ILD Muon System

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Analysis and Tools

Tasks of the muon system:

- Identification of muons and tracking (PFA segment)
- Tail catcher for HCAL

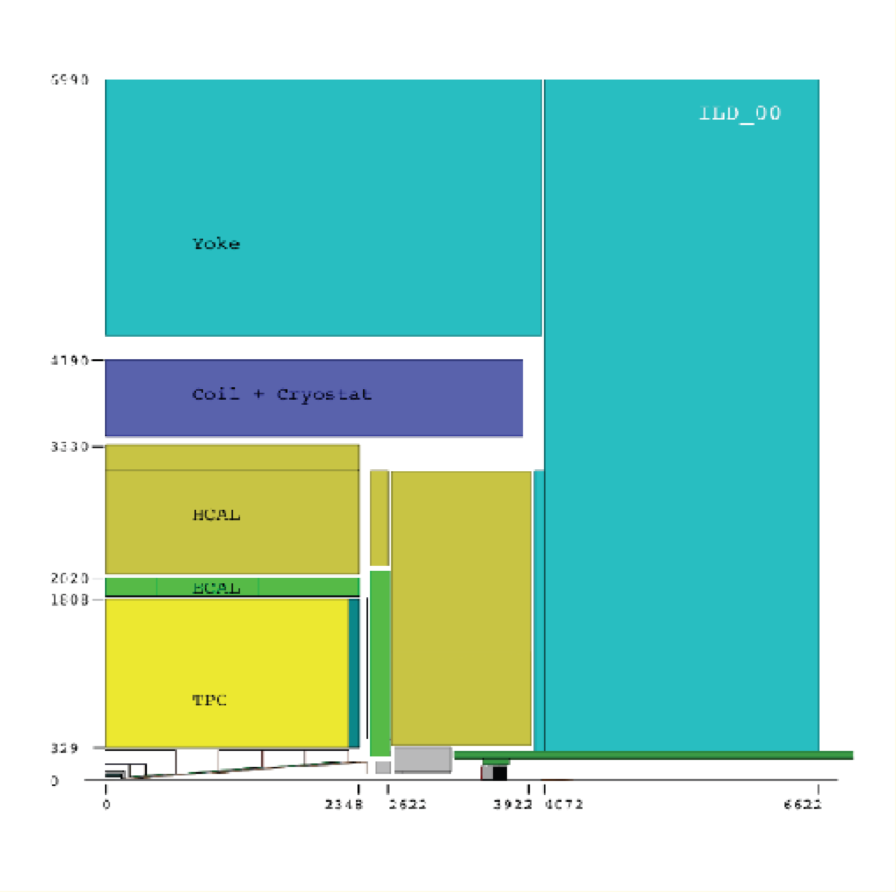
Topics of analysis:

- Study of the muon reconstruction (muon momentum, impact parameter)
- Study of the muon identification efficiency and μ/π separation

Analysis data and tools:

- Simulation with GEANT4, geometry described in MOKKA
- Reconstruction algorithm: PANDORA (MARLIN)
- Muons and pions are simulated in the ILD detector with initial momentum between 1 GeV and 500 GeV. The initial direction ranges between 93° (barrel) and 157° (endcap). 5000 events per point are simulated.

The Magnet and Muon System of ILD



LOI

Yoke:
- Barrel: 10x100 +3x560 mm
- EndCup: 10x100 +2x560 mm

Cryostat:
- Cylinder with 40 mm thick inner wall and 30 mm thick outer wall
- 750 mm distance between walls
- Instrumentation 2 double scintillator layers

Coil:
- 450 mm thick, segmented in 3x1650 mm + 2x1200 mm long modules

Muon Detector System:
- Scintillator Double Sensitive Layers in the Yoke Gaps: (10mm + 10mm scintillator)

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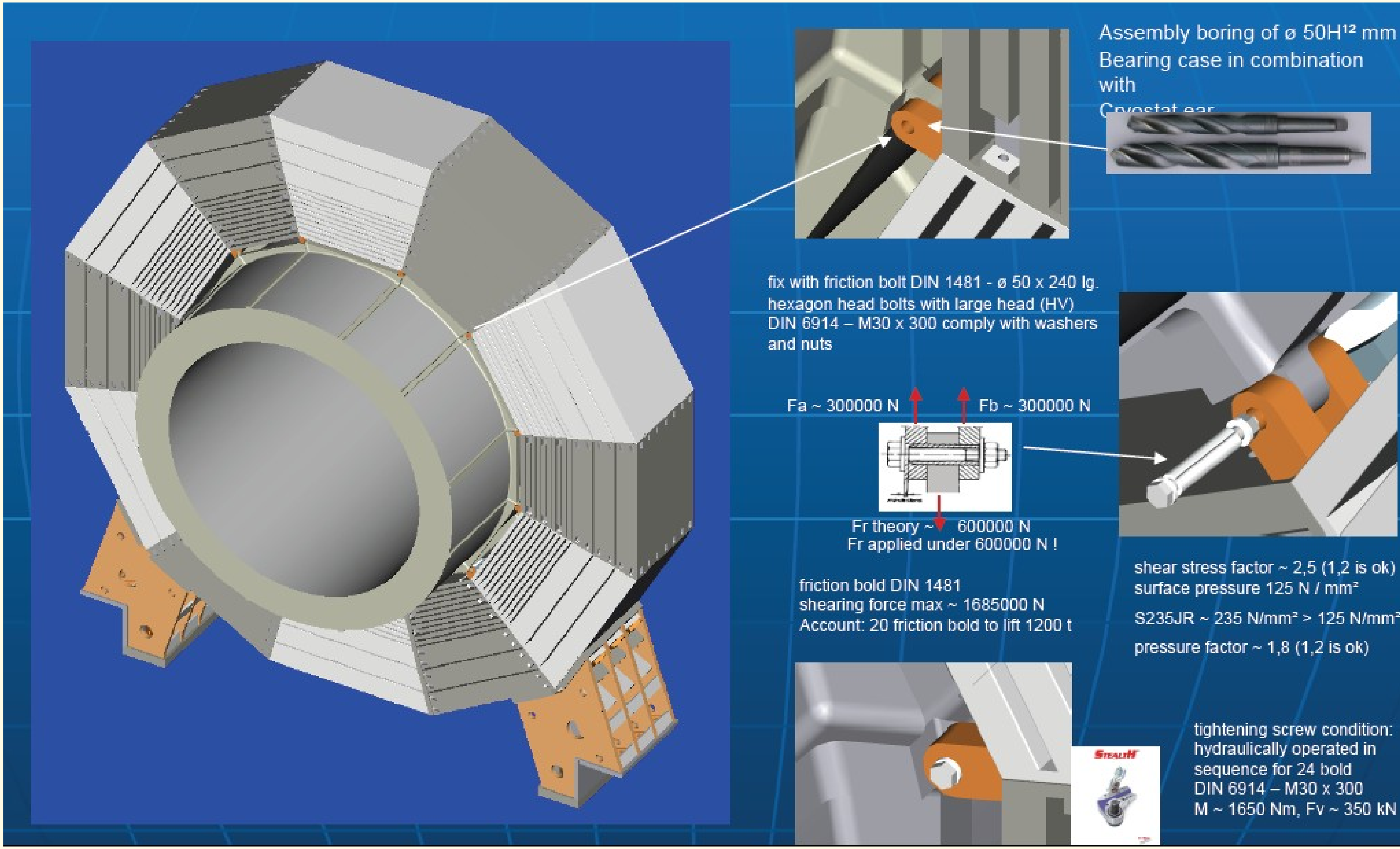
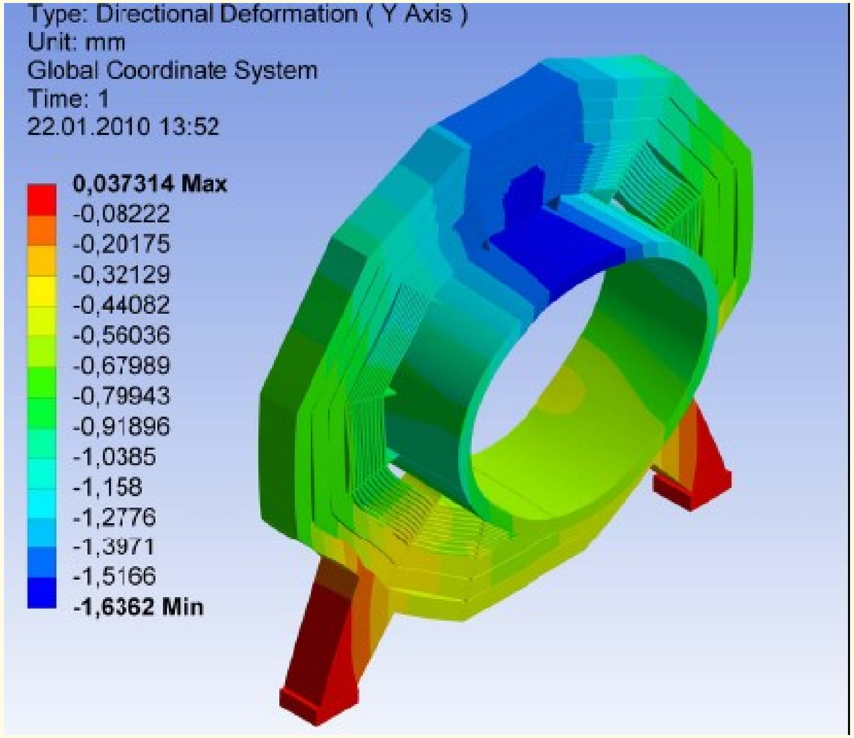
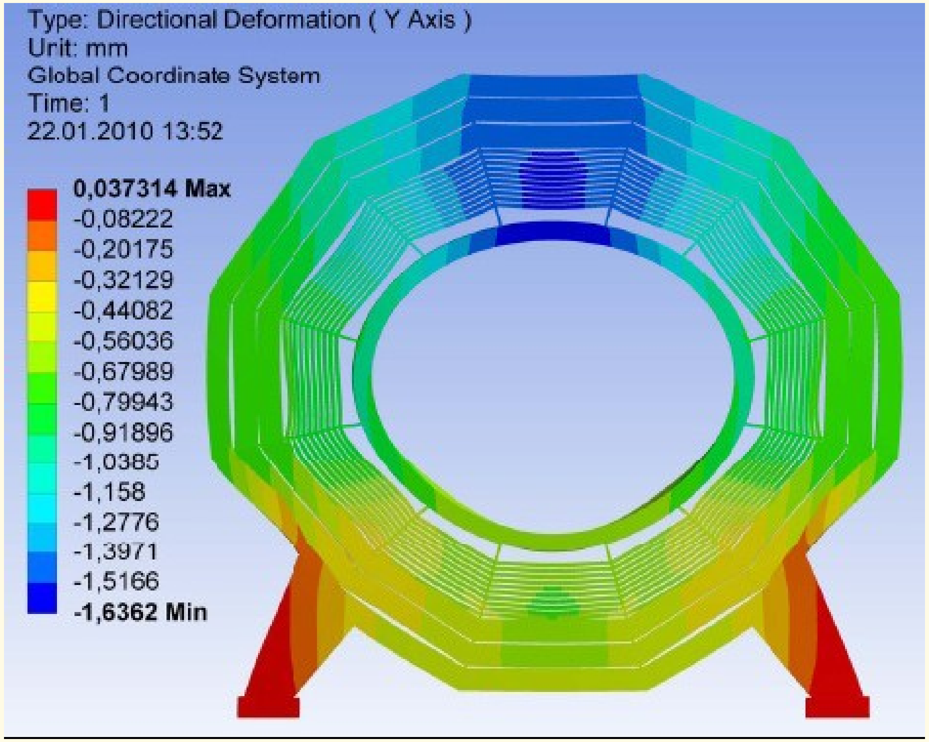


R. Stromhagen

The Magnet and Muon System of ILD

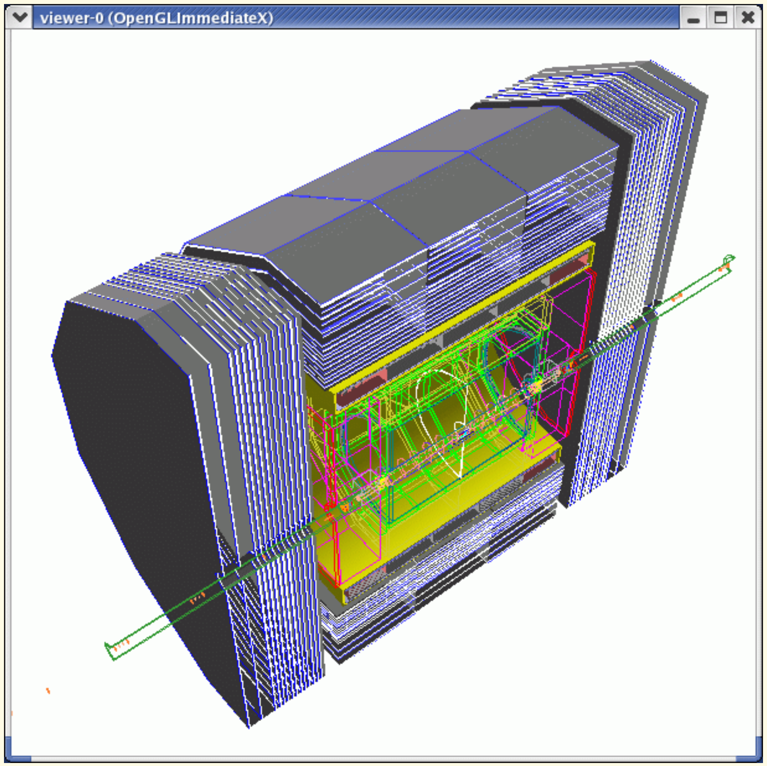


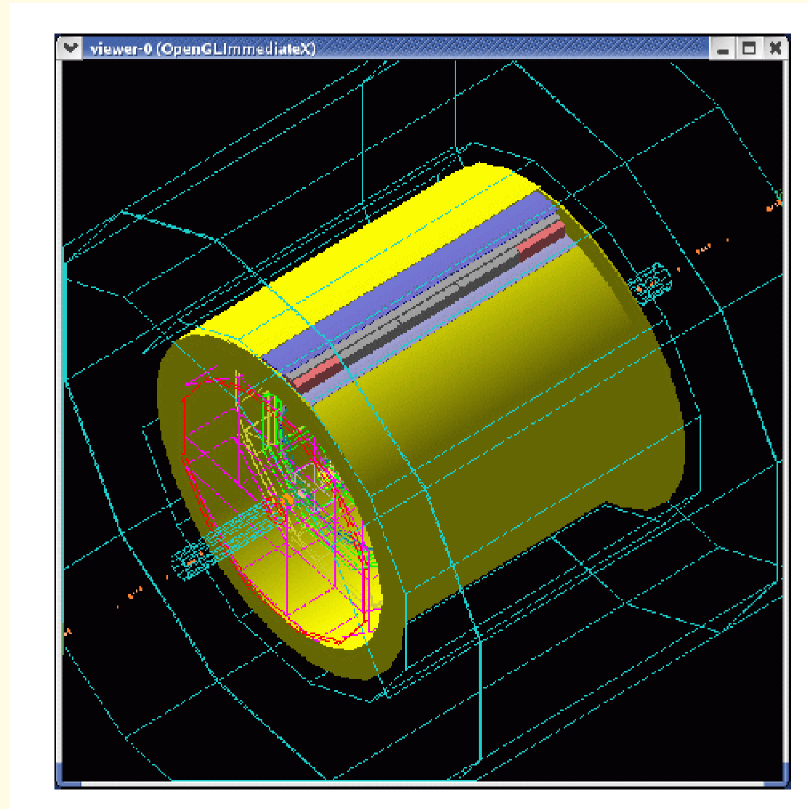


Vertical deformation of central wheel
Caveat: cryostat too stiff in this model

3D calculation M.Harz

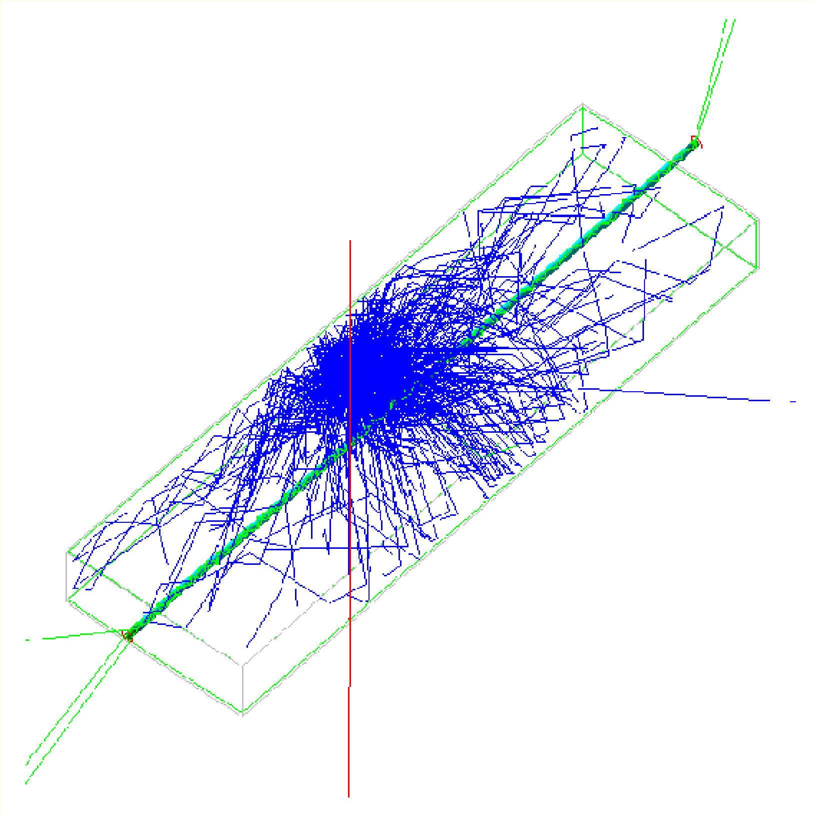
The Magnet and Muon System of ILD

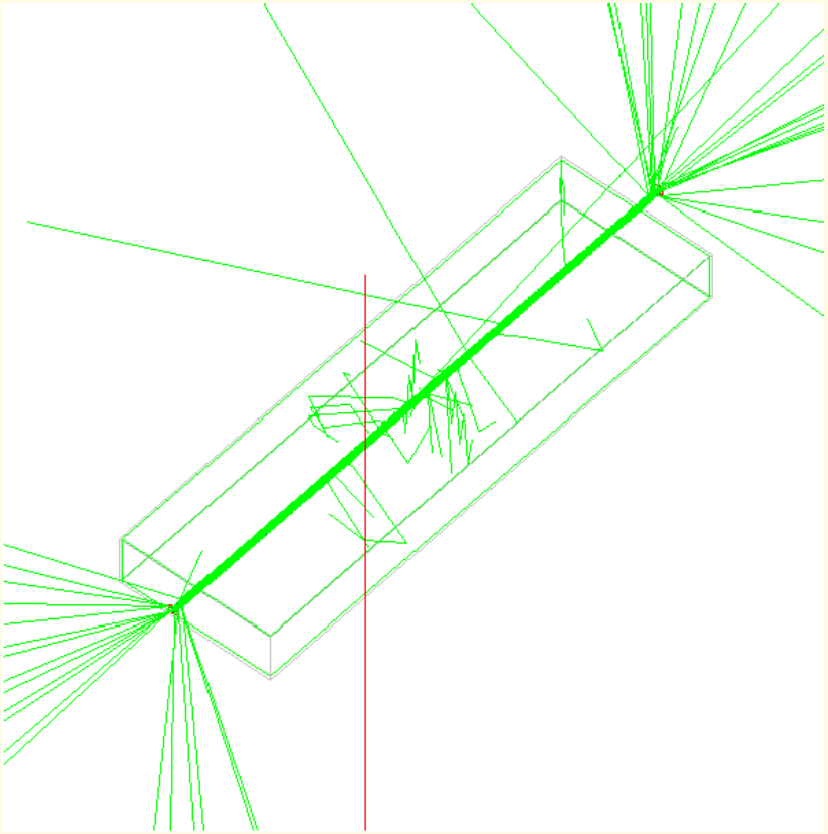




Yoke, Cryostat and Muon System of the ILD detector as described in MOKKA

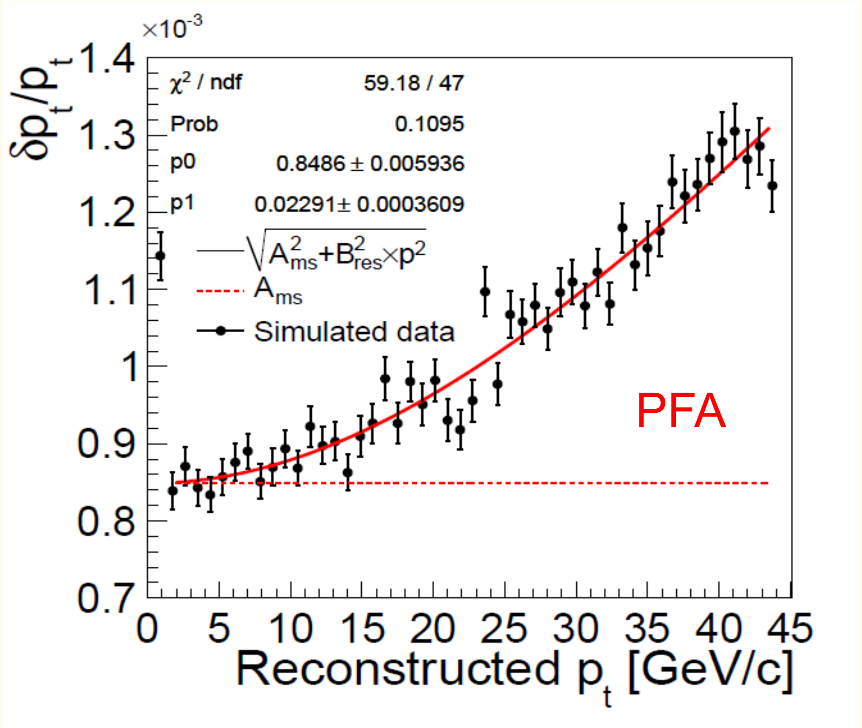
The Magnet and Muon System of ILD

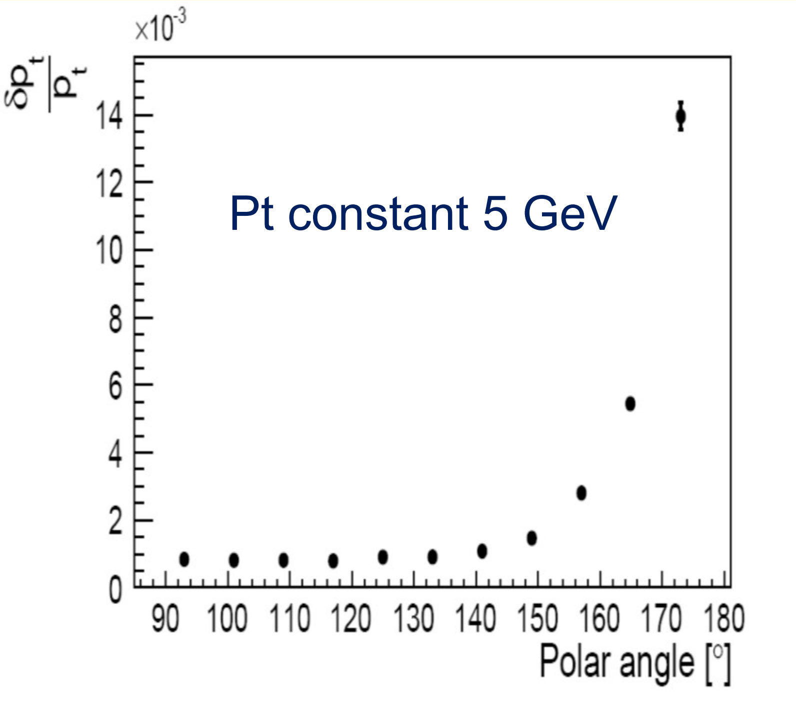




Detail model of the Muon Detector elements

Muon Momentum Resolution Study (PFA)





Multiple scattering:

$$A_{ms} = \frac{\text{٠.٠١٦} \times \sqrt{L / X_{\text{٠}}}}{\text{٠.٣} \int B dL};$$

Gluckstern Parameterization:

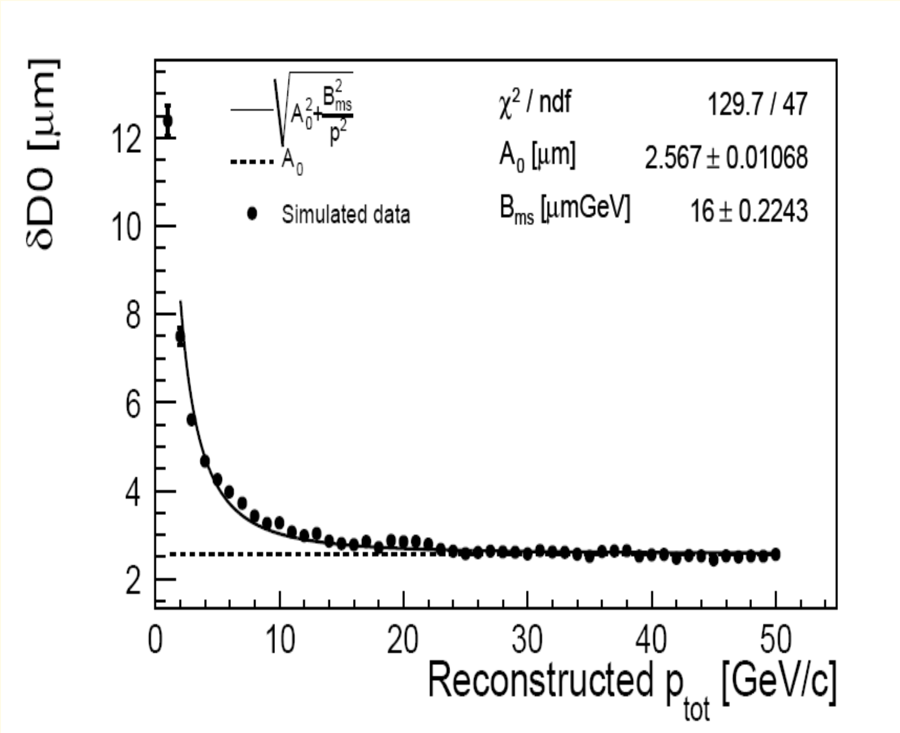
$$A_{ms} = 0.85 \cdot 10^{-3}$$

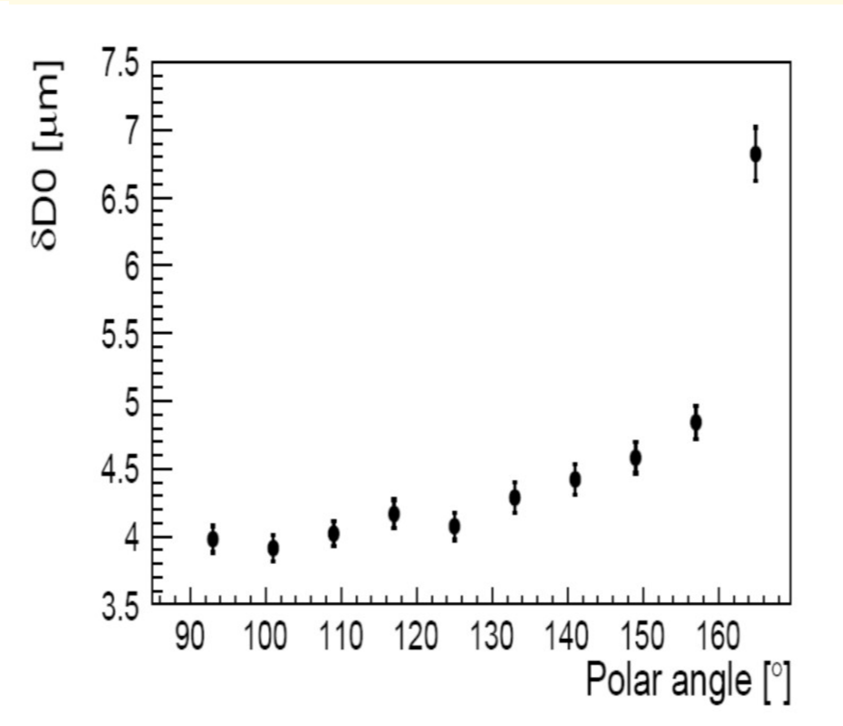
$$B_{res} = 2.3 \cdot 10^{-5}\, GeV^{-1}$$

Detector resolution:

$$B_{res} = \frac{\delta x \sqrt{\text{٧٢٠} / (N + \text{٥})}}{\text{٠.٣} \int B dL}$$

Impact Parameter Resolution (PFA)





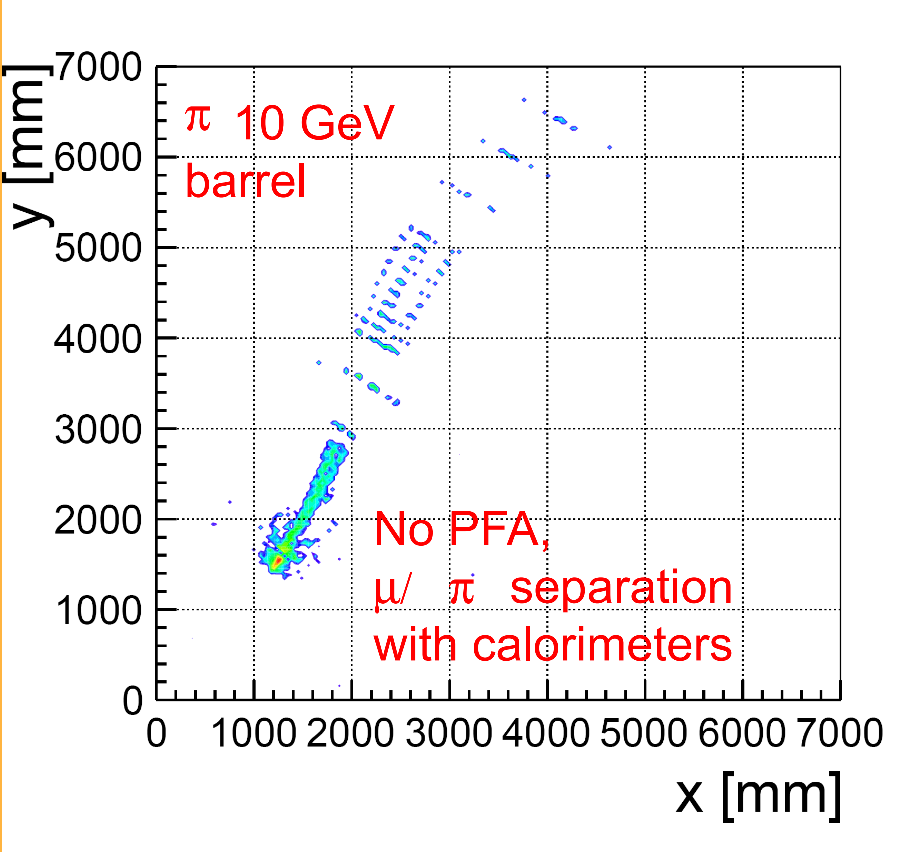
$$\delta D_0 = \sqrt{A_0^2 + \frac{B_{ms}}{p^2}}$$

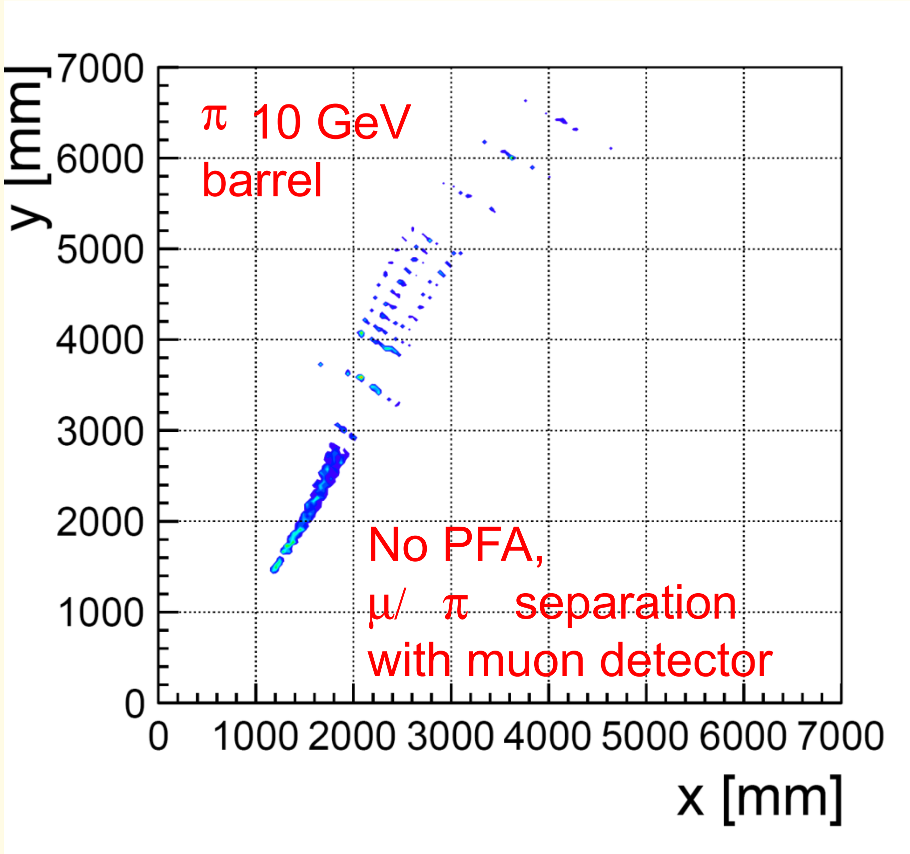
A_0: detector resolution term

B_{ms}: multiple scattering term.

$$A_0 = 2.5 \mu m$$

μ/ π Separation E=10 GeV

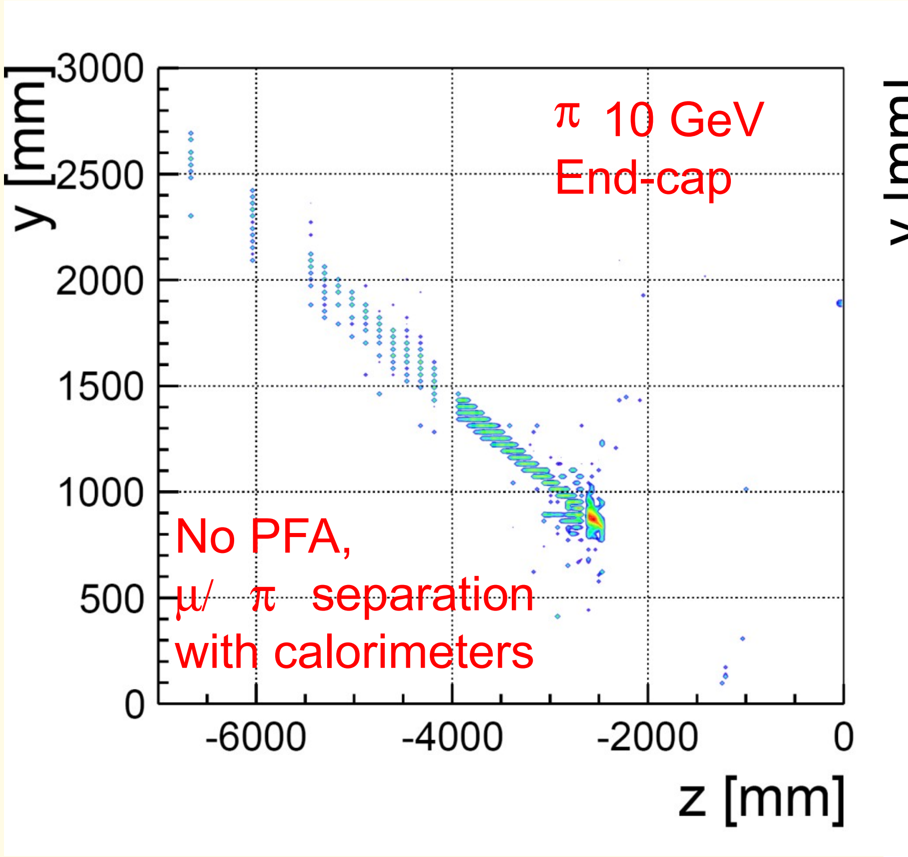


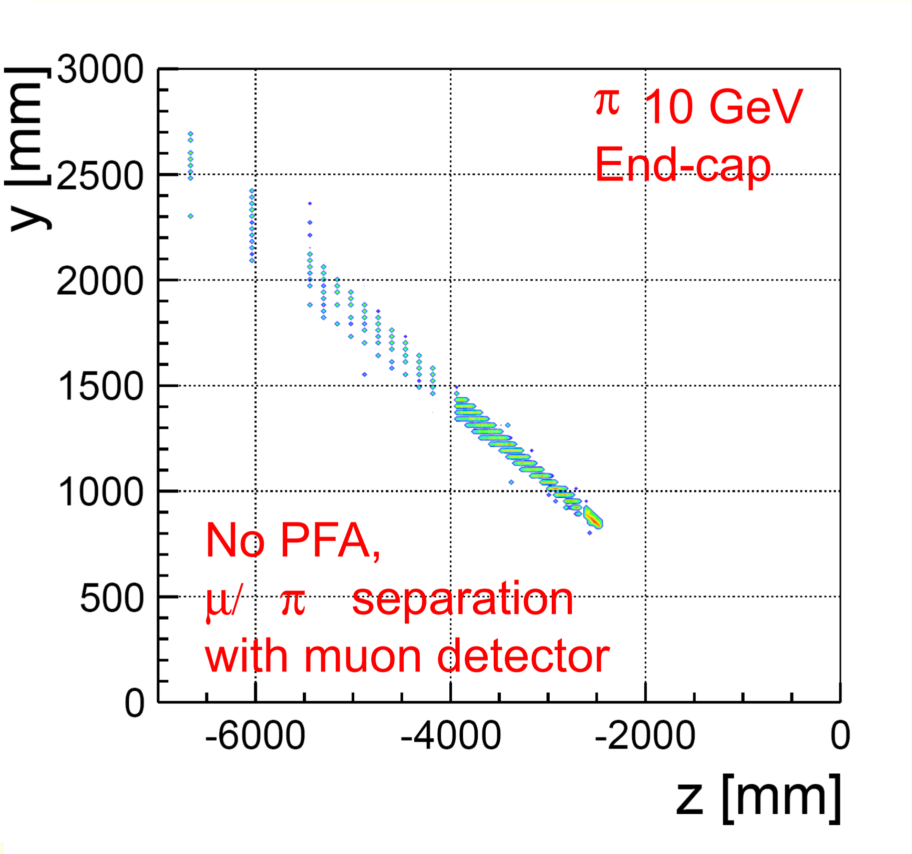


Selection based on visible energy in the calorimeters and in the muon detector

With muon ID, only in-flight decay pions ($\pi \rightarrow \mu\nu$) are misidentified as muons

μ/ π Separation E=10 GeV





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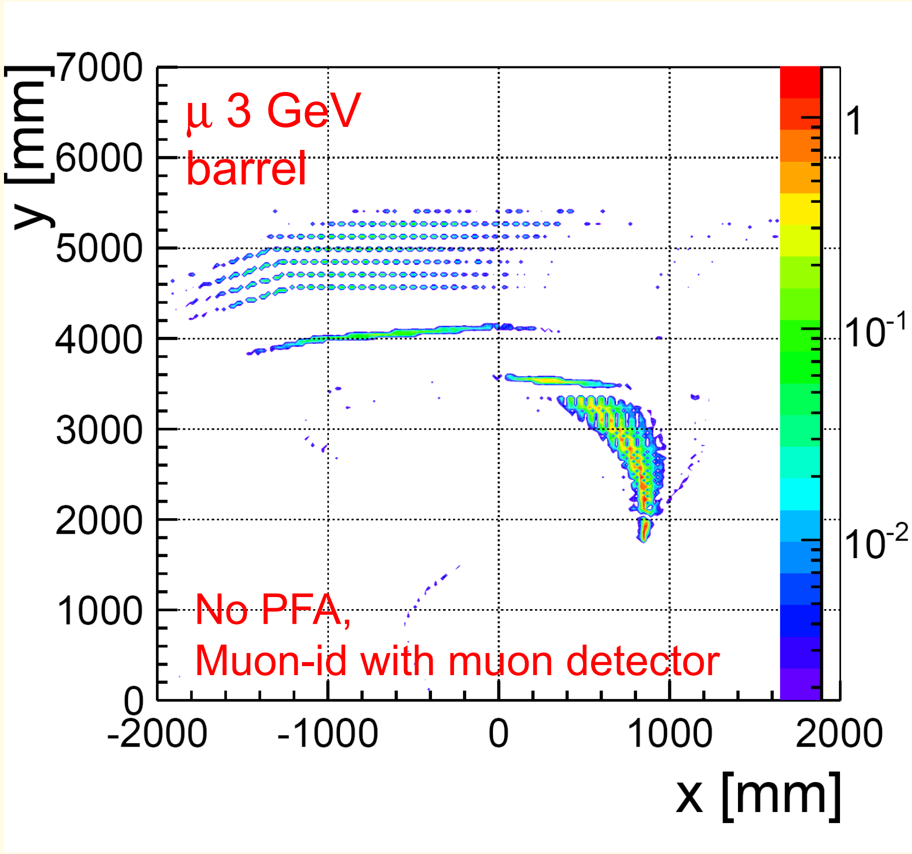
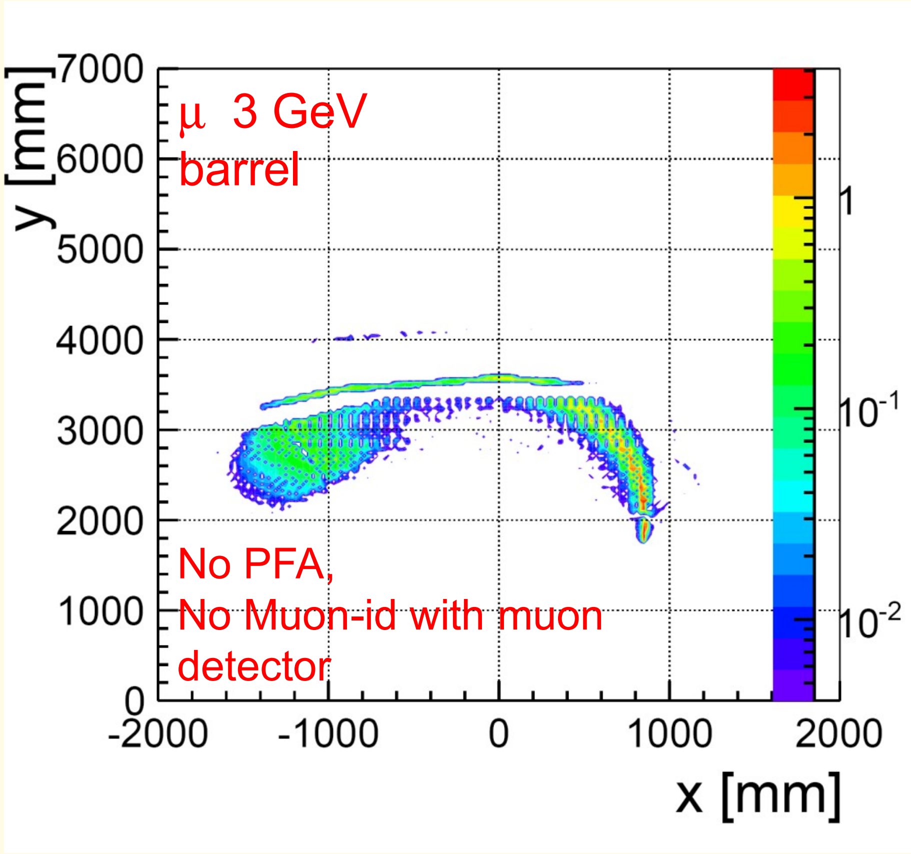
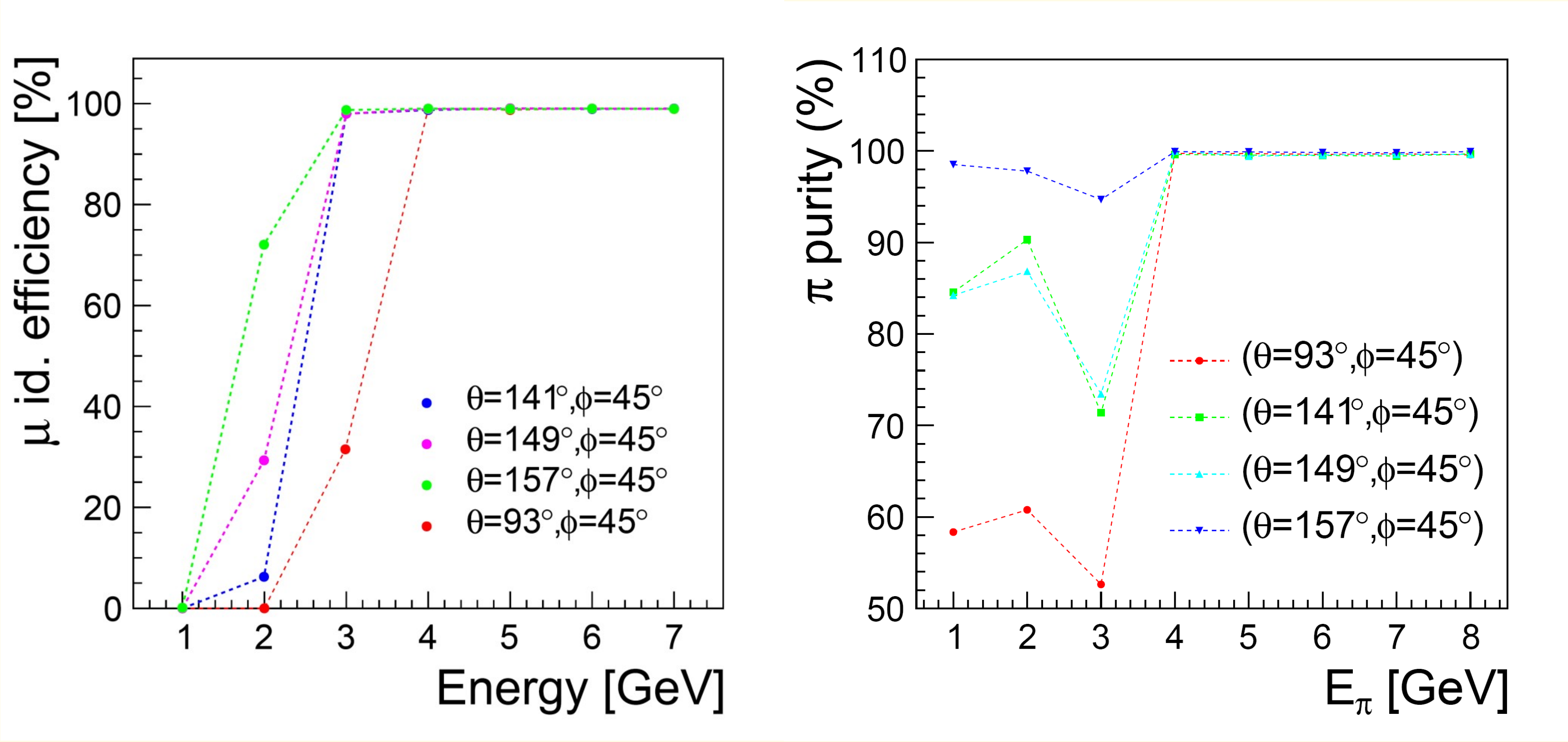
Problem at low Momentum





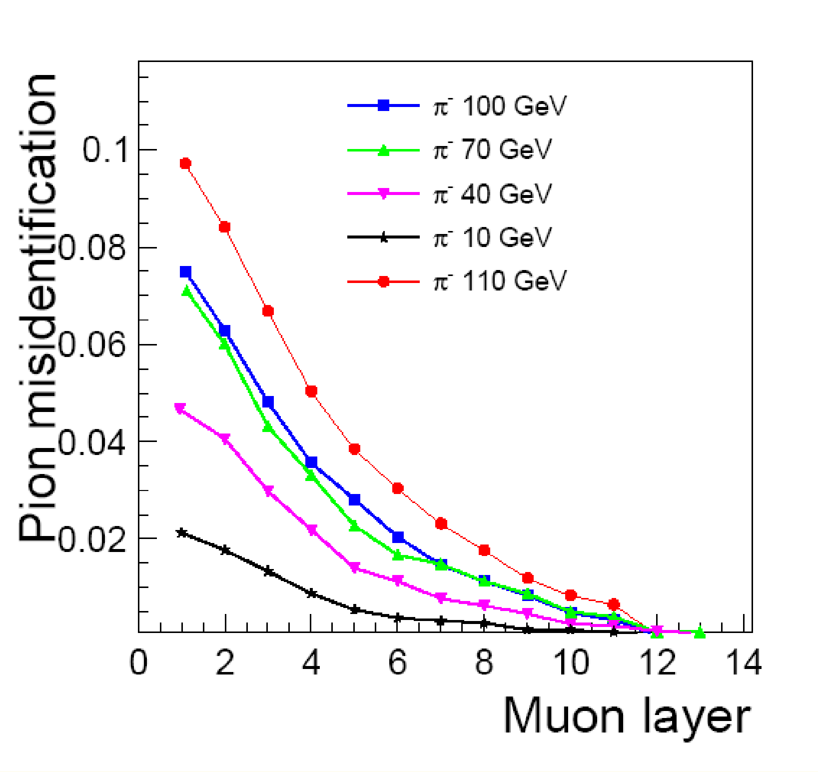
Barrel: Impact of the coil material on the muon identification

mu/pi Separation

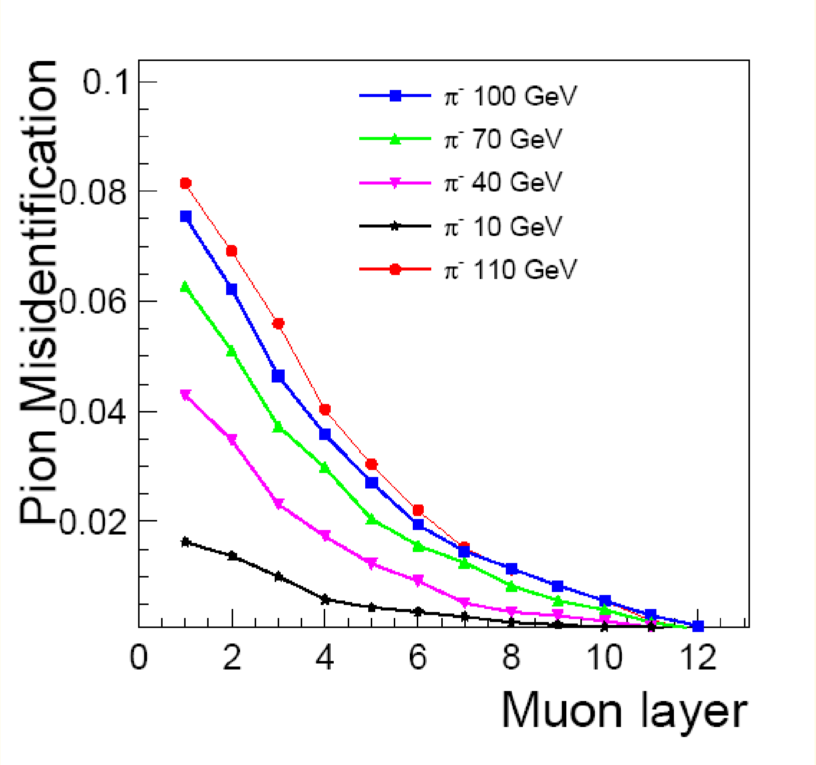


Effect of the coil material for soft muons:
the μ-id based only on the muon system is weak for energy lower than 4 GeV.

Pion Misidentification in Muon System



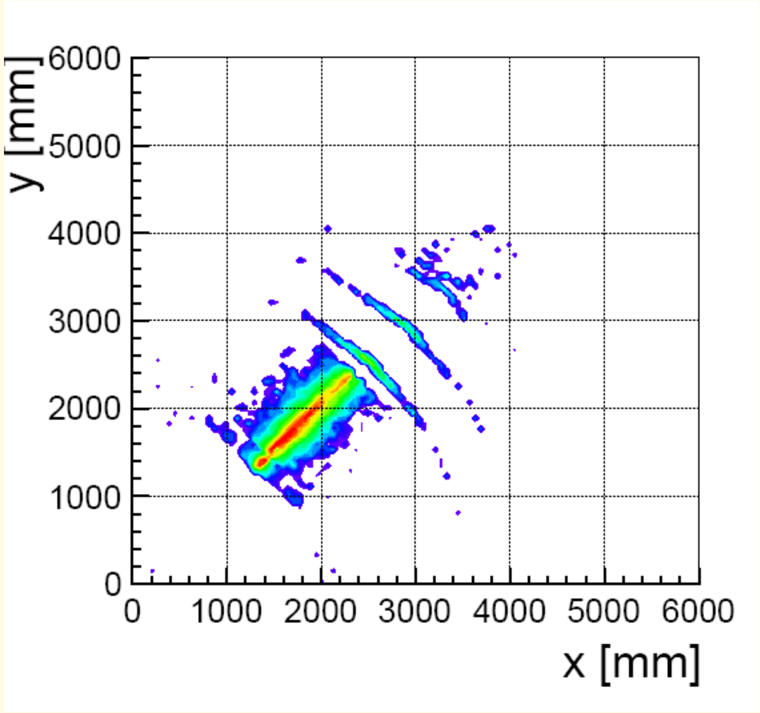
Barrel



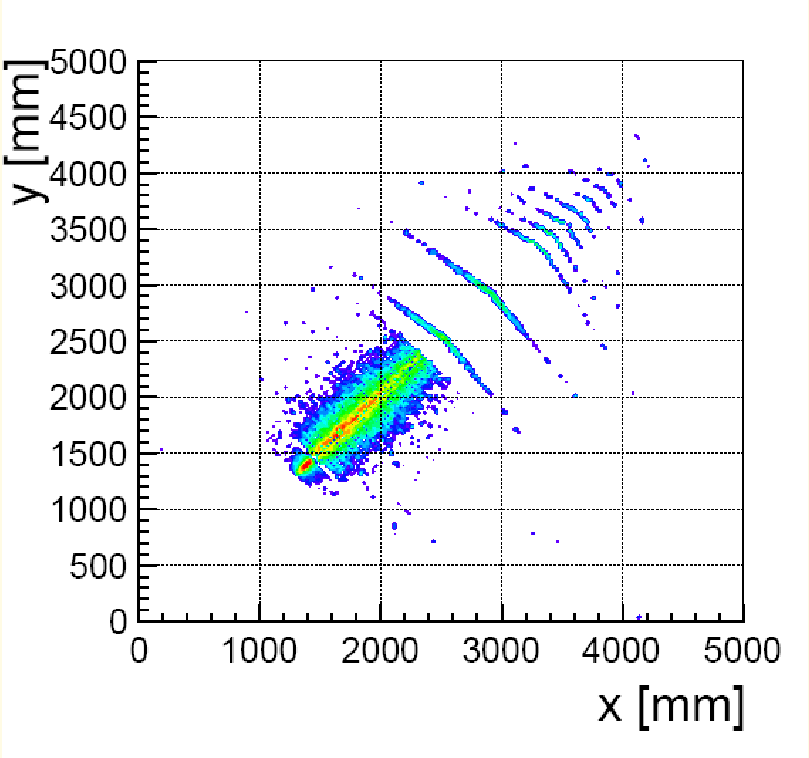
Endcup

Muon System Instrumentation: Pion Hits in the Muon Systems Layers

Muon System as Tail Catcher

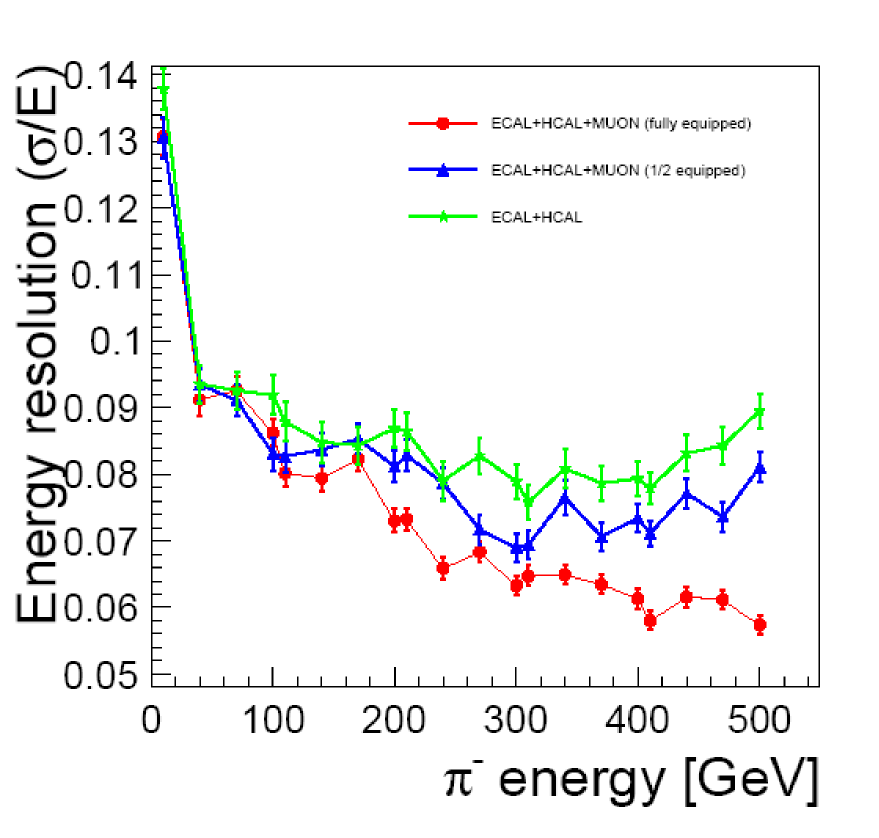


Barrel 140 GeV pions

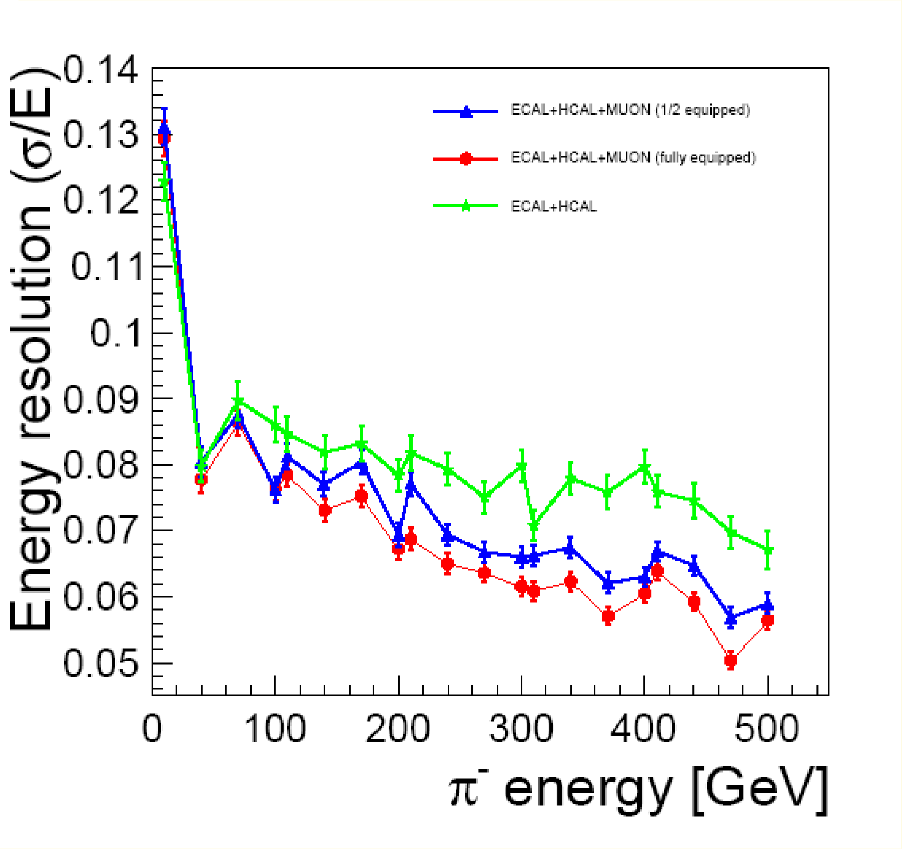


Barrel 350 GeV pions

Muon System as Tail Catcher

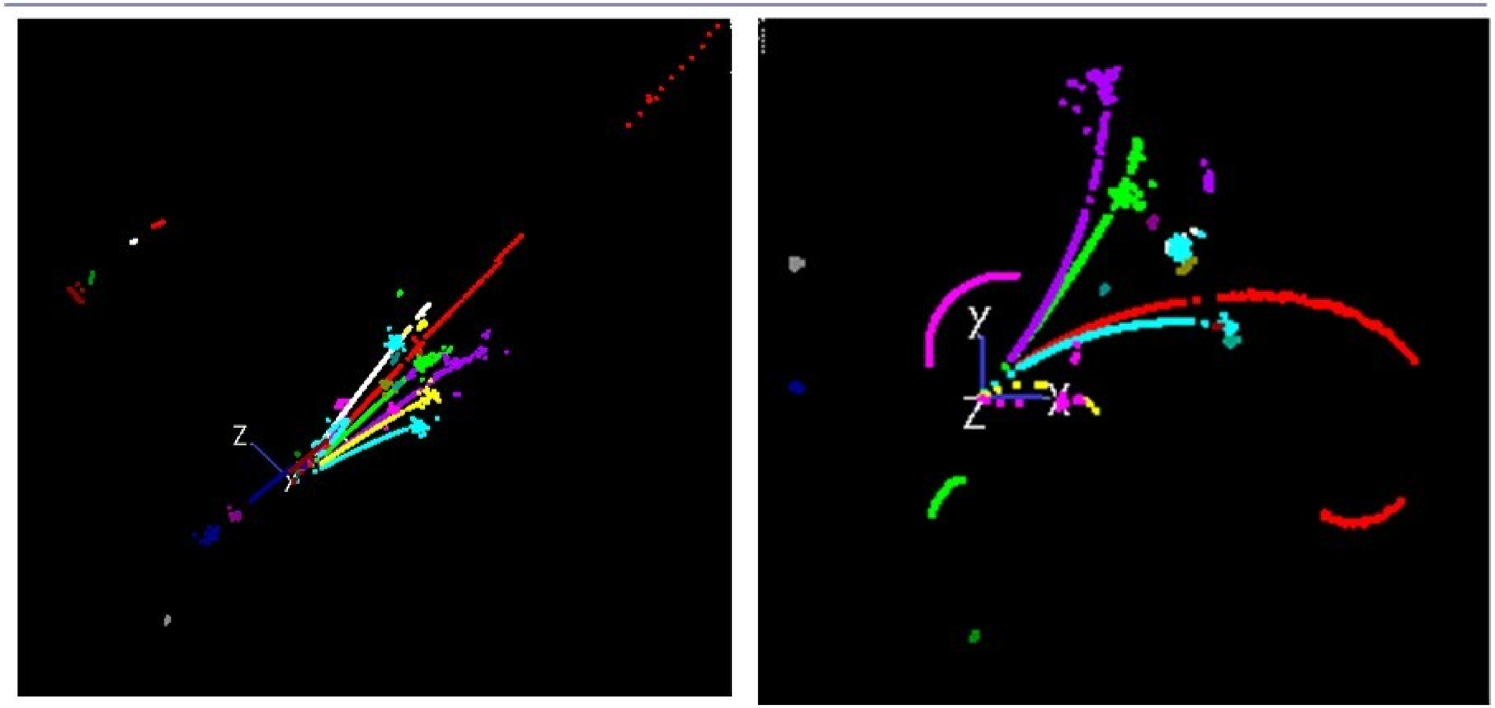


Barrel



EndCup

Performance with b-jet



50 GeV b-jet in the ILD , PFA reconstruction (red are muons tracks)

Results of analysis will come soon

Conclusions for Yoke Design

Tail-catcher

- Improves energy resolution. In particular at high energies
- Full thickness of yoke important for pion rejection (Also needed for achieving low stray field)
- Instrumentation of outer (thick) layers is useful for pion rejection. Much better than just one muon chamber layer on the very outside.

In addition, one very thick instead of three outer iron layers (each about 100tons) would be much more difficult to deal with (manufacturing, transportation and assembly)

- Increasing iron plate thickness from 10 to 20cm probably fine at low energies (low statistics so far), but significant degradation at high energies

Instrumented Coil

- Small improvement of energy resolution
- Might be useful for low energy muons and hadrons identification

Conclusions and Outlook

New geometry of the coil and the muon system for ILD introduced in MOKKA and tested

Muon Reconstruction in the ILD detector (PFA):

- $\delta(1/pt)$ = 2.3 10-5 GeV-1
- $\delta(D0)$ = 2.5 μm

Muon identification and $\mu/\ \pi$ separation:

- ~95% μ-identification efficiency and correspondingly about 99% π rejection at energy >4 GeV
- Lower pion rejection for muon energy < 4GeV. Needs dedicated analysis and

Muon system for hadronic processes:

- Endcap region equipment of muon system as tail catcher reasonable
- Performance of barrel region limited by the material of coil
- For high energy jets useful to improve performance, especially resolution

Detailed simulation of detection elements of muon system

All tools now ready for detailed studies

Summary of Discussion

Muon System/Tail Catcher simulation gives useful input,

Questions about transfer the forces from FE to Barrel:

- Have looked into stress at hard stops, should be fine,
- Question whether increasing thickness of 1'st barrel Iron plate from 10 to 20 cm would harm the muon system/tail catcher performance, - Probably not so good idea,

Question (H.V.) whether number of muon layers/thickness of plates could be reduced/increased. Developing better muon ID algorithm using HCAL:

- So far muon ID and pion misidentification mainly studied for single particles,
- Will be more challenging in high energetic jets,
- Independent muon ID is important, Can use HCAL or Muon System to determone efficiency. Otherwise have to relay on Monte Carlo

Summary of Discussion

Question concerning length of detector

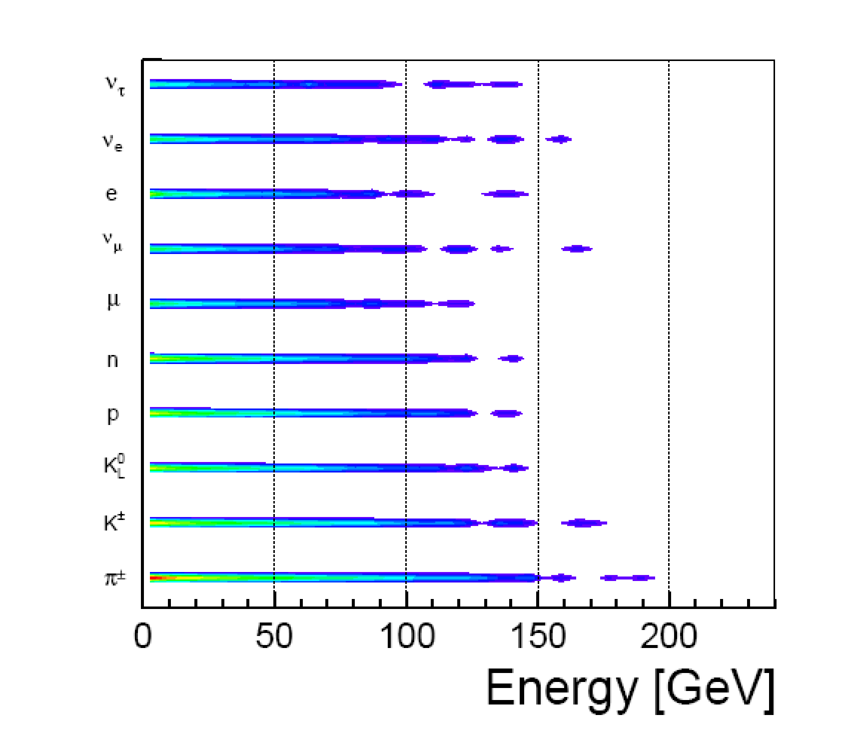
- Length determines available space when detector opened
- Thickness of yoke mainly determined by stray field
- Main stray field limit in radial direction
- Should look into reducing number of thick end-cap iron plates from 2 to 1. In principle, no hard limits for accelerator. Might be different in real live.

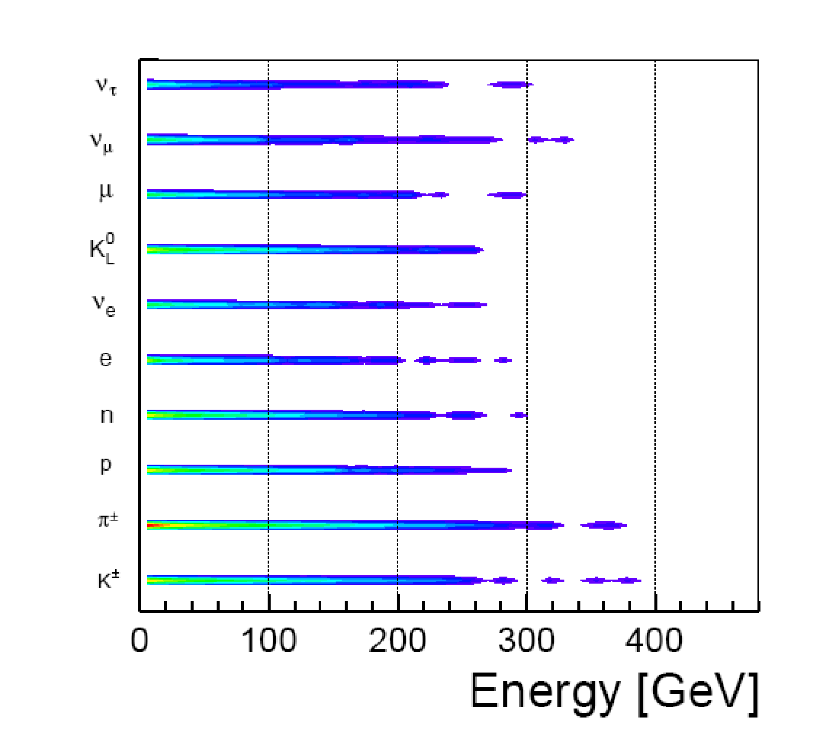
Question (A.H.) concerns about radial EC structure. Prefers horizontal block design as proposed by H.Gerwig

- Previously, did some compressions
- Both designs should work
- Both have pros and cons
- Don’t have man power to do a detailed (mechanical and physics performance) comparison
- Final design not needed at this point
- Propose to wait and see how CLIC detector yoke design develops

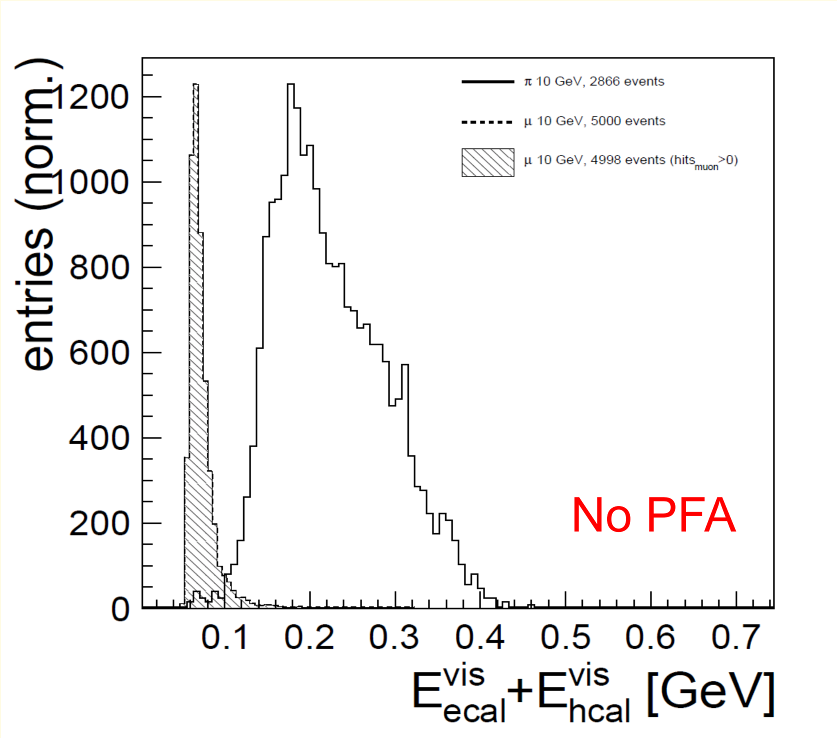
Backup

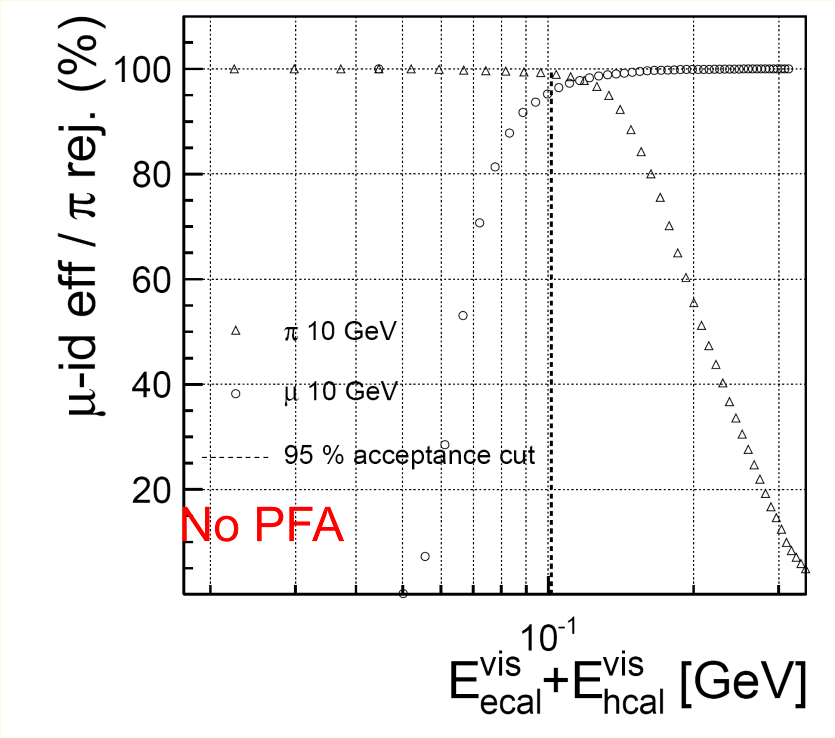
Energy in b-jet





μ/ π separation in calorimeters (E=10 GeV)





Muon efficiency:

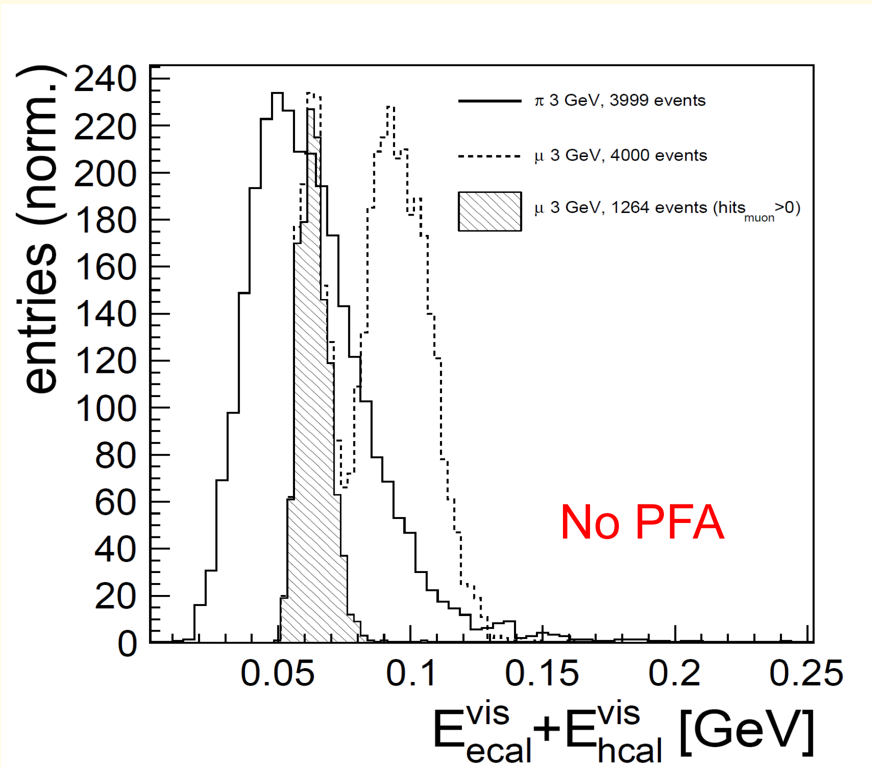
$$\alpha_{\mu}^{cal} = \int_{0}^{E_{+,95}} h_{\mu}(E)dE = 95\%$$

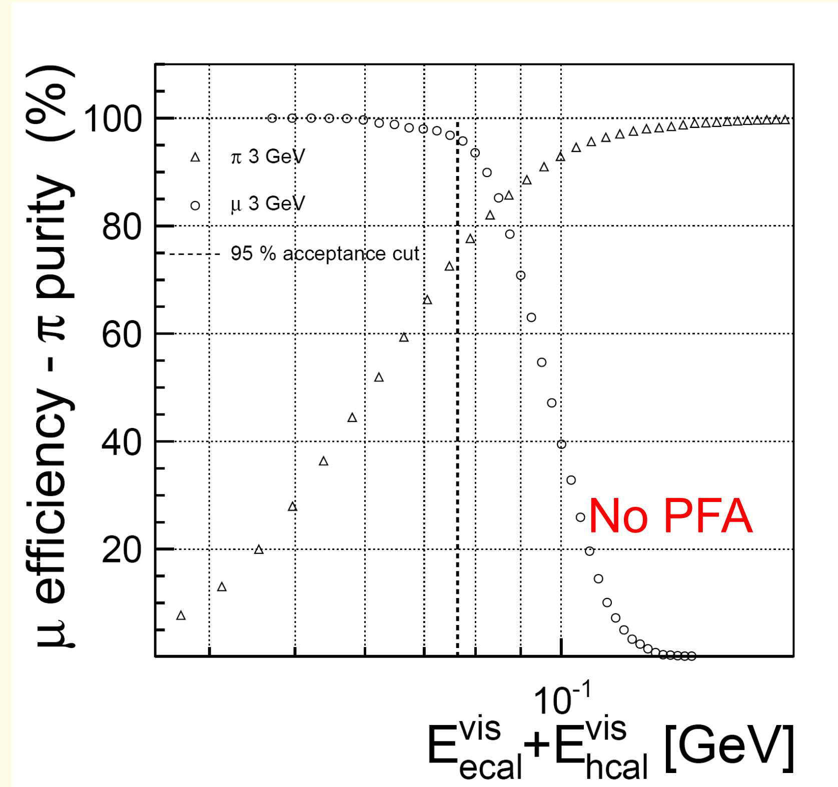
Pion rejection

$$\beta_{\pi}^{cal} = \int_{E+,95}^{\infty} h_{\pi}^{cal}(E)dE$$

95 % muon efficiency acceptance cut.
(98.98 ± 0.18)% pion rejection

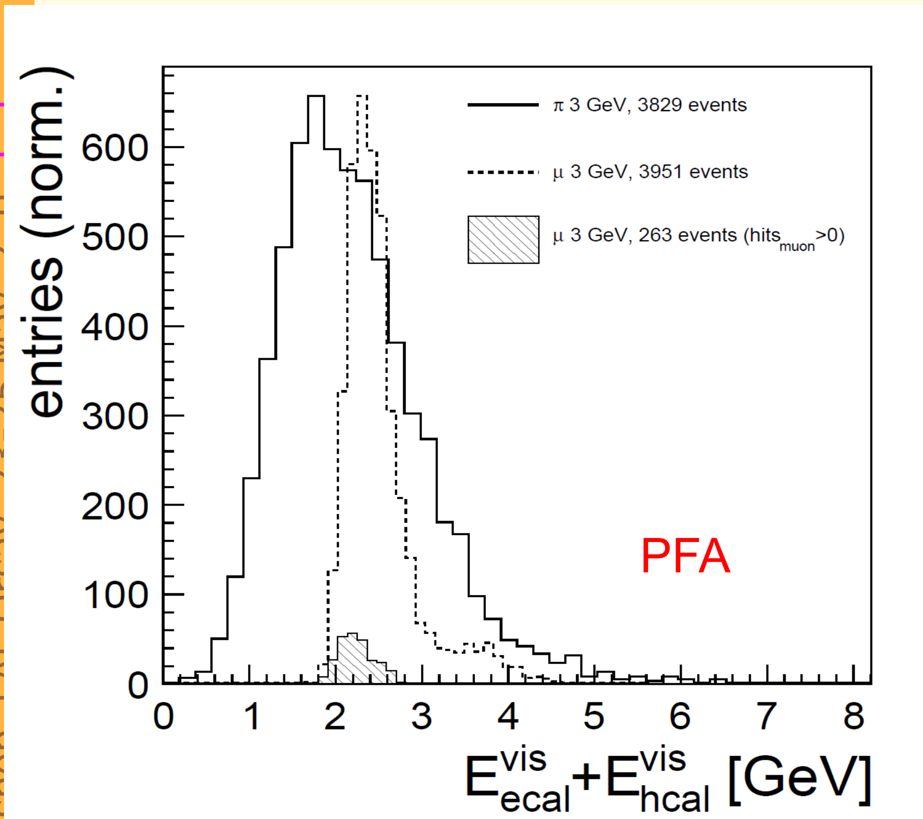
Problem at low momentum

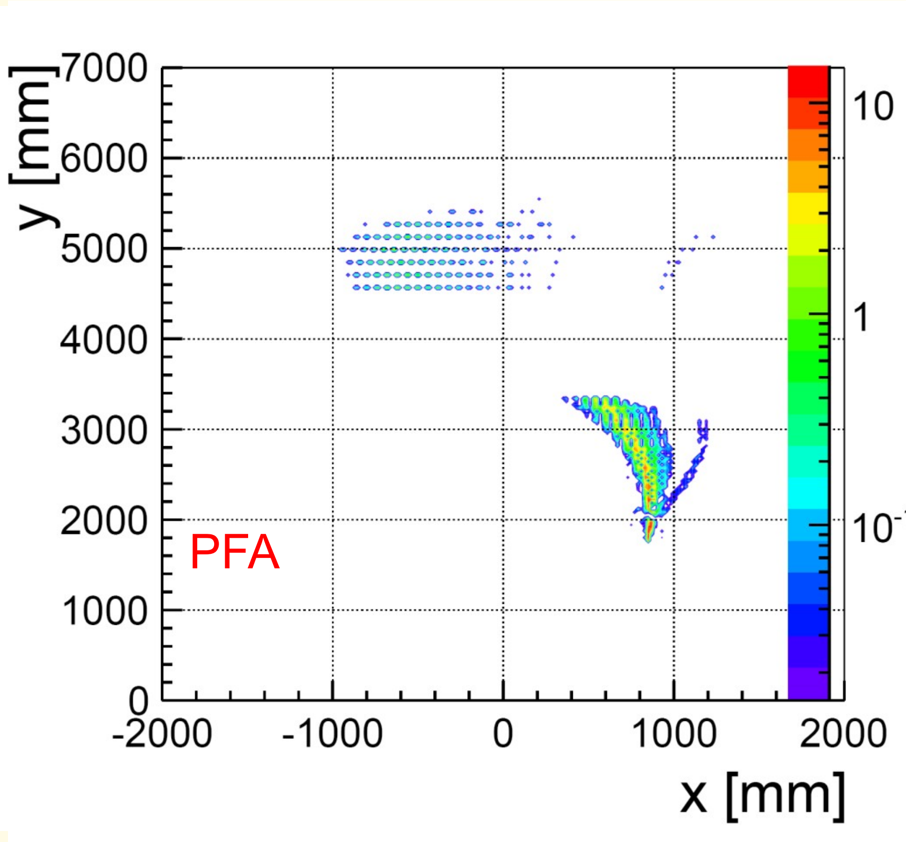




Low energy pions deposit energy mainly in ECA
For muons which not identified by the muon system, estimation for 95 % muon efficiency, pion rejection (73.75±0.69)%
Necessary special analysis method

Problen at low momentum





PFA algorithm unefficient in the connection between mip-like stubs in calorimeters and in the muon detector at low energy due to the curvature of the tracks (20% PFA muon reconstruction efficiency)

Good reconstruction and identification of low energy pions