Photodetectors in CALICE-like ECAL

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PRISMA+

Introduction

- SiPMs are the natural choice as photodetectors for a CALICE-like ECAL in the DUNE MPD
- The CALICE community working on the Analog Hadron CALorimeter has been collecting experience with SiPMs for several years, e.g.
  - 8k-channel AHCAL physics prototype operated 2006-2011
  - 22k-channel AHCAL technological prototype in operation since 2018
  - medical physics applications (EndoTOFPET-US)
  - HGCAL for the high luminosity upgrade of CMS
  - SHiP EM calorimeter (SplitCAL)

A bit of history

CALICE collaboration

CALICE is a collaboration with 59 institutes and 360 people from 4 continents.

Born in 2005 to provide the needed environment to develop a new generation of calorimeters for the new linear $e^+ e^-$ experiments for which new techniques are proposed: the **P**article **F**low **A**lgorithms (**PFA**)

The PFA techniques try to separate the contribution of each of the produced particles in a collision and then use the right sub-detector for the right energy/momentum measurement. This leads to an optimal **J**et **E**nergy **R**esolution(**JER**)
and an optimal reconstruction of the event.

Prototypes

Prototypes

Physics

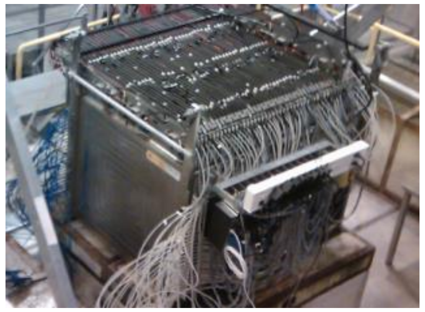
Granularity
Proof of principal

Technological

Power-pulsed
Embedded electronics
compactness

Si-W

DHCAL

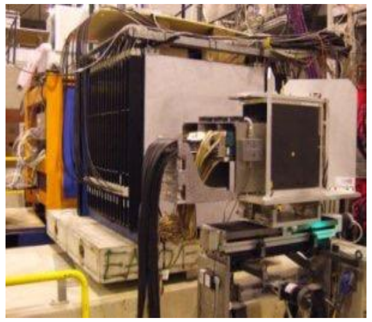


SDHCAL

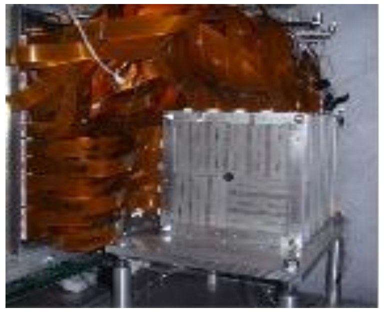
Si-W →

2005 — 2007 — 2010 — 2011 — 2012 — 2018 →

AHCAL



Scint-W

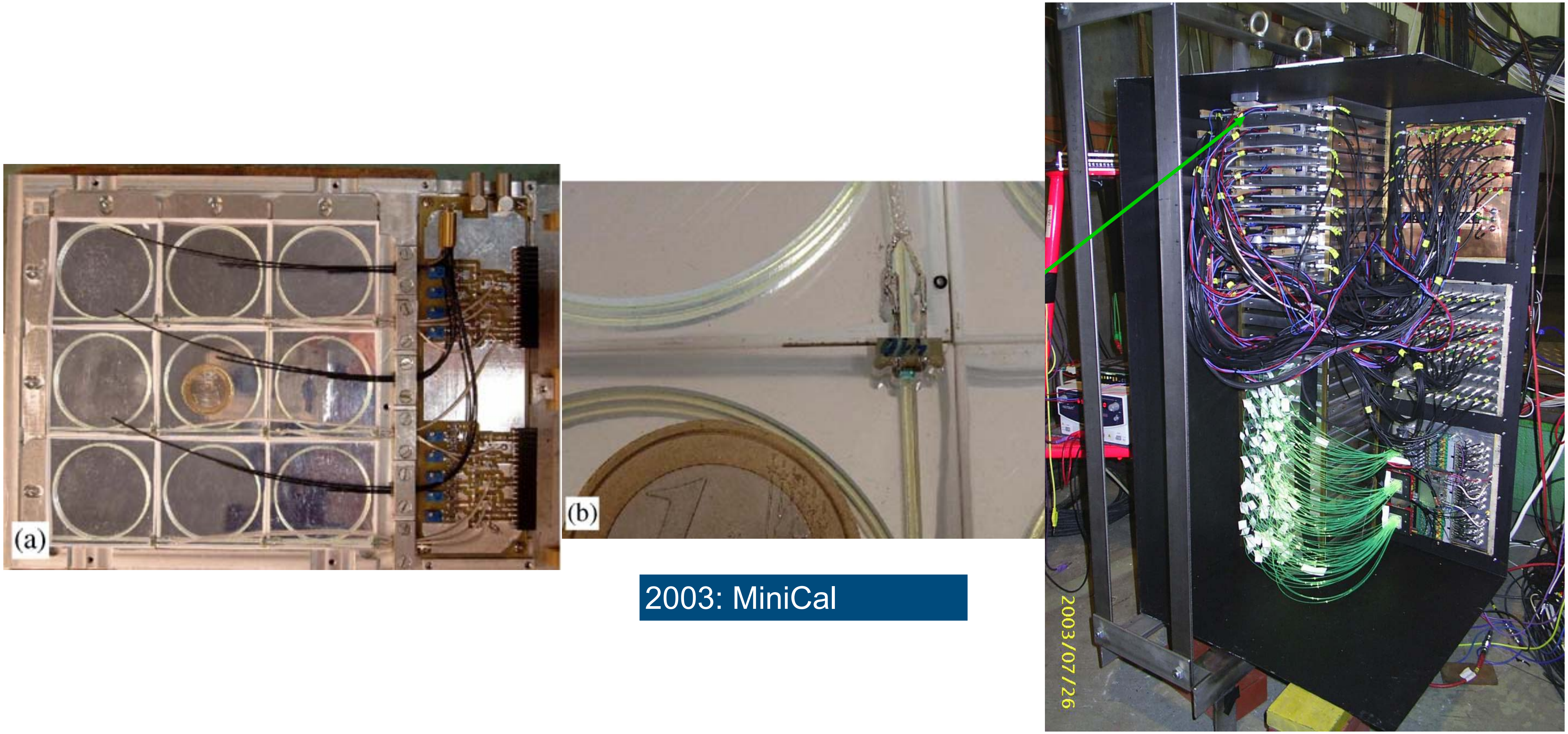


AHCAL

2003

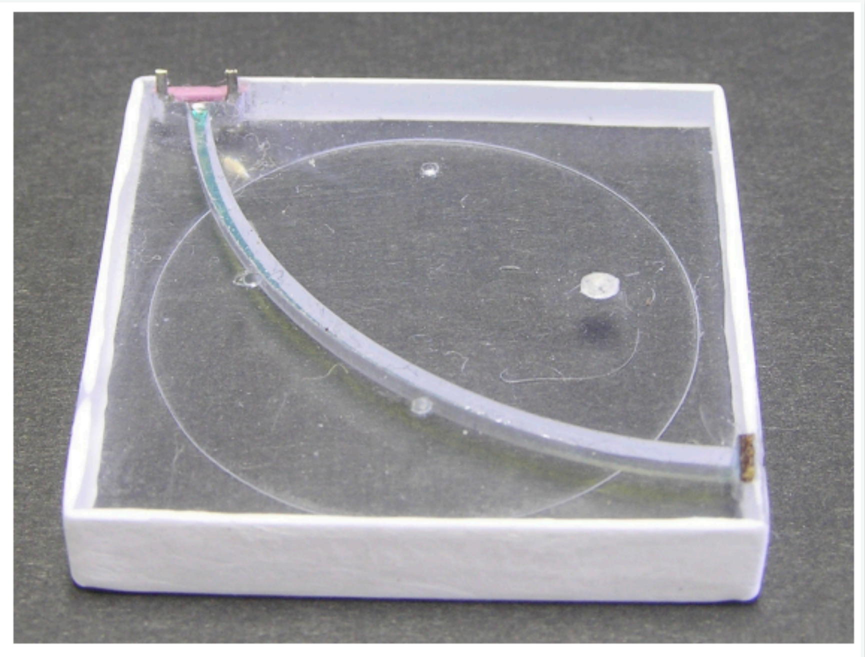
SiPM-on-Tile Evolution

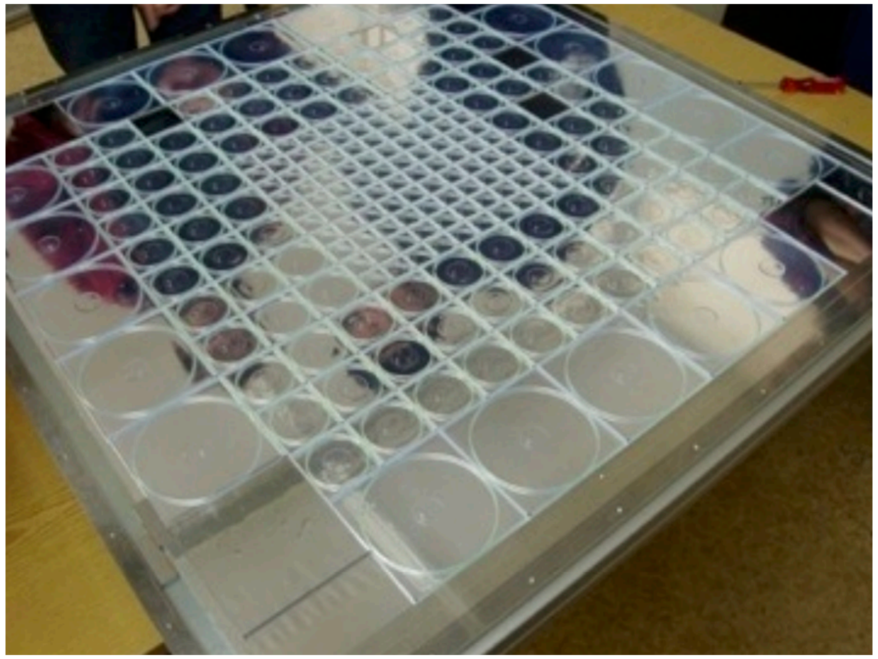
A long way

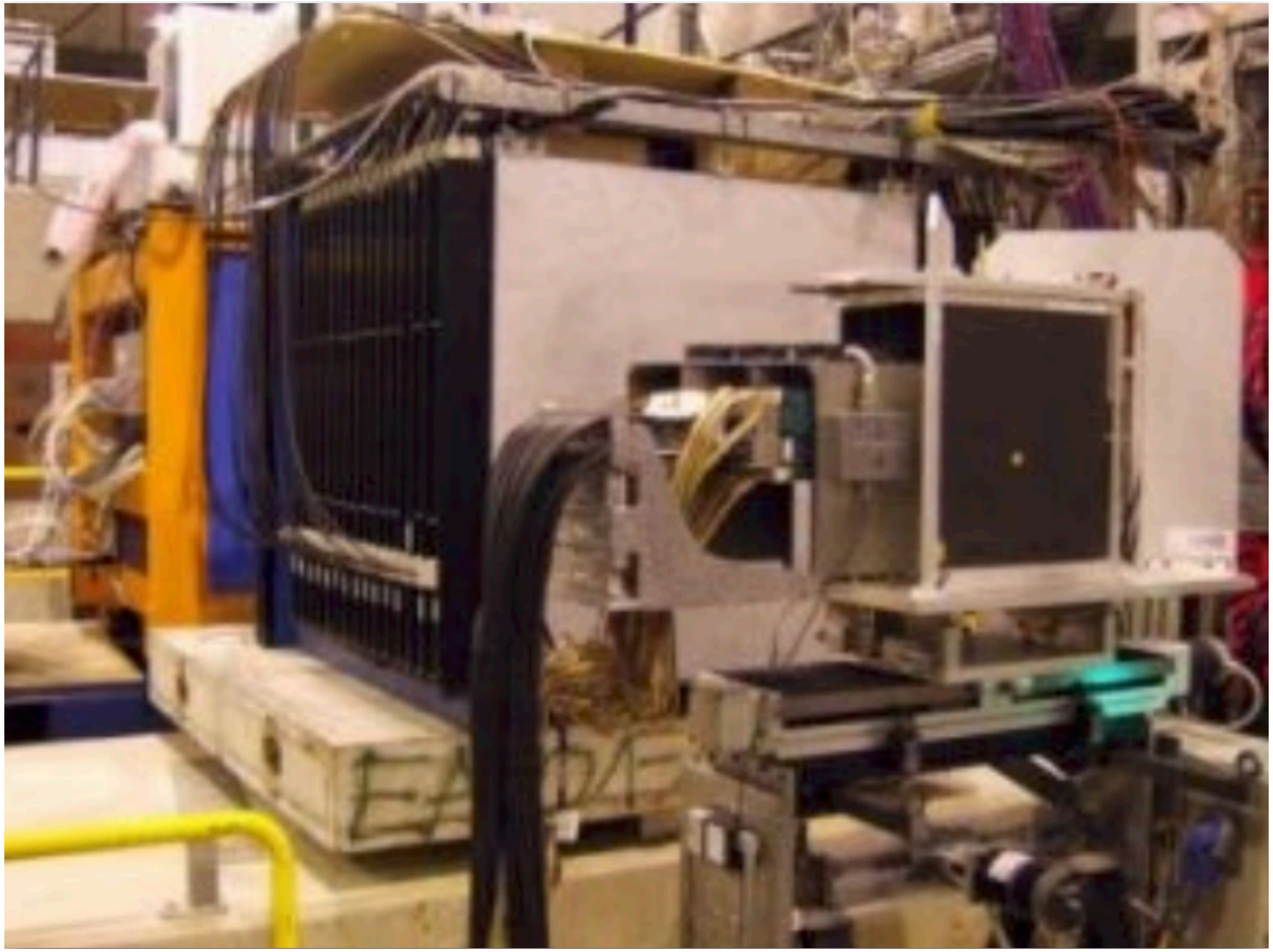


2003: MiniCal

2006: physics prototype



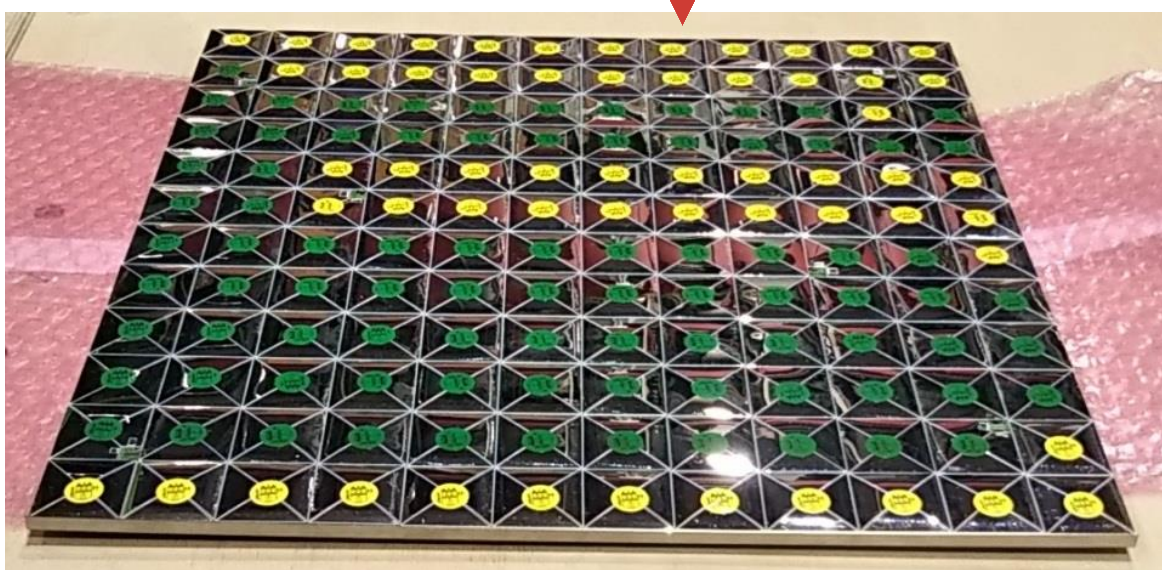


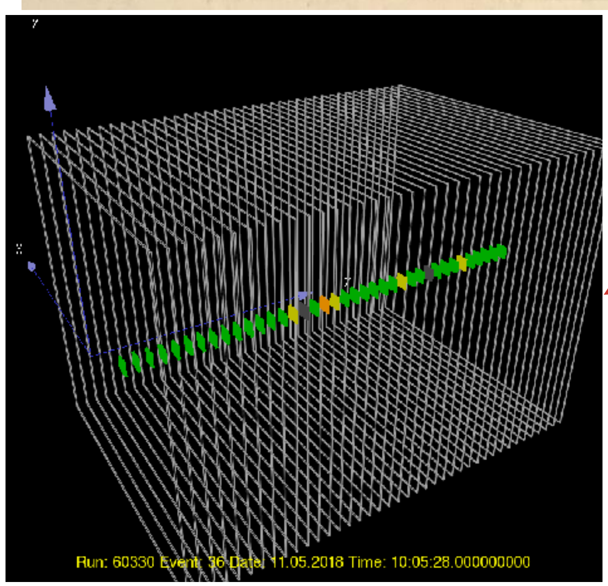


AHCAL technological prototype

General description

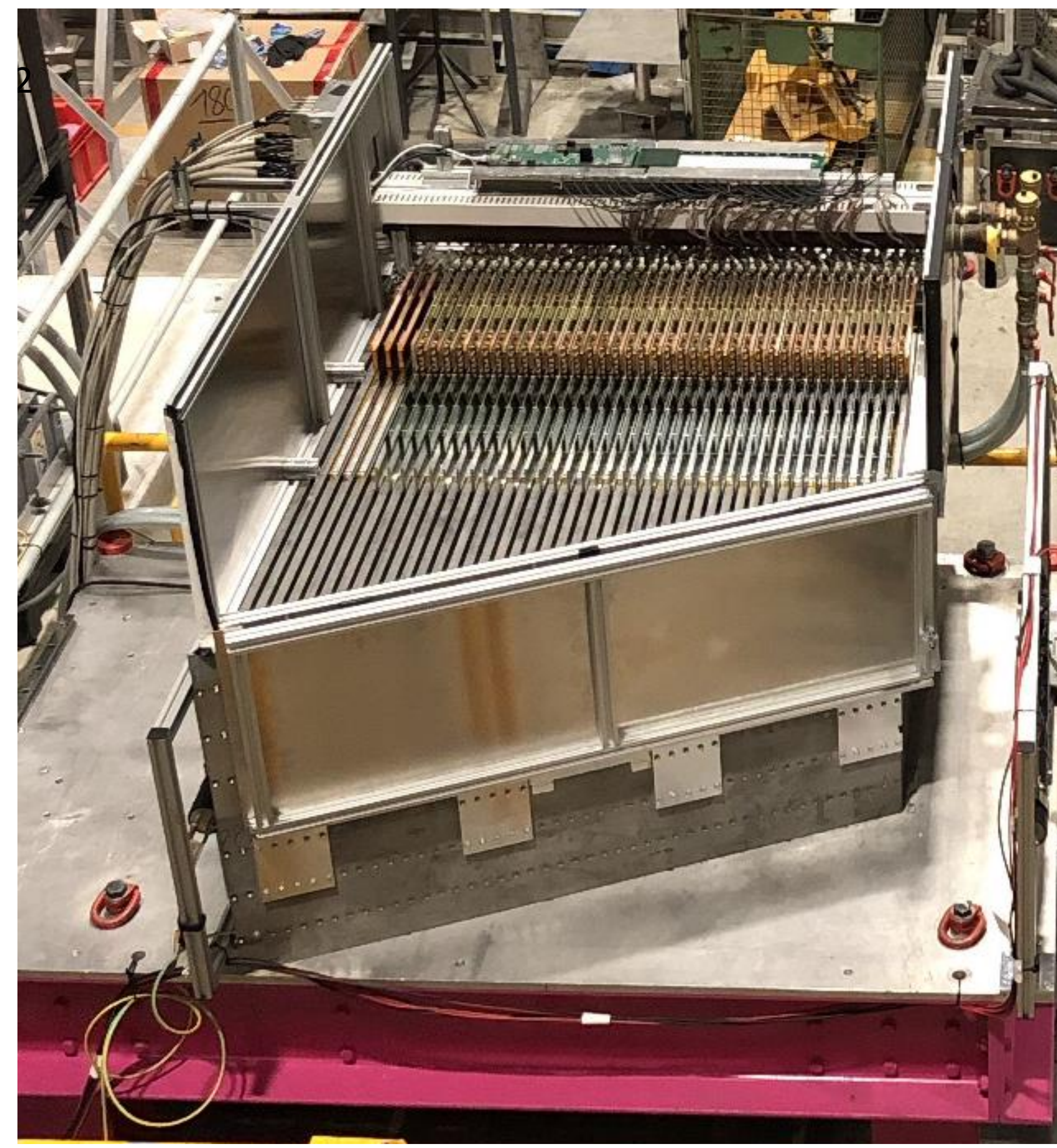
- 38 layers active (tiles on SiPM) + absorber (steel)
- Layer: 72x72 cm^2 → 4 boards per layer → 576 ch. per layer → 22k total ch.





online event display

data analysis ongoing

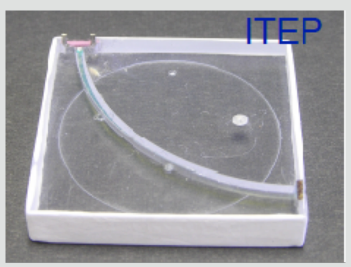


Choice of MPPCs

- Technological evolution over time
  - More pixels per unit area → larger dynamic range for MIPs and showers
  - Lower dark count rate using trenches → less noise via less cross talk
  - Better performance uniformity over a large number of MPPCs

Physics prototype

2006 - 2011



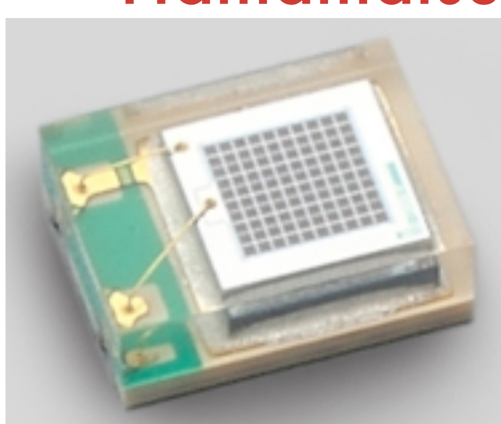
Old ITEP tiles with WLS fibre
1200 px SiPMs

Technological prototype

Surface mounted SiPMs & tiles
- with *MPPC* SiPMs 2700 px

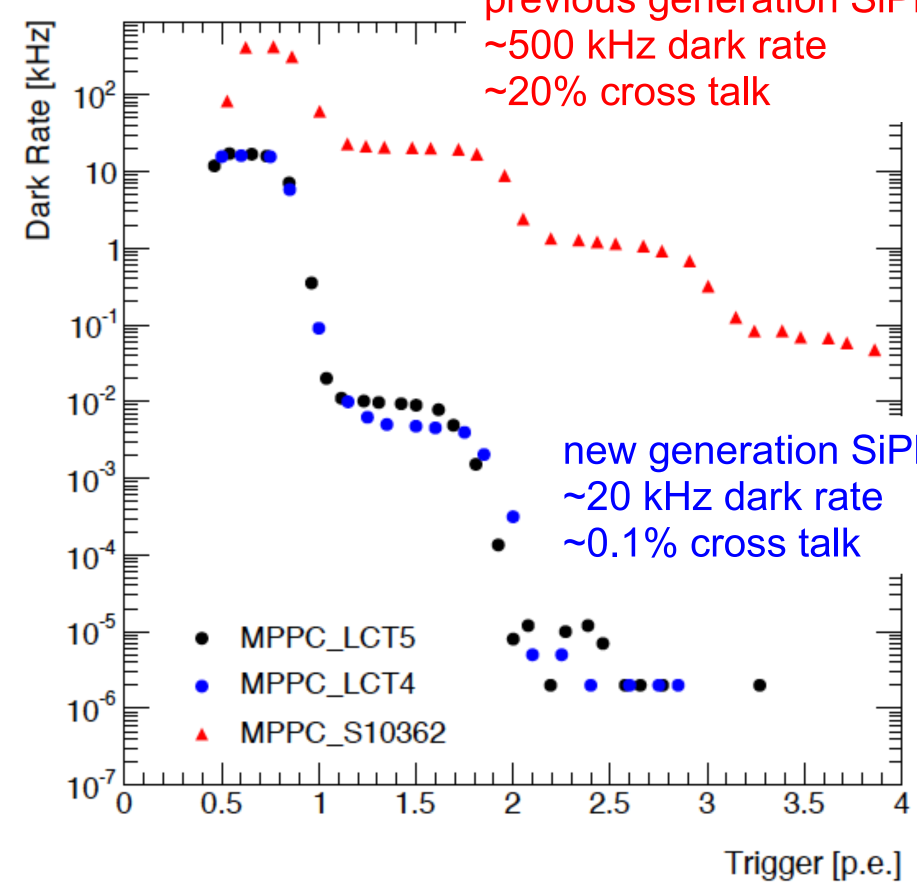
Suitable for automated mass assembly

Hamamatsu MPPC S13360-1325PE



Effective photosensitive area	1.3 × 1.3 mm
Pixel pitch	25 µm
Number of pixels	2668

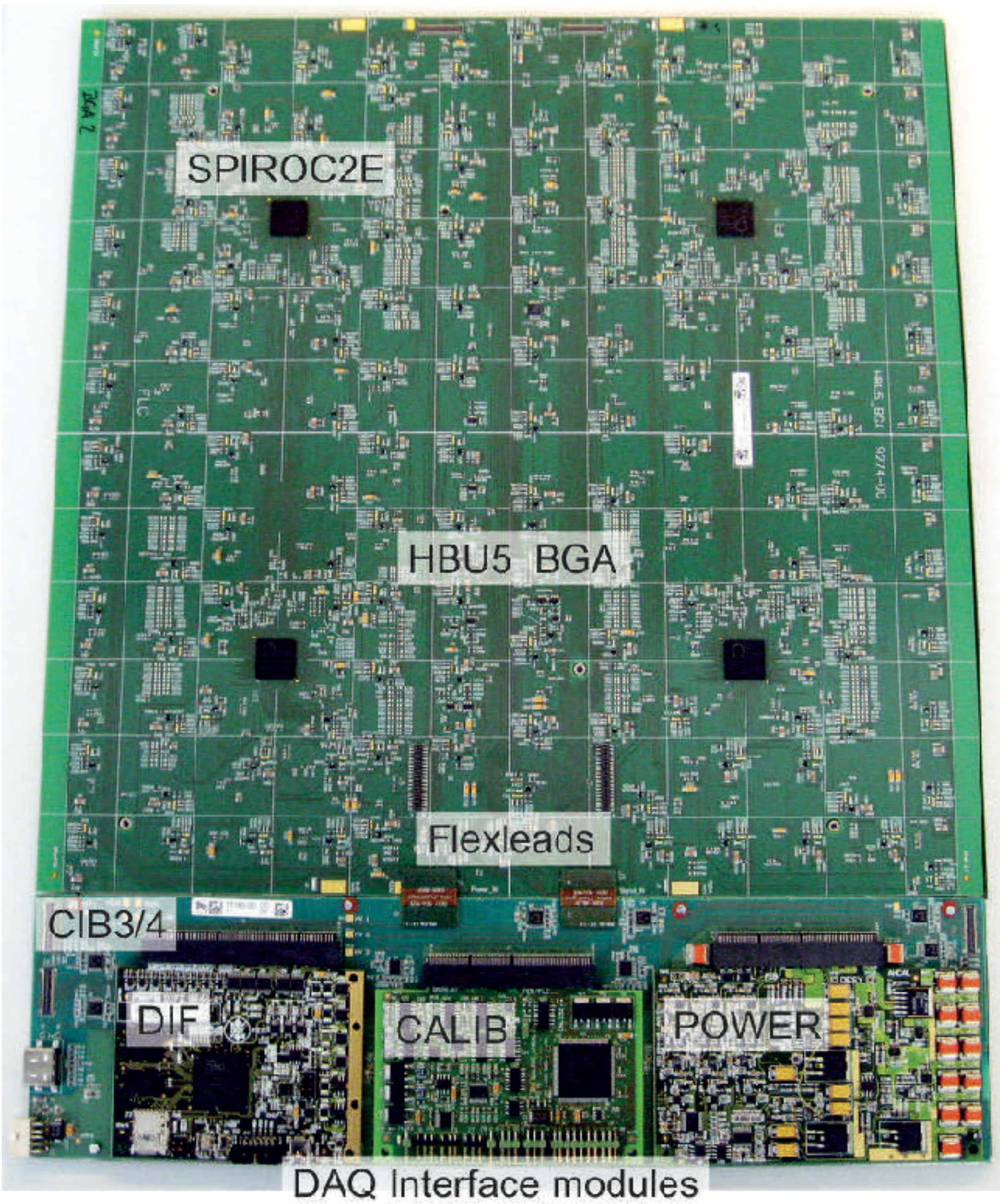
previous generation SiPM:
~500 kHz dark rate
~20% cross talk



new generation SiPM:
~20 kHz dark rate
~0.1% cross talk

for comparison: SiPMs in physics prototype
2 MHz dark rate, 30% cross talk

SiPM readout



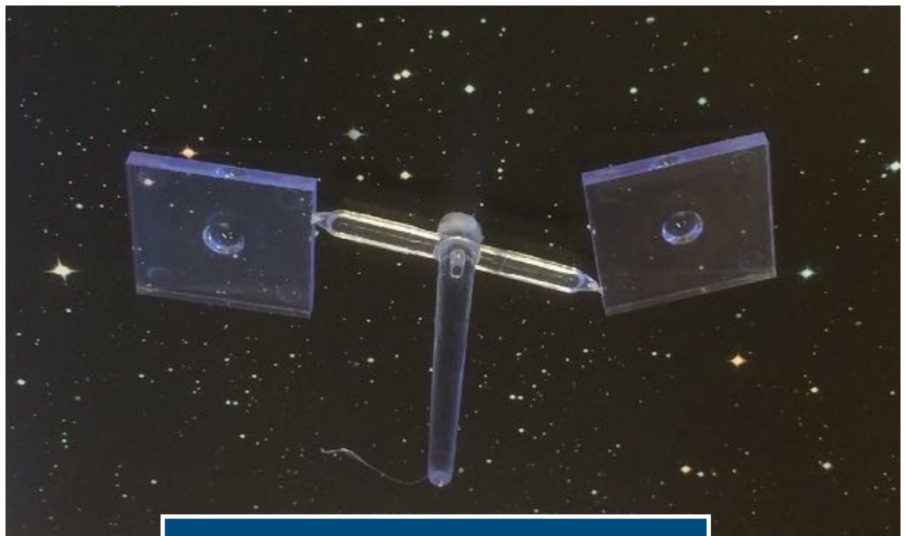
- HBU with 144 detector channels, 36x36cm².
- New SPIROC2E ASICs in BGA packages

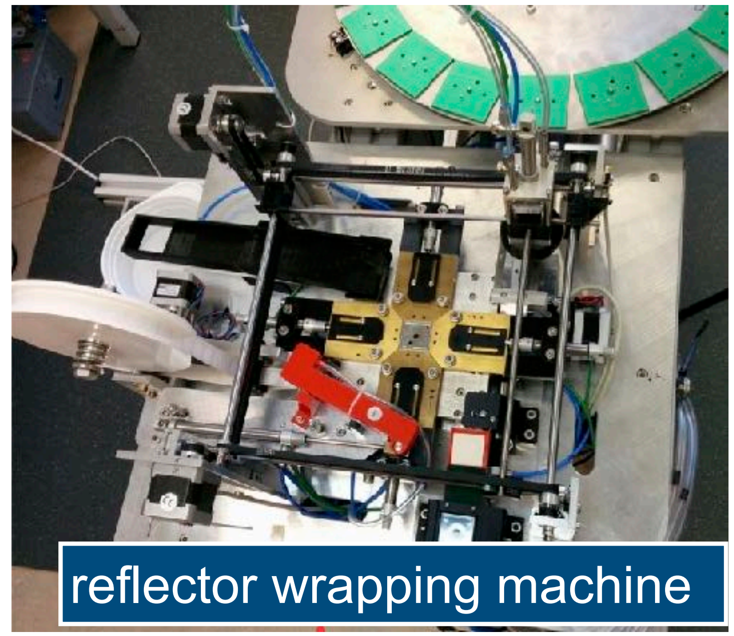
SPIROC: readout ASIC for SiPMs

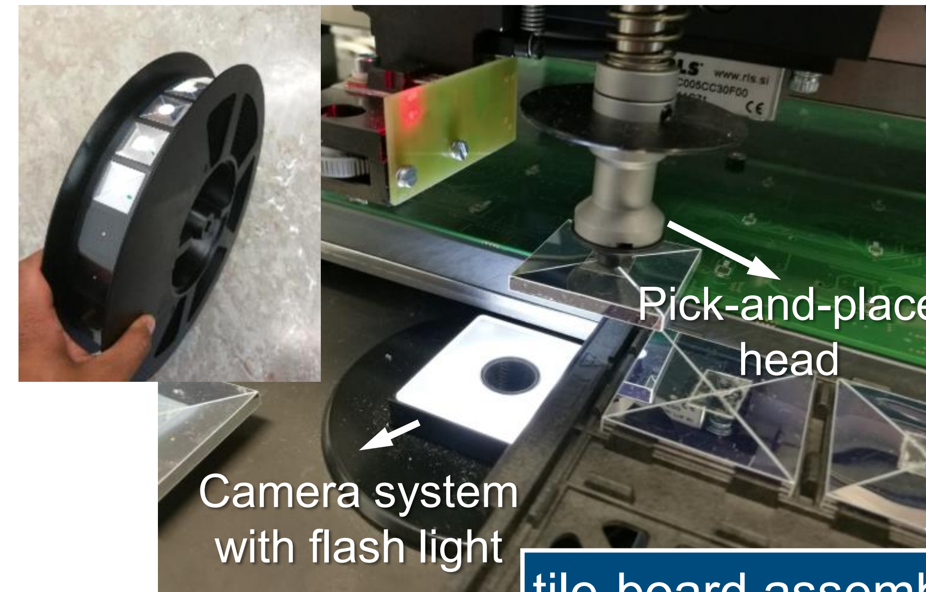
- designed for power pulsing
- 36 channels
- channel-wise HV and gain adjustment
- 3 trigger modes: external trigger (LED calibration), auto trigger without and with validation
- SPIROC2B: working horse so far
- **SPIROC2E**: many improvements: better time measurement, less pedestal shift, reduced power

- Interface modules DIF, CALIB and POWER
  - DAQ and control interface, LED steering, power management

Automated assembly


injection-moulded tiles


reflector wrapping machine

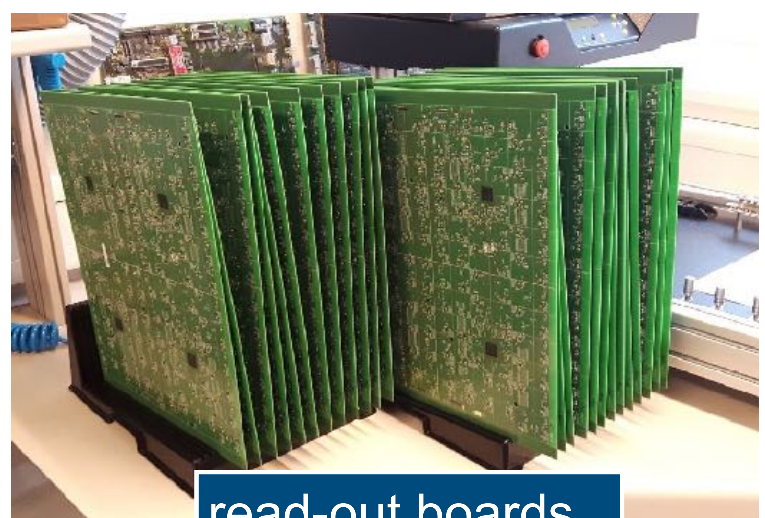


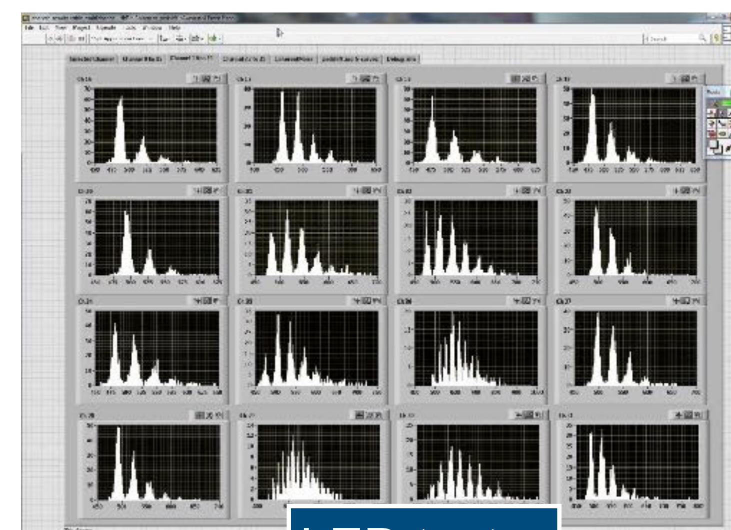
tile-board assembly

In addition test infrastructures:

- Multi-channel SiPM tests
- Automated ASIC tests
- PCB tests using LEDs
- Coscmic tests after tile assembly

AIDA2020

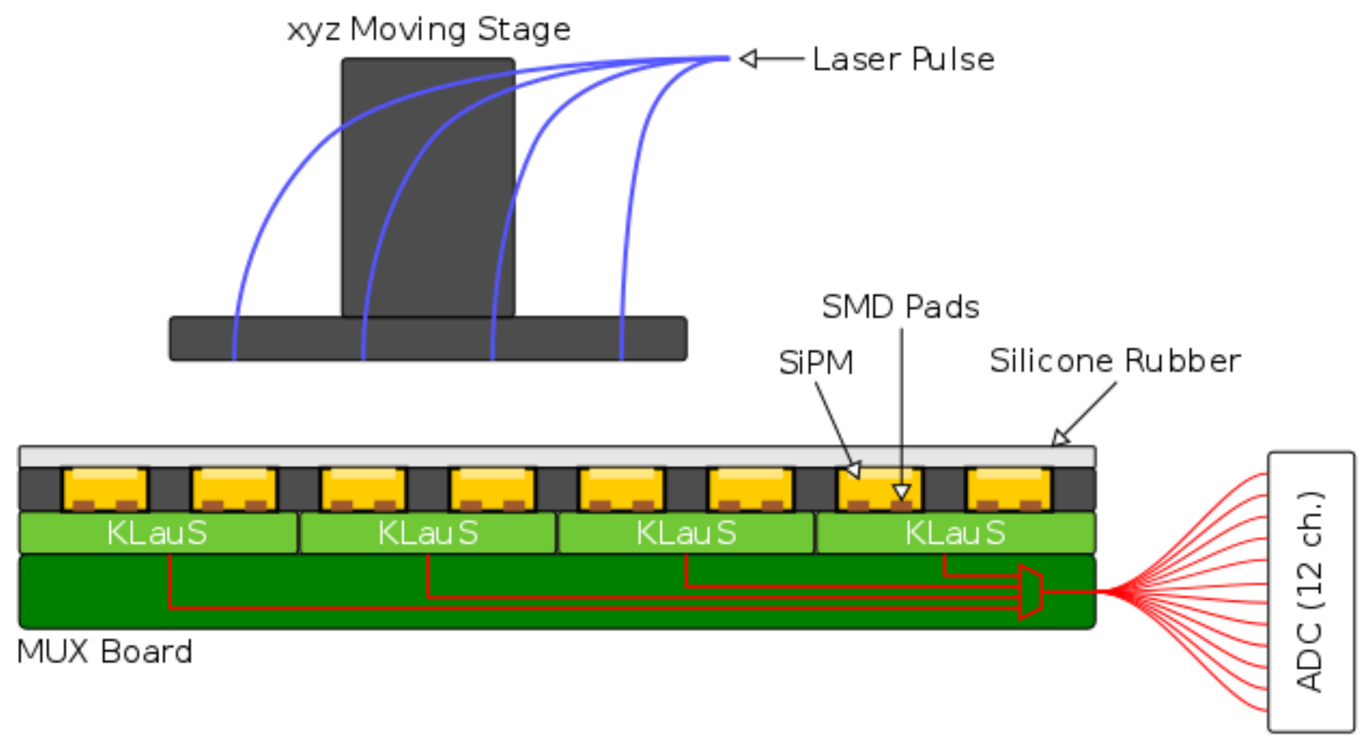

read-out boards


LED tests

SiPM performance

SiPM QA: standalone

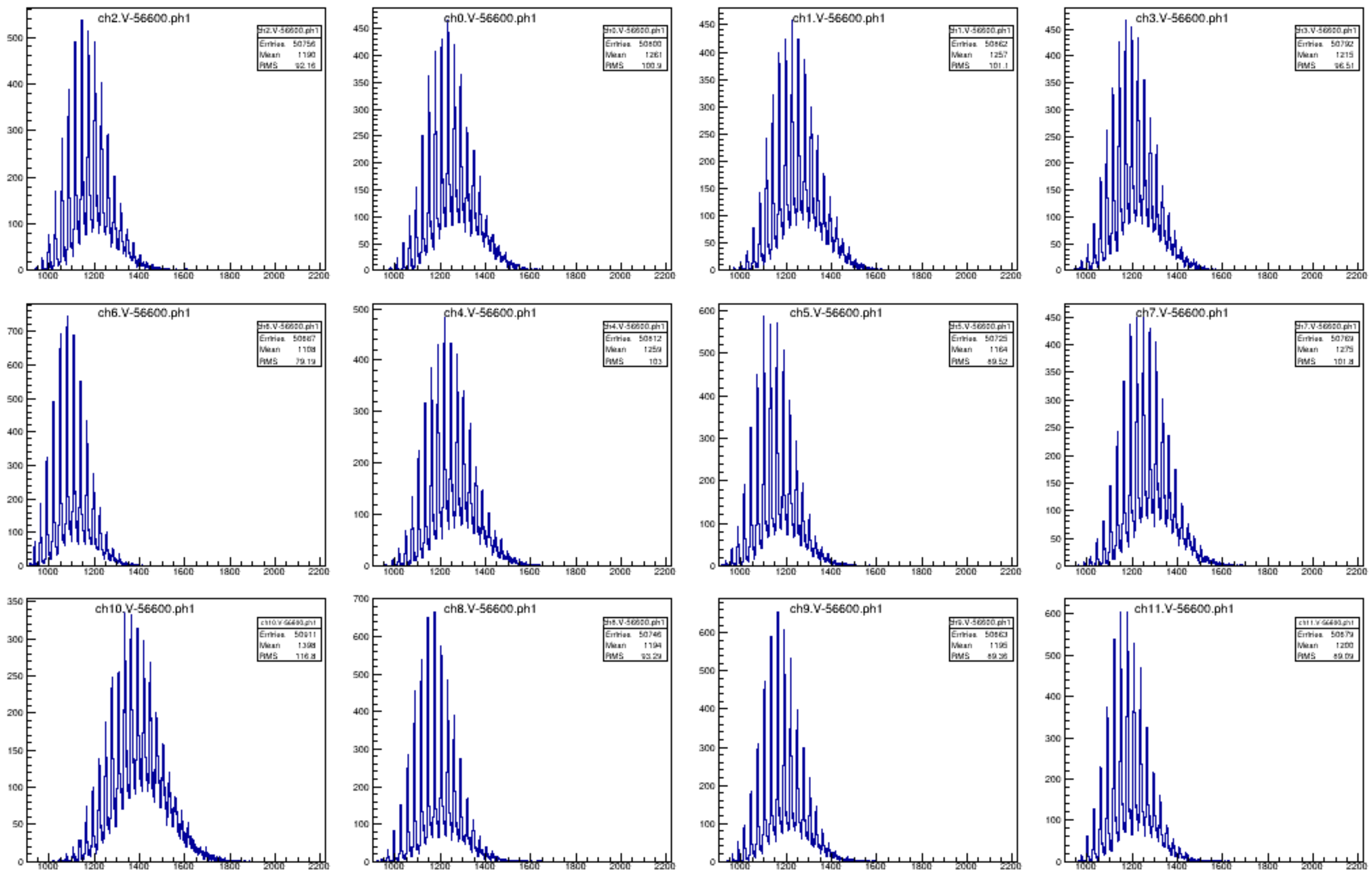
- **Performed tests:**
  - DCR < 500KHz
  - Cross-talk < 3%
  - PDE (@420nm) >20%
  - Gain >3x105
  - dV/dT < 1% of excess bias voltage (~50mV/k)
  - V_{bd} spread min-max within a batch 200 mV
- From each batch of 600 SiPMs 24 are tested
- Batch rejection if fails > 1/24



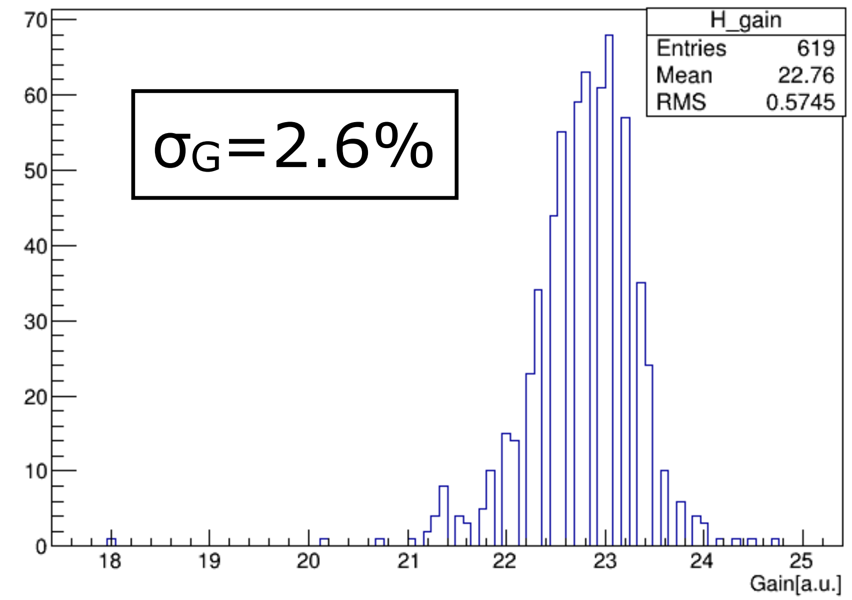
SMD SiPM schematic view

All batches (~40) tested, none rejected

SiPM QA: standalone



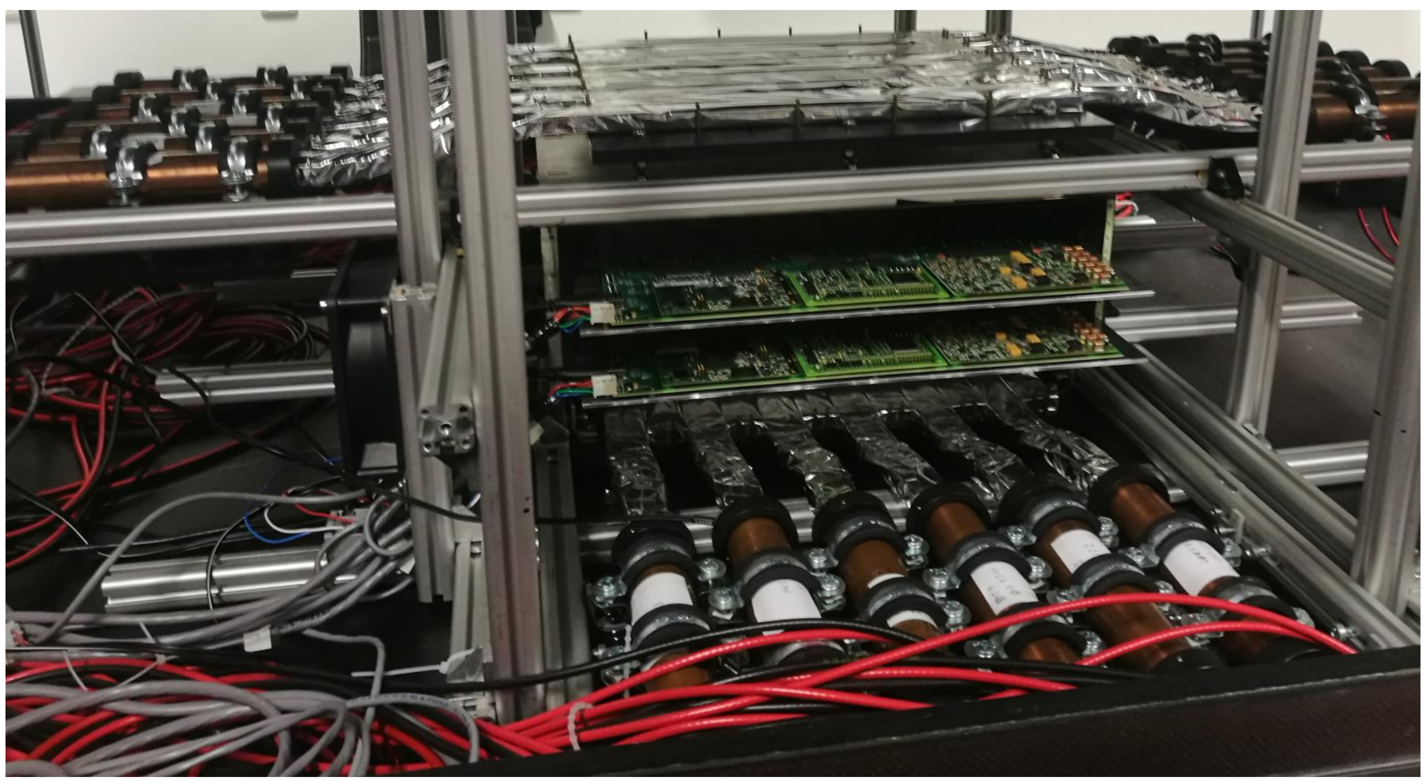
Example SPS from the online monitoring system at 57V

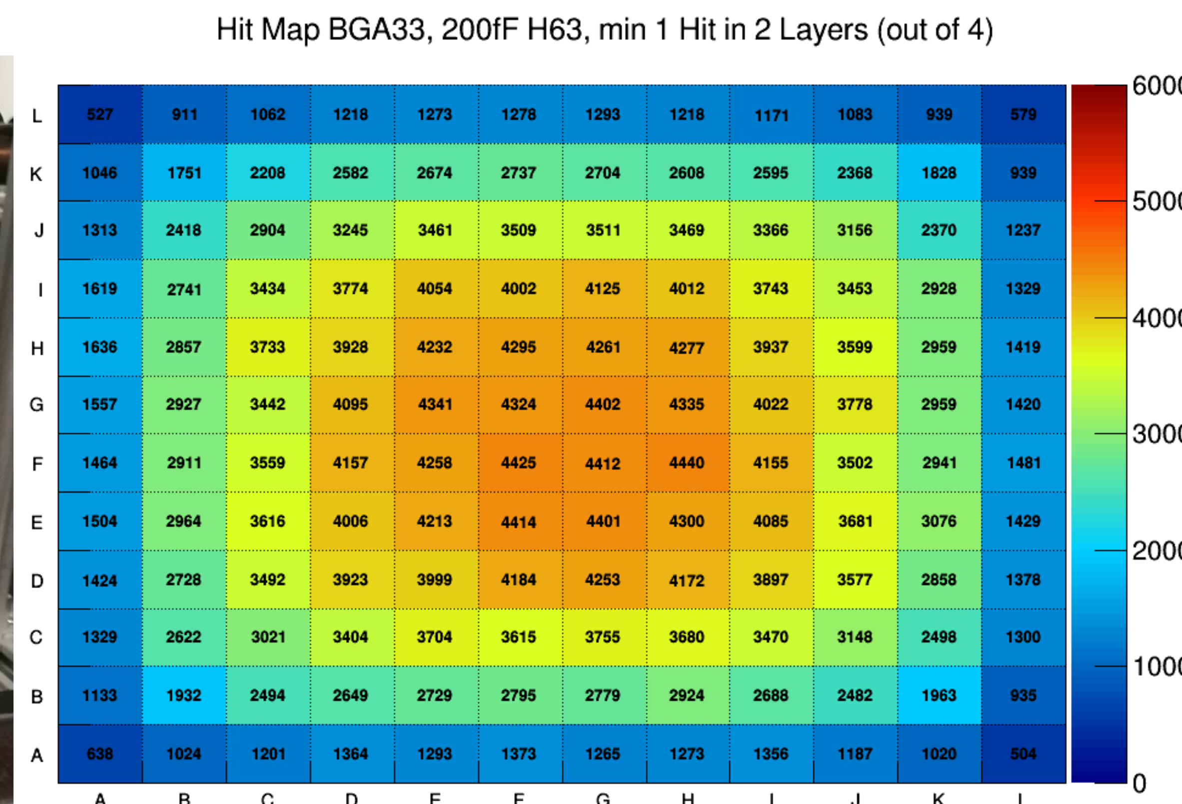


Very uniform performance within a batch (expected)
but also among batches (positive surprise)

SiPM QA: on HBU

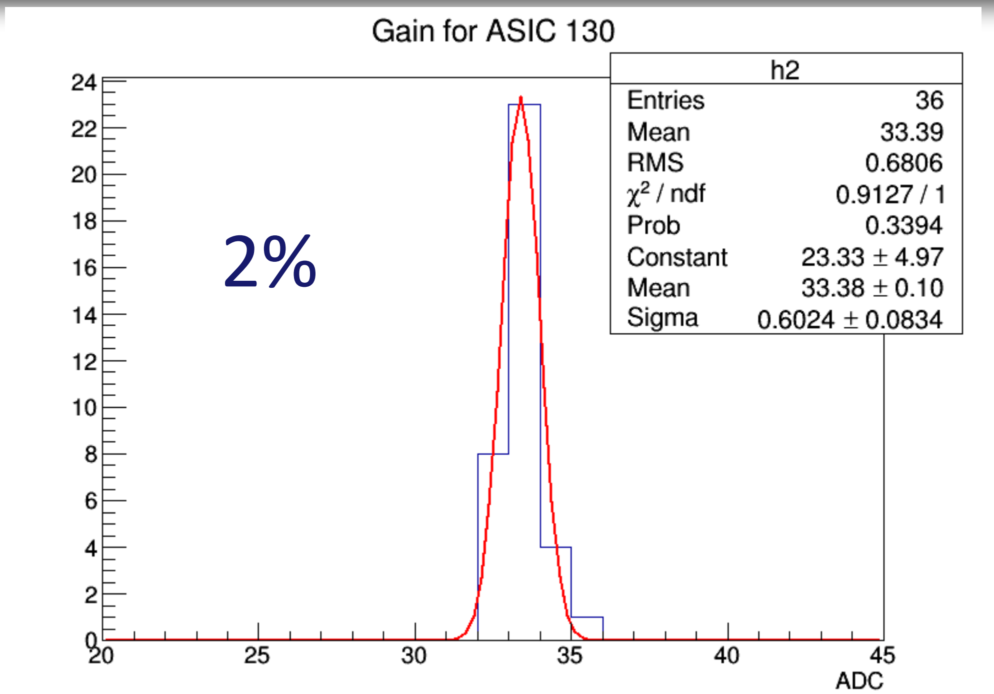
- All channels tested after assembly in a cosmic ray test setup
  - Measurements: pedestal, gain, light yield
  - Boards measured in parallel (mostly 4 can be up to 10), 1 day of data taking

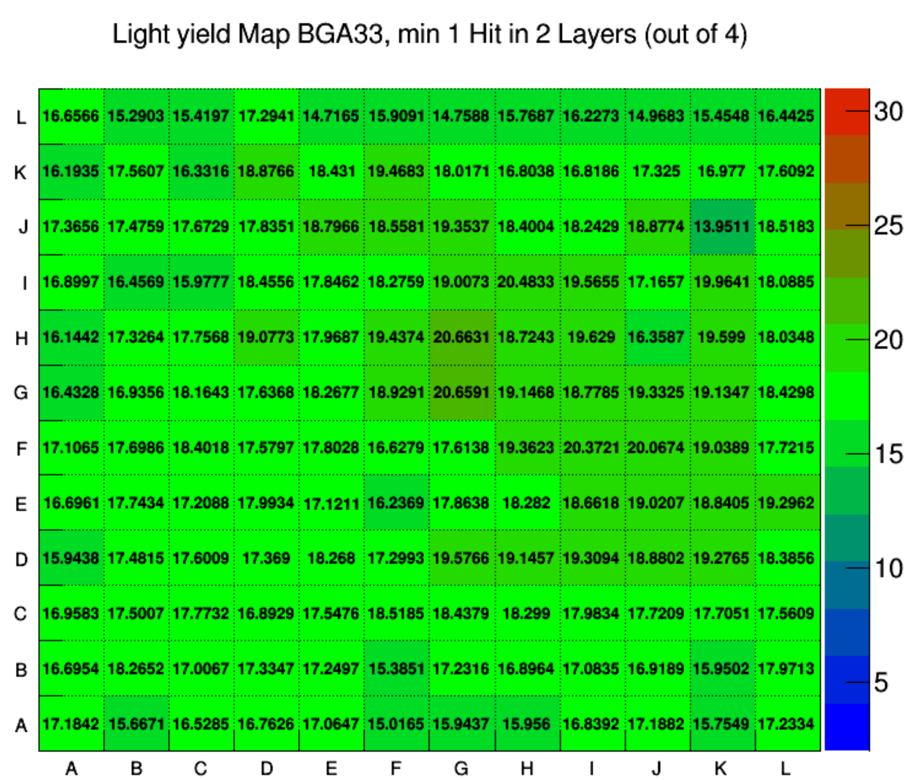


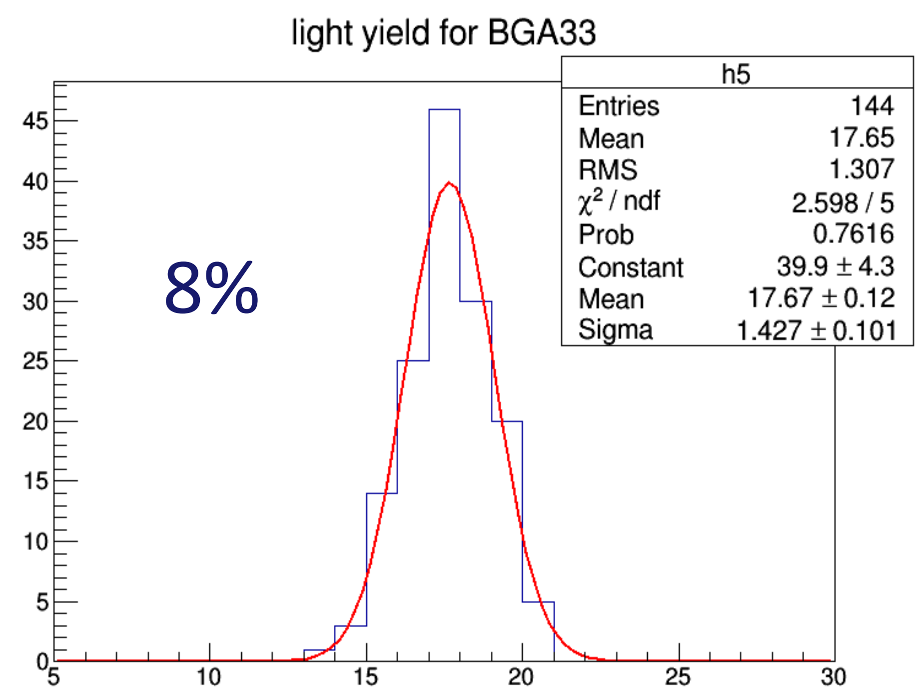


SiPM QA: on HBU

- Now gain depends on ASIC (4 per board) → SiPM uniformity can only be tested over one ASIC (36 channels)
- About 2.5% spread confirmed for all ASICs
- Light yield also very uniform over the whole detector (about 8%)

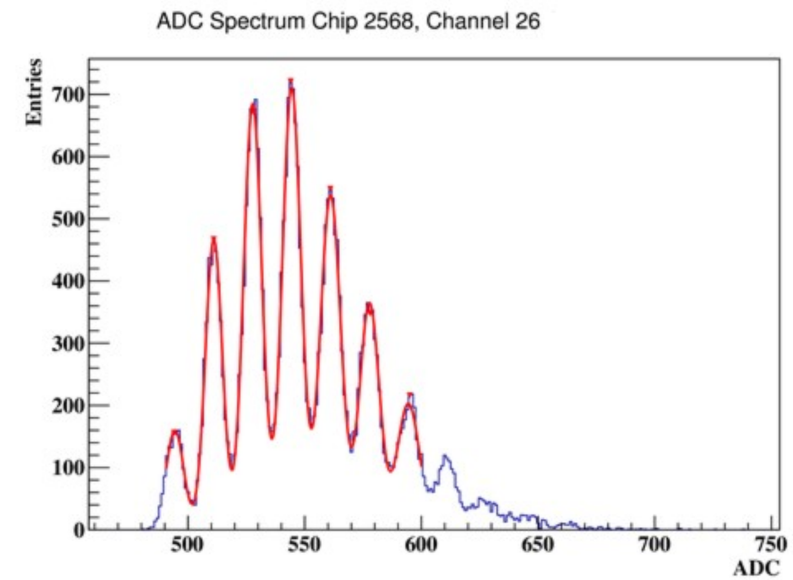


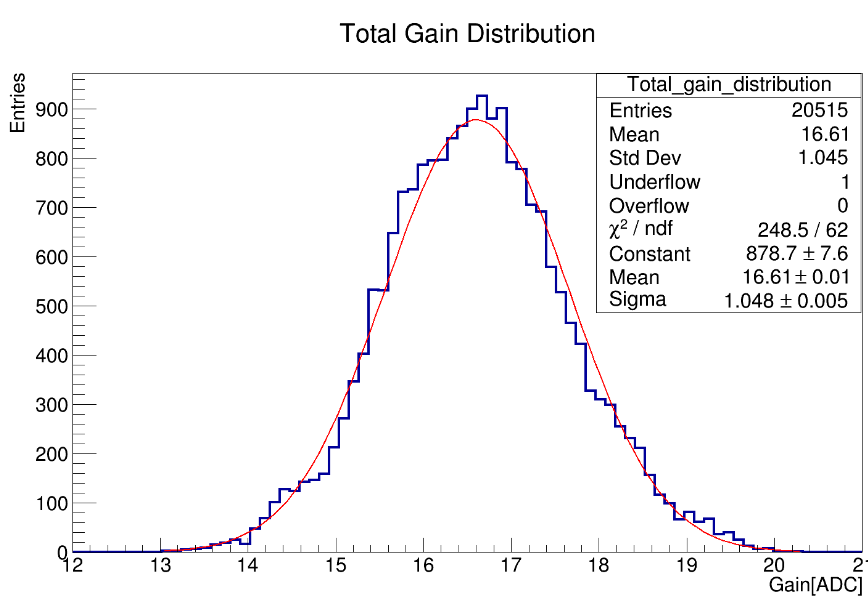


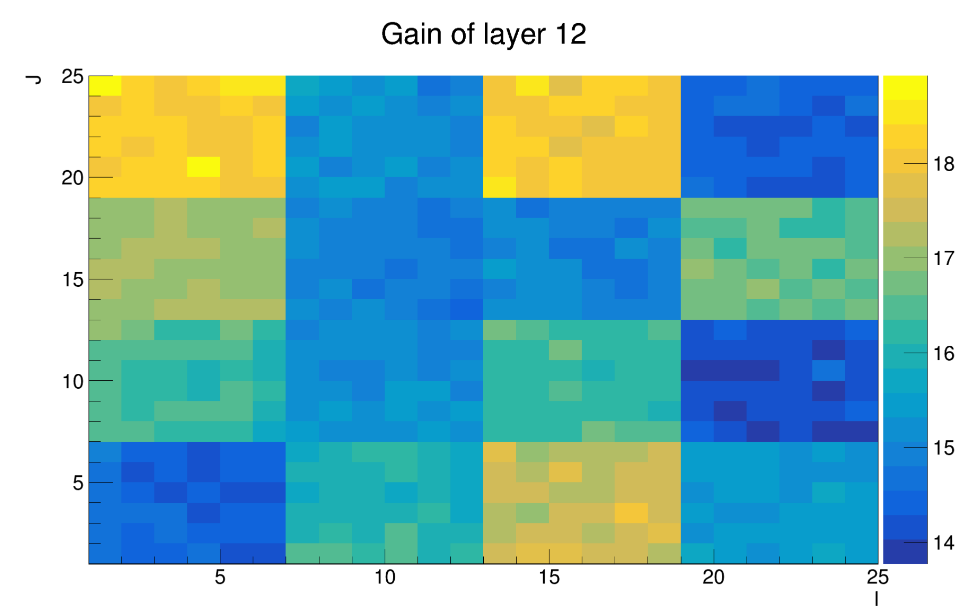


SiPM gain at testbeam

- product of SiPM (charge/pixel) and ASIC (ADC/charge) gains
- determined from single-pixel-spectra in LED runs
  - initial determination & daily checks
- μ=16.6 ADC/pixel, RMS=1.0 ADC/pixel (6%)
  - within an ASIC: ~2.5%
- **uniform and very stable gain**

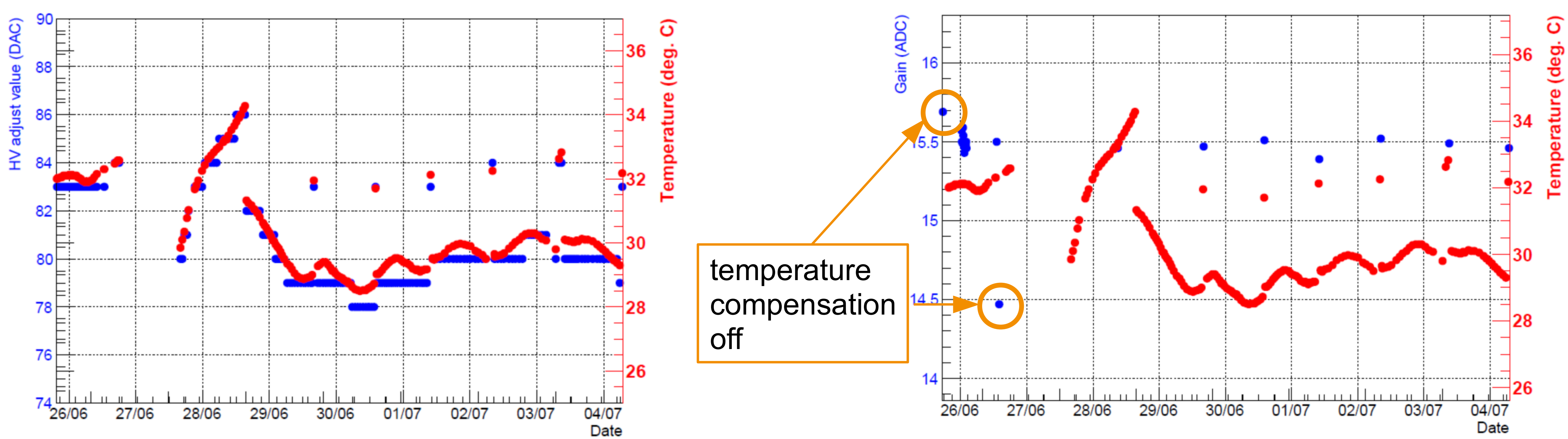






Temperature compensation

- gain and photon detection efficiency of SiPMs depend on temperature
  - can avoid changes by stabilizing temperature or adapting bias voltage (HV)
- temperature compensation: use mean temperature in a layer to adjust HV
- used routinely, HV changes as expected, gain stays stable

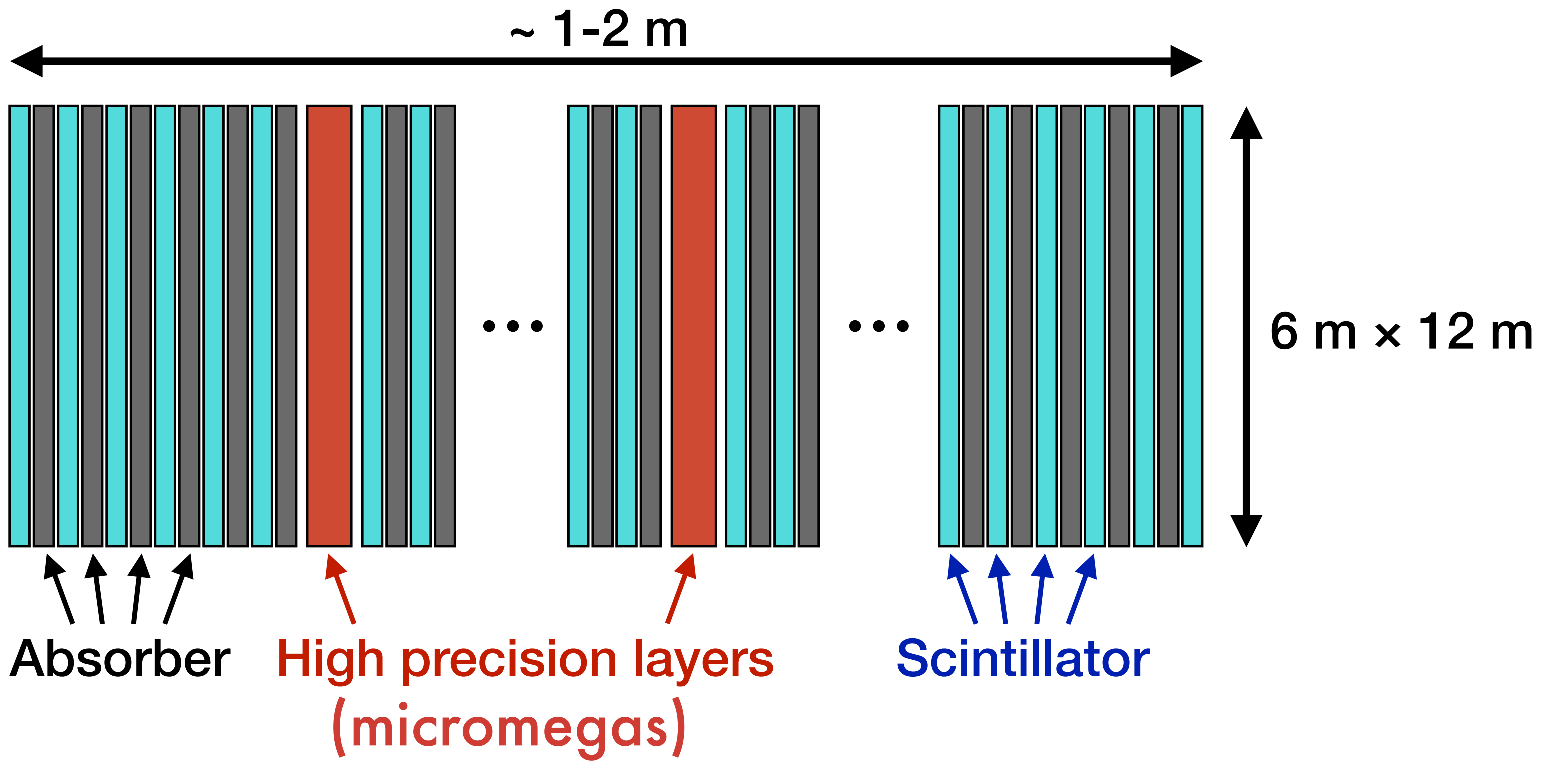


SHiP SplitCAL prototype

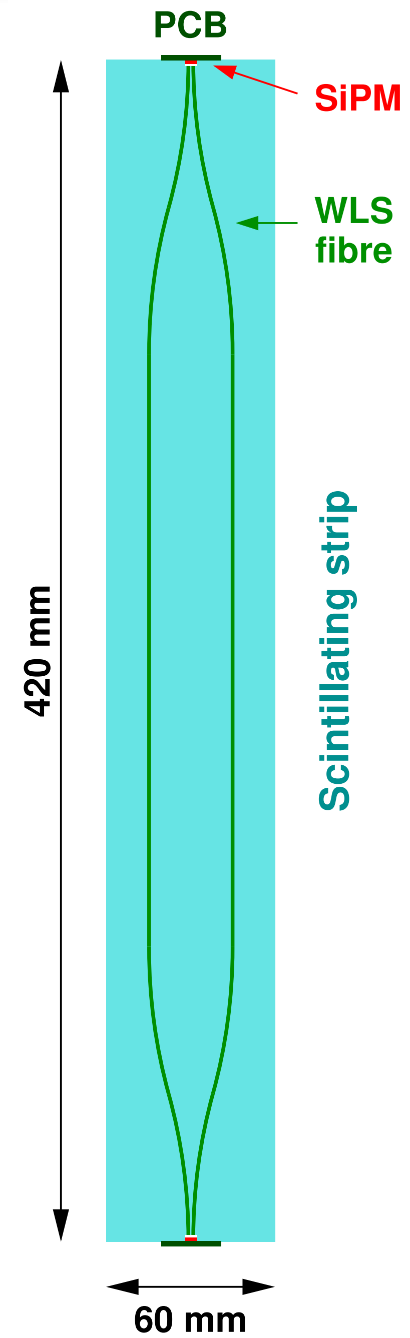
SplitCAL geometry

SplitCAL design:

- Large absorber planes of 6 m × 12 m cross section
  (changed from 5 m × 10 m previous presentations for MUV acceptance!)
- About 50 scintillating planes with strips alternating in *x* and *y* with WLS fibre readout.
- 2 or 3 high precision layers for measurements of the shower development ➜ photon direction in $X \rightarrow \gamma\gamma$ decays.

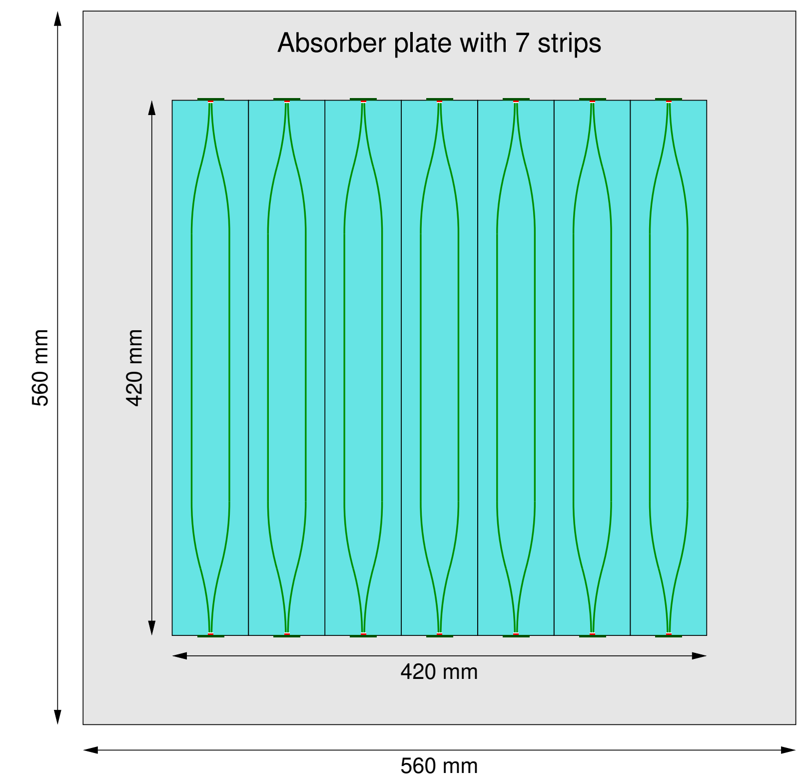


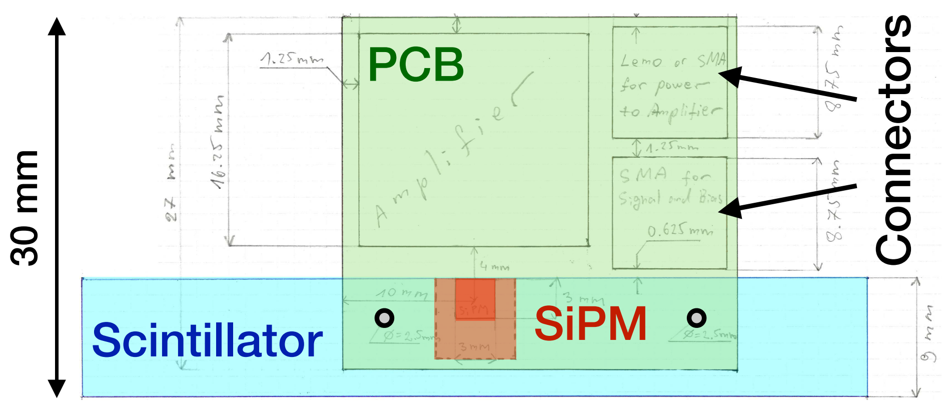
Scintillating planes



Each scintillating plane consists of one absorber plate, with 7 scintillating strips mounted.

- Double-sided readout ➜ 2 × 7 = 14 channels/plane.
- 2 horizontal & 2 vertical planes.
- SiPMs, preamps, and bias voltage mounted on a single PCB on the front faces of the strips.





SiPMs

Two types of SiPMs used:

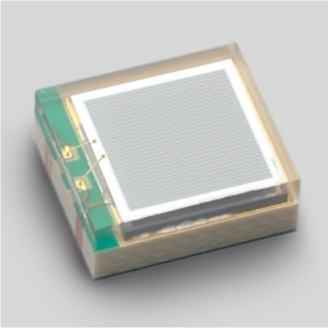
- **Hamamatsu S13360-3025PE**

  3 × 3 mm², 25 µm pitch, 14400 pixels.
  Used with WLS fibres of 1.2 mm diameter.

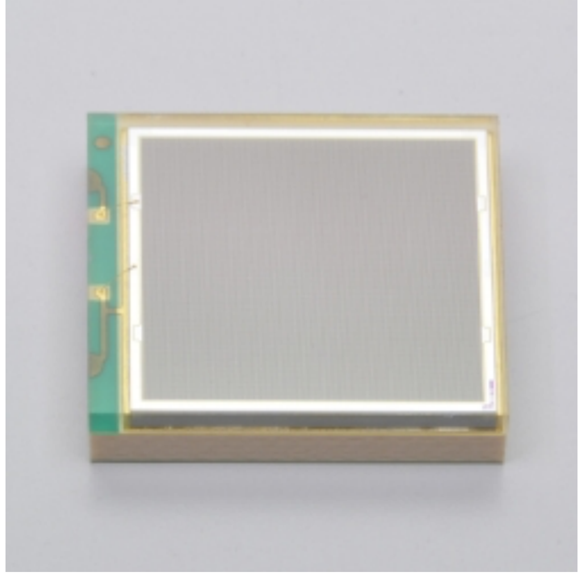
- **Hamamatsu S13360-6050PE**

  6 × 6 mm², 50 µm pitch, 14400 pixels.
  Used with WLS fibres of 2.0 mm diameter.

Large number of pixels necessary for dynamic range between MIPs and electron showers.



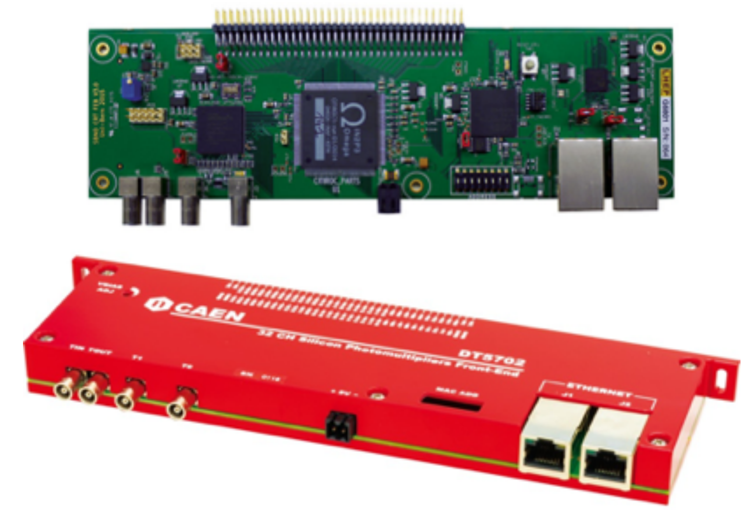
S13360-3025PE



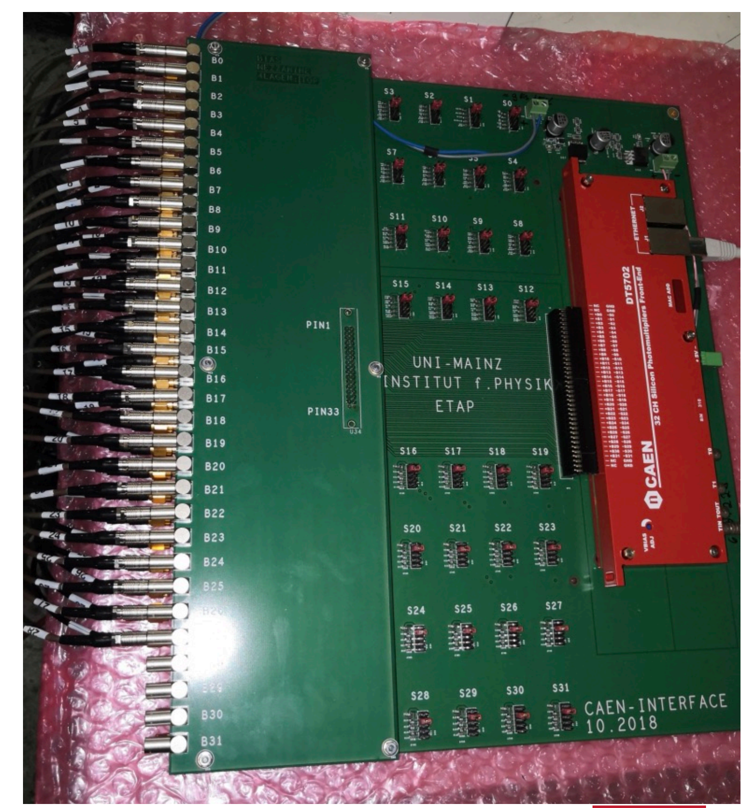
S13360-3025PE

SiPM readout

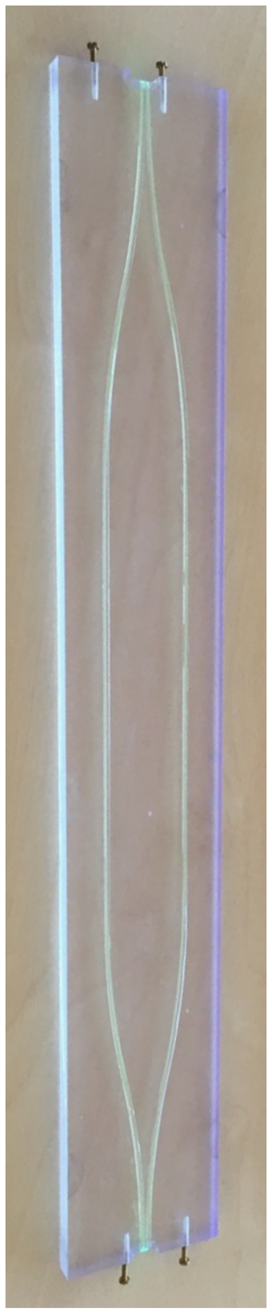
- **Preamps directly at the SIPMs.**
  - Amplify signal for transmission through ~ 4 m of coaxial cables.
- **Front-end electronics:**
  - Shaping and digitization of SiPM pulses.
  - Two CAEN DT5702 modules
    - Each 32 channels with individual V_{bias}.
    - Multiplexed output, QDC functionality.
    - ROOT based DAQ software.
    - Very sensitive input
      ➜ Amplified signal needs to be downsized!
- **Adapter board for CAEN DT5702**
  - Voltage dividers with 5 jumper settings for amplitude reduction.

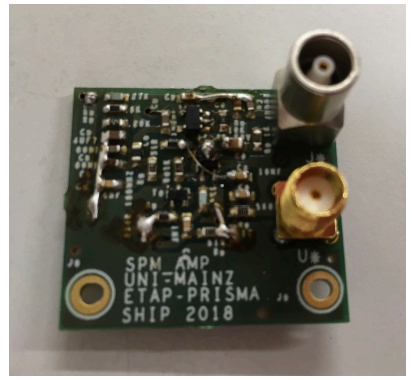


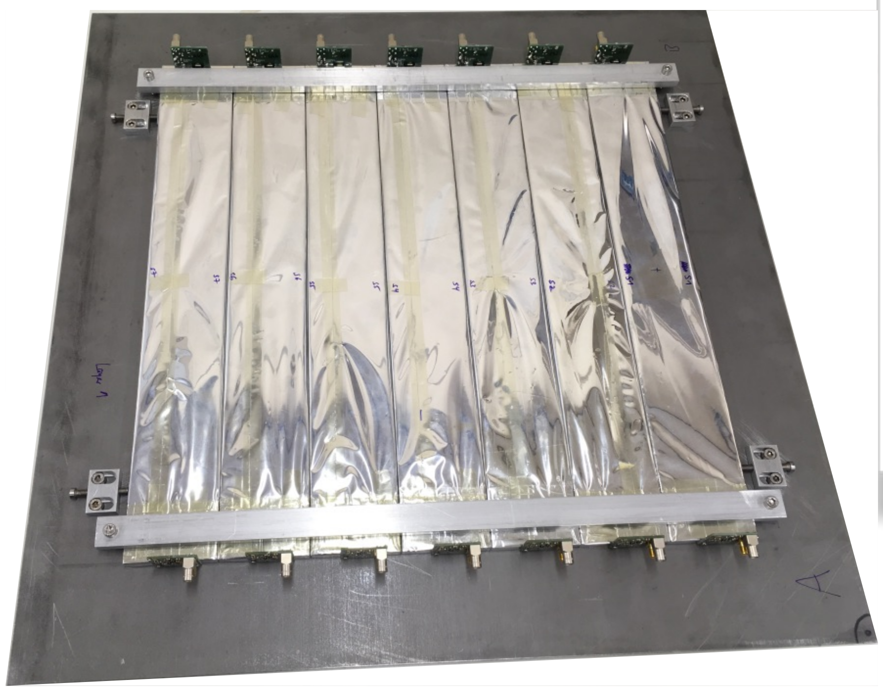
CAEN DT5702

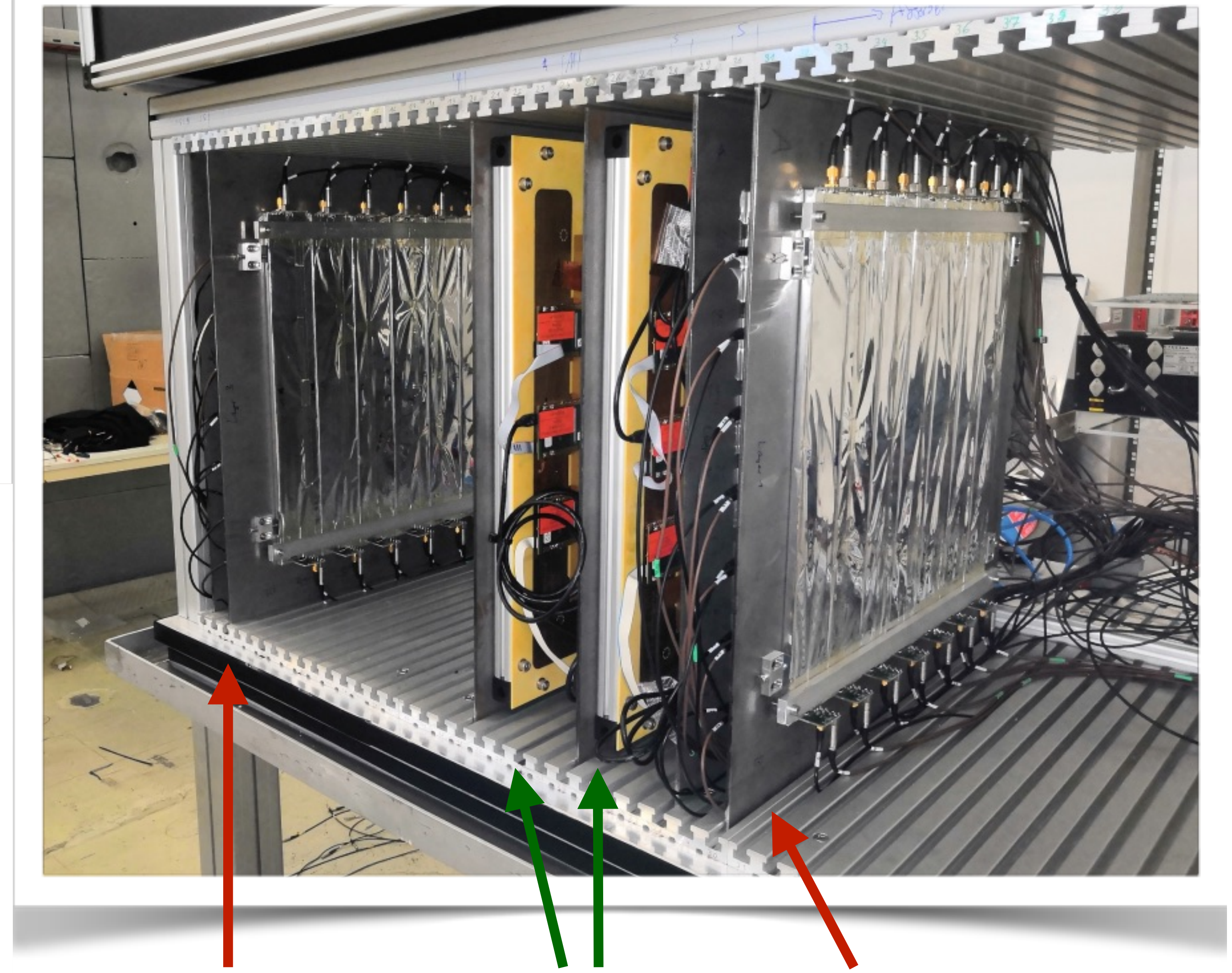


Beam test setup









First data taken end of 2018, analysis ongoing

Conclusion

Conclusion

- The CALICE community working on the Analog Hadron CALorimeter has been collecting experience with SiPMs for several years
  - SiPMs are nowadays performing much better than in the past in terms of DCR, uniformity and stability
  - Beam tests for both proposed high and low granularity configurations are ongoing and show very promising results
  - Last time we checked only Hamamatsu MPPCs could meet our requirements, would love to have the choice of more vendors!