The FACT Project

First G-APD Cherenkov Telescope

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ETH Zurich

The FACT Project

Key Question:

can newly developed Si-based photosensors [G-APD, SiPM, MPPC,…] be used in Cherenkov Telescopes ?

- reduction of operation complexity (less fragile, no HV)
- stable remote operation
- eventually lower cost and higher efficiency by profiting from development for large market for Si-based technology

Main Problem:

PMTs and G-APD have rather different features

==> 'difficult' to compare datasheets

Solution:

Build a CT using new photosensors and try

==> **F**irst G-**A**PD **C**herenkov **T**elescope

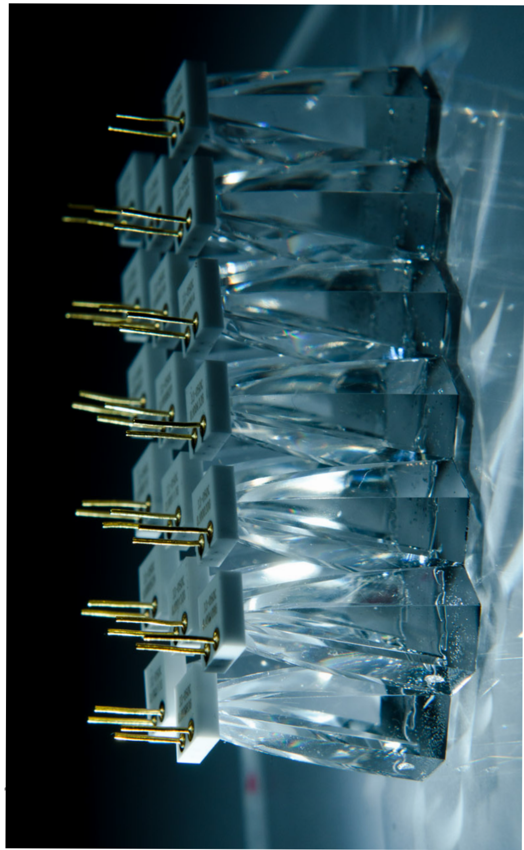
The FACT Project

Main Components:

- Refurbished HEGRA CT3 telescope at LaPalma
  (9.2m^2 mirror area, f/d = 1.4, new drive system)

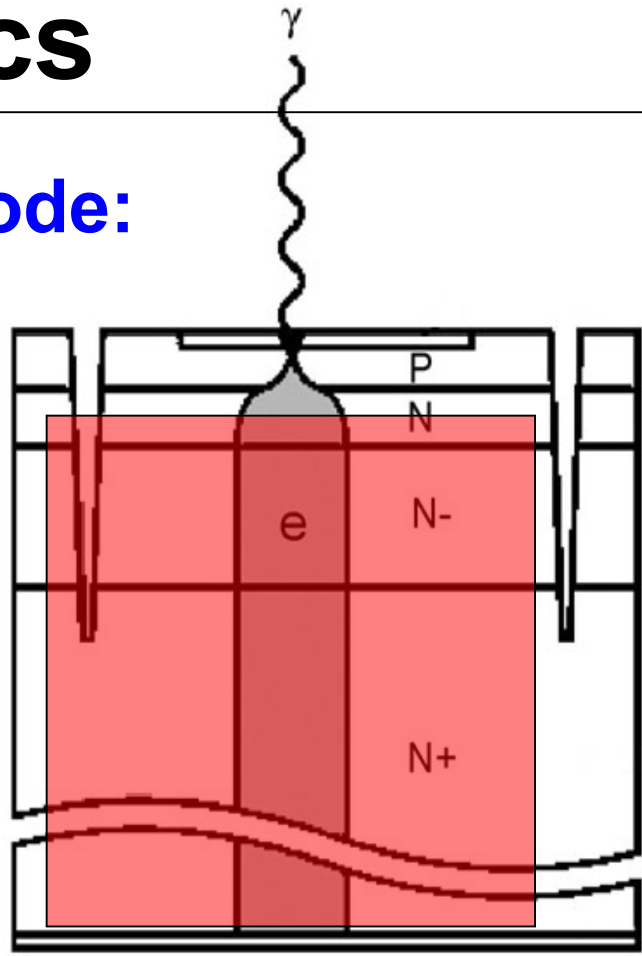
Camera:

- G-APDs (HAMAMATSU MPPC S10362-33-050C)
- Solid Light-Concentrators
- Electronics (DRS-4 based) in camera
- readout using standard ethernet




Refurbished HEGRA-CT3 Telescope at La Palma:
- new mirrors installed (refurbished from CT1)
- new drive system installed
- new container as 'counting house'
- awaiting camera ….
9.2m² mirror area (next to MAGIC with 2x 236m² mirror…)

G-APD Basics



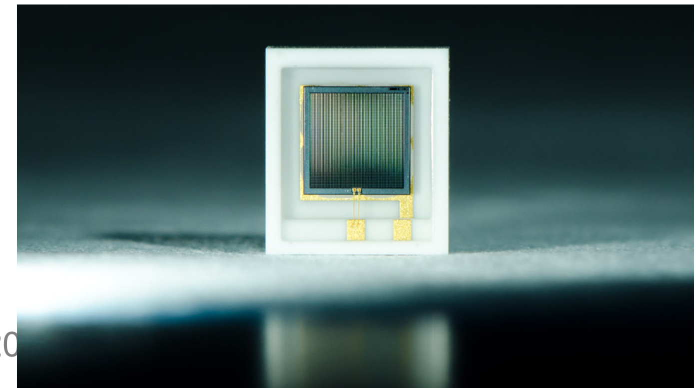
Geiger-mode Avalanche Photodiode:

(also called: SiPM, MPPC, PPD, …)

Pixelized Si-based photosensor:
a (single) photon hiting a cell has some probability to create a 'breakdown' -> always same signal

Many small cells ==>
total signal analogue sum of the isochronous single-cell signals

cell-sizes O(100x100 μm^2)



G-APD Basics

Typical values:

Bias Voltage: 50-100 V (no HV needed !)

Gain: 10^5 … 10^7

Photo-detection efficiency: 30...40 % (?)

[wavelength dependent]

no ageing (even if accidentaly exposed to daylight)

[but limited long-time experience]

several manufacturers:

CPTA/Photonique, Perkin-Elmer, Hamamatsu, Zecotec, MPI Semiconductor Lab, …

G-APD Features

Saturation (if >>10% of cells occupied; NSB!!!)

larger cell size --> higher PDE (less dead area)

but also worse saturation

FACT: use 50x50um^2 to be able to run with high NSB

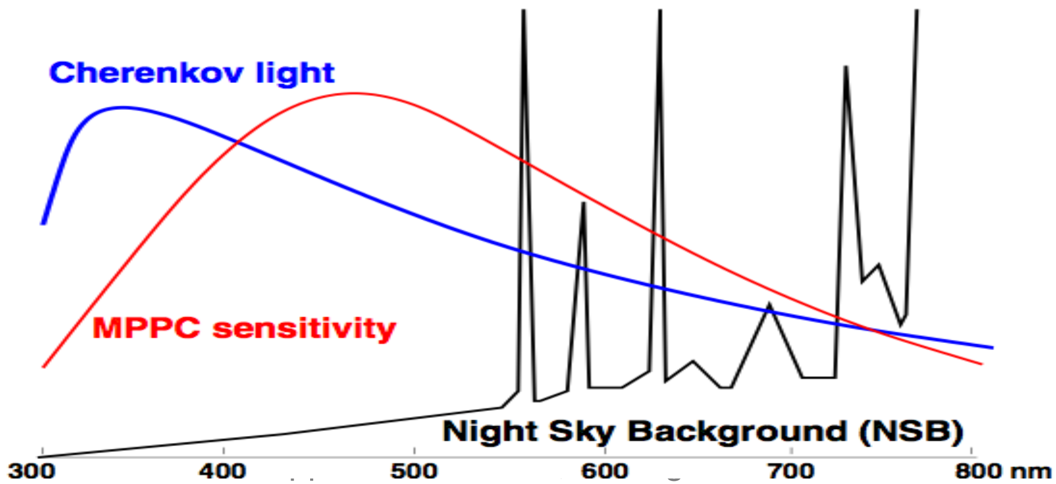
Temperature dependent gain (~5% / degree)

==> temperature stabilization or

gain stabilization via feedback system

Sensitive also >>700nm

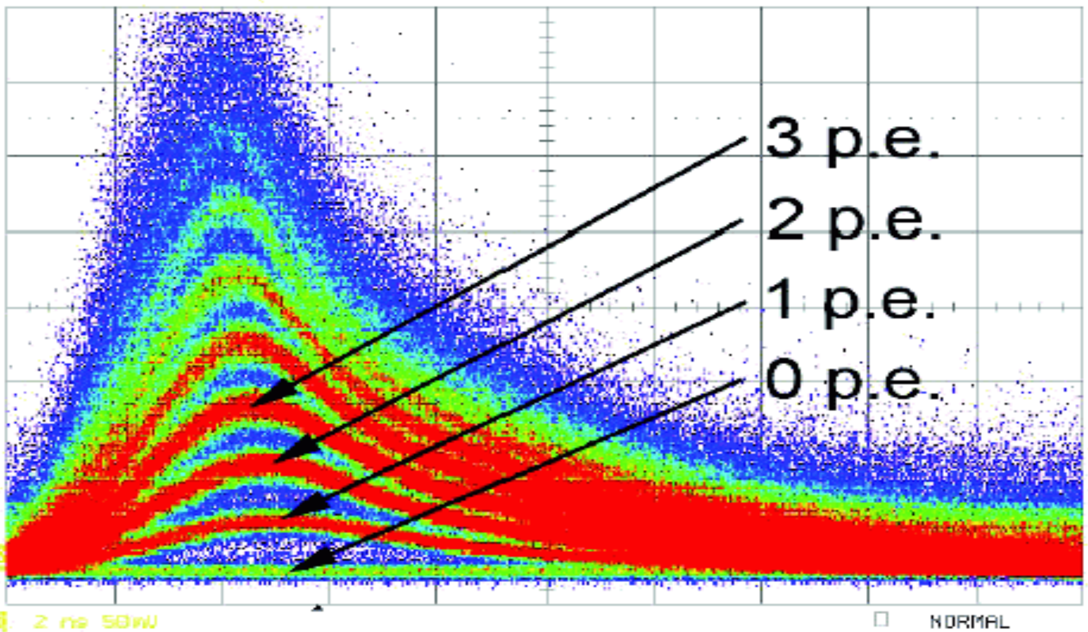
(==> more NSB)



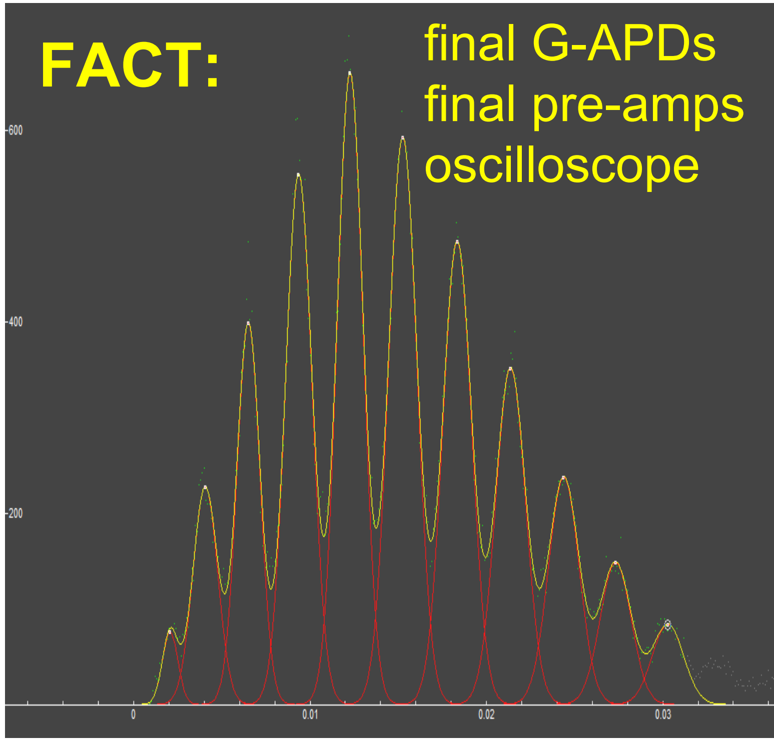
G-APD Features

slower rise and decay time than best PMTs,

but very constant signals (if constant gain)

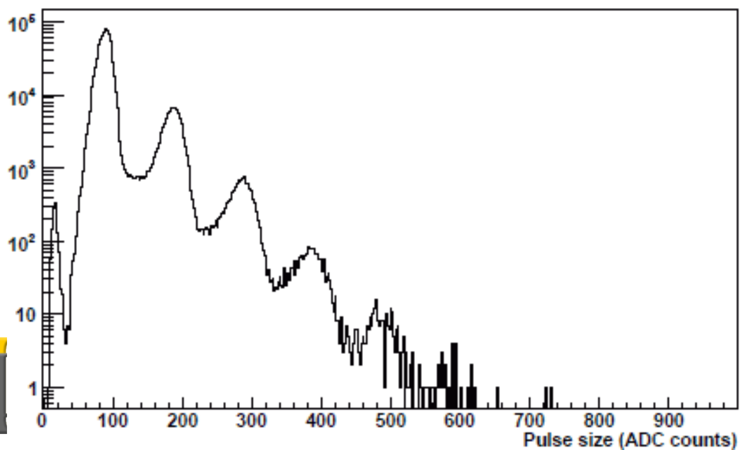


LED spectr., 2 ns horiz., 50 mV vert. spacing



G-APD Features

- Dark counts
  - Cells can be triggered by any free carrier, eg. thermally generated or field assisted tunneling.
  - Rate: some 100 kHz up to MHz per mm^2 at room temperature.
- Afterpulses
  - The delayed release of carriers trapped during a breakdown in a cell can trigger the cell again.
  - Afterpulse probability 5 – 20% depending on the gain.
- Crosstalk
  - Defines the spectrum of the two phenomena above.
  - Crosstalk probability 5 – 20% depending on the gain.



Typical dark count spectrum of a G-APD (crosstalk 13%). Peaks up to 6 triggered cells can be discerned. The spectrum also includes afterpulses of previous dark count events.

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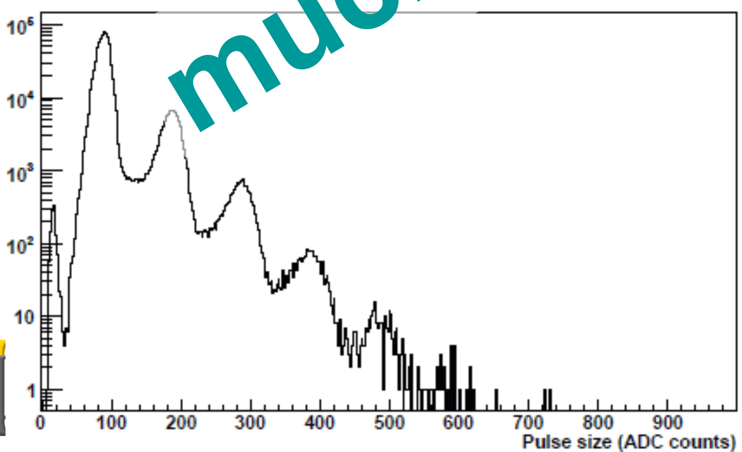
much worse than PMTs ???



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have to deal with much higher NSB

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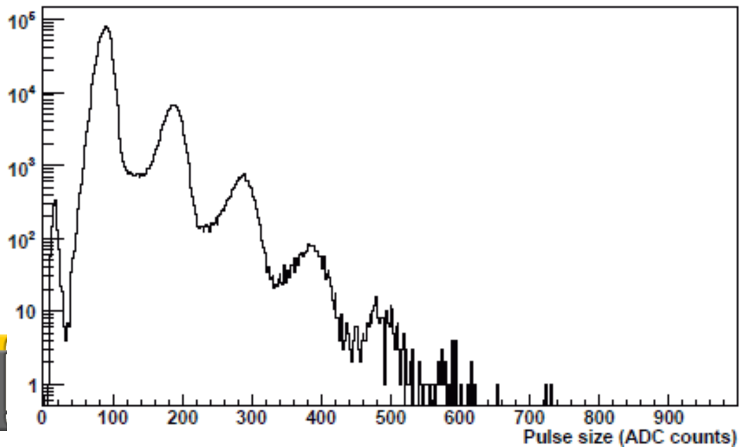

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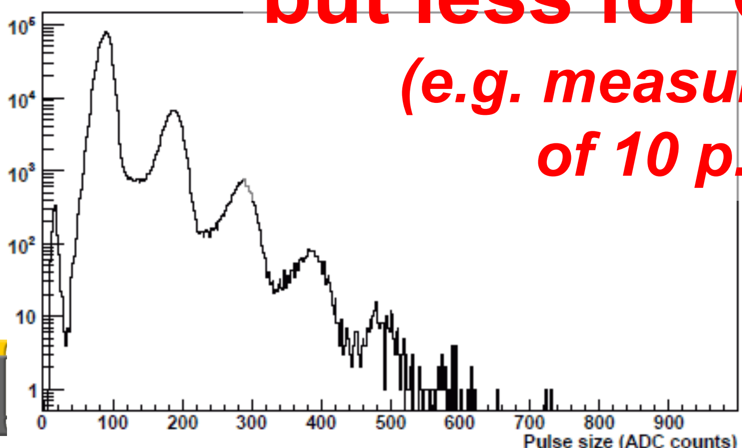
important for single photon counting, but less for CTs: can be calibrated

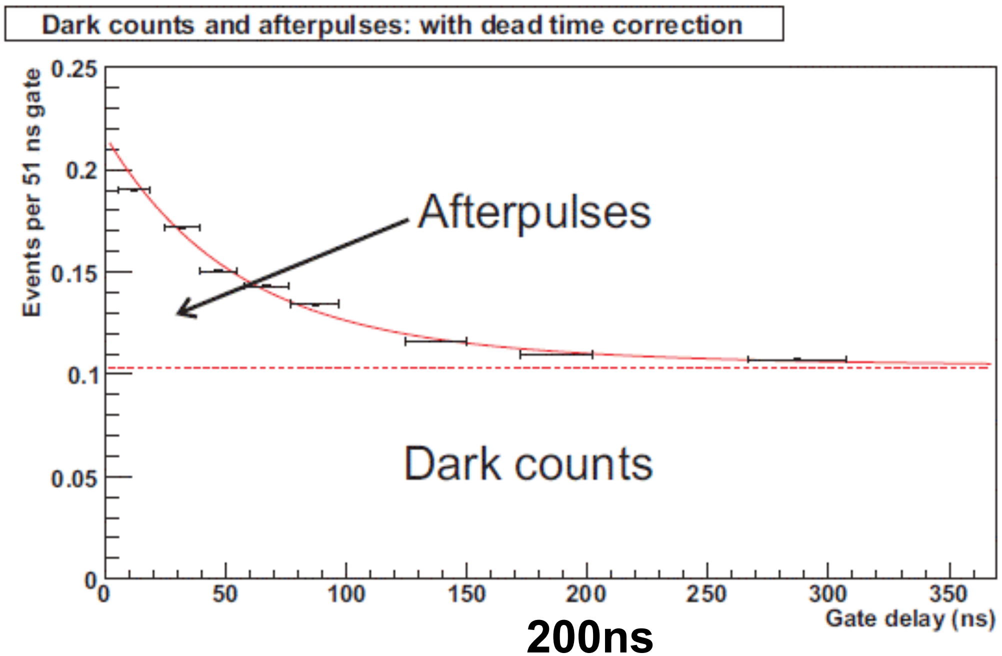
(e.g. measure on average 11 instead of 10 p.e. for 10% Crosstalk)



Typical dark count spectrum of a G-APD (crosstalk 13%). Peaks up to 6 triggered cells can be discerned. The spectrum also includes afterpulses of previous dark count events.

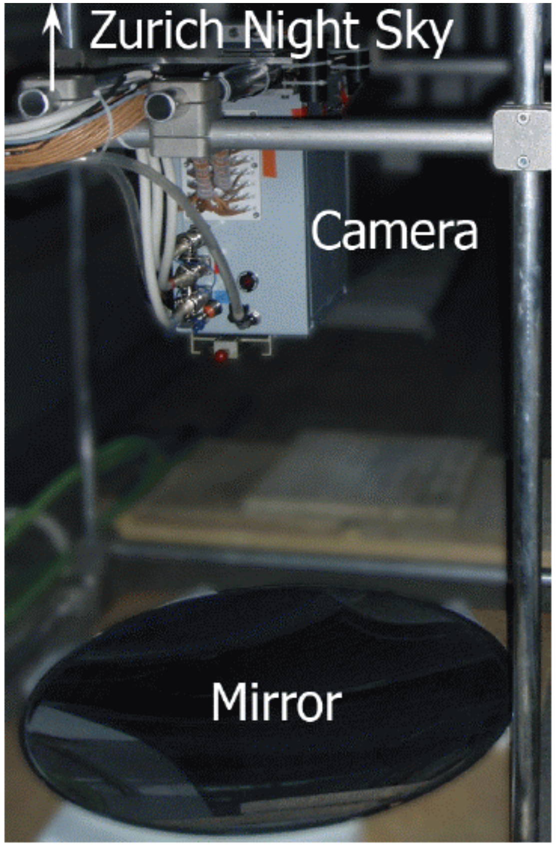
G-APD Features

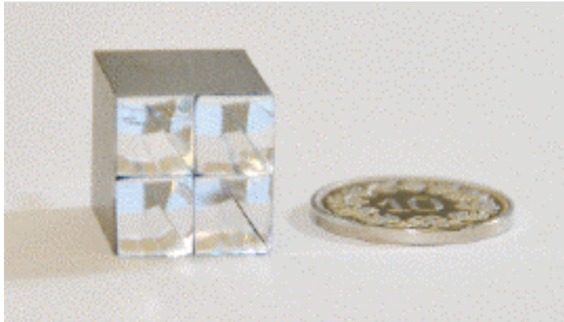
- Dark counts have a random time distribution.
- Afterpulses have an exponentially decreasing probability after an initial breakdown.



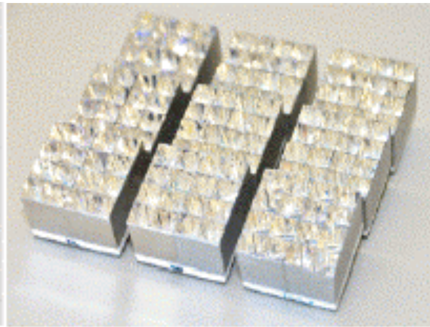
Number of pulses per gate for variable delays after an initial pulse. The number of pulses decreases exponentially to the level of dark counts.

Prototype Camera (2009)

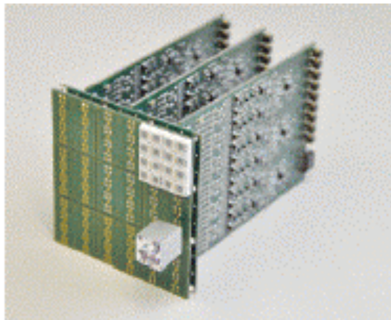




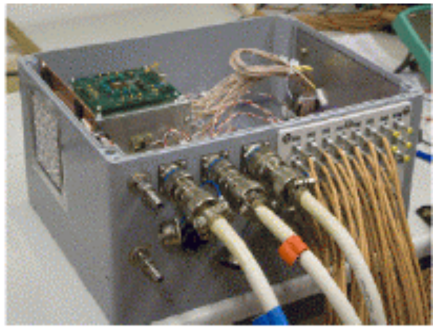
Hollow Cone: $(7.2\,\text{mm})^2 \rightarrow (2.8\,\text{mm})^2$
1 cone per G-APD, blocks of 4



4 G-APDs/pixel = 1 channel
36 pixels, each $(14.4\,\text{mm})^2$



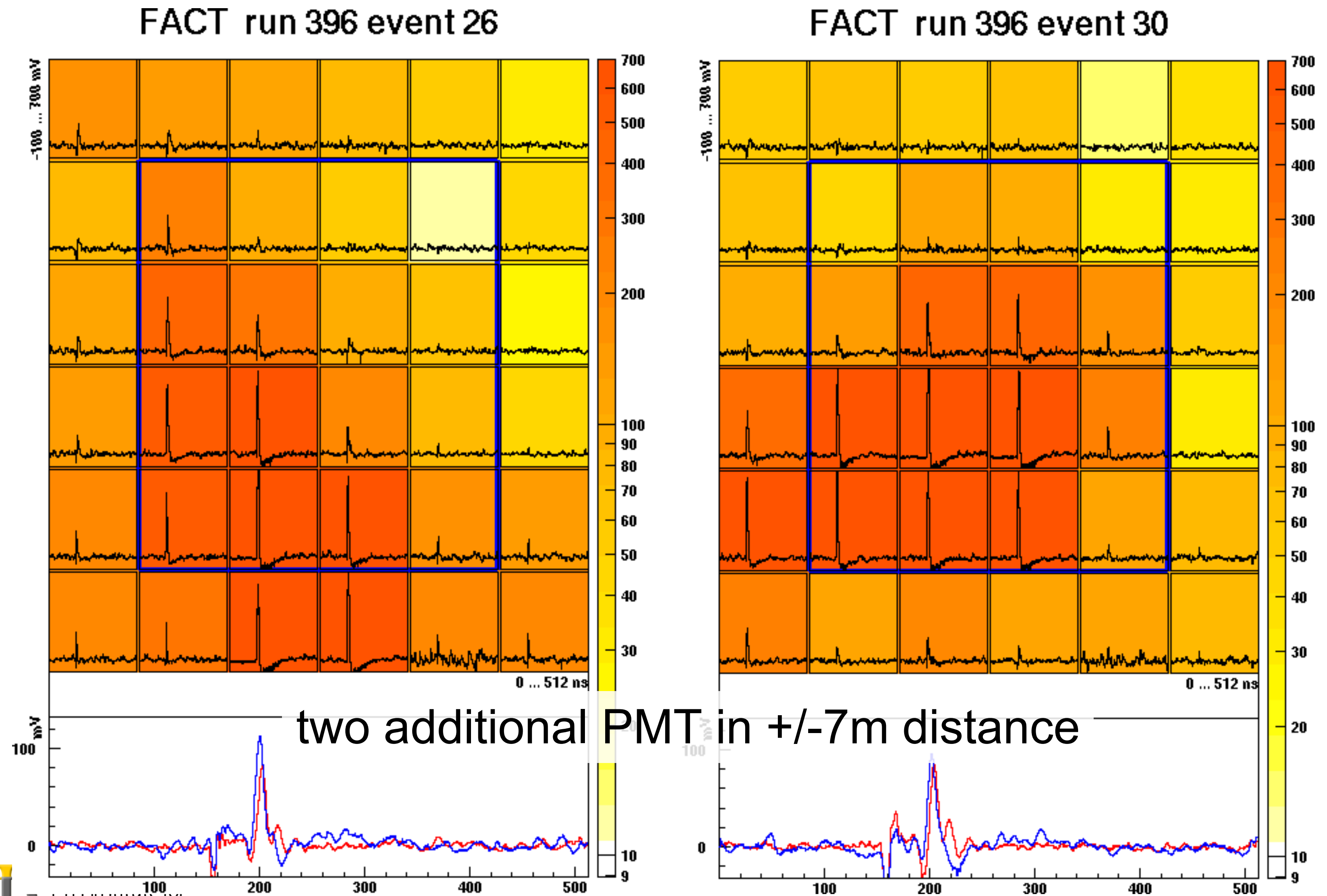
3 analog preamplifier boards
Distribution of bias voltage



Light and rain-tight box
Analog signal transfer

- Mirror with 80 cm focal length ⇒ 1° f.o.v / pixel
- NSB from buildings and moonlight: ∼ 300 MHz / G-APD (= 1.2 GHz / pixel)
- Meas. at 22° night temp., G-APD plane cooled to 18°, no voltage feedback

Prototype Results (2009)



two additional PMT in +/-7m distance

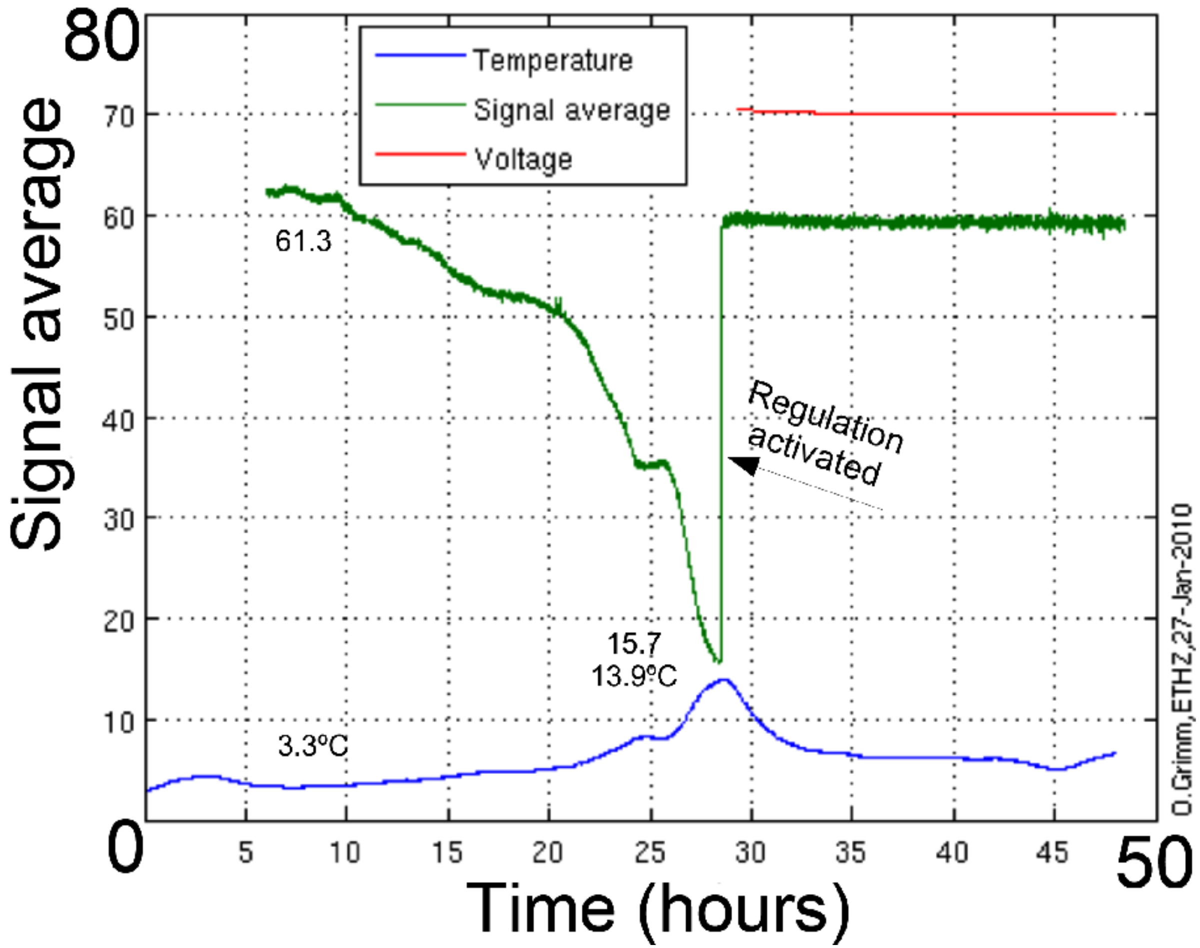
DRS-2 with known cross-talk problems

HV Feedback System

Not sufficient to correct for gain-variation in offline analysis:
Does also affect the trigger !!!

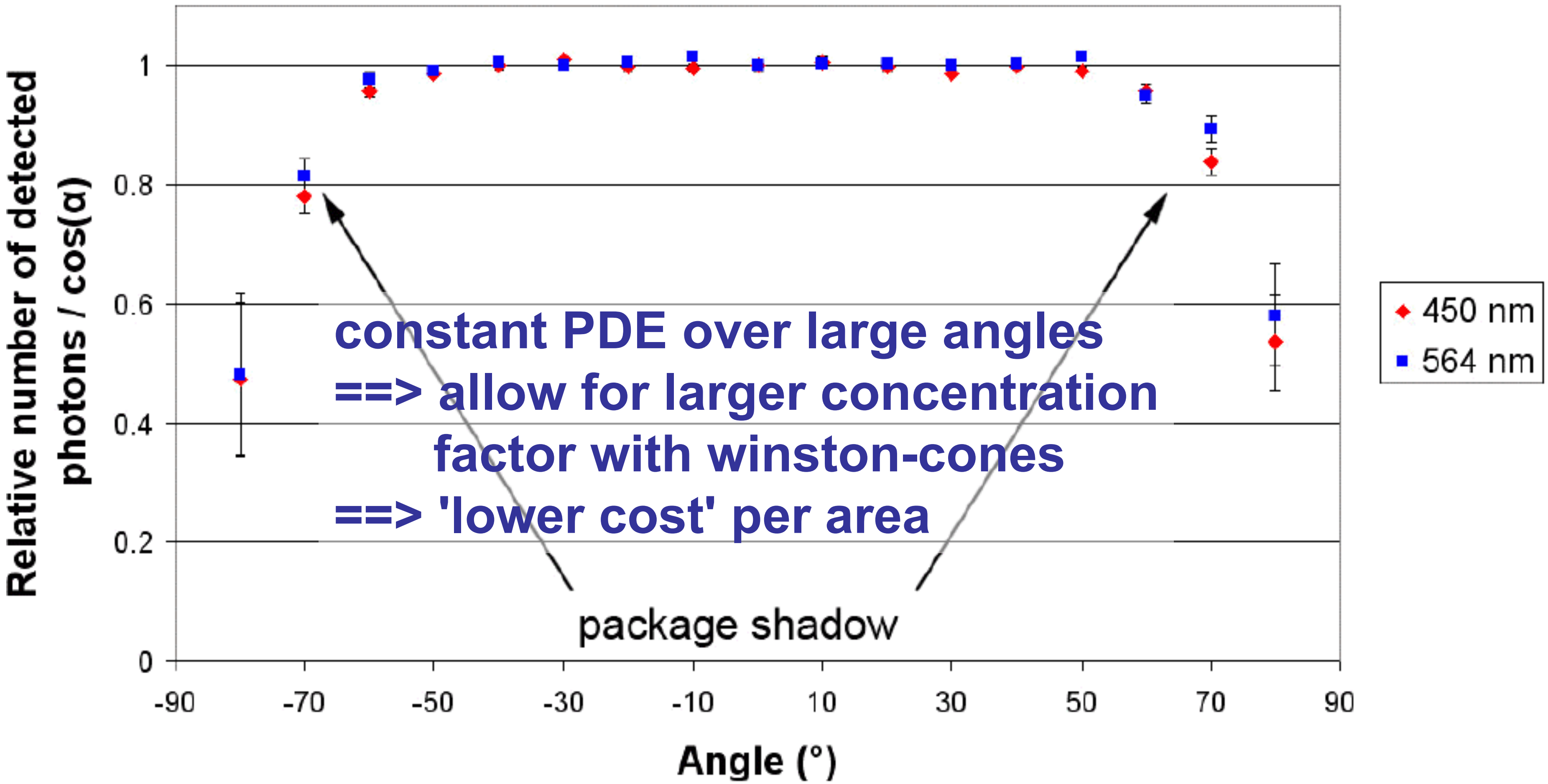
Instead of rather complicated Temp. stabilization, use 'feedback':

- stabilized calibration signal
- measure signal
- adapt voltage to keep signal const.



G-APD Features

angular acceptance:

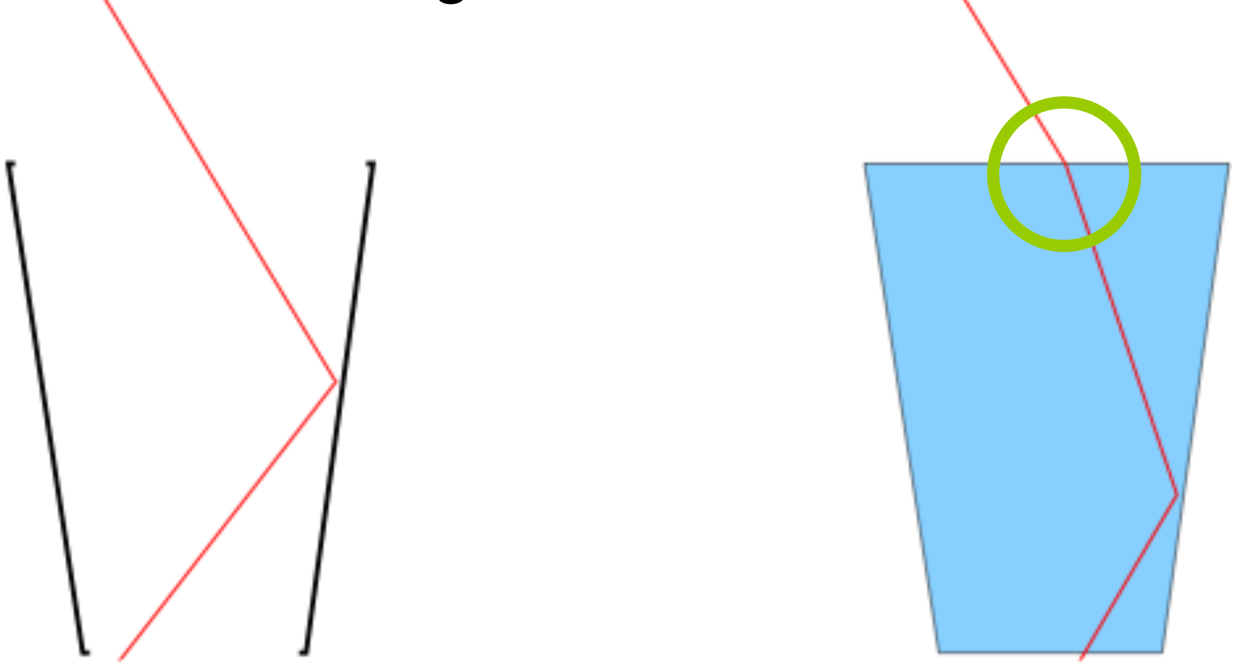


constant PDE over large angles
==> allow for larger concentration factor with winston-cones
==> 'lower cost' per area

Why Solid Light Concentrators

Liouville theorem: can not shrink phase-space

Area <----> Angular Distribution



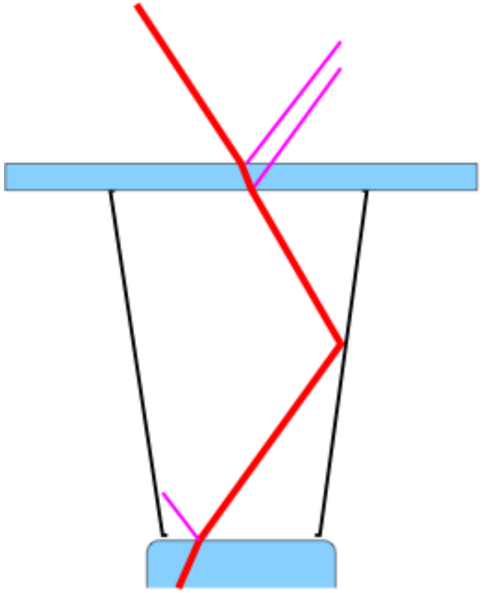
FACT:
~80mm^2

9.0mm^2
(7.8mm^2)

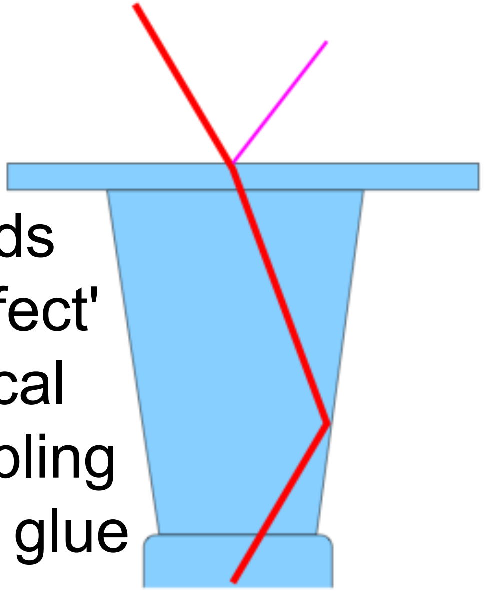
==> Solid cones allow higher area-concentration!

(important for photosensors with high cost/mm^2)

Why Solid Light Concentrators



needs 'perfect' optical coupling ==> glue

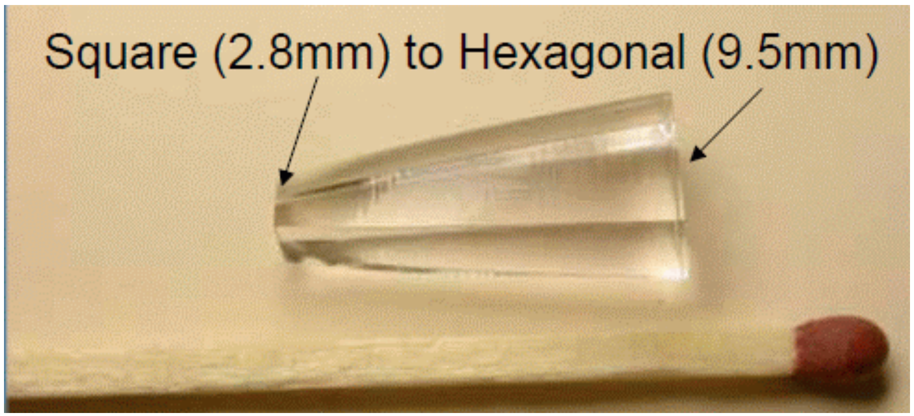


In case of sealed camera: less Frensel reflection

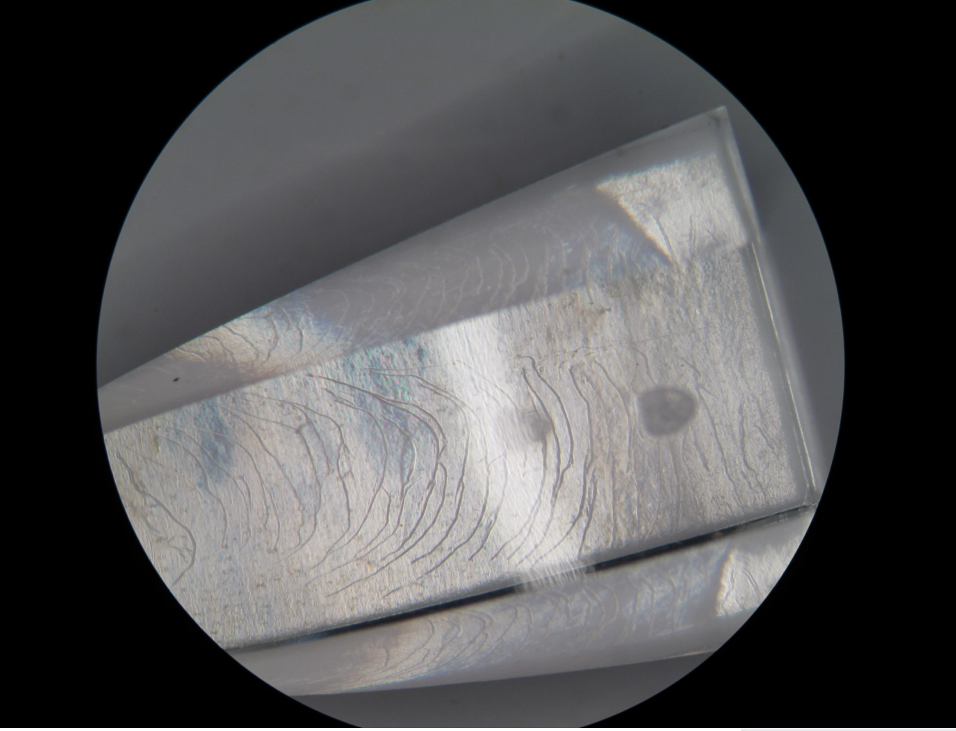
but: absorption
==> do not want too large G-APD area

Can use inexpensive casting (UV transparent PMMA)

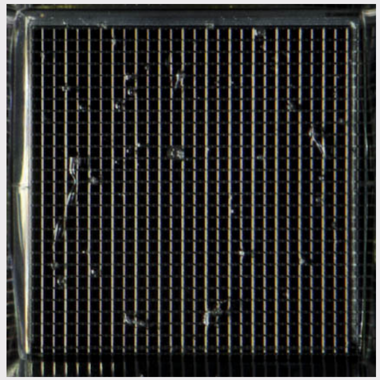
Complicated shapes possible
(FACT: square -> hexagon)



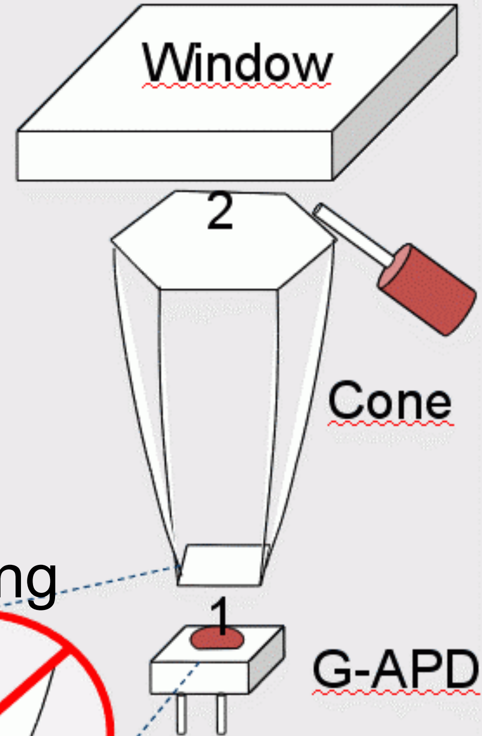
Problems



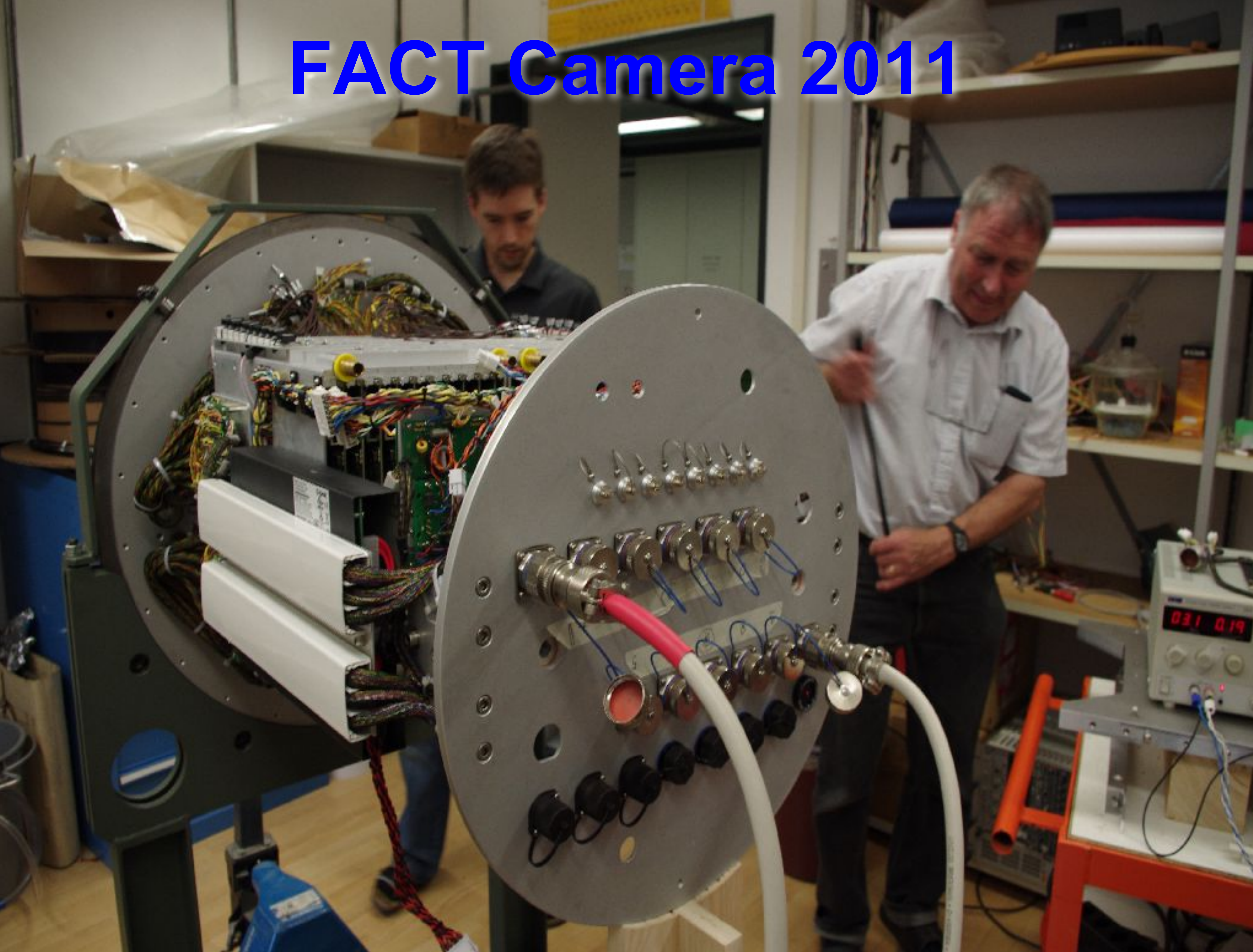
Too high pressure during casting reduces overall transmission (also micro-bubbles)



Tedious and time consuming glueing



FACT Camera 2011



FACT Camera (2011)

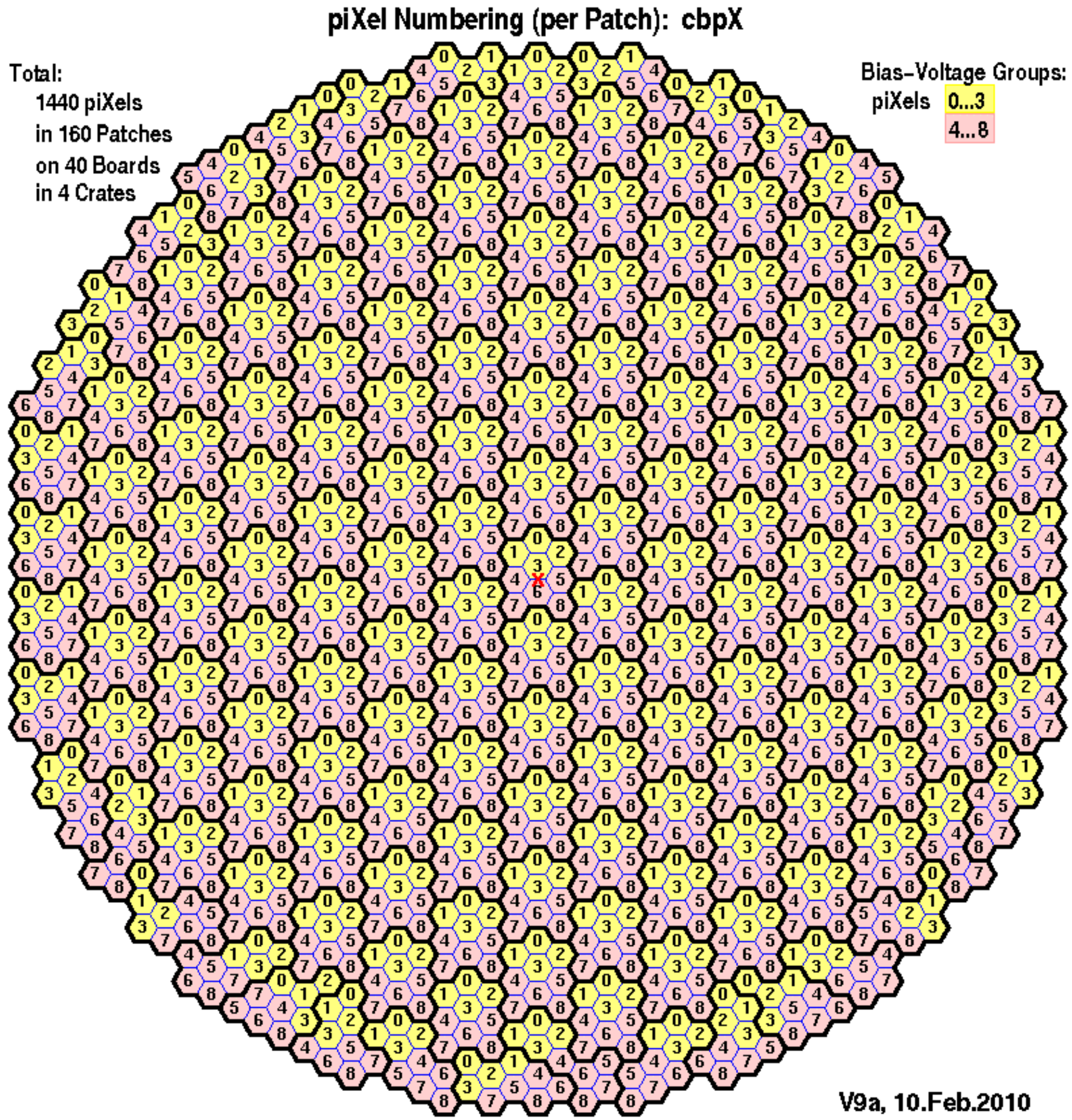
1440 G-APDS
=1440 Pixels
(0.1deg/Pixel
4.4deg FoV Camera)

320 HV Groups
for feedback system

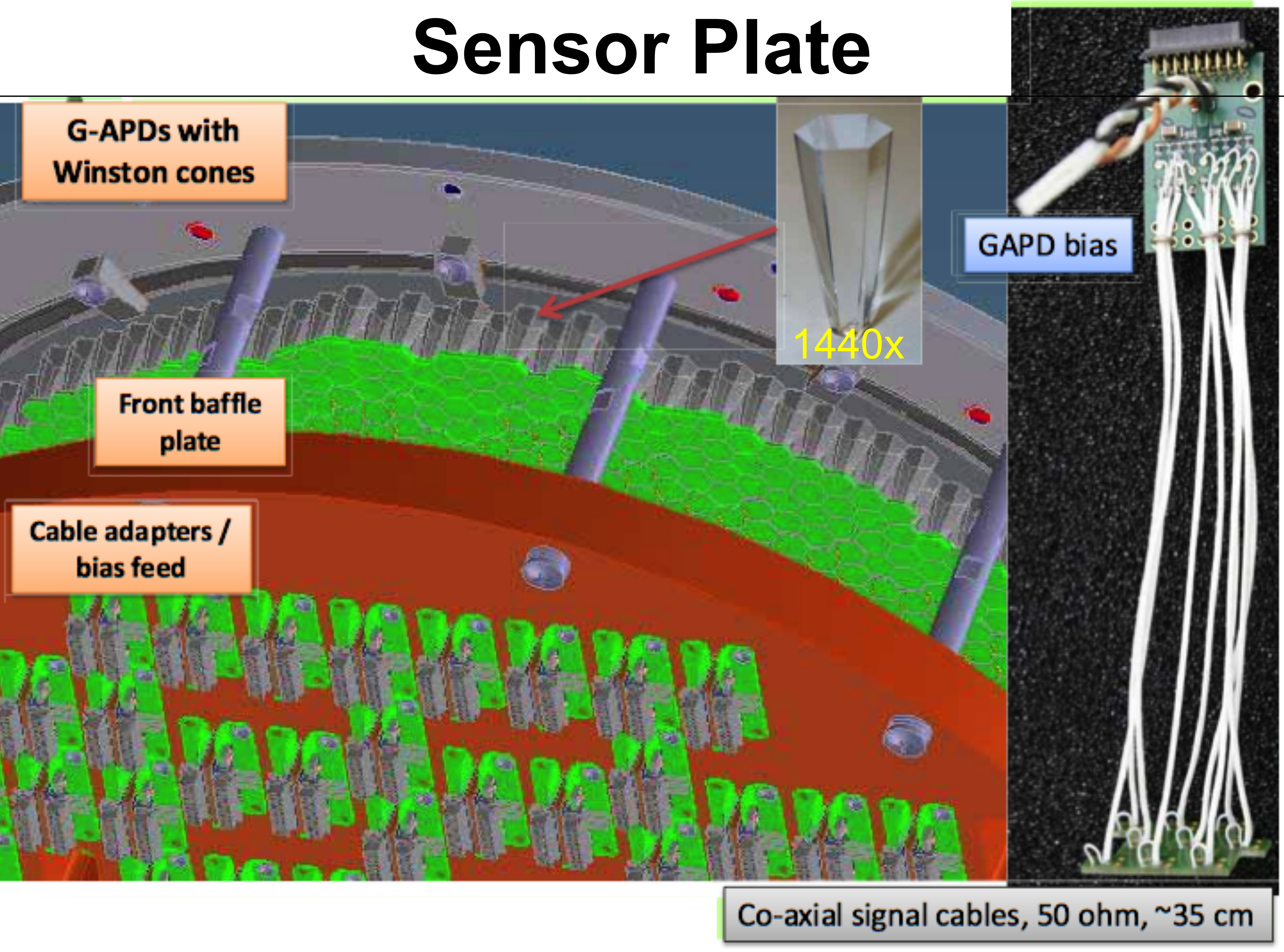
160 Trigger cells

40 Elec.Boards
in 4 Crates

Weight: ~200kg
Power: ~1kW
IP67



Sensor Plate



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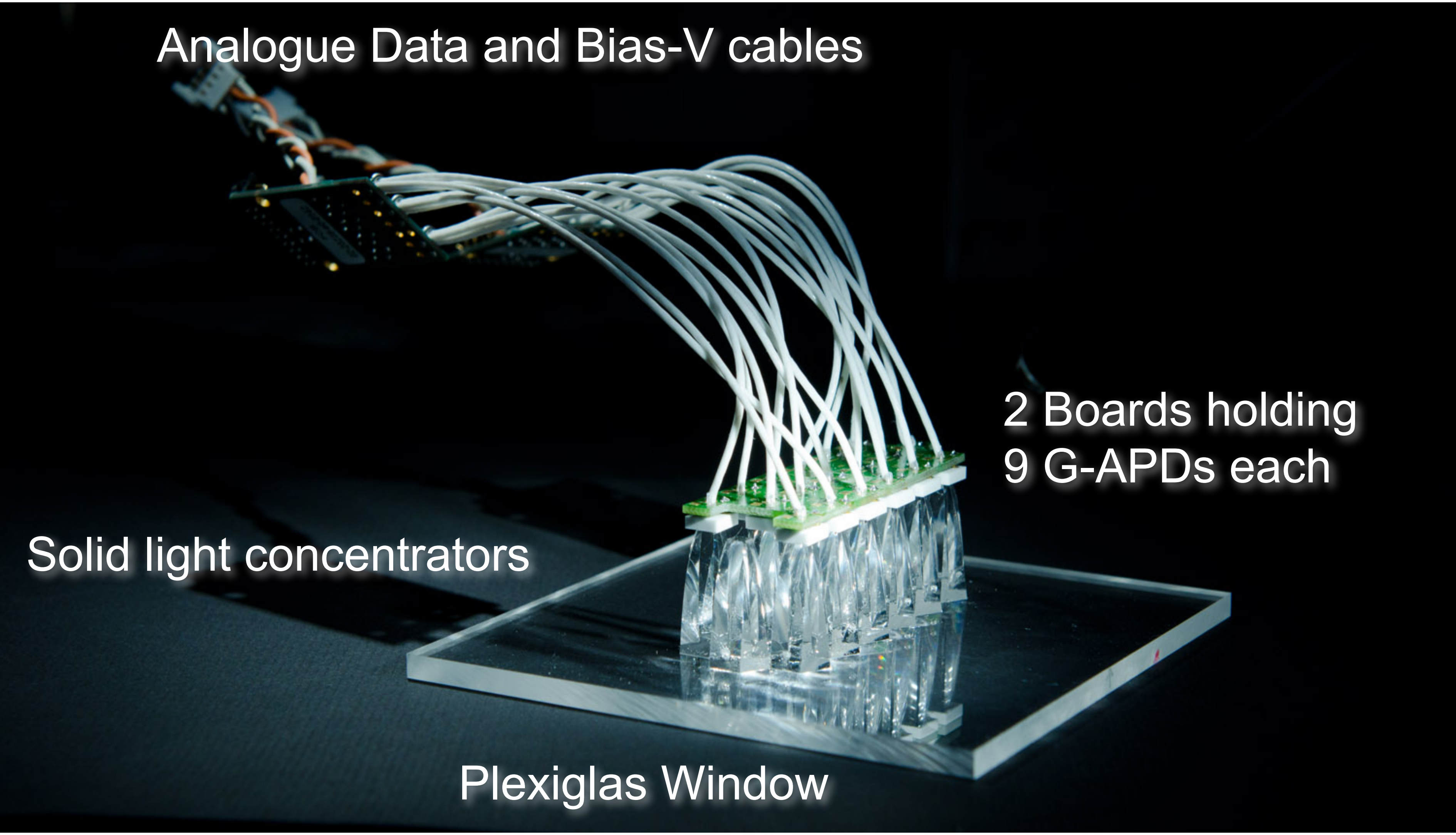
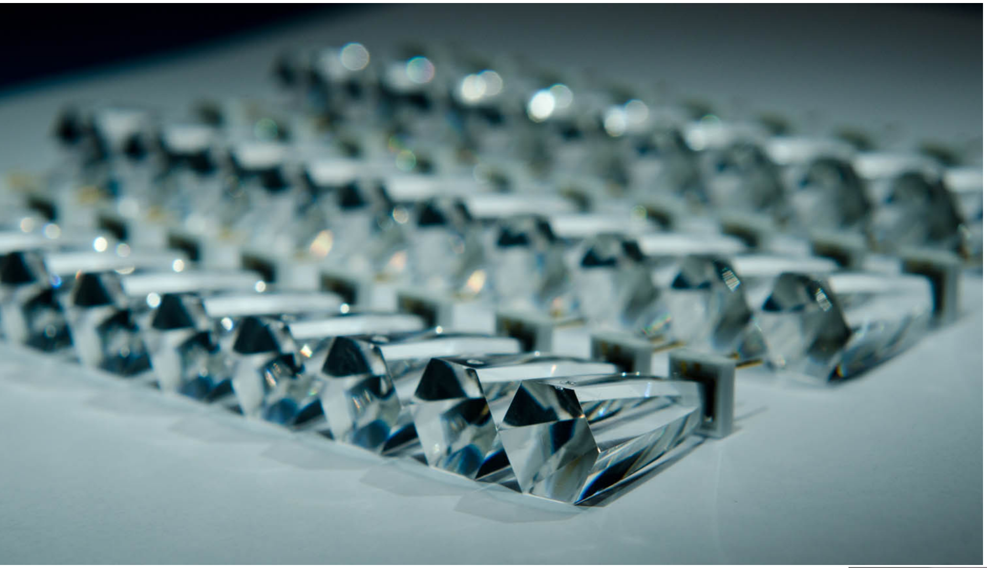


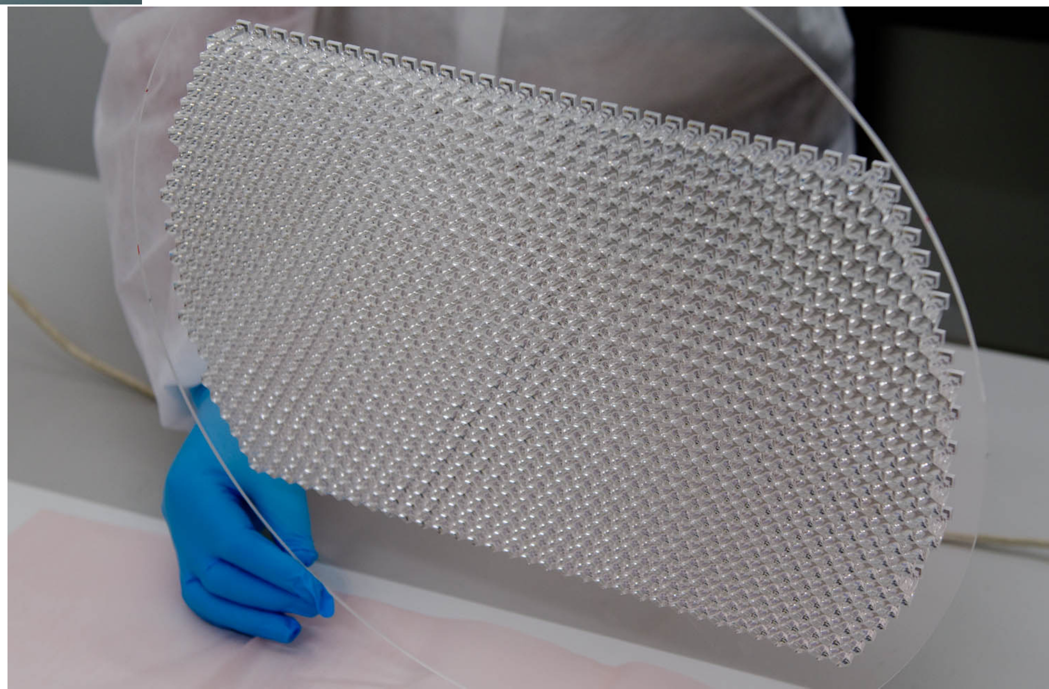
Sensor Plate (elec. side): Ready

Sensor Plate(window side): Progress

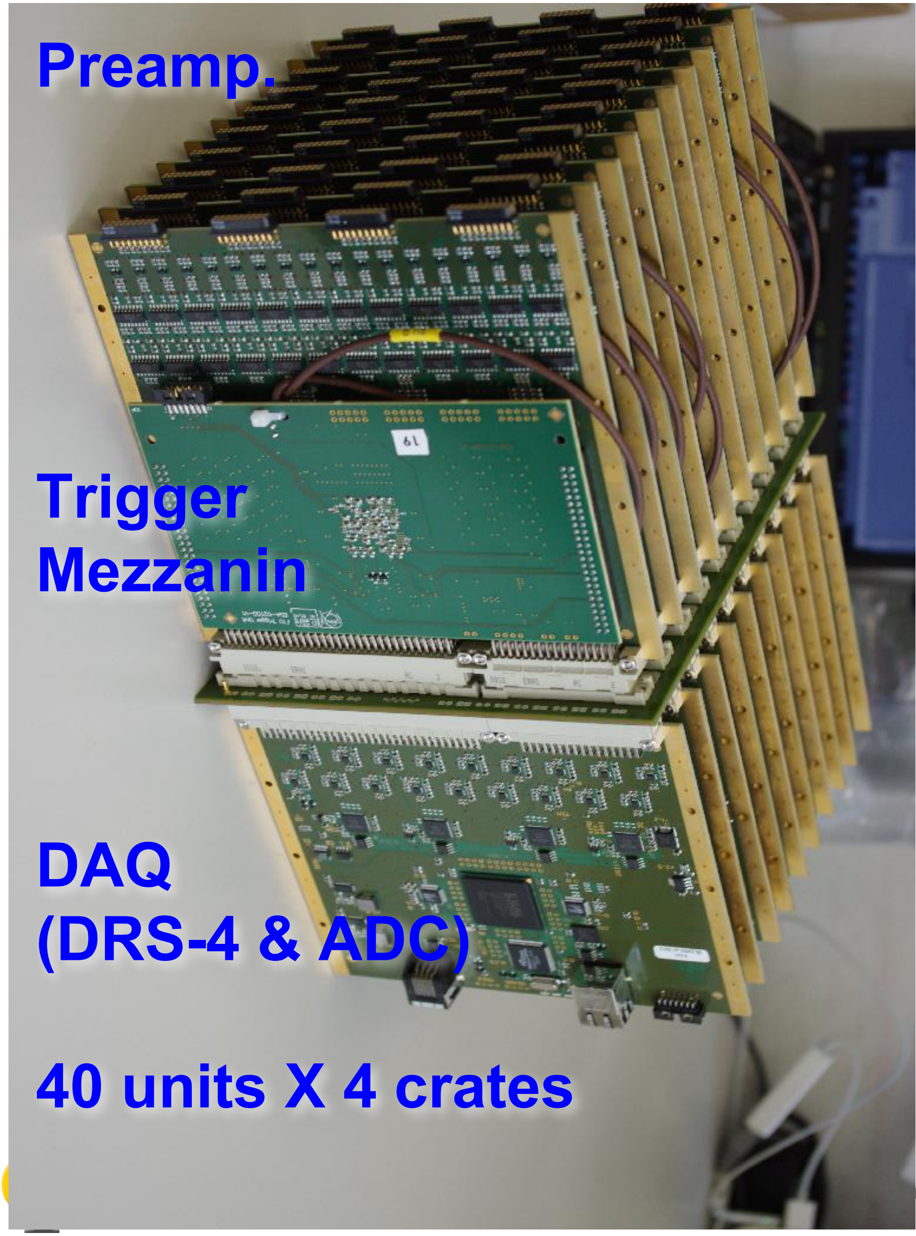


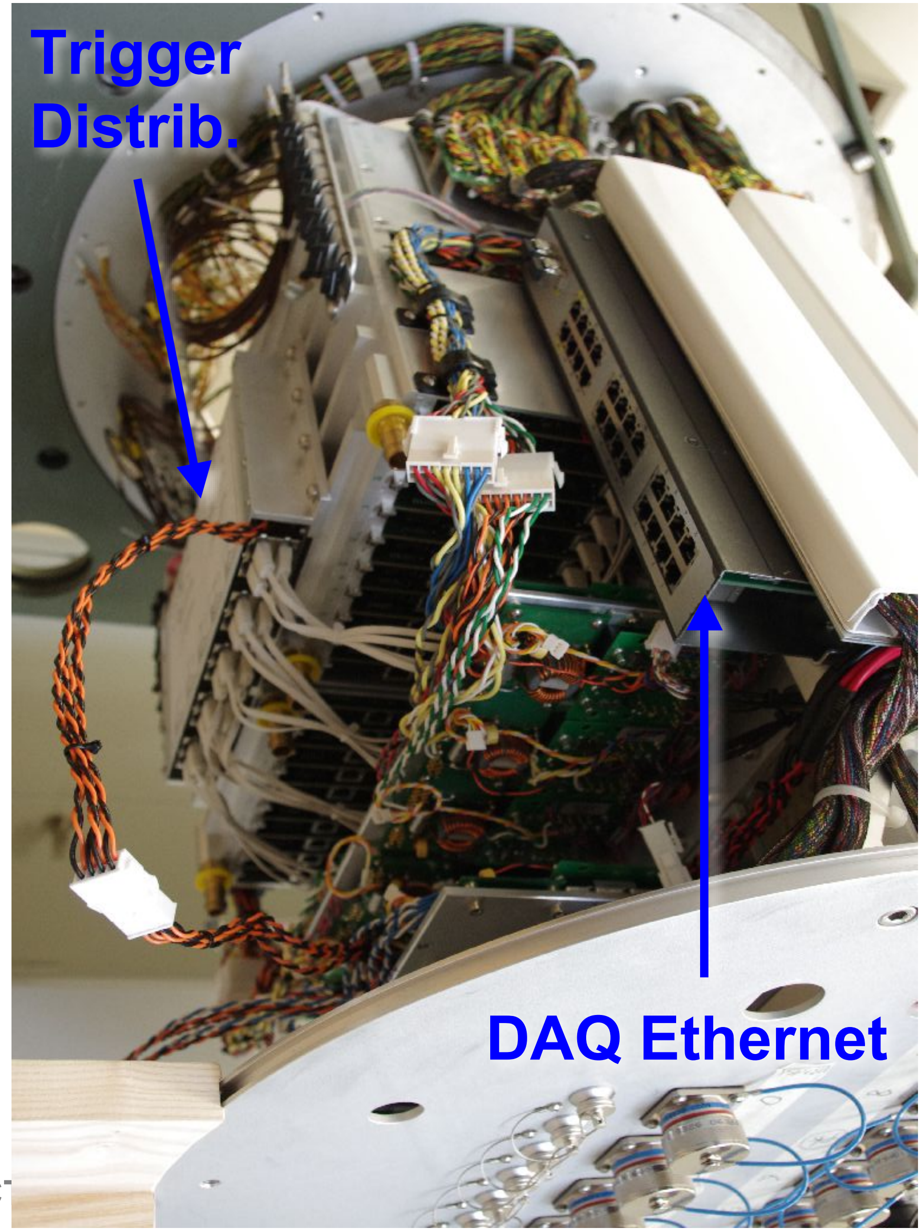
All ~1500 G-APDs glued to solid cones and tested

June 9th: >1000 cones with G-APDs gluded to front window (expect all done by end of this conference…)



Camera Electronics: Ready





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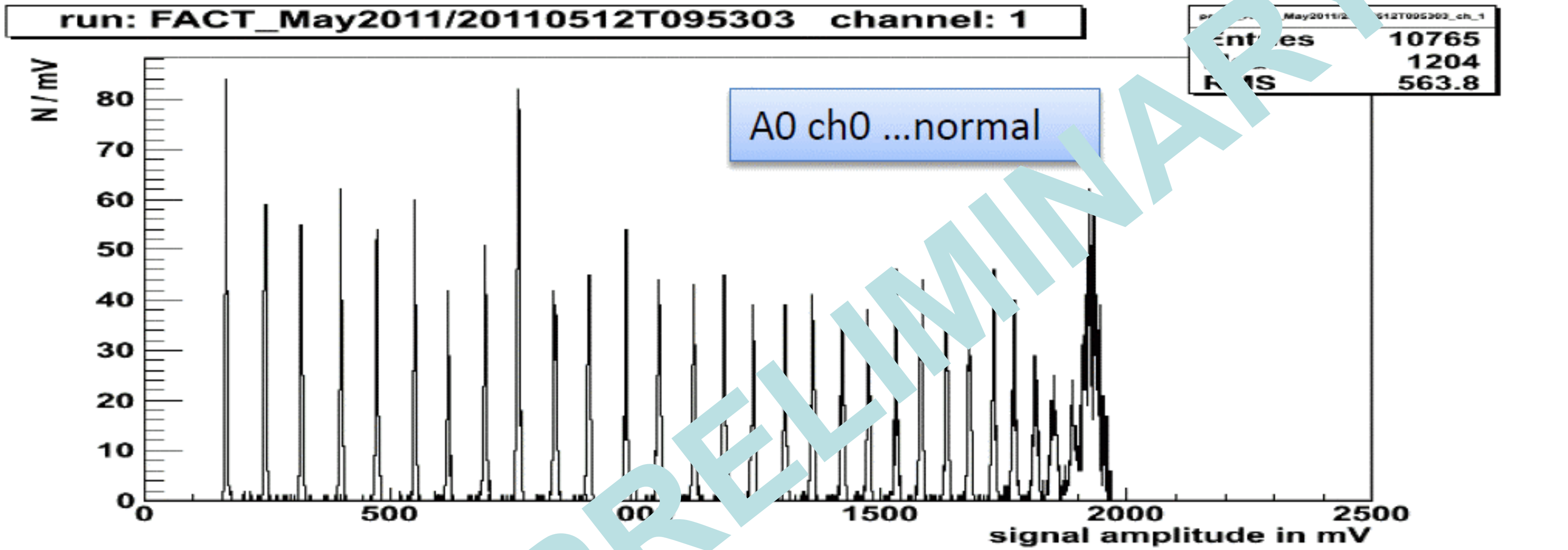
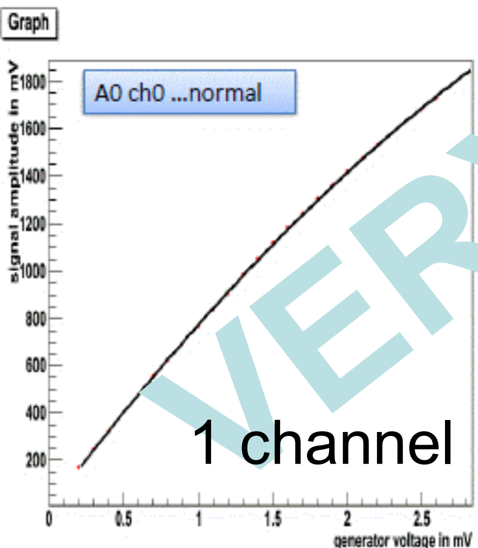
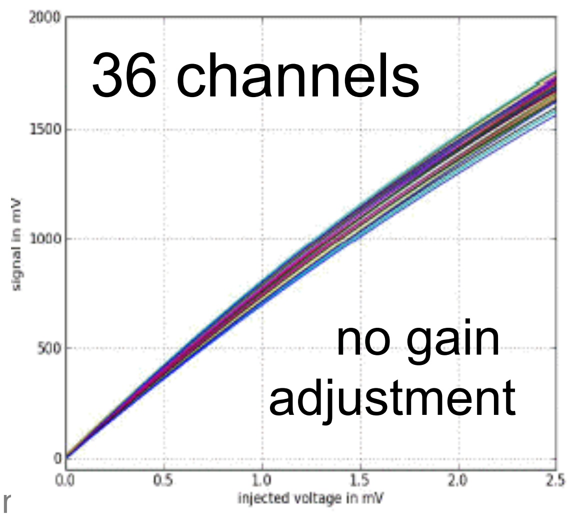




Linearity test of electronics
cables & preamp & DRS & ADC

Very linear
perfect fit with 2nd polynomial
(can‘t see the error bars ;-)



VERY PRELIMINARY

Data Acquisition 1: Ready

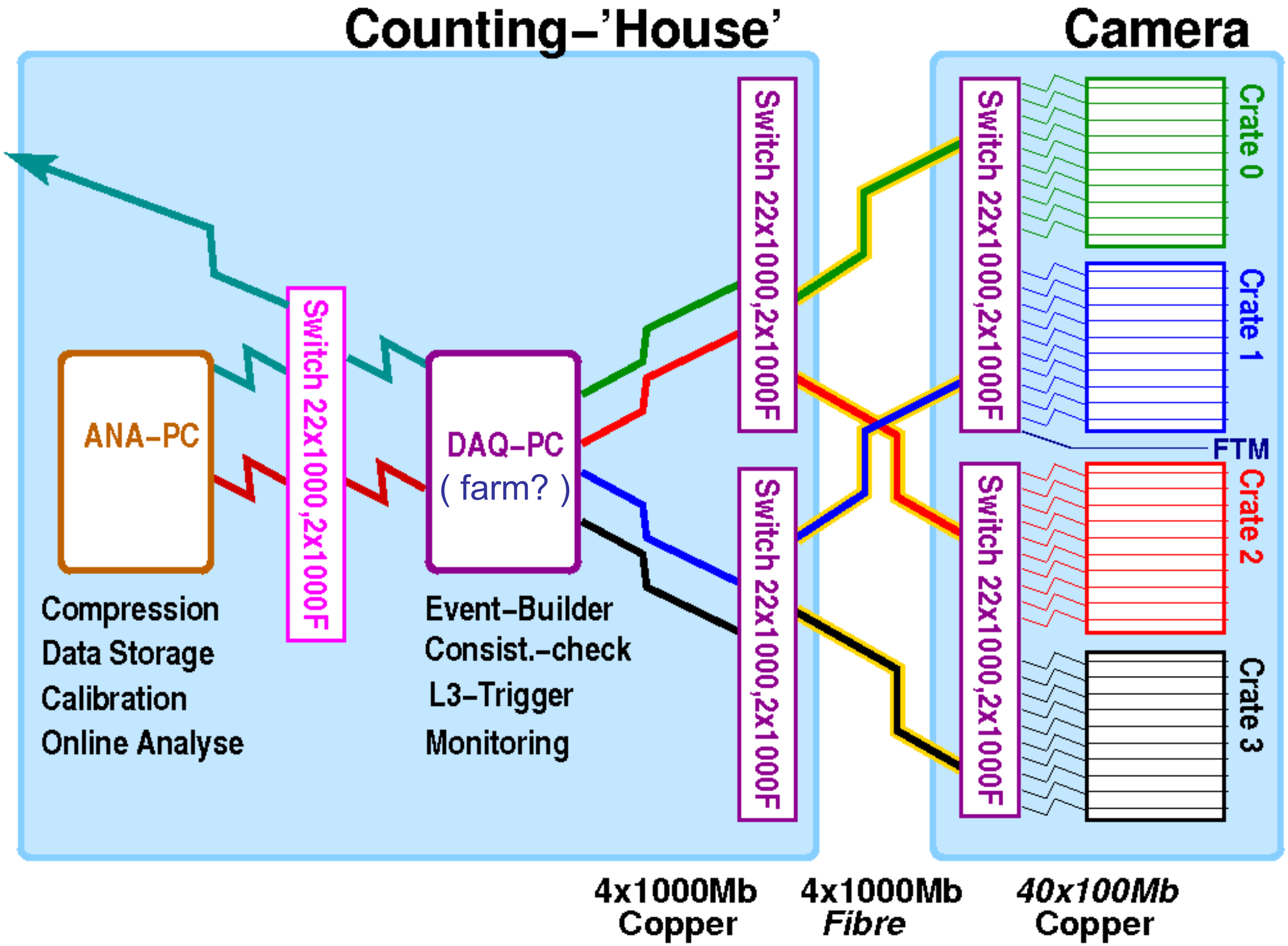
40 Boards a 36 Pixels

each board:
- 4x DRS-4 analog pipeline (0.7 - 5 GHz) with 9 Channels
- 4x serial ADC 33MHz
- FPGA, Ethernet

global Clock and Trigger signals

Data Acquisition 2: Ready

Standard Ethernet readout

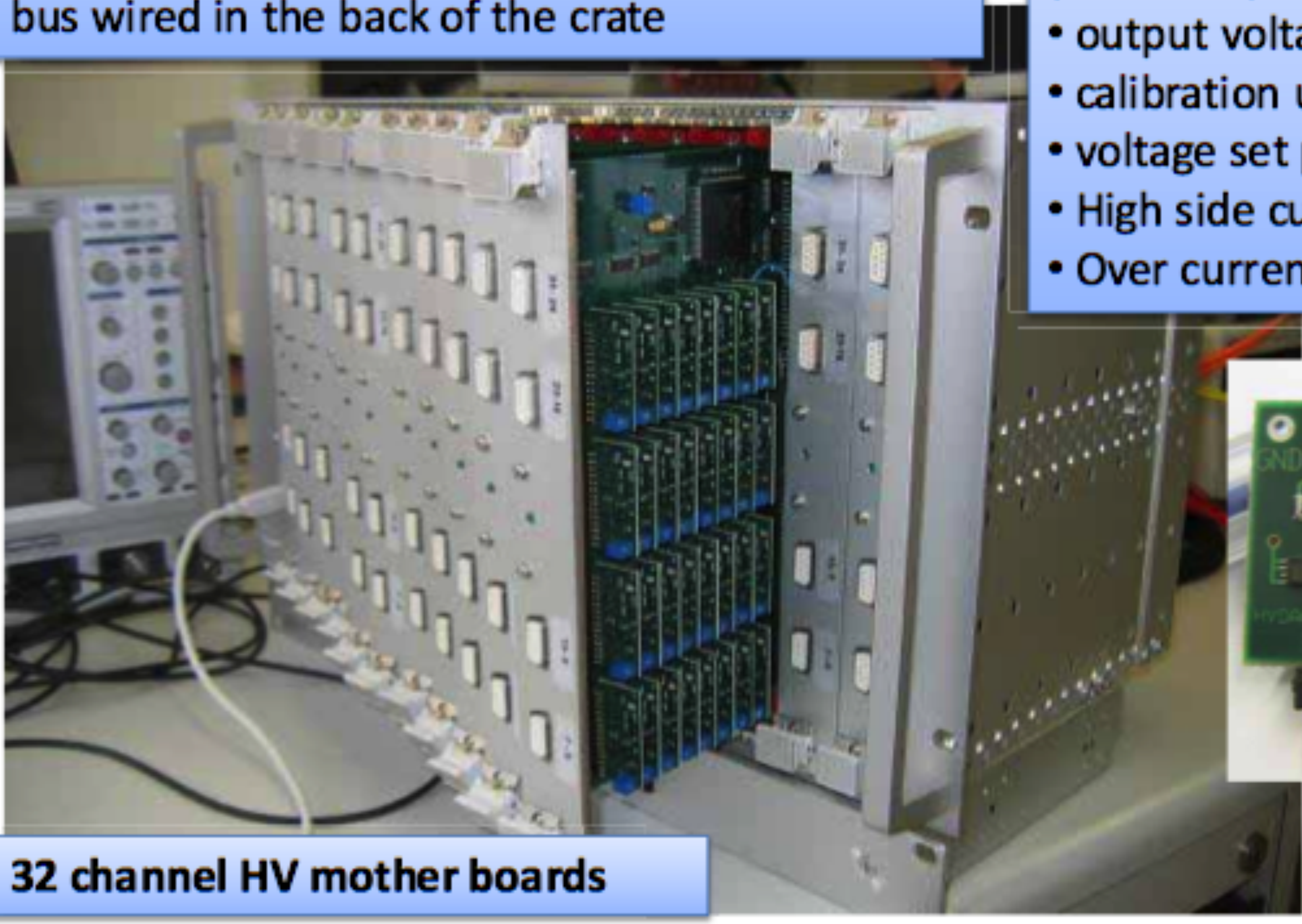


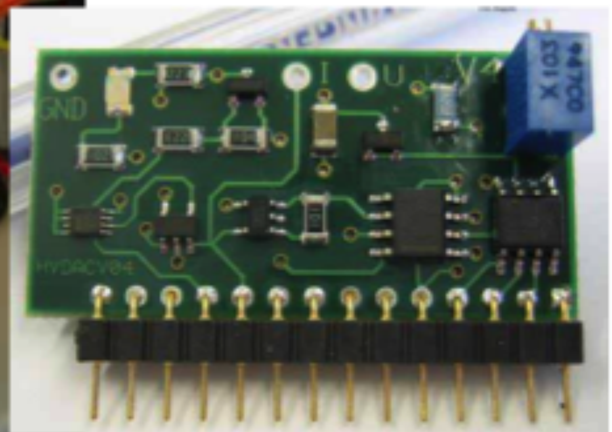
>5times higher througput possible
when using parallel ADCs and
1GB/10GB ethernet components
[but more power=> more cooling]

'HV' Power Supply: Ready

HV crate: 320 channels
- 1 crate controller with USB interface
- 10 HV mother boards ==> 320 Channels
- power conversion /distribution and control bus wired in the back of the crate

Single channel board
- HV operational amplifier OPA454
- controlled by a 12 bit serial DAC (DA8034U)
- output voltage adjustable (0 – 90) V
- calibration using trim potentiometer
- voltage set precision 22 mV
- High side current monitor (HV7800)
- Over current protection, limit (1-5)mA





32 channel HV mother boards

In counting house

FACT Status

- Telescope ready for comissioning

Camera:

- 'HV' built and tested
- Electronics: built, final tests going on
- solid cones: all tested
- G-APDs: all tested and glued to solid cones; glueing to front window almost finished
- final cabling of full camera going on

==> Delivery to La Palma: July 2011(?)

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First light: Summer 2011 (?)