Analog HCAL R&D

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for the CALICE Collaboration

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Calorimeter for ILC

Excellence Cluster
Universe

Outline: Issues under Study

- Technology: Proof of Principle
- Test beam validation of simulations
- Feasibility of integration
- Full detector simulation and reconstruction

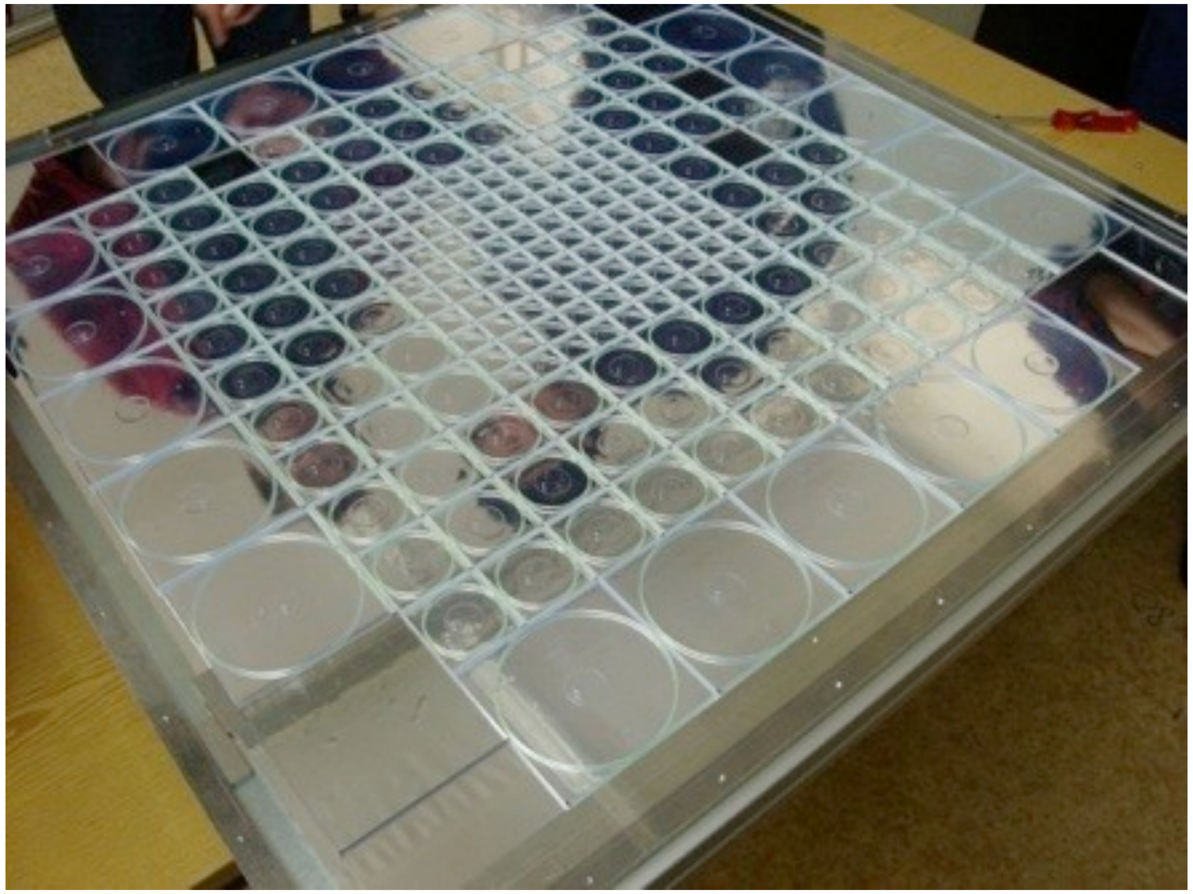
Proof of Principle & Validation

Exploiting the Physics Prototype

Proof of Principle: Technology & Long-Term Behavior

- Based on the successful operation of the physics prototype

38 layer analog HCAL
Scintillator-Steel
1 m^3 instrumented
test beam campaigns
DESY, CERN, FNAL
2006-2009



7608 scintillator cells with SiPM readout: First large scale detector with SiPM technology!

Proof of Principle: Technology & Long-Term Behavior

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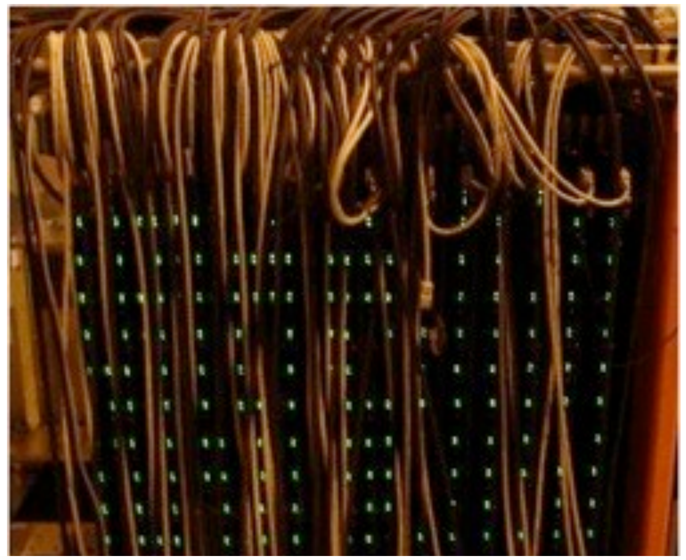

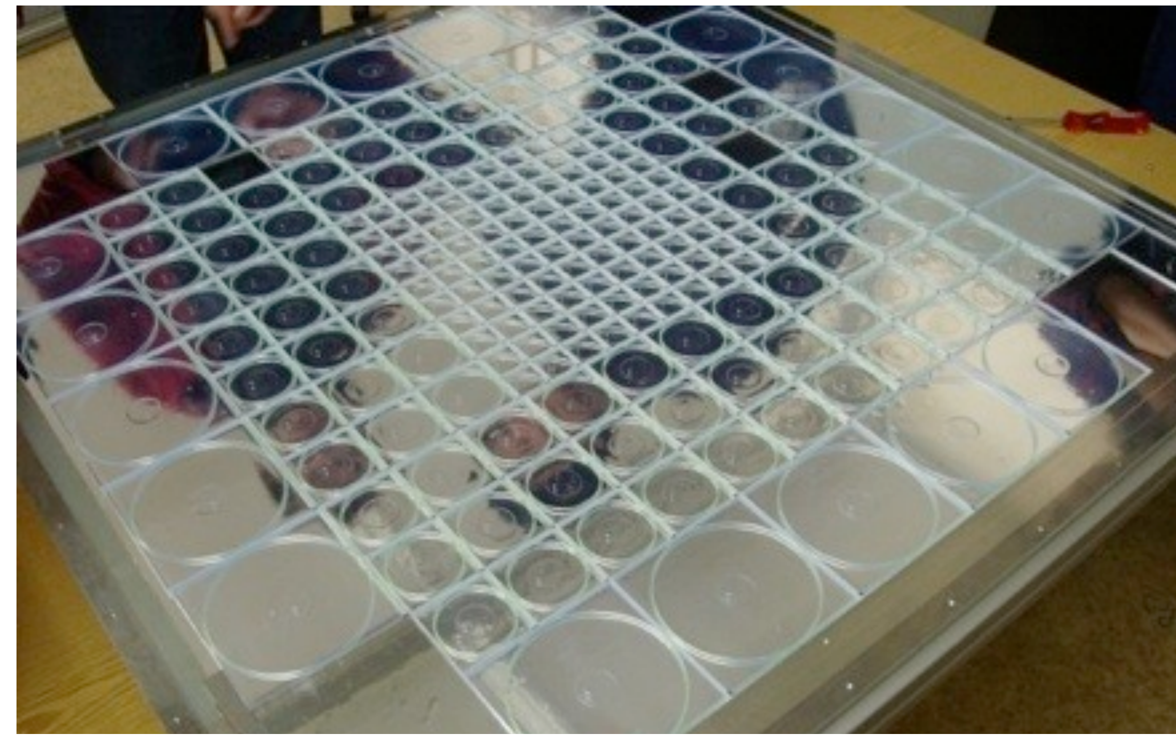

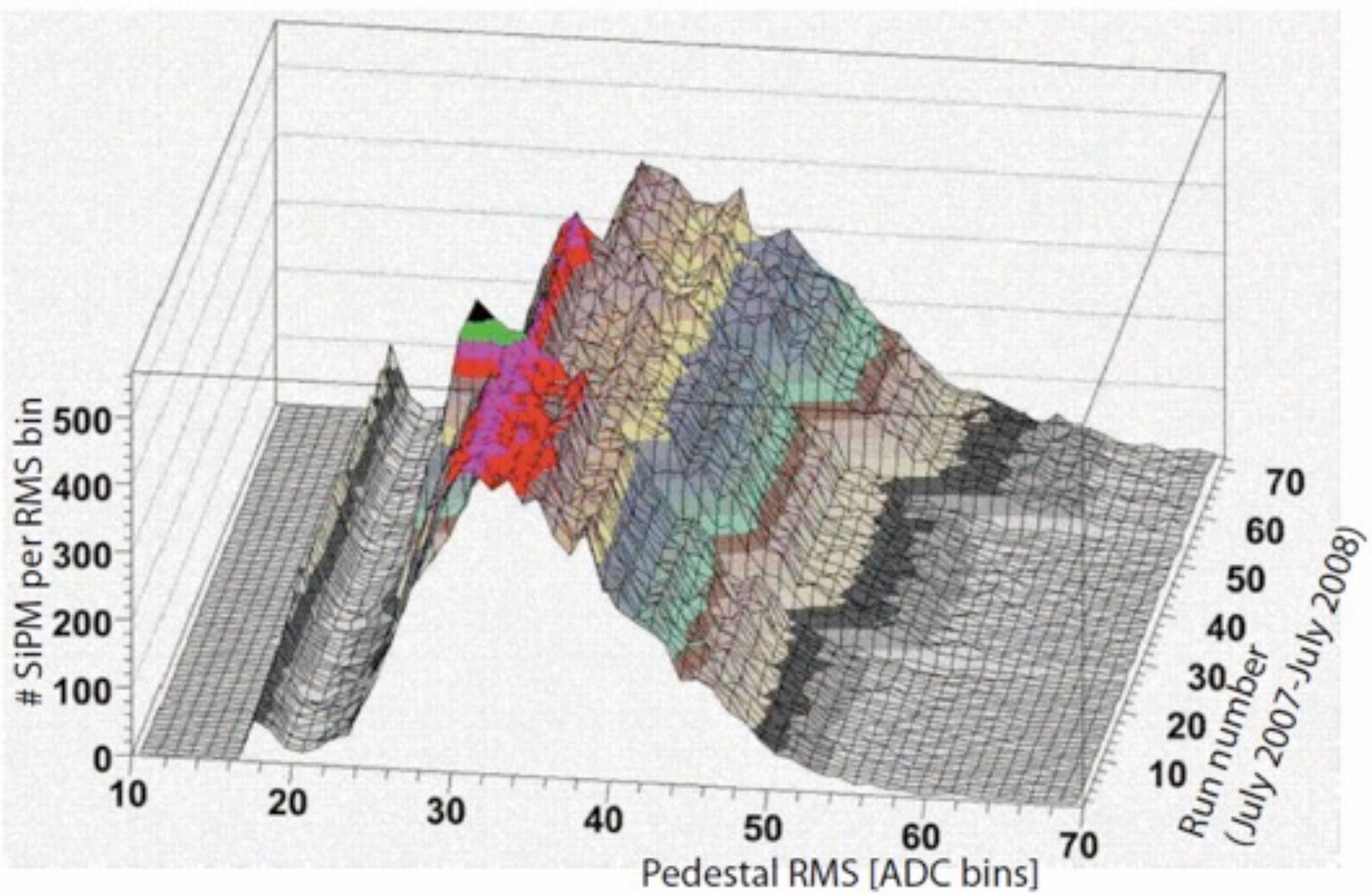

- stable performance over several beam periods, including intercontinental shipping
- no indication of substantial ageing or performance changes, problematic channels on the per-mille level
- ~ 2% dead channels due to initially bad soldering, broken connections, ...: fixed in new design!

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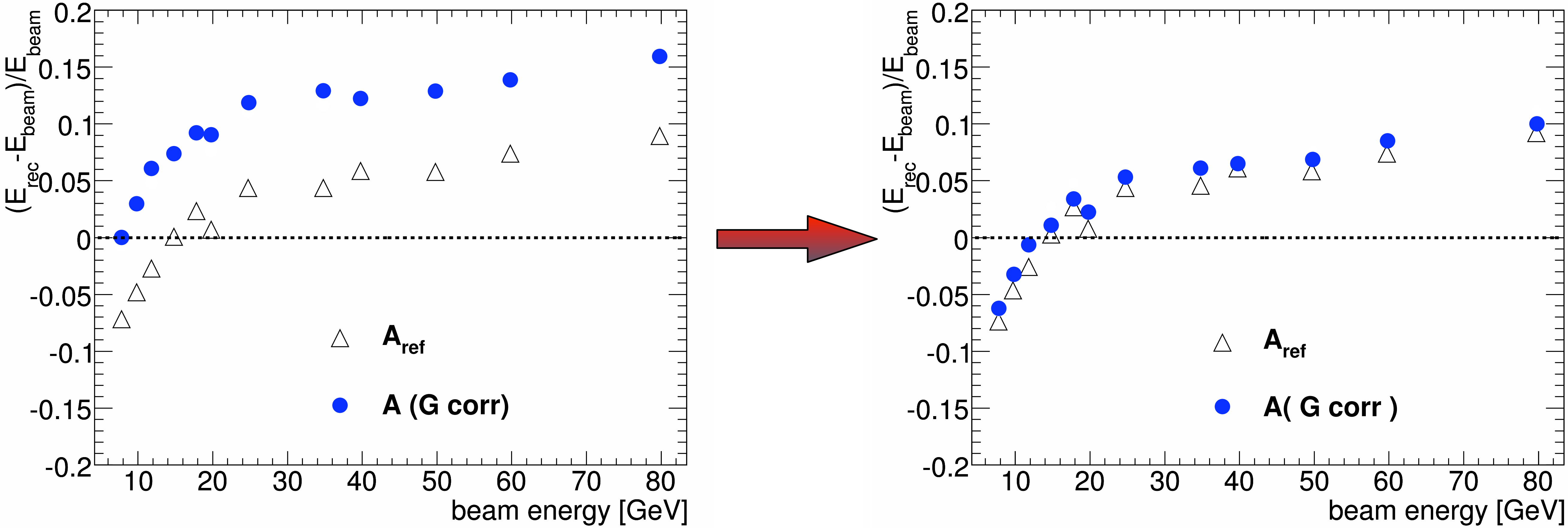
Proof of Principle: Calibration

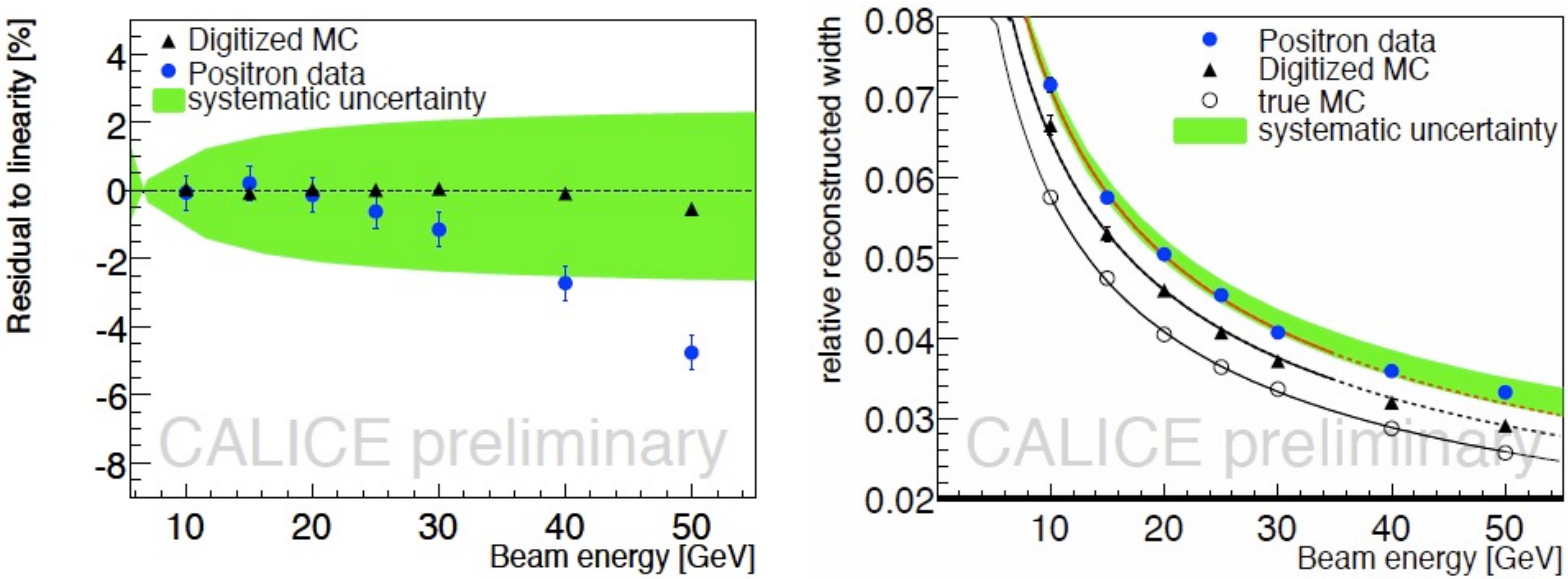
- Well-established and well-tested calibration procedure:
  - self-calibrating feature of SiPMs for gain determination, overall cell response with minimum-ionizing particles



- Transportation of calibration coefficients from FNAL to CERN data tested successfully: "Simulation" of a complete calibration strategy with pre-installation module test in beams, and only a layer-wise global adjustment after installation

Validation: Electromagnetic Response

- Already a high degree of detector understanding in simulations, demonstrated with electromagnetic data

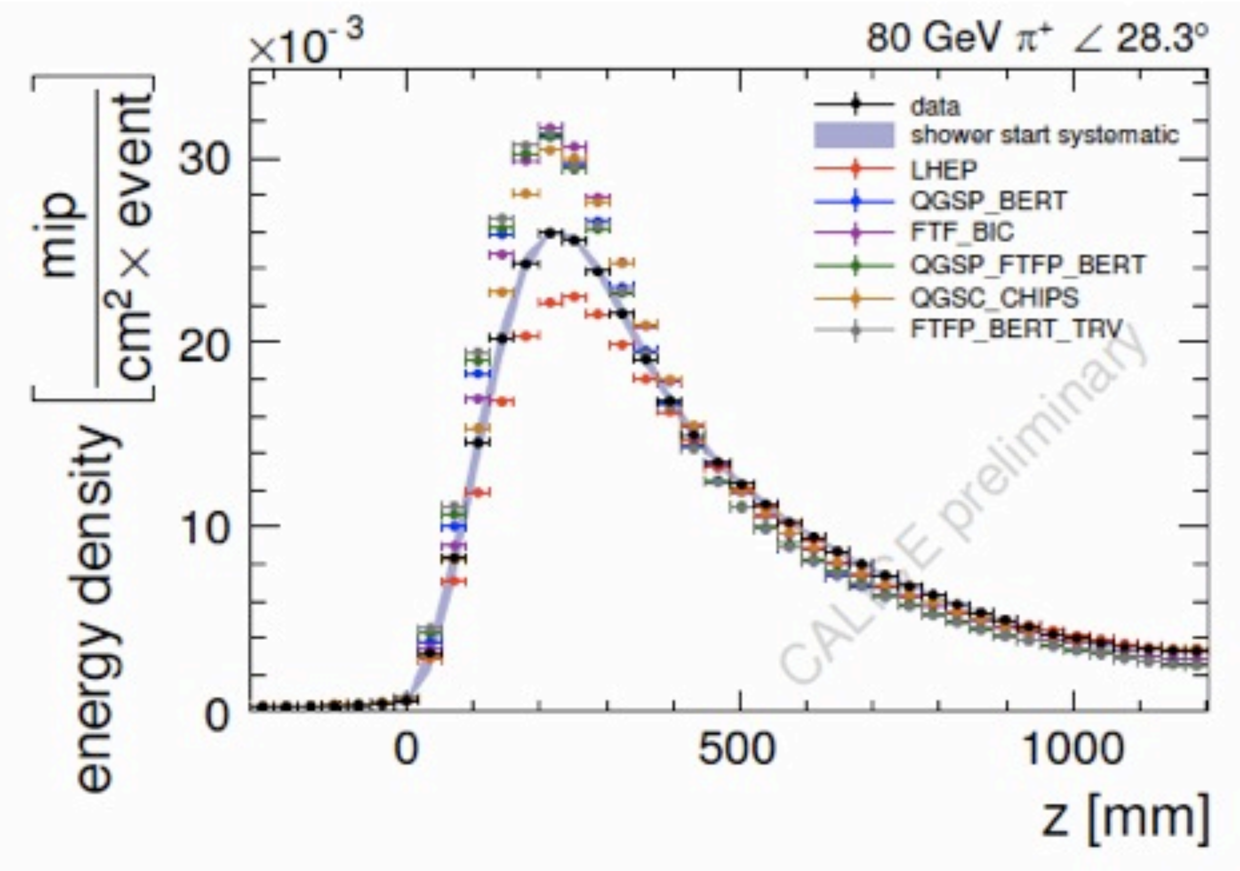


- Work under way to further improve the detector simulation, in particular the digitization: focus on the treatment of noise, cross talk, saturation

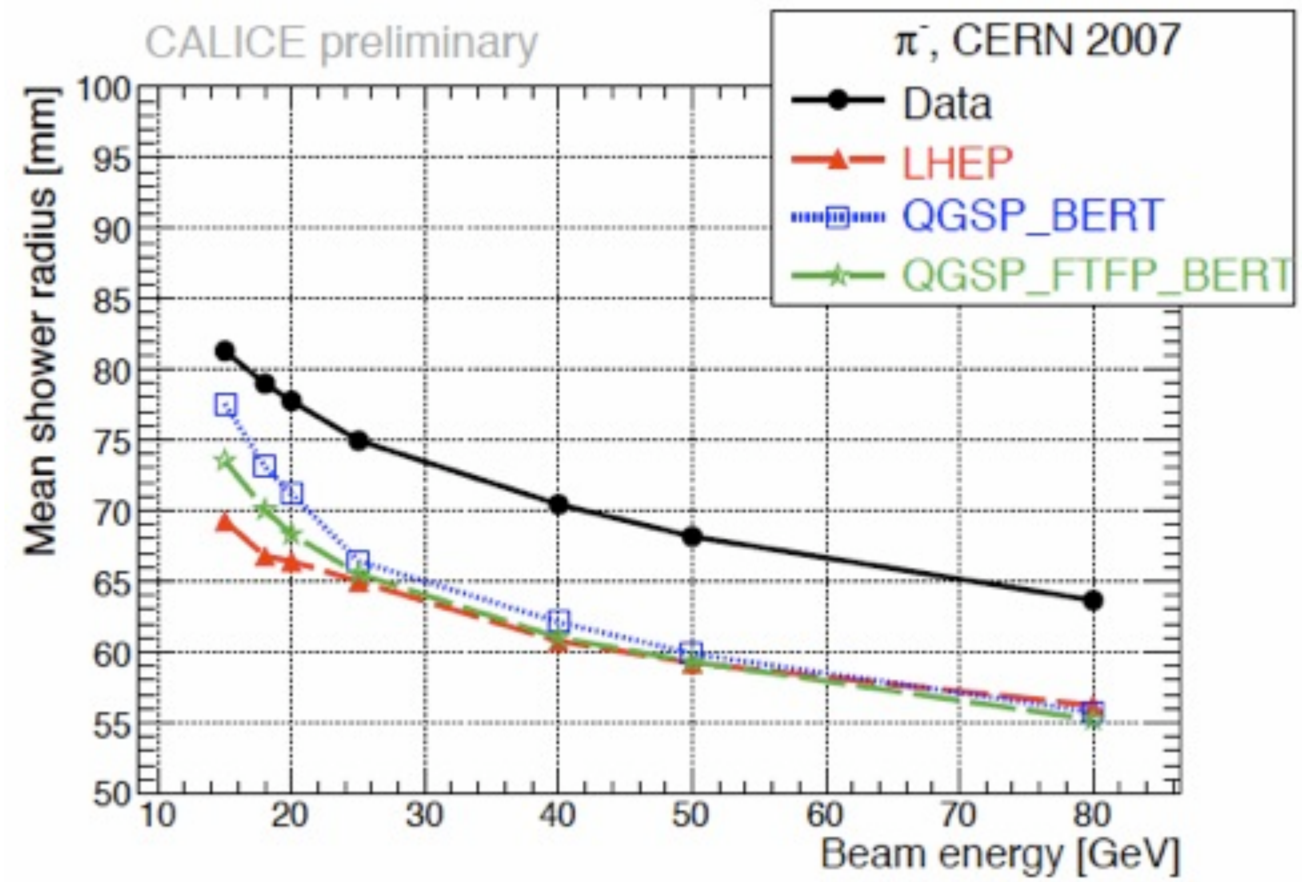
➯ Important for a realistic simulation of a full ILD Calorimeter

Validation: Hadronic Showers

- Detailed studies of shower profiles: Comparison to a variety of physics lists



- Longitudinal profile, measured from shower start point



- Mean shower radius as a function of energy

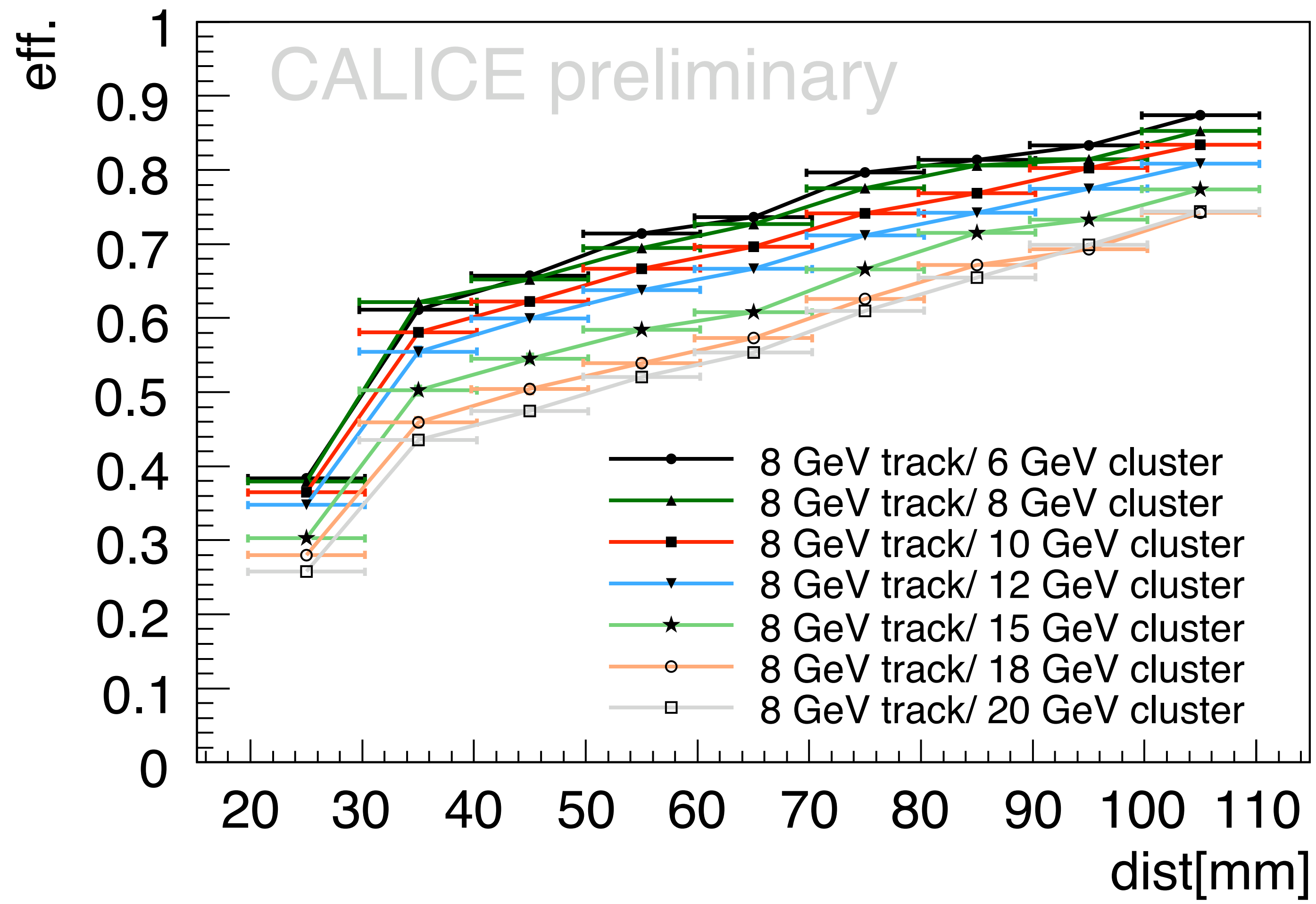
- Close collaboration with Geant4 developers to further improve hadronic physics lists

Validation: Shower Separation

- Separation of showers crucial for PFA performance

- First study with two overlayed showers and simple PFA-like clustering

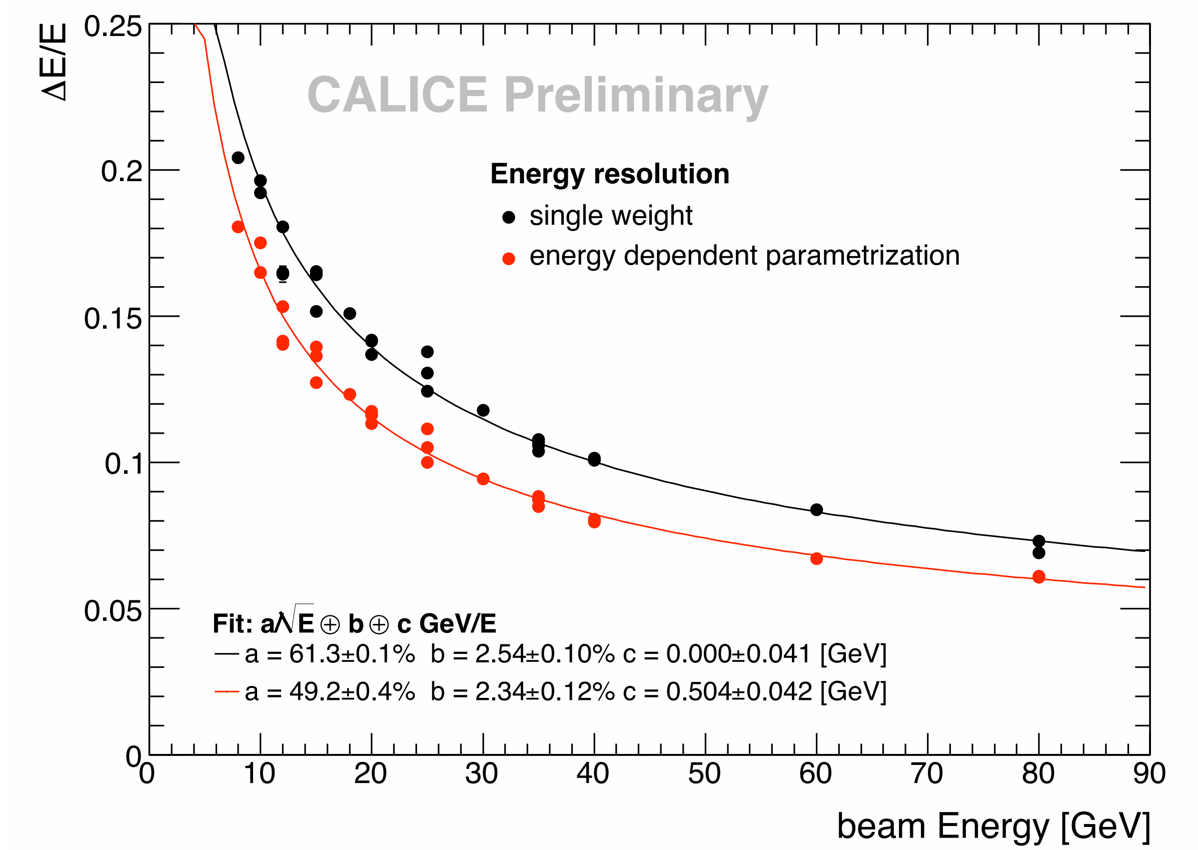
  Efficiency for correctly reconstructing the neutral particle with an energy within 3 σ as a function of shower distance
  - Currently only very small distances due to available data set

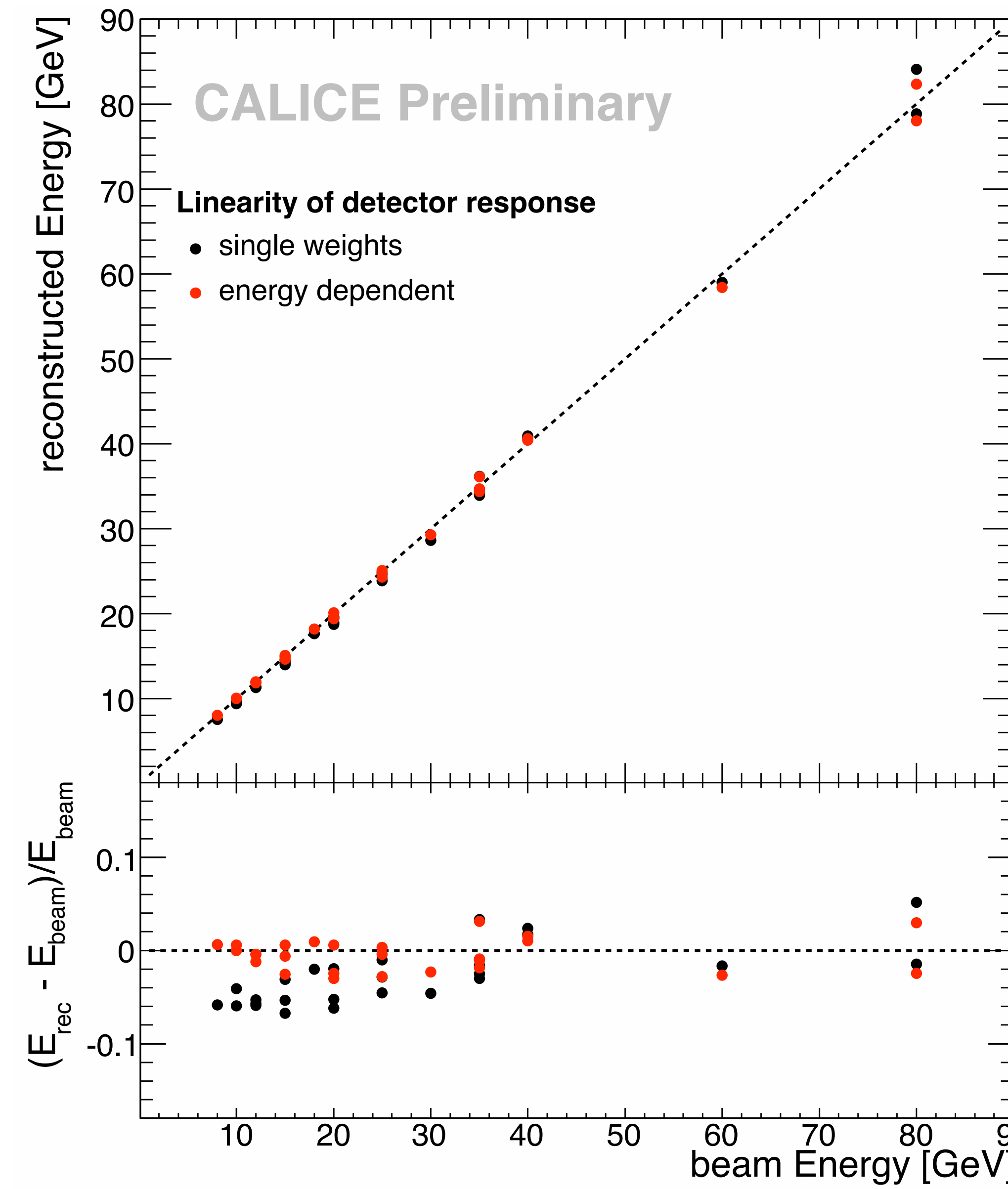


- Expansion to PandoraPFA currently in progress

Validation: Hadronic Energy Resolution

- Energy resolution for hadronic showers in the complete CALICE setup: ECAL, HCAL, TCMT
  - Use of a simple software compensation technique to improve resolution and linearity





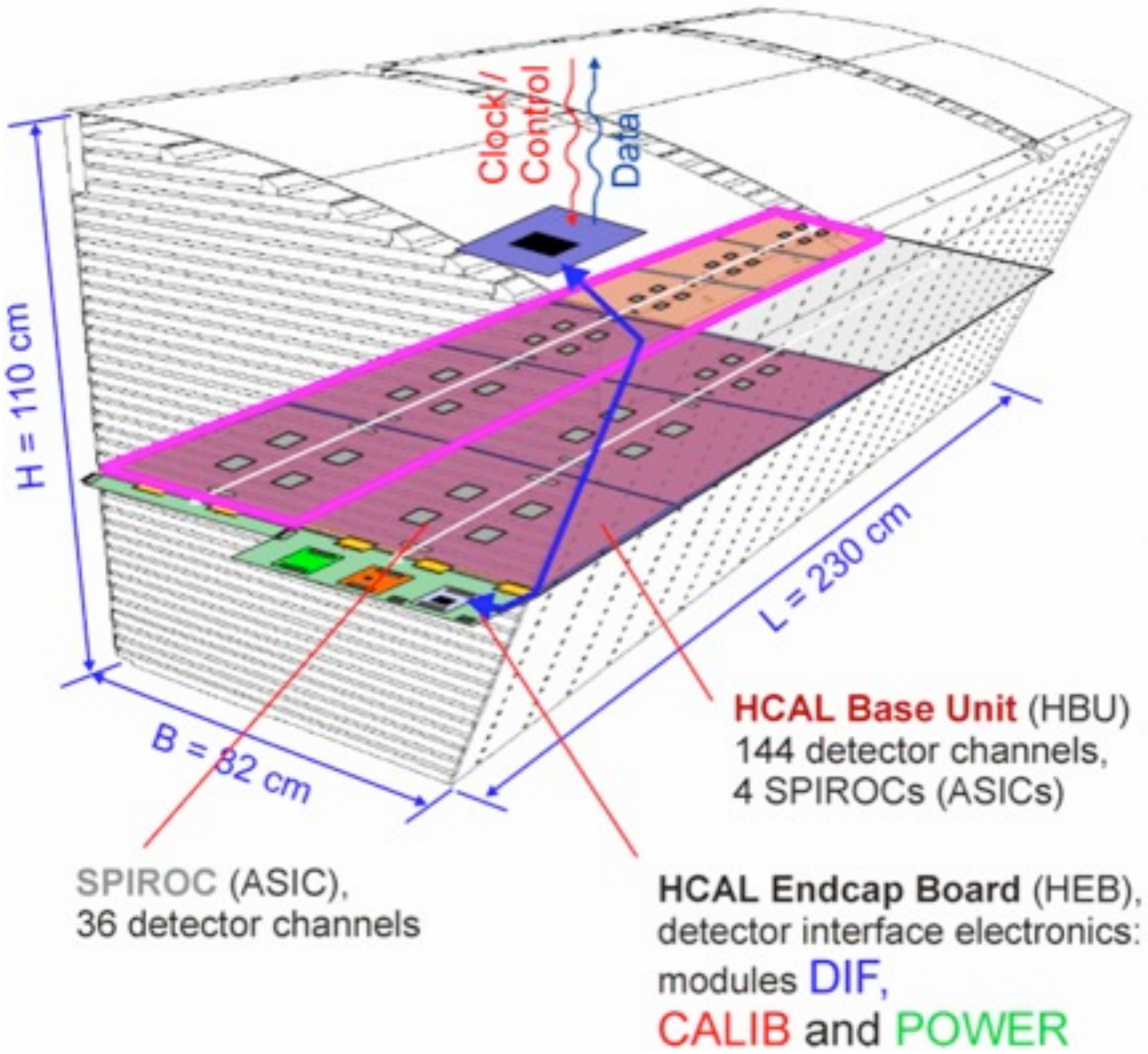
- Expansion of compensation studies
- Detailed comparisons to simulations with a variety of physics lists in preparation

Integration

Towards a 2nd Generation Prototype

The Second Generation

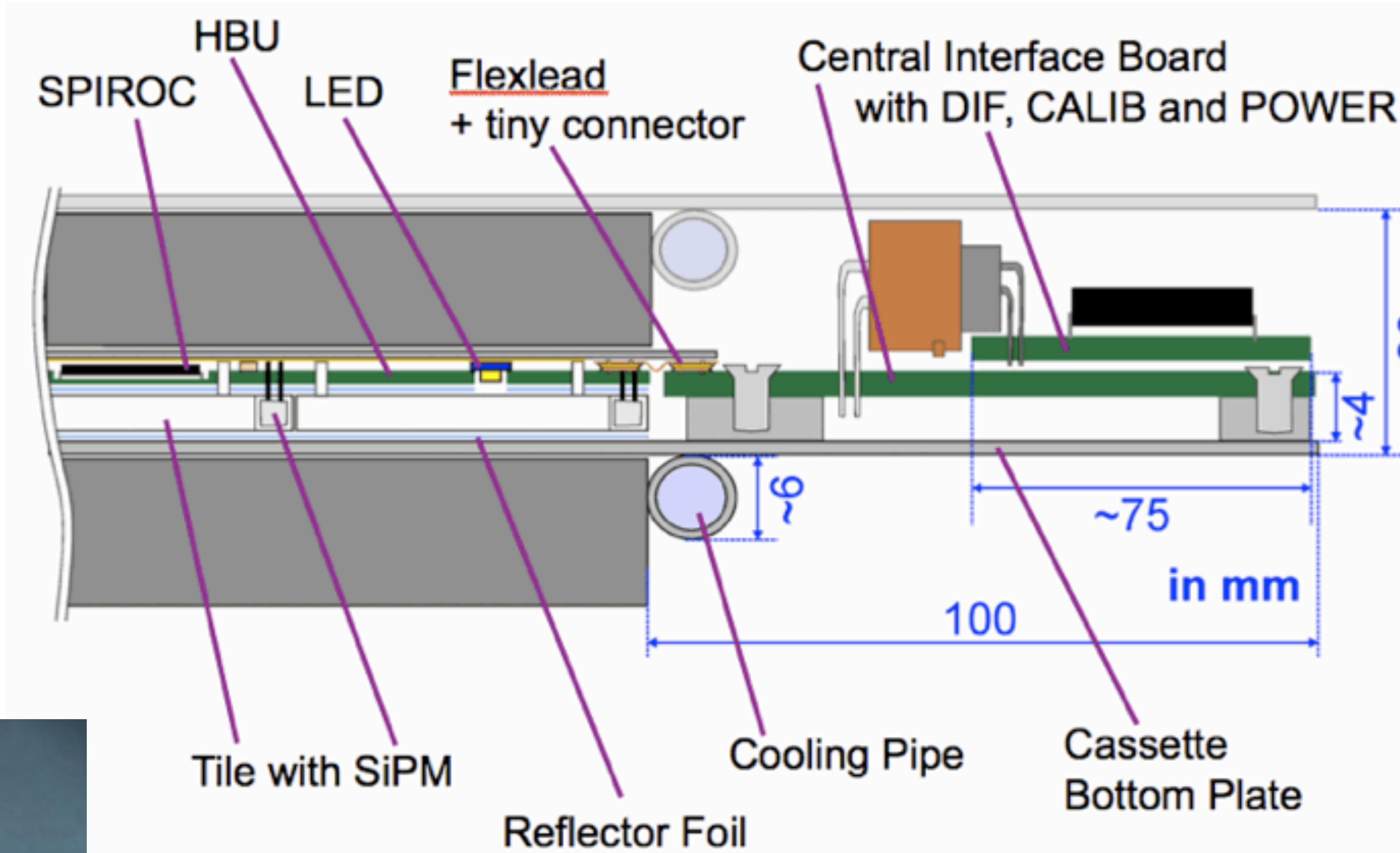
- Towards a scalable and compact detector
  - Realistic design:
    - Dead spaces, tolerances
    - Costing
  - Embedded front end ASICS
  - Mechanical structure with minimum dead space
  - Options for scintillator and photo-sensor integration

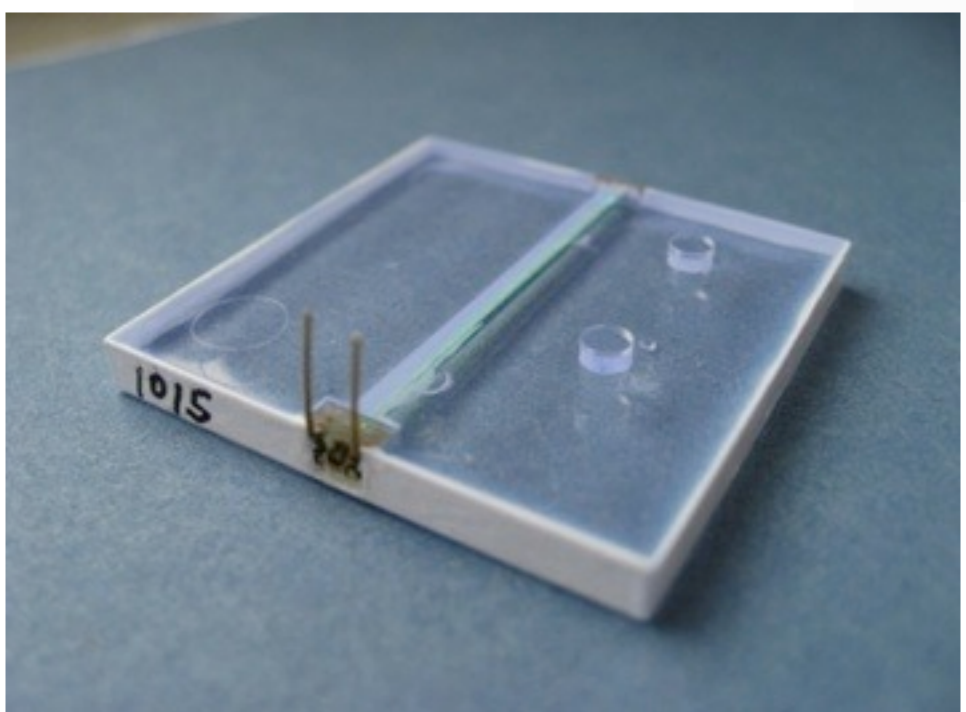


- Technical challenge:
  - Stability with power pulsing and online zero suppression

The Second Generation: Active Layers

compact layers:
3 mm thick tiles +
electronics in a
cassette





- New scintillator tiles and SiPMs (CPTA MRS-APDs): improved performance in terms of noise and cross-talk
  - tiles and electronics boards can simply be cut to accommodate changing layer dimensions

The Second Generation: Mechanics

- Vertical and horizontal test stacks already constructed

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

The Second Generation: Road Map

- Construct full read-out layer, test in DESY test beam (2010)
  - needs 6 HBU, ~ 1000 cells
- Reestablish performance with power pulsing and auto-trigger
  - noise occupancy, MIP S / N, efficiency
  - environmental stability
  - uniformity over full area

- Construct mini-tower (~ 2011): Electromagnetic calorimeter, ~ 12 layers instrumented with a single HBU
  - build on electromagnetic results with present physics prototype, validate 2nd generation detector in a complete calorimeter setting

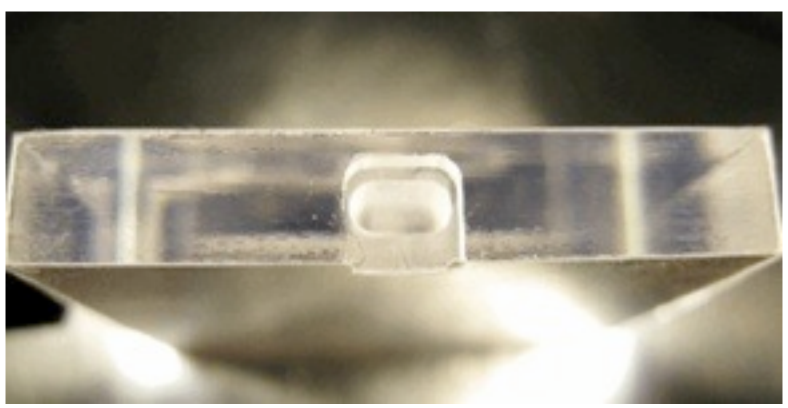
‣ completion of analysis by 2012 challenging

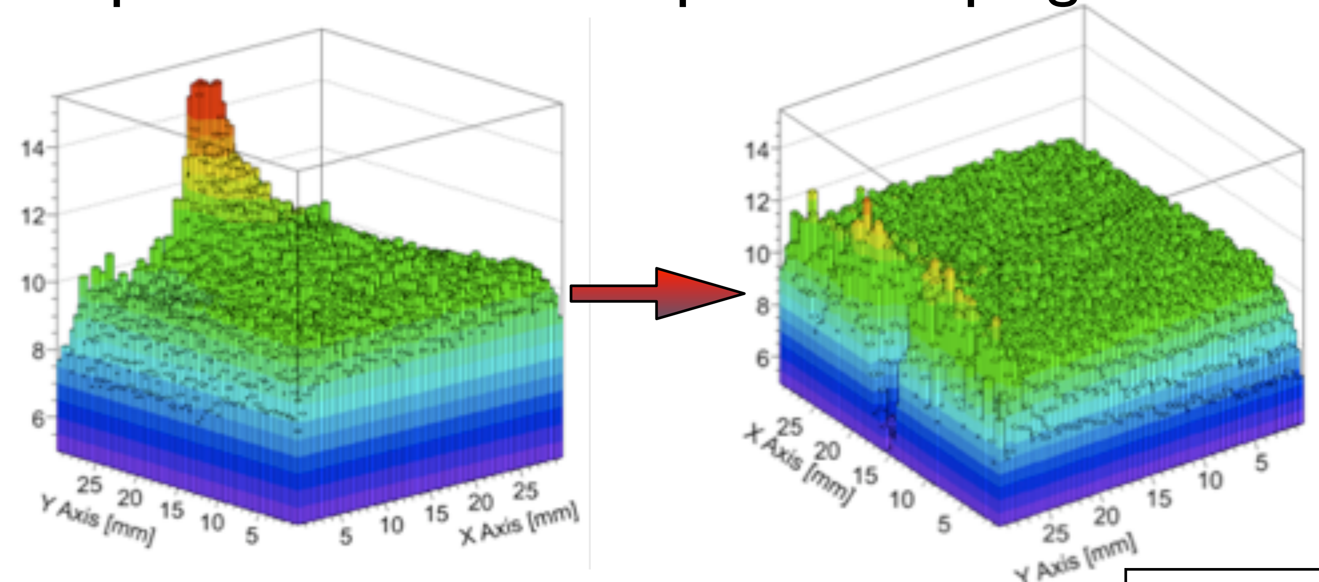
The Second Generation: Mechanical Integration

- Validation of mechanical construction
  - Module interconnection (maybe only barrel)
  - Stability under various orientations
  - ECAL HCAL integration
    - mechanics, cabling and cooling
  - active layers of varying dimensions, minimum dead zones
- Design barrel-endcap transition area
- Heat dissipation for (at least one) full area: test with fully equipped layer
- ILD cabling and cooling scheme
- Costing

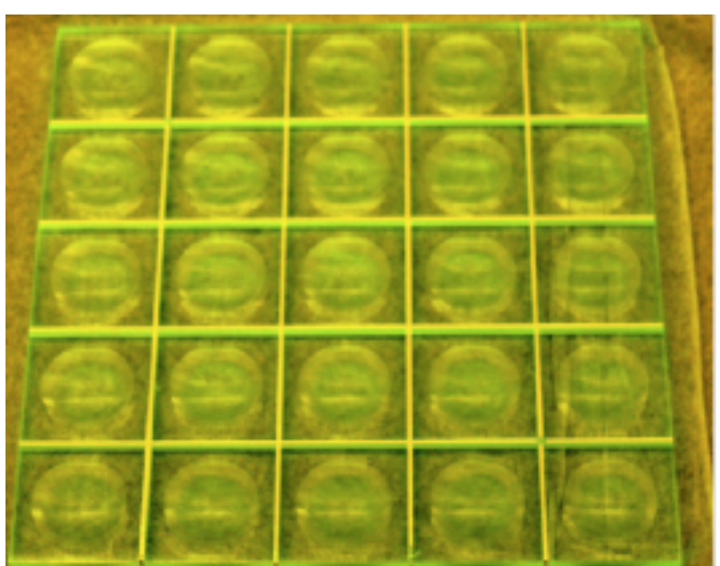
Alternative Photon Sensor Coupling

- Investigate fiberless coupling of SiPM to scintillator: Possible due to the availability of blue-sensitive sensors
  - faster response: improved time resolution
  - simplified production of scintillator cells, relaxed mechanical tolerances
  - ▸ A challenge: Uniformity of response: Solved with specific shaping of scintillators





arXiv:1001.4665 [physics.ins-det]

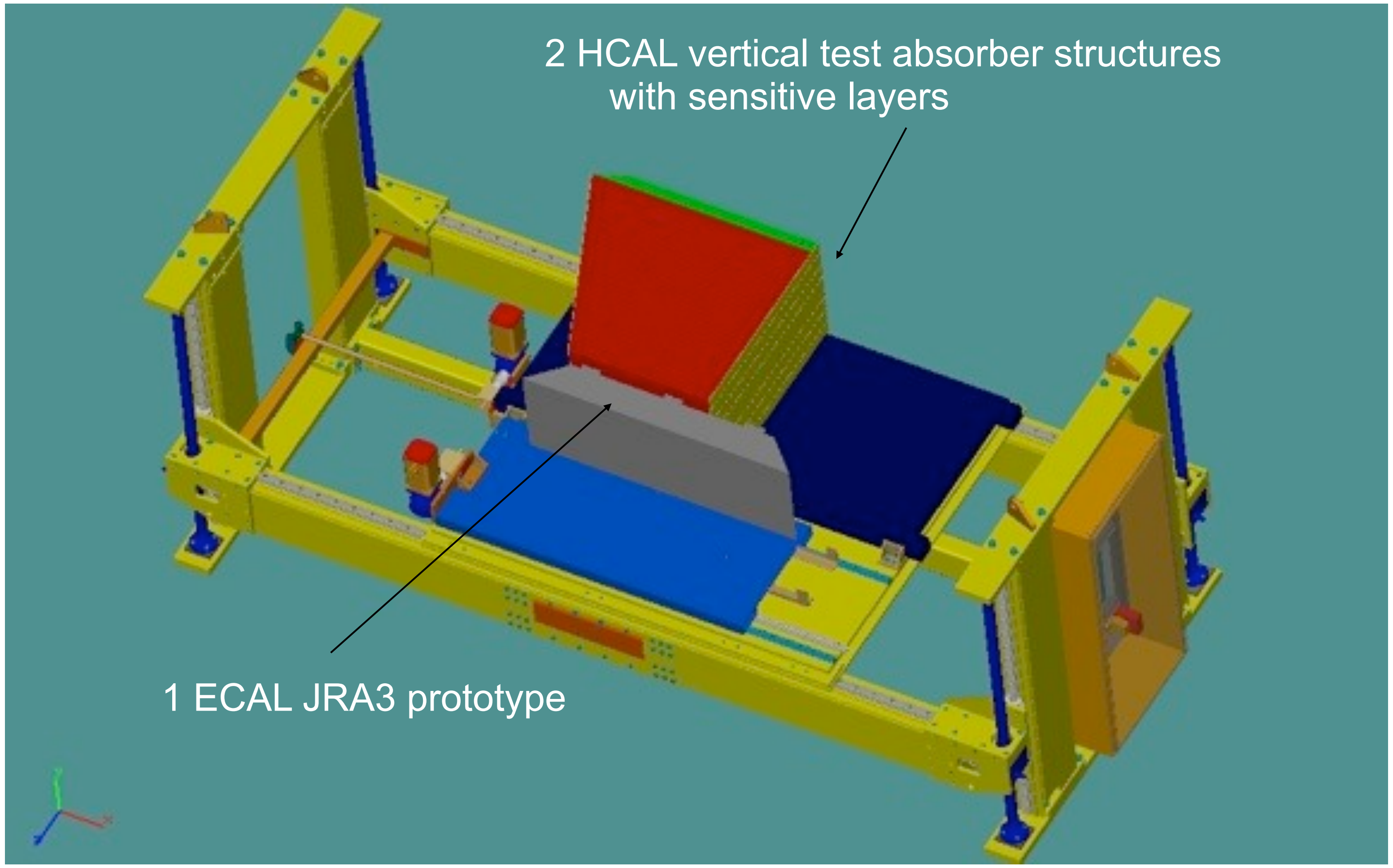


- Compatible with 2nd generation electronics boards with no or minimal modifications
  - ▸ Study performance with new electronics!

NIM A 605 277 (2009)

Beyond 2012: Further Steps

- Full 2nd generation module: At least one 1 m^3 instrumented, needed for full containment of hadronic showers
- Re-establish hadronic performance on full scale, building on the successful test beam campaigns with the physics prototype
- Study neutron timing in data, simulation and reconstruction: New electronics provides time stamping
  - "4D" Shower image: See the time structure of neutrons
  - pileup rejection: Crucial for CLIC
- Alternative absorbers: Iron and Tungsten
- Validate shower simulations in magnetic field



Simulation & Reconstruction

The analog HCAL in ILD

AHCAL in ILD: Roadmap

- Transport test beam model details to ILD
  - realistic simulation of all material, cell response (digitization), ...
- Define set of shower models to cover range of uncertainty from residual data MC mismatch
- Simulate realistic calibration uncertainties
  - Already achieved in selected areas, further studies under way
- Re-establish PFA performance
  - Study the benefits of software compensation, as tested with the physics prototype, for PFA (already under way)
  - Investigate the influence of neutron timing
- ▸ Extensive physics simulation studies: Also beyond 500 GeV

Summary

- A clear strategy of the Analog HCAL exists for the way to the DBD

- Well advanced in many aspects due to the comprehensive test beam campaigns with the physics prototype
  - Technological proof of principle, demonstration of long-term stability, calibration strategy...

- Clear path forward:
  - 2nd gen. active layers: Demonstration of power pulsing, time stamping in 2010
  - Mechanical integration, investigation of cooling issues,...
  - Extended simulation studies: Improved realism in the ILD AHCAL detector model based on test beam experience, advanced reconstruction methods, ...
  - Alternative photo sensor coupling & absorber materials: study potential for further improvement of detector, suitability for high (up to CLIC) energies