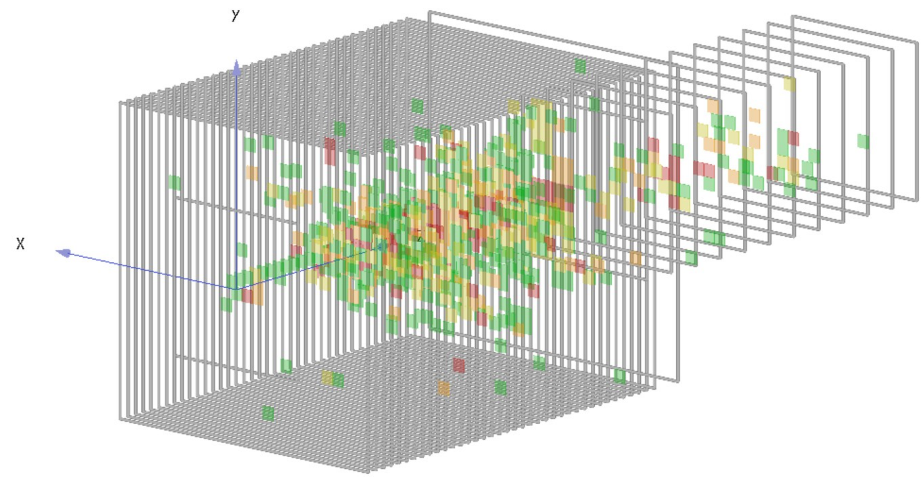
Status of AHCAL R&D work

AHCAL technological prototype

- Design
- Construction
- Data Taking
- Calibration, Stability and Analysis
- Further Developments

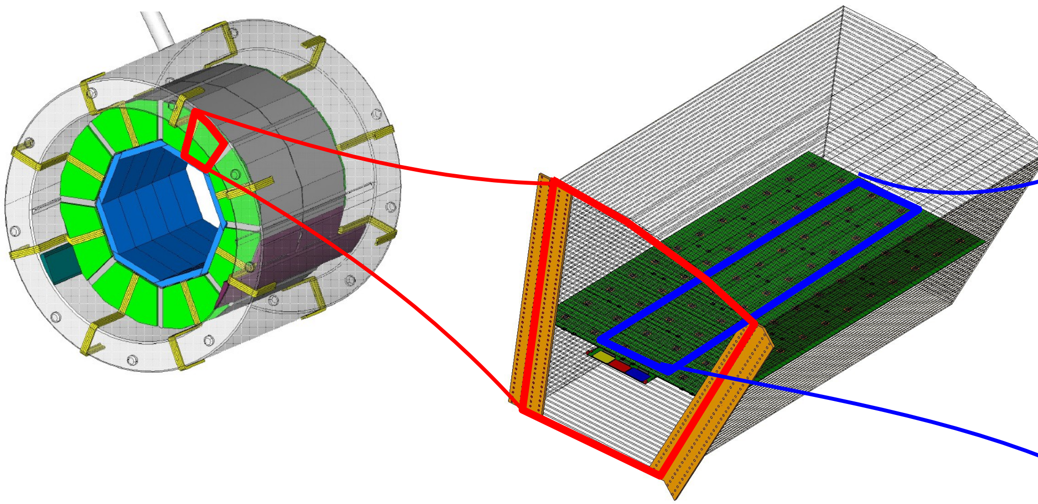


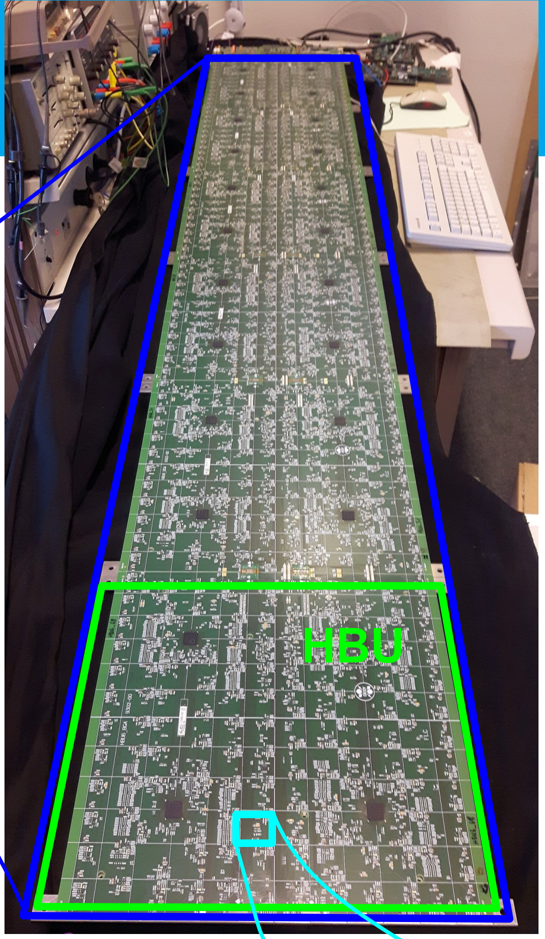
Katja Krüger, on behalf of the CALICE AHCAL groups

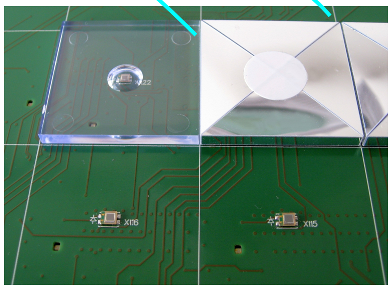
ILD Group Meeting
9. February 2021

HELMHOLTZ ASSOCIATION

AHCAL technological prototype: design



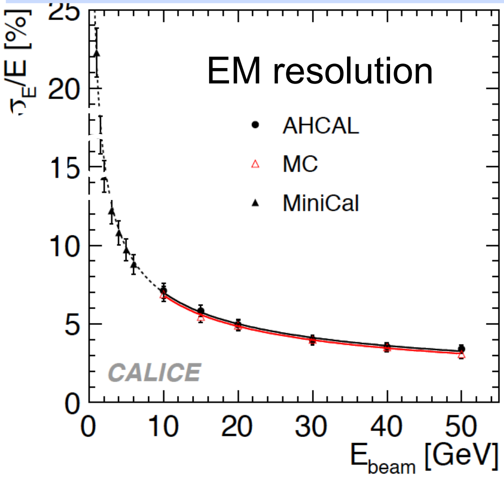




- highly granular scintillator SiPM-on-tile hadron calorimeter, 3*3 cm² scintillator tiles optimised for uniformity
- fully integrated design
  - front-end electronics, readout
  - voltage supply, LED system for calibration
  - no cooling within active layers
  - electronics adapted to ILC beam structure -> power pulsing
- scalable to full detector (~8 million channels)
- geometry inspired by ILD, similar to SiD and CLICdp
- **H**CAL **B**ase **U**nit: 36*36 cm^2, 144 tiles, 4 SPIROC2E ASICs
  - slabs of 6 HBUs, up to 3 slabs per layer

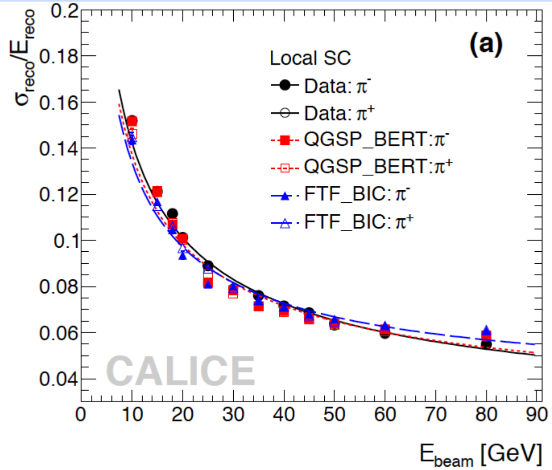
Reminder: AHCAL physics prototype results

Detector validation



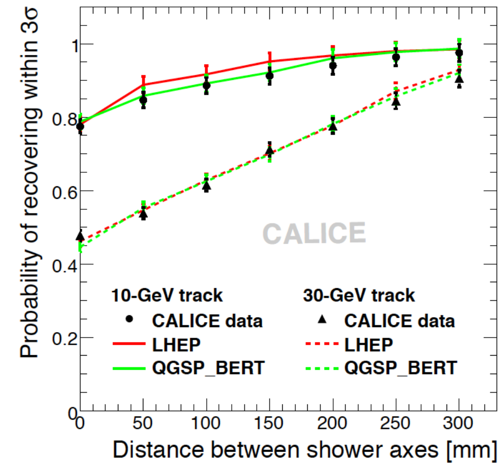
JINST 6, P04003 (2011)

Performance validation



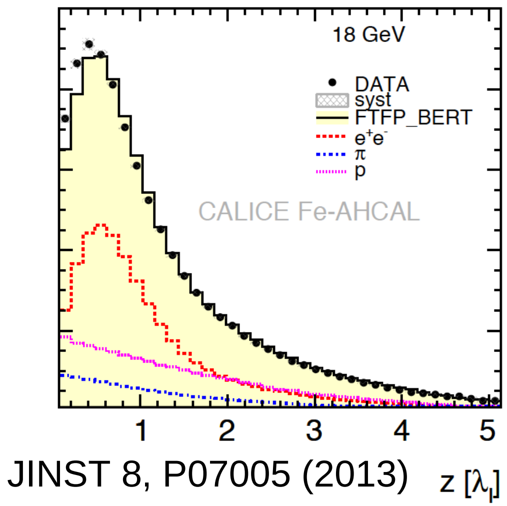
JINST 7, P00917 (2012)

Particle Flow validation



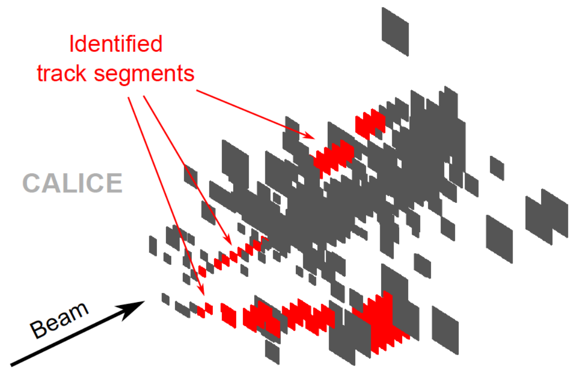
JINST 6, P07005 (2011)

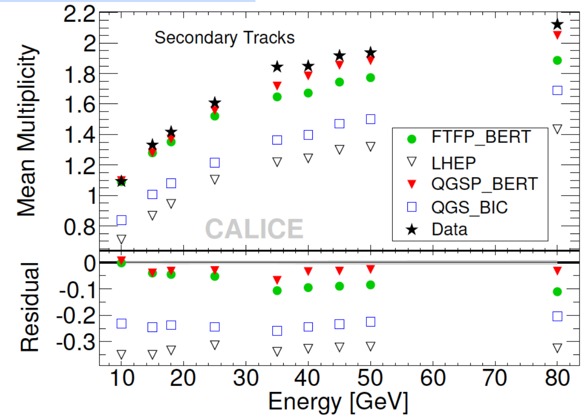
Geant 4 validation



JINST 8, P07005 (2013)

Imaging validation



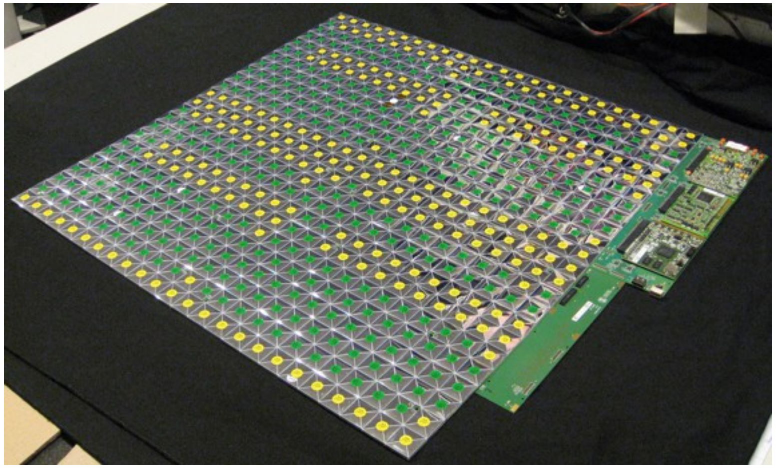


JINST 8, P09001 (2013)

Construction

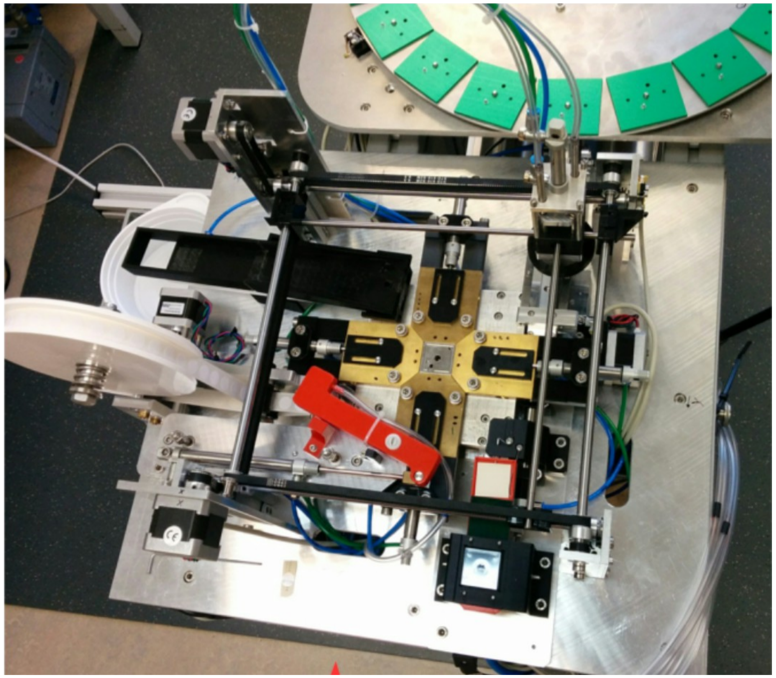
AHCAL technological testbeam prototype

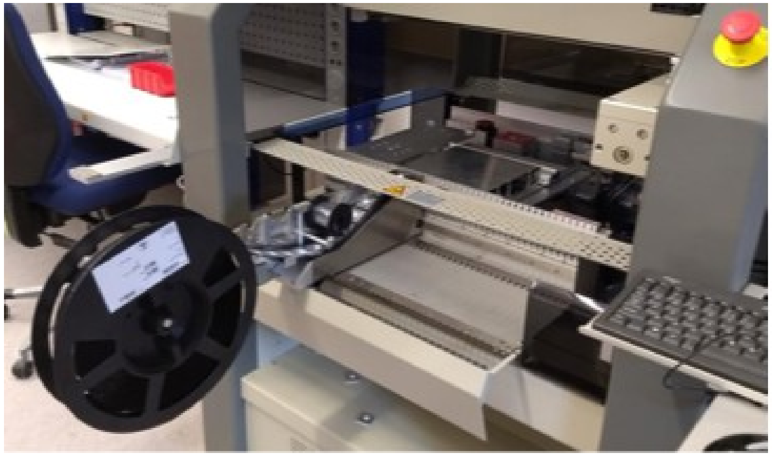
- 38 active layers of 72*72 cm²
- 4 HBUs per module
  - 16 ASICs, 576 channels of 3*3 cm² tiles
  - in total: 608 ASICs, ~22000 channels
- all modules with surface-mount MPPCs
  - S13360-1325PE
  - 2668 pixels
  - operated at 5V overvoltage
  - nominal operation voltage within 200mV in a module -> use same voltage
- all modules are interchangeable
- additionally in June and October: "Tokyo module" with 6*6 cm² tiles
- construction October 2017 – April 2018



Mass production

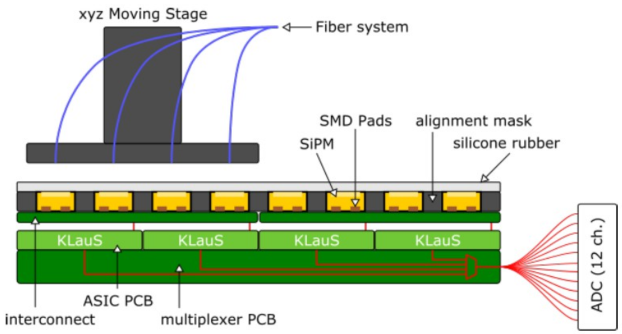
> design optimized for mass production
  - SMD SiPMs soldered automatically
  - injection-moulded polystyrene tiles, no further surface treatment
  - automatic wrapping in ESR reflector foil
  - glueing of tiles with screen printer and pick-and-place machine

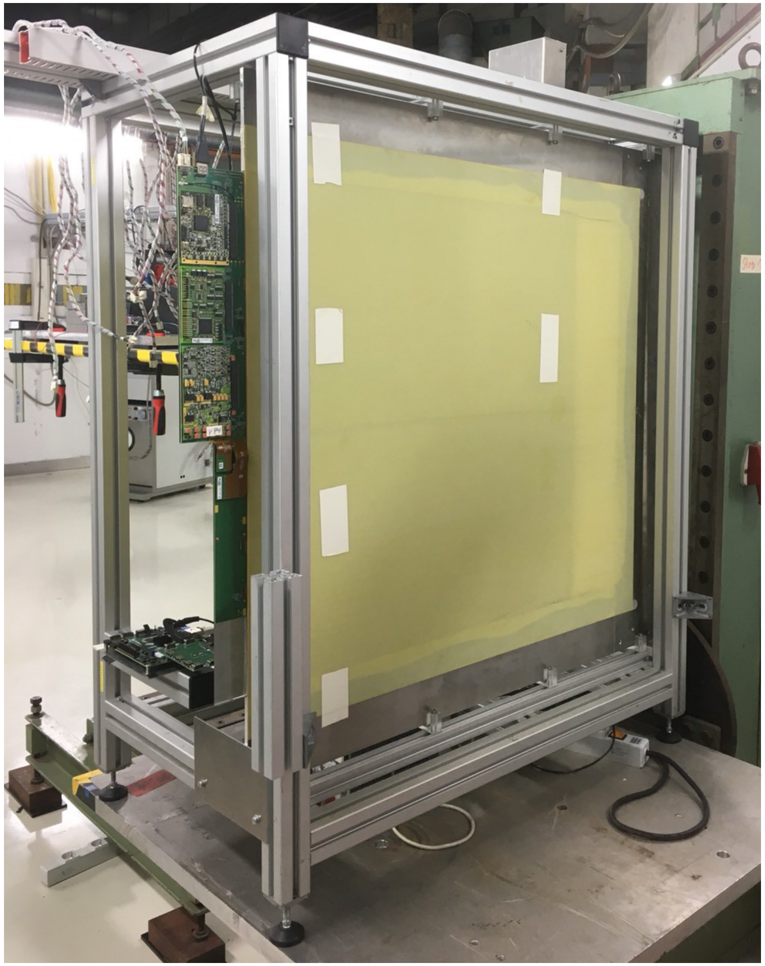




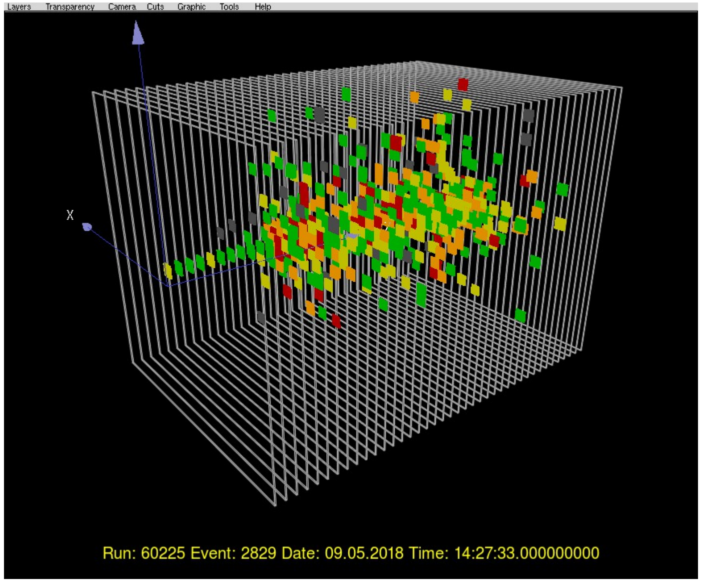
Quality assurance and calibration

- SiPM sample tests
- tile sample tests
- test of all ASICs
- all individual HBUs tested and calibrated with LEDs and cosmics
- all modules (2*2 HBUs) tested with cosmics
- all modules calibrated with LEDs and DESY beam
- result: overall quality very good
- **<1‰ dead channels**



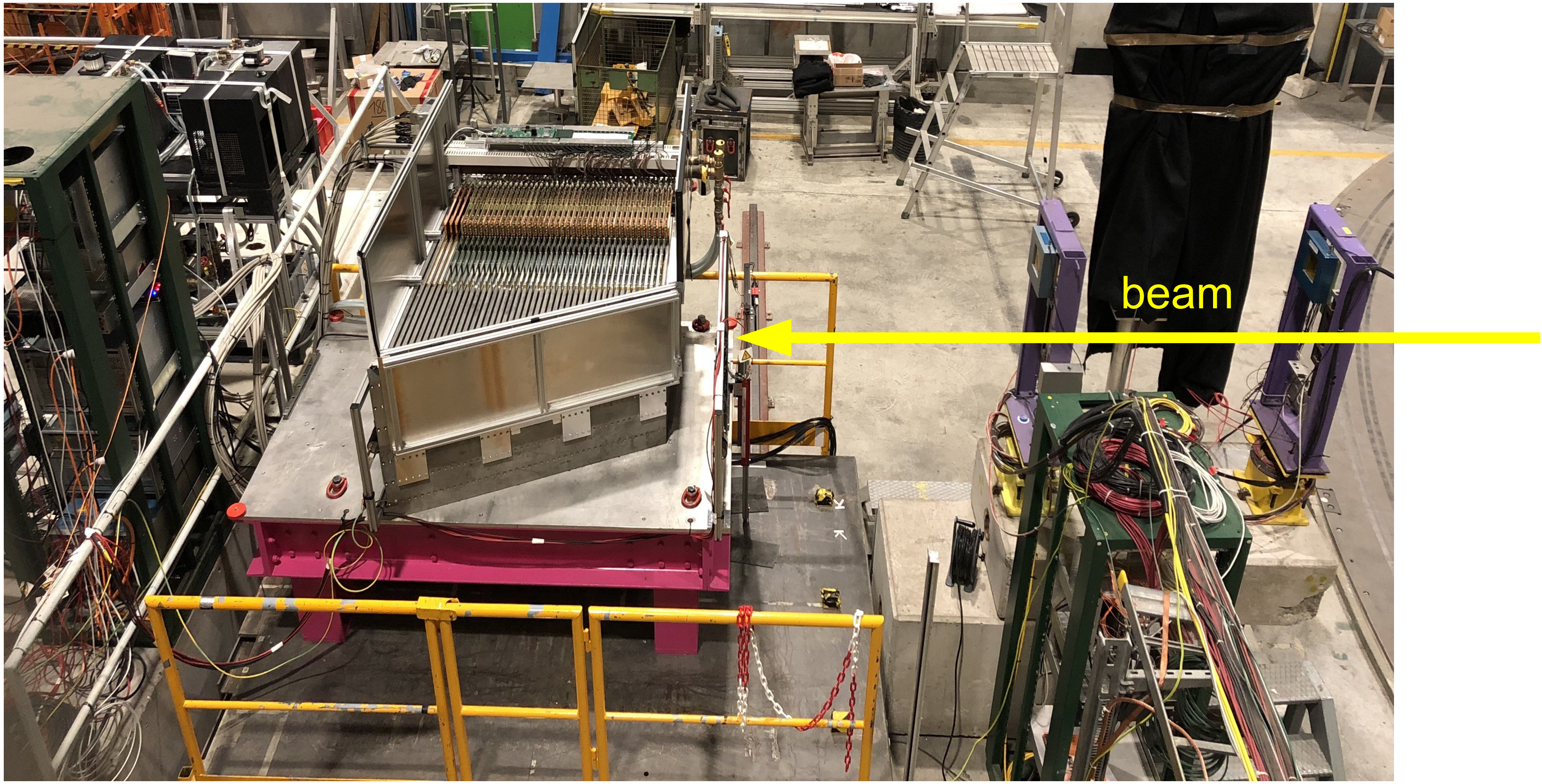


Datataking



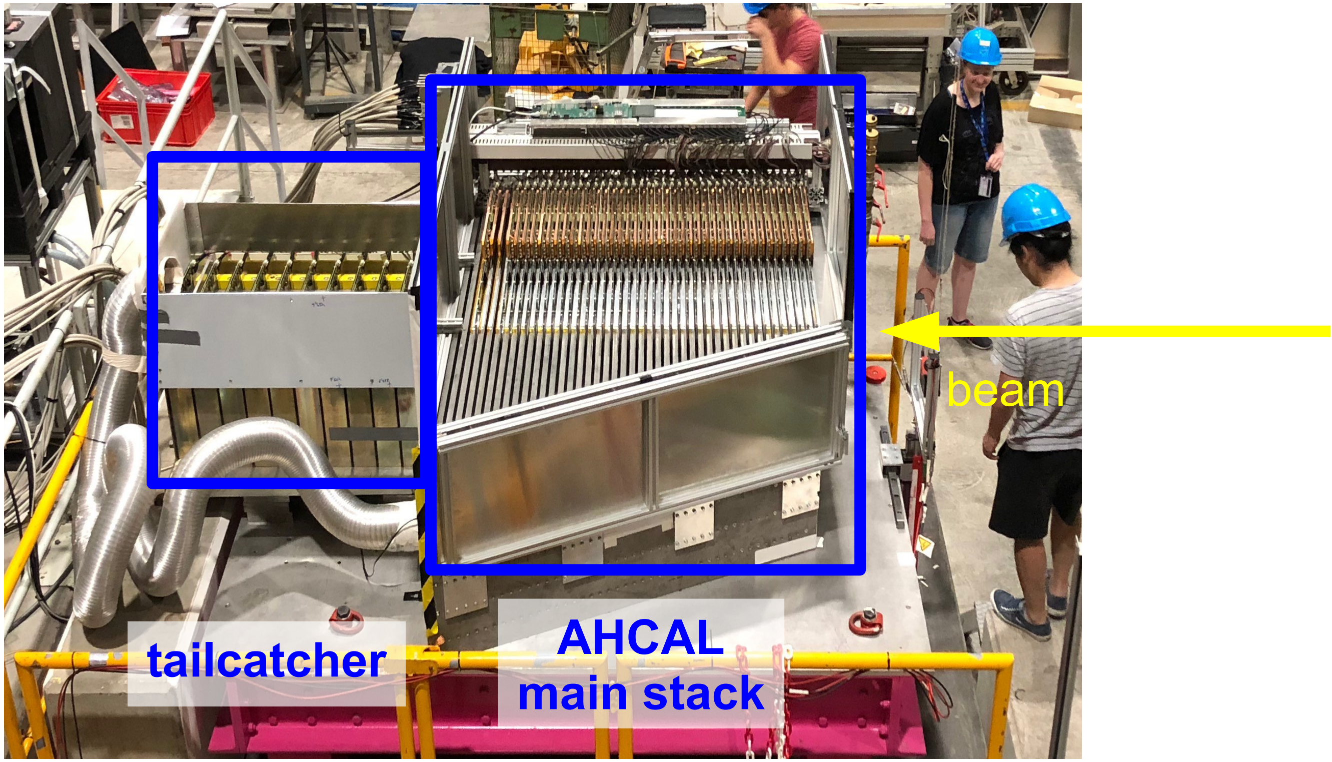
Layers Transparency Camera Cuts Graphic Tools Help
X
Run: 60225 Event: 2829 Date: 09.05.2018 Time: 14:27:33.000000000

Testbeam setup 9. – 23. May 2018 in H2 at SPS



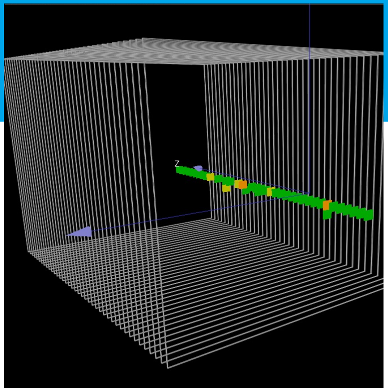
- 38 active layers of 72*72 cm² in steel absorber with 1.7 cm layer thickness (~4 λ)
- mounted on the movable platform ("scissors table") in H2
- beam instrumentation: wire chambers, trigger scintillators, Cherenkov detector

Testbeam setup 27. June – 4. July 2018 in H2 at SPS



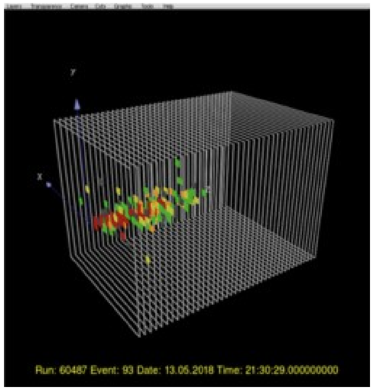
- as in May, plus:
  - added one module with 6*6 cm2 tiles
  - added CMS HGCAL “thick stack” (12 layers of 1 HBU, 7.4 cm steel absorber) as tailcatcher
  - added single HBU in front of absorber as “pre-shower” detector

Goals of SPS testbeam

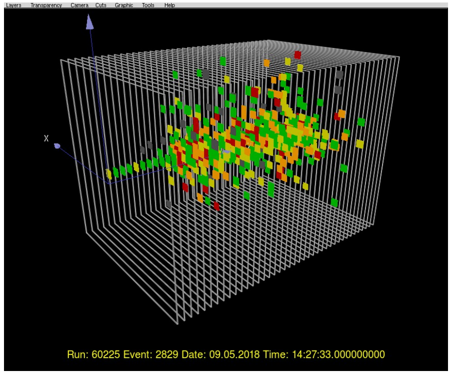


> technical
- demonstrate capabilities of SiPM-on-tile calorimeter concept with scalable detector design
- reliable operation of large prototype (with power pulsing!)

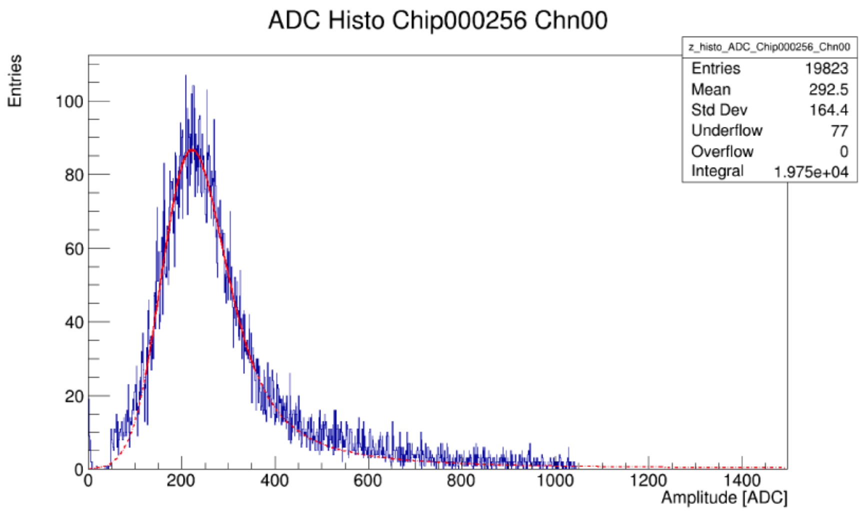
> scientific
- energy linearity and resolution for electrons and pions
- hit time correlations
- shower profiles
- shower separation



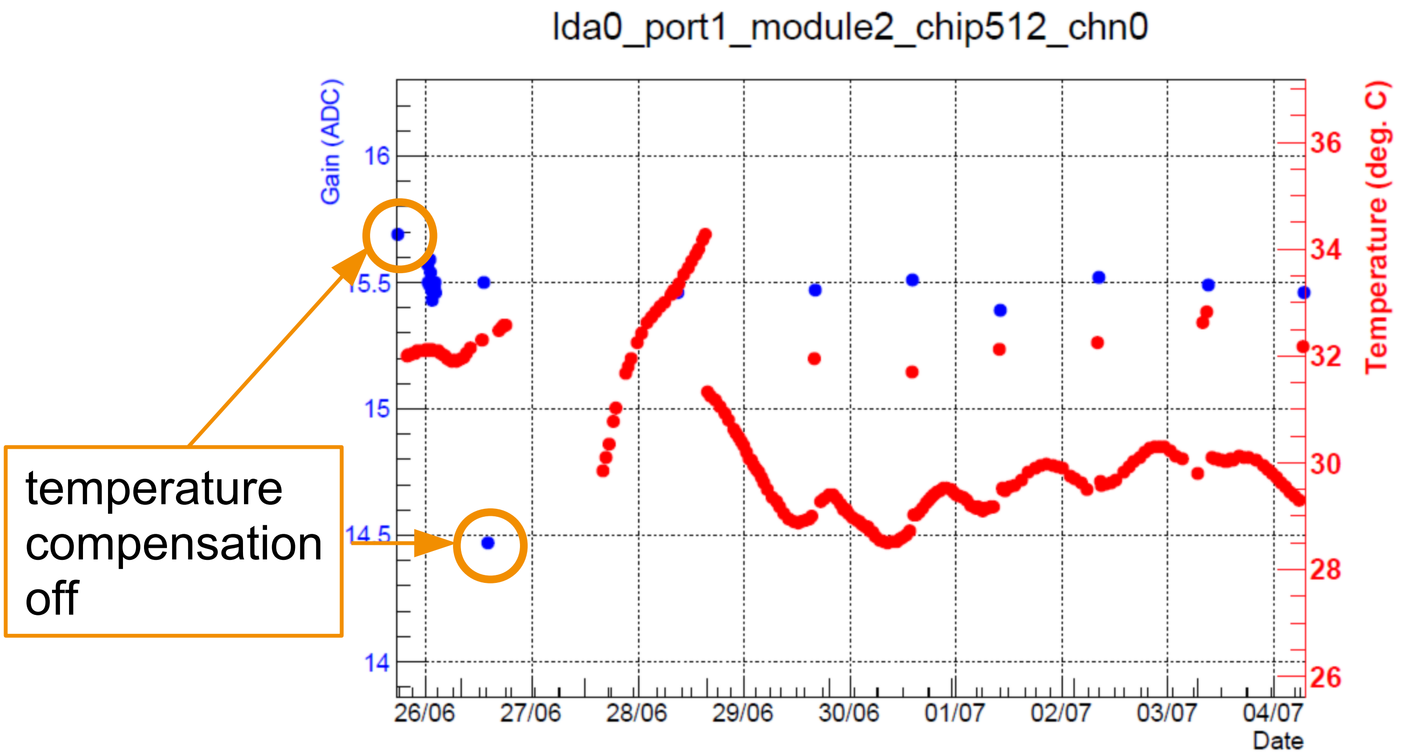
> data sets
- wide **muon** beam for (cross check of) MIP calibration
- energy scan for **electrons** (with and without power pulsing)
  - energies: 10, 20, 30, 40, 50, 60, 80, 100 GeV
- energy scan for negative **pions**
  - energies: 10, 15, 20, 30, 40, 50, 60, 80, 100, 120, 160, 200 GeV (+ test at 350 GeV)
- typically several 100,000 events per energy & particle type
- data at shifted beam positions



Calibration, Stability & Analysis



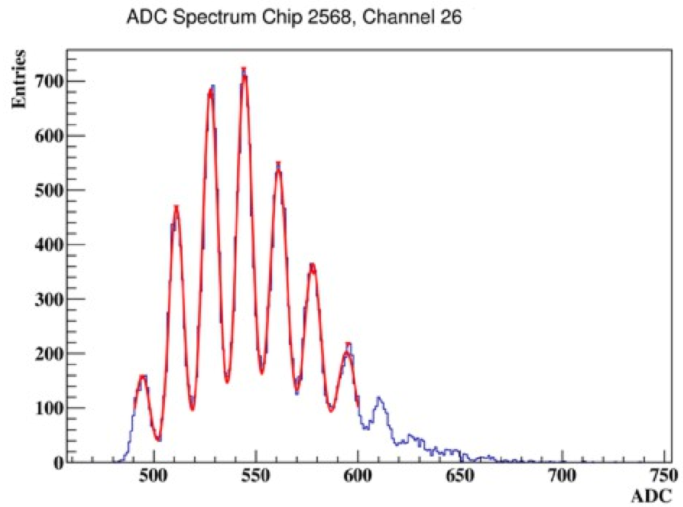
Stable operation: Temperature compensation

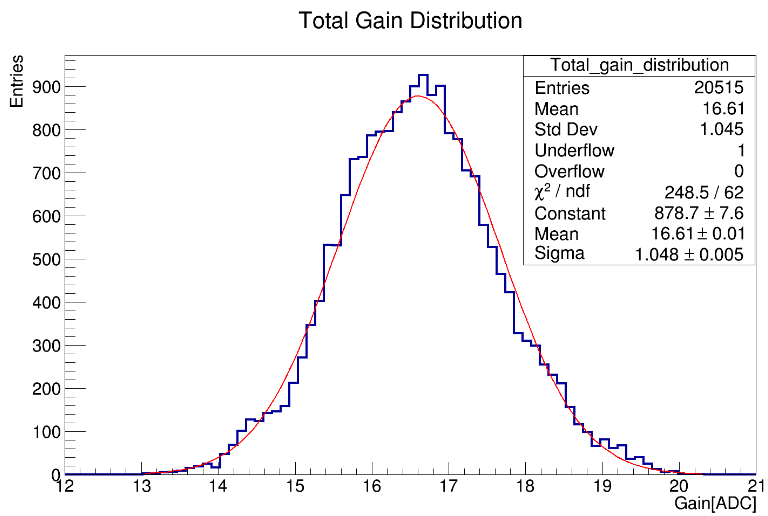


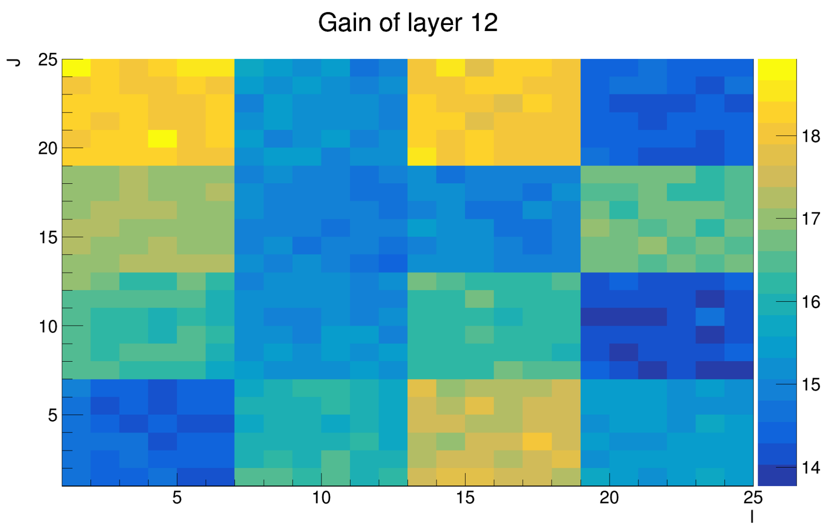
- gain and photon detection efficiency of SiPMs depend on temperature
  - can avoid changes by stabilizing temperature or adapting bias voltage (HV)
- temperature compensation: use mean temperature in a layer to adjust HV
- used routinely, HV changes as expected, gain stays stable

Uniformity and Stability: Gain

- product of SiPM (charge/pixel) and ASIC (ADC/charge) gains
- determined from single-pixel-spectra in LED runs
  - initial determination & daily checks
- μ=16.6 ADC/pixel, RMS=1.0 ADC/pixel (6%)
  - within an ASIC: ~2.5%
- **uniform and very stable gain**







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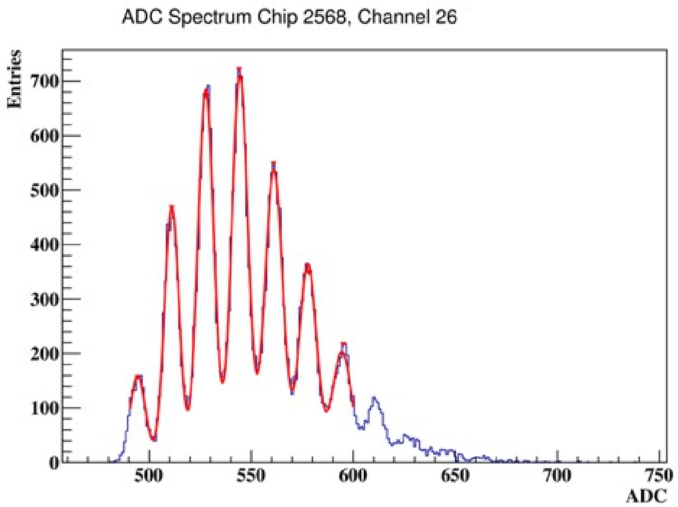
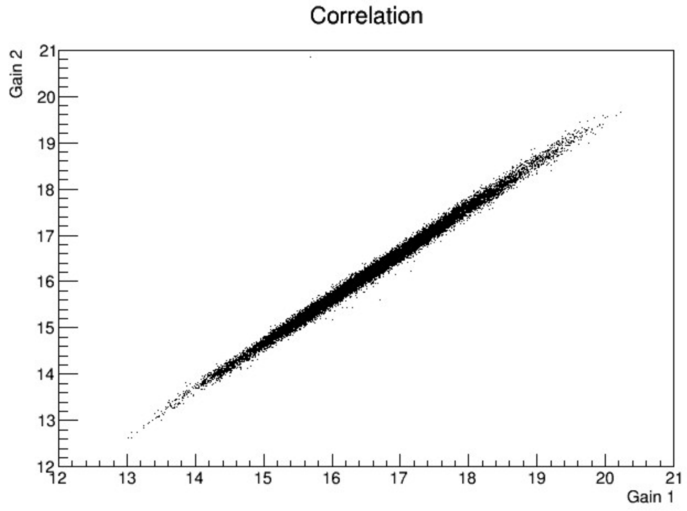
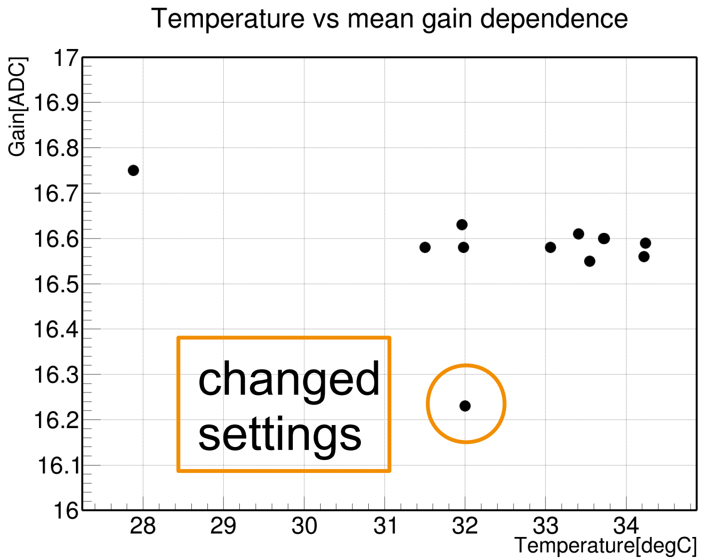


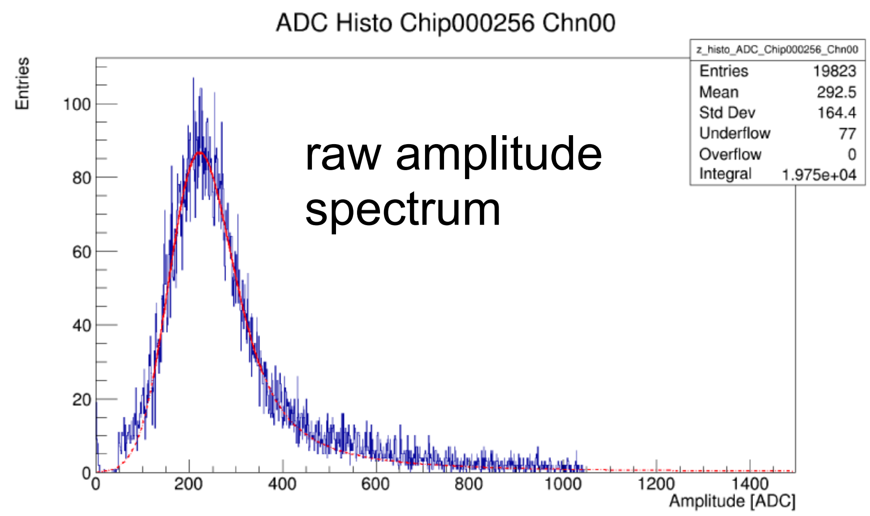


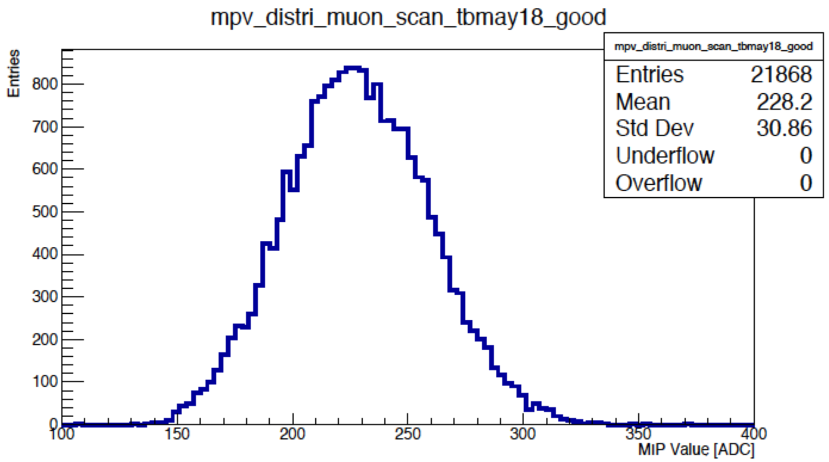


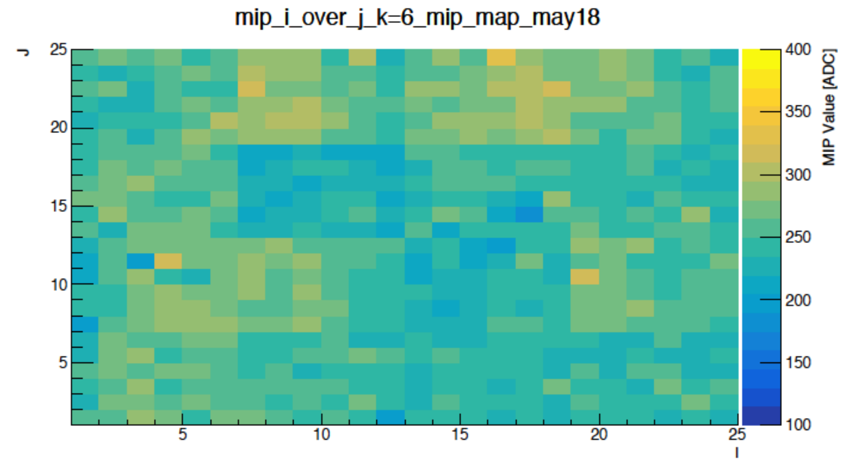
DESY.

Uniformity and Stability: MIP signal

- MIP signal: product of light yield (pixel/MIP) and gain (ADC/pixel)
- MIP value in ADC relevant for trigger threshold
- μ=228 ADC, RMS=31 ADC (14%)
  - **uniform** enough for same trigger threshold for all channels







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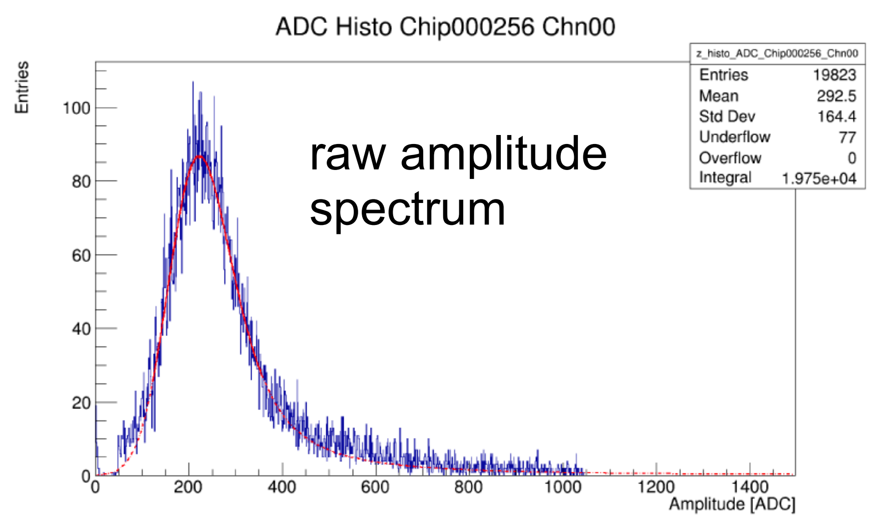
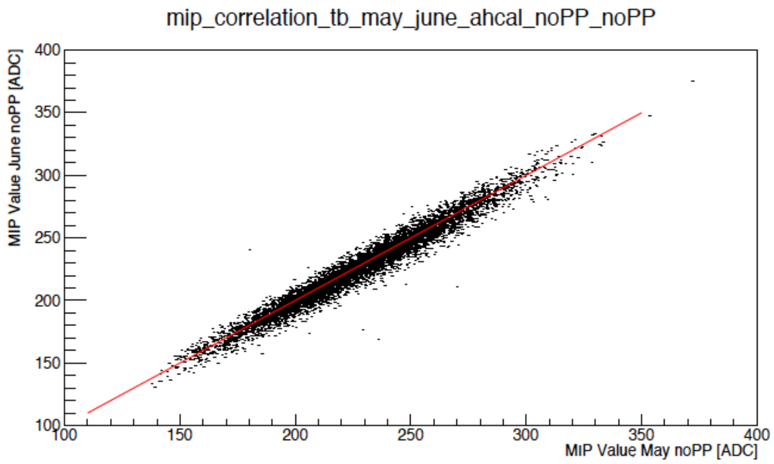
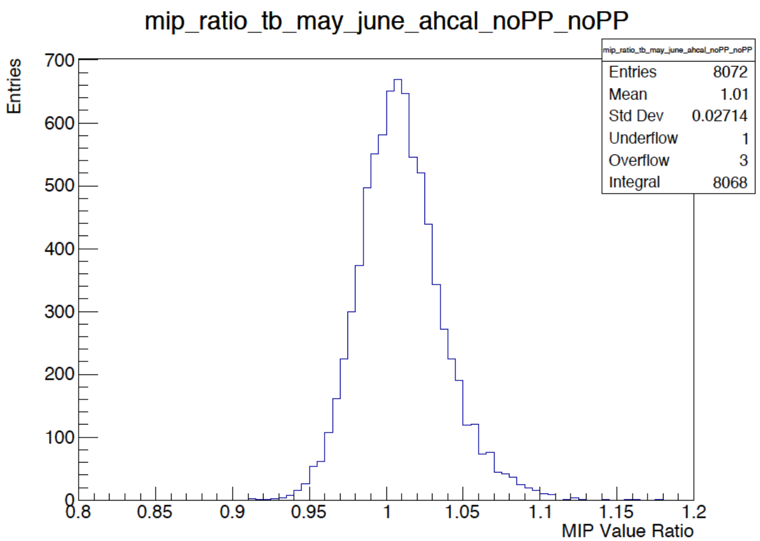
- MIP signal: product of light yield (pixel/MIP) and gain (ADC/pixel)
- MIP value in ADC relevant for trigger threshold
- μ=228 ADC, RMS=31 ADC (14%)
  - **uniform** enough for same trigger threshold for all channels
- **stable** between May and June runs

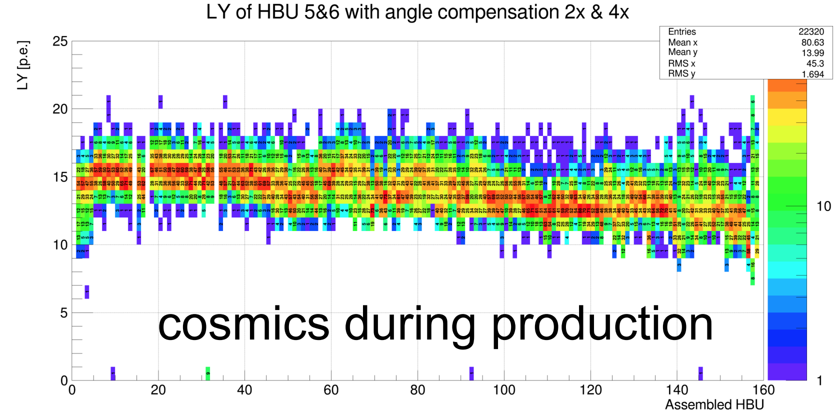


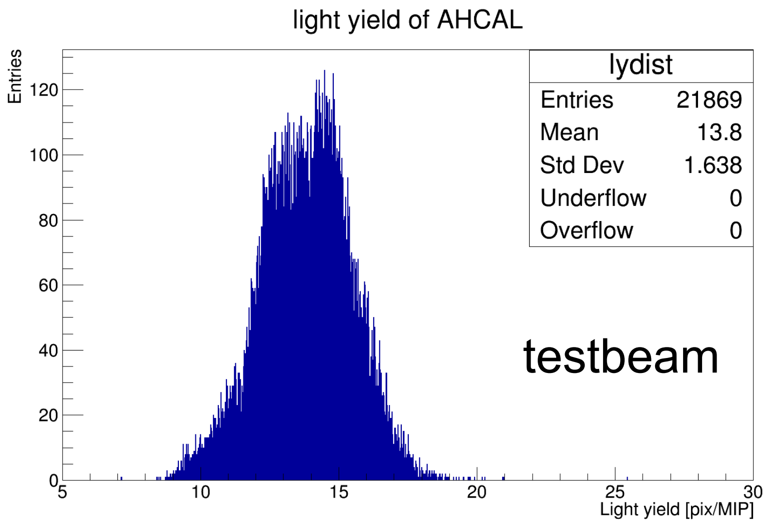


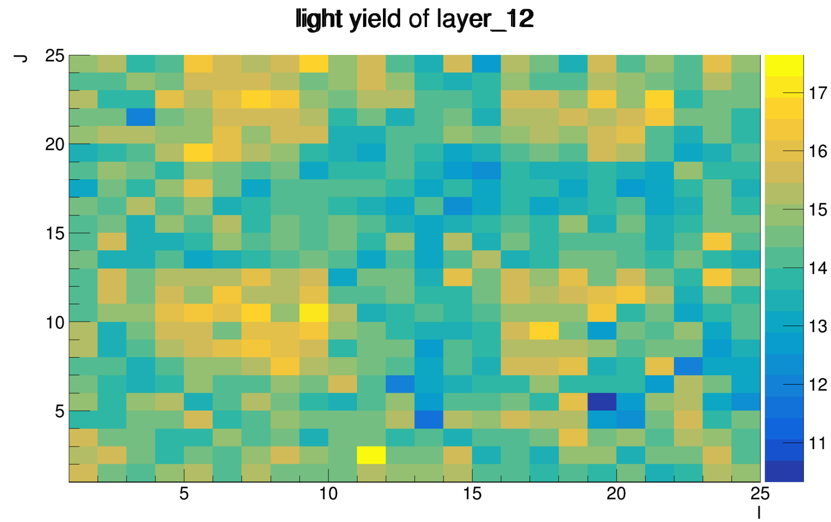


Uniformity and Stability: Light Yield

- light yield is characteristic of SiPM-tile system
- calculated from MIP signal and gain
- μ=13.8 pixel, RMS=1.6 pixel (12%)
  - smaller RMS than MIP value in ADC
  - small decrease during production
- **0.5 MIP threshold at ~7 pixels leads to negligible noise**
  (trigger threshold at ~0.3 MIP)

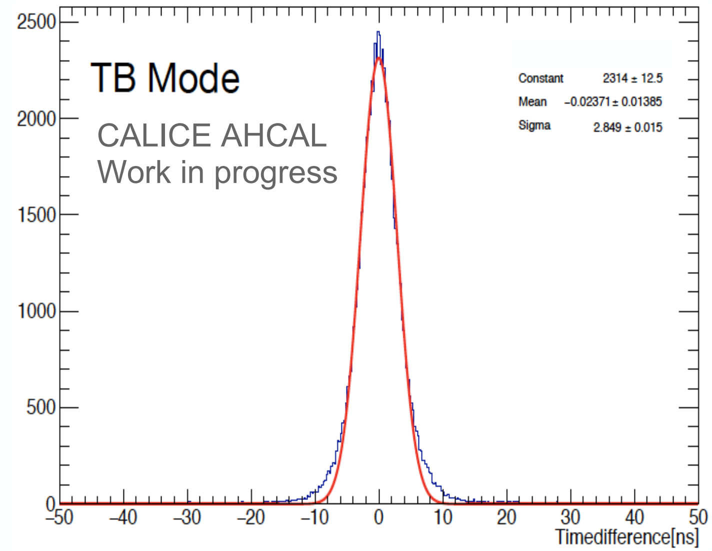


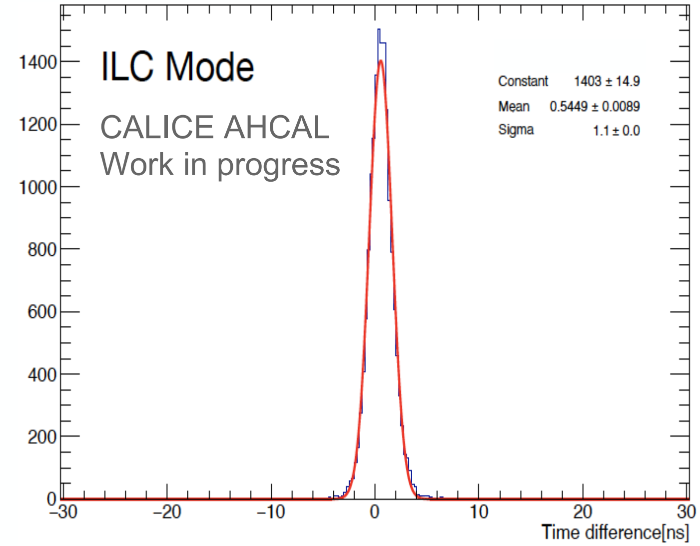




New feature: hit time measurement

- time is measured with a TDC, resolution depends on bunch clock
  - SPIROC ASIC can run with different bunch clocks: 250 kHz (testbeam mode) and 5 MHz (ILC mode)
- design goal is ~1ns resolution in ILC mode
- Use time difference between two channels (in different layers) to exclude contribution from time reference
- ~2 ns resolution in testbeam mode ~0.8 ns resolution in ILC mode
  - resolution deteriorates with number of hits in an ASIC

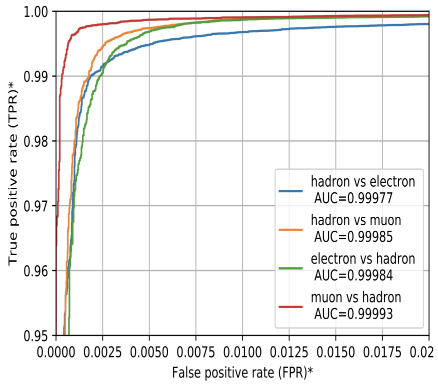


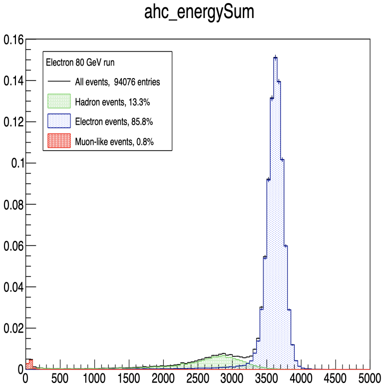


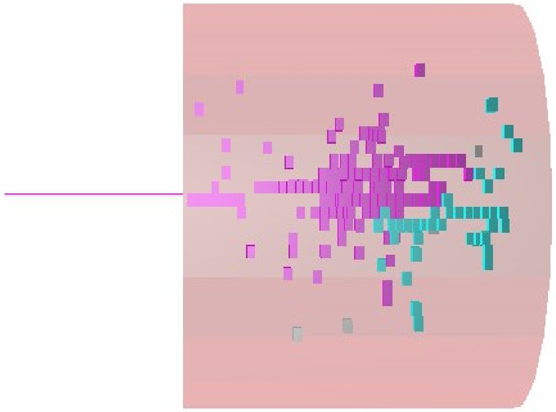
Ongoing Analyses

Analysis of 2018 data progressing well

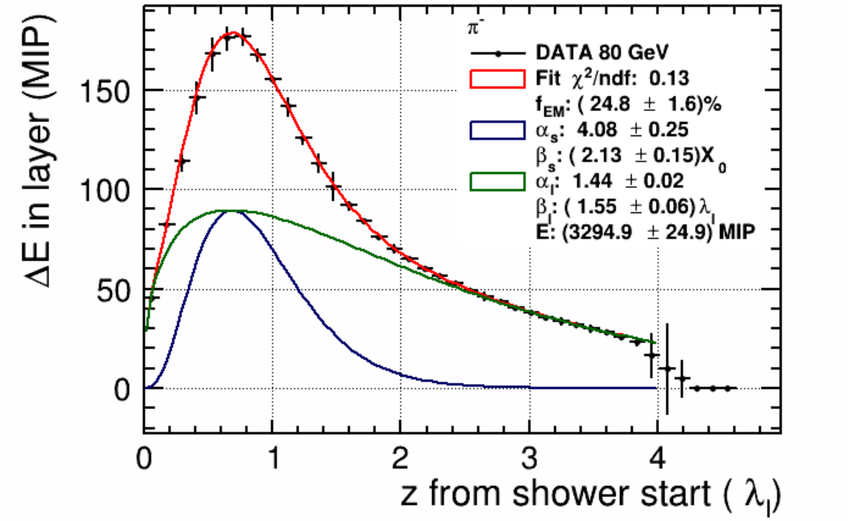
- All calibrations determined
- Large simulation samples produced
- High level analysis tools developed
- Particle ID based on BDT
- Application of PFA
- Shower shapes
- Machine Learning studies



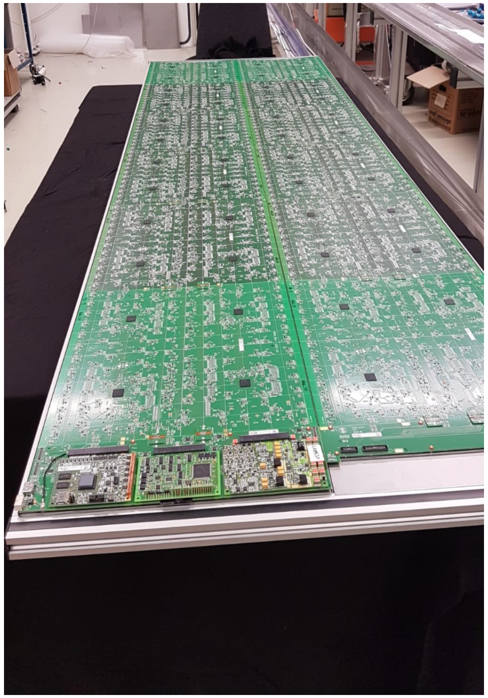




Magenta: Charged Hadron
Cyan: Neutral Hadron
Grey: Unclustered Hits

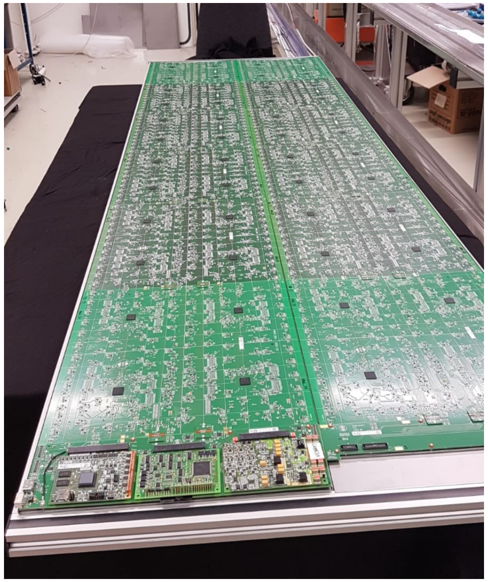


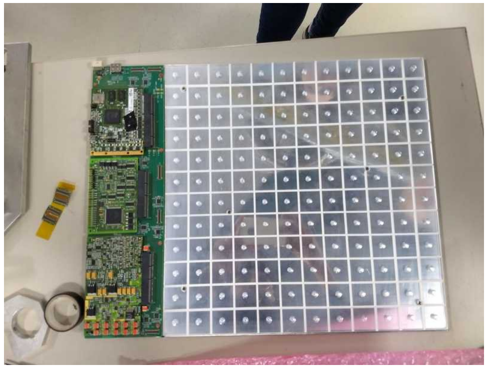
Further developments



AHCAL prototype: further developments and future plans

- AHCAL developments
  - test of full-sized ILD layers: have tested 2*6 HBUs
  - Megatiles: would allow larger units for mechanical assembly
  - alternative readout ASIC (KlauS): would allow continuous running
- Synergies with SciECAL
- Future tests with the large prototype
  - CERN SPS testbeam back in 2021
  - combined beam test with ECAL in front is highly desirable for realistic performance studies
  - beam tests with (existing) tungsten absorber structure

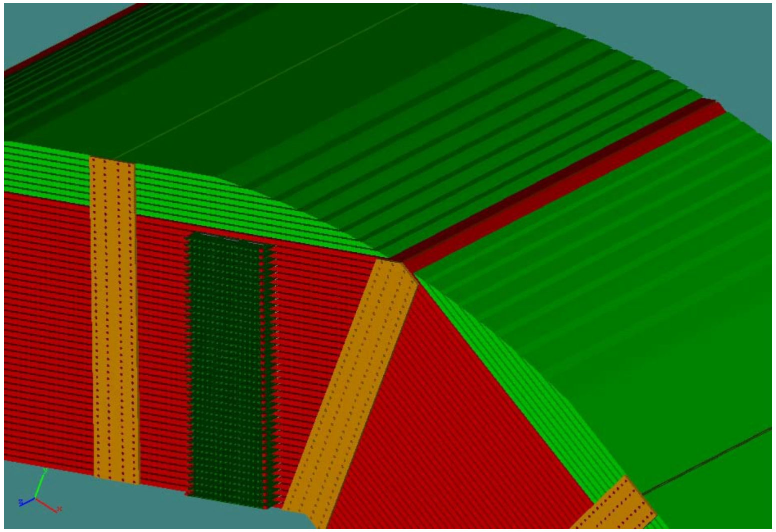


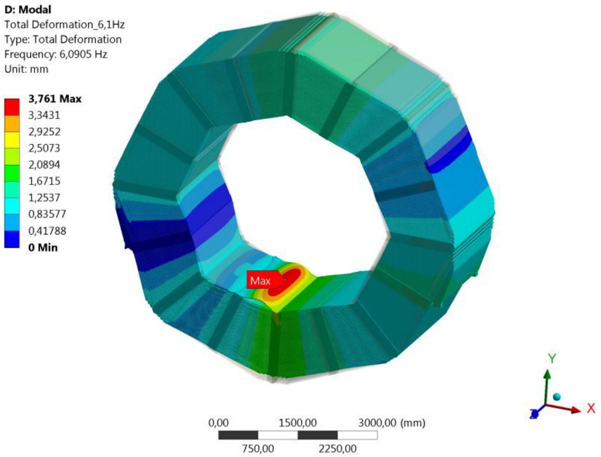


Mechanical Structure & Interfaces

- Tesla geometry
  - Allows easy access to all components that might affect a significant fraction of the detector
  - Strength shown in earthquake studies

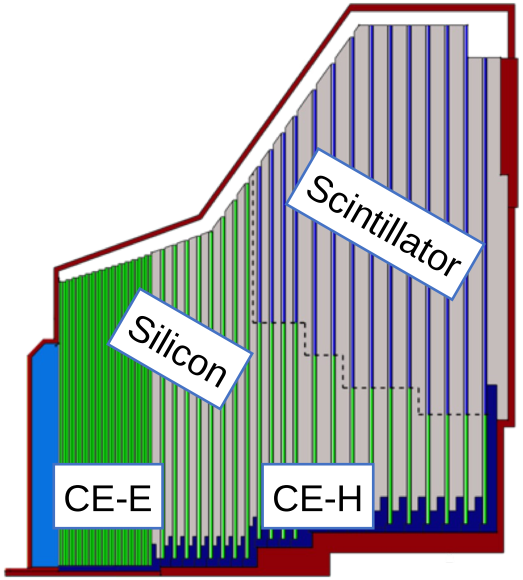
- Interfaces in barrel-endcap gap
  - Current size fits into available space in ILD
  - Further miniturisation might be possible → synergies with developments for SiECAL

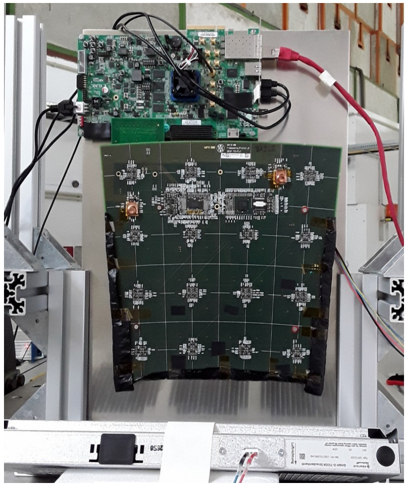




Developments for other SiPM-on-Tile Calorimeters

- Or: what do we learn from HGCAL?
- SiPM-on-Tile part of HGCAL follows AHCAL design to a large extent
  - Has factor ~10 more channels
  - Needs to be installed by 2026
  - Lives in a much harsher environment (radiation, data rates, ...)
- Building HGCAL will be an invaluable experience for scaling up a concept by a factor ~100 from a testbeam prototype to an ILC detector



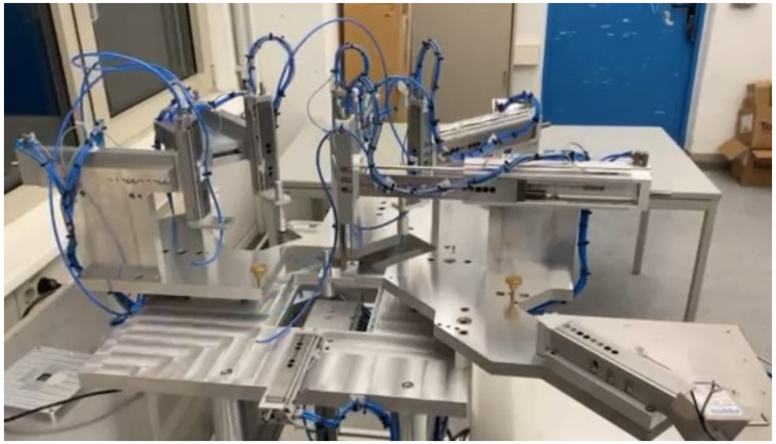


Developments for other SiPM-on-Tile Calorimeters

Recent developments in assembly procedures

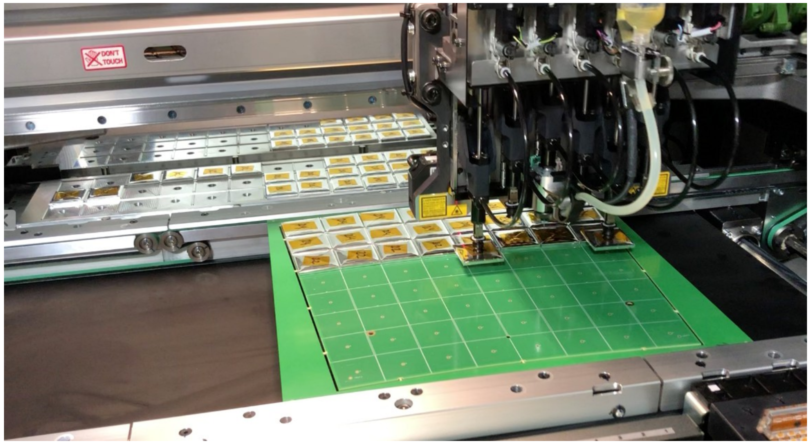
Tile Wrapping

- More robust tile wrapping machine



Tile Placing & Glueing

- New pick-and-place machine installed at DESY in the Detector Assembly Facility

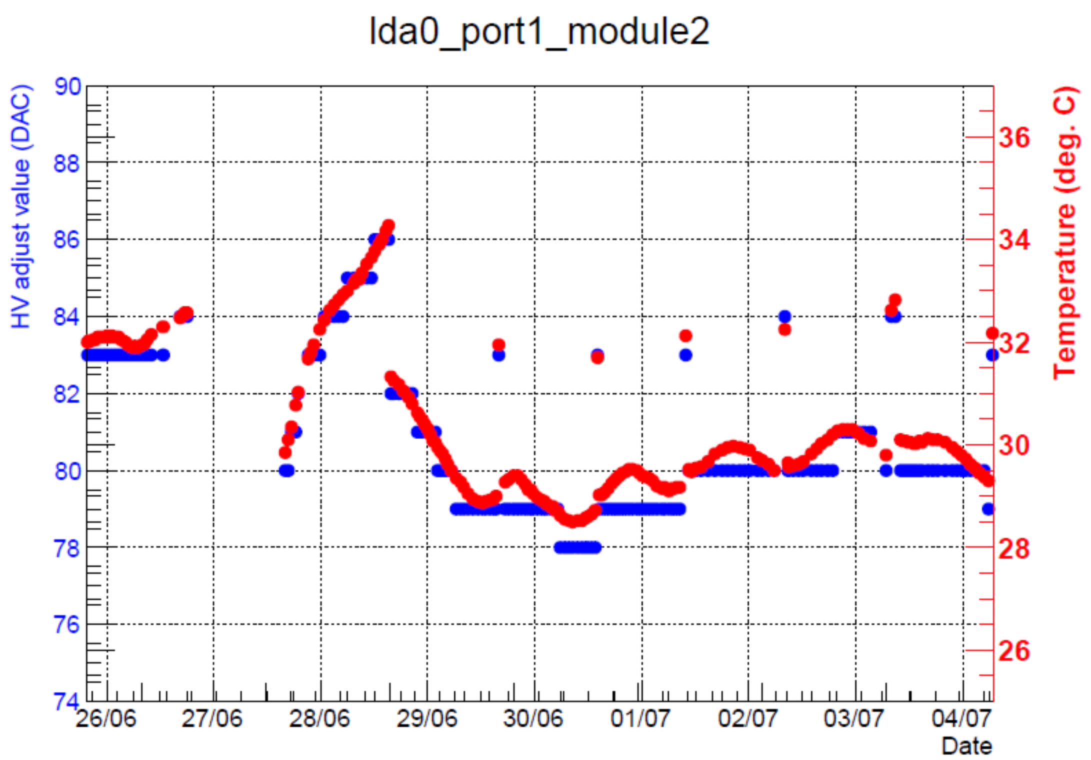


Summary

- Construction of large AHCAL technological prototype demonstrated:
  - design scalable to a linear collider detector
  - scalable production & assembly methods
- Testbeam operation in 2018 demonstrated:
  - very stable running
  - very good data quality
- Construction of SiPM-on-tile part of HGCAL will demonstrate:
  - next step on the way to an ILC detector

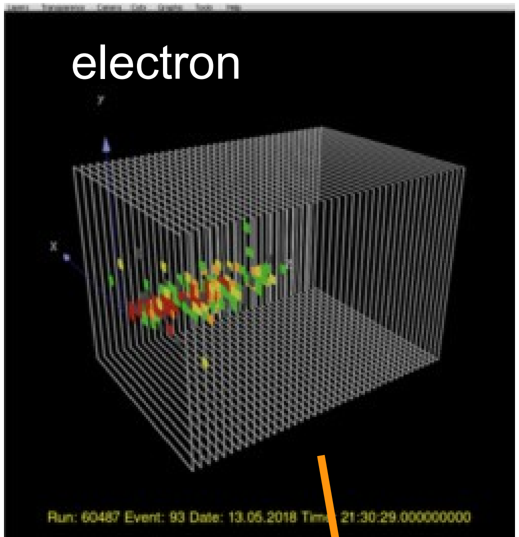
Backup

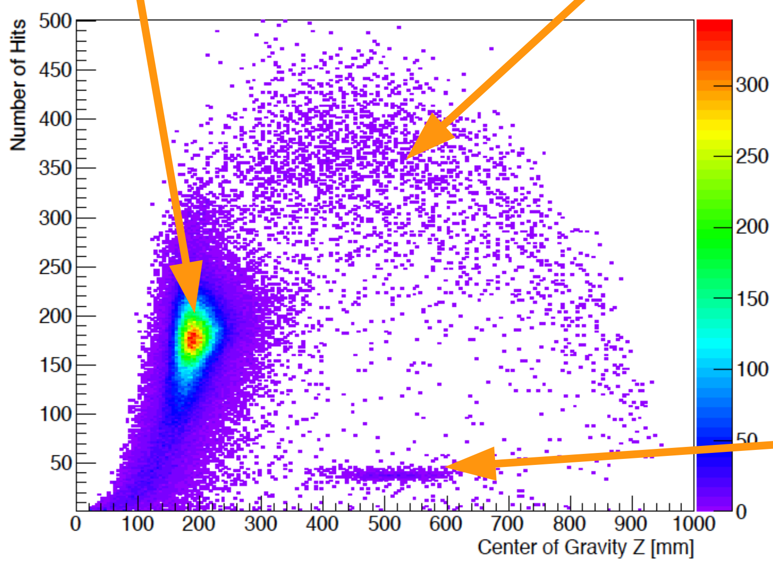
Stable operation: Temperature compensation

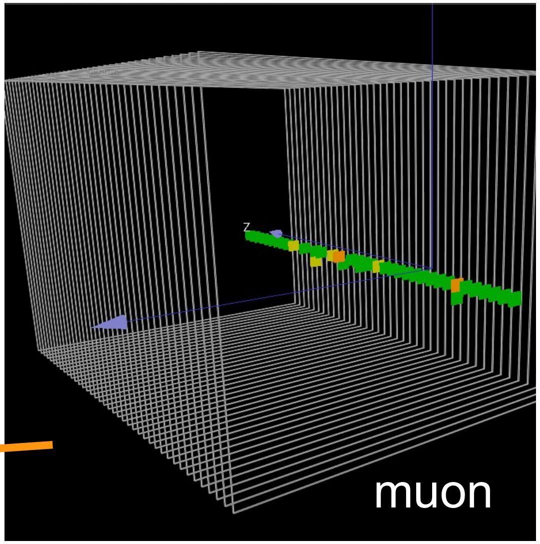


- gain and photon detection efficiency of SiPMs depend on temperature
  - can avoid changes by stabilizing temperature or adapting bias voltage (HV)
- temperature compensation: use mean temperature in a layer to adjust HV
- used routinely, HV changes as expected, gain stays stable

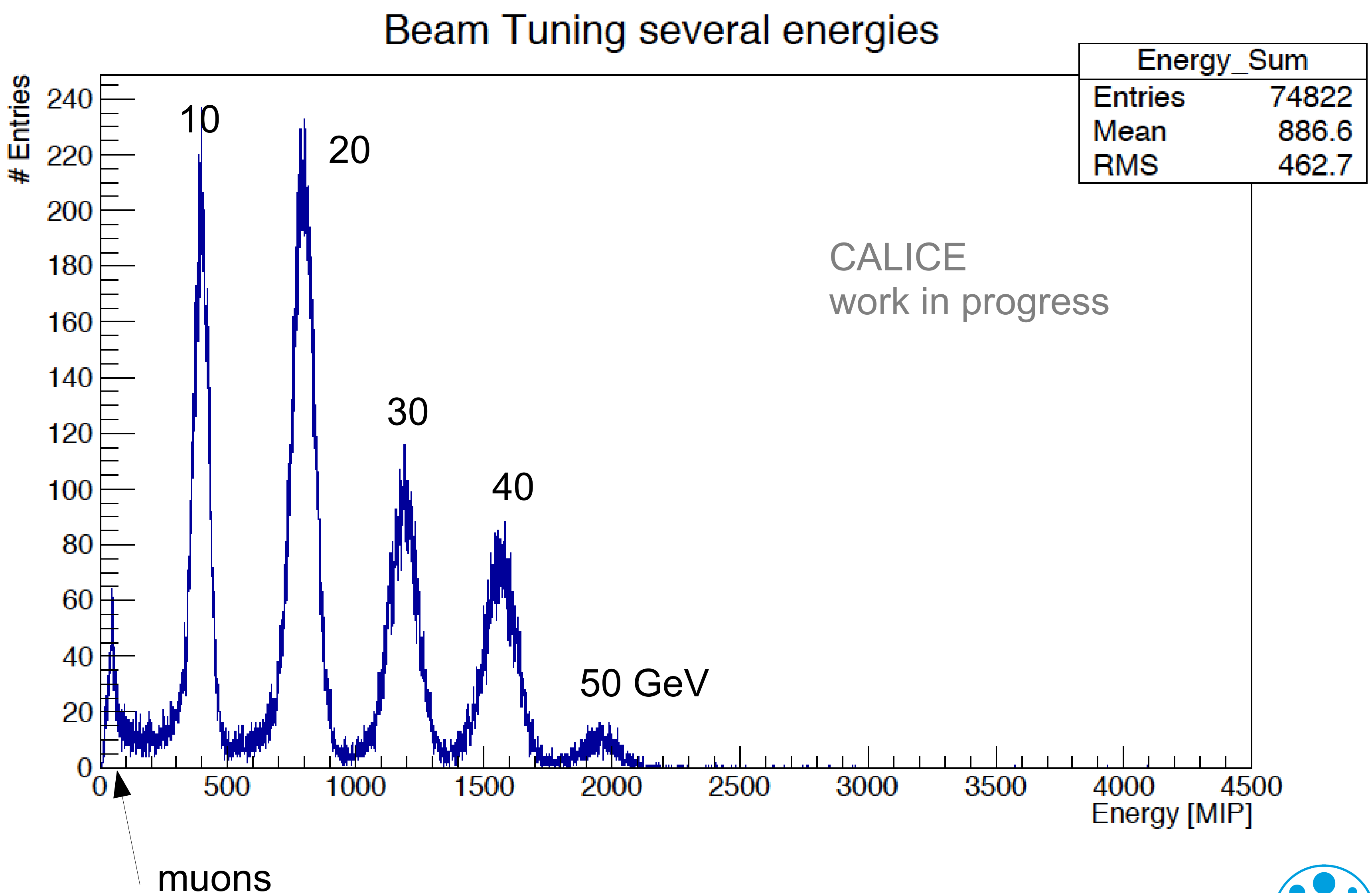
Very first look into data



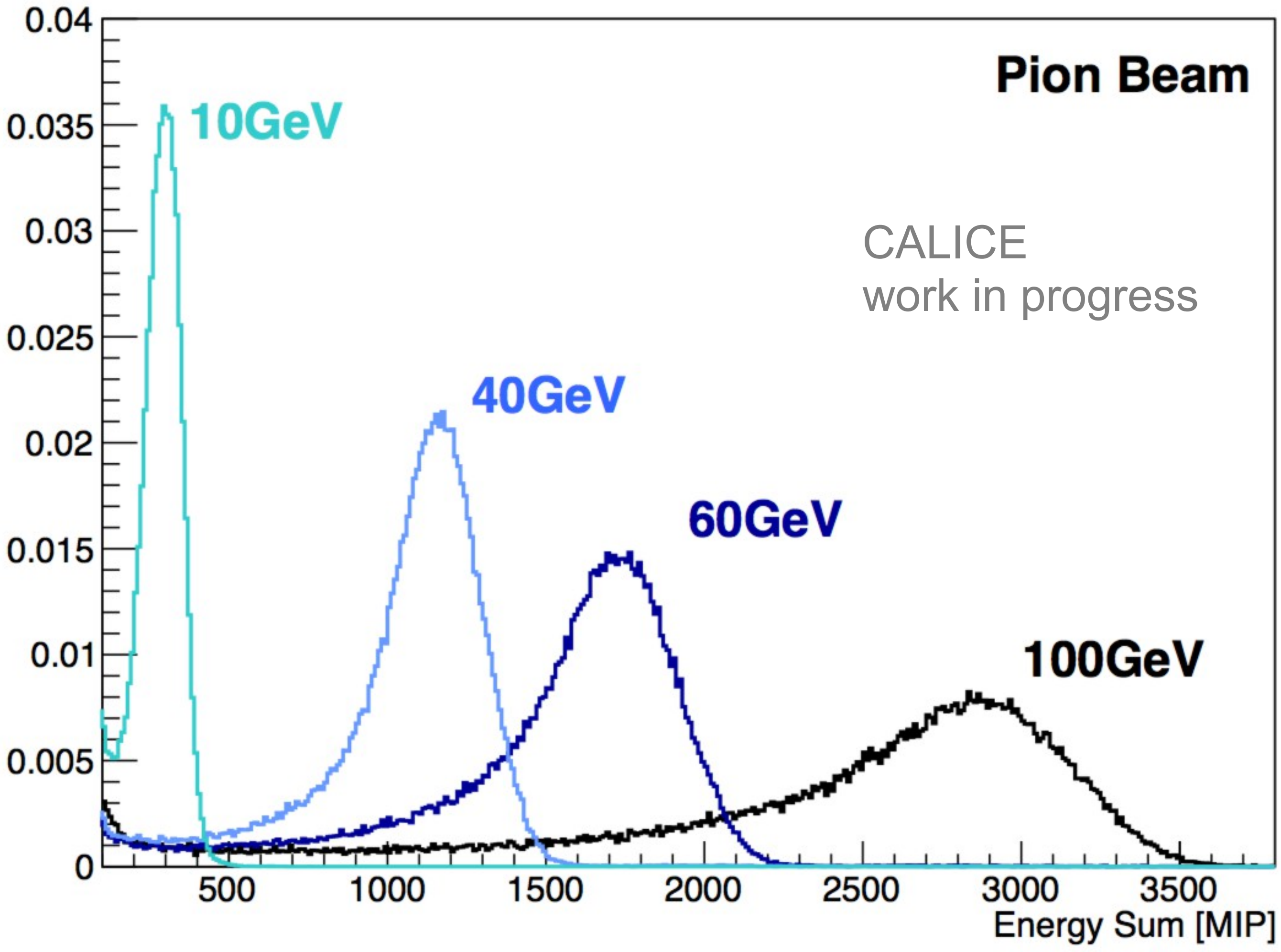




Electrons during beam tuning in June



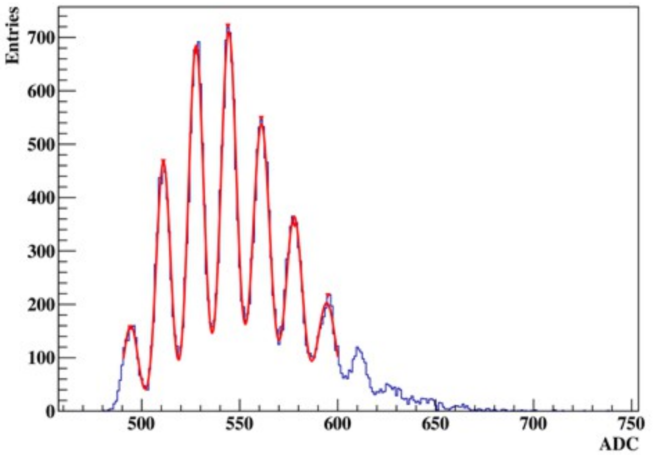
Very first look into pion data

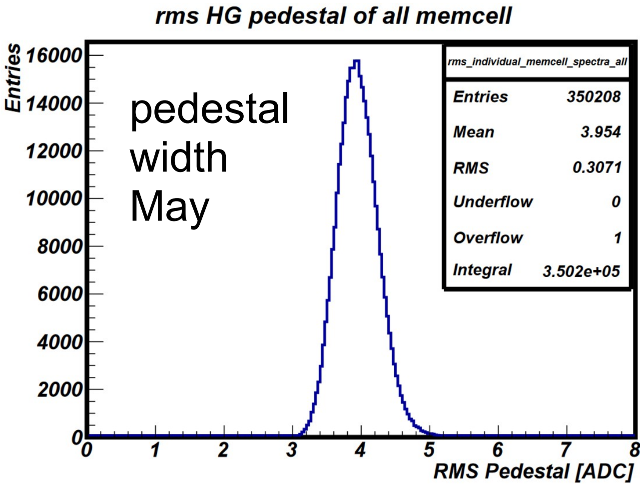


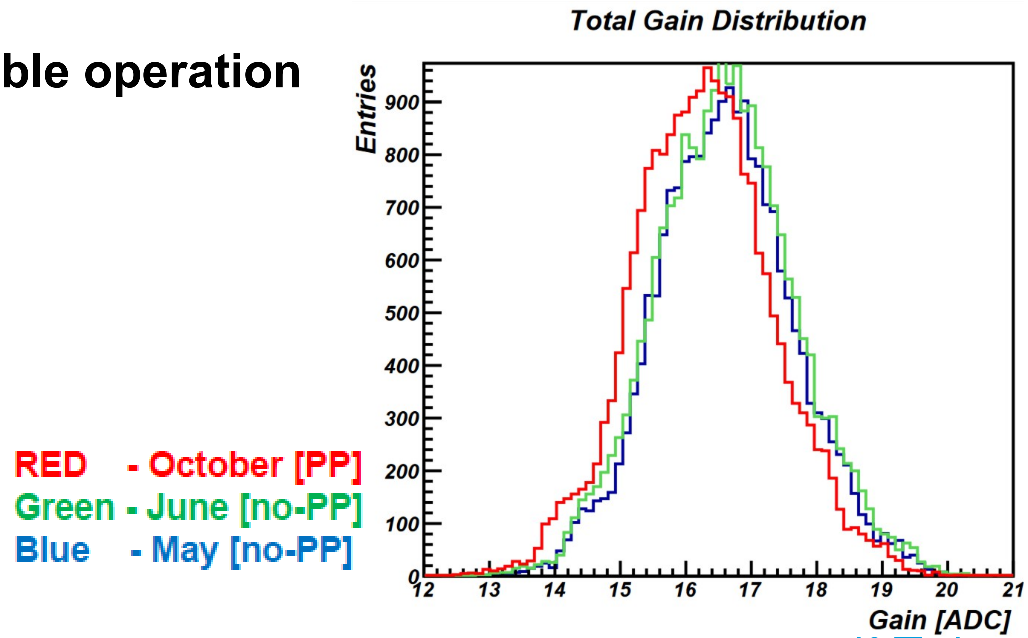
Calibration: gain

O. Pinto

- data: LED data taken with external trigger
- **pedestal** can give information on dead and noisy channels
- **gain** from single-pixel-spectra
  - translation of signals to pixel scale, needed for SiPM saturation corrections
  - monitoring of detector stability
- **<1‰ dead channels**
- **very homogenous gain, very stable operation**

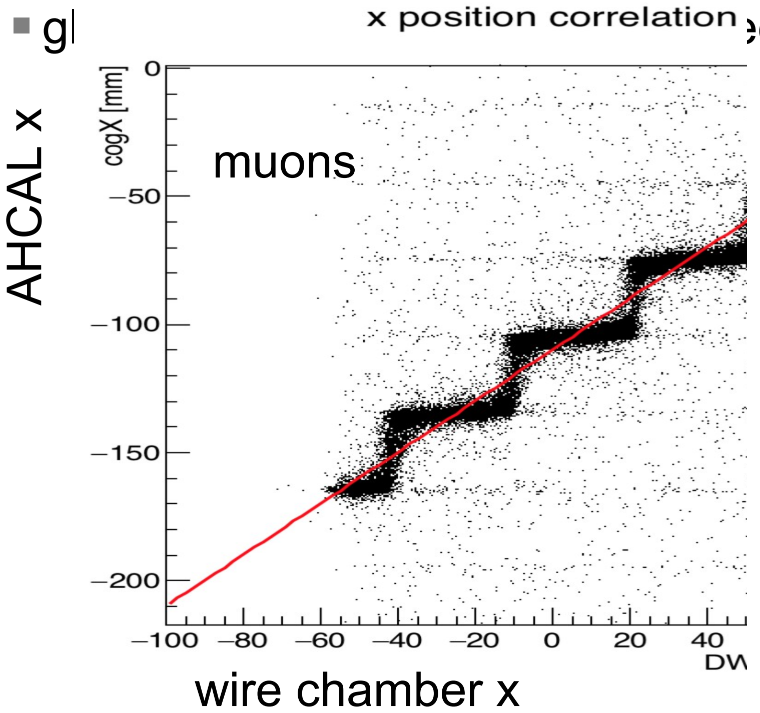


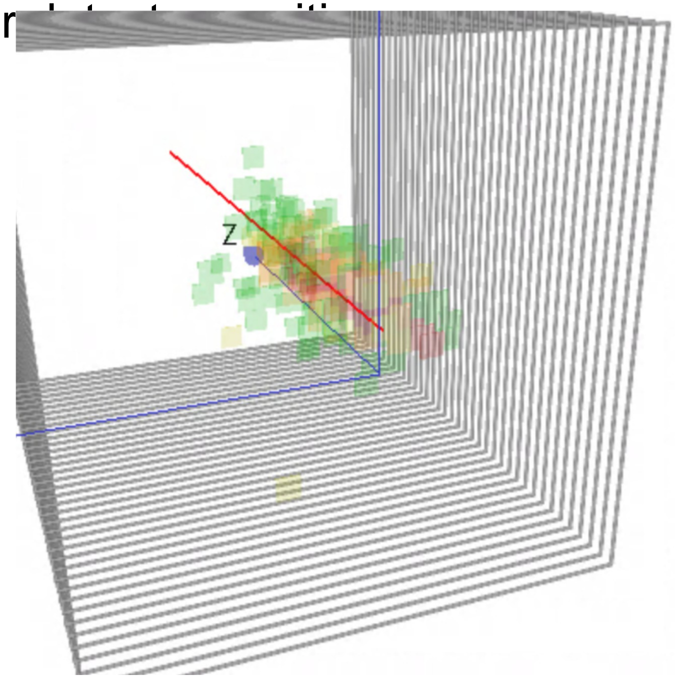




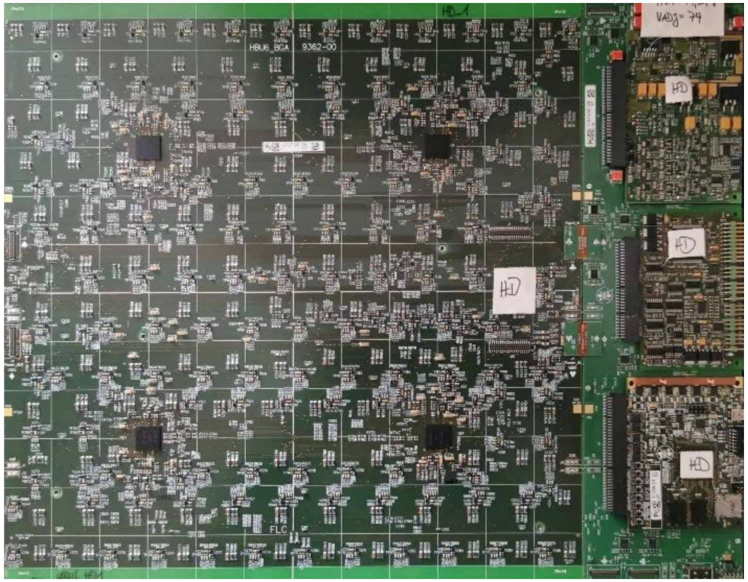
Wire chambers

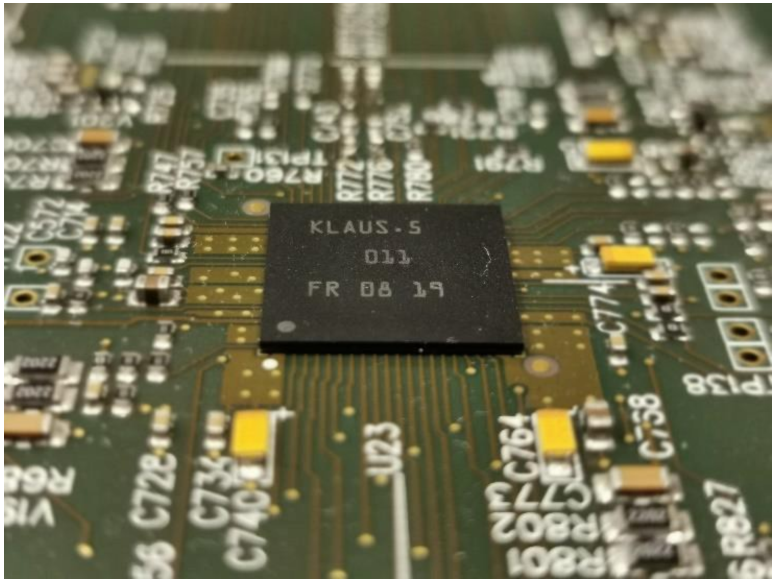
- wire chambers can give more precise position information
- wire chambers read out separately, assignment to AHCAL events by time
  - encountered some unexpected effects, solved
- **wire chamber information now available in reconstruction and event display**
  - gl ... ed per





Klaus HBU

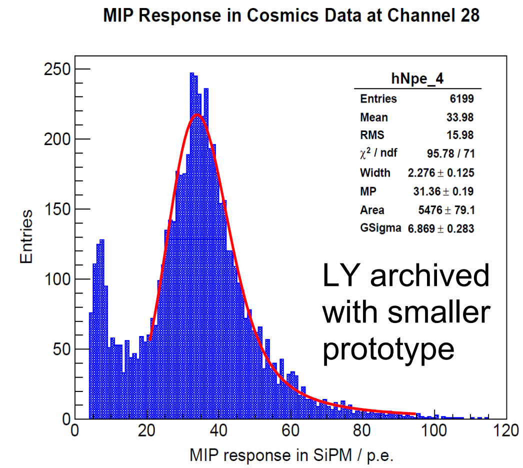


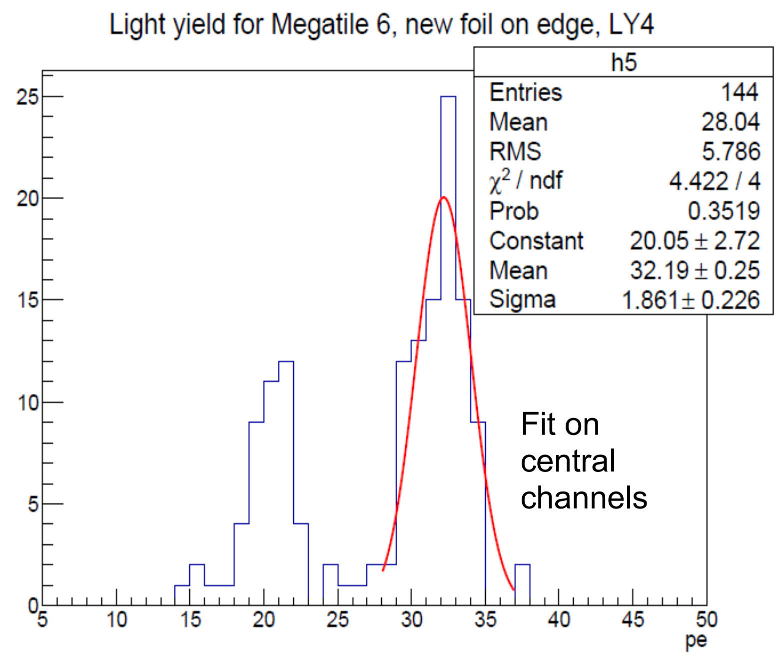


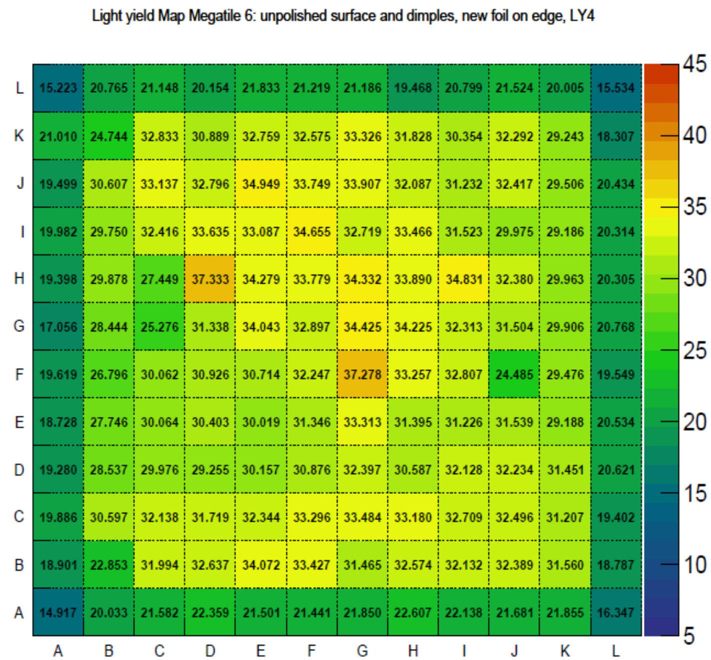
- dedicated HBU for KlauS readout ASIC
  - BGA packaged KLauS-5 ASIC (Uni Heidelberg)
  - new SiPM sensor with smaller pitch, Hamamatsu S14160-1315PS (smaller gain than our “standard” S13360-1325PE)
  - a few tiles have been assembled
- readout data format as close as possible to SPIROC2E to ease DAQ integration
  - stand-alone USB DAQ working, to be tested in March 2020 testbeam

New Megatile Prototype (MT 6): Light Yield Performance

- MT 6 measured with cosmic ray test stand
- Excellent light yield performance for Megatile 6
  - LY (~32 p.e) in central channels in perfect agreement with 3x3 prototype
- Large difference between edge and central channels
  - Reflective foil at corner slightly broken while cutting?
  - Needs improvement

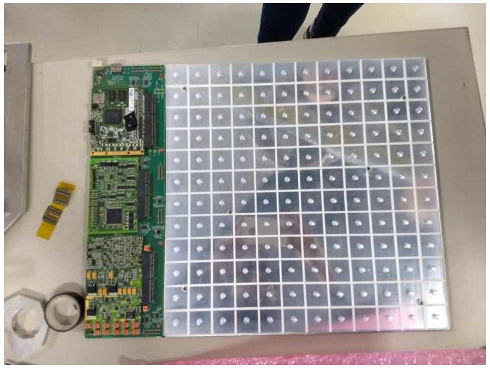






Scintillator Calorimetry: Future

Technological Developments



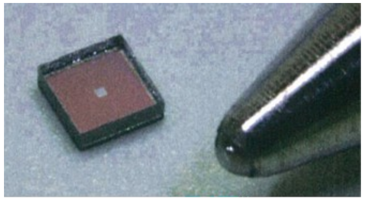
Development of alternative scintillator geometries

•Full characterisation of mega-tiles, towards large-scale production techniques, integration into the large prototype

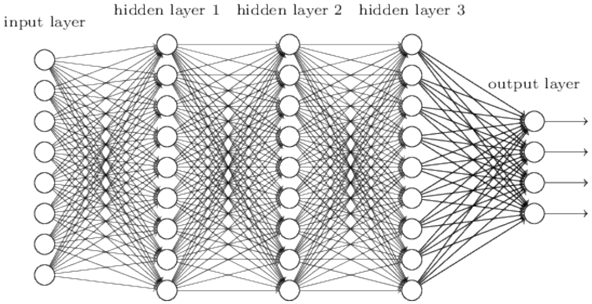
Development of readout electronics

•Klaus readout ASIC: construction of a full layer, integration into the large prototype

•compact readout and power interfaces, synchronised with developments for ECAL



Fundamental studies of rad-hard SiPMs



Development of advanced algorithms including Deep Leaning methods