Integration concepts for highly granular scintillator-based calorimeters

- analog hadronic calorimeter (AHCAL) for ILC: from physics prototype to engineering prototype
  - integrated electronics
  - calibration systems
- other applications

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on behalf of the CALICE Collaboration

CHEF2013

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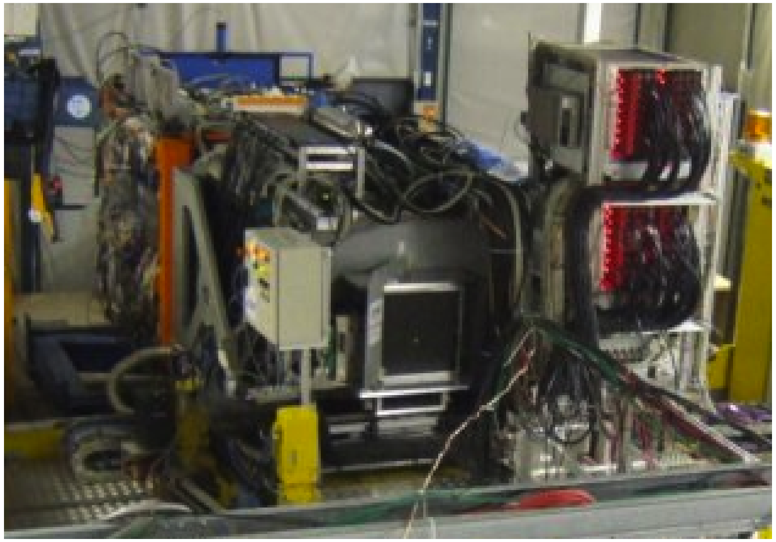
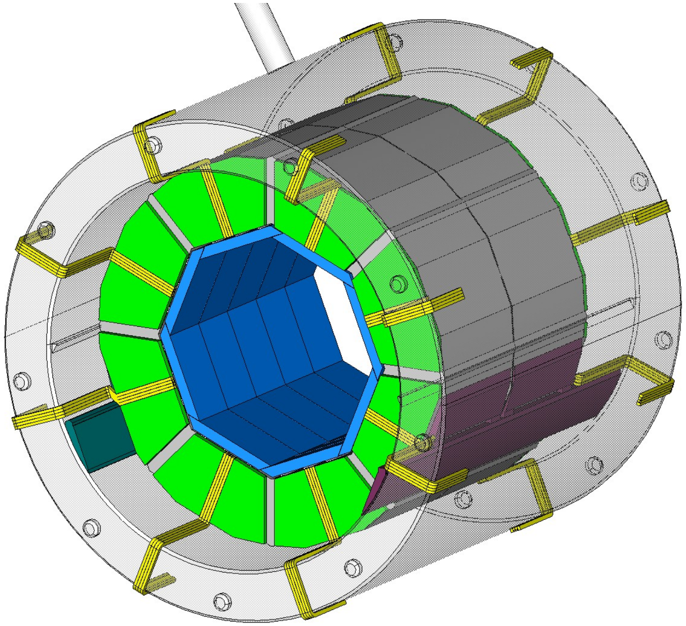
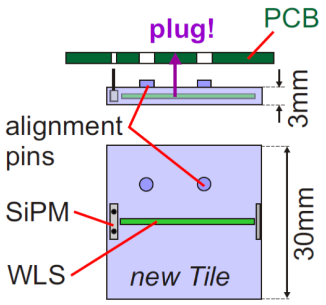
AHCAL: from Physics Prototype to Engineering Prototype

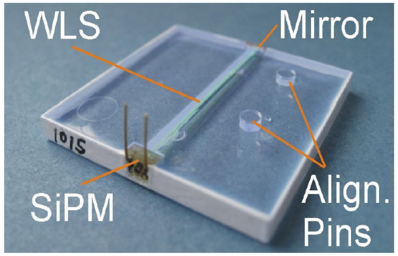


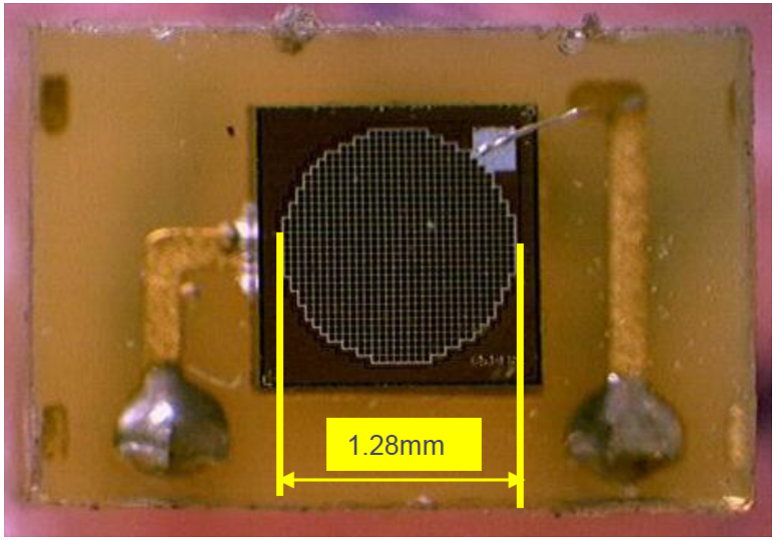


- Goal: go from a proof-of-principle detector to a scalable part of a linear collider detector
- requirements for compactness:
  - integrated electronics
  - no active cooling inside main detector volume → low power consumption

Tile and SiPM







tile:

- 3*3*0.3 cm^3 scintillator tiles with WLS fibres

SiPM:

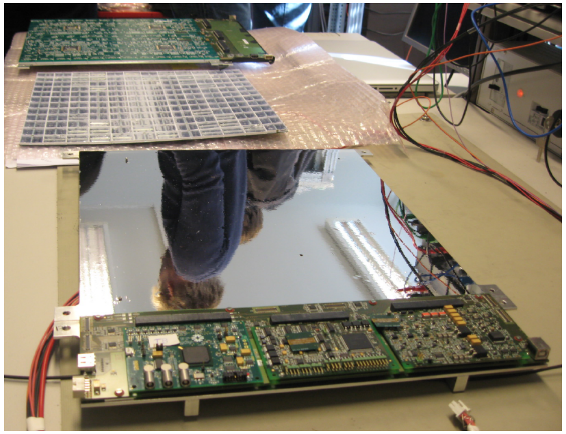
- pixelated Geiger-mode avalanche photodiodes
- insensitive to magnetic fields
- can detect single photons
- rather small and cheap

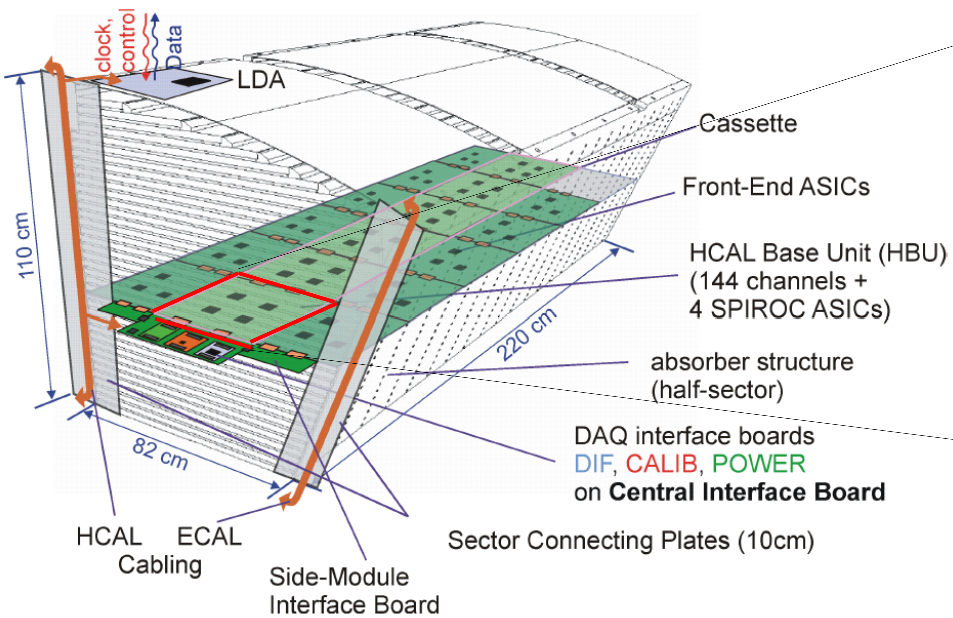
CPTA SiPM:

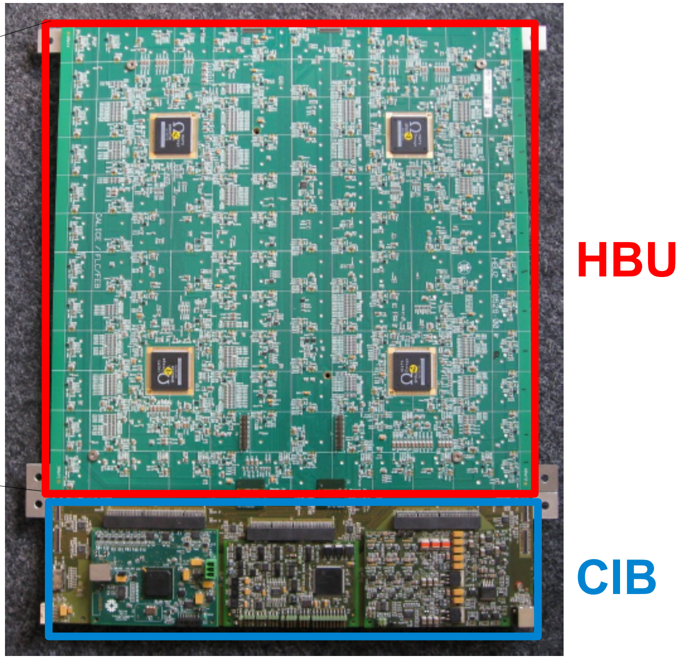
- 796 pixels
- gain 0.5-1.5 * 10^6
- come with some spread in amplification, bias voltages, … within a batch

AHCAL engineering prototype

- **H**CAL **B**ase **U**nit: 36*36 cm^2, 144 tiles, 4 readout ASICs
- **C**entral **I**nterface **B**oard: DIF, Calibration, Power for 1 layer



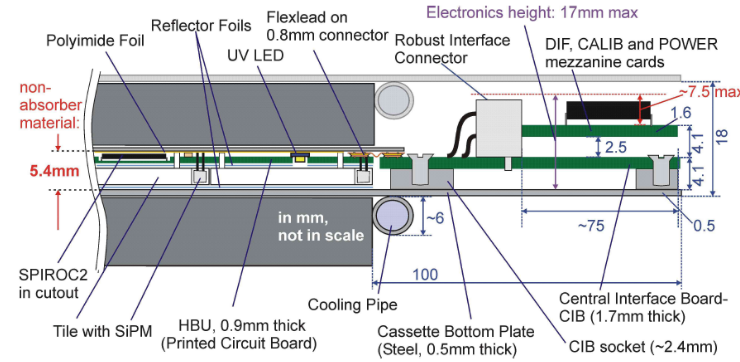




Integrated electronics

Compact detector:

- front-end electronics integrated in active layers
- thin layers → cut-outs for ASICs, only 5.4 mm thickness including 3 mm tiles



SPIROC: highly integrated specific chip for SiPM readout (system on chip)

- channel-wise bias adjustment
- channel-wise adjustable gain
- dual gain setup per channel, high gain/low gain ~10
- designed for ILC operation:
  - power pulsing → 25 µW/ch
  - auto-trigger mode, channel-wise fine adjustment of threshold
- has also special testbeam mode

more details in talk by Nathalie Seguin-Moreau

cut-out

→ **about 700 parameters per chip**

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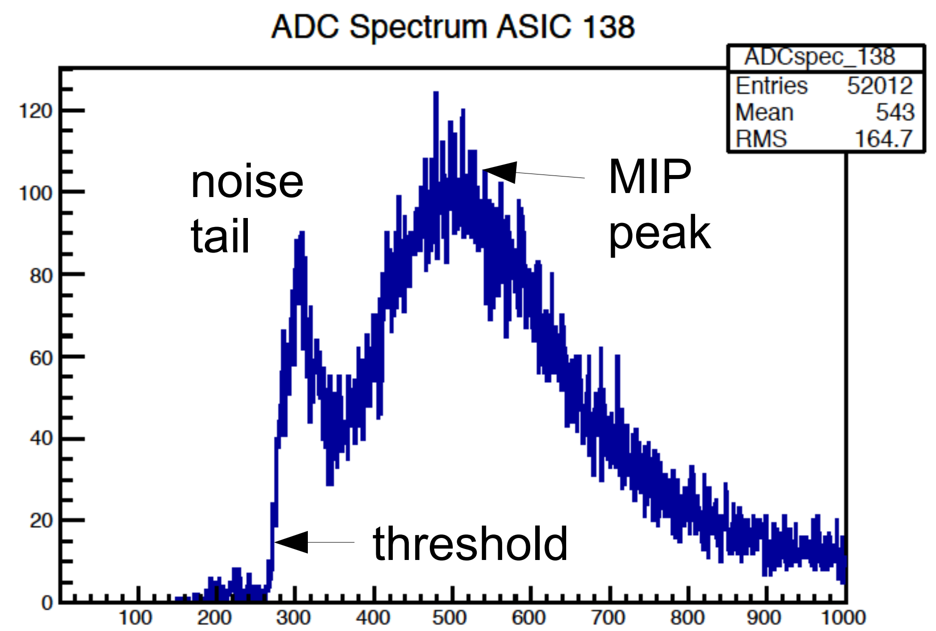
AHCAL electronics operation

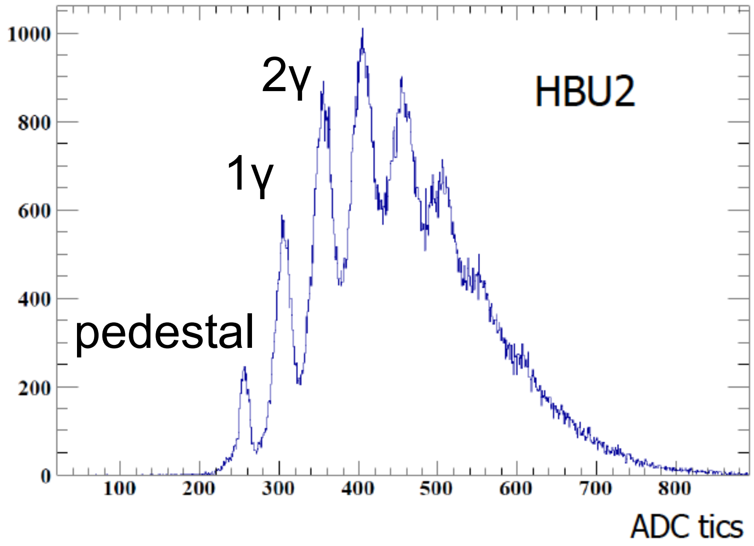
- flexible electronics allows equalisation of detector response

- demonstrated in muon testbeam
  - all 36 channels on one chip can be operated with a single trigger threshold
  - SiPMs from different batches (different gains, different bias voltages) can be operated within one layer



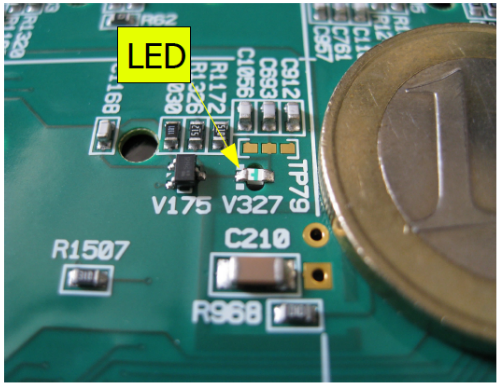
more details in talk by Marco Ramilli

LED calibration system



Single Pixel Spectra:

- for low light intensities, single photons result in discharges of single SiPM pixels
- distance between peaks corresponds to gain



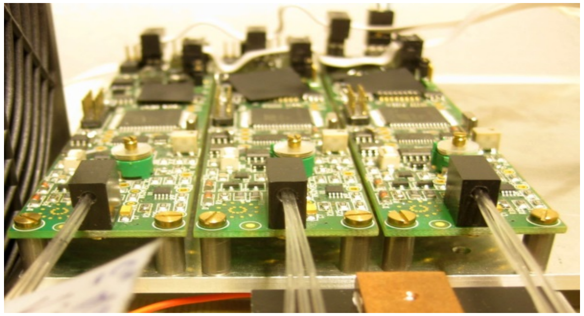
LED calibration system:

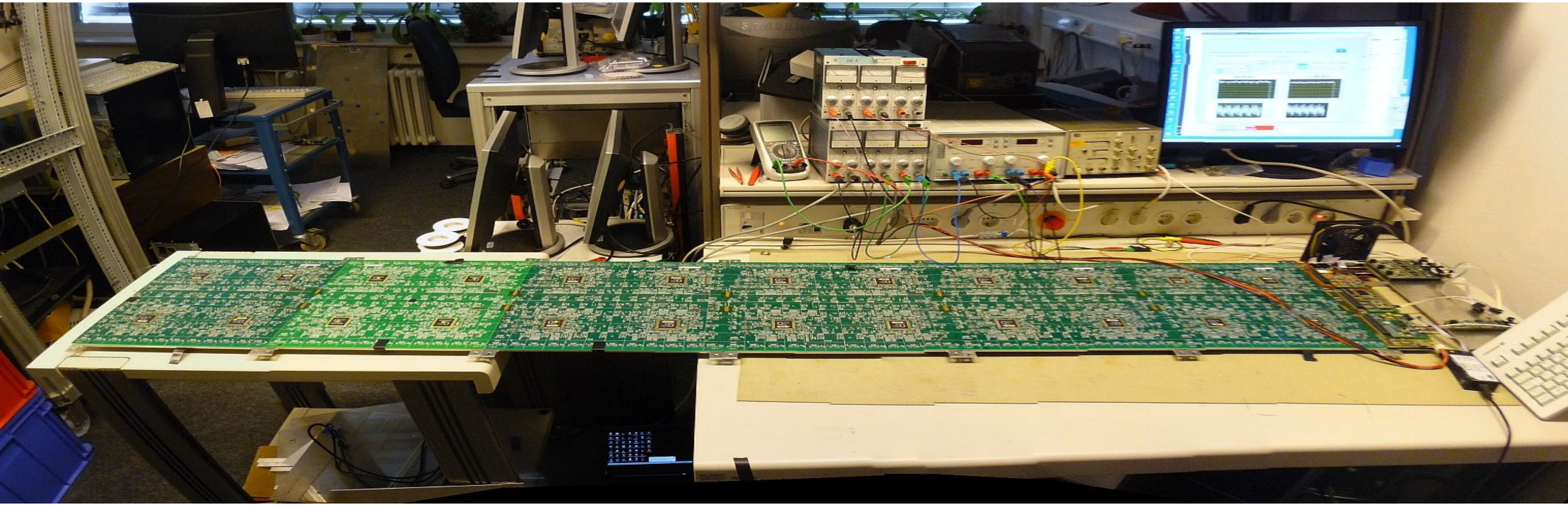
- light coupled directly into tile, 1 integrated LED per channel
- essential for equalizing the response of the detector

LED calibration system: alternative

1 LED illuminating many tiles by fibres

- 1 LED illuminates 3 fibres with 24 notches each (→ 72 tiles per LED)
- successfully tested with full slab
  - good signal quality read out over 2.2 m
  - good fibre uniformity





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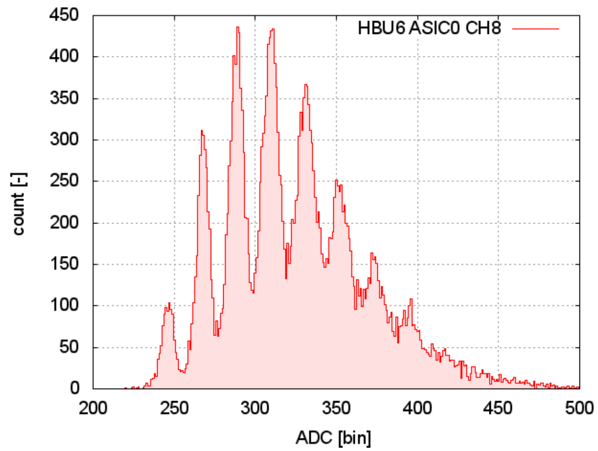
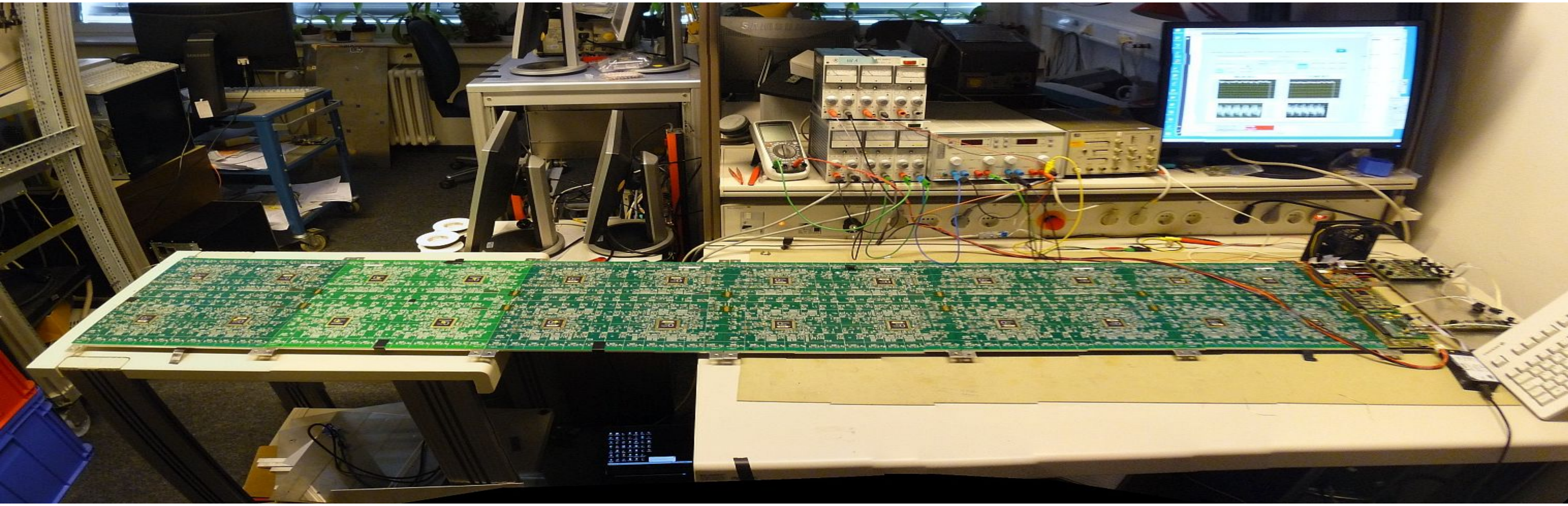




Flexible electronics

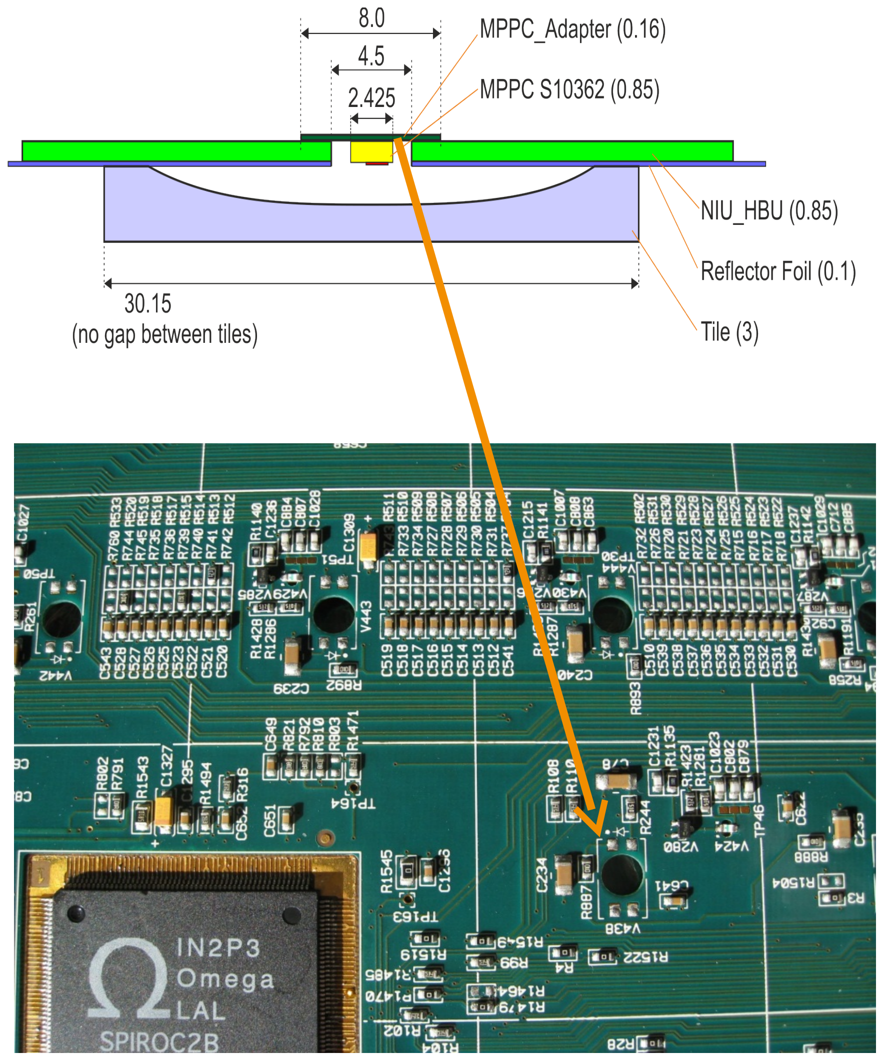
> AHCAL electronics is designed in view of operation in a full-scale collider detector

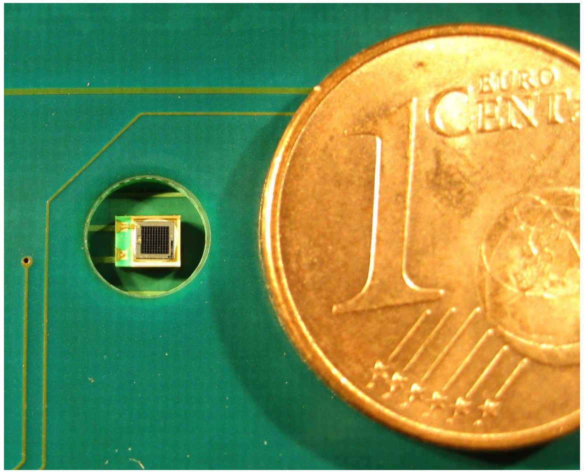
> but up to now, many detector options are not fully finalized
  - SiPM placement (side or top of tile)
  - tile design (WLS vs. direct coupling)
  - SiPM type
  - tile/strip geometry

> electronics have to be very flexible

Surface Mount HBU

- Mount SiPM on PCB, not in the tile
  (G. Blazey et al., NIM A605 (2009) 277,
  F. Abu-Ajamieh et al. NIM A659 (2011) 348)
- no gap between tiles → one "megatile" per HBU
- tiles have concave cavity to improve uniformity
- 2 surface mount HBUs produced, to be equipped with tiles





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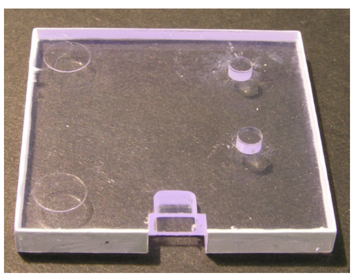
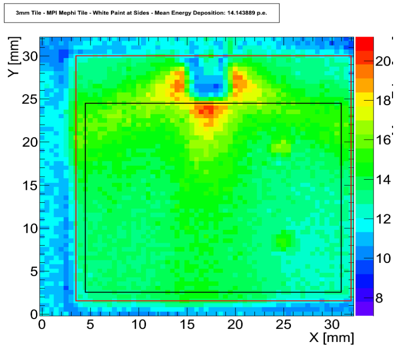
New tiles for direct coupling

- WLS fibre has two tasks:
  - shift wavelength to sensitive range of SiPM
  - improve light yield uniformity within a tile
- new SiPMs are sensitive in blue-UV range
- optimised tile design allows good uniformity without WLS
  (F. Simon, C. Soldner, NIM A 620 (2010) 196)

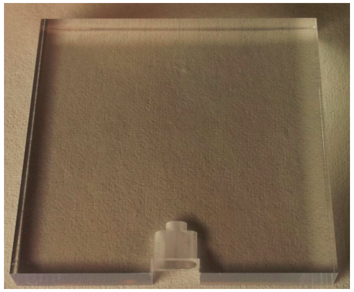
ITEP

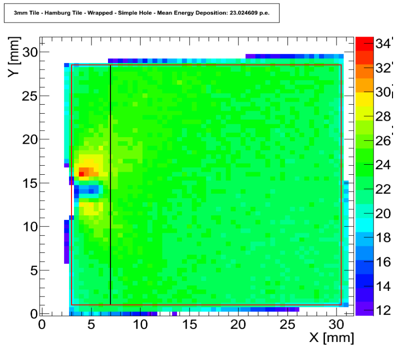




[p.e.]

Uni Hamburg





[p.e.]

- two different types:
  - ITEP: injection moulding, easily producible in large quantities
  - Uni Hamburg: machining
- both show good uniformity, Uni Hamburg type slightly better

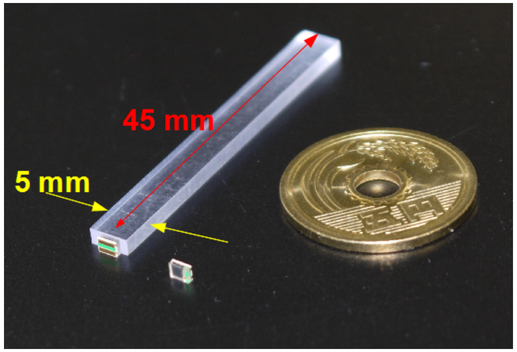
New SiPMs

- new SiPMs are sensitive in blue-UV range
- larger number of pixels reduces saturation effects
- typically better uniformity

	current SiPM	alternatives	
	CPTA	Ketek (Uni Hamburg)	Ketek (ITEP)
Gain [e-]	0.5 to 2 $\times 10^6$	0.8 $\times 10^6$	1 to 1.3 $\times 10^6$
Dark Count Rate (at 0.5 p.e.)	1 Mcps	1 Mcps	~1 Mcps
Cross-talk [%]	~ 1%	10 %	13 %
Breakdown [V]	28	26	24.6
Area	1.28 mm x 1.28 mm round	1.2 mm x 1.2 mm	2.2 mm x 2.2 mm
N of pixels	796	2300	12100

Other geometries: SciECAL

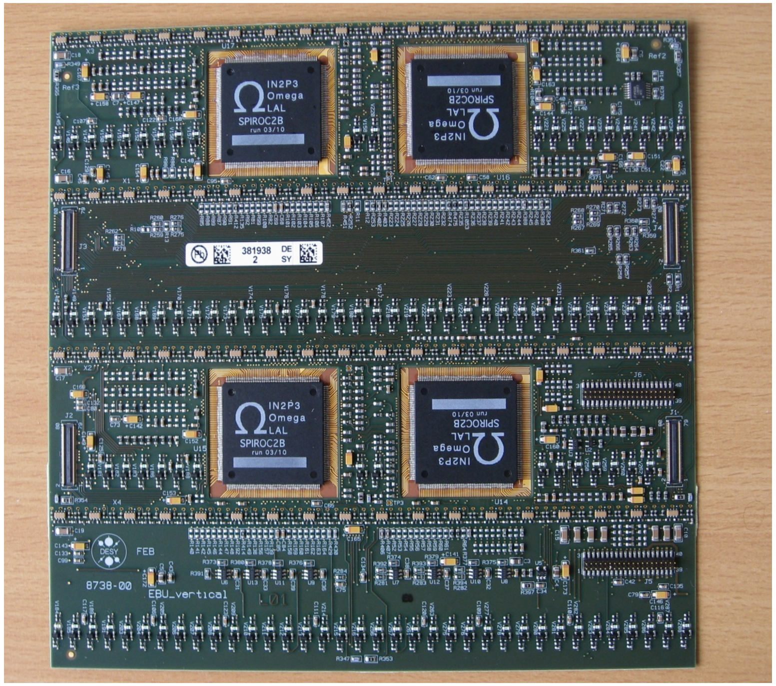
- ECAL option: needs finer granularity than HCAL
  - 45 * 5 mm² strips instead of 30 * 30 mm² tiles
  - 4 times larger channel density than HCAL
  - alternating orientation horizontal / vertical

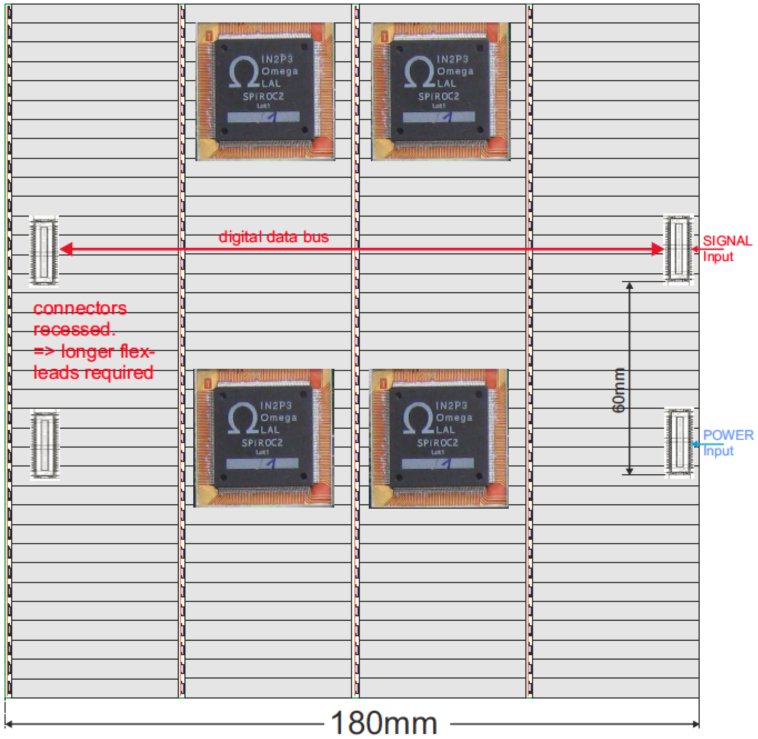


- SciECAL uses Hamamatsu MPPCs as SiPMs
  - 1600 pixels on 1 * 1 mm²
  - gain: a few 10^5
  - bias voltage ~70 V

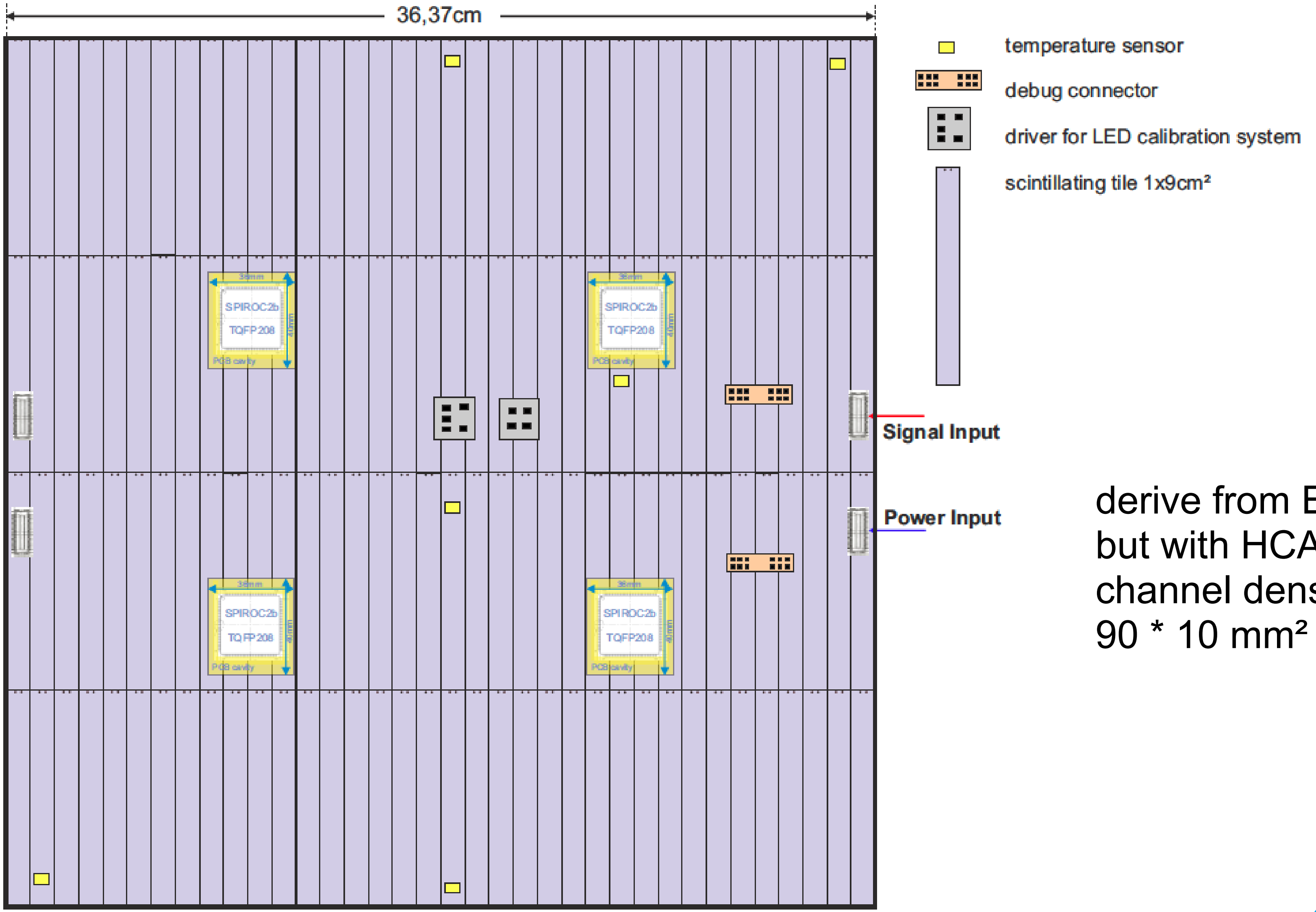
EBU

- two different PCB designs needed for different strip orientation
- 1 orientation produced and tested, other orientation in design



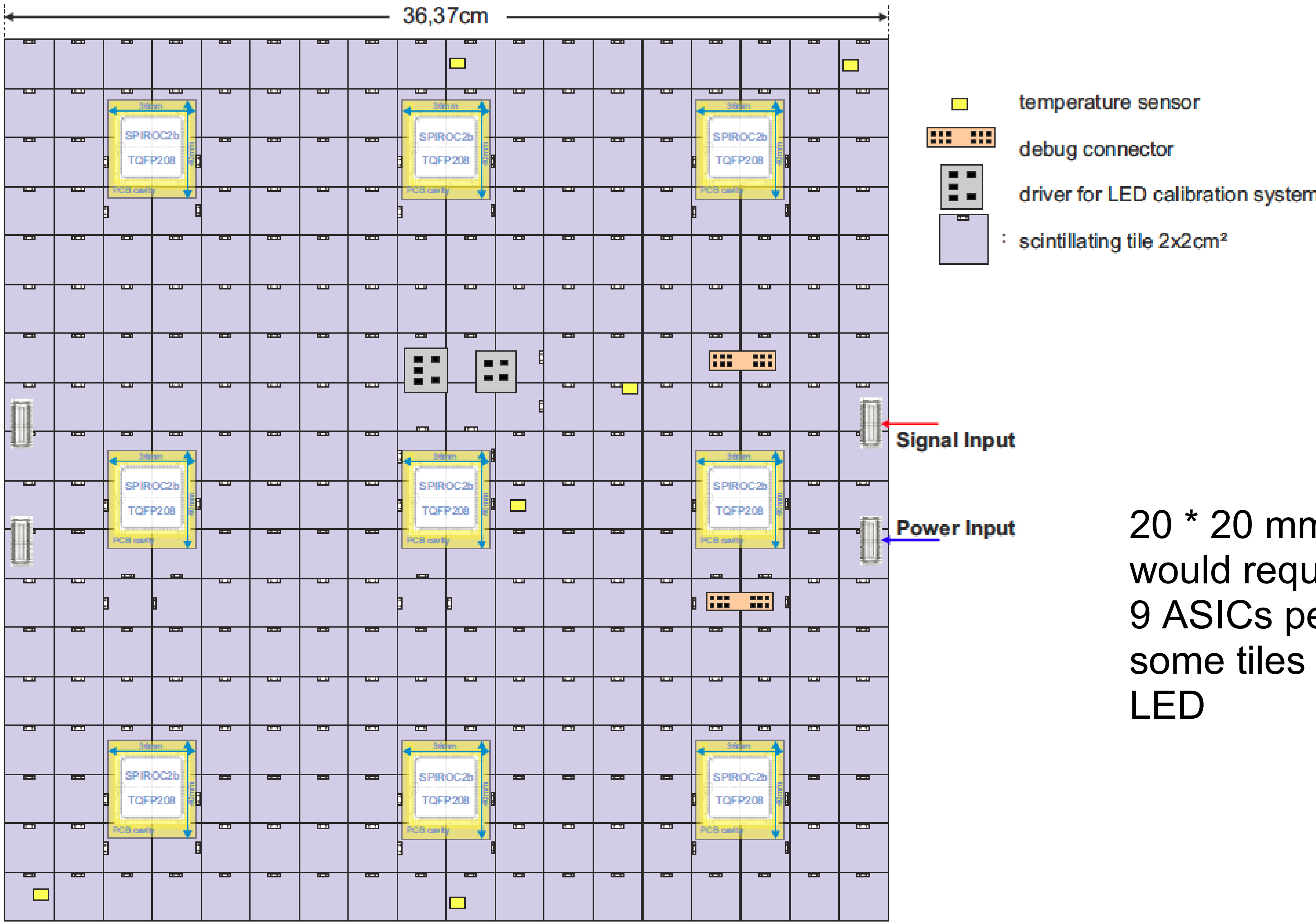


Other possible geometries: “strip HCAL”



derive from EBU, but with HCAL channel density: 90 * 10 mm² strips

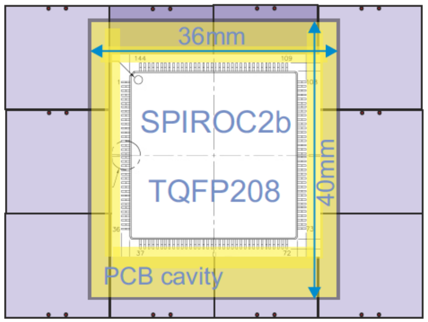
Other possible geometries: smaller tiles

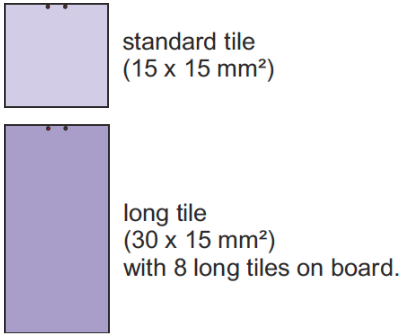


20 * 20 mm² tiles would require 9 ASICs per HBU, some tiles without LED

Other possible geometries: even smaller tiles?

- SPIROC in package requires cut-out of 36 * 40 mm² in PCB
- going smaller than 20 * 20 mm² for square tiles (e.g. 15 * 15 mm²) would require special solutions
  - special “long tiles” underneath the ASICs

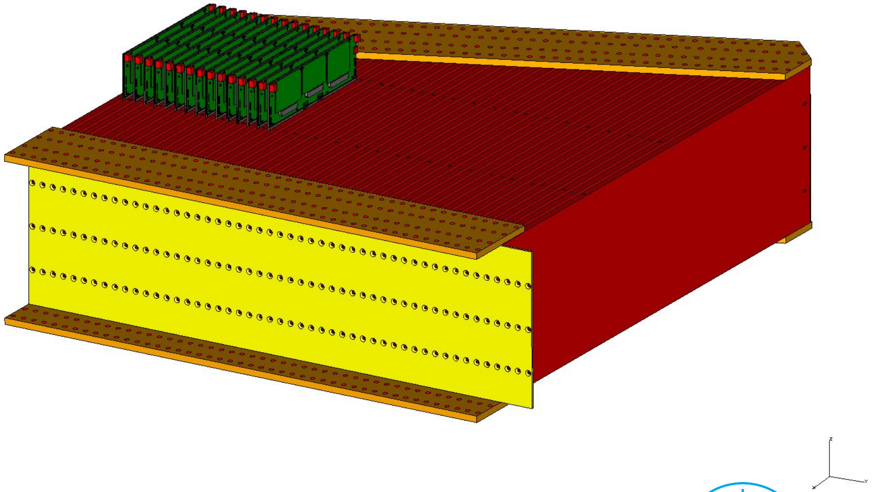




  - or trying to use the ASIC without package

Conclusions and Outlook

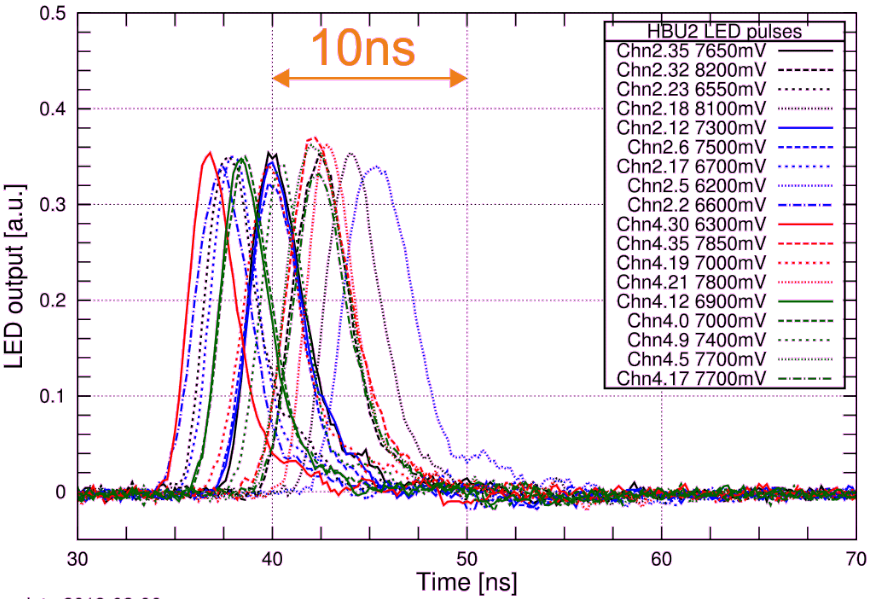
- developed electronics for scintillator based AHCAL for ILC
  - highly integrated
  - allows to equalize detector response
  - demonstrated in testbeam operation
- flexibility:
  - usable for many different SiPM types
  - adaptable to different geometries
- next steps: address system aspects
  - data concentration
  - cooling
  - power distribution
- next AHCAL milestones:
  - operation with several layers
  - operation with different tiles and SiPMs



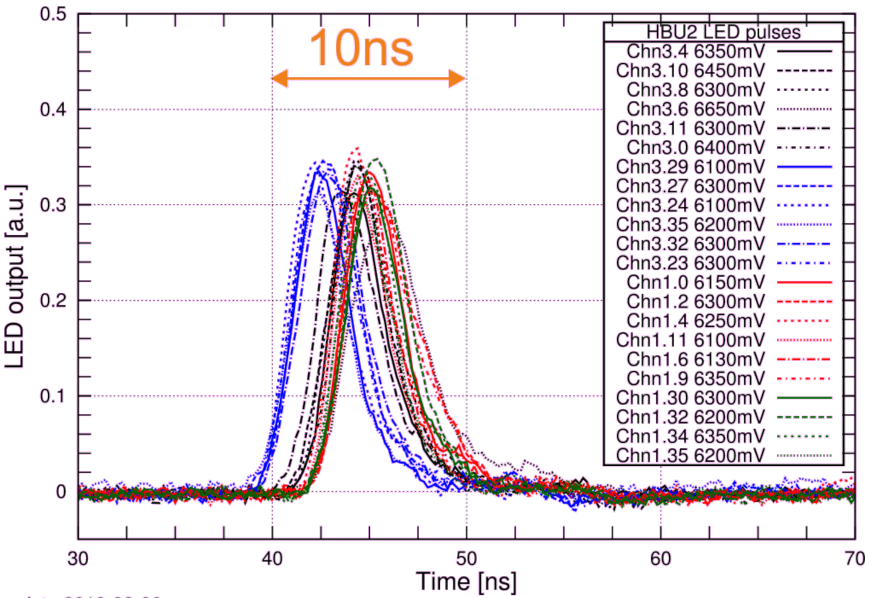
The AHCAL groups

Backup

LED performance – old and new circuit



old LED circuit



new LED circuit

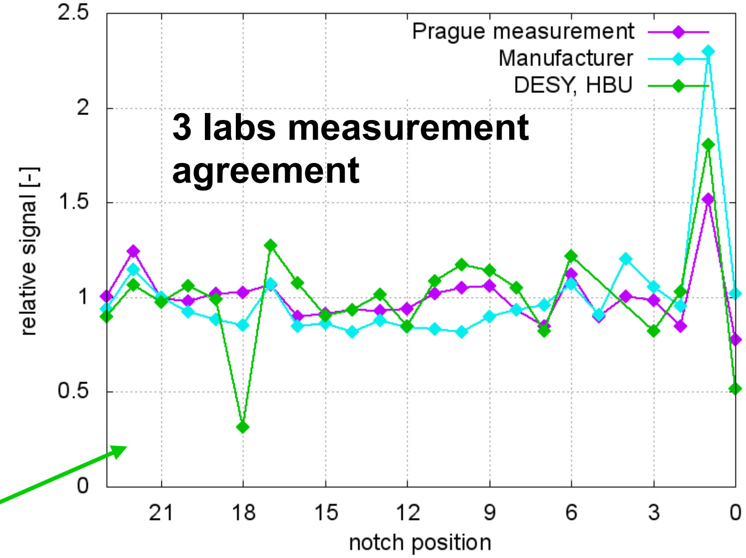
LED light measured with PMT H9858-01

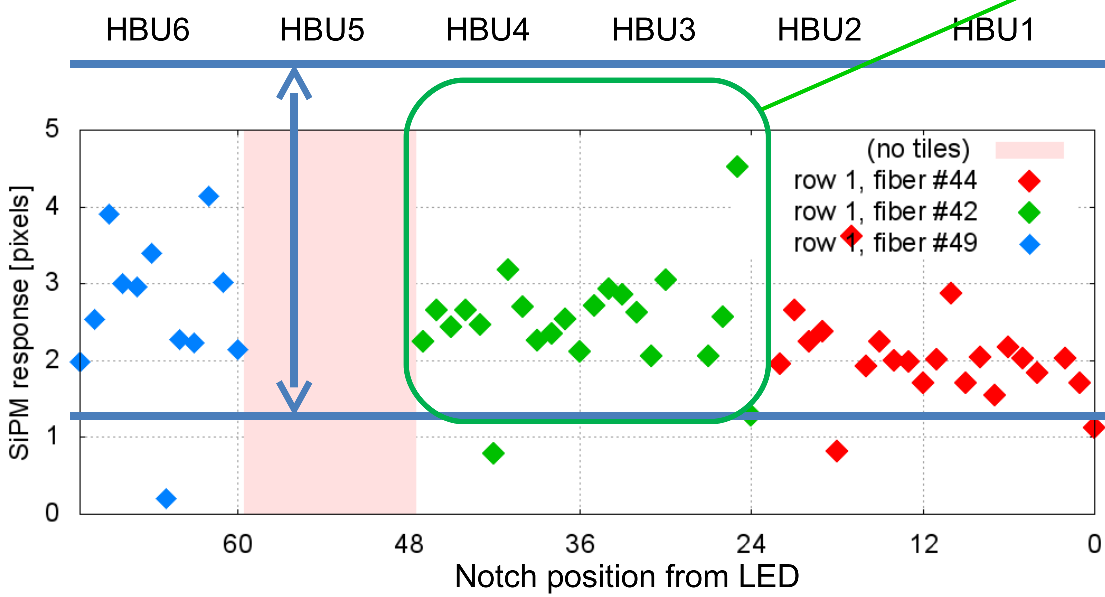
With new LED circuit:

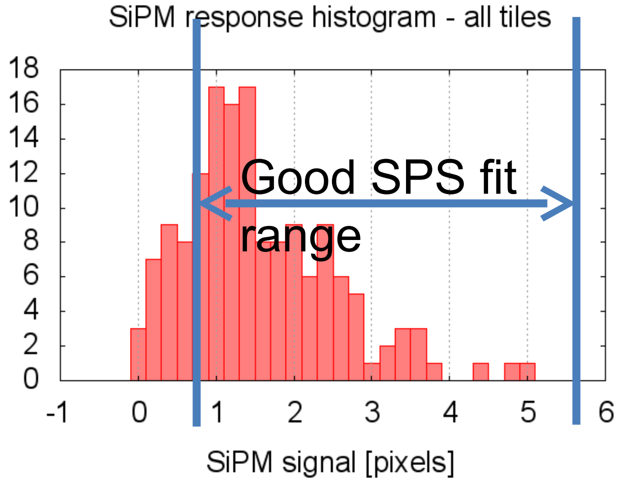
- delay spread is much smaller (but still a few outliers),
- channels of one repeater (one colour) are close together (2-3ns, 18 chns).
- No pulse widening (FWHM <5ns)

LED calibration system: alternative

- gain extraction successful for 92% of the working channels **within a single run**
- reasonable homogeneity of the light output along the fibres
- measurement results are reproducible during different production stages







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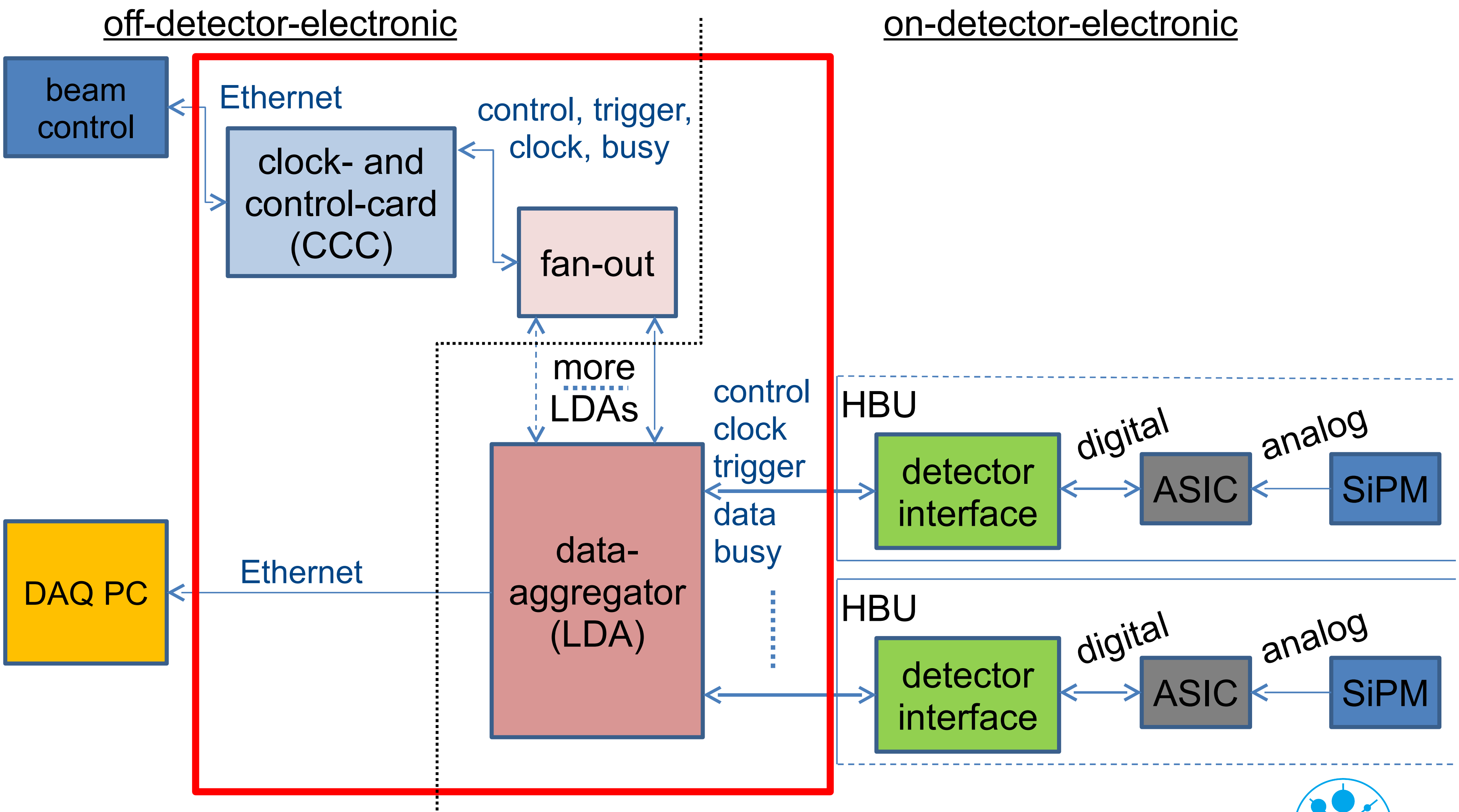
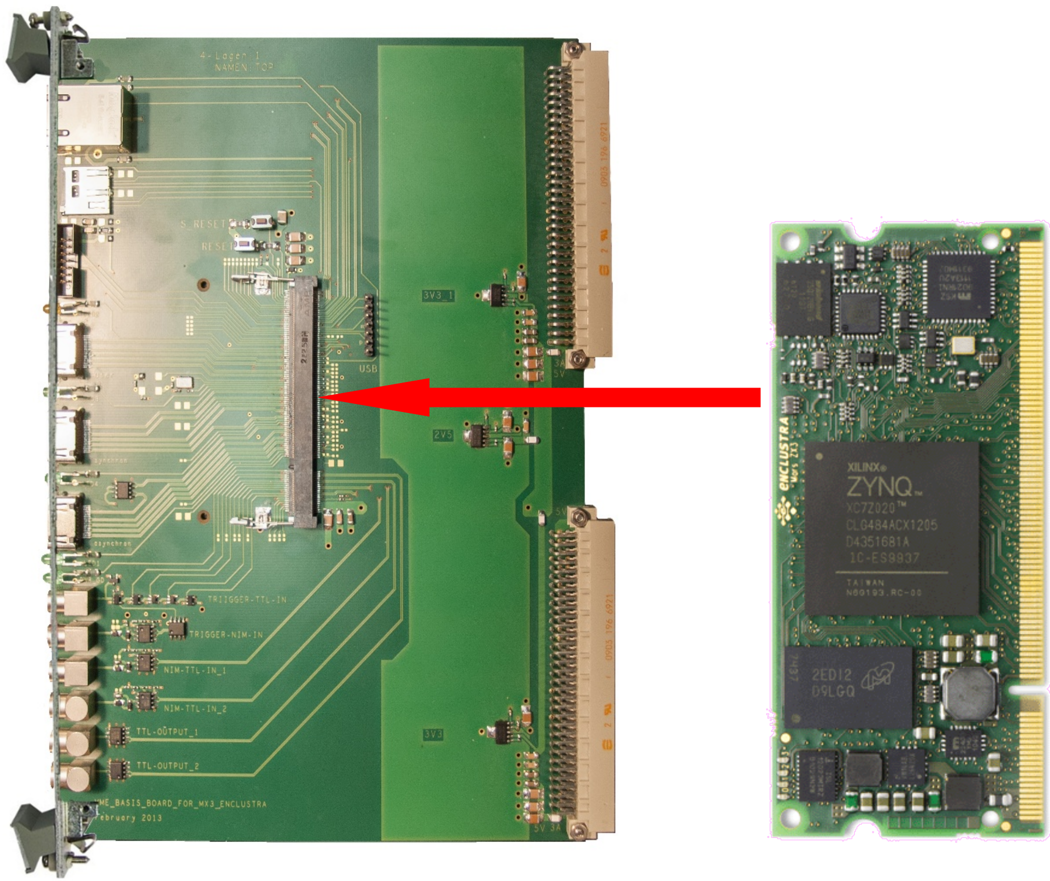
DAQ Hardware

- new CCC and LDA hardware, firmware and software (Mainz)



New CCC



6U VME board

based on ZYNC processor on Mars module

- 1 new CCC module is produced, more planned
- planned to be used in next AHCAL testbeam (May/June 2013)

New LDA for AHCAL

- new hardware design optimized to fit to AHCAL geometry
- hope to have one piece ready for next testbeam (May/June 2013)

only 2 cables to DAQ:
- clock from CCC
- ethernet to DAQ PC

layout consists of
1 central piece and
2 wings