The 2nd Generation Prototype of the CALICE Analog HCAL and highlights from the Physics Prototype

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KILC12, Daegu, Korea, April 2012

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Calorimeter for ILC

Excellence Cluster
Universe

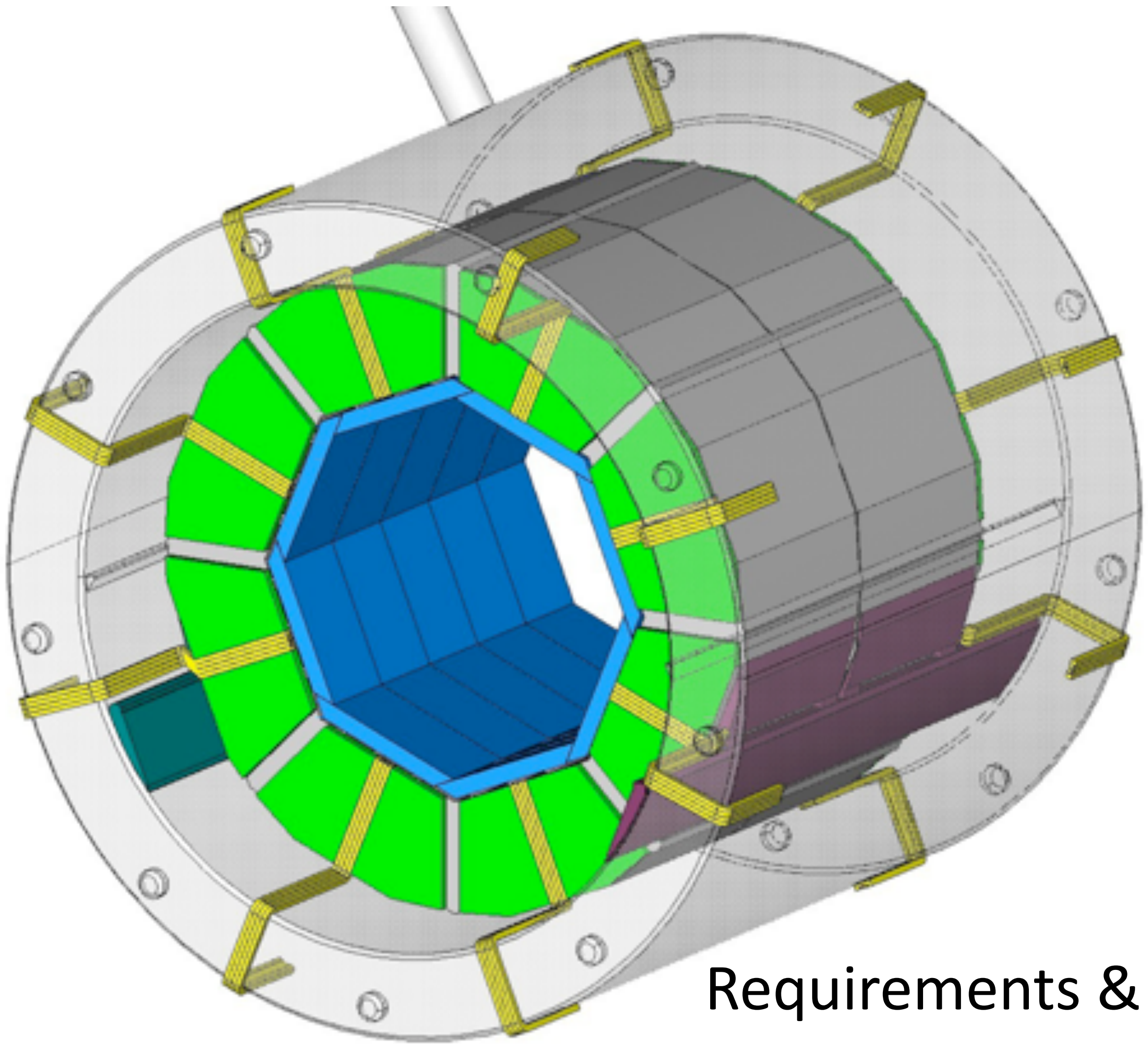
Outline

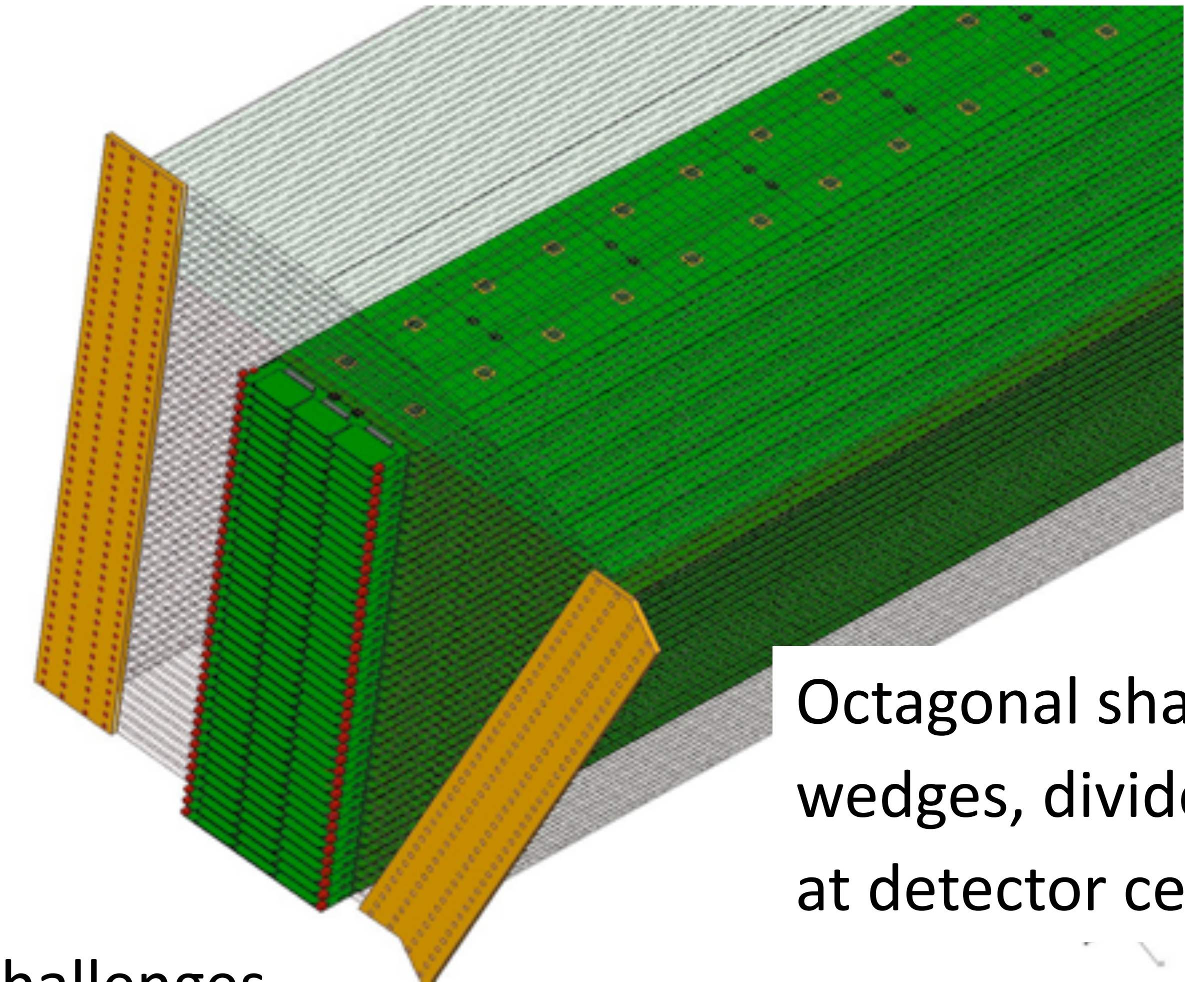
- Towards a technical demonstrator for the analog HCAL
  - Scintillator tiles & electronics
  - First test beam results
  - Mechanical studies
- Highlights from the physics prototype
  - Electromagnetic performance
  - Validation of shower models and PFA performance
  - Energy resolution for hadrons
- Summary

The Technical Demonstrator

A Technical Demonstrator for ILD

- A scalable calorimeter design for a collider detector





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

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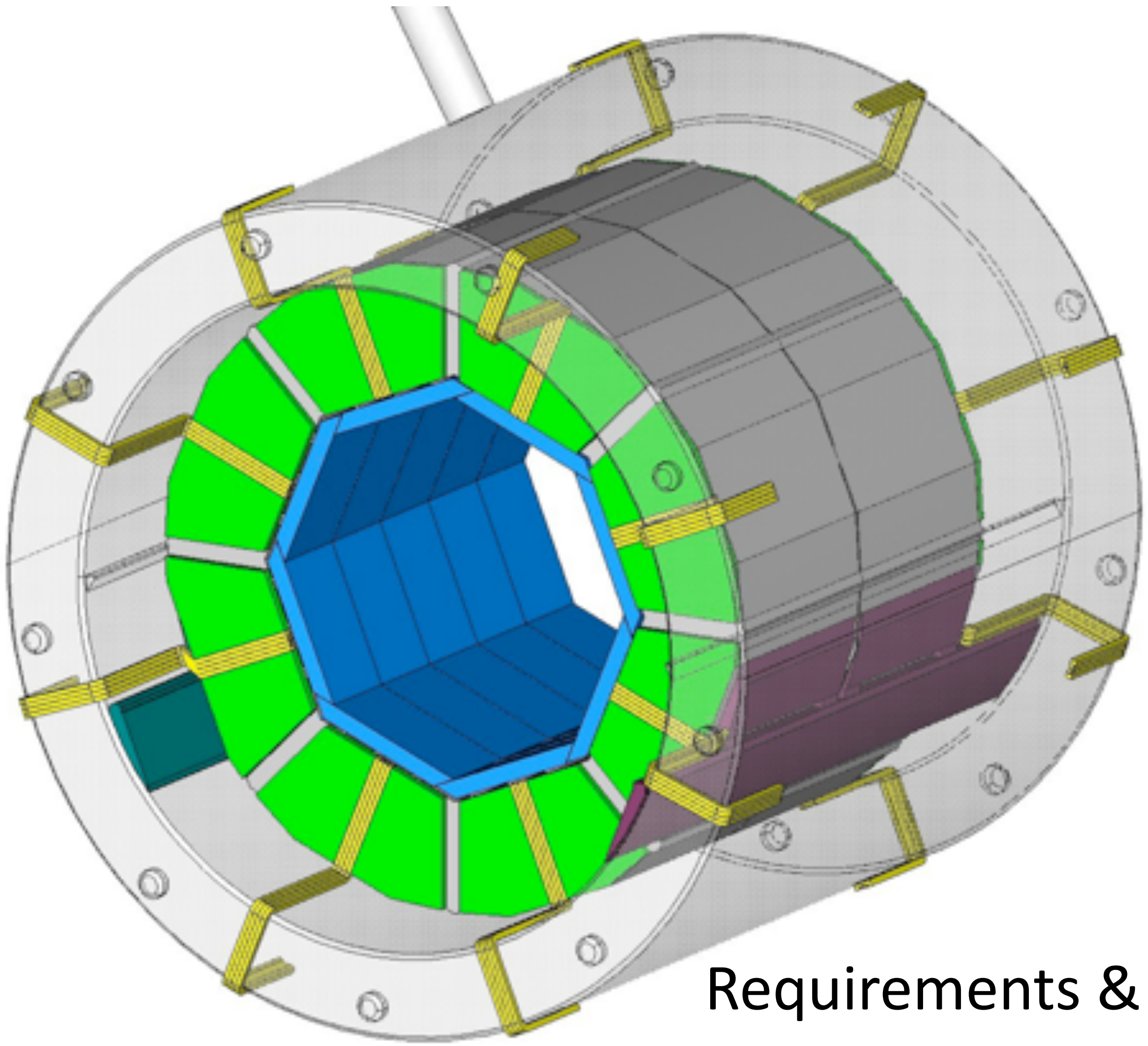

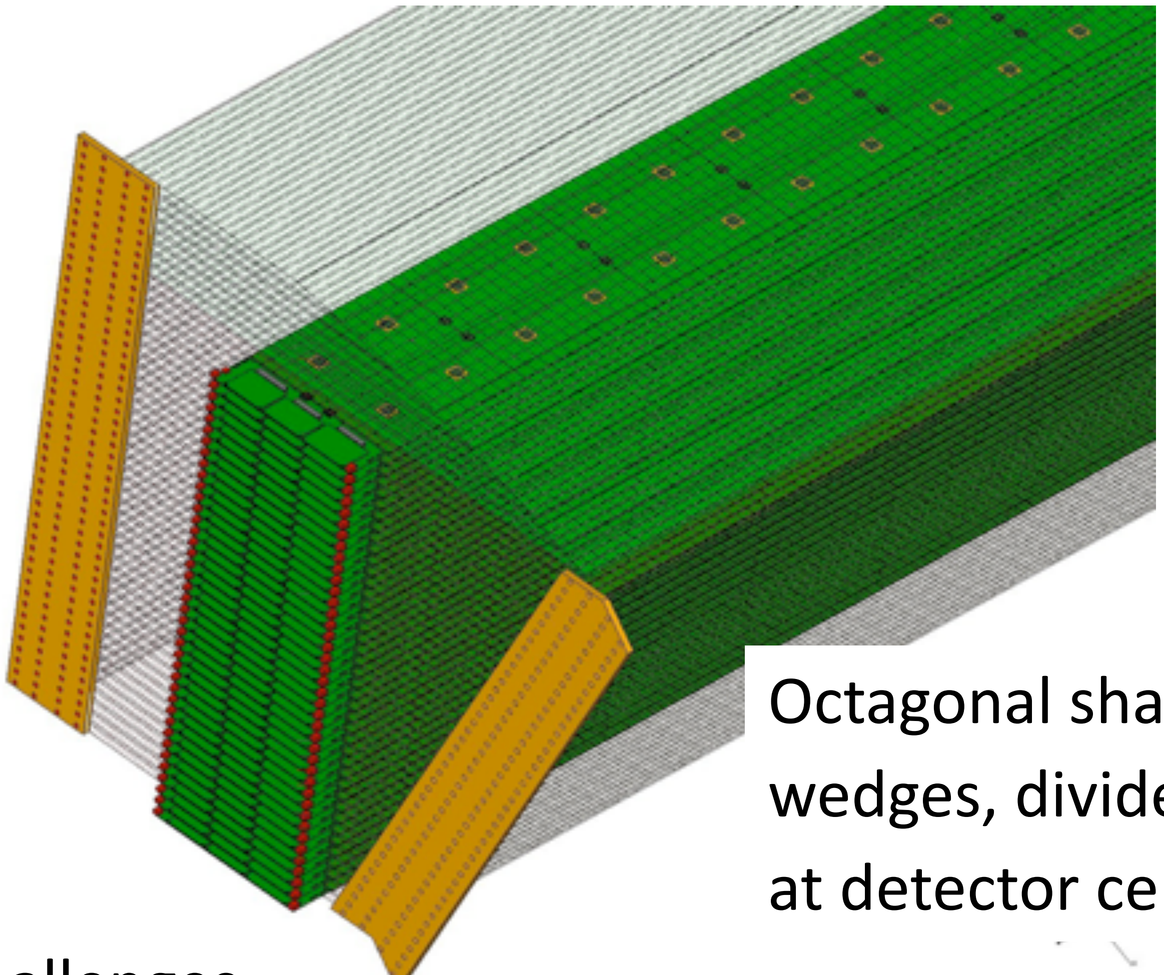

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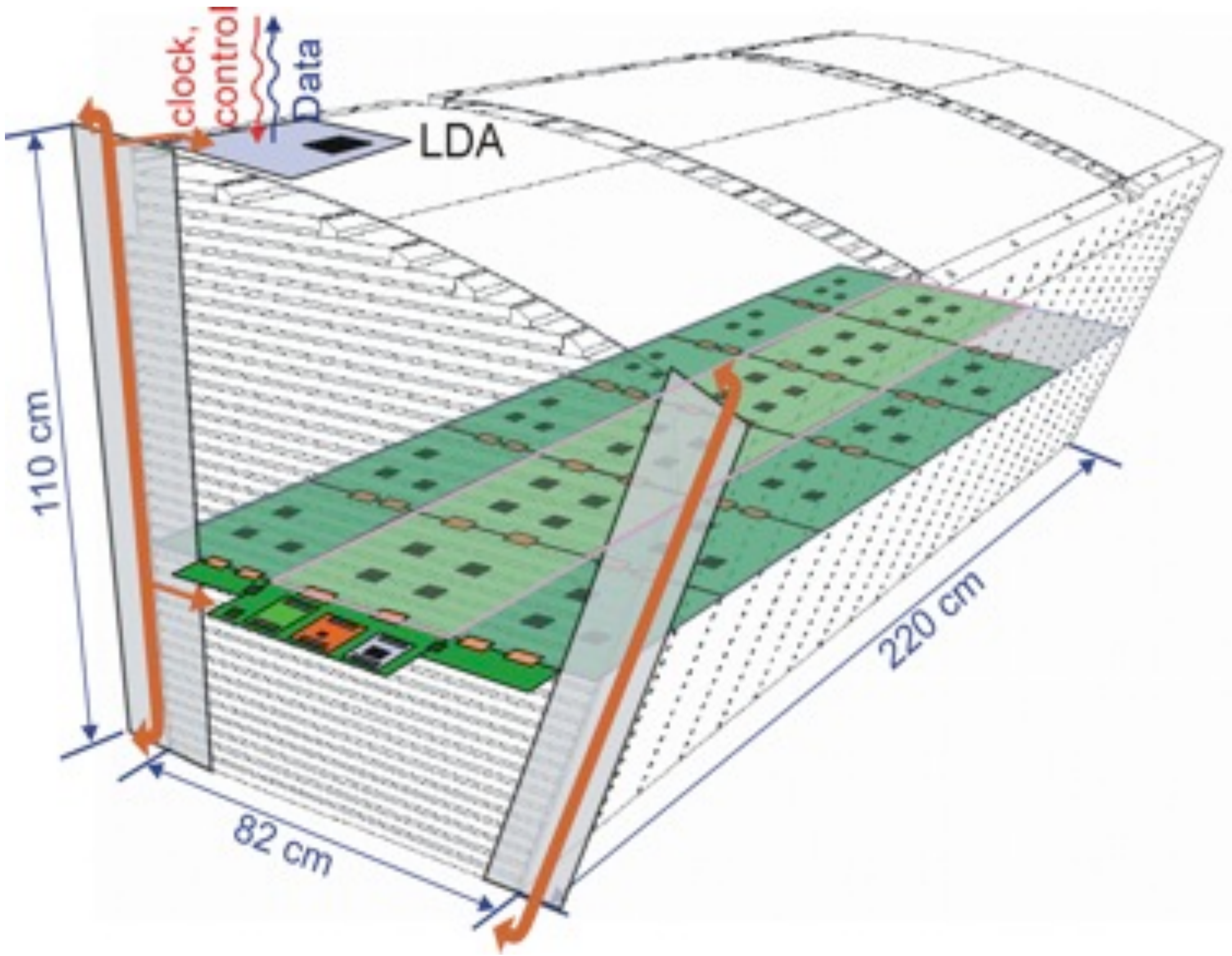
Only possible with integrated electronics!

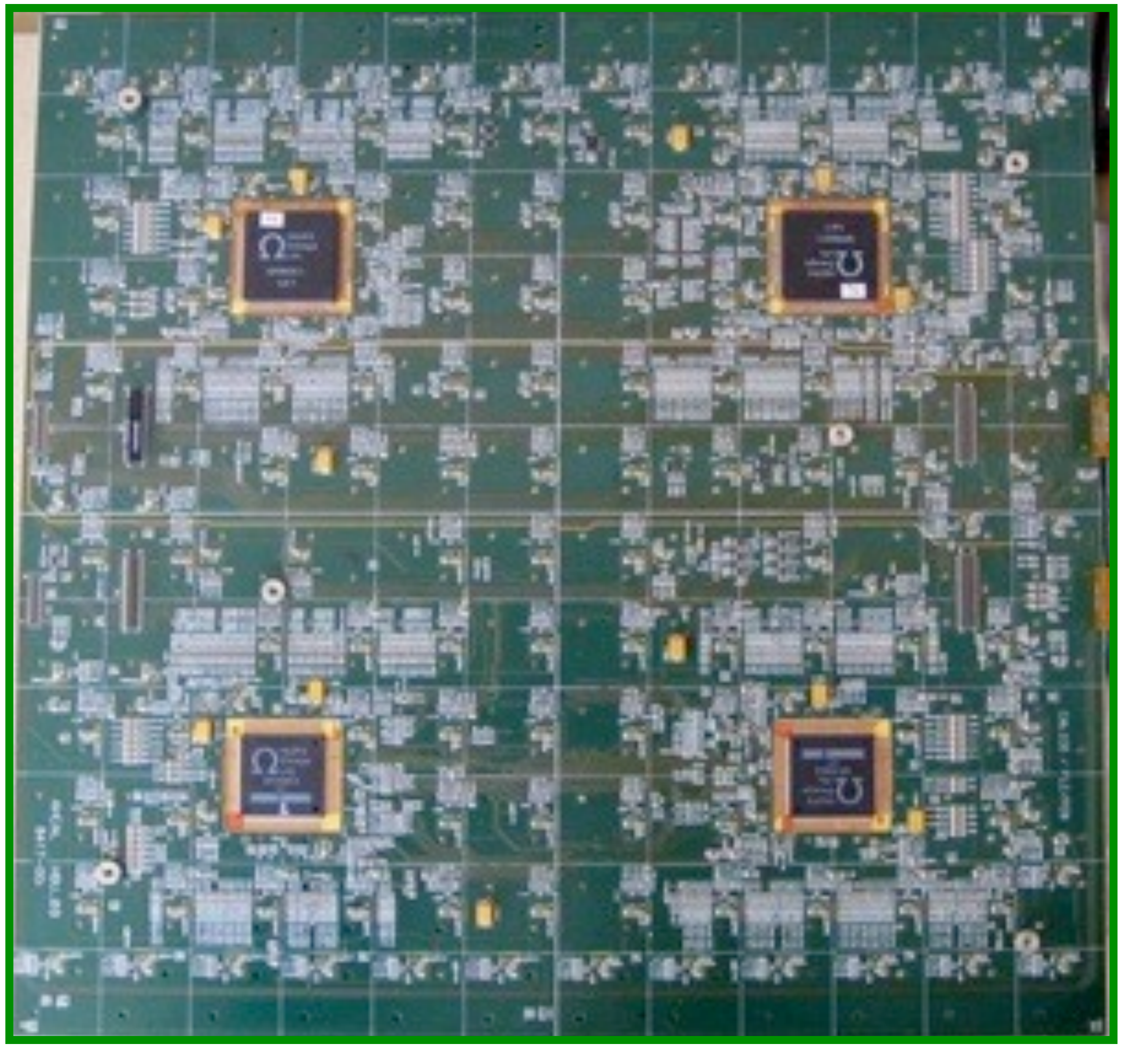
The Active Layers

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



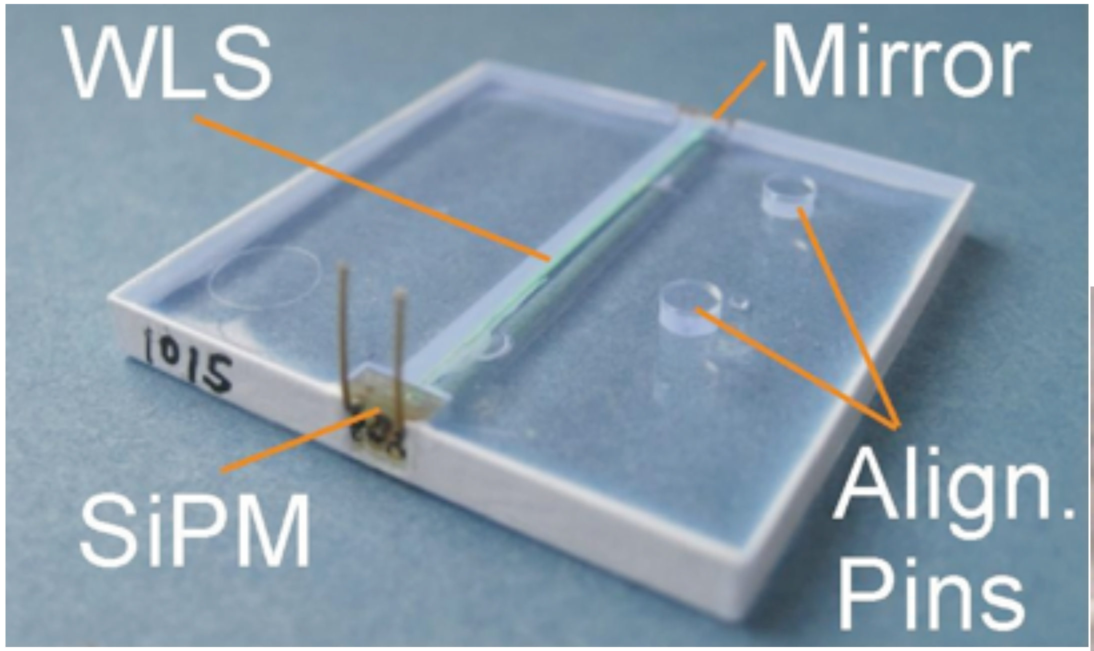
- Indivdual electronic boards (HBUs) with 144 channels, interconnected to form active layers

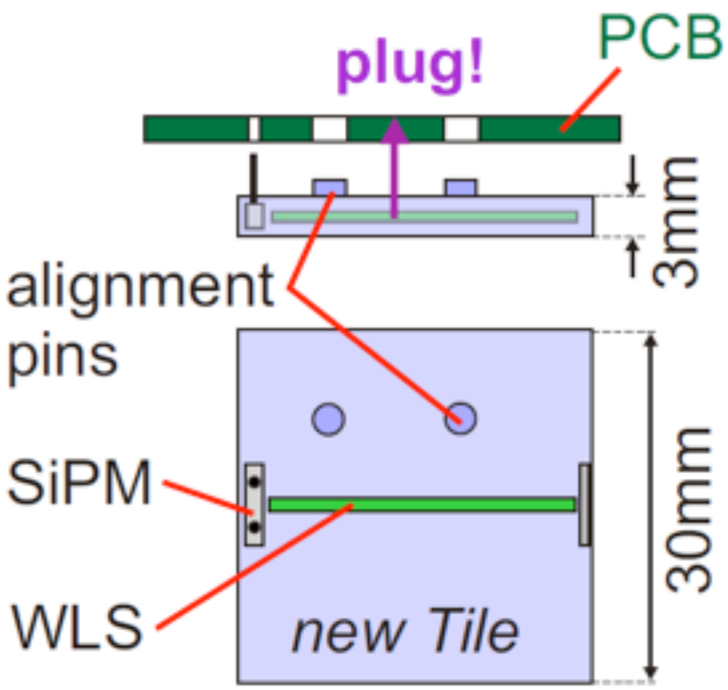
compact construction:
Minimized gaps, ASICs embedded in PCB



The Scintillator Tiles

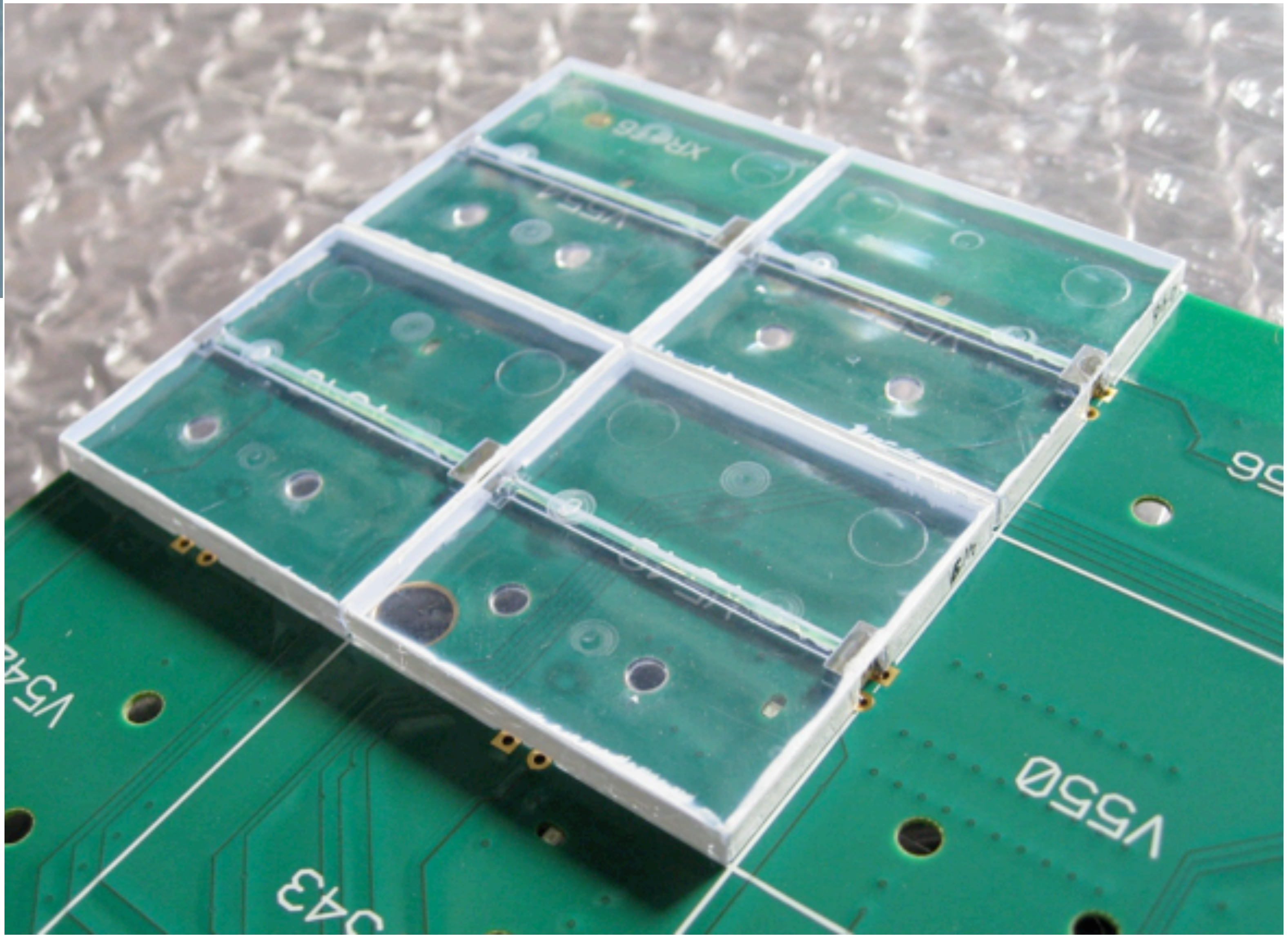
- 3 x 3 x 0.3 cm^3, molded tiles with embedded WLS fiber and SiPM





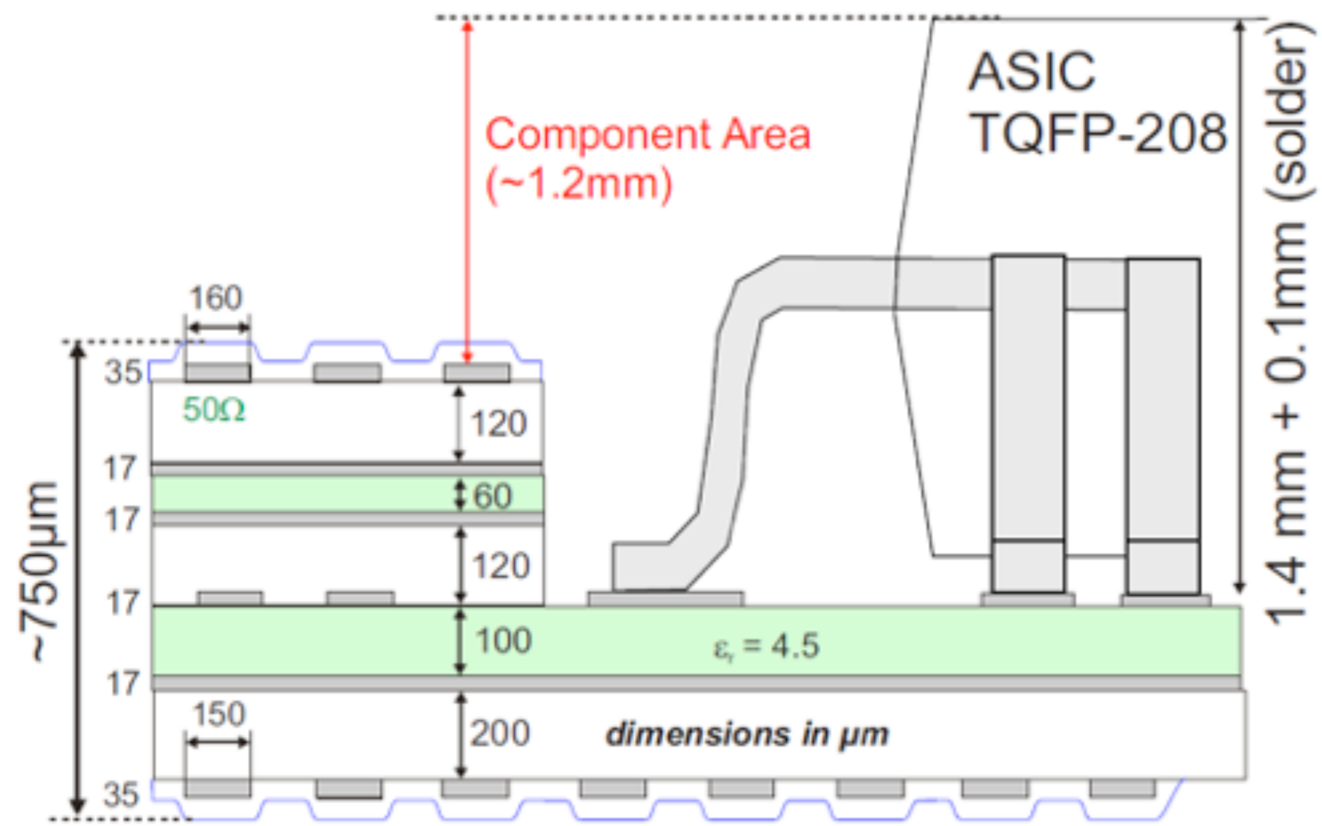
- From a sample of 450 tiles:

  15 ± 2 detected photons / MIP

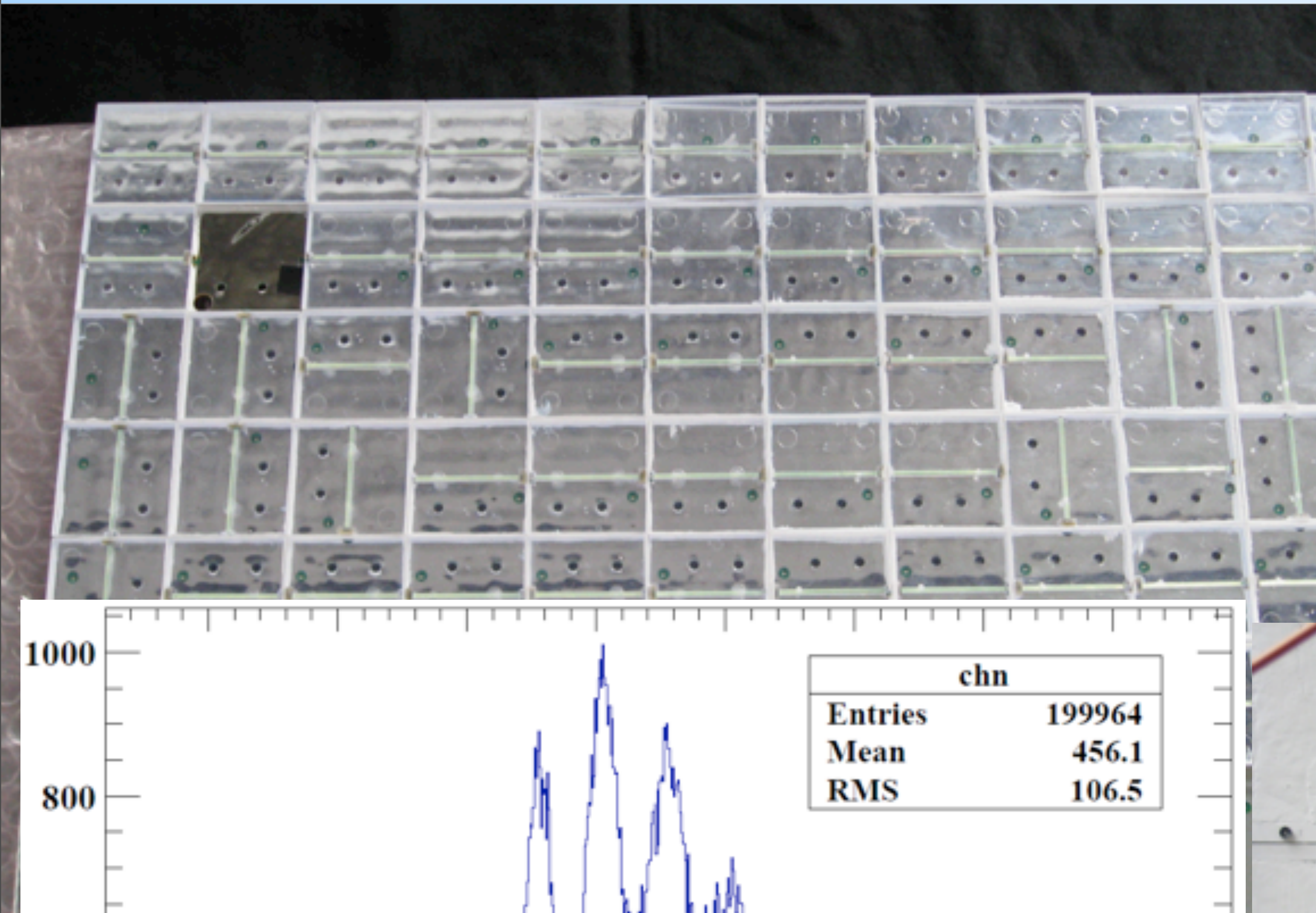


The Readout Chip: SPIROC2b

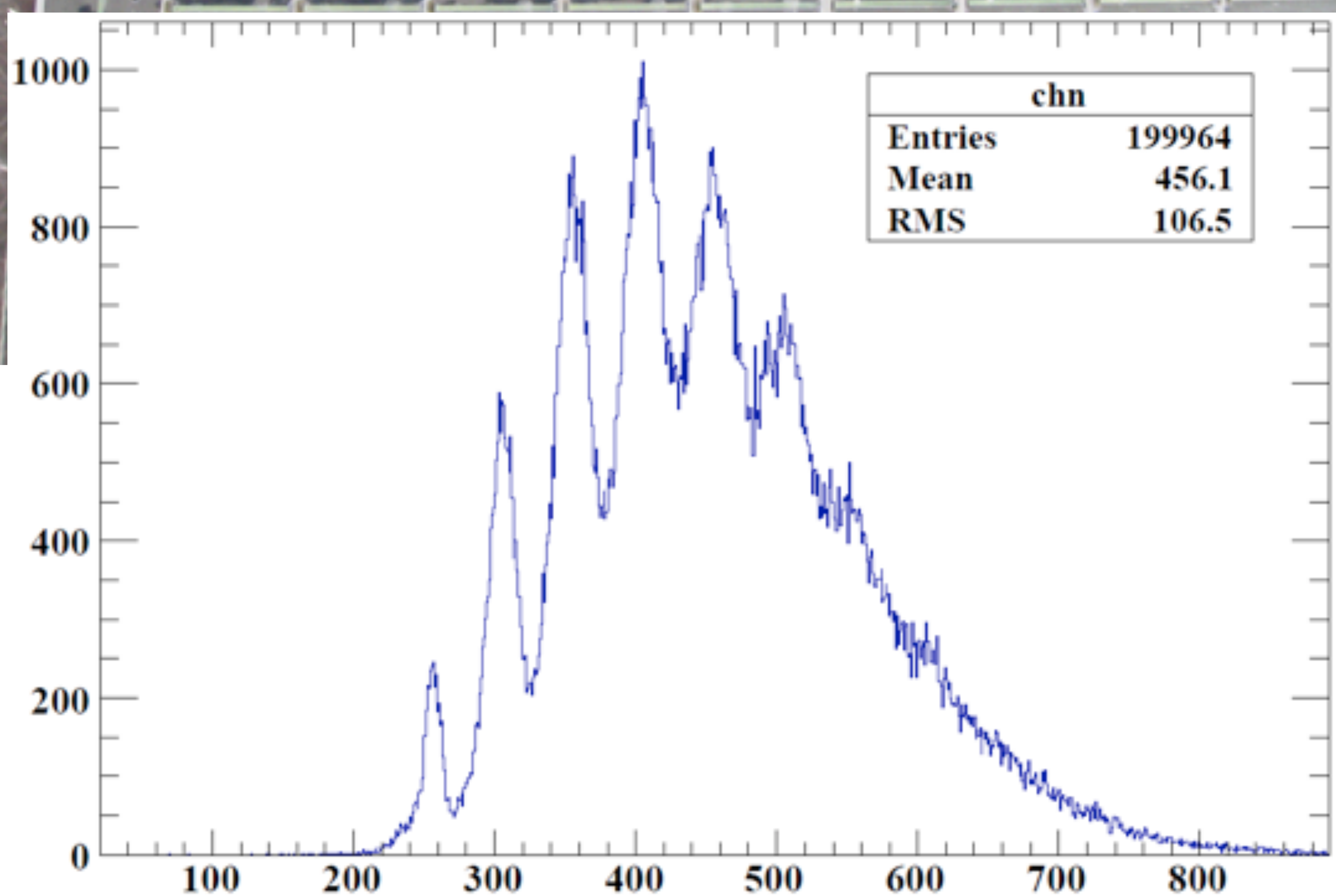
- The heart of the new electronics: SPIROC2b, designed by OMEGA/IN2P3
- 32 channels, independent bias voltage control for each channel
- Powerpulsing: 25 µW/channel
- Auto-trigger mode
- Time stamping capability
- Chip installed in cut-out in PCB to minimize layer thickness
- Thorough tests already performed,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

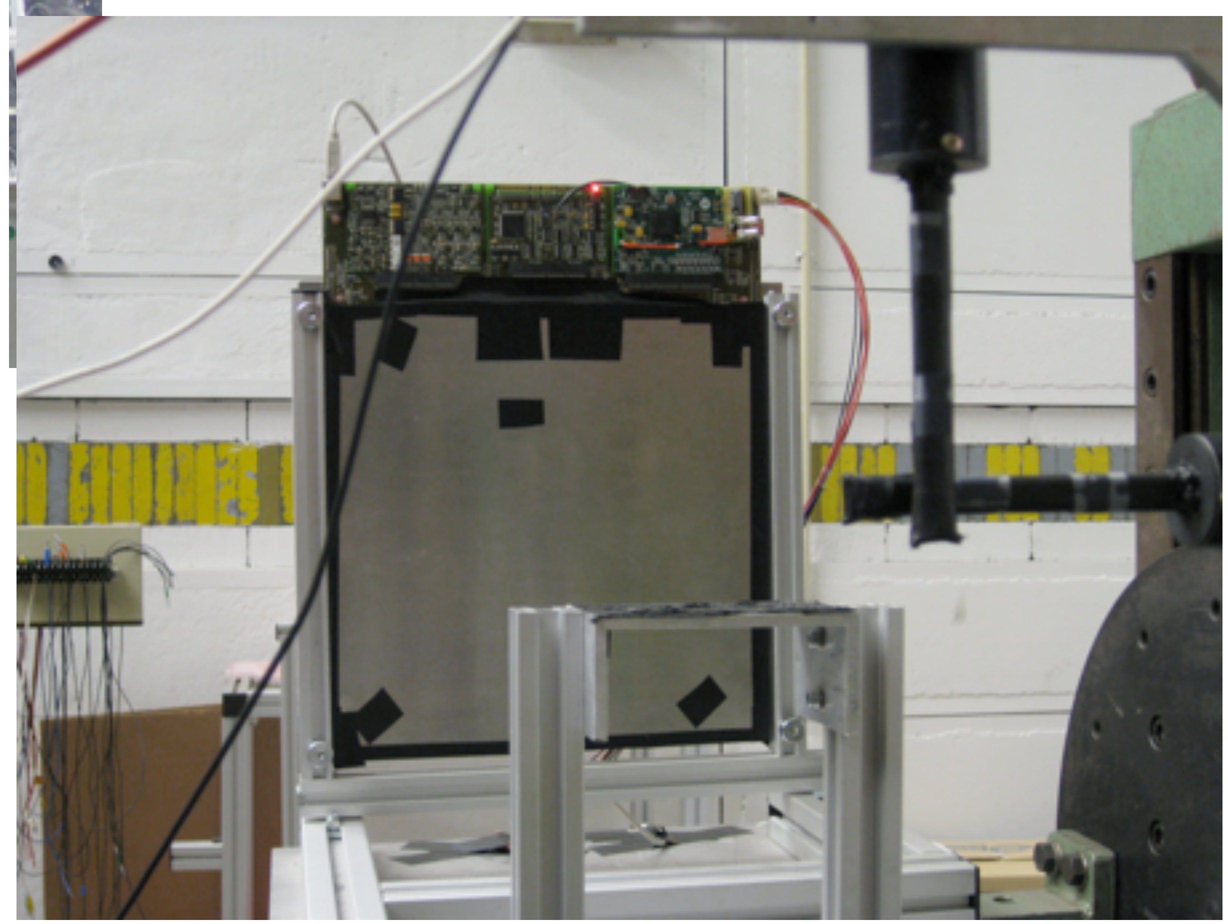


First Results in Beam



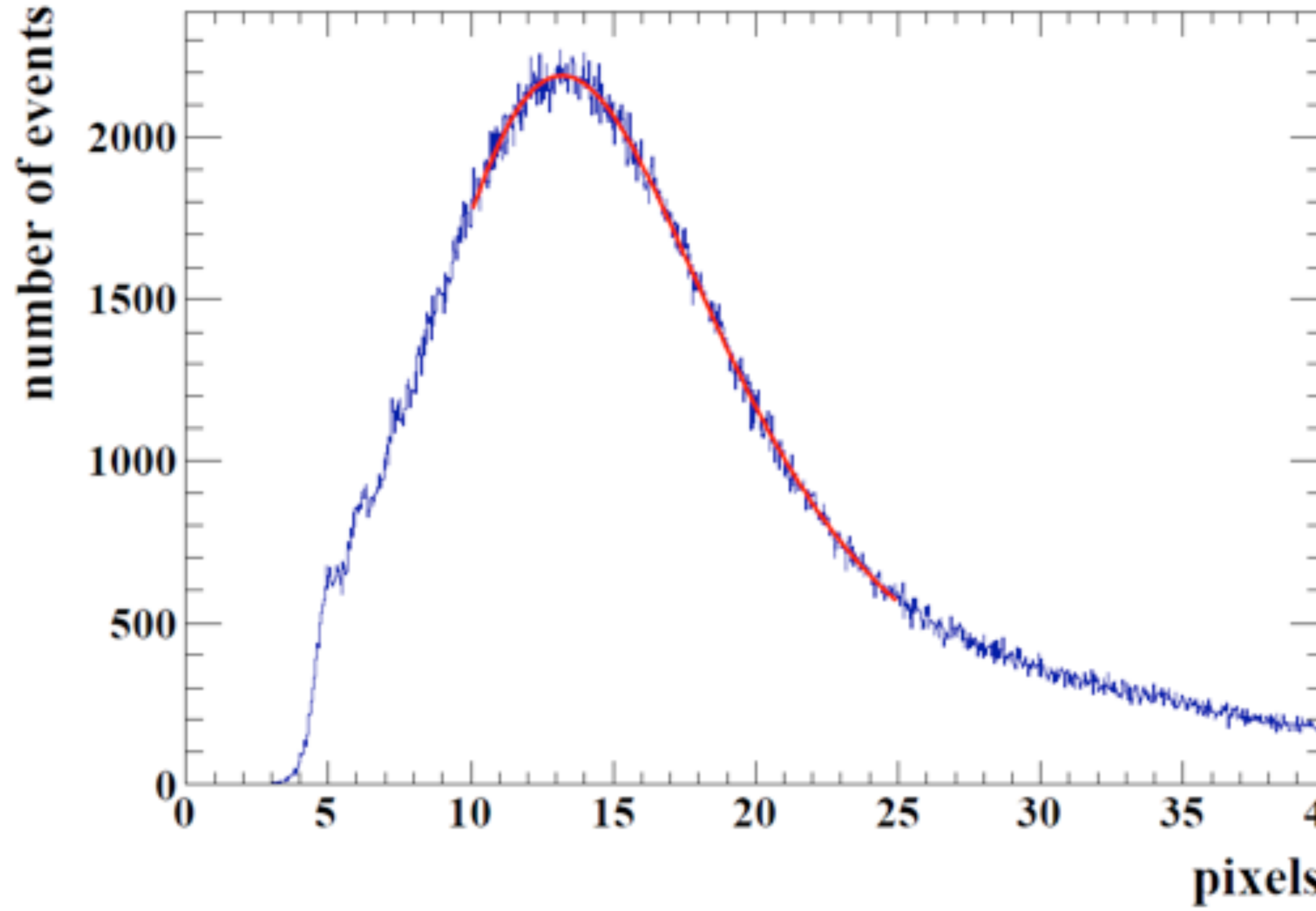
- 1 HBU with 70 tiles in the DESY test beam: Test response to MIPs with 2 GeV electrons
- Good single photon spectra observed with LED system!

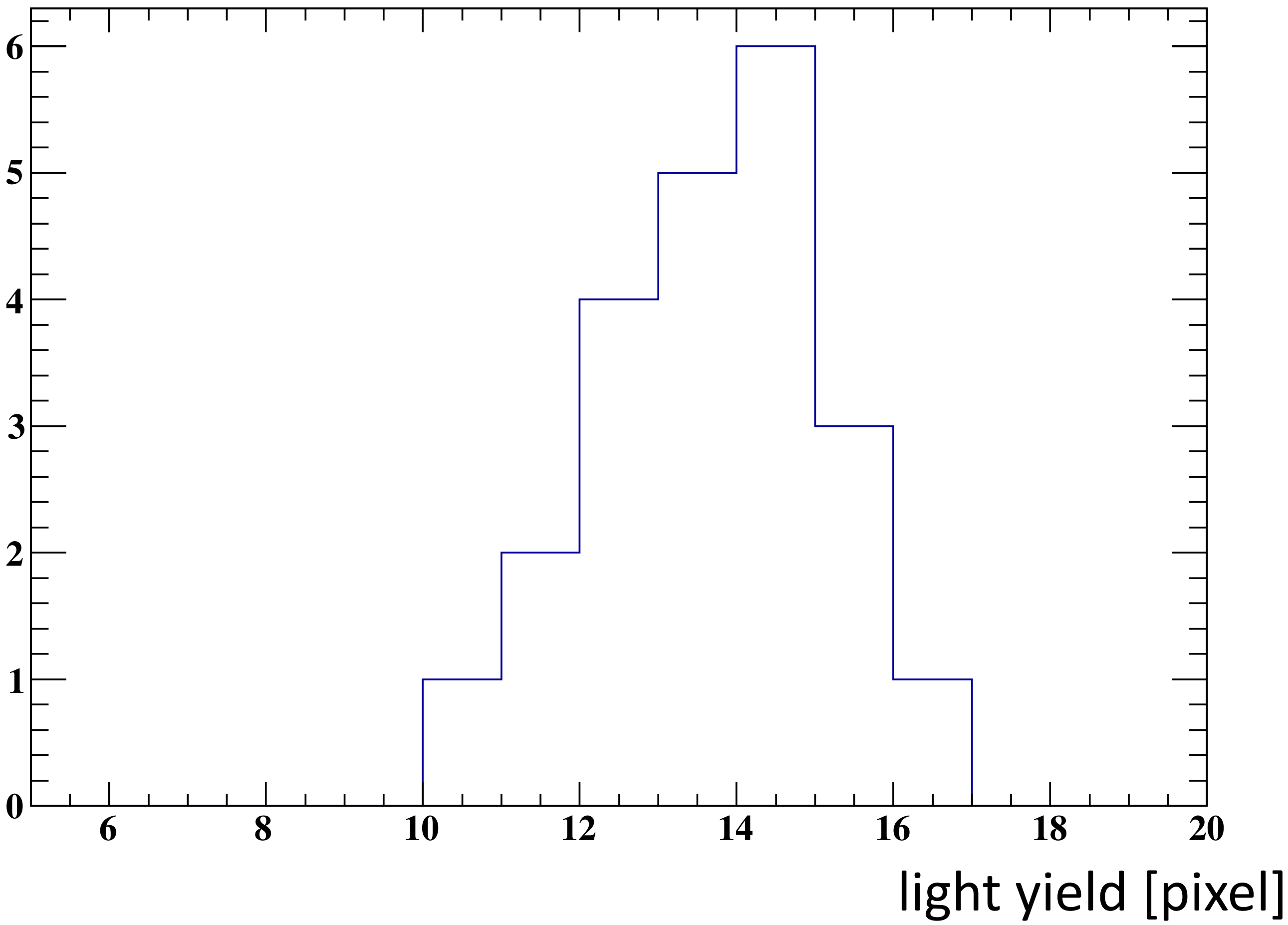




First Results in Beam

- Good response to MIPs
- Satisfactory cell to cell uniformity





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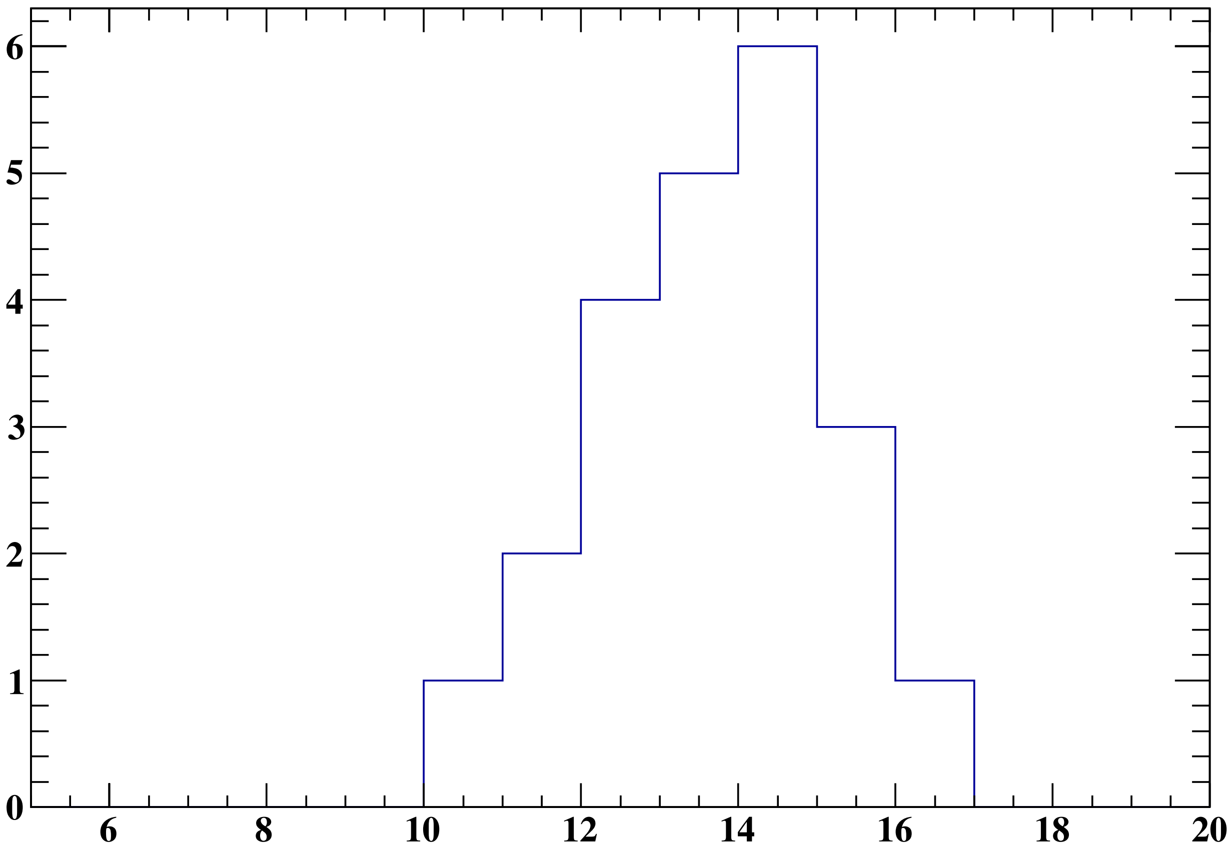
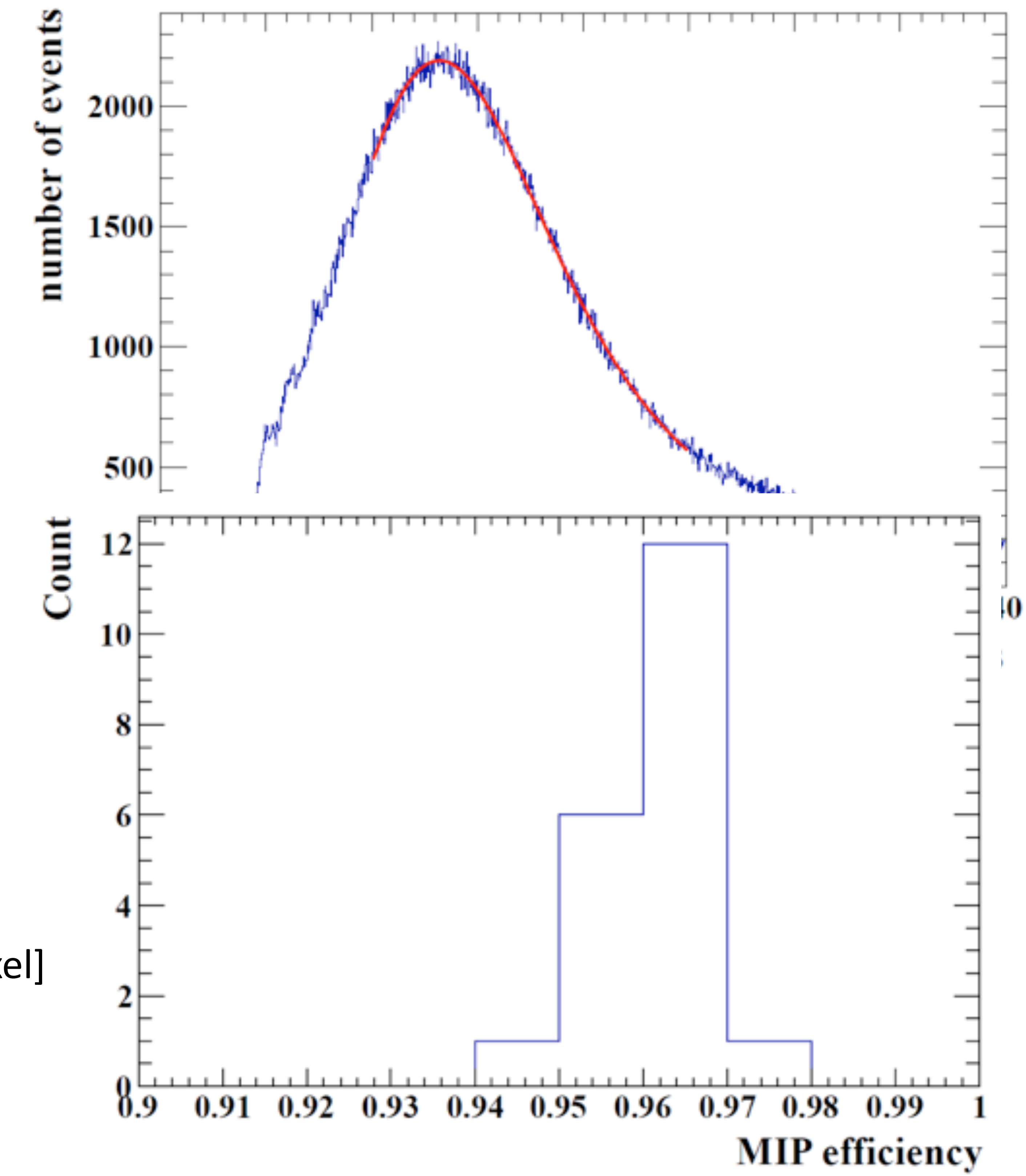


light yield [pixel]

- Good MIP efficiency with a cut at 0.5 MIP



Proving the Mechanical Concept

- Horizontal and vertical prototypes available
- Required flatness 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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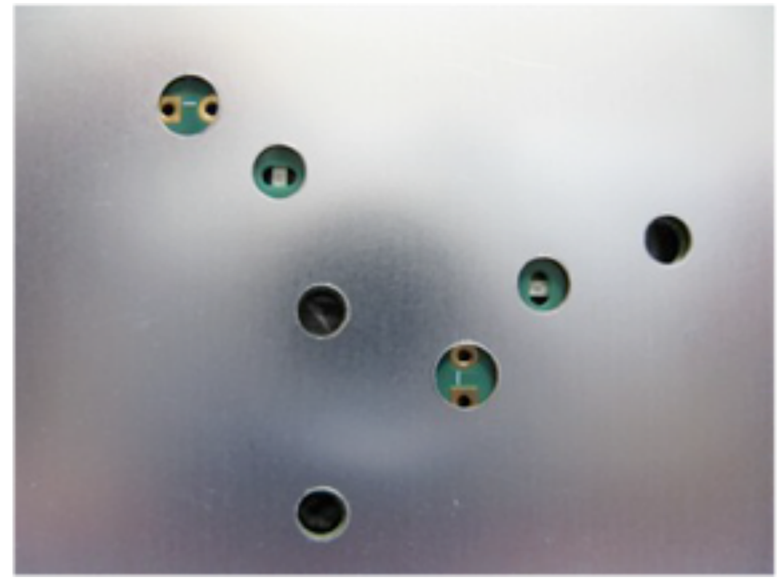
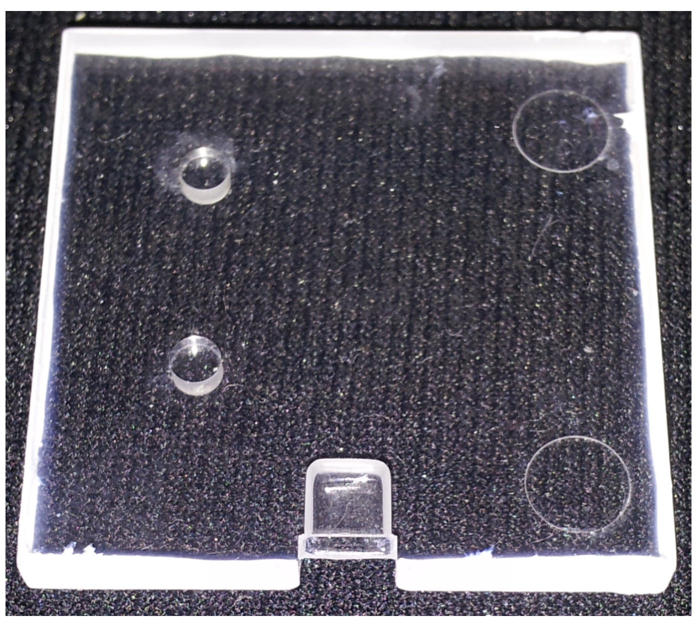
The design works in reality, with real steel,
not just in SolidWorks or AutoCAD!

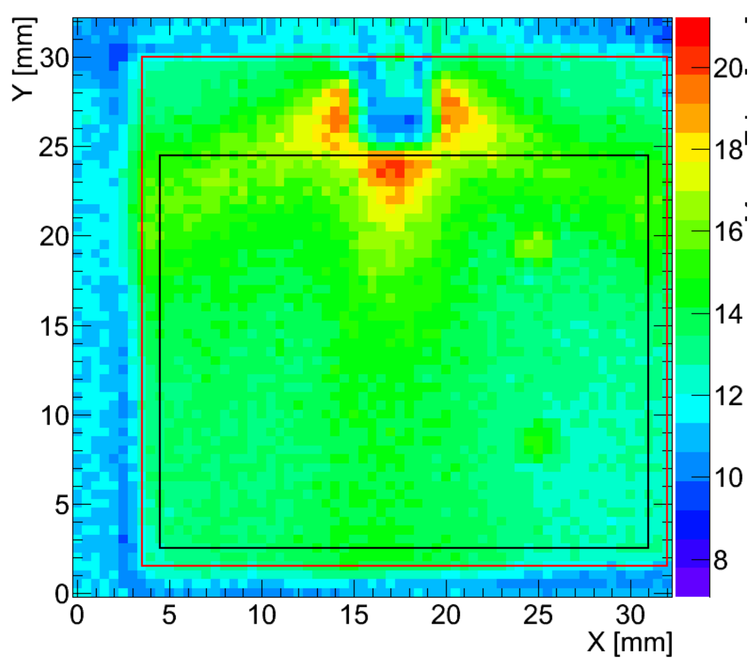
- Active layers fit in all slots: Mechanical tolerances and structural stability under control!
- ▸ Use 2nd generation demonstrator to study all integration issues with fully equipped active layer

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

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

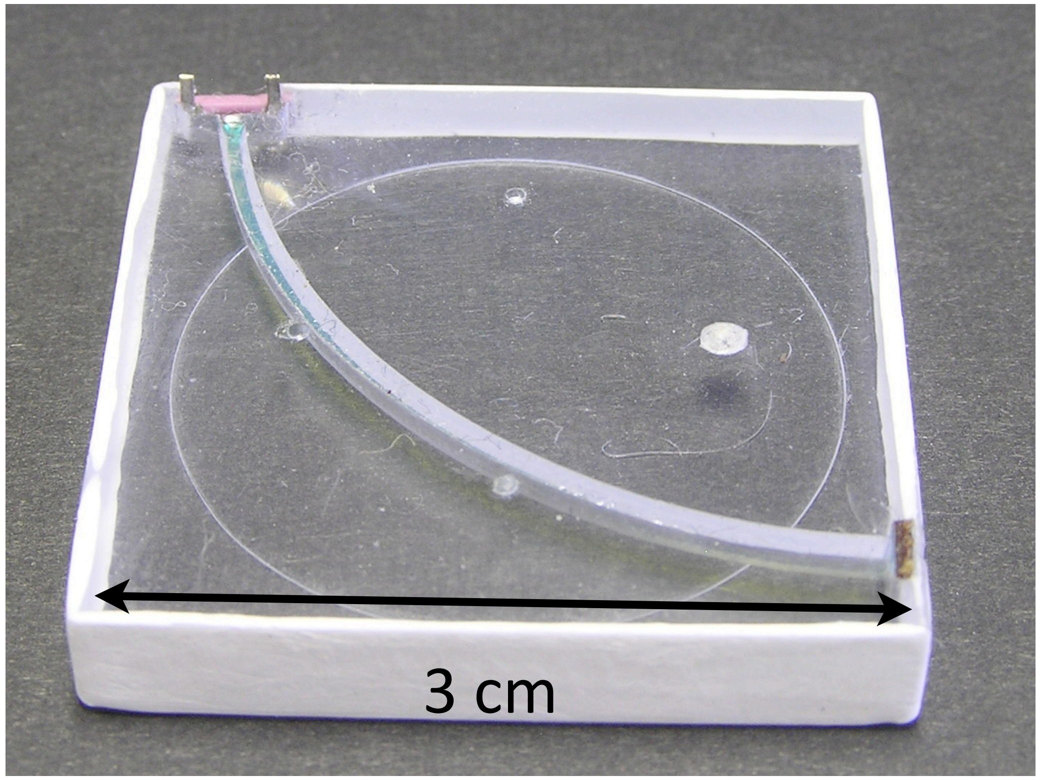
- Test of a full slab in absorbers to assess thermal and mechanical behavior

- Longer vision: Multiple layers, for example an ECAL-like tower with new absorber structure in beam

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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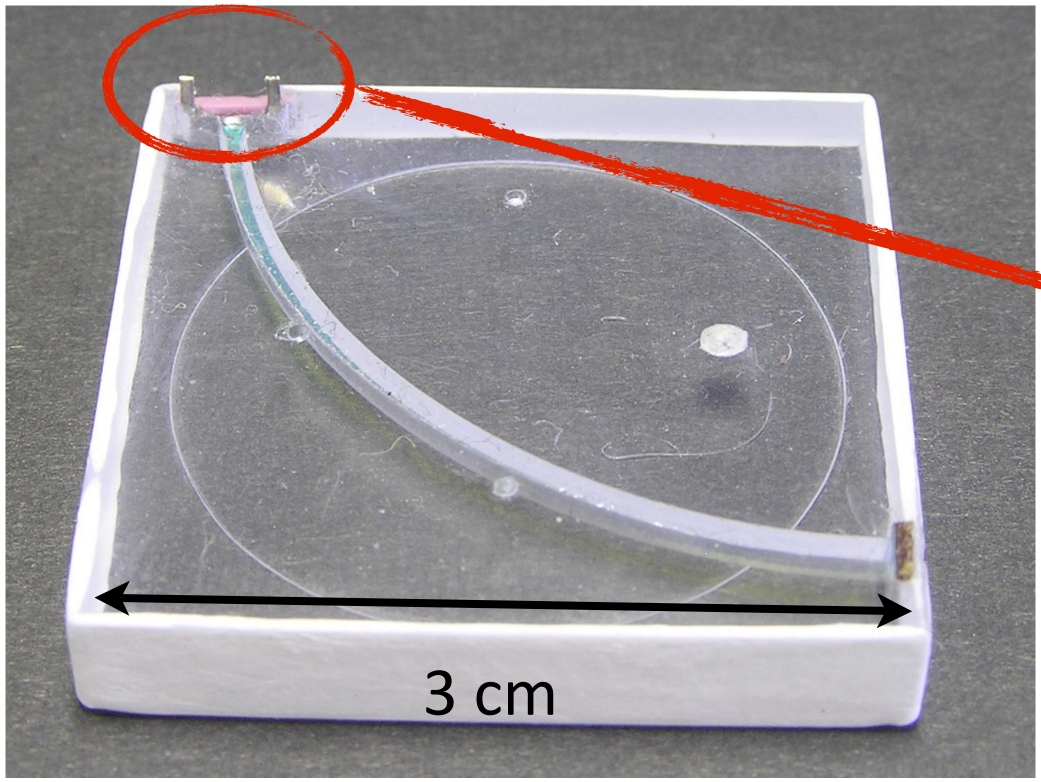
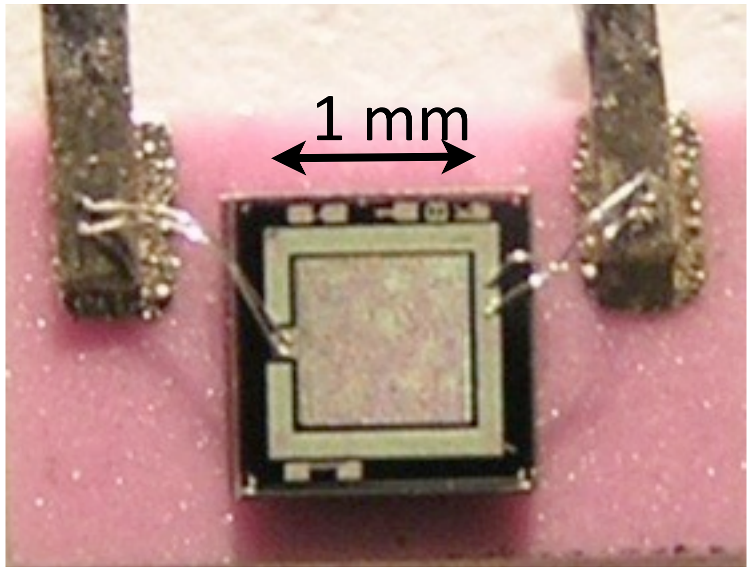


- SiPM: 1156 pixels, manufactured by MePhI/PULSAR



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

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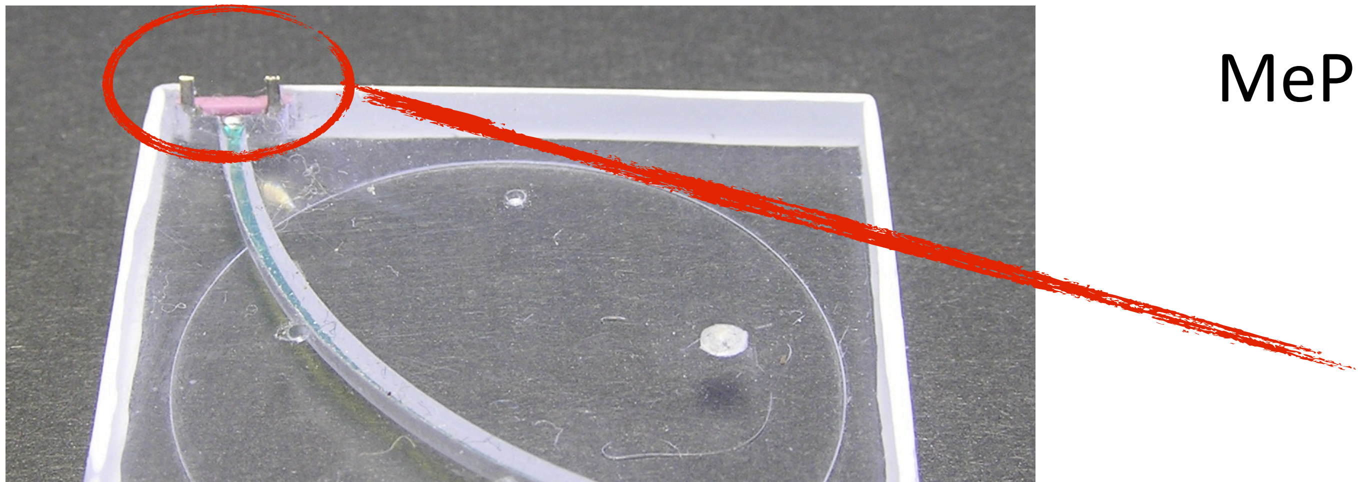
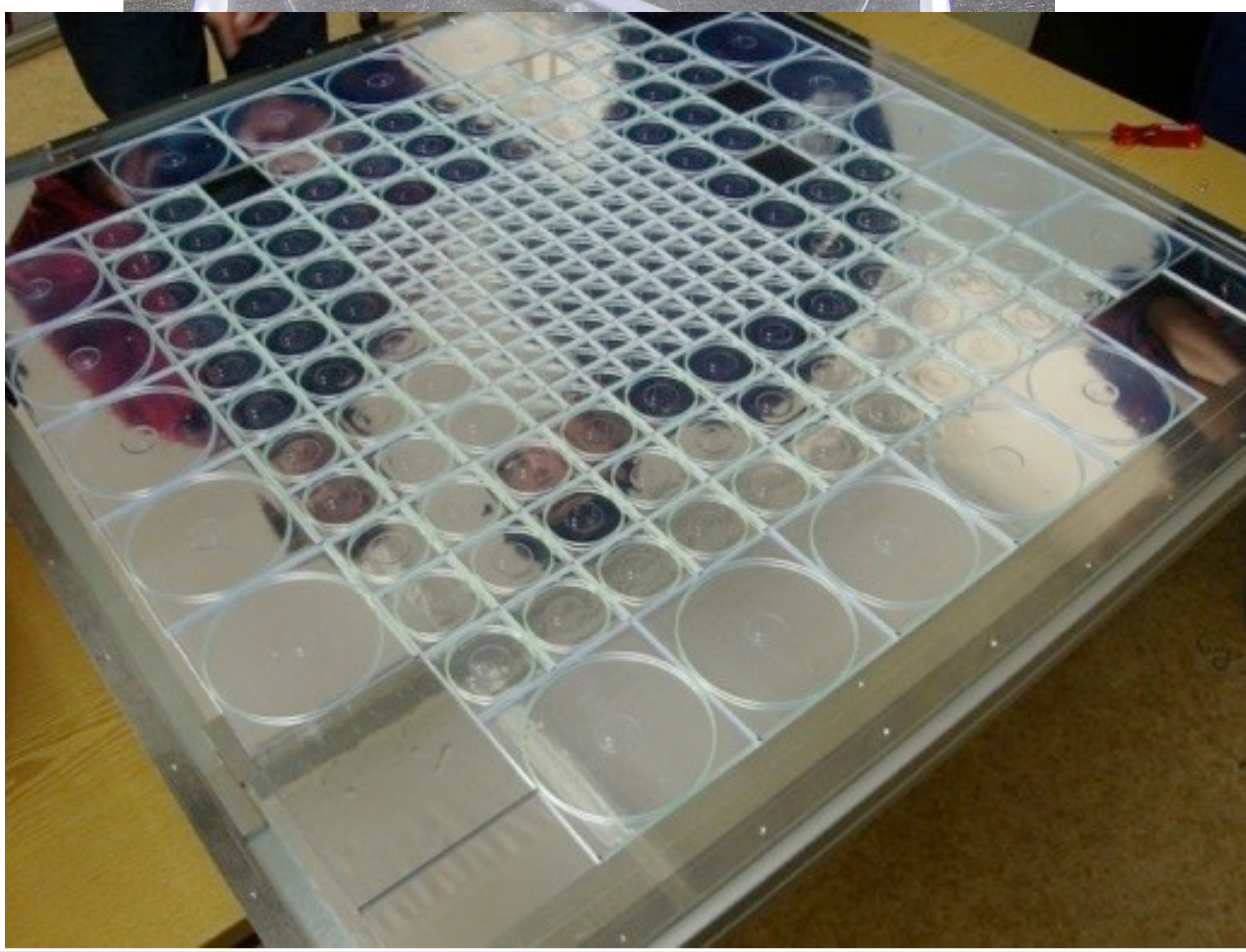
The AHCAL Physics Prototype

- The unit: scintillator tile with SiPM





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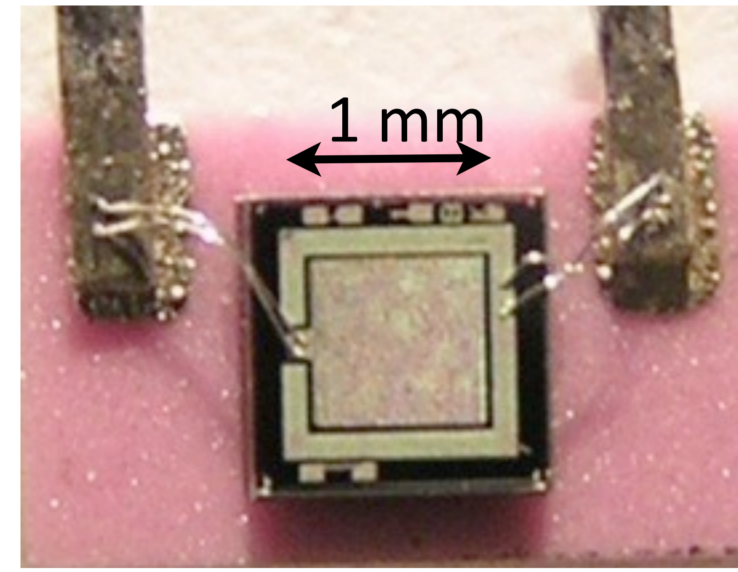


ximum efficiency in green spectral range: velength shifting fiber to collect and shift e scintillation light

- 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,...

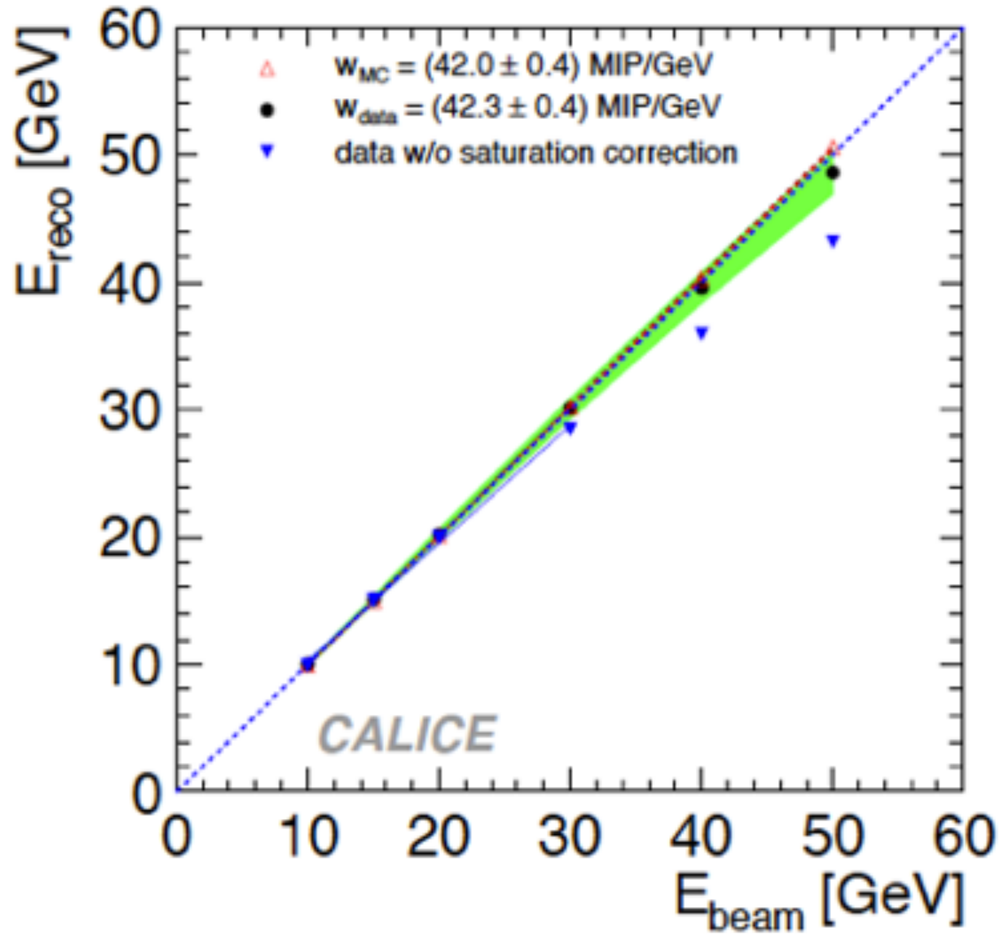
- The technology is extremely robust:
  The AHCAL active elements have completed 6 years of data taking
  - 2006 & 2007: CERN
  - 2008 & 2009: FNAL
  - 2010 & 2011: CERN

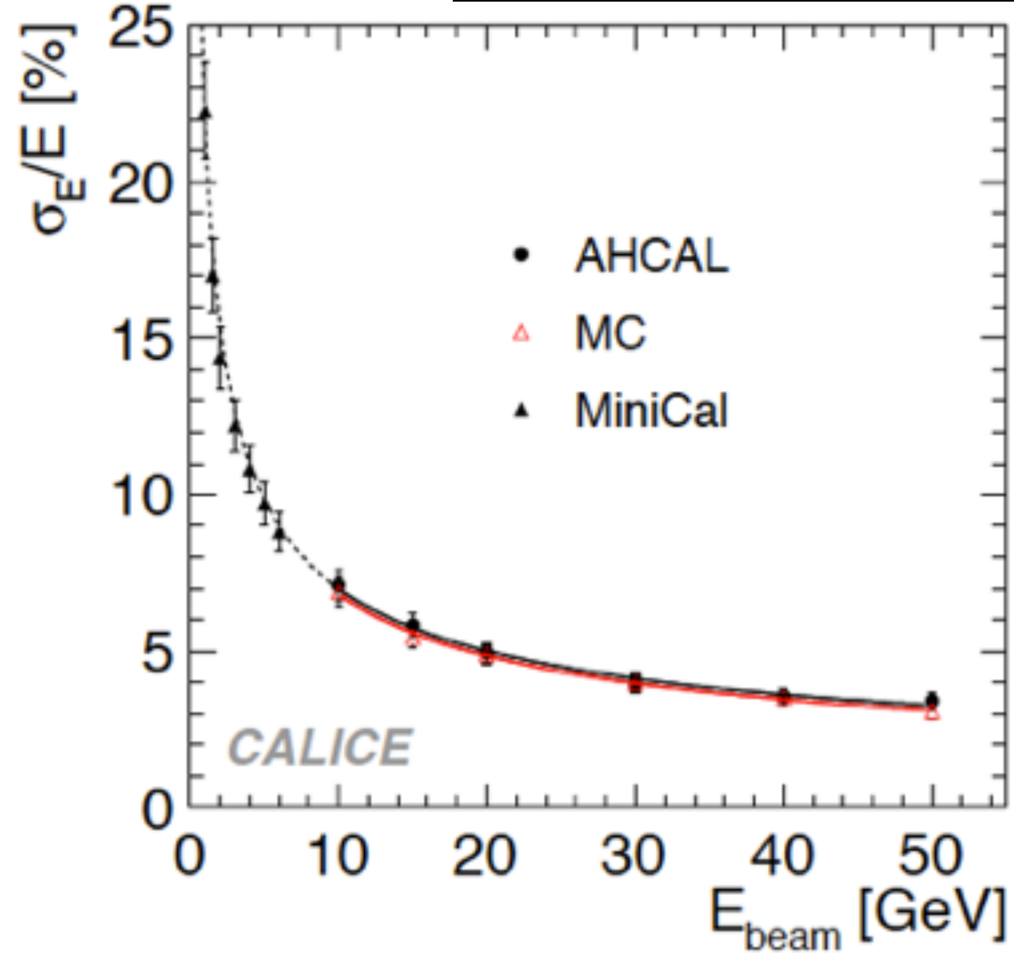
Many trips with disassembly & reassembly of the calorimeter:
DESY - CERN - DESY - FNAL - DESY - CERN PS - CERN SPS
... and the SiPMs survived without problems!

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)



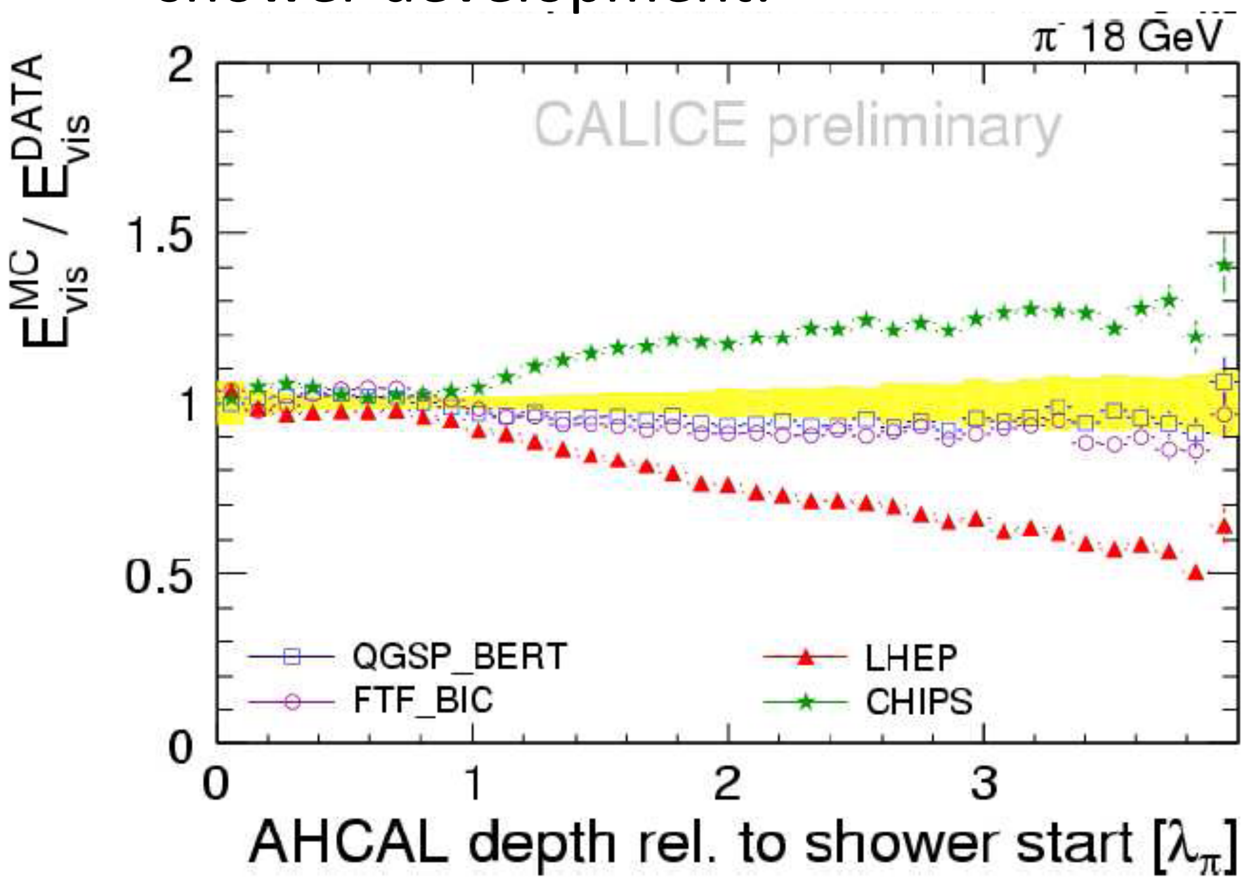


- Spectacular agreement, no surprises: AHCAL geometry description, simulation and digitization in excellent shape (no inclusion of non-uniformities necessary!)
- Energy resolution 22%/√E: Non-uniformities and cell-to-cell calibration uncertainties have no influence on hadronic measurements!

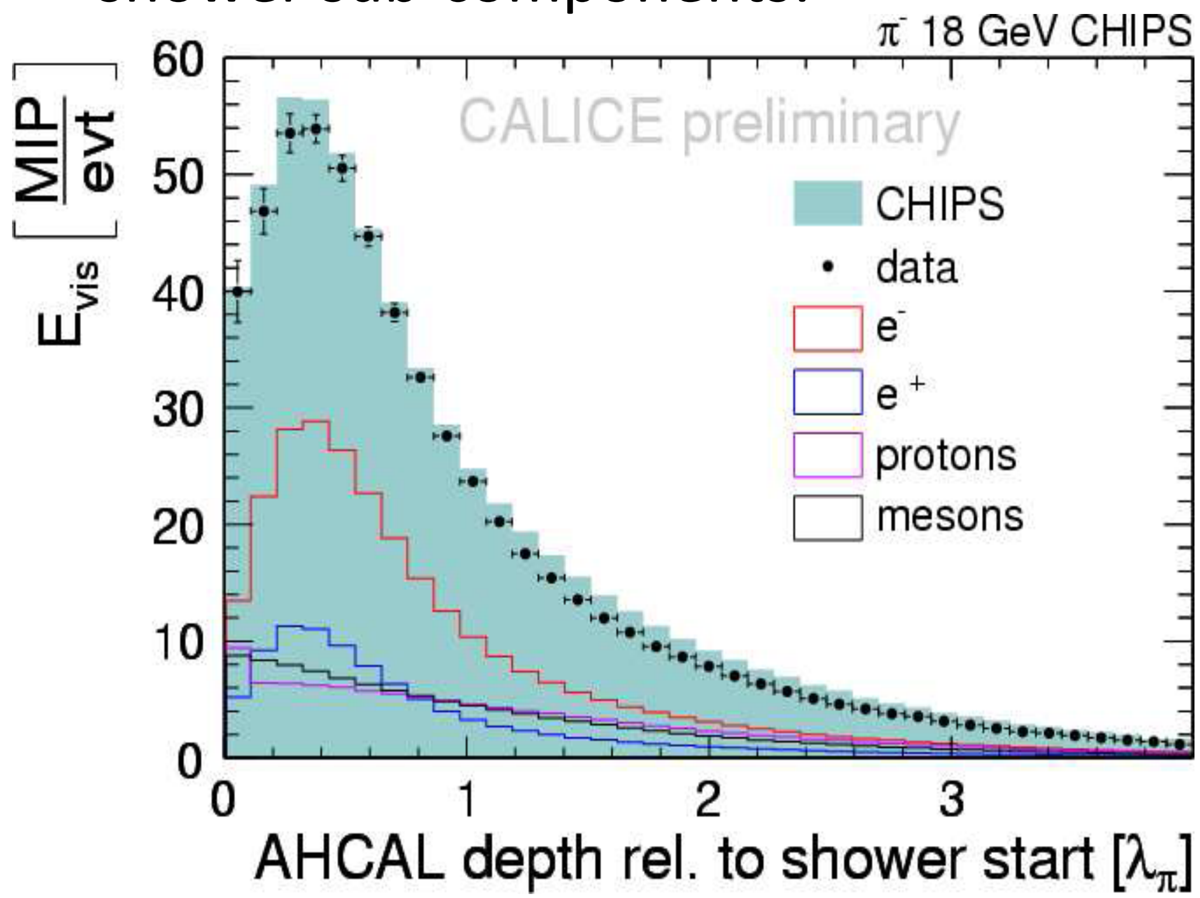
Validation of GEANT4 Simulations

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

shower development:



shower sub-components:



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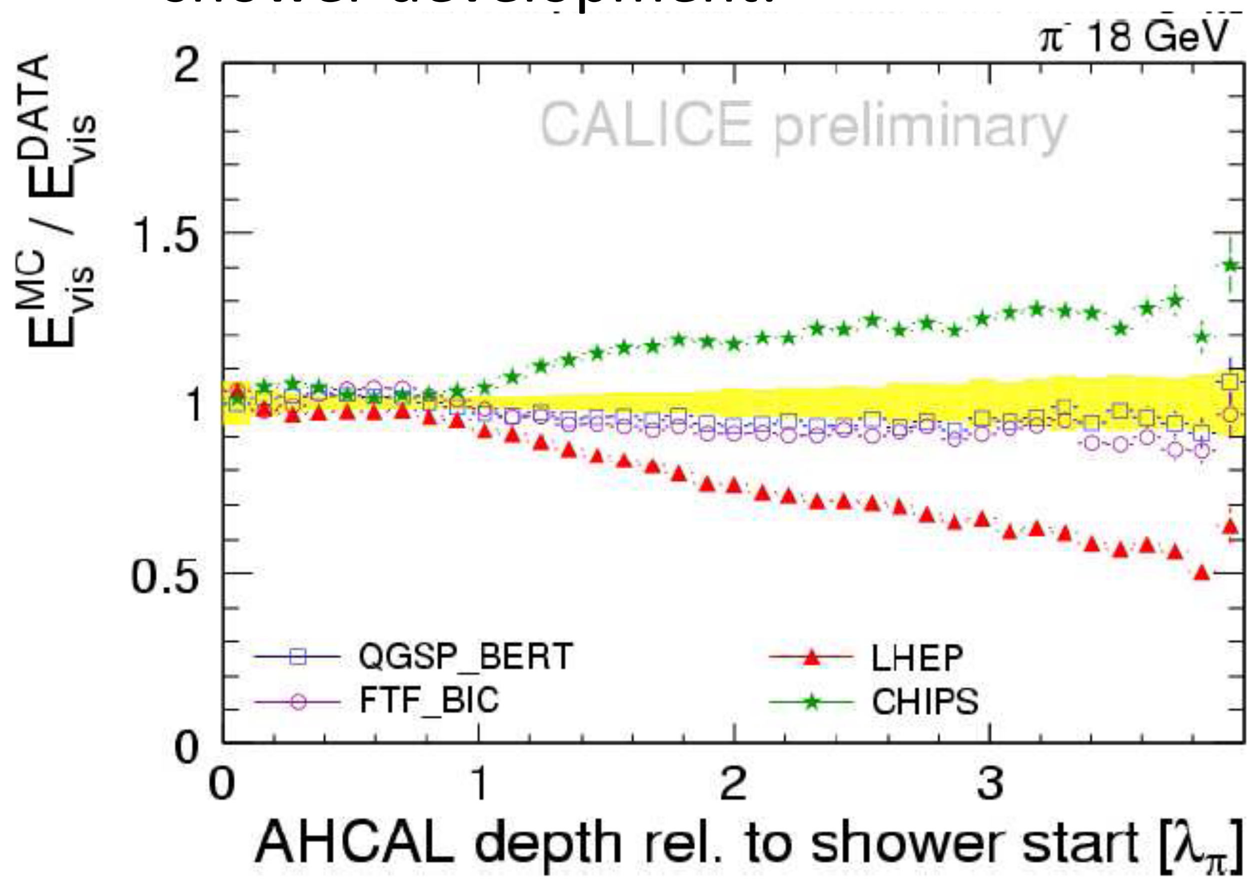
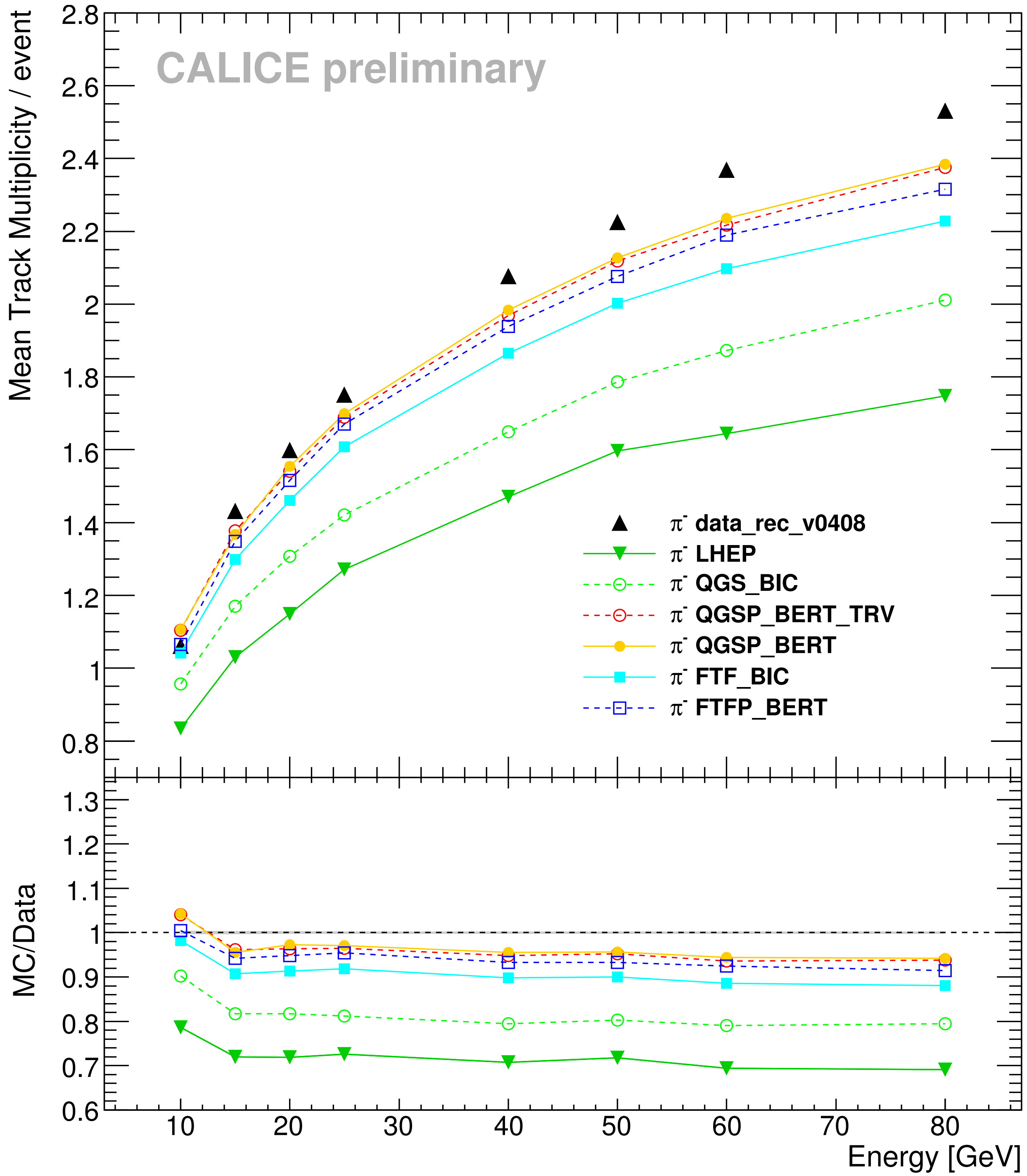


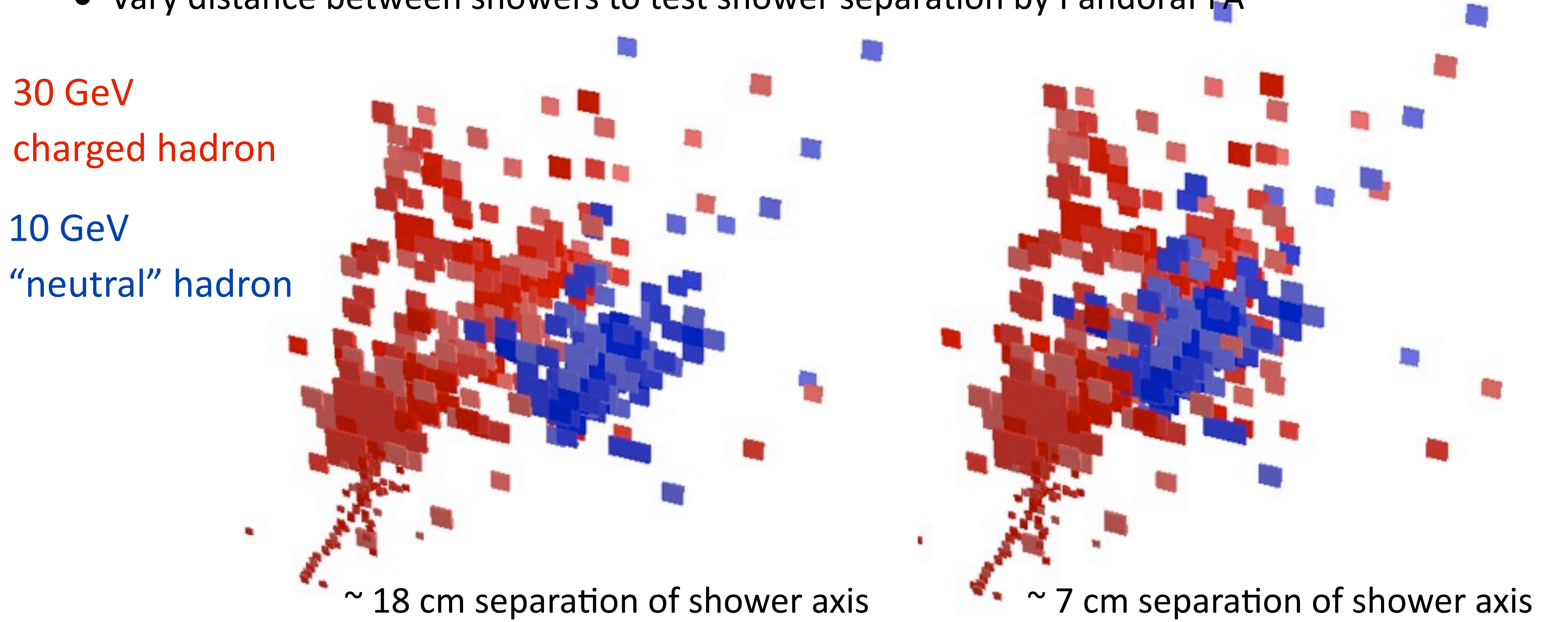
3D substructure: track segments, identified within hadronic showers



PFA Performance: Level of Realism?

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

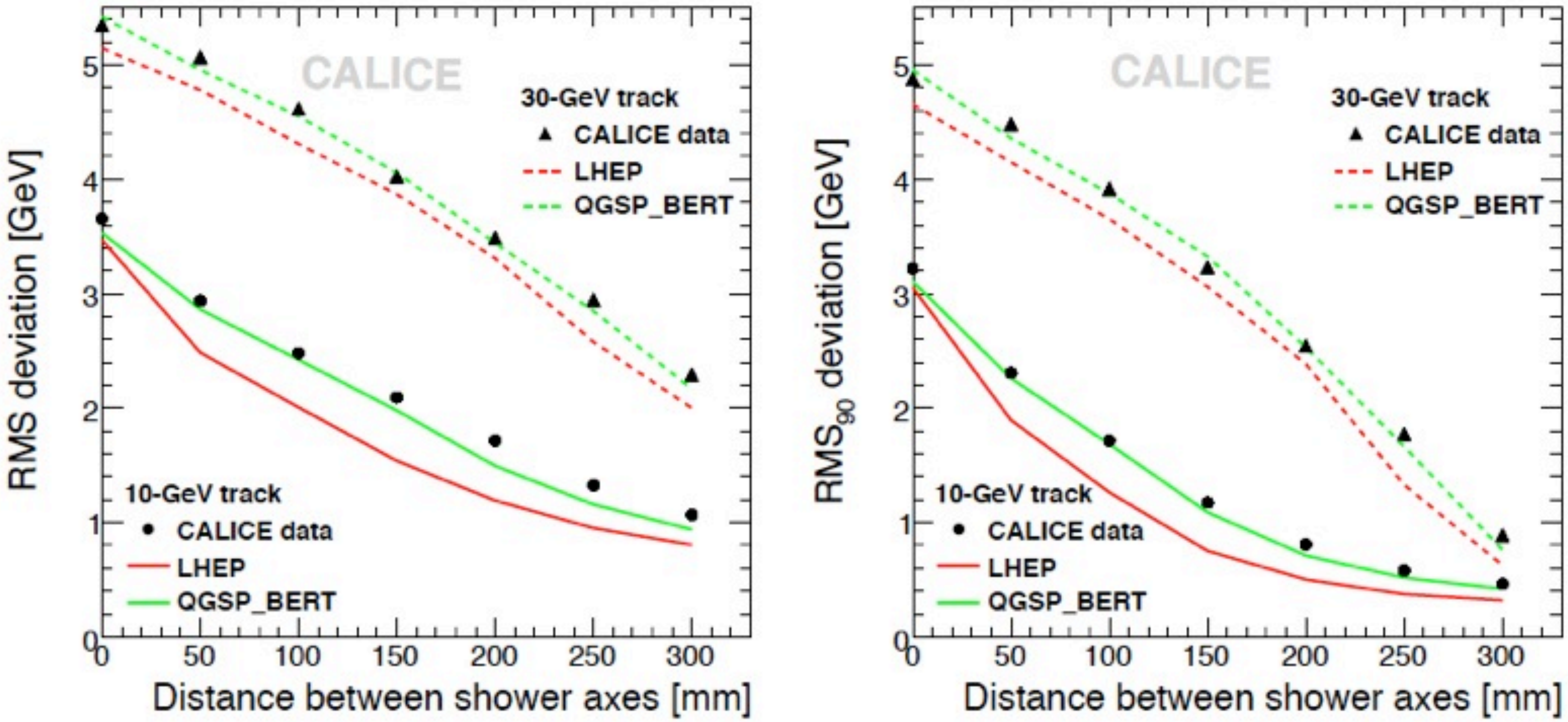
  Test it! ➫ Use real hadronic showers recorded with AHCAL, map them into ILD
  - Take one shower as a charged hadron (with tracking information), one shower as a neutral hadron (remove hits before the shower start)
  - Vary distance between showers to test shower separation by PandoraPFA



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)

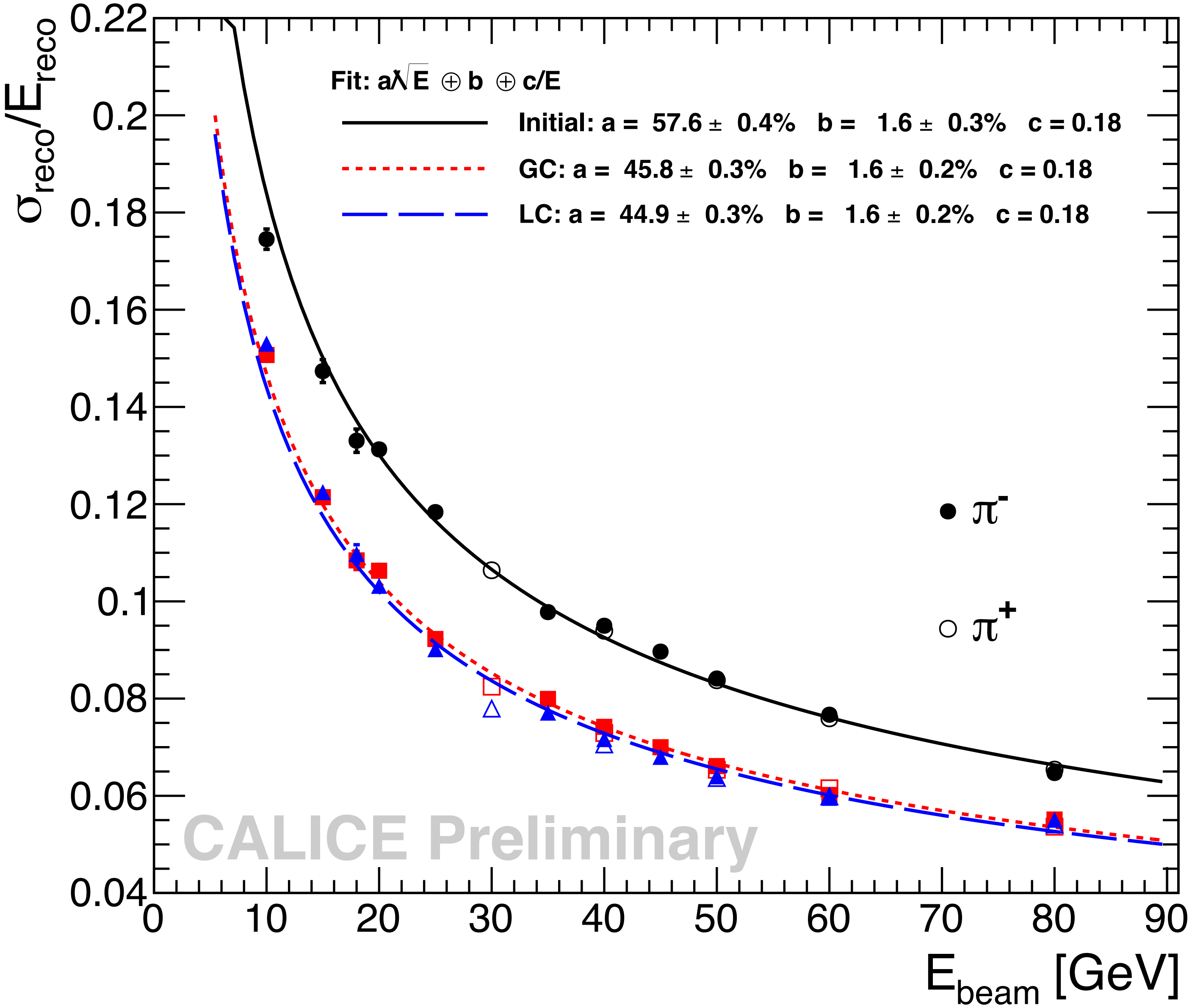


Note: Performance reduced compared to PFA in a real Experiment: No magnetic field, mapping of cells, ...

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

Summary

- The 2nd generation prototype ("technical demonstrator") of the AHCAL is progressing well
  - First successful test beam results with new electronics
  - Mechanics established
  - Plans for test beam using timing capabilities in fall 2012
- The physics prototype of the AHCAL has laid the foundations for analog hadron calorimetry at linear colliders
  - Excellent electromagnetic performance & simulation realism
  - Thorough tests of hadronic shower models
  - Good energy resolution

Backup