MPD ECAL: Performance/Optimisation.

DUNE ND Workshop

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DESY, 22nd October 2019

DEEP UNDERGROUND NEUTRINO EXPERIMENT

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

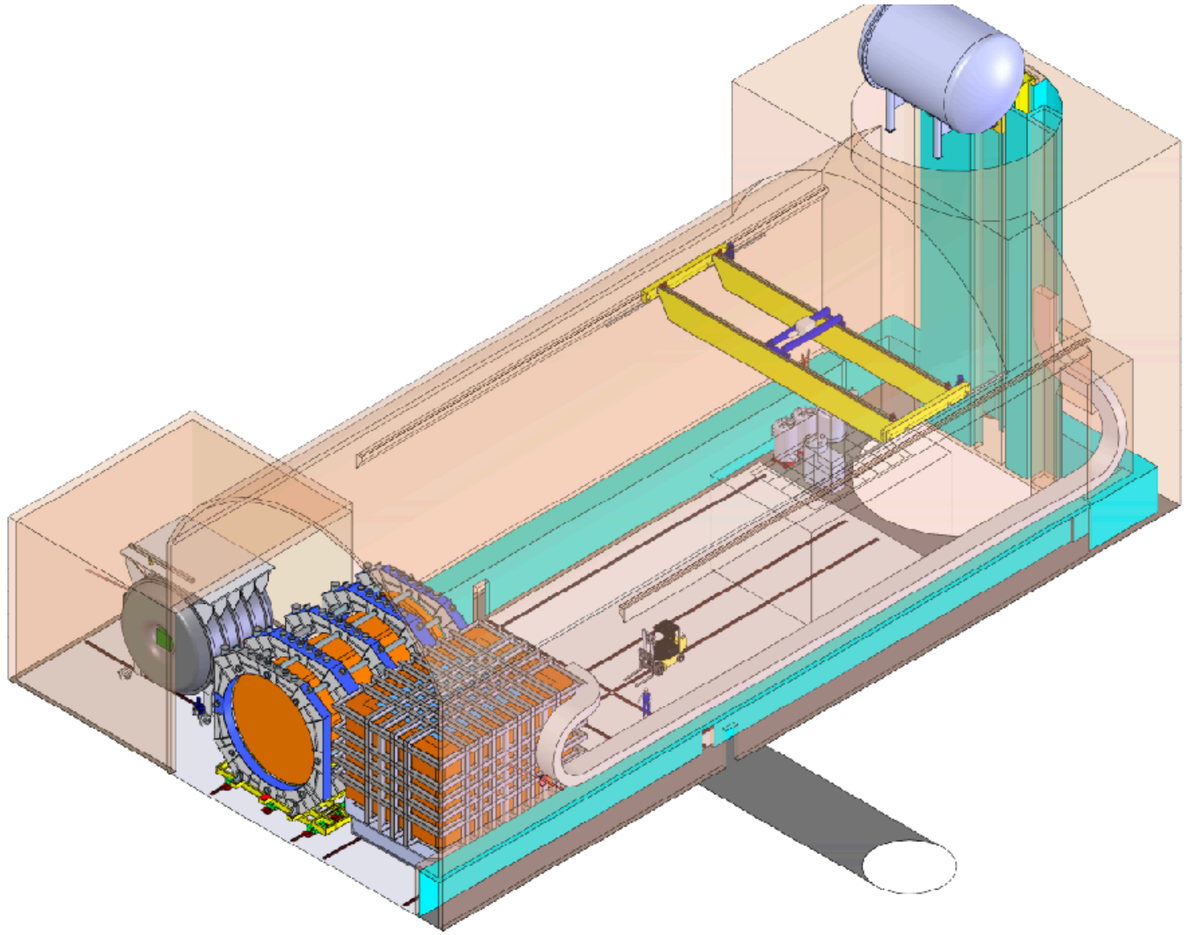
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

The Near Detector Hall.

The limited space

- The space in the near detector hall is very limited
- Imposes constrain on the side of the TPC + ECAL + Magnet
- The sizes:
  - TPC Radius 2.7 m / length 5 m
  - Magnet Radius 3.5 m
  - ➠ ~ 60-80 cm of space for the ECAL
  - ➠ ~ 60 cm for the muon tagger

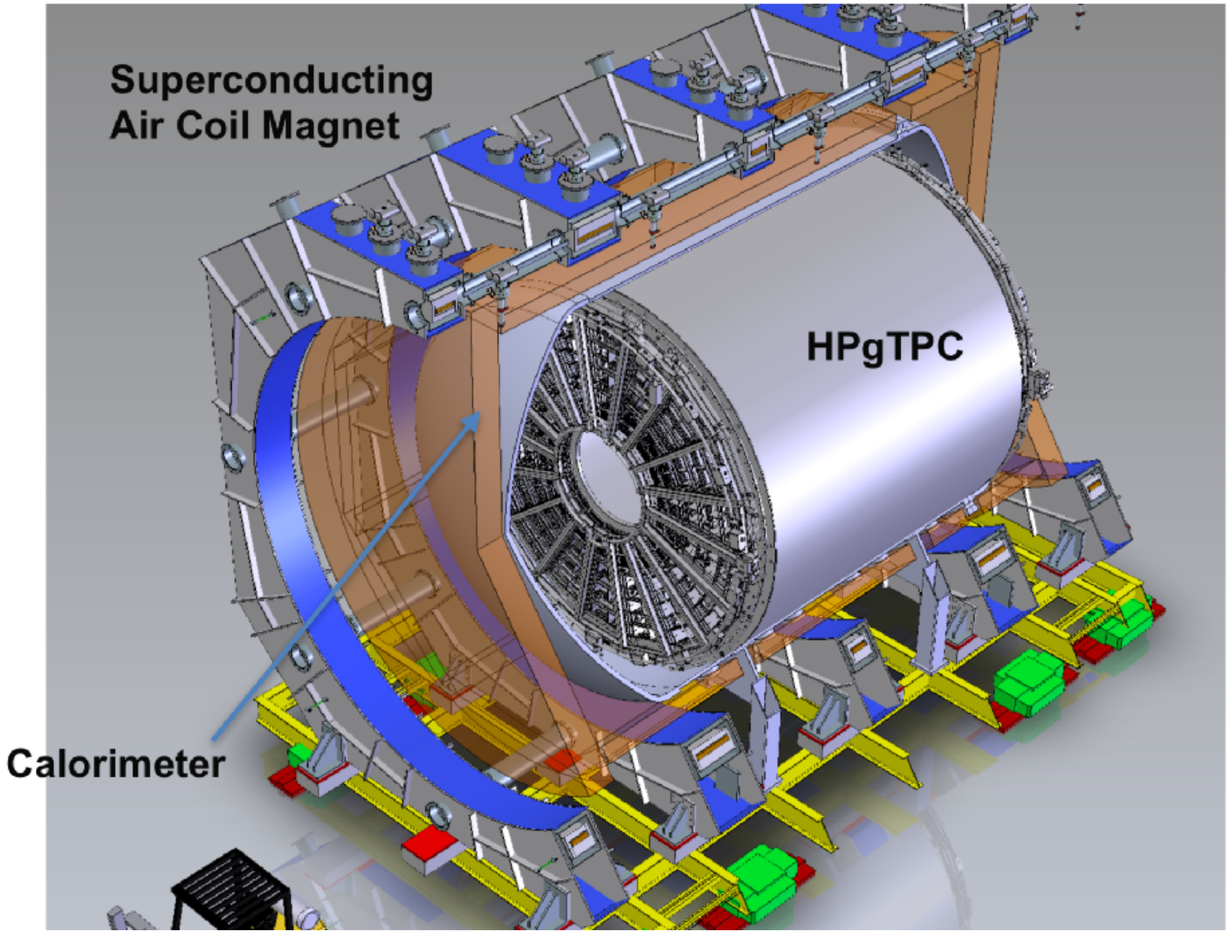


Bob Flight

The MPD ECAL.

Roles and key numbers

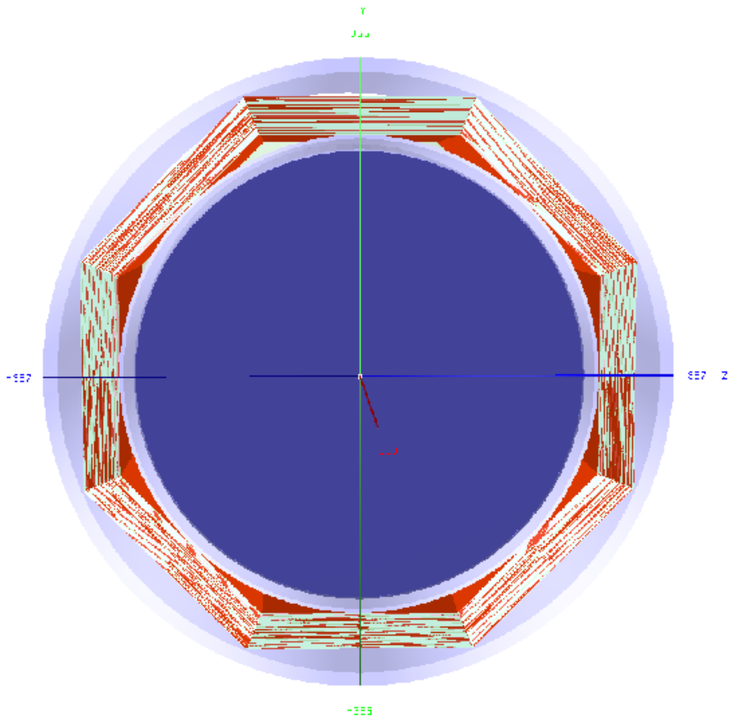
- The role of the MPD ECAL
  - Identify neutral pions (NC background) - photon energy and angle measurement
  - Provide accurate timestamp of the event (TPC-ECAL track matching)
  - Particle ID via calorimetric variables and ToF
  - Bonus: Neutron energy reconstruction
- Typical photon energy range: ~few MeVs ➠ small stochastic term needed
  - ~5-6%/Sqrt(E[GeV])
  - ~few deg /Sqrt(E[GeV])
- ➠ drives longitudinal segmentation / granularity
- Neutrons ➠ few 100 ps time resolution

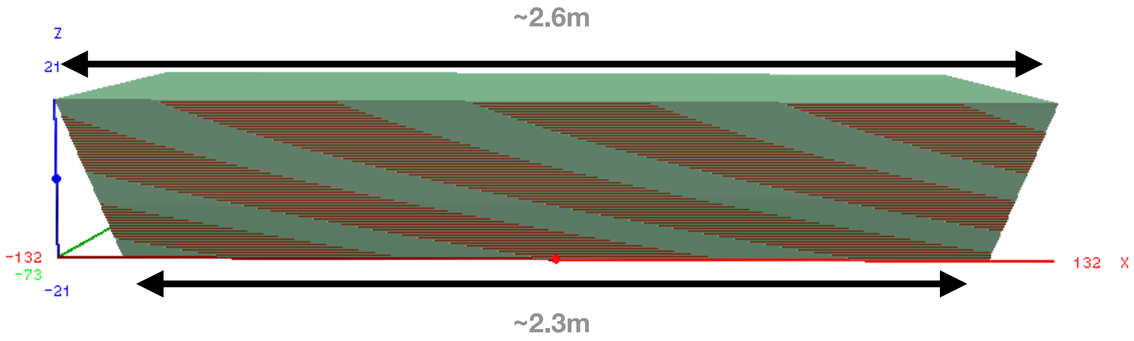


The ECAL baseline design.

Geometry

- Octagonal geometry
- Small side length ~2.3m, Large side length ~2.6m, Width ~1.5m
- Total surface ~ 120 m^2 at inner face
- Total weight ~ 200t (Barrel) + ~95t (Endcap)
- Layers
  - 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
- Absorber Cu
  - ~cm radiation length and “Small” moliere radius
    - ➠ thin absorber
    - ➠ larger spread of the shower along its main axis

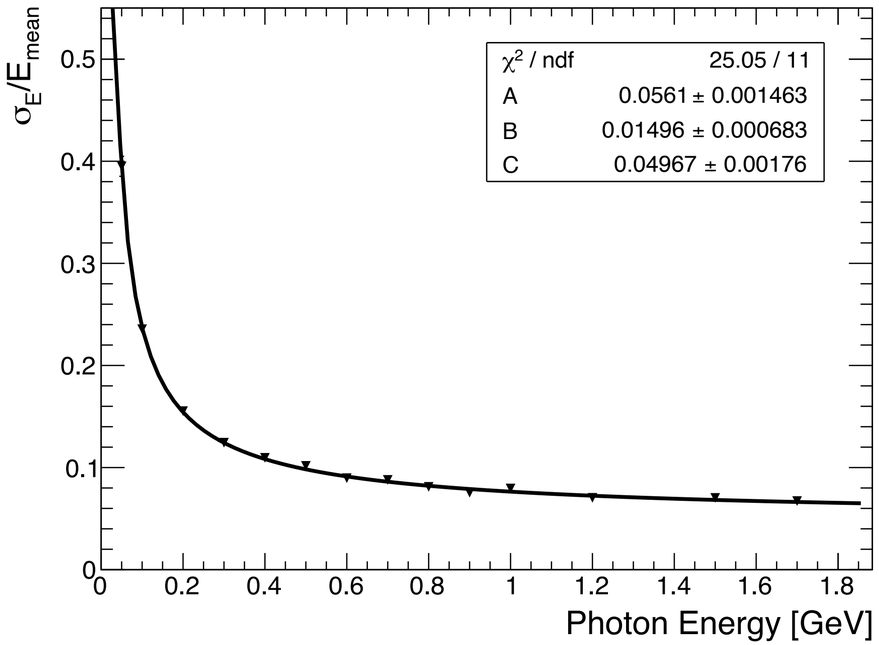


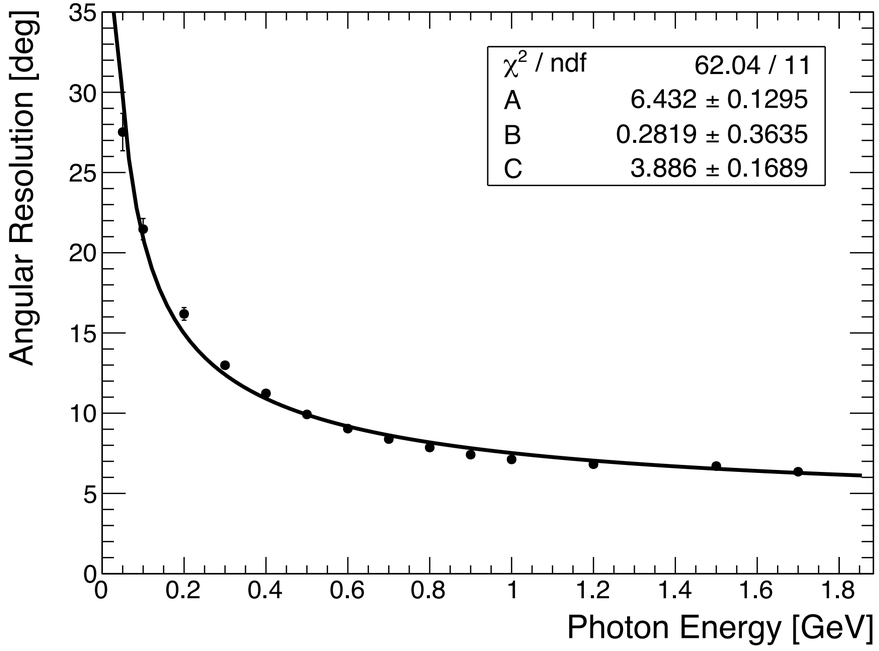


The ECAL baseline design.

Performance

- Sampling structure
  - 2 mm Cu / 5 mm Sc
  - 8 high granularity layers (tiles) and 52 low granularity layers (strips)
- “Best” performance so far
  - ~5-6%/Sqrt(E)
  - ~6-7deg/Sqrt(E)
- Optimising based on this
  - Detector shape (polyhedra with more sides)
  - Absorber type Cu ➠ Pb
  - Granularity (cost driver)
  - Neutron detection (more CH, less Absorber in front)

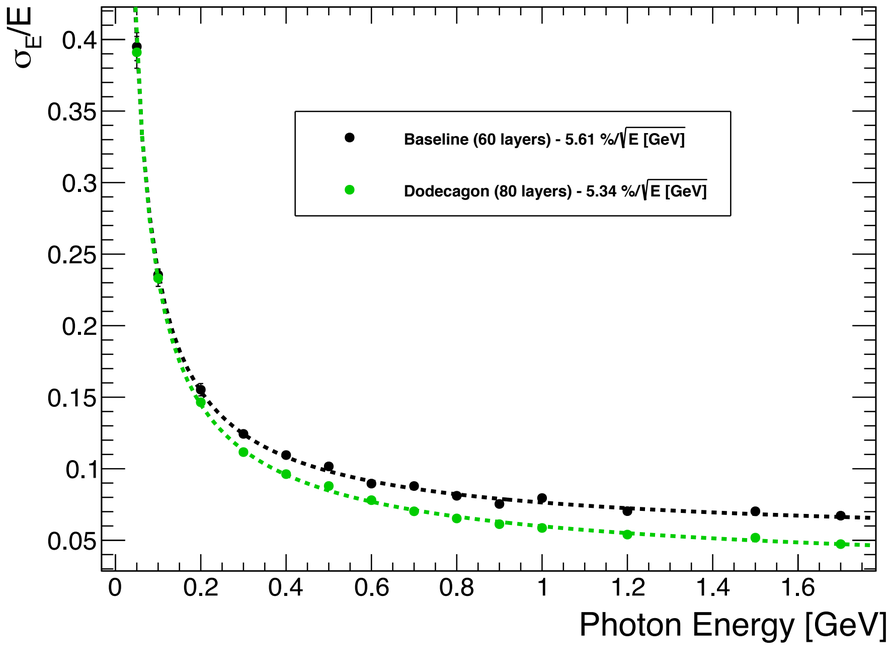


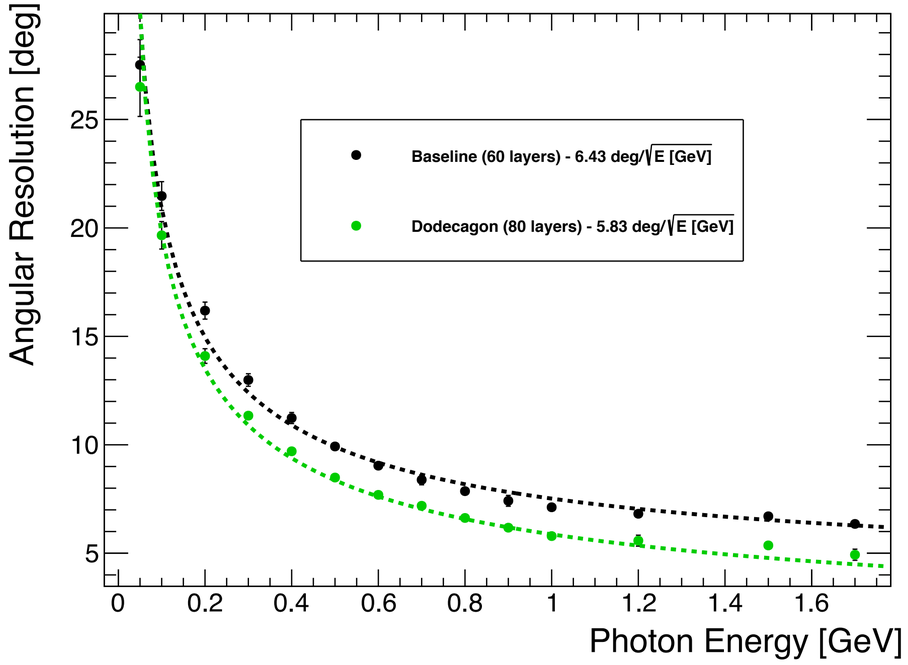


Optimisation of the shape.

Geometry

- Baseline shape ➠ Octagon
  - Not optimal in between “2” cylinders
- Going for higher number of sides ➠ Dodecagonal
- Advantage
  - Can fit more layers in the same space
  - Shorter modules (shorter strips)
- Disadvantage
  - Slight increase in cost (see Frank’s slides)
- Better Eres and Ares
  - Recover leakage with more layers. ~2-3% better at higher energies
  - Angular resolution better due to shorter strips?

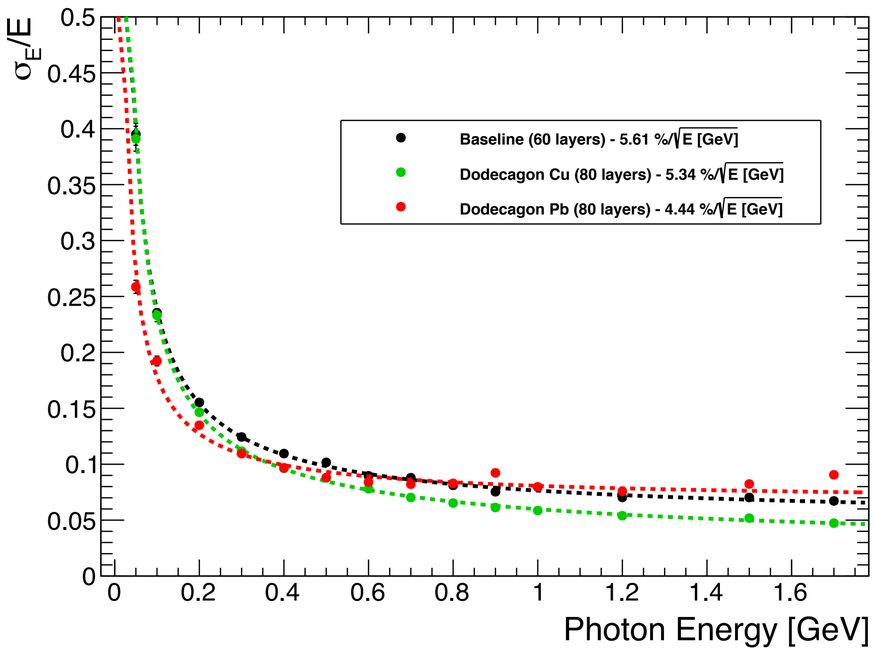


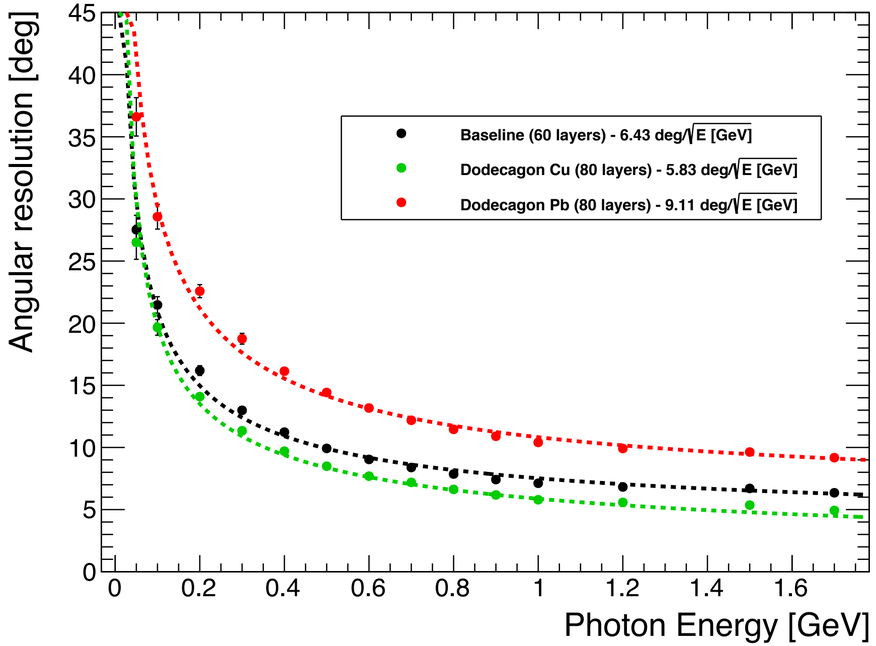


Optimisation of the absorber.

Revisiting lead as absorber

- Decided to revisit Lead
- Can fit 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 / 3 mm Sc
- Energy resolution
  - Better at lower photon energies ➠ slight increase in sampling frequency
- Angular resolution
  - Way worse due to larger moliere radius (shower looks more “blobby”)
  - Decrease of Sc thickness (analysis favors high energy depositions)
    - Will also impact neutron detection efficiency
- Does not look bad but
  - Need to increase Sc thickness
  - Limit number of additional layers to avoid increase of cost

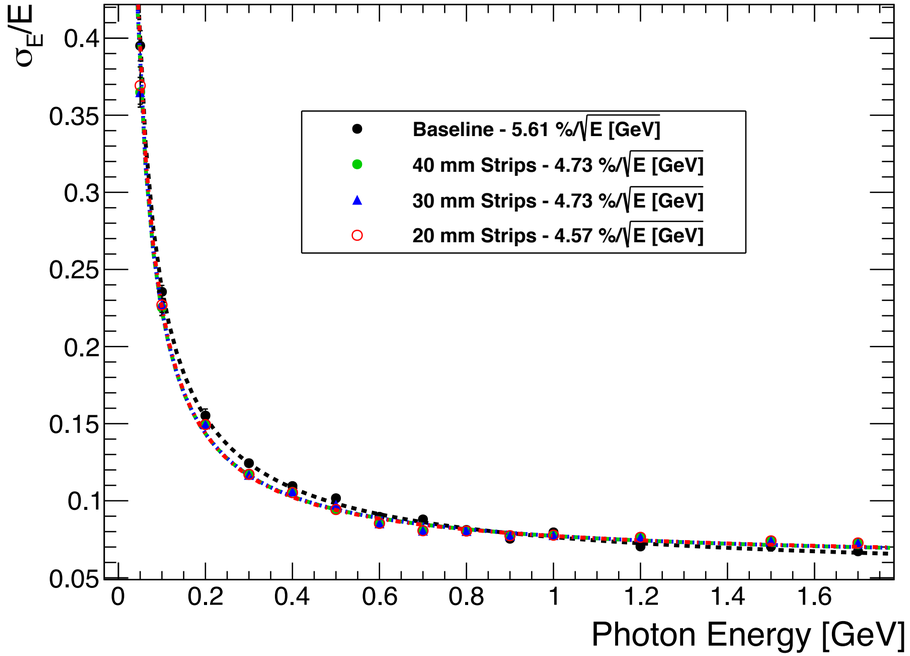


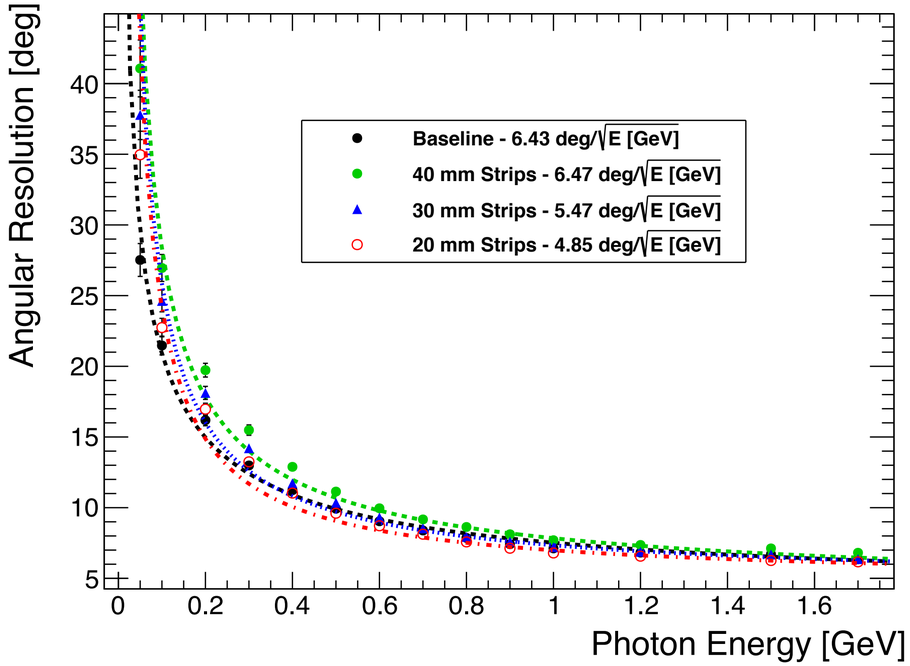


Optimisation of the granularity.

Going full strip

- What if we drop the high granular layers?
  - Main cost driver
- Different strip width 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
- May be an option, however
  - Timing ➠ Need for fiberless + more transparent scintillator
  - Effect on neutrons?

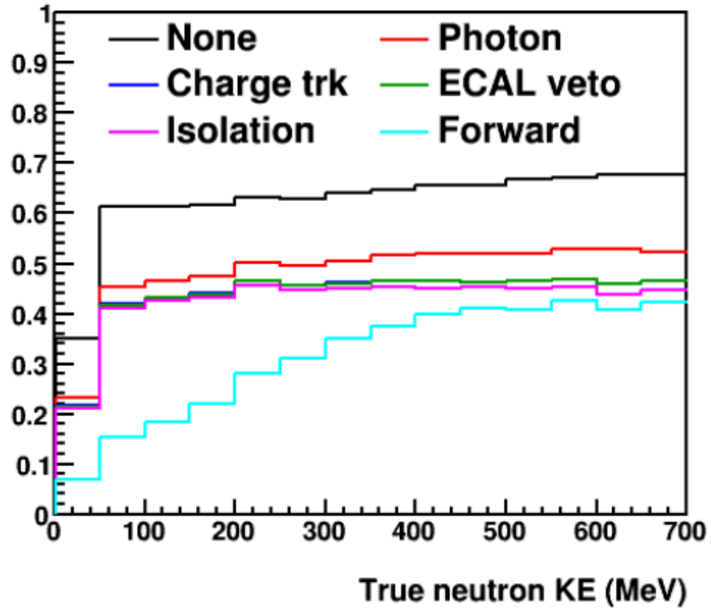




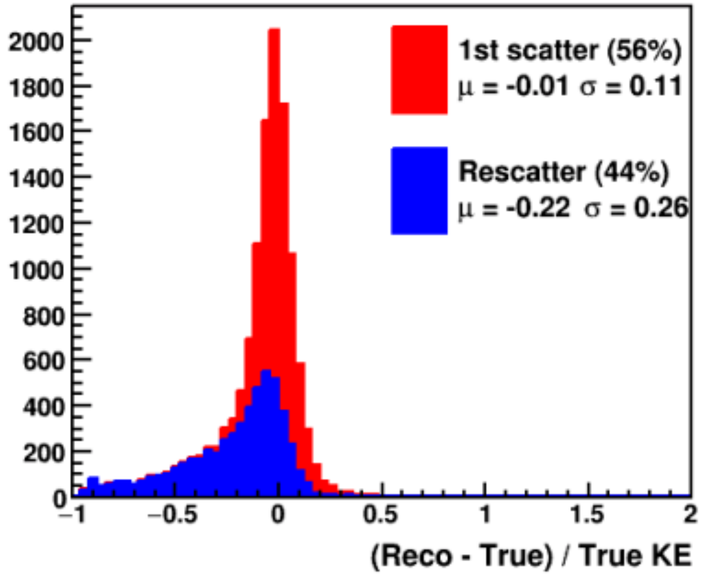
Neutron energy measurement.

Including backgrounds

- ECAL can be used for neutron energy reconstruction via ToF
  - Requires few tens ps time resolution
- Study with background done by Chris Marshall (See Chris's slides)
- Overall promising!
  - ~40% efficiency with ~40% purity
- Large amount of re-scatters (~50%) ➠ large tails in energy reconstruction and bias…
- Could be improved
  - Thicker scintillator slab in the front of the ECAL
  - Overall better absorber/Sc thickness ratio



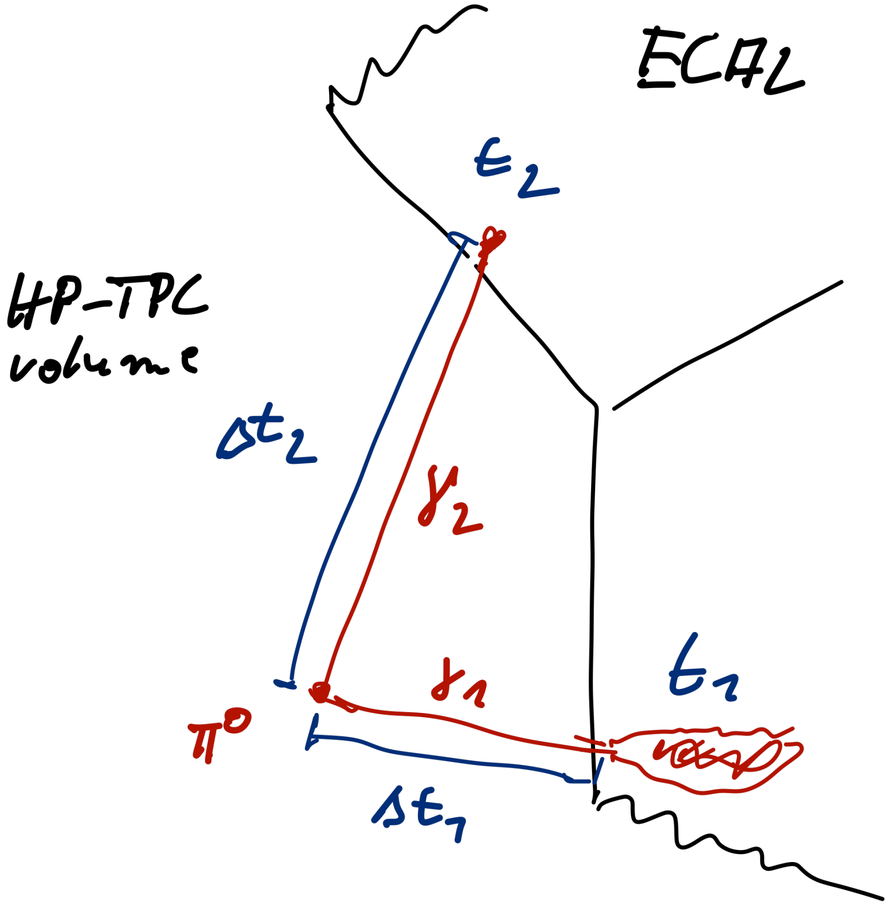
$50 < T_n < 100$ MeV



Time-assisted π^0 reconstruction.

Ongoing work

- See Frank's slides
- Previous results showed that π^0 mass reconstruction (few %) and vertex position (~20-30 cm) is quite good
- Need to be redone in the current framework
- Use of timing to improve the vertex position reconstruction
- Time-assisted π^0 reconstruction
  - Use the high energetic photon and time to get a rough knowledge of the vertex position (~few tens of cm) along the axis
  - Use this to determine the axis of the other photon
  - Reconstruct the invariant mass and chi2 minimisation using the mass information to improve the vertex position



Design ideas.

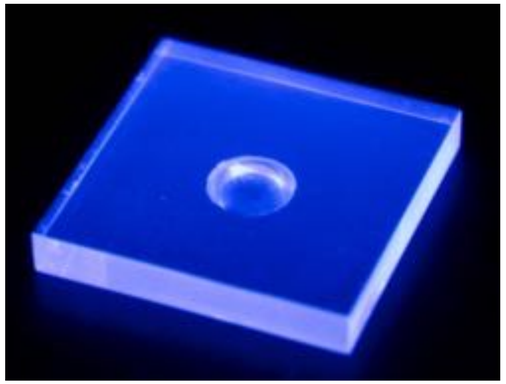
A little of brainstorming from Sunday

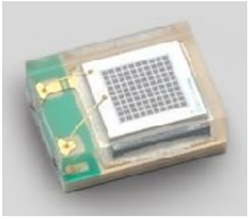
- Improve neutron detection/resolution
  - Going fully active ➠ Thick scintillator slab before the ECAL but limited in space…
  - Increase Sc thickness (larger Abs/Sc ratio ➠ less re-scatters)
- Reduce cost (see Frank's slides)
  - Going full strips (small width to keep angular resolution)
  - Partially equip the MPD (need enough angular coverage to cover for the full muon kinematics) ➠ need some studies (amount of backscattered events)
    - Couple of timing layers upstream ➠ fast time-stamping and better LAr-MPD track matching
- Integration ECAL and Muon "tagger"
  - Thin ECAL with "best" energy/angular resolution with thick slabs in the back (most of photons are low energy)
  - Integration between the magnet coils

Towards a TDR.

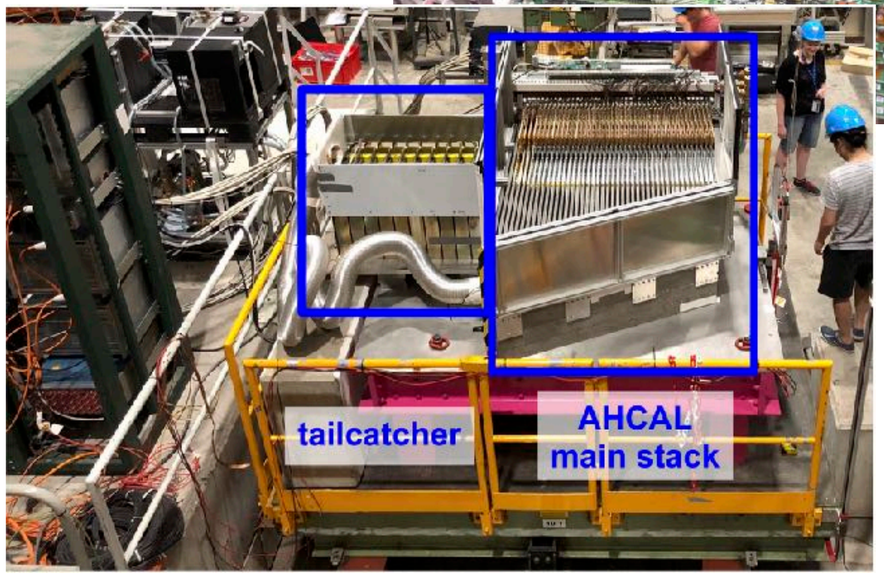
Prototyping?

- More a discussion here than a plan
- CALICE has been working hard on developing high granular calorimeters
- No show-stopper in terms of technology
  - Well under control in CALICE (SiPM technology, plastic, light yield, uniformity, mass-production, QA)
  - Fast-timing (~< ns) will need more work
  - Recent AHCAL prototype (22k channels) using 3x3x3cm^3 cells
  - CMS is building part of the HGCAL based on this technology
- All ingredients are technically in place
  - but dedicated funding is an issue





SMD SiPMs, modification of direct coupling



Conclusions.

and a look to the next year

- Baseline design (60 layers with Cu) will be the base for the CDR
- Optimisation of the ECAL is ongoing work
  - ECAL shape has limited influence (better containment)
  - Using Pb will heavily degrade the angular resolution (need much thinner Pb layers)
  - Granularity: going full strips is certainly an option but need to go to small width sizes (10-20 mm)
- The ECAL has a good (but not ideal?) neutron detection efficiency and energy reconstruction
- Analyses are ongoing work
  - pi0 reconstruction
  - physics

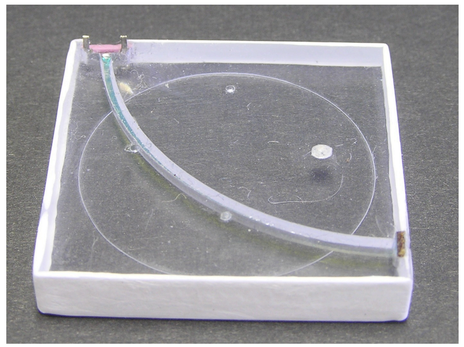
Backup Slides.

SiPM-on-Tile Technology

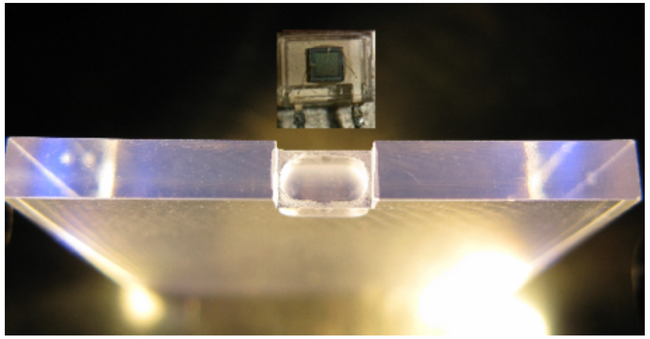
A closer look

- From the first large-scale application of SiPMs to the "***SiPM-on-tile***" technology

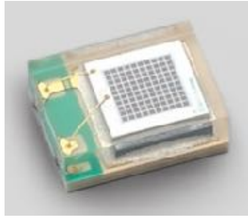
2008 - 2016



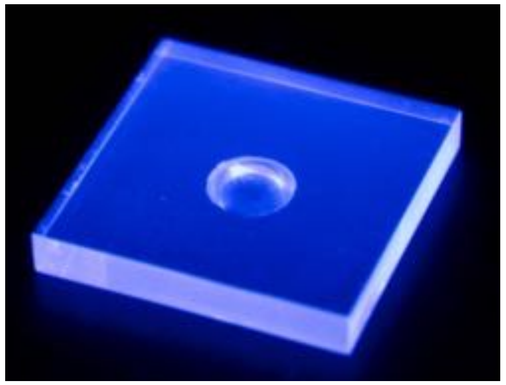
Physics Prototype

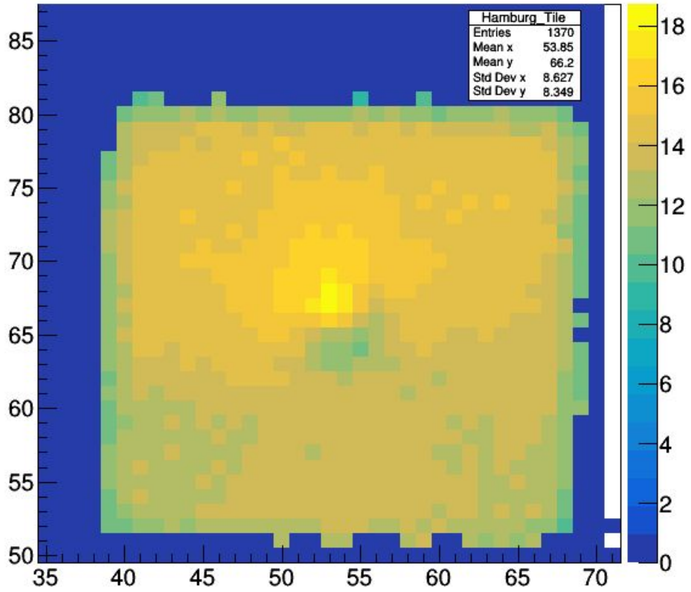


Direct coupling of tiles and photon sensors



SMD SiPMs, modification of direct coupling



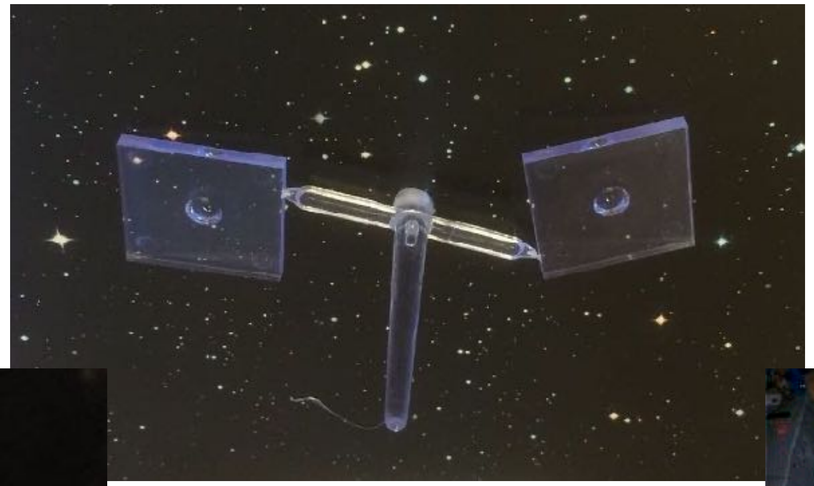


verification of tile performance in the lab

SiPM-on-Tile Technology

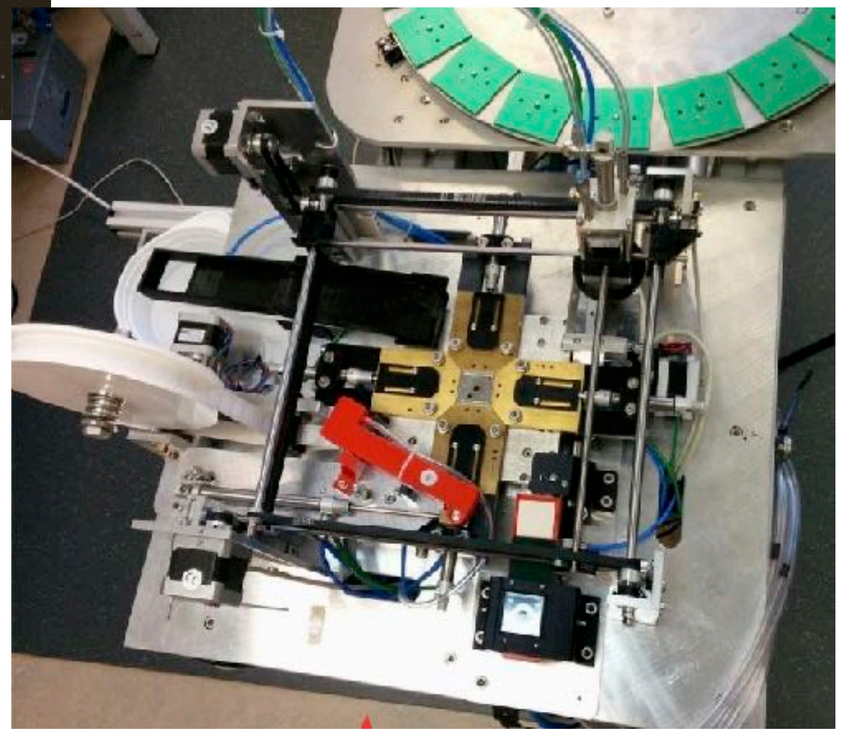
A closer look

- Mass production for a new 0.5 m^3, 22k channel prototype
  - 24k tiles produced & wrapped



injection molding of PS based scintillator tiles

09/2017



10/2017 - 01/2018

semi-automatic wrapping of scintillator tiles

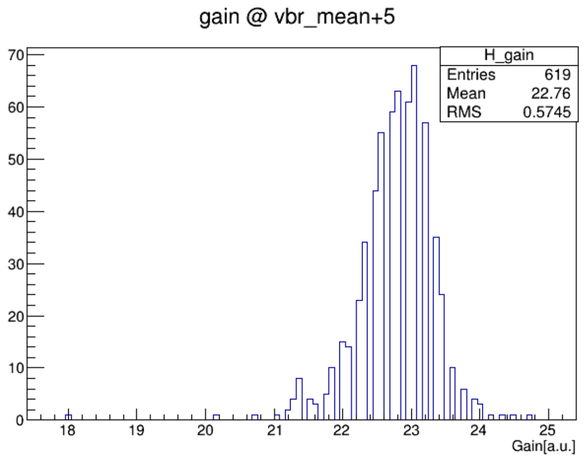
automatic placement of tiles on electronics board (HBU), fully assembled with SiPMs and ASICs

11/2017 - 02/2018

SiPM-on-Tile Technology

A closer look

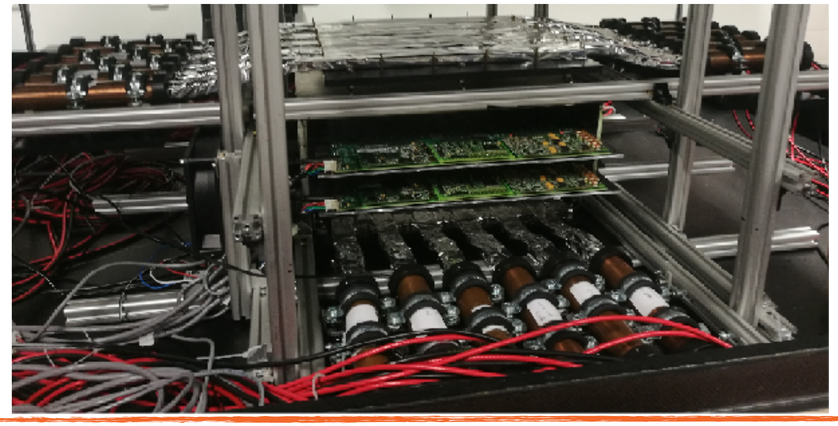
- A multi-step QA procedure



spot testing of few % of 22k SiPMs, acceptance of 600 pc batches according to pre-defined criteria - all batches accepted

test of all ASICs (~80-90% yield)

test of all assembled boards using built-in LEDs



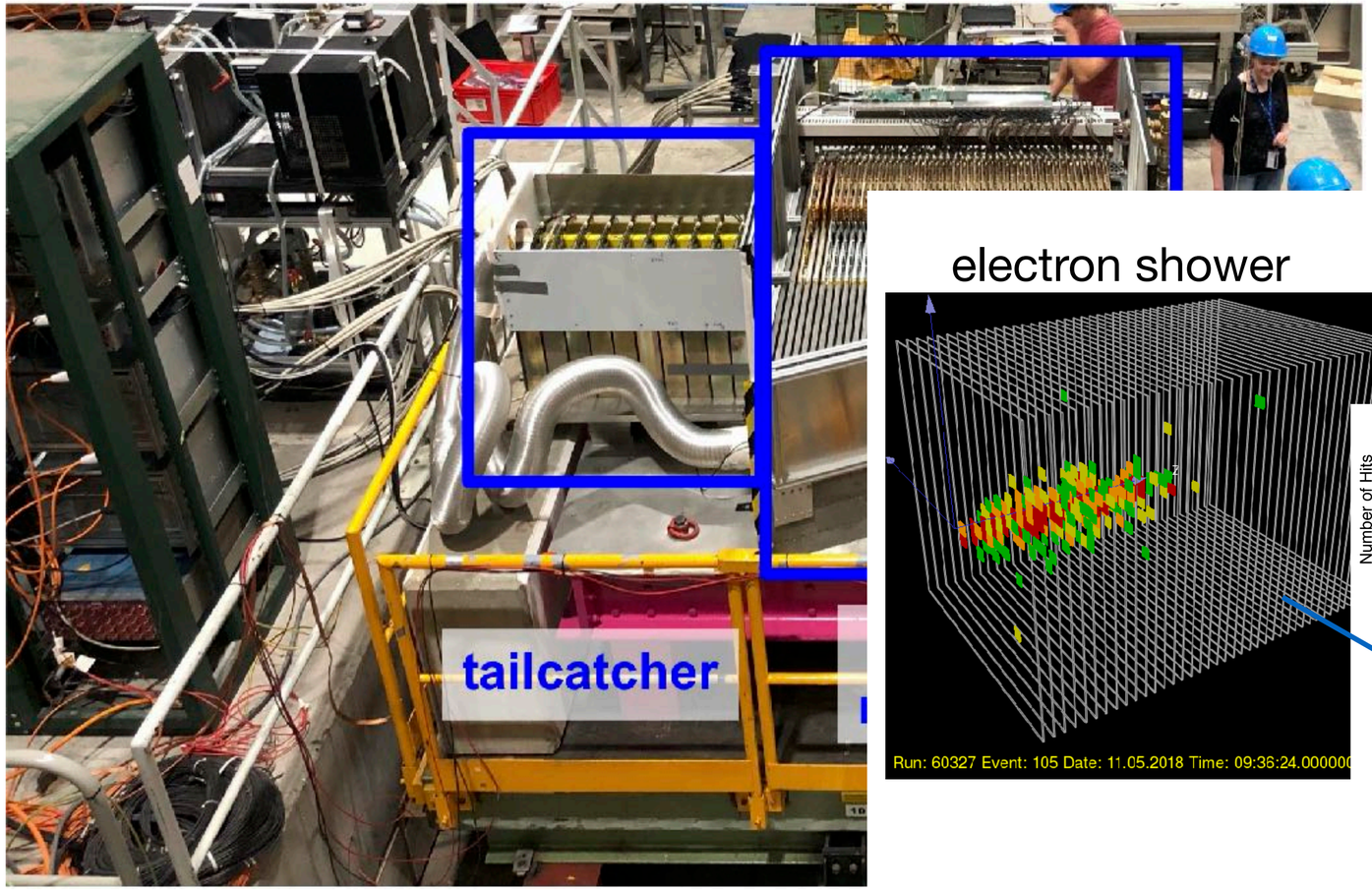
test and calibration of all channels with cosmics

integration of layers & interfaces, test in beam at DESY

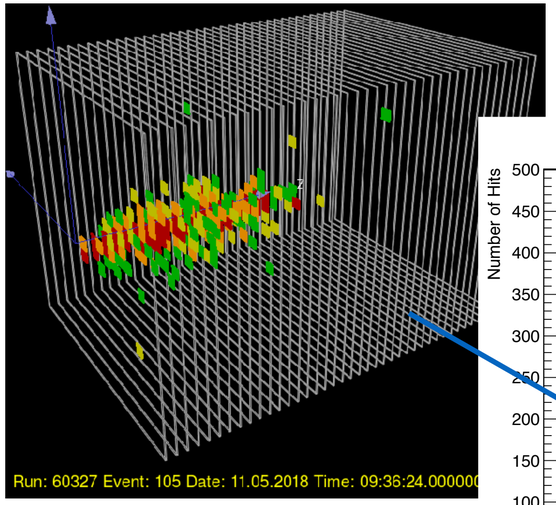
SiPM-on-Tile Technology

A closer look

- In May and June 2018: Test beam at CERN SPS - the smoothest CALICE test beams ever.

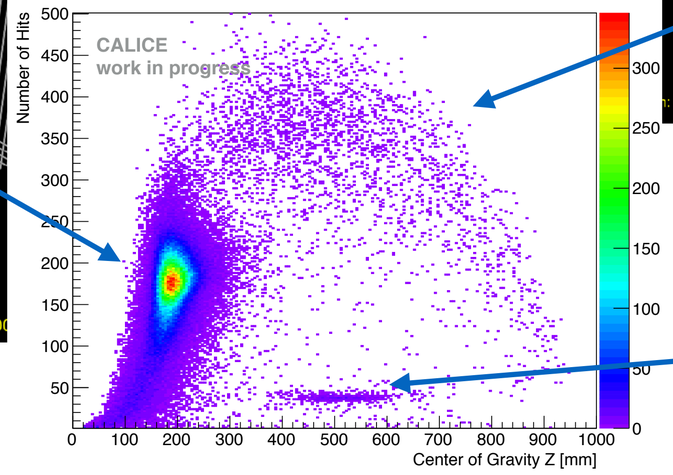


electron shower

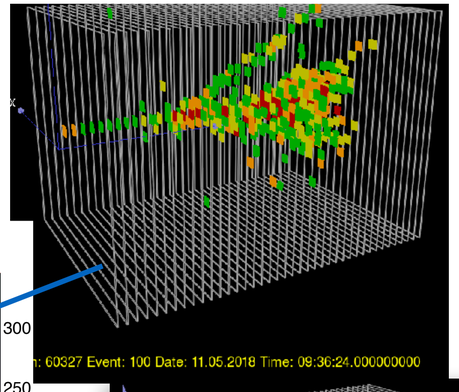


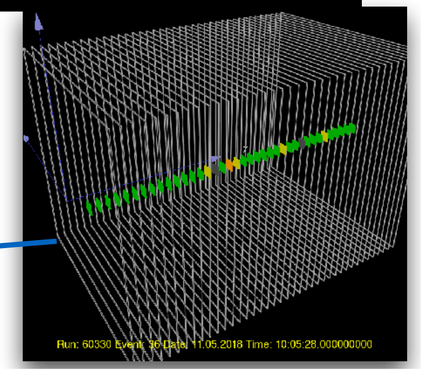
online data

50 GeV electron beam with pion and muon contamination



pion shower





muon track

- Analysis ongoing - first results soon