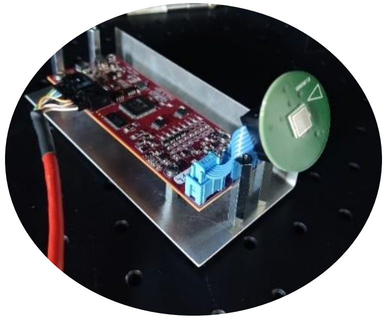
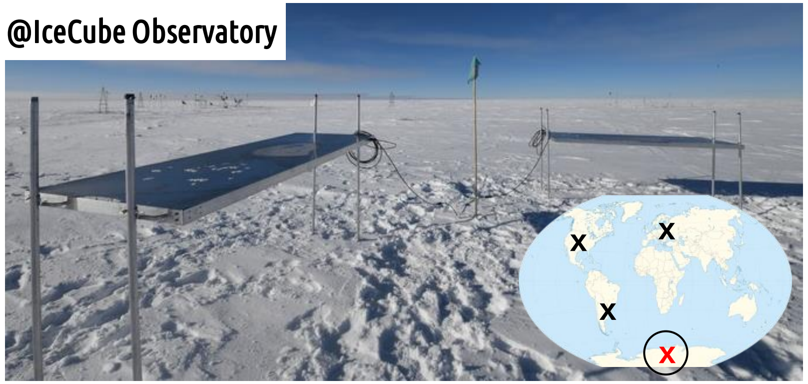
Karlsruhe Institute of Technology



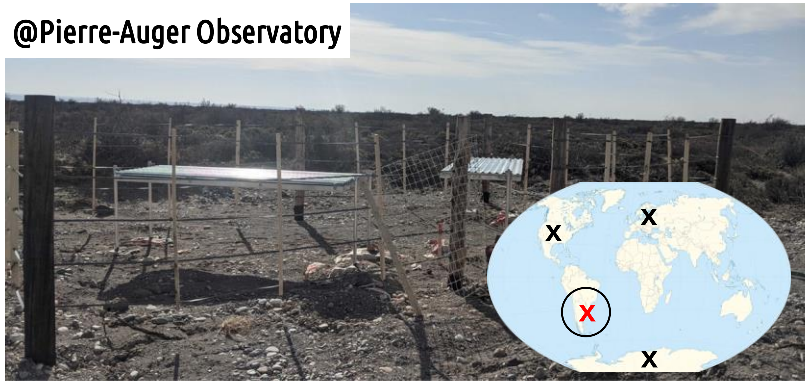
(SiPM-) Scintillation detectors, their readout electronics and calibration

Thomas Huber (KIT – IAP)

@IceCube Observatory

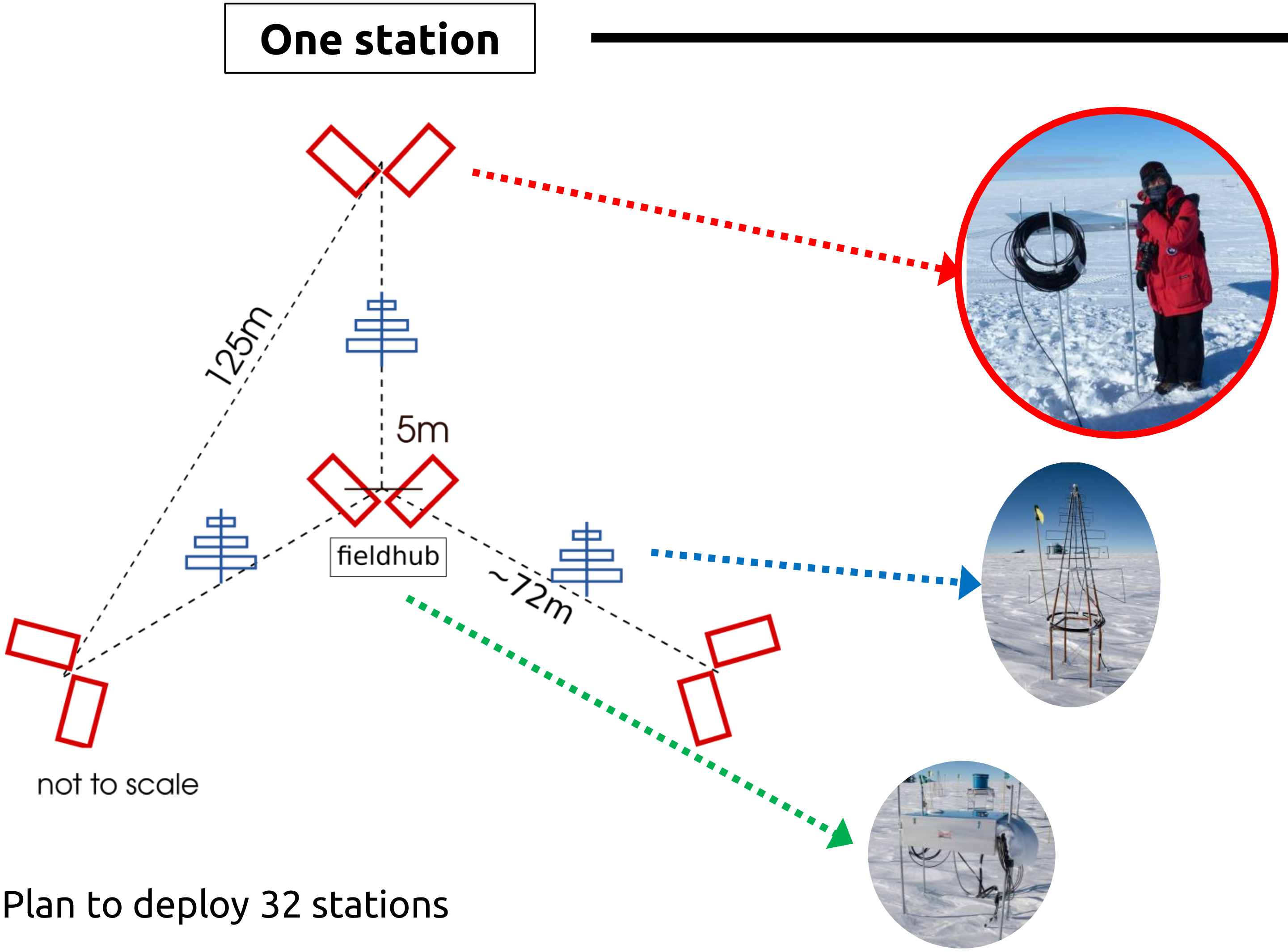


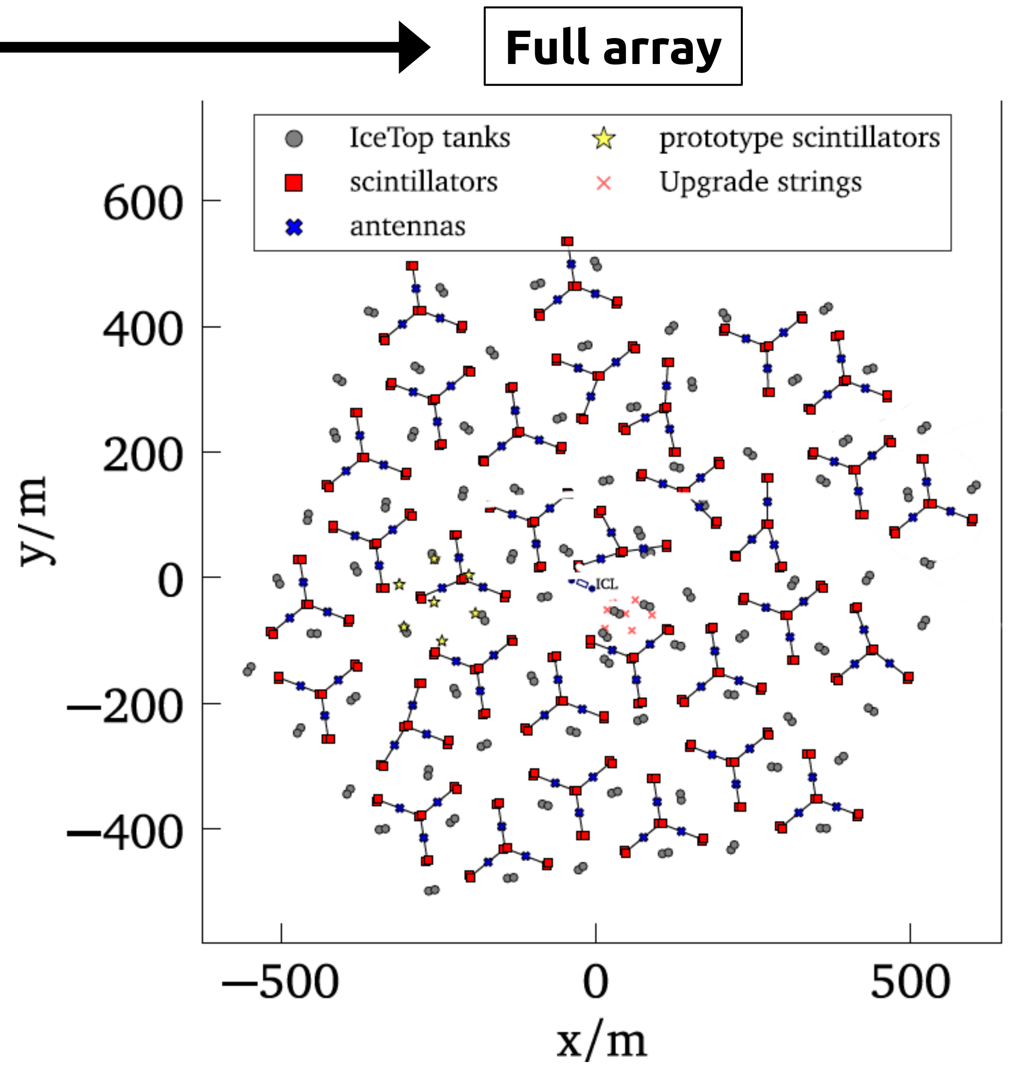
@Pierre-Auger Observatory



@Telescope Array

The IceTop surface enhancement scintillators





Plan to deploy 32 stations

- with 8 scintillation detectors, 3 radio antennas and a stations DAQ fieldhub each
- within the IceTop footprint

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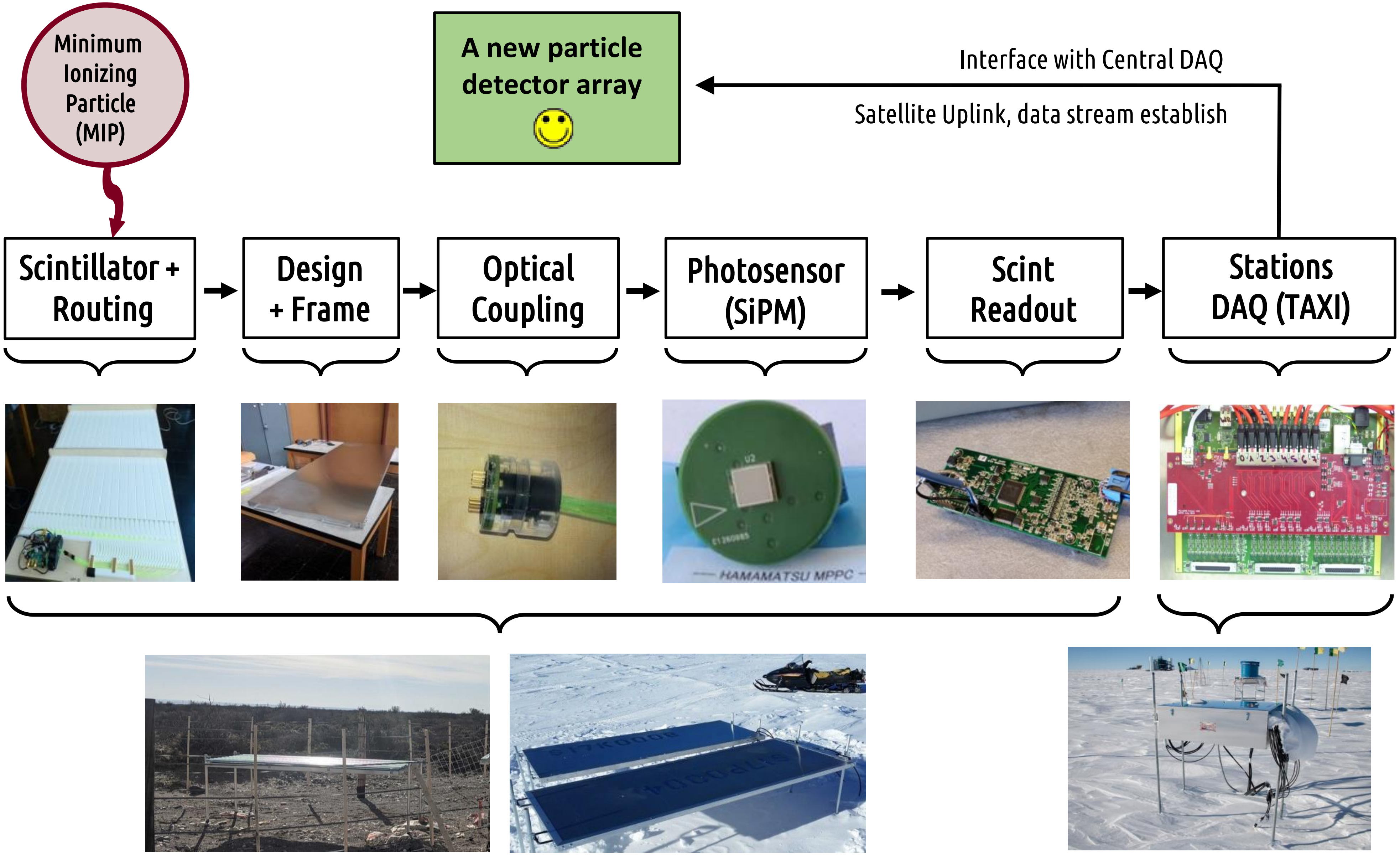
Overview: IceCube Scintillation detectors



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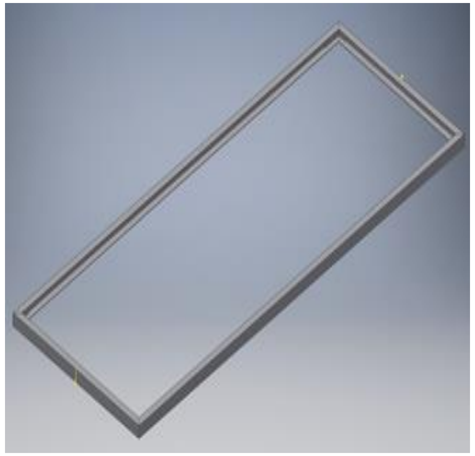
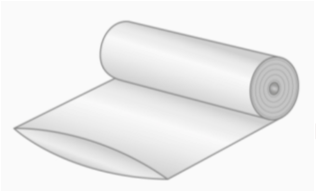
Production idea of the scintillators

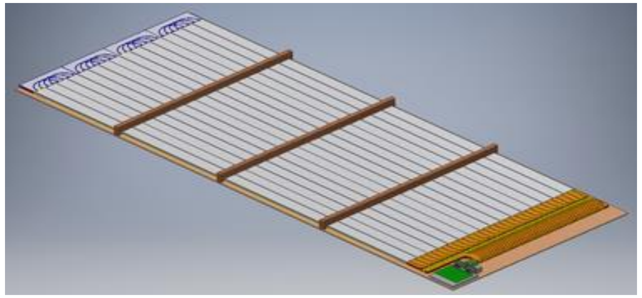
Splitting the production into two parts:



Frame / "housing"



Tube film (black)



Scintillation detector / "inlay"

Welded

+

Air evacuated

"Finished" detector

(Half) tube film:

- Electrostatic discharge film up to 10^3 Ohm (ESD)
- Material: Polyethylen LD
- 0,150mm thick

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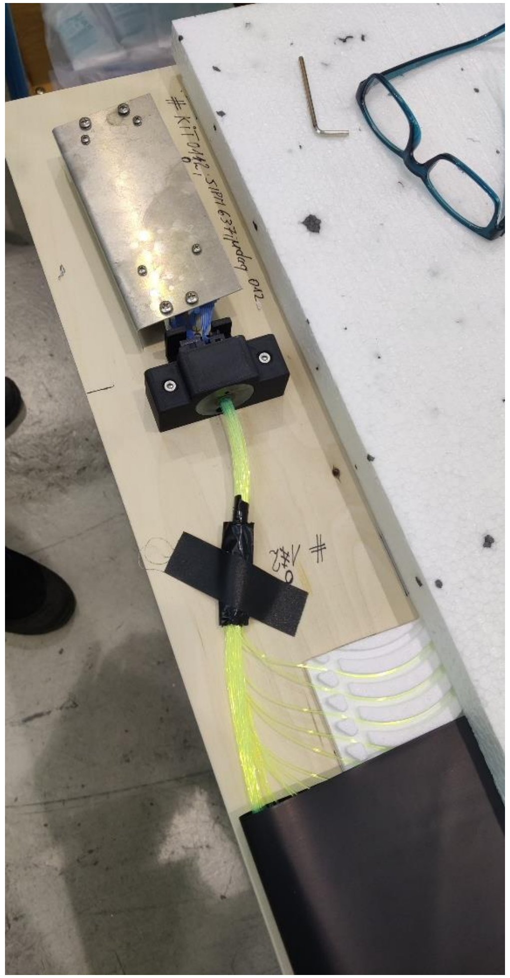
Production of the scintillators at KIT

Production of the housings

Detector inlay without routing

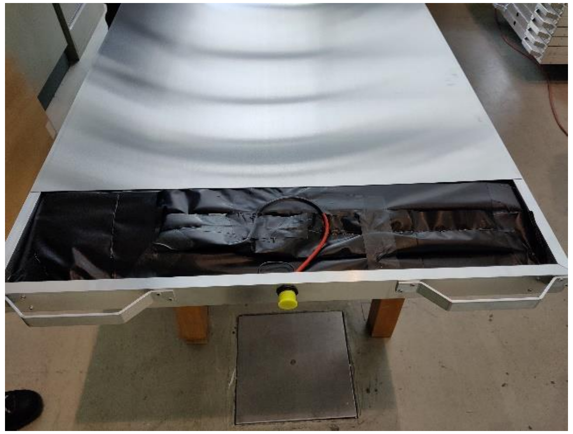
Installation of uDAQ readout



uDAQ, Cookie, Fiber, Routing

Assembling optical coupling

Placing the inlay into the housing



(Close to) finished detector

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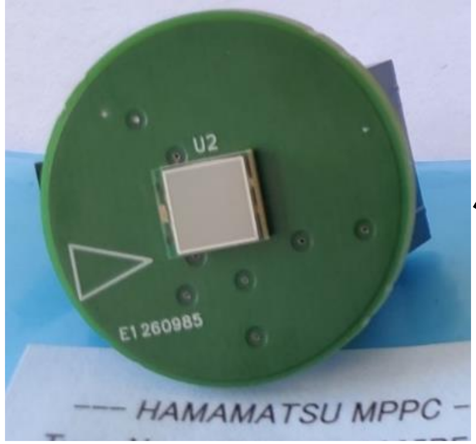
Optical coupling: Wavelength-shifting fiber <-> SiPM

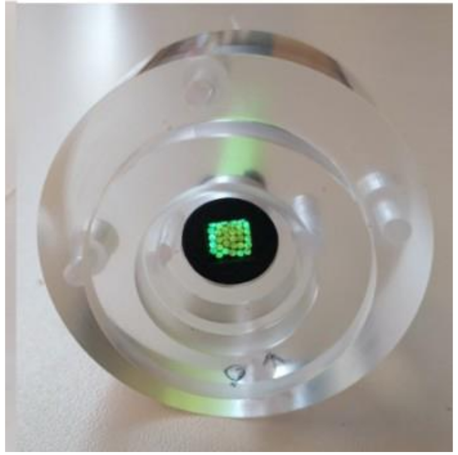
Primary goal of the optical coupling:

- Keeping the single detectors uniform
- The possibility to illuminate all APDs of the SiPM by the optical fiber to increase the dynamic range

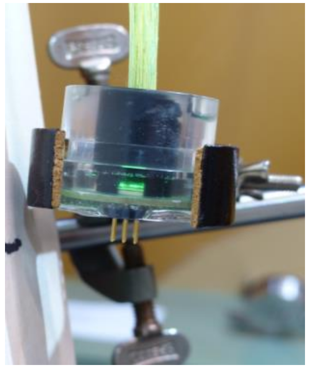


Cookie Board

Optical cement



Cookie



Optical fiber

Readout

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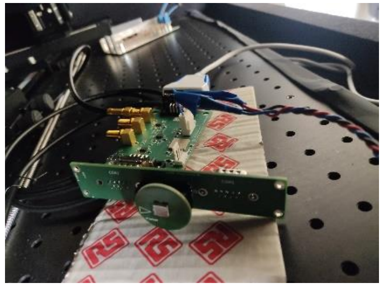
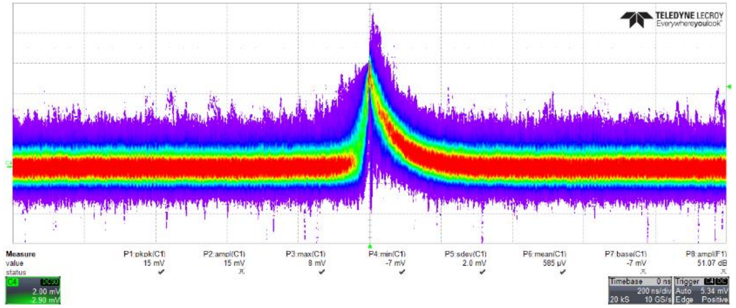
Examples of functional tests during prototyping

Functional tests by checking the waveforms of the SiPM

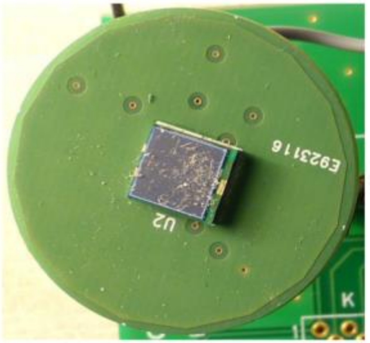
Aka: “Is there too much electronical noise at the cookie boards before gluing the cookie board to the optical fiber bundle ?”

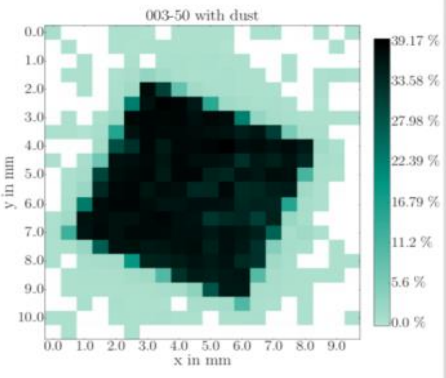




Effects of dust on the photosensitive SiPM area

Aka: “How much do we need to care about a visually clean surface before gluing the SiPM to the optical fiber bundle?



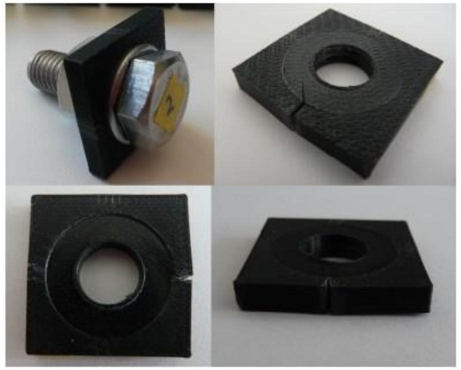


→ Photo Detection Efficiency (PDE)
lowered around 10% at the top right area

Low temperature stress tests of the used 3D printed components

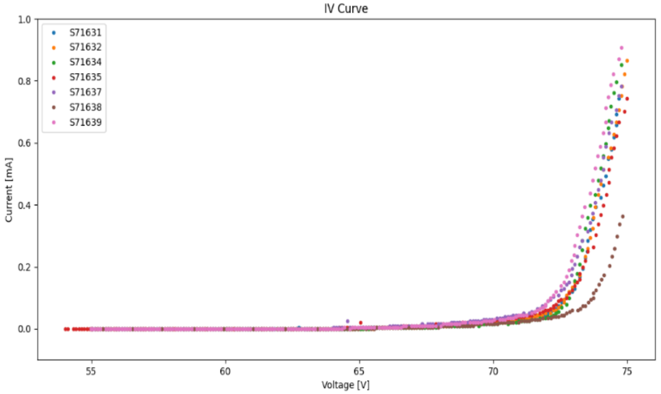
(and fibers, and scintillator bars, and and…)

Aka: “Will it break into 1000 pieces at -80°C?”



Checking the I-V curves of the Cookie Boards

Aka: “Is the SiPM capable to reach the avalanche region? What is the breakdown voltage of the SiPM?”



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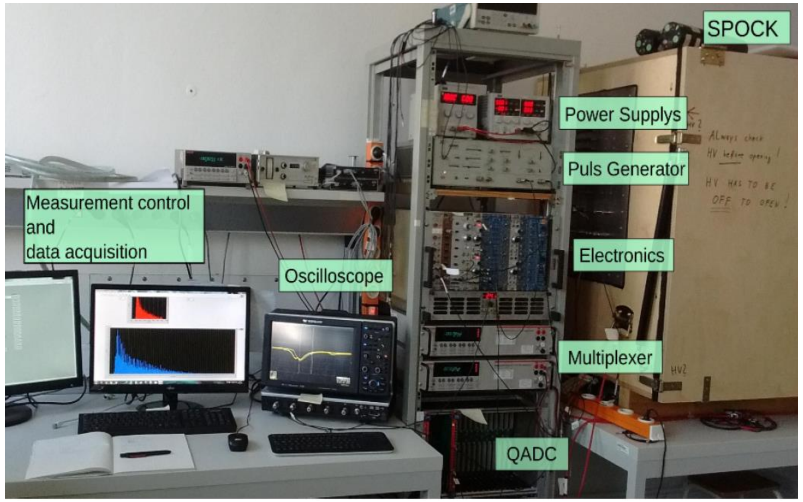
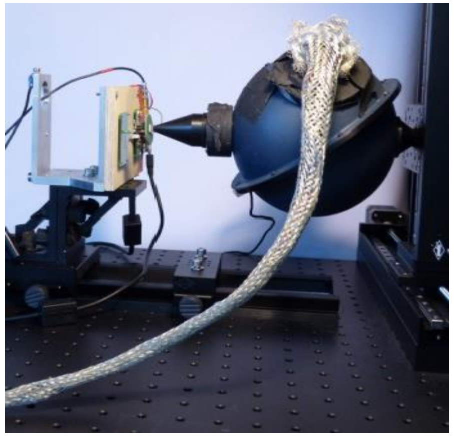
Examples of the SiPM photo-sensor calibration

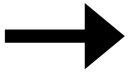
- **Functional tests** of electronic parts and its communication with the stations DAQ (TAXI)
- **Use of a calibration setup** to obtain the parameters of each SiPM cookie board before installation into the detectors

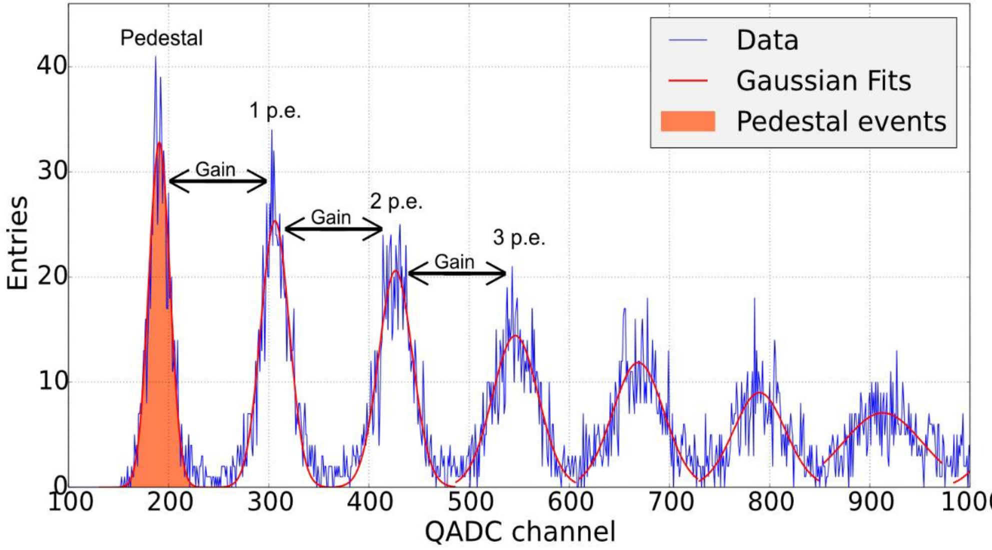


Single Photon Calibration Stand at KIT (SPOCK)

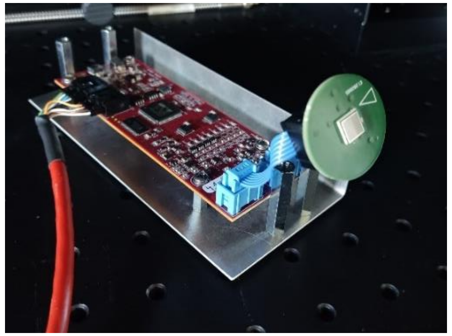


Inside of dark chamber





Finger spectra of a SiPM



Inside of dark chamber

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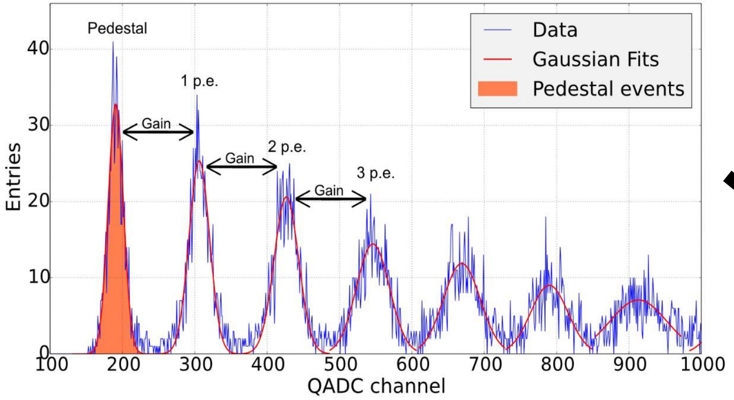
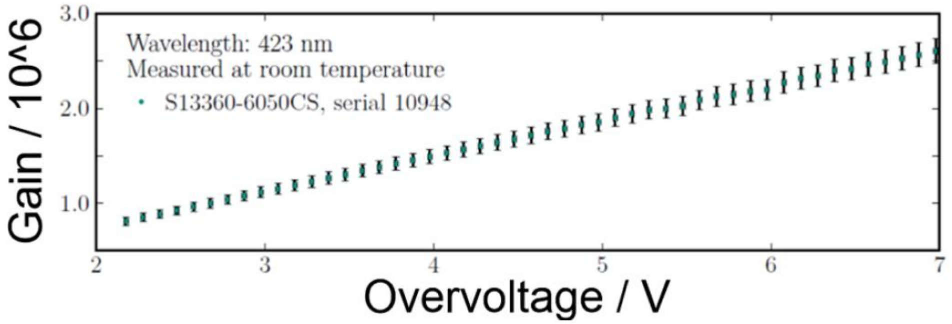
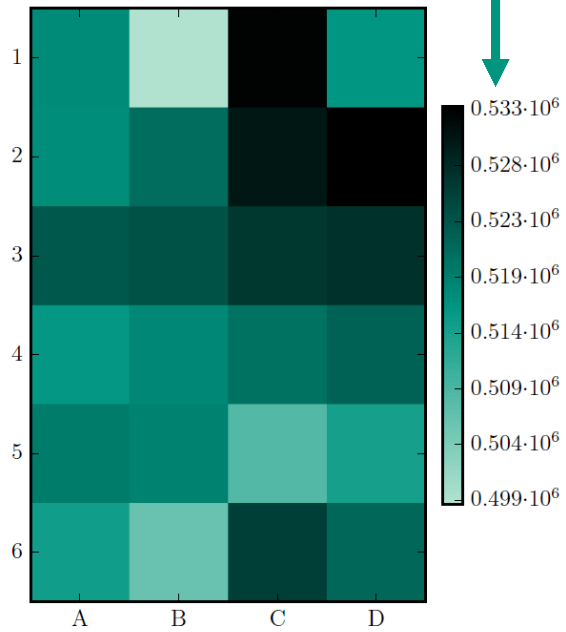
Example: SiPM gain at room temperature





One SiPM

2.2% variation



Variation of the SiPMs Gain of 24 SiPMs

→ Gain: To distinguish the charge deposit per MIP and to ensure an uniform detector array

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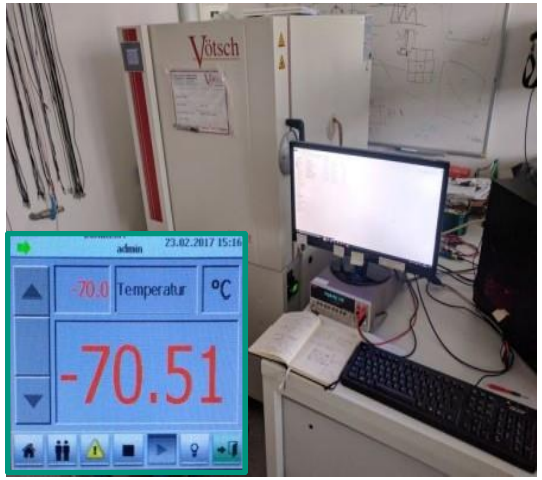
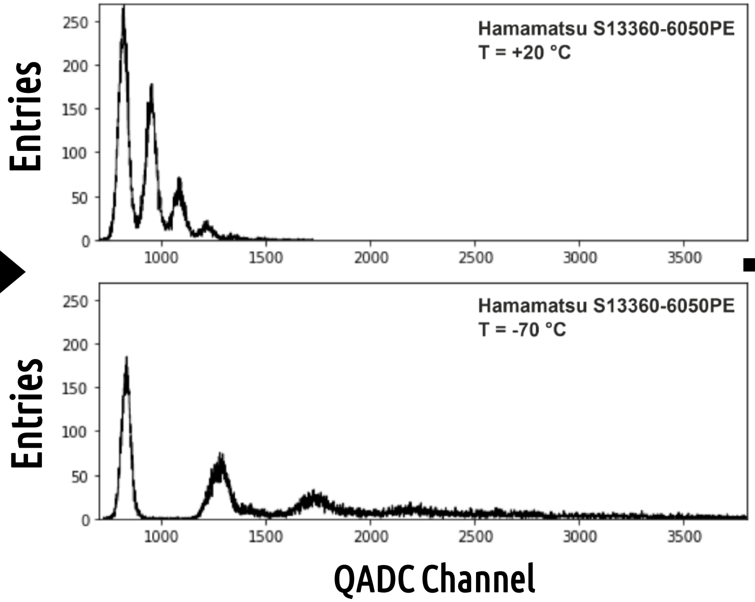
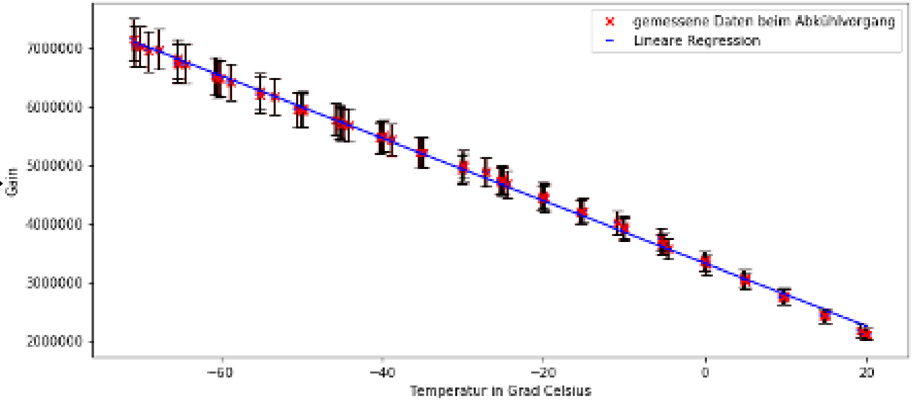
Example: SiPM gain at lower temperatures

- Low temperature tests of the electronical components (Cookie Board, uDAQ)
- SiPM calibration at different low temperatures







SiPM Gain vs. Temperature

→
The SiPM gain (and therefore the charge deposit to the DAQ at a MIP event) strongly depends on the temperature

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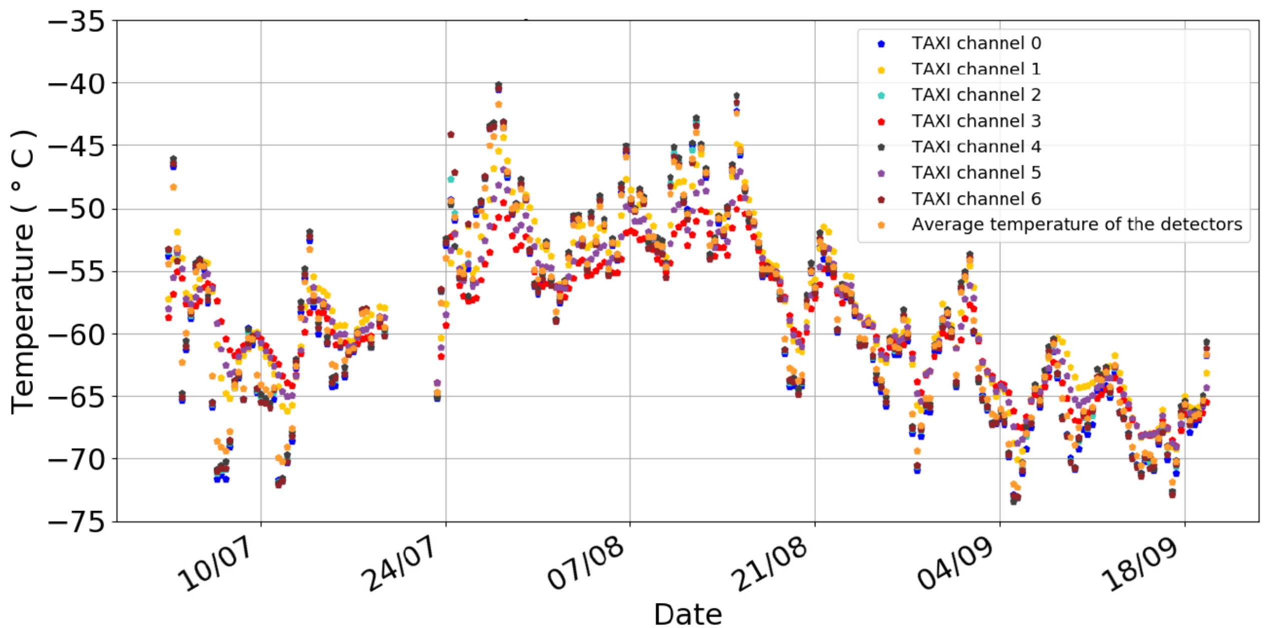
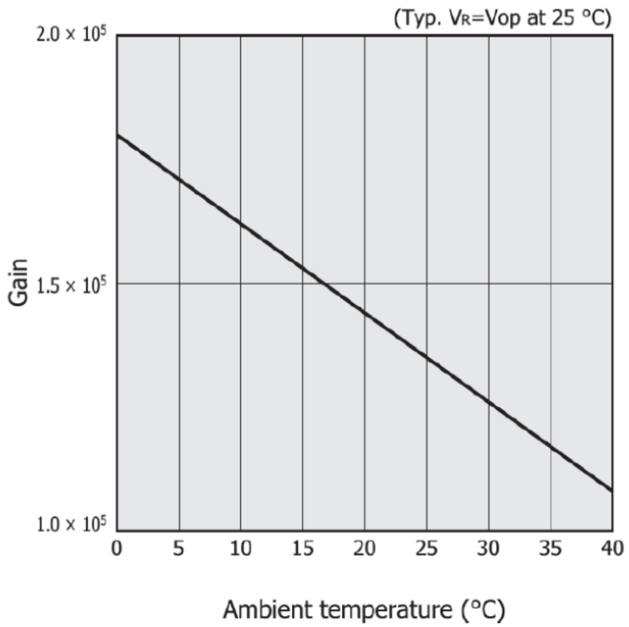
In-detector temperature fluctuations at the Pole



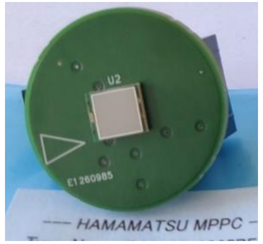
Temperature at the South Pole measured with Prototype station Scint panels

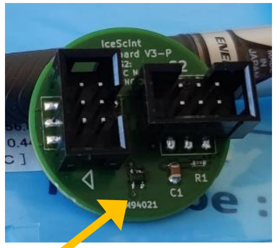


Hamamatsu SiPM data sheet

Example Control loop for one scintillation detector

$$U_{Panel\ 002_{(T)}} = 56.89V - 0.022\,\frac{V}{^\circ\mathrm{C}} \cdot \left(25^\circ\mathrm{C} - \frac{43562 - T_{dec}}{209}\right)$$





Temp. Sensor

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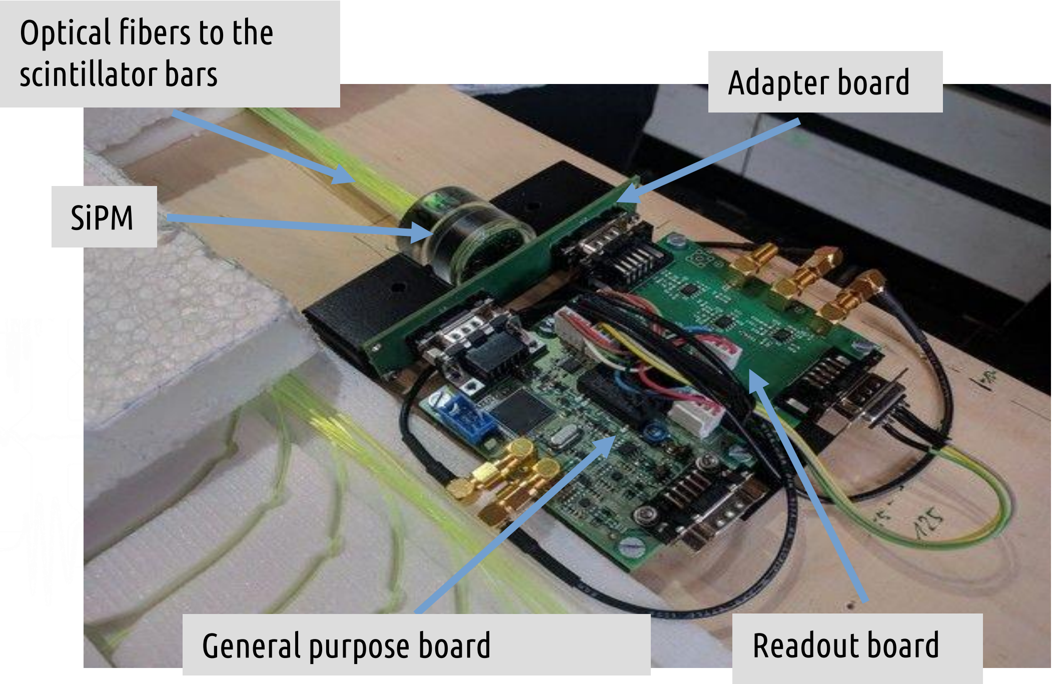
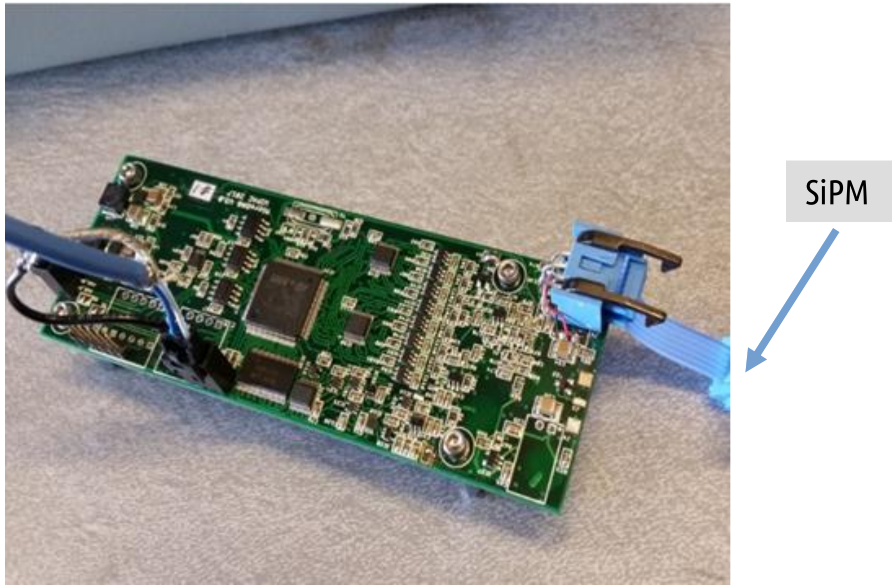
Two standalone one-channel SiPM front-end readouts developed





IceARM :

- **Waveform** readout of the SiPM
- High-/Medium-/Low- Gain (10x / 5x / 1x)
- Hamamatsu Power supply for the SiPM
- Temperature sensor next to the SiPM

Micro-DAQ :

- Transmission of the (signal integrated) **charge deposit**
- Cortex M4 32 bit microcontroller
- Three 12-bit ADCs
- SiPM temperature correction via Gain adjustment

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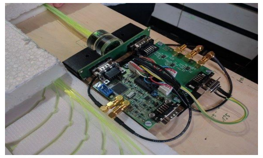
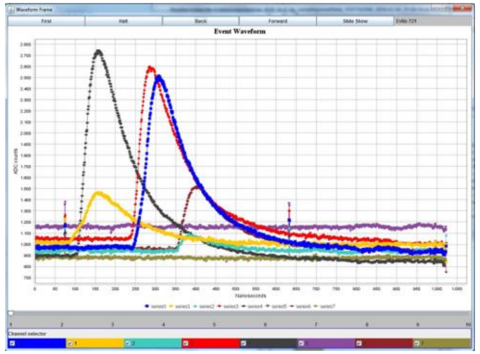
Two standalone one-channel SiPM front-end readouts developed

IceARM
Scint detectors :

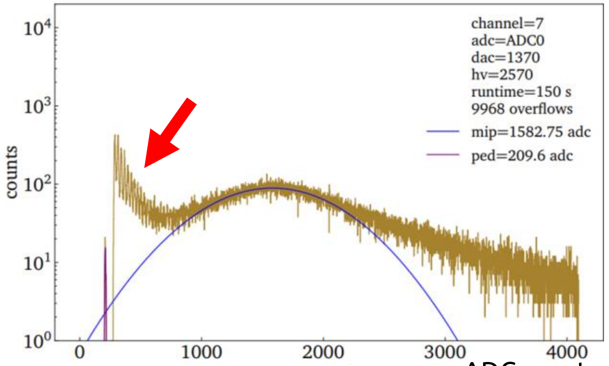




SiPM **waveforms** of 7x coincidence
- Air-Shower event

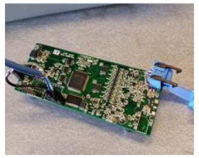
Main difference

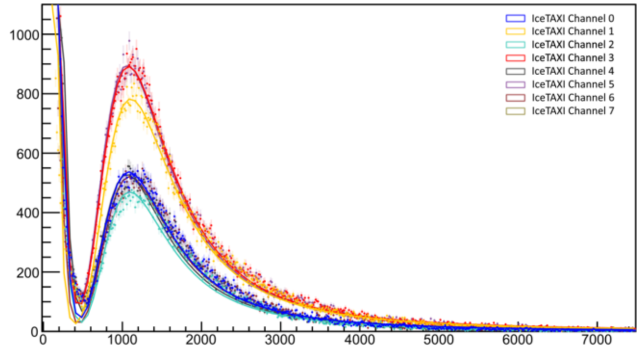
(Waveforms are transmitted
vs.
charge integration already in
the panel, no waveforms)



ADC spectra
with MIP peak **and p.e. finger**

Micro-DAQ
Scint detectors :

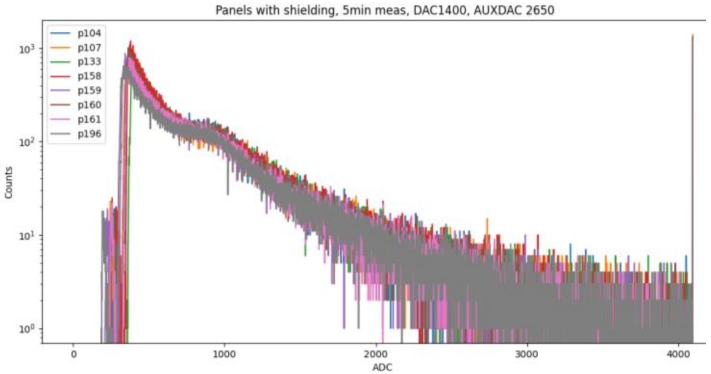




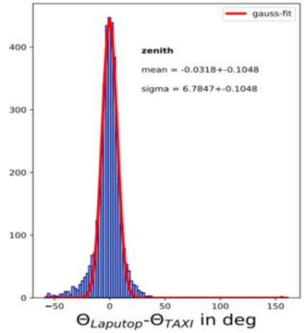
ADC spectra of all detectors of one **IceARM** scint station

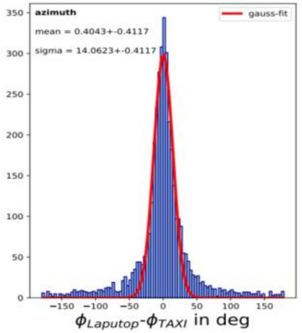
Both systems can be calibrated

(Shows one stations
detectors ADC spectra)



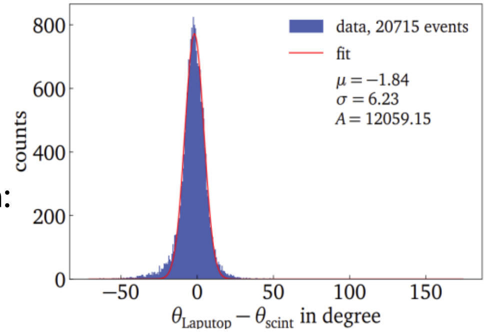
ADC spectra of all detectors of one **uDAQ** scint station

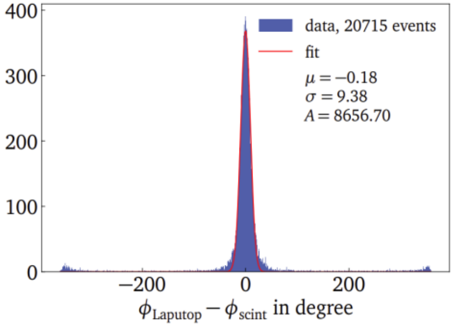




Both systems air-shower
reconstruction archived

(Angular differences in reconstruction:
Prototype station and IceTop)





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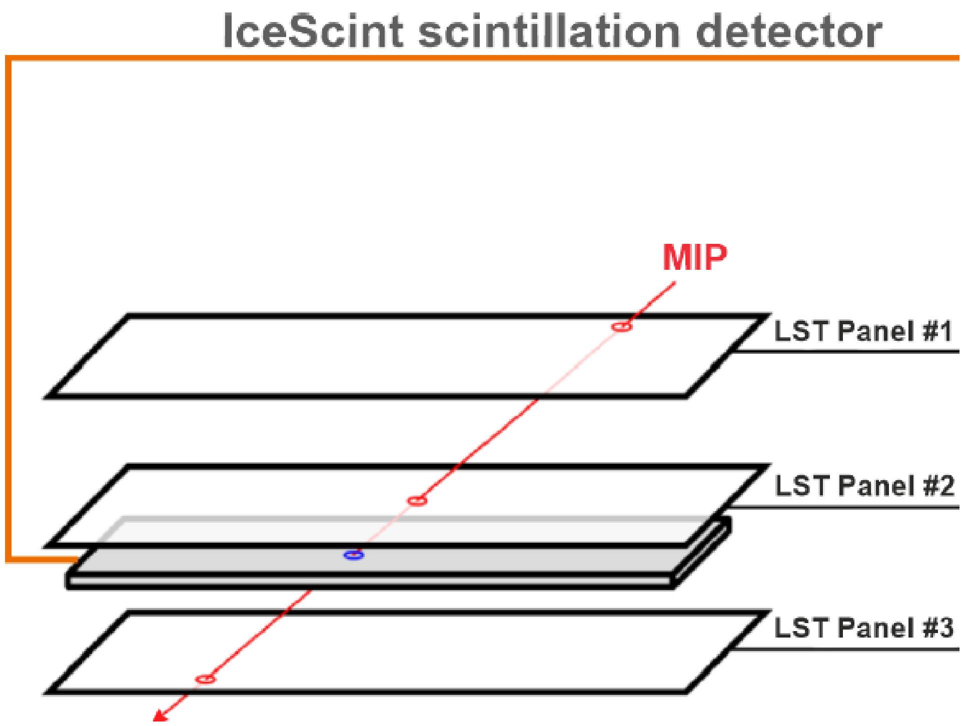
Muon Tower at KIT – First IceCube Scint detectors (2018)

Limited streamer tube panels with a spatial resolution of 1 cm²
to obtain the efficiency of an IceScint detector



Schematic of the setup

Photo of the setup (2017)

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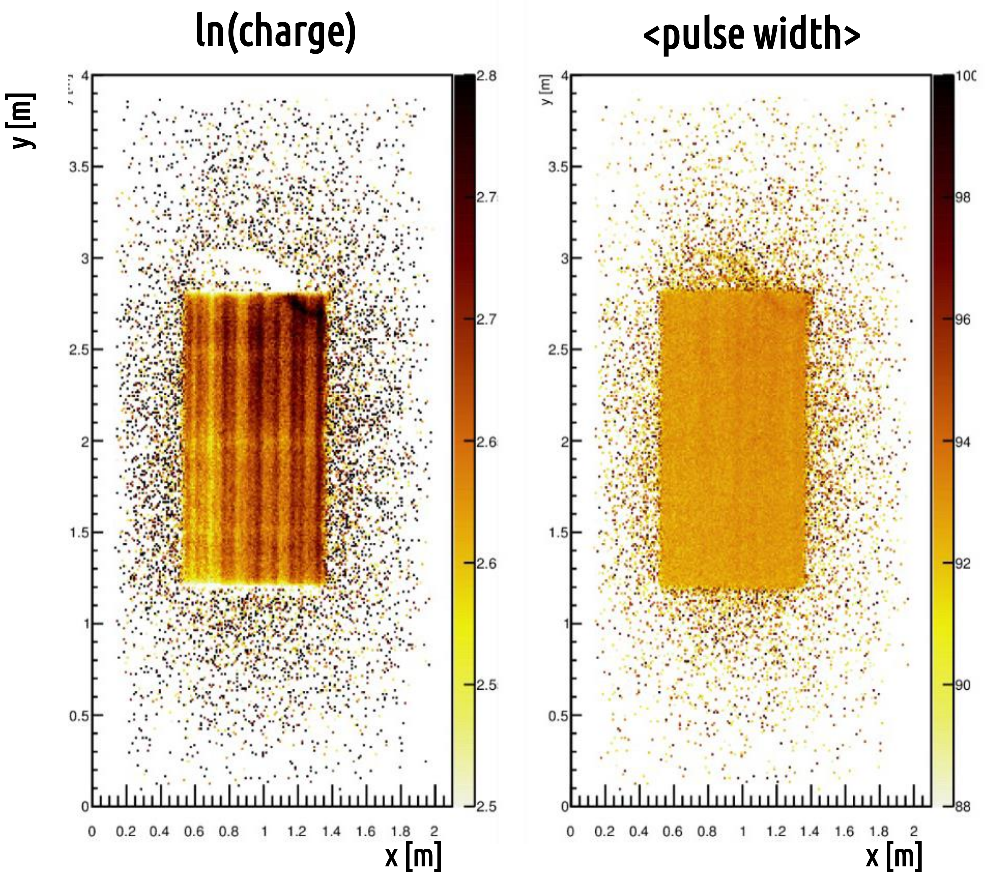
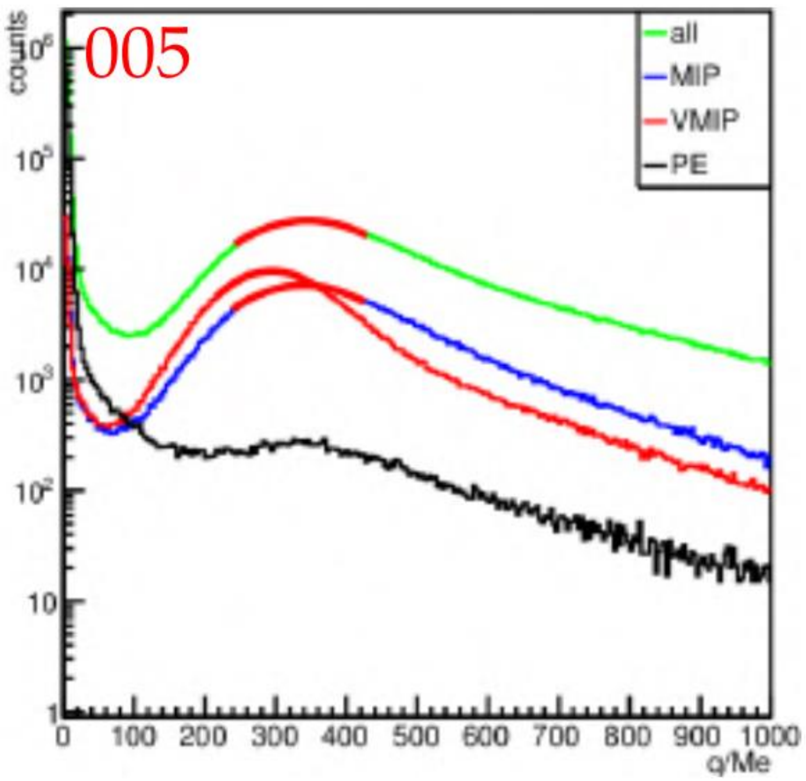
Muon Tower at KIT – First IceCube Scint detectors (2018)





Charge histogram

„Muon tomography" → Possible to check the finished detector for production issues before shipping
Charge histograms → To distinguish a.e. the PE/MIP ratio

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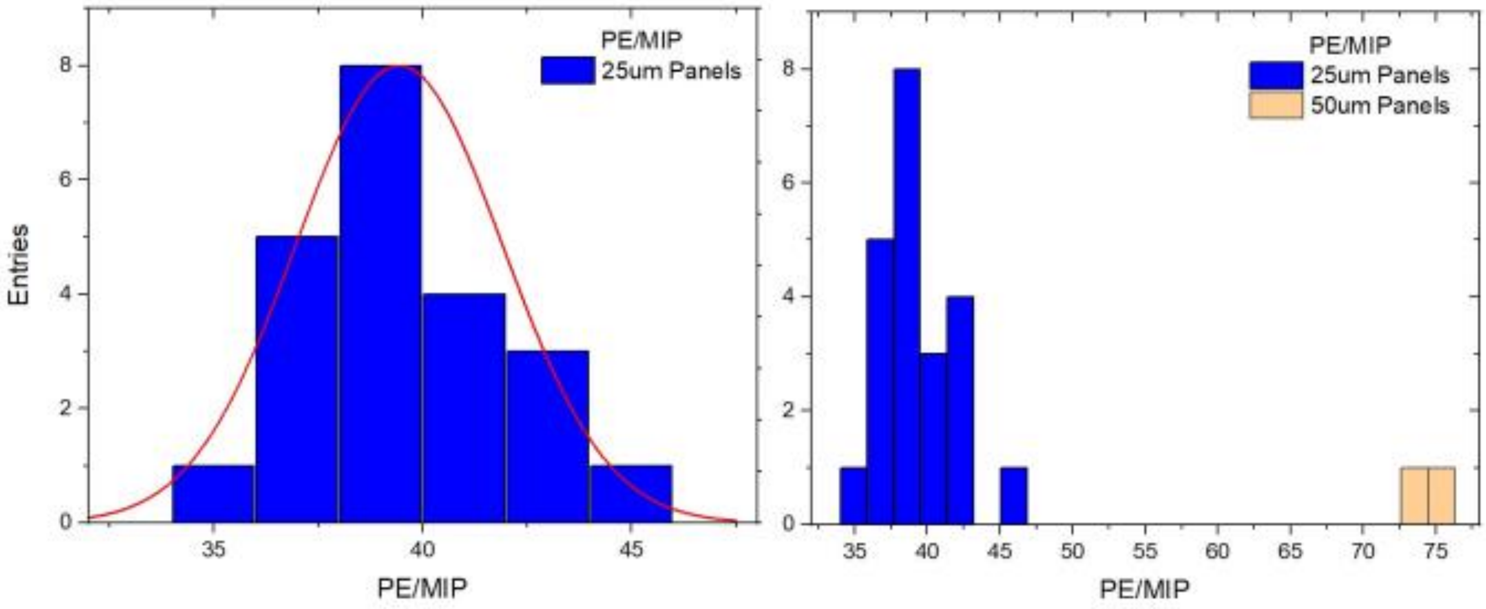
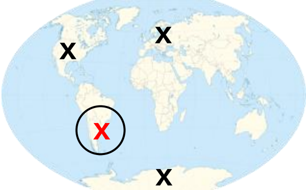
Distribution PE/MIP of the first 24 scintillation detectors



Maximum	$45.55\ \frac{PE}{MIP}$
Minimum	$35.56\ \frac{PE}{MIP}$
Mean	$39.43 \pm 0{,}57\ \frac{PE}{MIP}$
σ	2.47

IceCube Surface Enhancement Station at Auger Site

Full station deployed at Auger site (September 2022)



- Due to shipping delays the scintillators are not yet connected to the stations DAQ
- Data stream and continuous measurements are currently being set up

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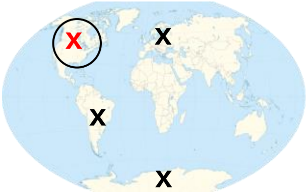
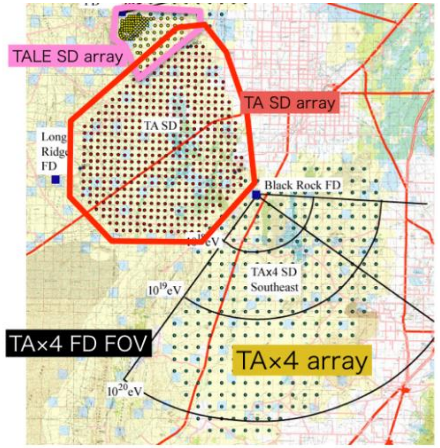
IceCube Surface Enhancement Station at Telescope Array Site



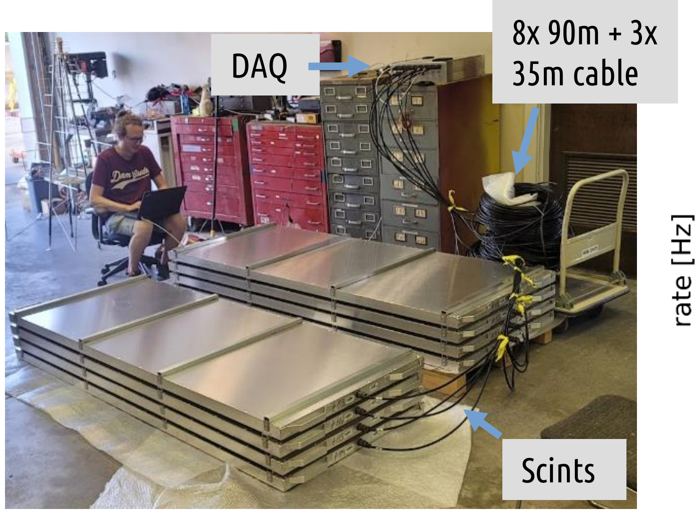
- New, denser infill region at TALE (TA low energy extension):
  Dimensions 100m, so similar to SAE station

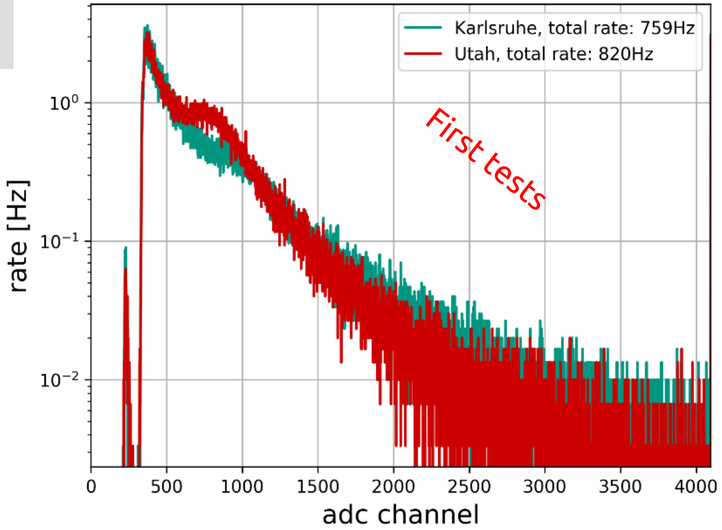


Challenges:
- Different infrastructure (data + power)
- Higher temperatures → test components at +50°C, design cooling for TAXI

DAQ powered via Car battery

Measurement of radio background on-site





Estimated schedule:
- Beginning of October: Tests and hodoscope setups near the workshop
- (November): Deployment in field, close to Middle Drum station

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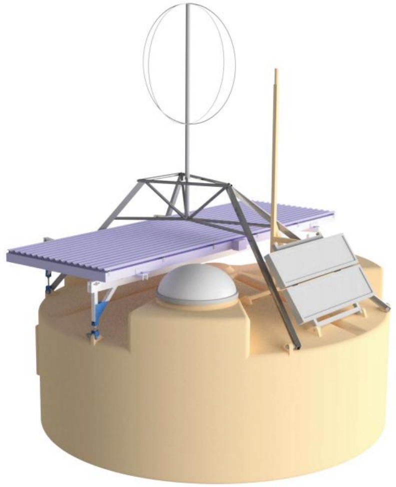
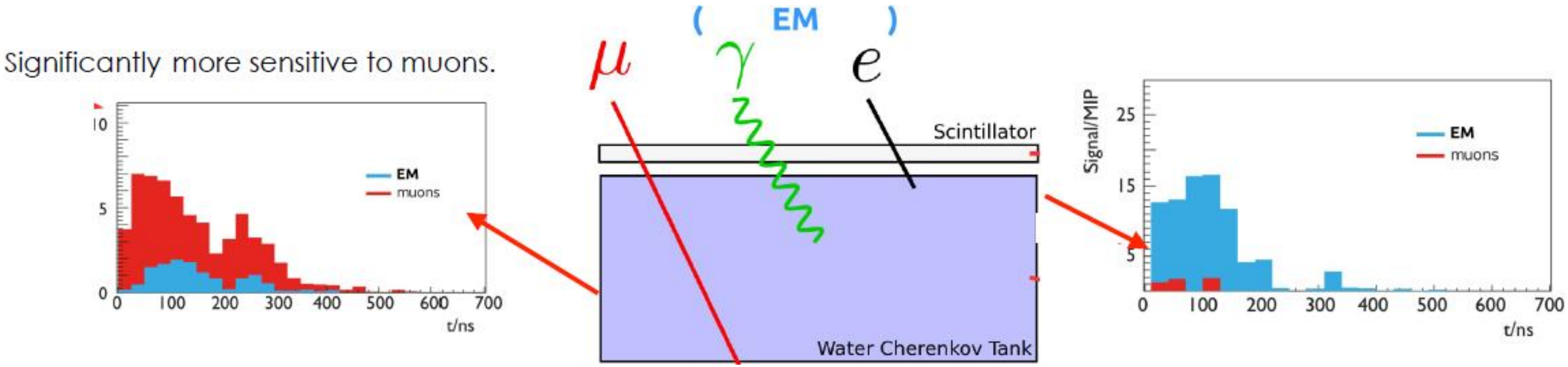
Additional Slides

AugerPrime Signal Shape Cherenkov-Tanks vs. Scintillator

- Not comparable with the Scint detectors shown in these slides
  - Different detector design
  - PMT instead of SiPM





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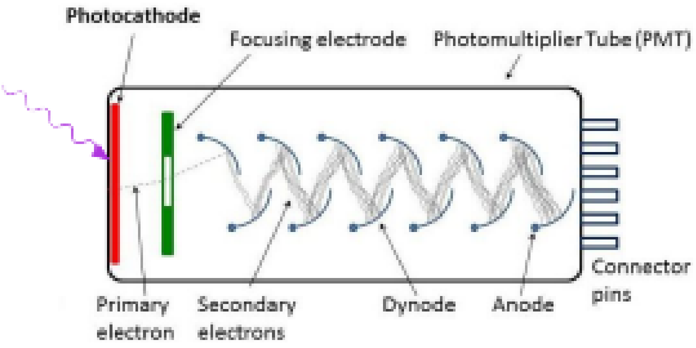
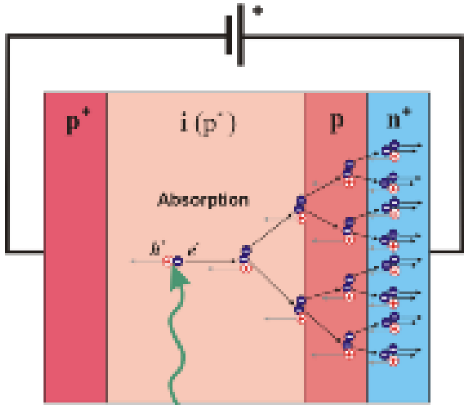
Photosensor: Why Silicon Photomultiplier (SiPMs)?

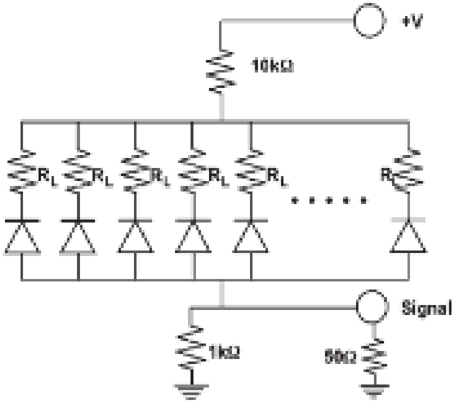
PMT



APD

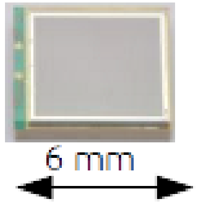


SiPM



	PMT	SiPM
PDE	20-40%	20-60%
Gain	10^6	10^6
Dark noise rate	~Hz	~MHz
Behaviour in magnetic fields		
Operation Voltage	1000+ V	50-70 V
Temperature sensitivity		
Robustness and compactness		

Our candidate:
Hamamatsu
S13360 series



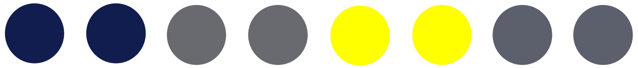
$$\text{PDE} = \frac{\text{Number of detected photons}}{\text{Number of incident photons}}$$

Example: Performance of the prototype station (20/21)

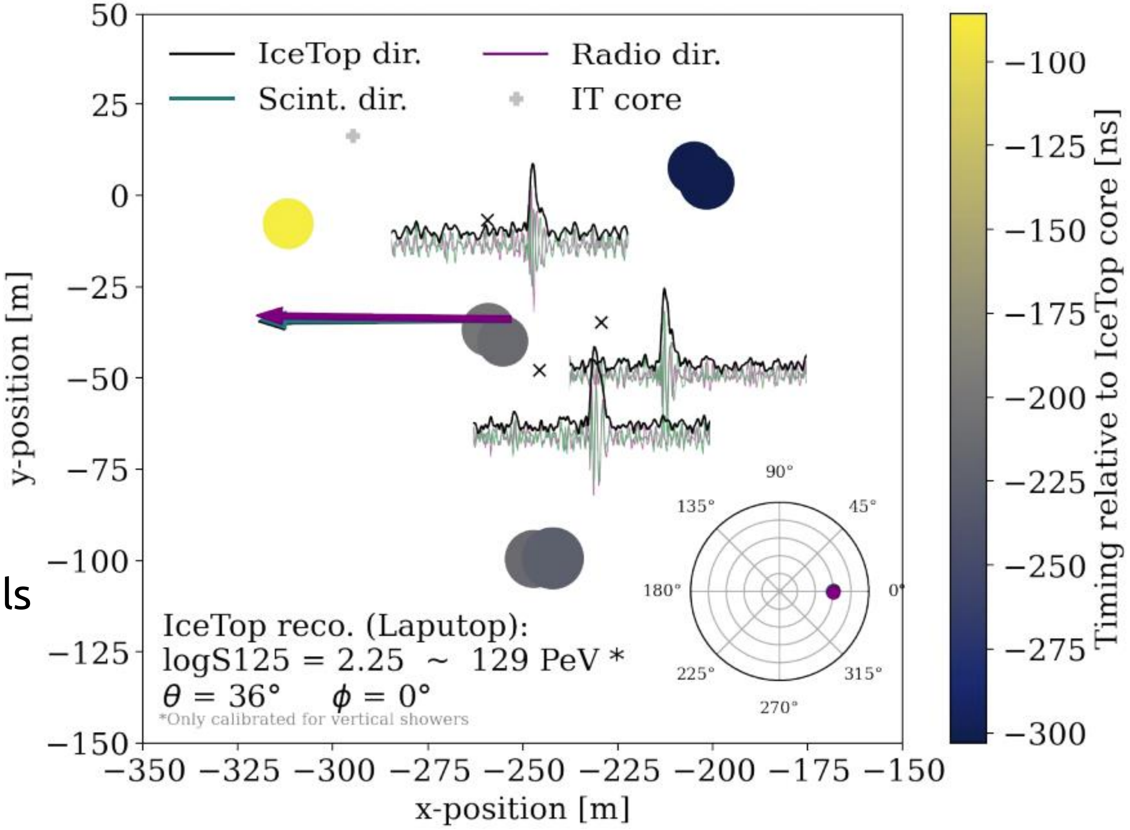
- Three different detection techniques (Scintillators, Radio antennas, IceTop) are measuring air-showers in coincidence

- Reconstruction methods:
  - Scintillators: Plane-wave approximation
  - IceTop: Laputop framework used
  - Radio: Plane-wave approximation

Coincidences plot on the right:

-  :
  → Scintillators + Timing relative to IceTop core
- Crosses:
  → Radio antennas
  with the waveforms (2x polarisations) of the signals
- Arrows:
  → Reconstructed directions projected to x-y
  (Length of the arrow indicates the zenith)

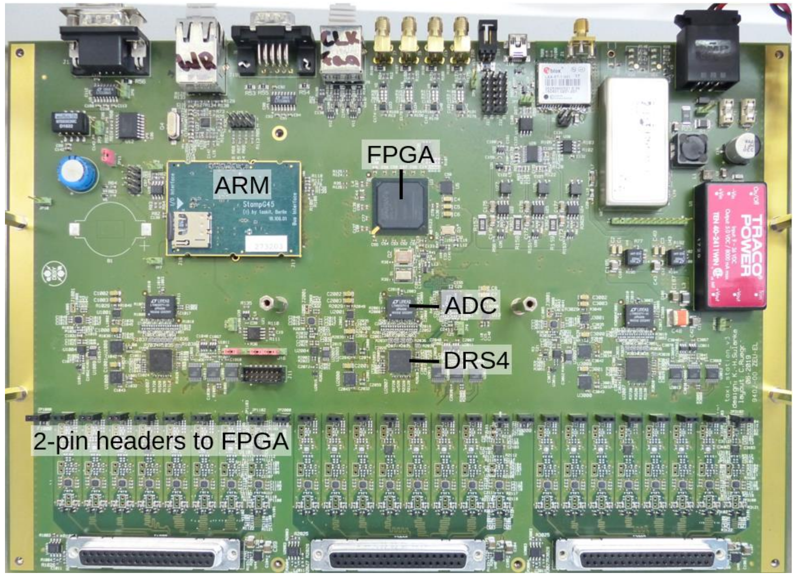
One example:



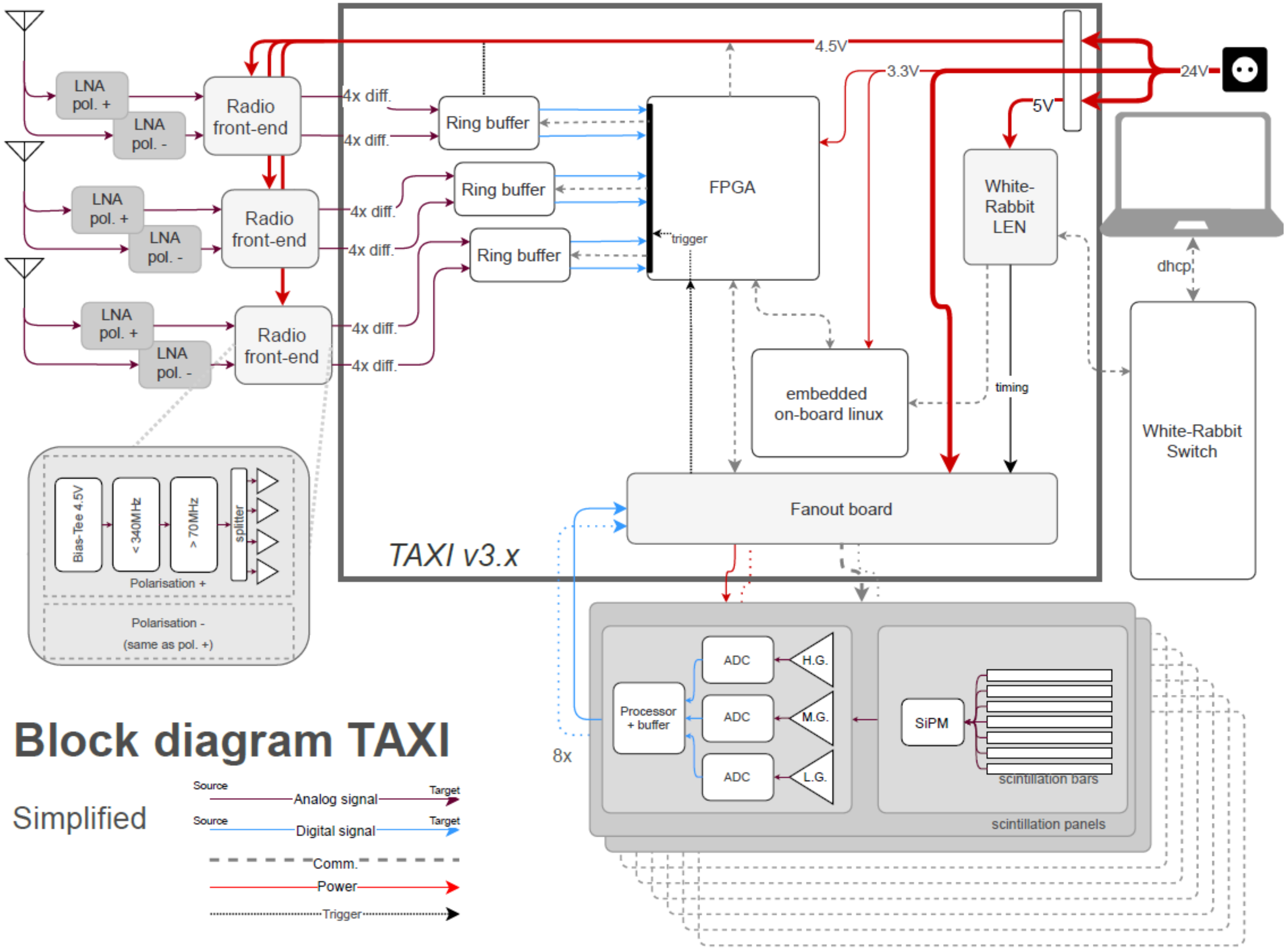
H. Dujmović (KIT-IAP)

thomas.huber@kit.edu

The IceTop surface enhancement - TAXI DAQ



- DRS4 Chips for waveform sampling, 1GS/s
- Spartan FPGA for data progressing
- ARM embedded Linux microcontroller



Block diagram TAXI

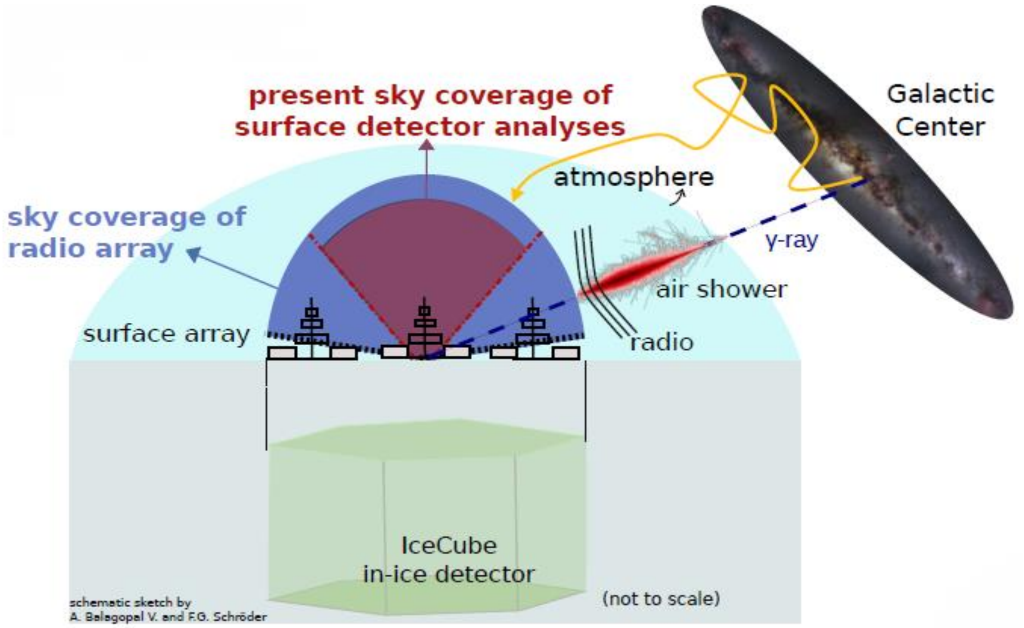
Simplified

R. Turcotte (KIT)

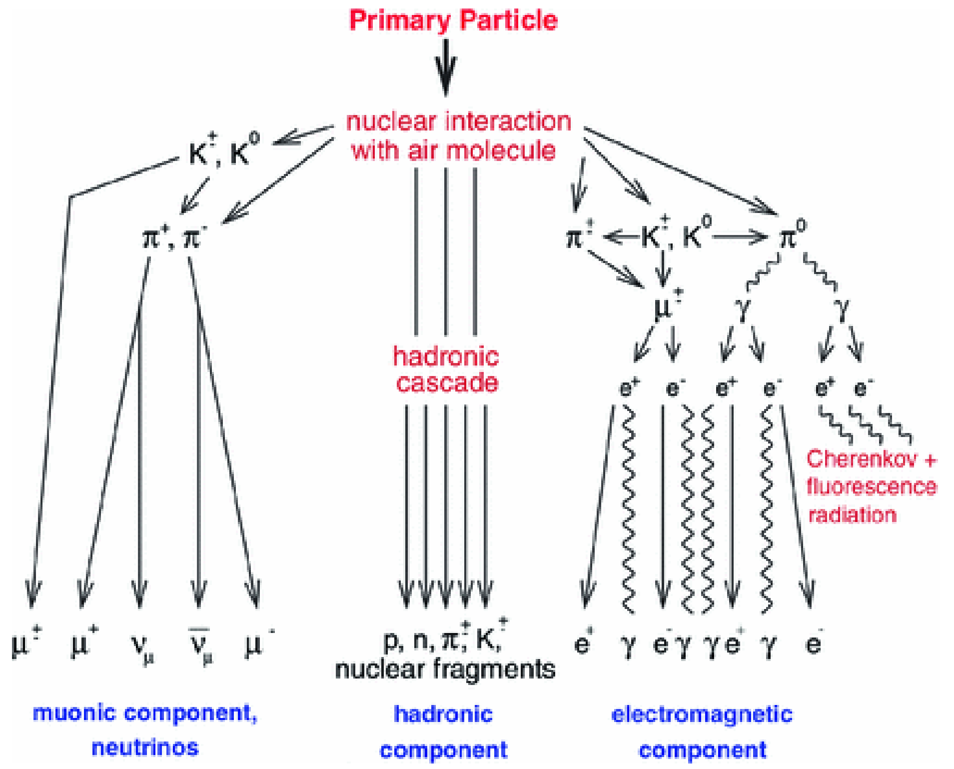
thomas.huber@kit.edu

Science cases for an enhancement of IceTop

- Improved in-ice veto capabilities by increasing the sensitive area
- Lowered threshold for air-shower observations
- Accurate reconstruction of air-showers at high energies by radio antennas
- Measurement of composition and γ-rays in large energy range
- Tests of different hadronic interaction models



F. Schröder (Uni Delaware, KIT)



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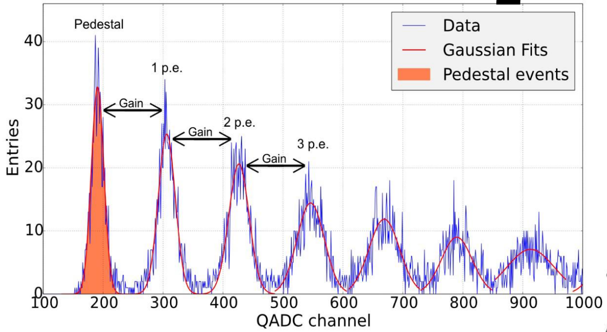
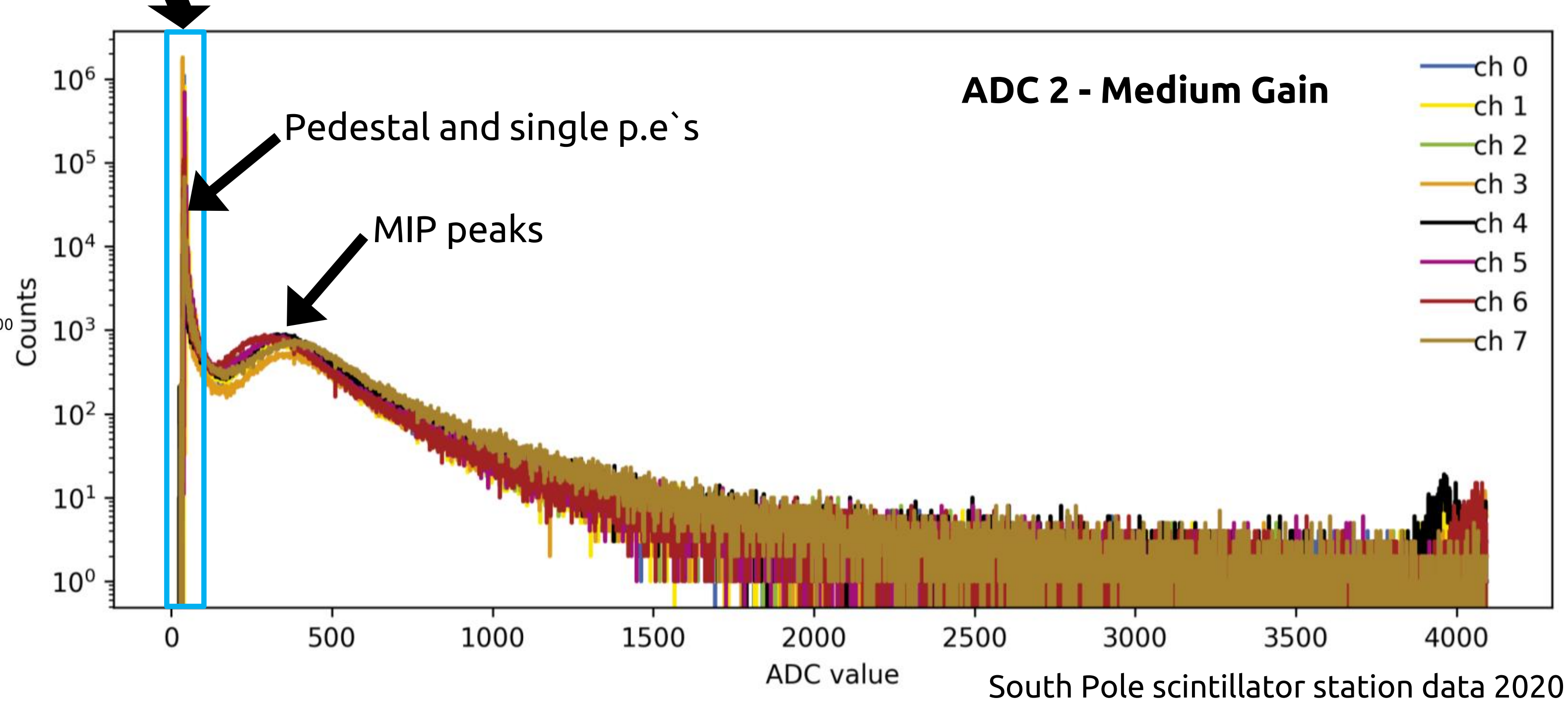
Uniformity of the scintillation detector station

Understanding the whole readout chain (Scintillator + Routing → Design + Frame → Optical Coupling → Photosensor (SiPM) → uDAQ → TAXI)

well enough to ensure an uniform scintillation detector array





South Pole scintillator station data 2020

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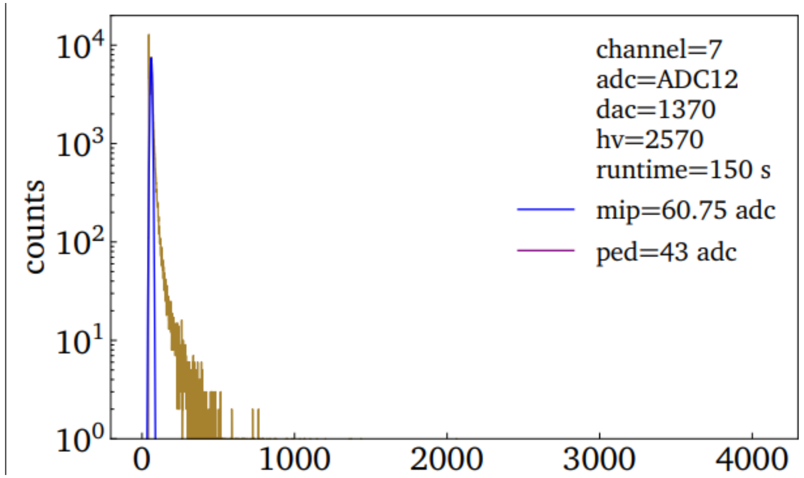
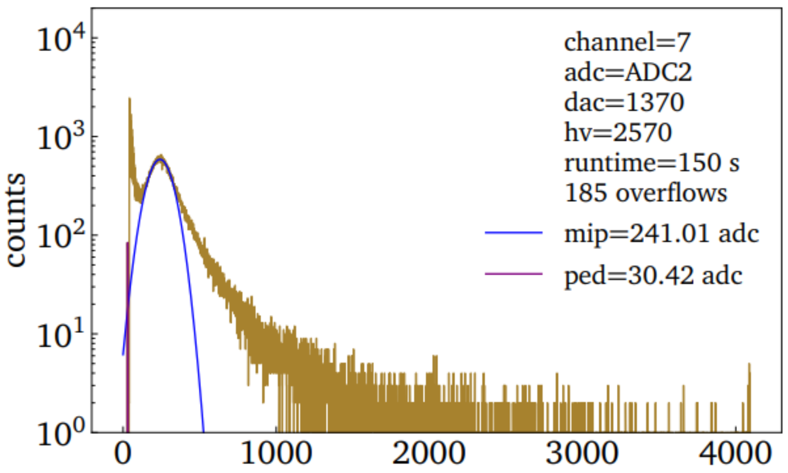
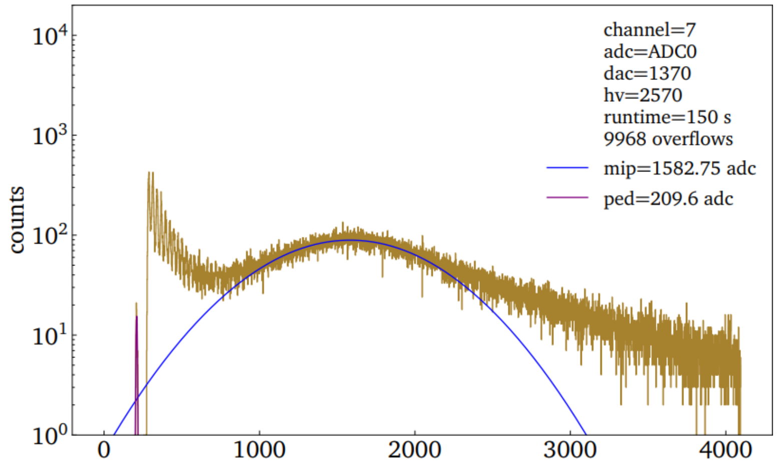
uDAQ – Low/Medium/High-Gain



Low-Gain



Medium Gain



High Gain

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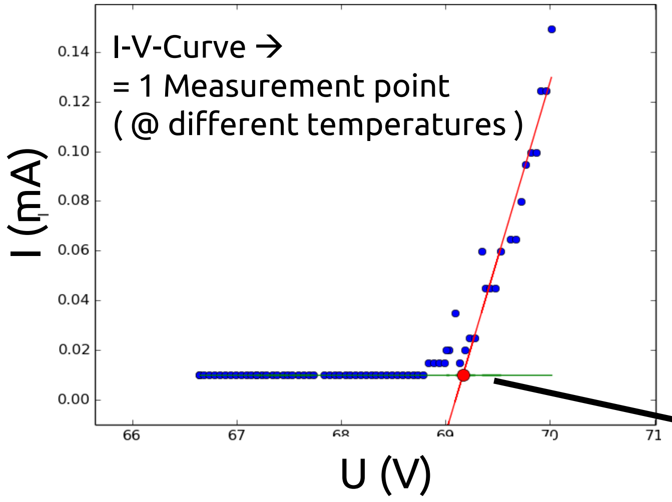
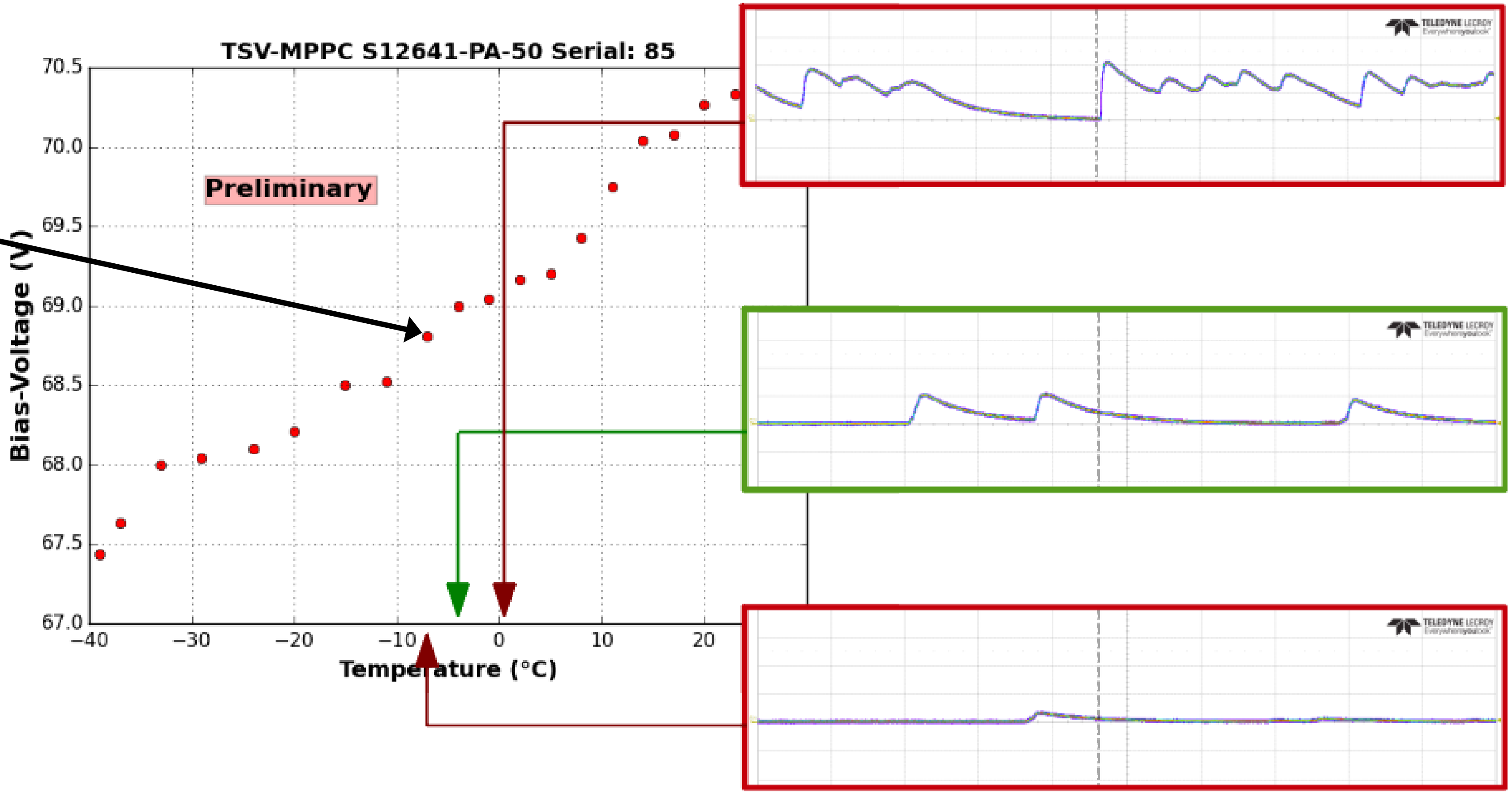
SiPM waveforms without gain adjustments



With a constant Bias-Voltage:



V: 50mV/div Timebase: 500ns/div

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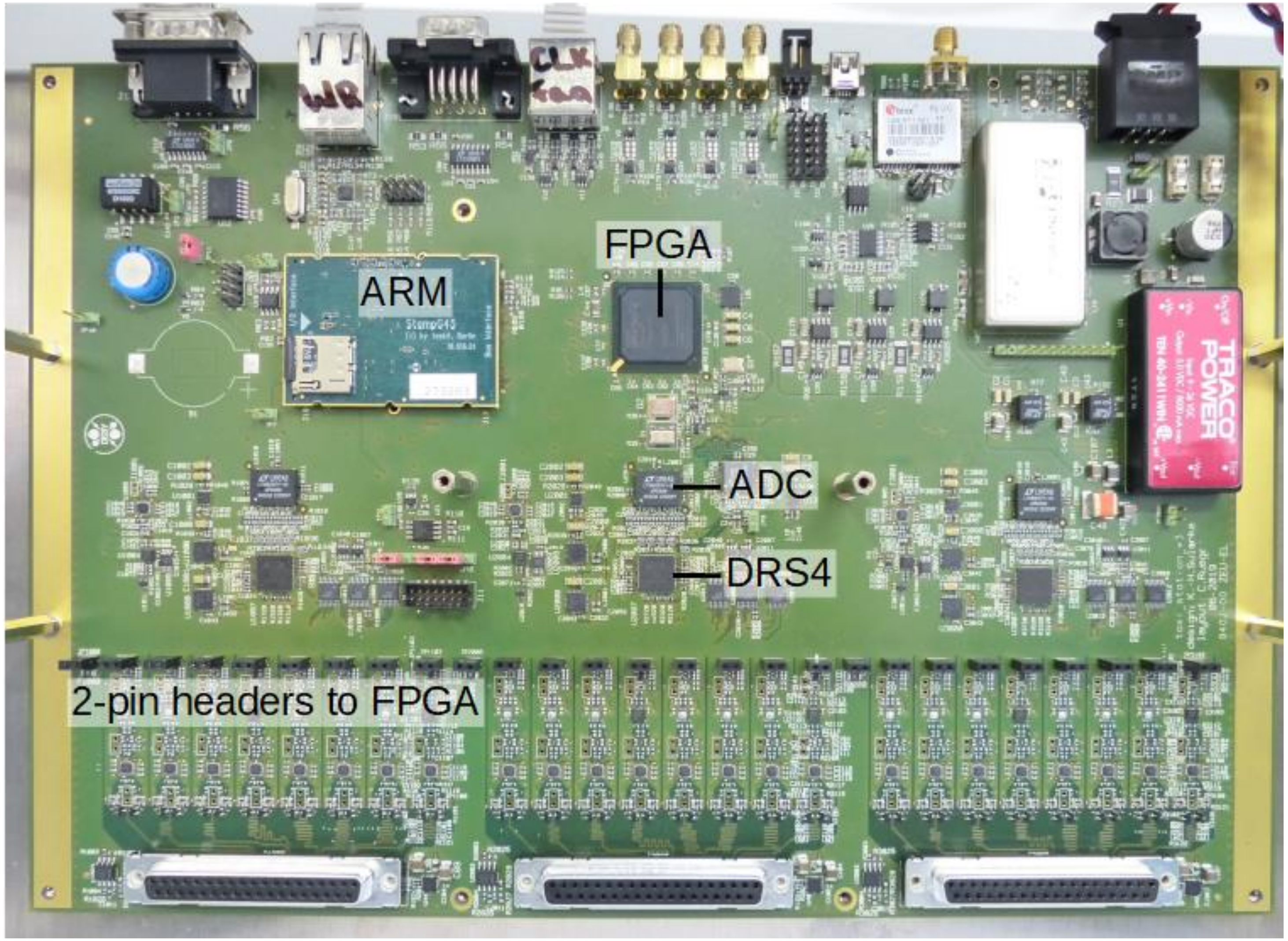
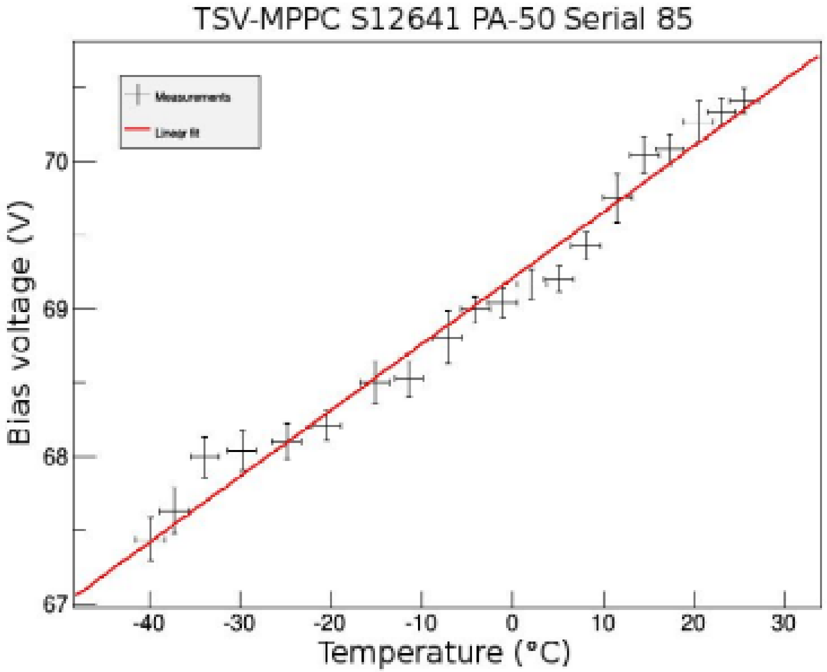
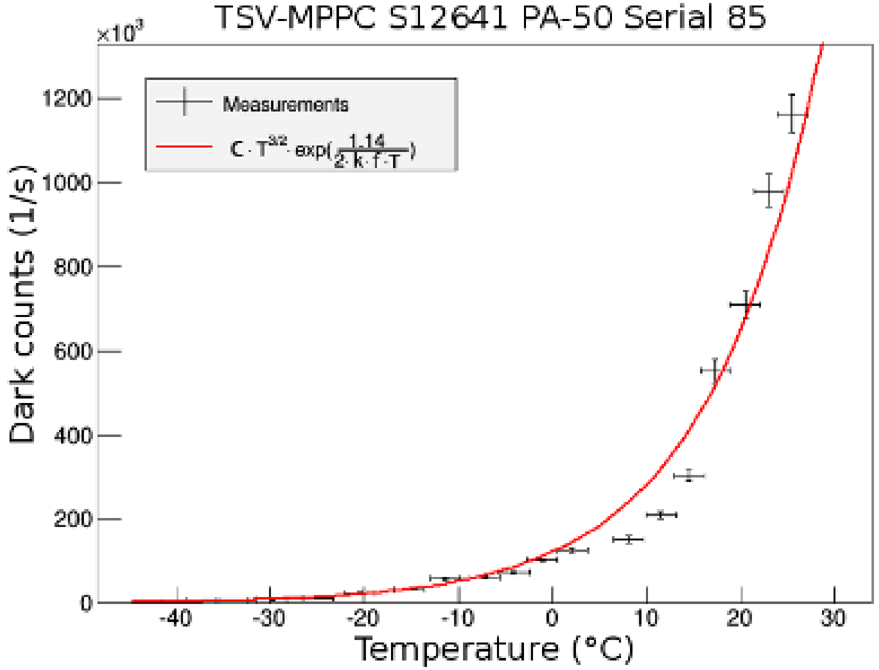
TAXI Mainboard



Why SiPMs as photosensors?



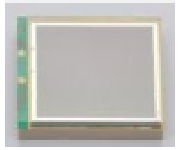


Performance increases at low temperatures:

- Less dark counts
- Less bias voltage needed
- Higher PDE
- ...

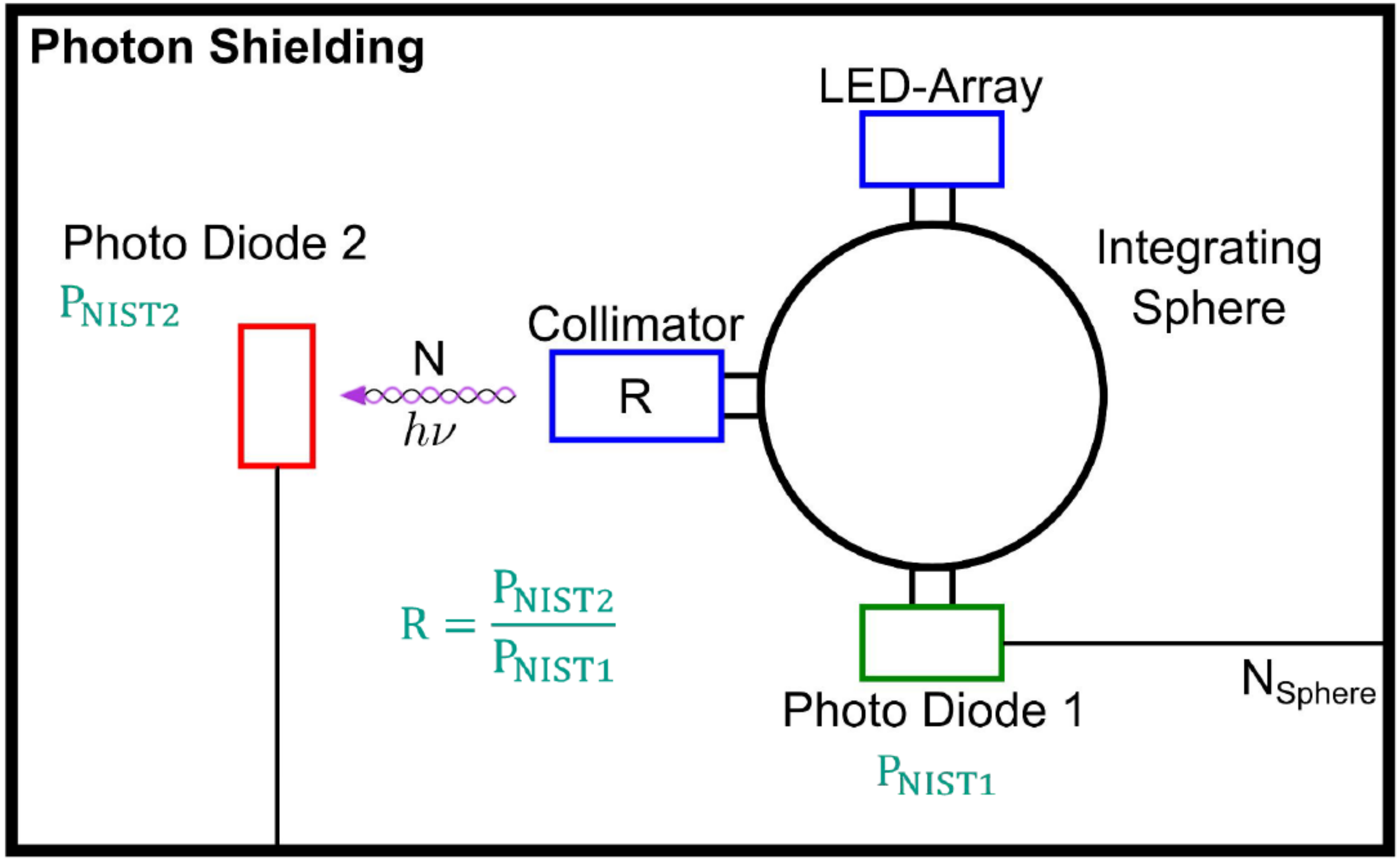
No better place on Earth (beside the Lab) to operate SiPMs than: At the South Pole

Used SiPM: Hamamatsu S13360-6025PE



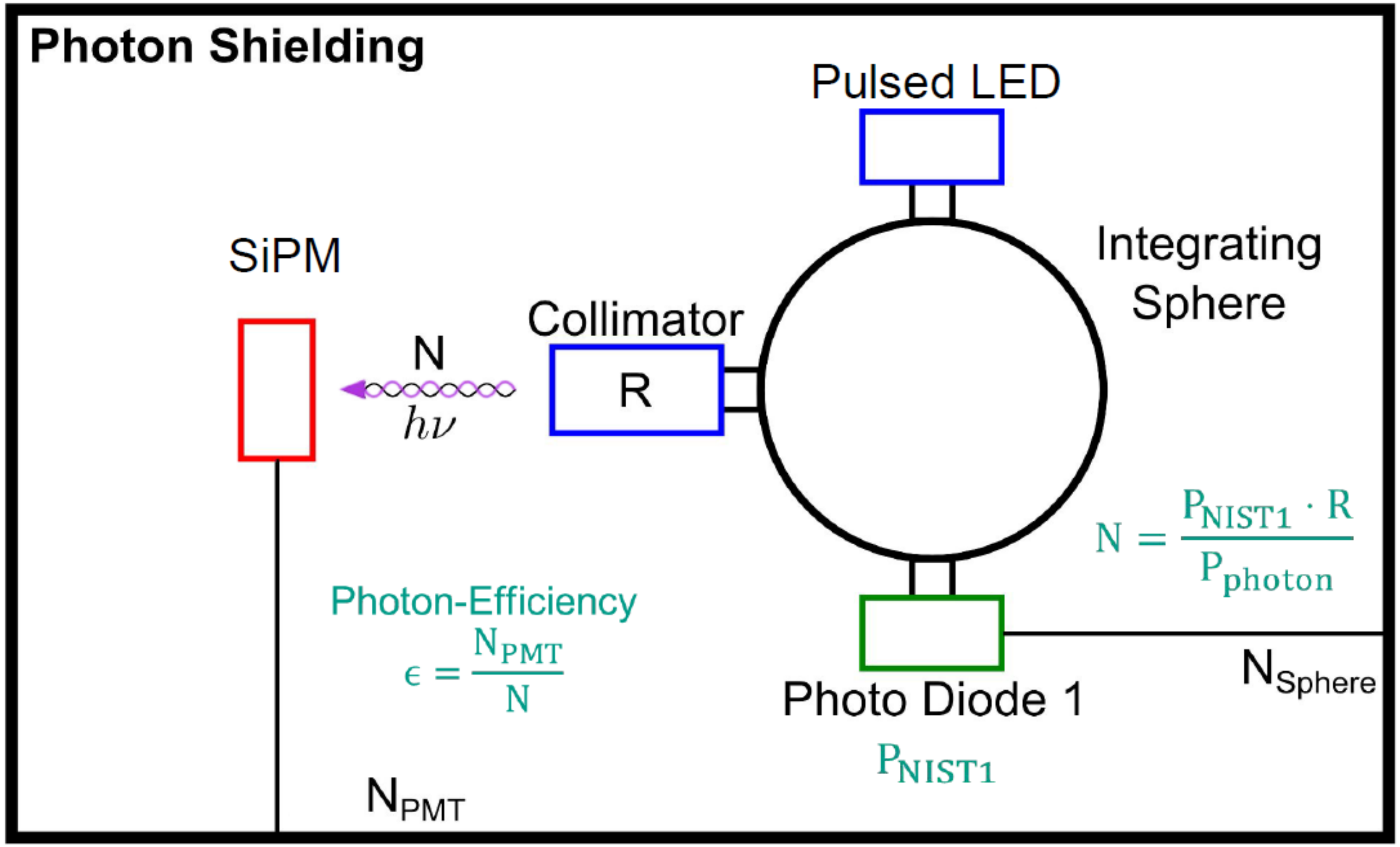
Simplified sketch of measurement method

1 st step: Calibrating the measurement setup:

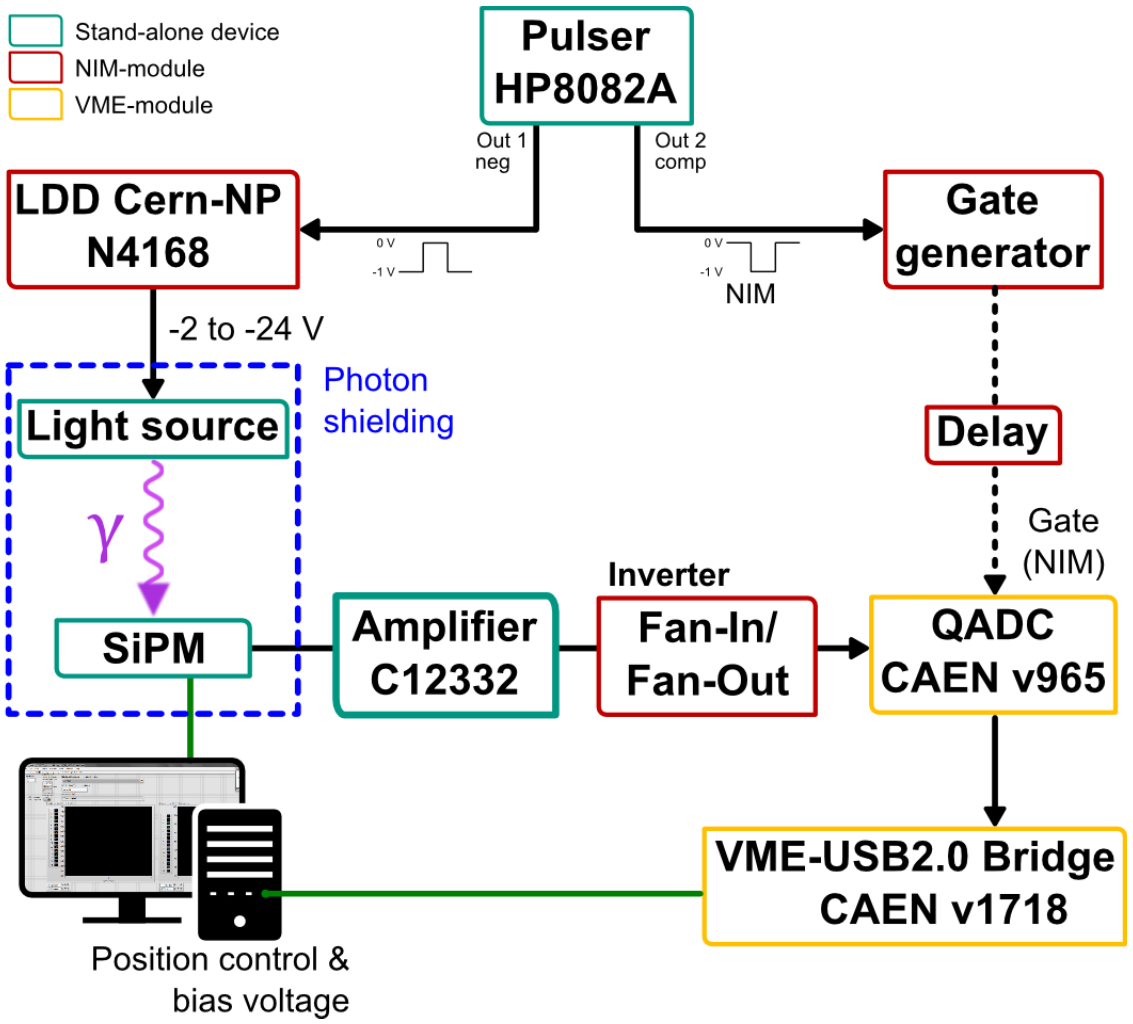


Simplified sketch of measurement method

2 nd step: Characterize the photo sensor

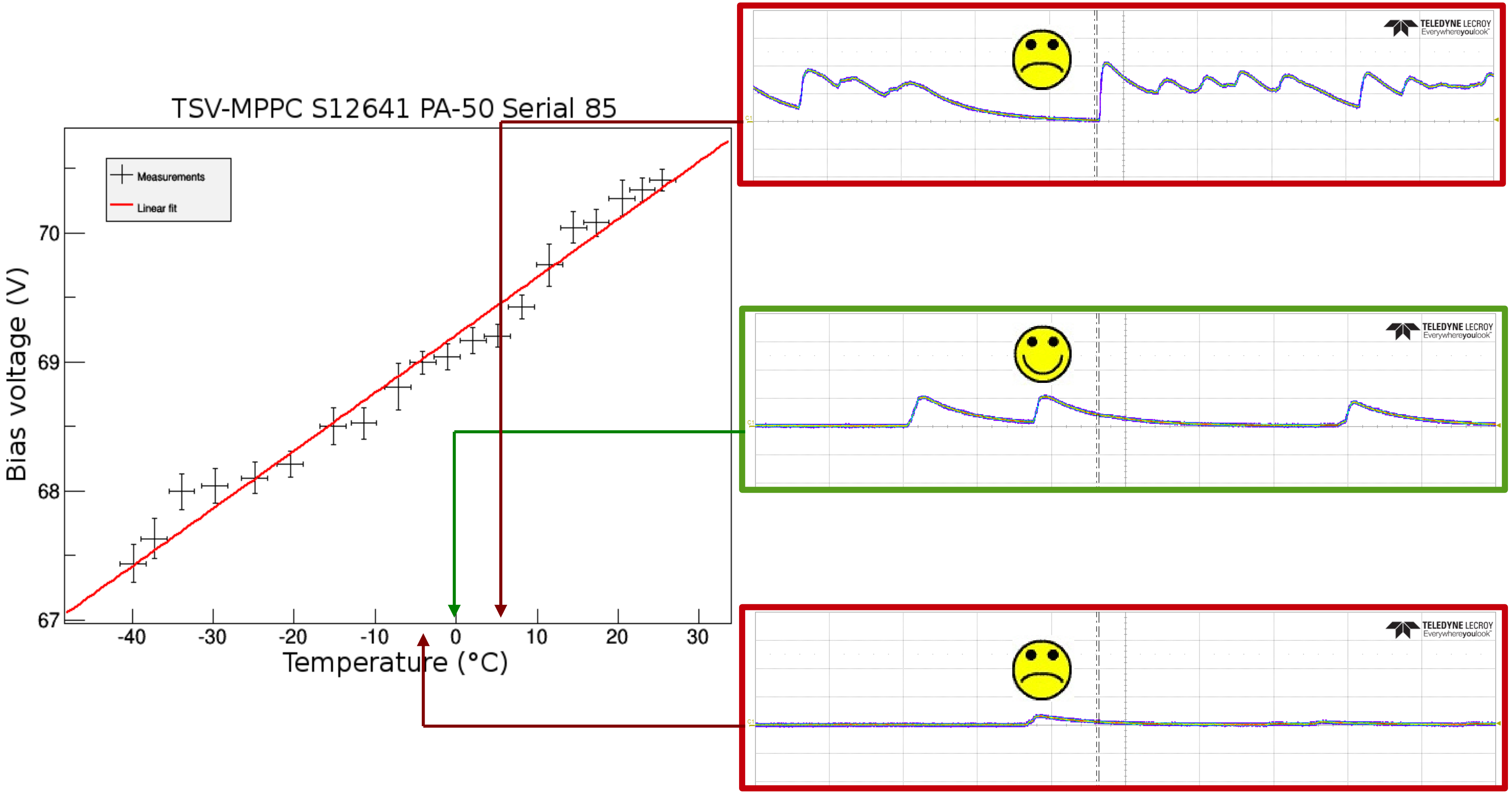


Characterizing SiPMs



Consequence of not adjusting the bias voltage

With a constant bias voltage:



V: 50mV/div Timebase: 500ns/div