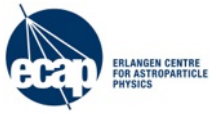
MPI für Kernphysik Heidelberg

University of Zurich[UZH]

JAGIELLONIAN UNIVERSITY IN KRAKOW

AGH University of Science and Technology



University of Innsbruck

Gerd Pühlhofer (IAA Tübingen), for the FlashCam Team

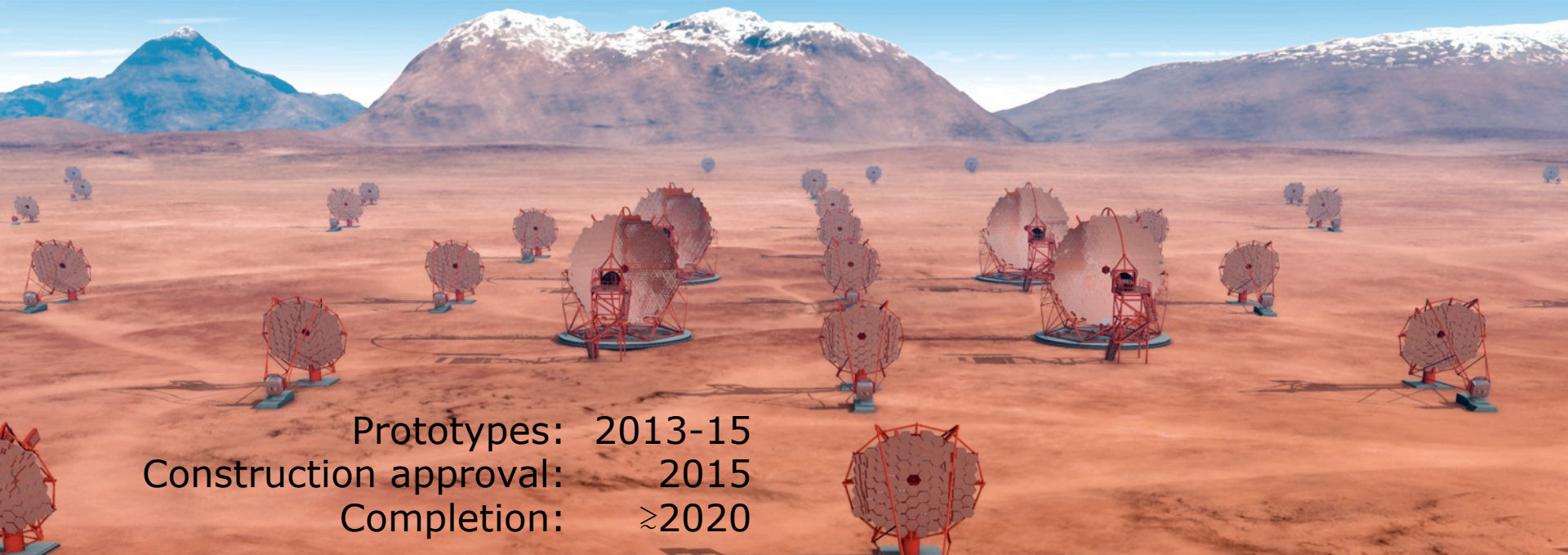
STATUS OF THE FLASHCAM PROJECT

GEFÖRDERT VOM

Bundesministerium
für Bildung
und Forschung

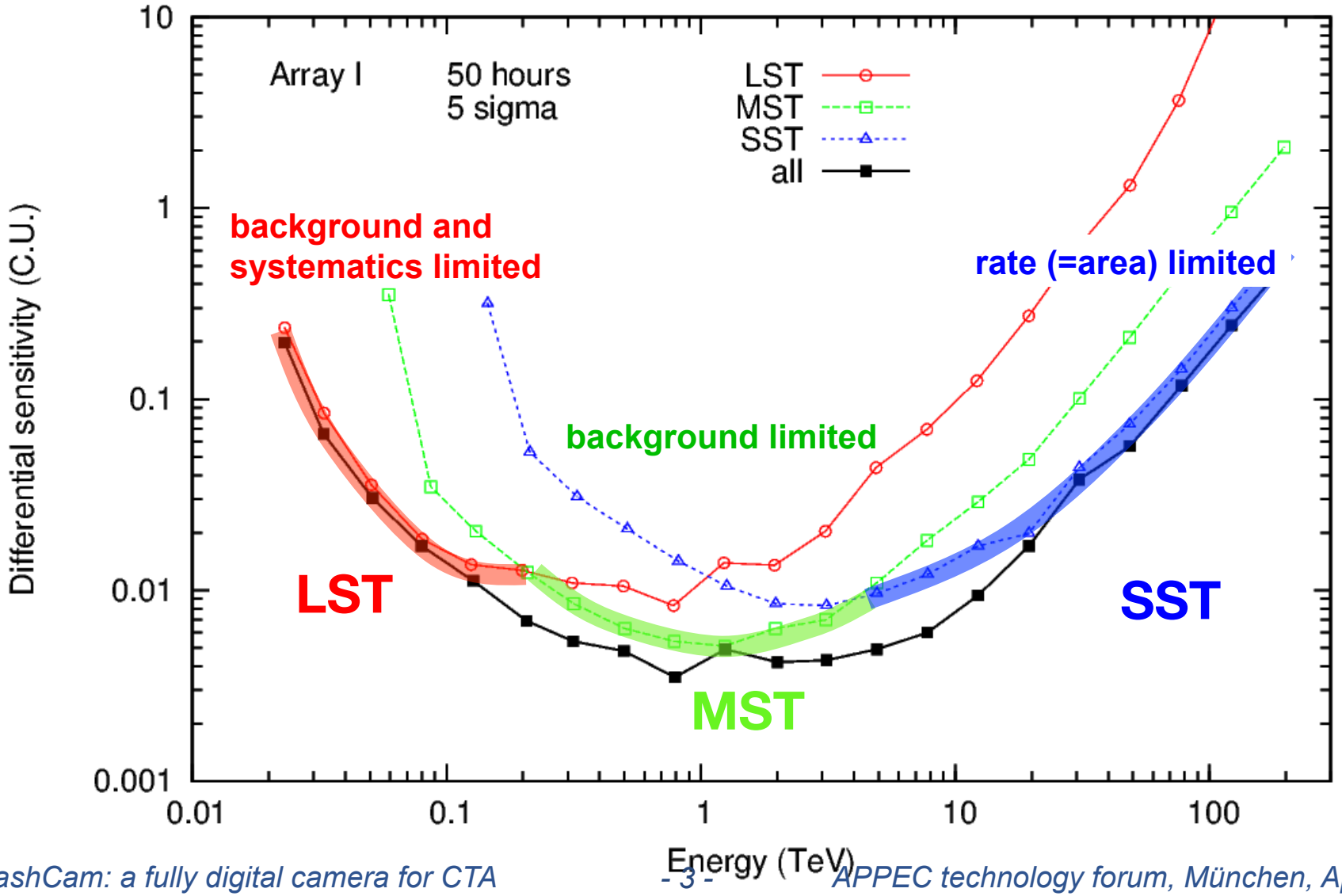
CTA:
The next Generation IACT ARRAY

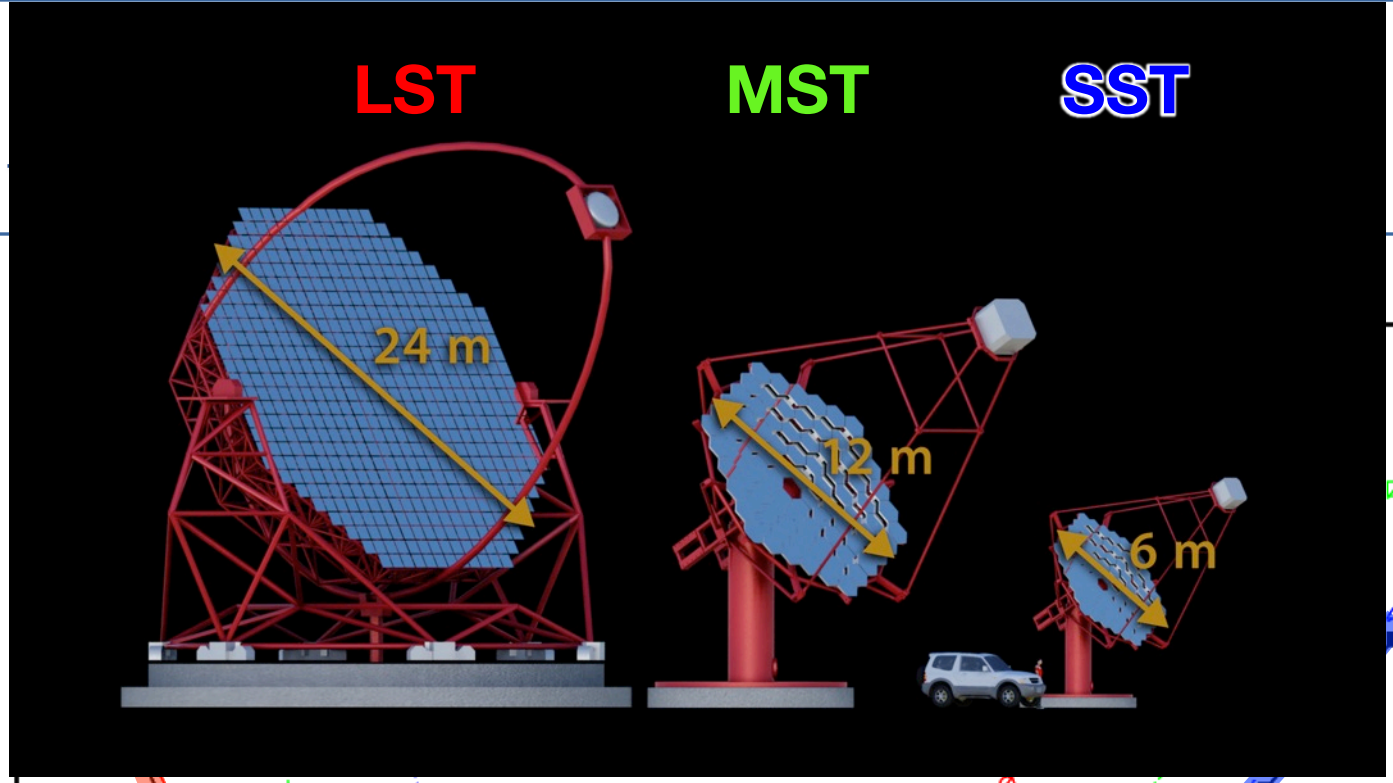
- A huge improvement in all aspects of performance
  - A factor ~10 in sensitivity, much wider energy coverage, better angular resolution, larger field-of-view, full sky, …
- User facility / proposal-driven observatory
  - Two sites with a total of >100 telescopes



Sensitivity (in units of Crab flux)

for detection in each 0.2-decade energy band




LST
MST
SST
24 m
12 m
6 m

Differential sensitivity (C.U.)
10
1
0.1
0.01
0.001
0.01
0.1
1
10
100
Energy (TeV)
LST
MST
SST

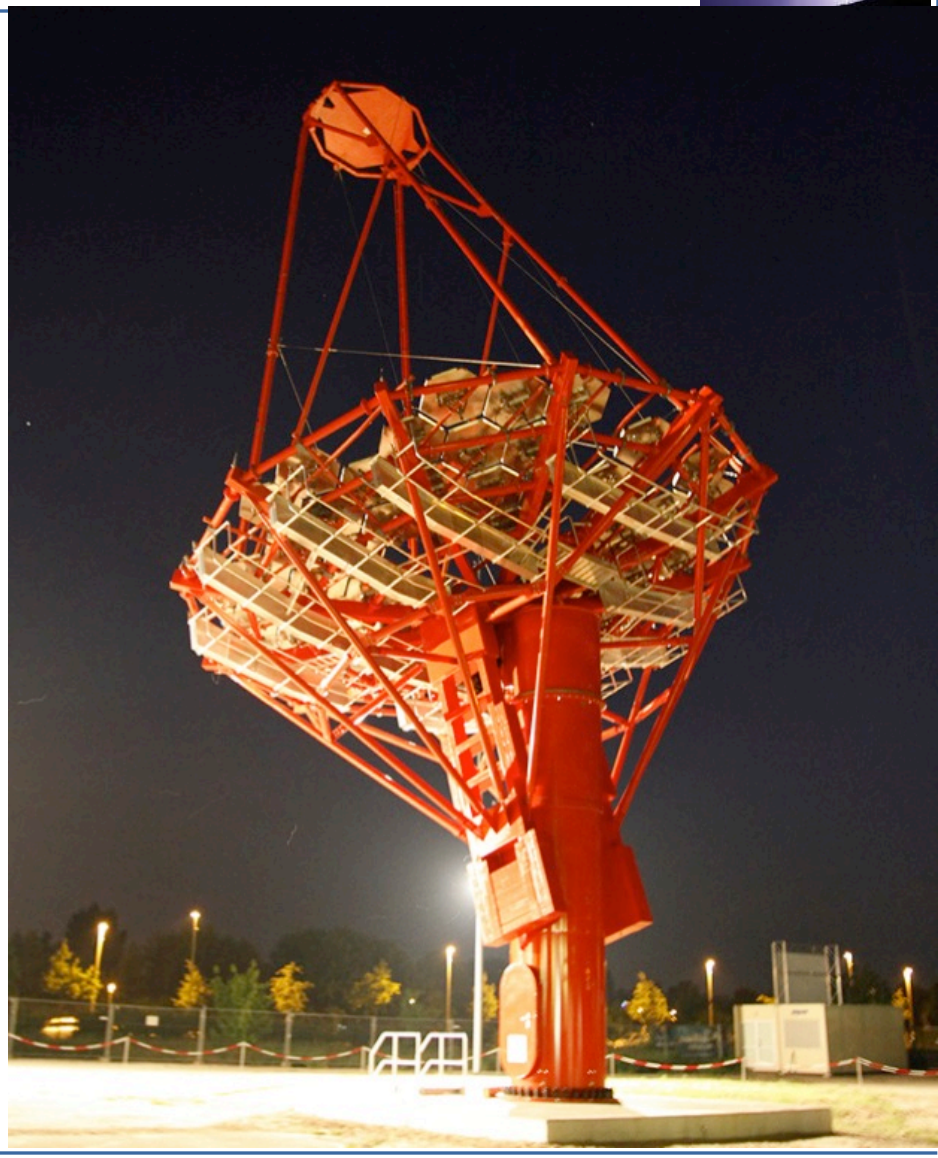
Medium-Sized 12 m Telescope
optimized for the 100 GeV to ~10 TeV range

100 m^2 dish area
16 m focal length
1.2 m mirror facets

8° field of view
~2000 x 0.18° pixels

25 MSTs on South site
15 MSTs on North site

Berlin - Adlershof
MST prototype
operational



Task of a Cherenkov Telescope Camera

- Self-triggered
- Background-dominated (cosmic rays)
  ➔ deadtime as small as possible
- Suppression of the night sky background (“NSB”)
  ➔ short integration times
  ➔ low afterpulsing rate

Cherenkov light, emitted by air shower particles

$\rho_{ph} \approx 100$ ph / m^2

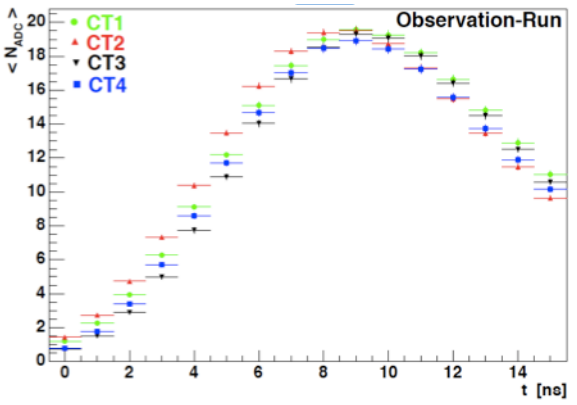
$\Delta t \approx 5$ ns

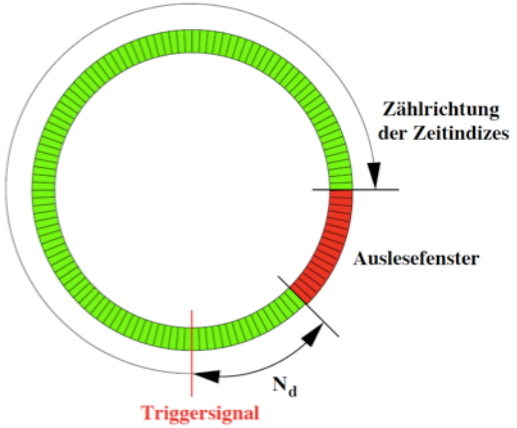
Photomultiplier-based Cameras

Recording signal waveform for “interesting” (triggered) images

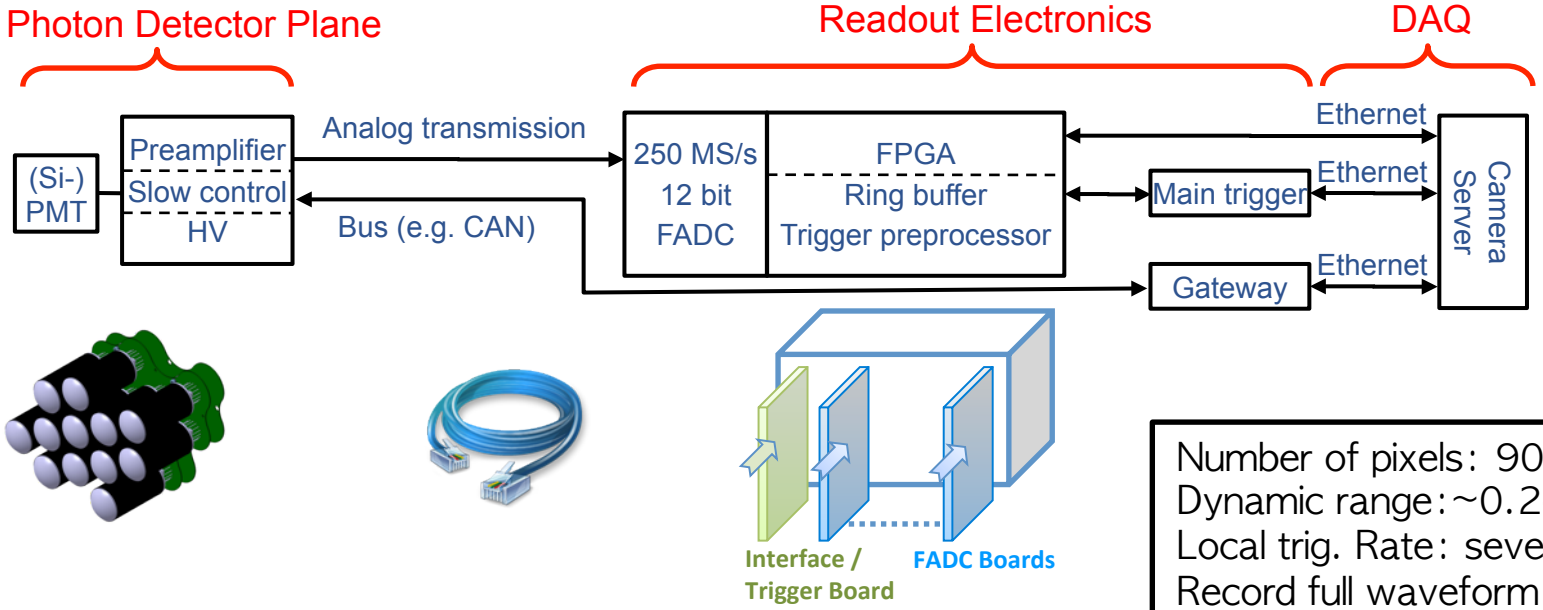
Options:

- Capacitor pipeline + analog trigger + (identical) “drawers”
  - → Digitization after trigger
  - → Separate digitization and trigger paths
- Flash-ADC + digital trigger + rack-based electronics
  - → FlashCam





FlashCam: A Novel Camera Architecture for IACTs



Number of pixels: 900-3600
Dynamic range: ~0.2-3000 PE
Local trig. Rate: several 10 kHz
Record full waveform

Horizontal architecture:

- **Self-contained PDP**
- **Adaptable for any photosensors**

Fully digital approach:

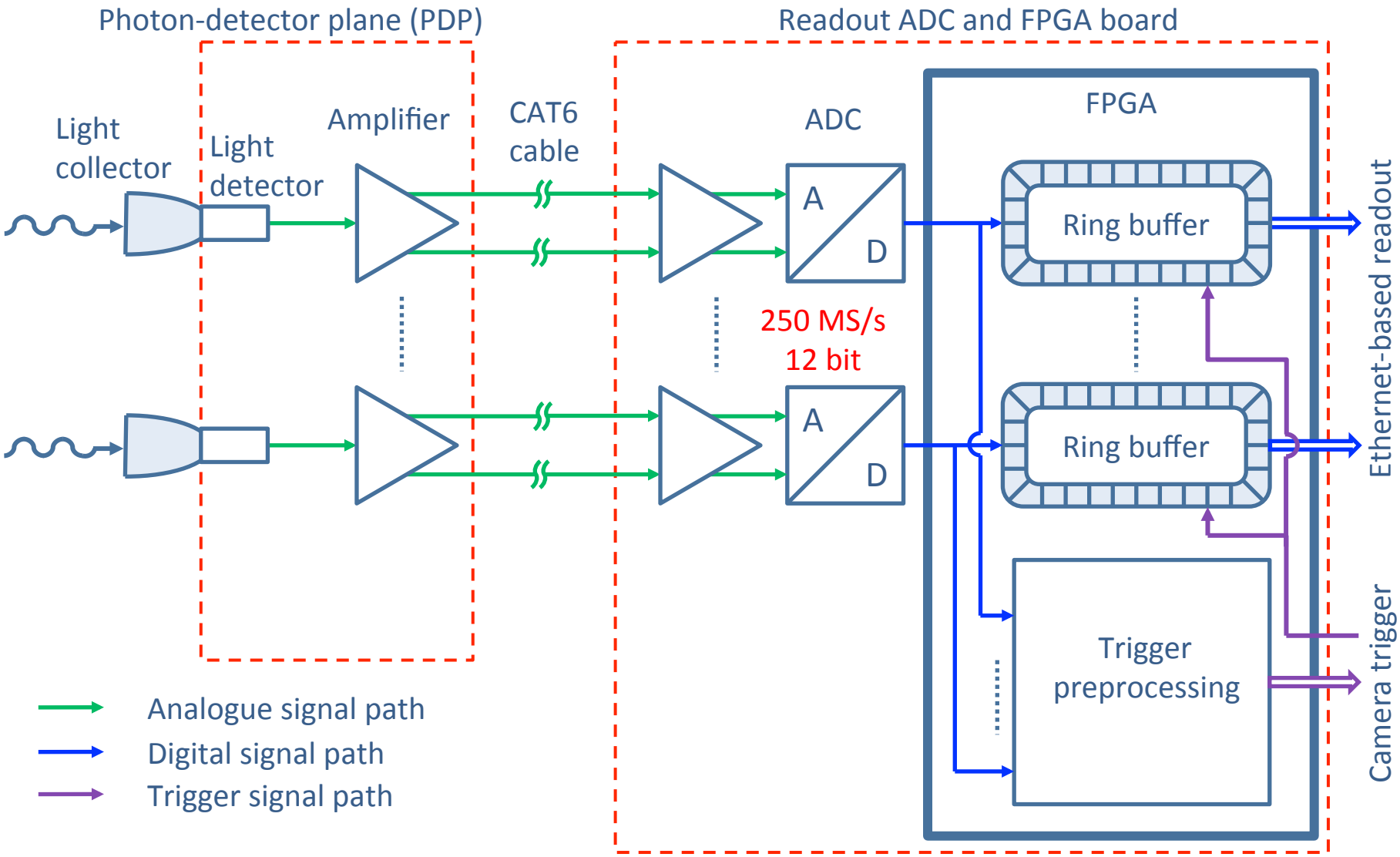
- **Continuous signal digitization**
- **Digital trigger**

Ethernet-based readout:

- **Front-end readout**
- **Off the shelf components**

- **Flexible and scalable system based on commercially available chips**

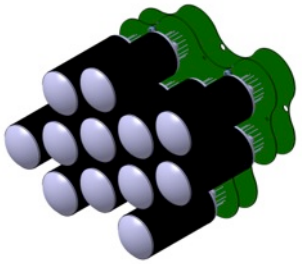
FlashCam: the concept

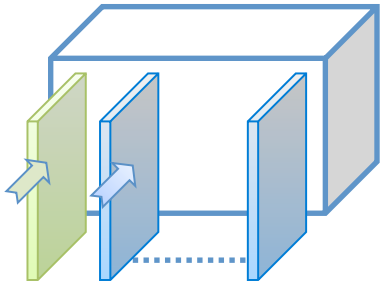


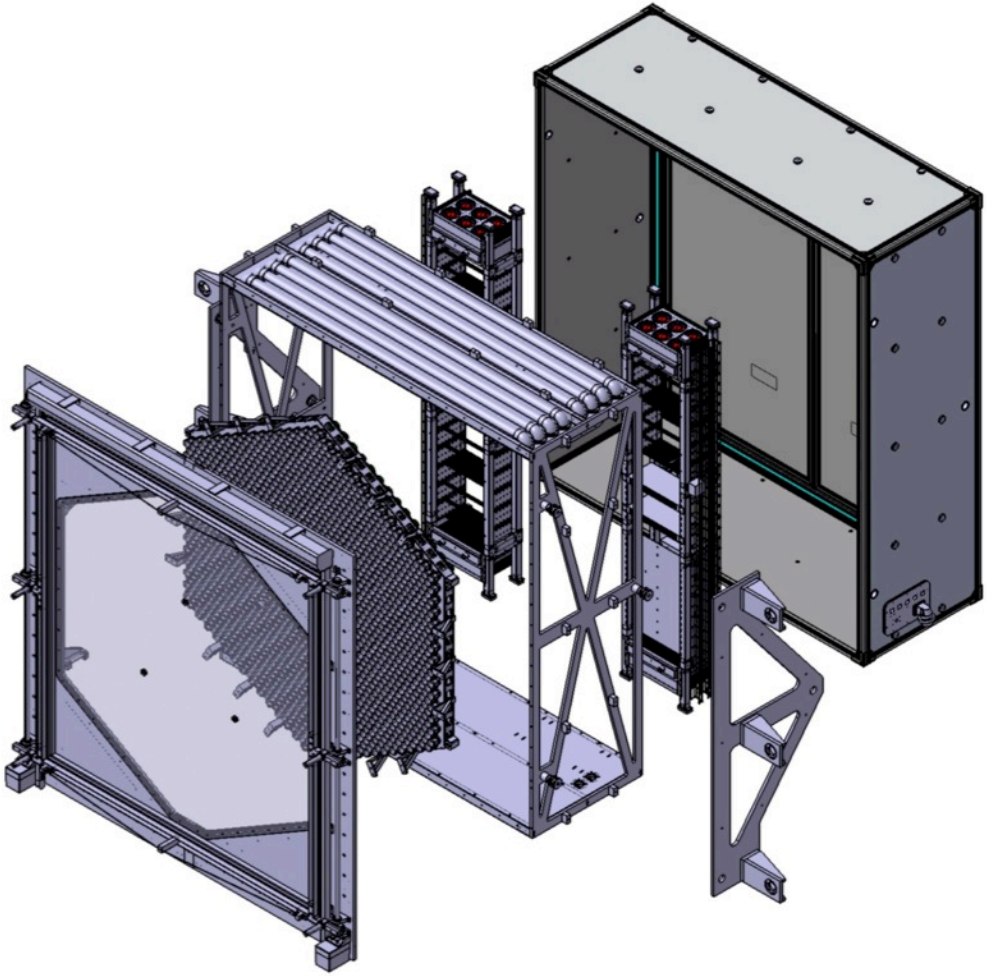
FlashCam: MST camera design

"Walk-in" camera:

Full easy access to all components for installation and maintenance







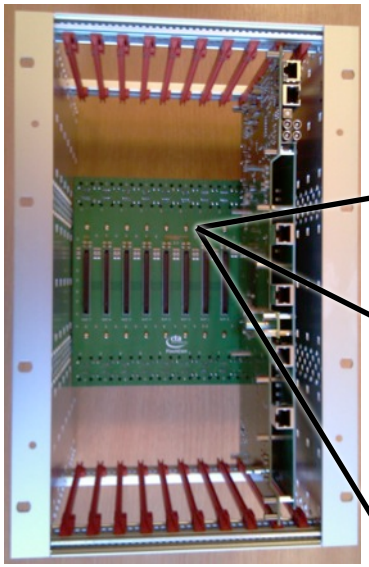
Cooling (near-sealed camera housing):

- PDP: power for 1764 pixels ~450 W
  ➔ passive
- Camera interior (crates): total power for 1764 pixel camera ~4 kW
  ➔ active by forced air flow
- (Total) heat exchange to the outside:
  ➔ closed-loop cooling

FlashCam PMT: Building blocks

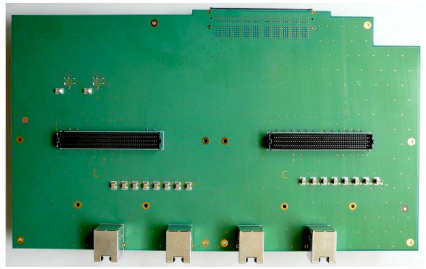
12 pixel PMT PDP module incl. HV

Crates incl. backplane



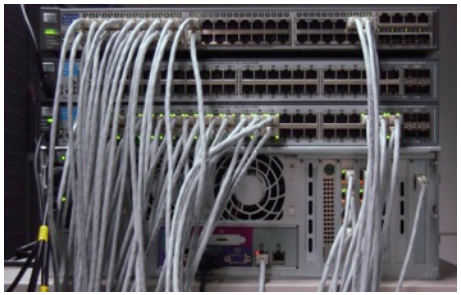
FADC-board piggy-back

Trigger-board piggy-back

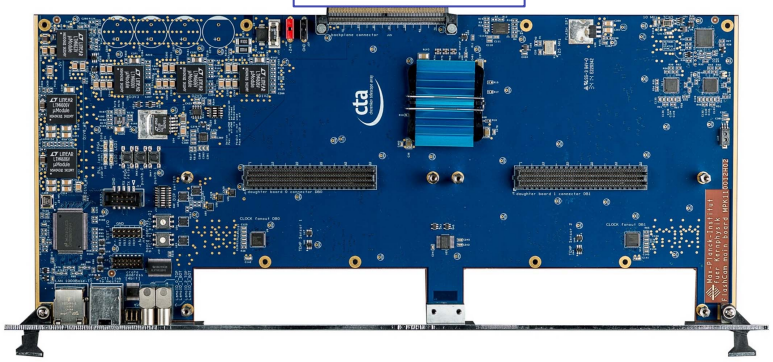


Raw Ethernet transmission protocol (1.6 GByte/sec)

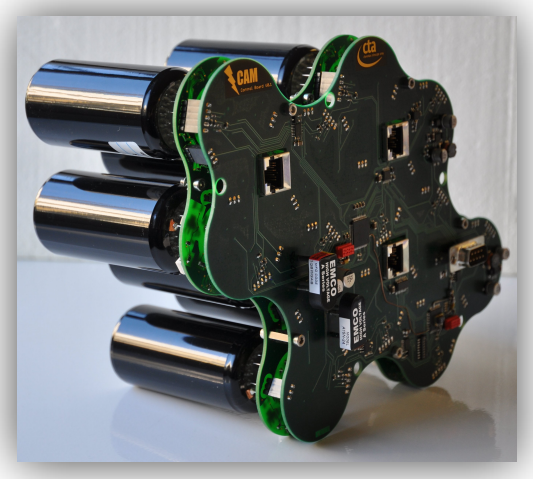
Camera server



Mother board

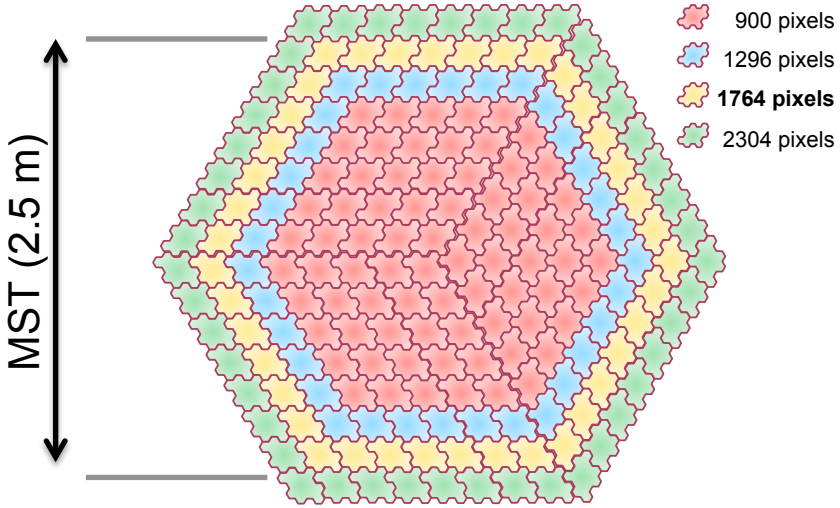


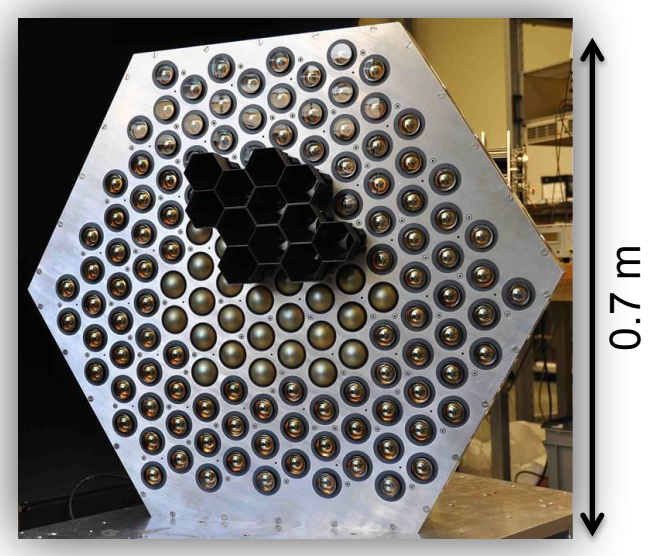
Photon detector modules



12-pixel 1.5” PMT modules:

- onboard HV, non-linear amplifiers, and slow control
- DC-coupled differential analogue transmission (using CAT6 cables)
- passive cooling

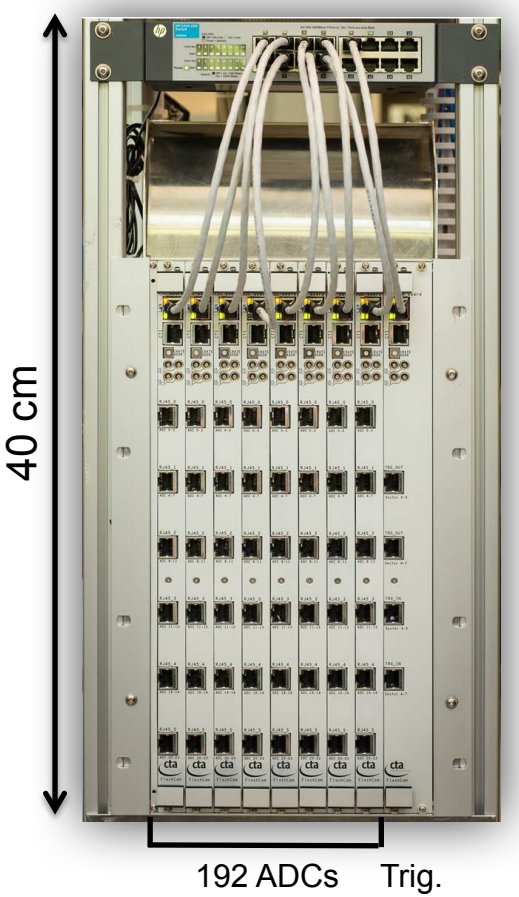




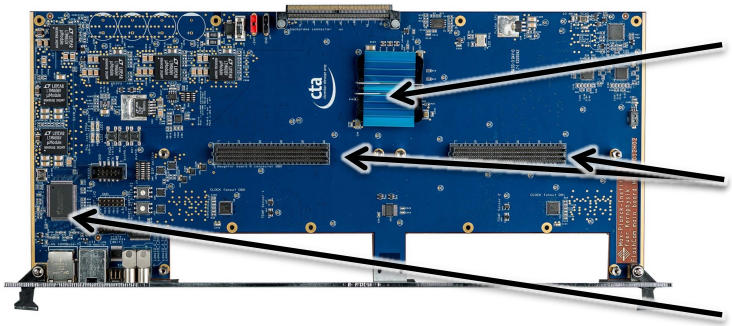
144-pixel mini camera

Readout Electronics: crate-based

Fully-equipped crate



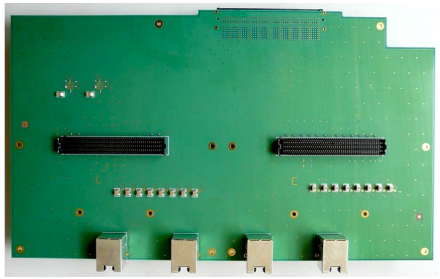
Common mother board



2 x 12-channel ADC

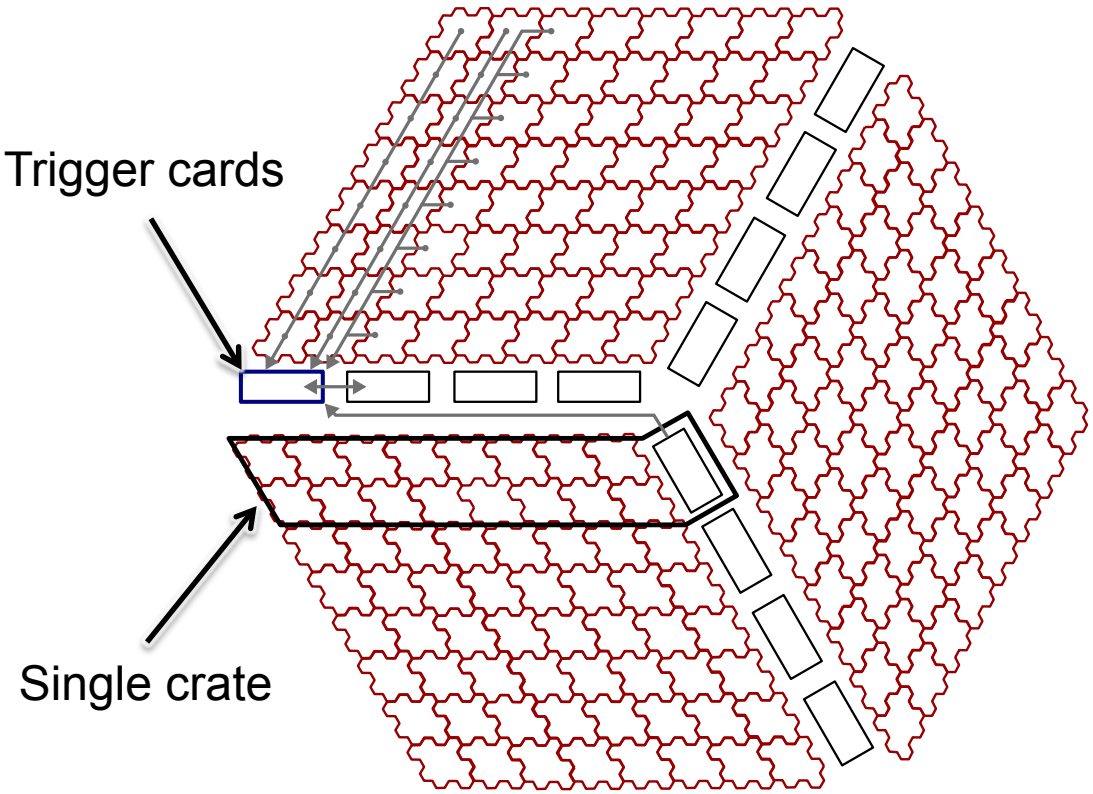
250 MS/s, 12 bit
< 1.5 W / channel

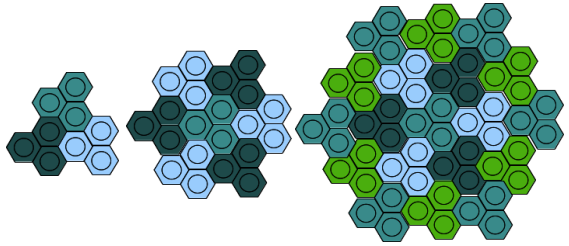
Trigger & Clock



Distribution of
clock, sync, trigger in & out

Trigger logic & Ethernet readout

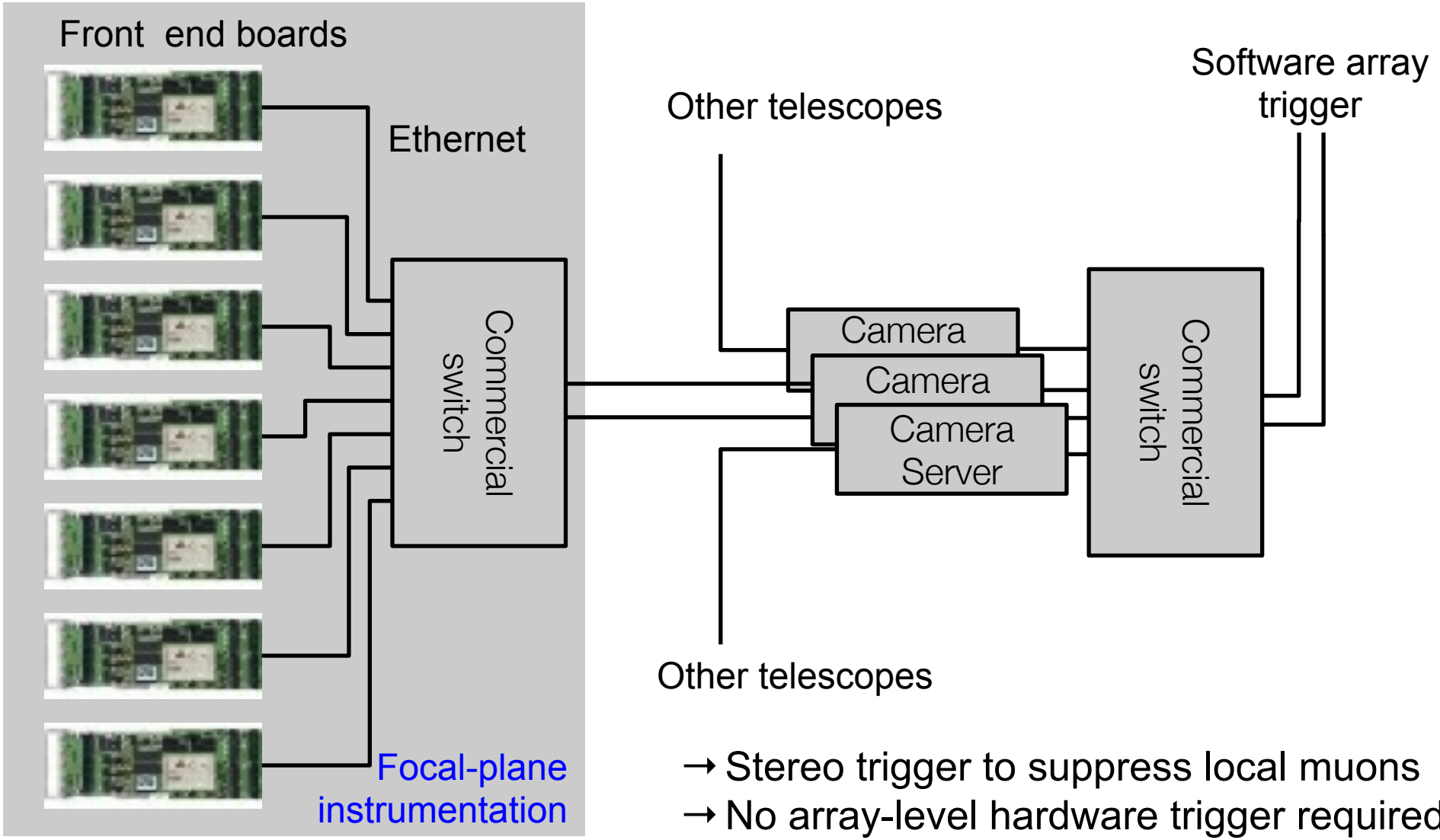




- Transmission capacity of twelve trigger cards: 2.7 Tbit/s
- Baseline trigger algorithm (programmable): *clipped amplitude sums* of seven 3-pixel patches (excellent sensitivity & honogeneity)
- Master trigger card generates camera-level trigger

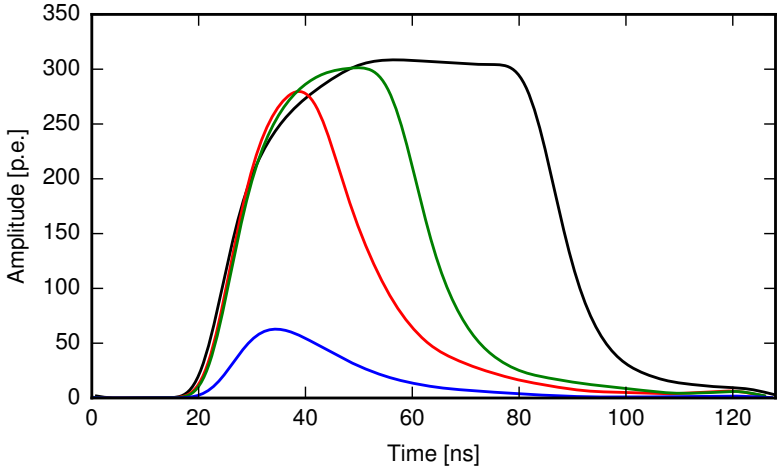
full readout via up to four 10 Gbit lines & event building:
deadtime-free up to >30 kHz

Data acquisition @ trigger



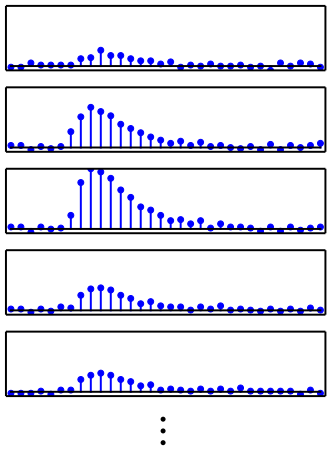
→ Stereo trigger to suppress local muons
→ No array-level hardware trigger required

Pulse reconstruction

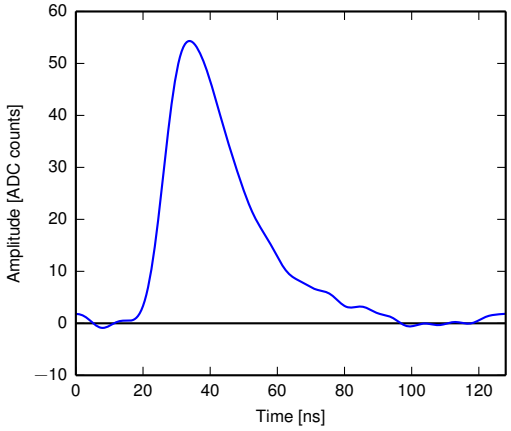


- linear amplification < 200 p.e.
- non-linear > 200 p.e.
- high gain & low gain in *one* channel
- amplitude-dependent reconstruction

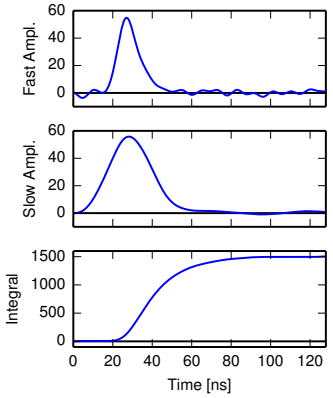
raw traces



upsampling



shaping



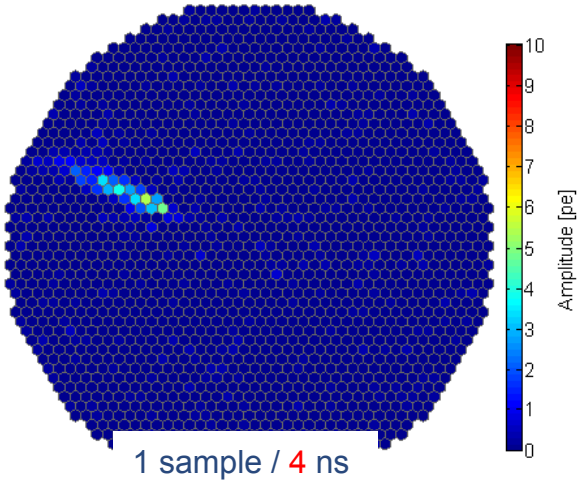
reconstruction

- „fast“ amplitude
- „slow“ amplitude
- Integration
- Pulse time

FlashCam: Monte-Carlo simulations

FlashCam

After digitization

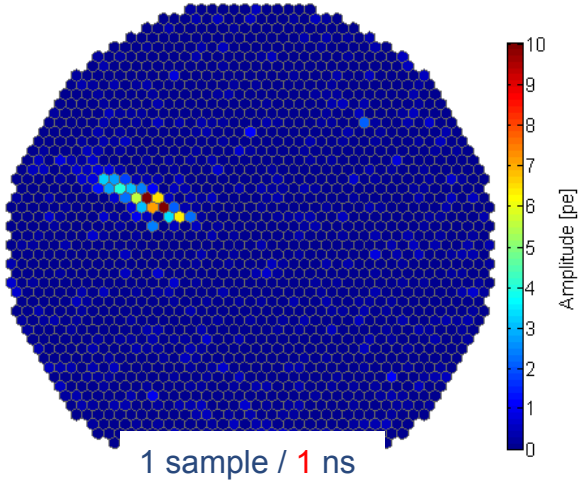


1 sample / 4 ns

FlashCam

After signal processing

- 'Up-sampling' to 1 GS/s
- Differentiation
- Pole-zero cancellation



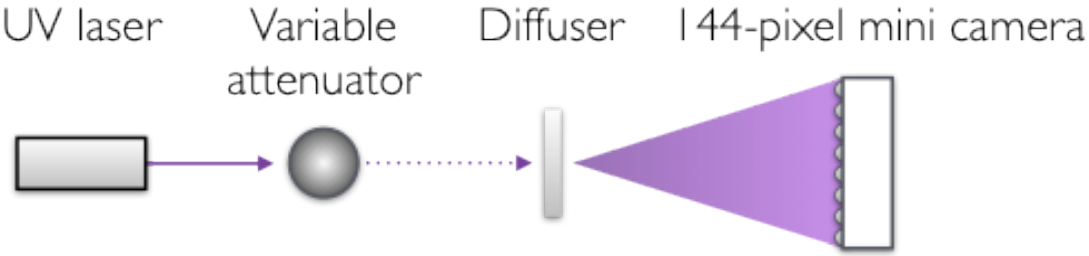
1 sample / 1 ns

250 MS/s raw data with FlashCam PMT pulse shape

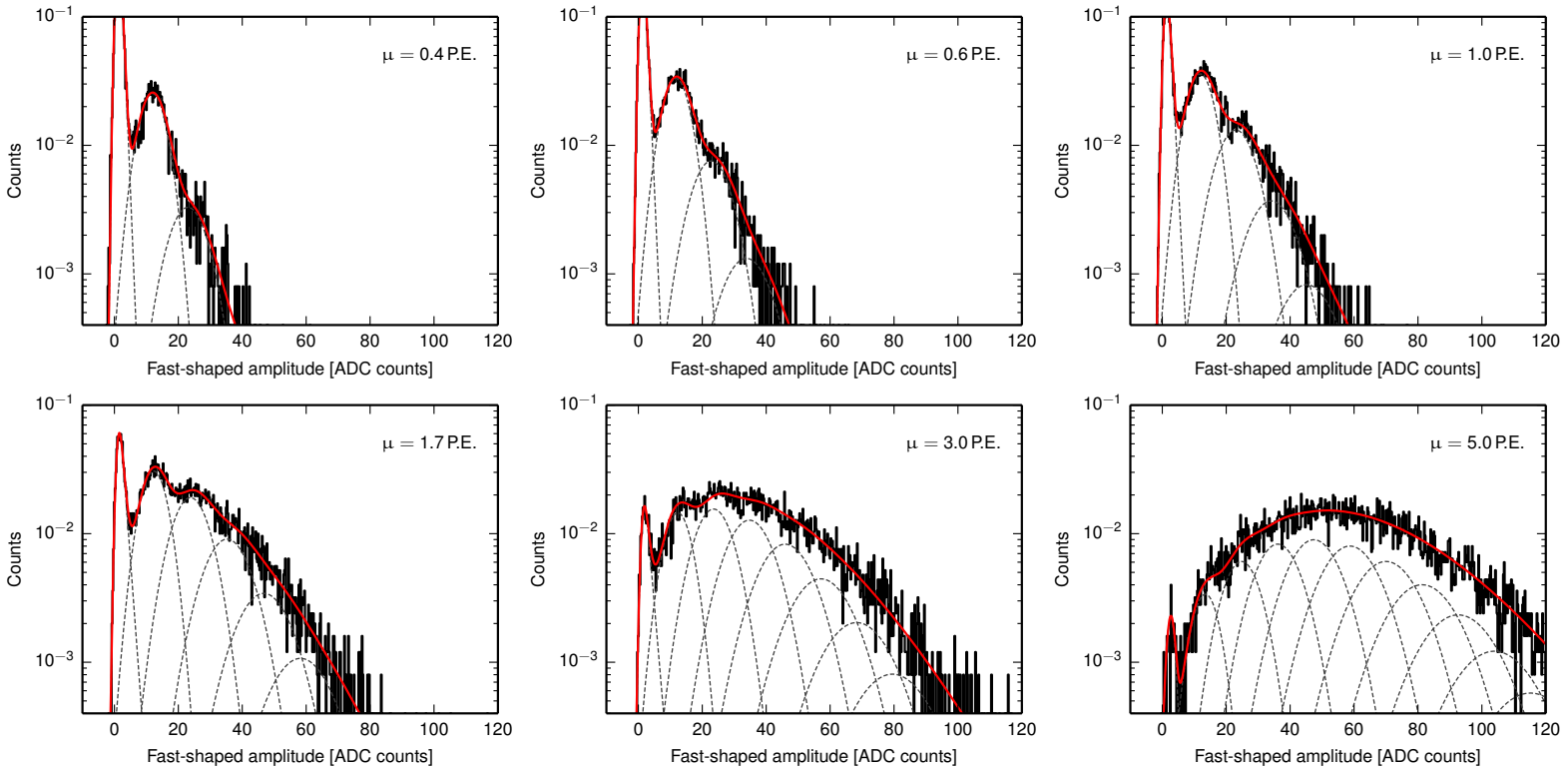
MC data from Konrad Bernlöhr

Gamma energy: 2.193 TeV; impact parameter: 231 m; telescope: MST;
FlashCam FADC: 100 ns = 25 samples PROD-1 ADC: 60 ns = 60 samples

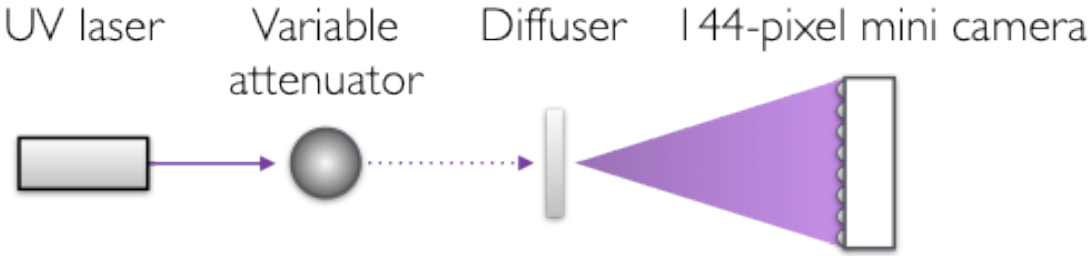
Measured charge resolution

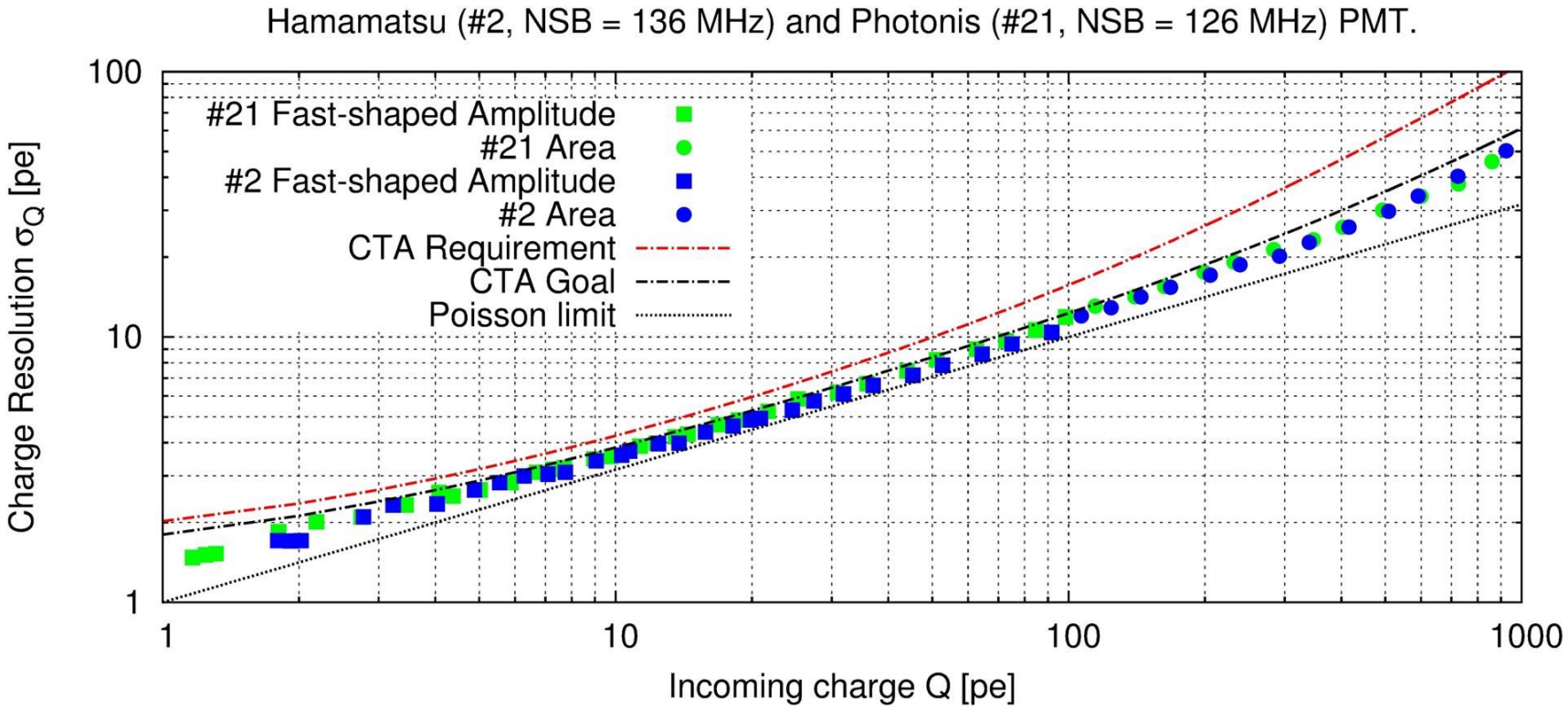


Single photoelectron calibration at low intensities



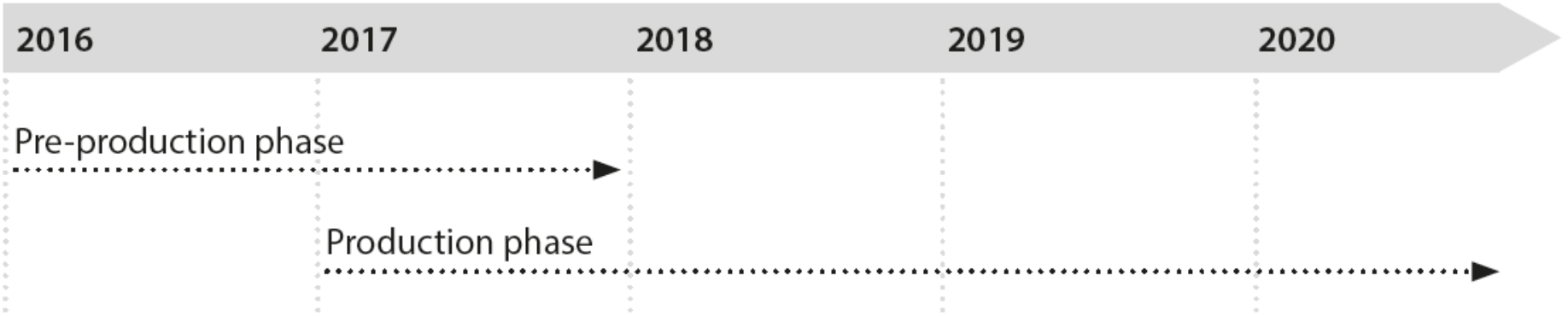
Measured charge resolution





FlashCam MST camera schedule

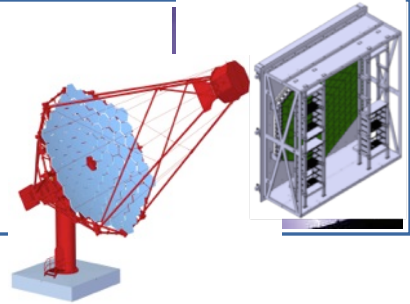
Schedule

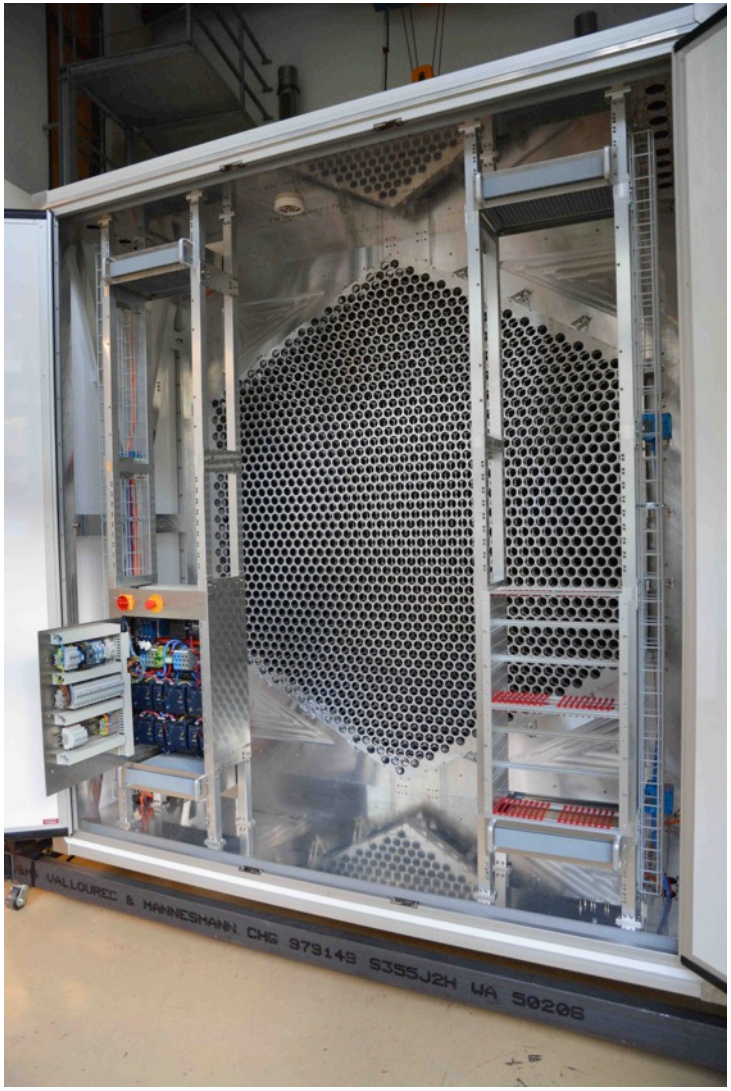


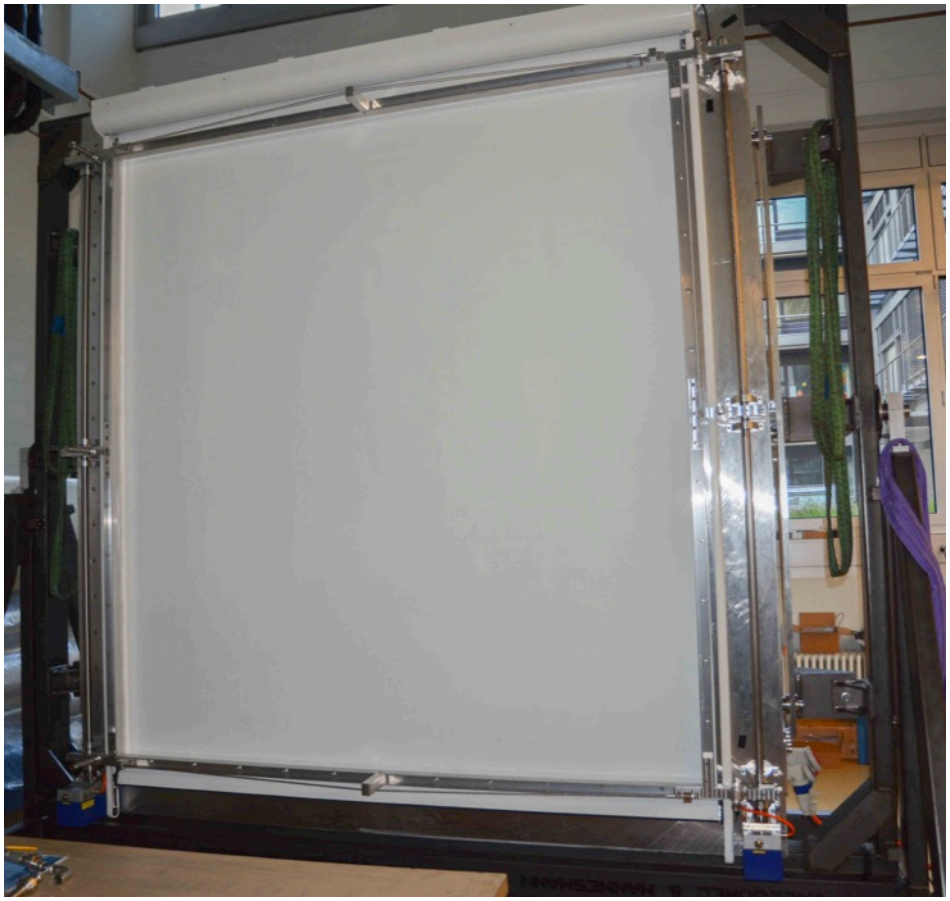
Now (2014-2015):

- Production of a full-scale camera prototype, fully equipped

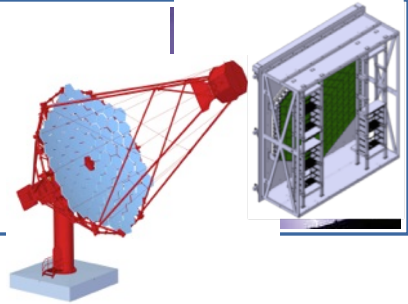
Impressions from the MST camera body

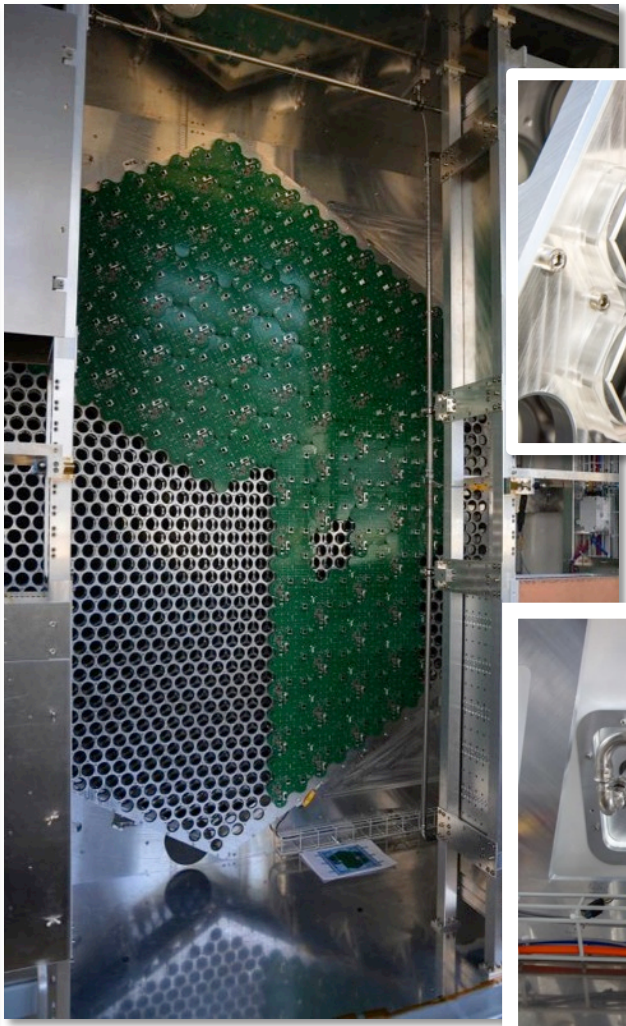


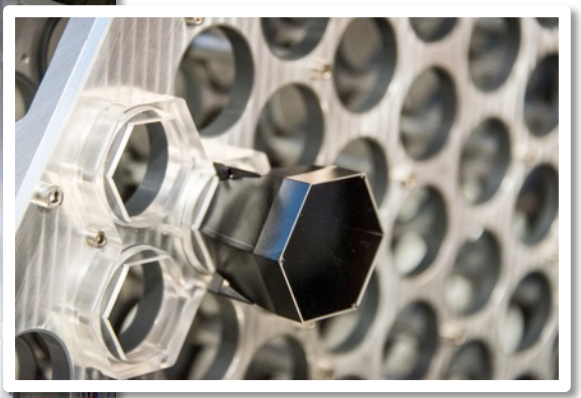


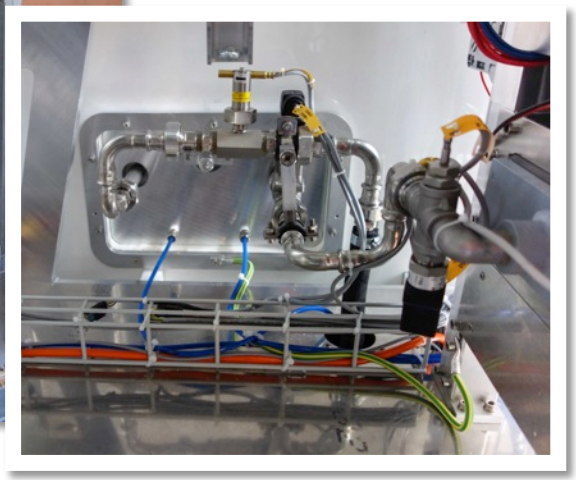


Impressions from the MST camera body

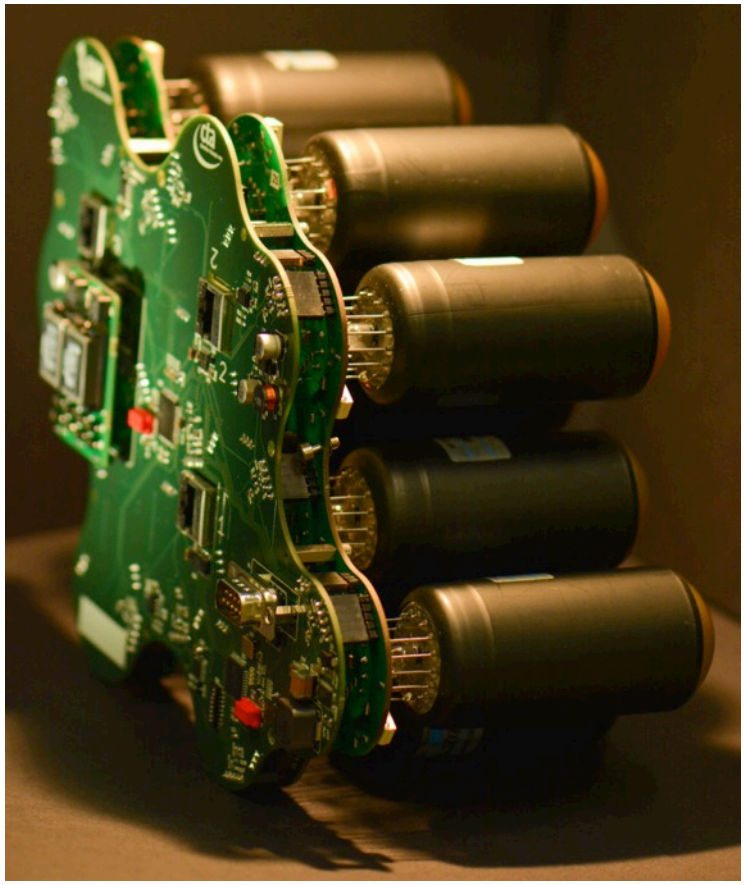






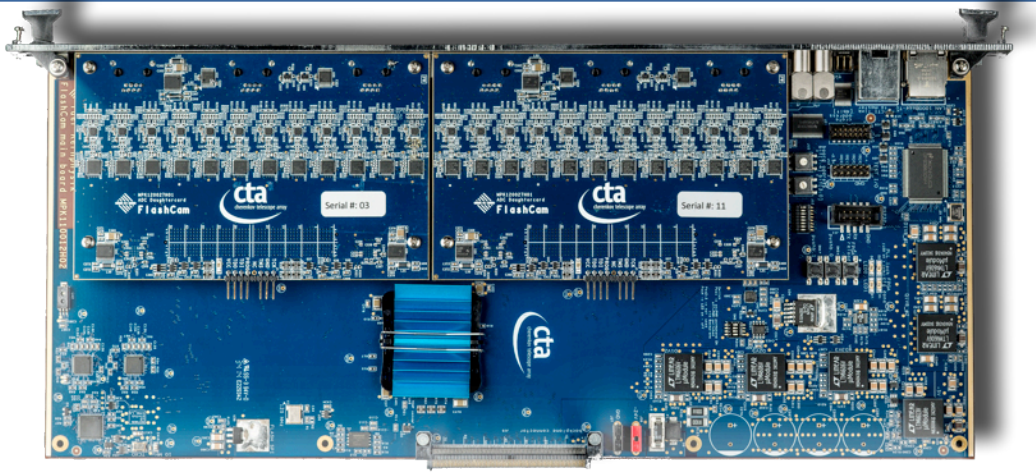


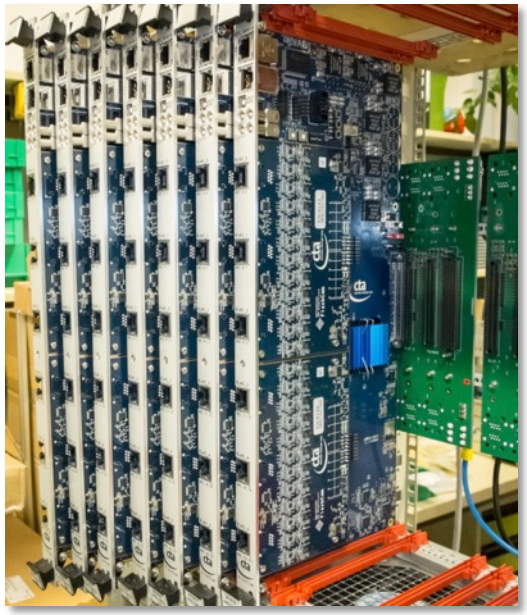
Prototype: PDP production

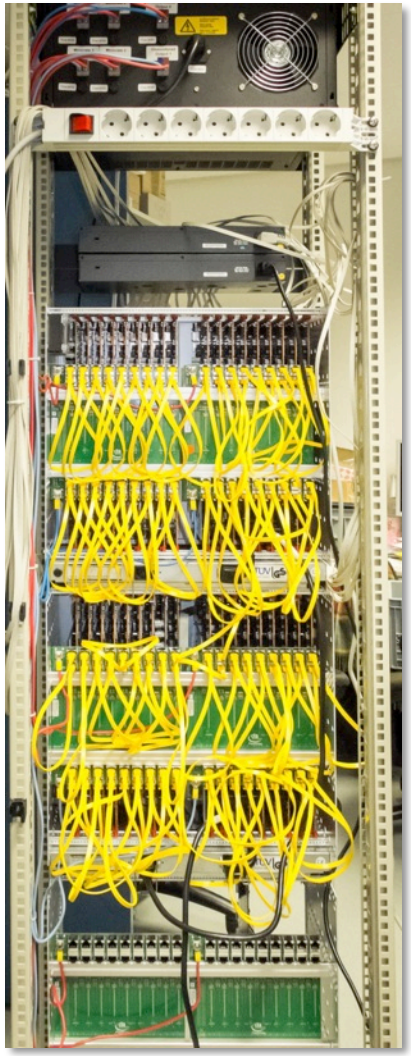


- 800 PMTs delivered
  - 400 Hamamatsu R11920-100 (8 dynodes)
  - 400 Hamamatsu R12992-100 (7 dynodes)
- PDP module production planned to be finished end of May
- Slow control system (CAN-bus based) in commissioning
- Additional PDP dummy boards permit full camera-equivalent PDP thermal + slow control tests
- Order to complete full 1764 pixel camera in preparation

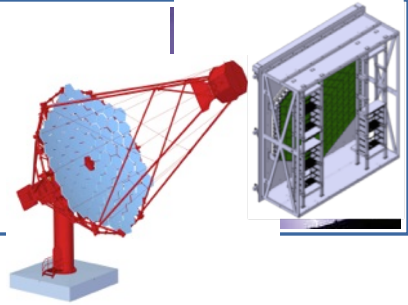
Readout electronics impressions







Prototype: Readout electronics production



- Readout electronics (FPGA motherboards, piggybacks, backplanes) for 50+ % of full camera ready since end of 2014, additional units for tests
- Procurement manufacturing with external companies (like series production)
- All tests satisfactory (noise, trigger, impulse response), order to reach 100% of camera is being prepared
- Crates/fans/power supplies available
- Ready for integration in camera body, after body tests have finished
- Efficient test procedures and equipment being developed towards mass production

Conclusions + Outlook

- Full-scale FlashCam MST camera – equipped with ~50% of all channels – expected for this summer
  - Extensive integration, thermal, reliability, and safety tests
  - Calibration strategy
- Winter 2015/16:
  - full camera prototype
  - preparation for pre-production
- In parallel: integration to CTA array control + data management system, trigger system