MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

Performance Verification of the FlashCam Prototype Camera for the Cherenkov Telescope Array

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Challenges for cameras of imaging atmospheric Cherenkov telescopes

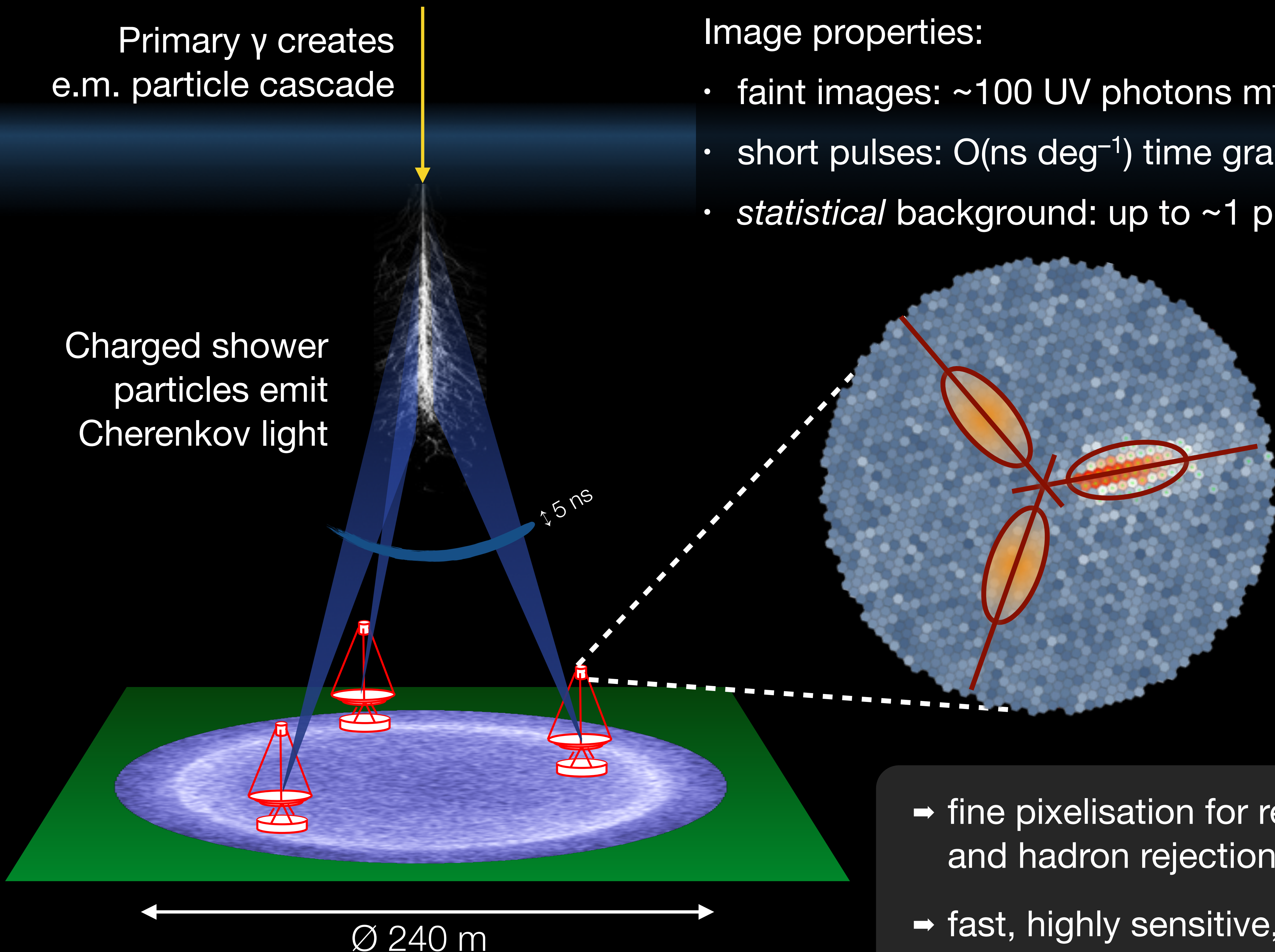


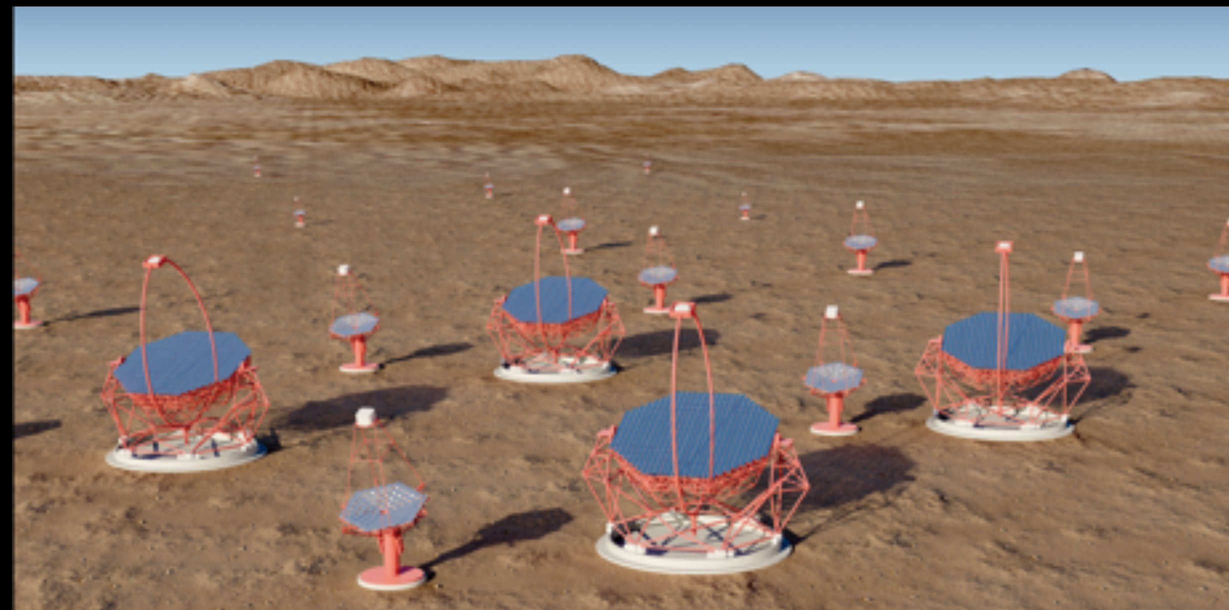
Image properties:

- faint images: ~100 UV photons m^{-2} at E_γ = 1 TeV
- short pulses: O(ns deg^{-1}) time gradients
- *statistical* background: up to ~1 p.e. ns^{-1} $pixel^{-1}$

➡ fine pixelisation for reconstruction and hadron rejection

➡ fast, highly sensitive, and *self-triggering* cameras

Cherenkov Telescope Array (CTA)

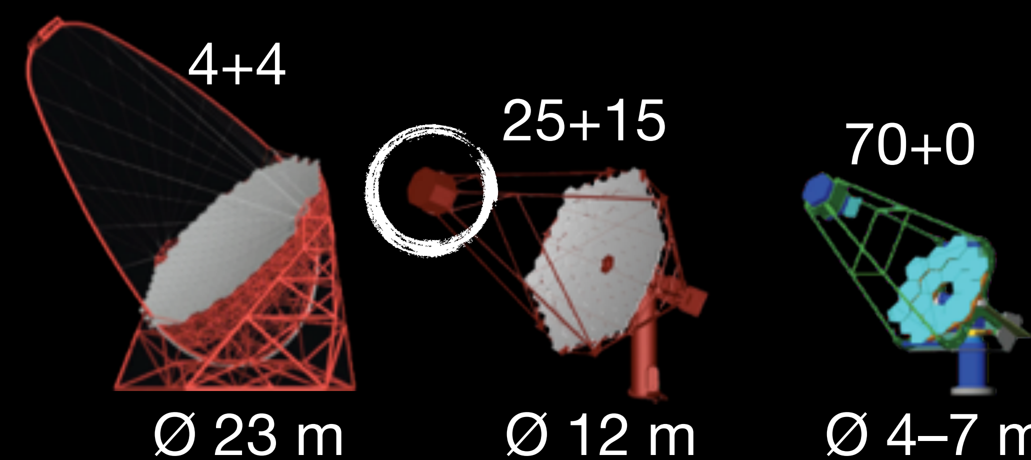


Two sites

Atacama desert, Chile

Roque de los Muchachos, La Palma

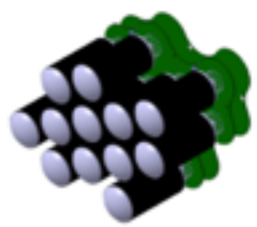
>100 telescopes over km^2 areas



cherenkov telescope array

32 countries
>200 institutes
>1300 members

FlashCam for the medium-sized telescopes: Architecture

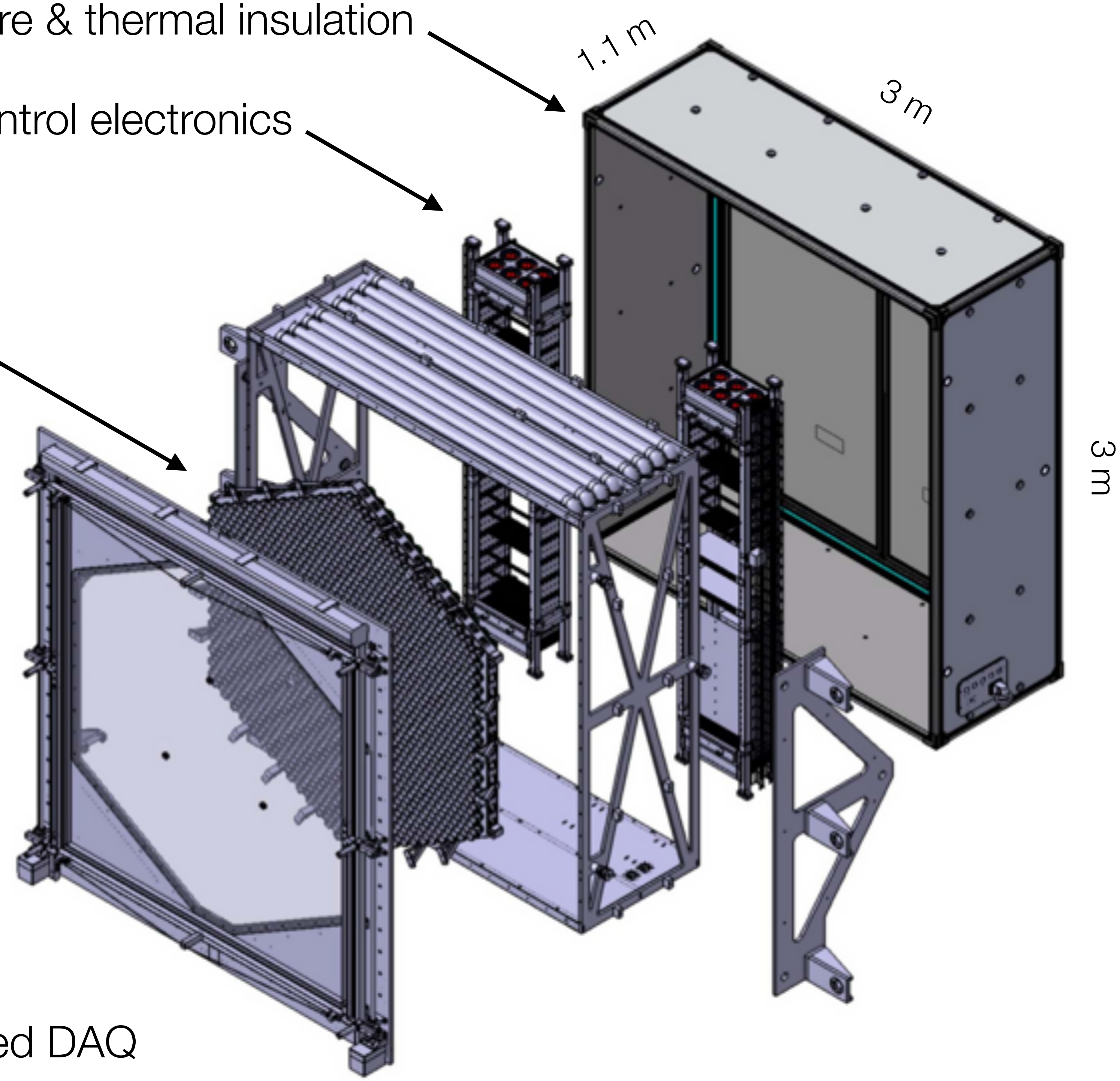


Mechanical structure & thermal insulation

Readout & safety control electronics

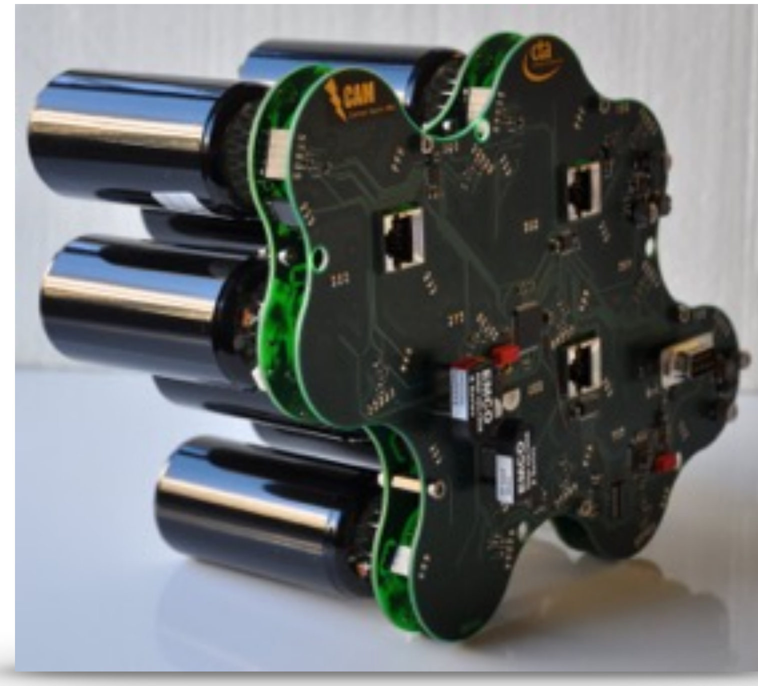
Photon detector plane

Window & shutter



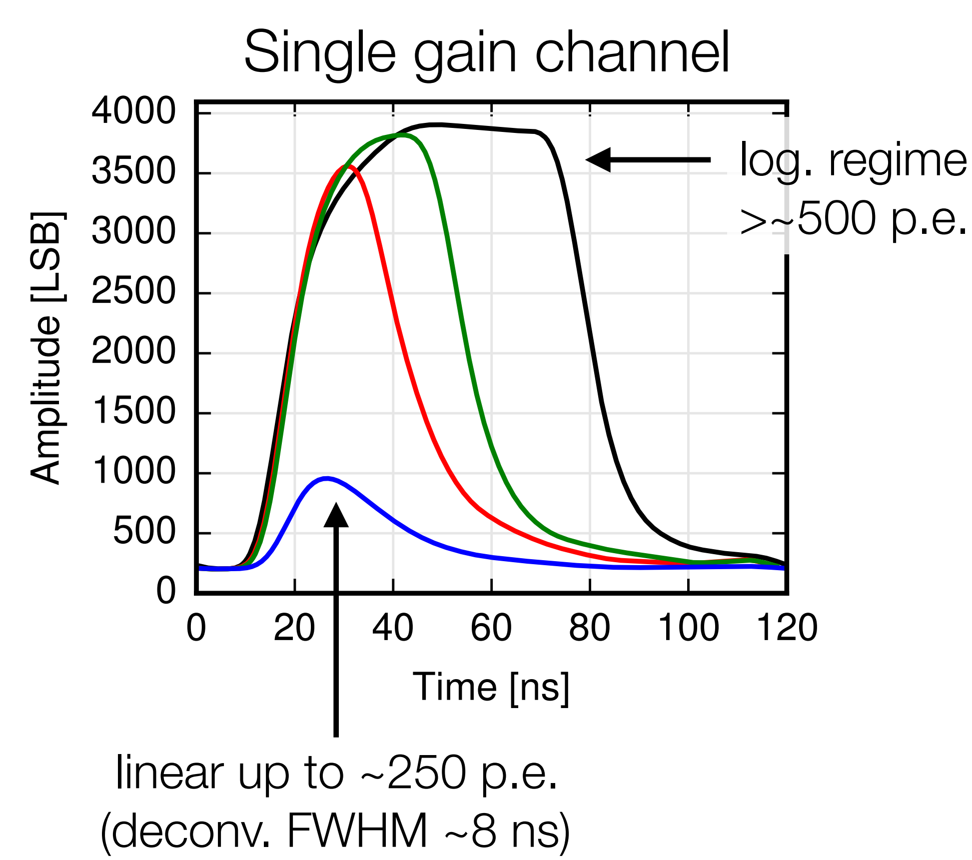
- 1758 pixels (PMTs), 7.7° FoV
- 0.2…3000 p.e. dynamic range
- continuous digitisation with 250 MS/s
- fully digital trigger formation & readout
- >20 kHz dead-time free Ethernet-based DAQ
- <4.5 kW power consumption

Photon detector plane



12-pixel groups with 1.5” PMTs:

- *highly integrated:* HV supply, preamp, slow control
- *clean interface* to readout system: DC-coupled analogue, differential signal transmission (cat. 6 cables)
- *passively cooled:* <3 W per module
- aluminium-coated light concentrators increase collection efficiency



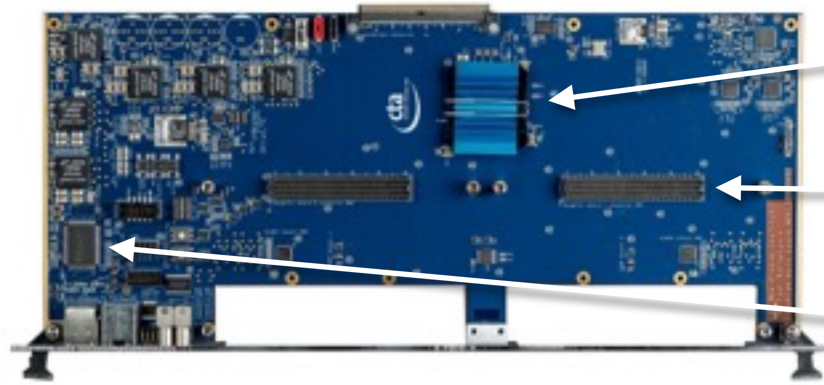
Modular readout system

"Mini crate"

40 cm

192 FADCs Trig.

Motherboard



low-power FPGA with soft core

2 connectors for mezzanines

readout via Gbit Ethernet

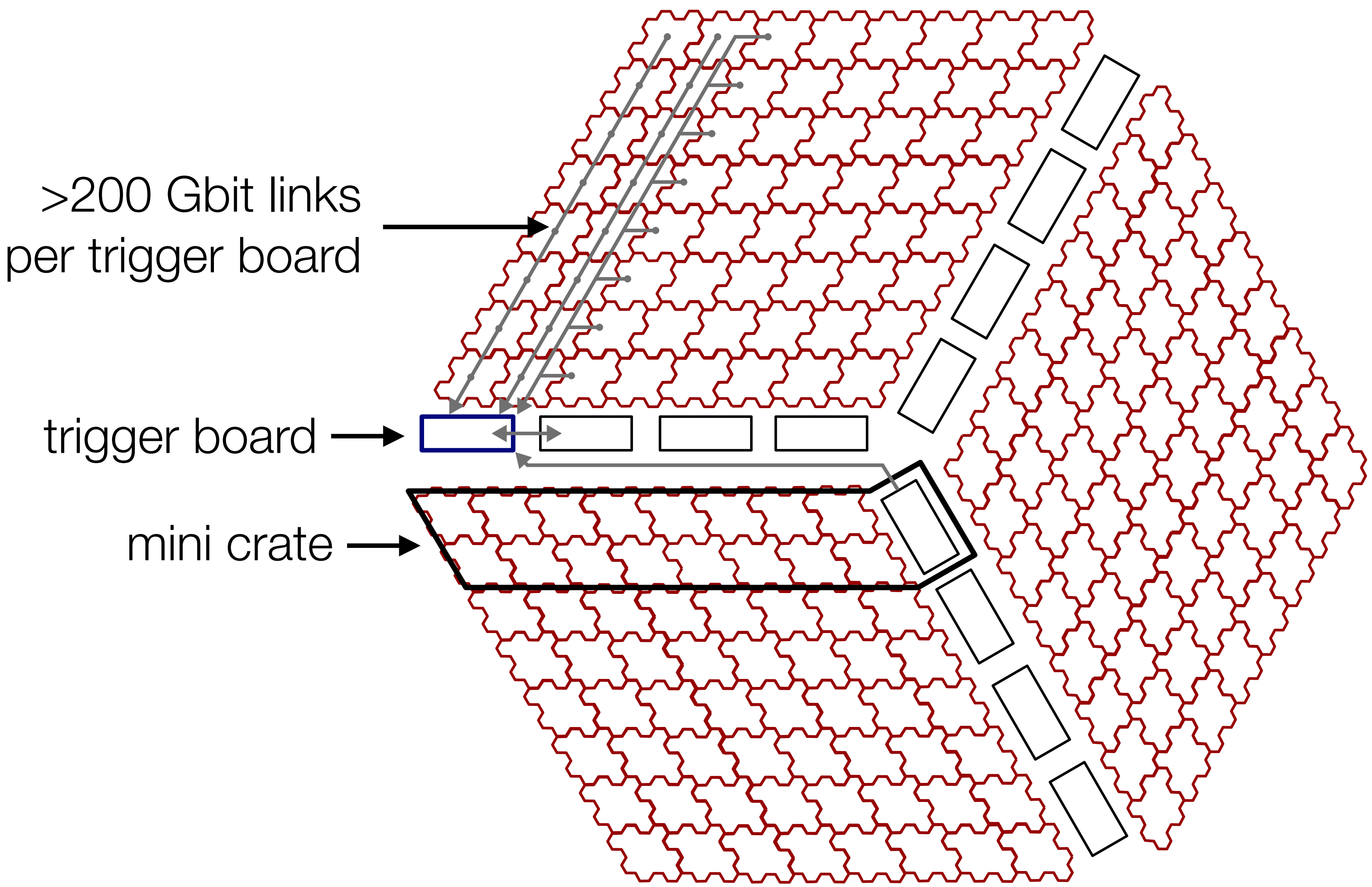
2x 12-channel FADC

250 MS/s, 12 bit
<1.5 W/channel

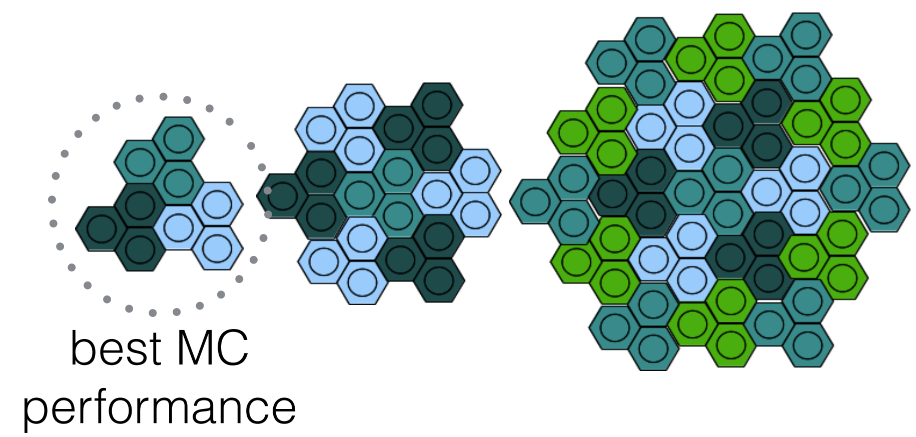
Trigger & clock distribution

semi-passive distribution of
clock, sync, and trigger I/O

Programmable digital trigger system



- 97 FPGAs buffer and analyse the digital traces *synchronously*
- transmission capacity of 12 trigger boards: 2.7 Tbit/s
- trigger on local, short light pulses; digital pre-processing & patch size configurable

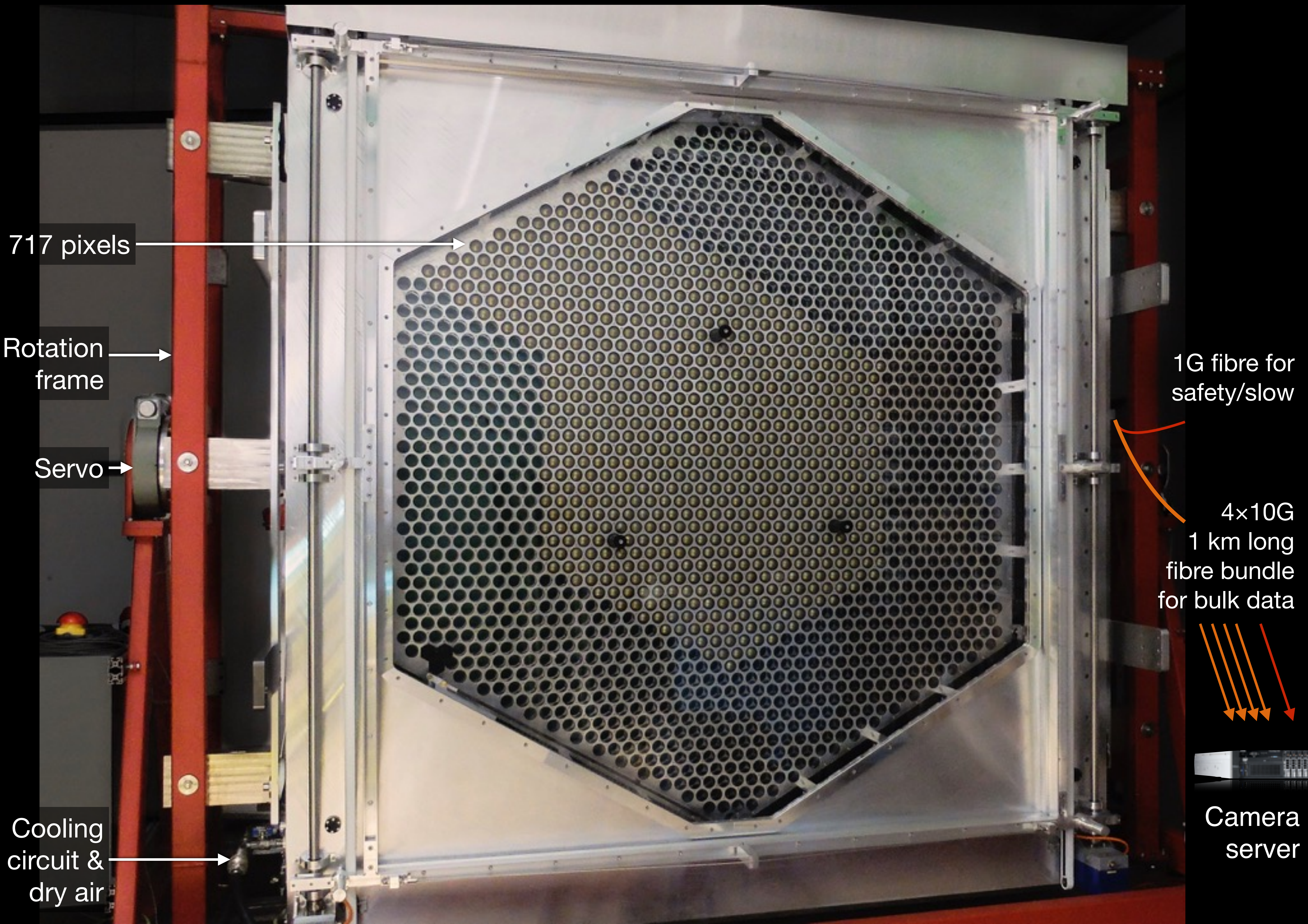


➡ *dead-time free* readout with >2 GByte/s (>20 kHz) via four 10 Gbit/s Ethernet fibres

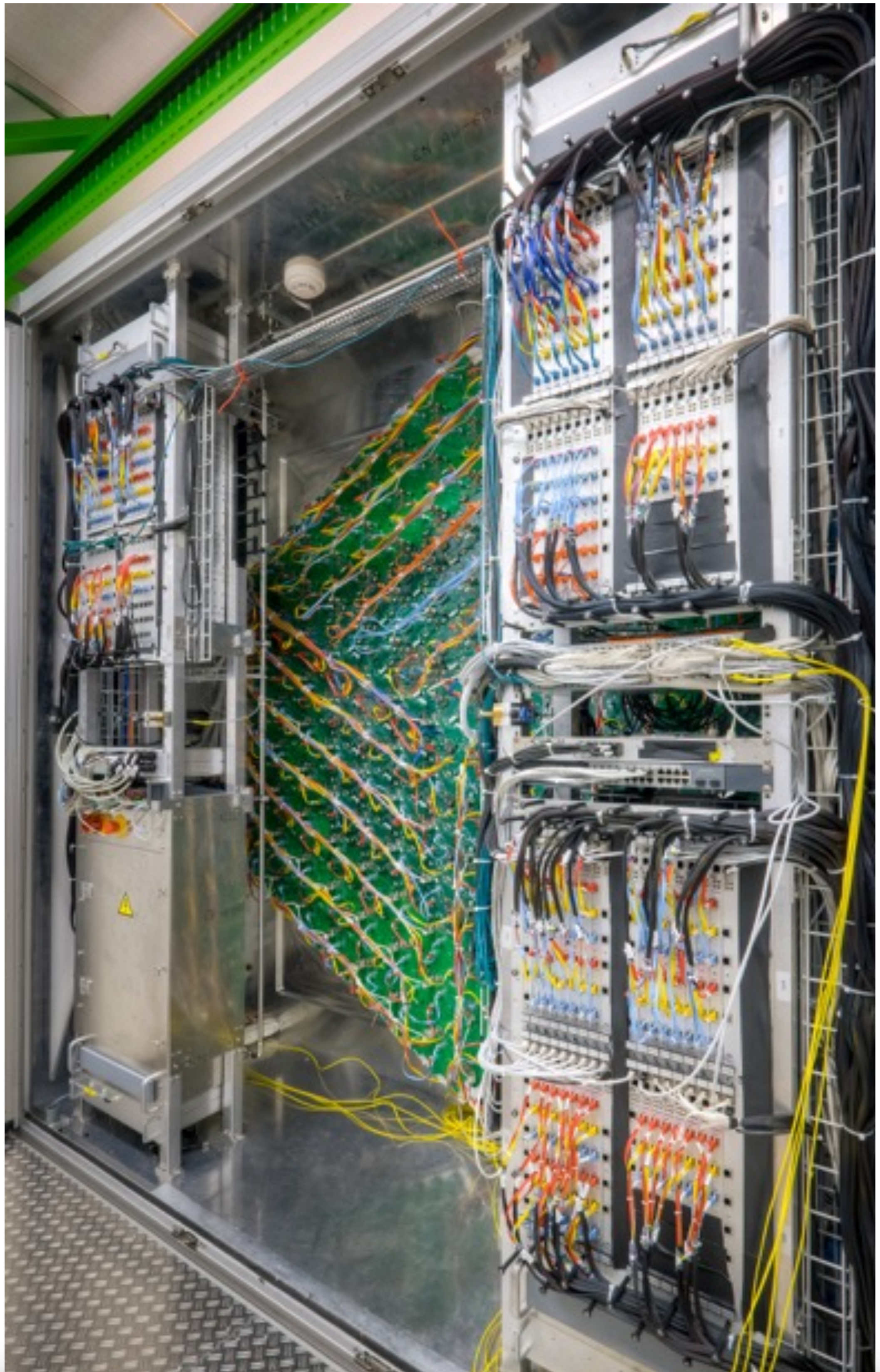
Tests of prototype camera mechanics on prototype MST structure

Arrival of prototype camera mechanics at integration lab

FlashCam prototype setup in dark room



Back view & current status



Two types of PMTs installed in PDP:

- 358 Hamamatsu R11920-100 (8 dynodes) &
  359 Hamamatsu R12992-100 (7 dynodes) tubes
- remaining slots filled with dummy heater modules

Readout system complete:

- readout electronics for up to 2304 channels installed
- cabling nearly complete (optimising for mass prod.)

Near final safety, power, and mechanics:

- power consumption of complete system as specified
- closed-circuit cooling with 5…35°C coolant works

Software development & interfacing in progress:

- DAQ over 1 km 4×10G fibres works
- remote control of all components works
- internal system analysis in progress

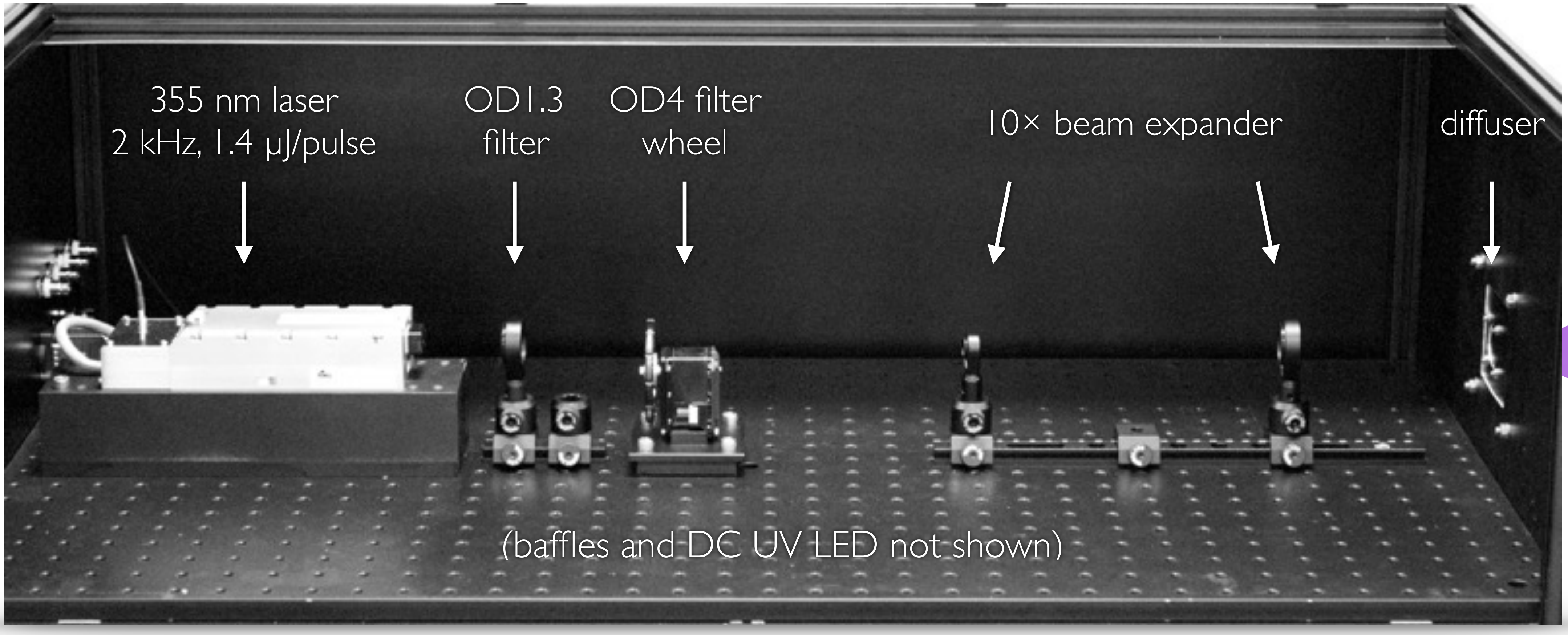
➡ continuous *full* operation since Aug. 2016

➡ >20 TByte of test data taken & analysed

From functionality tests to verification testing

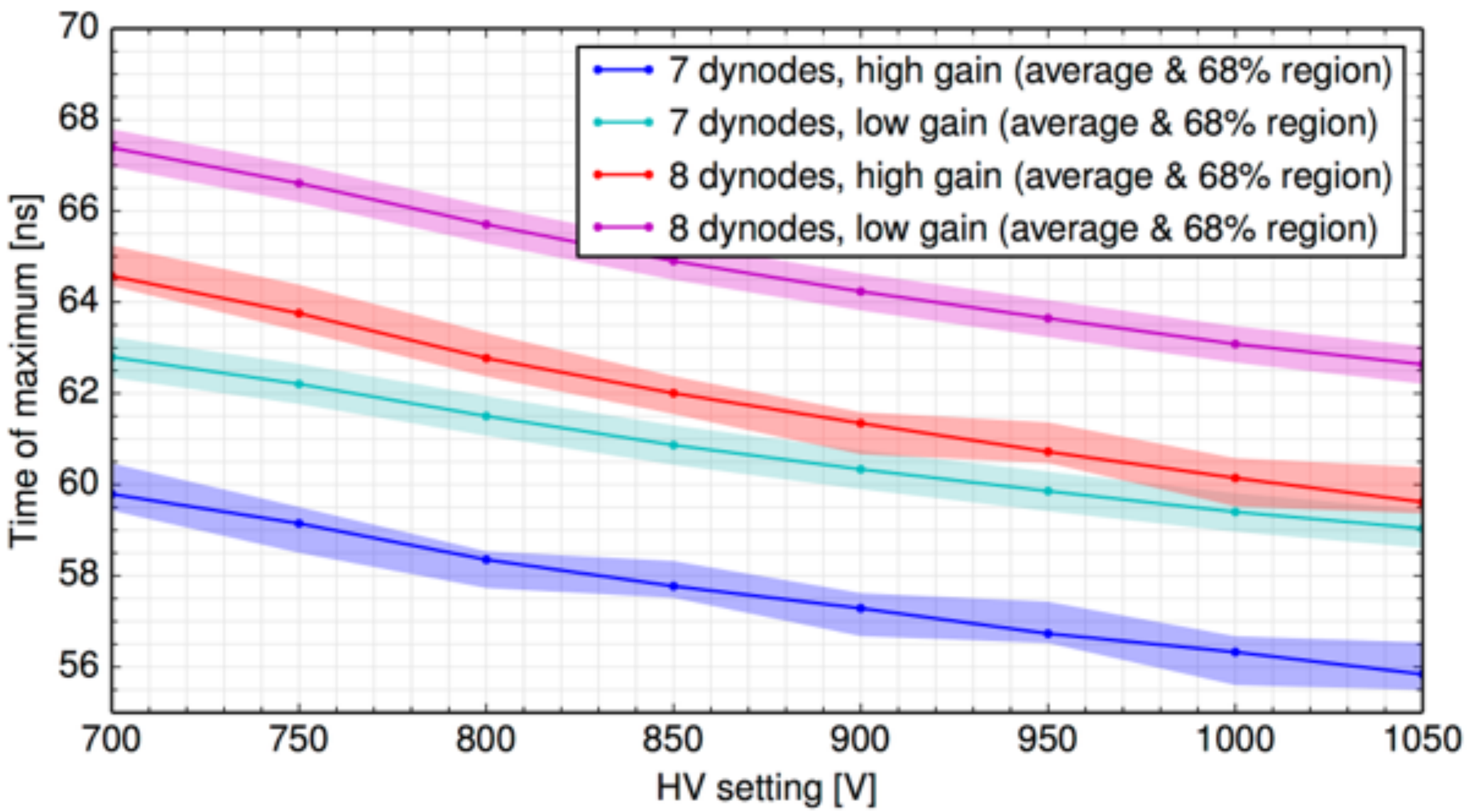
- products to be deployed on a CTA site have to fulfil a list of environmental, RAMS, and performance requirements
- will focus on performance requirements:
  - ➡ min. readout rate & max. allowed dead time
  - ➡ time synchronisation between channels
  - ➡ charge & time resolution of pulse reconstruction
  - ➡ longterm (temperature) stability of signal path

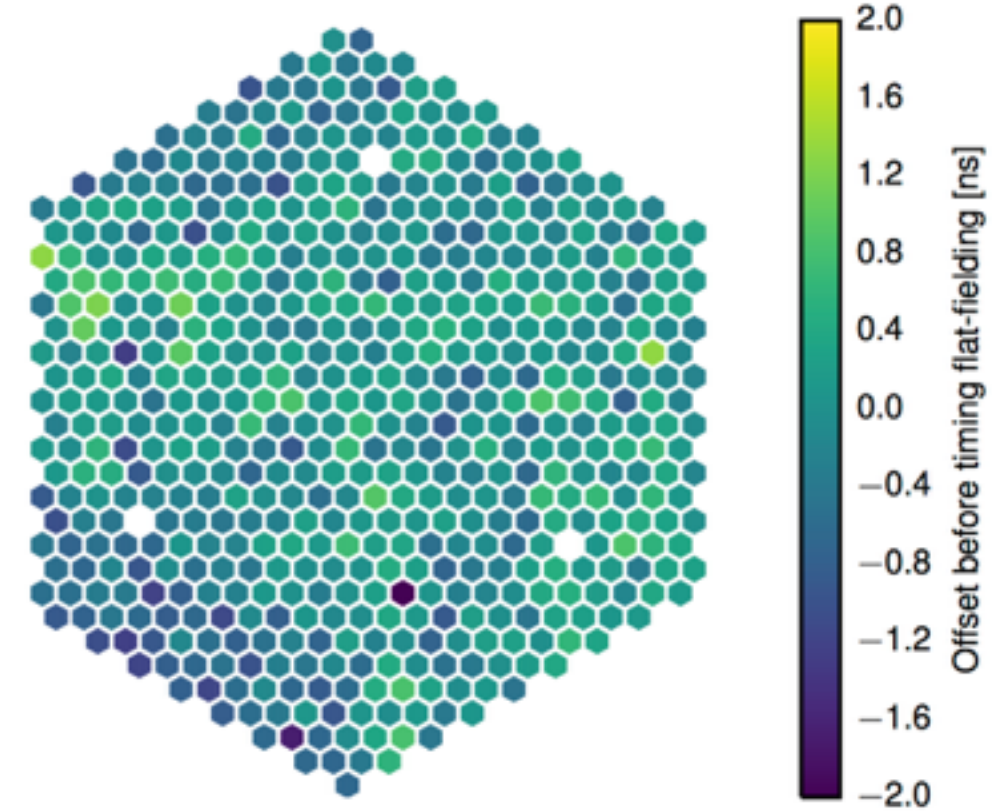
Main tool: Lab calibration unit



Readout & time synchronisation between FADCs

- full-camera readout verified at *>20 kHz* statistical trigger rates (2.2 GByte/s)
    - ➡ >5× required min. rate (>2.5× goal rate) with *no dead time*
- time synchronisation of all channels verified with equal HV settings
    - ➡ pulses of all 7/8-dynode tubes within ±1 ns *before* timing flat-fielding

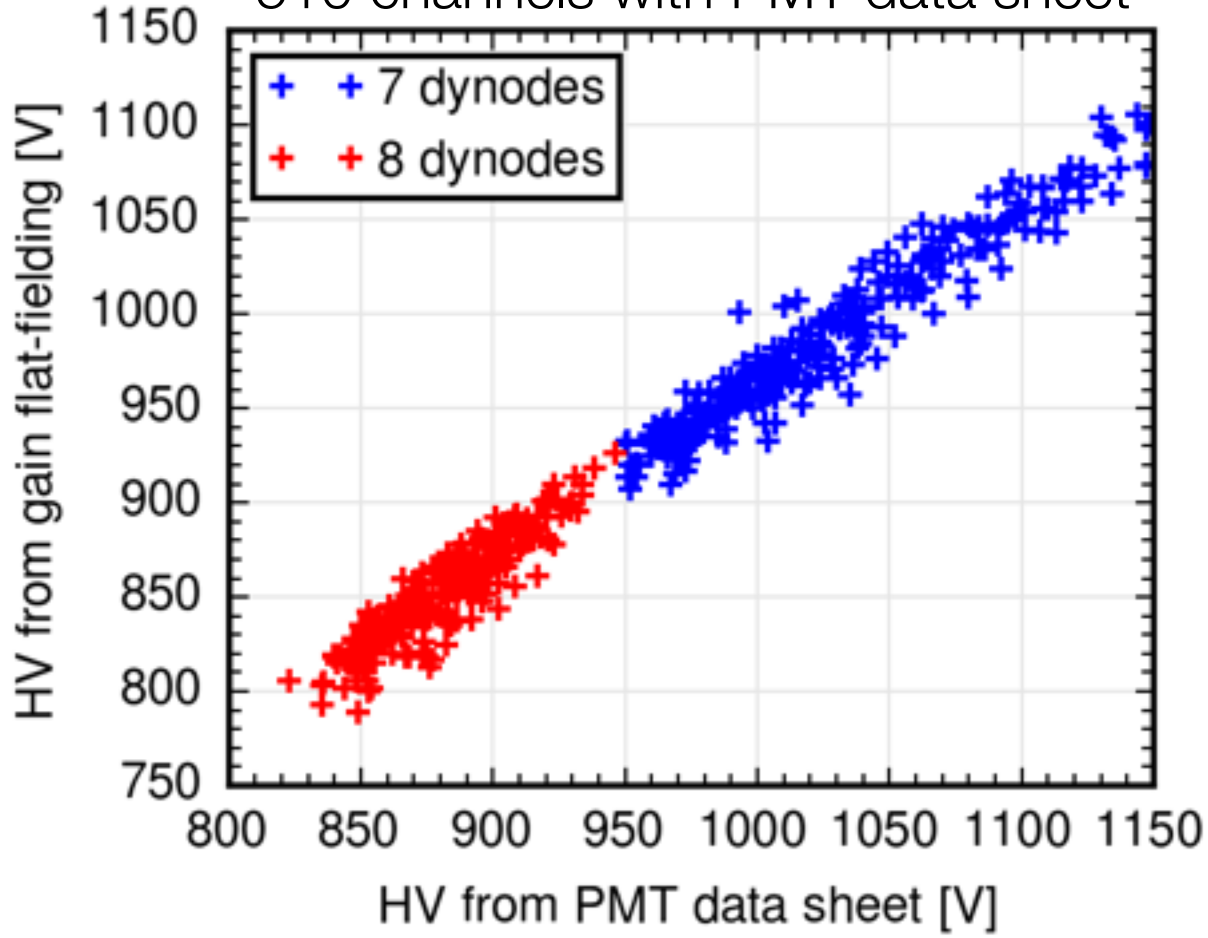




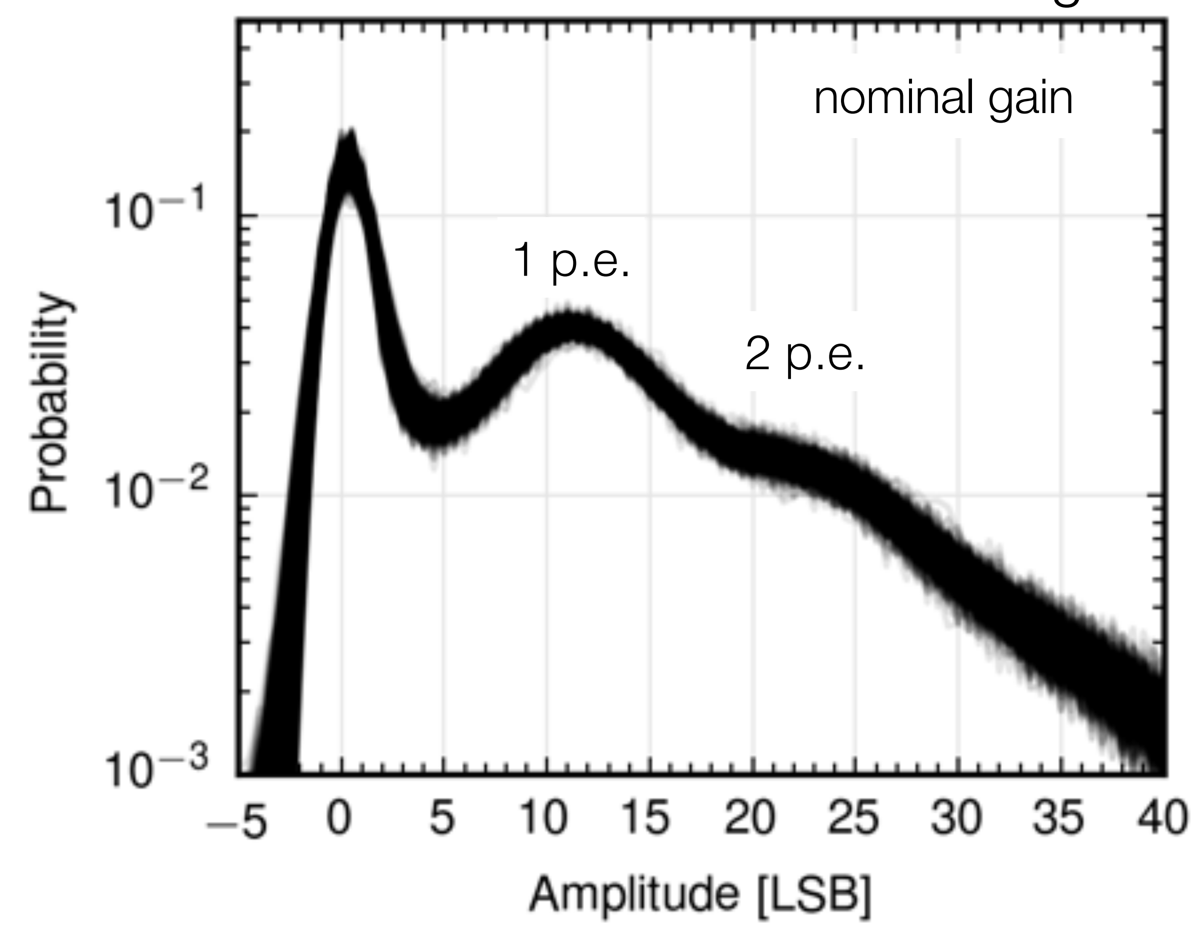
➡ *fully synchronous* readout system works as specified

Automatic gain flat-fielding before verifying charge & time resolution

HV correlation of
510 channels with PMT data sheet



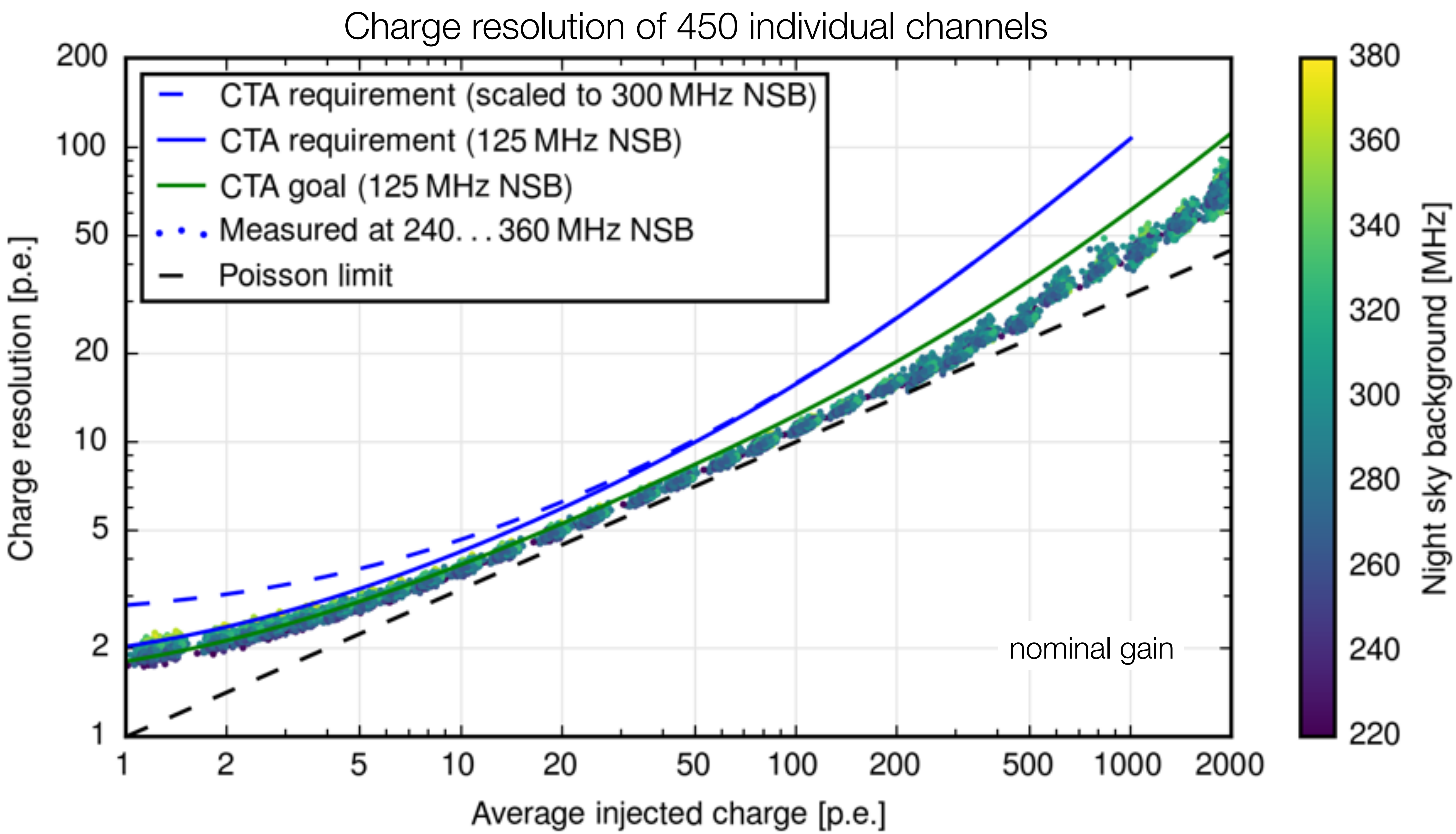
Multi-p.e. spectra of
510 channels after flat-fielding



- flat-field procedure based on prior knowledge of individual excess noise factors
- ~2% precision after few minutes (limited by max. repetition rate of laser)

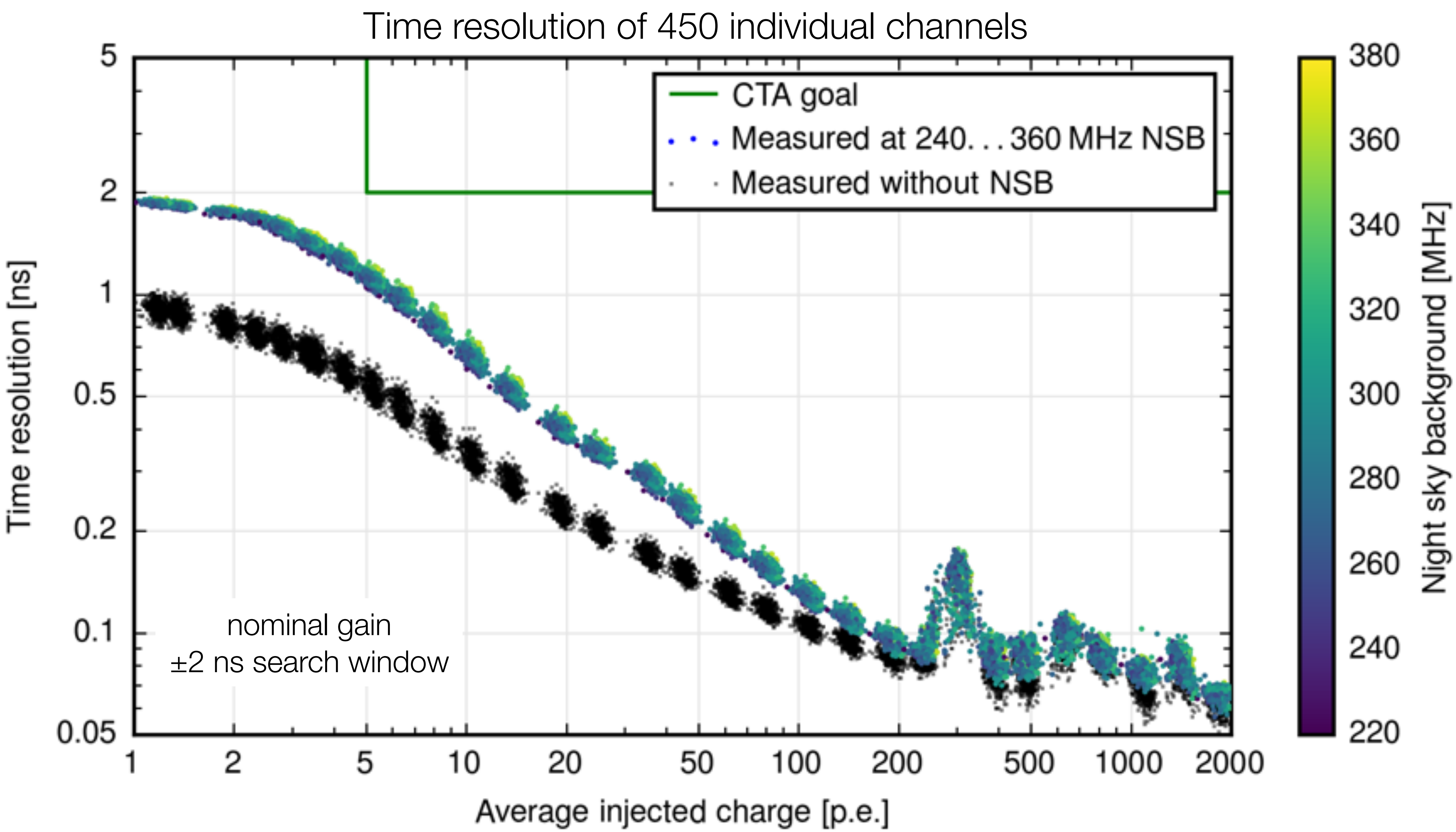
➡ standard procedure before all test measurements

Charge resolution verified at expected NSB rates and beyond

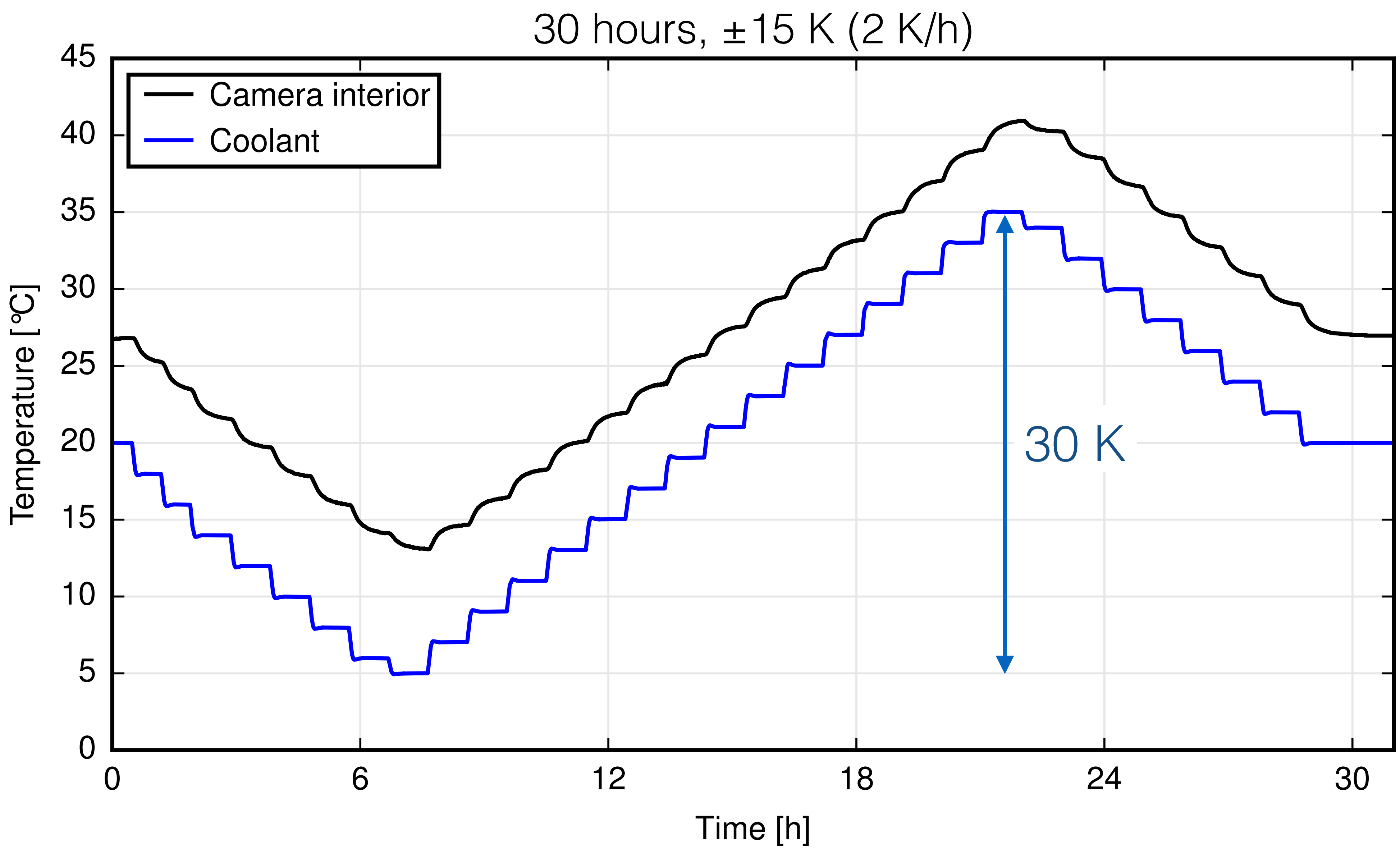


- from a large data set covering the whole operational range (up to >5,000 p.e./pulse & 3 GHz NSB)
- DC background in each pixel is estimated from baseline shift (~0.25 LSB/MHz)

Time resolution verified at expected NSB rates and beyond

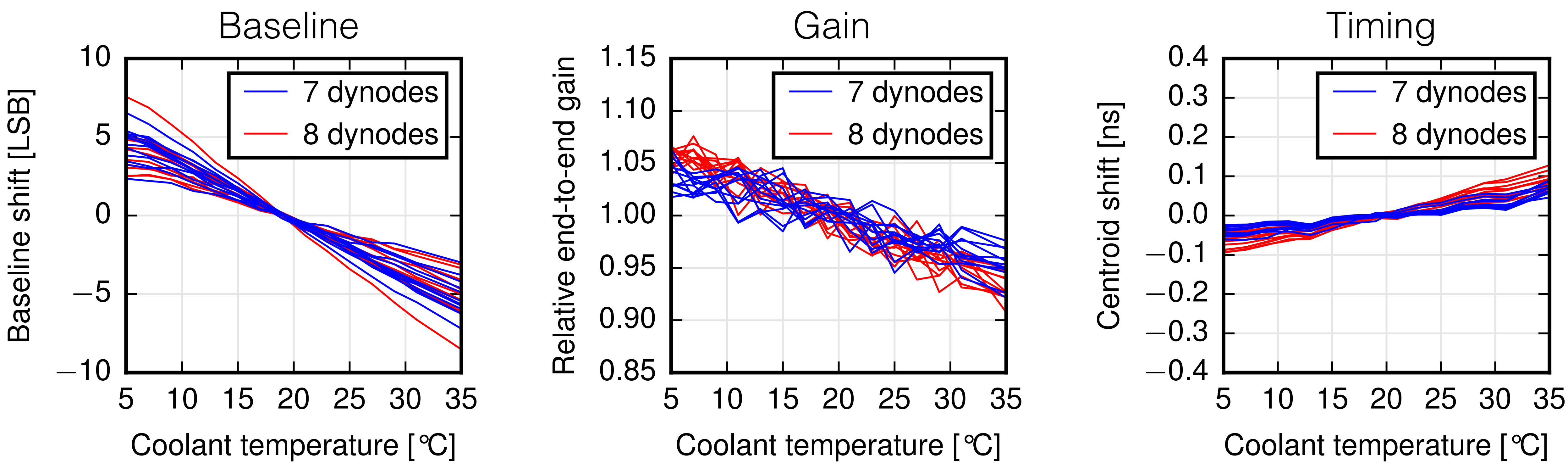


Longterm stability — Temperature cycling over 30 h



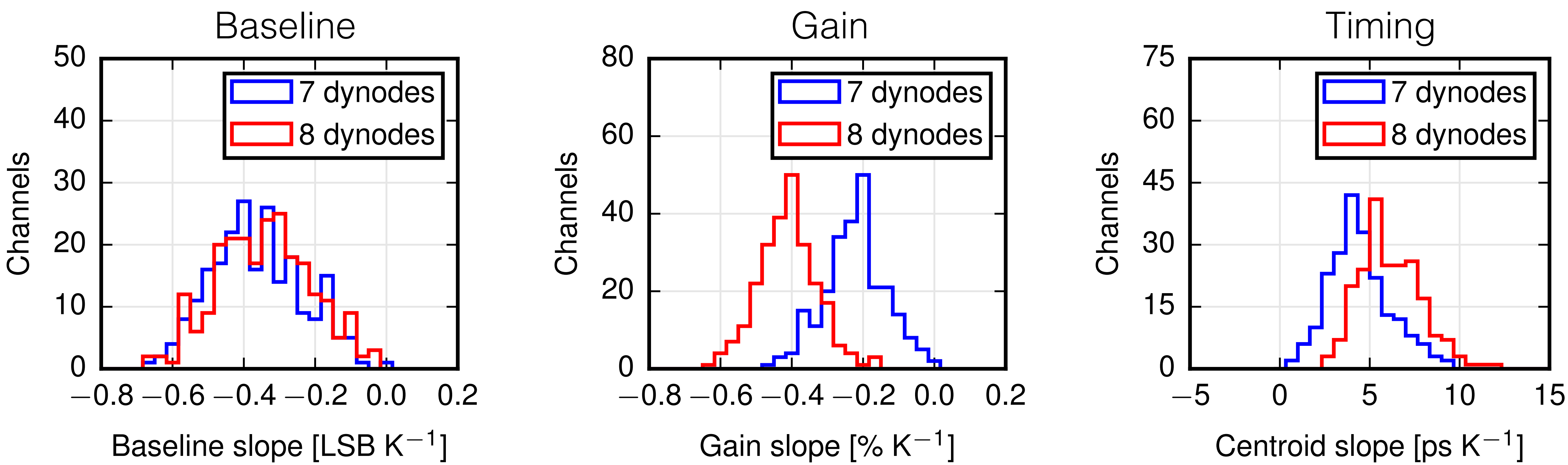
- FlashCams are thermally insulated and cooled via liquid/air heat exchangers
  ➡ interior temperatures are strongly coupled to coolant
- perform initial gain flat-fielding and baseline adjustment, let everything drift for 30 h and monitor changes

Longterm stability — Temperature drifts



- baseline drift: (–0.4 ± 0.1) LSB/K
- end-to-end gain and timing drifts seem to be dominated by PDP:
  - 7 dynodes: (–0.2 ± 0.1)%/K gain & (4 ± 2) ps/K transit time
  - 8 dynodes: (–0.4 ± 0.1)%/K gain & (6 ± 2) ps/K transit time
  - consistent with eff. HV change of about –0.5 V/K

Longterm stability — Temperature coefficients



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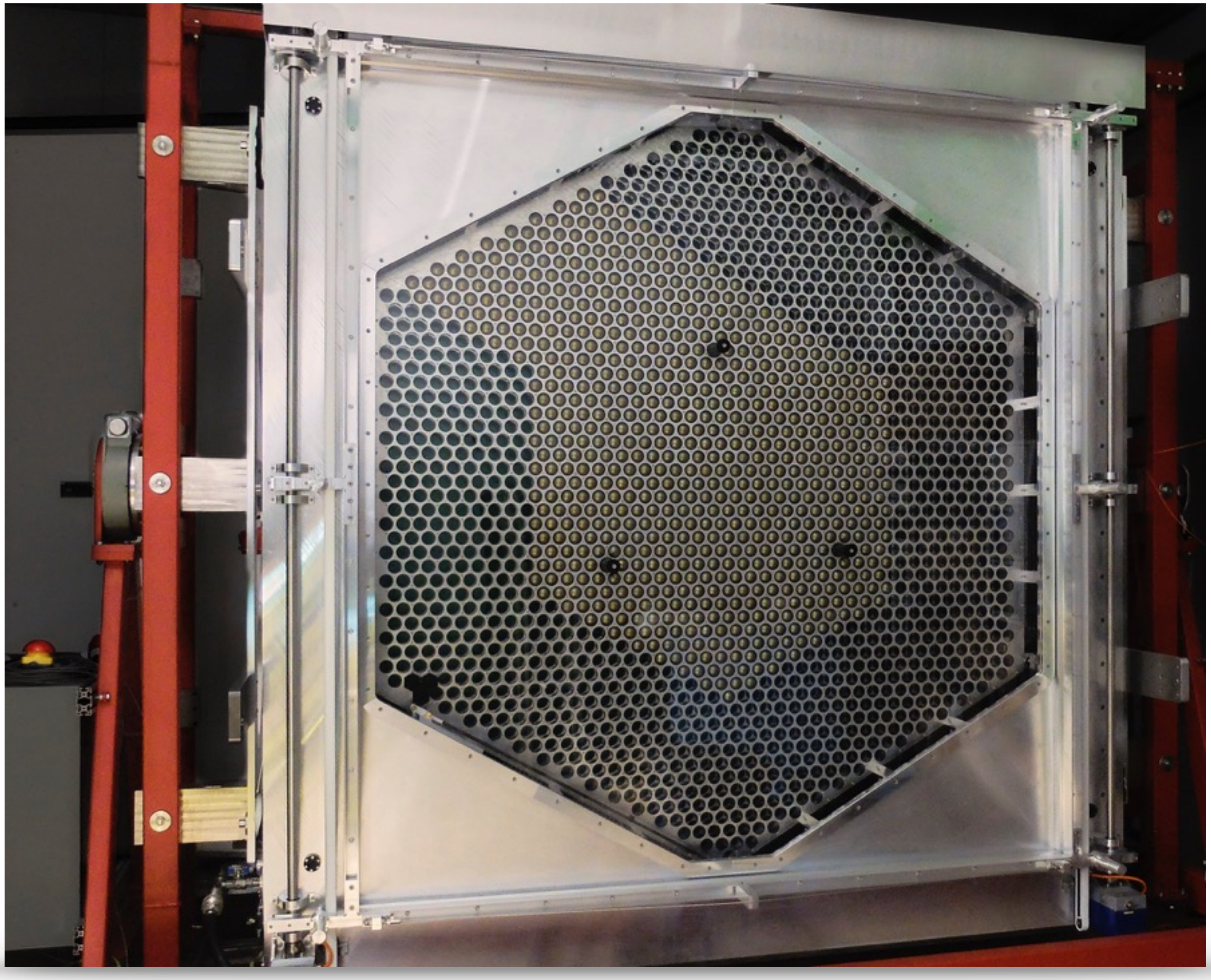
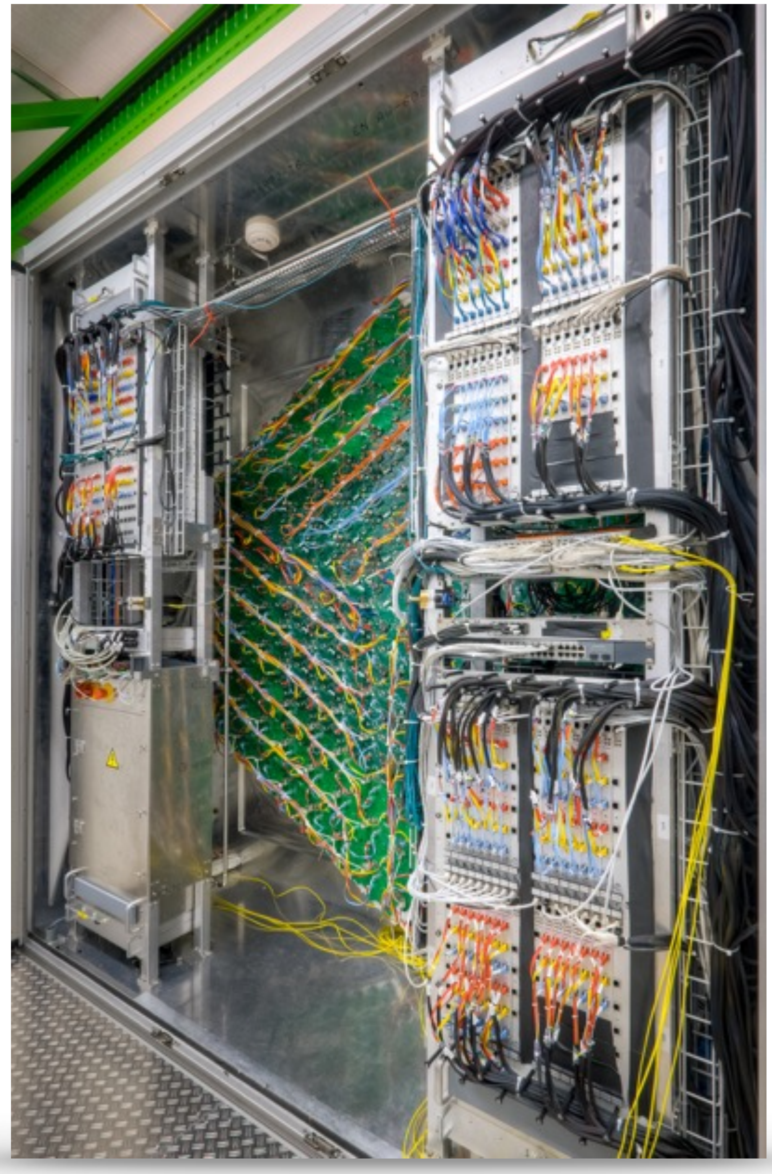
  - consistent with eff. HV change of about –0.5 V/K

➡ all reconstruction parameters are well-behaved and exceptionally stable

Summary & outlook





FlashCam is a stable, high-performance Cherenkov camera well-suited for CTA:

- all major performance parameters have been verified and exceed CTA requirements
- longterm stability & reliability tests are ongoing; trigger verification next
- pre-production of two cameras has started; aim for two pre-series cameras late 2017