An AHCAL-inspired ECAL for the DUNE Near Detector

Lorenz Emberger

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

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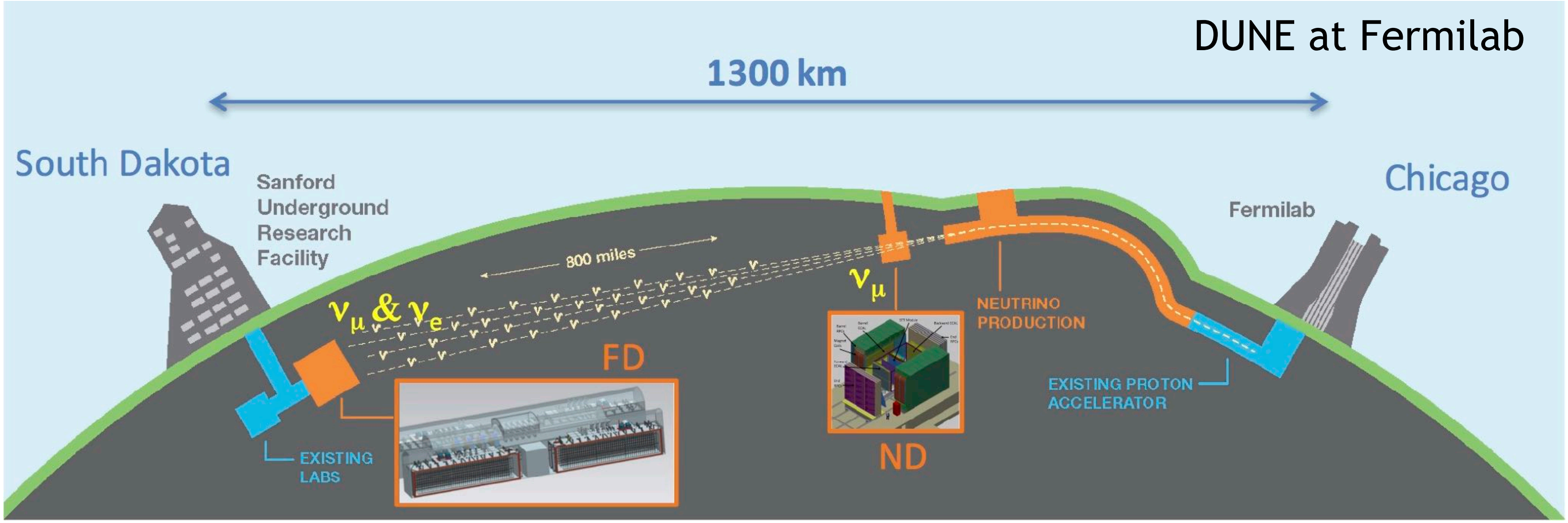
DUNE Experiment

- DUNE targets the precise study of neutrino mixing, including the potential discovery of CP violation



Far Detector: Liquid Argon TPC to measure oscillated spectrum - will see CP violation in ν_e/anti-ν_e appearance

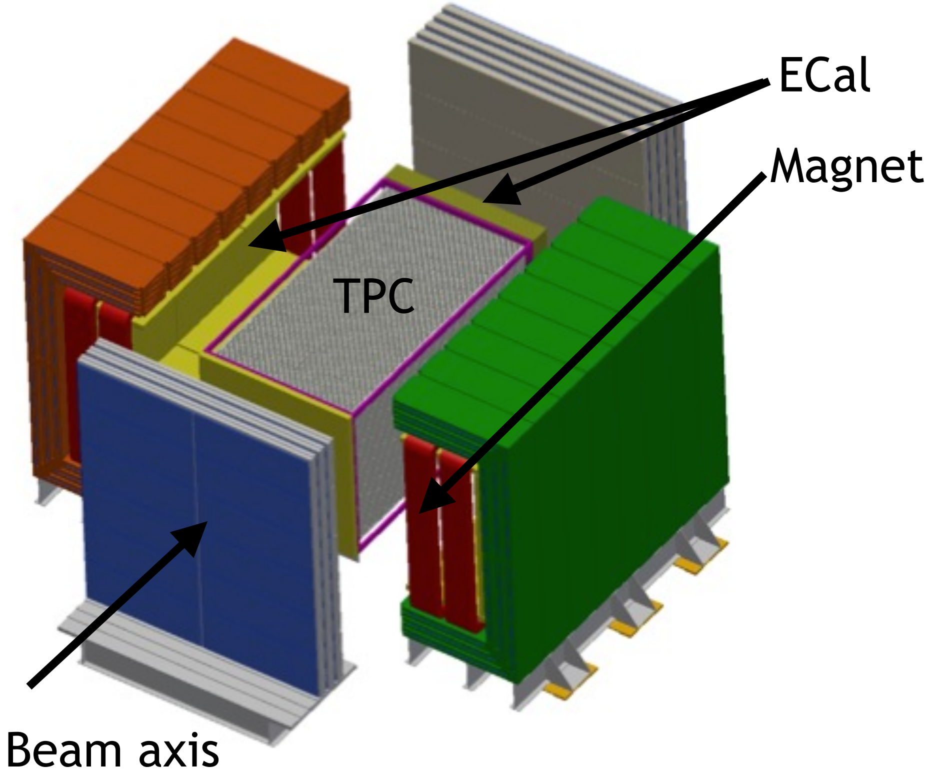
Near Detector: Measures beam before oscillation, required to understand initial flux and cross sections to understand FD signal

Near Detector Tasks

- Measure the energy spectrum of the beam, background rates and contamination
    - Provide precise extrapolation of event rates in the far detector
- Largest errors arise from uncertainties in neutrino-nucleon scattering amplitudes
- Especially: ν_μ-induced neutral current π^0 production
    - Photons from the Pion decay can mimic ν_e signal events
    - Excellent Photon detection and reconstruction is required
- High beam intensity gives rise to an extended physics program

Near Detector ECal

Possible layout: High Pressure Gaseous Argon TPC surrounded by an **electromagnetic calorimeter** and magnet



- Conversion probability for photons too low in TPC

  →tracker based π^0 reconstruction not possible

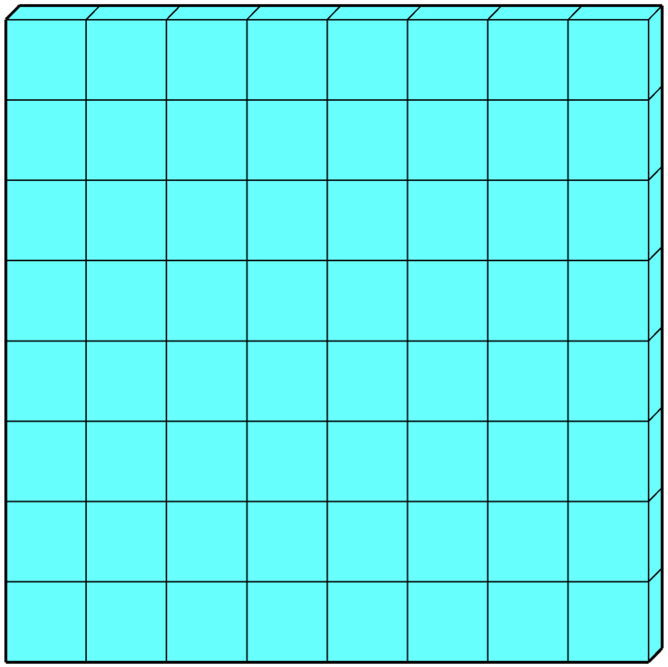
- Our interest: Can high granularity help?

  - Try to reconstruct π^0 decay vertex

<u>The Challenge</u>: Typical π^0 energies ~100MeV → Photon energies ~50MeV

Detector Concept

Calorimeter design is inspired by CALICE Highly Granular Calorimeter



- Sampling calorimeter with active material segmented in 20mm x 20mm tiles (default)

Detector Concept

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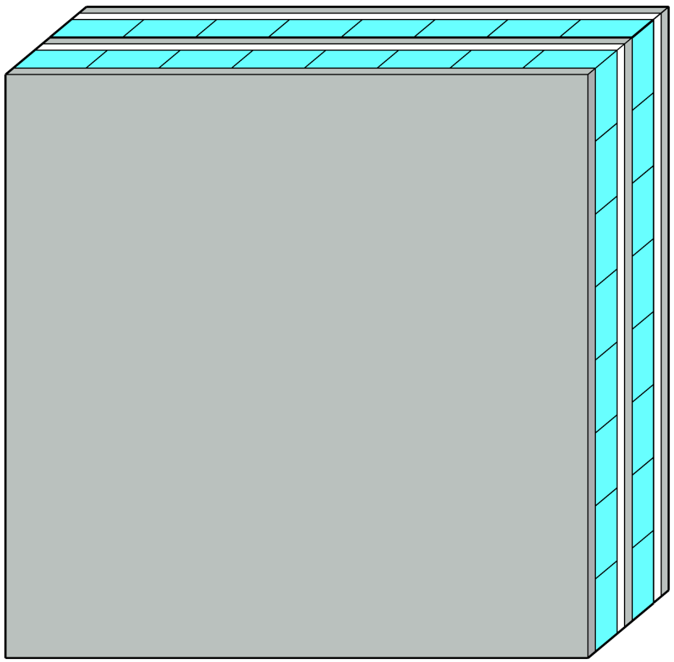
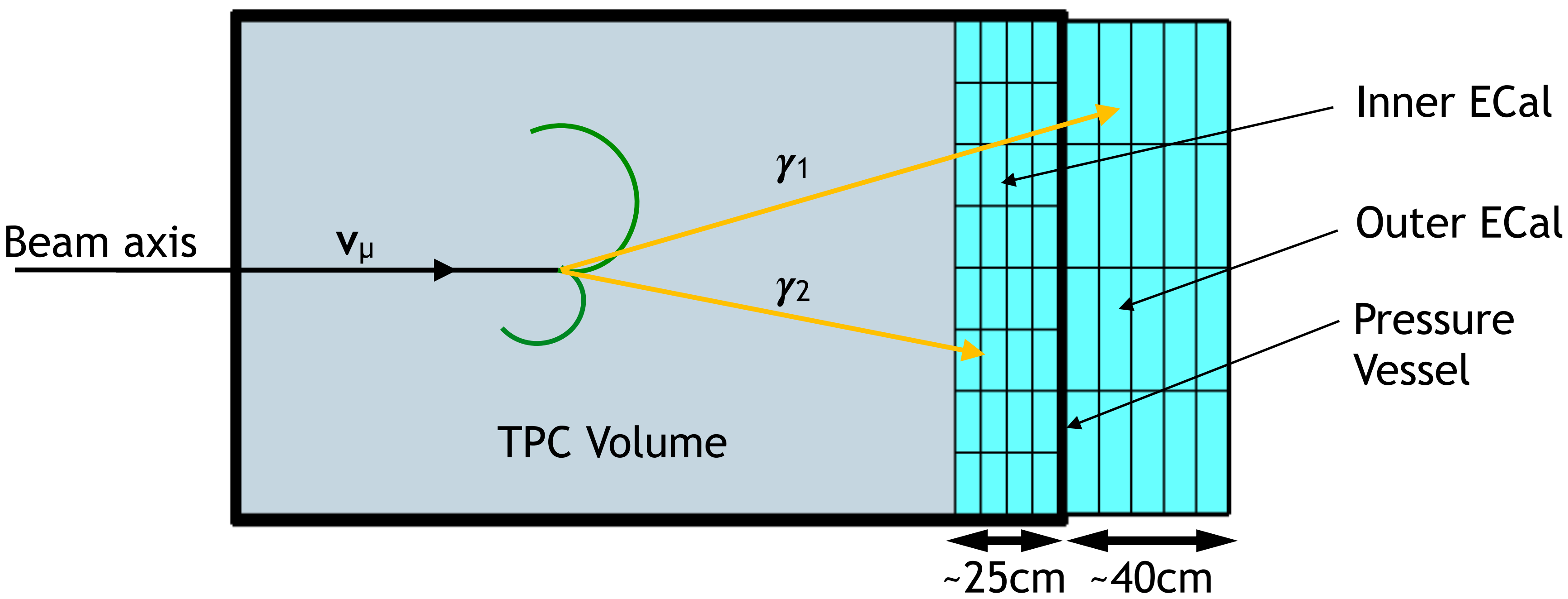


- Sampling calorimeter with active material segmented in 20mm x 20mm tiles (default)
- Default layer structure:
  - 1mm lead absorber
  - 5mm plastic scintillator
  - Gap for electronics
- SiPM readout

Detector Concept

Look at the scenario of a split ECal to instrument space in the TPC pressure vessel

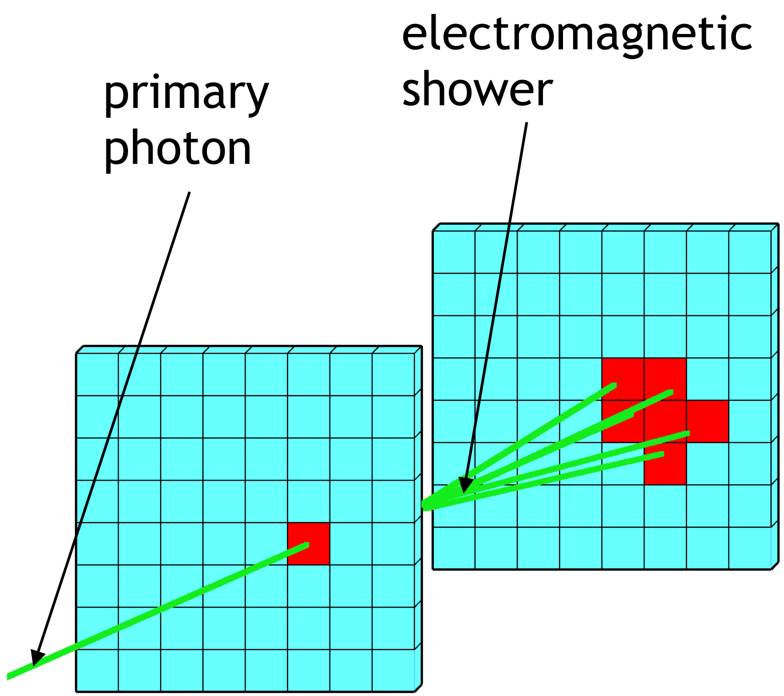
Possible vessel designs: 20mm Steel(~$1X_0$), 14mm Titan(~$0.4X_0$)



Inner ECal increases the chance to detect low energy photons

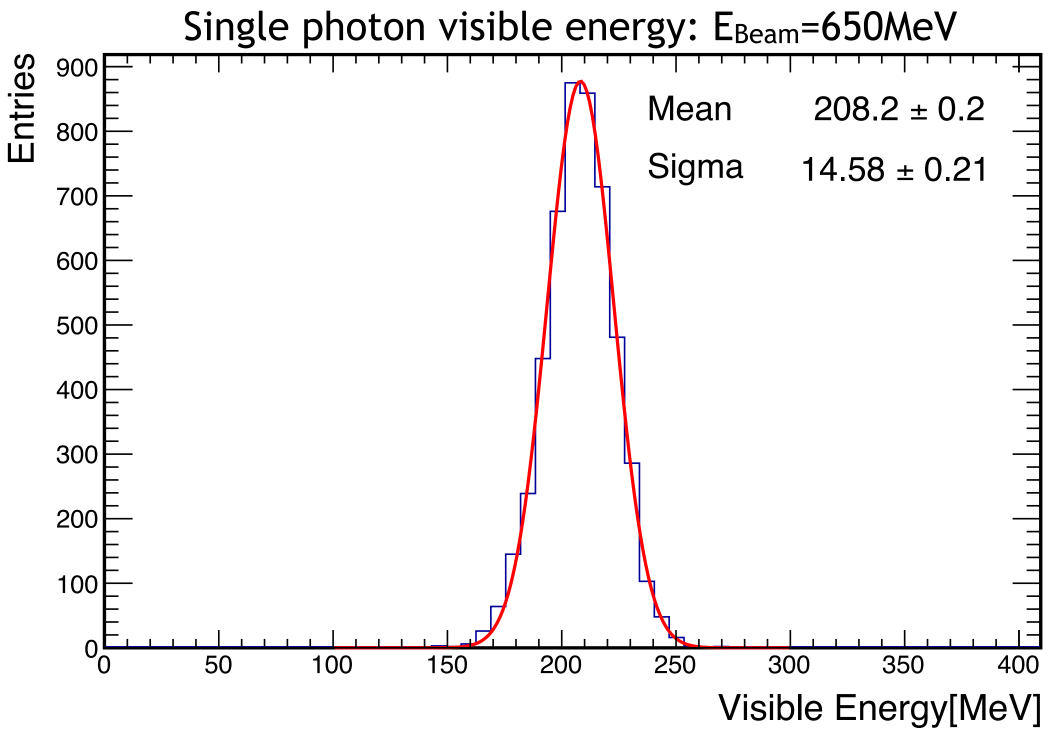
Simulation and Reconstruction

- Simulation is implemented in Geant 4.10.3
- Reconstruction:
  1. Apply 0.5 MIP energy cut and amplitude smearing to simulate readout noise
  2. Data preprocessing
  3. Calculate energy center of gravity in each layer
  4. Reconstruct direction with straight line fit of all centers of gravity
  5. Calculate angular and energy resolution
- In case of Pions:
  6. Use MC-truth to assign calorimeter cells to the photons from π^0 decay
  7. Reconstruct π^0 vertex



Energy and Angular Resolution

Energy resolution is an important parameter to compare different materials



1. Calculate energy sum over all channels per event
2. Plot sigma over mean for different energies

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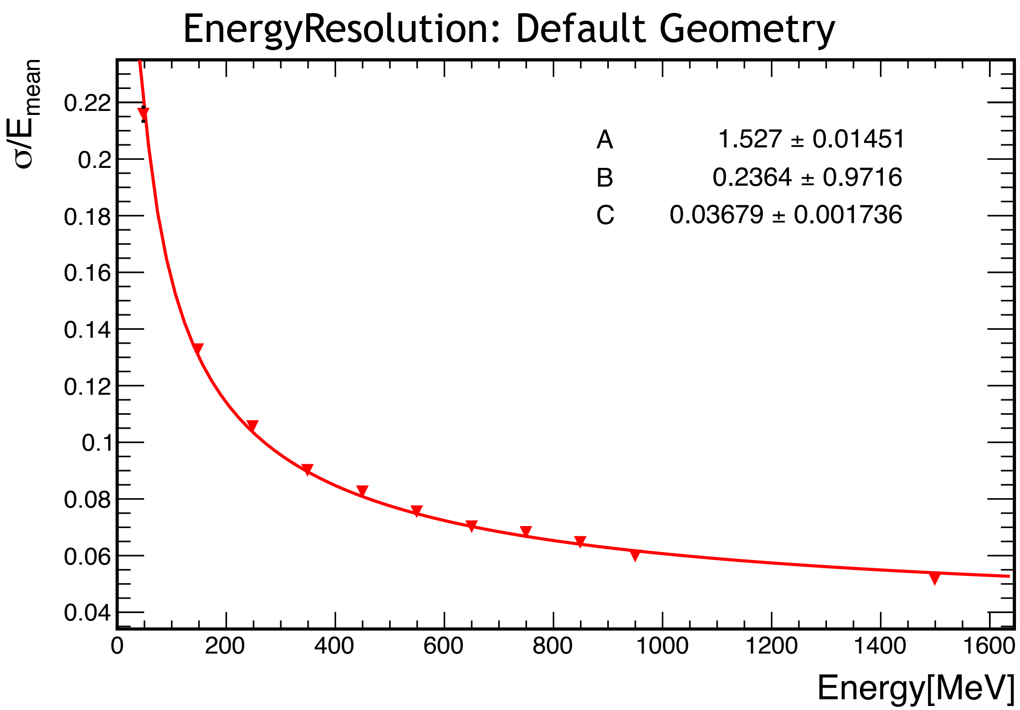


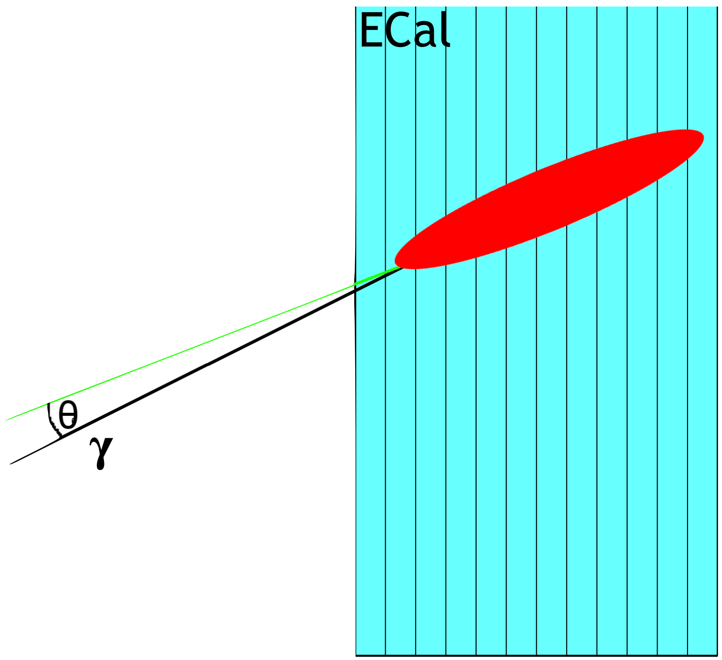
1. Calculate energy sum over all channels per event
2. Plot sigma over mean for different energies
3. Fit with

$$\frac{\sigma}{E_{mean}} = \sqrt{(\frac{A}{\sqrt{E}})^2 + (\frac{B}{E})^2 + (C)^2}$$

4.8% stochastic term, will get worse by simulating more readout/electronics

Energy and Angular Resolution

Angular resolution has direct impact on photon pointing



1. Find the distribution of the angle between true and reconstructed direction for every energy

Energy and Angular Resolution

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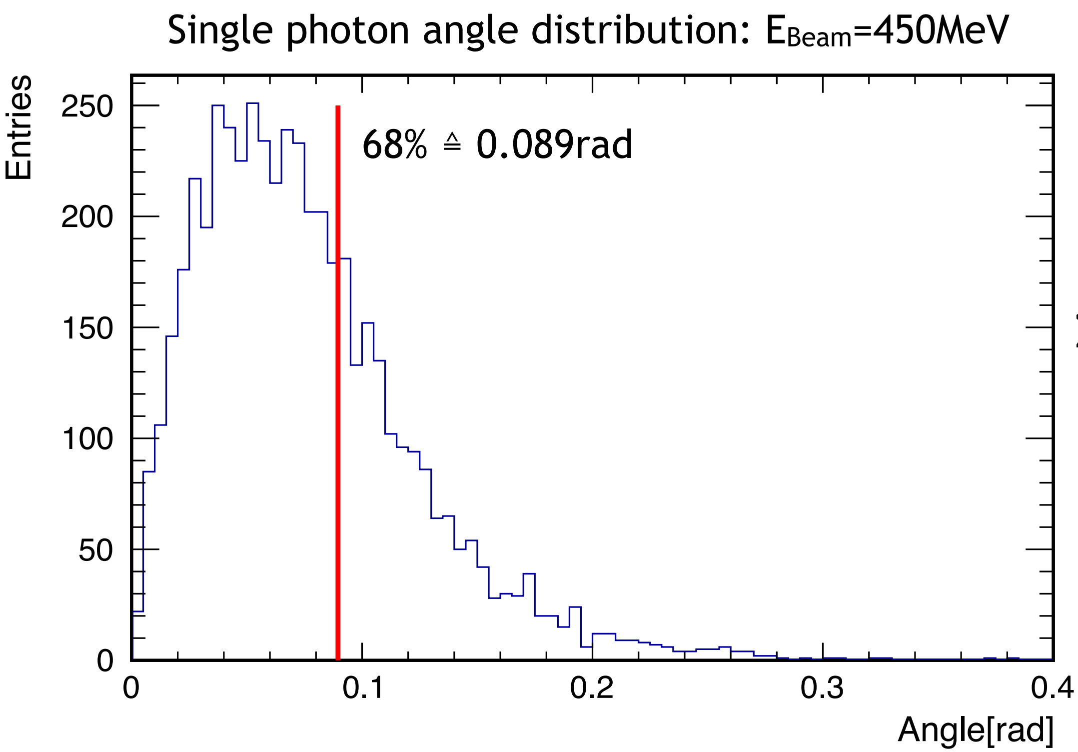

1. Find the distribution of the angle between true and reconstructed direction for every energy
2. Plot 68% integral for every energy

Energy and Angular Resolution

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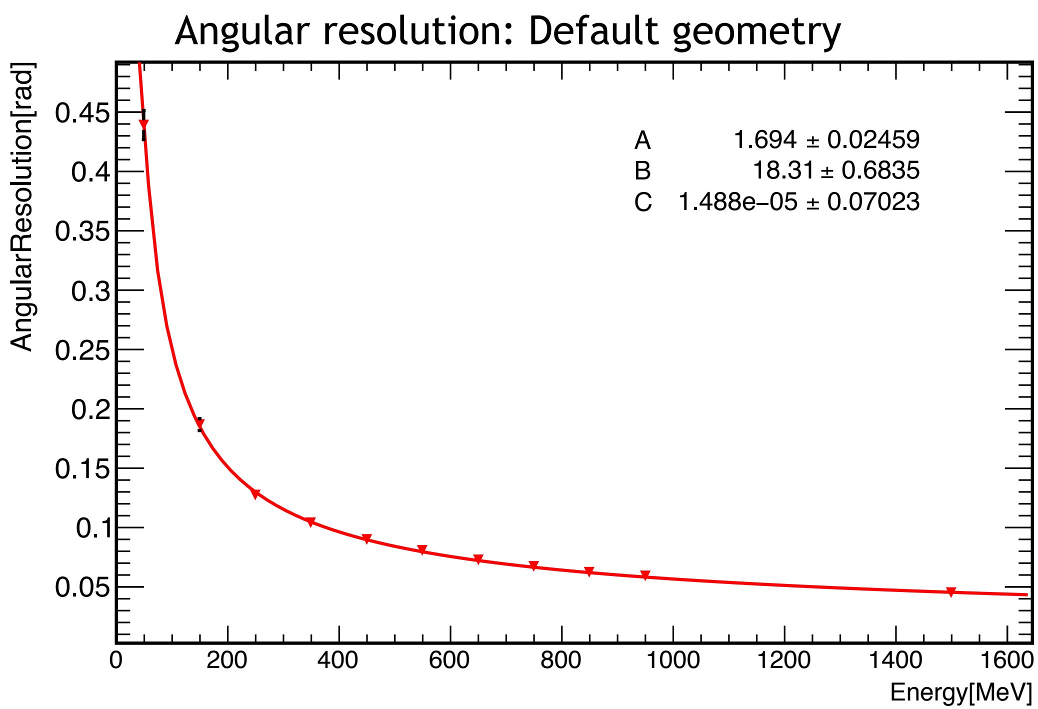


1. Find the distribution of the angle between true and reconstructed direction for every energy
2. Plot 68% integral for every energy
3. Fit with

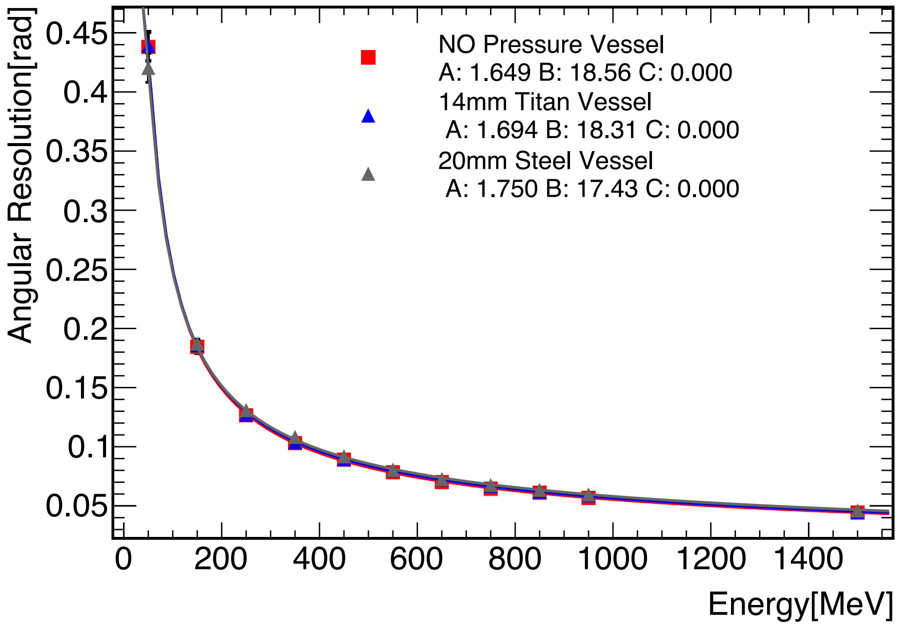
$$Resolution = \sqrt{(\frac{A}{\sqrt{E}})^2 + (\frac{B}{E})^2 + (C)^2}$$

Both resolutions are used to compare the performance of the calorimeter

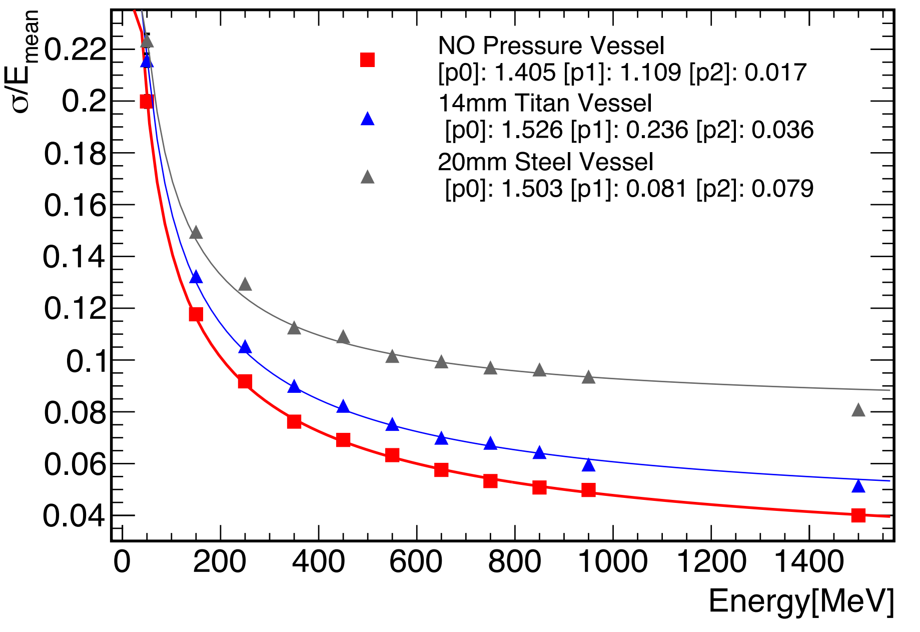
Influence of the Pressure Vessel

1mm lead absorber, Inner granularity: 20mm, Outer granularity: 40mm

Angular resolution



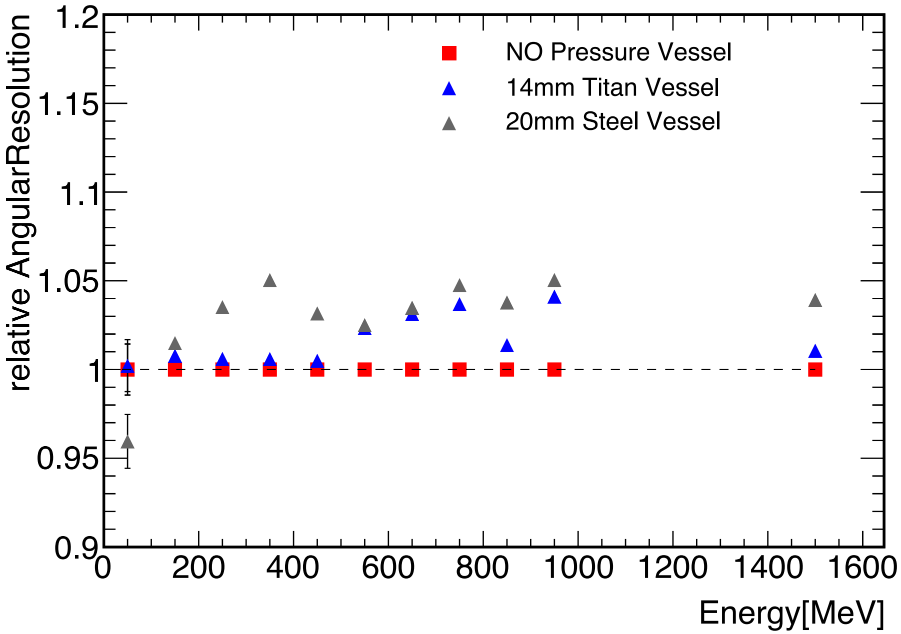
Energy resolution



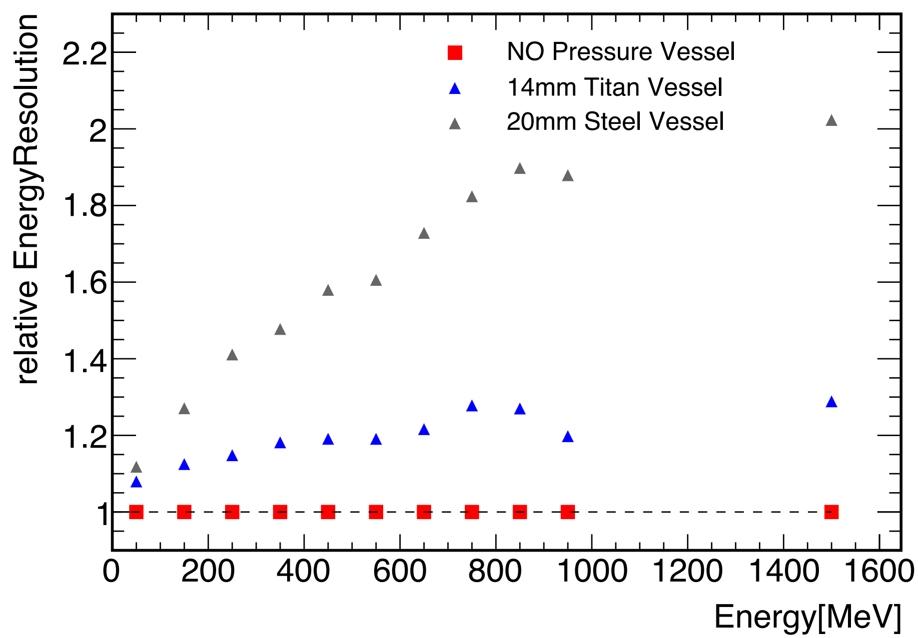
Influence of the Pressure Vessel

1mm Lead absorber, Inner granularity: 20mm, Outer granularity: 40mm

Relative angular resolution



Relative energy resolution

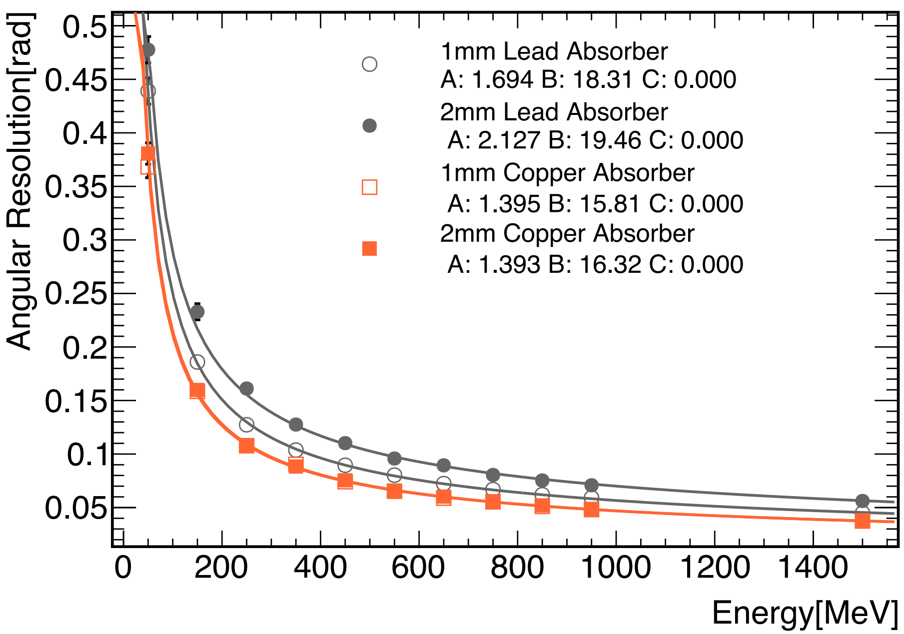


Conclusion: Thin titanium pressure vessel yields better results

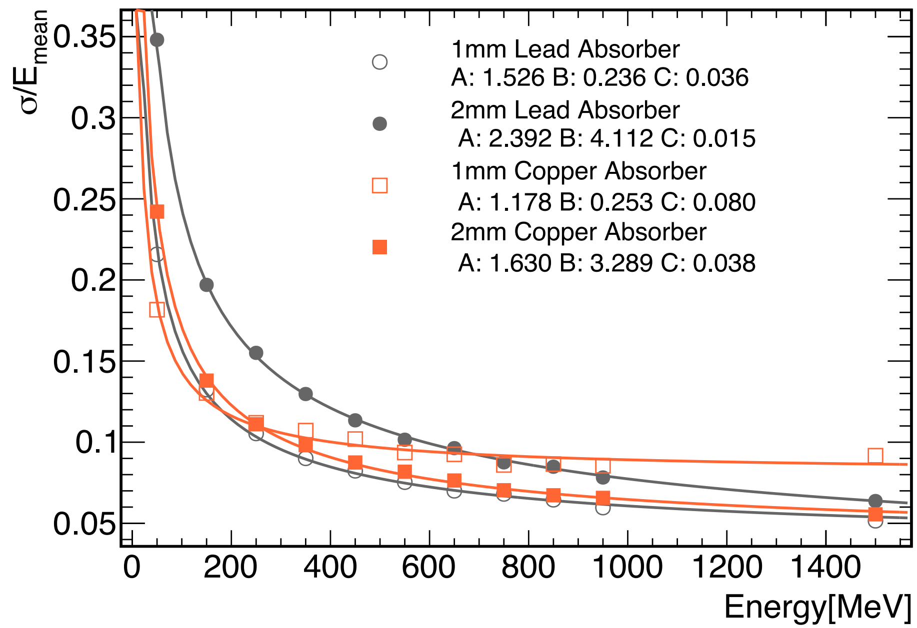
Influence of the Absorber

Inner granularity: 20mm, Outer granularity: 40mm, 14mm titanium vessel

Angular resolution



Energy resolution



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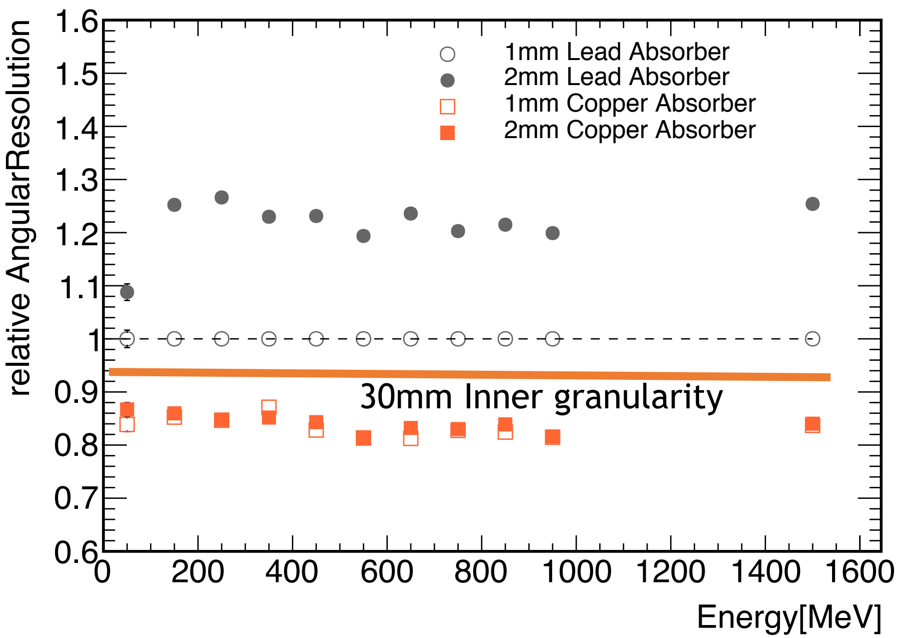
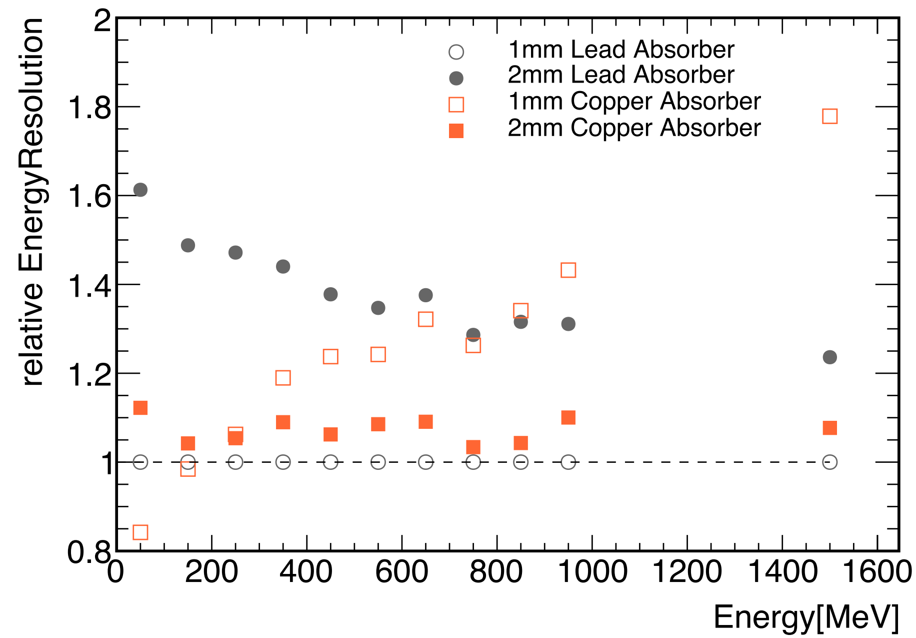


Relative energy resolution

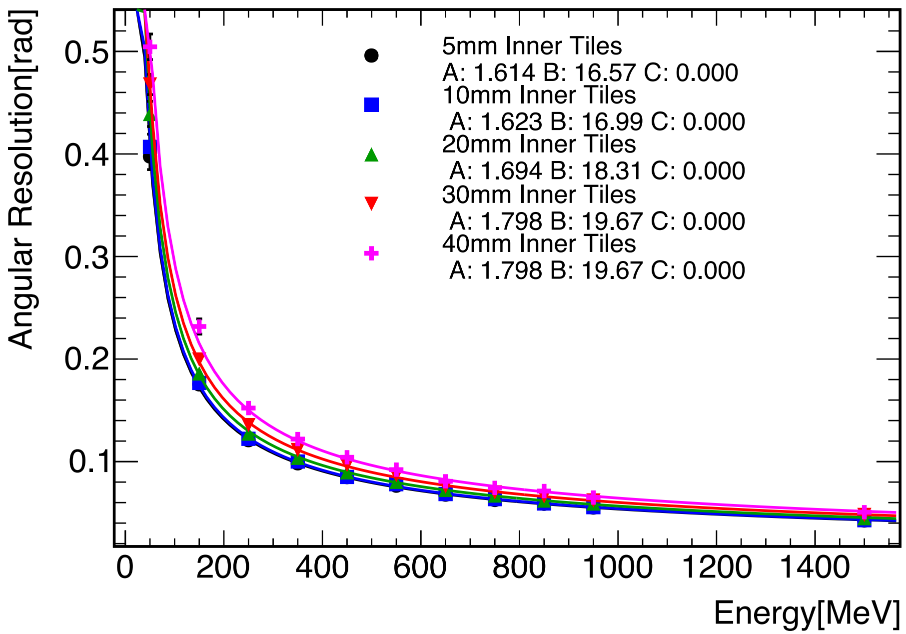


Conclusion: Copper yields better angular resolution, but 1mm copper is leaking very much energy

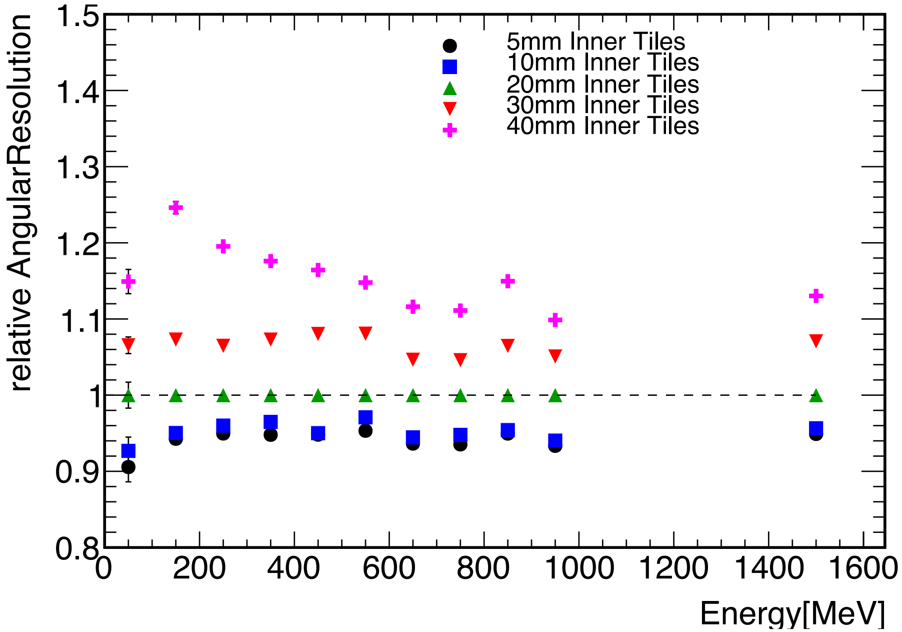
Influence of Inner Granularity

1mm Lead absorber, Outer Granularity: 40mm, 14mm Titanium vessel

Angular resolution



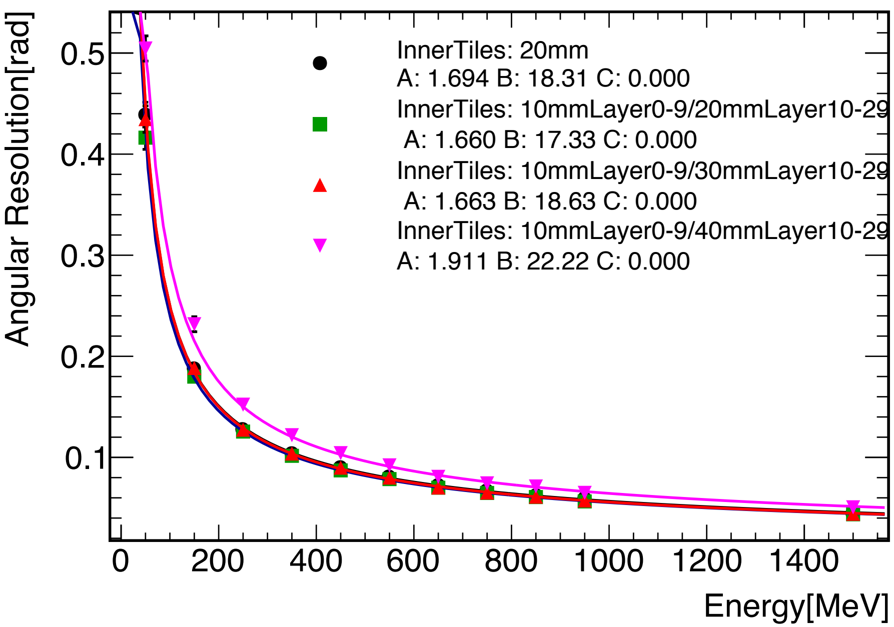
Relative angular resolution



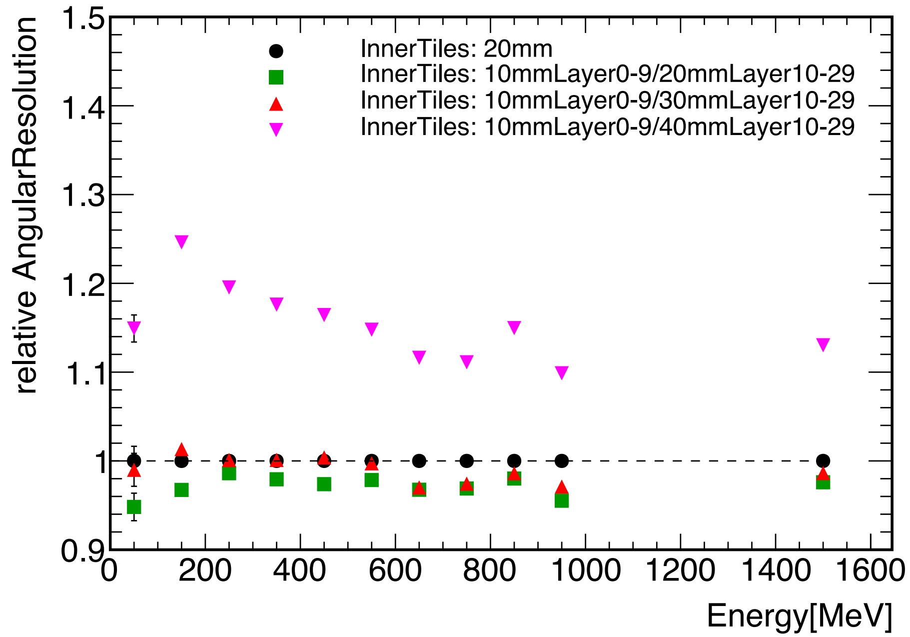
Influence of Inner Granularity

1mm Lead absorber, Outer Granularity: 40mm, 14mm Titanium vessel

Angular resolution

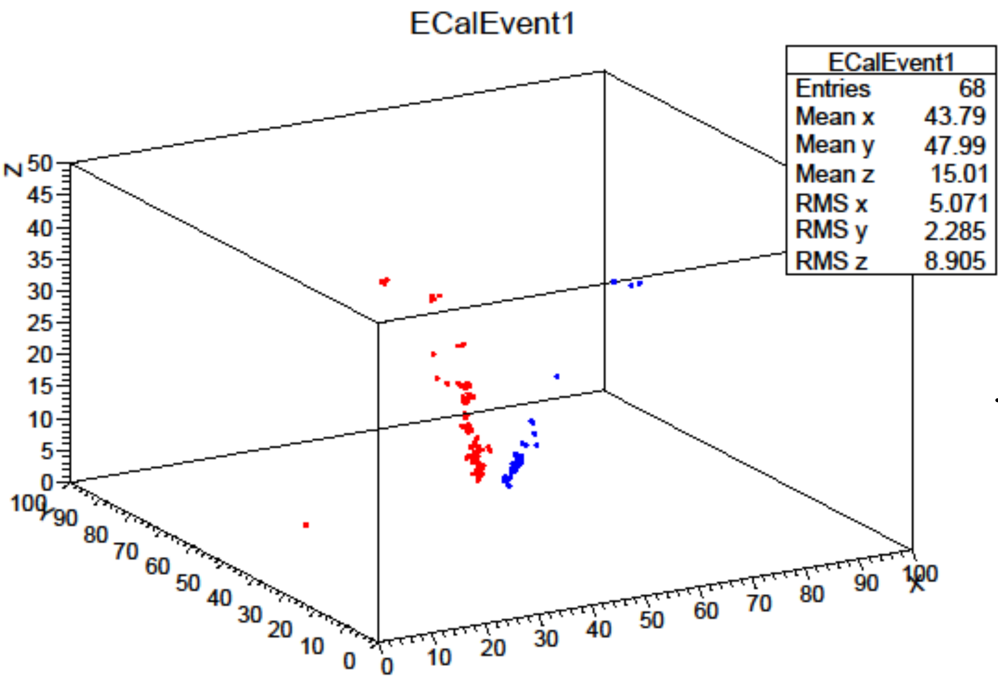


Relative angular resolution

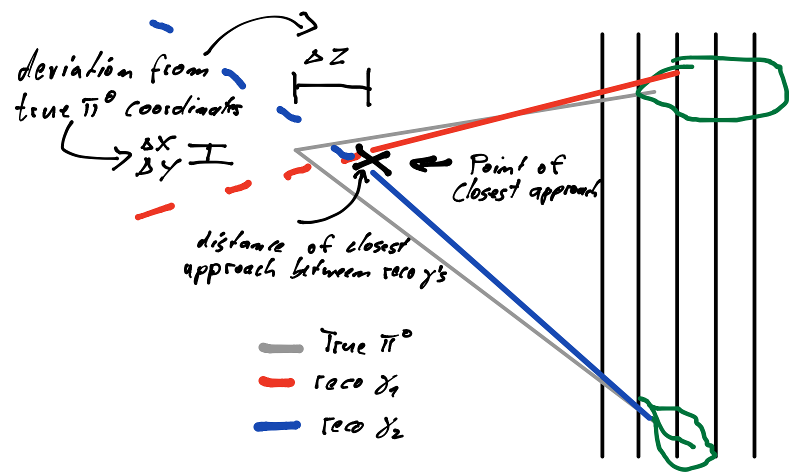


Conclusion: Granularity in first few X_0 has a major influence on overall angular resolution

Pion Reconstruction

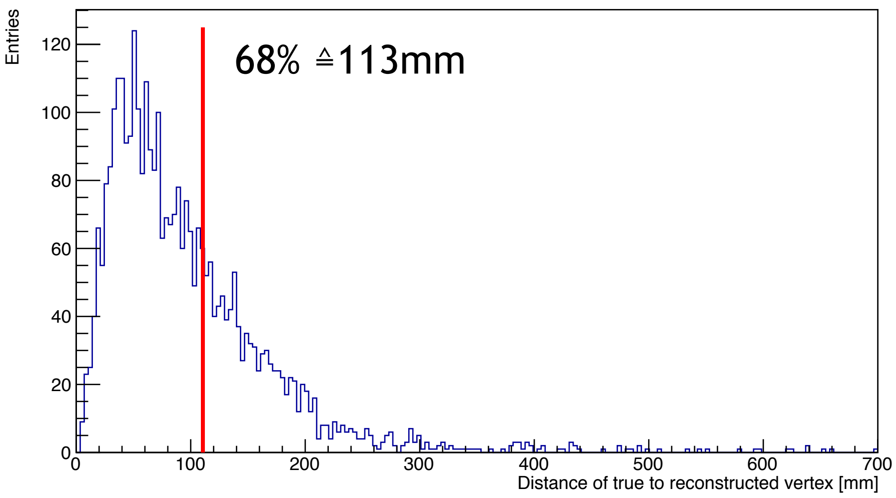


- Distinguish photon1 from photon2 by MC truth



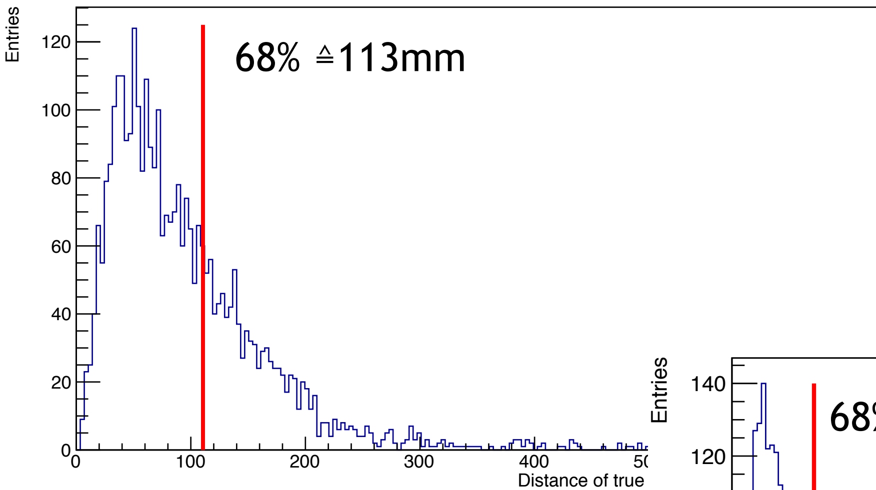
- Take point of closest approach of the reconstructed tracks as decay vertex

Pion Reconstruction



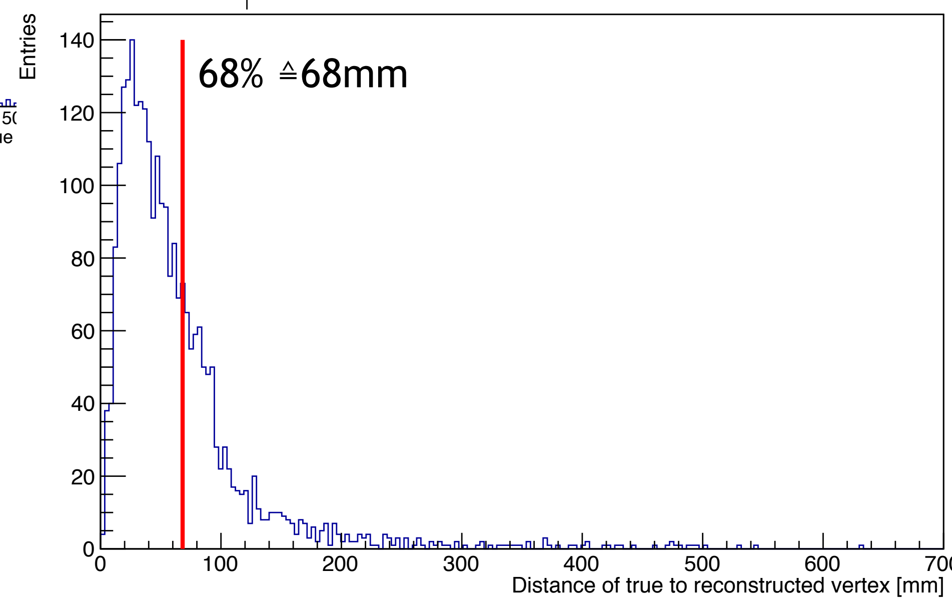
- 450MeV
- 1mm lead absorber
- Inner granularity 20mm, outer granularity 40mm

Pion Reconstruction



- 450MeV
- 1mm lead absorber
- Inner granularity 20mm, outer granularity 40mm

- 450MeV
- 2mm copper absorber
- Inner granularity 20mm, outer granularity 40mm



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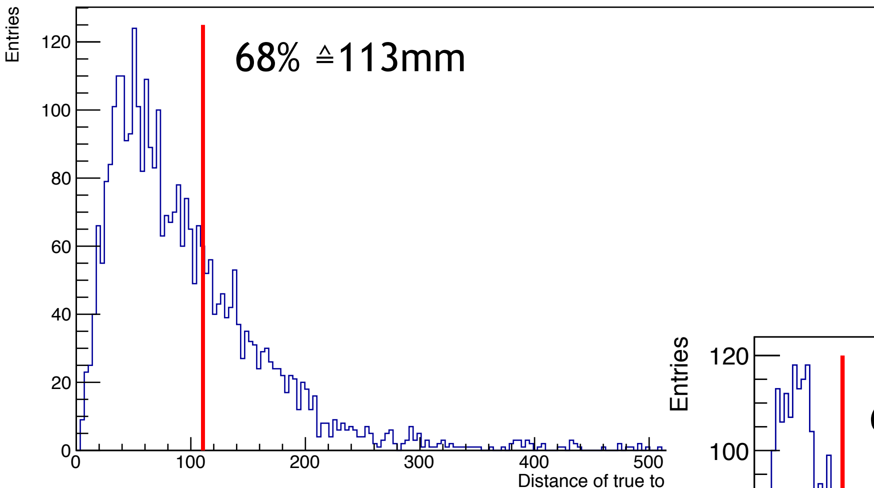
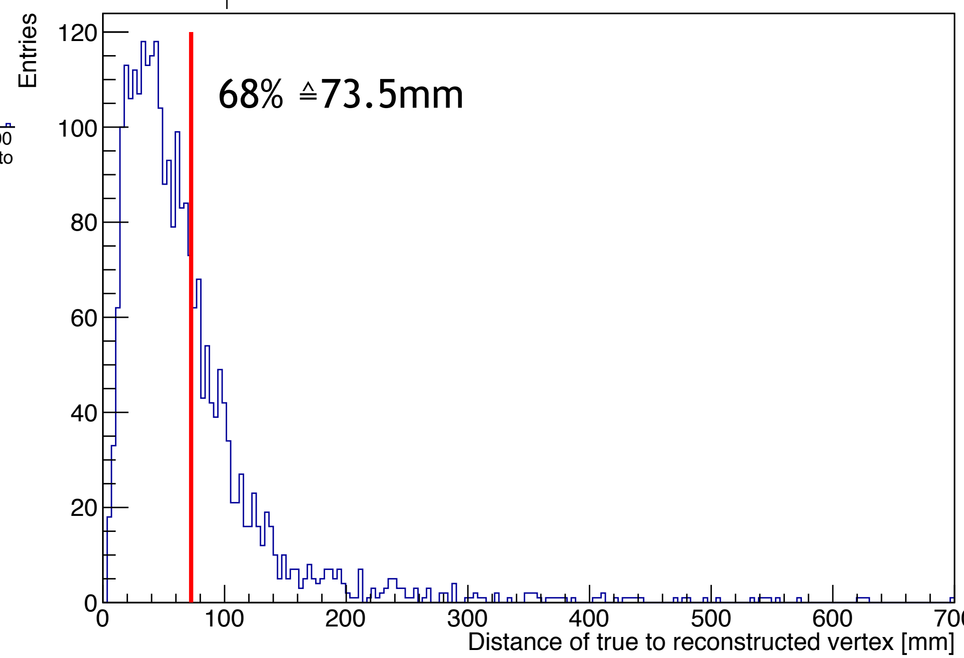


- 450MeV
- 1mm lead absorber
- Inner granularity 20mm, outer granularity 40mm

- 450MeV
- 2mm copper absorber
- Inner granularity 30mm, outer granularity 40mm



Hardware Studies

Several tiles with projective fiber readout ready/in production at the MPP

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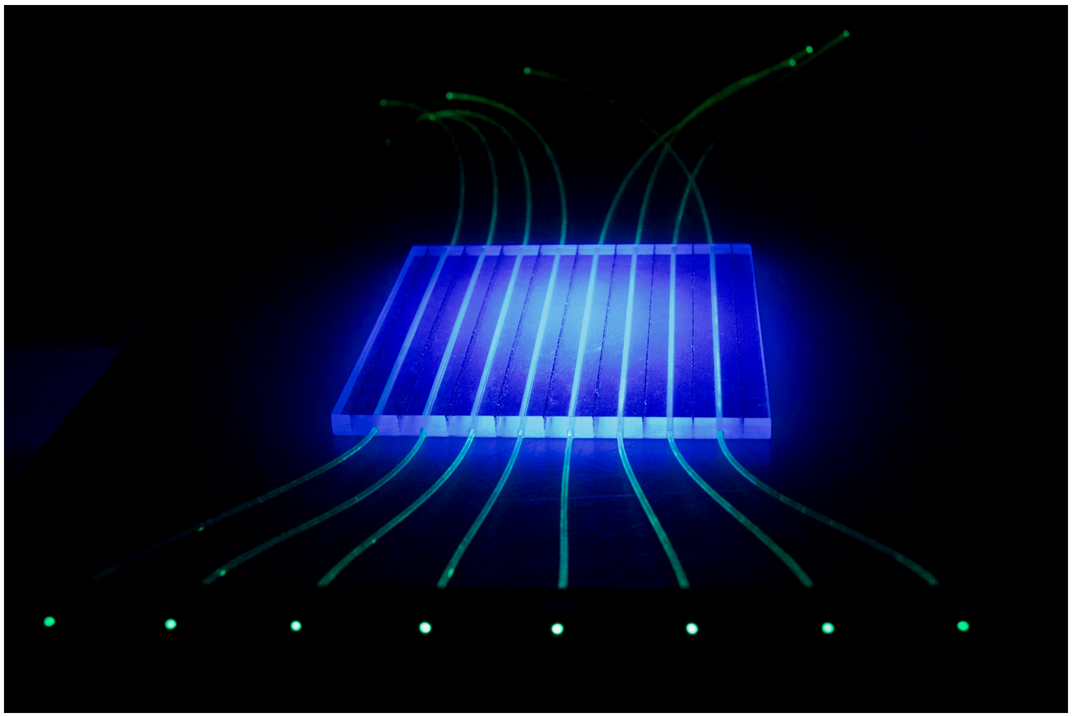
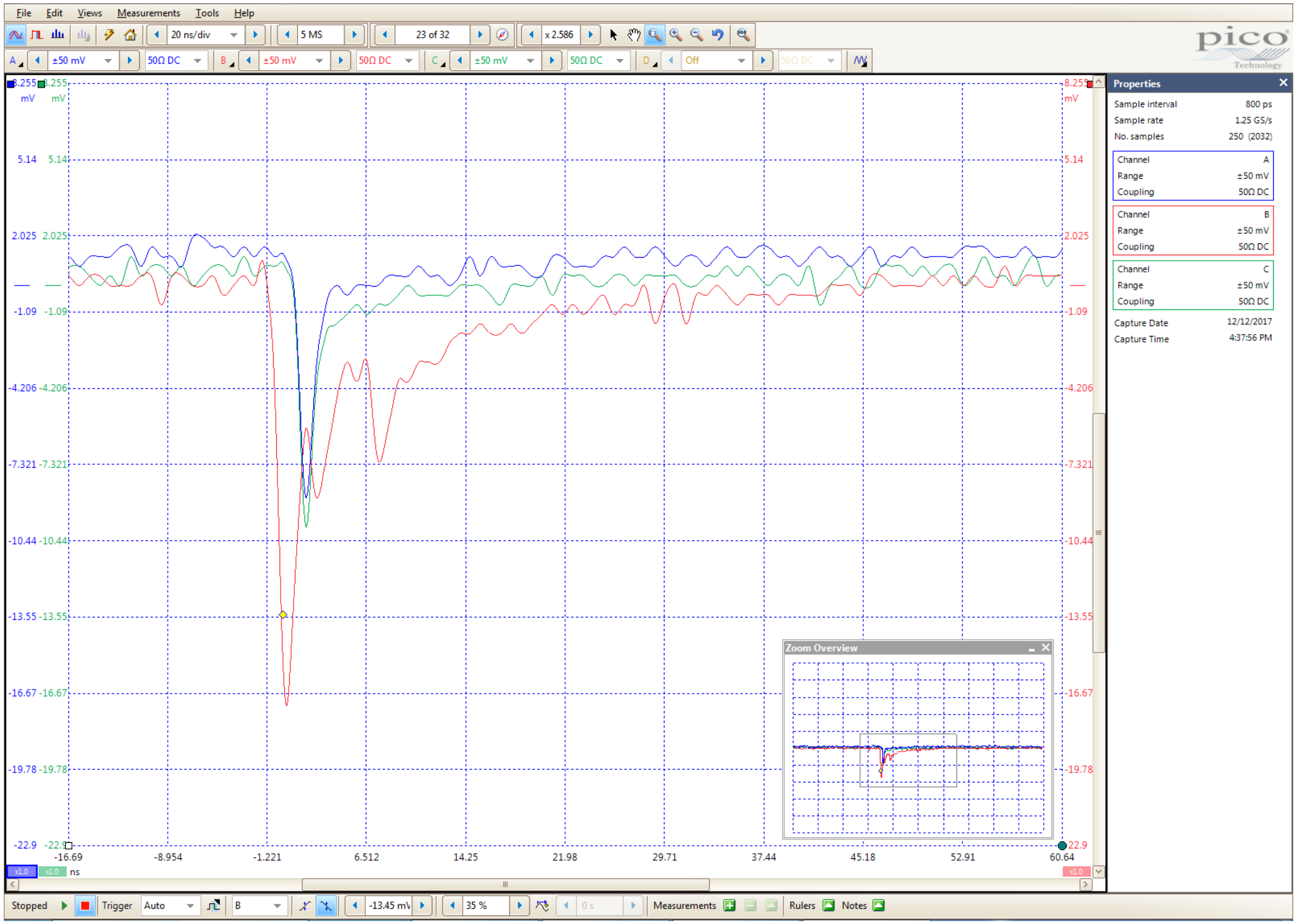


- 90x90x5mm scintillator Tile
- 8 fibers separated by 10mm
- Sub surface laser engraved optical barriers to separate channels
- SiPM readout for every fibre

Try to achieve higher granularity with crossed strip geometry

Hardware Studies



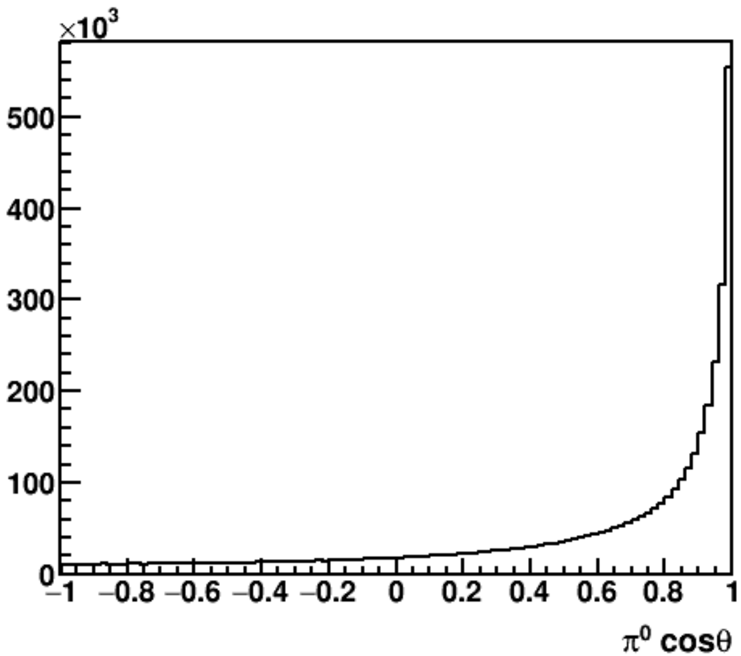
- Source on top of Channel 2
- Direct Neighbours:
  - Channel 1
  - Channel 3

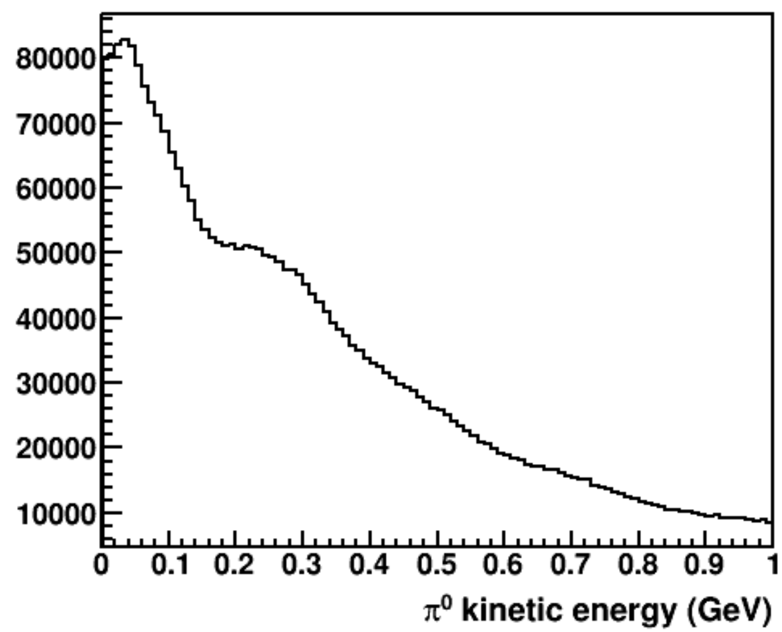
Summary and Outlook

- Pressure vessel worsens energy resolution in general
  - 14mm Titanium has less negative impact than 20mm Steel
- Absorber material influences angular and energy resolution
  - Copper is better than lead
- Granularity in first few X_0 influences overall angular resolution
- Pion reconstruction can be improved with information on angular and energy resolution
- Hardware studies continue at MPP

Backup

Pi0 Distribution





plots curtesy of Chris Marshall

30mm Inner Tiles, 2mmCopper