Electronics for the camera of the First G-APD Cherenkov Telescope (FACT) for ground based gamma-ray astronomy

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for the FACT collaboration

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Vienna

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Swiss Federal Institute of Technology Zurich

ETH Institute for Particle Physics

First Geiger-mode Avalanche Photodiode Cherenkov Telescope

The FACT collaboration:

ETH

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

technische universität dortmund

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

ISDC

Julius-Maximilians-UNIVERSITÄT WÜRZBURG

Basics of Cherenkov Astronomy

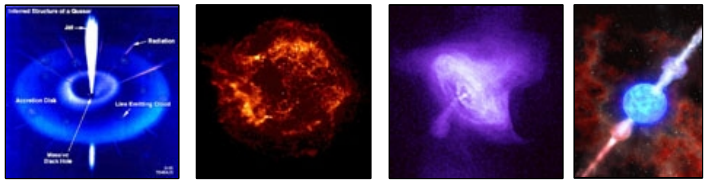
- Some cosmic sources emit γ-rays in the very high energy range (50 GeV – 100 TeV)

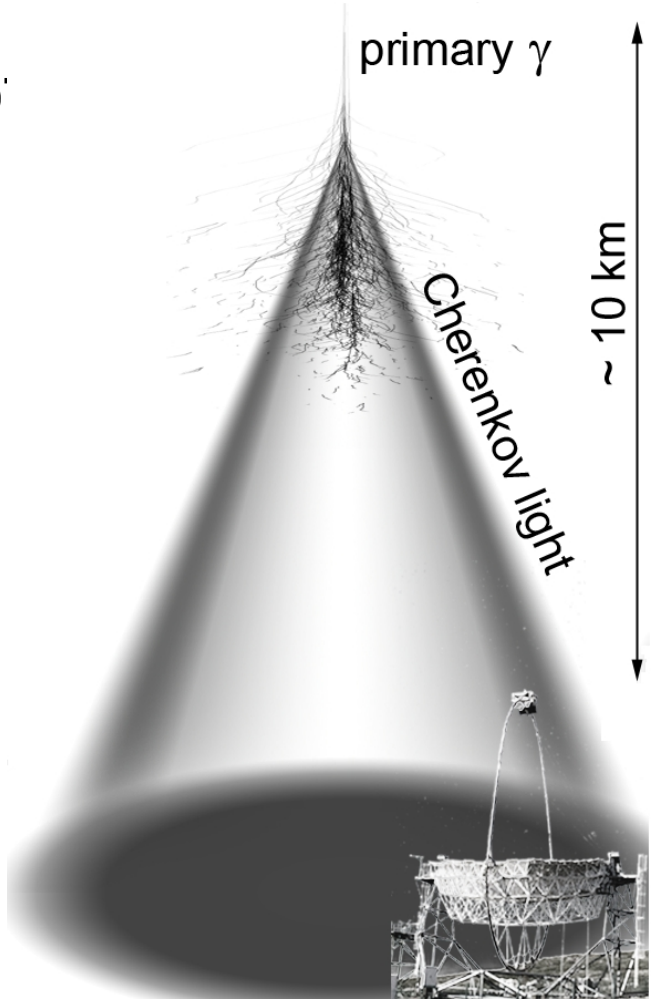
  → γ-radiation as a part o cosmic rays

- Indirect detection: using the earth's atmosphere as a calorimeter
- Cosmic ray induced airshower

  emit Cherenkov light in the visible and near UV range

  - Cherenkov light cone





Basics of Cherenkov Astronomy II

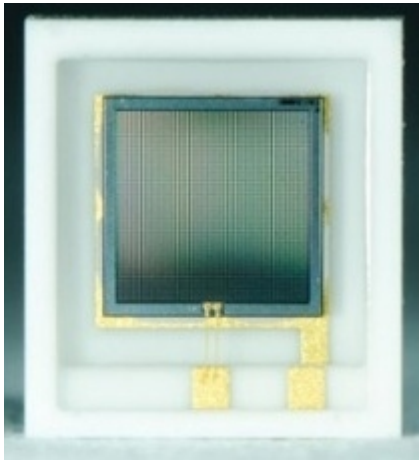
- Weak and fast light flashes: **few ns**

  ≈ 100 photons / m^2 @ 1 TeV primary γ-energy

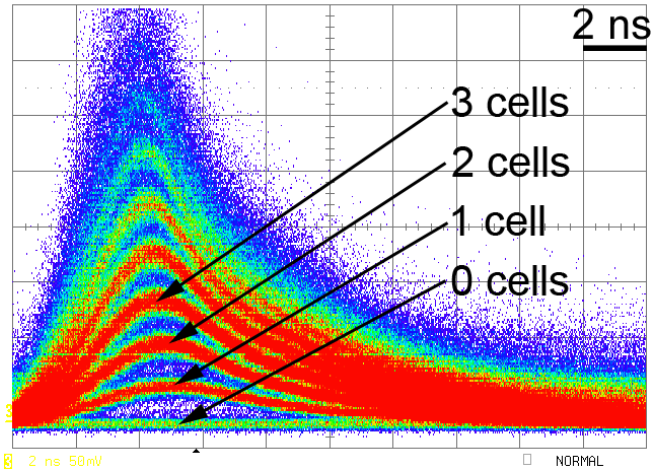
- Detection by Imaging Atmospheric Cherenkov Telescopes (IACTs)
- IACT cameras based on photomultiplier tubes (PMTs)

Why G-APDs ?

- All currently operational IACTs use PMTs
- G-APDs offer several advantages:



  - Single photon resolution
  - High photon detection efficiency
  - Insensitive to bright light
    i.e. nightsky background / moonlight
    → higher duty cycle
  - Much lower bias voltage (~70 V instead of kVs)
  - Mechanically more robust
  - Insensitive to magnetic fields
  - No known ageing



The FACT Camera: Overview

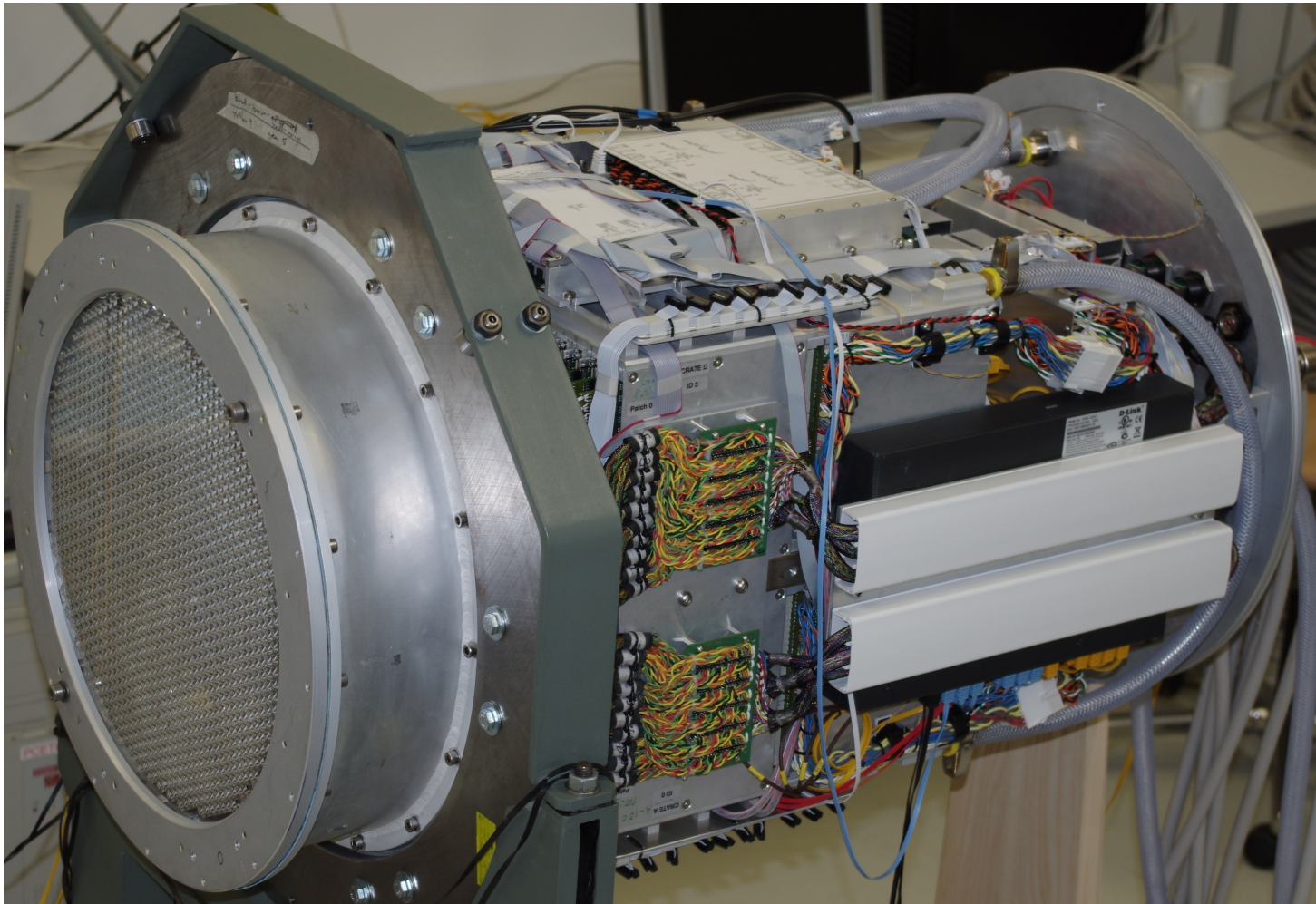
G-APD
& Winston Cones
Sensor compartment
Sensitive to few photons

Integrated digitisation based on the DRS4 chip
Readout electronics
Fast enough for flashes of few nanoseconds

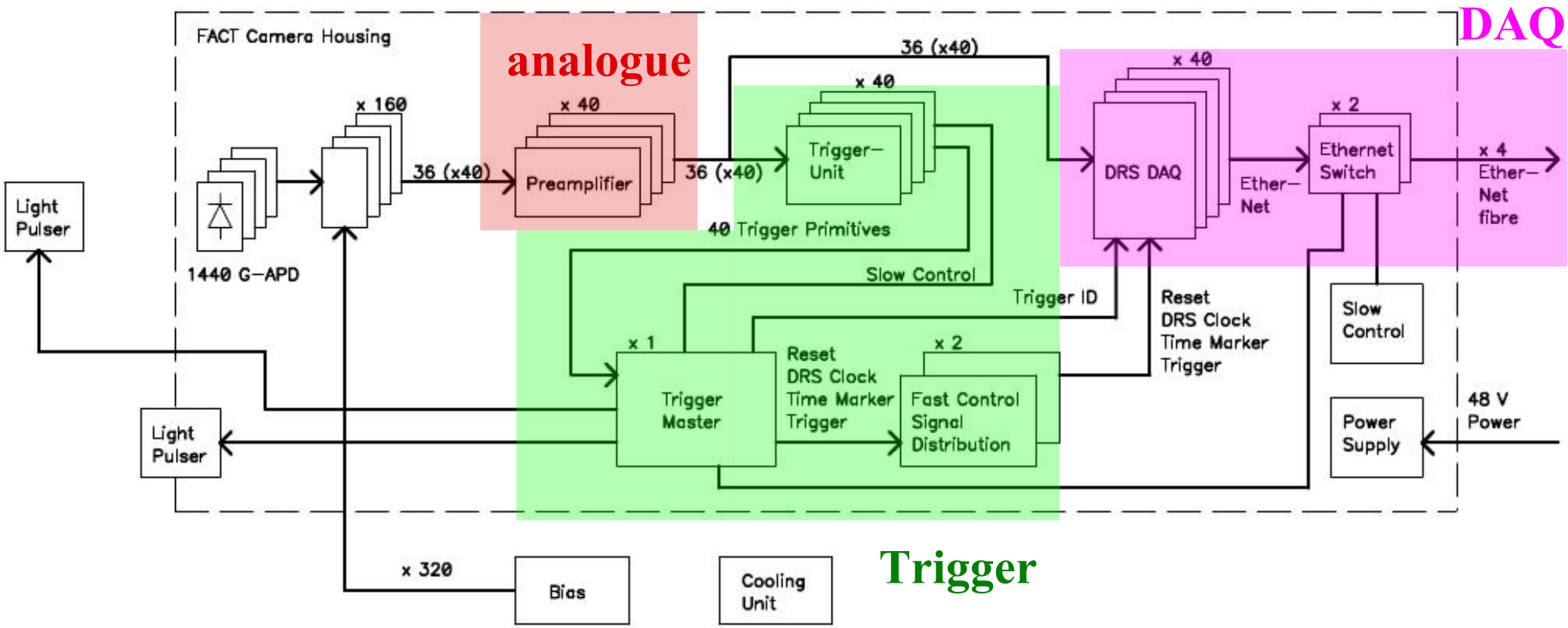
1440 Pixels

Pixel size:
9.5 mm hexagon
Corresponding
to 0.11° / pixel

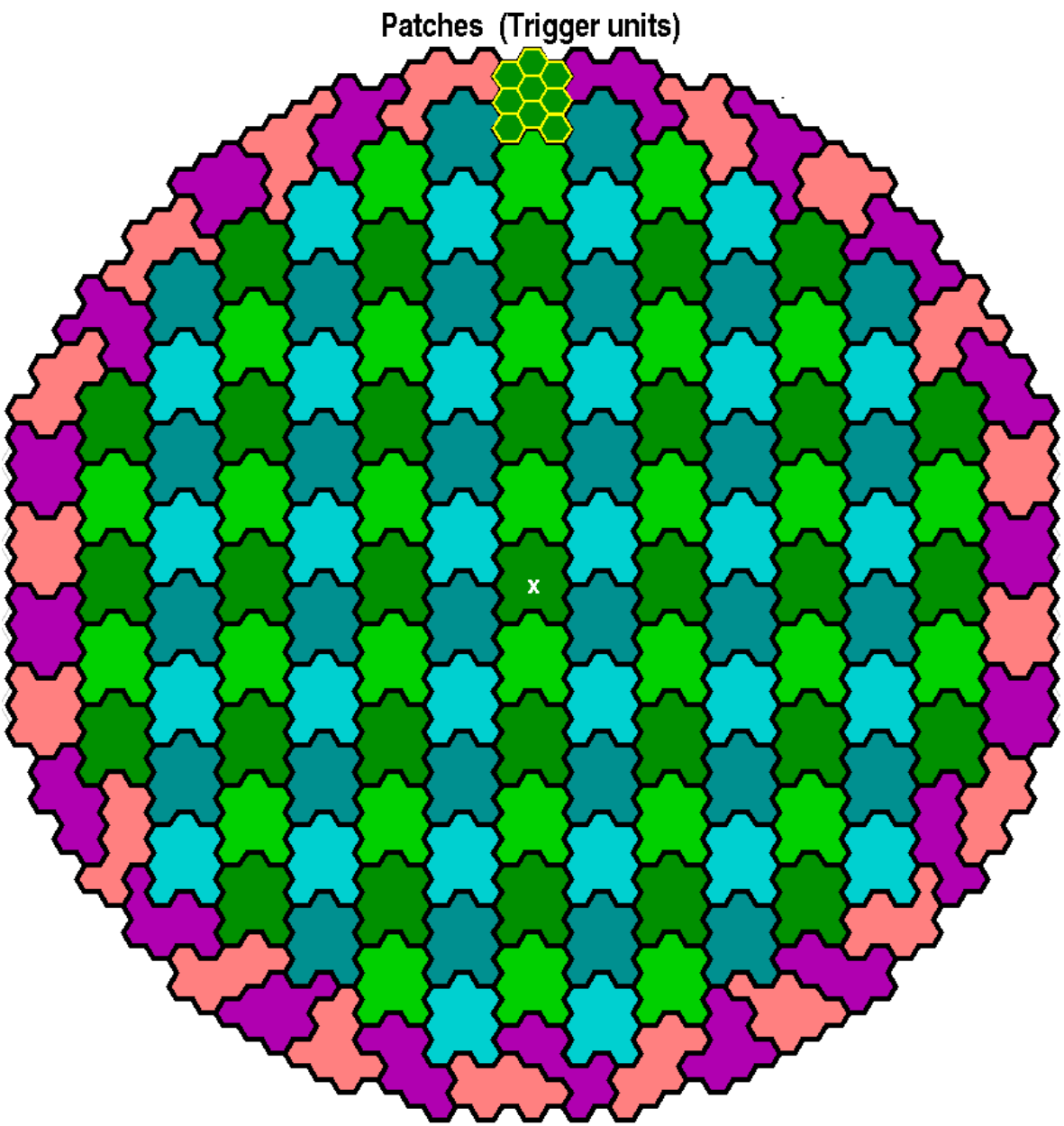
Front window
diameter:
40 cm



The FACT Camera Schematic

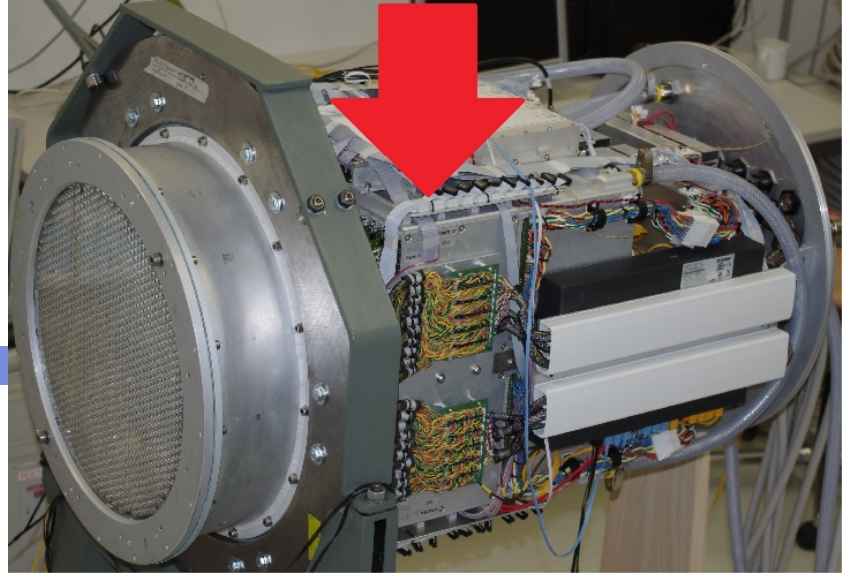


Trigger System Concept



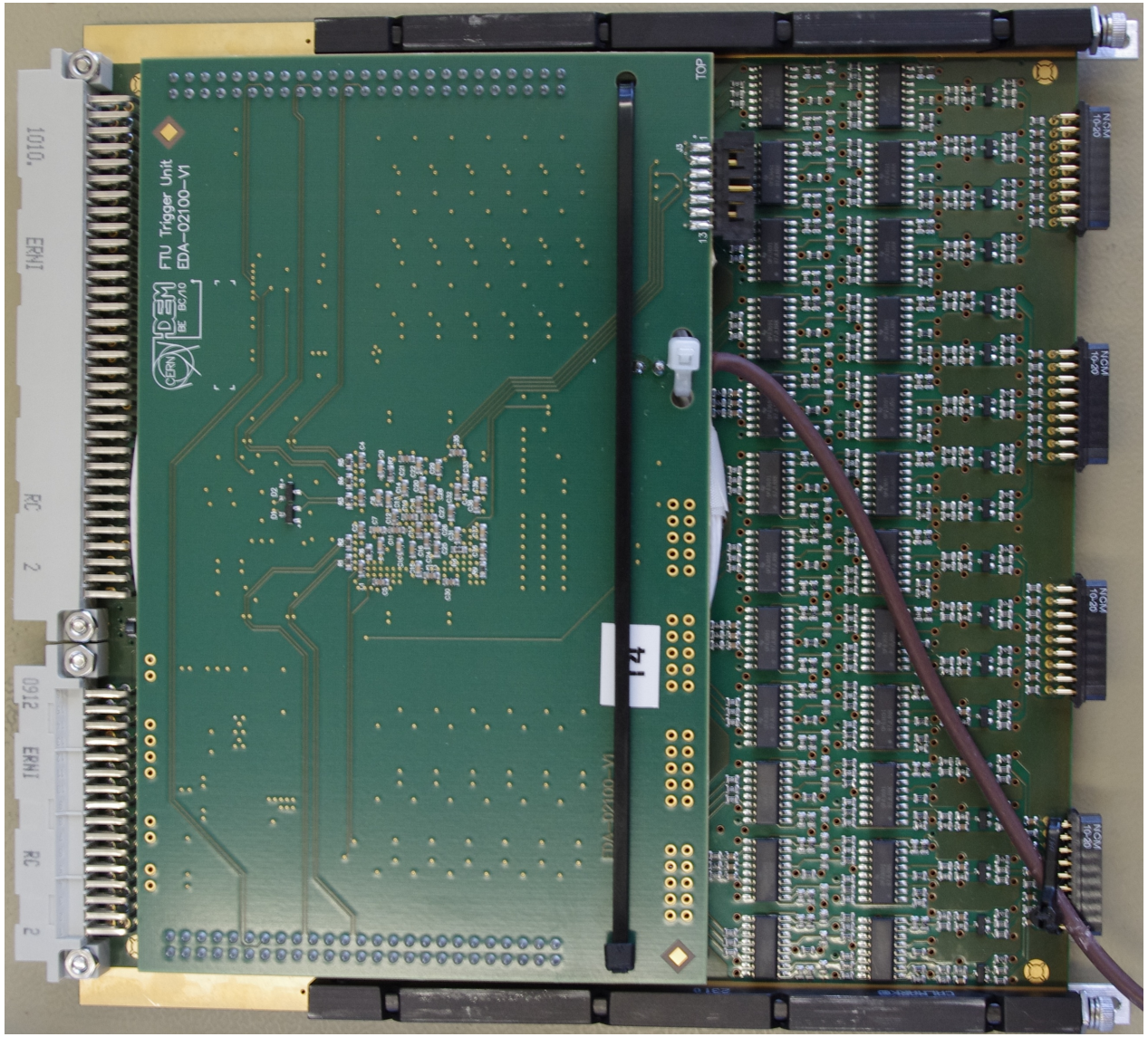
- analogue sum over the 9 pixels of one trigger patch
- Non-overlapping trigger patches
- central trigger master
- two fast signal distribution boards
- electronics fully integrated into the FACT-Camera
- trigger rates in the order of 50 Hz;
  up to 1 kHz possible in combination with a software trigger

Trigger Unit



- set a threshold to every patch of nine pixels
- trigger unit generates trigger primitives from 4 patches
- counting the rates in every patch
- each pixel can individually be excluded from the trigger patch, e.g. to exclude stars or noisy pixels
- RS-485 bus to the trigger master
- FPGA based (Xilinx Spartan®)

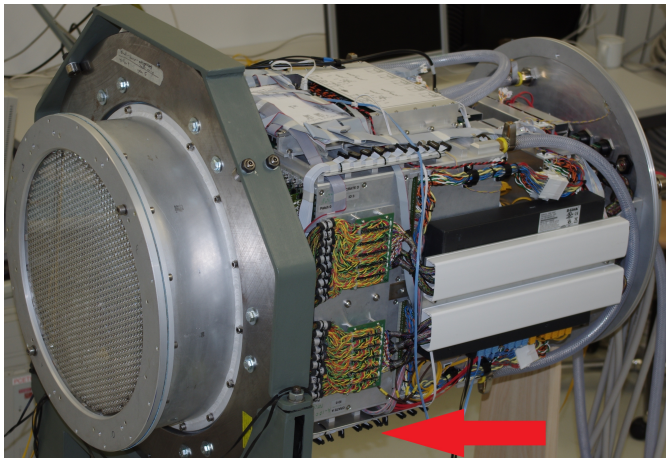
Preamplifier and Trigger Unit



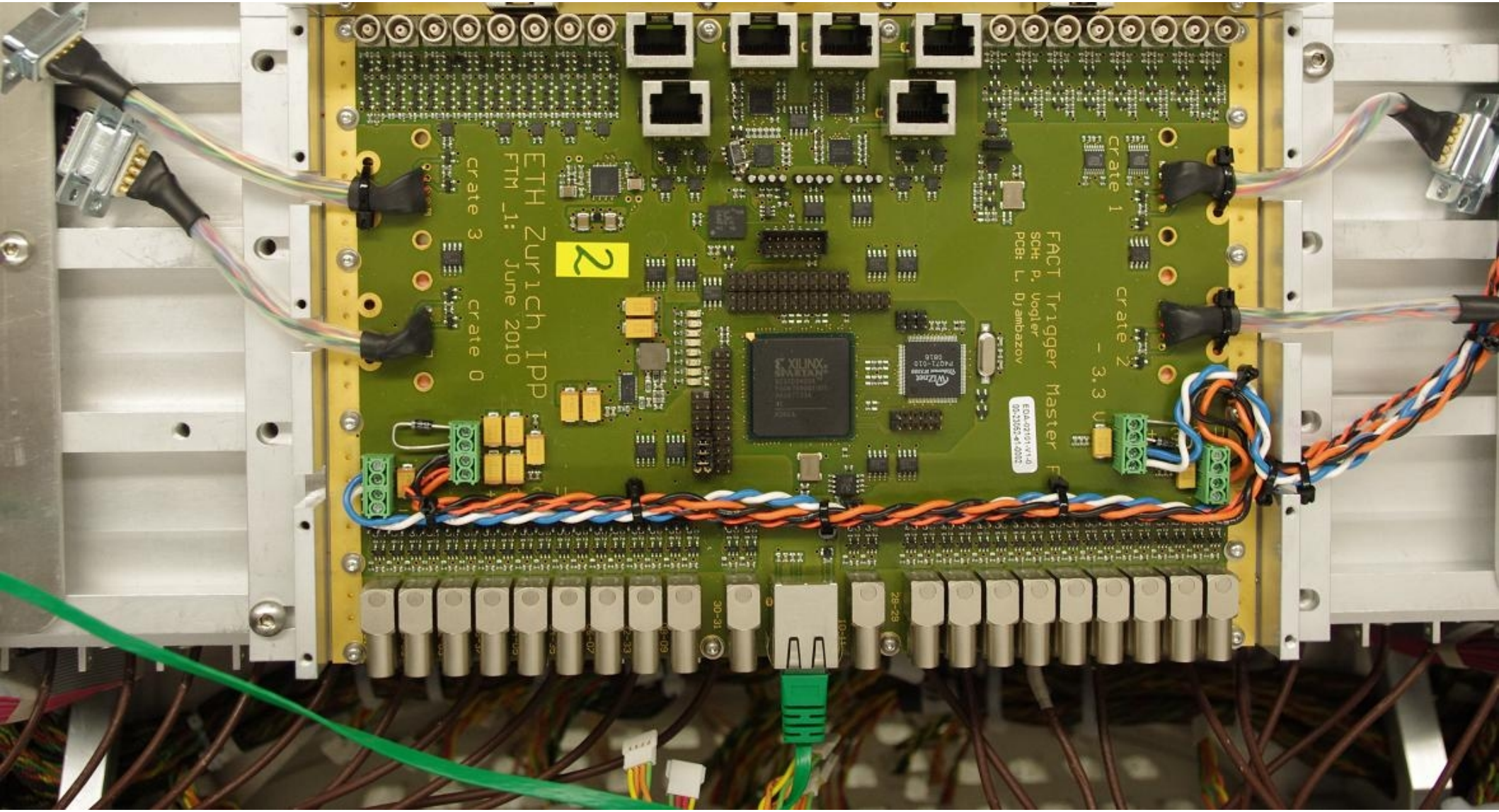
- A trigger unit sitting on the pre-amplifier board
- Minimum threshold ≈ 20 photoelectrons per patch (average of about 2 photoelectrons per pixel)

Trigger Master

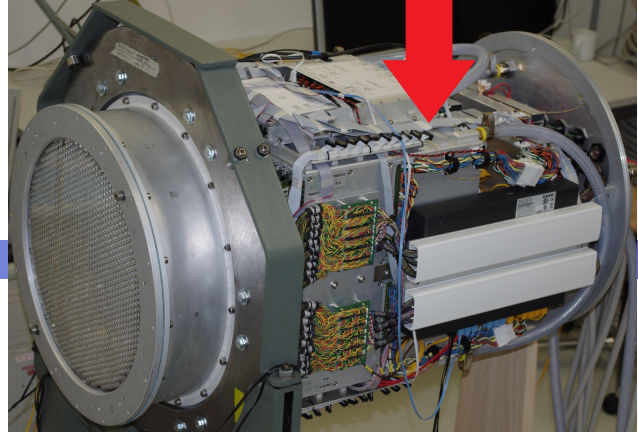
- collects the 40 trigger primitives
- generates:
  - Trigger signal
  - trigger-ID
  - calibration pulses (to lightpulsers)
  - DRS clock for the DAQ (clock conditioner)
- controlled via Ethernet
- performs trigger unit slow control (via RS-485)
- FPGA based (Xilinx Spartan®)



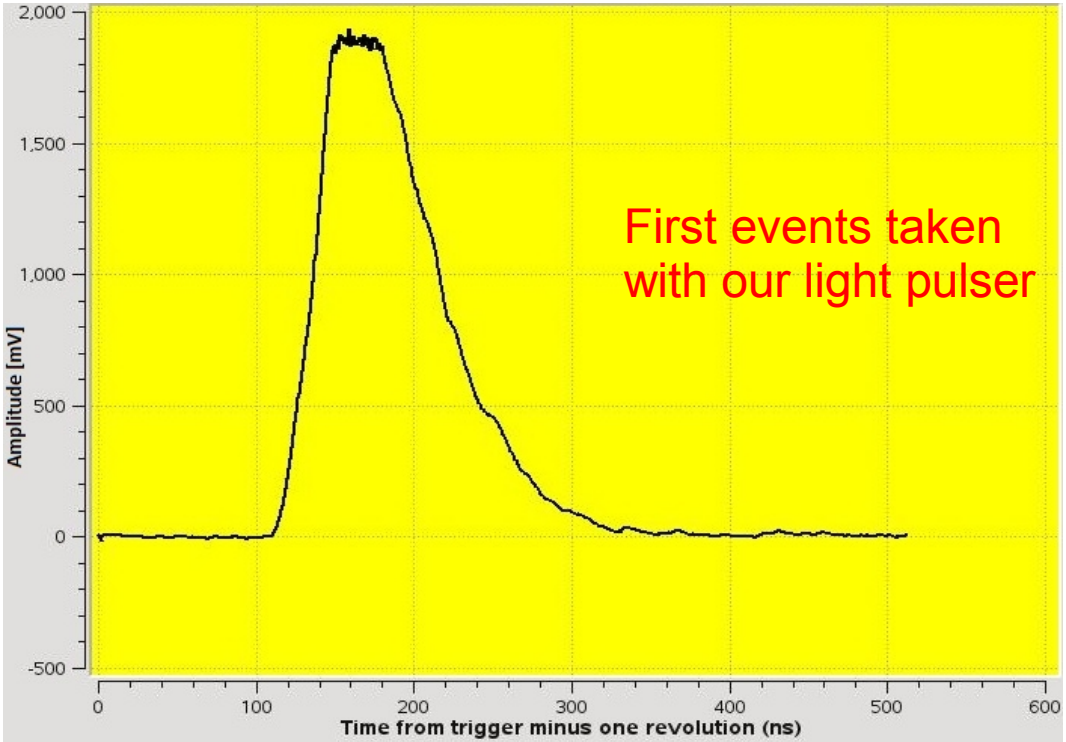
Trigger master



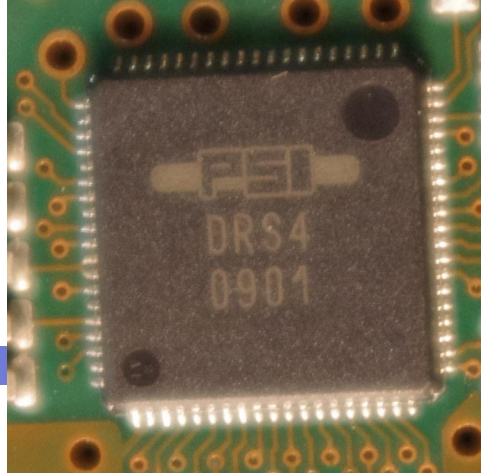
Data Acquisition



- 40 Boards with 36 channels each
- DRS-4 analogue pipeline
- sampling rate: 2 GSPS default
- 100 Mbps fast Ethernet interface on each board

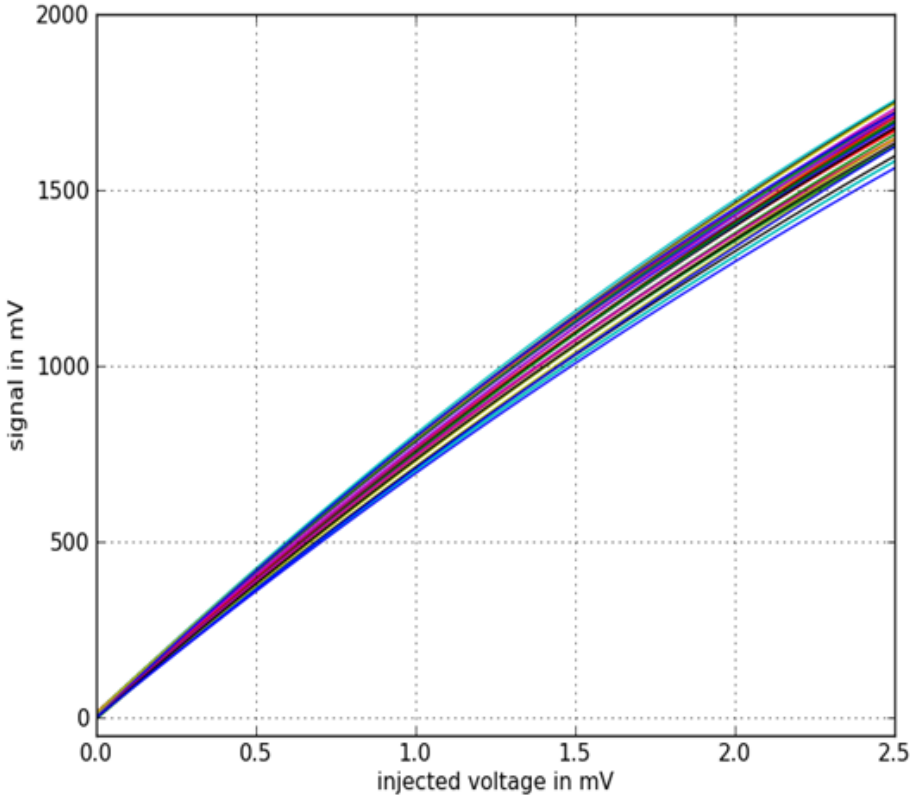


DRS – 4
Domino Ring Sampler

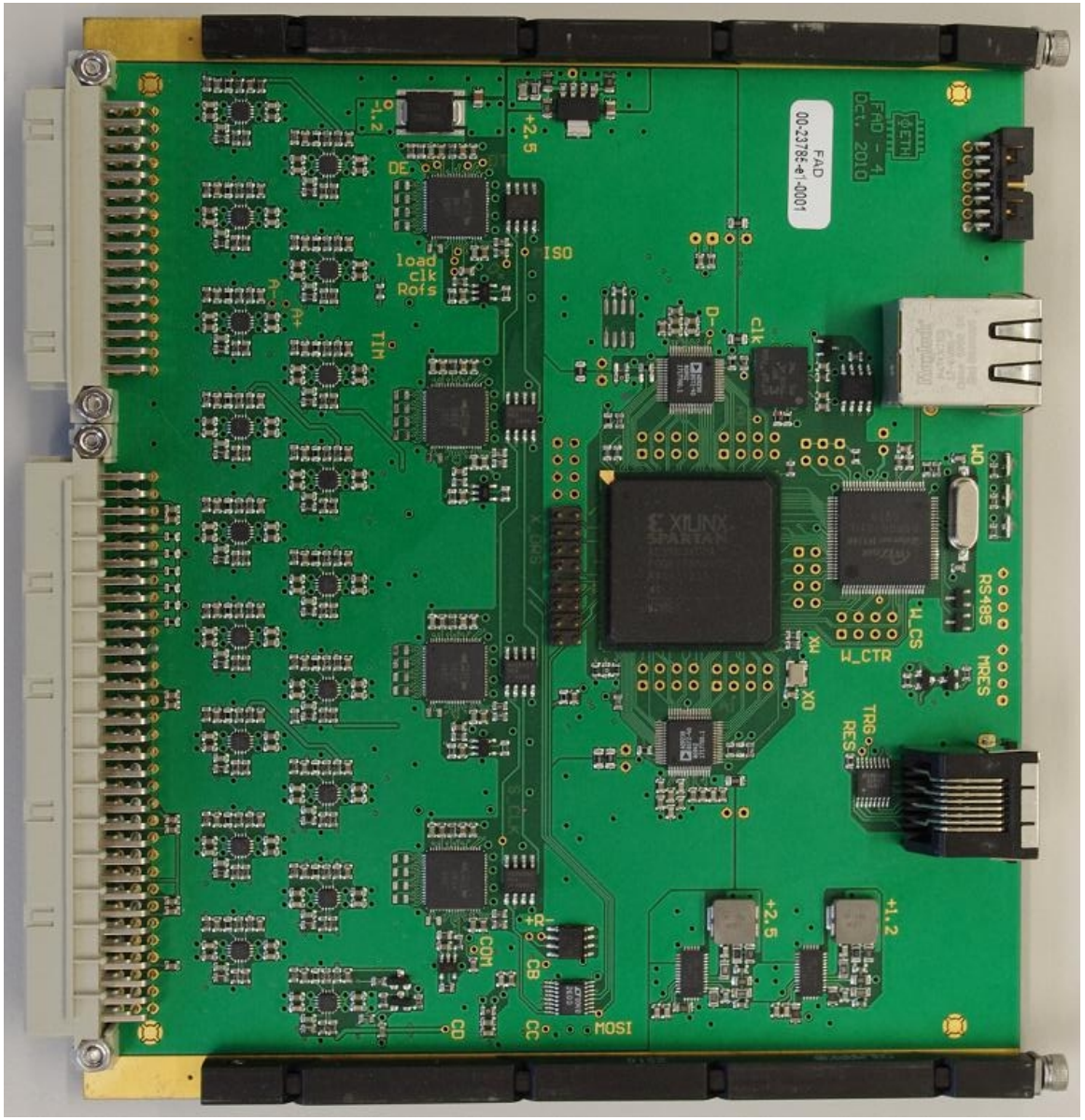


- Switched capacitor array
- External analogue-digital converter
- Developed at Paul Scherrer Institute
- Sampling rate: 700 MSPS – 5 GSPS
- 9 channels with 1024 storage cells each
- Dynamic range: 11.5 bits
- Region of interest (ROI) adjustable for each channel

Data Acquisition

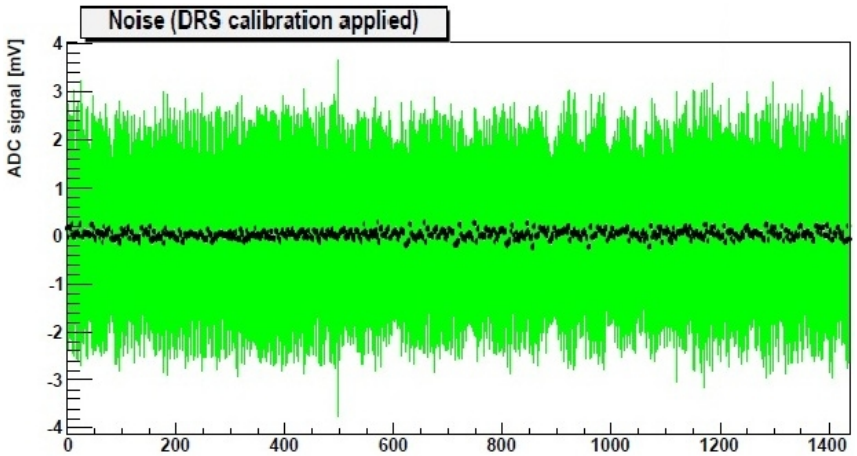


Linearity measurement, not calibrated

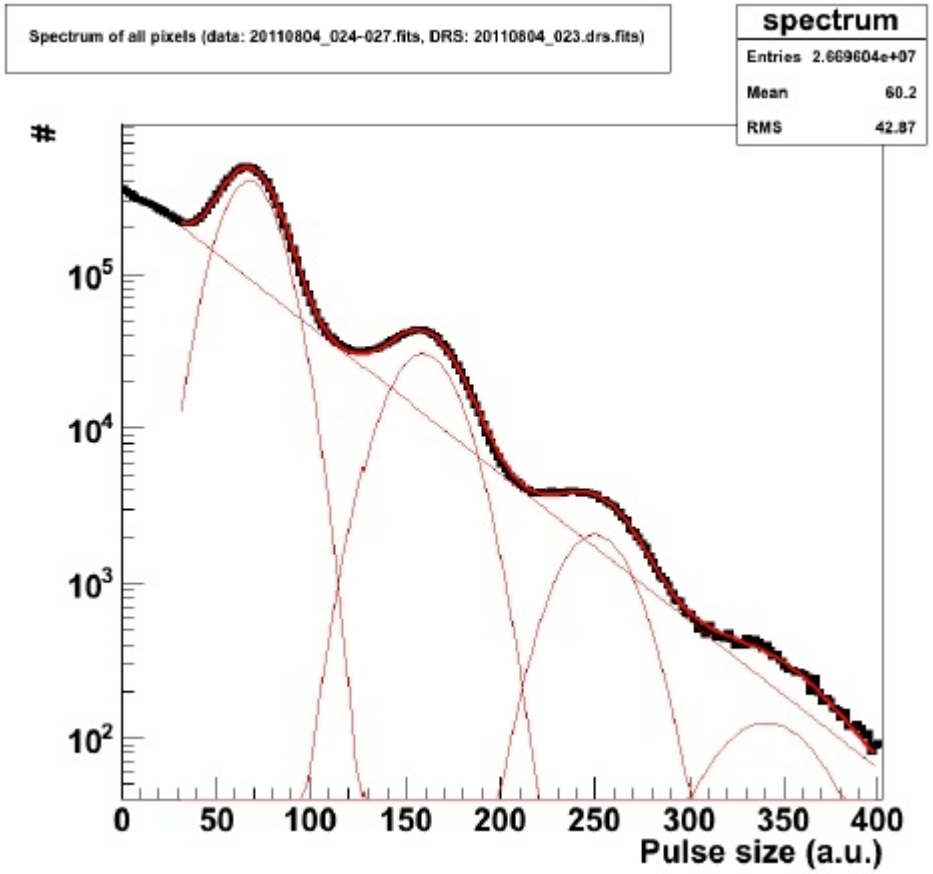


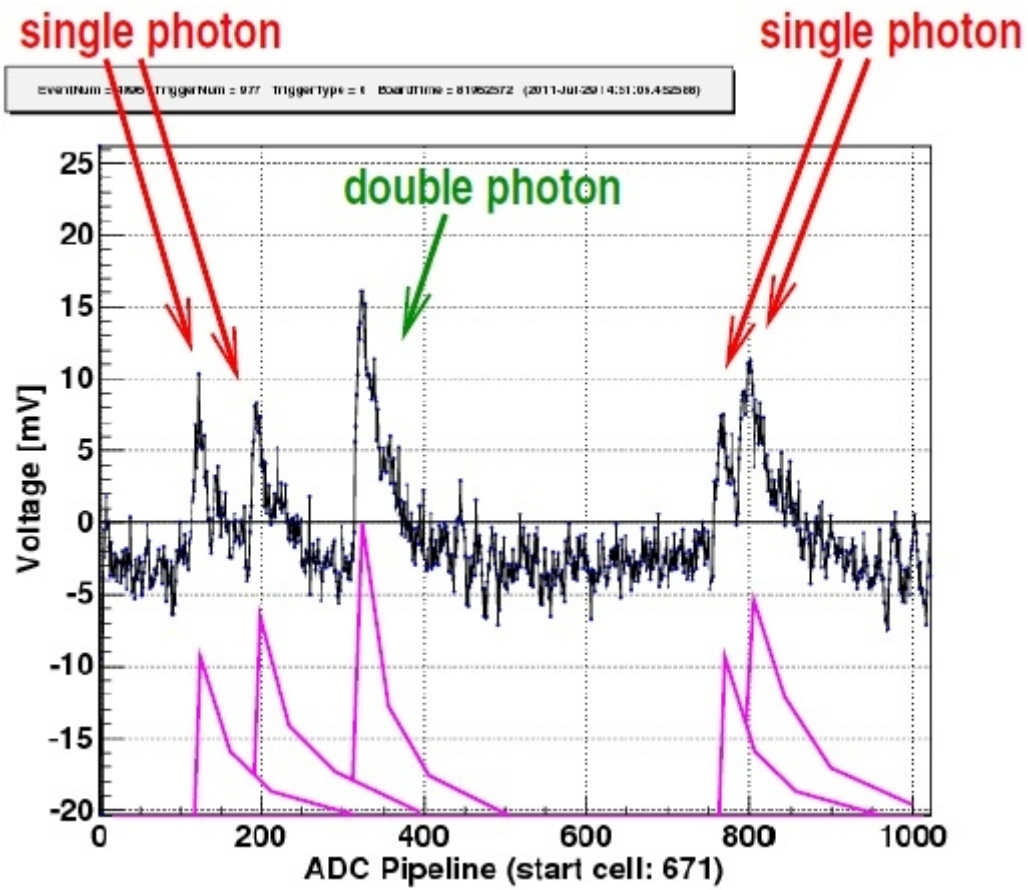
Data Acquisition

- 40 Hz “physics” plus 10 Hz interleaved calibration events reached in the lab with full ROI
- Interleaved calibration: keep G-APD gain constant i.e. compensate for temperature and NSB variations
- 2 mV electronic noise ↔ 10 mV photoelectrons
- Data rate: up to 300 MB/s



Single Photon Spectrum

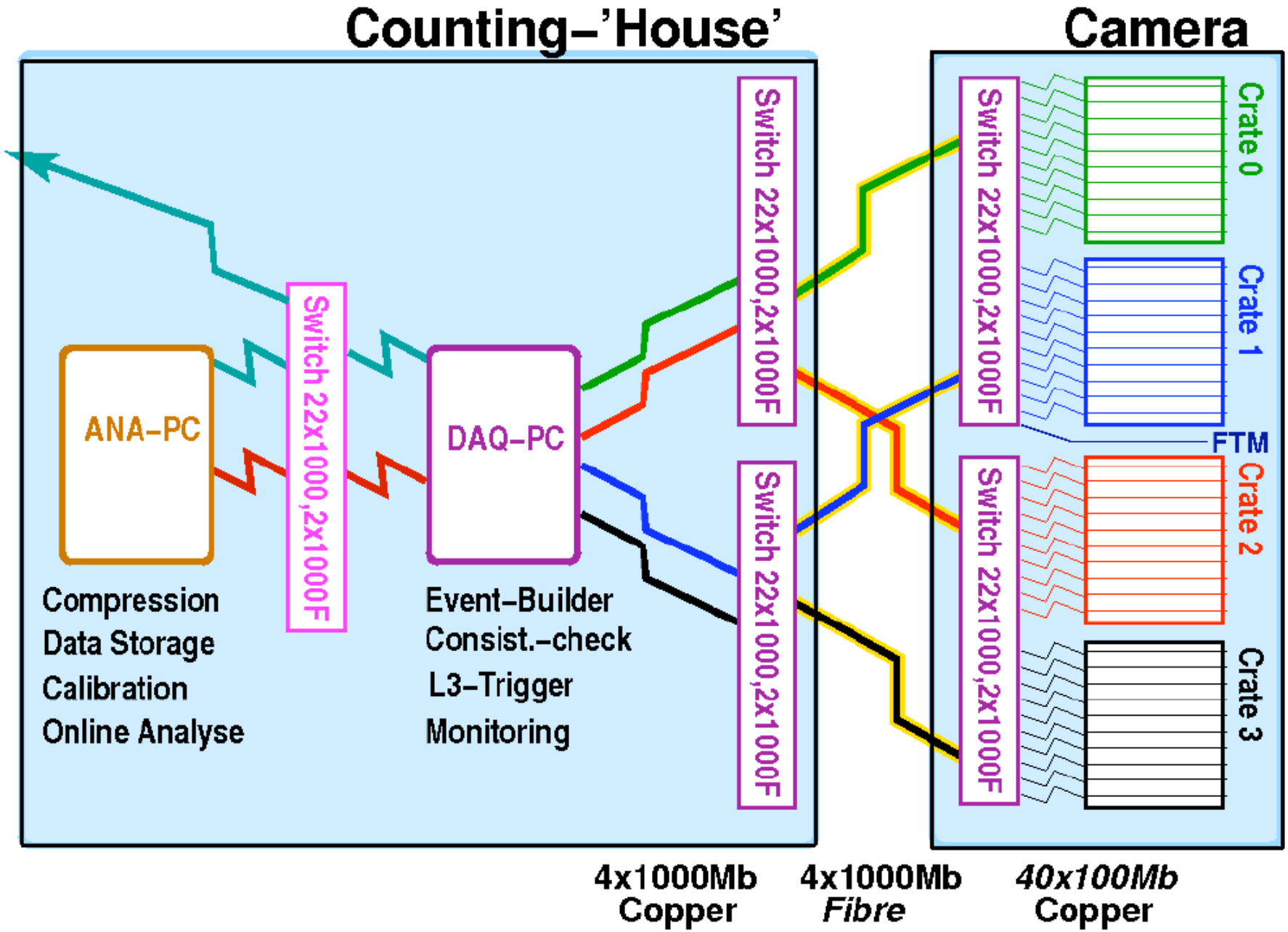




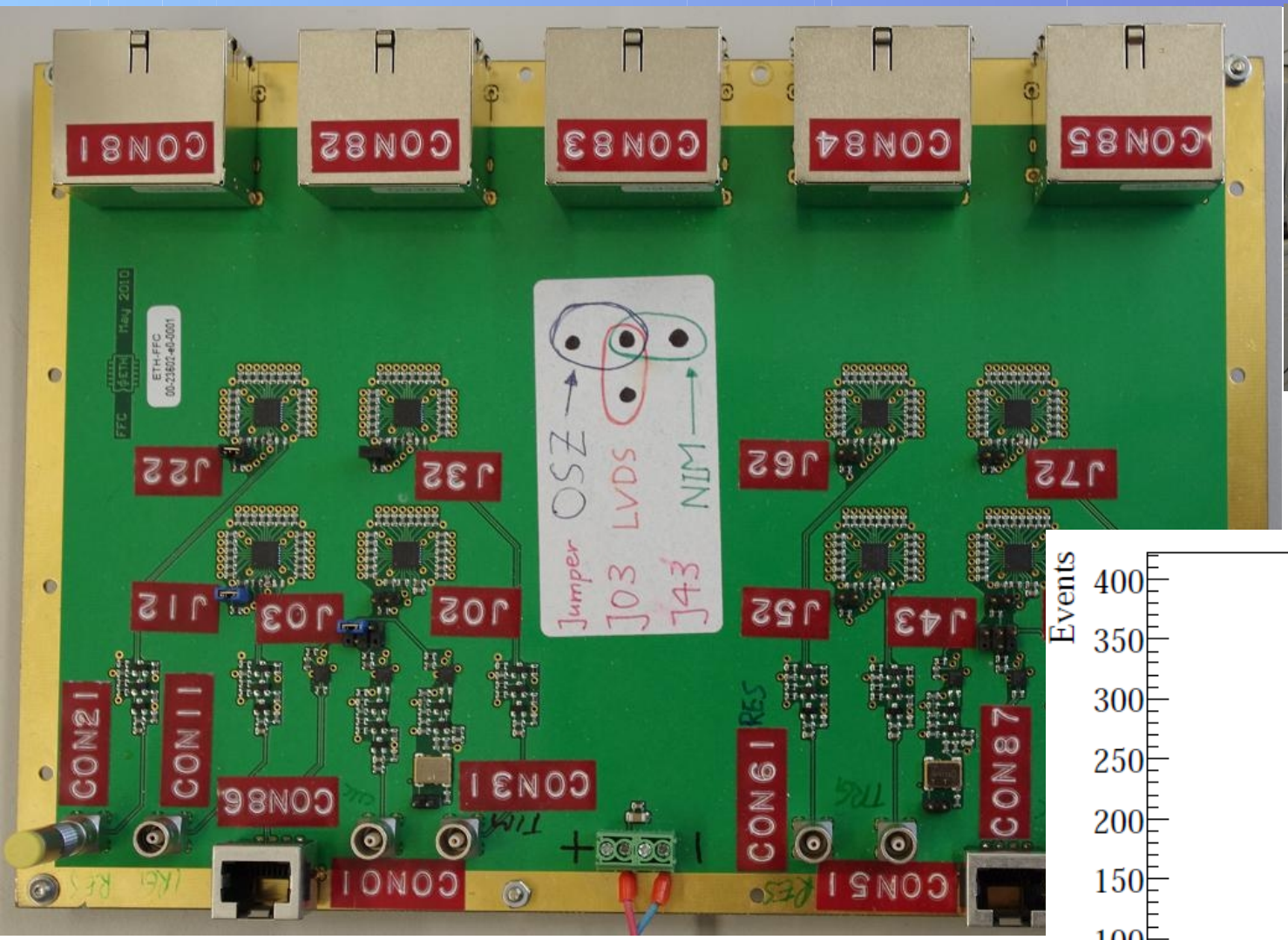
Single photon spectrum of all working pixels

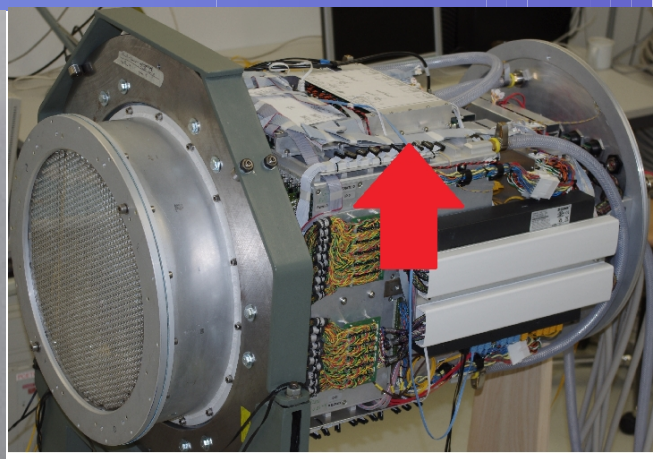
"out of the box" i.e. without calibration

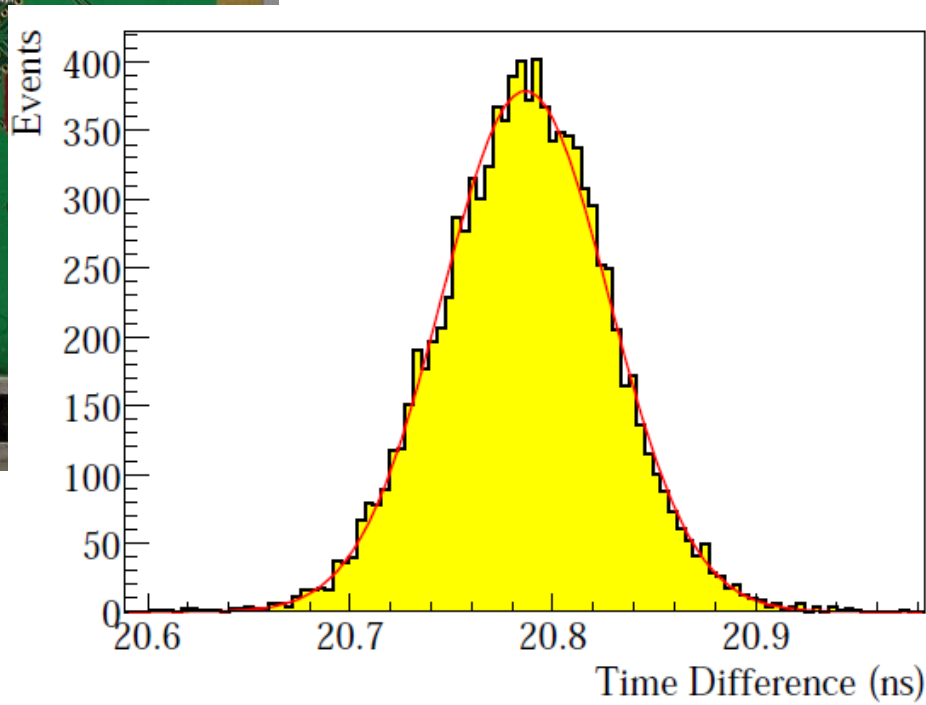
DAQ: Ethernet Readout



Trigger and Clock Distribution

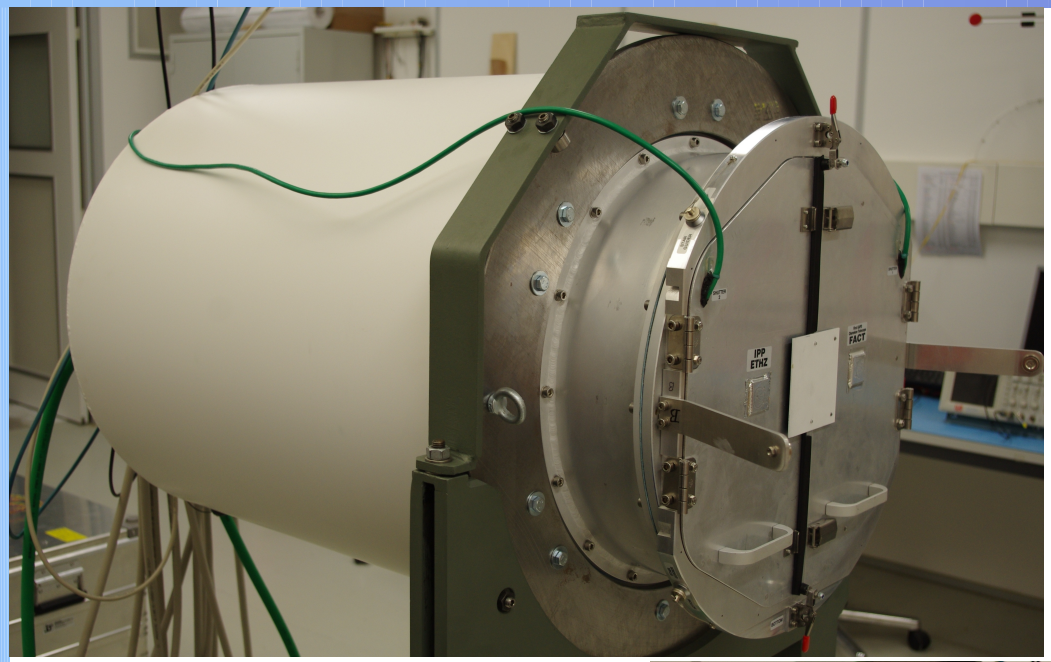


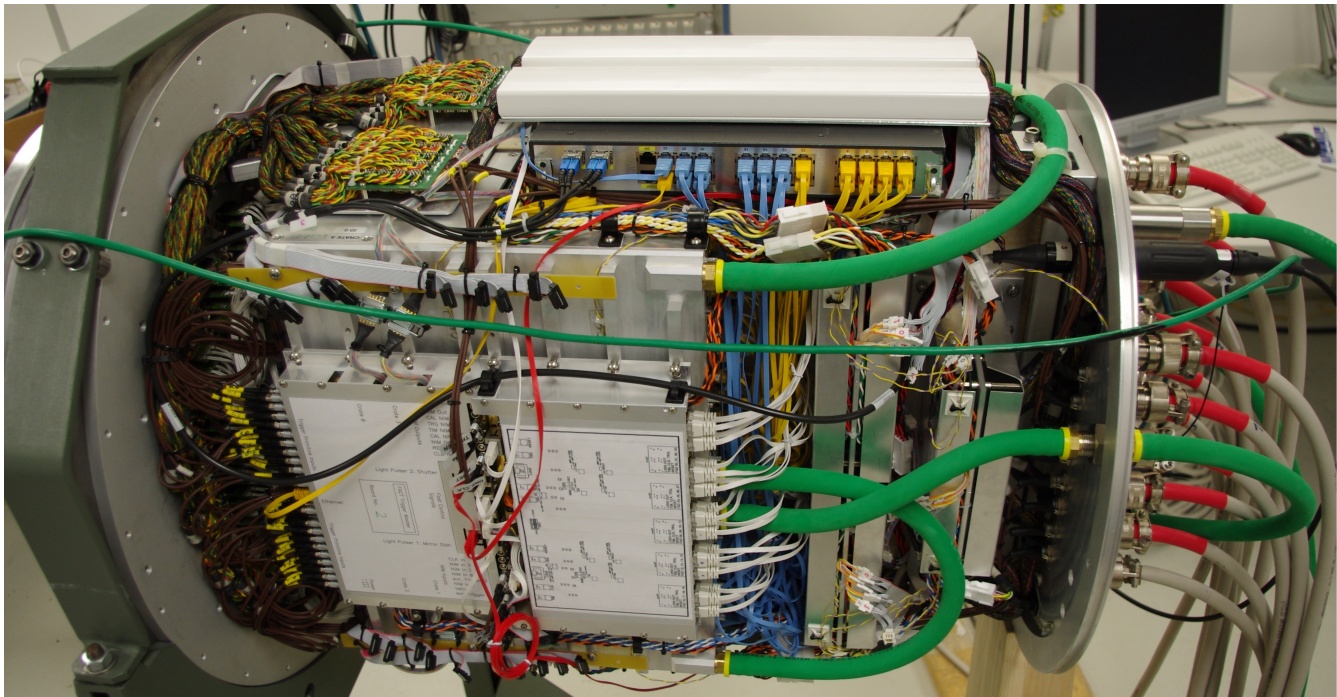




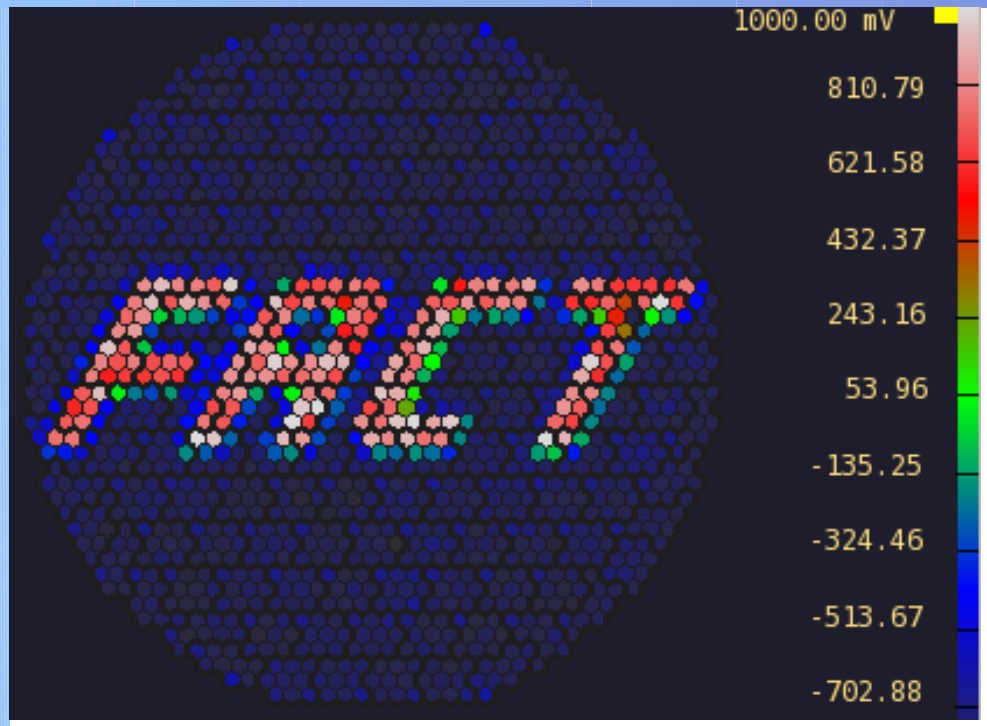
Channel to channel: Jitter < 20 ps
Skew < 250 ps

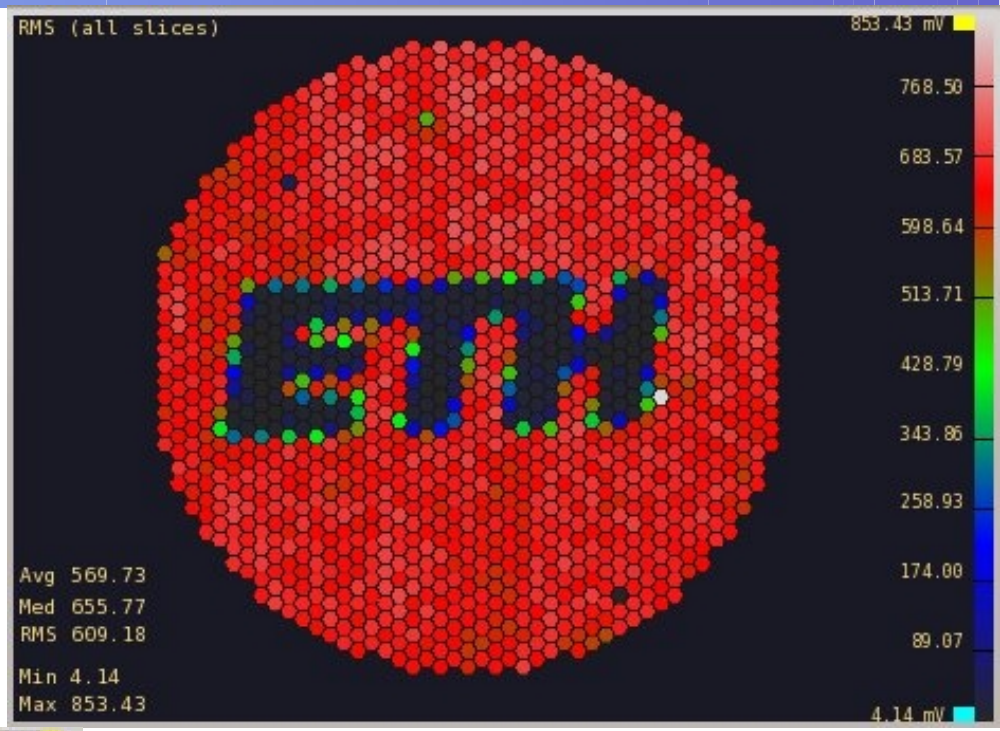
FACT in the Lab

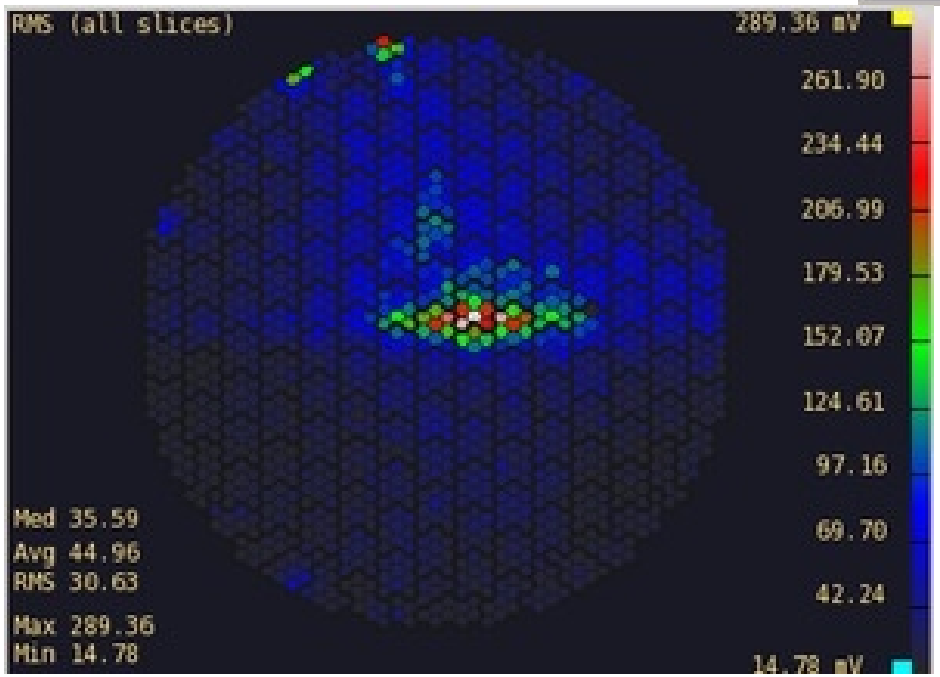




FACT in the Lab II







Images taken using FACT's external and Internal lightpulsers

Summary and Outlook

- All boards developed in-house
- Trigger and DAQ:
  - Hardware fully commissioned and installed in the camera
  - Firmware and control software ready and tested
- Various laboratory tests of the full system done data analysis still ongoing
- The FACT camera is on the way to La Palma

Summary and Outlook

Backup

Cherenkov Astronomy II

- First IACT: Whipple (Arizona, 1961)
- Current IACTs: MAGIC, HESS, VERITAS
- Future: CTA, Cherenkov Telescope Array
- Hadronic background: γ / had $\approx 10^4 - 10^5$