Muon Efficiencies and Resolutions in the central region of the ICAL detector

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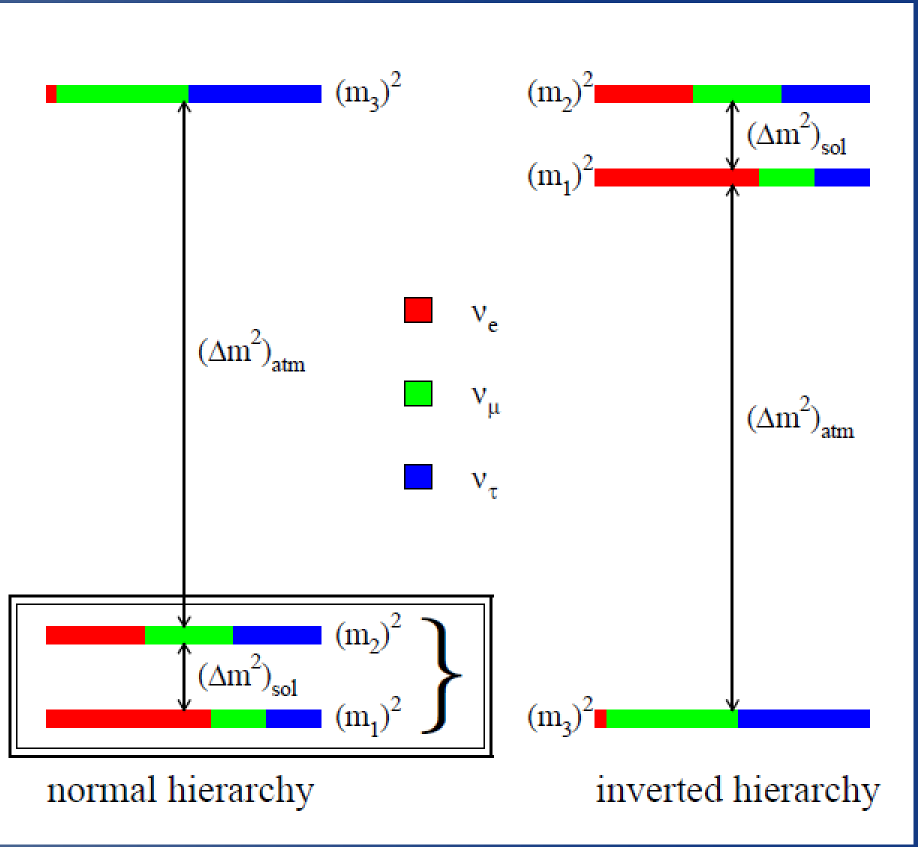
Plan of Talk....

- Motivation
- Introduction
- Inputs and Observations
- Results – Resolution, Reconstruction Efficiency, CID Efficiency
- Summary

Motivation:

- The main goals of ICAL are to determine the Neutrino oscillation parameters precisely and determining the sign of Δm^2_{32} using matter effect(mass hierarchy).
- Neutrino and anti neutrino interact differently with matter.
- In matter the survival probability of ν_μ can be expressed as



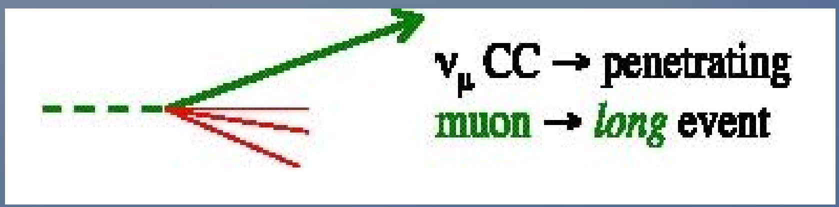
$$
\begin{aligned}
P^m_{\mu\mu} = 1 - \cos^2\theta^m_{13}\sin^2 2\theta_{23} \\
\times \sin^2\left[1.27\left(\frac{(\Delta m^2_{31}) + A + (\Delta m^2_{31})^m}{2}\right)\frac{L}{E}\right] \\
- \sin^2\theta^m_{13}\sin^2 2\theta_{23} \\
\times \sin^2\left[1.27\left(\frac{(\Delta m^2_{31}) + A - (\Delta m^2_{31})^m}{2}\right)\frac{L}{E}\right] \\
- \sin^4\theta_{23}\sin^2 2\theta^m_{13}\sin^2\left[1.27(\Delta m^2_{31})^m\frac{L}{E}\right].
\end{aligned}
$$

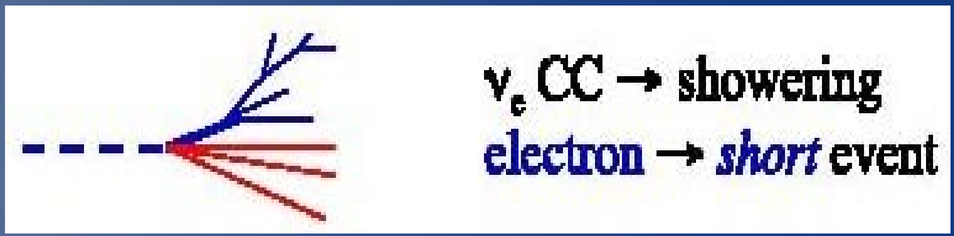
Where $A=\pm\sqrt{2}G_F N_e 2E$ which is positive for ν and negative for $\bar{\nu}$

Introduction:

- Neutrino Interactions:

  - Charged Current(CC):Neutrinos weakly interact through the exchange of a W^+/W^- boson to form charged particles.

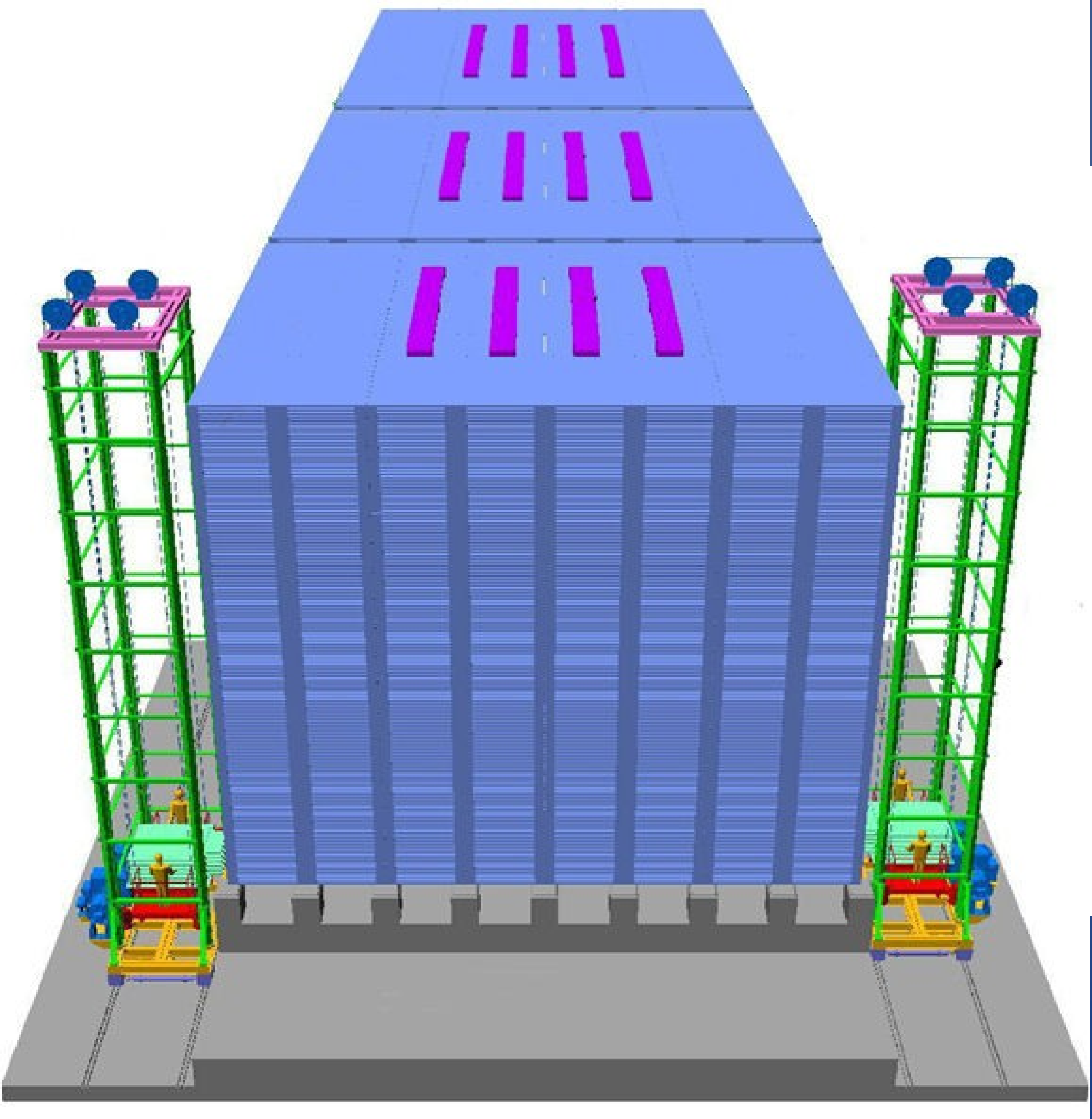




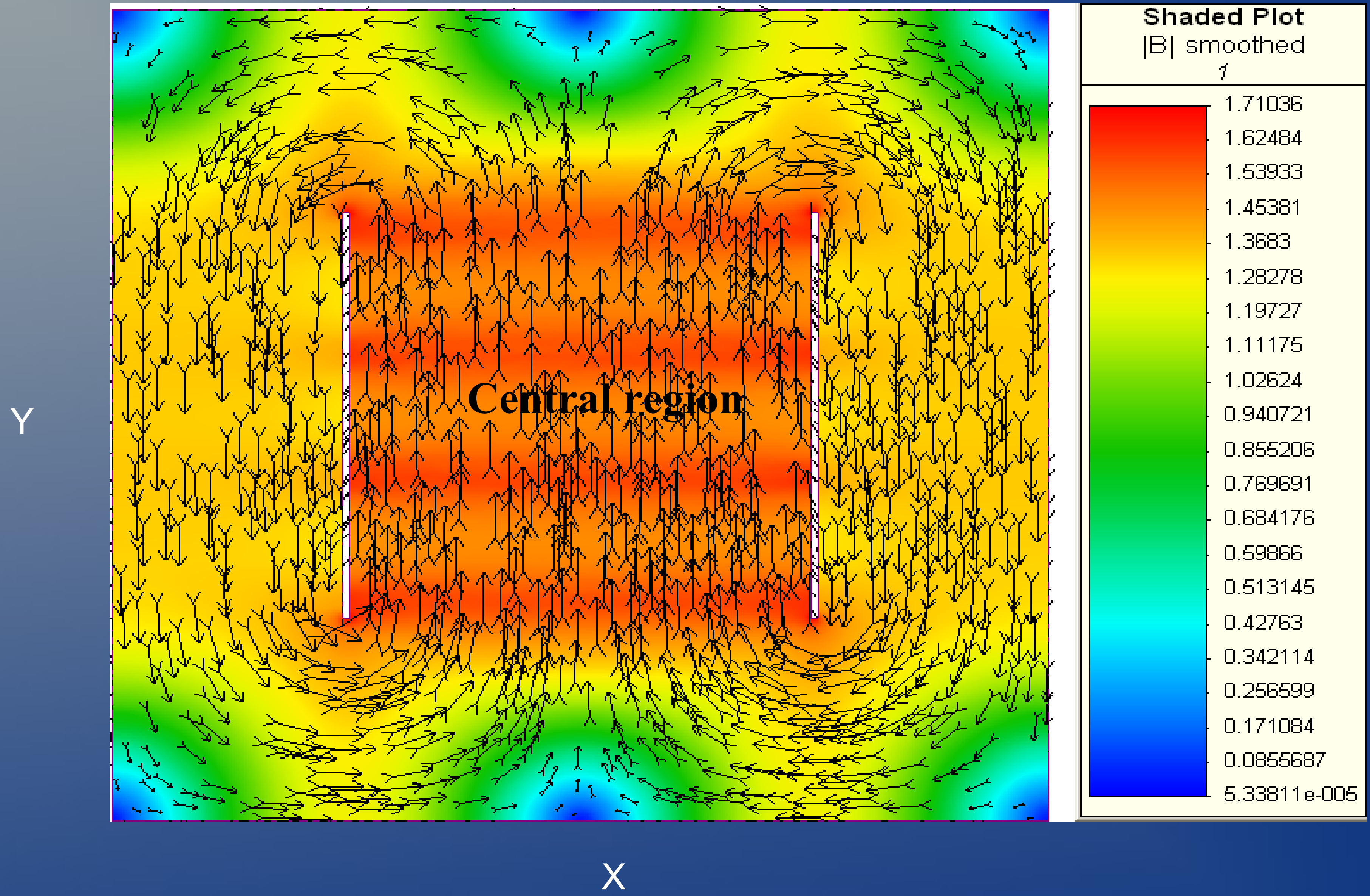
  - Neutral Current (NC): Neutrinos interact through the weak exchange of Z particles

Introduction(cont'd):

- Detector:



ICAL	
No. of modules	3
Module dimension	$16mX16mX14.4m$
Detector dimension	$48mX16mX14.4m$
No. of layers	150
Iron plate thickness	$5.6cm$
Gap for RPC trays	$4.0cm$
RPC	
RPC unit dimension	$2mX2m$
Readout strip width	$3cm$
No. of RPC units/ row/ layer	8
No. of rows/ layer/ module	8
No. of RPC units/ layer	192
Total no. of RPC units	28800
No. of electronic readout channels	$3.6X10^2$

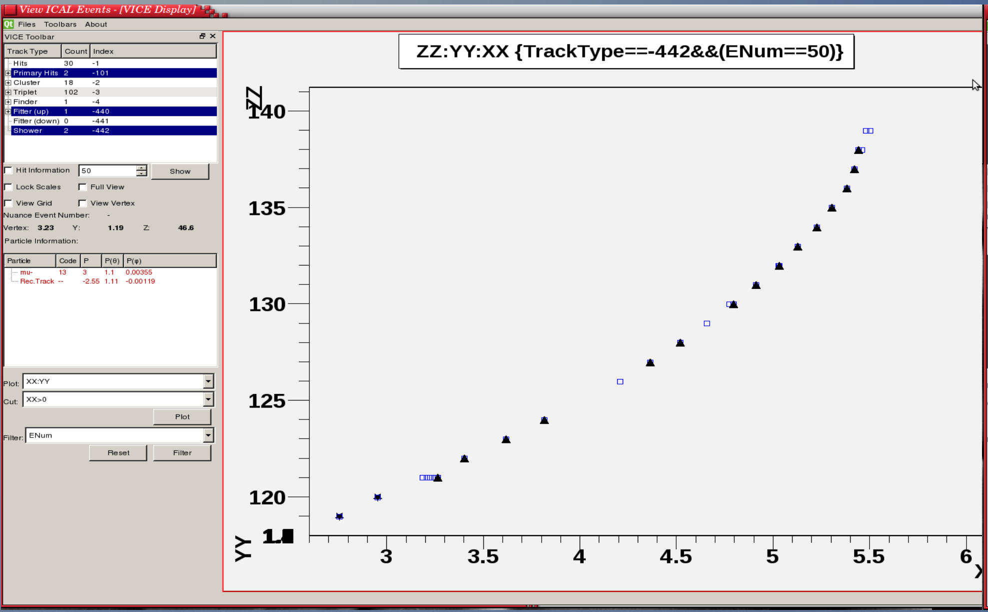


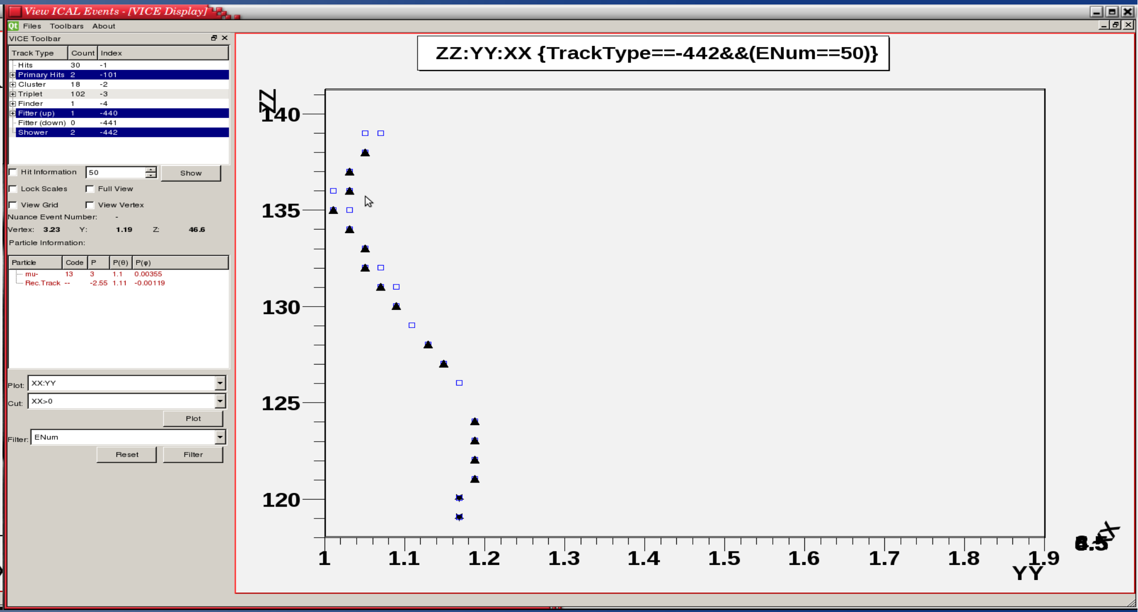
Field lines in a horizontal (x-y) plane of any of the iron plates

Inputs:

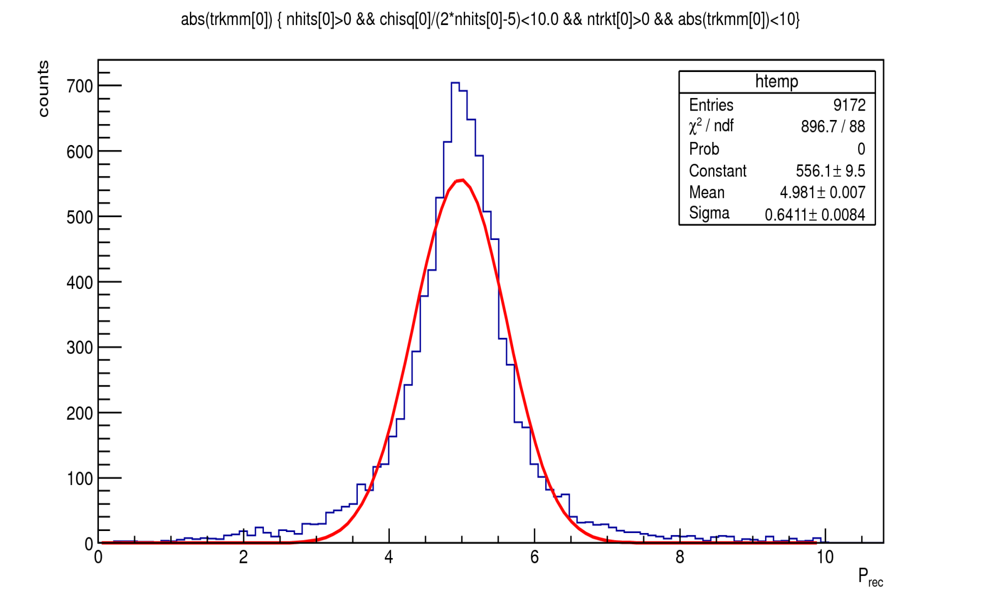
- Geant 4.9.4 p02 is used for the detailed simulation of ICAL geomerty and propagation of particle.
- Fixed Energy Muons (10000) are propagated from a vertex (0,0,0) cm smeared over (400, 400, 600) cm ie. smeared over the whole central region where the magnetic field is uniform.
- Muons with energies (1,2...,10,15,20GeV) are propagated in different cos θ bins (0.95,0.85,0.75,0.65,0.75,0.45,0.25). The energy and theta are not smeared, but phi is smeared (0-2π).
- The track of the particle is fitted using Kalman filter algorithm if the number of layers having hit is greater than 3.
- Reconstructed momentum of the track close to vertex, trkmm[0], is considered for analysis (with cut on $chi^2/ndf < 10$).

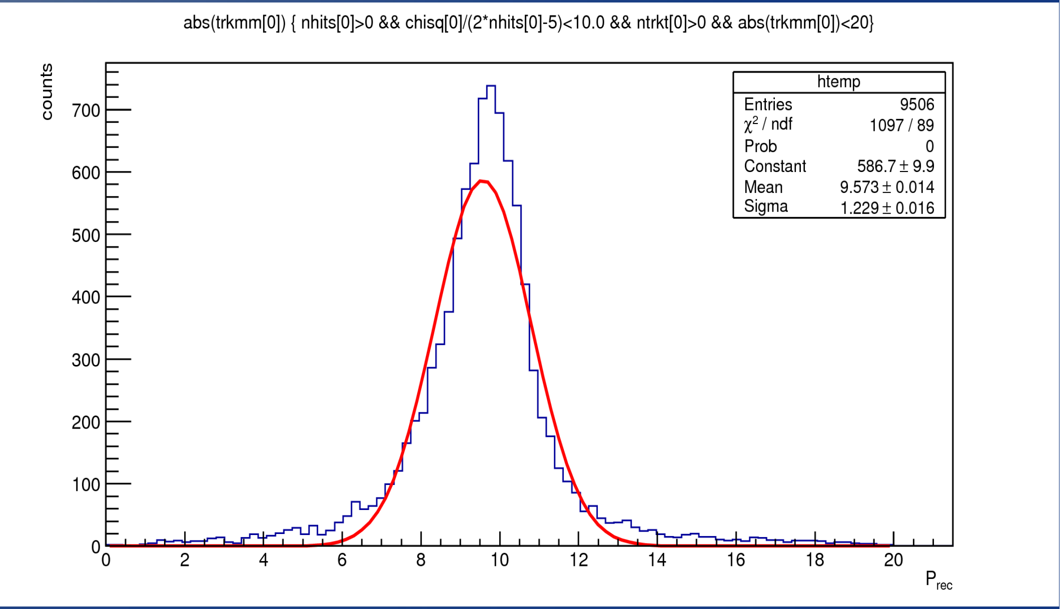
Reconstructed Tracks : Pin = 3GeV, cos θ = 0.45, Prec = 2.55GeV





Reconstructed Momentum distribution for cos θ = 0.65

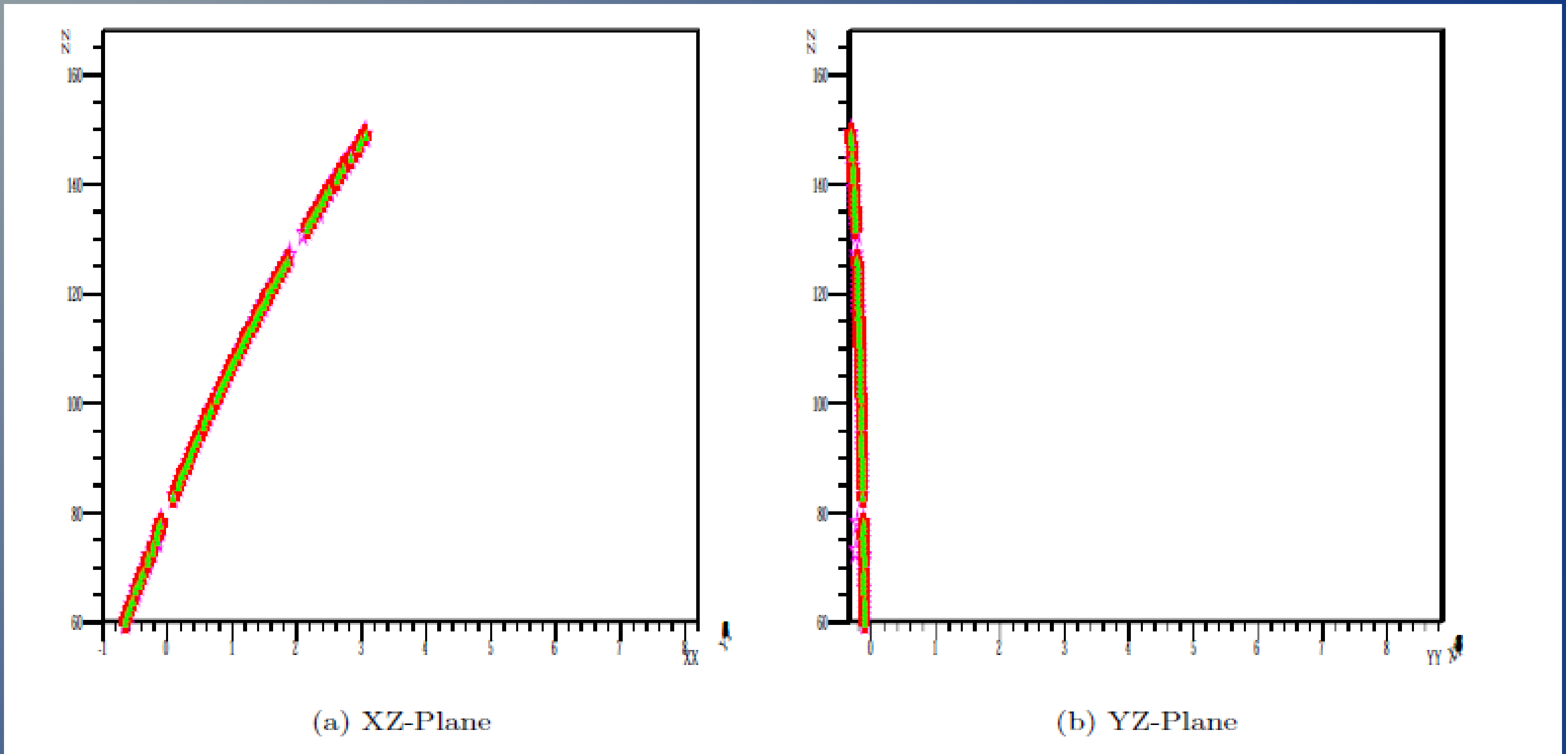




P_{in} = 5GeV

P_{in} = 10GeV

➔ long non gaussian tail



$P_{in} = 16$ GeV, $\cos\theta = 0.95$

- High energy tail : when only the initial part of the track which has less curvature is identified as muon track.
- Low enery tail : when only the part of the track which has larger curvature is identified as muon track.

Inputs(cont'd):

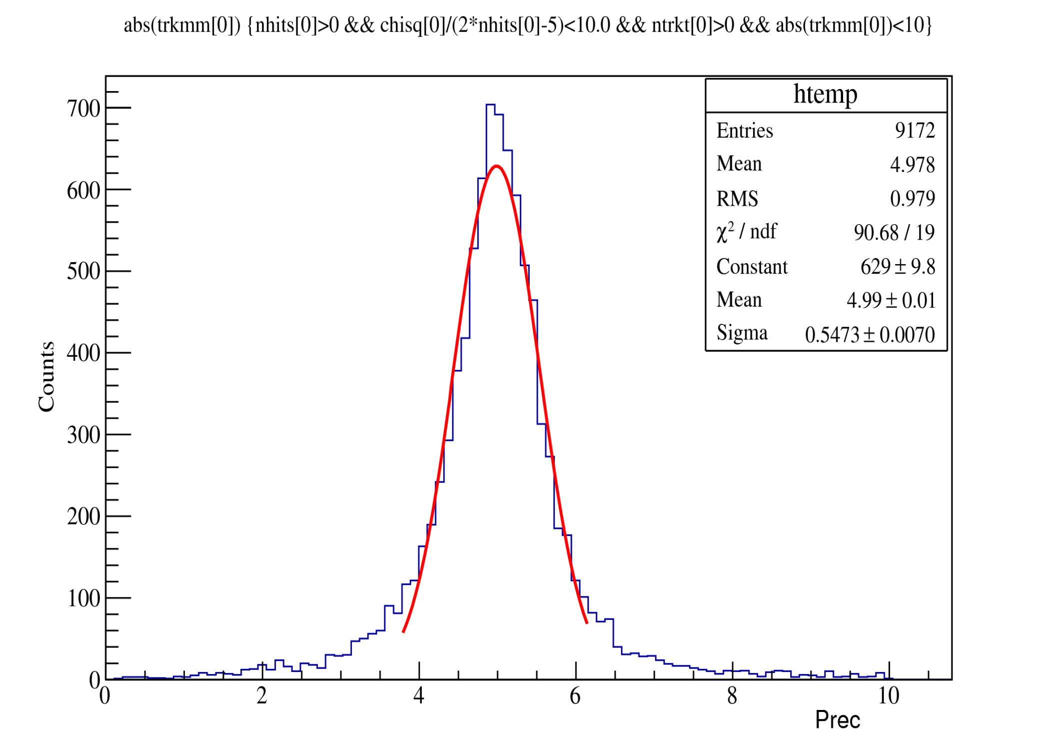
- trkmm[0] is plotted in the range 0 to $2P_{in}$ where P_{in} is the input momentum. The FWHM of the distribution is found. Then trkmm[0] is fitted in the range P_{in}-1FWHM to P_{in}+1FWHM using Gaussian Distribution in order to find out mean and sigma for the calculation of Resolution.

- REC Efficiency and CID Efficiency are calculated in the 3σ range with a cut .

- trkmm[0] for P_{in}=5GeV and

$\cos\theta = 0.65$ fitted in 1FWHM range

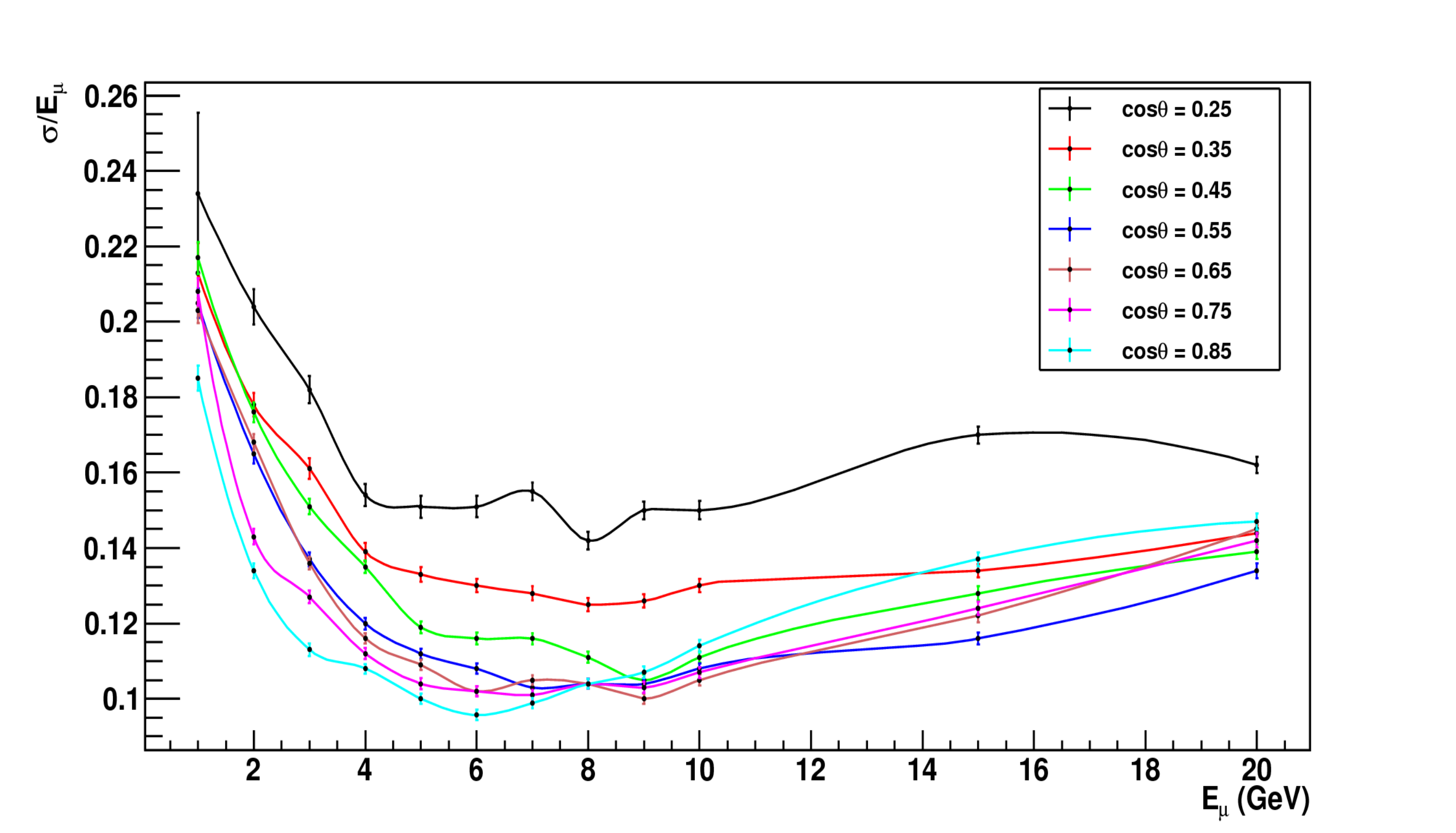
is shown.



Results:

- Momentum Resolution: R = (Sigma ± δSigma)/ (P ± δP)

$(\delta R/R)^2 = (\delta Sigma/Sigma)^2 + (\delta P/P)$ For calculations using P_{in}, $\delta P = 0$.

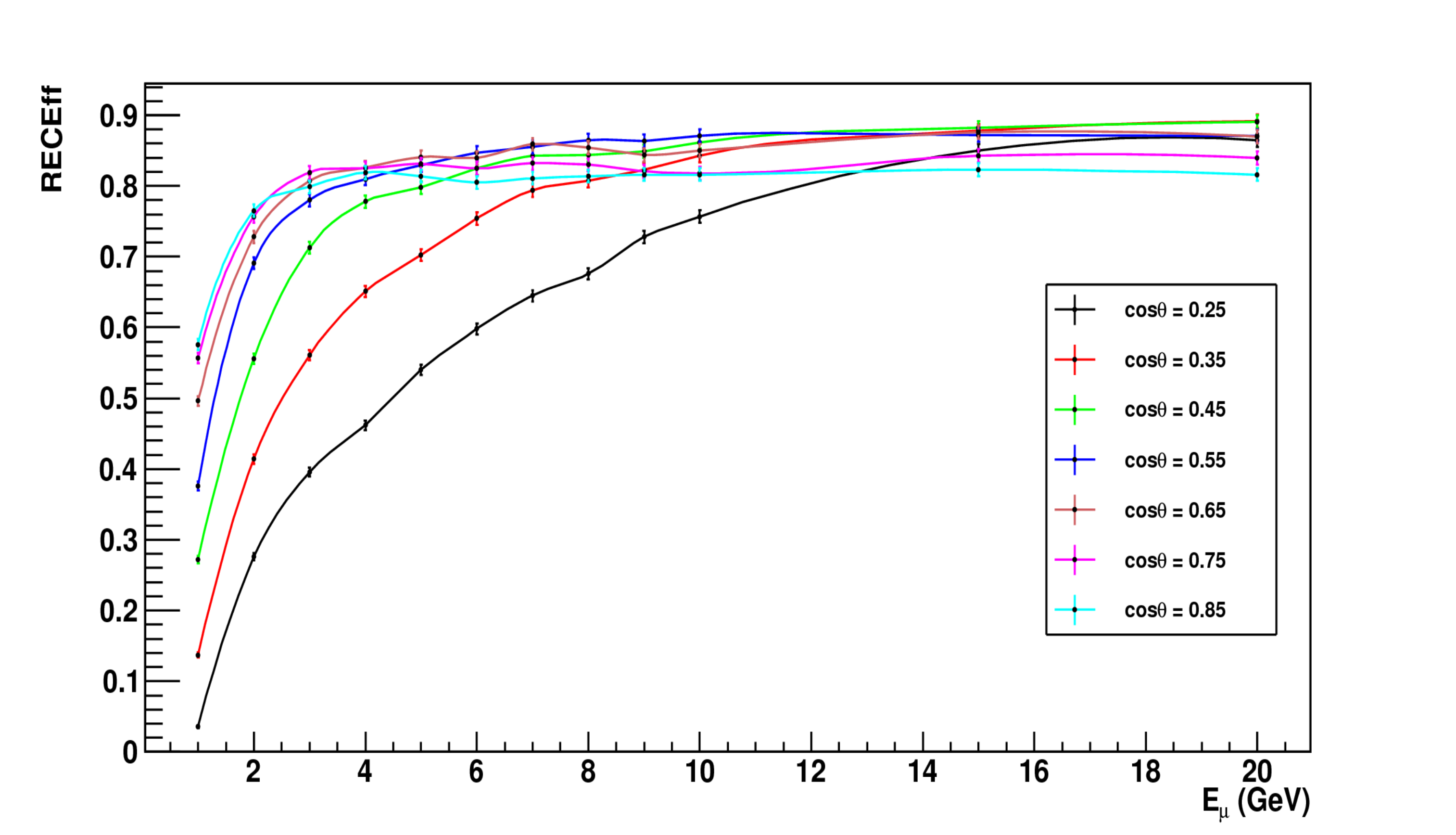


- At small energies, since the length of the track is not sufficient enough to reconstruct the momentum accurately, the resolution is worse.
- The resolution is best in the 4-7GeV range (depending on θ) and getting worse as Momentum increases.
- When momentum becomes ~6-8 GeV, the muon starts going out of the detector which make the mometum reconstruction poorer for higher energies.

Reconstruction Efficiency:

RECEff = (nREC ± δnREC)/N_{total} where nREC is the no. of reconstructed events (independent of charge) with cuts. There is no error in N_{total}.

$$(\delta RECEff / RECEff)^2 = (\delta nREC / nREC)^2.$$



- As input momentum increases the reconstruction efficiency also increases since the number of hits increases.
- At nearly horizontal angles, the reconstruction efficiency for small energies is smaller since the number of hits for reconstructing tracks are less.

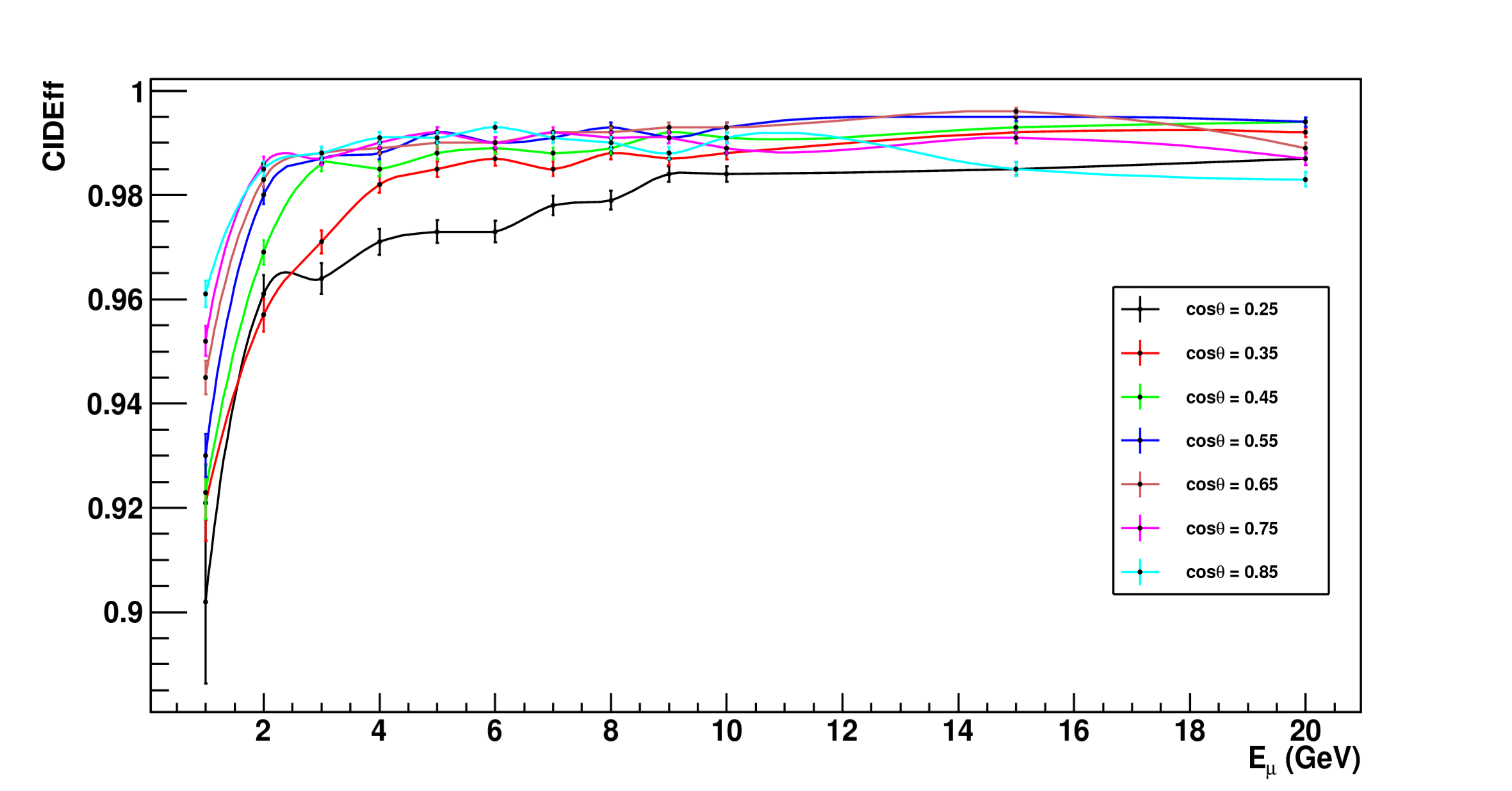
Relative Charge Identification Efficiency:

CIDEff = (nRCID ± δRCID)/(nREC ± δnREC) where nRCID = no. of events with right sign of particle.

Here δnRCID and δnREC are dependent. So the error in the ratio can be calculated using following equation

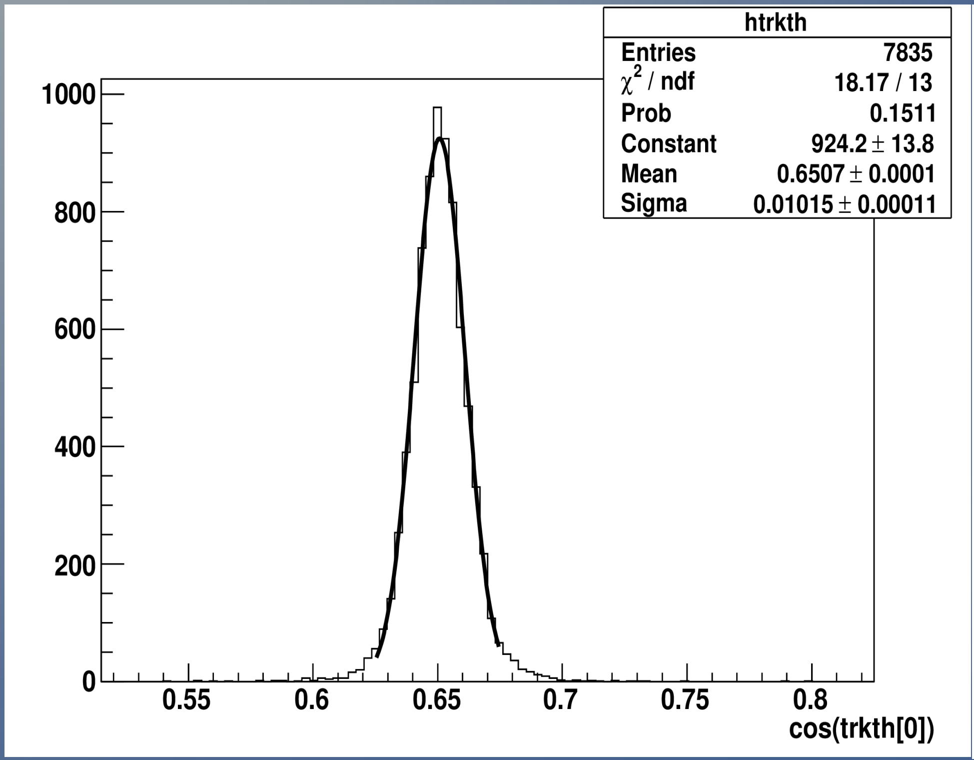
$$Standard\ Error = \sqrt{r(1-r)/n}$$

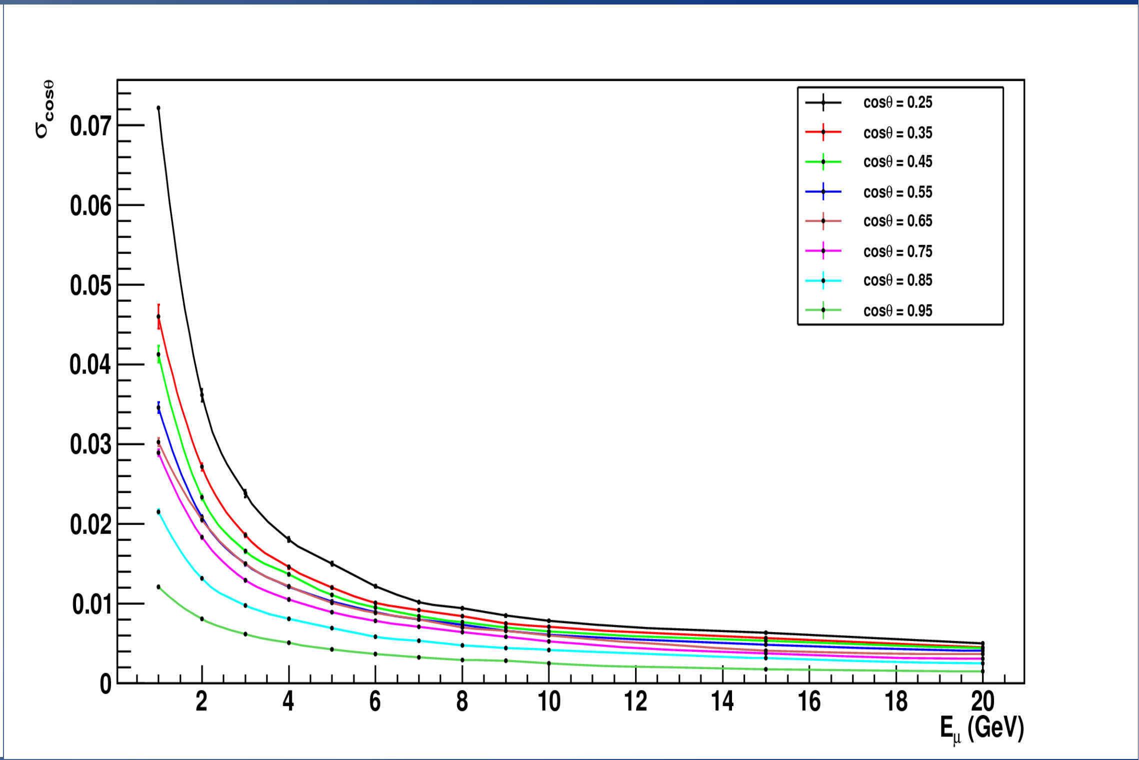
where r is the ratio (nRCID/nREC) and n is the no. of sample. Here r is CIDEff and n is nREC.



- The low energy Muon may undergo multiple scattering and the number of layers with hit may not be enough to reconstruct the direction accurately.
- Except for near vertical angles, the CID efficiency is almost constant for all energies from 5GeV to 20GeV.
- The charge identification efficiency becomes poorer as energy goes beyond 70-90GeV since the track curvature is not sufficient to reconstruct the charge.

cos θ resolution:





P_{in} = 5GeV, cos θ = 0.65

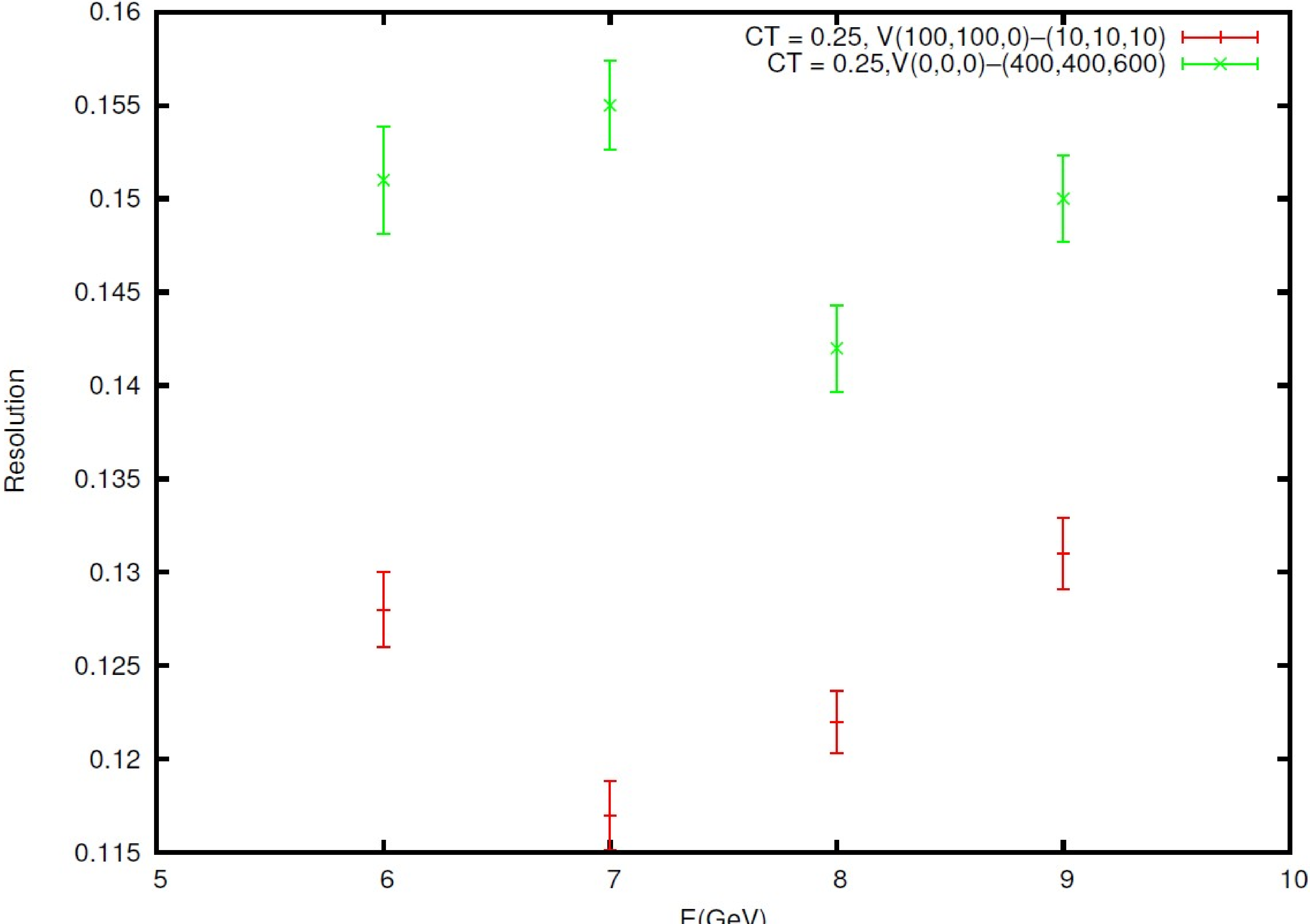
- For almost all the angles except for very low energy (~1GeV), the angular resolution is around ~ 1^0.
- For very horizontal and low energies angular resolution is around 2^0.

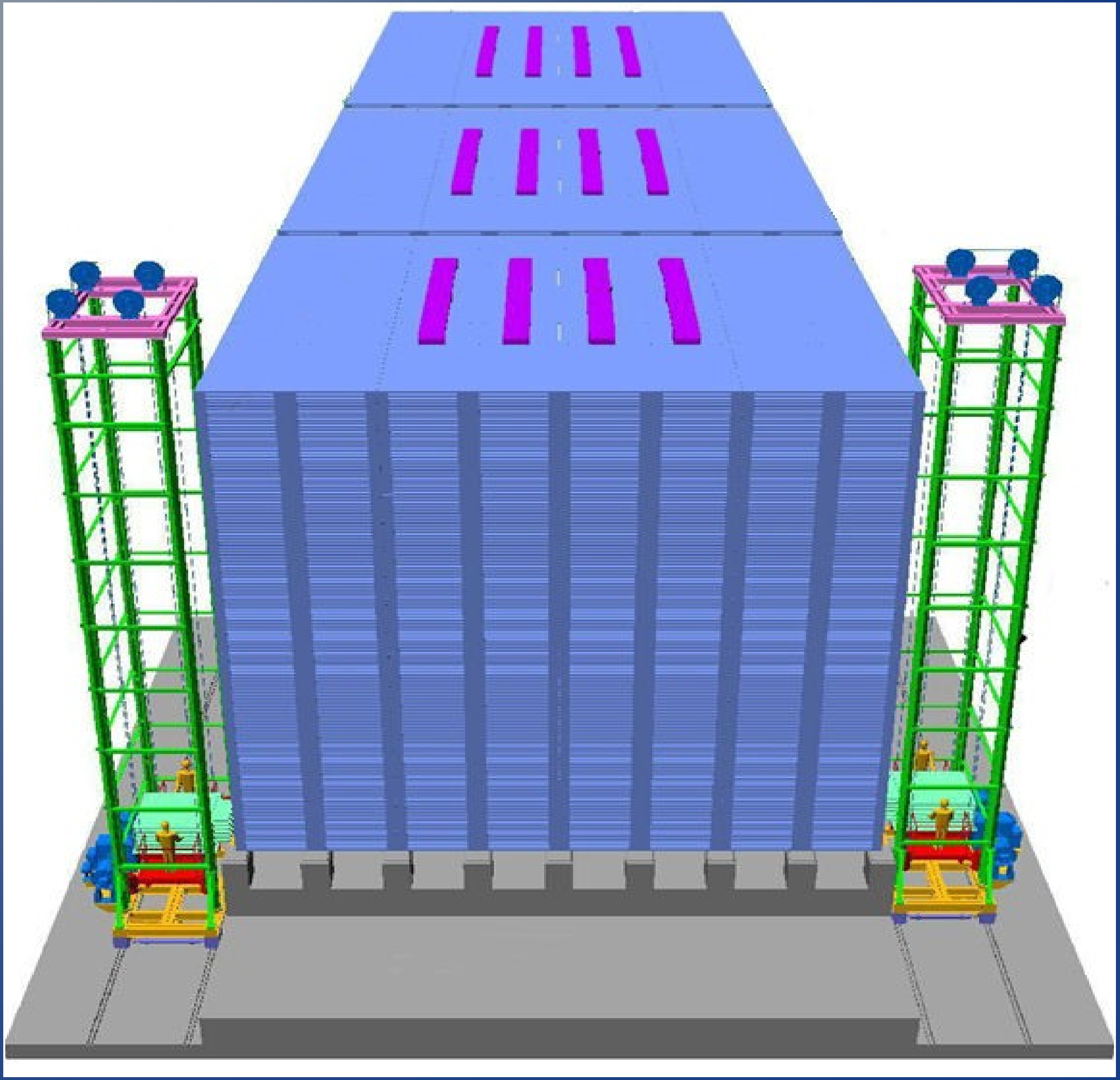
Summary:

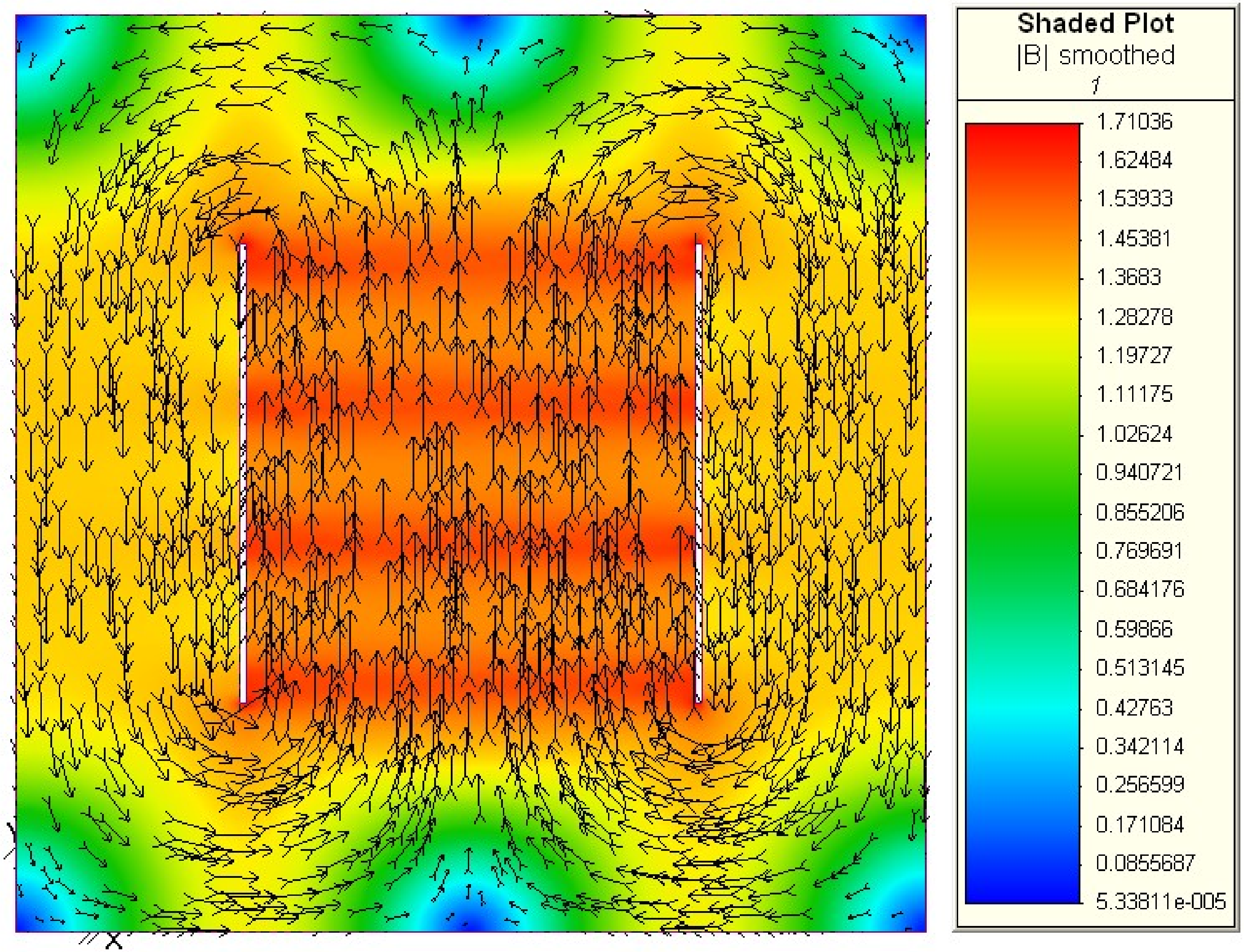
- The momentum and angular resolution, momentum reconstruction efficiency and relative charge identification efficiency for fixed energy muons are studied for the central region.
- The momentum resolution is between 10%-15% for all the angles except near horizontal angles.
- The momentum reconstruction efficiency is about 80% for energies greater than 2GeV for all the angles except near horizontal angles.
- The relative CID efficiency is about 98% except for very low energy (< 2GeV).
- The angular resolution is very good ($\sim 1^0$), for almost all energies and angles except for events with very low energy and near horizontal angles.
- Hence the ICAL detector is optimized for Muon.

Thank you

Backup


CT = 0.25, V(100,100,0)–(10,10,10)
CT = 0.25,V(0,0,0)–(400,400,600)
Resolution
E(GeV)
0.115
0.12
0.125
0.13
0.135
0.14
0.145
0.15
0.155
0.16
5
6
7
8
9
10





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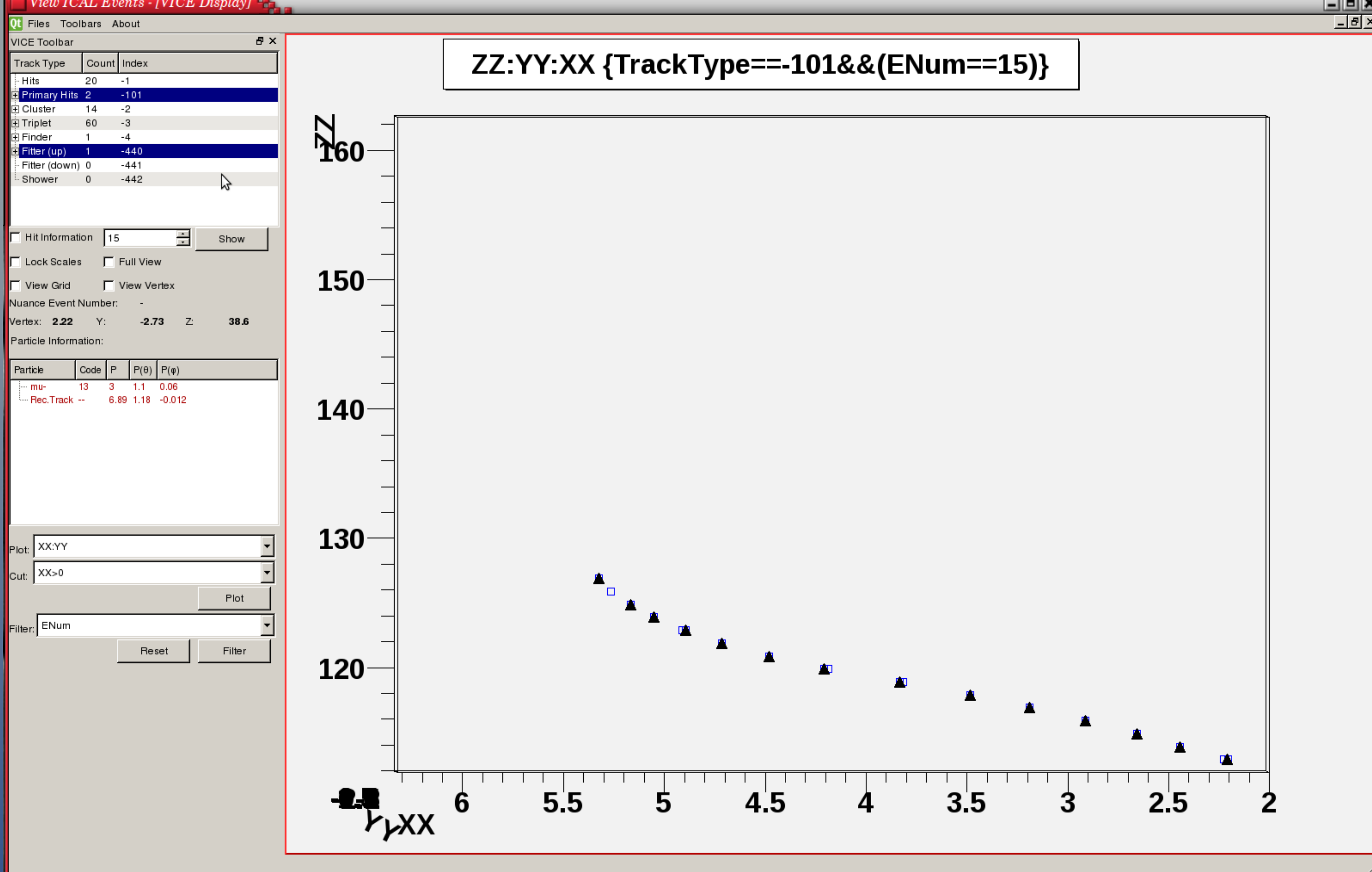
127.0.0.1
Educational Edition


View ICAL Events - [VICE Display]
Files Toolbars About
VICE Toolbar
Track Type Count Index
Hits 20 -1
Primary Hits 2 -101
Cluster 14 -2
Triplet 60 -3
Finder 1 -4
Fitter (up) 1 -440
Fitter (down) 0 -441
Shower 0 -442
Hit Information 15 Show
Lock Scales Full View
View Grid View Vertex
Nuance Event Number: -
Vertex: 2.22 Y: -2.73 Z: 38.6
Particle Information:
Particle Code P P(θ) P(φ)
mu- 13 3 1.1 0.06
Rec.Track -- 6.89 1.18 -0.012
Plot: XX:YY
Cut: XX>0
Plot
Filter: ENum
Reset Filter
ZZ:YY:XX {TrackType==-101&&(ENum==15)}
ZZ
160
150
140
130
120
6 5.5 5 4.5 4 3.5 3 2.5 2
YY XX

The MINOS Detectors Design Parameter Book

Version 1.3

February 2001

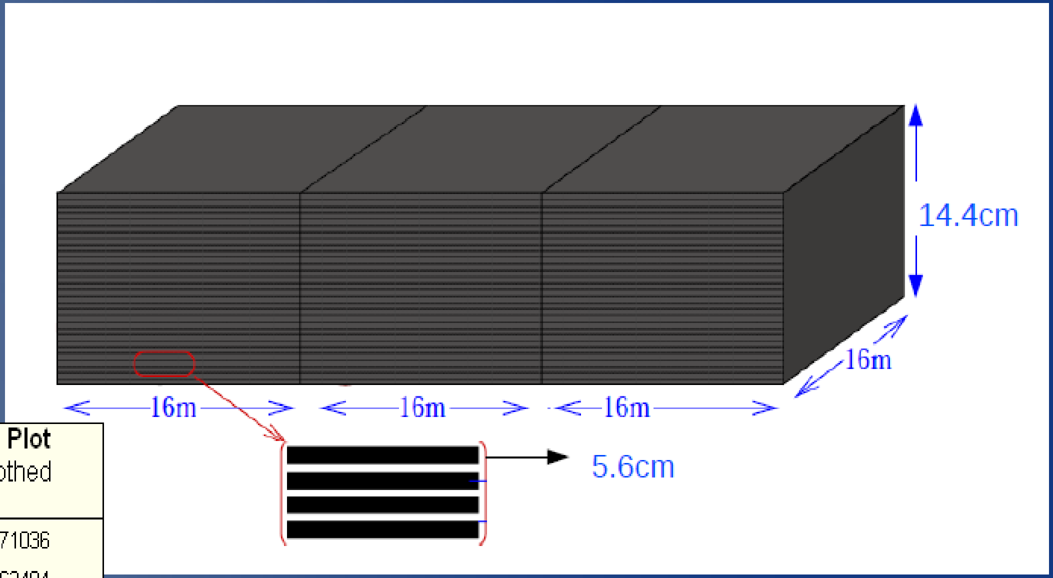
The MINOS Collaboration

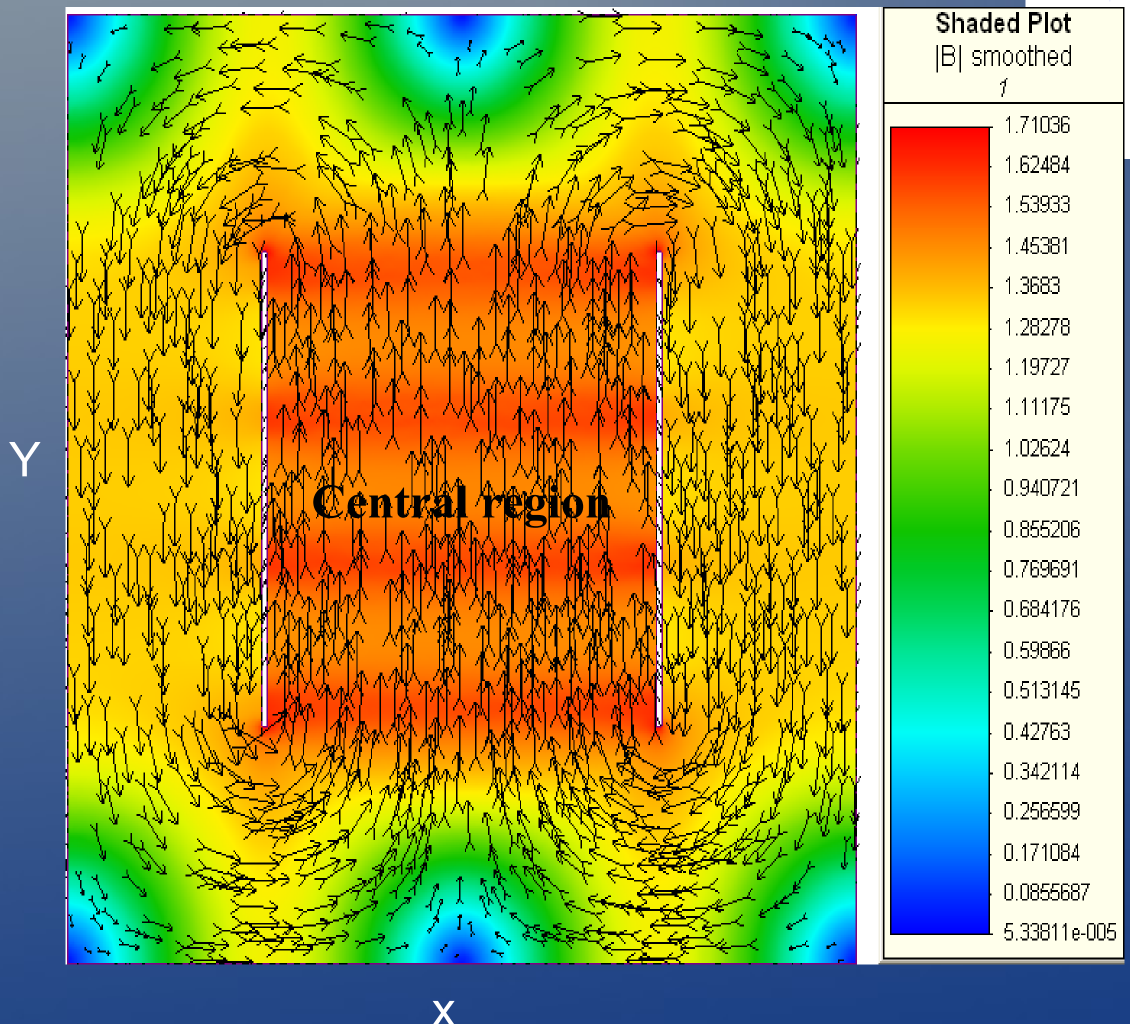
Cosmic ray rates	270 Hz in near det., 1 Hz in far det.
Neutrino energy range (3 configurations)	1 to 25 GeV
Detector energy scale calibration	5% absolute, 2% near-far
Detector EM energy resolution	$23\%/\sqrt{E}$ (<5% constant term)
Detector hadron energy resolution	$55\%/\sqrt{E}$ (<7% constant term)
Detector muon energy resolution	<12% (from curvature or range)
NC-CC event separation	Efficiency >85%, correctable to 99.5%
Electron/π separation	Hadron rejection $\sim 10^2$ for $\epsilon_e \sim 20\%$

http://www-numi.fnal.gov/Minos/detectors.html

Introduction(cont'd):

- Detector:





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