Plastic Scintillator material developments for calorimeters in CALICE and DUNE

JGU Mainz group

Volker Büscher || Phi Chau || Patrick Deucher || Asma Hadef || Antoine Laudrain || Lucia Masetti || Sebastian Ritter || Marisol Robles || Anna Rosmanitz || Christian Schmitt || Michael Wurm

including the PRISMA detector lab team:

Peter Bernhard || Anastasia Mpoukouvalas || Quirin Weitzel

Motivation

Future detectors CALICE, DUNE,..

full coverage and precise measurement of charged and neutral particles.

High energy resolution

High granularity ↓ Million of channels

Trackers

Particle Flow Algorithm (PFA)

Calorimeters ECAL, HCAL

absorbers

Active material

Lead

iron

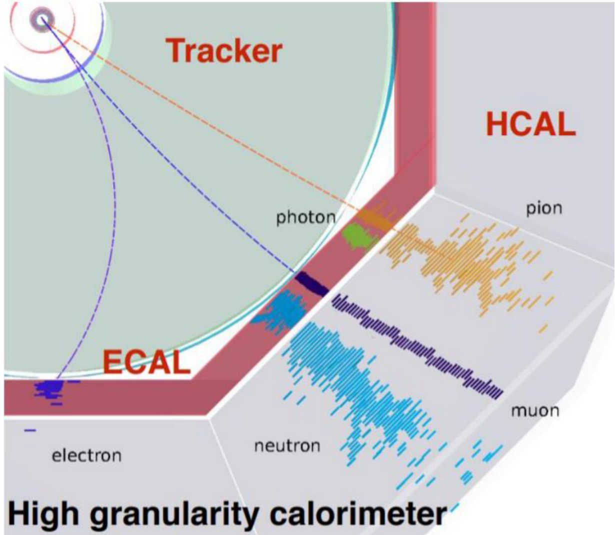
tungsten

copper

silicon

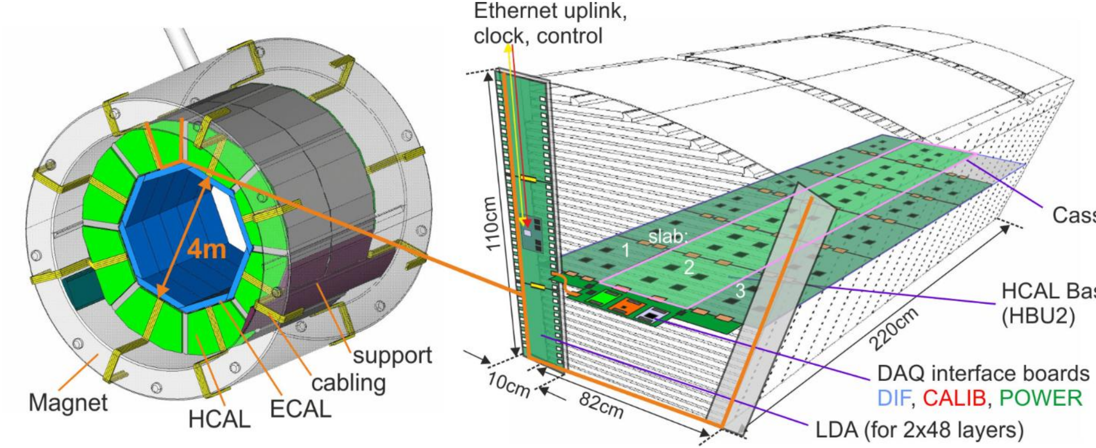
micromega

scintillators



Our expertise

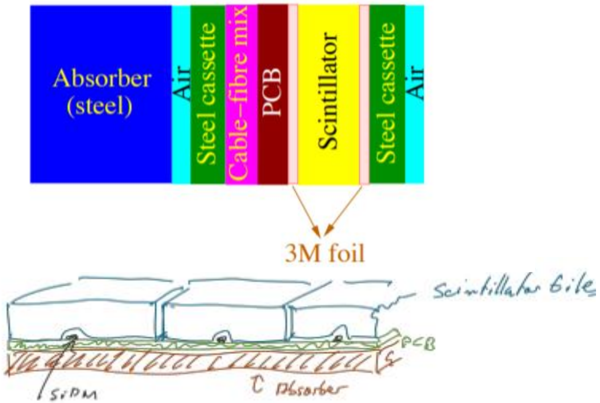
AHCAL @ ILC

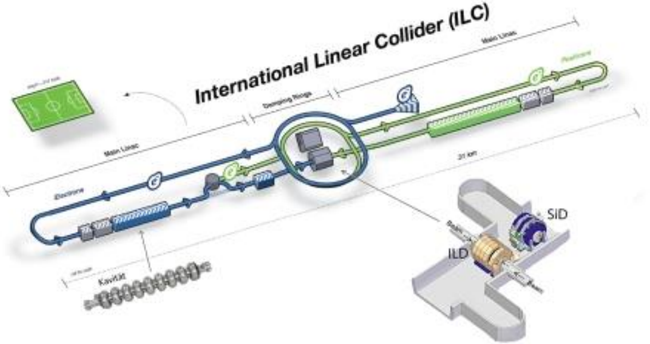


arXiv:1701.02232

48 layers with High-granular plastic scintillators

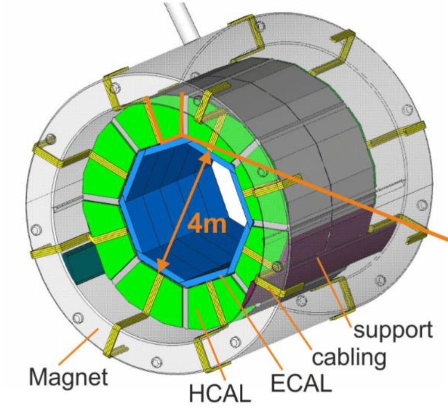
arXiv:1003.2662v1

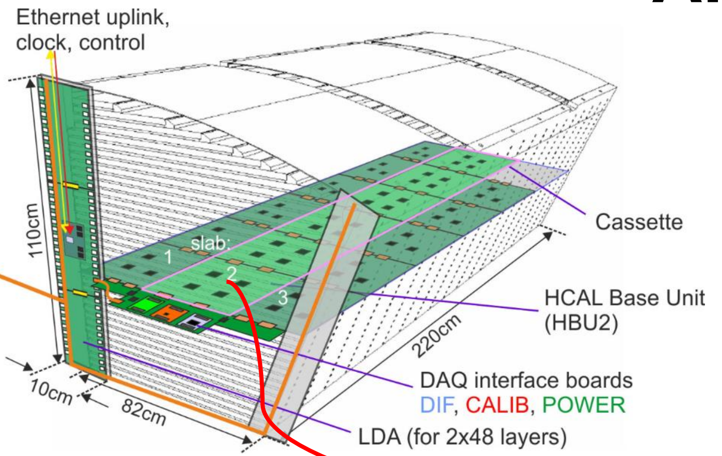


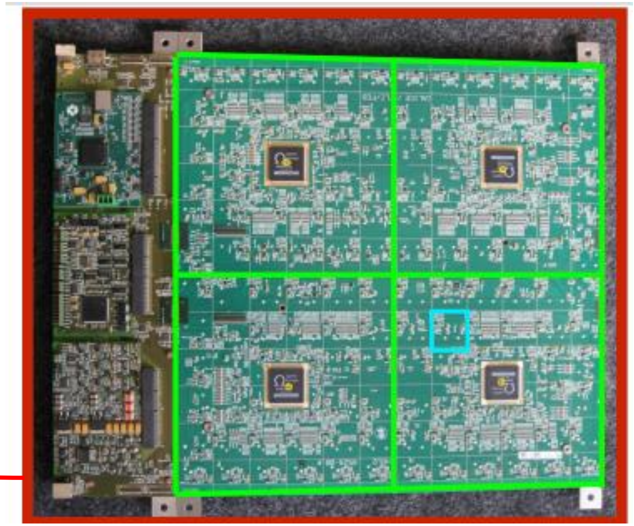


Layers of polystyrene scintillator as active material read out by silicon photomultipliers (SiPMs), sandwiched between absorber sheets.

AHCAL @ ILC







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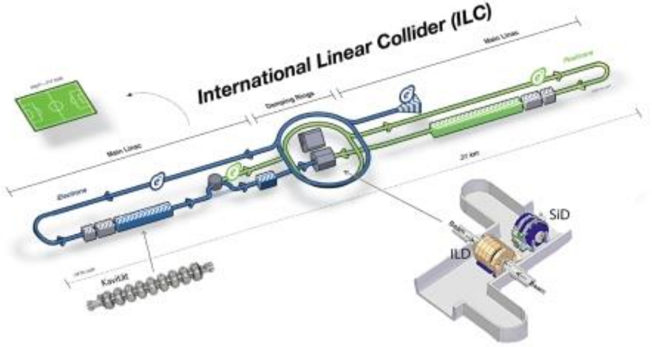
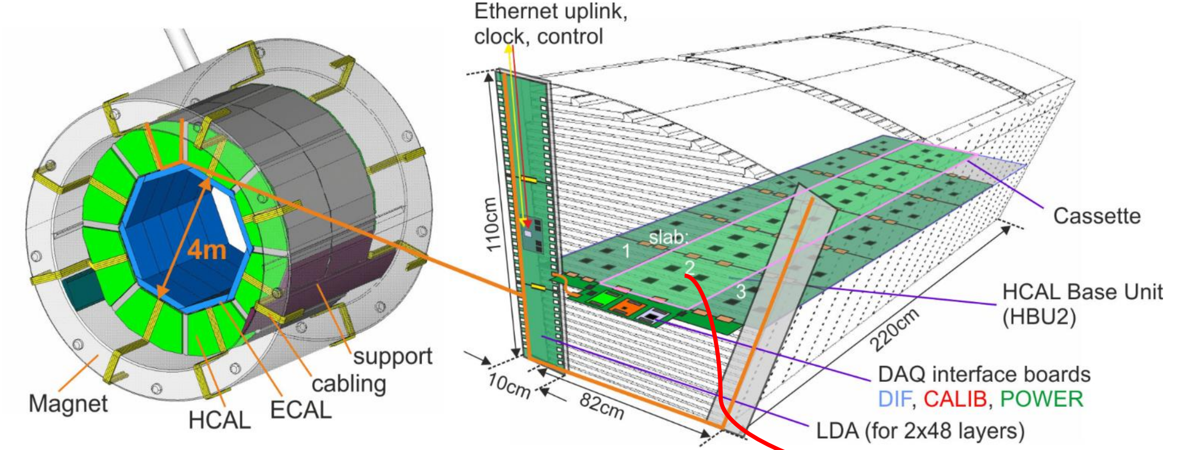
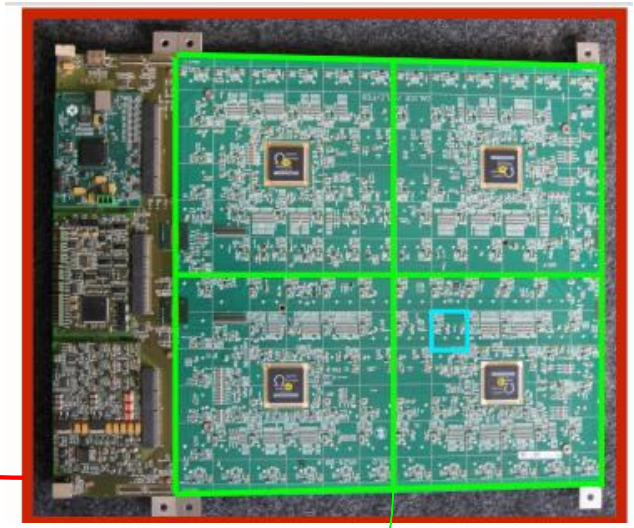


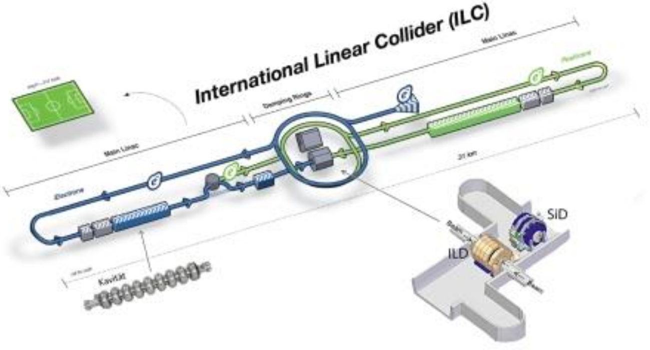
~ 55.5K boards.
~ 8M scintillator tiles.

AHCAL @ ILC





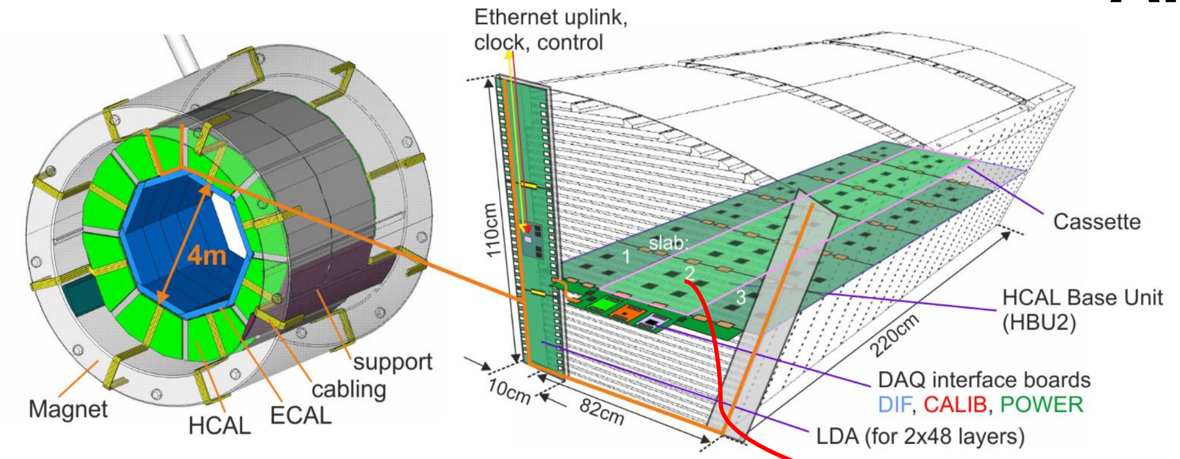
[arXiv:1701.02232](https://arxiv.org/abs/1701.02232)

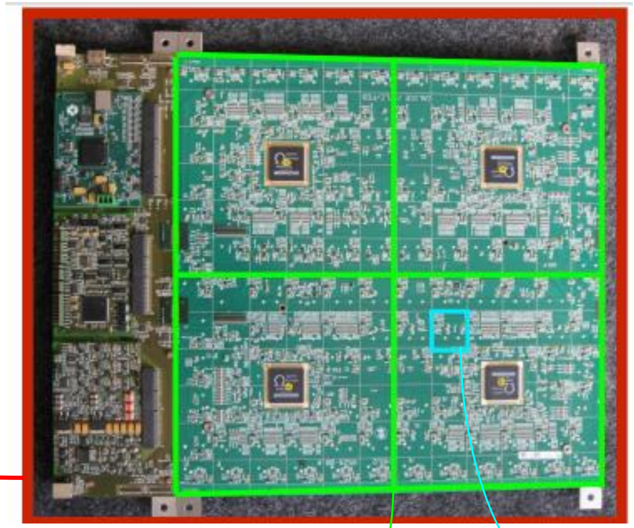


~ 55.5K boards.
~ 8M scintillator tiles.

1 board = 36x36cm² = 144 individual channels

AHCAL @ ILC





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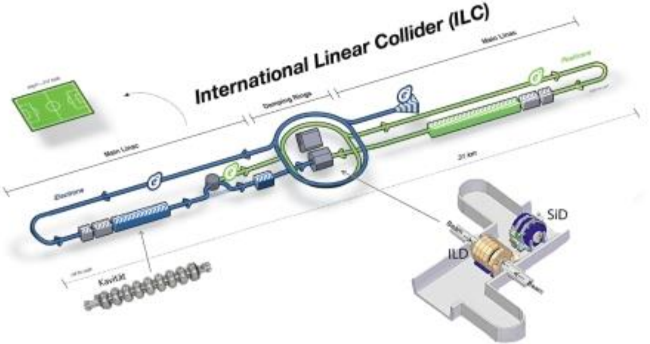
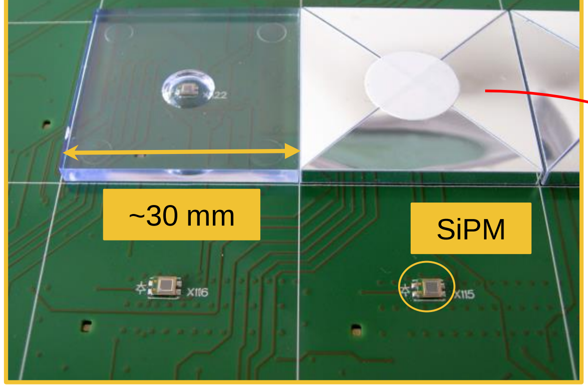


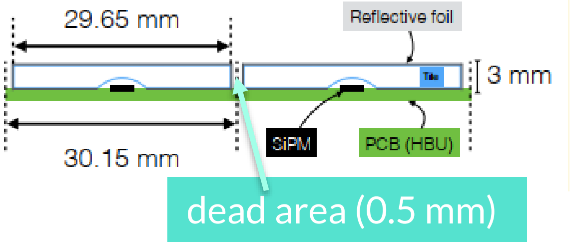
~ 55.5K boards.
~ 8M scintillator tiles.

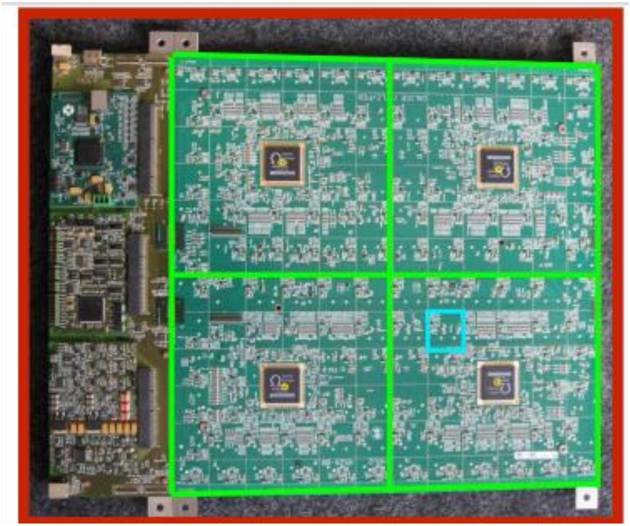
1 board = 36x36cm² = 144 individual channels

1 channel = 1 polystyrene scintillator tile (30x30 mm², 3 mm thick) + 1 SiPM (S13360-1325)

AHCAL @ ILC



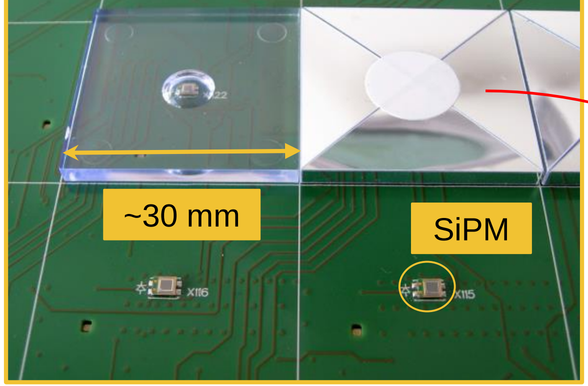


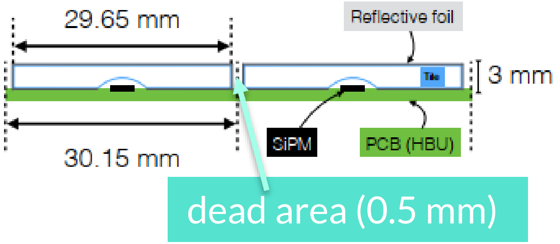


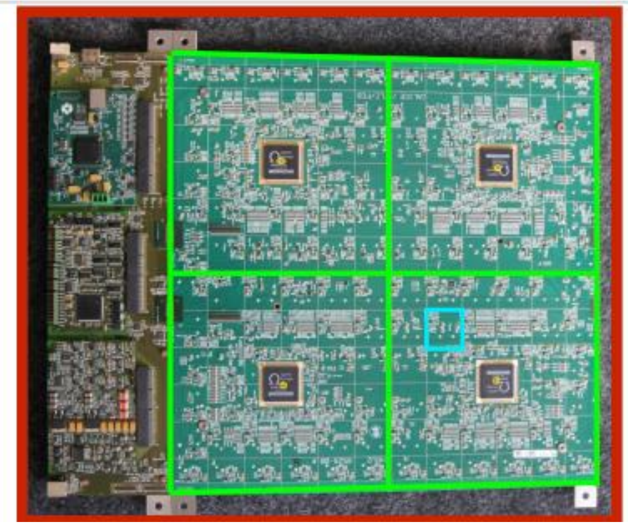
- ❑ Individually wrapped tiles in highly reflective ESR foil.
- ❑ Glued on HBU board individually.
- ❑ Process proven to work, can be automated
- ❑ Still painful + dead area between tiles!

~ 55.5K boards.
~ 8M scintillator tiles.

AHCAL @ ILC







- ❑ Individually wrapped tiles in highly reflective ESR foil.
- ❑ Glued on HBU board individually.
- ❑ Process proven to work, can be automated
- ❑ Still painful + dead area between tiles!

Solution:
One single 36x36 cm² tile: **Megatile**
+ no dead area
+ easier assembly
+ 55.5K Megatiles instead 8M single tiles

Our project

Megatile (MT) @ Mainz

Antoine Laudrain - BMBF 2020

Optical insulation techniques:

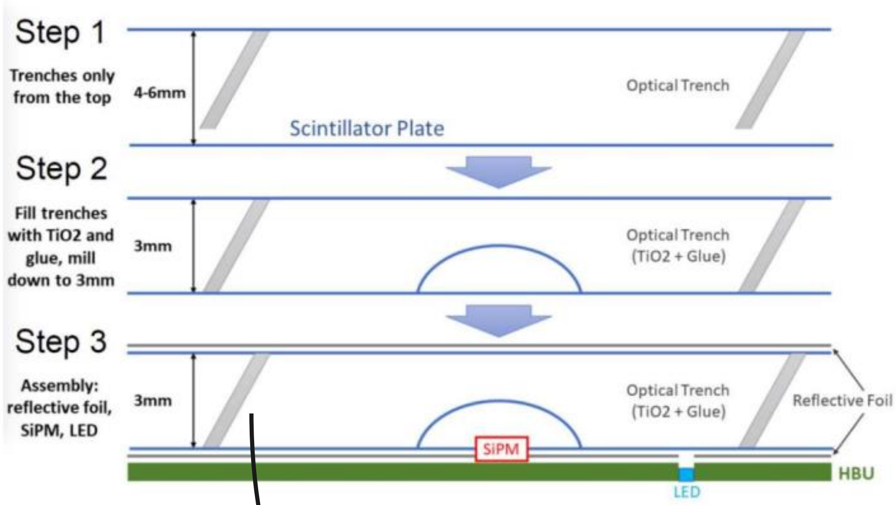
Inside: Cut trenches and fill with TiO2 + glue mixture.

Top and bottom: insulated with large reflective foil

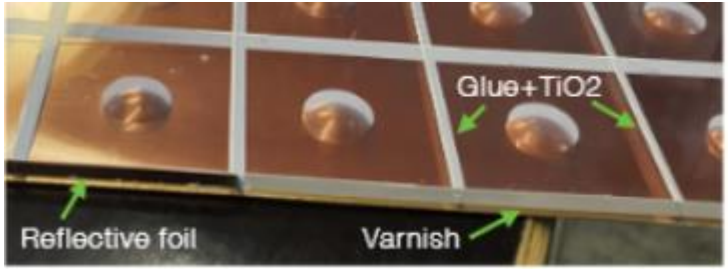
(laser cut holes for SiPM + calibration LED).

Air Gap (30-100 μm) to ensure total reflection.

Edges: varnish spray.

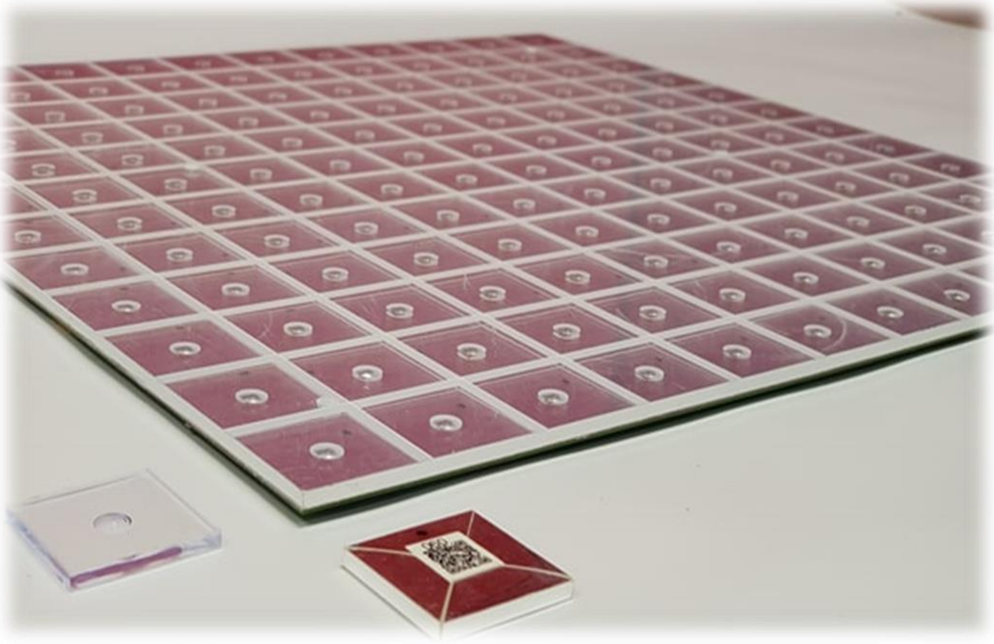


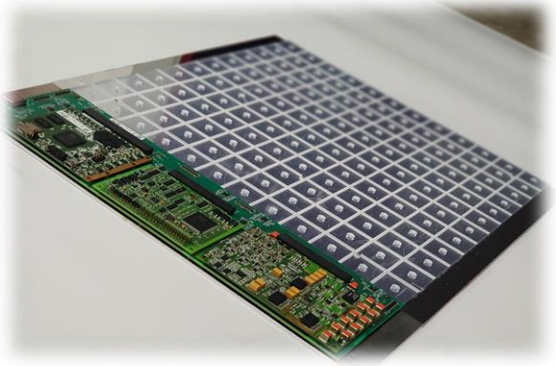
Angle = 30°: minimal dead area



Megatile (MT) @ Mainz

- ❑ Already 7 prototypes with steady Improvements since 2017.
- ❑ Already 3 test beams at DESY II.
- ❑ Continuous testing possible thanks to PRISMA+ cosmic ray test stand and Local testing facility essential for development.



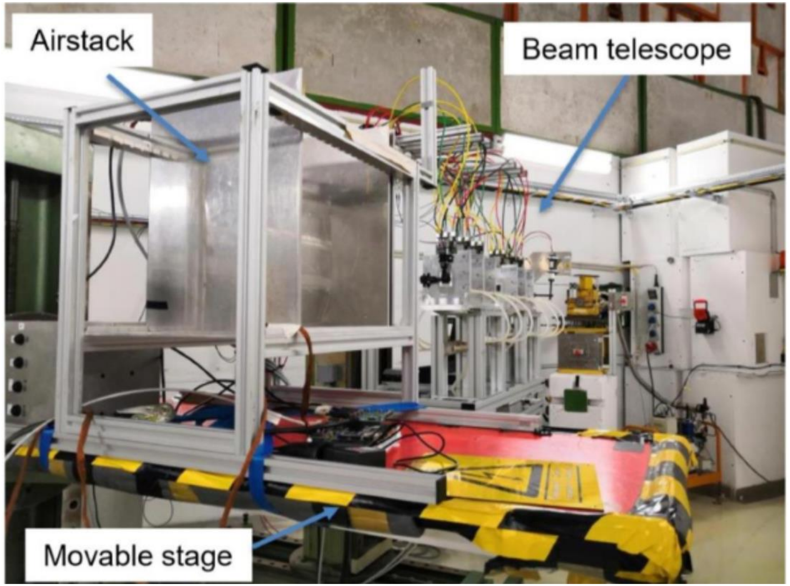


New!! (2020)

- ❑ measurements with MT6 in test beam @ DESY (August 2020).
- ❑ MT7: Best mechanical realisation so far, very careful treatment.

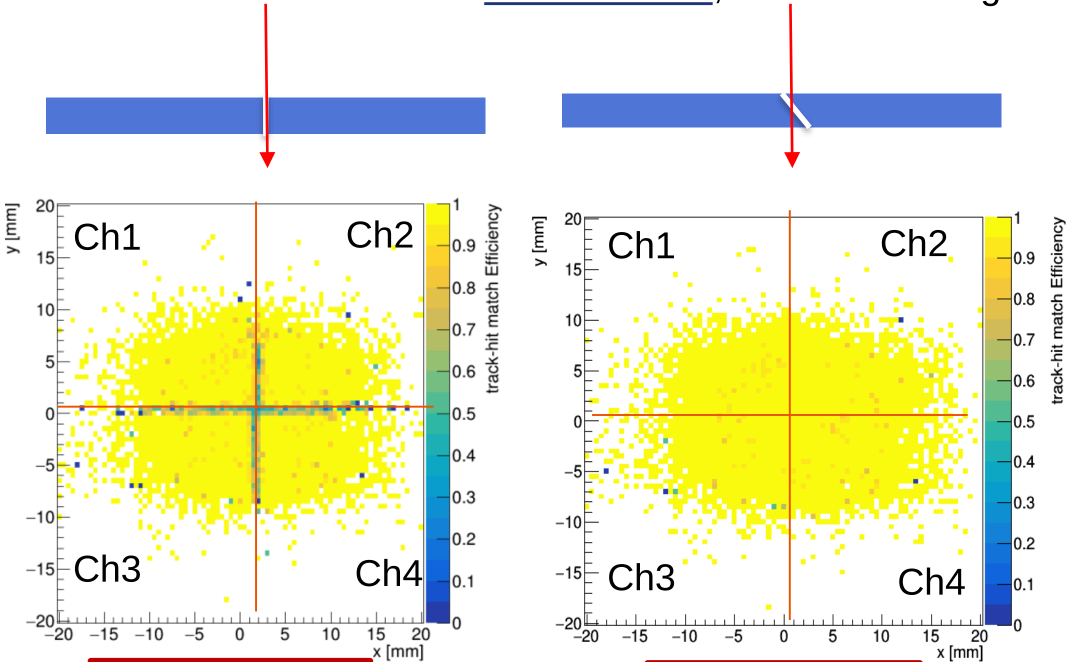
Megatile @ TestBeam

Jiri Kvasnicka, AHCAL meeting



"Megatile has less dead area"

- ❑ Confirmed in DESY test-beam data.
- ❑ Enable thanks to beam telescope.
- ❑ Beam hitting in the middle of 4 cells.

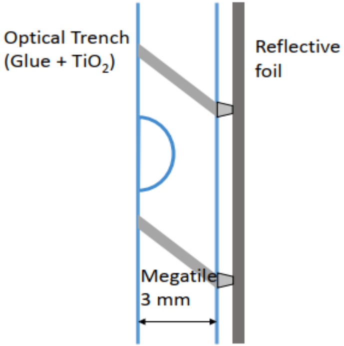


Single Tile (ST)

Megatile (MT)

Efficiency of a track reconstructed by the telescope that have a hit in the corresponding MT/ST cell

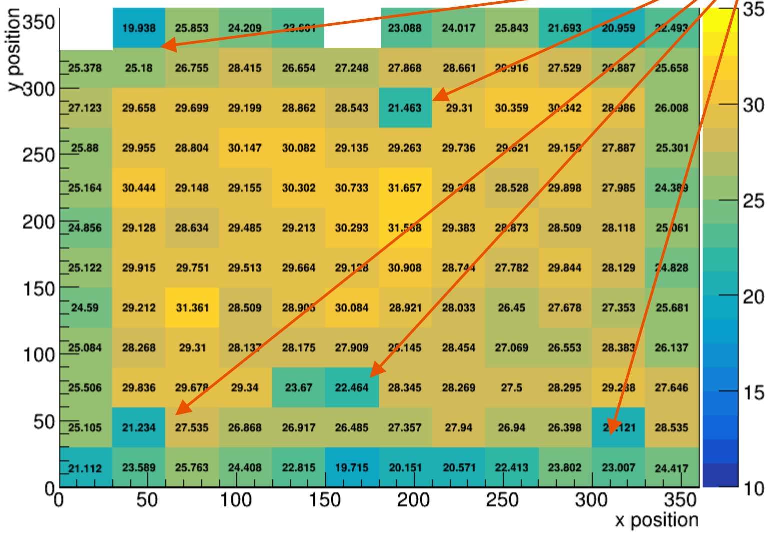
Megatile Performance



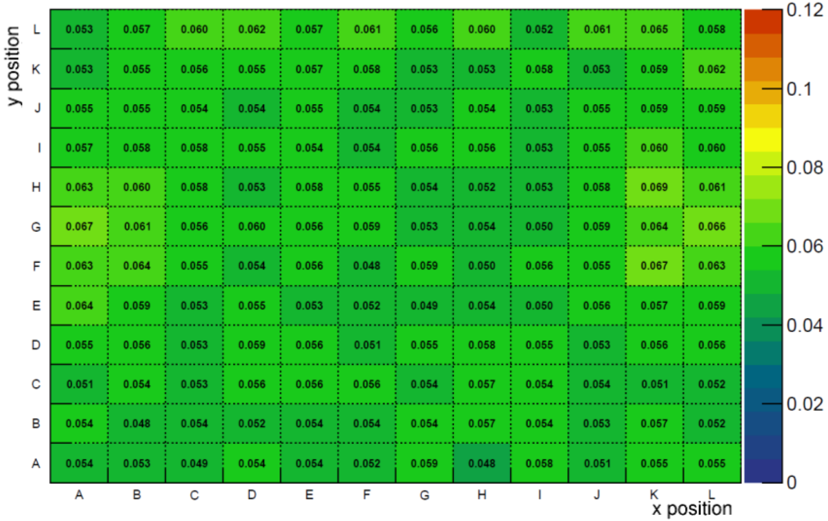
- Improved light yields uniformity.
- foil glueing to Megatile along the trenches to avoid foil bending.
- Cross talk at acceptable level (<7%).

Due to screws

Light Yield (MT6@TestBeam)



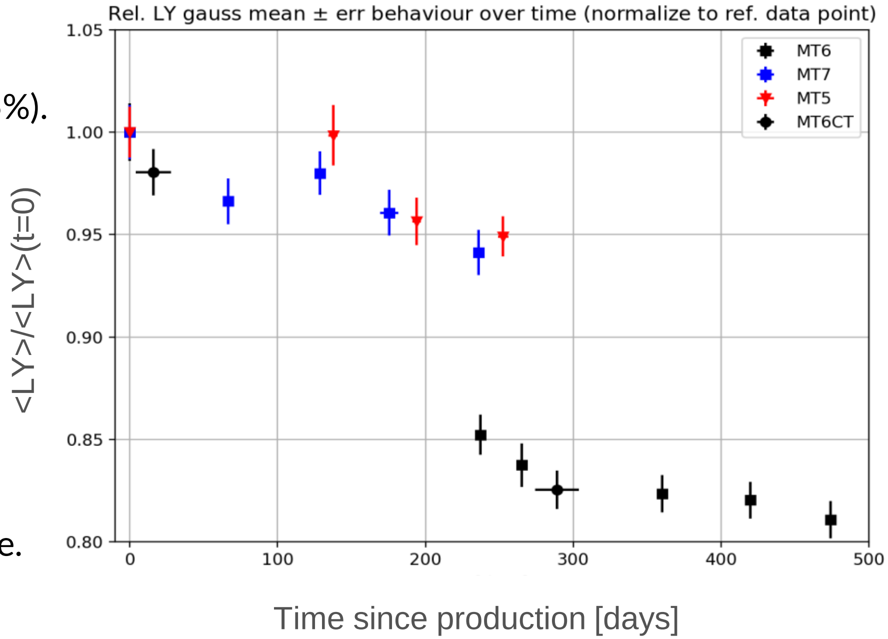
Cross talk (MT6@Cosmic Ray Test Stand)



Megatile Aging Studies

Fast ageing of MT6?

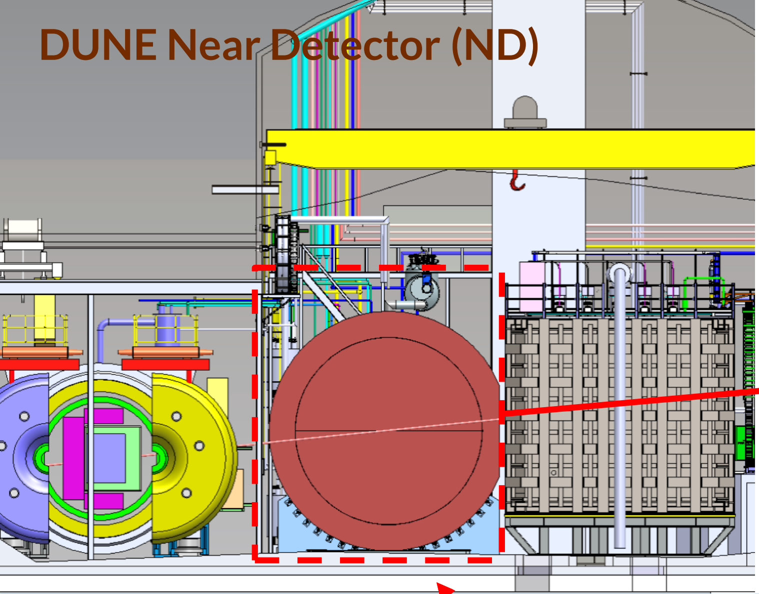
- ❑Large LY difference between Dec.19 and summer 2020 (10-15%).
- ❑Stabilised now.
- ❑Not observed in MT5/MT7 (only slow drift, expected).
- ❑Temperature ~stable (within 0.5℃) ➞ probably not in cause.
- ❑Most likely explanation:
    - ❑ bad storage during lockdown.
    - ❑ Not properly stored in closed cabinet.
    - ❑ Probable exposure to light for extended period of time.



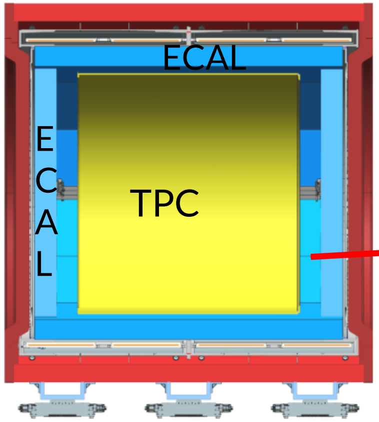
<u>Plan</u>

- ❑Build a new prototype and expose it to an intentional, controlled light source.
- ❑Continue taking periodic measurements to follow evolution of current prototypes.

ECAL @ DUNE ND



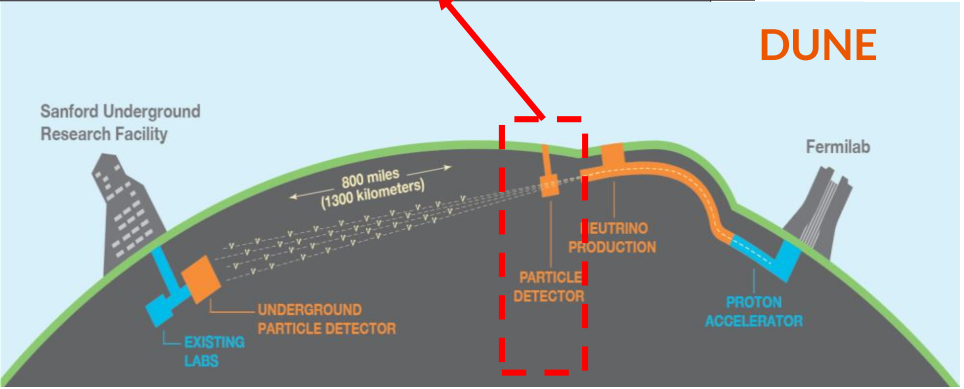
ND-GAr



42 layers with low and high granular plastic scintillators:

- HG layers using 0.7 mm lead / 5 mm Sc,
- LG layers using 1.4 mm lead / 10 mm Sc.

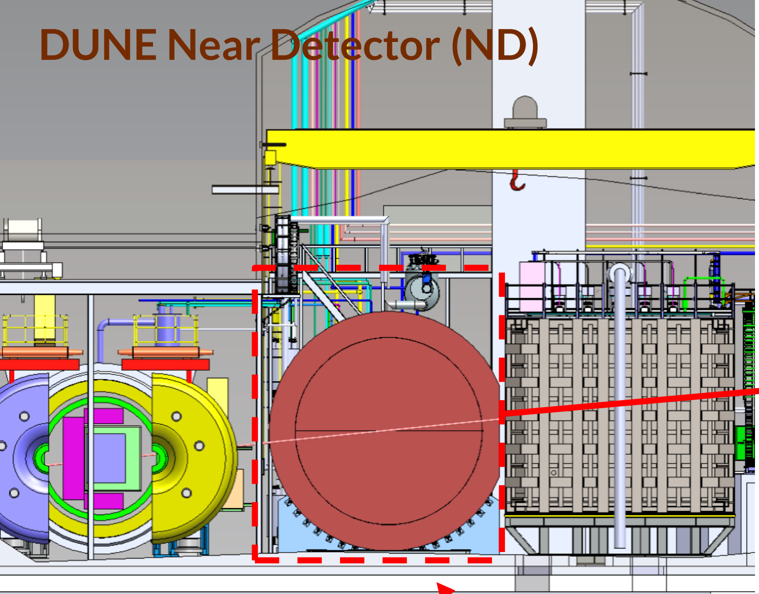
Inspired by AHCAL @ CALICE



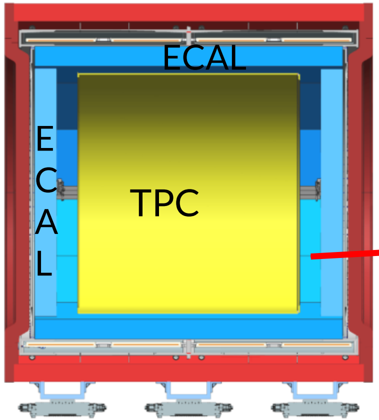
The ECAL has to provide:

- Photon energy measurement.
- Neutral pion reconstruction (2 photons from a common decay vertex).
- Particle identification (electron, muon, pion) together with tracker and muon detector.

ECAL @ DUNE ND



ND-GAr



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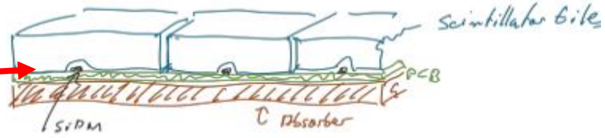

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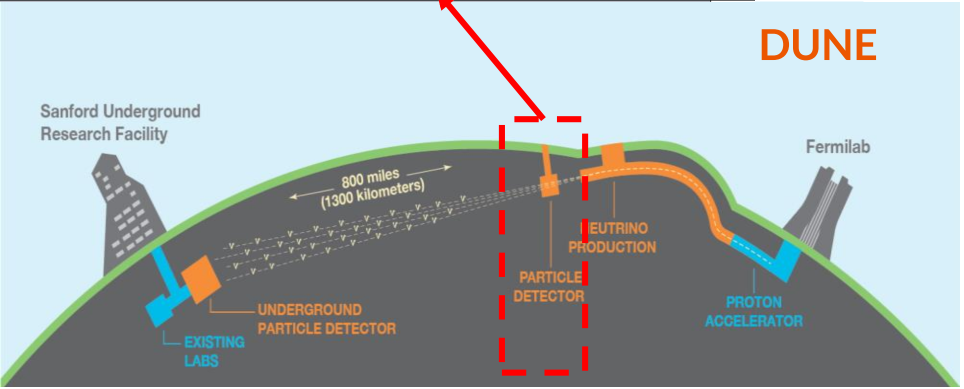
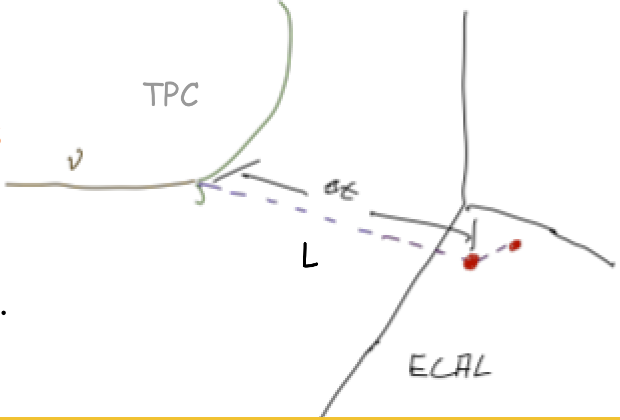


- Neutron detection and energy measurement.
- In this talk: **Neutron** reconstruction @ ECAL.
- The energy carried away by neutrons is challenging to detect and can bias the reconstructed neutrino energy.

ECAL @ DUNE ND

Expected performance - Neutrons



- Fast Neutrons with energies <100 MeV>:
  - created @TPC: from the interaction of incident neutrino beam (vertex).
  - detected @ ECAL: scattering → energy transfer to protons (<10 MeV).
- Neutron detection efficiency ~ 40%.

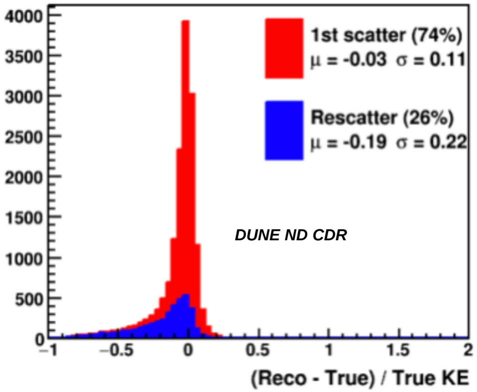
TOF = Δt = time (detected @ ECAL) - time (created @TPC)

- Reconstructing kinetic energy from **time of flight (TOF).**

$E = 1/2\, m v^2 \Leftrightarrow E = 1/2\, m L^2/\Delta t^2$

➔ precisely measuring the time and position of a neutron-induced hit and vertex.

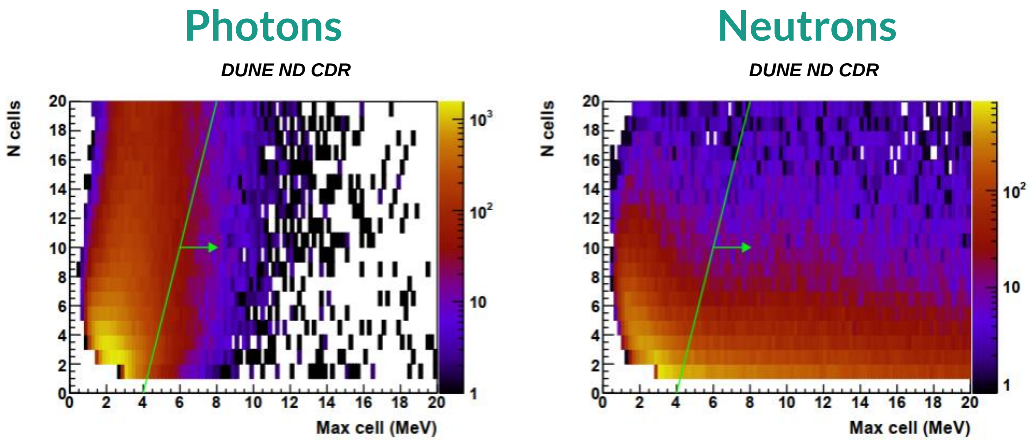
➔ timing at a few 100 ps - 1 ns level to enable energy measurement via TOF.



ECAL @ DUNE ND

Expected performance - Neutrons

Distinguish between photons from π^0 and neutrons.



Future optimization studies of ND-GAr will take into account both photon (π^0) and neutron reconstruction performance.

Neutron and photon-induced clusters are separated based on:

- Total number of hits in the cluster.
- Total energy of the cluster.
- Maximum hit energy.

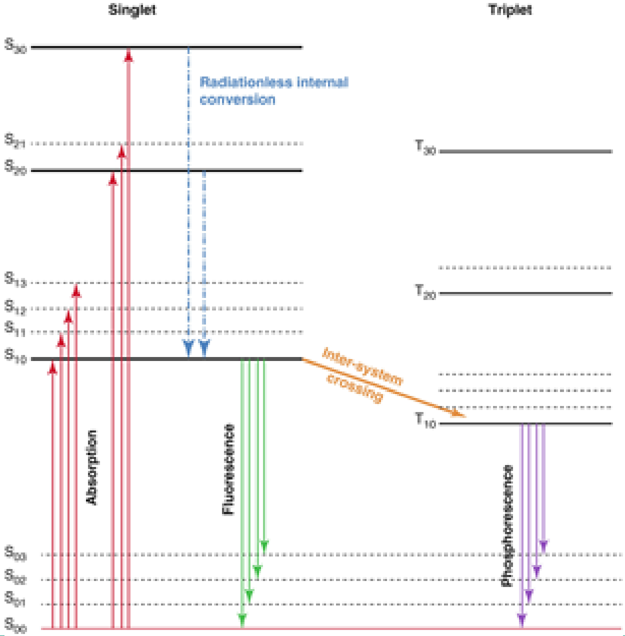
Additional idea:

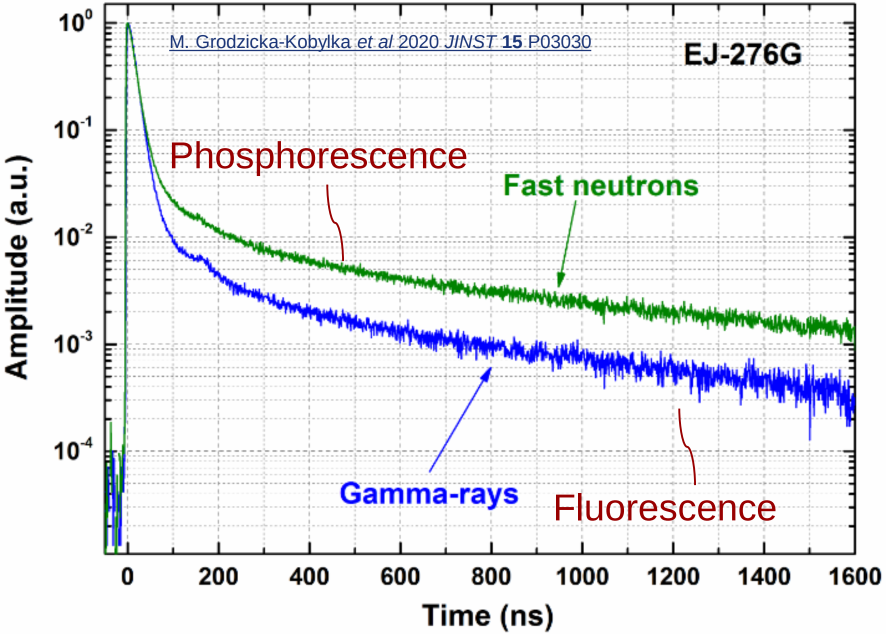
Identify neutrons at interaction level based on "scintillation pulse shape".

Our project

Neutrons Signal in Plastic Scintillator

- First interaction of a neutron in plastic scintillator is usually (back-)scattering of a proton with efficient energy transfer.
- due to higher ionization density, protons excite more (long-lived) triplet states in scintillator molecules:
  - → higher slow component in the signal (phosphorescence).
  - → different pulse shape: **stronger tail** component.



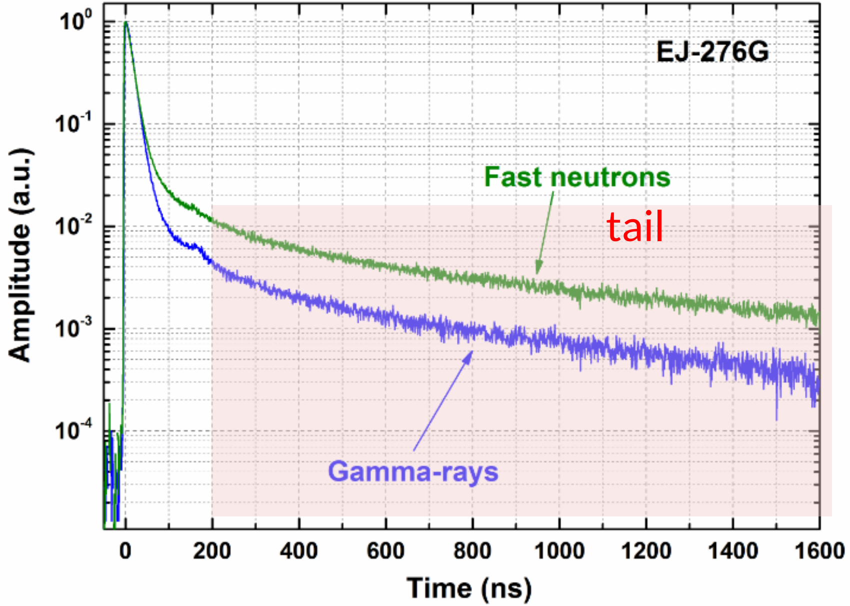


Pulse Shape Discrimination (PSD)

PSD techniques mostly concentrate on the difference in the long decay constants.

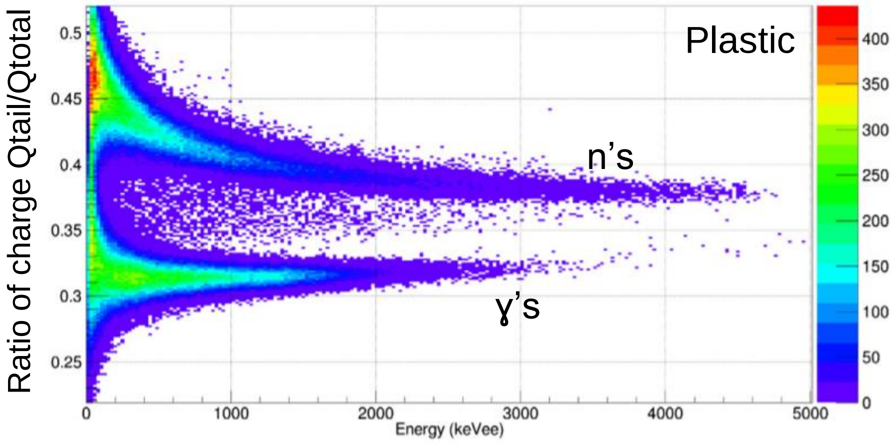
simple method: tail-to-total charge ratio

→ integrate the tail region of pulse and divide by total pulse area.



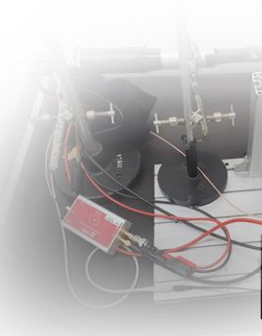
<u>Our goals:</u>

- neutron/gamma discrimination with a SiPM coupled to a plastic scintillator, using the pulse shape discrimination (PSD) method.
- High efficiency of neutron detection.



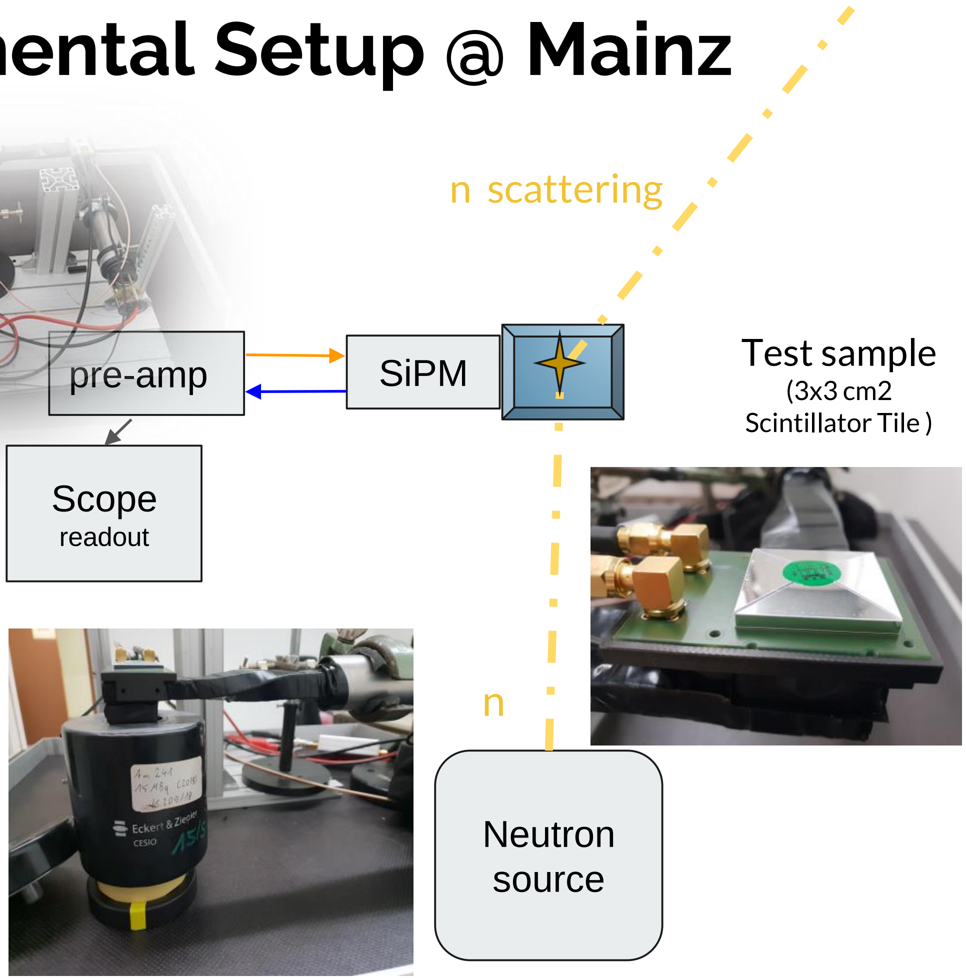
M.P.Taggart et al 2018 Elsevier 908 152

Experimental Setup @ Mainz



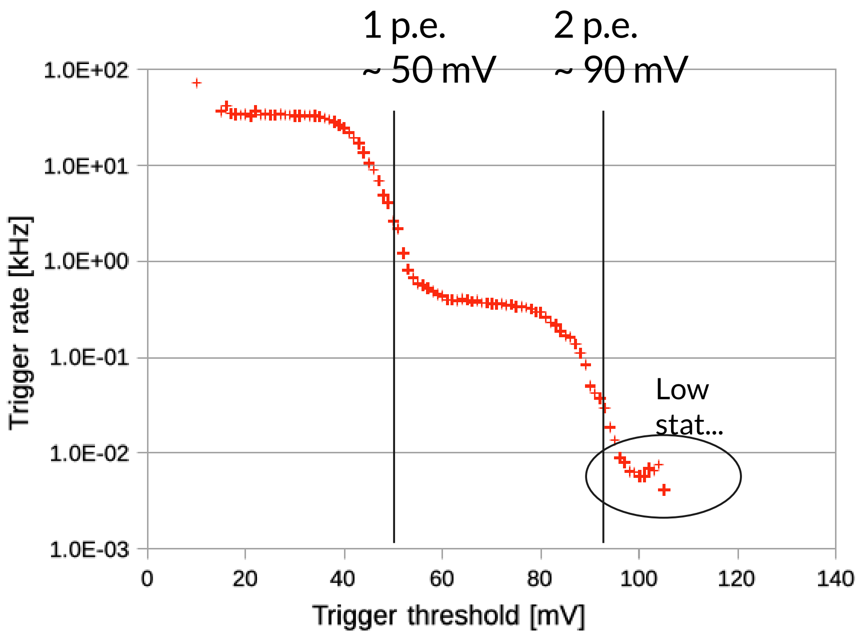
Experimental study: Optimise material to distinguish between neutrons and photons

- Gamma and neutron signals from an AmBe source.
- Test setup of small plastic scintillator samples with Silicon photomultiplier (SiPM) read-out.
- Starting point with scintillator samples from CALICE and commercial samples (Eljen).

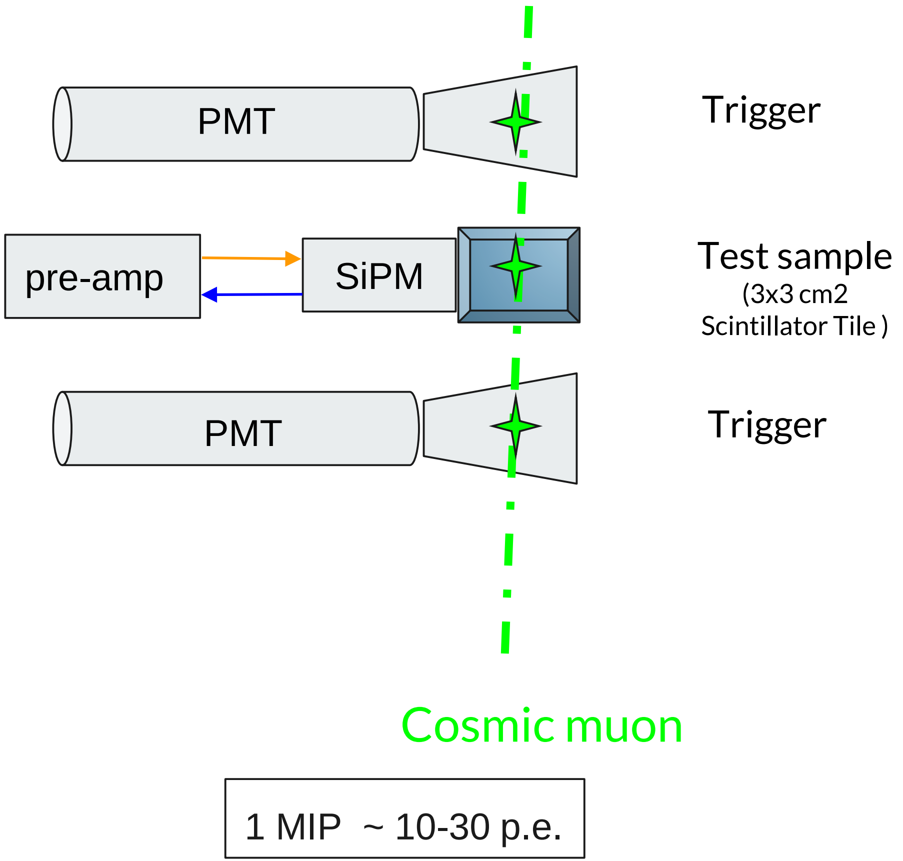


SIPM commissioning

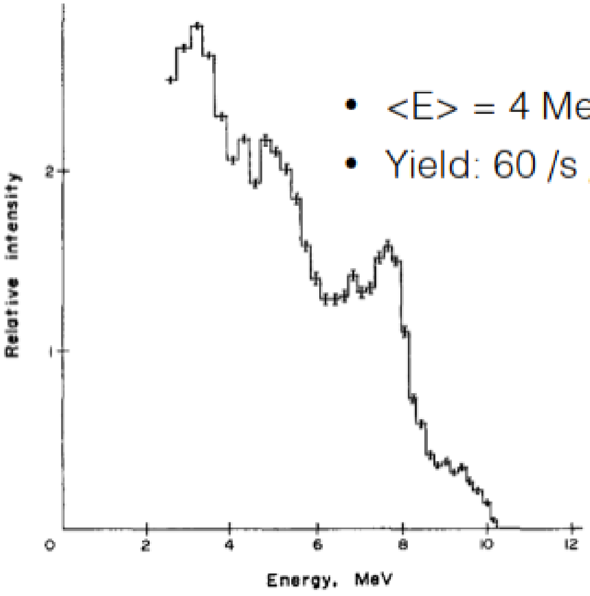
- noise at the 5 mV level.
- Dark noise events: 1p.e. and 2p.e. are clearly seen (step of ~40 mV).



Setup Commissioning



Neutron Source



- <E> = 4 MeV [PDG]
- Yield: 60 /s /MBq [PDG]

^{241}AmBe

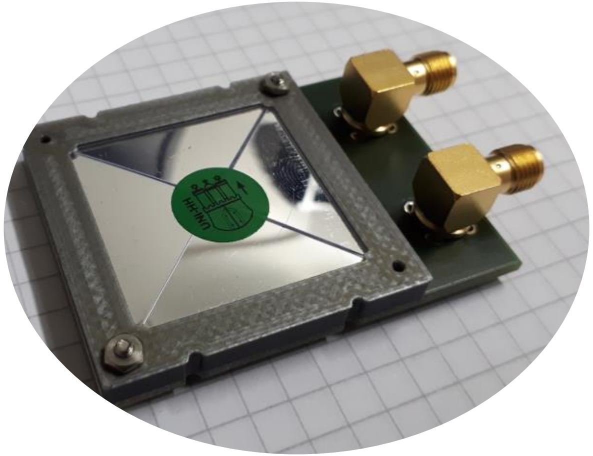
15 MBq source with **~100's detected neutrons/s.**

- Decay:
  - α: 100%
- Use Be as alpha → n converter:
  $^{11}Be + \alpha \rightarrow {}^{12}C + n + \gamma(4.4\ MeV)$

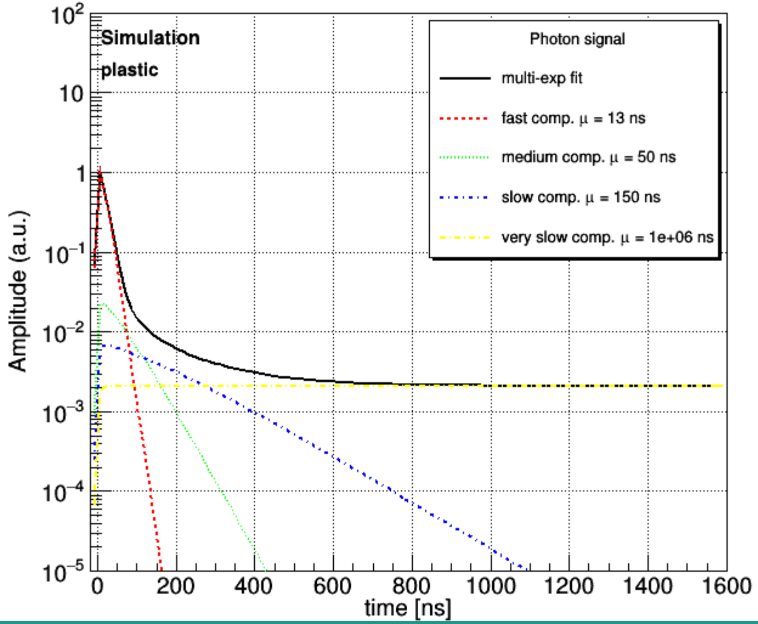
- Energies less than DUNE experiment (factor of 25).
- Need simulation for extrapolation.

Plastic Scintillator Tile

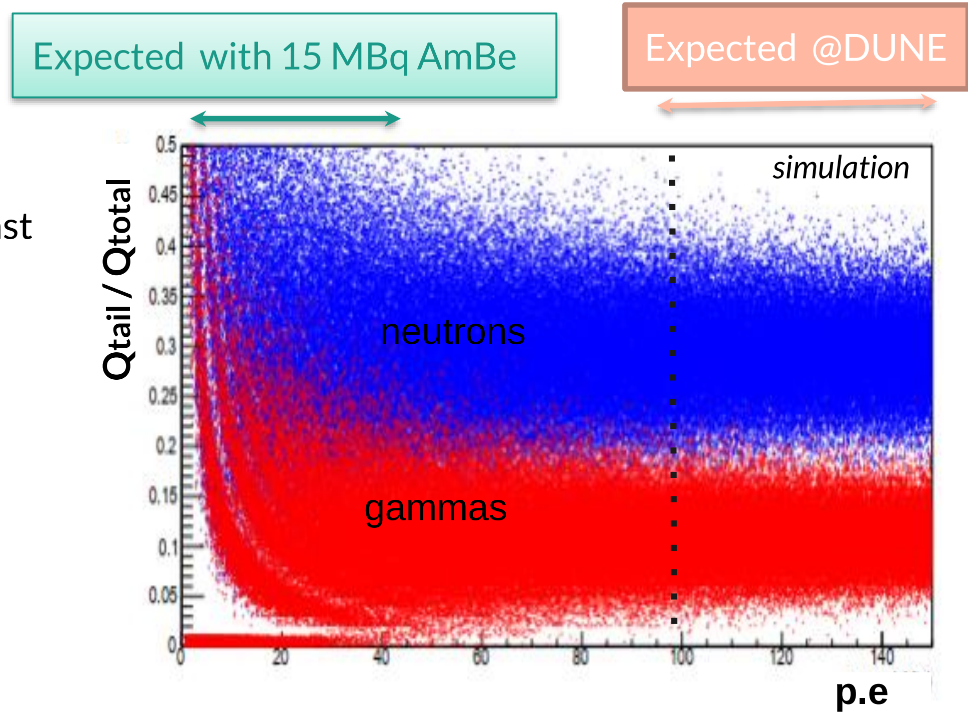
- Home made wrapping of 3 and 5 mm tiles using ESR foil.
- Redesign our own PCB to include LED for SIPM calibration.
- Tile fixed on PCB using 3D printed holder.



- Time components for different plastic scintillators will be measured in the spectro-fluorometer @ DetLab.
- To be plugged into simulation and compared to data.

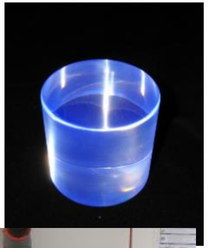


Commercial Plastic Scintillators



EJ-276:

- Ordered Ej208 and EJ-276G used for PSD plastic, Fast neutron-gamma discrimination (arrives end of June).



In-house Plastic Scintillators Production

- Test samples produced in PRISMA's Laboratory for scintillation and Fluorescence detectors.

Marc Breisch's talk

- Gamma/neutron separation is feasible for high LY.
- Toy simulation based on time profiles of a n/γ-optimized plastic scintillator.

Conclusion

CALICE (Megatile):

- Successful and improved Megatile prototype design.
  - Performs same level as the CALICE prototype.
  - Improved uniformity with no dead areas.
- 3 years of funding, still working on it.
- Closed to final design, ready to be tested with Klaus.

DUNE (n/γ discrimination using PSD with plastic scintillator):

- New test setup in Mainz ready:
  - Preparation for hardware + DAQ + simulation + homemade samples.
- Next steps: Test new samples and optimised in-house material scintillator production.

BACK UP