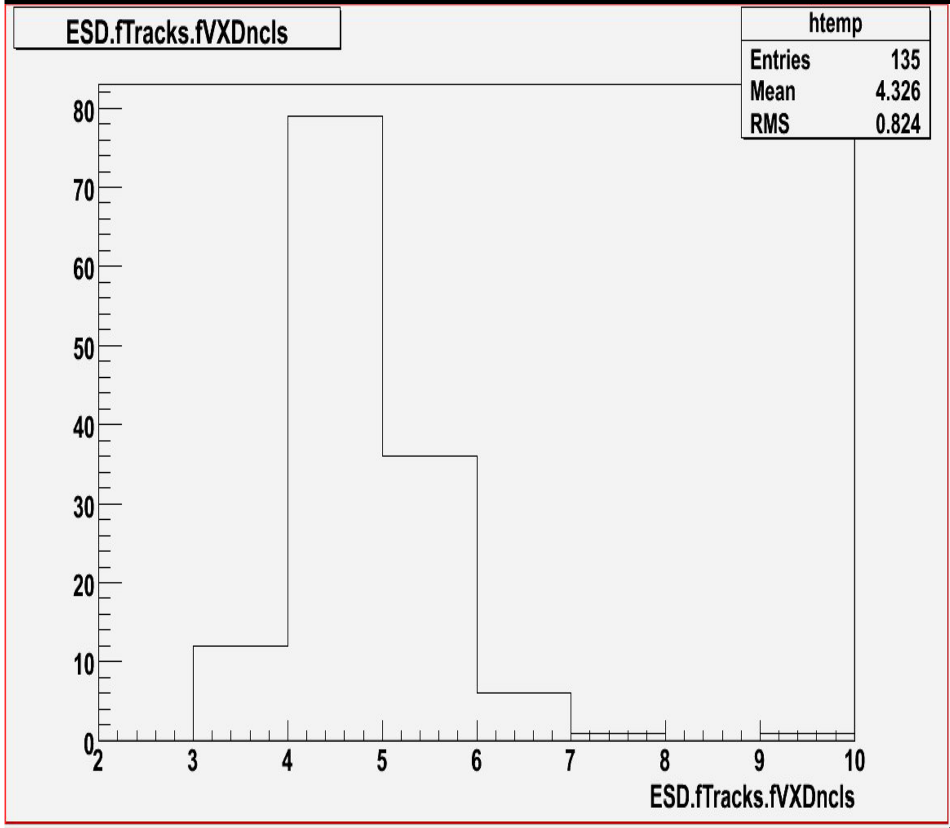


e^+e^- -> $t\bar{t}$ -> 6 jets

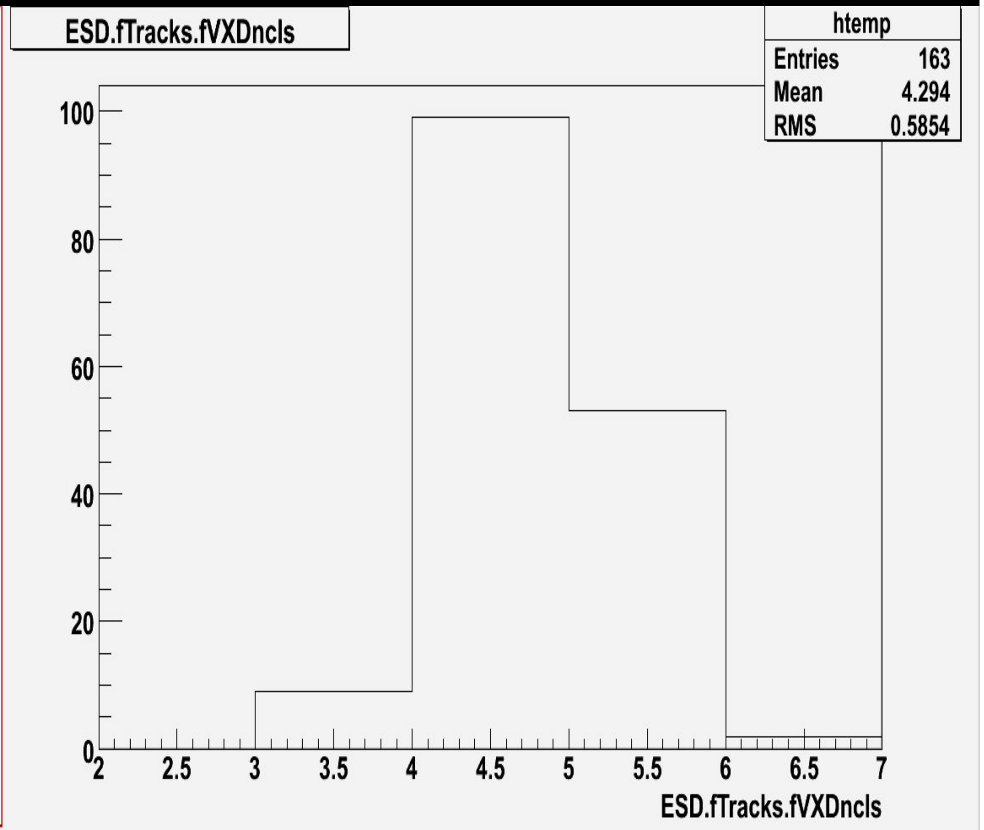


Kalman Fit Clusters Usage (Guinea Pig – 140 BX)

- FTD



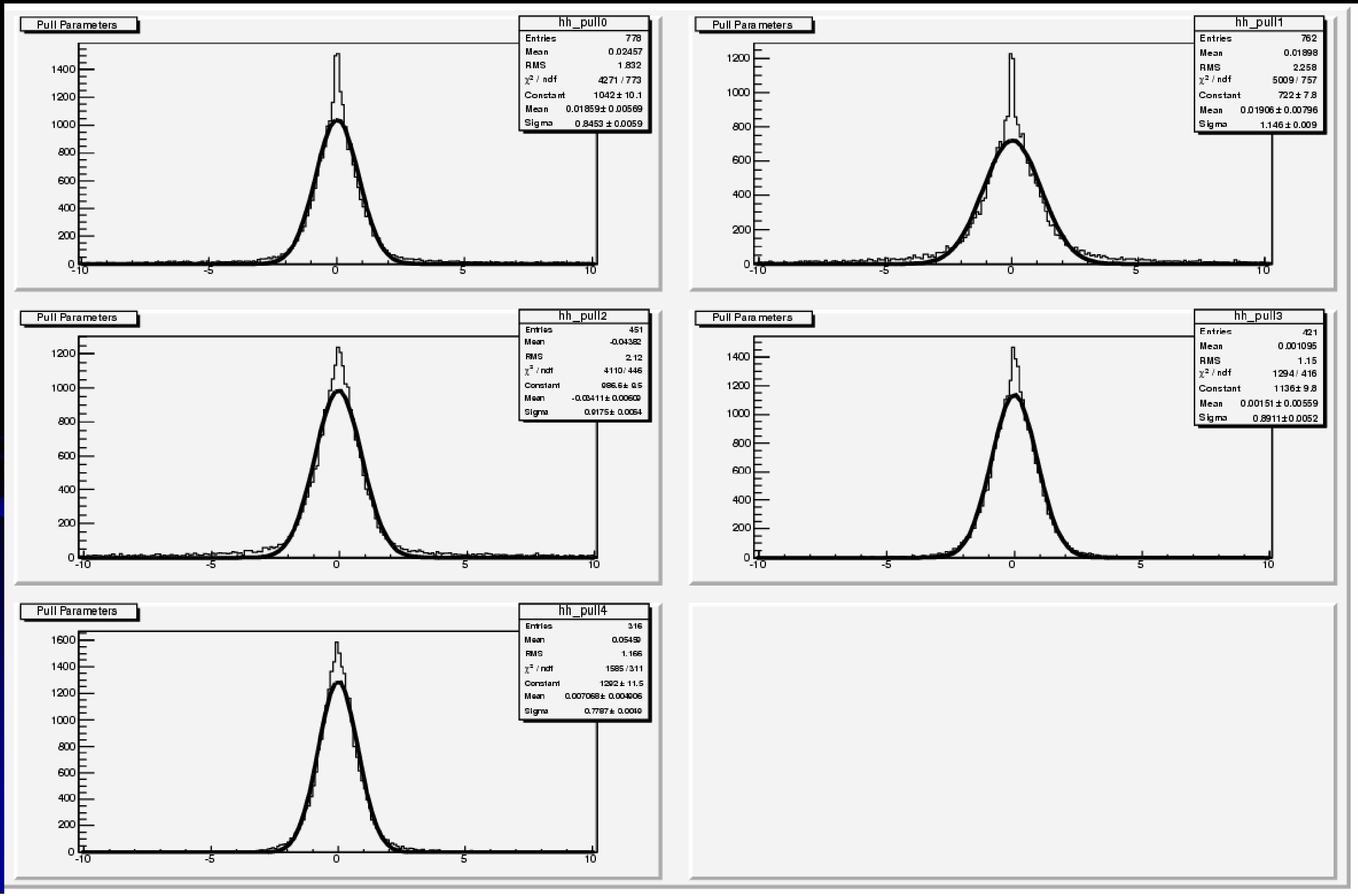
- VXD



TPC

Pulls from Kalman Filter

e+e- -> tt̲ -> 6 jets



Beam Background Cluster/Track