ECAL for the MPD.

DUNE ND Workshop

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DEEP UNDERGROUND NEUTRINO EXPERIMENT

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RESEARCH FOR GRAND CHALLENGES

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Outline.

- ECAL Motivation and Design
- Technical choices
- Performance
    - Geometry design
    - Absorber
    - Segmentation
- Ongoing work and future plans

The MPD ECAL - Concept.

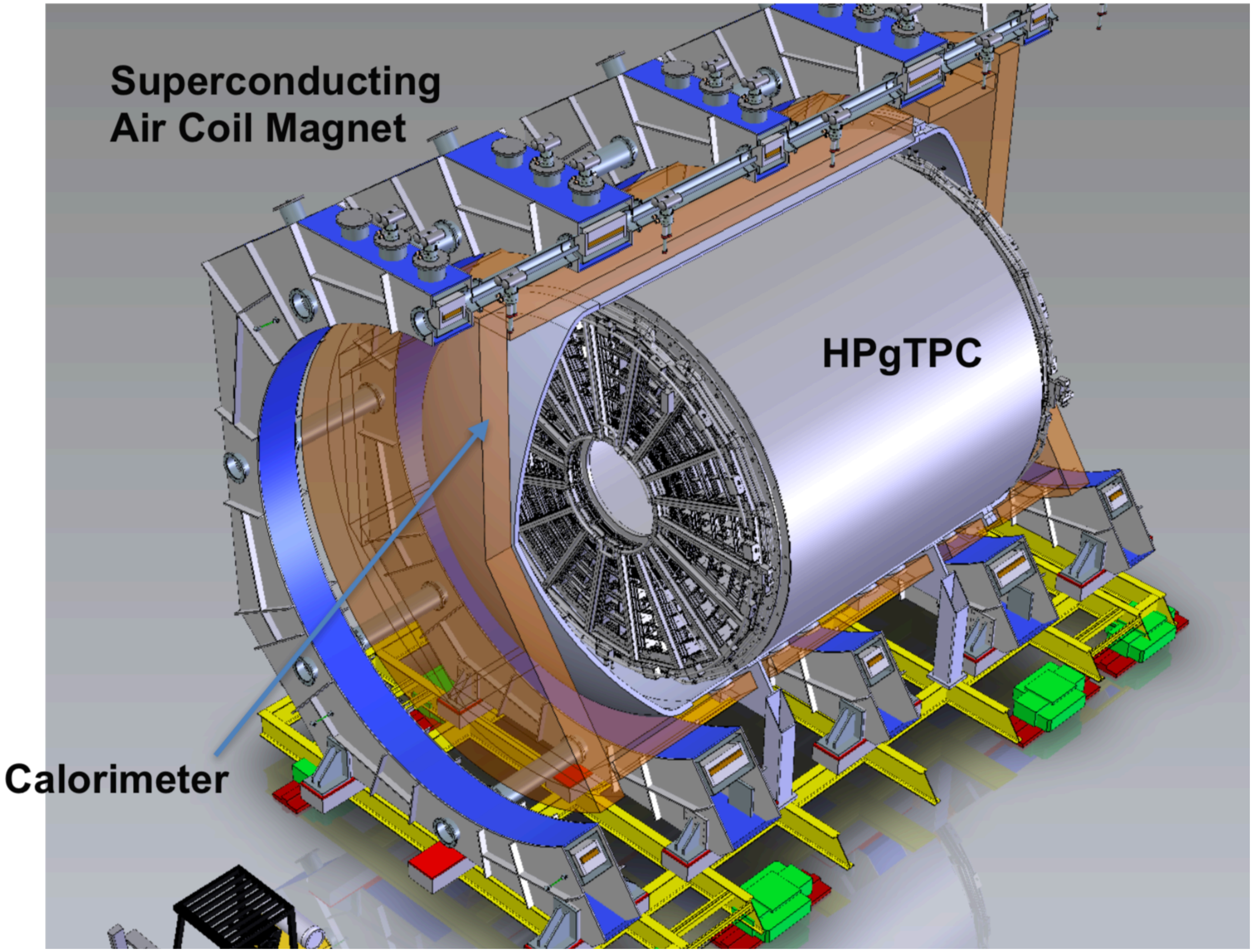
Goals

- MPD ➠ high precision measurements of neutrinos on Ar
  - Need for full coverage and precise measurement of charged and neutral particles
- The MPD ECAL will complement the HPgTPC by providing
  - Photon energy measurement
  - Neutral pion measurement
  - Particle identification (over 1 GeV/c)
  - Precise time measurement ➠ tagging the interaction window to reduce OFV background
  - Ideally ➠ detected neutrons and measure their energy
- Energy range between few MeVs to few GeVs!
  - ➠ requires a small stochastic term
  - ➠ longitudinal/lateral segmentation

The MPD ECAL.

Key numbers

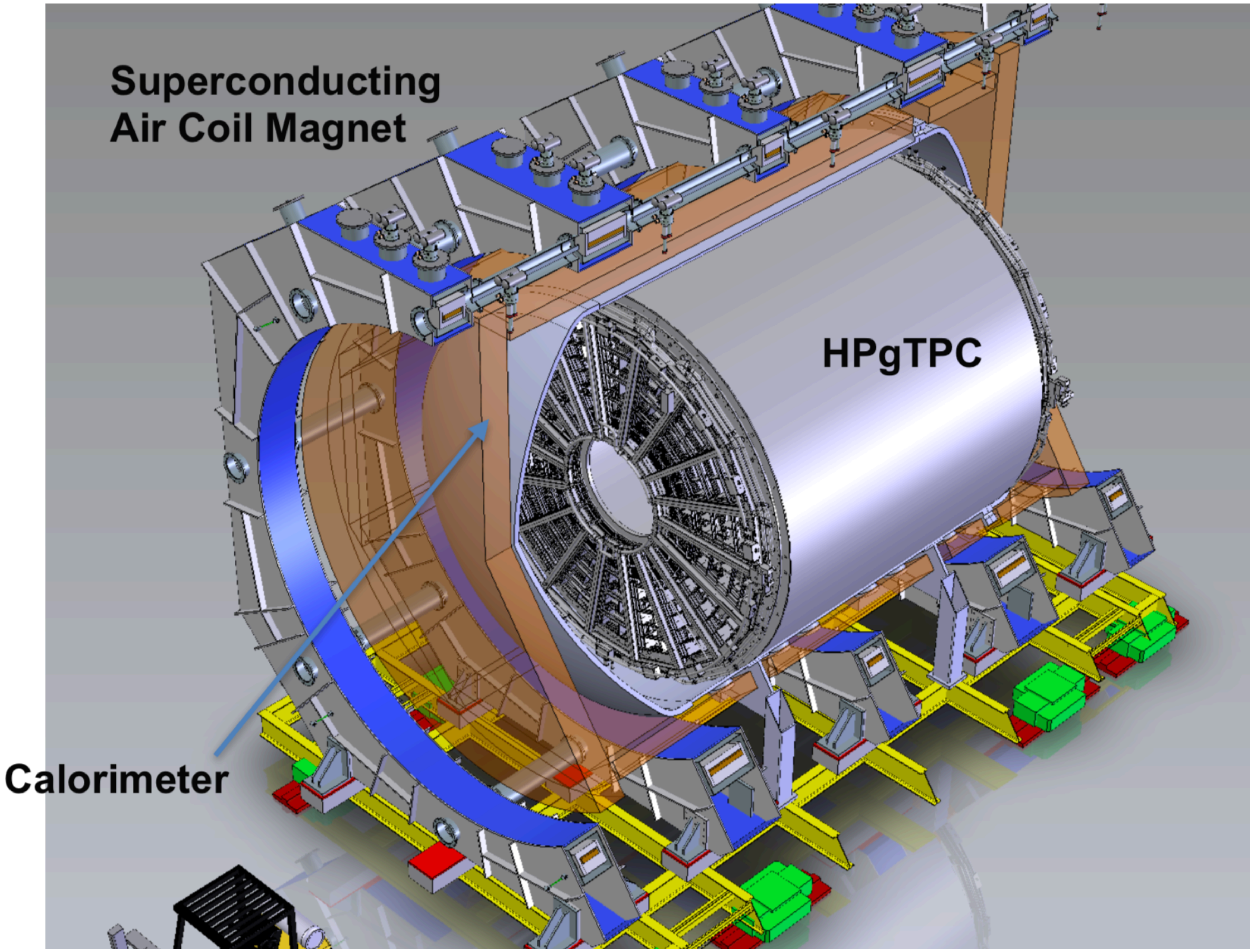
- Energy resolution
  - ~5-6%/Sqrt(E[GeV])
  - Need for thin absorbers
- Pointing resolution
  - ~few deg /Sqrt(E[GeV])
- ➠ drives longitudinal segmentation / granularity
- Neutrons ➠ few 100 ps - 1 ns time resolution



The MPD ECAL.

Bondary conditions

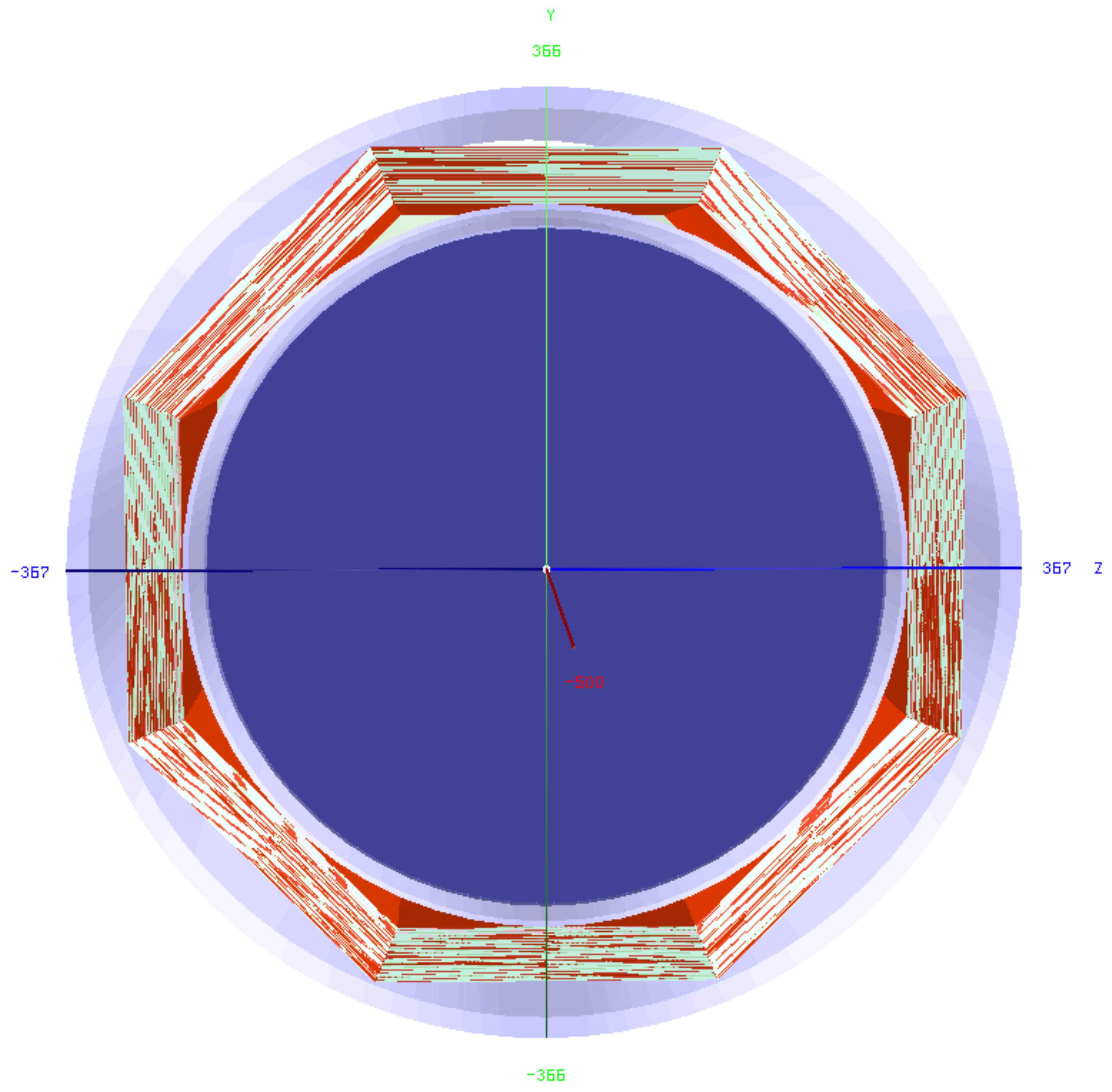
- ECAL surrounds the pressure vessel
  - TPC: 2.7 m radius, 5.5 m length
- ECAL needs to accommodate this and the PV
  - Radius 2784.5 mm
  - Length 7288.5 mm
- Total surface
  - 120 m2 for the barrel
  - 24 m2 per endcap
- This is huge!
  - Comparison CMS ECAL
    - 1.3 m radius, 5.8 m length

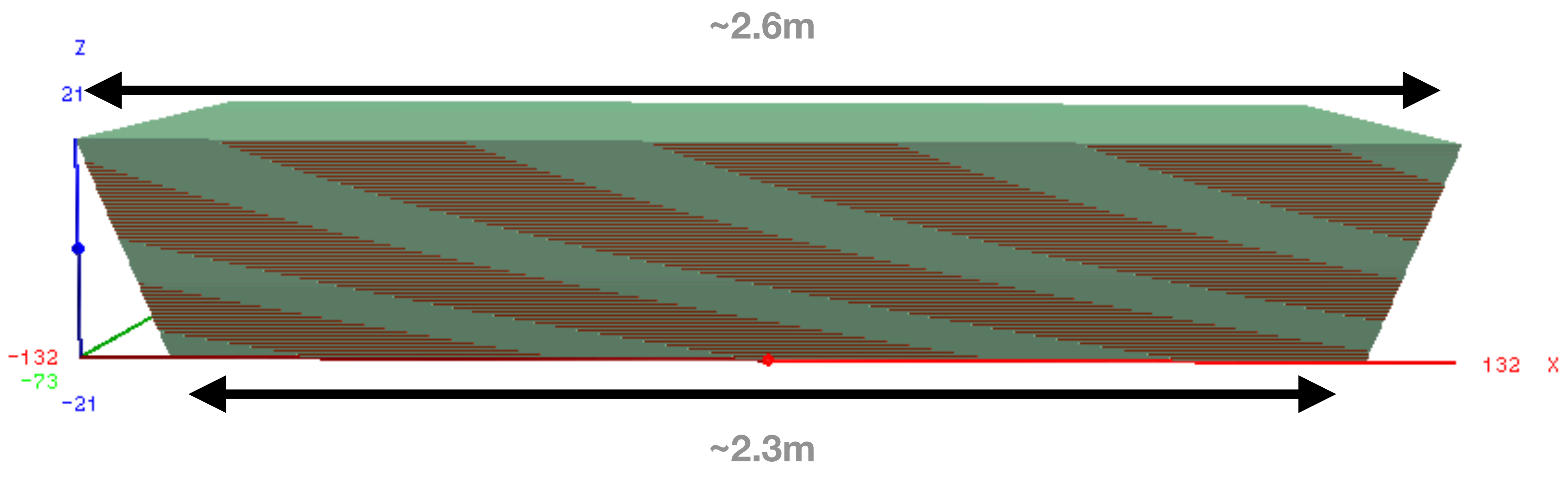


The ECAL design (as in the CDR).

Geometry (Baseline)

- Best approximation of cylinder
  - ➠ Octagonal geometry
- Small side length ~2.3m, Large side length ~2.6m, Width ~1.5m
- Total weight ~ 300t ➠ Lots of bkg! (~1/60 ratio between TPC/ECAL)
- Barrel divided in 5 sub-modules 1.46 m long
- Endcap divided in quarters - 4 modules per side

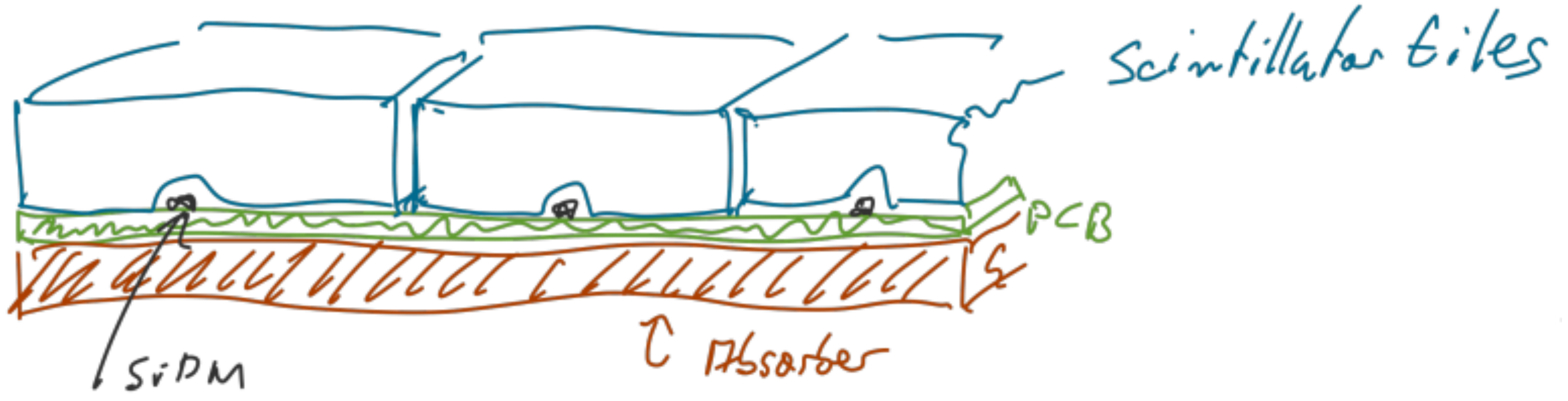


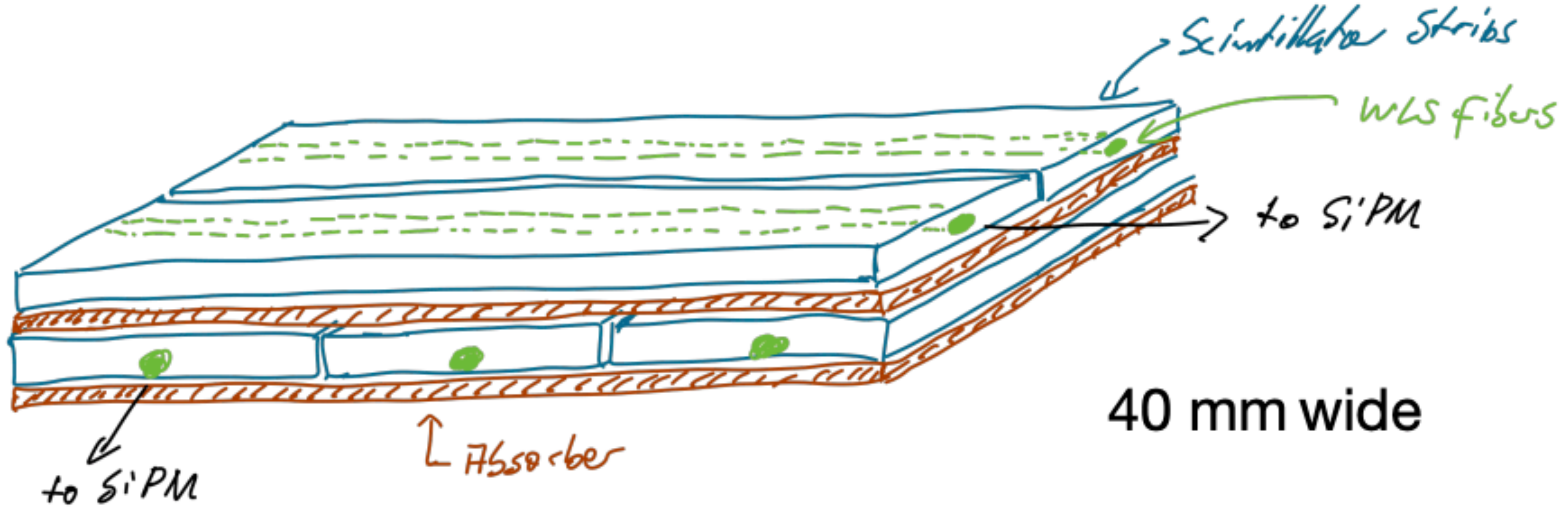


The ECAL design (as in the CDR).

Geometry (Baseline)

- Absorber using very thin sheets of copper (2 mm)
  - ~cm radiation length and “Small” Molière radius
    - ➠ larger spread of the shower along its main axis, helps in the reconstruction of the photon axis
- Granularity, two levels:
  - High granular layers with tiles of 2.5x2.5x5 cm^3 readout with SiPM
  - Low granularity layers with strips of 4 cm width readout on both sides
- High granularity only in first 8 (6) layers for 3 downstream (5 upstream) segments - under optimization
- Assuming spatial resolution along strip via time difference in two-sided readout
- Channel count:
  - 2,394,183 tiles and 142,030 strips



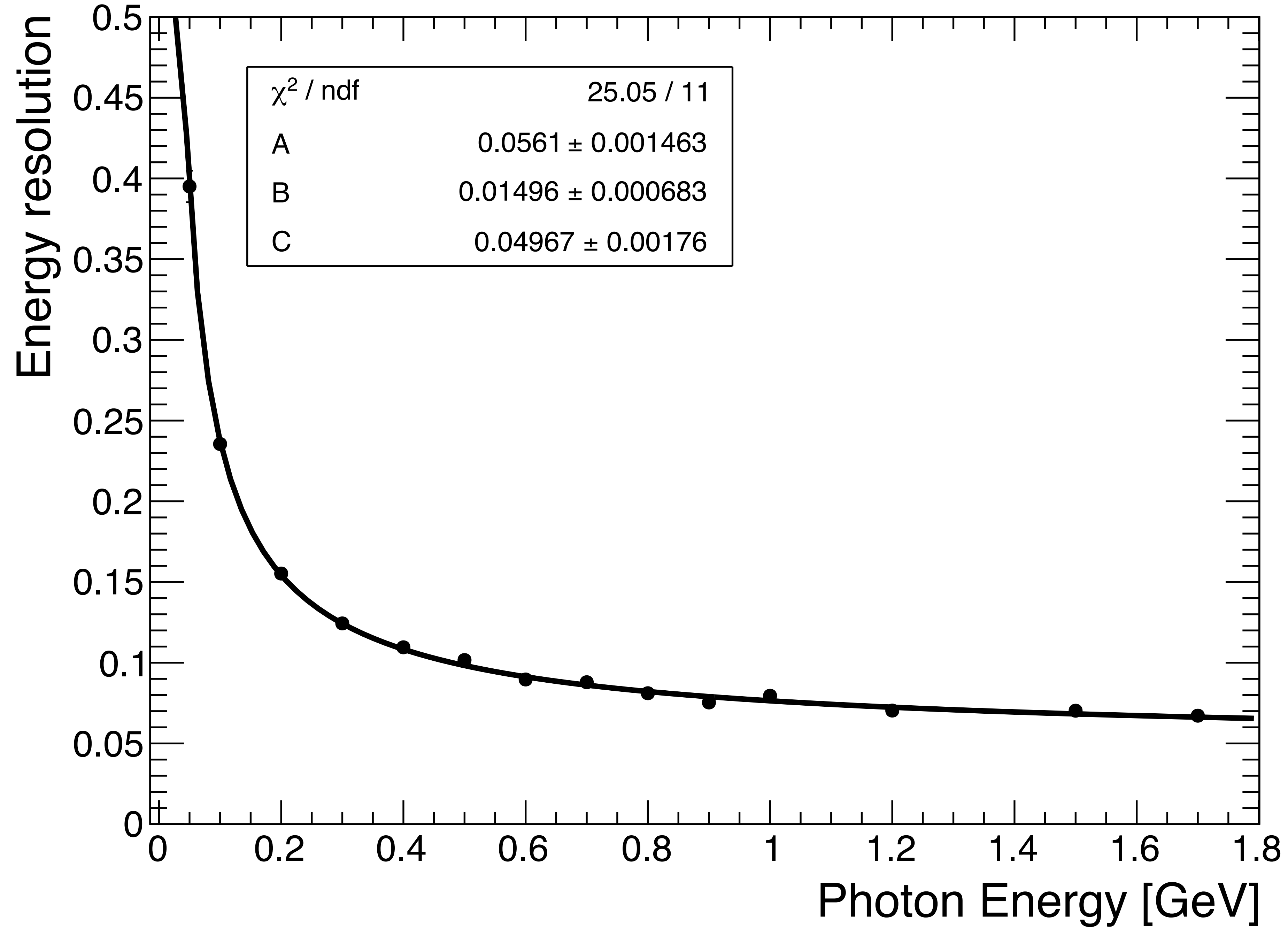


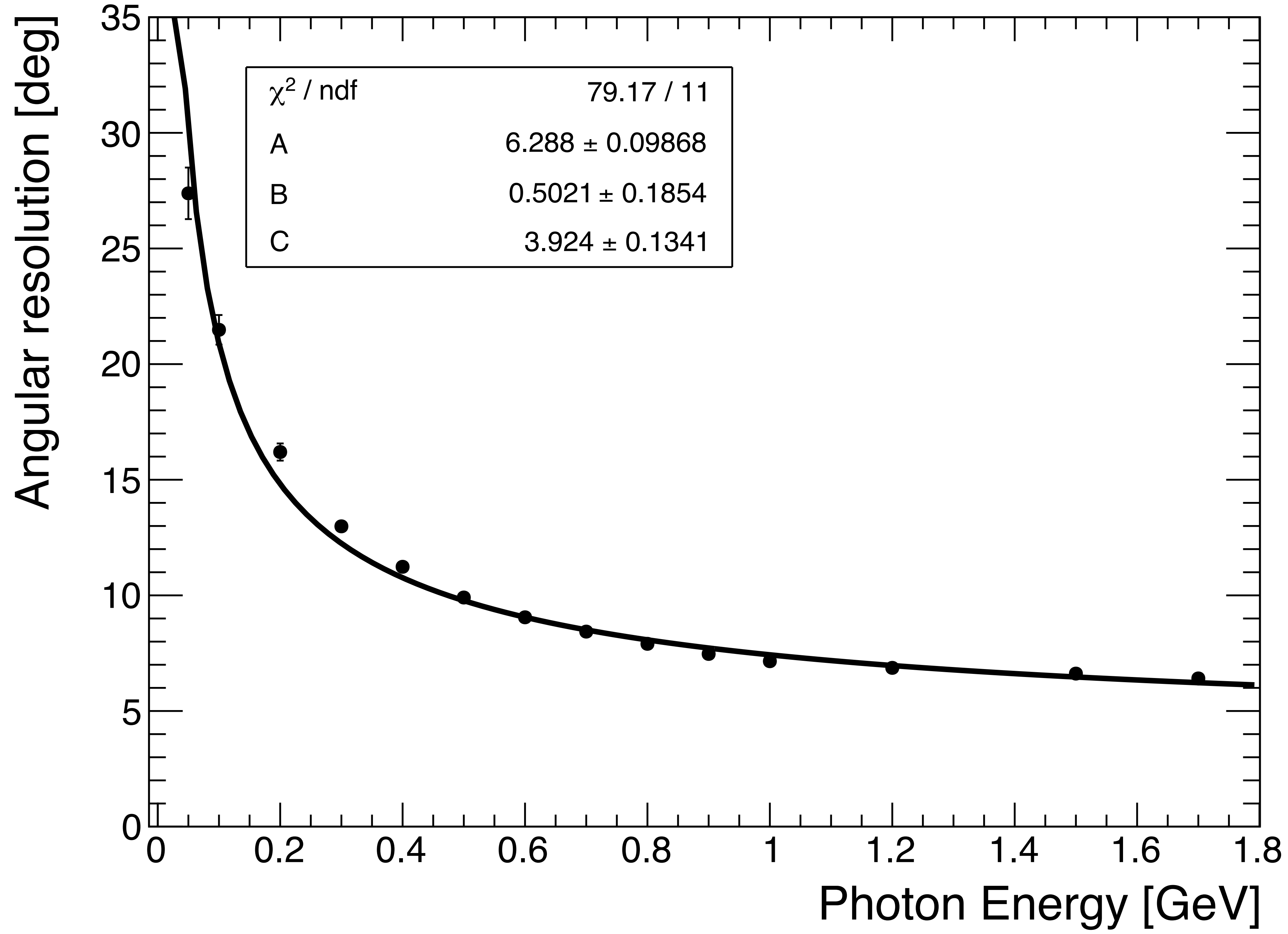
40 mm wide

The ECAL design.

Performance numbers (Baseline)

- Sampling structure
  - 2 mm Cu / 5 mm Sc
  - 60 layers: 8 high granularity layers (tiles) and 52 low granularity layers (strips)
- “Best” performance so far
  - ~5.6%/Sqrt(E)+ 4%
  - ~6.3deg/Sqrt(E) + 3.9 deg
- Optimising based on this
  - Detector shape (polyhedra with more sides to fit more layers)
  - Absorber type Cu ➟ Pb (cost)
  - Granularity (cost)
  - **Neutron detection!** (more plastic, less non-active material in front)

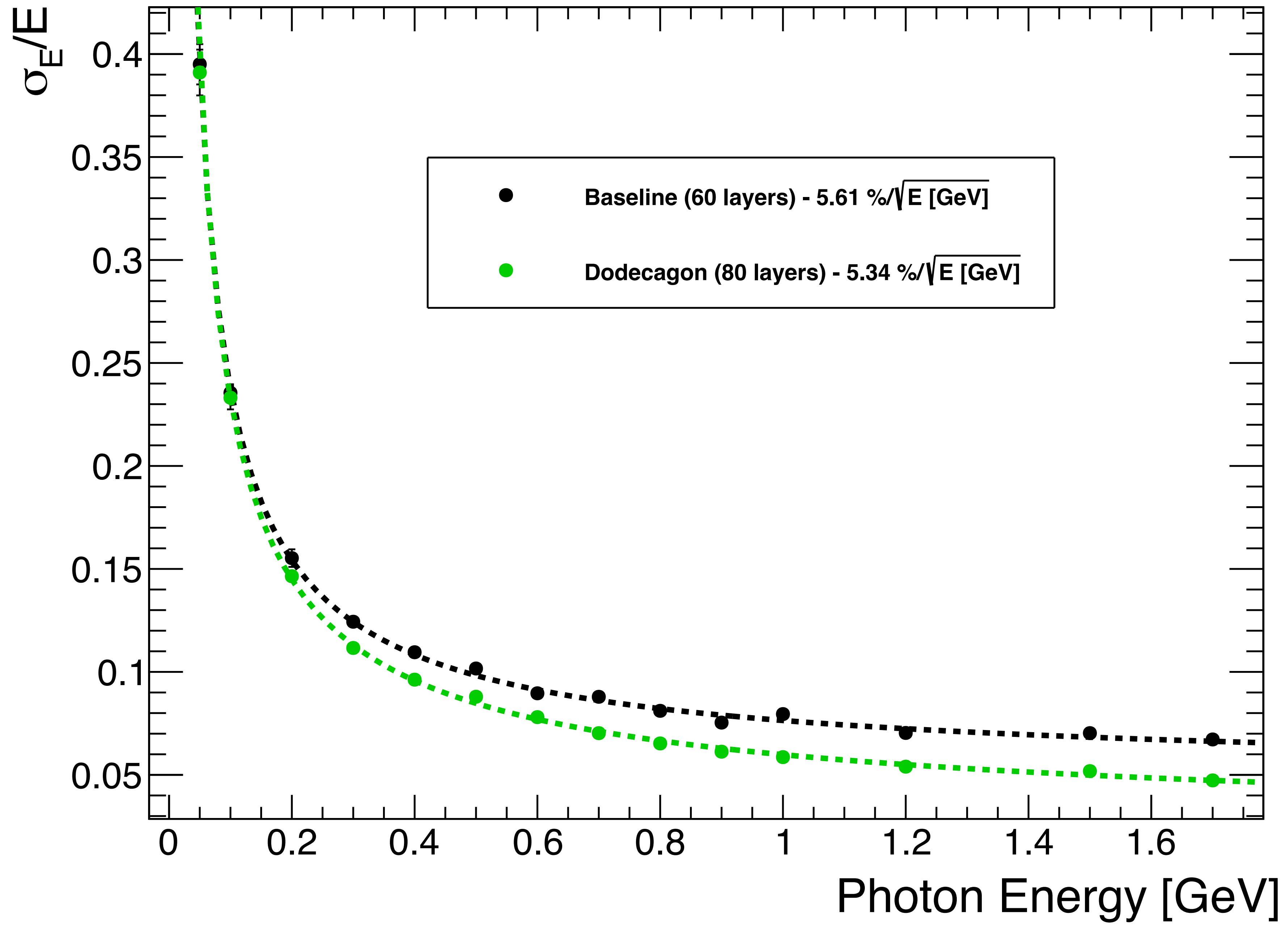


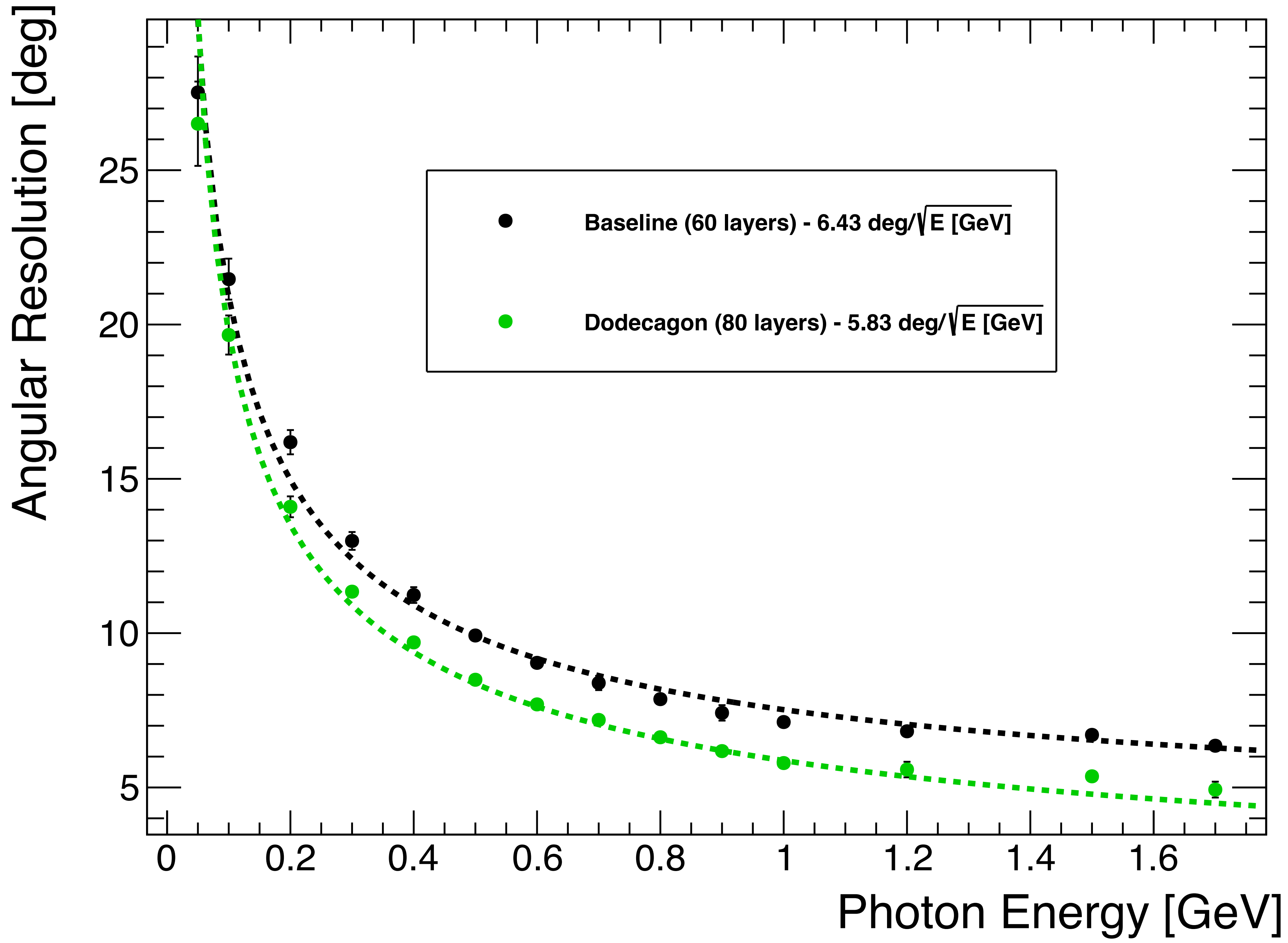


Impact of the ECAL geometry.

Geometry

- Baseline shape ➠ Octagon
  - Not optimal in between cylinders (TPC/Magnet)
- Going for higher number of sides ➠ Dodecagonal
- Advantage
  - Can fit more layers in the same volume
  - Shorter modules (shorter strips ➠ less attenuation/better timing)
- Better energy resolution and angular resolution
  - Recover leakage with more layers. ~2-3% better at higher energies, but may not be as important ➠ most photons have energies below 1 GeV
  - Angular resolution better due to shorter strips? ➠ need more understanding
  - Slight increase in cost (more layers)

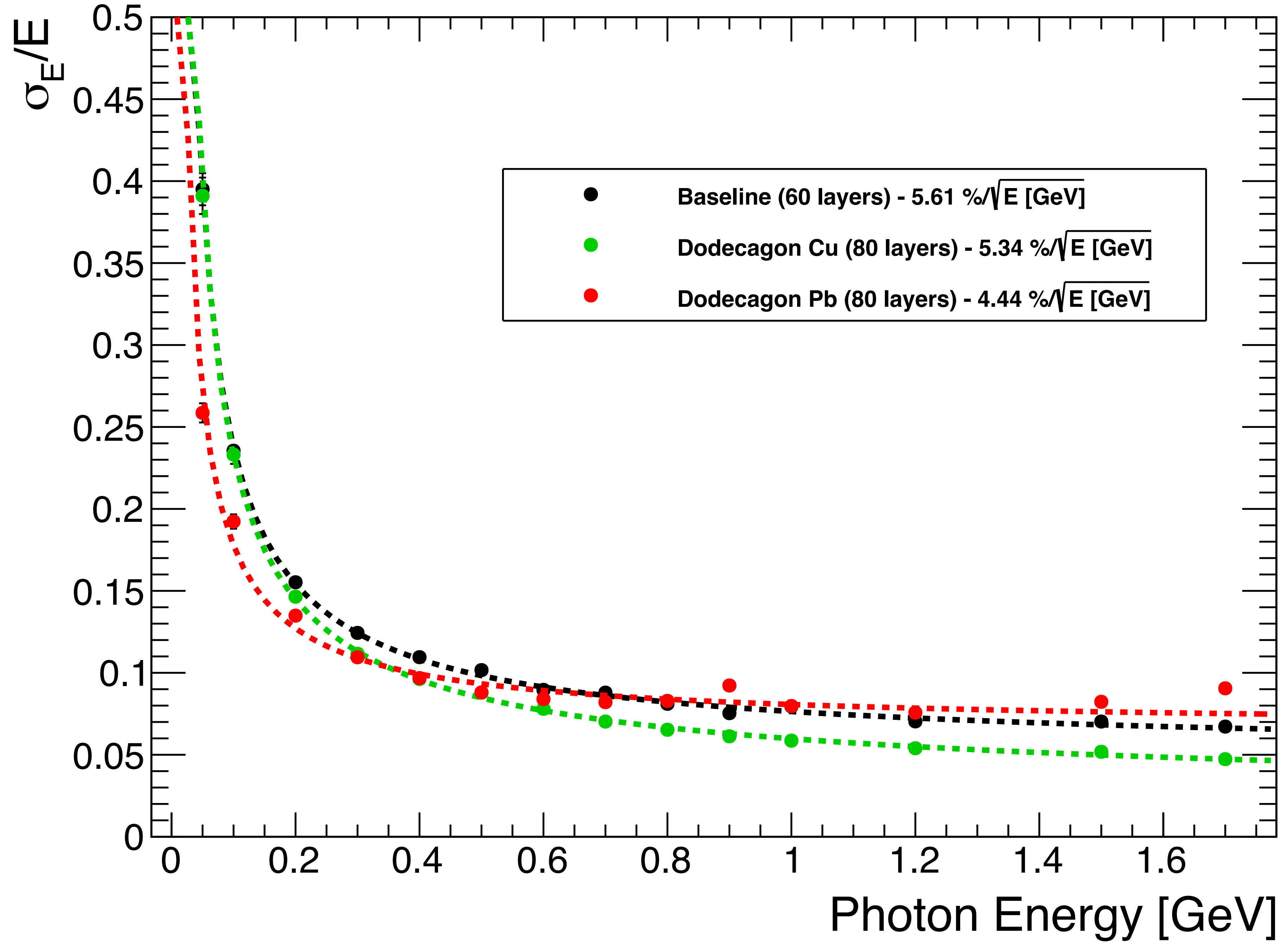


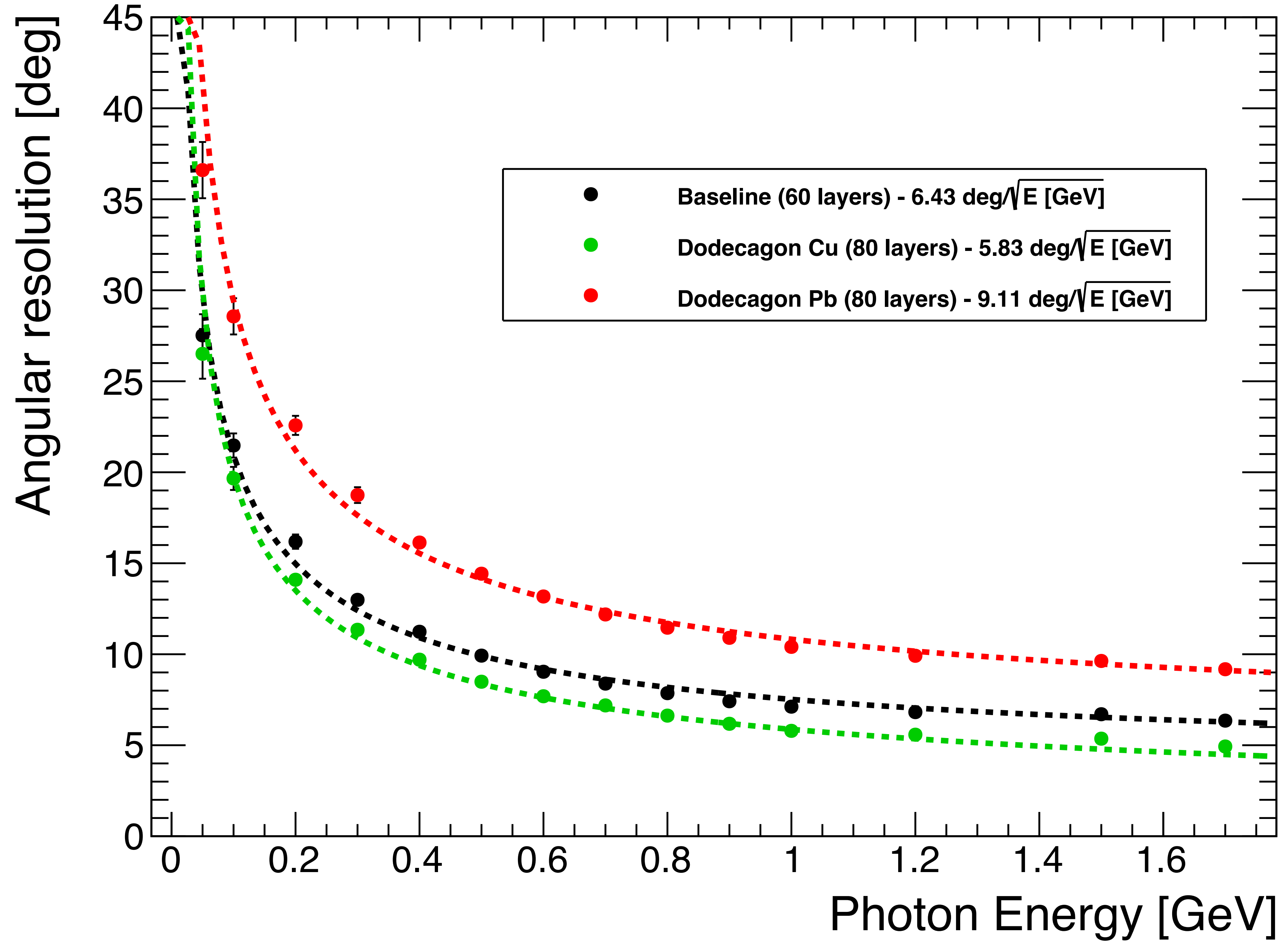


Impact of the absorber material.

Revisiting Lead

- Revisit Pb as Cu is expensive
- Geometry change
  - 8 HG layers and 82 LG layers + 2 thick slabs (130 mm) in the back
  - Increase from 1 λ to 1.5 λ (better for mu/pi ID)
  - Sampling structure: 0.5 mm Pb (keep same material budget as Cu) / 3 mm Sc (not optimized)
- Energy resolution
  - Better at lower photon energies ➠ slight increase in sampling frequency
- Angular resolution
  - Worse due to larger Molière radius (shower looks more “blobby”)
  - Decrease of Sc thickness (PCA favours high energy depositions)
    - ➠ Will also impact neutron detection efficiency!
- Optimization towards
  - Increase Sc thickness
  - Thinner Pb absorber layers in the front

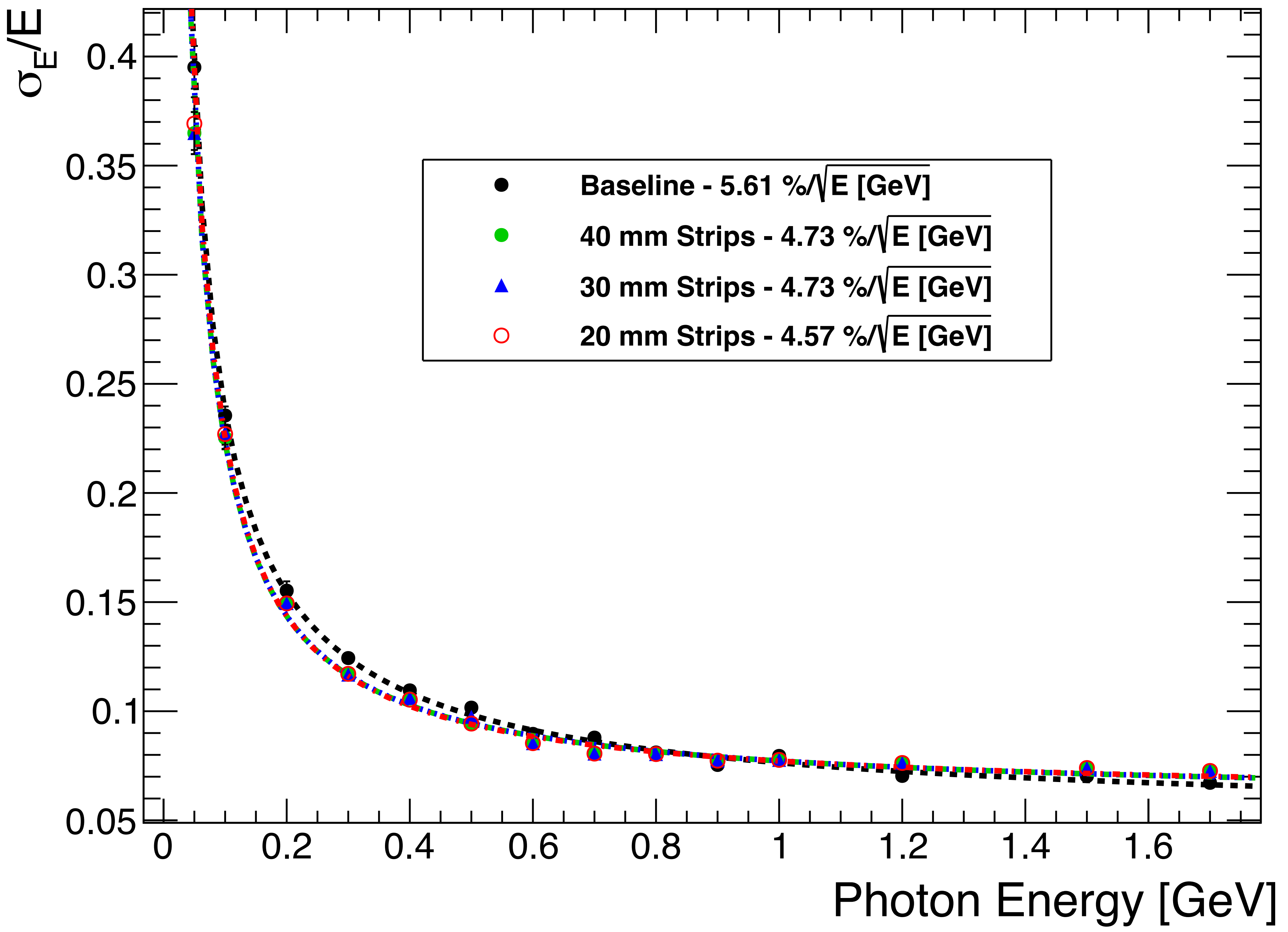


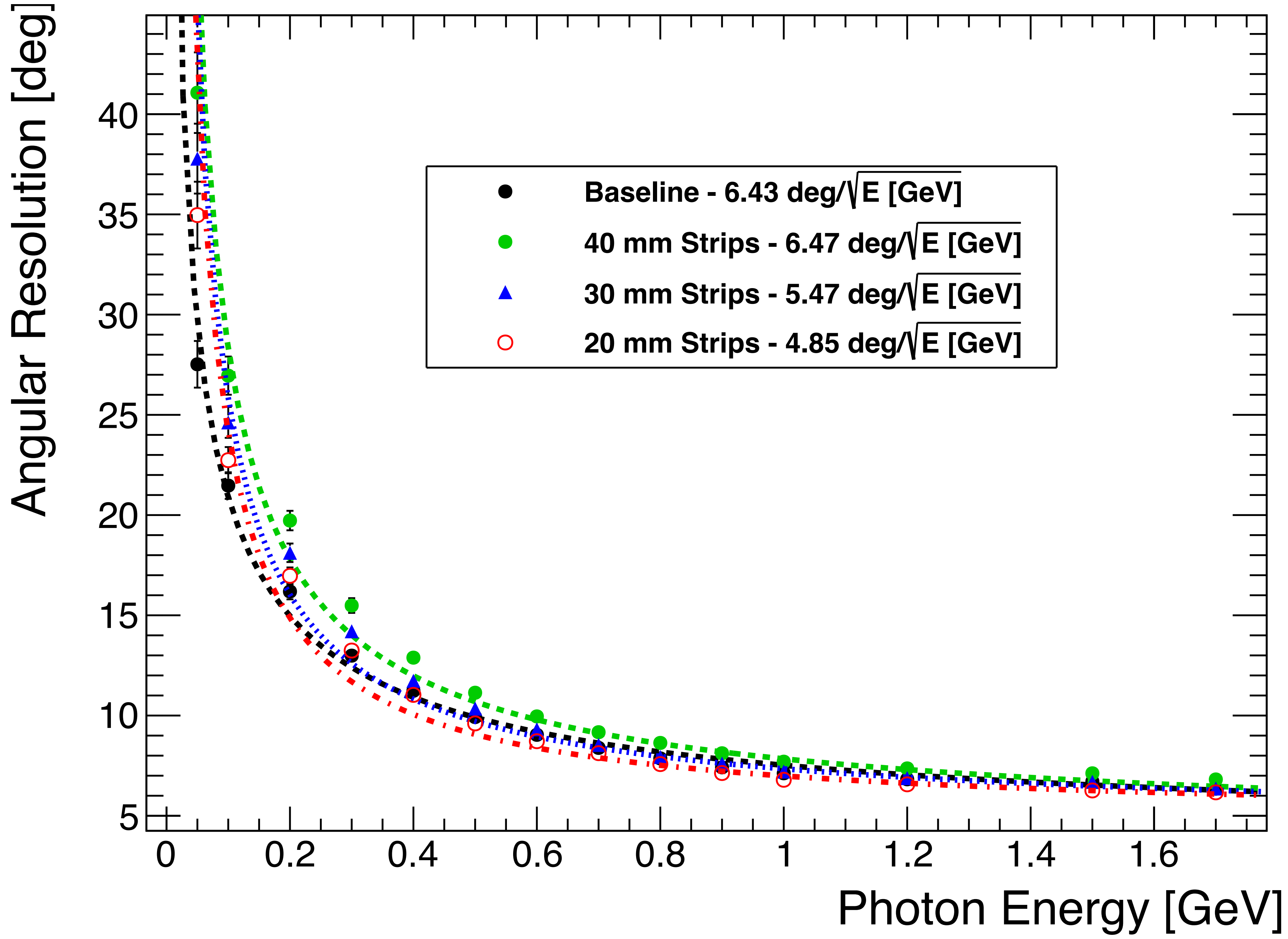


Impact of the lateral segmentation.

Replacing tiles with only strips

- Granular layers are a main cost driver
- Strip only
  - Different strip widths from 40 mm to 20 mm
- Energy resolution
  - As expected not much change compare to the baseline
- Angular resolution
  - Worse (~10 deg @ 50 MeV to ~few deg at GeVs) for large strip widths
  - Can be "recovered" with smaller strip width (10-20 mm)
  - May be improved with shorter strips (length)
- However:
  - Impact on timing ➟ Need for fiberless and more transparent scintillator (cost increase)
  - Effect on neutron detection and energy measurement?

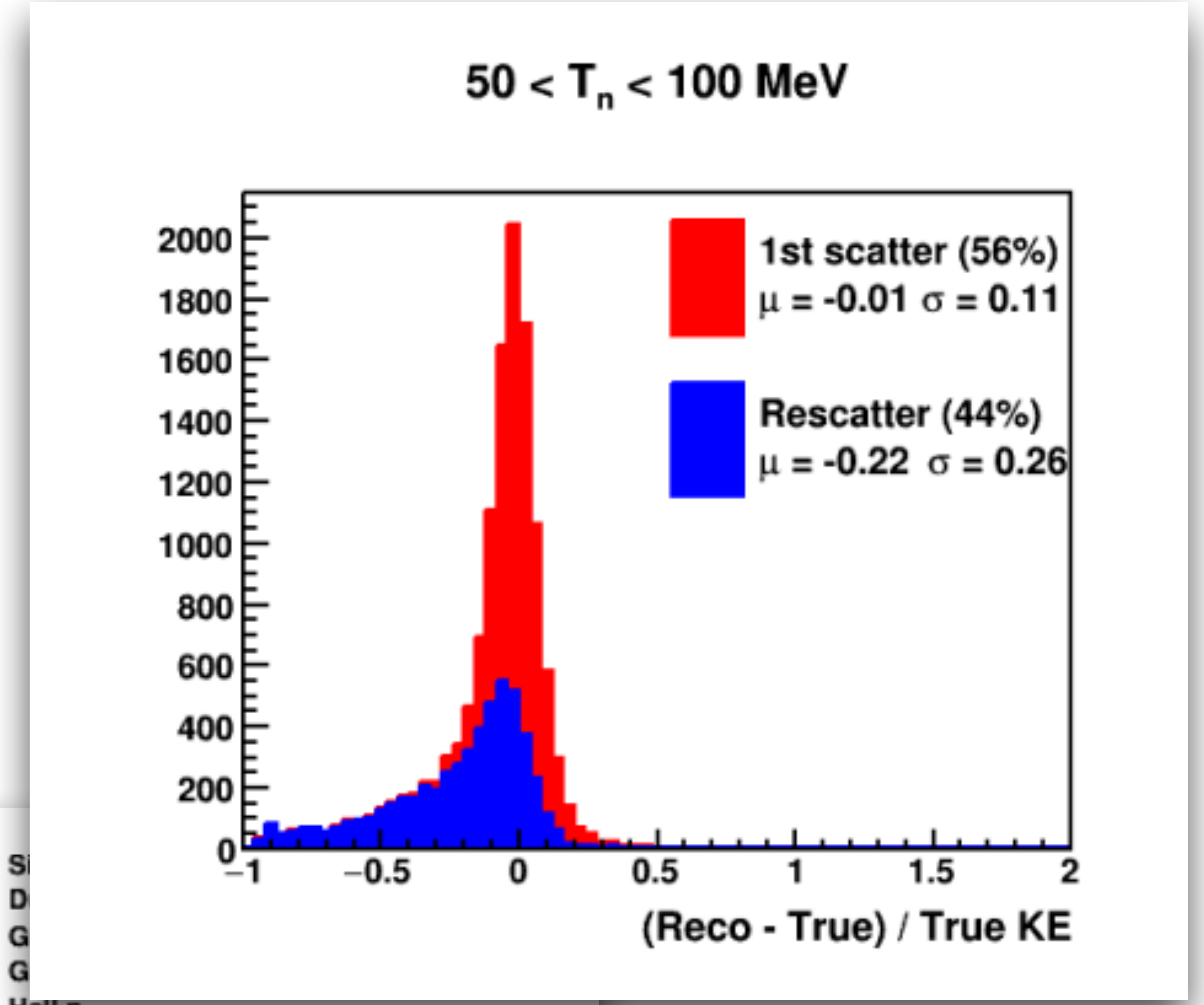


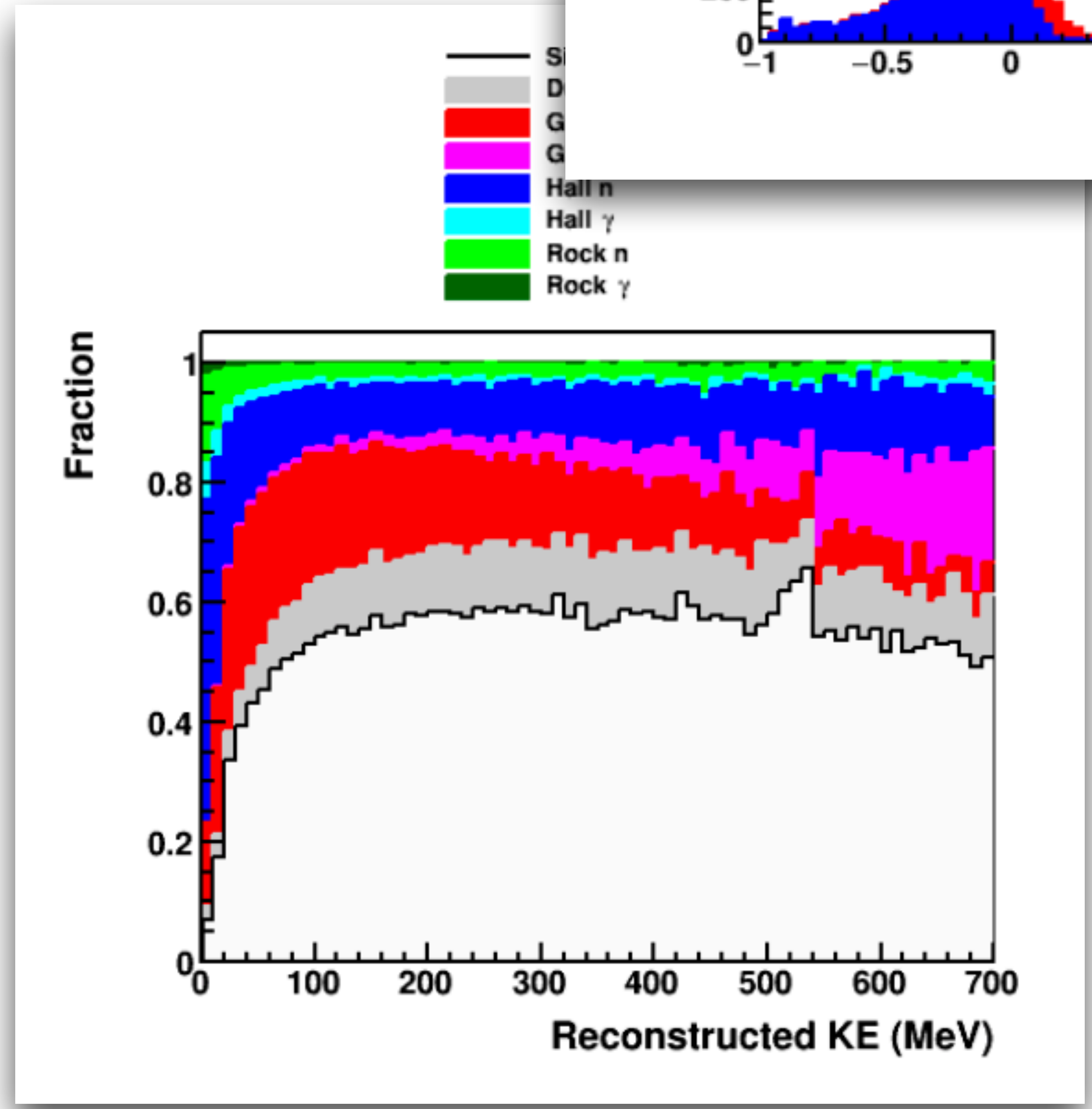


A strong point of the MPD ECAL.

Neutron energy measurement with background

- Neutron production is very uncertain in neutrino interactions
- LAr is limited due to secondary interactions
- GAr + ECAL can be powerful to measure neutrons via ToF
  - ➠ few 10-100s ps time resolution required
- Very detailed study done by **Chris Marshall** (https://indico.fnal.gov/event/20144/session/20/contribution/21/material/slides/0.pdf)
- The ECAL optimization will take into account this
  - Thicker scintillator slab in the front of the ECAL to reduce the scattered neutrons

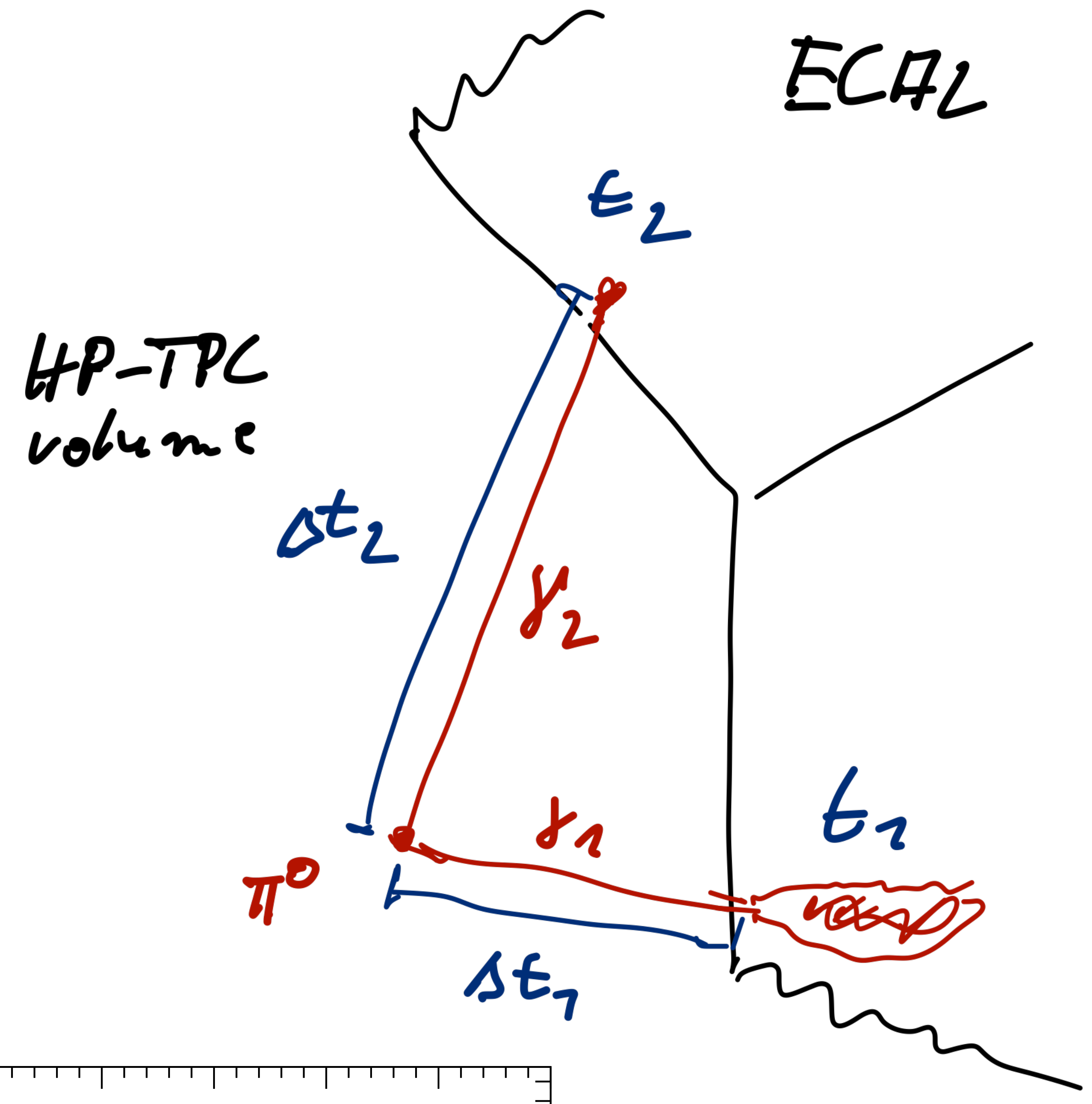


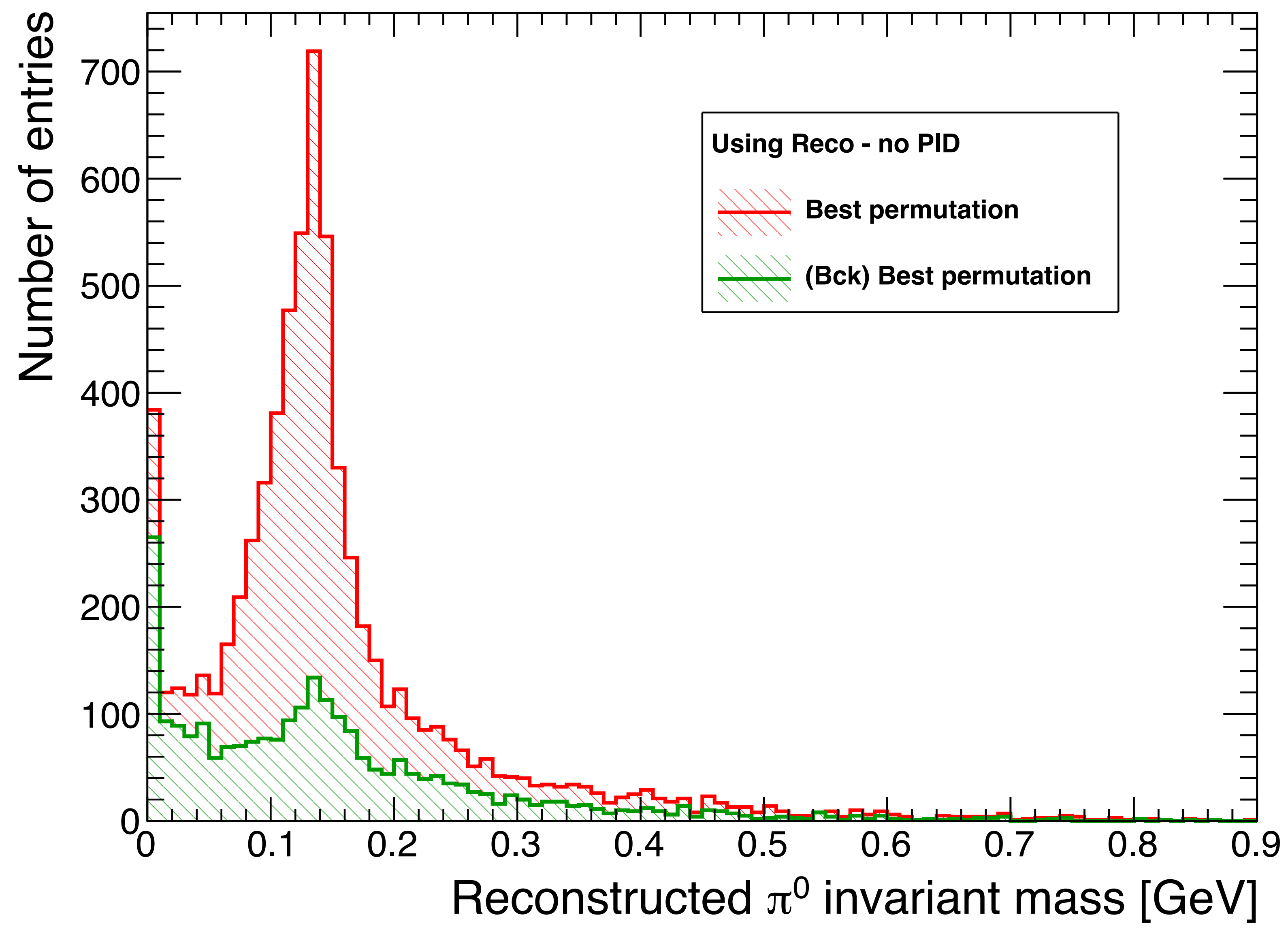


Time-assisted π^0 reconstruction.

Ongoing work

- Previous results (Lorenz's master) showed that π^0 mass reconstruction (few %) and vertex position (~20-30 cm) is quite good with the ECAL
- Ongoing work to redo the study with the current framework including backgrounds
- Optimisation
  - "Time-assisted" π^0 reconstruction
    - Use of timing to improve the vertex position reconstruction
- Needs a bit of work on the software side



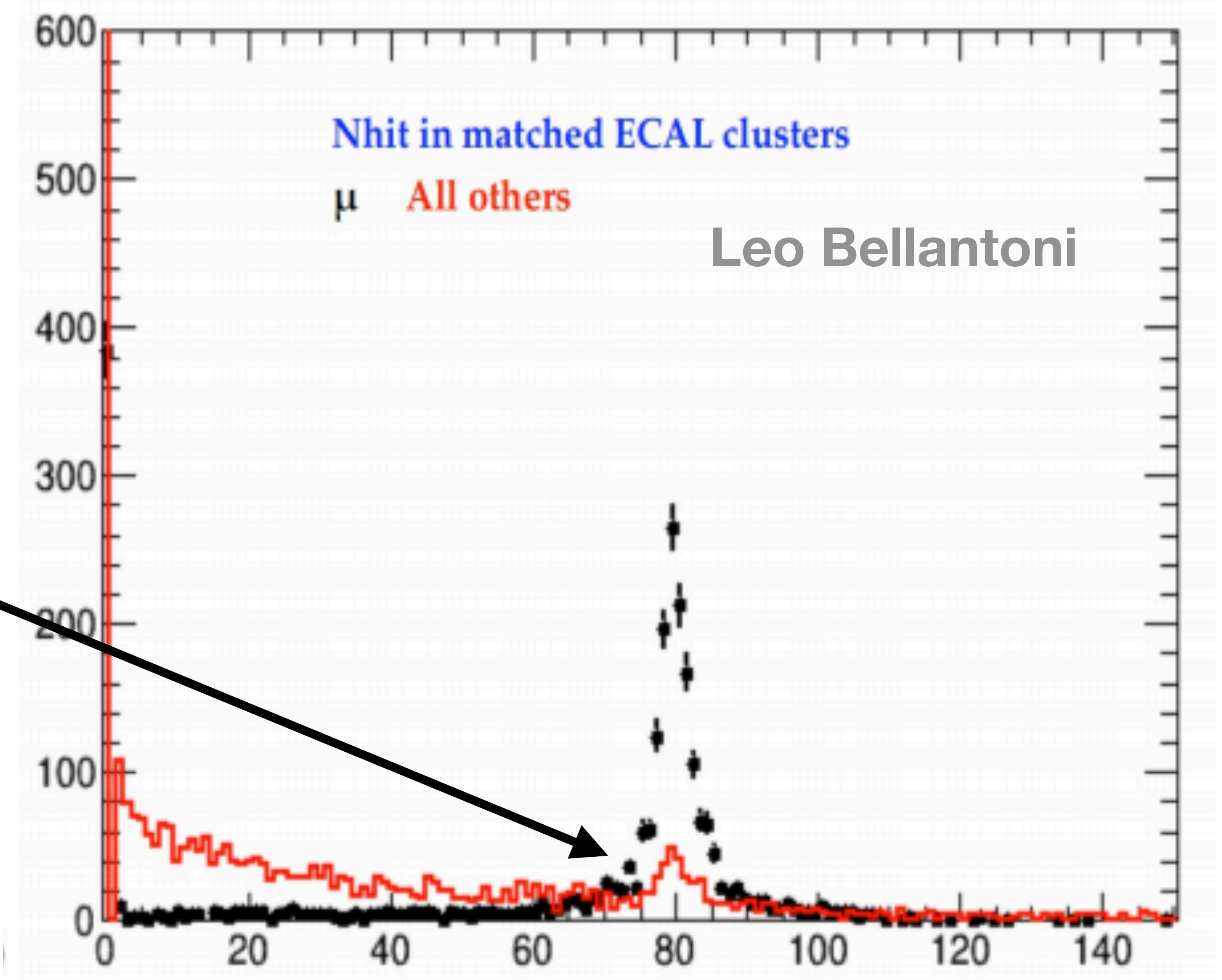


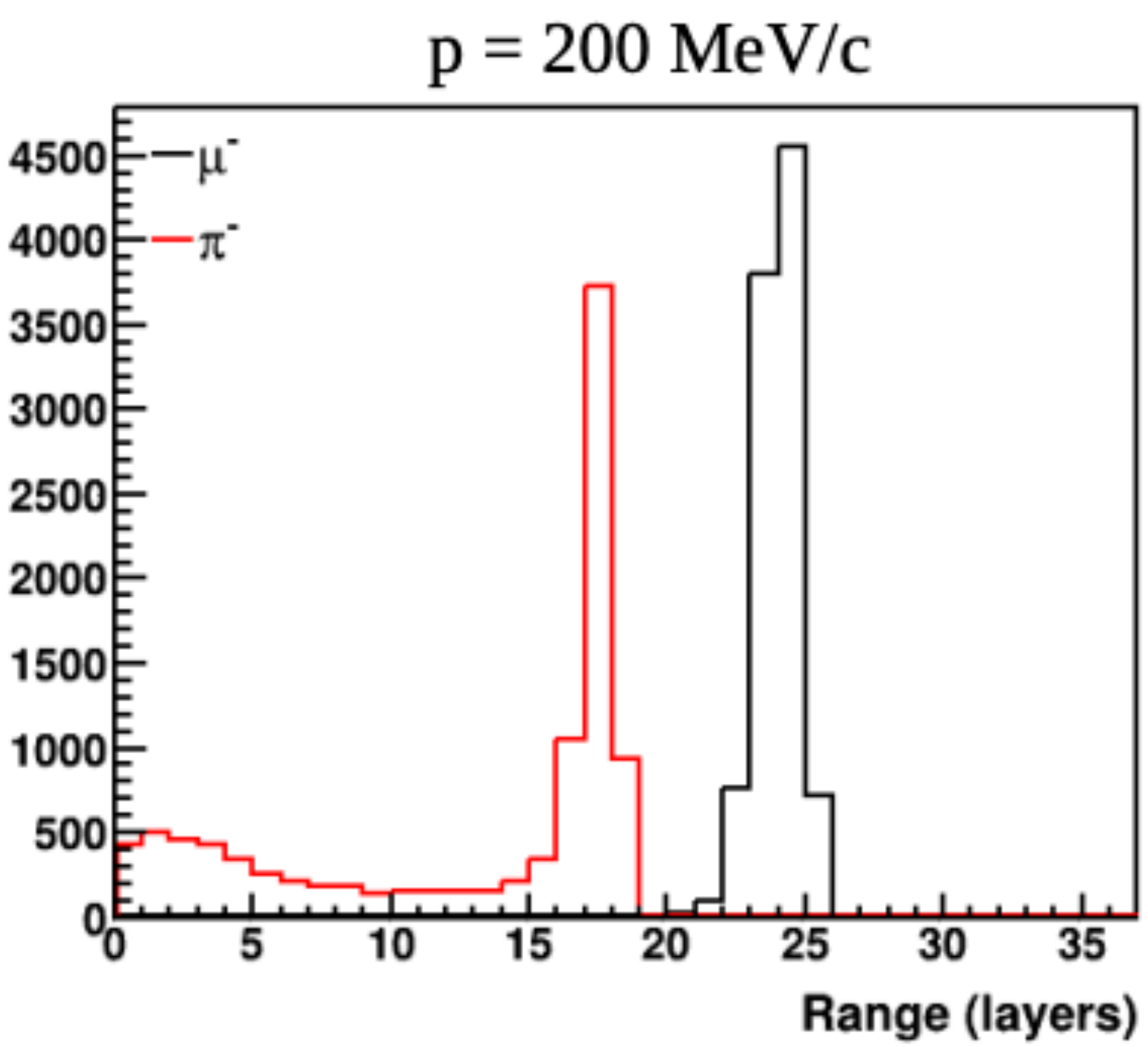
Muon/Pion separation in the ECAL.

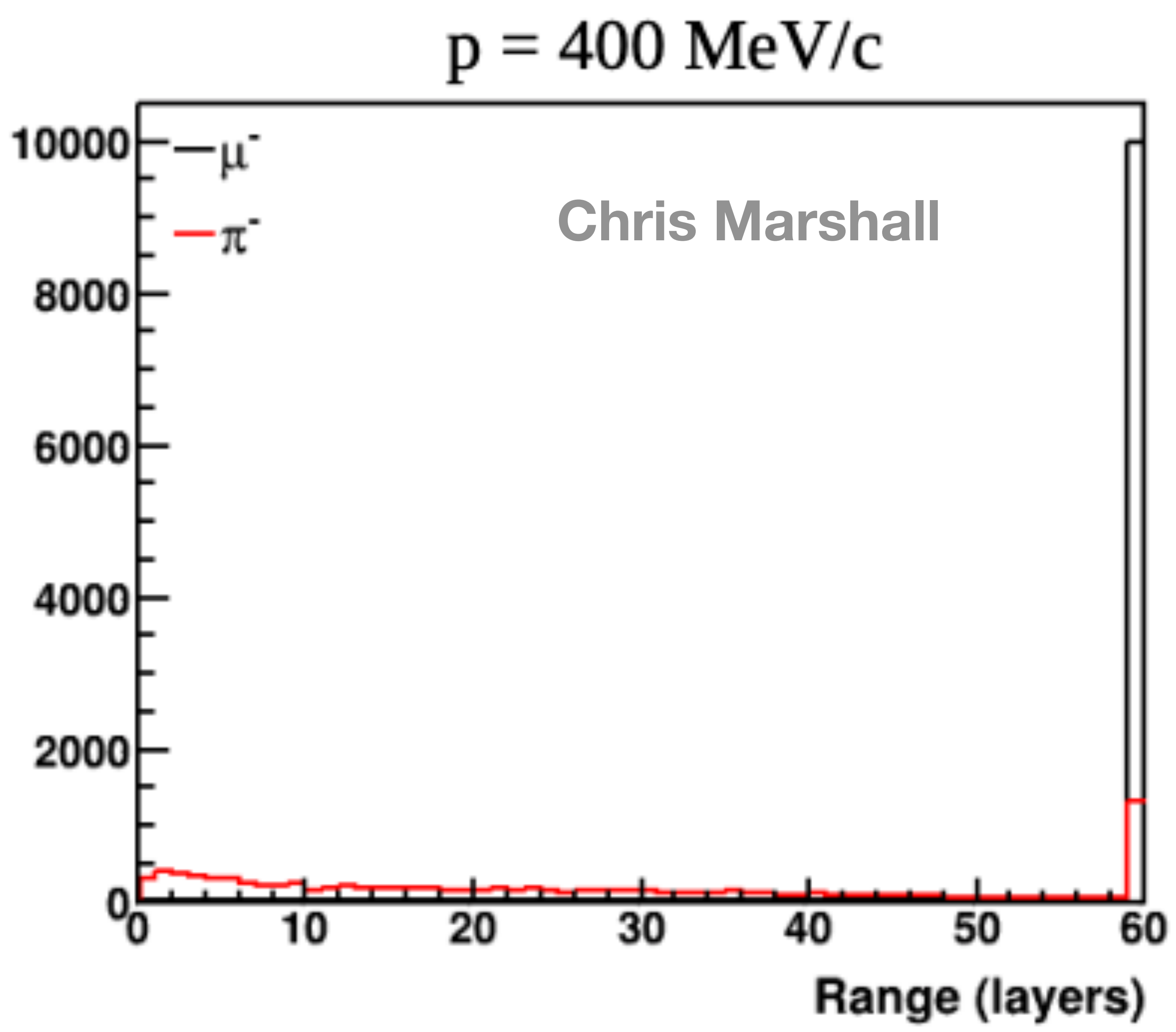
A must for a pure ν_μCC sample

- Baseline design
  - ➠ ~ 1 lambda
  - ➠ ~ 33% of pions will go through! Large signal contamination.
- ECAL design can partially fulfil such role
  - Most pion/muons will range out below ~350-400 MeV/c (12 cm of Cu + 30 cm CH ➠ ~200 MeV)
  - High momentum mu/pi will punch-through the ECAL
  - More ECAL layers would increase the cut-off (80 layers ➠ up to ~450-500 MeV/c)

Pion contamination!







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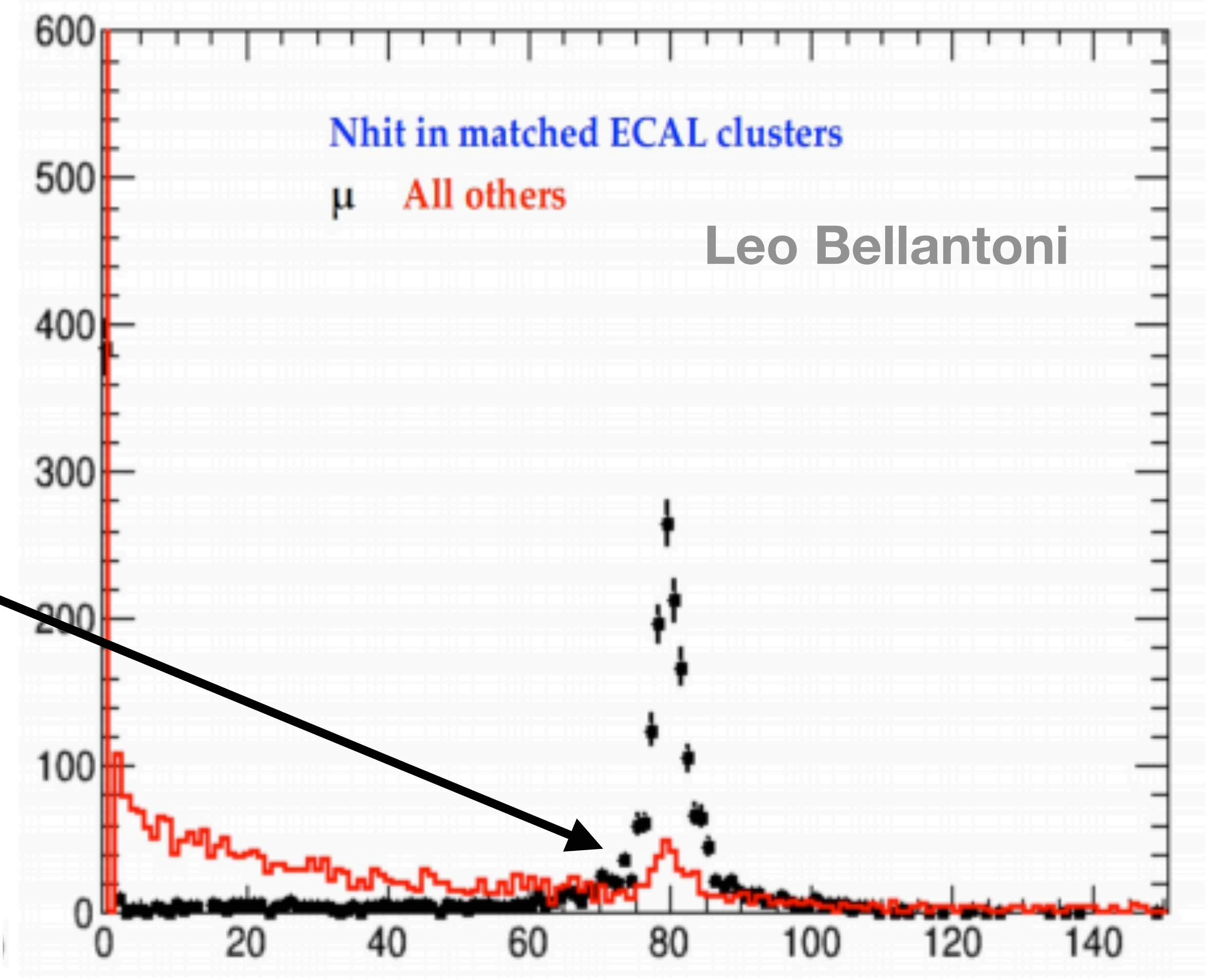
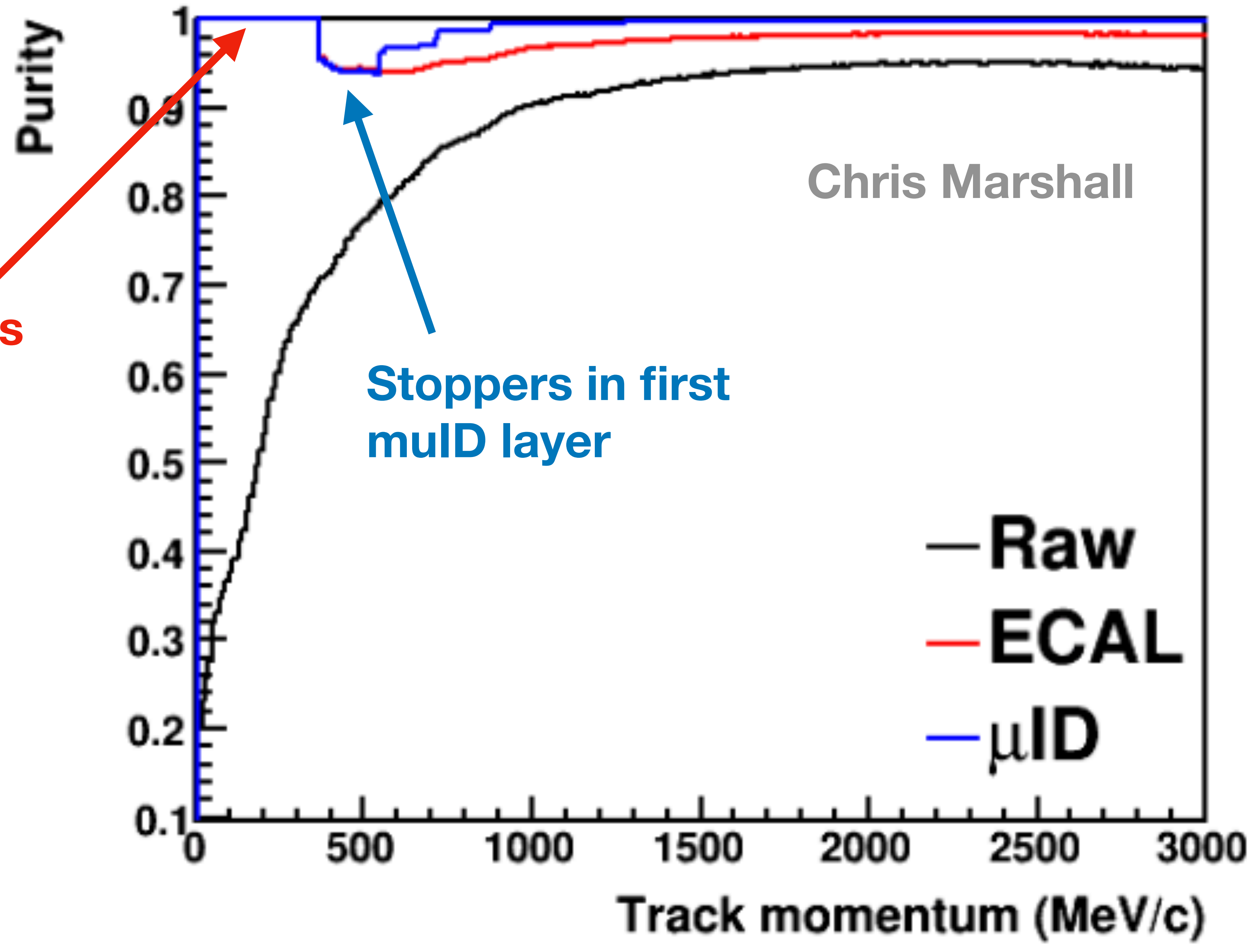
  - High momentum mu/pi will punch-through the ECAL
  - More ECAL layers would increase the cut-off (80 layers ➠ up to ~450-500 MeV/c)
- ν_μCC selection ➠ Very high purity (>95%) with muon ID system (3 layers of 10 cm Iron)
- ECAL design needs to follow the muon system design (see later talk)

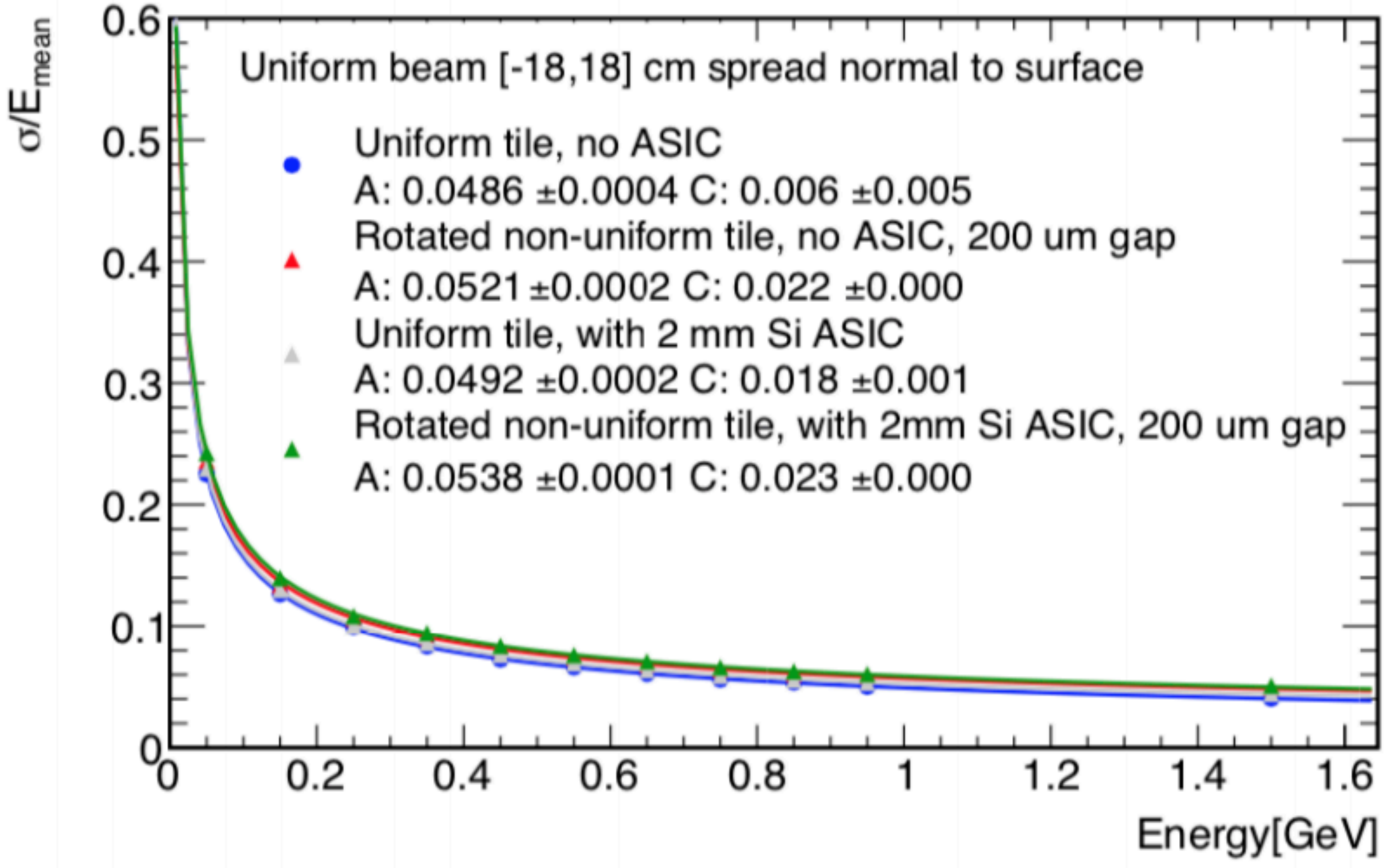


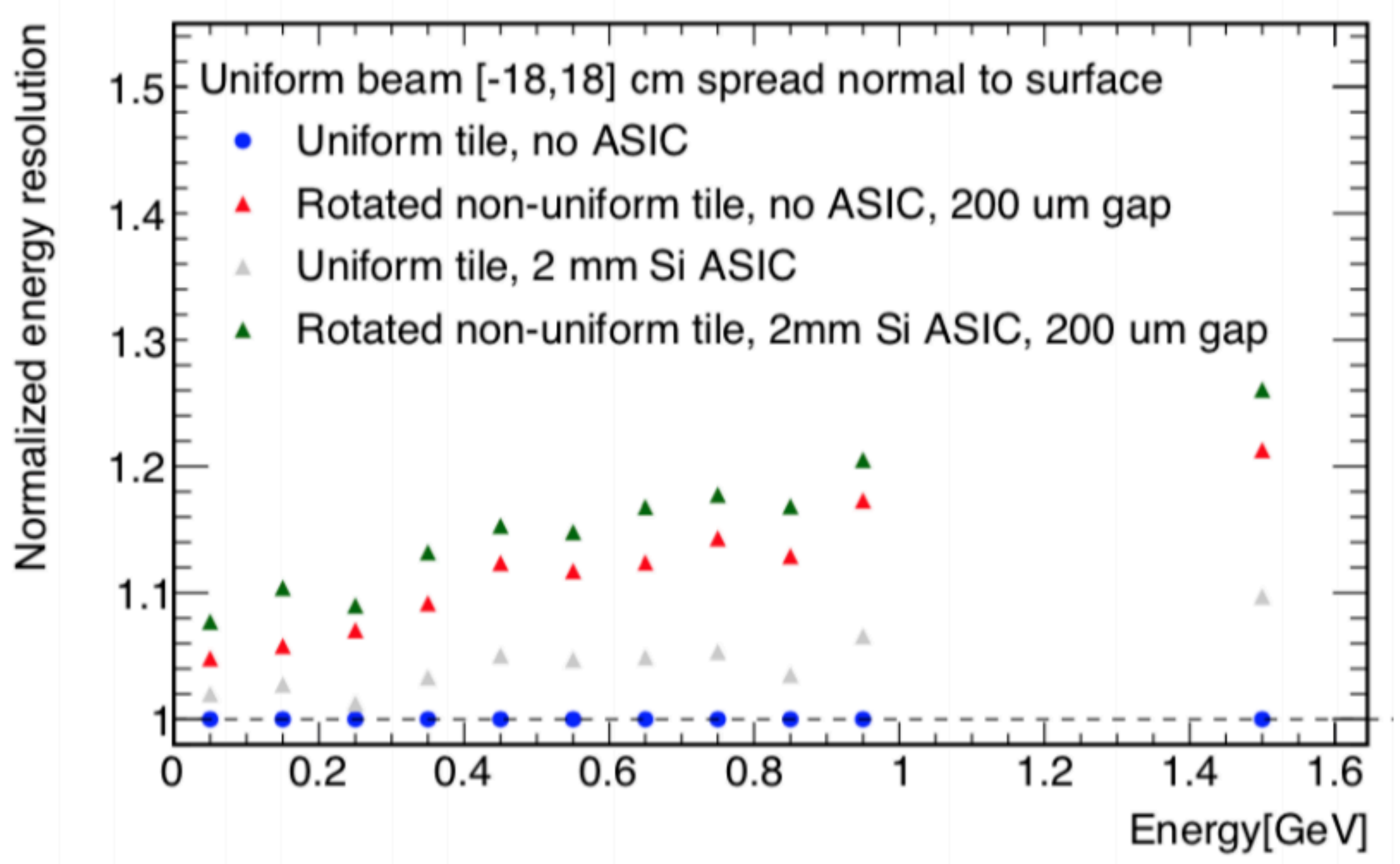


Impact of non-uniformities.

Important test in a low-energy regime

- Goal
  - Study effects of tile non-uniformity, gaps between tiles and material distribution (ASIC) on the energy resolution
- Principal impact on the constant term, negligible on the stochastic term
  - ASIC has an impact of around 5% on the Eres
  - Tile alignment is the dominant effect, around 10% degradation
- Not a show stopper





Next steps.

Further run of optimization/design

- Further optimize based on physics needs
  - Coverage ➠ muon angle, LAr/TPC matching..
  - Integration with the magnet/muon system
  - Neutrons/neutral pion performance
- Increase the reality of the detector
  - Improve the geometry
    - Services
    - Mechanical supports
  - Improve the digitization and reconstruction (software)

Conclusions.

- The ECAL design (60 layers with 2 mm Cu/5 mm Sc) is the base for the CDR
- Optimisation of the ECAL is ongoing and will be guided by physics requirements
- Current observations
  - ECAL shape has a small influence (less leakage)
  - Using Pb will heavily degrade the angular resolution (optimize Pb layer thickness)
  - Granularity
    - Strip-only is an option but need to go to small width sizes (10-20 mm) and impact on neutrons to be understood
  - Neutrons
    - Optimisation taking account of this golden measurement
  - Non uniformities is not a show stopper for the technology foreseen
- Ongoing work
  - π^0 reconstruction (incl. backgrounds), neutrons
  - Software
    - Realism in simulation (required for optimization)
    - Pandora integration for the reconstruction, similar as the FD
  - Small scale hardware, exploring strip options

Backup Slides.