AHCAL Status

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CALICE
Calorimeter for ILC

TUM
LMU
Excellence Cluster
Universe

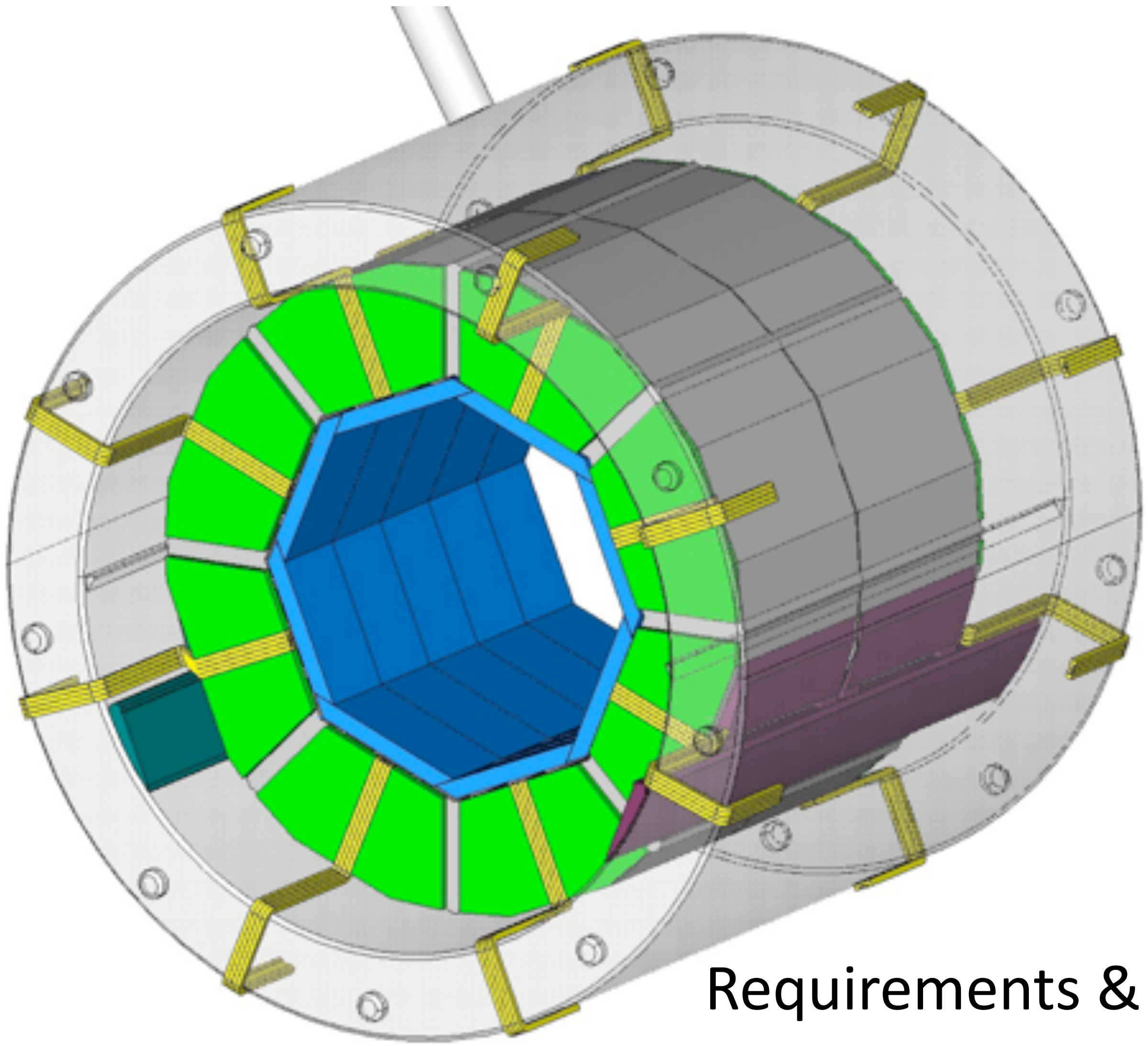
Outline

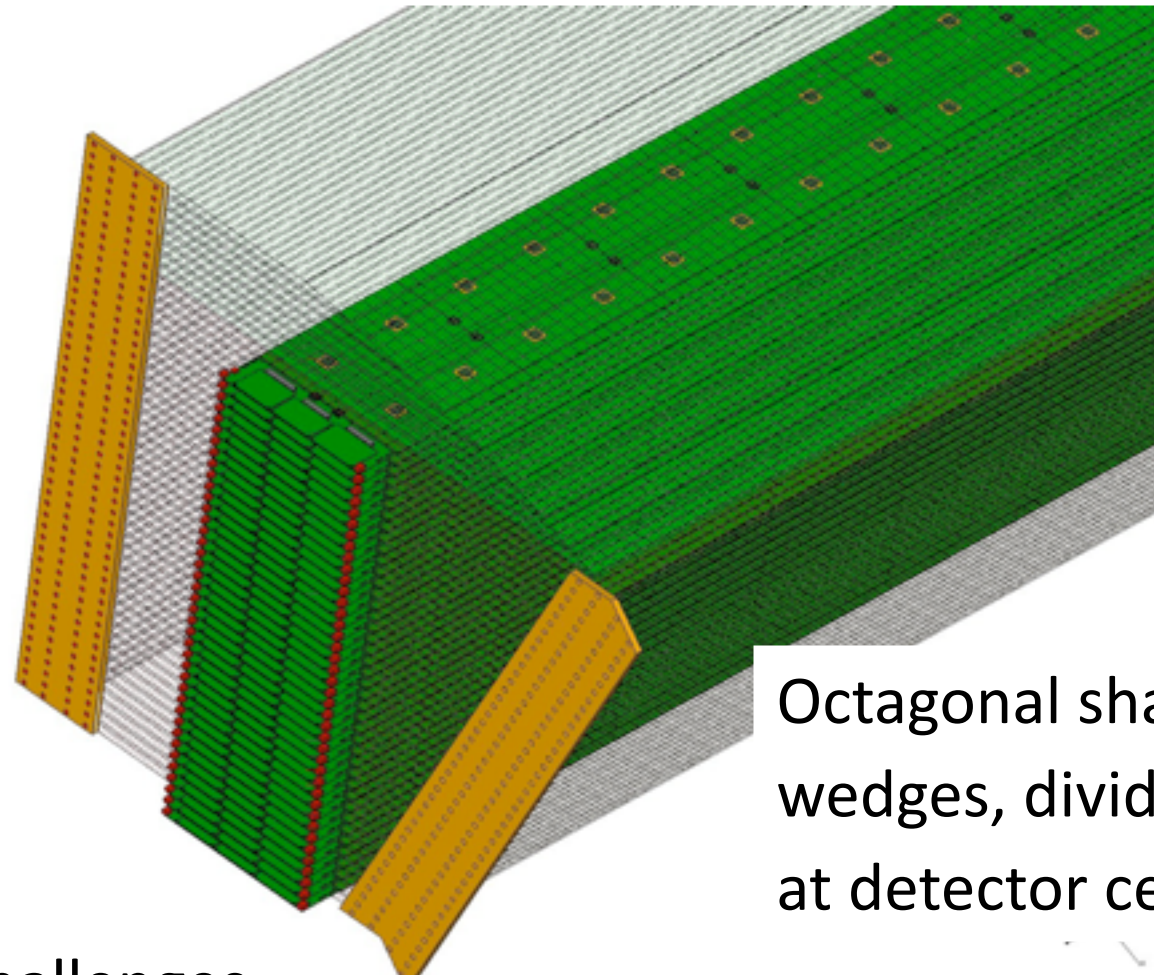
- Towards a technical demonstrator for the analog HCAL
  - The AHCAL in the DBD
  - Scintillator tiles & electronics
  - First test beam results
  - Mechanical studies
  - Simulation in ILD
- Highlights from the physics prototype
  - Understanding details: temperature, non-uniformities
  - Electromagnetic performance
  - Validation of shower models and PFA performance
  - Energy resolution for hadrons
- Summary

The Technical Demonstrator

A Technical Demonstrator for ILD

- A scalable calorimeter design for ILD





Octagonal shape, 16 wedges, divided in z at detector center

Requirements & Challenges

- Highest possible density: Minimized thickness of active layers
- Minimum dead space between wedges
- Minimum dead space between barrel and endcap

A Technical Demonstrator for ILD

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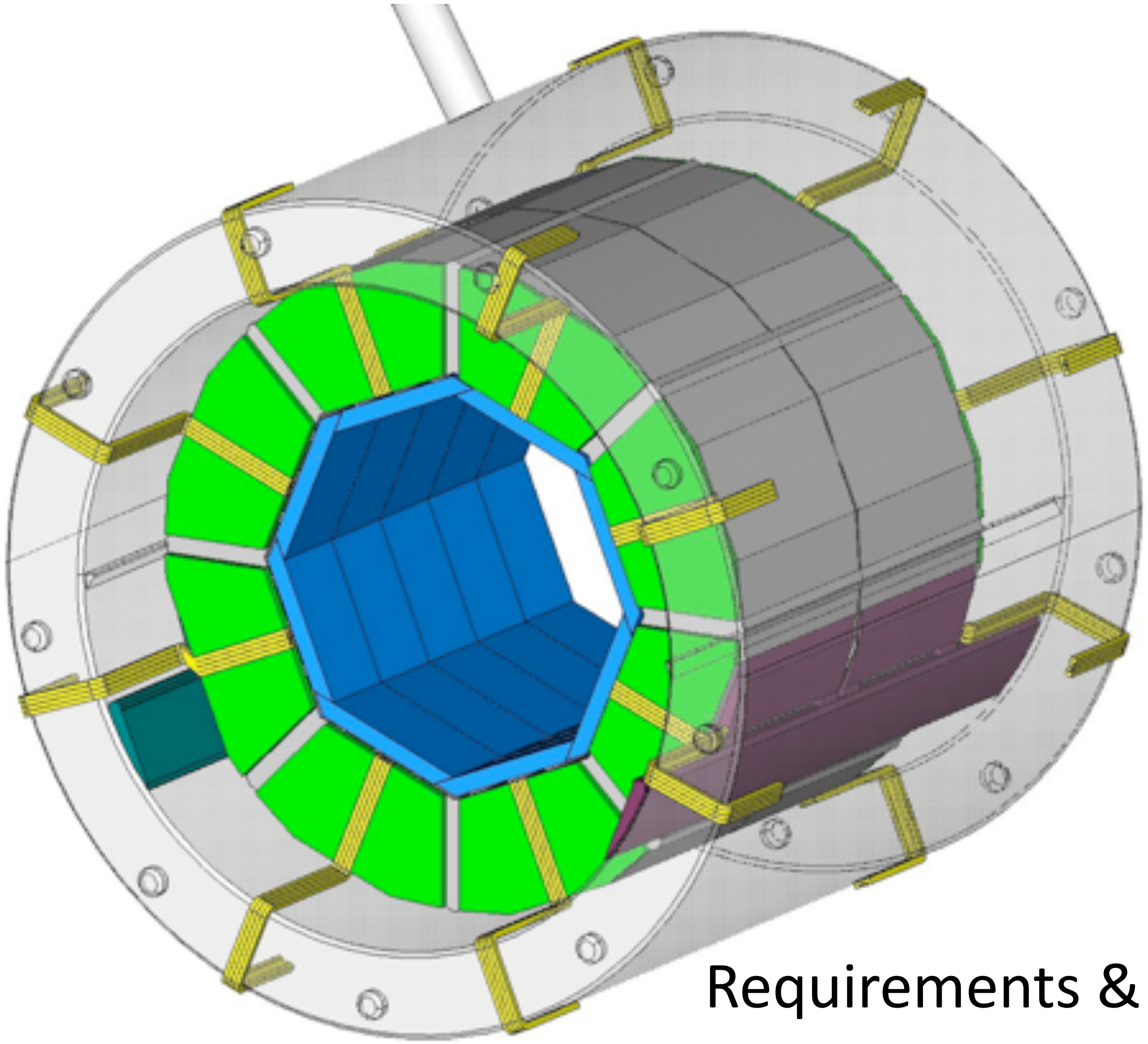

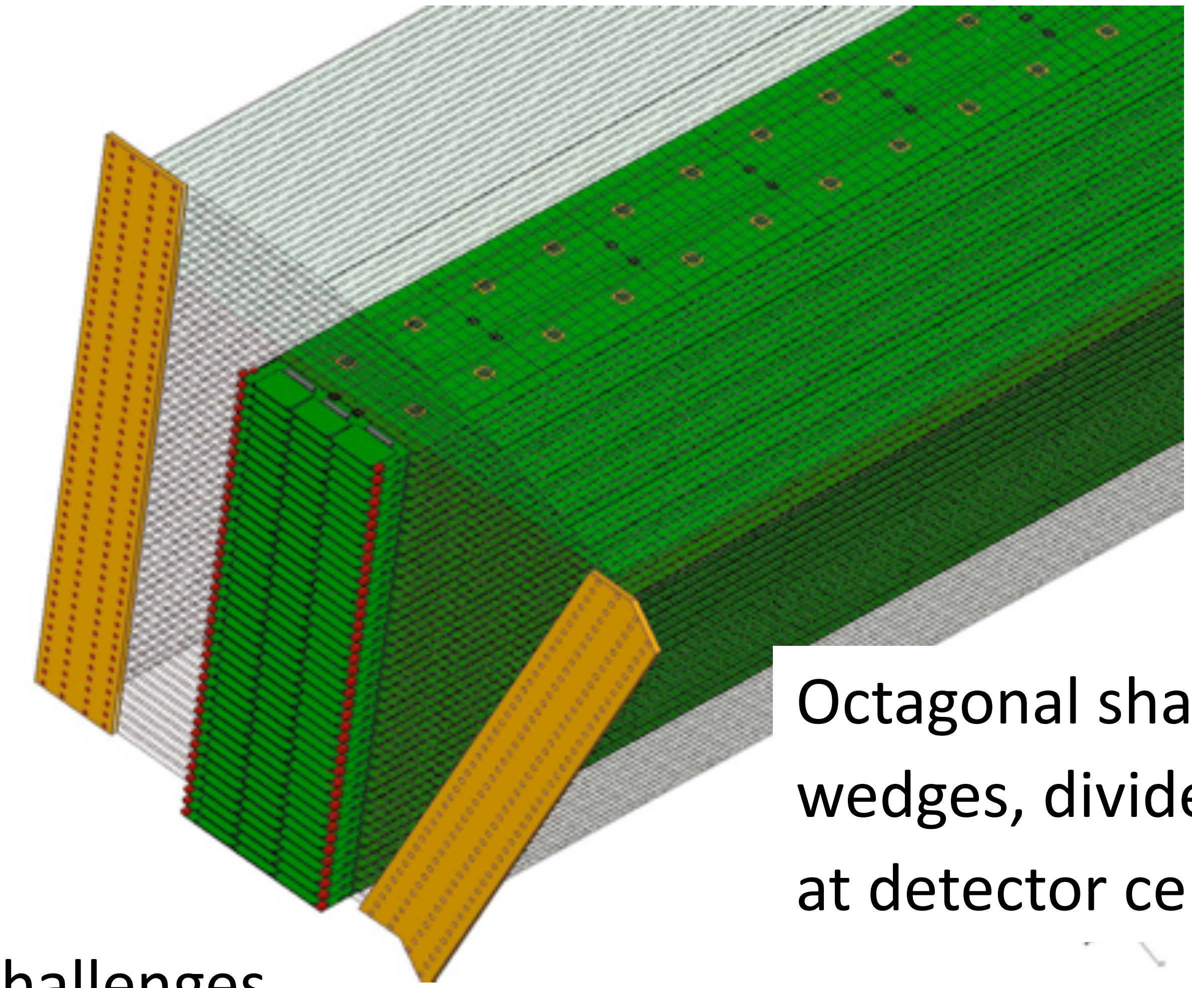

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Only possible with integrated electronics!

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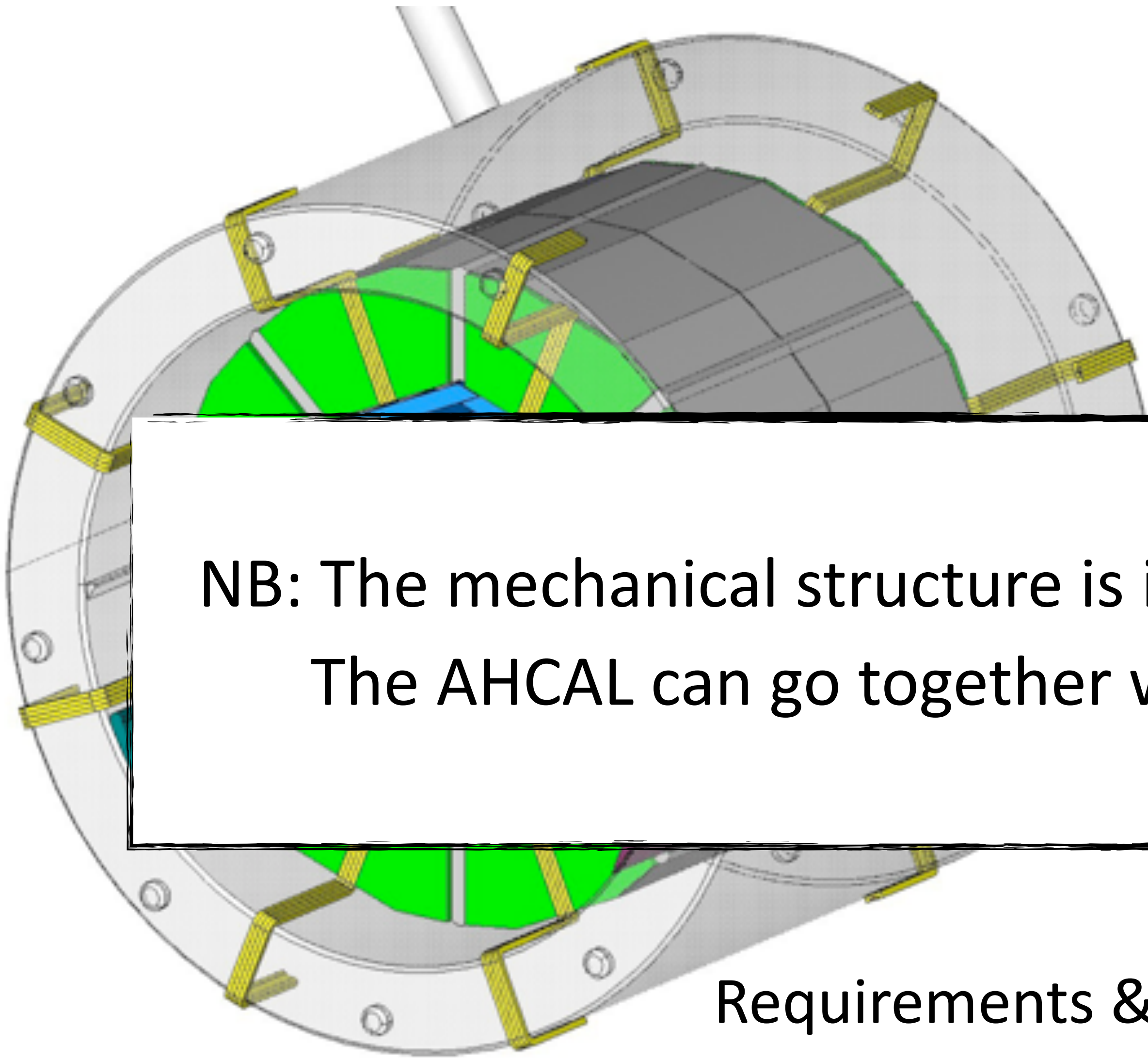

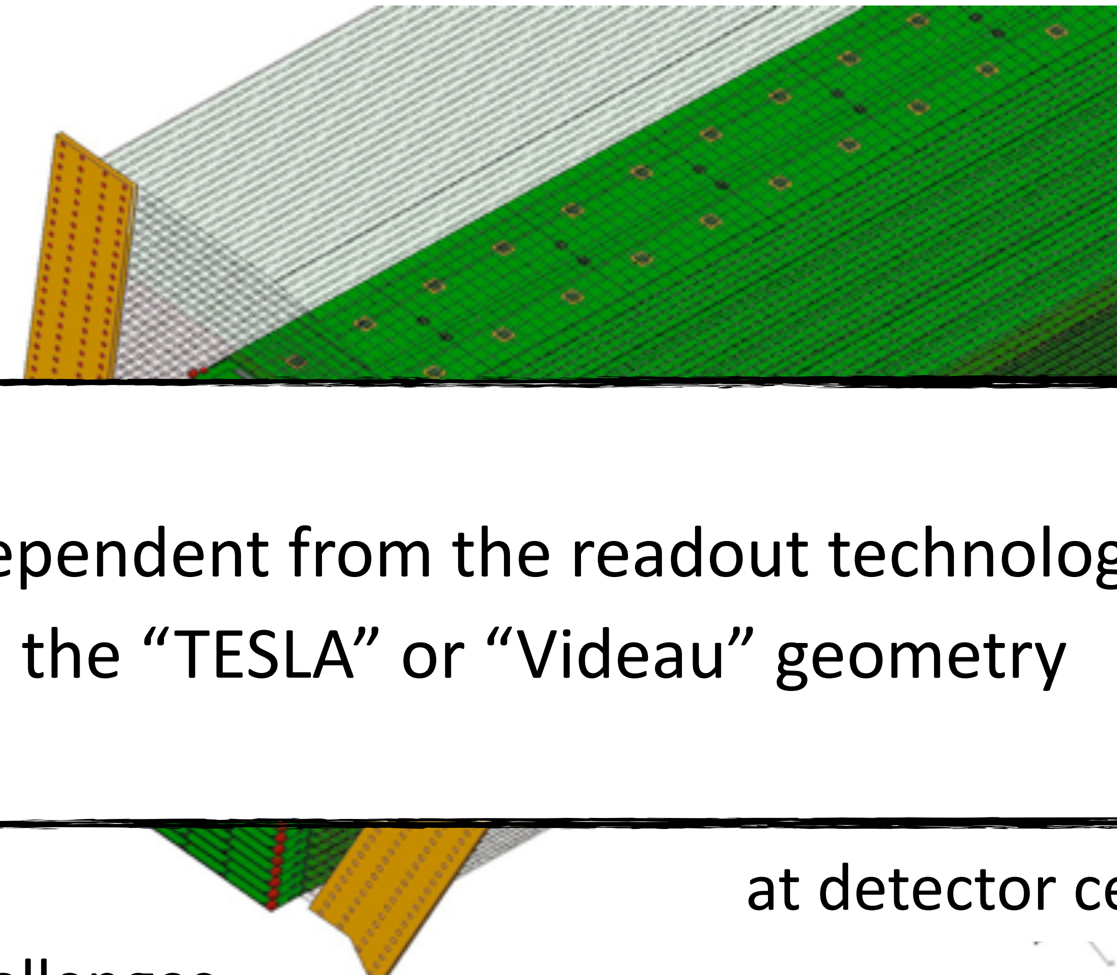

NB: The mechanical structure is independent from the readout technology:
The AHCAL can go together with the “TESLA” or “Videau” geometry

16

z

at detector center

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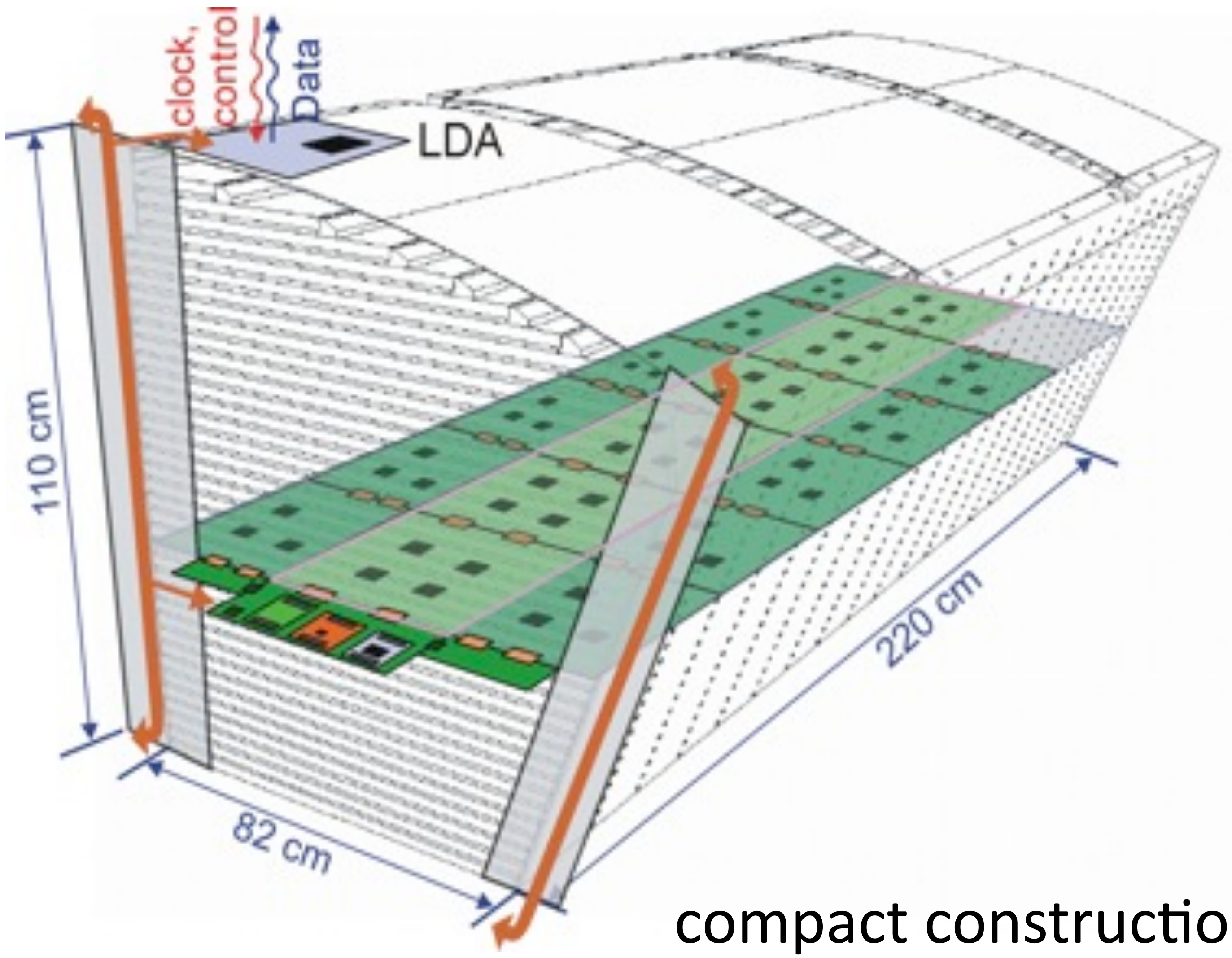
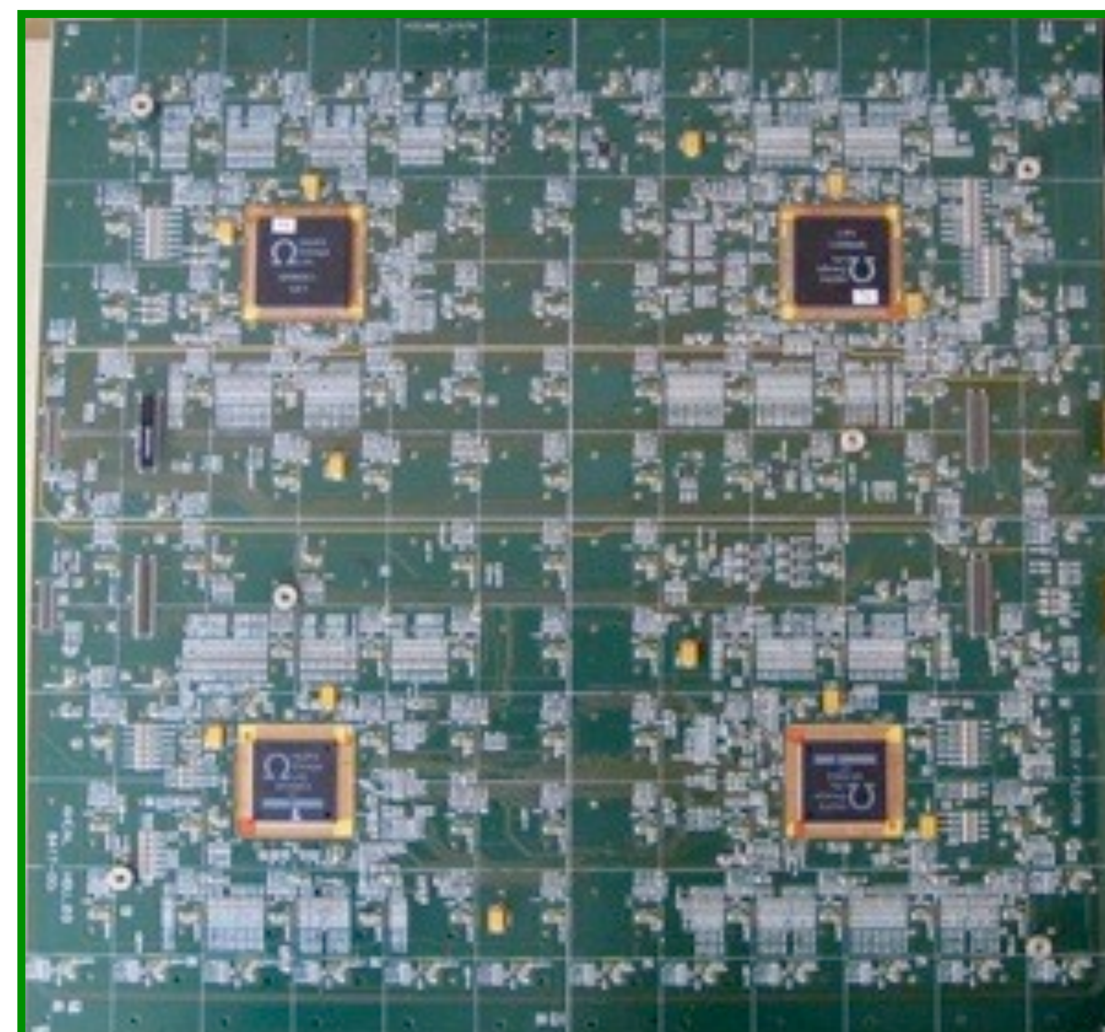
Only possible with integrated electronics!

The Active Layers

- Based on SPIROC ASIC, powerpulsing to eliminate need for active cooling



- Individual electronic boards (HBUs) with 144 channels, interconnected to form active layers

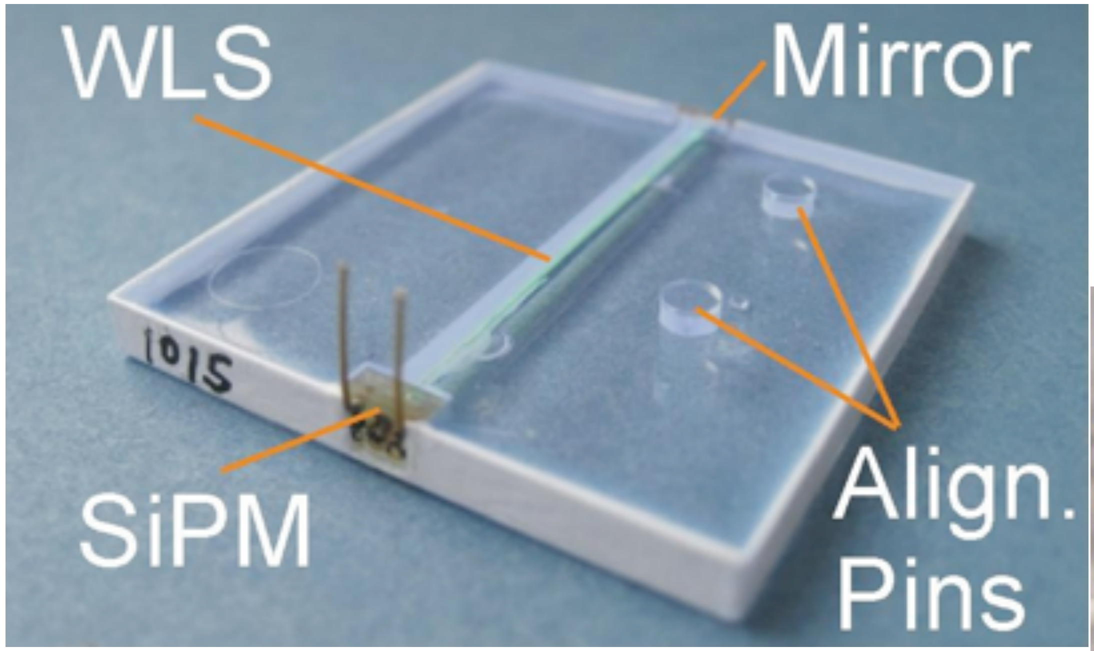


compact construction: Minimized gaps, ASICs embedded in PCB

width of board and scintillator tiles can be adjusted in 1 cm steps to accommodate changing layer width

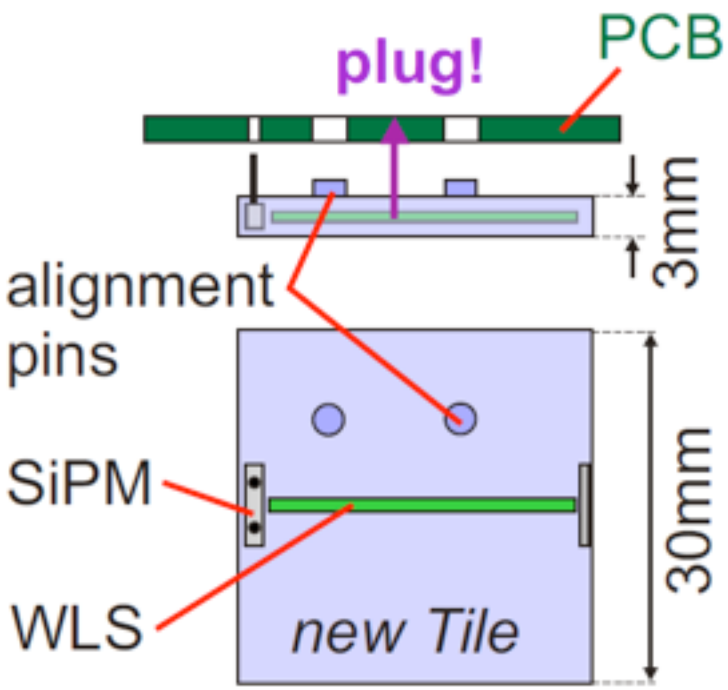
The Scintillator Tiles

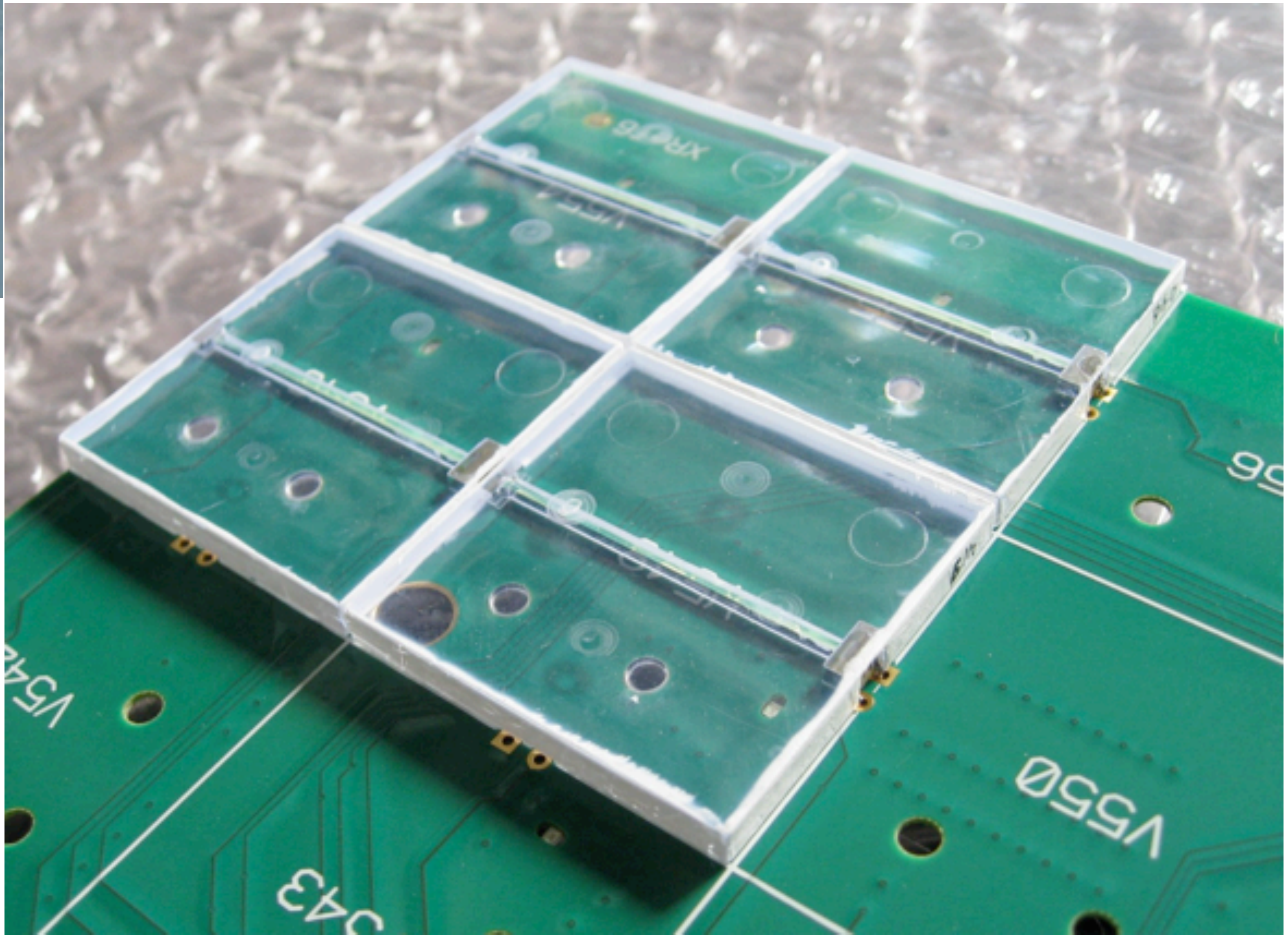
- 3 x 3 x 0.3 cm^3, molded tiles with embedded WLS fiber and SiPM



- From a sample of 450 tiles:

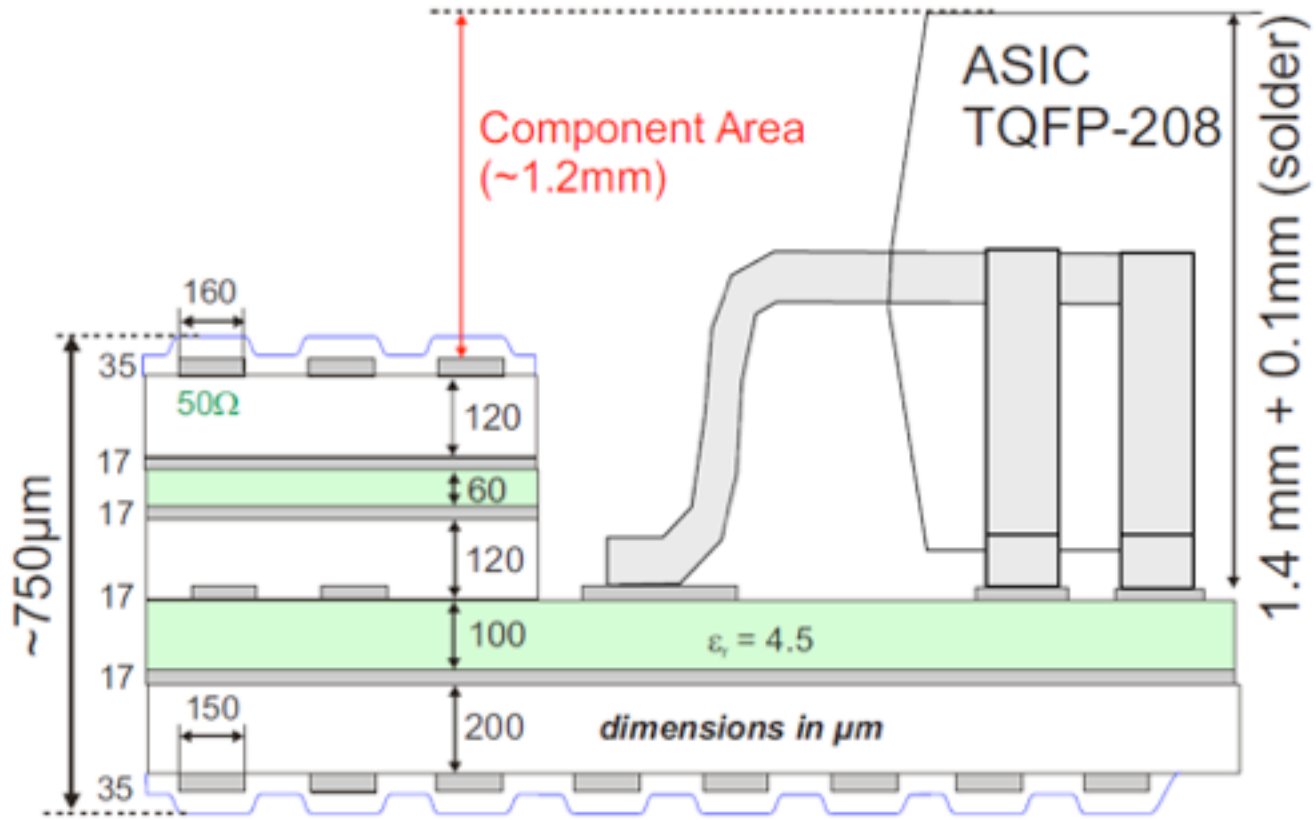
  15 ± 2 detected photons / MIP



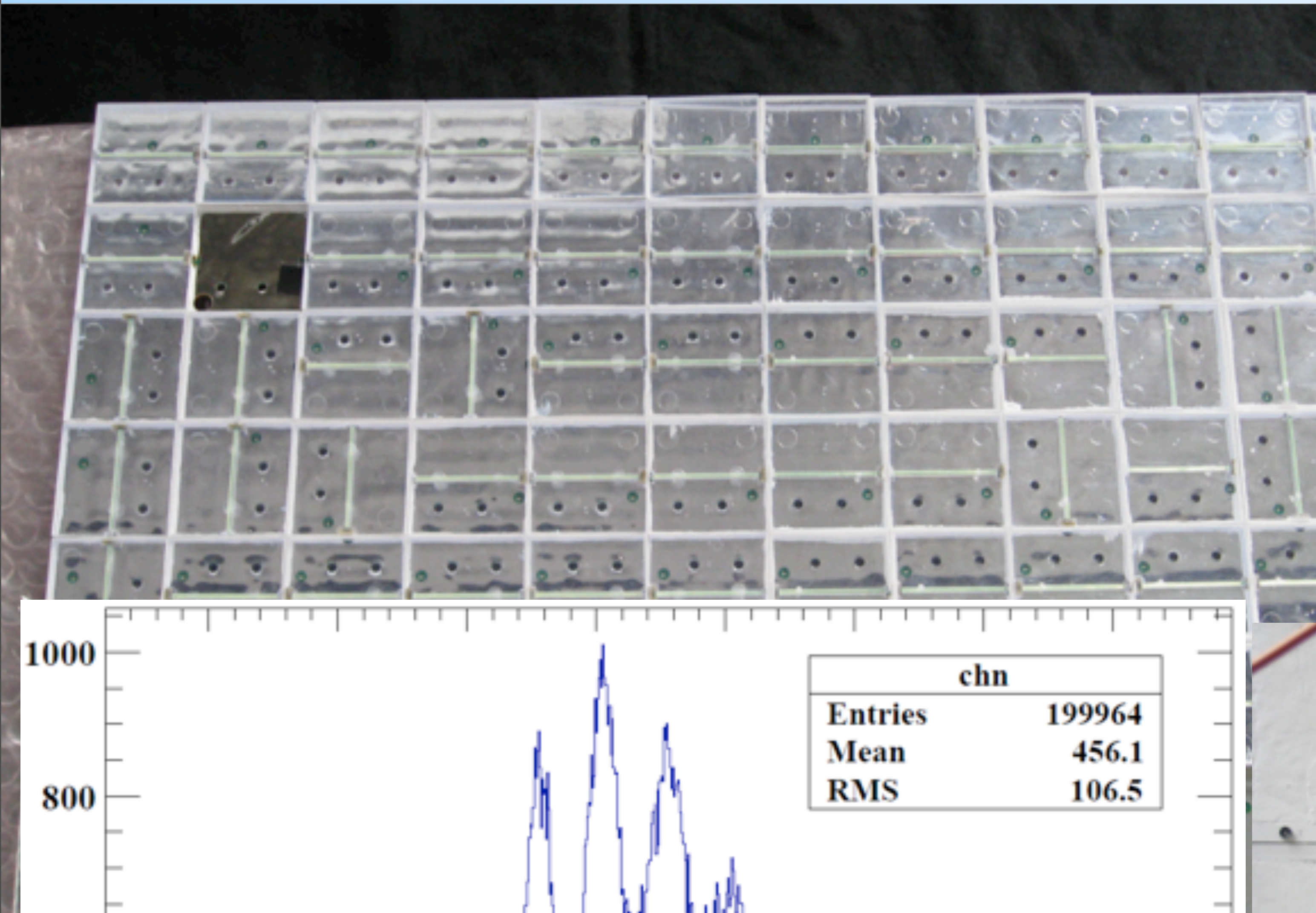


The Readout Chip: SPIROC2b

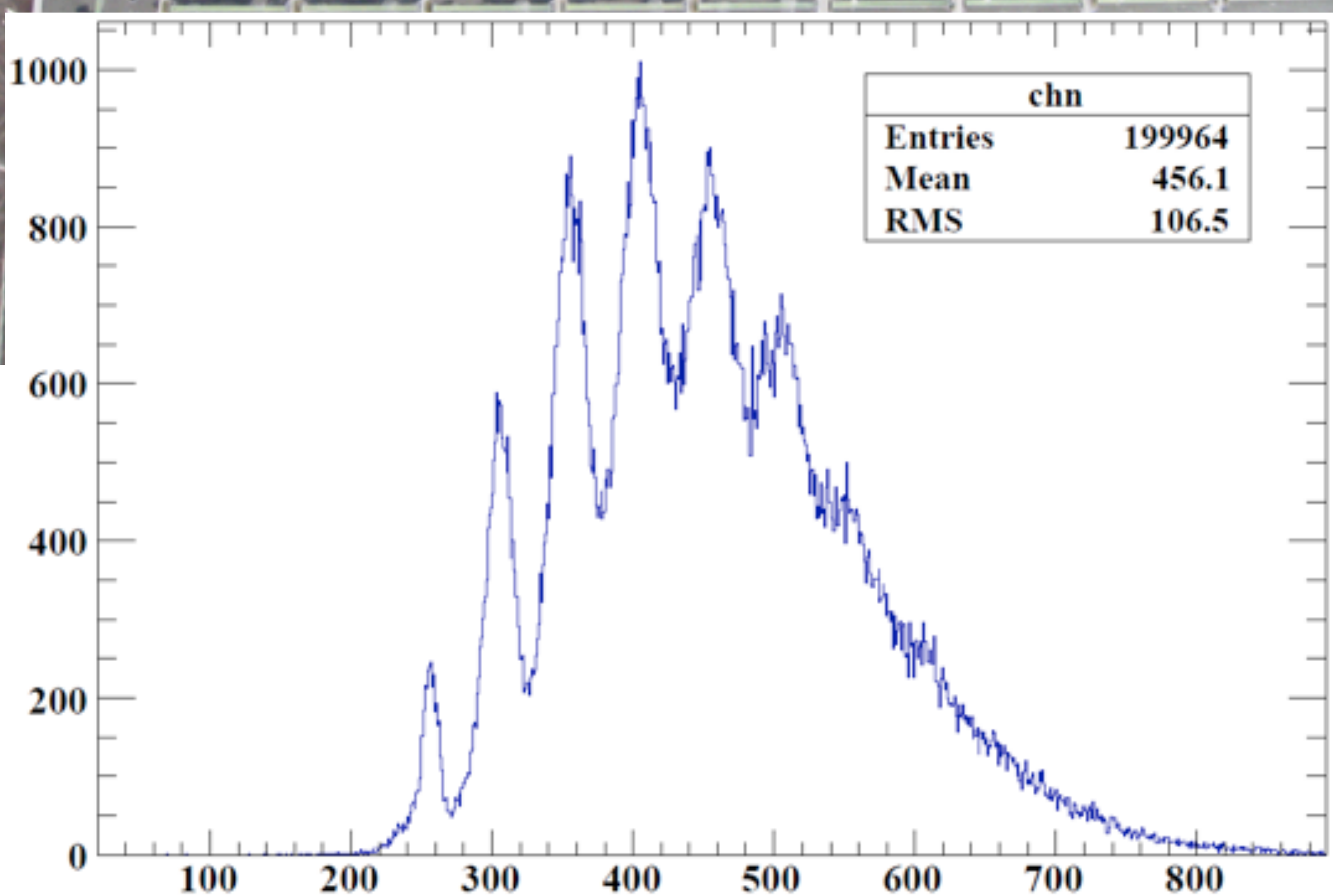
- The heart of the new electronics: SPIROC2b, designed by OMEGA/IN2P3
- 32 channels, independent bias voltage control for each channel
- Powerpulsing: 25 µW/channel
- Auto-trigger mode
- Time stamping capability
- Chip installed in cut-out in PCB to minimize layer thickness
- Thorough tests already performed, further improved version (SPIROC2c) on the way

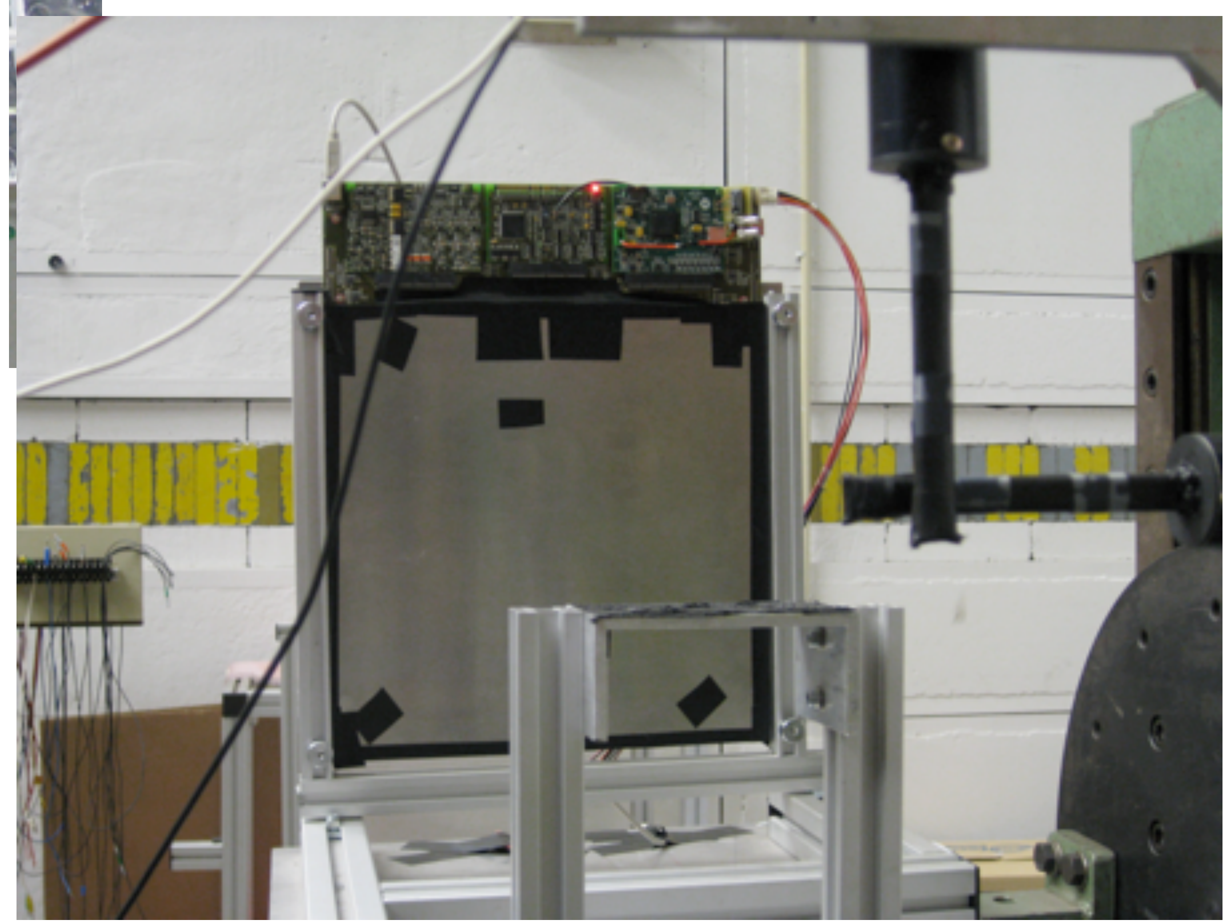


First Results in Beam



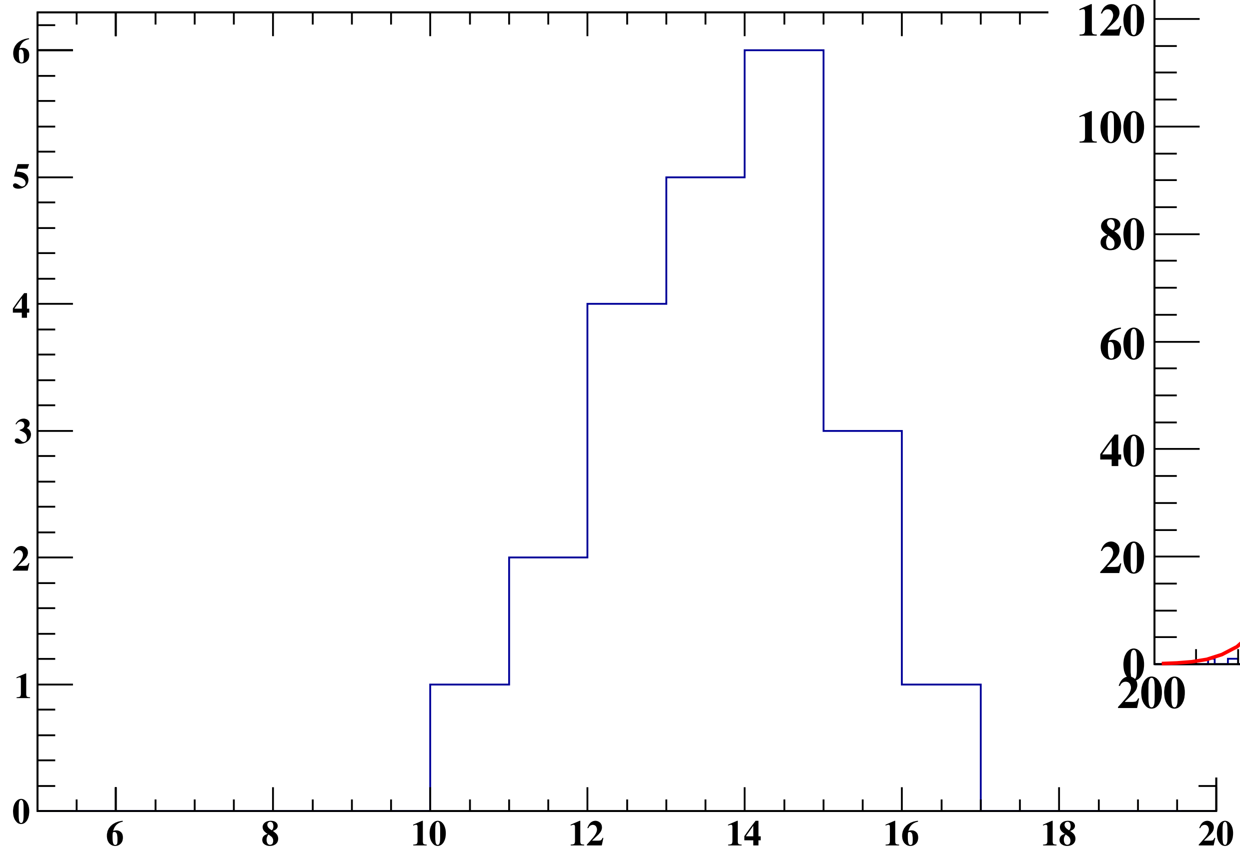
- 1 HBU with 70 tiles in the DESY test beam: Test response to MIPs with 2 GeV electrons
- Good single photon spectra observed with LED system!



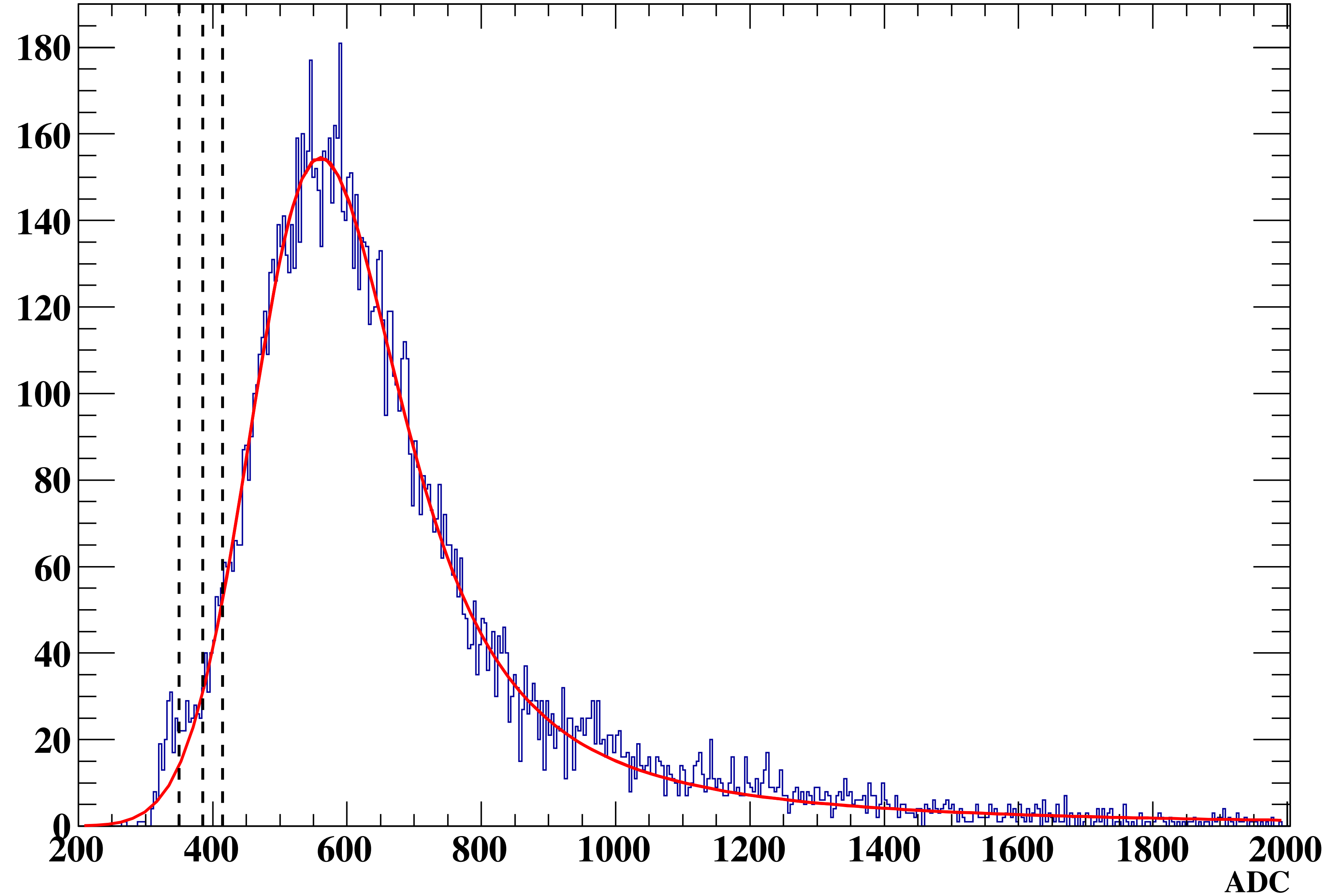


First Results in Beam

- Good response to MIPs
- Satisfactory cell to cell uniformity



light yield [pixel]



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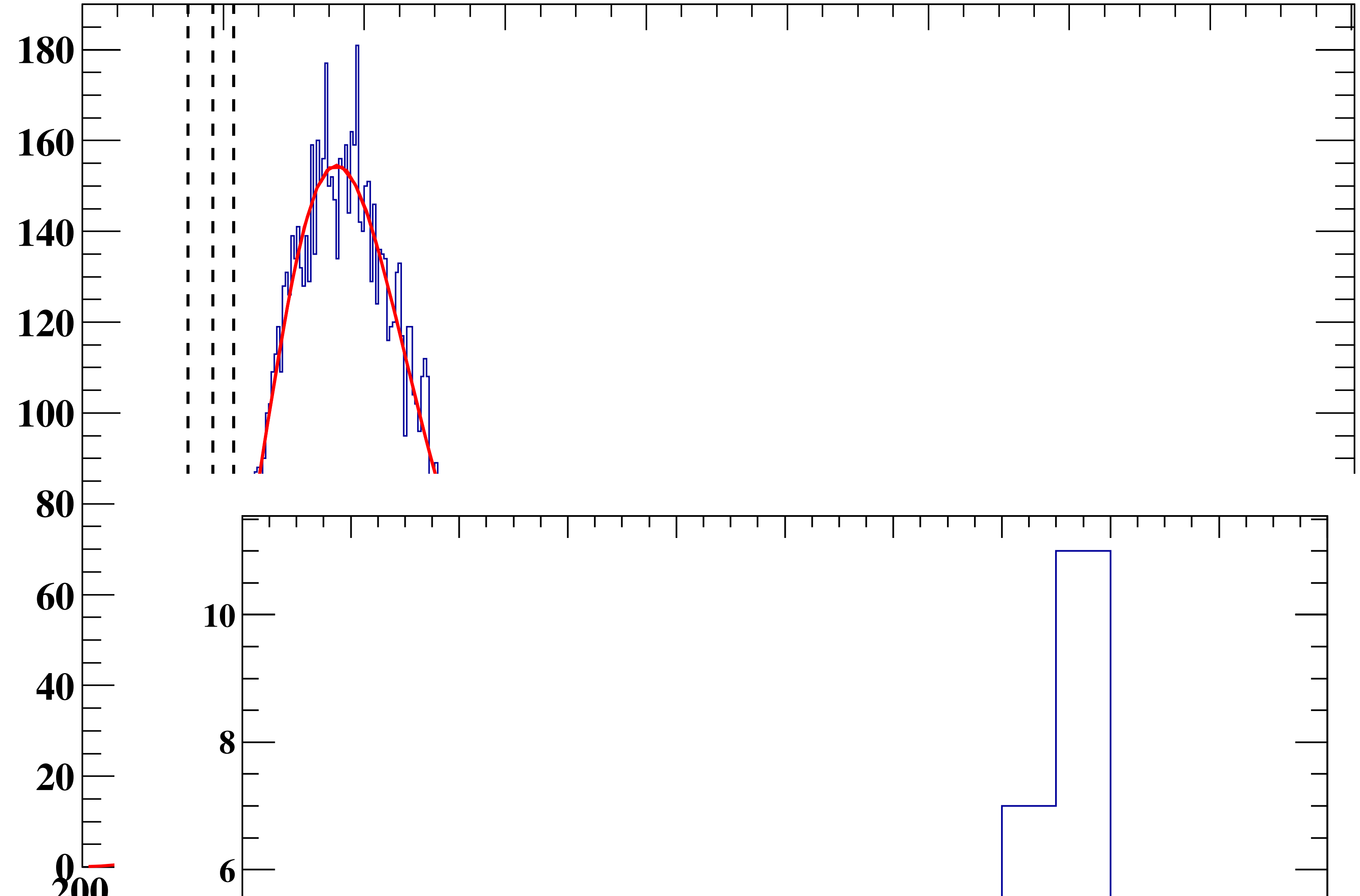
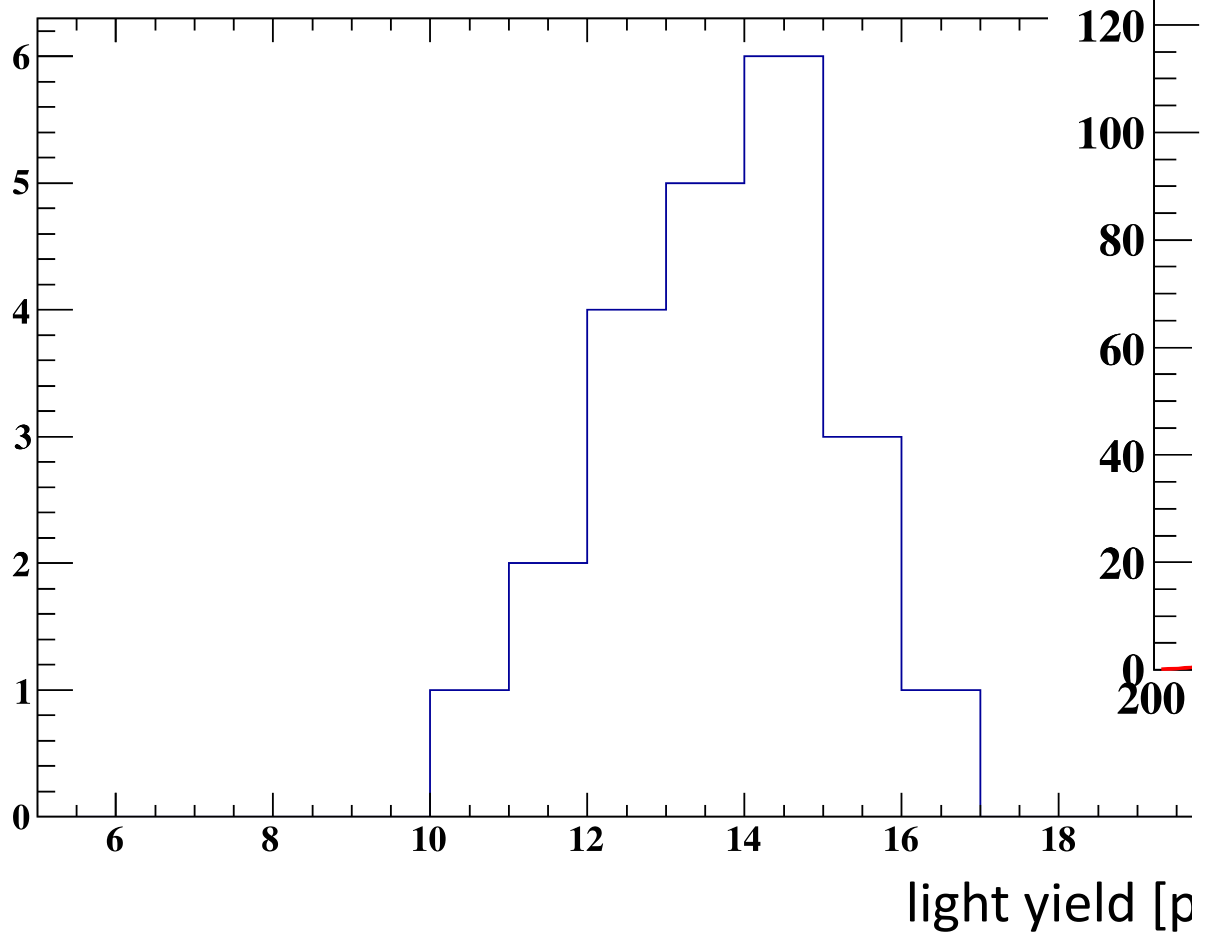
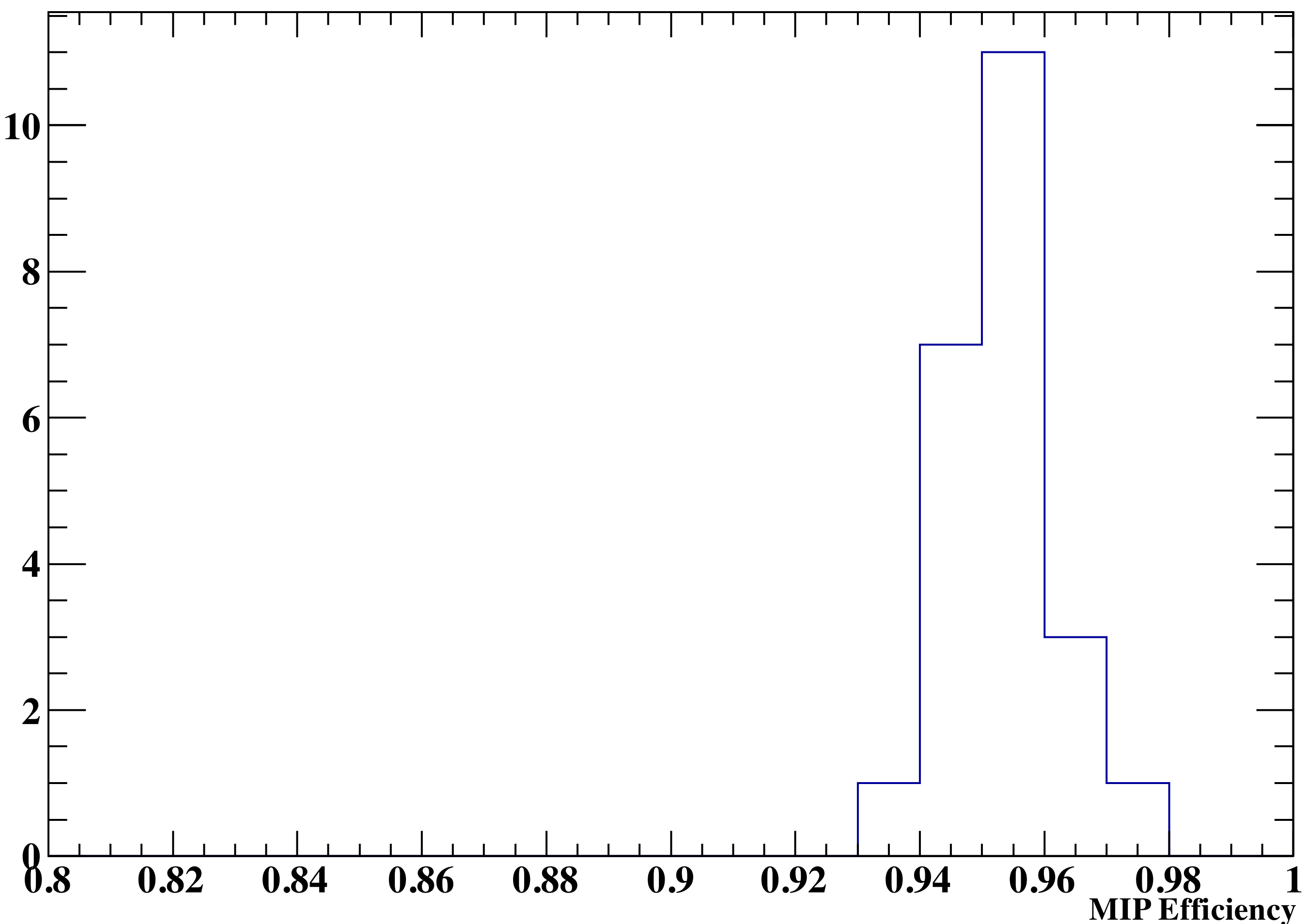




- Good MIP efficiency with a cut at 0.5 MIP



Proving the Mechanical Concept

- Horizontal and vertical prototypes available
- Required flatness (1 mm over full length) of absorber plates achieved with roller leveling
  - No machining required: Saves a factor of 3 in cost!

- Active layers fit in all slots: Mechanical tolerances and structural stability under control!
- ▸ Use 2nd generation demonstrator to study all integration issues with fully equipped active layer

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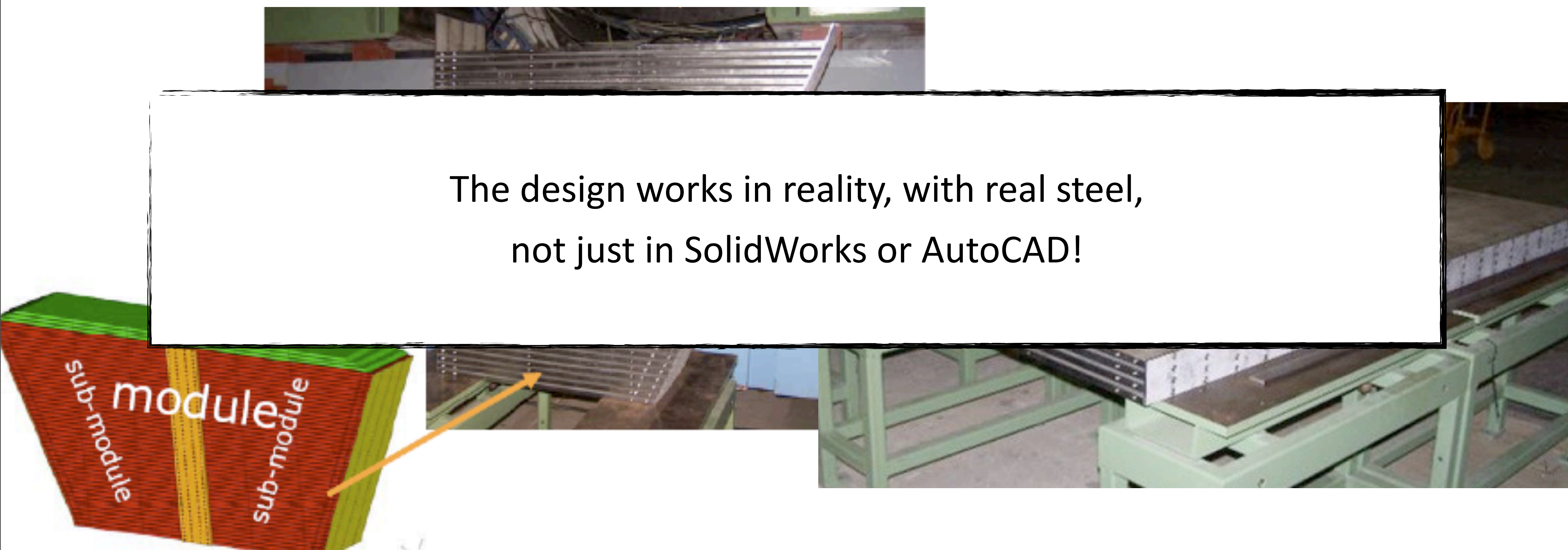
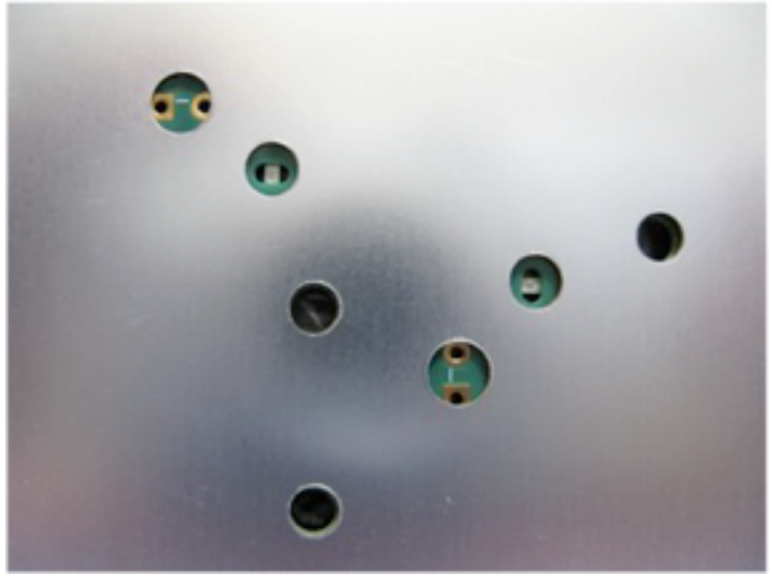


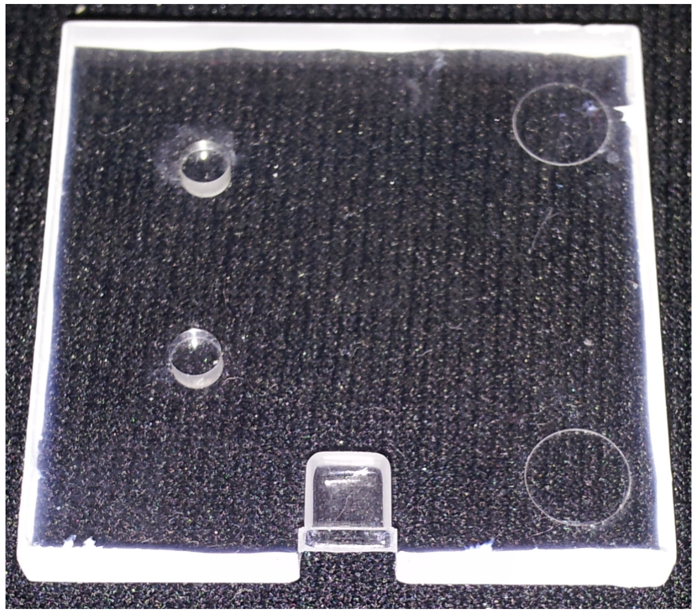
The design works in reality, with real steel,
not just in SolidWorks or AutoCAD!

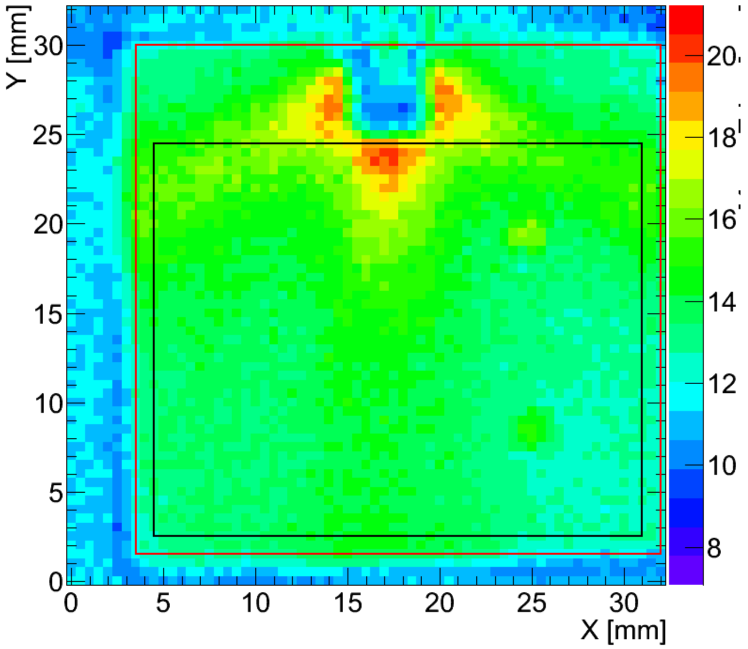
- Active layers fit in all slots: Mechanical tolerances and structural stability under control!
- ▸ Use 2nd generation demonstrator to study all integration issues with fully equipped active layer

Cost and Industrialization

- Progress towards establishing a real mass production:
  - Reflector foils produced by automated laser cutting
  - Molding of scintillator tiles, also with fiberless coupling, chemically matted sides





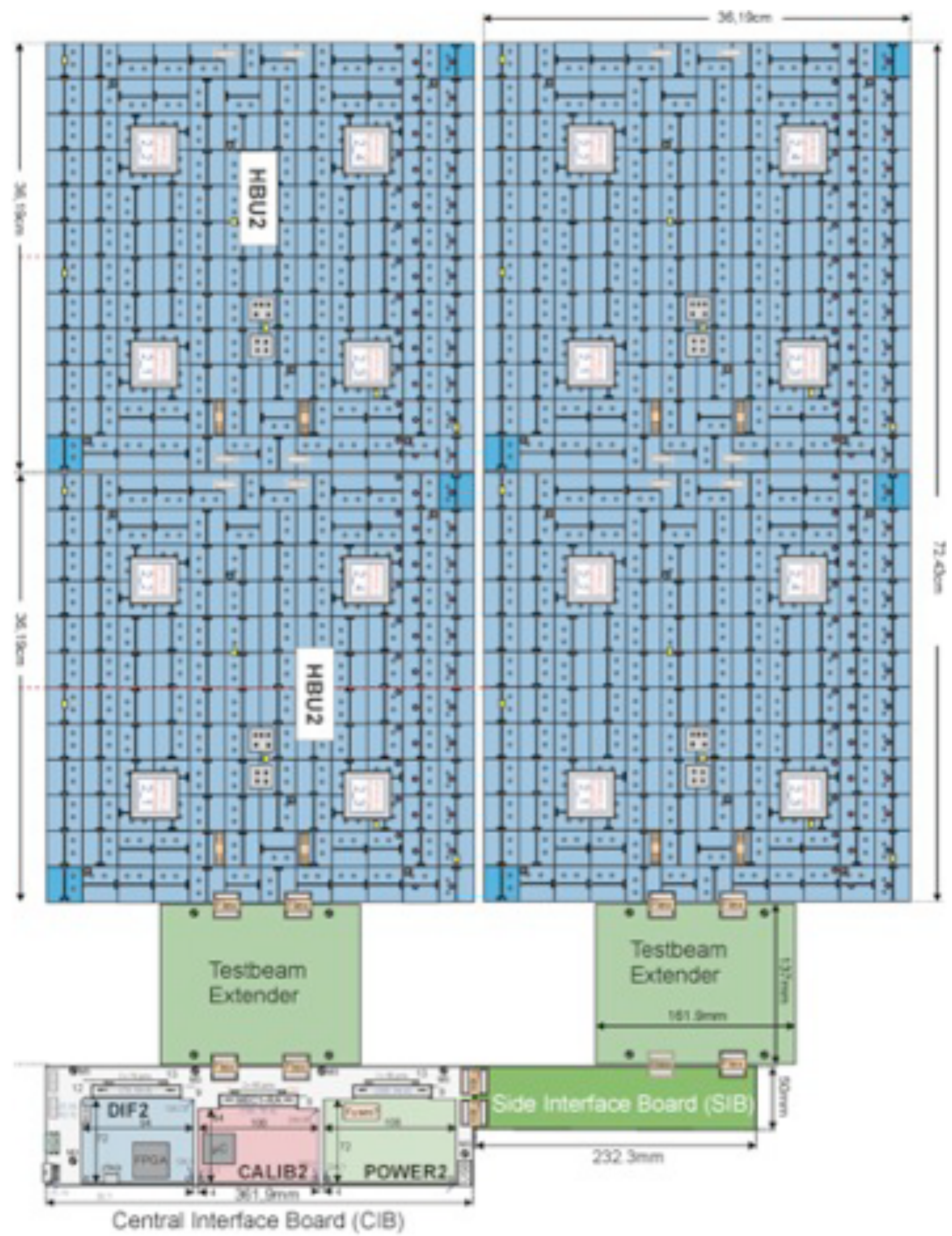


First tests show already promising results for light-yield and uniformity

- Cost for photon-sensor under control: ~ 1 USD/SiPM for Million-Channel systems

Next Steps / R&D Issues

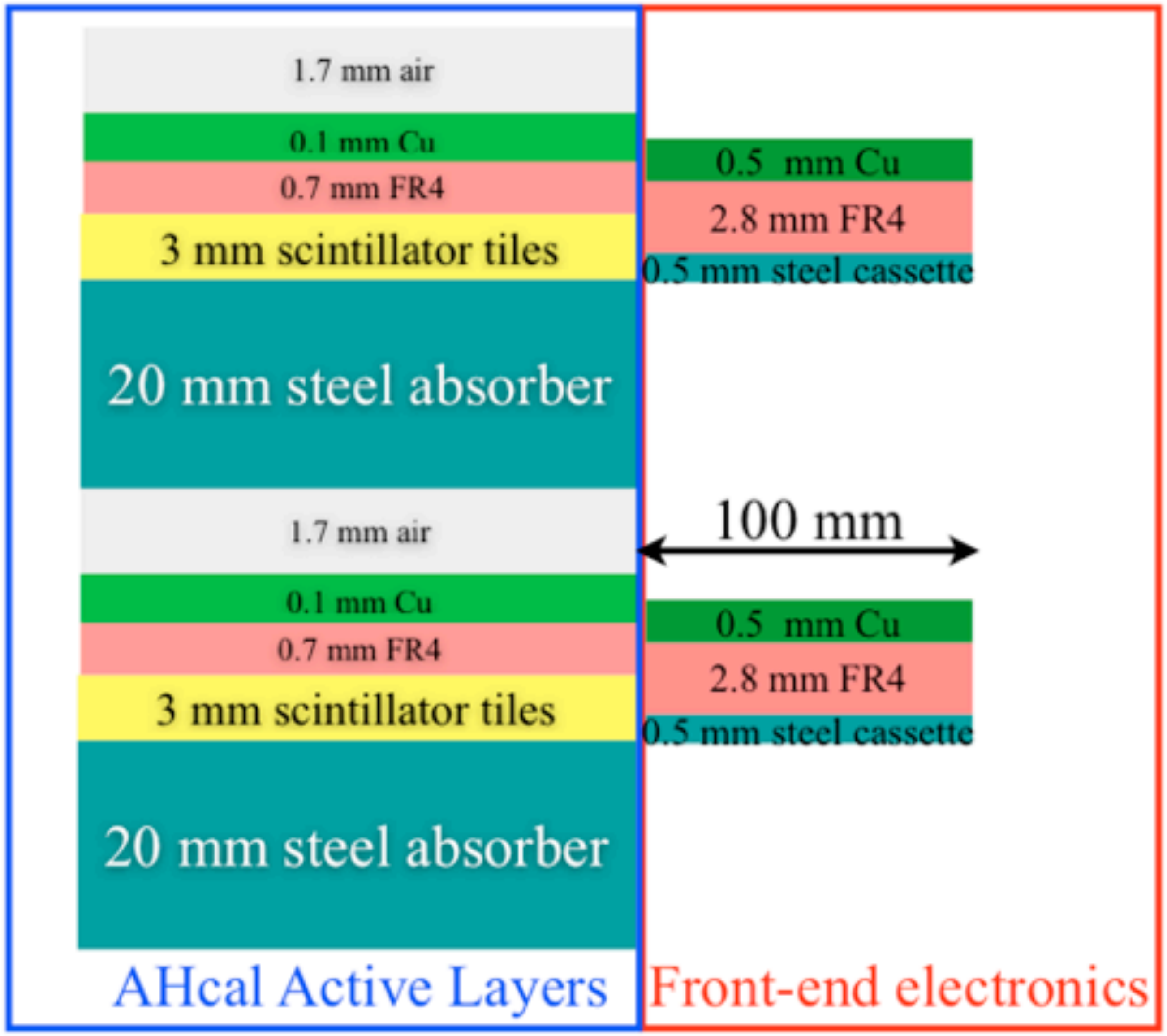
- Preparing for a hadron test beam with one layer (4 HBUs)
  - Measure time-structure of showers (increase coverage compared to T3B, see next talk)



- Test of a full slab in absorbers to assess thermal and mechanical behavior
- Longer vision:
  - Multiple layers, for example an EM tower with new absorber structure in beam
    - Full demonstration also of online SiPM gain adjustment and and zero suppression
  - Full modules / layers with fiberless readout
  - Potentially a full second generation HCAL

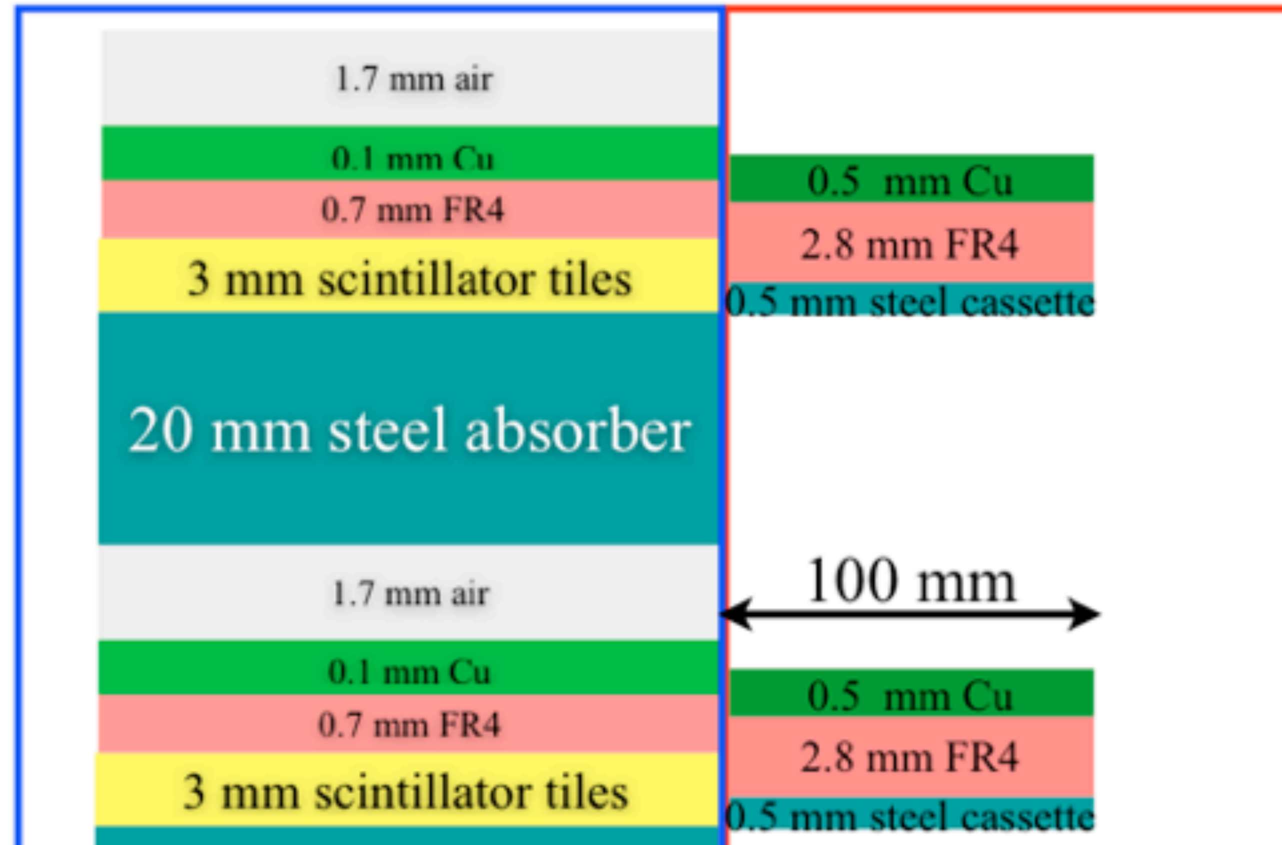
AHCAL Implementation in MOKKA - Ready for DBD

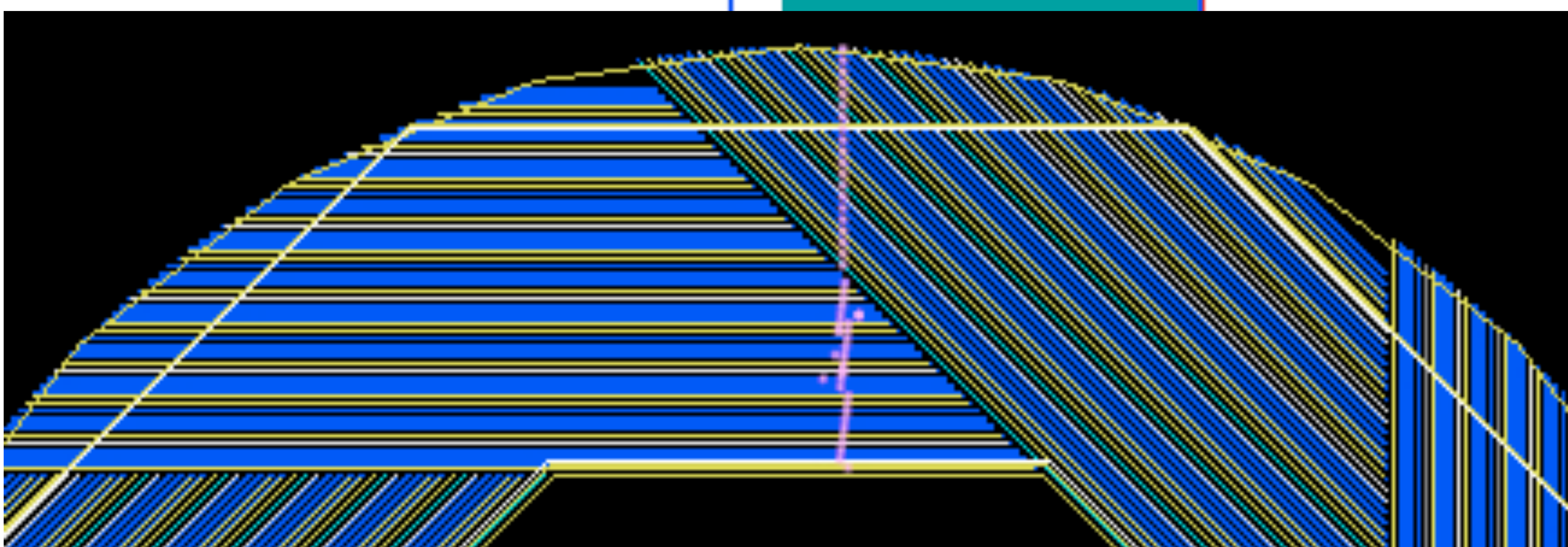
- Detector structure and front-end electronics fully implemented



AHCAL Implementation in MOKKA - Ready for DBD

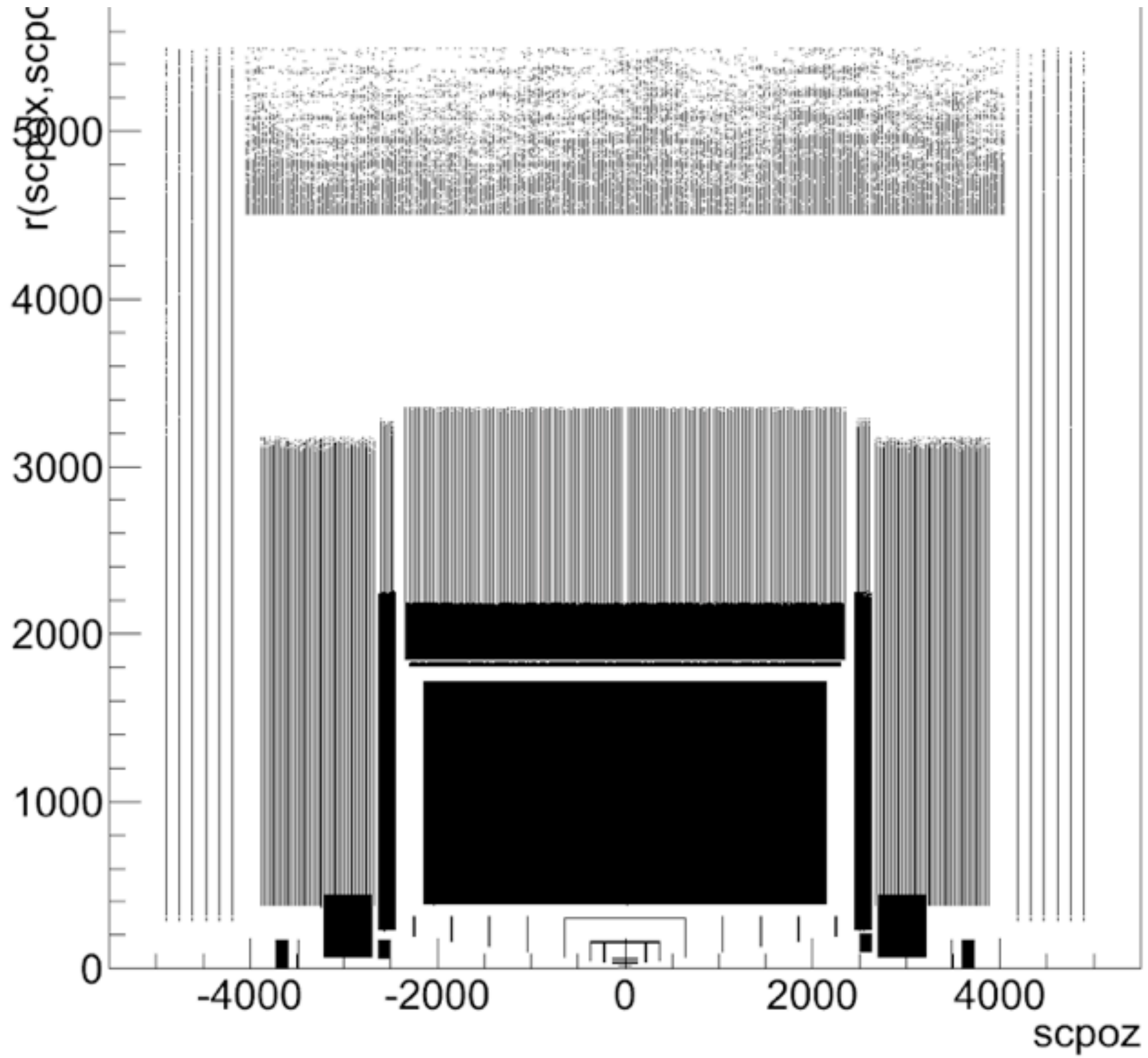
- Detector structure and front-end electronics fully implemented
- AHCAL also available (and tested!) in “Videau” geometry





AHCAL Implementation in MOKKA - Ready for DBD

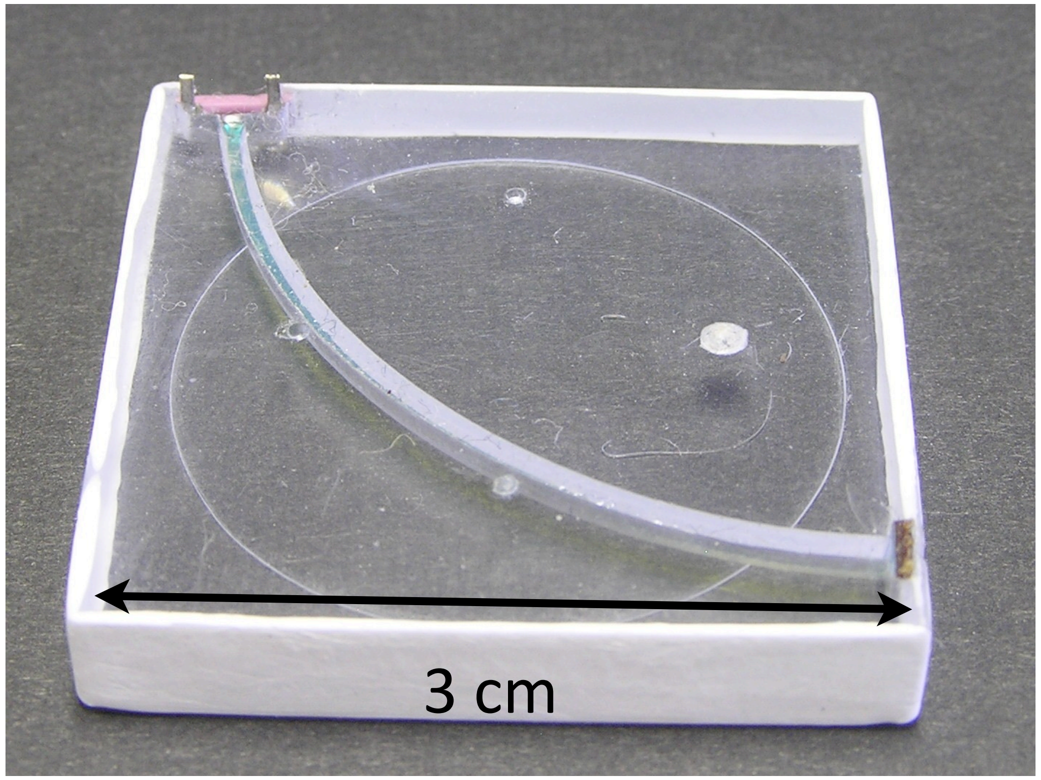
- Geometry complete with non-instrumented gaps for services, front end electronics, ...



The Basis: Highlights from the Physics Prototype

The AHCAL Physics Prototype

- The unit: scintillator tile with SiPM



Key SiPM properties:

- extremely compact
- insensitive to magnetic field
- high gain, low operating voltage, very low power consumption

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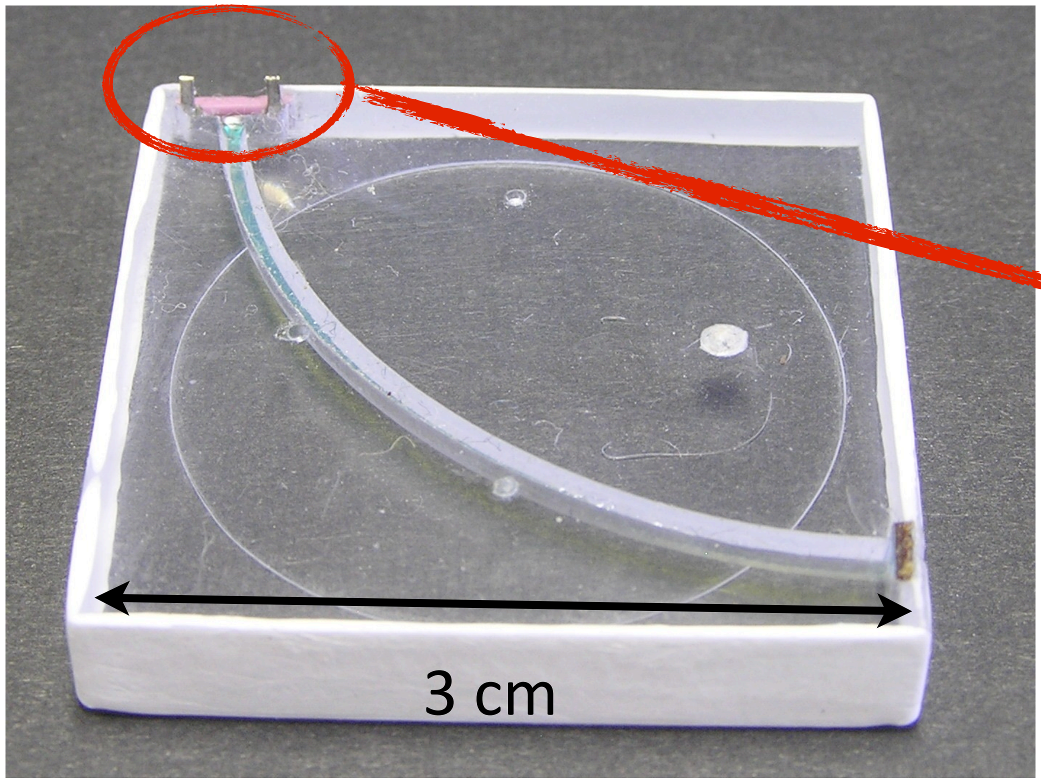
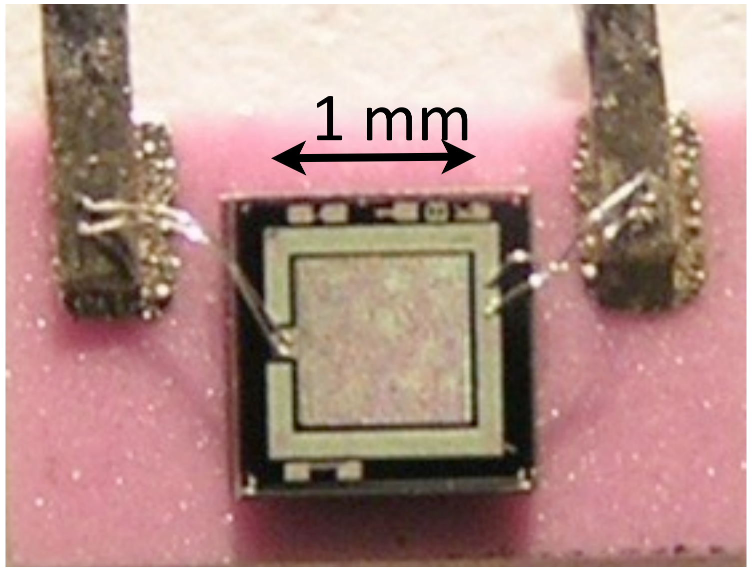


- SiPM: 1156 pixels, manufactured by MePhI/PULSAR



Maximum efficiency in green spectral range: Wavelength shifting fiber to collect and shift blue scintillation light

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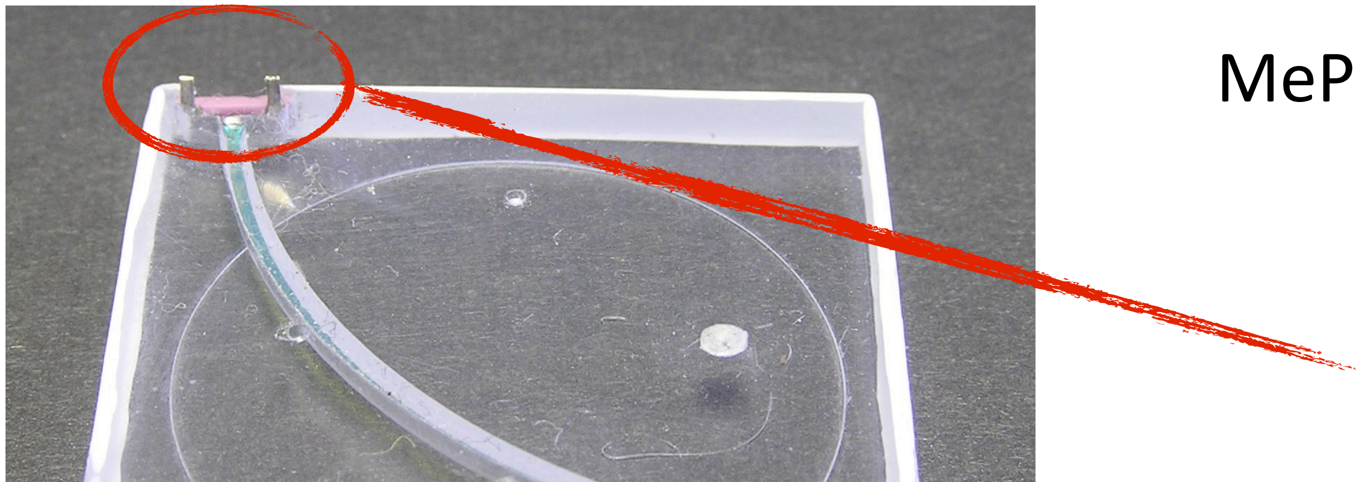
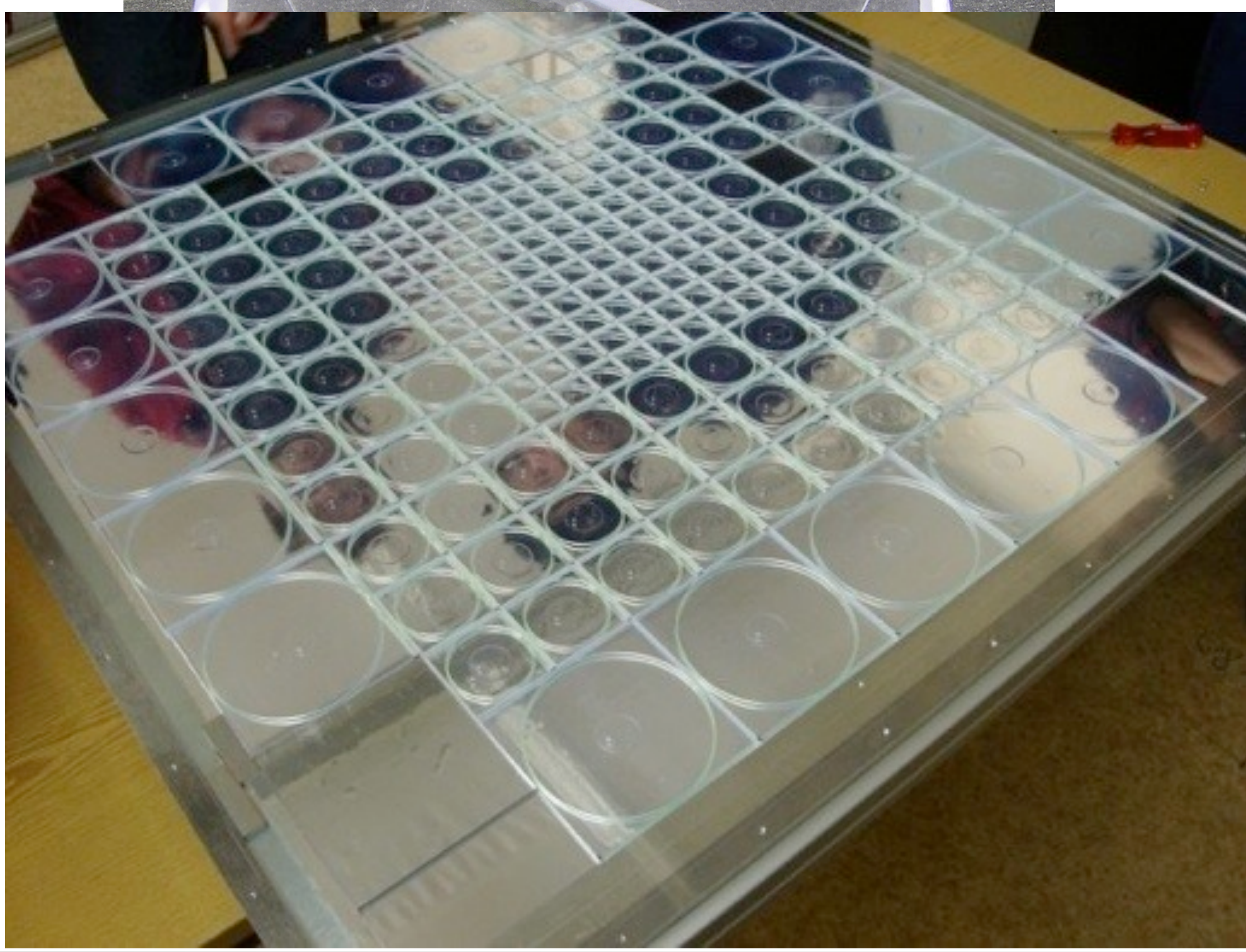
The AHCAL Physics Prototype

- The unit: scintillator tile with SiPM





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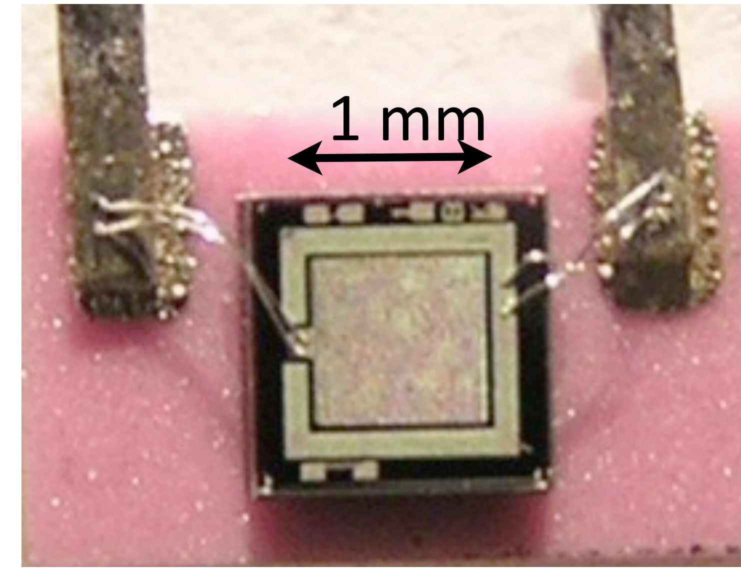


ximum efficiency in green spectral range:
velength shifting fiber to collect and shift
e scintillation light

- Active layers: 90 x 90 cm^2
  212 scintillator tiles (100 in high granular core)

The AHCAL Physics Prototype

- Remember: The AHCAL was constructed in 2005/6 (first ideas from 2003):
  The first large-scale use of SiPMs in HEP world-wide!

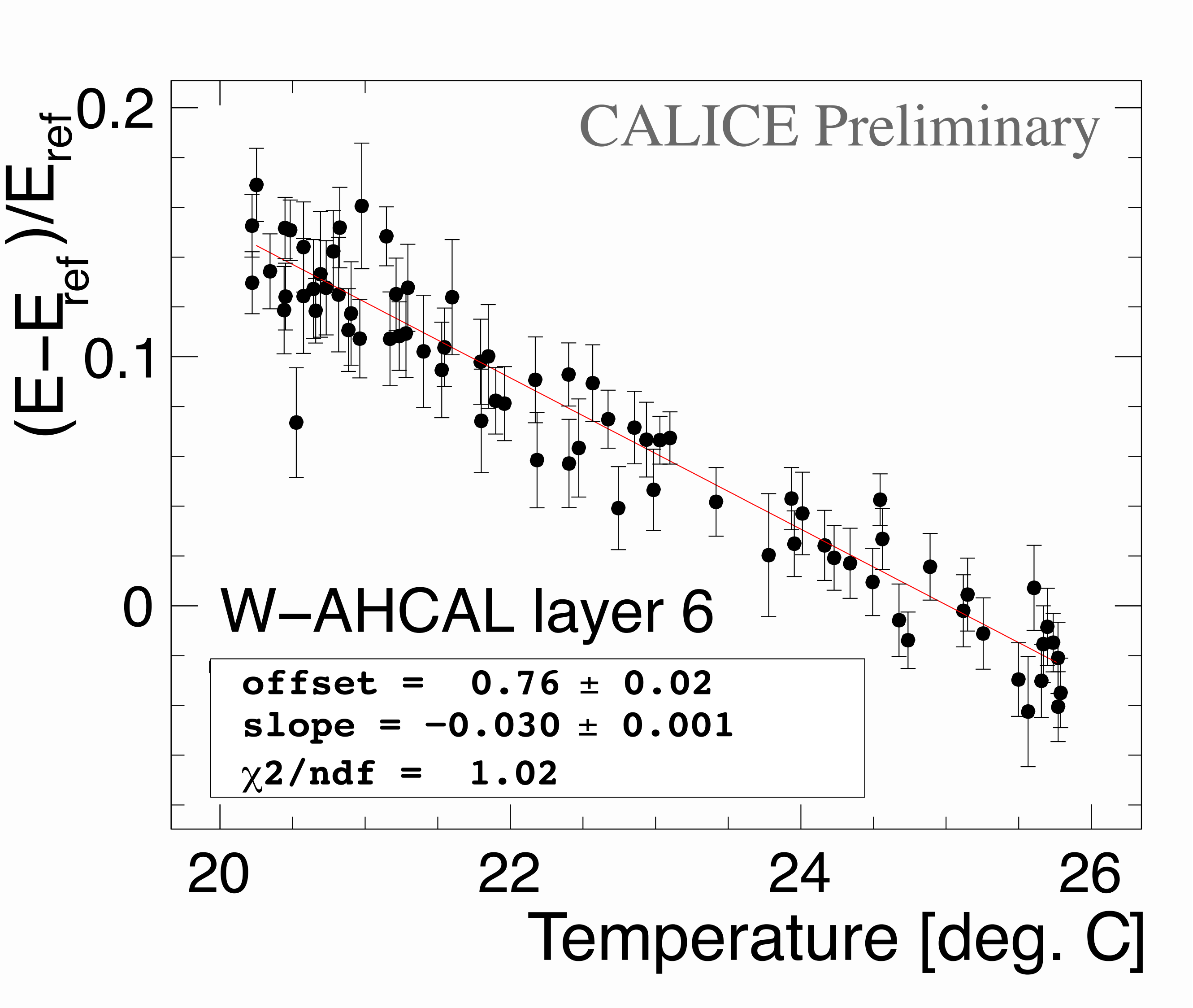
The CALICE AHCAL has been at the front of the global trend towards SiPMs
Now many other users: T2K, various medical imaging projects, CMS upgrades,...

- The technology is extremely robust:
  The AHCAL active elements have completed 6 years of data taking
  - 2006 & 2007: CERN
  - 2008 & 2009: FNAL
  - 2010 & 2011: CERN

Many trips with disassembly & reassembly of the calorimeter:
DESY - CERN - DESY - FNAL - DESY - CERN PS - CERN SPS
... and the SiPMs survived without problems!

Controlling Systematics: Temperature Variations

- The gain and photon detection efficiency of SiPMs depends on temperature



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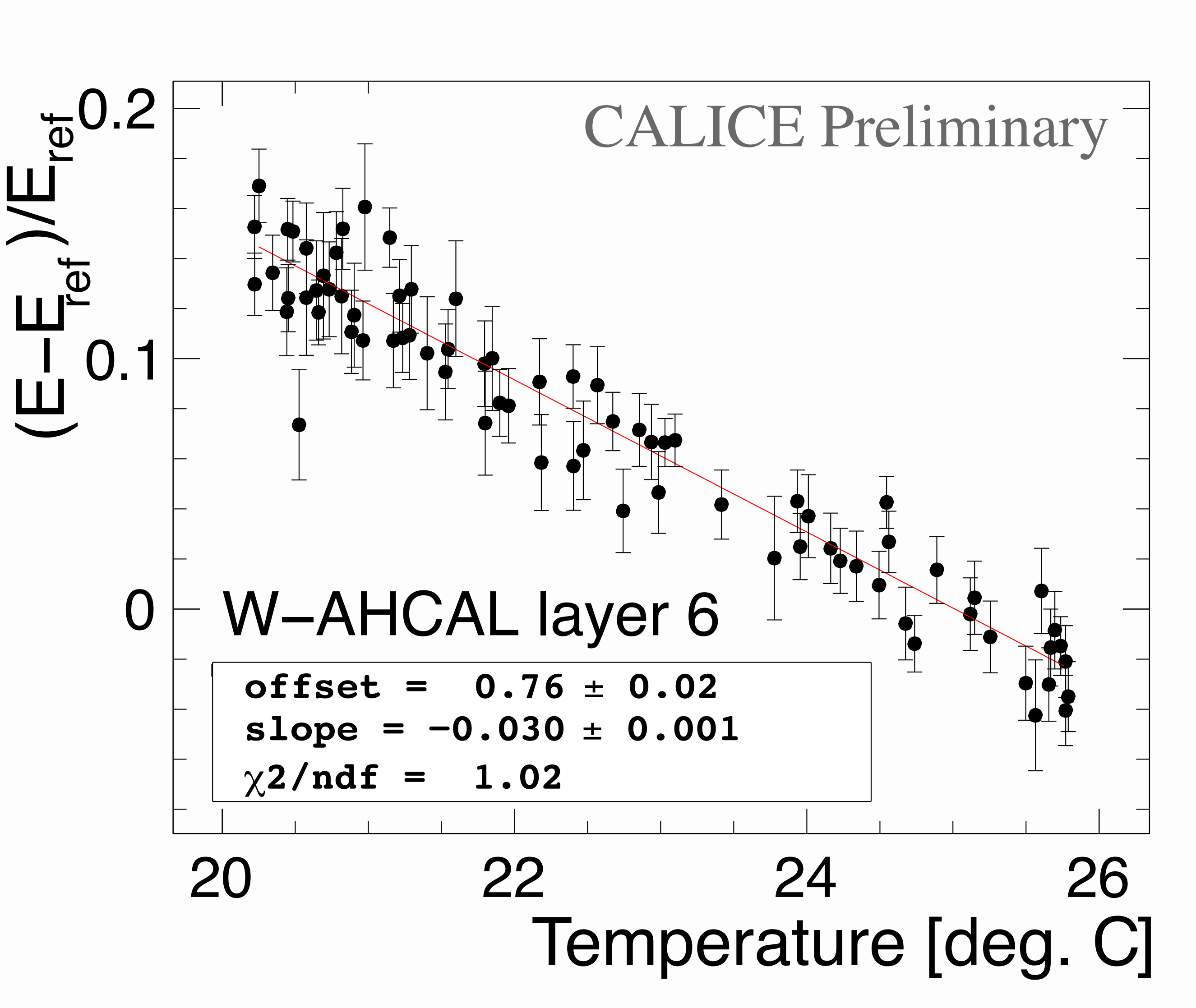
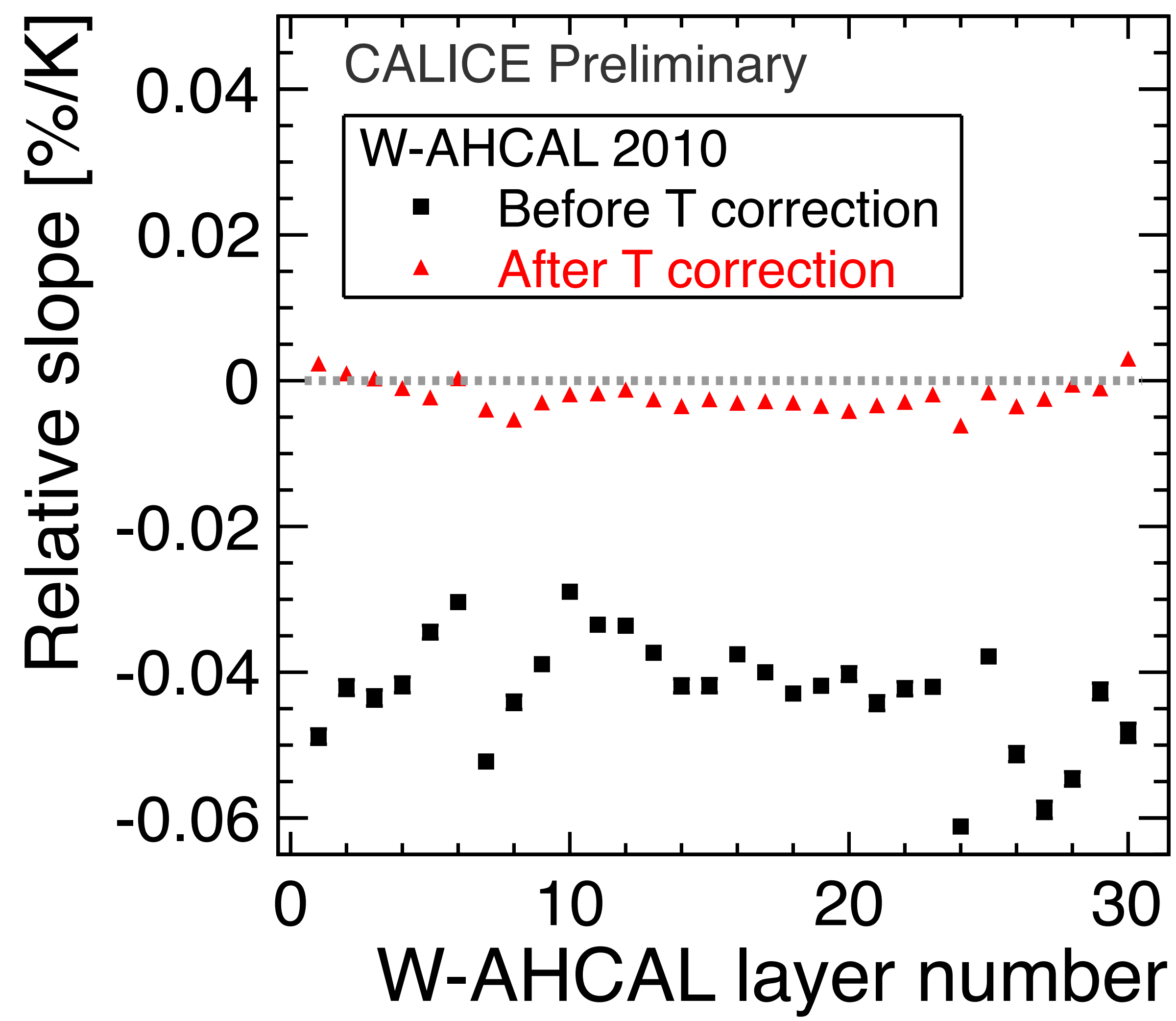
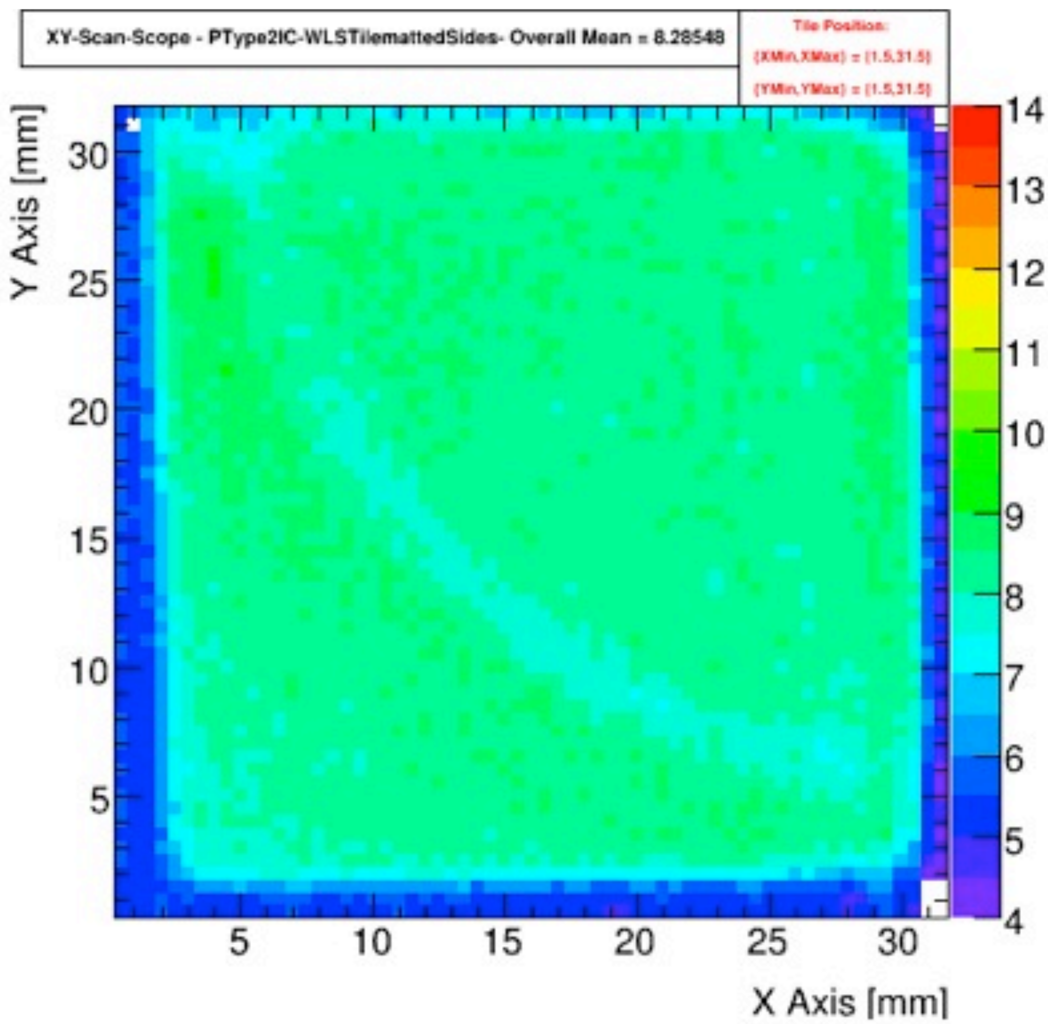




- With temperature monitoring (or using the intrinsic self-calibration of the SiPM, successfully demonstrated for T3B), this dependence can be corrected for to high accuracy over a temperature range far beyond what is expected in ILD

Understanding the Details - Non-Uniformities

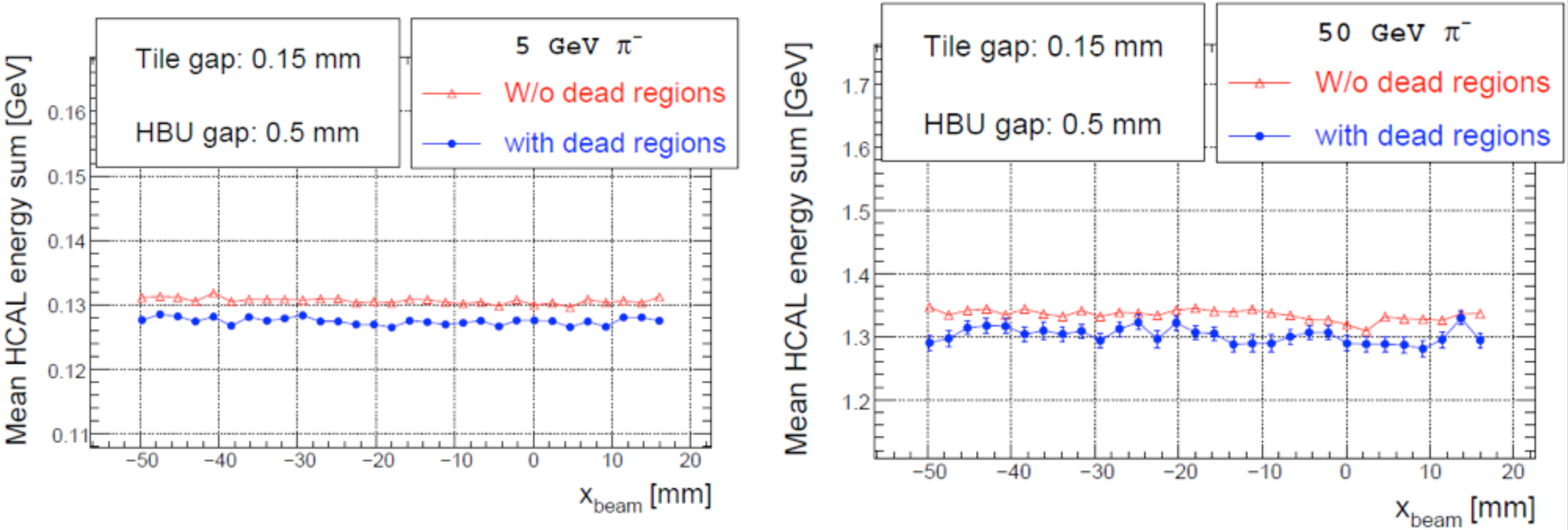
- The performance of the AHCAL technology was investigated very detailed on a microscopic level - far beyond what is needed for a hadron calorimeter
- Prominent example (surprisingly still leads to misunderstandings): non-uniformities



The response of the AHCAL tiles depends on the position of the particle:
~ 10% reduction of signal on WLS fiber
loss of signal in gaps between tiles, 50 µm - 100 µm dead space between tiles (tolerances, chemical etching of tile sides)

Understanding the Details - Non-Uniformities

- Impact of non-uniformities on energy reconstruction: detailed simulation studies (including SiPM & scintillating fiber effects!)



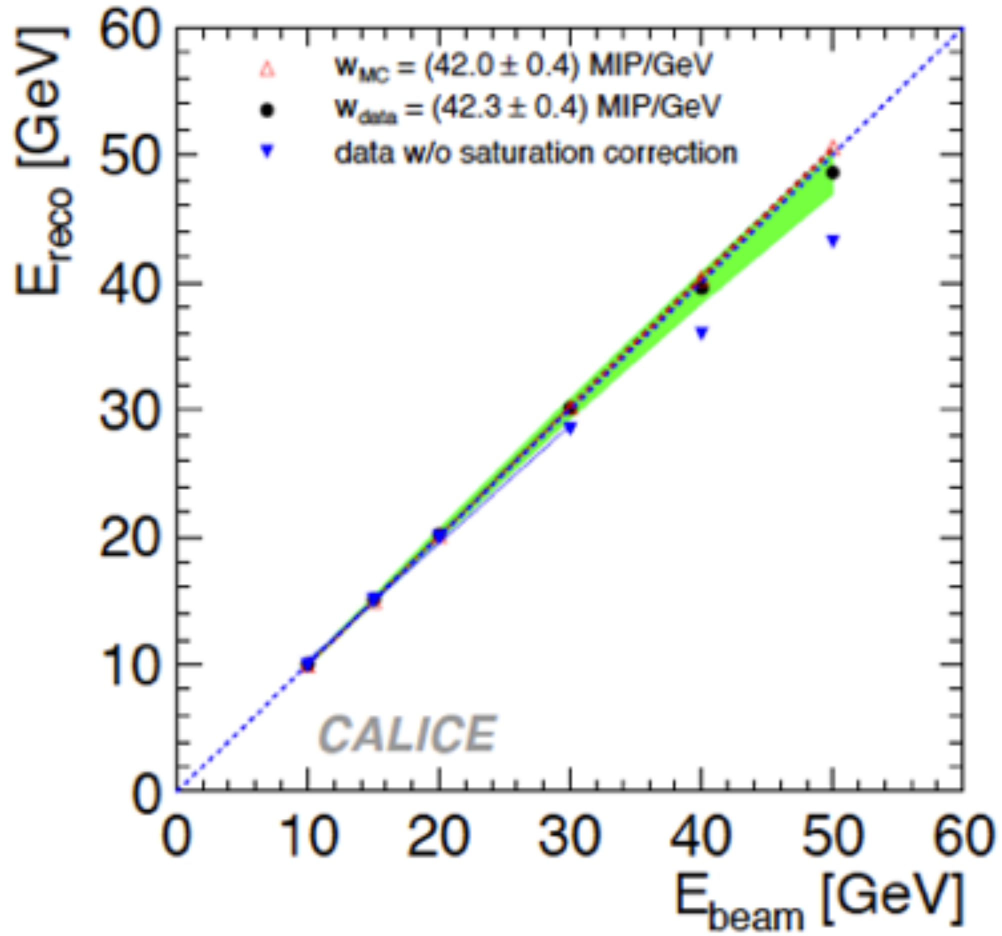
- Neither tile nor HBU boundaries affect the energy reconstruction for hadrons (even more true for smaller response variations within the tile area)
  - Only effect of non-uniformities: Overall lowering of response: just calibration!

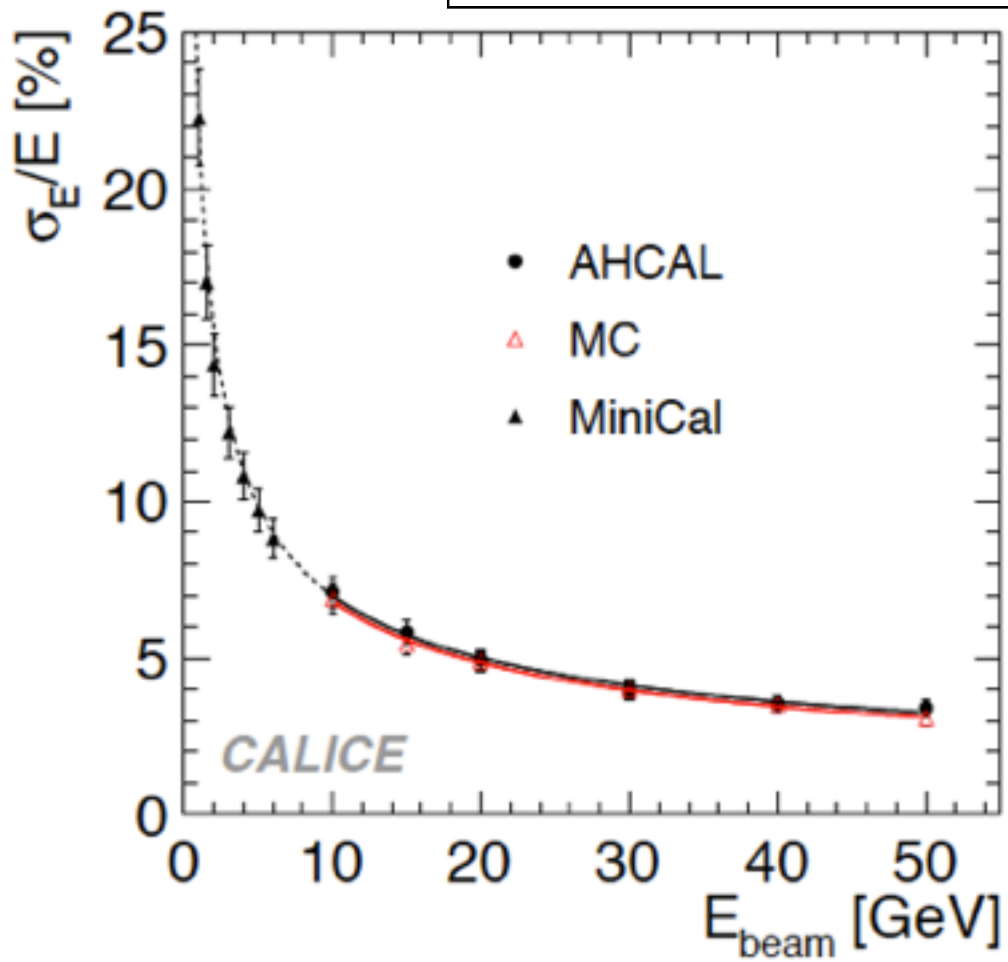
Documented in arXiv:1006.3662

Electromagnetic Performance of the Prototype

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

Published in JINST 6, P04003 (2011)



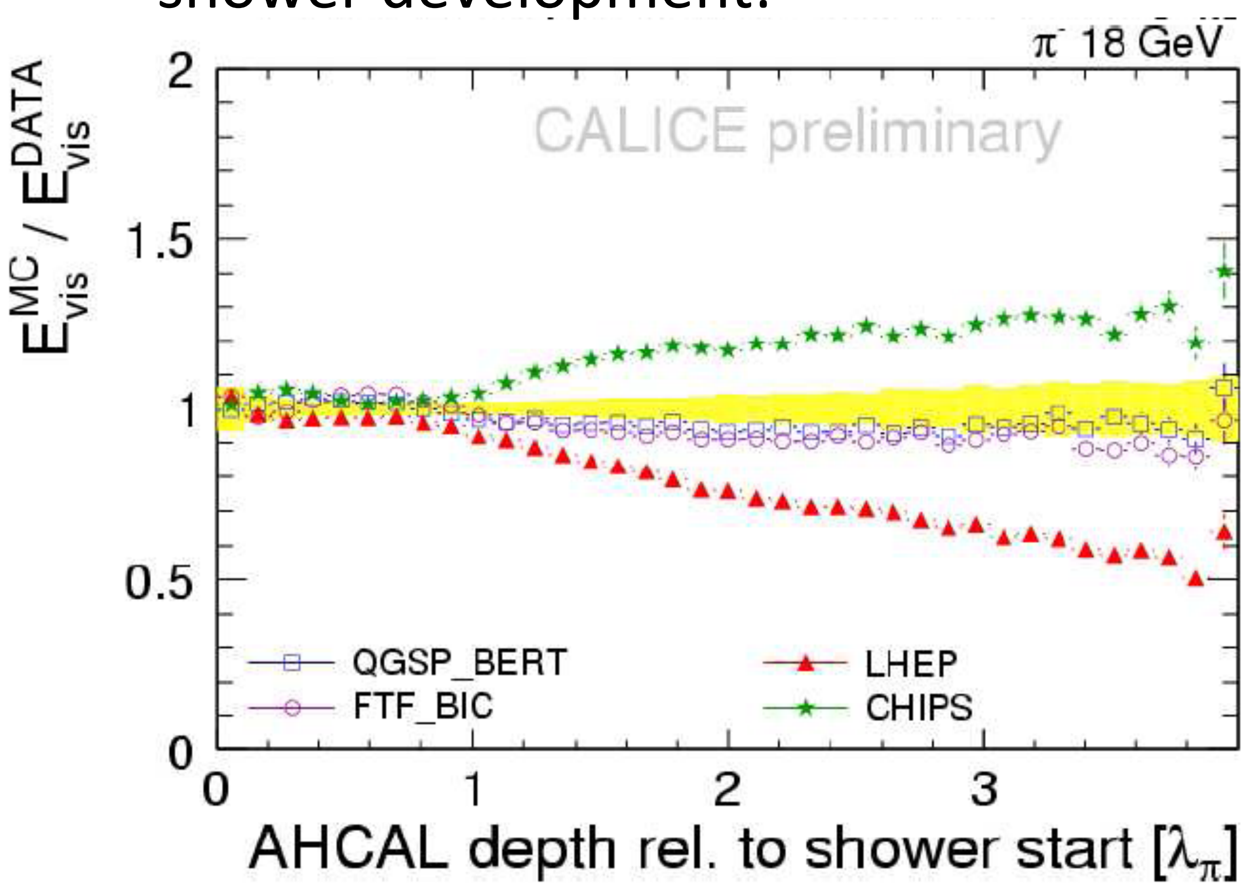


- Spectacular agreement, no surprises: AHCAL geometry description, simulation and digitization in excellent shape (no inclusion of non-uniformities necessary!)
- Energy resolution 22%/√E: Non-uniformities and cell-to-cell calibration uncertainties have no influence on hadronic measurements!

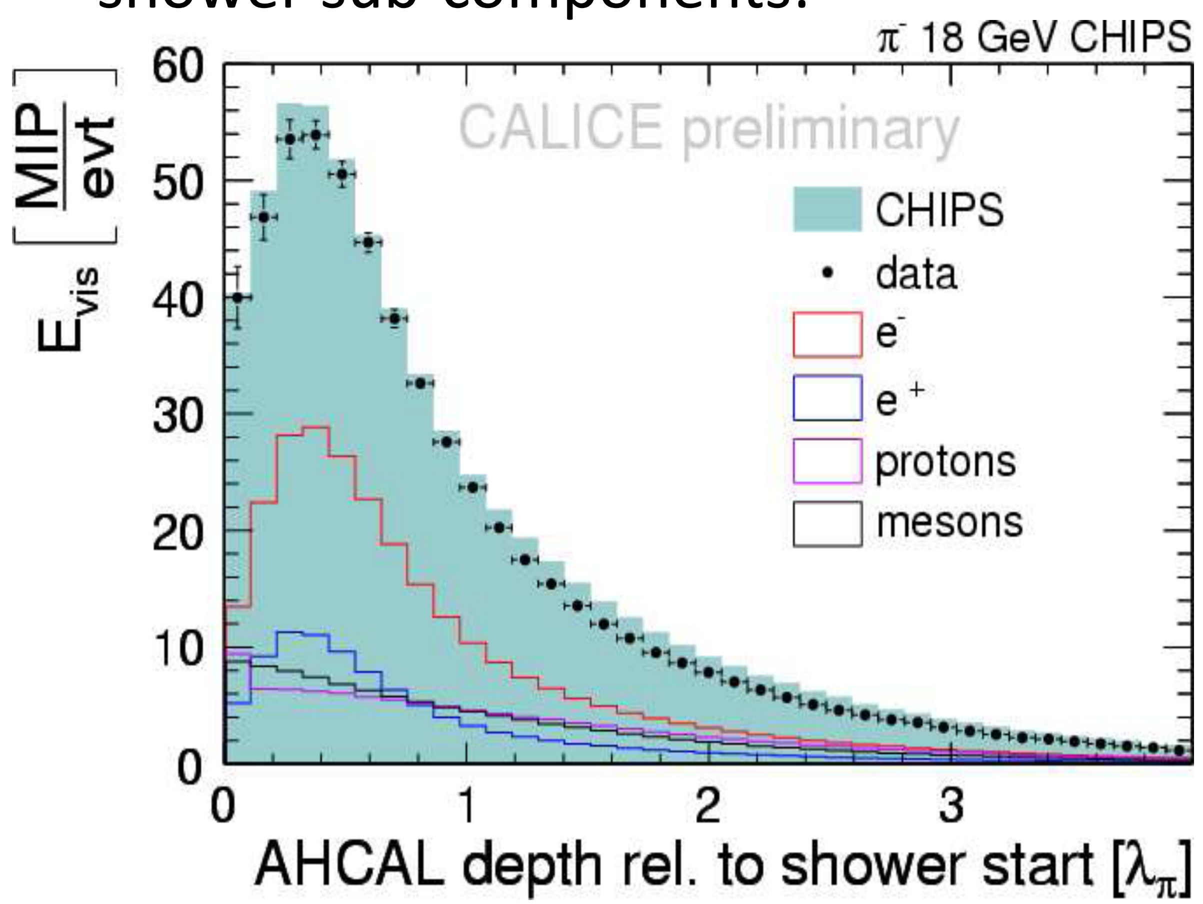
Validation of GEANT4 Simulations

- All our performance studies depend on GEANT4: To what level can we trust it?

shower development:



shower sub-components:



publications in preparation

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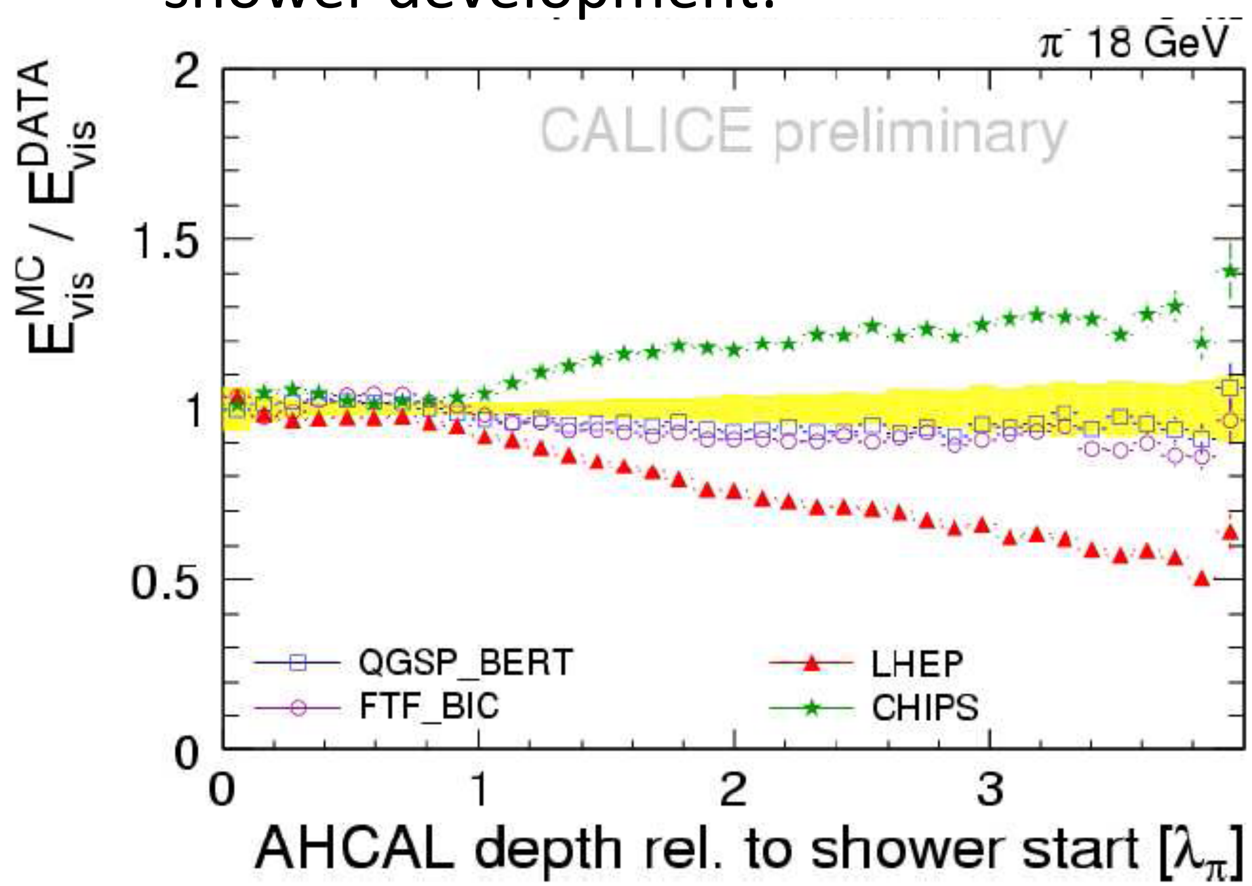
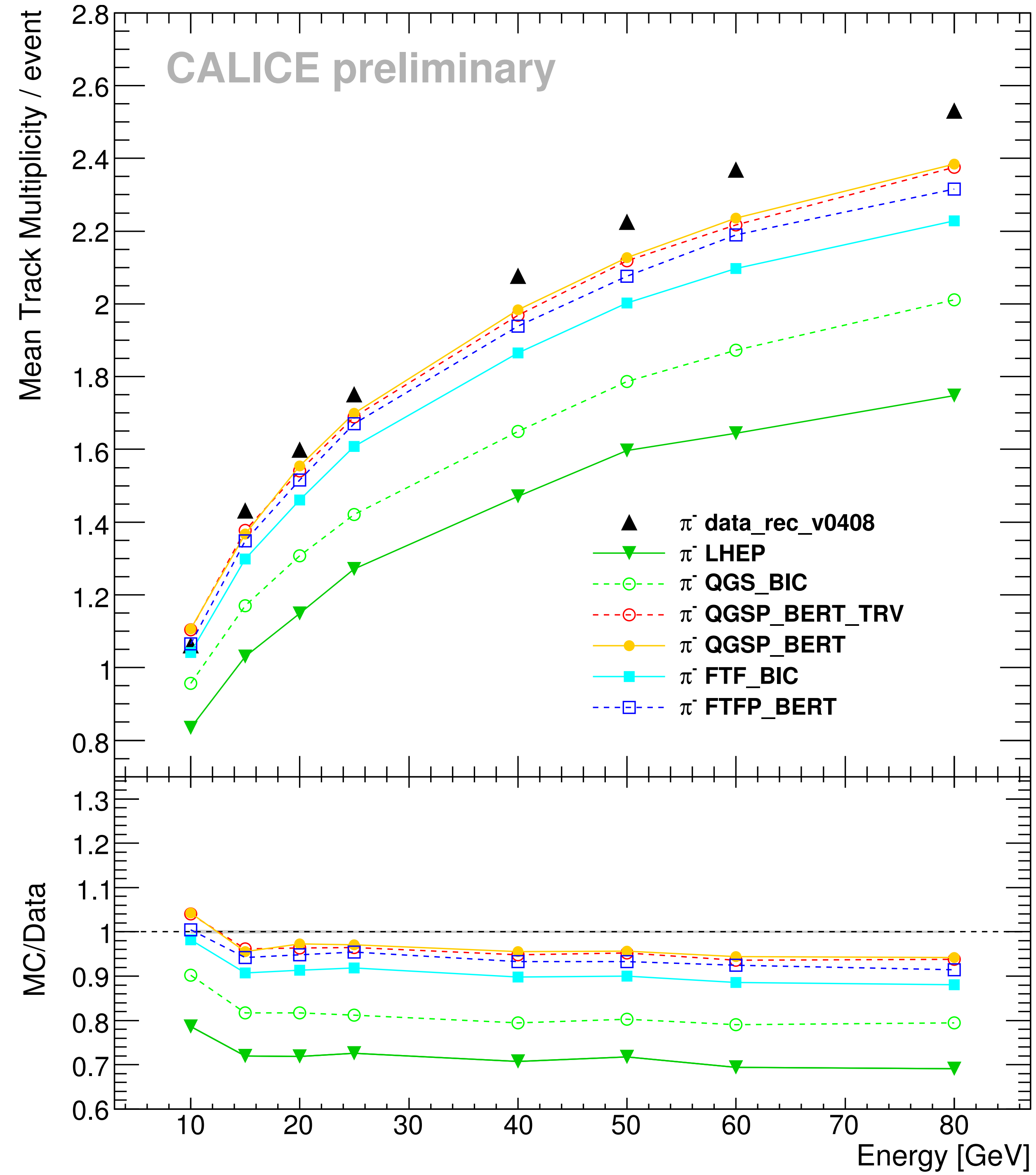


3D substructure: track segments, identified within hadronic showers



publications in preparation

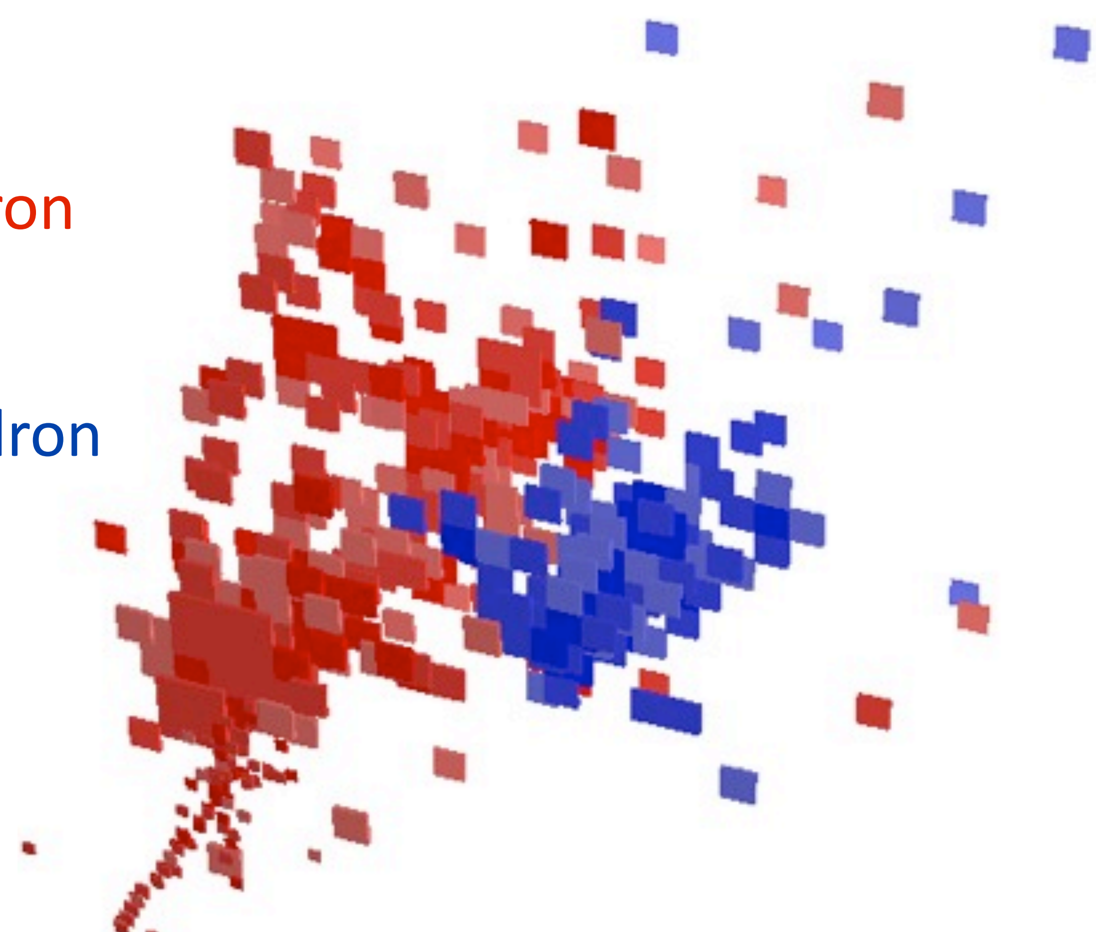
PFA Performance: Level of Realism?

- A key question: Can we trust the PFA performance predicted by full simulations with an analog HCAL?

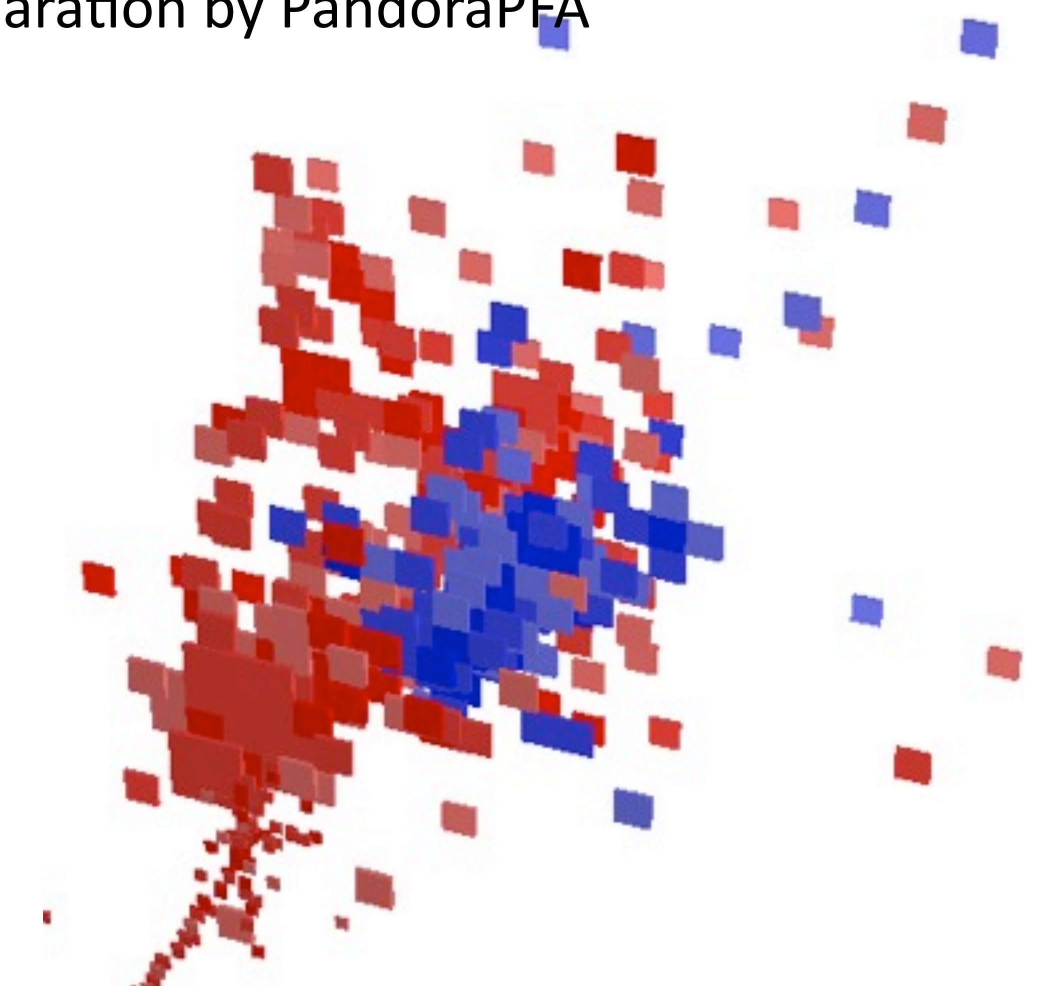
  Test it! ➪ Use real hadronic showers recorded with AHCAL, map them into ILD
  - Take one shower as a charged hadron (with tracking information), one shower as a neutral hadron (remove hits before the shower start)
  - Vary distance between showers to test shower separation by PandoraPFA

30 GeV
charged hadron

10 GeV
“neutral” hadron



~ 18 cm separation of shower axis

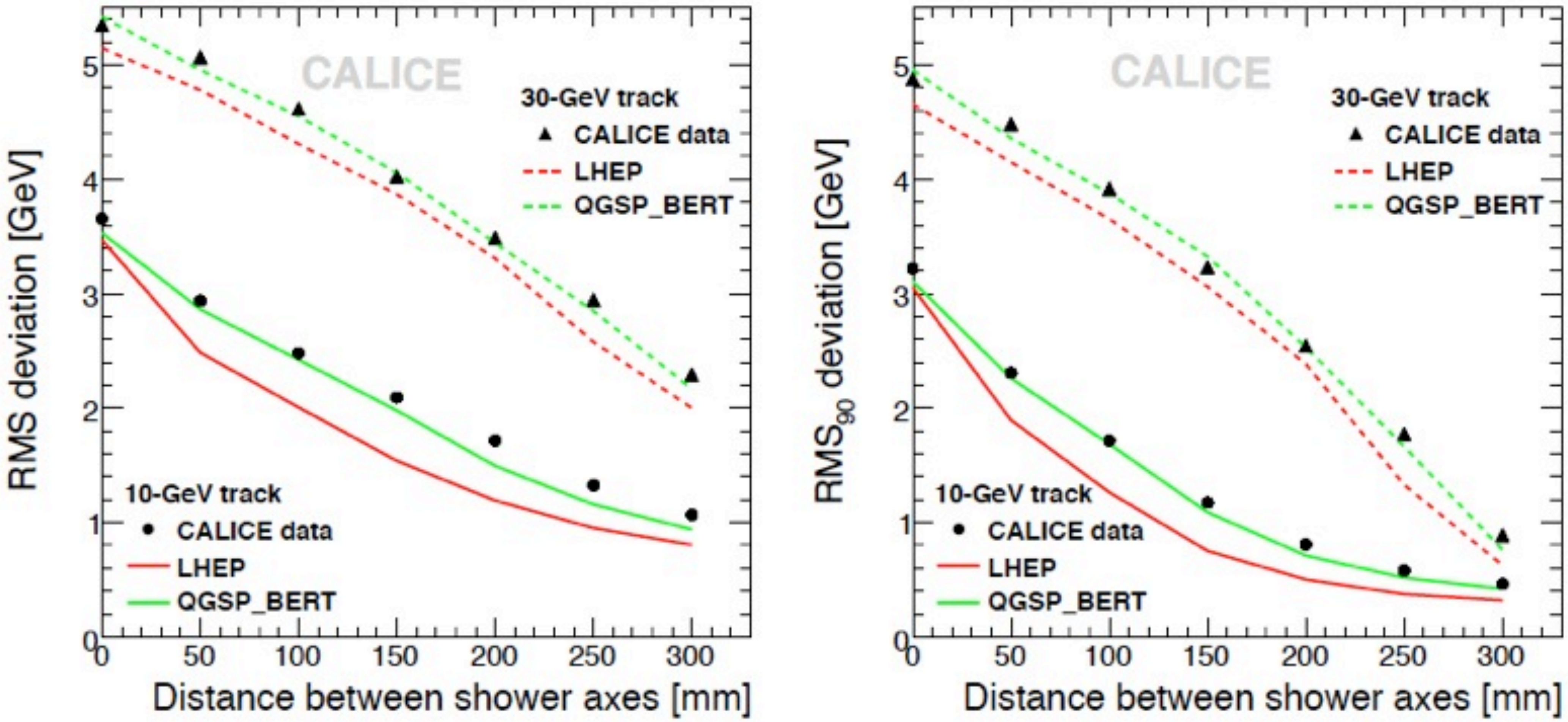


~ 7 cm separation of shower axis

Shower Separation: Energy & Distance

- Energy recovery for neutral hadron close to a 10 (30) GeV track
  - ~ 15 cm distance required to provide energy association comparable to hadronic resolution of calorimeter

Published in JINST 6, P07005 (2011)

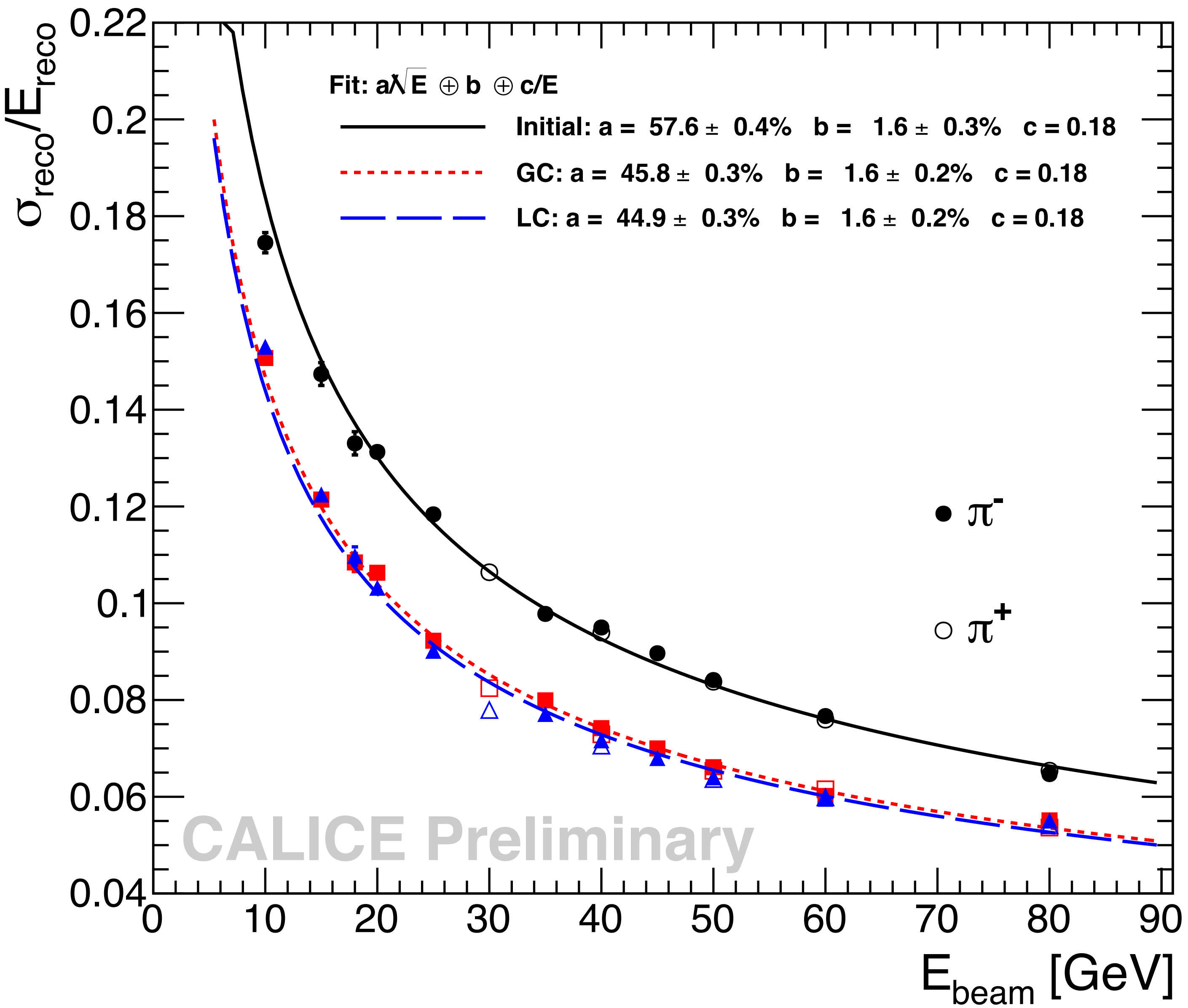


Note: Performance reduced compared to PFA in a real Experiment: No magnetic field, mapping of cells, ...

Key point: Validation of simulations - PFA for AHCAL works as expected from simulation
we can trust our full detector simulation!

Energy Reconstruction & Software Compensation

- The AHCAL is non-compensating: e/π ~ 1.3 (energy dependent)
- High granularity provides detailed information that can be used for software compensation: Can be done on local (cell) or global (cluster) level



Resolution of 45%/√E with small constant term for pions ***in data***

Linear energy reconstruction within 1.5% over the full energy range from 10 GeV to 80 GeV

Simulations with QGSP_BERT predict ~ 10% better energy resolution (both with and w/o SC), in agreement with observations by LHC experiments

paper draft circulating in CALICE, submission imminent

Summary

- The 2nd generation prototype (“technical demonstrator”) of the AHCAL is progressing well, the design for ILD is fully established
  - First successful test beam results with new electronics
  - Mechanics established
  - Plans for test beam using timing capabilities in fall 2012
  - Geometry with all details implemented and tested in MOKKA
- The physics prototype of the AHCAL has laid the foundations for analog hadron calorimetry at linear colliders
  - Detailed understanding of temperature
  - Excellent electromagnetic performance & simulation realism
  - Thorough tests of hadronic shower models
  - Good energy resolution

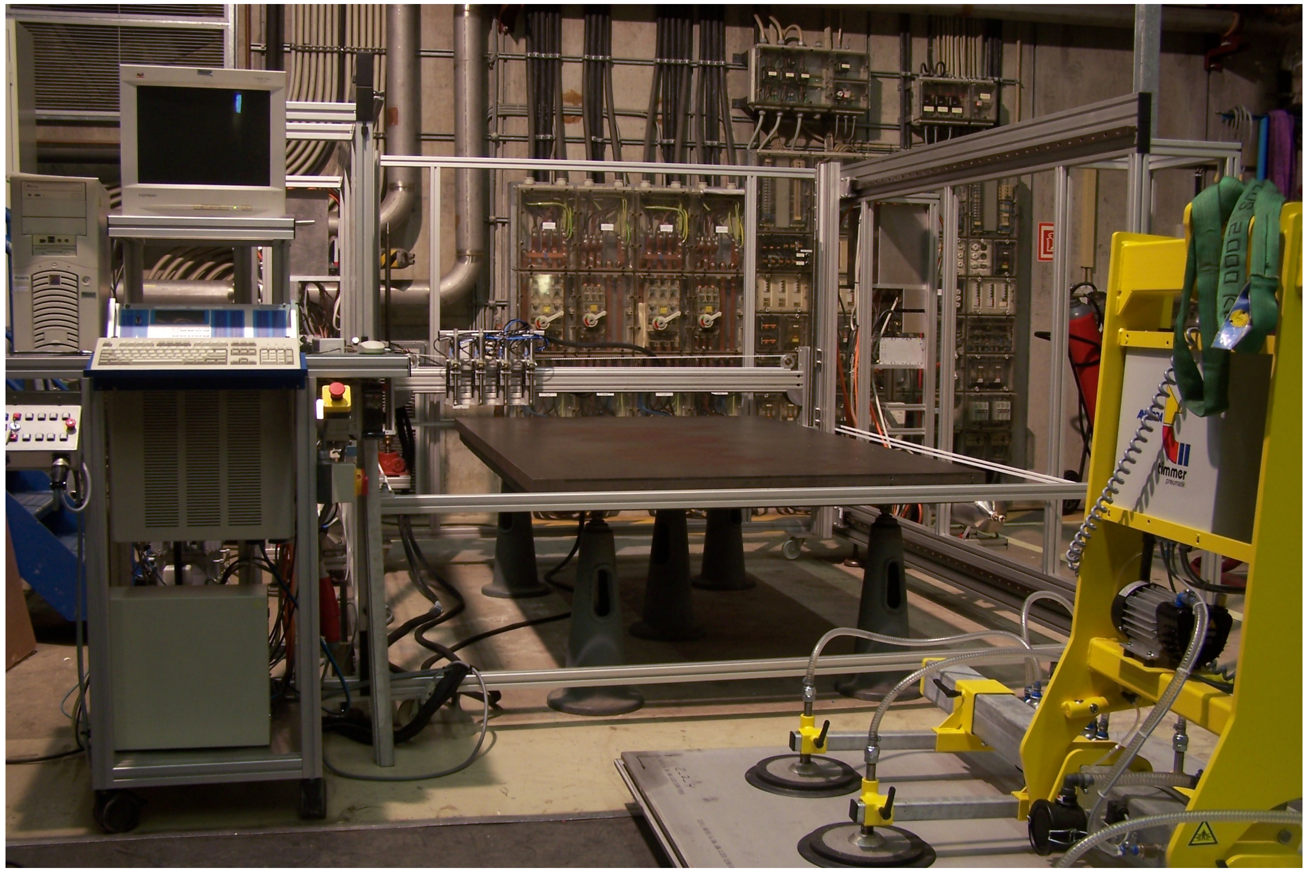
Summary

- The 2nd generation prototype (“technical demonstrator”) of the AHCAL is progressing well, the design for ILD is fully established
  - First successful test beam results with new electronics
  - Mechanics established
  - Plans for test beam using timing capabilities in fall 2012
  - Geometry with all details implemented and tested in MOKKA
- The physics prototype of the AHCAL has laid the foundations for analog hadron calorimetry at linear colliders
  - Detailed understanding of temperature
  - Excellent electromagnetic performance & simulation realism
  - Thorough tests of hadronic shower models
  - Good energy resolution

➩ The AHCAL is ready for the DBD

Backup

Steel Structure: Achieving the required Flatness

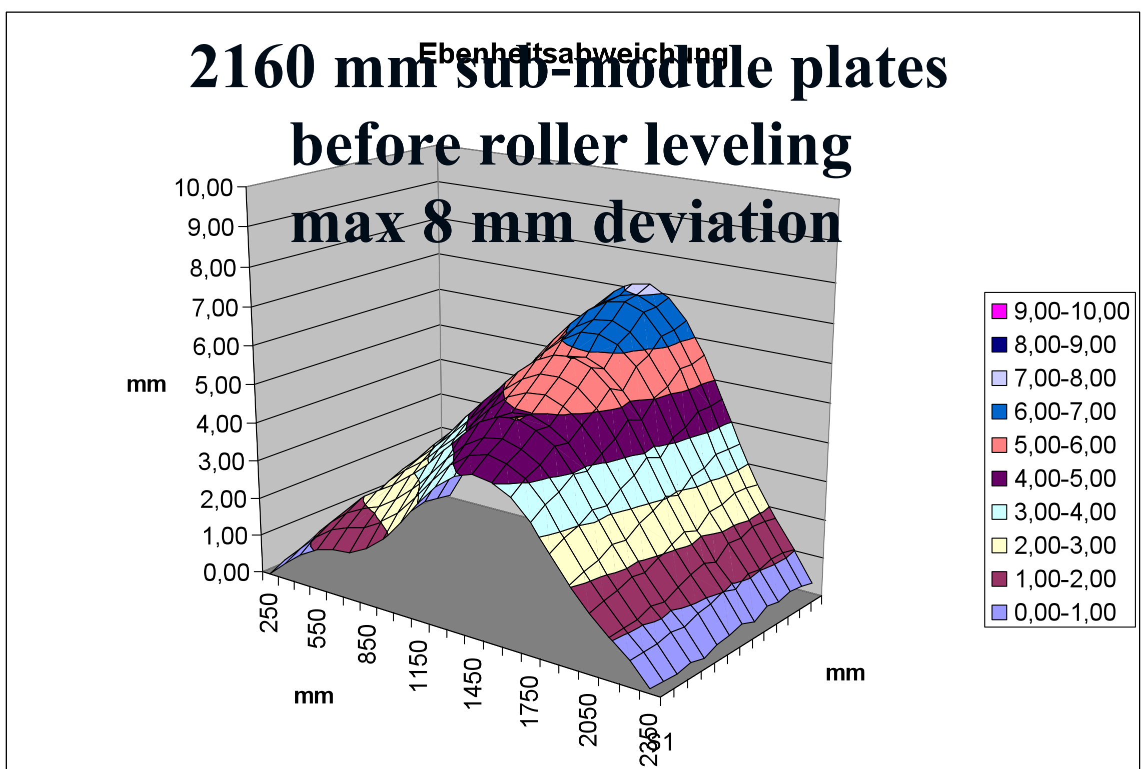


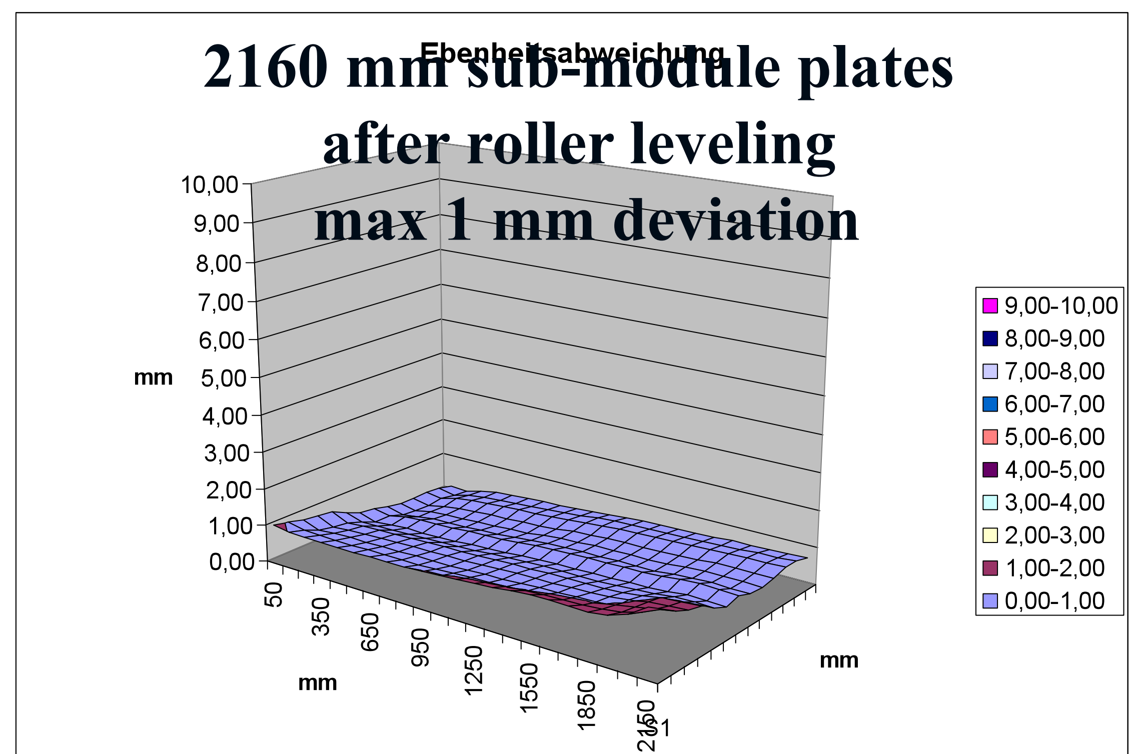
- At DESY: Facilities for precise measurement of large steel plates

  Specifications for purchased steel:
  - thickness -0.3 + 1.6 mm
  - flatness:

    < 10 mm over 1 m

    < 13 mm over 2 m

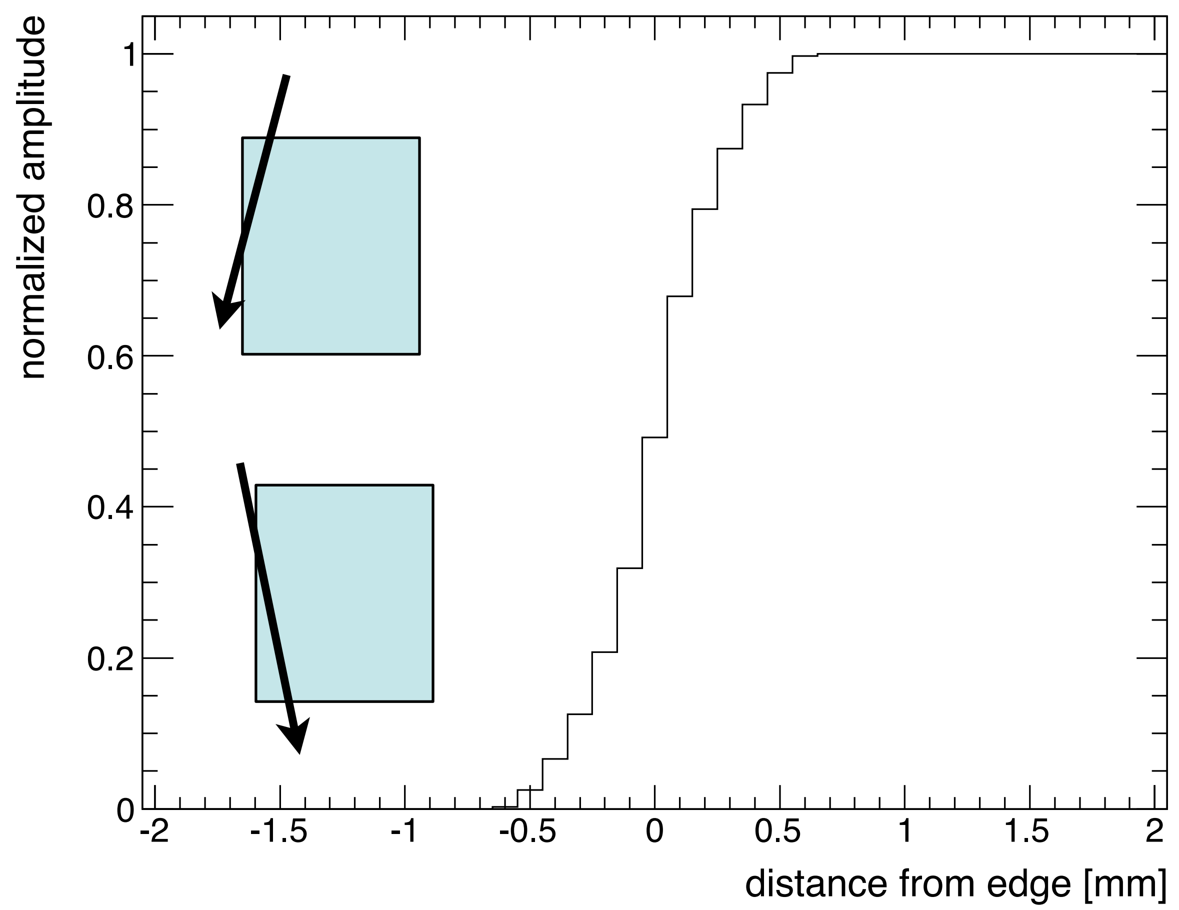




Understanding the Details - Non-Uniformities

Fact: The apparent width of the signal loss at the edges of 1 - 2 mm is due to the divergence of the beam from ^{90}Sr sources used in the tests

- simulation of a “perfect edge” in our scanner



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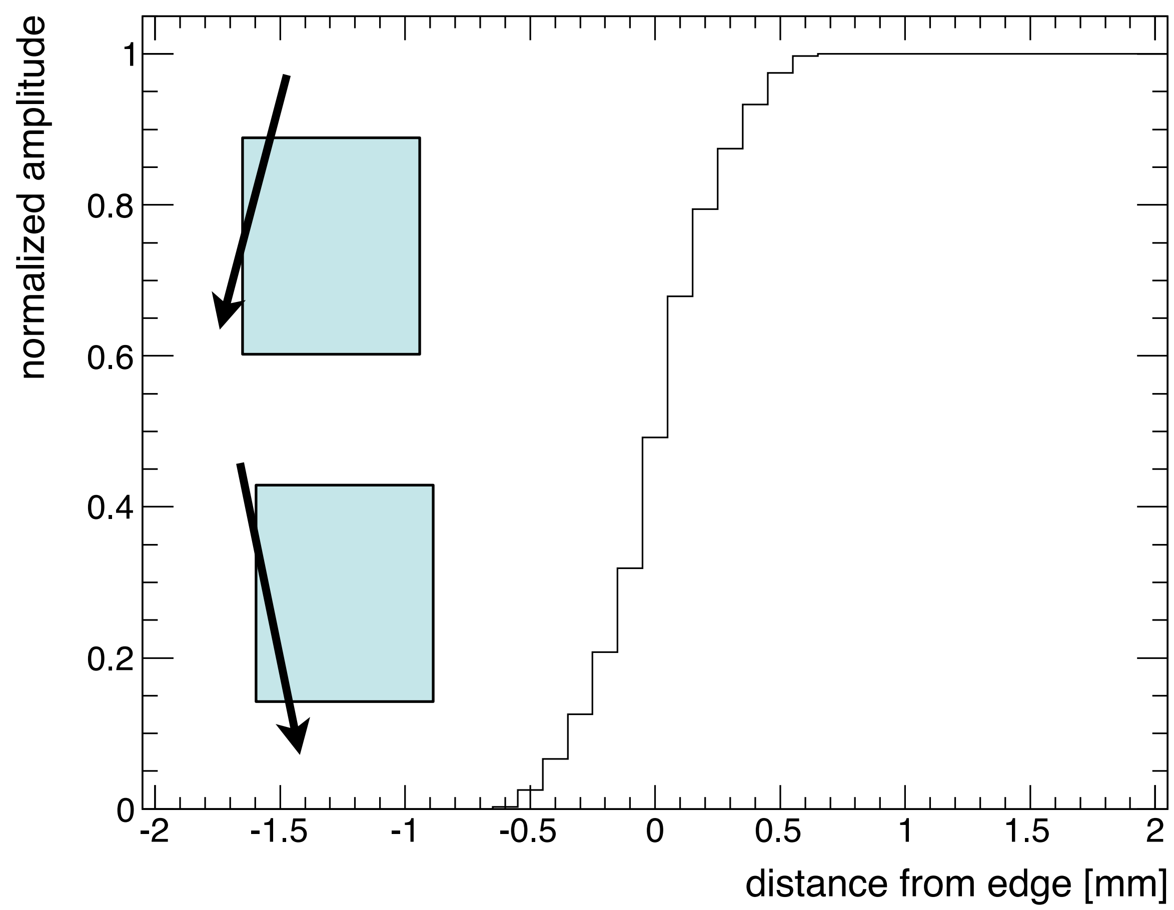
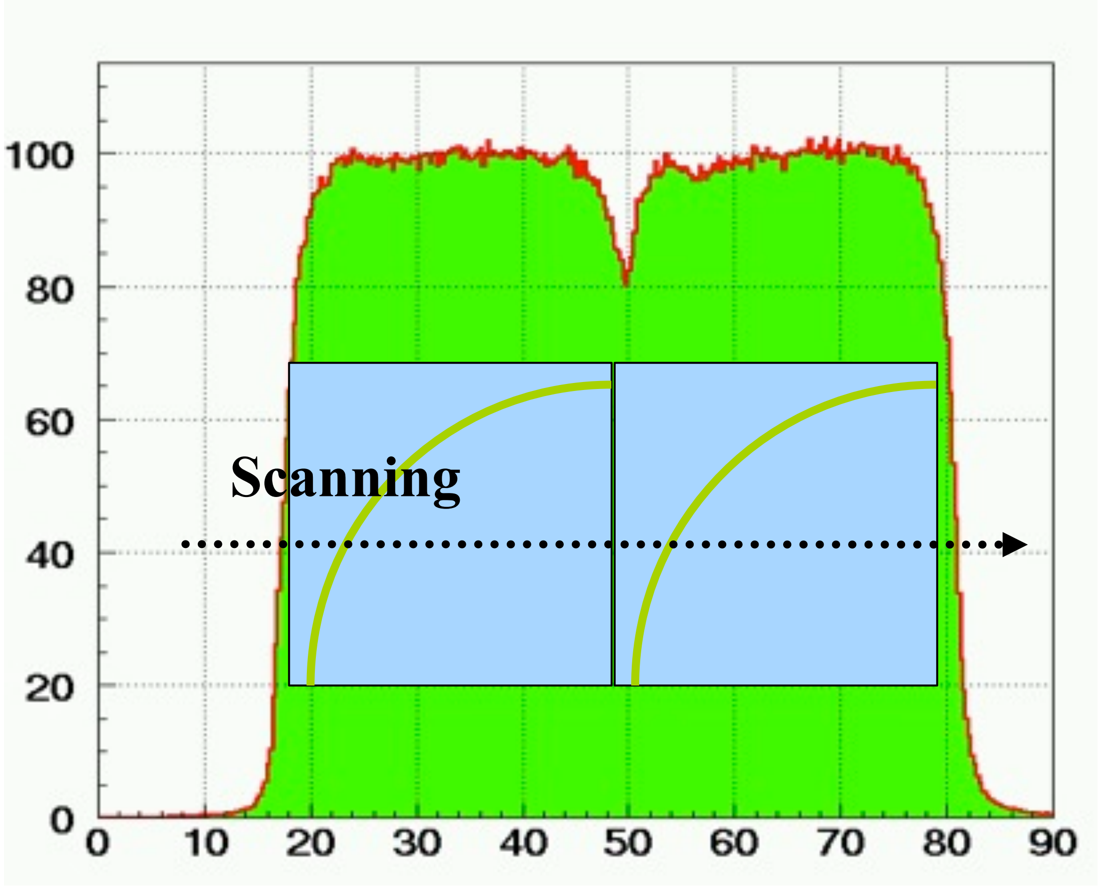


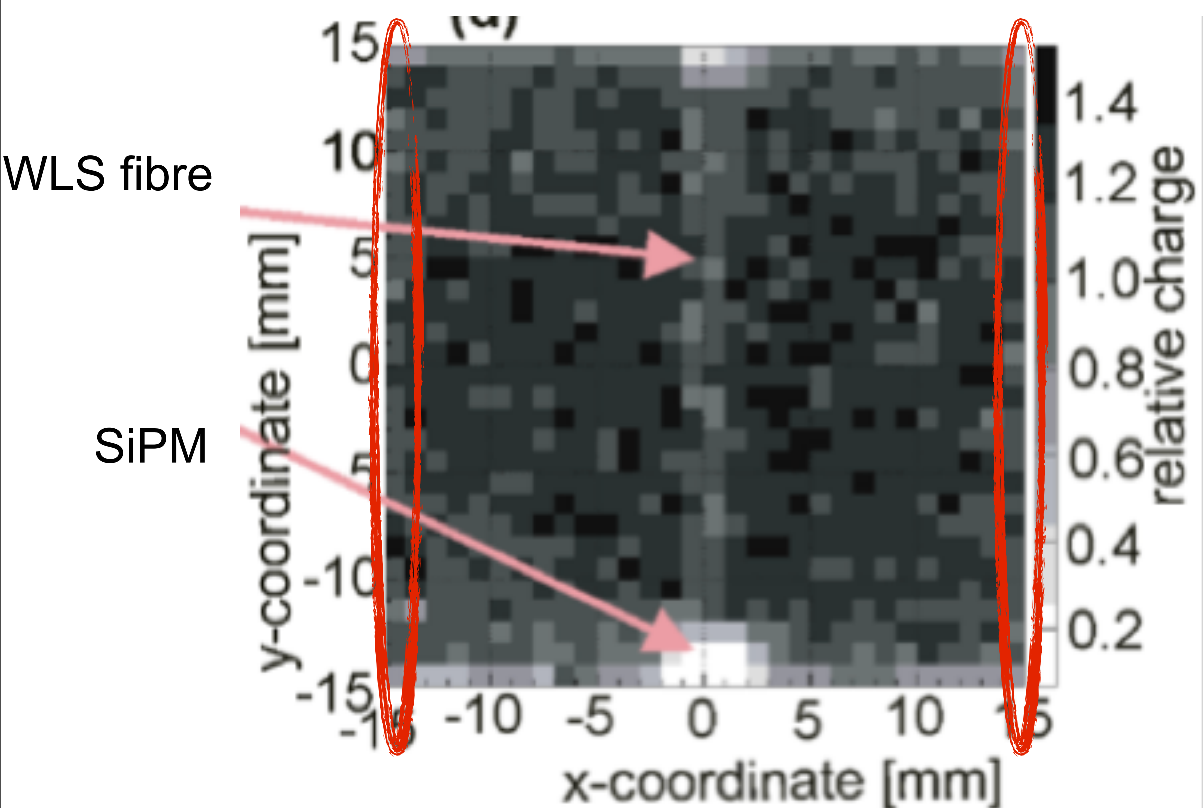


- scanning over two tiles with both tiles read out: signal loss at edge (resolution!), overall ~ 2% signal loss taking the full tile area
- observation consistent with 50 µm - 100 µm dead area between tiles due to air gap, chemical treatment of edge

Non-Uniformities: Details

- Measurements at ITEP test beam with wire chambers (~ 1 mm resolution)

~ 5% - 10% reduction of mean amplitude at tile rim, when reading also neighboring tile



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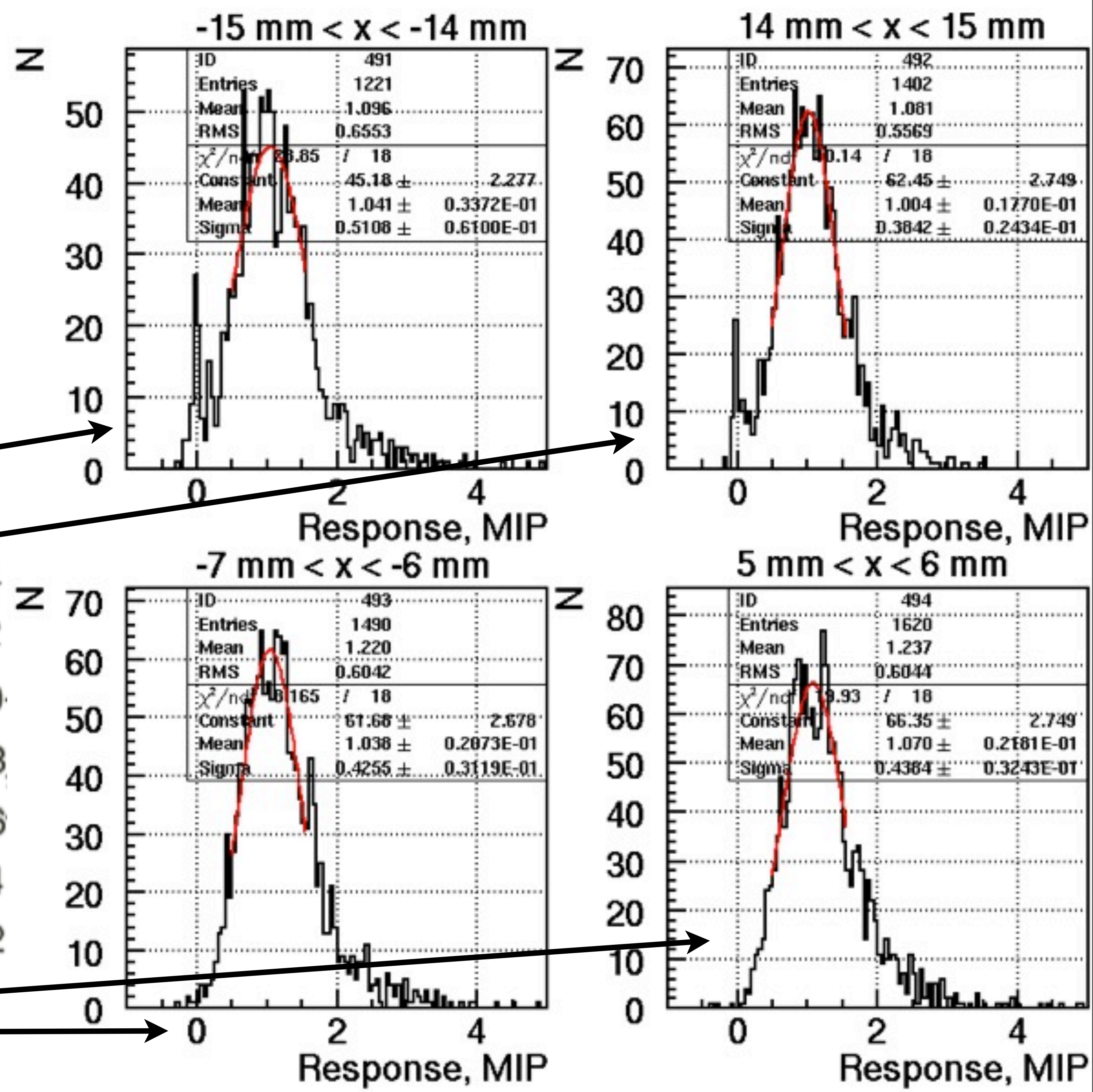

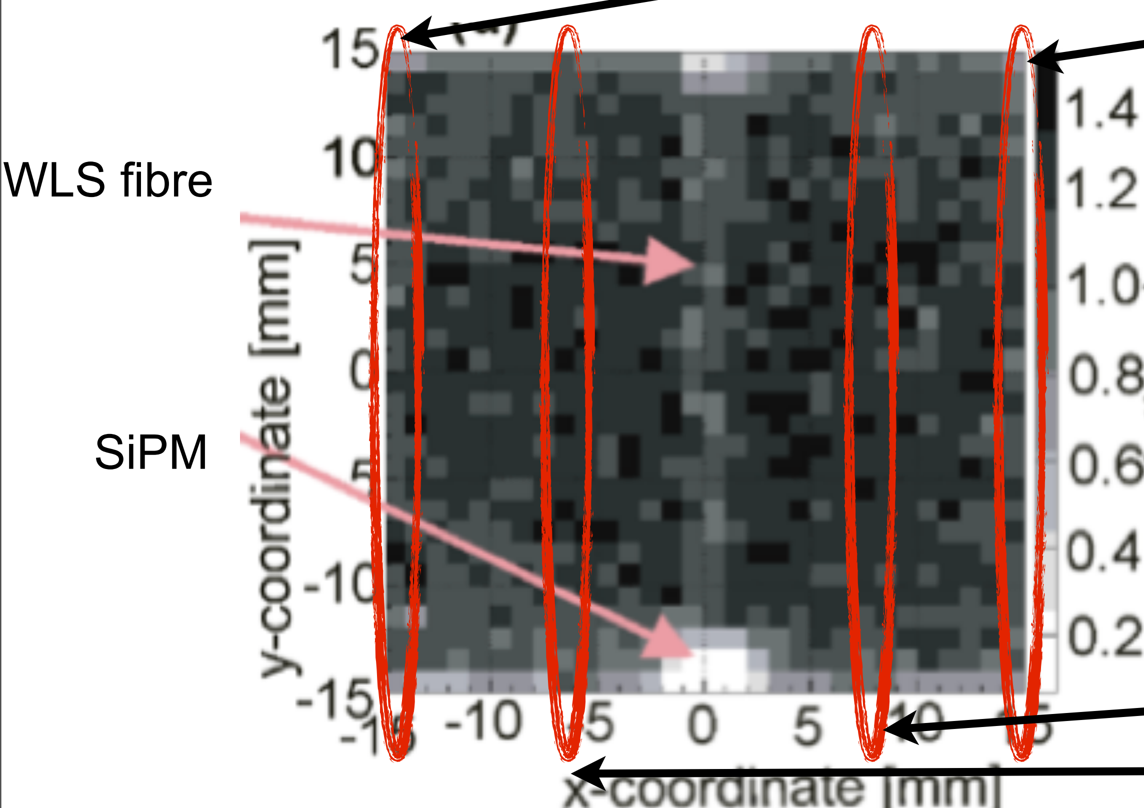

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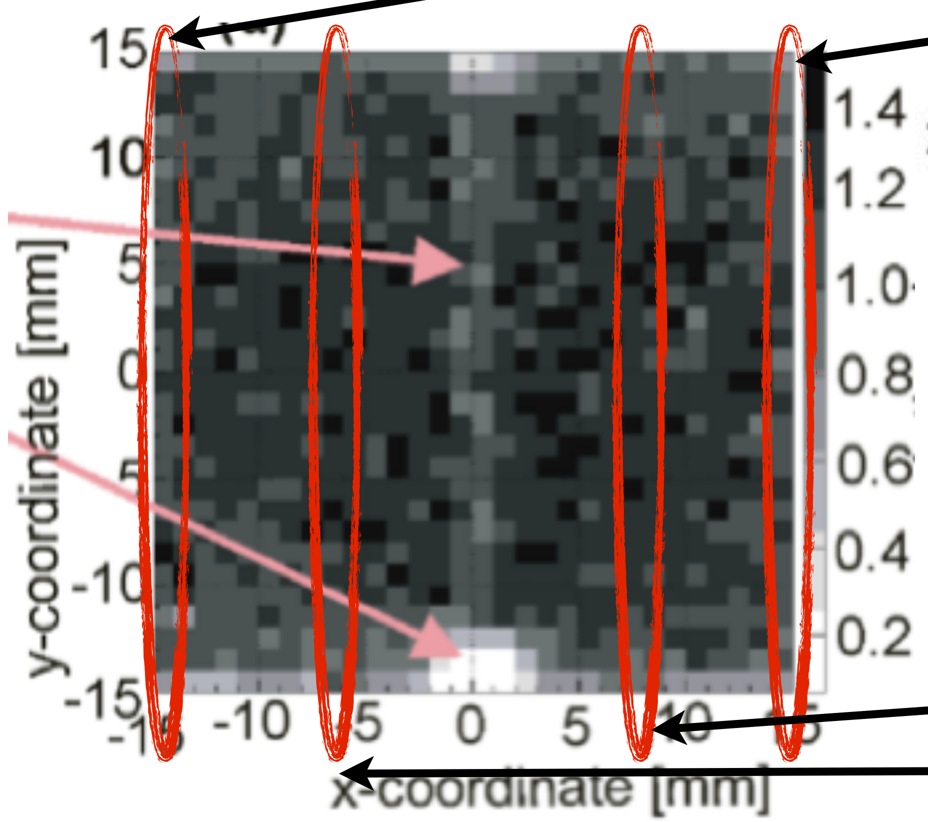

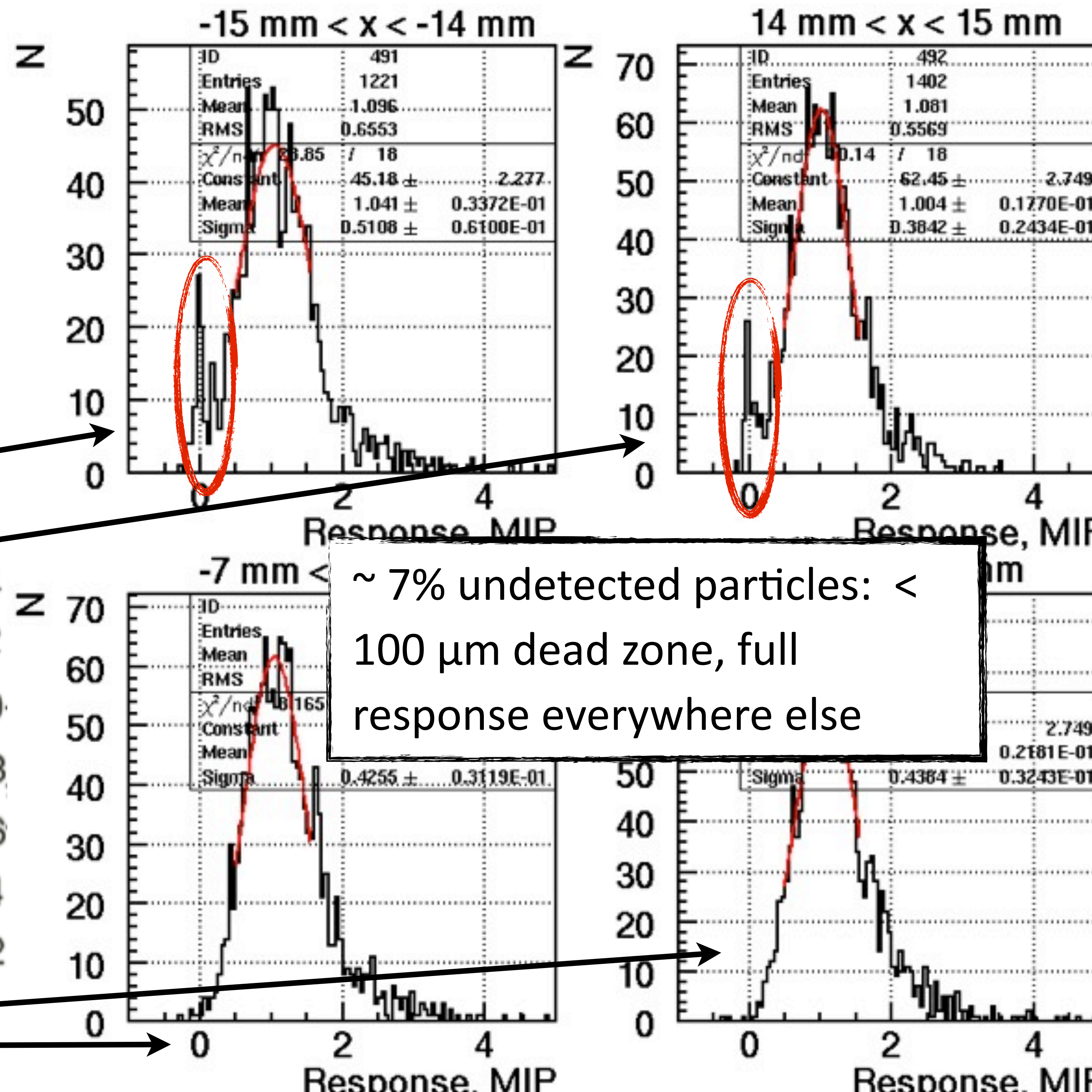

~ 7% undetected particles: < 100 µm dead zone, full response everywhere else

Cell and Module Boundaries

- In a realistic detector, there is a very small gap, and corresponding local loss of efficiency for ionizing particles, between tiles and at module boundaries: Do these effects need to be simulated, or is 3 x 3 cm^2 simulation granularity sufficient?

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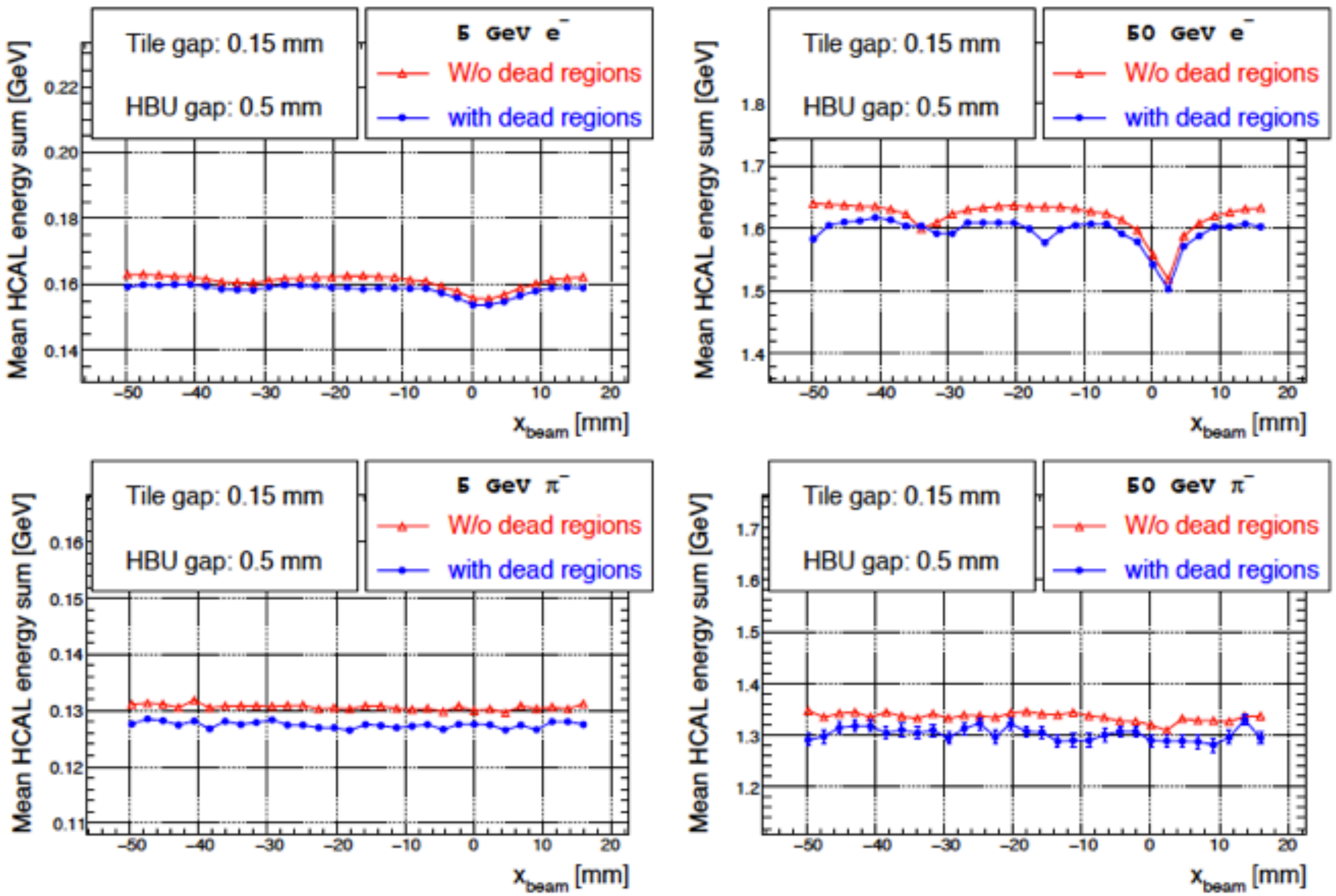


Clear answer:

No simulation necessary!

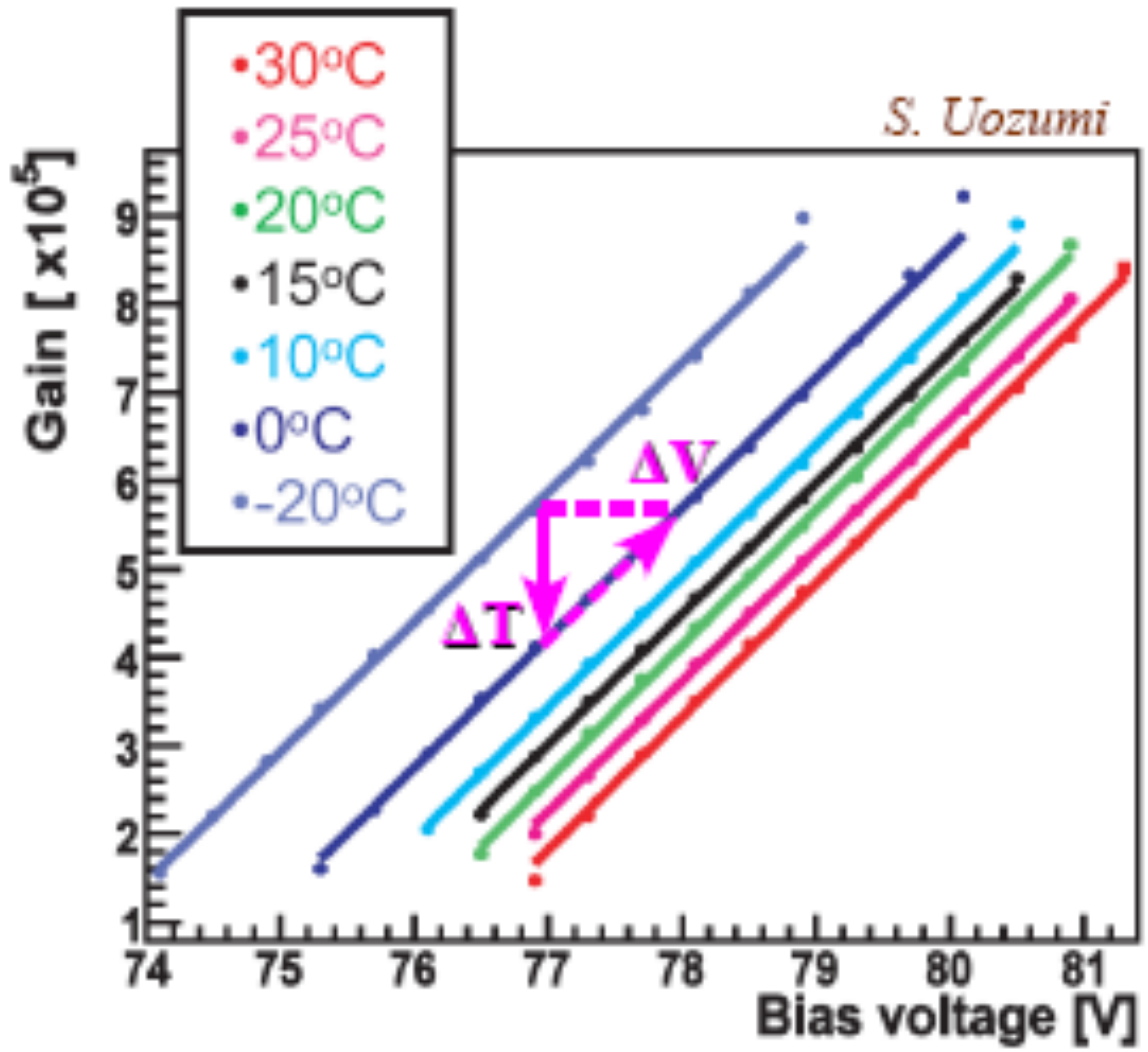
Detailed studies show some effect at HBU gaps for electrons (almost no effect at tile gaps)

No effect (beyond overall scale) for hadrons

Documented in arXiv:1006.3662

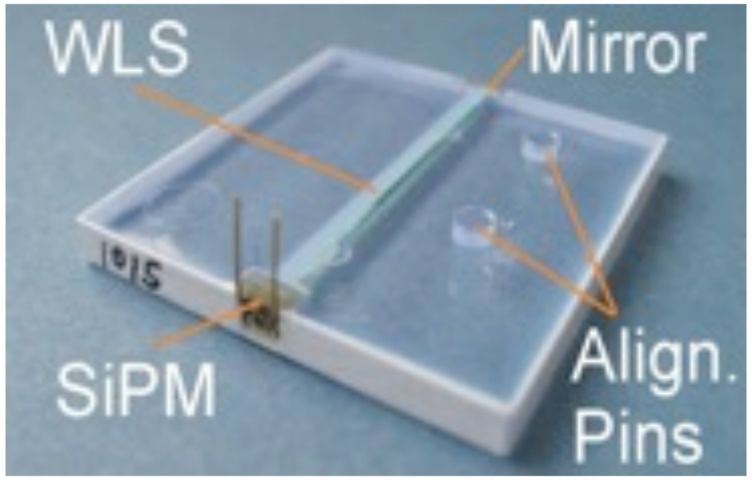
Open R&D Issues: Online Gain Stabilization

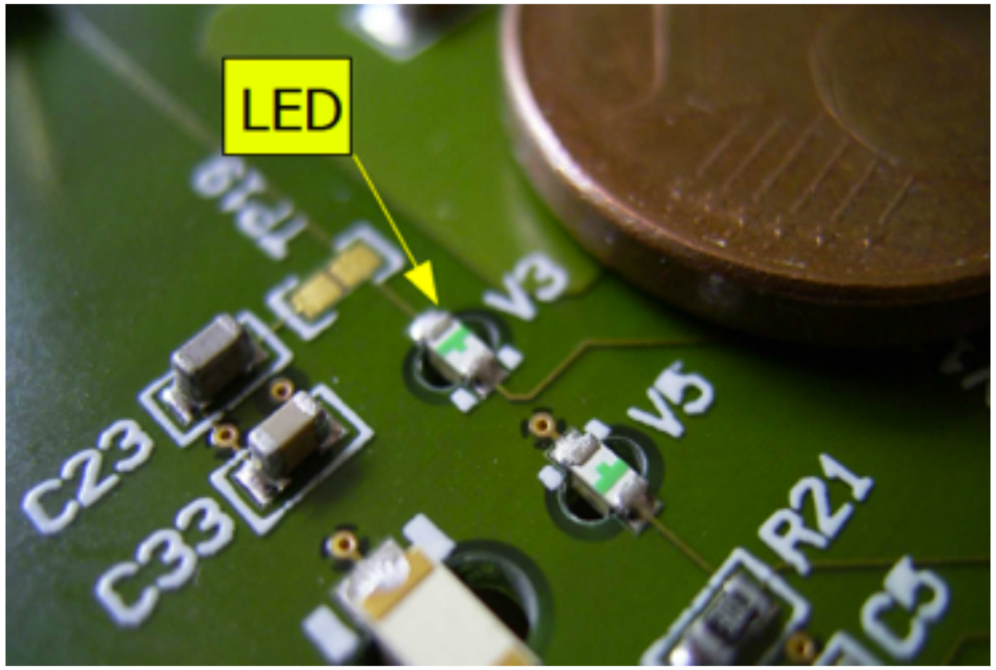
- New electronics provides online zero suppression: Requires online stabilization of the photon sensor gain
  - Automatic gain adjustment based on temperature provided by the SPIROC
  - Monitoring of gain already established with built-in LED system



- To be demonstrated with upcoming prototypes:
  - Performance in large-scale systems
  - Full test with particle showers (em, potentially also hadronic)

2nd Generation Prototype





- SMD LEDs embedded in PCB, one for each Tile: Easy, robust calibration

3 mm thick scintillator tiles integrated SiPMs "Lego" alignment Easy testing and characterization before installation

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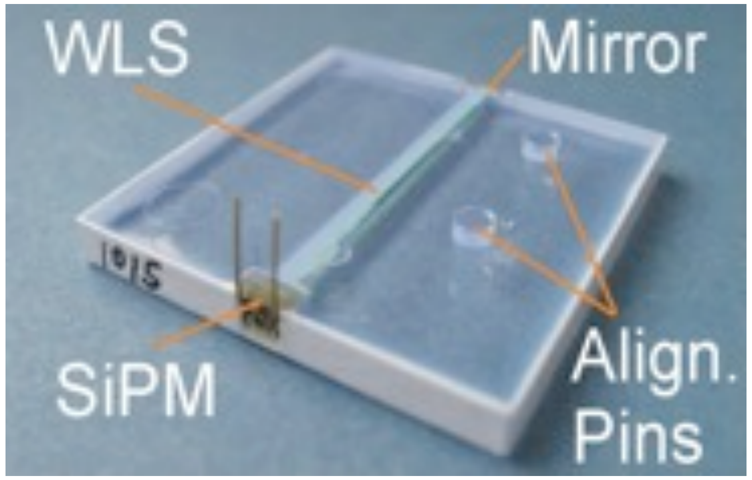

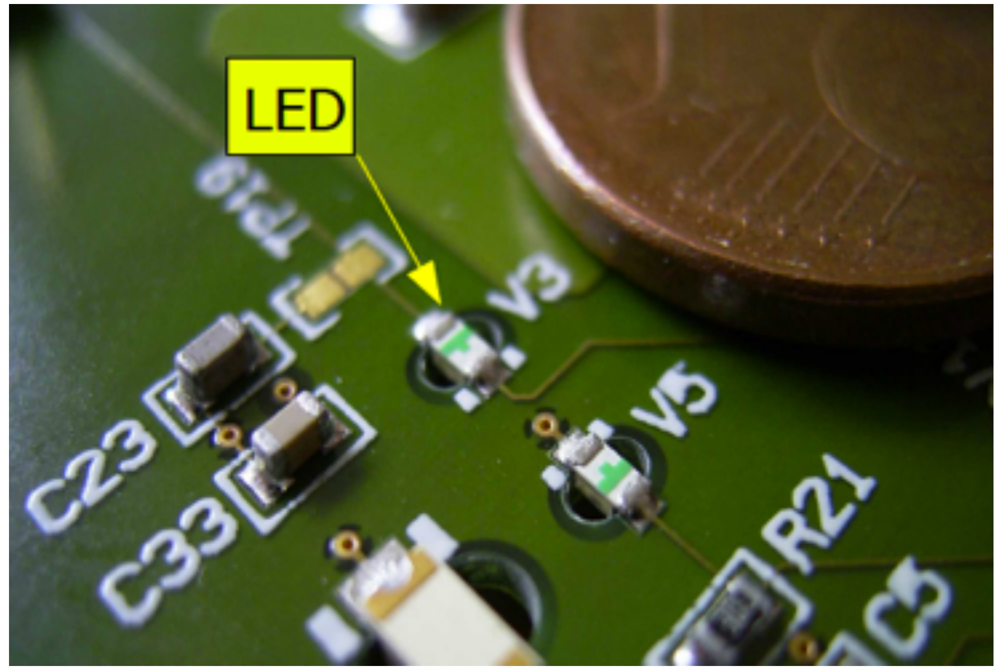

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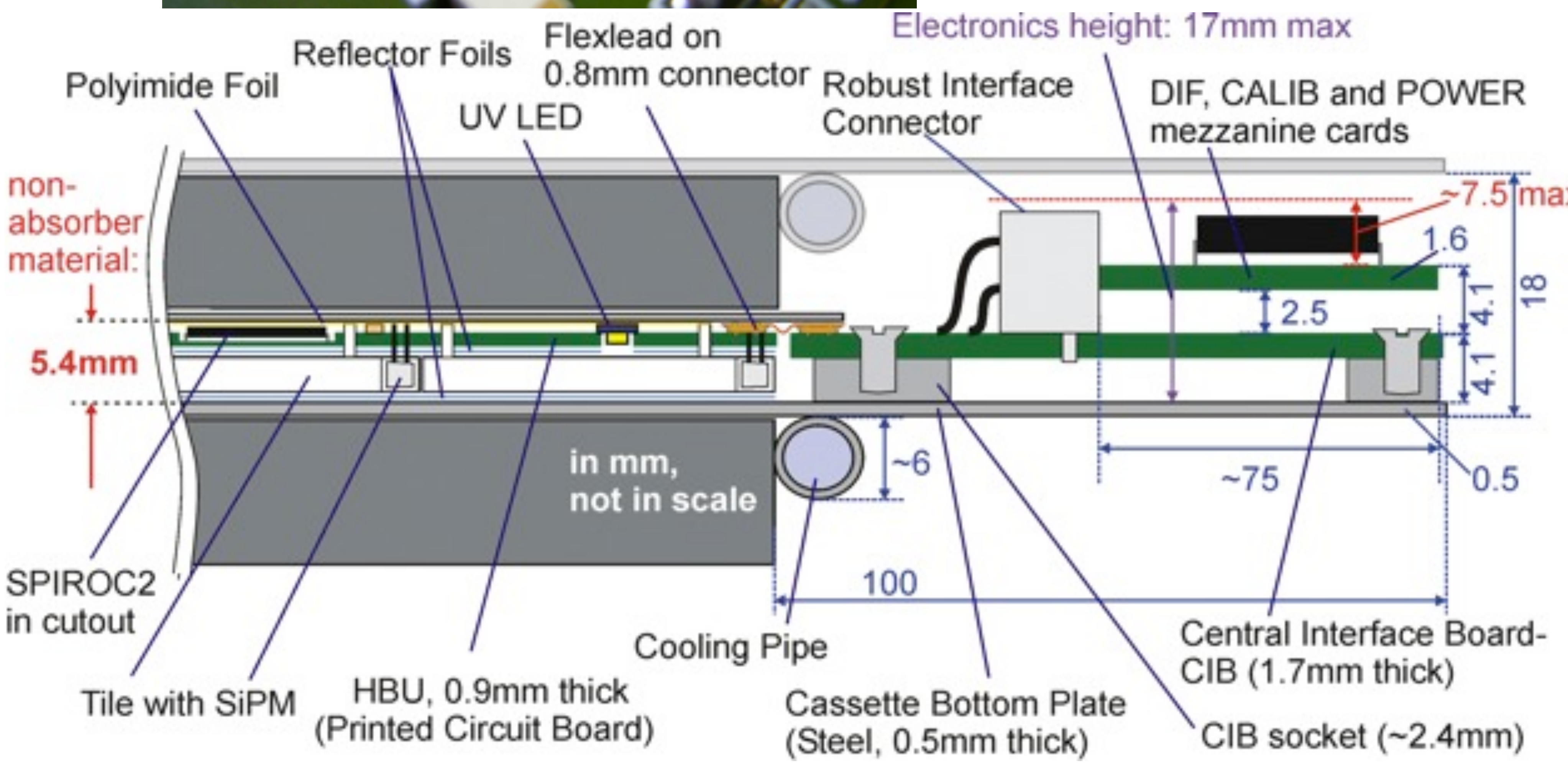


5 mm vs 3 mm: Resolution

- Quick simulation study to compare energy resolution for hadrons for AHCAL with 5 mm and 3 mm thick scintillator
  - 2 cm absorber, 2 mm PCB, scintillator
  - no ECAL in front, “infinite” thickness: 100 layers, 0.5 MIP reconstruction cut
  - QGSP_BERT, pi-
  - Resolution given as RMS90/Mean

	5 mm	3 mm	3 mm / 5 mm
10 GeV	12.1%	13.0%	1.07
20 GeV	8.7%	9.2%	1.06
50 GeV	5.6%	5.7%	1.02

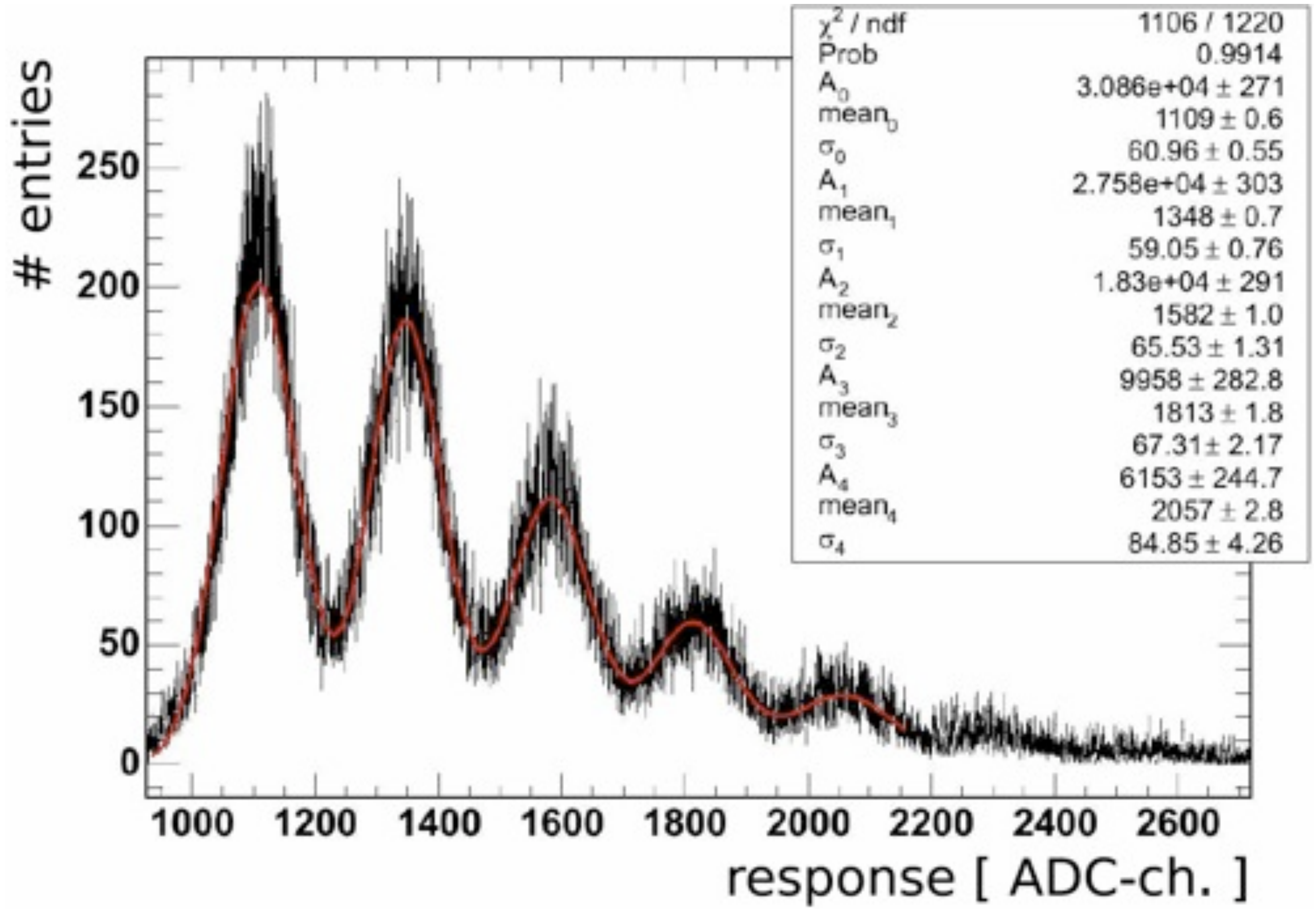
NB: In the ILD detector, the effect will be smaller due to the unchanged ECAL!

Calibrating the Detector

- Actually it is very easy: Per cell, we need
  - A MIP constant (determined with muons)
  - The saturation scale (can be determined on the test bench)
  - The gain (needed for saturation correction, can also be used for temperature corrections!)
- Global factors in addition: Calibration to the em scale, e/pi ratio to get hadronic scale
- The required precision for a hadronic calorimeter is actually very moderate!
- For the physics prototype, we push far beyond those requirements to
  - Fully understand all aspects of high granular calorimetry with SiPM readout
  - Also provide excellent performance for electromagnetic showers

How we Calibate

- Auto-calibration of SiPM gain: Individual photons can be resolved
  - Low-intensity LED light coupled into each detector cell
  - In prototype: Light distributed by fiber, can also be done trivially by



Documented in arXiv:0811.2431, paper in preparation

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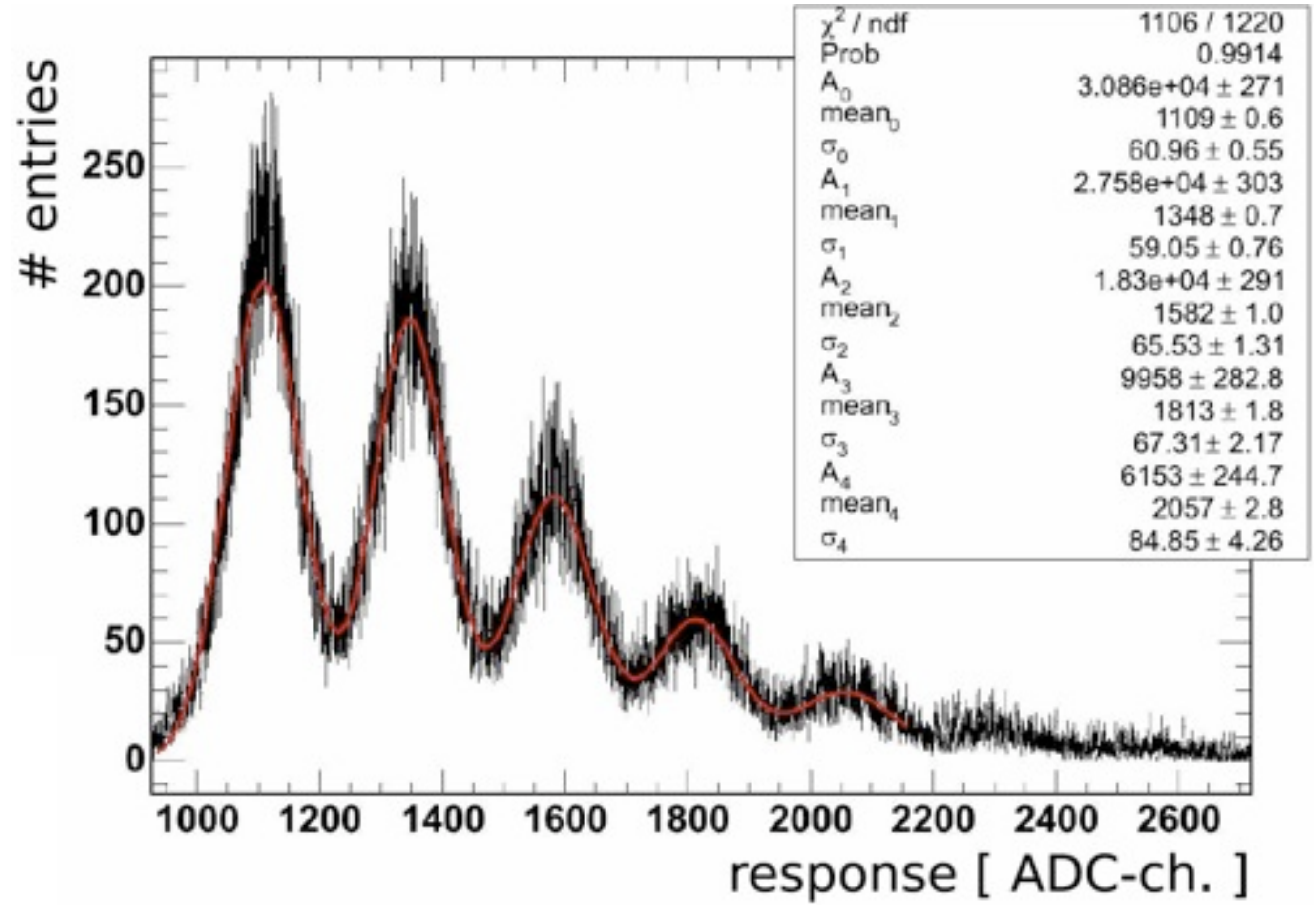
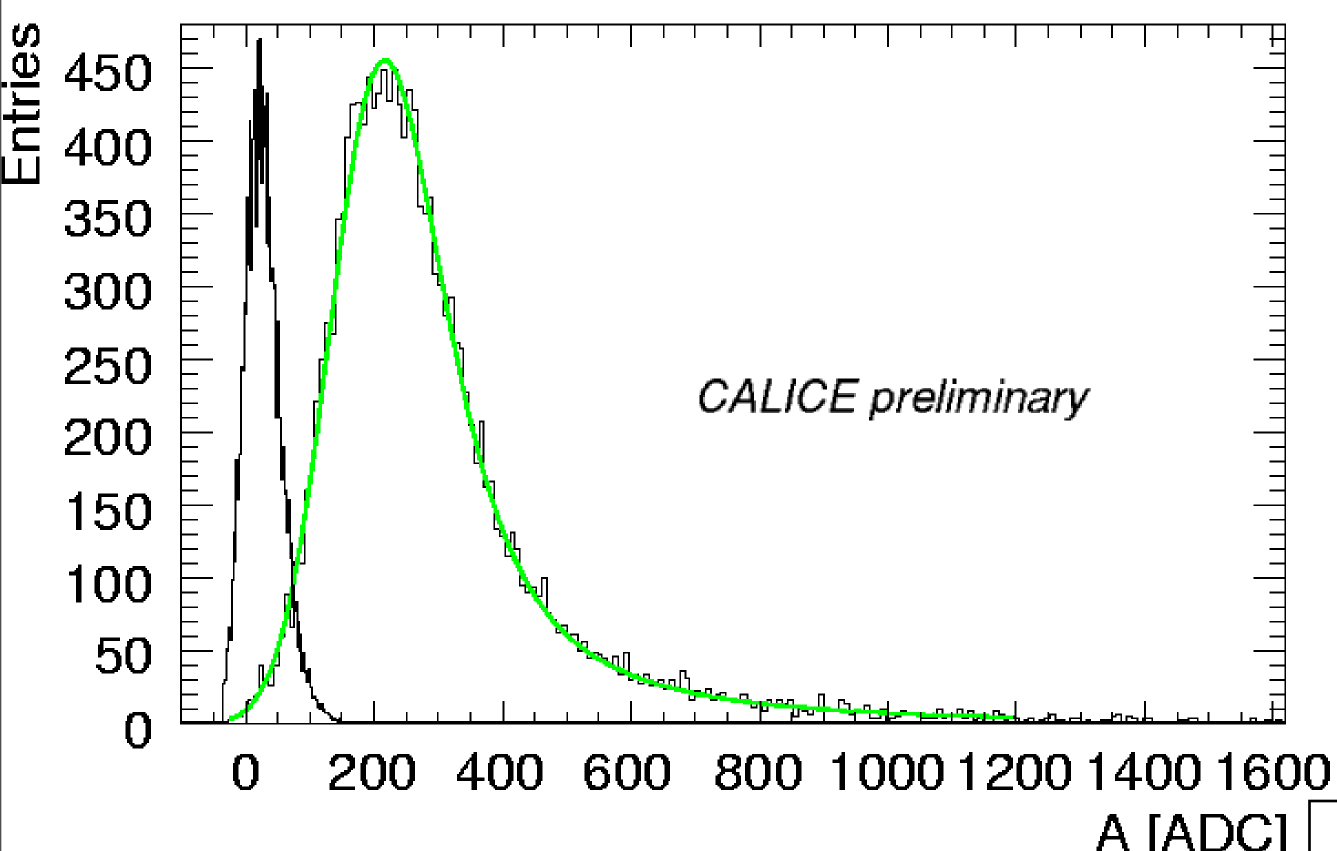


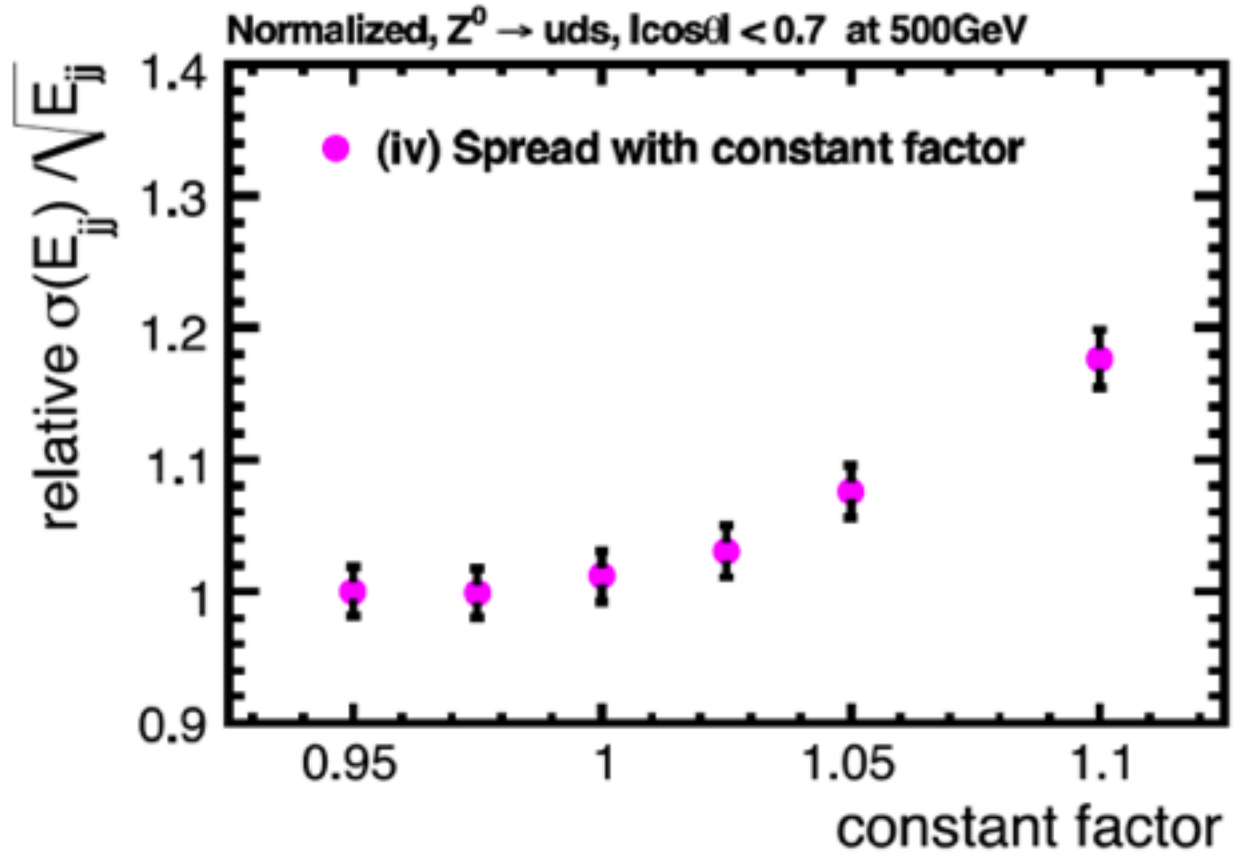


- MIP-Calibration with Muons
  - Complete detector illuminated with high energy muons
  - equalization of response of all cells by matching the MPV position

Documented in arXiv:0811.2431, paper in preparation

Calibration Requirement

- Study of required HCAL calibration precision for a complete detector:
  Full simulations with PandoraPFA reconstruction



Overall energy scale needs to be well controlled, in particular upward shifts are dangerous

Documented in ILD LOI & arXiv:0910.3820

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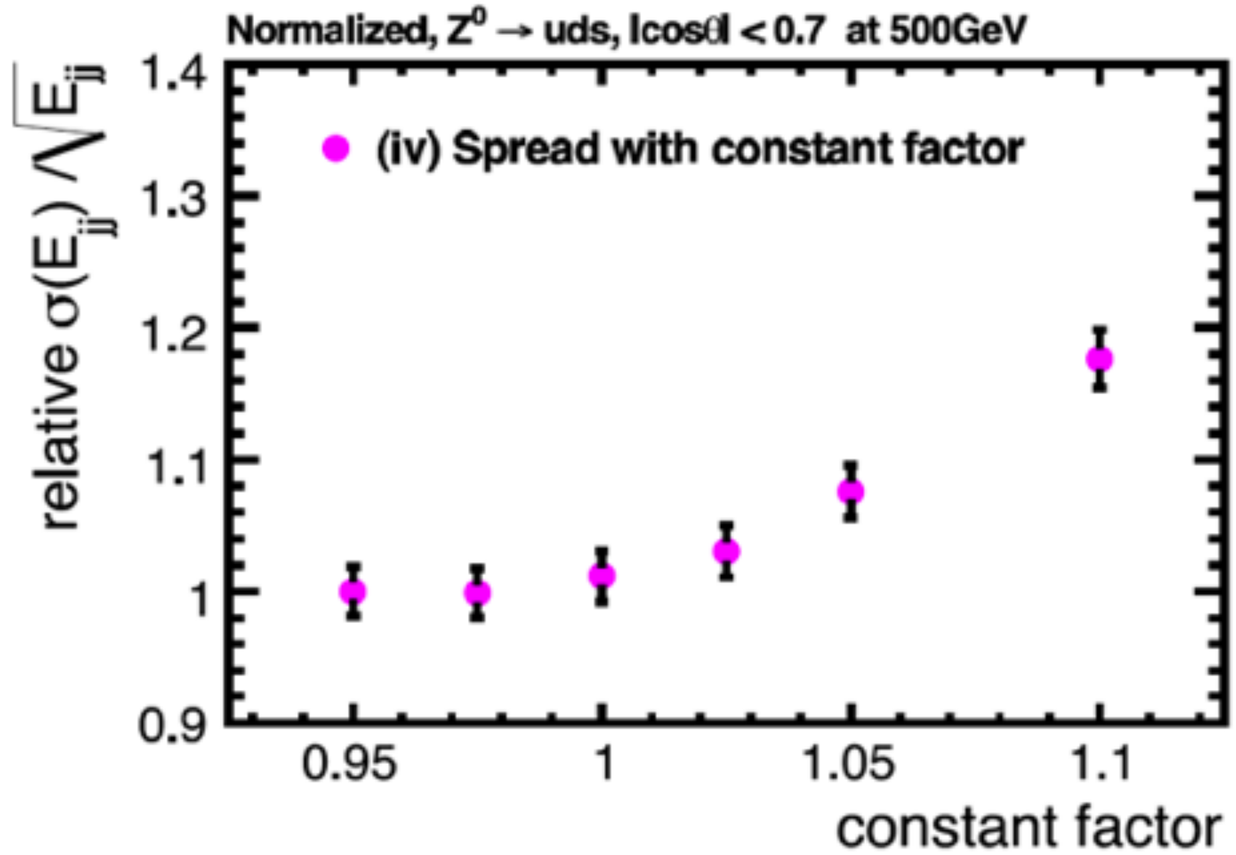

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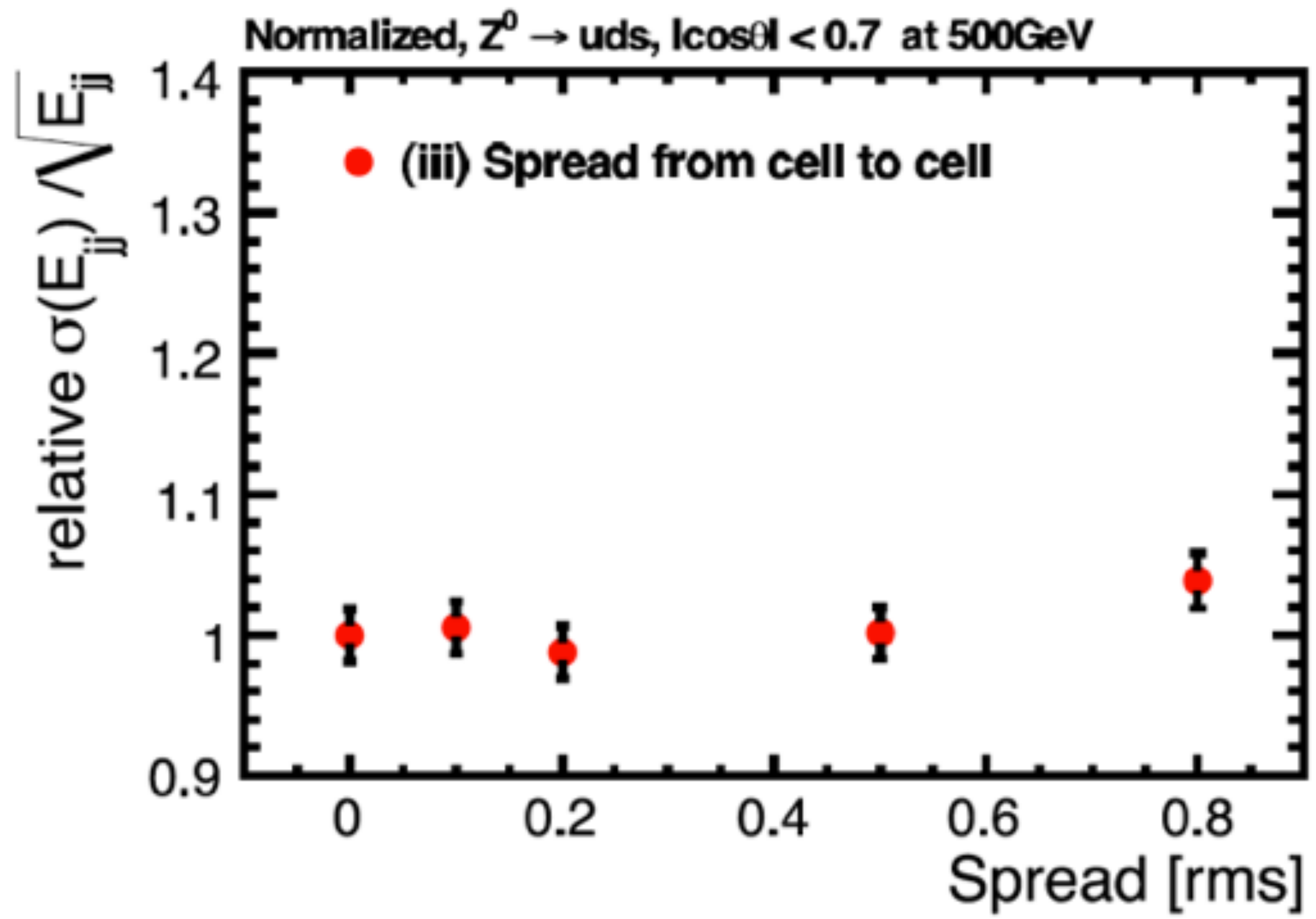


Statistics saves you: Large cell-to-cell variations can be tolerated, since many cells contribute to the signal.

Requirement here is not set by resolution, but by possibility for calibrating in groups

Expected requirement: ~ ± 10%

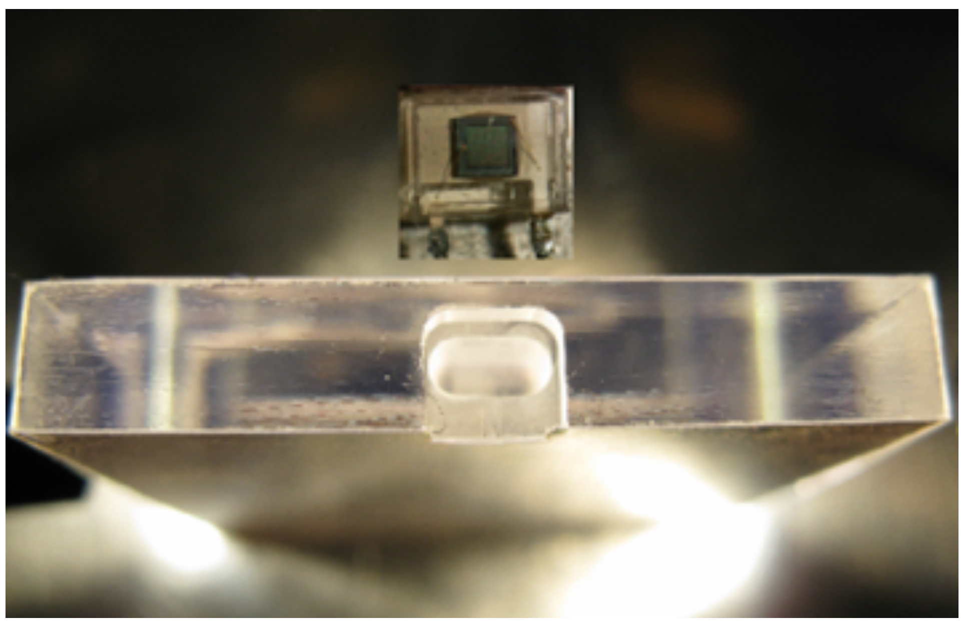
Documented in ILD LOI & arXiv:0910.3820

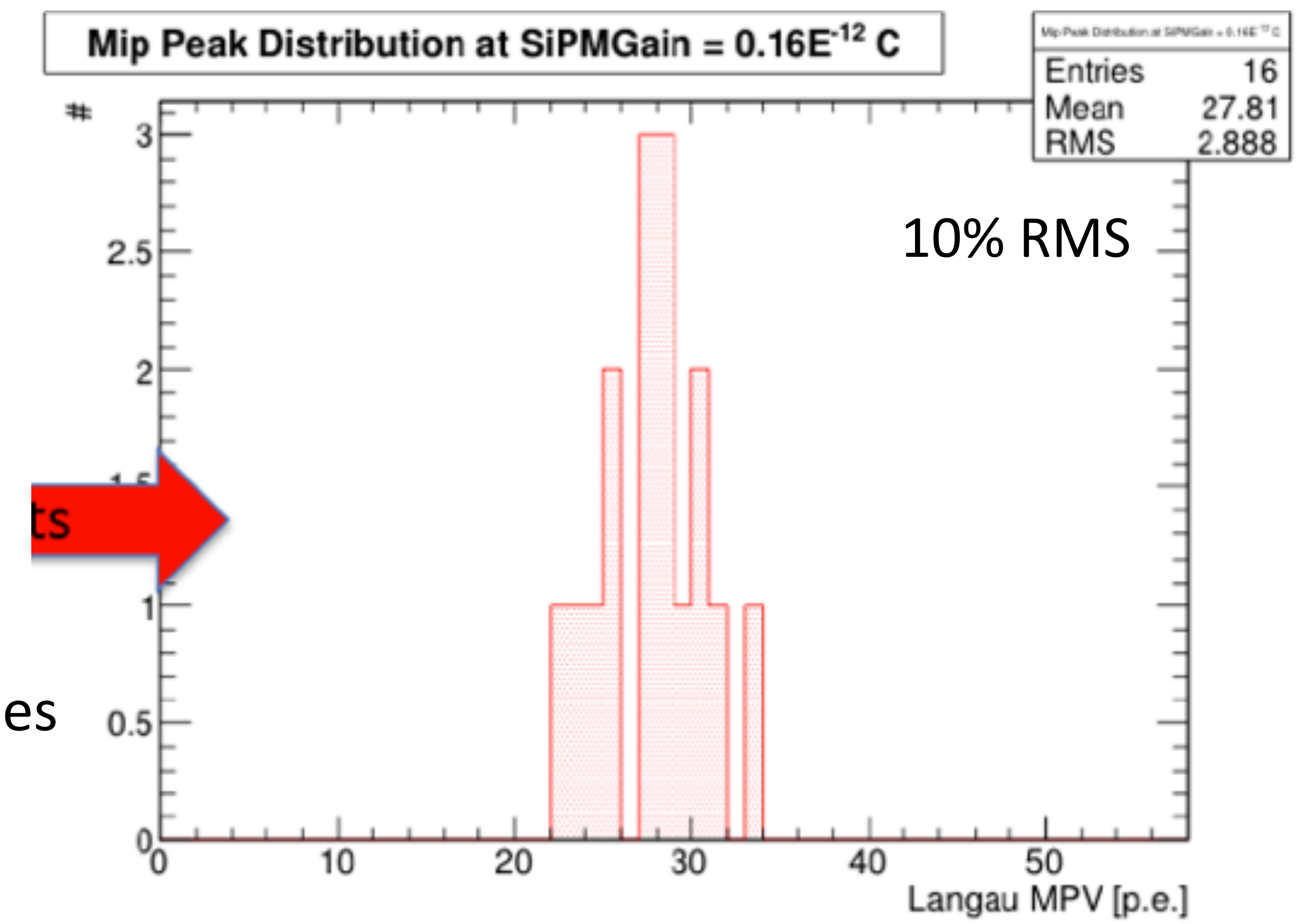
Alternative Options for Scintillator Tiles: Direct Readout

- Current commercial SiPMs (Hamamatsu MPPC, ...) have their sensitivity maximum in blue spectral range: No need for a WLS fiber
  - Reduced mechanical complexity: no fiber to integrate
    Relaxed tolerances: No alignment of SiPM wrt fiber

Strategy: Reduce scintillating material close to photon sensor, diffuse light in air gap

Coupling at bottom face (low signal): NIM A605, 277 (2009), at side: NIM A620, 196 (2010)





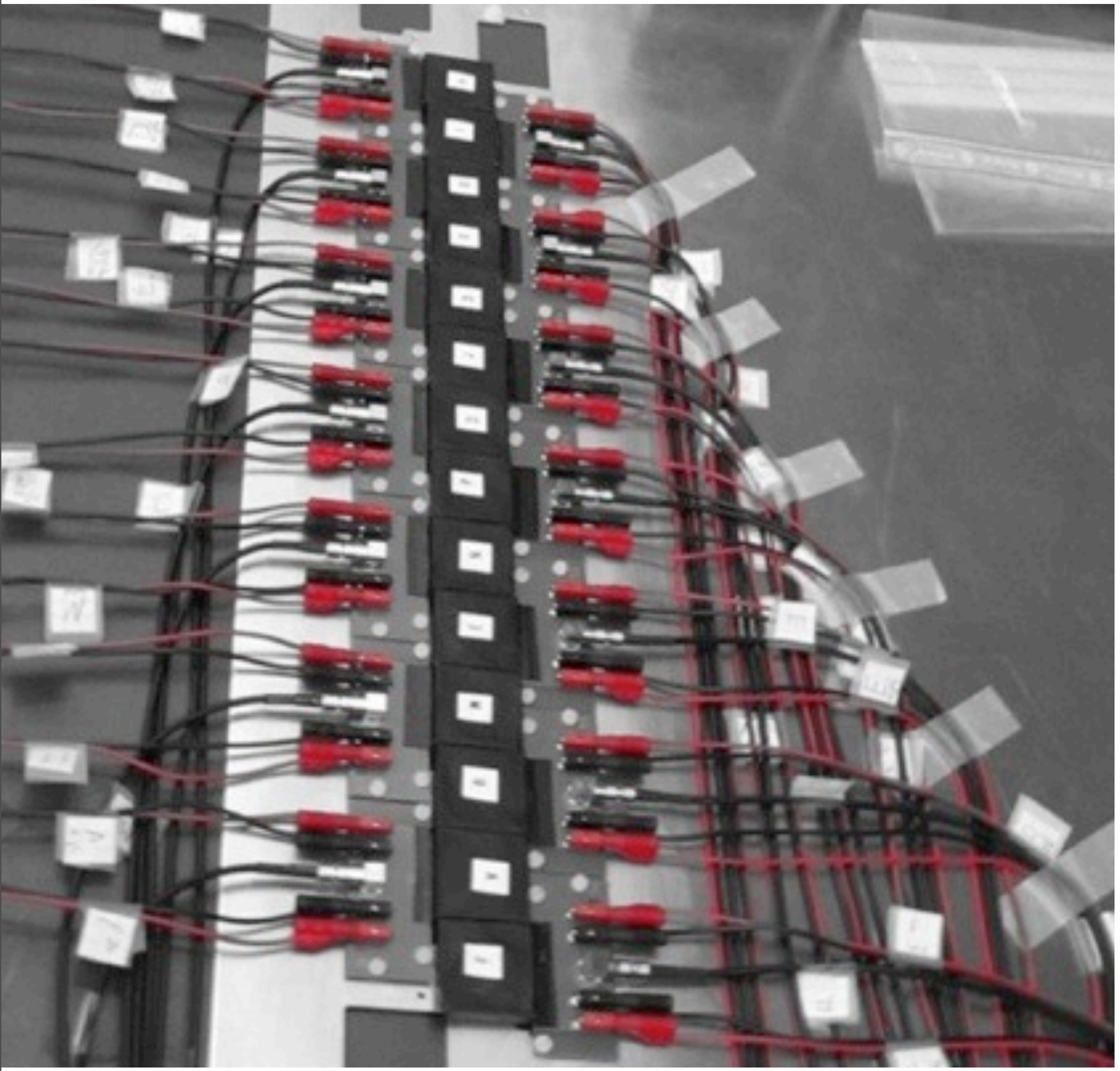
Light yield distribution of 16 hand-drilled tiles

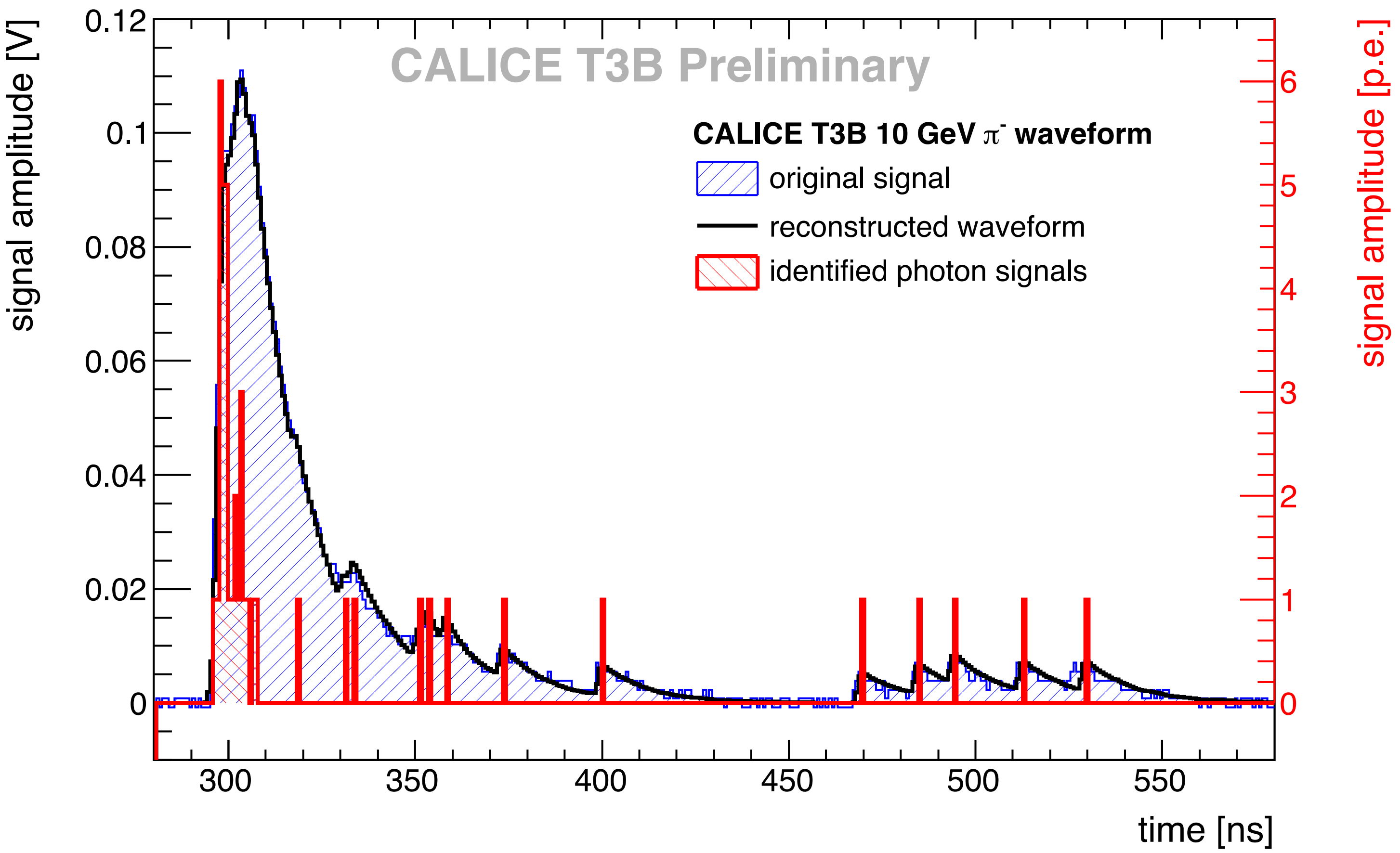
expect even better uniformity

with mass-production techniques

T3B - Pushing the Possibilities of SiPM Readout

- Runs currently together with the Tungsten analog HCAL, at a depth of 4 λ
  - 15 scintillator cells (direct coupling), read out with fast digitizers over 2.4 μs with 800 ps sampling
  - Identify the time of arrival of each photon on the SiPM - Measure time structure of response by averaging over many events





Signal on one tile, decomposed into individual single photon signals