Electromagnetic Calorimeter for DUNE ND

Detector Optimization, π^0 Reconstruction & Readout Electronics

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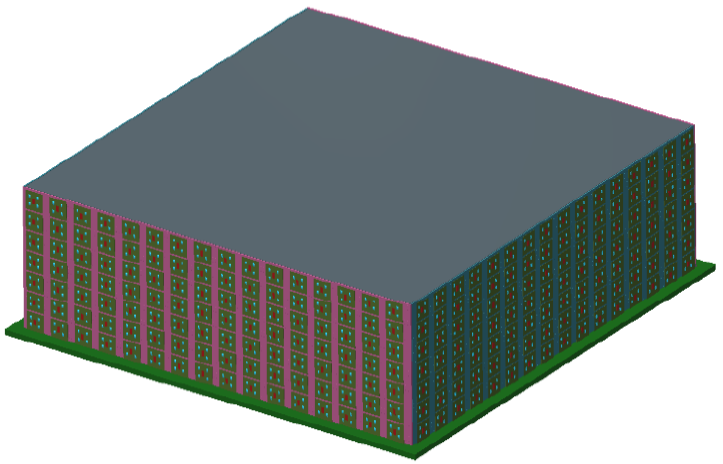
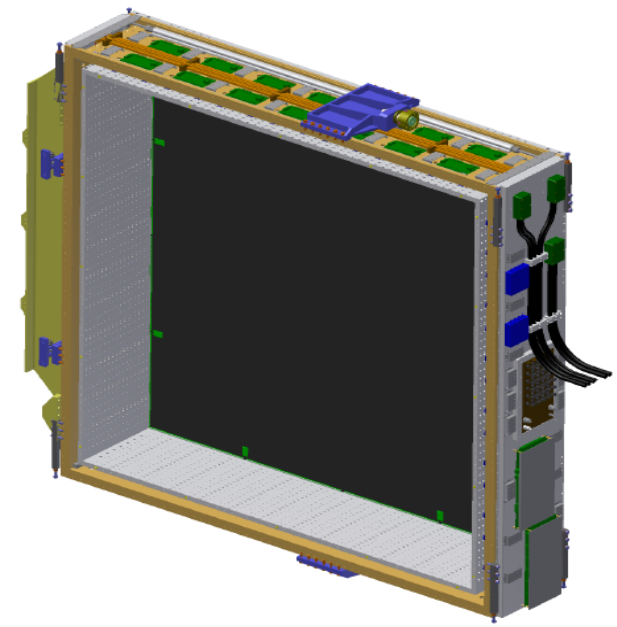
Electromagnetic Calorimeter for DUNE ND

- The design and the readout of the ECAL presented in this talk is based on erstwhile FGT ECAL
- ECAL is required for the identification of EM showers (e^-/e^+, γ showers) & for reconstruction of neutral hadrons such as π^0
- Forward & Backward ECAL modules are made of alternating layers of lead and plastic scintillators (XYXYX... config). '60' layers for Forward and '16' for the Backward ECAL
- Each of the extruded plastic scintillator bars of all layers are readout by a WLS fibre and photon counters (MPPCs), attached at ends.
- expected energy resolution $\approx 6\%/\sqrt{E}$ for the Forward ECAL
- provide high segmentation on lateral & transverse directions for reconstruction

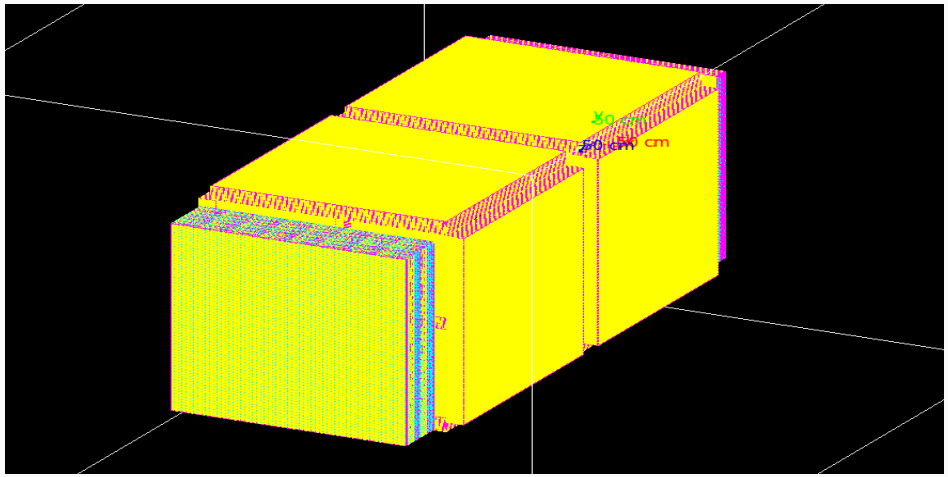


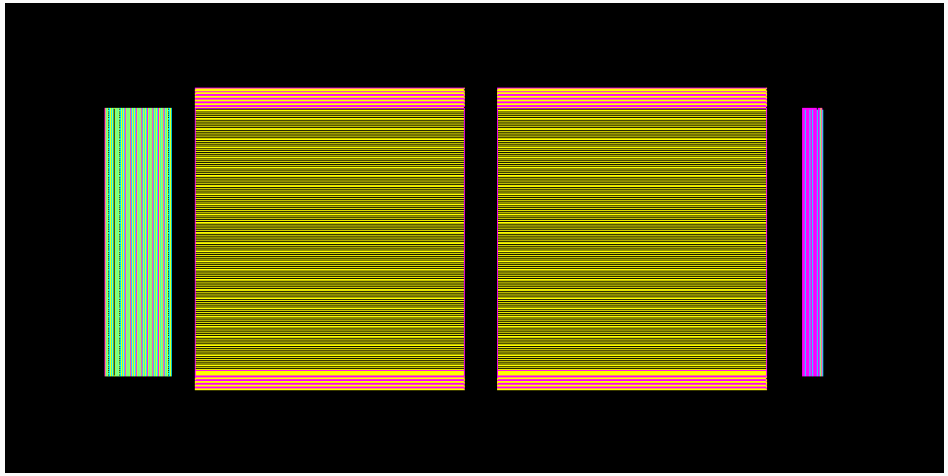


DUNE-ND ECAL

Detector Geometry Optimization

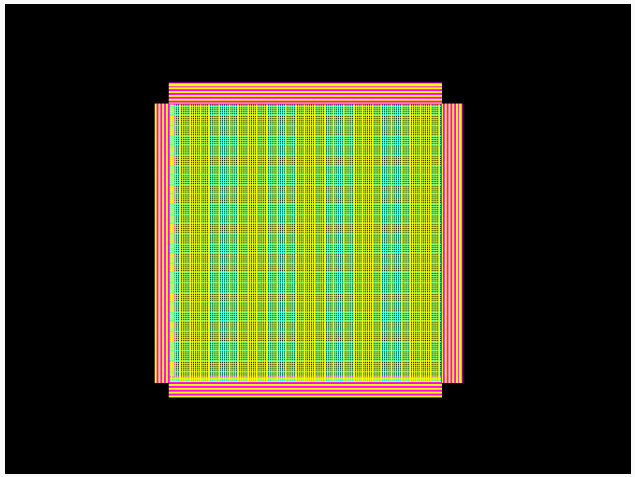
- Forward ECAL design with 160 plastic scintillator bars of dimensions (25 mm X 10 mm X 4000 mm) with lead sheets of 1.75 mm as absorbers (initial design)
- GEANT4 detector optimization was carried out with varying thickness of scintillation bars (10 mm, 15 mm, 20 mm) and Absorber sheet thickness (1 mm, 1.5 mm, 1.75mm, 2 mm) keeping the overall dimension fixed at 4000 mm X 4000 mm x 60 layers
- Simulations with different Absorber materials (Lead, Copper, Stainless-Steel)
- Use γ and π^0 particles in GEANT4 to study the energy resolution, shower containment, position resolution and angular separation of the gammas in the π^0 reconstruction.
- Complete ECAL geometry from CDR 2015 on right (bottom:sideview, space between modules is for visualization only)



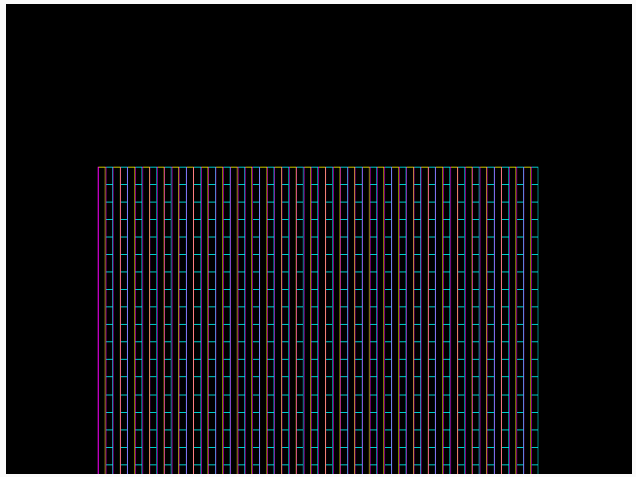


DUNE-ND ECAL

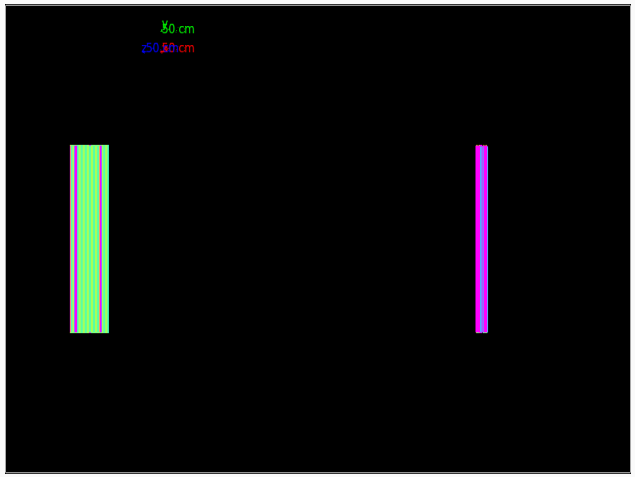
Detector Geometry Optimization



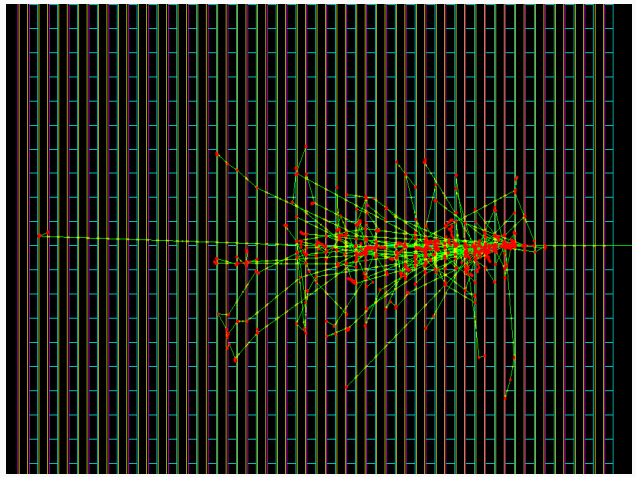
front view Forward ECAL



Close up Forward ECAL



between ECAL modules other detectors (like the STT) may be placed

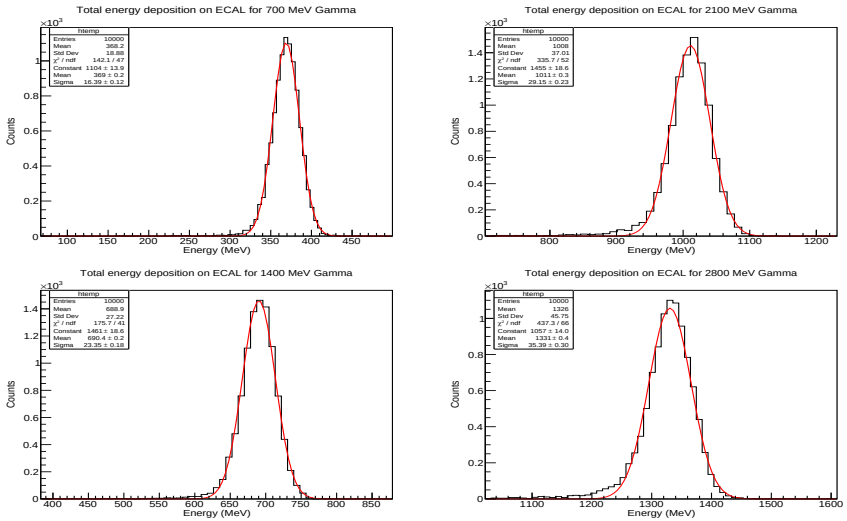


γ interaction in Forward ECAL

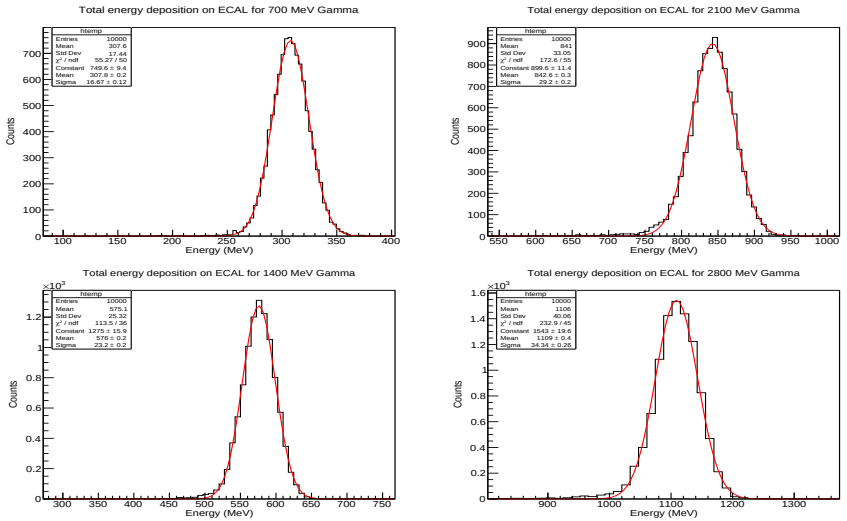
Forward ECAL: Detector Optimization

Energy Deposited for different configurations of absorber & scintillator (best 4)

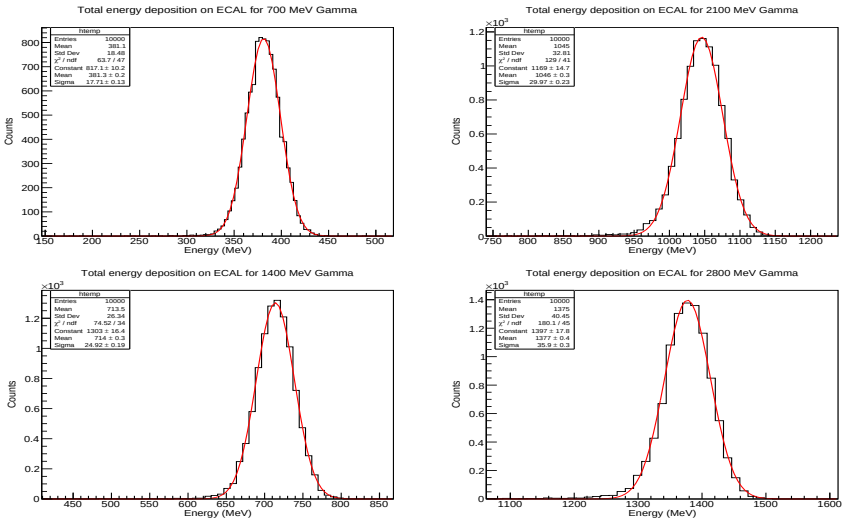
γ Edep for Cu as Abs [2.0 cm Sci + 3.0 mm Abs]



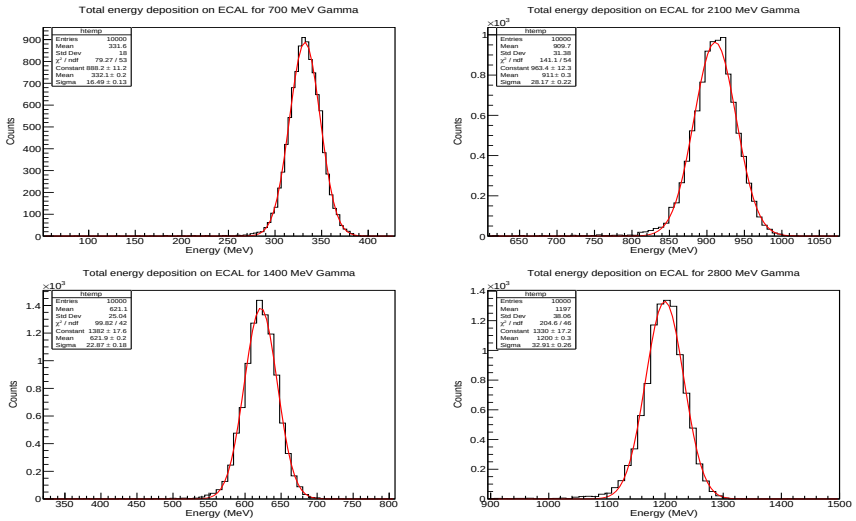
γ Edep for Pb as Abs [1.0 cm Sci + 1.5 mm Abs]



γ Edep for Pb as Abs [1.5 cm Sci + 1.5 mm Abs]



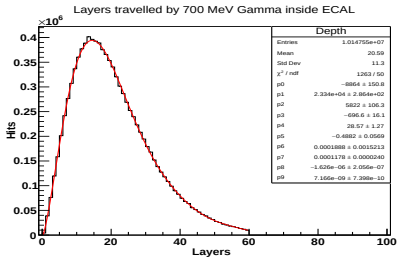
γ Edep for Stainless-Steel as Abs [2.0 cm Sci + 4.0 mm Abs]

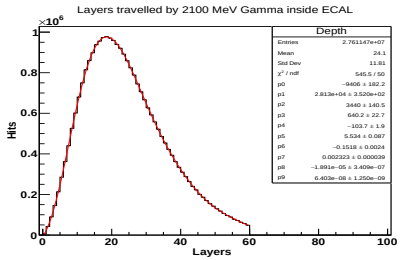


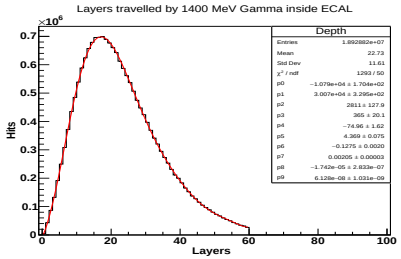
Forward ECAL: Detector Optimization

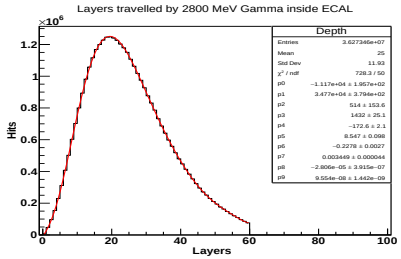
Shower containment for different configurations of absorber & scintillator (best 4)

Layers traversed for Cu as Abs [2.0 cm Sci + 3.0 mm of Abs]

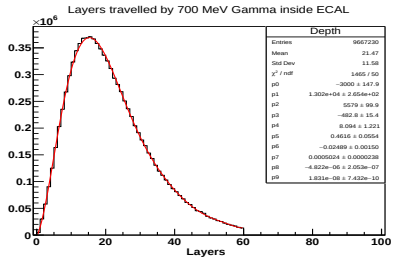


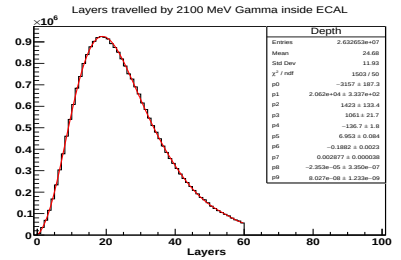


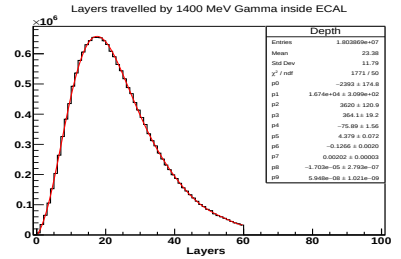


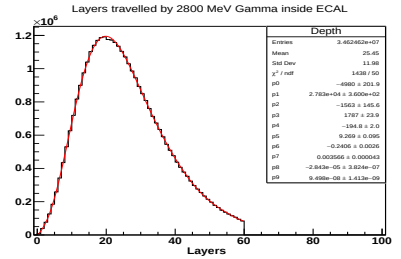


Layers traversed for Pb as Abs [1.0 cm Sci + 1.5 mm Abs]

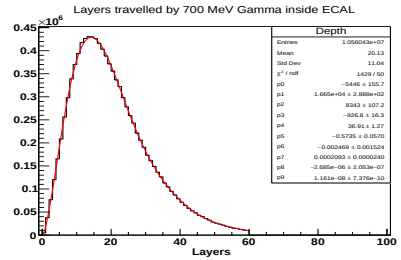


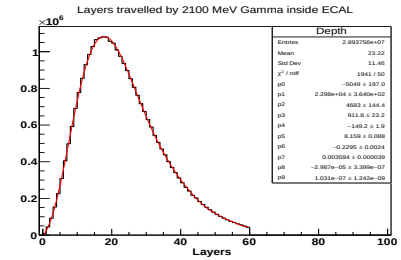


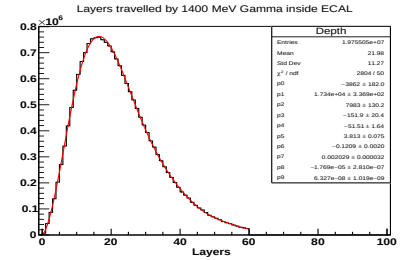


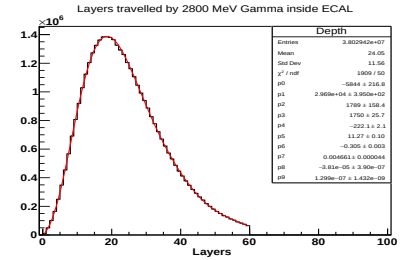


Layers traversed for Pb as Abs [1.5 cm Sci + 1.5 mm Abs]

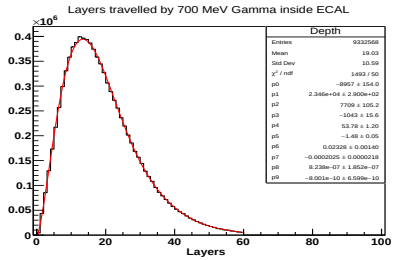


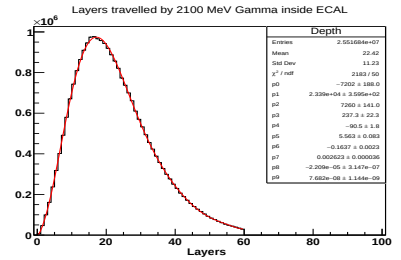


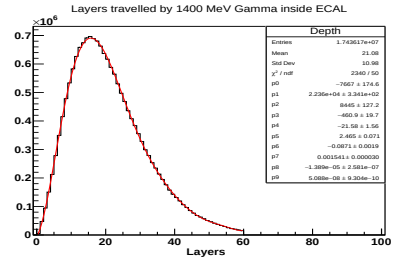


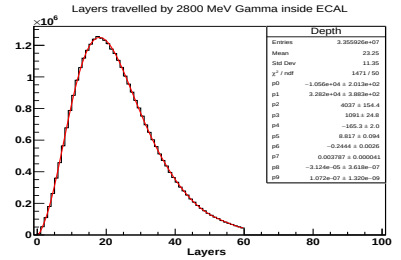


Layers traversed for Stainless-Steel as Abs [2.0 cm Sci + 4.0 mm Abs]



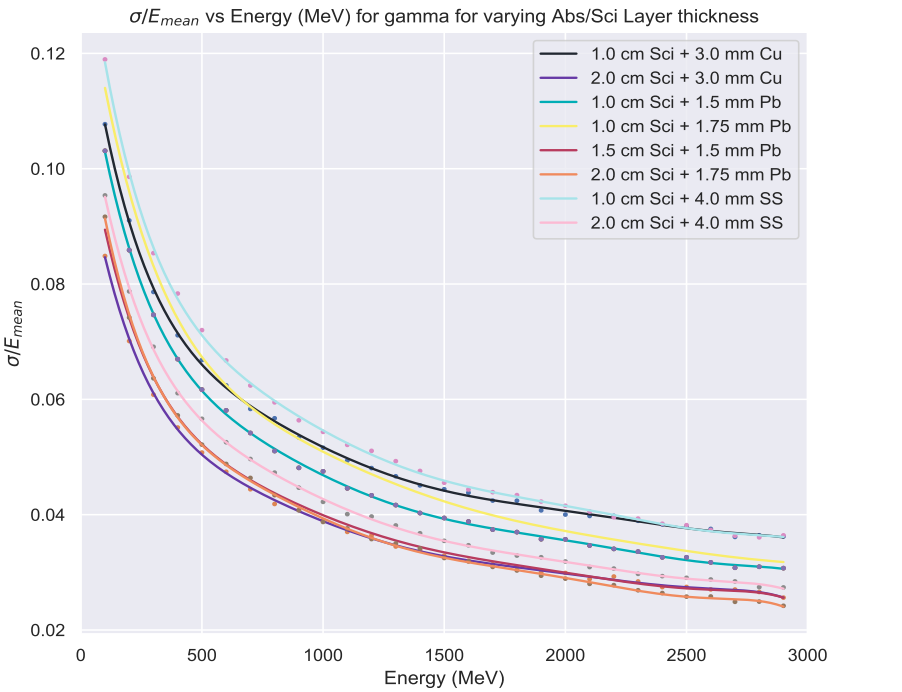


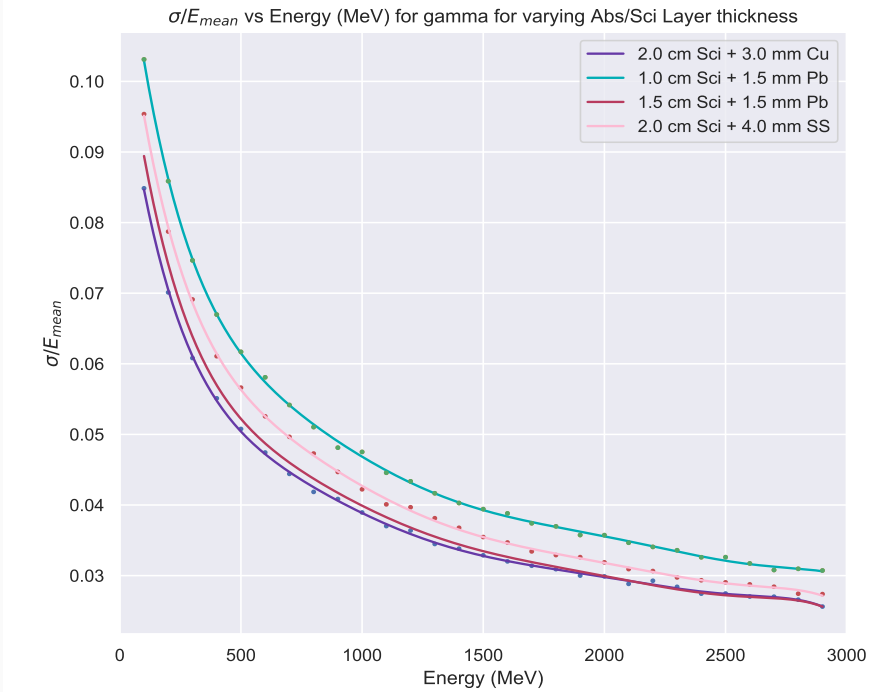




Forward ECAL: Detector Optimization

Energy resolution comparison between configurations

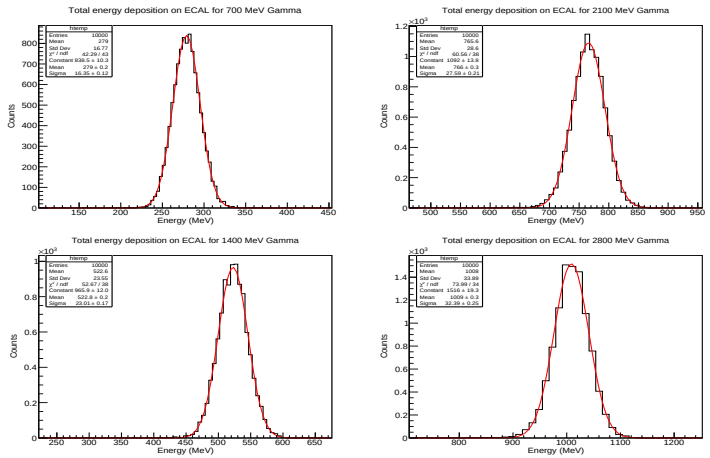




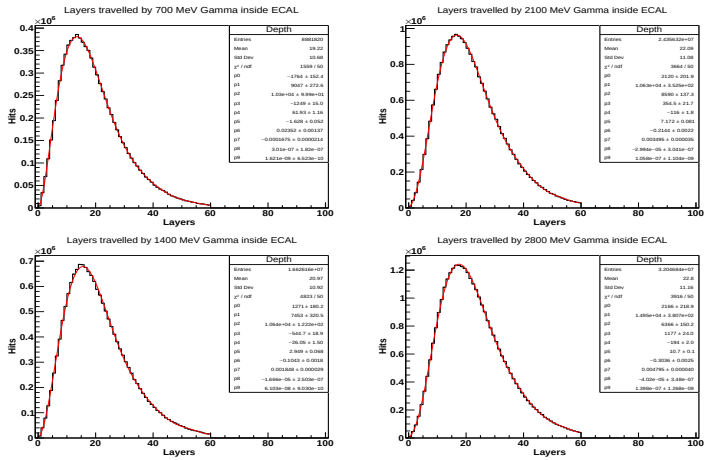
Forward ECAL: Detector Optimization

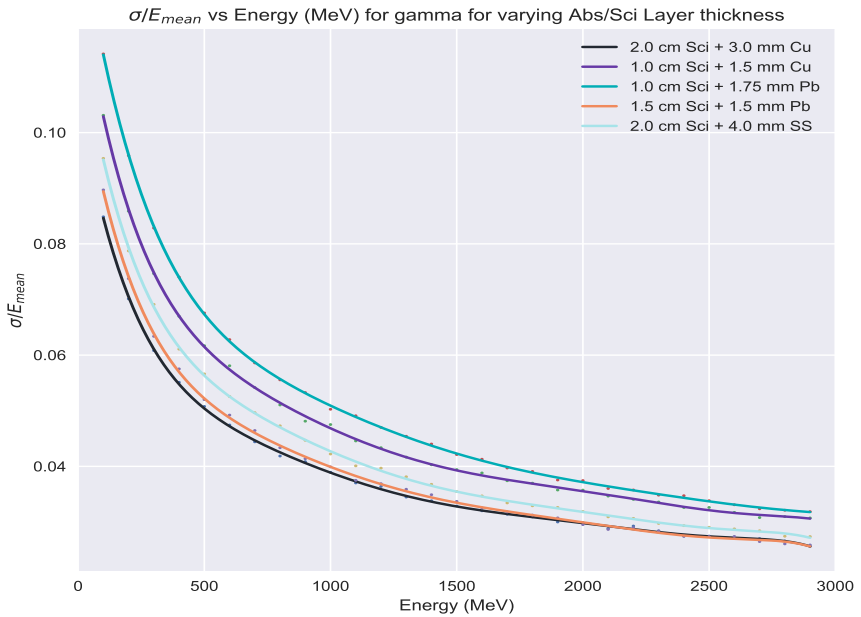
Energy resolution comparison between configurations

γ Edep for Pb as Abs [1.0 cm Sci + 1.75 mm Abs]



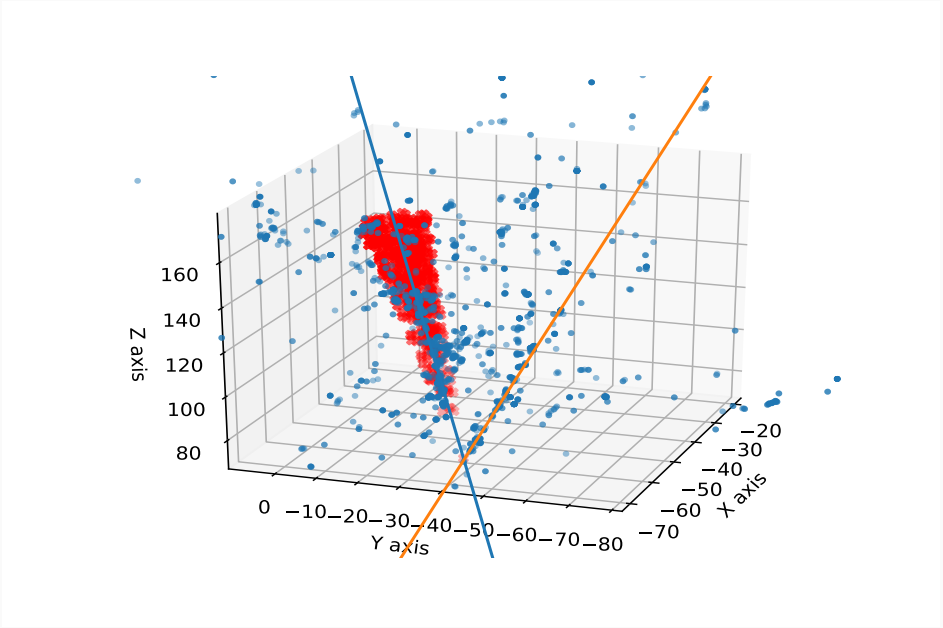
Layers traversed for Pb as Abs [1.0 cm Sci + 1.75 mm of Abs]





Forward ECAL: π^0 reconstruction

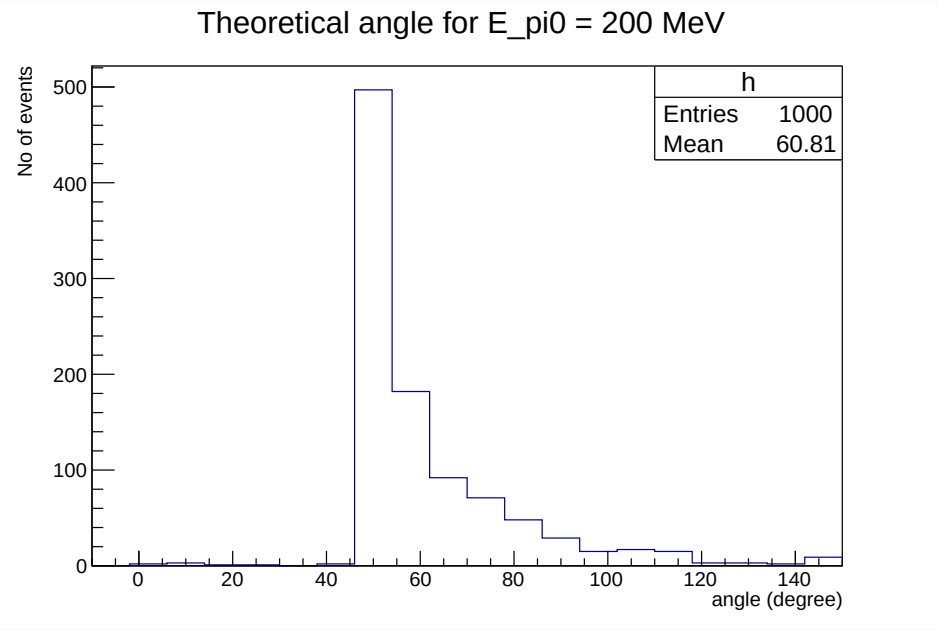
- Hough transform applied on complete dataset, this will give the axis for first cluster
- Using the axis, construct a cone according to the density variation. Then the cone is radially enlarged till the point where density falls to 1/e of maximum density.
- Points within the cone are removed and hough transform applied on remaining points, giving the axis of second cluster
- Use the axes to calculate the angle between the two gammas
- Based on distance from the axis, points are assigned to either of cluster 1 or 2
- Invariant mass is calculated using total energy in the cluster e1, e2 and angle
- Process is repeated for 4 different energies: 0.2 GeV, 0.5 GeV, 0.8 GeV, 1.2 GeV

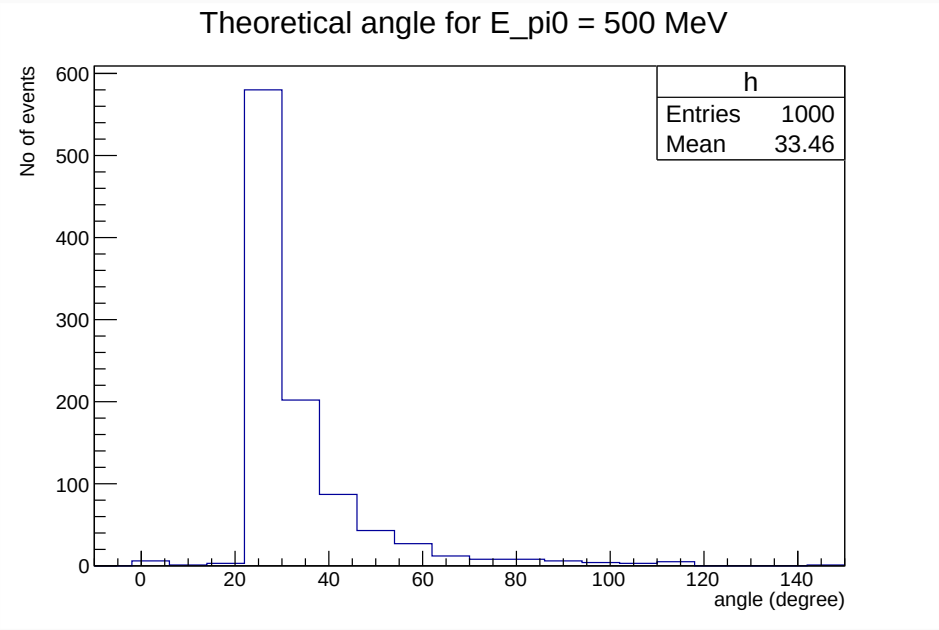


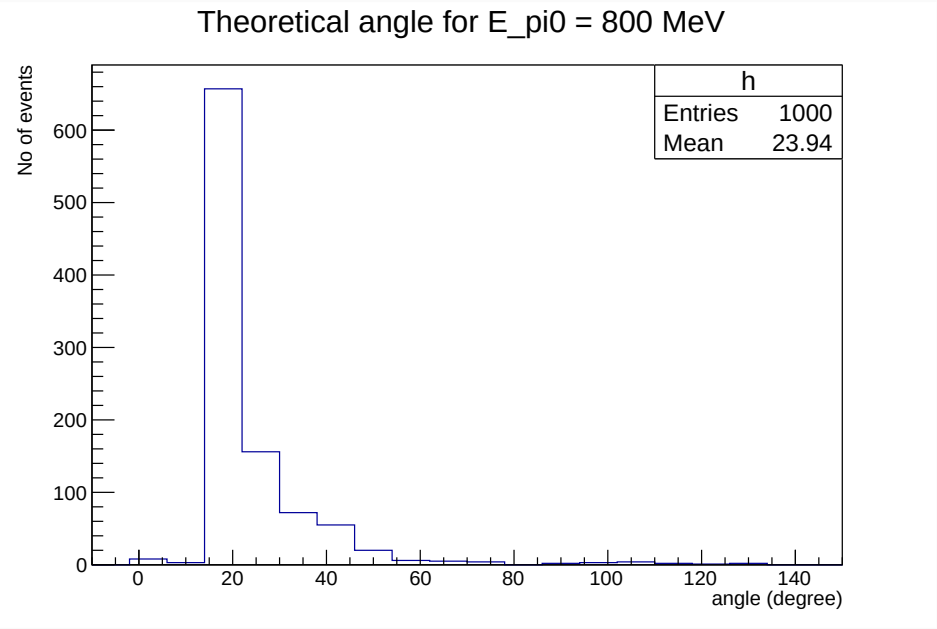
Reconstruction process π^0

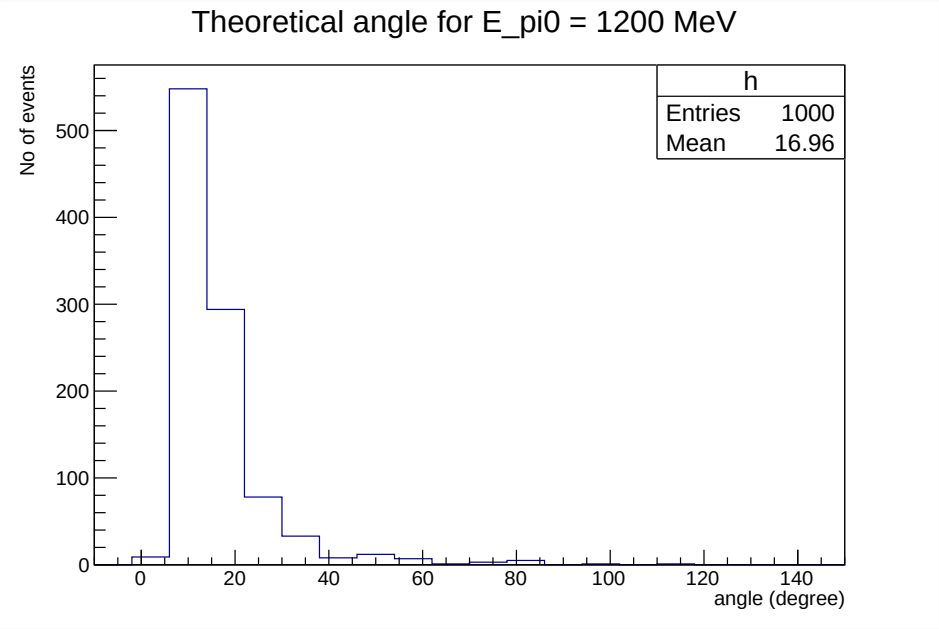
- world material: argon gas
- detector material: plastic PLASTIC_SC_VINYLTOLUENE
- 1 bar: 4 m x 2.5 cm x 0.5 cm
- total bars in 1 sheet: 160
- total layers: 60 plastic + 59 lead
- lead dim: 4 m x 4 m x 0.25 cm

Expected angular separation between gammas



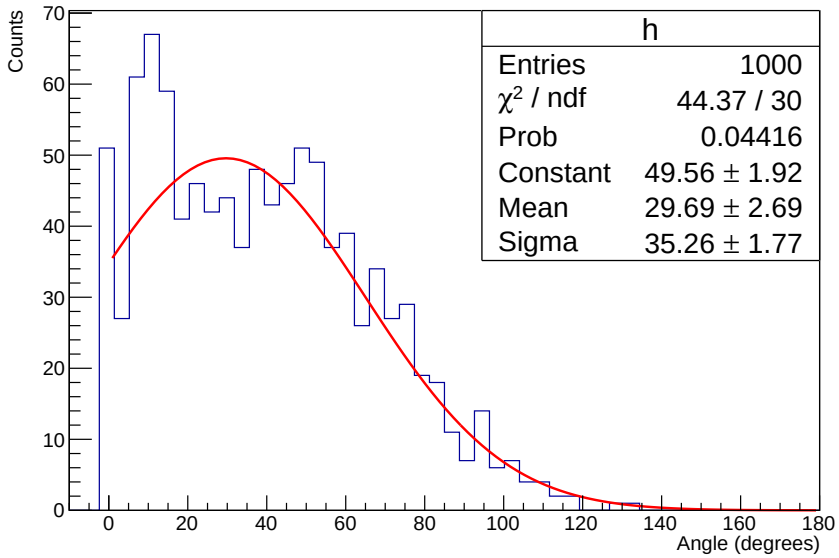




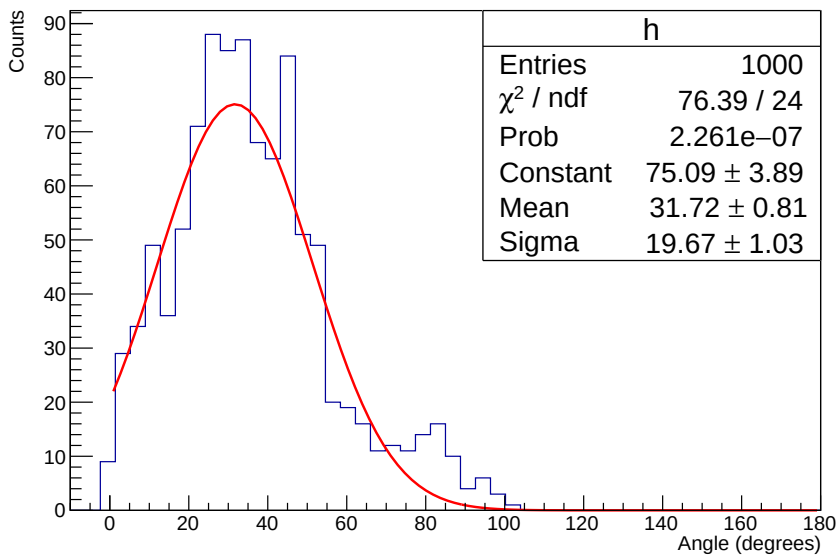


Reconstructed angles between two Gammas of π^0 with energies: 0.2, 0.5, 0.8, 1.2 GeV

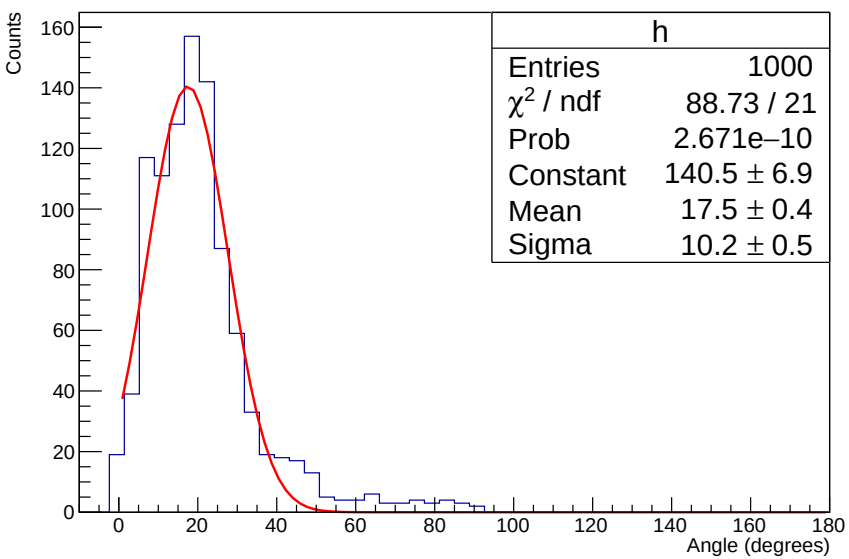
Angle distribution for E_pi0 = 200 MeV



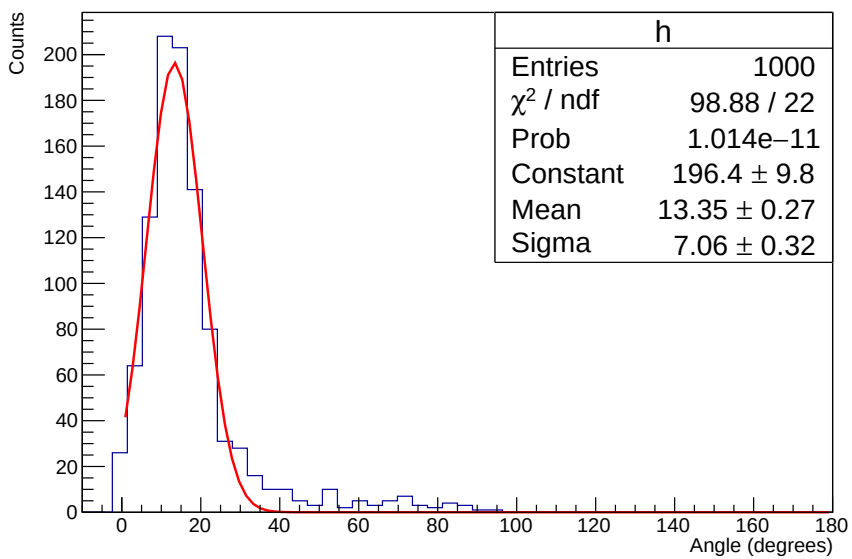
Angle distribution for E_pi0 = 500 MeV



Angle distribution for E_pi0 = 800 MeV

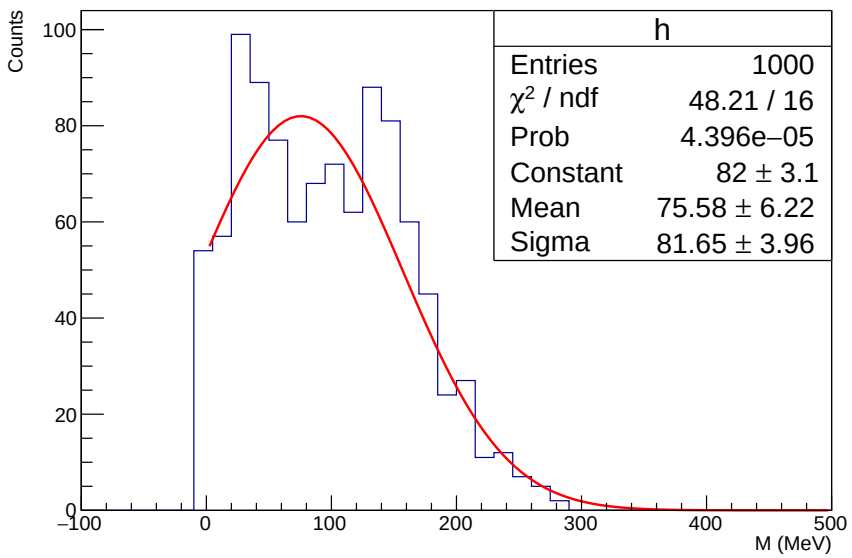


Angle distribution for E_pi0 = 1200 MeV

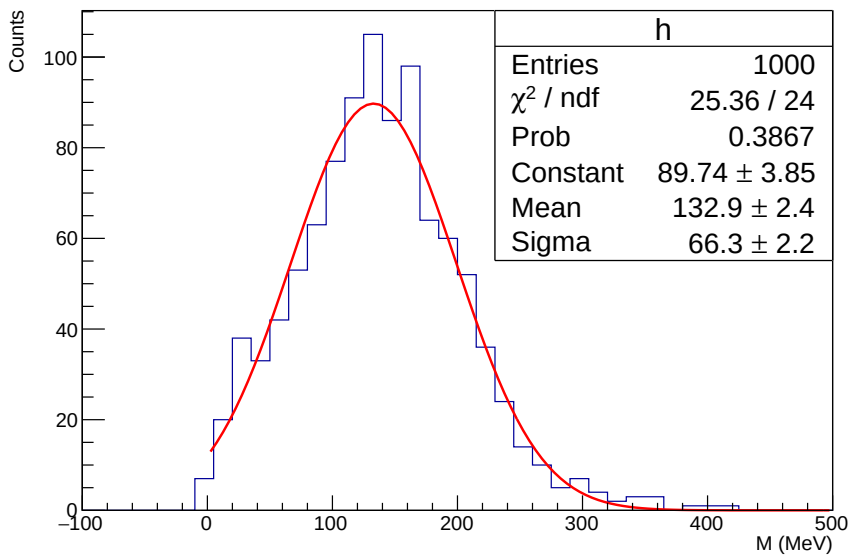


Reconstructed invariant mass for π^0 with energies: 0.2, 0.5, 0.8, 1.2 GeV

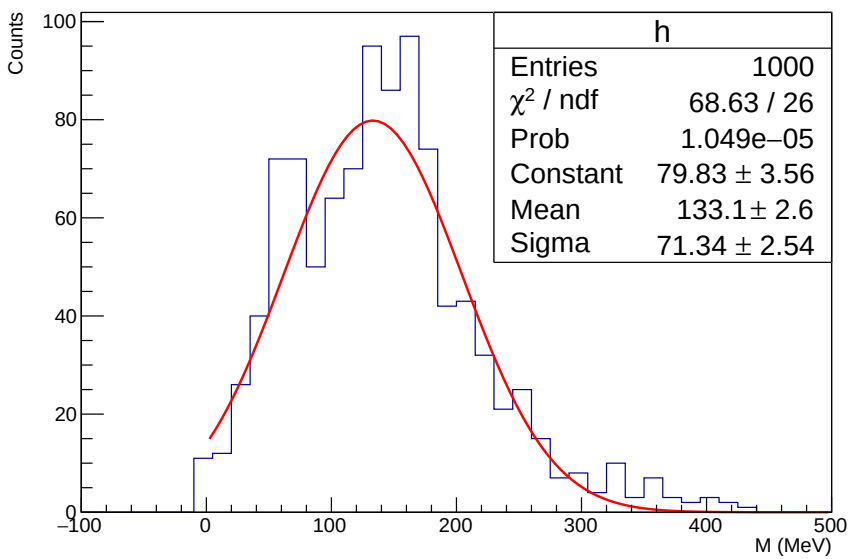
Mass distribution for E_pi0 = 200 MeV



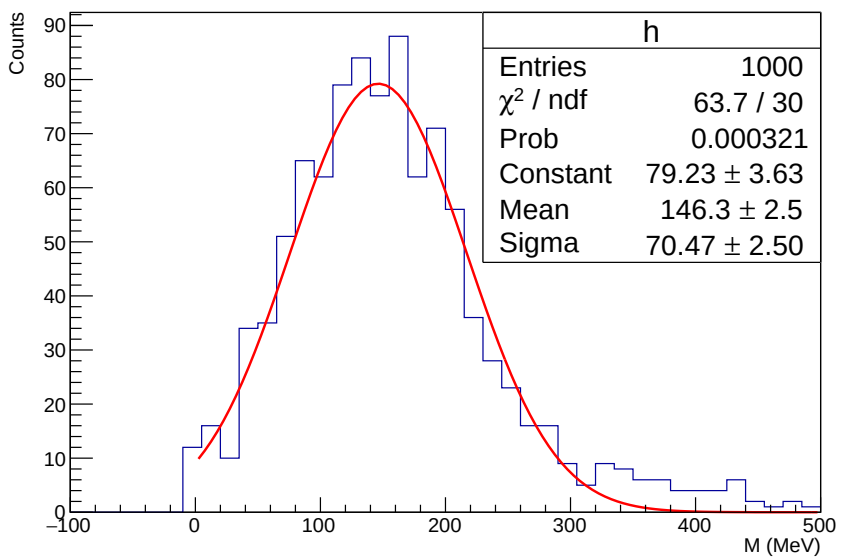
Mass distribution for E_pi0 = 500 MeV



Mass distribution for E_pi0 = 800 MeV



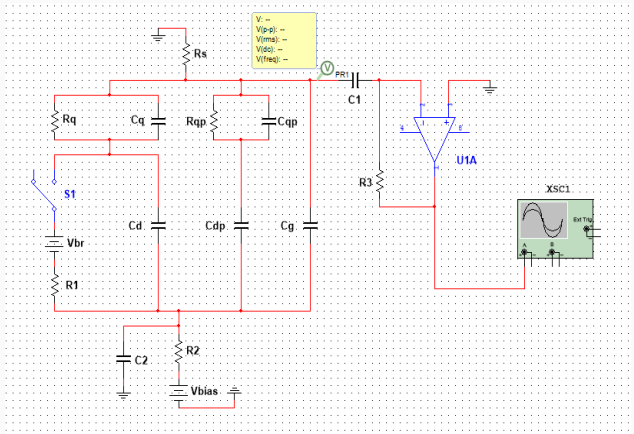
Mass distribution for E_pi0 = 1200 MeV



Forward ECAL: Readout Electronics

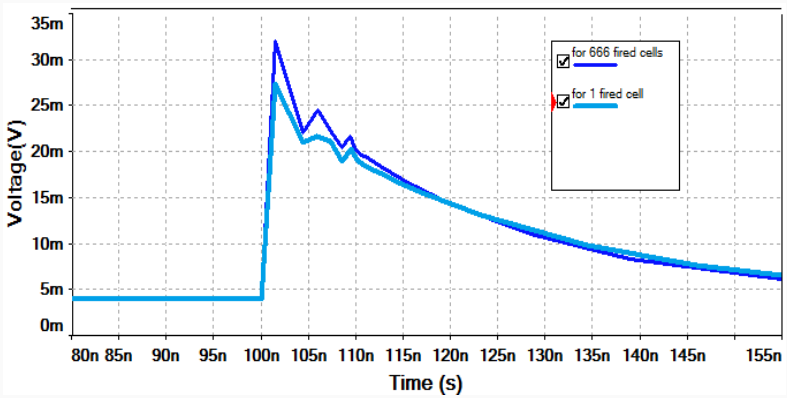
Photon Counter (MPPC) & readout

- We propose to use MPPCs to readout the scintillator bars
- Selection of MPPCs was based on the T2K ND280-ECAL, with specifications below:
  - Hamamatsu Hamamatsu S13360-1350CS
  - 1.3 x 1.3 mm^2 active area, 667 pixels (50 μm pixel pitch), ceramic device
  - Gain ($1.7x10^6$) with $V_O \approx 53$ V
  - Photon Detection Efficiency (PDE) at 550 nm: 40%
  - Dark count rate 270 kcps at threshold 0.5 p.e.



SPICE sim of MPPC (S. Seifert, IEEE'09)

- Simulation and MPPC characterization to determine best signal rise/recovery times of scintillation pulses
- And for designing preamp., amplifiers, shapers and ADC

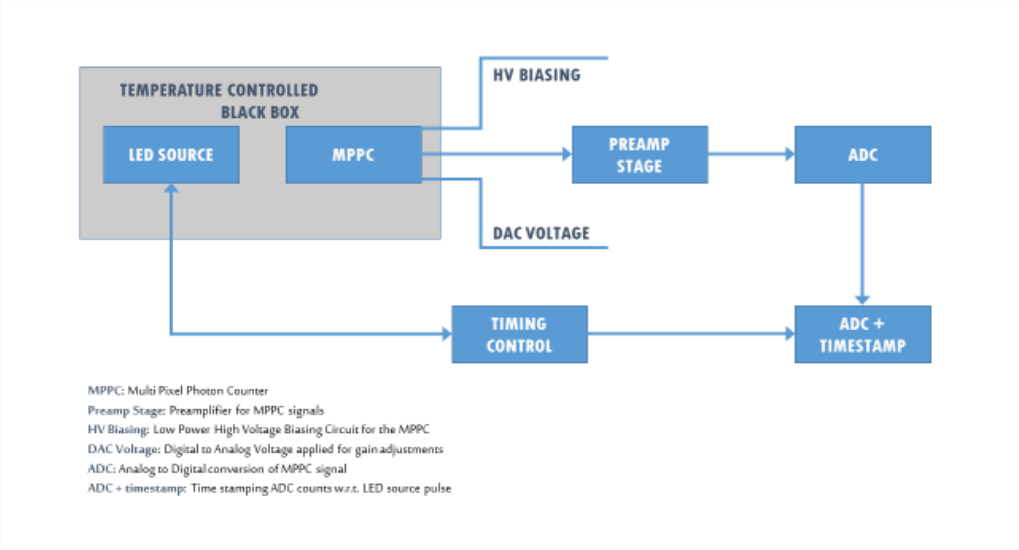


Simulated signal in MPPC

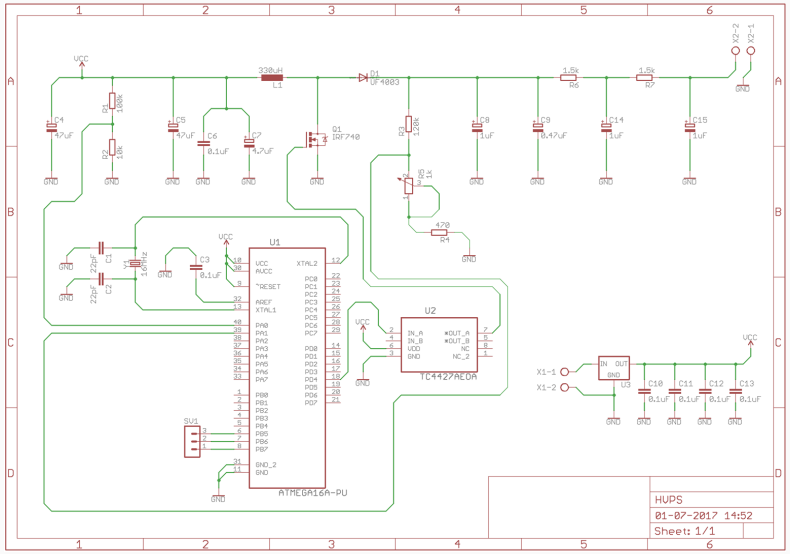
MPPC

Forward ECAL: Readout Electronics

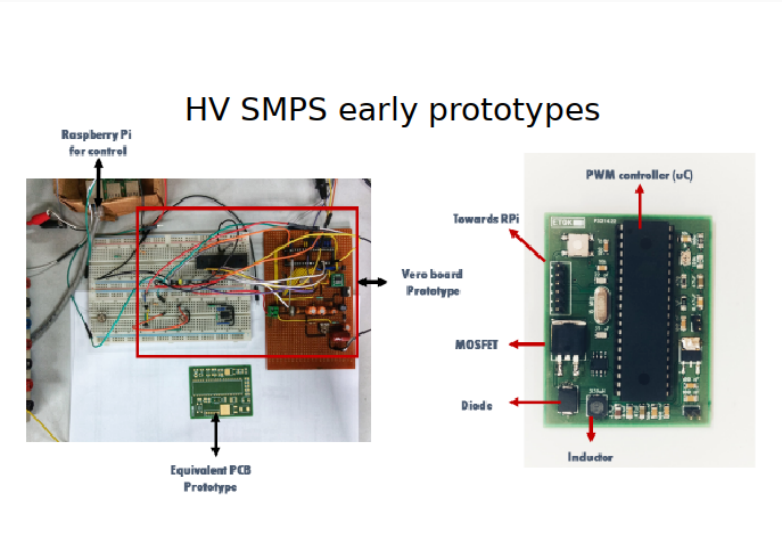
Photon Counter (MPPC) & readout

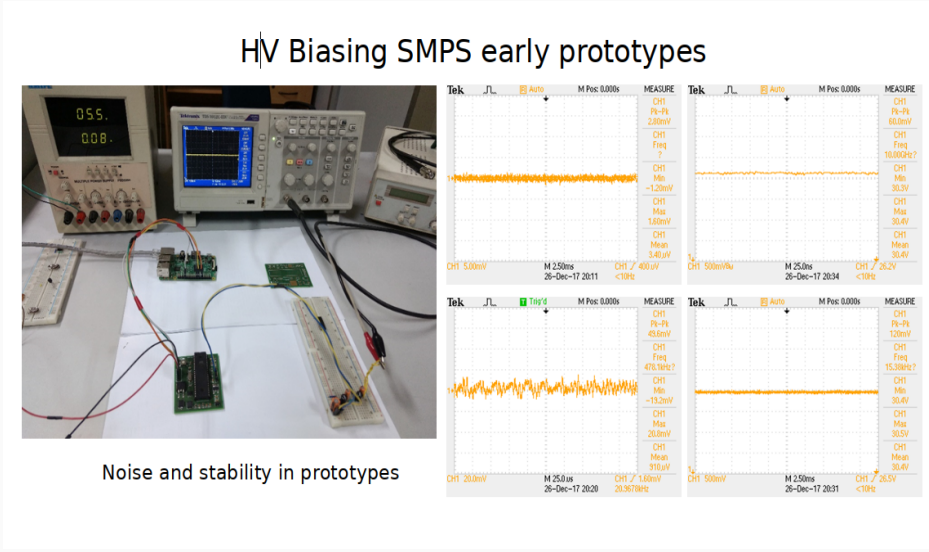


Setup for Testing and Characterizing MPPCs



Older prototype for a HV Biasing Power Supply



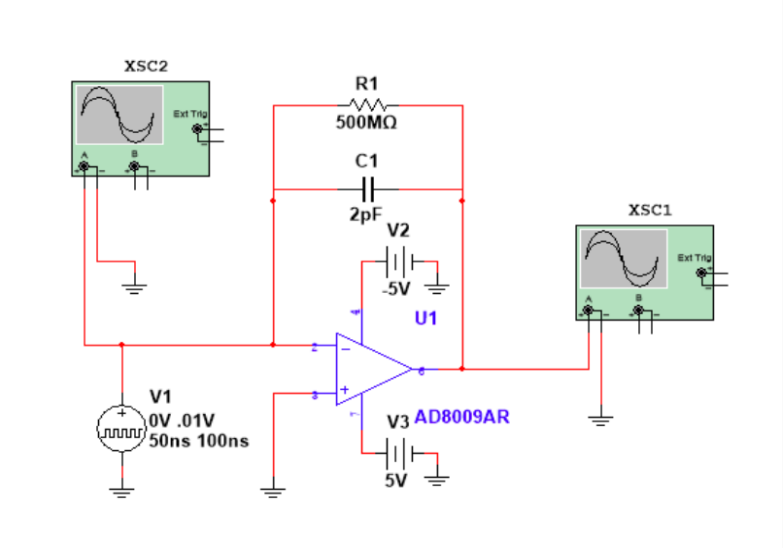


Noise and stability in prototypes

Forward ECAL: Readout Electronics

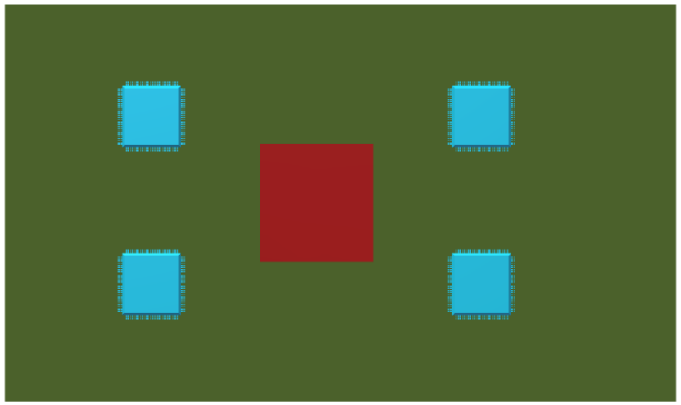
Photon Counter (MPPC) & readout

- A prototype FEB with 8-16 channels is under development for testing multiple MPPCs. Comprising of HV Biasing, preamplifiers, Amplification stages, Shapers and ADC on board with an FPGA (Intel/Altera Max10) for basic control
- Suitable ASICs may be implemented in the Front-end Board to scale up for 64/128/higher number of channels.
- The FEB design is inspired from the TripT Readout Board used in T2K ND280-ECAL



preamp simulation

Front end board in model: 16cm x 9cm



Summary

- After Geometry optimization, four different configurations are selected. The selected designs meet the required specifications on energy resolution of $6\%/\sqrt{E}$
- Currently developing the reconstruction algorithm for single photon and π^0. Preliminary results are presented in this talk.
- Prototype Readout electronics Board under development to test and characterize multiple MPPCs. ASICs supporting higher number channels to be selected for the Front-End Board of Forward ECAL, followed by the full working FEB prototype.
- Readout design may be useful either for the MPD calorimeter readout or for replacing the KLOE readout PMTs with MPPCs.

Summary contd.

- Indian group was involved with the development of the STT based tracker (FGT) during LBNE. [DUNE CDR Volume 4]
  - Successfully led the DOE CD1 review, Director's CD-1 Refresh Review and DOE CD-1 Refresh Review during May-July, 2015.
    - **DUNE ND Design Review, May 28-29, 2015.**
      https://web.fnal.gov/project/LBNF/ReviewsAndAssessments/DUNE%20ND%20Design%20Review/SitePages/Home.aspx
    - **Director's CD-1 Refresh Review of LBNF-DUNE, June 2-4, 2015,**
      https://web.fnal.gov/organization/OPSS/Projects/LBNFDUNE/SitePages/Director%27s%20CD-1%20Refresh%20Review%20of%20LBNF-DUNE,%20June%202-4,%202015.aspx
    - **DOE CD-1 Refresh Review of LBNF-DUNE, July 14-16, 2015,**
      https://web.fnal.gov/organization/OPSS/Projects/LBNFDUNE/SitePages/DOE%20CD-1%20Refresh%20Review%20of%20LBNF-DUNE,%20July%2014-16,%202015.aspx
  - Will support any effort to enhance the physics capability of the current DUNE ND complex:
    - **e.g. KLOE with STT design has the potential to significantly enhance the physics capability of the DUNE ND facility.**
      https://docs.dunescience.org/cgi-bin/private/ShowDocument?docid=13262
    - **In synergy with the proposal submitted to the European Strategy Group:**
      https://indico.cern.ch/event/765096/contributions/3295805/

Thank you