FACT First GAPD Cherenkov Telescope

Light 2011 – Workshop on the development of new Photo-Detectors

30 Oct – 4 Nov 2011, Ringbergschloss, Rottach, Germany

W. Lustermann, ETH Zurich on behalf of the FACT collaboration

Collaboration

- TU Dortmund, Dortmund, Germany
- ISDC, Geneva, Switzerland
- EPFL, Lausanne, Switzerland
- University of Würzburg, Würzburg, Germany
- ETH, Zurich, Switzerland

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- Introduction
- Catching the photons
- Camera construction
- First Results
- Summary / Outlook

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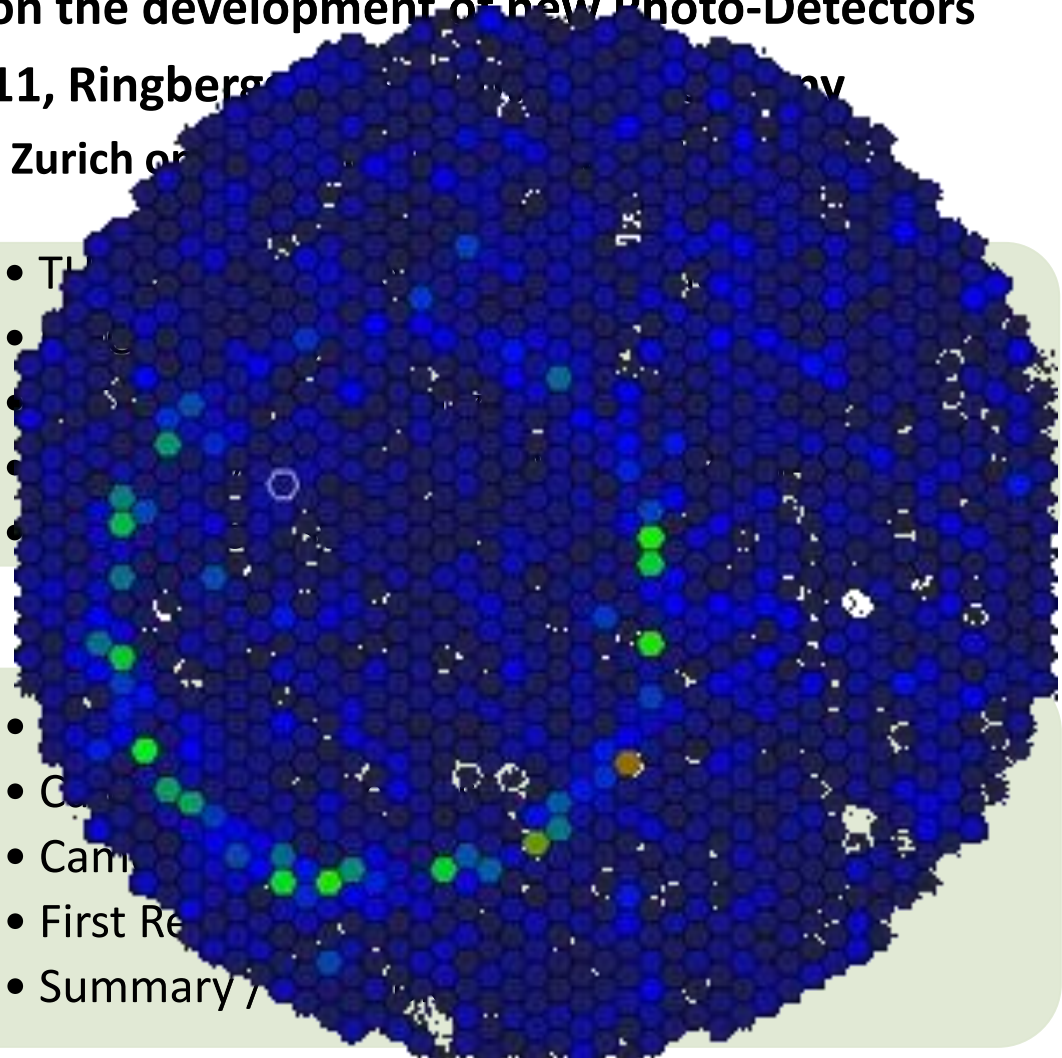

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- First Re
- Summary /

The MAGIC Site + FACT

FACT Project

FACT project objectives

- Construction of the first imaging air-shower Cherenkov telescope using G-APDs (Geiger mode avalanche photo diodes) as photo-detectors
- gain operation experience
- observation and monitoring of bright TeV Blazars

Two new technologies for IACTs

- G-APDs as photo-detectors
- Solid light concentrators

FACT instrument: Hegra CT3 Telescope, La Palma (thanks to MPI Munich)

- **Location:** European Northern Observatory, Roque de los Muchachos, Canary Island La Palma
  - altitude: 2200 m, longitude: -17deg 53m 26s, latitude: 28deg 45m 42s
- Close to the MAGIC telescopes

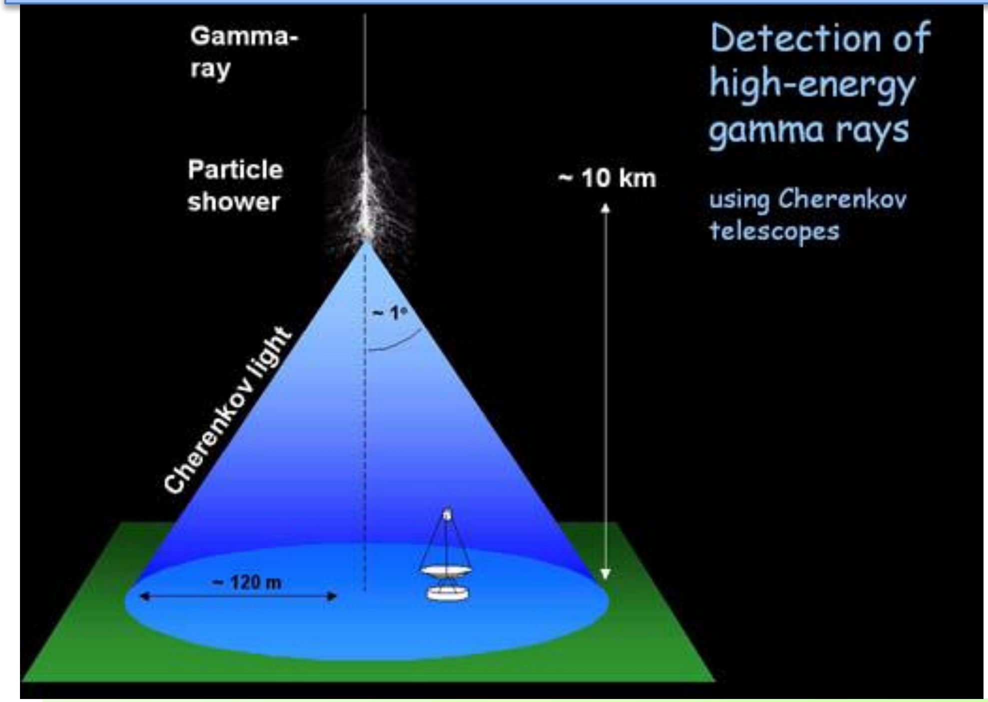
Mirror Dish

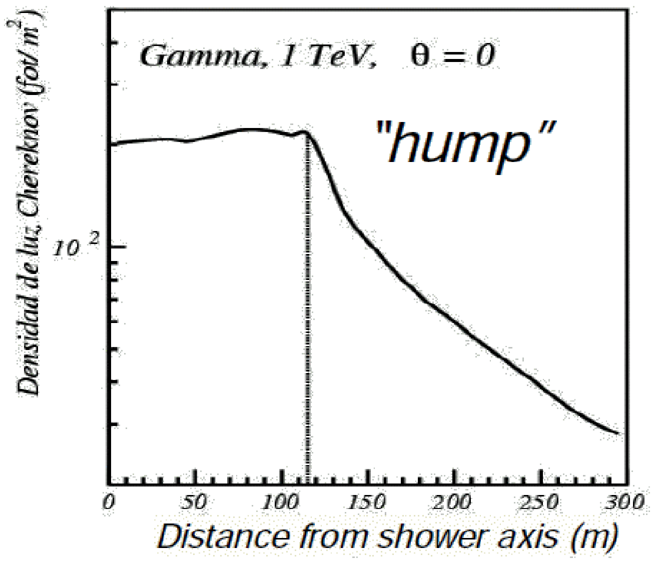
- **Number of mirrors:** 30
- **Mirror arrangement:** 1 ring of 6 and two rings of 12 mirrors, no central mirror (camera shadow)
- **Diameter:** 3.885 m
- **total mirror surface:** 9.51 m^2
- **Surface coverage:** 82.9 % (not counting the missing central mirror)

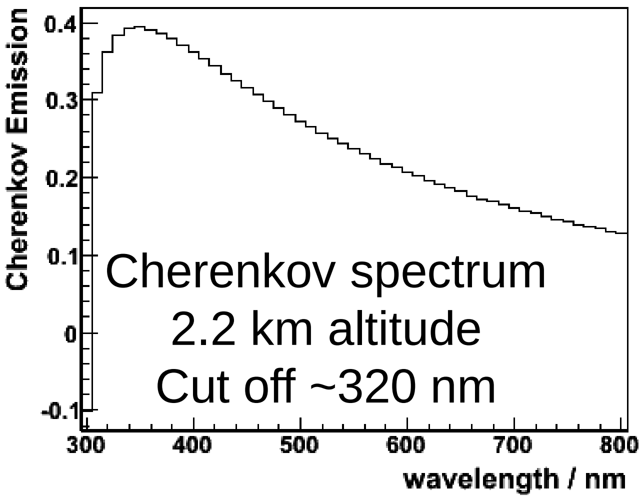
Detection of Air Cherenkov Showers

Signal amplitude: 200 photons / m^2 (1 TeV γ-ray)
Spectrum: (300 – 600) nm
Duration: few ns
Night sky: up to several GHz

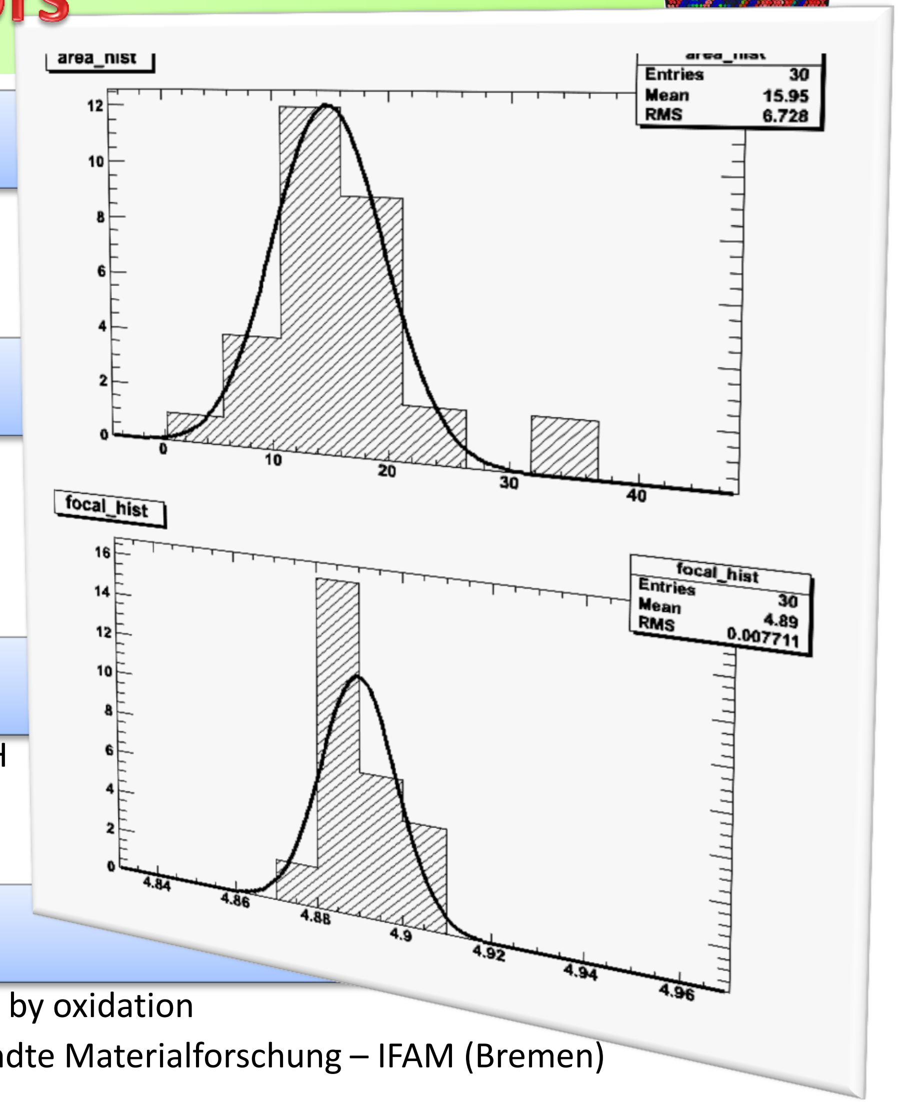
Optical imaging system (causes losses)
Mirror → light concentrators → photo-detectors







Mirrors



Mirrors (re-use existing Hegra CT1 mirrors)

- Spherical mirrors with hexagonal shape
- Diameter (inner circle): 60.6cm
- area: 0.317 m^2

Sandwich construction:

- Al base plate, 1 mm thick
- Al honeycomb (hexcell)
- Al alloy (AlMgSi 0.5) front plate, 5 mm thick
- Weight: ~6 kg

Surfaces were re-machined

- diamond milling by LT ultra Precision Technology GmbH
- Mean focal length: (4.890 ± 0.008) m
- Average spot size at 2f: 16.0 mm^2 (0.033 deg)

Surface finish

- Sputtering of Silicon in a Methan-atmosphere followed by oxidation
- Fraunhofer-Institut für Fertigungstechnik und Angewandte Materialforschung – IFAM (Bremen)
- thickness: ~120 nm
- reflectivity maximum around 450 nm, average reflectivity of ~90% between (300 and 500) nm

Main Features

Camera

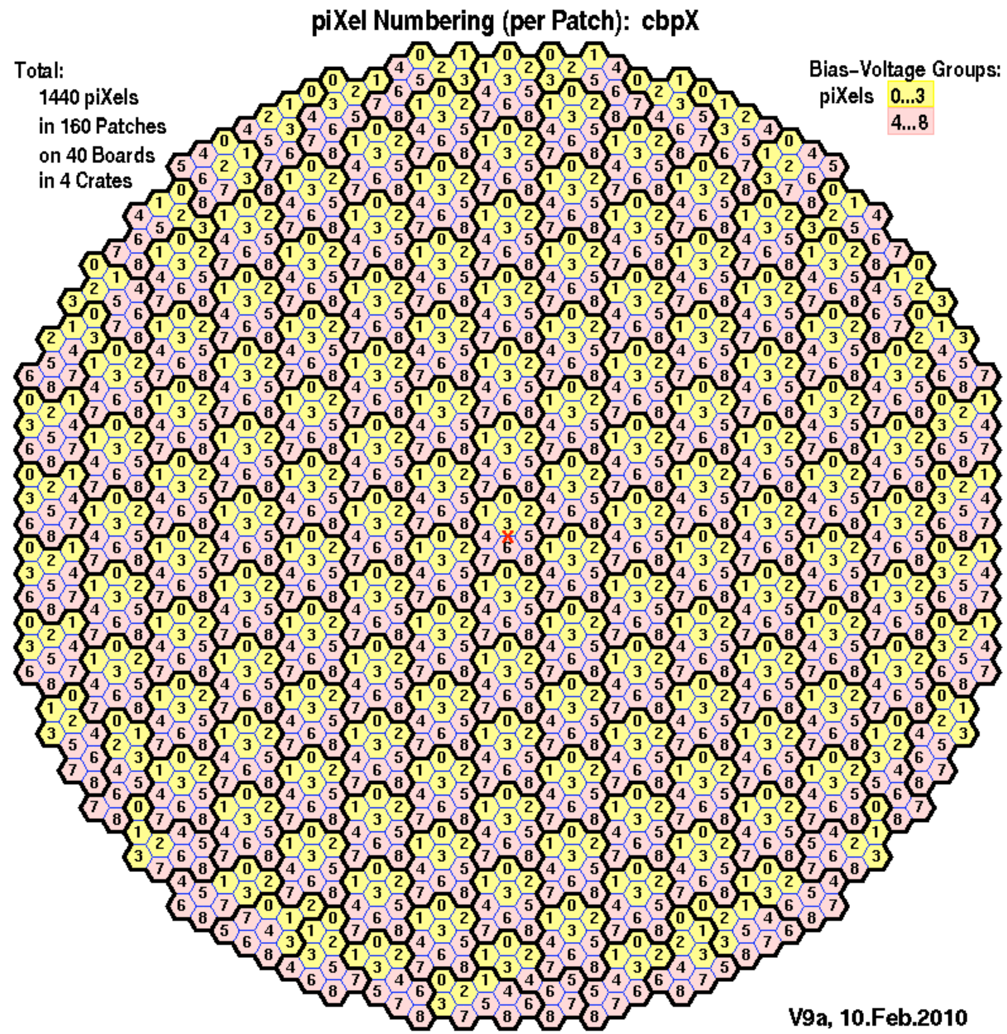
- Dim: Length 812 mm, diameter 532 mm,
- Weight: ~ 150 kg
- 1440 pixels (G-APDs)
- FOV: 0.11 deg / pixel (4.5 deg total)
- Sensor and electronics compartment thermally separated

Photo-detection

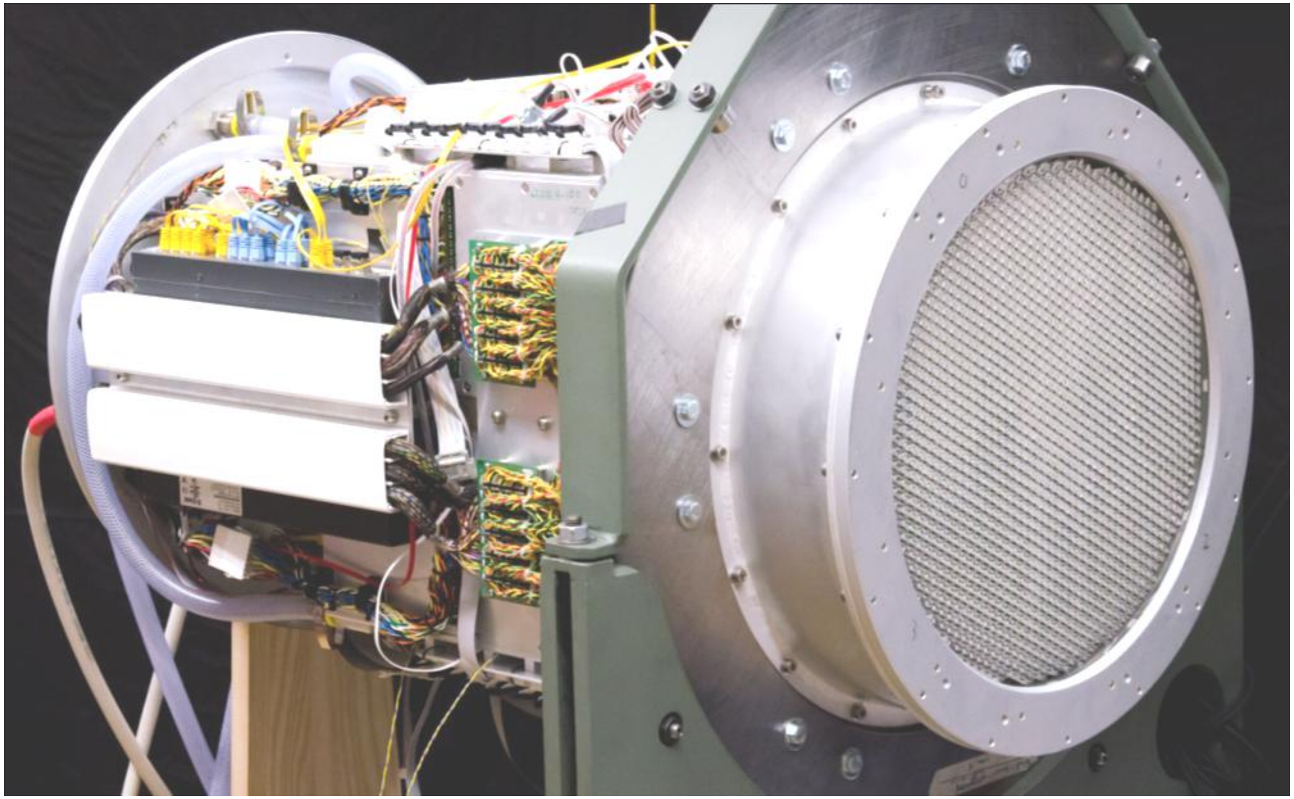
- PMMA 7M entrance window, transm. > 82% for > 300 nm
- G-APDs
- Solid light concentrators

Electronics

- Integrated into camera
- Single 48 V supply + VICOR DC-DC converter
- 320 ch bias supply, external
- Power Consumption: 550 W + 150 W (G-APD bias)
- Water cooling
- Gigabit Ethernet readout and control via optical fibers
- nominal digitization: 2 GHz (DRS 4)
- single photon resolution -> calibration



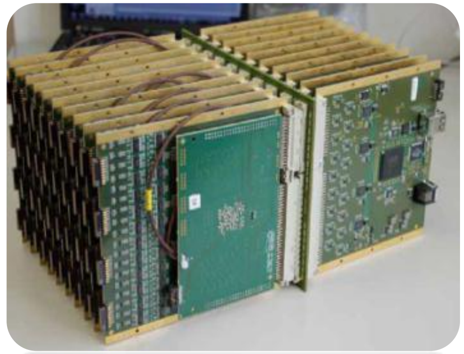
Camera and Camera systems

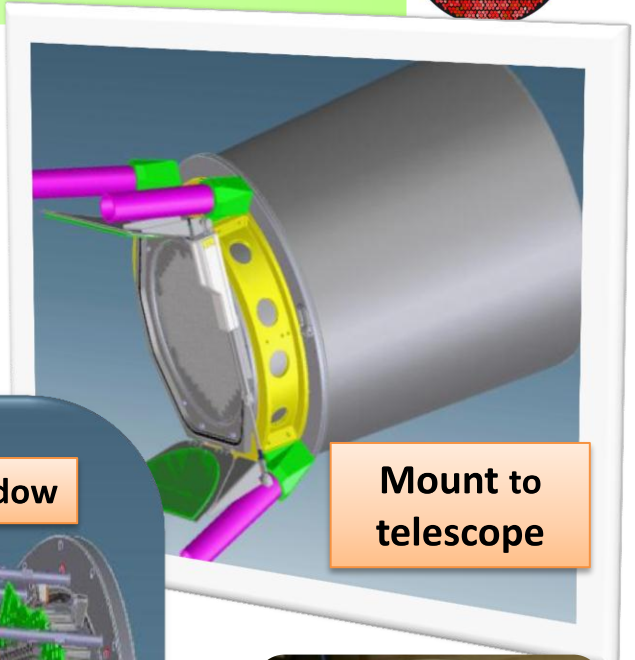


- Drive calibration system
- Readout electronics
- Trigger system
- Temperature and Humidity monitoring
- G-APD bias supplies
- LV power supplies

- Infrastructure (power, Ethernet, hut, …)
- Water cooling system
- Internal light pulser
- External light pulser (bias supply feedback)
- Telescope Drive system

Camera Construction





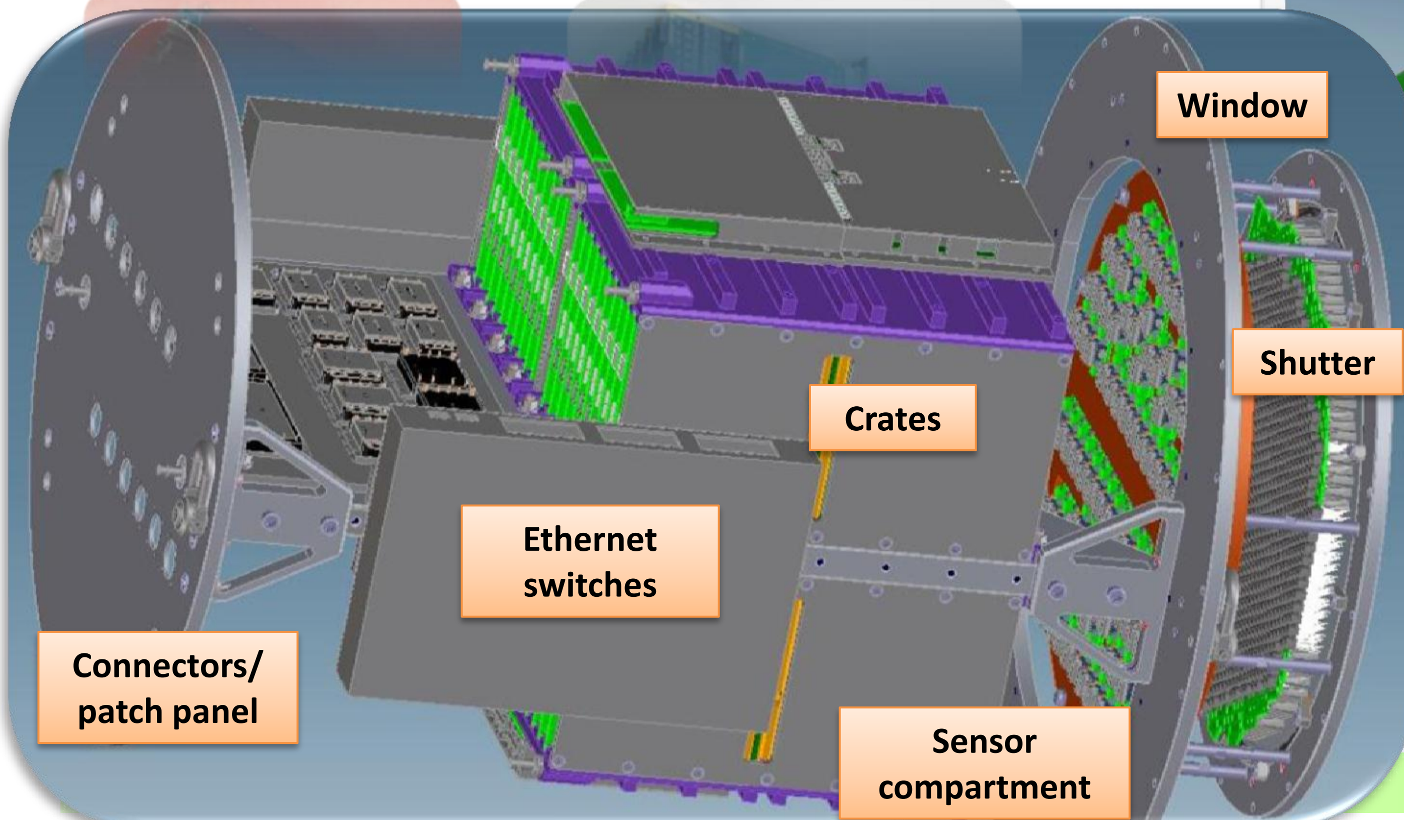


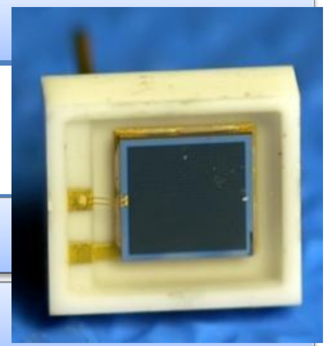
Photo Detectors (G-APDs)

Photo detectors: MPPC

Manufacturer: Hamamatsu Photonics K.K.

Type: S10362-33-050C

- active area: 3 x 3 mm^2
- 3600 pixels of (50 μm)^2
- Ceramic package 5.9 x 6.6 mm^2



Operation voltage: ~70 V

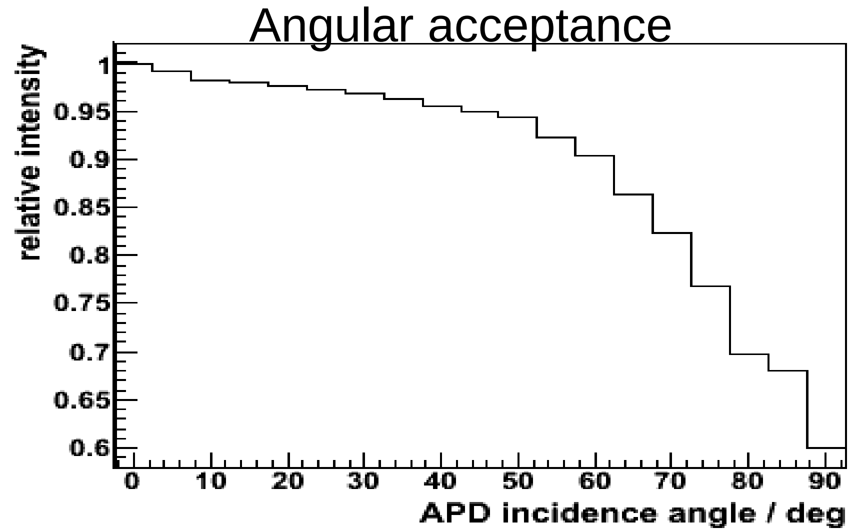
Gain (nominal): 7.5 x 10^5

Photon detection efficiency: ~35%

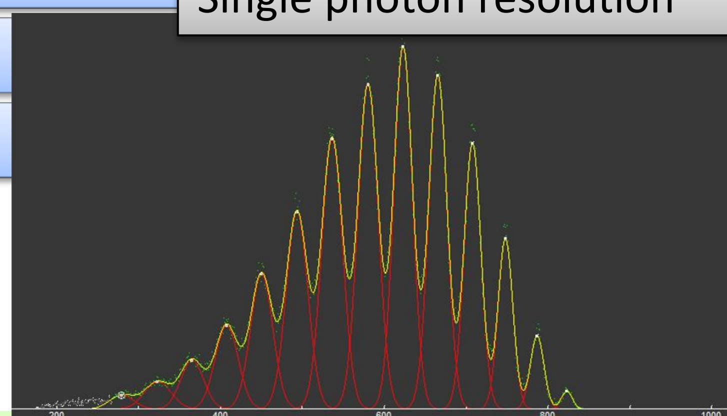
Optical cross talk and after pulsing: ~20%

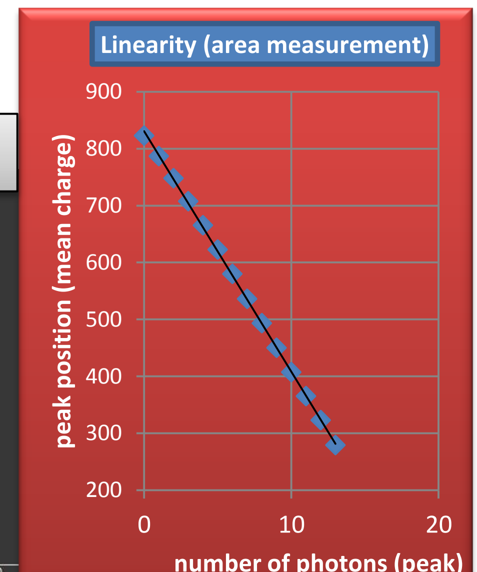
Peak sensitivity ~430 nm

T dependence of V_b: -60 mV/K



Single photon resolution

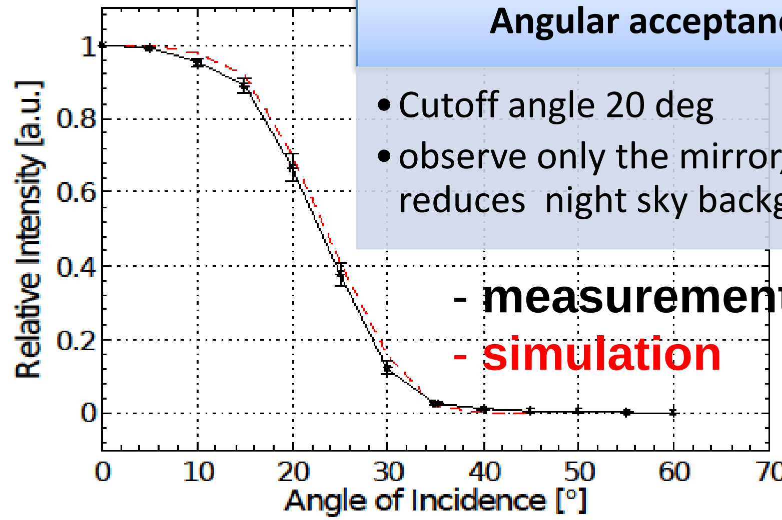




Light Concentrator (no Winston Cones)

Height: 19.939 mm
IN: Hexagon: 9.5 mm
OUT: Square: 2.8 mm
Concentration: ~10
Solid cones → use total internal reflection
Normal parabola shape

Thanks for the support of University of Zurich.

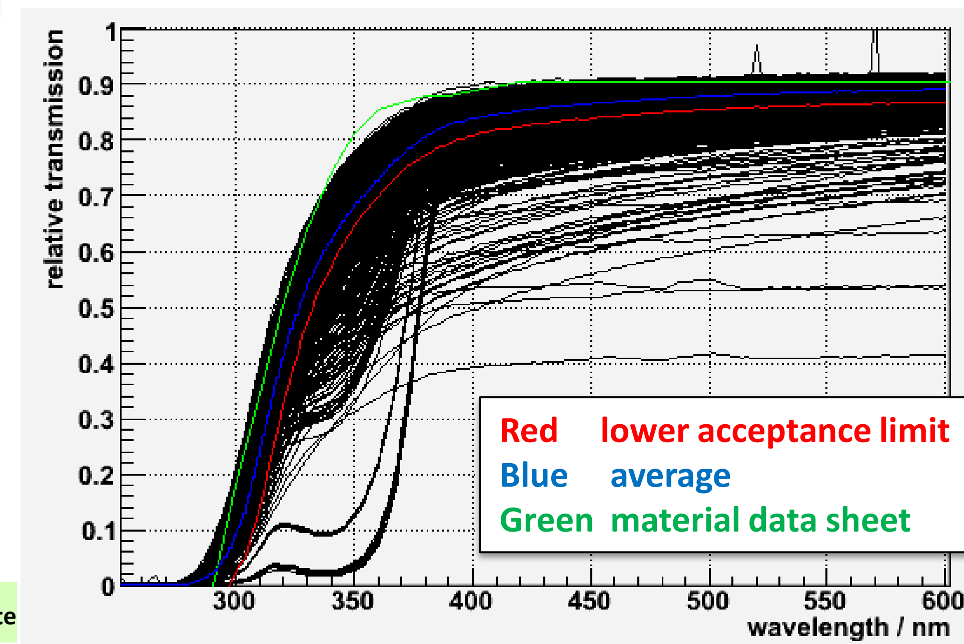


Angular acceptance

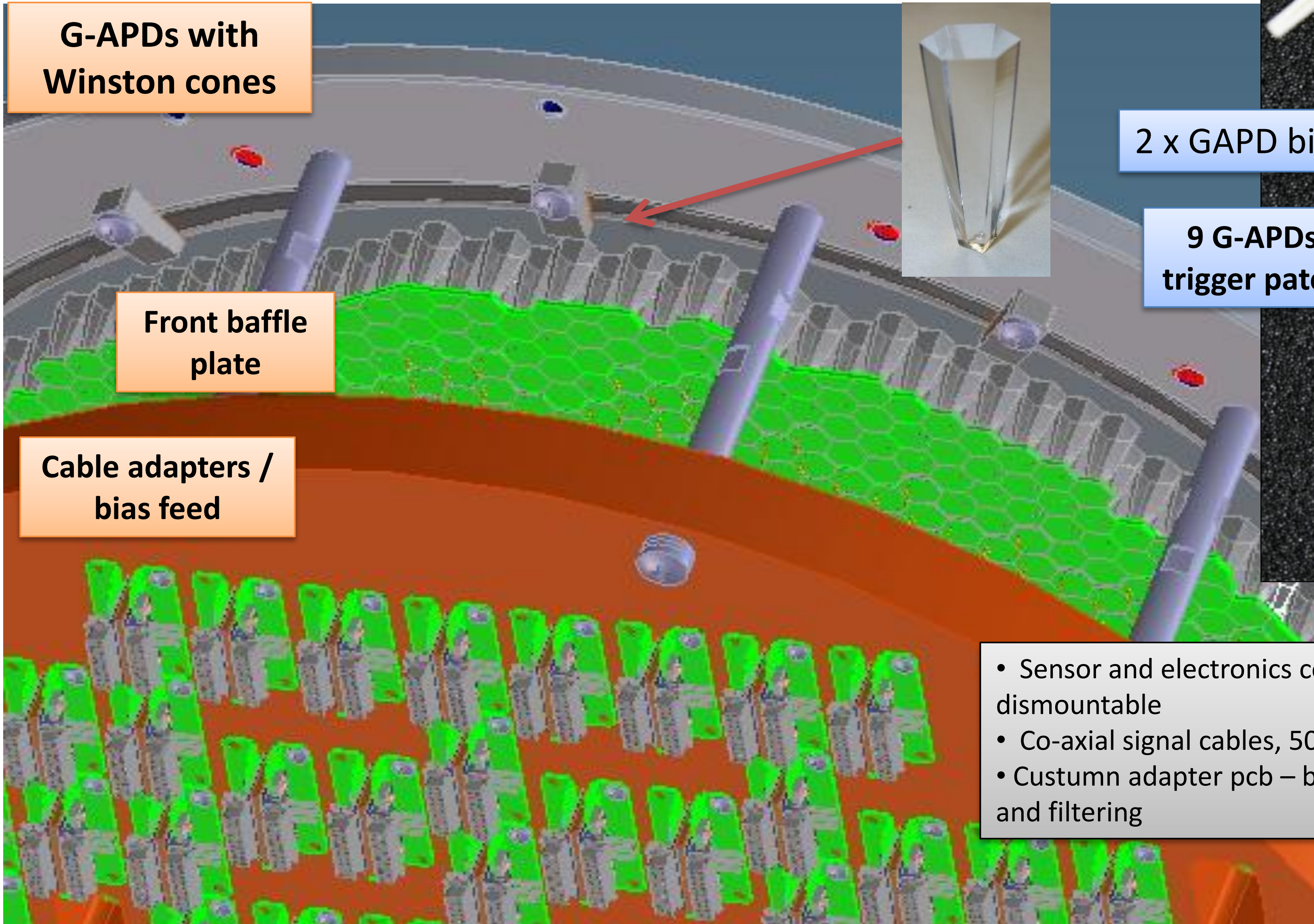
- Cutoff angle 20 deg
- observe only the mirror, reduces night sky background

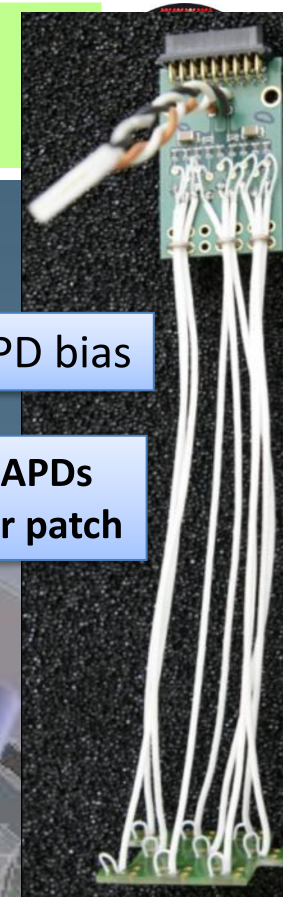
Light Concentrating Cones

- UV transparent PMMA
- Fabricated by injection moulding → **non trivial**
- Transmission spectrum of ~2350 cones measured using a spectrometer →→→



Sensor Compartment





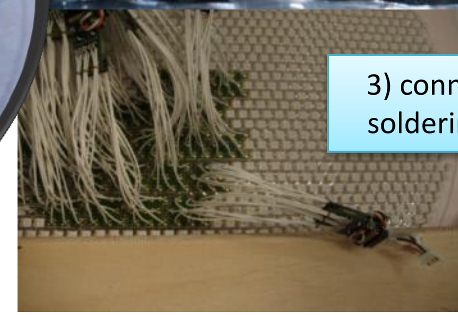
- Sensor and electronics compartment dismountable
- Co-axial signal cables, 50 ohm, ~35 cm
- Custumn adapter pcb – bias connection and filtering

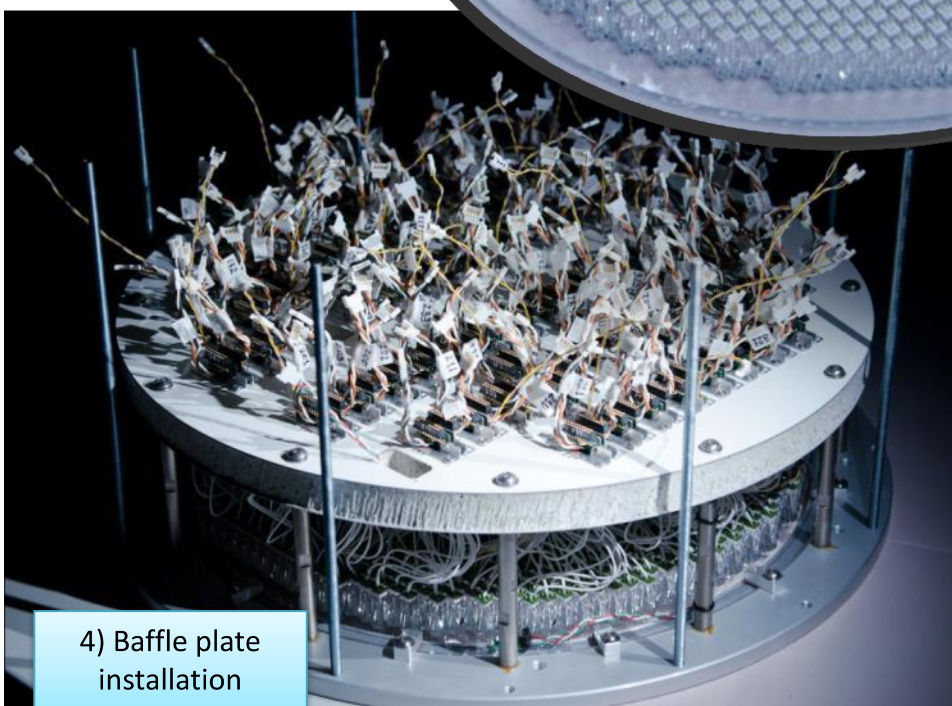
Sensor Plane Assembly

1) MPPCs – cone gluing

2) cone gluing to front window

3) connector cable soldering to MPPC

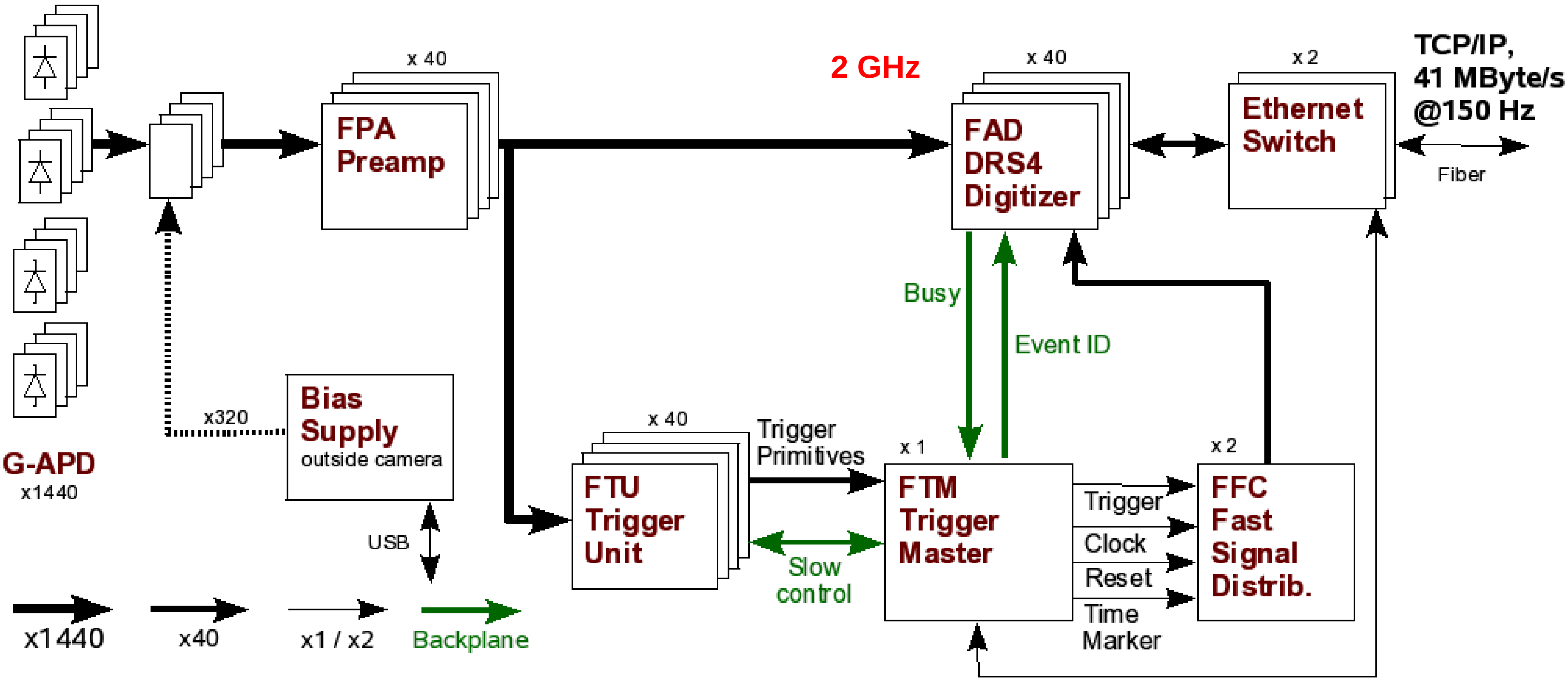




4) Baffle plate installation

Completed sensor plane

Electronics Systems Overview

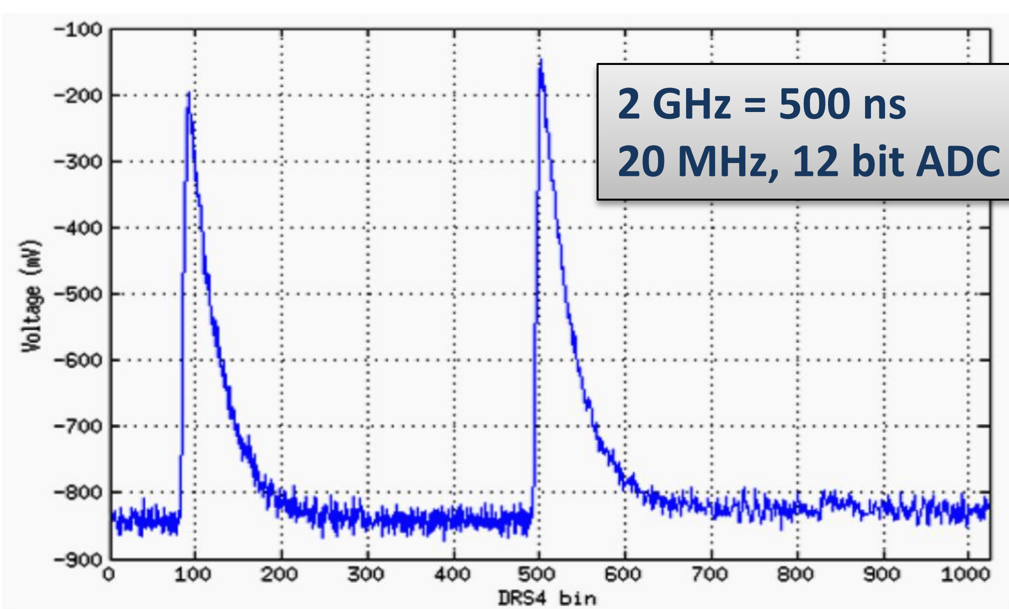


FLV: low voltage conversion
FSC slow control (Temp., rel Humidity, voltages)
FLP light pulser
FDC drive calibration

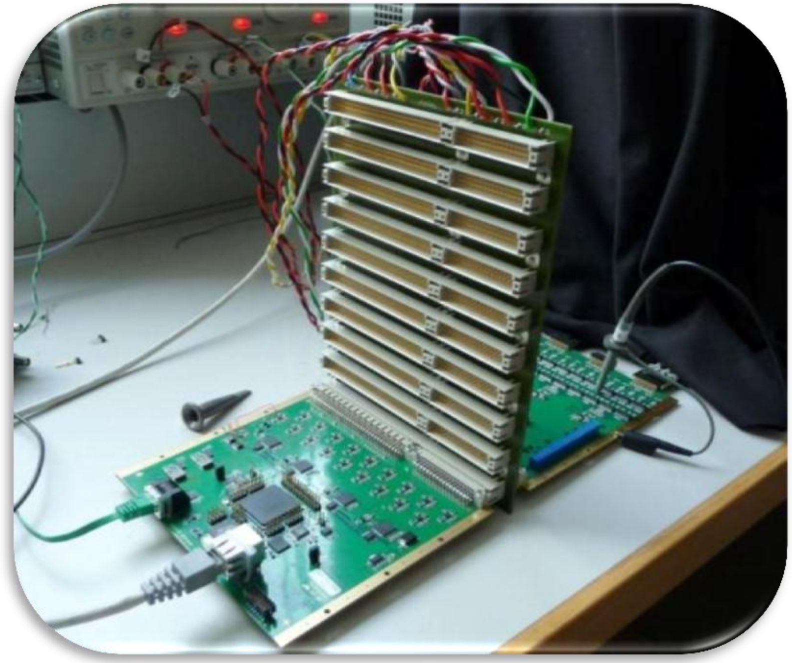
FACT DAQ – Digitization

Readout system

- Dynamic range: ~250 photons / pixel
- Resolution: < 0.5 photons (for less than 10 photons)
- Timing resolution: 300 ps
- Double hit resolution: 5 ns
- Operation also under twilight/moon (background rate up to 1 GHz / pixel)
- readout window 200 time slices = 100 ns
- ~700 Hz sustainable trigger rate



2 GHz = 500 ns
20 MHz, 12 bit ADC



Pre-amplifier board (FPA) and analog pipeline ASIC (DRS4) & digitization board (FAD) connected via the mid plane (FMP) distributing power and slow control signals

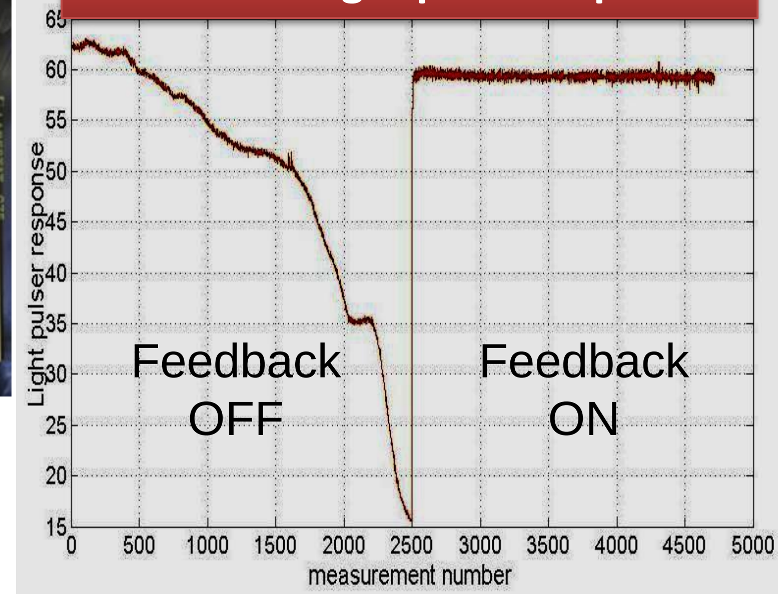
LED flashes registered by an MPPC connected to the FACT readout system

Trigger system & HV Feedback

Trigger unit (FTU) – 40 pieces
- Uses 4 sums of 9 pixels for a majority decision
- Mezzanine card on the FPA

Trigger master (FTM) – 1 piece
- Provides trigger decision upon 40 FTU inputs
- Provides CLOCK, TRIGGER and RESET signals

Measured light pulse response

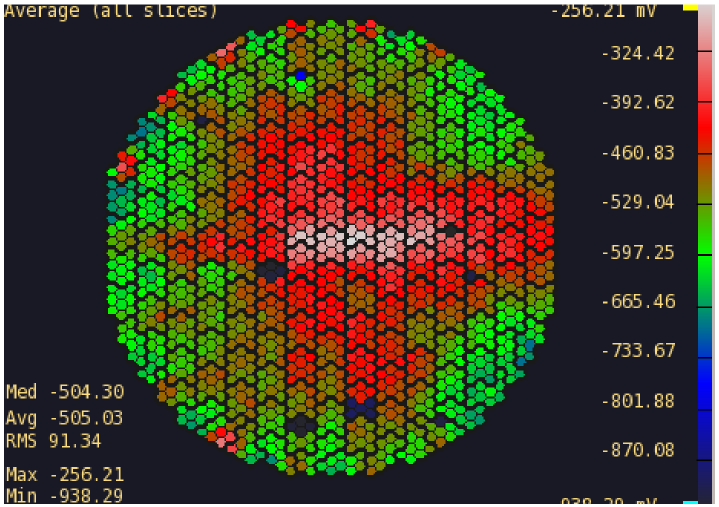


32 channel GAPD bias card
- Computer controlled (USB)
- Counting hut

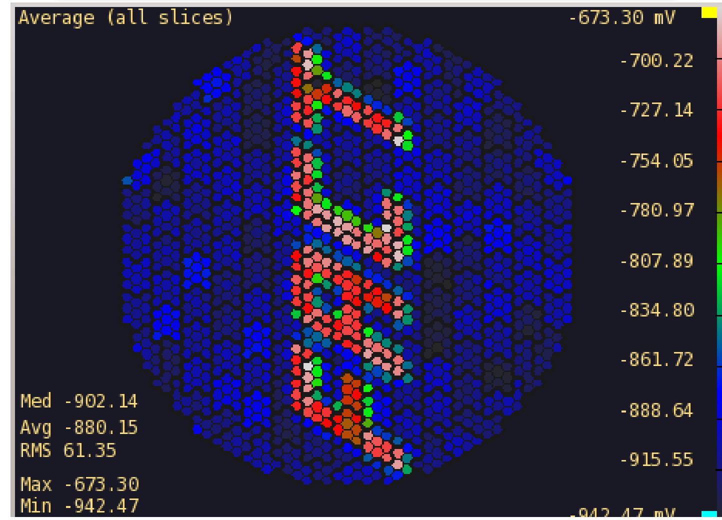
Active bias supply feedback
- Light pulses of 9 LEDs (FLP) are triggered by the FTM and read out
- Deviations from nominal values are converted into GAPD bias corrections and applied.

Various Tests

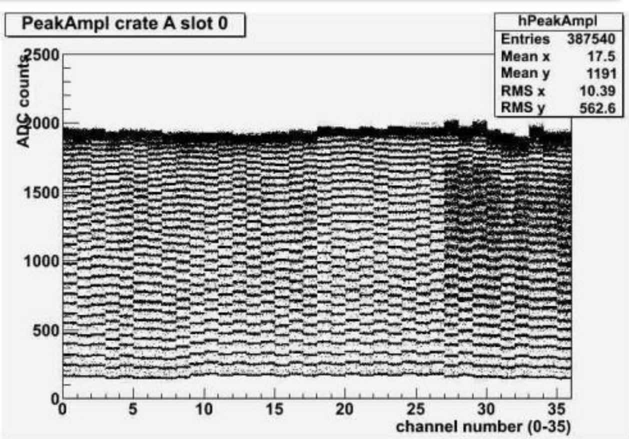
Internal light pulser test: spots HV problems



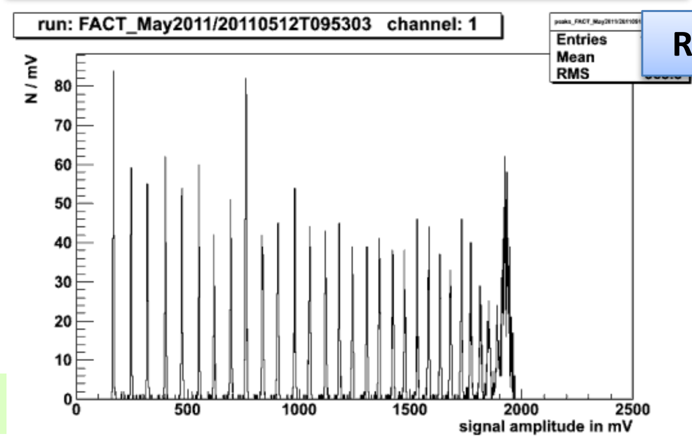
external light pulser test: spots FACTs



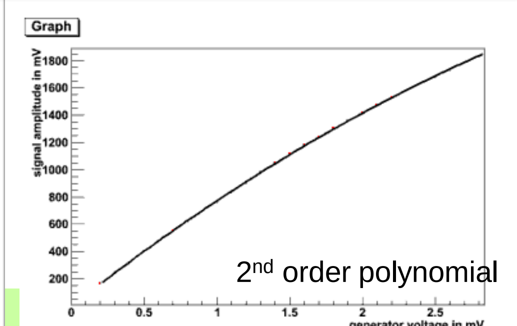
Charge inject into all channels of 1 FAD card



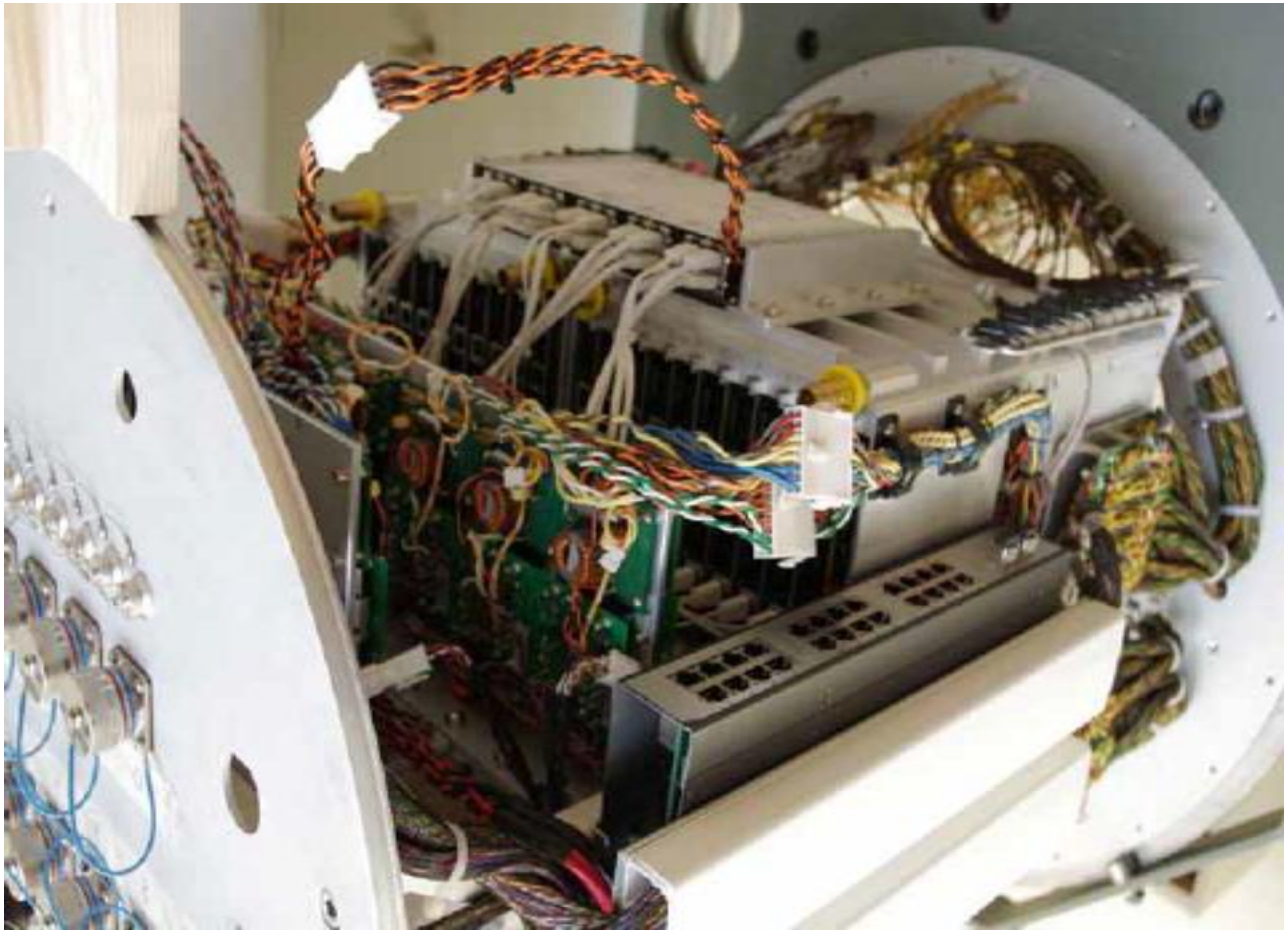
Projection crate A slot 0



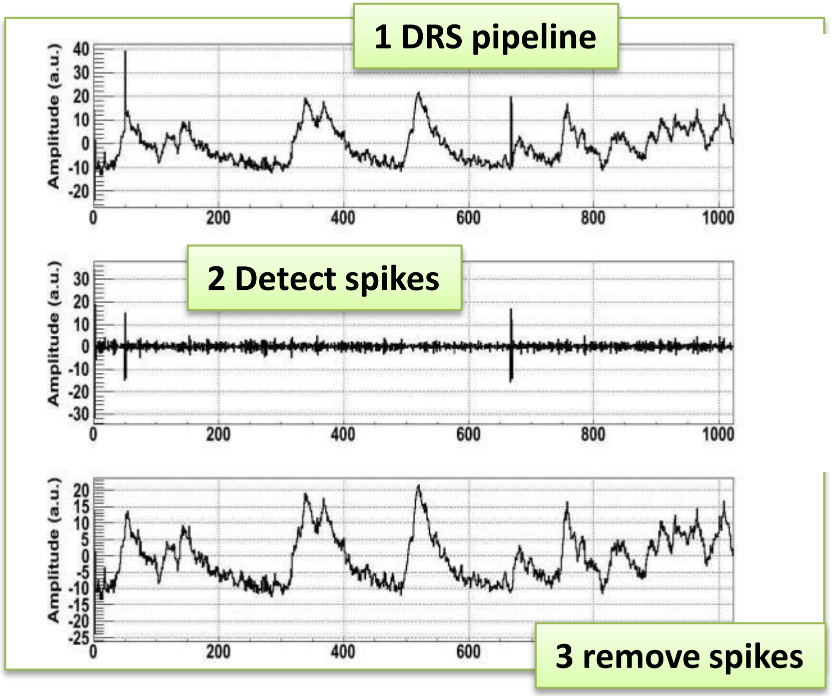
Response crate A slot 0 channel 0

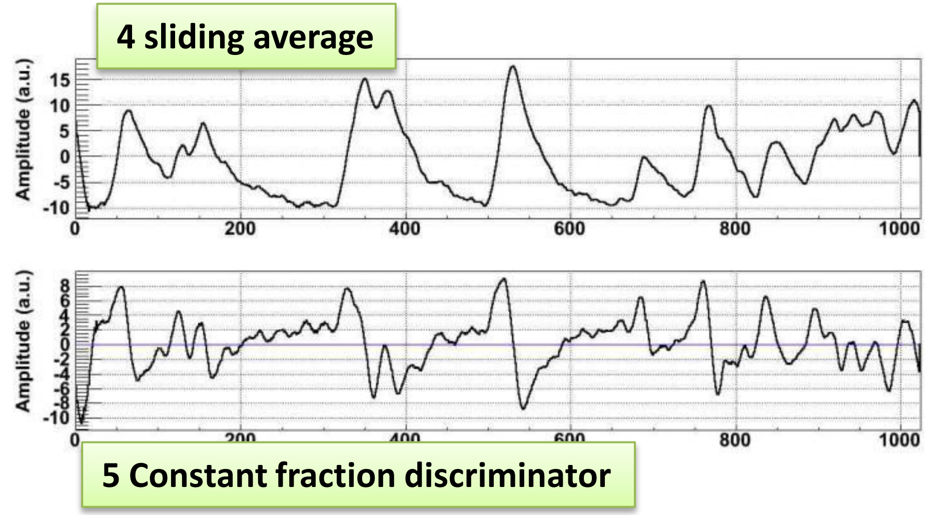


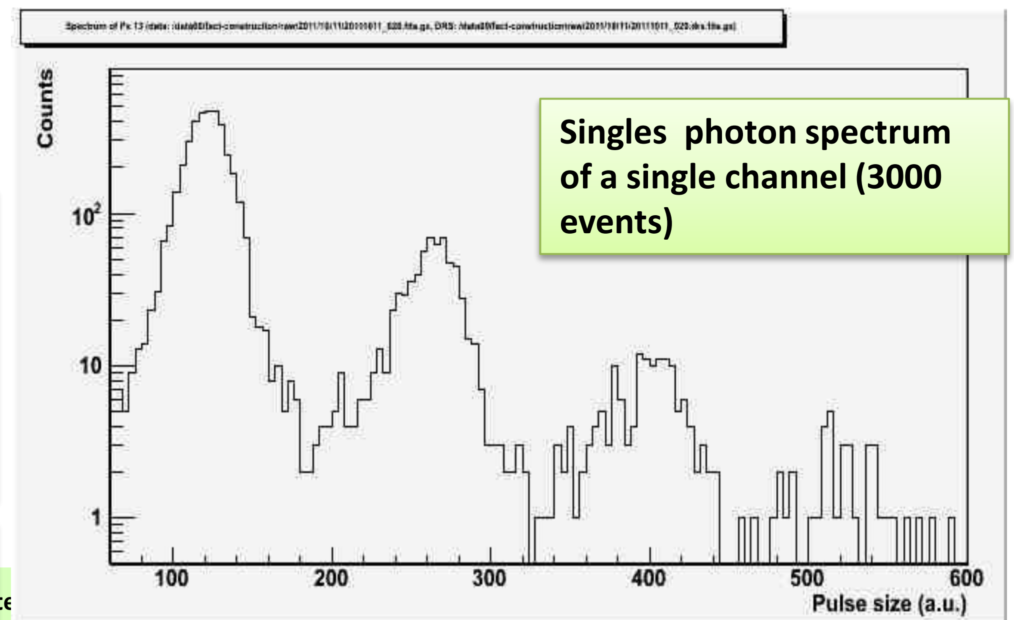
Camera Integration



DRS data





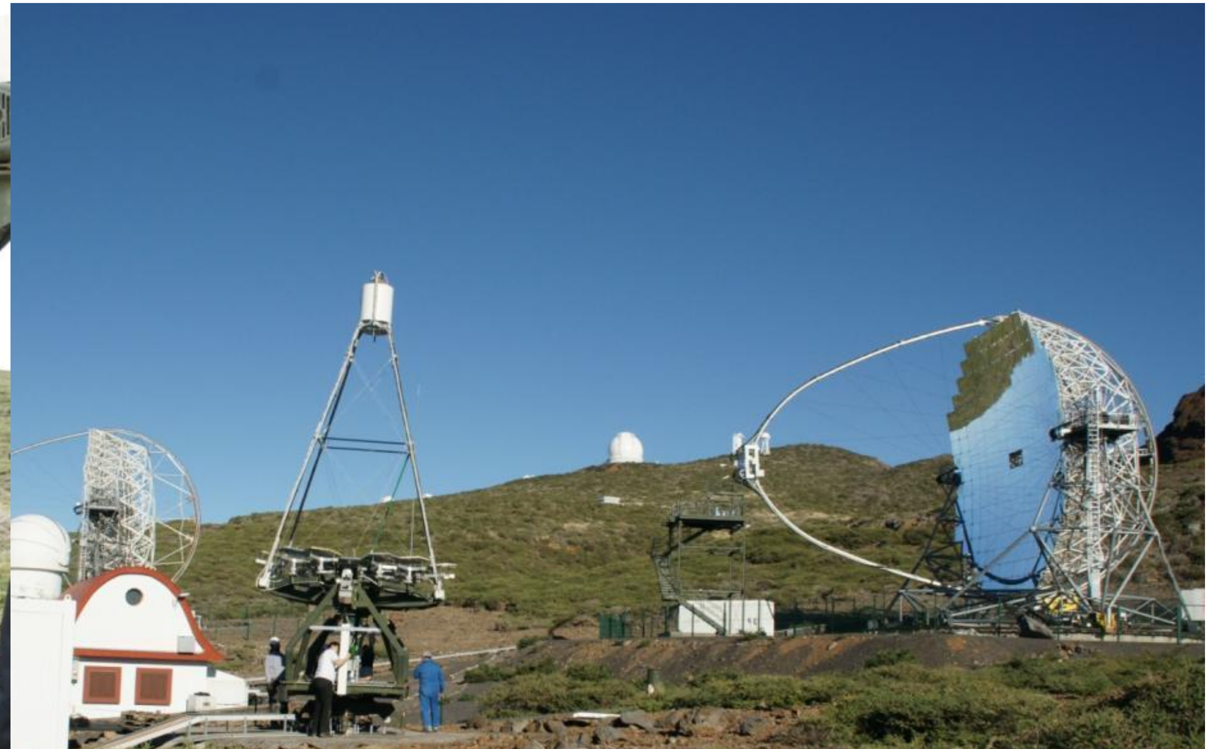


- Excellent single photon resolution allows precise inter-calibration
- Digitized data allow post-processing of data – increasing understanding and performance

Analysis not complete: baseline subtraction and other things missing

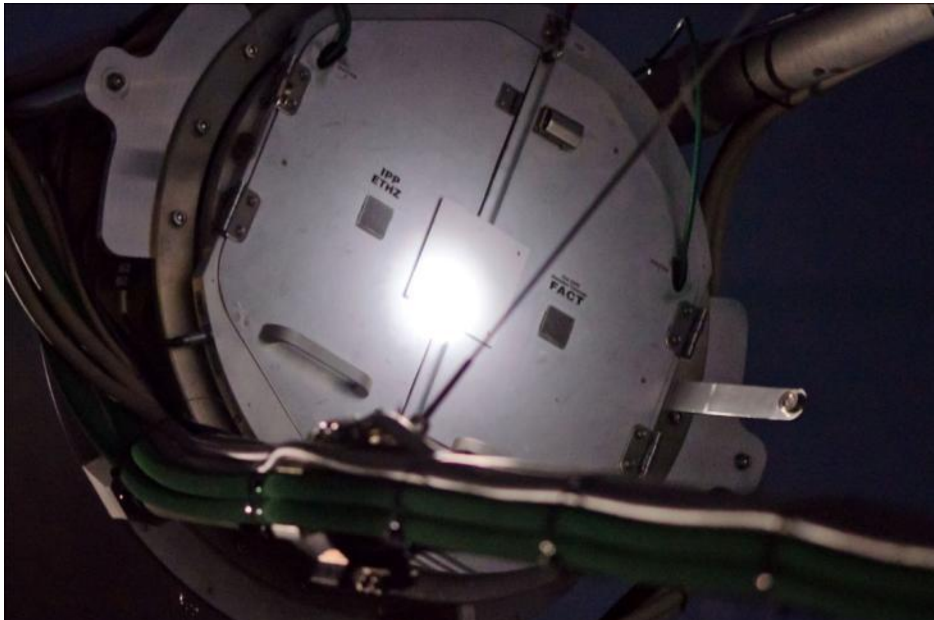
Mounting the Camera

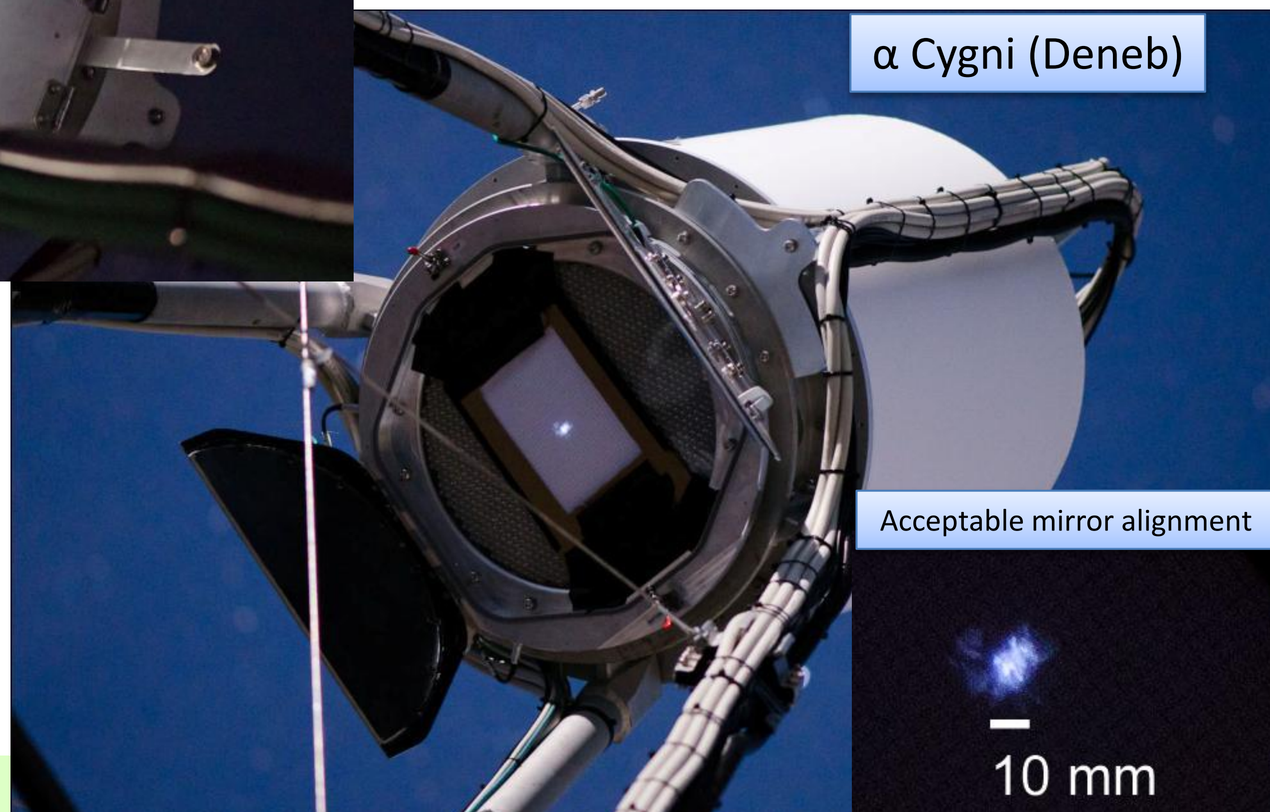
Cabling and Testing



First Night

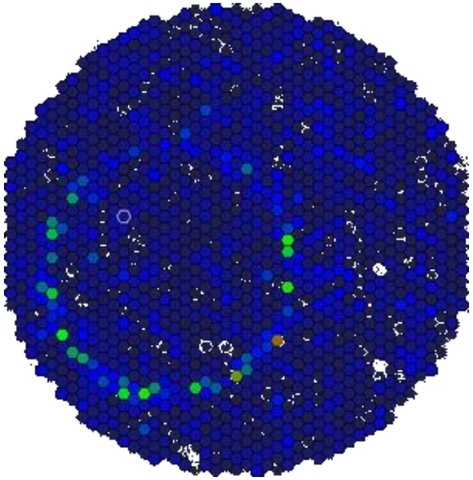
Night of 11 – 12 Oct 2011
Full moon

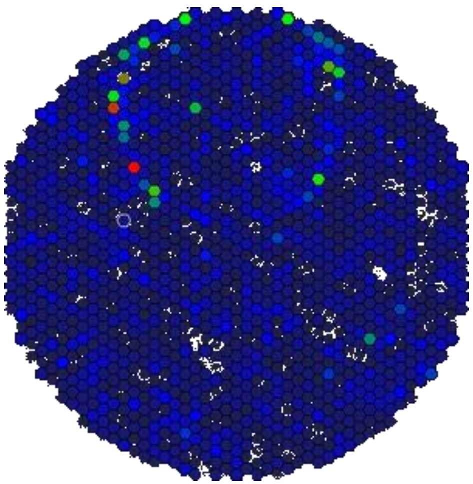


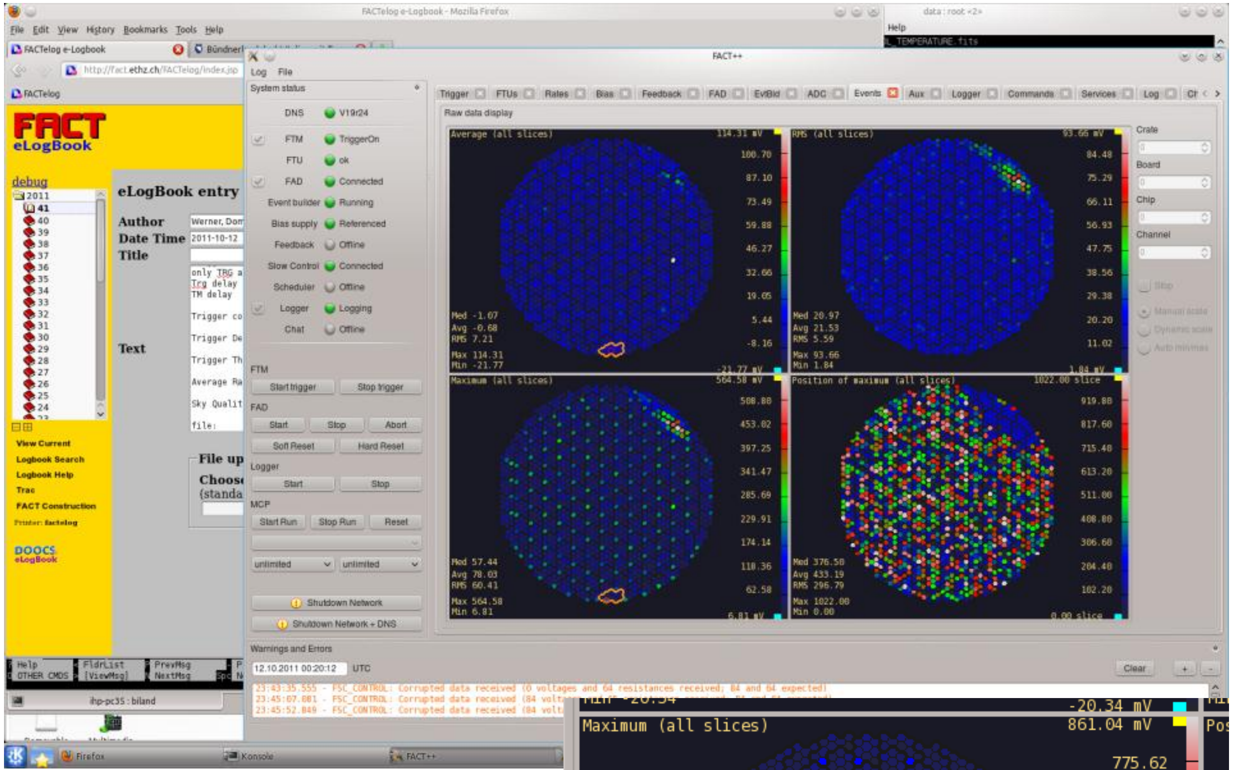


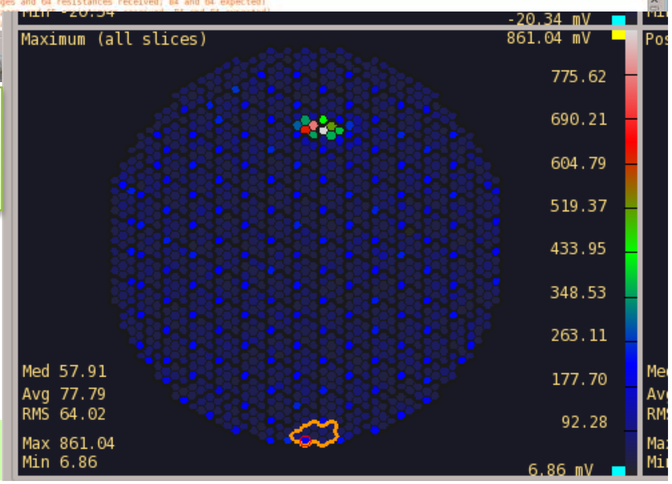
First Images

Muon rings (T. Bretz)



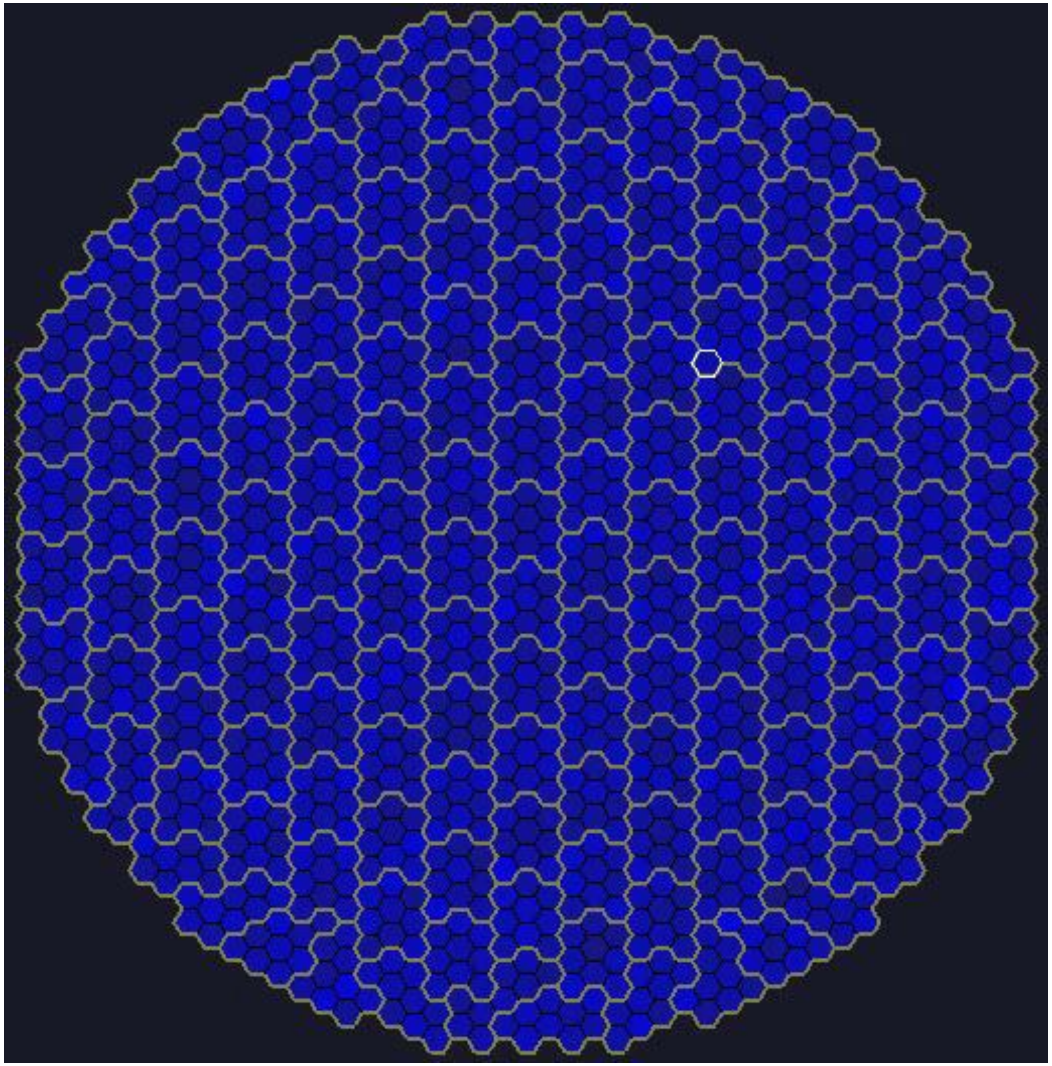






First events on the online display

Movie



0.5 ns / frame

Movie prepared by T. Bretz
EPF Lausanne

Summary

> Camera successfully installed
> First Cherenkov showers observed
> Commissioning ongoing
> Plan for first signal this year

Acknowledgements

We gratefully acknowledge the important contributions from

- The ETH Zurich grant ETH-10.08-2
- The funding of novel photo-sensor research by the german BMBF Verbundforschung

We also thank

- Instituto de Astrofisica de Canarias allowing us to operate the telescope at the Observatorio Roque de los Muchachos in La Palma
- the Max-Planck-Institut fuer Physik (MPI Munich) for providing us with the mount of the former HEGRA CT3 telescope
- Eckart Lorenz as the ‘father’ of the project