Status of the Silicon Photomultiplier Telescope FAMOUS for the Detection of UHECR

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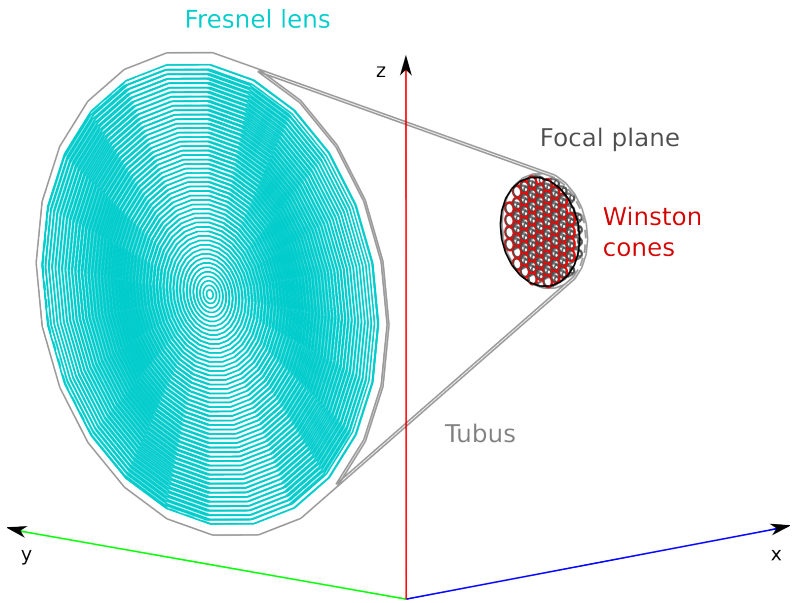
Outline

FAMOUS

1. Introduction
2. Silicon Photomultipliers
3. Baseline Design of FAMOUS
4. Night-Sky Measurements with FAMOUS$^{\text{ONE}}$
5. Current Status of FAMOUS$^{\text{SEVEN}}$
6. Summary & Outlook



Who is FAMOUS?

- Lisbon

Pedro Assis, Pedro Brogueira, Miguel Ferreira, Luís Mendes, Mário Pimenta

- Granada

Antonio Bueno, Sergio Navas, Angel Ruiz

- Aachen

Franz Adamczyk, Michael Eichler, Josef Grooten, Thomas Hebbeker, Tobias Kowalew, Markus Lauscher, Lukas Middendorf, Tim Niggemann, Christine Peters, Barthel Philipps, Johannes Schumacher, Maurice Stephan, Franz-Peter Zantis

(Senior Researcher, Junior Researcher, Technician)

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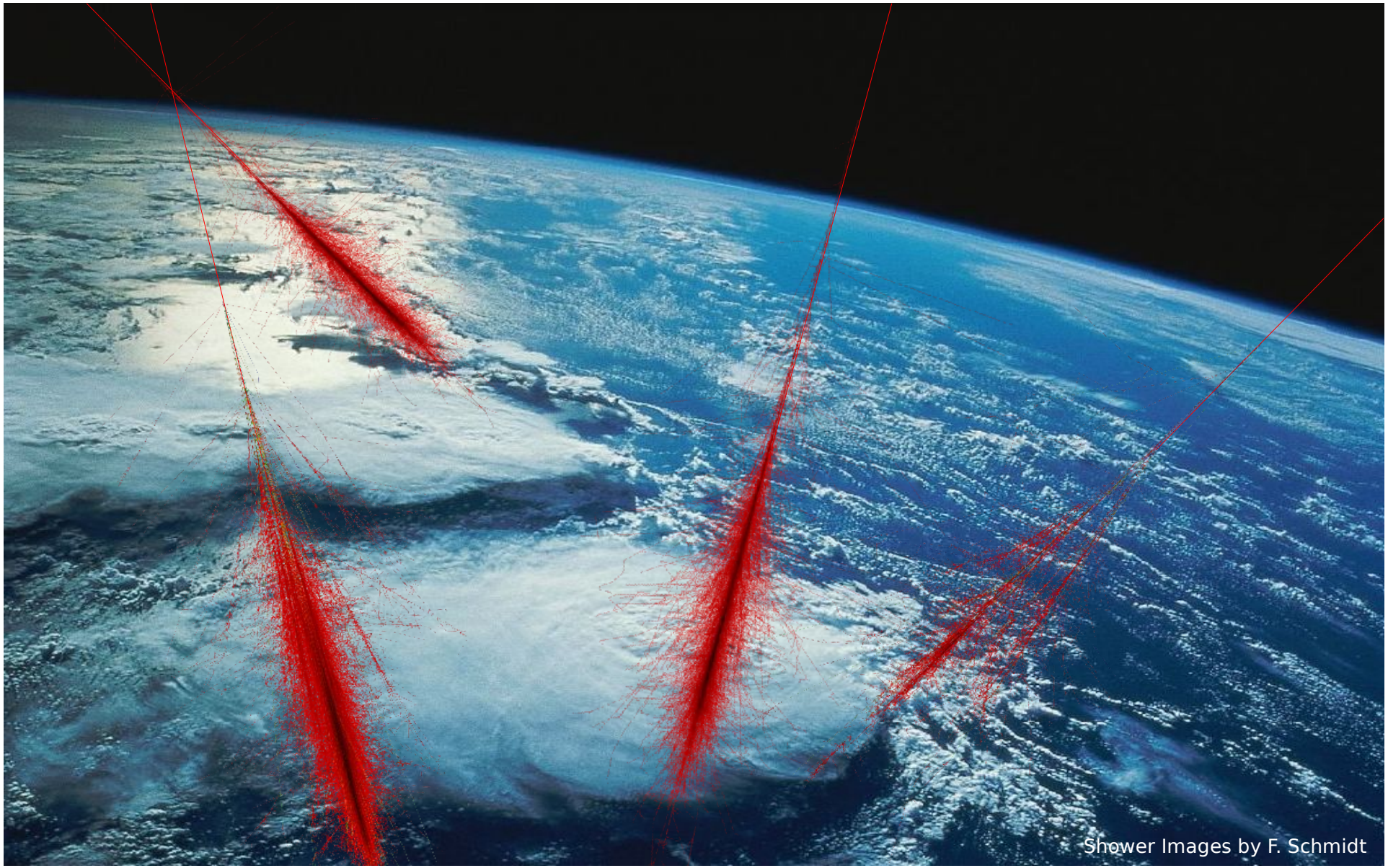
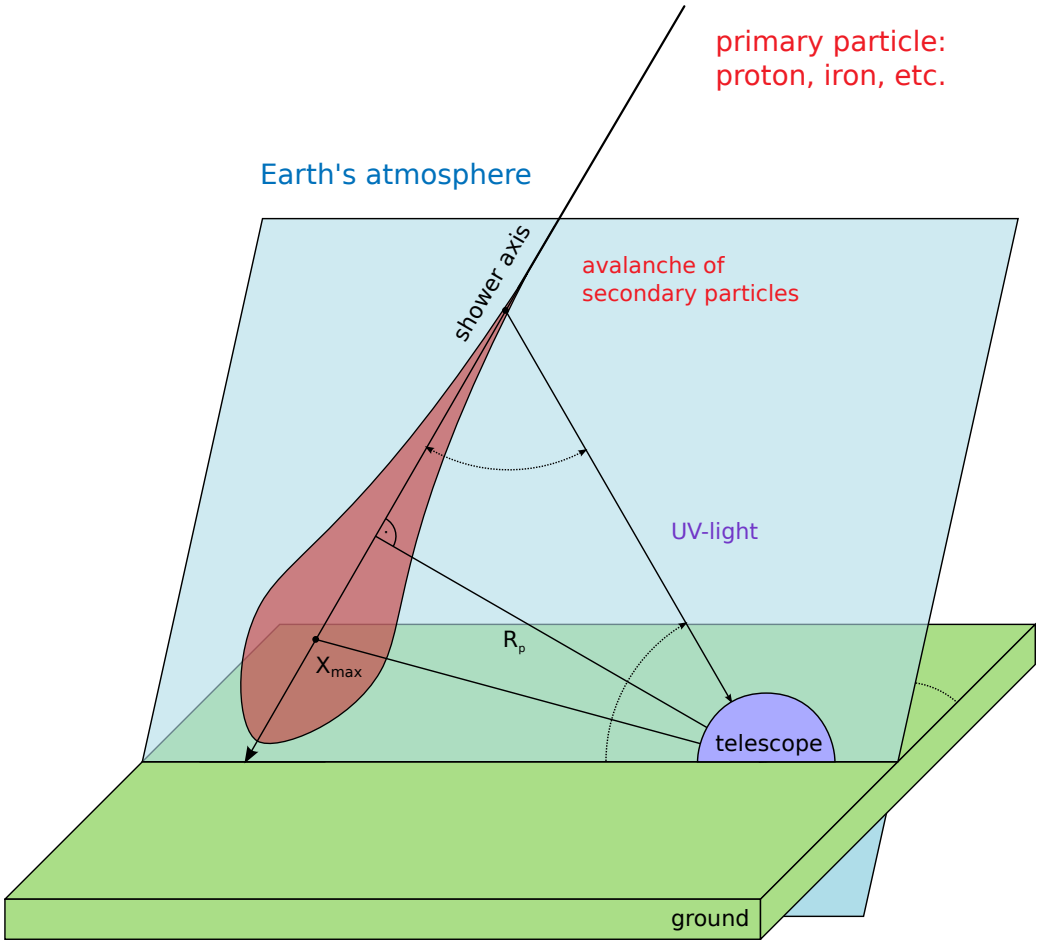
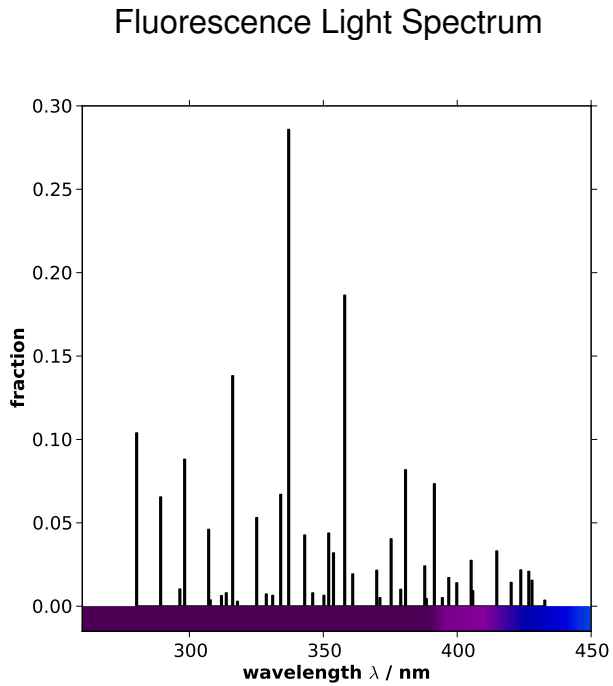
QREN QUADRO DE REFERÊNCIA ESTRATÉGICO NACIONAL PORTUGAL 2007.2013
UNIÃO EUROPEIA Fundo Europeu de Desenvolvimento Regional
FCT Fundação para a Ciência e a Tecnologia MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

What do we want to measure?



Fluorescence Detection of High-Energy-Cosmic Rays

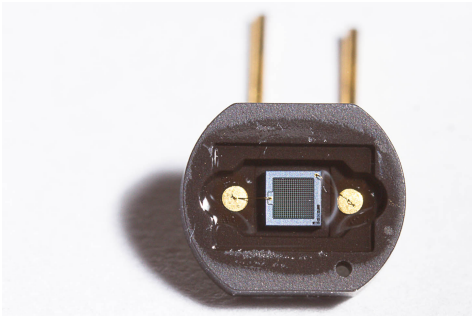


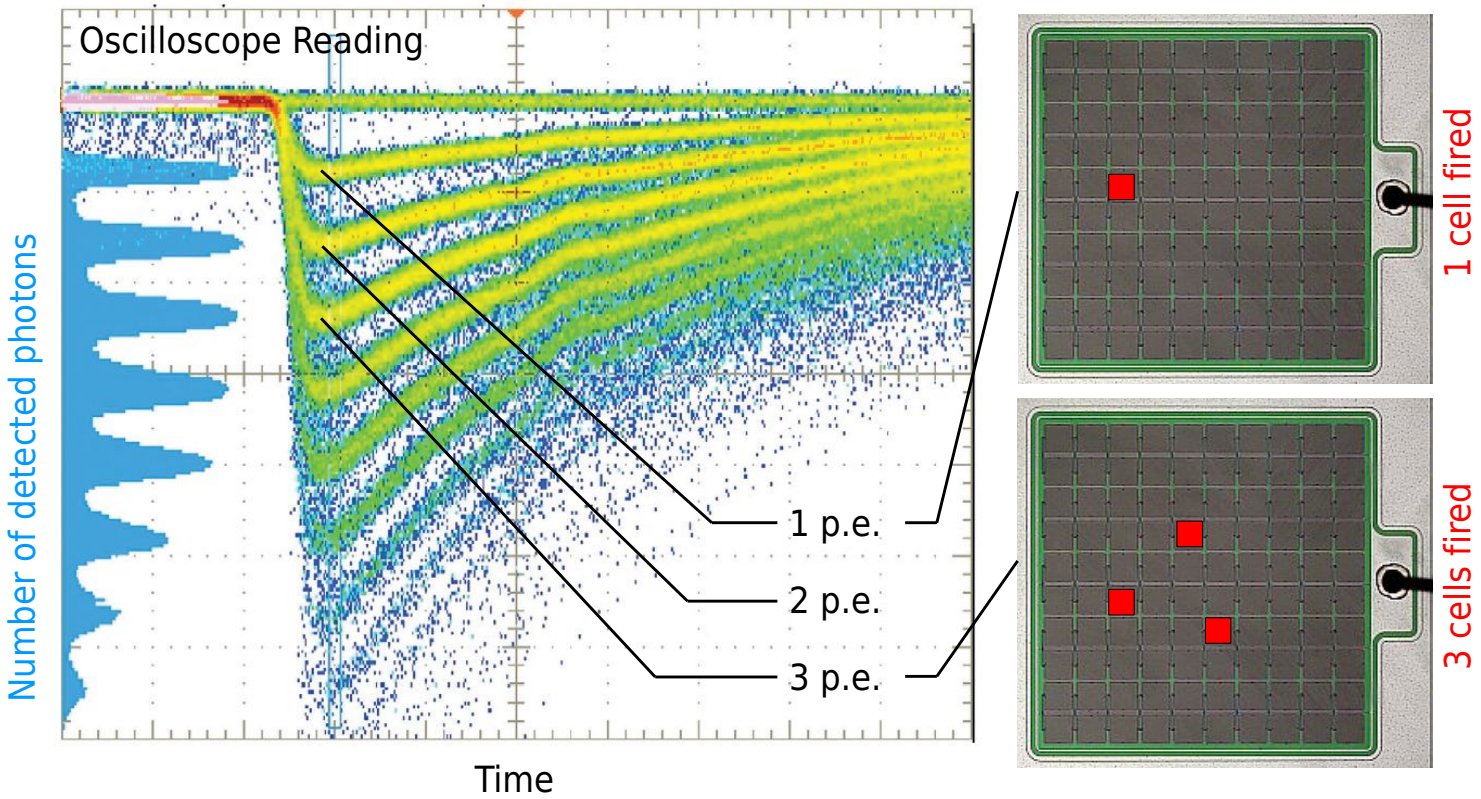


- Secondary particles excite nitrogen $\rightarrow$ emittance of fluorescence light
- Gain information on the primary particle (origin, energy, even chemical composition?)

Silicon Photomultipliers

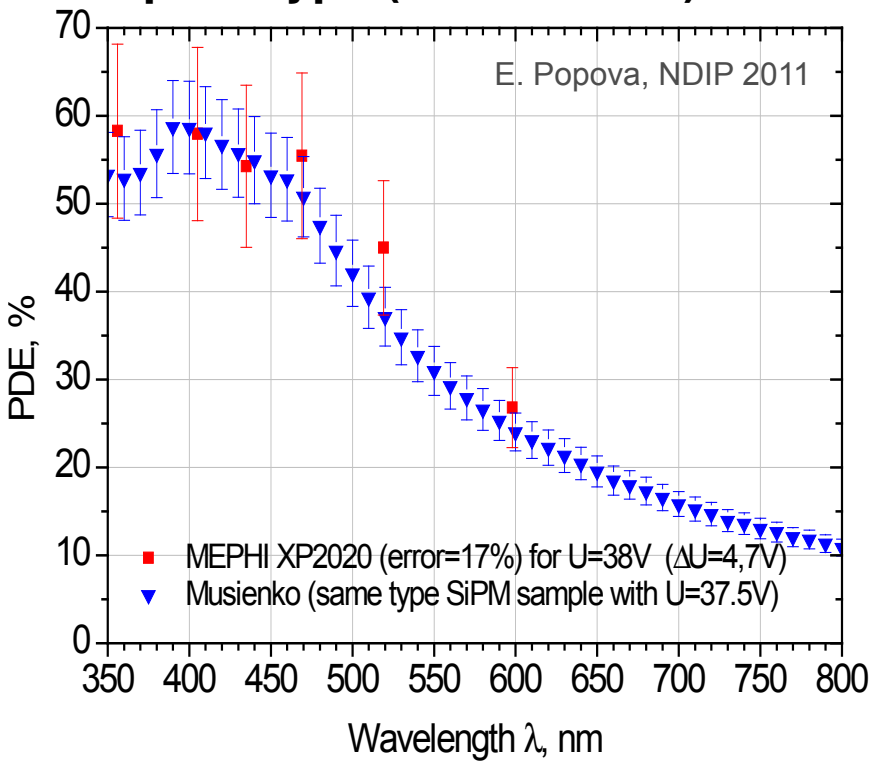
- Light detectors with single photon detection capability
- Made up of cells $(100, 3600, 14400, ...)$
- Small form factor $(1 \times 1\,\mathrm{mm}^2, 3 \times 3\,\mathrm{mm}^2, 6 \times 6\,\mathrm{mm}^2, ...)$
- Promise high photon detection efficiency $> 40\,\%$
- Dark noise rate $\approx 10\,\mathrm{kHz/cell}$





Photon Detection Efficiency of SiPMs

SiPM prototype (MEPhI 100B)

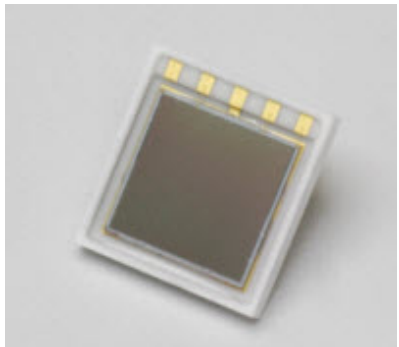


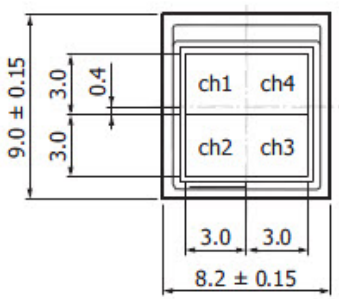
Very high PDE in UV regime up to $60\,\%$

Not yet commercially available!

Hamamatsu S10985-100C

- 3600 cells
- PDE in UV regime $\approx$ $25\,\% - 36\,\%$
- Extensively studied in our laboratories
- Used for FAMOUS





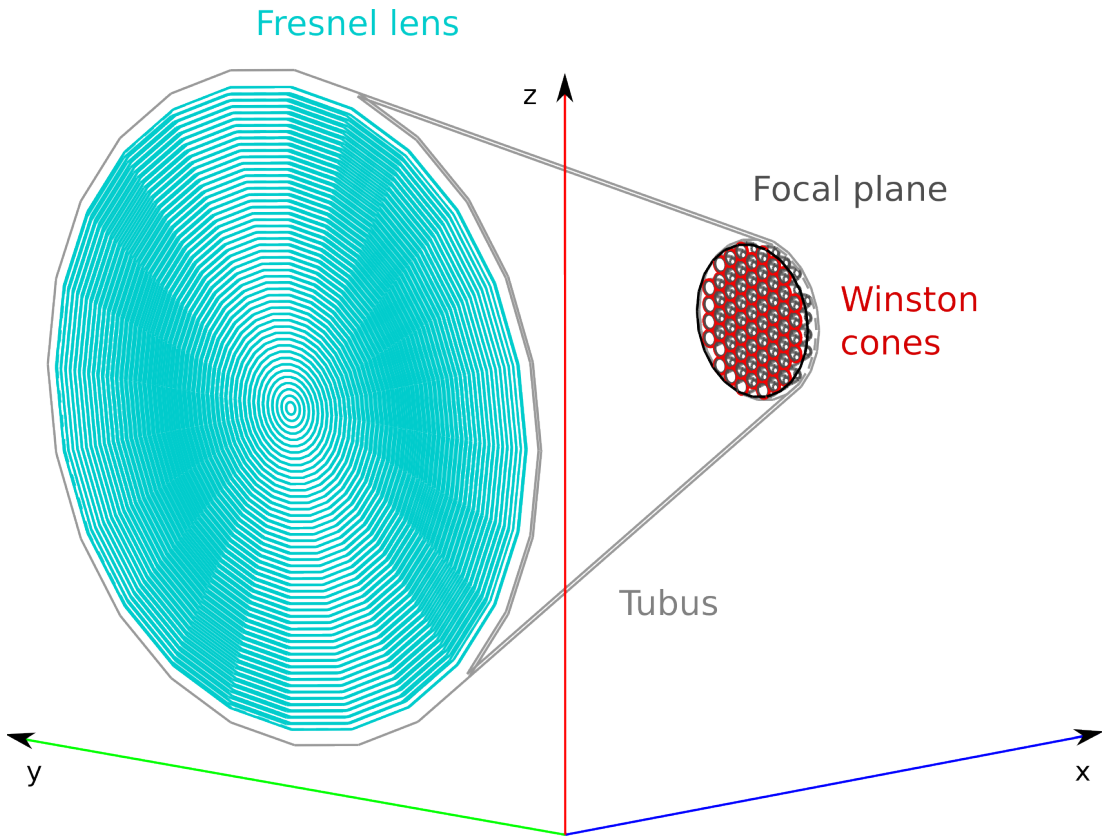
- Typical PDE of photomultiplier tubes used in fluorescence detection telescopes $\approx 27\,\%$, $\approx 35\,\%$ (optimized in Wuppertal)

Baseline Design of FAMOUS

- Modular & simple refractive design

- 64 hexagonally arranged pixels
- $1.5\,°$ field of view per pixel
- $12\,°$ total field of view

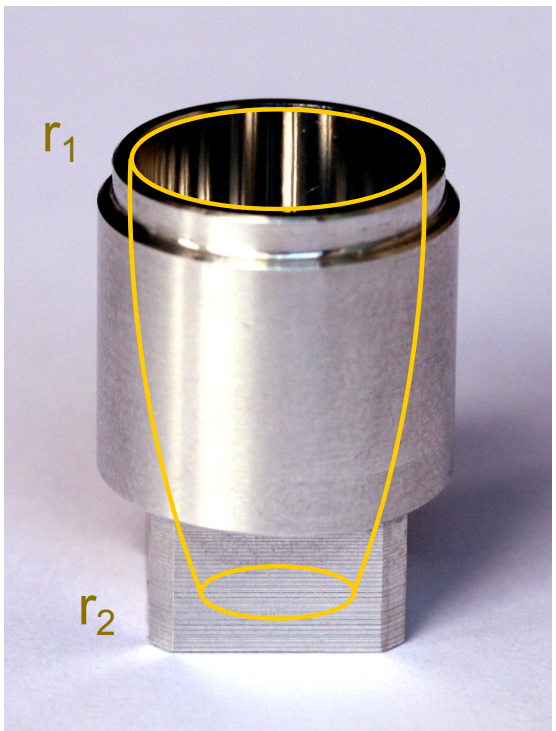
- Fresnel lens with $f = D = 510\,\text{mm}$
- Pixel = Light funnel + four $3 \times 3\,\text{mm}^2$ SiPMs (Hamamatsu S10985-100C)

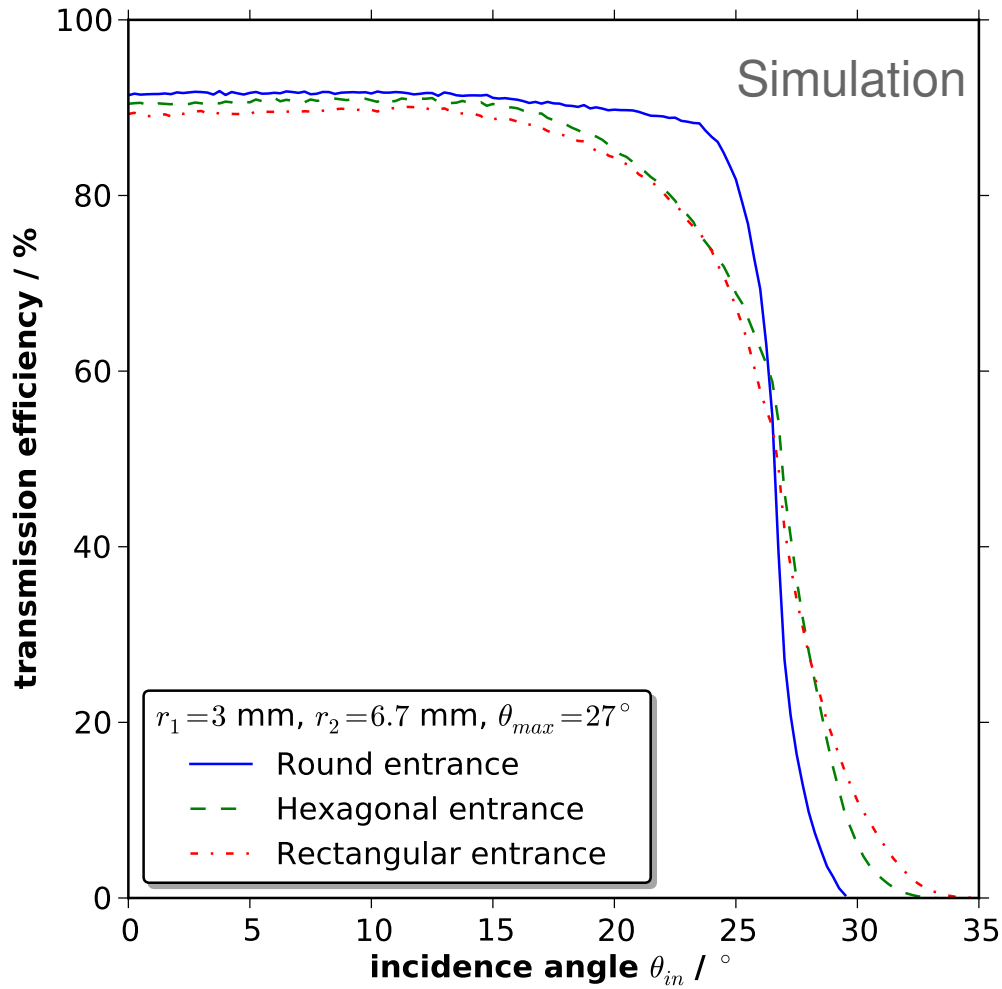


- Transmission efficiency of the Fresnel lens $\approx 80\,\%$
- Transmission efficiency of the system w/o SiPMs $\approx 80\,\% \cdot 69\,\% = 55\,\%$

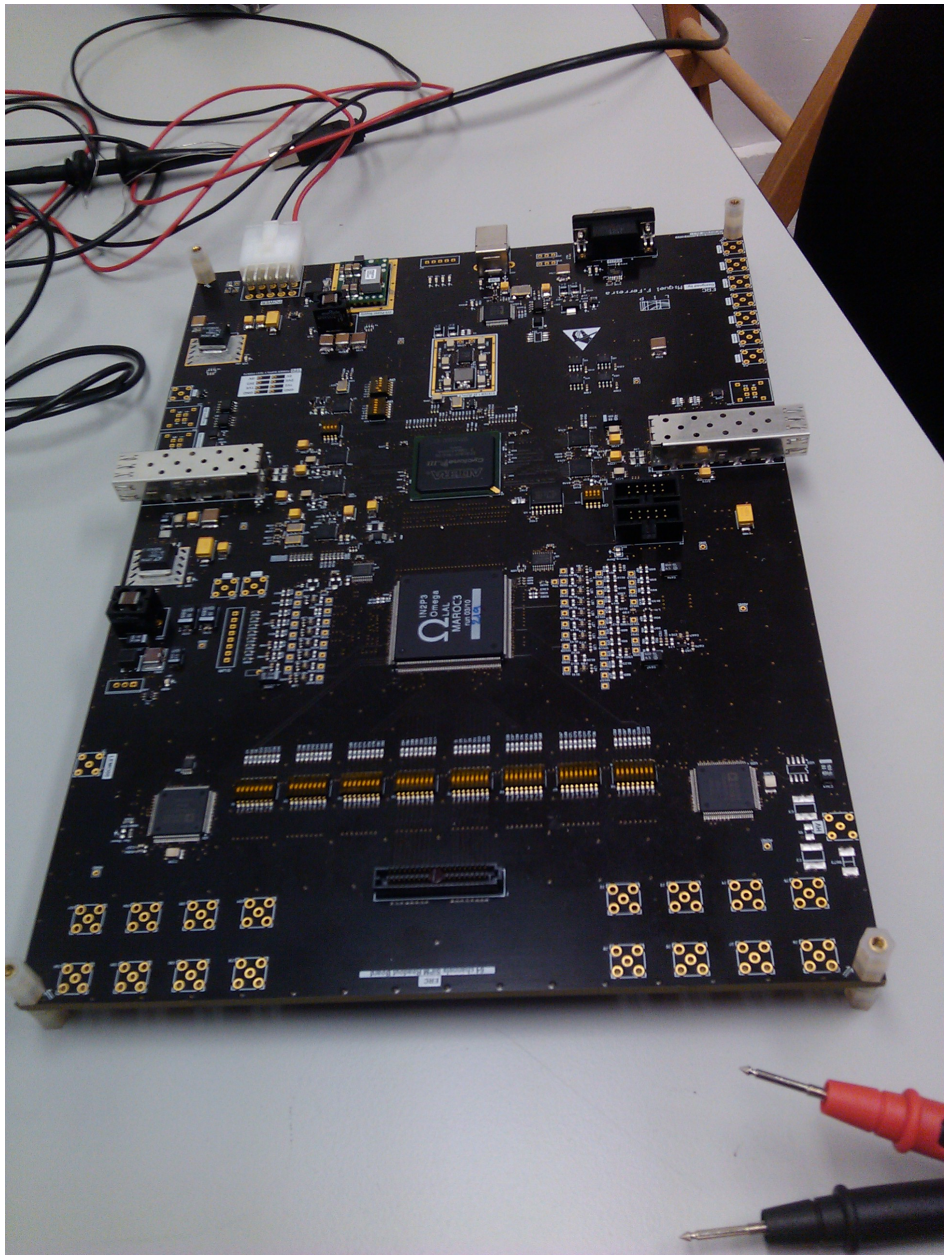
Light Funnel: Winston Cone

- Entrance radius $r_1 = 6.7\,\text{mm}$
- Exit radius $r_2 = 3\,\text{mm}$
- Maximum allowed incidence angle $\theta_{max} = 27\,°$
- Polished aluminum (reflectivity studied in Aachen)
- Successful production in Aachen & Lisbon





Readout Electronics

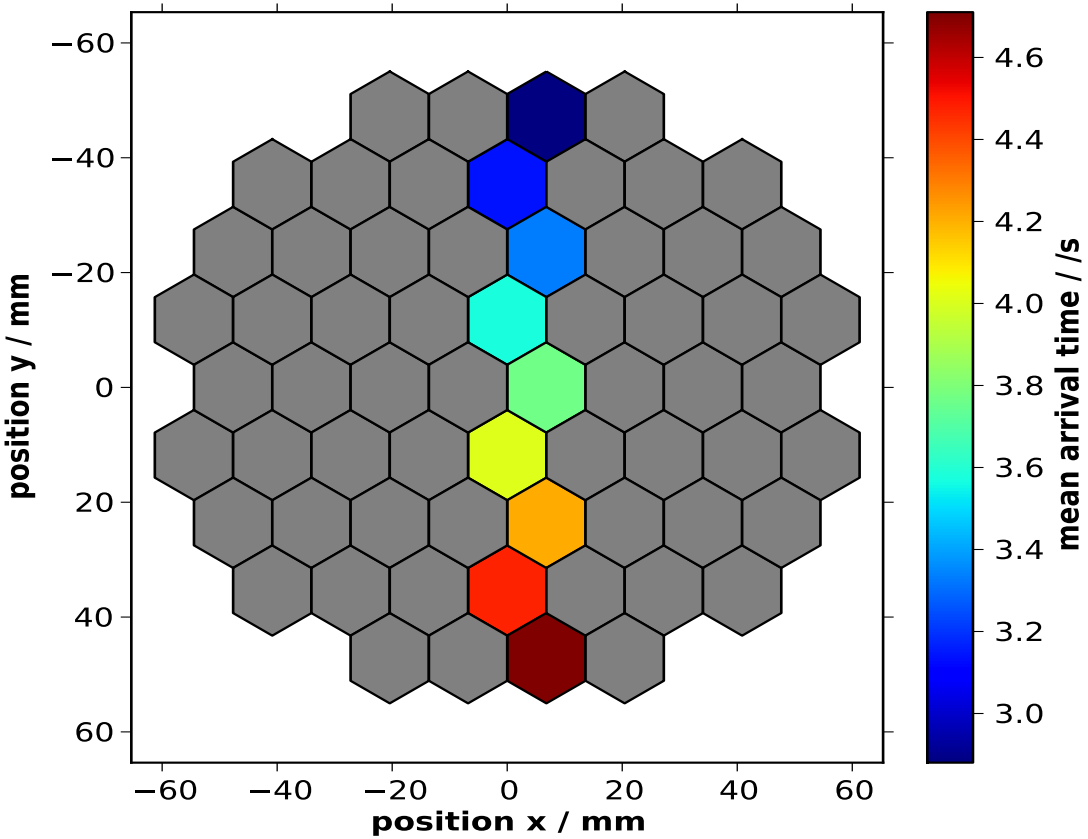


- Readout electronics developed by LIP
- Based on MAROC3 chip
- 64 channels with two discriminators each
- ADCs for charge digitization
- Individiual bias voltage control for each of the 64 SiPMs
- FPGA for digital signal processing including triggers

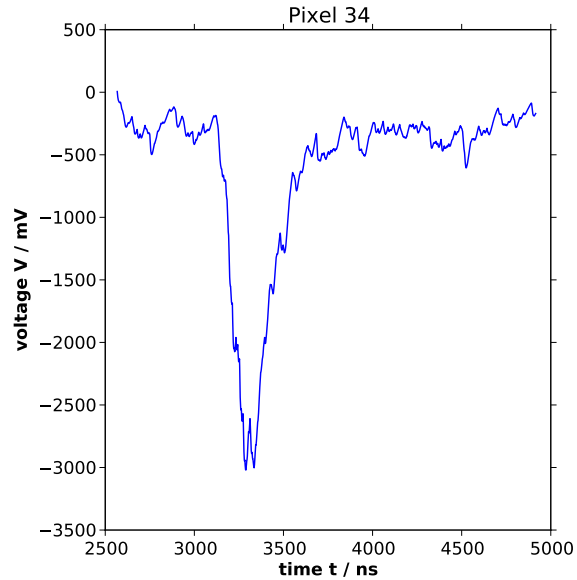
- Electronics currently beeing tested and development of firmware started

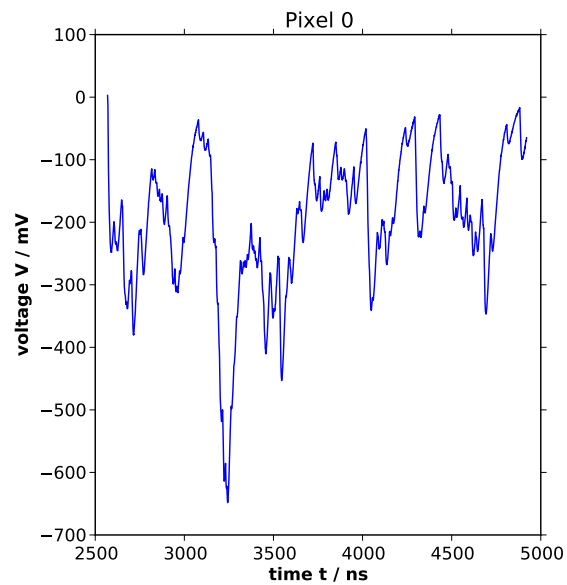
Full Detector Simulation

- CONEX air shower simulation
- Geant4 for raytracing and response simulation
- G4SiPM: dedicated SiPM simulation developed by our Auger & CMS groups in Aachen



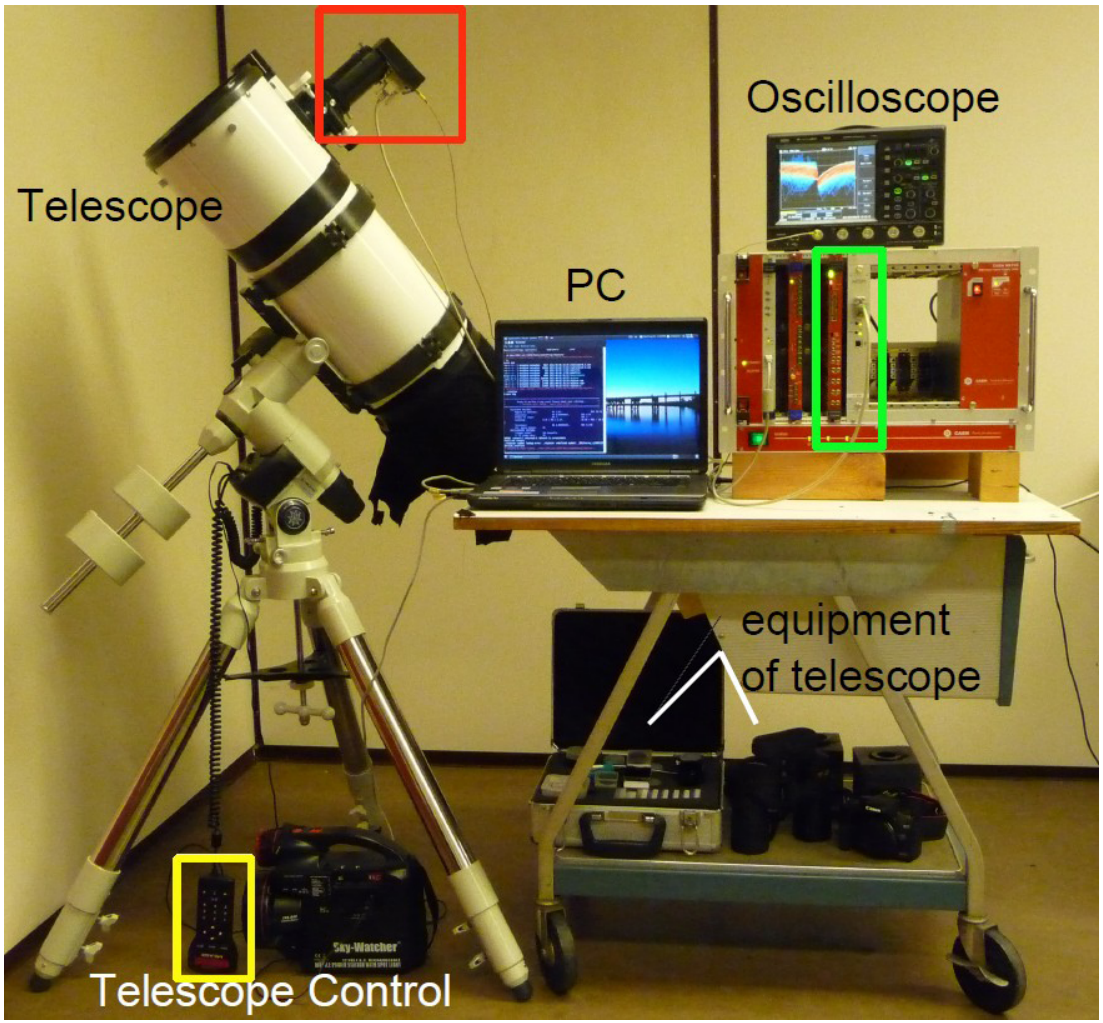
vertical $E = 10^{18}$ eV shower, 4 km distance

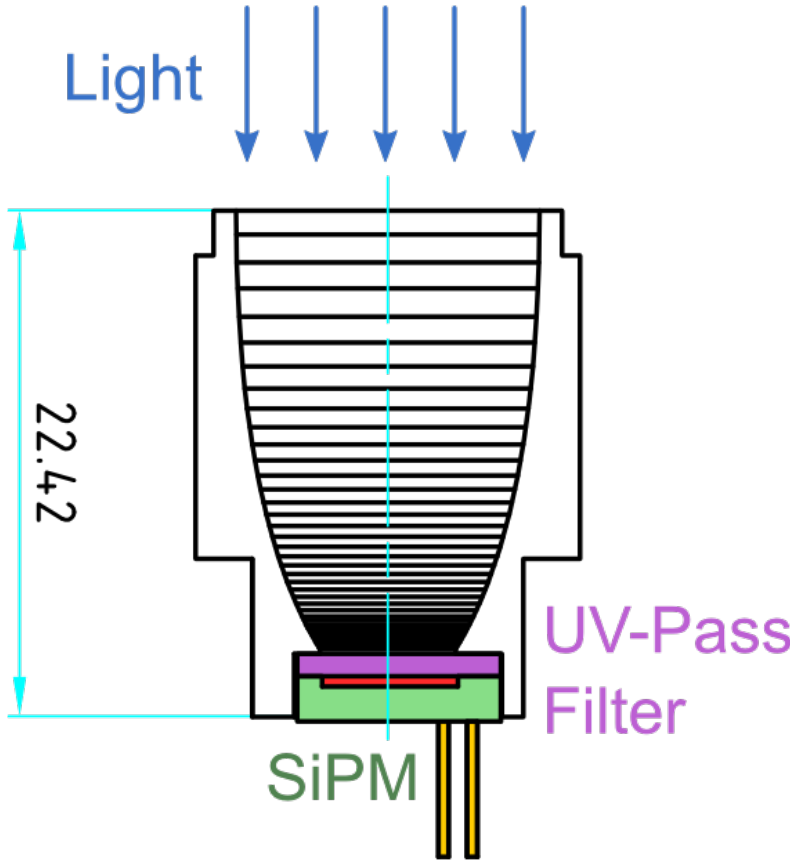




FAMOUS^{ONE} Setup

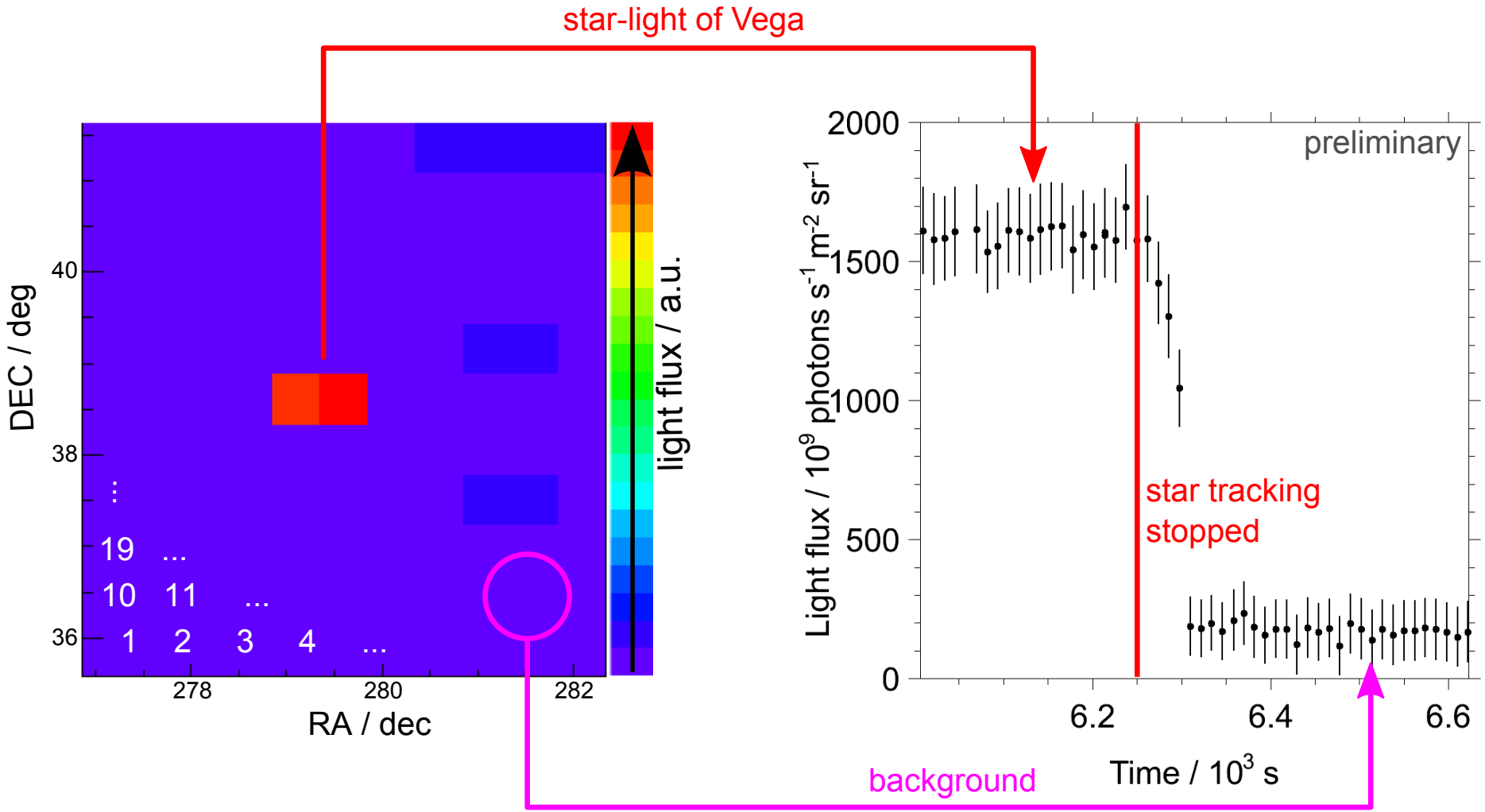
- Measure night-sky brightness
- Commercial Newton reflector ($D = 20\,\mathrm{cm},\ f/4$) with one single FAMOUS pixel





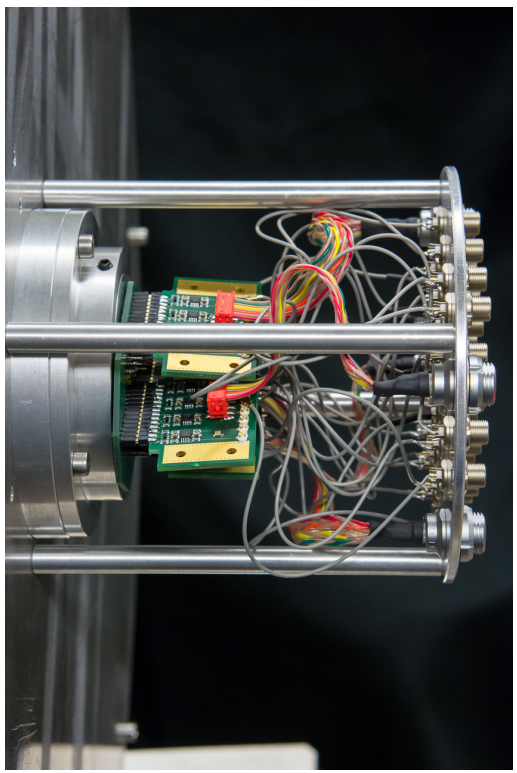
Sky Scan with FAMOUS^{ONE}

- Sky scan around Vega
- Field of view of a single measurement $\alpha_{\text{fov}} = (0.71 \pm 0.02)\,°$



- Night-sky background radiance (after UV pass filter) between $L \gtrsim 60\,\text{m}^{-2}\text{ns}^{-1}\text{sr}^{-1}$ (moonless) and $L \lesssim 450\,\text{m}^{-2}\text{ns}^{-1}\text{sr}^{-1}$ (full moon) in Aachen

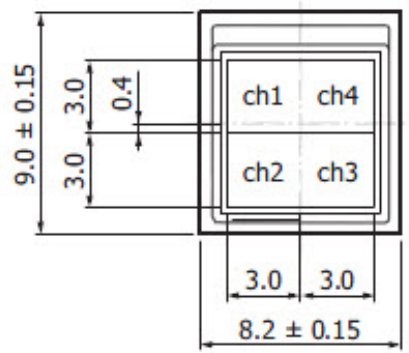
FAMOUS^{SEVEN}

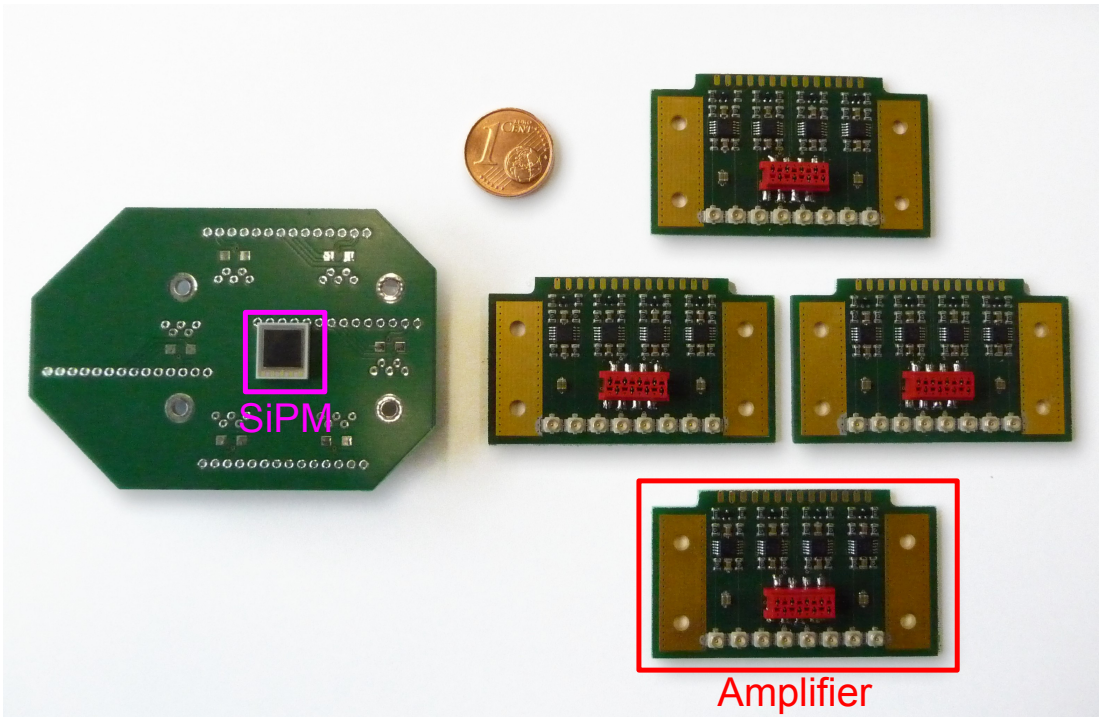


- Final baseline design of FAMOUS but with 7 pixels to test construction
- Modular design easily extendable to 64 pixels
- Made in Aachen's mechanical facility
- Mechanical design for 7 pixels fully constructed

FAMOUS^{SEVEN} Readout Electronics

- Amplifiers are attached perpendicularly to the SiPM breadboard
- Each of the four signals of the SiPM 2×2 array is processed separately
- Data acquisition and digitization with common NIM / VME hardware

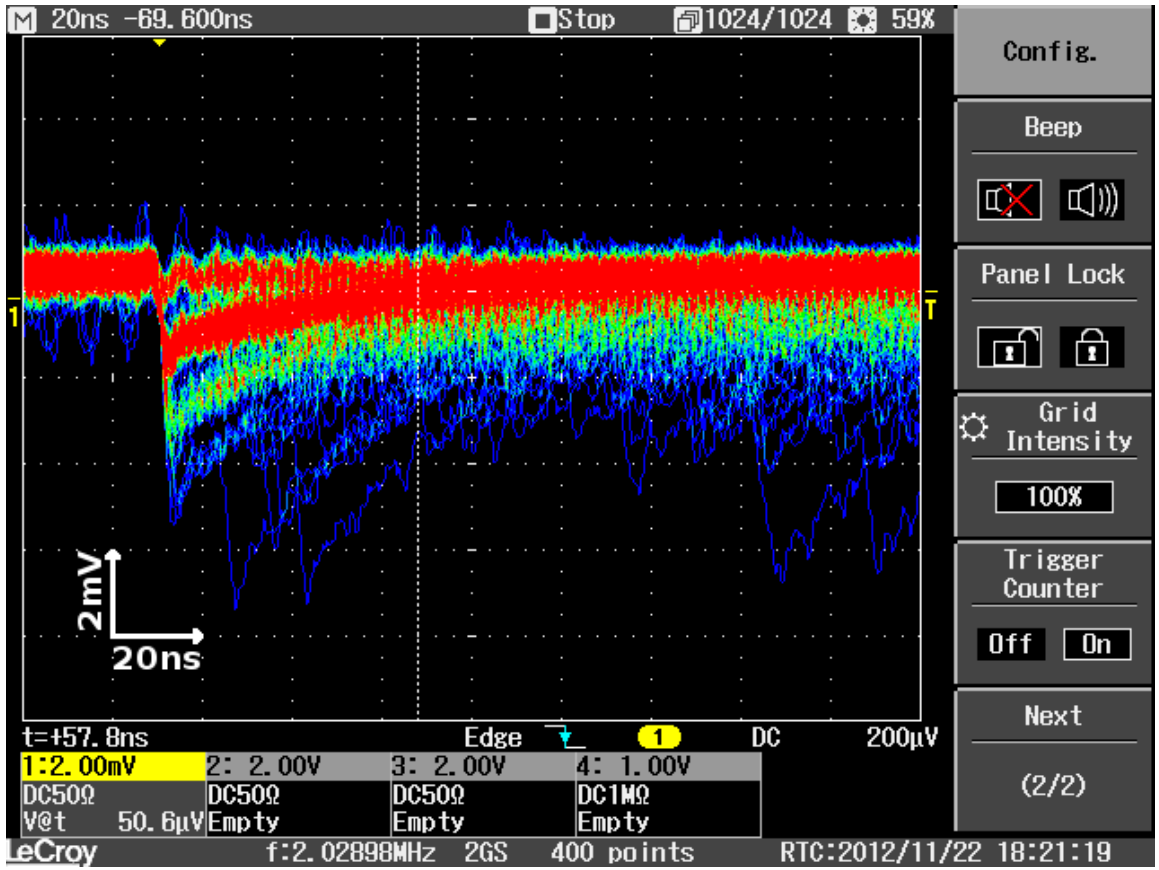




NIM Bias control unit

First Darknoise Measurements

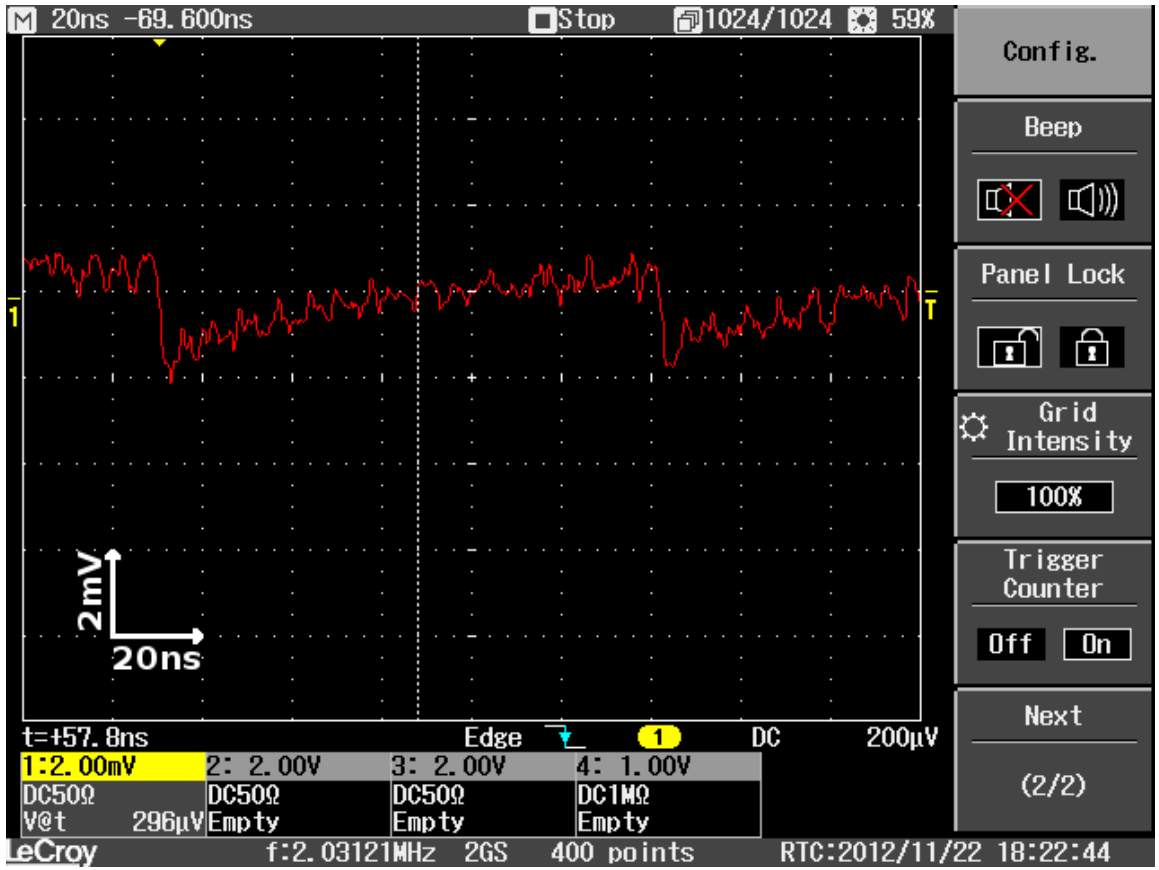
Oscilloscope Reading



- 1, 2 & 3 photon equivalent pulses clearly visible
- Baseline noise smaller than 1 p.e. pulse
- Dynamic range currently limited by amplifiers to 500 p.e.

First Darknoise Measurements

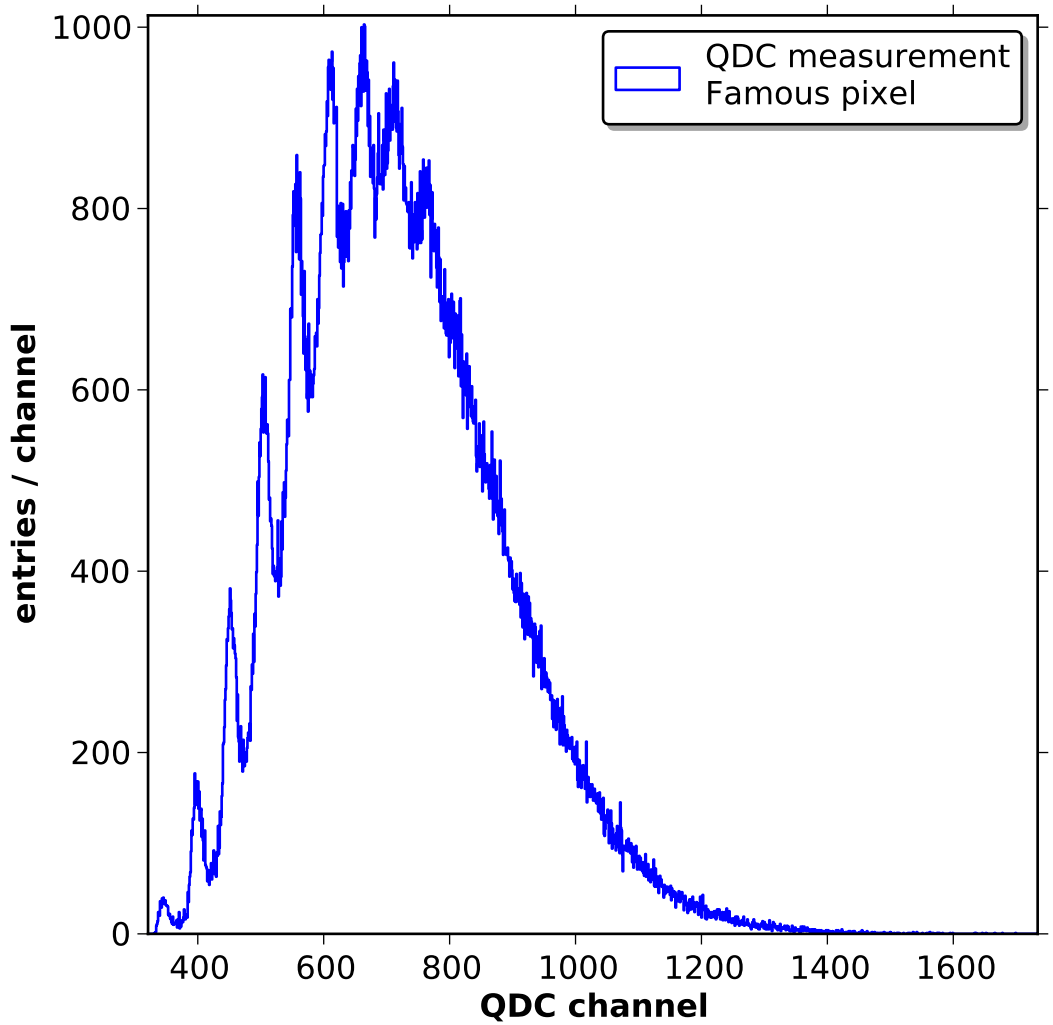
Oscilloscope Reading



- 1, 2 & 3 photon equivalent pulses clearly visible
- Baseline noise smaller than 1 p.e. pulse
- Dynamic range currently limited by amplifiers to 500 p.e.

First Light Measurements

- Charge Spectrum of a measurement with a pulsed UV LED



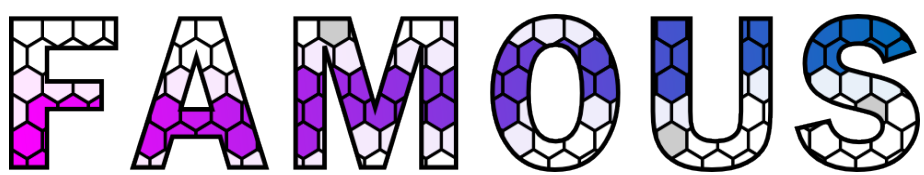
- QDC spectra with single photon resolution possible

Summary

- **FAMOUS** = small fluorescence telescope prototype with **silicon photomultipliers**
- Simple refractive telescope, up to 64 pixels
- Full detector simulation to evaluate performance
- Dedicated and cross-checked SiPM simulation G4SiPM (journal paper & public release in preparation)
- Telescope with seven pixels fully assembled
- Electronics for upgrade to 64 pixels currently being programed

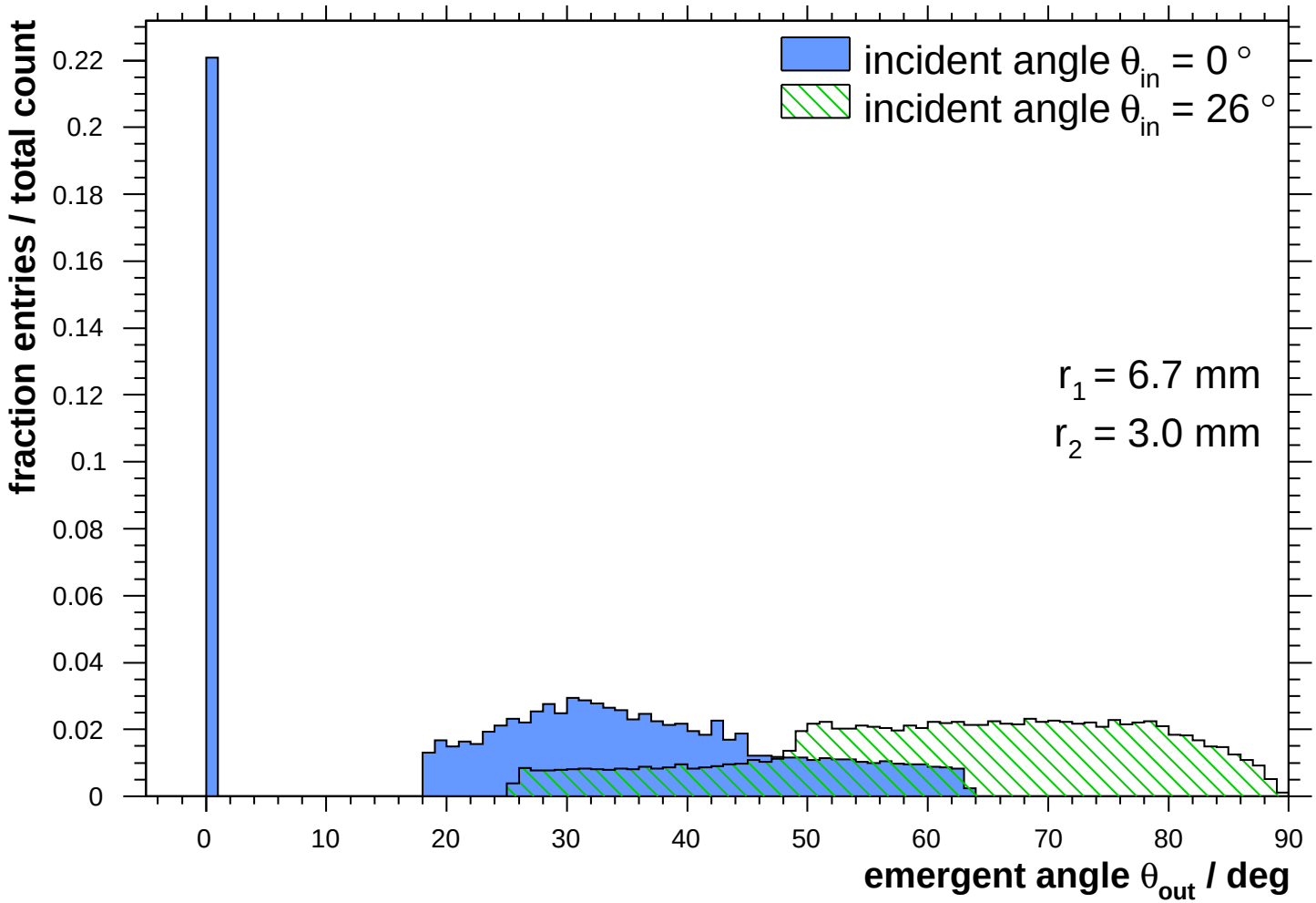
Outlook

- Star tracking with FAMOUS$^{\text{SEVEN}}$
- DAQ interface for FAMOUS (Bachelor thesis starting in April)
- Flat-fielding and focus check of FAMOUS$^{\text{SEVEN}}$ (Master thesis in progress)
- Study designs and applications beyond FAMOUS (Master thesis in progress)
- Upgrade to 64 pixels

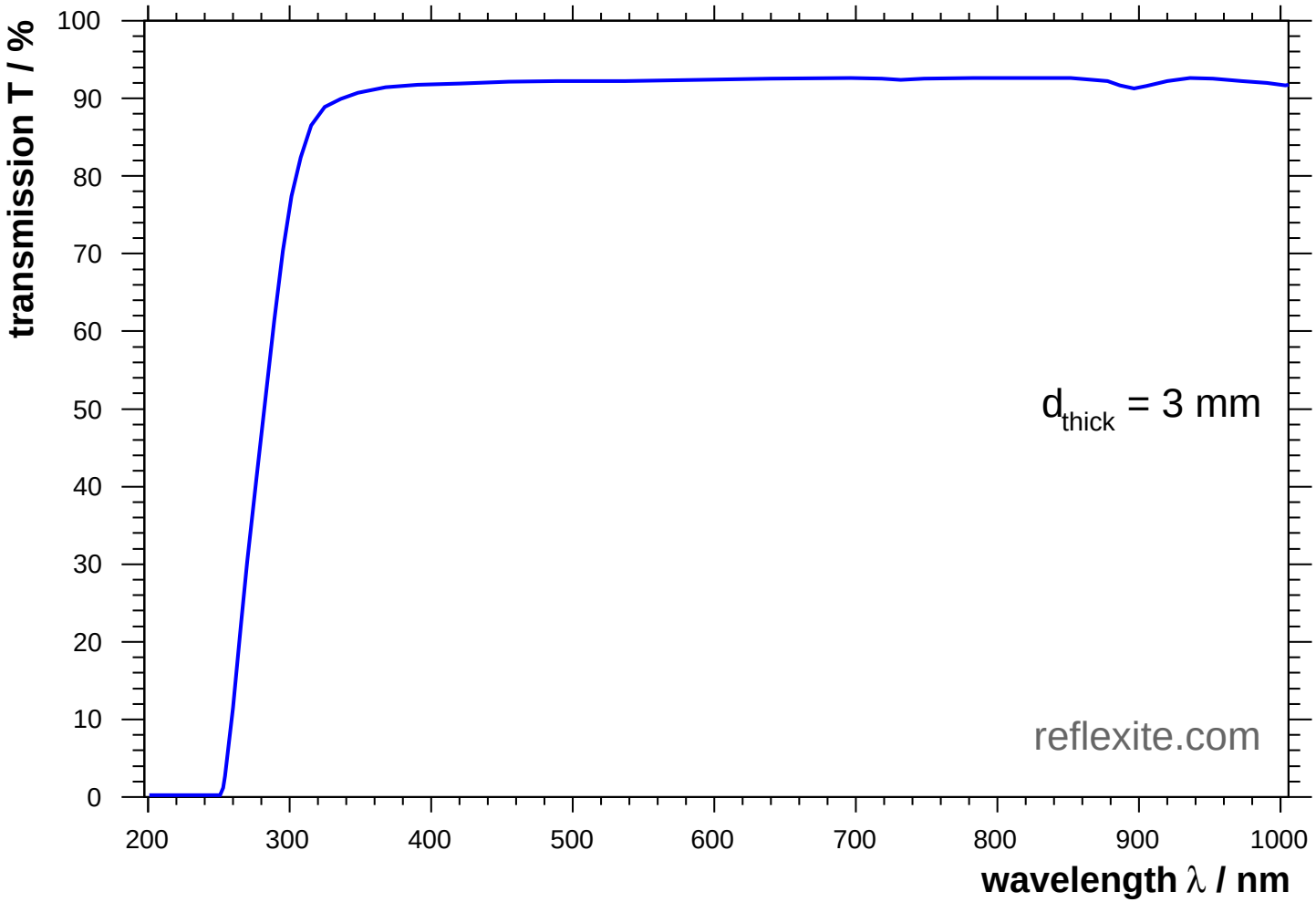


Backup

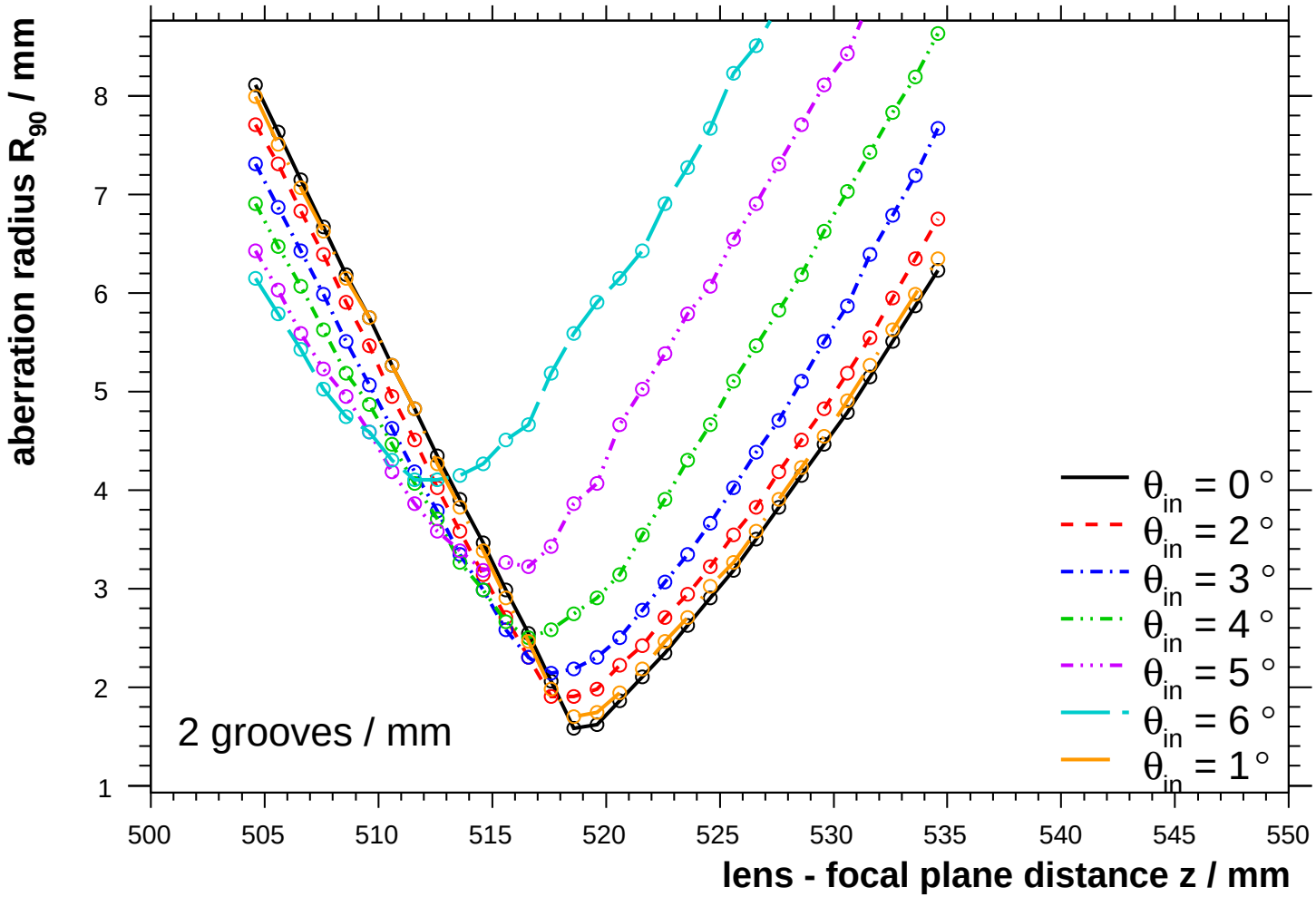
Exit Angles of the Winston Cone



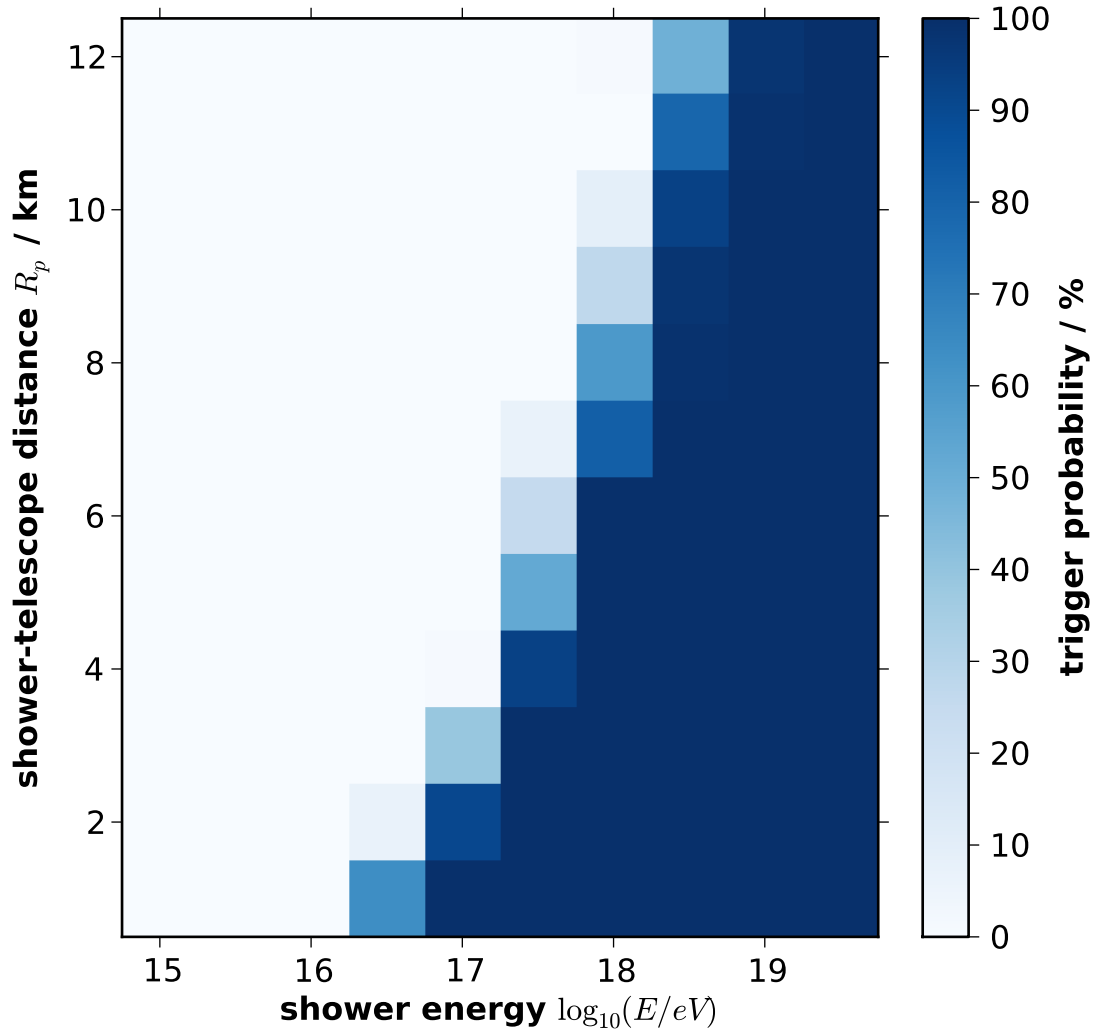
Transmission Efficiency of PMMA



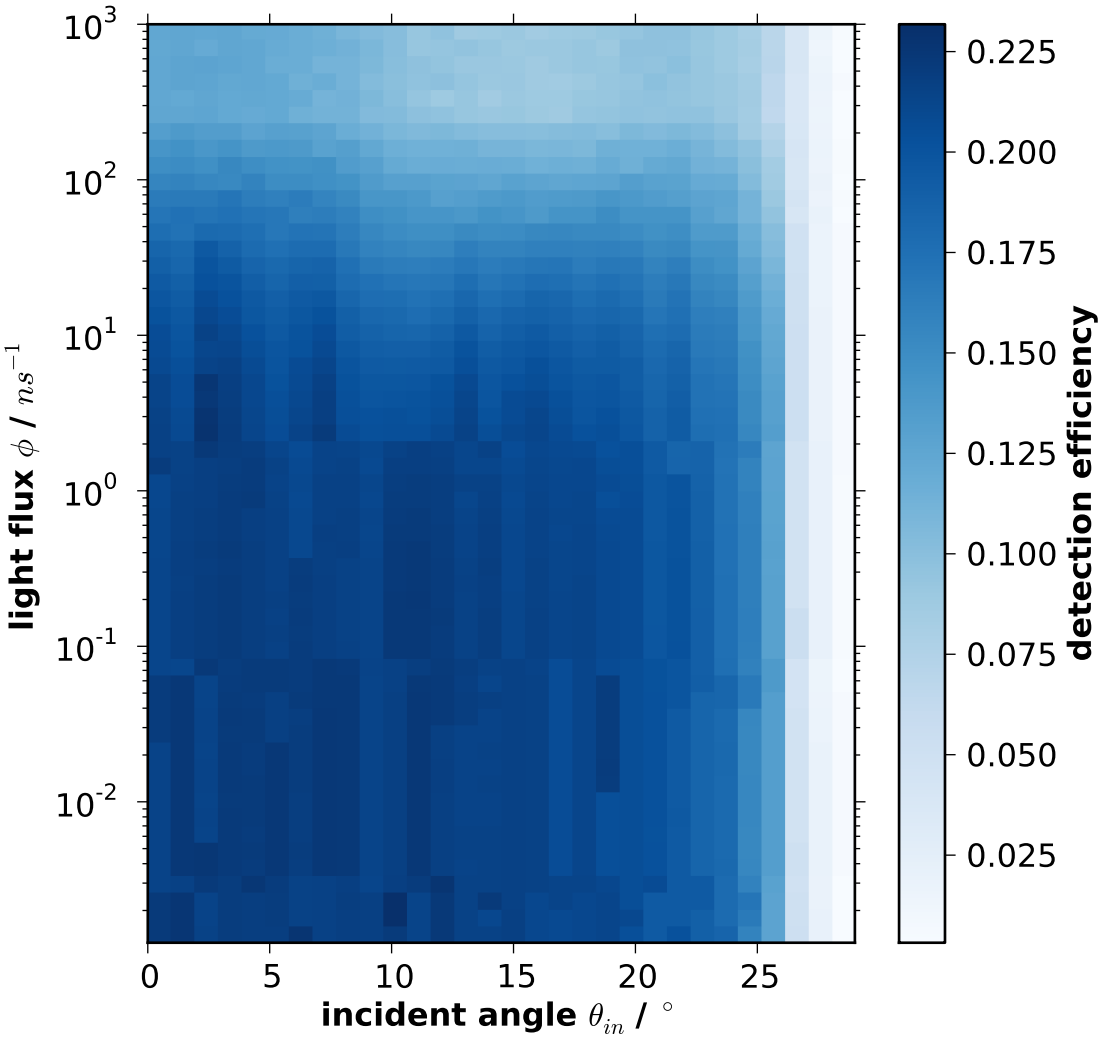
Aberration Radius R_{90} of the Fresnel Lens



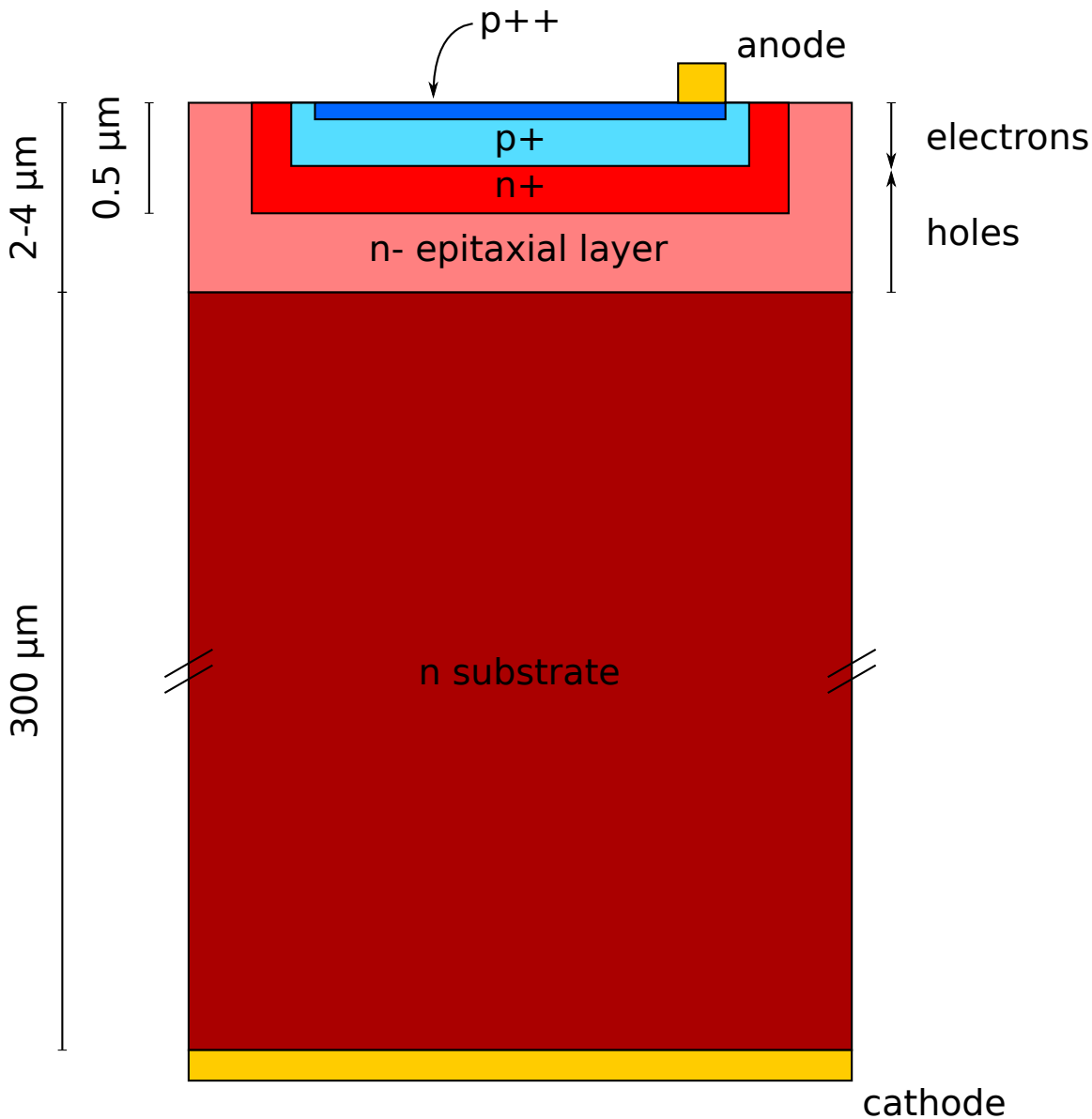
Trigger Efficiency of FAMOUS



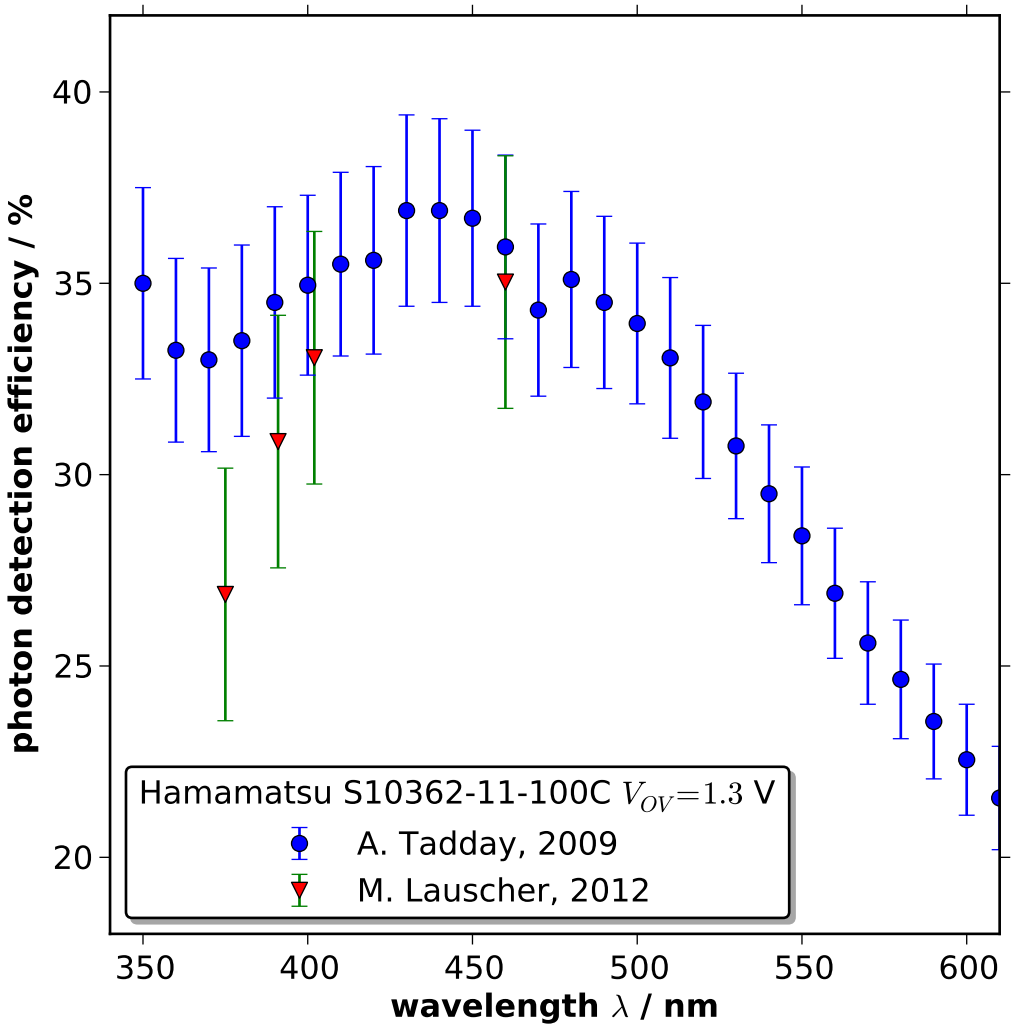
PDE of a pixel of FAMOUS (Winston cone + Hamamatsu S10985-100C SiPM)



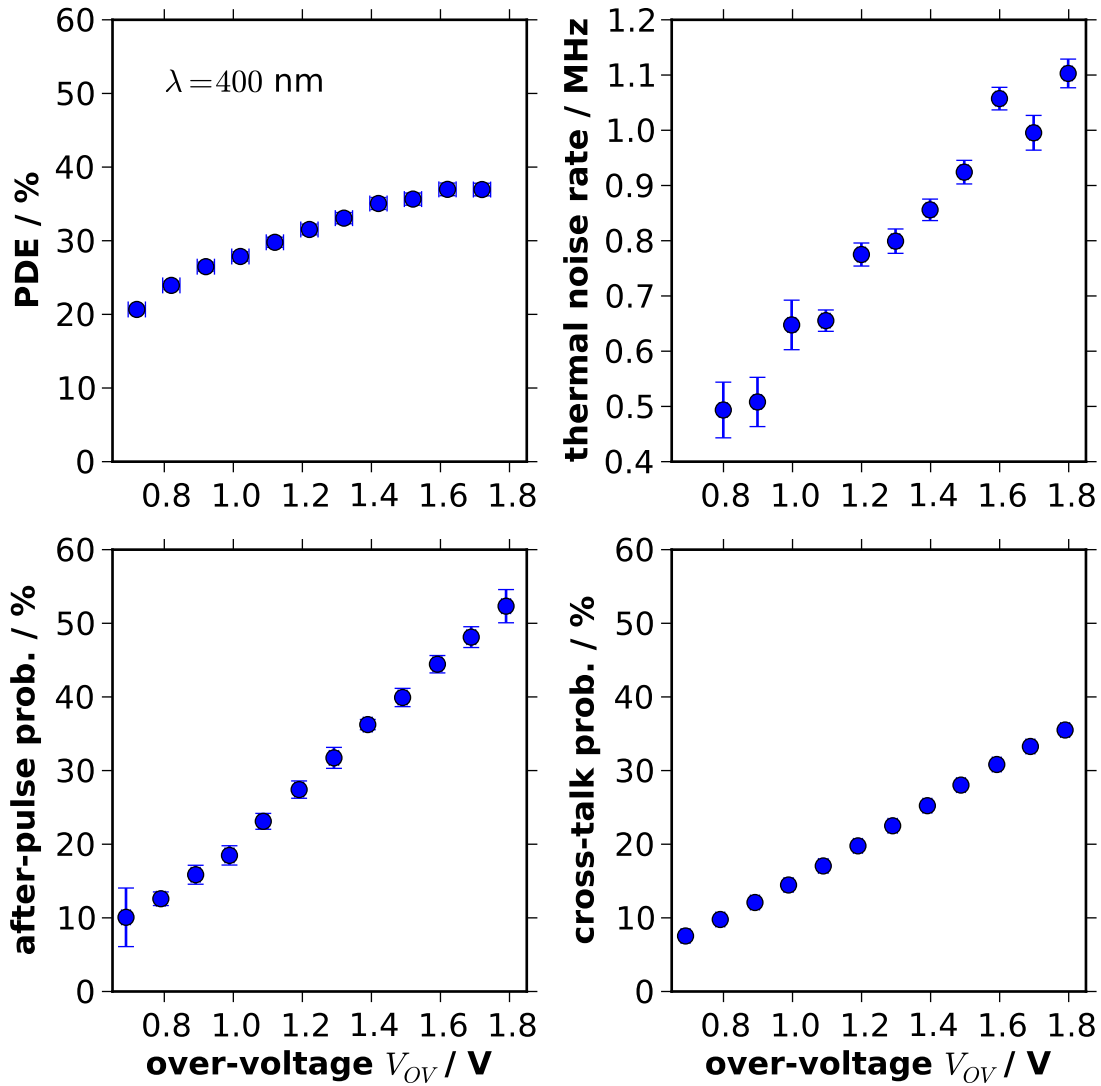
Geiger-mode Avalanche Photodiode



Photon Detection Efficiency of the Hamamatsu S10362-11-100C



Overvoltage Dependency of the Hamamatsu S10362-11-100C



UG-11 Transmission