Studies of Highly Granular Calorimeters in Long Baseline Neutrino Near Detectors:

Simulation and Scintillator Tile Studies

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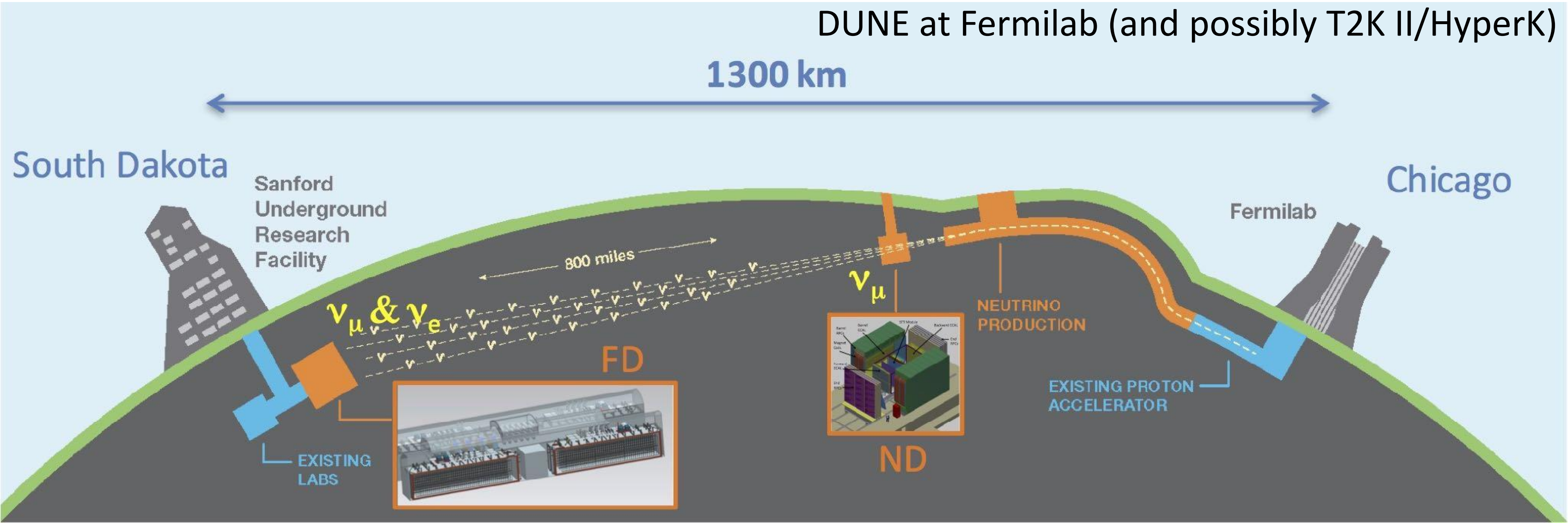
Introduction

- Long Baseline Neutrino experiments target the precise study of neutrino mixing, including the potential discovery of CP violation



Far Detector: measures neutrinos after oscillation, would see evidence for CP violation in ν_e / anti-ν_e appearance

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

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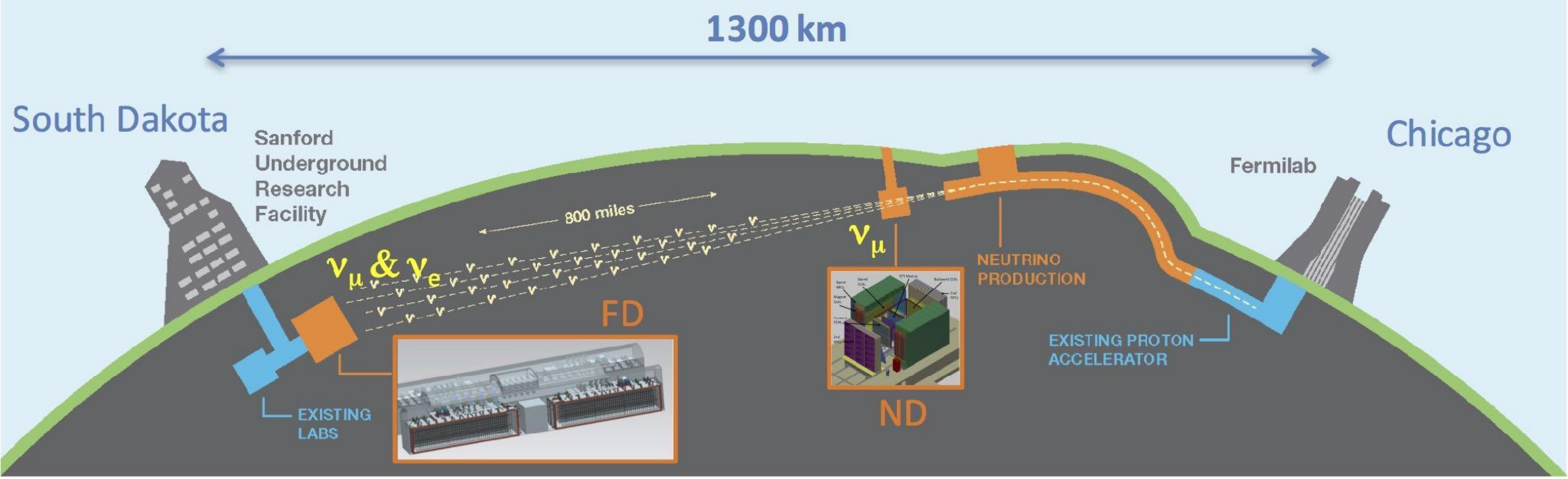
DUNE at Fermilab (and possibly T2K II/HyperK)

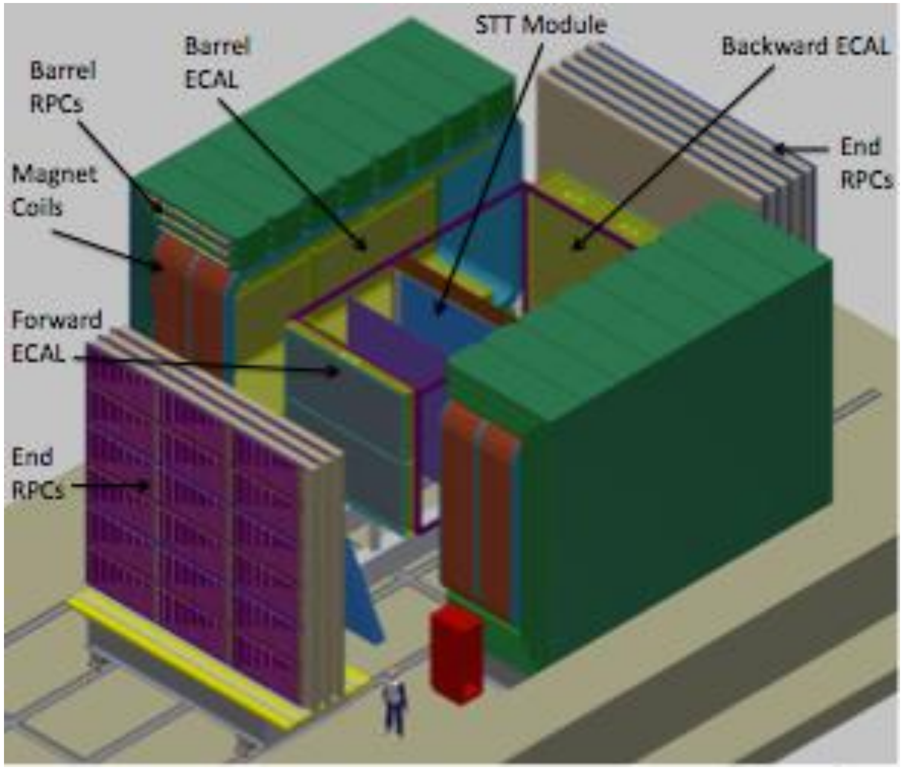


Far Detector: measures neutrinos after oscillation, would see evidence for CP violation in ν_e / anti-ν_e appearance

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

Near Detector ECal

- Near detector systems typically complex systems with various subdetectors - among them **electromagnetic calorimeters**



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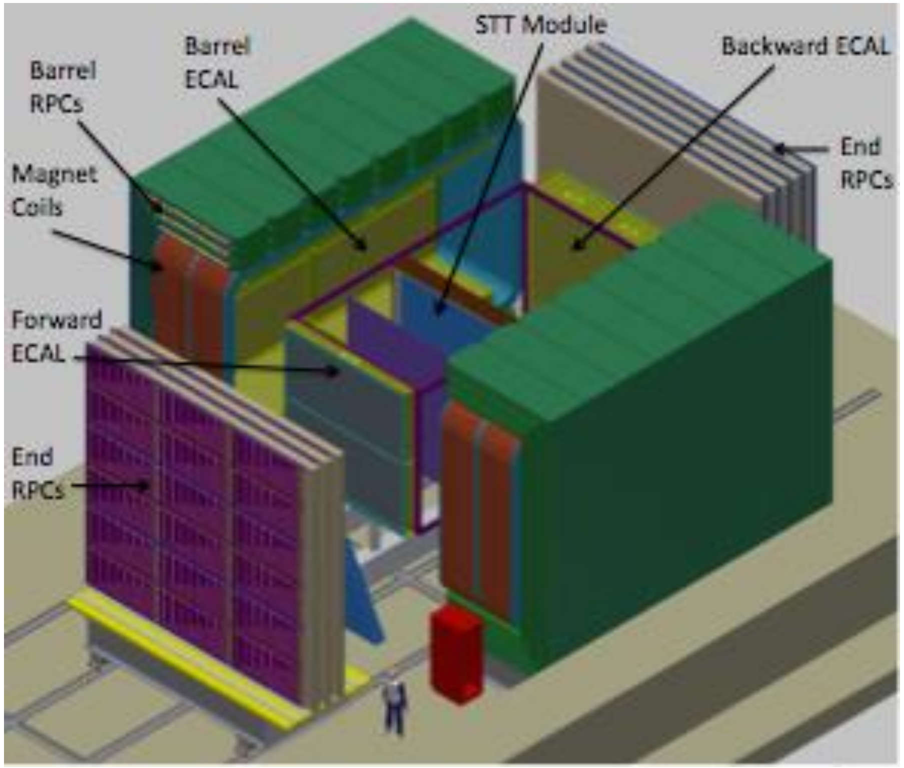

- Primary goal of the ECAL: identify π^0 produced in neutrino interactions
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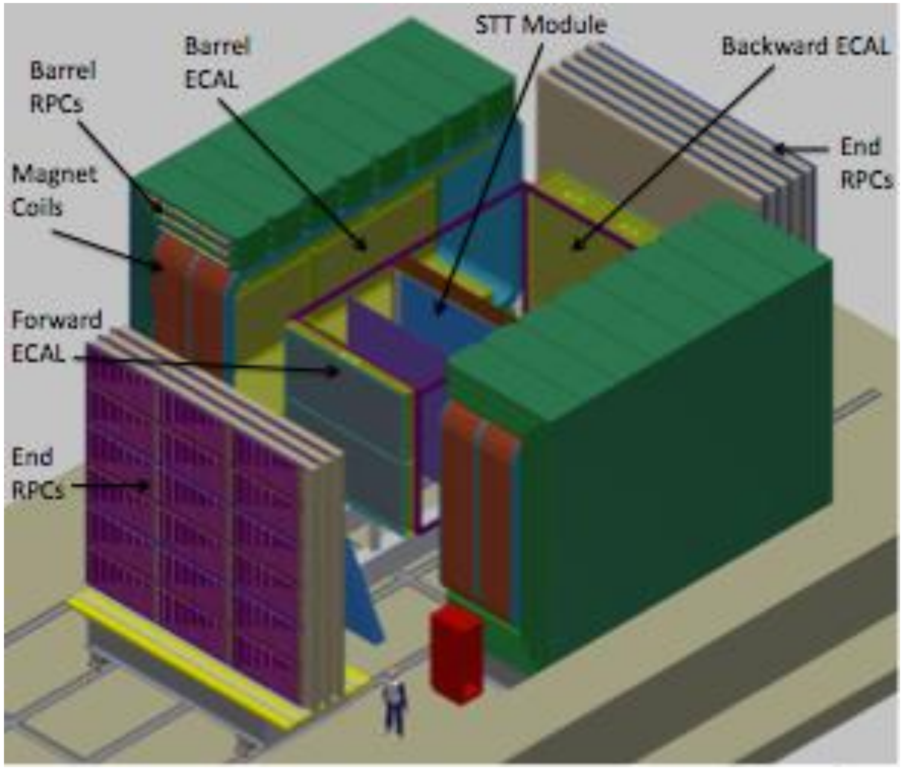
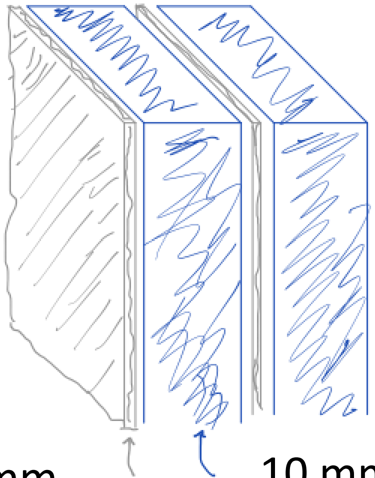


- Primary goal of the ECAL: identify π^0 produced in neutrino interactions
  - particularly important: Understanding of π^0 production in neutral current interactions - such events may fake signal in far detector
- Our interest: can high granularity help?
  - for example in the location of the point of origin of π^0?
- The challenge: Typical energies are low: π^0 with a few 100 MeV kinetic energy - deal with photons as low as 50 MeV

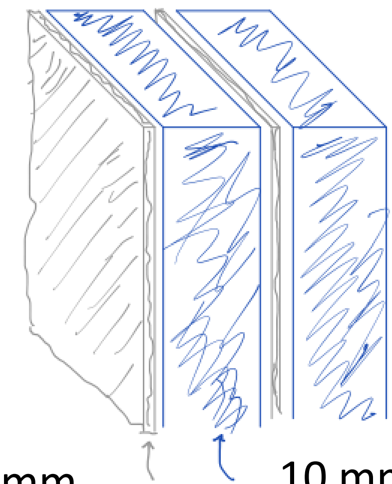
Detector Concept



1mm
lead absorber

10 mm
plastic scintillator

Detector Concept



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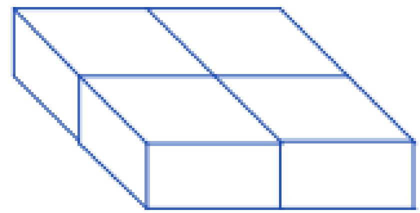

- Active material is segmented in tiles (10mm x 10mm)

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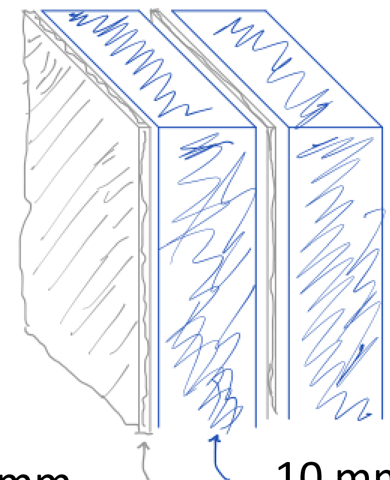

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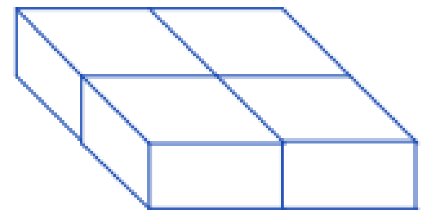

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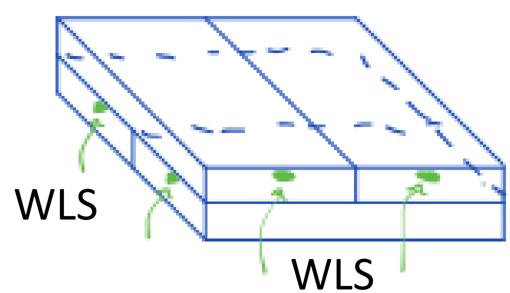
- **More realistic:**
  Orthogonal scintillator strips with WLS and SiPM readout

- R&D starting at MPP



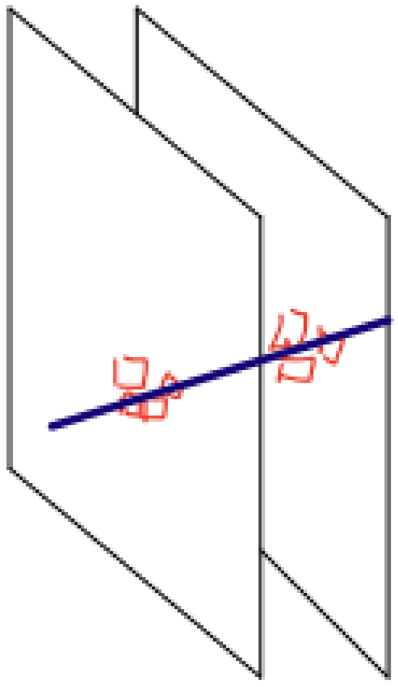
Simulation and Reconstruction

Detector implementation in Geant 4.10.03:

- Currently 50 layers simulated
- Layer structure:
  1 mm lead
  10 mm scintillator
  10 x 10 mm^2 granularity, using a Sensitive Detector

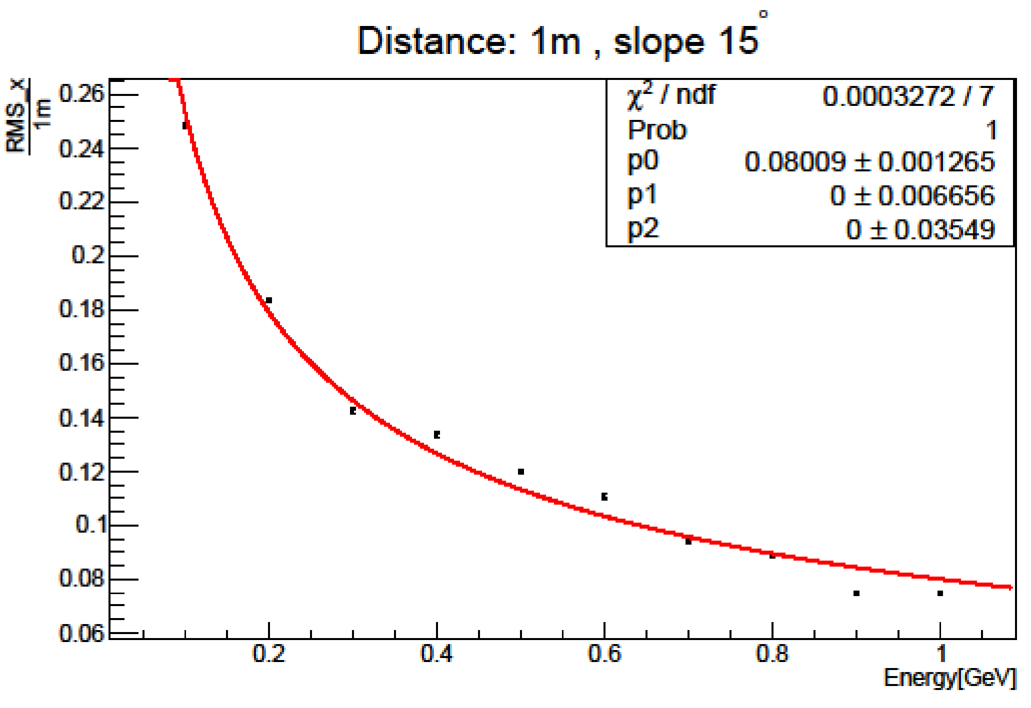
Reconstruction:

- Simplified
- Using Monte Carlo truth information to assign cells to photons in π^0 –Reconstruction
- Calculation of 2D center of gravity for each layer
- Straight line fit through COGs weighted by energy deposit



Single Photon-Angular Resolution

- Determination of angular resolution is necessary for pion vertex reconstruction



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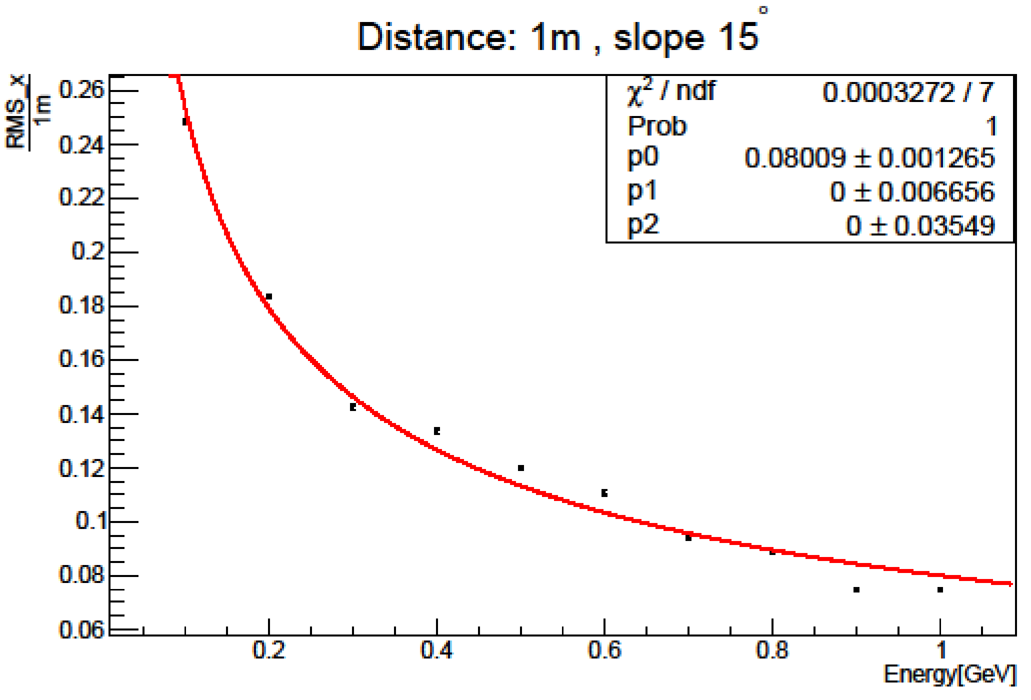

- Extrapolation of the photon track to a plane 1m from the calorimeter front face
- Plot the RMS of the resulting spatial distribution for different energies
- Fit $\frac{\sigma_{RMS}}{E} = \sqrt{\left(\frac{p0}{\sqrt{E}}\right)^2 + \left(\frac{p1}{E}\right)^2 + (p2)^2}$

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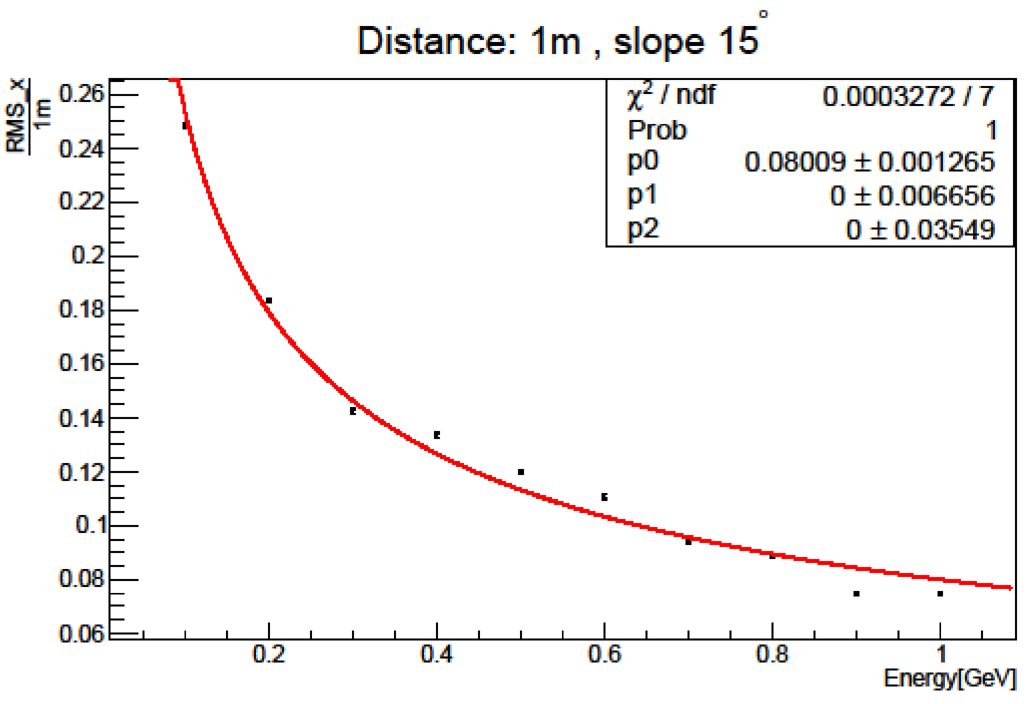

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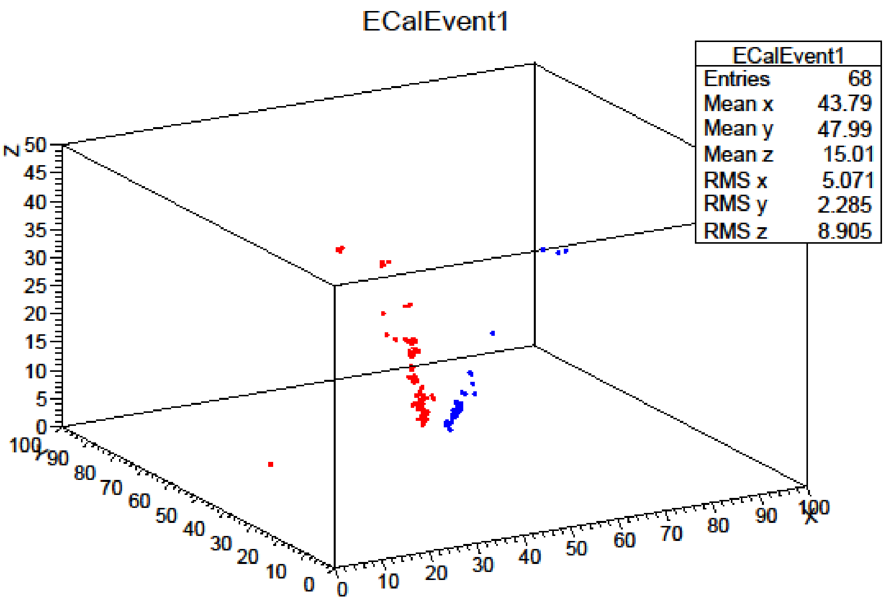
- Resulting resolution is independent of simulated inclination
- Noise and constant term are 0, because no noise or readout is simulated

Single Pion Event



300 MeV Pion event

- Distinguish photon1 from photon2 by MC truth

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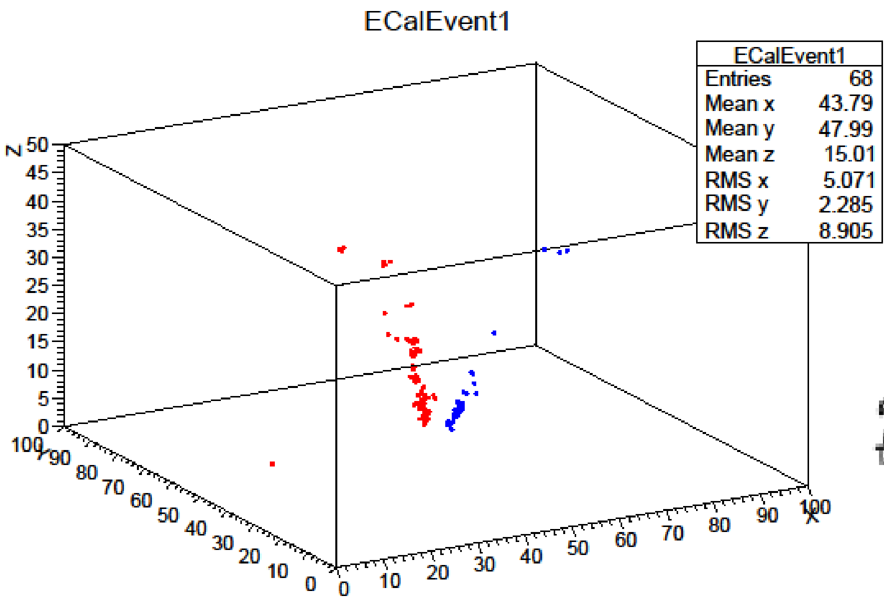

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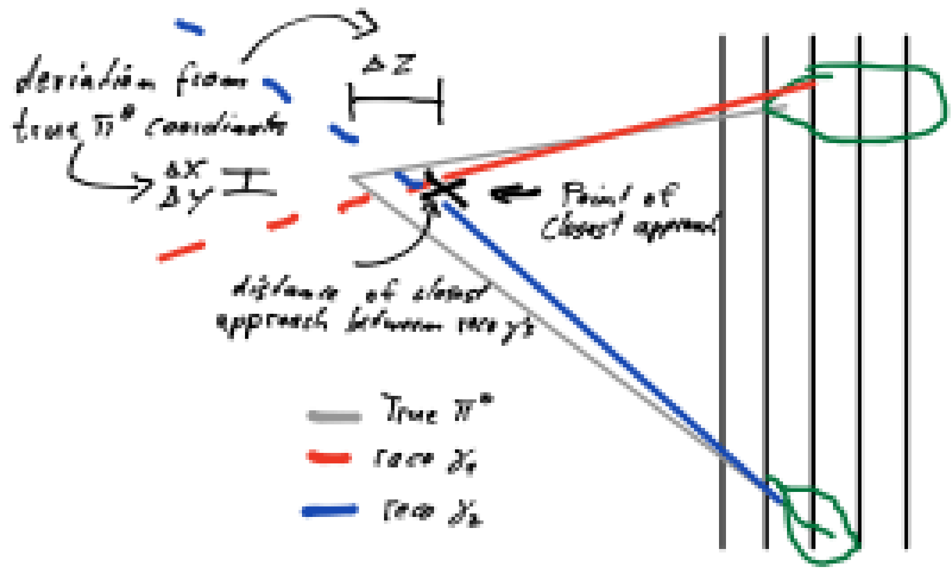
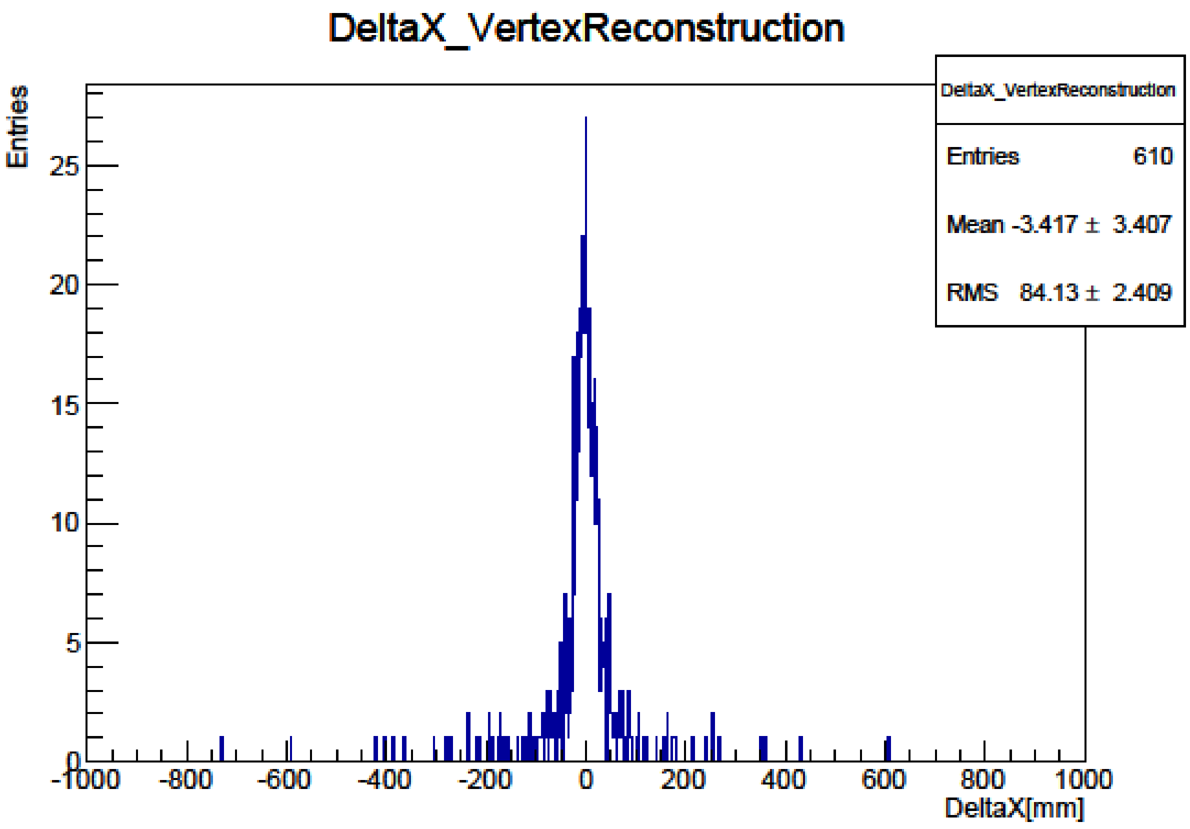


- Take point of closest approach of the reconstructed tracks as decay vertex

Pion Reconstruction

- Plot difference between true vertex coordinates and reconstructed coordinates
- Pion propagates in Z direction



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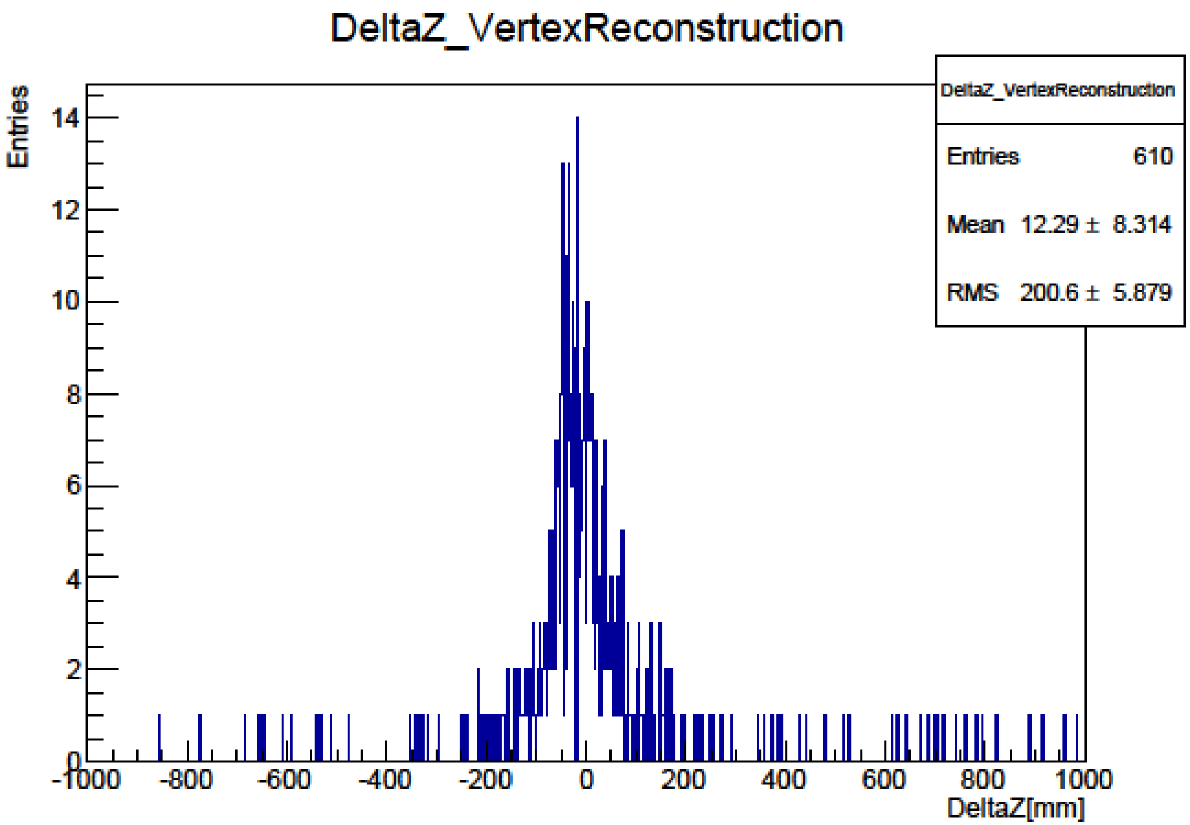

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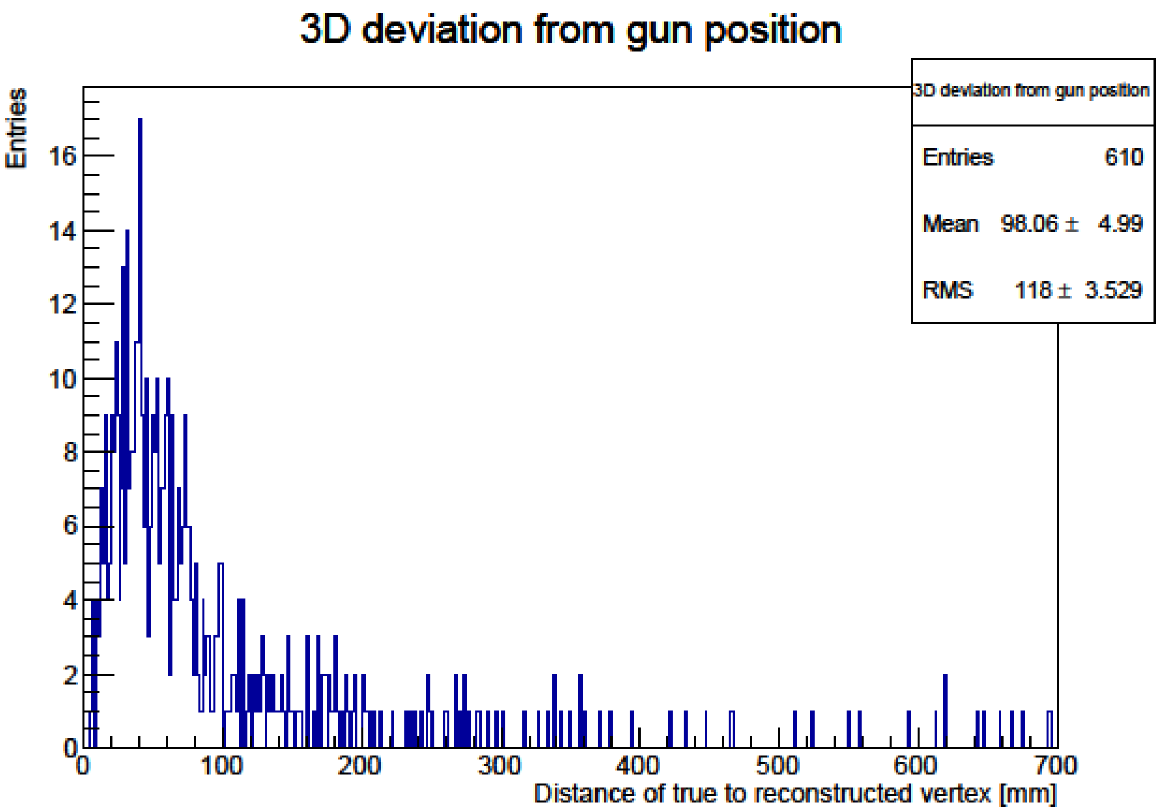
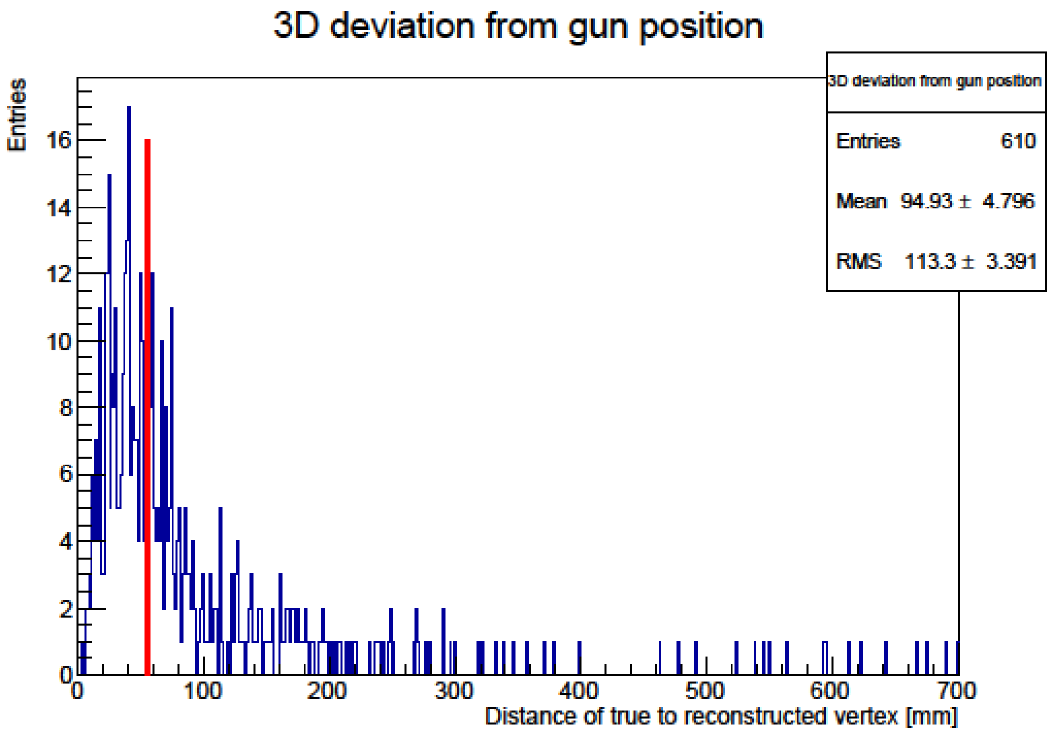


- Reconstruction in Z direction (pion direction) worse than X and Y direction

- Spatial deviation from true vertex has a long tail

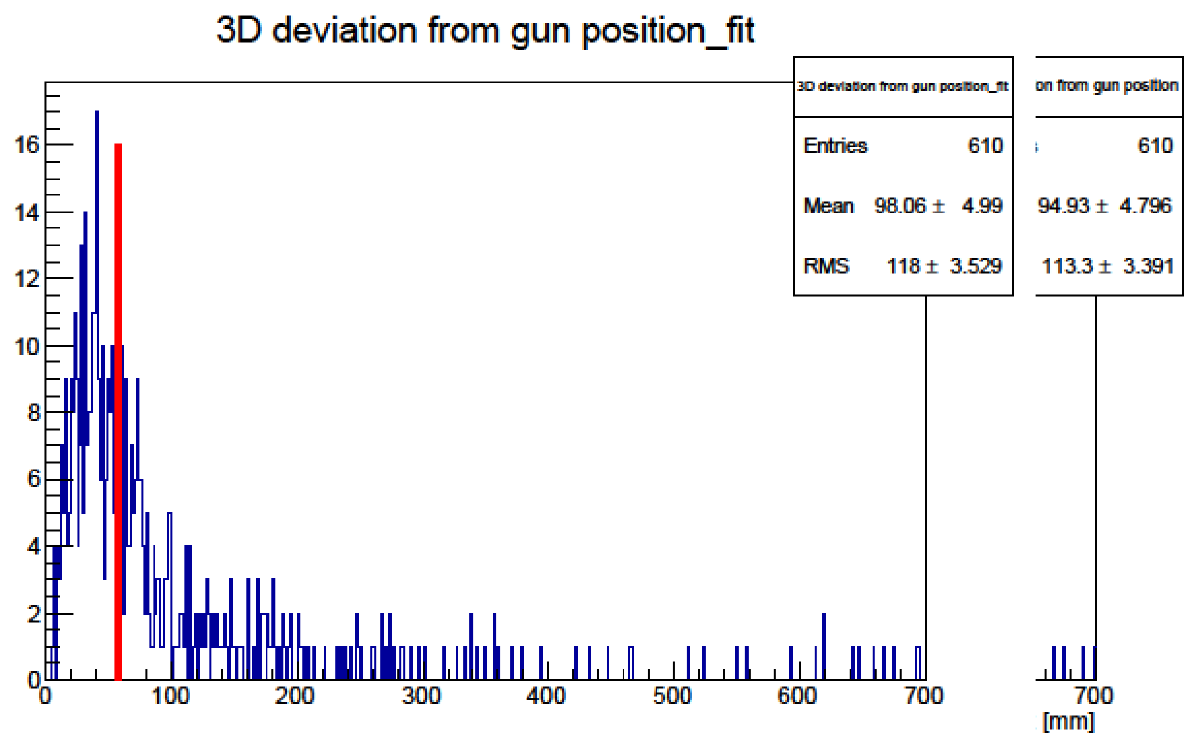
Pion Reconstruction

- Try to enhance the vertex reconstruction
- Take 3D vertex position as parameter for minimization
- Try to minimize the distance of the vertex to the reconstructed tracks

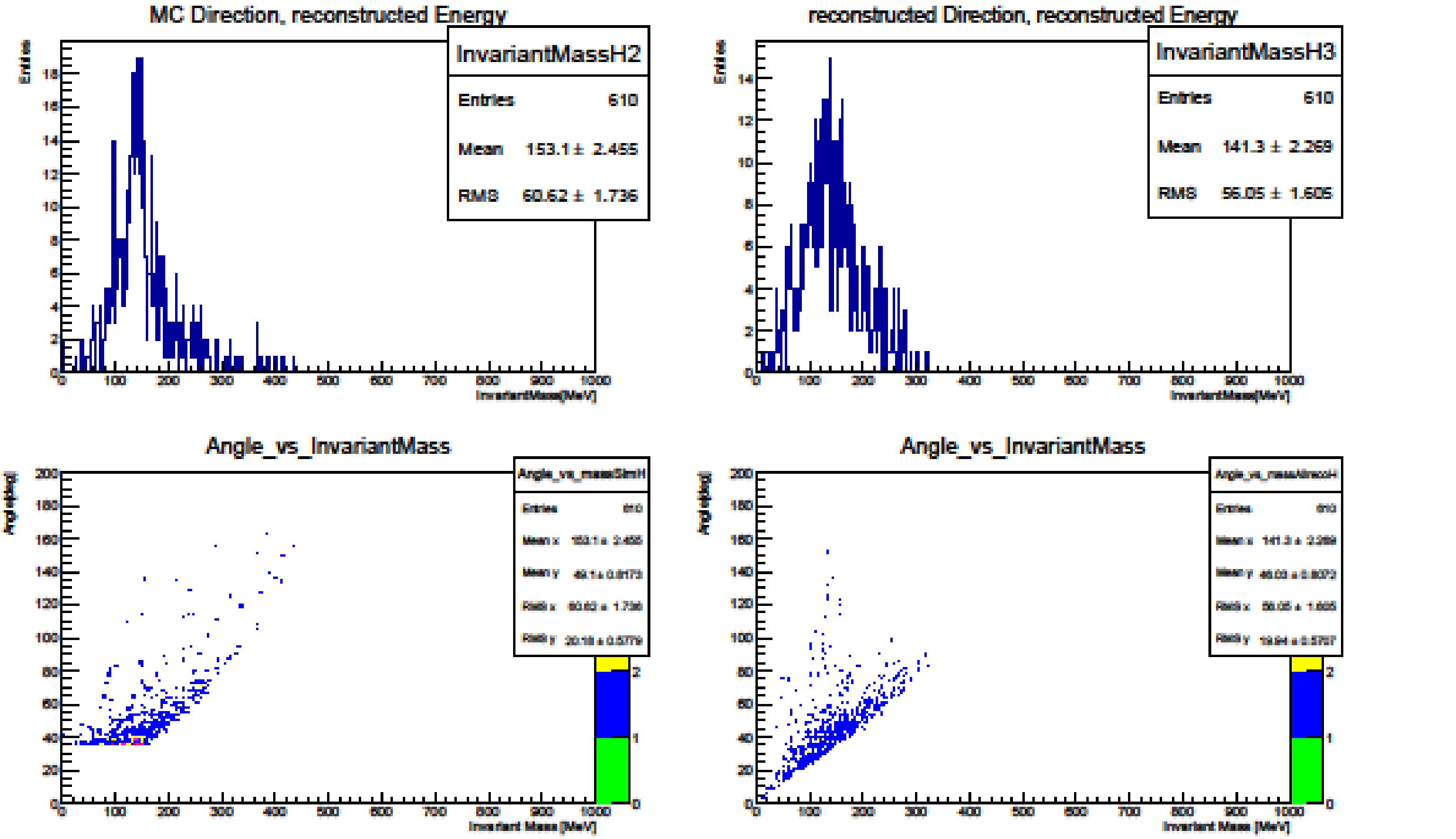


Pion Reconstruction

- Try to enhance the vertex reconstruction
- Take 3D vertex position as parameter for minimization
- Try to minimize the distance of the vertex to the reconstructed tracks
- Result: no significant difference



Invariant Mass Reconstruction



- Take Invariant mass information to further enhance the vertex reconstruction

Next Steps

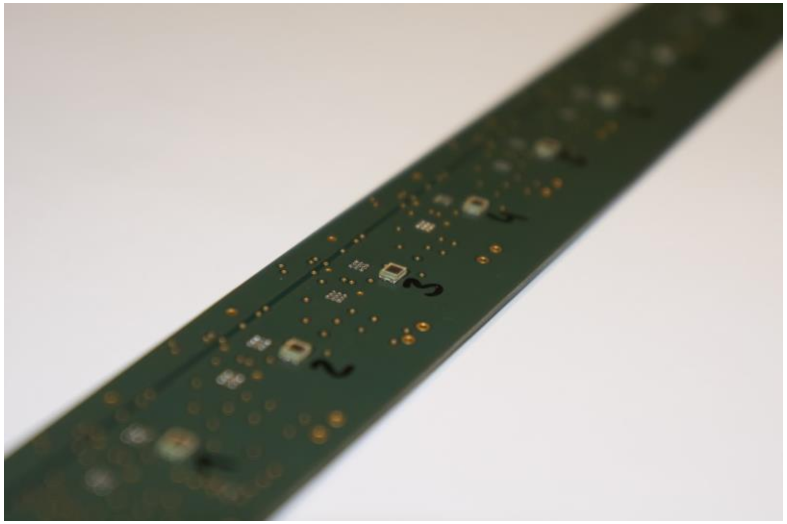
- Use new 4π geometry to better study π^0 performance
- Improve photon track and vertex reconstruction
- Extended analysis of different granularities
- Study different layer thickness and absorber material

Scintillator Tile Studies at MPP

- At the moment primarily scintillator tiles for SuperKEKB commissioning
- In addition: study of new scintillating materials (PEN)
- WLS Fiber based projective readout of larger scintillator elements

Scintillator Tile Studies

- Assembly and calibration of a CLAWS detector module at MPP using BC-408 Tiles



Module equipped with SiPMs

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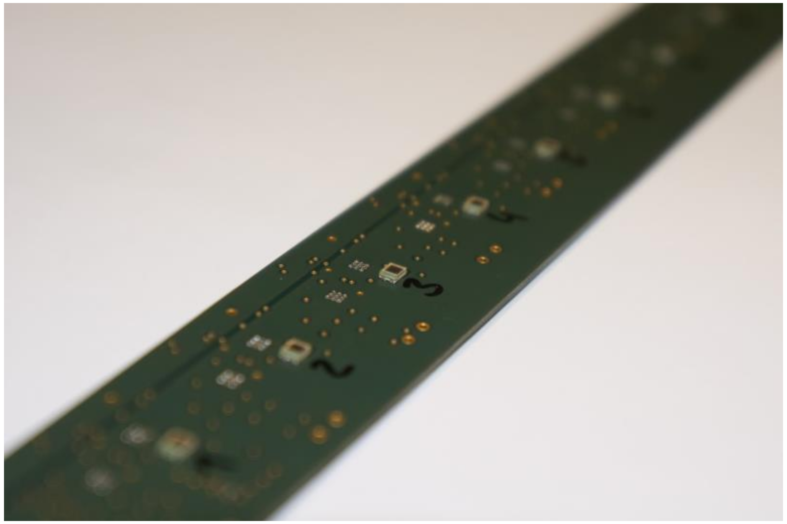

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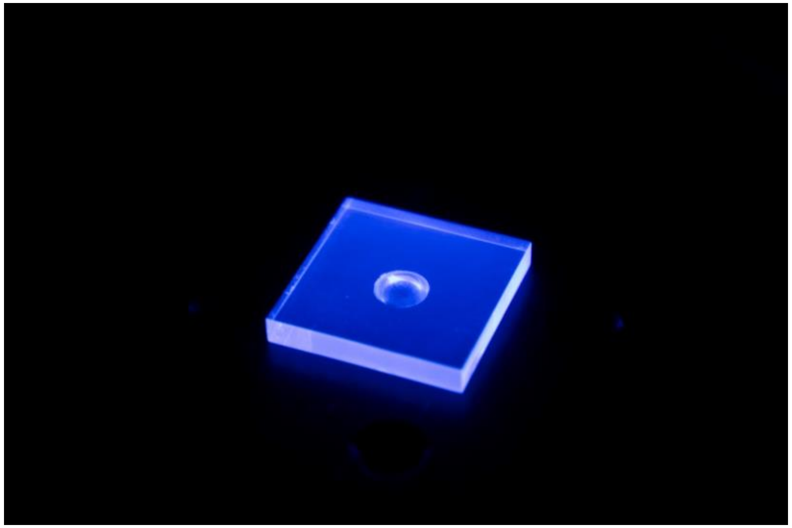

BC-408 Scintillator tile

- 8 channels per module, SiPM readout in the dimple of the scintillator tile
- Preamplification on the PCB

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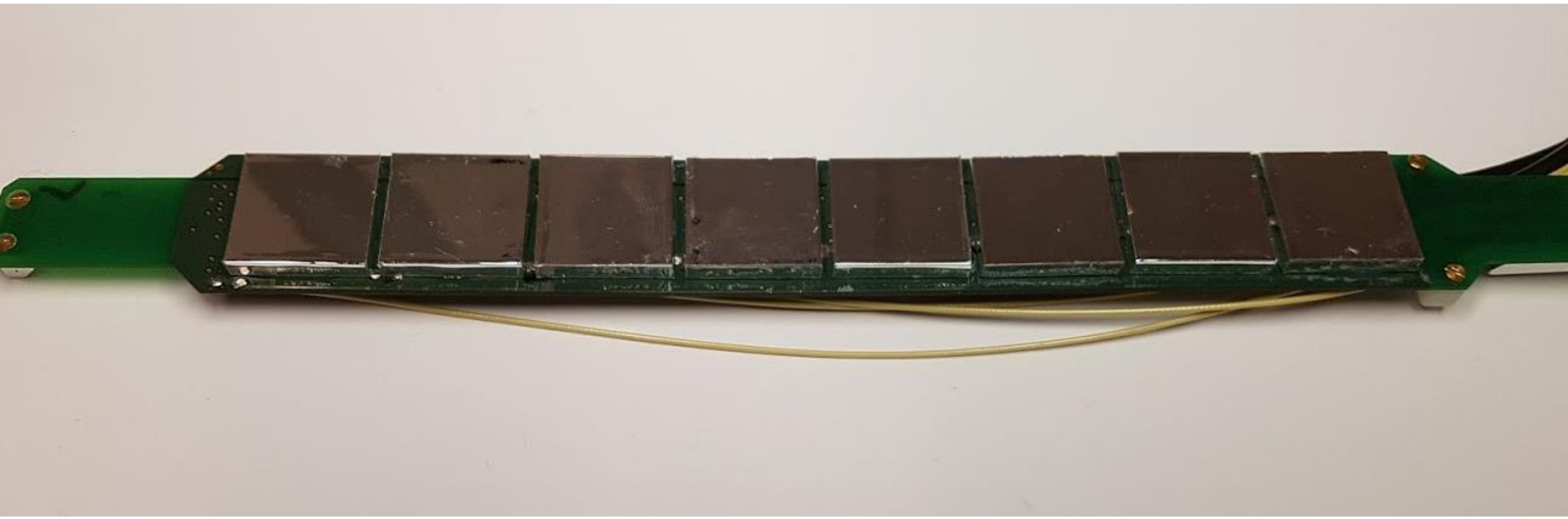
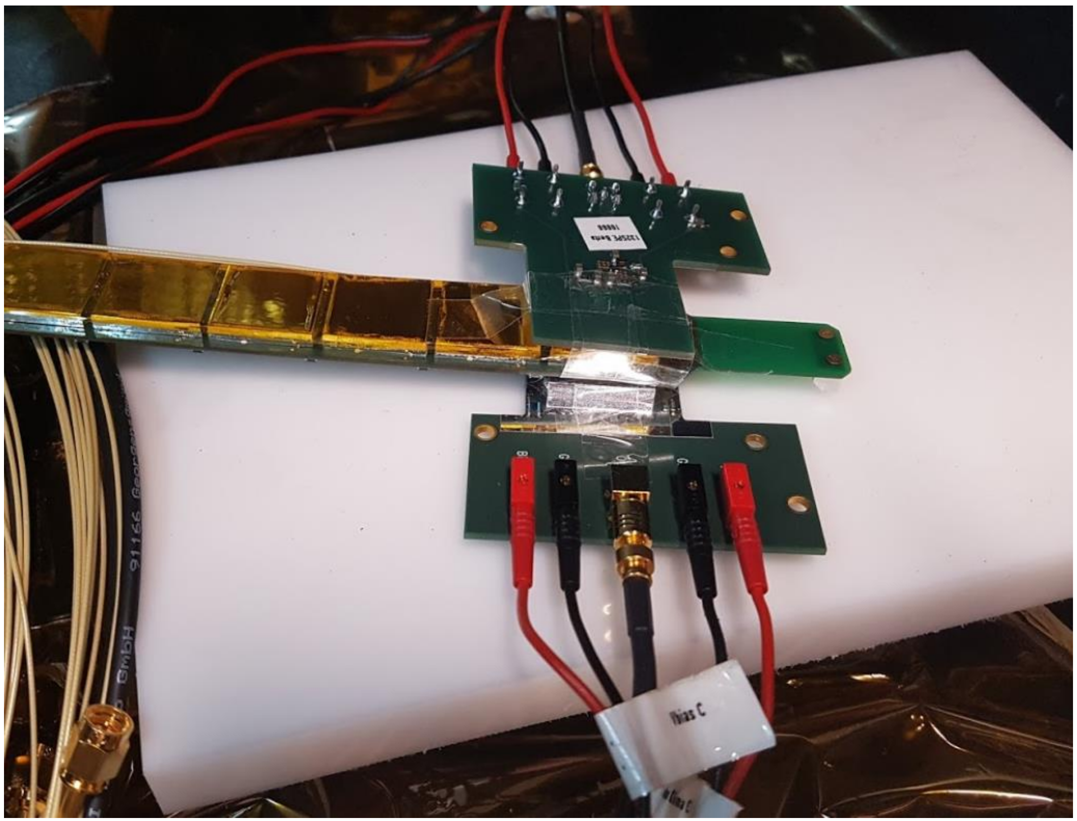


- Fully equipped CLAWS module with readout cables and mounting structure
- Currently being installed at KEK for the Belle II comissioning (BEAST II, February 2018)

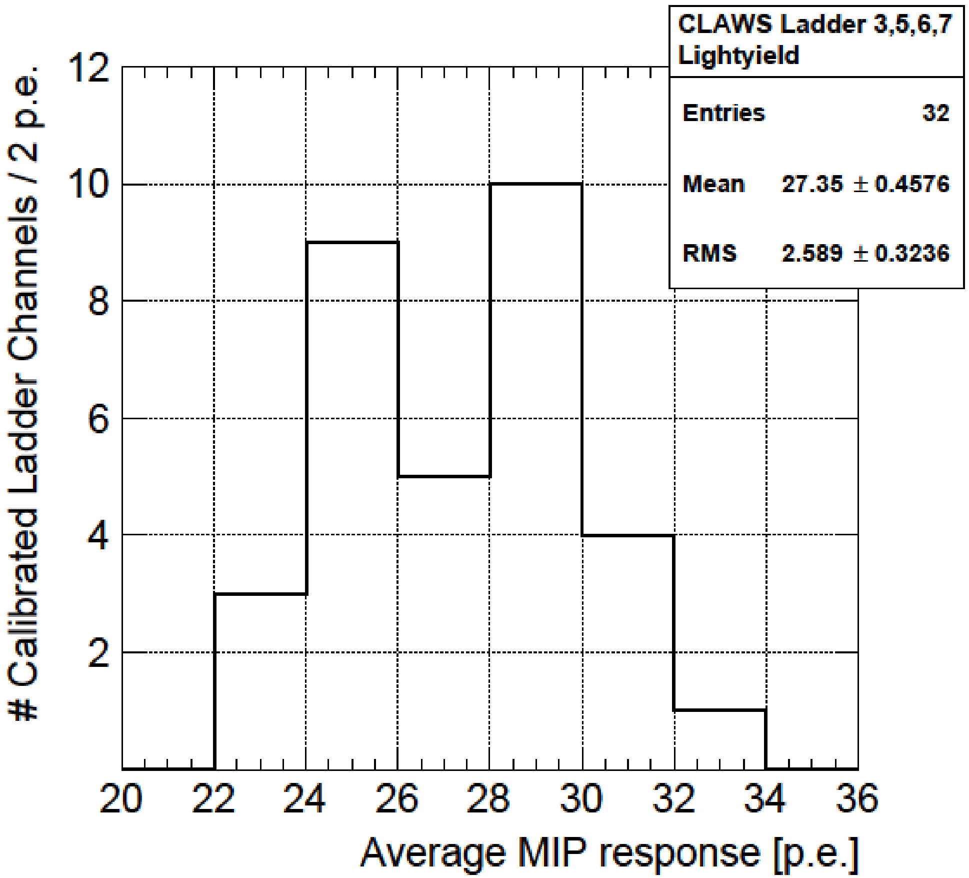
Calibration with Atmospheric Muons

- To calibrate the light yield, atmospheric muons are used
- Measurement takes place in a climate chamber, under controlled conditions



- Two single SiPM boards are mounted above and below a ladder channel to get a coincidence trigger
- Signals are digitized with Picoscopes (500ps resolution)
- For each channel 1000 muon events and 1000 background events are recorded

Light Yield Measurement



Cumulative plot for 4 ladders (32 channels)

- RMS below 10% for 32 channels
- Sufficient for Hadronic calorimetry
- Measurement used to correct BEAST II data

Conclusion

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  - improve track reconstruction
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  - improve track reconstruction
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- Knowledge gained from small scintillator tiles for CALICE can be used
  - extend to WLS readout
  - try different materials

Thank you