A high granularity calorimeter for a future linear collider

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LC Forum 2013,
October 10th 2013

Overview

- Goals of calorimetry at a future linear collider
  - Particle Flow Algorithms
  - The CALICE Collaboration

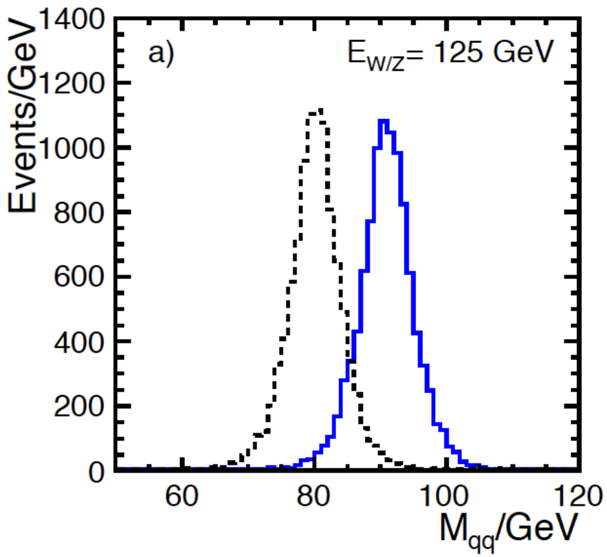
- The CALICE AHCAL physics prototype

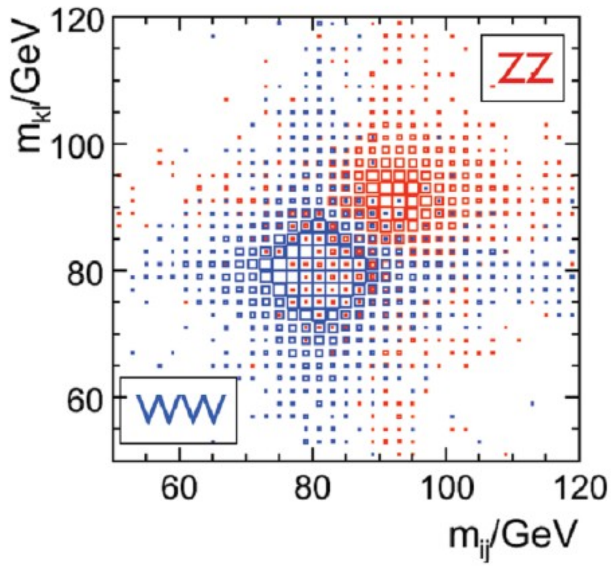
- Technical prototype
  - Mechanical integration
  - Electronic integration
  - Tile options
  - Automation/Industrialisation

- Summary
- Outlook/future plans

Calorimetry at a future linear collider

- Design goal: differentiate full hadronic W and Z decays from jet energy reconstruction
- Needs jet energy resolution
  $\sigma(E_{jet})/E_{jet} \approx$ 3-4% for E_{jet}=40-500 GeV
- Classic hadronic calorimeter:
  $\sigma(E_{jet})/E_{jet} \approx 60\%/\sqrt{E(\text{GeV})} \rightarrow$
  $\sigma(E_{jet})/E_{jet} \approx 10\%$ for E_{jet} = 50 GeV
- ILD approach: **P**article **F**low **A**lgorithms

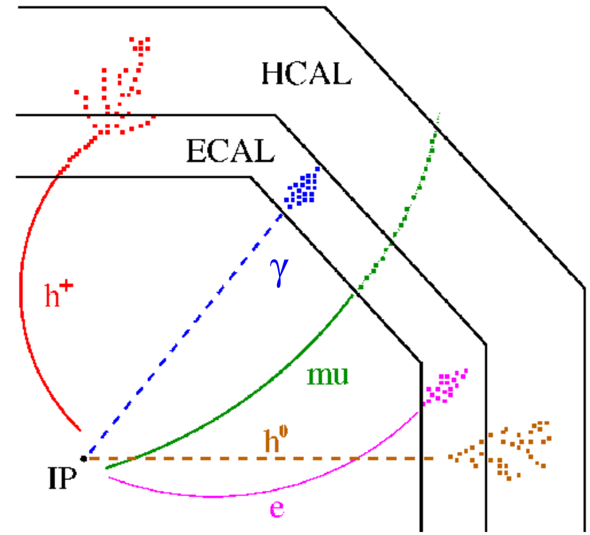


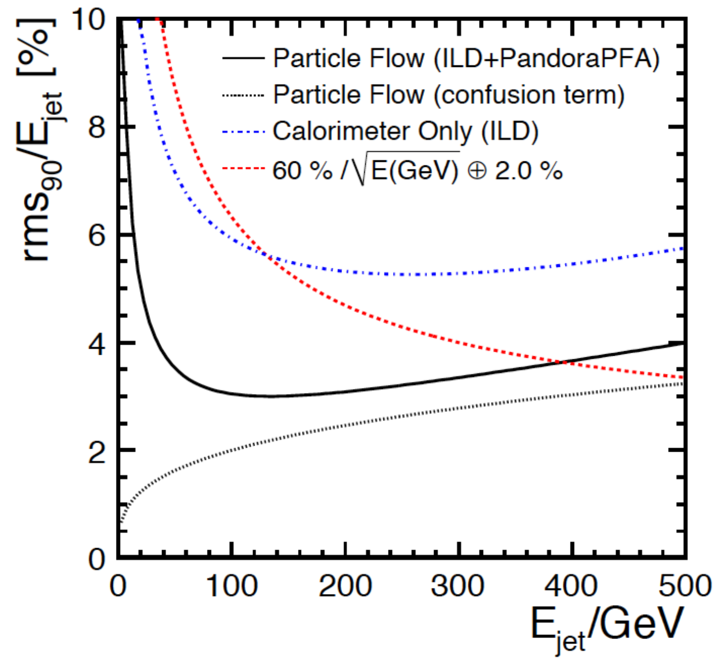


Particle Flow Algorithm

- Momentum resolution in trackers is orders of magnitude better than energy resolution in calorimeters
- Idea: Use detector with best resolution for each particle in a jet
  - Ideally only neutral particles are measured in calorimeter (27% photons, 10% neutral hadrons)
- Problem: confusion from overlapping showers
  - Needs very high calorimeter granularity

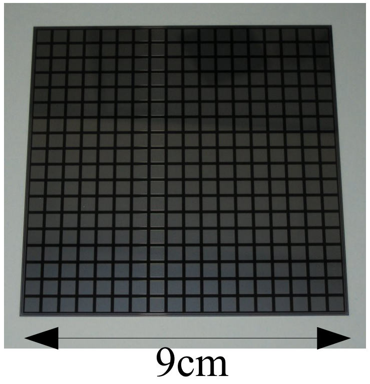
  → **Imaging calorimetry**
- Total performance always improved by PFA
  - E_{jet}<100GeV governed by calo resolution
  - E_{jet}>100GeV governed by confusion

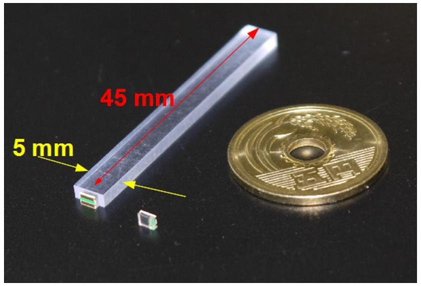




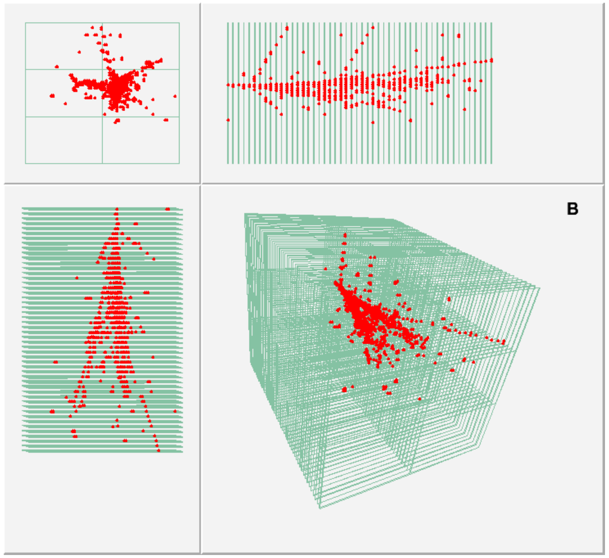
CALICE Collaboration

- CALICE: **CA**lorimeters for a **LI**near **C**ollider **E**xperiment
- International effort to explore different options for ILC calorimeters
- Electromagnetic Calorimeters (ECAL):
  - W absorbers
  - Readout options:
    - Silicon (5*5mm^2 pads)
    - Scintillator (5*45mm^2 strips)



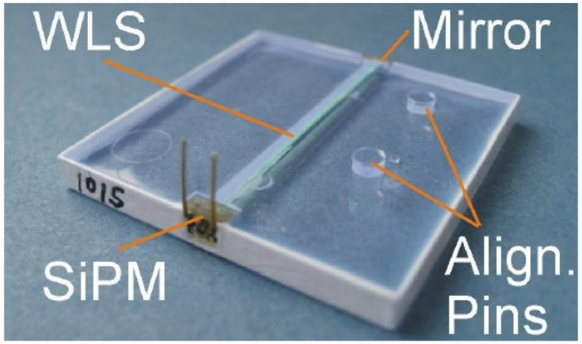


- Hadronic Calorimeters (HCAL):
  - Fe absorbers (W under consideration for higher energy collider)
  - Readout options:
    - Gaseous (1*1cm^2)
      - RPCs, GEMs (1-2 bit digitization)
    - Scintillator (3*3cm^2)
      - 12bit digitization

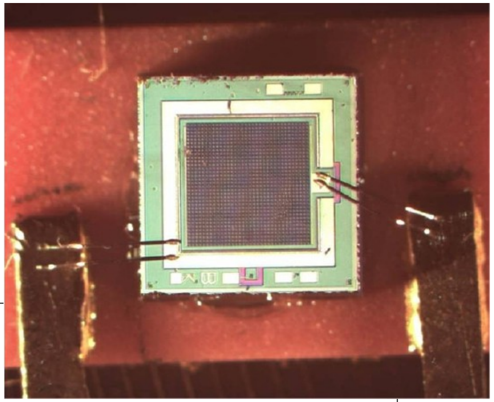


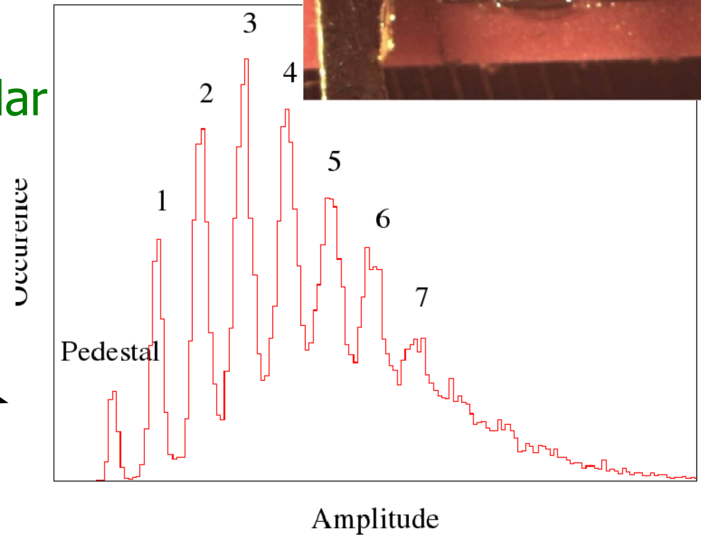
AHCAL Readout Technology

CALICE **A**nalog **H**adronic **CAL**orimeter (AHCAL)



- Scintillator tiles:
  - Plastic scintillator material, $3*3cm^2$
  - Fiber enhances homogeneity of response
  - Wavelength shift to increase SiPM efficiency
- Silicon Photomultiplier (SiPM):
  - Multi pixel array of Geiger-mode photodiodes
  - Single photons can fire pixels
  - Smaller, cheaper, lower bias voltage at similar gains compared to PMTs
  - Non-linear, gain is temperature dependent
    - Calibration required
      → Single photon spectra
      → Saturation curves

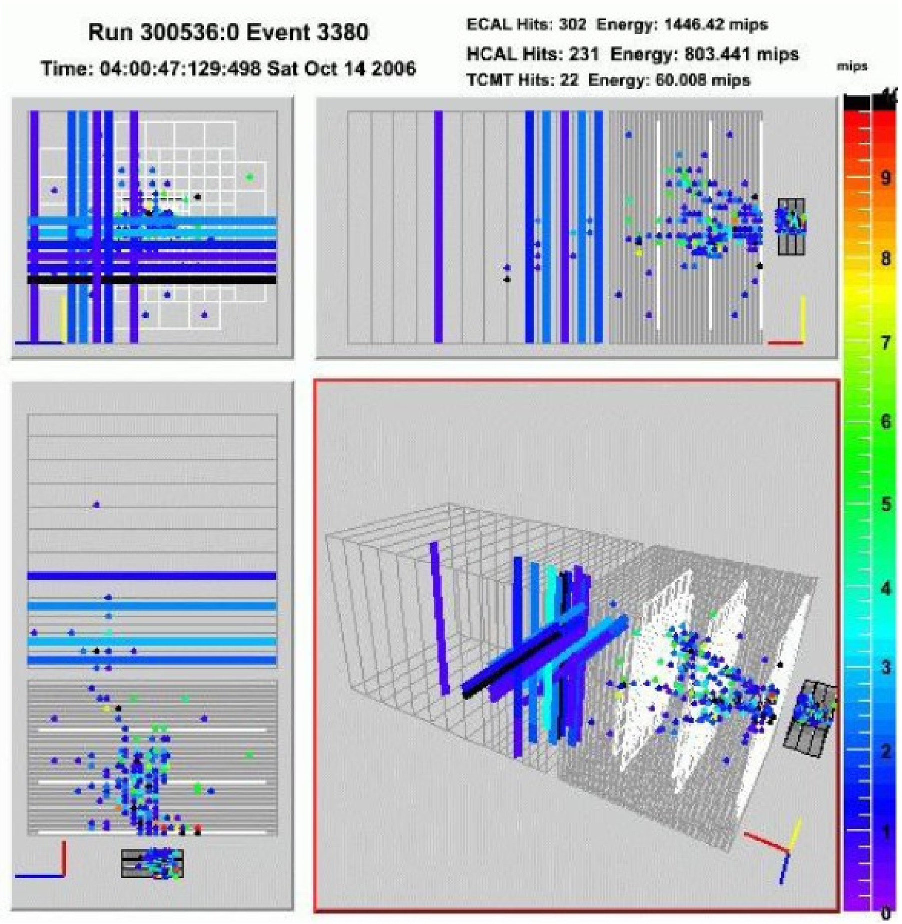


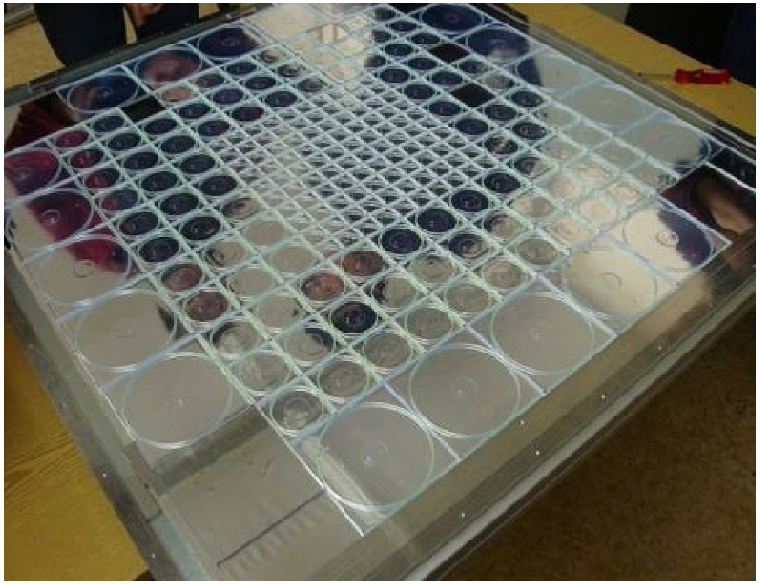


AHCAL Contributors

CALICE AHCAL

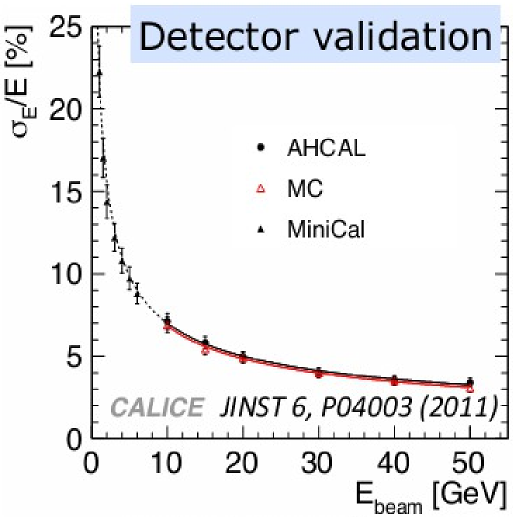
- $1m^3$ physics prototype used in different testbeams 2006-2012

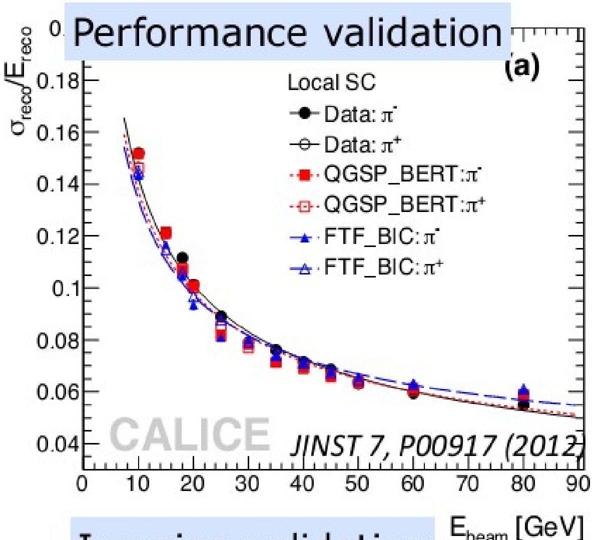


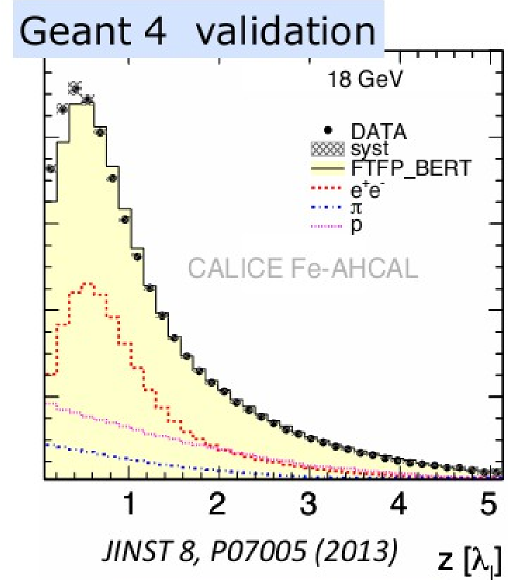


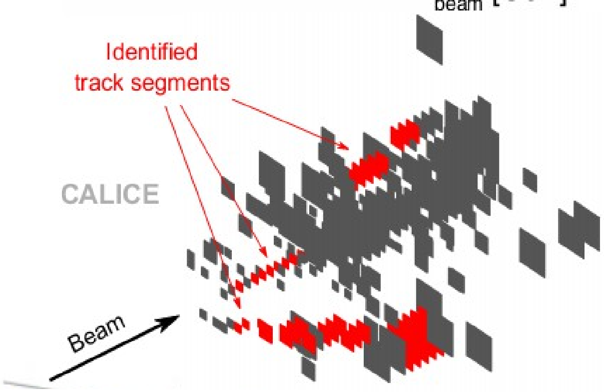
AHCAL Performance

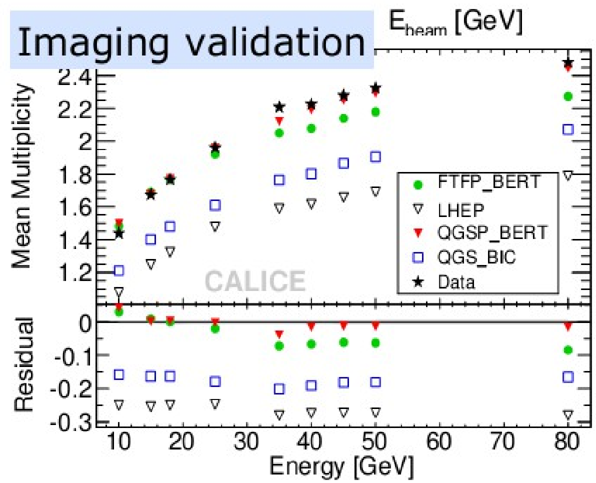
- Performance of concept validated with prototype
- Various published results

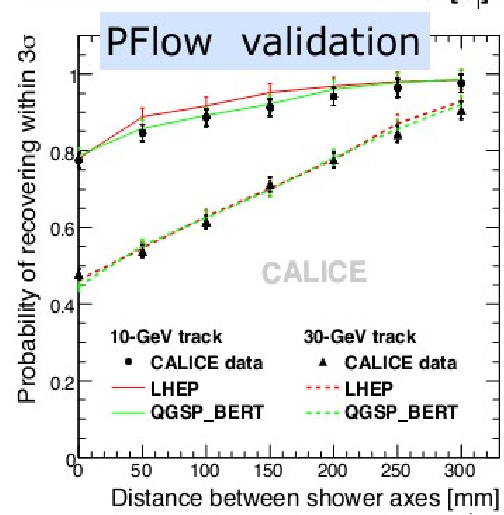




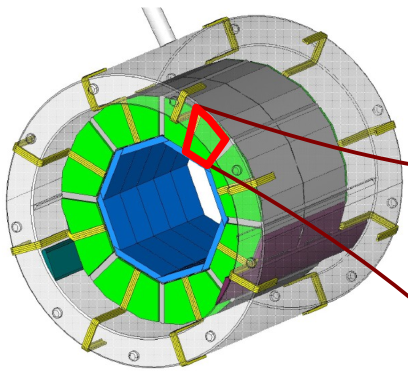


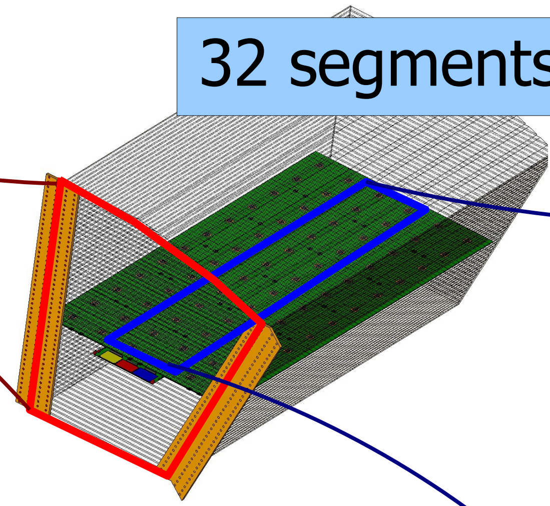




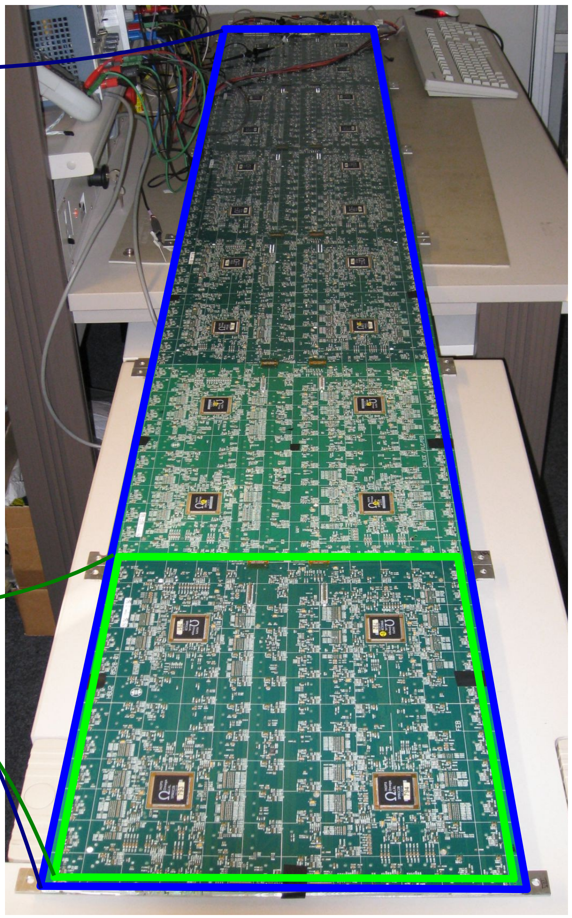


The AHCAL Engineering Prototype





32 segments (16 in φ, 2 in z)



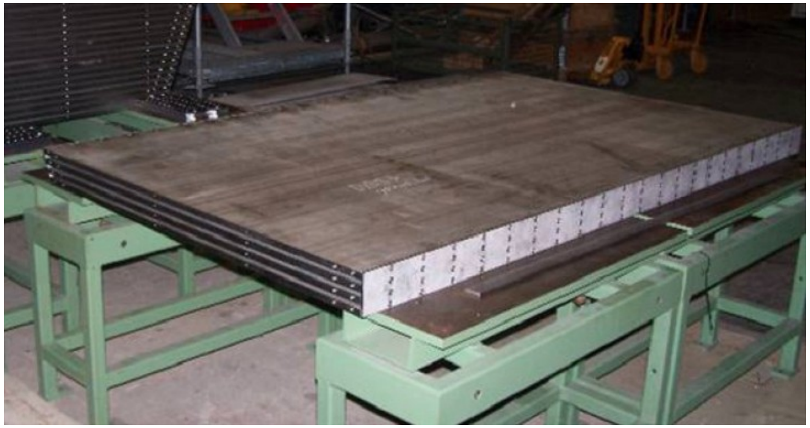
- 40 layers per half-octant
- 3 *slabs* of 6 PCBs per layer
- 8 Million channels! 50000 boards (HBU)!
- Challenge: Integration
  - Mechanics
  - Electronics
  - Tiles
  - Automation

Mechanical Integration

Mechanical Integration – Absorbers

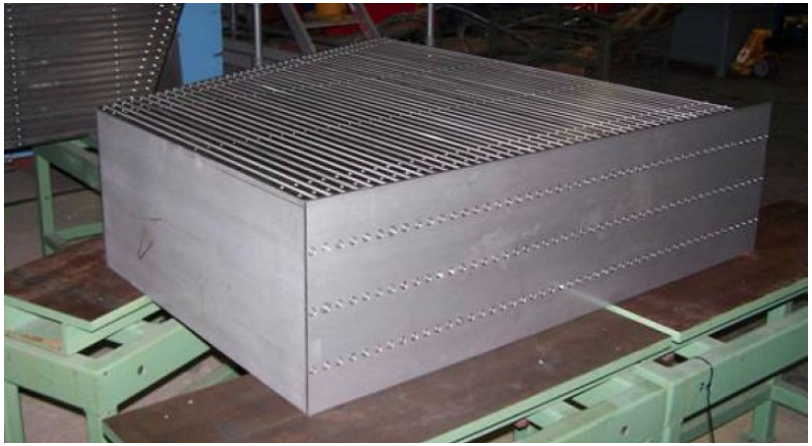
Full layer test stack

- 4 layers of ILD HCAL absorber
  - Largest plates in ILD stack
  - Full layer dimensions (6*3 HBUs)
- Heat dissipation and power pulsing

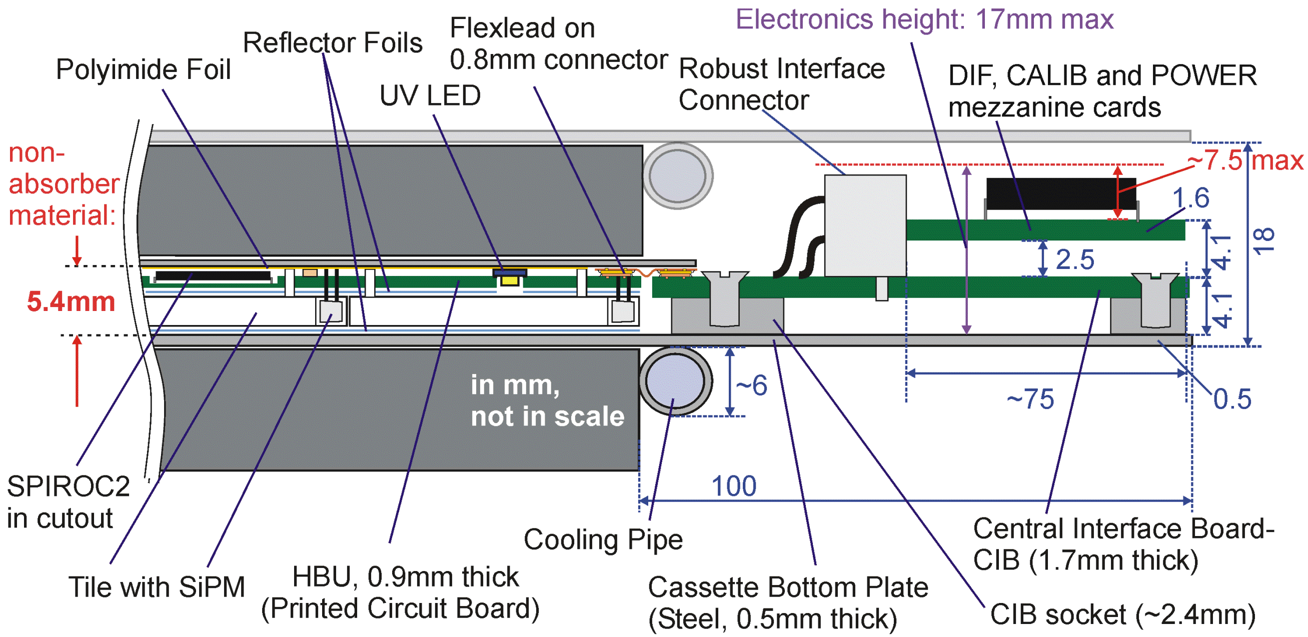


Half octant test stack

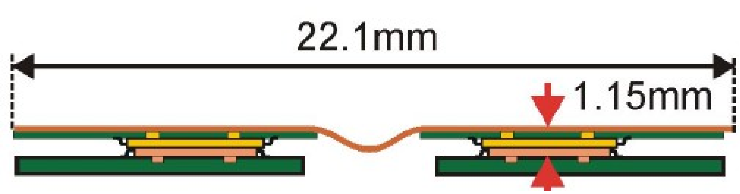
- 1/6 HCAL segment (1 HBU depth)
  - 2pcs available, stackable
- Current and future testbeam setups
- Integration of infrastructure
  - Power supplies
  - Cooling systems
- Stress tests (earthquake safety!)



Mechanical Integration – Active Layers



- Minimal space between absorbers
  - 2.4mm for full electronics
  - No cooling inside absorbers
- Needs very thin connectors
  - Power lines: ~3 Amps!



Electronic Integration

Electronic Integration - HBU

HCAL **B**ase **U**nit (HBU)

- 4 ASICs, 144 channels per PCB
  - SPIROC chip family by Omega, France
  - Full digitisation on chip
  - <1ns time stamping
  - Power pulsing
  - Separate developments for analog part by Uni Heidelberg: KlauS ASIC
- One Central Interface Board (CIB) per layer
  - Power board
  - Calibration and trigger controller
  - DAQ interface
- 5 HBUs equipped and calibrated in DESY electron beam
  - 8 fresh HBUs to be equipped with tiles

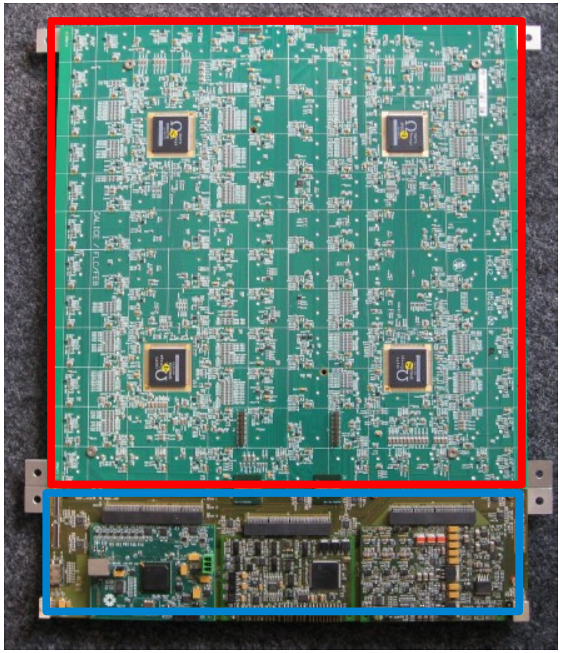
MICRO

UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

DESY

HBU

CIB



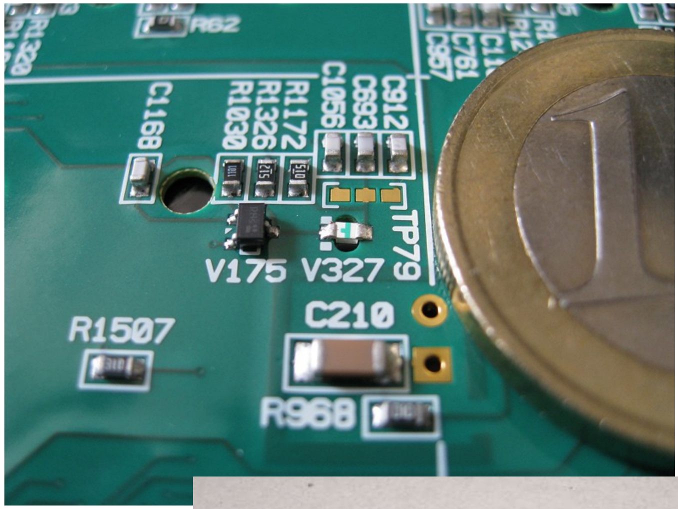
Electronic Integration - Calibration Systems

BERGISCHE
UNIVERSITÄT
WUPPERTAL

FZÚ

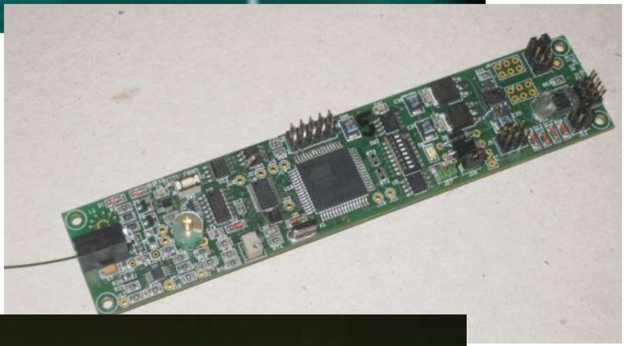
Uni Wuppertal

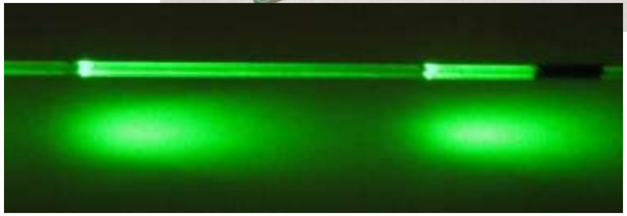
- Single LED per tile
  - Minimal material per channel
  - Covers full amplitude range from single photons to SiPM saturation
- Integrated on current HBUs



Institute of Physics Prague

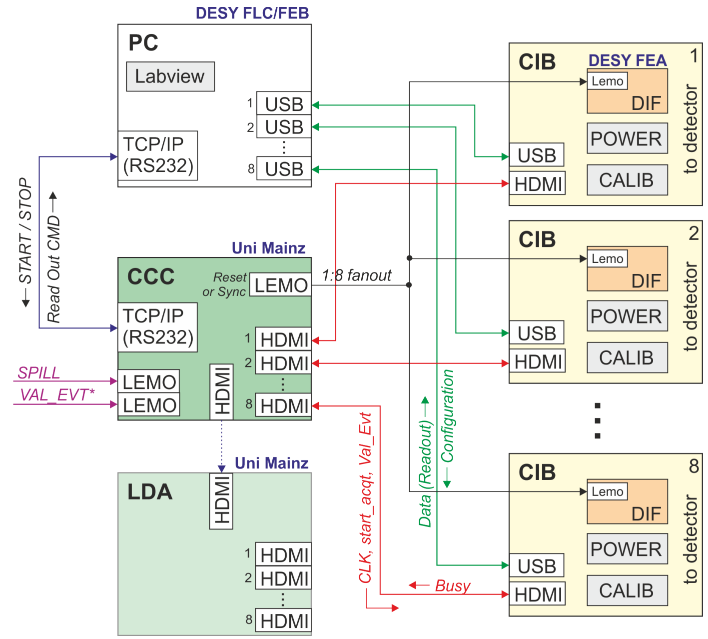
- Single LED on external board
- Light distribution via notched plastic fiber
- Excellent pulse shape and stability





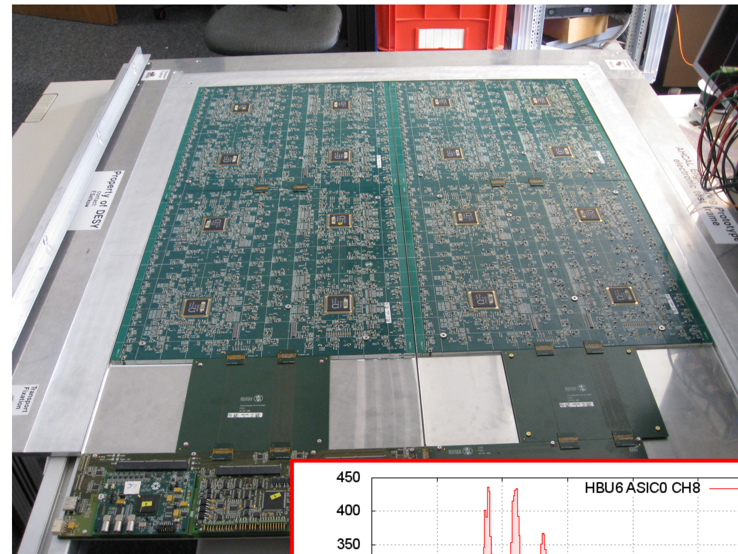
Data Acquisition System (DAQ)

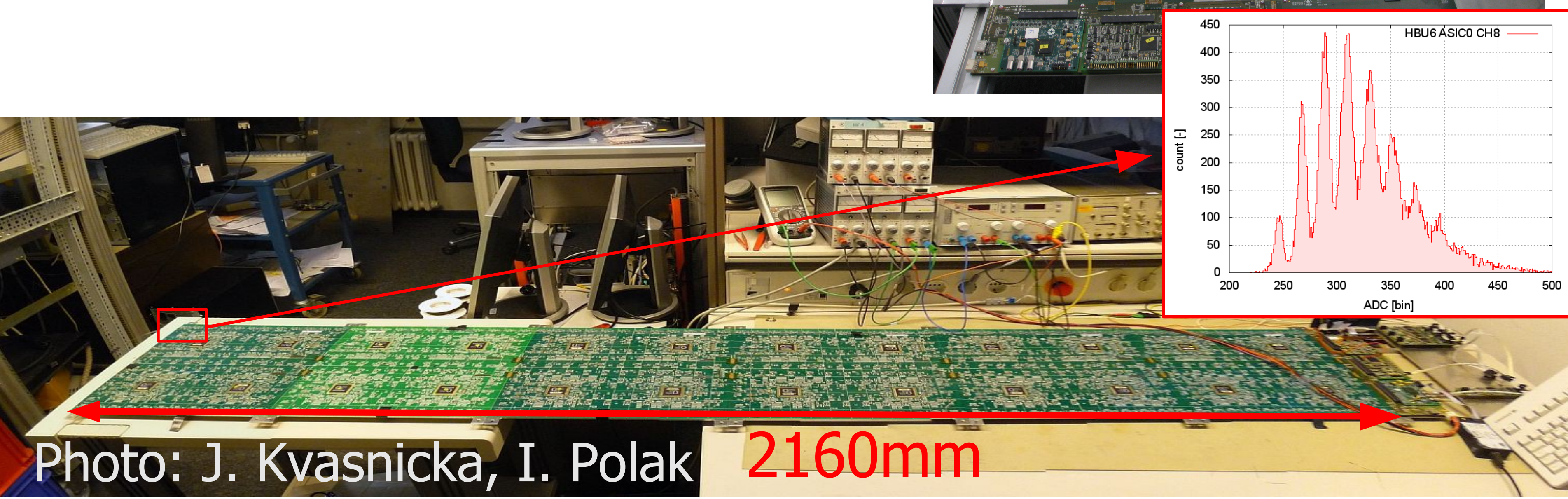
- DAQ developments based on redesigns of common CALICE DAQ hardware
  - DAQ interface (DIF): NIU/Fermilab
  - Fast signal distribution (CCC), Data aggregation (LDA): Redesigned by Uni Mainz (based on work of UK groups)
- Started from single layer system, now stepwise development to full scale
  - Already very fast and stable operation
- Conceptually close to CALICE DAQ designs
  - Will be able to integrate other CALICE detectors



Single HBUs to Full Slab

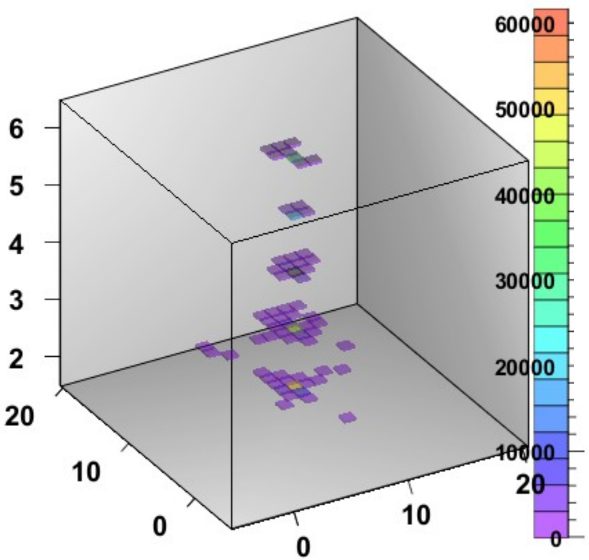
- Single HBUs extensively operated and in lab and DESY testbeam
- Full length ILD slab, 2*2 layer assembled and operated
- Power pulsing tests on full slab ongoing
- Timing behaviour characterised on 2*2 layer

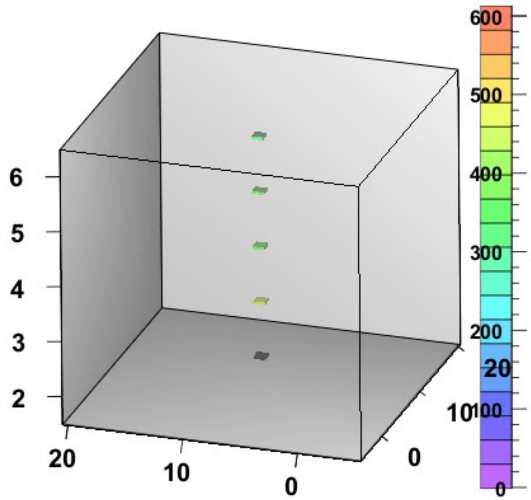


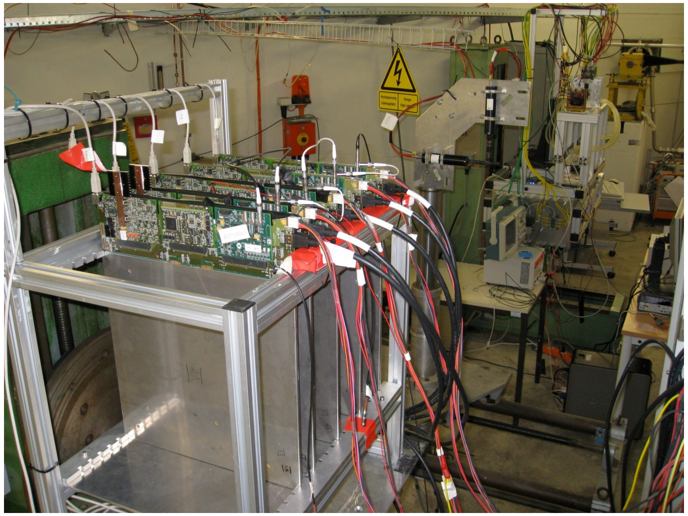


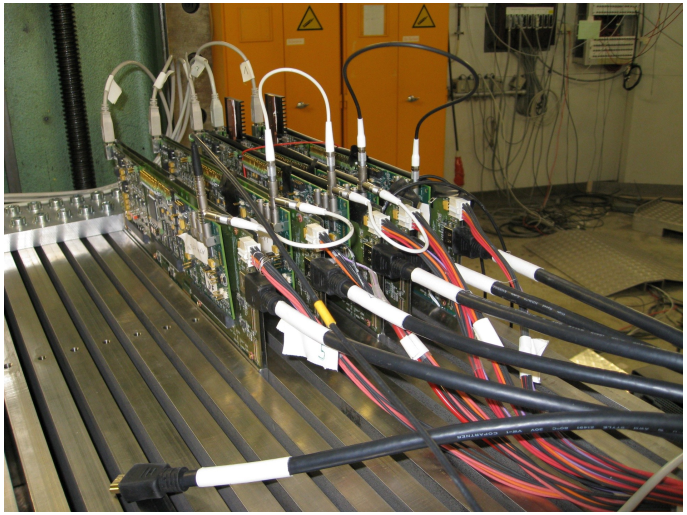
Multilayer Test Beam

- Operation of 5 synchronous layers
  - Fully self-triggered
  - Airstack for MIP calibration
  - ILD absorber for first calorimetric data
  - All mechanics already in ILD format!
- More to come soon!









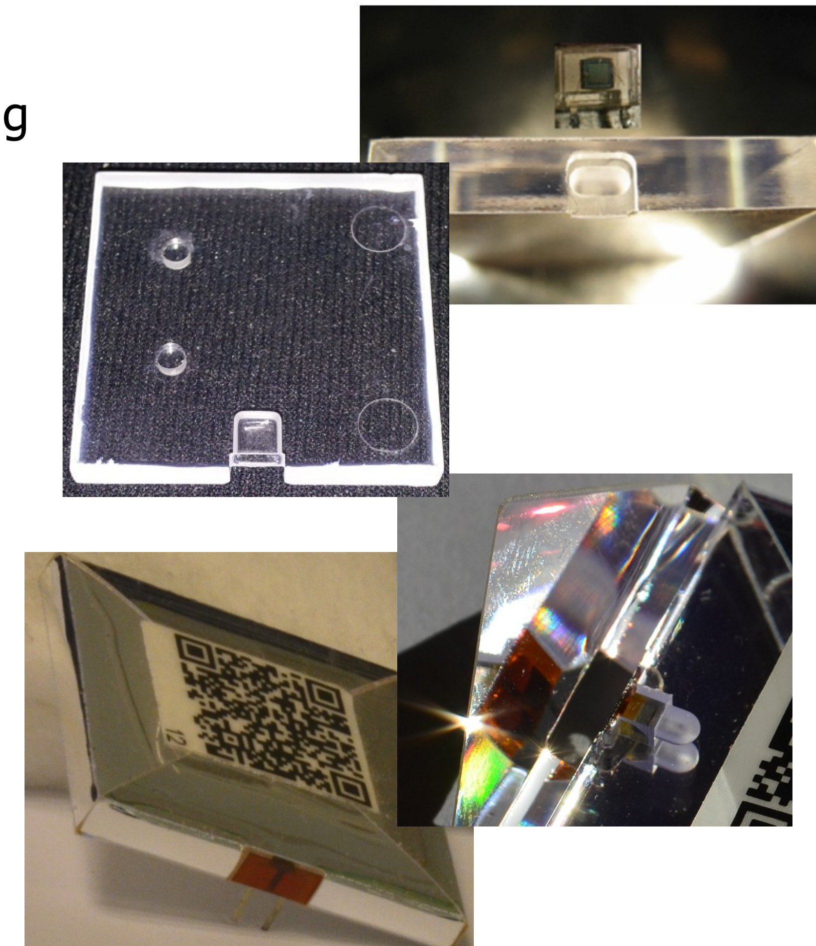
Tile Developments

Fiberless Tiles

- Machined dimple around SiPM enables uniform response without fiber
  - MPI Munich: first concepts, machined
  - ITEP: injection molded fiberless tiles
  - UHH: improved shape for easier machining

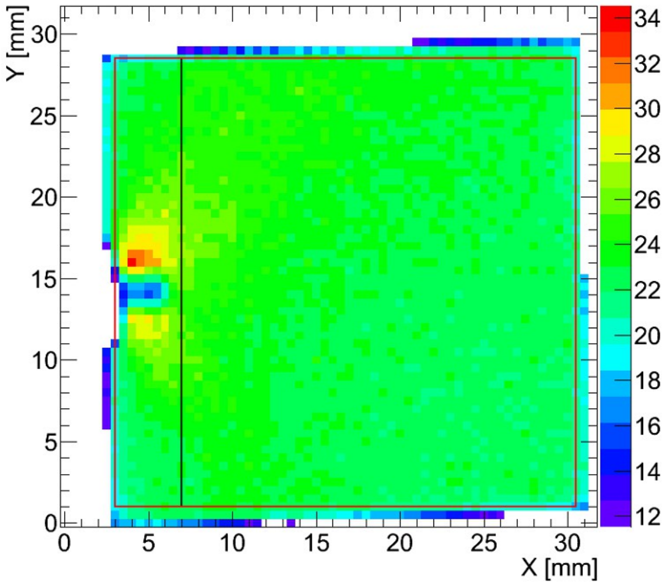
UHH tile development:

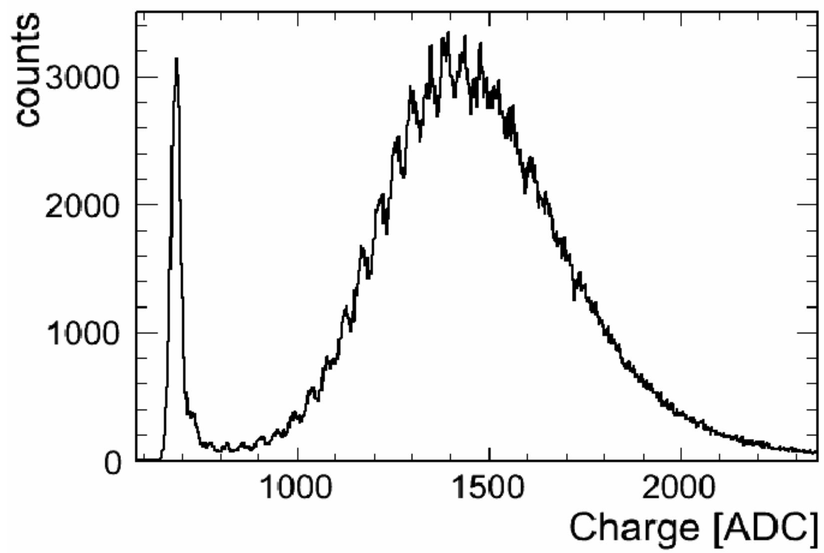
- Machined tiles, individually wrapped
  - Reduced inter-tile crosstalk
- New commercial SiPM (KETEK)
  - 2300 pixels (up from ~800)
    - Less saturation effects
  - Greatly reduced dark rates
  - Lower device by device variation (gain, bias, etc.)



UHH Tiles

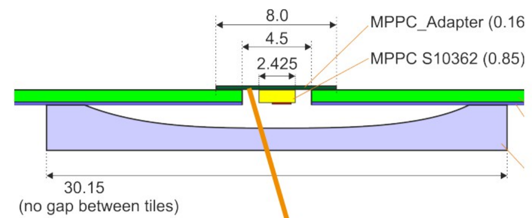
- First batch of 12 tiles assembled and characterised
  - High quality MIP spectra (Sr90 source)
  - Good homogeneity of response across tile
- Material for 1200 tiles available (8 HBUs)
- First beam tests on HBU boards starting soon
- Process already designed for mass production
  - Lasercut reflective foil
  - Automated tile wrapping

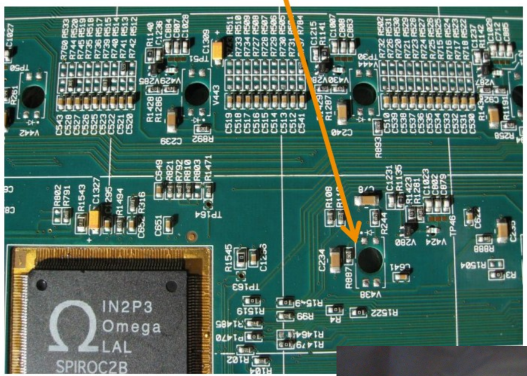


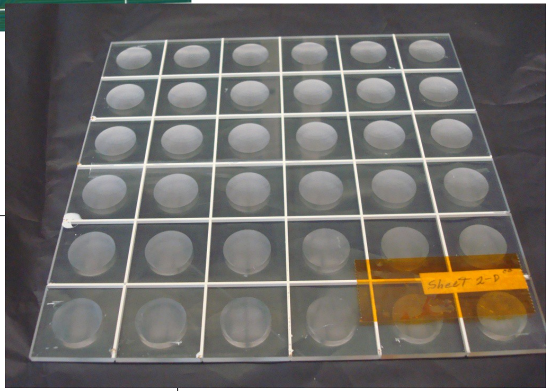


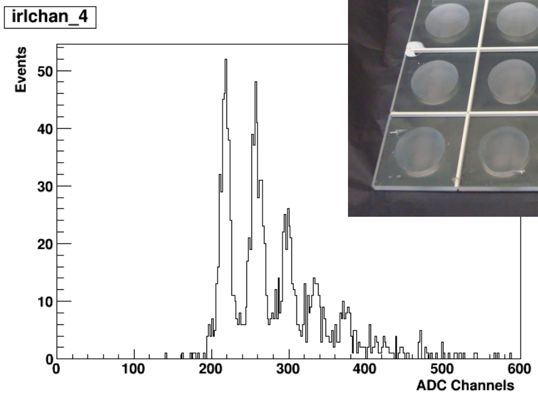
NIU Megatile

- NIU concept: Surface mounted SiPMs
  - SiPMs mounted on top of tile
  - Concave dimple in tile for uniformity
- *Megatile* scintillator
  - $18*18\text{cm}^2$ divided into $3*3\text{cm}^2$ cells
  - Optical isolation by white epoxy
- Easy assembly
  - SiPMs assembled like standard components
  - Scintillator is equipped in larger pieces
- Modified HBU designed and produced at DESY
  - First calibration spectra obtained by NIU



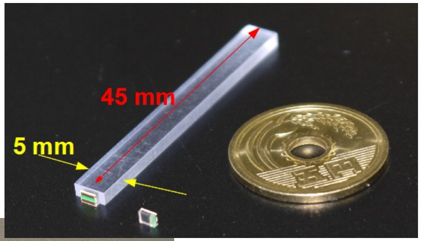




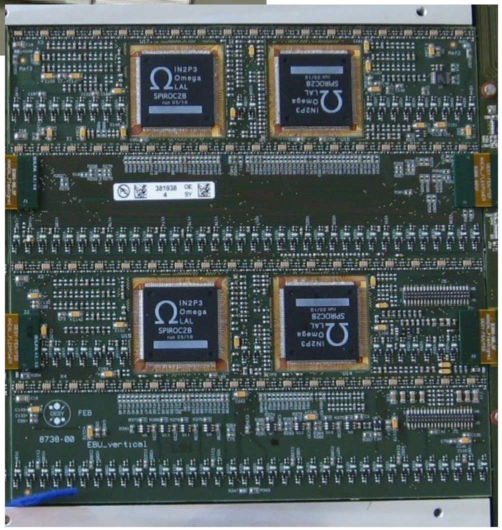


Scintillator Strip ECAL

- Scintillator ECAL concept (Uni Shinshu, Kyushu, Tokyo, Japan)
  - 45*5mm^2 scintillator strips
  - SiPM readout at end of each strip
  - Layers with alternating strip orientation



- Mounted on HBU redesigned for strip geometry (EBU)
  - PCB scaled down to ¼ size
  - Identical connection to interface boards, DAQ



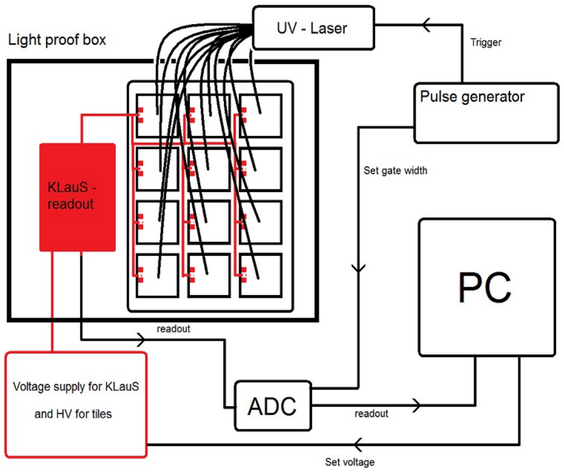
- Fully operational in lab and testbeams

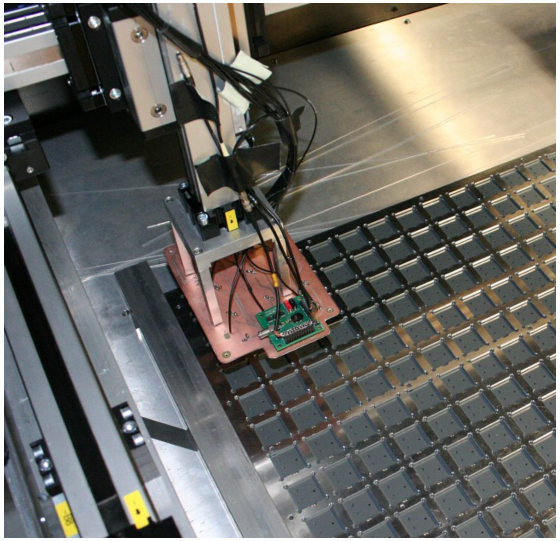
→ HBUs (EBUs) operating in each major region!

Automation/Industrialisation

Mass Tile Characterisation

- Studies for automated mass tile characterisation by Uni Heidelberg
- Goal: Simultaneous full characterisation of 12 tiles at once, 216 tiles per run
- Readout by KlauS ASIC
- System commissioning and test runs with first 12 UHH tiles



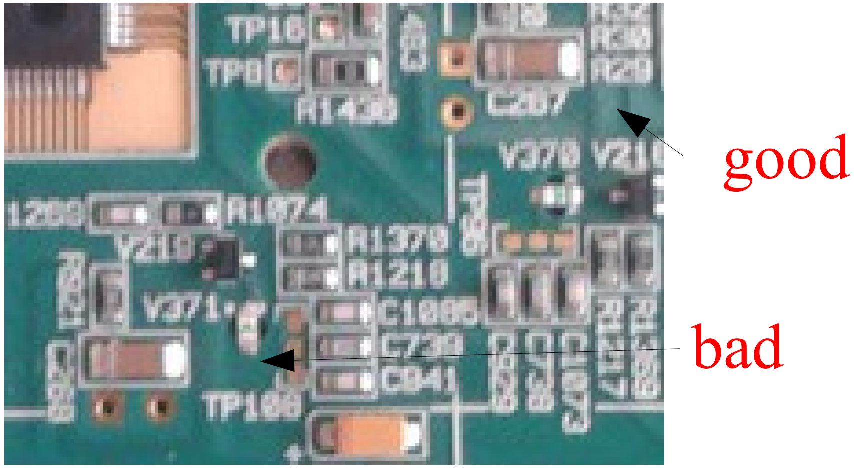


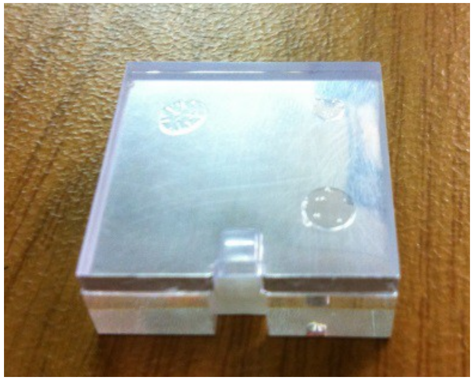
Mass Tile Assembly

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Studies by Uni Mainz:

- Mechanical connection tile ↔ HBU
  - Detailed study of glueing tiles to HBU as an alternative to alignment pins
- Electric connection tile ↔ HBU
  - Soldering SiPMs to the HBU is fastest with commercial wave soldering
  - Needs to be reflected in PCB design





Summary and Outlook

Summary

- The CALICE collaboration develops calorimeters for a future linear collider
- The AHCAL is a scintillator-SiPM based concept for a hadronic calorimeter
  - Physics performance has been proven in various testbeam campaigns
- Now we are developing a prototype that is scalable to a full detector
  - Mechanical integration within ILD constraints is well advanced
  - The first multilayer setups have recently been tested in the DESY beams
- Various options for scintillator tiles under development
  - Focus on scalability of production and assembly
- Studies on automated assembly and commissioning are underway

Outlook

Short term:

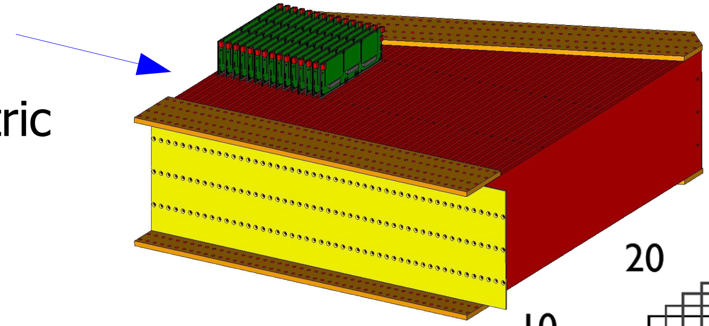
- Assemble >10 HBUs for first calorimetric data
  - EM performance in DESY beam
  - 4 weeks beam time end of 2012

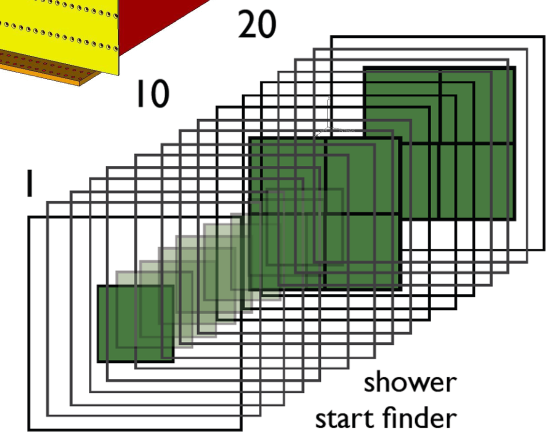
Medium term:

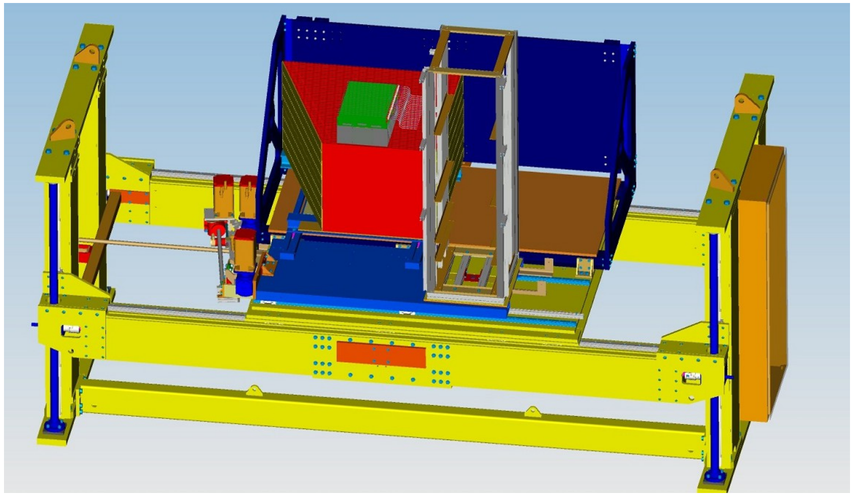
- Timed hadron shower imaging
  - ~10 single HBU layers (interaction finder)
  - ~2 full (2*2 HBUs) layers
  - Similar to T3B, but full layers

Long term:

- Full 1m3 technical prototype
  - ~40 full layers
  - Demonstrate full integration, production automation







Thanks to the many people of whom
I borrowed slides and material!
(and this template)