CALICE AHCAL overview

Yong Liu (IHEP),

on behalf of the CALICE collaboration

Nov. 13, 2018

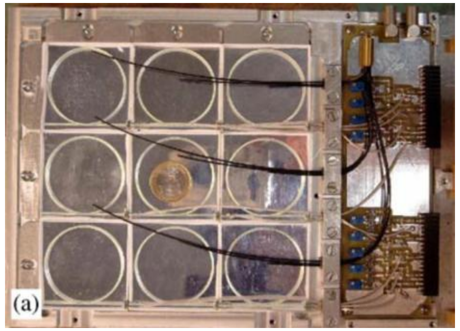
中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

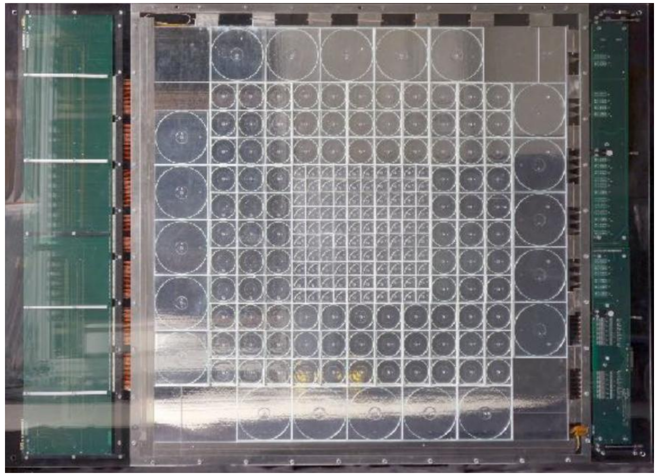
Outline

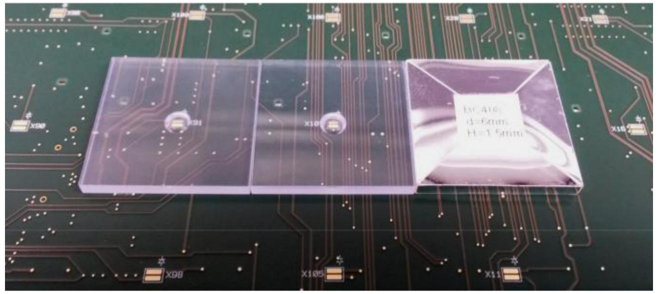
- Overview
- Construction: AHCAL technological prototype
- Test beam activities

High granularity and SiPM: a brief history

- 2001: CALICE founded
  - Aim to develop high-granularity calorimeters at a future linear collider
- 2003: MiniCal (100 tiles+SiPMs)
- 2006-2011: AHCAL Physics Prototype
  - Test beam data at CERN and FNAL
  - Detailed shower studies
- 2012: CLIC studies triggered LHC interest
  - Particle-flow paradigm and pile-up rejection with high granularity in harsh conditions
- 2014-2017: CMS HGCAL design
- 2016-2018: AHCAL Technological Prototype for ILC
  - Demonstrate the scalability to build a full detector

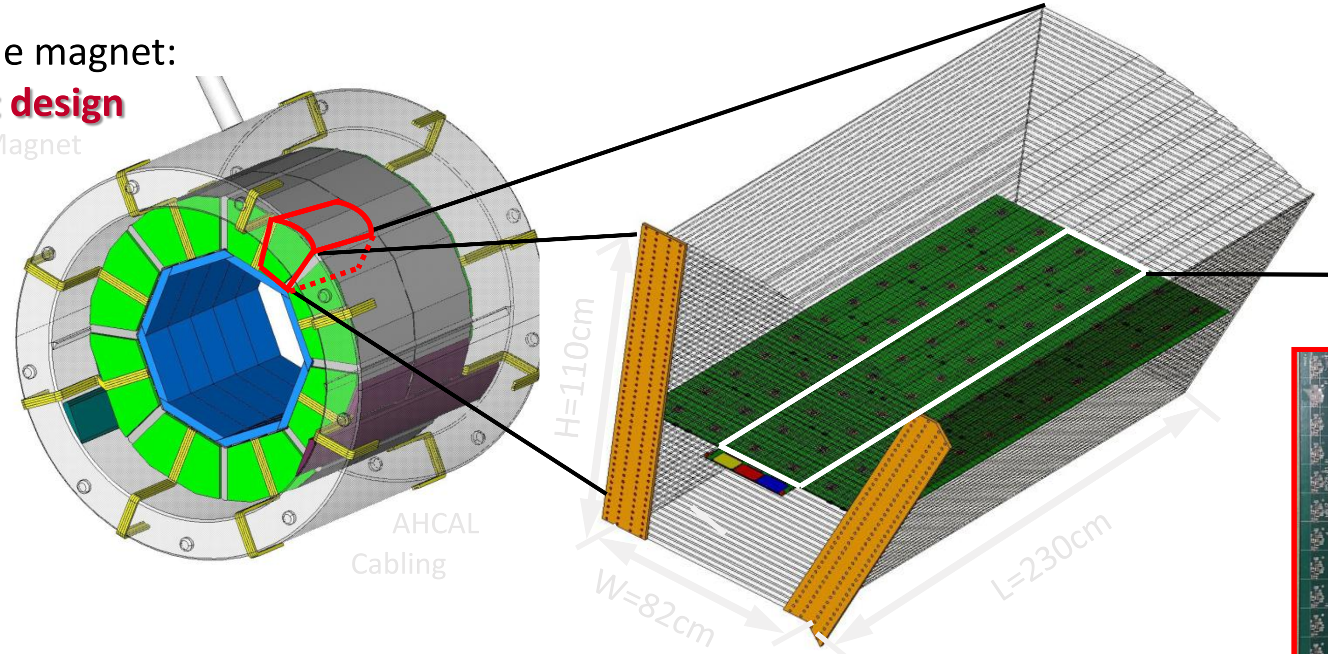


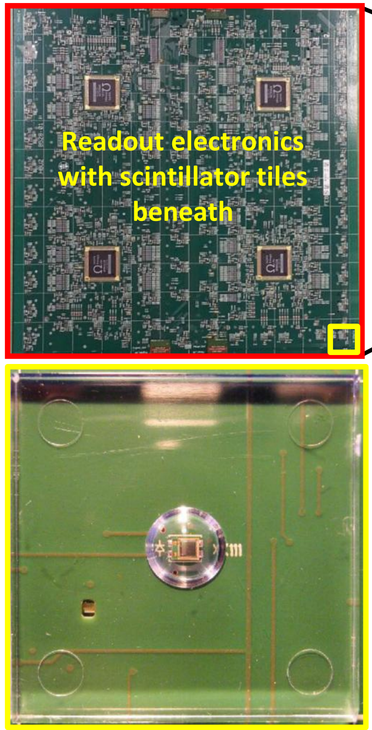


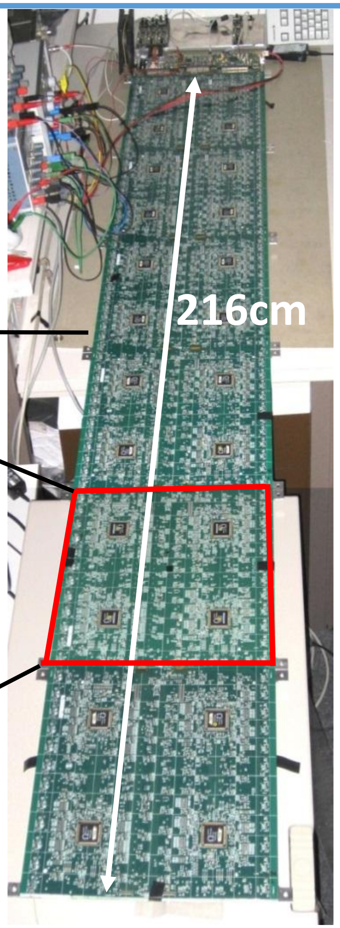


AHCAL overview

AHCAL inside magnet:
compact design



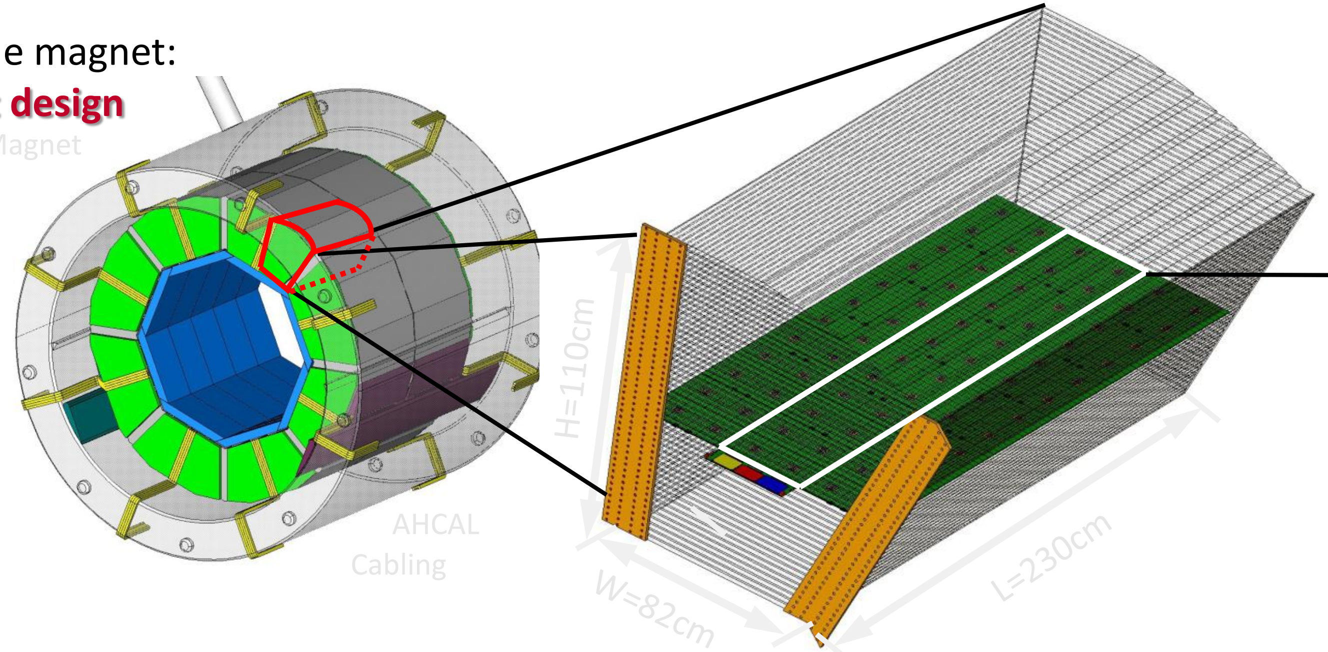


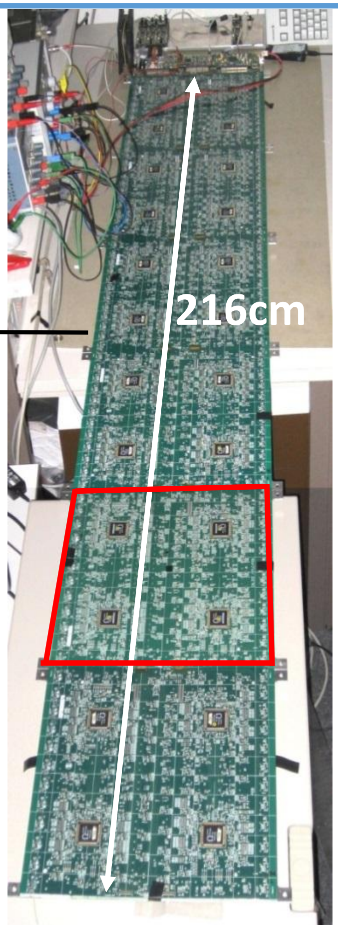


- Sandwich calorimeter: scintillator-SiPMs with steel absorbers
  - Electronics fully integrated into active layers
- High granularity: 8M channels in total
- Challenges for mass assembly and data concentration
- Power-pulsing at ILC: passive cooling for active layers

AHCAL overview

AHCAL inside magnet:
compact design

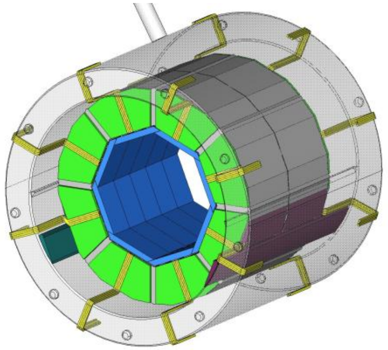


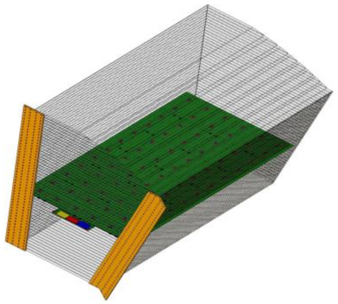


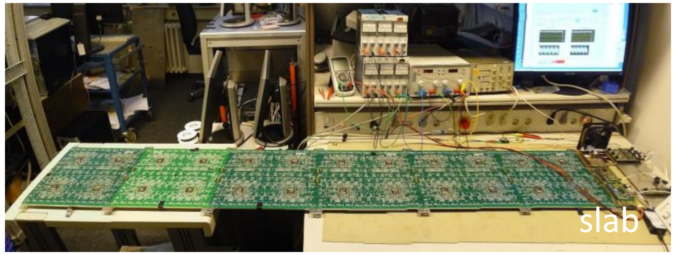
- Passive cooling for AHCAL active layers at ILC
  - Power-pulsing at ILC: low duty cycle (1%) with bunch trains at 5 Hz
  - FE electronics designed for the ILC bunch structure
- Challenges for CEPC: no power pulsing
  - Electronics: continuous readout
  - Cooling scheme

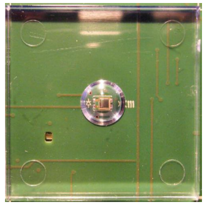
High granularity: numbers!

- AHCAL
- 60 sub-modules
- 3000 layers
- 10,000 slabs
- 60,000 HBUs
- 200,000 ASICs
- 8,000,000 SiPMs + tiles







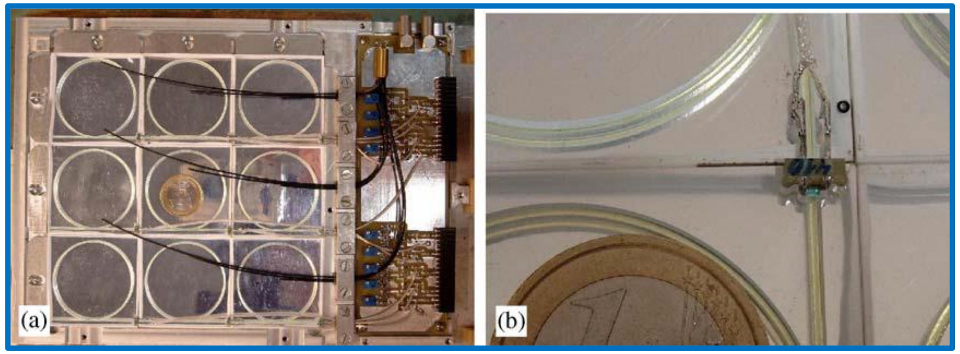


- 1 year
- 46 weeks
- 230 days
- 2,000 hours
- 120,000 minutes
- 7,200,000 seconds

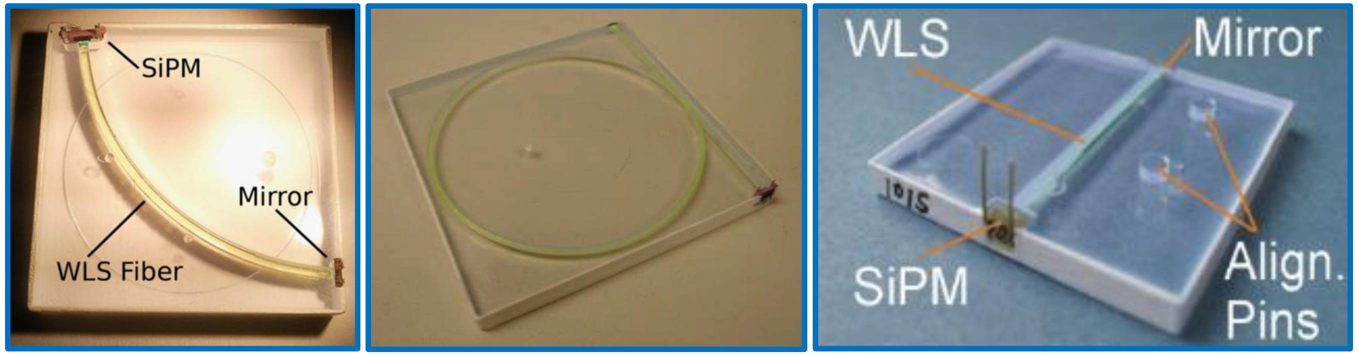
Key: automated mass assembly

Evolution of the SiPM-tile design

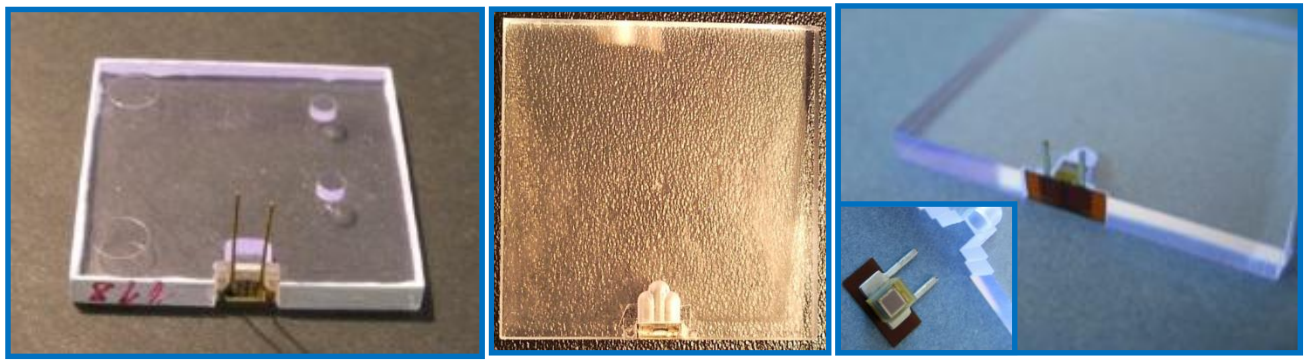
2003: MiniCal



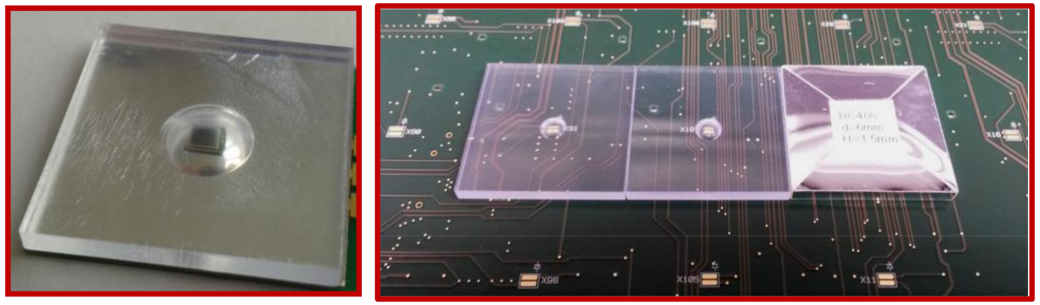
2005-2012: tile with WLS



2009-2014: tile without WLS, side-coupling



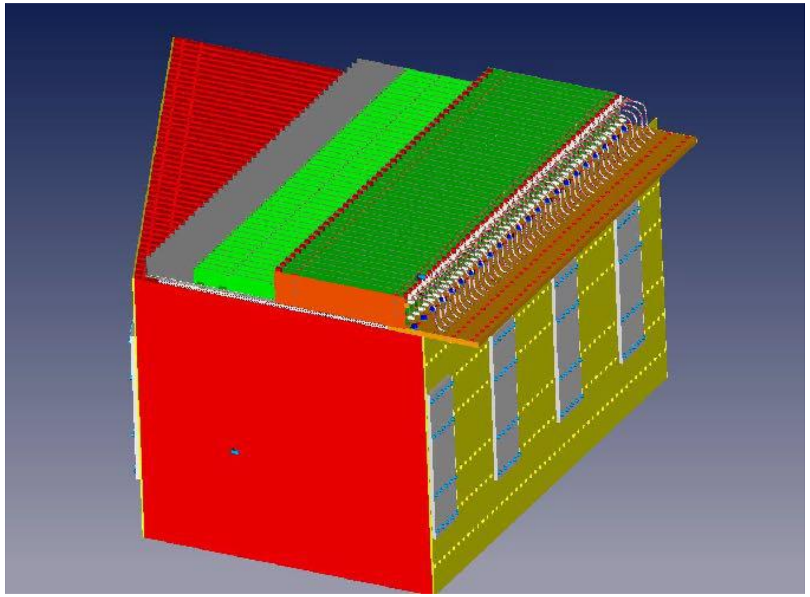
2013-2016: SiPM-on-tile, bottom coupling



A long way to the design for automated mass assembly

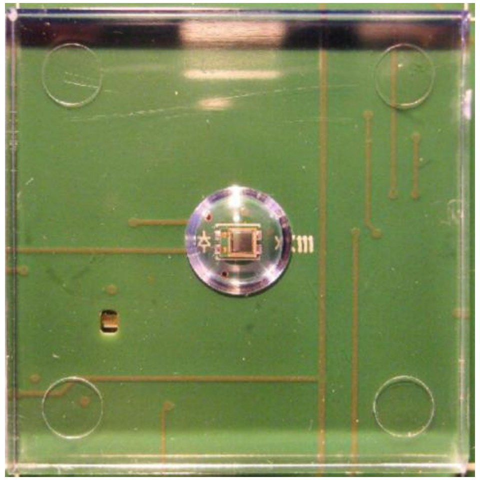
AHCAL tech. prototype: goals

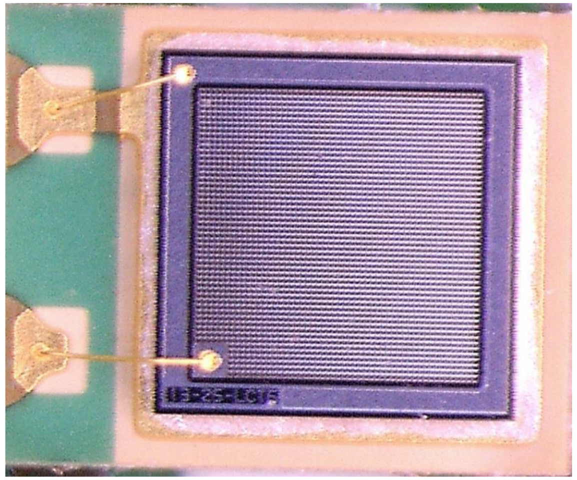
- Technology
  - Demonstrate the scalability to build a final detector
  - Validate automated assembly and QA procedures
  - Evaluate the performance with
    - Active temperature compensation
    - Power pulsing
- Physics
  - Study showers in 5D
    - Energy, 3D position and timing (ns)
  - Validate simulation models in Geant4
  - Study timing in particle flow

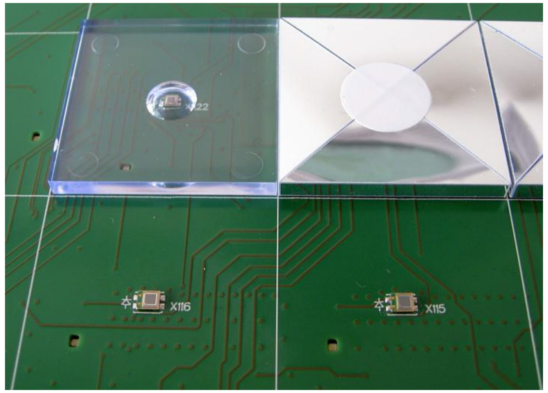


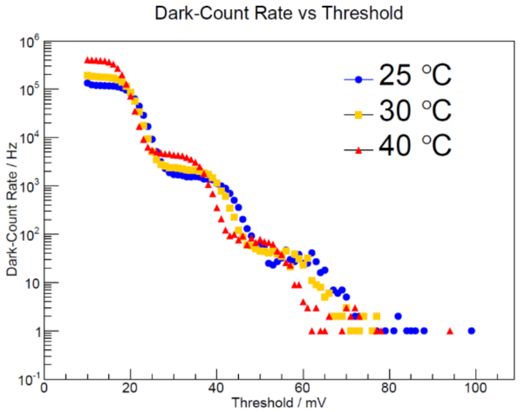
Detector unit: SiPM-on-tile design

- SiPM: greatly improved performance
  - Reduced dark count
  - Lower inter-pixel crosstalk
    - Noise rate decreases quickly with threshold
  - Good uniformity (operational voltage, gain)
    - Simplifies in-situ calibration
- Tile design
  - Simple for tile mass production (by injection molding)
  - Excellent response uniformity
  - Suitable for automated mass assembly with surface-mounted SiPMs

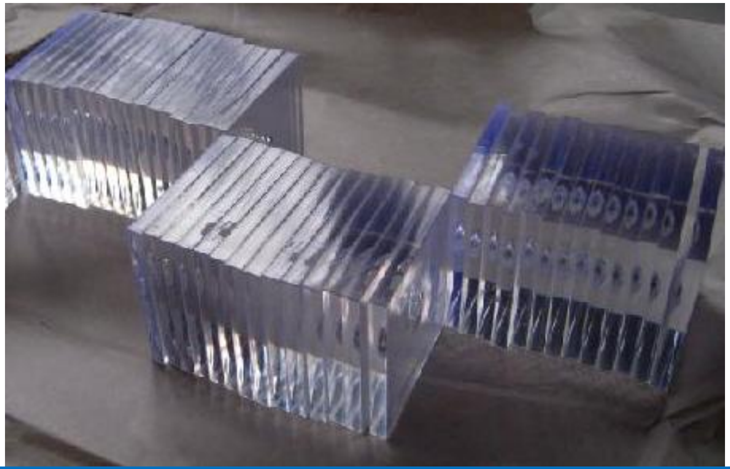


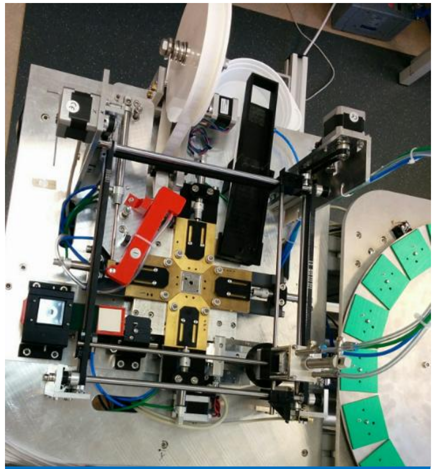


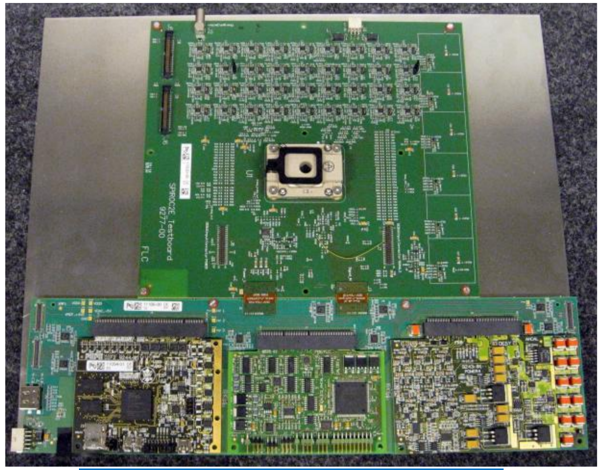


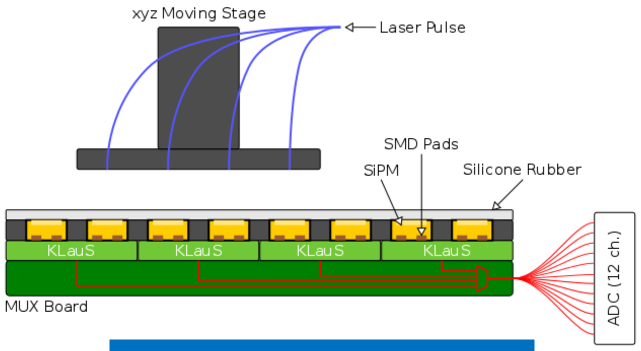


Construction and QA


Scintillator tiles by injection molding

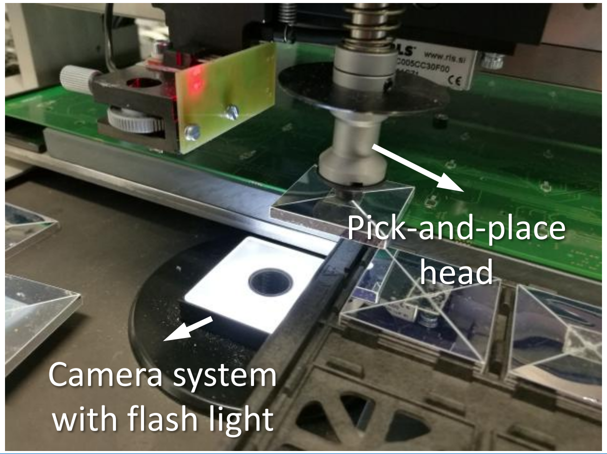

Wrapping machine


ASIC test stand

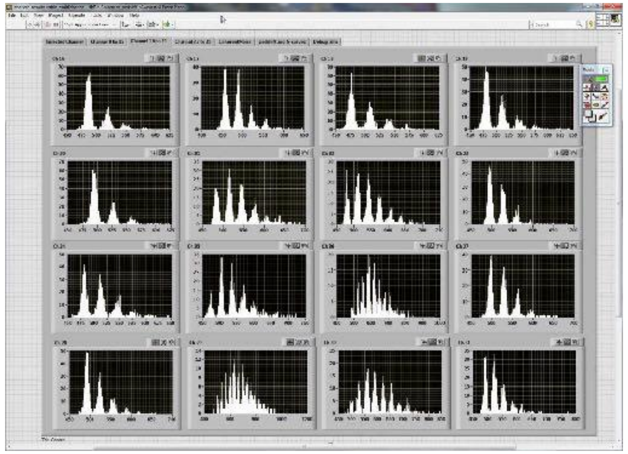


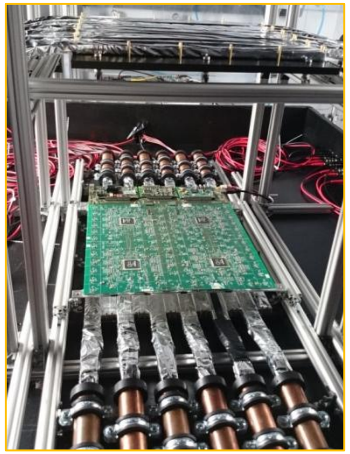
SiPM test stand with laser


Readout modules



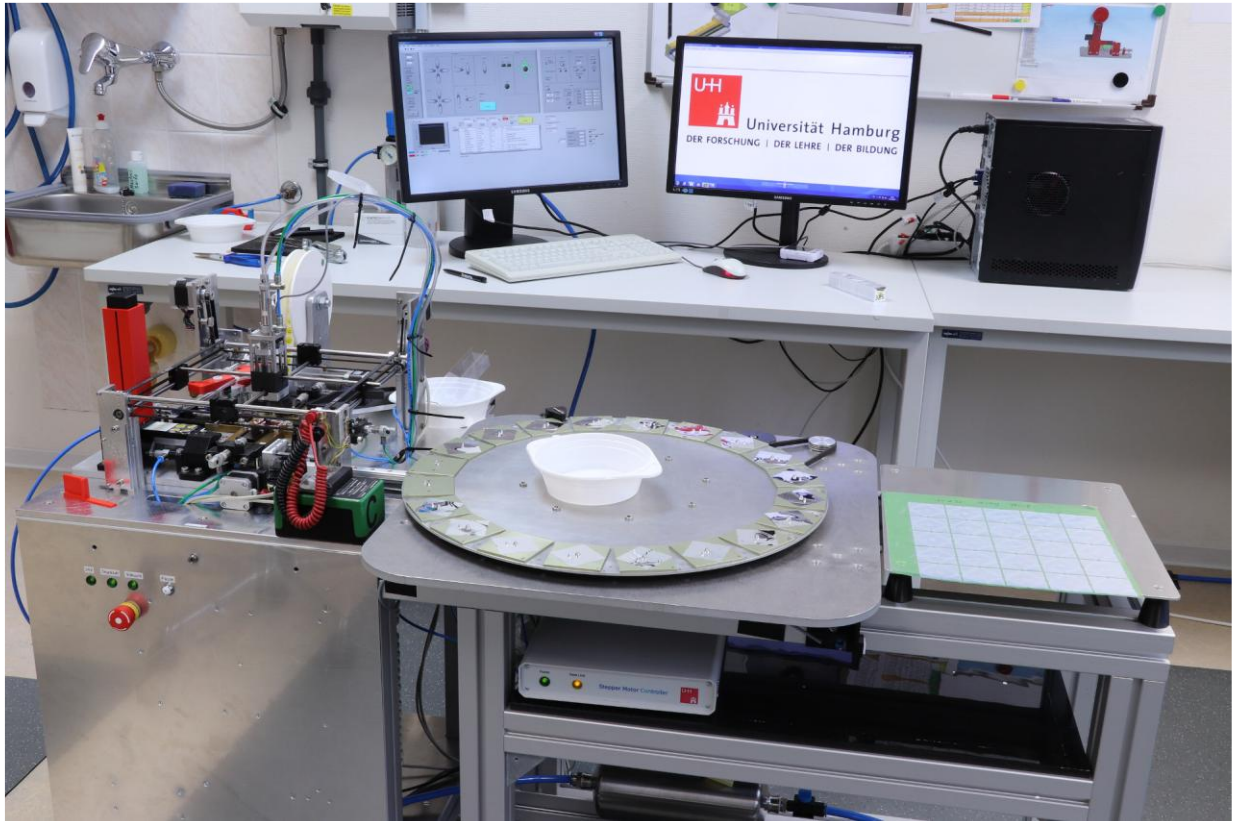
Automated assembly machine

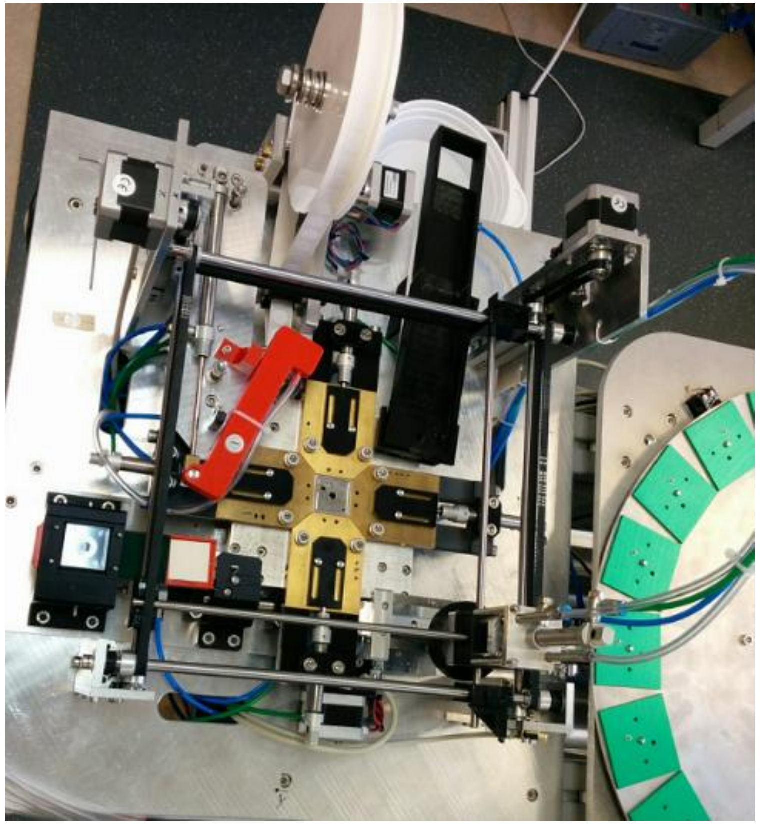

On-board LED testing


Cosmic test stand

Tile wrapping

University of Hamburg





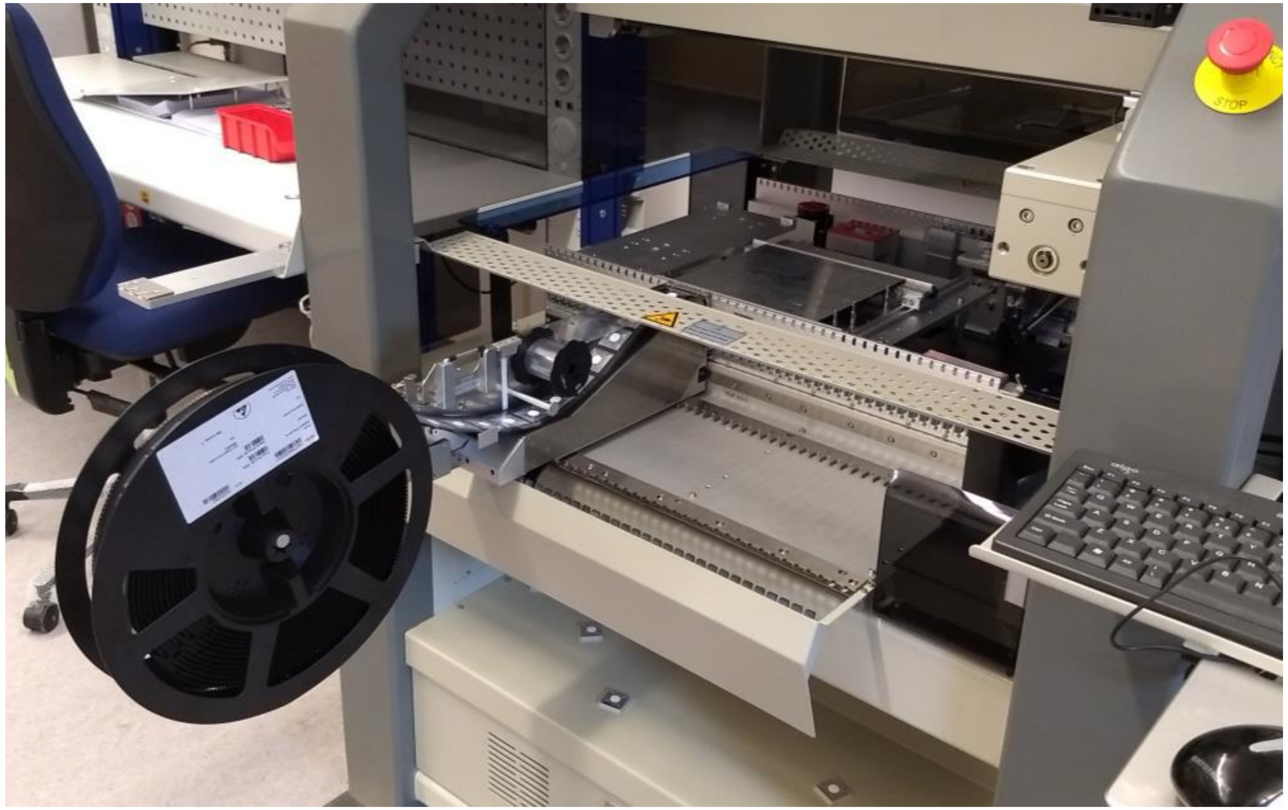
25k tiles in total

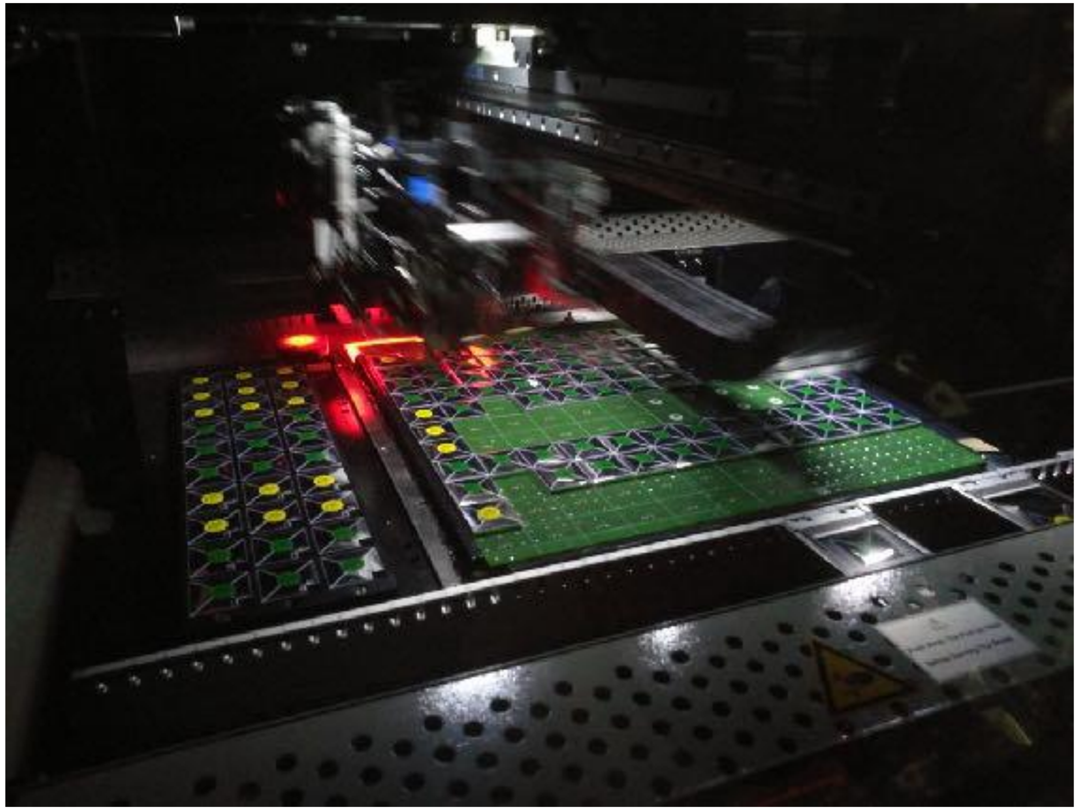
- Scintillator tiles need wrapping with reflective foil for optimal performance
- A custom-made machine for wrapping

Started in Oct. 2017

Tile assembly

University of Mainz



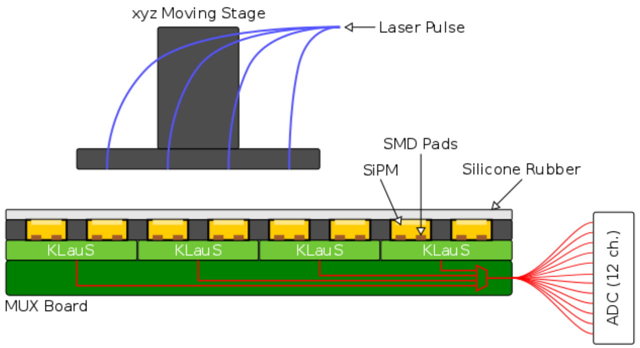


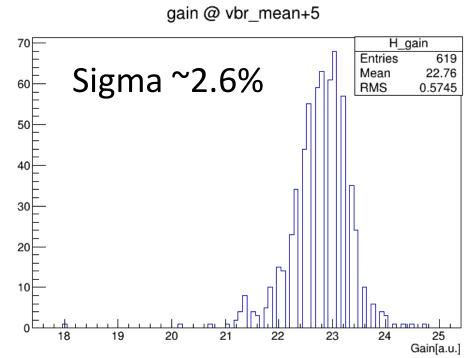
- Glue dispensing machine: put glue on PCB before tile assembly (not in photos)
- Pick-and-place machine (industry standard): trained for tile assembly

Started in Nov. 2017

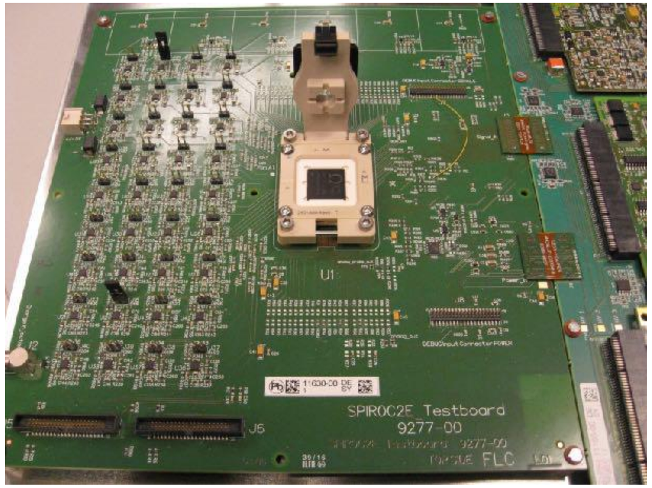
Quality Assurance (1)

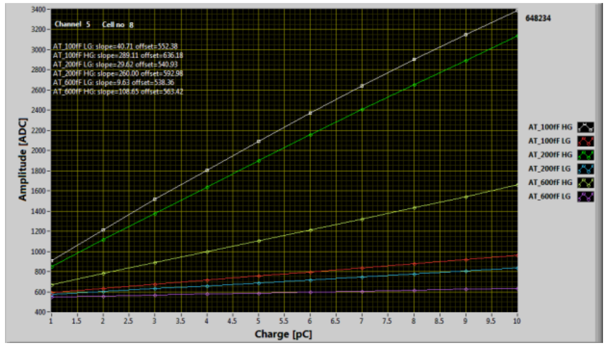
- Scintillator tiles
  - Spot check for mechanical tolerances
  - Some deviations affected automated wrapping and assembly
- SiPMs:
  - Spot check for break-down voltage, gain, noise, cross-talk
  - All samples passed, excellent uniformity
- ASICs
  - Semi-automated tests on a dedicated board
  - Yield 80~90%





University of Heidelberg

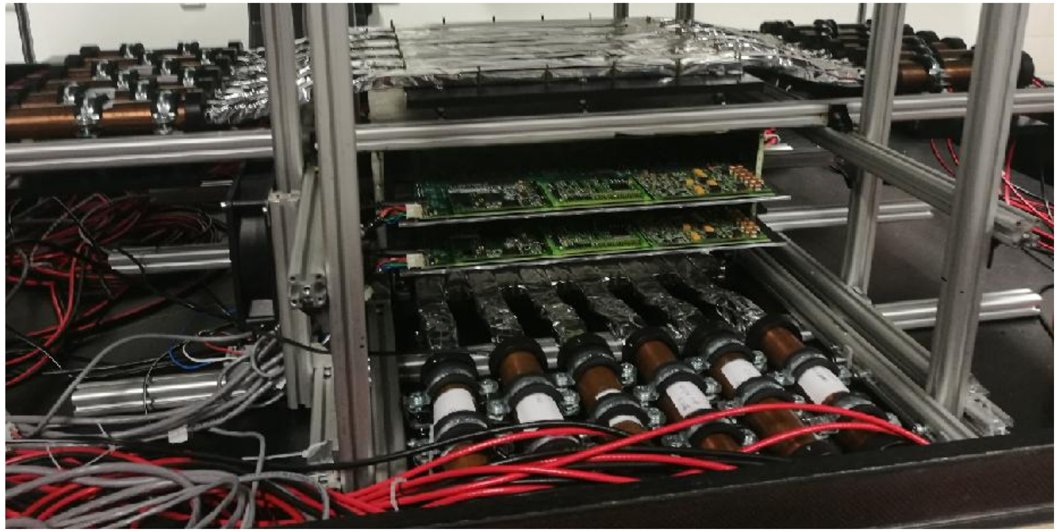


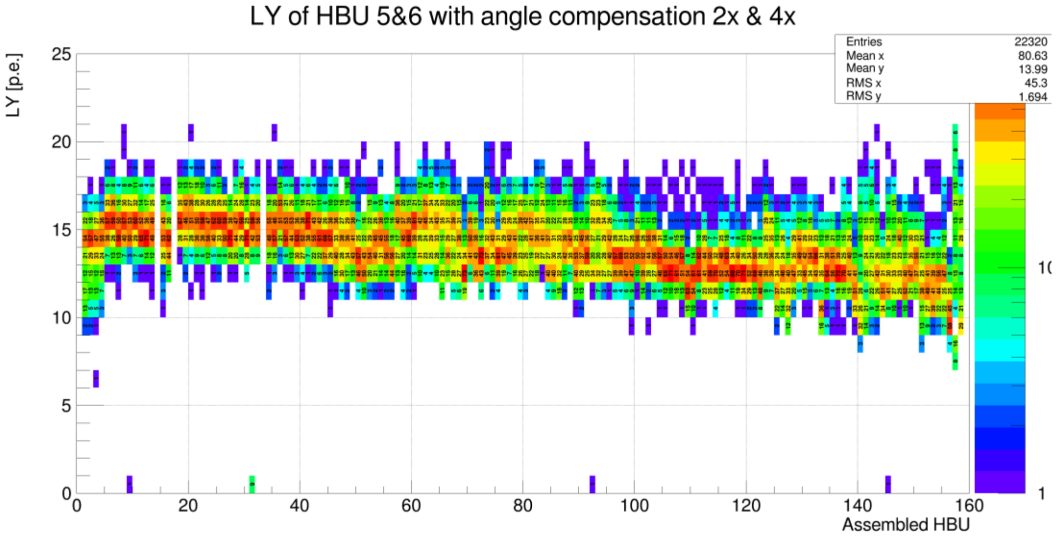


University of Wuppertal

Quality Assurance (2)

- Readout modules (HBUs) without tiles
  - Tested with on-board LEDs system before tile assembly
  - 158 out of 160 boards OK
- HBUs with tiles
  - Extensive tests with cosmic muons
  - Most boards: very good light yield uniformity

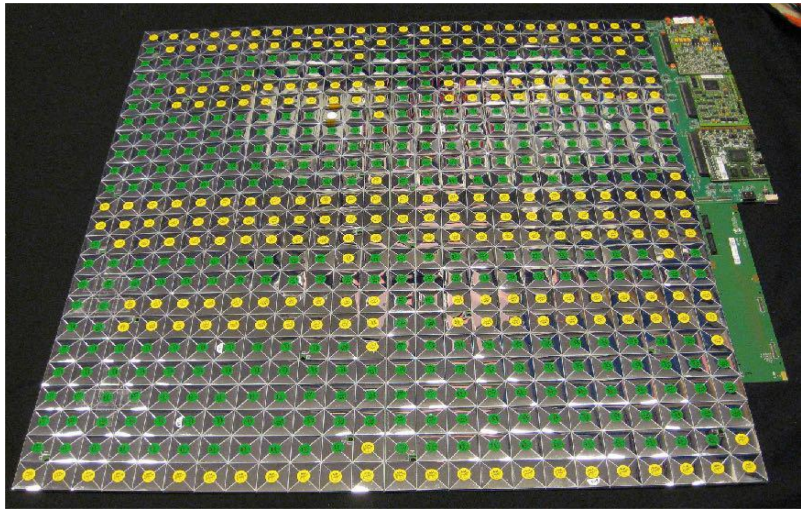




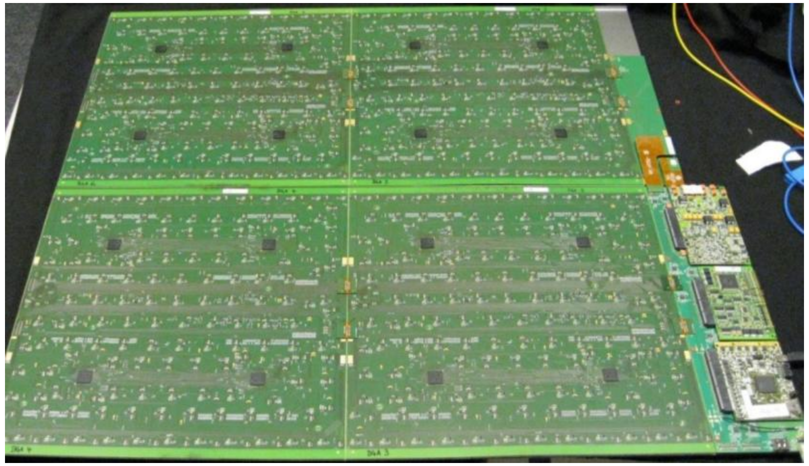
Active layer: integration and commissioning

DESY

- Interface boards
  - A set can serve up to 18 readout modules for the ILC HCAL
  - DIF: interface between ASICs and data concentrator
  - CALIB: control on-board LEDs
  - POWER
    - Power distribution and regulation
    - Cycling capacitors for power pulsing



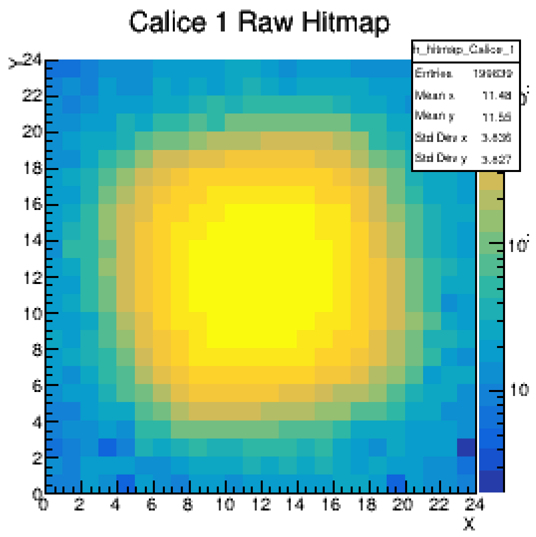
An active layer: 2x2 HBUs with a set of interface boards

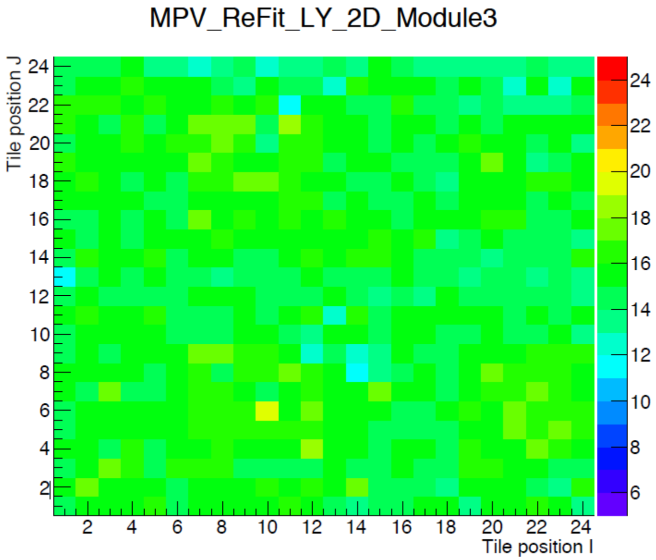


Active layer: commissioning

DESY

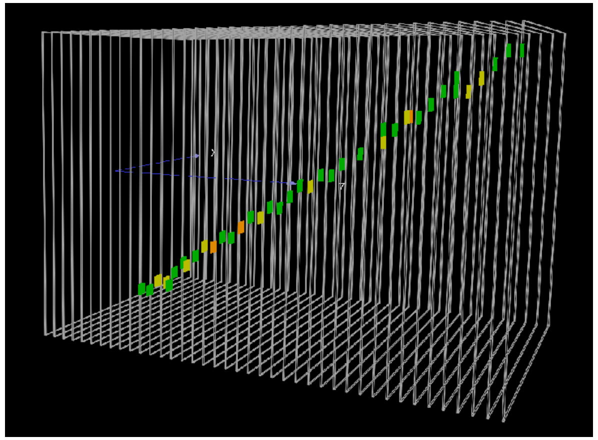
- Commissioning with cosmic muons:
  - Light yield
  - DAQ stability
- Commissioning with DESY electron beam
  - 5 layers at a time without absorbers (in “air stack”)
  - Initial MIP calibration: automatic scan for all channels
  - Active temperature compensation for SiPMs
- 8 dead channels out of 21,888 in total

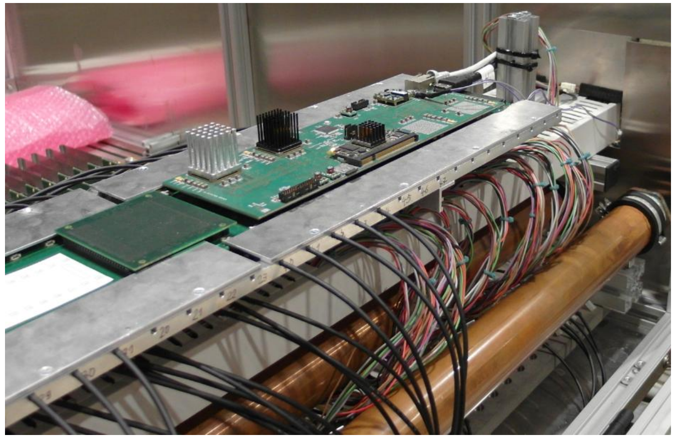




Stack integration and commissioning

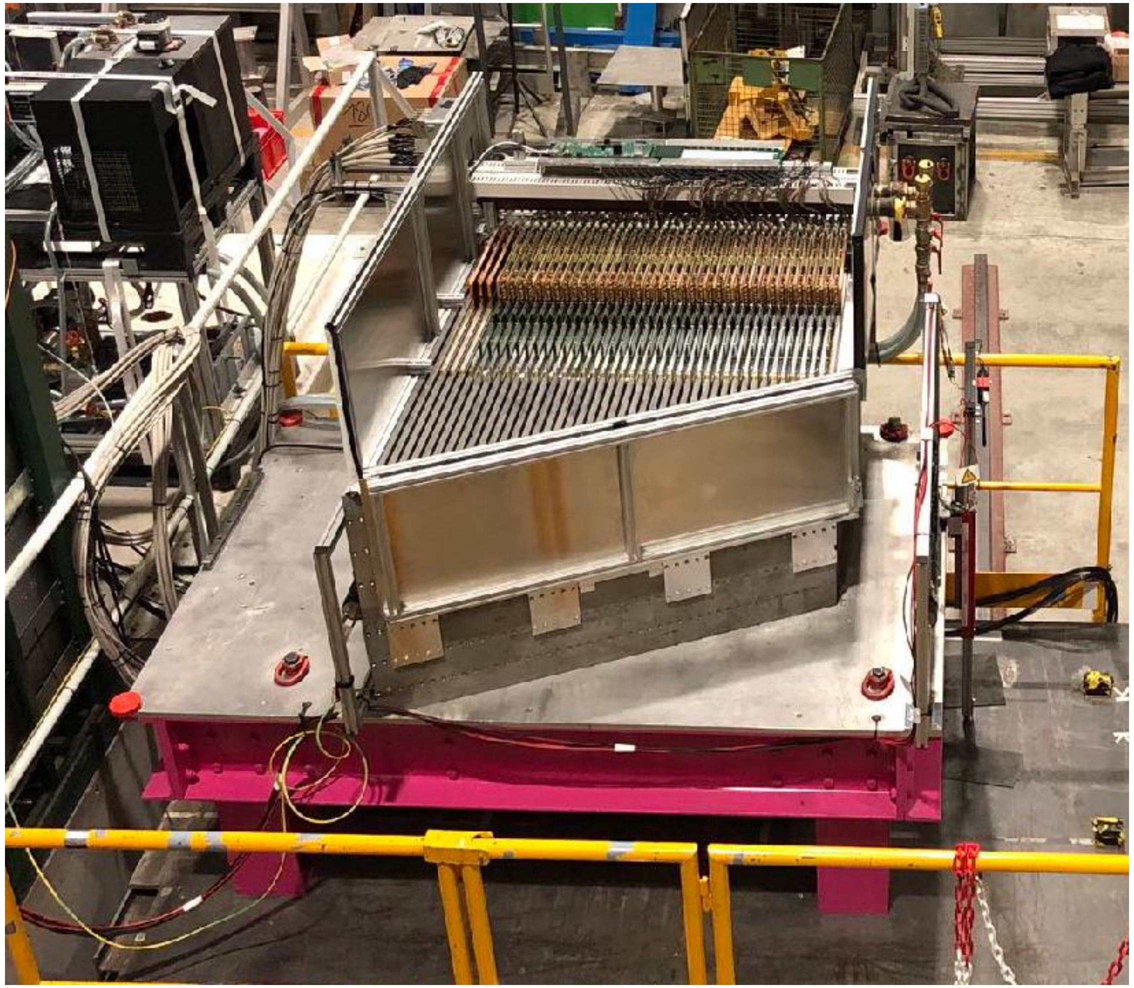
- Integration
  - Stack: dimensions for a module of the final full collider detector
  - Data concentration
    - Wing-LDA (hardware)
    - 1x Ethernet for data from all layers
  - Data acquisition: EUDAQ
  - Cooling system
    - Only for interface boards
- Commissioning with cosmics
  - Test the full software chain





AHCAL technological prototype

- 38 active layers
  - 21,888 channels
  - 608 ASIC chips
  - 2x2 HBUs (72x72 cm^2) per layer
    - 576 channels
- Absorber structure
  - 40 layers (EUDET stack)
  - 1.7cm thick per layer
  - ~4λ in total

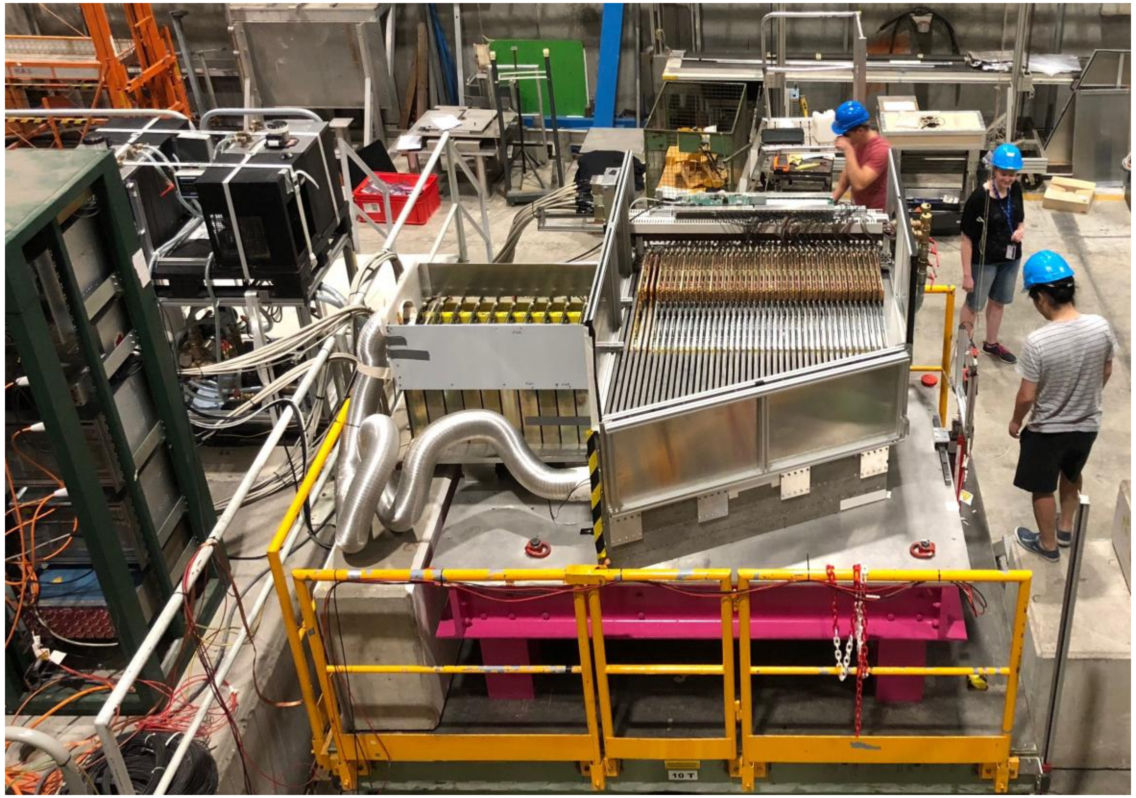


Goals of SPS beam tests

- Technology
  - Demonstrate capabilities of the SiPM-on-tile calorimeter concept with a scalable detector design
  - Achieve reliable operation of a large prototype
- Physics
  - SiPM-on-tile HCAL performance: energy linearity and resolution up to 100 GeV
    - For single particles: electrons, pions
  - Shower profiles and separation
  - Shower timing

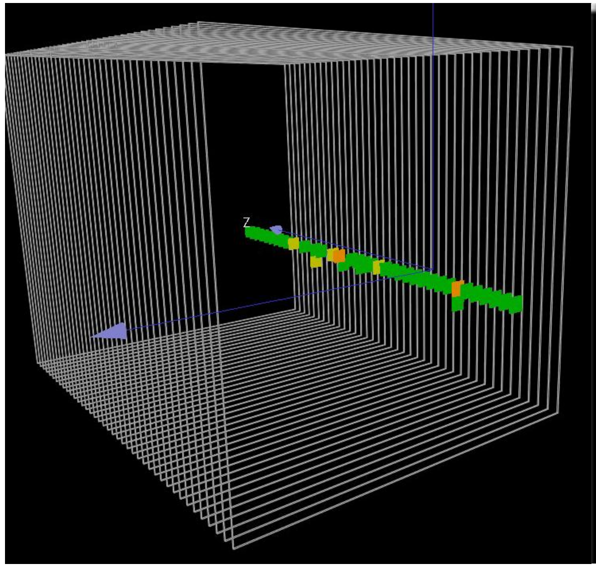
Beam tests at CERN SPS in 2018

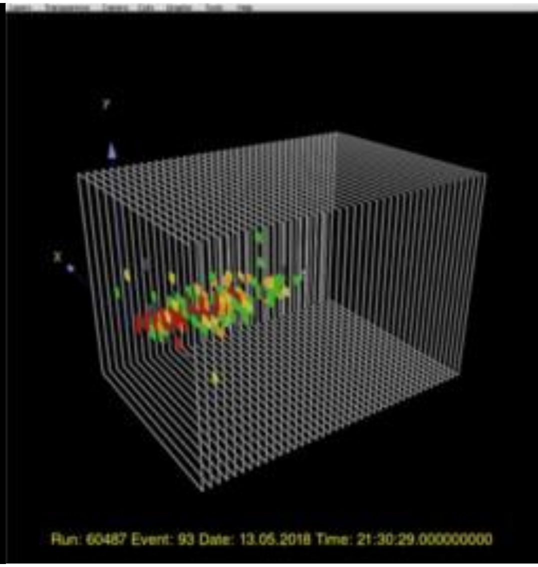
- 2 beam periods at SPS H2
  - 2 weeks in May 2018
  - ~1 week in June-July 2018
- Setups
  - In May: AHCAL main stack
  - In June: as in May, plus
    - One module with 6x6 cm² tiles
    - Tail-catcher, CMS HGCAL "thick stack" (12 layers of single HBU, 7.4 cm thick steel absorber)
    - Single HBU in front of absorber as pre-shower
  - Mounted on the movable platform
- Beam area instrumentation
  - Wire chambers
  - Trigger scintillator
  - Cherenkov counter

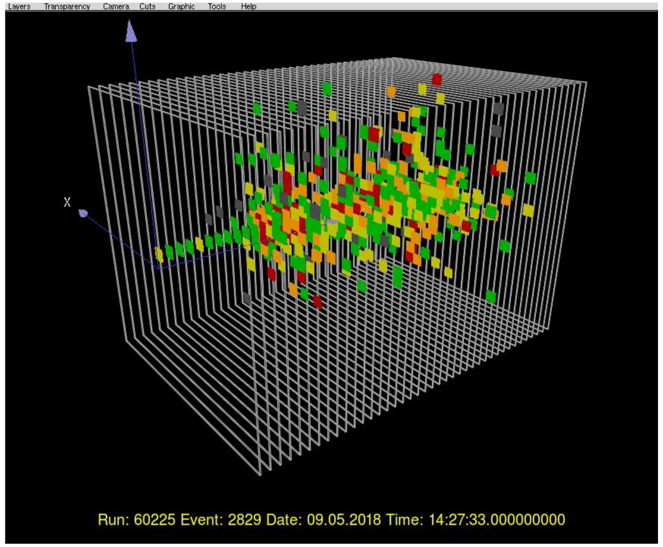


Data taking status

- General
  - Stable running
  - All layers working well, <0.1% dead channels
- Muons: MIP calibration
  - Scanning at several positions
- Electron: energy scan
  - Range: 10-100 GeV
  - 0.2~0.4 M events per energy point
  - With and without power pulsing
- Pion (negative): energy scan
  - Range: 10-200 GeV
  - 0.4~0.6 M events per energy point
  - With and without power pulsing

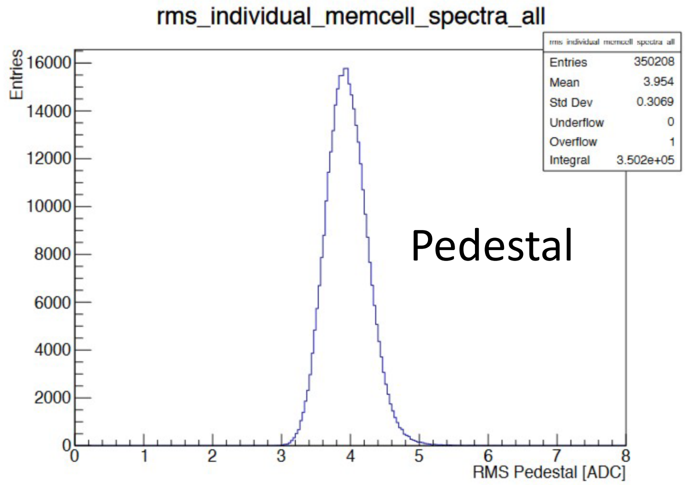


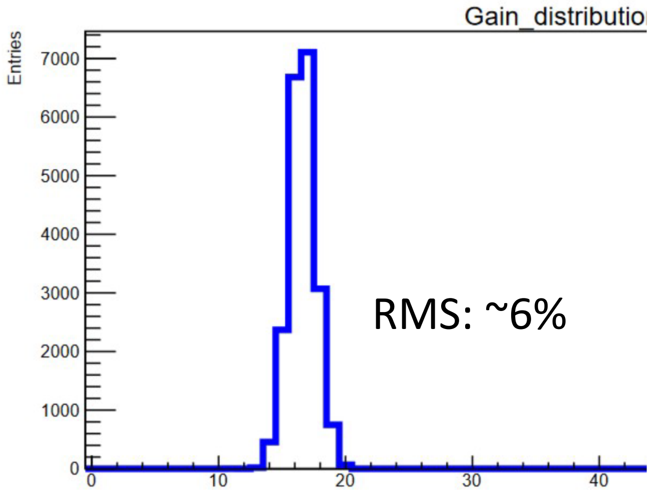


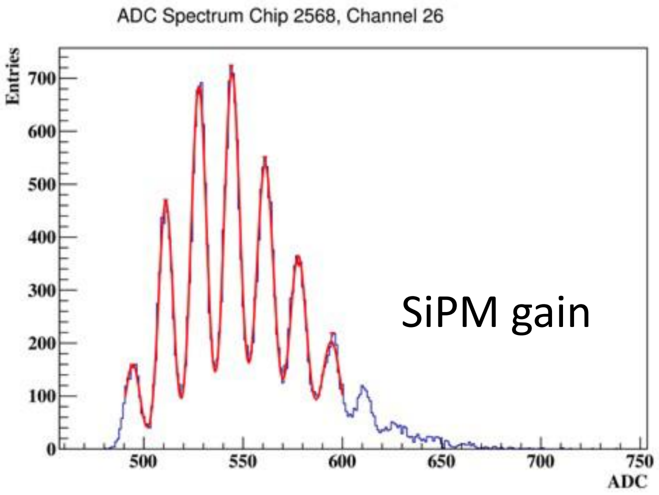


Gain calibration

- Extracted from on-board LED data
- Pedestal
  - Hints on noisy/dead channels
- SiPM gain
  - ADC translated to #pe in SiPM
  - Basis for SiPM saturation calibration
  - Monitoring SiPM/detector stability
- Status
  - Homogeneous gain
  - Stable operation



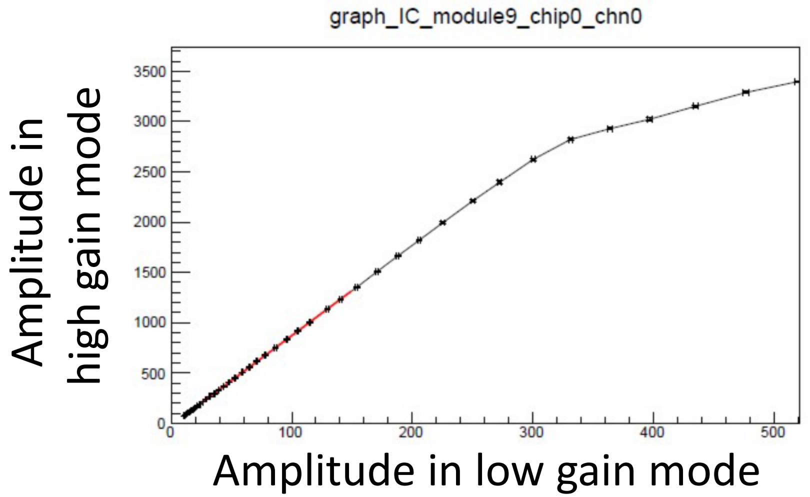


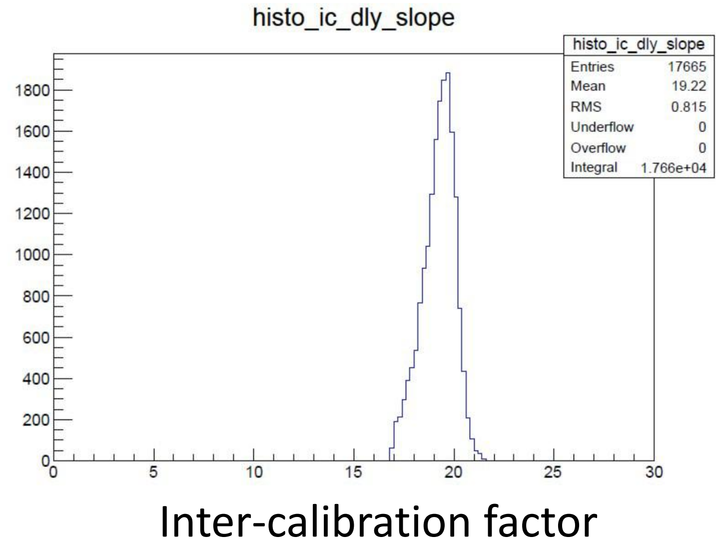


Inter-calibration: high gain and low gain

- 2 modes: High gain vs low gain
  - Two preamps in ASIC with different amplification factors
  - To increase the dynamic range
  - The ratio of two amplification factors: inter-calibration
  - Extracted from LED data

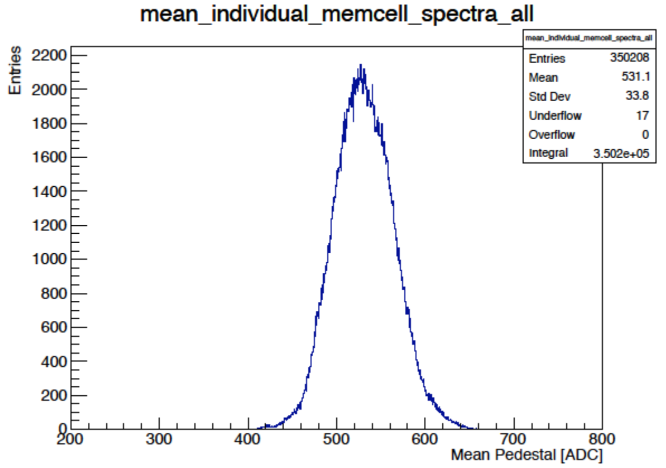
- Next steps
  - Pedestals in low gain mode
  - Application to testbeam data

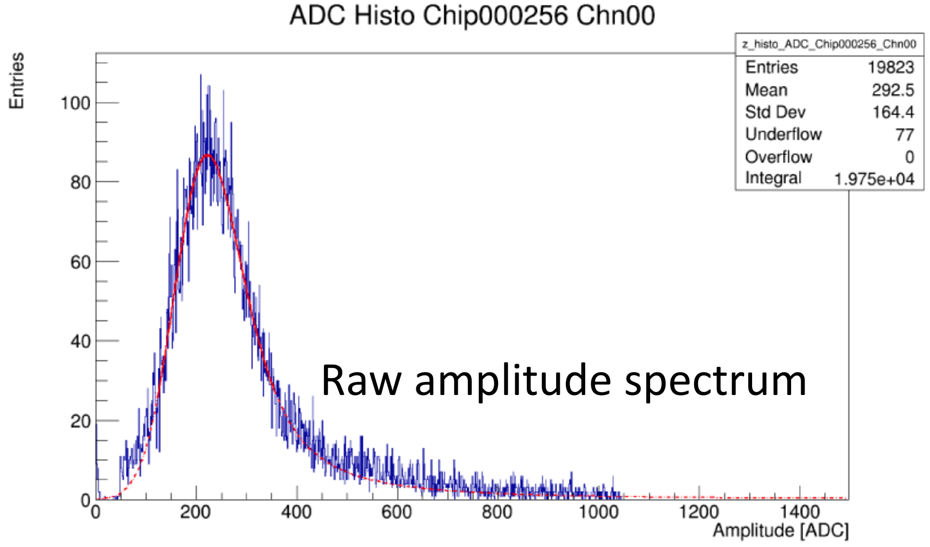




MIP calibration

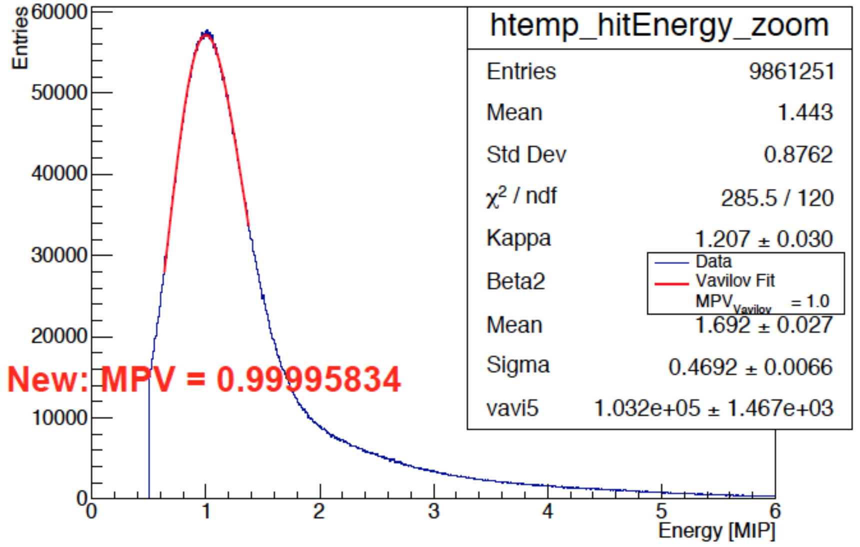
- Muons: position scan of the full detector
  - Use pedestals from non-triggered channels (~350k constants!)
  - Determine MIP scale for all channels (~22k channels)
- Calibrations for May and June data: done
  - Without and with power pulsing





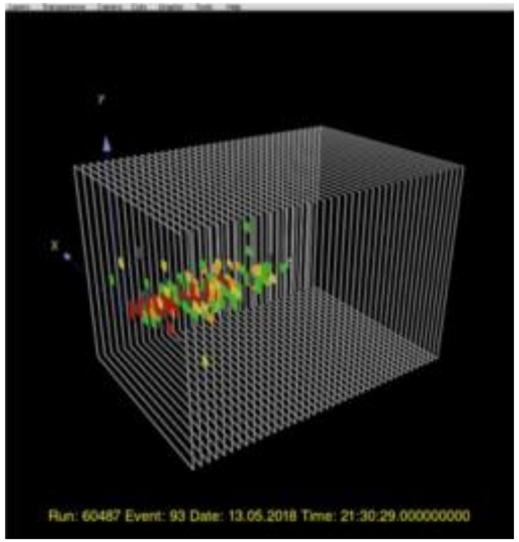
Raw amplitude spectrum

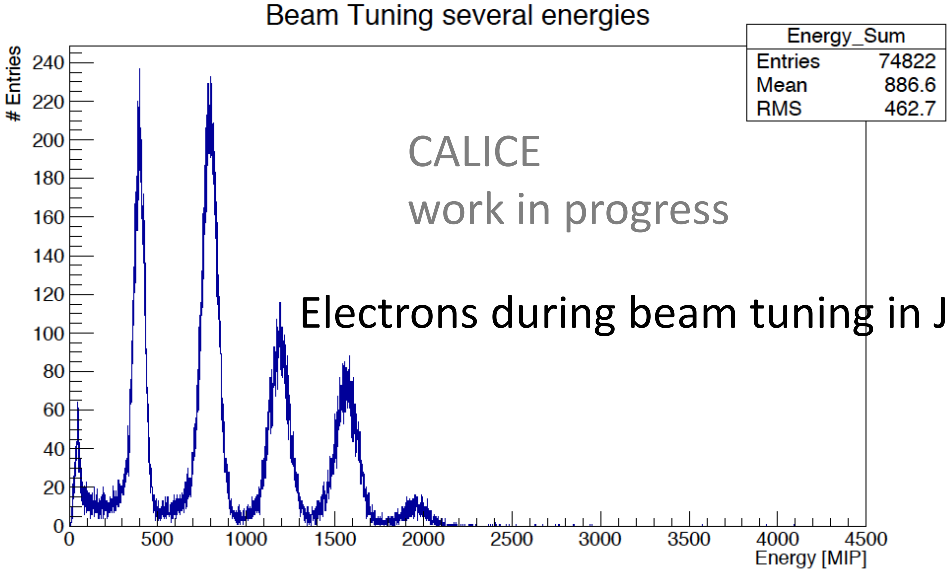
Calibrated amplitude spectrum



First glance at testbeam data

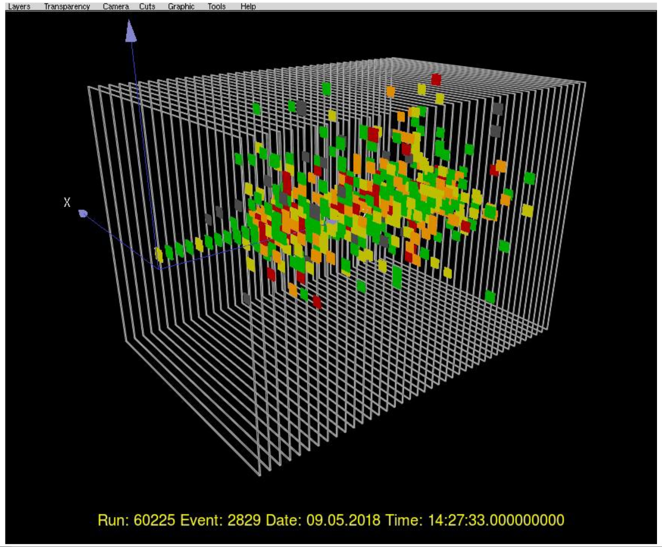
Electrons

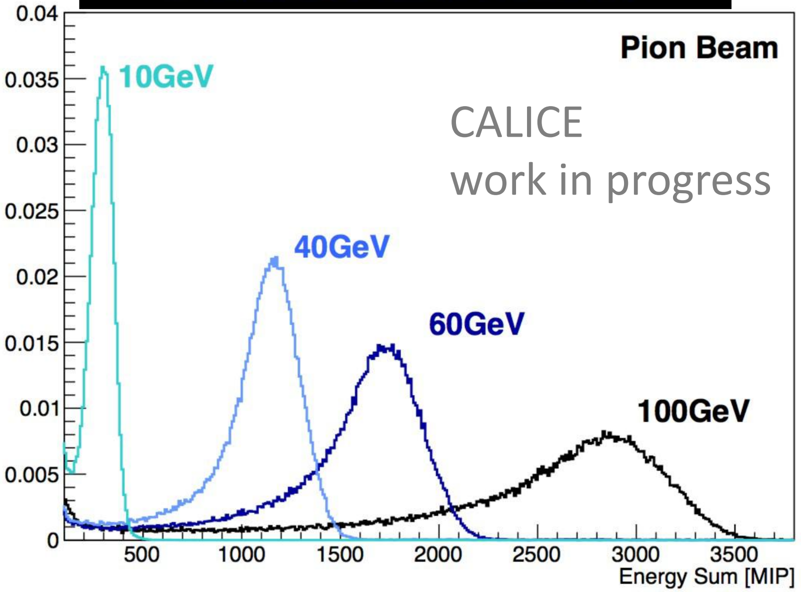




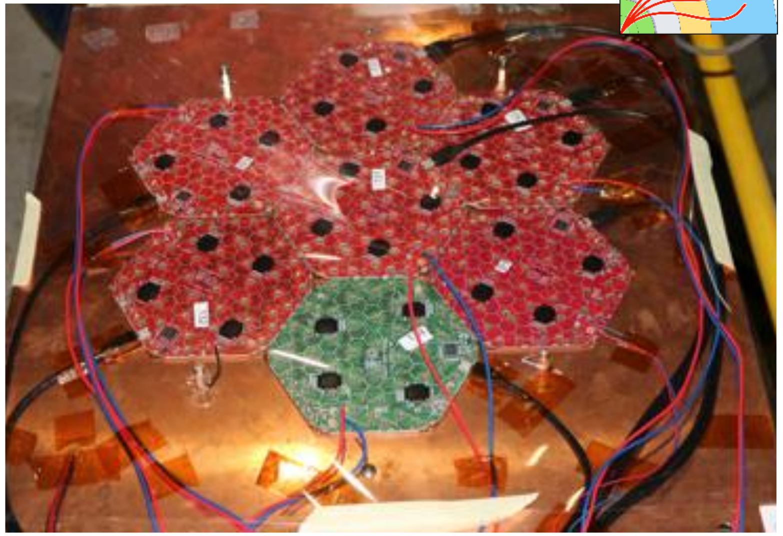
Electrons during beam tuning in June

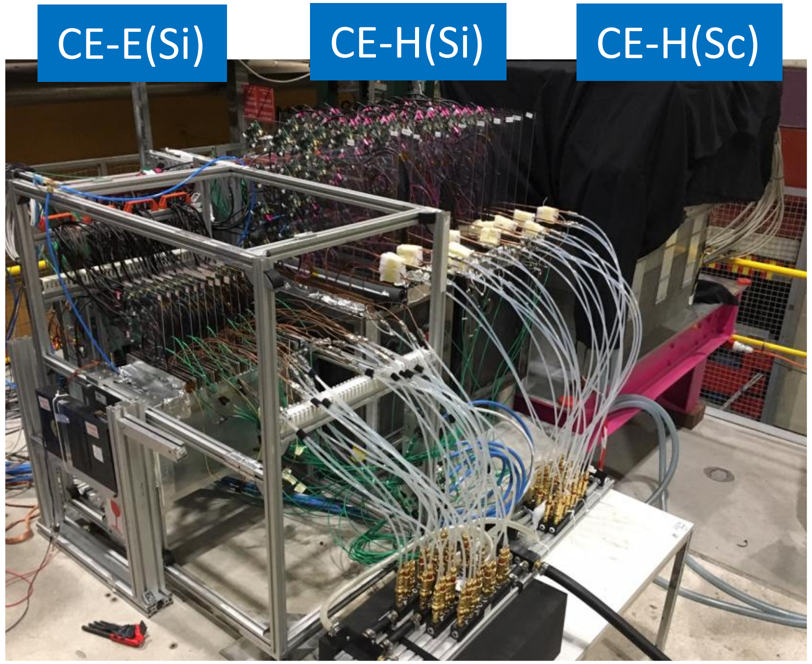
Pions

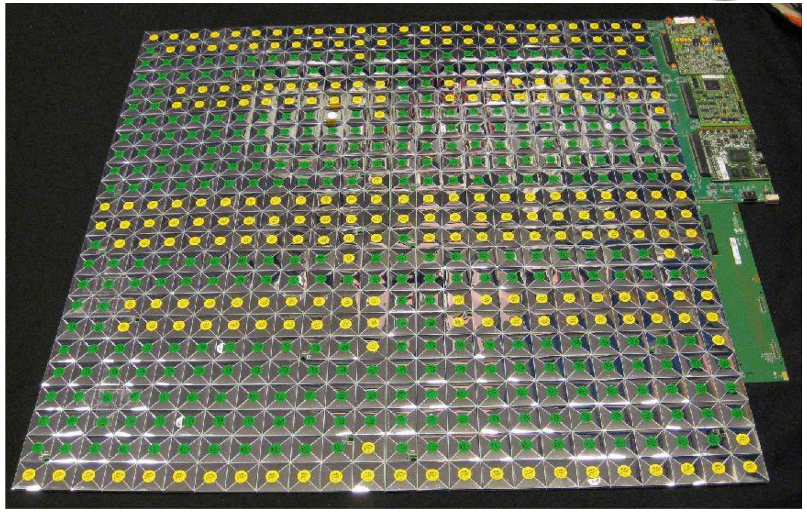




Common CALICE-CMS beam test



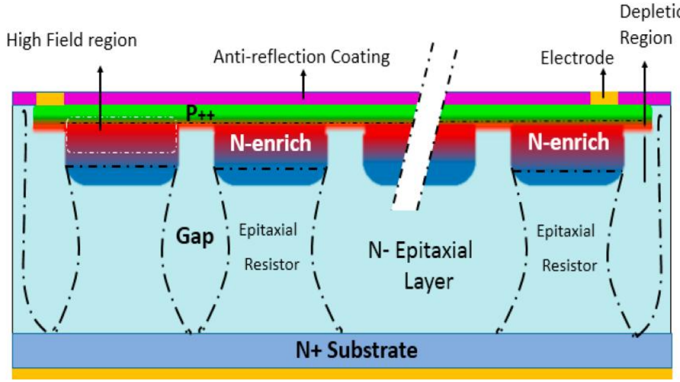




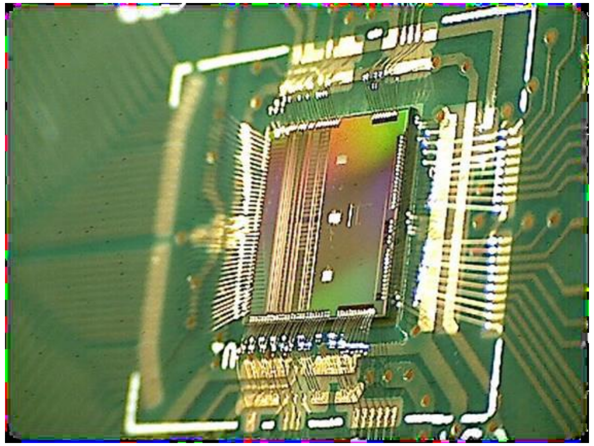
- CERN SPS H2: 2 weeks in Oct 2018
  - 94 silicon modules (6”) in the ECAL and front HCAL section (up to 40 layers)
  - 156 SiPM-on-Tile modules (39 layers) in the HCAL back section
    - =CALICE AHCAL prototype
  - Common DAQ: EUDAQ2 (AIDA2020)

Further R&D: new SiPM and ASIC

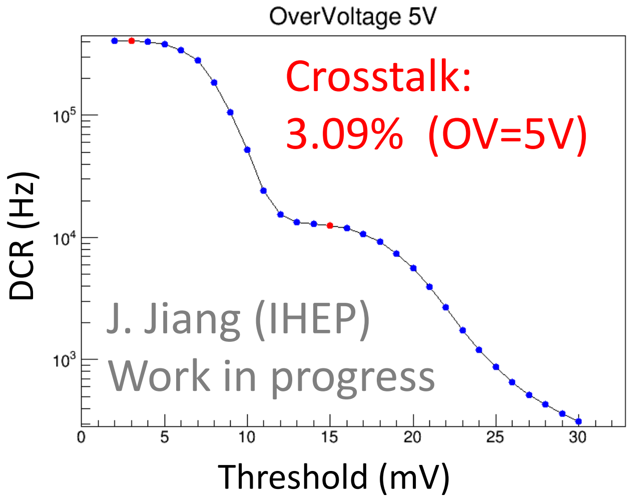
- New SiPM developed at NDL (Beijing Normal University)
  - High PDE with high pixel density (>=10k pixels per mm^2)
    - Vertical quenching resistor: high fill factor -> high PDE
  - High dynamic range: mitigate non-linearity effect with strong signals
  - Promising candidate to measure EM showers

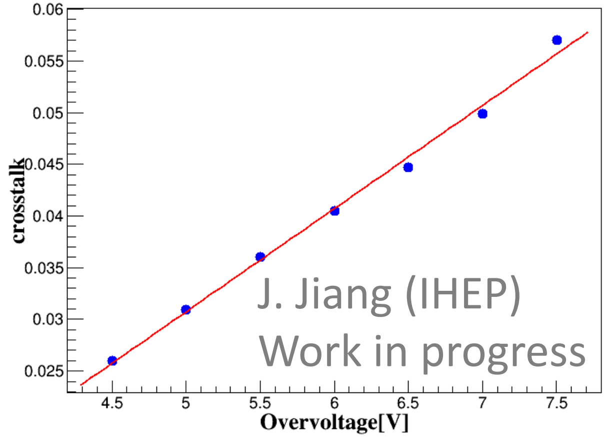


- KLauS ASIC (KIP, University of Heidelberg)
  - Low noise, low power dissipation
  - High precision for low-gain SiPM (small pixel size, e.g. ~10µm)
  - Continuous readout without dead time



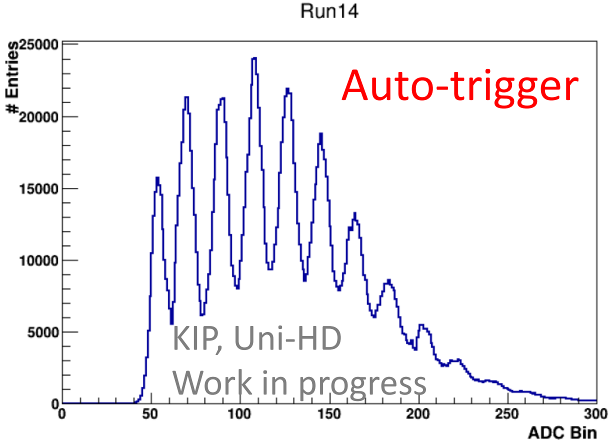
Further R&D: SiPM studies with Klaus

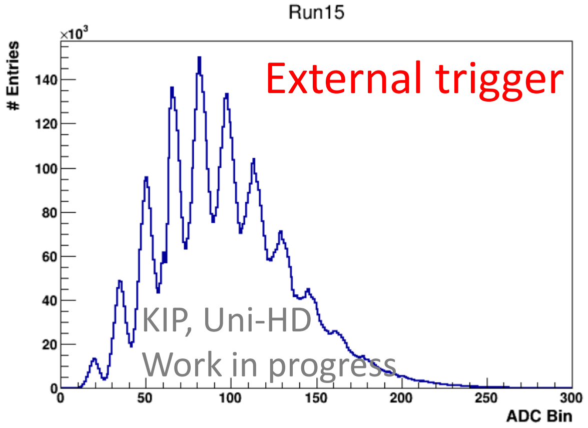




NDL-SiPM (1x1mm²) tested at IHEP

Low crosstalk (a few percent level) can ensure fast noise drop with threshold





NDL-SiPM tested with Klaus at KIP, Uni-HD

Single photons can be well distinguished (for small SiPM gain (on the order of 10^5)

Summary

- CALICE AHCAL technological prototype successully built and commissioned
  - ~22,000 channels (156 readout modules)
- Demonstrated scalibility to build a full detector
  - Novel detector design: SiPM-on-tile
  - Procedures for construction and quality assurance
- First beam tests with the AHCAL new prototype
  - Smooth and successful data taking
  - Calibrations finished
  - More analysis efforts ongoing
- Further R&D efforts
  - SiPM and ASIC, mega-tile, ...
- Plans: more beam tests (fast timing, tungsten absorber, ...)