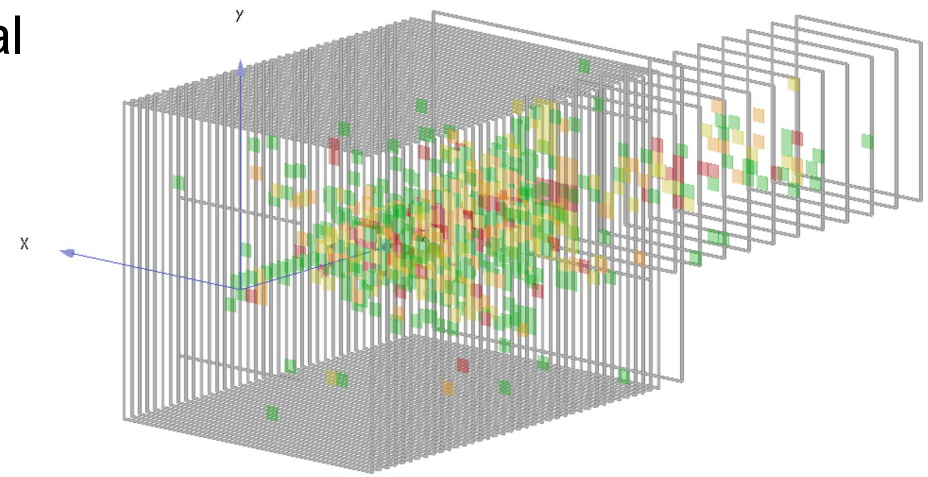
CALICE AHCAL technological prototype: overview and CERN testbeam analysis

- Motivation
- The large AHCAL technological prototype
  - Construction and commissioning
  - Testbeam: calibration and analysis
- Outlook



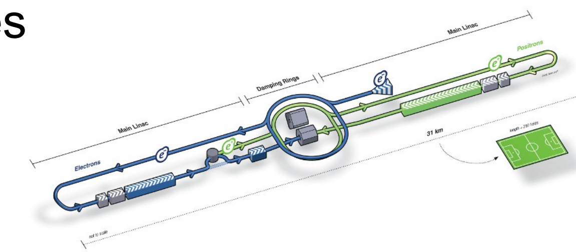
Katja Krüger, for the CALICE Collaboration

BMBF Scintillator R&D general meeting
6. July 2020

Motivation

Motivation: Future Higgs factories

- Higgs factory identified as next priority in European Strategy Update
- future e+e- colliders offer unique physics possibilities
  - precise model-independent Higgs couplings
  - precision measurements of W, Z and top properties
  - indirect and direct searches for BSM physics
- ILC: under political consideration in Japan
  - Initial √s of 250 GeV, upgradeable to 1 TeV

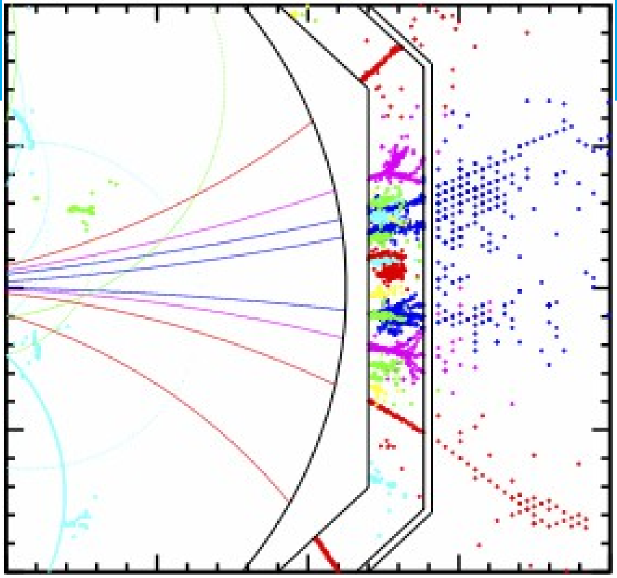


- CLIC: proposed at CERN
  - Initial √s of 380 GeV, upgradeable up to 3 TeV
- FCCee: possible first stage of FCC project at CERN
  - initial √s of 90 GeV, stages up to 350 GeV
- main interest for calorimeters at Higgs factory: jet energy resolution

Physics Process	Measured Quantity	Critical System	Physical Magnitude	Required Performance
Zhh $Zh \to q\bar{q}b\bar{b}$ $Zh \to ZWW^*$ $\nu\bar{\nu}W^+W^-$	Triple Higgs coupling Higgs mass $B(h \to WW^*)$ $\sigma(e^+e^- \to \nu\bar{\nu}W^+W^-)$	Tracker and Calorimeter	Jet Energy Resolution $\Delta E/E$	3% to 4%

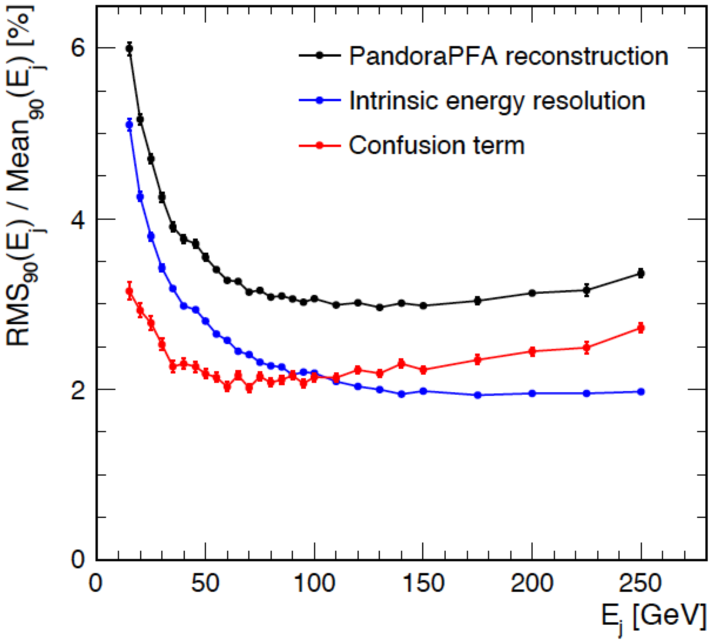
from ILC TDR

Jet reconstruction at a Linear Collider

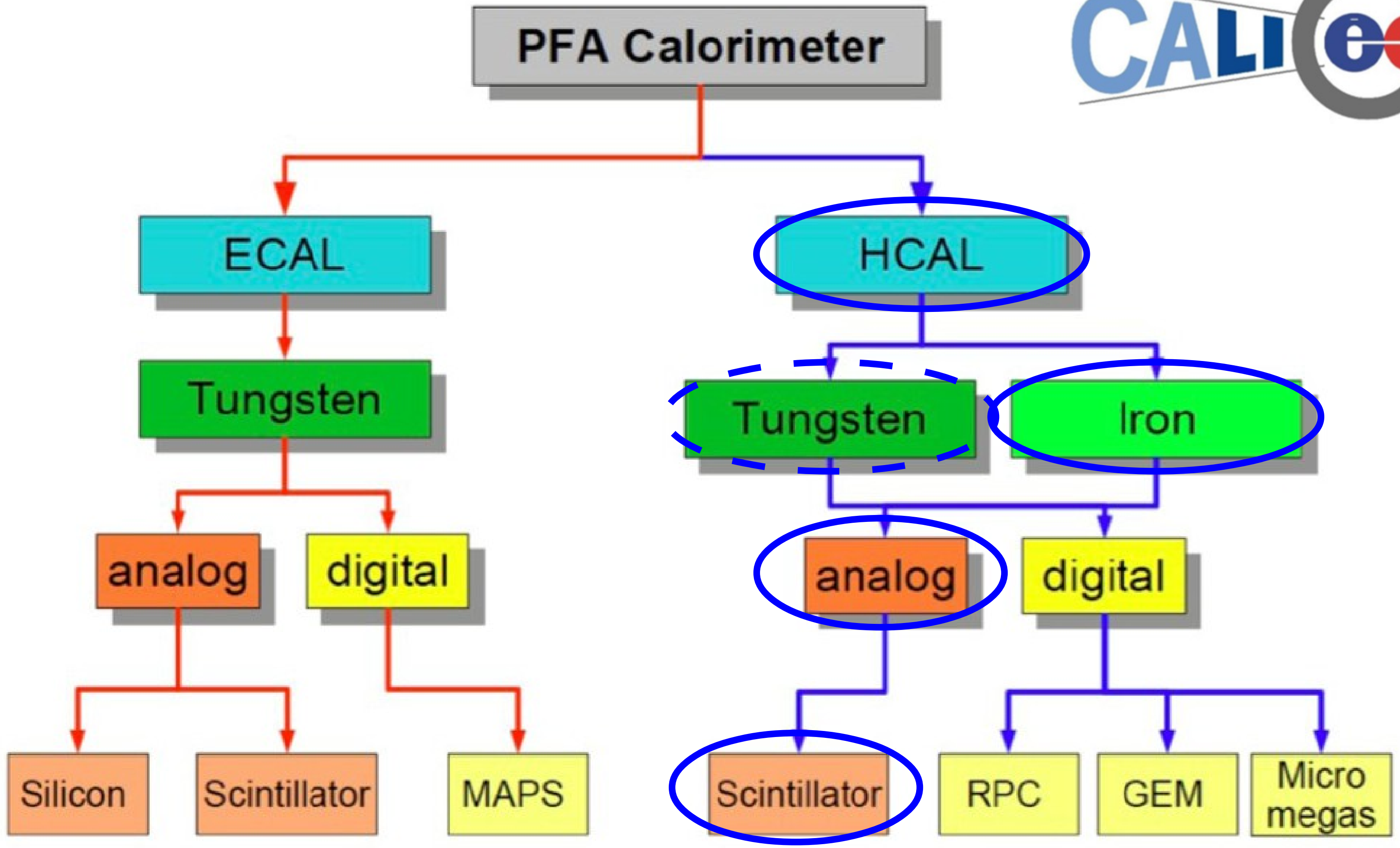


- goal: want to distinguish Z → jet jet from W → jet jet
- requires σ(E)/E ≈ 3-4%
- can be reached by particle flow algorithms (PFA)
  - for each particle within a jet: use the subdetector with optimal resolution
  - need to avoid double counting
- need an imaging calorimeter!

- requirements for the calorimeter:
  - highly granular
  - reconstruction of neutral particles: good energy resolution
  - calorimeter has to be within magnet coil: very compact

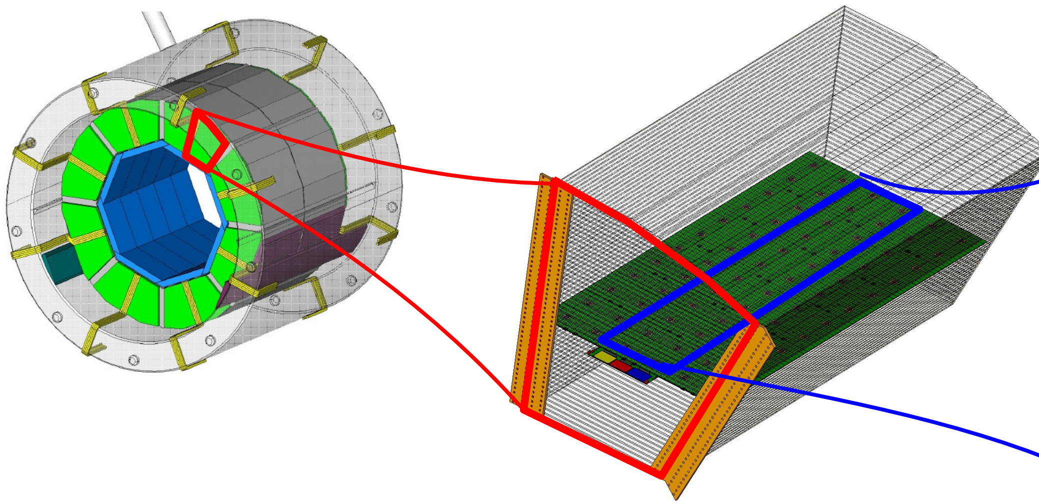


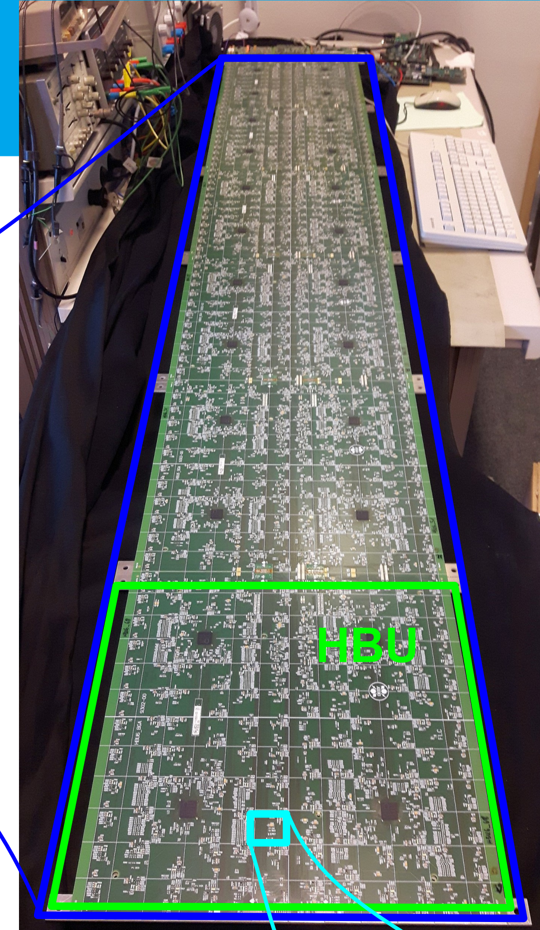
Calorimeter Technologies for Linear Collider detectors

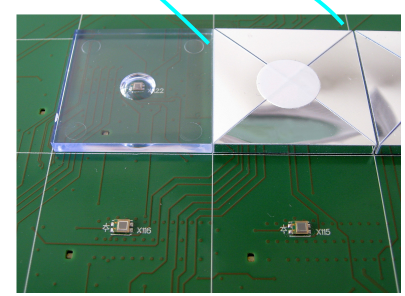


The AHCAL Technological Prototype

AHCAL technological prototype: design



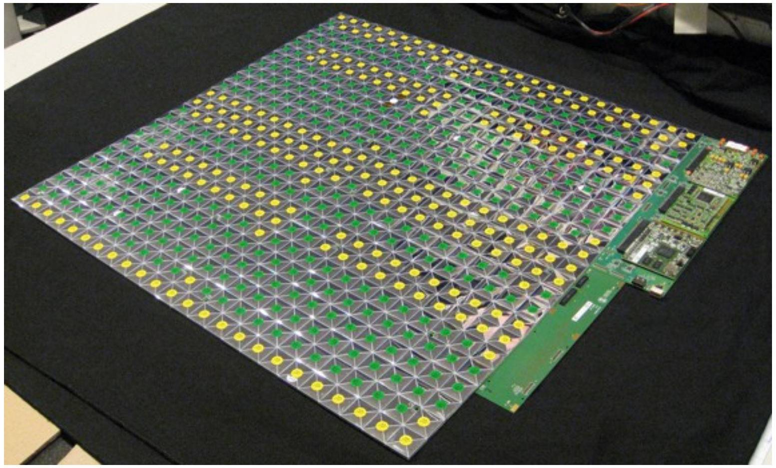




- highly granular scintillator SiPM-on-tile hadron calorimeter, 3*3 cm² scintillator tiles optimised for uniformity
- fully integrated design
  - front-end electronics, readout
  - voltage supply, LED system for calibration
  - no cooling within active layers
  - electronics adapted to ILC beam structure -> 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

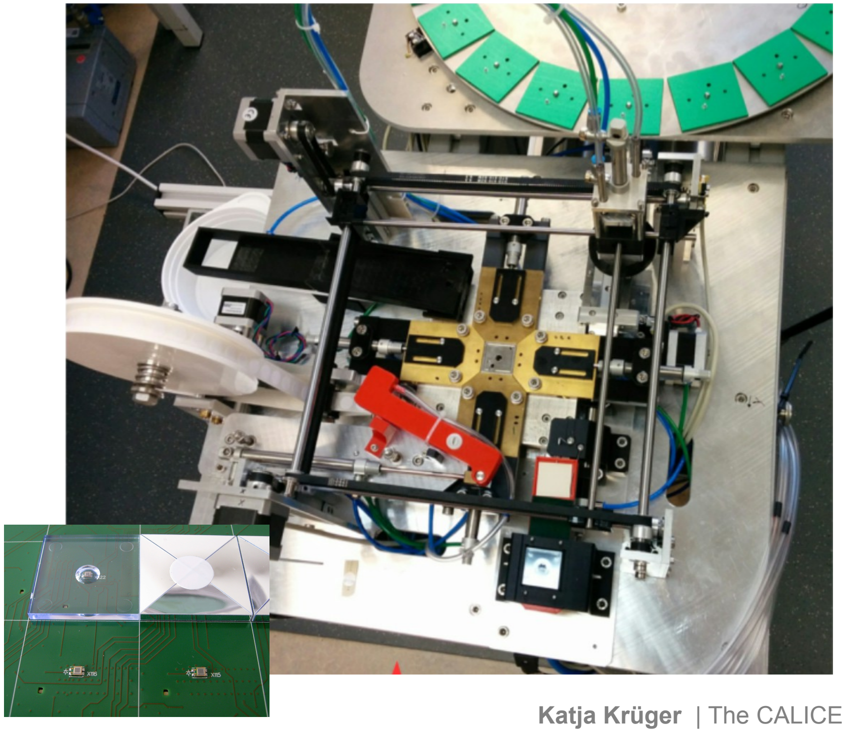
AHCAL technological testbeam prototype

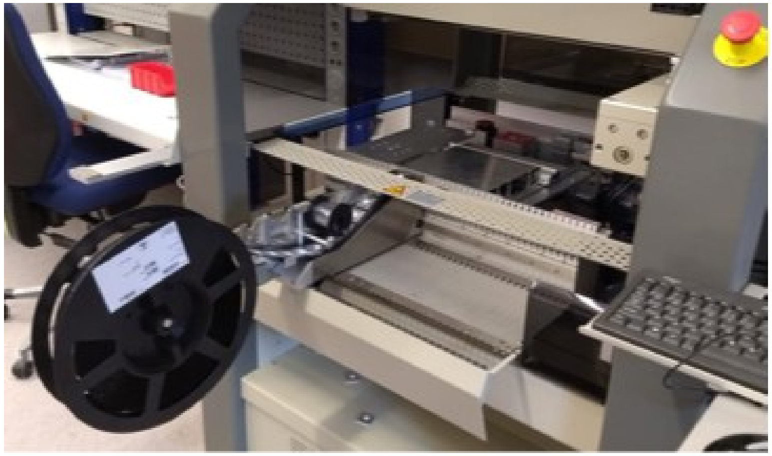
- 38 active layers of $72*72$ cm²
- 4 HBUs per module
  - 16 ASICs, 576 channels of $3*3$ cm² tiles
  - in total: 608 ASICs, ~22000 channels
- all modules with surface-mount MPPCs
  - S13360-1325PE
  - 2668 pixels
  - operated at 5V overvoltage
  - nominal operation voltage within 200mV in a module -> use same voltage
- all modules are interchangeable, so positioning in stack according to quality (worst modules in the back)
- additionally in June and October: "Tokyo module" with $6*6$ cm² tiles



Mass production

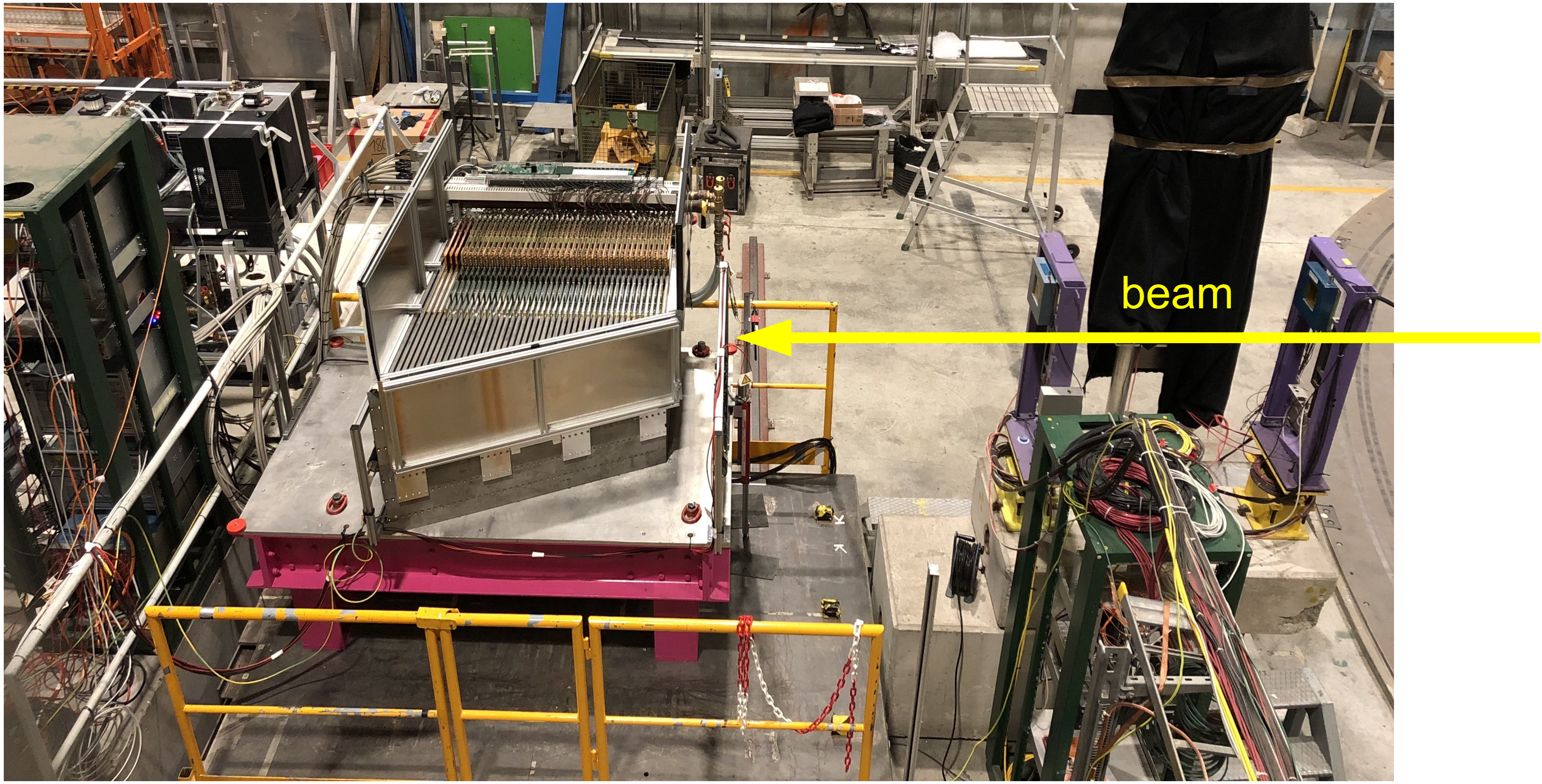
- design optimized for mass production
  - SMD SiPMs soldered automatically
  - injection-moulded polystyrene tiles, no further surface treatment
  - automatic wrapping in ESR reflector foil
  - glueing of tiles with screen printer and pick-and-place machine





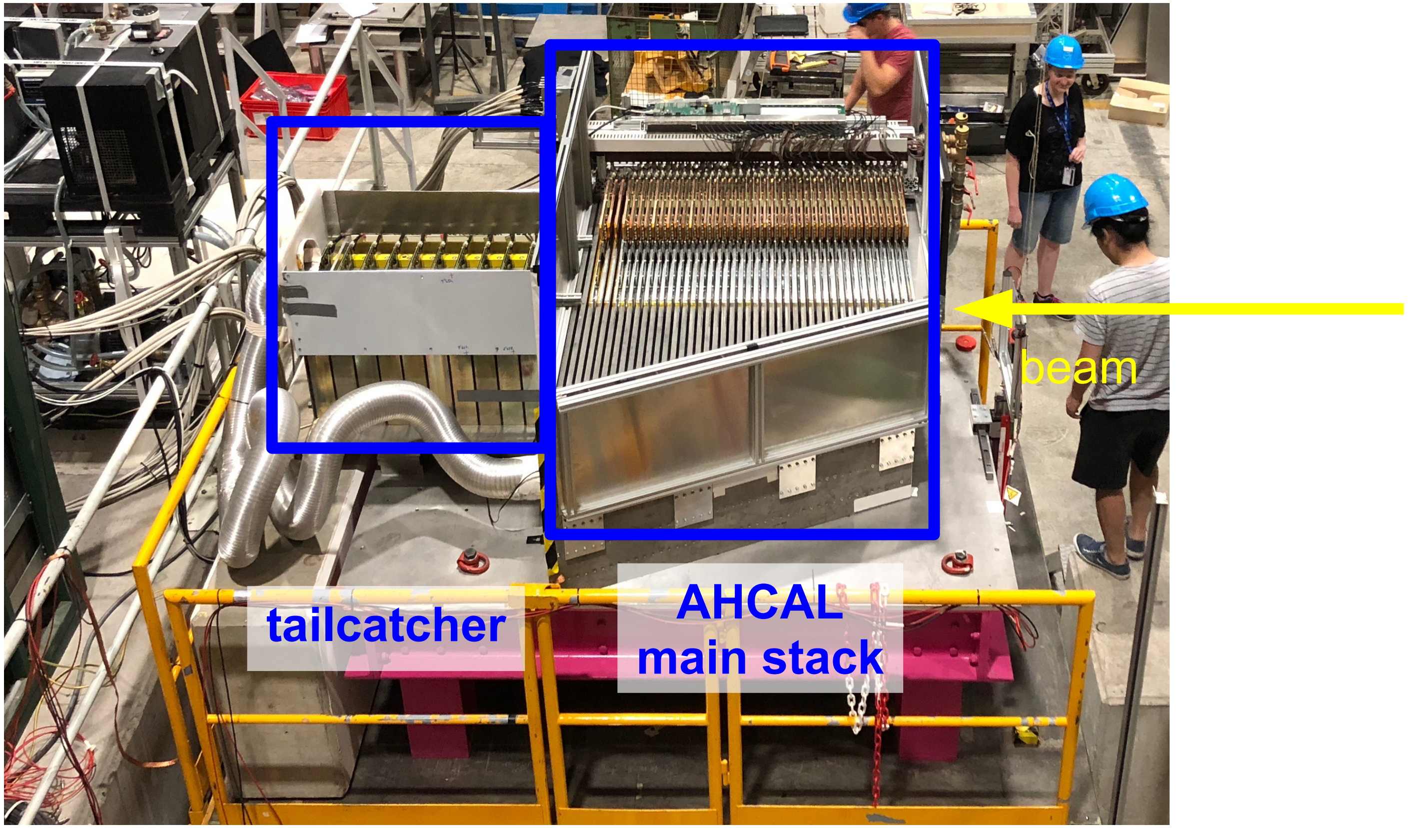
The Testbeam at CERN SPS

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



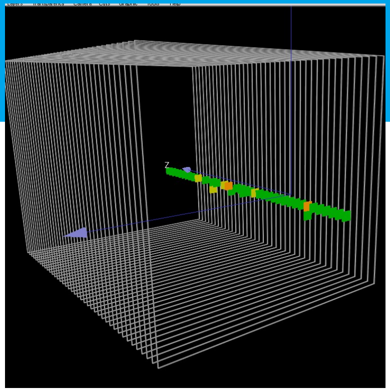
- 38 active layers of 72*72 cm² in steel absorber with 1.7 cm layer thickness (~4 λ)
- mounted on the movable platform ("scissors table") in H2
- beam instrumentation: wire chambers, trigger scintillators, Cherenkov detector

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



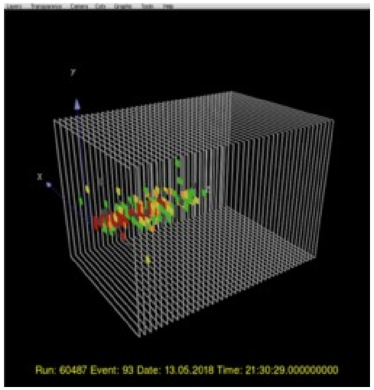
- as in May, plus:
  - added one module with 6*6 cm2 tiles
  - added CMS HGCAL “thick stack” (12 layers of 1 HBU, 7.4 cm steel absorber) as tailcatcher
  - added single HBU in front of absorber as “pre-shower” detector

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!)

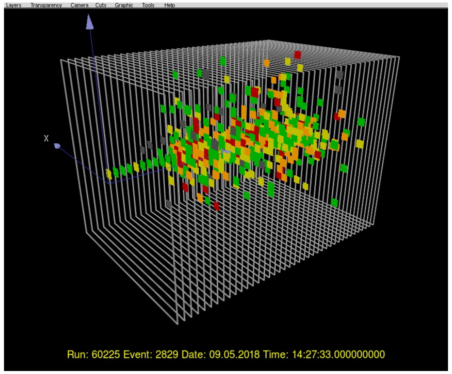


> scientific

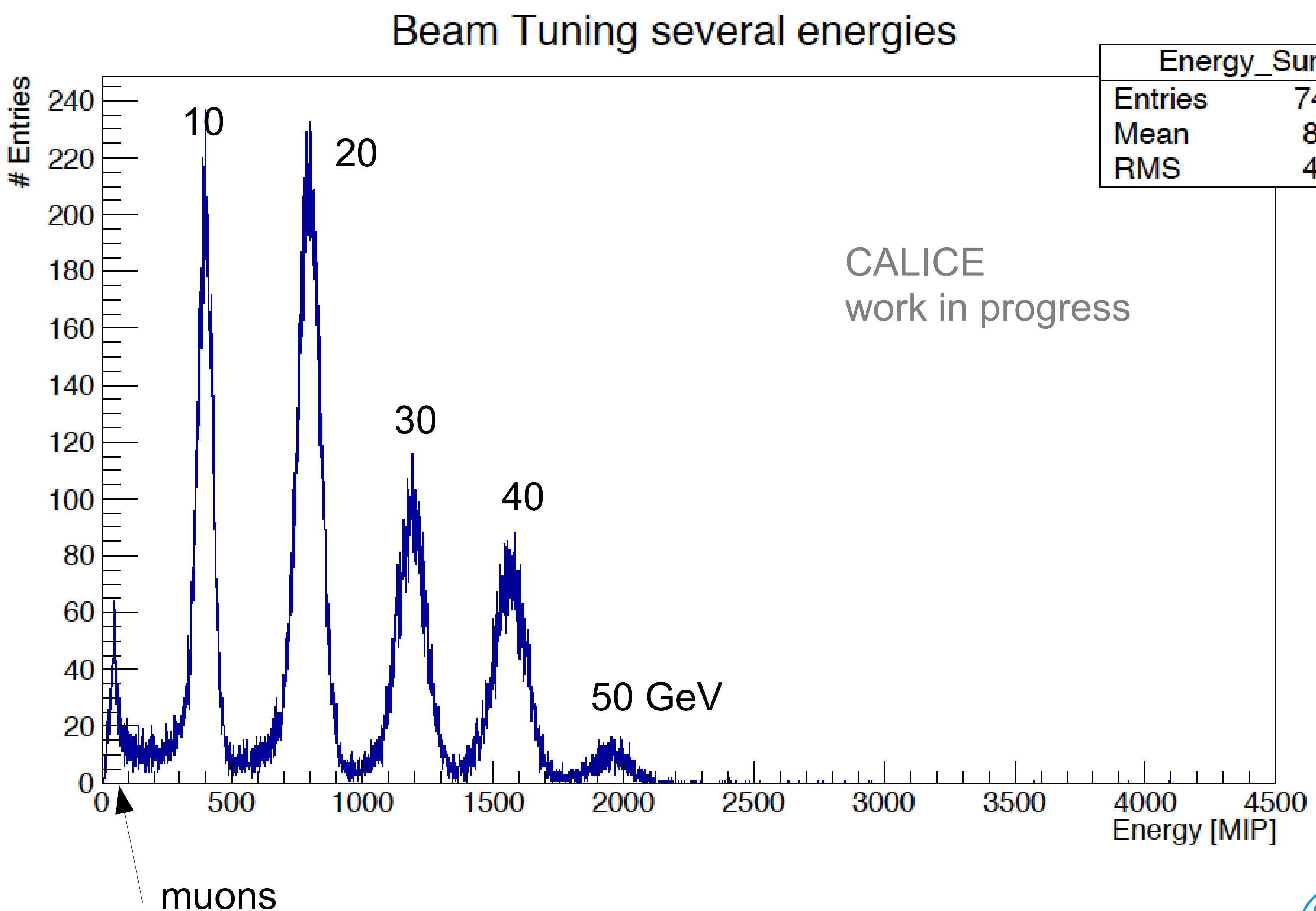
- energy linearity and resolution for electrons and pions
- hit time correlations
- shower profiles
- shower separation

> data sets

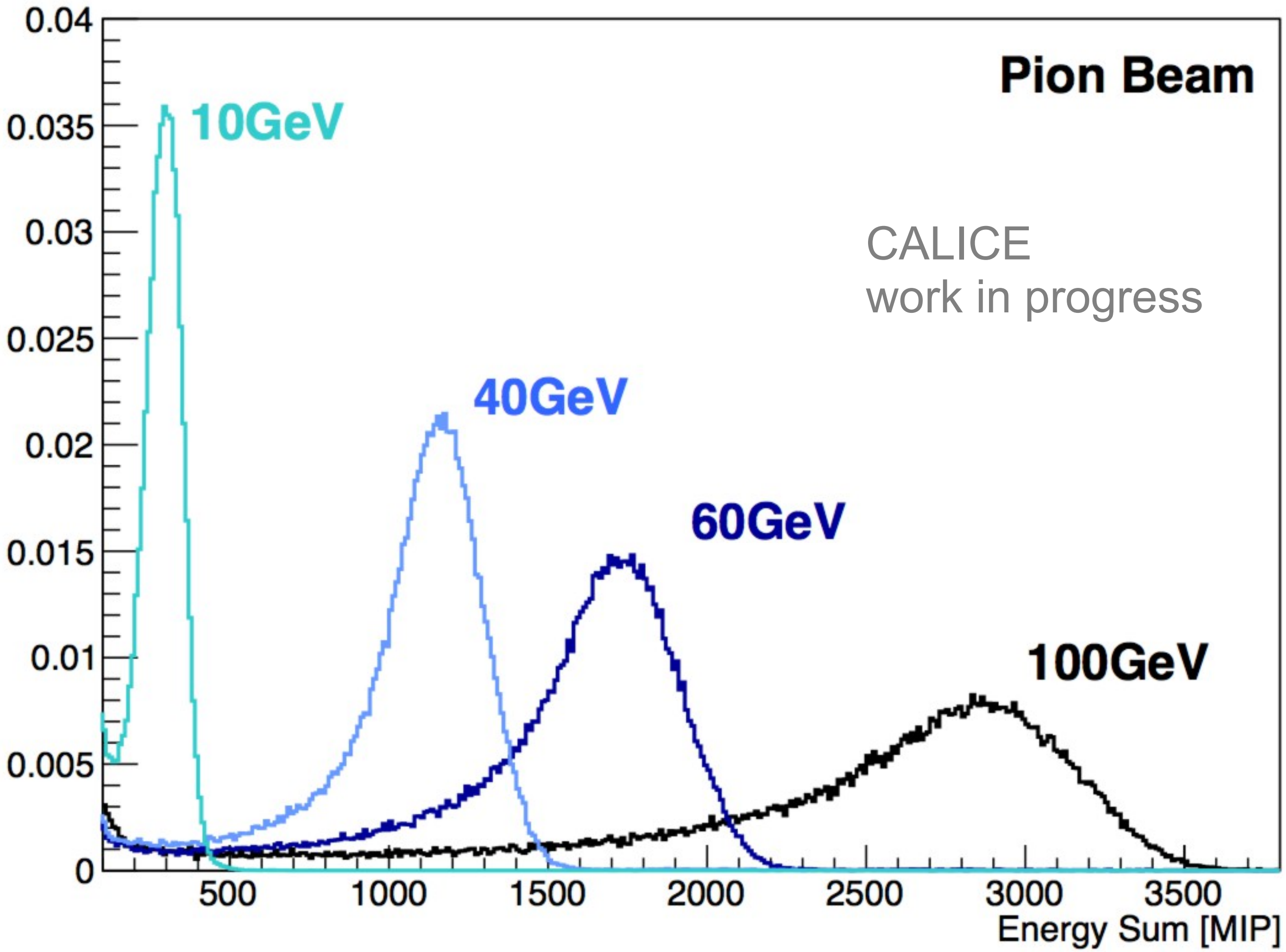
- wide **muon** beam for (cross check of) MIP calibration
- energy scan for **electrons** (with and without power pulsing)
  - energies: 10, 20, 30, 40, 50, 60, 80, 100 GeV
- energy scan for negative **pions**
  - energies: 10, 15, 20, 30, 40, 50, 60, 80, 100, 120, 160, 200 GeV (+ test at 350 GeV)
-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



Electrons during beam tuning in June



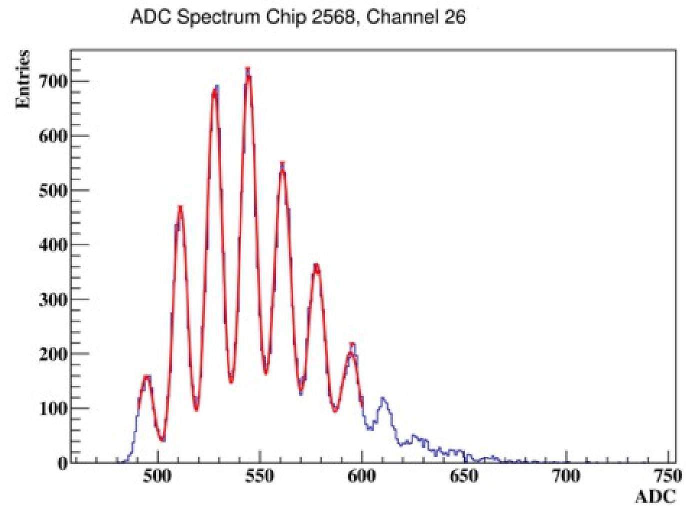
Very first look into pion data

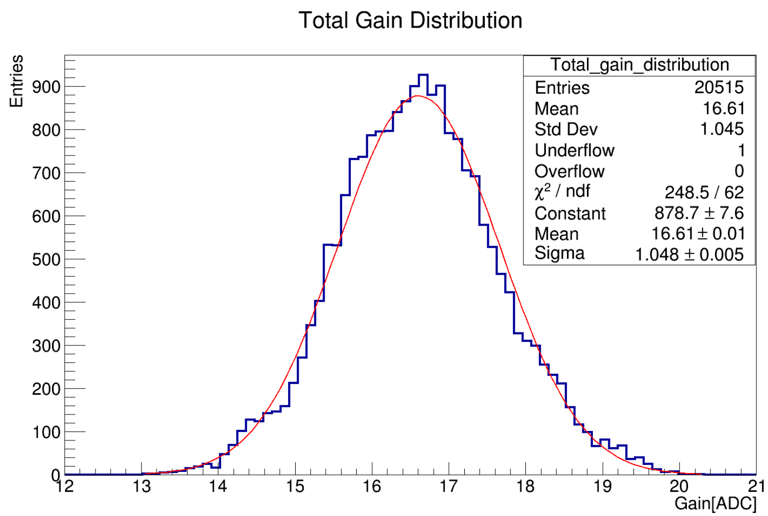


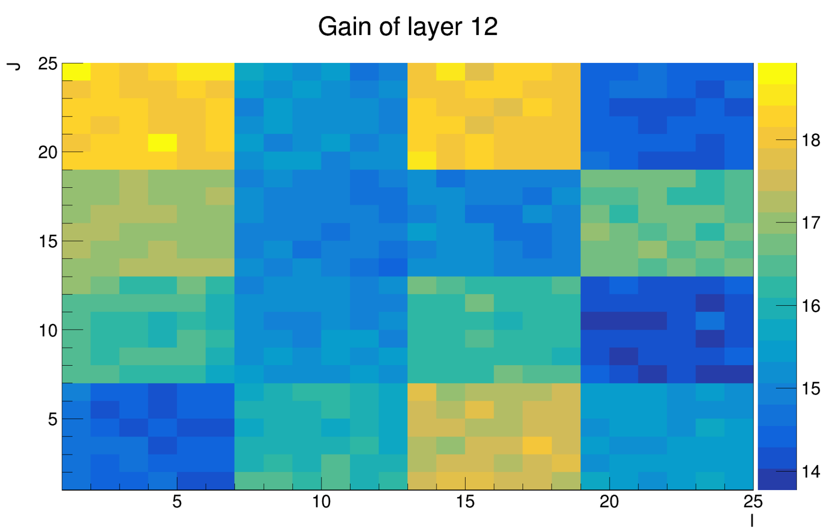
Calibration

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**

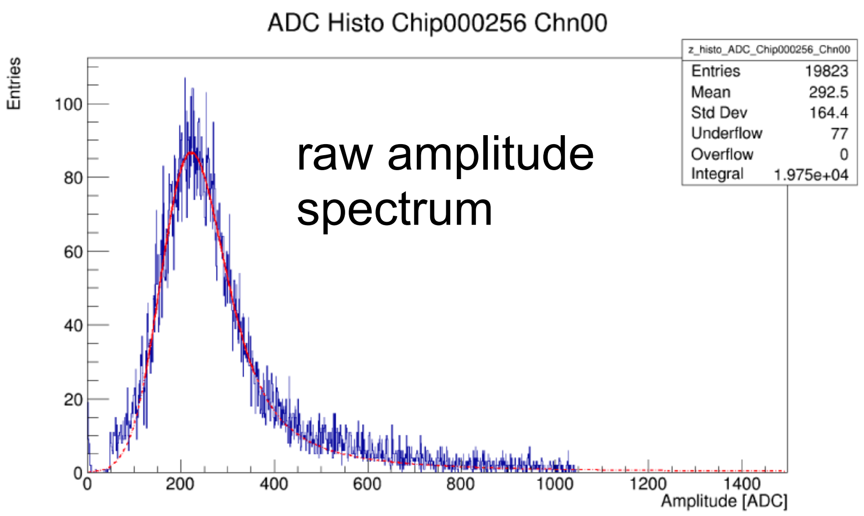


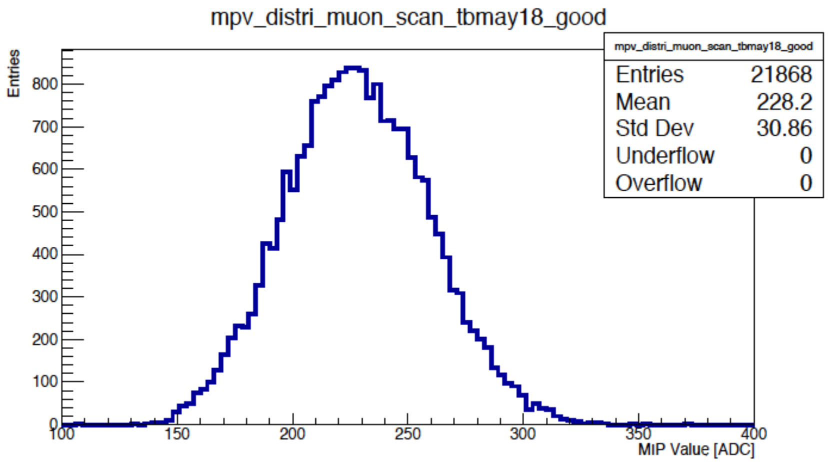


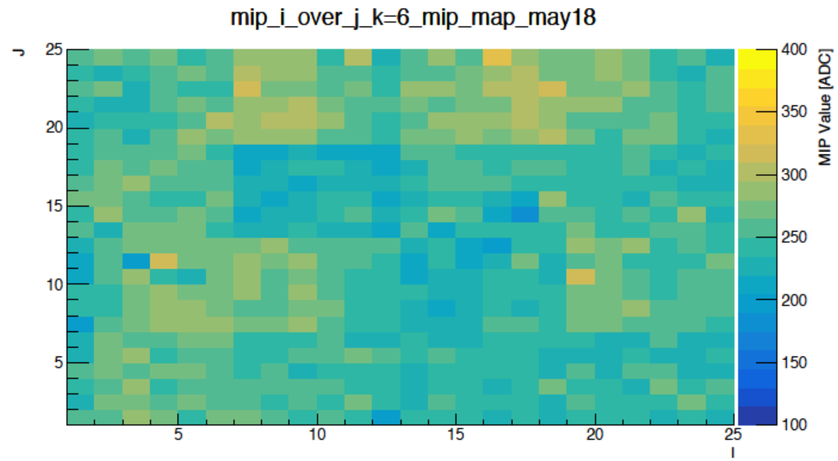


Uniformity and Stability: MIP signal

- 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

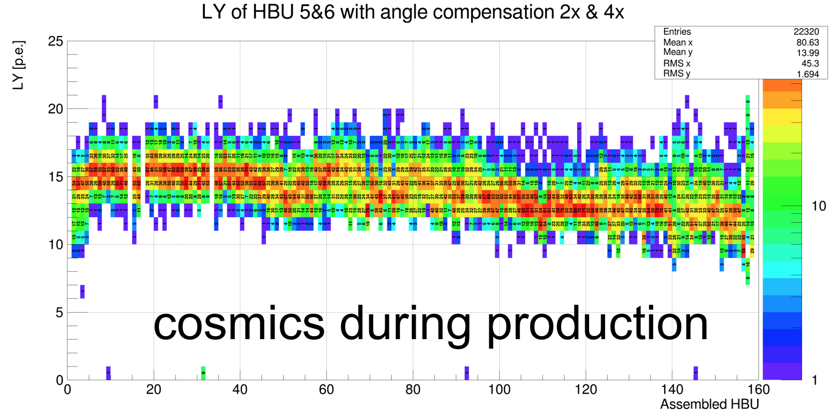


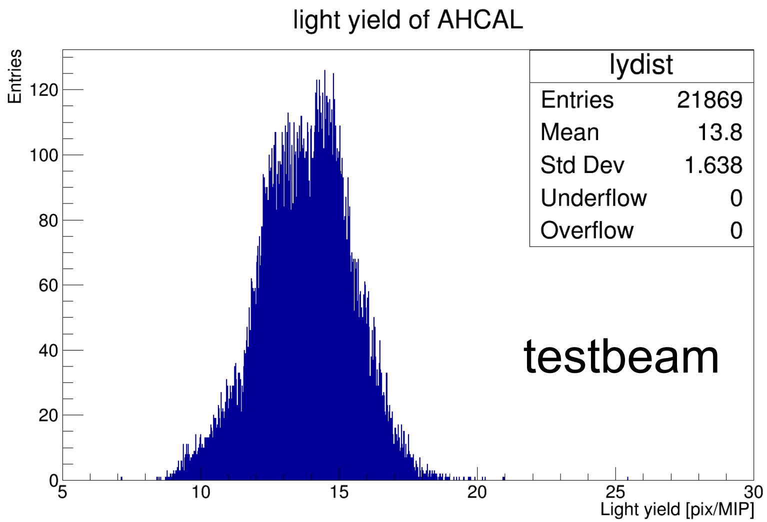


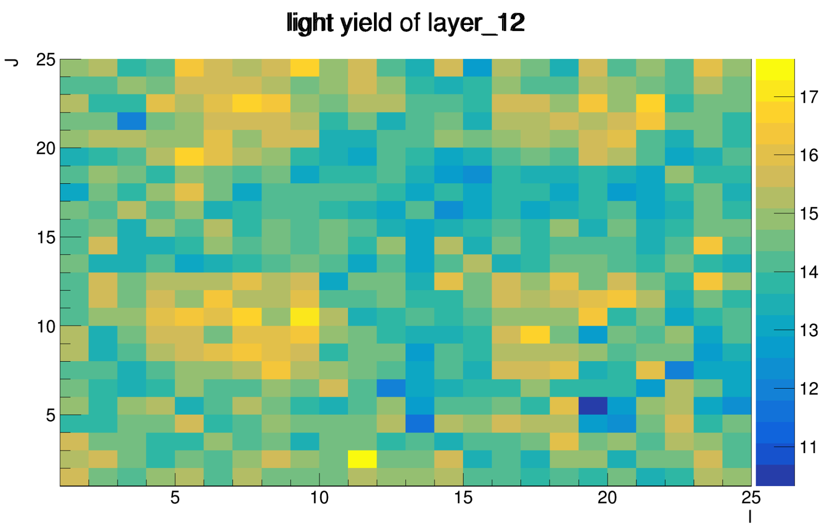


Uniformity and Stability: Light Yield

- 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)



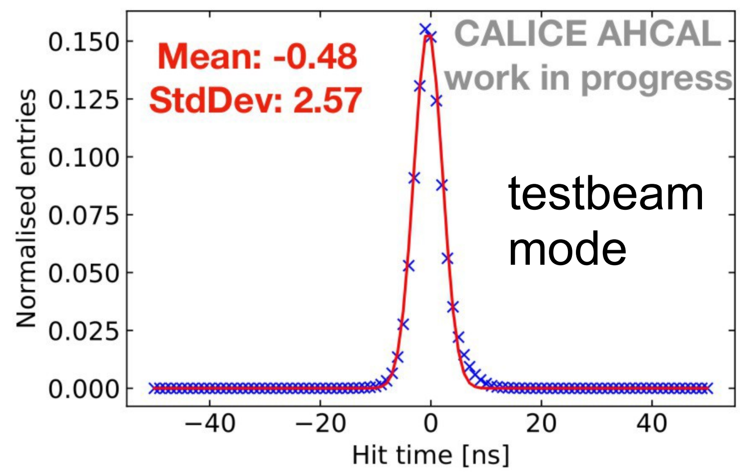


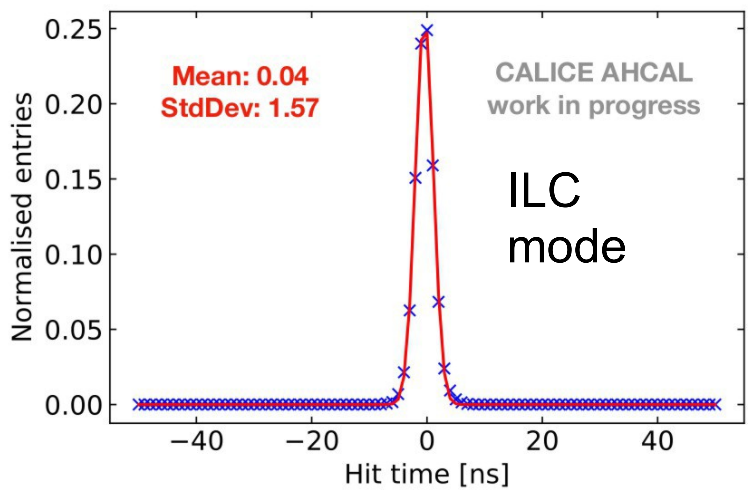


New feature: hit time measurement

Lorenz Emberger (MPI Munich)

- 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
- obtained for muons:
  ~2.6 ns resolution in testbeam mode
  ~1.6 ns resolution in ILC mode
  - resolution deteriorates with number of hits in an ASIC
- further studies ongoing



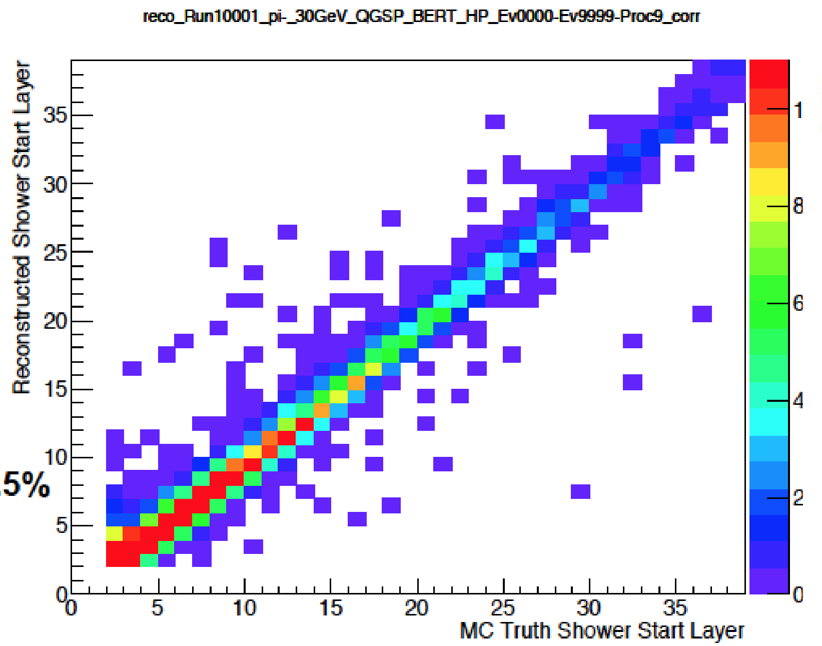


Analysis

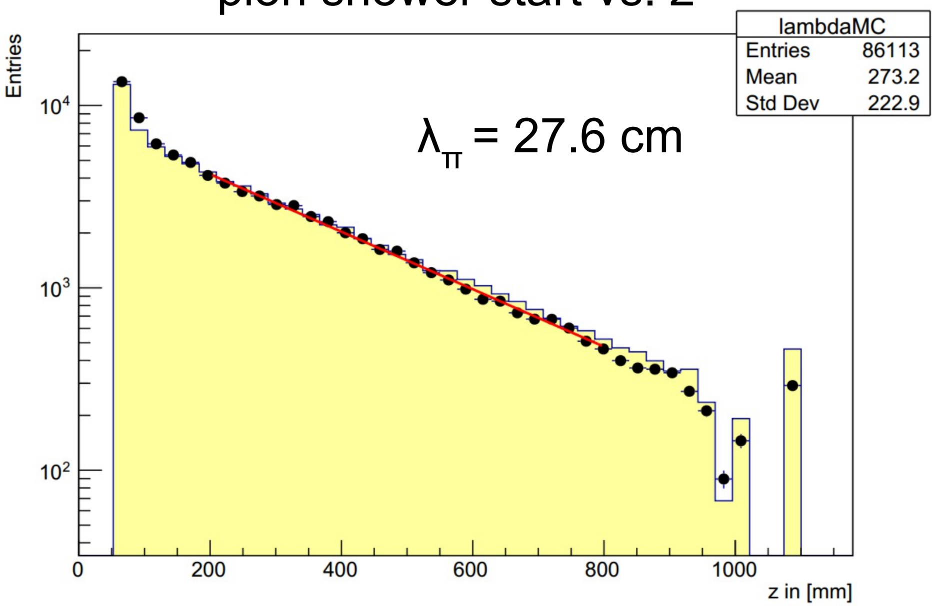
Analysis tools: Shower start finder

Daniel Heuchel (DESY, Uni HD)
Jonas Mikhael (Master Uni HD)

- optimised shower start finder
  - based on number of hits and energy in sliding window of layers
  - reach >90% of events correctly reconstructed within +-2 layers
  - can be used to measure pion interaction length of AHCAL
  - important ingredient in particle identification



pion shower start vs. z



BDT classification

Model and input. TBJune18.

Software and model:

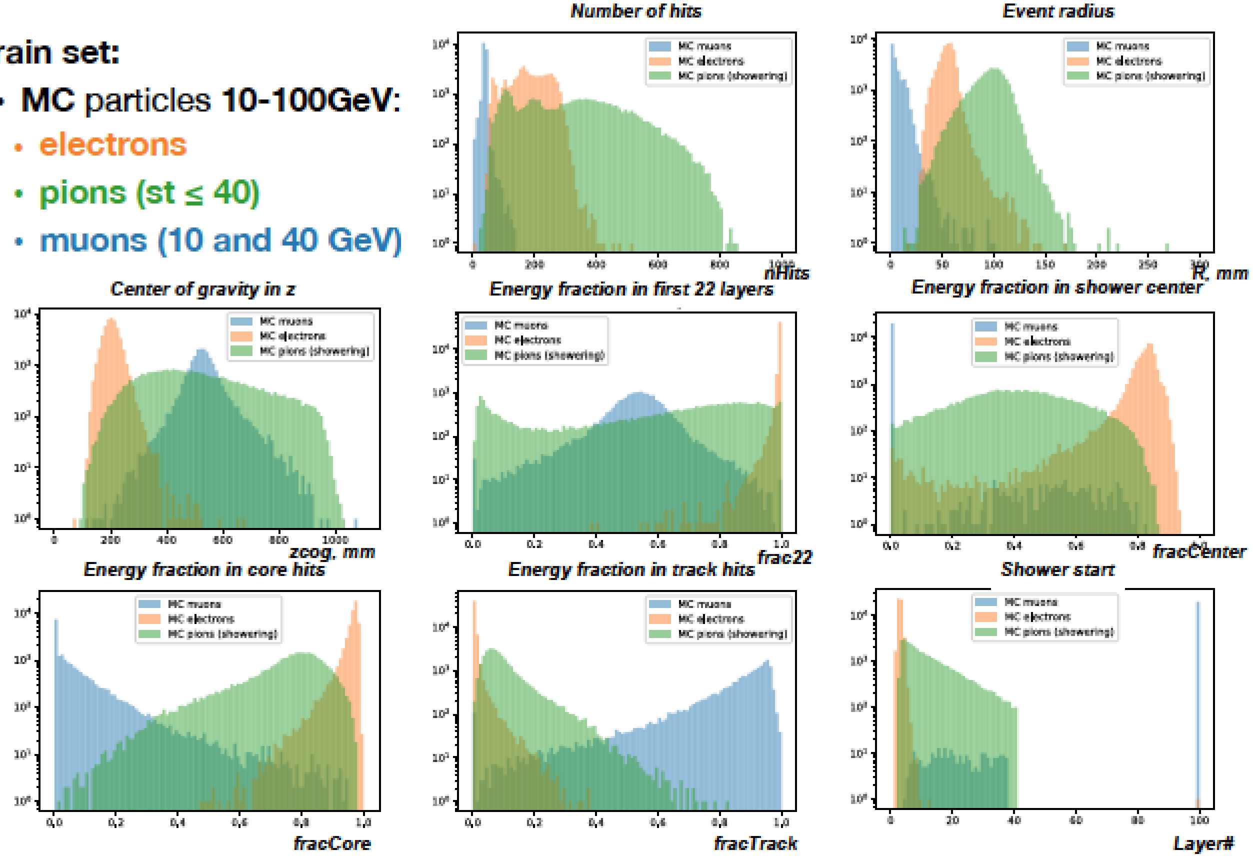
- **LightGBM**
- Multi-class **gbdt**
- **Multi log** loss function
- model to .C converter (**m2cgen**)
- implementation in **Marlin** processor was tested

Observables:

- Number of hits
- Shower radius
- Center of gravity in z
- Energy fraction in first 22 layers
- Energy fraction in shower center
- Energy fraction in shower core
- Energy fraction in track hits
- Shower start

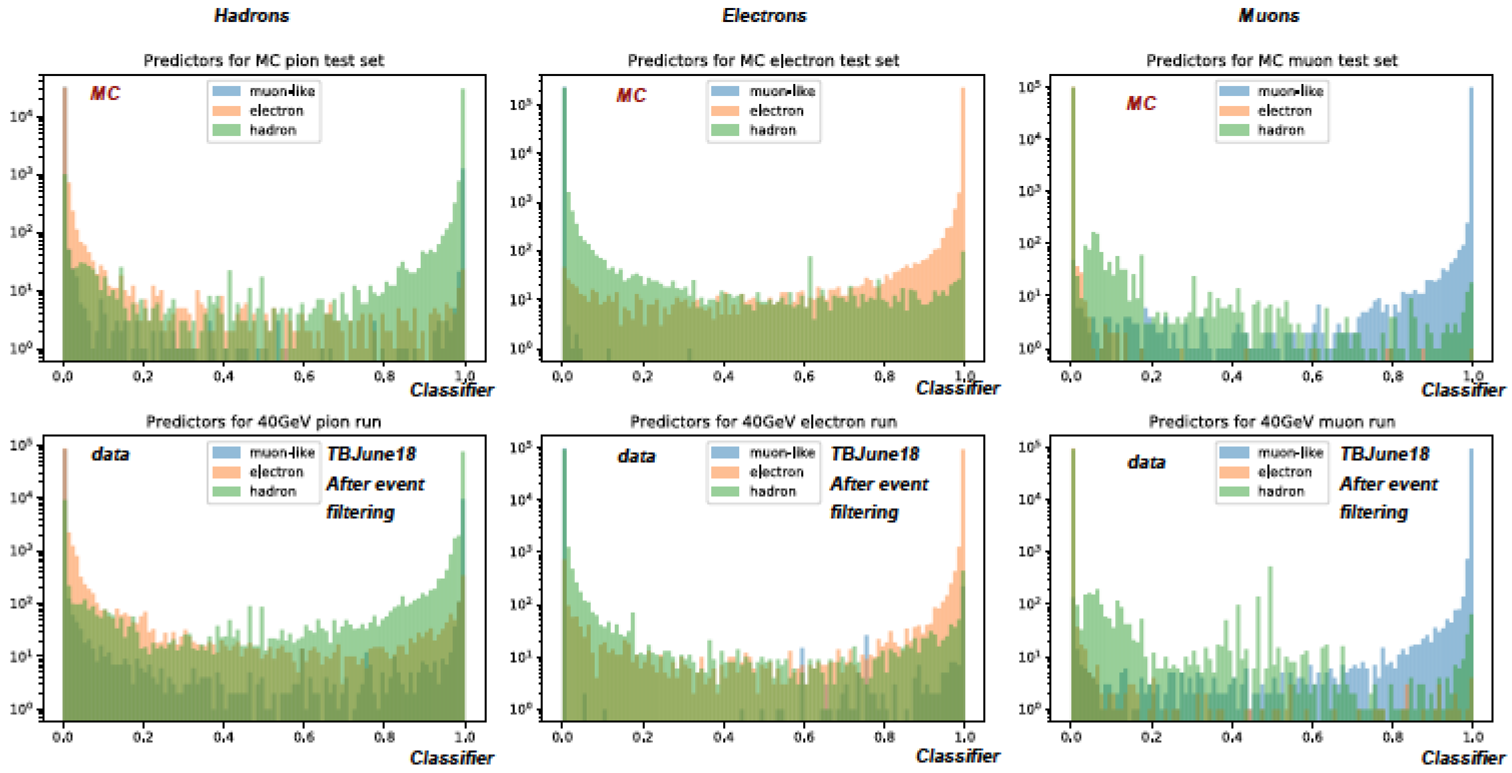
Train set:

- **MC** particles **10-100GeV**:
  - **electrons**
  - **pions (st ≤ 40)**
  - **muons (10 and 40 GeV)**



BDT classification

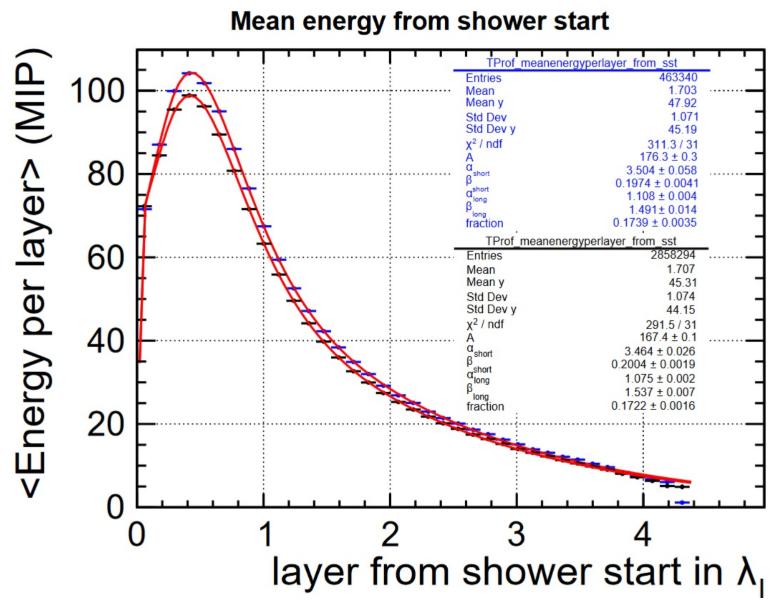
Output. Comparison with data.

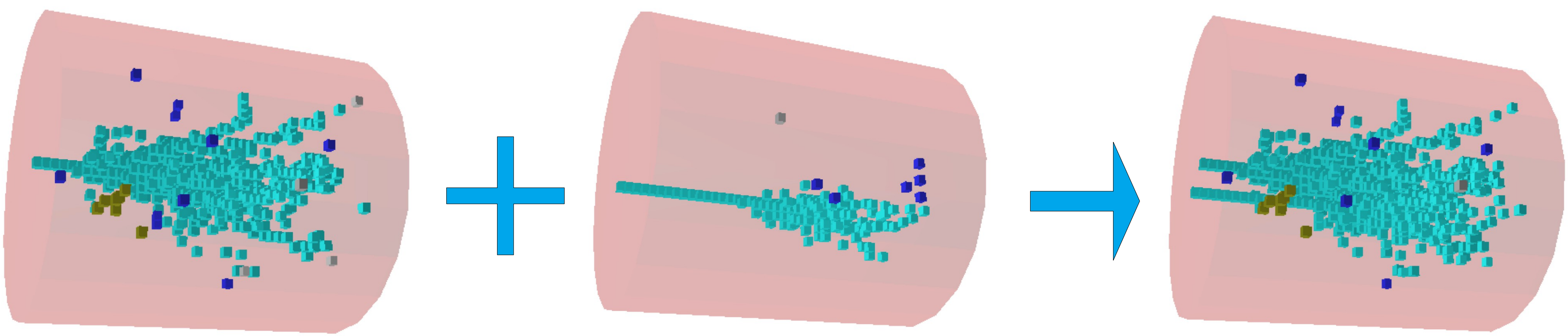


Shower Shapes and Particle Flow Analysis

Olin Pinto
Daniel Heuchel

- started detailed analysis of electron and hadron shower data
  - longitudinal and radial shower shapes
- preparation of data analysis with PandoraPFA
  - overlay of several measured shower events



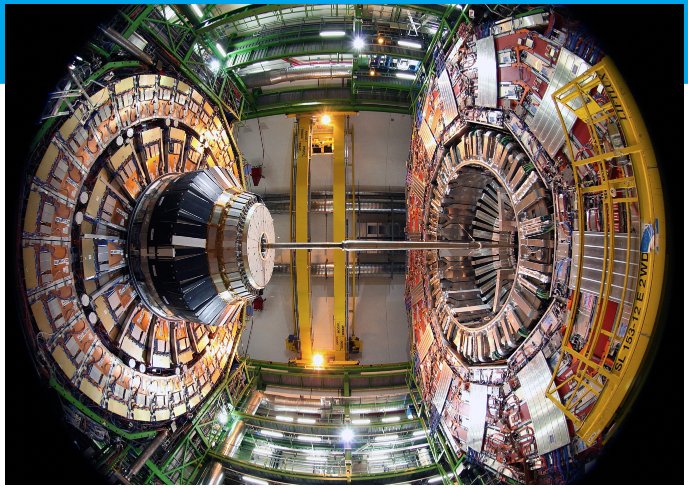


60 GeV pion

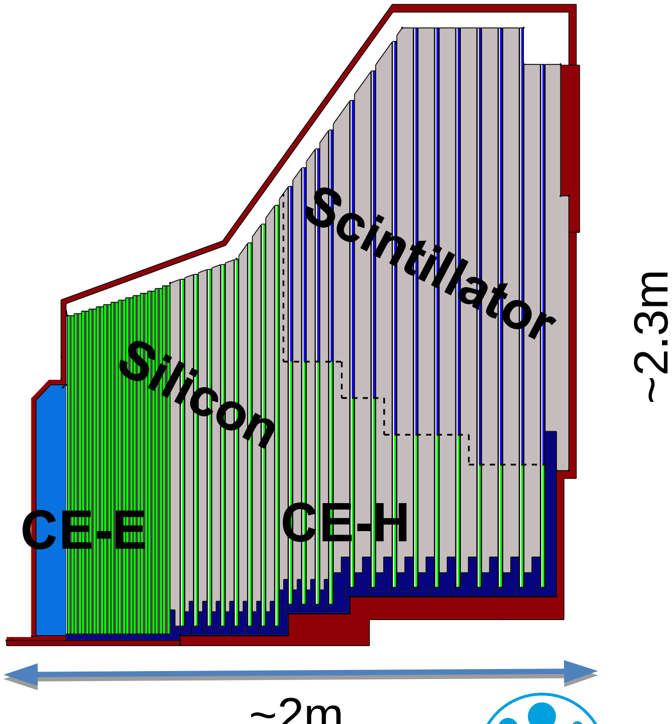
30 GeV pion

Bonus Feature: CMS HGCAL

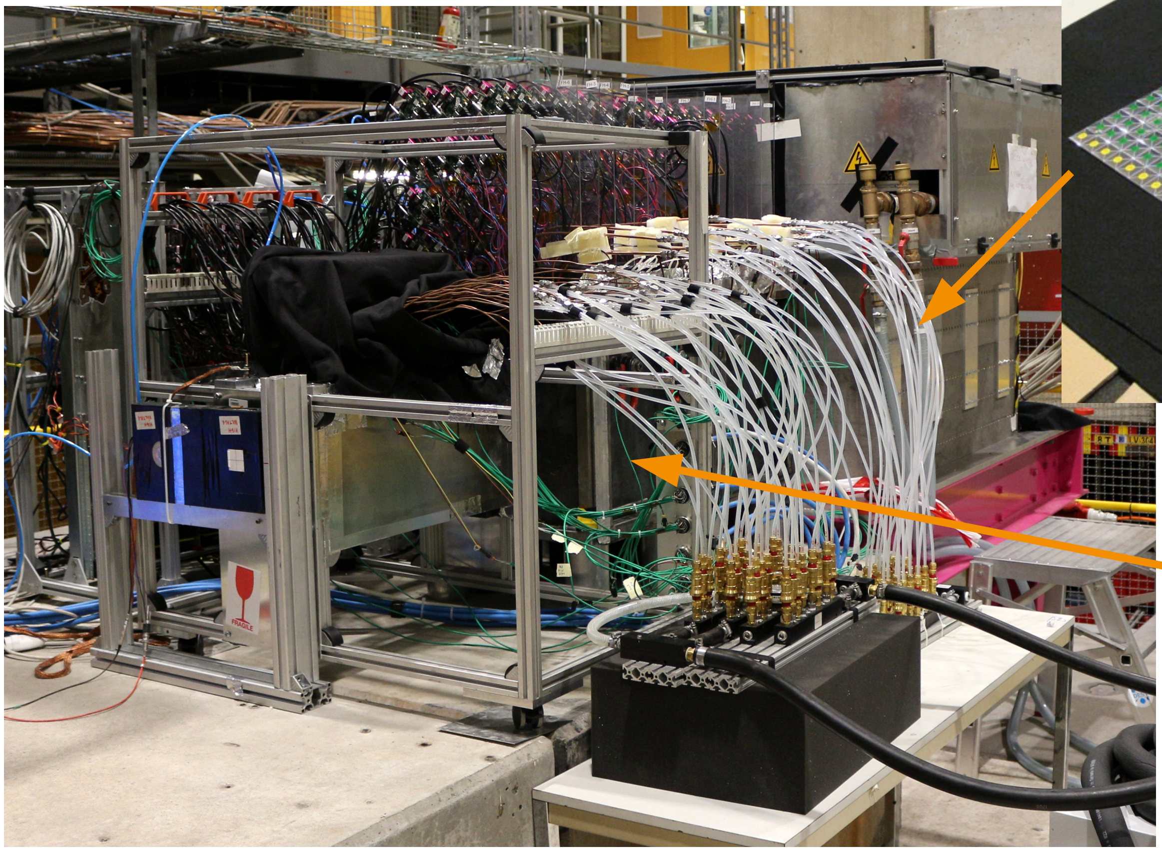
CMS HGCAL

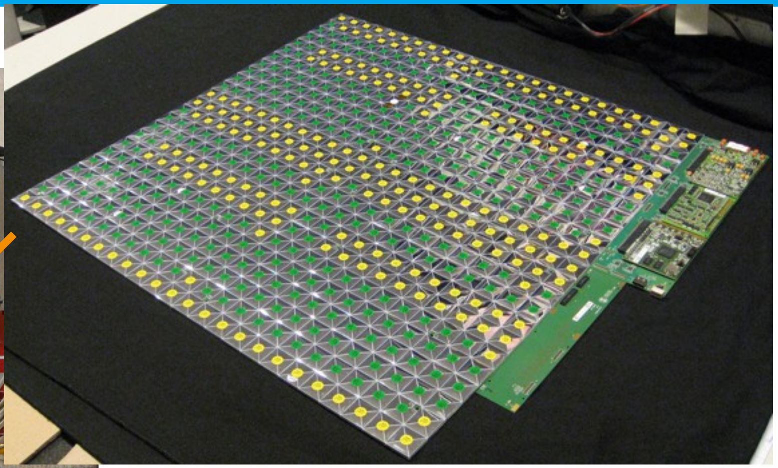


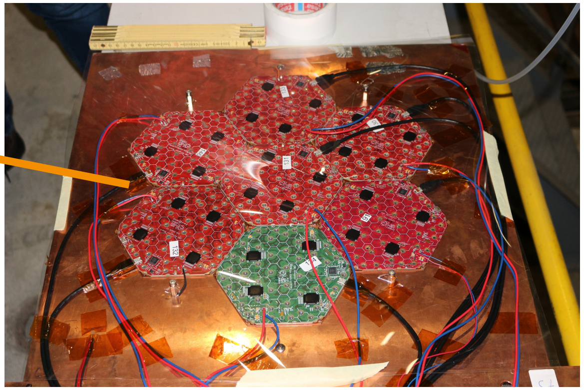
- high-granularity upgrade of the CMS calorimeter endcap for HL-LHC
- ~620m2 silicon, ~400m2 scintillator
- to be installed in 2025
- DESY involved in the scintillator part, capitalising on AHCAL experience
  - design of readout boards (“tileboards”)
  - further development and application of assembly techniques
    - scintillator wrapping (Uni HH)
    - tileboard assembly (Uni Mainz)
  - beam tests
  - new challenges:
    - Radiation → studies of rad-hard SiPMs at Uni HH
    - operation at -30°
    - data rates



Testbeam setup October 2018 in H2 at SPS: HGCAL + AHCAL



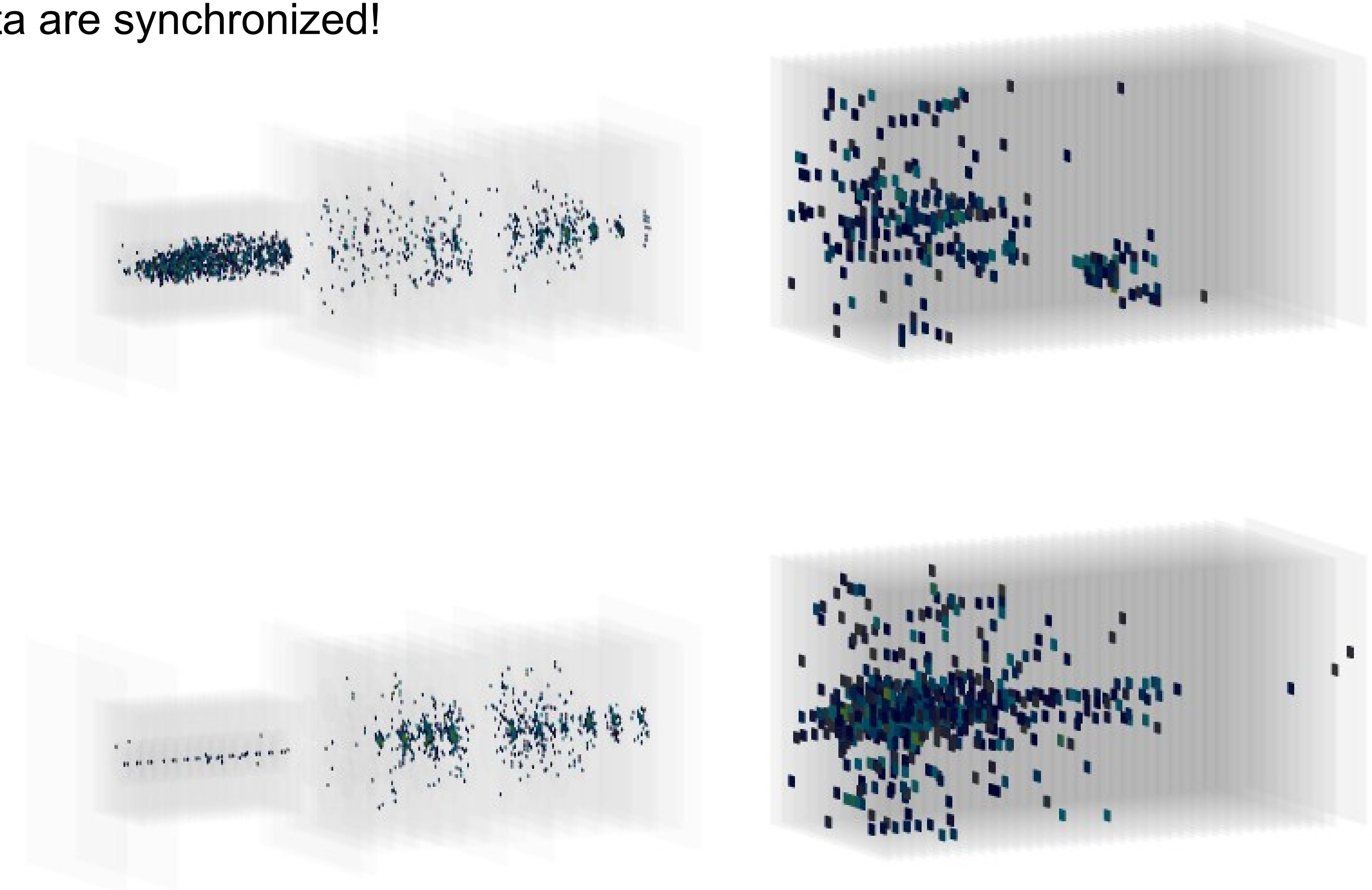




> 28 layers HGCAL EE (silicon/lead), 12 layers HGCAL FH (silicon/steel), 39 layers AHCAL (scintillator/steel)

Event displays: 300 GeV hadron showers

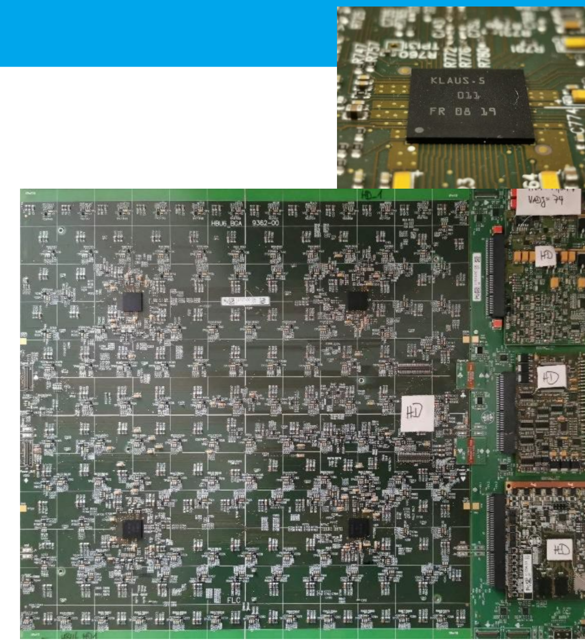
data are synchronized!

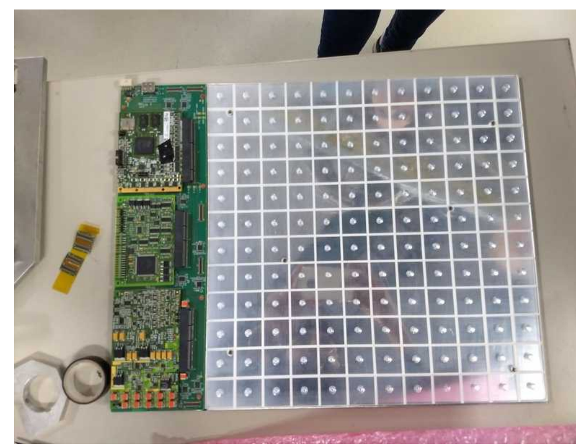


from A. Steen

Further tests and future plans

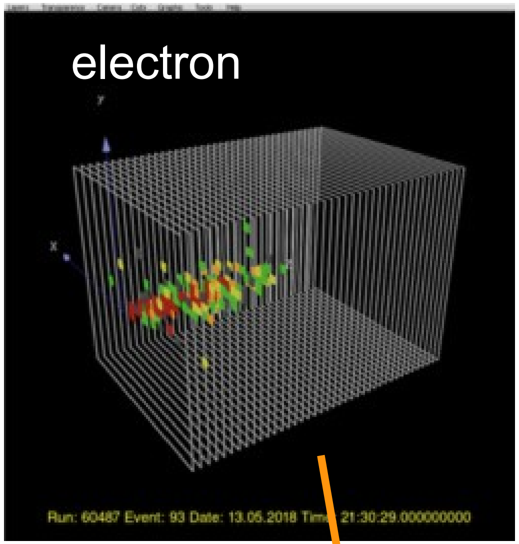
- have collected a unique dataset in 2018
  - analysis has high priority now
- AHCAL tests in 2019 & 2020: smaller setups
  - alternative readout ASIC (KlauS)
    - ASIC by Uni HD
    - HBU by DESY
  - beam tests of a megatile layer (Uni Mainz)
  - DESY will continue to provide testbeam support
- future tests with the large prototype
  - hadron beam with best timing measurement (ILC mode)
  - beam tests with (existing) tungsten absorber structure
  - combined beam test with ECAL in front

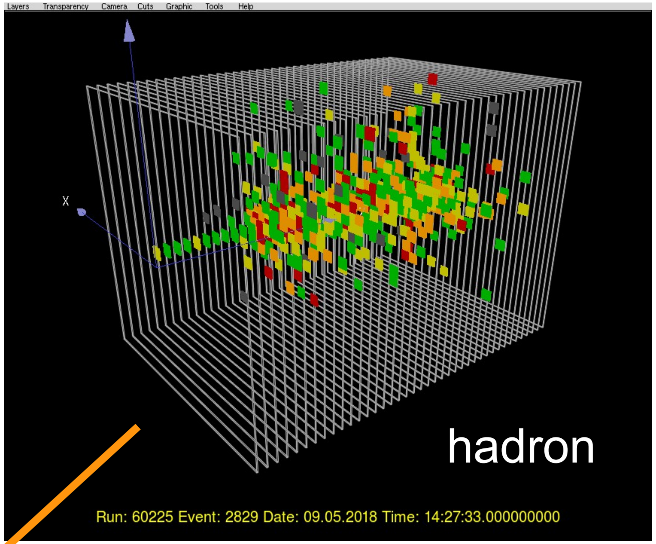


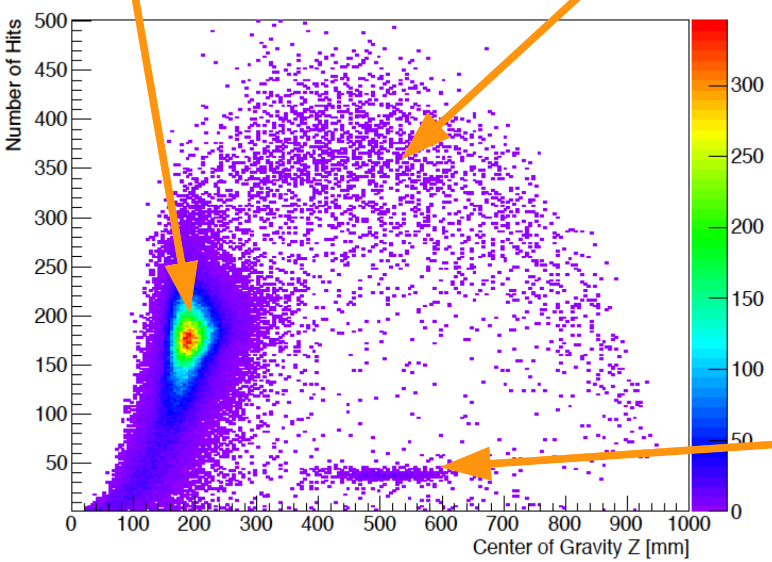


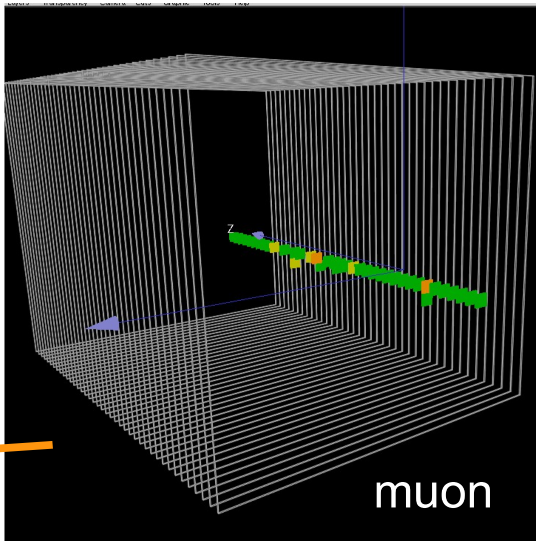
Backup

Very first look into data



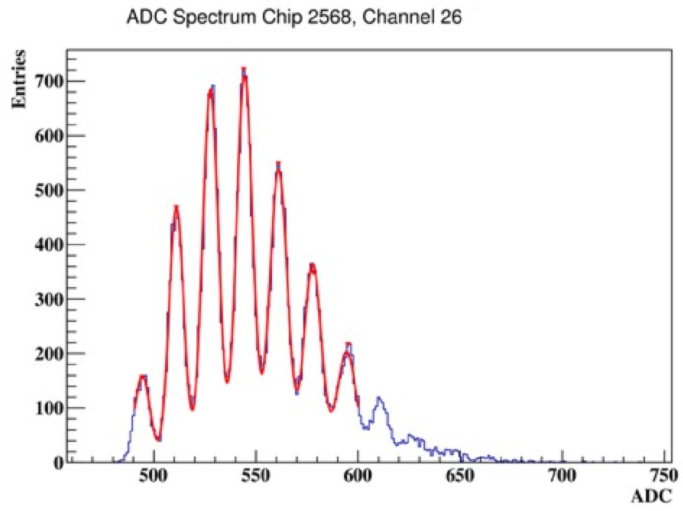


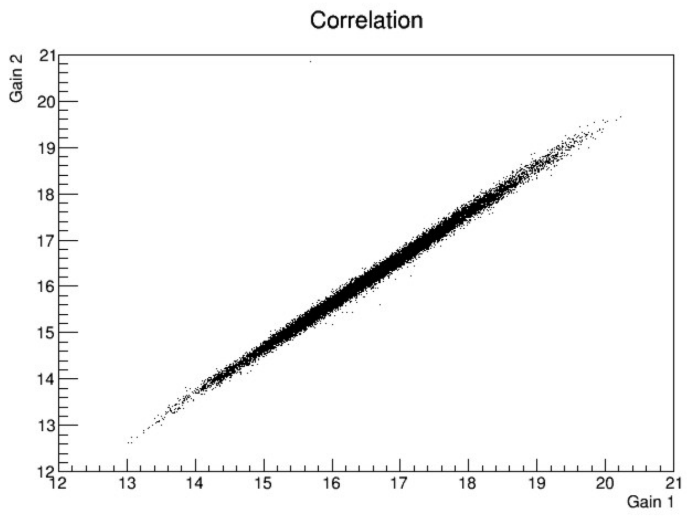


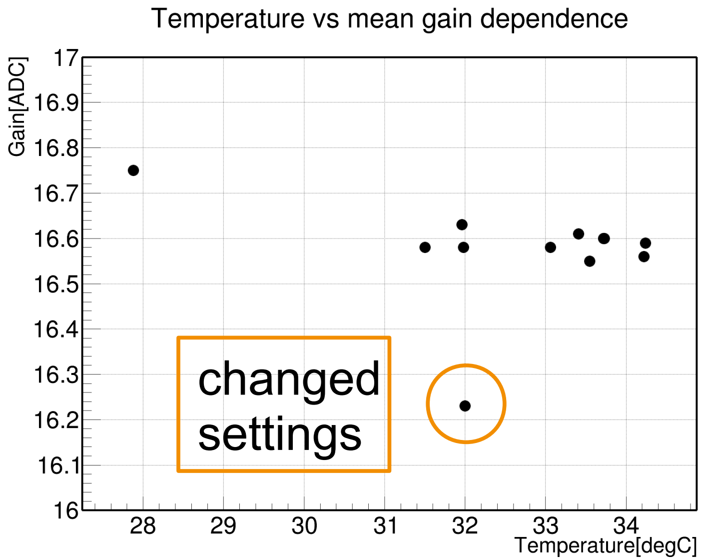


Uniformity and Stability: Gain

- 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**

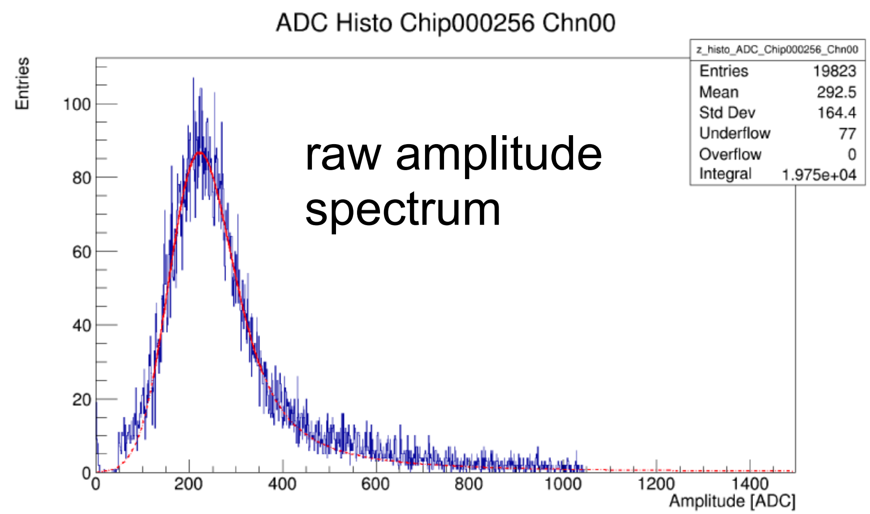


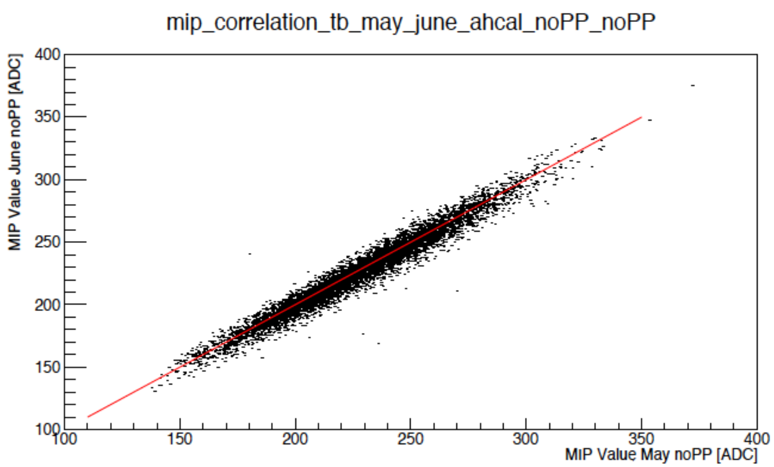


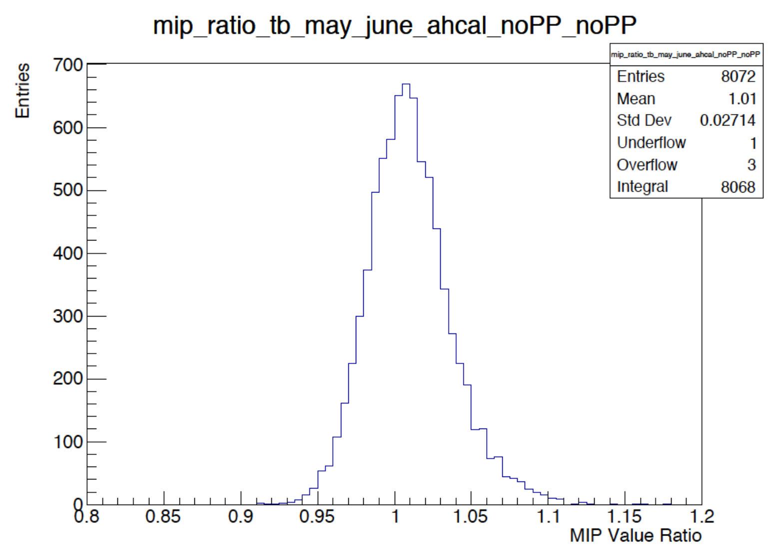


Uniformity and Stability: MIP signal

- 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
- **stable** between May and June runs



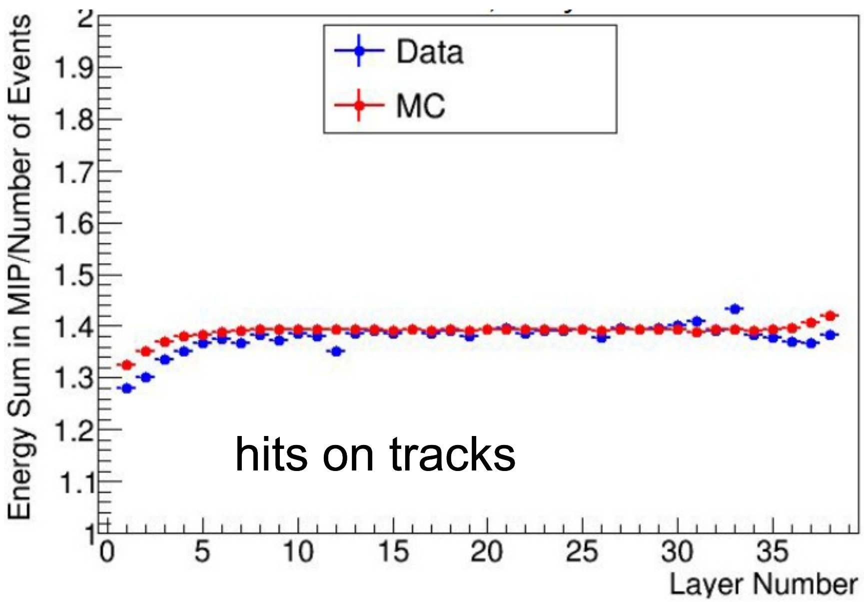


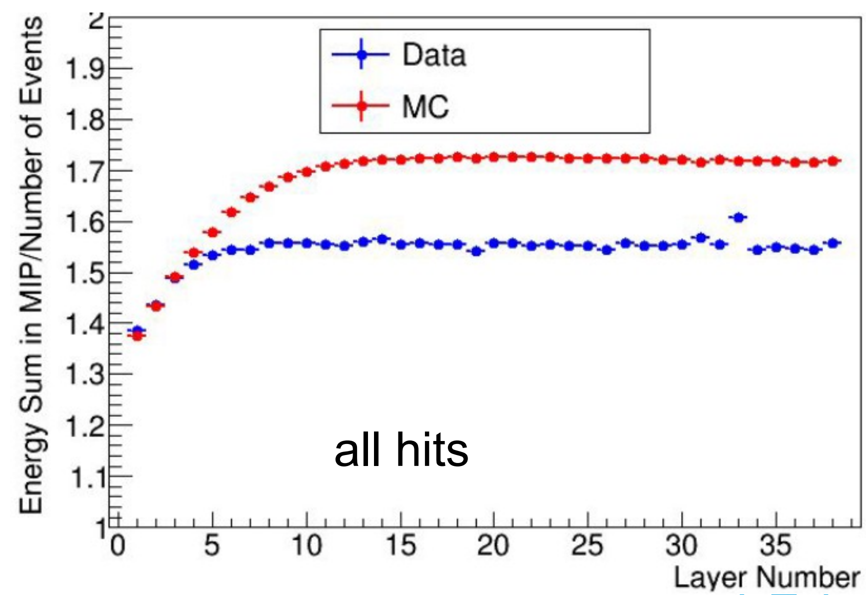


MIPs: standard candle with surprises

S. Huck

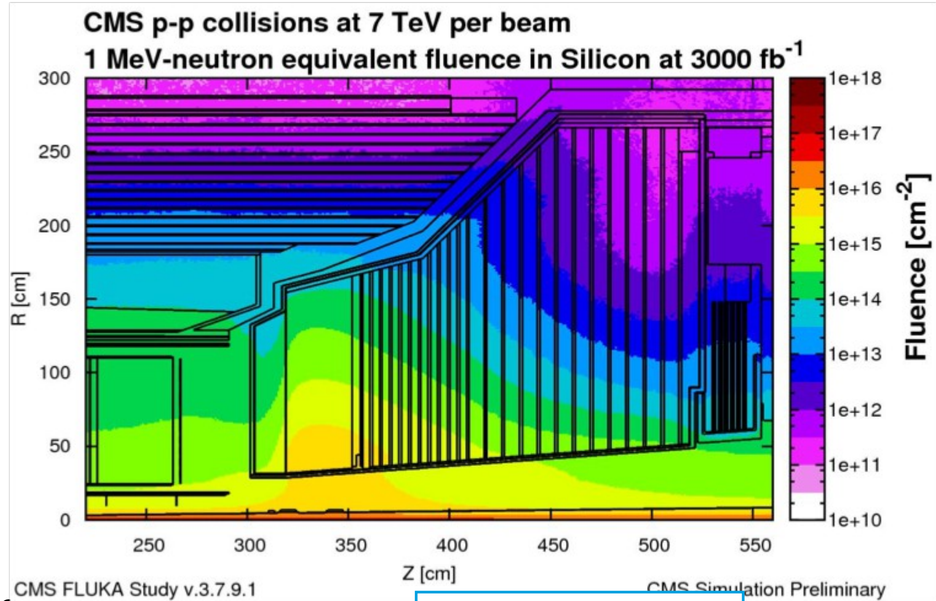
- well-defined energy deposition makes MIPs ideal standard candle for calibration and cross check of detector simulation at small hit energies
- for hits on track: simulation describes data very well
- outside of tracks (possible thanks to low noise SiPMs): more hits and more energy in MC
  - under investigation: detector setup in simulation or genuine difference in muon-detector interaction





CMS HGCAL

Driving Layout and Granularity



Active Elements:

Hexagonal modules based on Si sensors CE-E and high-radiation regions of CE-H

Scintillating tiles with SiPM readout in low-radiation regions of CE-H

Key Parameters:

~215 tonnes per endcap, full system at -30°C

~620m2 Si sensors in ~30000 modules

~6M Si channels, 0.5 or 1cm2 cell size

~400m2 of scintillators in ~4000 boards

~240k scint. channels, 4-30cm2 cell size

Power at end of HL-LHC:

~125 kW per endcap, transferred via front-end DCDC. Two phase CO2 cooling

Fluence up to 1e16 n/cm^2
Dose up to 200 Mrad

Electromagn. calorimeter (CE-E):

Si, Cu & CuW & Pb absorbers, 28 layers, 25 X0 & ~1.3λ

Hadronic calorimeter (CE-H):

Si & scintillator, steel absorbers, 22 layers, ~8.5λ

CMS HGCAL + AHCAL testbeam: HGCAL configurations

1st config : 10-17 October

- EE with 28 modules (14 mini-cassettes)
- FH with
  - 9 layers with 7 modules
  - 3 layers with 1 module in the back

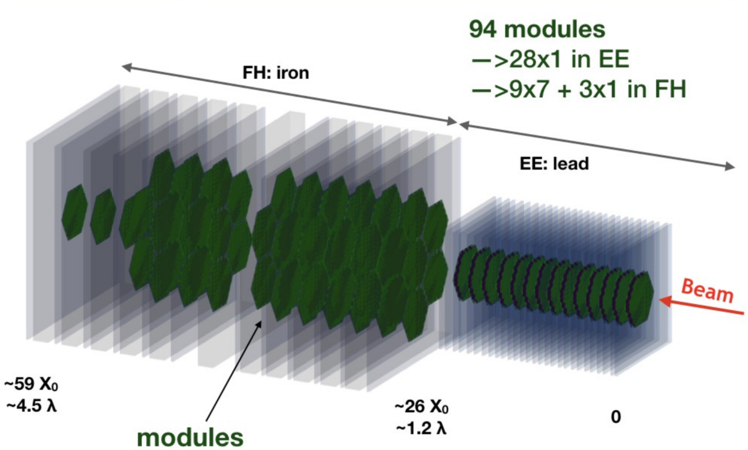
2nd config : 17-22 October

- EE with 28 modules (14 mini-cassettes)
- FH with
  - 2 layers with 1 module in the front (no absorber between these 2 layers)
  - 9 layers with 7 modules

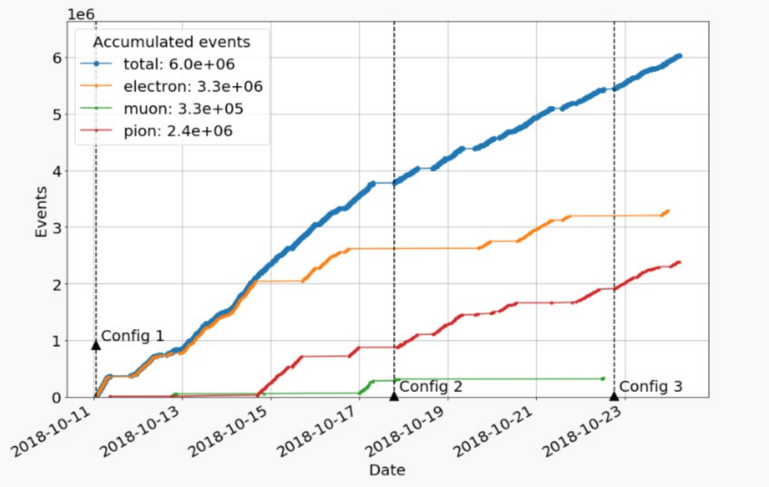
3rd config : 22-24 October + 10 days of parasitic data taking

- EE with 8 modules (only on one face of the cooling plates)
- FH with
  - 12 layers with 7 modules

HGCal configuration #1



Thorben Quast - 04.12.18 1



from A. Steen