ECal for a Gaseous Argon Detector

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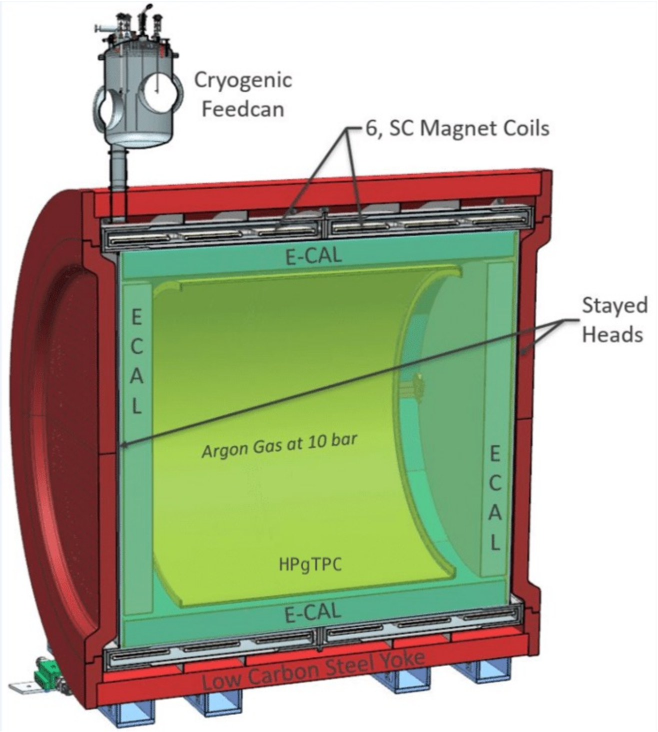
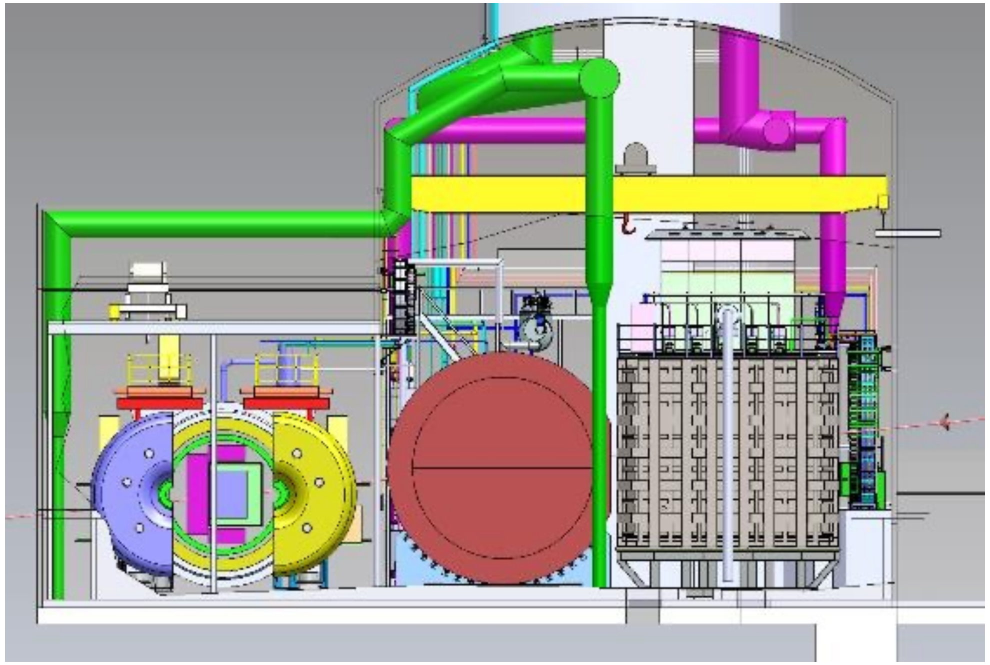
Near Detectors of DUNE Phase-II

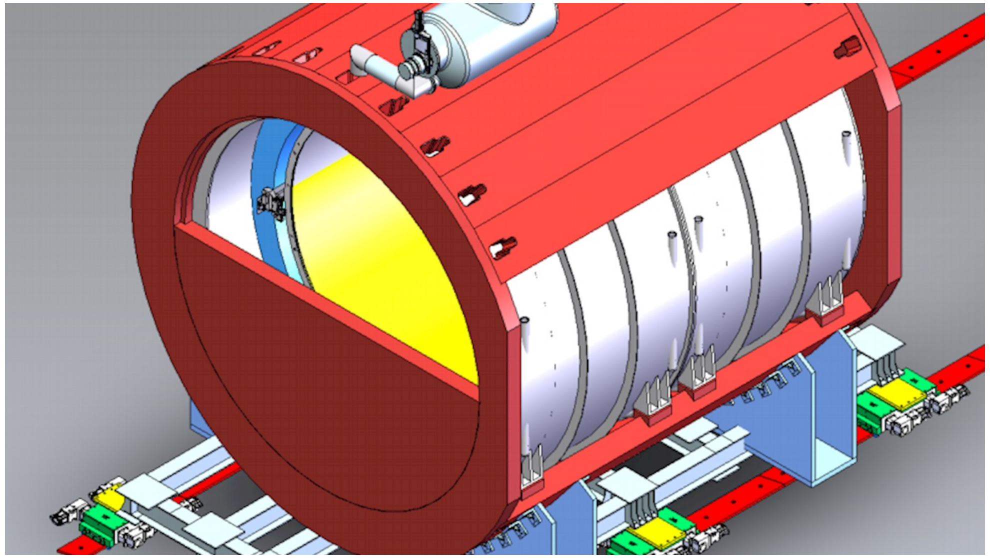
Imperial College London, 20-Jun-2023

gAr Detector

- Main detector components
  - High pressure (10 bar) gas TPC
  - ECAL
  - SC magnet
- Interactions on argon gas

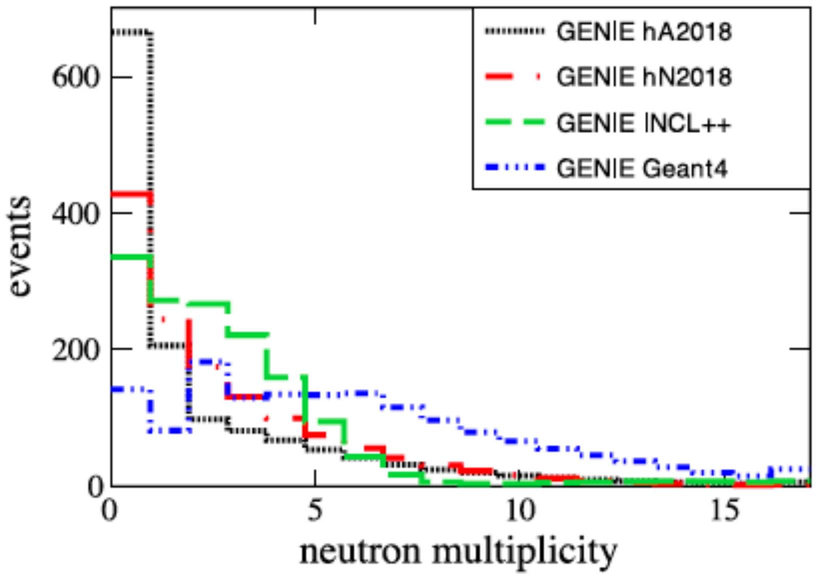


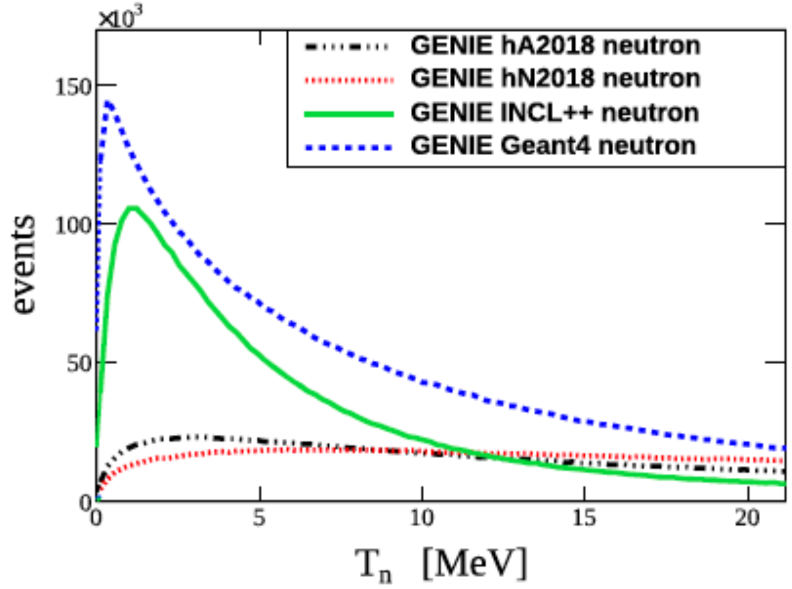




Neutrino Interactions

- Tricky Problem
  - How to relate neutrino and measured energy?
  - Neutrino energy unknown
  - Nuclear recoil not measurable
  - Nucleus will absorb some energy
- Charged and neutral particles
  - p from curvature in B-field
  - E from range
  - Calorimetric energy for γ
  - β from ToF of neutron (recoil)



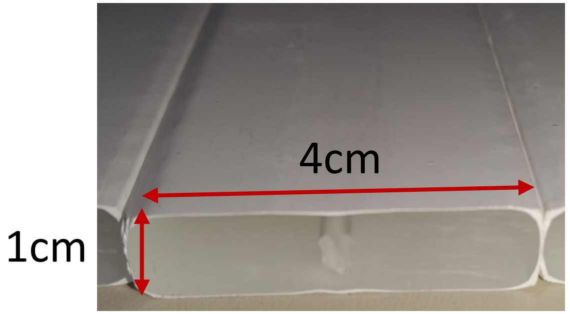


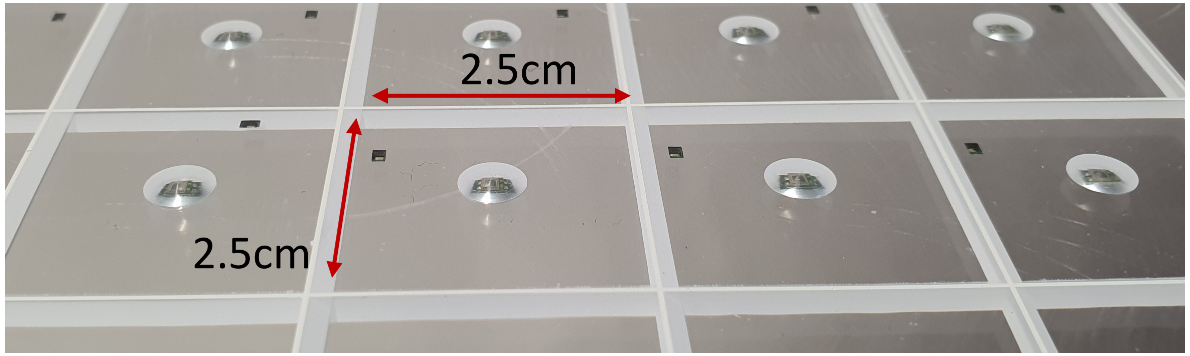
Design Philosophy

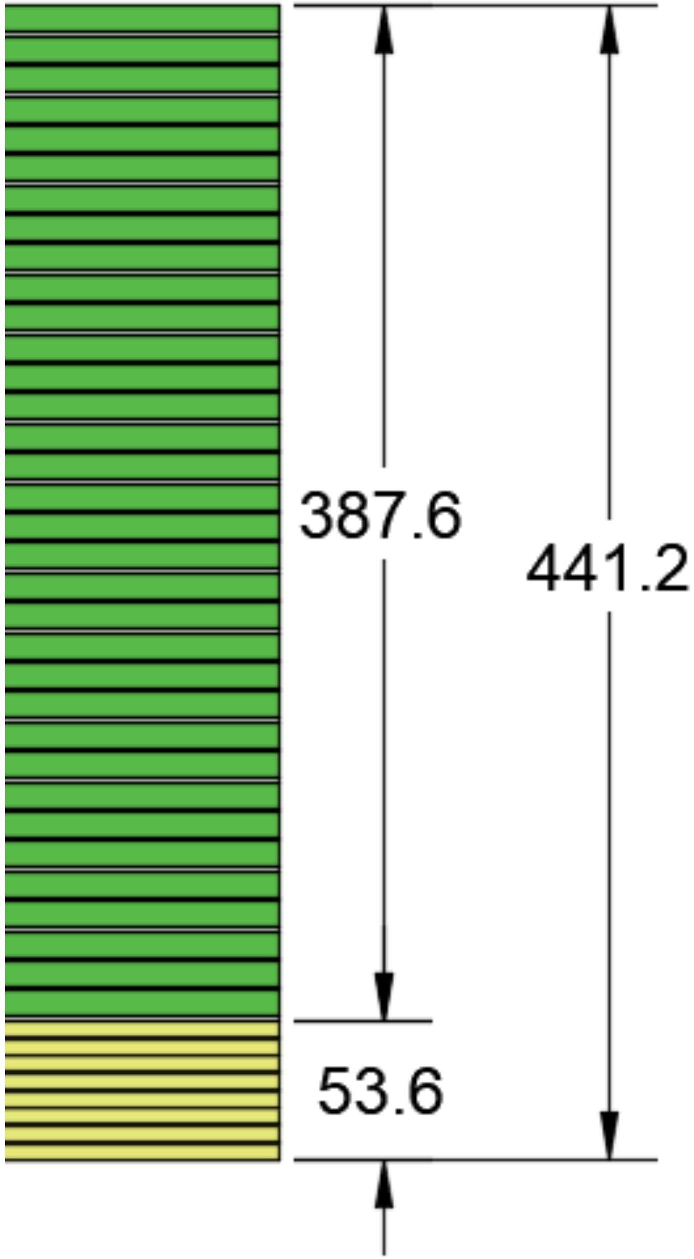
- gas TPC
  - Interactions on argon
  - Homogeneous efficiency for charged particles
  - Particle ID
  - Low threshold
  - Can’t detect neutral particles
- not really an **E** or **Cal**
  - Measure energy and direction of neutral particles
  - Photons: calorimetry
  - Neutrons: energy from time of flight
  - Muon-Pion separation

ECal Composition

- Scintillator + Lead Sandwich
- Total ECal thickness around 450 mm
- 8 high granular tile layers for **high granularity**
  - 0.7 mm lead + 6 mm scintillator
- 34 crossed strip layers
  - 1.4 mm lead + 10 mm scintillator
- All readout SiPM based

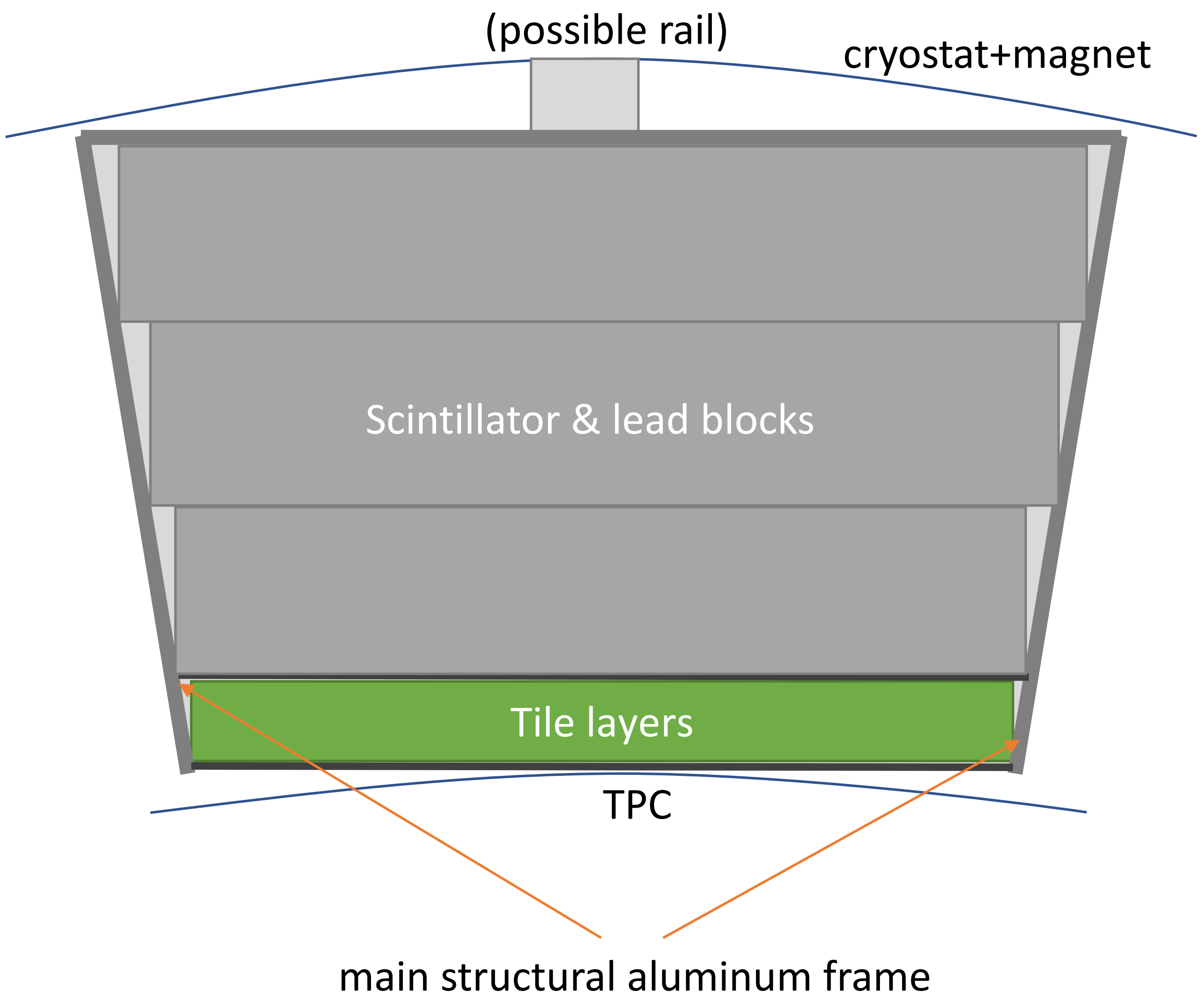






Modular Structure

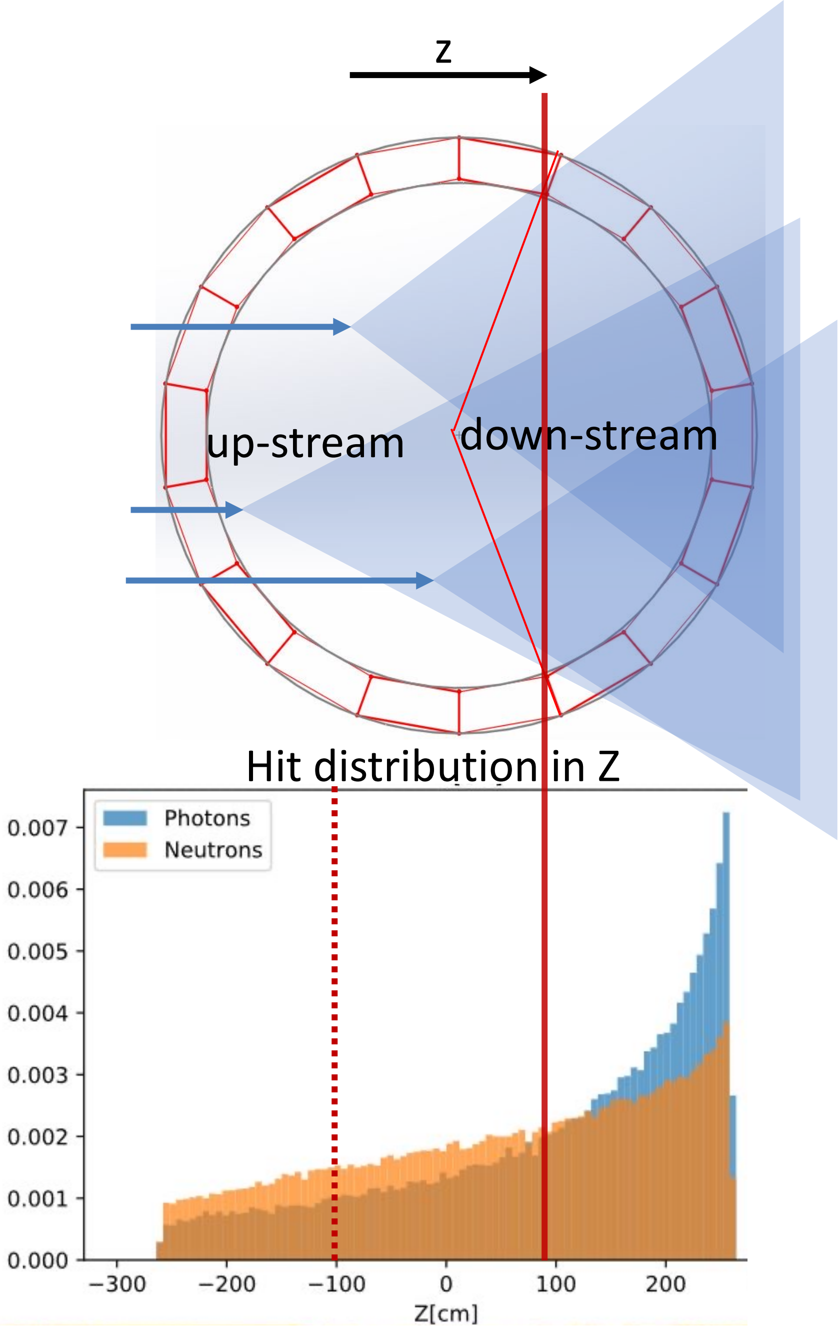
- Main frame made of aluminum
- Support towards TPC made of carbon fiber
- Minimal un-instrumented area between active elements
- Module internals separated in different segments
  - Tile layers
  - 10-15cm thick strip segments



Fixed Target Kinematics

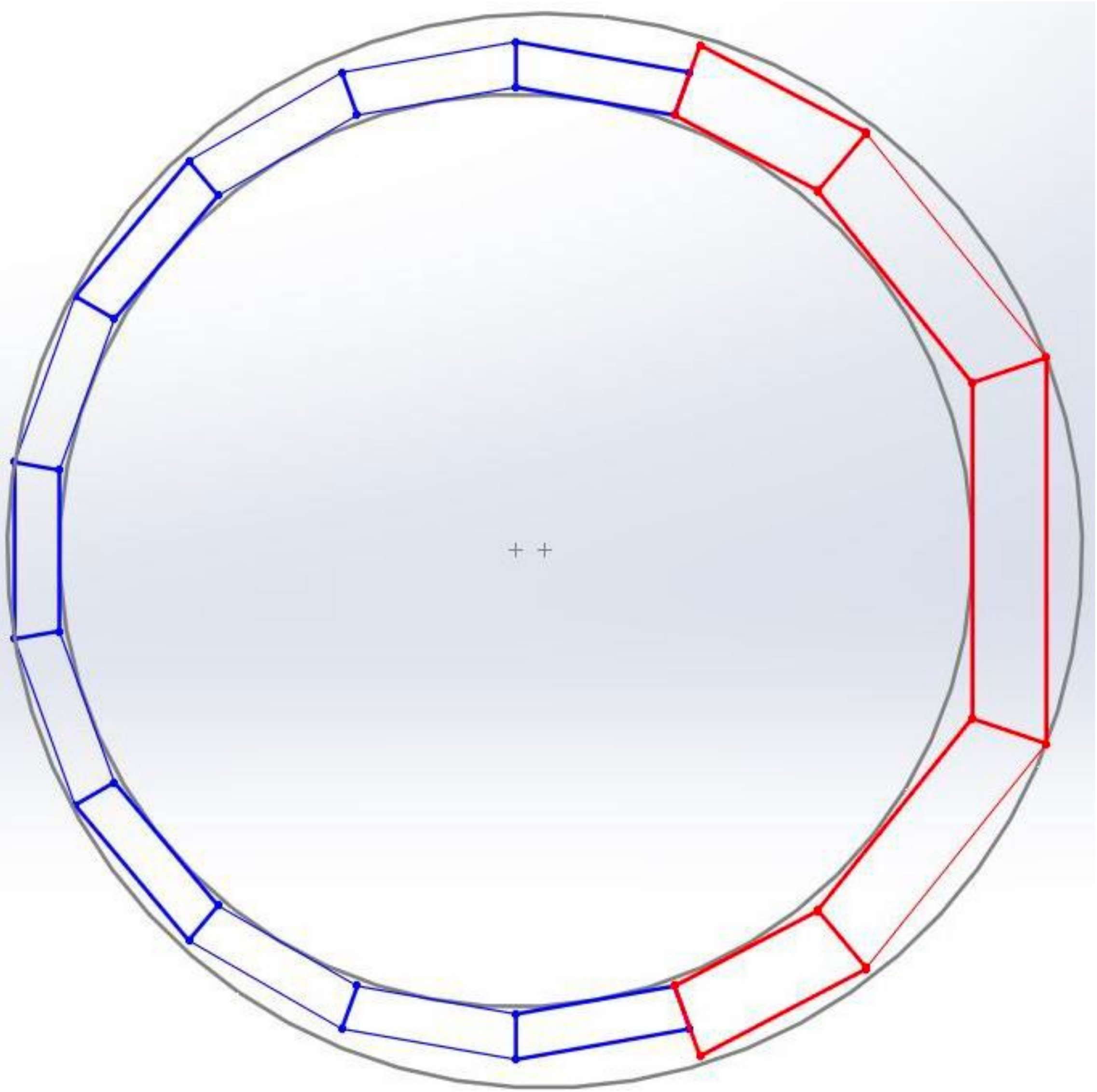
- Main energy deposition in experiment in down stream direction
- Use of resources should be focused on down stream detector
- Idea: off-center TPC, less ECAL up-stream

- Important variables for design considerations:
  - Un-instrumented area in forward direction
  - Cost / # of channels (double sided strip readout)
  - Outer radius / clearance in shaft



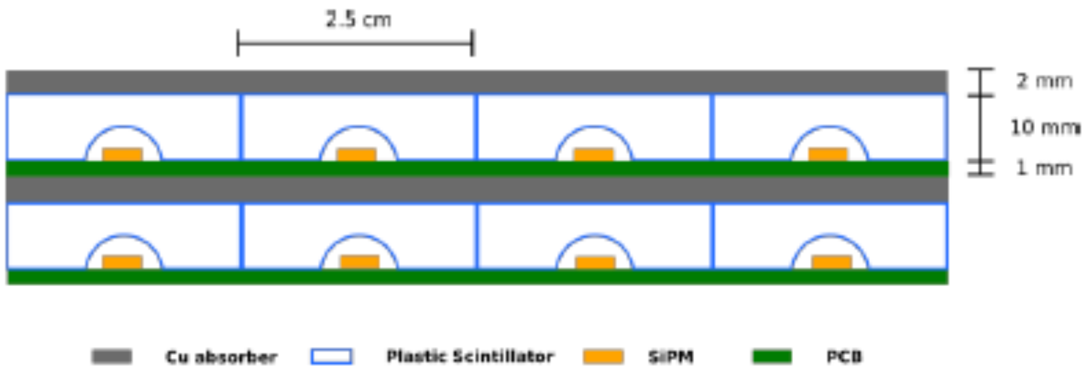
Module Structure

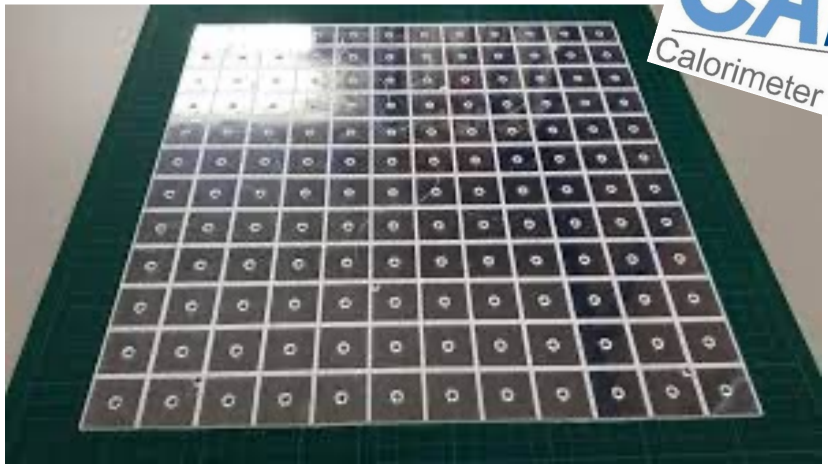
- ECal does not have to be the same in all directions
  - More particles go forward
  - Higher energy particles go forward
- Optimisation
  - Thinner detector in backward direction
  - Different absorbers
  - Optimise for low energy photons
- 0^{th} order could look like this
- Detailed optimisation has not been performed

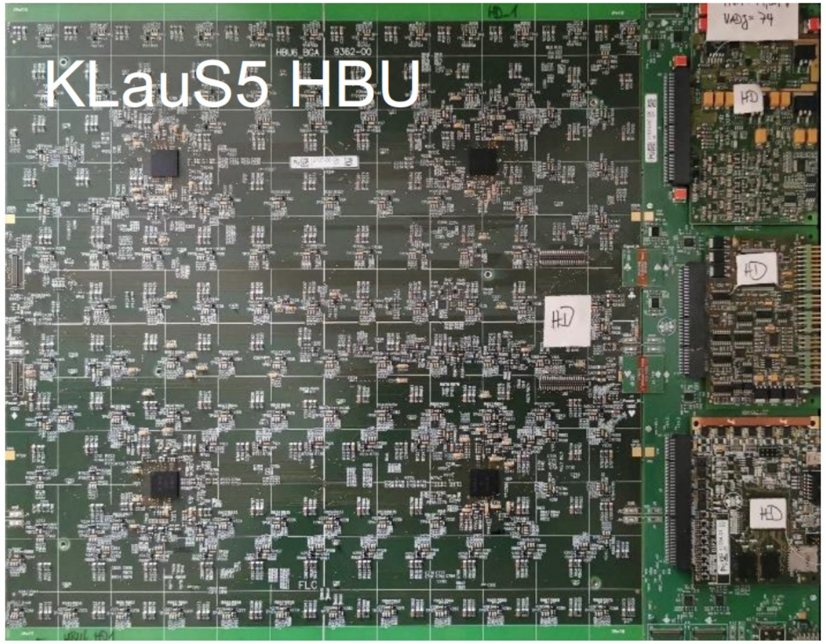


Tile Layer

- Technology developed for particle flow calorimetry
- Scintillating tiles & SiPMs
- Electronics based on KLauS ASIC
- Flexible design
  - Granularity
  - Absorber/scintillator thickness

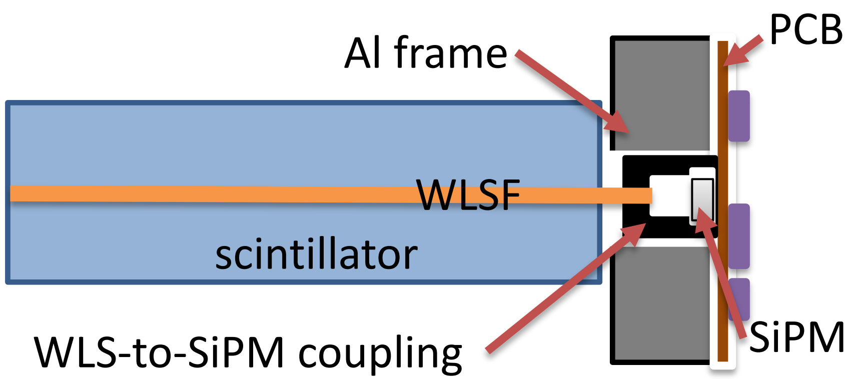


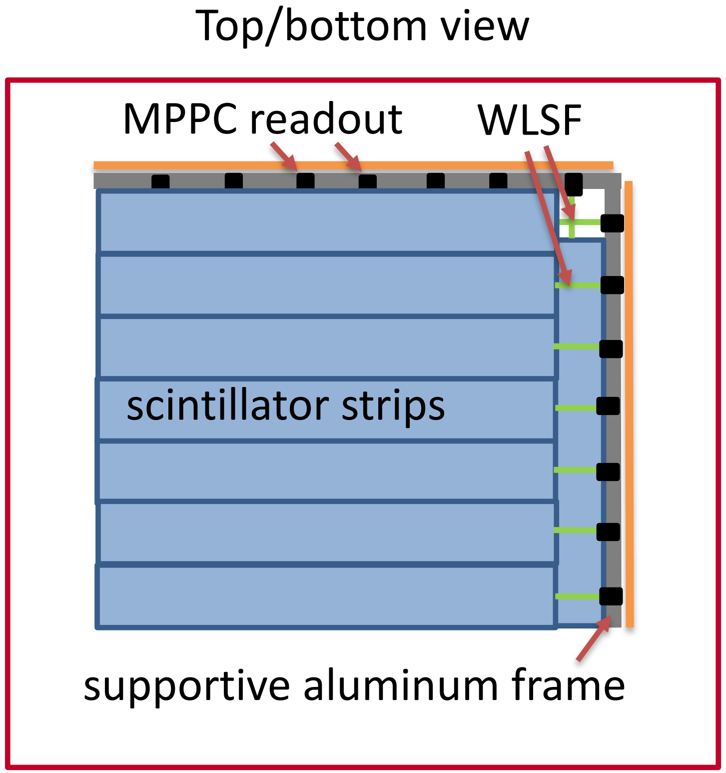


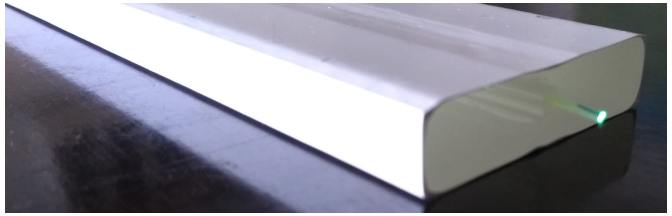


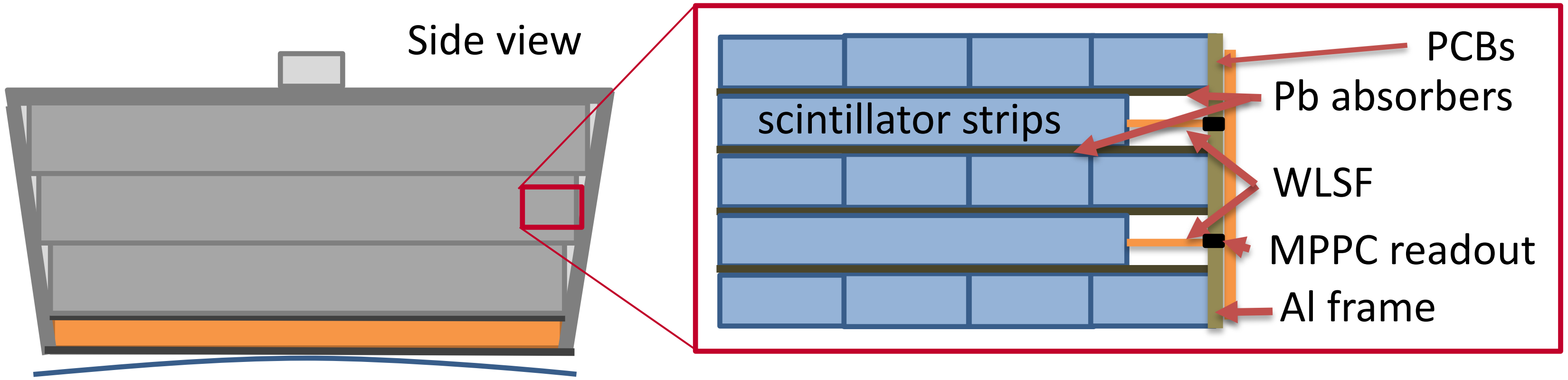
Strip Layers

- Reduced granularity (projective geometry)
- Can adjust
  - Absorber, scintillator, dimensions
- WLS fibre & SiPM readout
- KLauS ASIC



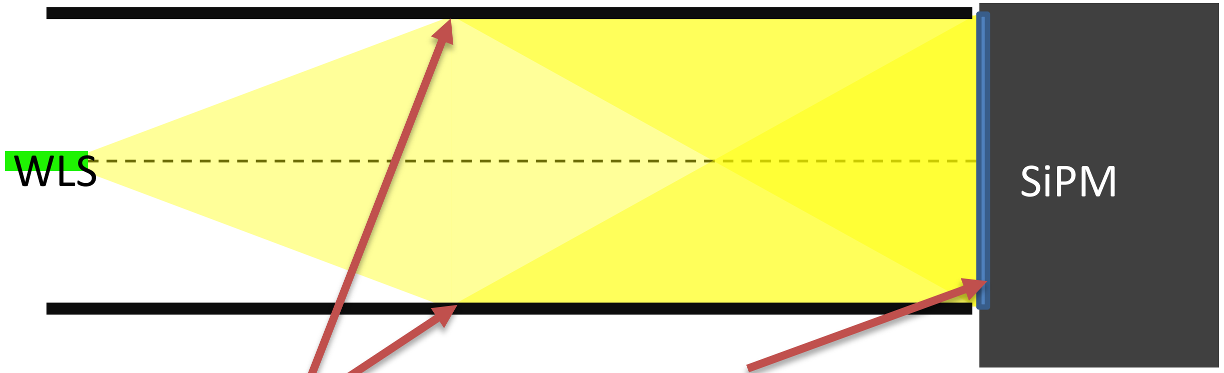


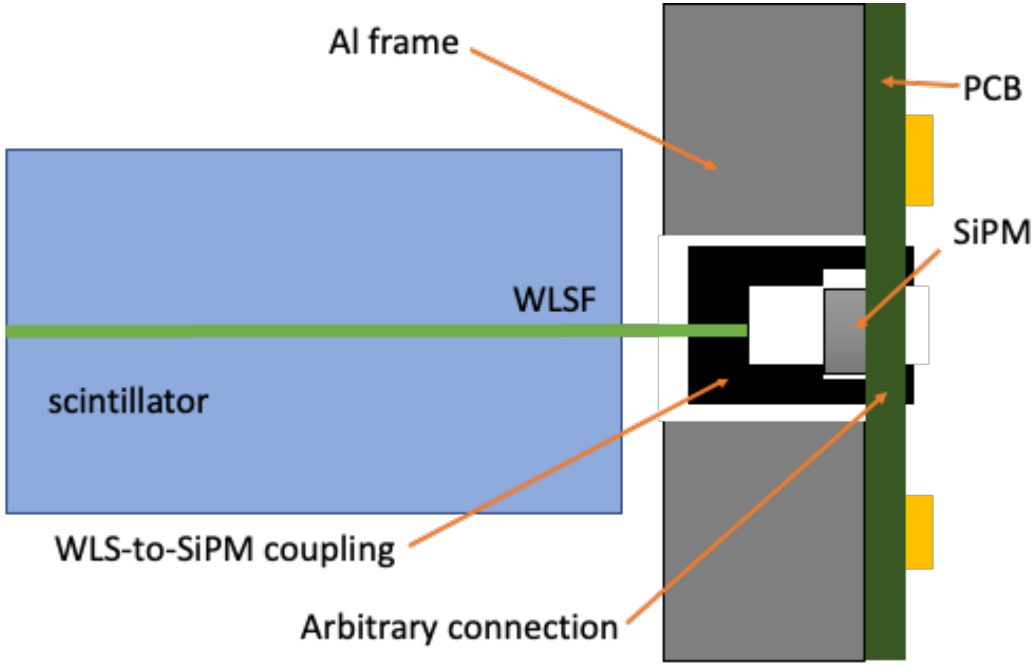


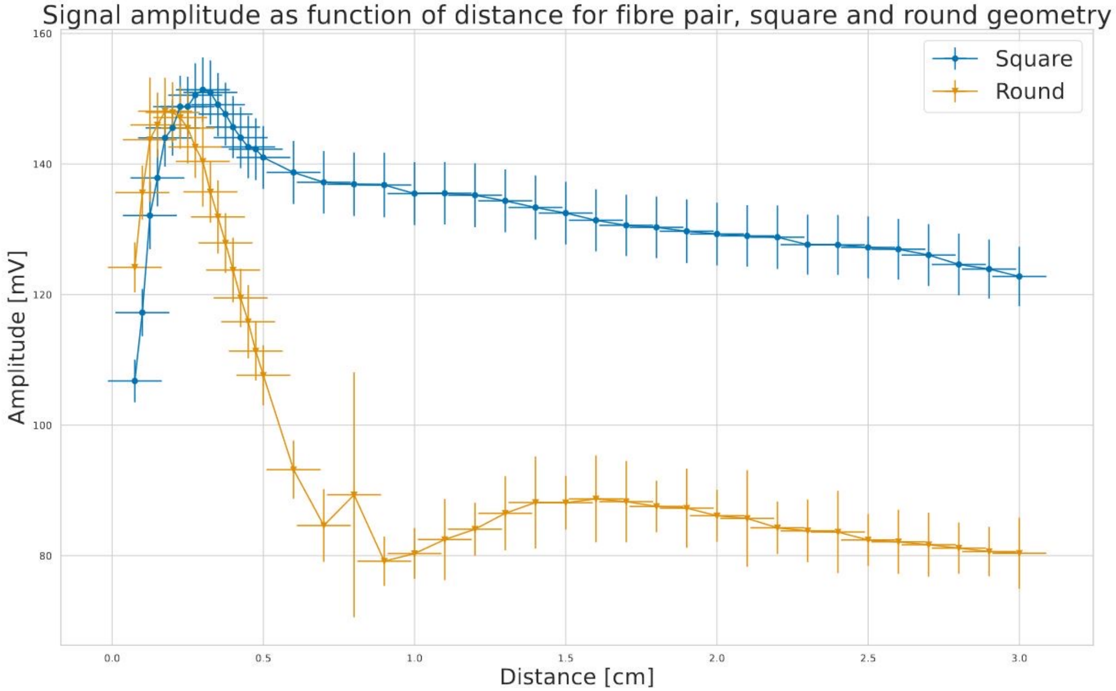


SiPM to Fibre Coupling (II)

- Consideration
  - Maximize light on SiPM
  - Illuminate SiPM homogeneously
  - Don't loose any photons



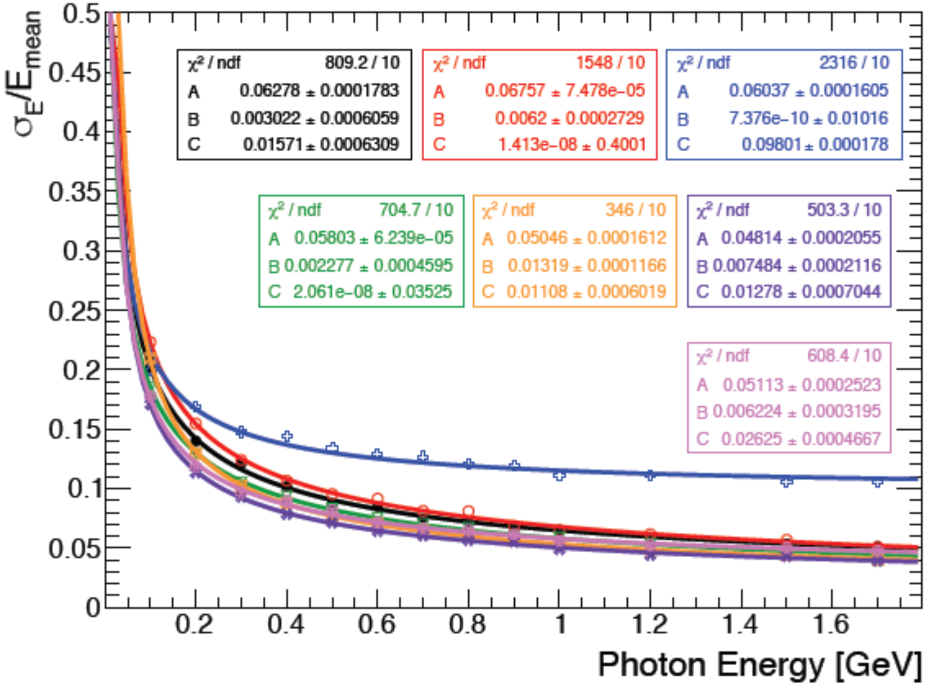


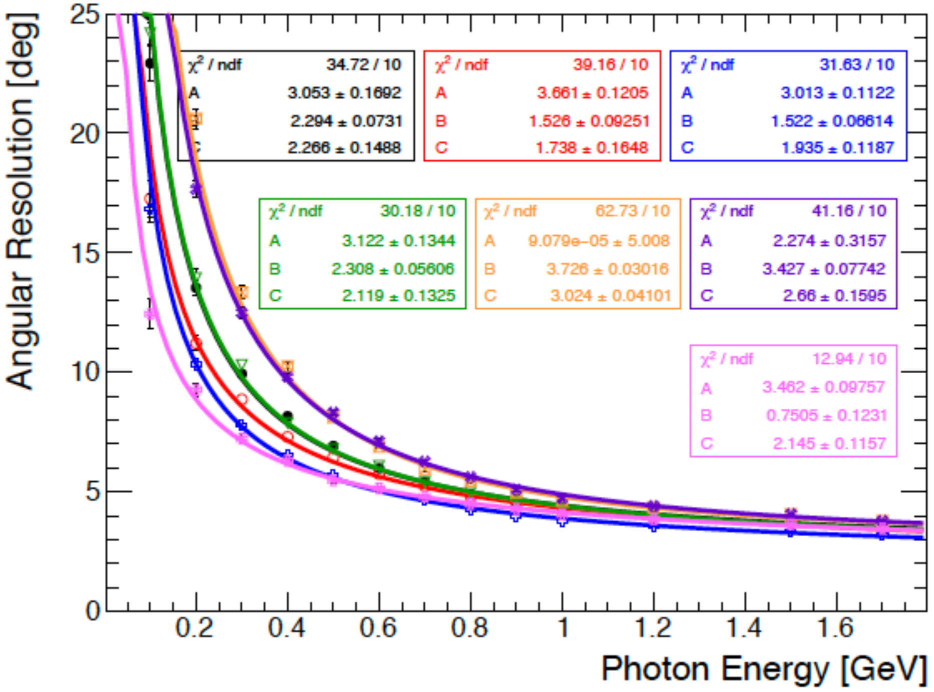


Angular and Energy Resolution for EM-Particles

- Try different configurations
  - location of tile layers
  - Absorber material/thickness
  - Scintillator layers

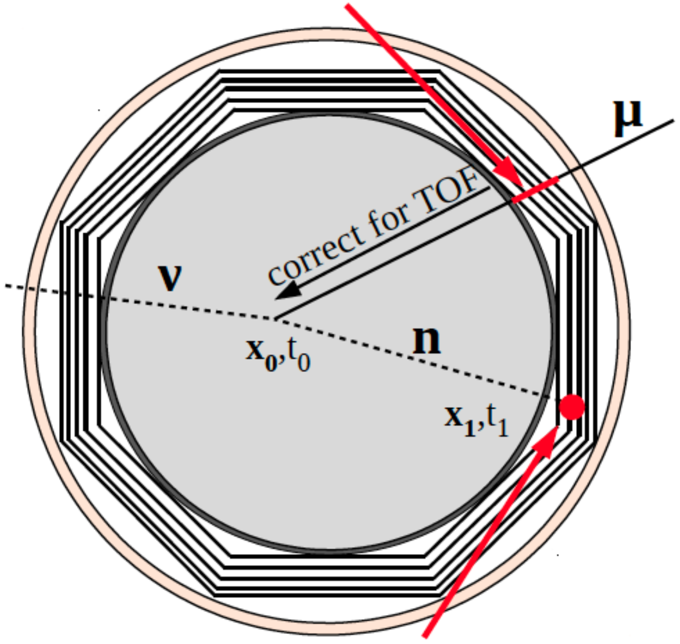
- **Design**:
  - All - *keeping the overall same ECAL thickness* (~14 X_0)
  - **Setup 1** (black) → 8 HG + 16 LG + 4 HG + 31 LG (HG: 2mm Cu, 10 mm tile/LG: 4 mm Cu, 5 mm strip)
  - **Setup 2** (red) → 8 HG + 47 LG (HG: 2mm Cu/LG: 4 mm Cu) → **arrangement of HG/LG layers**
  - **Setup 3** (blue) → 8 HG + 12 LG, 2 mm Cu + 35 LG, 4 mm Cu → **thinner absorber in front layers**
  - **Setup 4** (green) → 8 HG + 92 LG, 2 mm Cu, cross-layers → **thinner absorber for LG layers**
  - **Setup 5** (orange) → 8 HG, 3 mm tile + 100 LG, 2 mm Cu, cross-layers → **thinner HG tile**
  - **Setup 6** (purple) → 8 HG, 5 mm tile + 97 LG, 2 mm Cu, cross-layers → **thinner HG tile**
  - **Setup 7** (light pink) → 80 HG, 5 mm tile → **sanity check with Lorenz results**

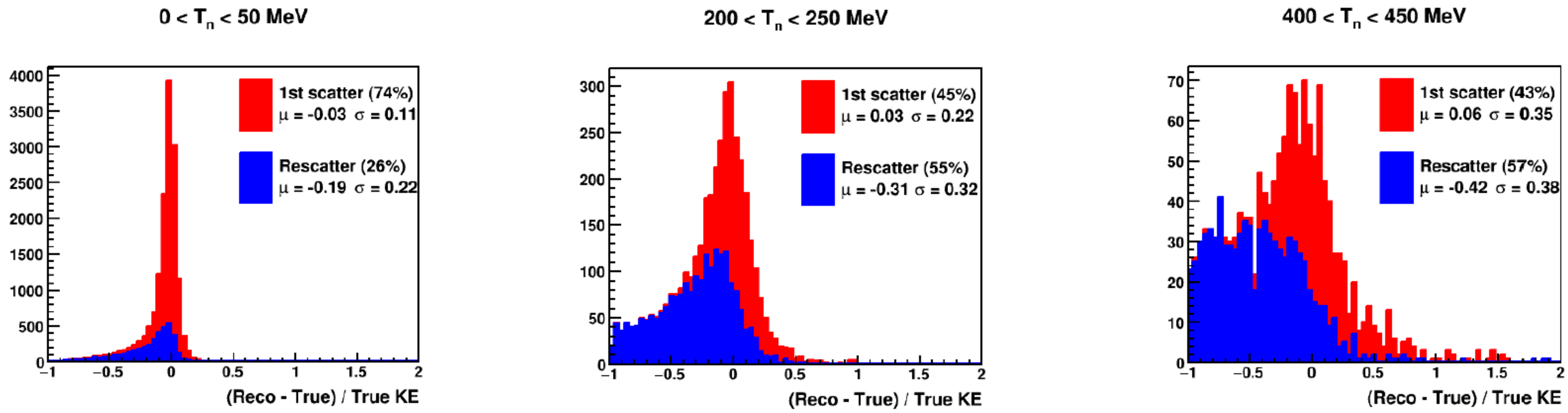




Neutron Detection and ToF

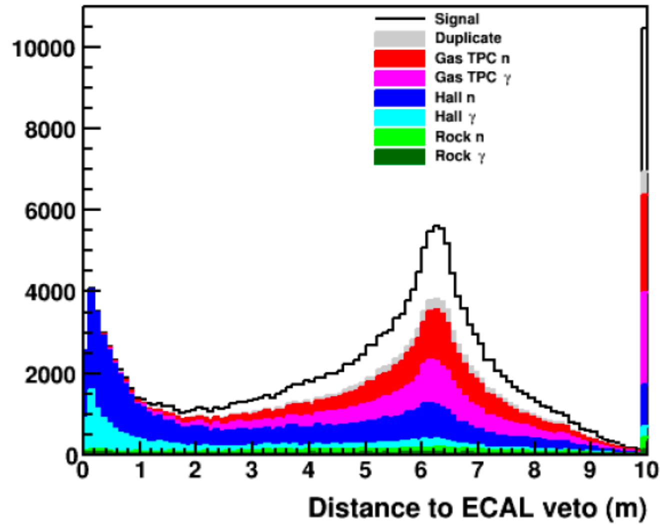
- Determine neutron energy from time-of-flight
- t_0 from
  - Scintillation light in argon
  - back propagation of muon timing
- t_1 from single hit in ECal

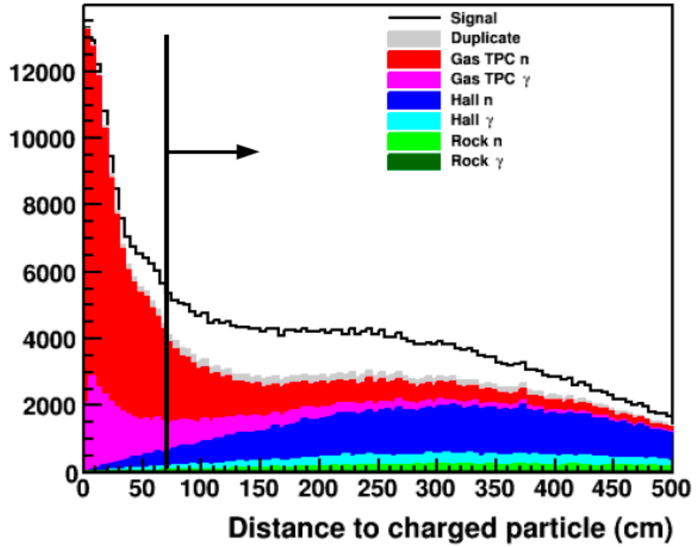


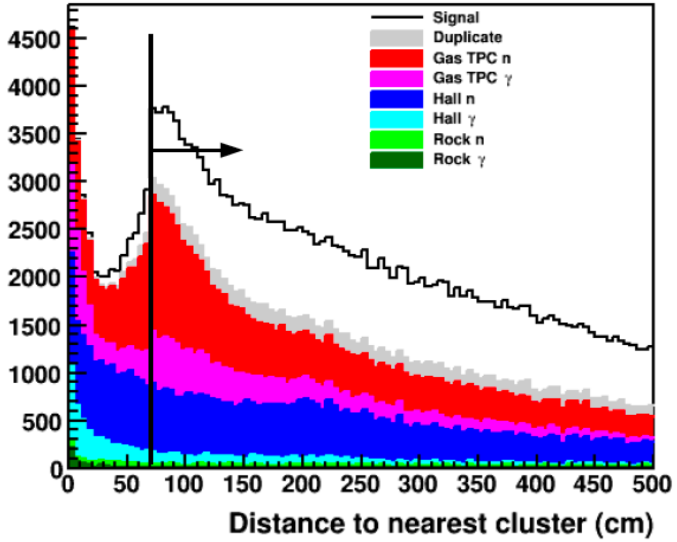


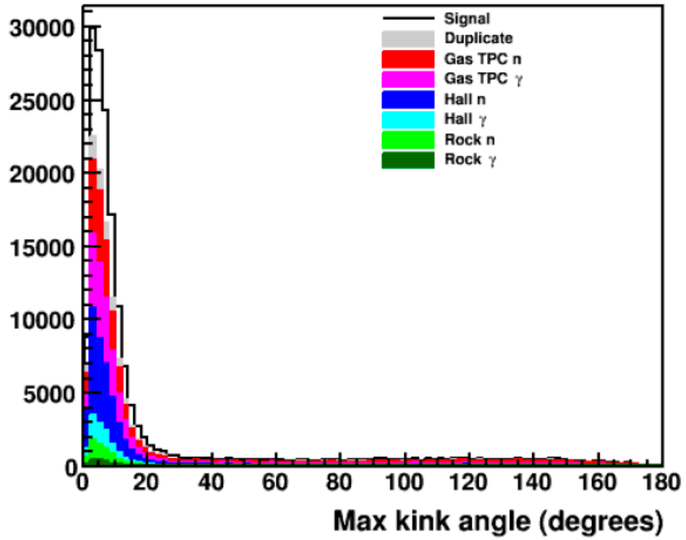
Neutron Selection

- Full simulation of full spill including rock interactions
- Selection
  - Distance to charge particles
  - Distance other EM activity
  - Kinks in TPC tracks



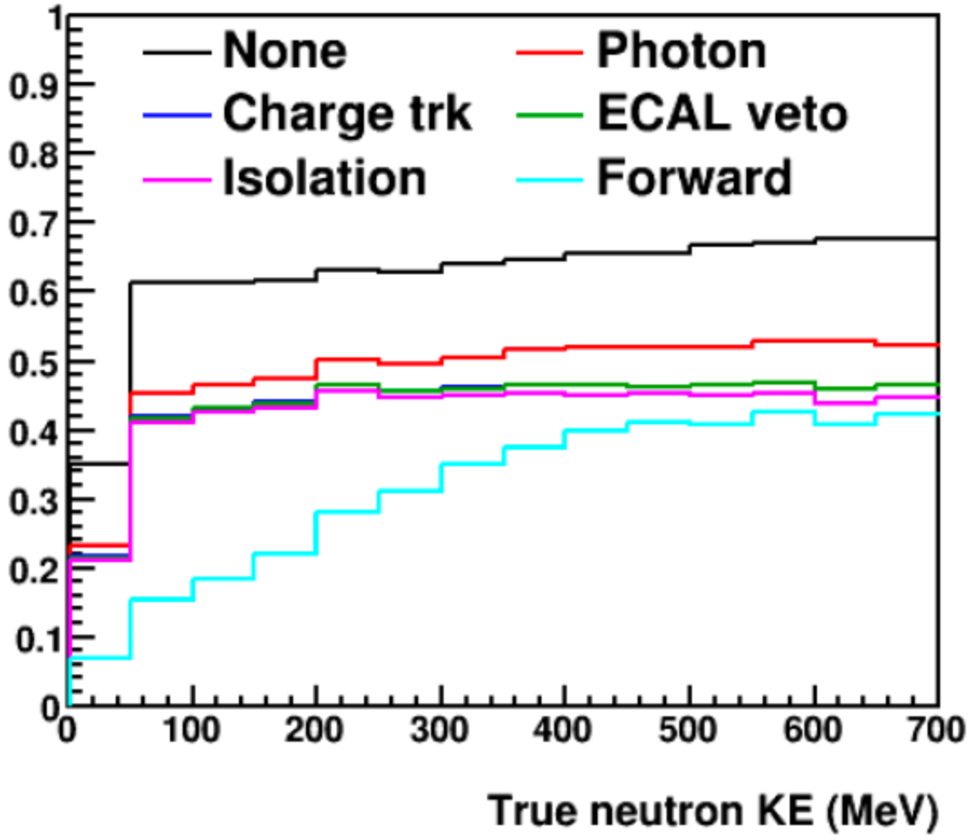


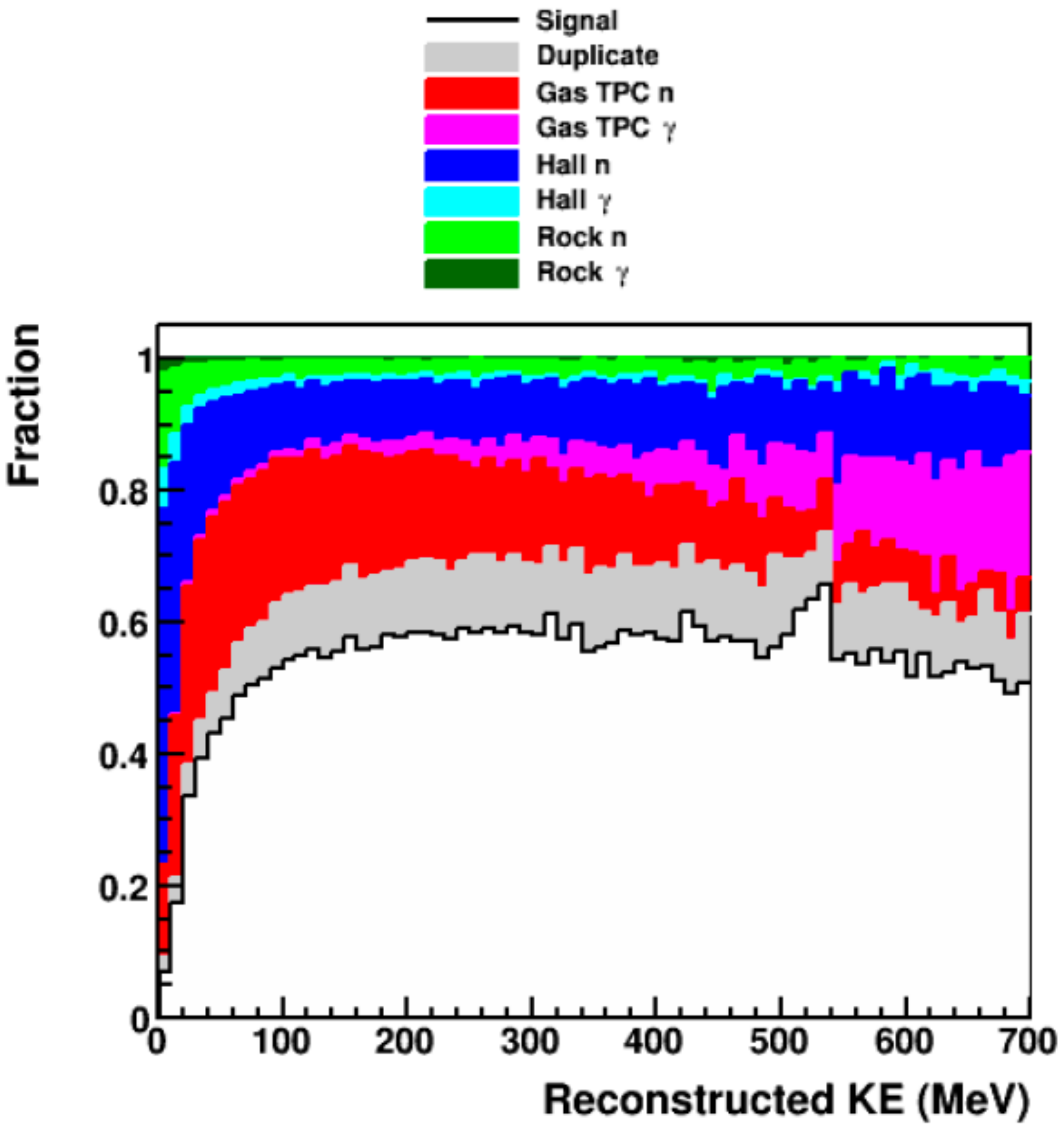




Neutron Detection and ToF

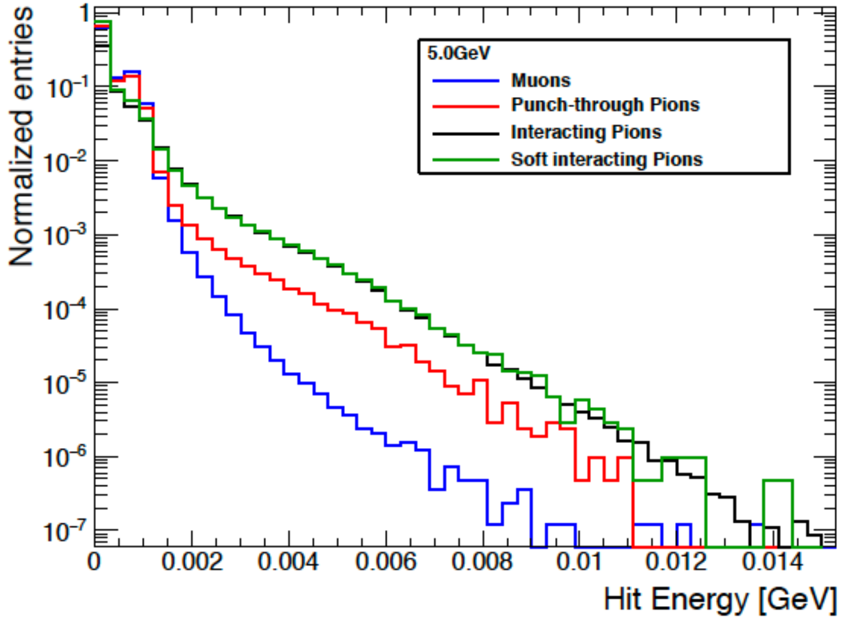
- Neutron can be identified
  - 50% purity
  - 20-40% efficiency

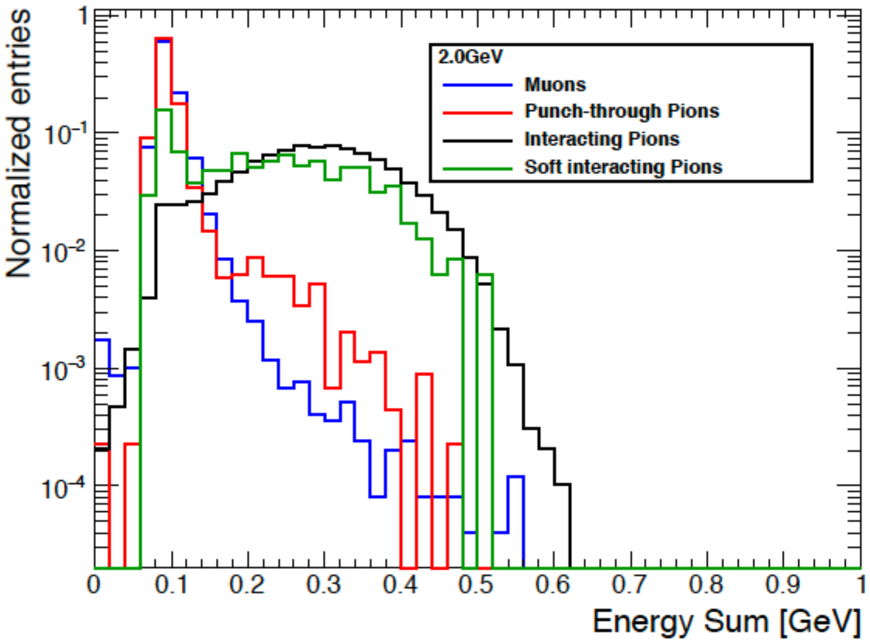




Muon/Pion Separation

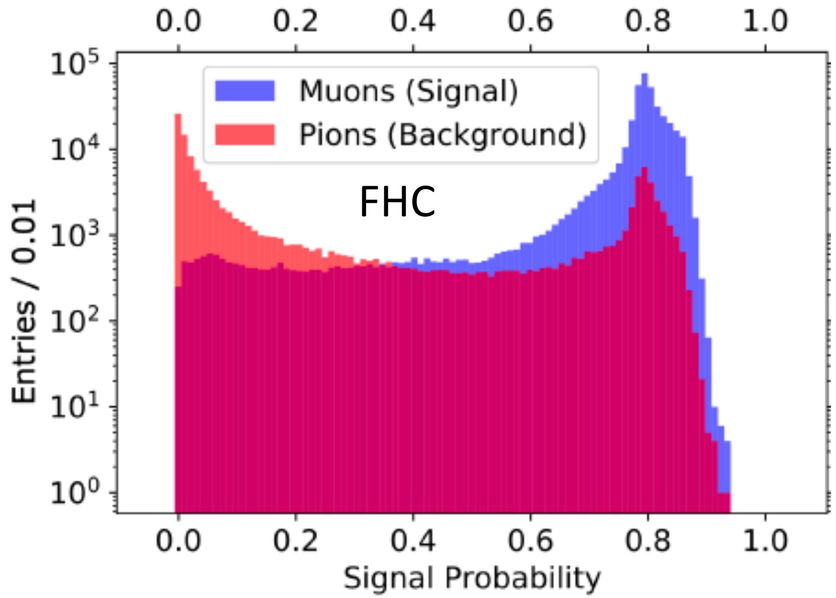
- Pions and muons cannot be separated in TPC via dE/dx
- Hadronic interaction of pion helps PID
- Interactions in magnet yoke
  - Current design has no instrumentation in or ouside yoke
- Interaction in ECal
  - Substantial fraction of pions punch through
  - Could change back of ECal material
- Use ECal variables in BDT

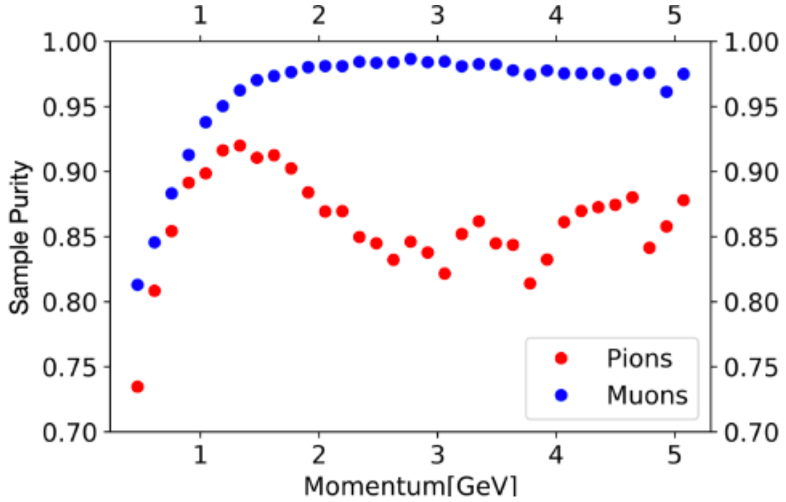


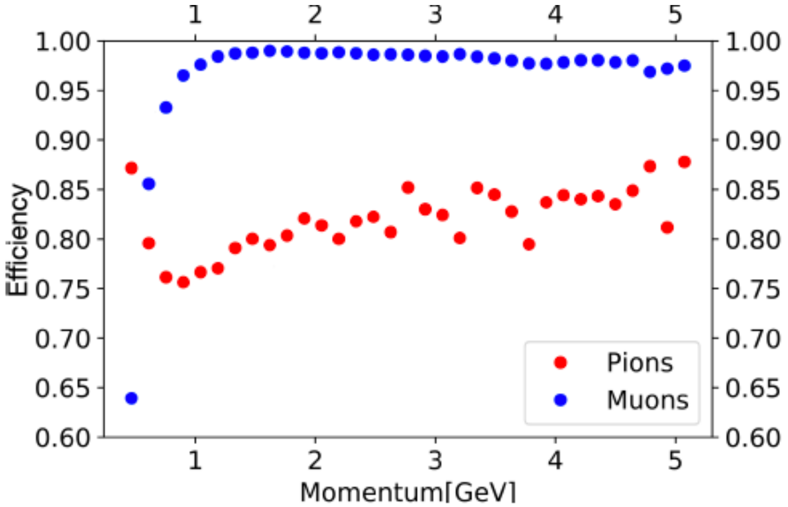


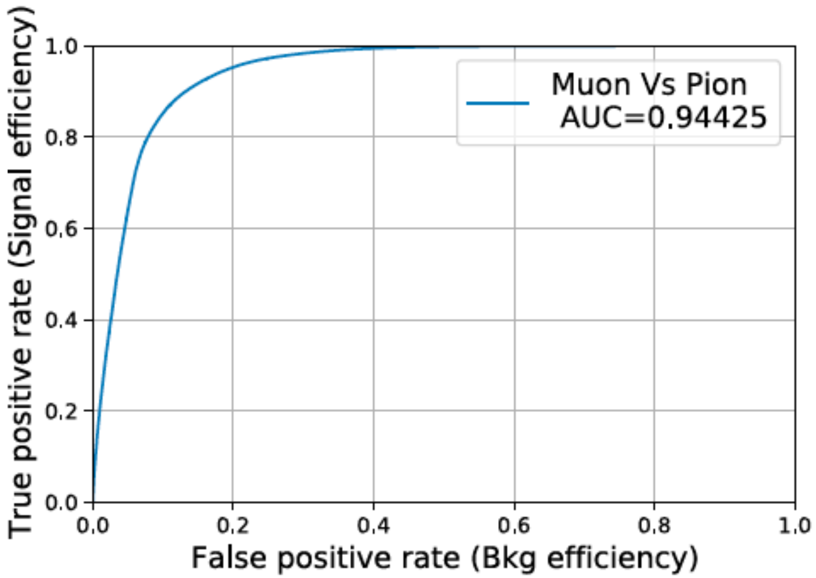
BDT for muon/pion PID

- **Energy Sum**: Reconstructed energy sum of an event in the calorimeter
- **Energy Sum - MuID**: Reconstructed energy sum of an event in the muon ID
- **Number of Hits**: Reconstructed number of hits in the calorimeter
- **Number of Hits - MuID**: Reconstructed number of hits in the muon ID
- **Mean Hit Energy**: Mean hit energy in the calorimeter
- **Mean Hit Energy - MuID**: Mean hit energy in the muon ID
- **StdDev Hit Energy**: Standard deviation of hit energies within one event in the calorimeter
- **StdDev Hit Energy - MuID**: Standard deviation of hit energies within one event in the muon ID
- **Maximum Hit Energy**: Maximum hit energy in the calorimeter
- **Maximum Hit Energy - MuID**: Maximum hit energy in the muon ID









Open Questions & To-Dos

- No complete detector design
- Figures of merit
  - Photon energy & angular resolution
  - Pion/muon separation
  - neutron ID and ToF
- No comprehensive optimisation for physics nor cost
- What does the detector have to do?
  - Physics channels
  - How does it improve oscillation systematics?
- Detector & cost optimisation
  - Will need preliminary engineering design

Summary

- The not only ECal device is an important component of a geasous argon detector
  - El.mag. Calorimetry
  - Neutron ToF
  - Pion/muon separation
- Version 1 design and optimisation has been performed
  - as part of the ND-GAr concept
  - Further optimisation is possible/needed
    - Cost & performance
  - Will need to be adapted to potentially different detector layouts
- New ideas welcome!

Backup

SiPM to Fibre Coupling

- Fibre needs to optimally matched to fibre
- Objectives
  - Mechanical stability
  - Maximum dynamic range
  - High light level