Muon Analysis in the Peripheral Region of INO-ICAL

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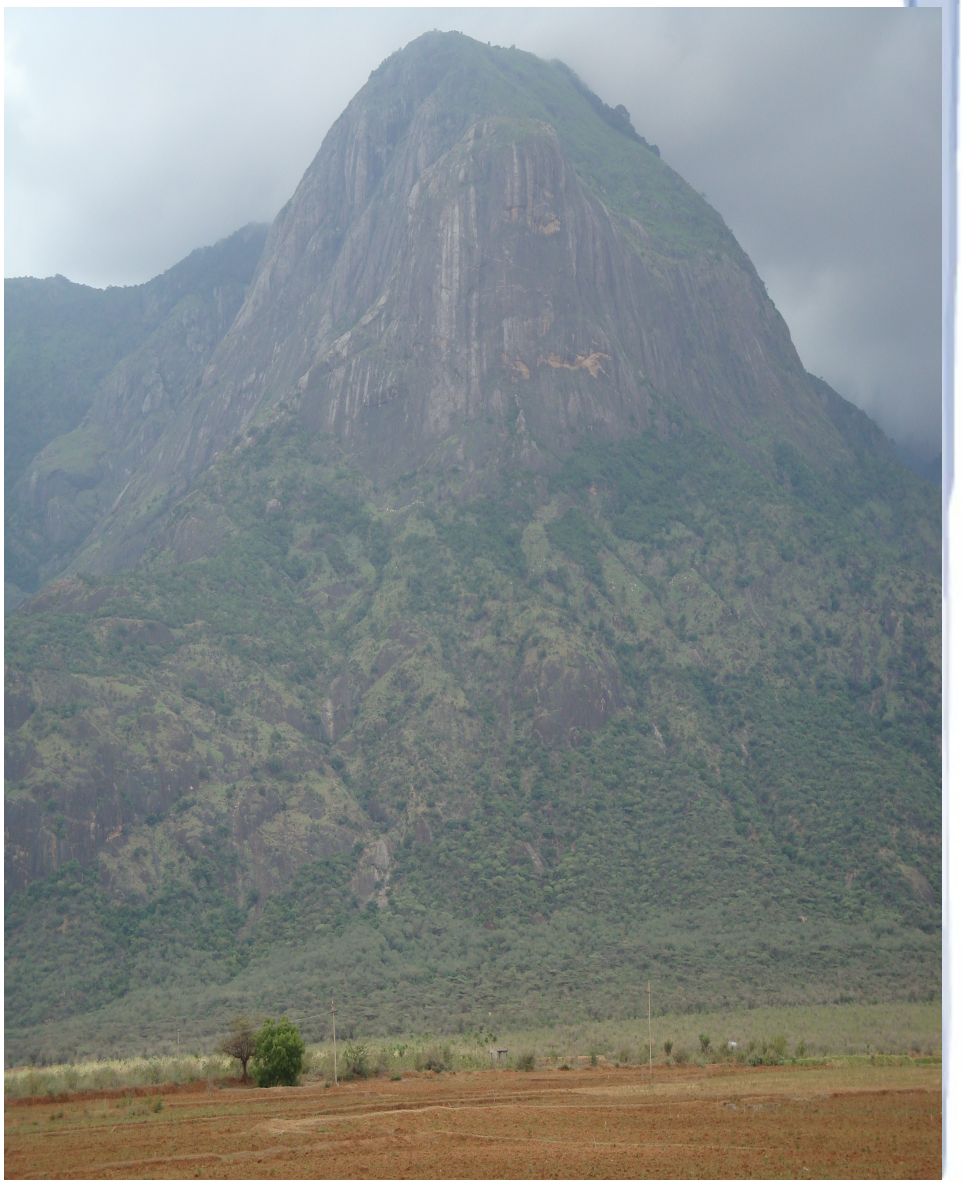
Outline of the Talk

- Motivation of the Study
- Magnetic field mapping
- Data generation and method of calculation
- Results
  - Momentum Resolution
  - Efficiencies
  - cosθ resolution
- Summary

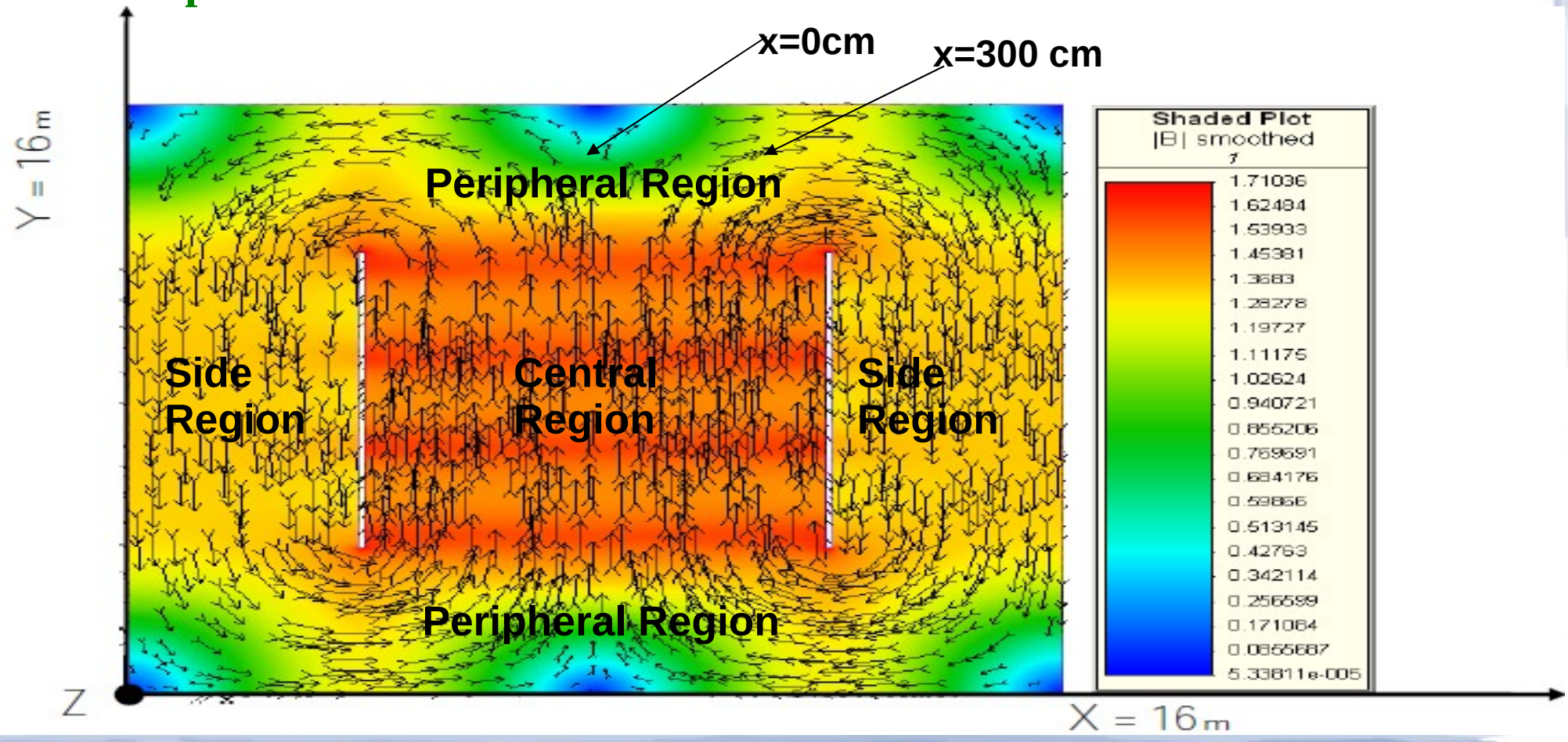


Motivation of the Study

- Proposed magnetised Iron Calorimeter (ICAL) detector at India-based Neutrino Observatory (INO) aims to determine neutrino oscillation parameters precisely with atmospheric muon neutrinos, matter effect in neutrino oscillations and the sign of Δm^2_{32} using matter effect
- ICAL, mostly sensitive to atmospheric muon neutrinos, detected through interaction with iron layers via charged-current (CC) and neutral-current (NC) interactions producing mainly muons
- Muon momentum can be reconstructed through the curvature of their track
- Muons are reconstructed according to INO-ICAL code through a Kalman filter algorithm that returns both the magnitude and direction of the muon momentum
- Selection criteria is applied to select muons whose track is closest to the vertex
- Preliminary results on muon momentum and angular resolution and momentum reconstruction and charge identification efficiencies in the peripheral region is presented here,
- ICAL detector is sensitive to non-horizontal particles which makes large angle with B (magnetic field) in perpendicular direction; which gives resolution better in peripheral region than as what we expected

Magnetic Field Mapping

- Central Region – Uniform magnetic field
- Side Region – Uniform magnetic field but smaller (15% less) and opposite than central region. Acceptance effects
- Peripheral Region – Changing magnetic field, smaller in magnitude. Acceptance effects



Data Generation

- Softwares used: Geant 4.9.4.p02, INO-ICAL codes: inoical0_20112011
- 10000 MC events generated for μ-
- Energy values taken: 1-25 GeV
- Cosθ = 0.95, 0.85, 0.65, 0.45, 0.35, 0.25 without smearing
- (0-2π) smearing in φ
- Vertex:

Region	Vertex (cm)	Smearing (cm)
Peripheral	(0,600,0)	(800,100,600)
Peripheral	(0,y,0) (300,y,0) y= -450,-550,-650,-750	(10,10,10)
Side	(-2070,100,0),(0,2200,0)	(10,10,10),(100,400,600)
Central	(100,100,0), (0,0,0)	(10,10,10),(400,400,600)

- Cuts taken:

Momentum Resolution	Reco and Cid Efficiency	Angular Resolution
$0 - 2P_{in}$, nhits[0]>0, $\chi^2/(2*nhits[0]-5) < 10$, ntrkt[0]>0	$P_{in} \pm 3*\sigma$, nhits[0]>0, $\chi^2/(2*nhits[0]-5) < 10$, ntrkt[0]>0	cosθ ± 0.15

Methods and Calculations

- For momentum resolution: abs(trkmm[0]) is plotted in the range 0 to 2 P_{in}, where P_{in} is input momentum. Where, trkmm[0] is momentum distribution of muon
- For cosθ resolution: cos(trkth[0]) is plotted in the range cosθ ± 0.15. where, trkth[0] is theta distribution of muon
- FWHM is taken from the distributions

  abs(trkmm[0]) fitted in the range P_{in} ± 1FWHM with single gaussian, mean & sigma are taken for calculation of resolution
- Resolution $R_{mom} = \sigma / P_{in}$
- Error on R_{mom} is:

  $\delta R = R \times \delta\sigma/\sigma$, since $\delta P_{in} = 0$

  where error propagation formula used is: $(\delta R/R)^2 = (\delta\sigma/\sigma)^2 + (\delta P_{in} / P_{in})^2$
- Resolution $R\cos\theta = \sigma / \cos\theta$
- Error on Rcosθ is:

  $\delta R = \delta\sigma / \cos\theta$

Contd...

- Reconstruction efficiency is the ratio of total no. of reconstructed μ+ or μ- to the total no. of incident μ+ or μ-
- If the sign of input particle and reconstructed momentum are same then it is called right charge identification (Cid)
- Cid efficiency is ratio of total no. of rightly identified μ+ or μ- to the total no. of reconstructed μ+ or μ-
- Reco efficiency defined as Reff = nR / N

  where nR = no. of reconstructed events with all cuts and conditions

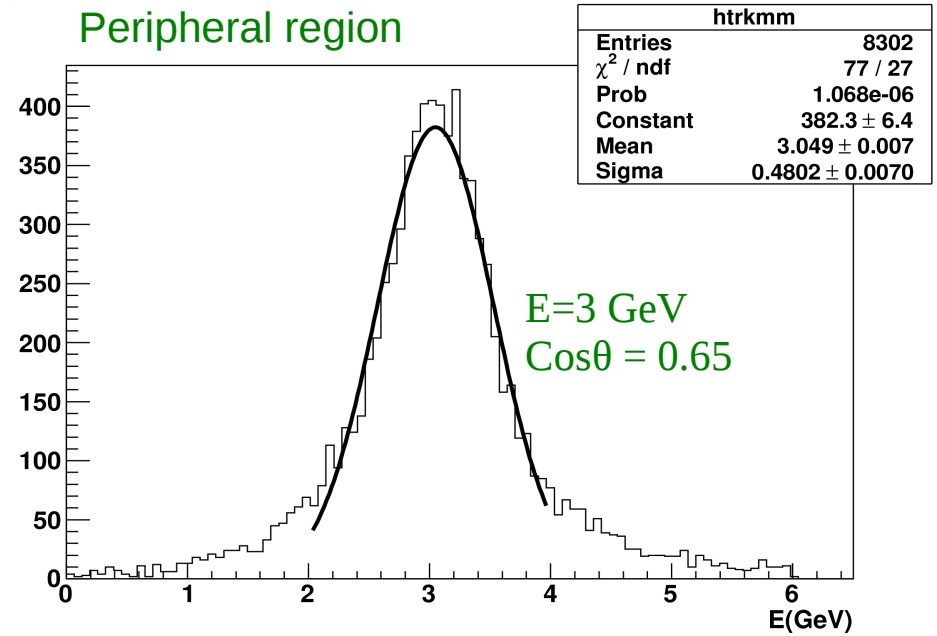
  N = Total no. of particles generated
- Error on Reco efficiency δReff = Reff X δnR/ nR
- Cid efficiency defined as Cideff = nRcid / nR

  where nRcid = no. of events with the same sign as that of input particle
- Error on Cid efficiency taken using standard error formula = sqrt(r(1-r)/nR)

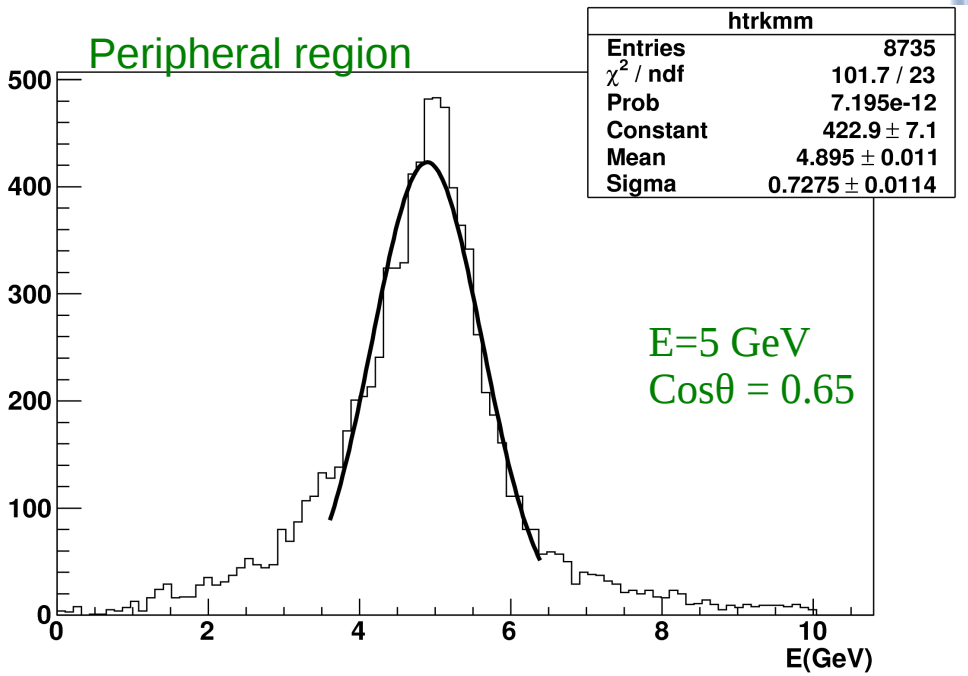
  where r = cid efficiency

Momentum Distribution

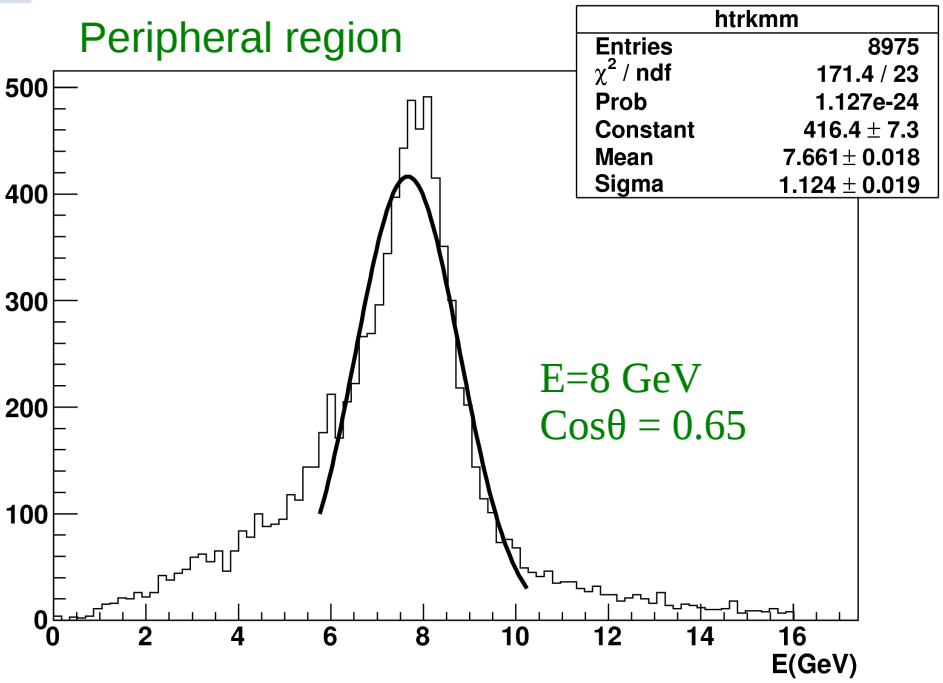
Peripheral region



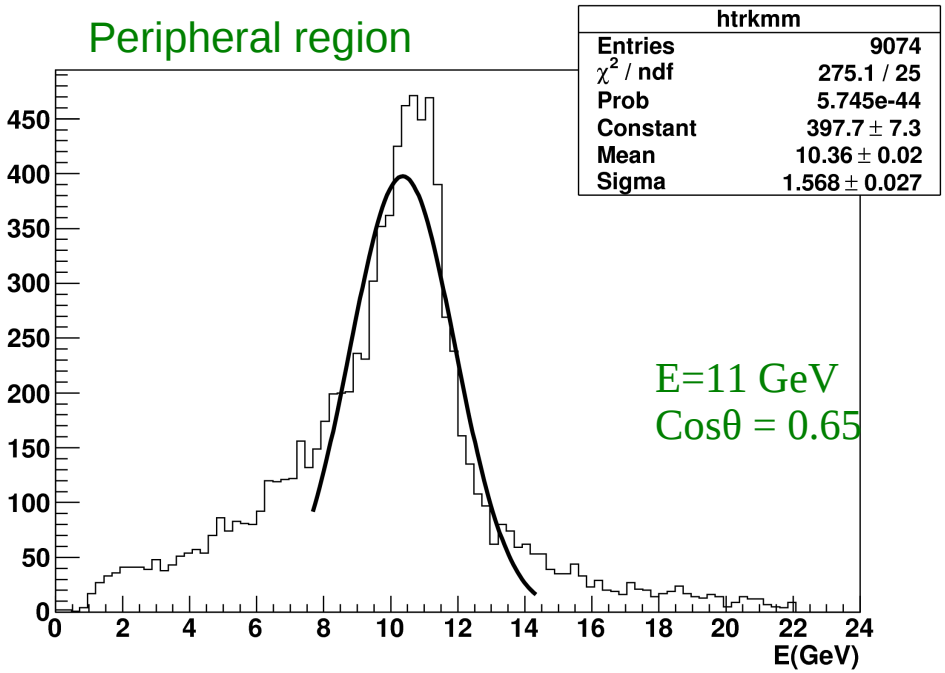
Peripheral region



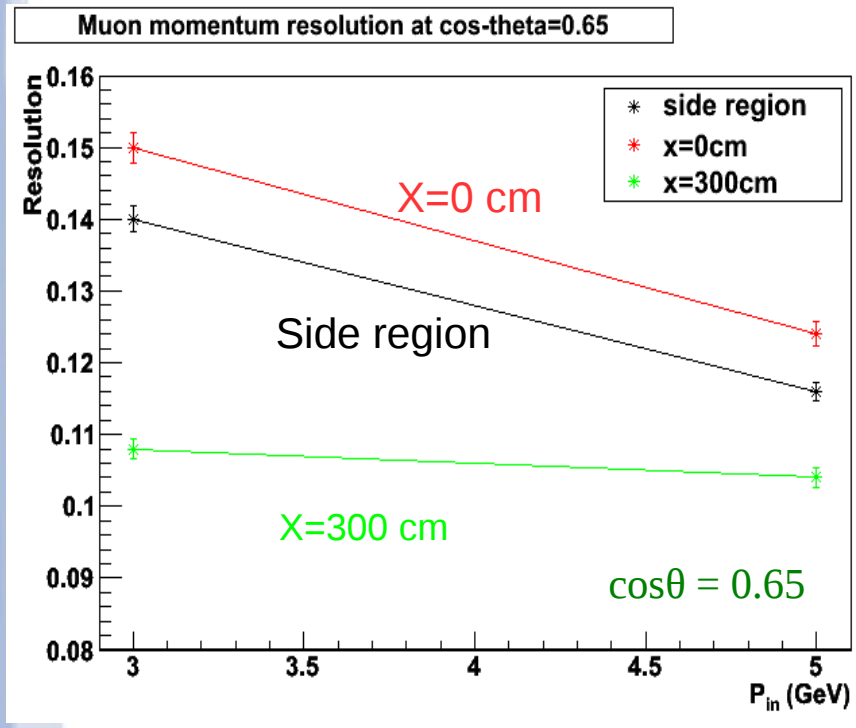
Peripheral region

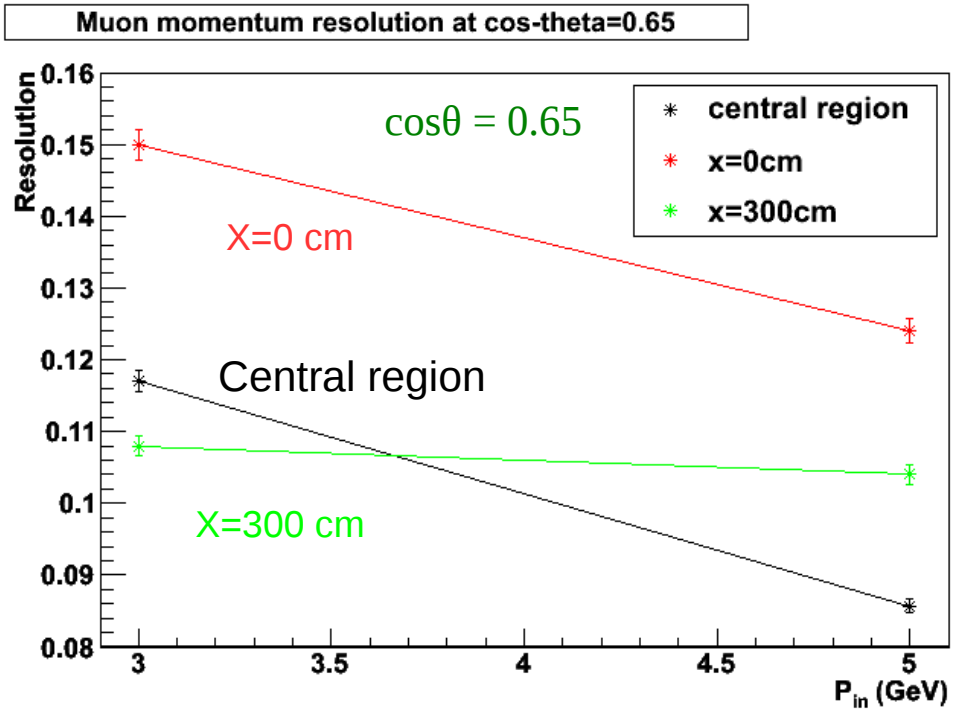


Peripheral region



Comparison with Side and Central Region

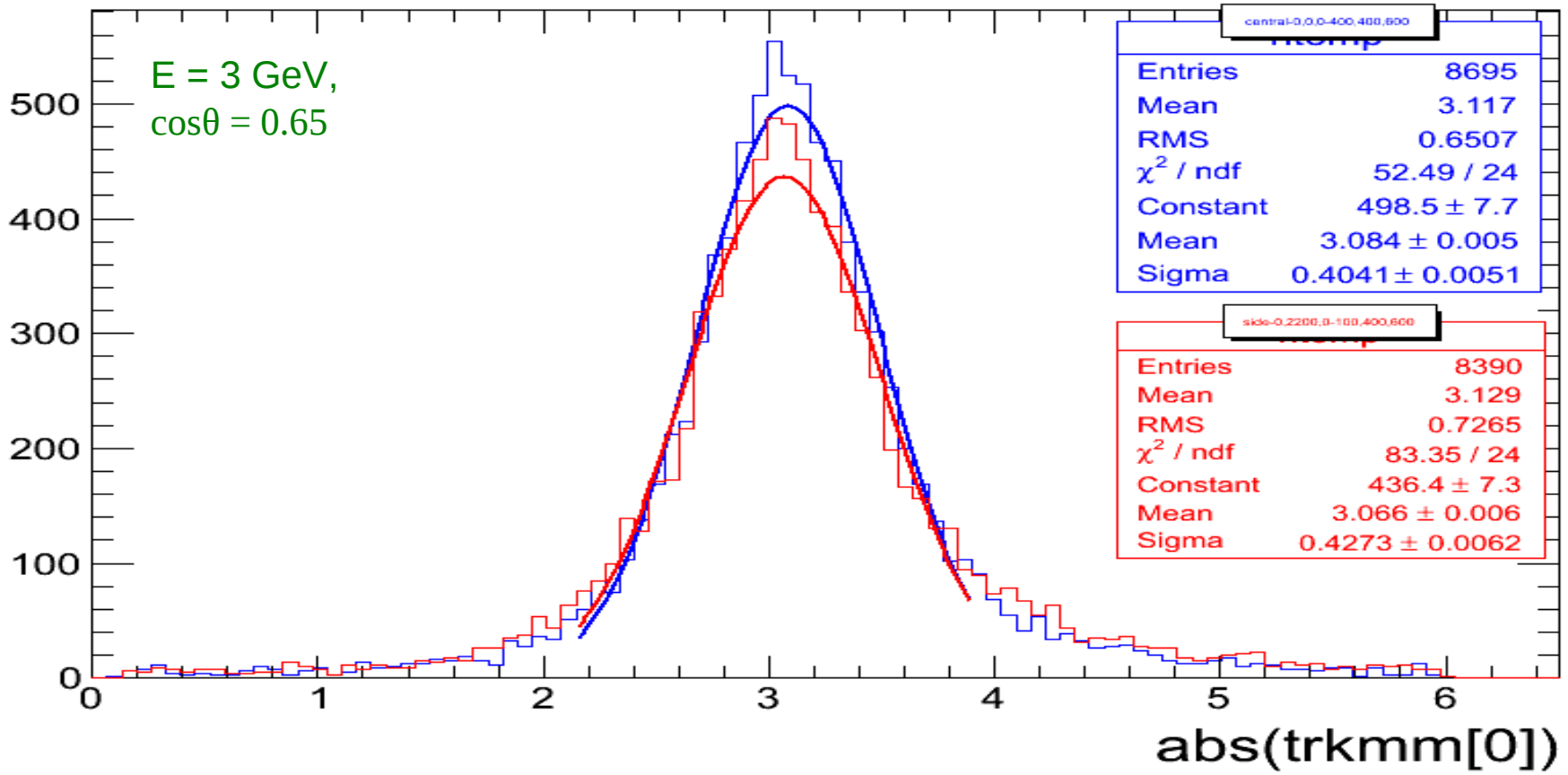




- Side Region: (-2070,100,0)cm, smearing (10,10,10)cm
- Peripheral region: (x,-550,0)cm, smearing (10,10,10)cm, where x = 0,300 cm
- @ side region: resolution worse since near to support structure
- @ x = 300 cm resolution is better since both B_x, B_y present
- @ x = 0 cm, resolution is worse magnetic field is less

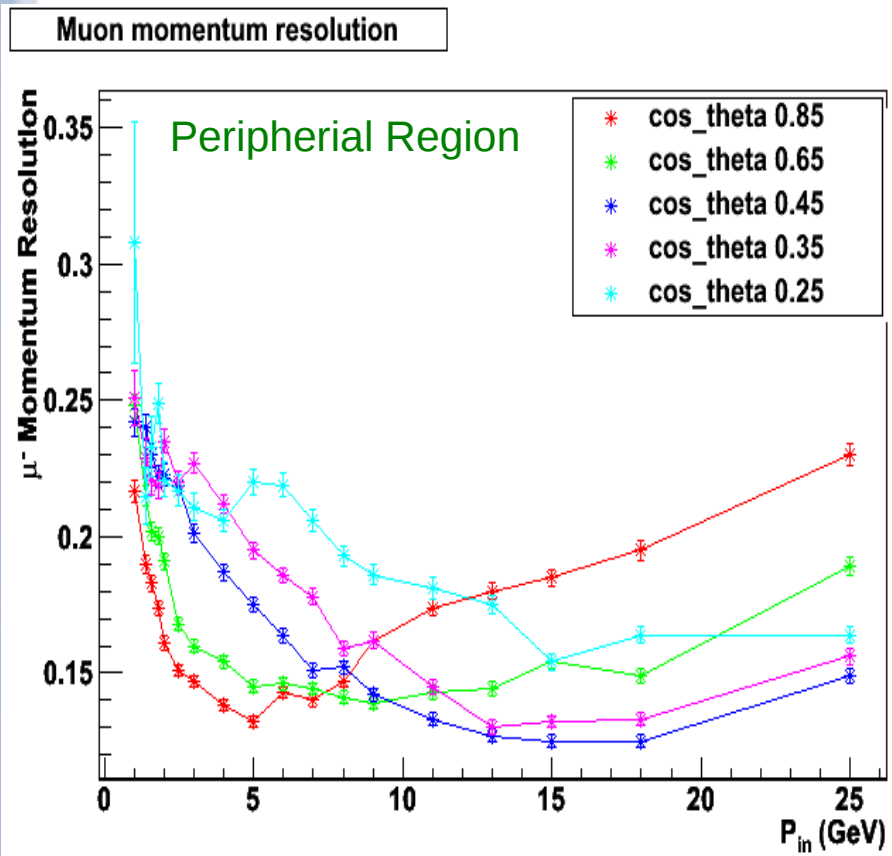
- Central Region: (100,100,0)cm, smearing (10,10,10)cm
- Peripheral region: (x,-550,0)cm, smearing (10,10,10)cm, where x = 0,300 cm
- @ 3 GeV,peripheral region, both components of magnetic field, hence better than central
- @ 5 GeV, peripheral region, events go out of detector Hence worse than central region

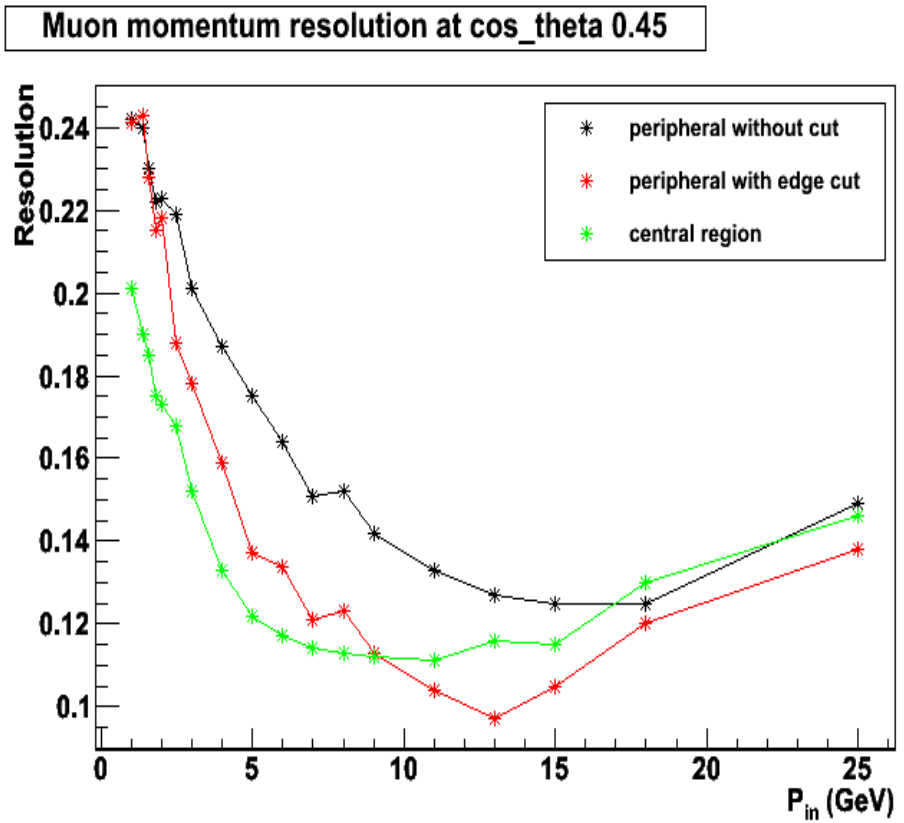
Side and Central Region



- Side Region: (0,2200,0)cm, smearing (100,400,600)cm, full smearing
- Central Region: (0,0,0), smearing (400,400,600)cm, full smearing
- Sigma of side region worse since less magnetic field than central region (15% less) and due to edge effects
- Even then good fraction of events reconstructed since its +ve x which will let most of the events to go inside

Momentum Resolution

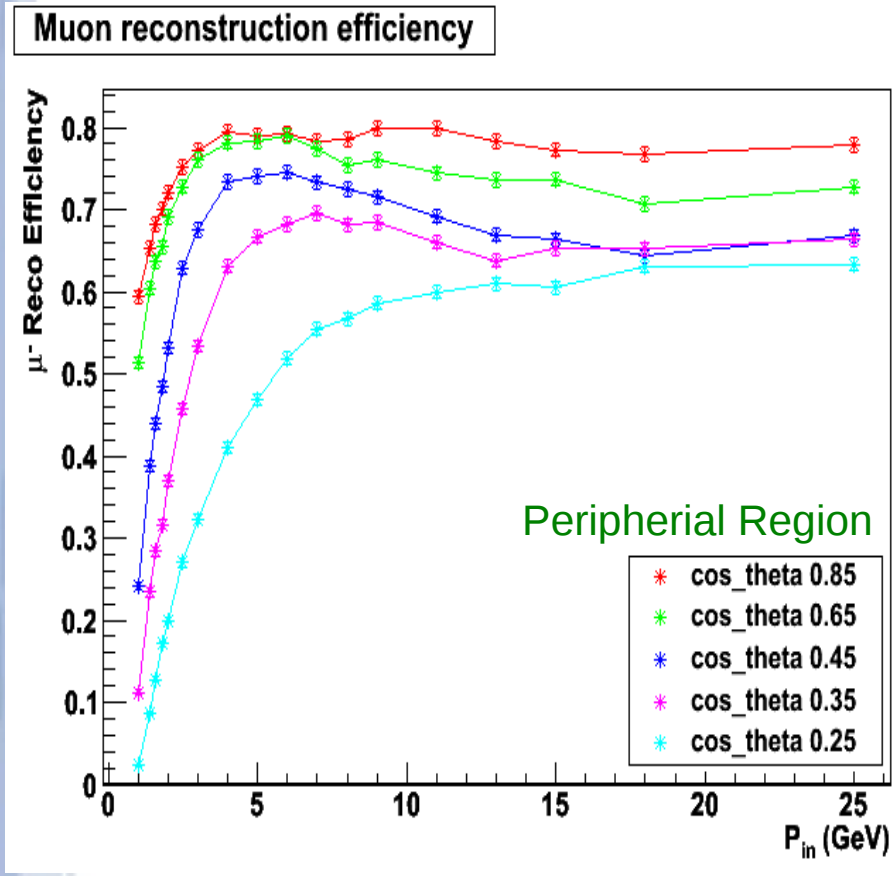


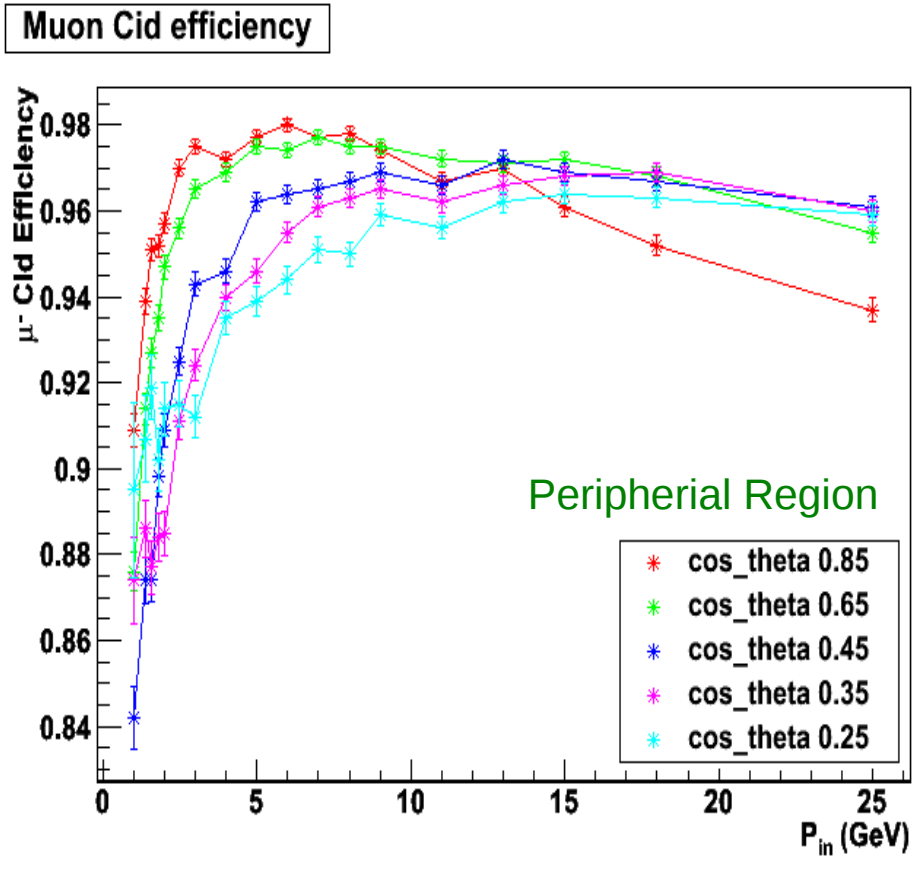


Resolution in peripheral region with full smearing
- Best @ E = 15 GeV, cosθ = 0.45
- @ High energy particle goes out of detector, hence, resolution getting worse
- @ low energy, high angle, particle not fully reconstructed

Comparison of central region with peripheral region at cosθ = 0.45, full smearing
- After making events fully contained in detector resolution in peripheral region improved
- Resolution even better than in central region due to both components of magnetic field

Muon Efficiencies

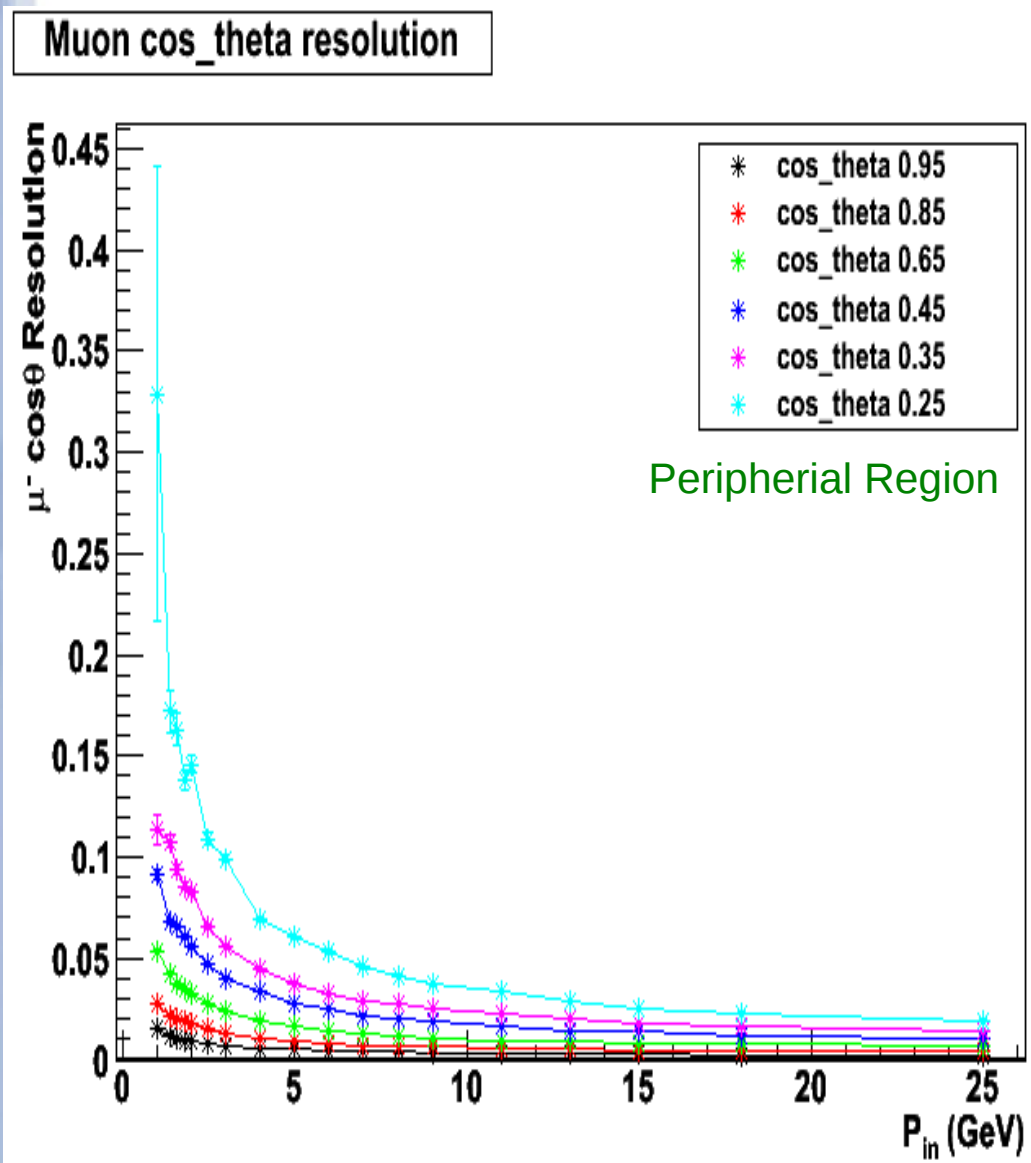




Reconstruction Efficiency
- Increases with energy and decreases with angle
- Highest at E = 9 GeV, cosθ = 0.85
- Reco Eff 10% less than central region due to edge effects

Cid Efficiency
- Increases with energy and decreases with angle
- Highest at E = 8 GeV, cosθ = 0.85
- Cid Eff 2% less than central region

Cosθ Resolution



Peripherial Region

In Peripheral Region:
@ E = 5 GeV, cosθ = 0.85,
Resolution = 1.1°
@ E = 5 GeV, cosθ = 0.45,
Resolution = 1.6°

Cosθ resolution in peripheral region is almost similar to central region

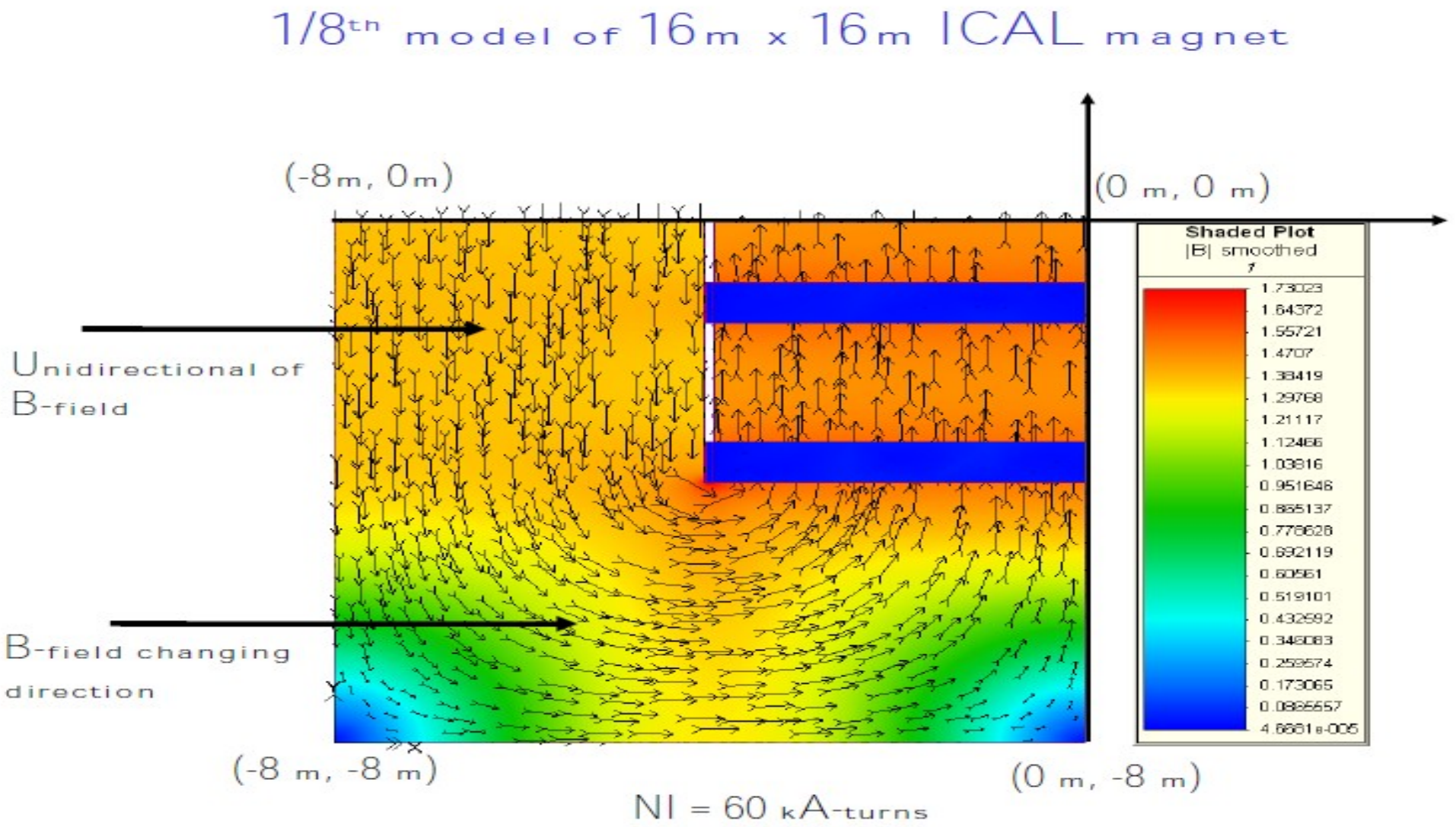
Summary

- Resolution in peripheral region is somewhat worse than in central region
- Reconstructed good fraction of events in peripheral region
- B_x, B_y both are non-zero, which makes reconstruction better in peripheral region
- Cid efficiency and cosθ resolution are similar as in central region
- Understood muon response in whole ICAL region

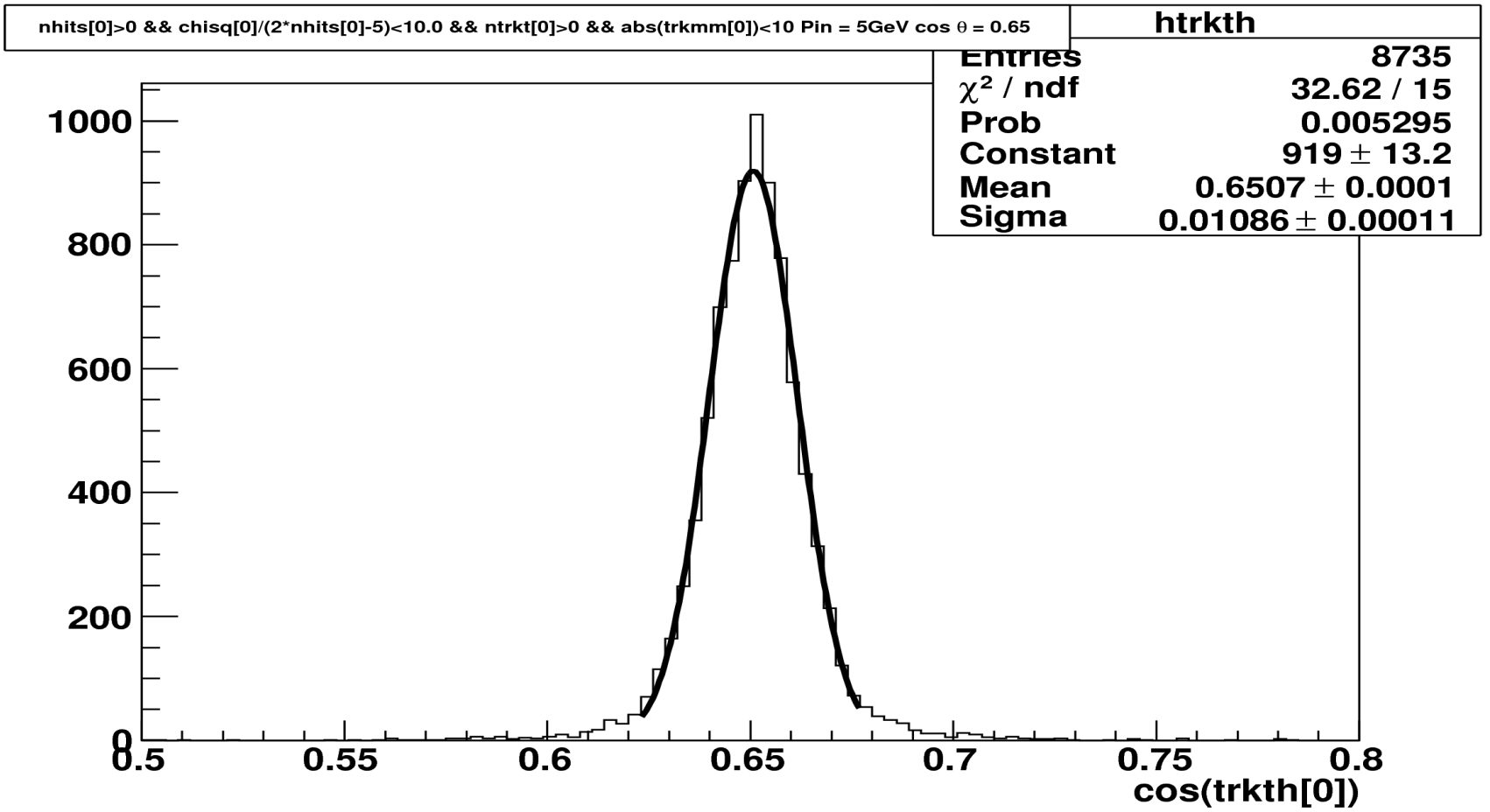
Thank you for your kind attention ! 

Back up Slides

Back up Slide 1



Back up slide 2

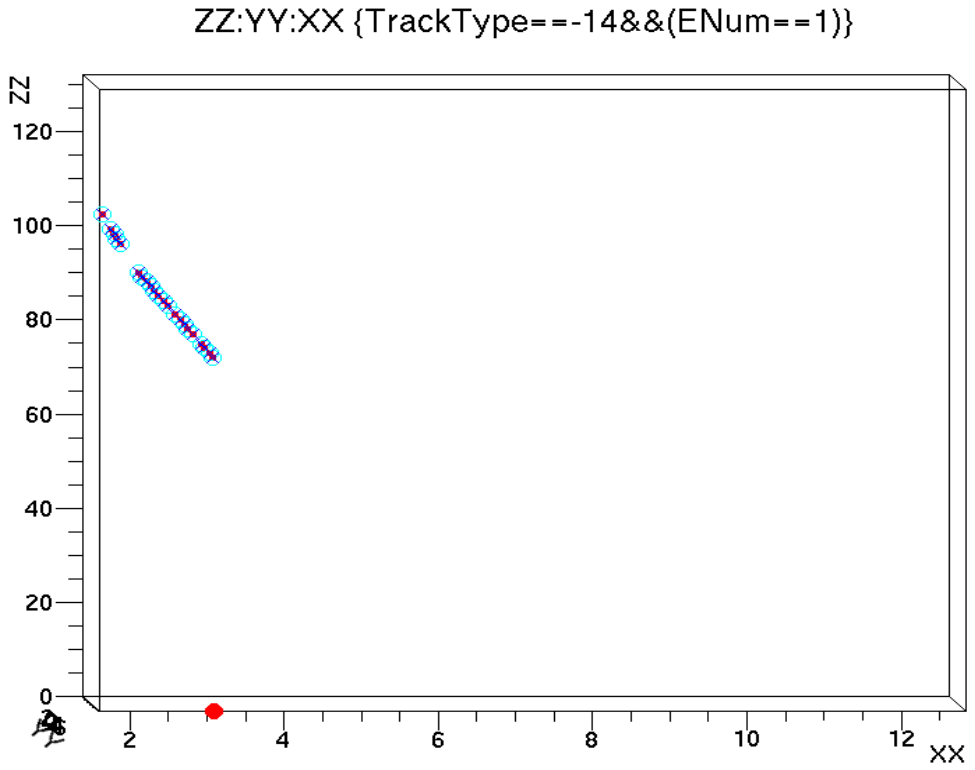


Cosθ resolution: @ E = 5 GeV, cosθ = 0.25, Resolution = 4.14°

Fitted distribution of momentum E = 5 GeV, Cosθ = 0.65

Back up slide 3

Central Region: Momentum resolution is b/w 10%-15% for all the angles except near horizontal angles.
- Reconstruction efficiency is about 80% for energies greater than 2GeV for all the angles except near horizontal angles.
- CID efficiency is about 98% except for very low energy (< 2GeV).
- Angular resolution is ~1°, for almost all energies and angles except for events with very low energy and near horizontal angles.



X=300 cm, y = -750, E = 3 GeV
Cos-th = 0.85

Back up slide 4 (INO)

INO: Proposed underground facility at Bodi West hills of Theni District of Tamil Nadu, with rock cover of approx 1200 m, which is desirable to look for atmospheric muon neutrinos

ICAL:

- Good charge resolution
- Good tracking and energy resolution

Overview of detector:

- Dimension: 48 m × 16m × 14.4m

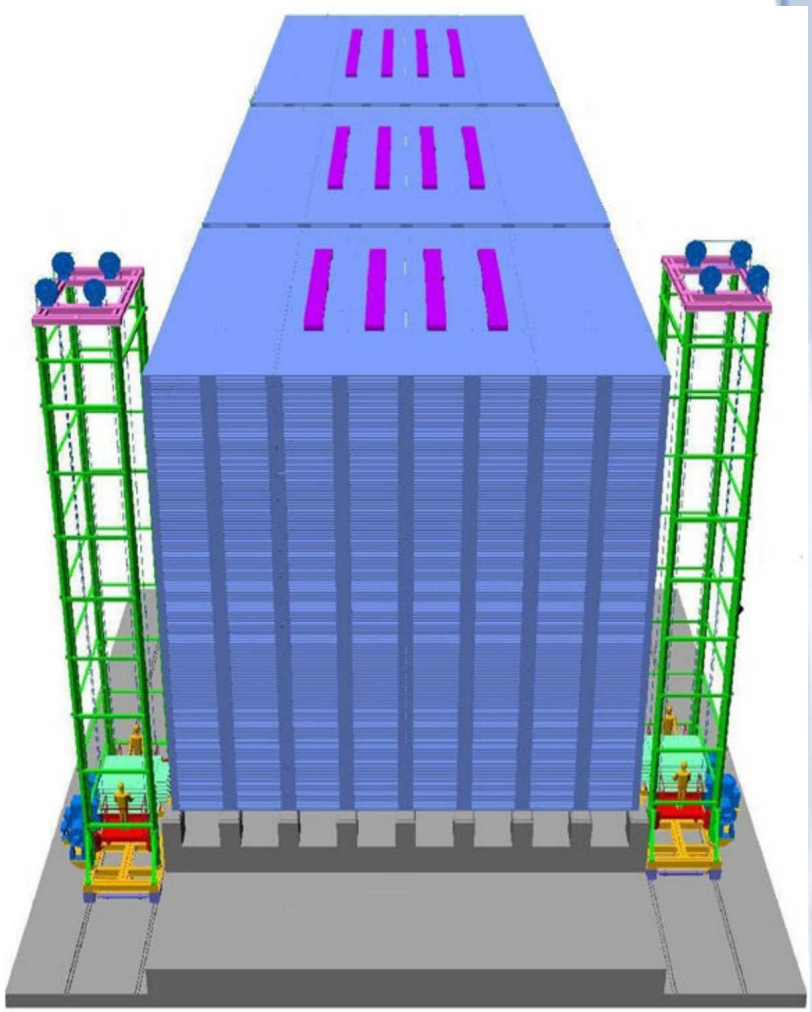
(3 modules of dimensions 16 m × 16m × 14.4m each)

- Mass: 50 kTon (approx)

- Absorber: Iron plates of thickness 5.6 cm

- Active detector volume: Resistive Plate Chamber (RPC) (2m × 2m × 8mm). The readout of the RPC is carried out by external orthogonal pick up strips (X & Y strips)

- Inhomogenous Magnetic Field: ~ 1.4 Tesla



A sketch of proposed INO-ICAL detector