Silicon PMs for future detectors at the Pierre Auger Observatory

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Obertrubach-Bärnfels, BY

SPONSORED BY THE
Federal Ministry of Education and Research

PIERRE AUGER OBSERVATORY

ASPERA

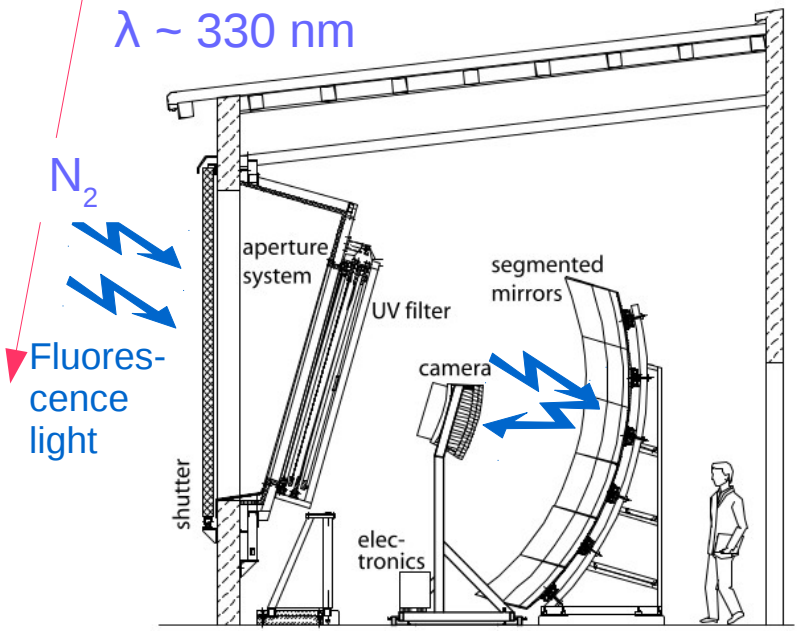
FAMOUS

III. Physikalisches Institut

RWTH AACHEN UNIVERSITY

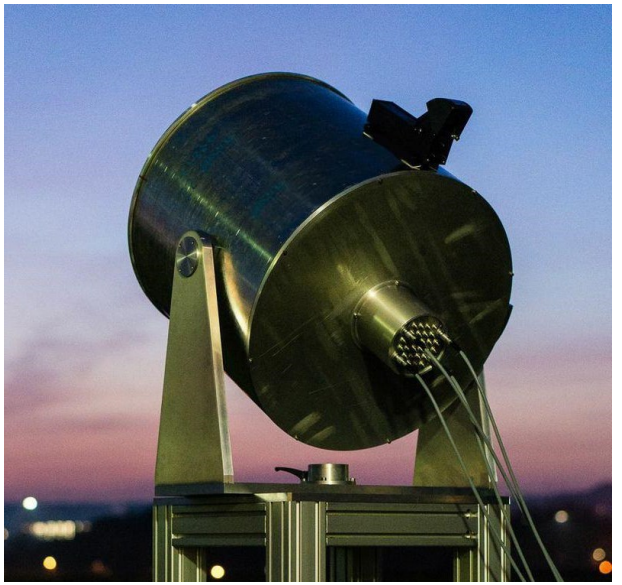
Fluorescence detector

FD



- Fluorescence telescope
- Schmidt telescope design
- 440 pixel PMT (QE ~ 25%) camera
- Duty cycle: ~13%

FAMOUS



- Fluorescence telescope prototype
- Refractive telescope design
- 64 pixel SiPM (PDE ~ 35%) camera
- Duty cycle: ?

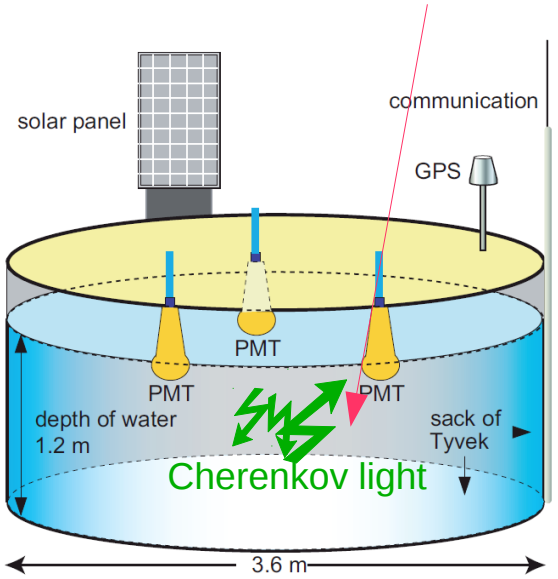
→ increase sensitivity!

faint, distant showers - increase duty cycle

Muon detector

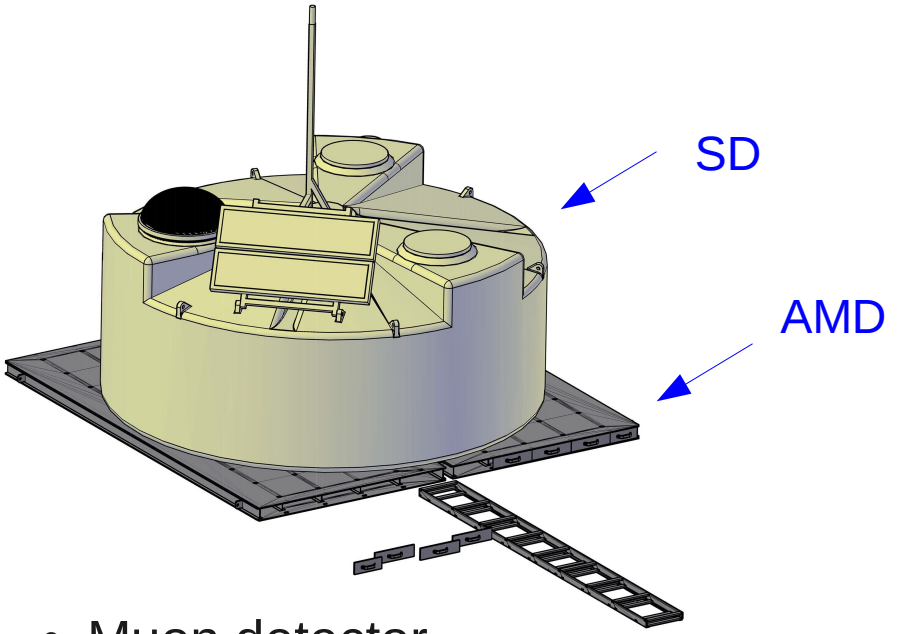
SD

Shower particles



- Surface detector
- Water Cerenkov detector
- 3 PMTs
- Duty cycle: ~100%

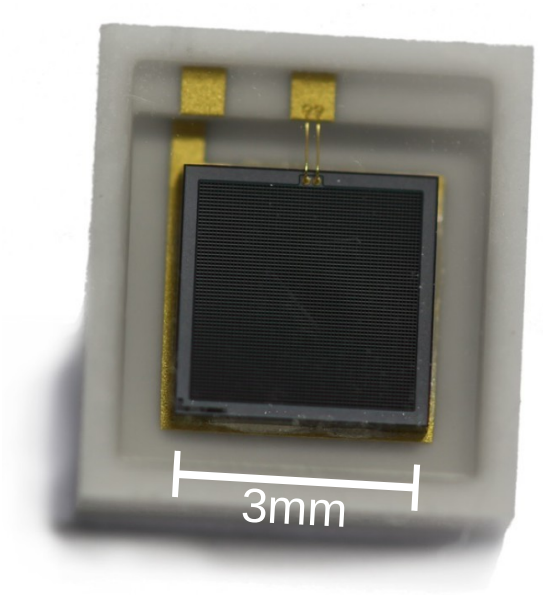
AMD

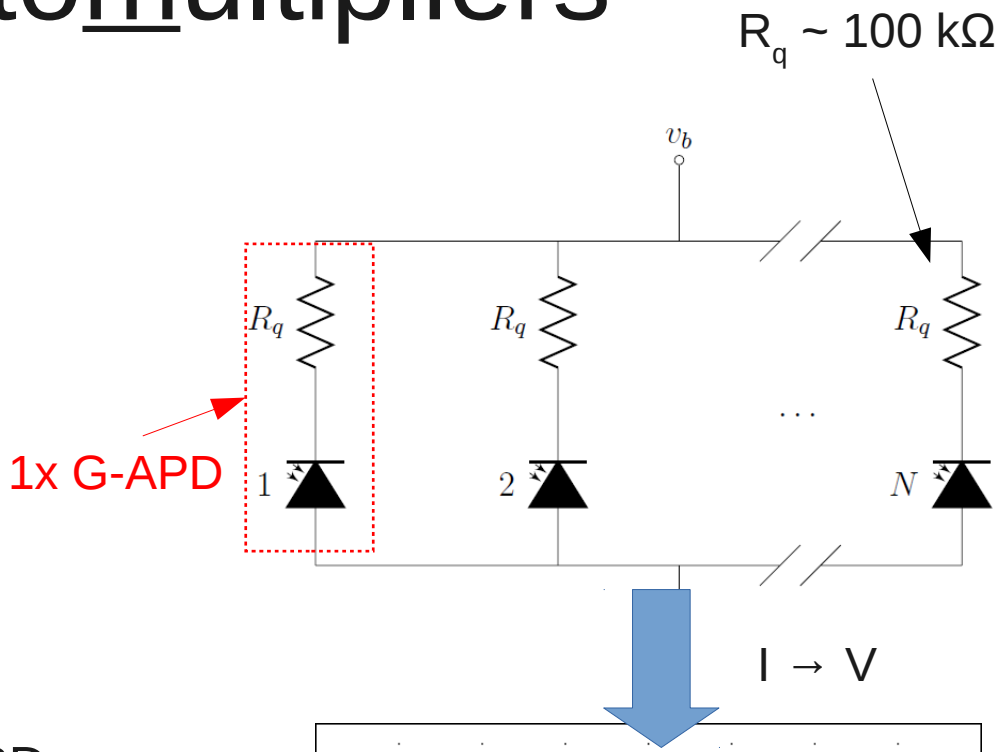


- Muon detector
- 64 scintillating tiles
- 64 SiPMs
- Duty cycle: ~100%

→ measure muon component

Silicon photomultipliers





- SiPM: Pixelated photo detector
- hundred to several thousand G-APDs connected in parallel
- Passive quenching through quenching resistor Rq

- Size: few mm^2 per SiPM

Silicon photomultipliers

Newest Hamamatsu SiPMs

prototypes

- ✔ High PDE (45% - 60%)
- ✔ High spatial / time resolution (~100 ps)
- ✔ Moderate supply voltage $V_b < 100$ V
- ✔ Robust technology
- ✔ Low cost

Dramatically reduced in new SiPMs

- ✗ (Correlated) noise (70 kHz mm^{-2})
- ✗ Temperature dependence
  Gain ~ $g0 (1 – \beta (T – T_0))$, β ~ 2-3 % K^{-1}

compensable

- ✗ Small size (→ a lot of read-out channels needed)

challenging

Silicon photomultipliers

- ✔ **High PDE** (45% - 60%)
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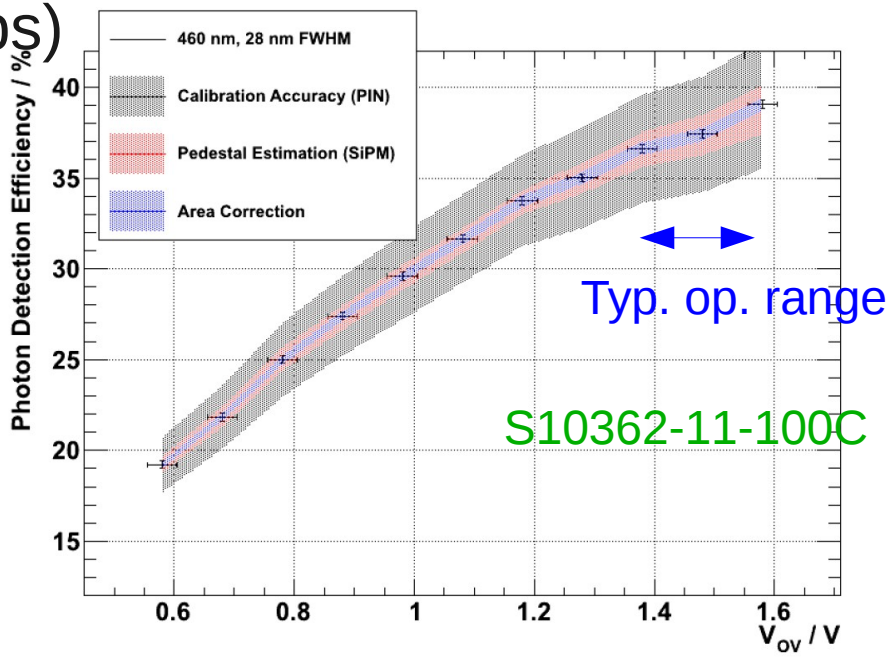

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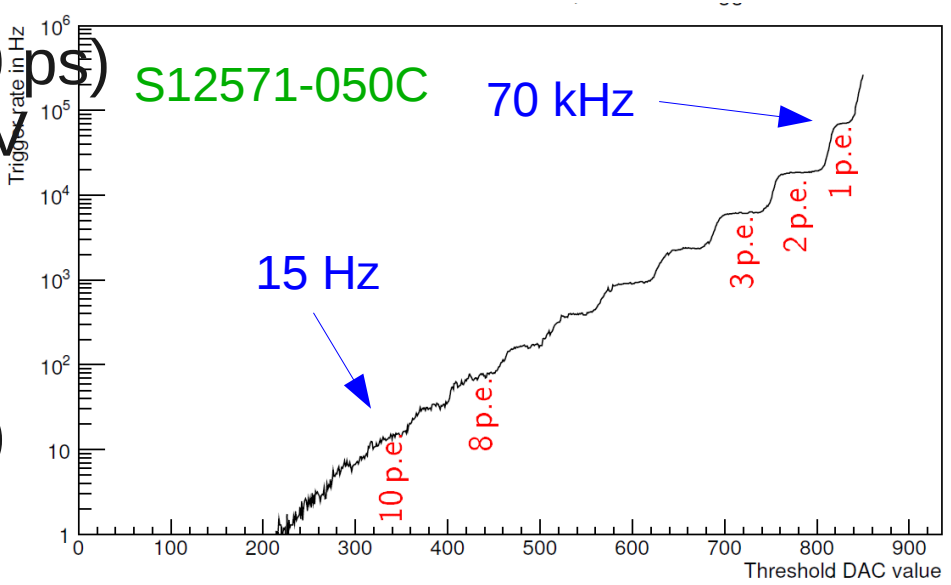

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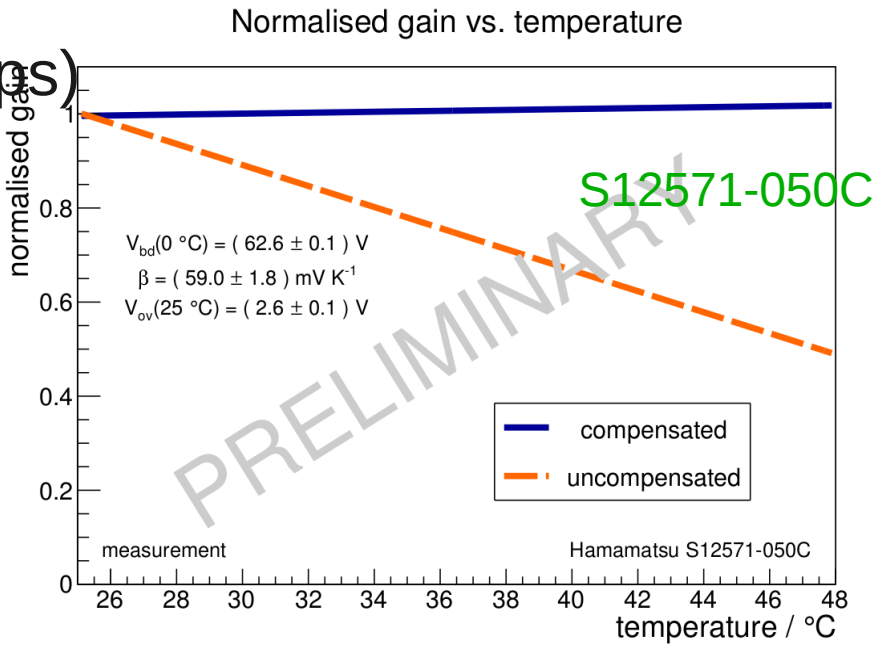
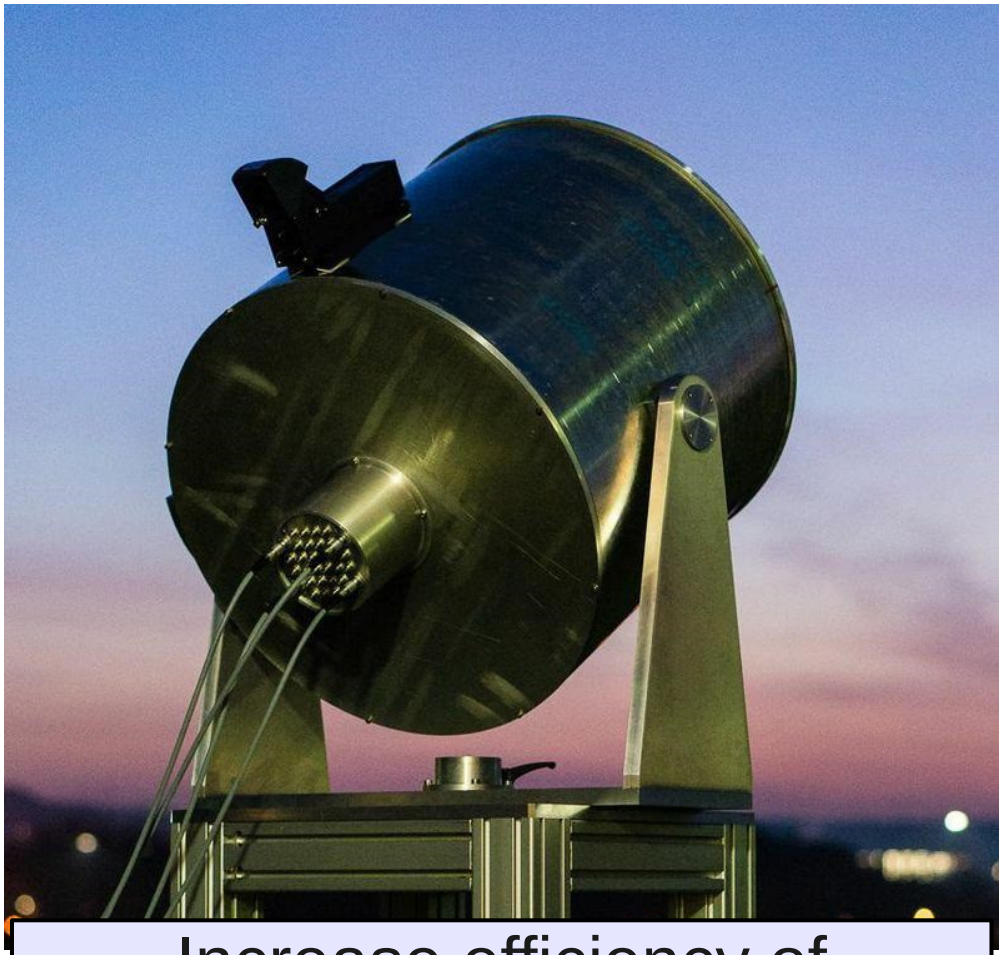


FAMOUS*



Increase efficiency of fluorescence detectors by using SiPMs

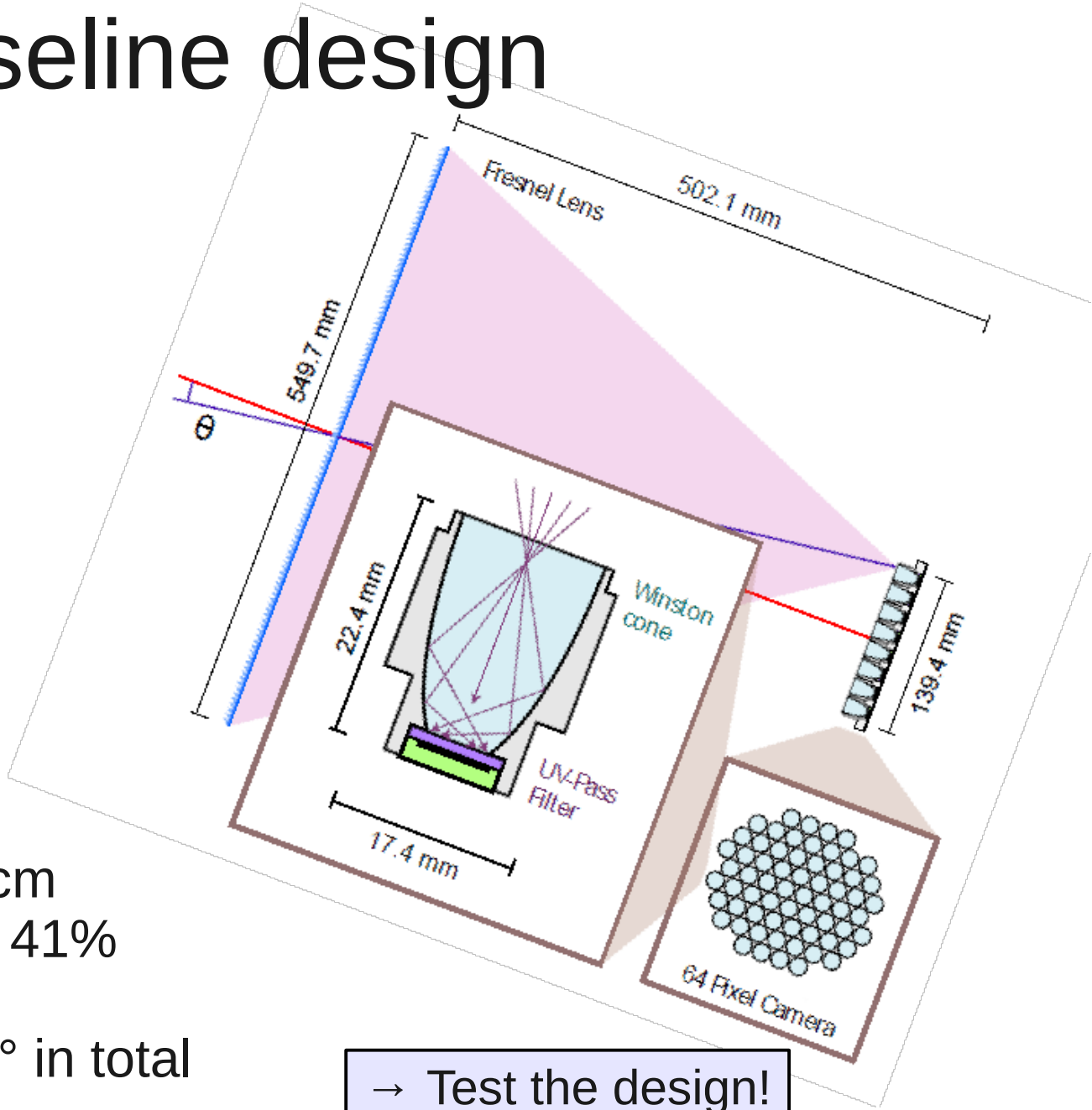
FAMOUS / FAMOUS^{64}
64-pixel telescope

FAMOUS^{7}
7-pixel telescope prototype

* First Auger Multi-pixel photon counter camera for the Observation of Ultra-high-energy air Showers

In cooperation with Lisbon & Granada

Baseline design



- Fresnel lens, d ~ 50 cm
- Total transmittance ~ 41%
- 64 pixels
- FoV = 1.5° / pixel, 12° in total

→ Test the design!

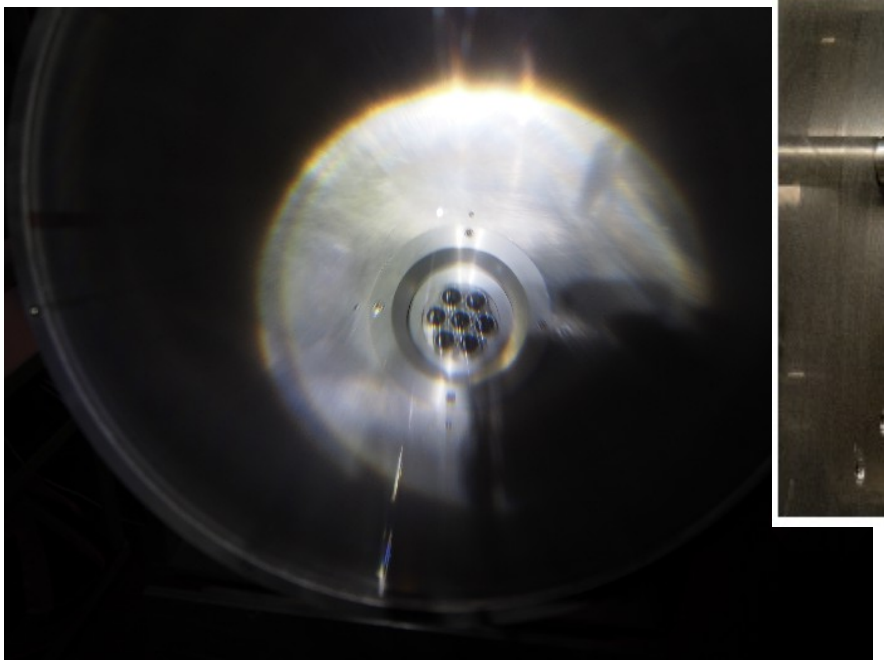
(with 7-pixel telescope)

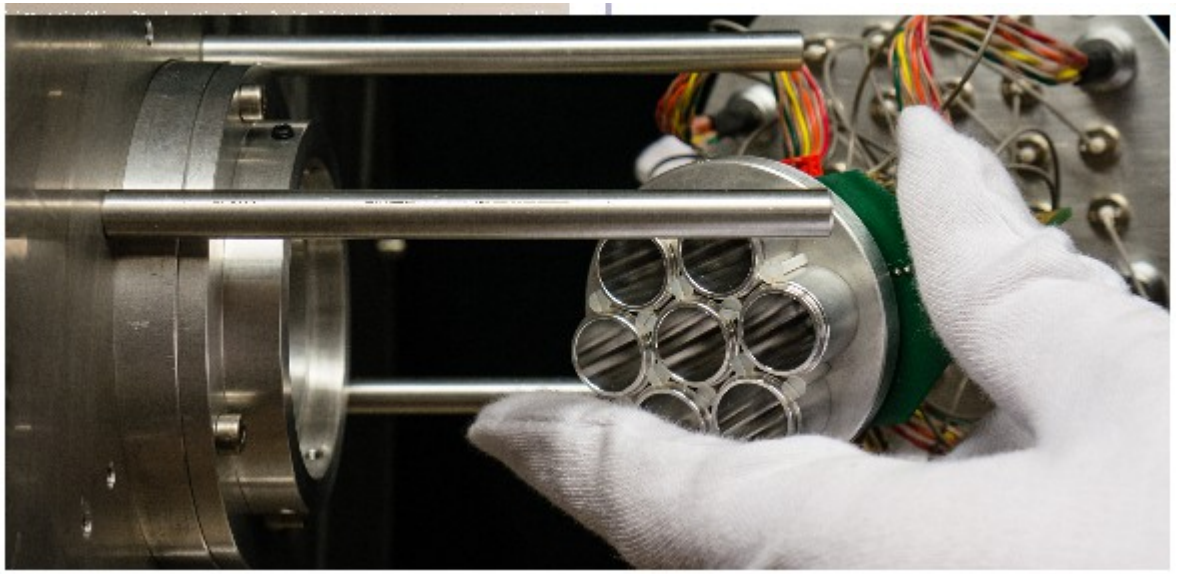
FAMOUS^7 overview

7-pixel variant of FAMOUS
- Hamamatsu S10985-100C (4 channel SiPM)

Electronic read-out
- Analogue sum (4 channels / pixel)
  → digitisation using a QDC*

Pre-prototype evaluation





* QDC = Charge to digital converter

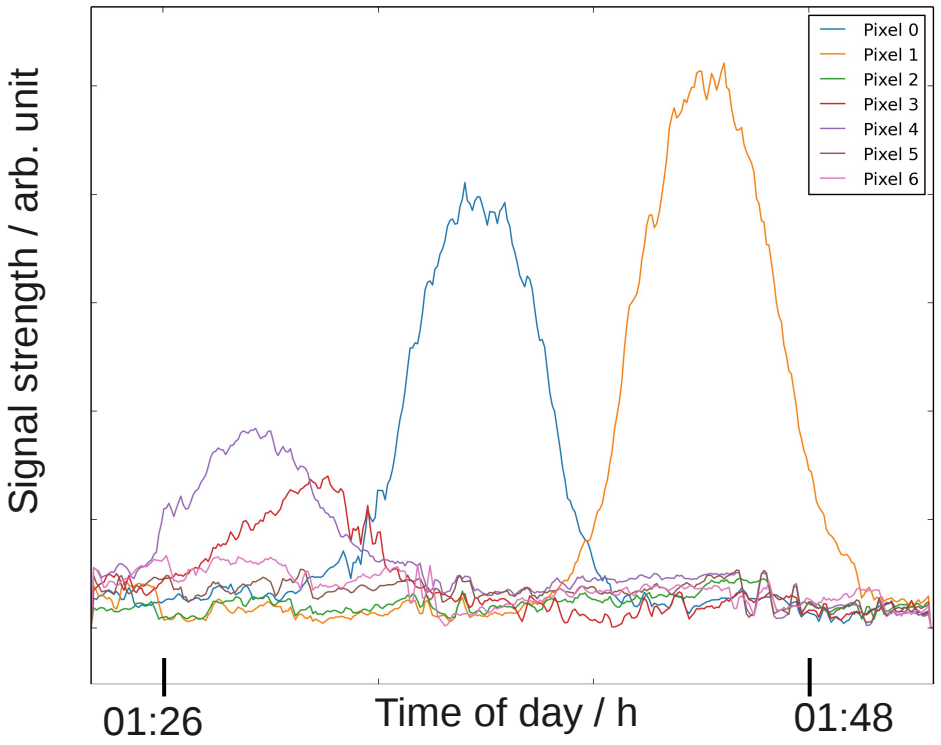
→ Ready for testing!

FAMOUS[7] commissioning

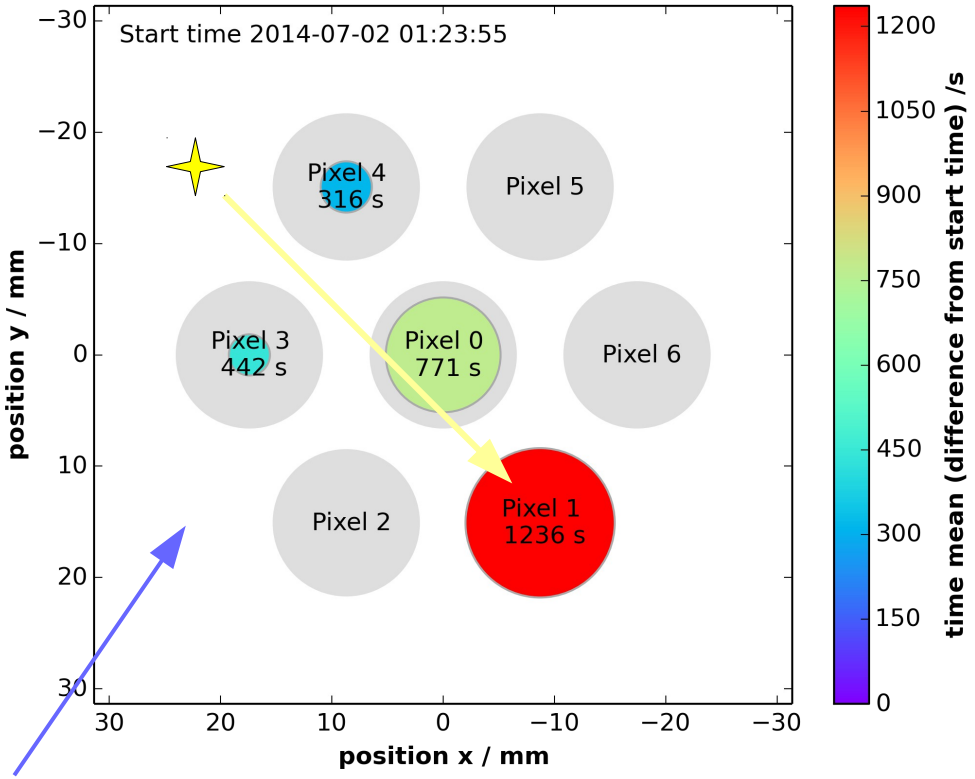
July 2014

Star (Arcturus) transit measurement

200 ns charge integral



Colour-coded: time information
Bubble size: light intensity



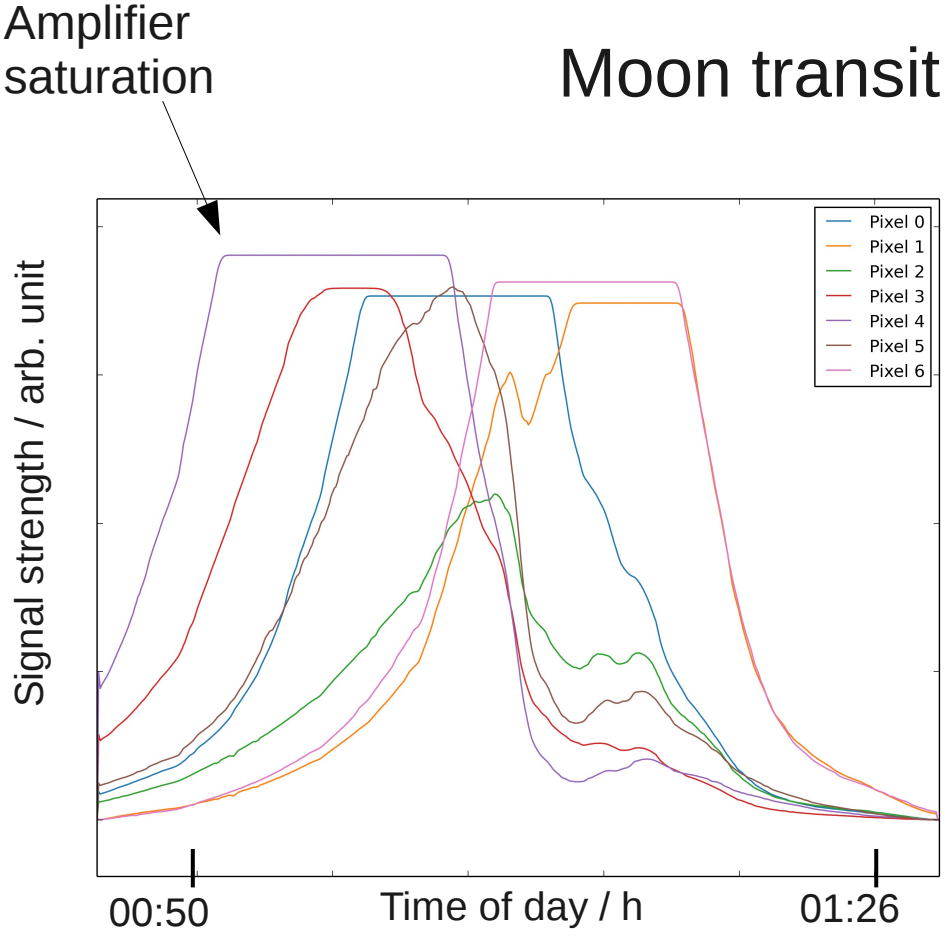
Focal plane pixels

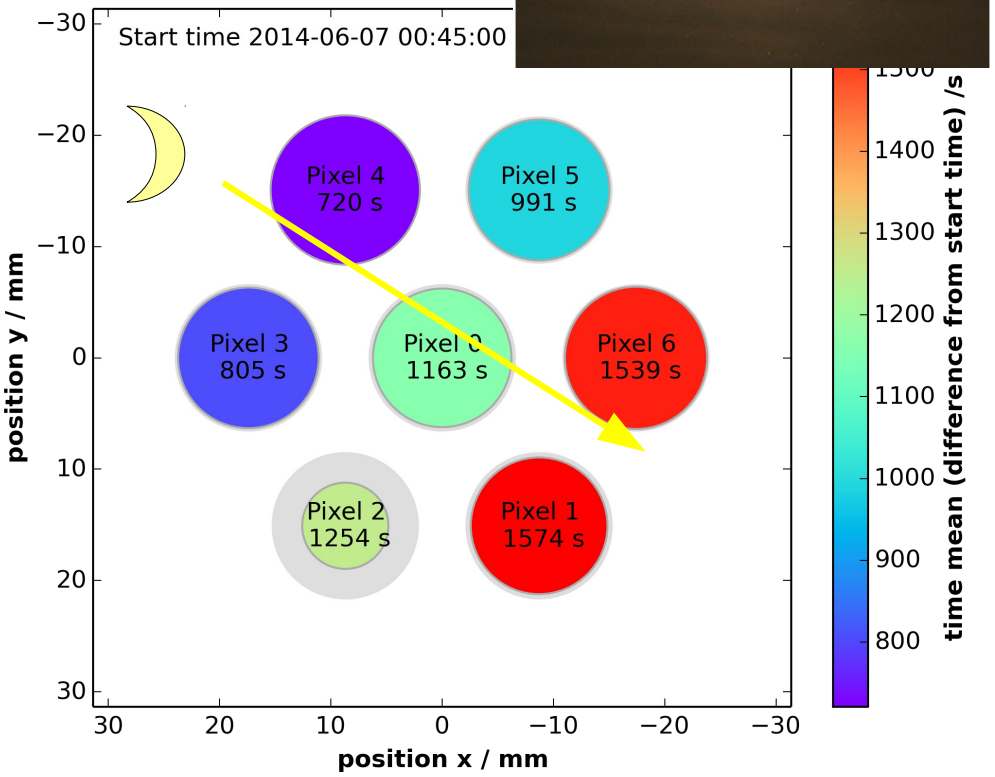
In cooperation with IceCube

FAMOUS[7] commissioning

June 2014

Moon transit measurement

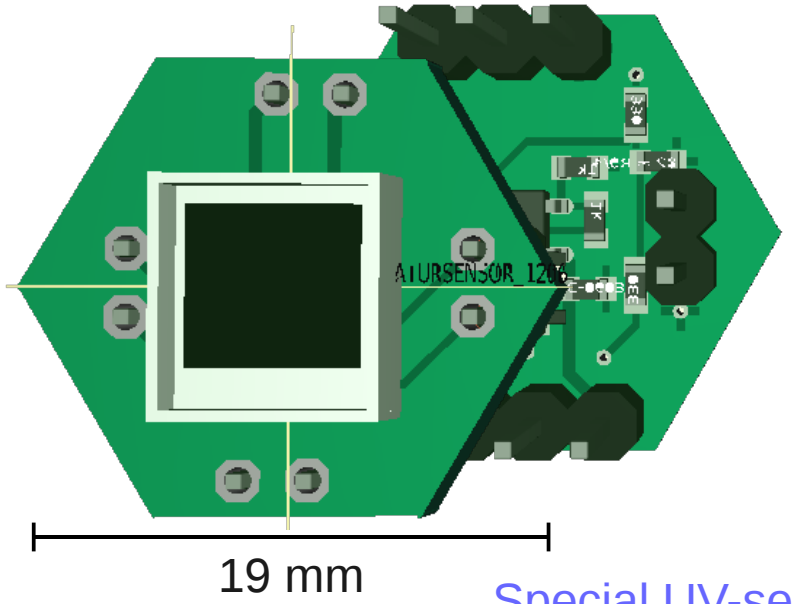




In cooperation with IceCube

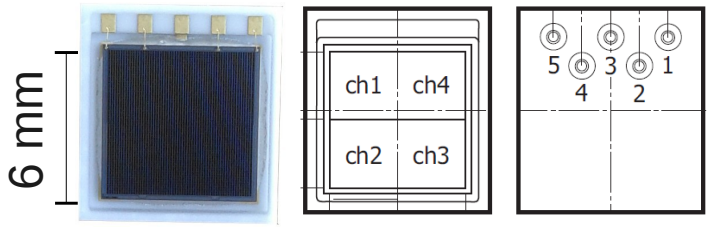
...towards FAMOUS^{64}

Read-out prototype



Special UV-sensitive SiPM for FAMOUS

Hamamatsu S12573-3580X



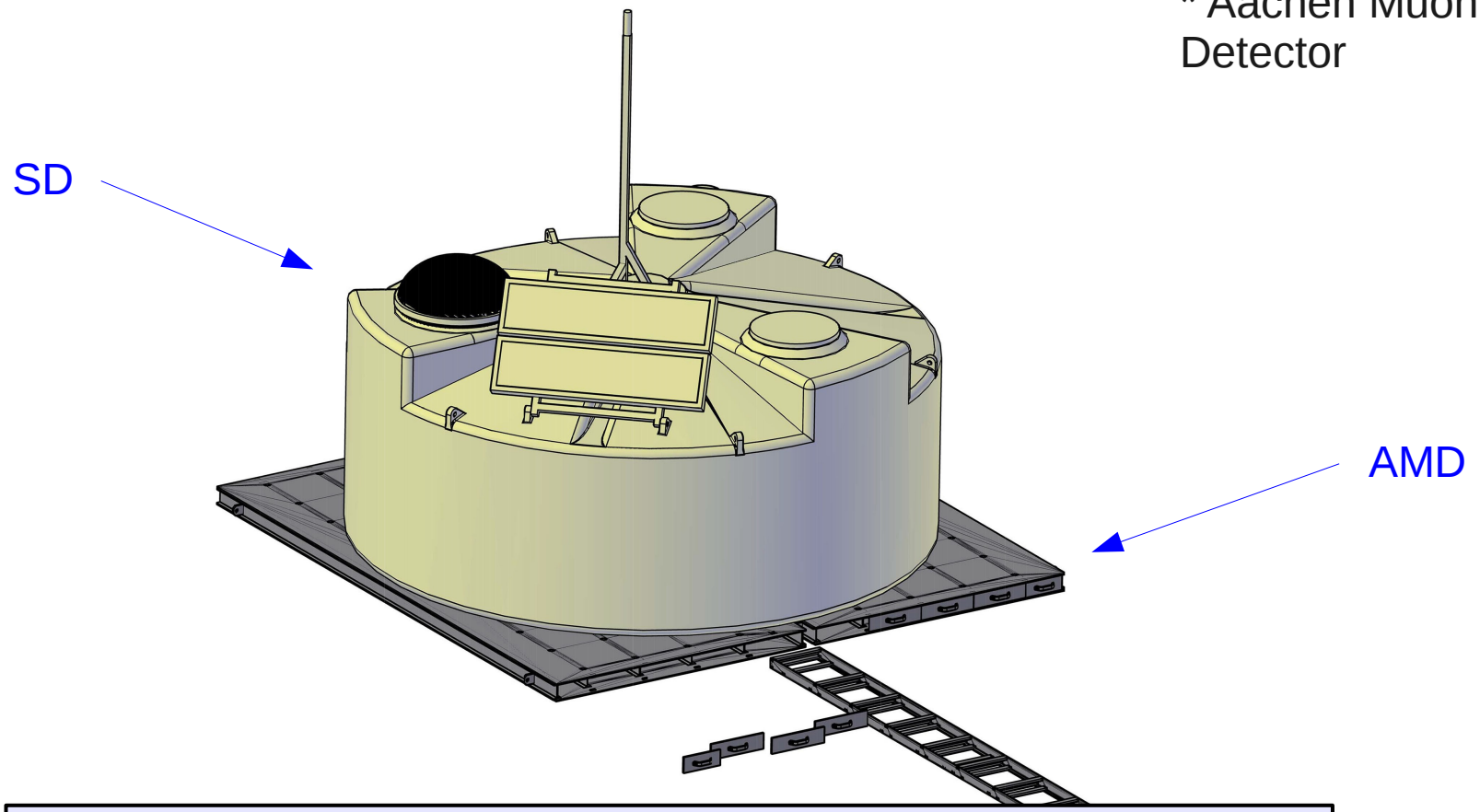
- PDE > 35% in UV
- 4 channel 6x6 mm²

- Read-out electronics prototyping:
  - Analog signal amplifiers, FADC digitisation, Temperature compensation

SiPMs arrived

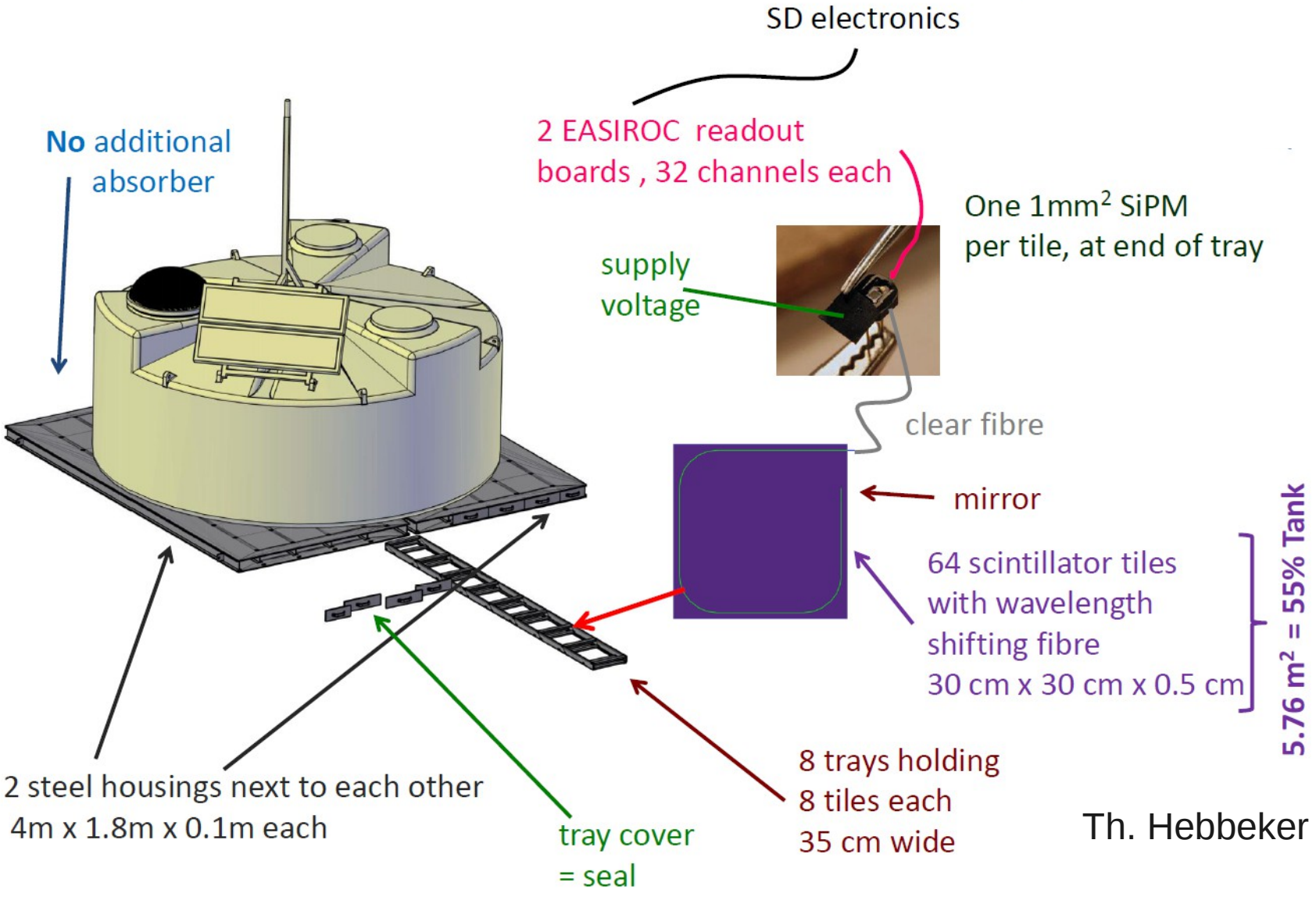
AMD*

* Aachen Muon Detector



Measure muon component with Scintillator tiles & SiPMs

Overview

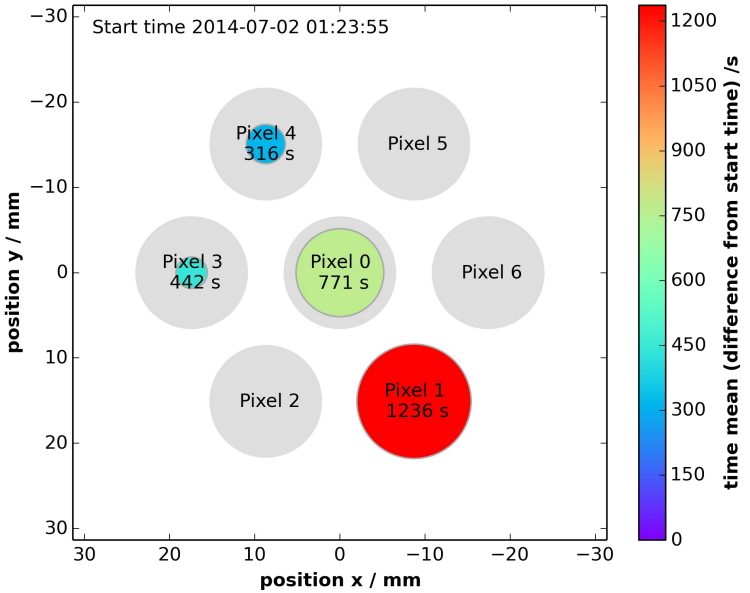


Th. Hebbeker

Summary

FAMOUS

Characterisation finished, 7-pixel version measured star and moon transits



AMD

Funding, Steel-housing, read-out electronics, detector performance simulations

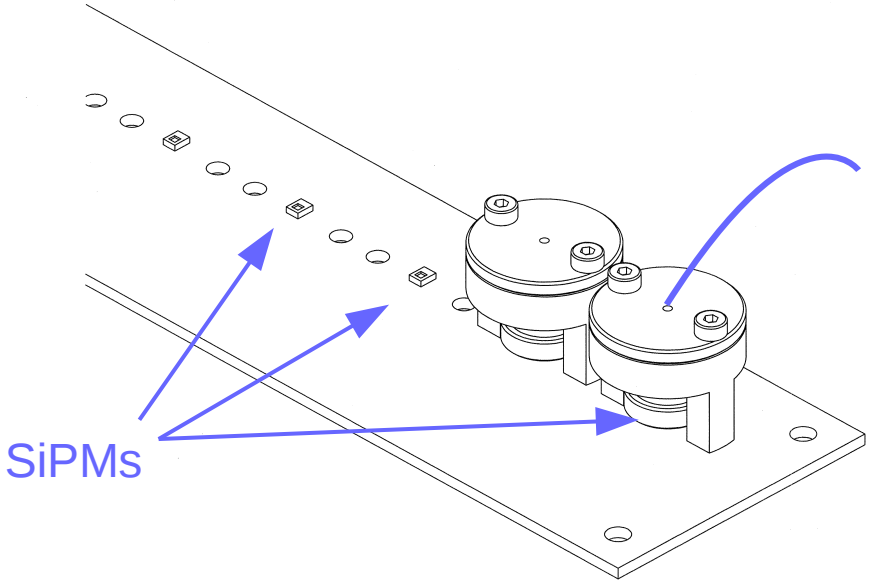
Outlook

FAMOUS

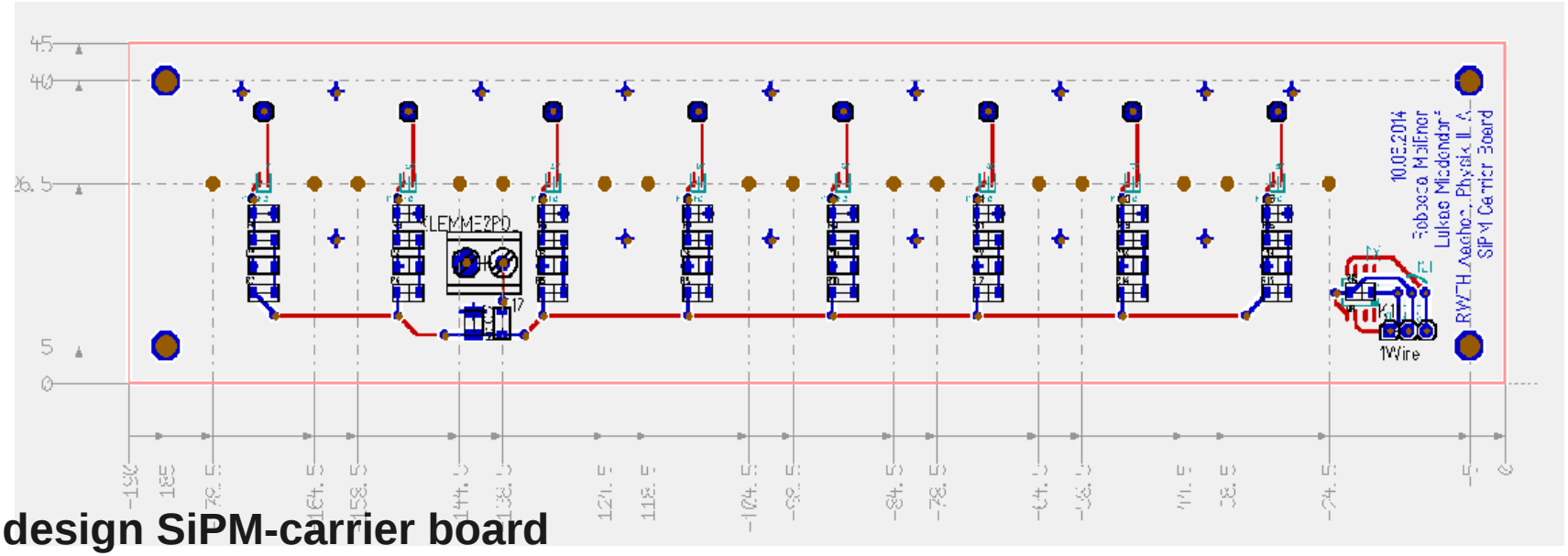
Upgrade to 64 pixels, trigger analysis

AMD

Fiber-SiPM coupling, advanced detector simulations, detector construction

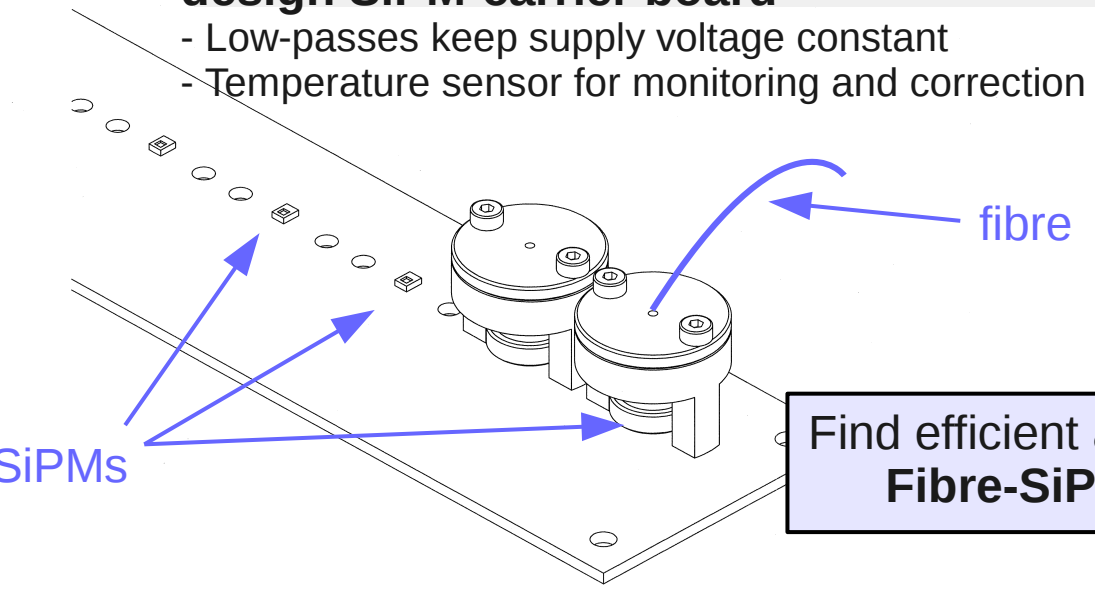


SiPM – Fiber coupling

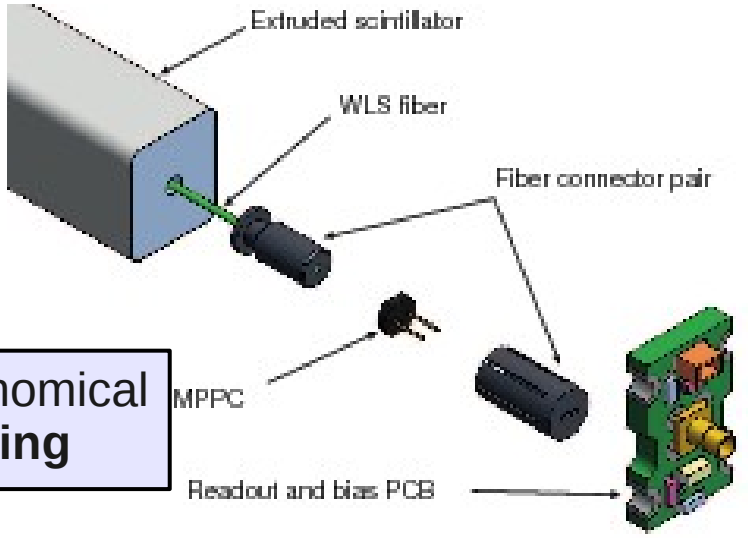


design SiPM-carrier board

- Low-passes keep supply voltage constant
- Temperature sensor for monitoring and correction



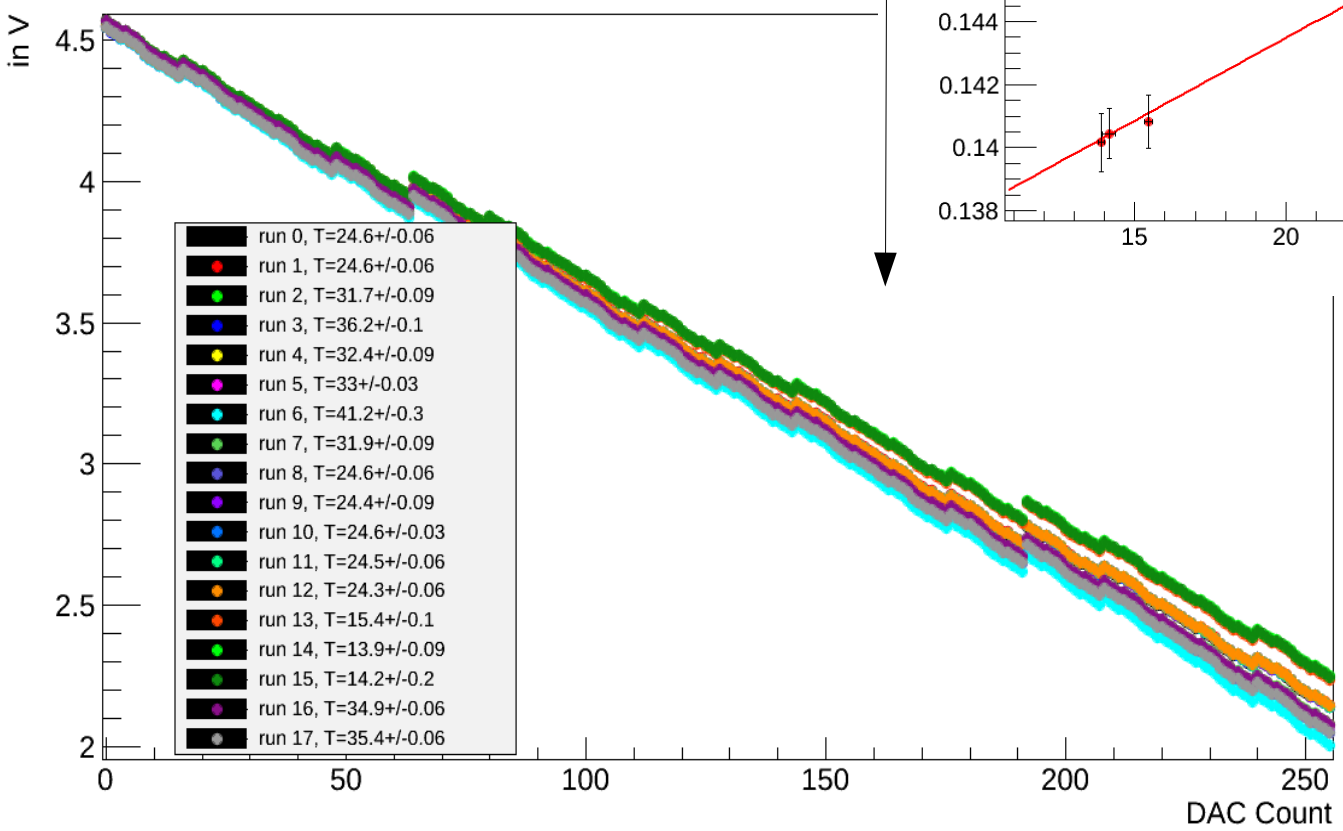
Find efficient and economical
Fibre-SiPM coupling

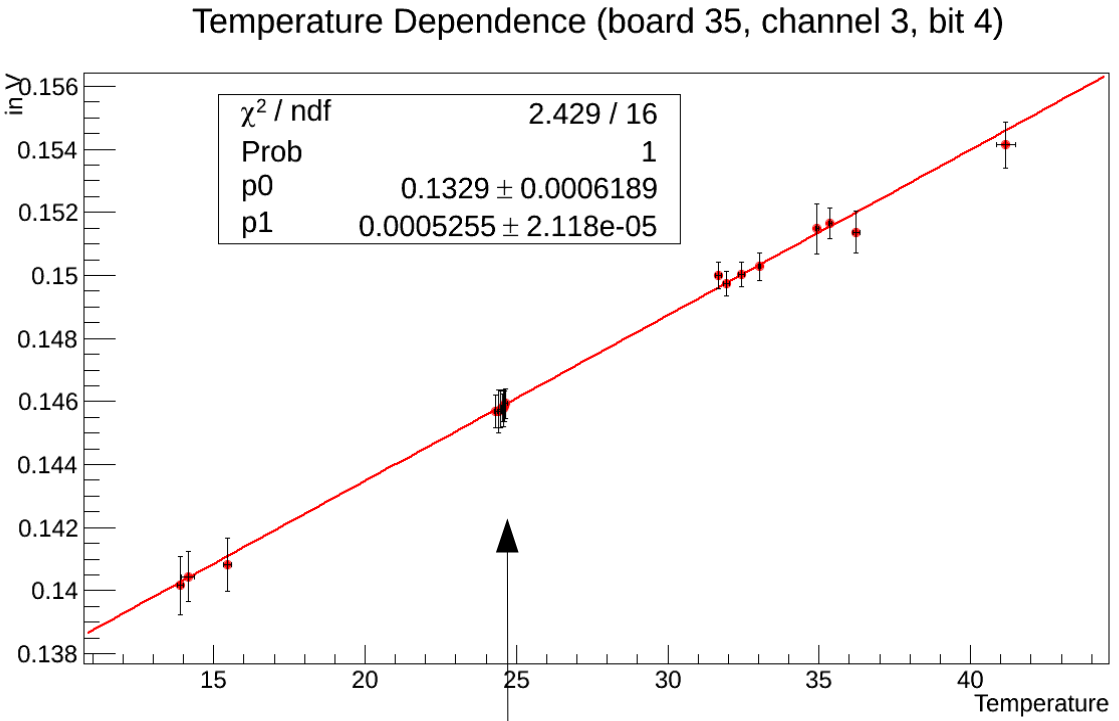


Read-out electronics

Voltage output of external power supply shows temperature dependence

Steps occur when switching on/off single bits





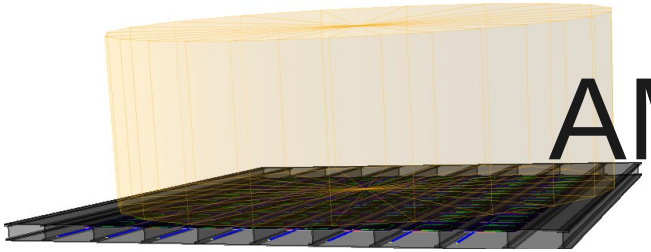
Voltage changes linearly with temperature for each bit

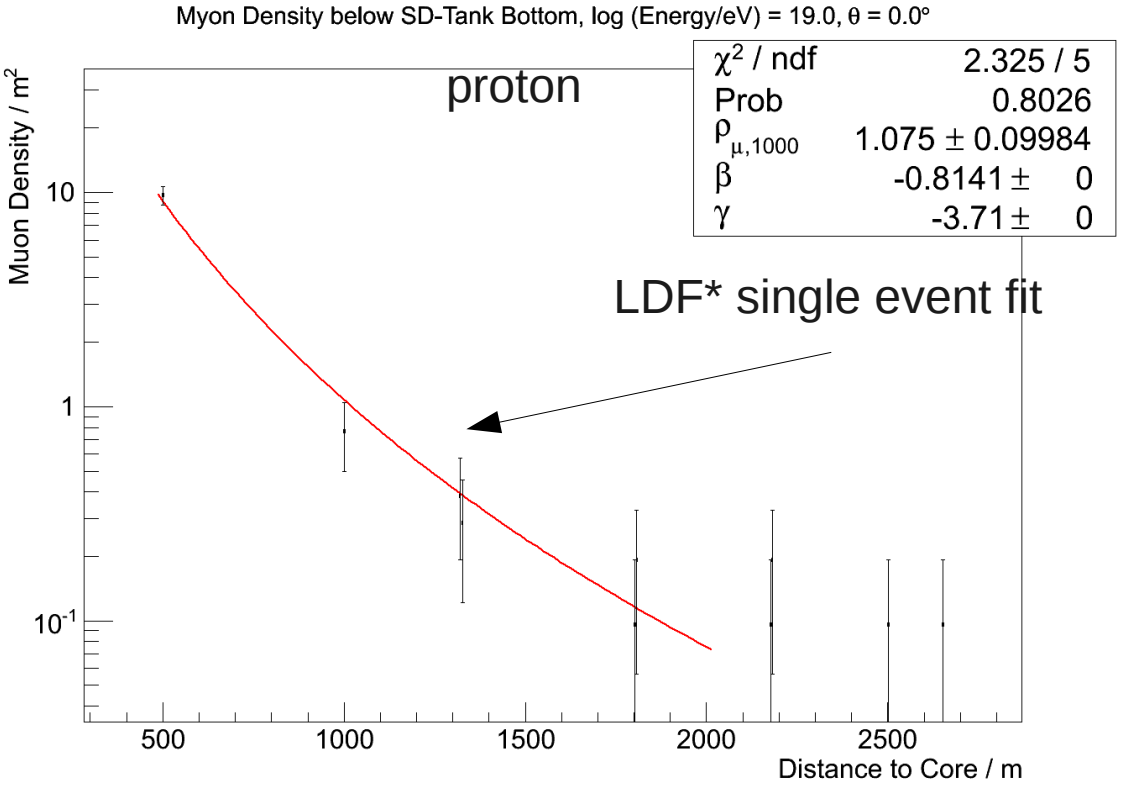
→ no problem

(can be corrected on)

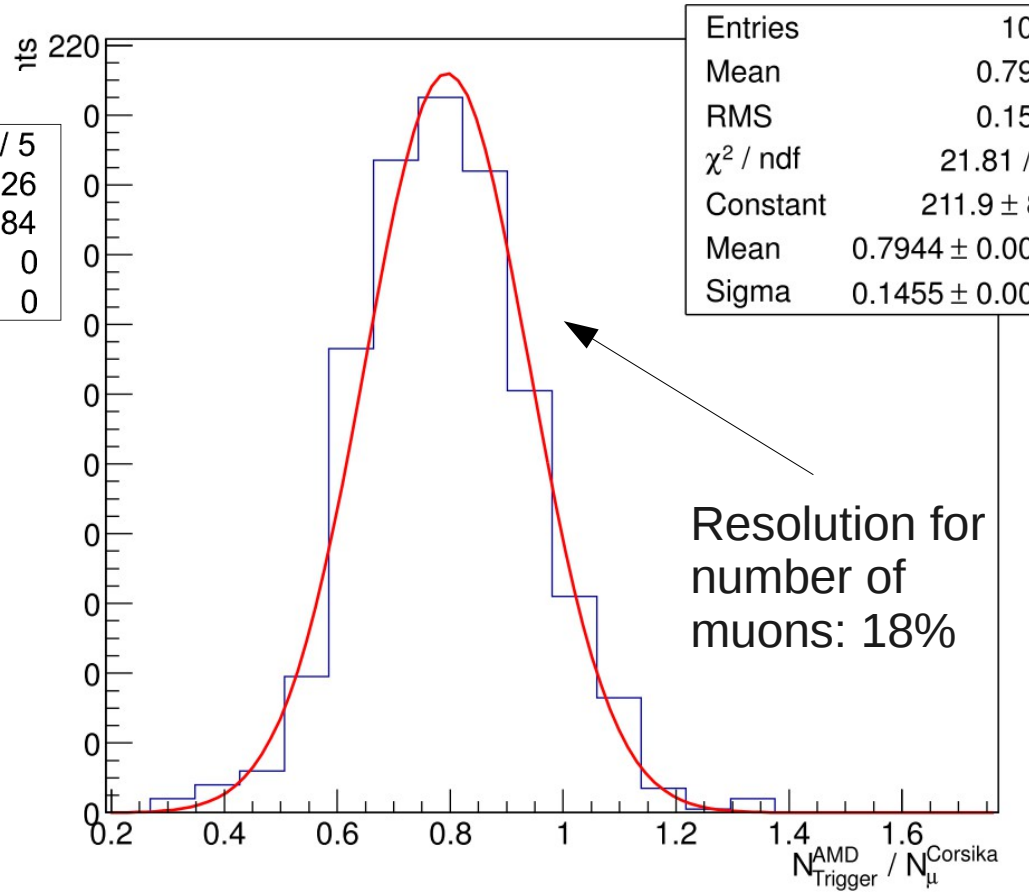
AMD simulations

10 MeV threshold





LDF* single event fit



Resolution for number of muons: 18%

*LDF = Lateral distribution function

$$\rho(r) = \rho_{1000} \, (r / 1000\ \mathrm{m})^{\beta+\gamma \ln (r / 1000\ \mathrm{m})}$$

integrate → Number of detected muons N_μ

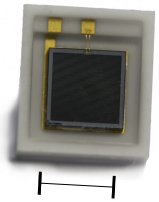
Simulations ongoing

→ performance similar to other prototypes

Backup

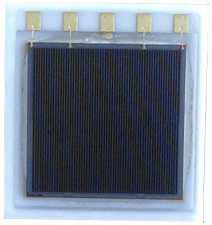
Michael Eichler, Julian Grothoff, Thomas Hebbeker, Franziska Knuth, Tobias Kowalew, Markus Lauscher, Sebastian Mann, Rebecca Meißner, Lukas Middendorf, Tim Niggemann, Christine Peters, Barthel Philipps, Johannes Schumacher, Maurice Stephan, Daniel Wilson, Franz-Peter Zantis

SiPM arrays



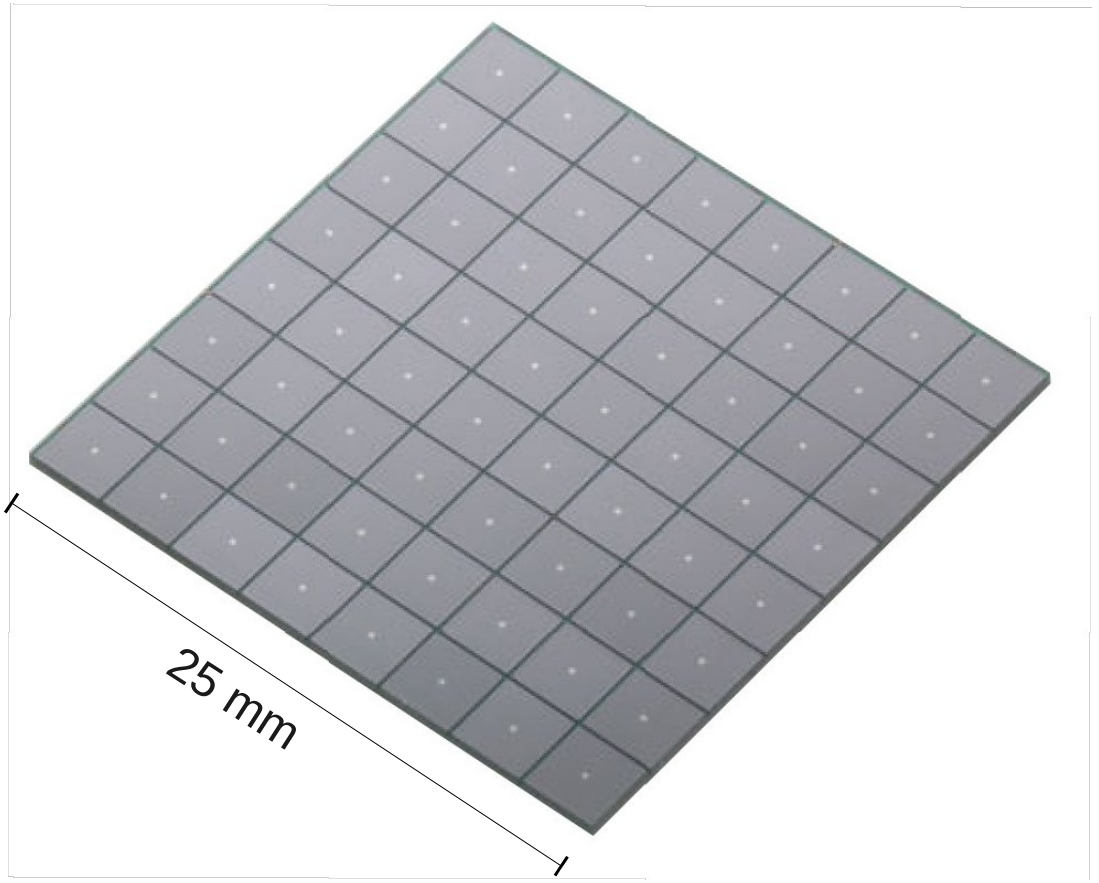
3 mm

1-channel



6 mm

4-channel

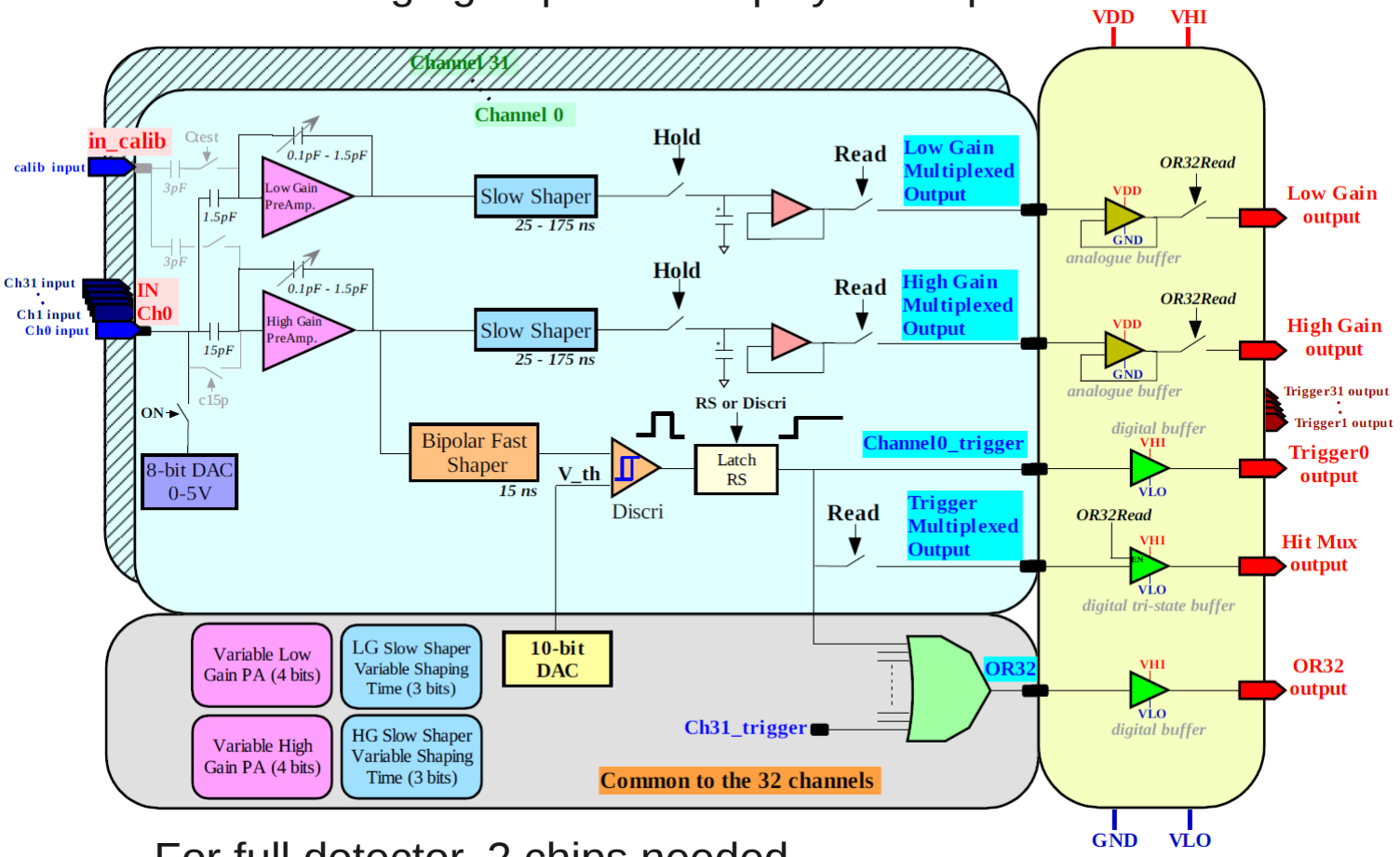


64-channel

EASIROC Read-out electronics

- Extended Analogue SI-pm ReadOut Chip
- 32 input channels with 2 parallel pre-amplifiers (VGA)
- Fast discriminator output
- individual bias voltage regulation

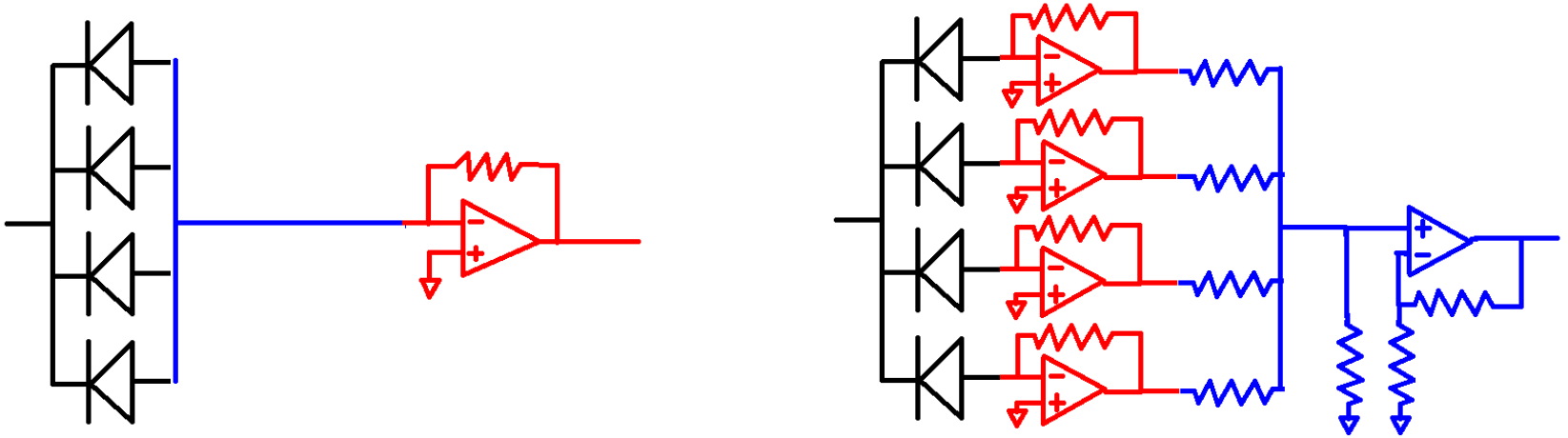
Omega group at École polytechnique



For full detector, 2 chips needed

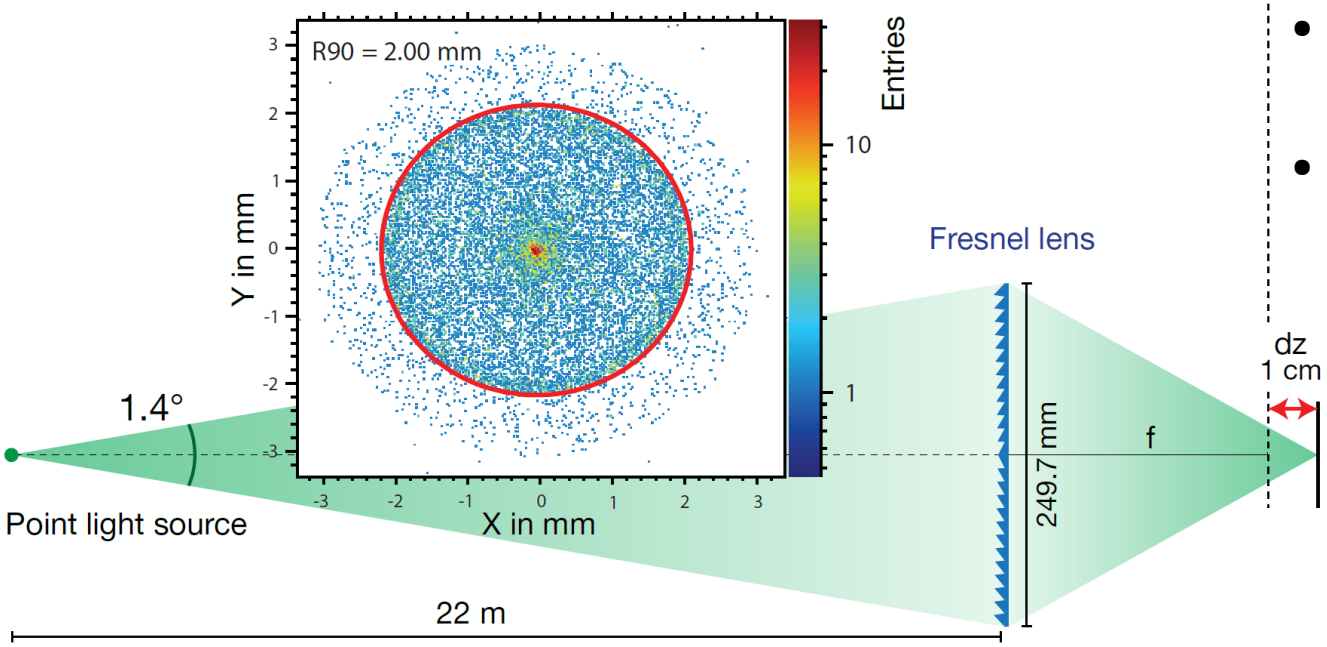
→ Firmware written, tests ongoing

SiPM array read-out



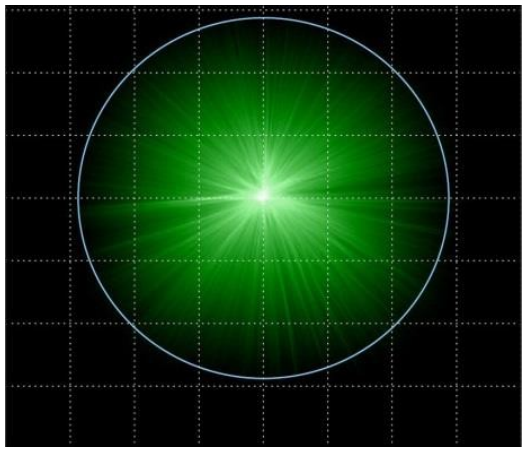
(MA Niggemann, Peters, Eichler)

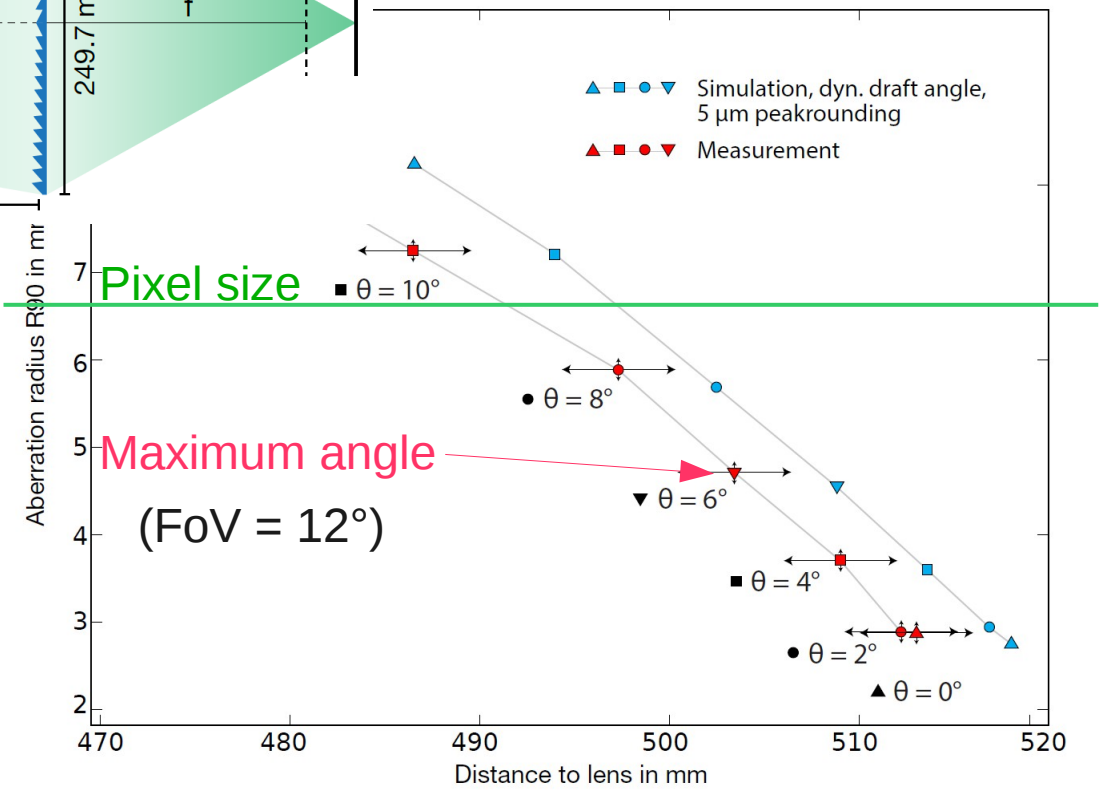
Fresnel lens characterisation



- R_{90} = 90% encircled light intensity
- Overall transmittance w/o photo sensor ~ 41 %

FD: ~ 50%

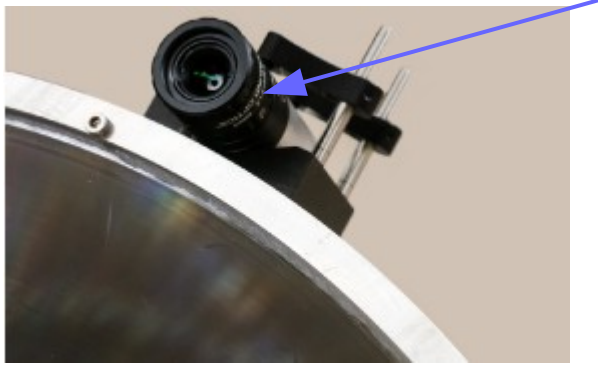




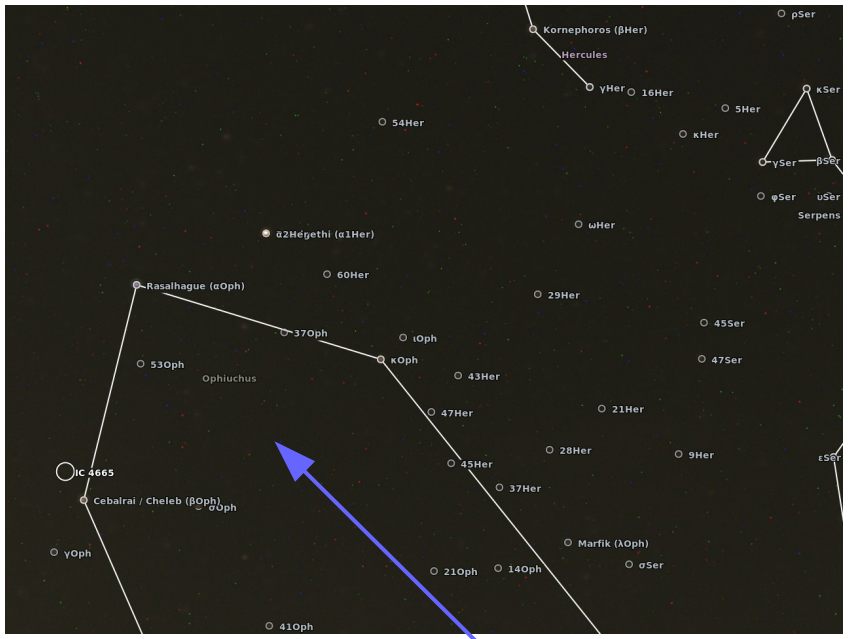
(BA Grothoff, Knuth), Sommer

FAMOUS[7] slow control & event selection

SkyCam



CMOS camera

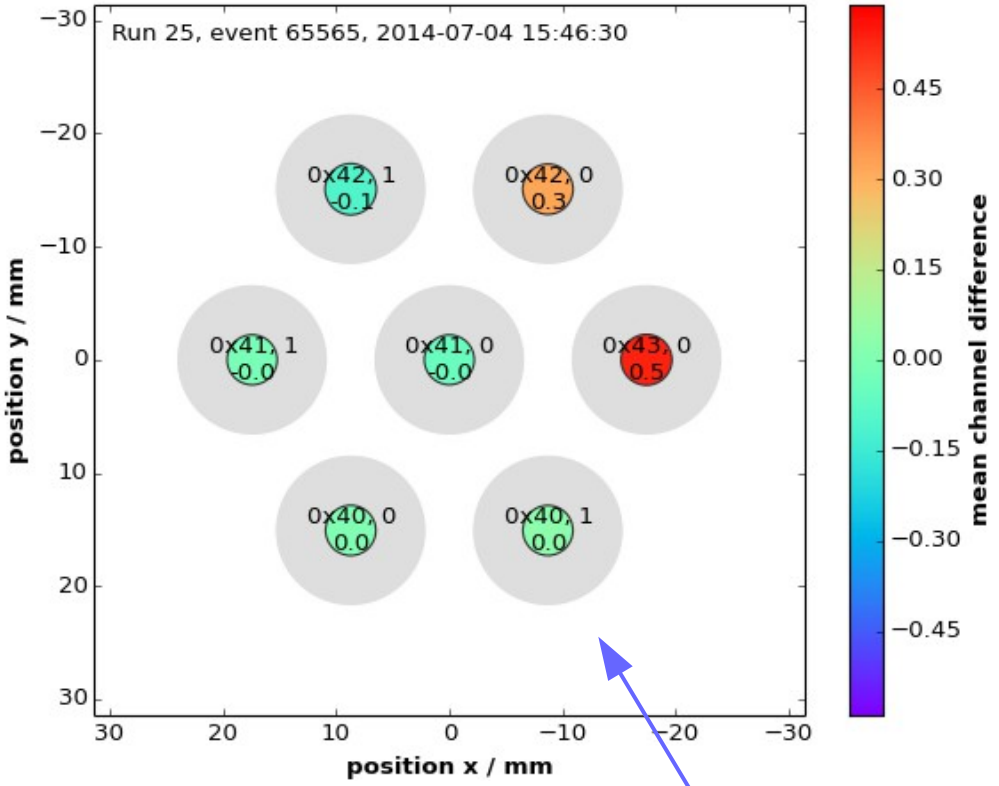


Astrometry found Ophiuchus constellation

Slow control

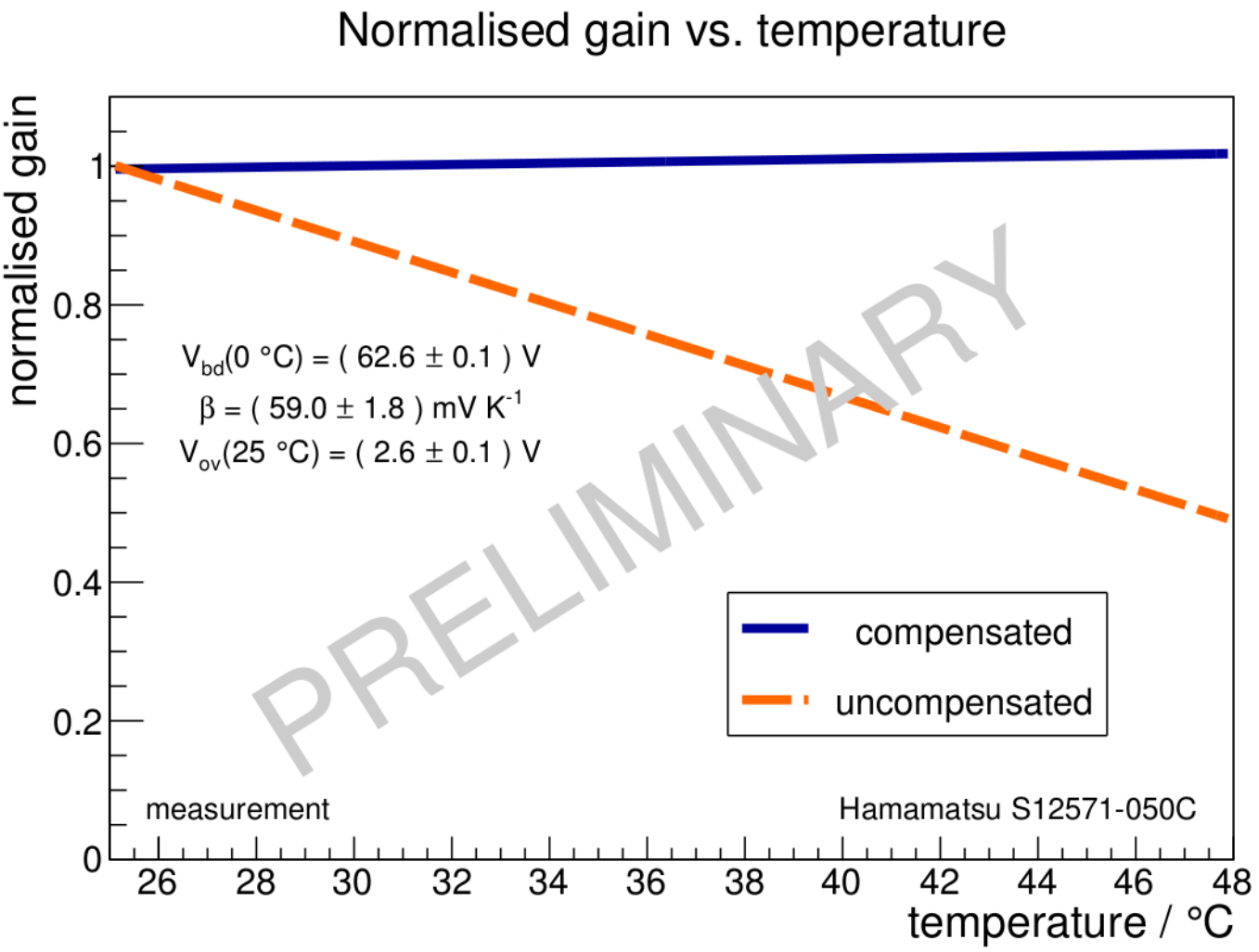
Temperature, air pressure, humidity, system load, GPS position & time, ...

Event viewer

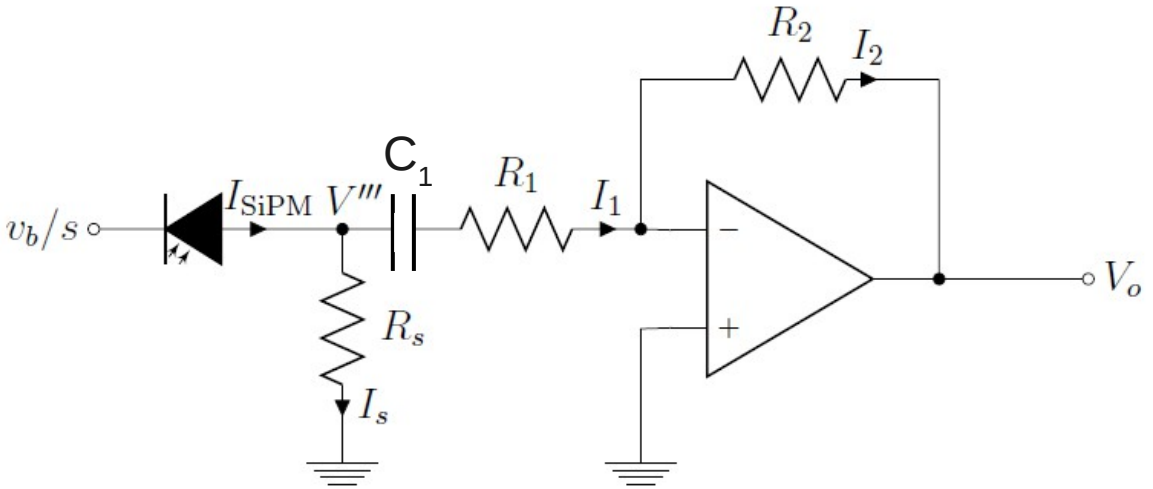


Focal plane pixels

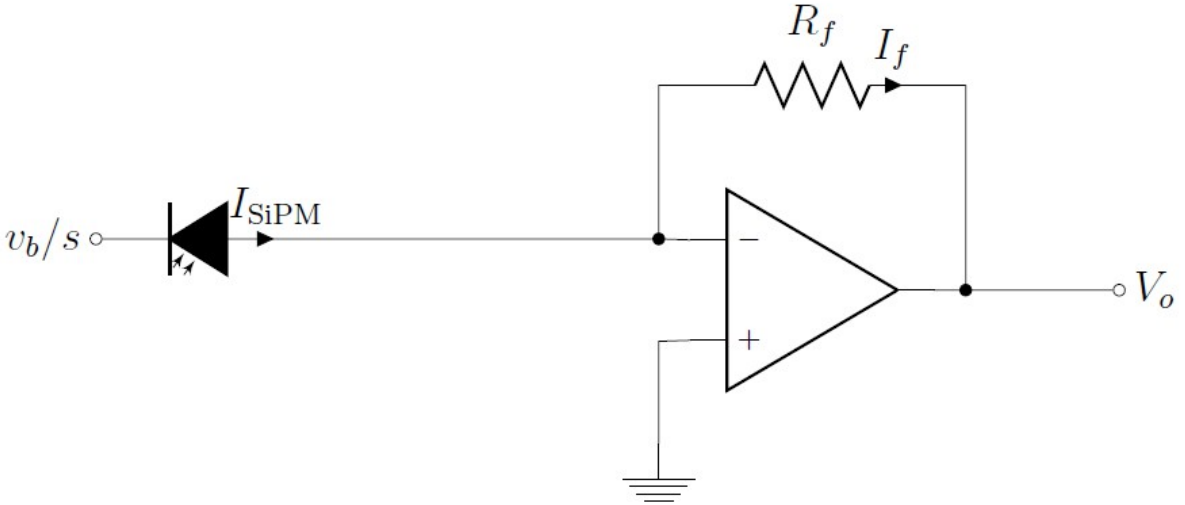
SiPM gain compensation



SiPM read-out

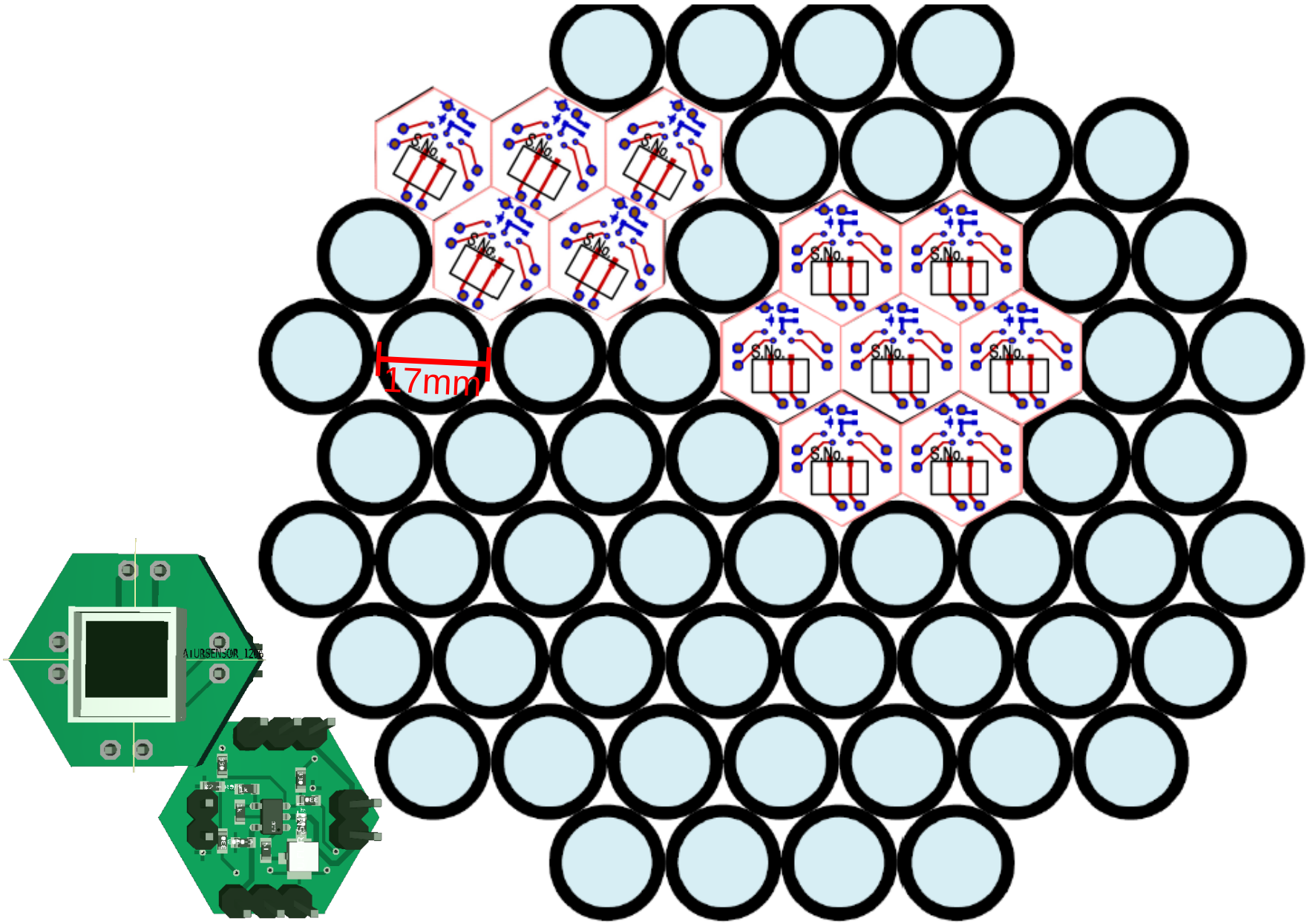


(typical)

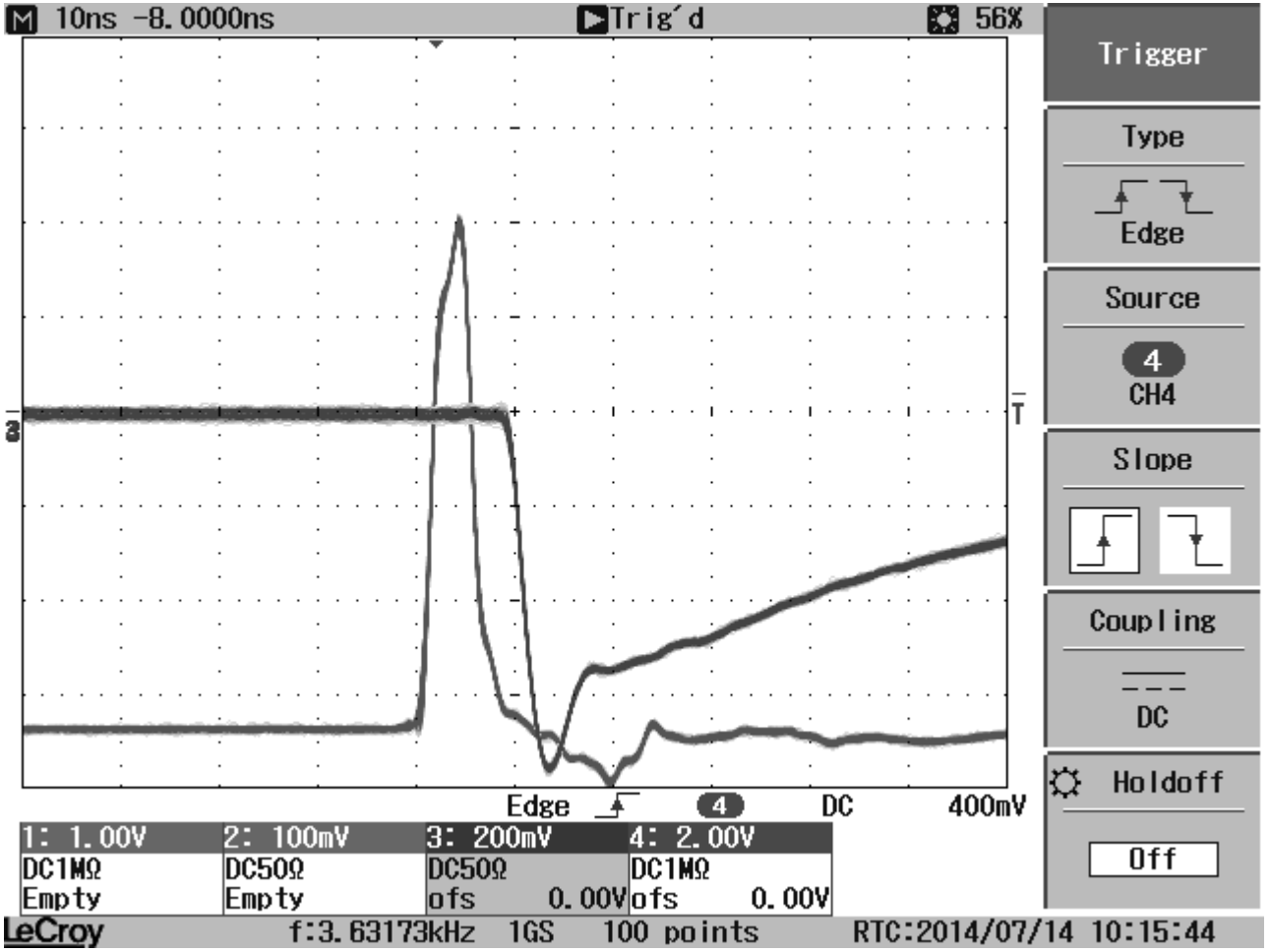


(MA Schumacher)

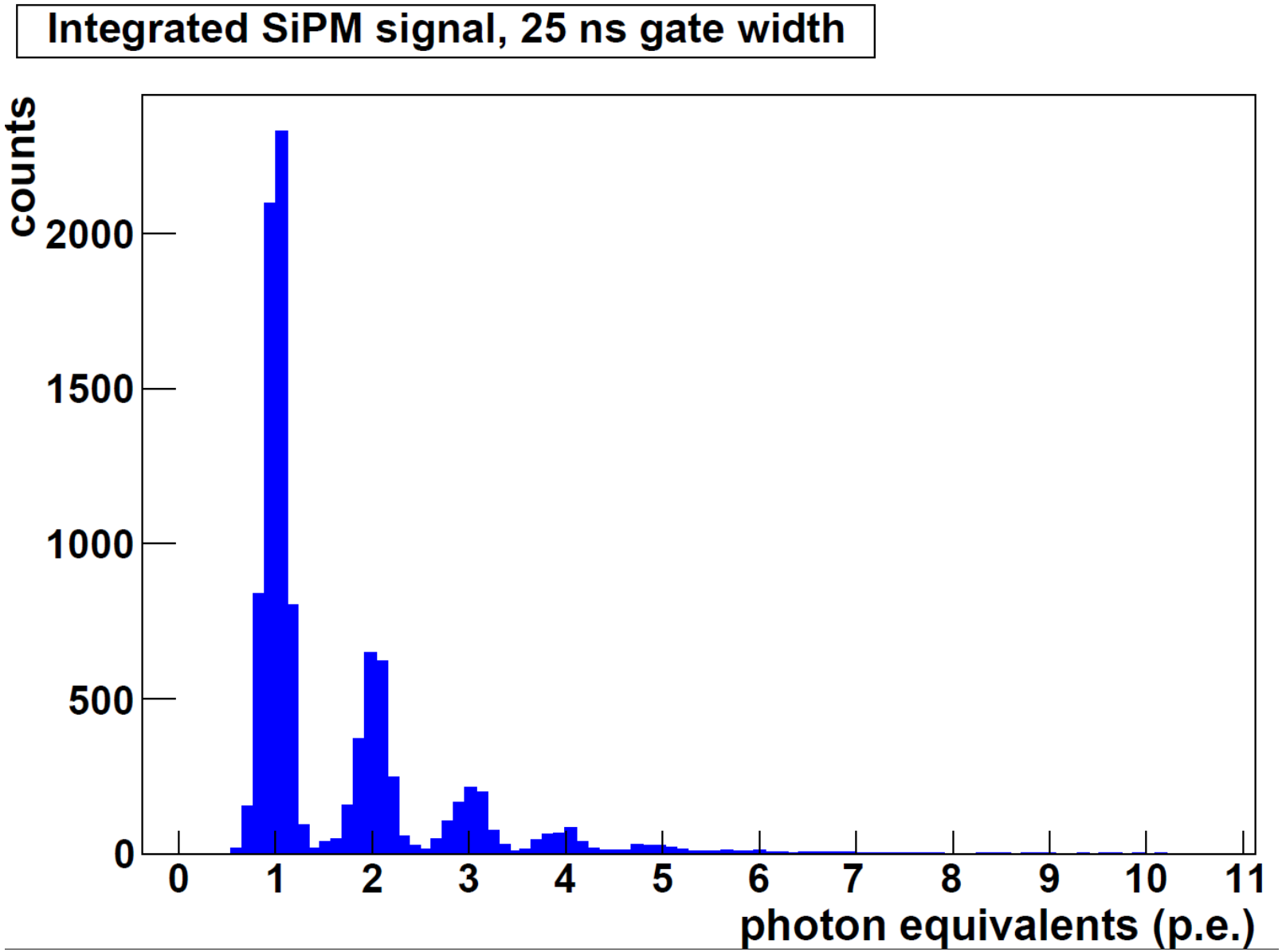
Camera design



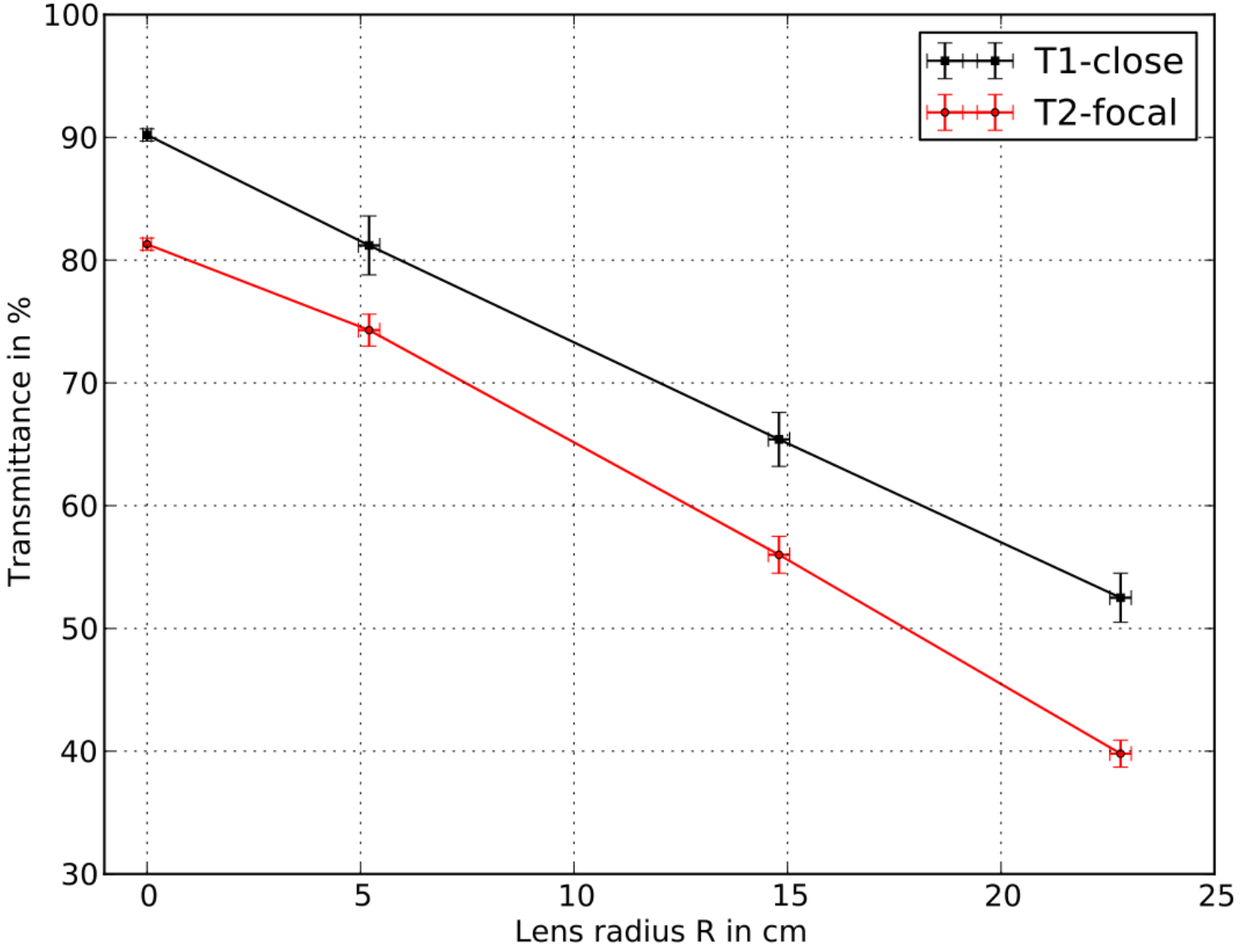
SiPM large pulse performance



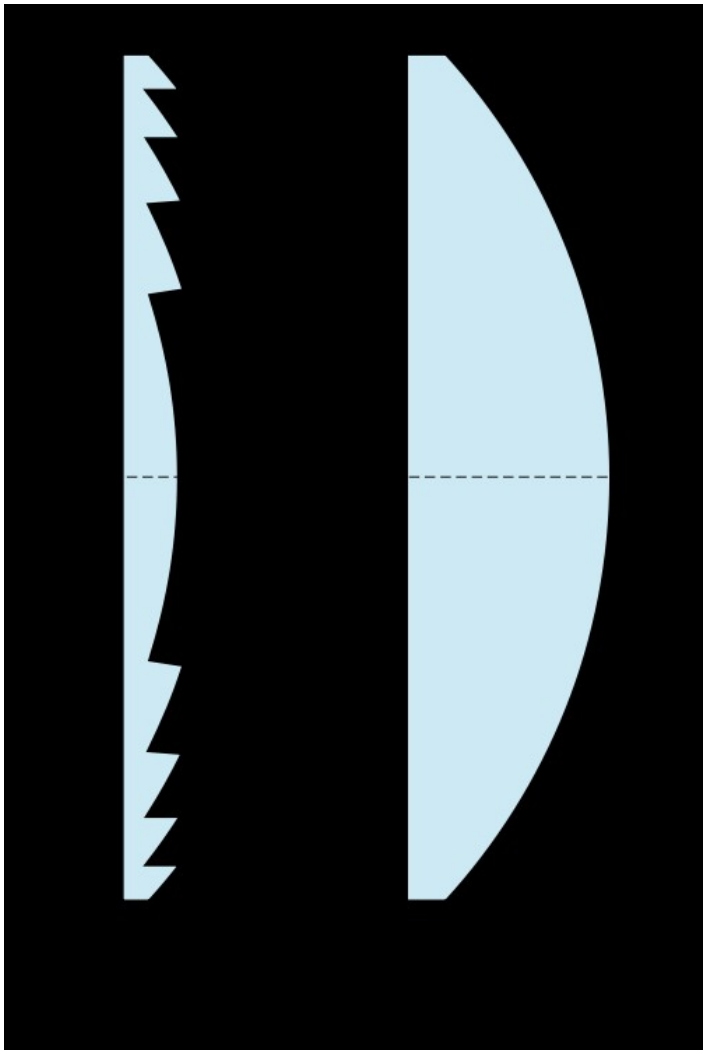
QDC


Integrated SiPM signal, 25 ns gate width
counts
2000
1500
1000
500
0
0
1
2
3
4
5
6
7
8
9
10
11
photon equivalents (p.e.)

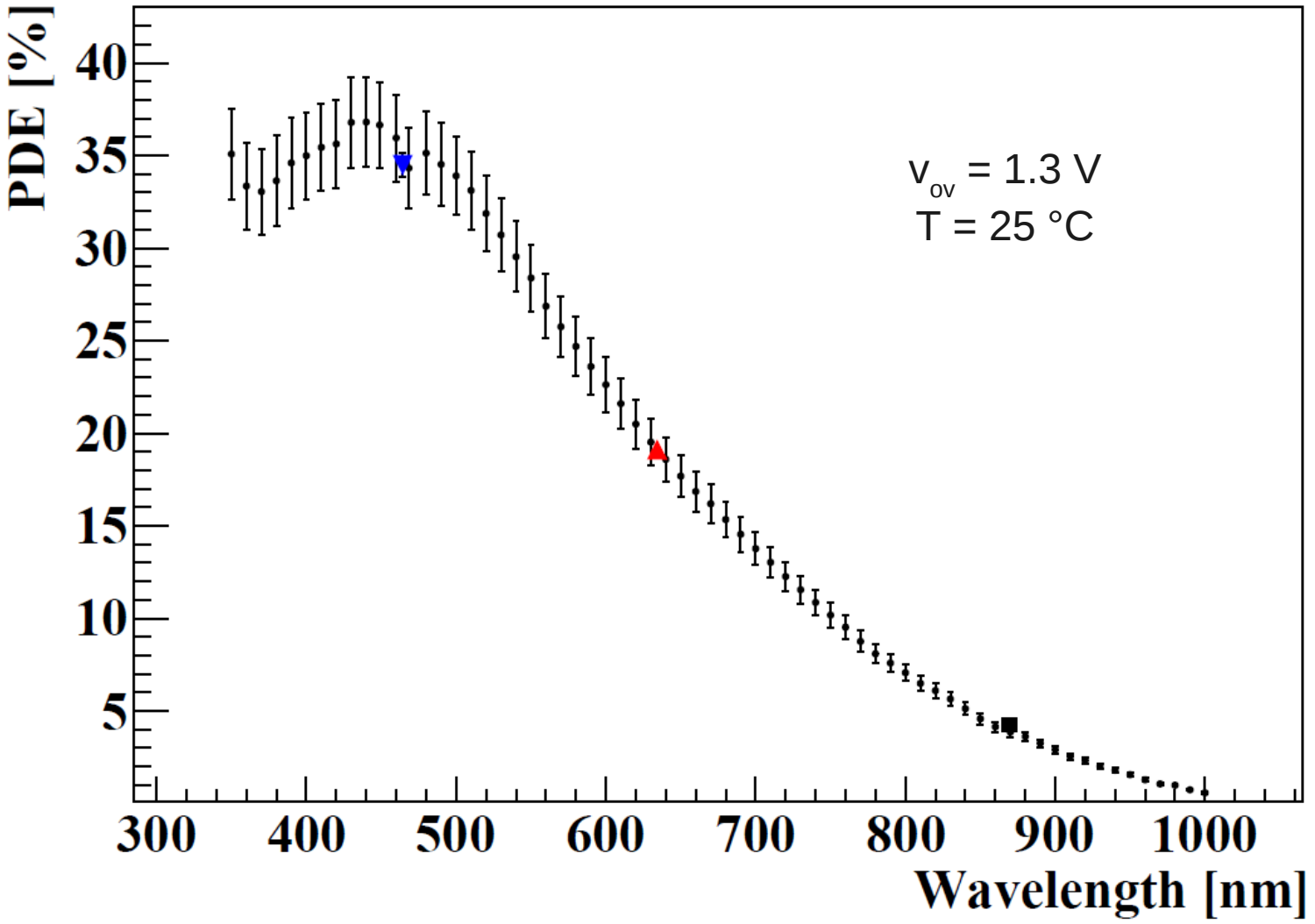
Fresnel lens transmittance



Fresnel lens

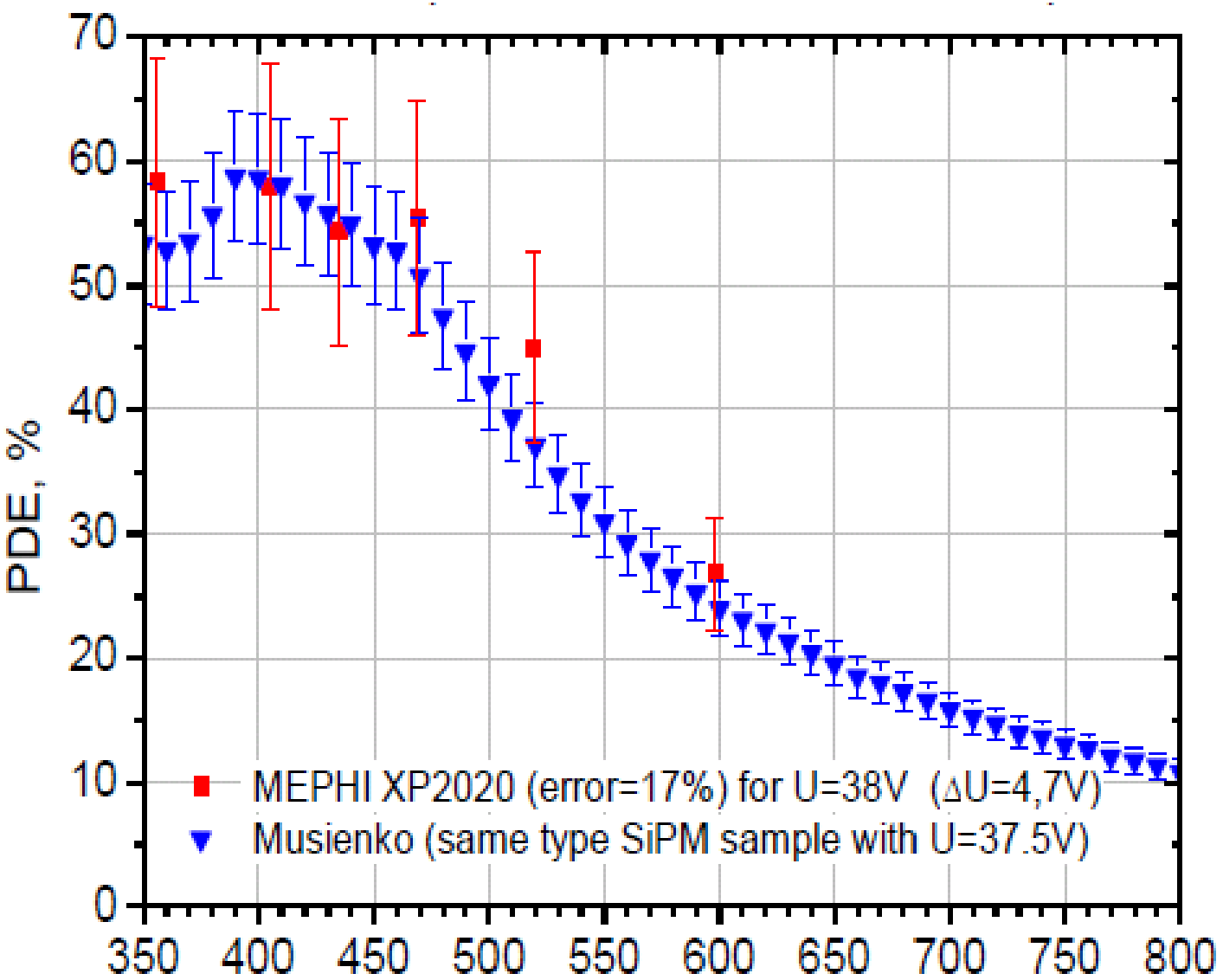


PDE

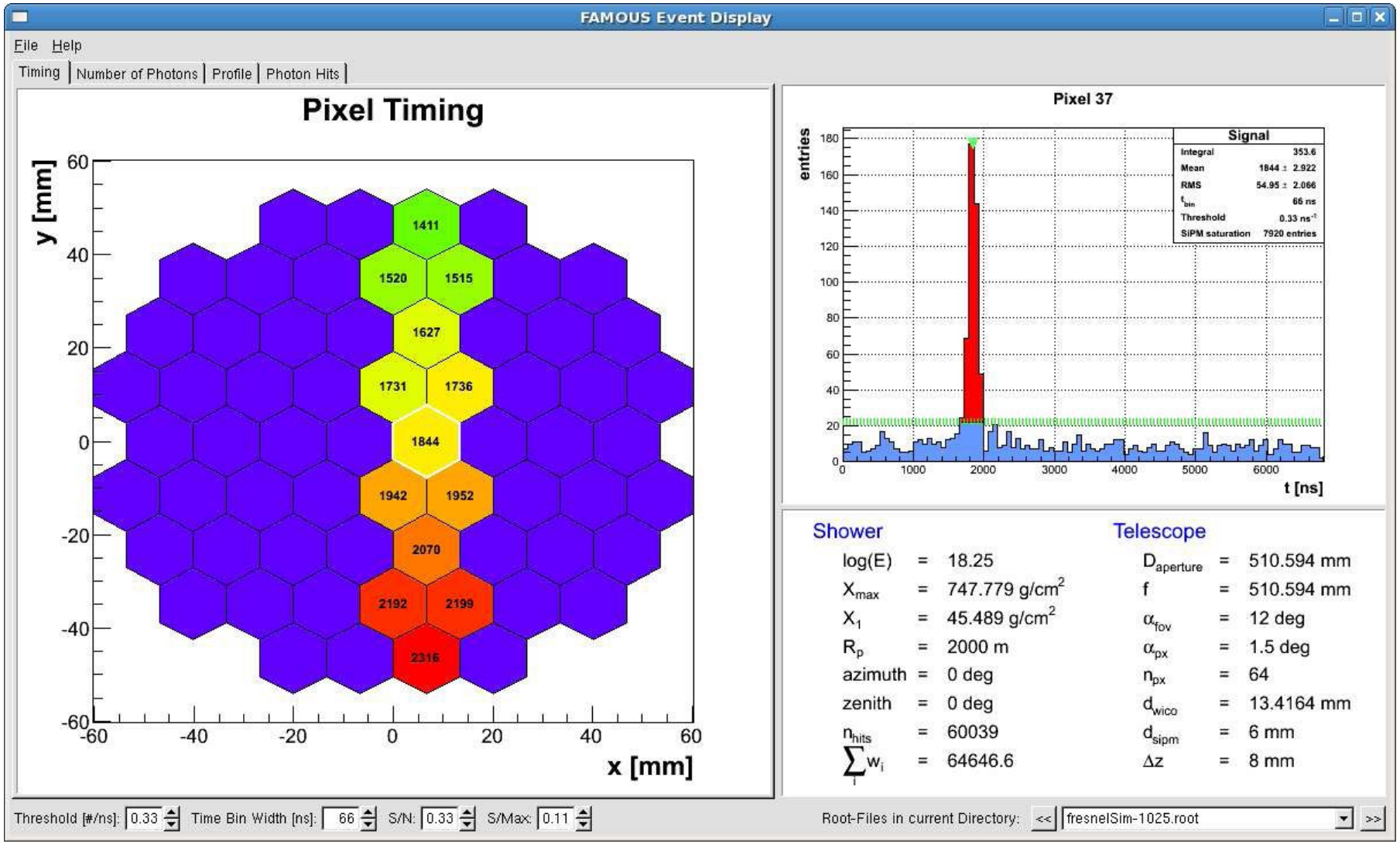


Hamamatsu S10362-11-100C, Tadday 2010

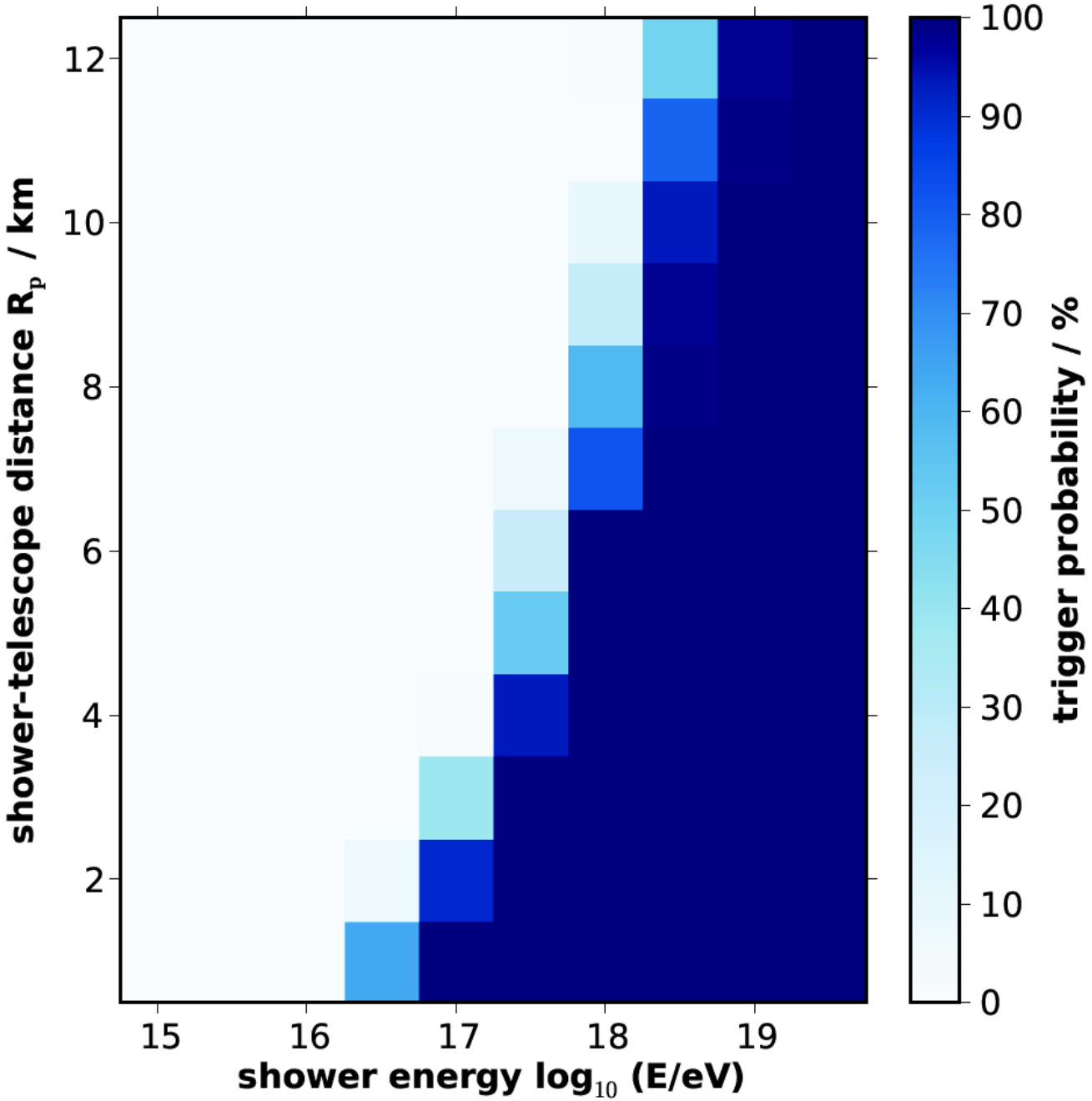
PDE


PDE, %
70
60
50
40
30
20
10
0
350
400
450
500
550
600
650
700
750
800
MEPHI XP2020 (error=17%) for U=38V (ΔU=4,7V)
Musienko (same type SiPM sample with U=37.5V)

Famous-64 event display

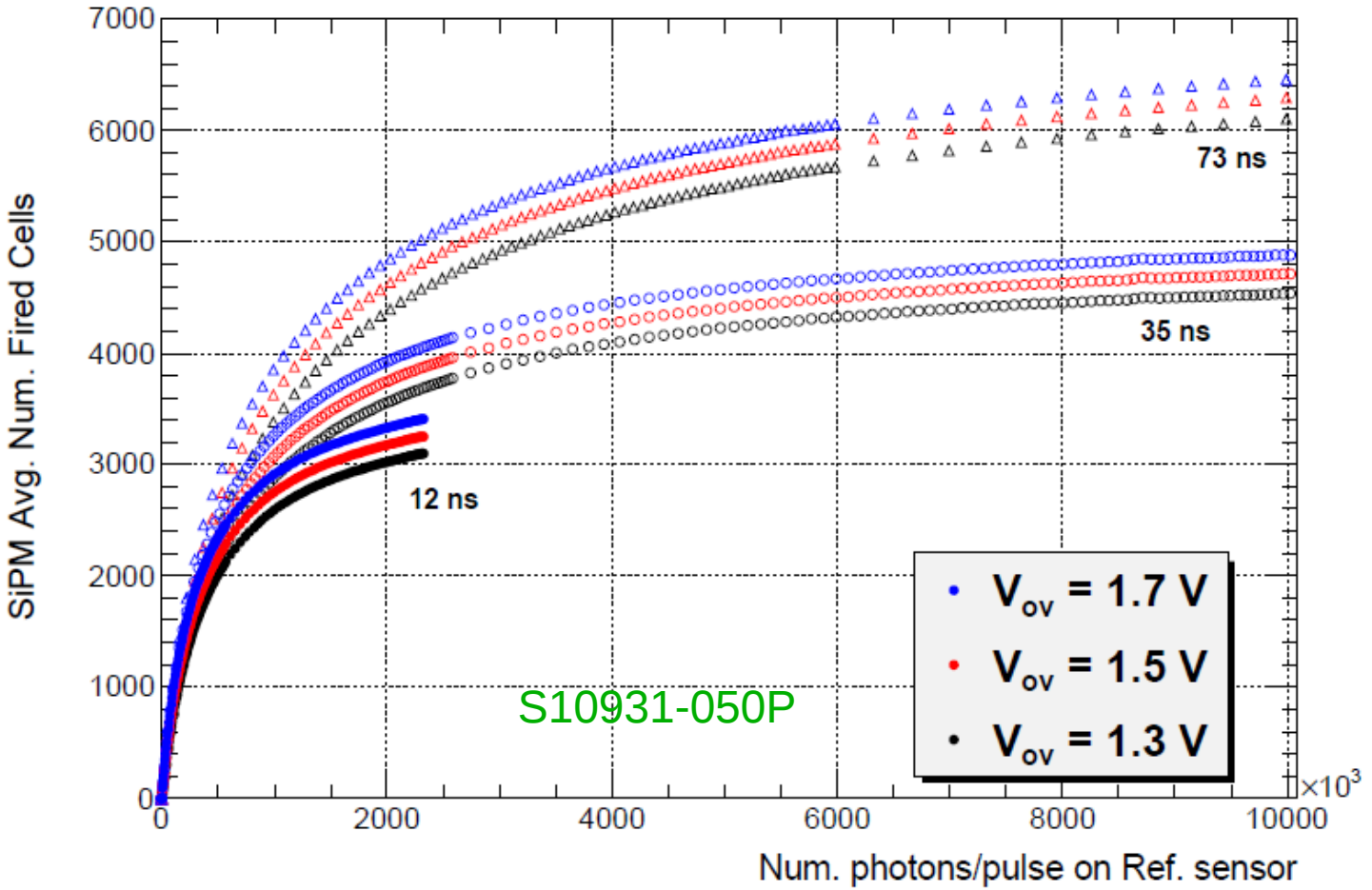


Trigger probability



Silicon photomultipliers

Geant4 simulation framework available!



AMD performance