Field experience with SiPMs in Cherenkov and Scintillator Detectors

Thomas Bretz

Physics Institute III | RWTH AACHEN UNIVERSITY

SiPM (A selection)

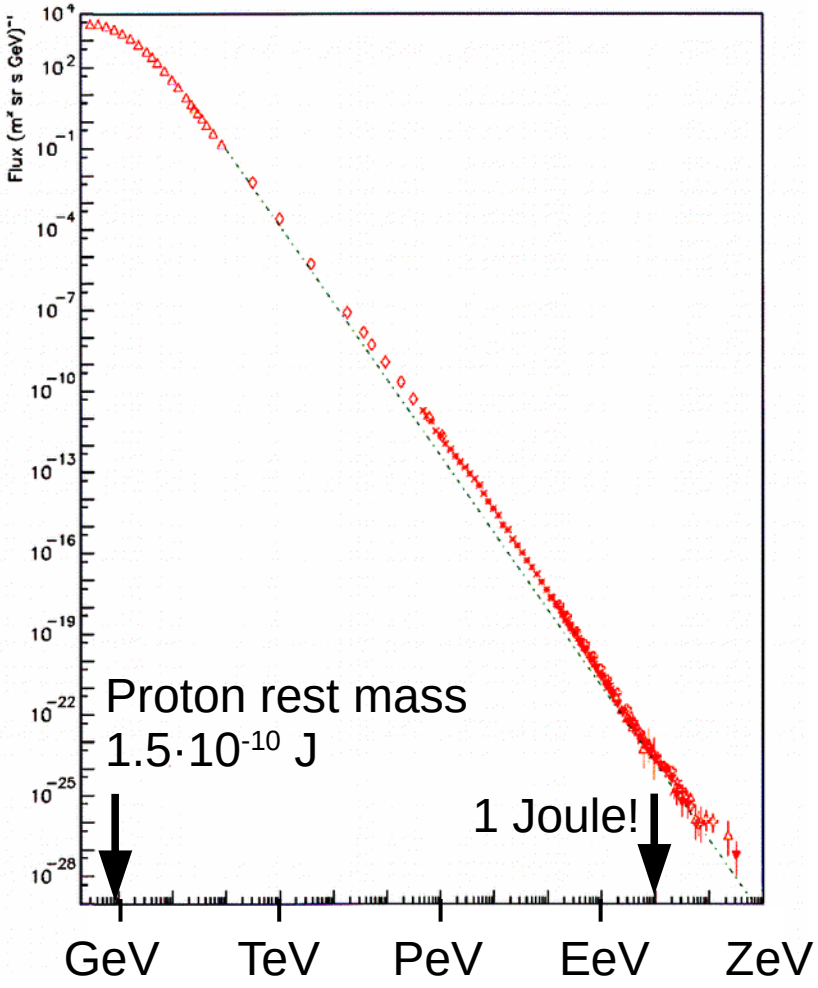
- High Photo Detection efficiency (up to 50%)
- Very robust (semi-conductor, illumination)
- Single Photon resolution

- Small sensitive area
  - significant increase possible by light guides

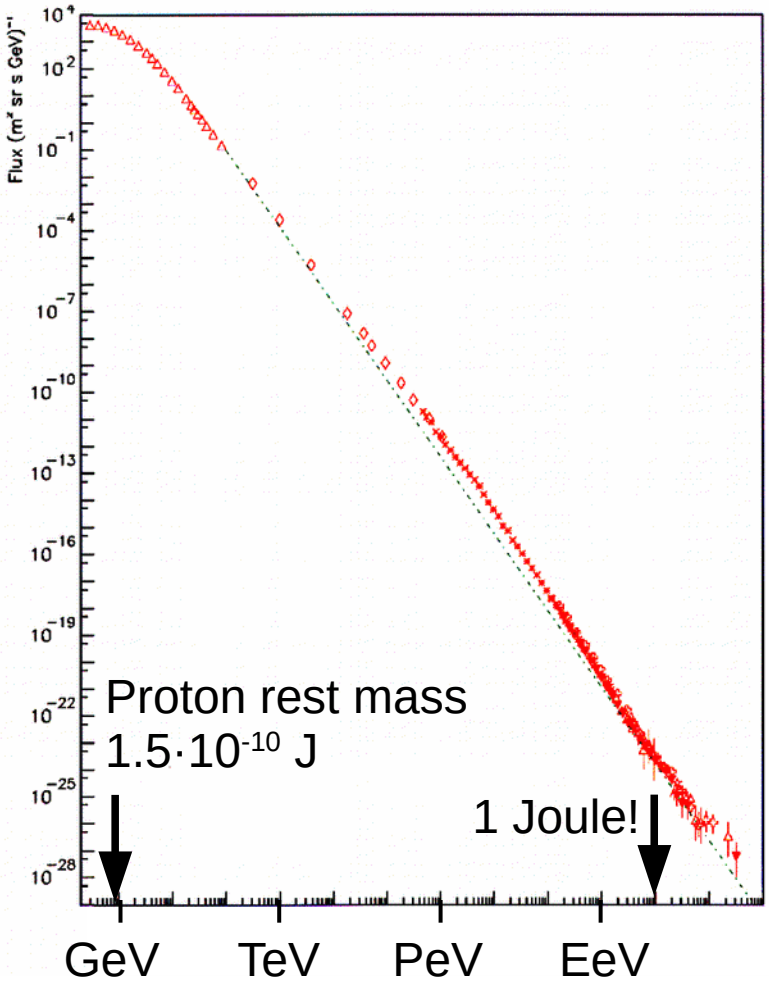
- Gain stability
  - needs voltage regulation

- Dynamic range limited by number of G-APD cells
  - needs good understanding of properties for unfolding

The cosmic ray spectrum (all particles)



The cosmic ray spectrum (all particles)



F(E>10^9 eV) ~ 1 particle / s m²

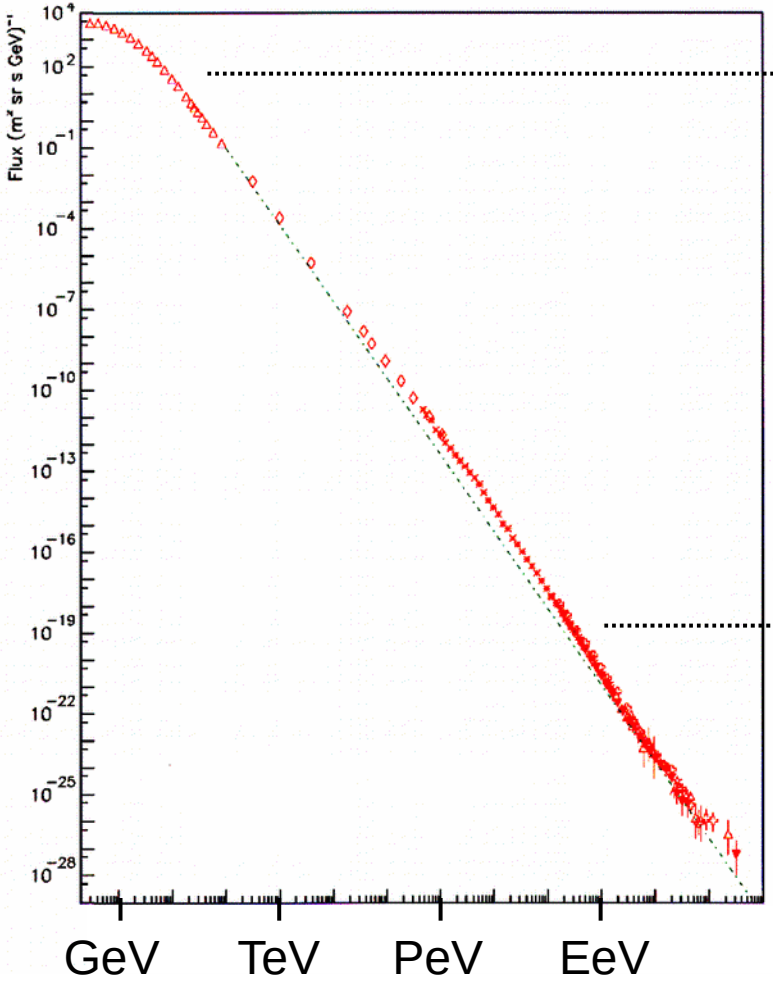
Amazon river: 206 000 000 litre / s

F(E>$10^{19.5}$ eV) ~ 1 particle / century km²

1 drop / month

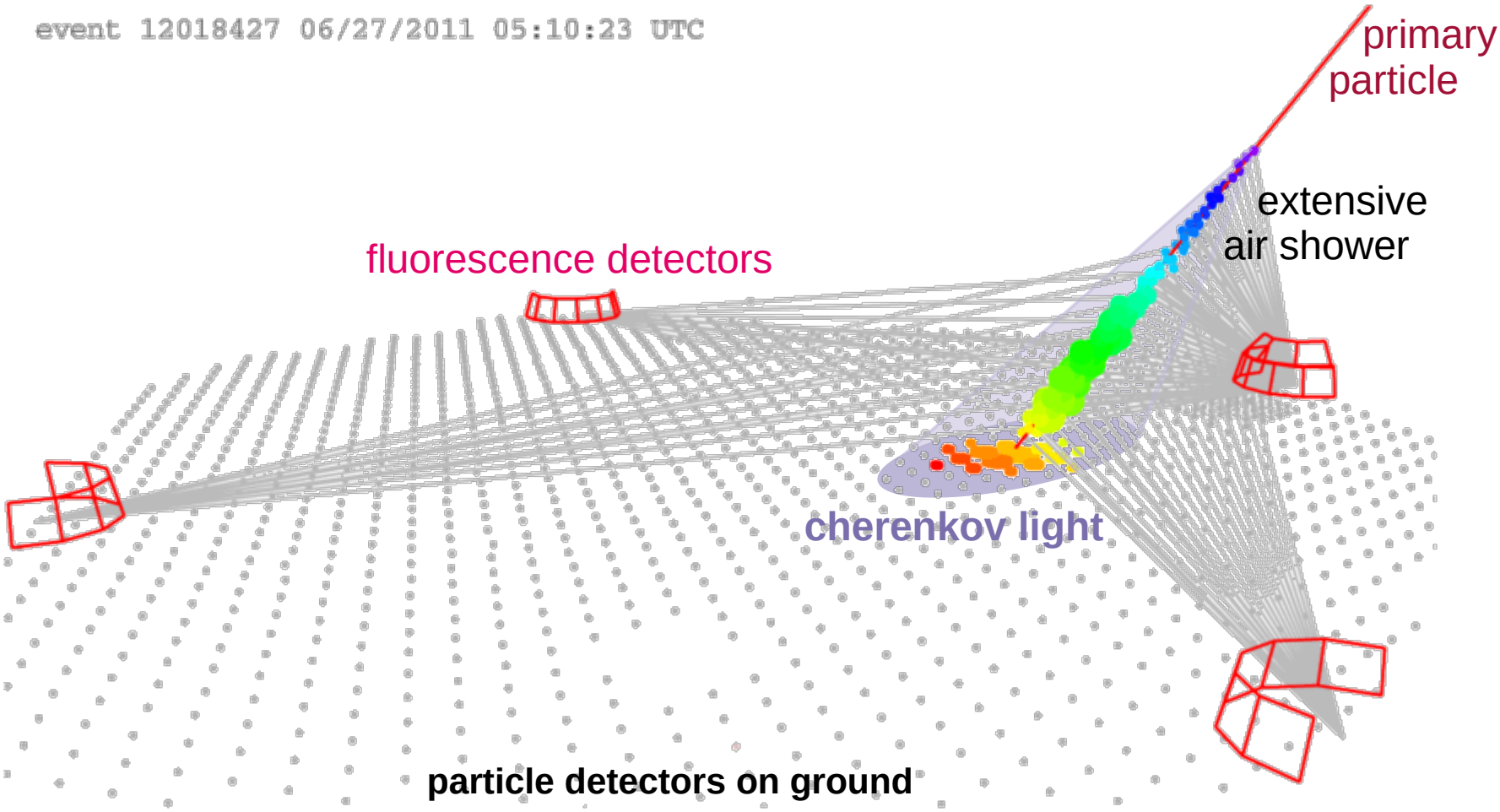
(1 drop ~ 5mg)

The cosmic ray spectrum

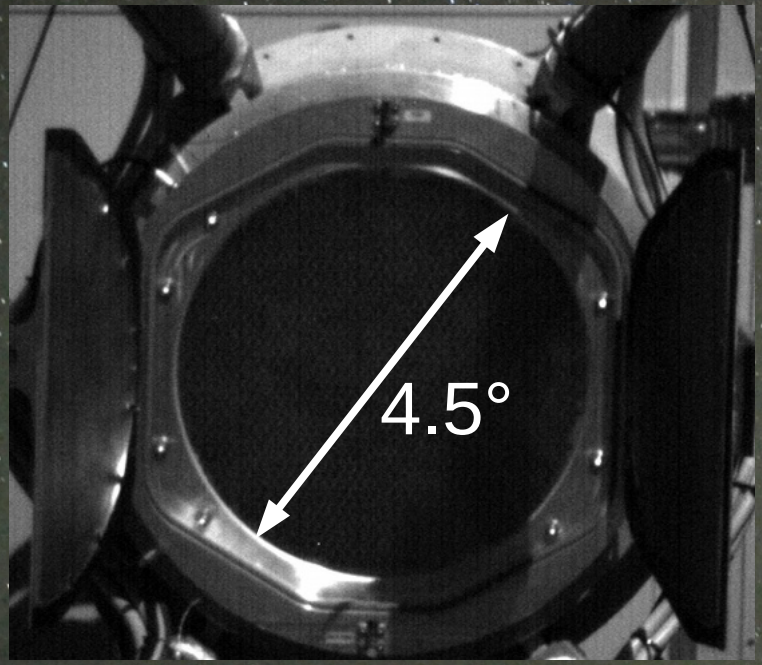


can only be measured from ground through extensive air showers

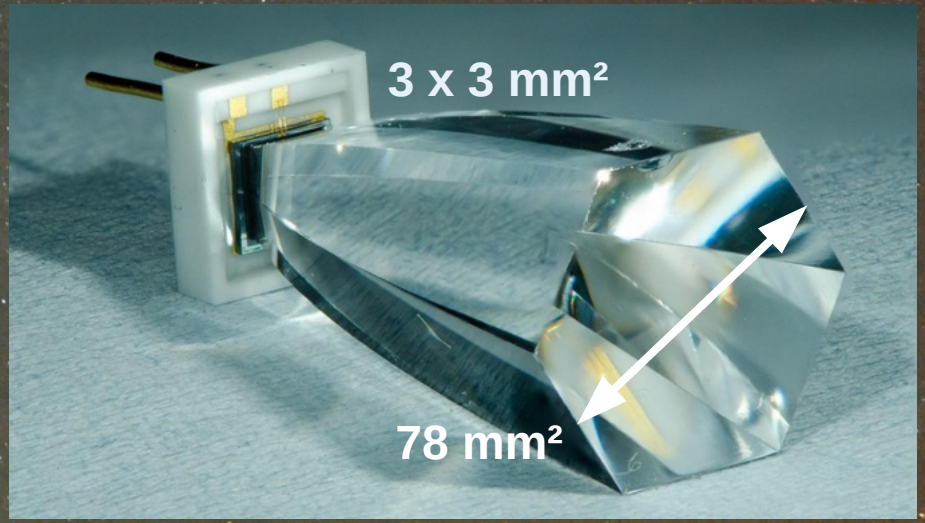
Hunt for the origin of cosmic rays



FACT – The First G-APD Cherenkov Telescope



1440 SiPM with solid cone



9.5 m²

JINST (2013) 8 P06008
JINST (2014) 9 P10012

Selected events (first light: Oct 11th 2011)

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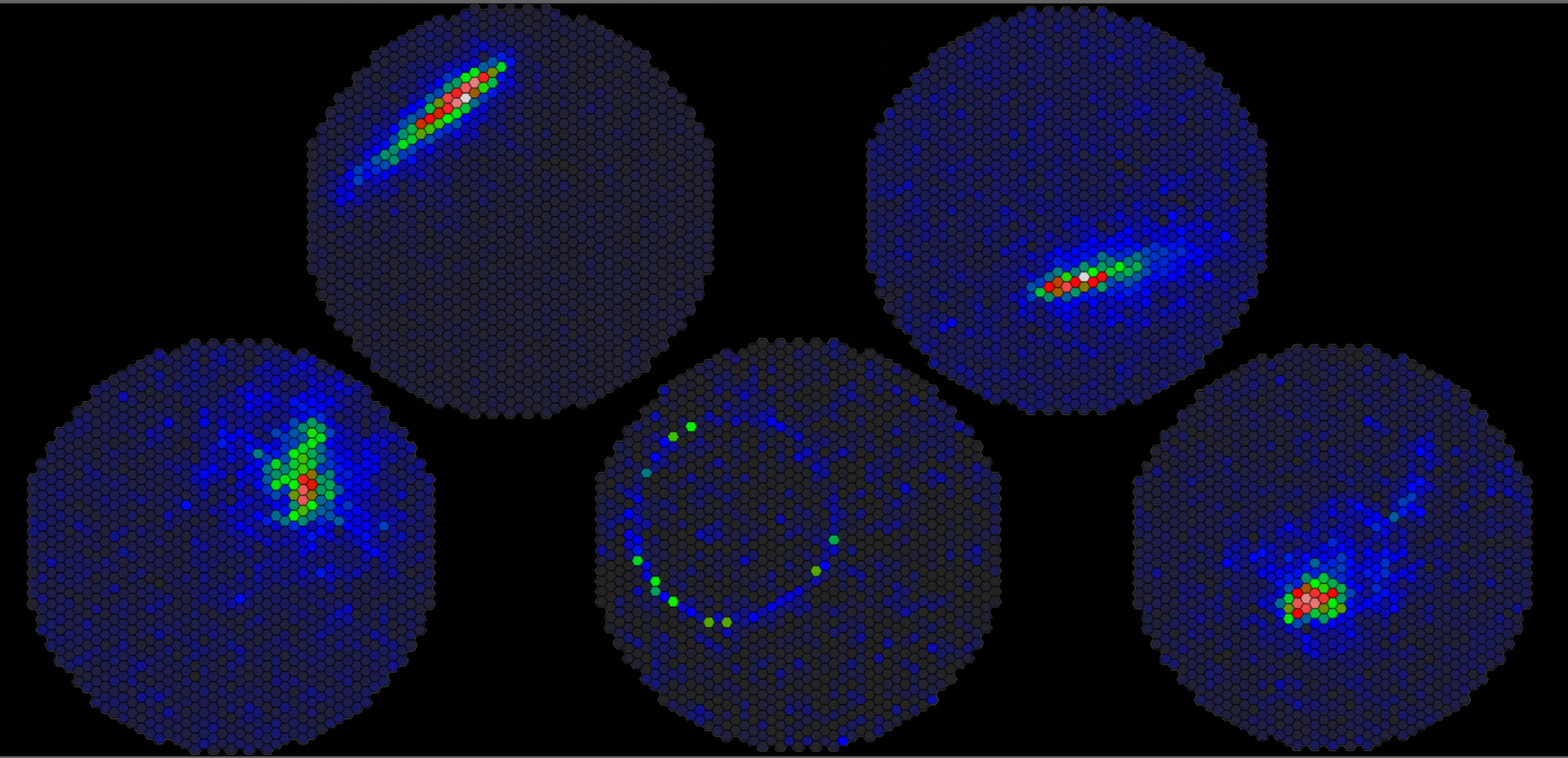
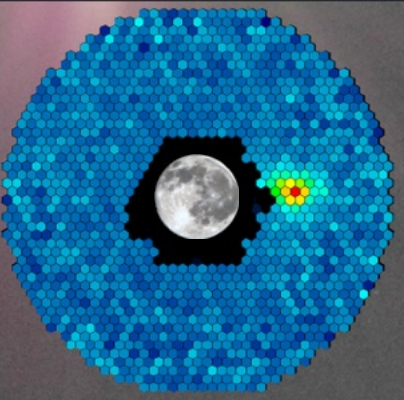
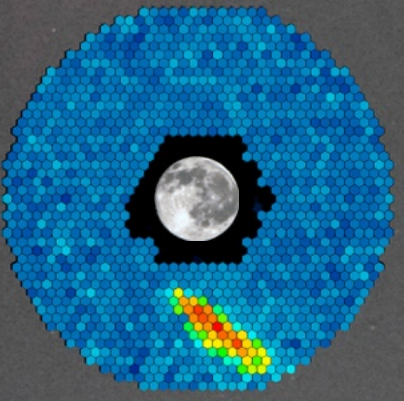
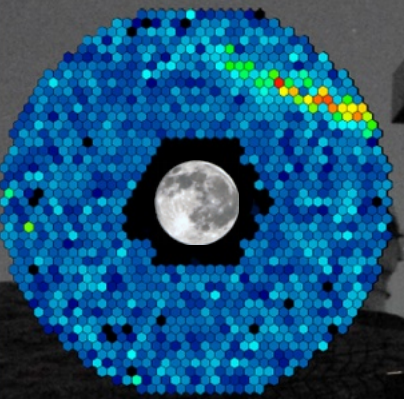
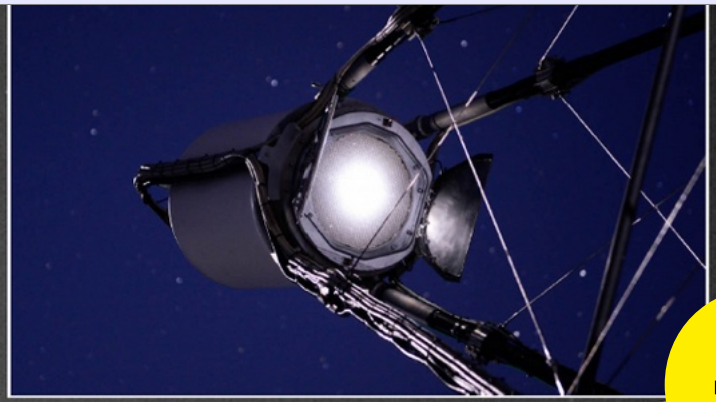


Operation during moon light





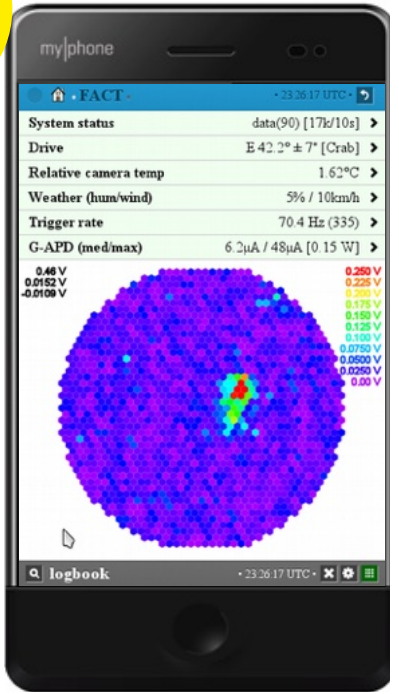




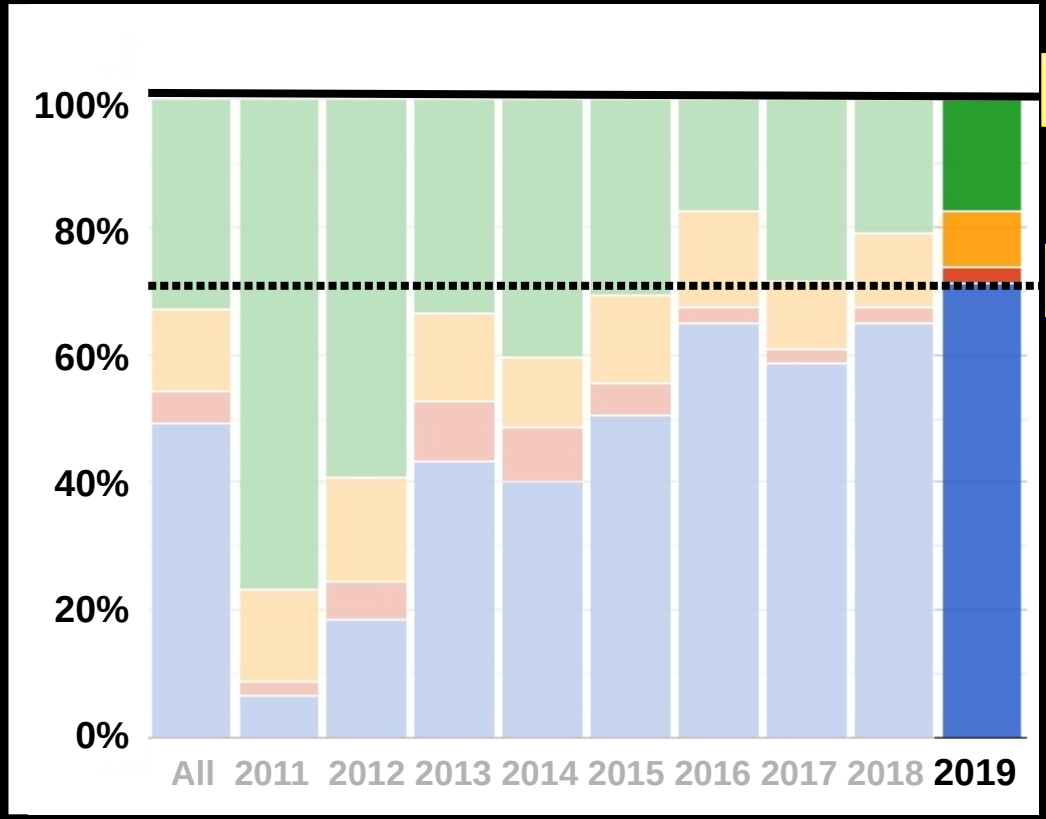
+

no calibration required

unattended and automatic data taking



www.fact-project.org/smartfact



42% Night time per year

~71% Physics data per year

→ 0.42 · 0.71 = 30%

2600 h

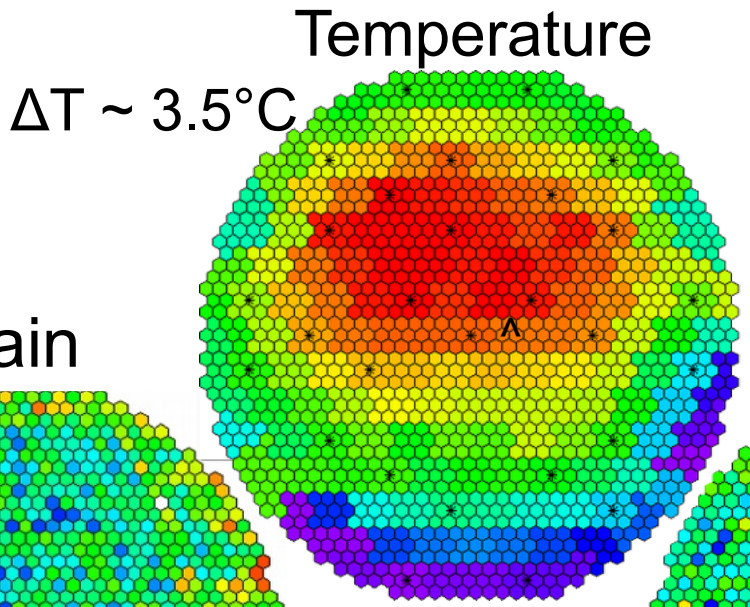
possible

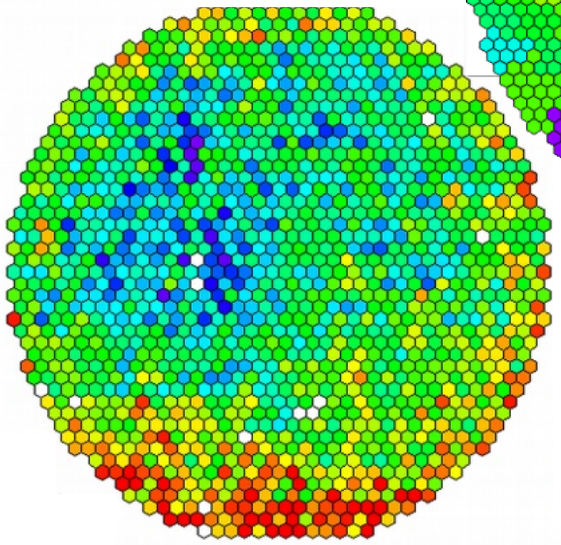
→ x 1.16 = 35%

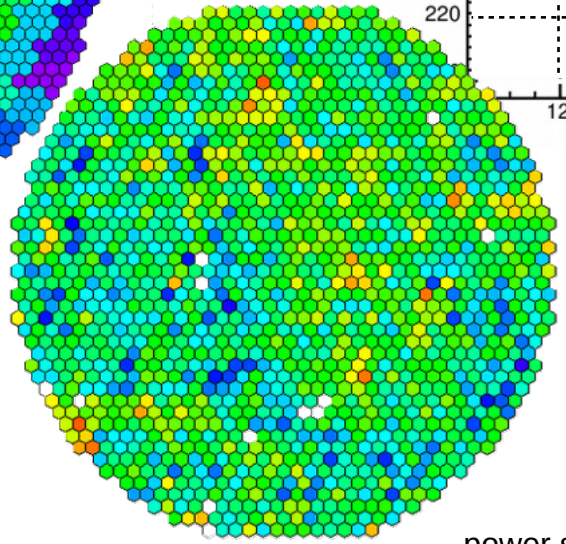
3000 h

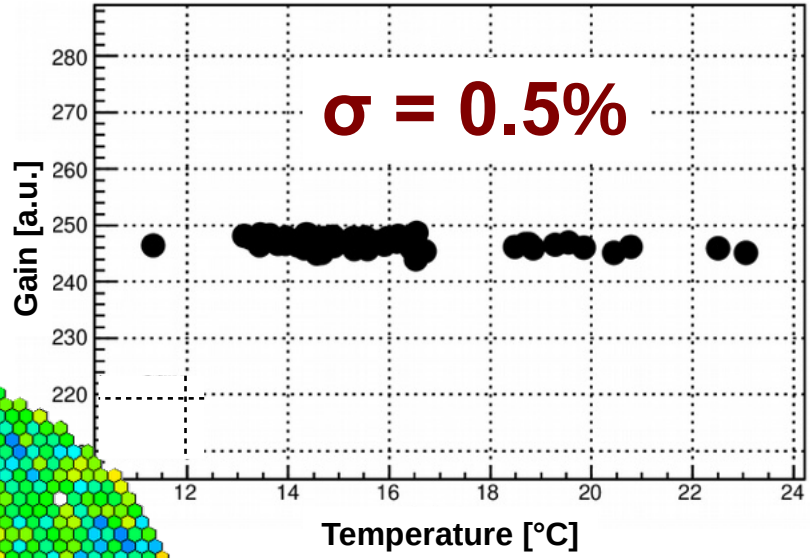
→ ideally suited for monitoring

Temperature and gain distribution in the camera







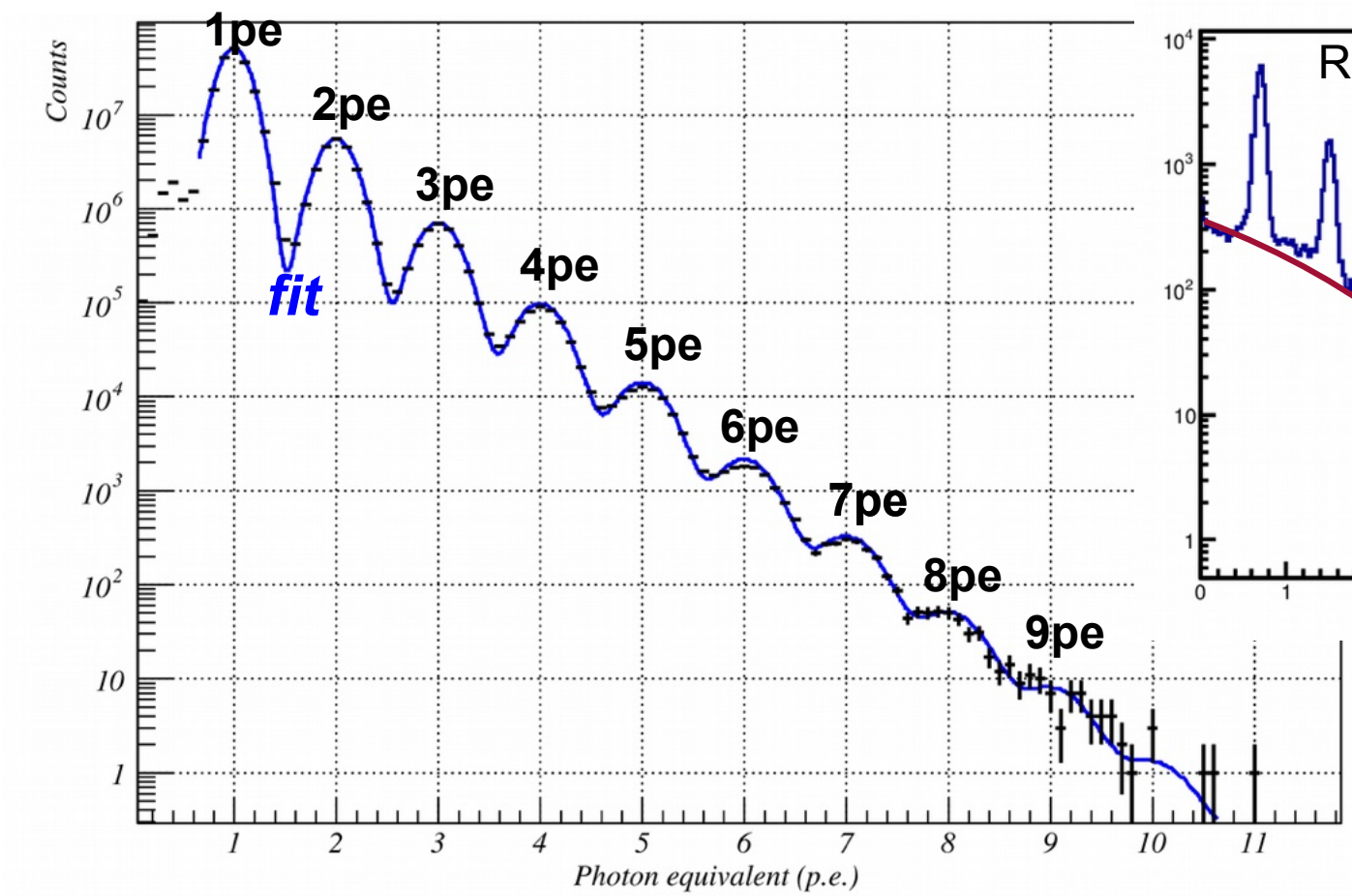


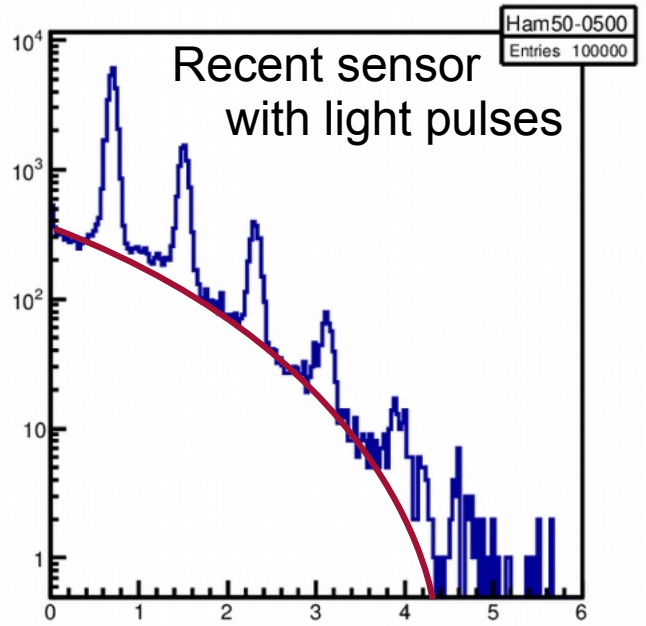
Voltage correction applied

power supply precision

Self calibrating / Stability

all pixels; **one year**; temp: ~0°C – 25°C





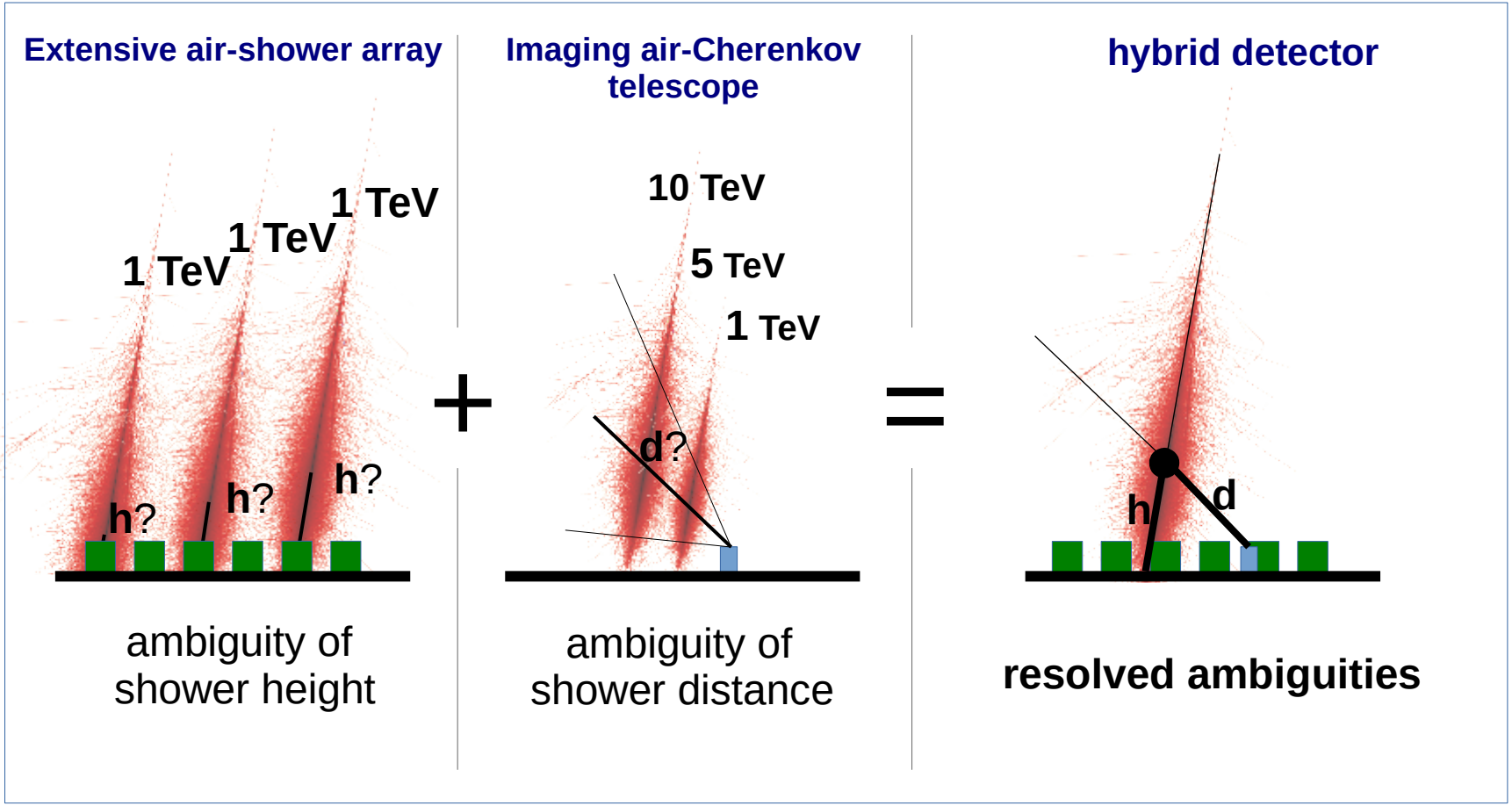
A compact and light-weight telescope

- *A compact and light-weight refractive telescope for the observation of extensive air showers* JINST (2018) 13 P07024

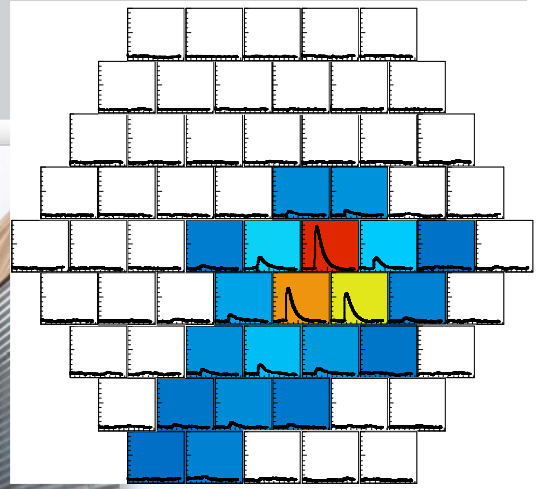
50cm Fresnel lens

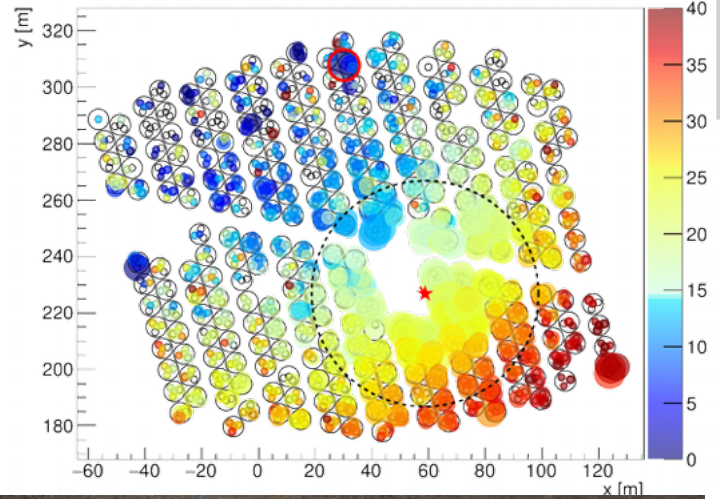
The (over-simplified) Cherenkov concept

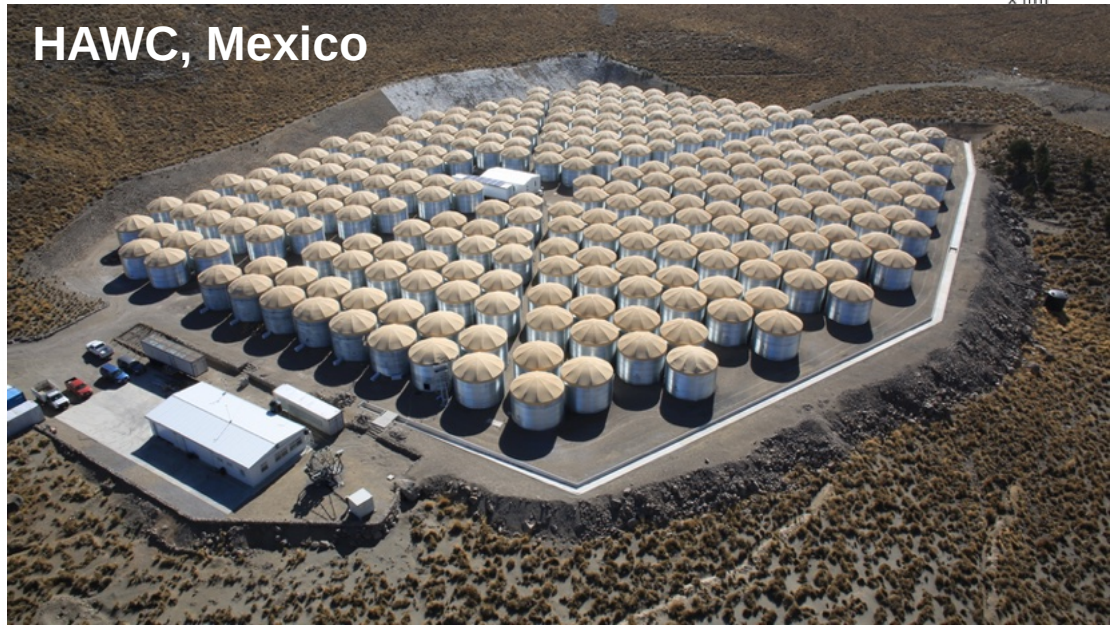
Pos (ICRC2017)786



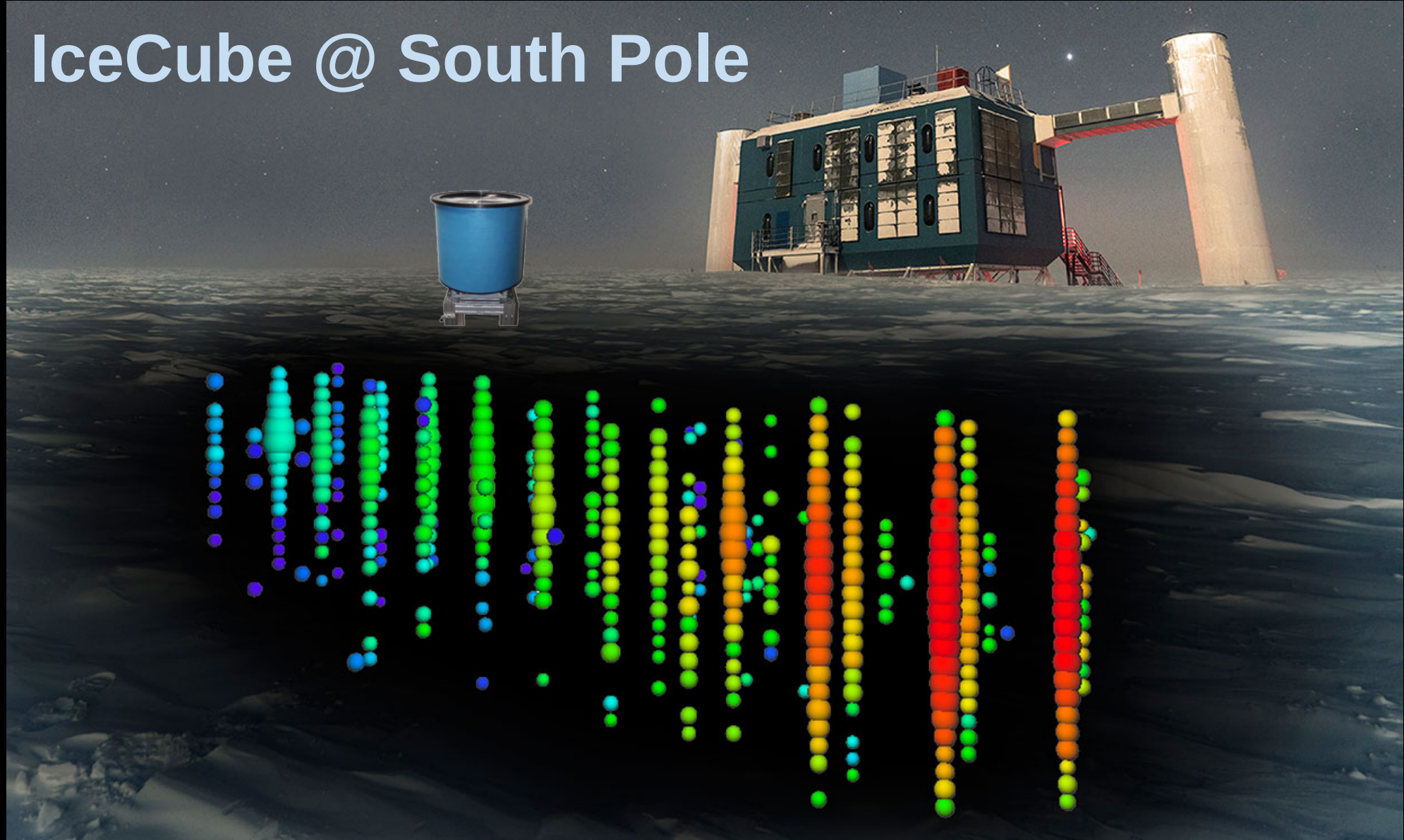
HAWC's Eye – First light



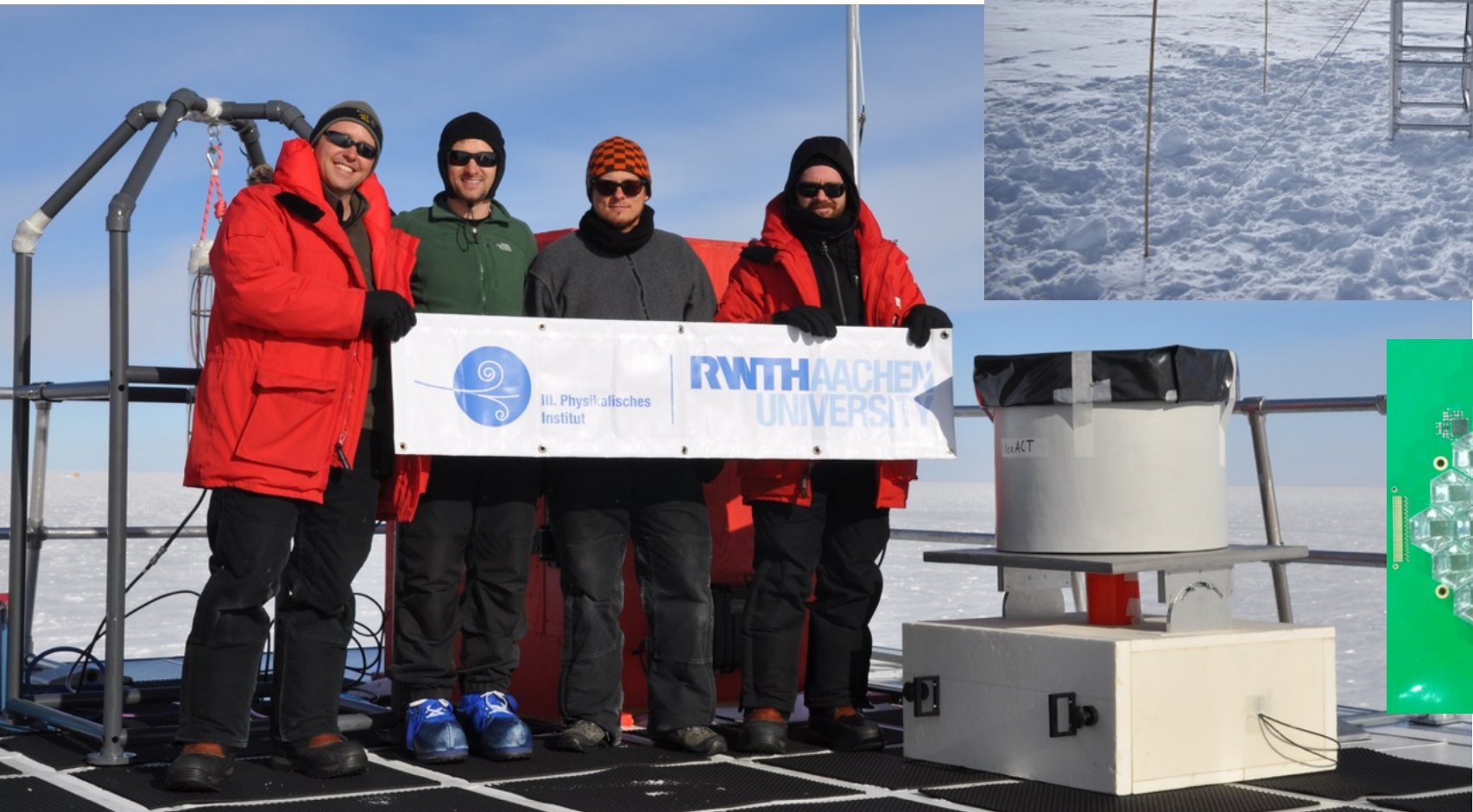


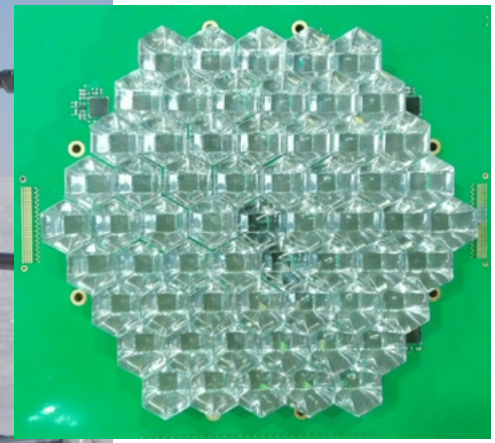


IceCube @ South Pole



Veto / CR Composition at the knee

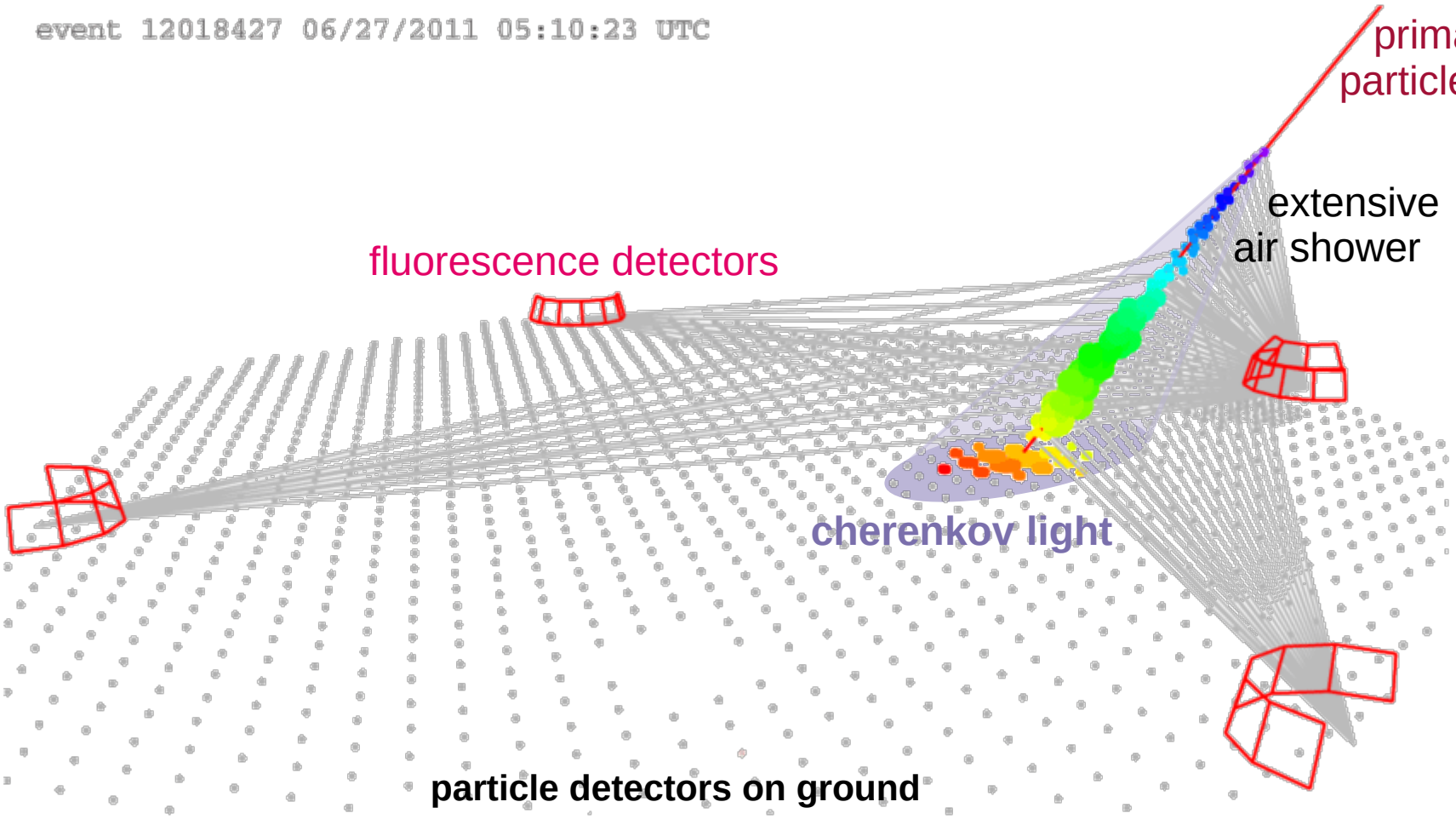




Student lab course astroparticle physics

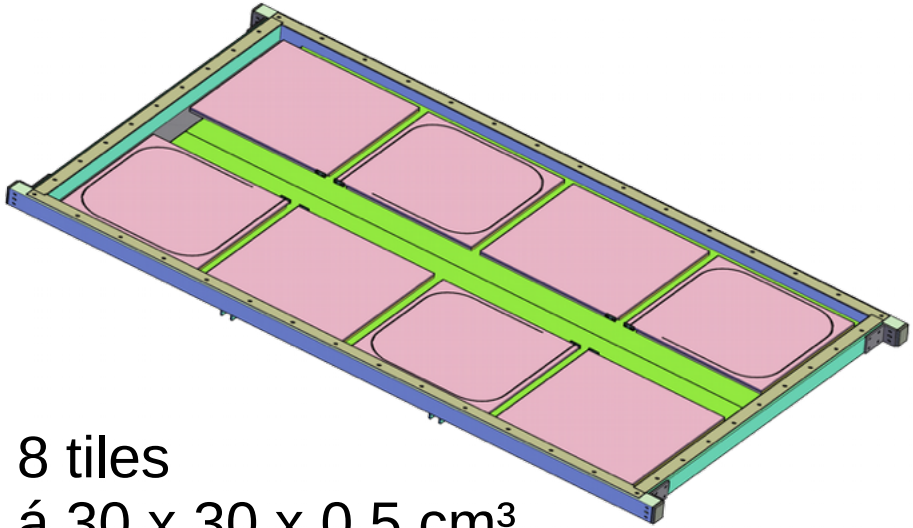
cosmic ray physics
air shower physics

Hunt for the origin of cosmic rays

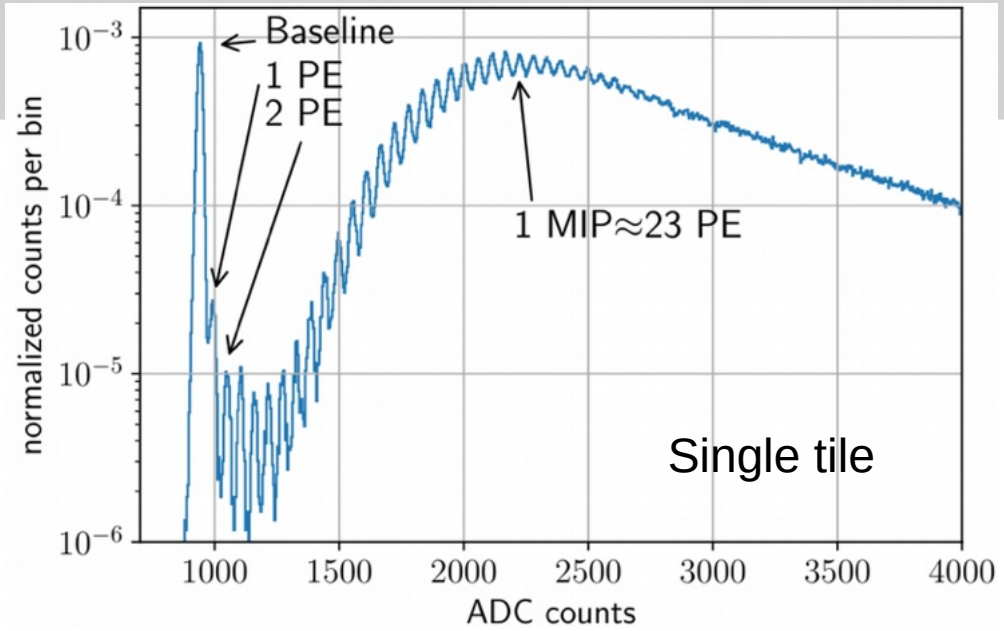


Aachen Muon Detector

- Dedicated application of SiPM
- Wavelength shifting fibers
- One 1mm² SiPM per tile



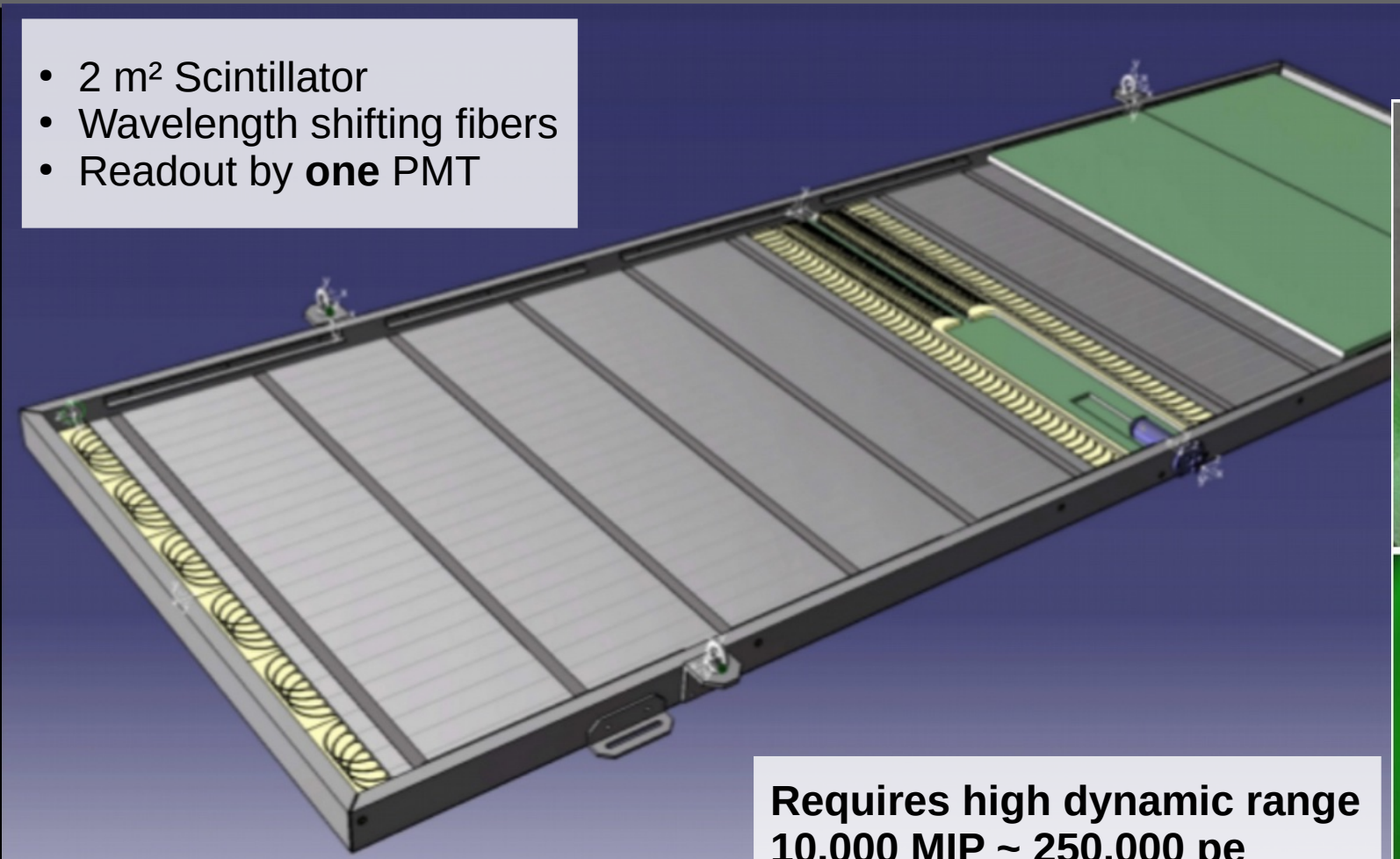
8 tiles
á 30 x 30 x 0.5 cm³

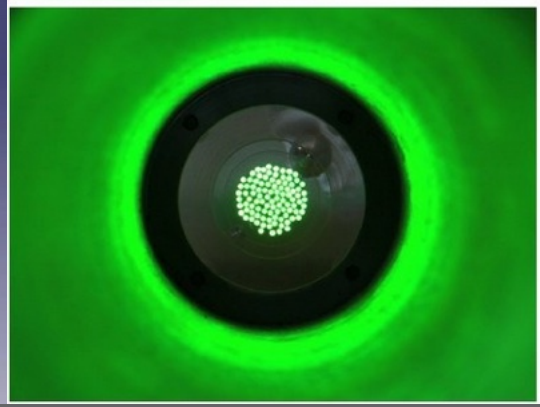


PoS ICRC2015 (2016) 596
JPS Conf. Proc. 19, 011030 (2018)

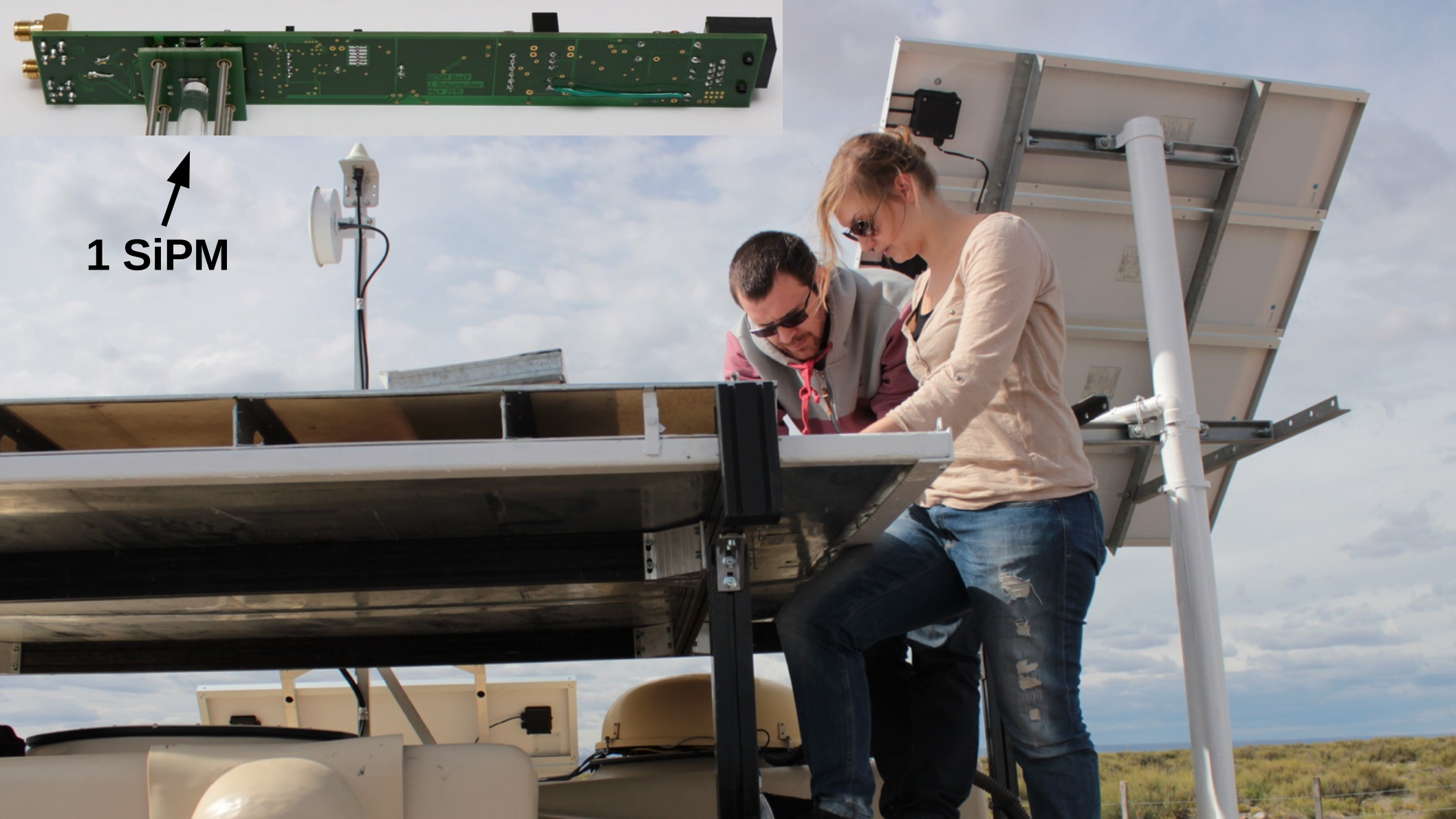
Scintillator Surface Detector (Pierre Auger)

- 2 m² Scintillator
- Wavelength shifting fibers
- Readout by **one** PMT

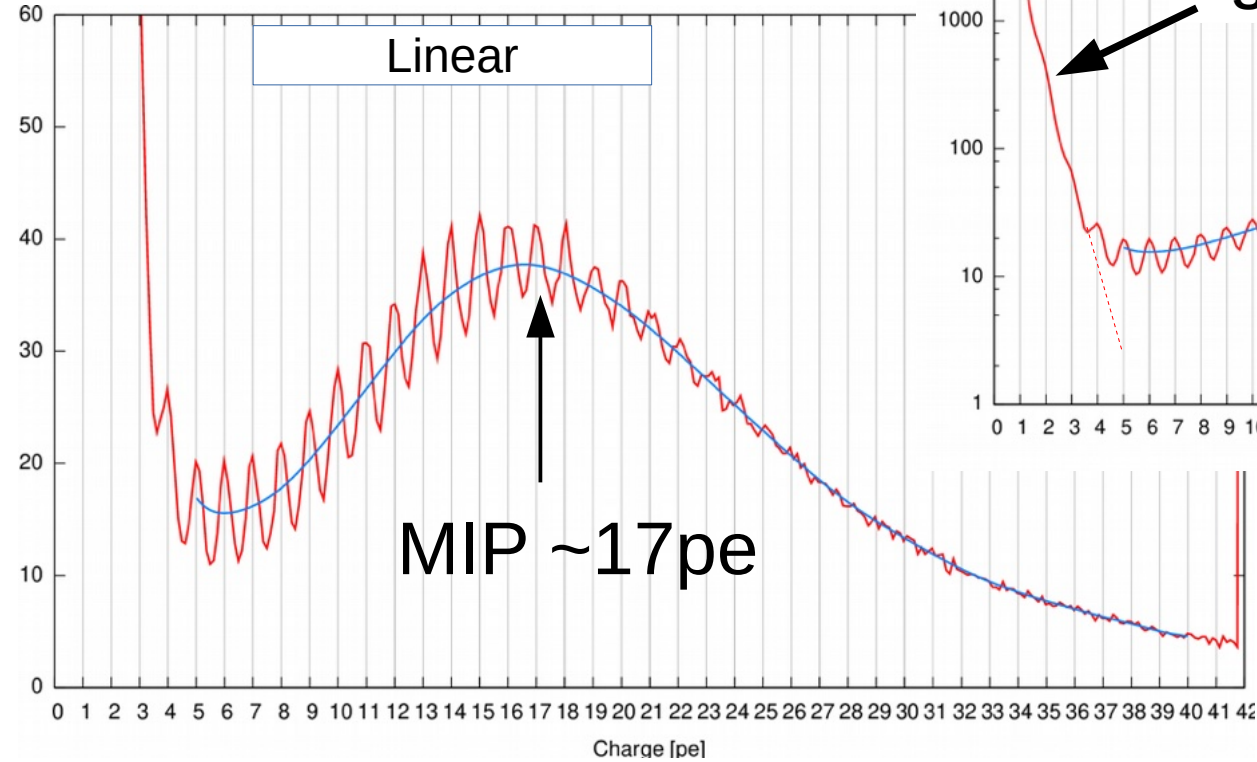


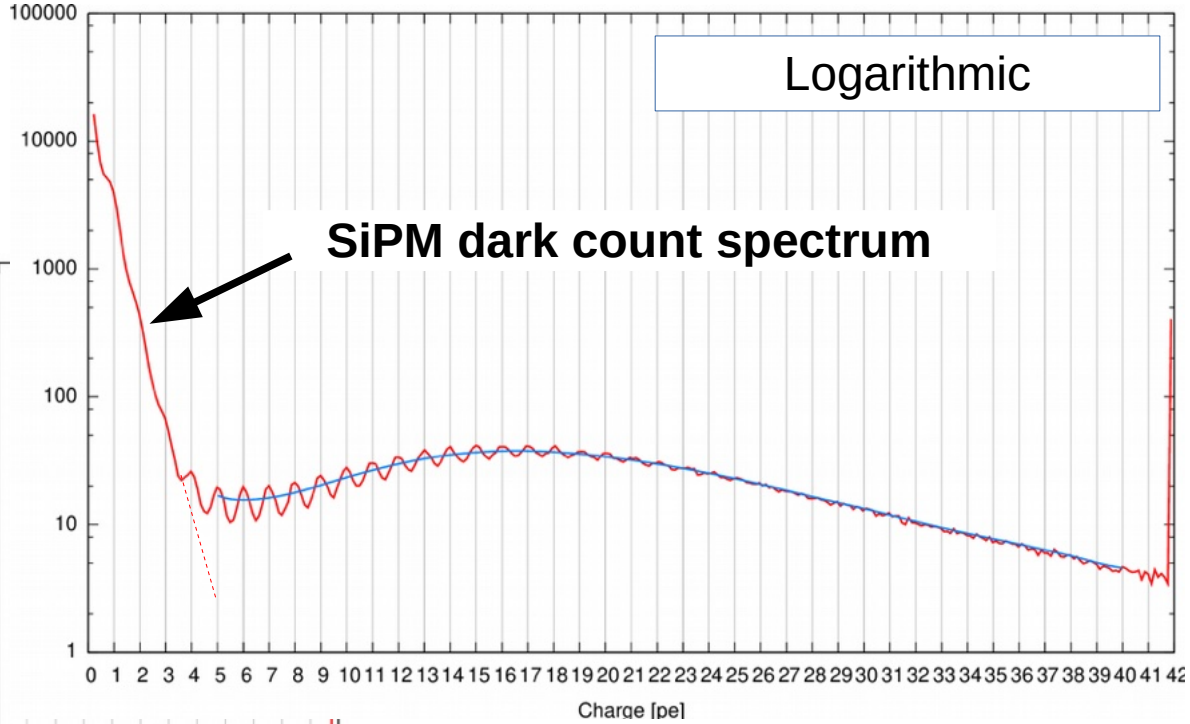


Requires high dynamic range
10,000 MIP ~ 250,000 pe


1 SiPM

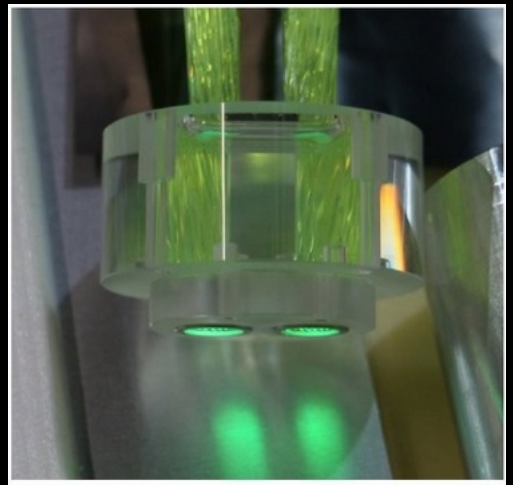
Converted to N_{pe}
by just counting

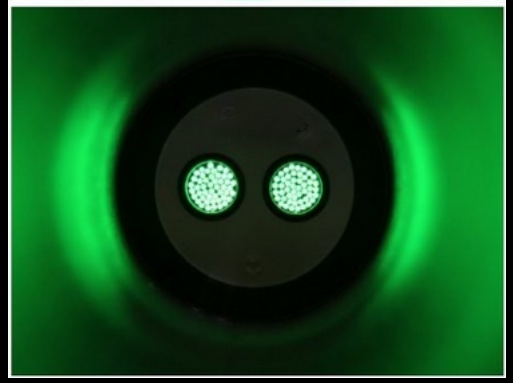




SSD Production

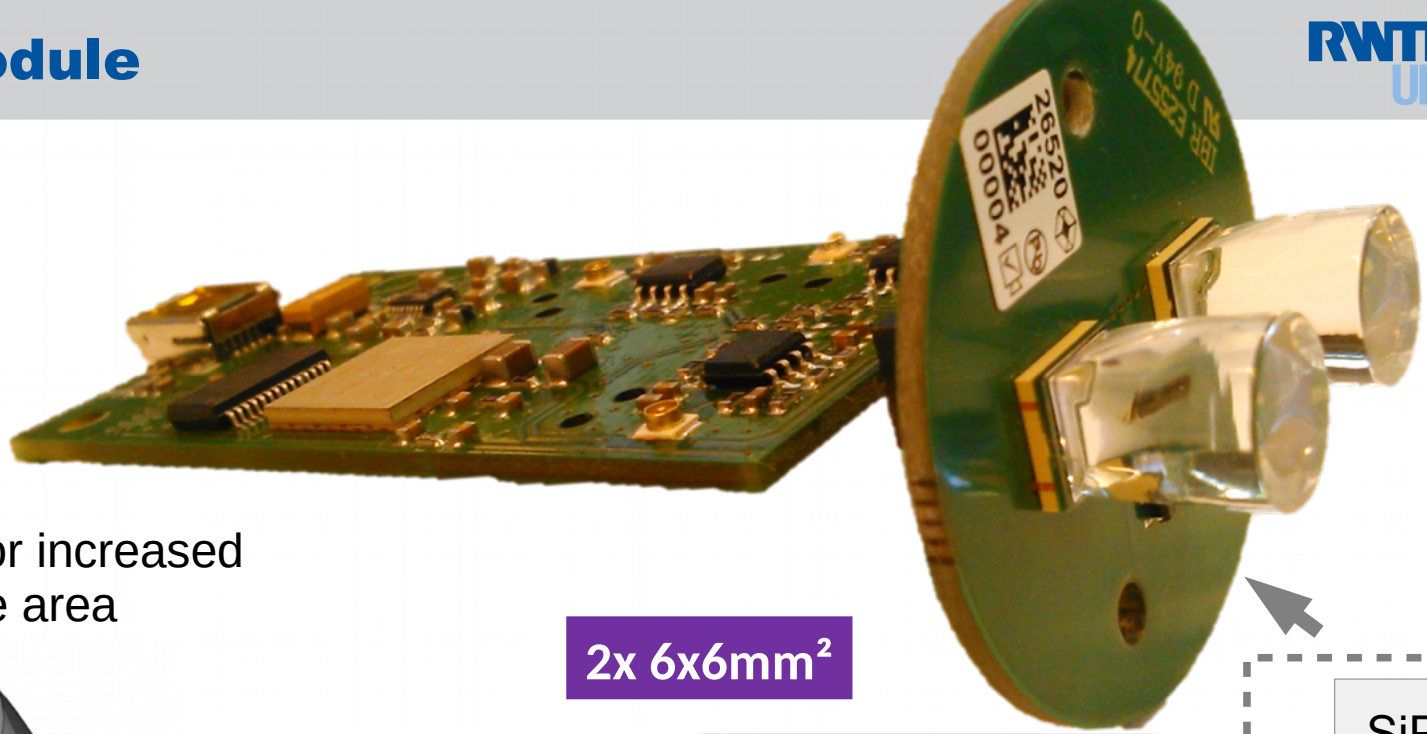
Some special detectors



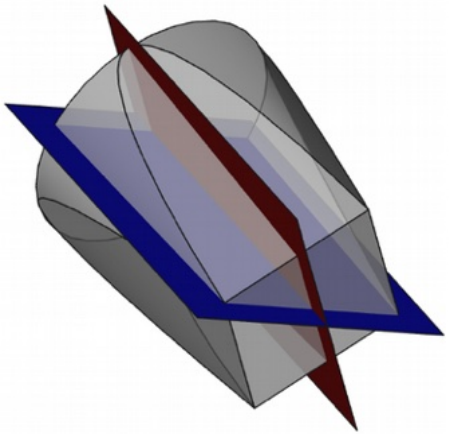


Adapt to area of SiPM

The optical module

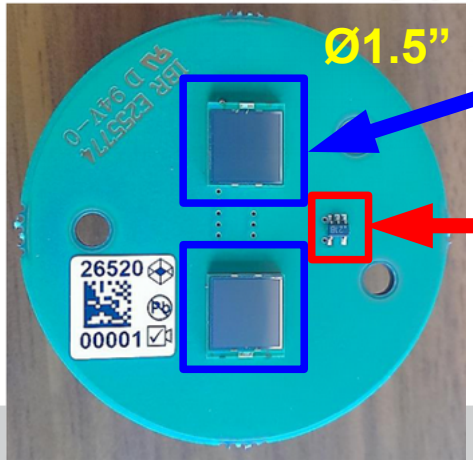


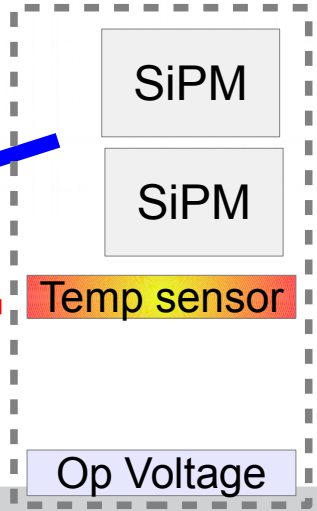
Light guides for increased sensitive area



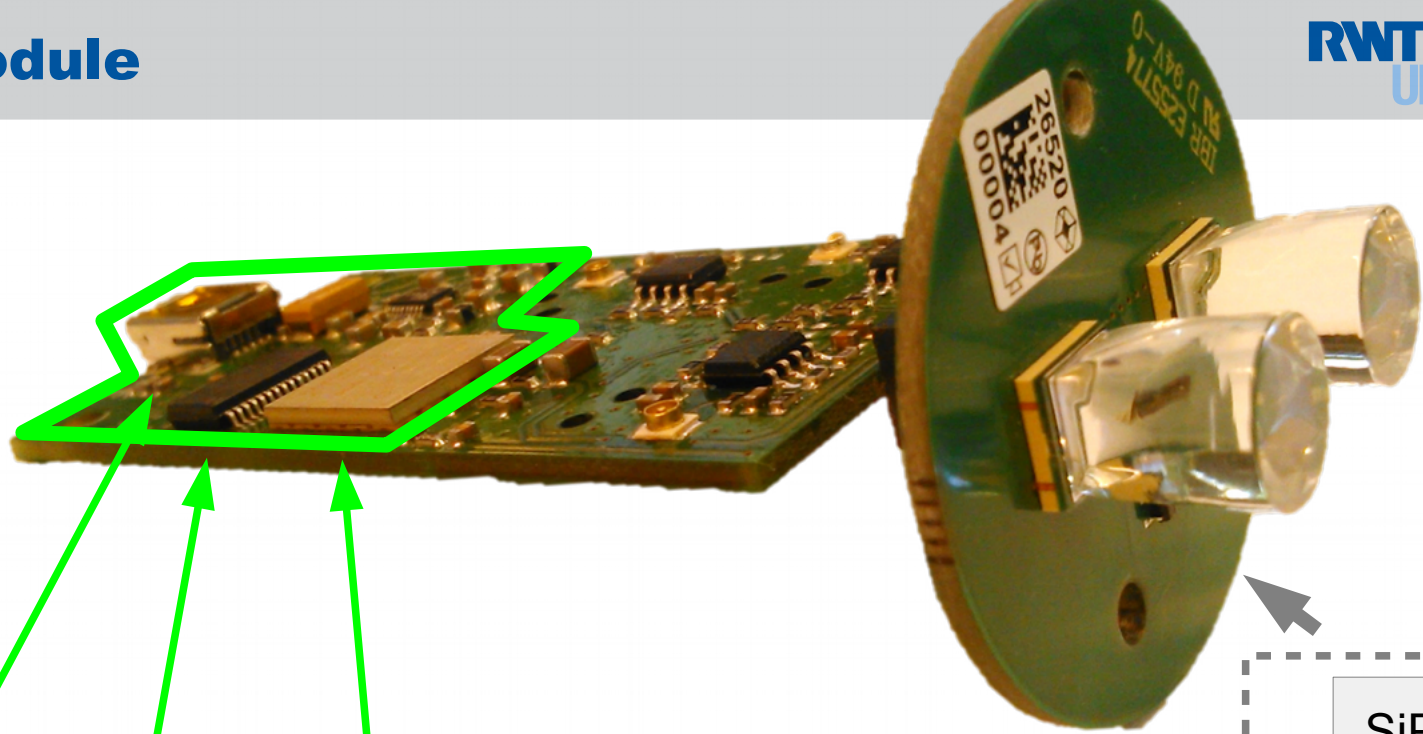
2x 6x6mm²

SiPMs sorted by breakdown voltage





The optical module



Power and communication

USB

FTDI

Hamamatsu C11204-02

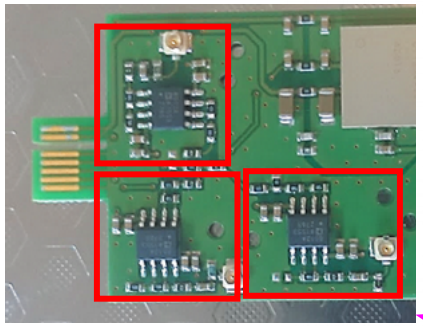
SiPM

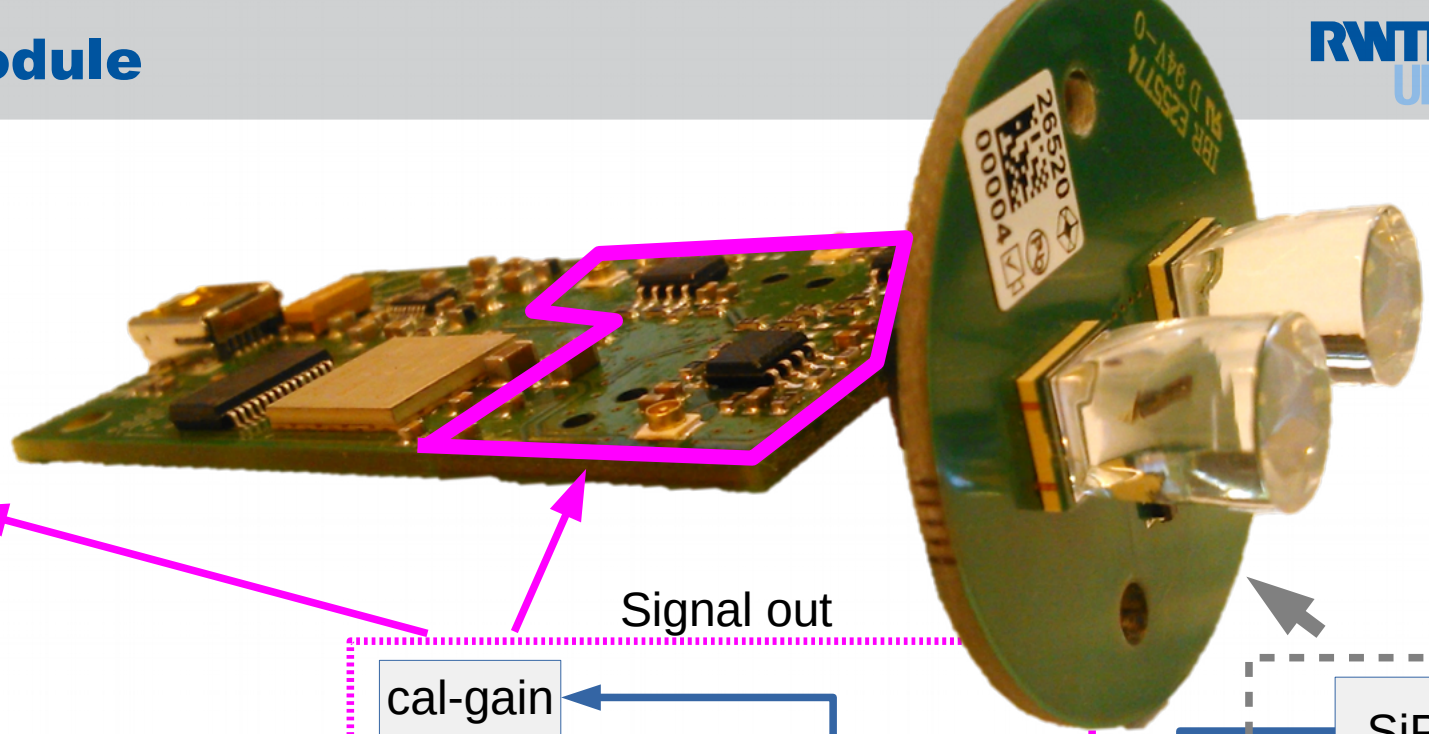
SiPM

Temp sensor

Op Voltage

The optical module





Signal out

cal-gain

hi-gain

lo-gain

sum + decoupling

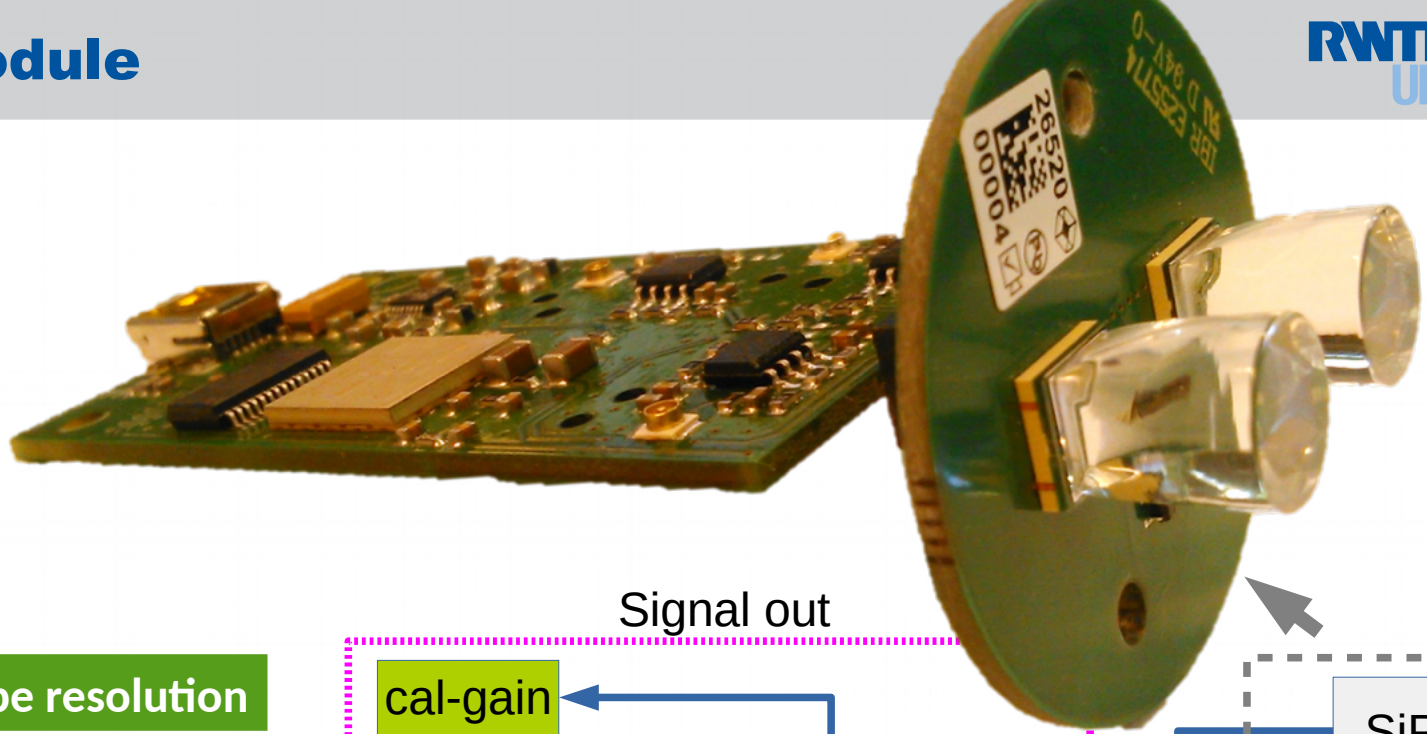
SiPM

SiPM

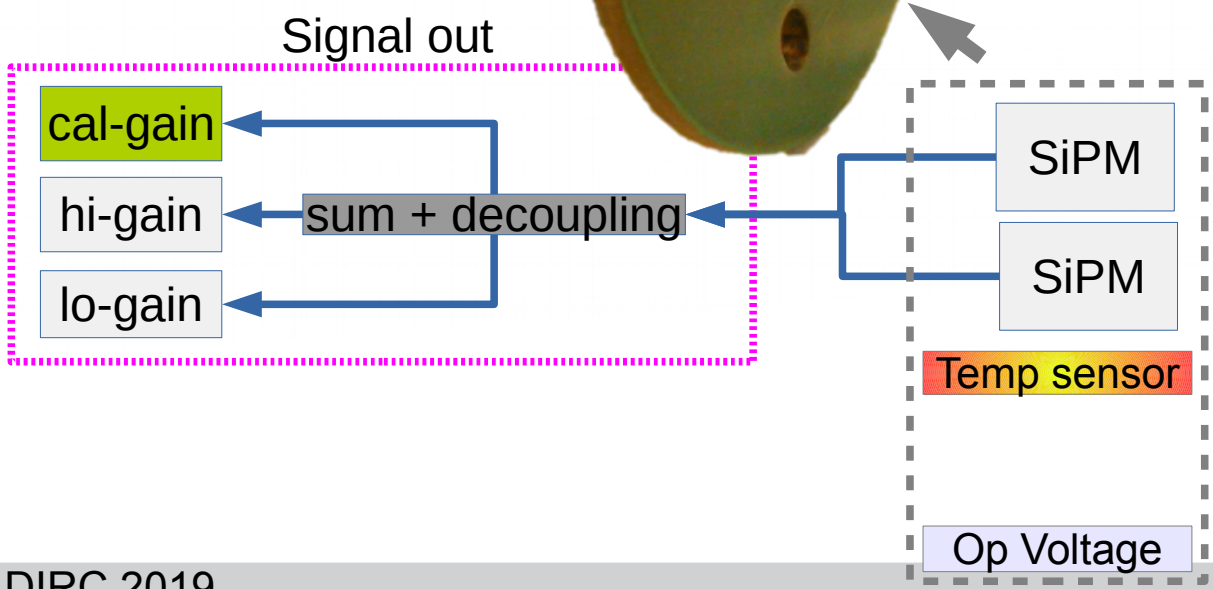
Temp sensor

Op Voltage

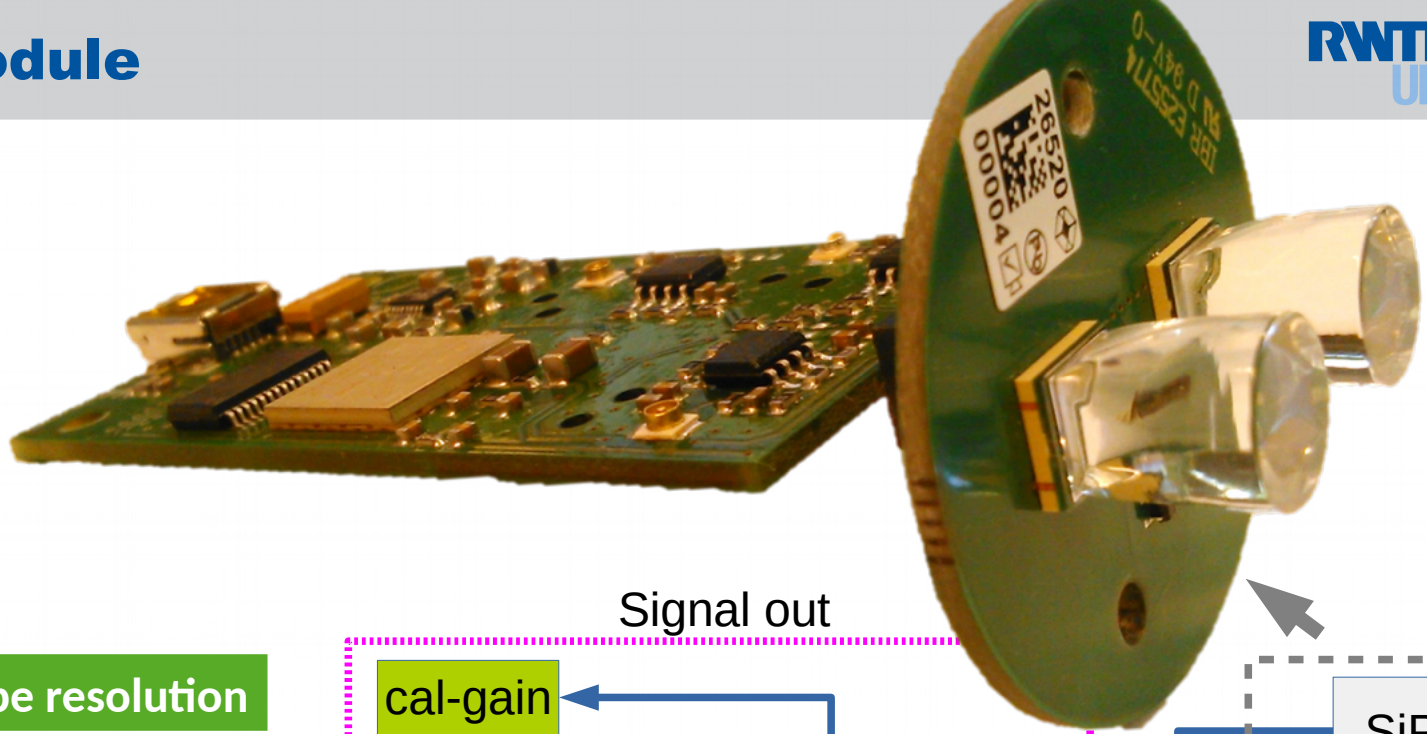
The optical module



single pe resolution

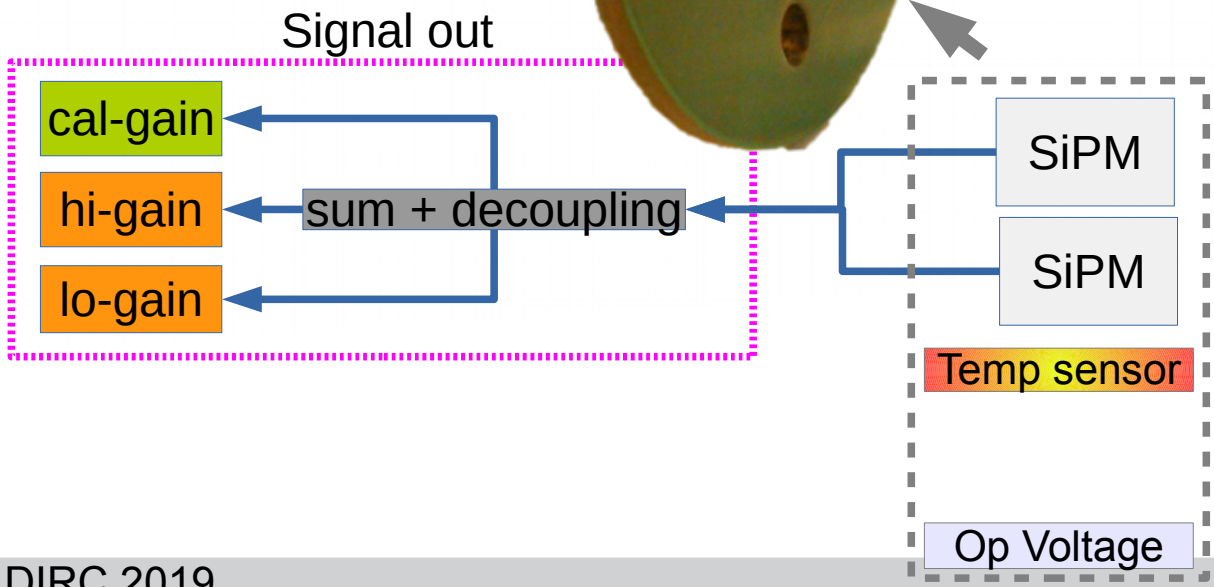


The optical module

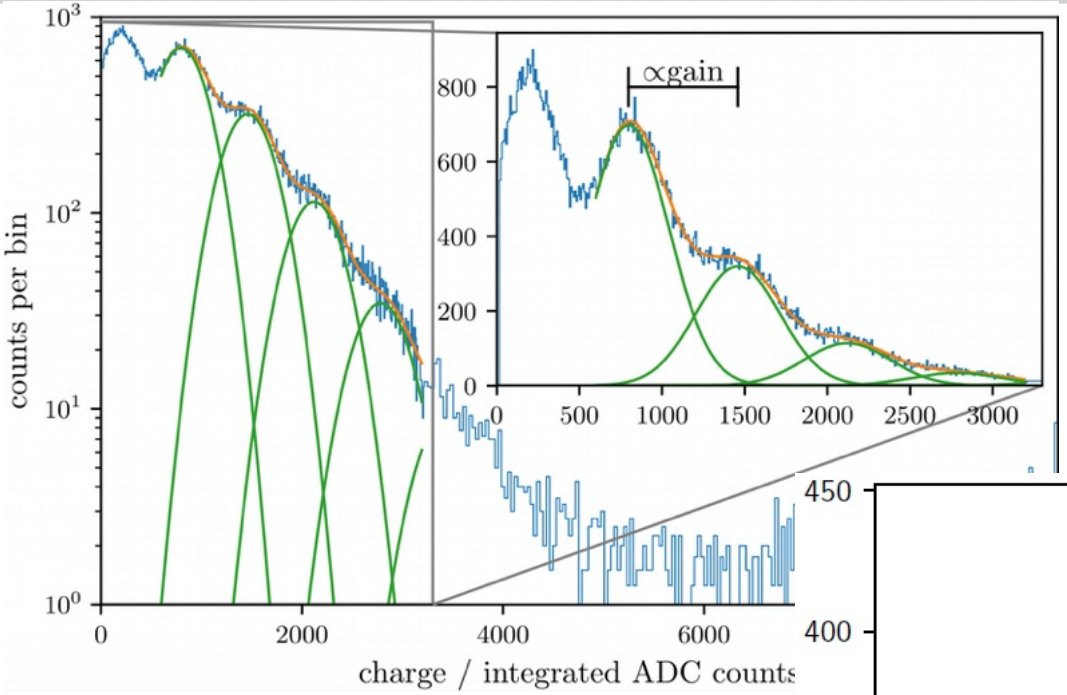


single pe resolution

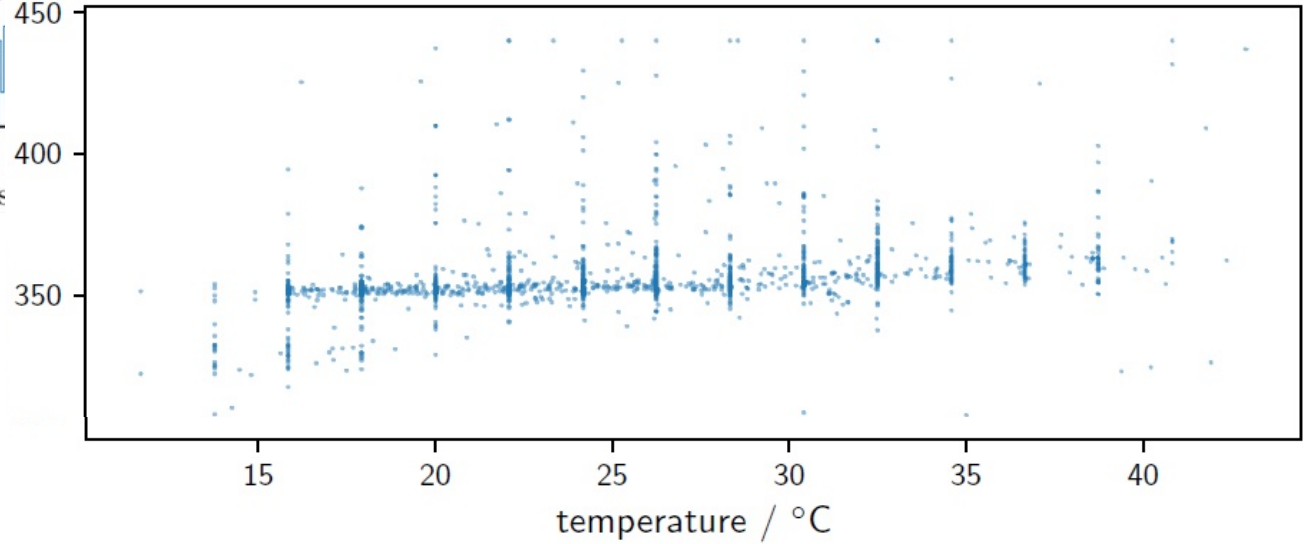
physics / MIP, high dyn. range



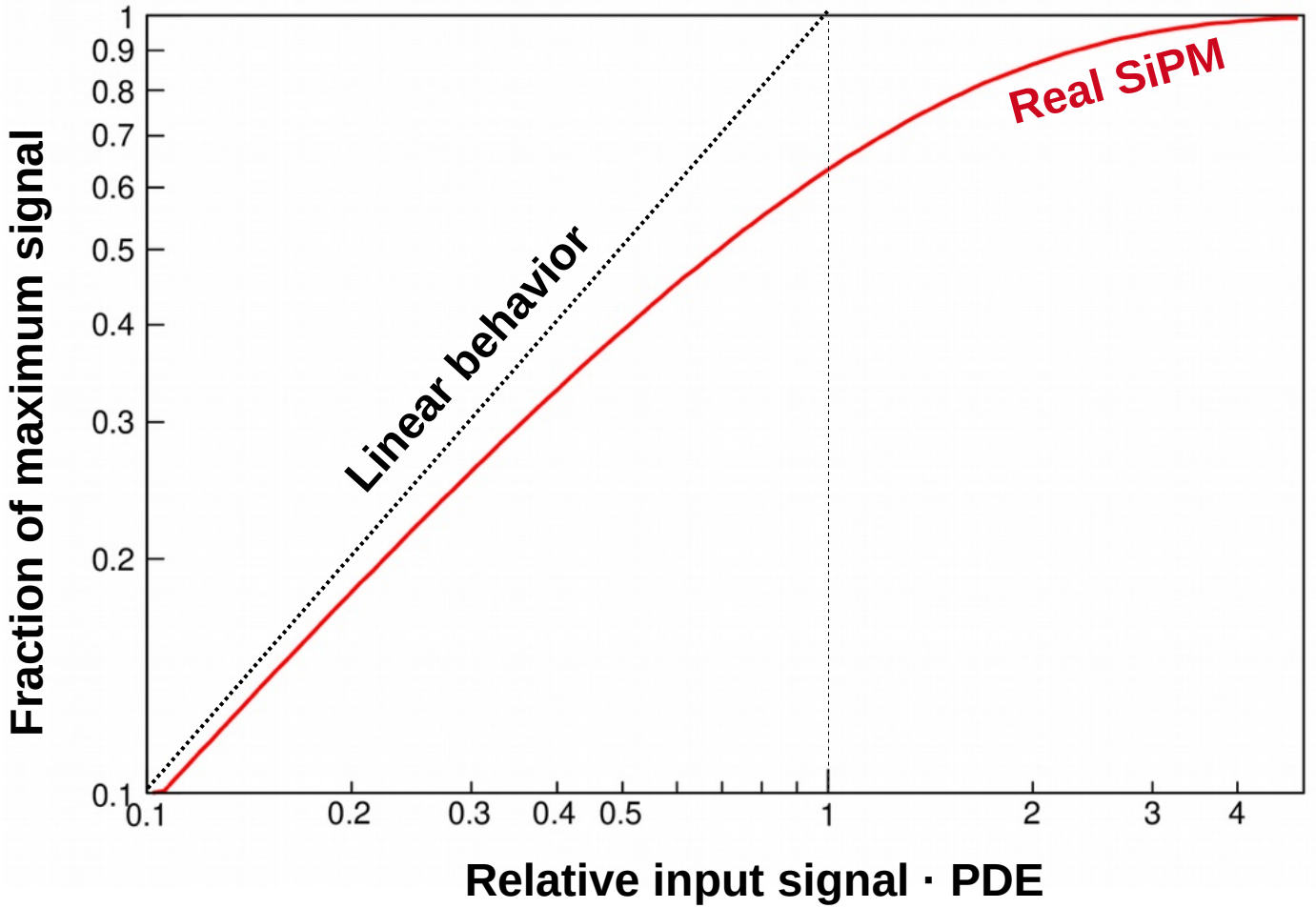
Gain in the field (Pampa Amarilla, Argentina)



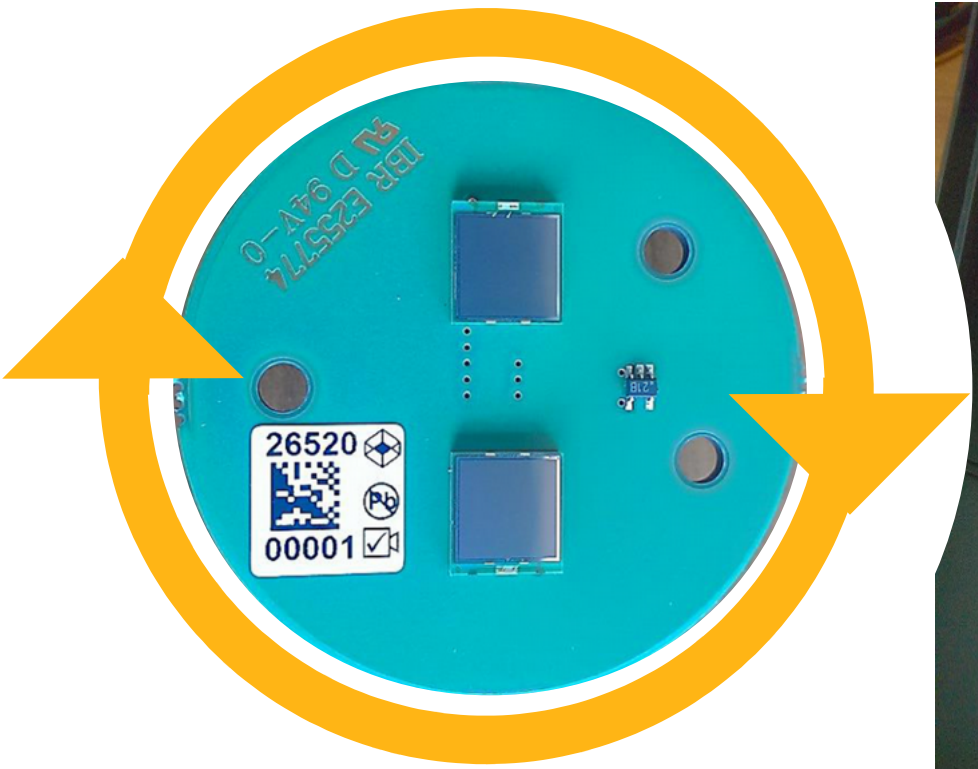
Gain vs Temperature

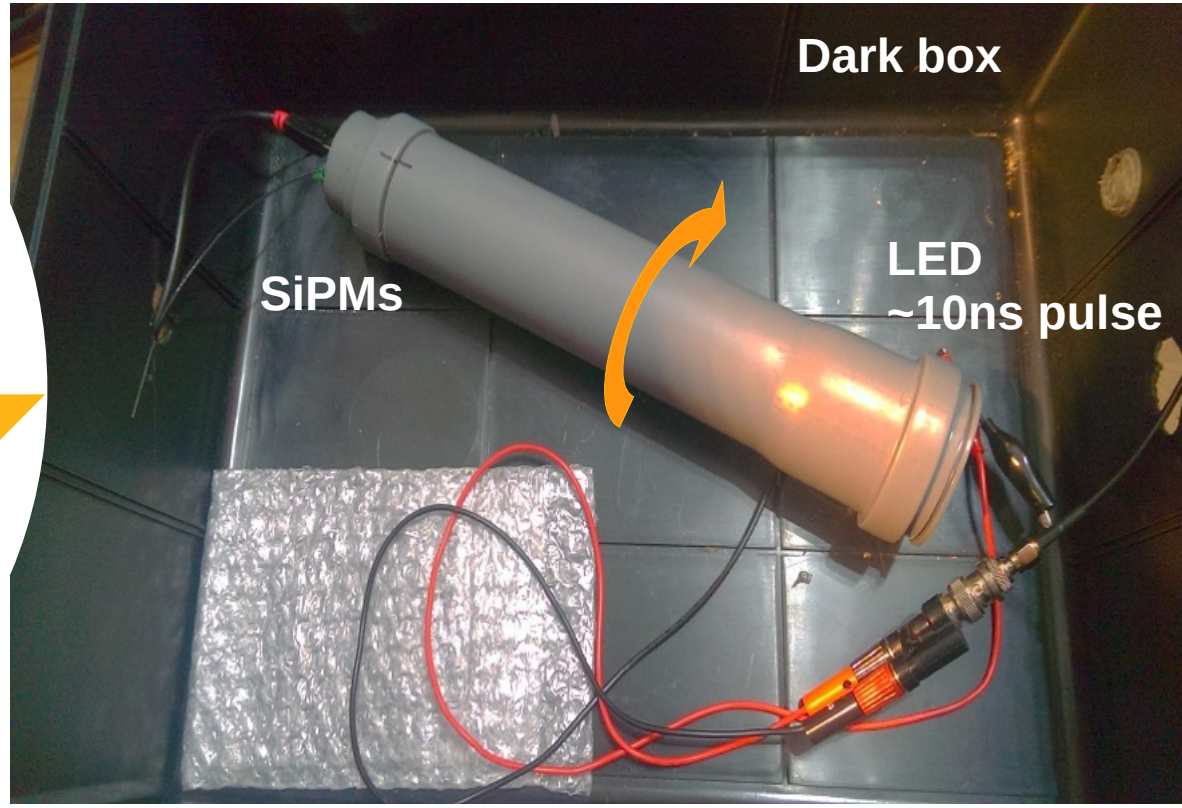


Saturation behavior well known



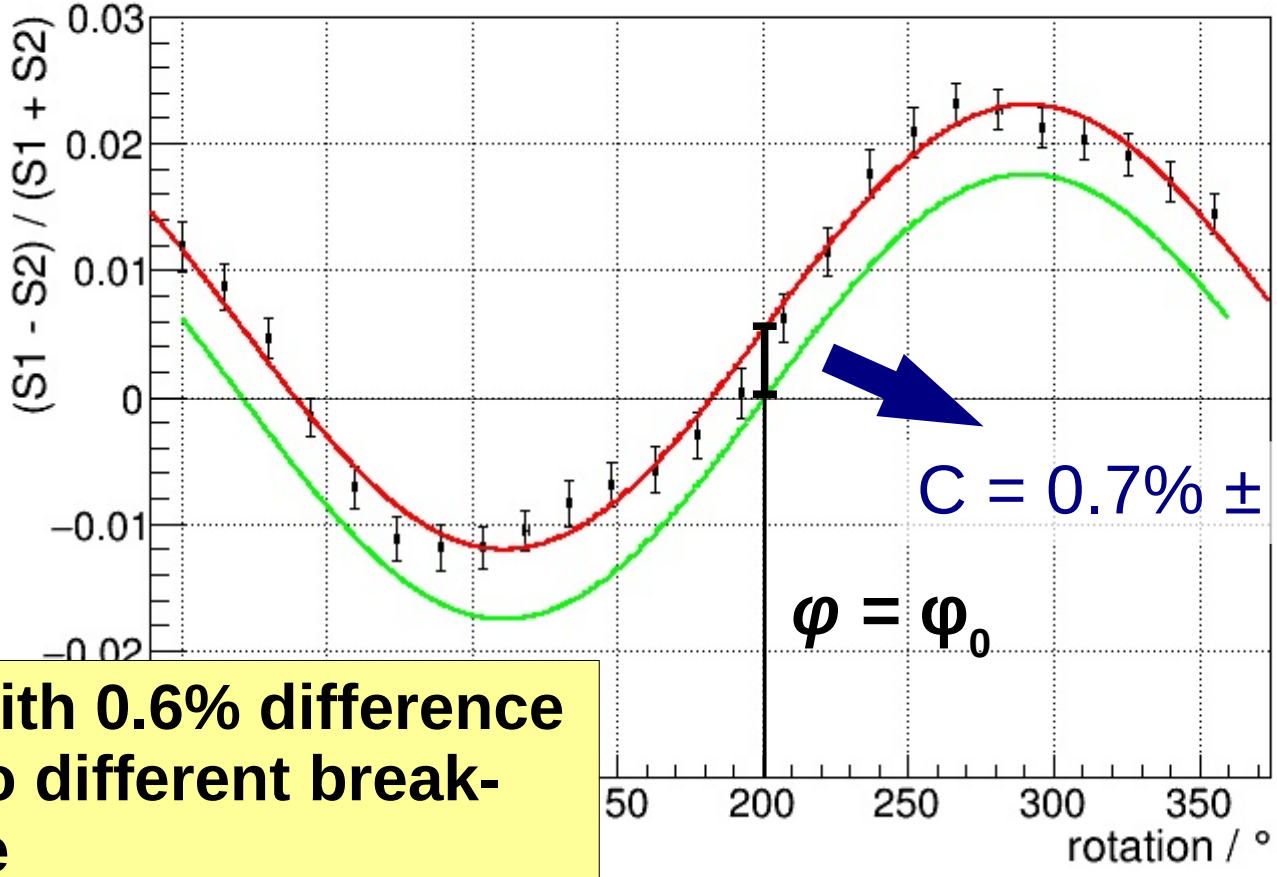
Compare two devices of same type





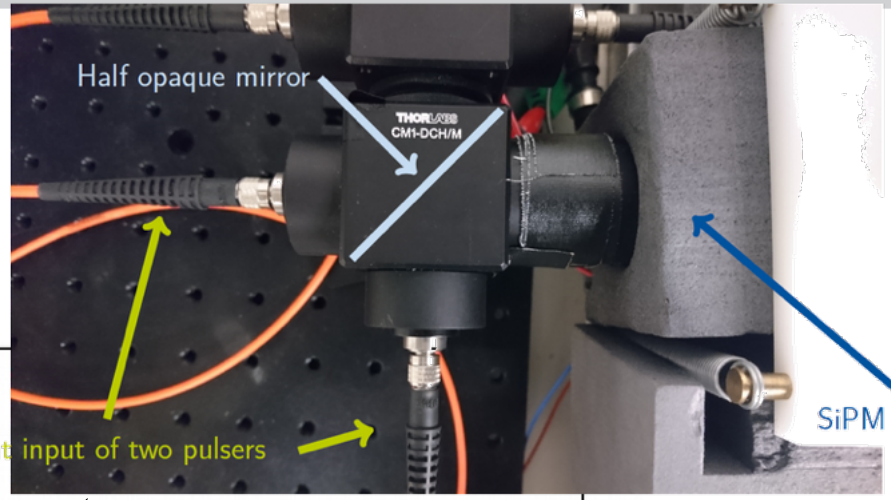
Determine systematic error

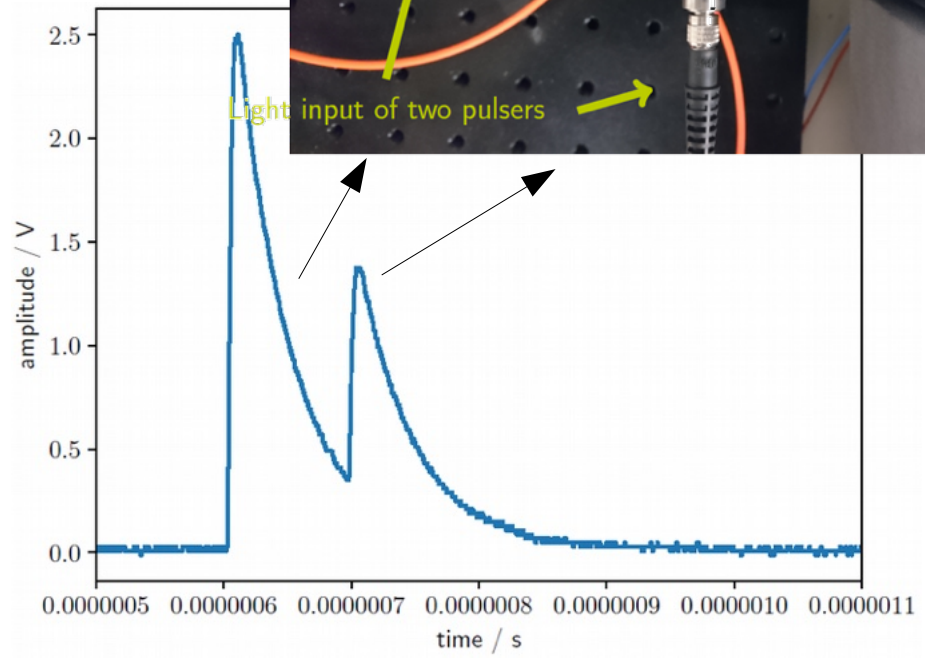
Fit: $f(\varphi) = C + A \cdot \sin(\varphi - \varphi_0)$

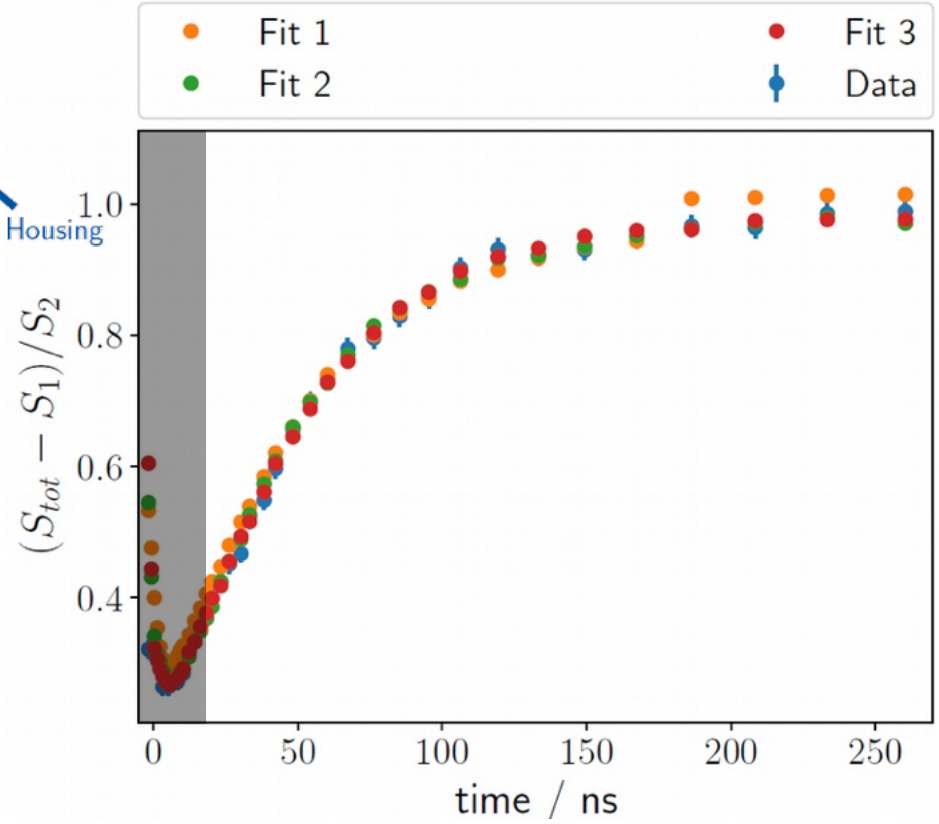


Consistent with 0.6% difference in gain due to different break-down voltage

Understanding the response of consecutive pulses

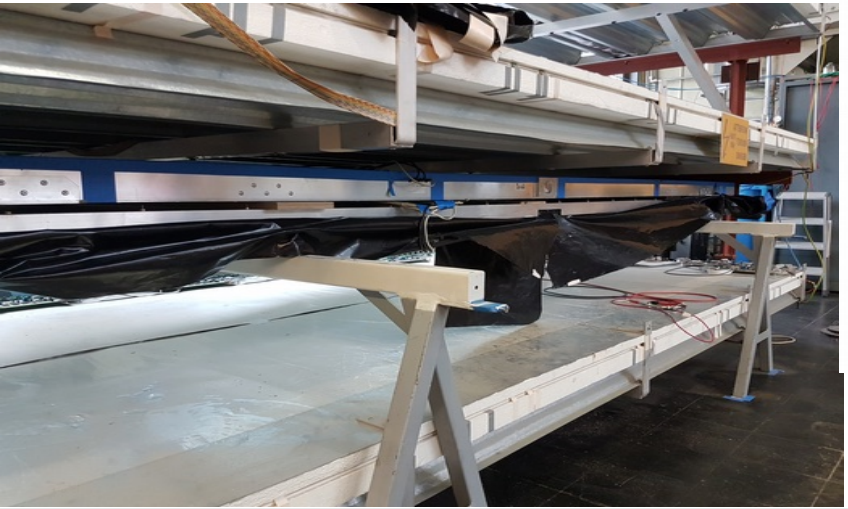


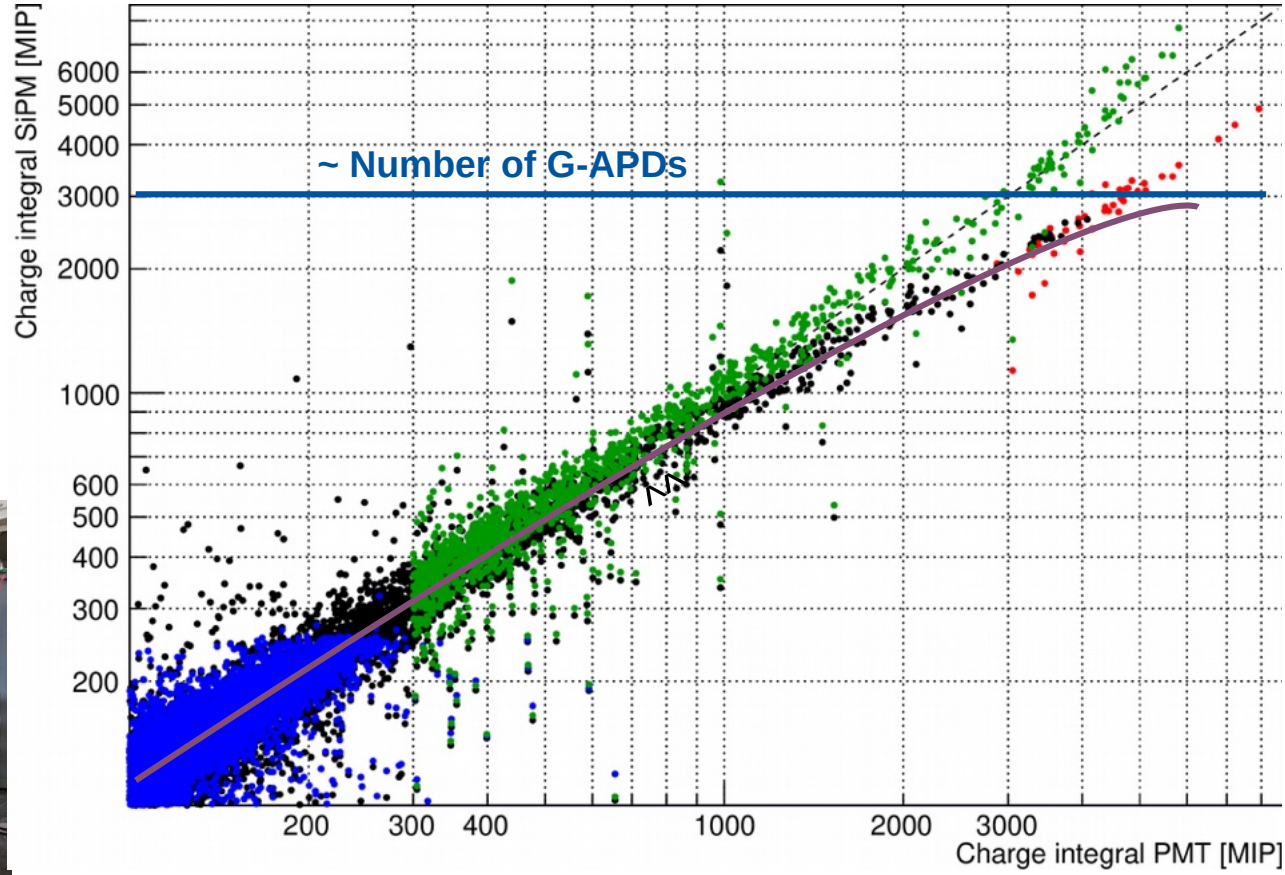




Unfolding of dynamic range

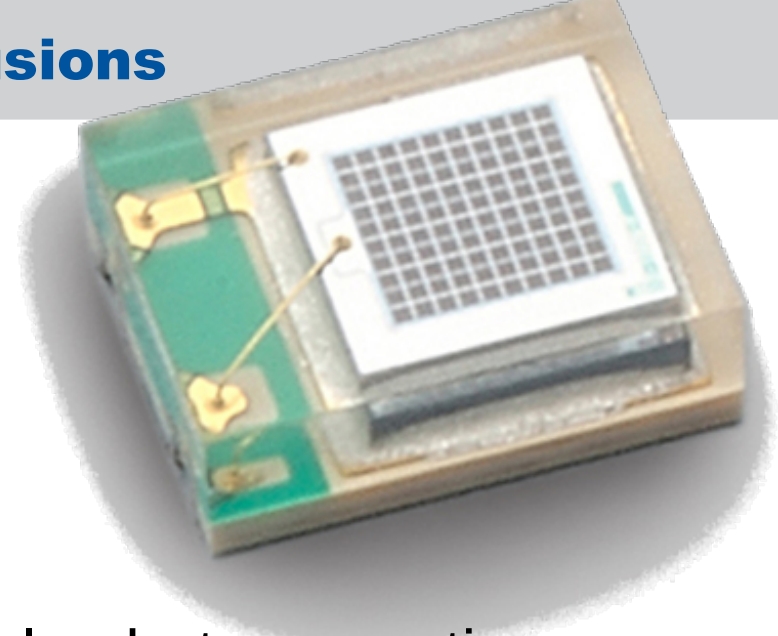
One detector with SiPM between two detectors with PMTs



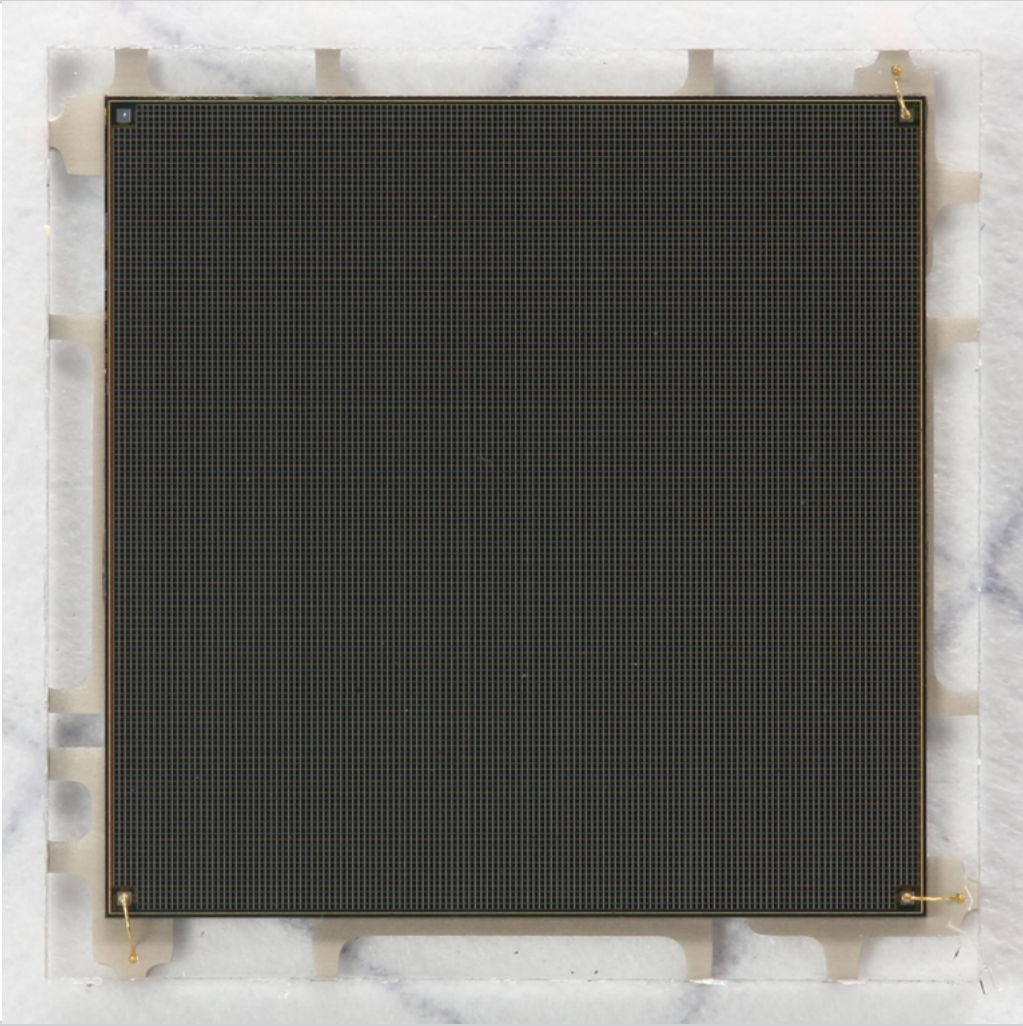


PRELIMINARY

Conclusions

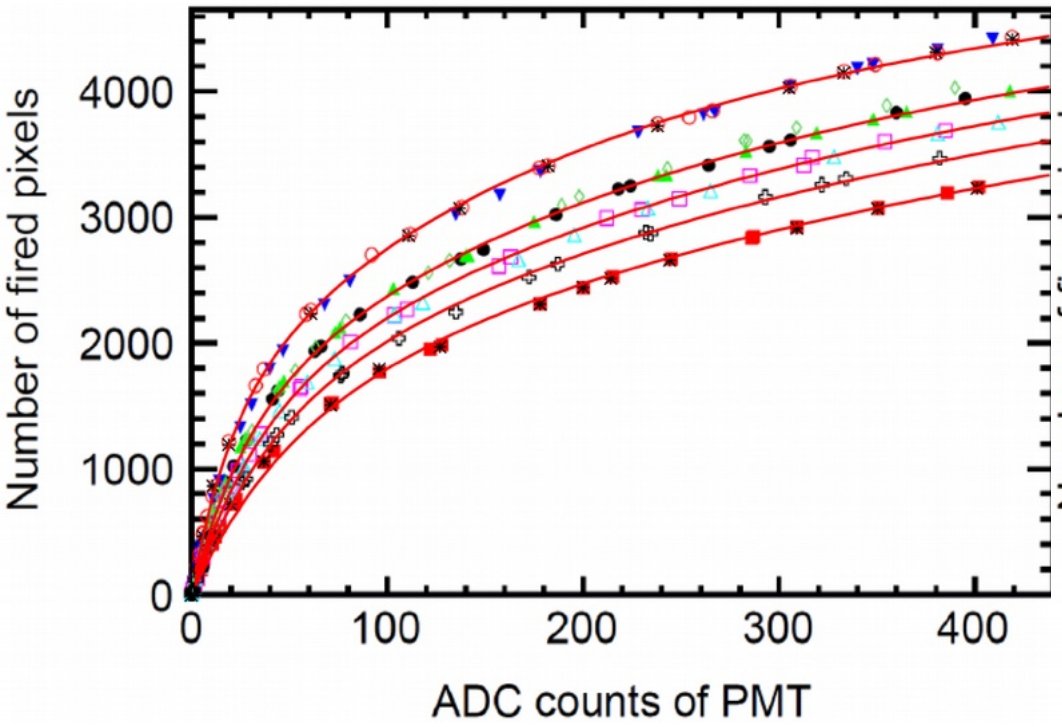


- Single photon counting
  → calibration included
- Gain as stable as precision of power supply
- Also applicable in high dynamic range applications



arXiv:1510.01102v4

Fit with an analytical function from paper



Simulation
(Hamamatsu 25μm, same parameters)