Status of the AHCAL technology

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CALICE collaboration meeting

Matsumoto, March 7th, 2012

Overview

- The AHCAL physics prototype
  - Hardware + beam tests
  - Established performance
  - Validated simulations
- Scalable technology solutions
- Mechanics and simulation
- Future R&D plans

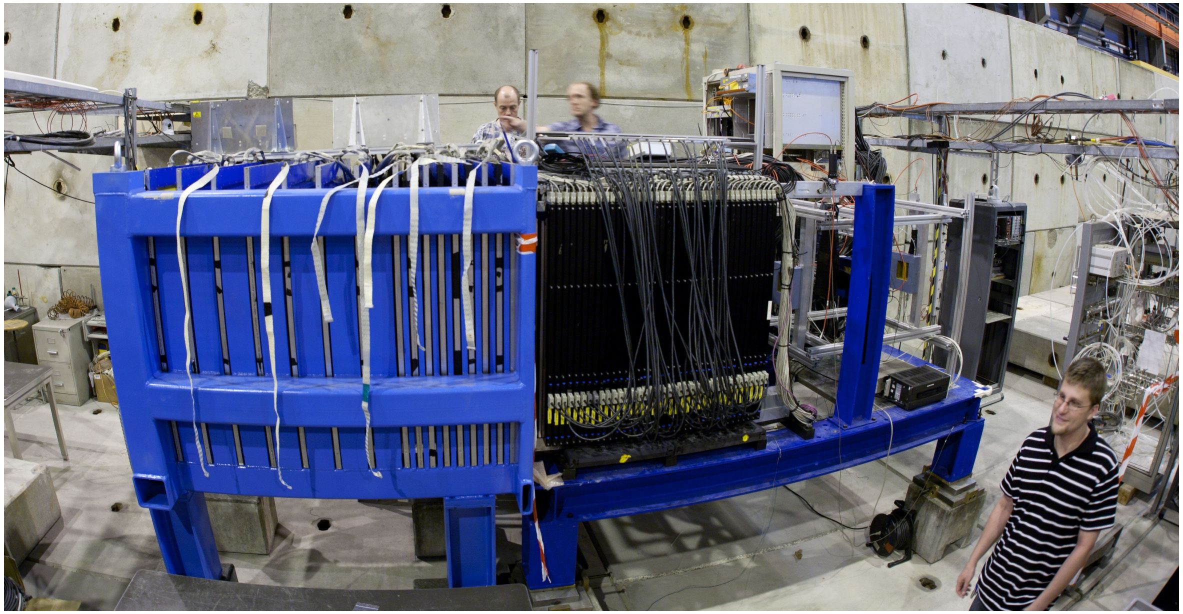
The AHCAL physics prototype

The AHCAL physics prototype

- Constructed in 2006 and used in **many successful testbeams** since then
- **First large scale use of SiPMs** in HEP, now many other users in HEP, astrophysics, medical technology, …
- SiPMs survived many trips with dissembly/reassembly (now: 3.5% dead channels)

→ No signs for aging, no increase of noise

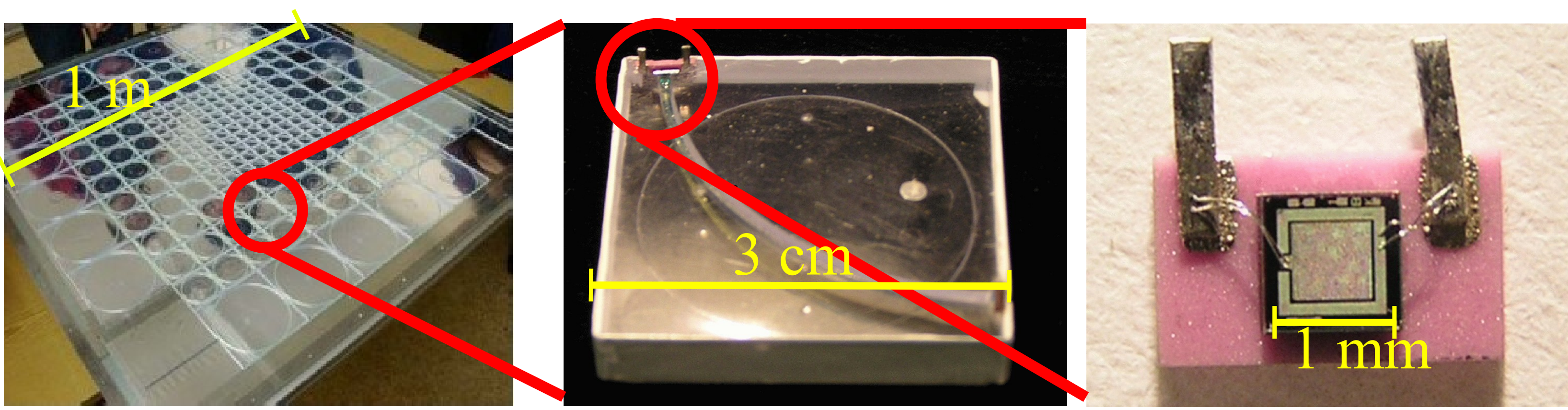
→ Extremely robust technology



Scintillating tiles and SiPMs

- **Base unit:** 3x3x0.5cm³ scintillator tile with SiPM (1156 pixels), manufactured by MePhI/PULSAR, now many manufacturers (advances concerning dark rate)
- Maximum efficiency in green spectral range

  → Wavelength shifting fiber to collect and shift blue scintillation light
- **Features:**
  - Extremely compact, very low power consumption
  - Insensitive to magnetic fields
  - High gain, low operation voltage
  - Prototype **noise occupancy of ~10^{-4} no problem to achieve**

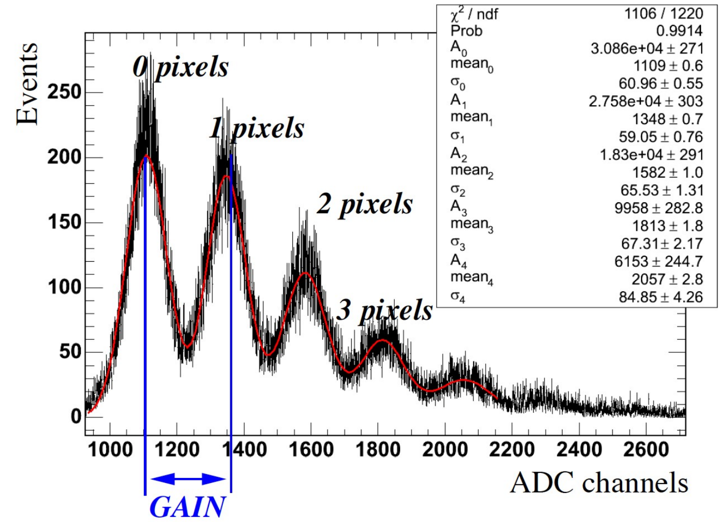


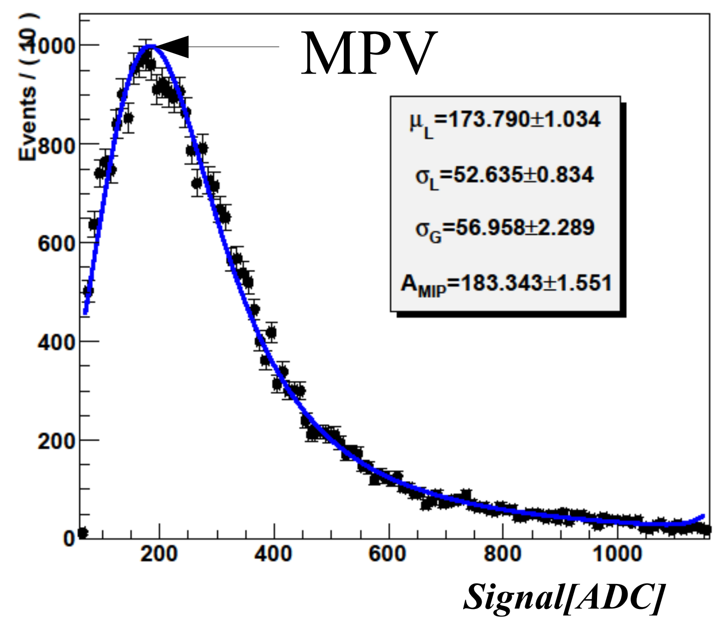
How to calibrate the AHCAL

- **Simple calibration procedure** per cell:
  - MIP constants
  - Saturation behaviour
  - Gain (for saturation and temperature correction) and intercalibration
- **Global calibration to electromagnetic scale**, e/pi ratio for hadronic scale
- Required single cell precision for hadronic calorimeter is moderate, collective effects easy to control

→ Go beyond this to fully understand all aspects of SiPM operation

→ Provide excellent performance for electromagnetic showers

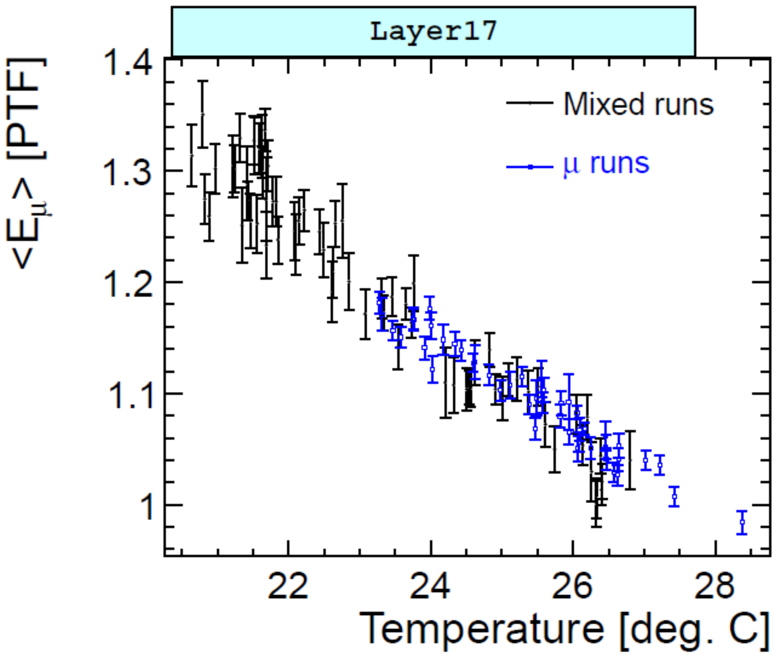


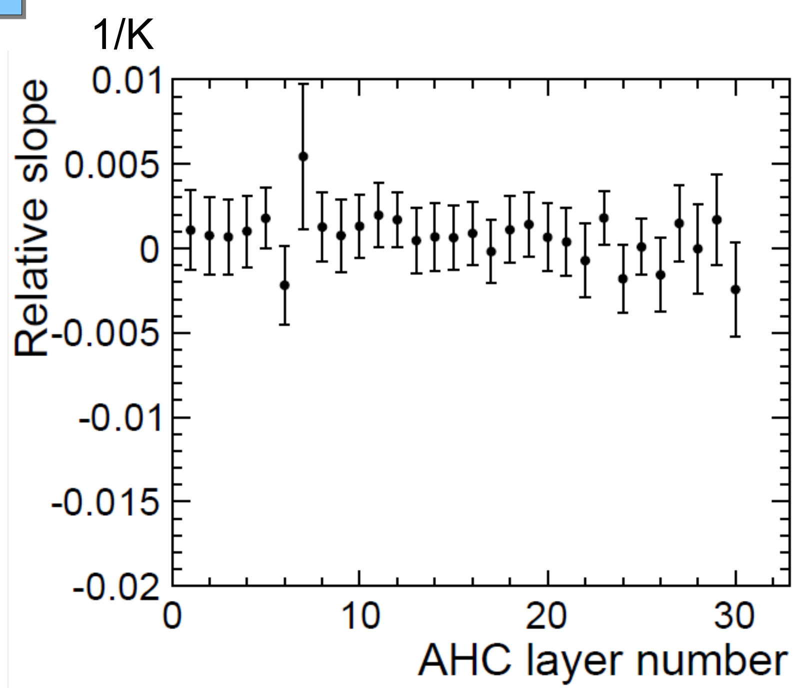


Temperature dependence

- Gain and MIP response are **temperature dependent**
  → Monitor temperature to correct detector response in offline analysis
  → Take MIP and gain runs at different temperatures
- Requires better test bench data and optimized procedures, nevertheless:

Method successfully used in data analyses



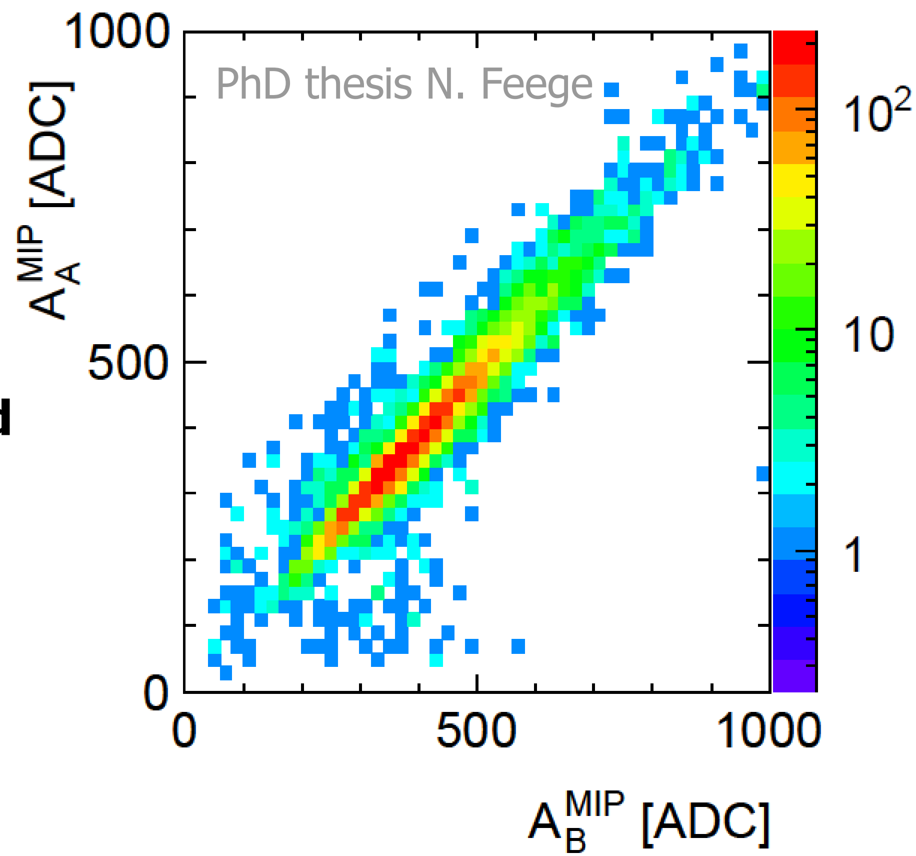


Portability of calibration constants

How to calibrate LC detector with MIPs?

- Can calibration constants be ported to different environmental conditions?

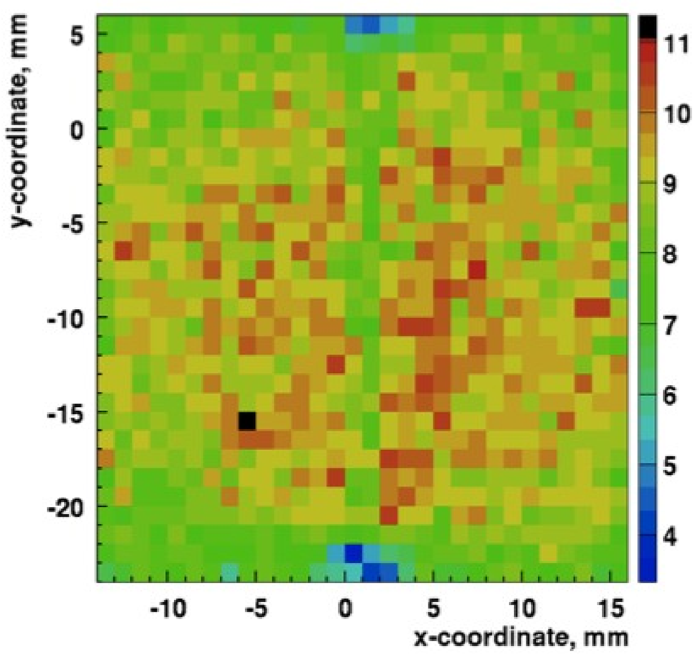
  → **Yes**, if temperature and voltage corrections are applied
- CERN 2006 calibration has been applied successfully to FNAL 2009 data
- Identified **track segments can be used** for MIP calibration

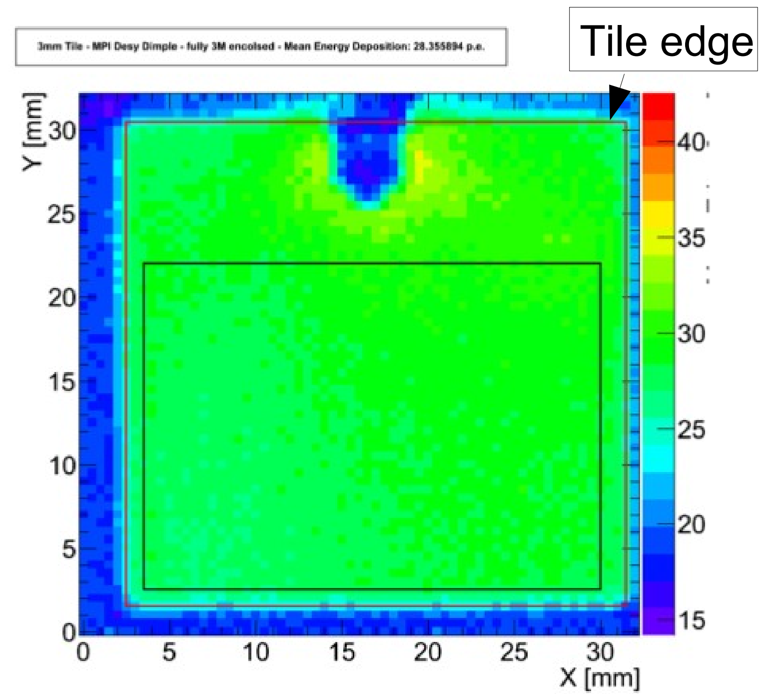


→ All aspects of calibration under control

Response non-uniformities

- **How uniform is the tile response?**
- Tiles with fiber (2nd generation 3mm tile):
  - Slightly reduced response in area of fiber and SiPM area
- Tiles without fiber (tile from UHH, MPI design):
  - Reduced response in dimple and SiPM area





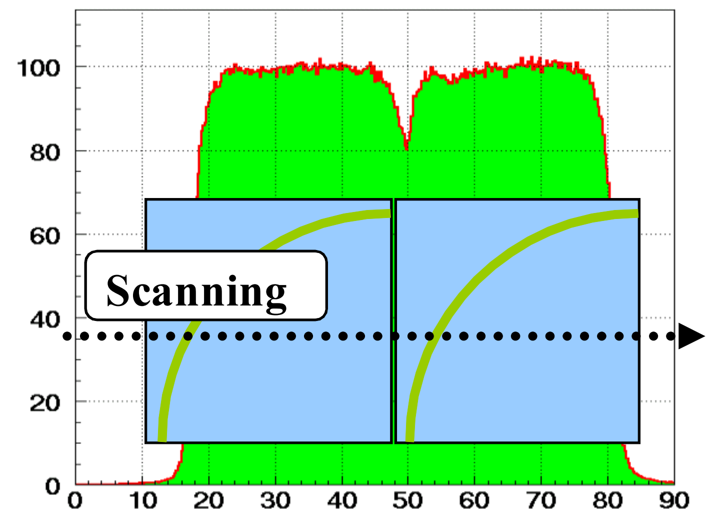
The tile edges

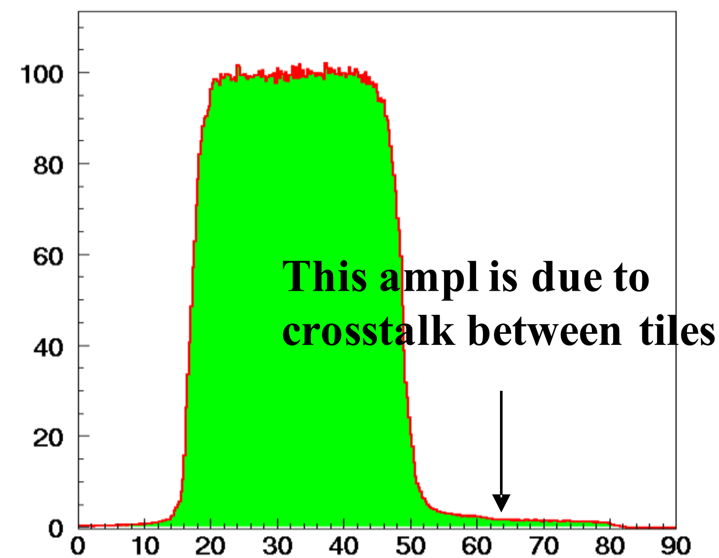
- **Gradient of response at tile edges:**

  → Observation consistent with known angular distribution of electrons from ^{90}Sr source

→ No indication of sizeable edge non-uniformities beyond assembly tolerances and matting

- ^{90}Sr tests at ITEP with two adjacent tiles
  - Overall efficiency loss ~2% due to edges
  - Cross talk through matted side and over reflective covering

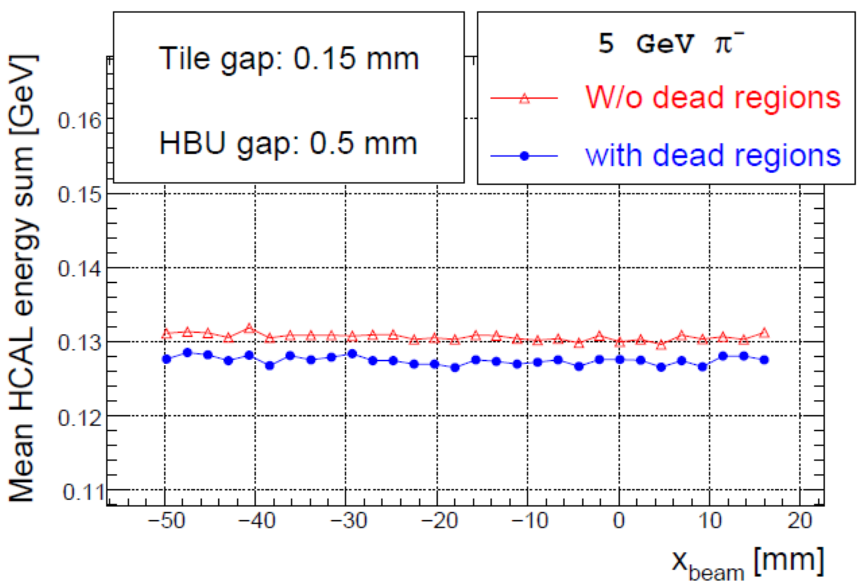


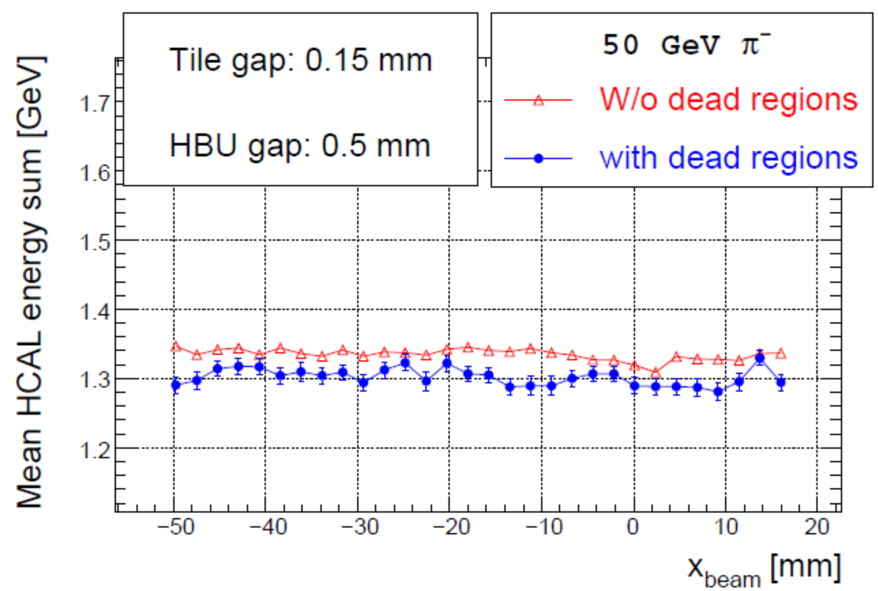


Impact of non-uniformities

- Effect from non-uniformities visible in response to muons
  → Single particle, tiles aligned from layer to layer
- Effect is **negligible for hadronic showers**
  → Higher multiplicity, particles spread over active tile area
- Simulation in ILD with realistic gaps between tiles and HBUs
  → Simulation model **validated with electromagnetic showers**

→ No impact on energy resolution observed

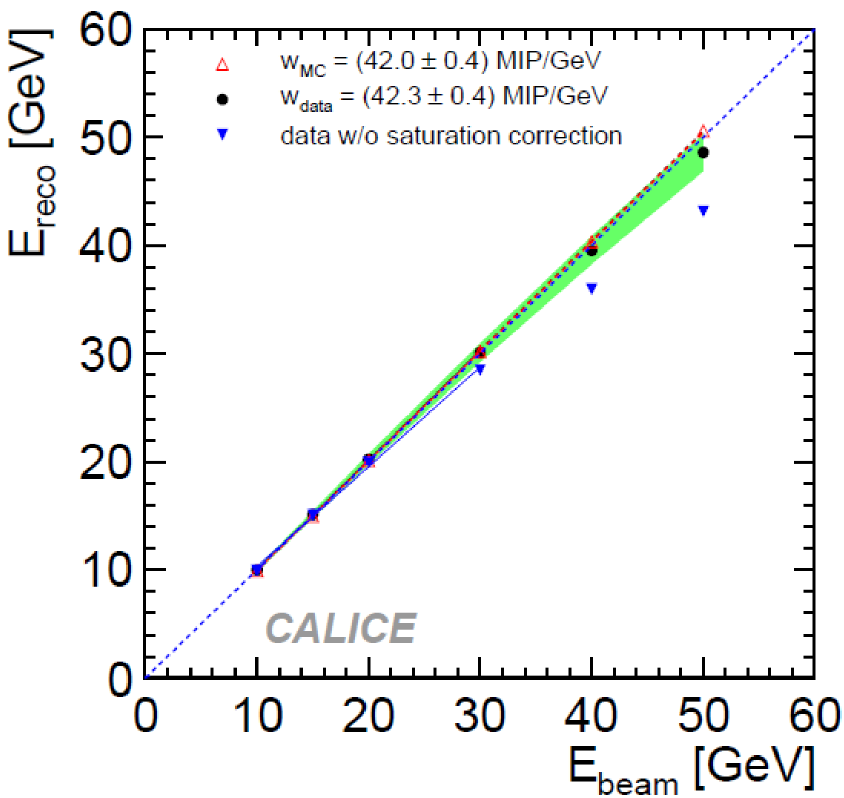


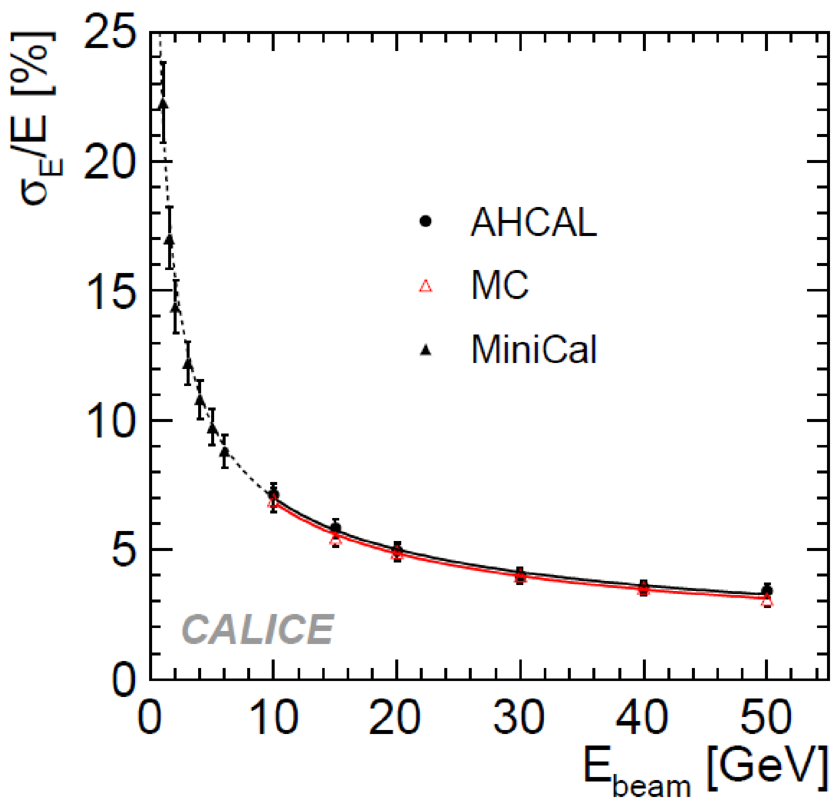


Validation with electron data

- Detector performance for electrons and positrons provides a detailed **validation of the simulation model** of the AHCAL

→ AHCAL geometry description, simulation and digitization in **excellent agreement with data**



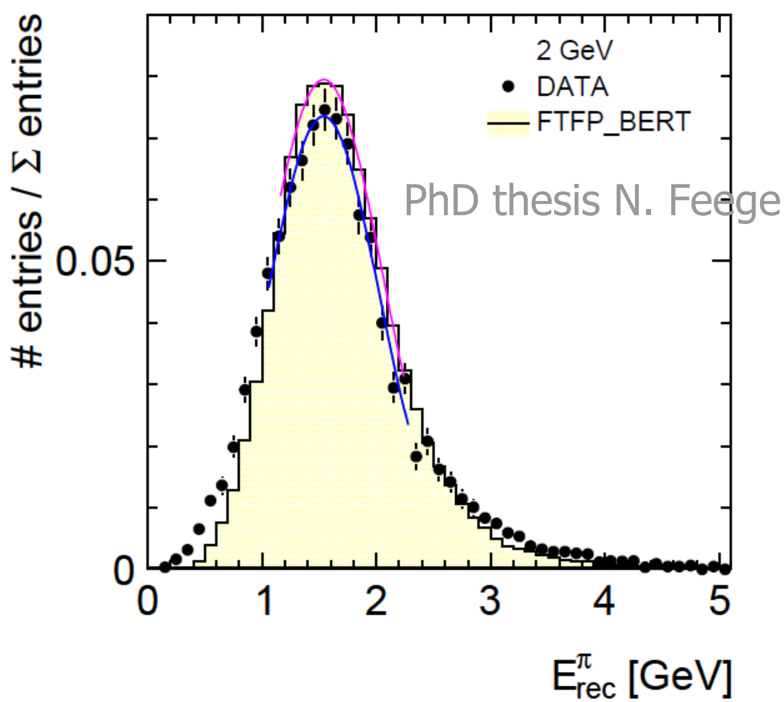


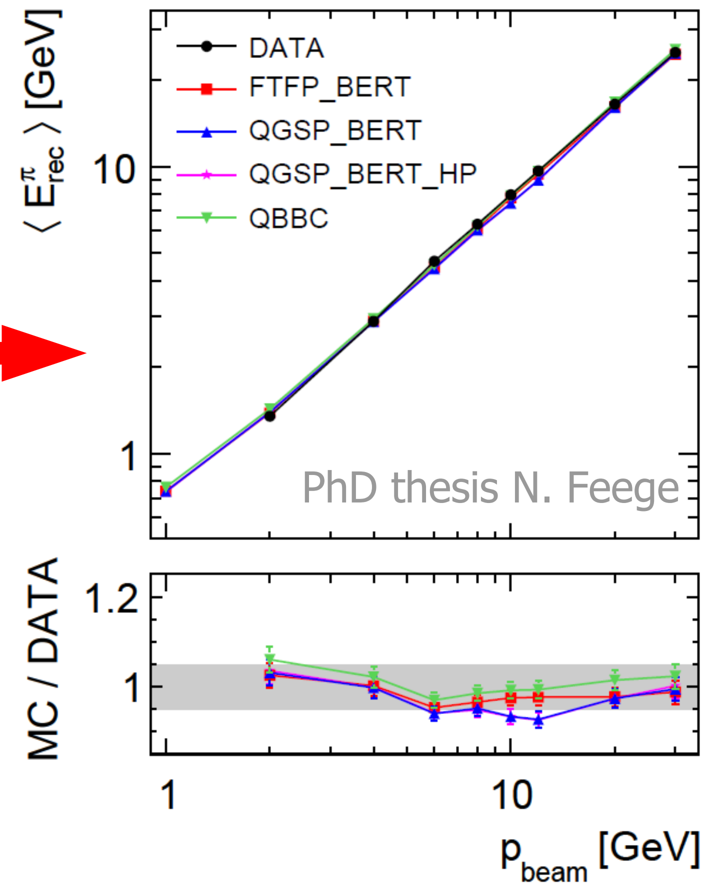
Selected results from data analyses

GEANT4 - Reconstructed energy

How well can GEANT4 describe out data?

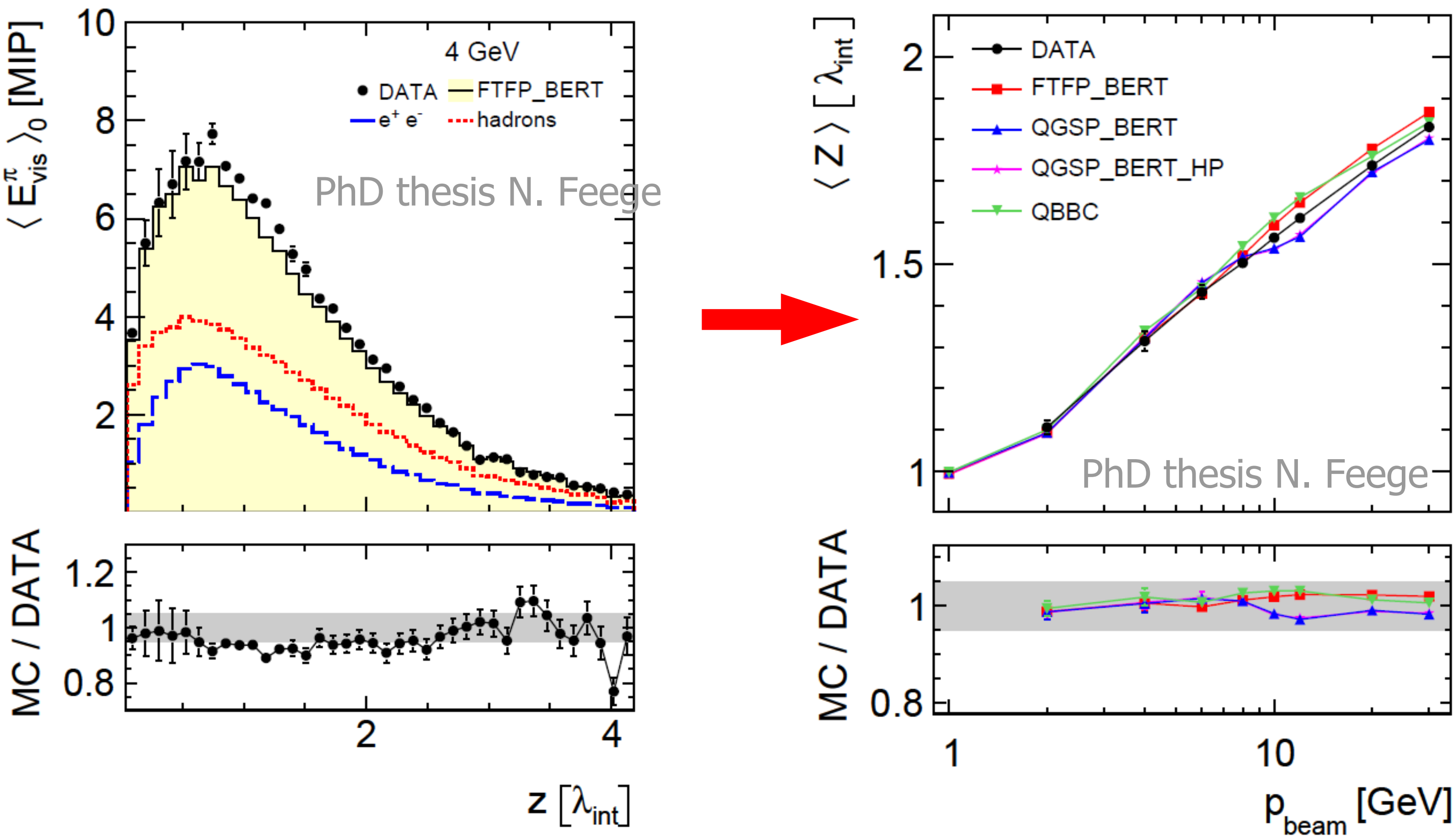
- Simulation only tuned with muon data
- Compare **reconstructed energy** in data with MC predictions





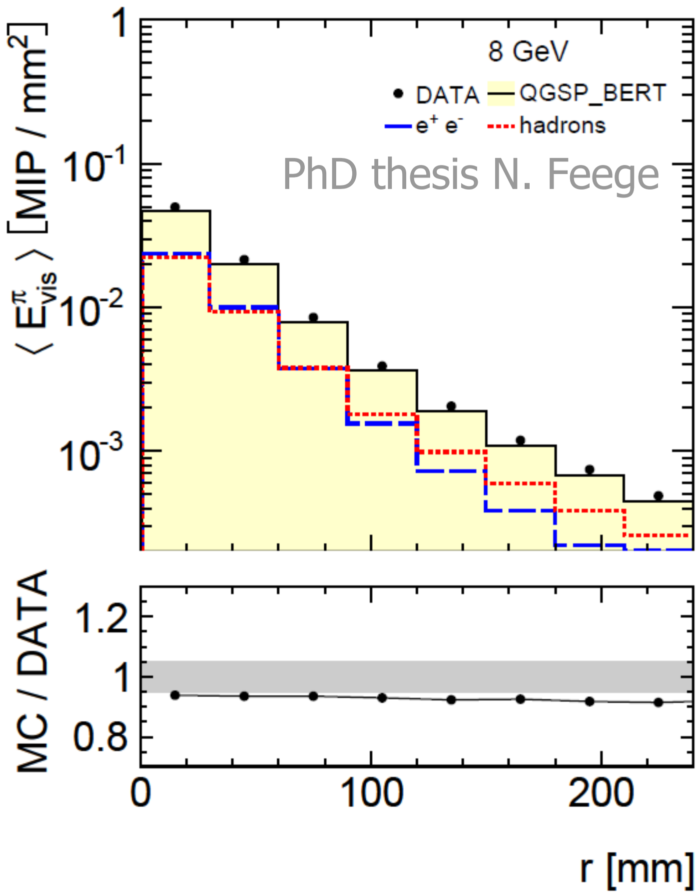
Longitudinal shower profile

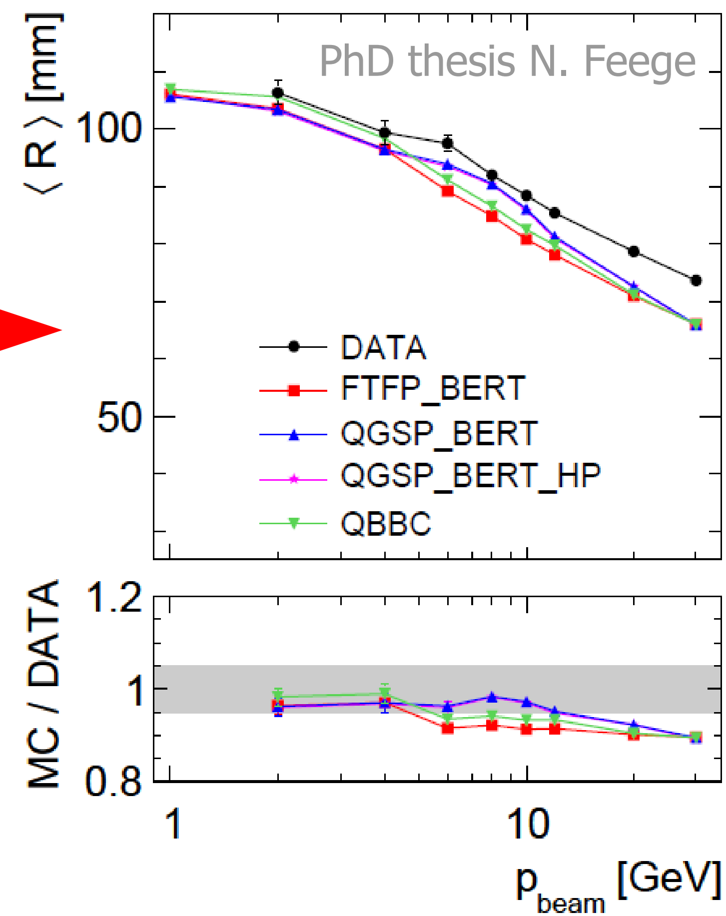
- High granularity allows to measure **shower shapes** in detail
- Measurement sensitive to electromagnetic fraction of cascades



Radial shower profile

- High granularity allows to measure **shower shapes** in detail
- Radial profile underestimated by MC → Doesn't affect 2 particle separation

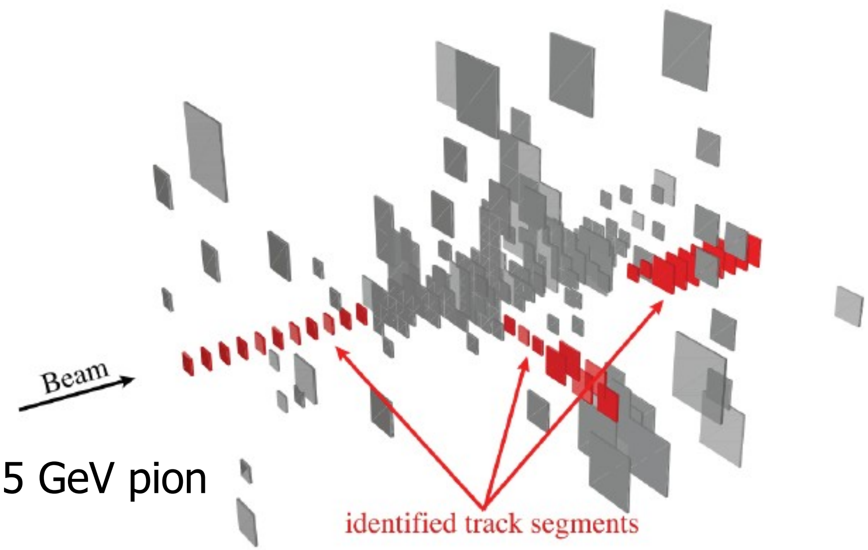




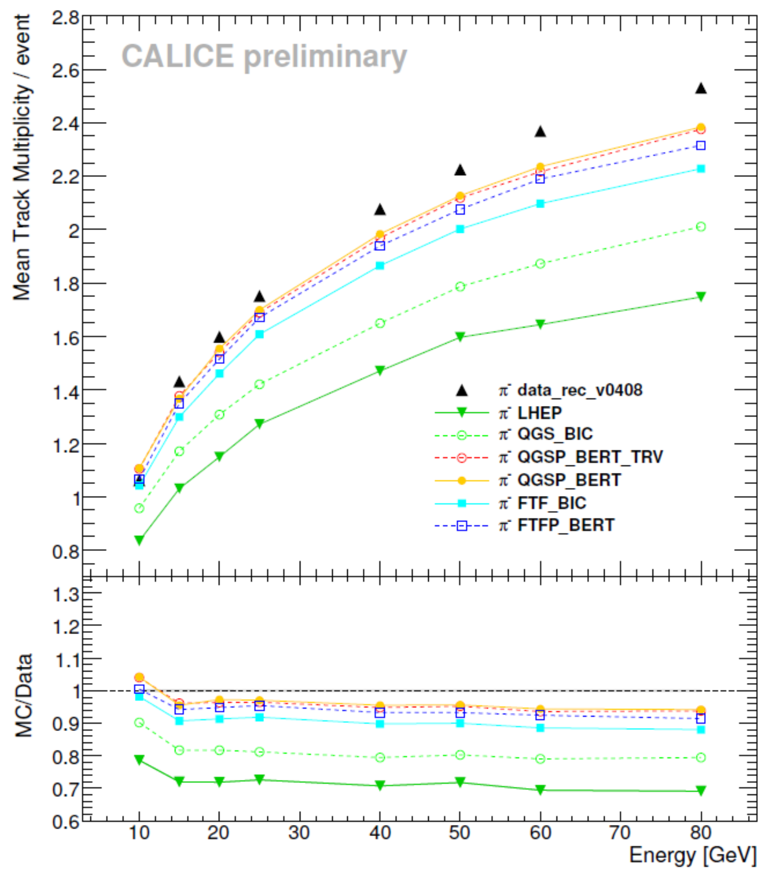
Shower sub-structures

- High granularity also allows measurements of **shower sub-structures**
- Here: **number of track segments**

Modelled surprisingly well in new models

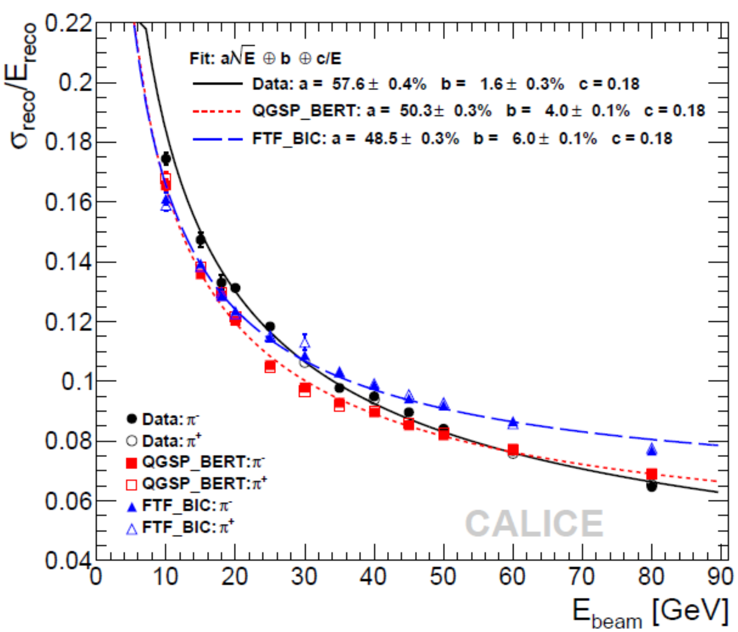


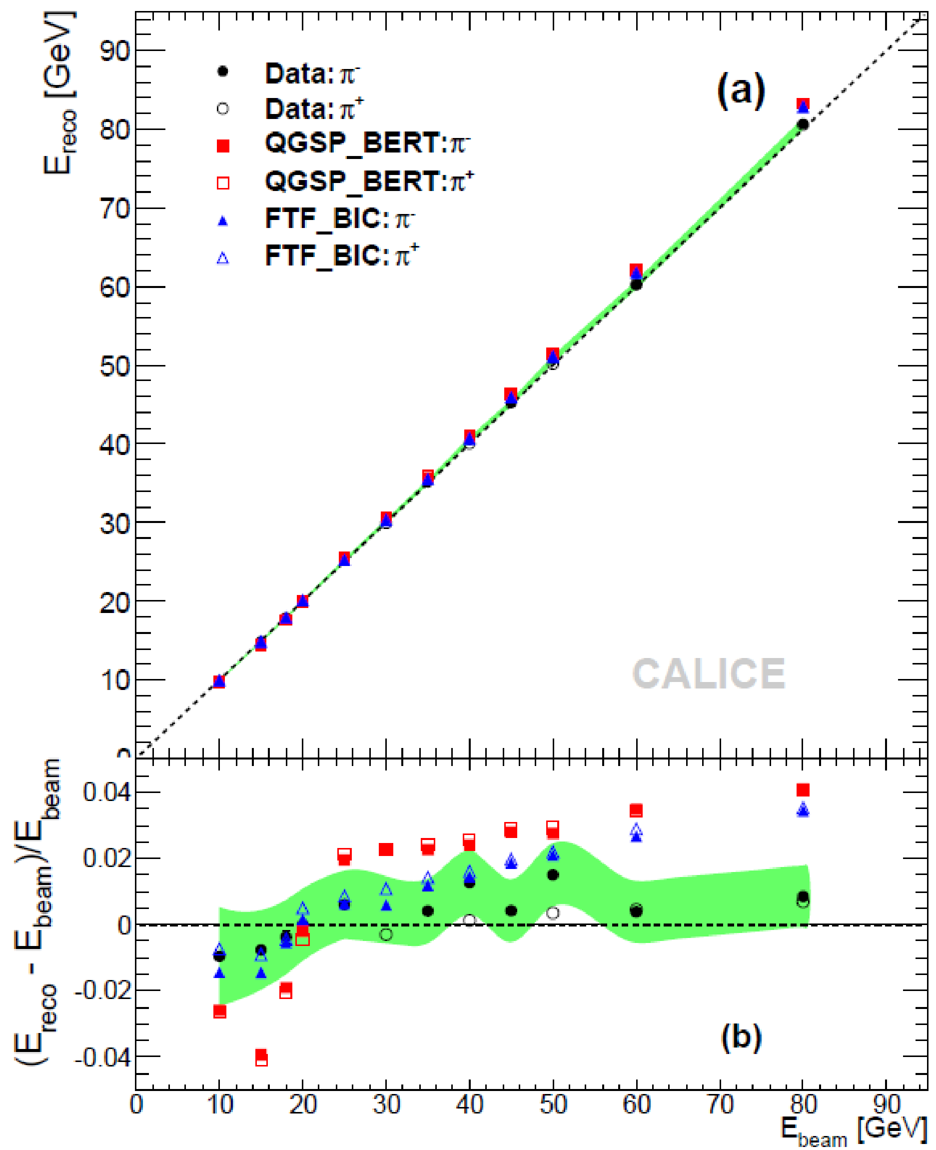
25 GeV pion



Energy resolution and linearity

- In spite of imaging capability: Need to measure **shower energy**
  - → Linearity?
  - → Energy resolution?
- Slightly different behaviour of simulations compared to data





Software compensation

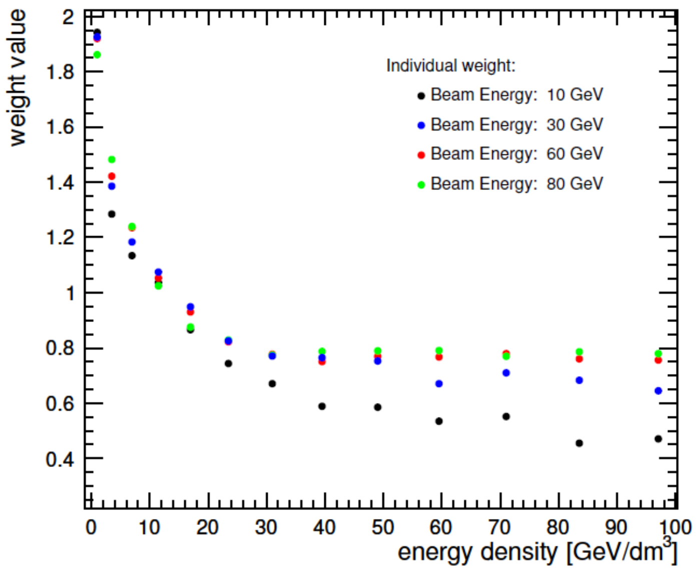
- Energy dependent electromagnetic fraction requires **compensation**
- **Local** and **global** compensation techniques have been developed

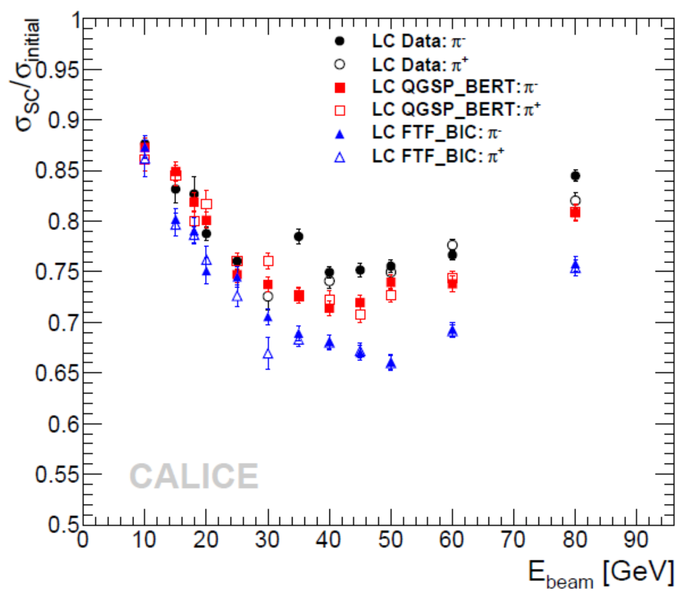
  → Comparable performance
- Improvement of energy resolution between **12% and 25%** (depending on beam energy)

  → Improvement described well by simulations

  → Successful proof of principle in **full ILD simulations** with local SC integrated into PandoraPFA

Stochastic term improved **from ~58% to ~45%**



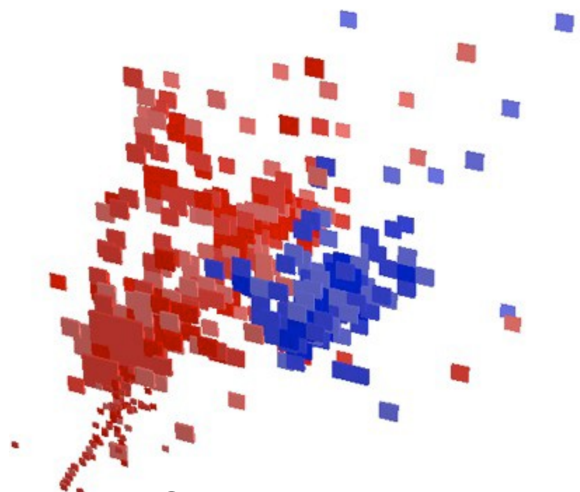


Particle Flow with test beam data

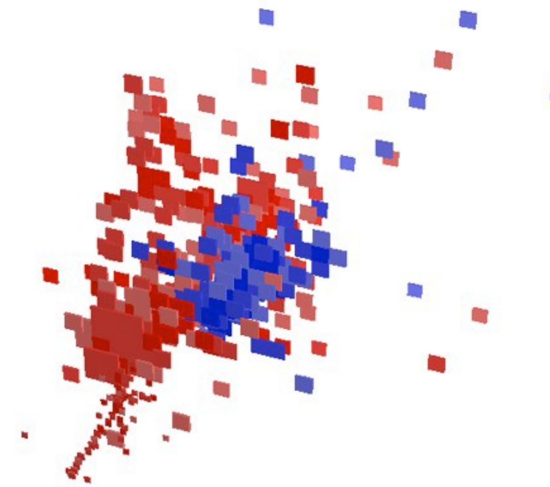
Test MC models with important particle flow analysis!

Method:

- Take 2 pion events and map them to ILD geometry
- Assume one is neutral
- Vary distance between the 2 pions and test **how well the energy of neutral hadron is reconstructed**



~18 cm separation of shower



~7 cm separation of shower

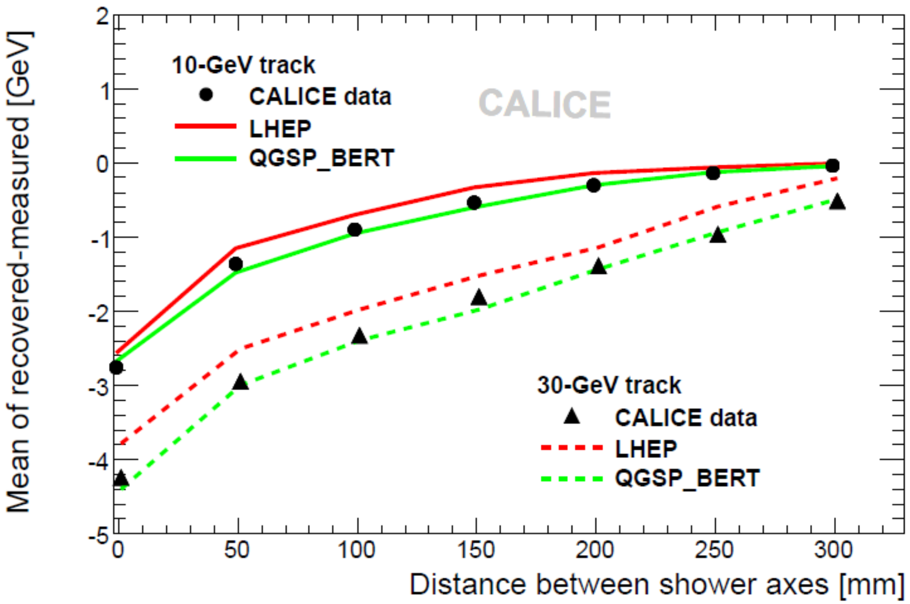
30 GeV charged hadron

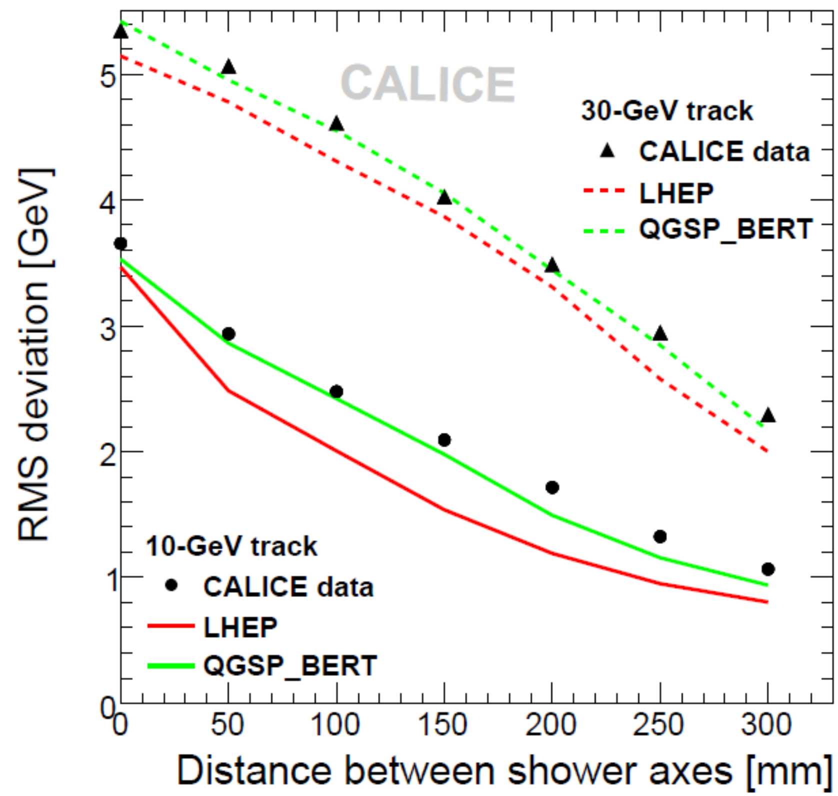
10 GeV 'neutral' hadron

Particle Flow with test beam data

Confusion depends on radial distance between showers and their energy

→ Good agreement between data and MC

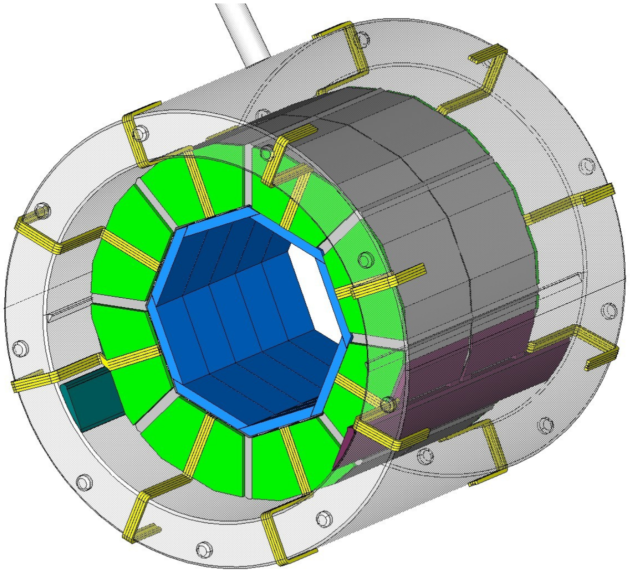




The next generation prototype

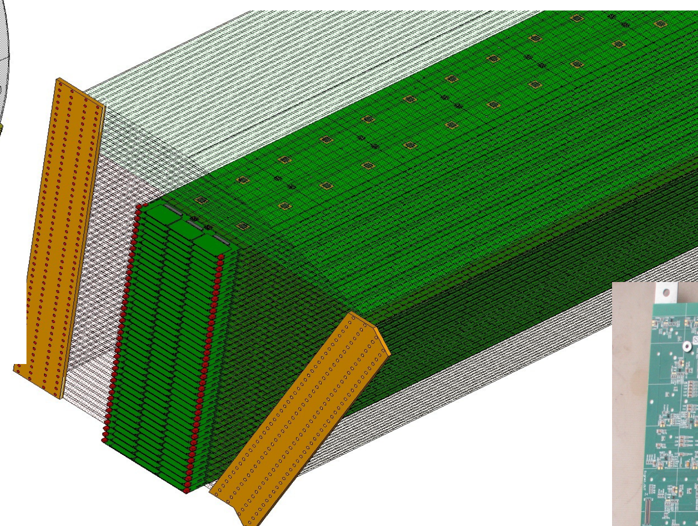
The engineering AHCAL prototype

Development of **scalable LC detector** based on successful experience with physics prototype

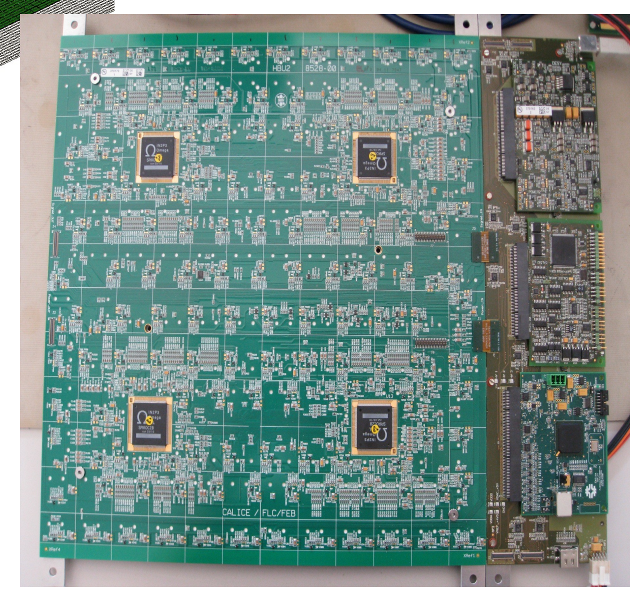


Inspired by ILD, looks similar for SiD

Octagonal shape, 16 equivalent wedges, segmented in two along z



PCB with 4 ASICs, 144 scintillator tiles, SiPM readout



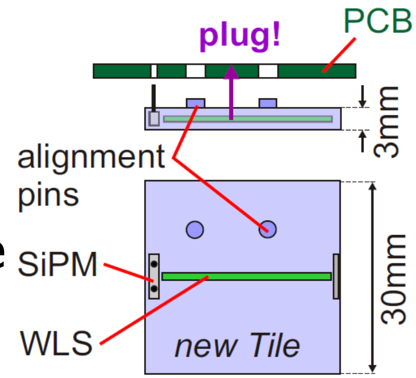
Challenges:

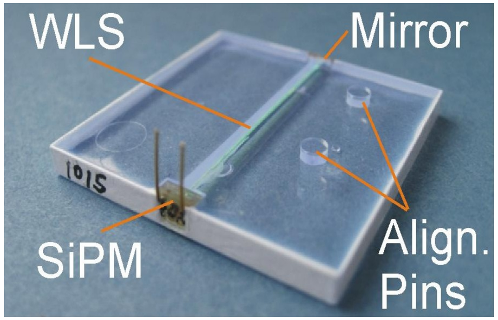
- No spacer between layers
- Minimize dead material between wedges
- Minimize gap between barrel and endcap

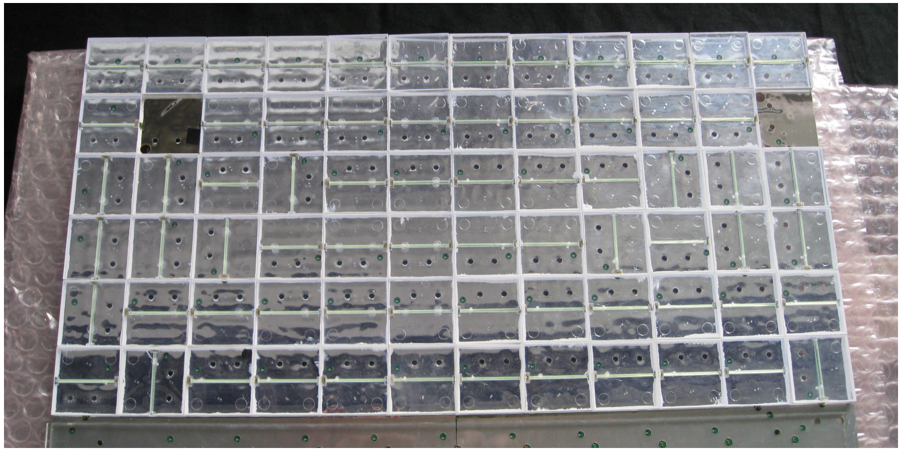
→ Integrated readout electronics

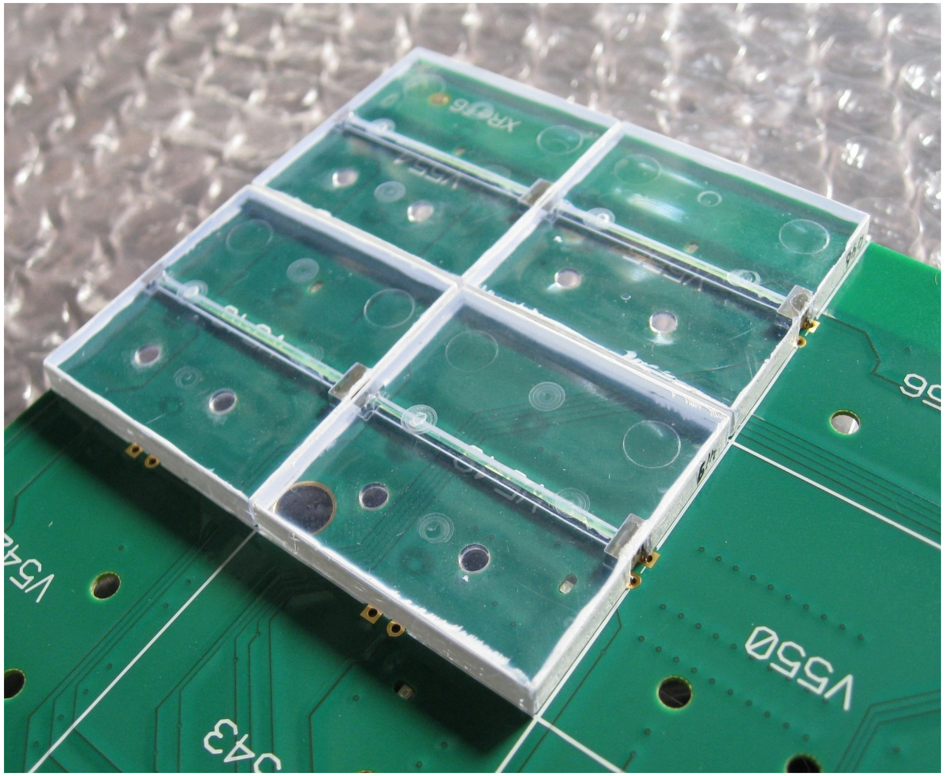
Scintillating tiles

- Signal sampled by **scintillating tiles**
  - → 3x3x0.3cm^3, ~2600 tiles per layer
  - → **Tiles can be cut**, pins on same side
- **Many new tiles** from ITEP tested
  - → Very good results so far
  - → Equipment of several new HBUs
  - → Important step to multi-HBU-setup now possible









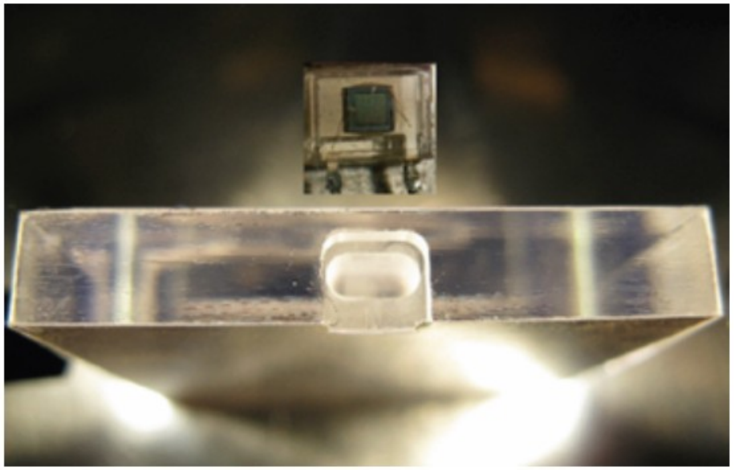
Alternative option: direct tile readout

- Commercial SiPMs (Hamamatsu MPPC, ...) have **sensitivity maximum in blue spectral range**

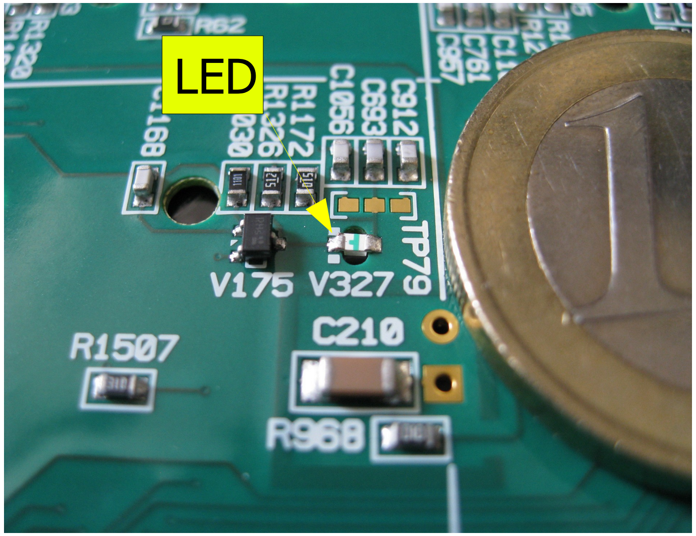
  → No need for wavelength shifting fiber

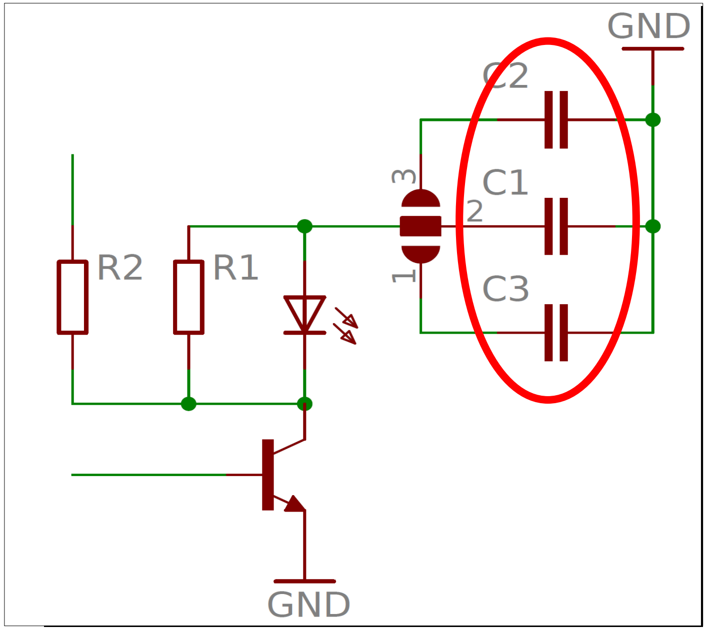
  → Reduced mechanical complexity, no alignment of SiPM
- To achieve good uniformity reduce scintillating material in front of SiPM
- ITEP can produce such tiles via injection moulding (first results promising)

→ Achieved very good results in light yield measurements (uniformity)



LED calibration systems





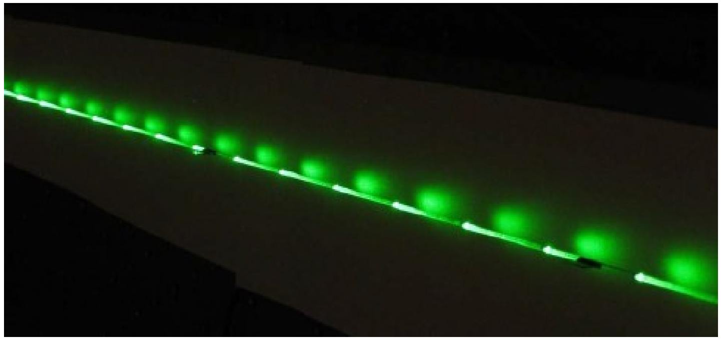
Wuppertal solution:

- Light directly coupled into tile by **1 integrated LED per channel**
- Light output equalization via C1 – C3
- New design implemented in HBU2 and is currently tested extensively

Prague solution:

- Light coupled into tile by notched fiber

  → First tests performed in DESY lab with new electronics and new tiles



The readout chip - SPIROC2b

Specific chip for SiPM readout:

- Input DAC for channel-wise bias adjustment (36 channels)

Designed for ILC operation:

- **Power pulsing** → 25µW/ch
- Dual-gain setup per channel

  → channel-wise amplification factor

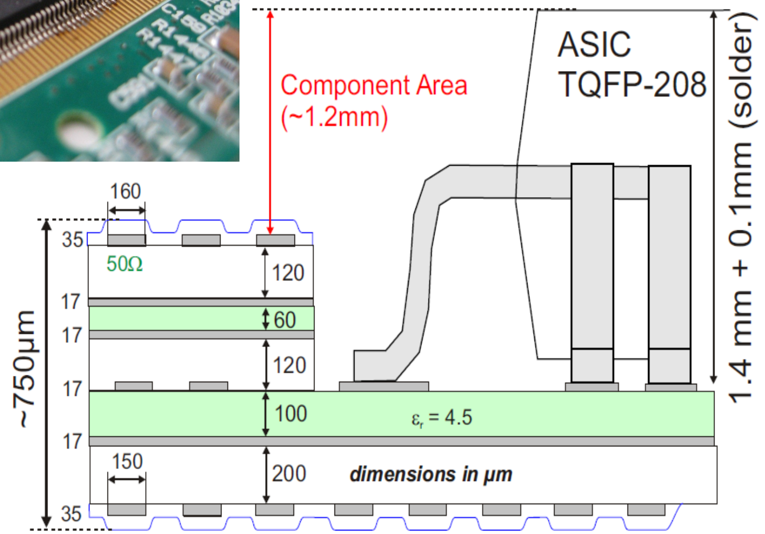
  → Channel-gain equalization perfectly possible for ITEP tiles

- **Auto-trigger** mode

  → channel-wise adjustable threshold

- **Time stamp** (12-bit TDC)
- Many tests have been performed to gain profound understanding of the chip

Designed by OMEGA/IN2P3



Placement of components in PCB cutouts

→ 500µm/layer

→ 50mm in total!

New HCAL Base Unit (HBU2)

- 4 **new HBUs** in DESY lab

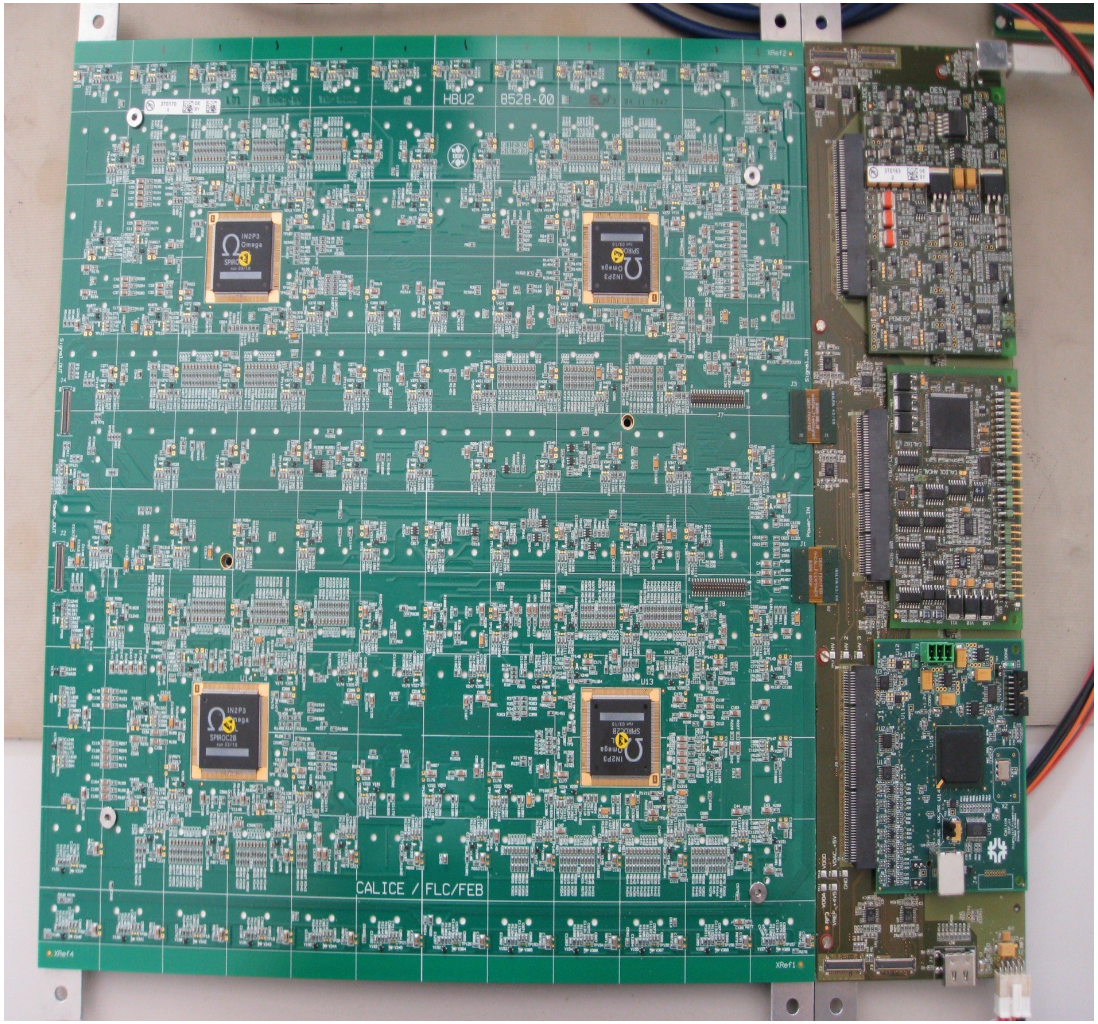
  → Successful tests of ASICs, calibration system, tiles
- 1 HBU2 connected to 2nd generation DAQ modules for first tests

  → Firmware under development
- 1 HBU2 in **DESY test beam**
- We ordered 6 new HBU2s for **full slab test**:

  → Quality of electrical signals

  → Mechanics, temperature

  → DAQ



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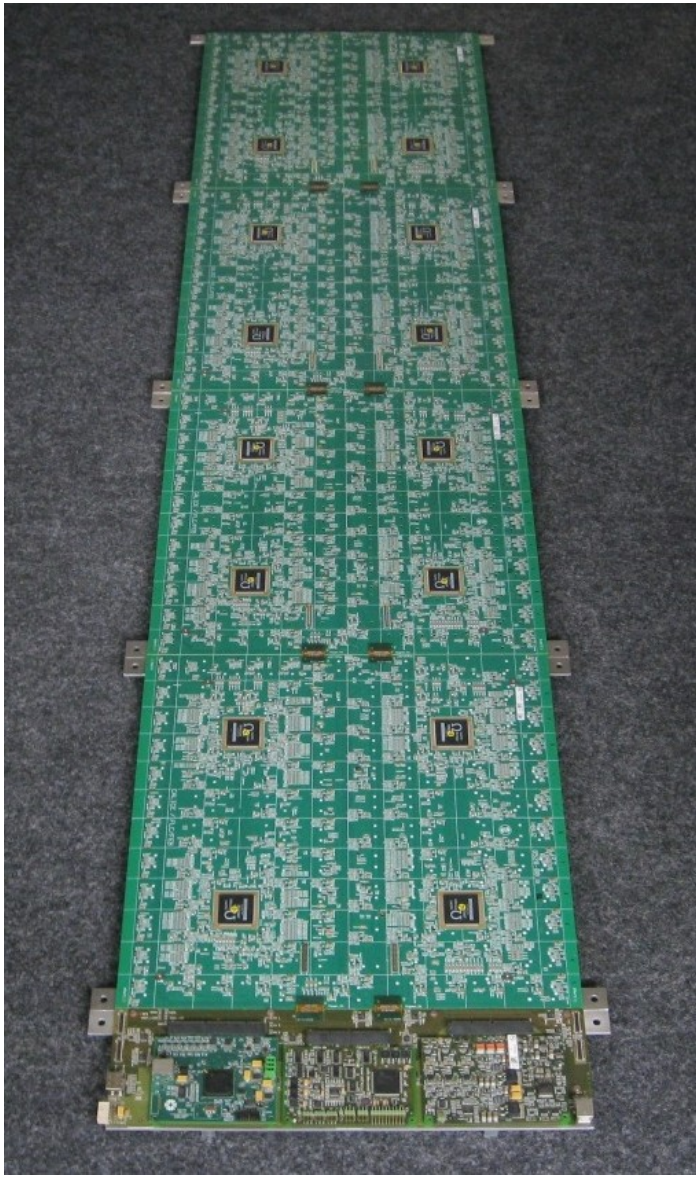

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- We ordered 6 new HBU2s for **full slab test**:

  → Quality of electrical signals

  → Mechanics, temperature

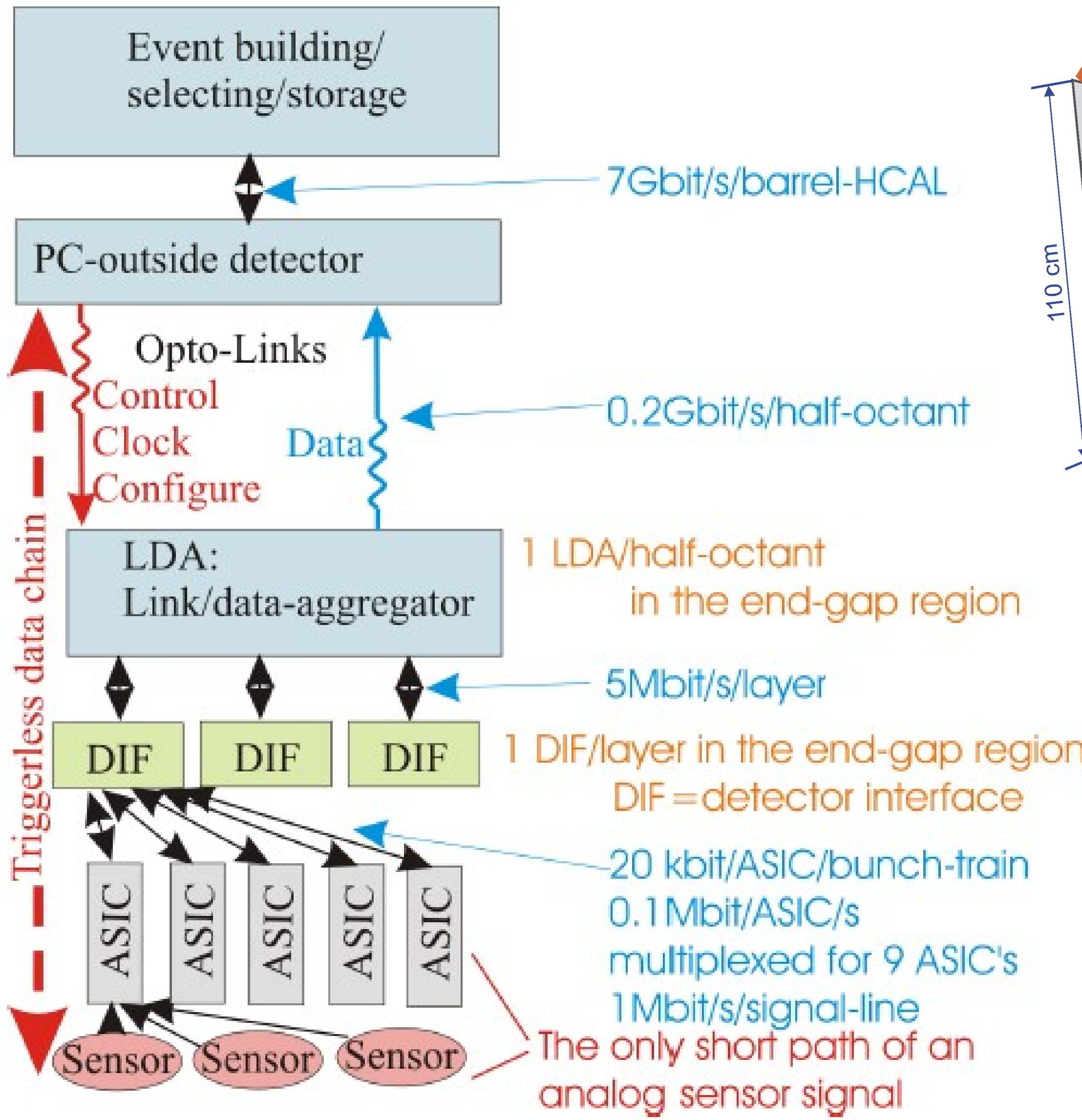
  → DAQ

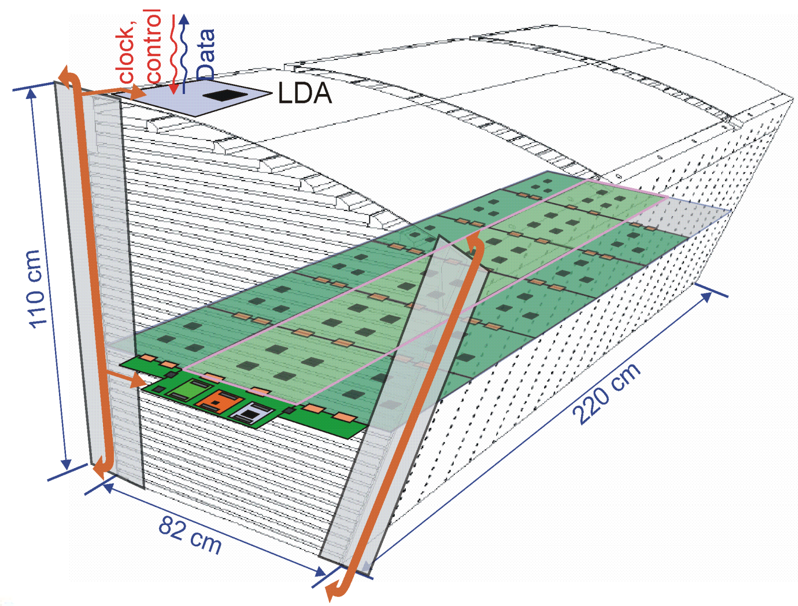
- **Mechanics is in place** since long time

  → Use it to perform temperature tests

  → Use it for small stack

Data acquisition



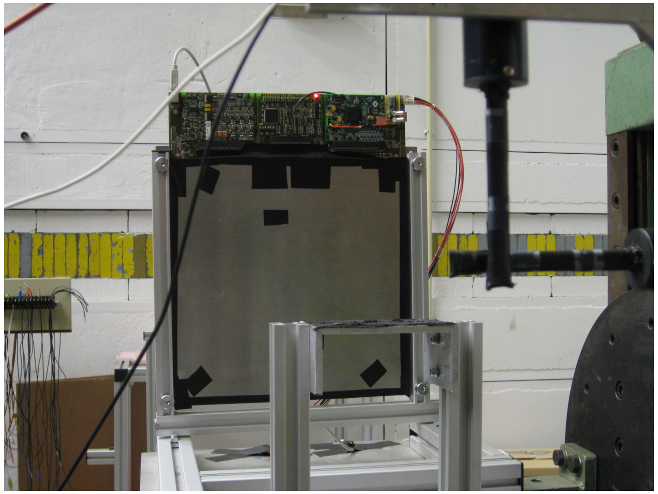


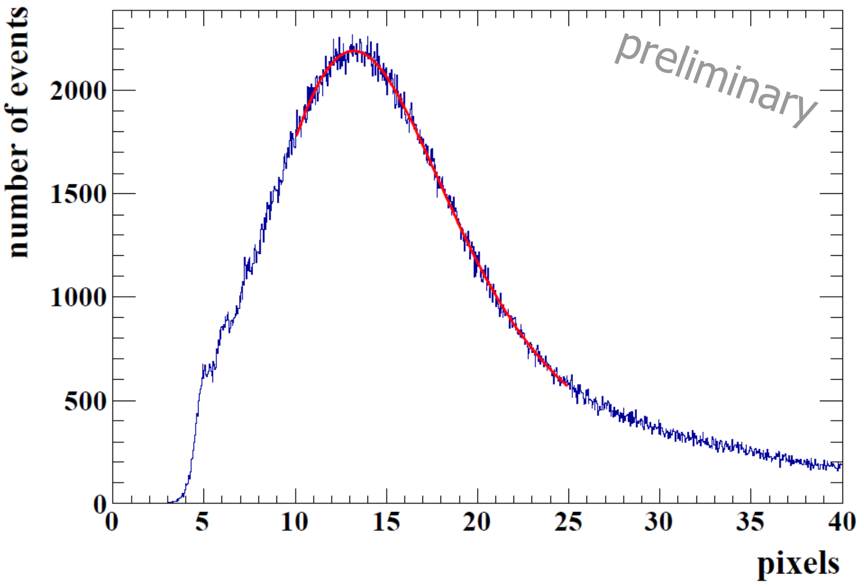
- **Moderate data rates** using channel-wise self-triggering

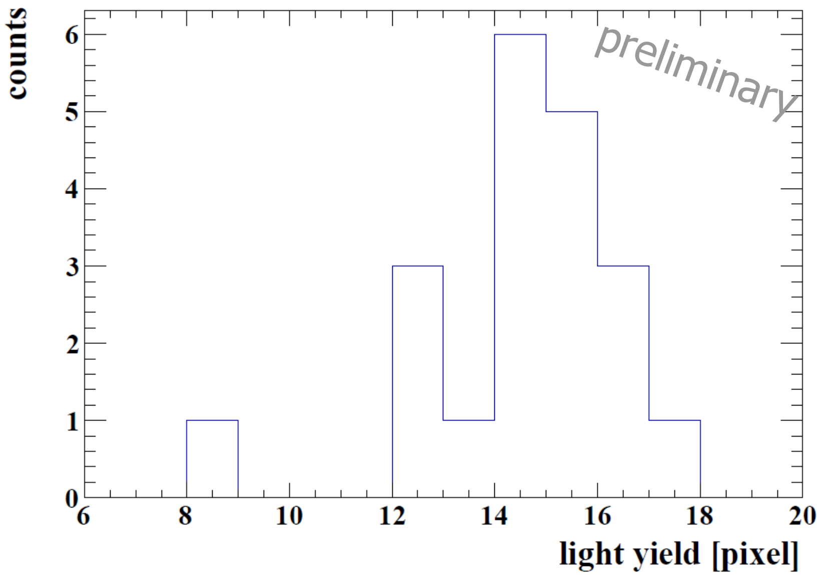
  → No need for further front-end event selection
- **2nd generation DAQ** under development

Test beam – First MIP results

- **HBU2 in DESY test beam**
  - Test functionality in test beam environment
  - Measure MIPs with 2 GeV electron beam
    → **~15 pixels per MIP**
  - Test channel-wise gain and autotrigger adjustment and **optimize MIP efficiency**
    → **Good results so far**







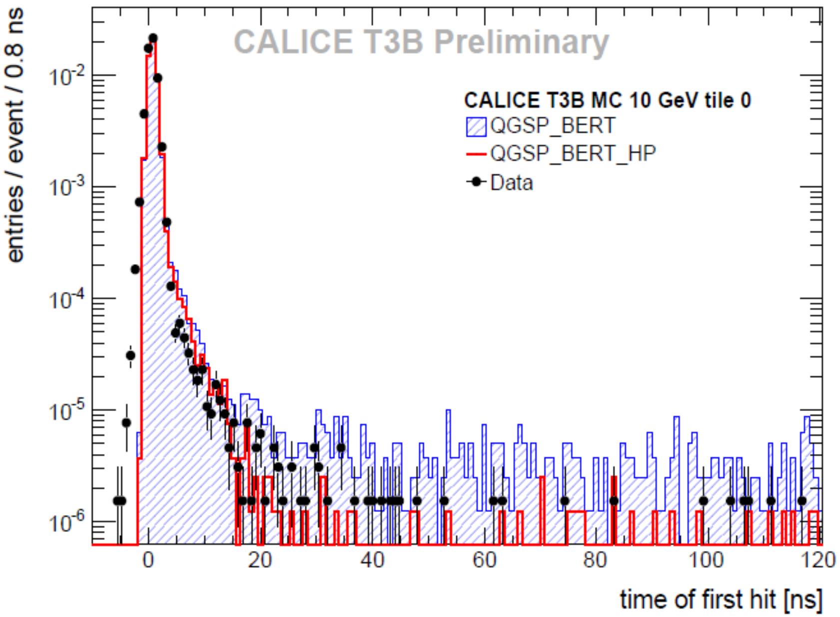
Power pulsing

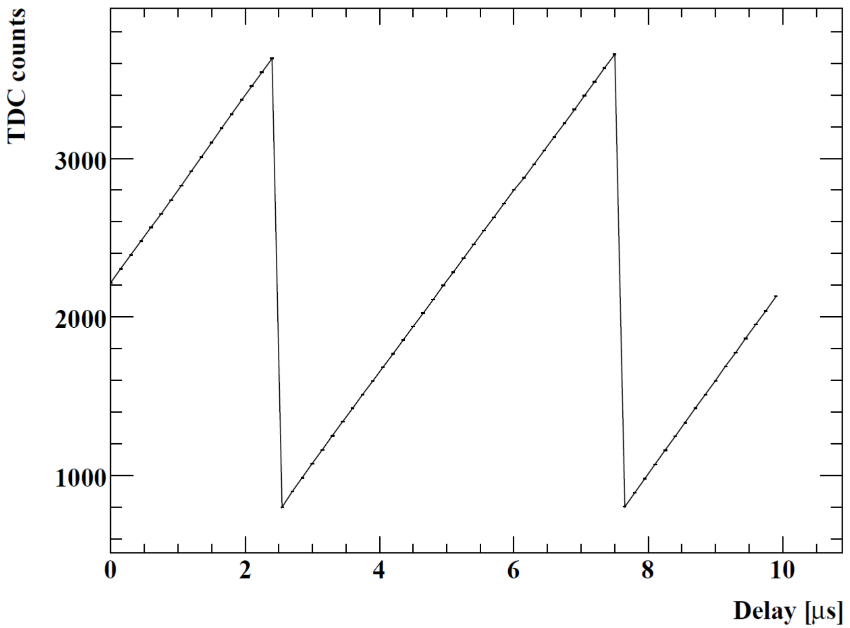
- Concept of power pulsing already tested on ASIC test bench

  → Working so far, but has to improve
- Need to verify power distribution and signal integrity in larger system

  → **Use multi-HBU setup** (2012)
- **Validate heat dissipation calculations** with realistic steel plates (2012)

Shower timing measurements





- T3B measured **radial development of shower in time**
  → Repeat measurement with **full layer** or even multiple layers
- ASIC measures time in auto-trigger mode relative to bunch clock

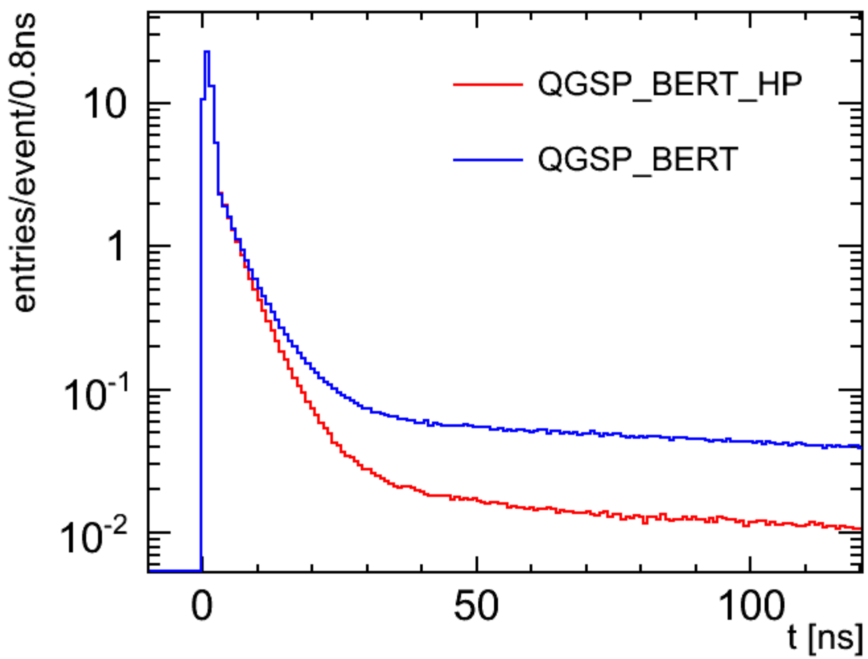
→ **Resolution:** ILC mode = **300ps**, testbeam mode = **1-2ns**

Simulation of time development

- Implementation of **time information in simulation** done
- Digitization is currently under development

  → Realistic analyses of simulation data with timing information started

→ Prepare for future 4D testbeam measurements

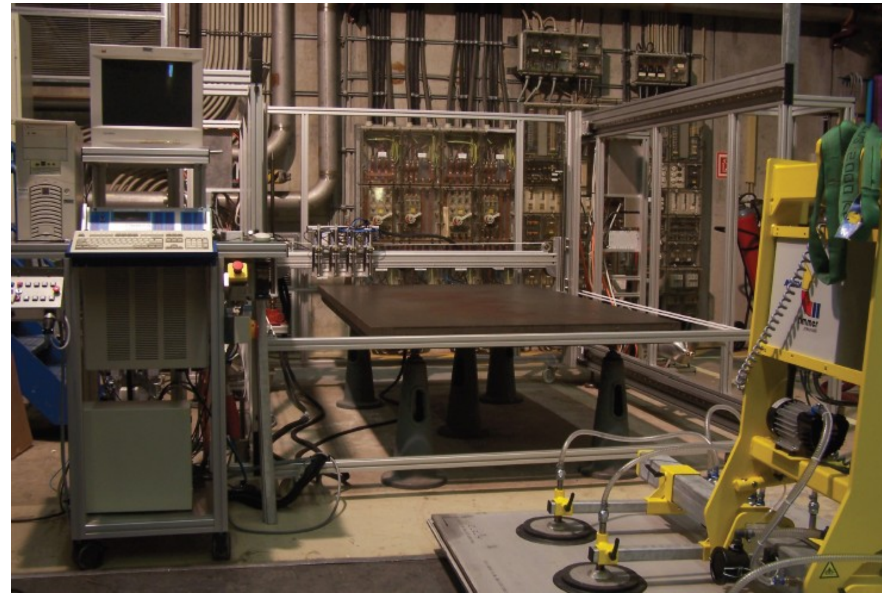


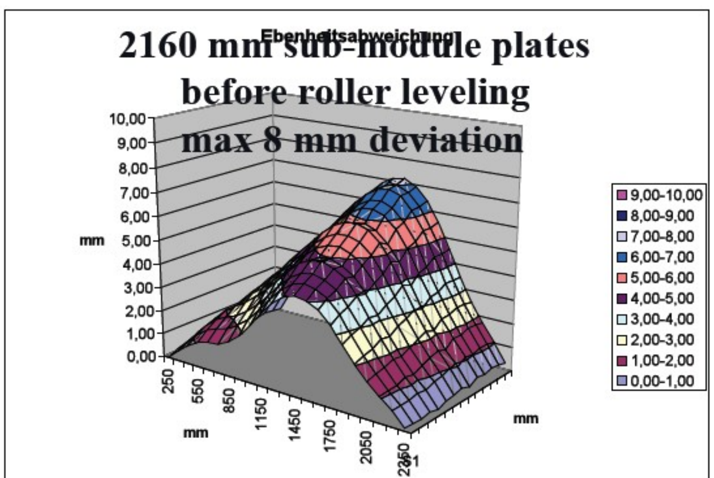
Mechanical concept and simulation model

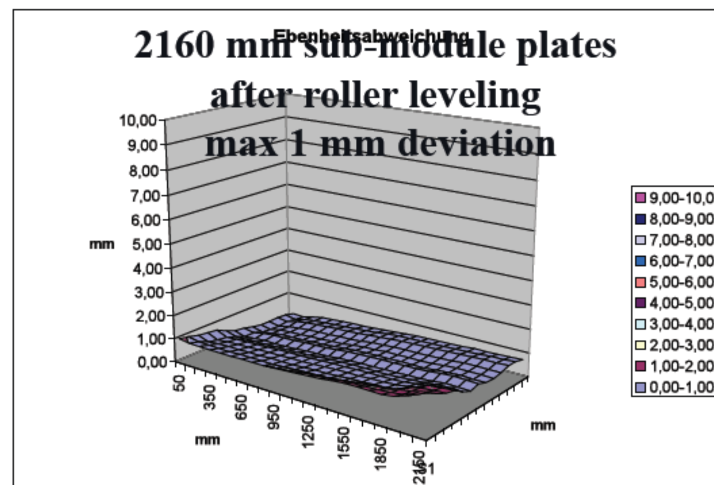
Manufacturing of steel plates

- **Precise measurement of large steel plates** possible at DESY
- Specifications:
  - Thickness: -0.3 +1.6 mm
  - Flatness: < 10 mm over 1 m

    < 13 mm over 2 m
- Flatness achieved **w/o machining** with cheap production procedure and **rolled steel**

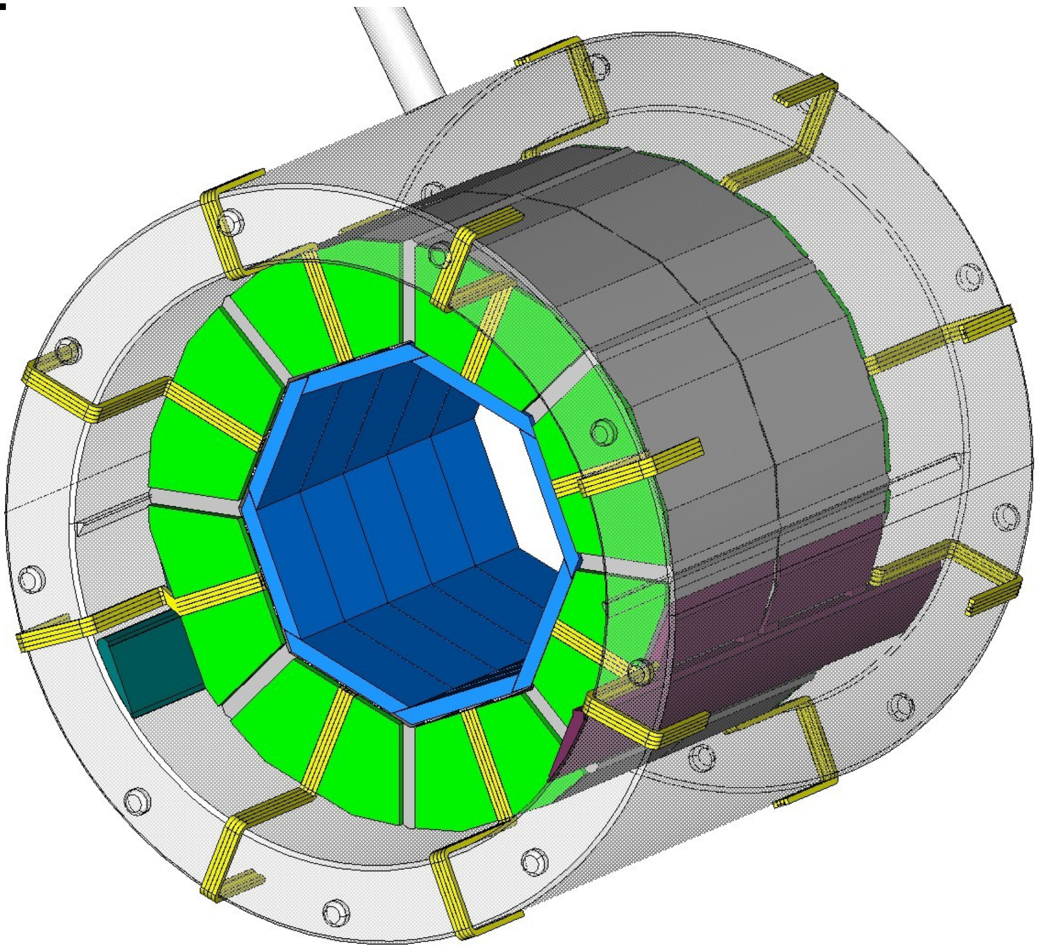






The AHCAL in the ILD

- **Full implementation of AHCAL in ILD available**
  - Support structures
  - Front-end electronics
  - Cabling
- Realistic **implementation of gaps** between half barrels, sub-modules, within modules and layers
- Installation scenario is known
- AHCAL rotation under discussion



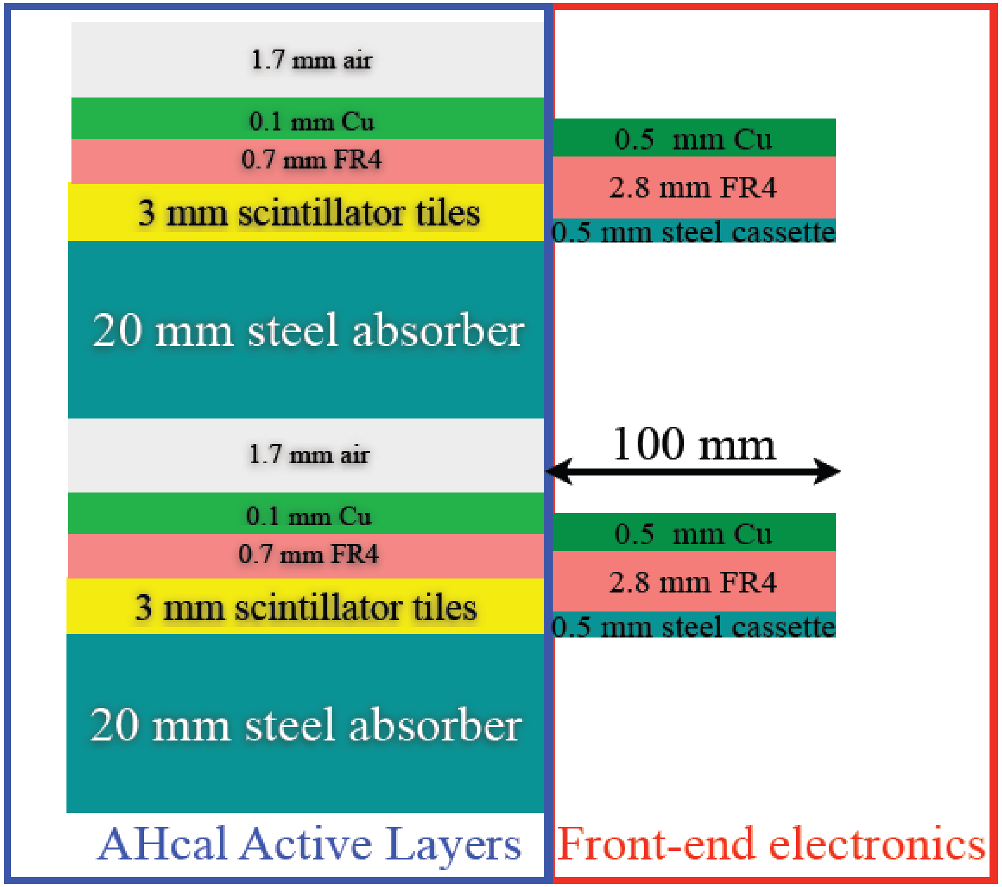
→ **High level of realism**

Current simulation geometry

- Current implementation of AHCAL contains front-end electronics

  → More realistic

- **Detector layers:**
  - 20mm steel absorbers (including cassettes)
  - 3mm scintillator tiles
  - Readout board with integrated ASICs
  - 1.7mm air gap for connectors, solder pins …
- **Front-end electronics**
  - 0.5mm steel cassette



Realistic simulation ready to be used for ILD physics analyses

Future R&D

New prototype, technology

- Re-establish performance, stability and monitoring of new prototype

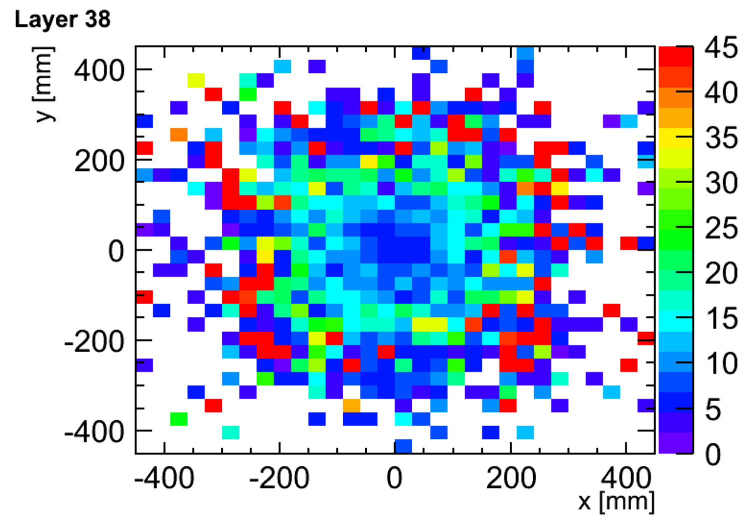
  → **More critical with auto-trigger and zero suppression**
- Development of a robust and compact **power distribution system** for an LC detector
- Development of a **compact data collection scheme** for an LC detector
- **Optimization of tile + SiPM system** following industrial trends
- Establish **mass production and quality assurance** procedures

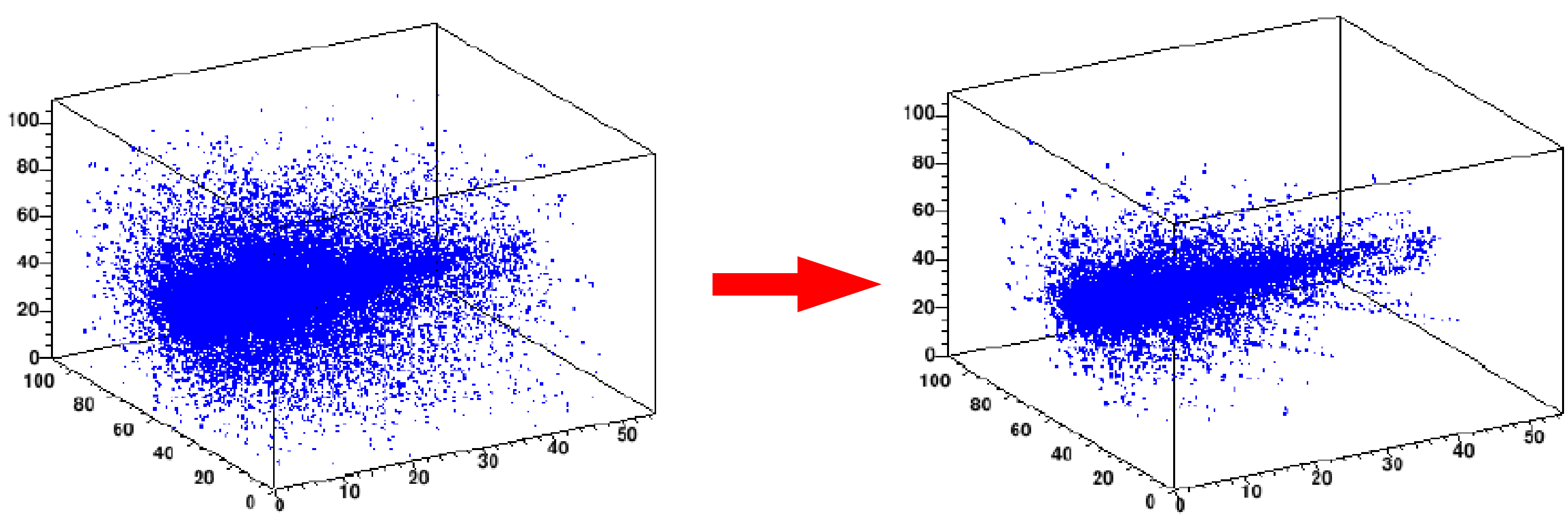
Shower timing and particle flow

- Measurements of shower timing

  → Verify simulations

  → **Explore timing information for particle flow reconstruction**



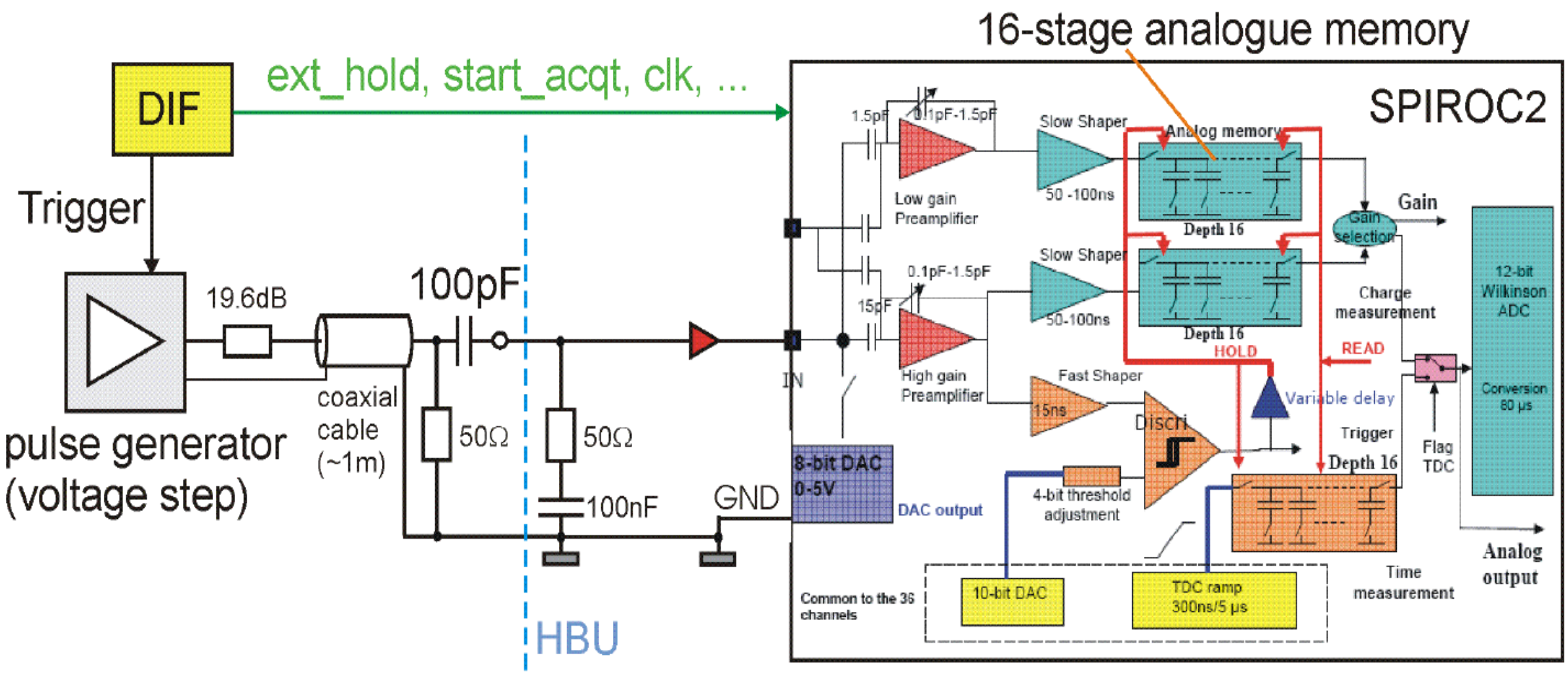


Summary

- The AHCAL has been used **successfully over many years**:
  - First large-scale detector with SiPM readout
  - **Large number of results**, from calibration to shower studies and energy resolution
- Proof of key concepts of event reconstruction:
  - **Particle flow performance validated** with real data
- Path forward:
  - **Technological prototype**: first demonstration at full layer level in 2012
  - Electronics integration and **4th dimension**
  - Full system in next R&D phase

Backup

SPIROC2b

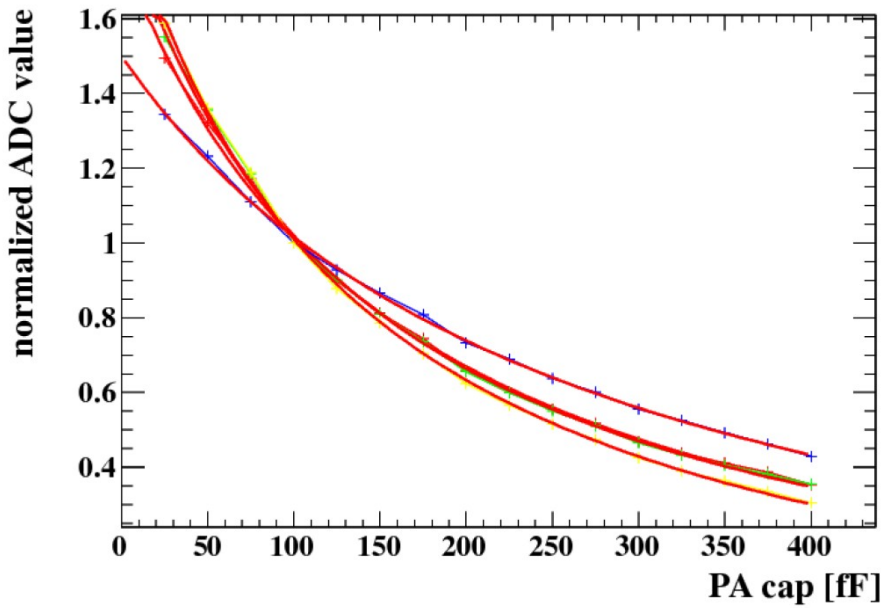

16-stage analogue memory
DIF
ext_hold, start_acqt, clk, ...
Trigger
19.6dB
100pF
pulse generator
(voltage step)
coaxial
cable
(~1m)
50Ω
50Ω
100nF
GND
HBU
IN
SPIROC2
1.5pF
0.1pF-1.5pF
Low gain
Preamplifier
Slow Shaper
50 -100ns
Analog memory
Depth 16
Gain
Gain
selection
0.1pF-1.5pF
15pF
Slow Shaper
50-100ns
Depth 16
Charge
measurement
12-bit
Wilkinson
ADC
Conversion
80 µs
HOLD
READ
High gain
Preamplifier
Fast Shaper
15ns
Variable delay
Discri
Trigger
Depth 16
Flag
TDC
8-bit DAC
0-5V
DAC output
4-bit threshold
adjustment
Analog
output
Time
measurement
Common to the 36
channels
10-bit DAC
TDC ramp
300ns/5 µs

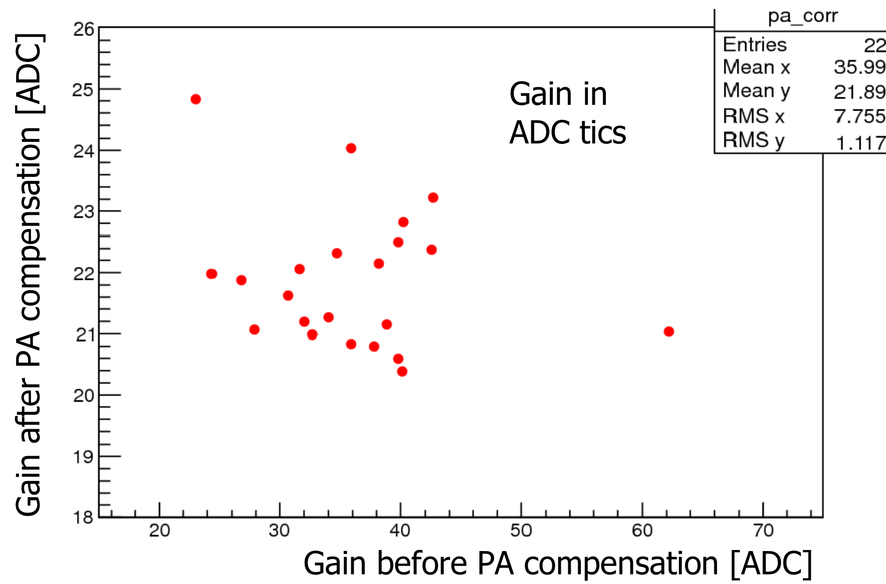
Channel-gain equalization

- **How to set online thresholds?**
  → New tiles have gains between 500k and 2000k, but uniform light yield!
  → Channel-wise threshold tuning?
- Channel-gain equalization with pre-amplifier feedback capacitors
  → Capacity range 25-1575fF in 25fF steps
- Normalize to e.g. 100fF measurement

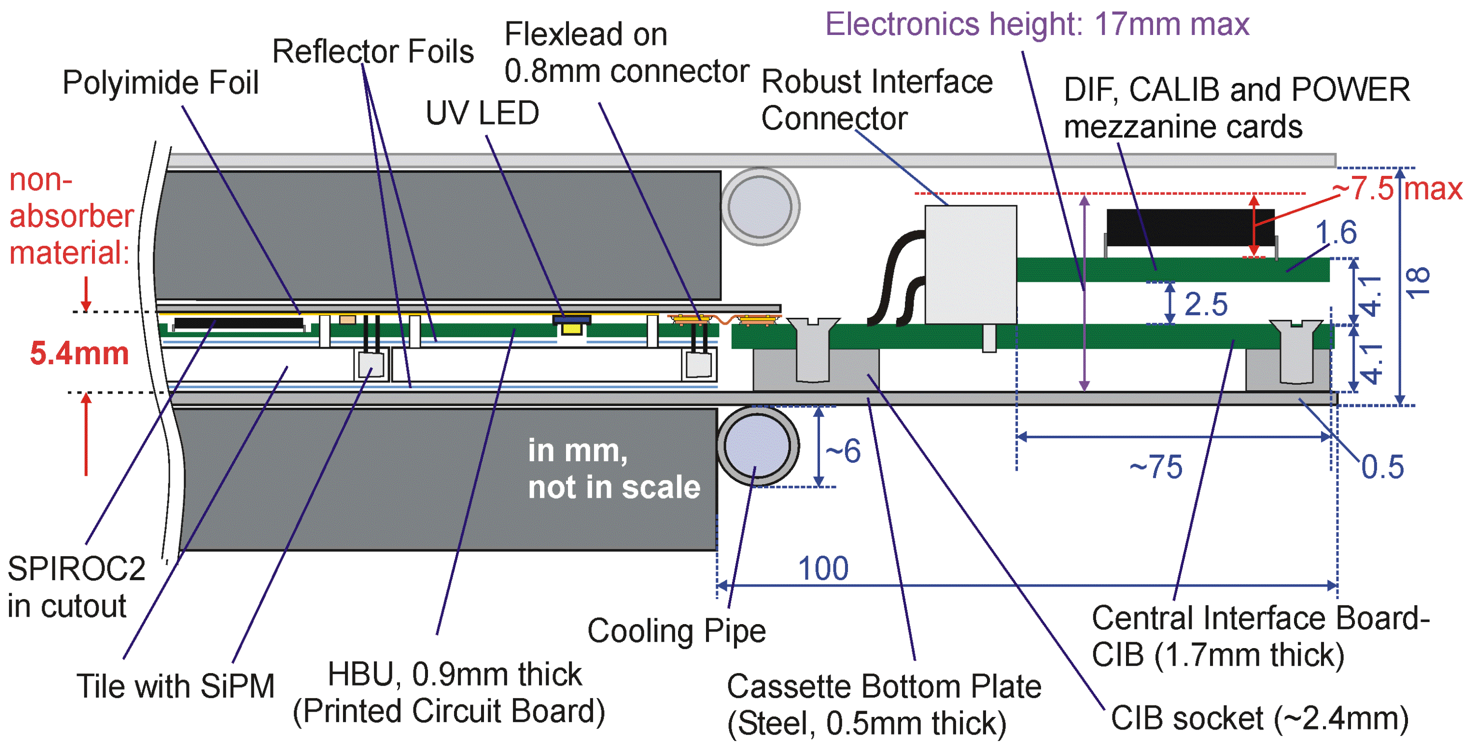
→ **Factor 4** gain spread possible to compensate with SPIROC2b!

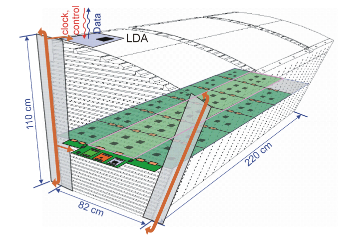
→ **Gain spread ~5%** after equalization!





AHCAL layer – cross section

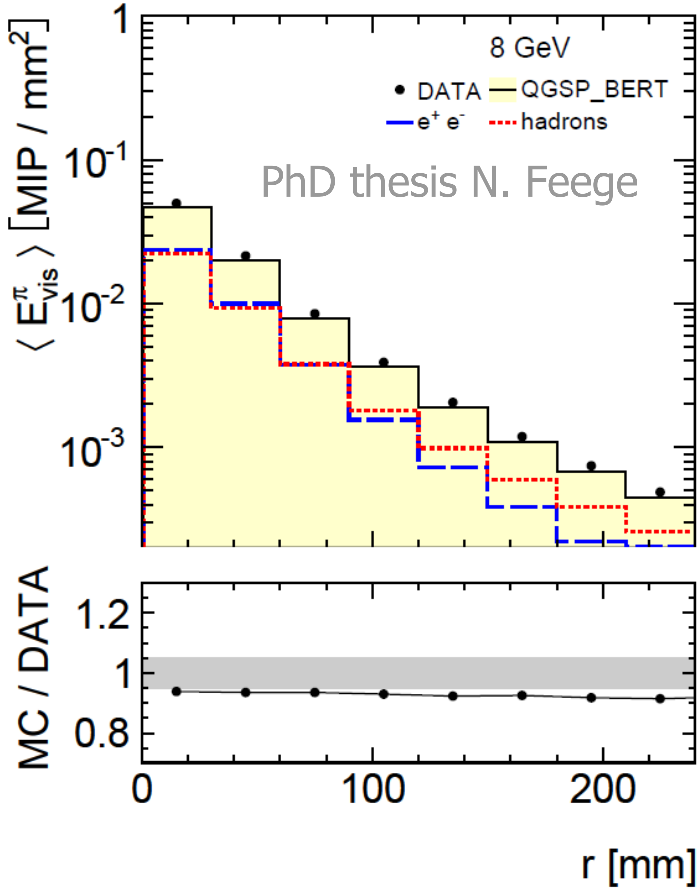


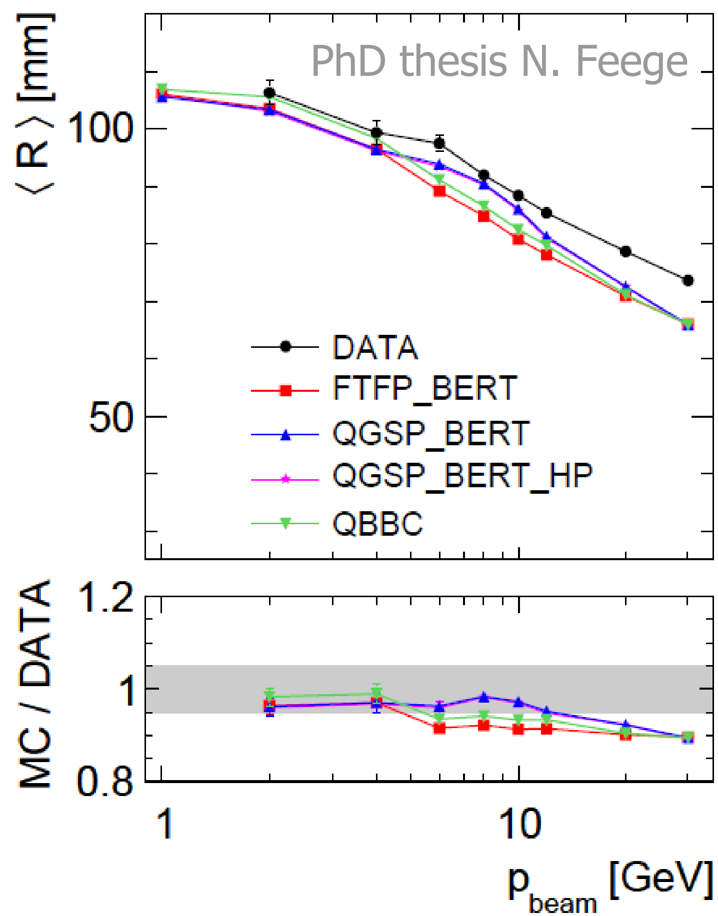


Abbr.	Name
DIF	Detector Interface Board
CALIB	Steering for LED calibration
CIB	Central Interface Board
HBU	Front-end board

Radial shower profile

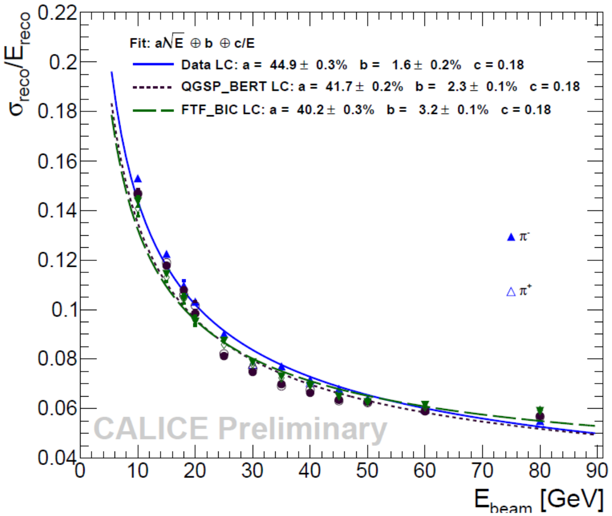
- High granularity allows to measure **shower shapes** in detail
- Measurement sensitive to electromagnetic fraction of cascades

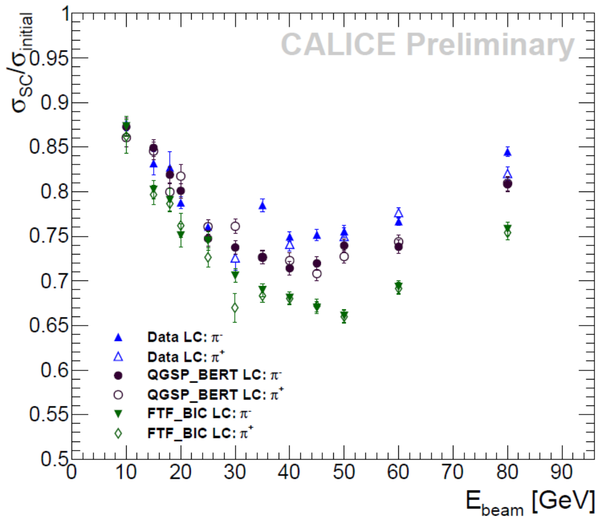




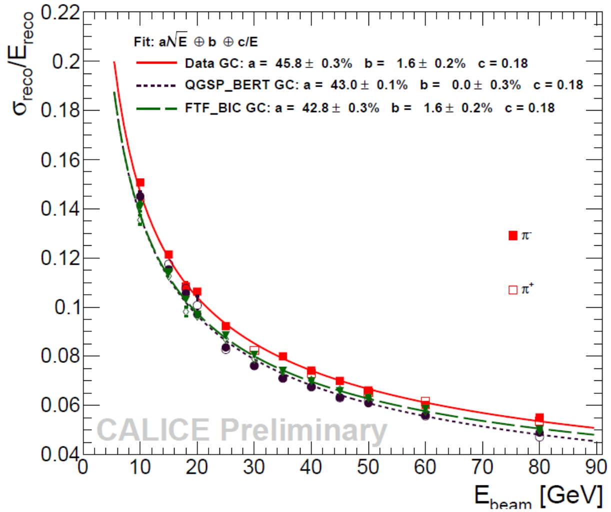
Compensation – MC vs data

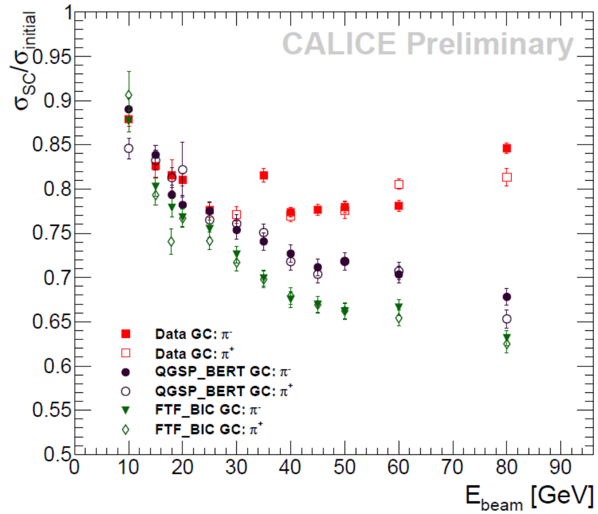
Local compensation





Global compensation





- **Local:**

  MC describes data well

- **Global:**

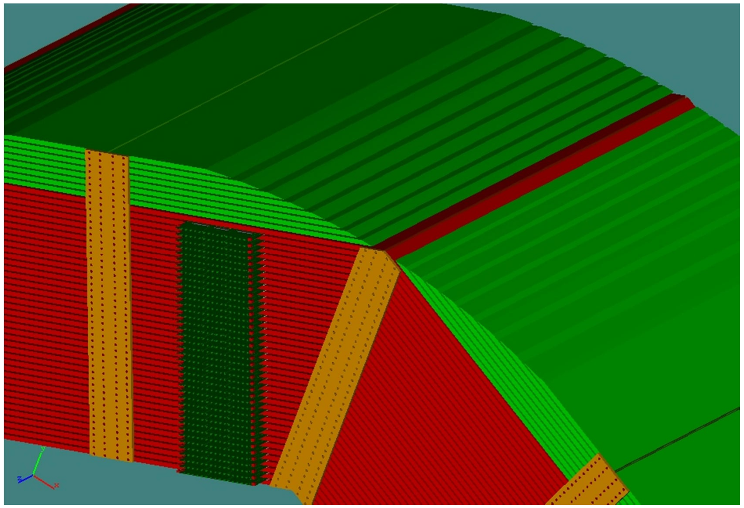
  MC predicts further improvement above 40 GeV

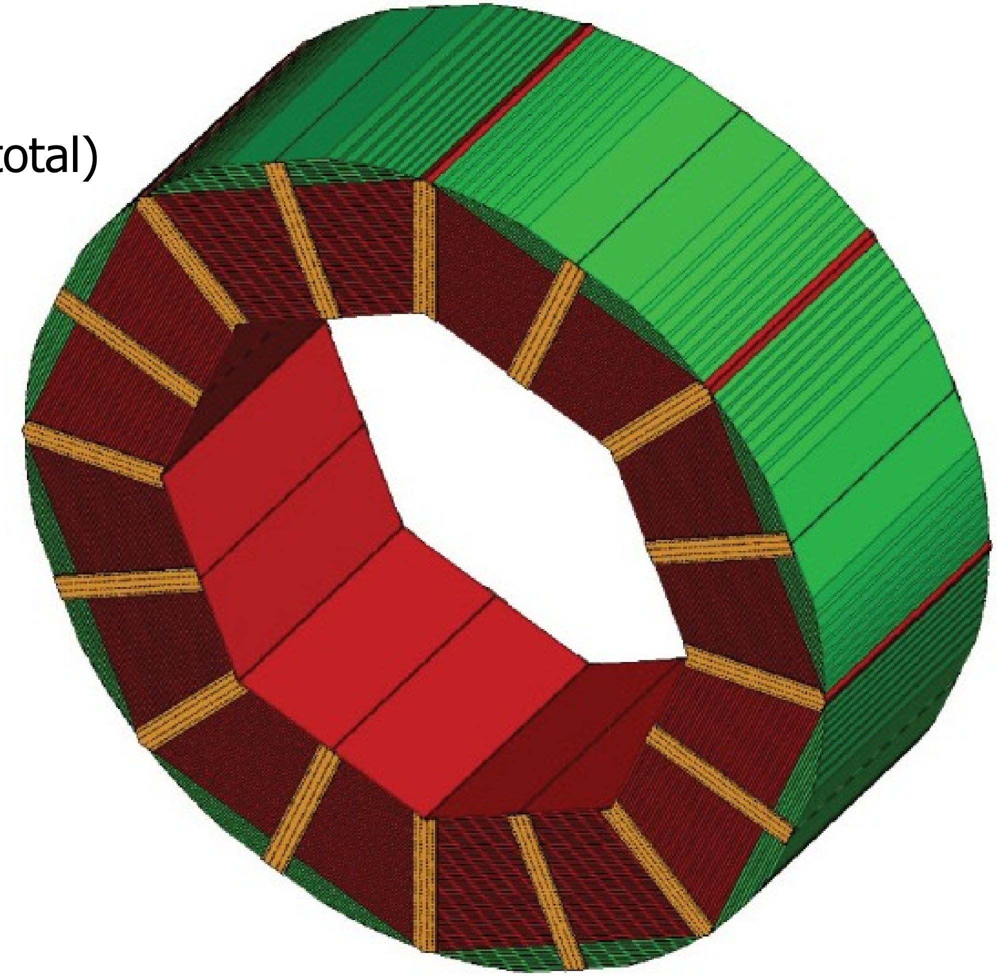
Mechanics and simulation model

- **Fully engineered design** exists for ILD AHCAL
- **AHCAL half barrel:**
  - 16 half-octants, 40 layers (5.2λ)
  - 16 backpacks, 8 layers (5.7λ in total)
  - 32 connector bars
  - 16 back plates

    → fill gap between half barrels

    → avoid air gaps at z=0





ILD AHCAL endcap

- **Detailed endcap designs** available
- 48 sensitive layers, 49 absorber plates
- 16 top towers, 14 bottom towers

  → 5-8 base boards per slab
- Front-end electronics implemented
- Installation scenario known
- Few details to be studied about supply routes and interfaces