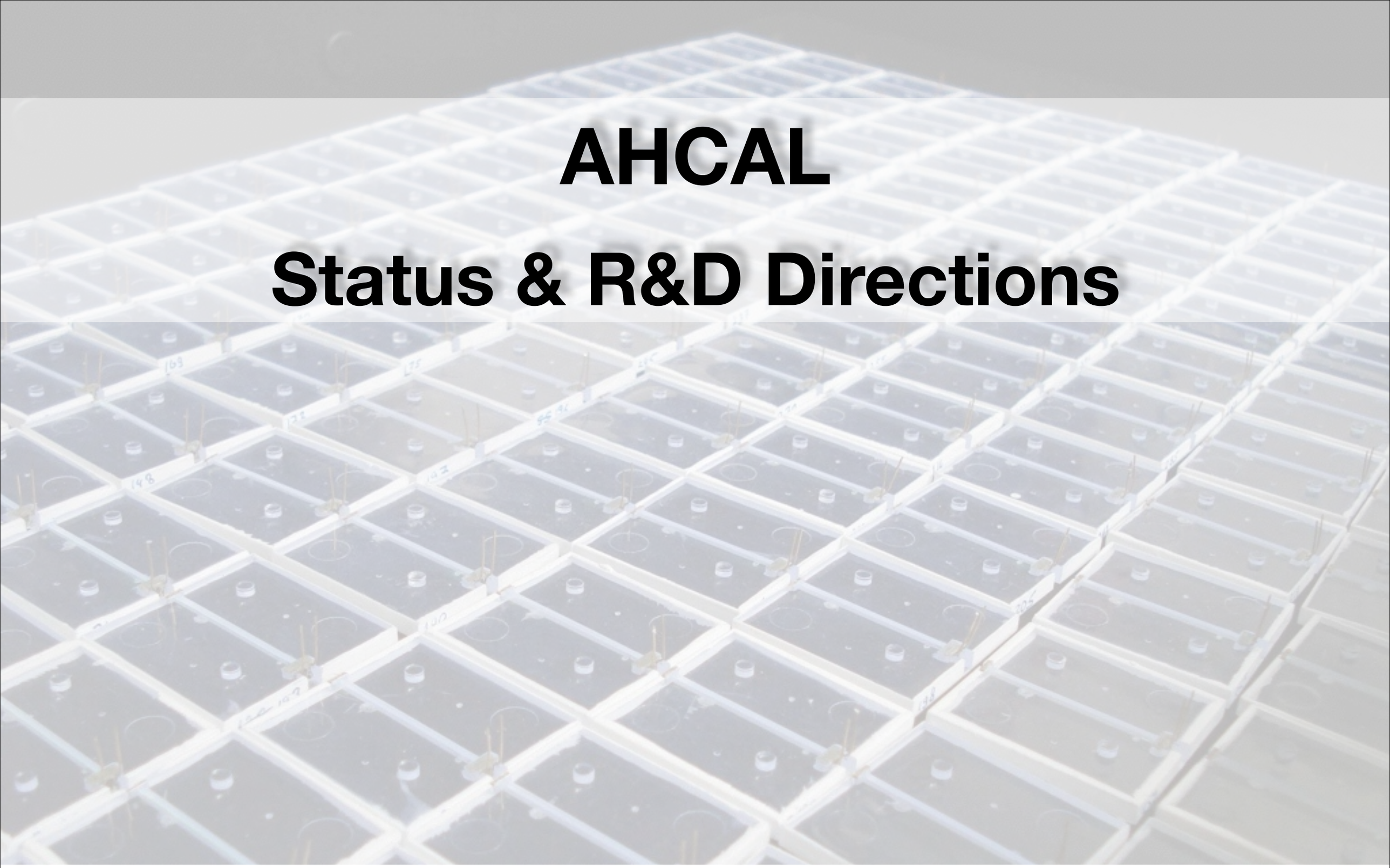
AHCAL

Status & R&D Directions



CALICE Collaboration Meeting
Argonne Nat'l Lab, March 2014

Frank Simon
Max-Planck-Institute for Physics

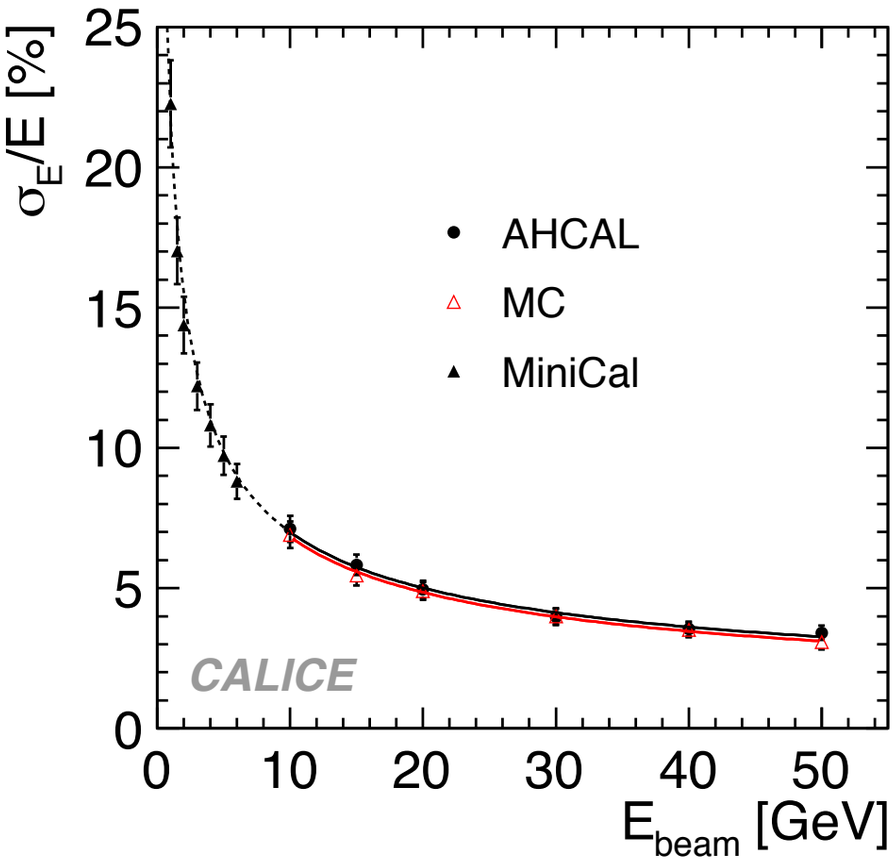
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Outline

- The Physics Harvest
- R&D Directions
  - Photon Sensors
  - Scintillator Tiles
  - Large-scale QA and assembly
  - Electronics & DAQ
  - Calorimetry Mechanics
- Test Beam Plans
- Conclusions

Includes material from Felix, in particular on QA issues for surface-mounted SiPMs and tiles

Continuing Harvest from Physics Prototype



- Validation with electrons

JINST 6 P04003 (2011)

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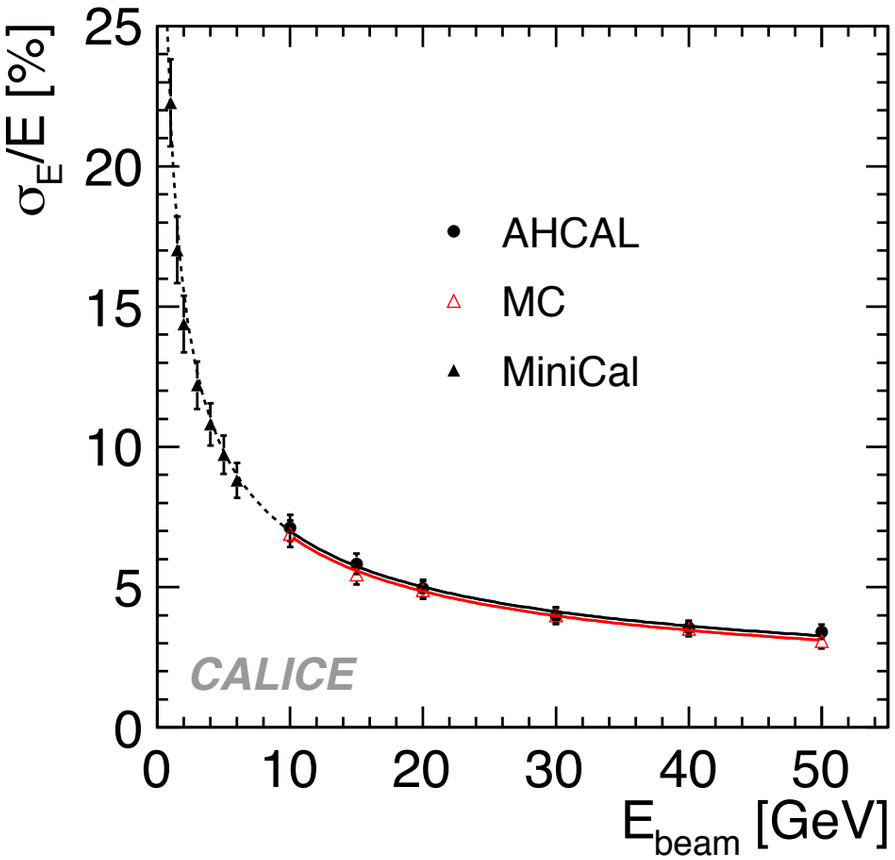

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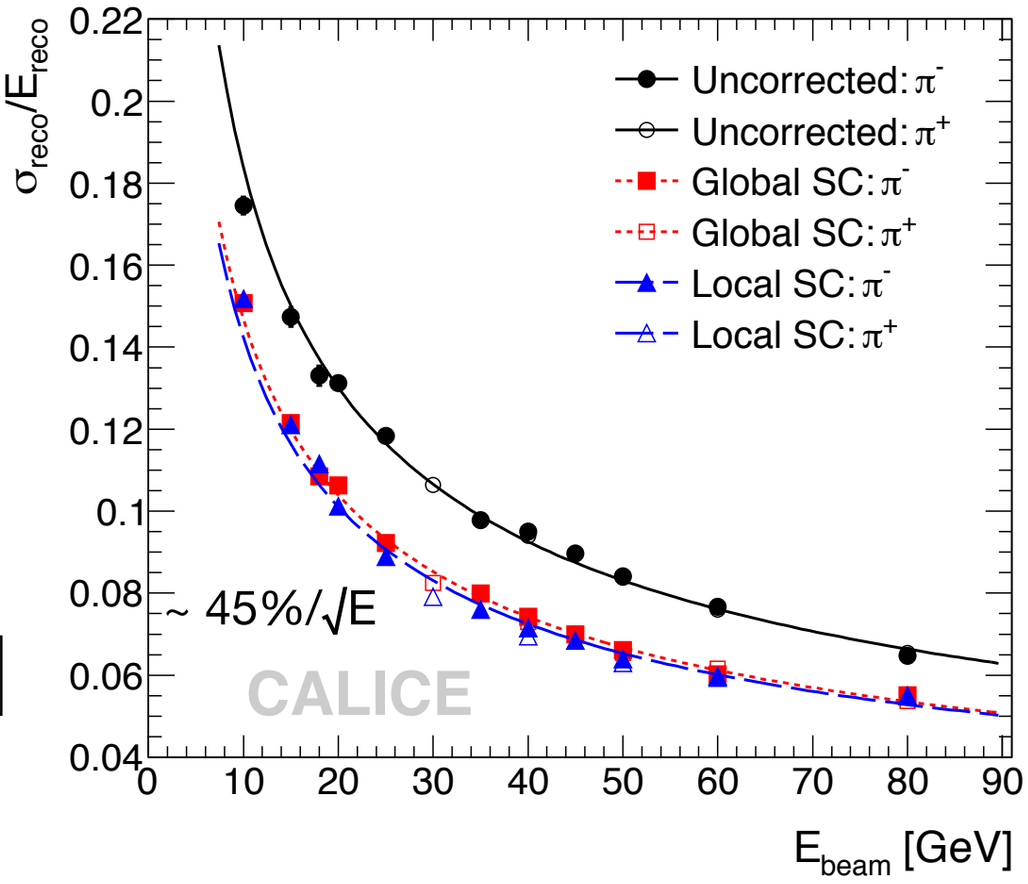
JINST 7 P09017 (2012)



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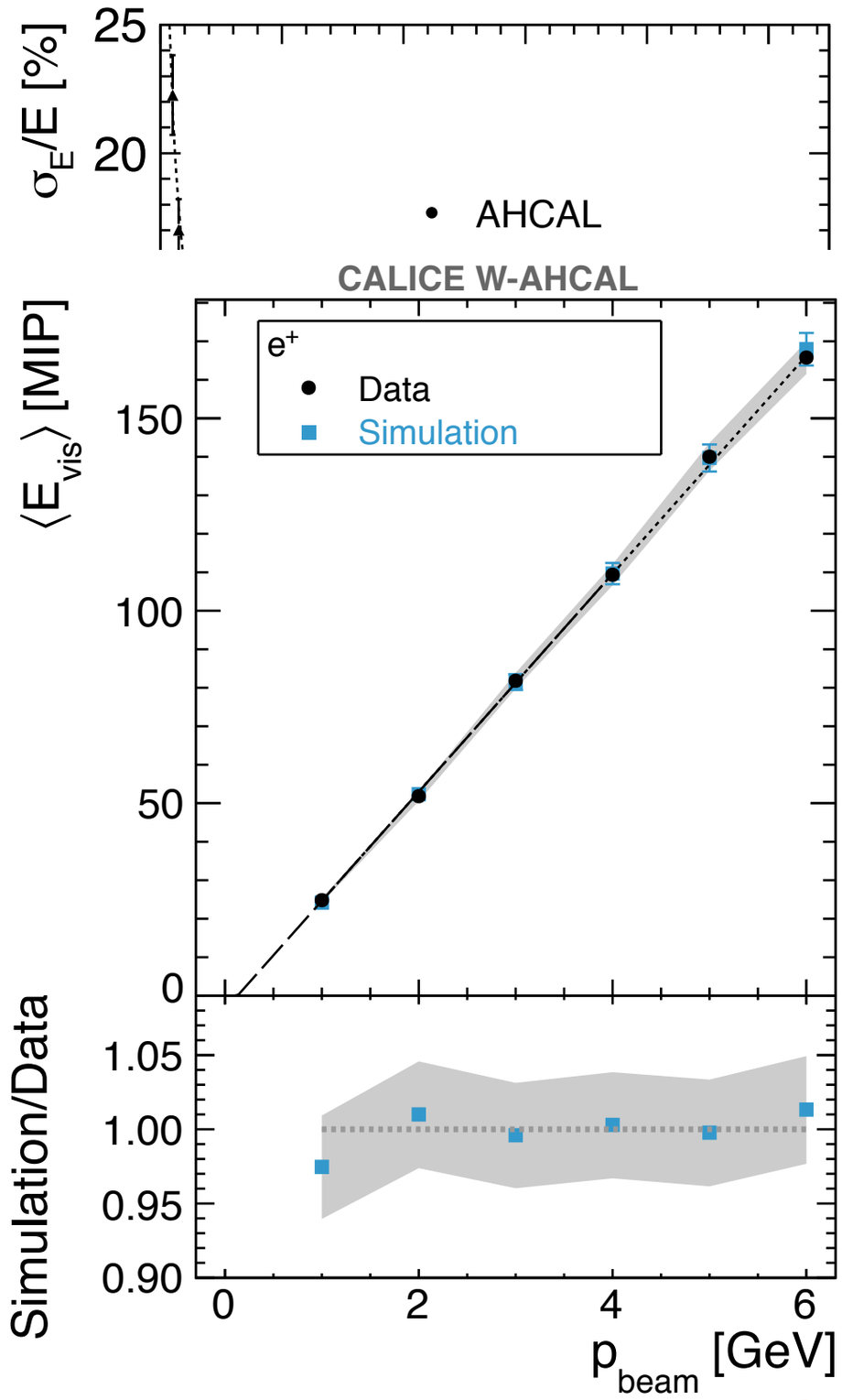

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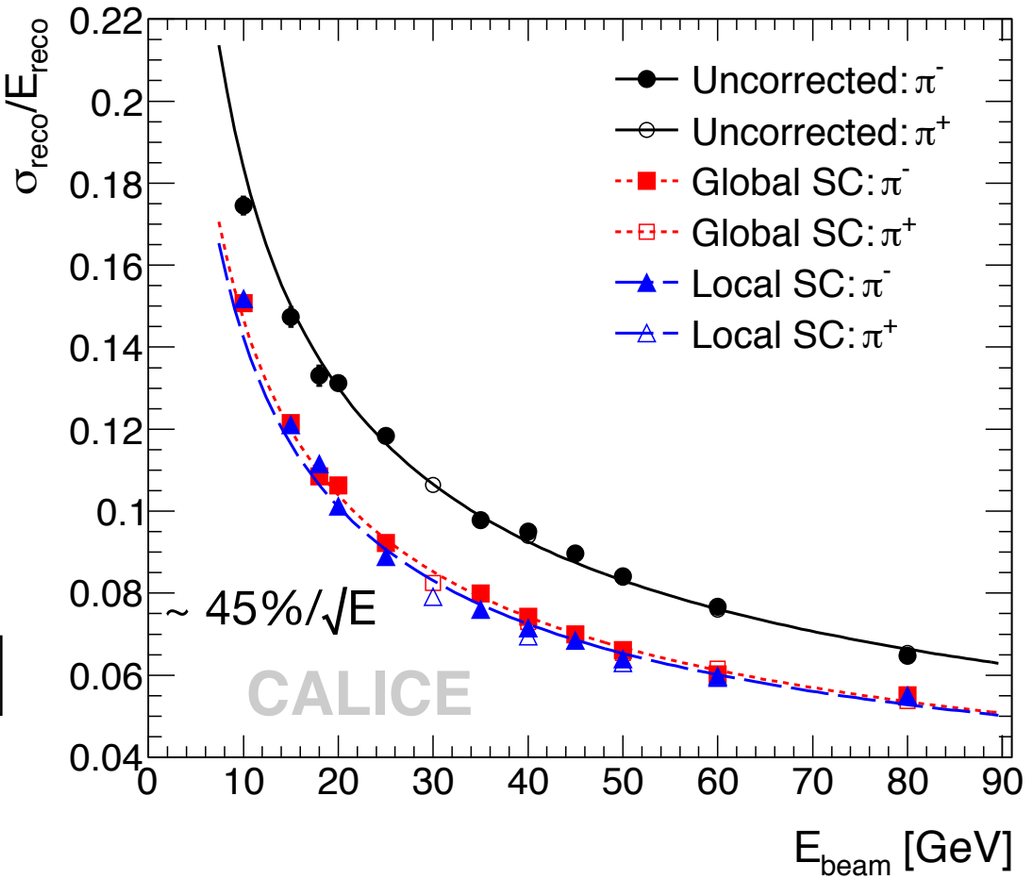

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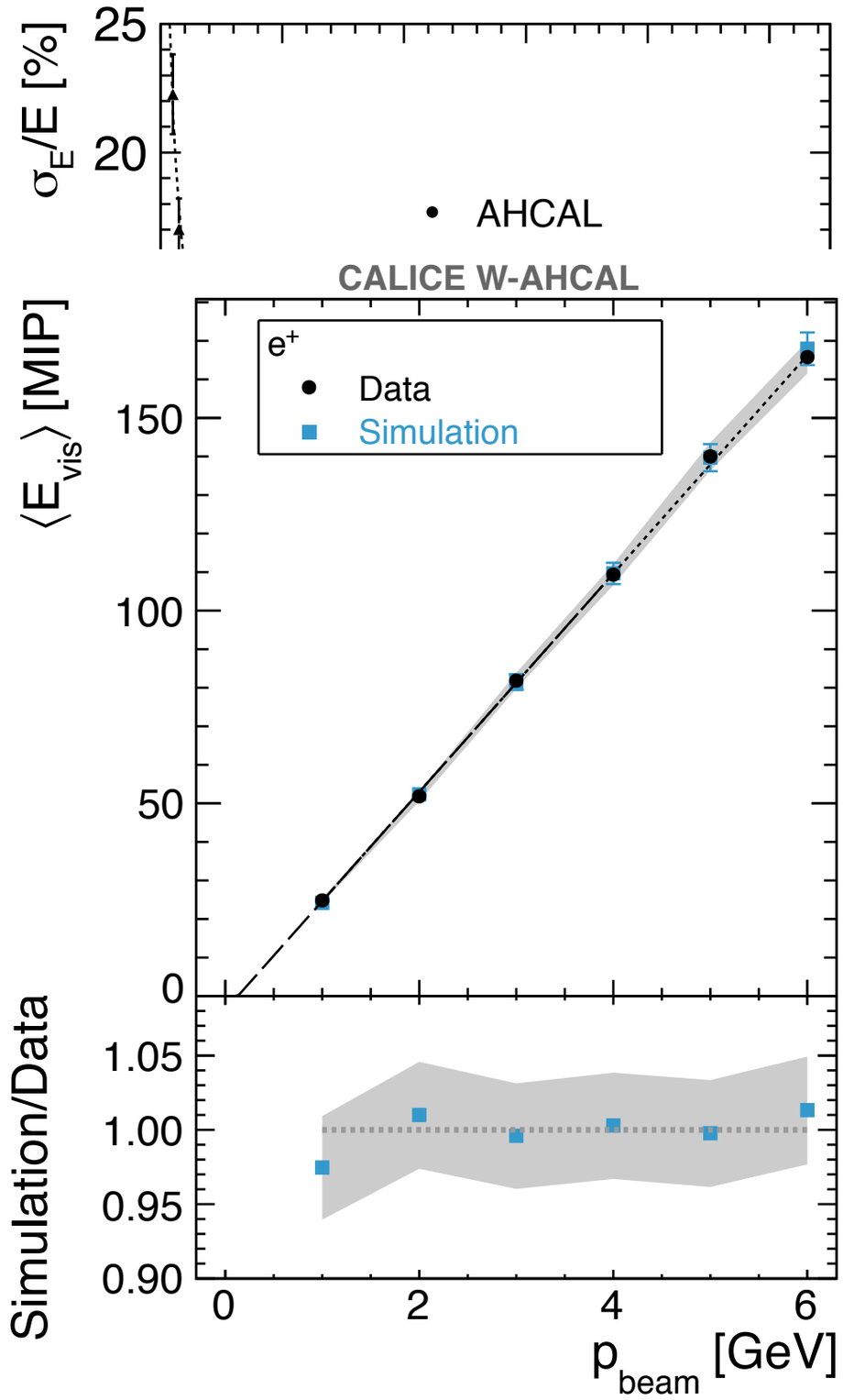

- Validation with electrons

JINST 6 P04003 (2011)

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JINST 7 P09017 (2012)

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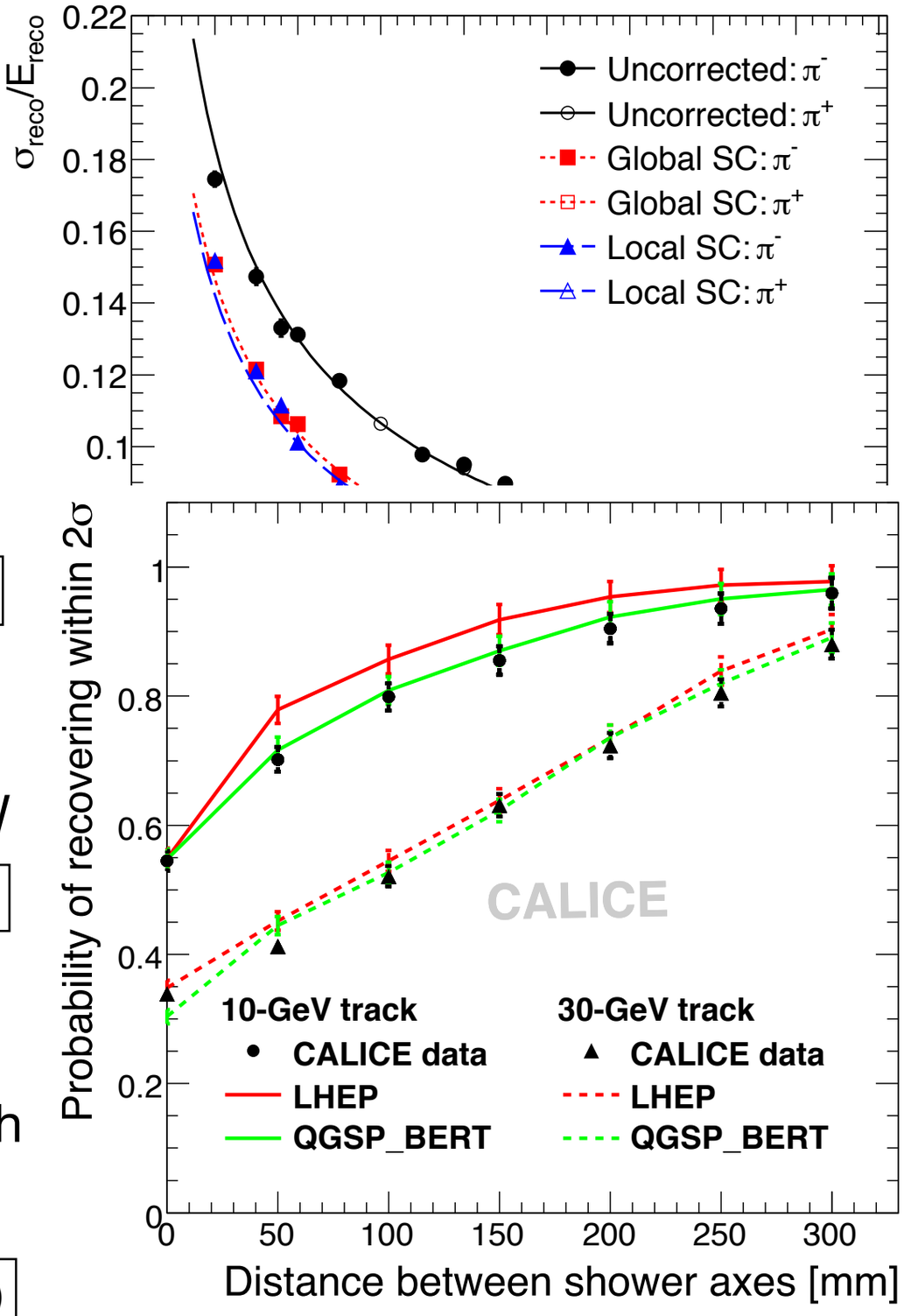
JINST 9 P01004 (2014)

- PFA validation & performance (with SiWECAL)

JINST 6 P07005 (2011)



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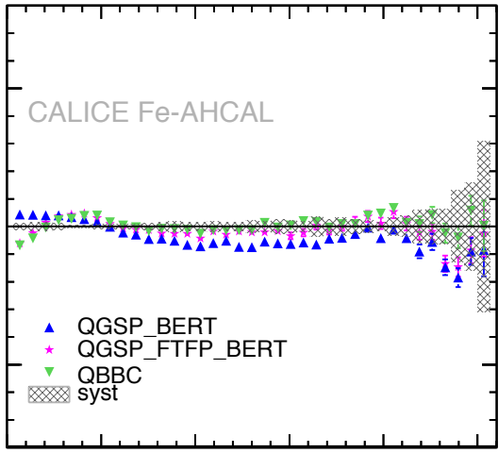

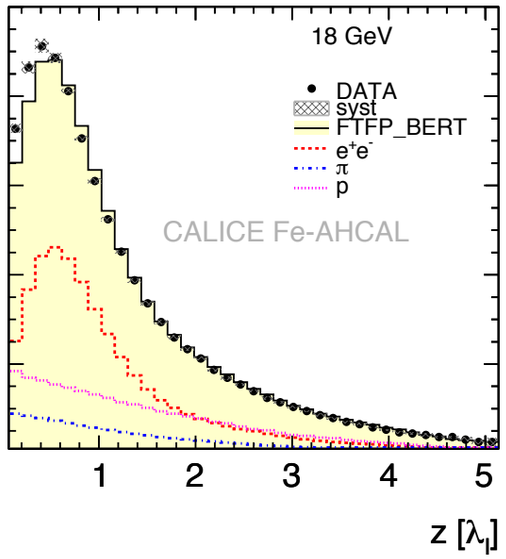

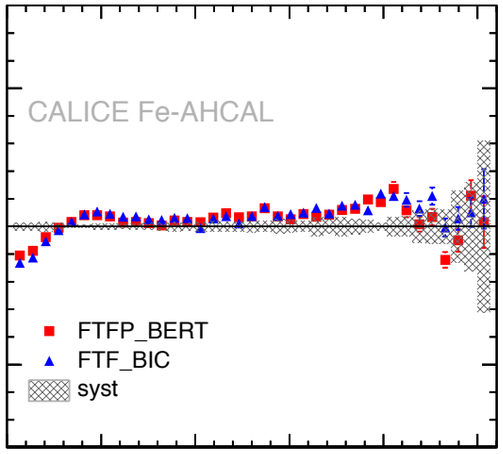

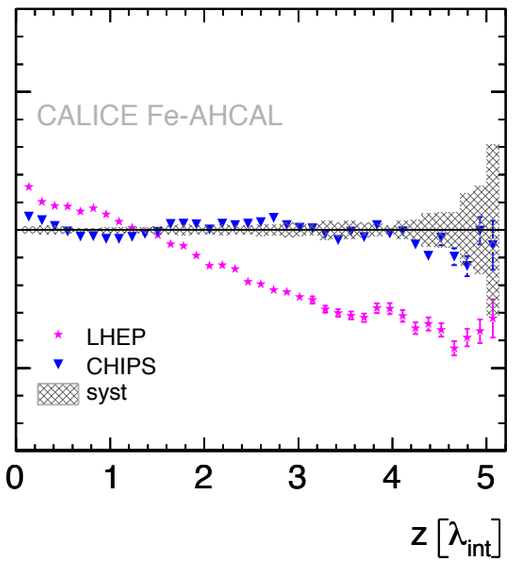

- GEANT4 shower models: Global observables

JINST 8 P07005 (2013)

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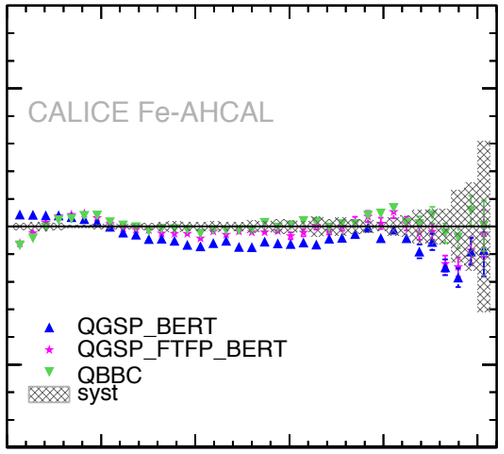
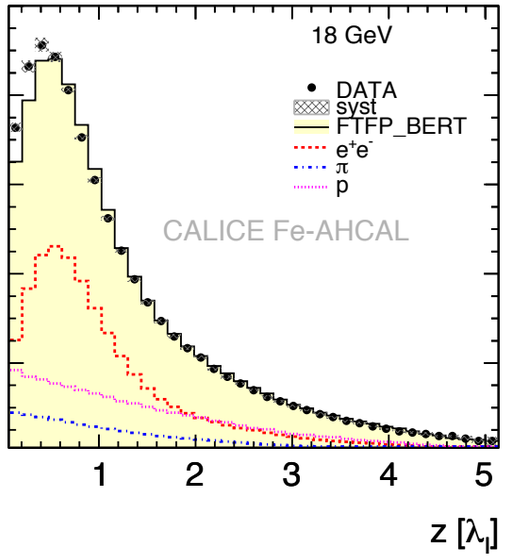
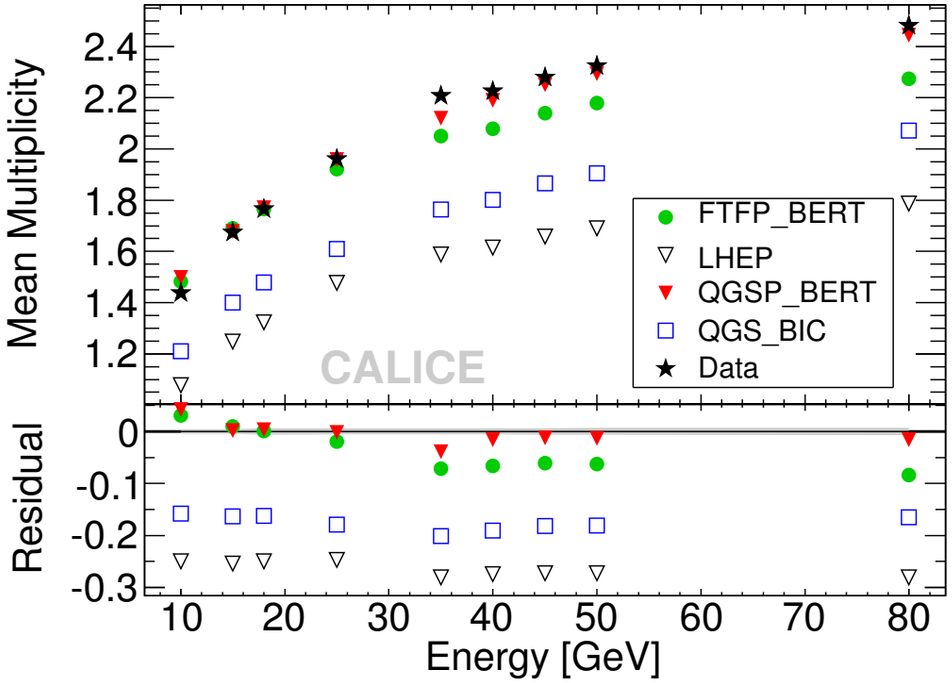
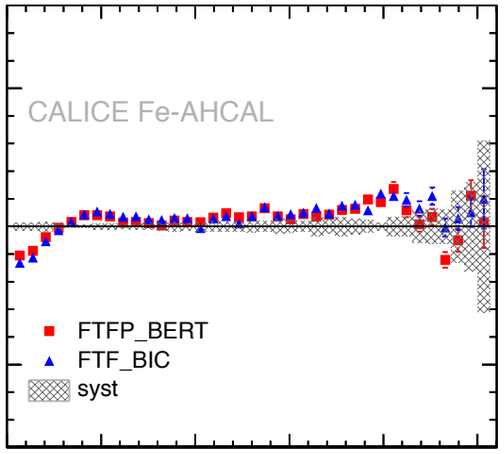


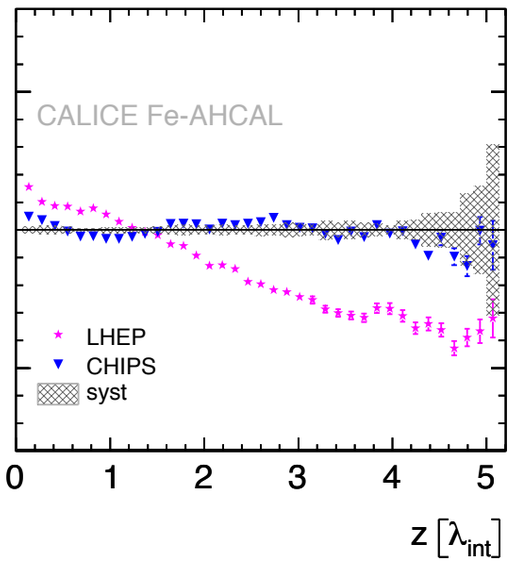


- GEANT4 vs shower substructure

JINST 8 P09001 (2013)







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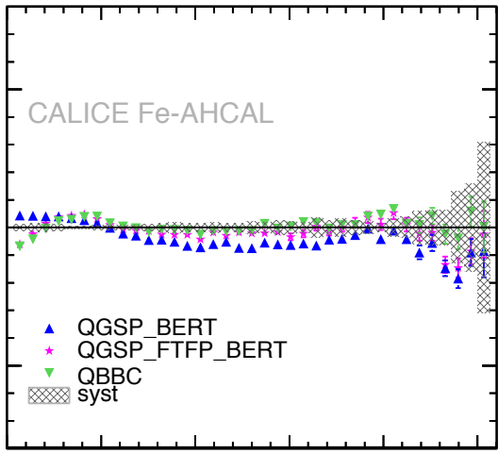

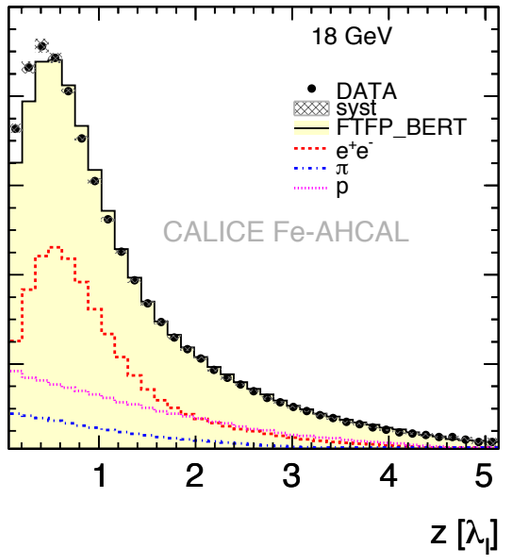

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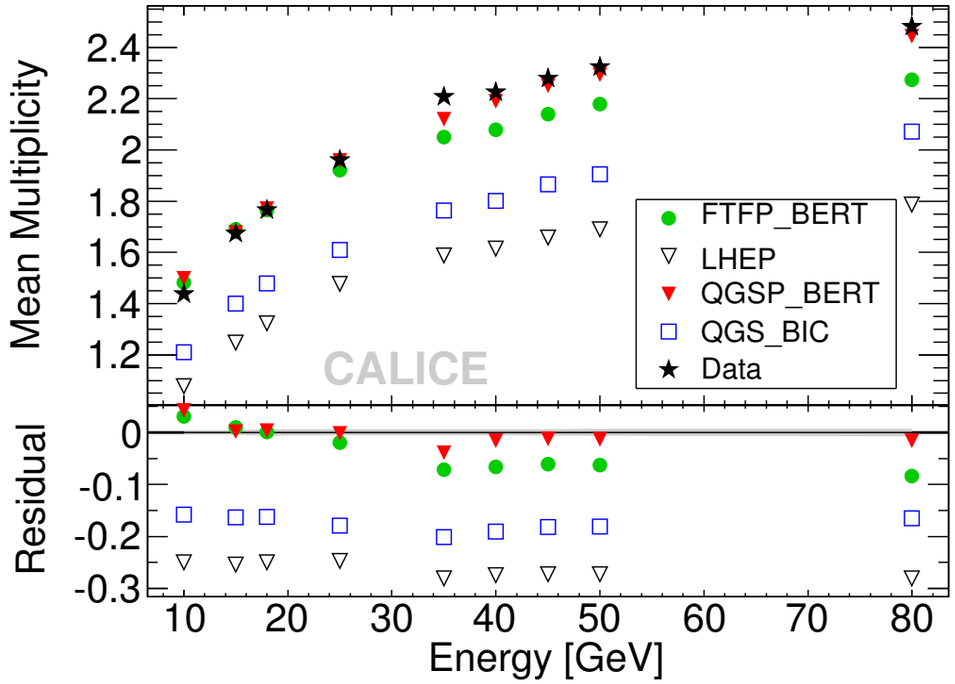

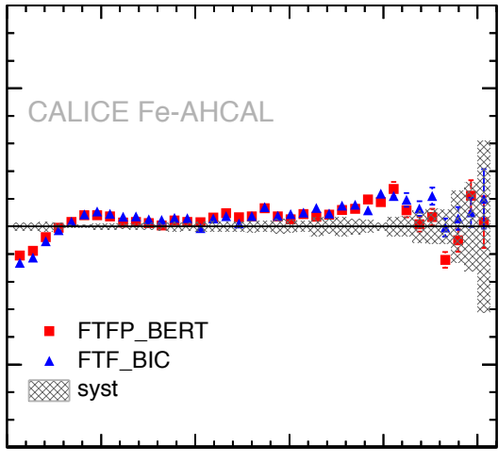

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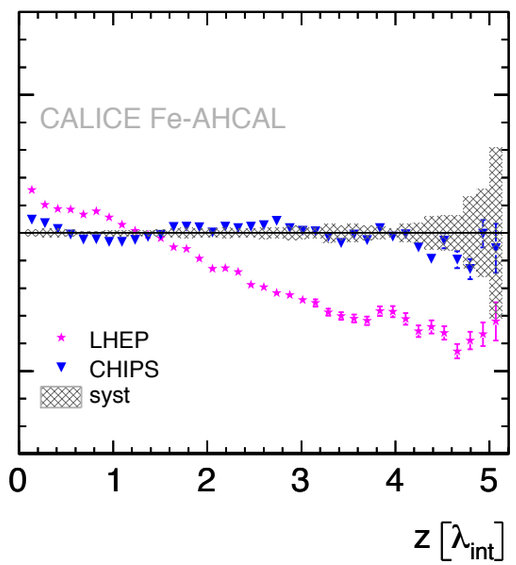
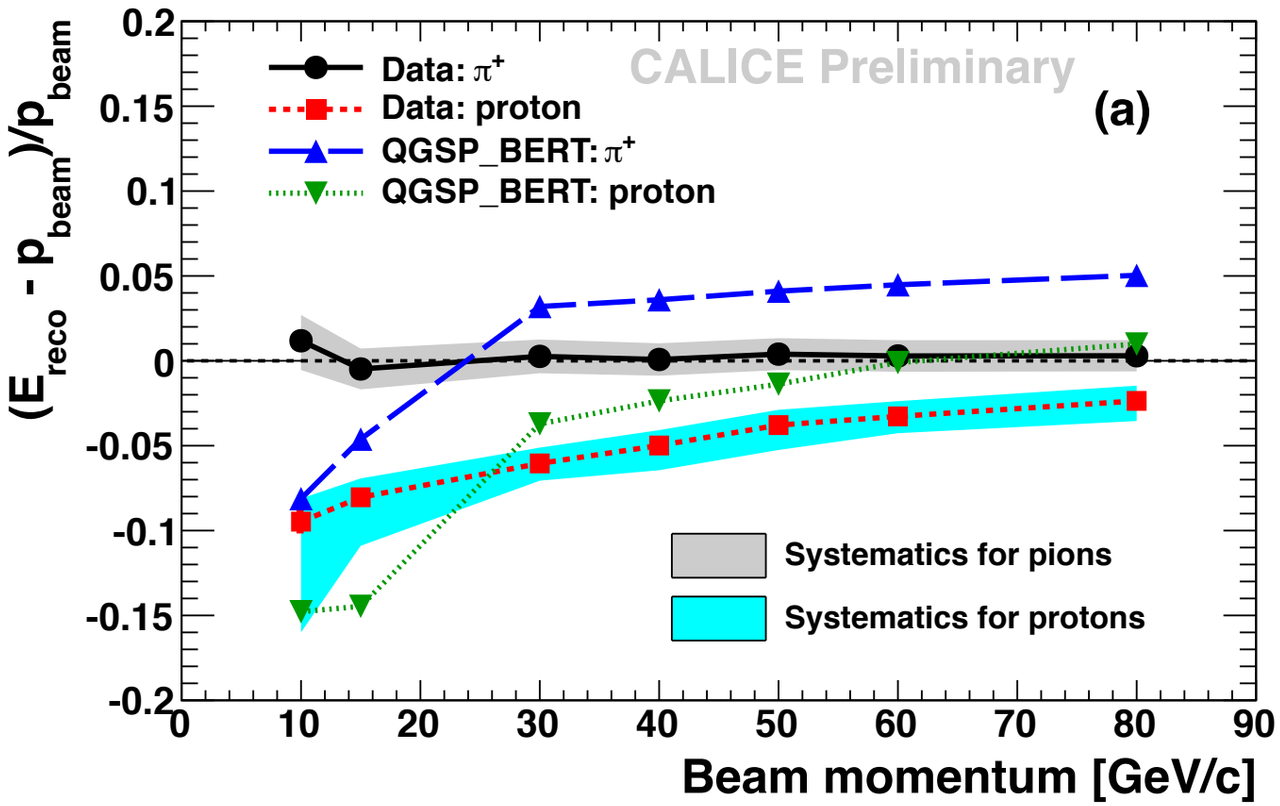


- Protons vs pions - comparison to GEANT4

CAN-040 (2013)



Continuing Harvest from Physics Prototype

- More in the pipeline
  - Further extension of proton vs pion studies
  - Extension of software compensation to full CALICE setup (already documented in CAN-015 (2009), now with full calibration)
  - …
- Spin-offs:
  - Time structure of hadronic showers with T3B

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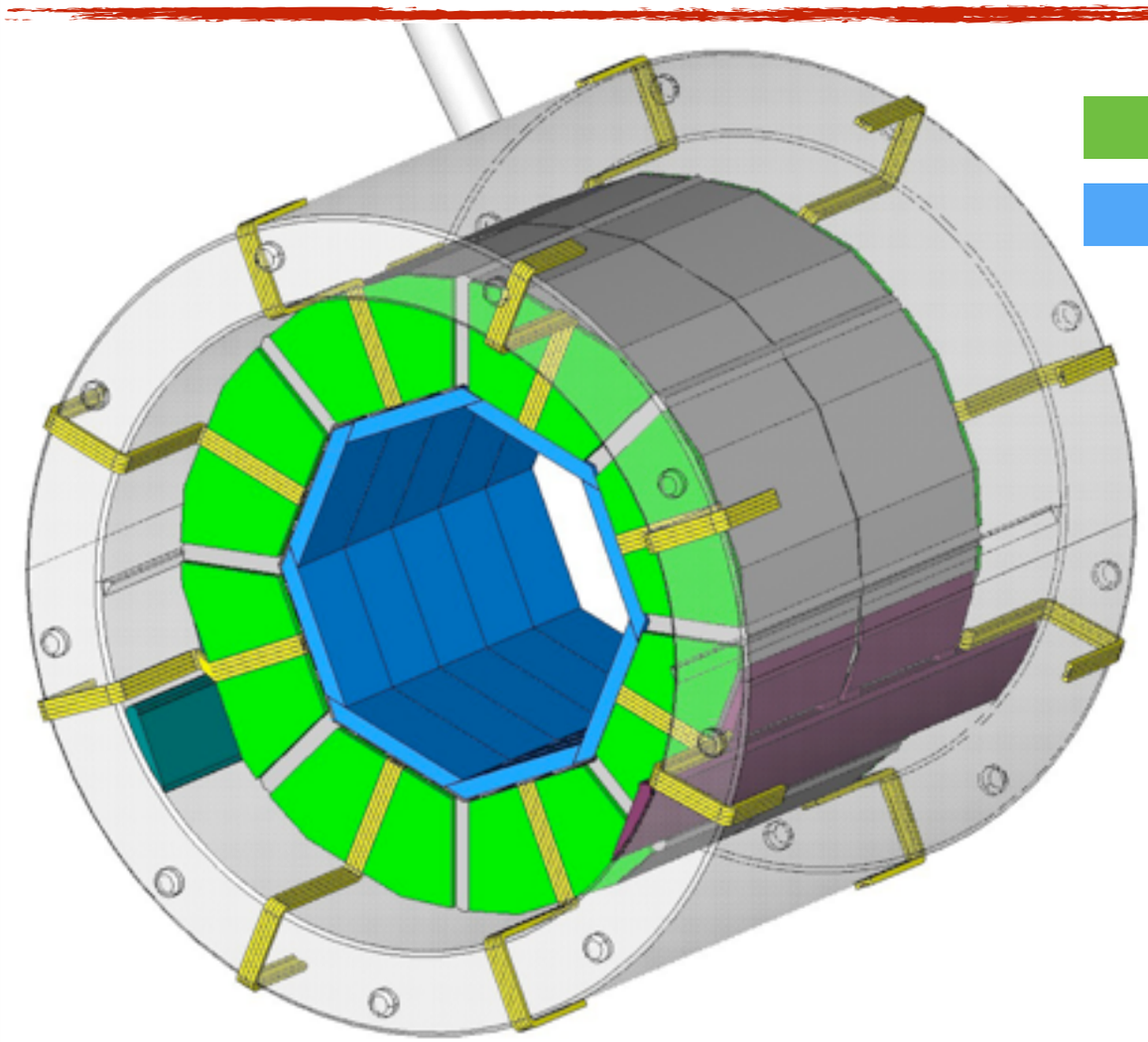
  - …
- Spin-offs:
  - Time structure of hadronic showers with T3B

Test beams with next-generation prototype have begun - focus more technical, but also expect additional physics results

- For example: Timing capability over full volume

Preparing for a Real Detector: Design Overview



HCAL

ECAL

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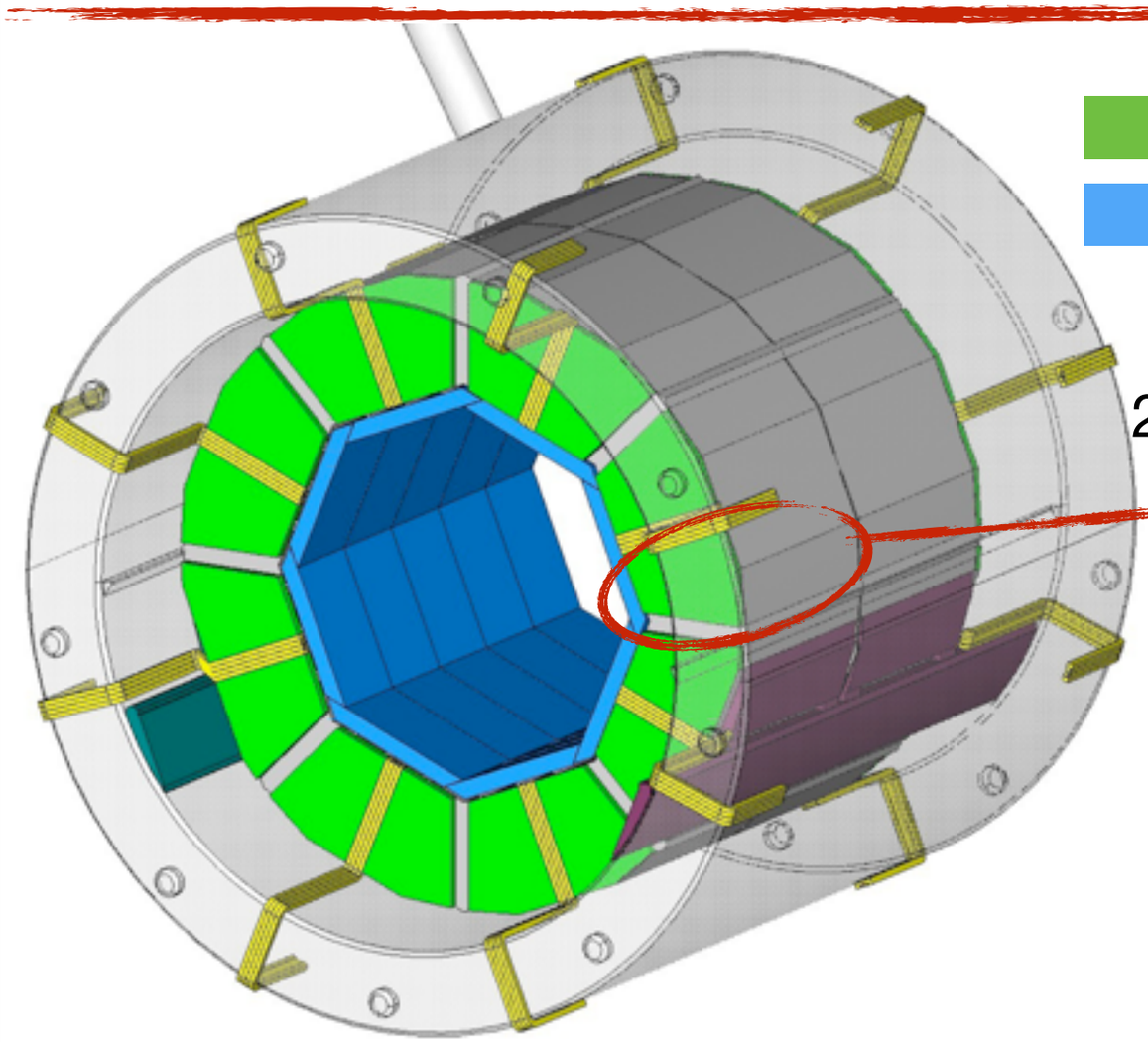
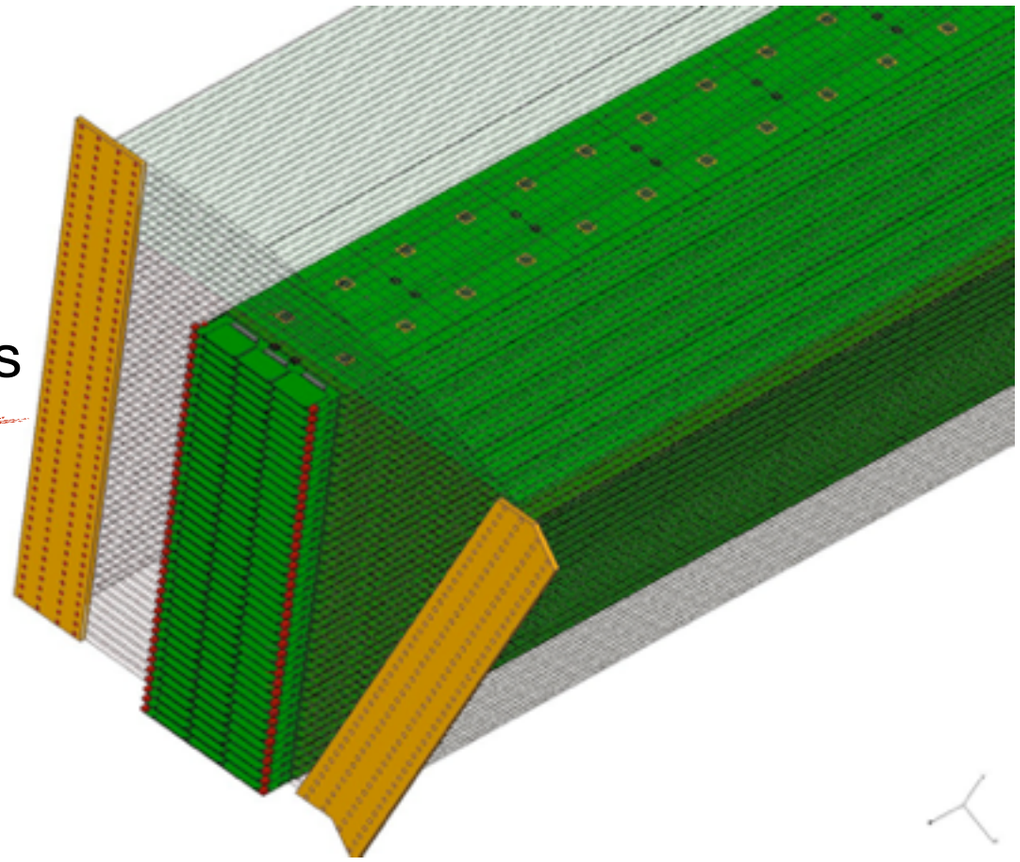


HCAL

ECAL

2 x 16 wedges



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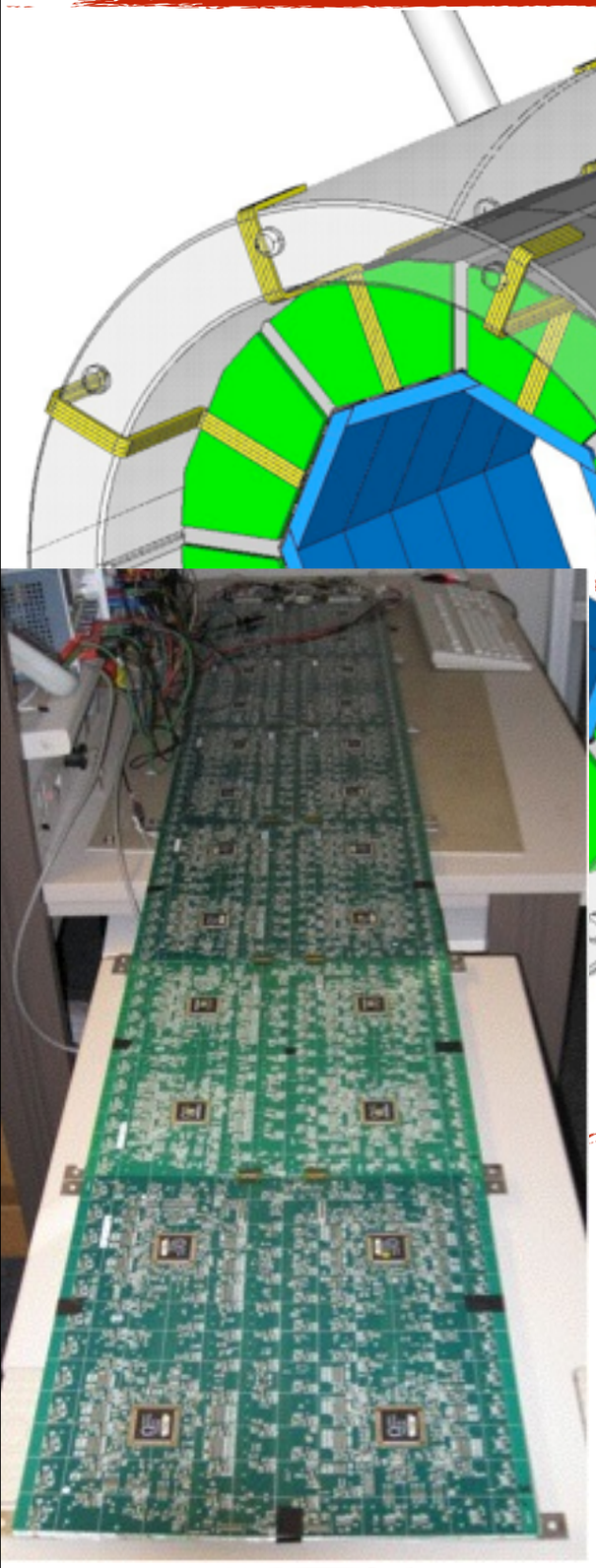

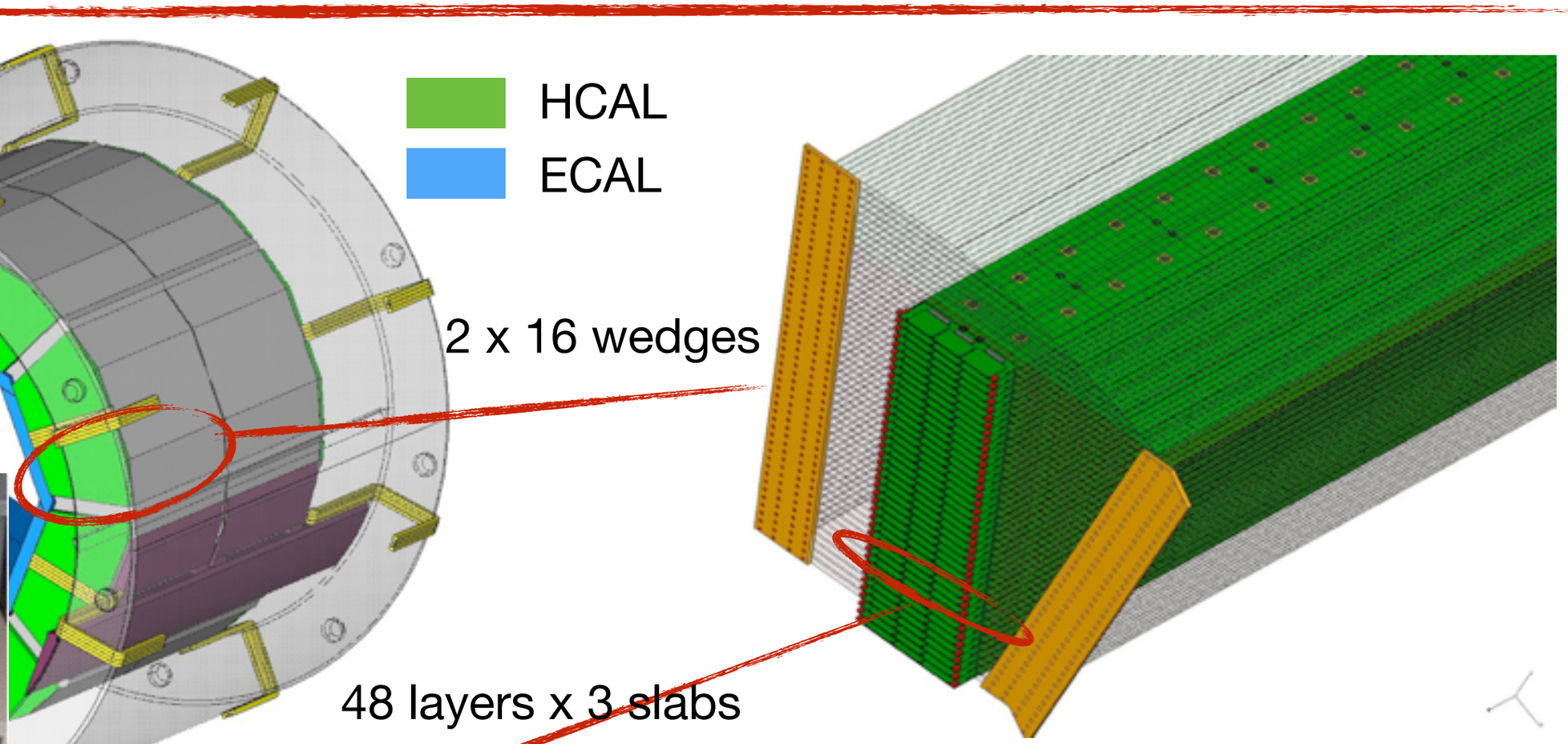

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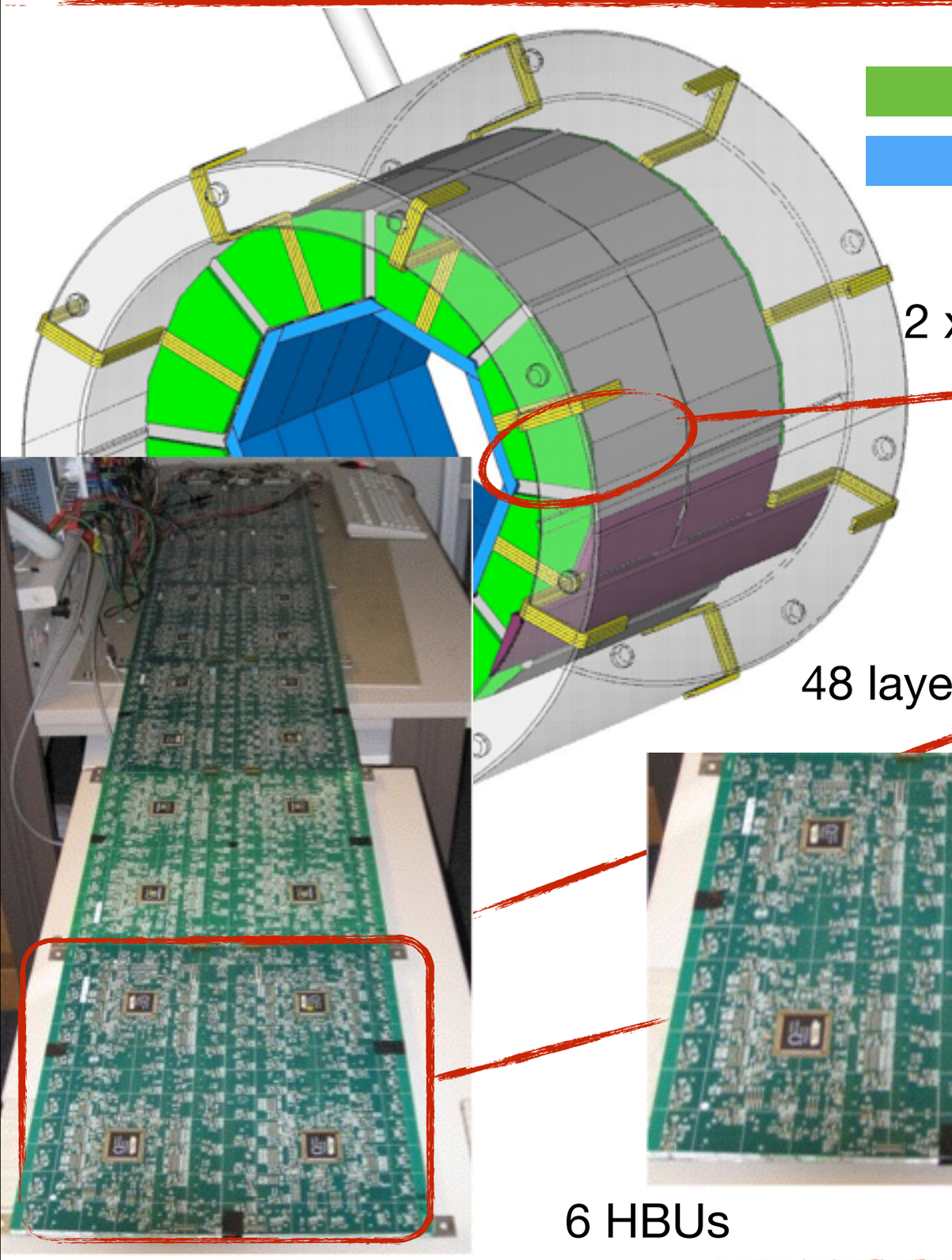

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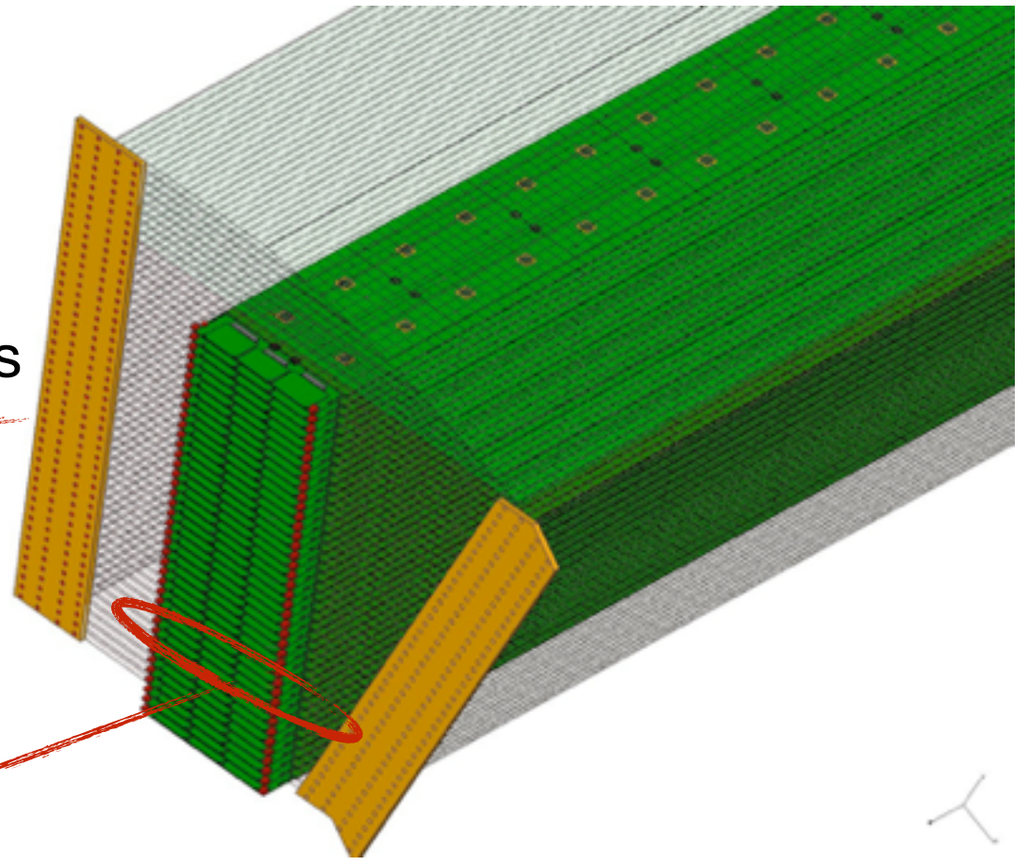

48 layers x 3 slabs

6 HBUs

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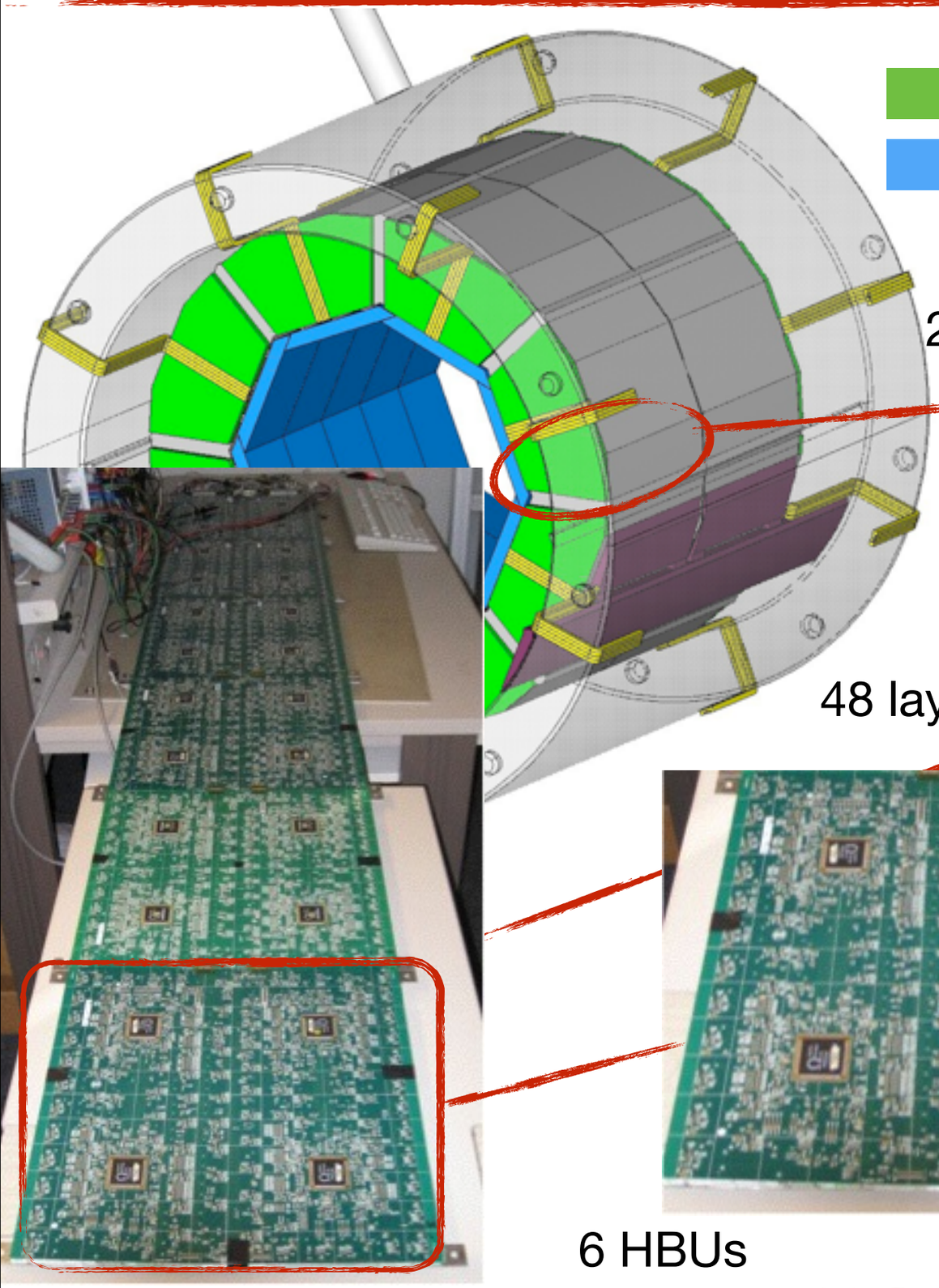

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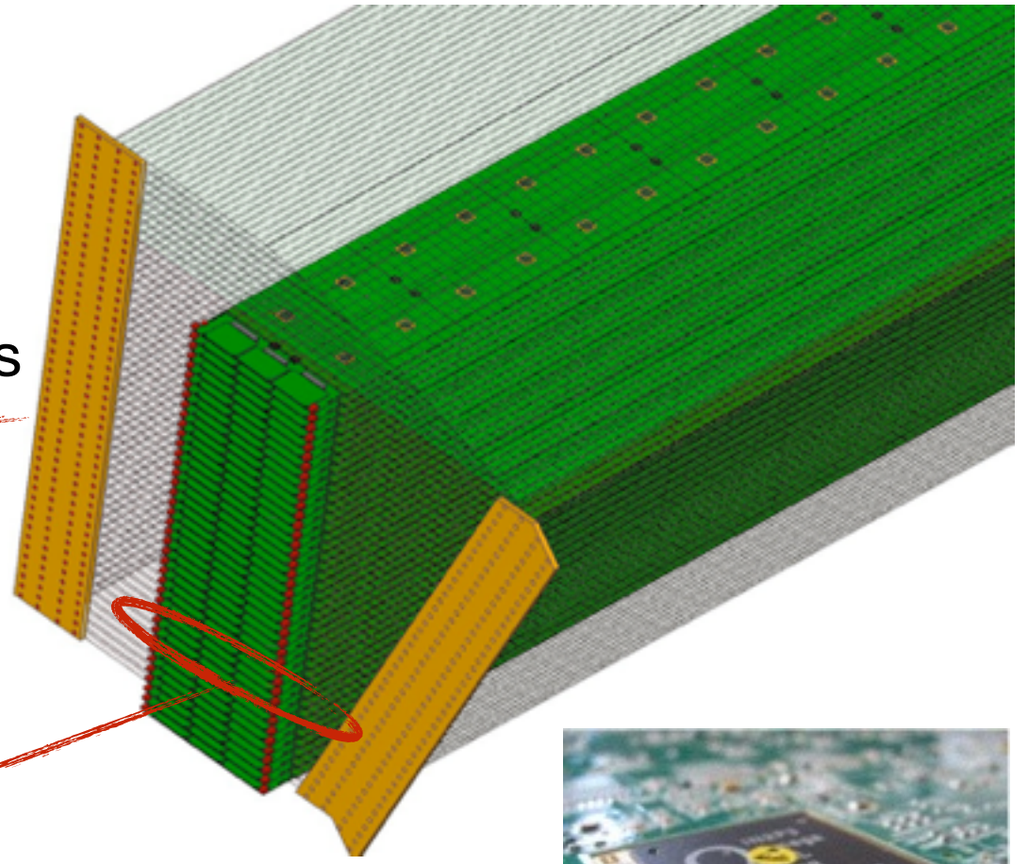

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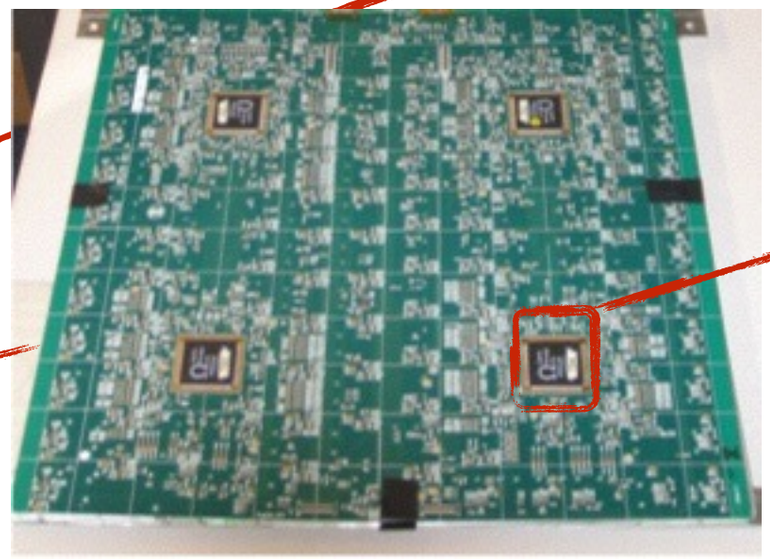
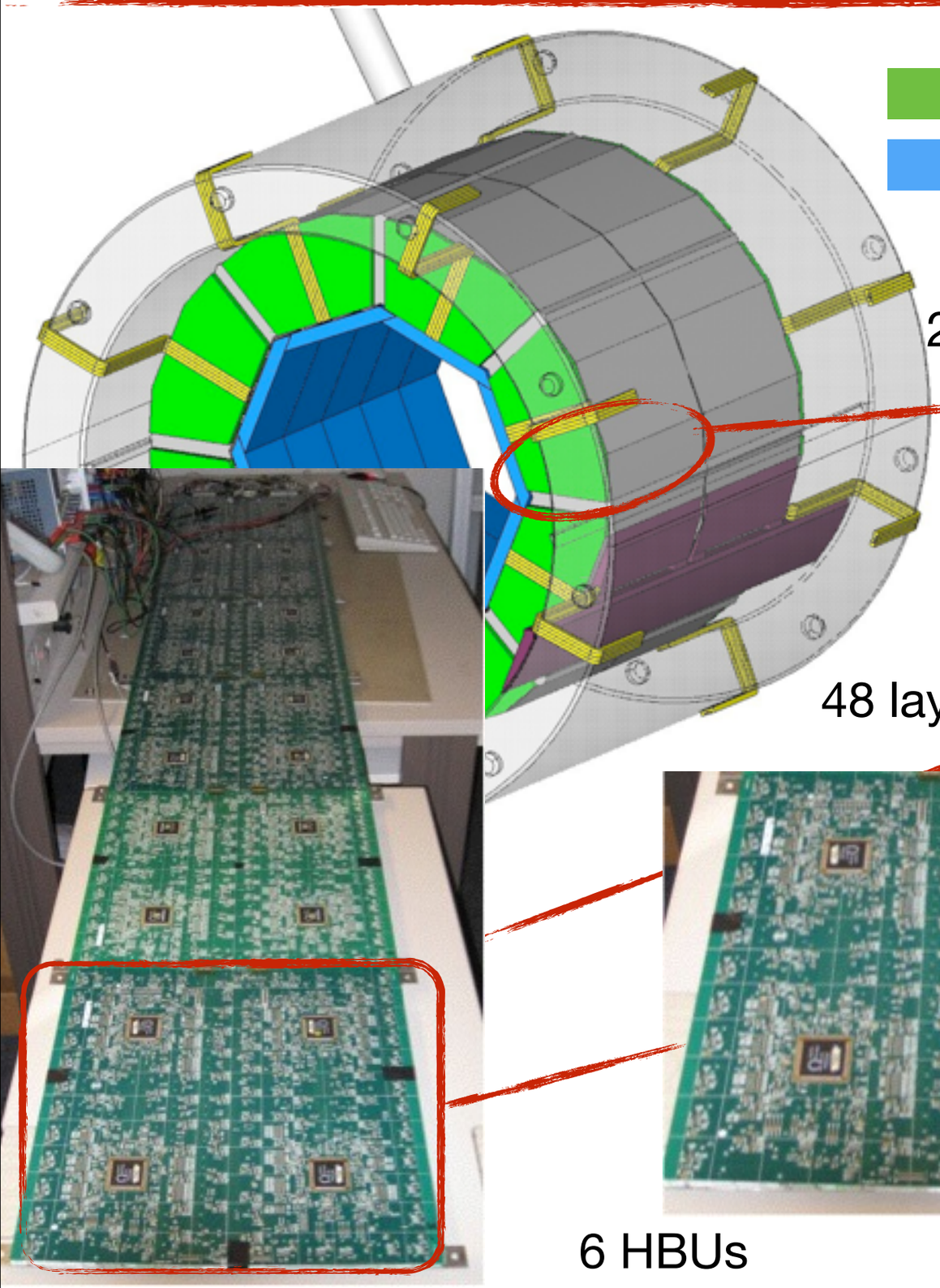


6 HBUs

4 ASICs

Preparing for a Real Detector: Design Overview



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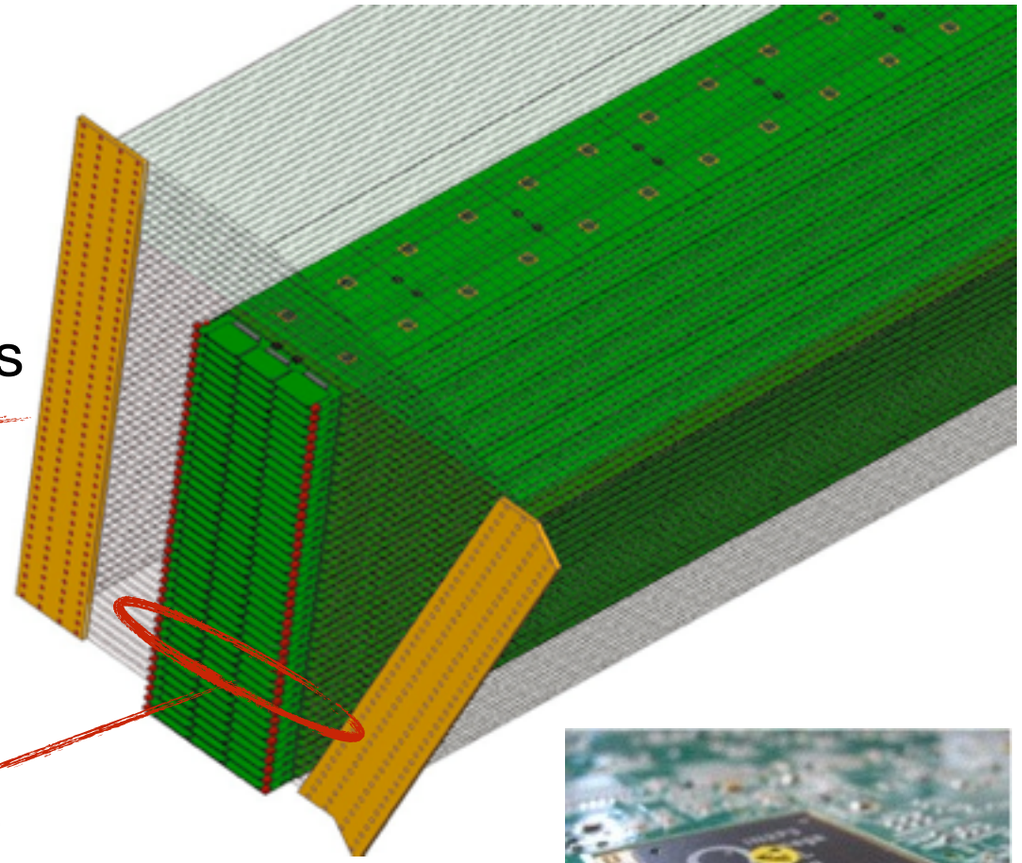

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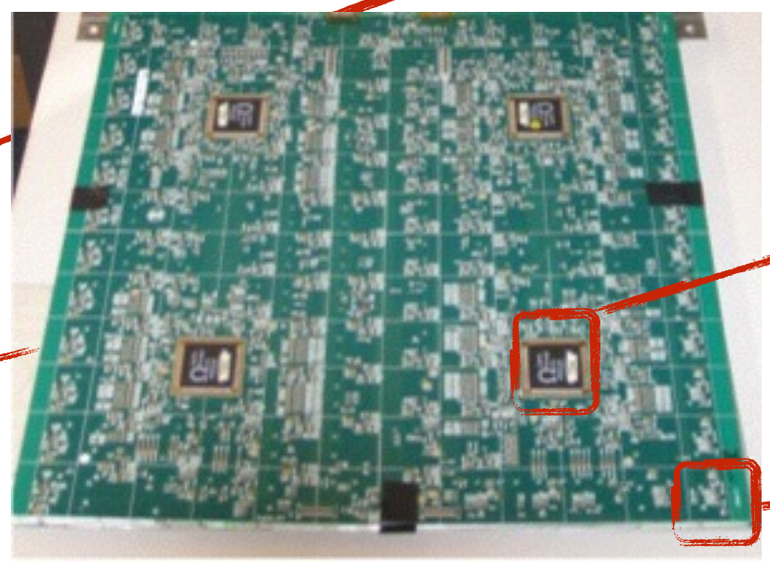

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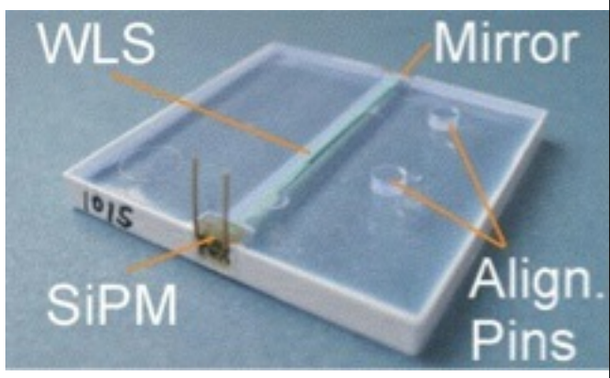
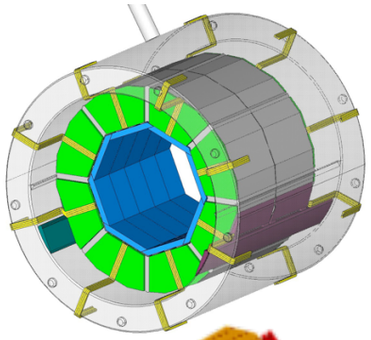
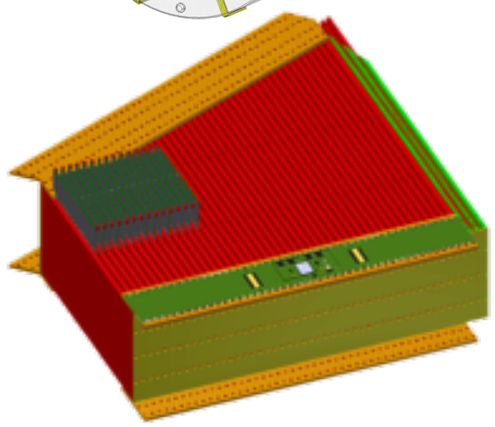


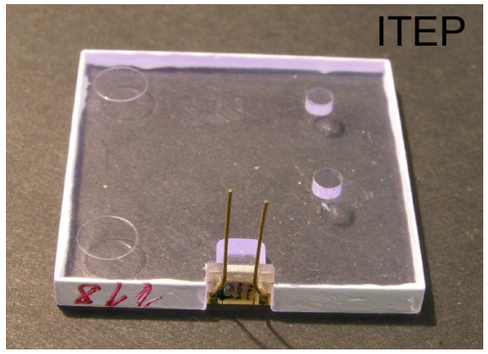
144 tiles

The Challenges of Large Numbers

- 1 calorimeter
  (barrel + 2 end-caps)
- 60 sub-modules
- 3 000 layers
- 60 000 HBUs
- 200 000 ASICs
- 8 000 000 Tiles + SiPMs







- 1 working year
- 46 weeks
- 230 days
- 2 000 hours
- 100 000 minutes
- 7 000 000 seconds

Main R&D Topics

- Optimization / Re-thinking of key components
  - SiPMs - Profit from industrialisation, large number of possible suppliers - R&D (with one exception) not done within “our” community - but active exchange with various manufacturers
  - Scintillator tiles - Automatic assembly a key challenge, explore alternative ideas for coupling of SiPMs and tiles, re-optimize design

- Establish a production concept
  - QA of all key components prior to assembly - What / which level is needed?
    - Automatization of QA steps
  - Automatic assembly procedures if small components (at least up to HBU level)

The Photon Sensor

- The CALICE AHCAL was the first large-scale use of SiPMs!

  … and the technology has evolved quite a bit since then - now used “everywhere”, with many possible producers.

- What we need:
  - Decent efficiency
  - Reasonable noise rate
  - Reasonable dynamic range
  - Low cost

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(allow ~0.3 - 0.5 MIP thresholds)

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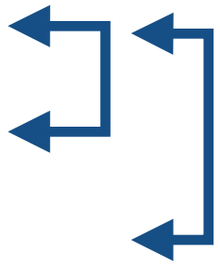

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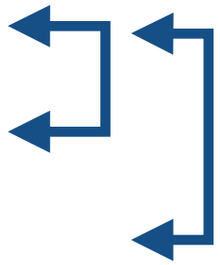

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1000 - a few 1000 pixels normally provides sufficient dynamic range

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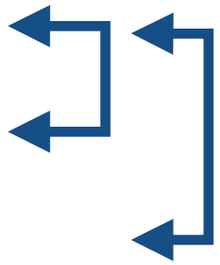

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Packaging is important:
- Compactness to reduce dead area
- Long-term stability of materials (on the level of decades!)
- Robustness for installation / storage before further assembly
- ▸ Need experience with producers (and experienced producers! - Bad surprises recently)

Photon Sensor: Noise Limits

- The requirements change substantially when moving to realistic detectors:
  Auto-trigger - Have to avoid accidental signals at the ~ 0.2 - 0.4 MIP level!
  (stricter requirement than with external beam trigger)

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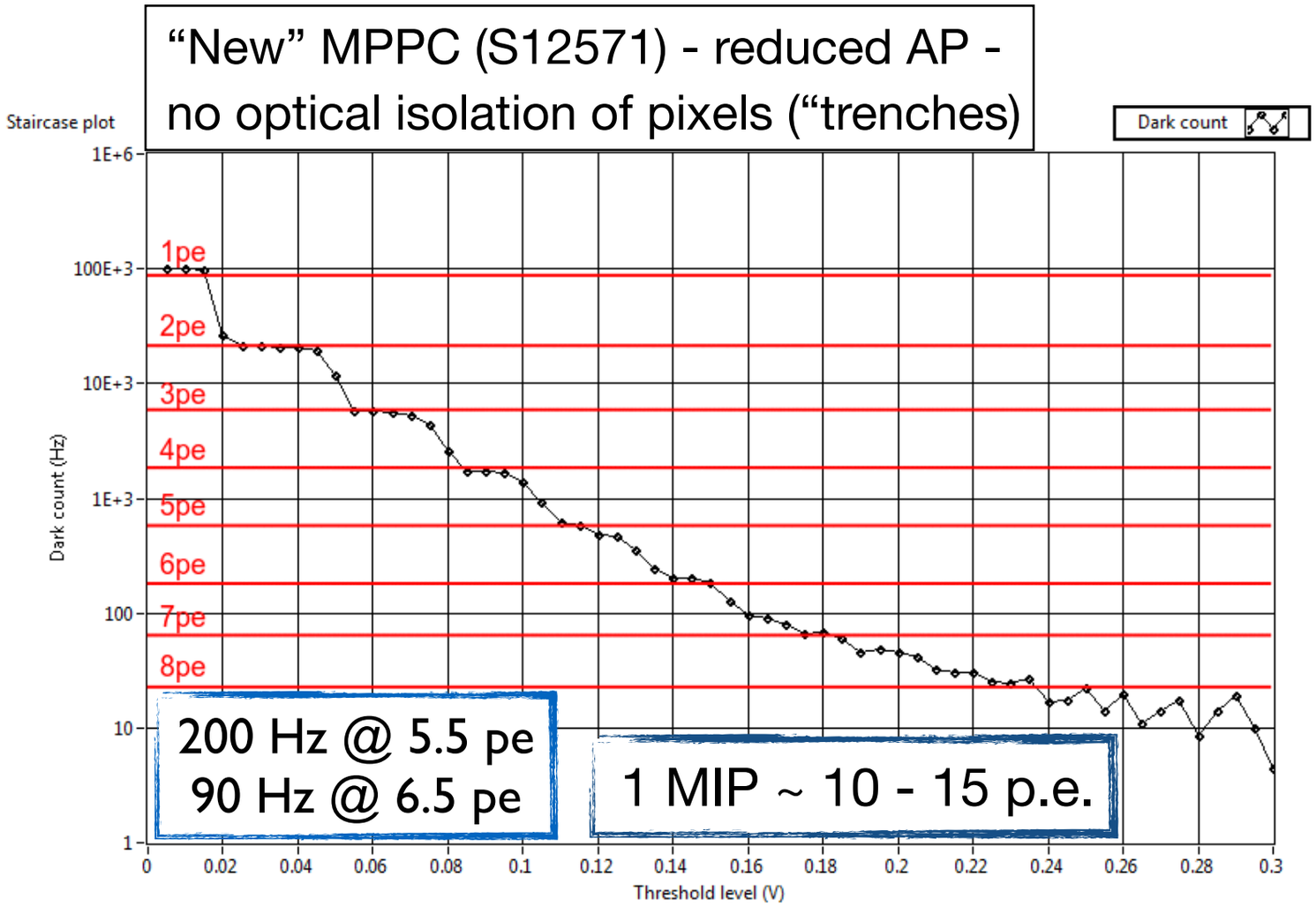

MPPC cross-talk level:
~ 25% - 30%

KETEK PM1125, with "trenches"
(used at UHH)
cross-talk level: ~ 5%
results in 0.1 Hz noise rate
at 0.2 MIP with UHH tiles

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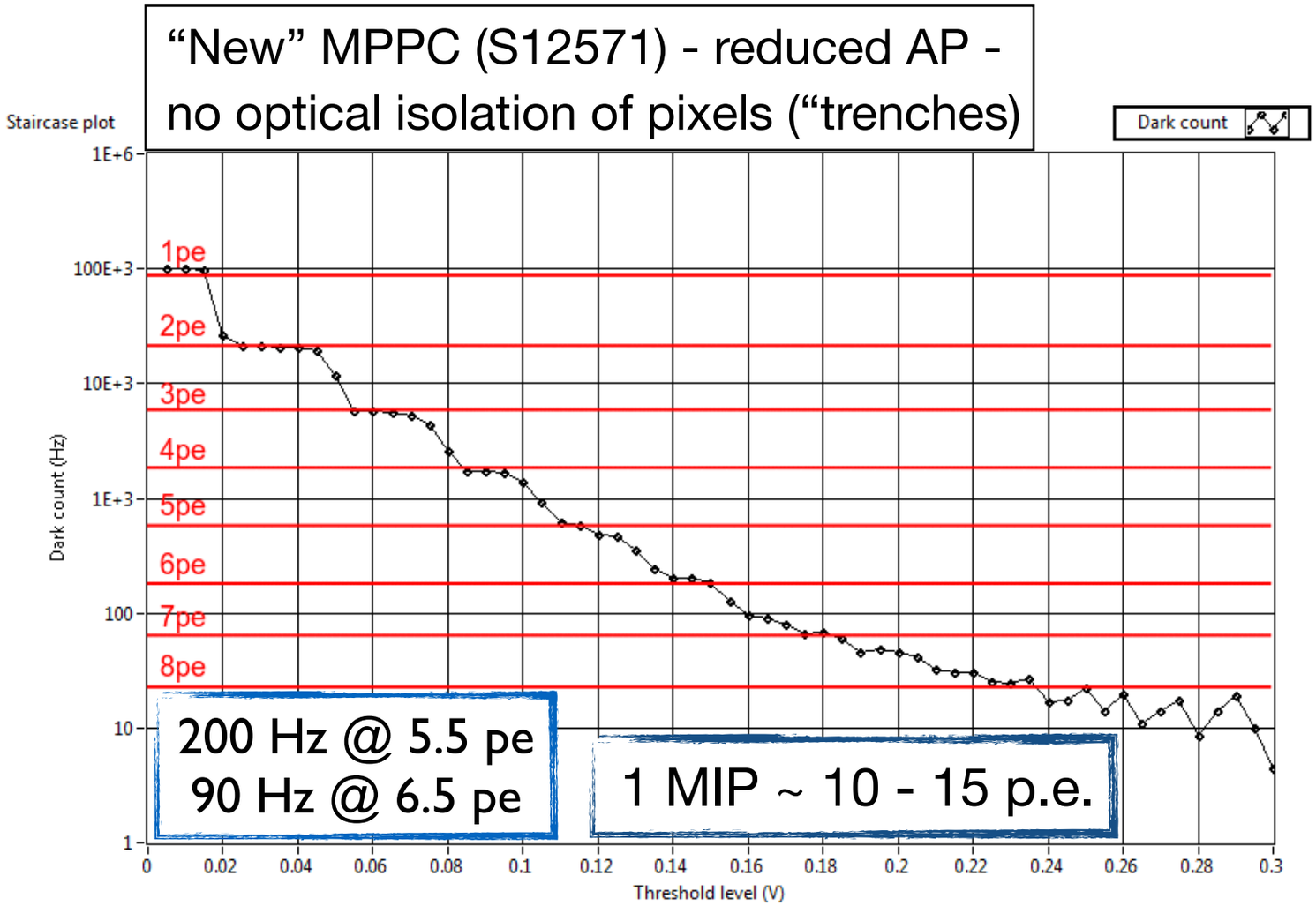


MPPC cross-talk level:
~ 25% - 30%

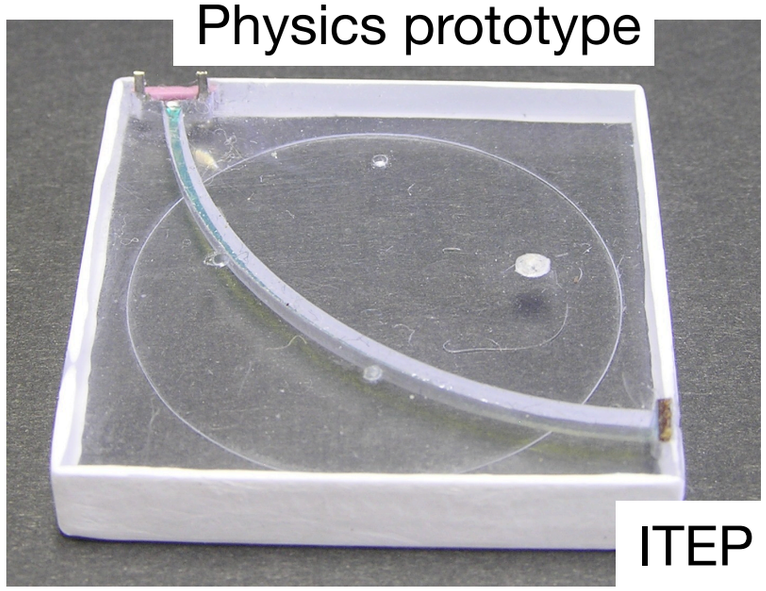
KETEK PM1125, with "trenches"
(used at UHH)
cross-talk level: ~ 5%
results in 0.1 Hz noise rate
at 0.2 MIP with UHH tiles

NB: Cross-talk depends on operating conditions. Impact depends on active area of sensor!

The Scintillator Tiles

- The smallest “building block” of the Calorimeter (with integrated SiPM) - Mass production and mass testing important!
- Has undergone quite some evolution since first prototype:

Physics prototype



ITEP

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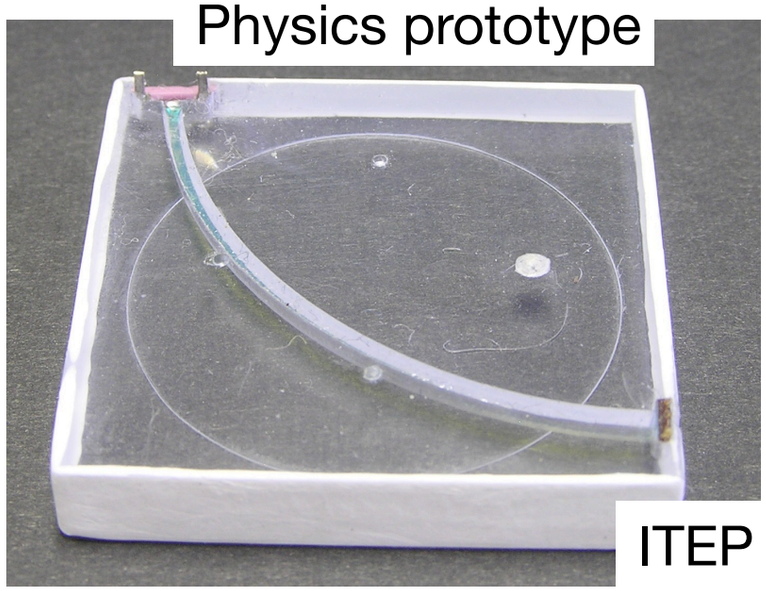
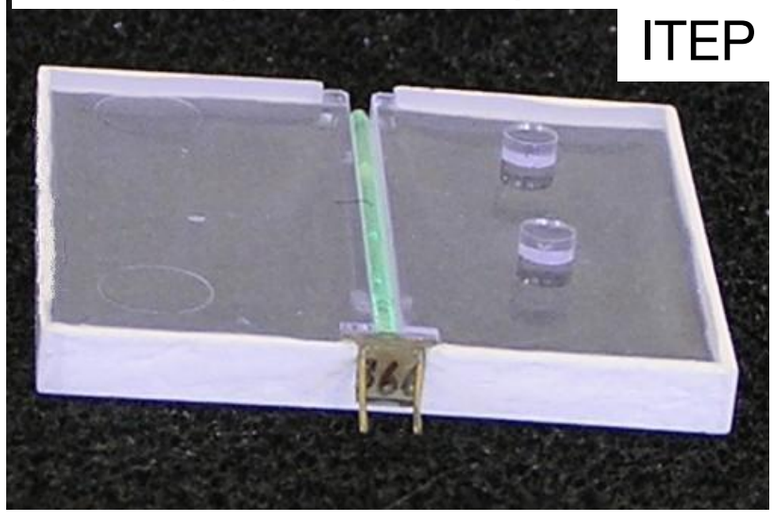


ITEP

easier tile assembly,
mounting pins for
placement on HBU

1st design for tech. prototype



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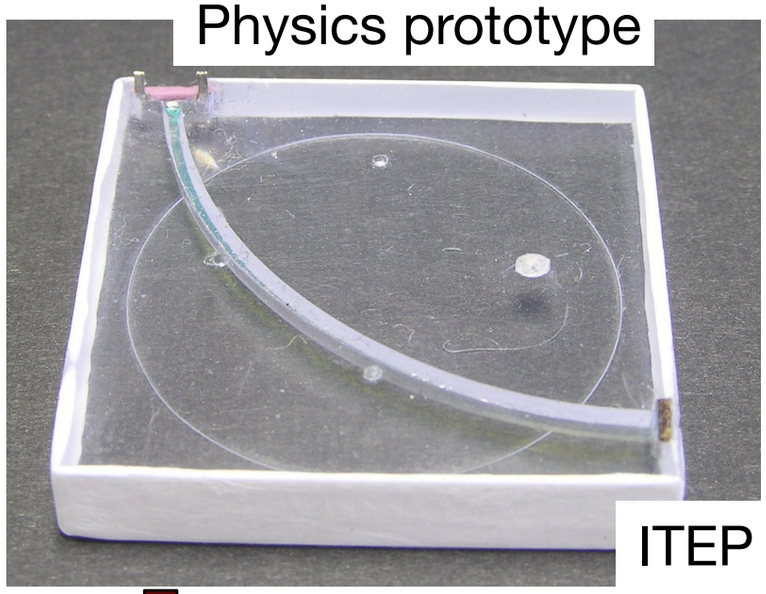

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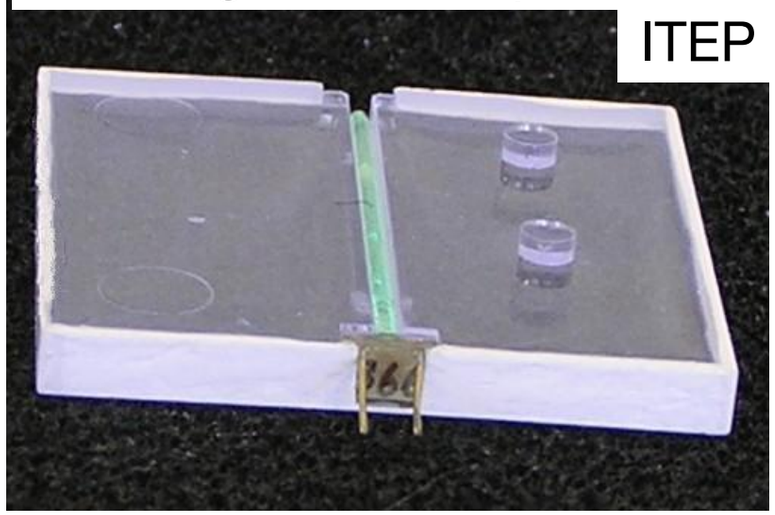
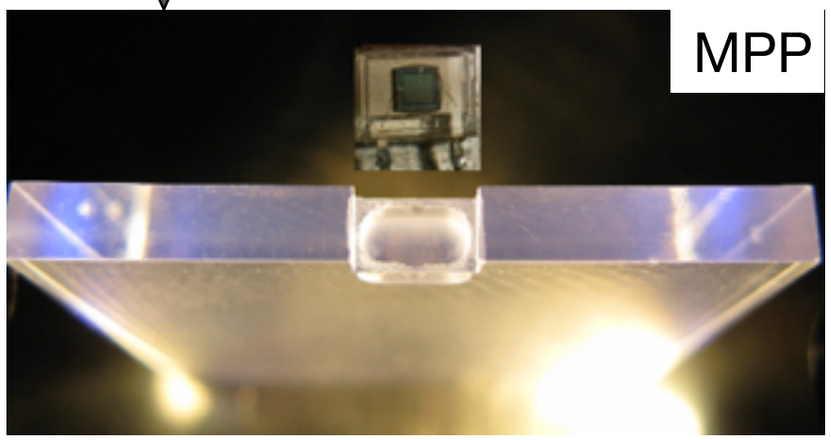


ITEP

fiberless coupling: easier manufacturing, increased tolerances



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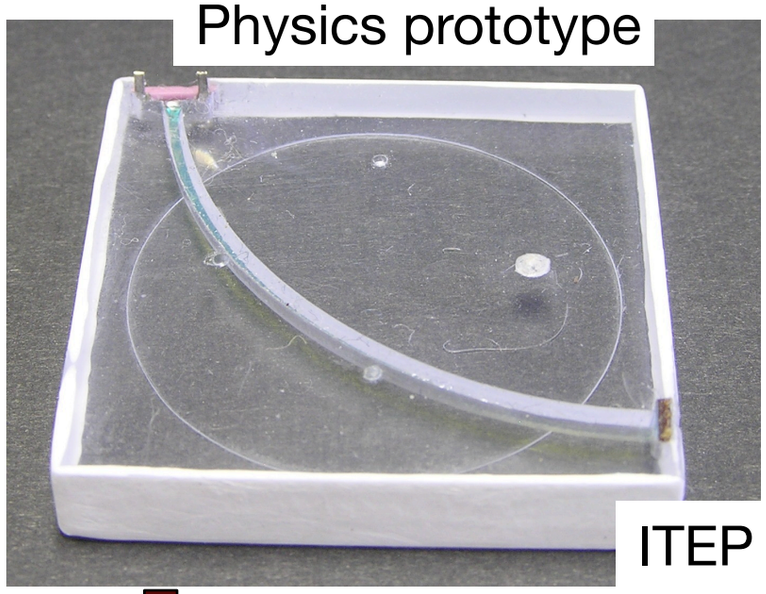

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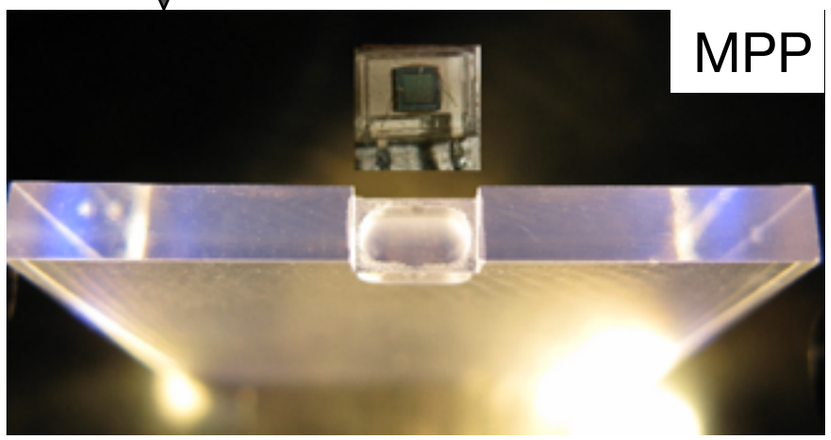

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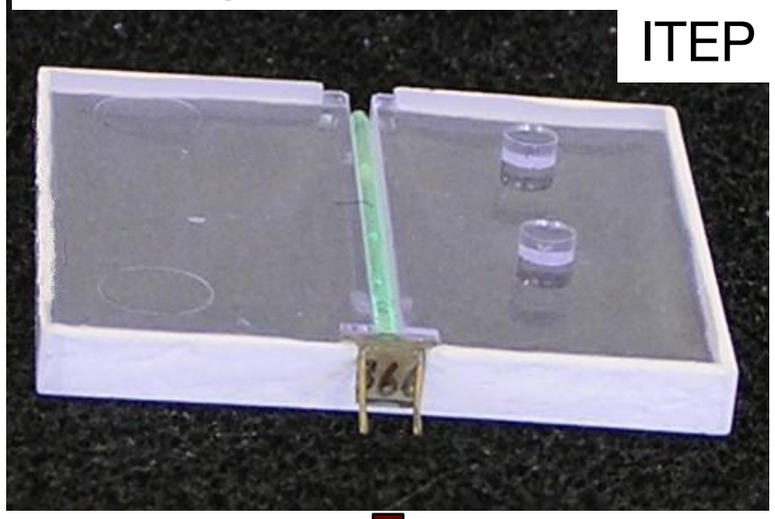
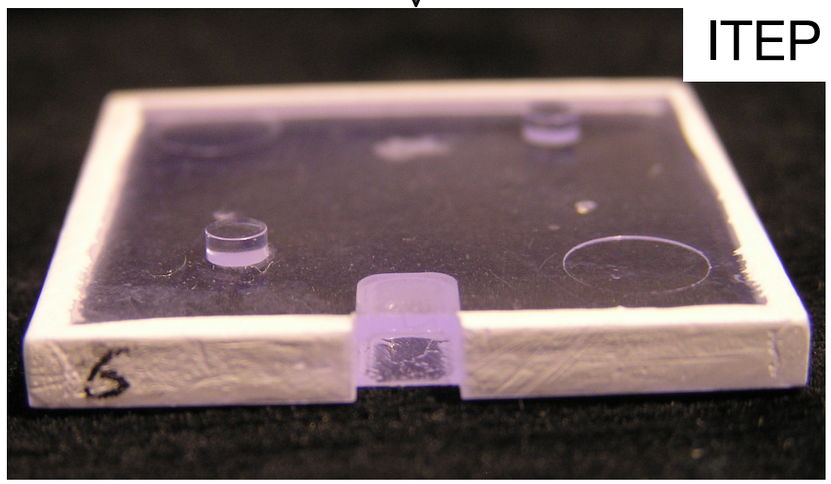


ITEP

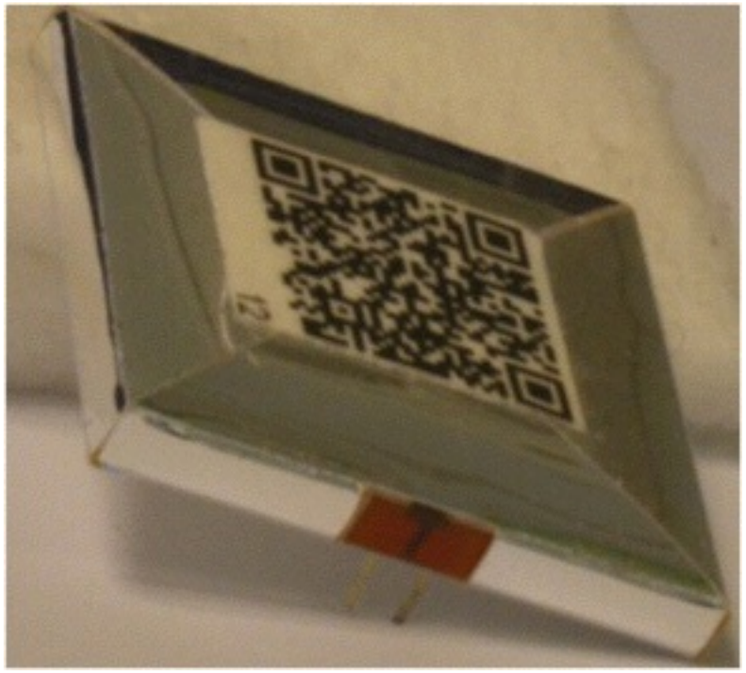
proof of principle: fiberless coupling, injection molding

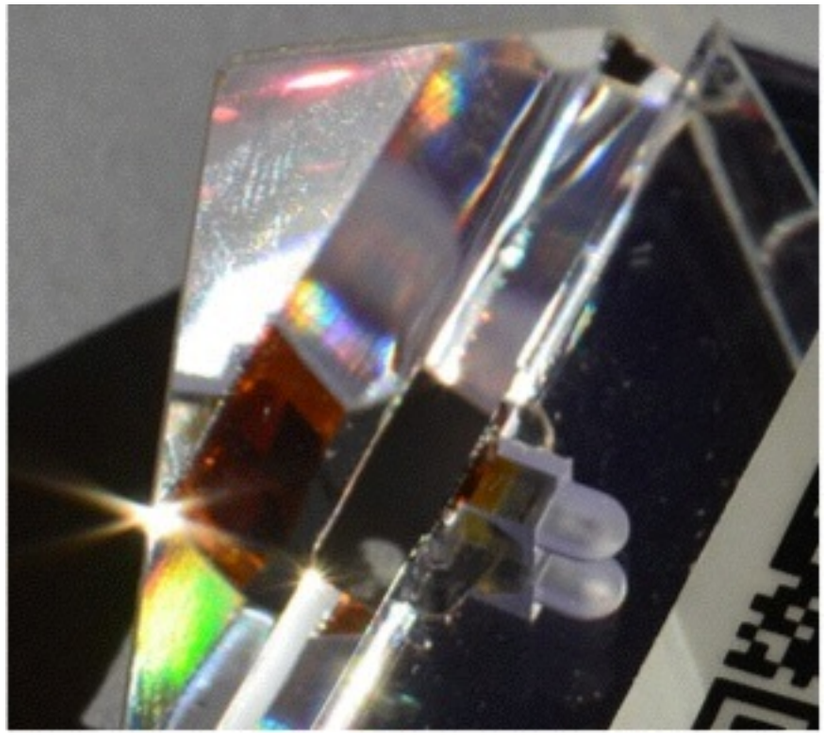


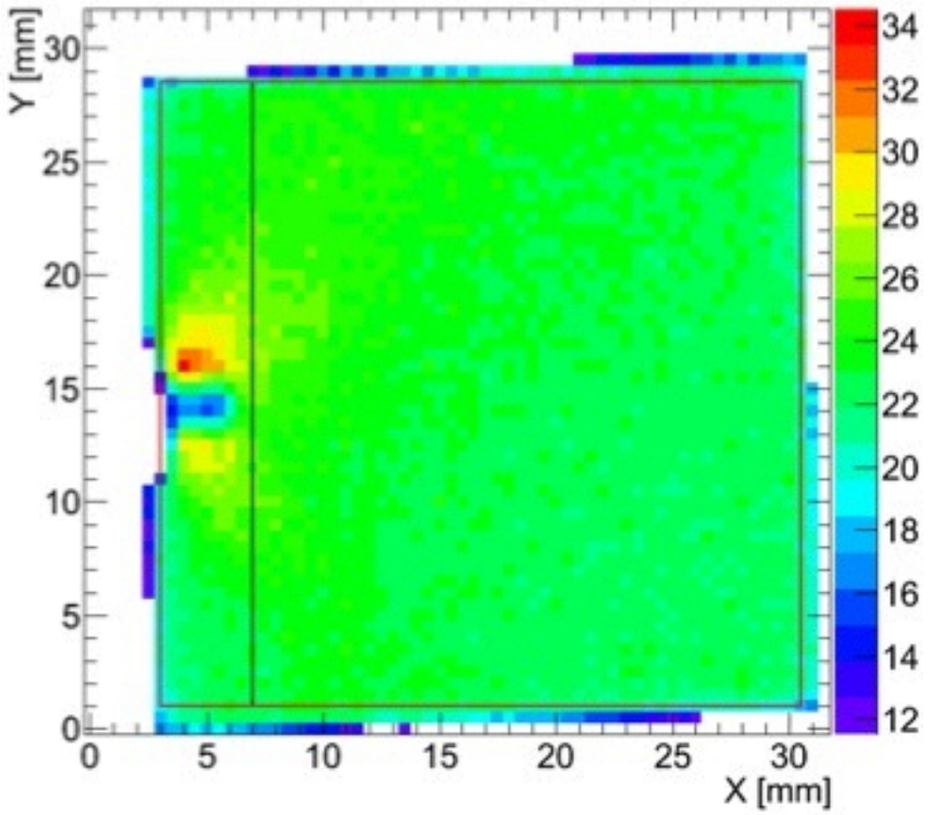
ITEP

Large-Scale Tile Productions…

- Larger batches (several 100) of fiber and fiberless tiles have been produced at ITEP
- Ongoing production at UHH -> machining with slightly adapted MPP design
  - semi-automatic packaging of tiles in laser-cut (non-adhesive) reflector foil







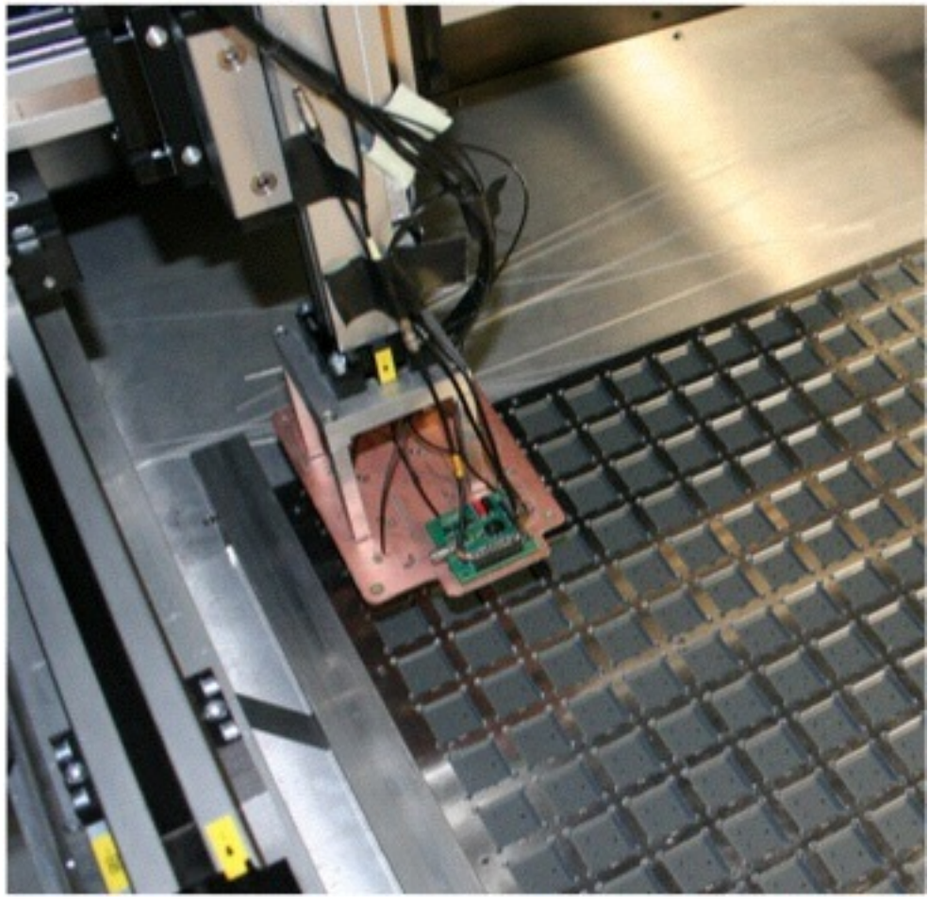
- New generation of KETEK SiPMs: High light yield
- High degree of response uniformity

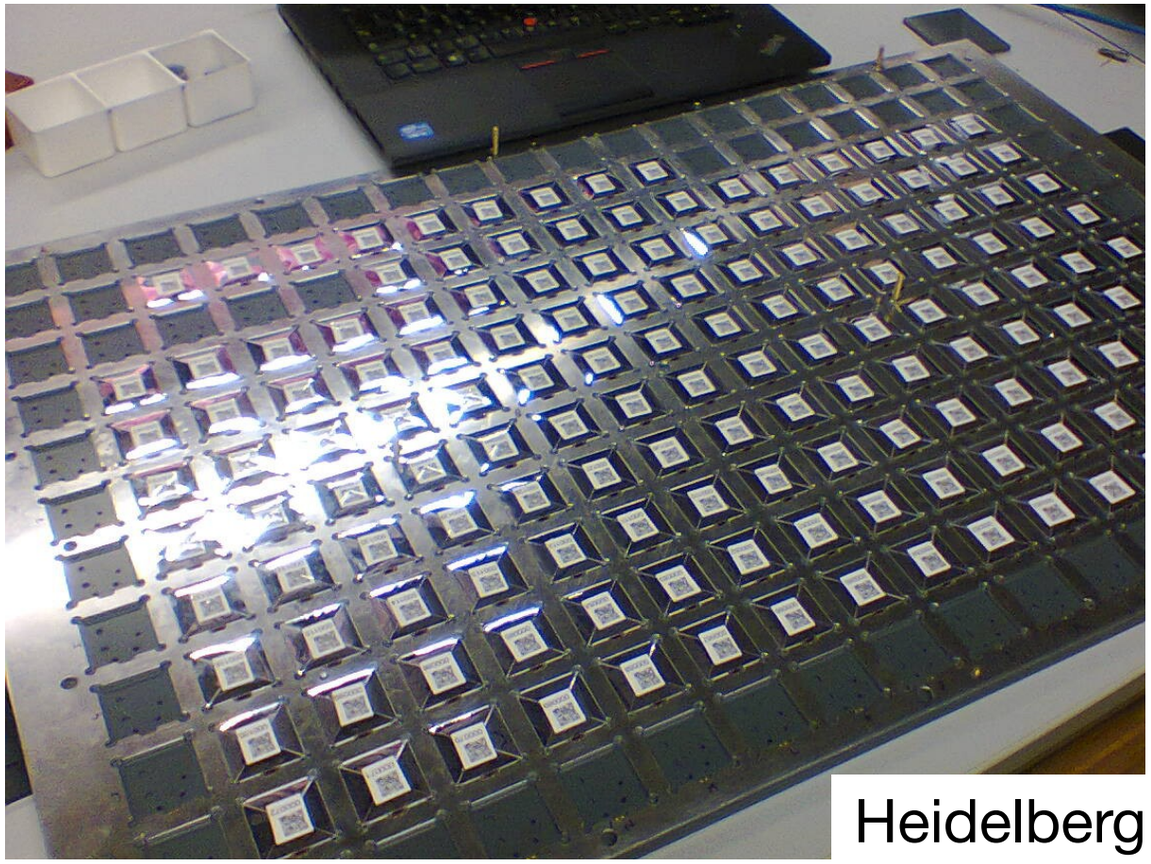
Large-scale QA

- Need QA for each component and at each integration step
- For high device uniformity characterisation becomes QA, but precision requirements on test procedures remain the same
- Present scheme:
  - test scintillator LY (source)
  - test SiPM
    - gain, noise, noise over threshold (cross talk)
  - test SiPM on tile
    - adjust HV working point to equalise light yield
    - effective dynamic range
  - test ASICs (test board, need to automatise)
  - test HBU
  - HBU with tile
    - gain / threshold equalisation
- Open issues:
  - are we still sensitive to optical coupling variations?
  - if not, LY equalisation could be done with bare SiPM
  - would be obsolete with sufficient signal / noise and dynamic range
  - same for effective dynamic range

Large-scale Testing of Tiles with SiPMs

- Fast testing of tiles prior to installation - basic functionality test with LED (measure gain, cross-check light collection from tile)





Heidelberg

- Several 100 tiles already tested - currently with 15 point voltage scan
- ▸ 2 minutes for 12 tiles (measured in parallel), then repositioning of head

Automated Assembly

- Large number of tiles require automatic assembly of full HBUs
- ▸ Requires precise placement of Tiles with SiPMs in HBU boards, followed by soldering

Challenge 1: Placement precision and tolerances

- ▸ Higher stability expected w/o alignment pins: Precise placement of SiPM pins, tile fixed by fast-curing glue put on board via screen printing prior to tile placement

extensively studied at Mainz

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Challenge 2: Soldering of pre-assembled and heat-sensitive components

- Have to avoid detachment of HBU SMD components, heat damage of tiles

- ▸ Two options to study
  - Selective (point-by-point) soldering - disadvantage: rather slow, can be sped up by multi-point head, would profit from symmetric soldering positions
  - Wave soldering - fast, but heats up everything: Needs thermal protection mask, special requirements for clearance between tile solder points and components

extensively studied at Mainz

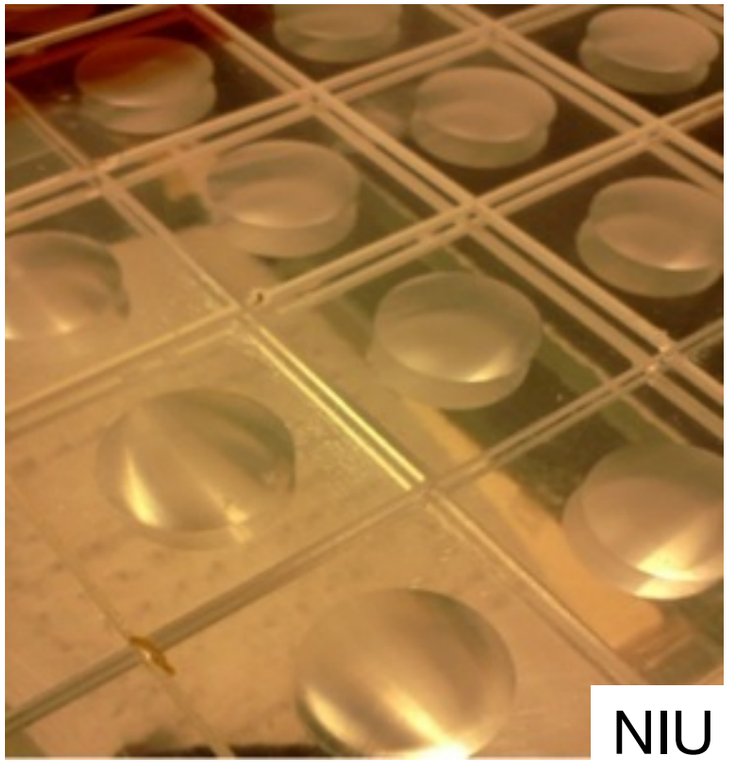
Re-thinking the Tile Design

- Alternative tile concept: SiPMs on electronics, tiles coupled via bottom - avoids soldering with tiles - Proof of principle from NIU, adaptations by ITEP and Mainz

Many (all?) issues to be addressed again:

- Light yield optimisation
  - trade-off with LY uniformity: understand performance impact
  - trade-off with SiPM size: understand cost and noise impact
  - trade-off with alignment precision requirements (PCB and scint.)
  - under mass production assembly constraints
  - includes reflective coating schemes
- tile to PCB mechanical fixture and alignment
  - SiPM package and solder (un-solder?) procedure
  - With mega-tiles, additional questions:
    - optical cross-talk, uniformity of it, impact on performance
    - mechanical precision: alignment and flatness
    - tile, tile-to-tile and mega-tile to mega-tile uniformity

ITEP



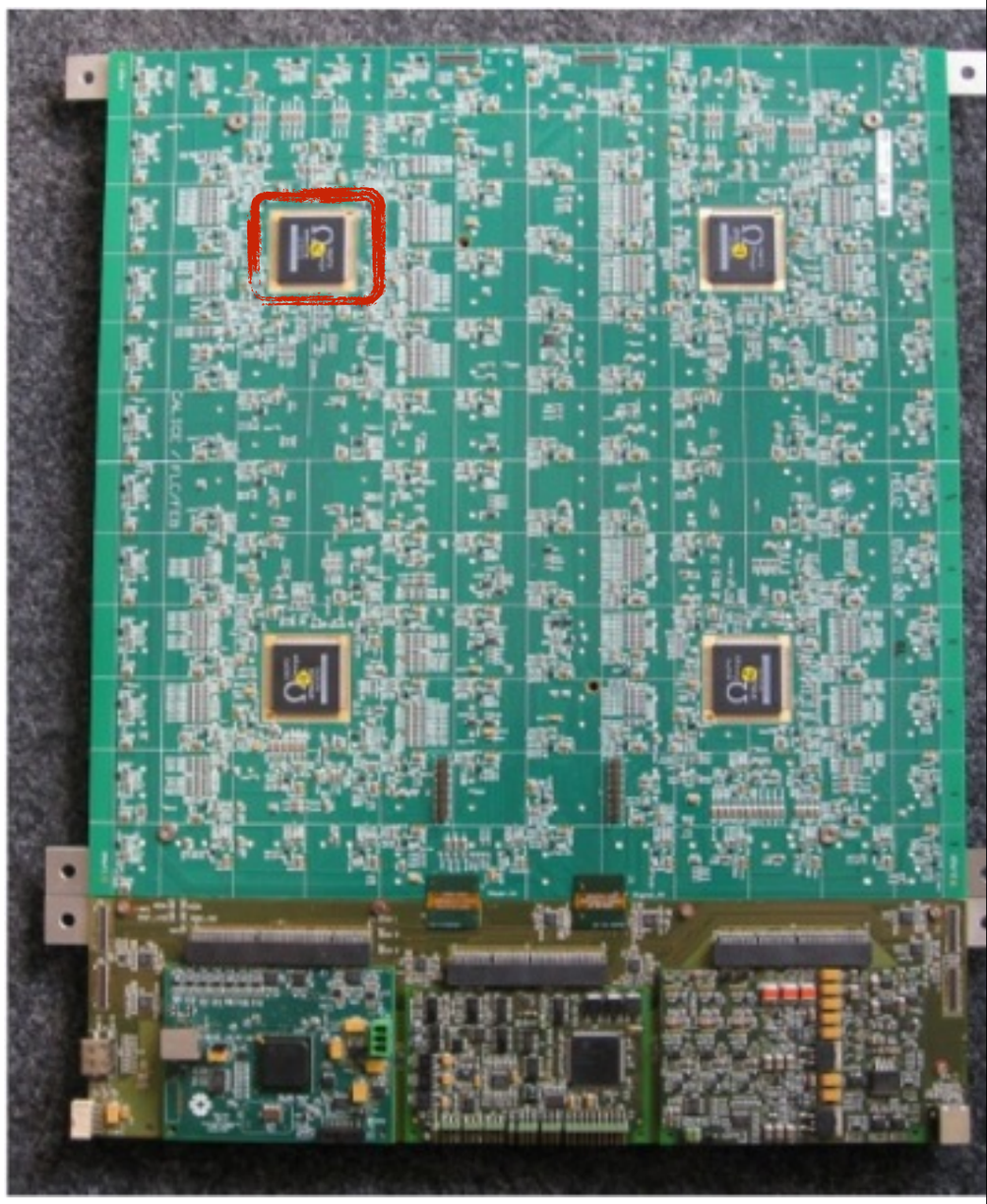
NIU

Specific QA Challenges for on-Board SiPMs

- SiPM testing before assembly
  - connect and disconnect
  - identify and store
- SiPM testing on board
  - limited by electronics of final detector vs lab set-ups
  - without tile? reproducible illumination, damage protection
  - with tile? light intensity and rate limitations
- Implications on sequence and parallelisation
  - in present scheme, SiPM production and characterisation drives the schedule
  - decoupled from schedule for ASICs and PCBs
  - with SiPM on board more tightly linked, and less time for ASIC development

Reading It Out…

- Need a versatile front-end chip
  - sub-p.e. resolution for calibration, large dynamic range for sub-MIP to > 100 MIP signals
  - ns - level time stamping (background rejection for CLIC, exploit time structure in clustering, …)
  - Cell-by-cell auto-trigger: Triggerless readout
  - Powerpulsing: Compact layer!
  - SPIROC ASIC - Alternative analog part: KlauS, ADC currently being developed



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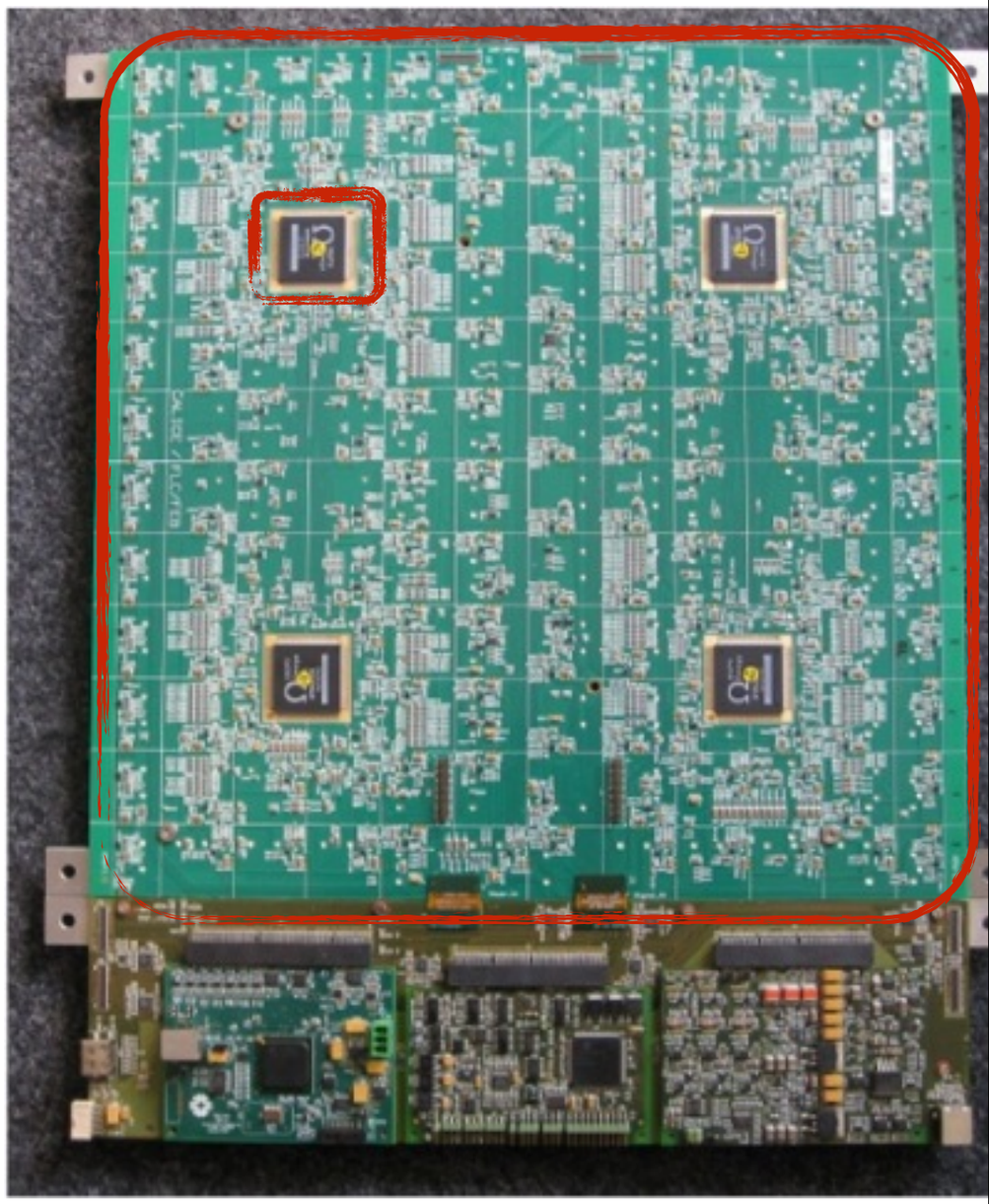

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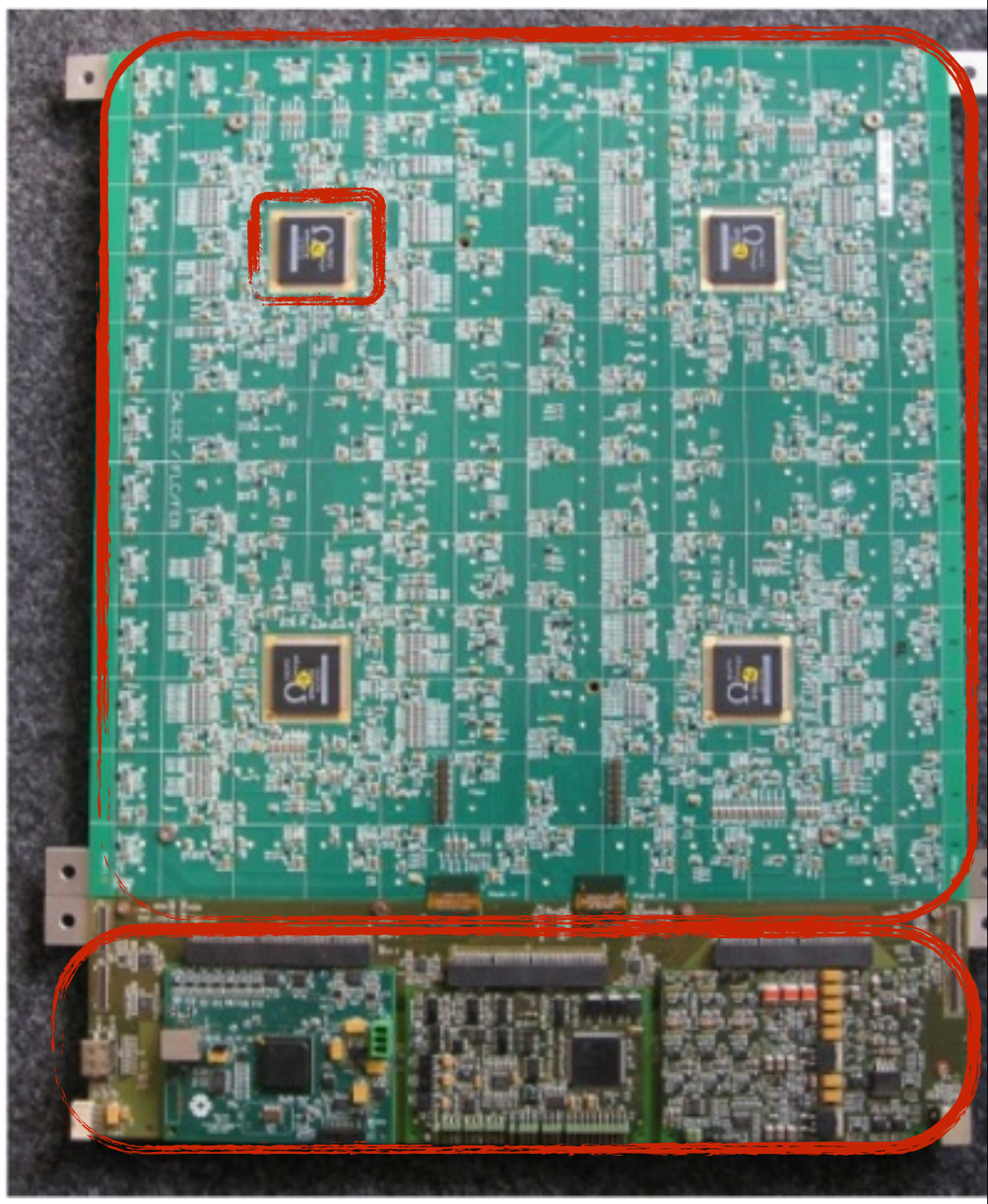
- Control of a full layer (3 x 1 string of up to 6 HBUs): Control & Interface Board CIB
  - DAQ Interface
  - Calibration and trigger controller
  - Power



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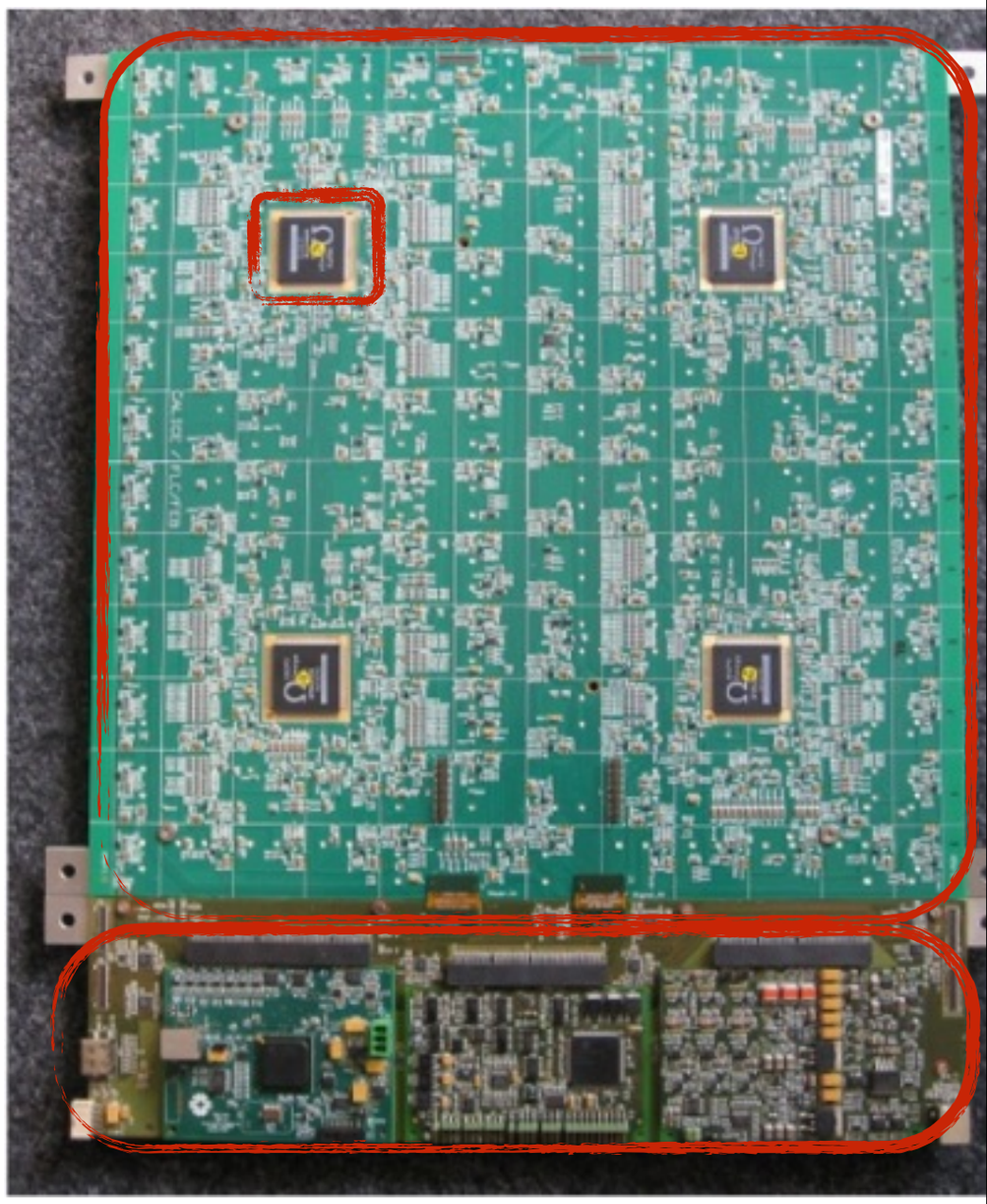
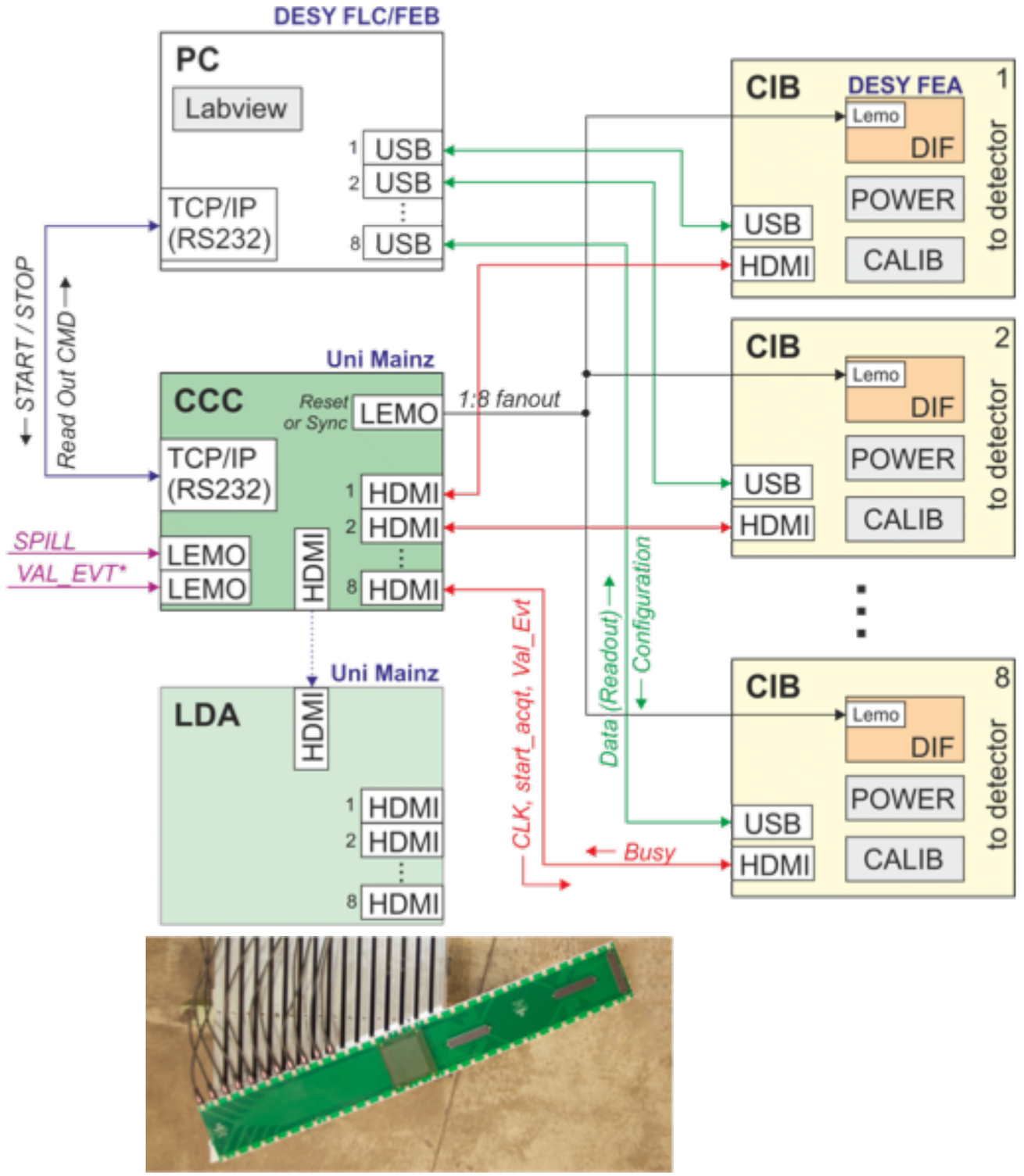


Identical requirements for scintillator ECAL - with x2 higher channel density: More complex PCB layout, same functionality

… and getting it on Tape

- Complete, flexible system:
  - can integrate other CALICE calorimeters
  - provides possible starting point for full experiment DAQ
  - Based on original CALICE DAQ, further development of second-generation DAQ
- DAQ Interface: DIF - part of CIB
- Fist signal distribution: CCC
- Data aggregation: LDA



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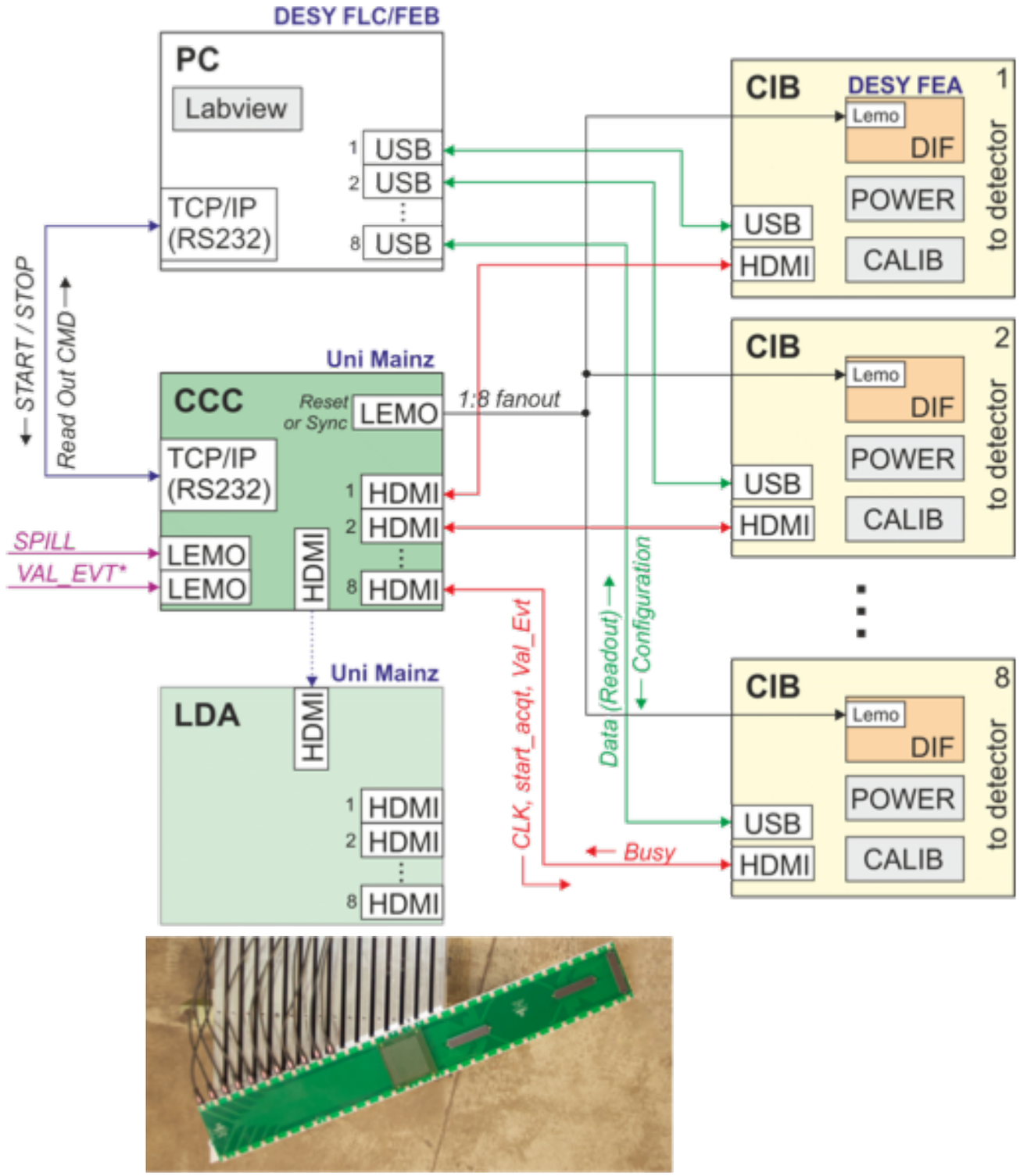
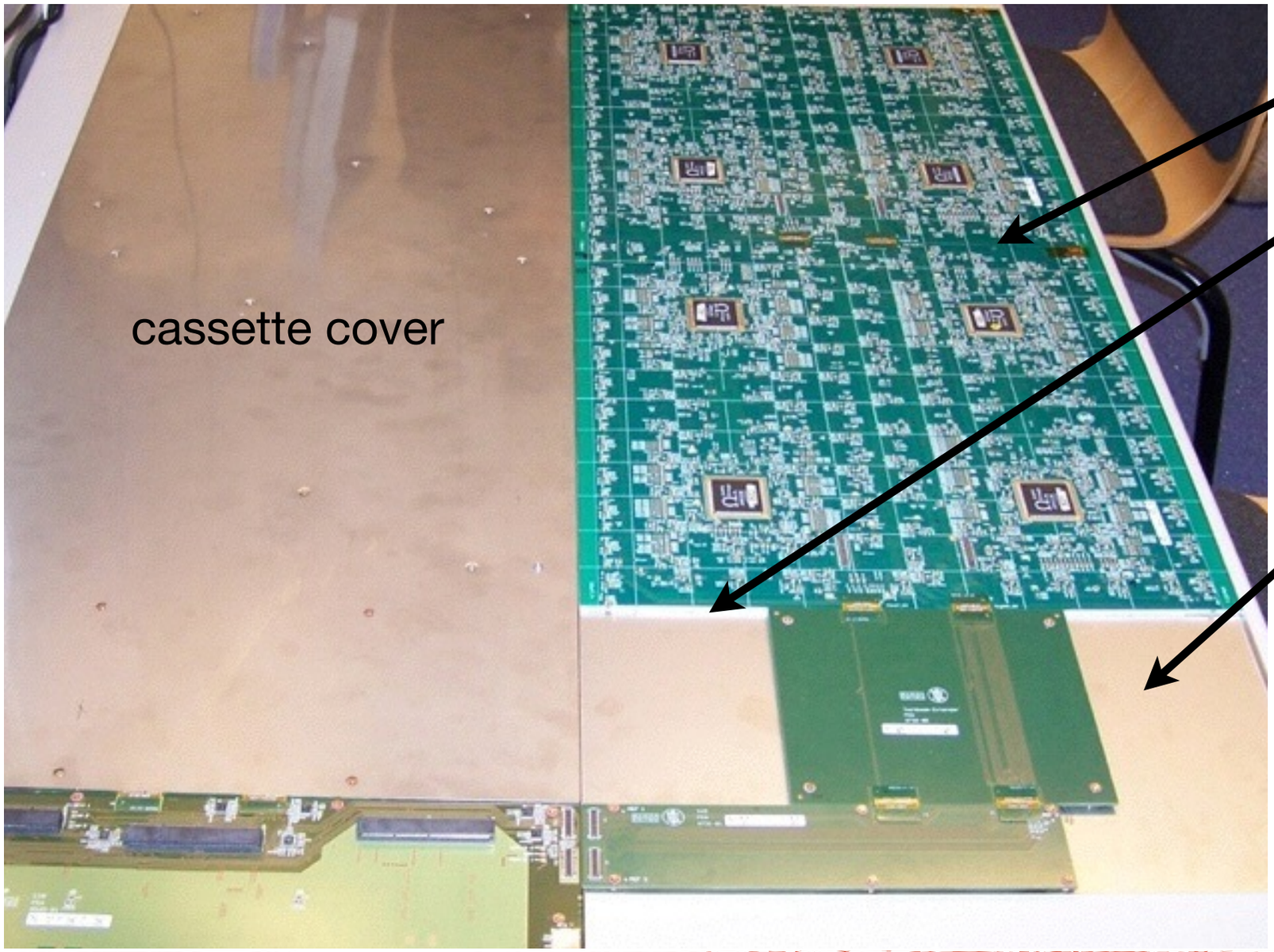
Successfully used for single and multiple HBUs, stepwise development to full scale ongoing



Mechanics - Cassettes

- Provide mechanical stability and protection to HBUs with tiles - Creates insertable readout layers

  Proof of principle: Cassettes for technological prototype - designed at DESY, manufactured at Munich using precision welding

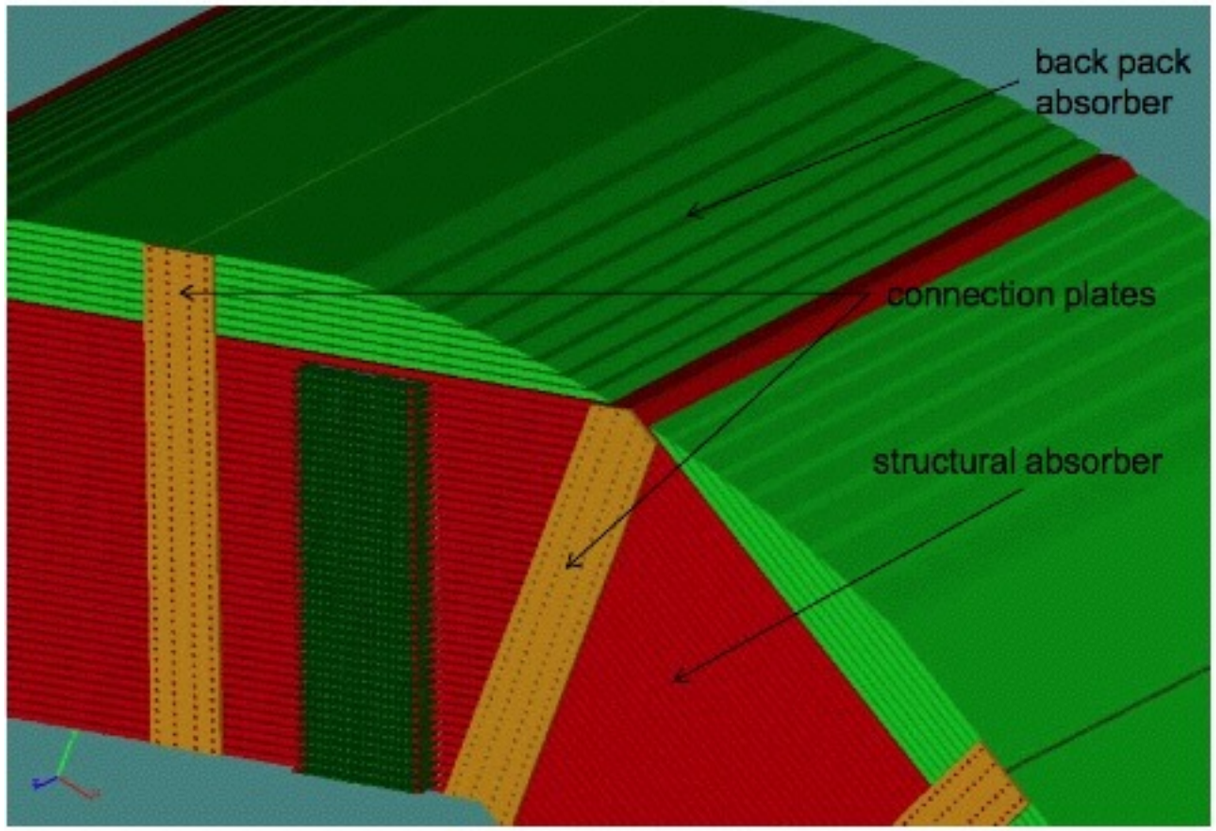


4.5 mm

Total thickness of unit:
6.5 mm (incl. 1 mm steel)

Mechanics - Absorber Structure

- Octagonal structure, 19 mm thick stainless steel plates



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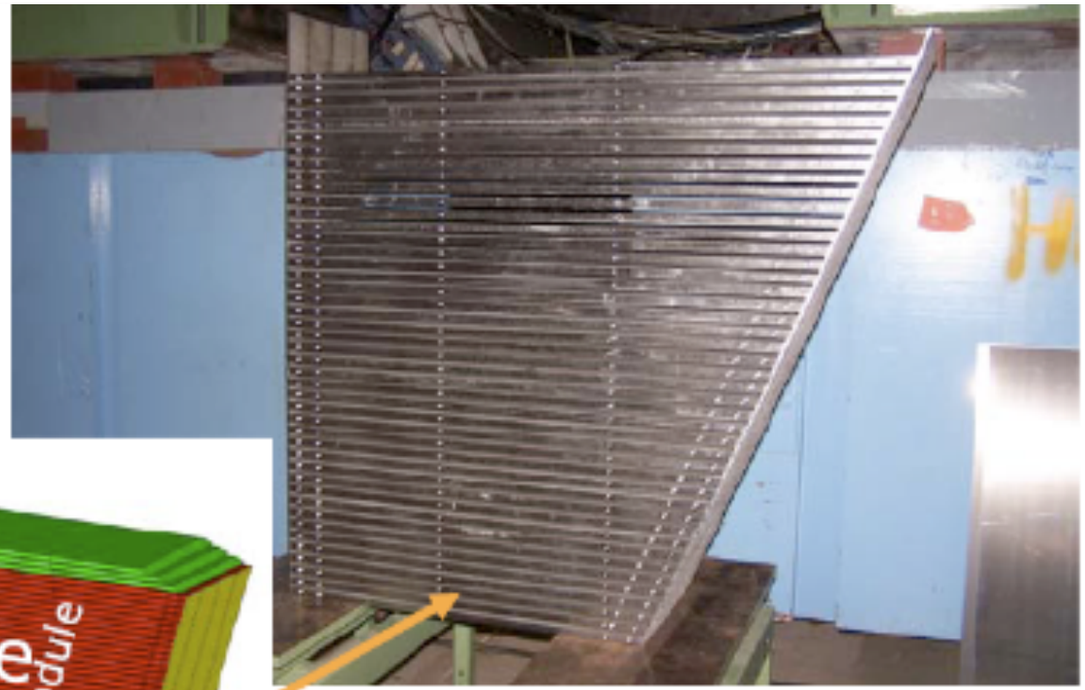
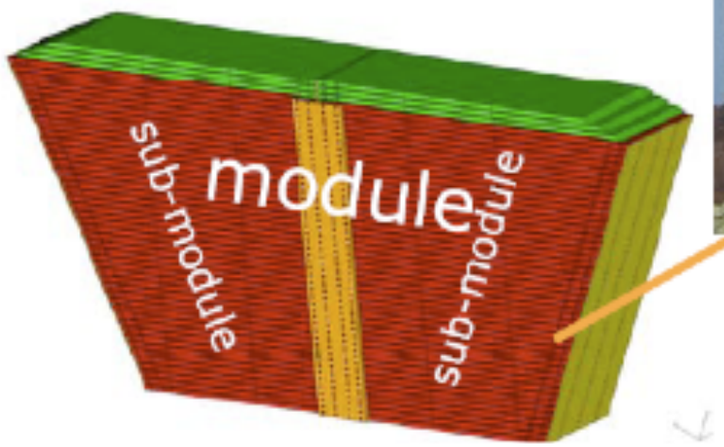




Prototypes:

- one HBU-deep full 48 layer stack
- full size 4-layer unit

Steel plates from manufactures are far from the flatness requirements

- Flatness better than 1 mm over full length reached with roller levelling - substantially cheaper than machining

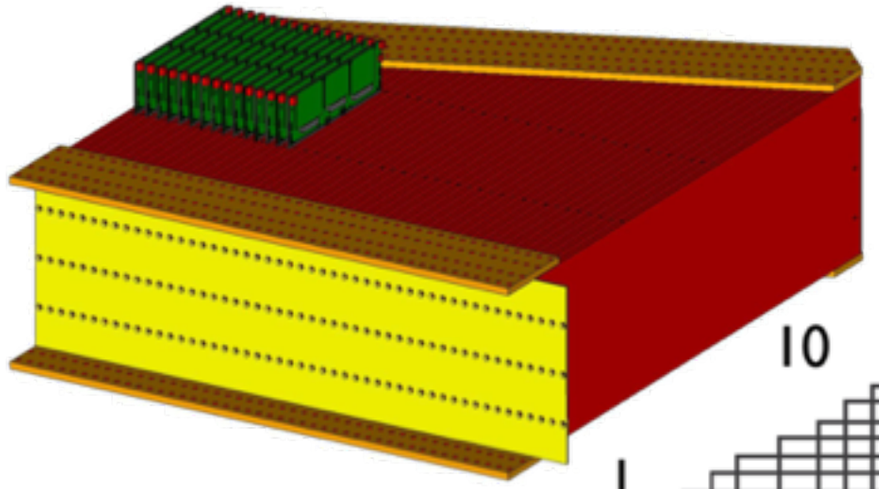
Test Beam Plans

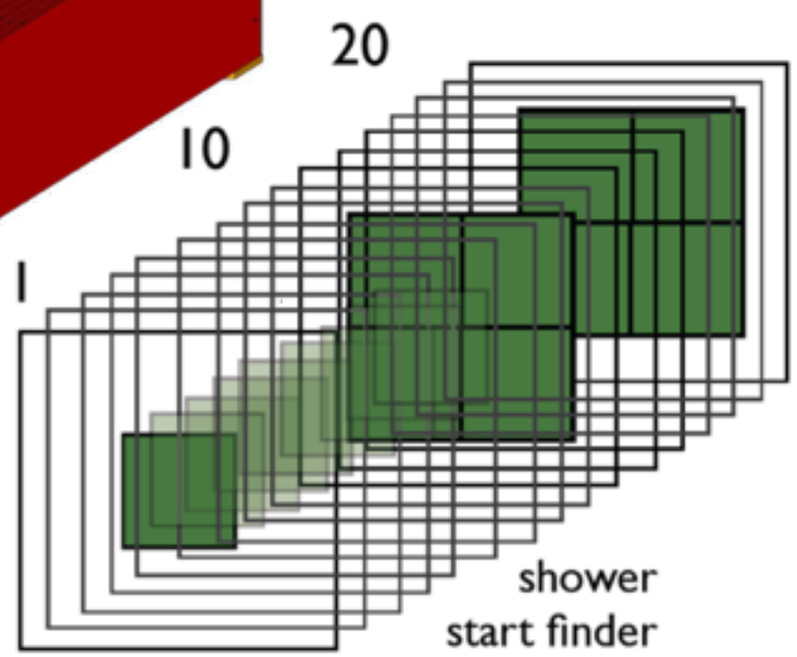
- Single layer tests (few HBUs)

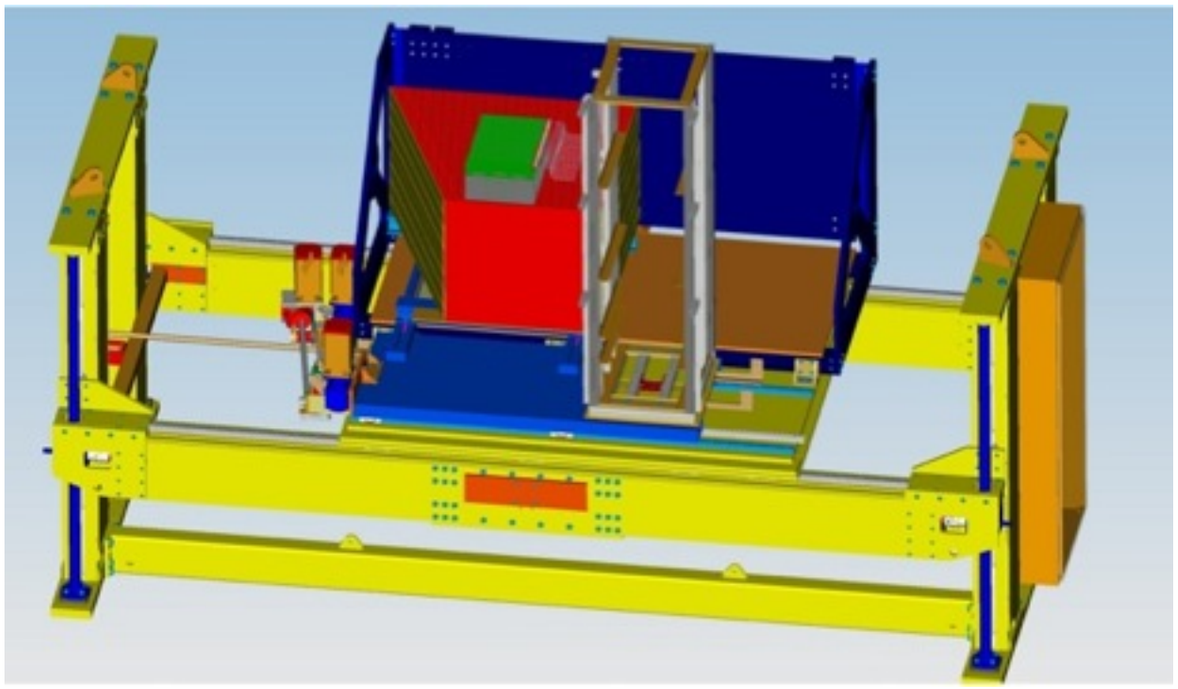
- First electromagnetic performance measurements with ~ 10+ HBUs

- Hadronic tests with a few full layers and a shower start finder - allows full profile measurements (“a la T3B”)

- Gradually build up full hadron calorimeter as HBUs become available







Summary & Outlook

- The AHCAL Physics Prototype delivered a wealth of results - and continues to do so
  - From validation to performance to shower physics - extending the traditional scope of calorimeter R&D

- A complete concept for a full detector exists - with key R&D issues identified
  - Photon sensor - picking the optimum
  - Scintillator tiles - Re-examine optimization, investigate alternatives
  - Mass QA and production - What is needed, on what level?
  - Electronics & DAQ
  - Detector mechanics (active layers & absorbers)

- More test-beams to come: Study performance of technical prototypes, study different designs