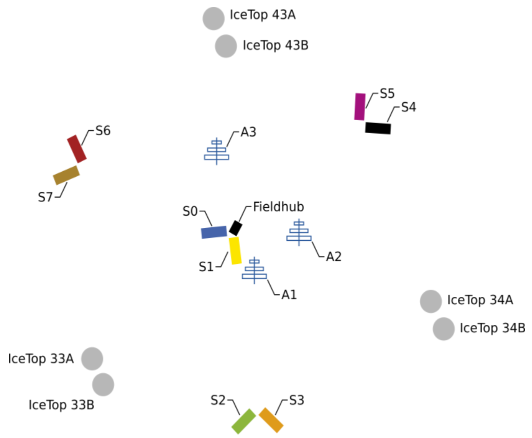
Karlsruhe Institute of Technology

ICECUBE
SOUTH POLE NEUTRINO OBSERVATORY

Characterisation and pre-calibration of the scintillation detectors of the IceTop surface enhancement

Thomas Huber for all involved

09.04.2021



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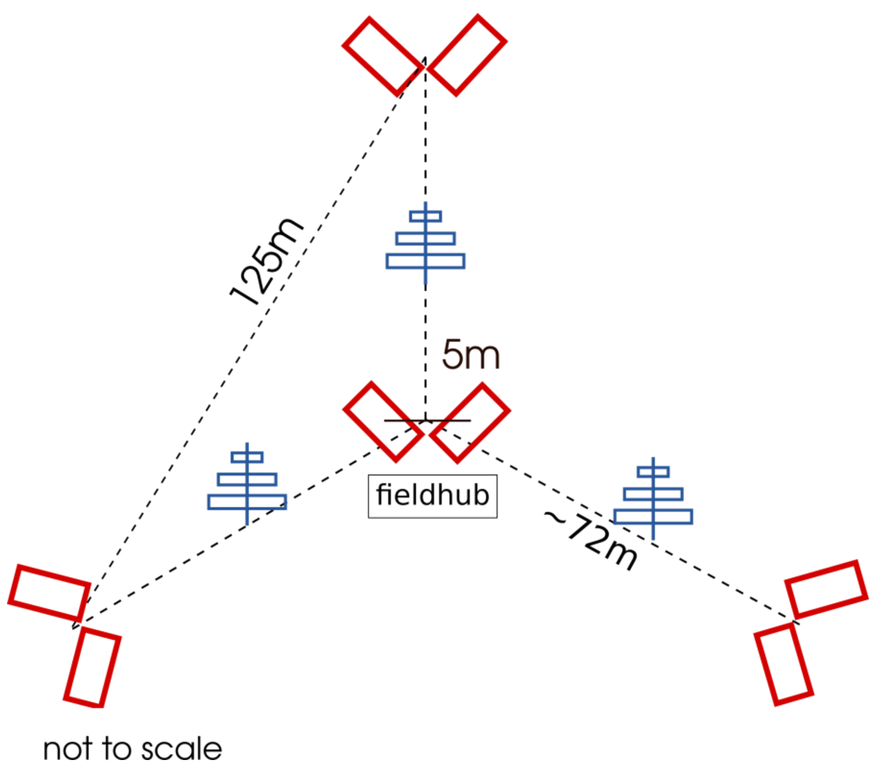
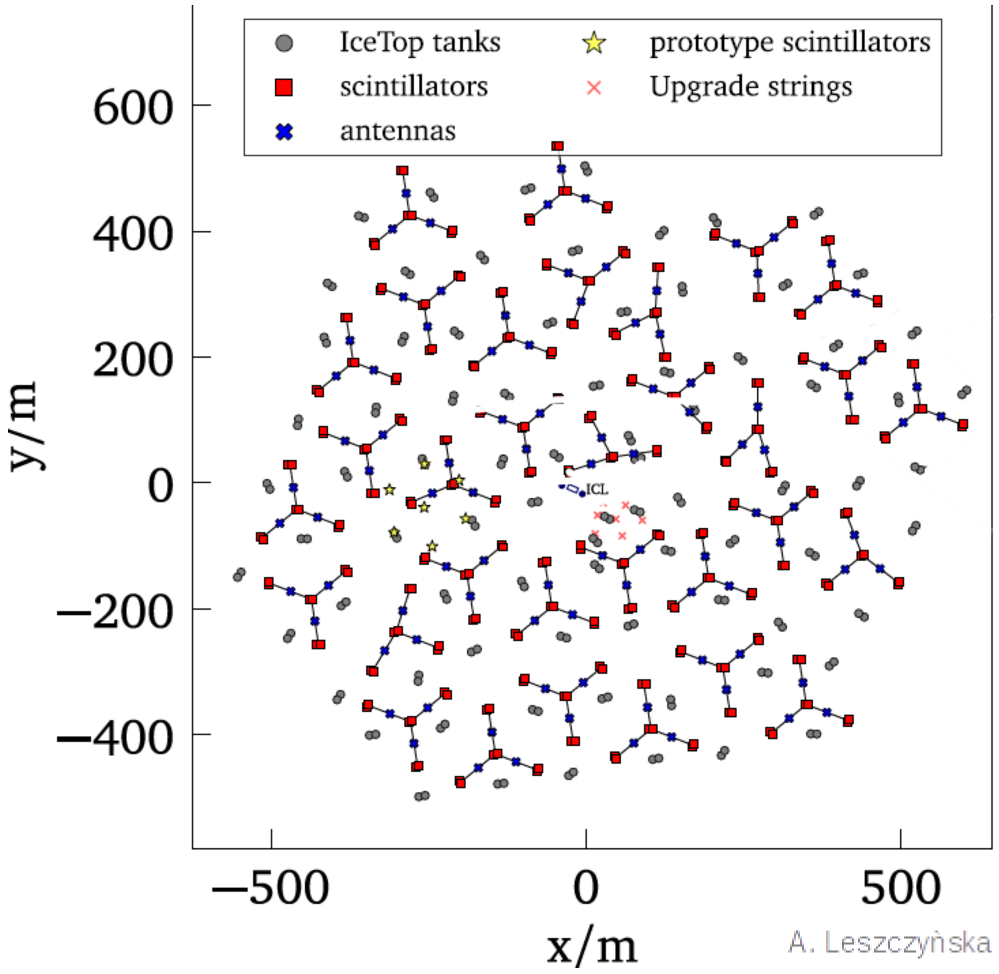
The IceTop surface enhancement

One station



Full array

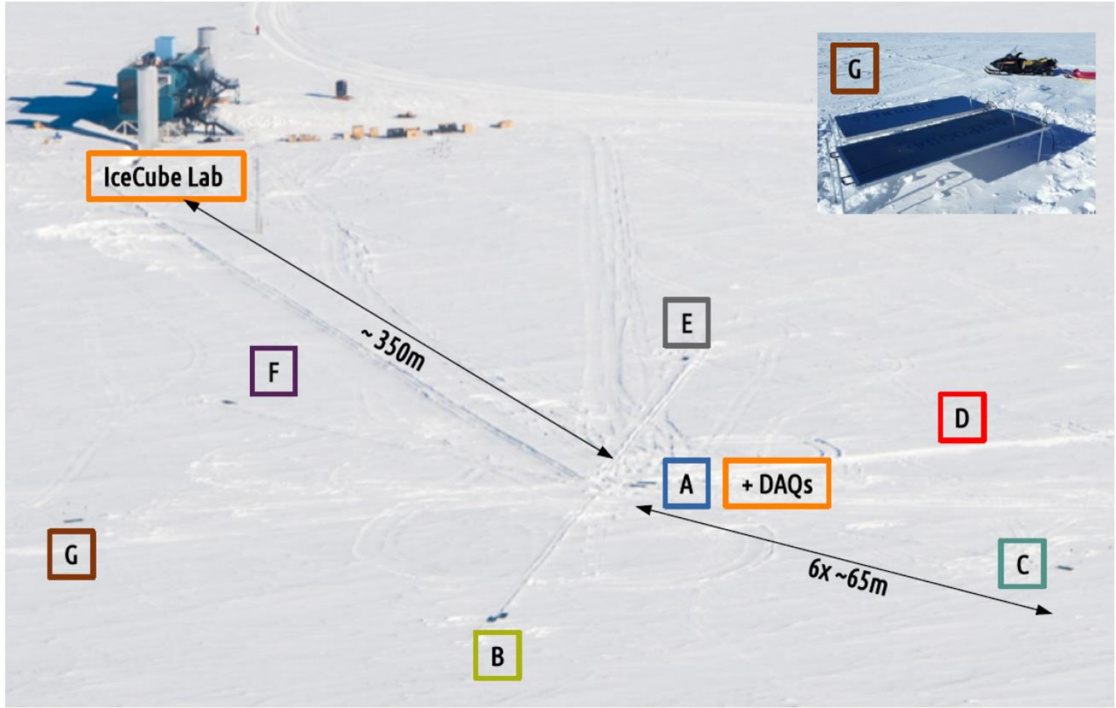


Plan to deploy 32 stations
- with 8 detectors and 3 radio antennas each
- within the IceTop footprint

thomas.huber@kit.edu

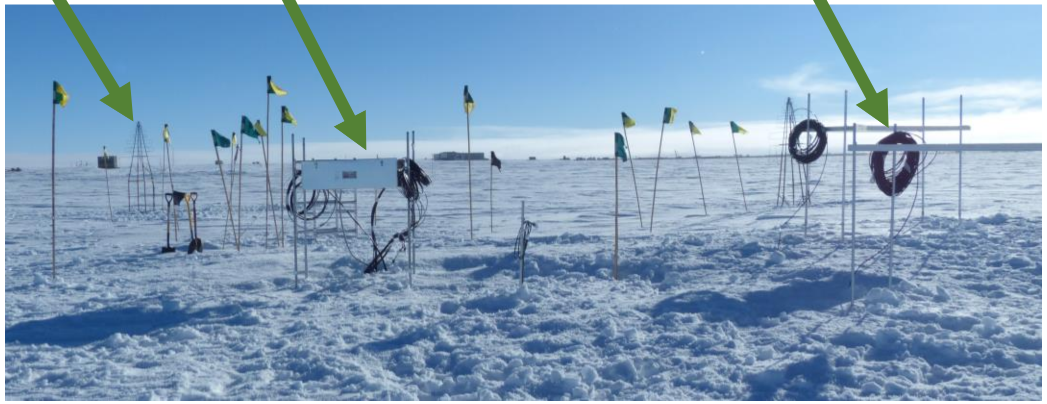
The IceTop surface enhancement – Prototype station

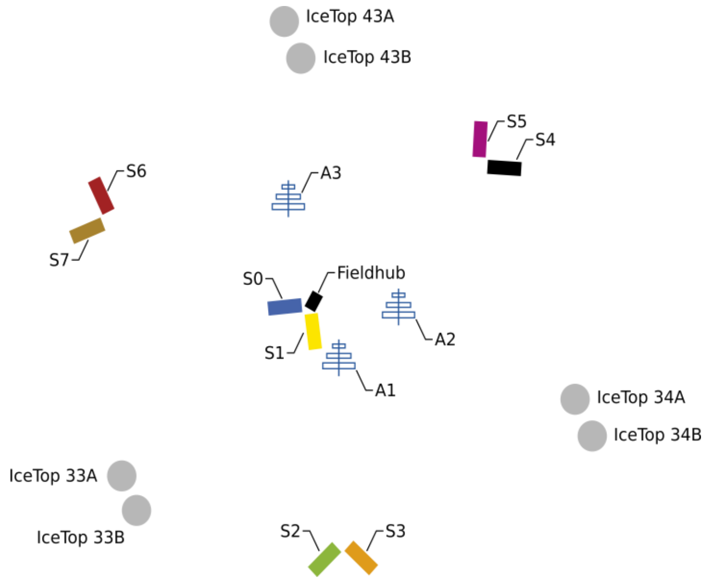
2017/18-2020



2020 -

Antenna Fieldhub Scintillator





2020:

- New alignment, new scintillator readout, 8 instead of 7 detectors
- New radio antennas
- New Fieldhub (with new TAXI DAQ)

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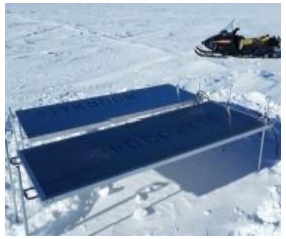
Towards IceCube Gen2 surface in respect of the IceTop surface enhancement

Scintillators



First station deployed
2017/18

Scintillators

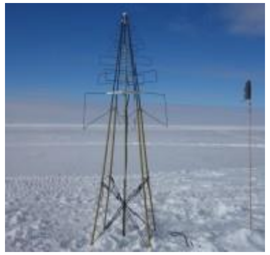
Station enhanced
2019/20

IceTop Surface Enhancement

Radio antennas

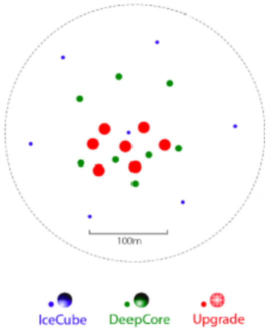
Three antennas deployed
2019/20

Radio antennas

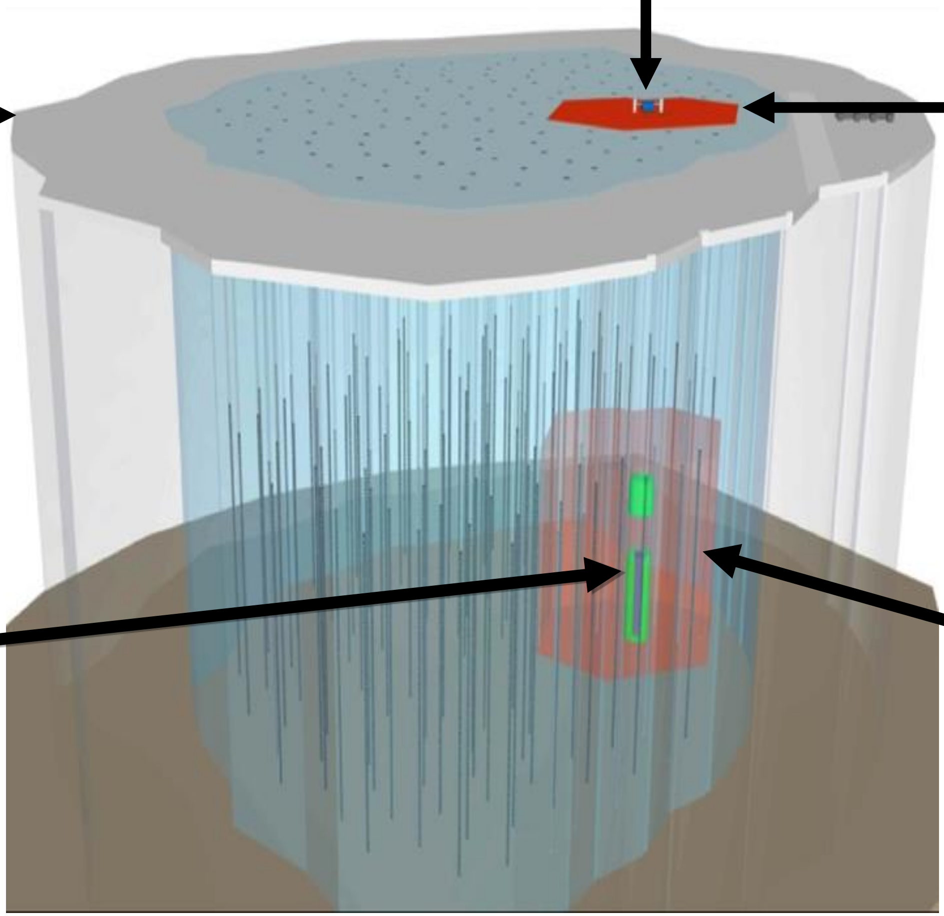


First antennas deployed
2018/19

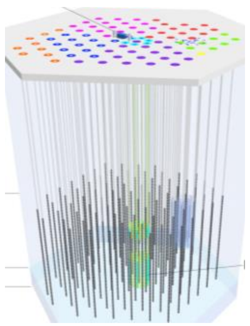
IceCube Upgrade



2022/23+



IceCube



Present

Possible IceCube Gen2 Observatory

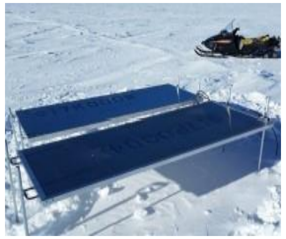
thomas.huber@kit.edu

Talks these Friday sessions

Calibration of the Gen2 in-ice arrays using the Gen2 surface array
→ **Frank**

IceTop Surface Enhancement

Scintillators



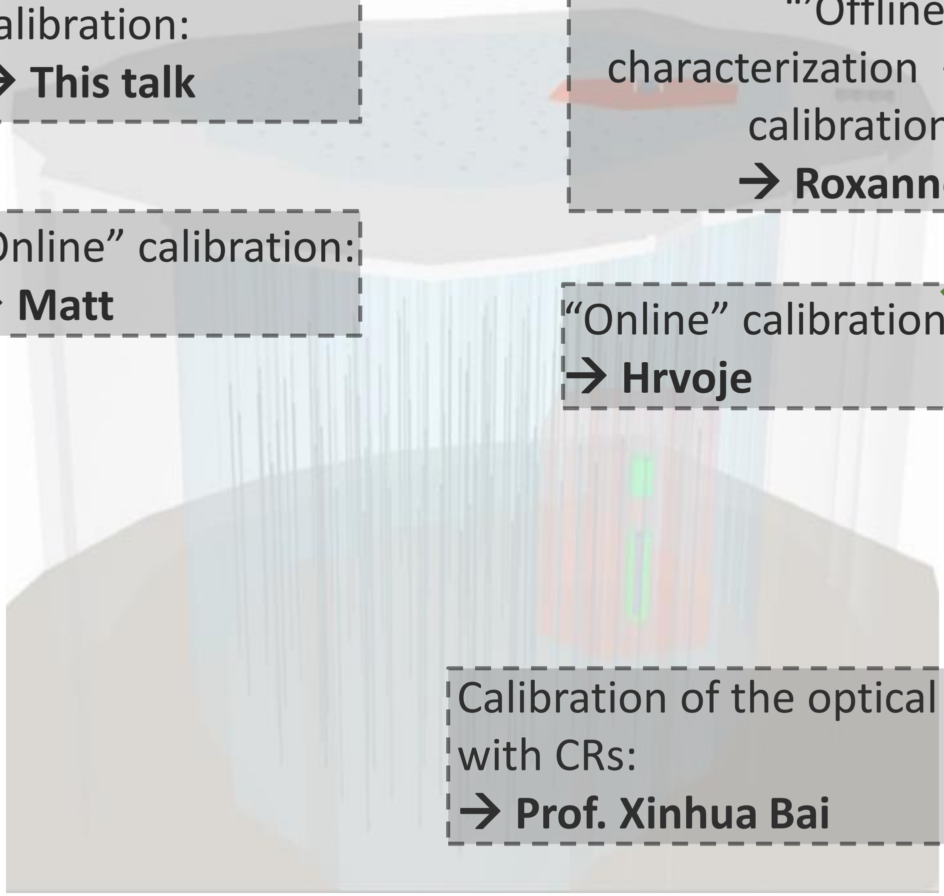
First station deployed
2017/18

Scintillators

Station enhanced
2019/20

"Offline" characterization + calibration:
→ **This talk**

"Online" calibration:
→ **Matt**



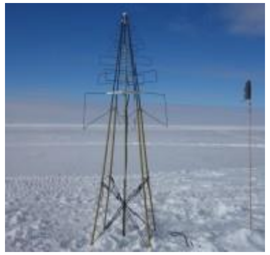
"'Offline" characterization + calibration:
→ **Roxanne**

"Online" calibration:
→ **Hrvoje**

Radio antennas

Three antennas deployed
2019/20

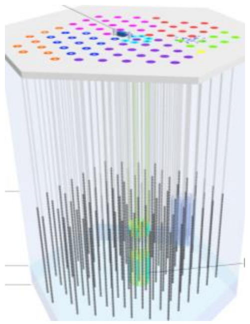
Radio antennas



First antennas deployed
2018/19

Calibration of the optical array with CRs:
→ **Prof. Xinhua Bai**

IceCube



Present

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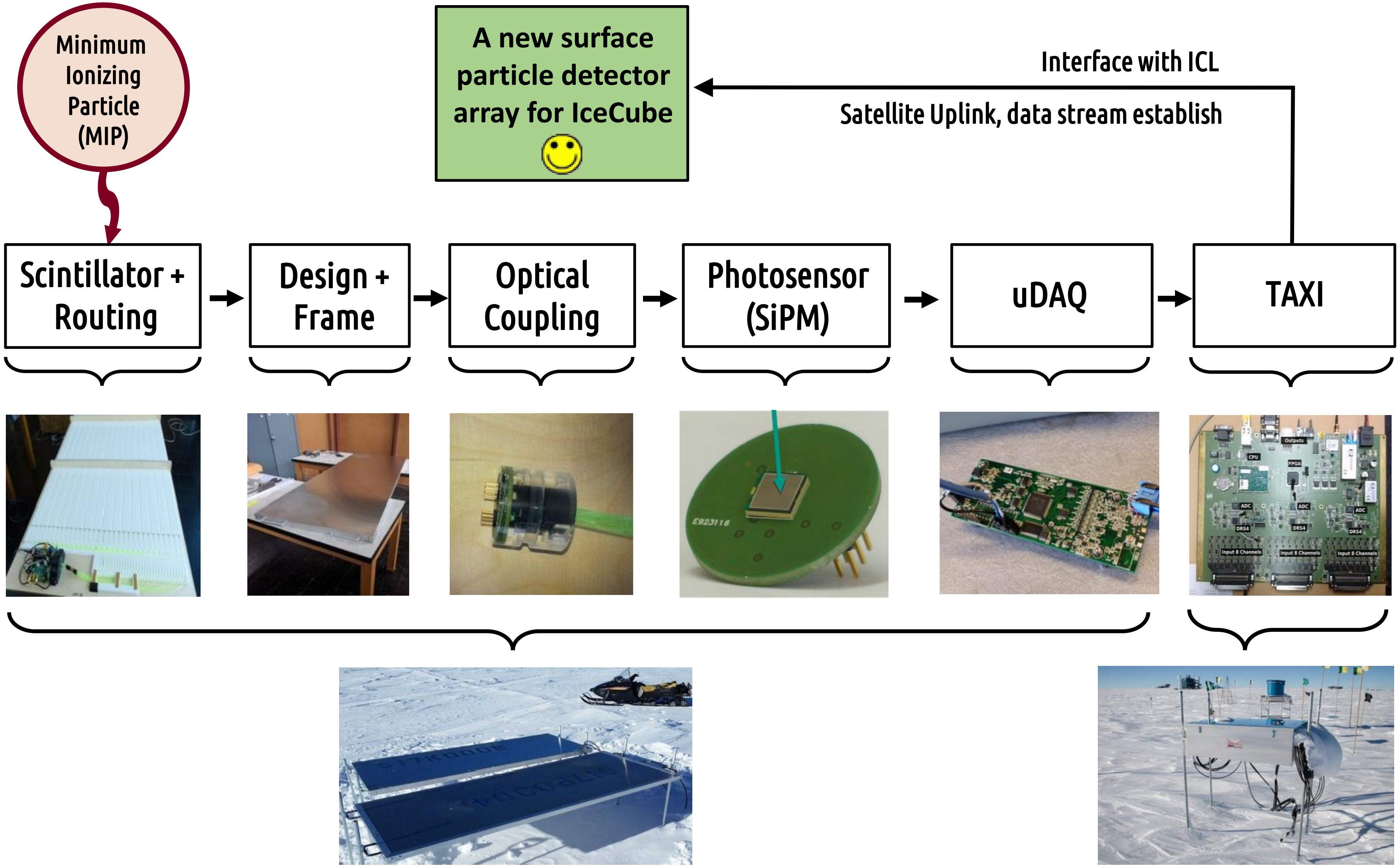
Overview scintillation detectors



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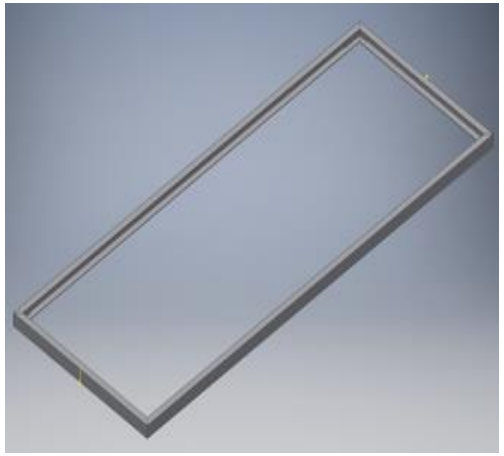
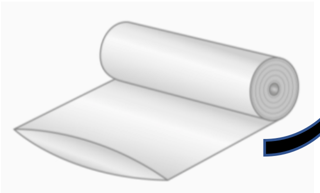
Production of the scintillators

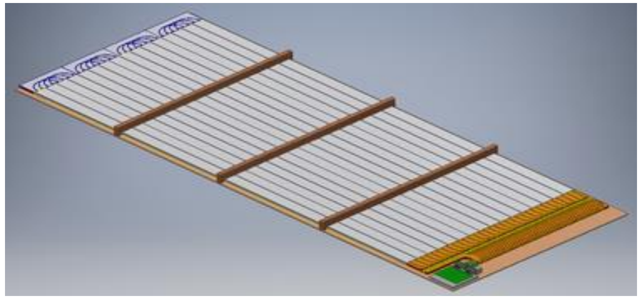
Splitting the production into two parts:




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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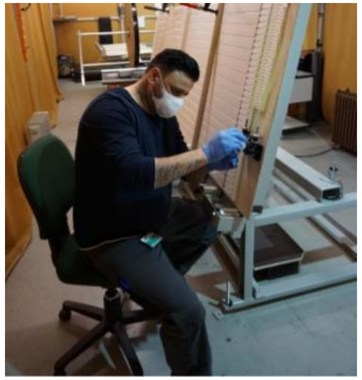
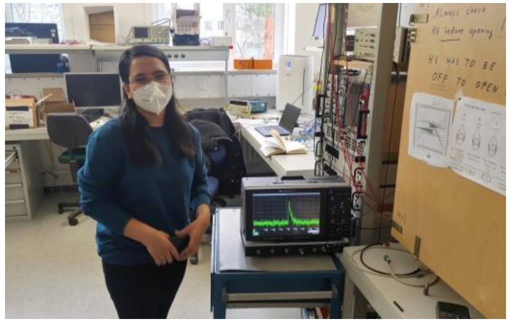
Covid-19 “impact”

Before

Now





“Placeholder” for

Andreas W. & Bernd

Günter & Heiko

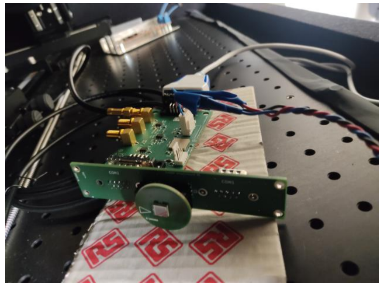
- Fixed “work couples”
- Laboratory use and office occupancy split by day
- Almost all meetings virtual
- Discussions during “walks” or/and limited times in offices

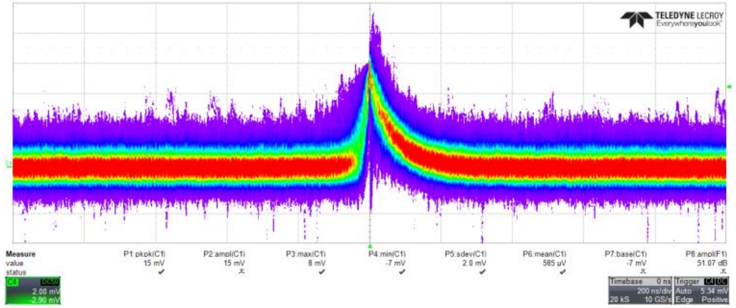
thomas.huber@kit.edu

Some examples of the functional tests for the scintillators

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 ?”

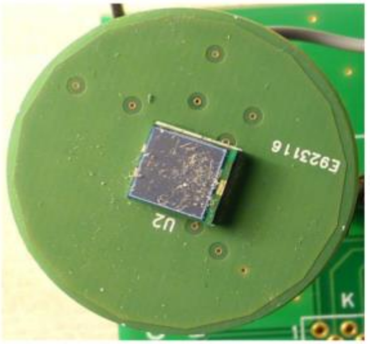


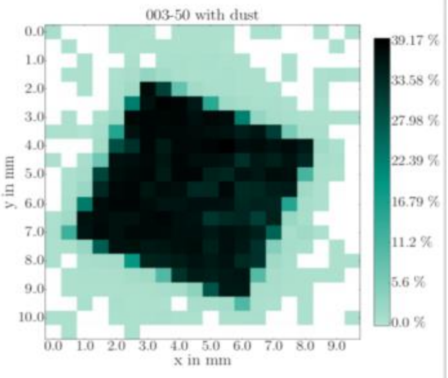


Shefali

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?





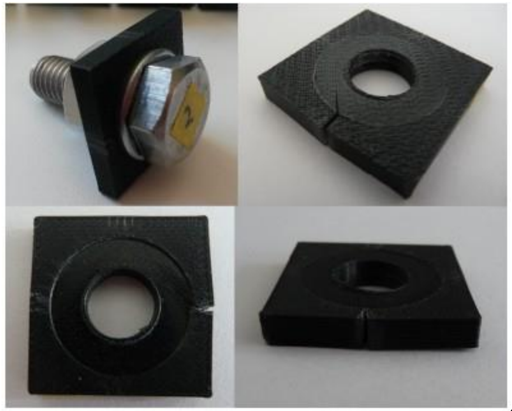
→ Photo Detection Efficiency (PDE) lowered around 10% at the top right area

M. Oehler

Low temperature stress tests of the used 3D printed components

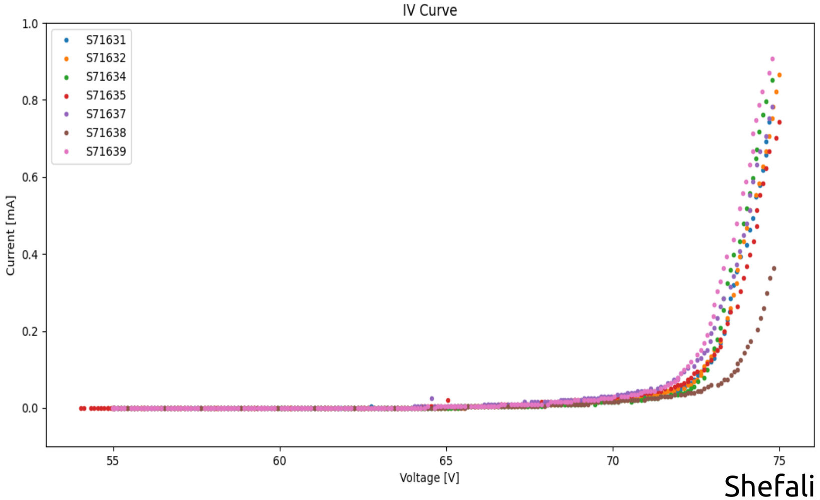
(and fibers, and scintillator bars, and and…)

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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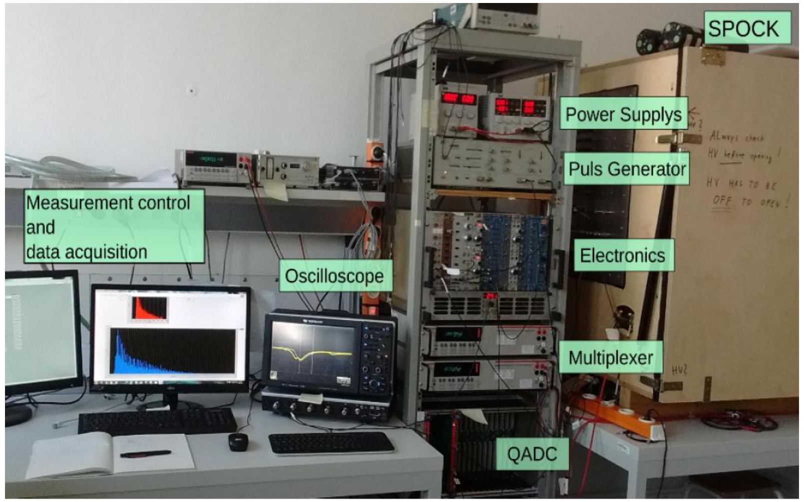
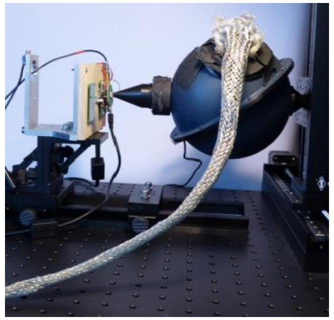
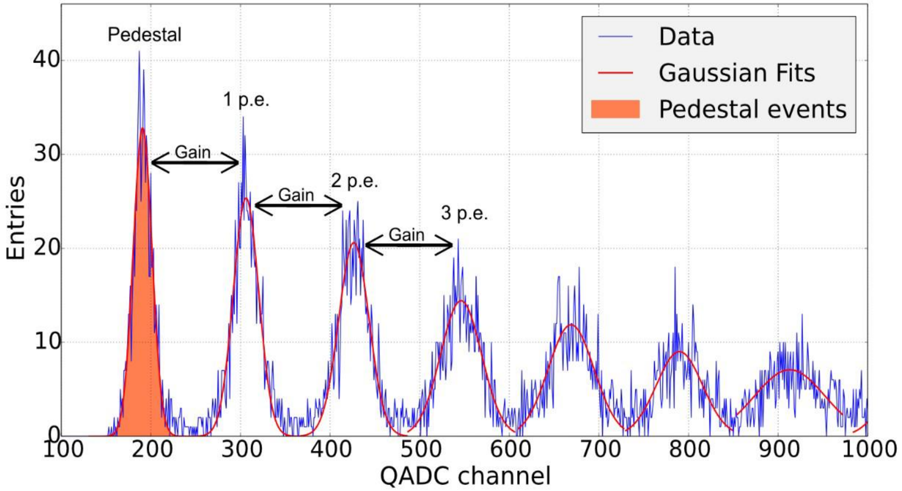
Example functional tests and SiPM calibration: "Finger spectra"

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

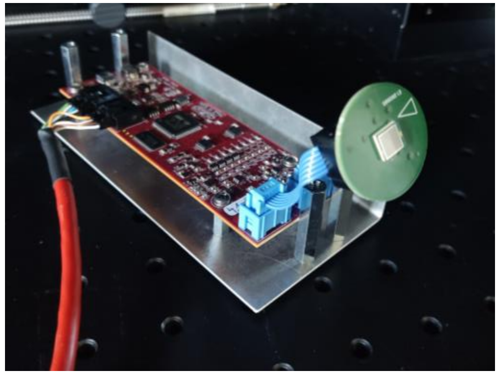


Single Photon Calibration Stand at KIT (SPOCK)

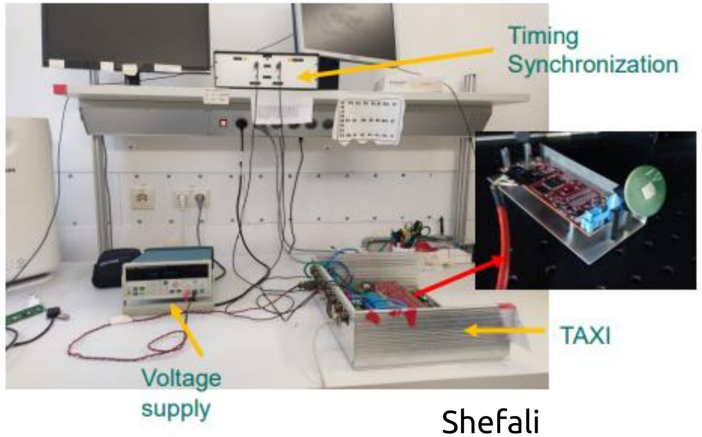




Finger spectra of a SiPM



SPOCK adjustments for new TAXI and new detector readout (uDAQ) ongoing



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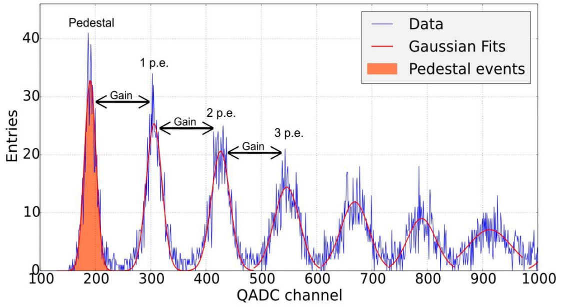
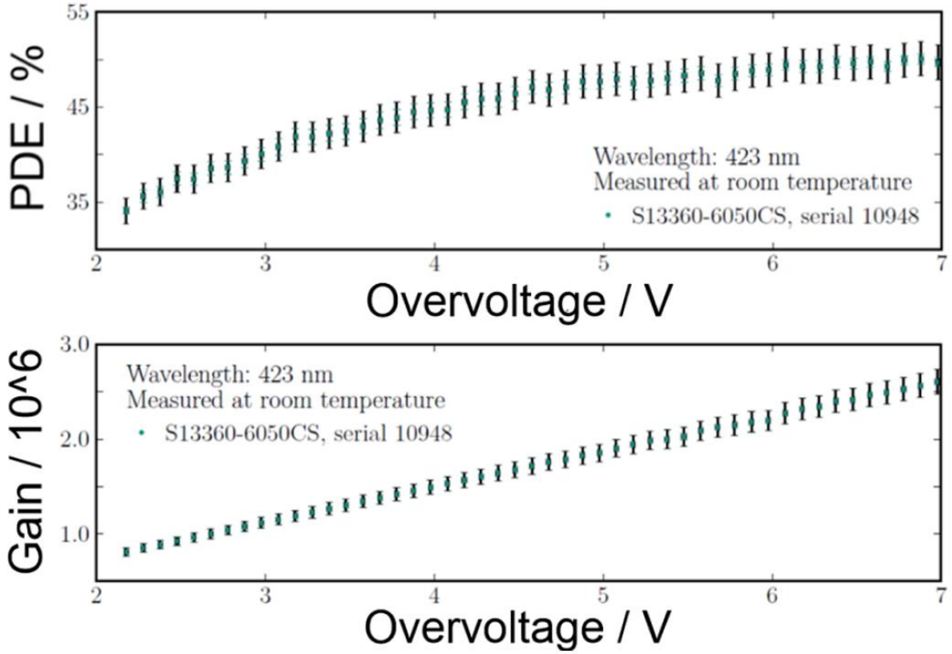
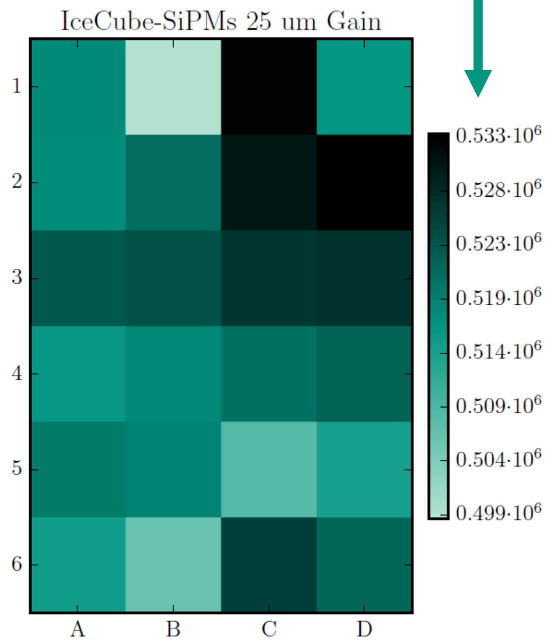
Example SiPM Cookie Board characterization – PDE & Gain at room temperature





One SiPM

2.2% variation



Variation of the SiPMs Gain

→ PDE: As example influences the PE/MIP light yield of the scintillator

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

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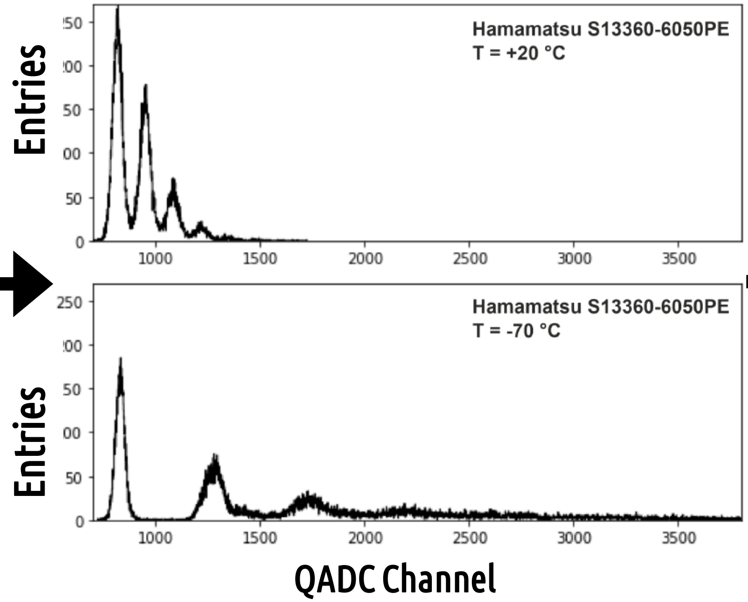
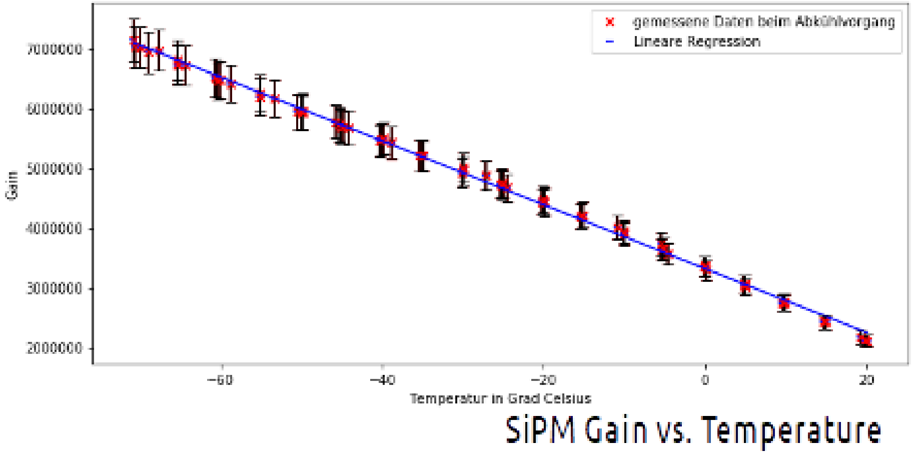
Example calibration: SiPM Gain at low temperatures

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





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

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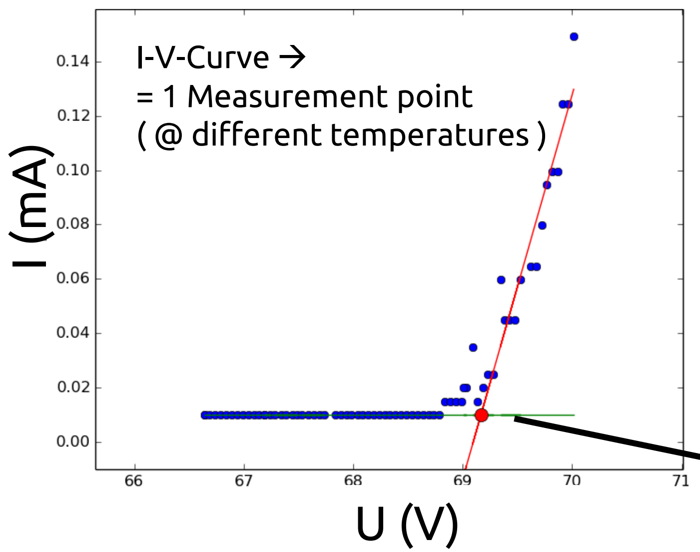
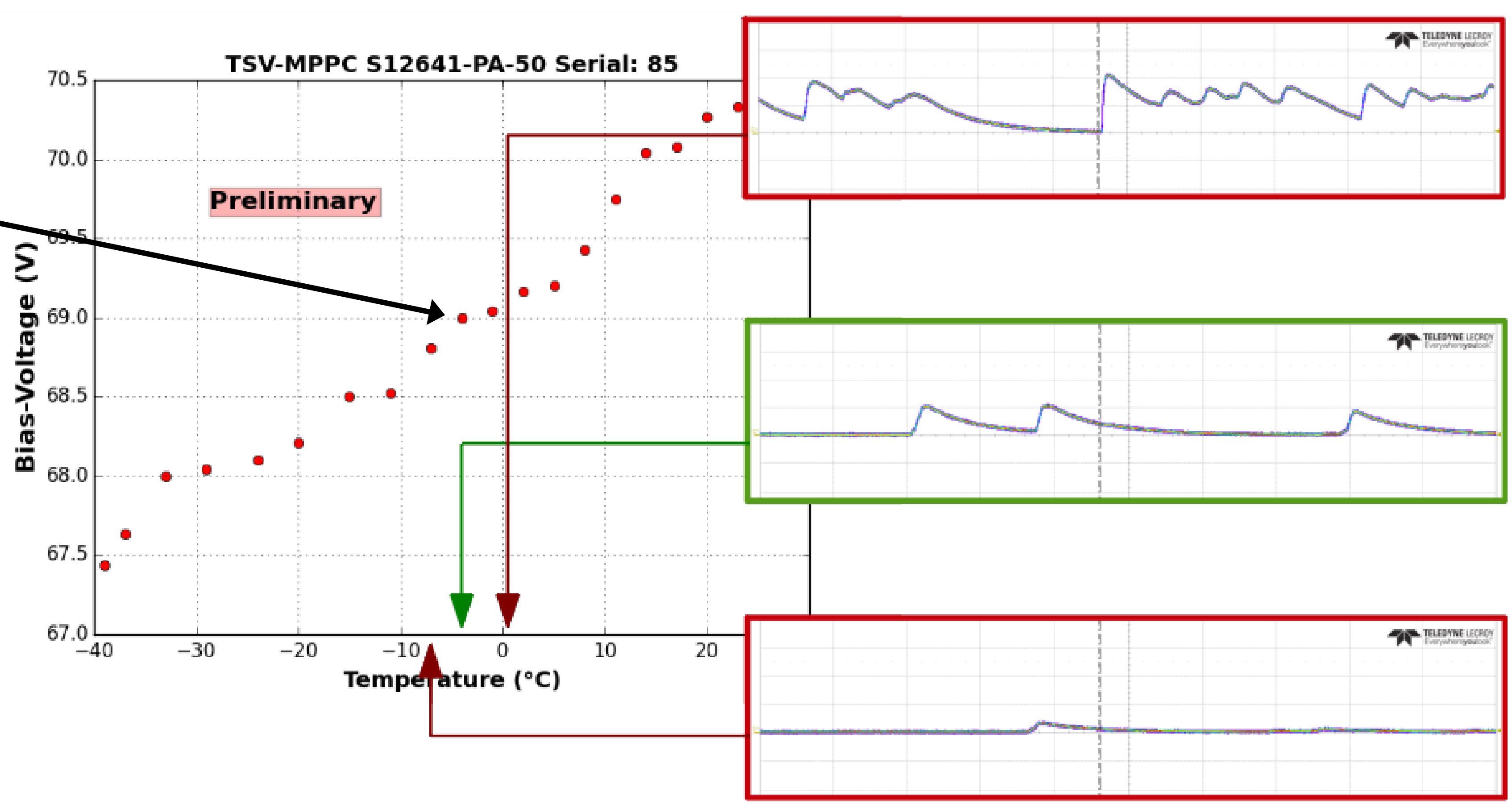
SiPM waveforms by not adjusting the bias voltage at different temperatures



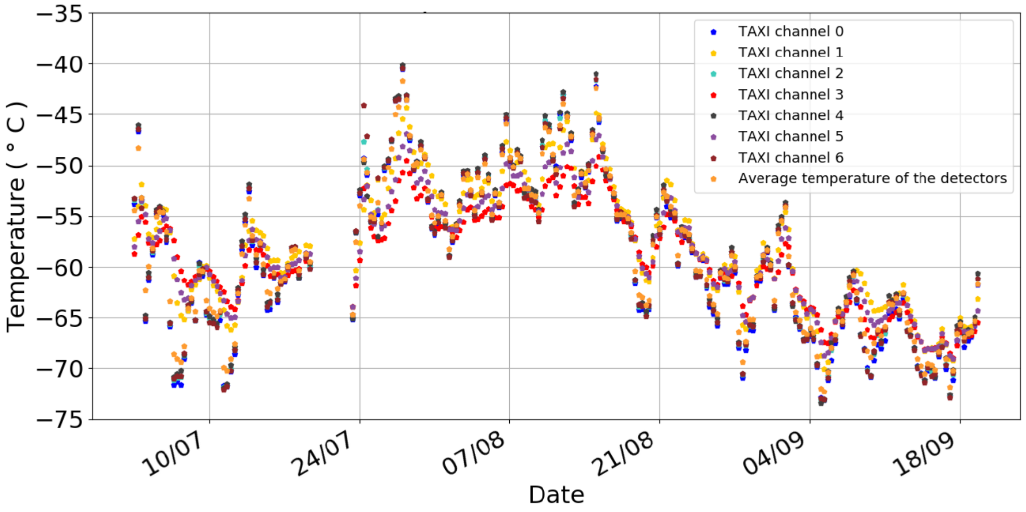
With a constant Bias-Voltage:



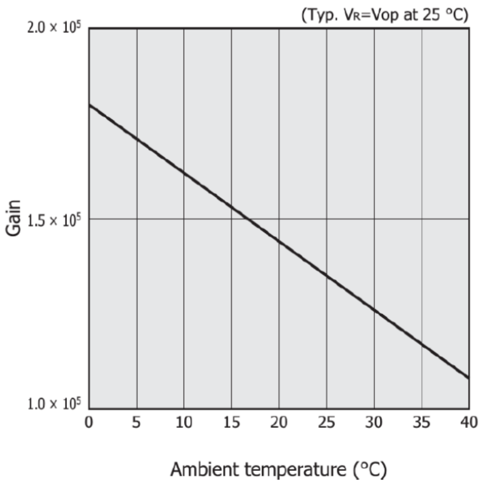
V: 50mV/div Timebase: 500ns/div

thomas.huber@kit.edu

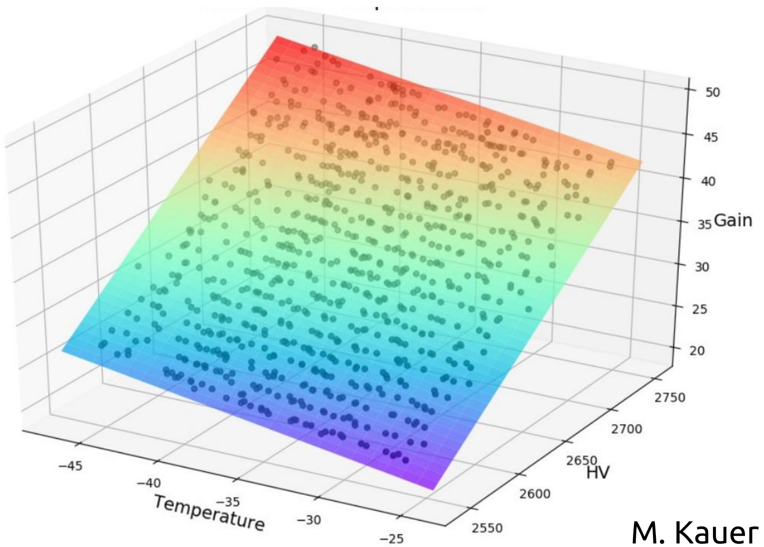
In-detector fluctuations of the temperature at the Pole



Temperature at the South Pole measured with Prototype station scint panels



Hamamatsu SiPM data sheet



M. Kauer

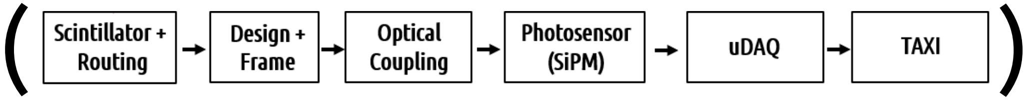
Example Control loop for one scintillation detector

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

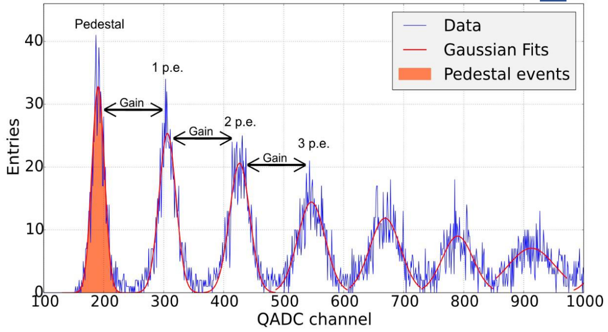
thomas.huber@kit.edu

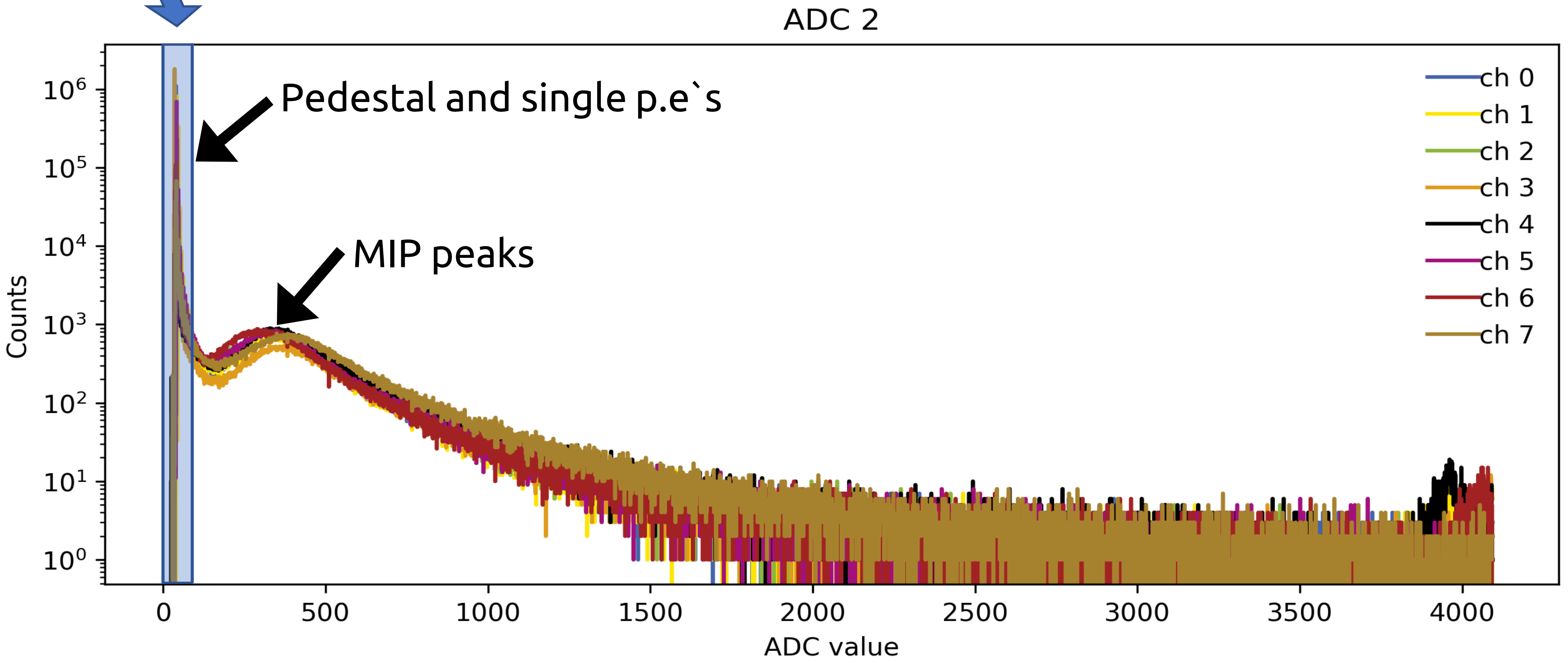
One goal of: Charge deposit uniformity

Understanding the whole readout chain



well enough to ensure an uniform detector array





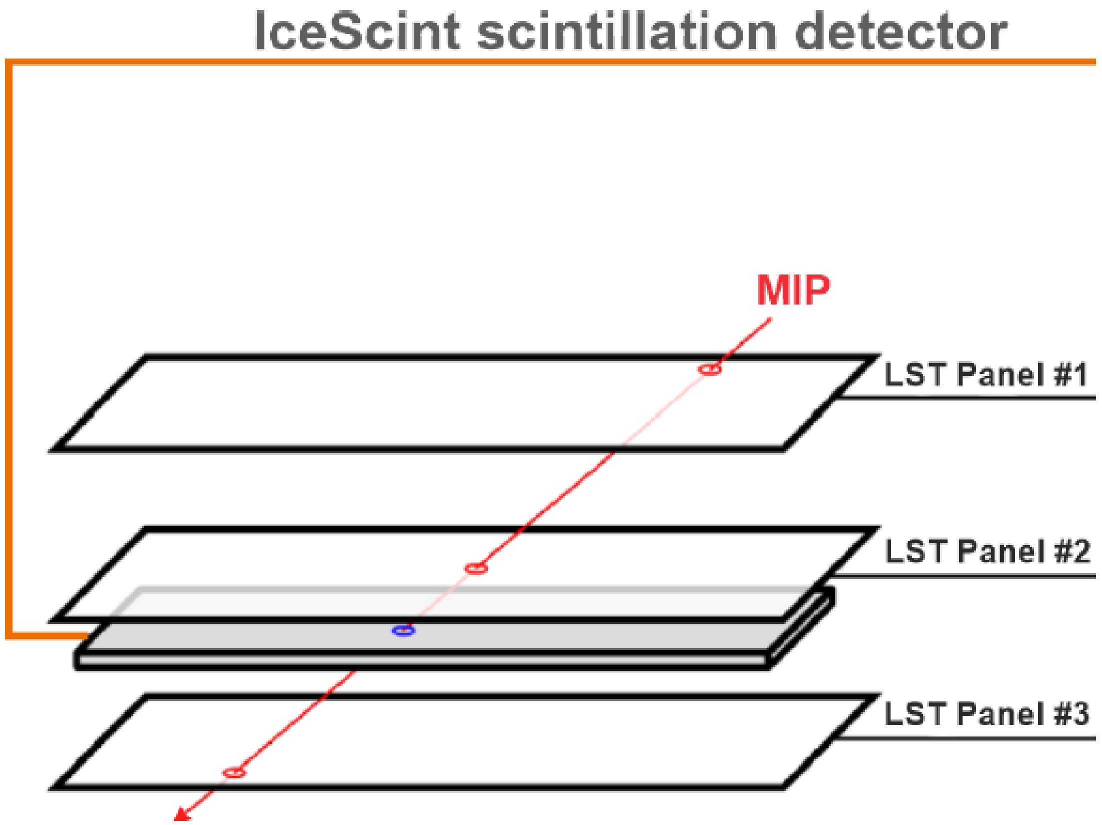
South Pole scintillator station data 2020 (M. Oehler)

thomas.huber@kit.edu

Muon Tower at KIT

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

Adjustments for new TAXI and new detector readout (uDAQ) ongoing



Schematic of the setup

Photo of the setup (2017)

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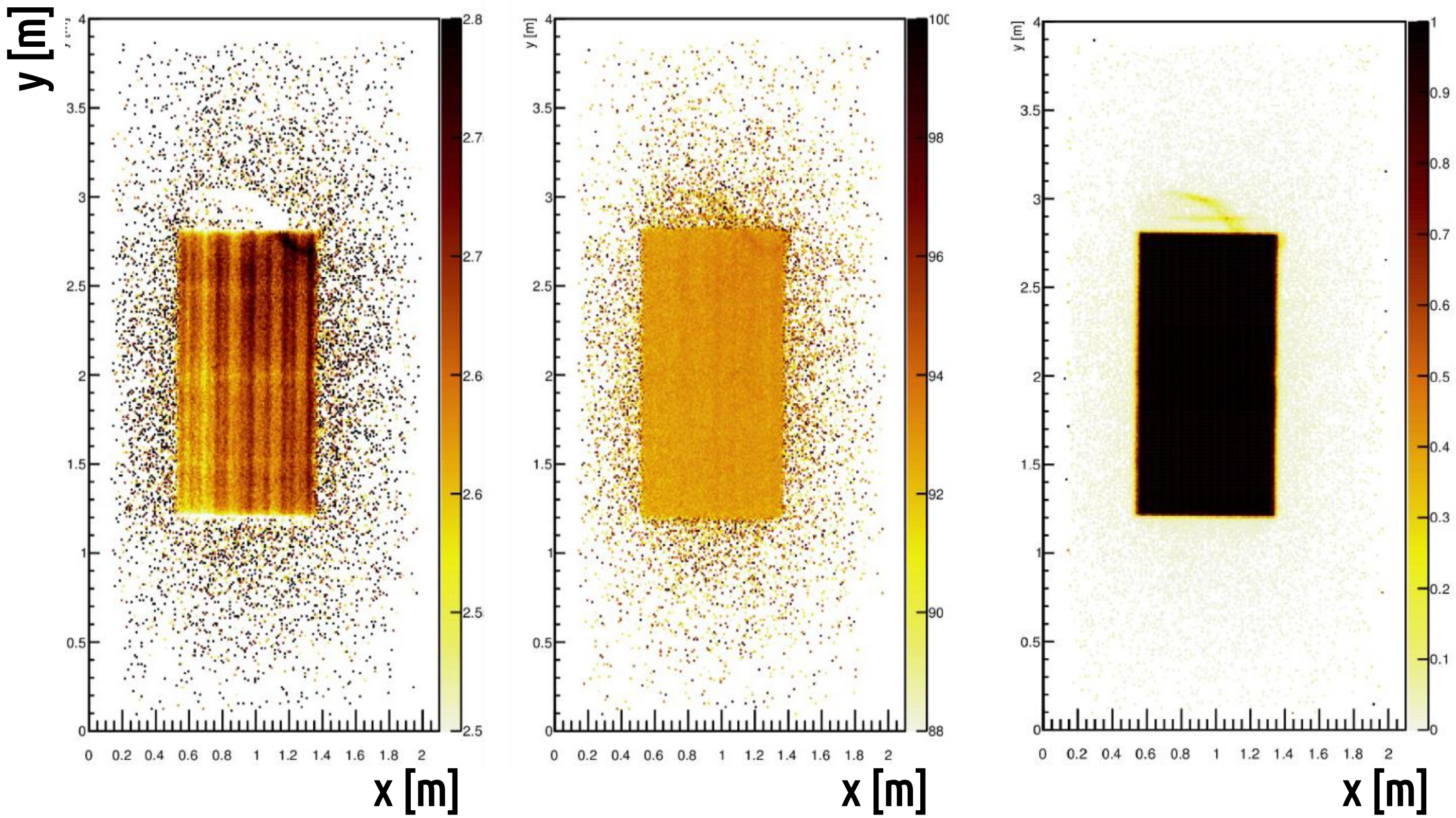
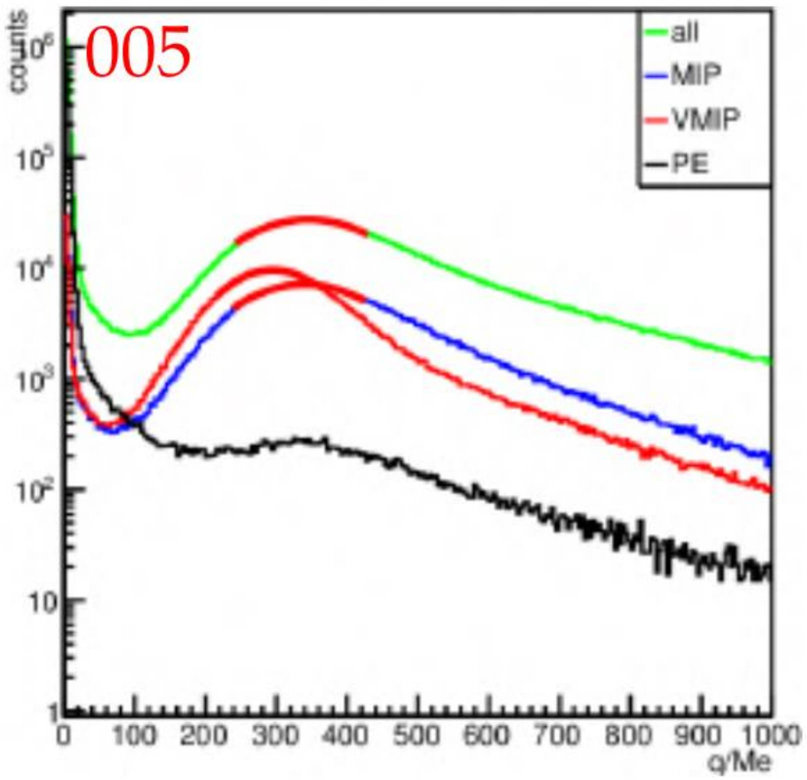
Muon Tower at KIT – Results with first batch (2017) of scintillators

ln(charge) <pulse width> efficiency



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

thomas.huber@kit.edu

Calibration results with first batch (2017) of scintillators

Muon tower PE/MIP results and SPOCK SiPM gain results for each detector

Time	Detector	Cookie Board	Gain	V_Bias+3V	MIP (all, Me)	PE per MIP	Gain SPOCK *10^5
07.08.2017, 09:42	002-25	9	High Gain	56,56	389,70	41,19	5,17
07.08.2017, 10:42	003-25	10	High Gain	56,58	416,00	45,56	4,99
07.08.2017, 16:00	004-25	11	High Gain	56,76	385,47	39,52	5,33
08.08.2017	005-25	12	High Gain	56,45	345,83	36,62	5,16
08.08.2017	006-25	13	High Gain	56,84	402,94	42,59	5,17
09.08.2017	007-25	14	High Gain	56,64	382,59	40,13	5,21
10.08.2017	008-25	15	High Gain	56,89	414,33	42,72	5,30
11.08.2017	009-25	16	High Gain	56.61	413,41	42,38	5,33
06.09.2017	010-25	17	High Gain	56,70	374,03	39,08	5,23
11.08.2017	011-25	18	High Gain	56,75	341,08	35,57	5,24
16.08.2017	012-25	19	High Gain	56,58	359,71	37,30	5,27
14.08.2017	013-25	20	High Gain	56,75	366,52	38,00	5,27
17.08.2017	014-25	21	High Gain	56,83	384,73	40,74	5,16
2. Run: 04.09.2017	015-25	22	High Gain	56,40	367,70	38,94	5,16
18.08.2017	016-25	23	High Gain	56,64	399,34	41,97	5,20
18.08.2017	017-25	24	High Gain	56,52	361,62	38,00	5,28
21.08.2017	018-25	25	High Gain	56,70	369,26	38,80	5,20
21.08.2017	019-25	26	High Gain	56,32	372,74	39,17	5,23
22.08.2017	020-25	27	High Gain	56,51	394,84	41,49	5,15
22.08.2017	021-25	28	High Gain	56,40	354,14	37,22	5,12
23.08.2017	022-25	29	High Gain	56,52	369,49	38,83	5,10
23.08.2017	023-25	30	High Gain	56,53	352,81	37,08	5,20

Notes SPOCK measurements:

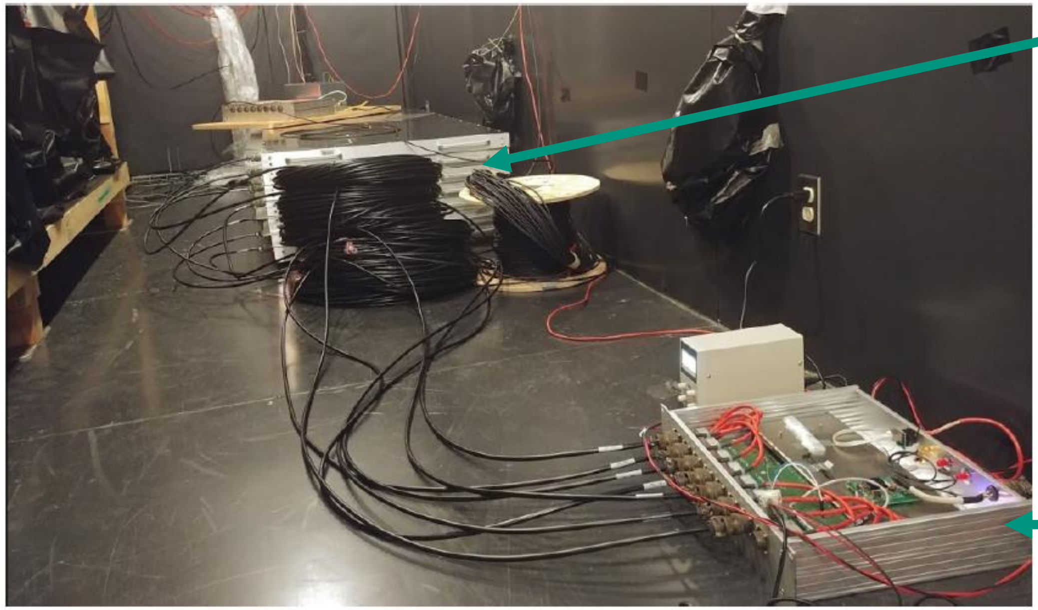
Room temperature and a light source wavelength of 423 nm

Notes muon tower measurements:

010-25:	Strange signal behaviour in first run due to new power supply of muon tower
015-25:	Second Run: Changed PWR cable GPB->ARM

Next step(s): Full system test in Madison / PSL cooling chambers

2017 (and 2019) :



Scintillators

TAXI
(Older version)

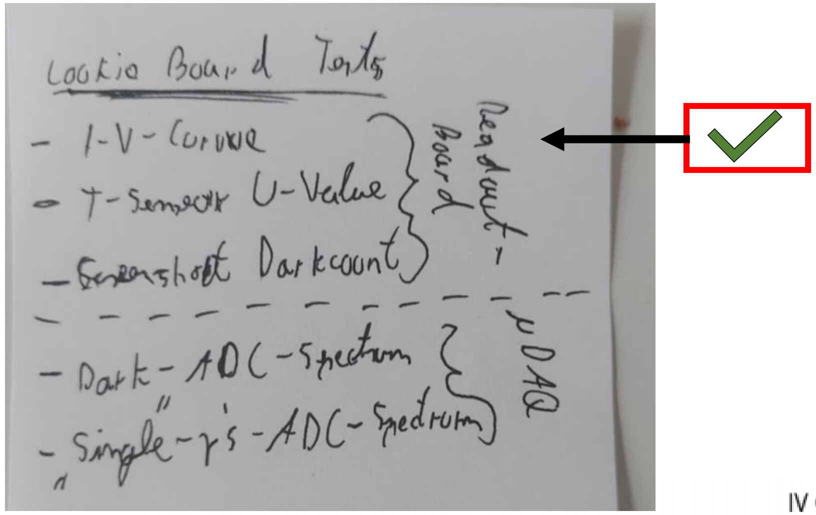
Necessary (among others…) :

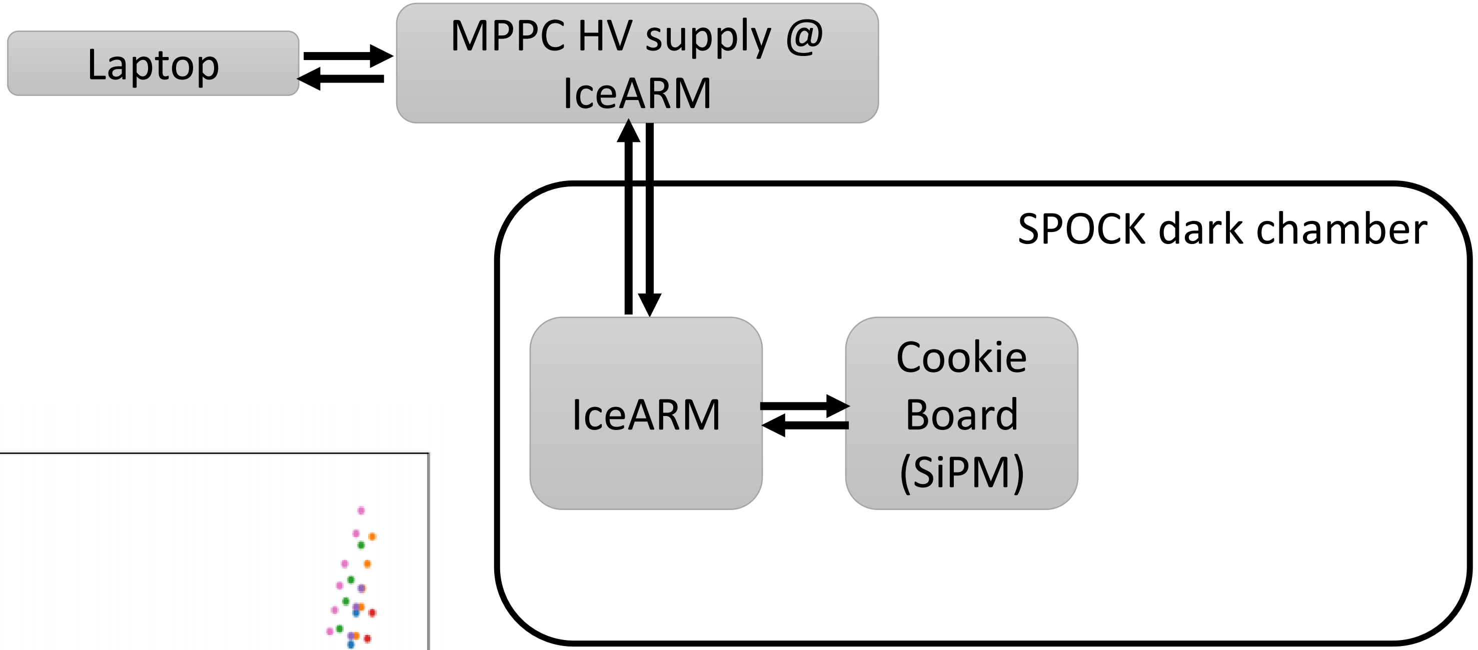
- A calibrated “ready to ship” TAXI
- Finishing the calibration setups with uDAQ and TAXI in the labs
- Understanding Scintillator panel readout <-> TAXI pipeline
- 8 fully calibrated scintillators at room temperature
- A “full system test” at room temperature at KIT

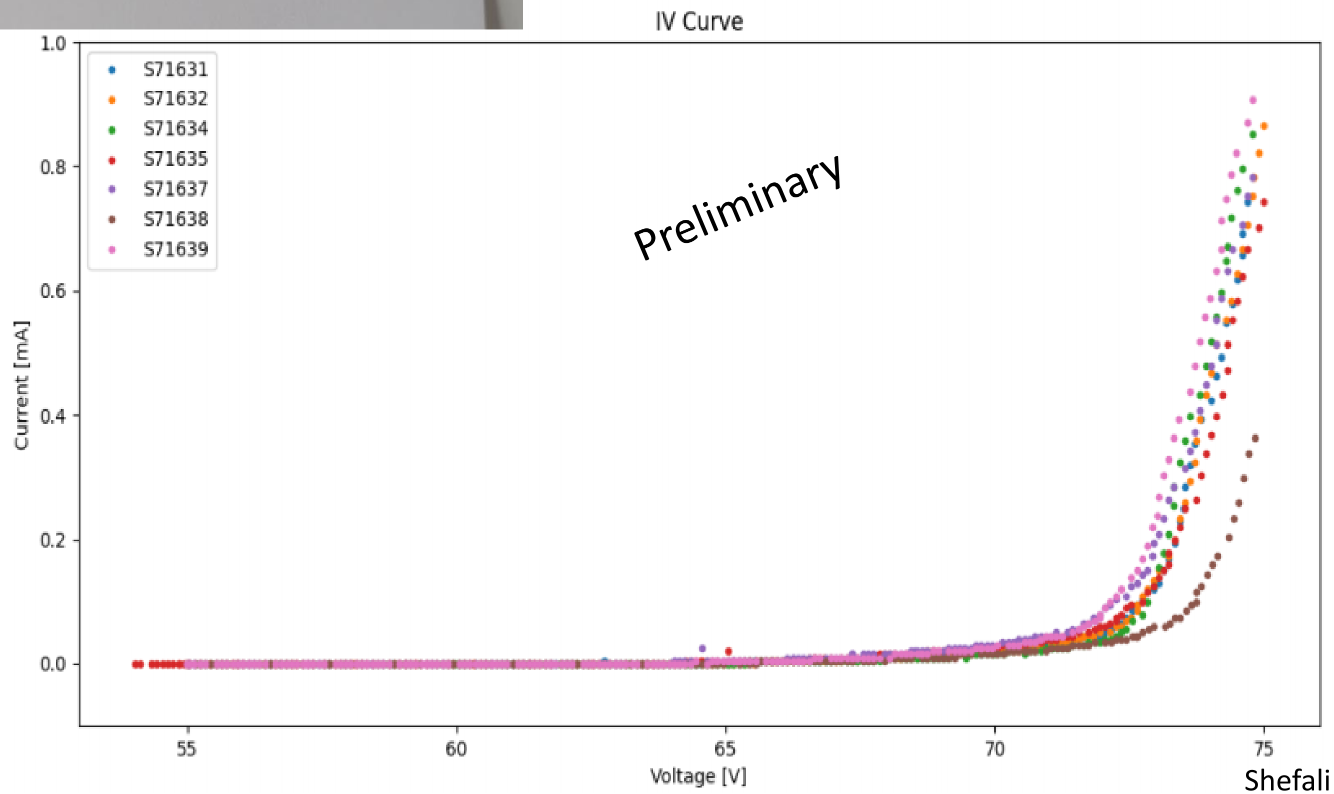
thomas.huber@kit.edu

Additional Slides

Status SPOCK Lab for uDAQ / Cookie Board / Scints (roughly): IV-Curve, breakdown voltage



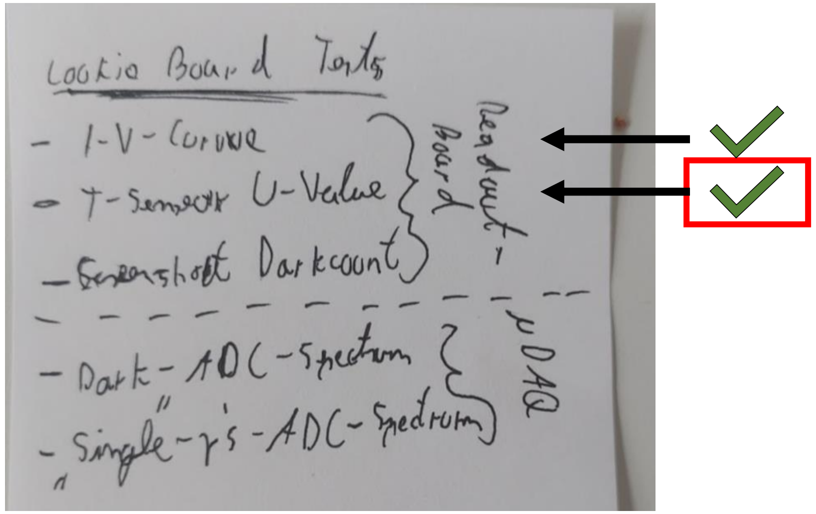


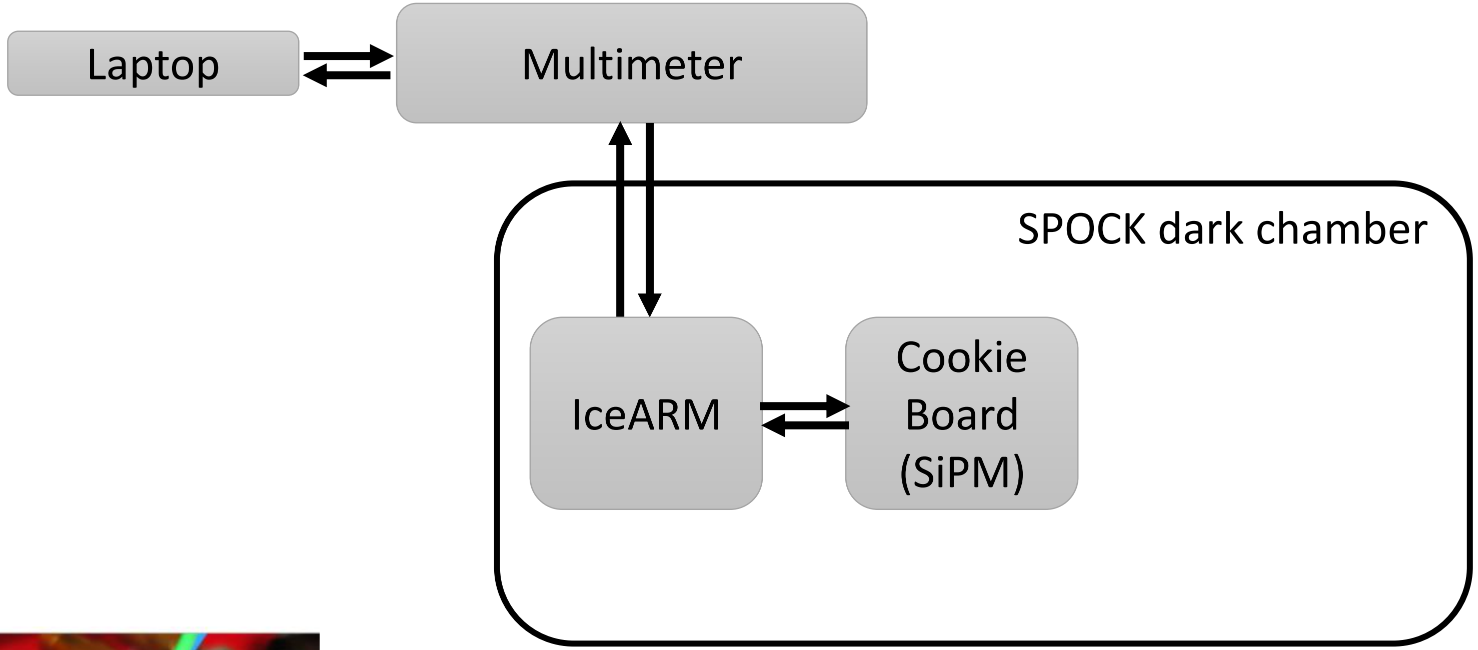


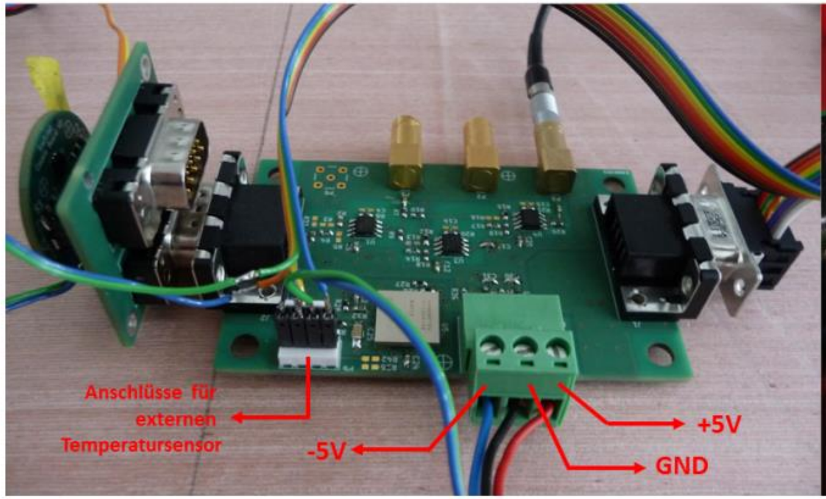
Shefali

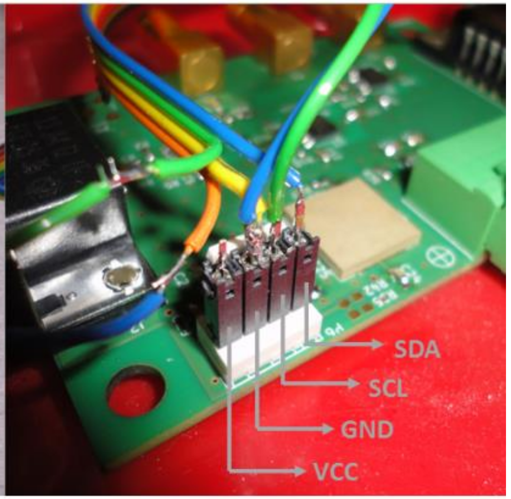
thomas.huber@kit.edu

Status SPOCK Lab for uDAQ / Cookie Board / Scints (roughly): Temperature sensor test







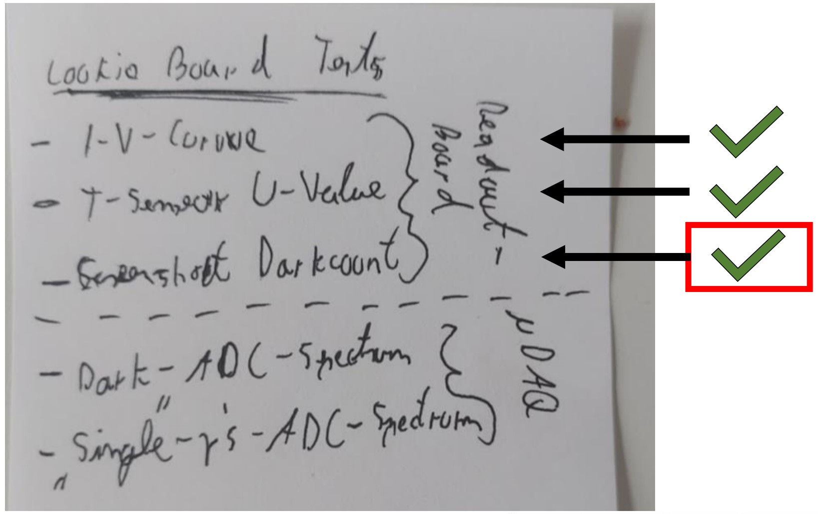


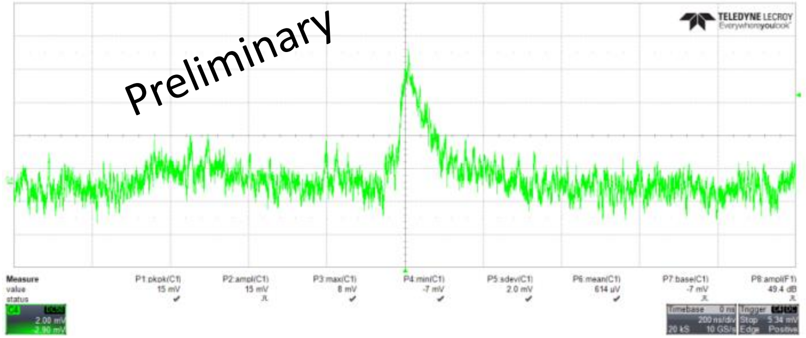
Cookie-Board	Spannung in mV	gemessene Temperatur
003-50	892	26,09
004-50	888	26,82
005-50	891	26,28
006-50	893	25,91

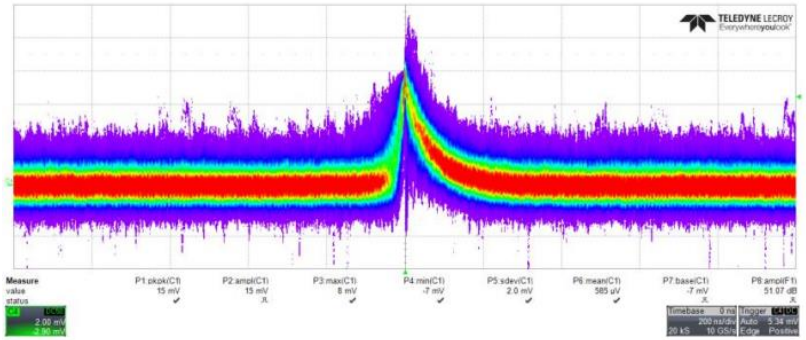
Exemplary

thomas.huber@kit.edu

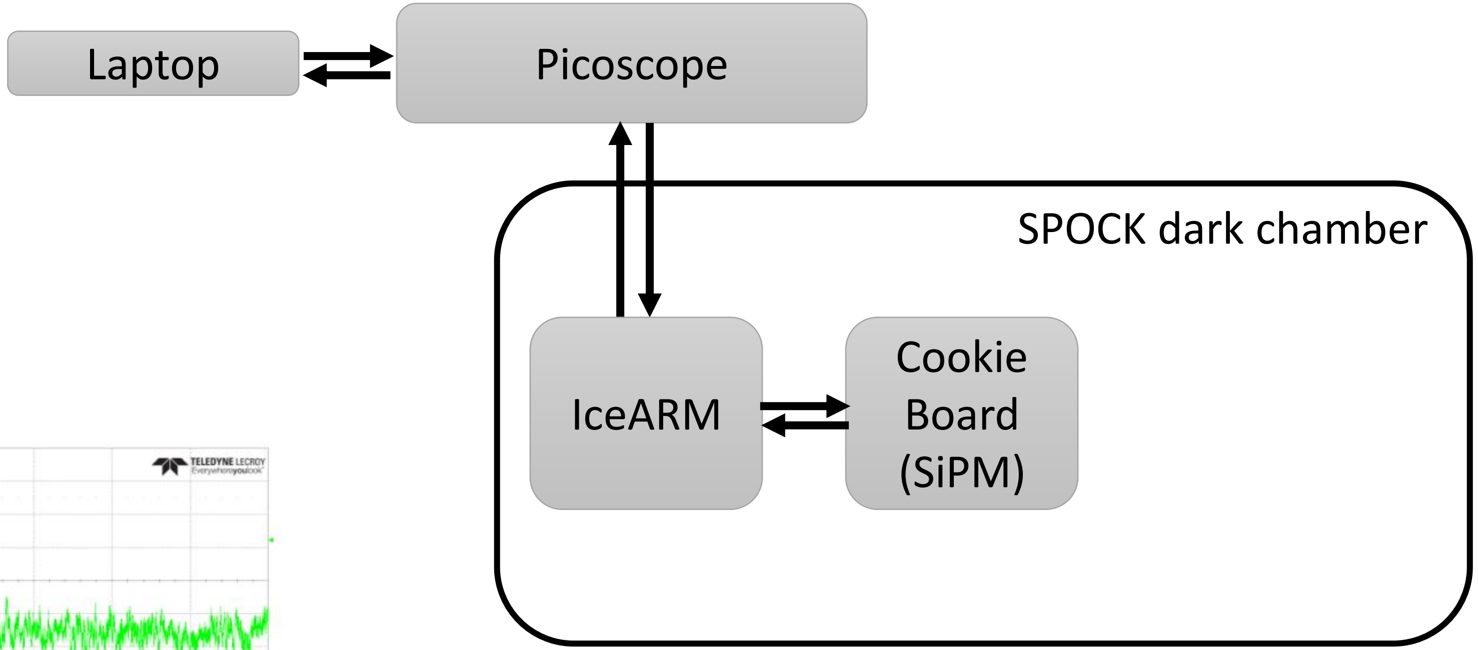
Status SPOCK Lab for uDAQ / Cookie Board / Scints (roughly): Checking SiPM waveforms w. Cookie boards





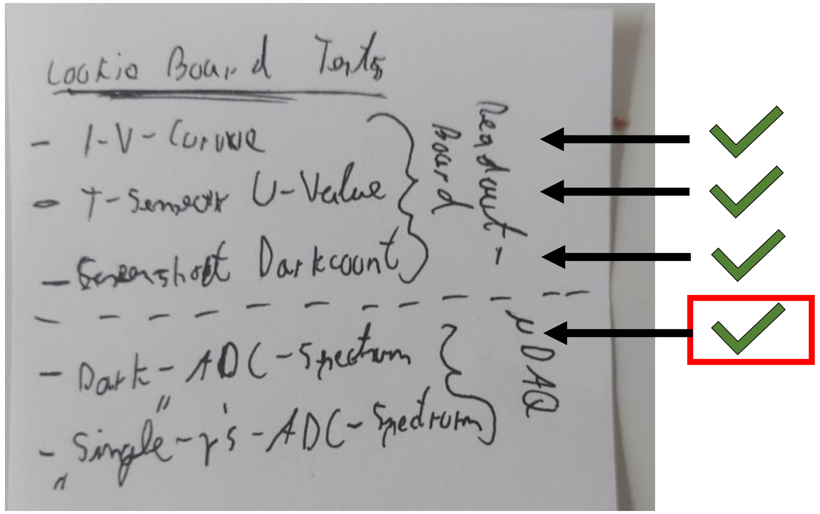


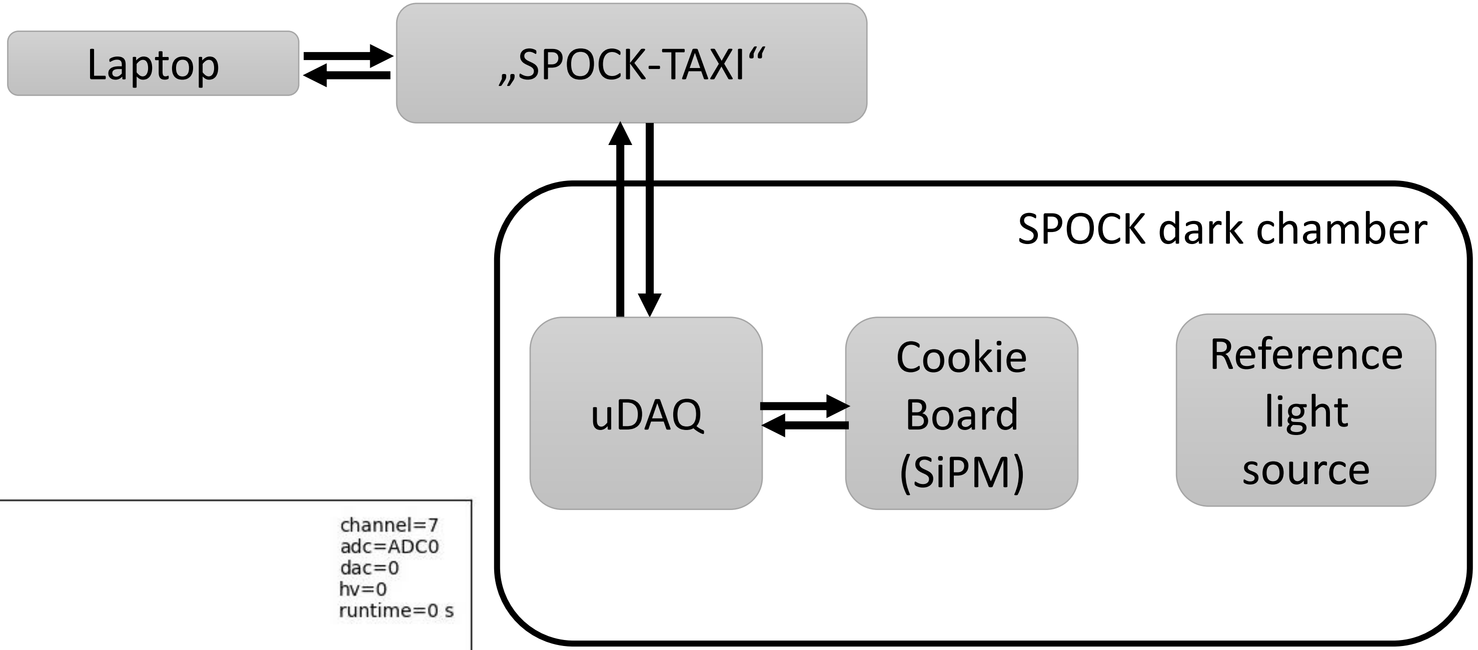
Shefali

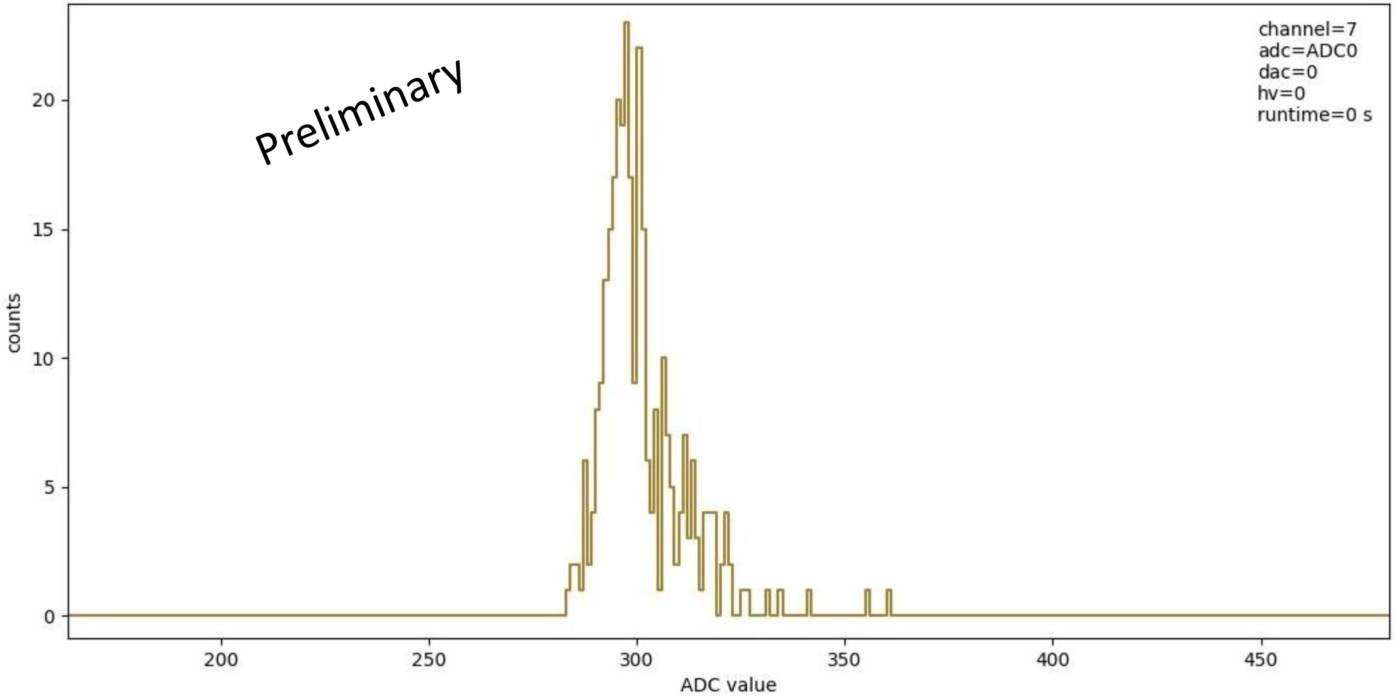


thomas.huber@kit.edu

Status SPOCK Lab for uDAQ / Cookie Board / Scints (roughly): Dark count spectra







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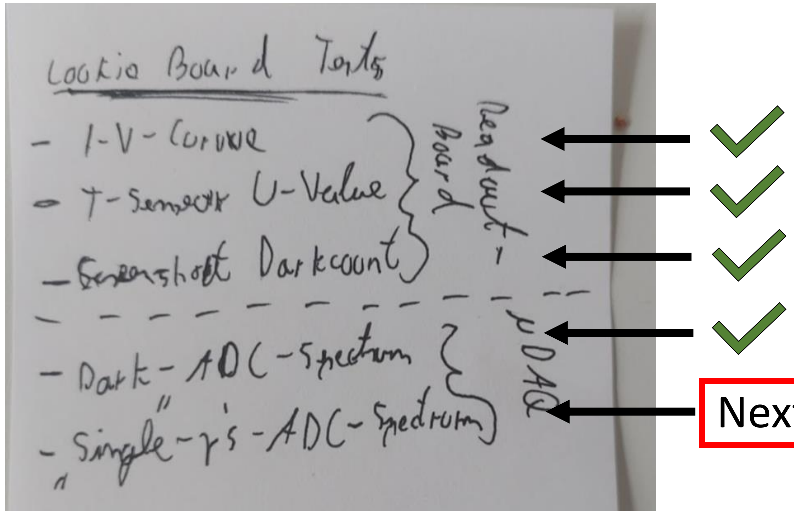
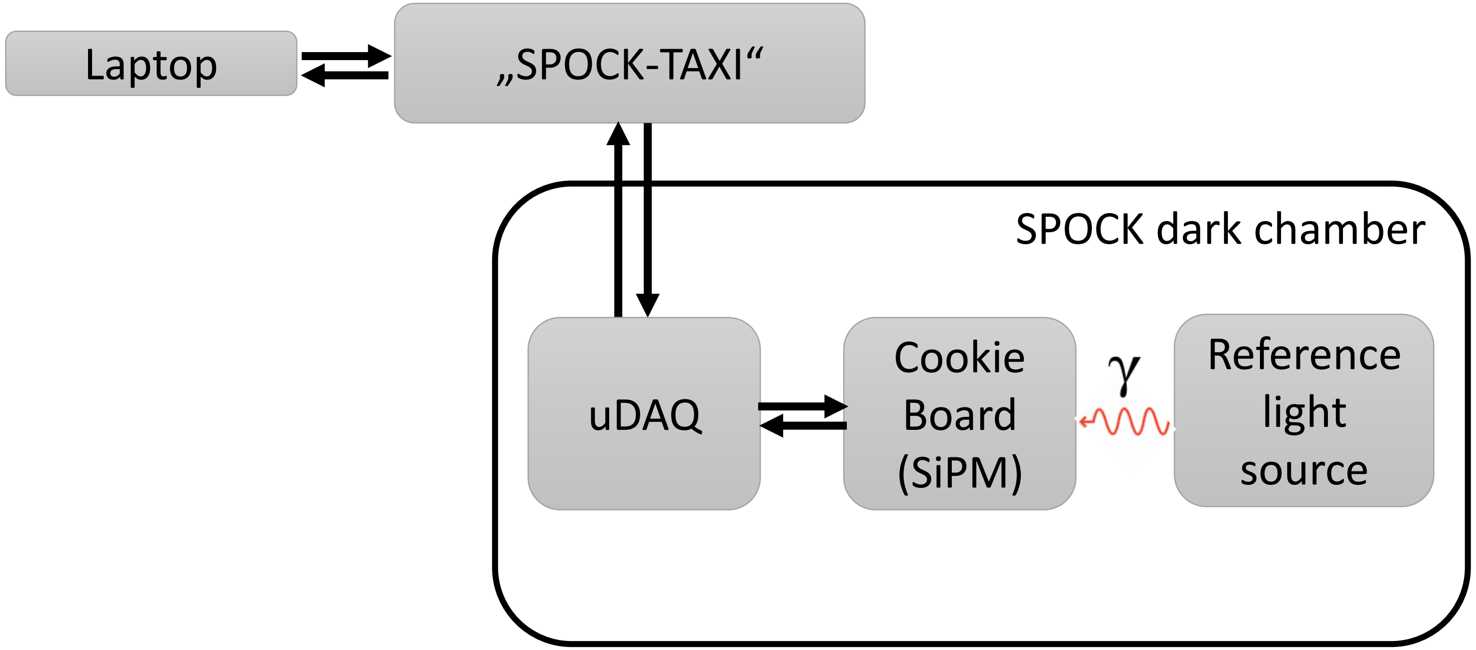
Status SPOCK Lab for uDAQ / Cookie Board / Scints (roughly): Finger spectra



Next step



thomas.huber@kit.edu

Muon tower measurements with uDAQ

Before (Old IceScint panels):

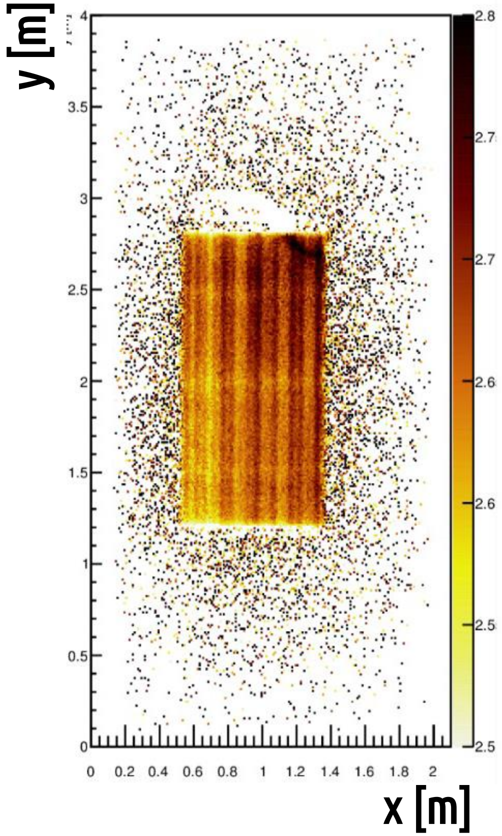
- Analog Signal of the IceScint Detector
- 3x Analog Signal of the Muon Tower LST panels

- Waveform integration for the charge deposit
- mean pulse width calculation

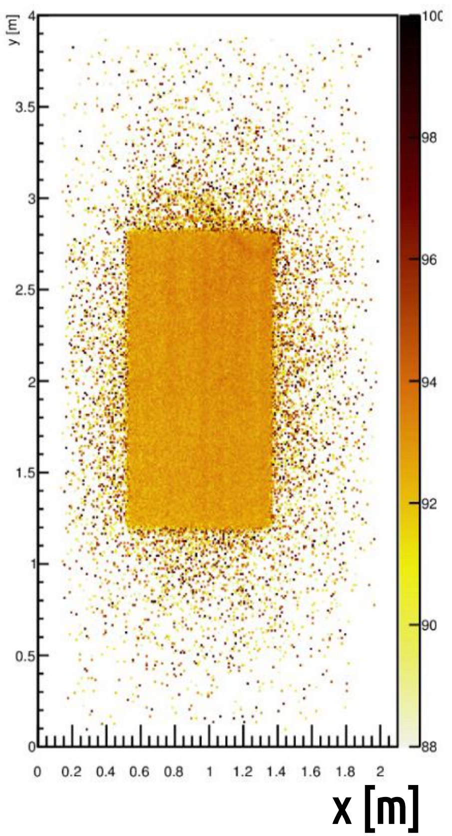
done by muon tower DAQ and software

Resulted in:

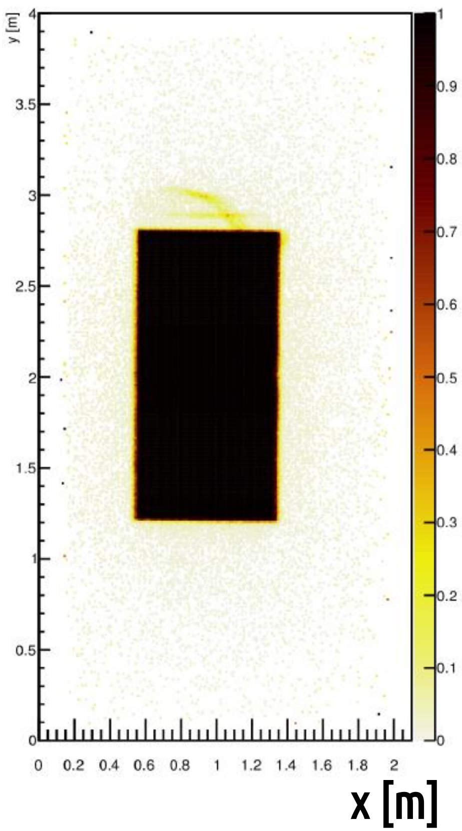
ln(charge)

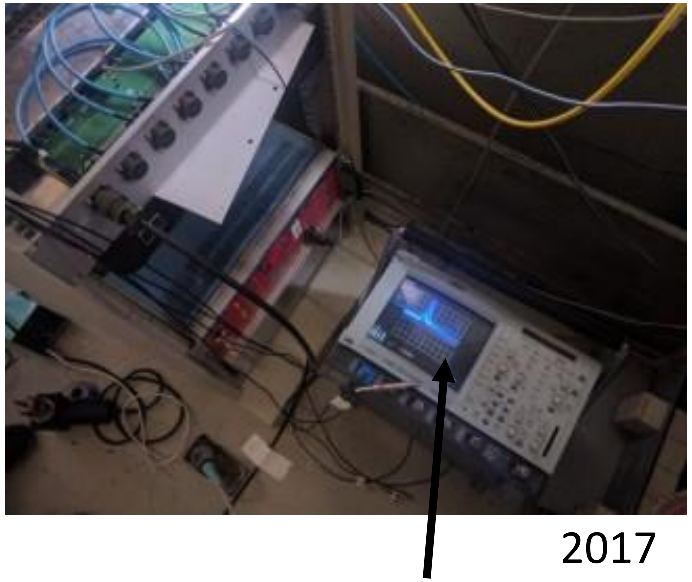


<pulse width>



efficiency





2017

Muon tower measurements with uDAQ

Now (New IceScint panels):

- No waveform, integrated charge deposits of the IceScint Detector
- 3x Analog Signal of the Muon Tower LST panels

But:

- uDAQ trigger out for radio antennas…!

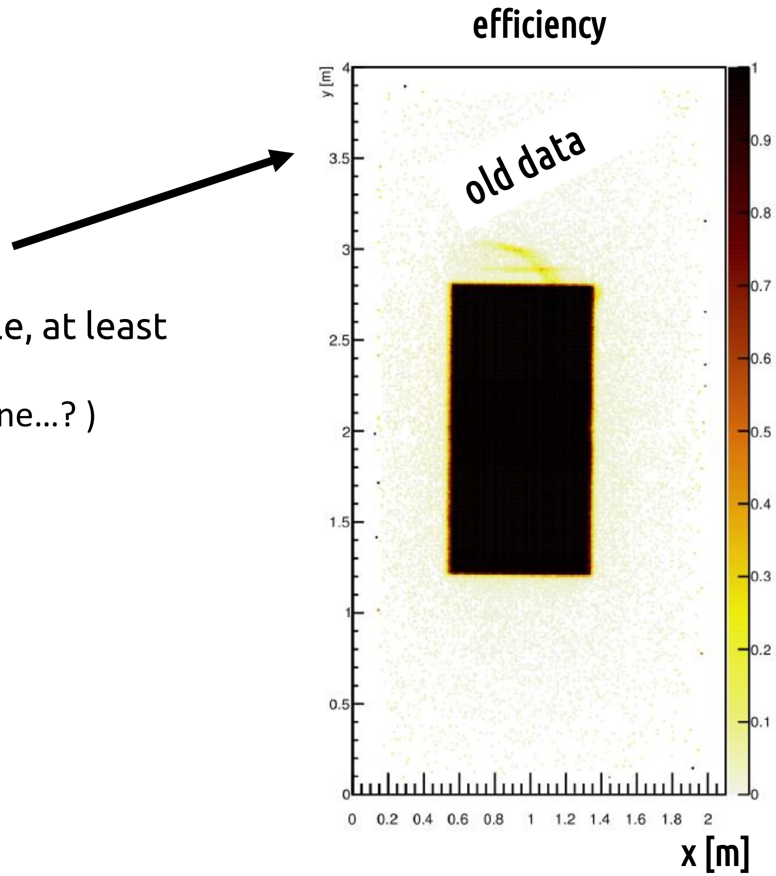
→ Via the new TAXI →

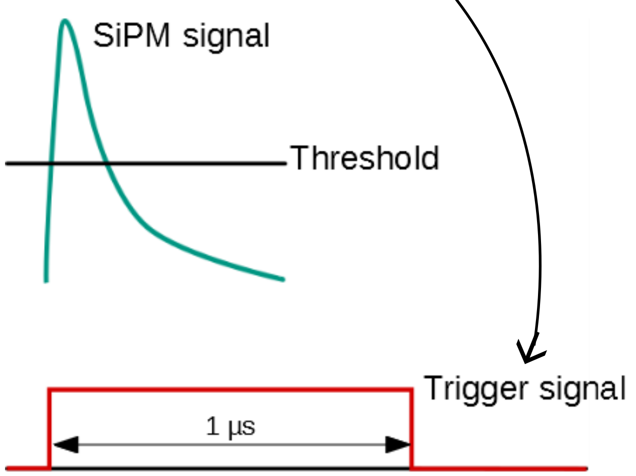
→ Trigger signal seen by muon tower DAQ and software

Results in:

Time will tell ☺

Should be doable, at least
(and probably the
most important one…?)



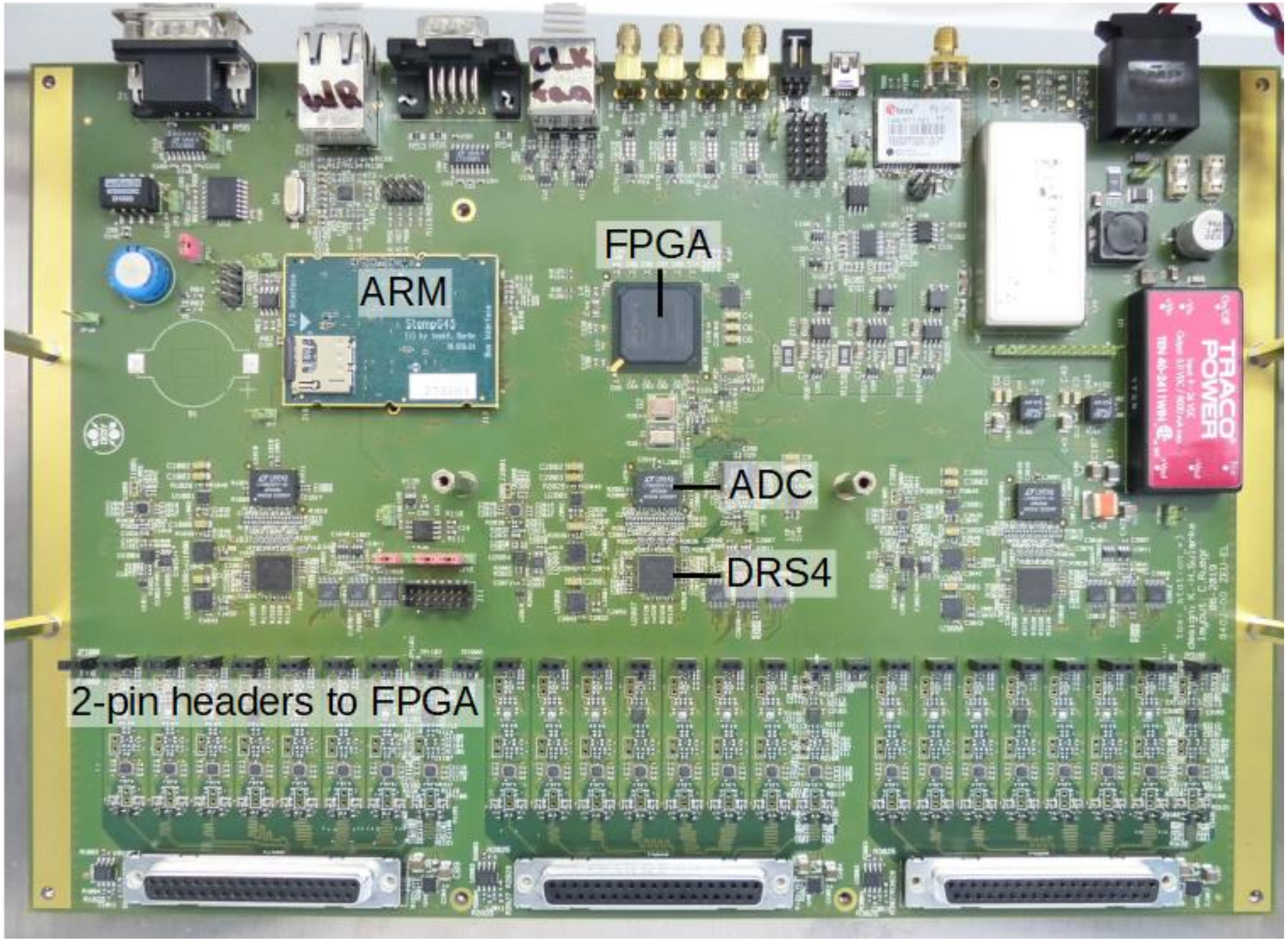


uDAQ trigger signal (red) sent to radio antennas

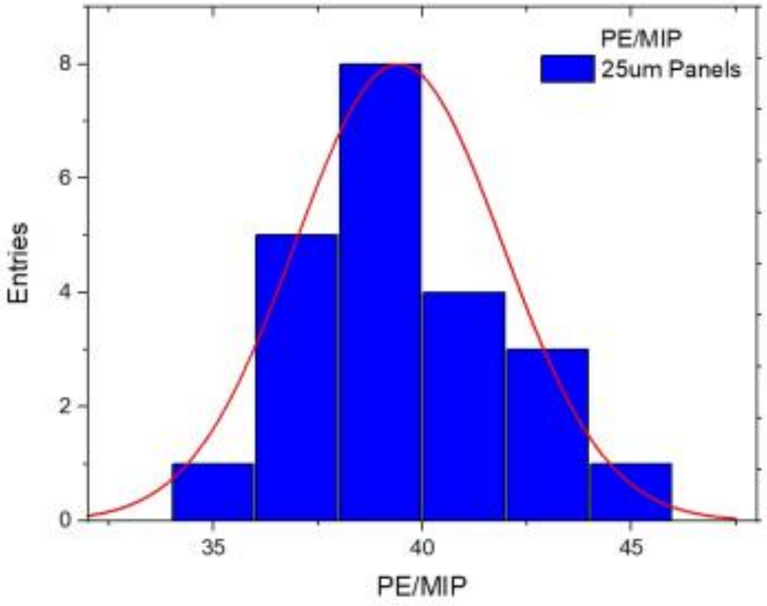
Equals:

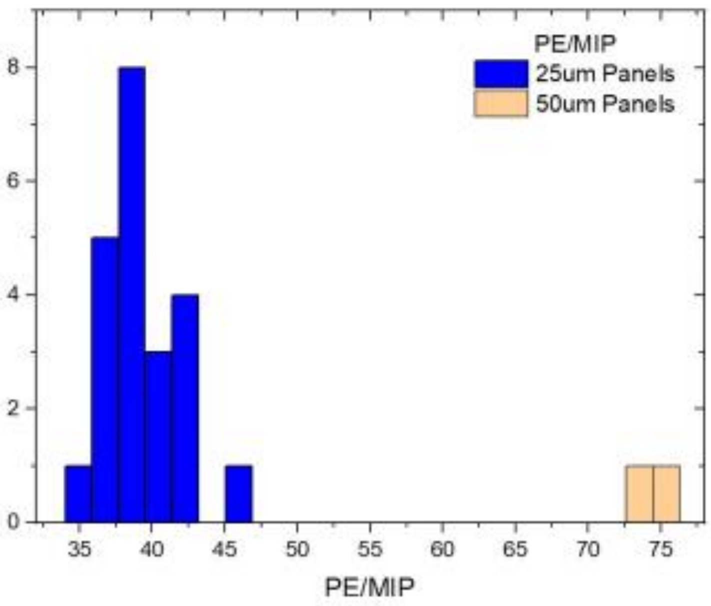
→ uDAQ trigger signal (red) sent to the muon tower DAQ

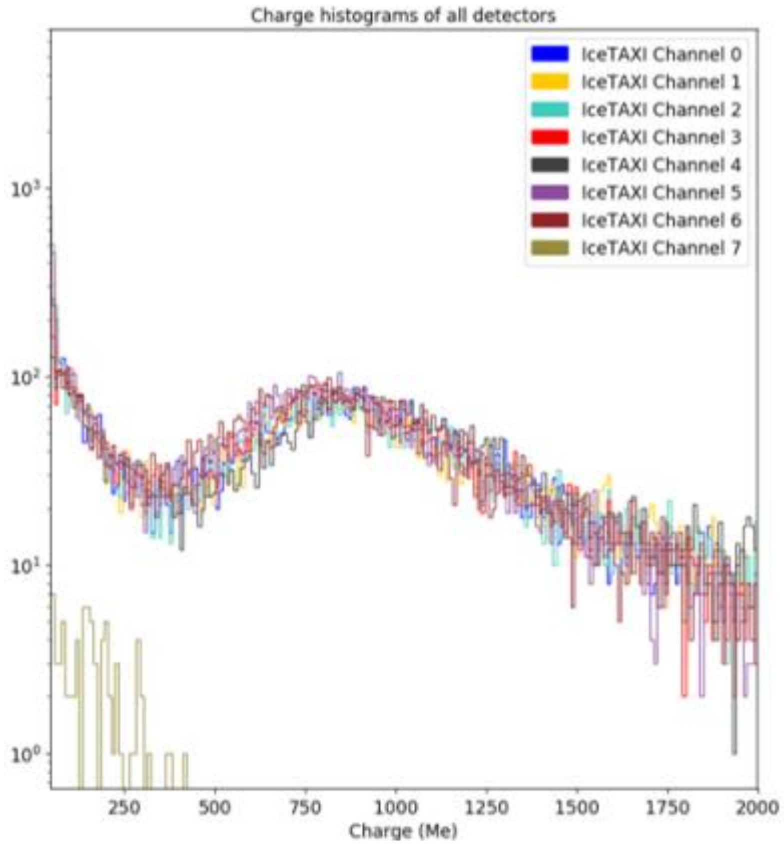
TAXI Mainboard



Distribution PE/MIP of the first 24 scintillation detectors

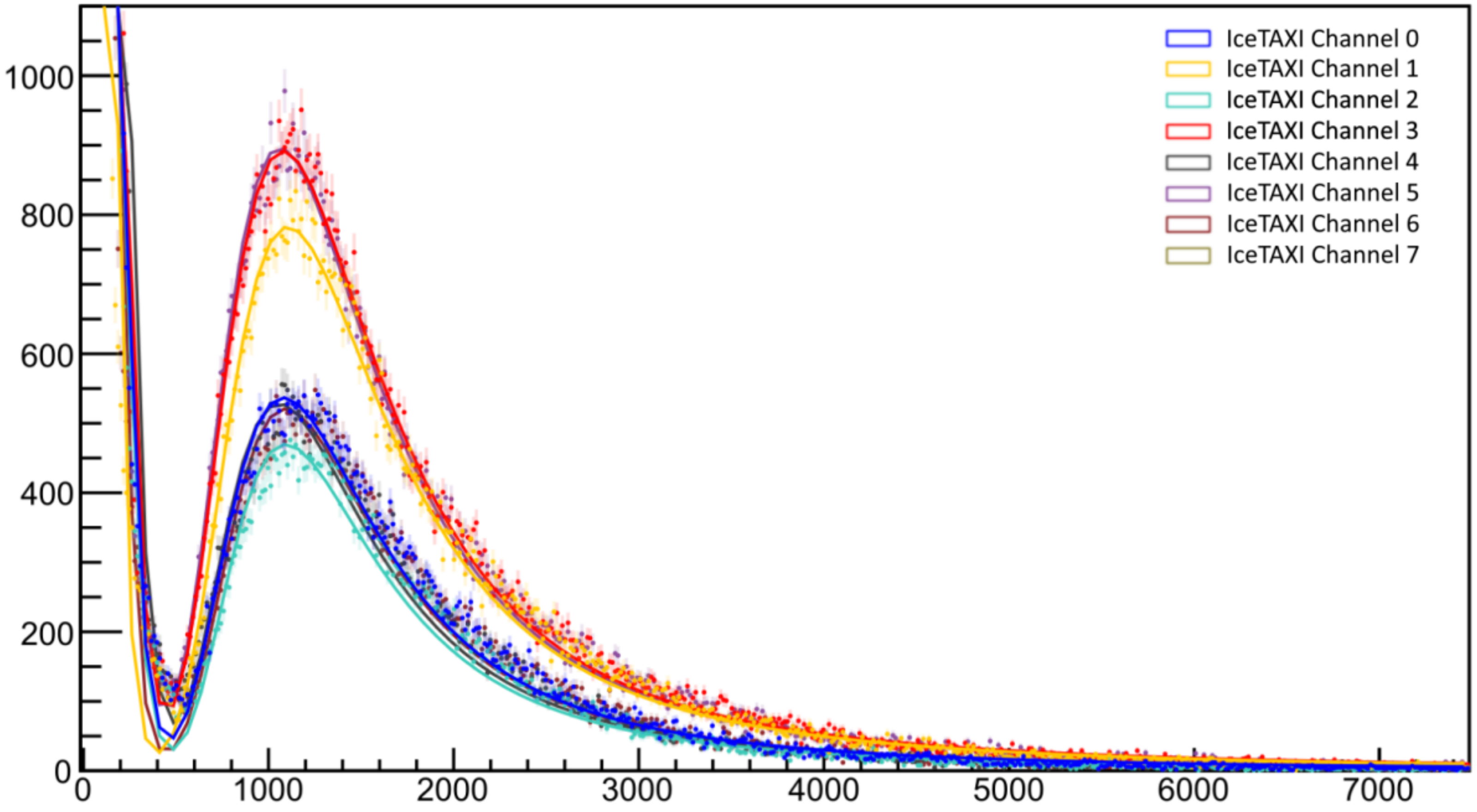






Maximum	$45.55\ \frac{PE}{MIP}$
Minimum	$35.56\ \frac{PE}{MIP}$
Mean	$39.43 \pm 0{,}57\ \frac{PE}{MIP}$
σ	2.47

Charge spectra fit season 2017 scint panels

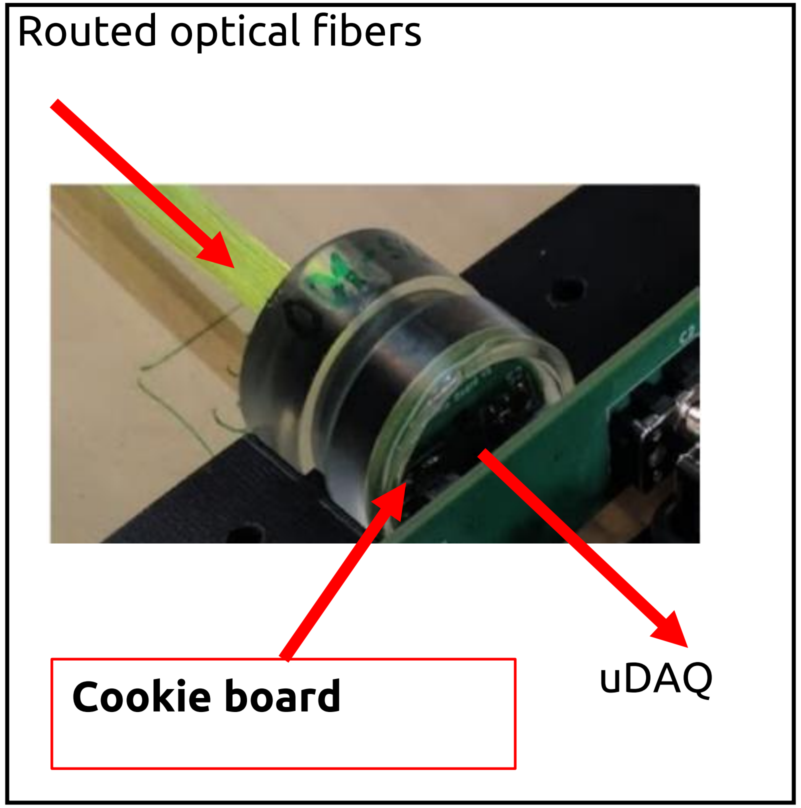


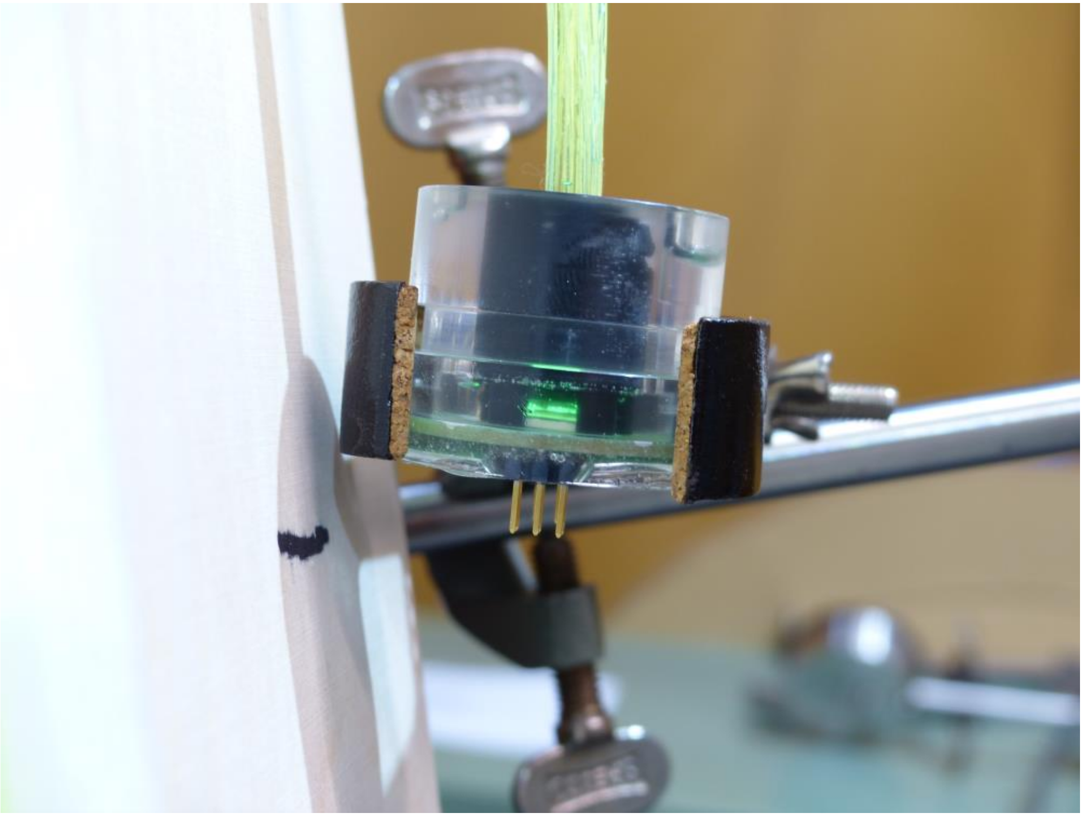
$$p(x) = p_0 \cdot \frac{1}{p_2\sqrt{2\pi}} \exp\left(-0.5\left(\frac{x-p_1}{p_2} + \exp\left(-\frac{x-p_1}{p_2}\right)\right)\right) + \exp(p_3 + p_4 \cdot x) + \exp(p_5 + p_6 \cdot x).$$

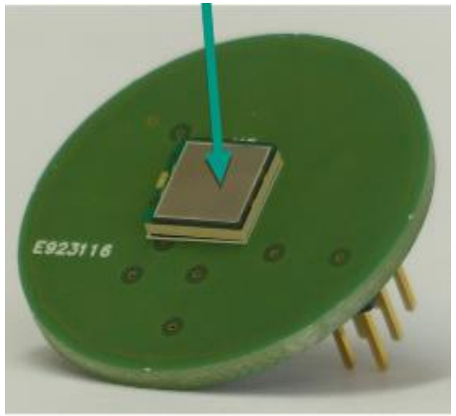
Fit Parameter Channel 3, LG

Entries	500
Mean	664.8
RMS	1056
χ^2/ ndf	8107 / 492
p0	4934 ±25.6
p1	1137 ±2.0
p2	270.2 ±1.1
p3	1.733e+04 ±6.082e+01
p4	−0.01497±0.00011
p5	1.805e+04 ±6.178e+01
p6	−0.01497±0.00010

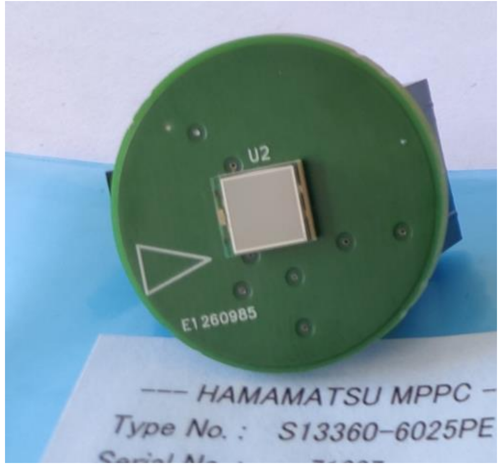
Optical Coupling SiPM / fiber bundle / Cookie Board

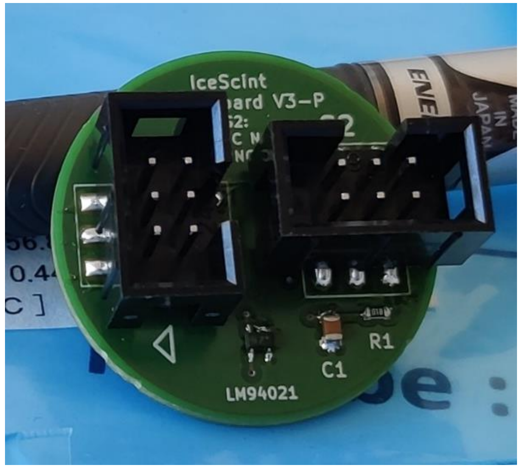


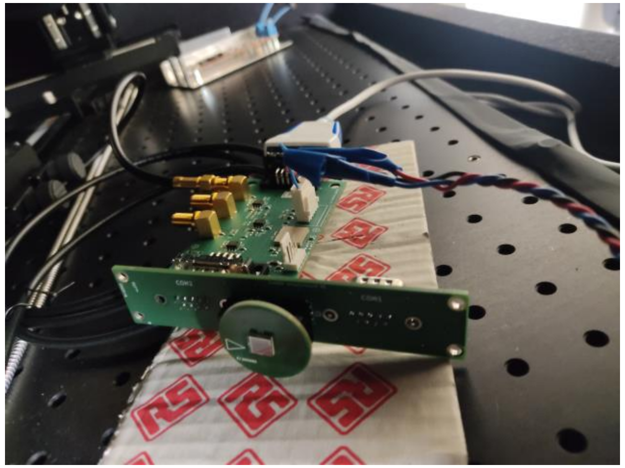


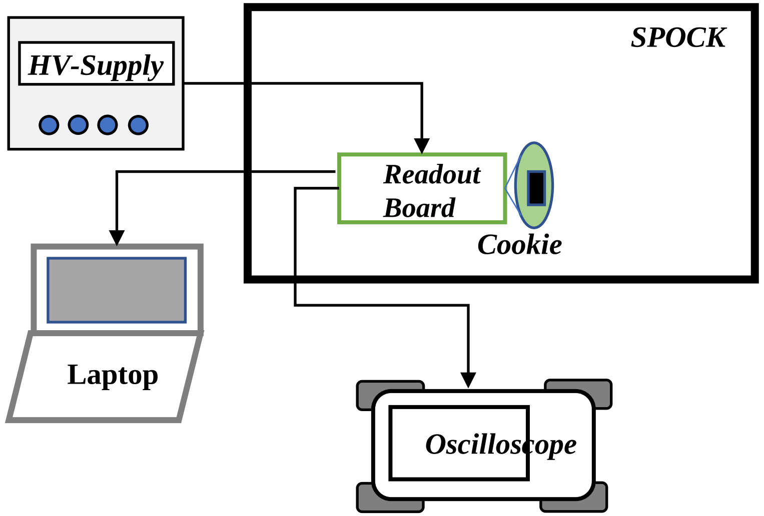


New Cookie board + Waveform test with SPOCK



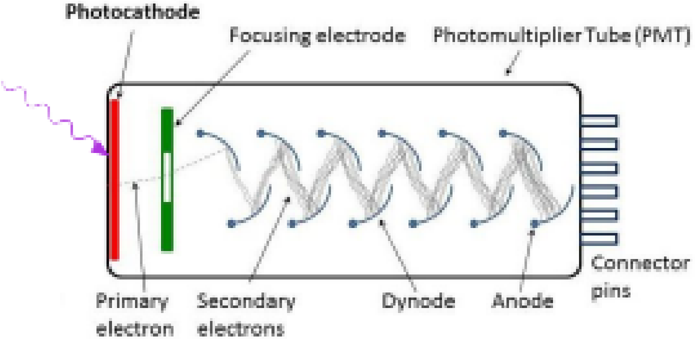




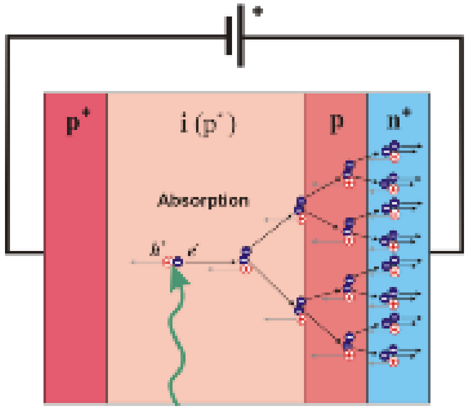


Photosensor: Why Silicon Photomultiplier (SiPMs)?

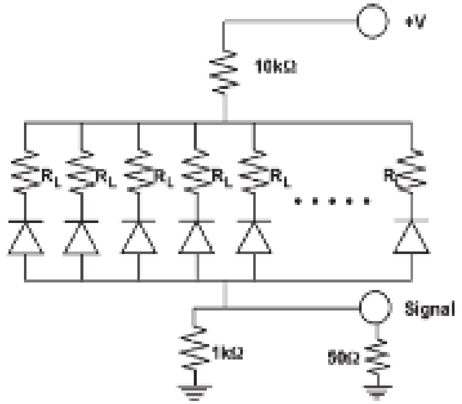
PMT



APD

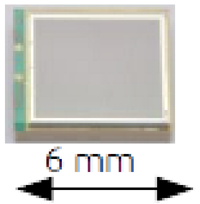


SiPM



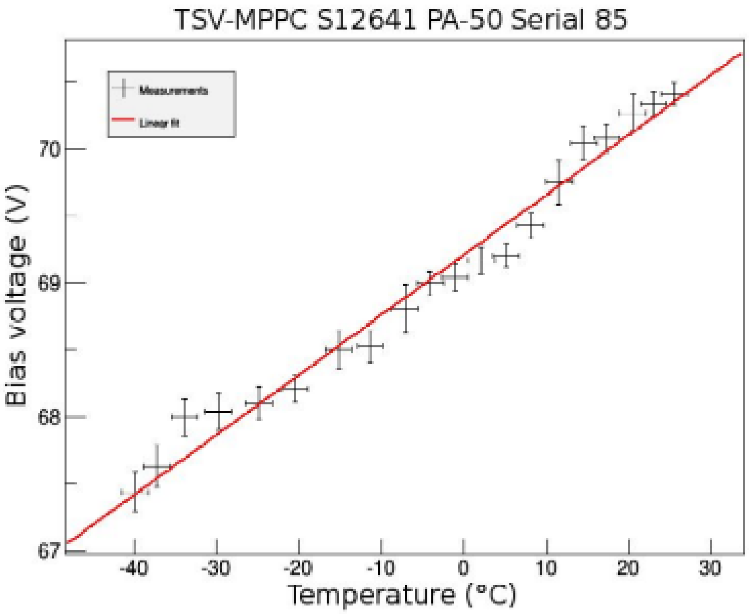
	PMT	SiPM
PDE	20-40%	20-60%
Gain	10^6	10^6
Dark noise rate	~Hz 🙂	~MHz 🙁
Behaviour in magnetic fields	🙁	🙂
Operation Voltage	1000+ V 🙁	50-70 V 🙂
Temperature sensitivity	🙂	🙁
Robustness and compactness	🙁	🙂

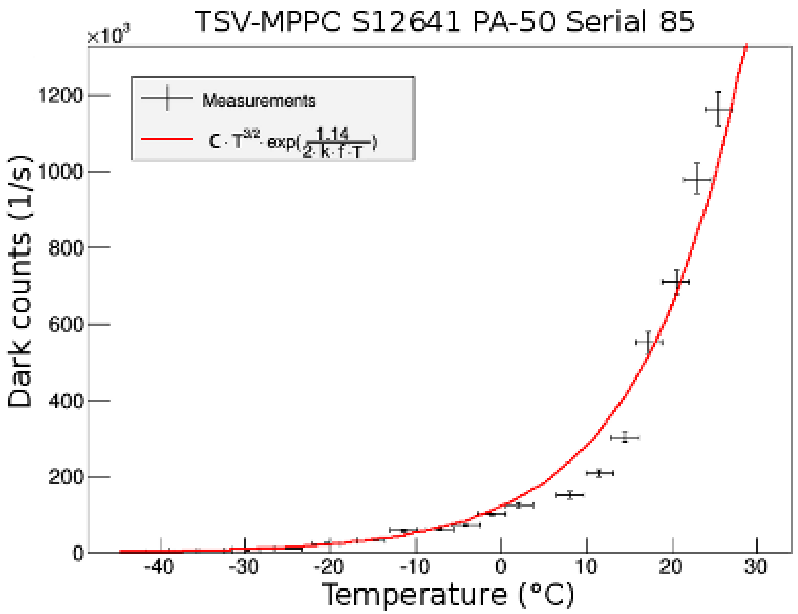
Our candidate:
Hamamatsu
S13360 series



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

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