CALICE-style ECAL.

DUNE MPD WS

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DESY
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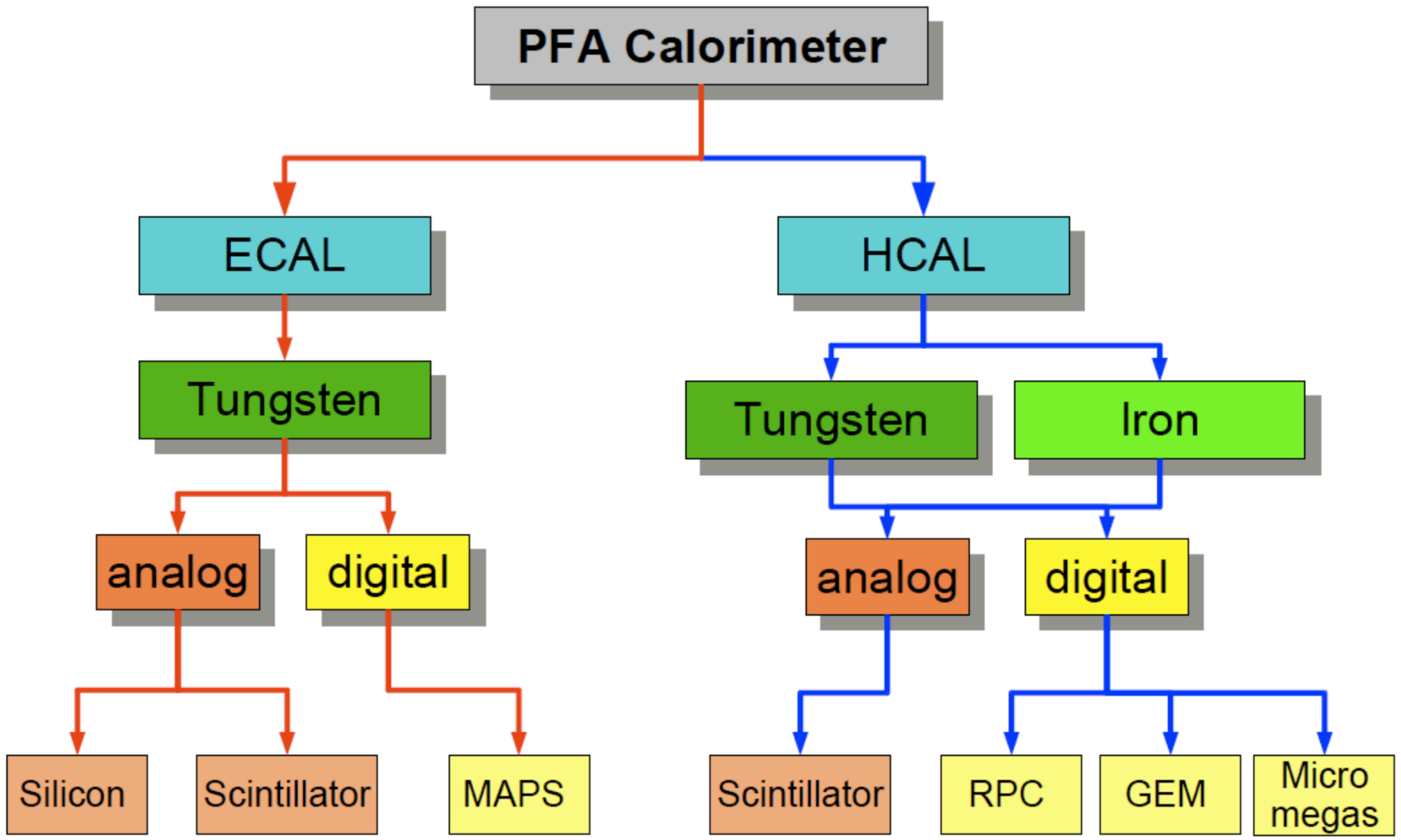
CALICE
DESY.

The CALICE Collaboration.

R&D for high granular calorimeters

- High granular calorimeters motivated by requirement for future e+e- linear collider
  - Need to develop the technology ➠ Dedicated R&D program
- Very rich program for high granular calorimeters
- Most of the technologies tested in beam ➠ *physics prototypes*



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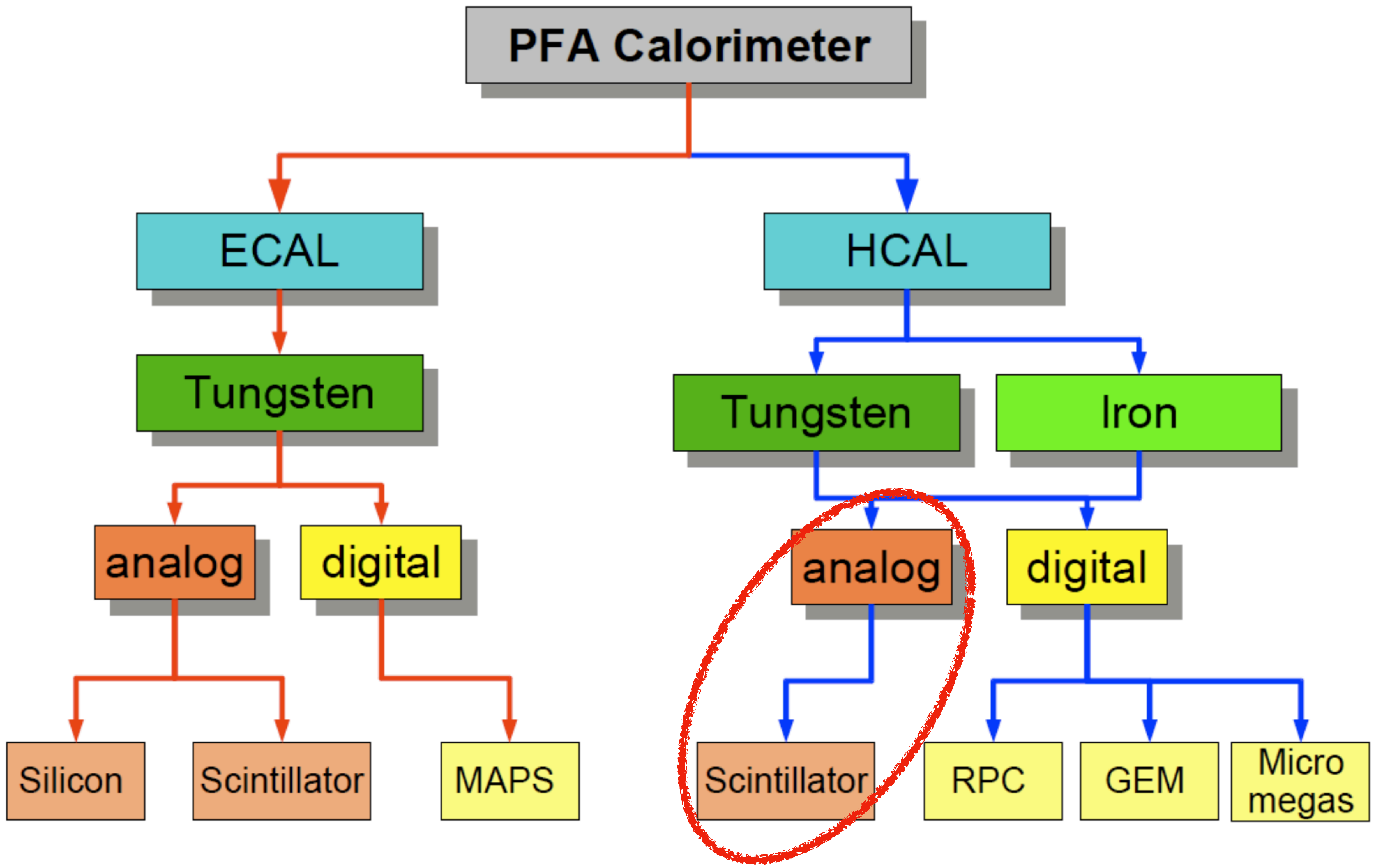
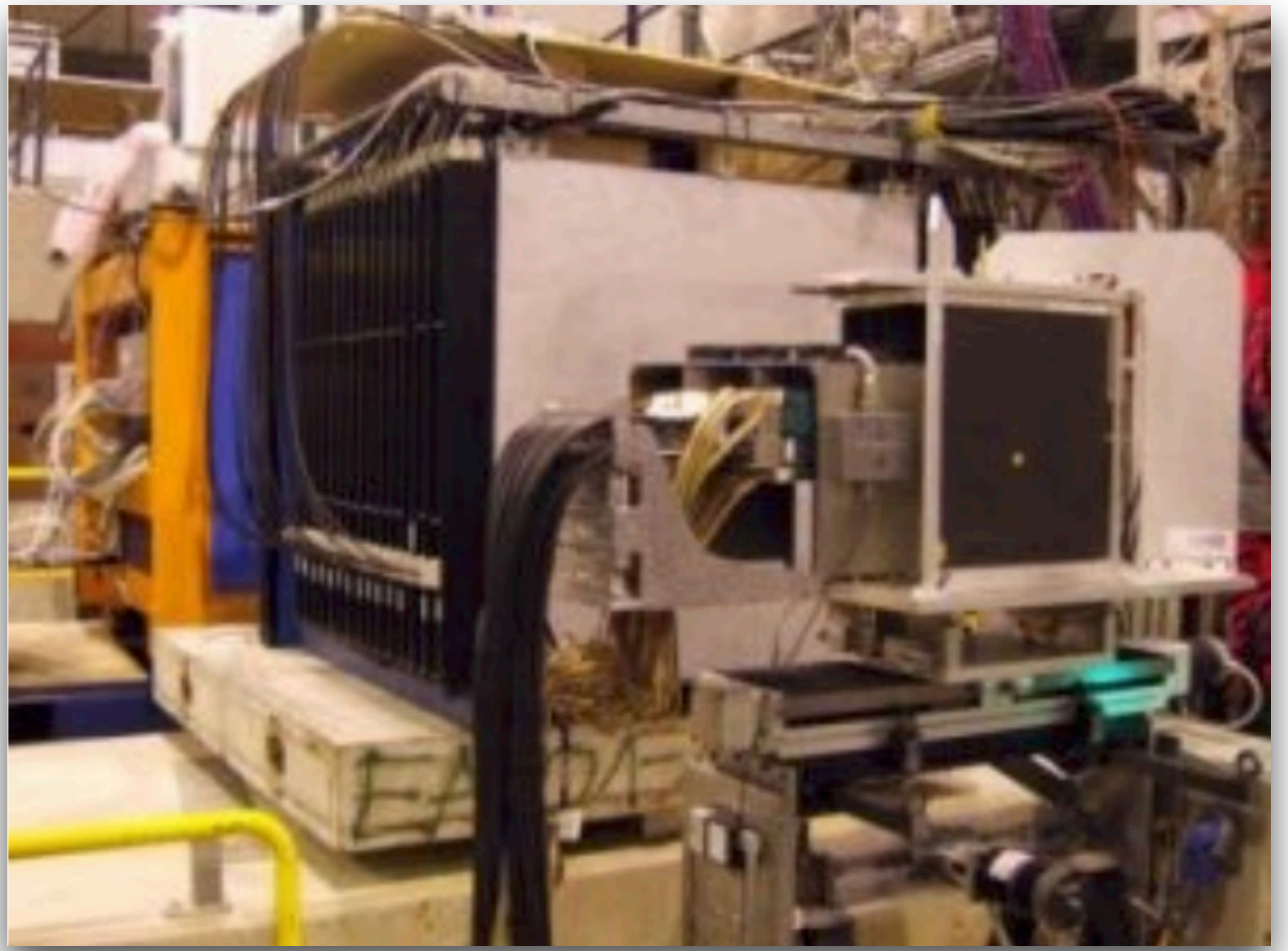
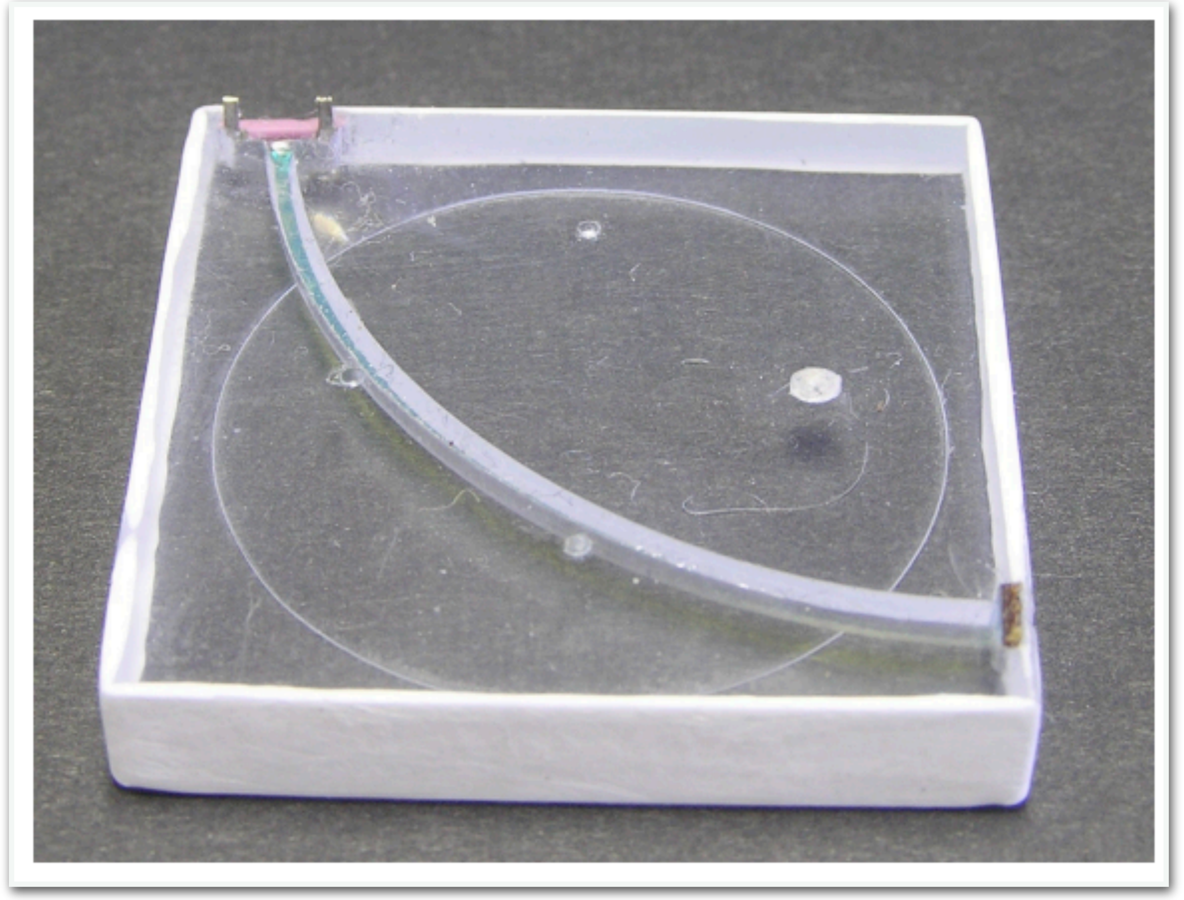


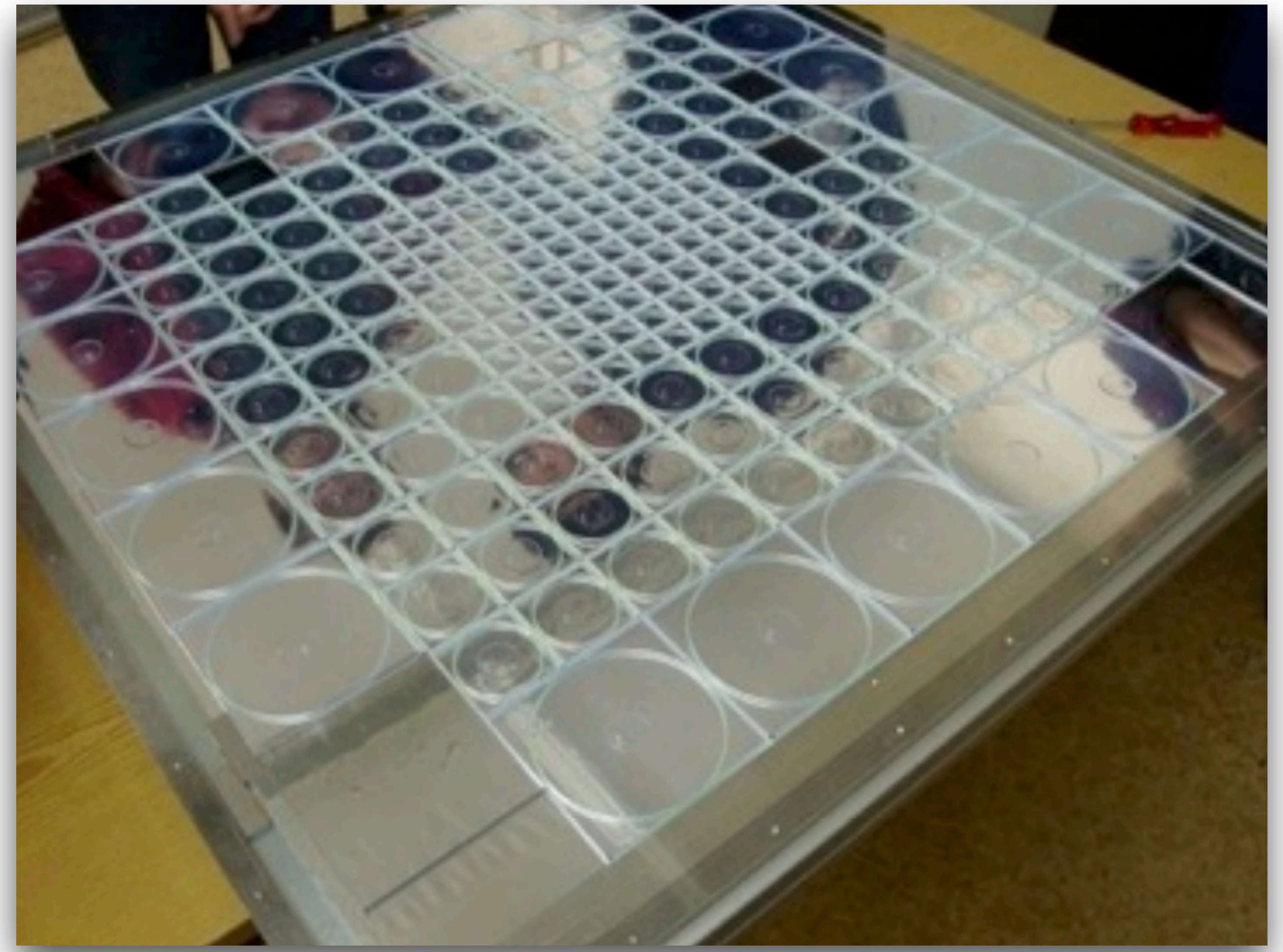
The CALICE Analog Hadron Calorimeter.

Applicable to DUNE ND?

- First large scale use of SiPM: **~8k channels** used between 2006-2011 at DESY/CERN/FNAL
- Based on 3x3x0.5 cm^3 plastic tiles with WLS fiber, MEPhI/PULSAR SiPM, 1.1 x 1.1 mm^2, 1152 pixels (32 x 32 µm^2)
- Custom readout electronics outside, LED calibration system







JINST 5 (2010) P05004

JINST 6 (2011) P04003

JINST 8 (2013) P07005

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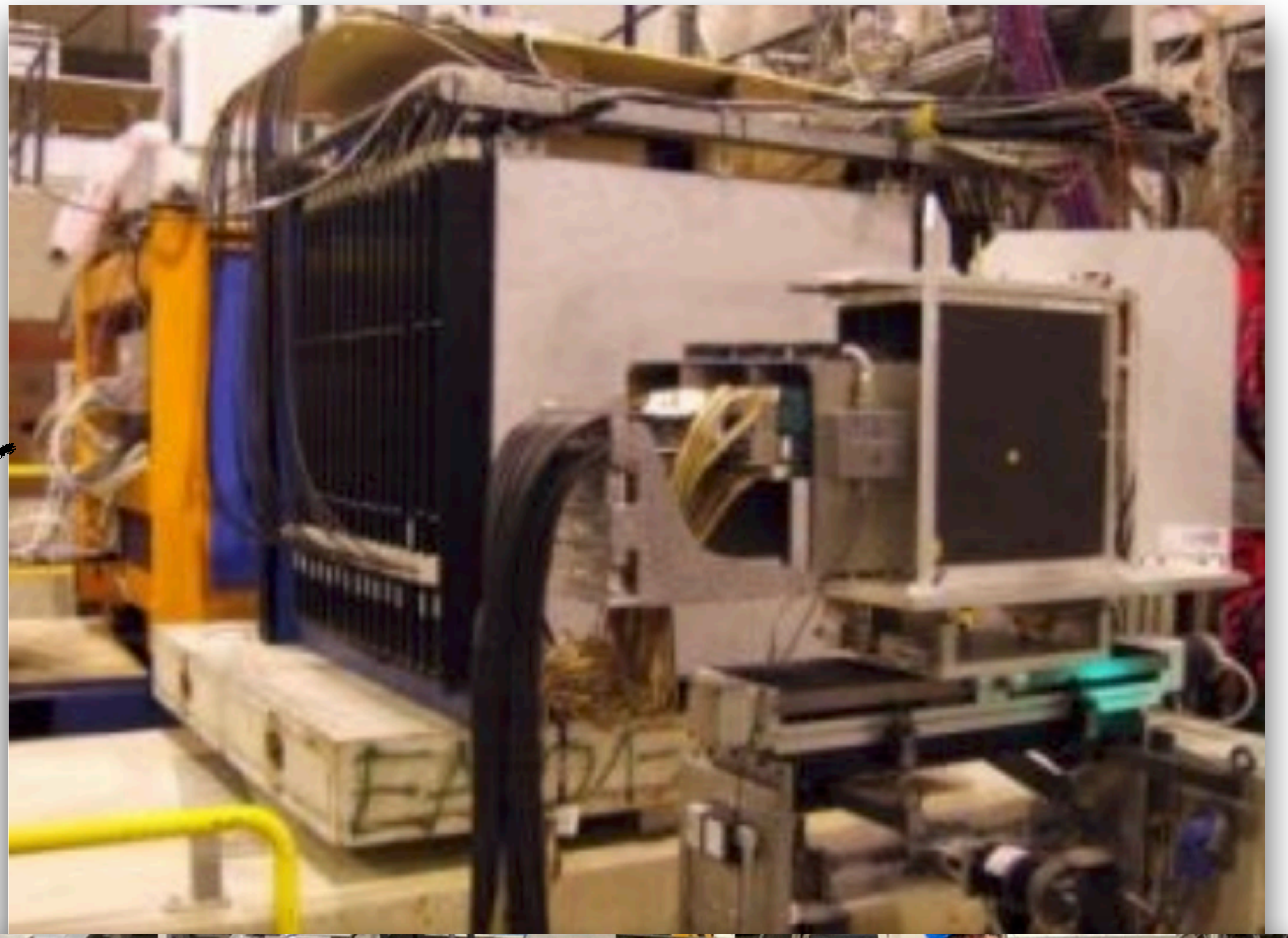

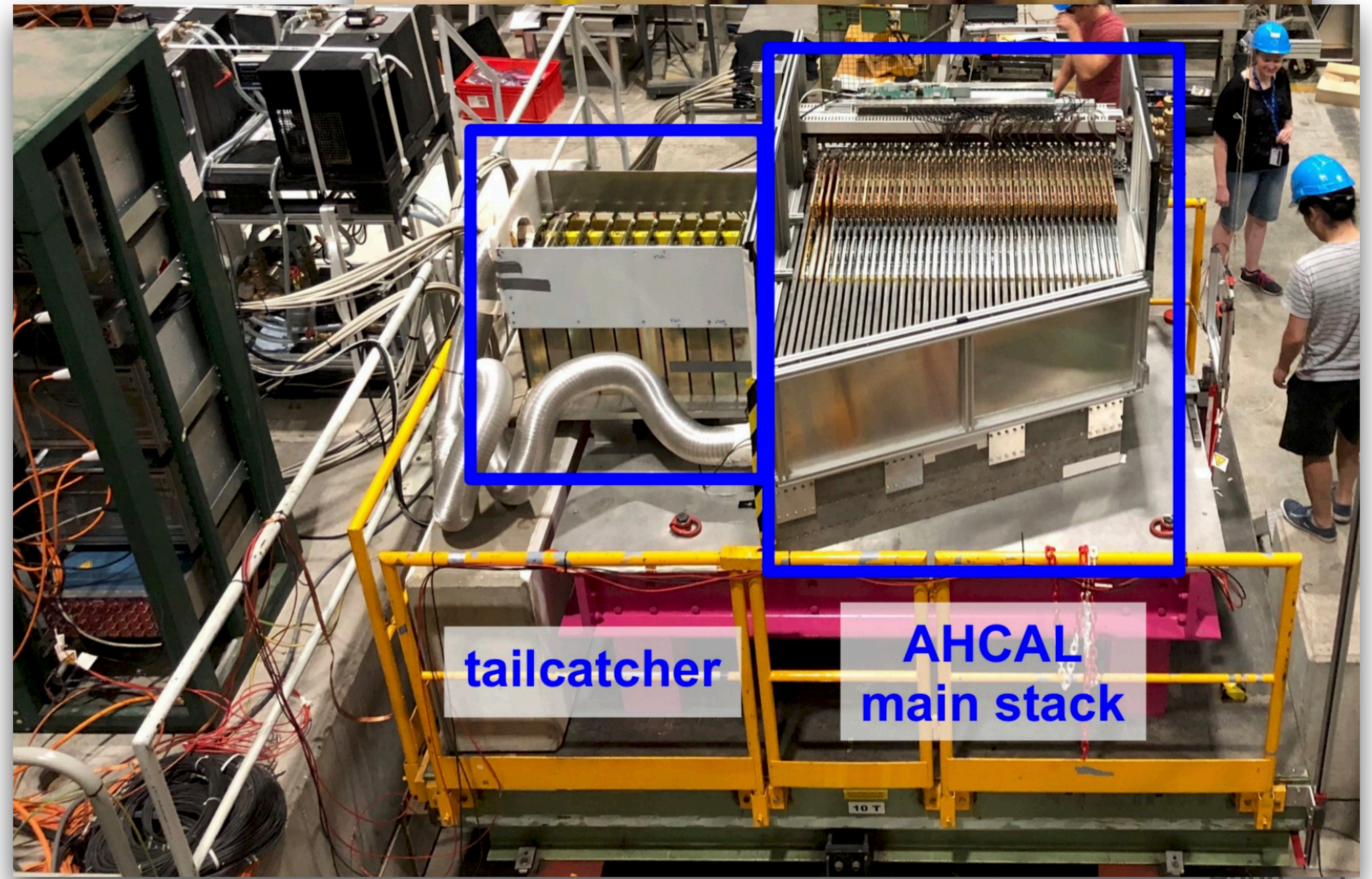

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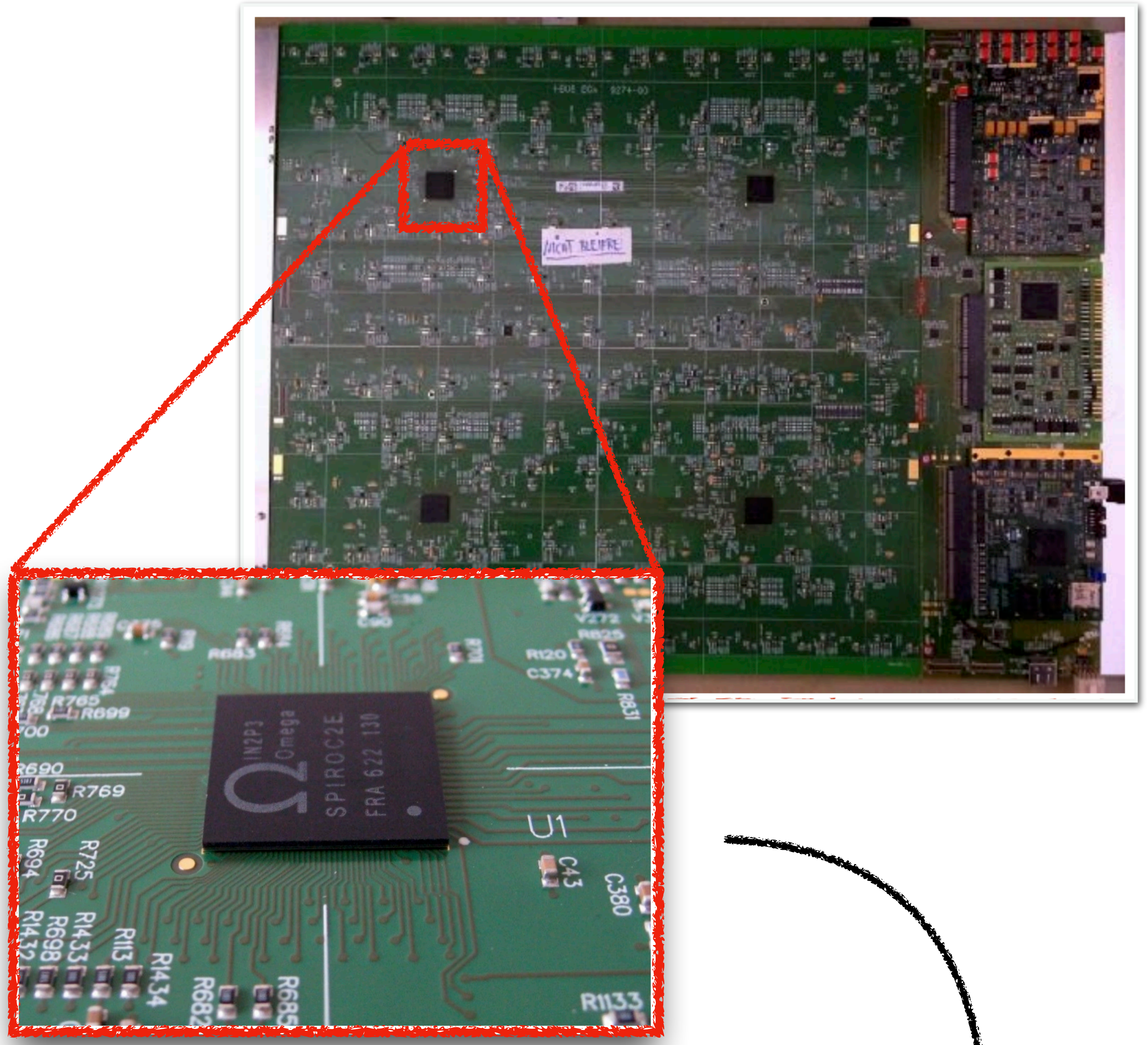
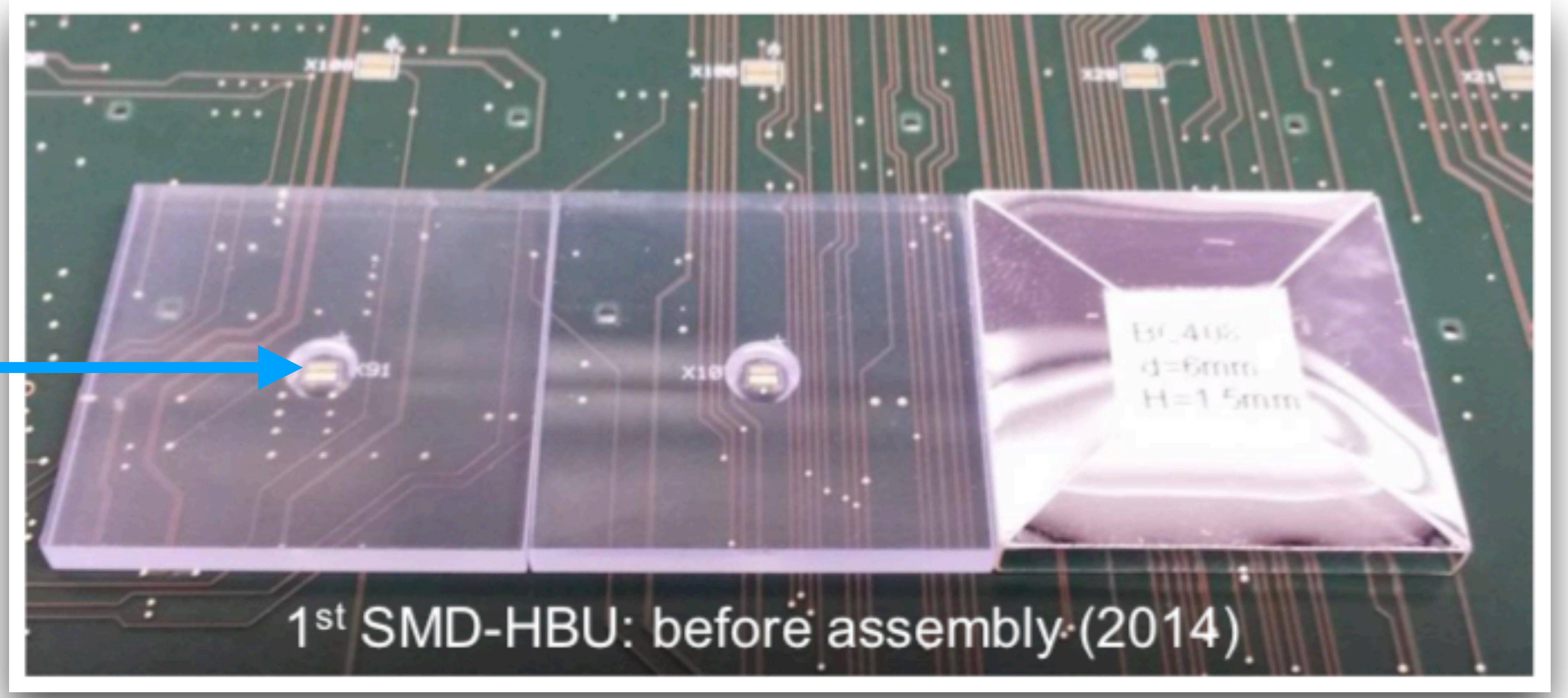
- Custom readout electronics outside, LED calibration system
- Today ➟ *test beams of technological prototype - ~**22k channels** on 40 layers*
    - Tiles of 3x3x0.3 cm^3, Hamamatsu SiPM S13360-1325PE
    - *Integration of the readout electronics* on the layer -> ASIC
    - *Integrated LED calibration* system
    - *Mass-production*, large scale feasibility
- **Very good potential as a basis for the DUNE ND ECAL**

See Lucia's talk tomorrow



SPIROC2e ASIC

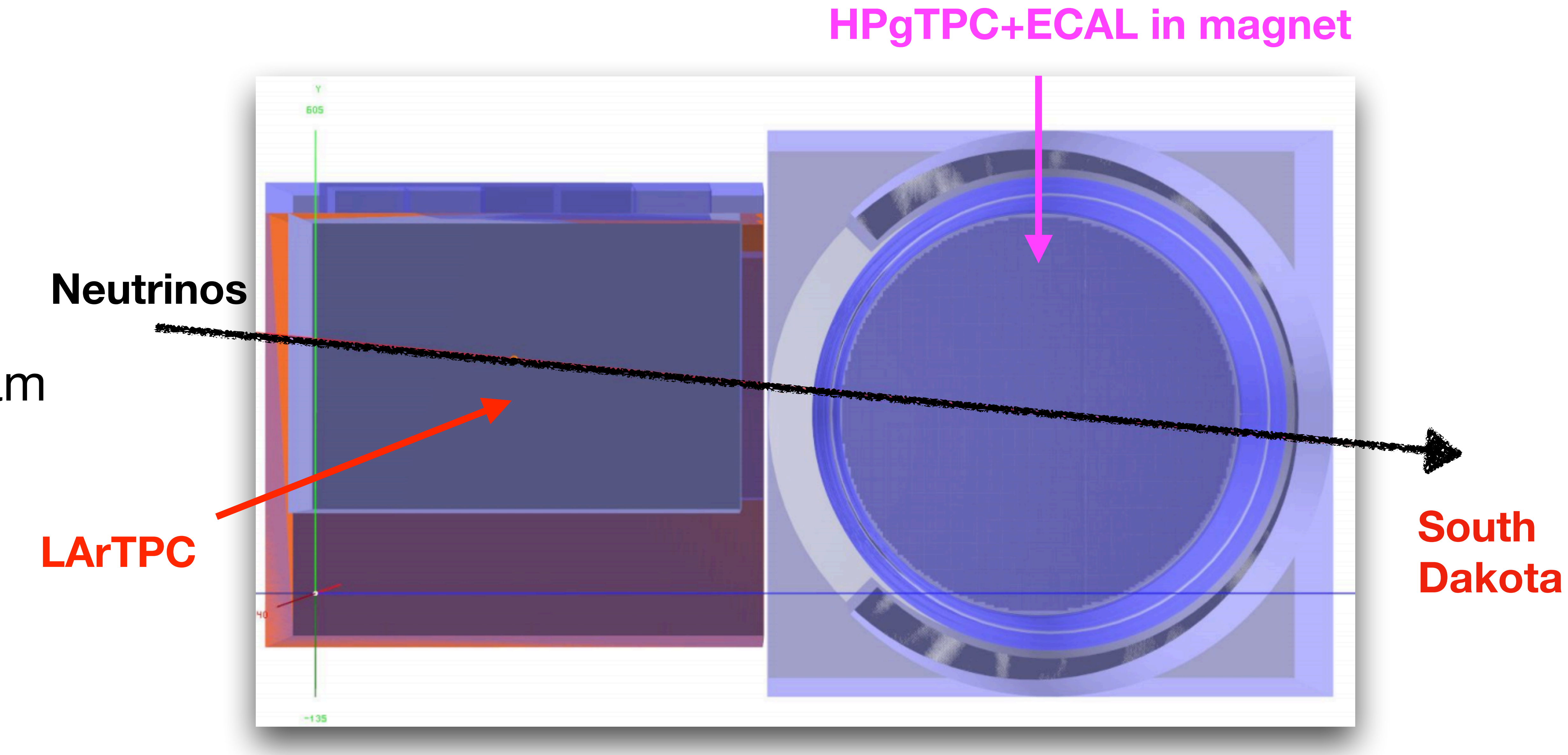
SMD SiPM
"SiPM-on-tile"

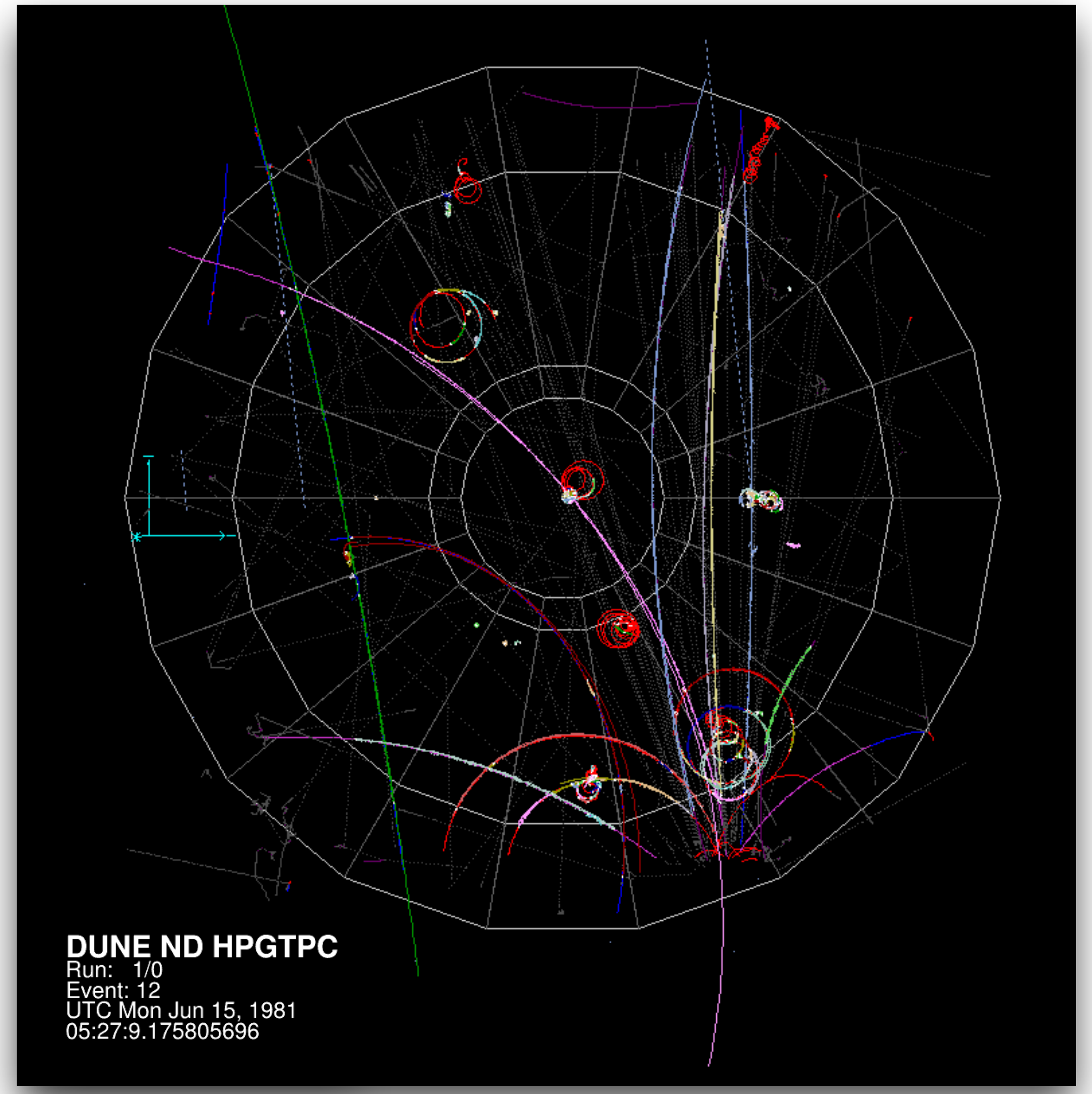


The goals for the ND ECAL.

Physics requirements

- **The role of the ND** is to provide constraints on systematics: beam energy spectrum, beam composition, model ν-Ar interactions…
    - ➠ Rich physics potential!
- **The role of the ECAL**
    - Primarily needed to reconstruct photons / electrons (identify neutral pions and electrons from NC, CC events)
        - ➠ Good ***energy resolution*** needed over a broad range of energies from few MeV to few GeV
    - Reconstruction of the π^0 energy and association to decay vertex
        - ➠ ***Angular resolution***
    - Identification of neutrons coming from ν-Ar interactions
        - ➠ ***Precise timing*** for ToF measurement
    - Help in **background rejection** (reject events outside the TPC/ coming from the ECAL)
    - Additional: Particle catcher + muon id/tracker from the LArTPC
- ➠ **A case for a high granular ECAL!**



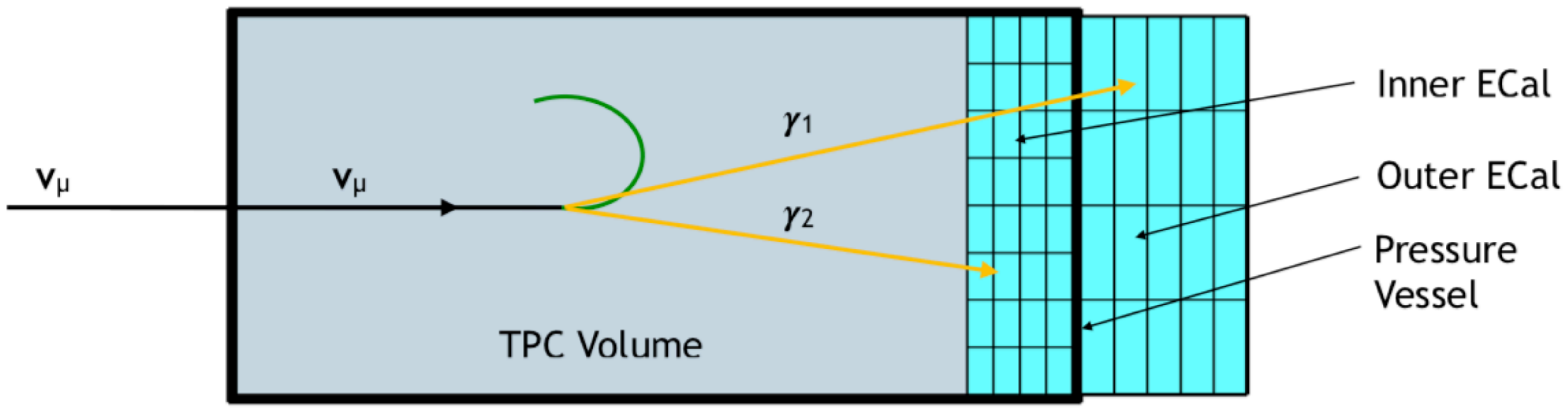


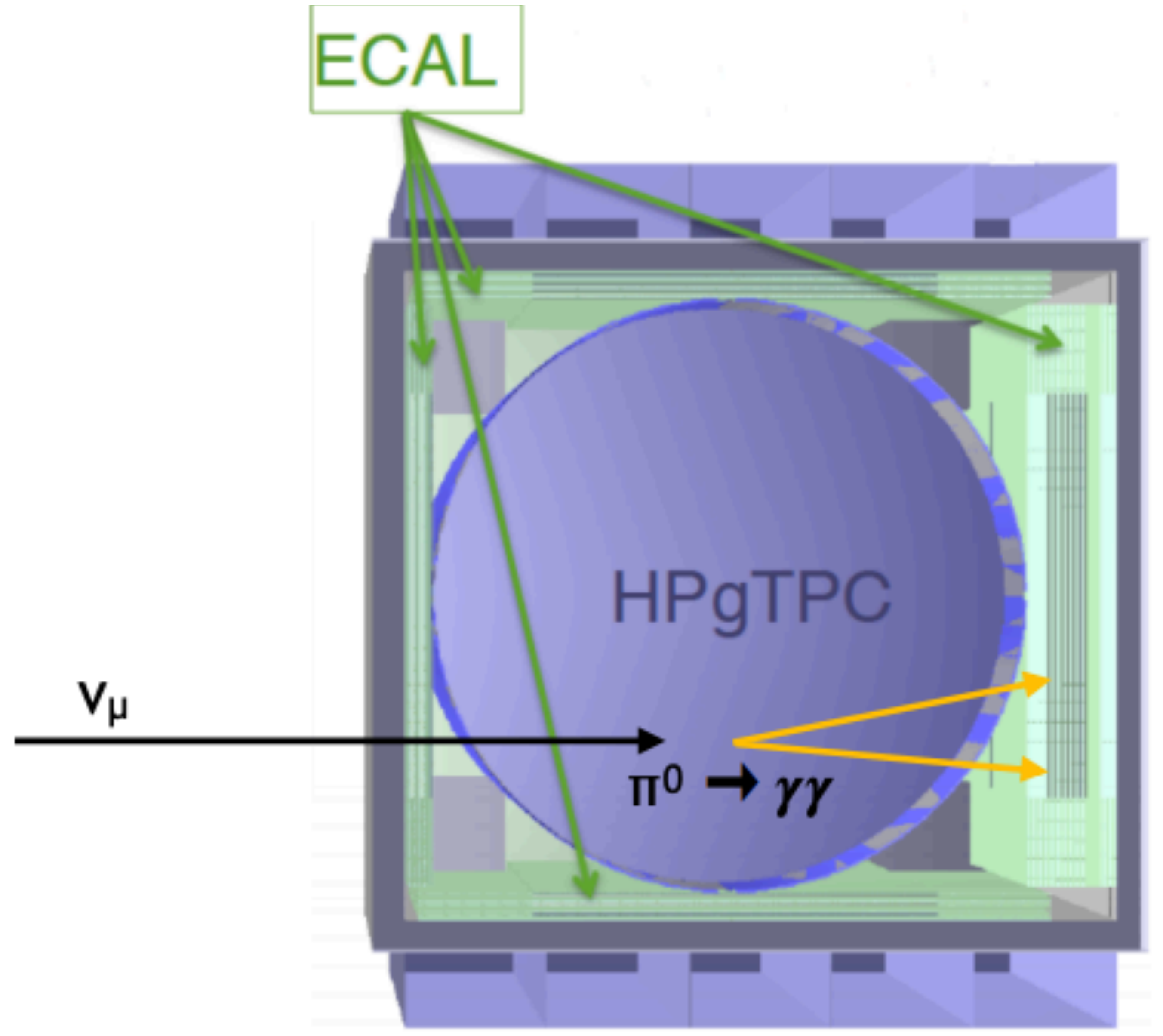
10 nu-interaction per spill (~x4 more)

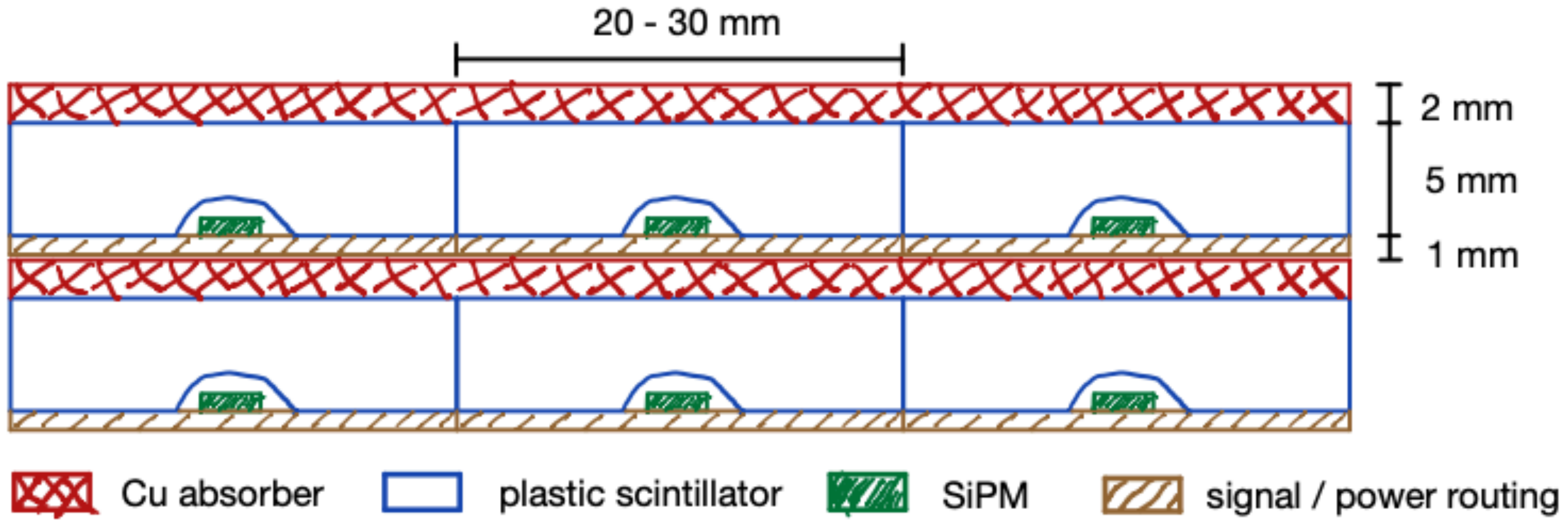
Previous Studies.

First detector concept

- **First simulation studies** have been done at MPP in the last years *(Lorenz Emberger)*
  - Motivation stated in the last slide
- First rough concept implemented in Geant4
  - Sampling calorimeter based on CDR geometry : 1.8 mm Pb absorber + 1 cm plastic scintillator
- Studies of calorimeter performance
  - **2D/3D segmentation** of the active material ➠ study of the benefits of granularity
  - **Influence of the absorber** material, thickness
  - **Influence of the pressure vessel**
  - **Neutral pion** identification and vertex reconstruction
  - **Neutron detection** efficiency
- Provided first **understanding** of the capabilities of such concept and dependency of the performance on some parameters





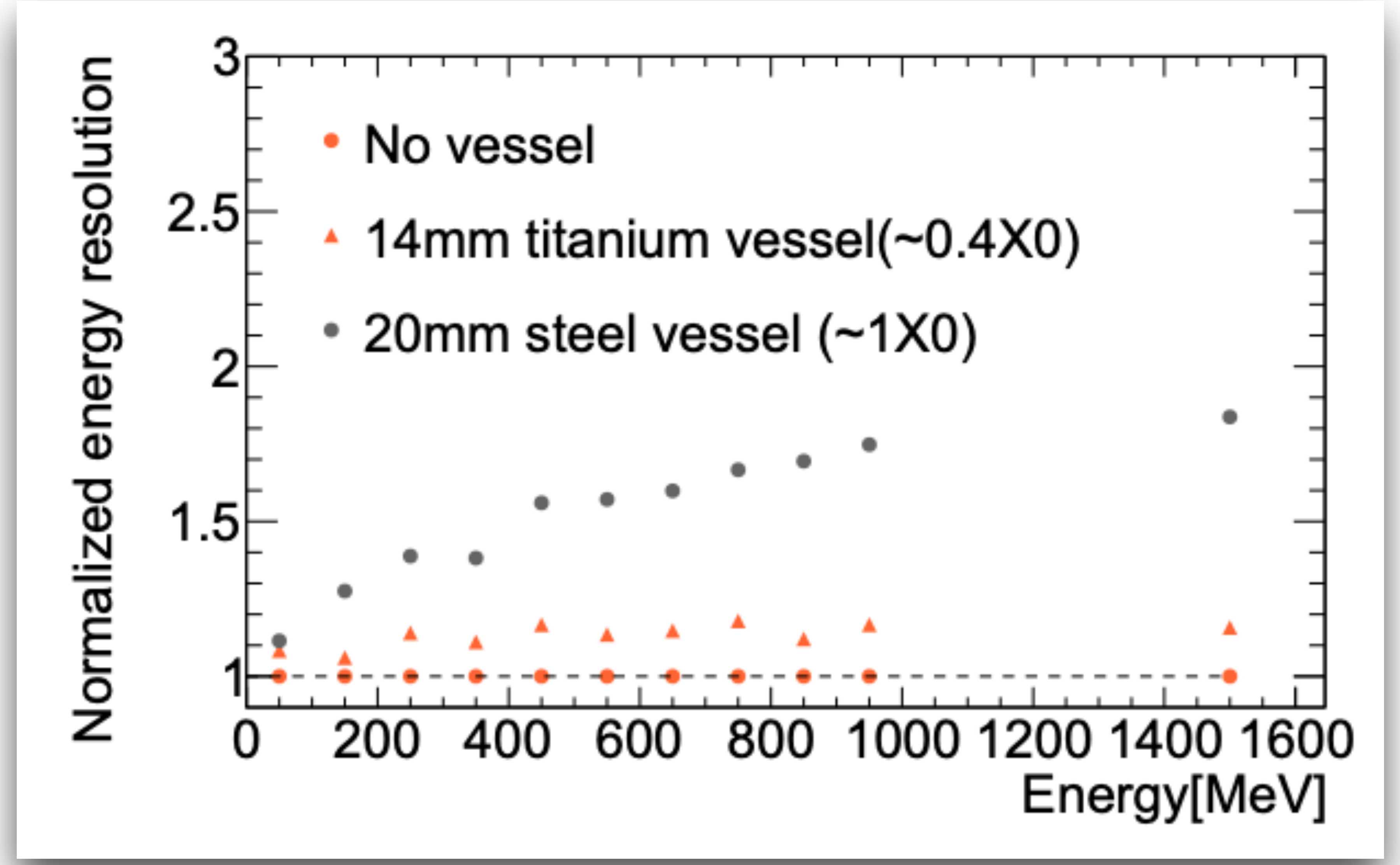


Lessons learnt.

Where to start for optimisation?

arXiv:1810.03677

- **Pressure vessel thickness** affects the energy resolution ➠ if possible ECAL inside PV / limit the thickness of the PV



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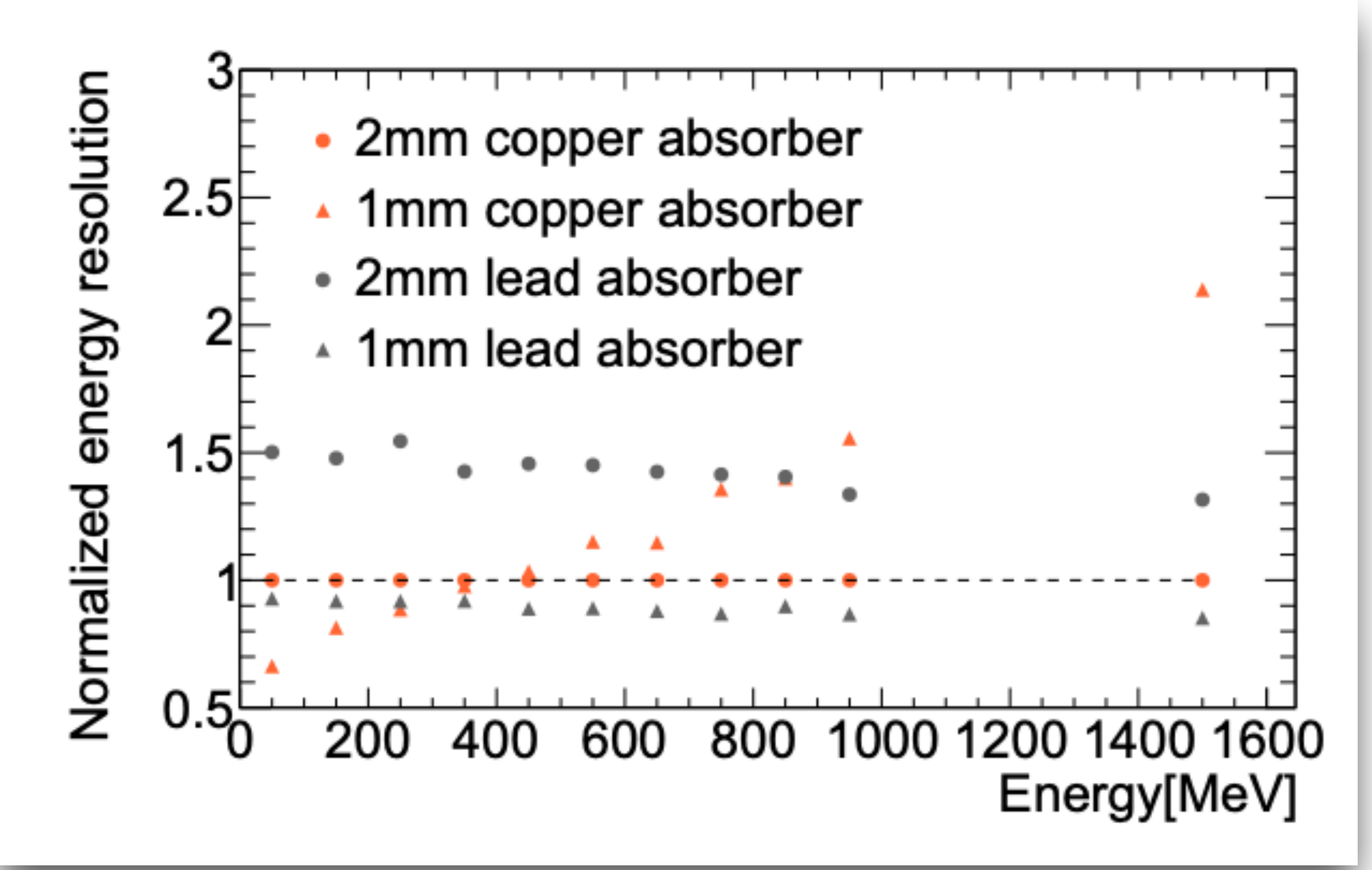
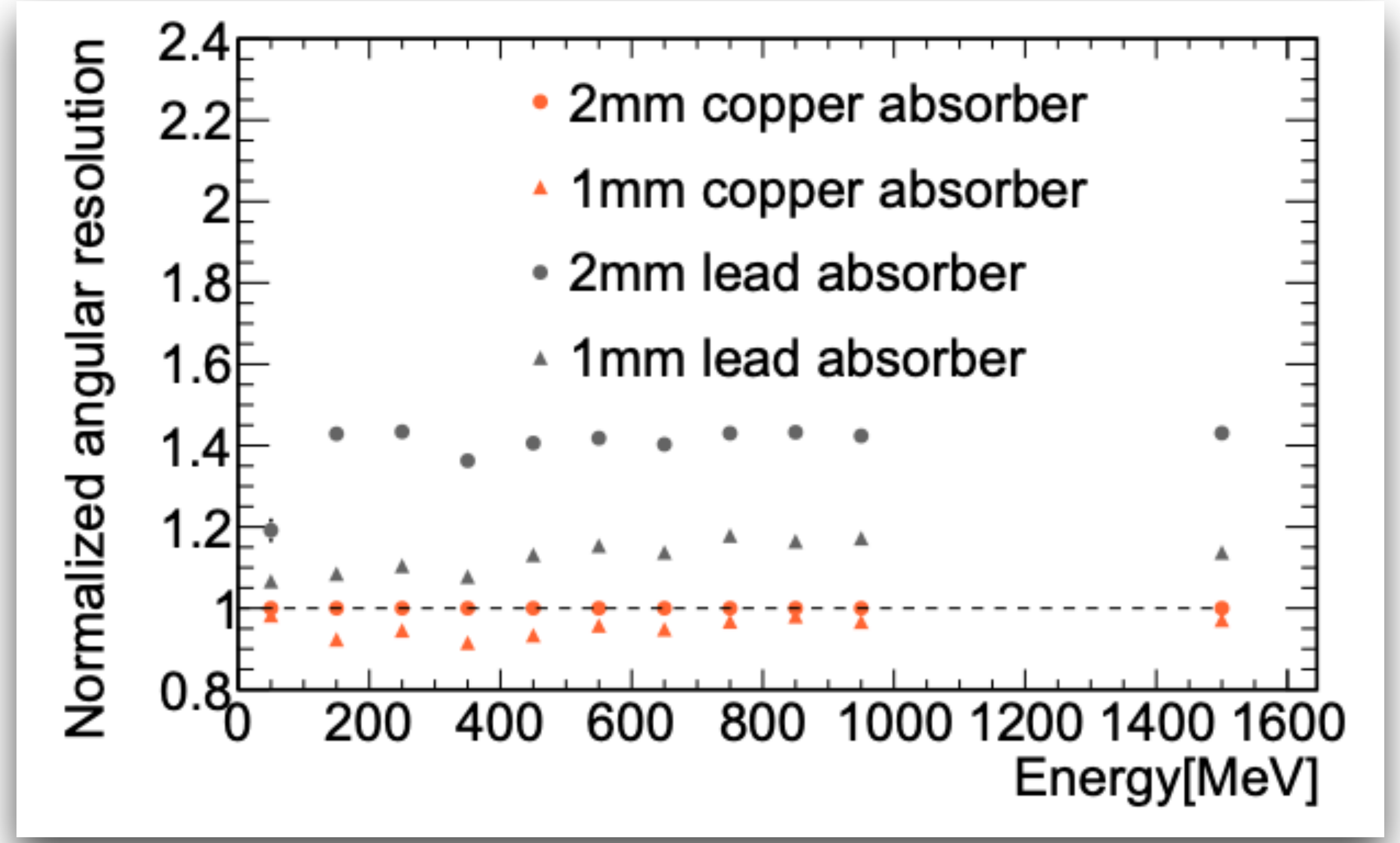
Where to start for optimisation?

- **Pressure vessel thickness** affects the energy resolution ➟ if possible ECAL inside PV / limit the thickness of the PV
- **Absorber type**
  - Pb compared to Cu ➟ change in effective Molière radius (shower more compact in Cu, improved angular resolution) / sampling fraction (degraded energy resolution for same thickness)
- **Absorber thickness** is important for shower containment, energy resolution and angular resolution
  - Thin ➟ better angular resolution (higher lever arm) but worse energy res at high energies (leakage)





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- **Absorber thickness** is important for shower containment, energy resolution and angular resolution
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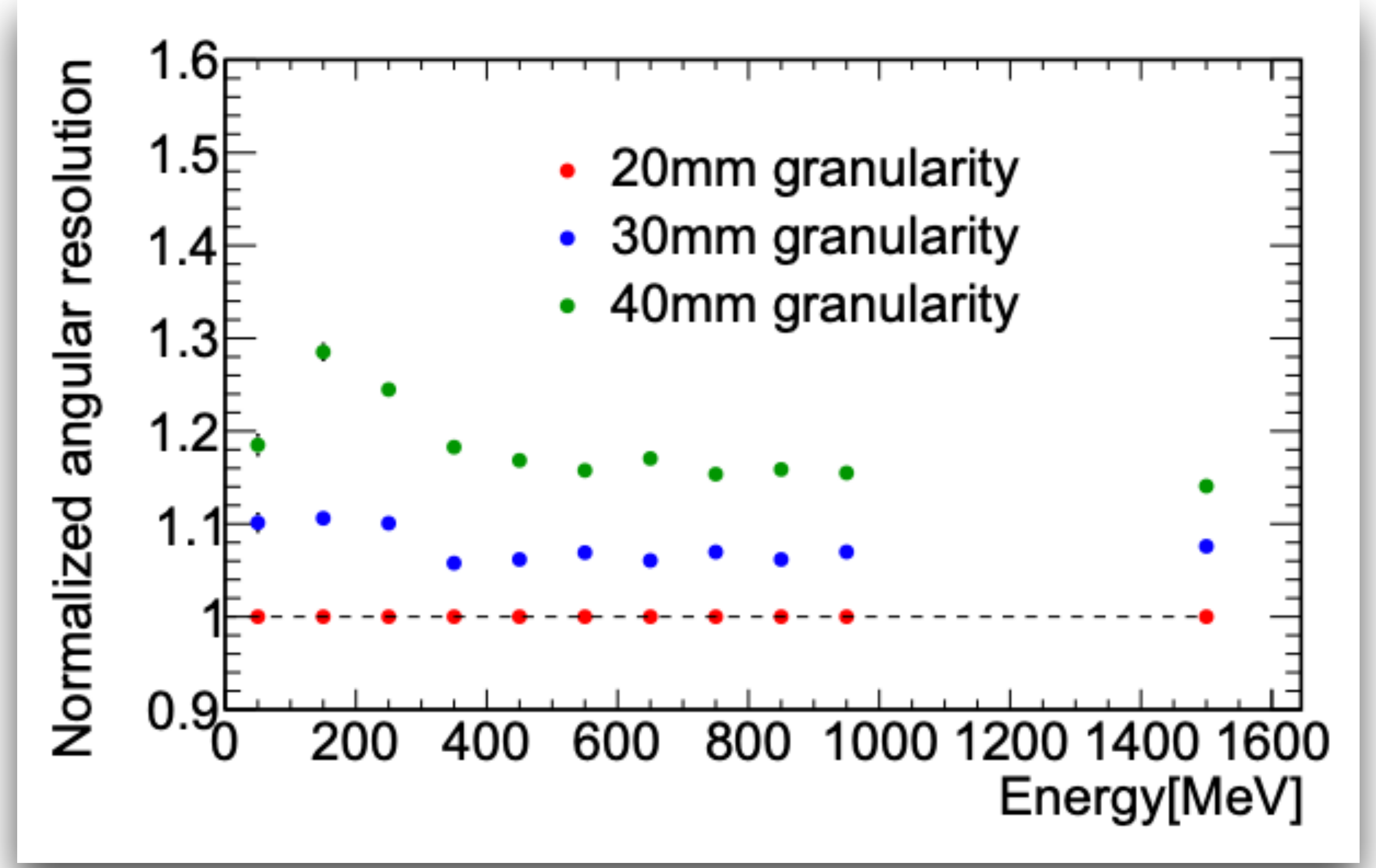
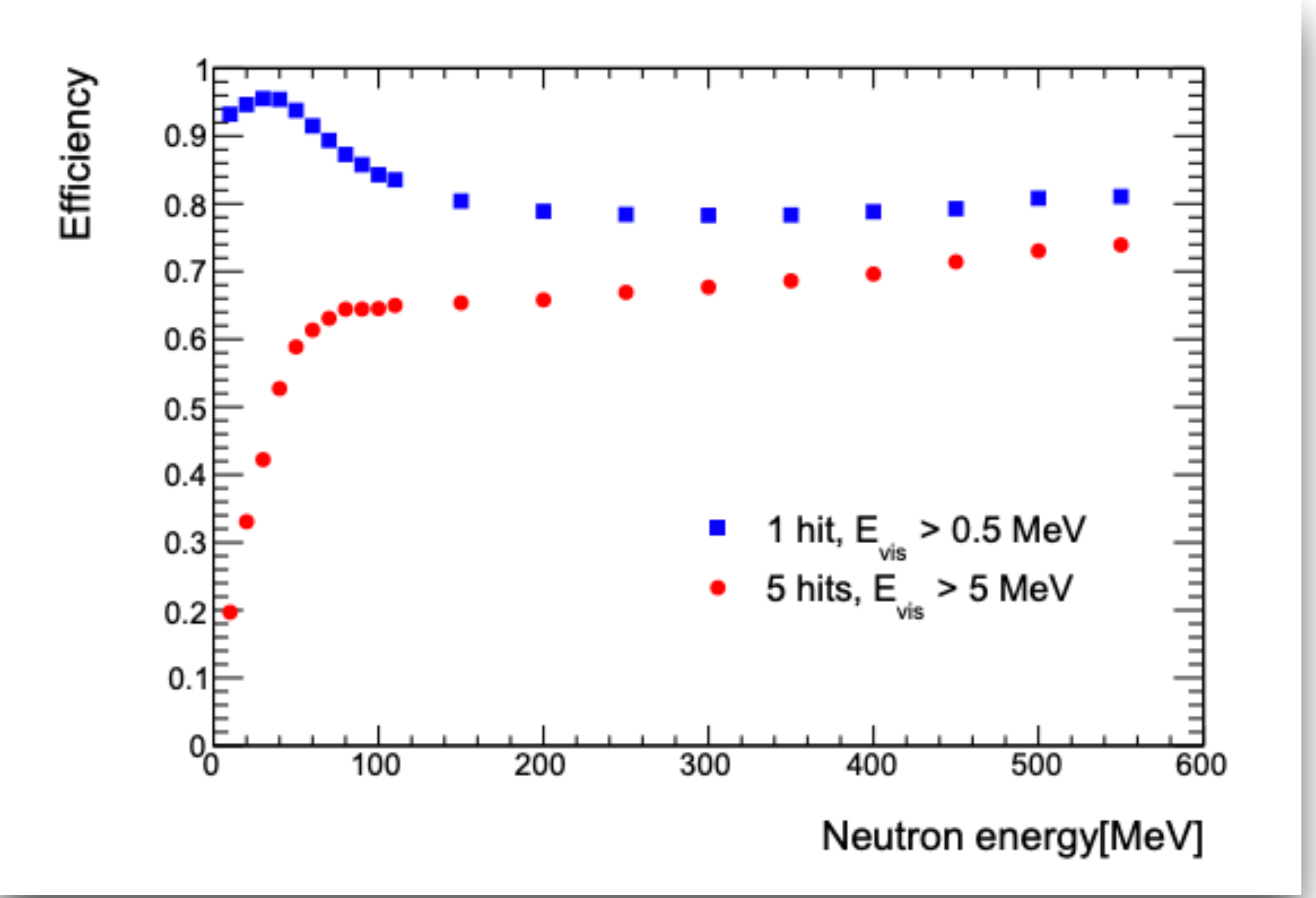
- **Granularity**
  - Granularity of the back layers has almost no impact on the angular resolution ➠ can reduce channel count
  - Granularity of the first layers is the main driver for the angular resolution
- Potential for **neutron detection** (> 60% over 100 MeV)



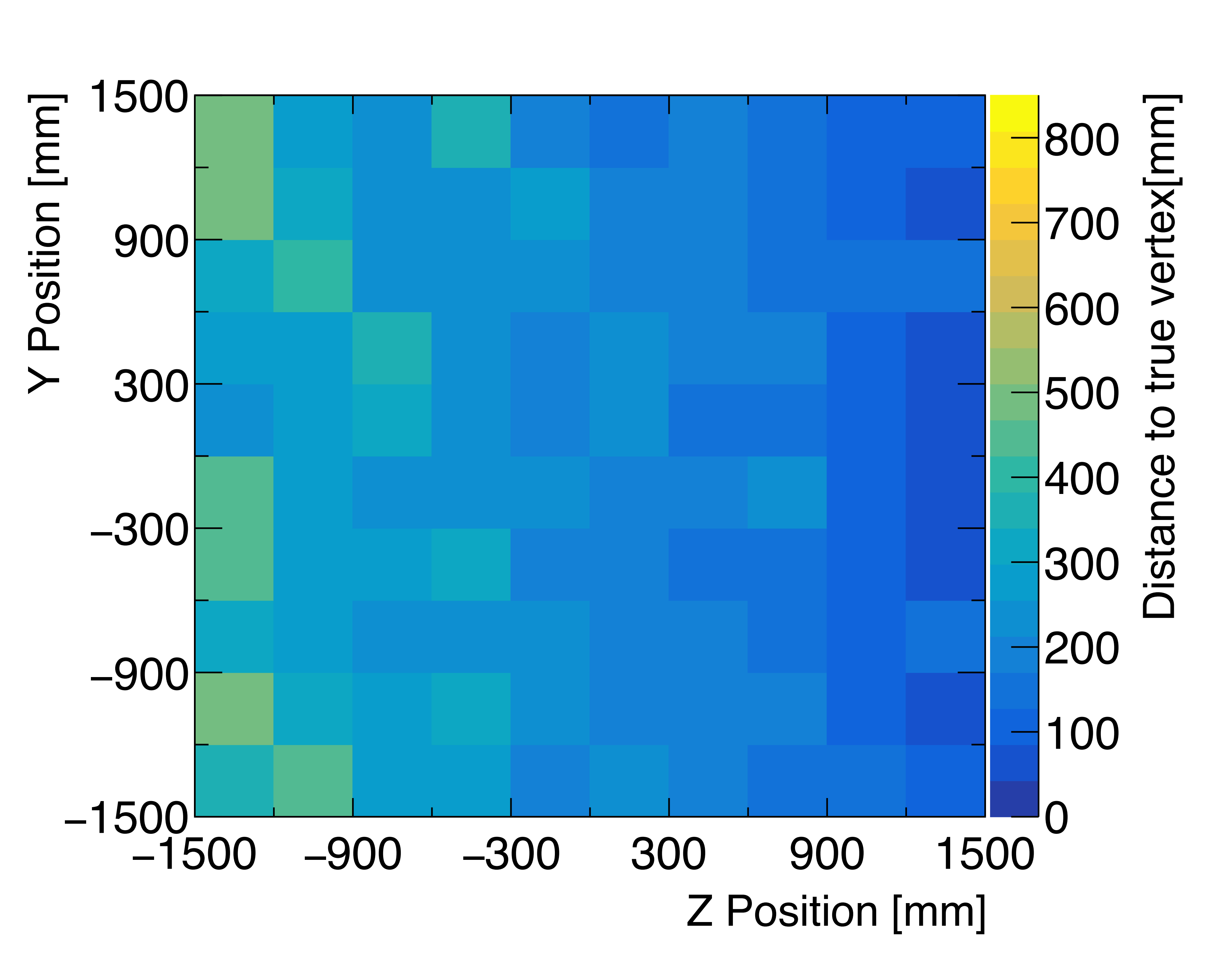


Lessons learnt.

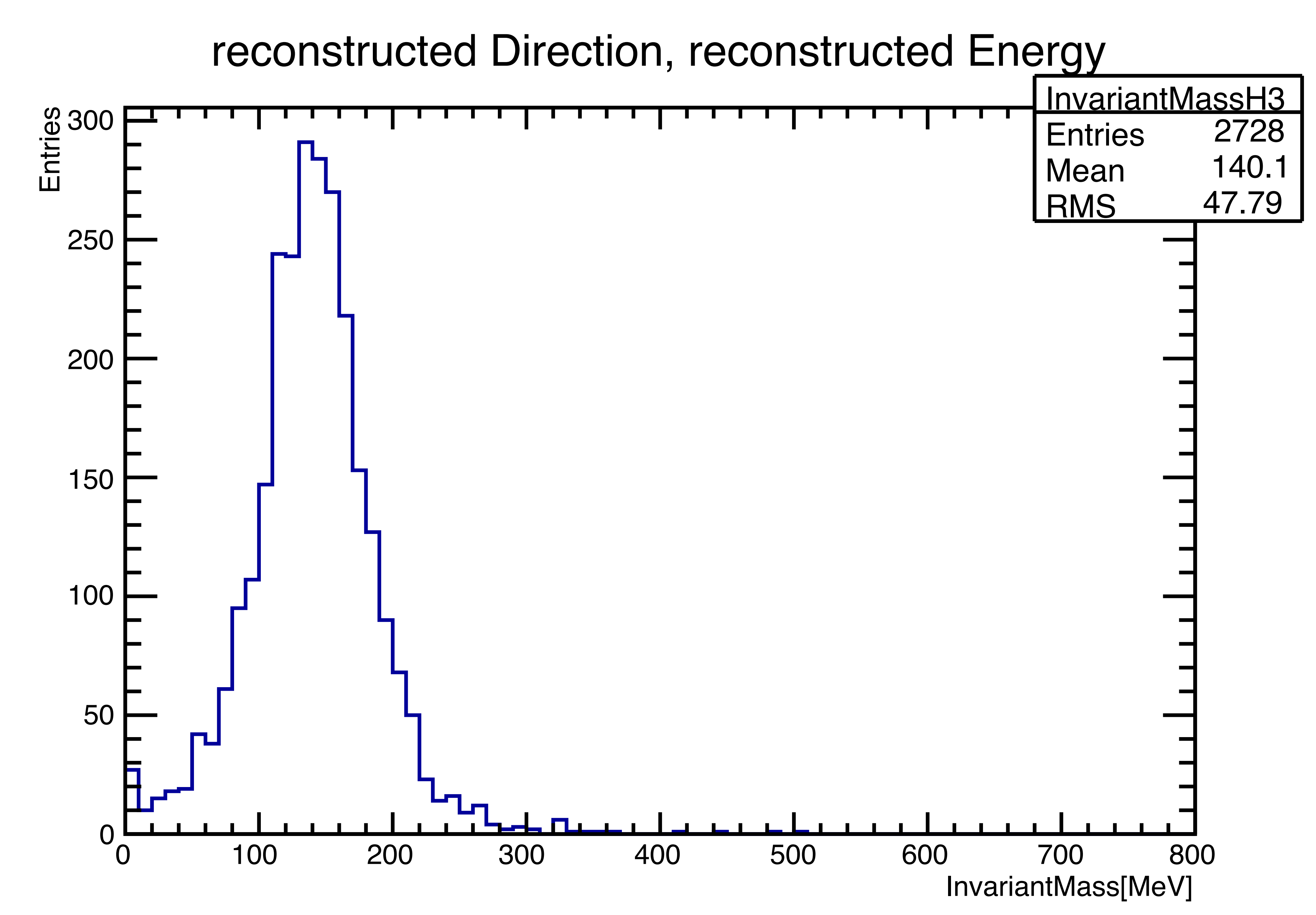
Where to start for optimisation?

arXiv:1810.03677

- First π^0 reconstruction study
  - Decay vertex determined to a precision ~10-40 cm depending on the location and energy
  - Identification via mass reconstruction possible



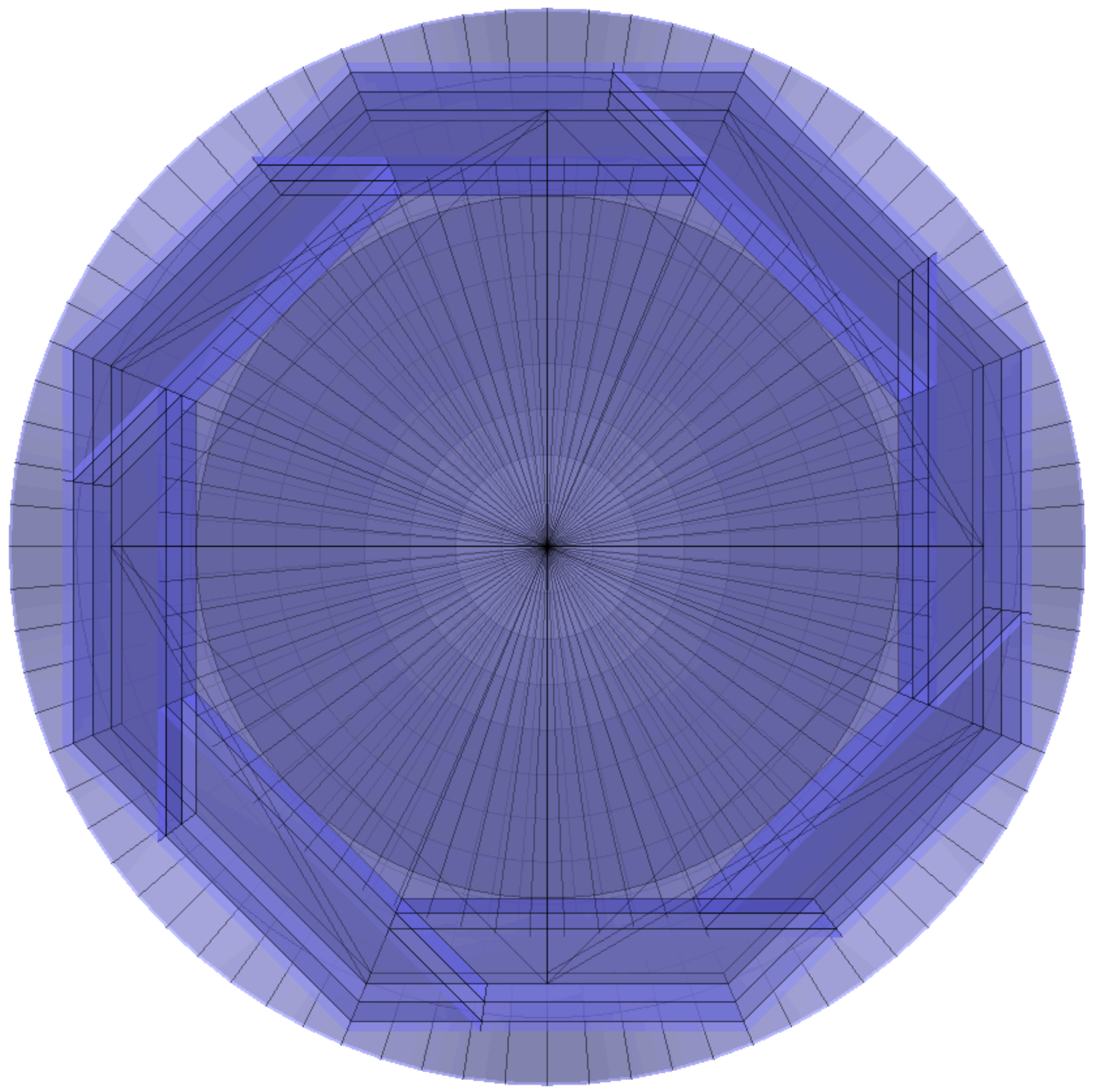
400 MeV kinetic energy



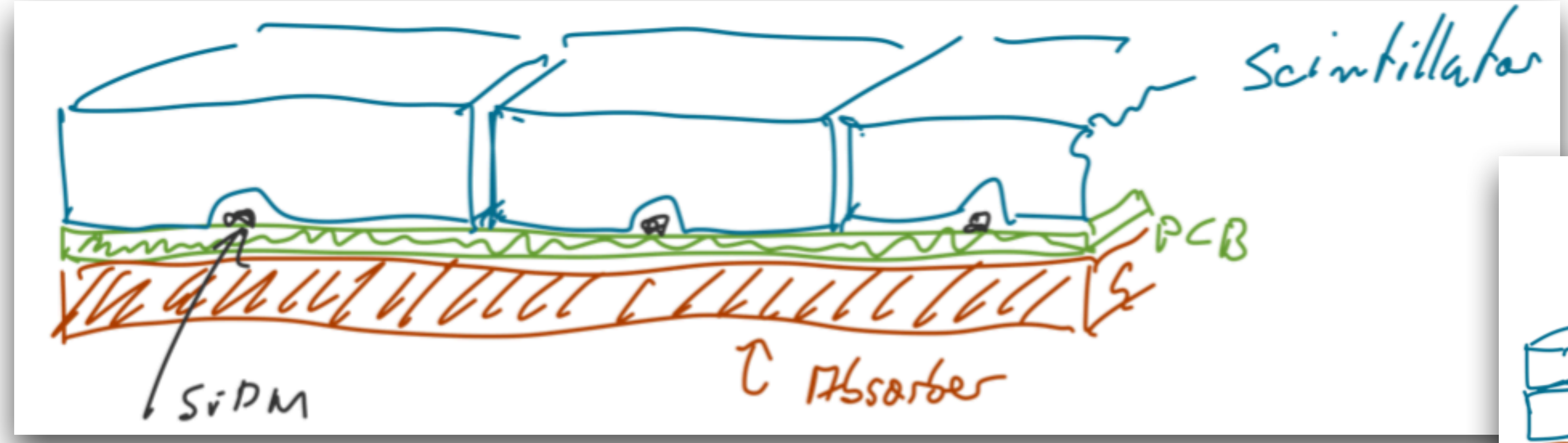
400 MeV kinetic energy

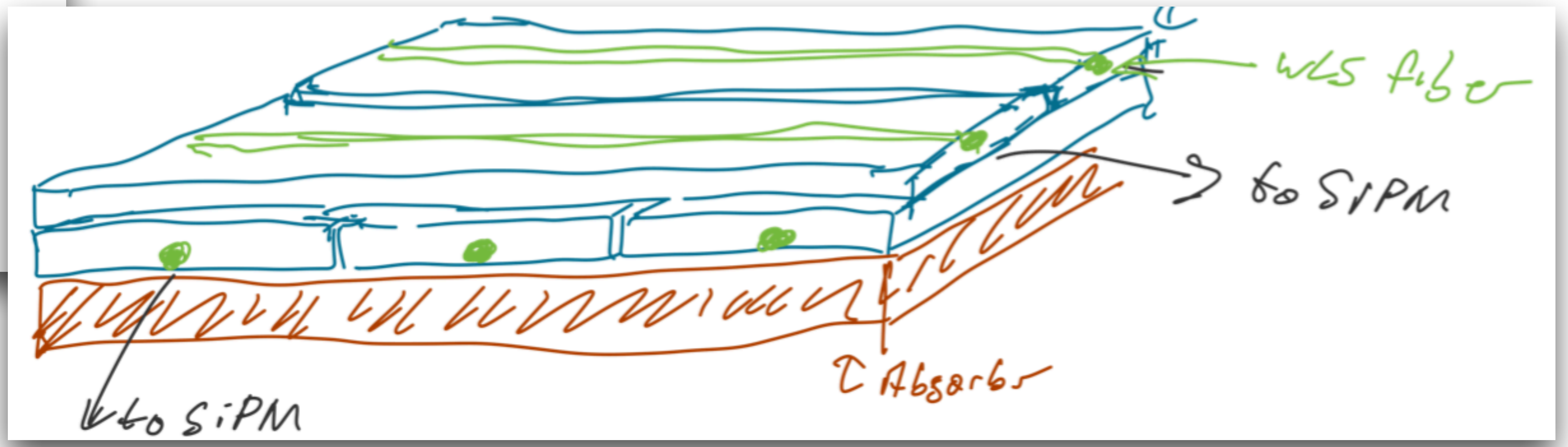
Towards a more realistic detector.

Geometry and integration with GArSoft



- Previous studies based on standalone Geant4
    - Need to integrate into a common framework → GArSoft
    - More realistic ECAL geometry (cubic → octagonal)
- Full granularity → excessive channel count → not necessary as shown in former study
    - Combine high granularity layers (HG) using SiPM-on-tile and low granularity layers with strips (LG) - crossed on same layer or every consecutive layer
    - See Lucia's talk: SHiP studies (scintillator bars)
    - Experience from T2K, MINOS and CALICE Tail Catcher





Towards a more realistic detector.

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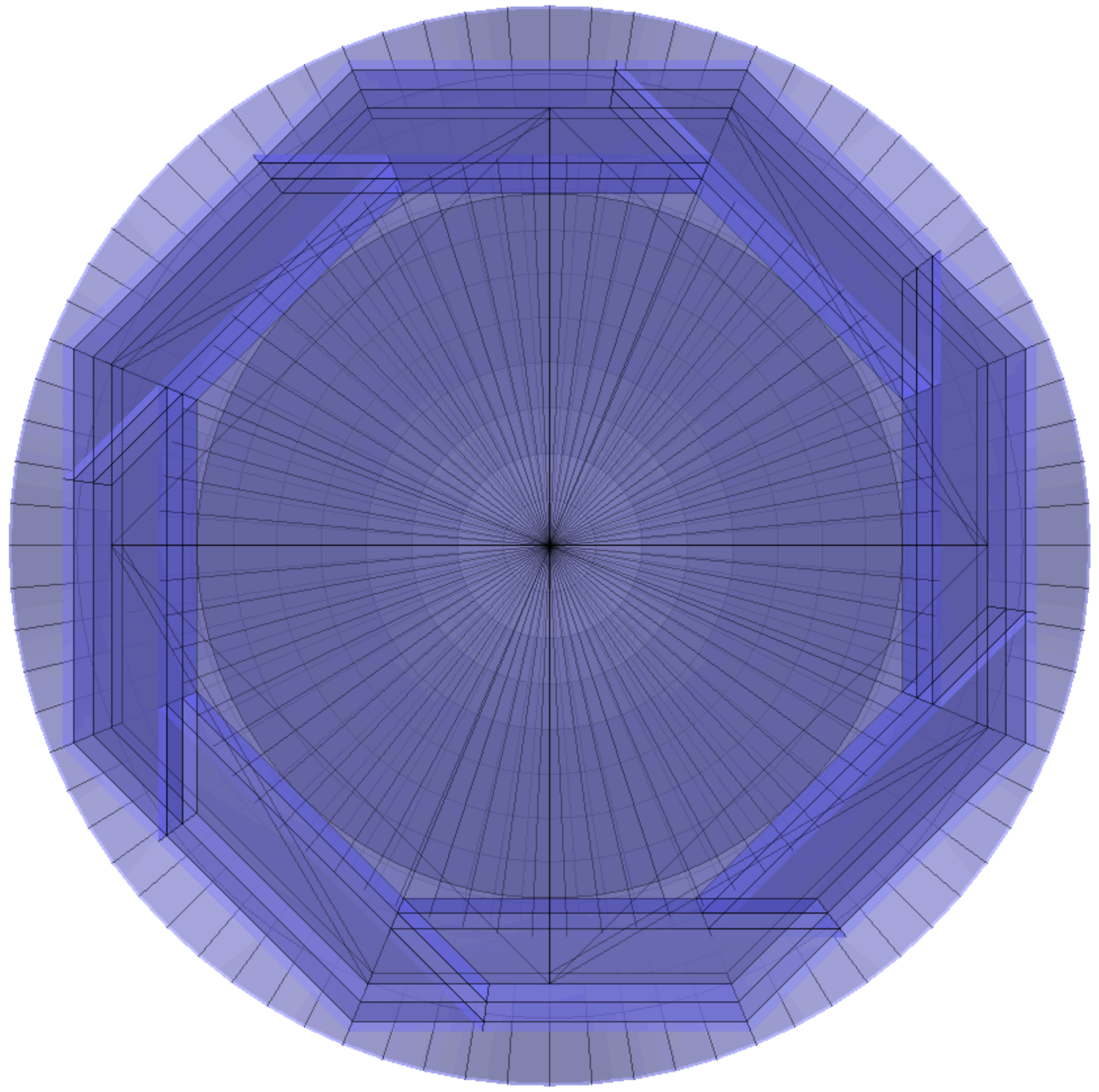
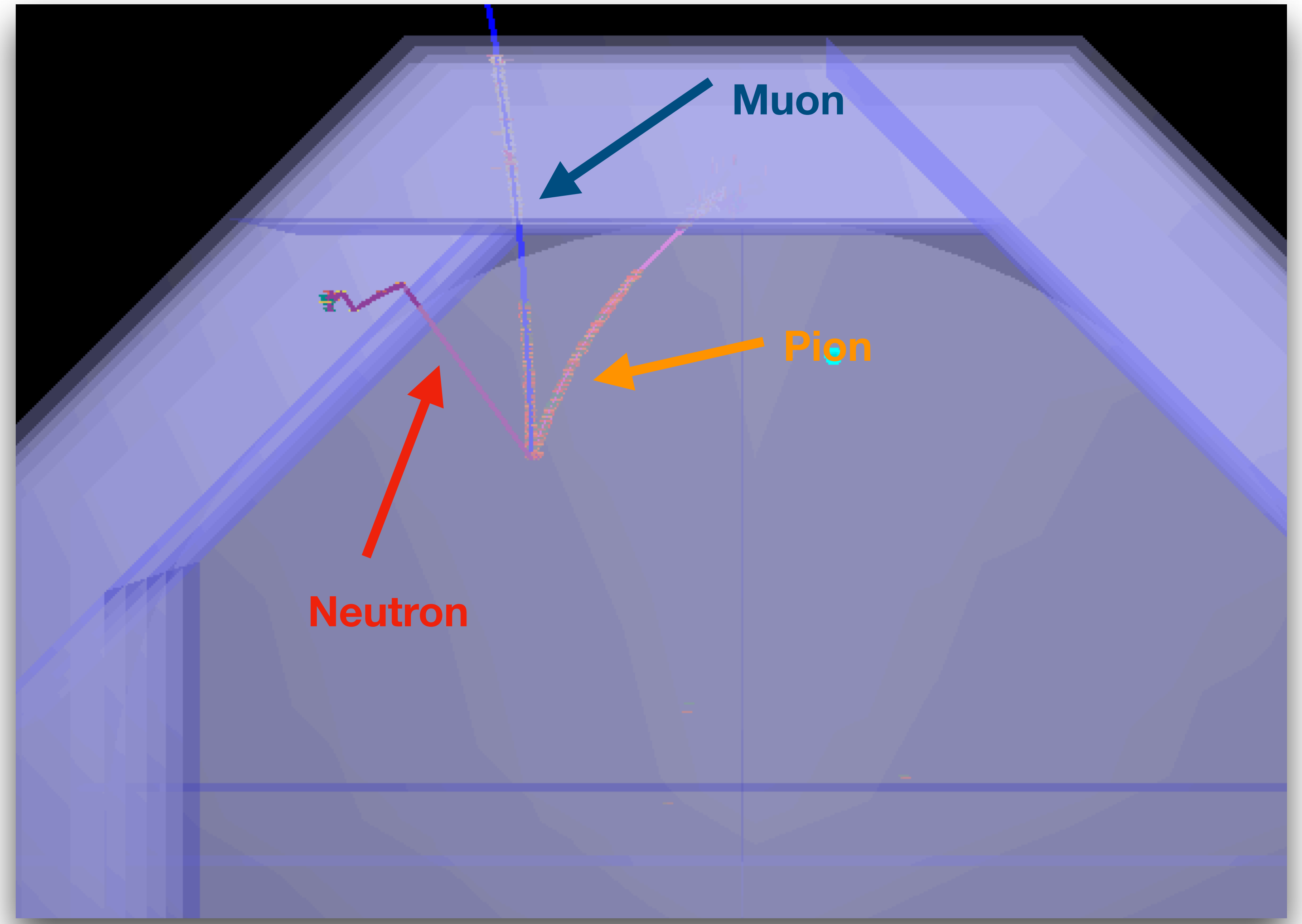
  - See Lucia's talk: SHiP studies (scintillator bars)
  - Experience from T2K, MINOS and CALICE Tail Catcher
- ECAL fully integrated into GArSoft
  - Simulation (Geant4 / GENIE)
  - Digitisation
    (generic to allow change in granularity / readout technology…)
  - Reconstruction
    (hit reconstruction, clustering, particle identification…)
  - 3D Event display





2 GeV ν event

Optimisation goals.

Taking into account the physics

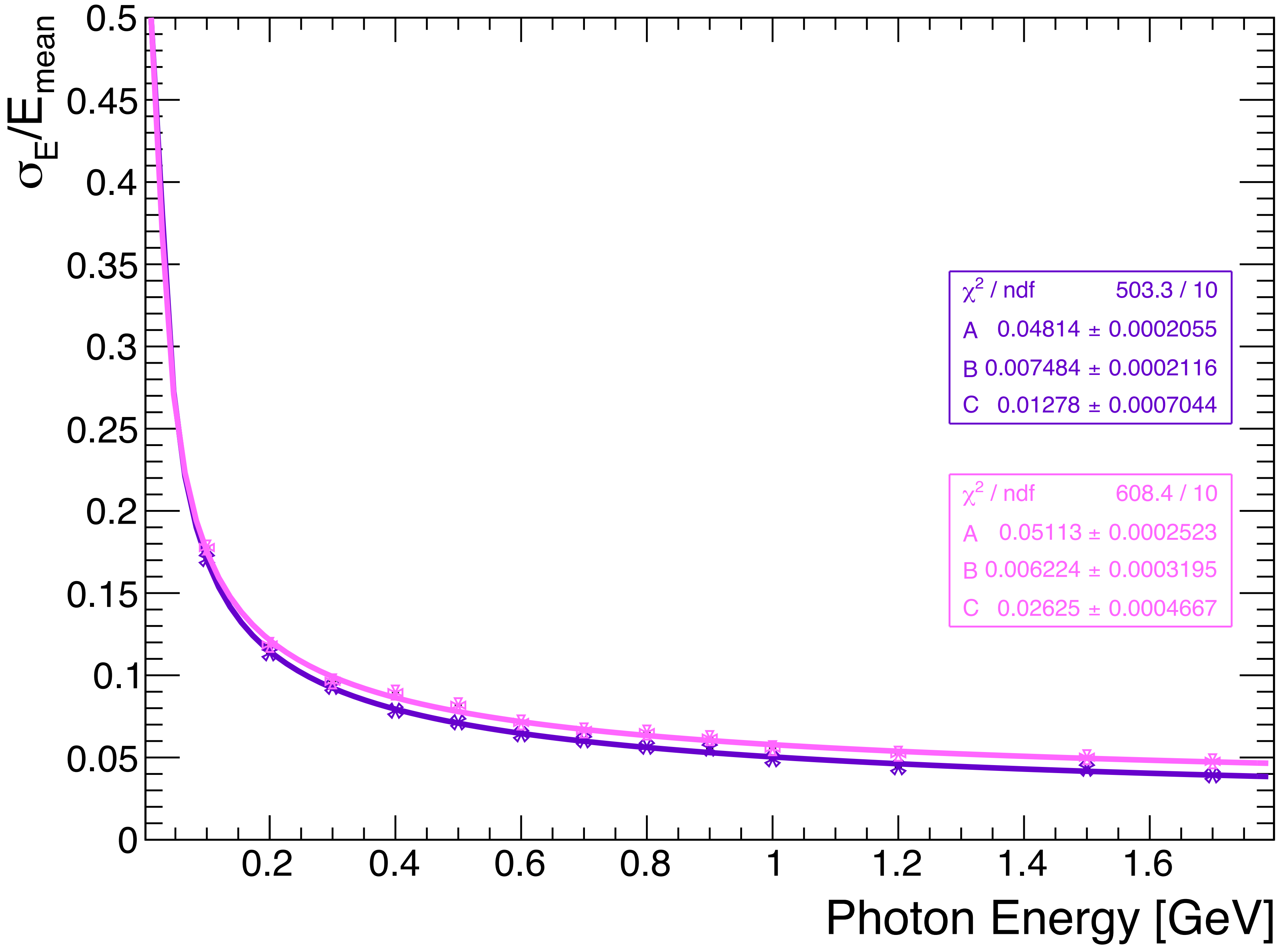
- **Goals**:
  - Optimisation of the overall design guided by former results
  - Optimisation of the **cost**: absorber/scintillator material, channel count.. etc…
  - Main design driver → **calorimeter energy resolution**, **angular resolution!**
  - Software framework versatile now enough to study several designs!
- **Design**:
  - Setup A (light pink) → 80 HG, 5 mm tile → sanity check with Lorenz results (fully granular ECAL)
  - **Setup B** (purple) → 8 HG, 5 mm tile + 97 LG, 2 mm Cu, cross-layers, 5 mm Sc → **Granularity for the back layers**
  - **Setup C** (red) → 8 HG + 47 LG (HG: 2mm Cu/LG: 4 mm Cu), cross-strips, 10 mm Sc→ **Sc/absorber thickness**
  - **Setup D** (blue) → 8 HG + 12 LG, 2 mm Cu + 35 LG, 4 mm Cu, 10 mm Sc → **thinner absorber in front layers**
  - **Setup E** (green) → 8 HG, 10 mm Sc + 92 LG, 2 mm Cu, cross-layers, 5 mm Sc → **thinner absorber for LG layers**
  - Setup F (orange) → 8 HG, 3 mm tile + 100 LG, 2 mm Cu, cross-layers, 5 mm Sc → thinner HG tile

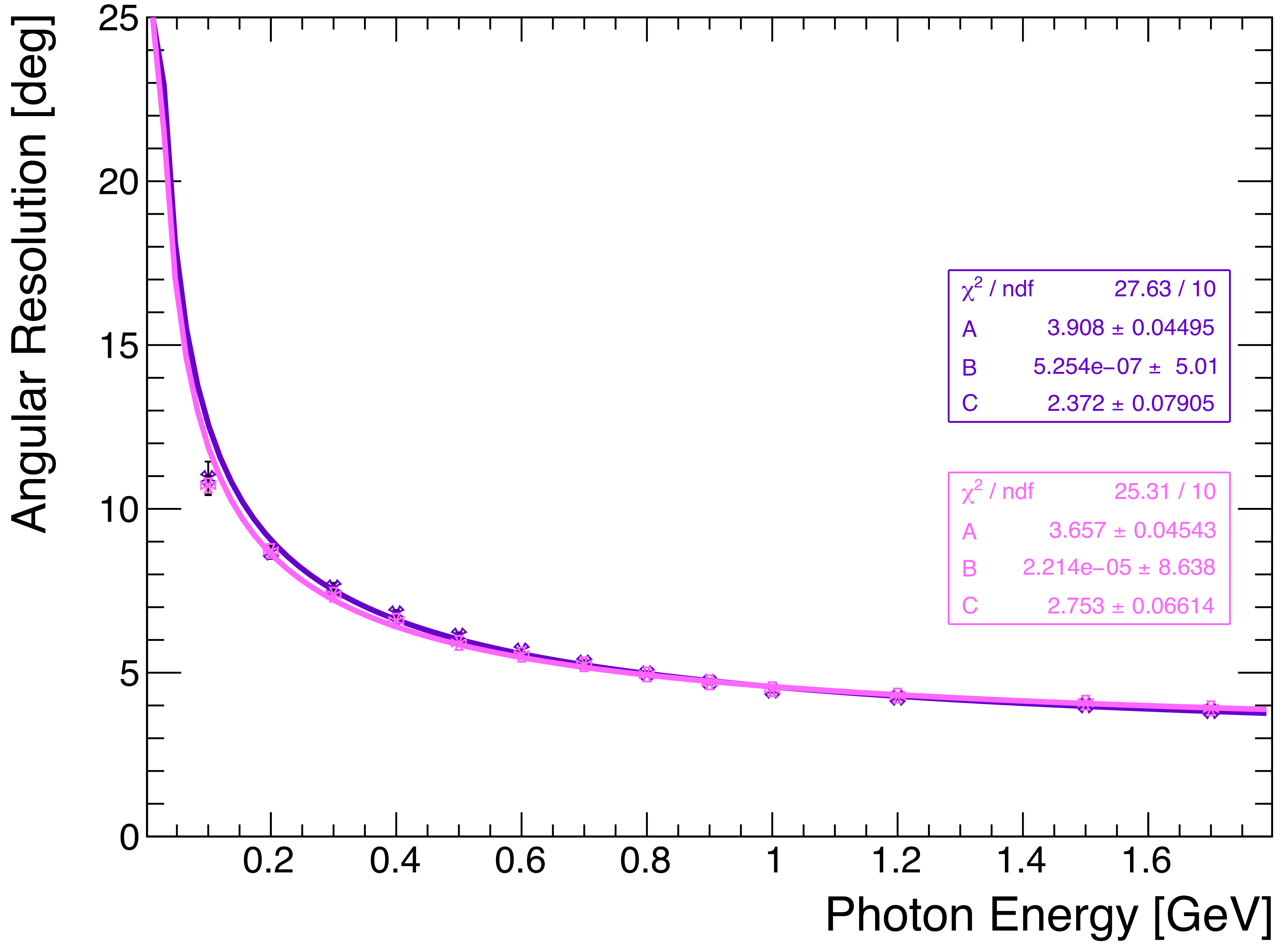
Color index used as legend for the following plots

Simulation studies.

Influence of the granularity

- Change of the granularity of the back layers
- Using strips with WLS crossed perpendicularly between layers



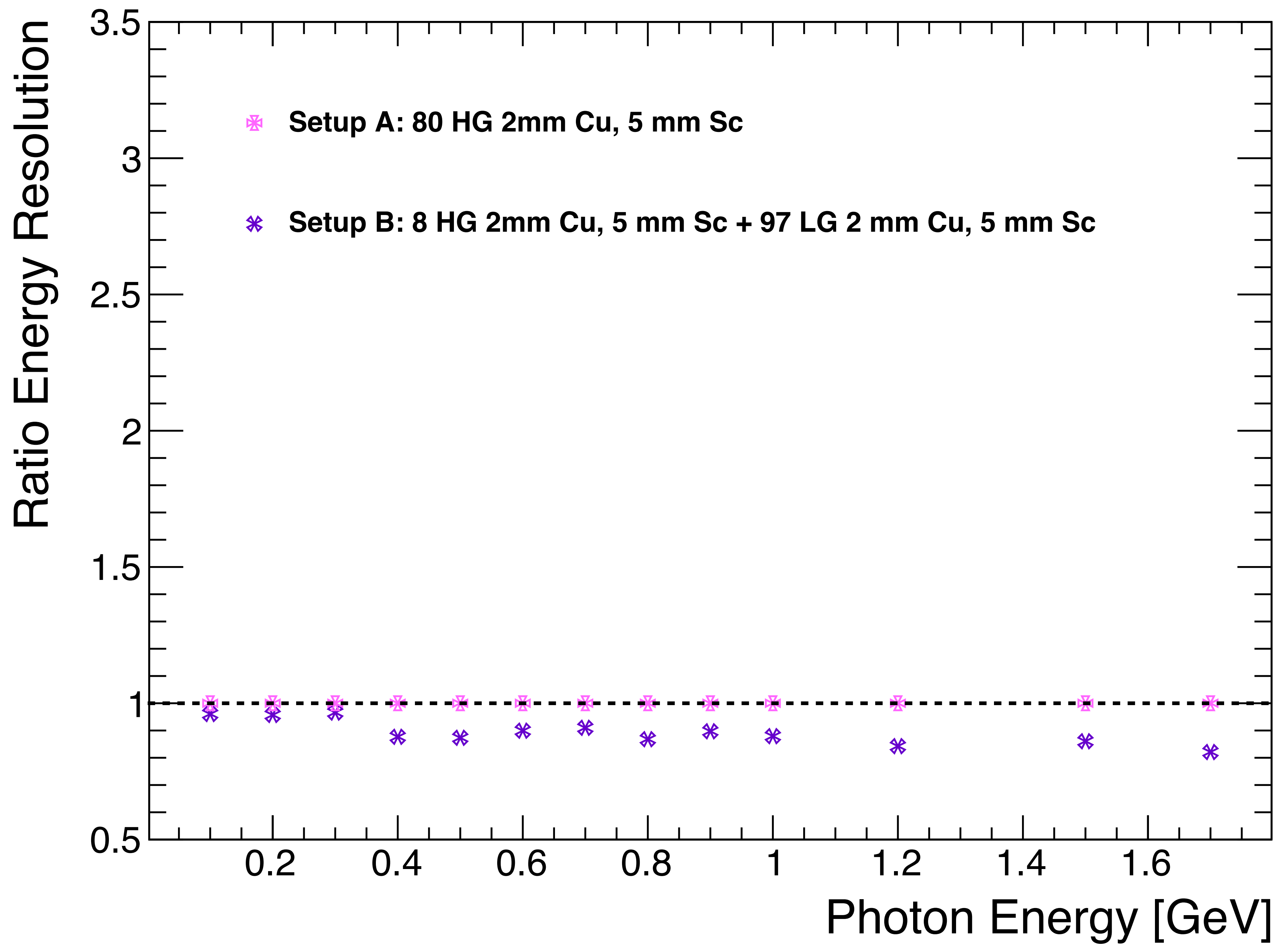


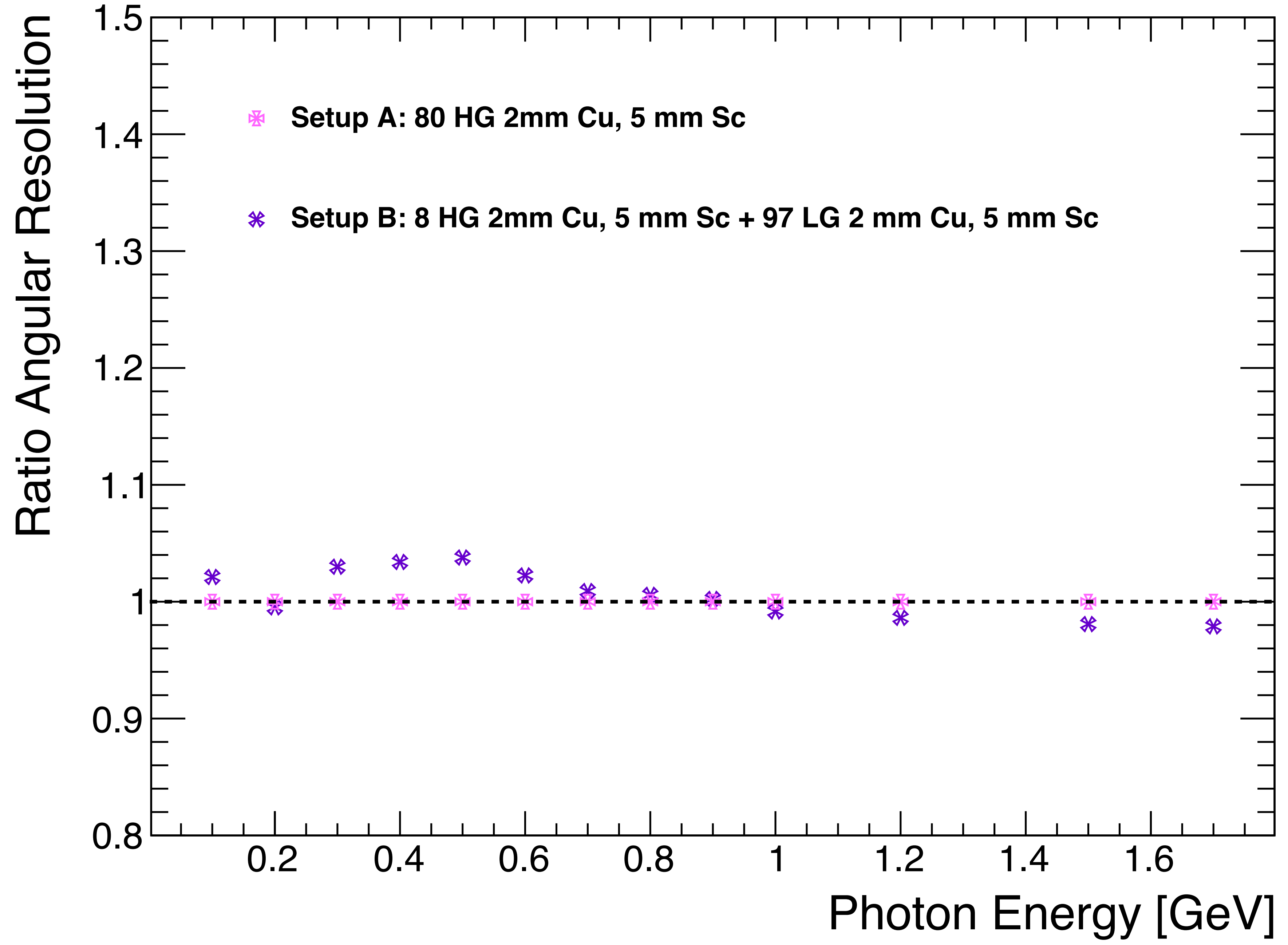
Simulation studies.

Influence of the granularity

- Change of the granularity of the back layers
- Using strips with WLS crossed perpendicularly between layers

- Slight improvement of the energy resolution ~5-10% → more layers → less leakage
- Angular resolution not much affected (~2%) by using strips instead of tiles → viable option to reduce channel count!

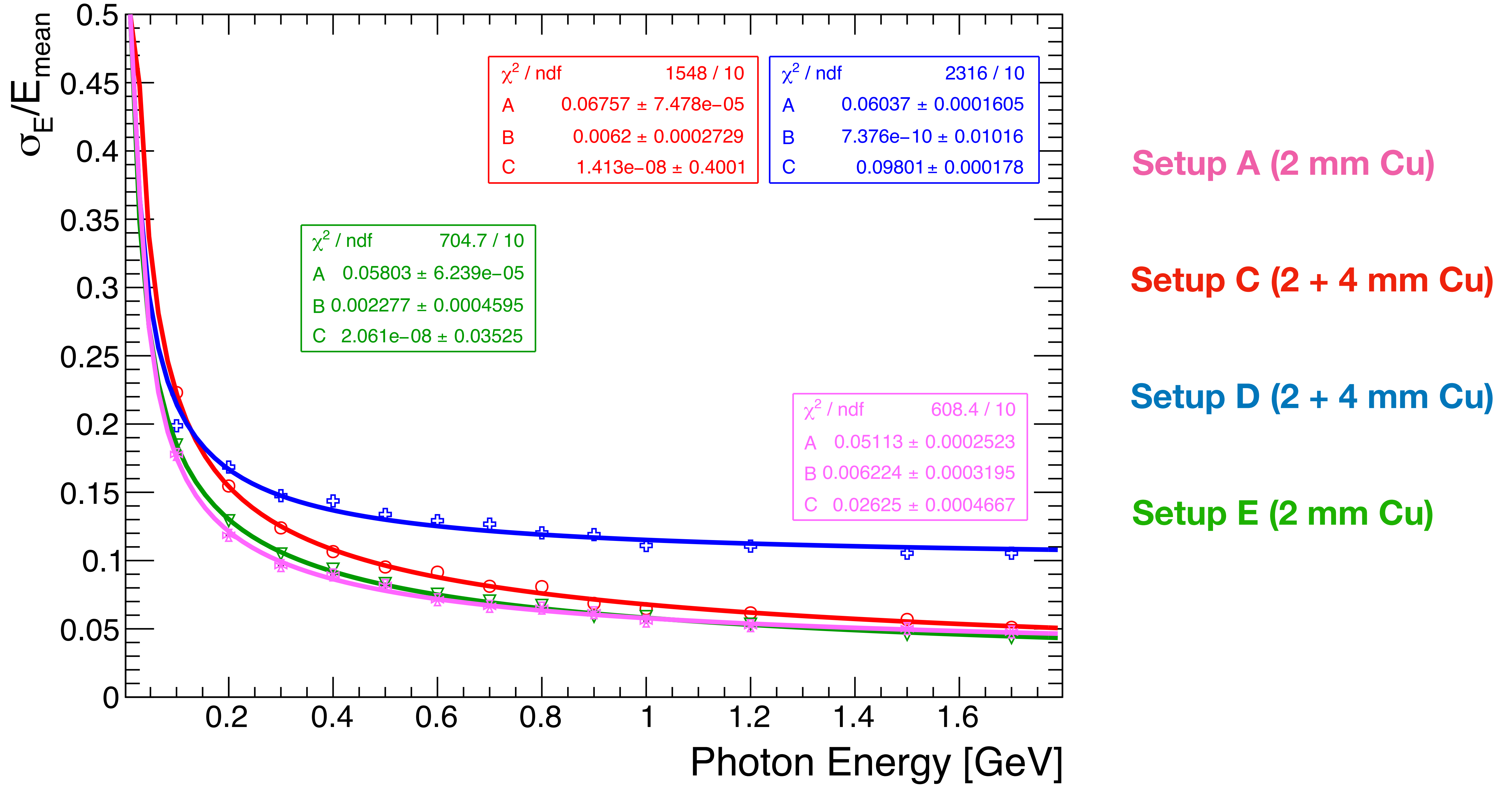


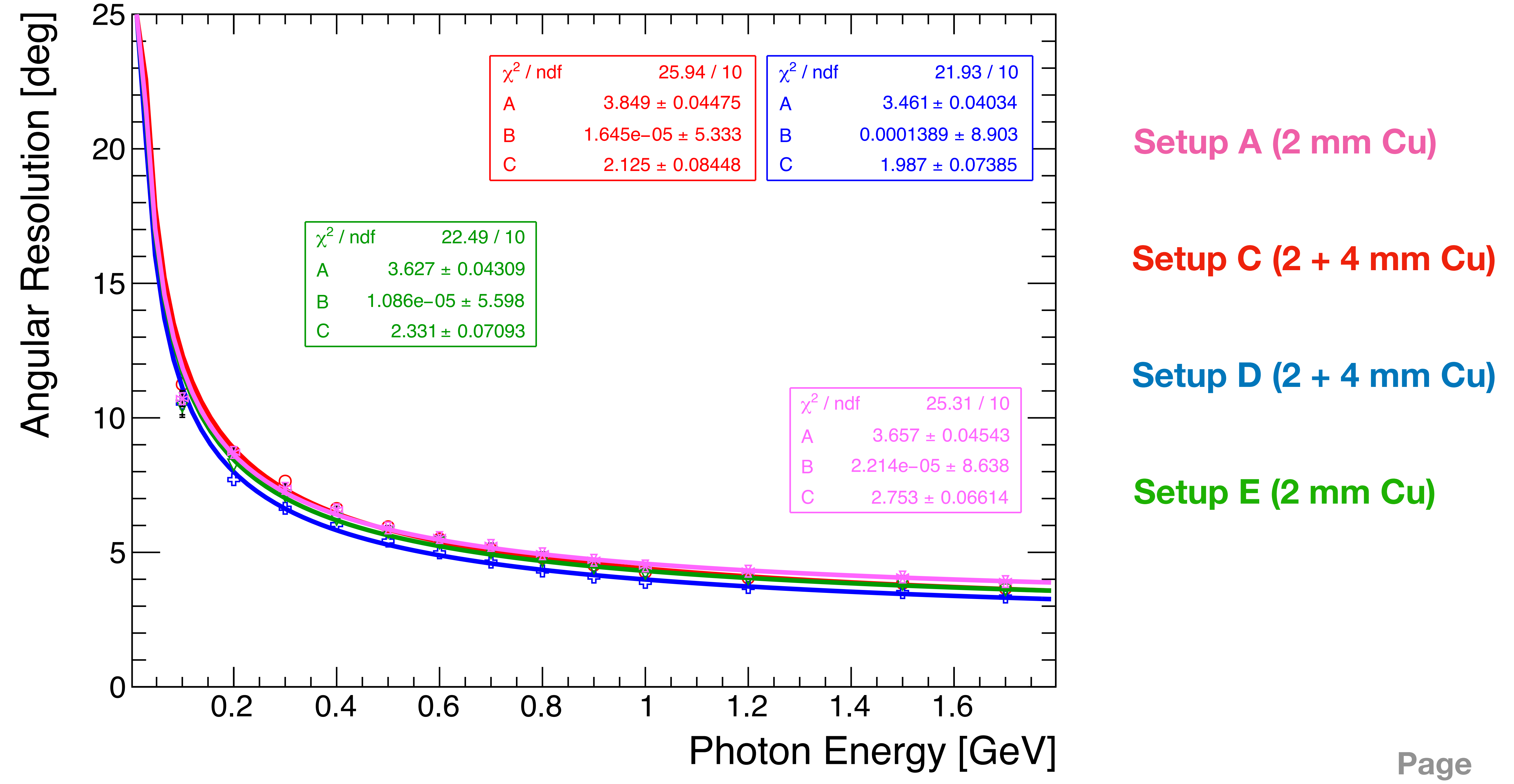


Simulation studies.

Influence of the absorber thickness

- Change of the absorber thickness
  - 2 mm Cu for HG layers
  - 2/4 mm Cu for LG layers

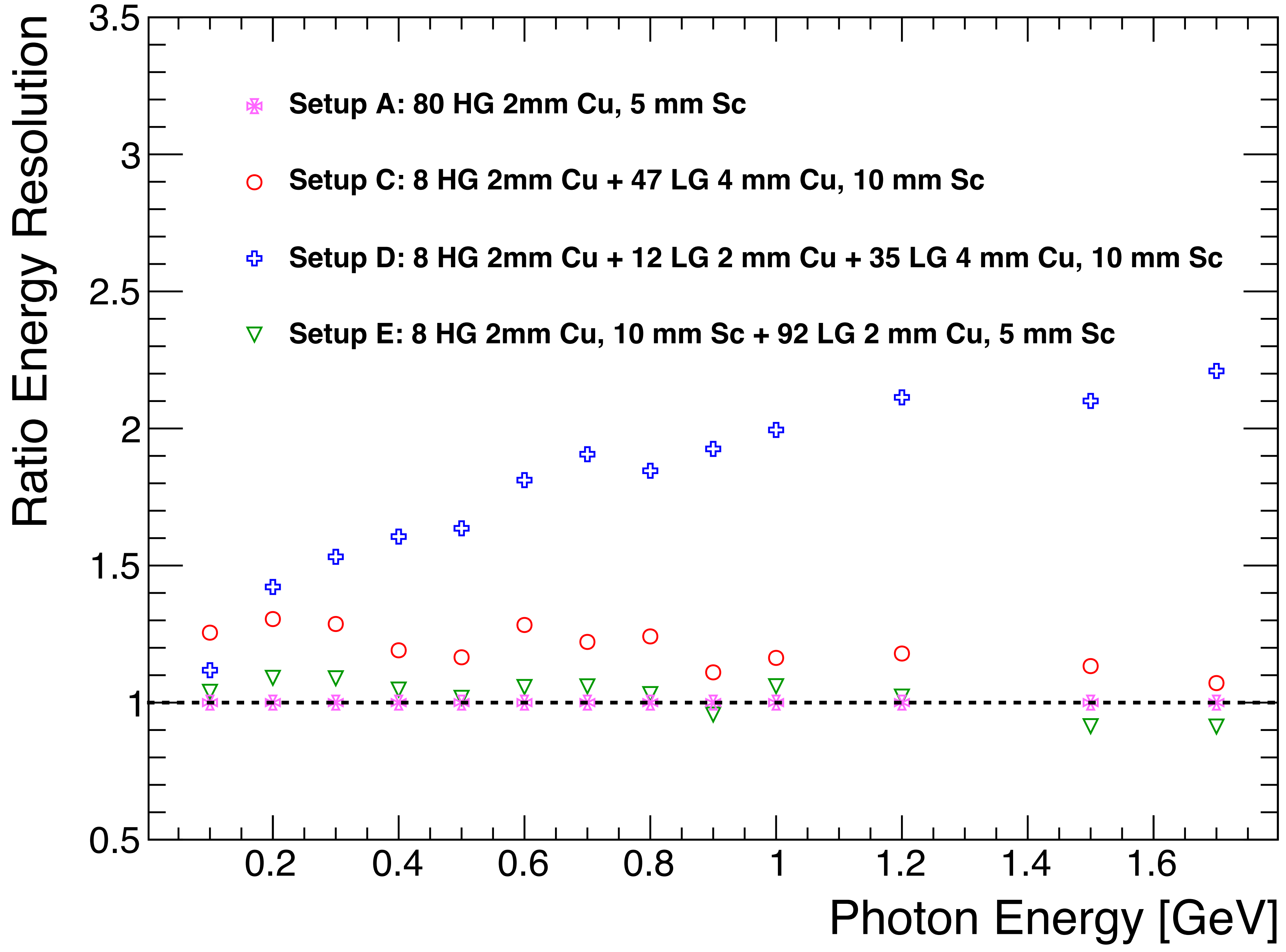


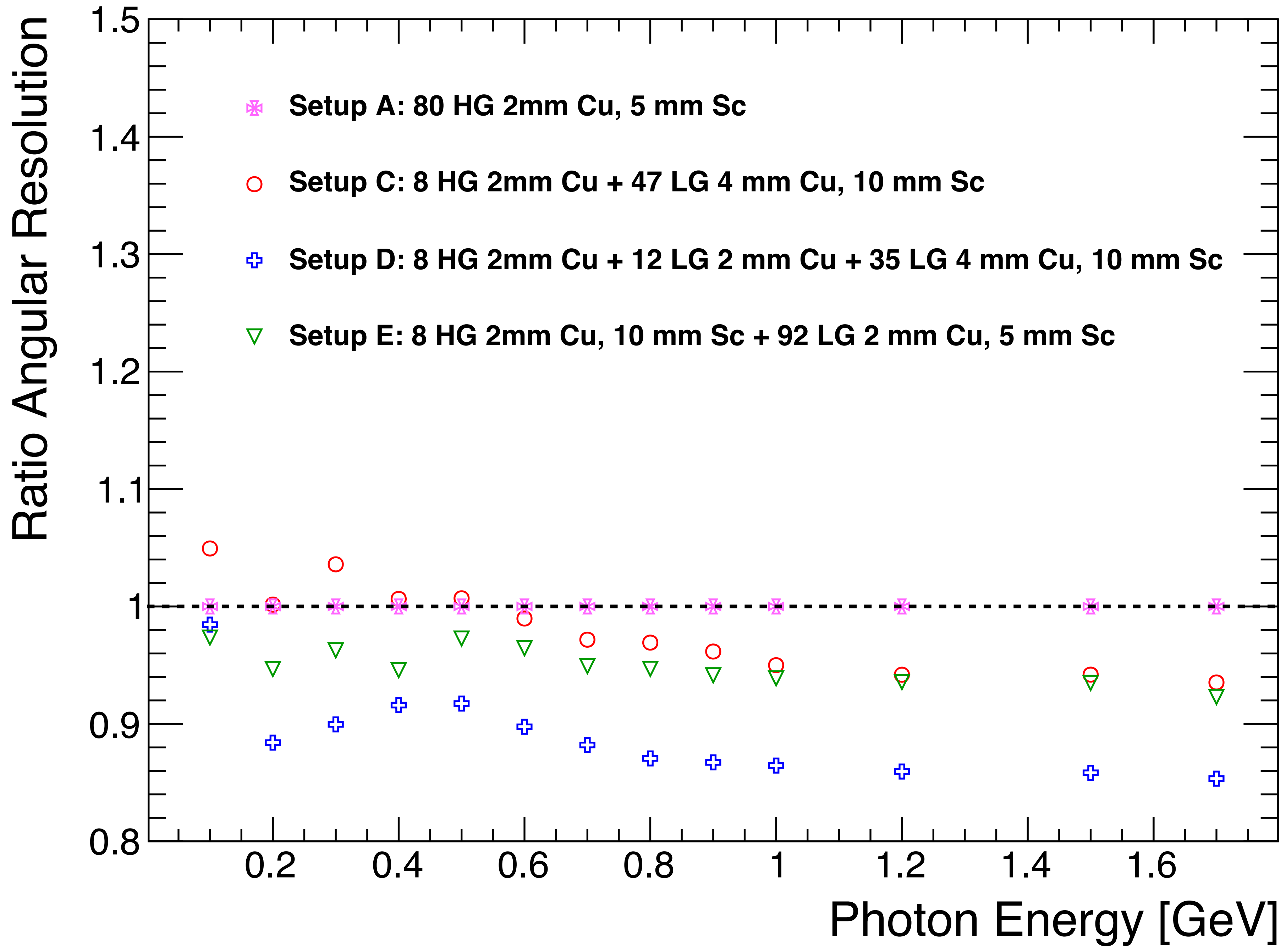


Simulation studies.

Influence of the absorber thickness

- Change of the absorber thickness
  - 2 mm Cu for HG layers
  - 2/4 mm Cu for LG layers
- Energy resolution mostly affected by
  - change in ratio scintillator thickness / absorber thickness → sampling fraction
  - Leakage
- Angular resolution is slightly affected depending on the configuration
  - Mainly dominated by front layers
  - → thinner absorber in the front layers → shower evolves deeper in the calorimeter, gives better lever arm on the direction

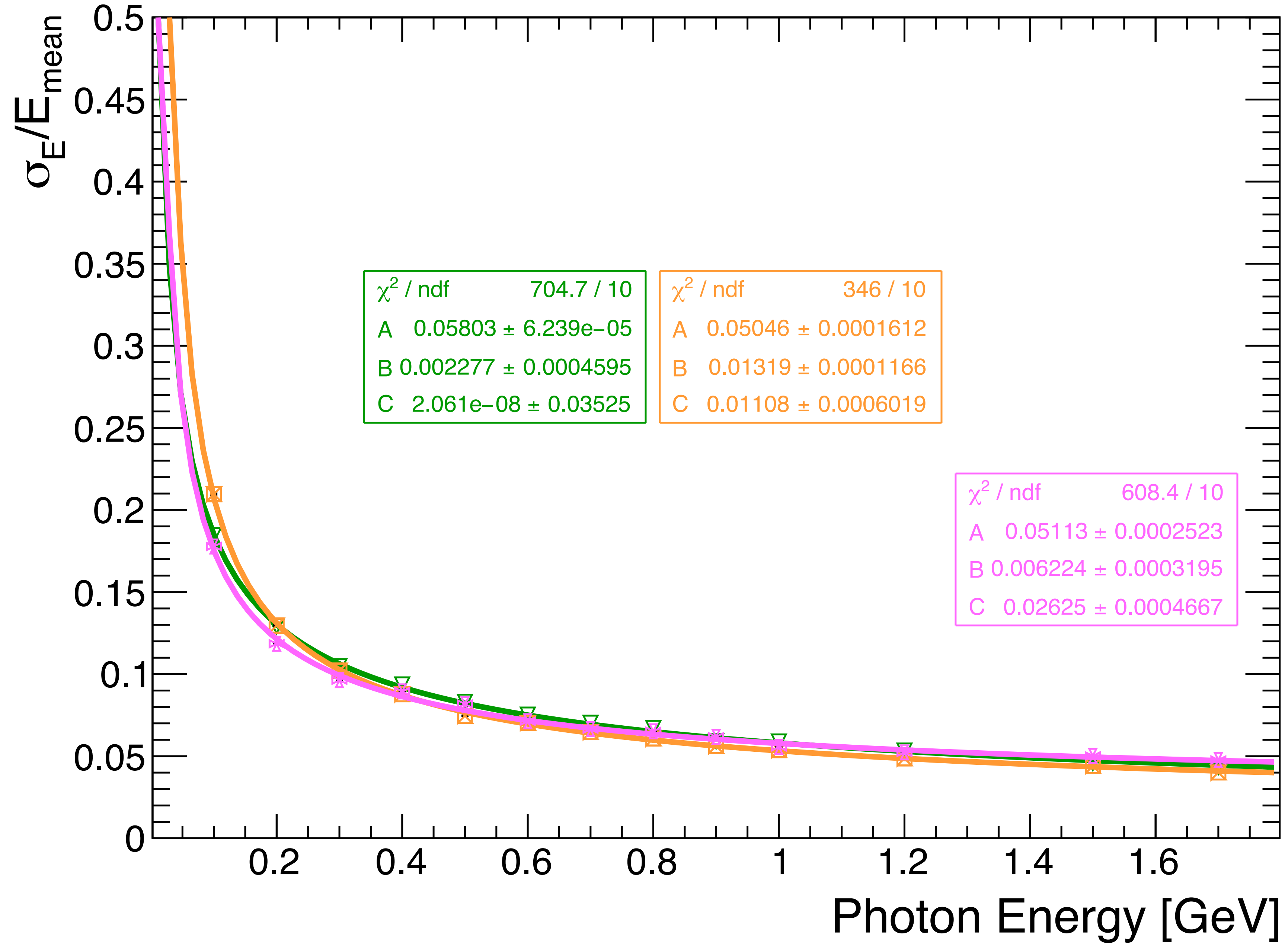




Simulation studies.

Influence of the scintillator thickness

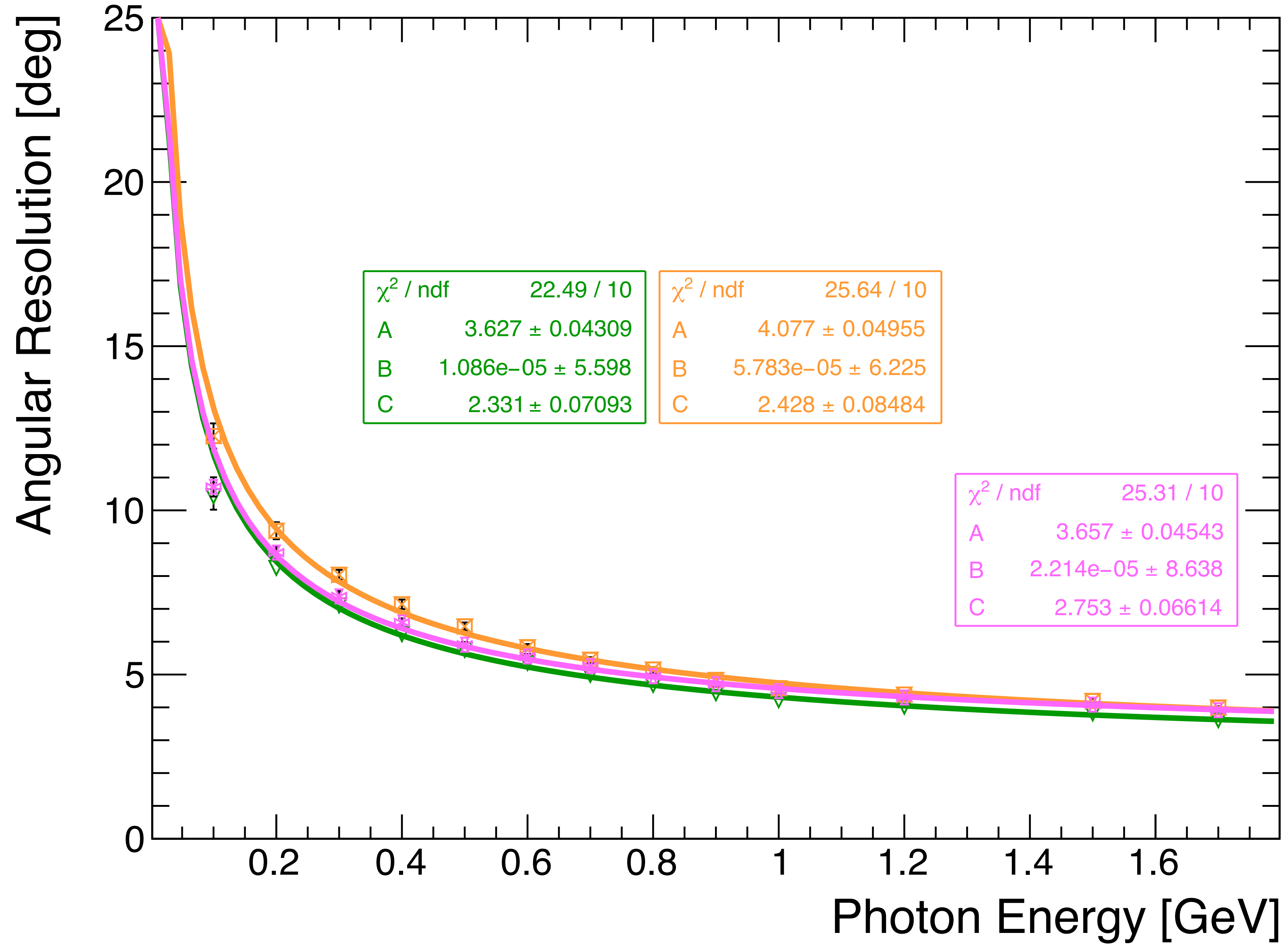
- Change in scintillator thickness for the front layers
  - 3, 5 and 10 mm
- Overall, not much change except at low energies



Setup A (5 mm Sc)

Setup E (10 mm Sc)

Setup F (3 mm Sc)



Setup A (5 mm Sc)

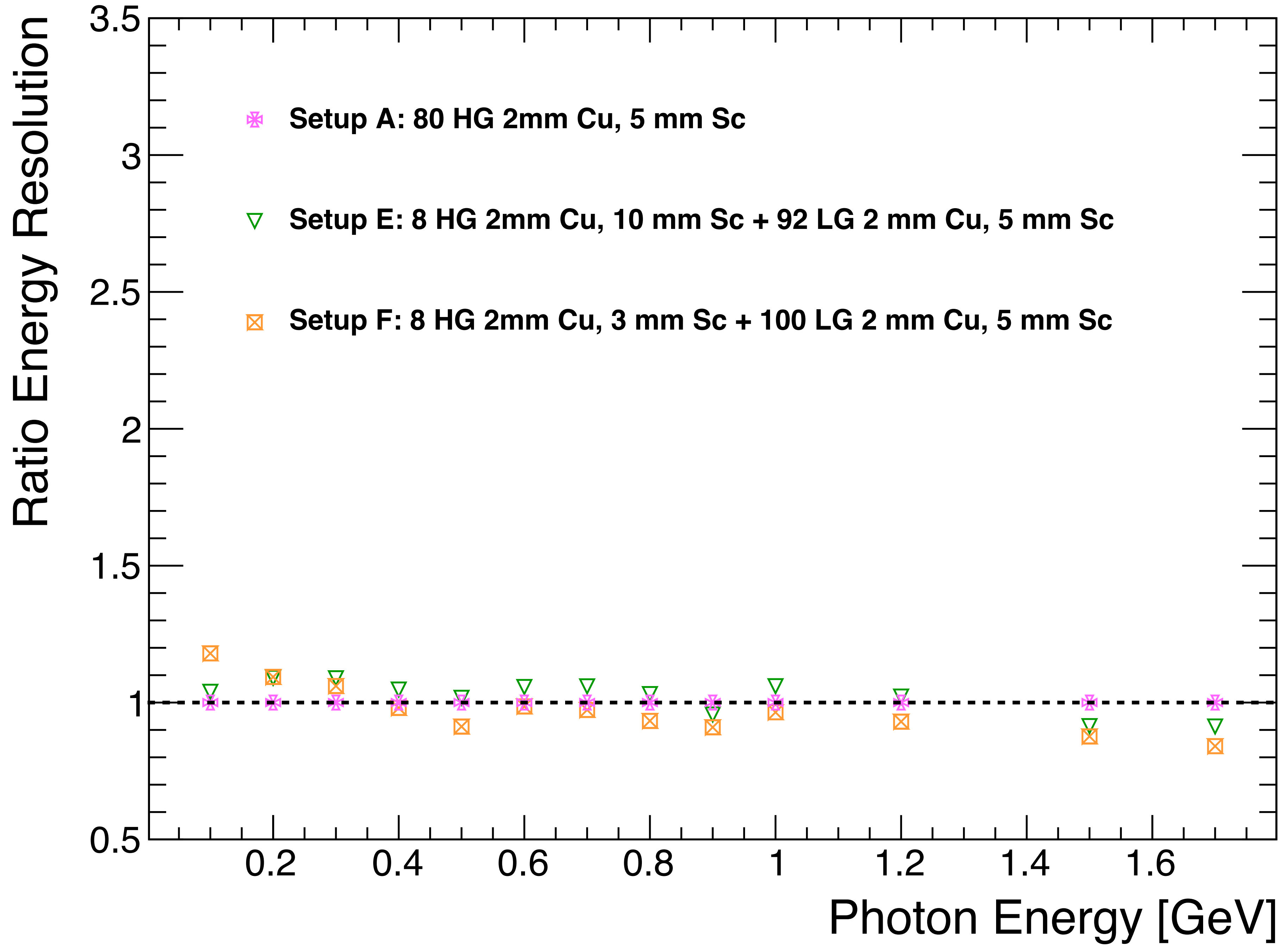
Setup E (10 mm Sc)

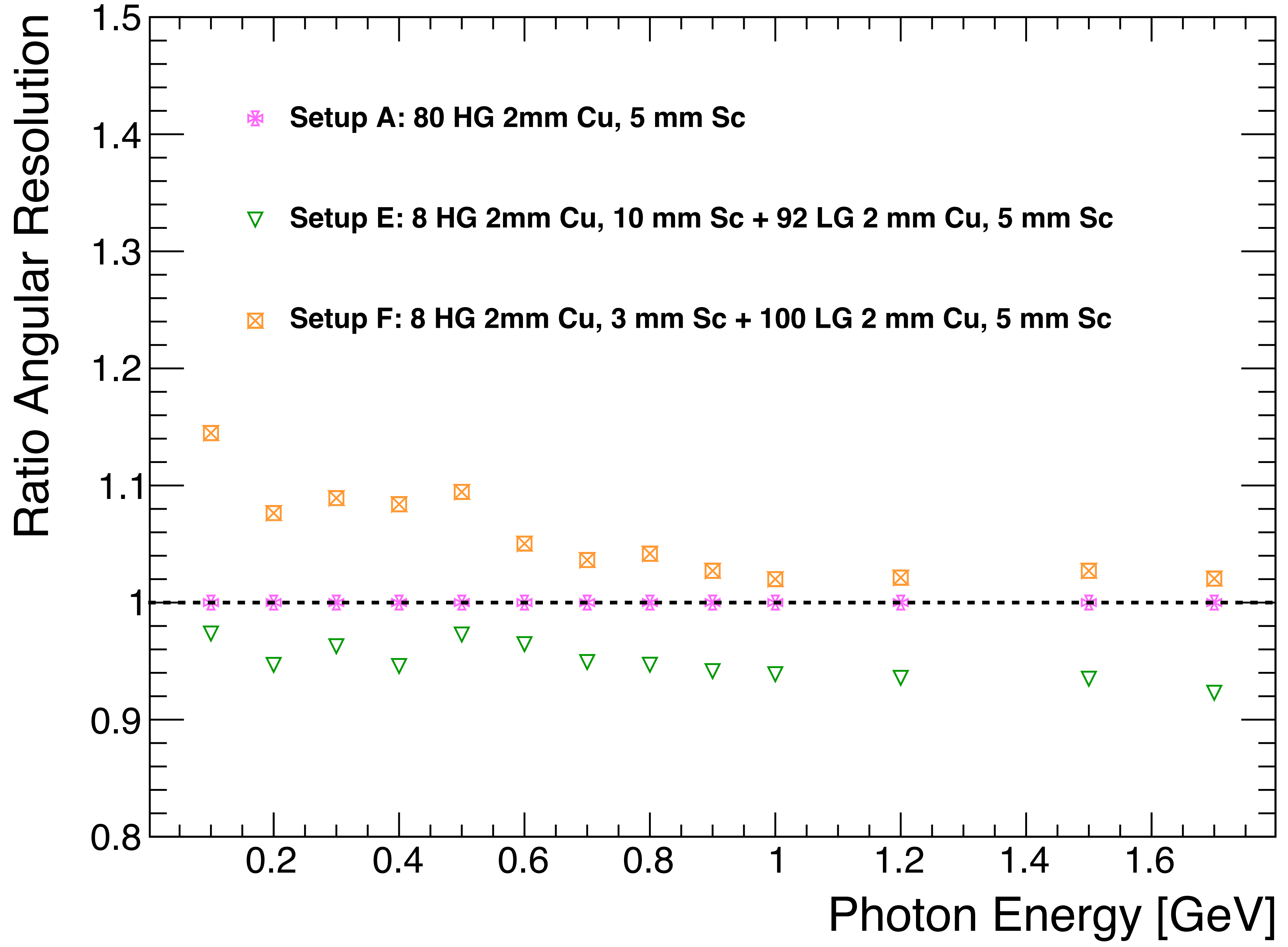
Setup F (3 mm Sc)

Simulation studies.

Influence of the scintillator thickness

- Change in scintillator thickness for the front layers
  - 3, 5 and 10 mm
- Overall, not much change except at low energies
- Change most significant for 3 mm tiles especially at low energies → effect of the threshold
- Better angular resolution for thicker tiles
  - → Mostly due to the PCA that favours high energetic depositions

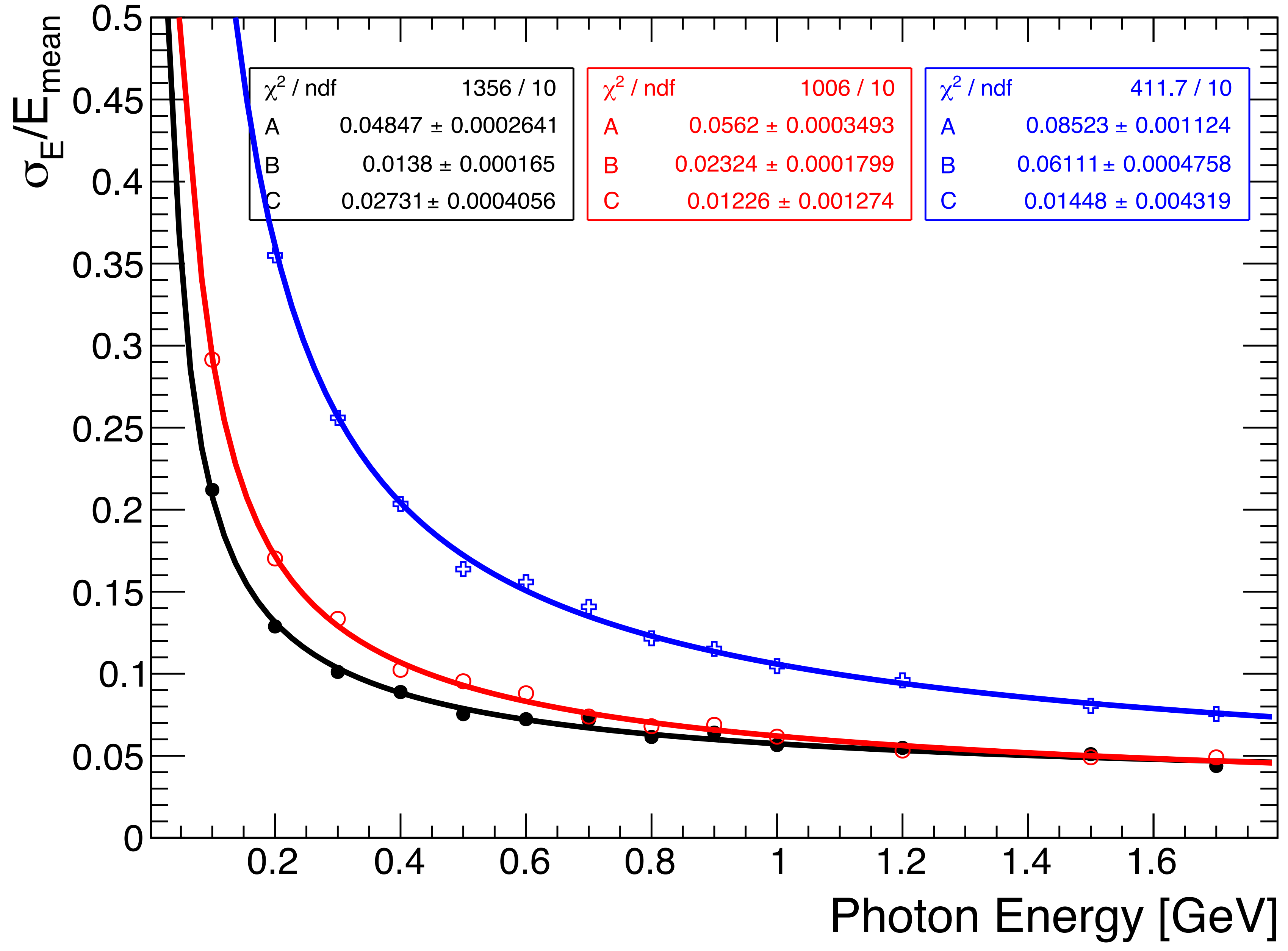


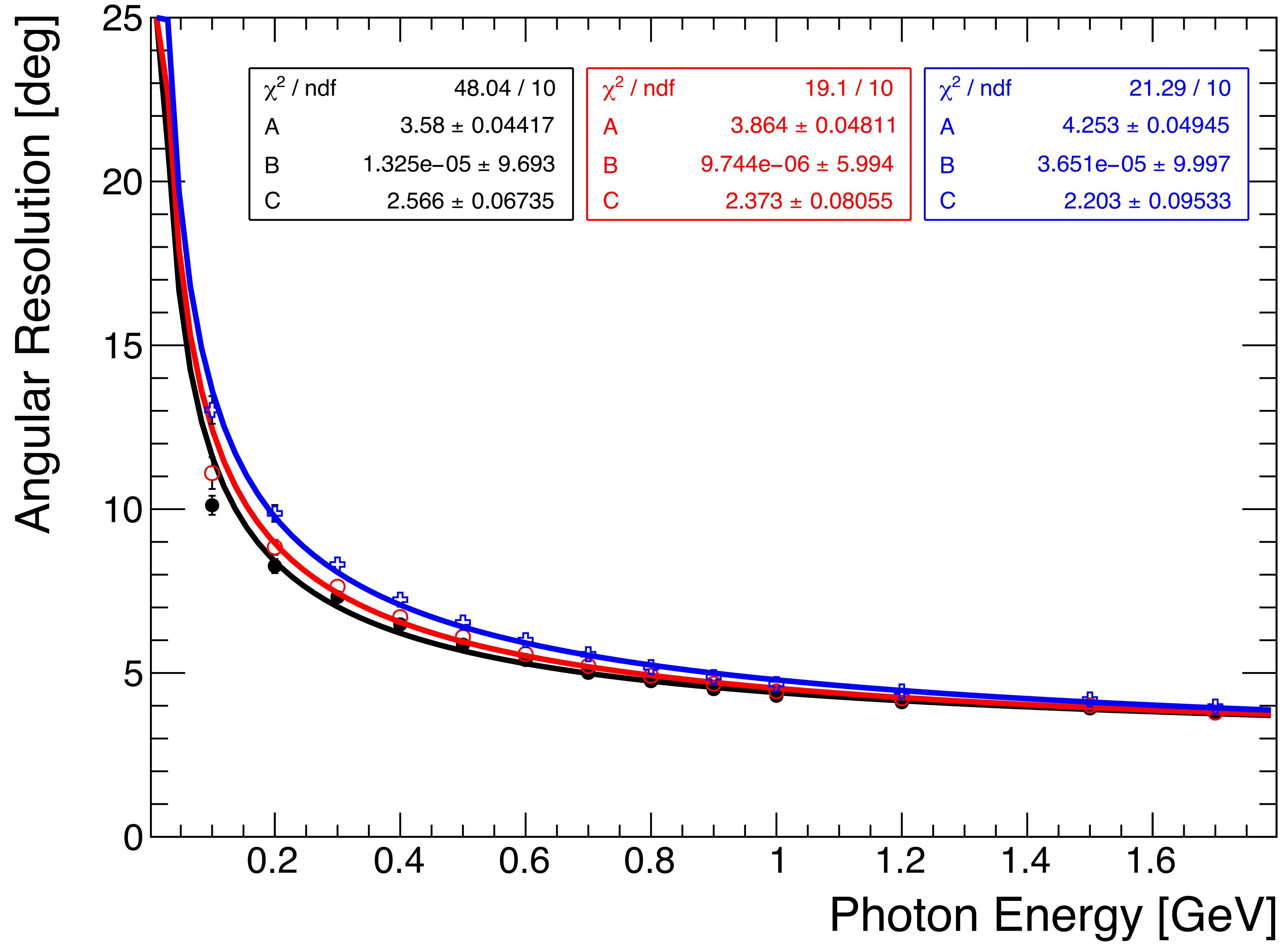


Simulation studies.

Influence of the pressure vessel

- Look at the influence of the pressure vessel
  - Case if the ECAL is fully outside the PV → easier from the engineering side
- Different thicknesses
  - **0.5**, **1** and **2** X_0 of steel
- Until when the pressure vessel becomes a significant problem?
- Angular resolution get slightly affected over $1X_0$
- Energy resolution gets heavily affected → pressure vessel should stay below $1X_0$ to keep energy resolution below 6% / Sqrt(E)

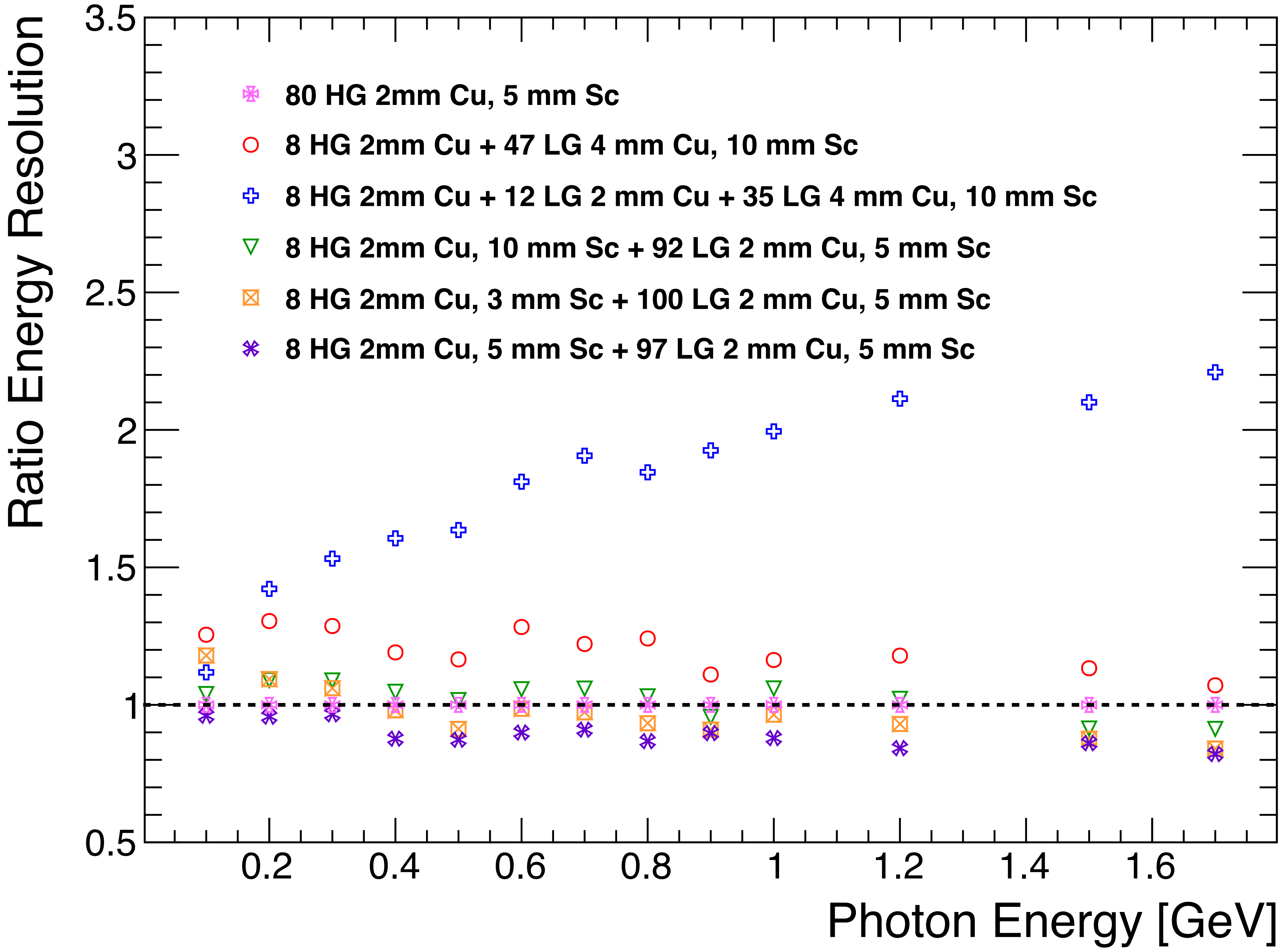


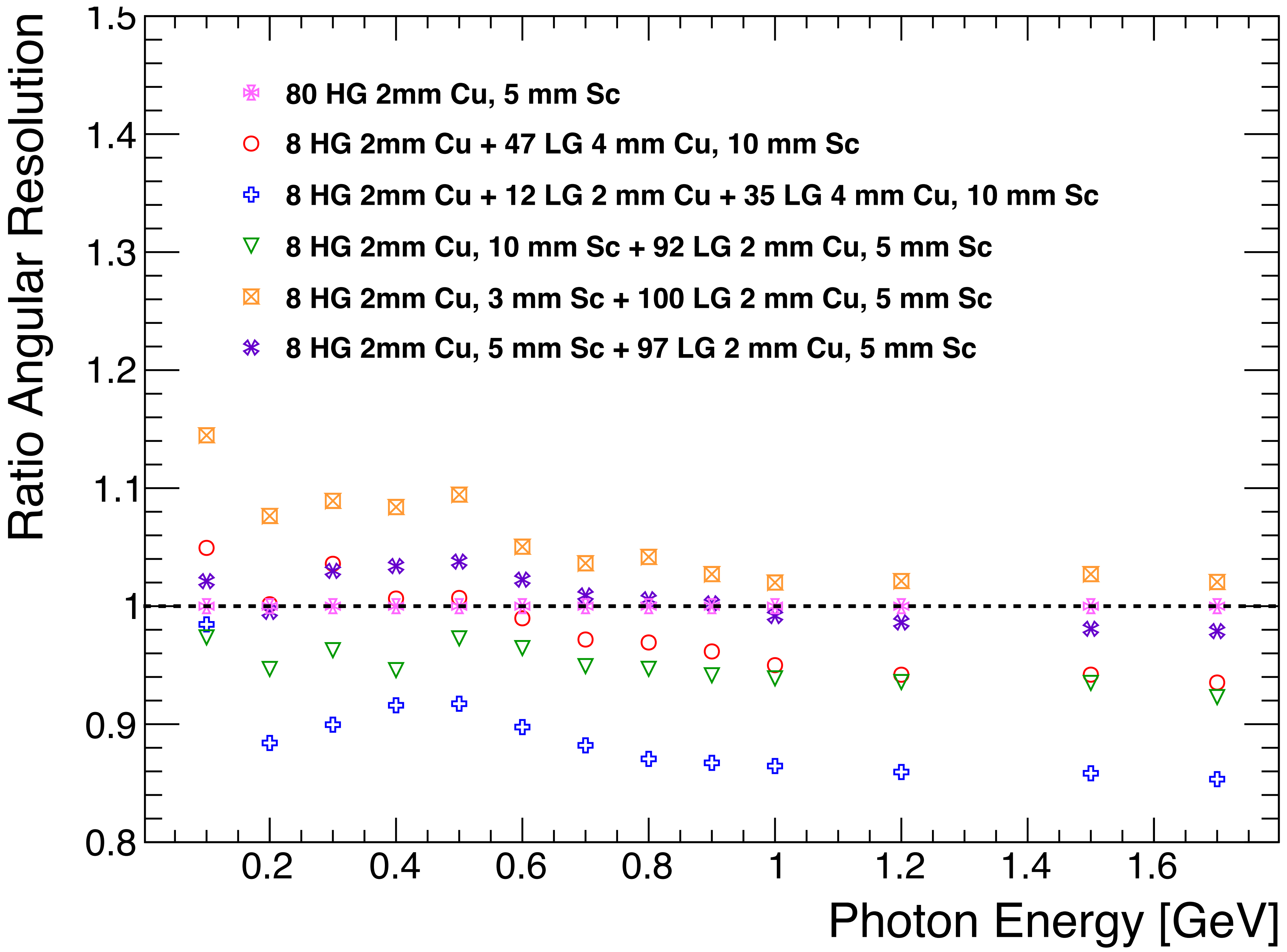


Simulation studies.

Full comparison

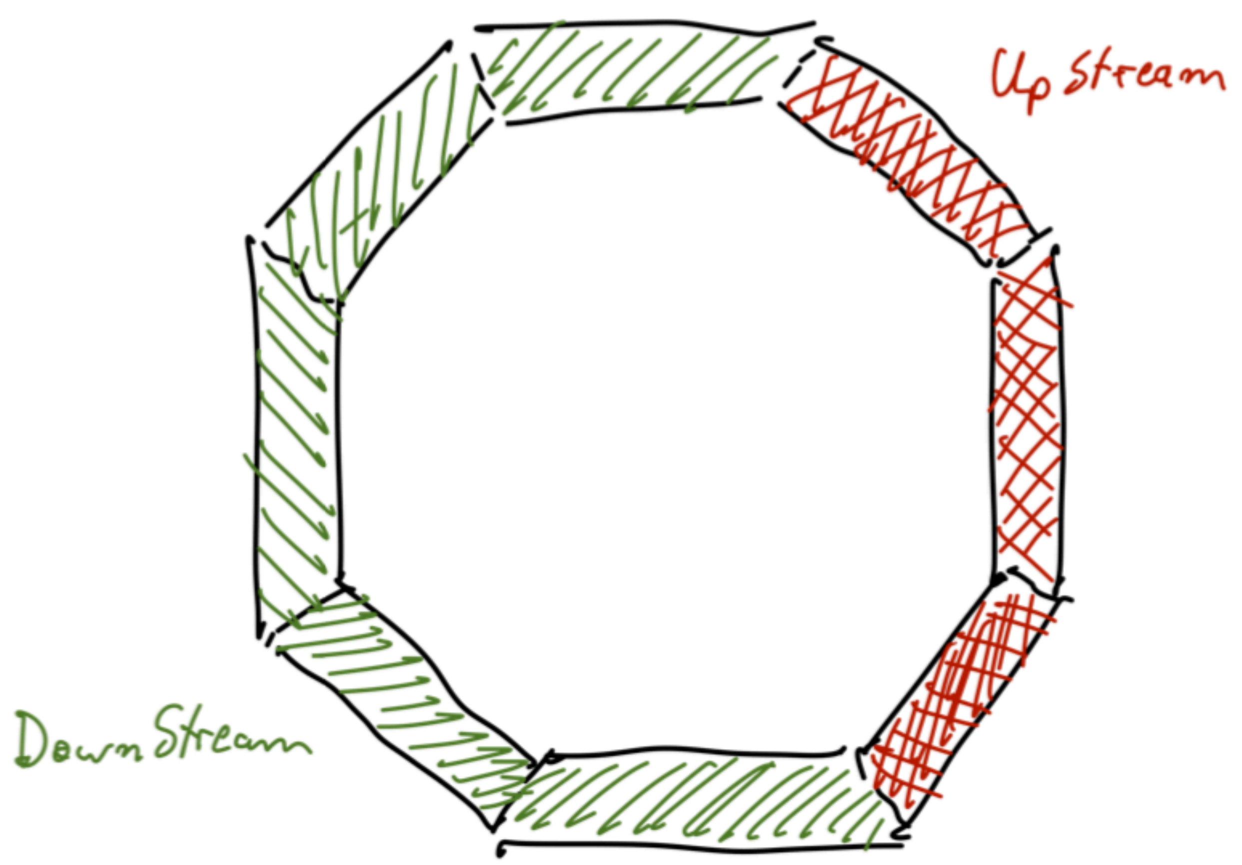
- Full comparison between the setups
- To take away
  - Angular resolution dominated by front layers → granularity in the back layers does not matter much → strips can be used
  - Thinner absorber with small Molière radius in the front is preferred for angular resolution
  - Shower containment is important for high energies → more layers or thicker absorber in the back → around 12-14 X_0 needed
  - Thicker scintillator in the front helps in the angular resolution





Real considerations.

Trade between performance, cost, feasibility..



- Limited space: place inside the pressure vessel? Feasible?
- Cost: cost scales with size of the TPC, mostly the surface, number of layers and granularity
- Fixed-target style → different ECAL modules upstream/downstream
- Use strips with WLS fibres to reduce the channel count

	DS Segments (3)	US Segments / Endcap (7)
HG Layers (0.5 cm of Sc)	8	6
HG Tile size	2.5 x 2.5 cm^2	2.5 x 2.5 cm^2
HG Absorber thickness (Cu)	2 mm	2 mm
LG Layers	72	54
LG strip width (0.5 cm of Sc, crossed)	4 cm	4 cm
LG Absorber thickness (Cu)	2 mm	2 mm
Total thickness	11 X_0	9 X_0
Number of channels	~ 2.8 - 3 M	
Copper volume	~ 31.8 m^3	
Sc volume	7 m^3 (tiles) - 63 m^3 (strips)	
Fiber length	~ 320 km	

Conclusion and Outlook.

Summary

- CALICE calorimeters primarily used for colliders are good candidates for a ND ECAL
- Some modifications:
  - Thinner absorber for angular/energy resolution also at lower energies
  - Less granularity is sufficient→ using strips in the back layers
  - Precise timing for background rejection available
  - Electronics can be easily adapted?
- Optimization studies of the ECAL design are ongoing
  - Reduce channel count / cost
  - Keep/Improve energy, angular and neutron performance
  - → What is the best compromise we can achieve?
  - → Understand the details of the calorimeter implementation on low/mid-level performance parameters
- However, still need to understand the impact of performance on oscillation analysis → study to be done
- Mechanical constrains. Can we have the ECAL inside the pressure vessel? → engineering challenge

Backup Slides.