Status of **MAGIC** and **FACT**

Adrian Biland, ETHZ

Roque de los Muchachos, La Palma, 2200m asl

The MAGIC Telescope(s)

Major **A**tmospheric **G**amma-ray **I**maging **C**herenkov

- Roque de los Muchachos (La Palma, Canary Islands), 2200m asl
- 17m dish with active mirror control, f/d=1.0, 3.5deg FoV
- analog signals transferred to counting house (fibres)
- regular data taking:
  first telescope since 2004
  second telescope/stereo since Sept. 2009

ETH Institute for Particle Physics

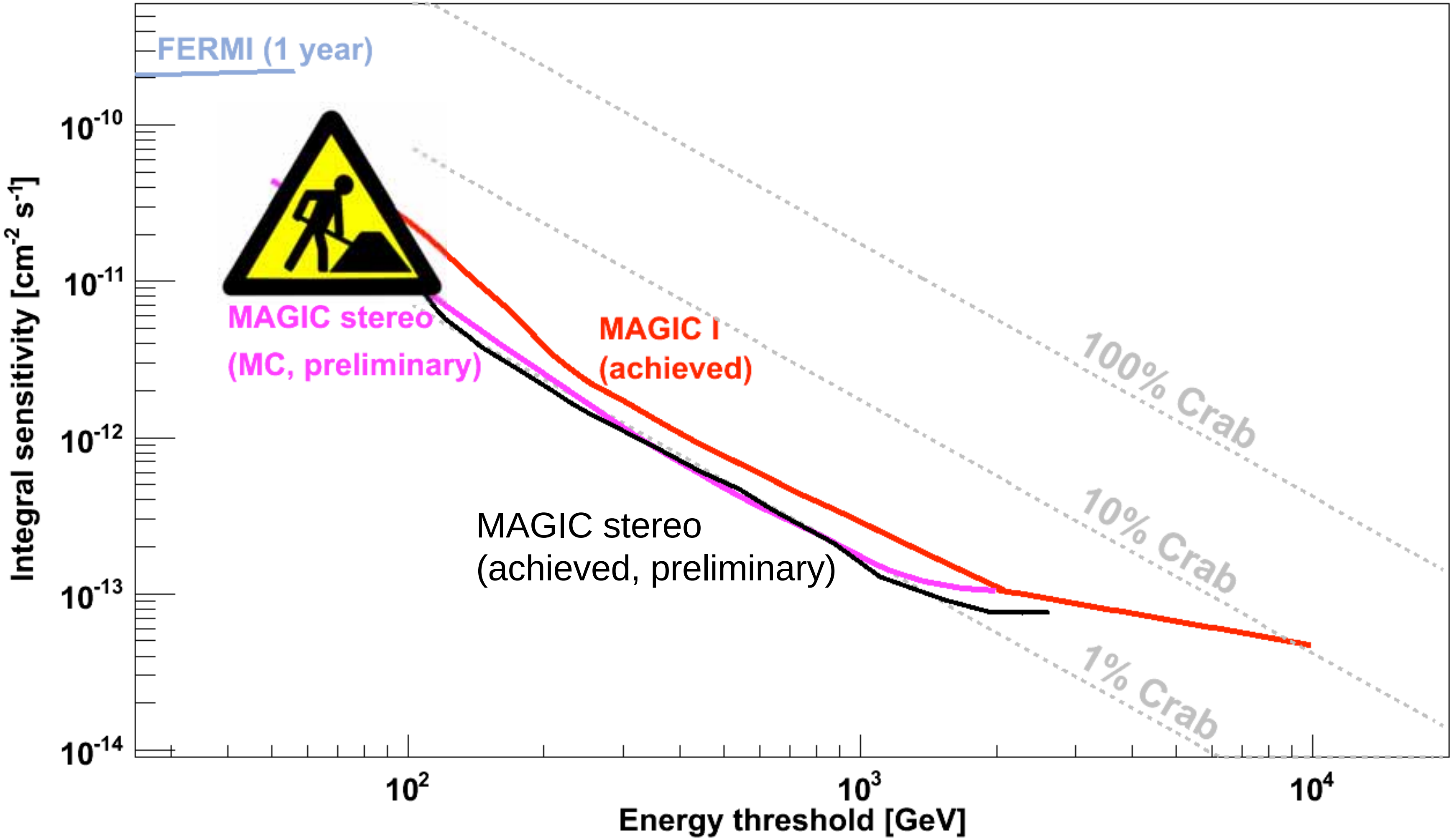
The MAGIC Telescope(s)

Major **A**tmospheric **G**amma-ray **I**maging **C**herenkov

- Trigger threshold ~50 GeV (~25 GeV for Pulsars only)
- Analysis threshold >60 GeV **(stereo: ~50 GeV)**
- Energy resolution ~20% **(stereo: ~15%)**
- Integral sensitivity 50h: 1.6% Crab **(stereo: <1% Crab for E>100GeV)**
- Fast repositioning: <20s

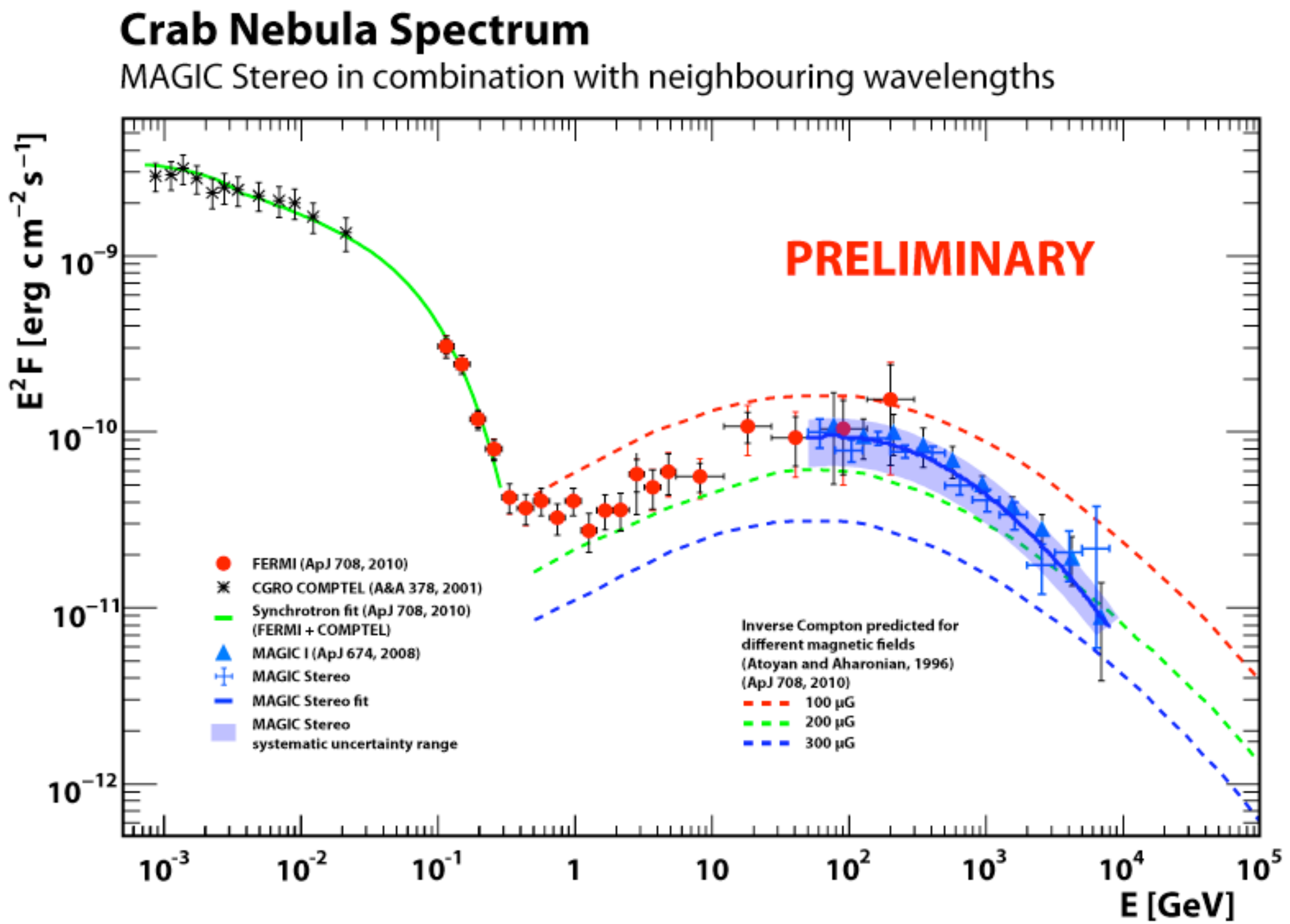
The MAGIC Telescope(s)

Major Atmospheric Gamma-ray Imaging Cherenkov



The MAGIC Telescope(s)

Major **A**tmospheric **G**amma-ray **I**maging **C**herenkov



Some MAGIC Results

ATELs since MAGIC-stereo observation started:

#2431 (10.Feb.2010): M87 flare
#2510 (25.Mar.2010): IC310 detection
#2543 (9.Apr.2010): M87 flare
#2684 (19.Jun.2010): 4C +21.35 detection
#2753 (22.Jul. 2010): 1FGL J2001.1 detection
#2910 (7.Oct.2010): B3 2247 detection
#2916 (10.Oct.2010): NGC 1275 detection
#2967 (23.Oct.2010): no indication of Crab-flare
#3100 (6.Jan.2011): 1ES1215 detection
and 1ES1218 high state

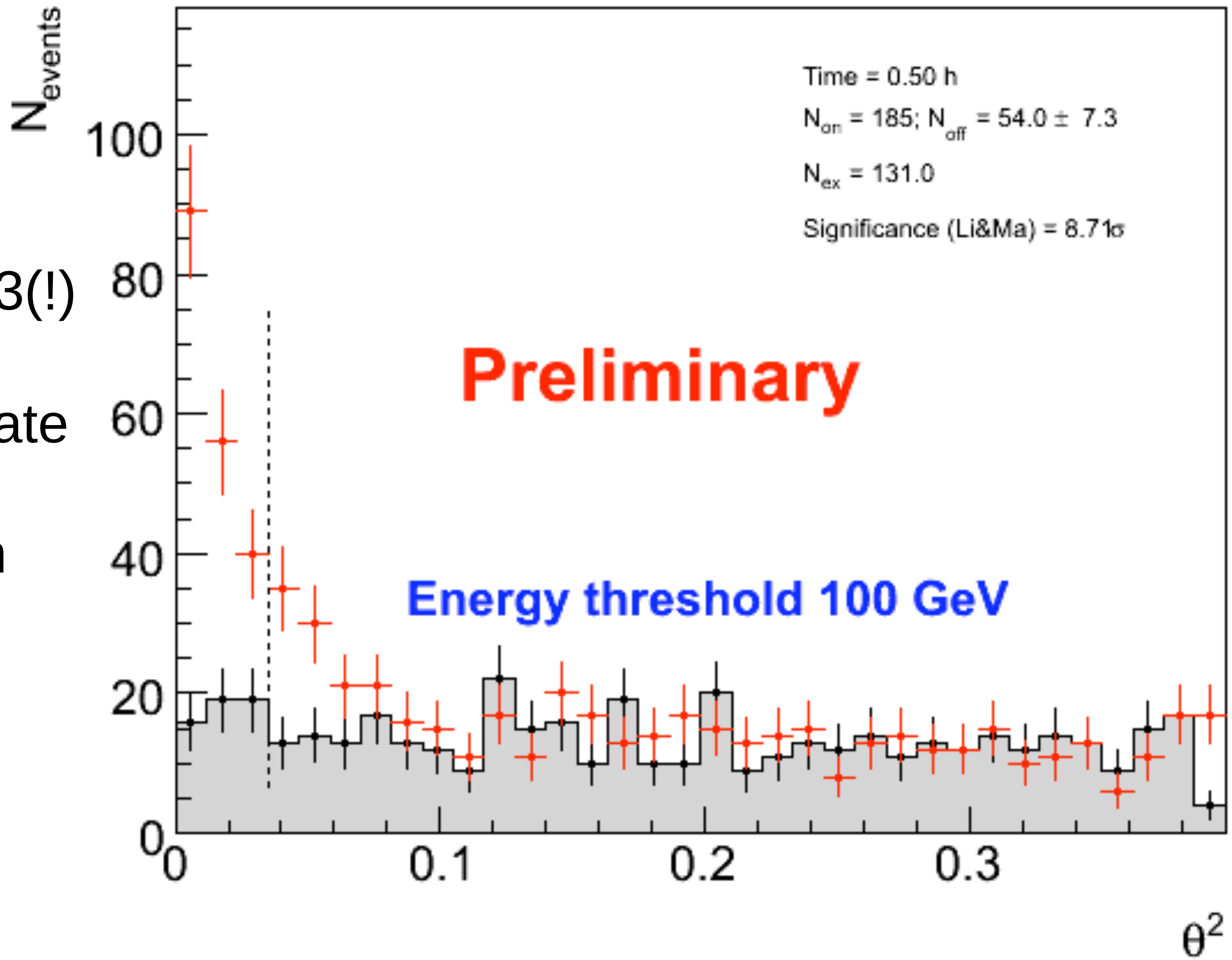
taking into account terrible weather in Nov.&Dec.==> ~1ATEL / month

4C+21.35 (PKS 1222+21)

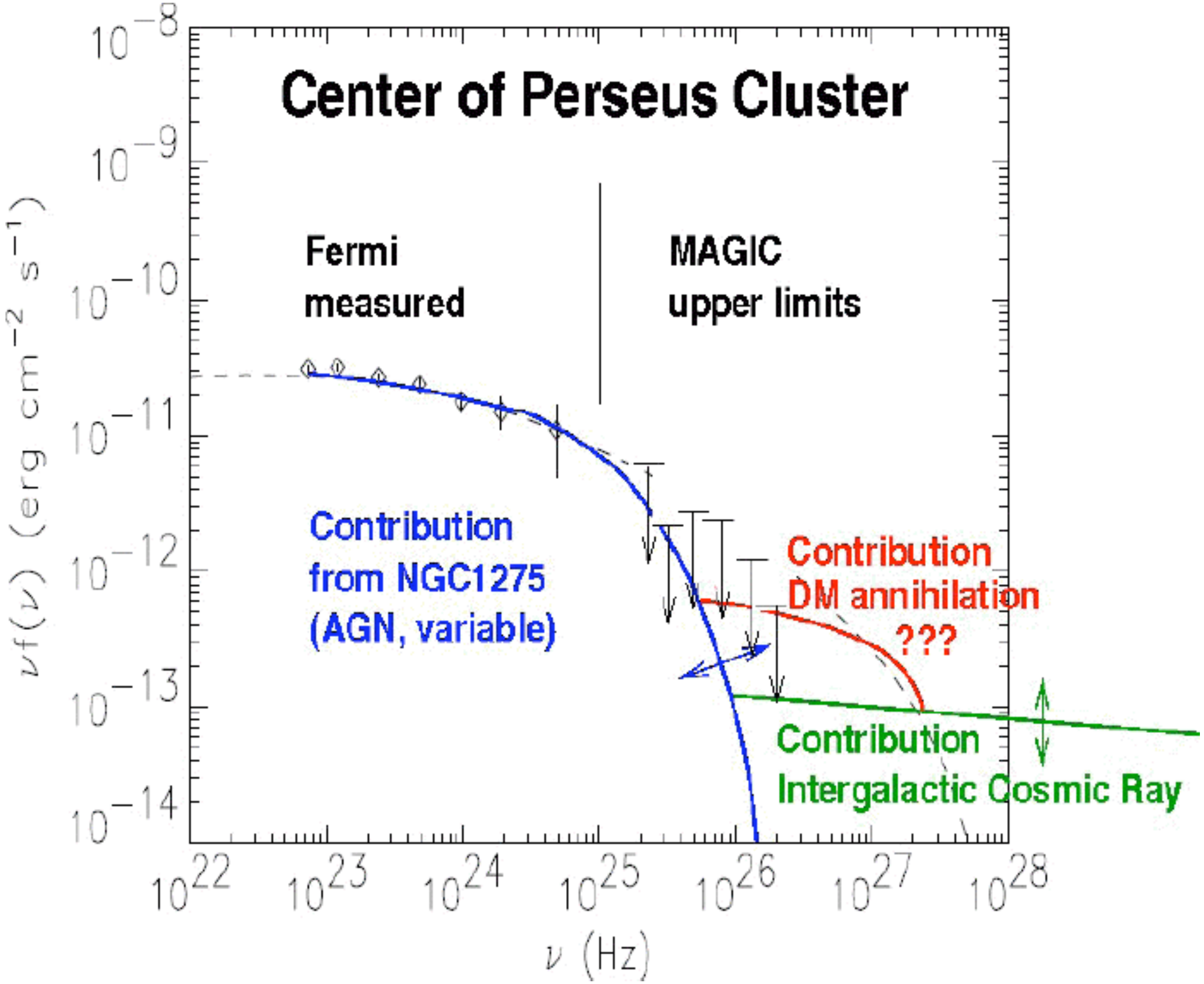
FSRQ, z=0.43(!)

Fermi high state

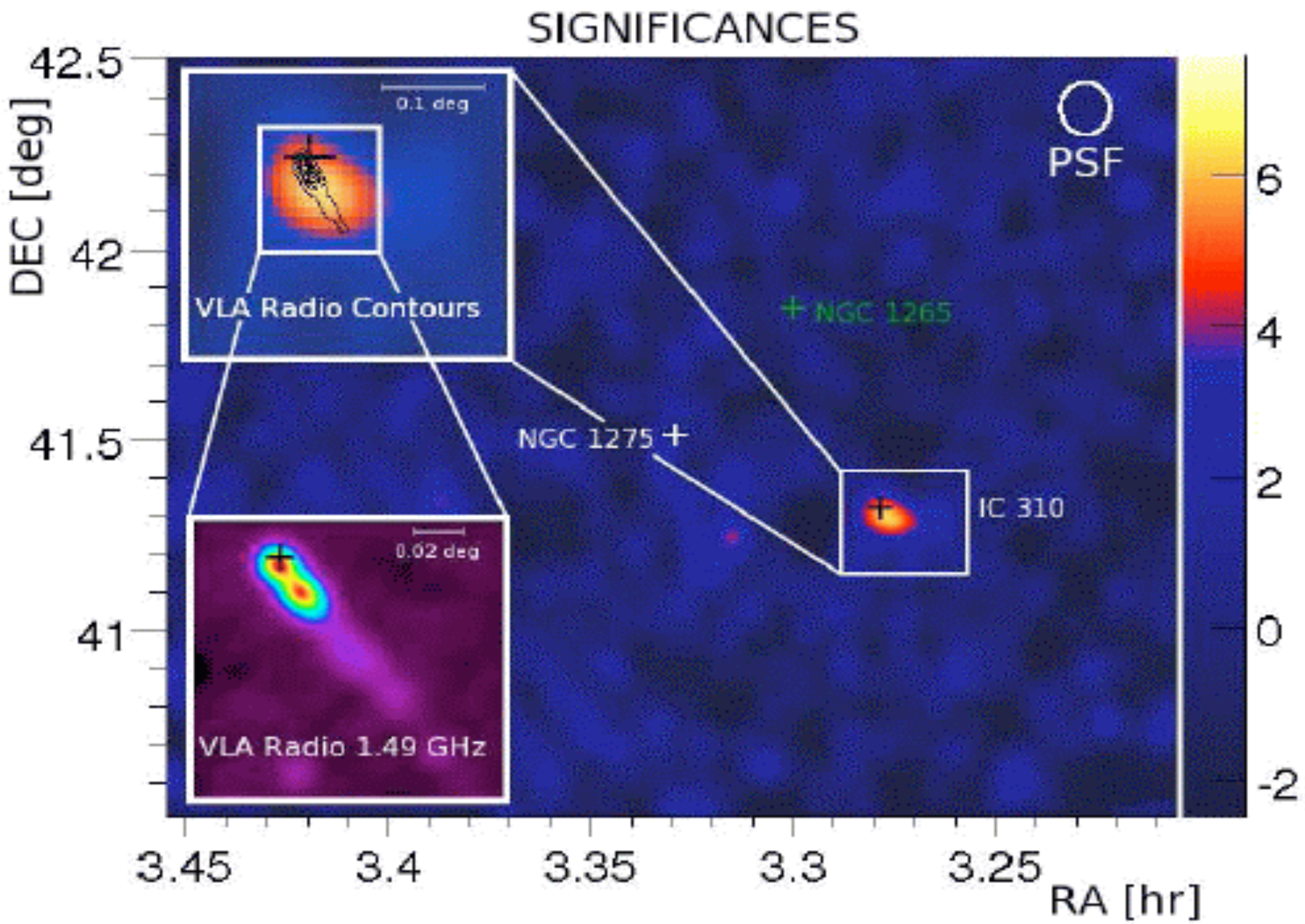
8.7σ in 30min



Perseus Cluster



Perseus Cluster



Serendipity detection of IC310

(in FoV of NGC1275/ Perseus for one wobble position)

IC310

Head-tail radio galaxy (similar to NGC1265 in Fig):

AG(N) flying fast through Perseus Cluster

Friction with IGM bends the jets

VHE emission could be:
- Blazar like (variable) or
- interaction of jets and IGM

(no VHE emission from NGC1265)

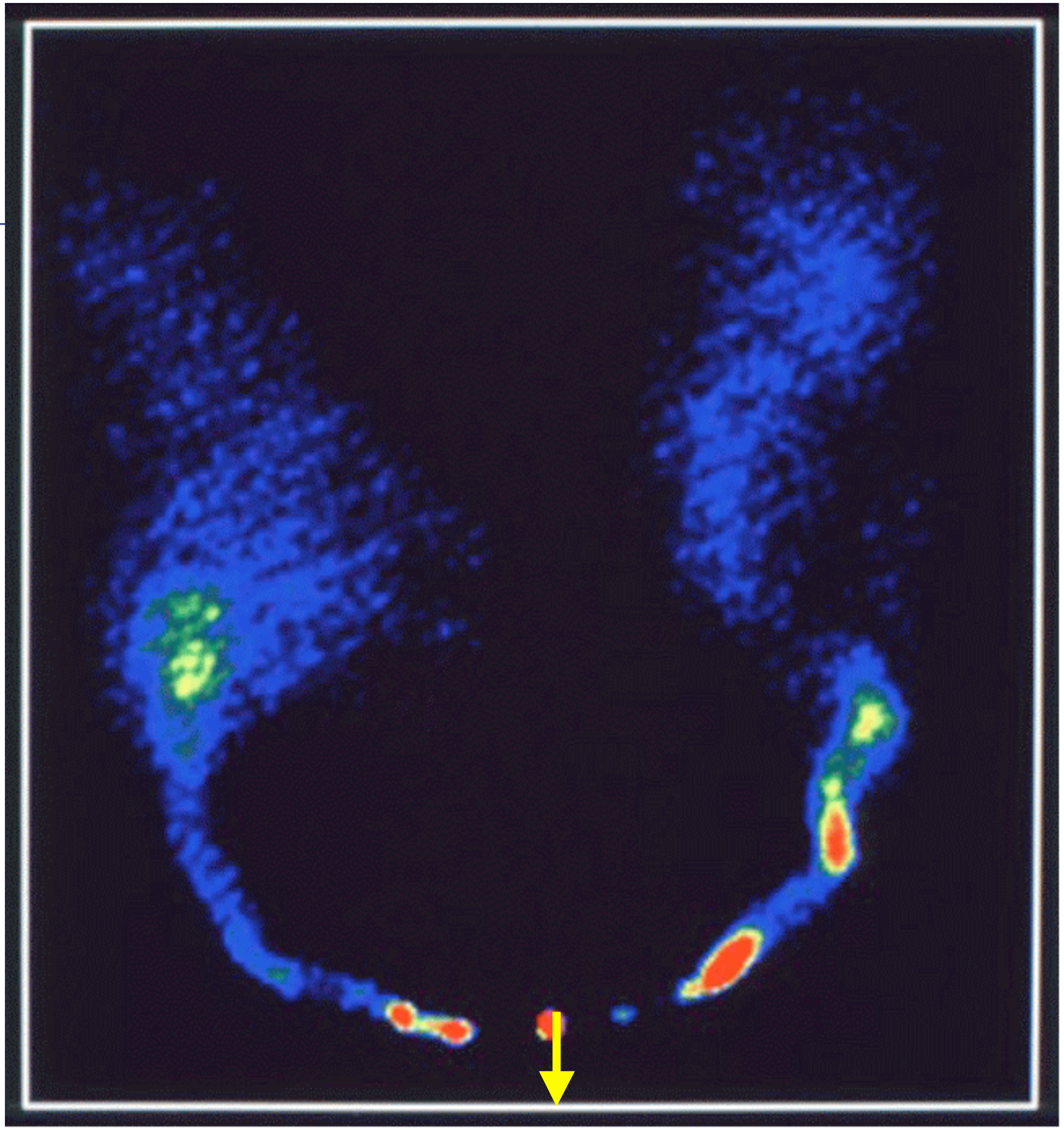
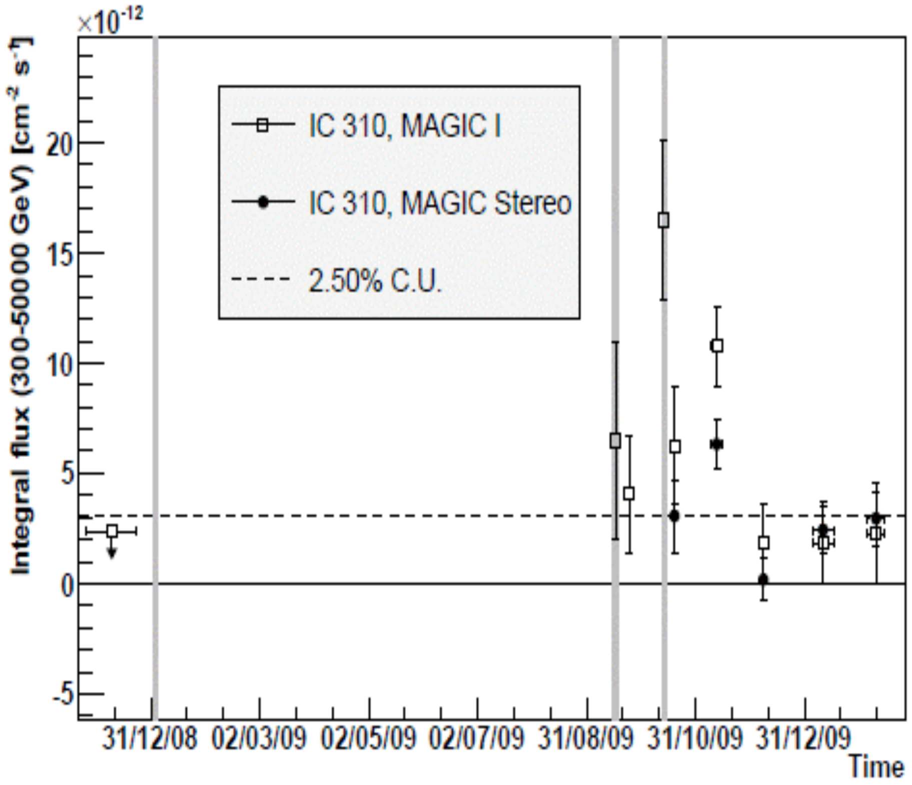
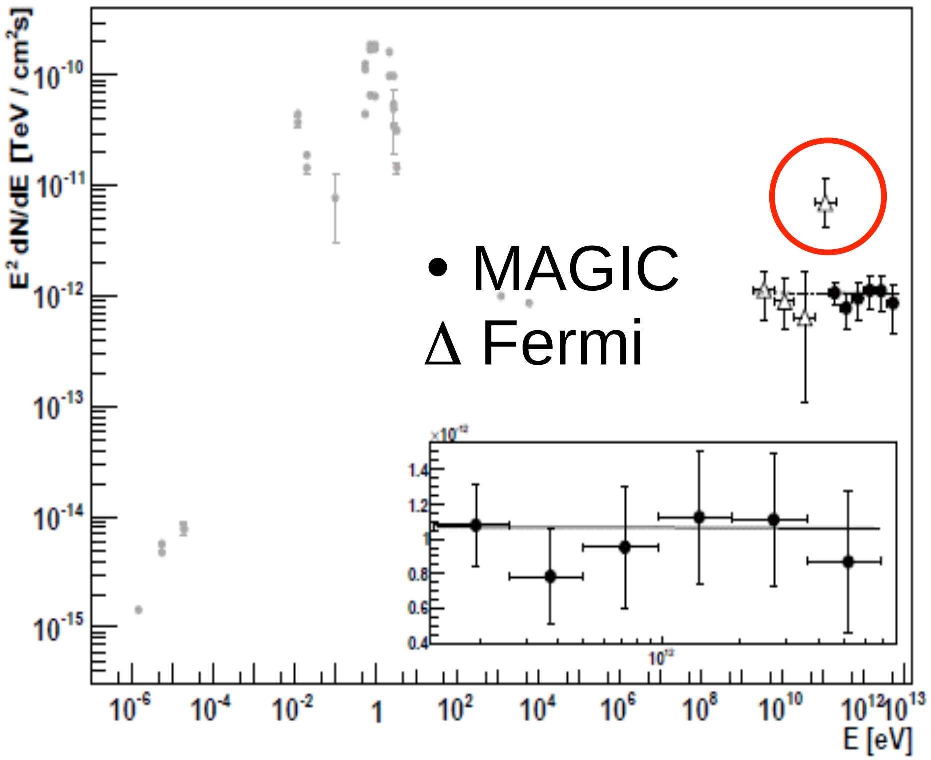


Figure 2: Like the recently detected head-tail radio galaxy IC 310, also NGC 1265 is a member of the Perseus cluster and presumably very similar in nature to IC 310. This false-color image of the radio jets from the radio galaxy NGC 1265 shows in red regions of intense radio emission, while blue shows regions of fainter emission. The center of the radio galaxy is at the location of the red circle at the bottom center of the image. The galaxy is moving through the intergalactic medium of the Perseus Cluster at a velocity of about 2000 km/s. It is thought that twin beams of plasma ejected from the galactic nucleus are bent by the ram pressure exerted by the external gas, producing the 'U' shape.
Picture credit: Image courtesy of NRAO/AUI/NSF and C. O'Dea & F. Owen.

IC310: Variability ???

ApJ 723 (2010) L207





MAGIC statistics not sufficient to claim variability

Line in VHE spectrum, or extreme VHE flare in Fermi?
(just before MAGIC stereo started);
or stat. fluctuation [only 5γ] ?

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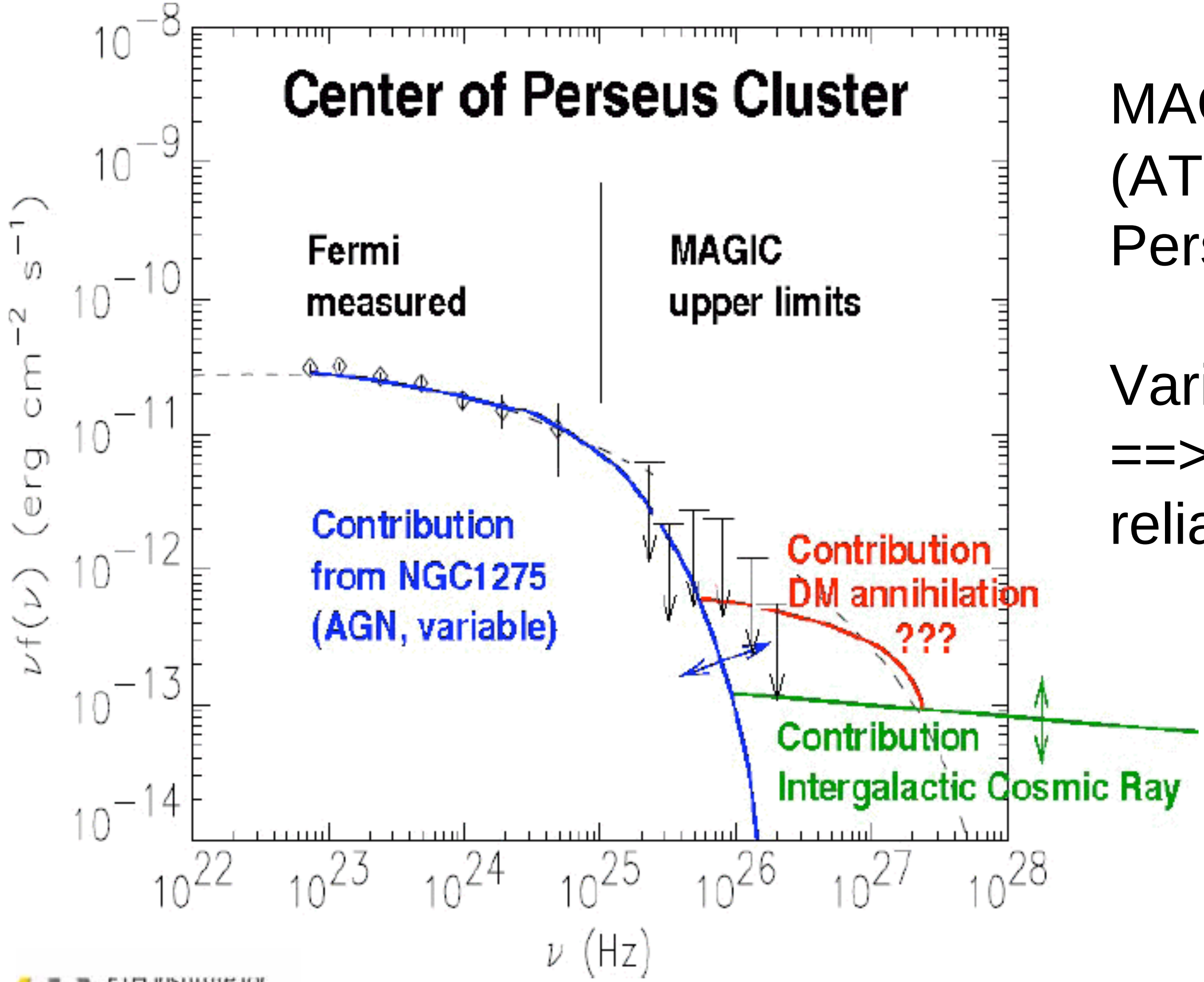
Perseus Cluster



MAGIC reached >5σ (ATEL 2916) from Perseus / NGC1275

Variable source ==> sufficient for reliable spectrum ??

The MAGIC Telescope(s)

Major **A**tmospheric **G**amma-ray **I**maging **C**herenkov

Summary:

MAGIC stereo system working very well

==> many interesting publications in the queue

(weak point: telescopes have different cameras [FoV for trigger]
==> new MAGIC-I camera and DAQ under construction)

The FACT Project

First G-APD Cherenkov Telescope

The FACT Collaboration:

TU Dortmund, U Geneva,
EPF Lausanne, U Wuerzburg
ETH Zurich

The FACT Project

Important Question:

can newly developed Si-based photosensors [G-APD, SiPM, MPPC,...] be used in CTs ?

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

Refurbish HEGRA-CT3 Telescope at La Palma:

- new mirrors installed (refurbished from CT1)
- new drive system installed
- new container as 'counting house'
- awaiting camera ….

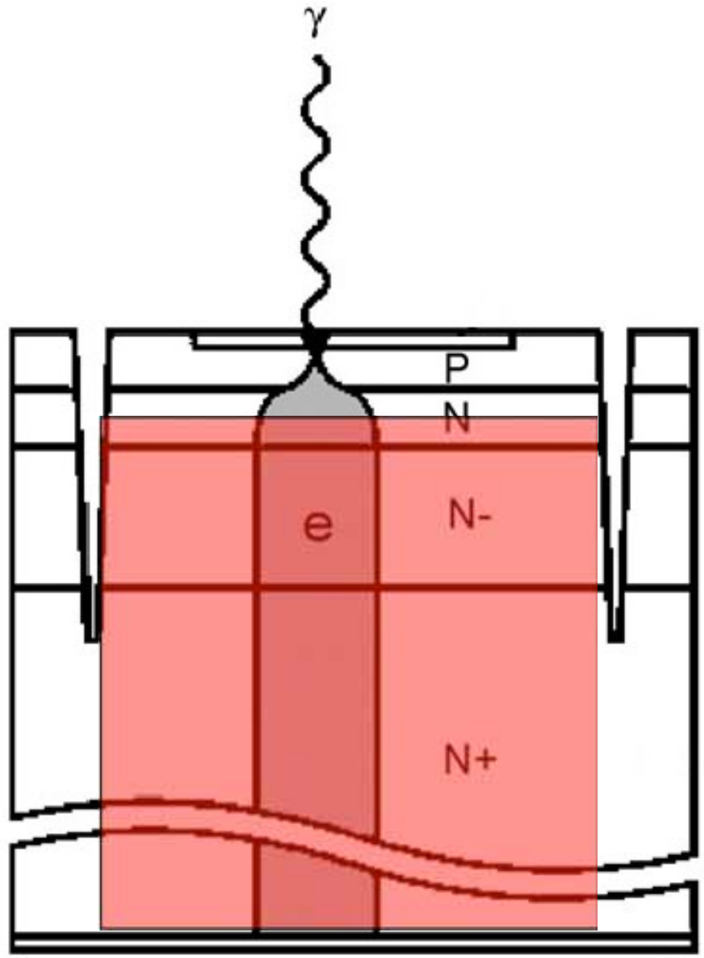
G-APD Basics

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
is 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: $10^5 \ldots 10^7$

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

[wavelength dependent]

no ageing (even if exposed long time to sunlight)

[but limited long-time experience]

several manufacturers:

CPTA/Photonique, 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

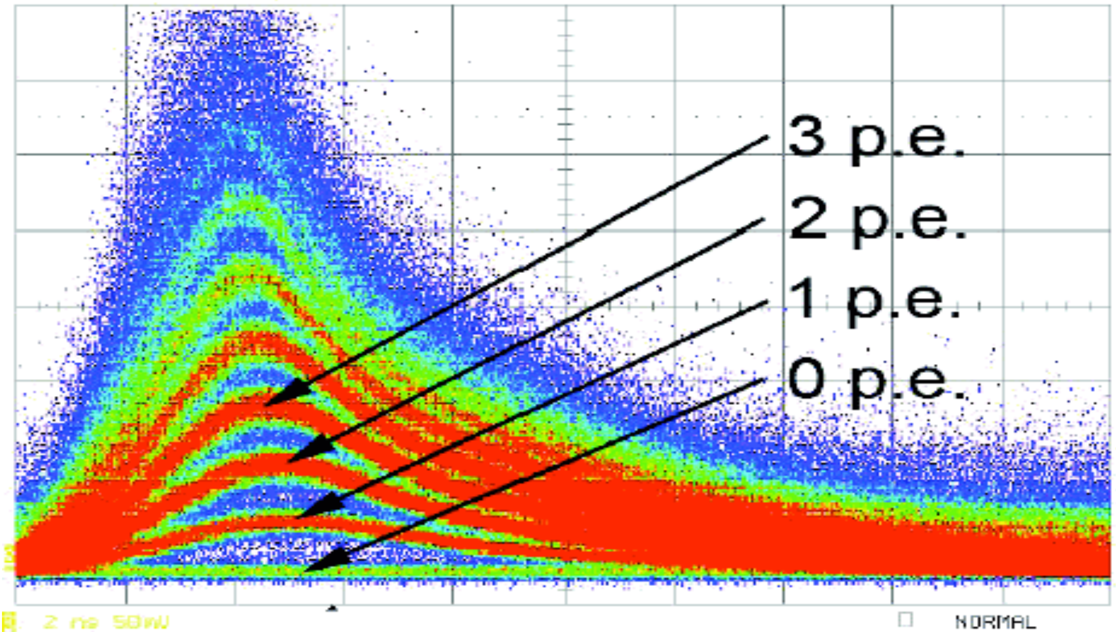
- **temperature dependent gain** (~5% / degree)
  ==> *temperature stabilization or*
  gain stabilization via feedback system

- **sensitive also >>700nm** *(==> more NSB)*

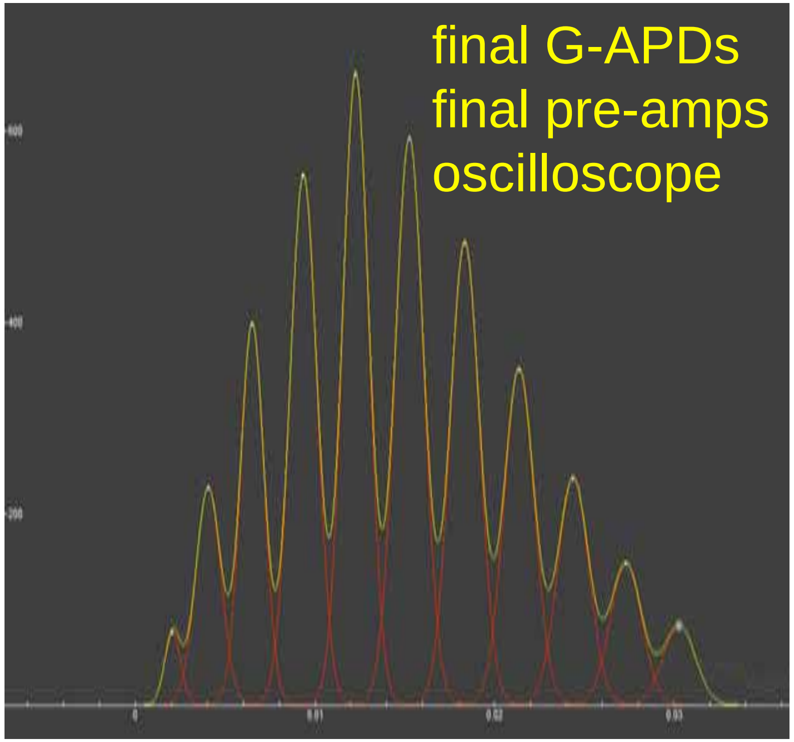
G-APD Features

slower rise and decay time than best PMTs,

but very constant signals (if constant gain)

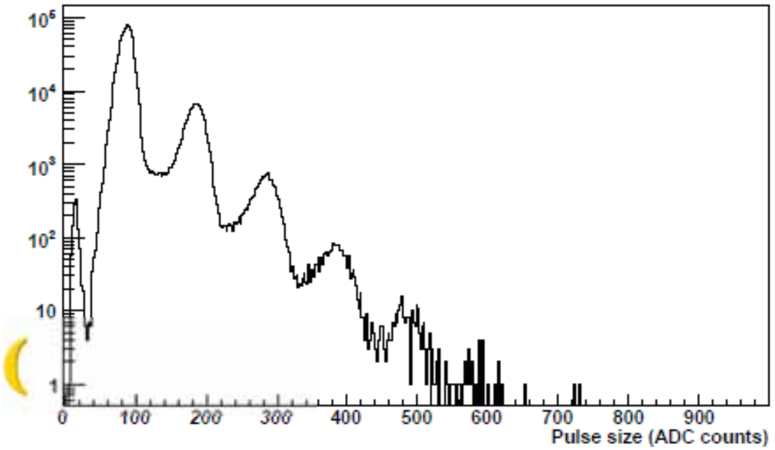


LED spectr., 2 ns horiz., 50 mV vert. spacing



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.

G-APD Features

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  - Rate: some 100 kHz up to MHz per mm^2 at room temperature.
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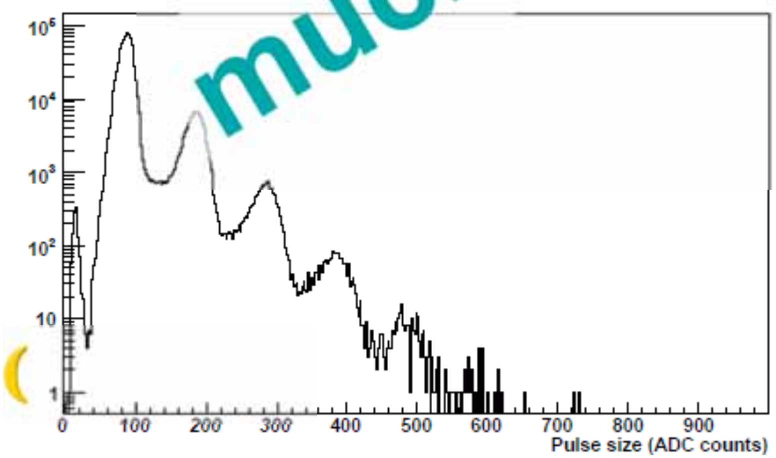
  - Defines the spectrum of the two phenomena above.
  - Crosstalk probability 5 – 20% depending on the gain.

much worse than PMTs ???



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

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have to deal with much higher NSB

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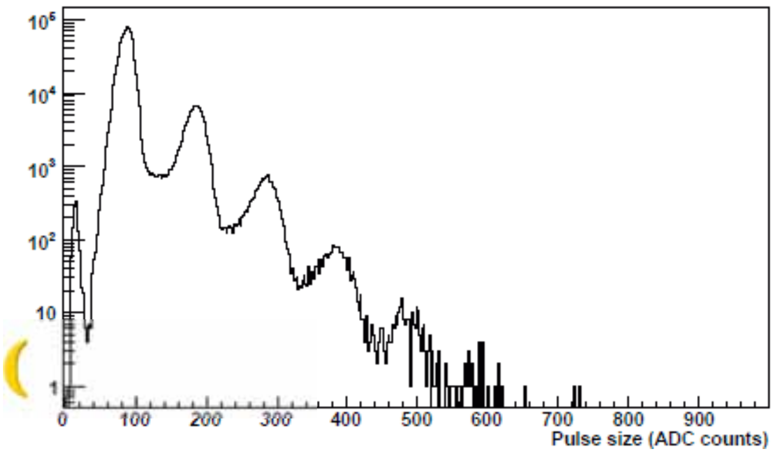


Typical dark count spectrum of a G-APD (crosstalk 13%). Peaks up to 6 triggered cells can be discerned. The spectrum also includes afterpulses of previous dark count events.

G-APD Features

- Dark counts
  - Cells can be triggered by any free carrier, eg. thermally generated or [illegible]

have to deal with much higher NSB

  - 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.

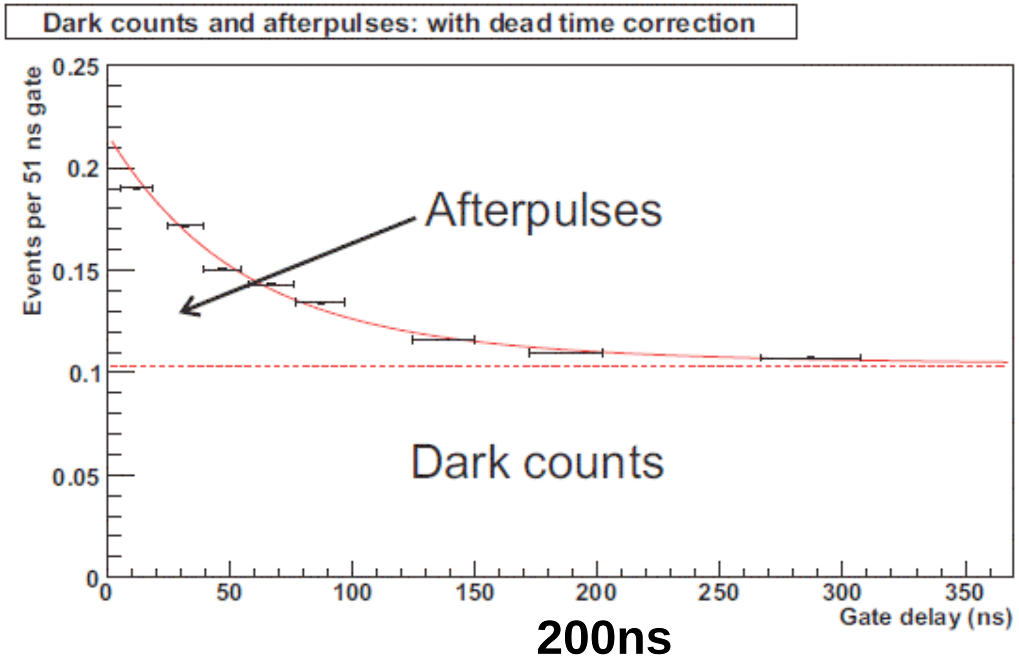
important for single photon counting, but not for CTs: can be calibrated

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

Typical dark count spectrum of a G-APD (Crosstalk [illegible]). 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.

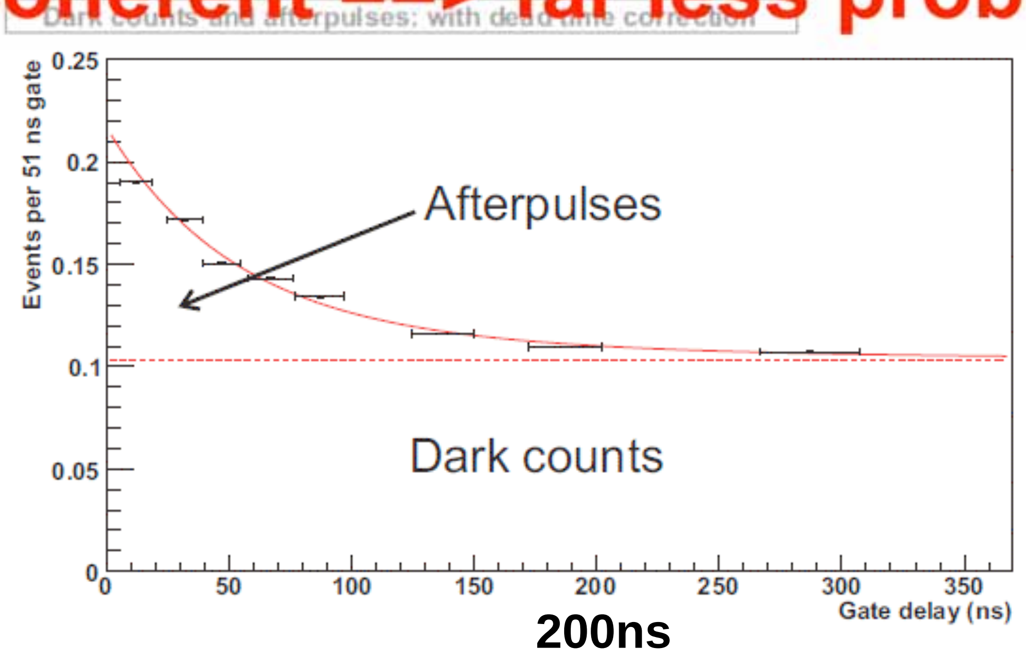


Number of pulses per gate for variable delays after an initial pulse. The number of pulses decreases exponentially to the level of dark counts.

G-APD Features

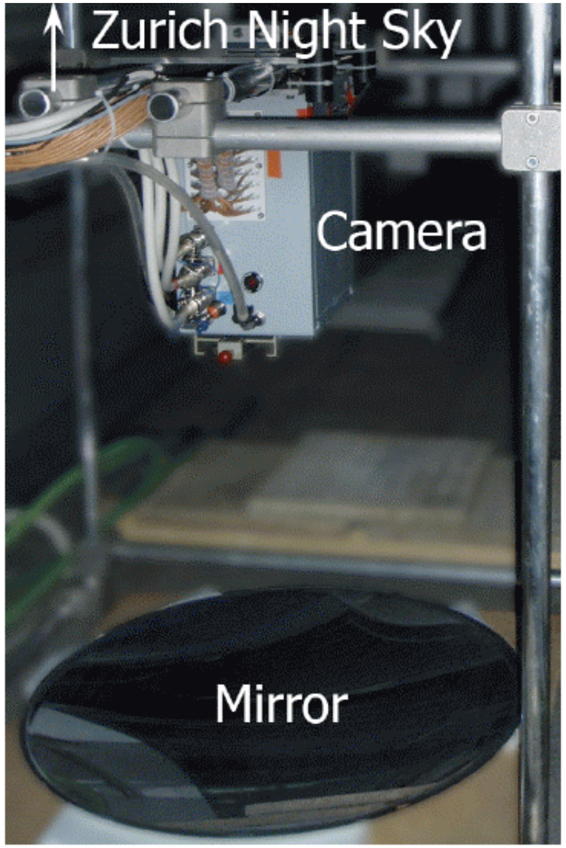
- Dark counts have a random time distribution.
- Afterpulses have an exponentially decreasing probability after an initial breakdown.

i.e. incoherent ==> far less problematic



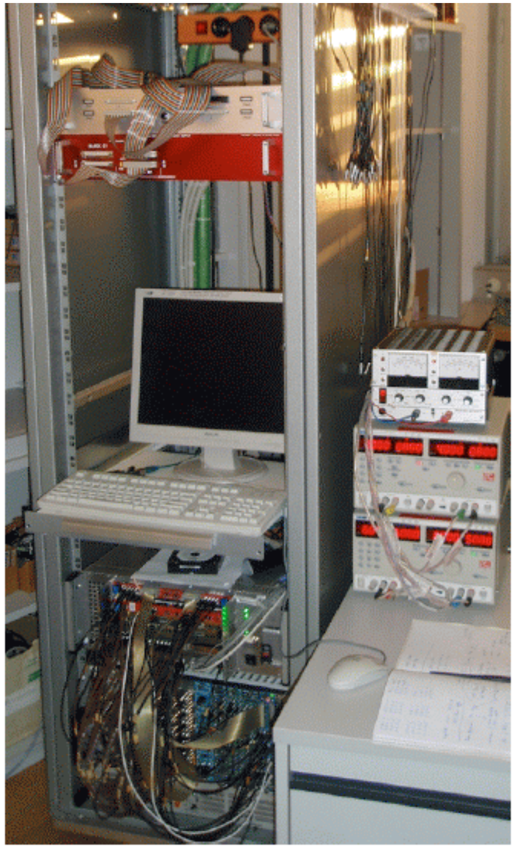
Number of pulses per gate for variable delays after an initial pulse. The number of pulses decreases exponentially to the level of dark counts.

mod0 Prototype (2009)



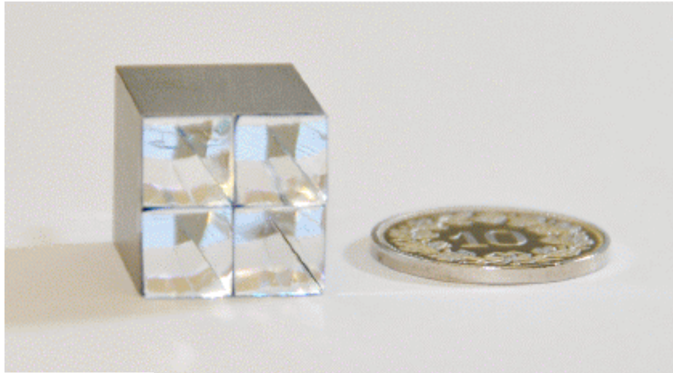
← Outdoor

Indoor →

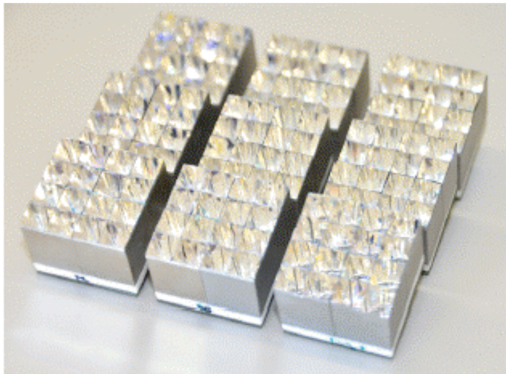


- Mirror with 80 cm focal length ⇒ 1° f.o.v / pixel
- NSB from buildings and moonlight: $\sim$ 300 MHz / G-APD (= 1.2 GHz / pixel)
- Meas. at 22° night temp., G-APD plane cooled to 18°, no voltage feedback

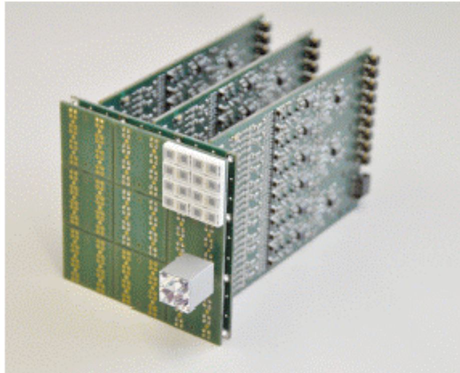
mod0 Prototype (2009)



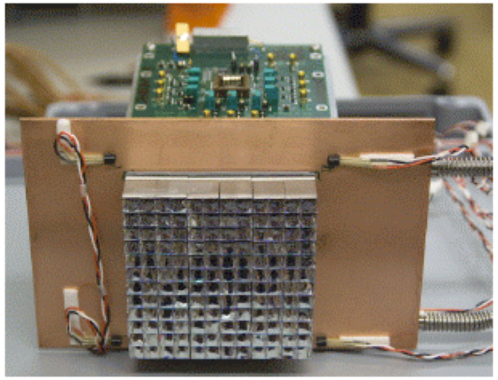
Hollow Cone: $(7.2\,\mathrm{mm})^2 \rightarrow (2.8\,\mathrm{mm})^2$
1 cone per G-APD, blocks of 4



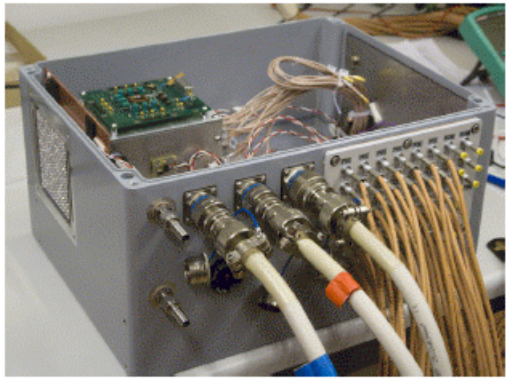
4 G-APDs/pixel = 1 channel
36 pixels, each $(14.4\,\mathrm{mm})^2$



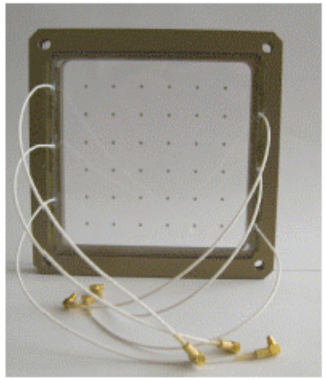
3 analog preamplifier boards
Distribution of bias voltage



Water cooling, thermal coupling
6 temperature + 1 humidity sensor

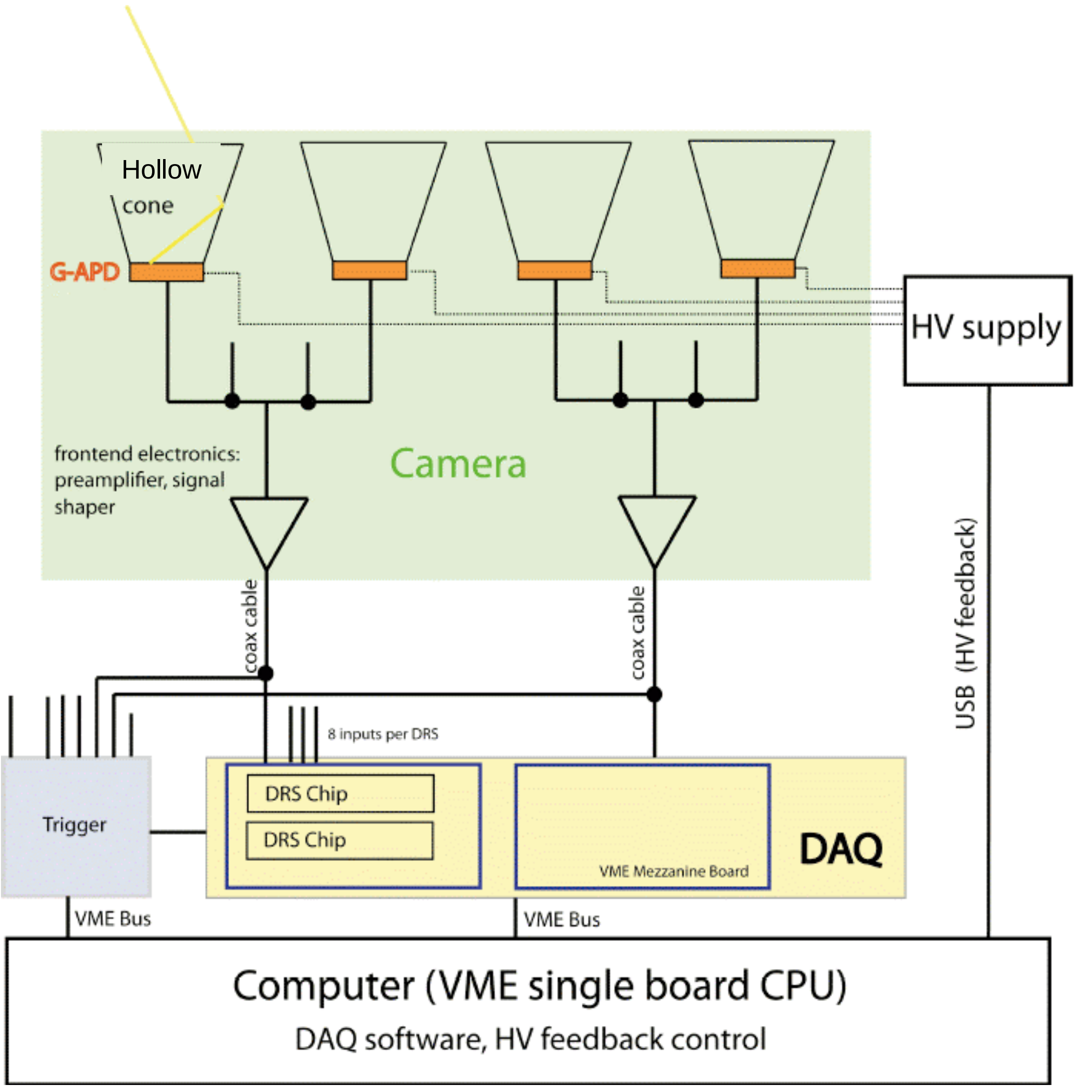


Light and rain-tight box
Analog signal transfer



Window + separat shutter
LEDs for artificial signals

mod0 Prototype (2009)



Data Acquisition (DAQ):

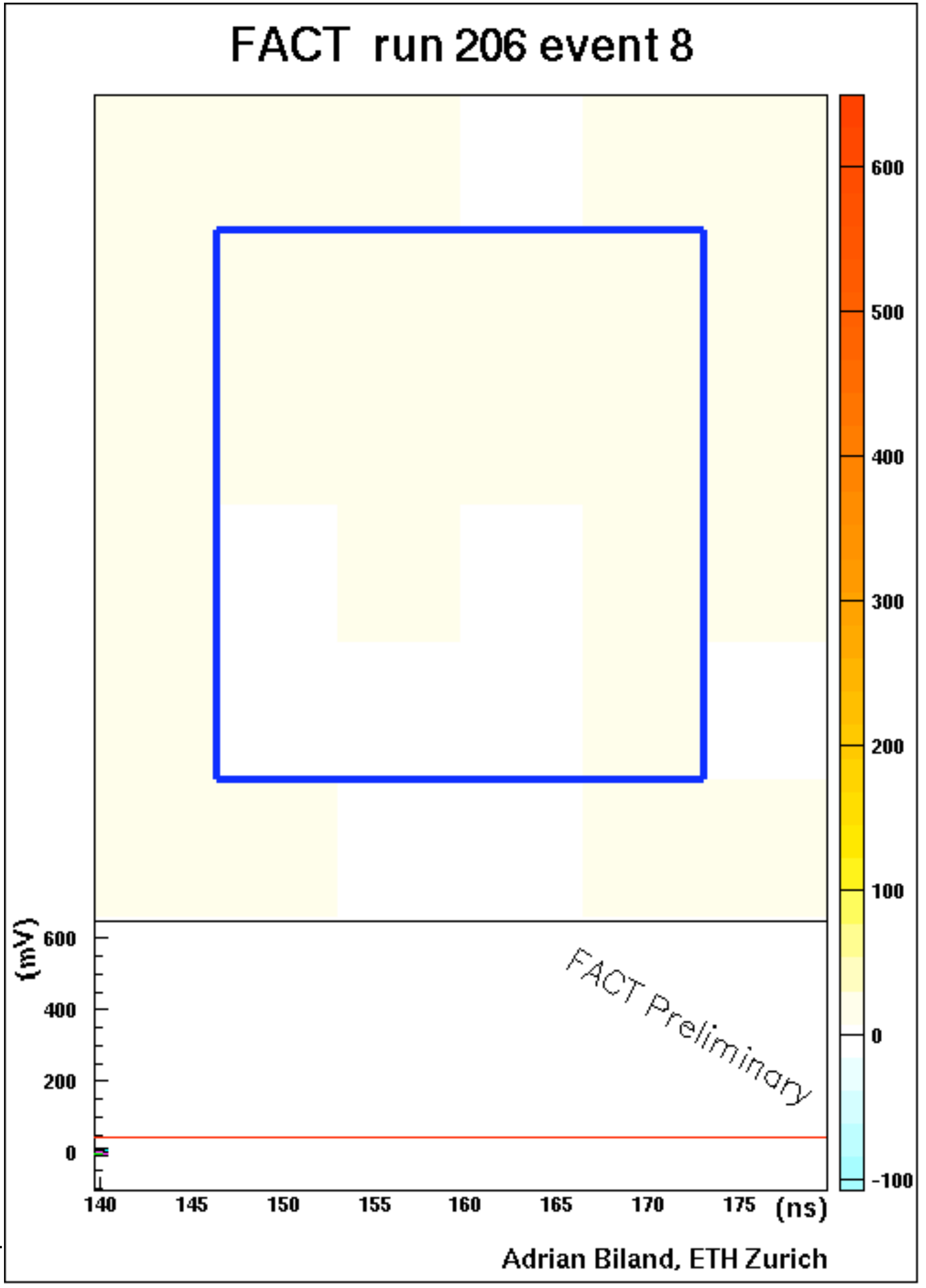
- Domino Ring Sampling chip (DRS2)
- Anal. pipeline: 1024 cells
- 0.5 - 4.5 GHz
- Multiplexed 12 bit ADC
- VME housing and CPU

Trigger System:

- Majority coincidence of 16 innermost pixels
- VME boards and scaler

mod0 Results

self-triggered,
extremely high
energetic
air-showers
recorded
(very similar results
 from independent
 project at MPI Munich)



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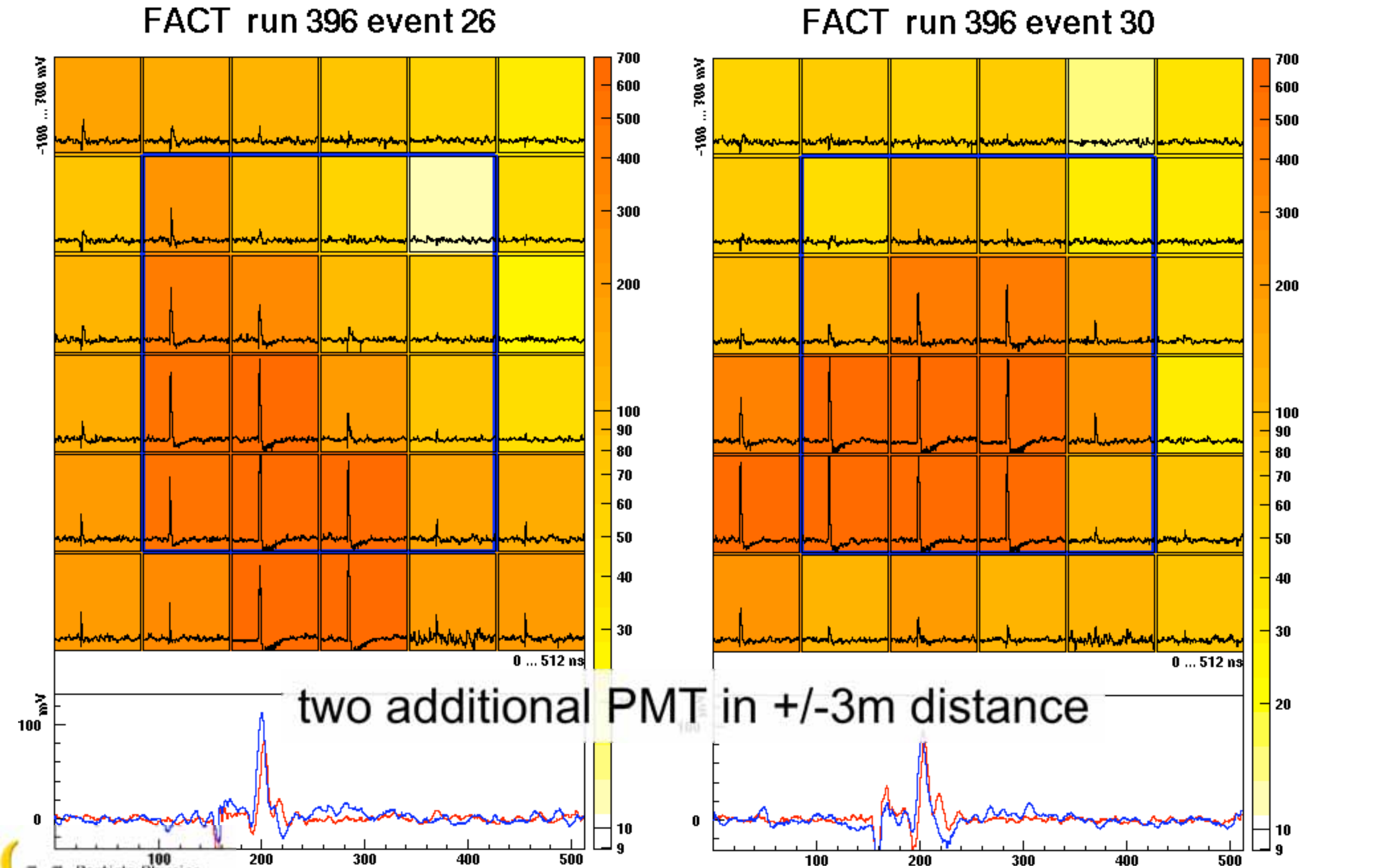
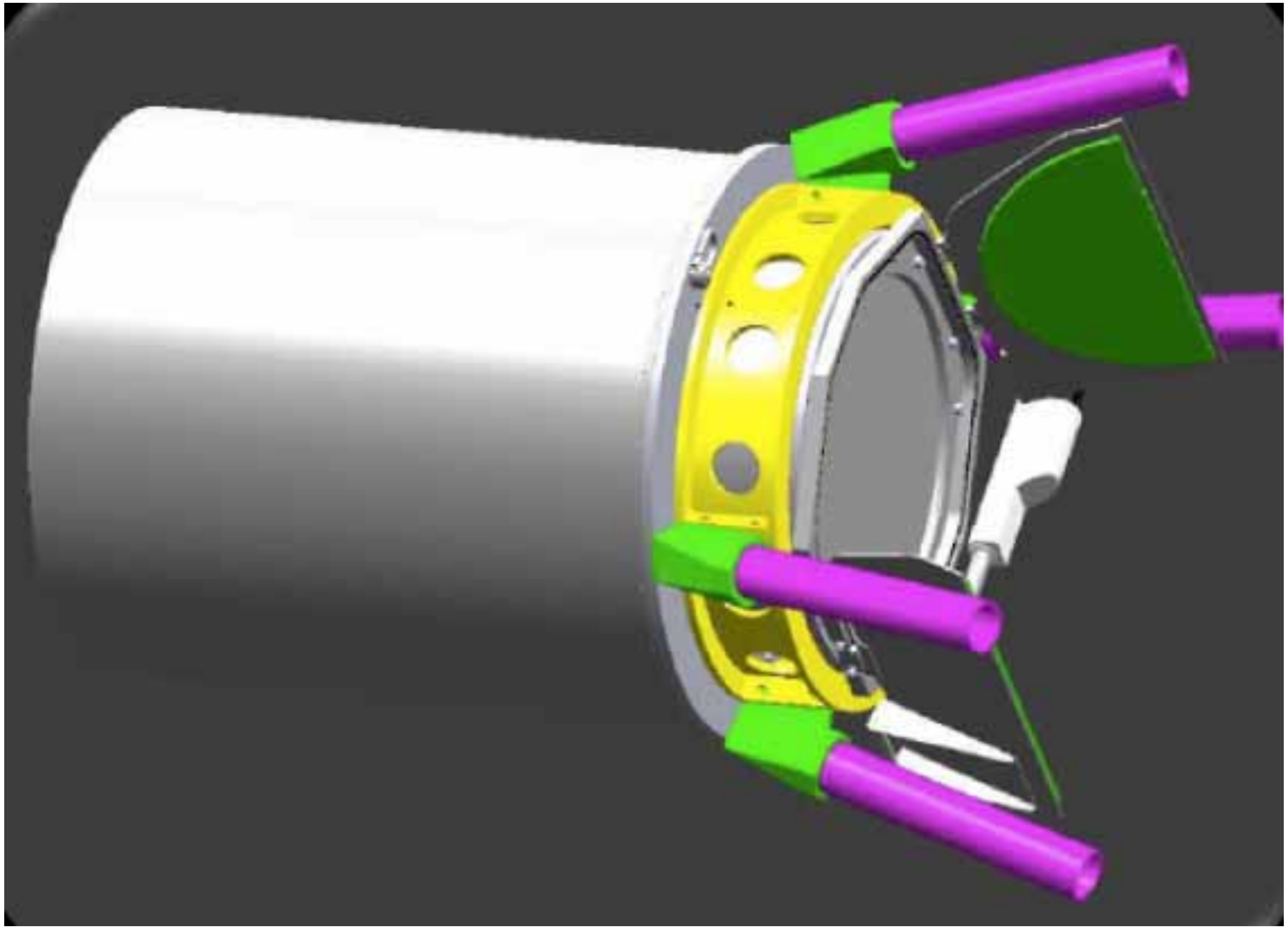
mod0 Results (2009)



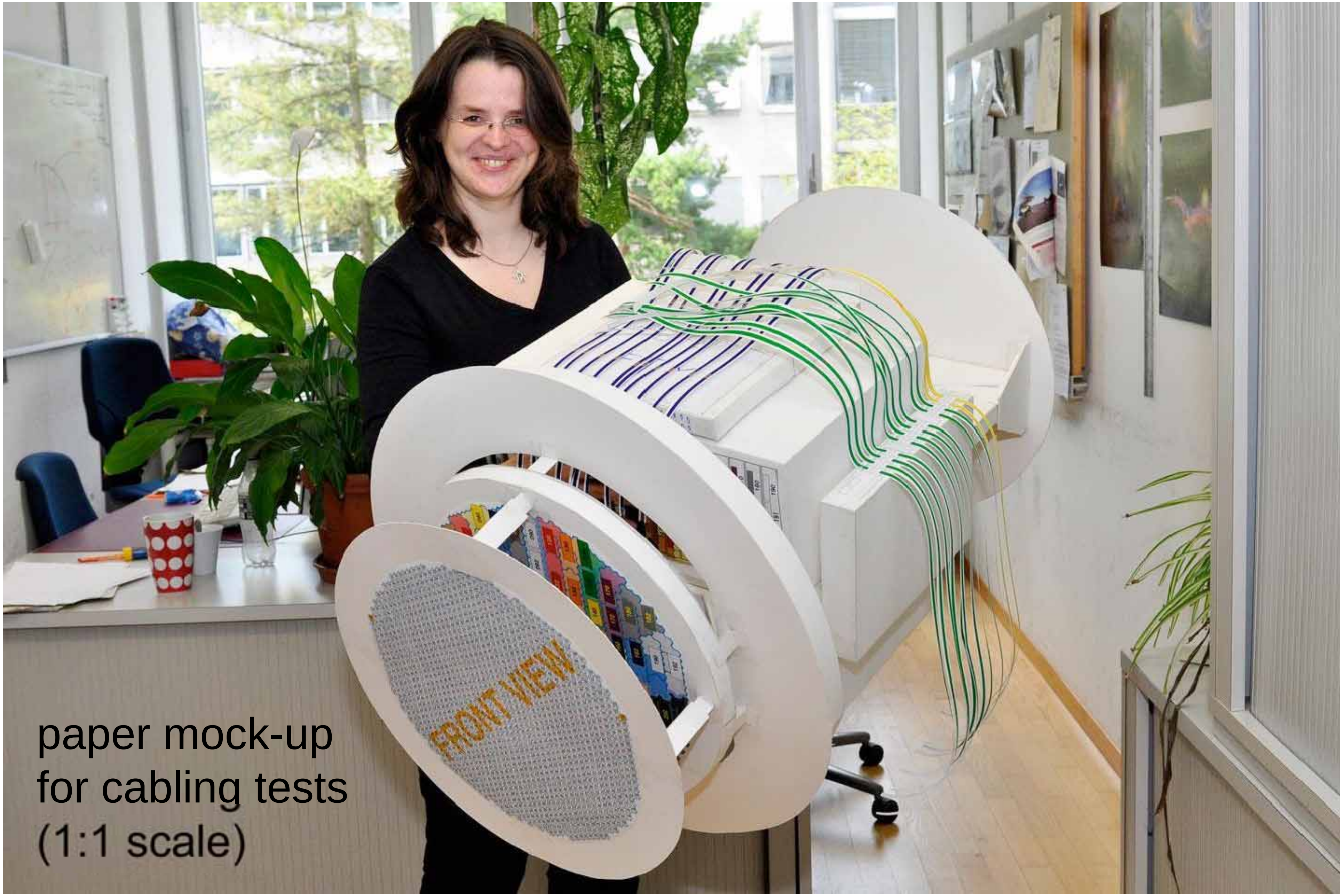
FACT Camera



Weight: ~150kg , Power Consumption ~1kW, IP67

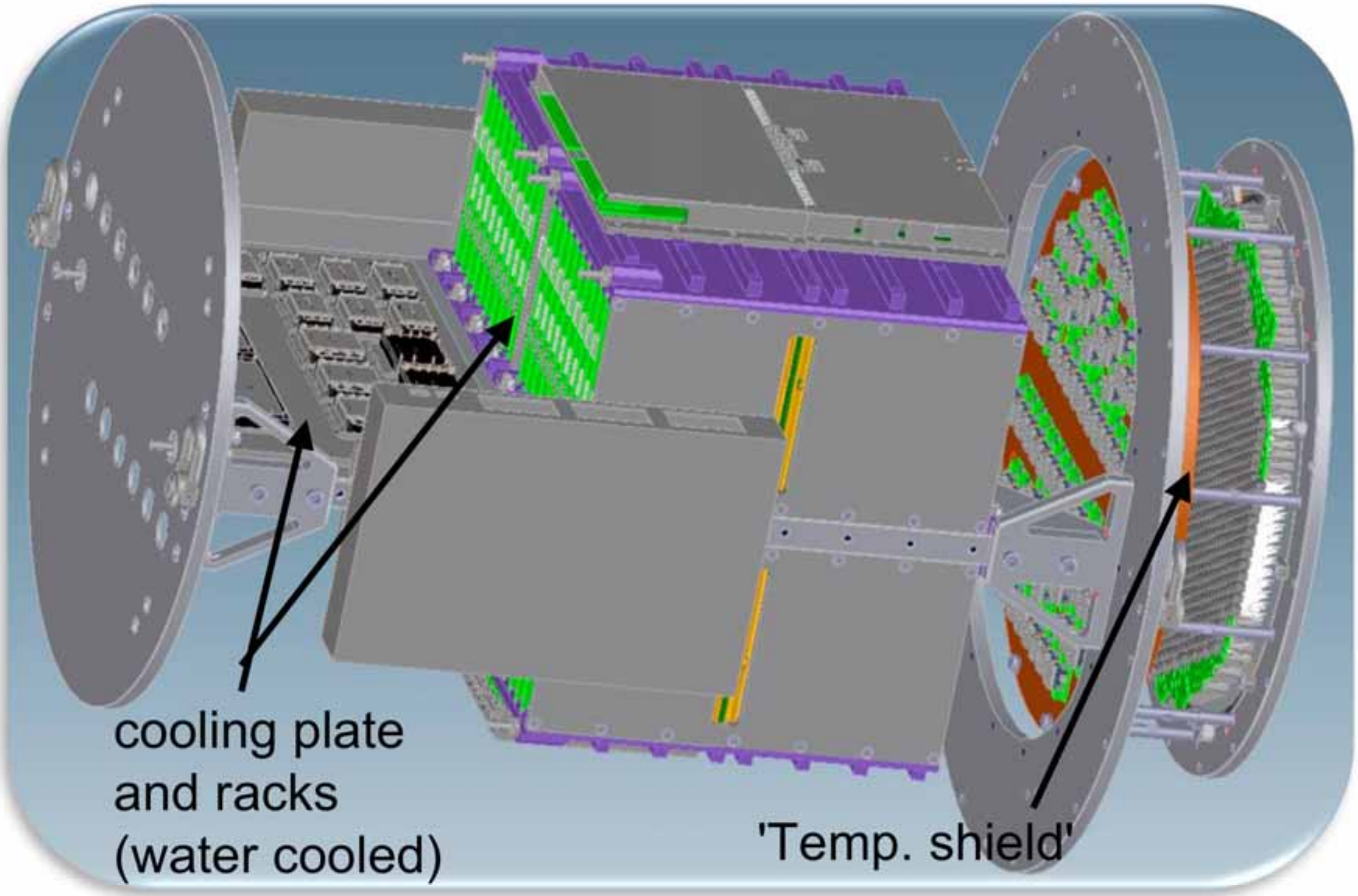
Will fit in existing holding structure of CT3

Camera

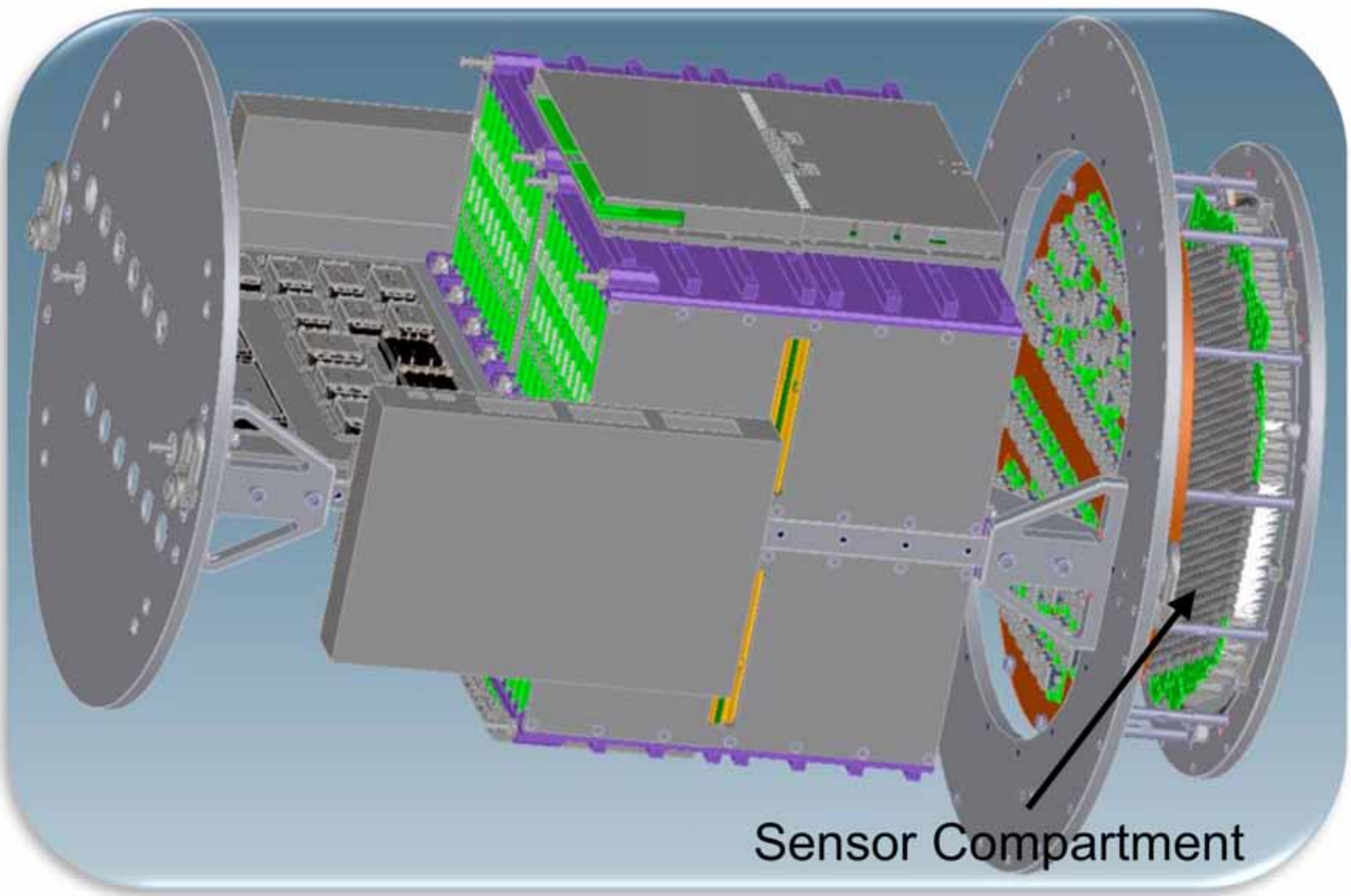


paper mock-up
for cabling tests
(1:1 scale)

Camera

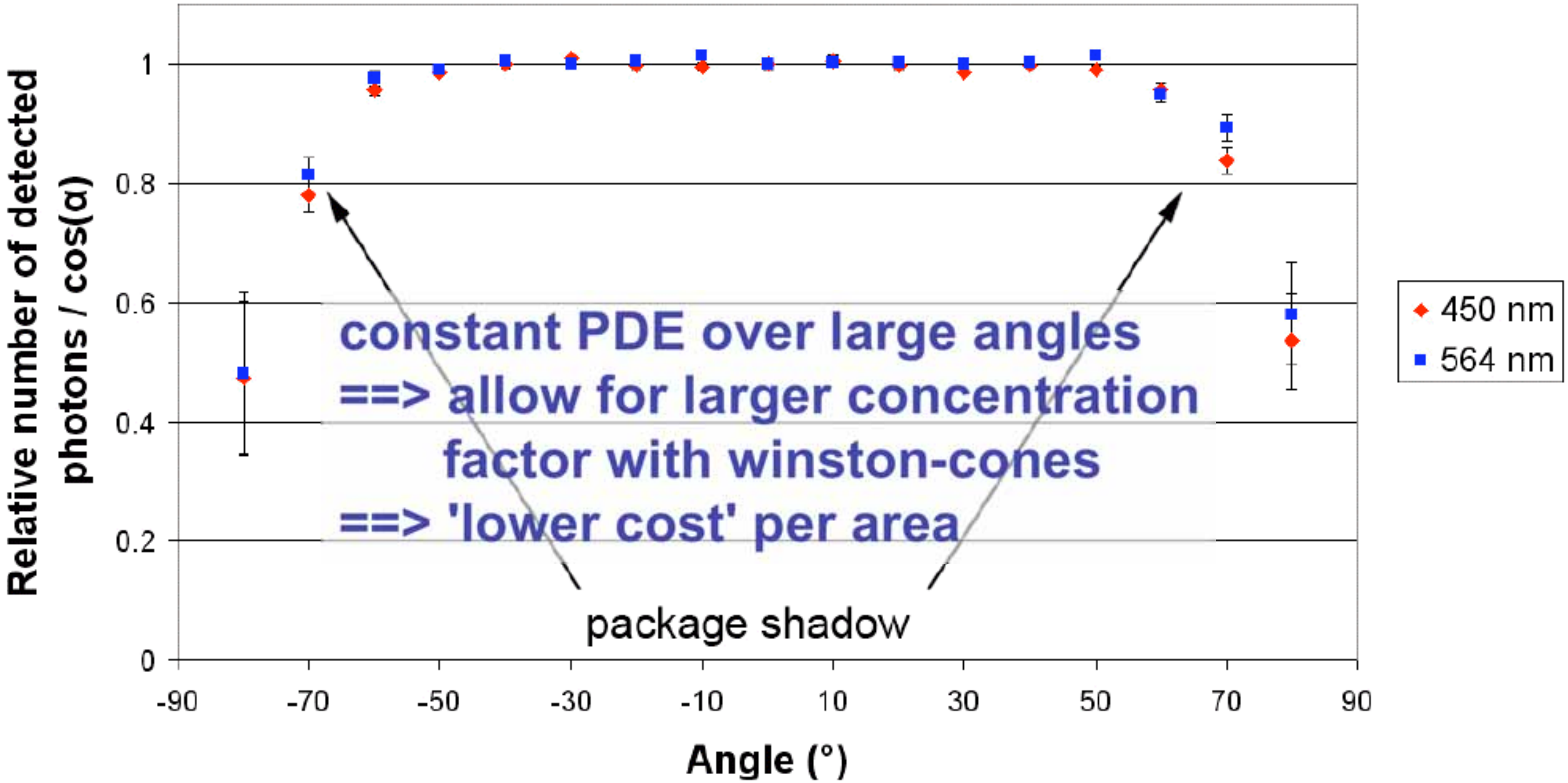


Camera

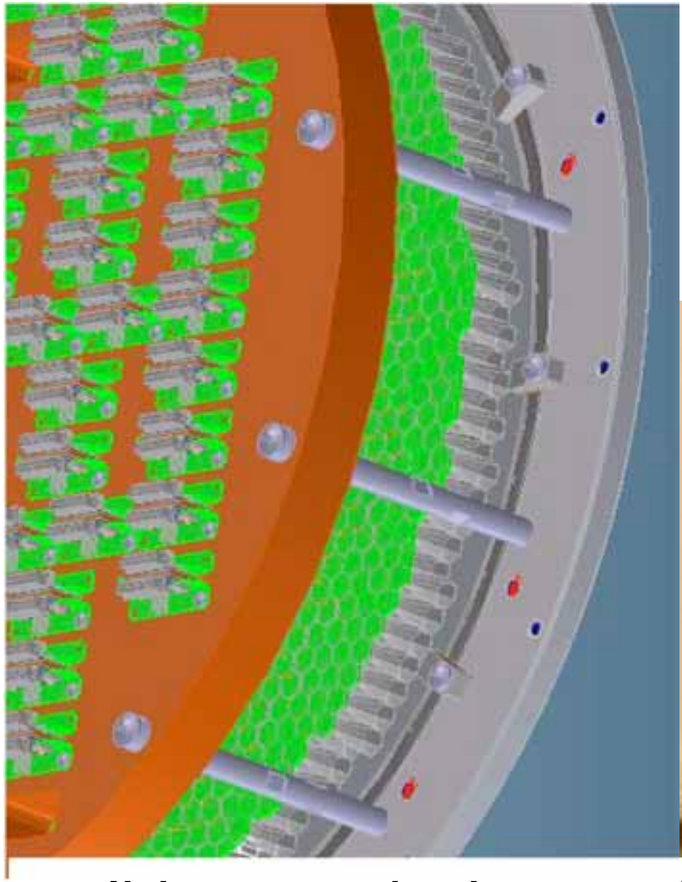


G-APD Features

angular acceptance:



Sensor Plate

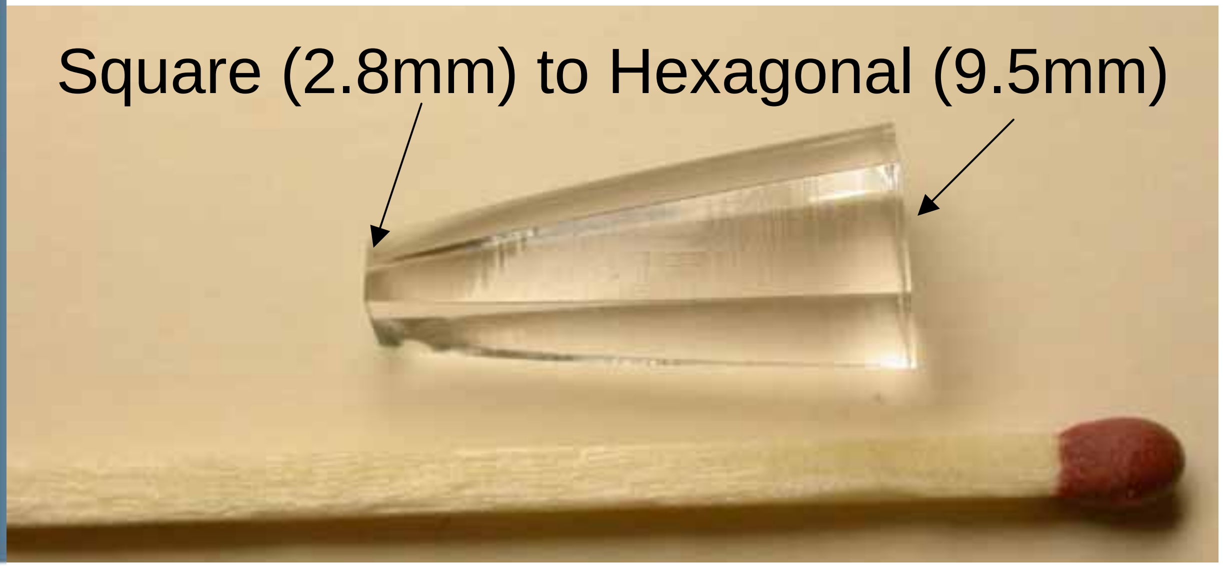


1440 G-APD (Hamamatsu S10362-33-50C):

3x3mm, 3600 cells (50x50um)

each equipped with solid light guide

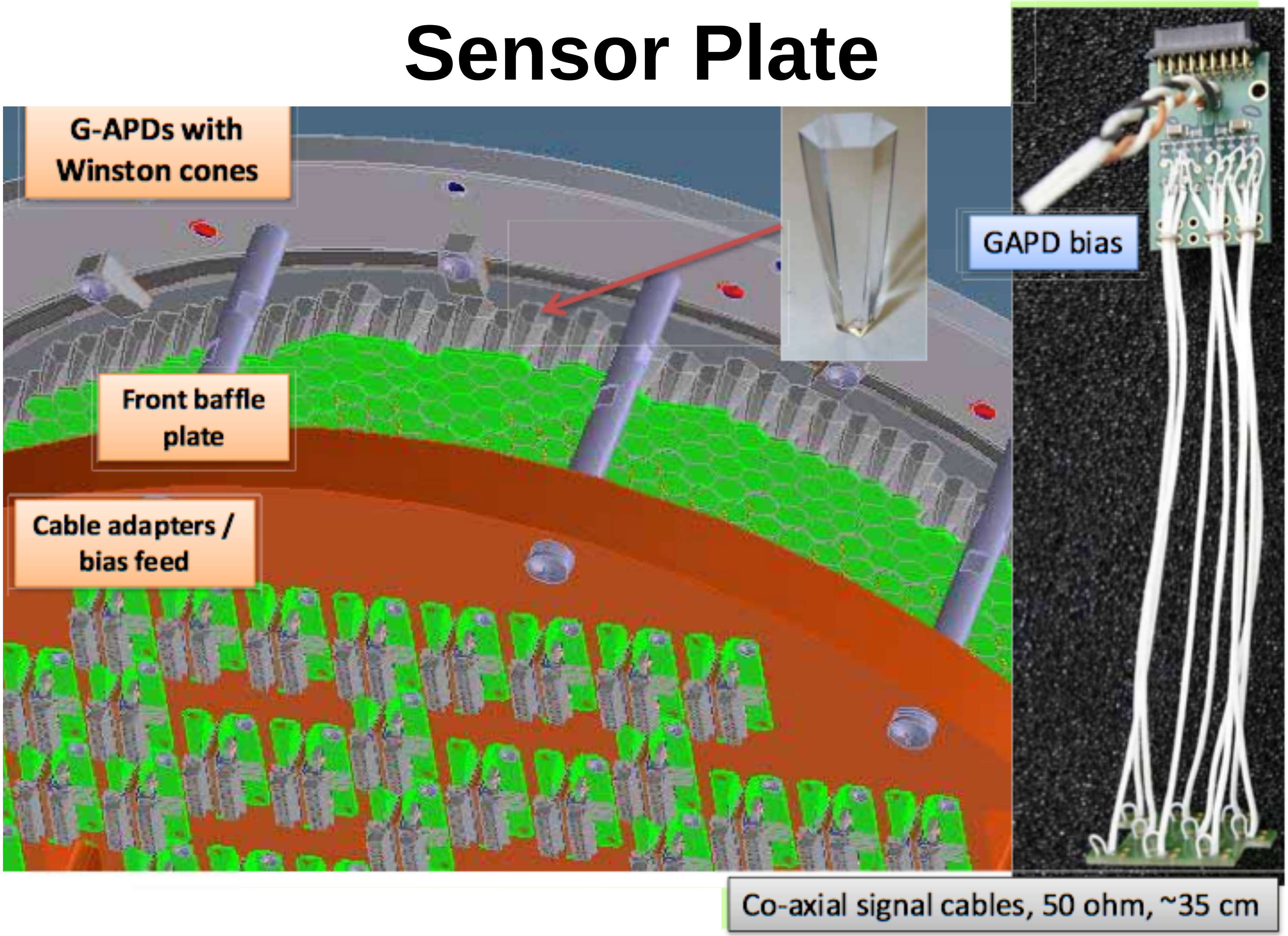
==> 0.1deg/Pixel, 4.4deg FoV Camera



Solid cones (using total reflection):

- because of large angl. acceptance of G-APD allow higher conc.
- cheaper and easier(??) to produce (but coupling to G-APD ?!)
- rather complicated shapes possible

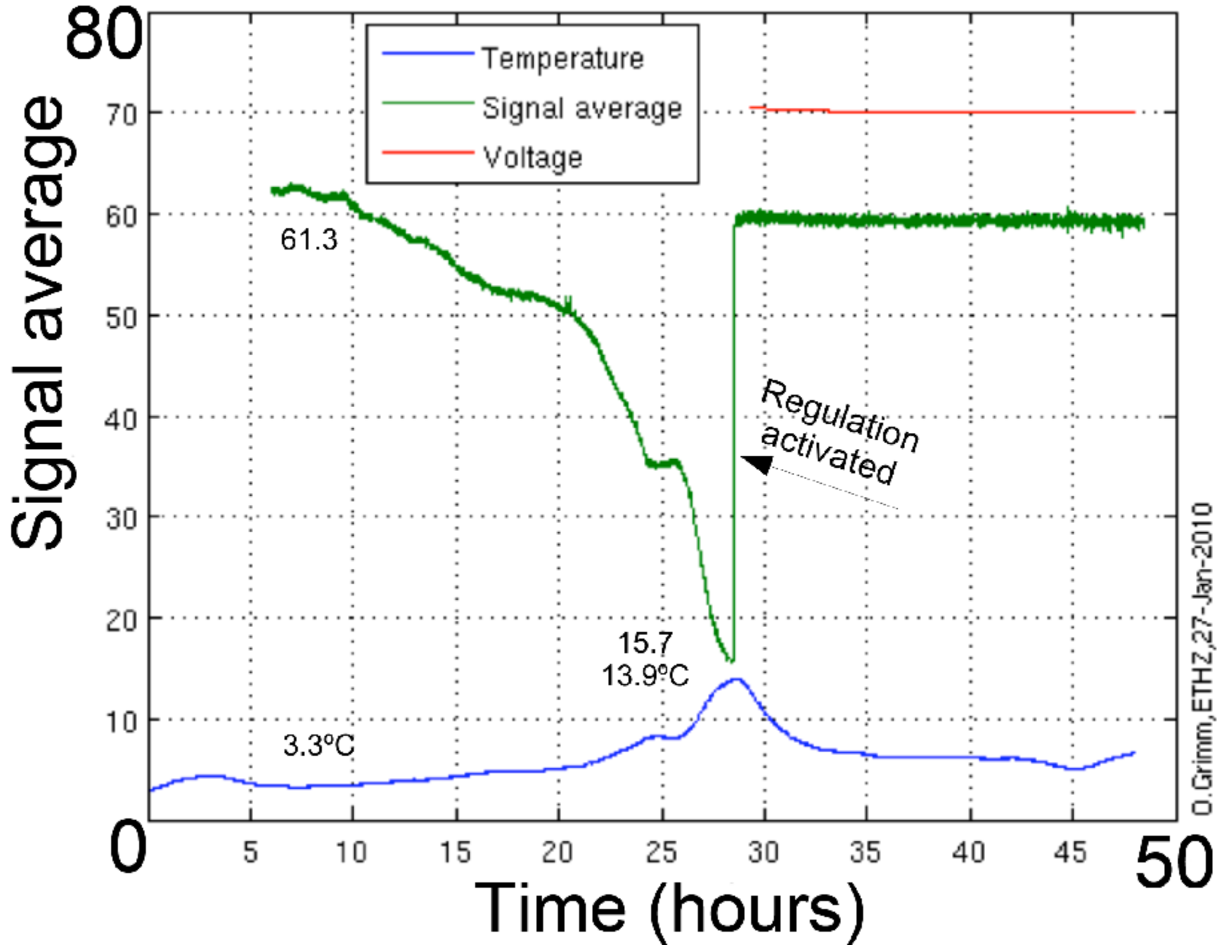
Sensor Plate



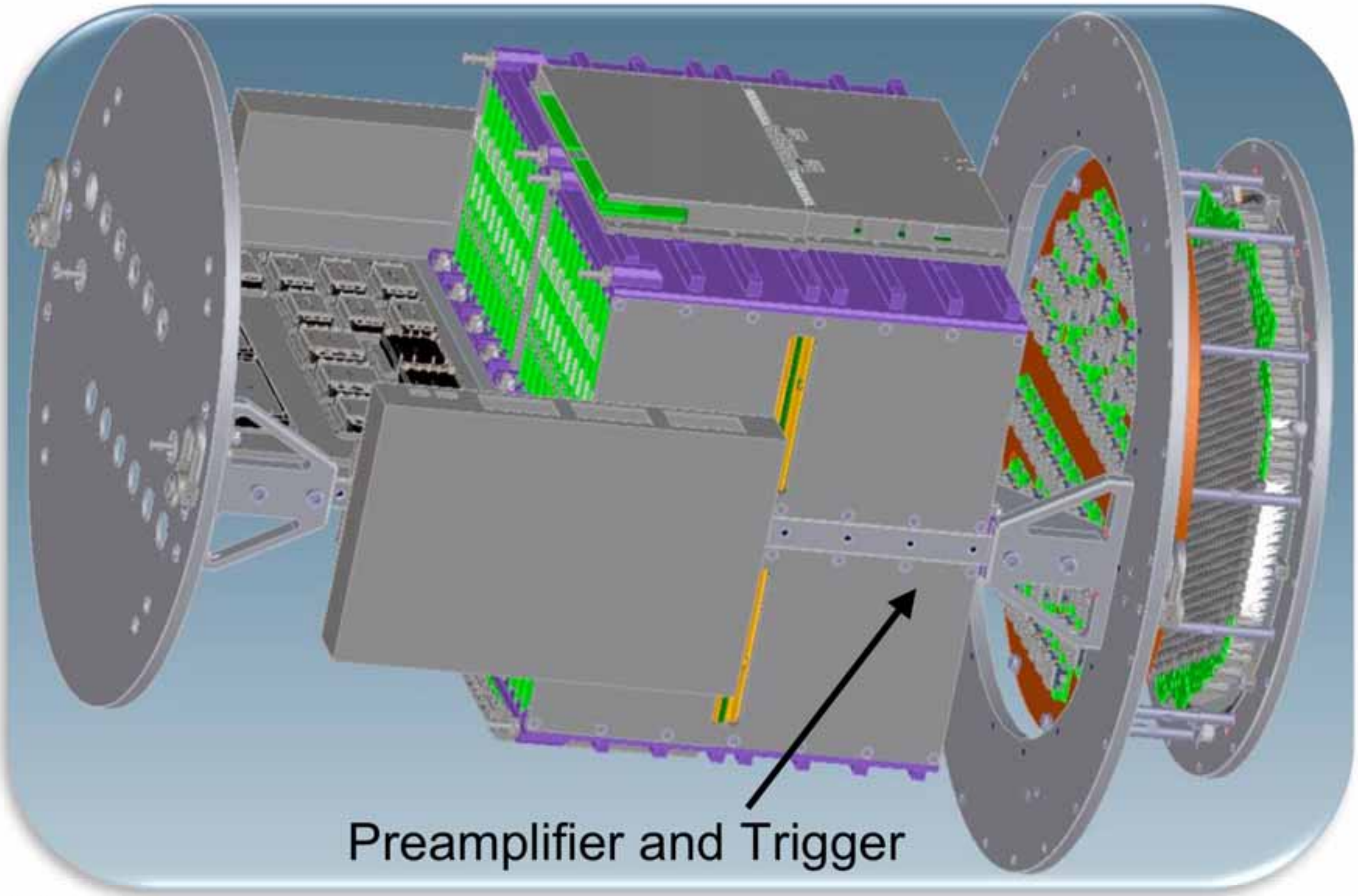
Sensor Plate

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

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



Camera



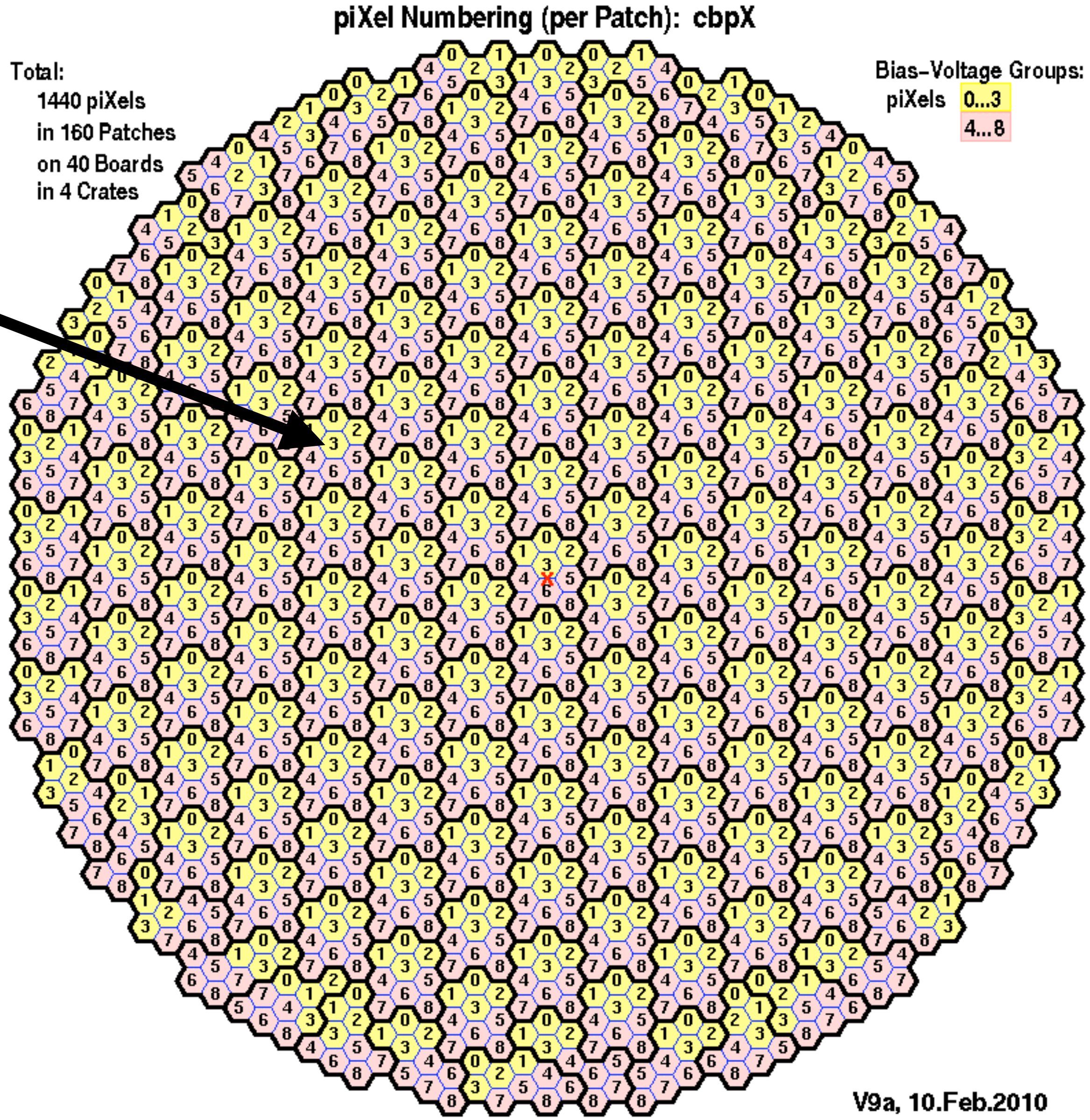
Trigger

Trigger cell:
analogue sum
of 9 pixels
(no overlaps!)

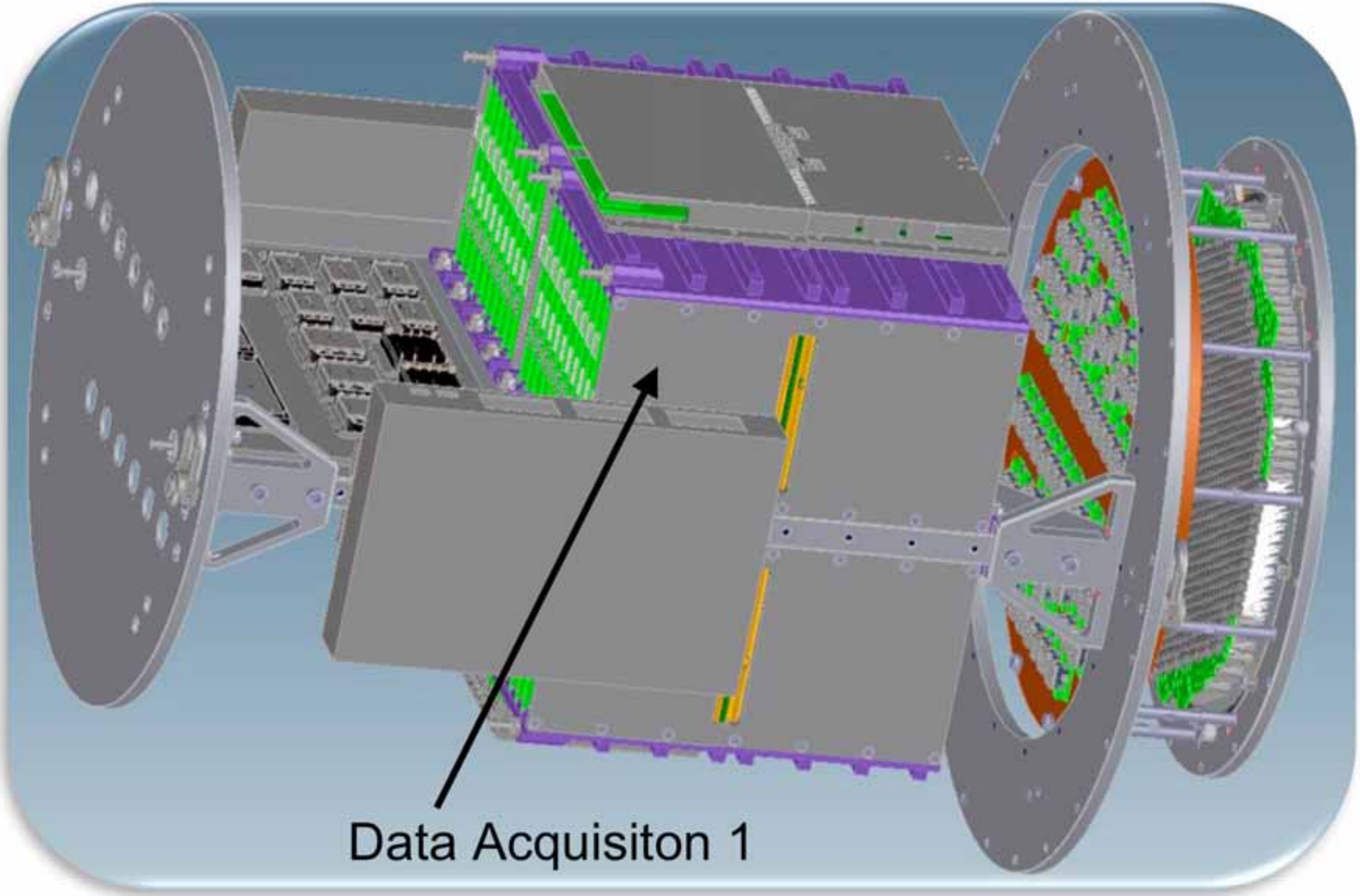
Condition:
1 cell above
threshold

Add. software trigger
in DAQ PC(-farm)

40 Boards with
36 Pixels
= 4 Cells each



Camera



Data Acquisition 1

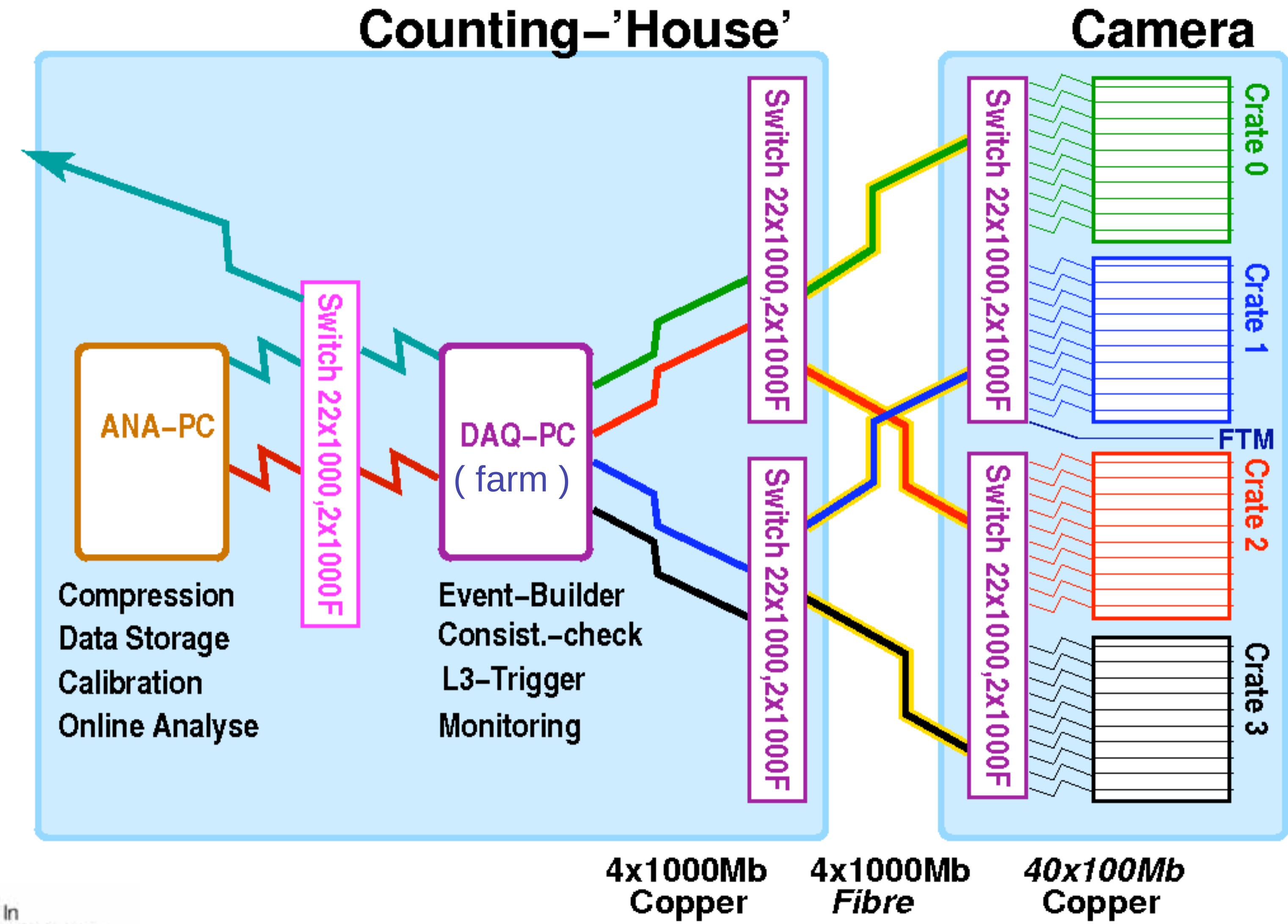
40 Boards a
36 Pixels

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

Standard Ethernet readout



Data & Trigger Rates

DRS4 -> ADC deadtimes
and ethernet bandwidth balanced

For reading 50ns window per trigger:

DRS4 sampling rate *programable*	<-->	(max) Trigger rate
700MHz		~2000Hz
1000MHz		~1400Hz
2000MHz		~700Hz

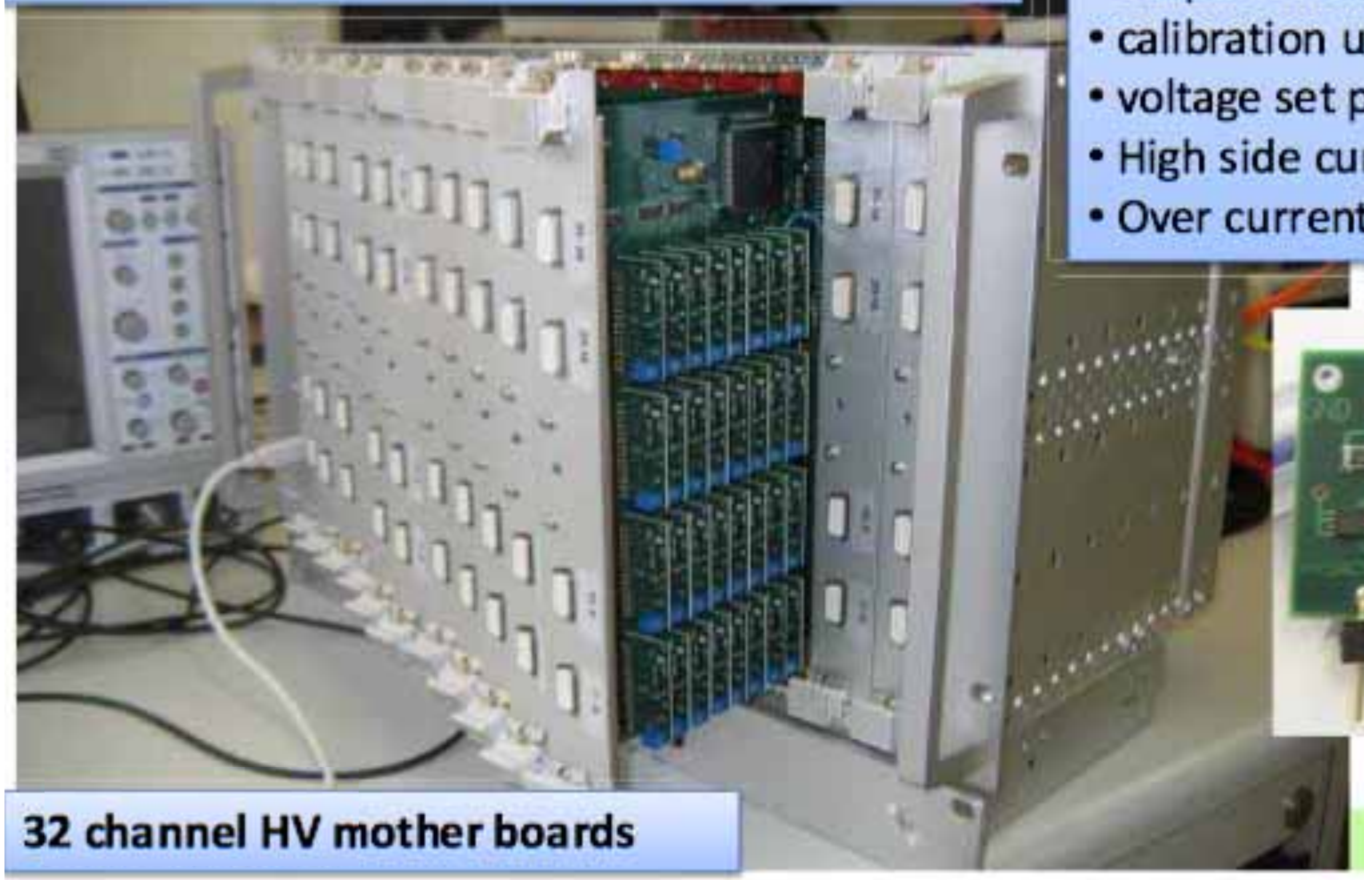
Factor 5-10 higher with some hardware modifications possible, but much higher power consumption

<--> expected hadron rate: 50Hz - 70Hz

'HV' Power Supply

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



32 channel HV mother boards

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

Camera Status

- all G-APDs in hand and tested
- all DRS-4 in hand and tested
- 'HV' built and tested
- Ethernet: all components in hand and tested
- Light Guides (Cones): in production
- Cooling and mechanics: in production
- Elec Boards: in production (final prototypes tested)
- Firmware: development in progress

assembly 1440 pixels & cones need several months

Camera Status

- all G-APDs in hand and tested
- all DRS-4 in hand and tested
- 'HV' built and tested
- Ethernet: all components in hand and tested
- Light Guides (Cones): in production
- Cooling and mechanics: in production
- Elec Boards: in production (final prototypes tested)
- Firmware: development in progress

assembly 1440 pixels & cones need several months

First light: Summer 2011 (?)