Results from latest CALICE AHCal test beams

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On behalf of the CALICE Collaboration

BTTB 2022 — 24/06/2022

Calorimeter for ILC

Bundesministerium für Bildung und Forschung

AIDA 2020

PRISMA+ DETECTOR LAB

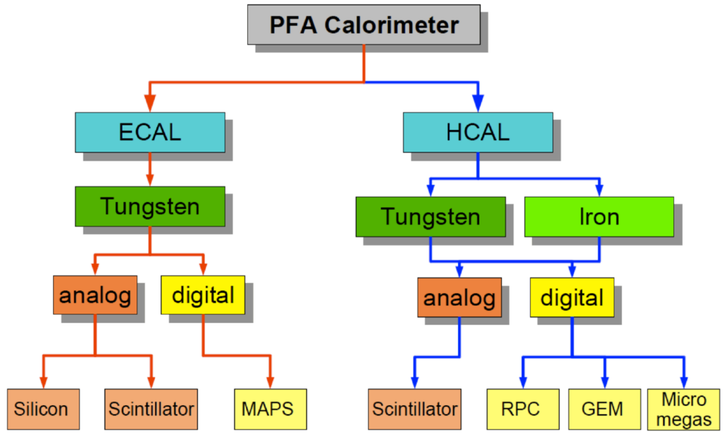
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

JG|U

Calorimeters for future colliders

- **CALICE**: development of **calorimeters** for future colliders.

- Target **hadronic calorimetry with a few % resolution**.
  - Not possible using calorimetry alone.
  - Extensive usage of **particle-flow algorithms**.
  - Requires **high granularity**.
- → “Imaging” calorimeter: resolve jet components.



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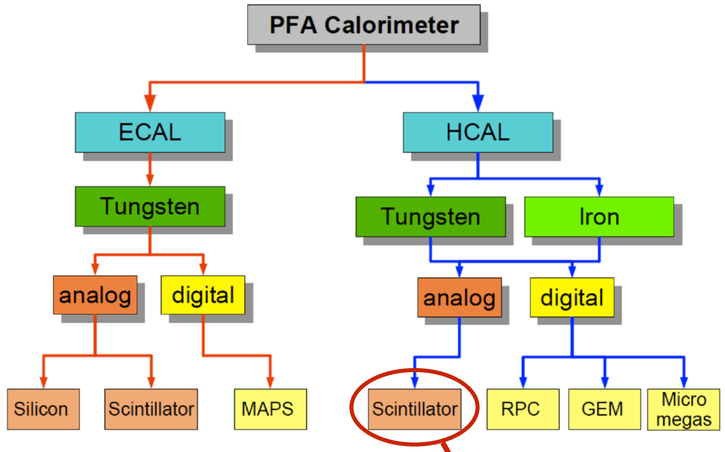
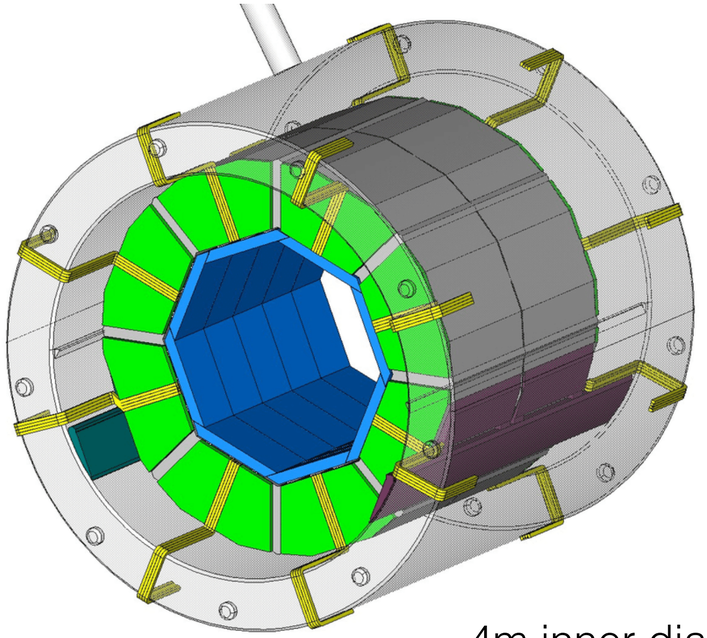
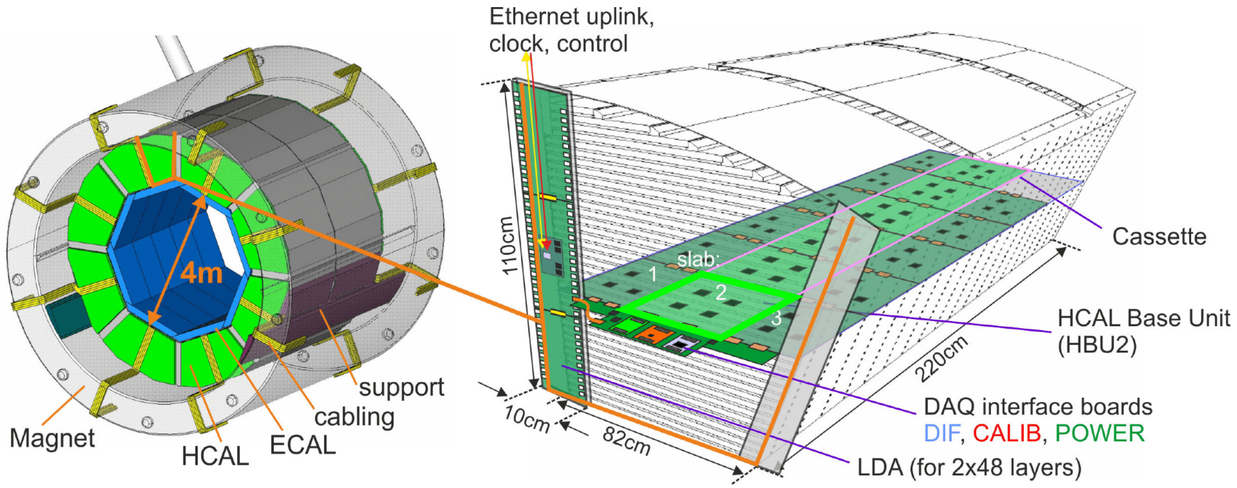


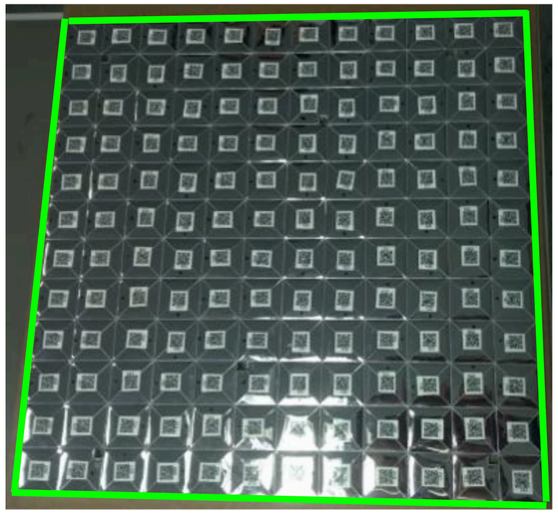
- **AHCal**: **Analogue Hadronic Calorimeter**
  - Plastic scintillator tiles.
  - **SiPM readout**.
  - Total **8M channels**!



4m inner diameter and length

The Analogue Hadronic Calorimeter





- 1 board = 36x36 cm^2 (144 channels)
  - Fully integrated (readout, power supply, calibration LED)
  - 4 readout chips (SPIROC-2), 36 channels each

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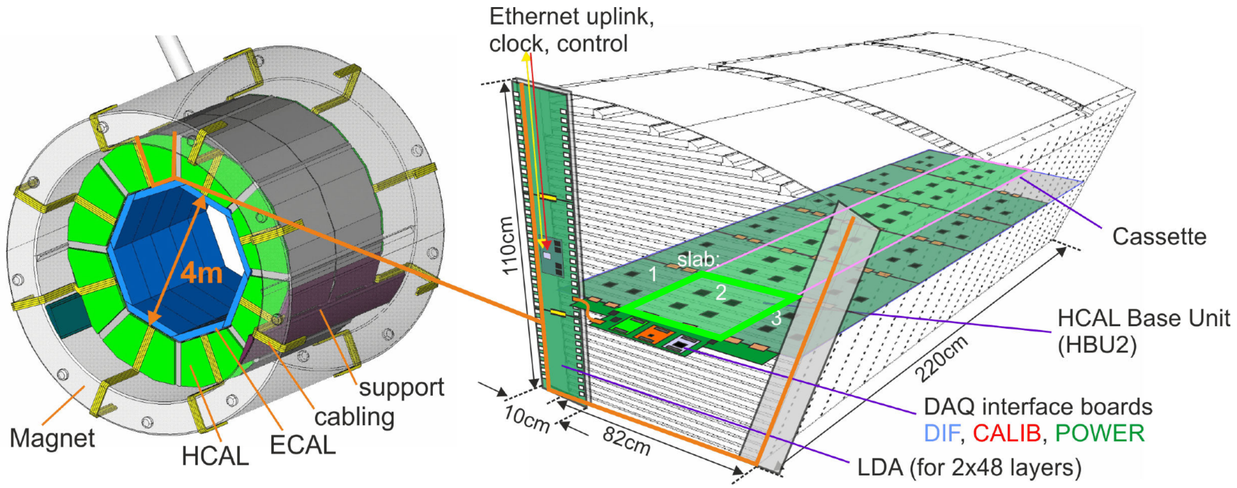
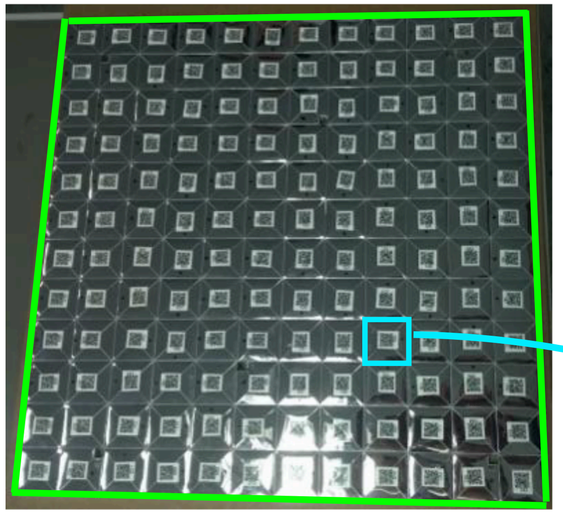
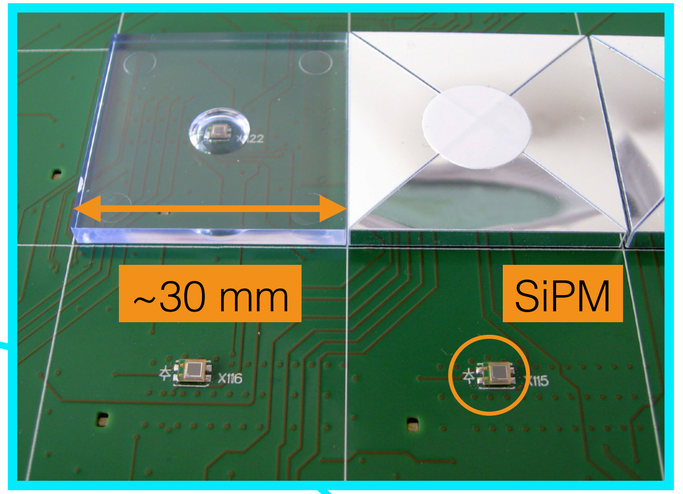
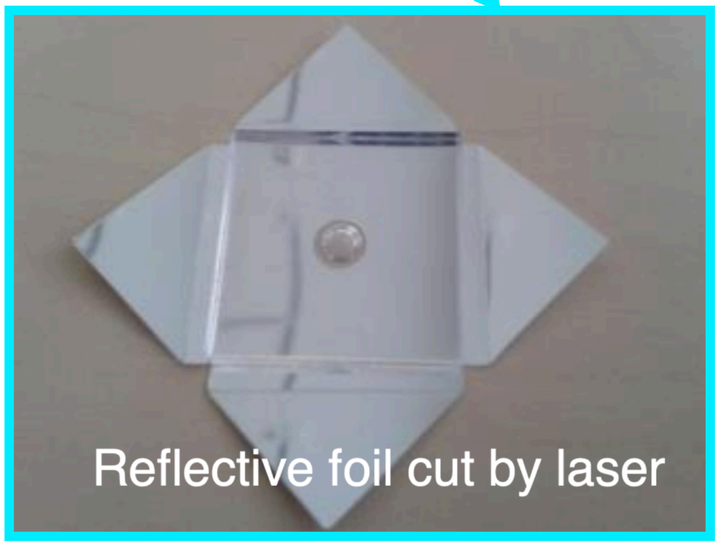




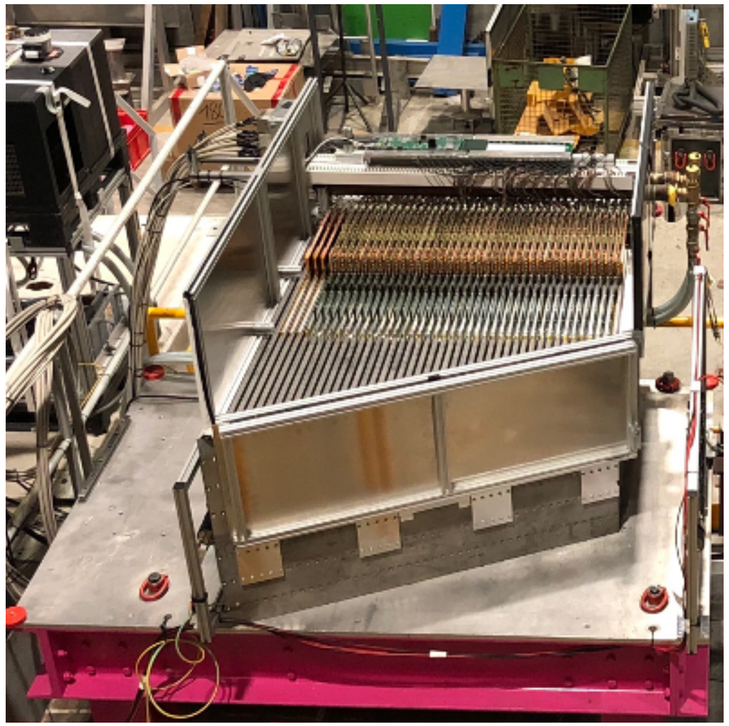


- 1 board = 36x36 cm^2 (144 channels)
  - Fully integrated (readout, power supply, calibration LED)
  - 4 readout chips (SPIROC-2), 36 channels each

- 1 channel =
  - 1 **SiPM** (Hamamatsu S13360-1325)
  - 1 **scintillator tile** (30 x 30 mm^2, 3 mm thick), polystyrene.
- Individually wrapped in reflective foil, and glued on PCB.



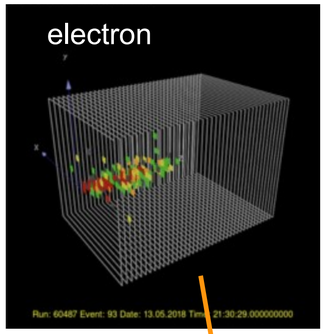
Technological prototype: 2018 TB @ SPS (CERN)

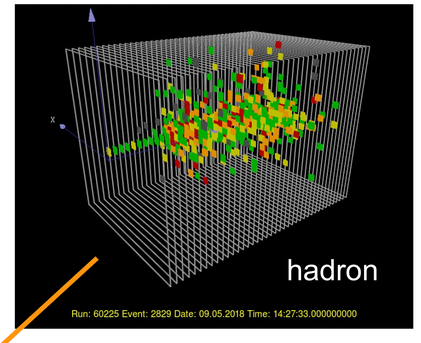


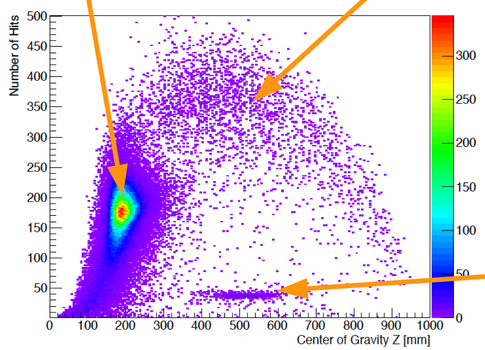
← Beam:

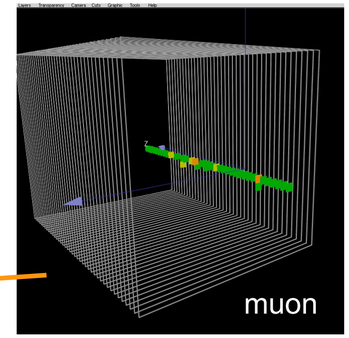
- Muons
- Electrons, 10-200 GeV
- Pions, 10-200 GeV

Total: ~100M events









- **Test-beams @ CERN SPS** in 2018:
  - 38 layers (72x72 cm^2: 4 boards each) with 1.7 cm steel absorber (4λ)
  - ~ 22’000 channels, < 1‰ dead channels
  - Very stable running, basically noise-free!

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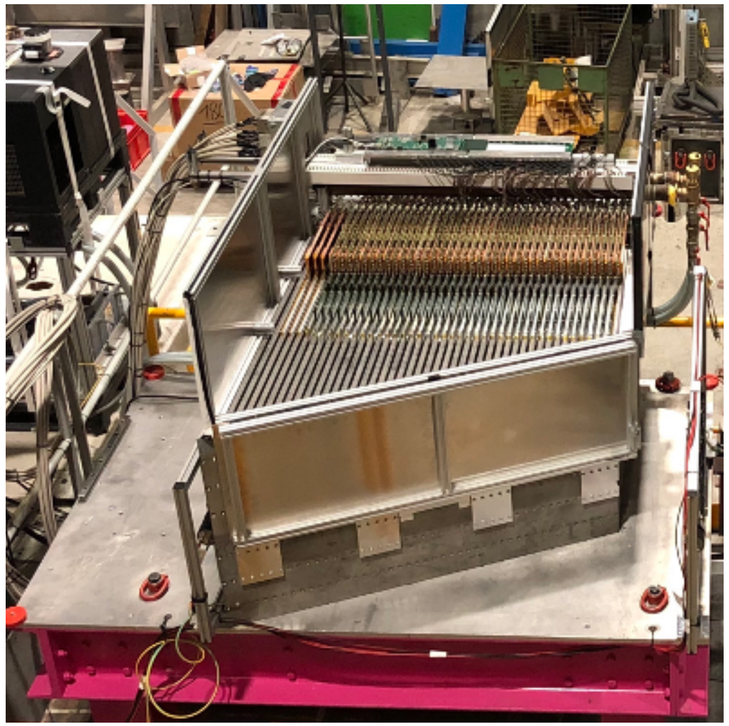

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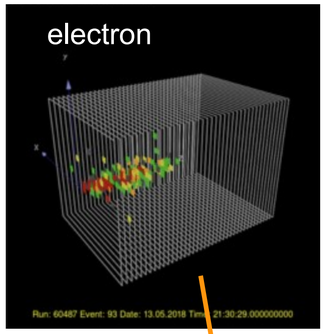

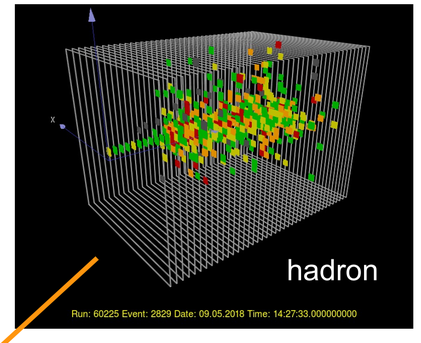

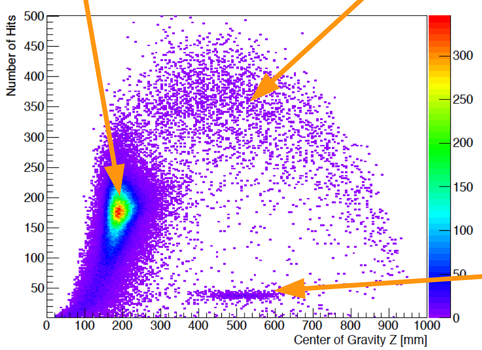

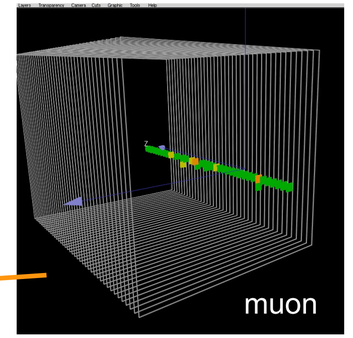

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  - 38 layers (72x72 cm^2: 4 boards each) with 1.7 cm steel absorber (4λ)
  - ~ 22'000 channels, < 1‰ dead channels
  - Very stable running, basically noise-free!
- Since then, **many more TB @ DESY** with smaller & more dedicated setups.

Megatile concept

Assembly of such large scale prototype demonstrated, but tedious. => How to improve?

- Build **one single** 36x36 cm^2 **tile**.
- **Cut trenches** and fill with **optical insulation**.
- Pour flowing **glue + TiO_2 mixture** → reflectivity.
- Optimal angle: 30°, minimise dead area.

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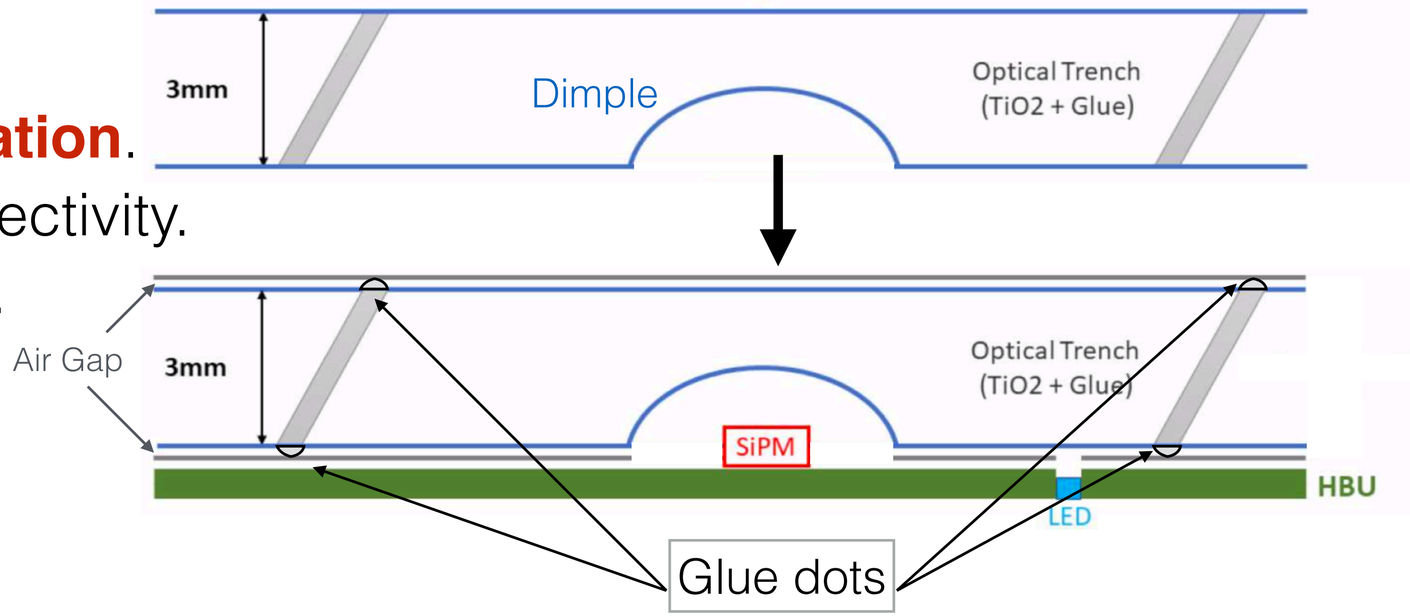

- **Air gap** (<100 µm) to ensure total reflection.

- <u>No change to SiPM:</u>
  - Same electronics boards.
  - Same readout.

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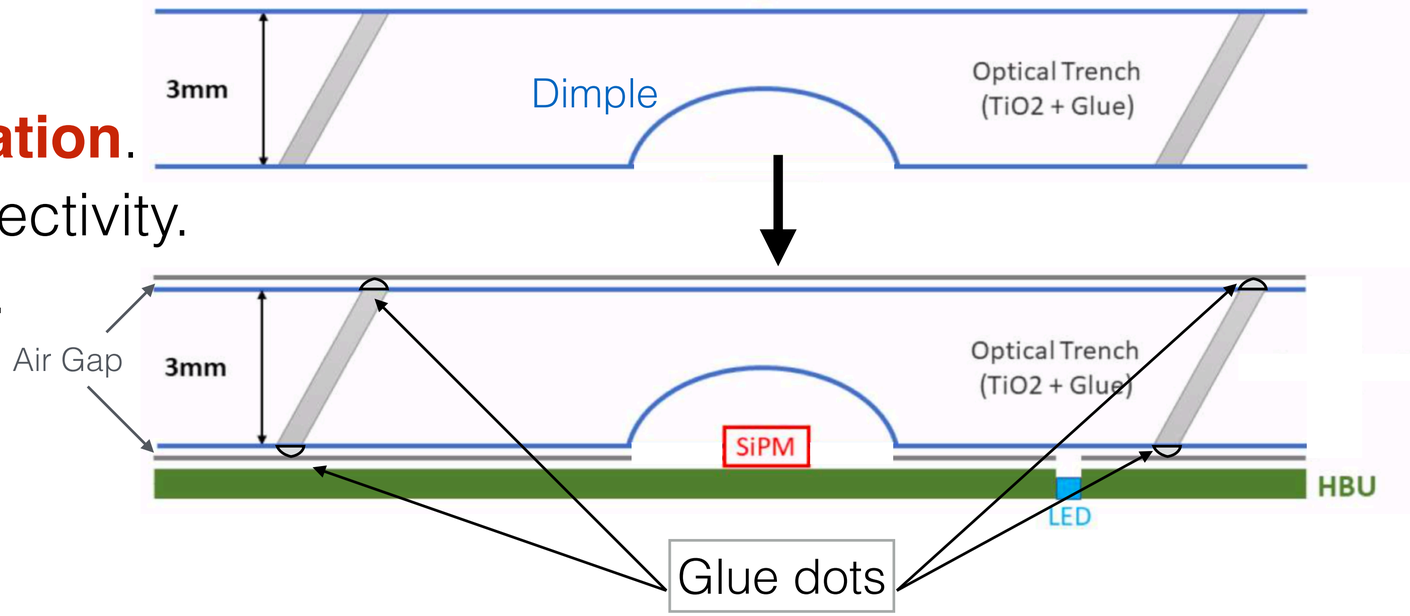

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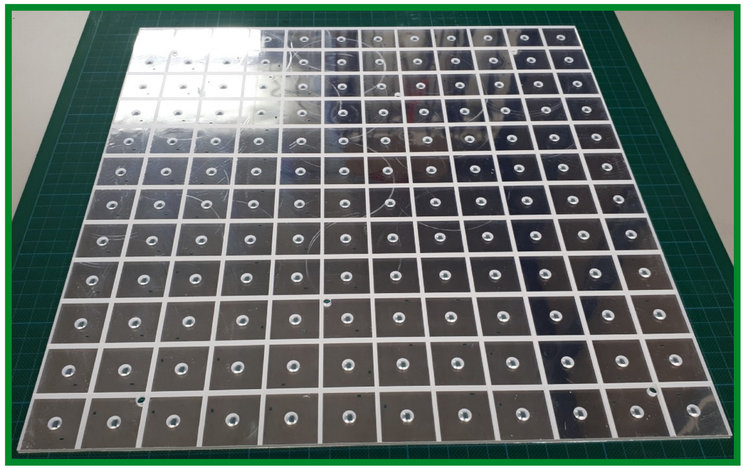
In real life:



- 👍 ~ **No dead area**!
- 👍 **Easier assembly**.

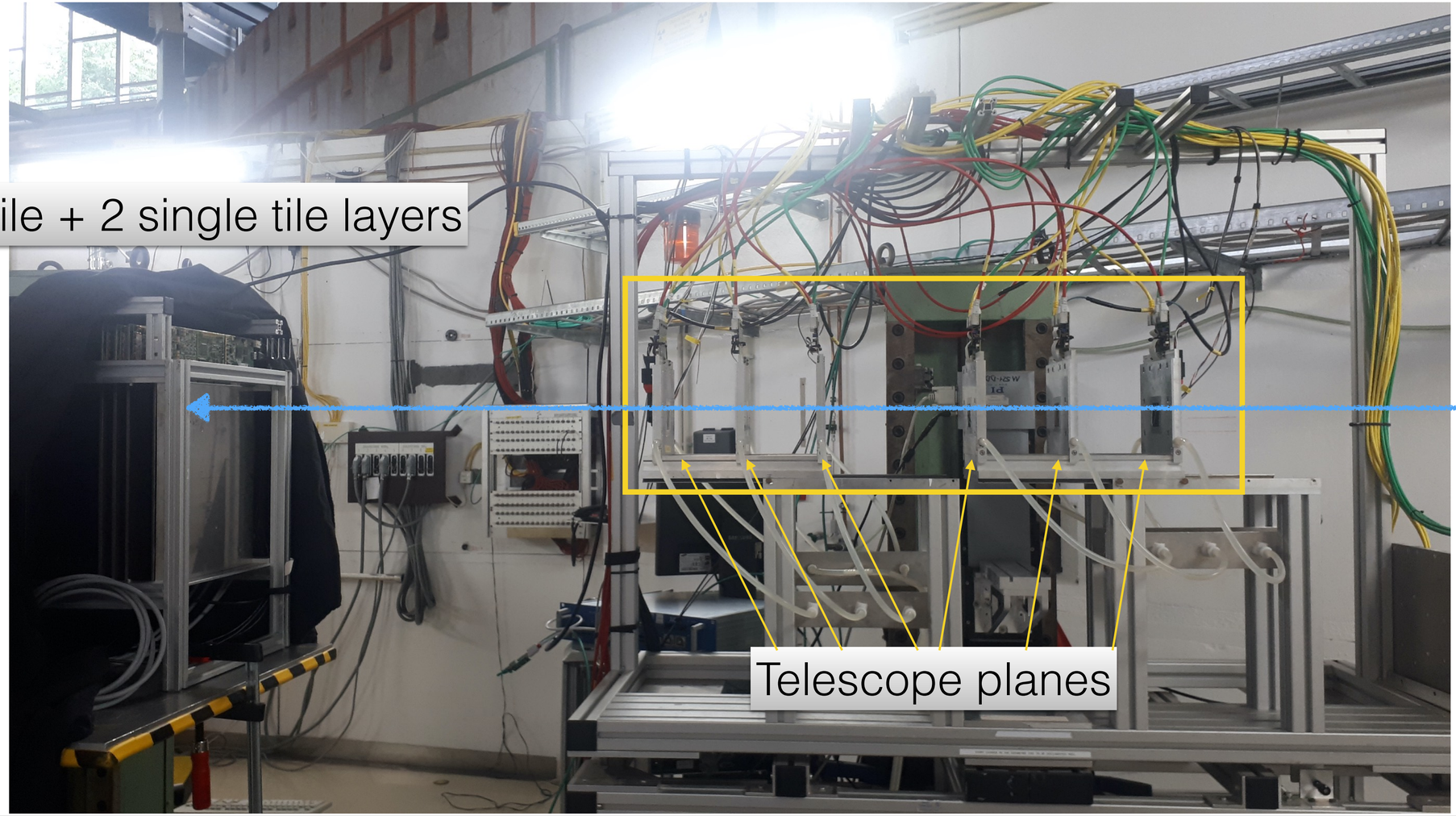
Disclaimer:

Focus here on 2021/2022 beams.

See BTTB 2021 talk for previous results.

No dead area!

- Using the beam telescope in DESY test beam to pin-point particle trajectories:
- Precise positioning of particles => **very fine scan of the transition between two channels**.



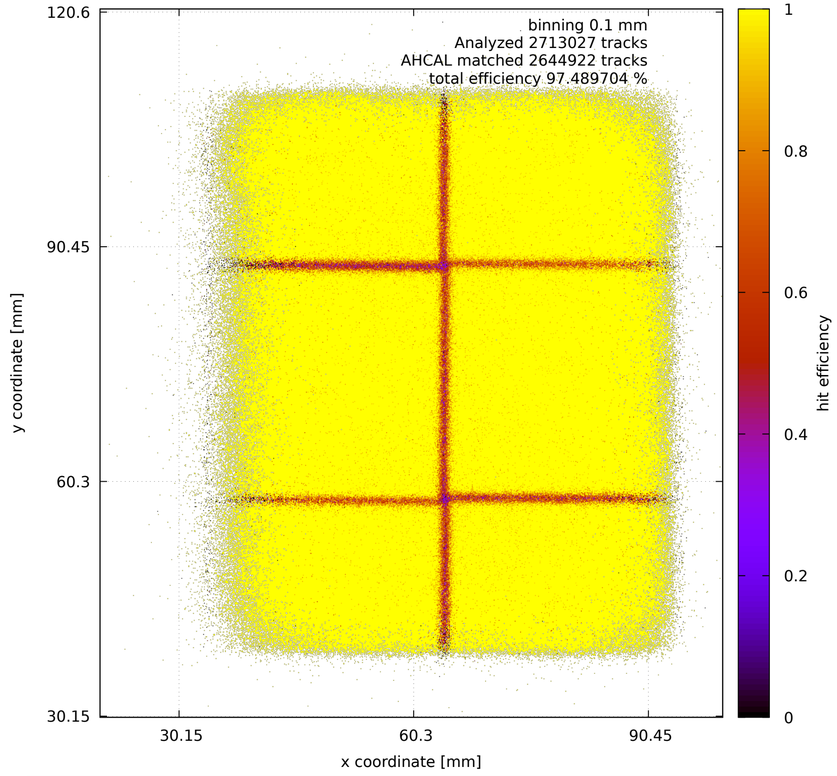
September 2021

No dead area!

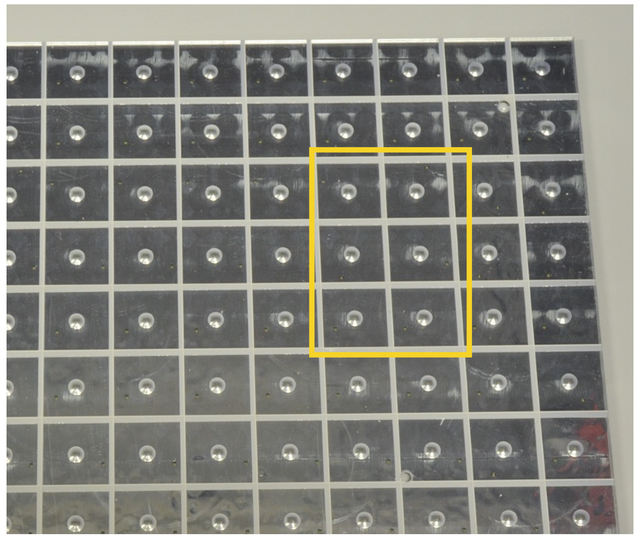
- Using the ALPIDE telescope (+ AIDA TLU) in DESY test beam to pin-point particle trajectories:
- Precise positioning of particles => **very fine scan of the transition between two channels**.
- **Hit efficiency map**: given a track in the telescope, was it detected in the tile layer?

Individual tile layer:

100% inside, **50% between tiles**

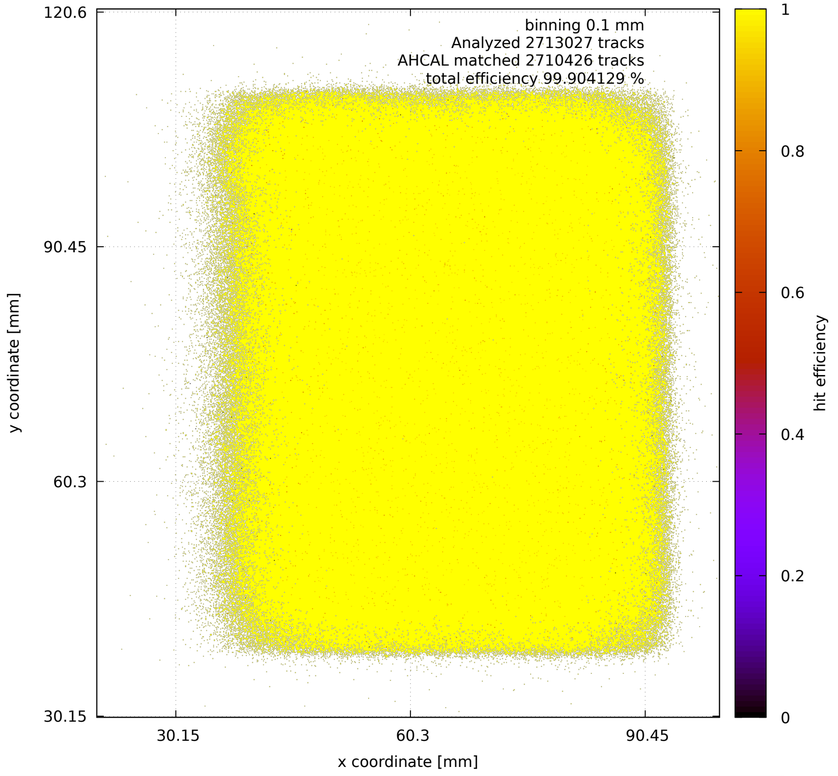


Scanned area



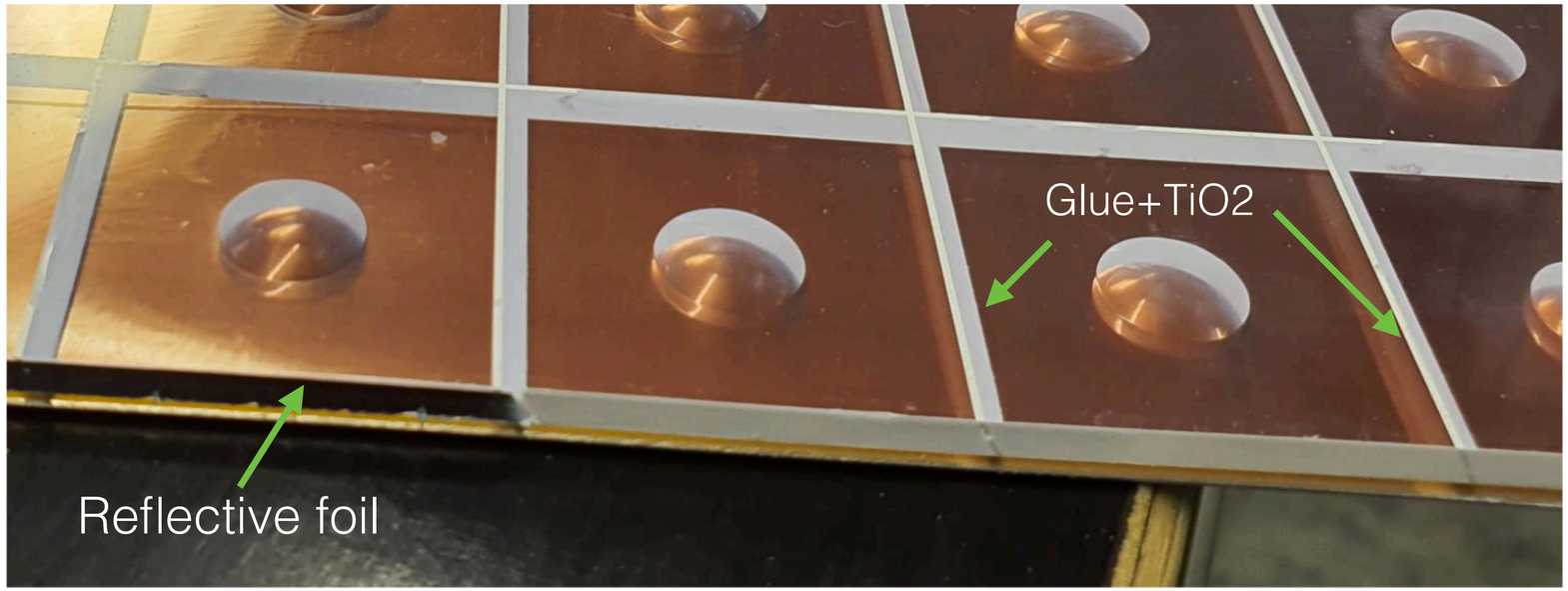
Megatile layer:

100% everywhere.



Megatile's last challenge: edge coating

- **High and uniform light-yield**, except for the edge channels (~30–50% lower).
- **Reason: coating of edge channels is difficult**.
  - Baseline solution: stick an auto-adhesive reflective foil, but limited improvement.



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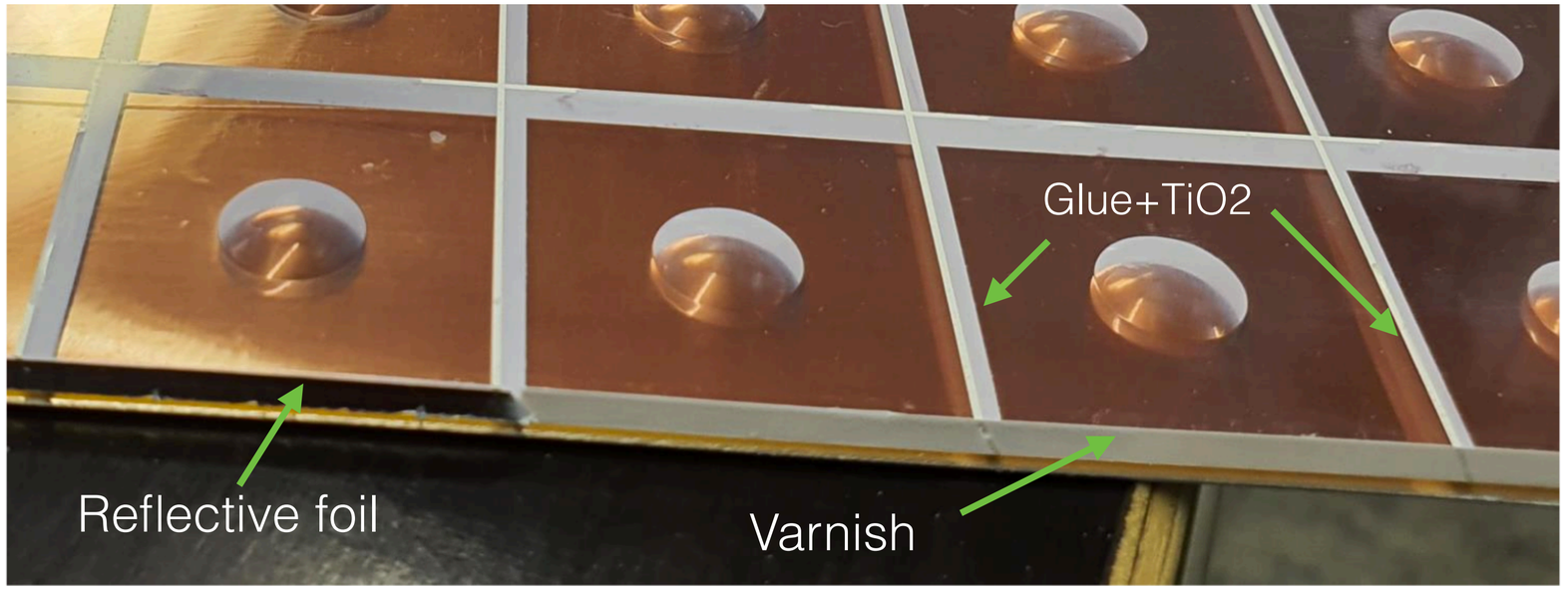
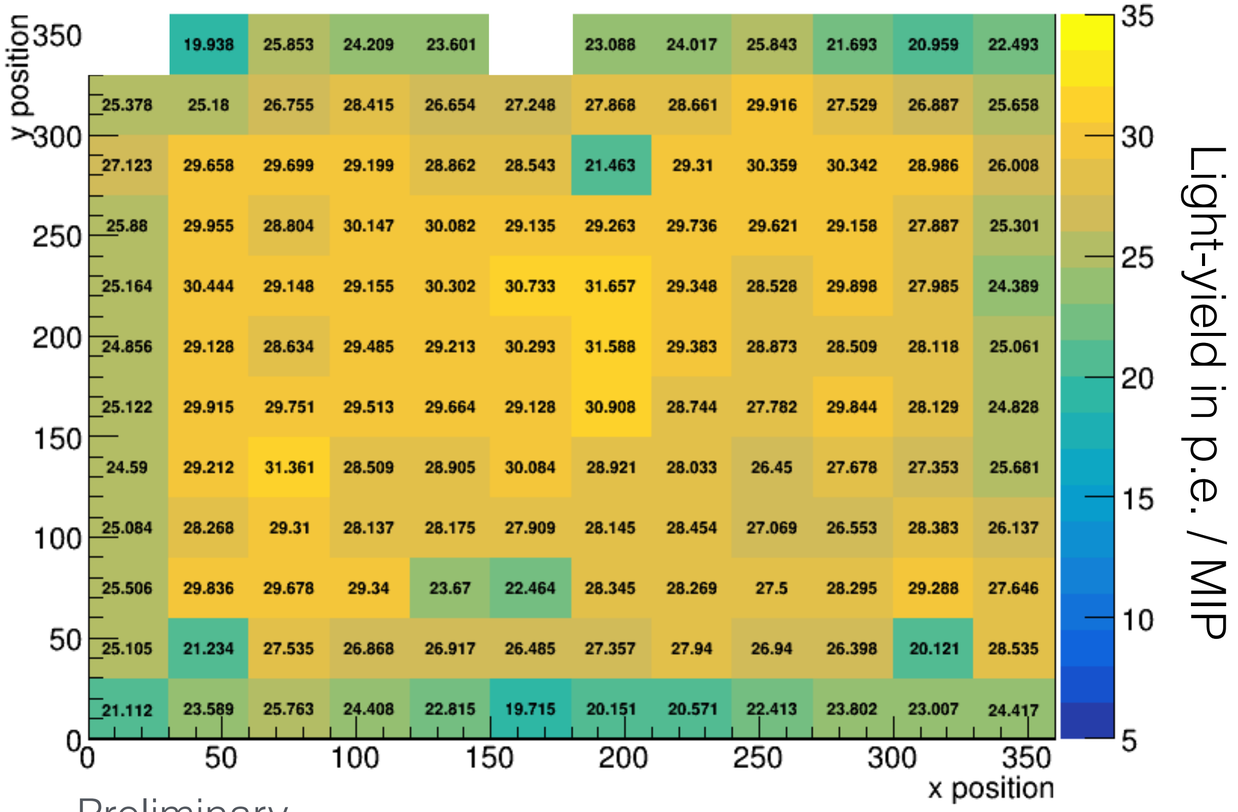
- **High and uniform light-yield**, except for the edge channels (~30–50% lower).
- **Reason: coating of edge channels is difficult**.
  - Baseline solution: stick an auto-adhesive reflective foil, but limited improvement.
  - **Improved solution: spray a white varnish**.
    - **Up to perfect light-yield performance recovery**, yet with large efficiency variation. **Encouraging**!
    - **Under final developments**.



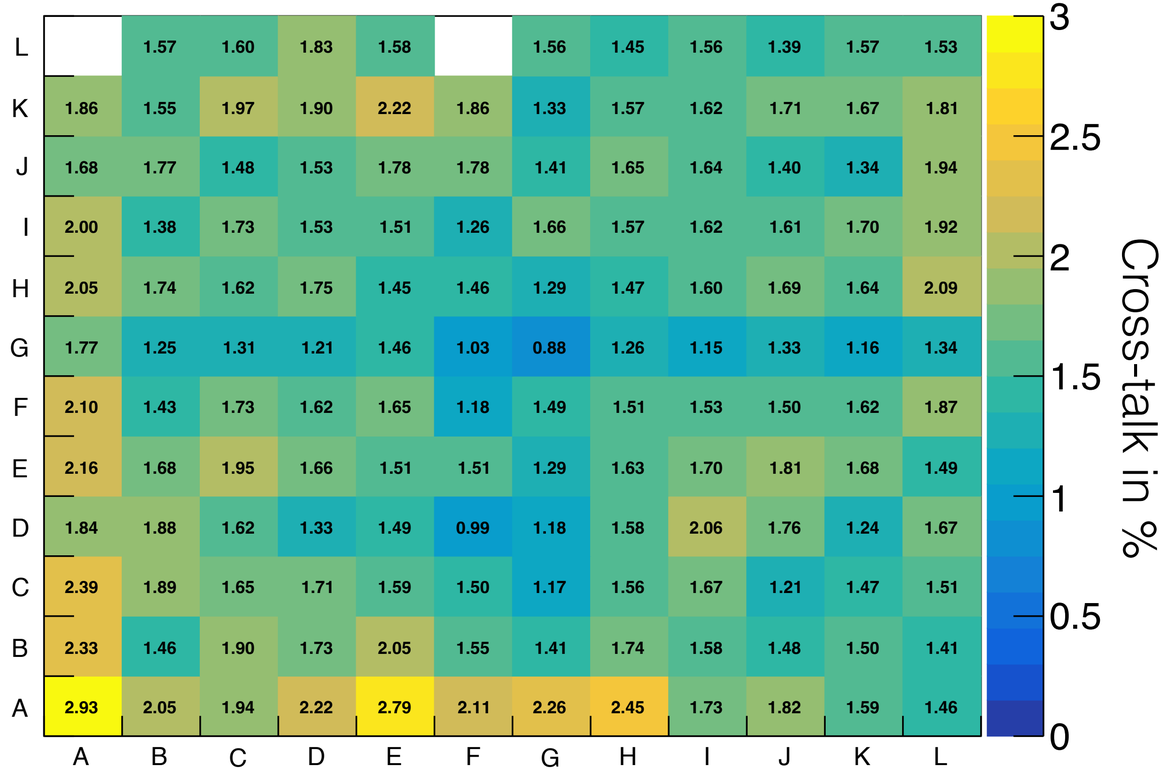
Megatile performance

High and uniform light-yield:
~30 p.e. / MIP



Preliminary

Low cross-talk, under control:
~1.5 %



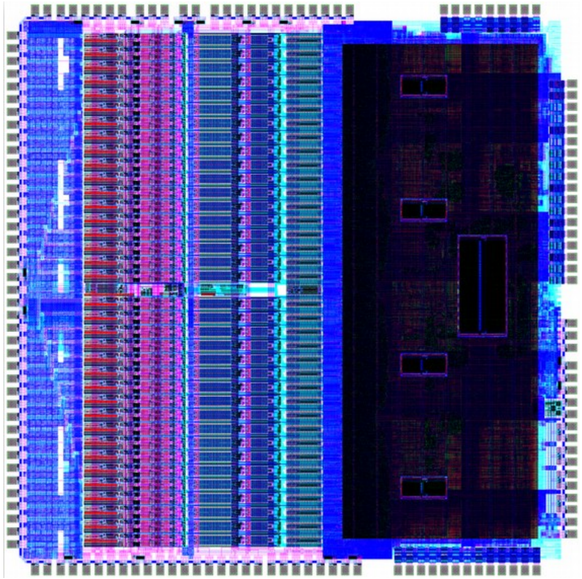
Preliminary

KLauS ASIC

- Active development of new ASIC (Uni Heidelberg).
  - Version 6 currently under test.
  - Target **100 ps time resolution**,
  - **Power pulsing**, low power
  - **2 gain paths**,
  - Spill mode for acquisition

  } Same as baseline ASIC

  - **Optimised for low gain SiPMs**.



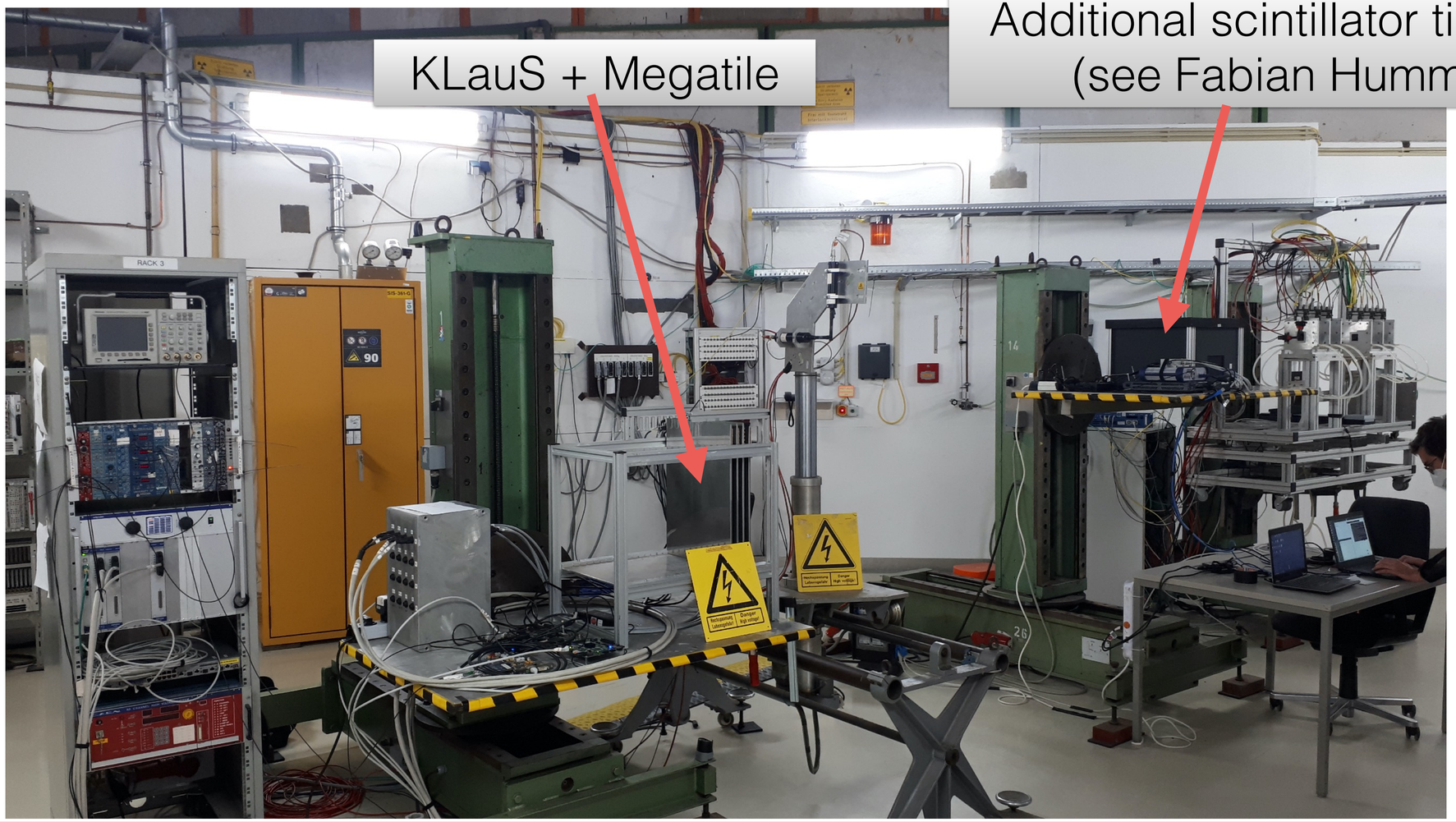
KLauS6 (5x5 mm²)

- More versatile design than SPIROC2.
  → Enable continuous data-taking.

- **One KLauS-5 full-size HBU (144 channels) is available => combined test**!

DESY, October 2021

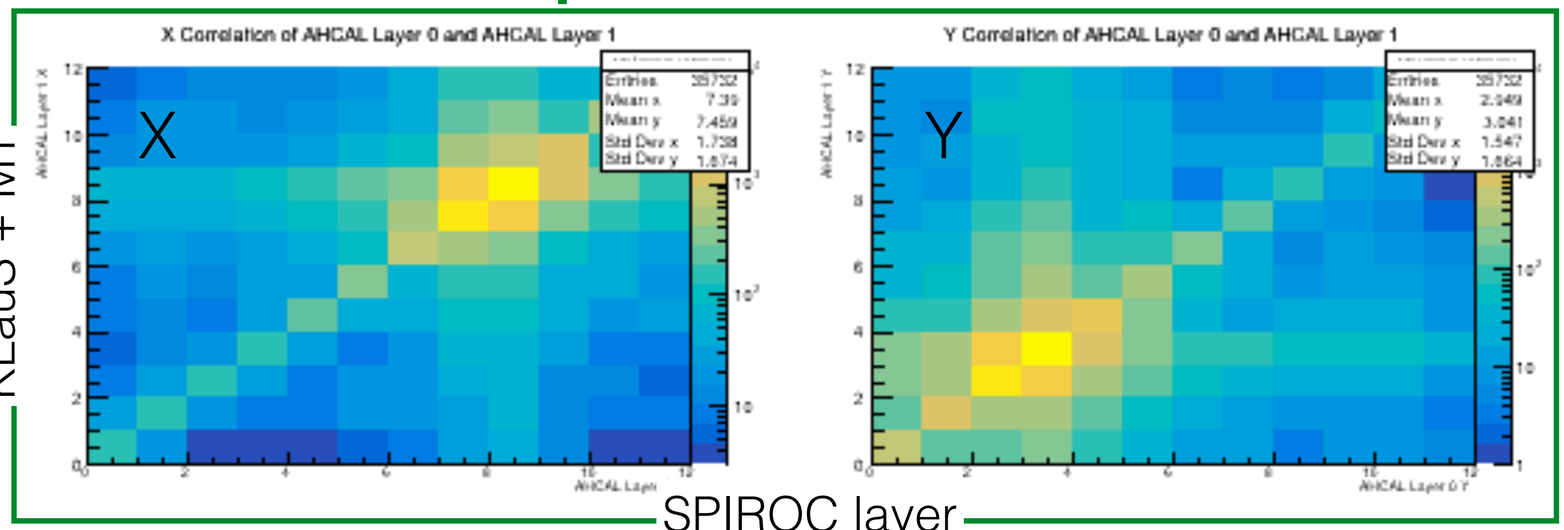
- **Combined KLauS + Megatile & SPIROC layers** test beam.
- **Main goal: synchronisation between SPIROC and KLauS**.

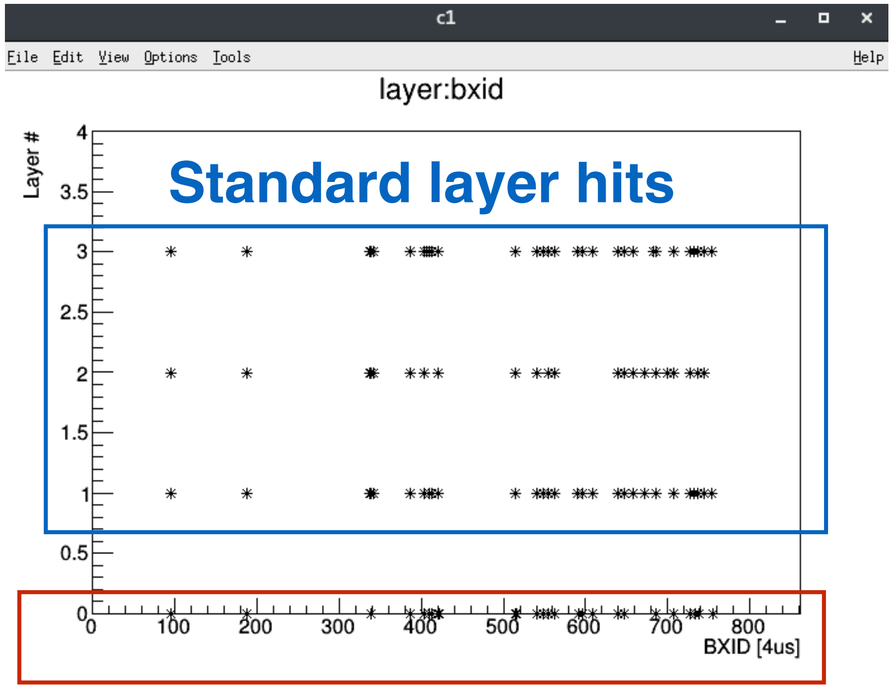


Setup and testbeam plan

- **Combined KLauS + Megatile & standard layers** test beam.
- **Main goal: synchronisation between SPIROC and KLauS layers**.

Spatial correlations





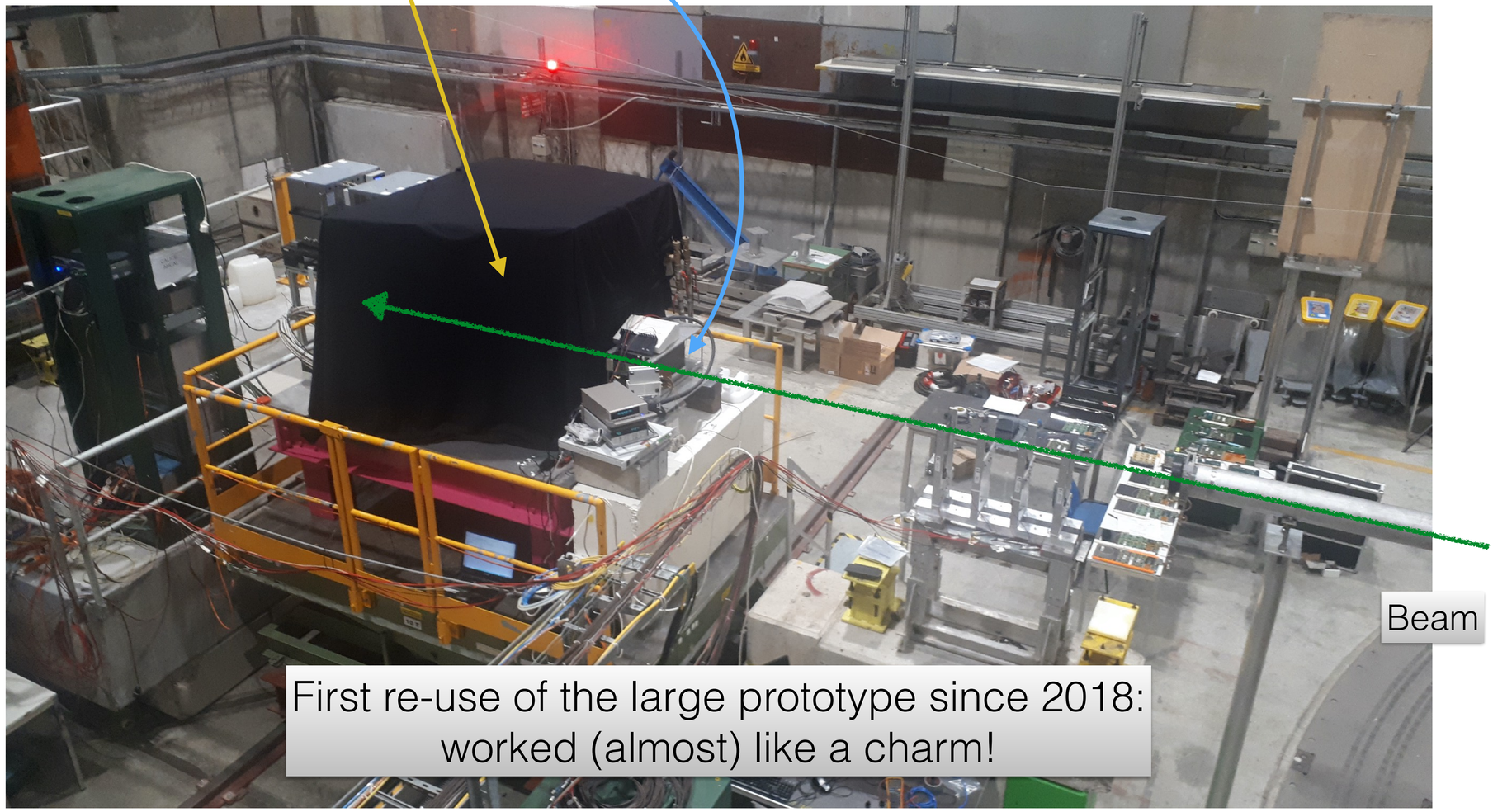
KLauS hit correlated!

Good space and time correlations observed!

Very latest results

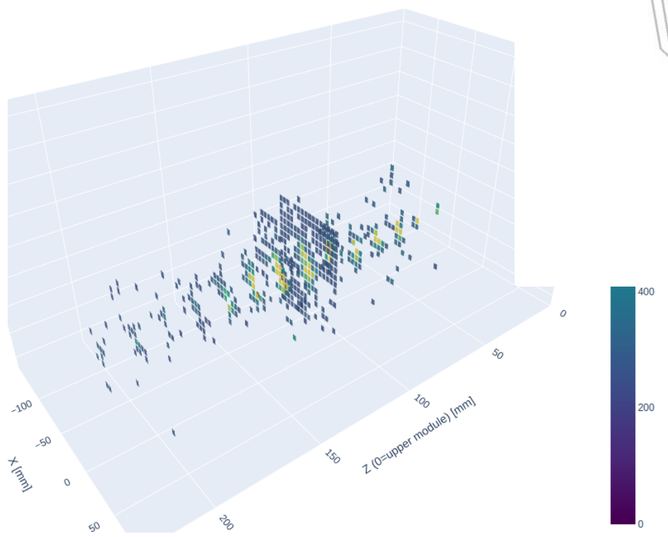
Test beam at CERN-SPS 08-22/06 (last week!).
Combined AHCAL + SiW-ECAL

- Combined DAQ
  - Using EUDAQ-2.
- **Efficient data taking** with beams of
  - Muons 150 GeV
  - Electrons 10-150 GeV
  - Pions 20-200 GeV
- Suffered from **issue on extraction line for several days**, but **physics program mostly completed**!

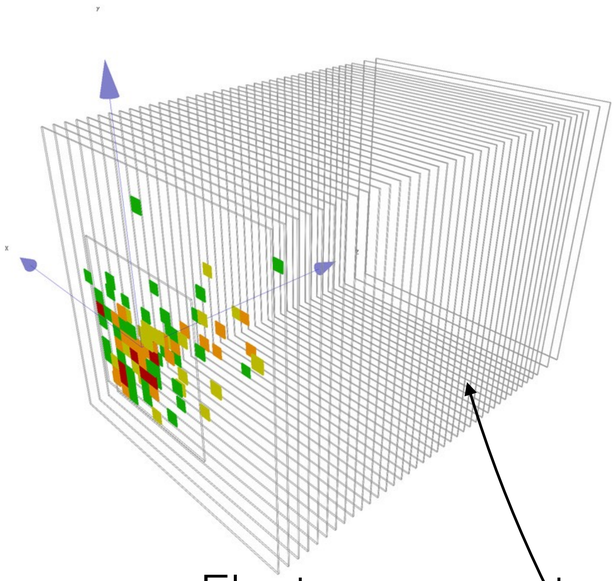


First re-use of the large prototype since 2018: worked (almost) like a charm!

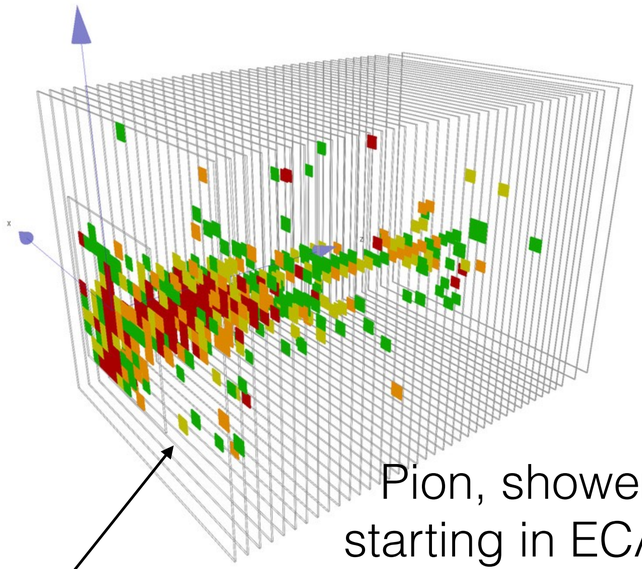
O(10 M) events collected



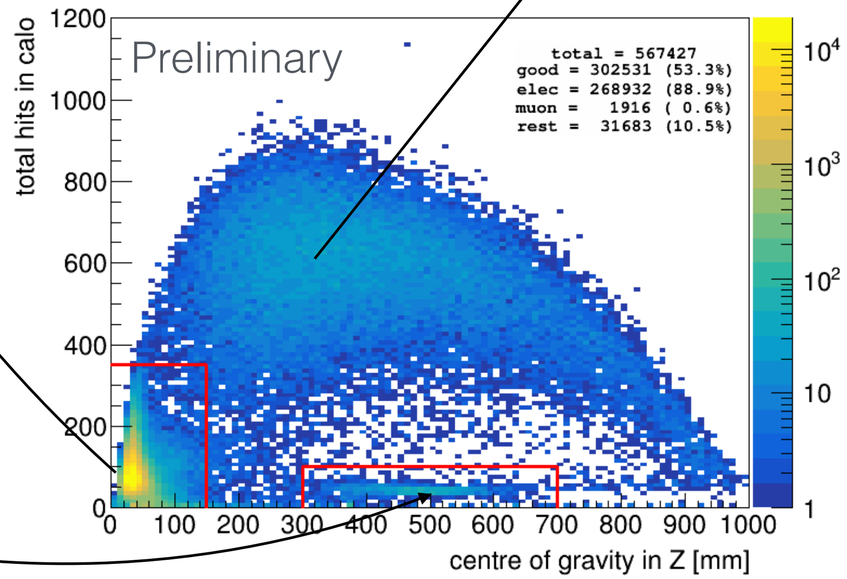
Electron in ECAL



Electron remnant in AHCAL



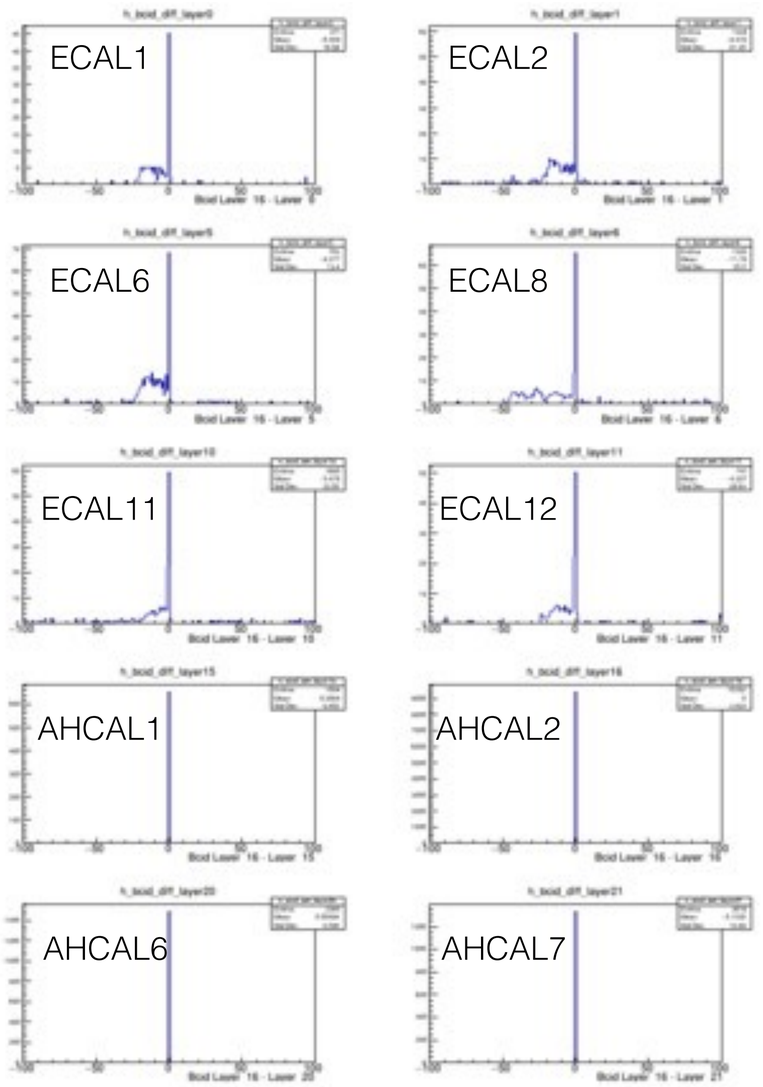
Pion, shower starting in ECAL



Muon

Synchronisation between AHCAL & ECAL

- **Time correlation between AHCAL and ECAL achieved**!



Difference of BCID between AHCAL or ECAL layers and reference time for each event, (example for a few ECAL layers).

Summary and future

- **Long journey since the 2018 test beam of the 22'000 channel prototype**!
  - **Development of the Megatile to improve scalability** of assembly while maintaining high performances.
  - **Development of the more versatile KLauS chip**.

- **Many smaller-scale test beams at DESY**. In 2021: 2 successful test beams!
  - Confirmed **Megatile design has no dead area**.
  - Confirmed **Megatile cross-talk in under control**.

  } Megatile is a great design for the future!

  - First KLauS + SPIROC chips combined running, first KLauS + Megatile coupling! **Successful**!

- **In 2022, test beam at CERN**: just finished!
  - **First hadron beam** (and high-energy electrons) for the **Megatile**.
  - First AHCAL + ECAL combined runs in beam!!! **Very successful**!

} Many analyses to be done!

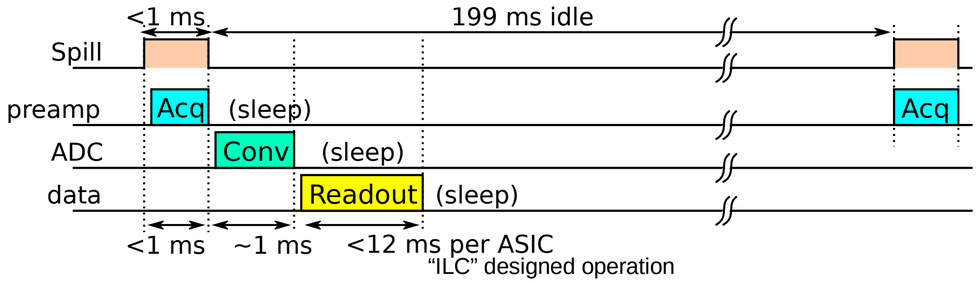
- Short term wishes:
  - KLauS-6 full size HBU with Megatile.
  - Side-by-side negatives to study transition region.
  - More beam at CERN for standalone AHCAL.

Thank you for your attention!

BACKUP

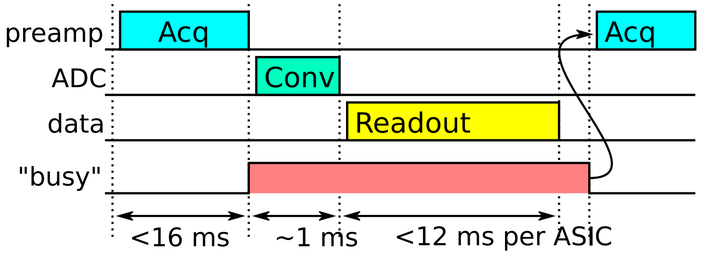
AHCAL prototype operation (intro)

- Designed for **very low duty cycle** of ILC machine
  - <1 ms spill followed by 199 ms idle
  - Bunch Crossing (collisions) within acquisition every few hundreds of ns
  - Separate power for Acquisition, Conversion and Readout stages
    → significant reduction of power & **heat dissipation**
- The SPIROC ASIC has 16-events deep **analogue memory cells**,
  - store the signal amplitude (High & Low gain) + TDC value for all channels
  - 1728 capacitors!
  - Converted after acquisition



"ILC" designed operation

- Hits are **self-triggered** (discrimination typically at the level of several single-photo-electrons) → Hits are **not** triggered externally
  - Event *validation (*everything not validated is rejected*)* is possible order to reduce the noise occupancy
    → not needed and not used since 2018 due to **very low-noise SiPMs** (typical 0.1-0.2 Hz / Tile, incl. cosmics)
- ILC timing is **inefficient** with CERN/DESY Beams → need some tricks for TB
  - Acquisition phase is prolonged to 16 ms
  - Acquisition phase is stopped earlier if any asic fills its all memory cells (propagation via "busy" signal)
  - Wait until all modules are done with readout, then restart immediately

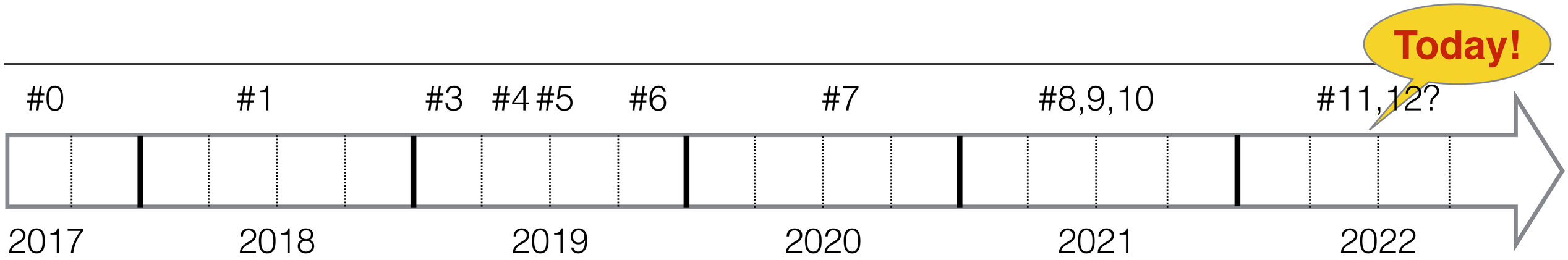


Testbeam operation

- Acquisition rate strongly depends on particle type, hit occupancy and beam rate
  - Typical achieved data taking rate in TB mode is **hundreds evt/s** (100-800 evt/s)
  - Maximum acquisition duty cycle in TB mode: **90%** (cosmics)
- Effort put into **combined data-taking** and hardware/software synchronisation with other detectors
  - Calice ECAL, Mimosa Telescope, eudet-TLU, AIDA-TLU, CMS-HGCAL, mini-TLU
  - Intrinsically, events are addressed by an Acquisition cycle & BXID
    → External timestamping and trigger counting implemented in the DAQ concentrator card ("LDA")

The Megatile experience

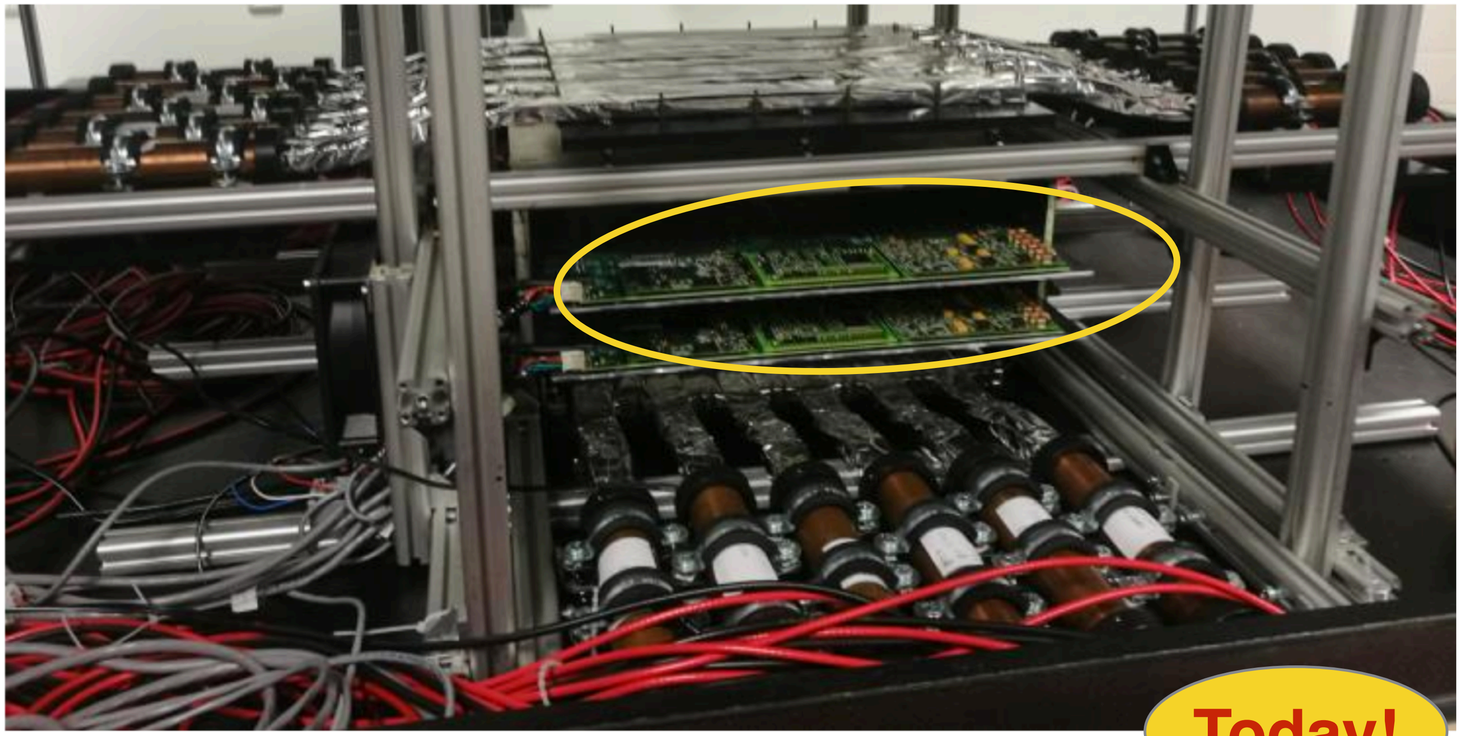
- **Project started in 2017**.
- **Already 10 prototypes built** with **continuous improvement**.



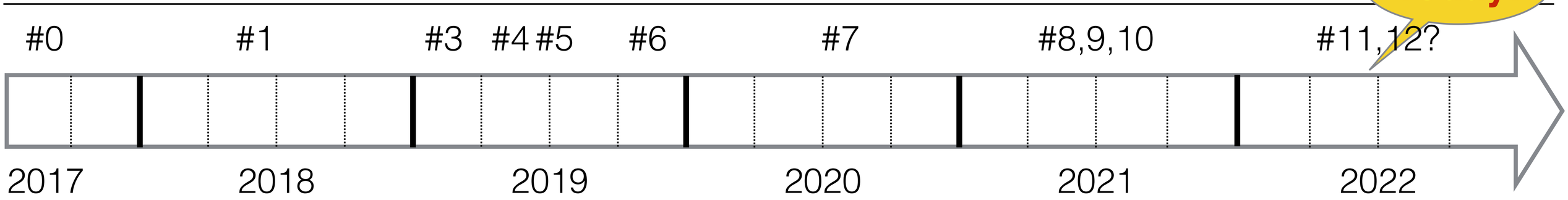
The Megatile experience

Cosmic test stand @ Mainz detector lab

- **Project started in 2017**.
- **Already 10 prototypes built** with **continuous improvement**.



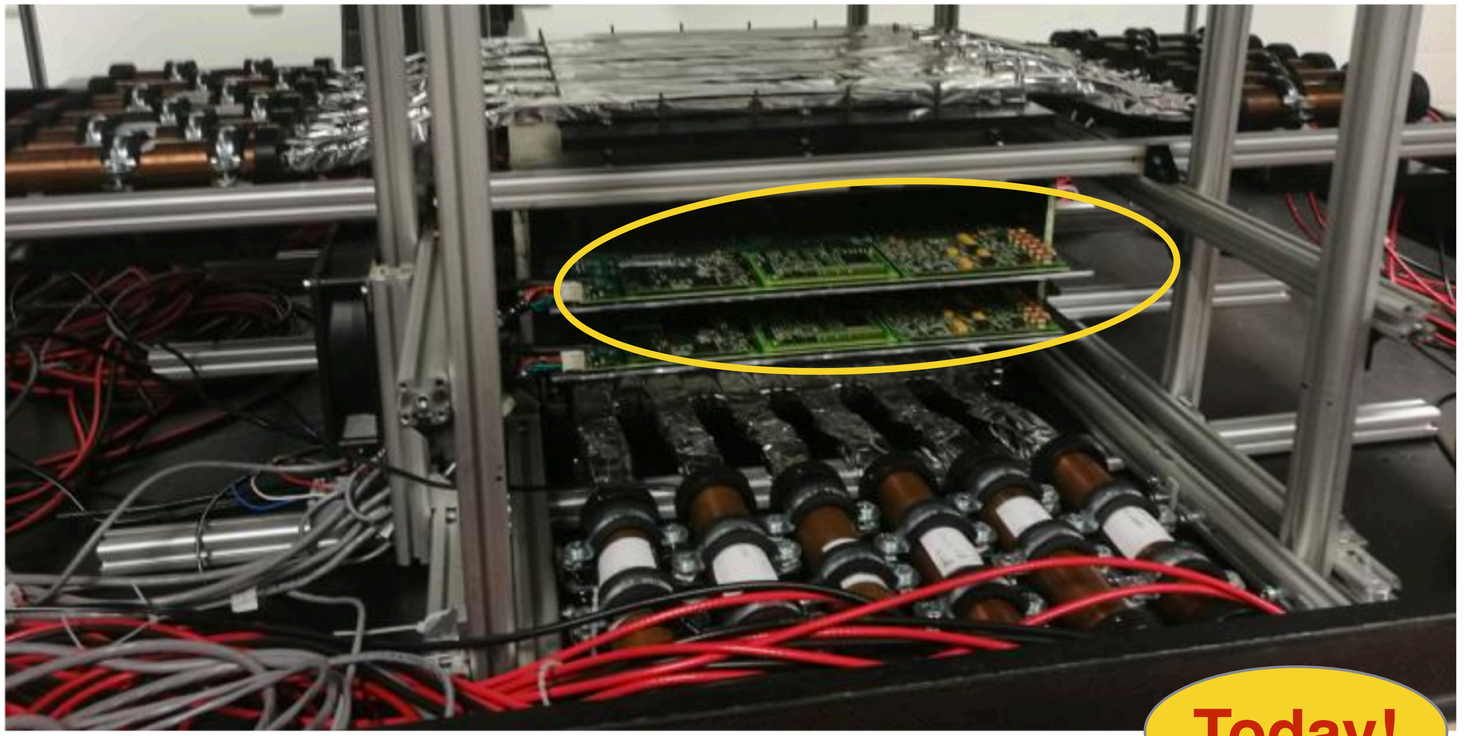
- **Continuously tested** in **cosmic test stand @ Mainz**.



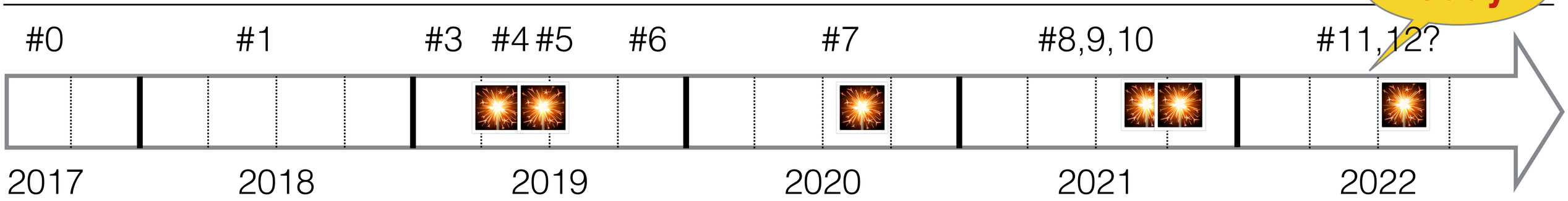
The Megatile experience

Cosmic test stand @ Mainz detector lab

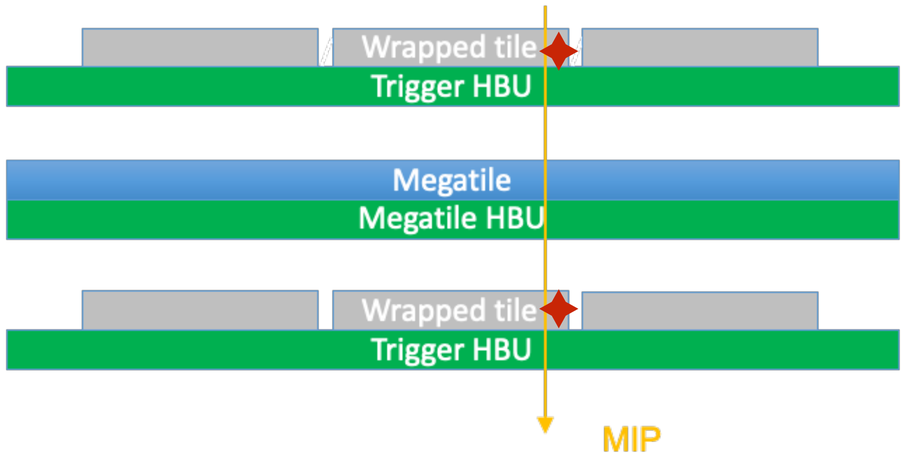
- **Project started in 2017**.
- **Already 10 prototypes built** with **continuous improvement**.



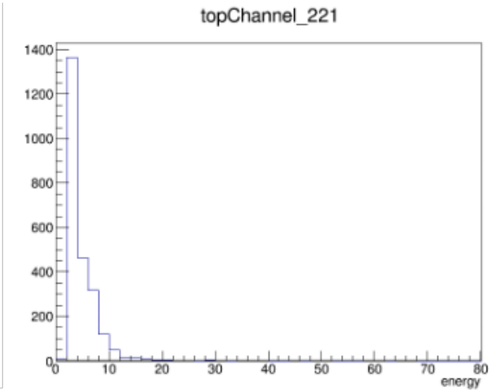
- **Continuously tested** in **cosmic test stand @ Mainz**.
- Already **5 test beams** @ **DESY II**

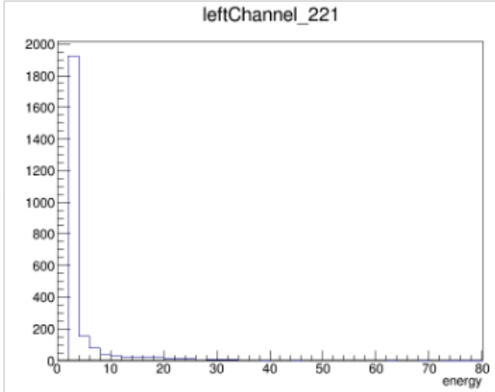


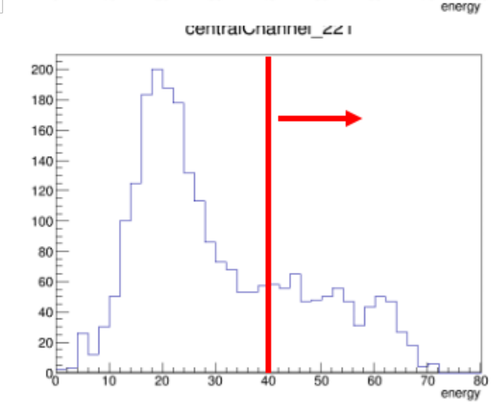
Megatile: cross-talk analysis

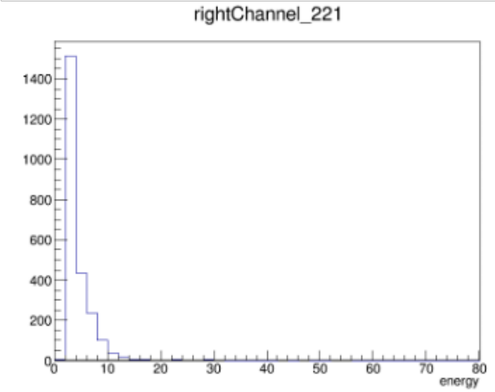


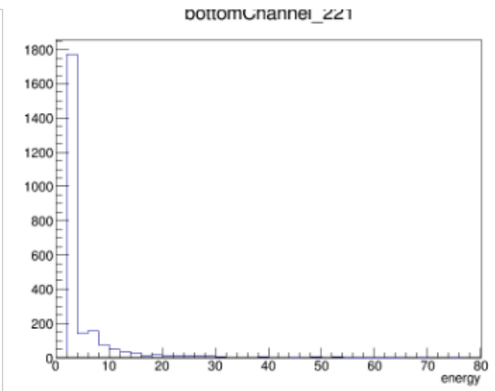
1. Central tile defined as Megatile channel aligned with two single tile channels in coincidence.











2. Cut on central tile p.e. (select only high energy events).

3. XT < [pe in neighbour] / [pe in central]

Megatile: cross-talk analysis

Cuts:

- Exactly 1 hit in each single tile layer.
- Hit energy in single tile layer > 0.7 mip.
- Energy in neighbour < 0.7 mip.
- Energy in central > 0.5 mip.