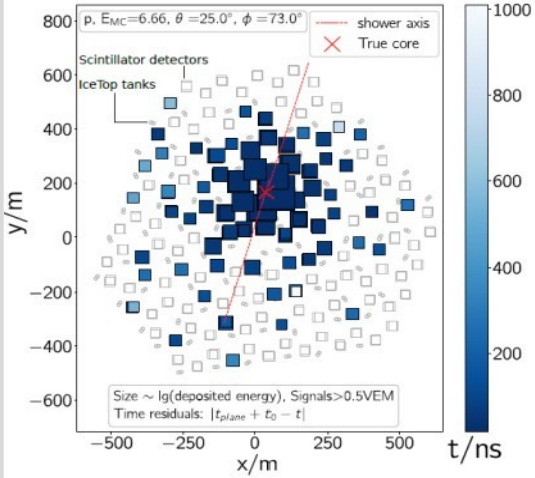
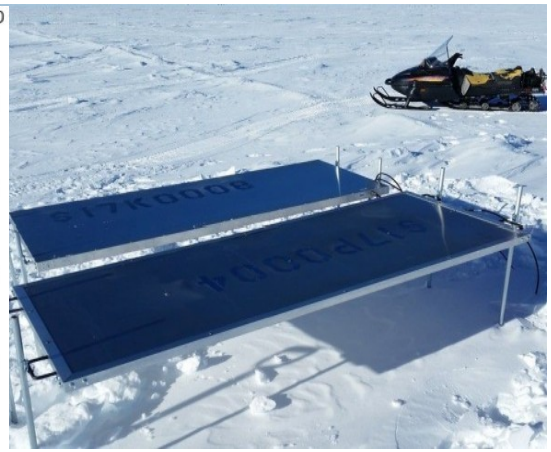
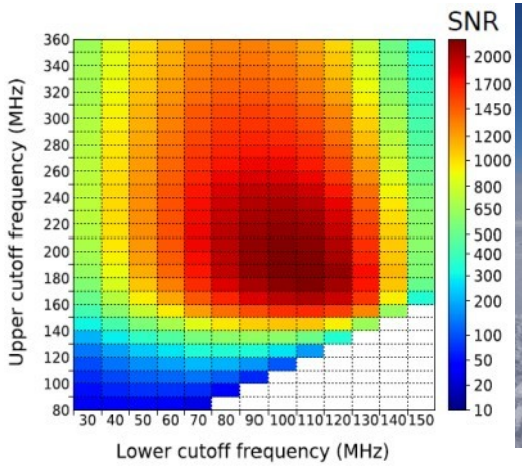
The Prototype for the IceCube - IceTop Surface Detector Upgrade

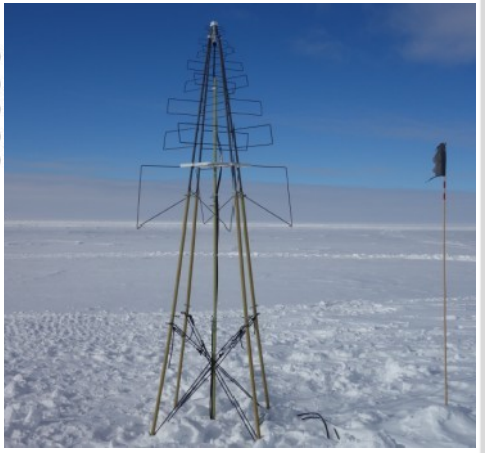
(...and how to get there to work)

Thomas Huber for the KIT / DESY IceCube Group

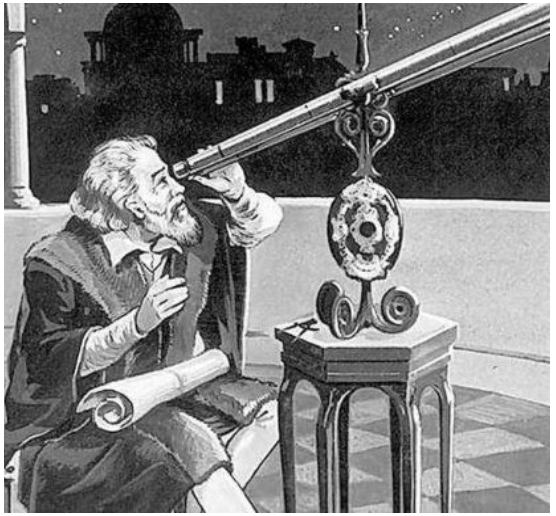


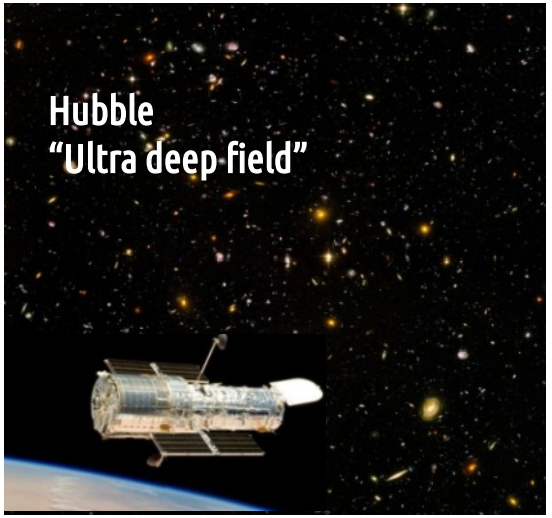




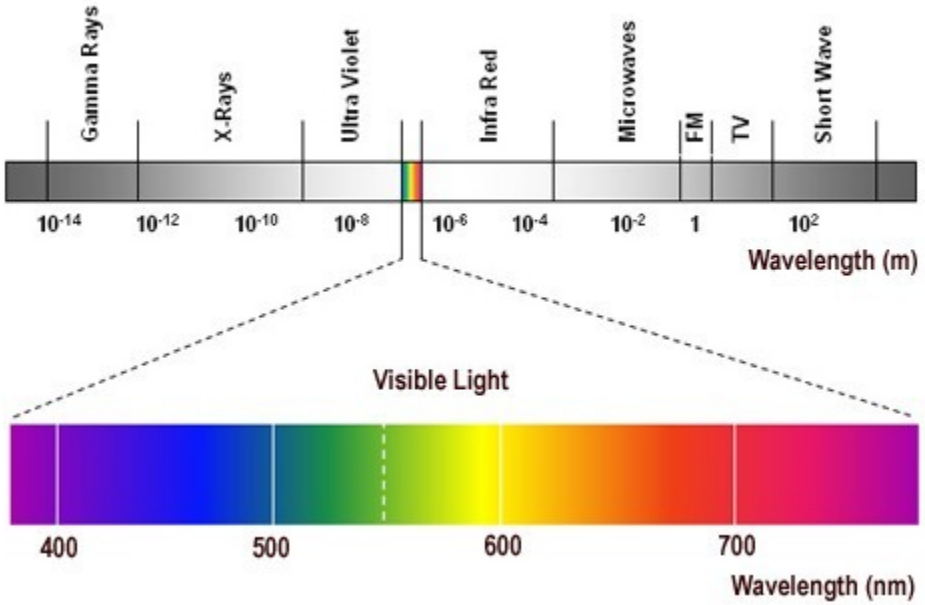


How to (steady) find something out about the universe





→ Steady upgrade of the human “Instrumentation” (= The eye)



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The optical sky – Visible via human eyes

Wavelength = 10^{-6} m $\leftrightarrow$ 1eV

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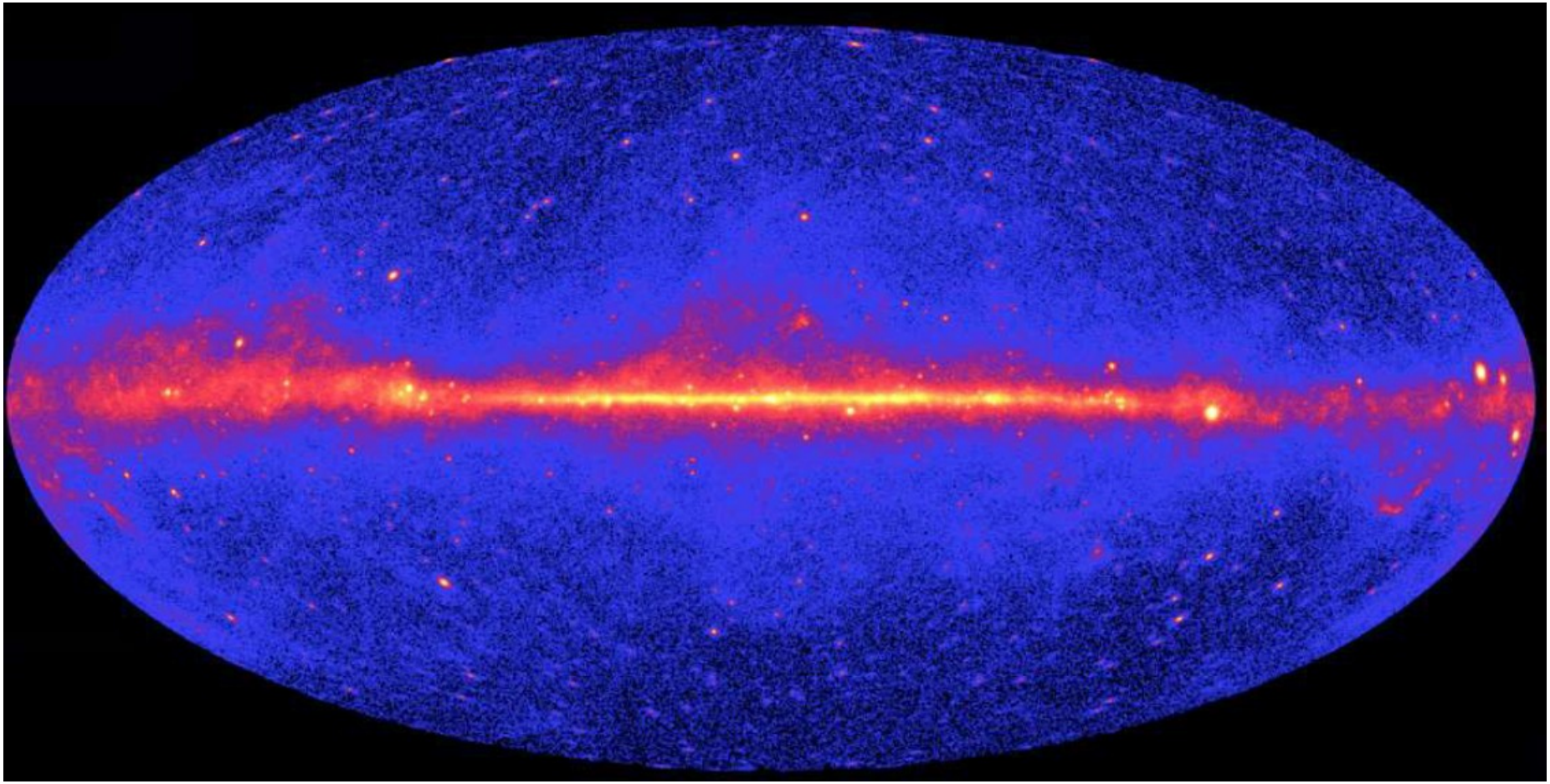
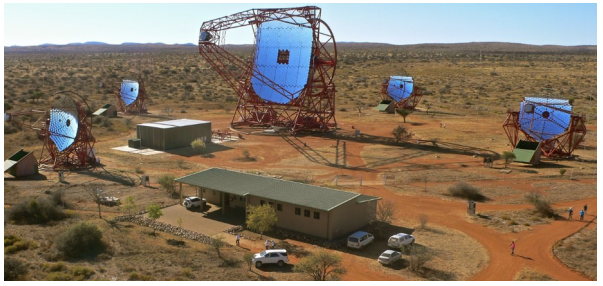
The optical sky – Visible via detecting gamma rays



Wavelength = 10^{-15} m ↔ 1 GeV



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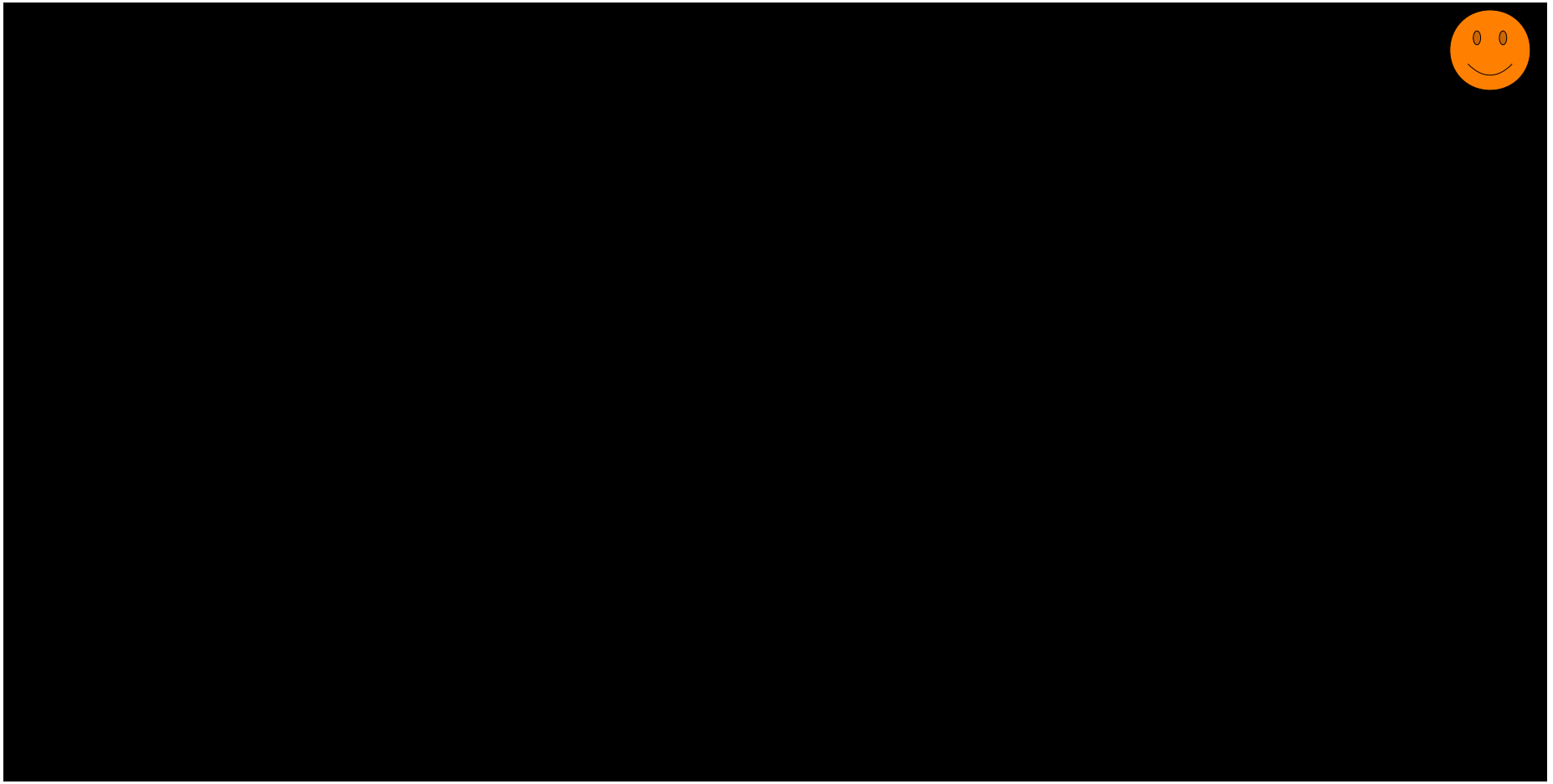
The optical sky – At very high energies



Wavelength = 10^{-15} m ↔ 1 PeV

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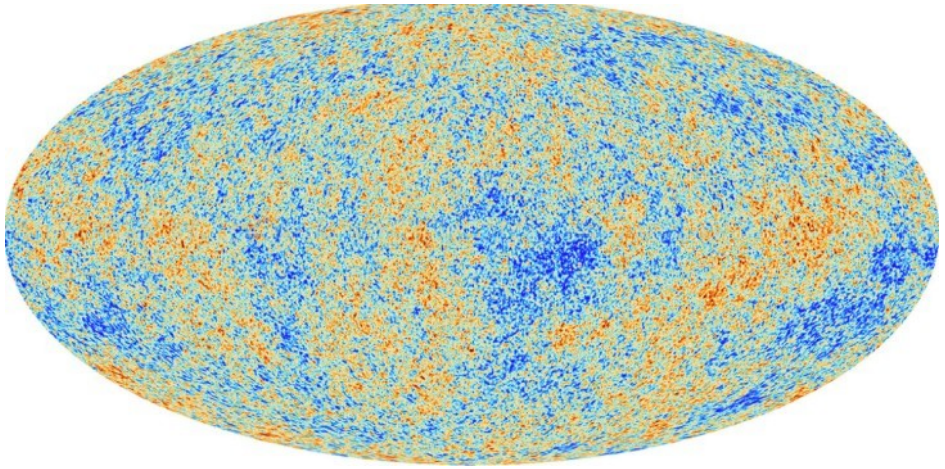
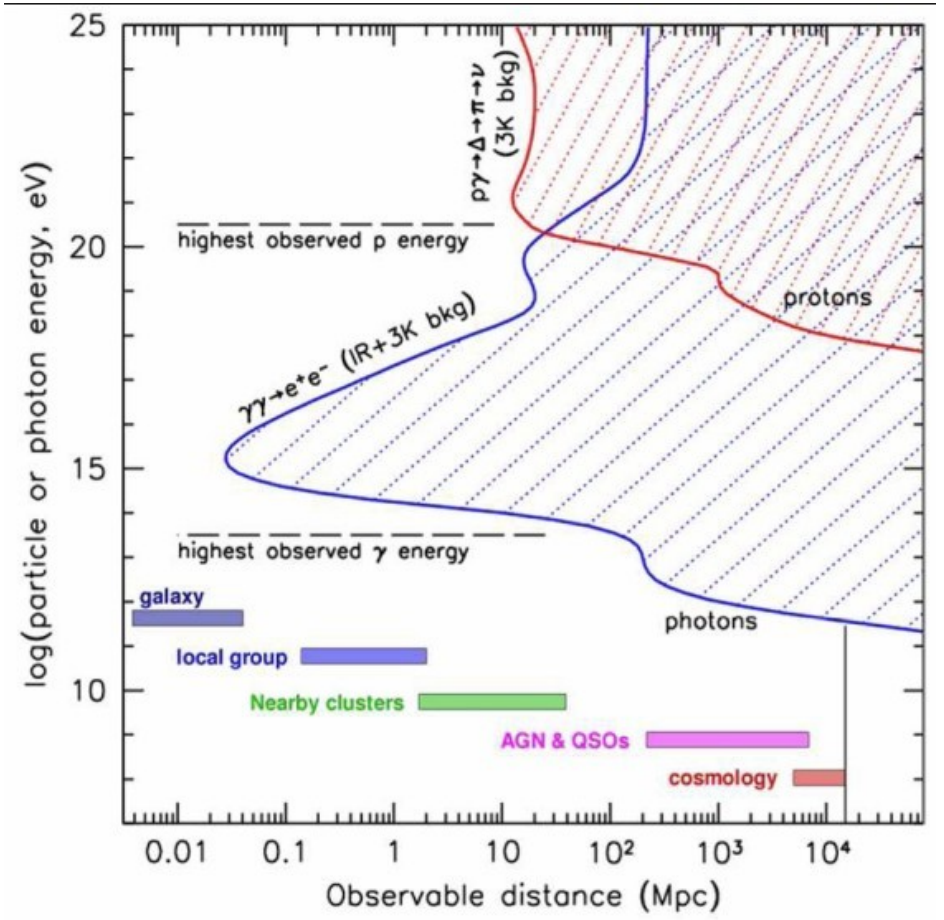
The optical sky – At very high energies



Cosmic Microwave Background (CMB)

$$\gamma_{PeV} + \gamma_{CMB} \rightarrow e^+ + e^-$$

PeV Photons are interacting with CMB Photons (411/ cm³) before reaching our telescopes



→ **We need other “messengers”**

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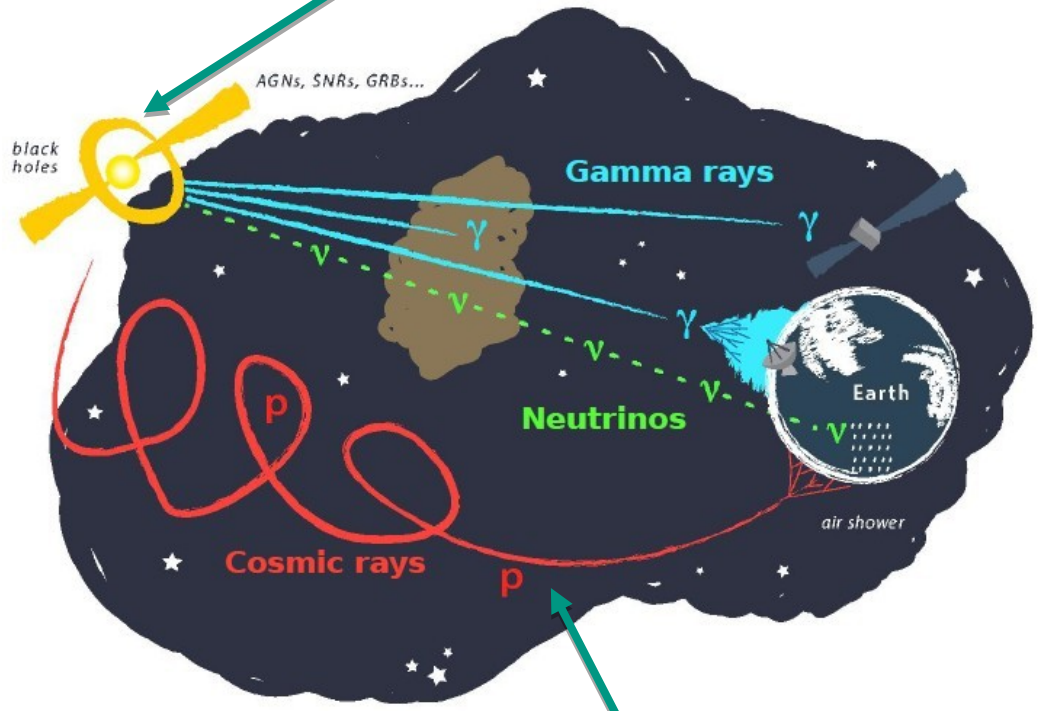
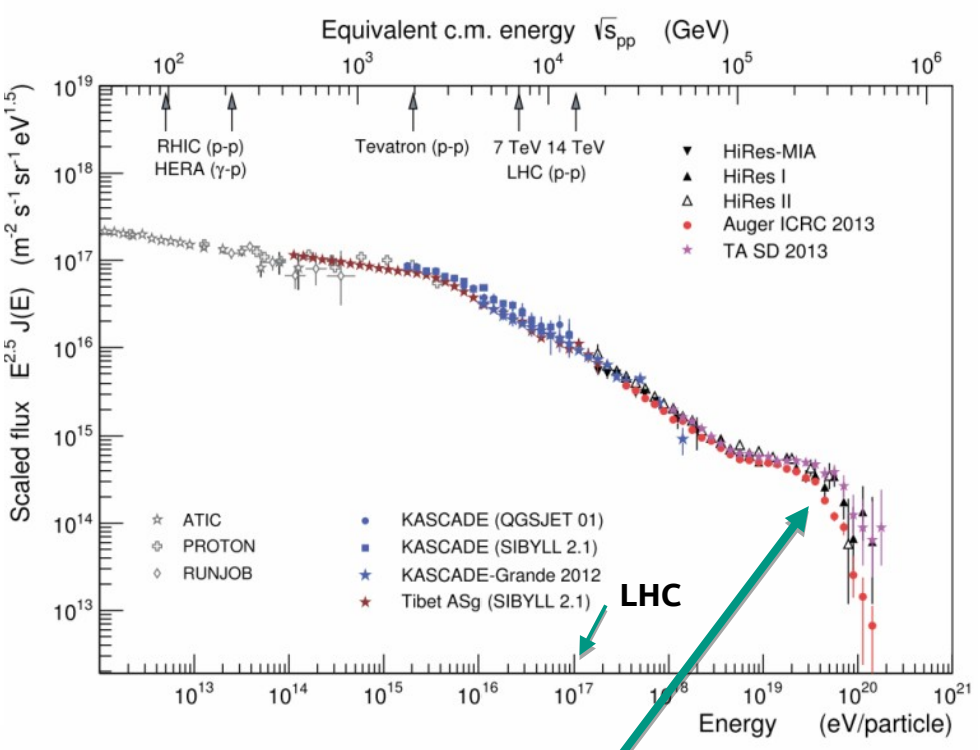
Astroparticle physics: Another window into the universe - Cosmic Rays

Sources?
Accelerators?





Cosmic rays:
Protons? Nucleons?
Composition?

$$1 \cdot \frac{1}{km^2 \cdot year}$$

Large instrumentation(s) needed!

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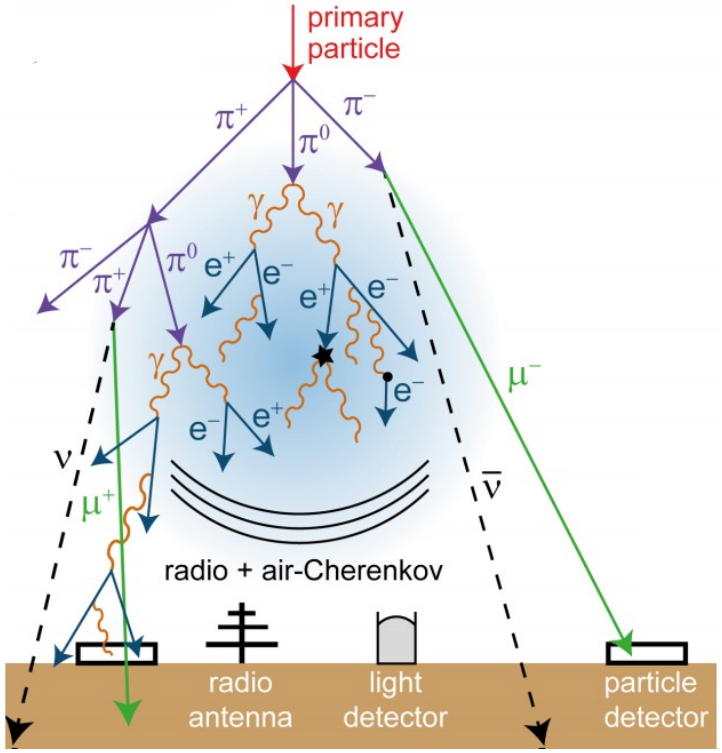
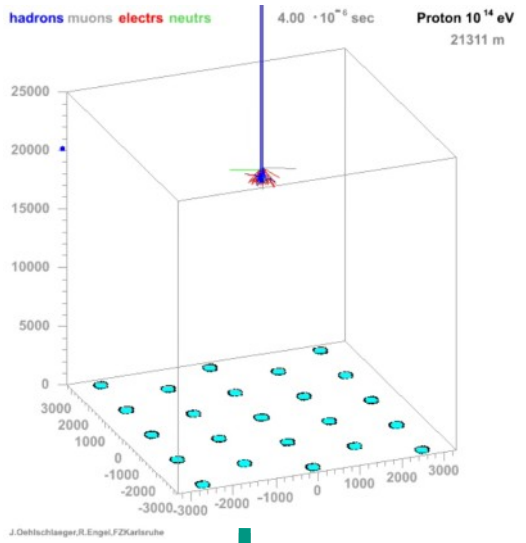
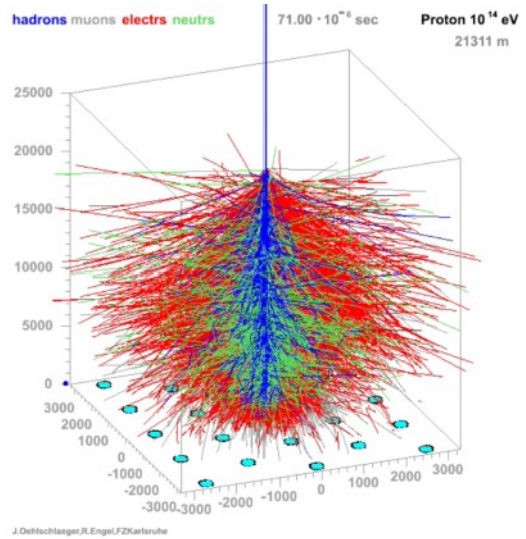
Astroparticle physics: Another window into the universe - Cosmic Rays: Extensive Air-Showers



F. Schröder (KIT-IKP, Uni Delaware)



Δt ~ 65 Microseconds



J. Oehlschläger, R. Engel, (KIT-IKP)

Extensive Air-Showers: Detectable!

KASCADE

Pierre-Auger Observatory

IceCube : IceTop

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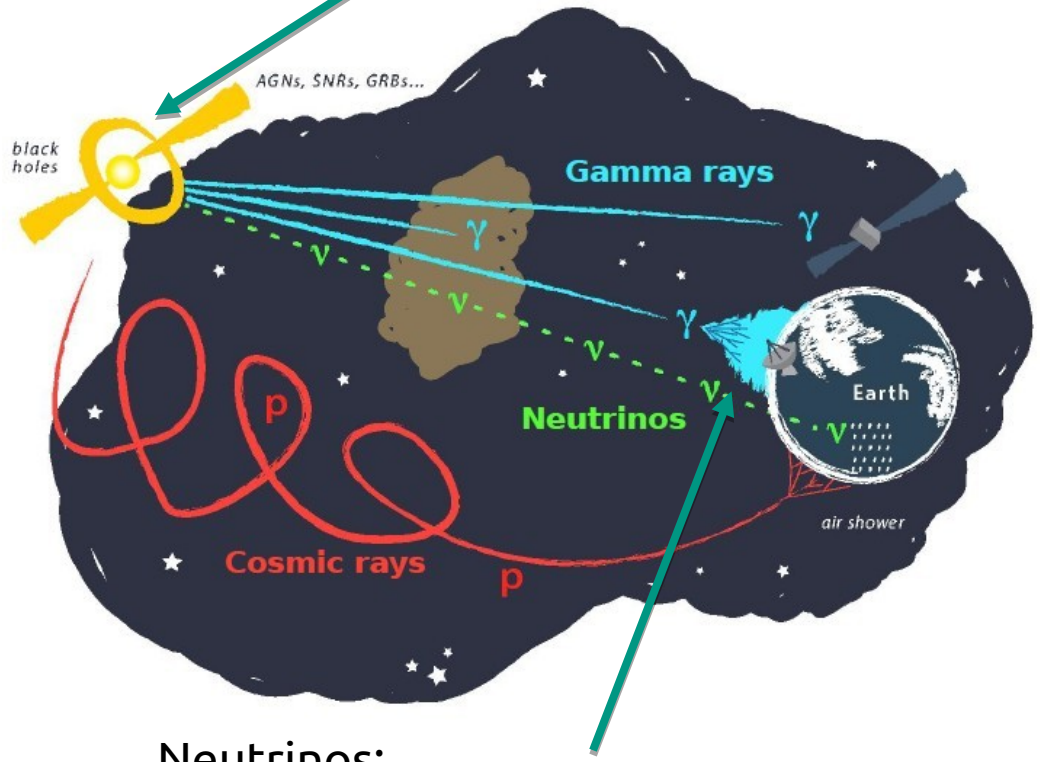
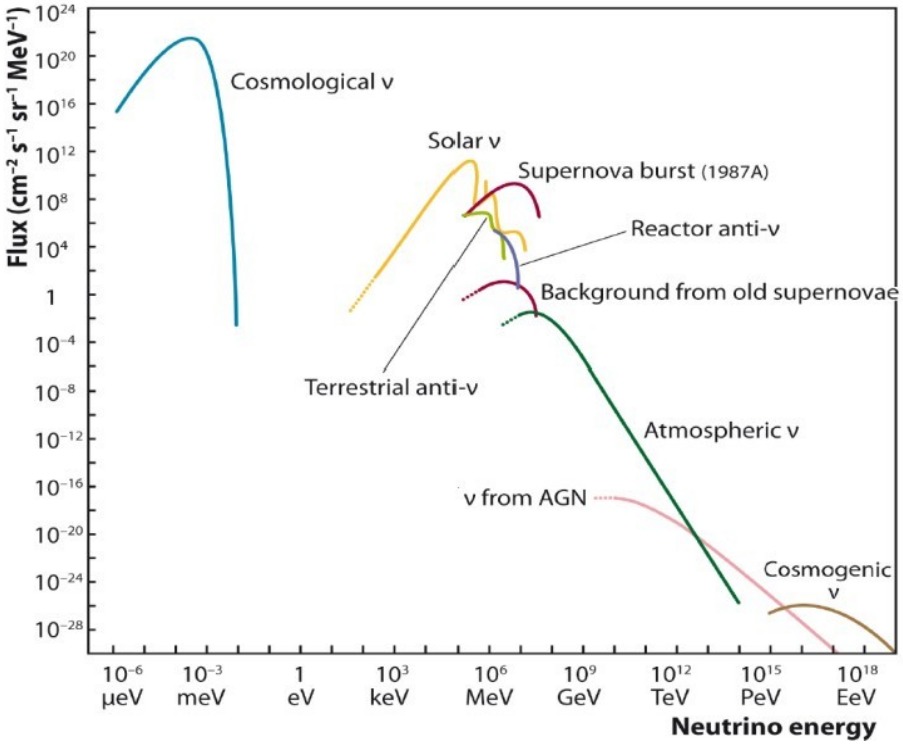
Astroparticle physics: Another window into the universe - Neutrinos

Sources?
Accelerators?





Neutrinos:
Flux? Origin? → Pointing to sources!
Correlated to cosmic ray sources?

"Only" weak interaction: Small cross-section → Large instrumentation(s) needed! (Again)

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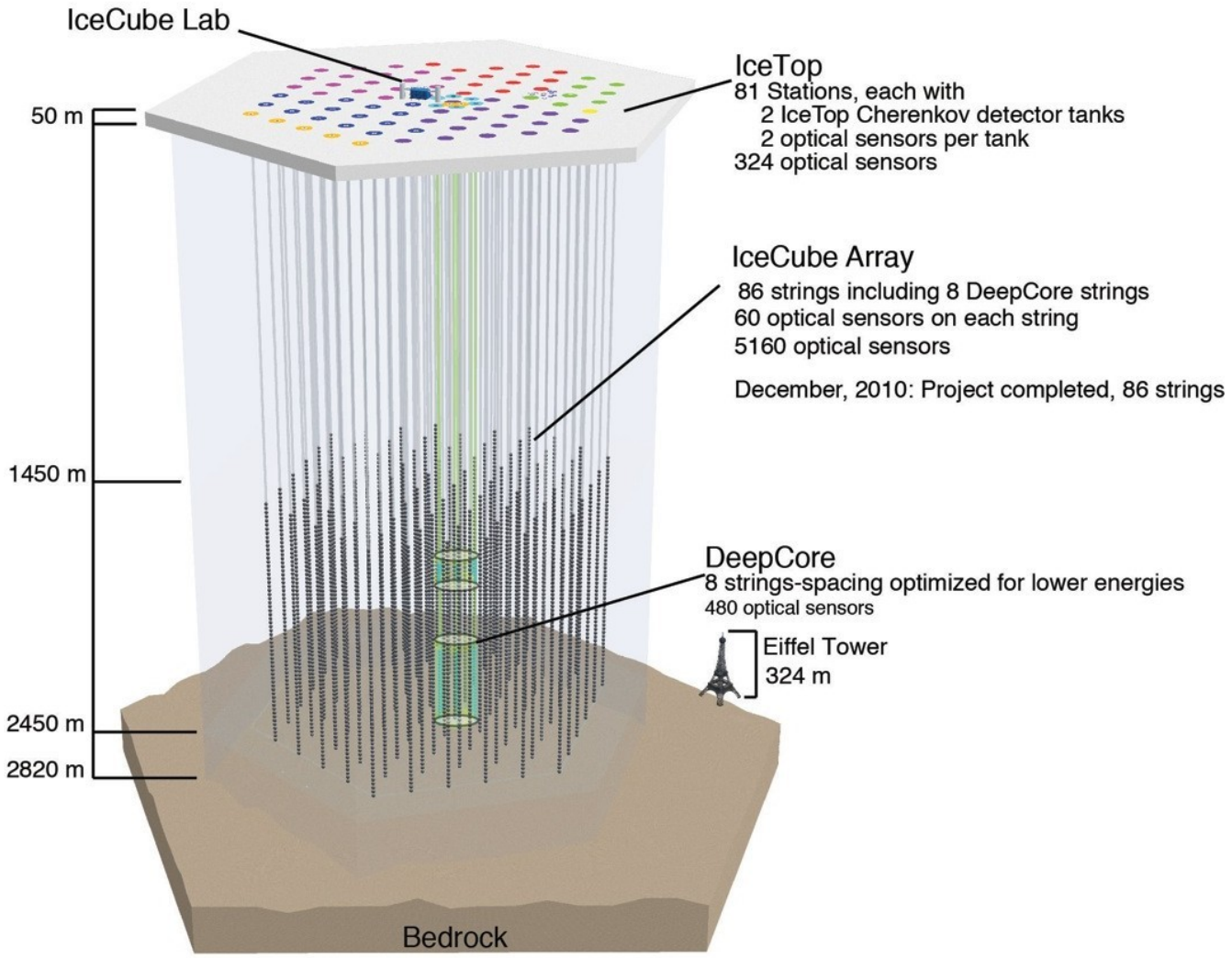
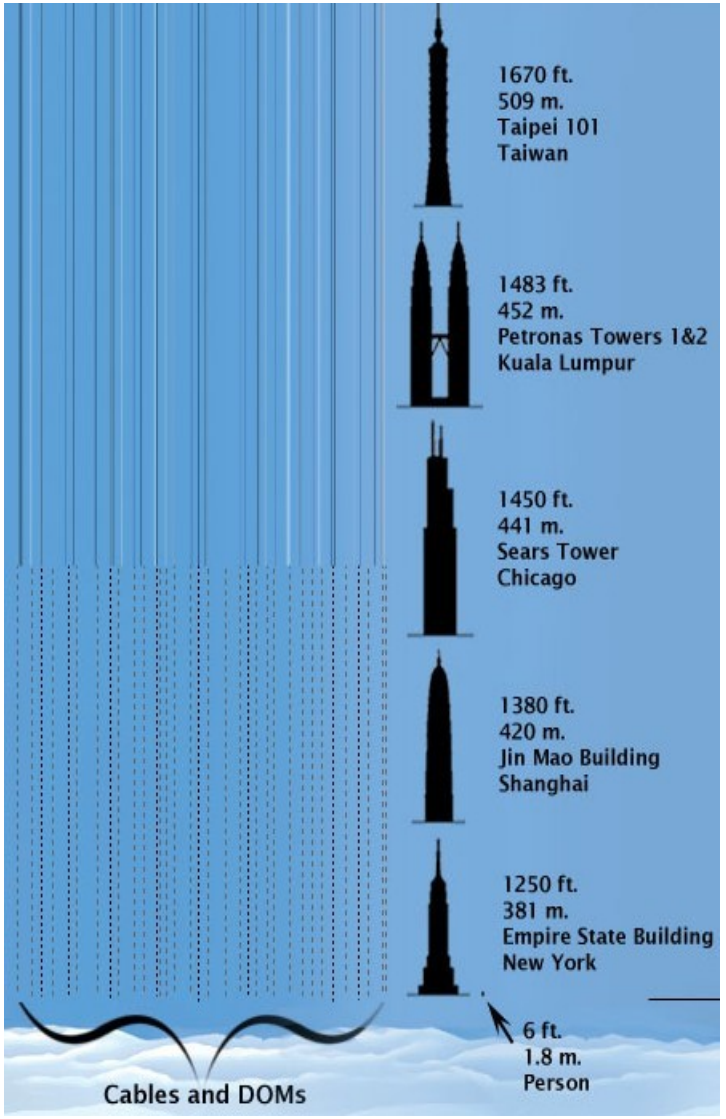
The IceCube Observatory





For scale...

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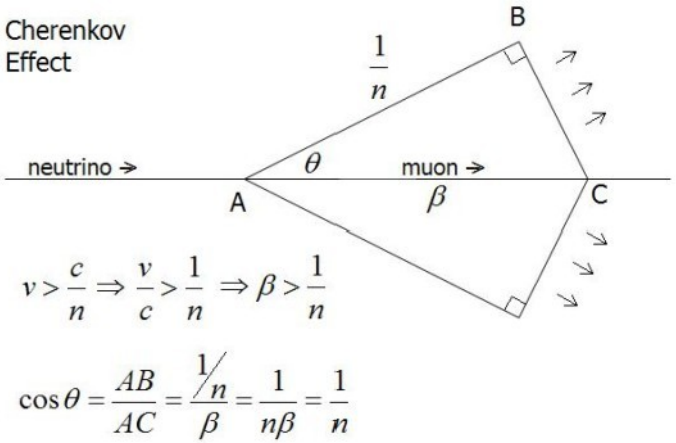
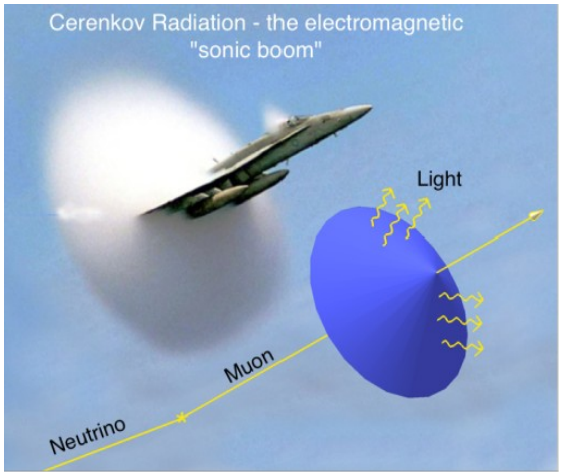
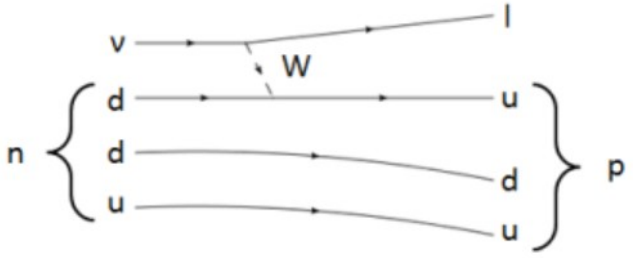
How IceCube Signals looks like – How you „see“ a Neutrino



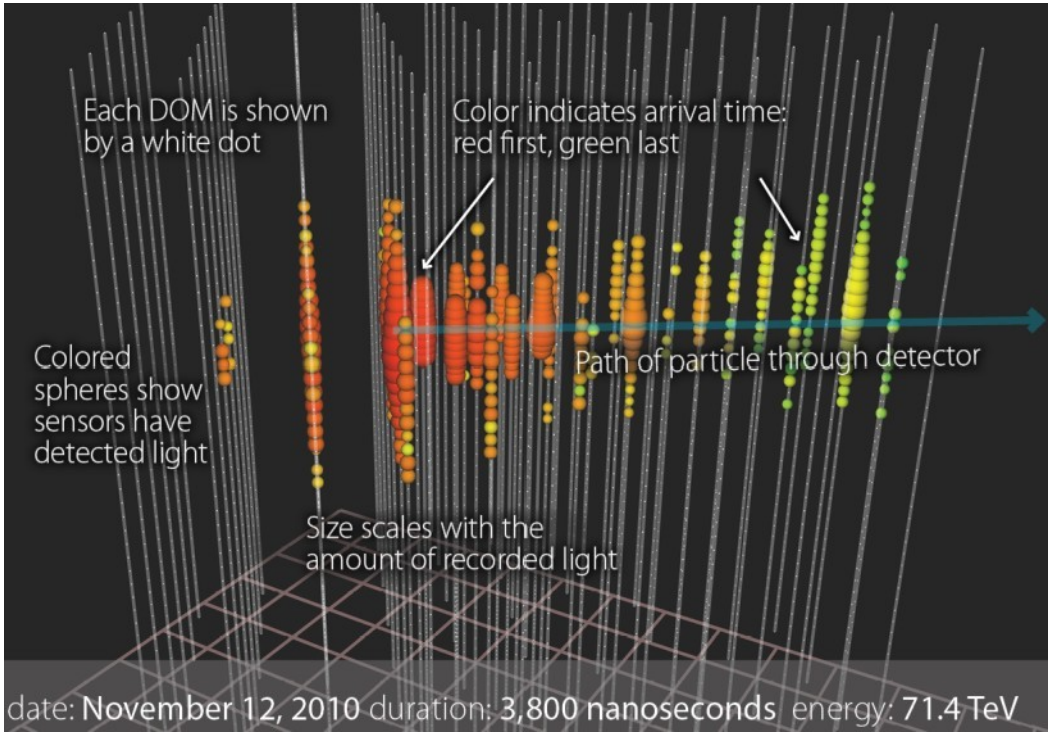
Neutrino detectable if it weakly interacts and creates a charged particle

(Muons, Electrons, Tauons)





Weakly interaction



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How IceCube Signals looks like – How you „see“ a Neutrino

Karlsruhe Institute of Technology

Movie “Cherenkov”

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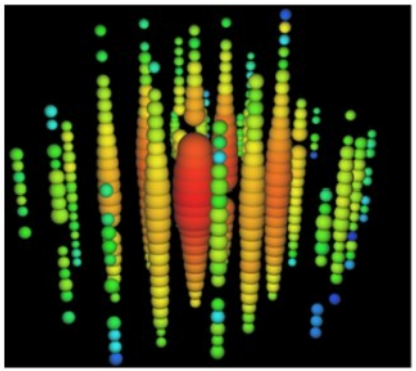
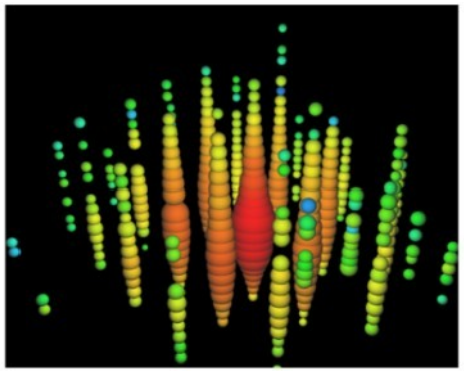
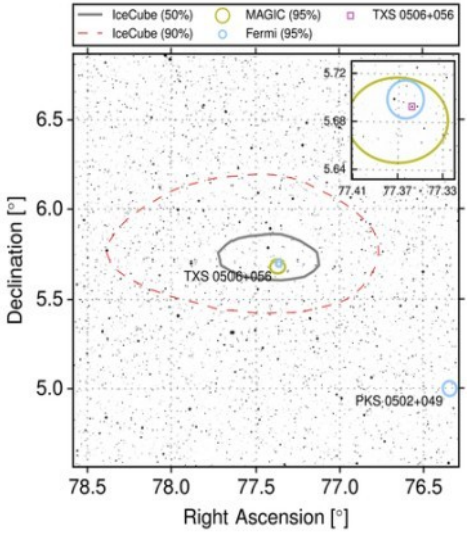
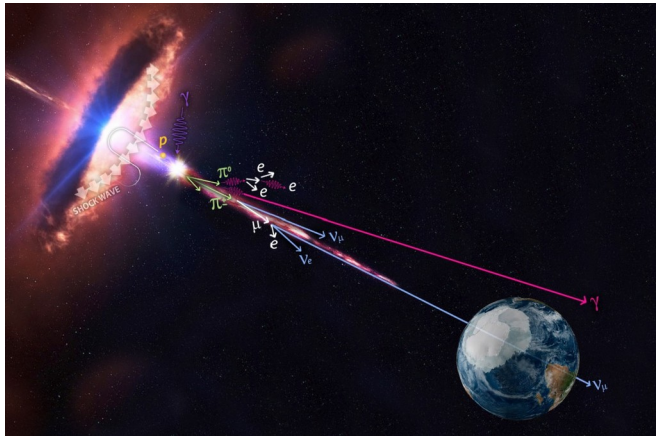
Is IceCube working? Seems like


2013: Signature of "Ernie" (1.1 PeV) and "Bert" (1.3 PeV)
→ The first observations of PeV Neutrinos of astrophysical origin

Blazar TXS 0506+056





2018: First time that a neutrino detector has been used to locate an object in space and that a source of cosmic rays has been identified → **Multi-Messenger astronomy**

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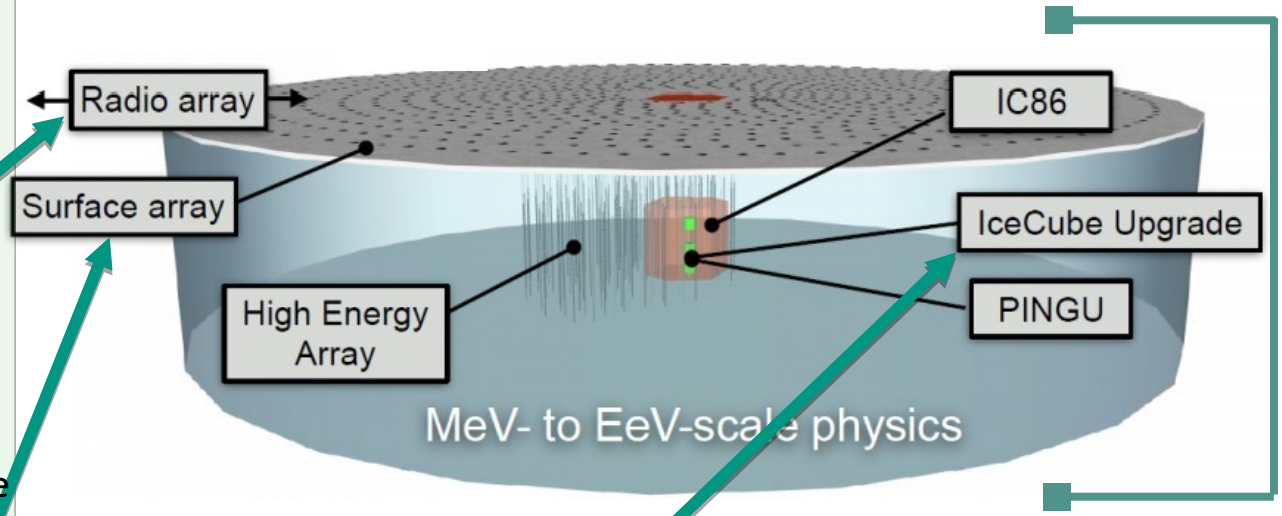
Is IceCube working? Seems like → So lets upgrade it!

Surface array:

Prototype deployed **2018/19**

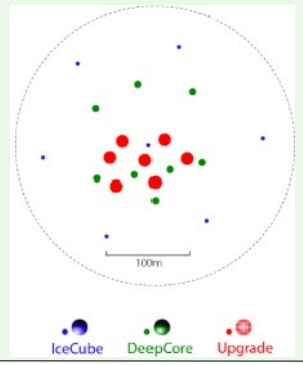
Prototype Station deployed **2017/18**

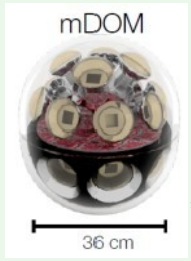


IceCube-Gen2

S. Blot, (DESY)

In-Ice upgrade:

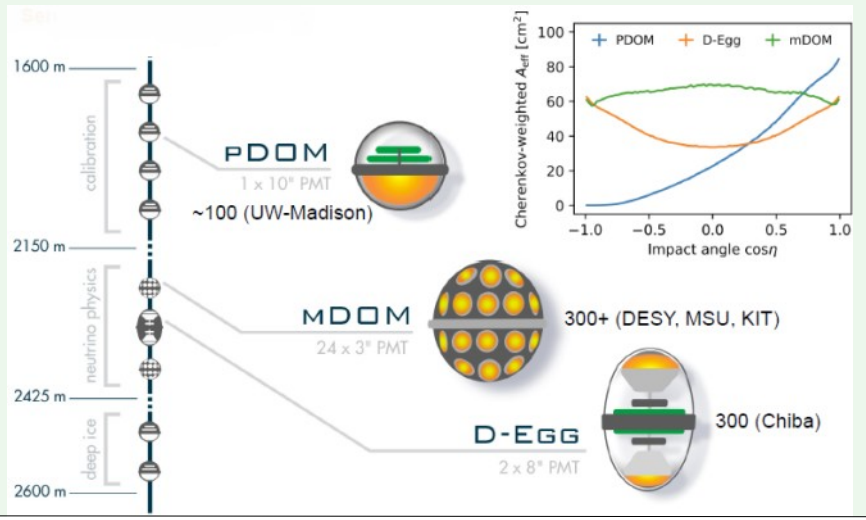




DESY, MSU, KIT

"IceCube Upgrade" :

- 7 new strings
- More sensitive for Neutrino oscillation
- DOM(s) "benchmark" for Gen2



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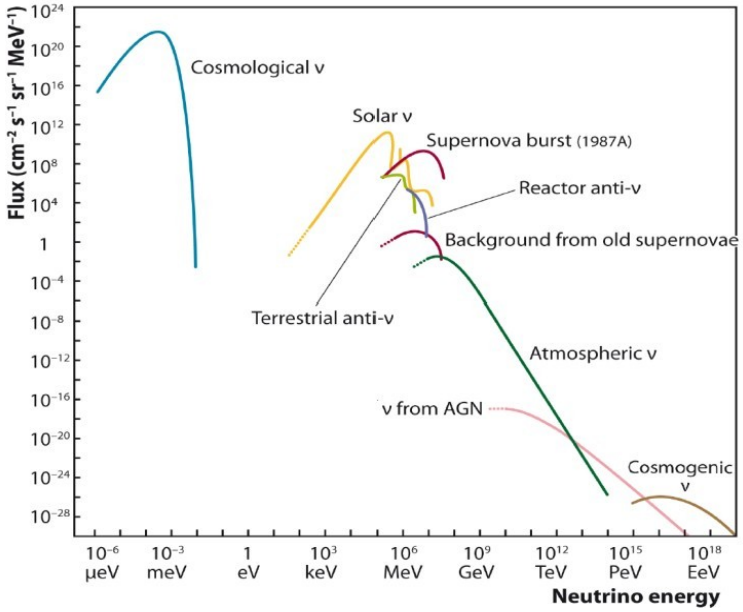
The scintillator surface extension “IceScint“

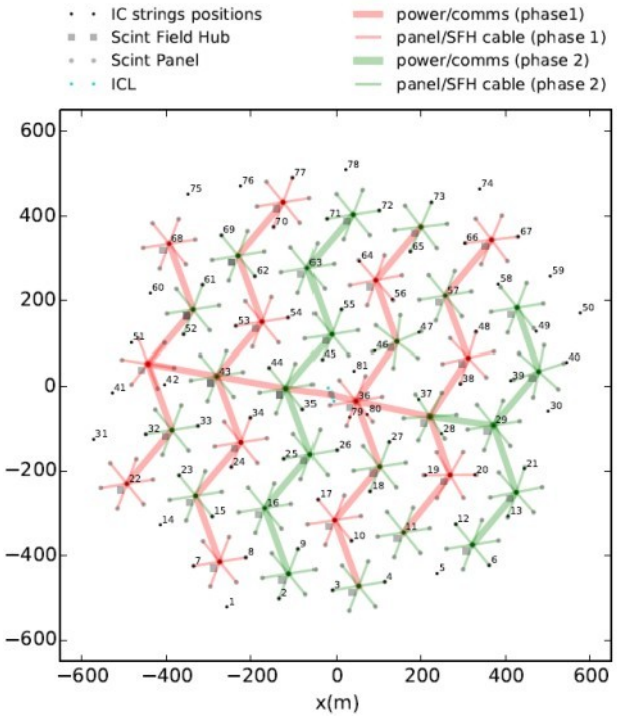
Upgrade of the surface array with scintillation detectors:

- Improvement of the veto capabilities for neutrinos at the surface
- Cross calibration with the IceTop Tanks
- Improved capabilities for studying cosmic rays

Plan to build up to 37 stations with 7 detectors each within IceTop footprint



IceCube : IceTop
Deployment finished 2010



First map of the full scintillator array

https://pos.sissa.it/301/401/pdf

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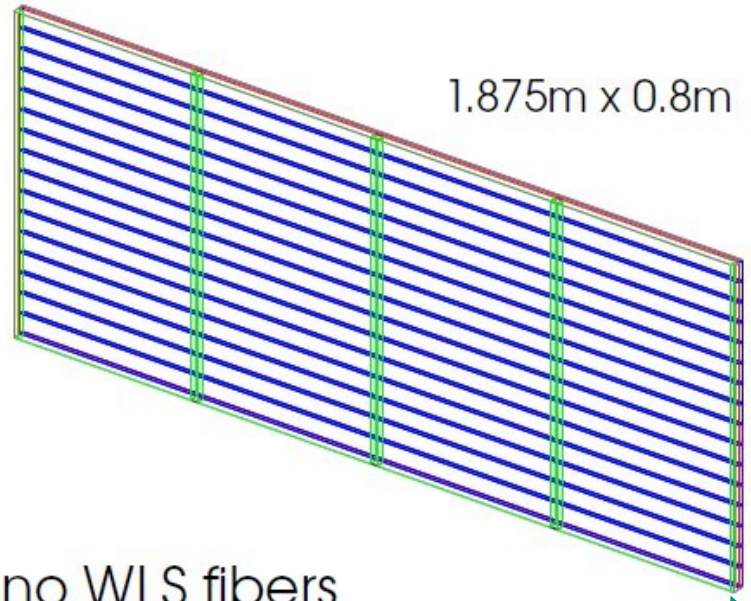
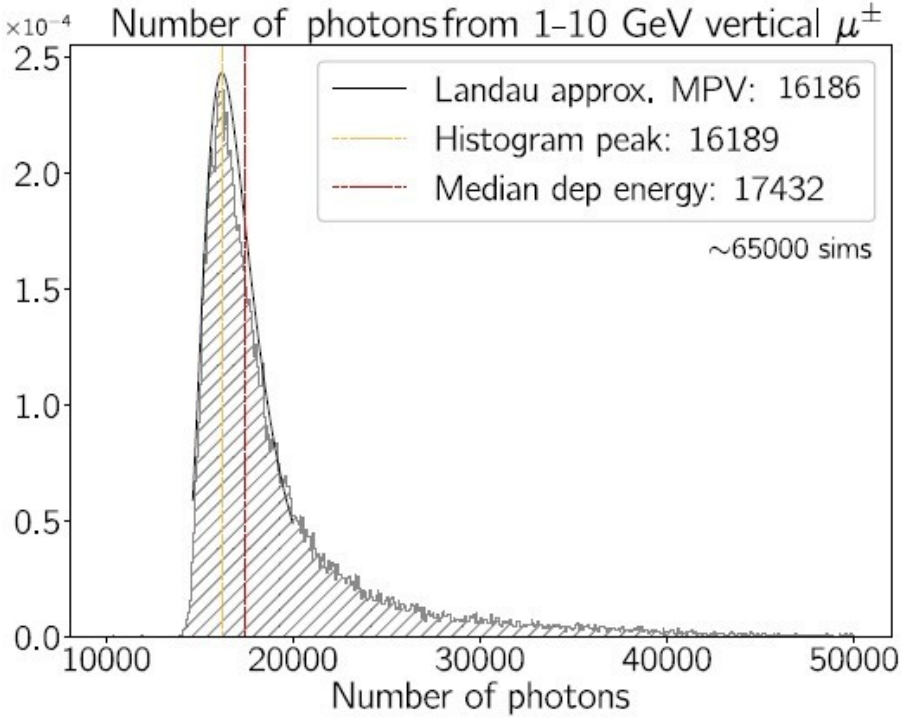
Simulation of a scintillation detector

Deposited energy of every particle → Number of photons 56%, Birks' law → Expressed in number of photons from 3GeV vertical muon (VEM)



no WLS fibers included in the simulation



(Scintillator working principle explained soon)

A. Leszczynska, (KIT-IKP)

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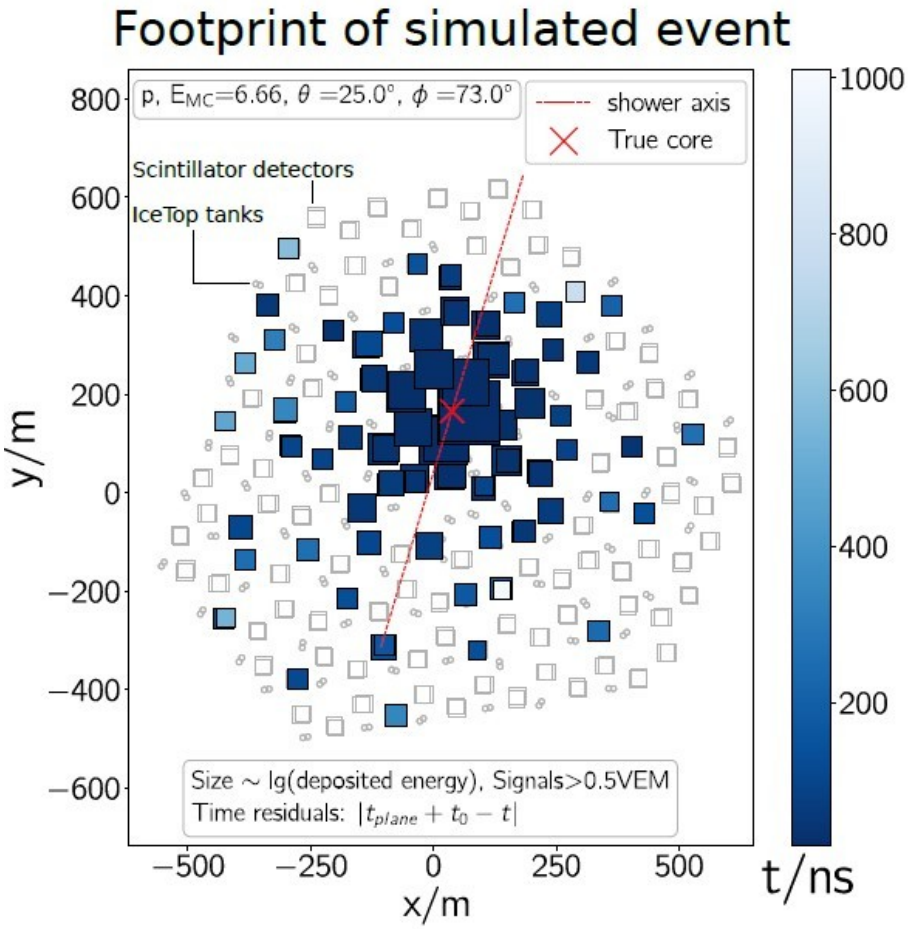
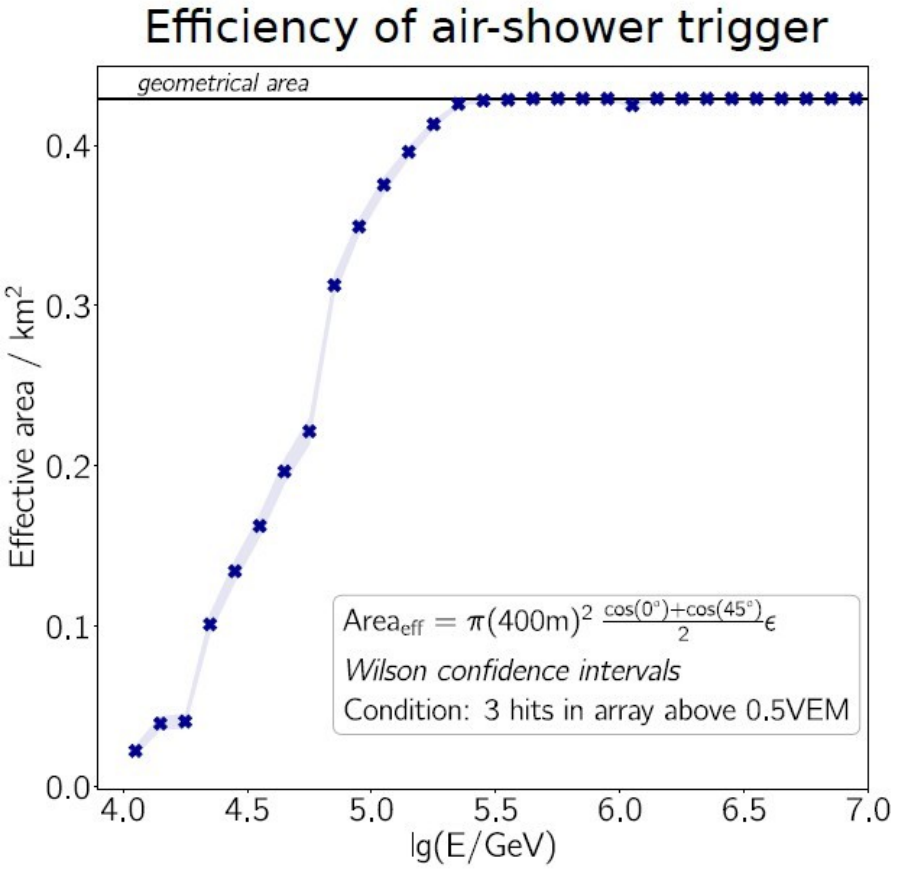
What to expect by a large scintillation detector array





The full scintillation detector array:

- Can efficiently measure cosmic rays in the "knee" region
- Has potential of veto capability for IceCube in-ice measurements

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How to measure MIPs

Minimum Ionizing Particle (MIP)

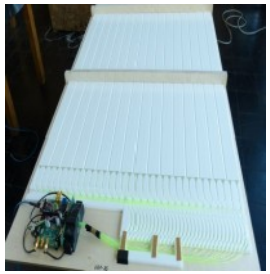
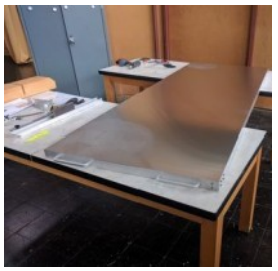
A new surface detector array for IceCube

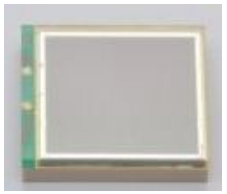
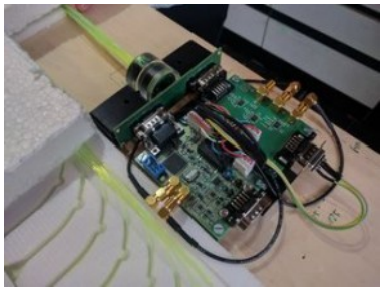
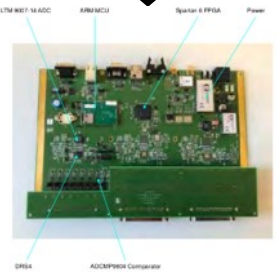
=

Synchronization with ICL, Trigger, Fieldhub connection

Datastream, Sat-Uplink, White Rabbit compatibility

Scintillator → Frame → Optical Coupling → Photosensor (SiPM) → Analog Readout → DAQ System

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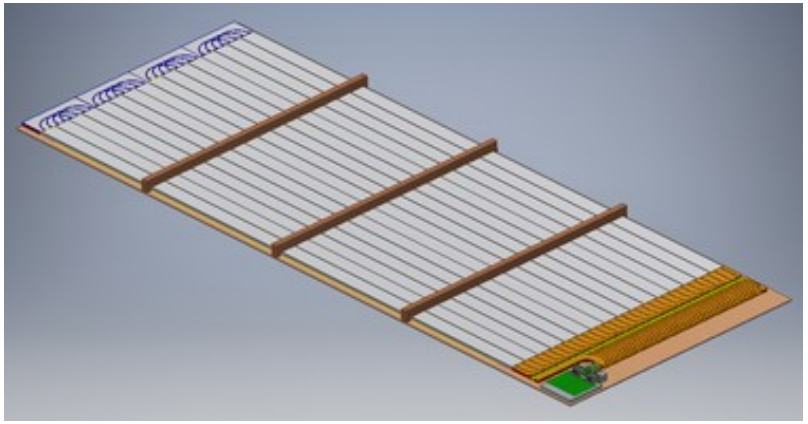
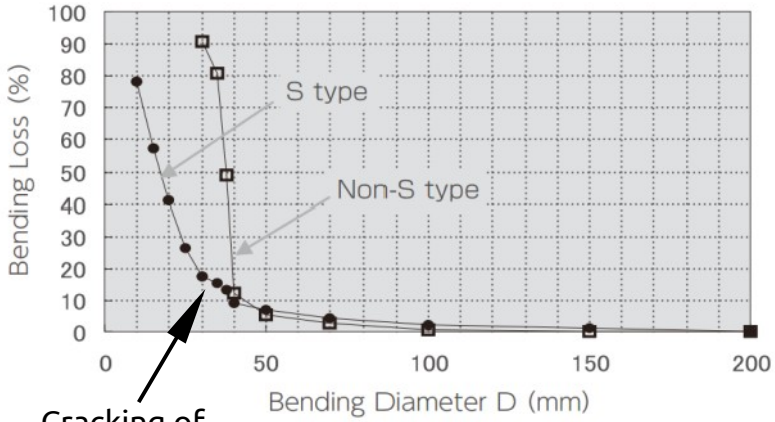
Used scintillator material and optical fibers

- **Scintillator material:**
  Fermilab scintillator bars
- **Wavelength shifting fibers:**
  "Kuraray Y-11" optical fibers



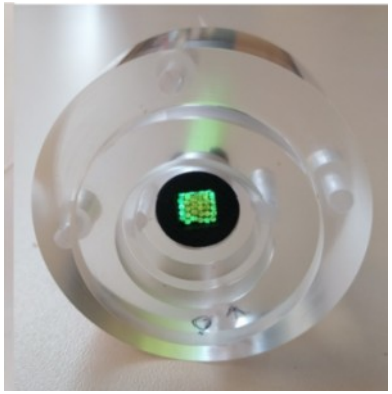
CAD of the detector



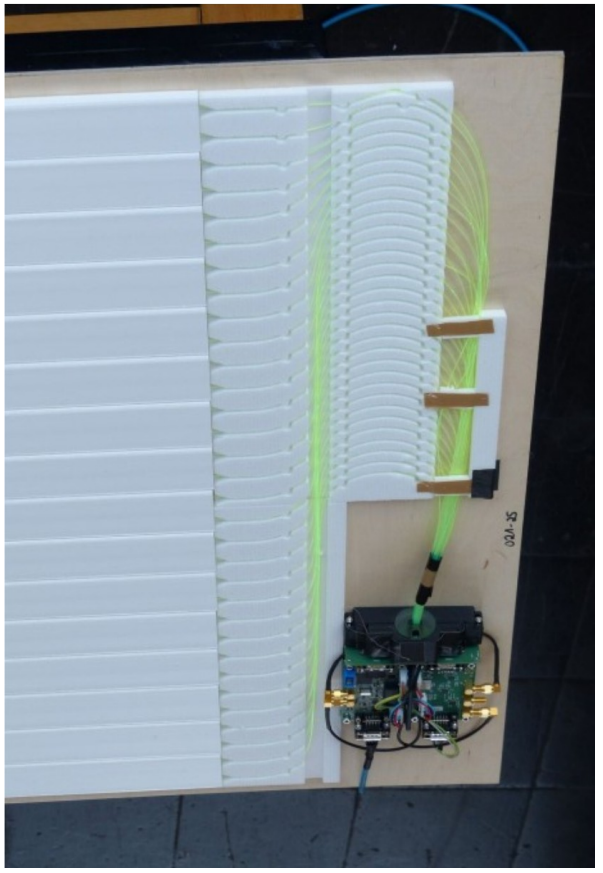
Cracking of fiber core

Sensitive scintillator area:
0.8m x 1.875m = 1.5m²

Routing of the fibers:
16 optical fibers = 32 fiber ends to the SiPM



Optical coupling



Fixed routing of the optical fibers to ensure an uniform detector

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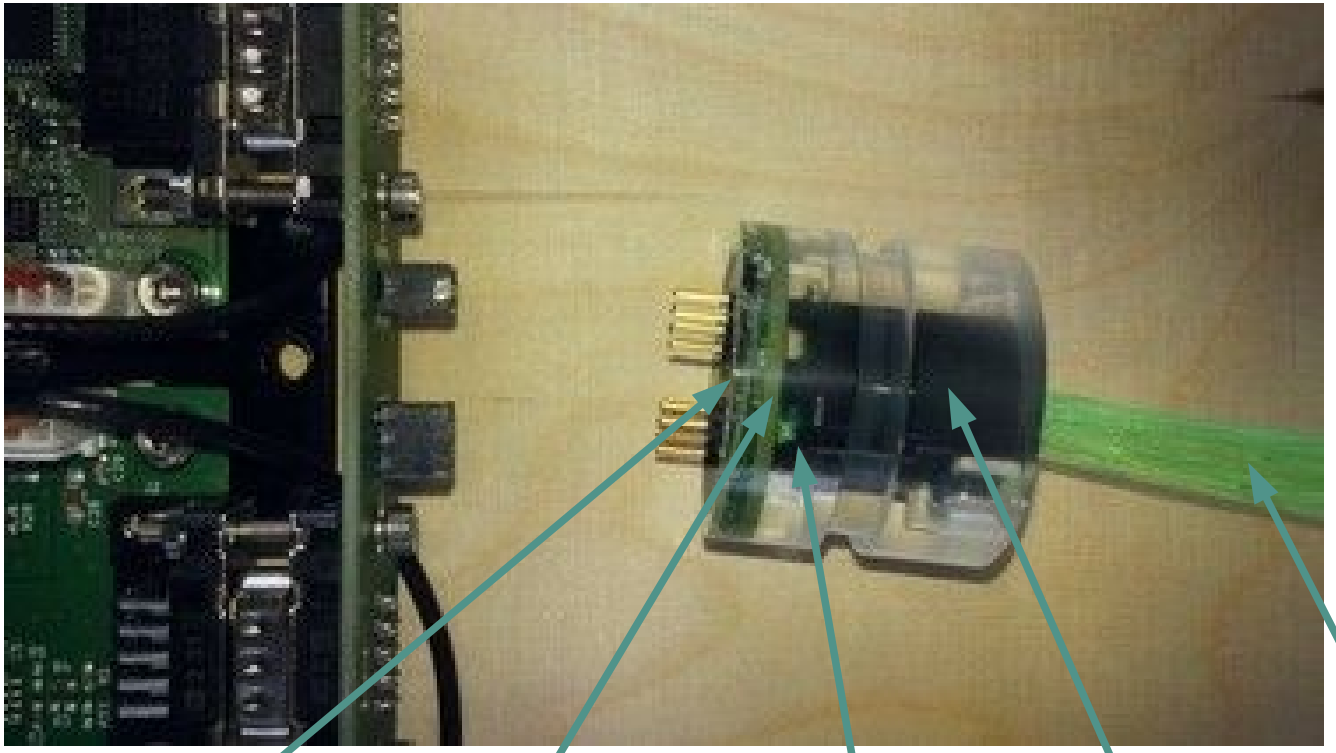
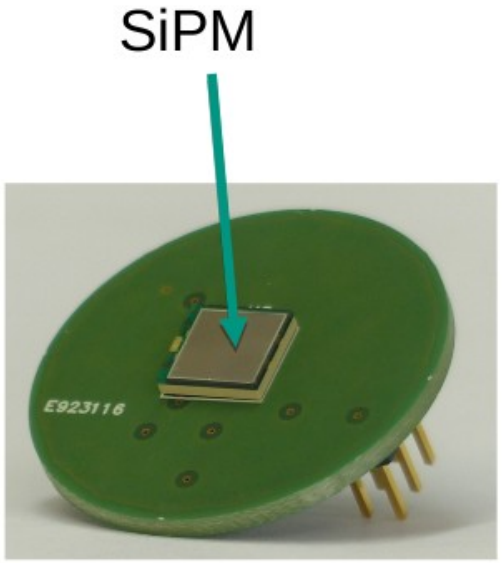
Optical coupling to the photosensor (SiPM)





Breakout board

(+ Temperature sensor)

Photosensor

(SiPM)

Glued optical coupling

(With optical cement)

3D printed socket

32 fiber ends

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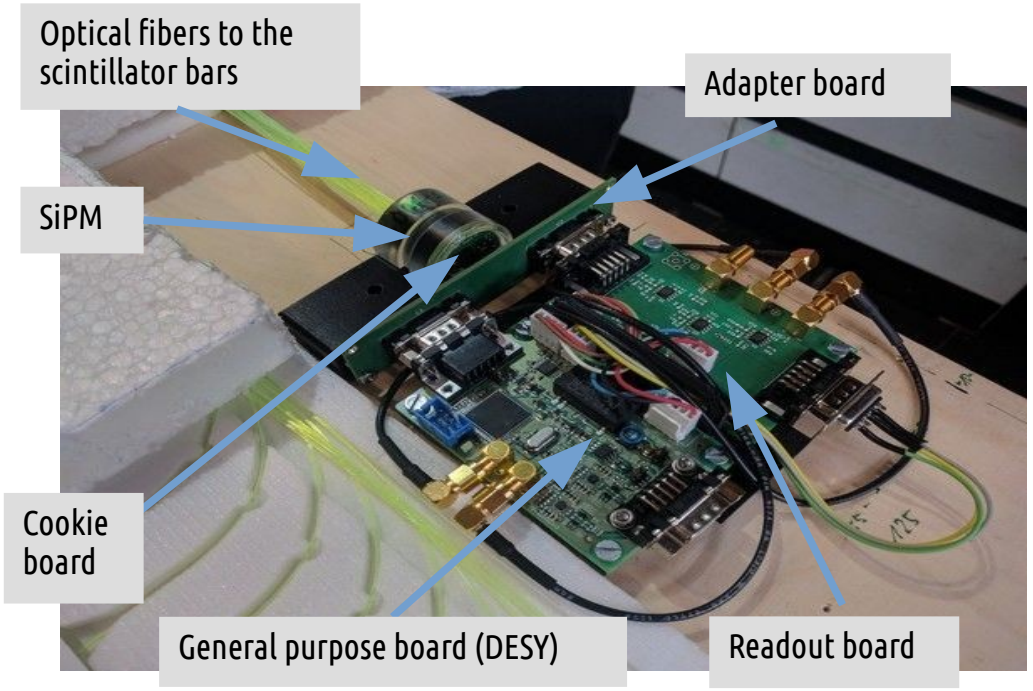
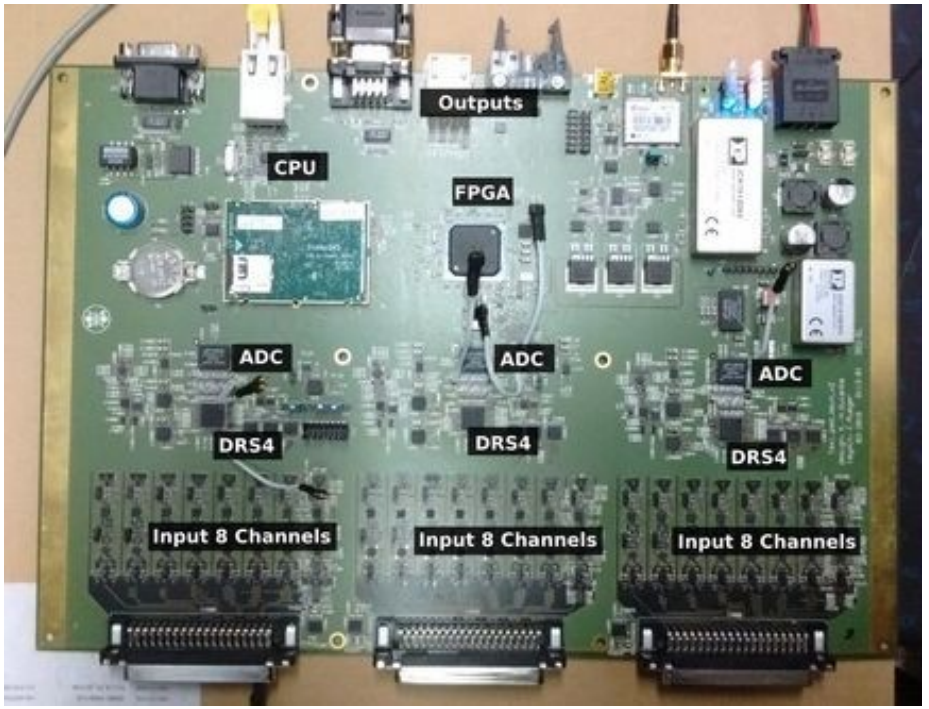
Used DAQ electronics for the scint detector array





T. Karg, K-H. Sulanke, M. Kossatz (DESY)

IceARM (Analog Readout Modul) :

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

IceTAXI:

- Developed by DESY Zeuthen
- 1 or 3 DRS4 sampling chips, 8 input channels each
- Adjustable sampling rate up to 5 Gigasamples/s
- Triggered by signal-over-threshold

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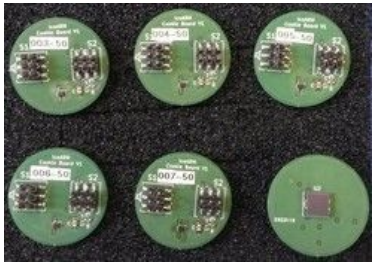
A lot of function tests + specifications + documentation

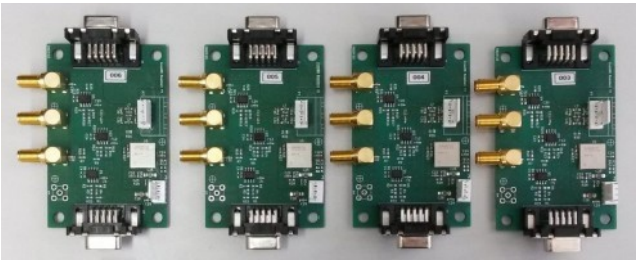
Tested, measured and documented: (**incomplete!**)

- **SiPM**:
  - Breakdown Voltage / Operation voltage
  - Photo Detection Efficiency, Gain, Crosstalk %, Darkcount rate
  - Breakdown Voltage at different low temperatures (ongoing)
- **Electronics**:
  - Cookie Board → SiPM connections, temperature sensor
  - Adapter board → Connection to readout board
  - Readout board:
    - Communication Hamamatsu power supply
    - Outgoing bias voltage to the SiPM
    - Amplification factors of the Op-Amps
    - Signal shape of high / low gain
    - …
  - GP-Board:
    - Function test
    - RS485 interface test
    - Amplification factor after 65m of cable

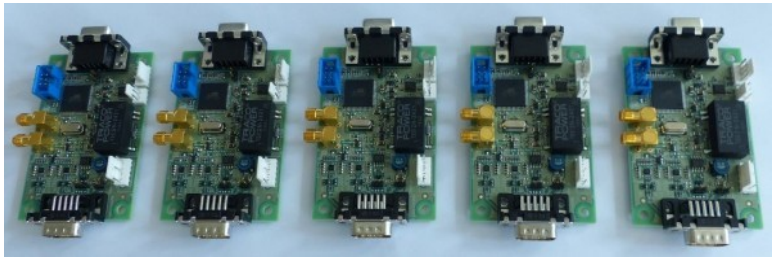
And a lot of tests...



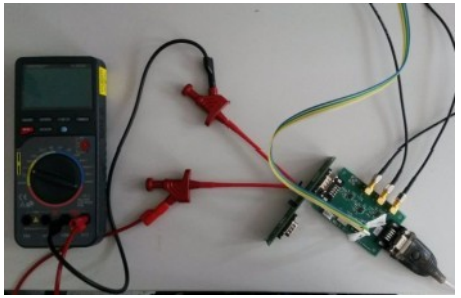
Cookie boards



Readout boards



GP-boards (DESY)



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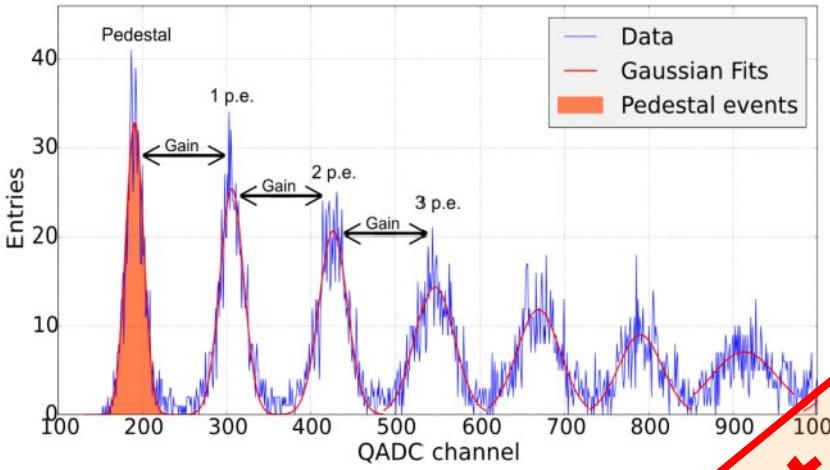
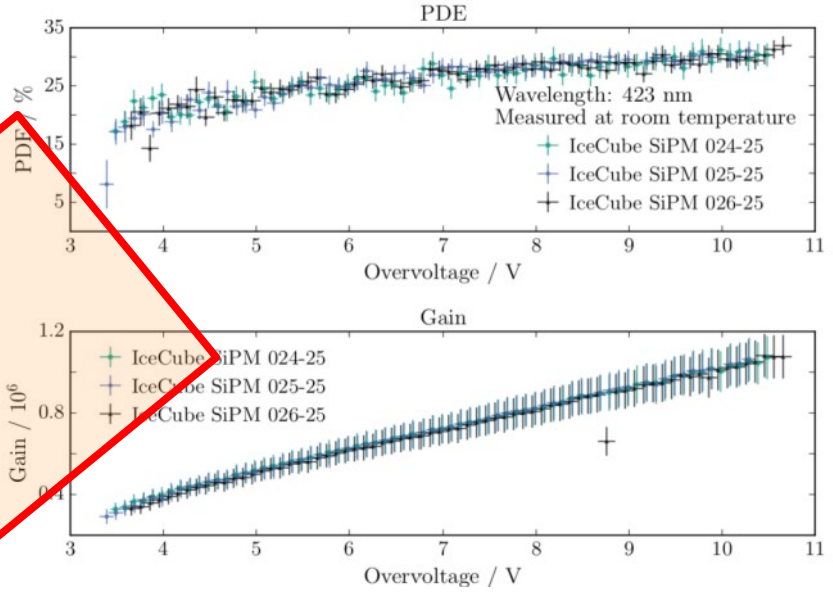
SiPM Photosensor calibration and tests

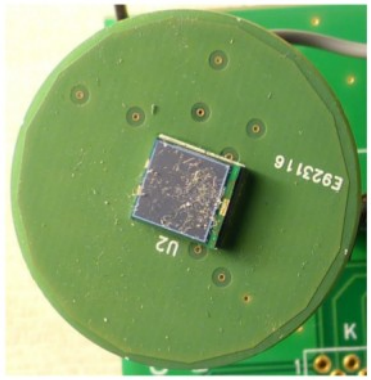


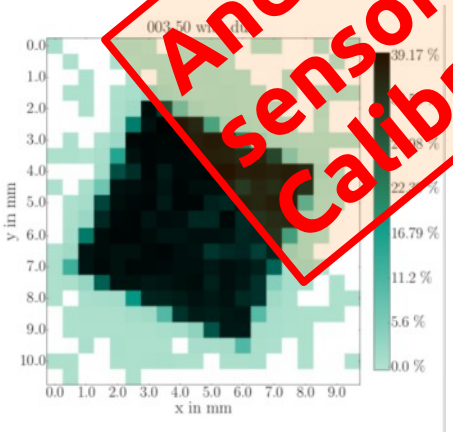
Charge finger spectra of an used SiPM
for obtaining Gain, Efficiency, dark count rate, …



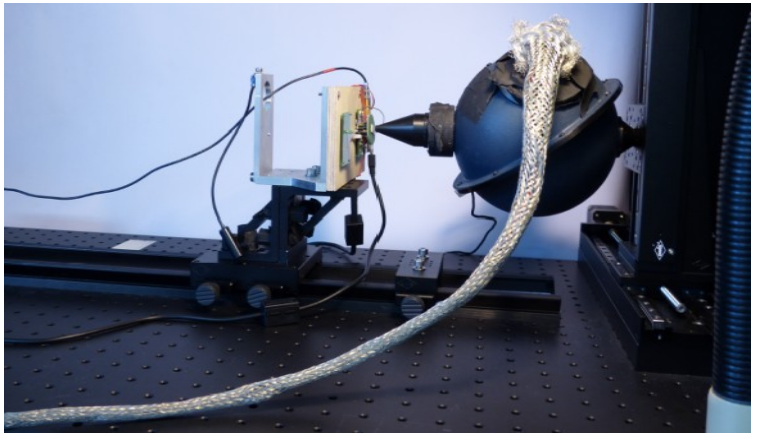
Part of the characterization of every used SiPM for the detectors

And a lot of Photo sensor (SiPM) Calibration…





Effects of dust on the photosensitive SiPM area
- Lowers PDE at around 9% at the right area



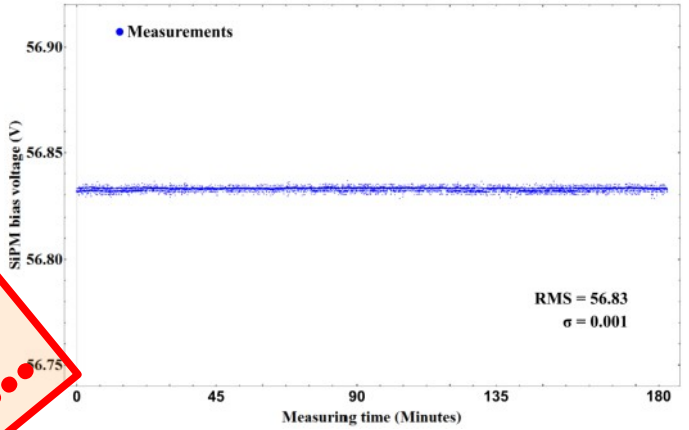
Singe Photon Calibration Setup at KIT (SPOCK)

M.Oehler, (KIT-ETP)

thomas.huber@kit.edu

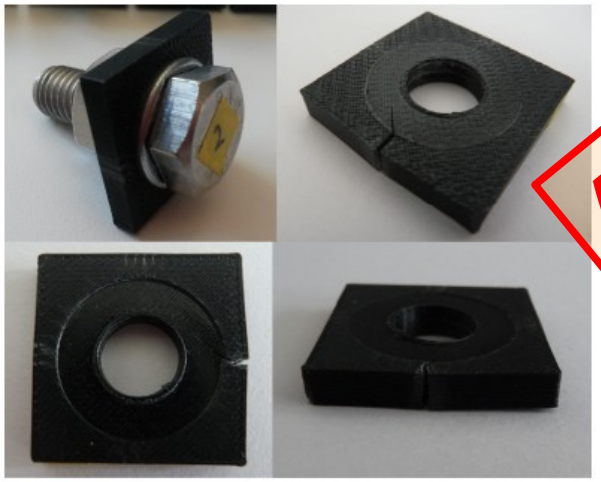
Testing of all components if they “survive” the Pole

“Inverse Oven” at KIT-IKP



Test for T-Stability of the SiPM power supply at -70°C

And a lot of low temperature tests...



Low temperature stress tests of the used 3D printed material (A. Schmidt, KIT-IKP)

Full system tests a the IceCube cooling chambers with T. Karg (DESY) Madison, Physical Science Lab (PSL)

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Production and testing of the scintillators

And a lot of production of three Scintillator stations...

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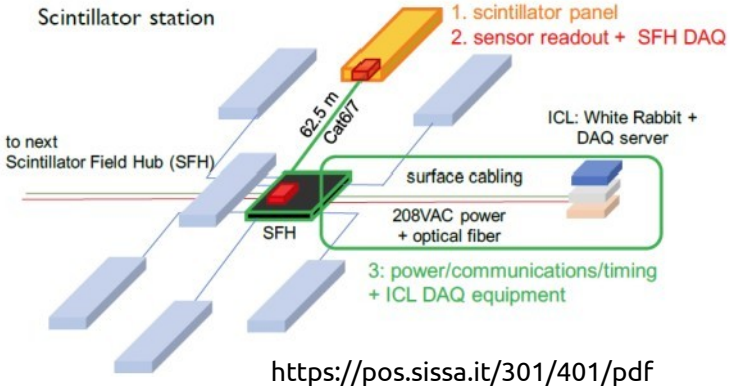
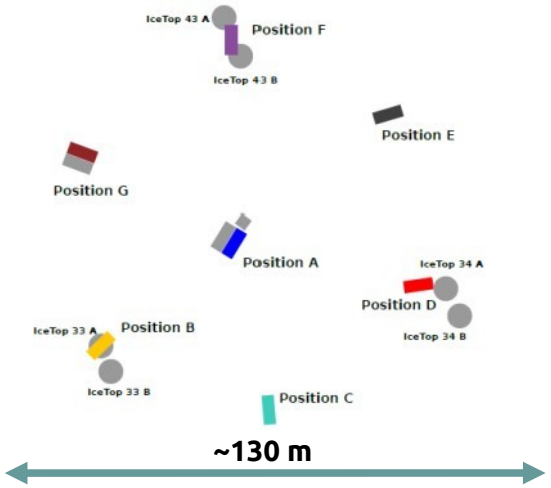
Deployment – Season 2017/18

- 2 different scintillator prototype stations
- Main difference:
  - Digital transfer of the detector signal to the DAQ (uDAQ, UW-Madison)
  - Differential analog signal transfer to the central DAQ and possibility to investigate the SiPM Waveforms (TAXI, KIT/DESY)

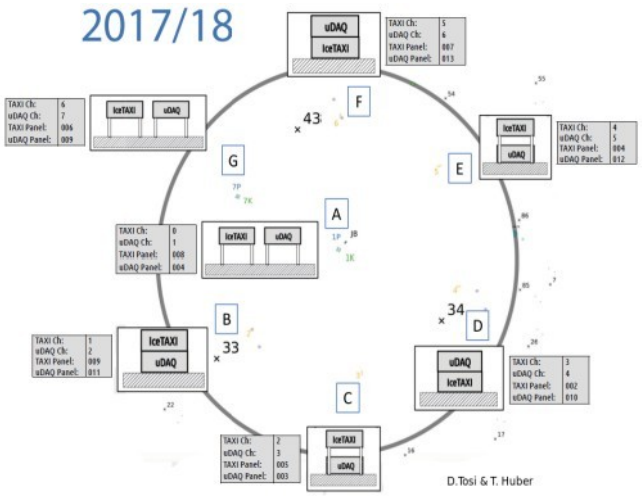


https://pos.sissa.it/301/401/pdf



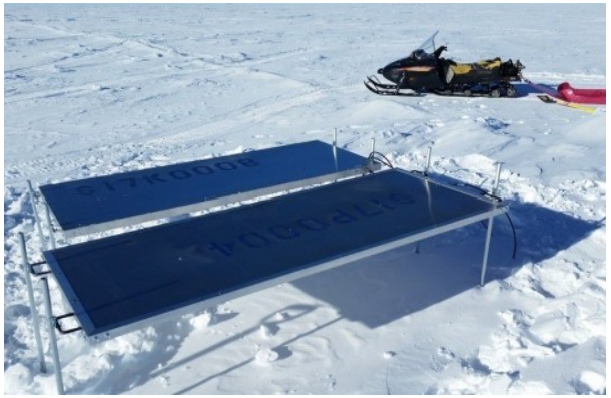
Scaled detector array positioning

(A. Schmidt, KIT-IKP)



Different alignments to compare both DAQ systems and the influence of snow covering

Detector "on the way"



Deployed detectors

Data acquisition

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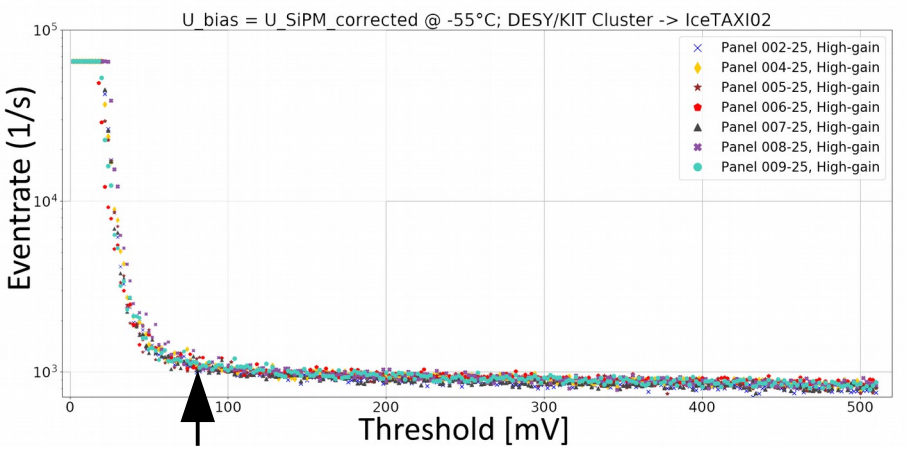
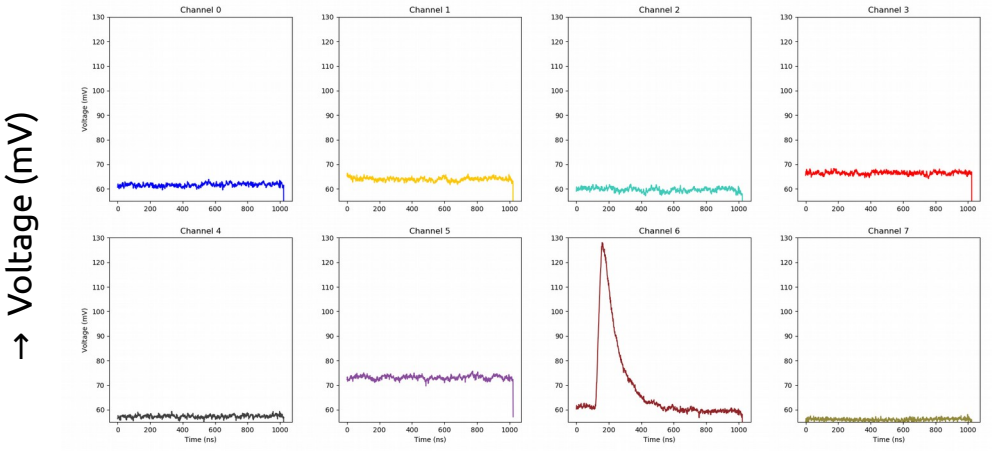
Is it working? How the scintillator signals look like

Threshold-Scan

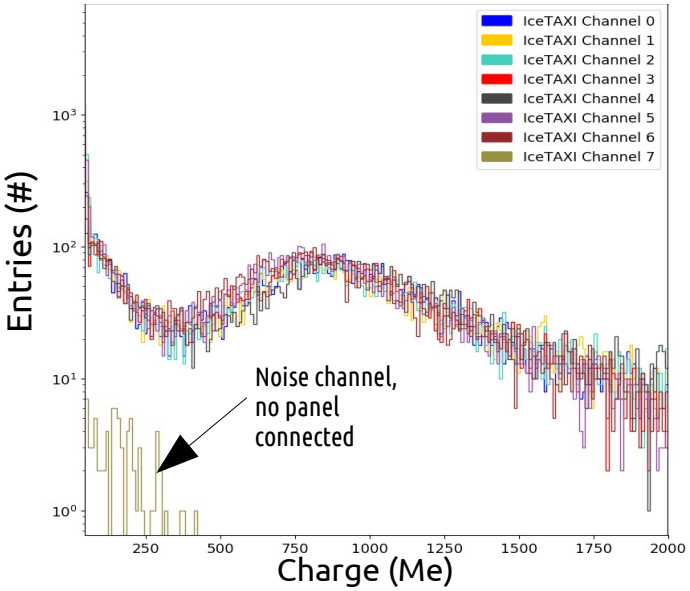


Threshold to start
processing MIP events only

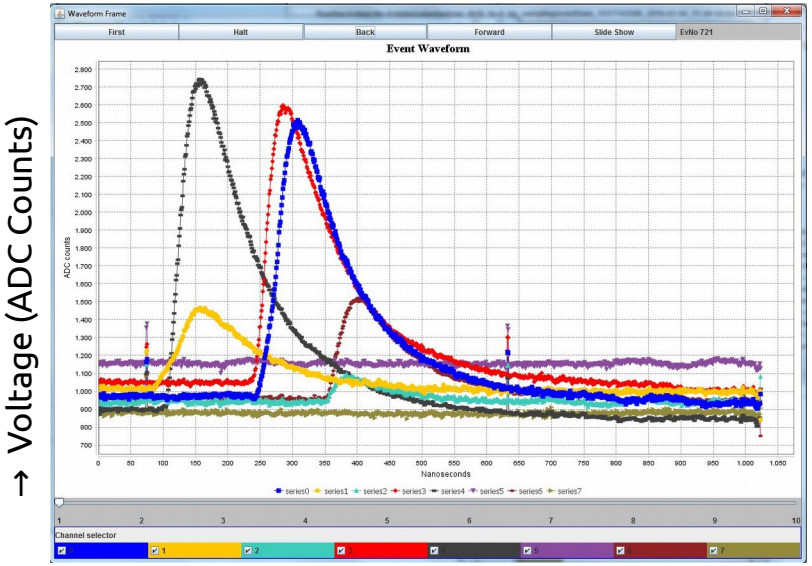
Signal-Over-Threshold SiPM Peak



Charge histogram



Waveforms Air-Shower event



jTAXI Tool
(A.Weindl, KIT-IKP)

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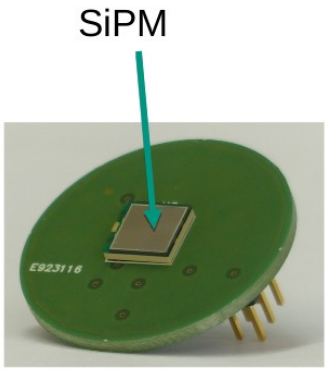
Is it working? SiPM Bias-Voltage<->Temperature control loop

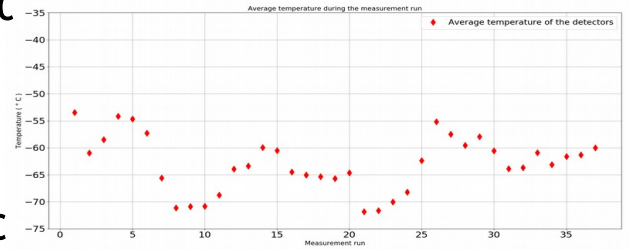


Gain of the SiPM is a function of the temperature

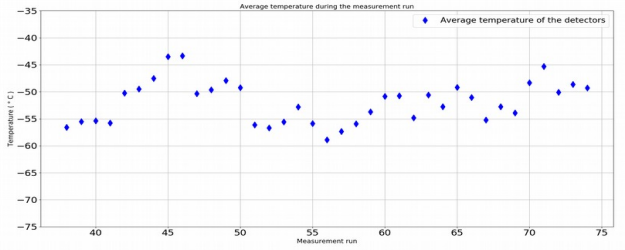
Temperature curve during the run

-35°C

-75°C



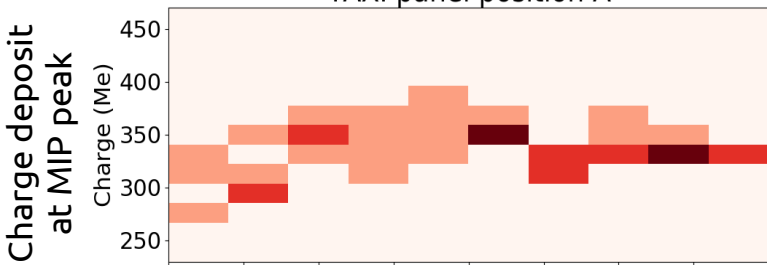
Temperature curve during the run



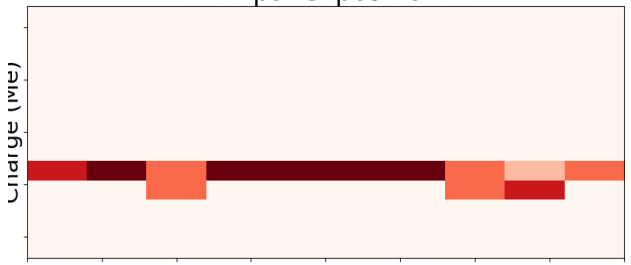
Disabled control loop

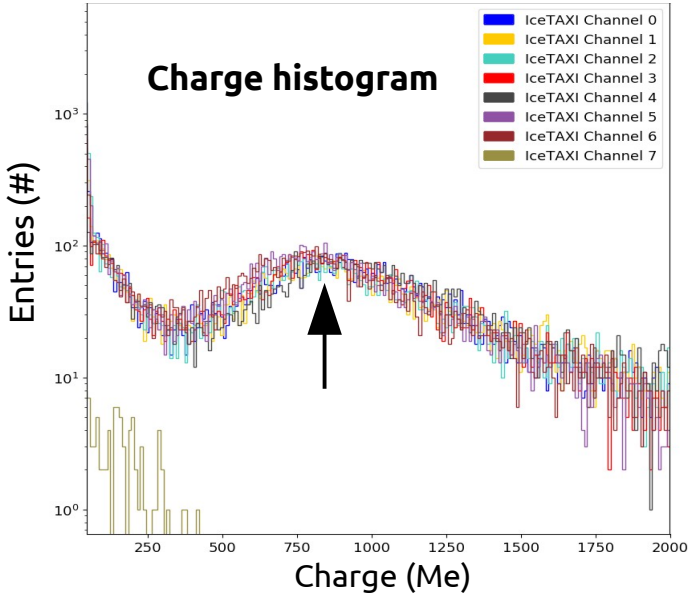
Enabled control loop

TAXI panel position A



TAXI panel position A





Uniform,
Gain stabilized,
detector array.

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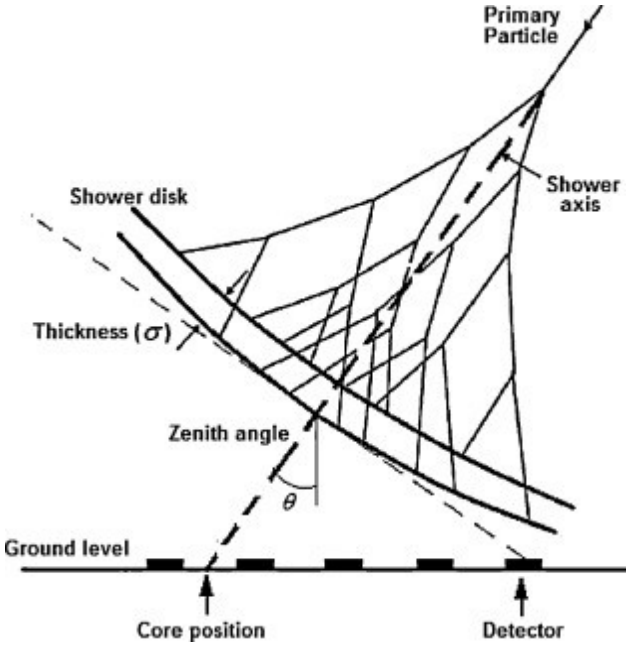
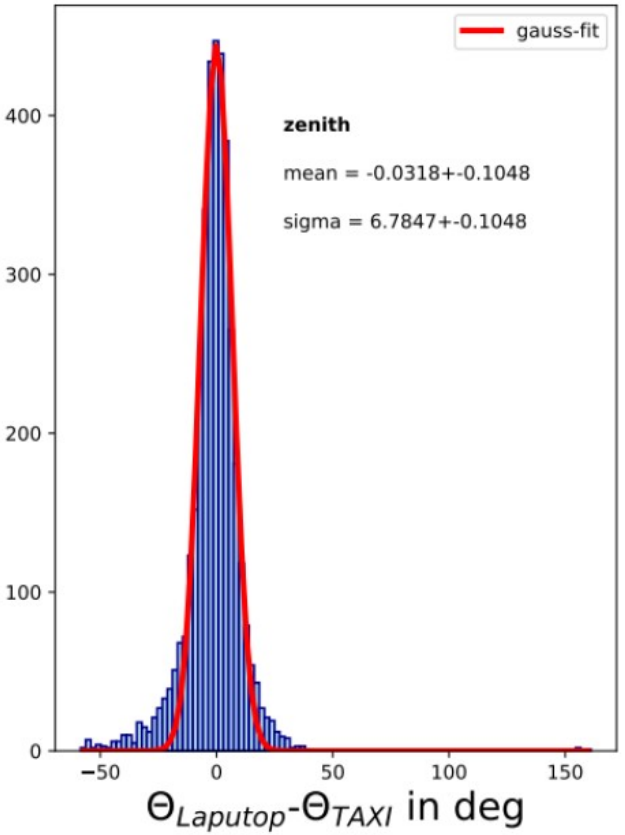
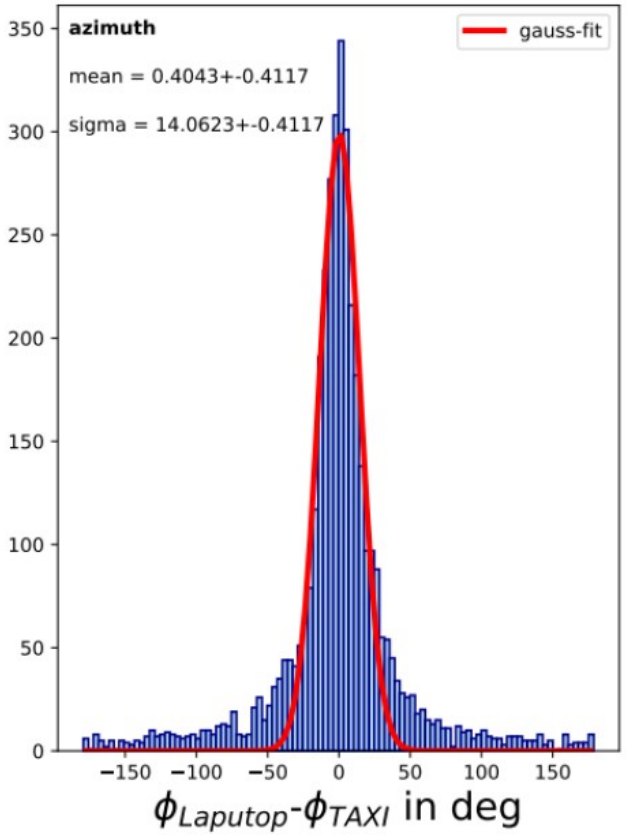
Is it working? Scintillators <-> IceTop reconstruction



Difference between scintillator station and IceCube: IceTop shower axis reconstruction (3834 events)



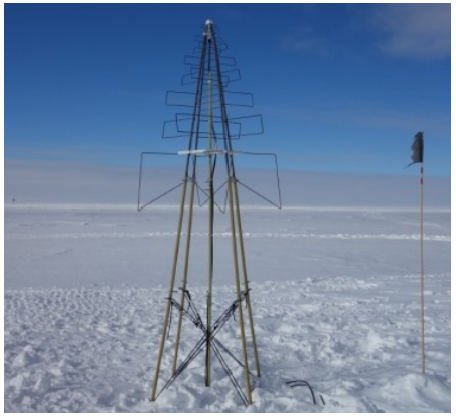


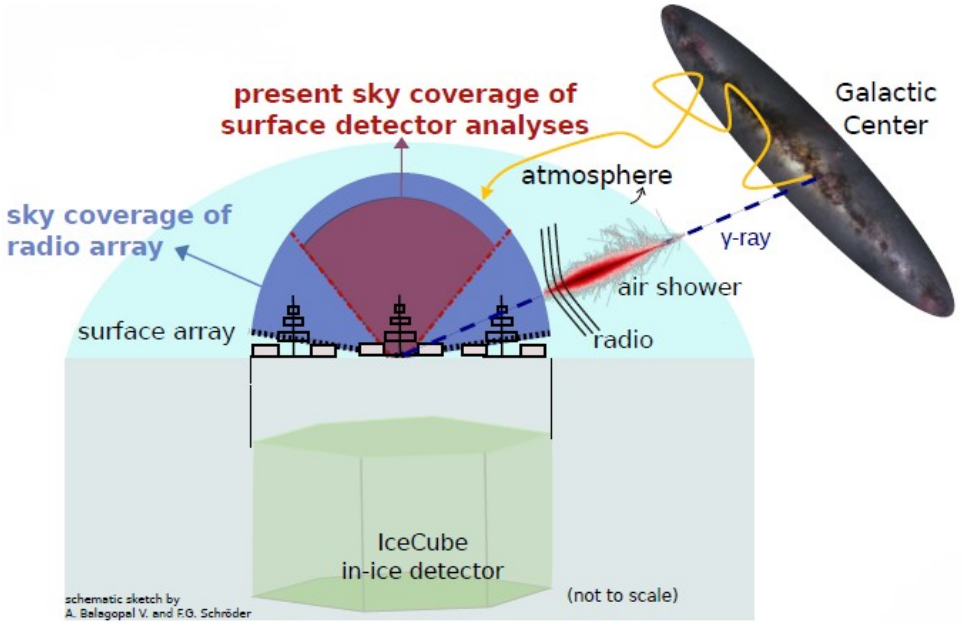
F. Ellwanger, (KIT-IKP)

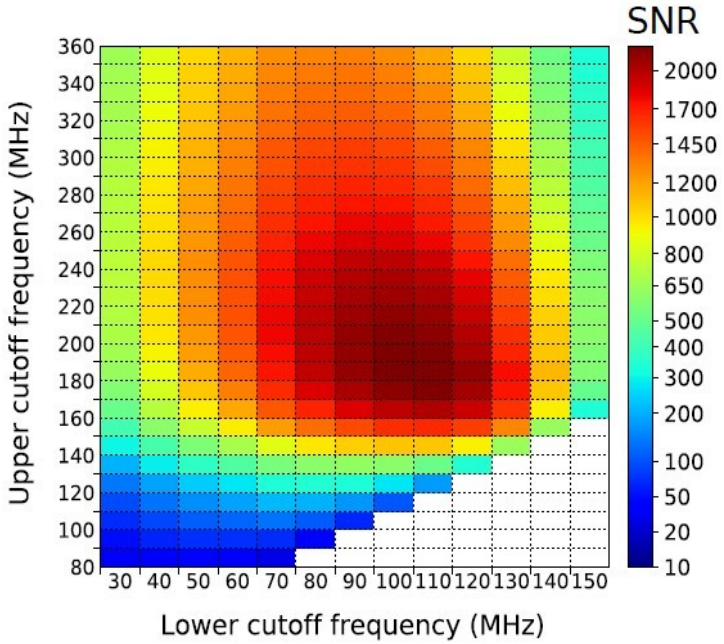
thomas.huber@kit.edu

Adding radio antennas? – Simulations and motivation

Electromagnetic radiation of Air Showers (induced by Askaryan or geomagnetic effect) detectable with radio antennas.







- Optimal frequency band of 100-190 MHz improves SNR and lowers threshold
- Radio enables measurement of very inclined air showers
- Search for PeV gamma rays from the Galactic Center

A. Balagopal , (KIT-ETP) and F. Schröder (KIT-IKP, Univ. Delaware)

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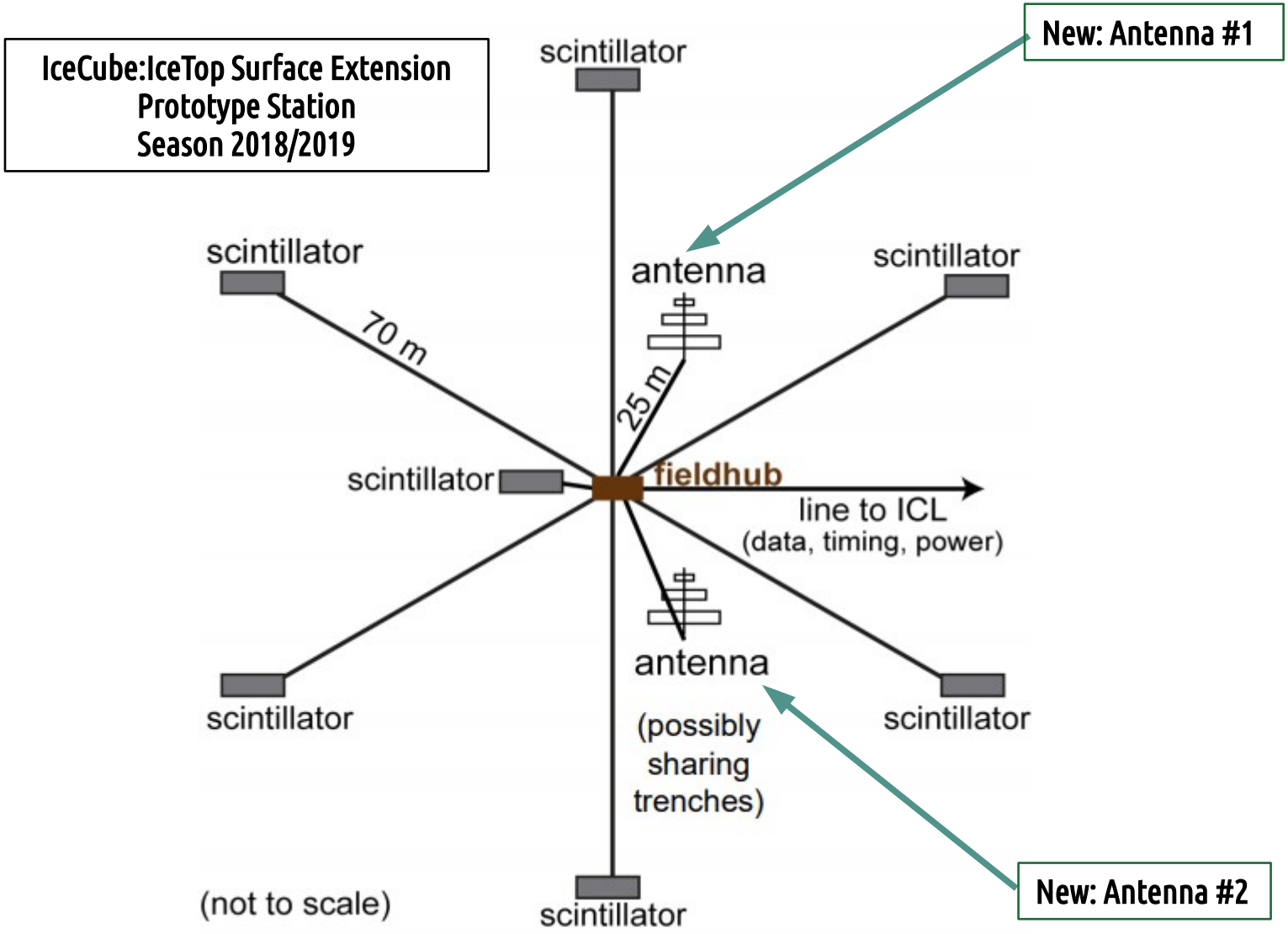
Adding radio antennas – Preparation for deployment



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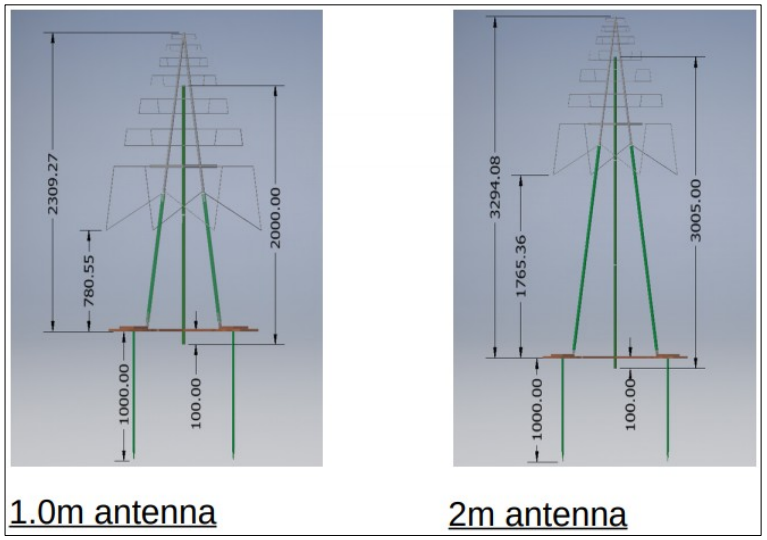
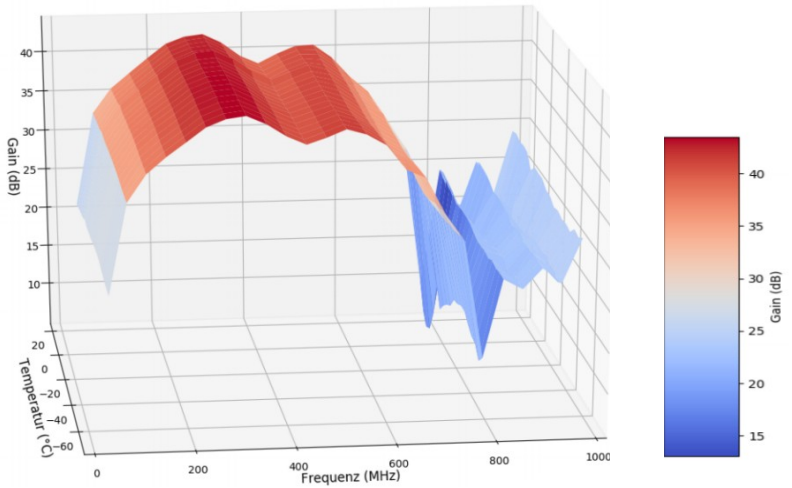
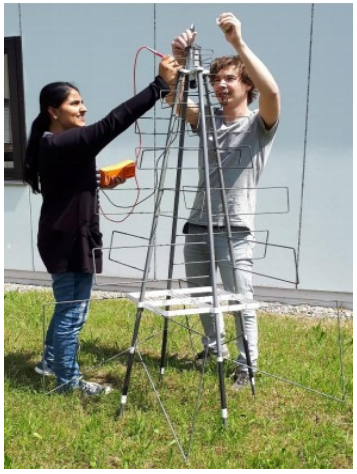
Adding radio antennas – Preparation for deployment



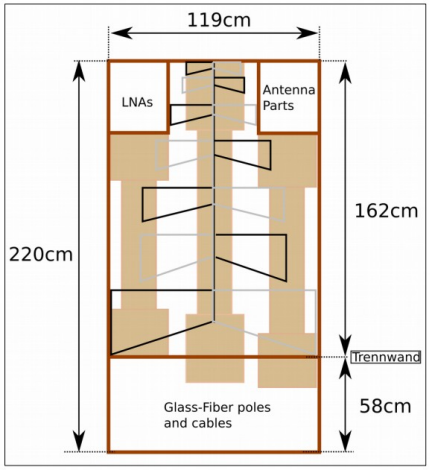
How to avoid that are antennas flying around at the South Pole



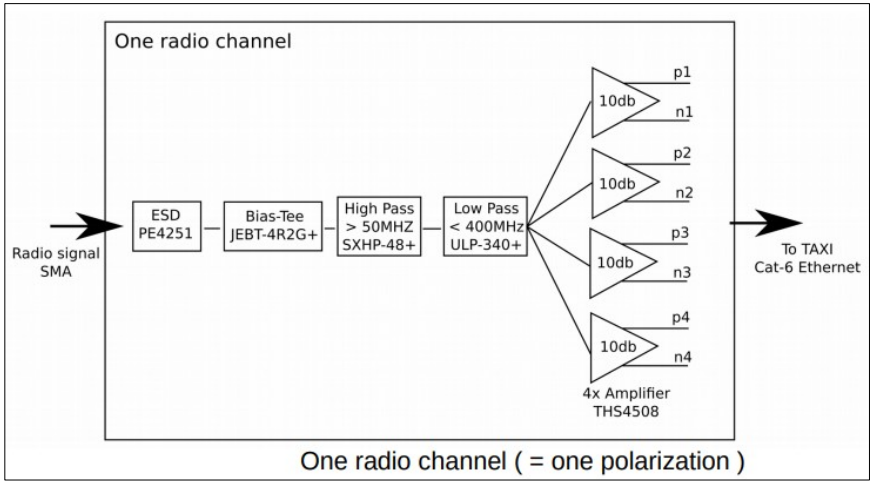
T-Stability tests of Frequency vs. Gain at different of the antenna electronics



Antenna testing



How to ship it to the South Pole



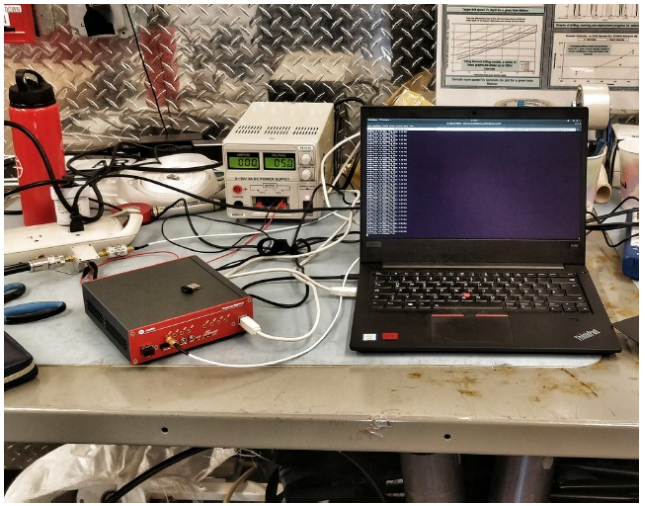
Filtering and amplification of the radio signals

M. Renschler, M. Weihrauch, P. Steinmüller, M. Riegel (KIT-IKP)

thomas.huber@kit.edu

Adding radio antennas – Deployment Season 2018/19

Max Renschlers LC-130 Hercules into the cold

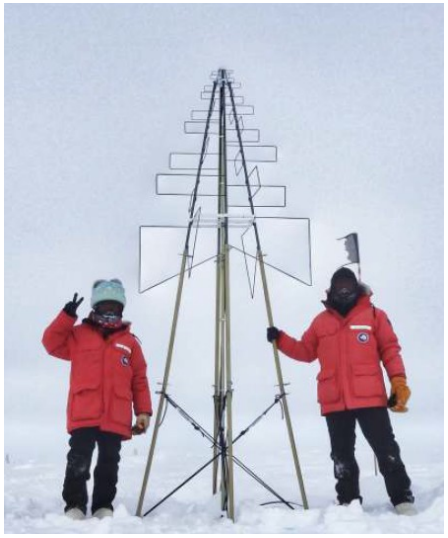


Antenna testing in the IceCube Lab

Assembled antenna

Shoveling out the DAQ of last season

Shoveling the trench for the cables

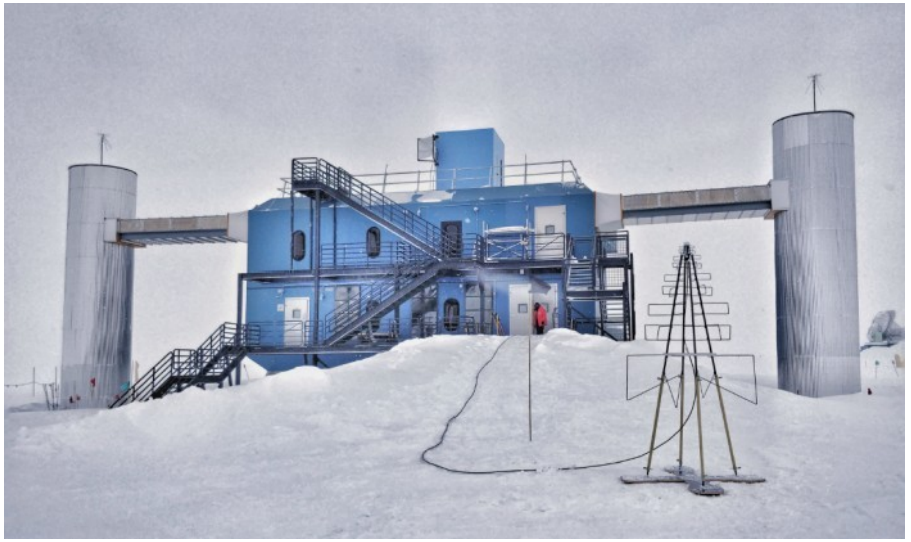


Deployed antenna

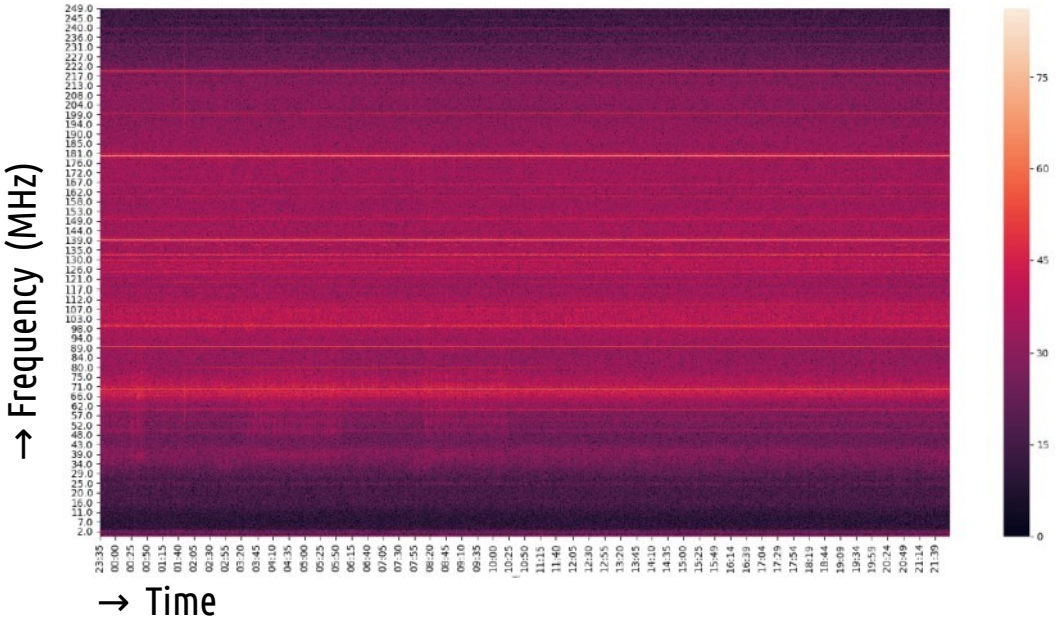
thomas.huber@kit.edu

Adding radio antennas – First measurements

- Background measurement with a DAQ at the ICL
- Measurement time ~24h, data taking every 5 seconds
- Antenna parallel to the ICL



By Lu Lu, Chiba University



- Frequency bands with higher signal visible
- Some time depending structures are showing up

→ Might get more uniform (less bands) by larger distance to ICL

M. Renschler, (KIT-IKP)

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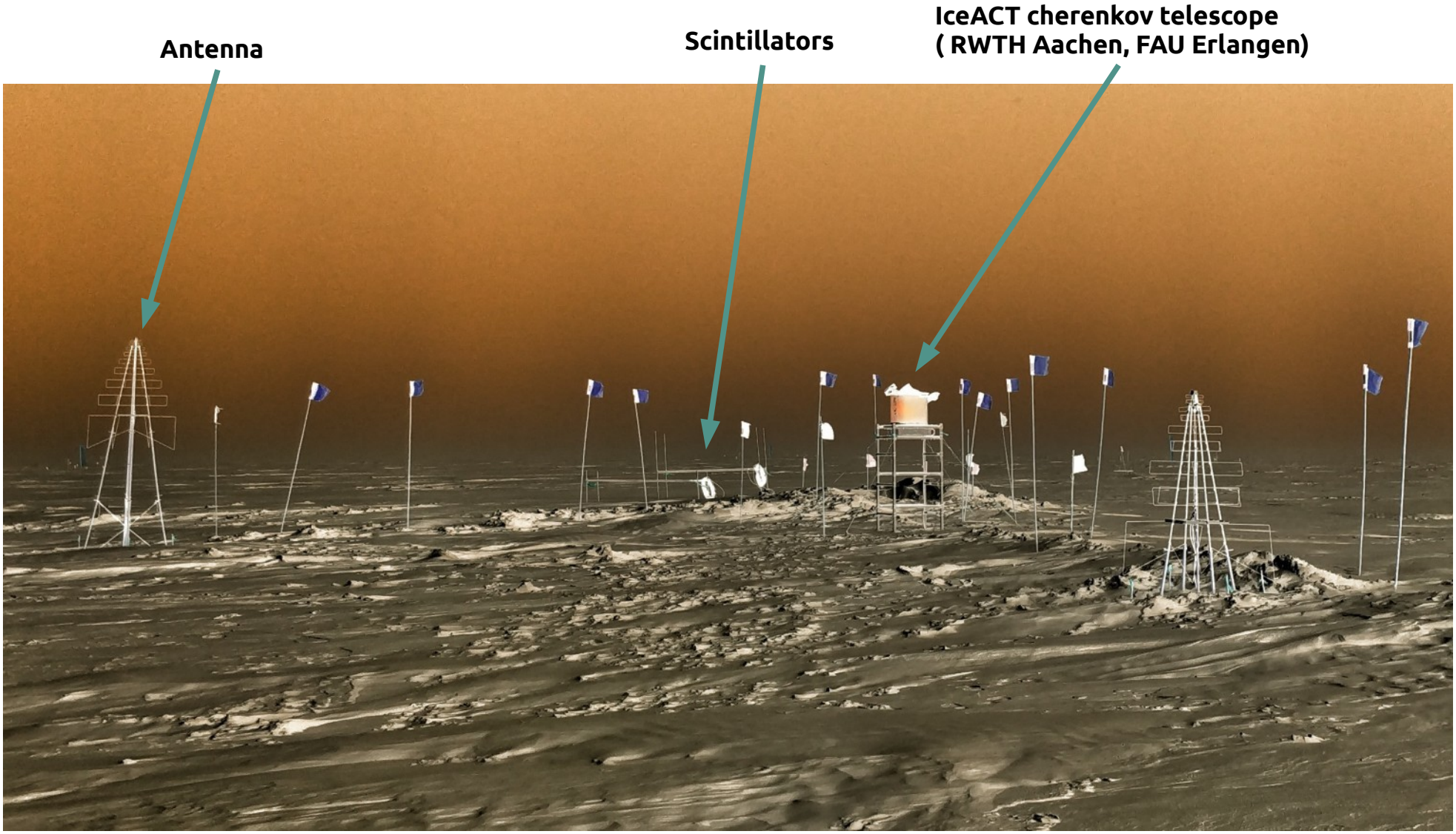
The surface extension Prototype: Season 2018/2019



The IceCube surface extension Prototype

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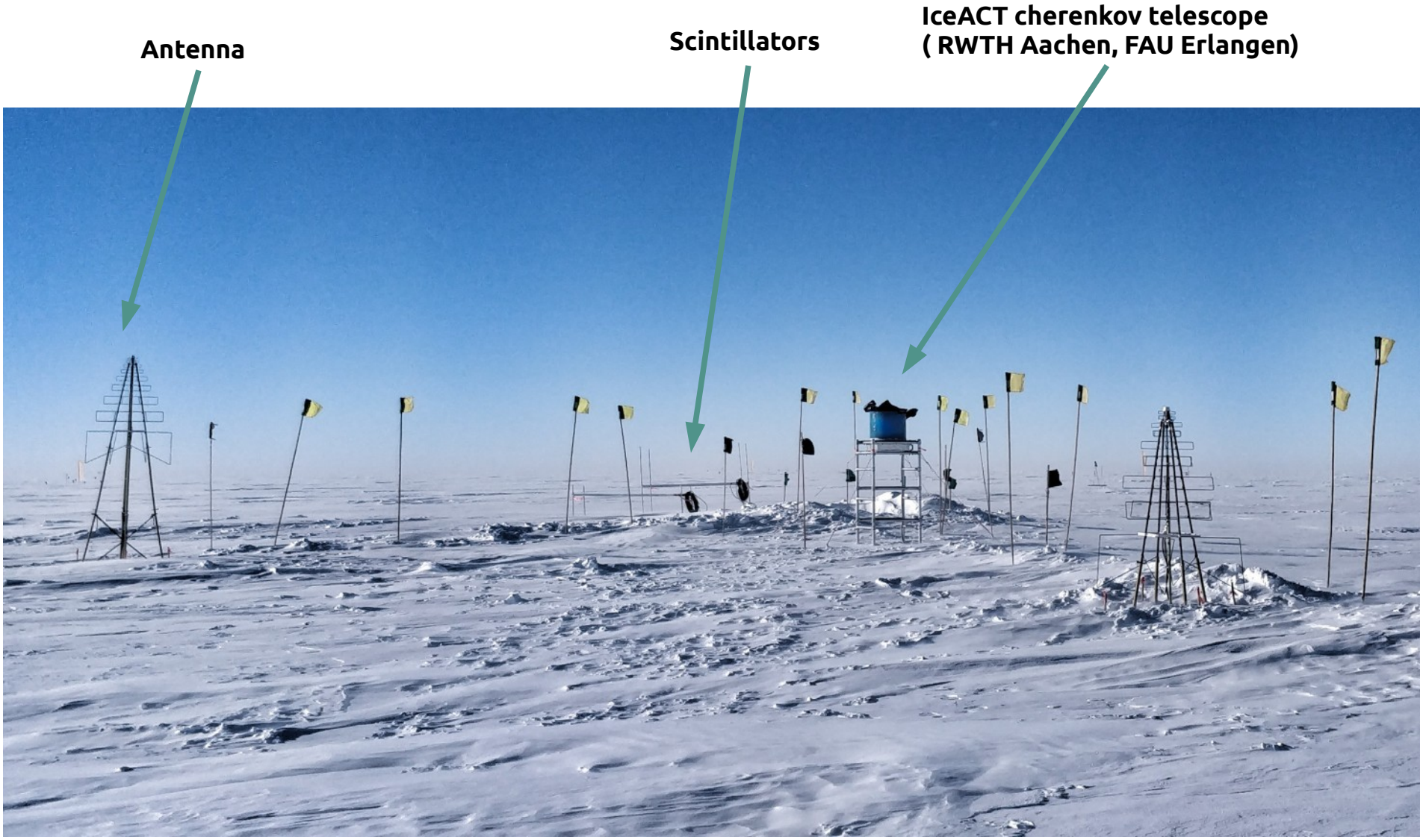
The surface extension Prototype: Season 2018/2019



The IceCube surface extension Prototype

thomas.huber@kit.edu

That was the physics.

Lets switch to a “Diavortrag” :-)

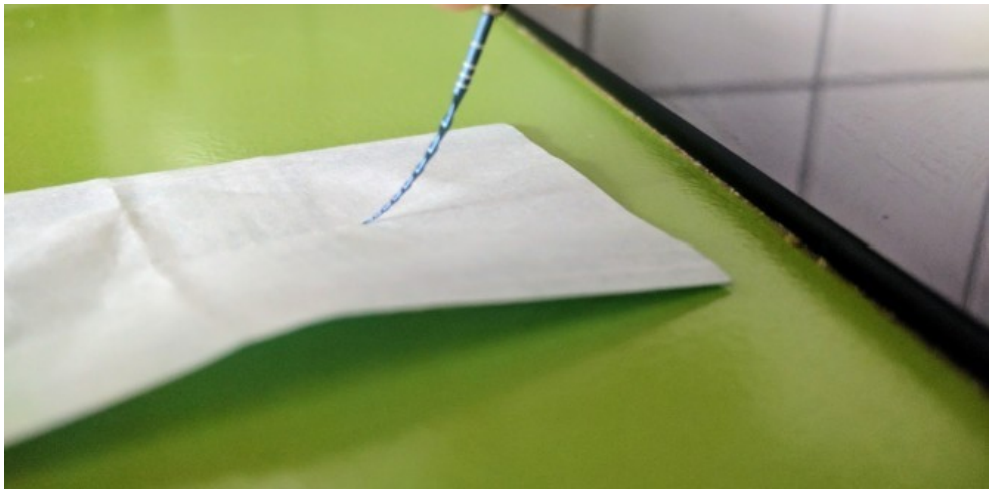
What's it like to travel to the South Pole?

thomas.huber@kit.edu

(...and how to get to the South Pole to work)

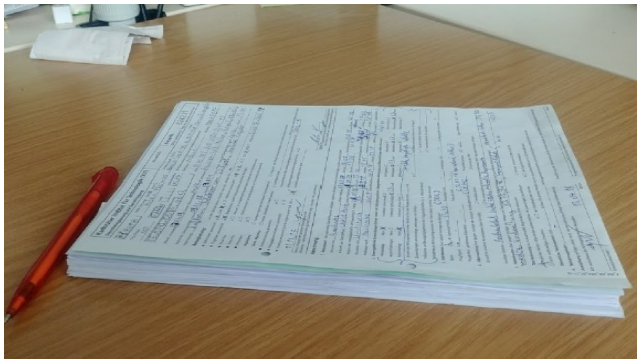
- **Tremendous** amount of paperwork
- A lot of medical and dental tests if you (and your teeth) survive at the South Pole
- Better do not have any wisdom teeth left

14 pages of blood count

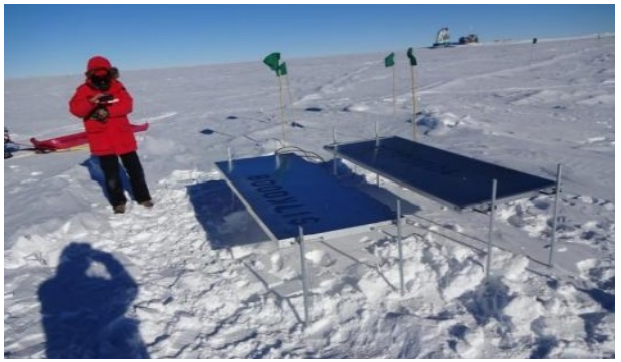


Dental “tests”...

How to survive



I guess that travel form (~100 pages) is a new KIT record



And you need some pretty good reason (= experiment) to go to the Pole

thomas.huber@kit.edu

(...and how to get to the South Pole to work)

- And a **lot** of travel...

thomas.huber@kit.edu

(...and how to get to the South Pole to work)

- And a lot of **strange** travel...

Christchurch – USAP Terminal

Christchurch – USAP Terminal

Christchurch – Getting clothes

Inside of a LC-130 Hercules

Inside of a LC-130 Hercules

McMurdo Station - Runway

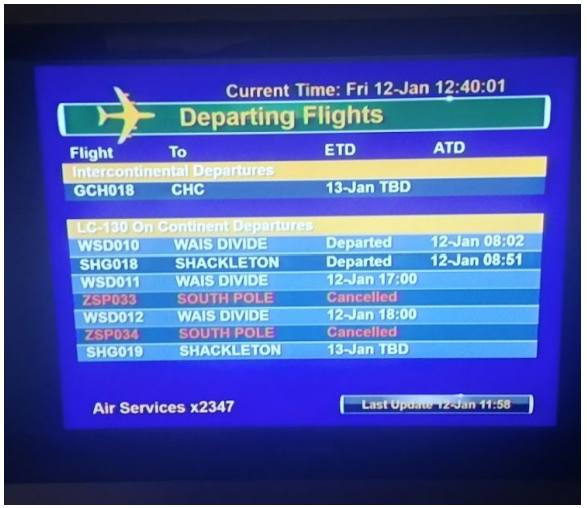
thomas.huber@kit.edu

(...and how to get to the South Pole to work)

- And a lot of **delay/waiting/** for good weather to travel to Mc Murdo Station and the South Pole Station (and back)

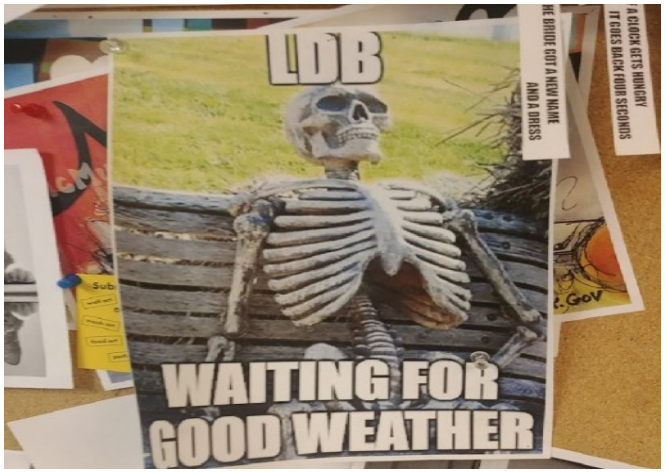
McMurdo Station

McMurdo Station



McMurdo Station

Christchurch - USAP



McMurdo Station

McMurdo Station

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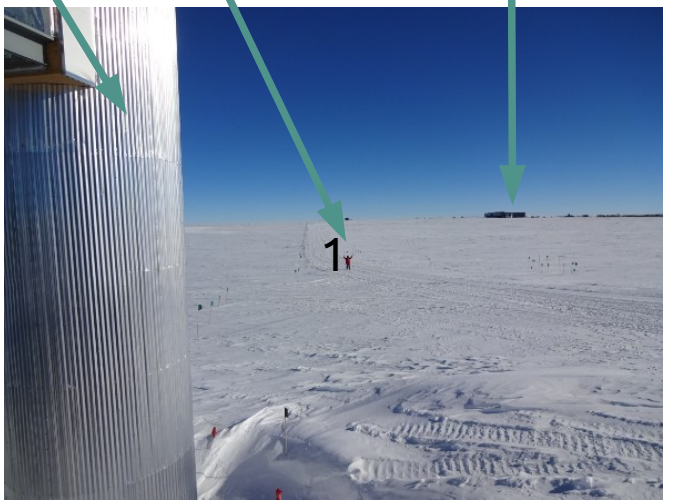
(...and how to get to the South Pole to work)

- But with **nice views**…

Towards South Pole

Towards Mc Murdo



View from ICL to South Pole Station

Hiking / Staying in shape / Waiting McMurdo

Hiking / Staying in shape / Waiting McMurdo

Hiking / Staying in shape / Waiting McMurdo

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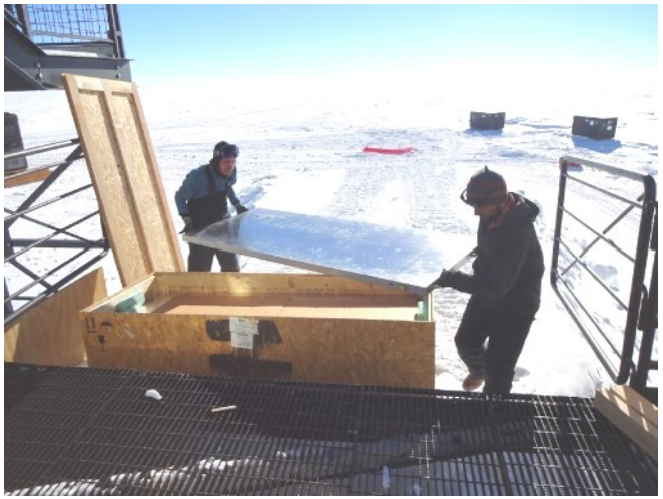
(...and how to get to the South Pole to work)

- But it is… **work** :-)



South Pole - ICL

South Pole - ICL

South Pole - ICL

South Pole – Somewhere nowhere

Digging out the DAQ

Recabling the DAQ

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(...and how to get to the South Pole to work)

- But: It is all not that **dead serious** :-)

South Pole Odyssey

Mc Murdo Station – M. Kauer, (UW Madison)

South Pole – T. Huber, M. Kauer, M. Kossatz (DESY)

Mc Murdo Station

ICL - South Pole -M. Kauer, (UW Madison)

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(...and how to get to the South Pole to work)

“Path” to the IceCube Lab and back to the South Pole Station

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Backup

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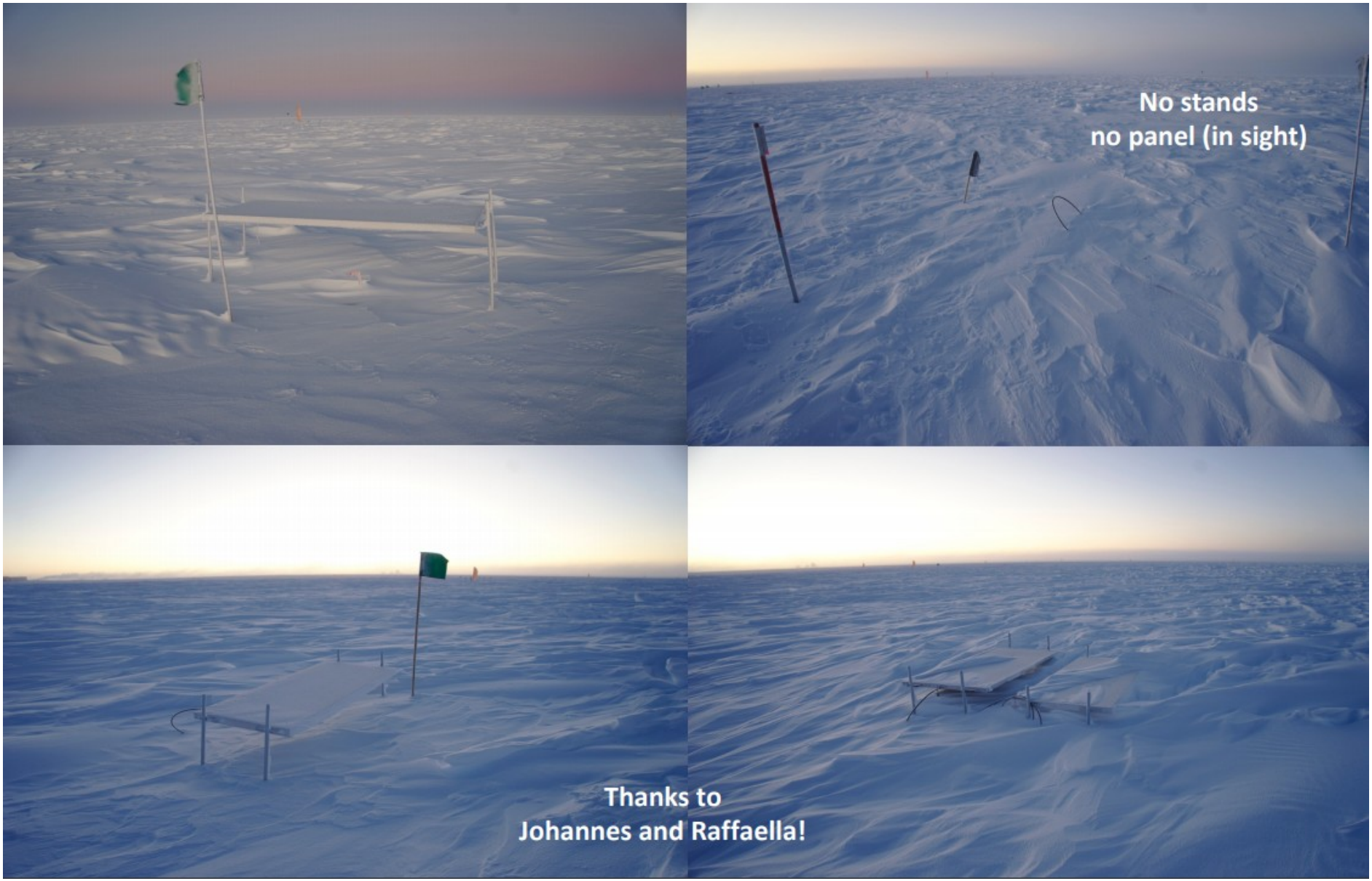
How the scint station looks like after one season



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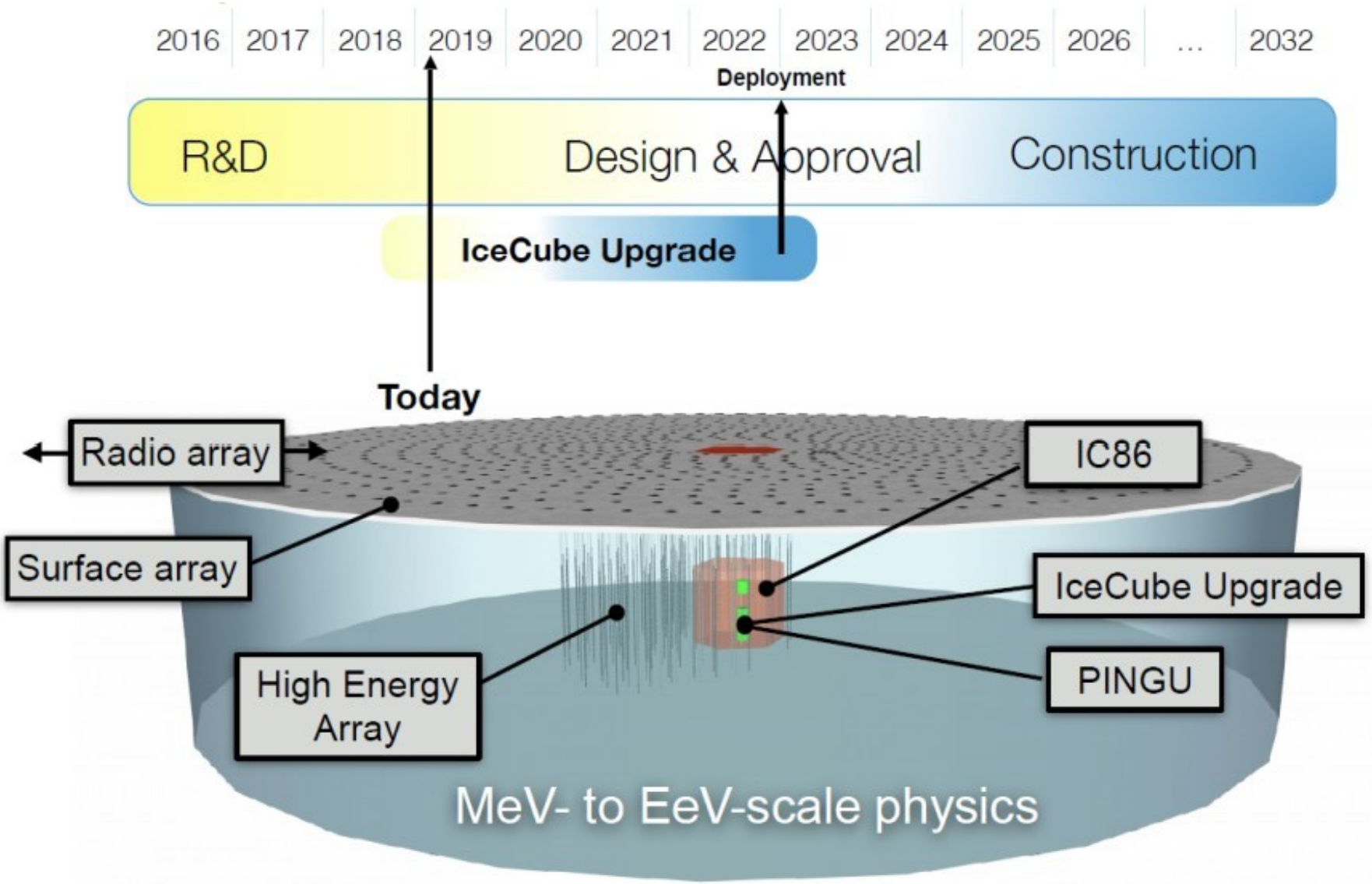

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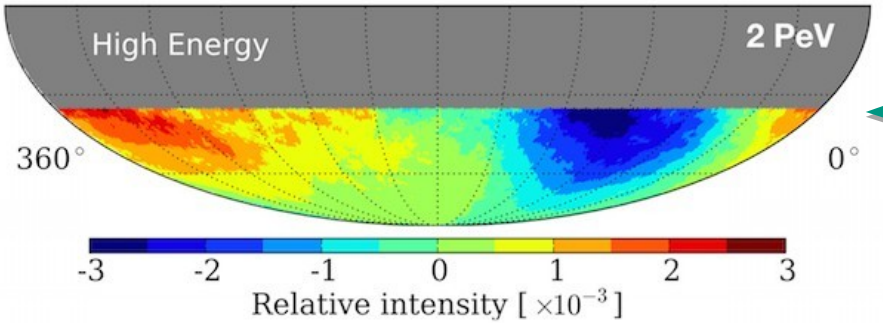
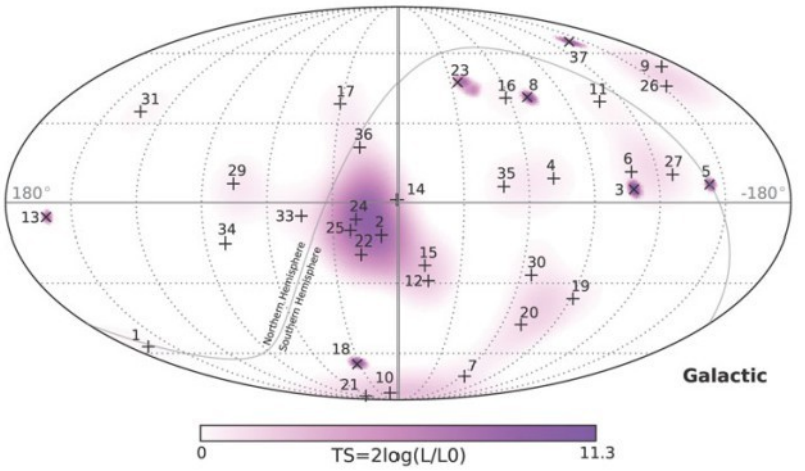
Multi messenger approach

Cosmic sky:

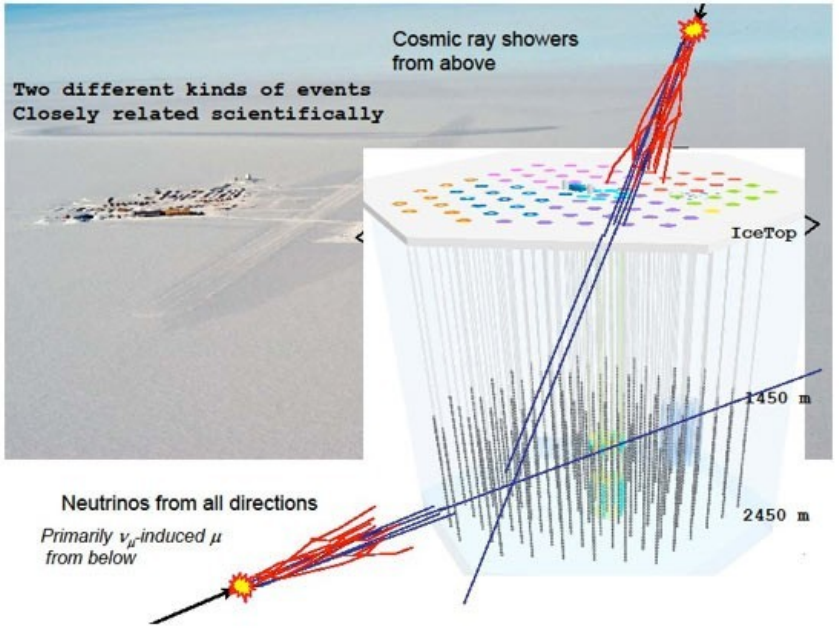


Cosmic-ray anisotropy sky map from IceCube.

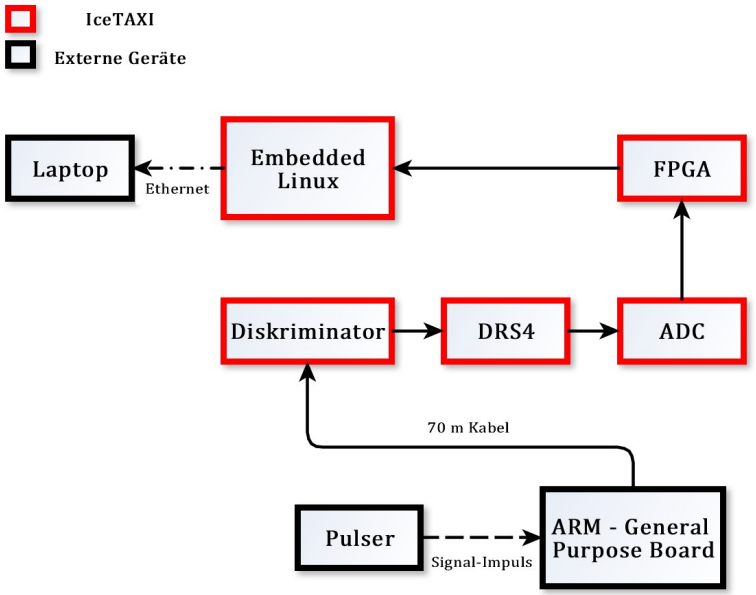
?



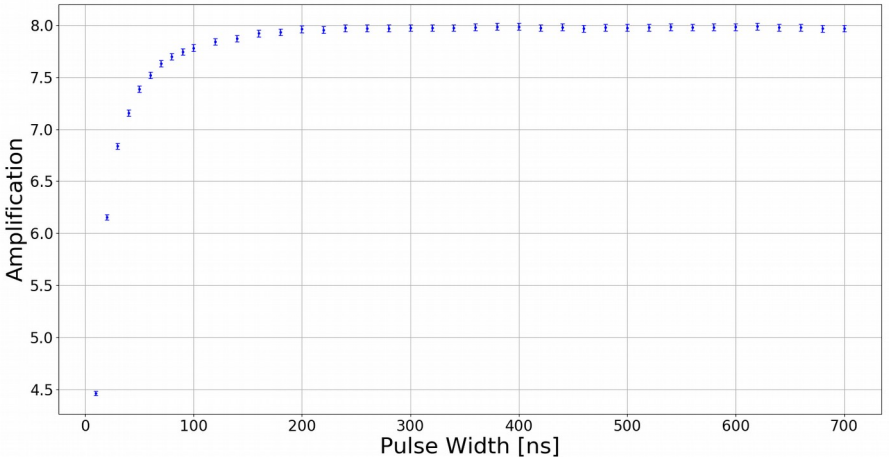
Arrival directions of 37 high energy neutrino events found analyzing three years of data. No significant clustering was observed yet.



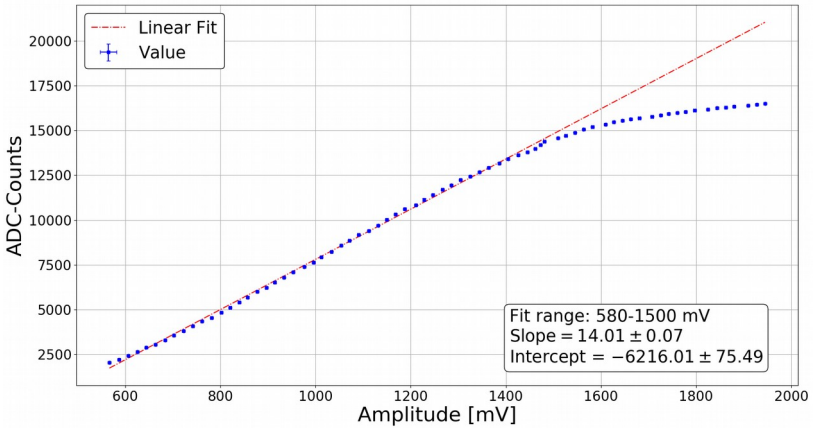
TAXI DAQ Calibration



Same readout chain like TAXI at the Pole



Amplification at high gain



Example: High gain channel 7

Used for calibration of
the charge deposit into TAXI of a MIP event
(see slide later)

Bachelor thesis E. Raspupin (KIT-IKP)

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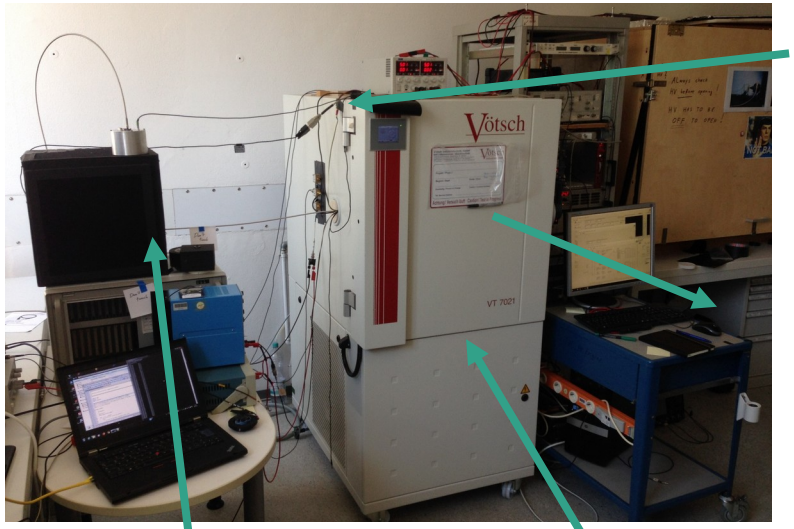
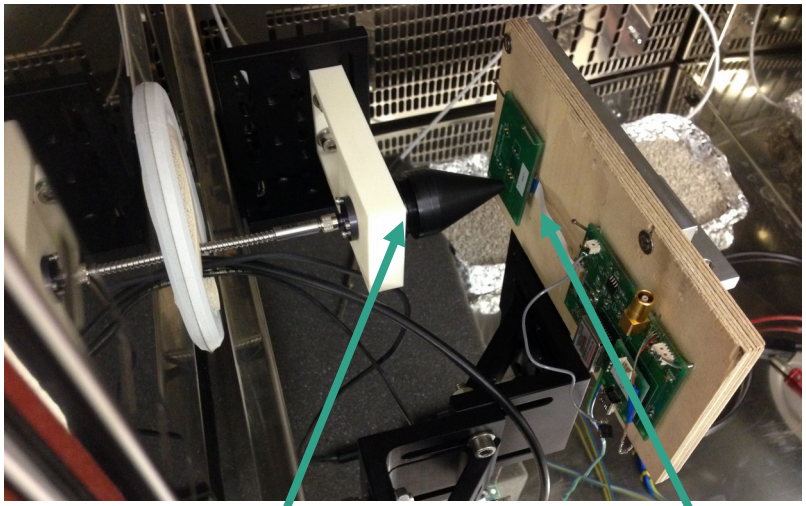
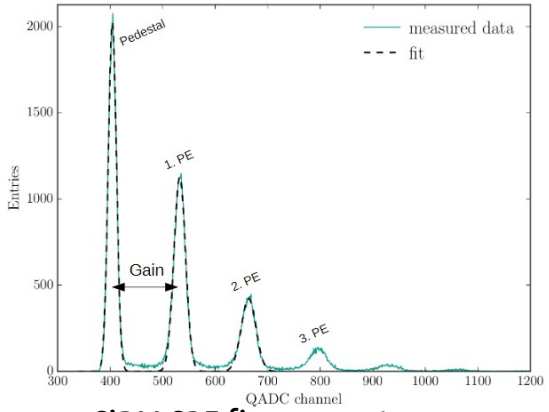
TAXI calibration : SiPM Gain at low temperatures

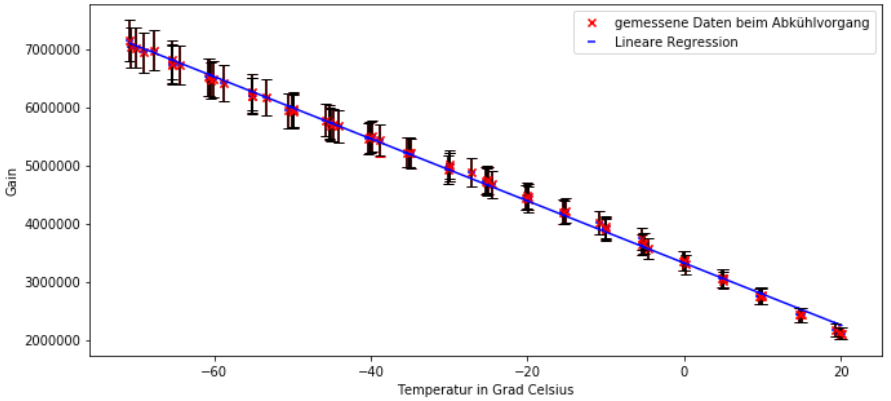






SiPM SPE finger spectrum

20 °C to -70 °C



SiPM Gain vs. Temperature

→ Used to check if the p.e. TAXI amplification chain is understood
(- SiPM Gain; - el. Gain, + cable supression → ~ 50 SPE/MIP

Bachelor thesis B. Mitic (KIT-IKP)

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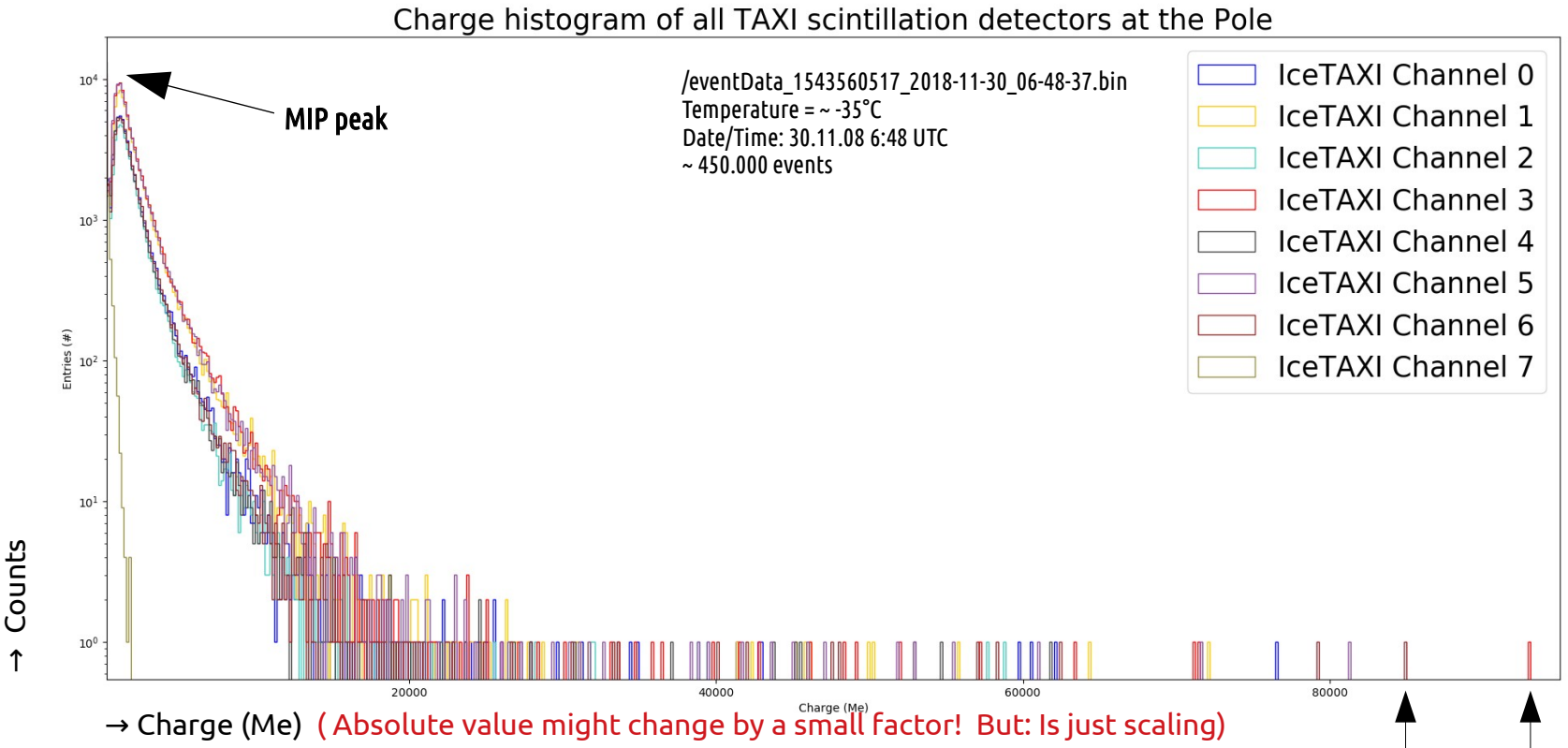
Run #2.1 – Dynamic range via offline integration

- Tom

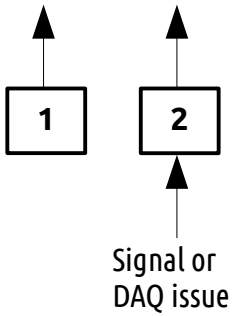


(Absolute value might change by a small factor! But: Is just scaling)

MIP-Peak at ~ 1100 Me

Largest integrated SiPM peak into a Charge: ~92500 Me or 84000 Me

Dynamic Range : 1 MIP to 84x MIP or 1 MIP to 76x MIP



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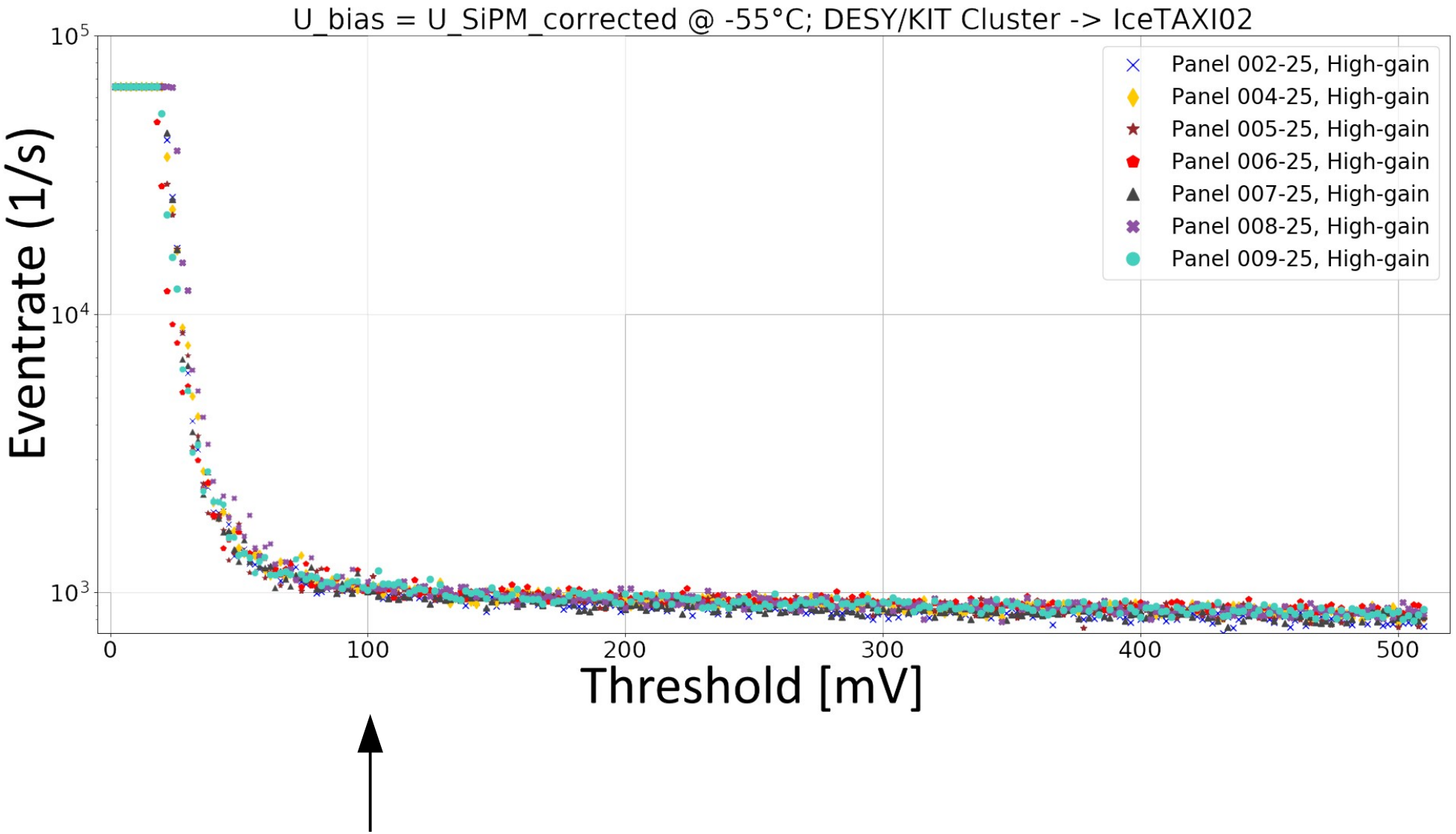
Commissioning runs – Threshold Scan



Threshold for start proccessing of MIP events only

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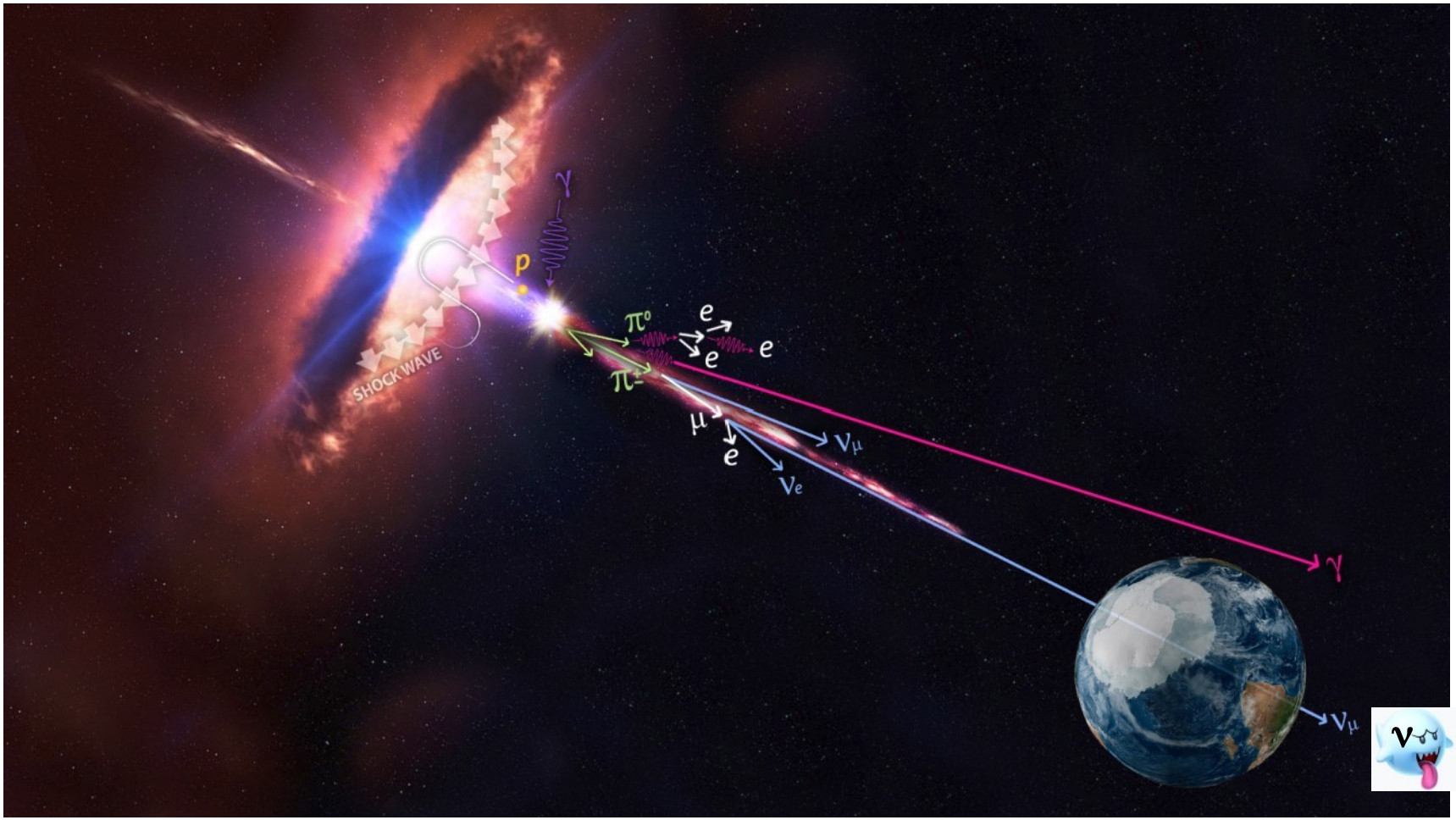
Is IceCube working? Seems like

So you can point back to strange sources in the Universe! → **Neutrino Astronomy**



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(...and how to get to the South Pole to work)

South Pole / ICL during Winter Season

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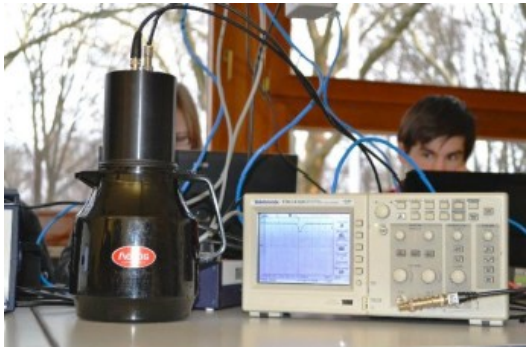
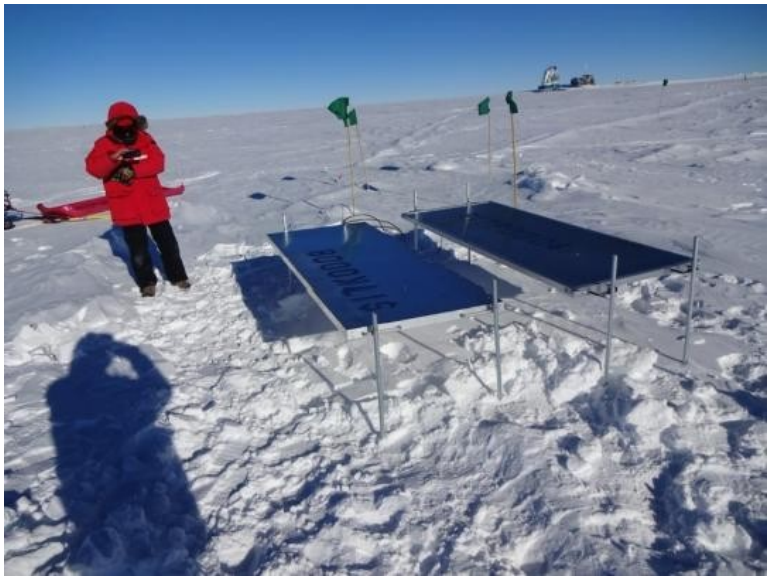
Cherenkov detectors

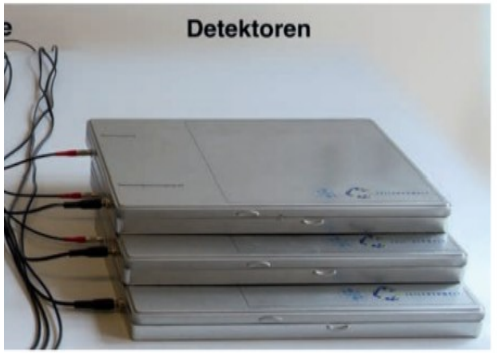
IceCube IceTop, South Pole



Scintillation detectors



IceCube IceScint, South Pole



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Decades of research and development by Neutrino detectors

...to find out more about the properties of Neutrinos and the Universe itself

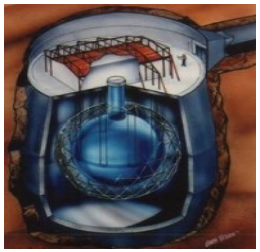
Catching them

A lot of different experiment were (and are going to be) built to hunt for Neutrino properties (and using them for astroparticle physics):

Neutrino mass

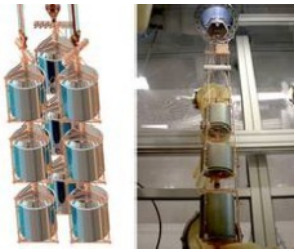
KATRIN, Karlsruhe

Neutrino oscillation



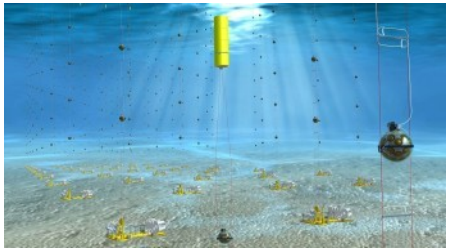
SNO, Canada

Neutrinoless double beta decay



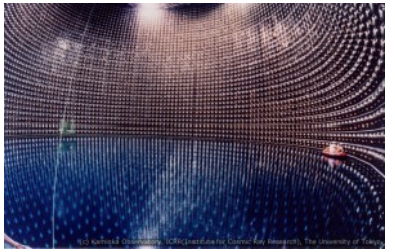
GERDA, Italy

Neutrino telescope



KM3Net, Mediterranean sea

Neutrino oscillation



Super-Kamiokande, Japan

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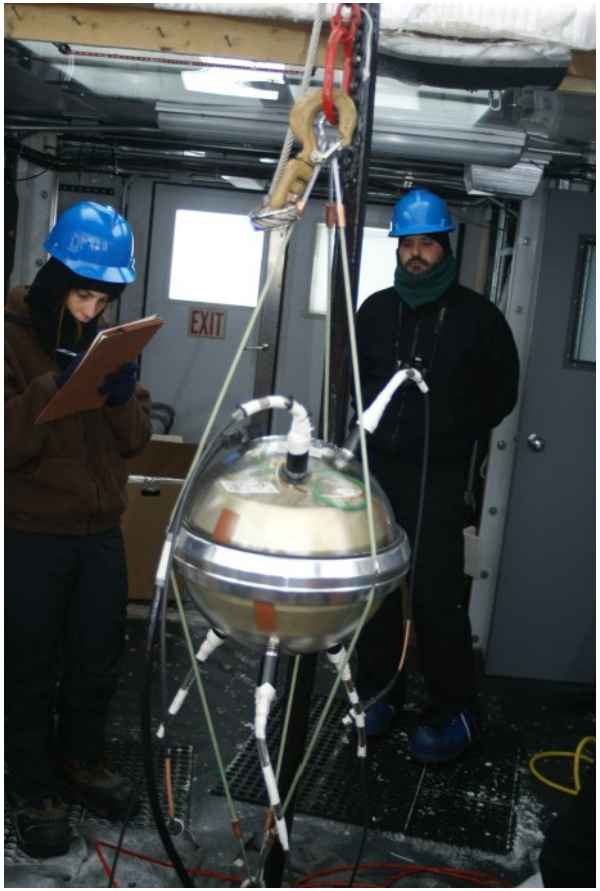
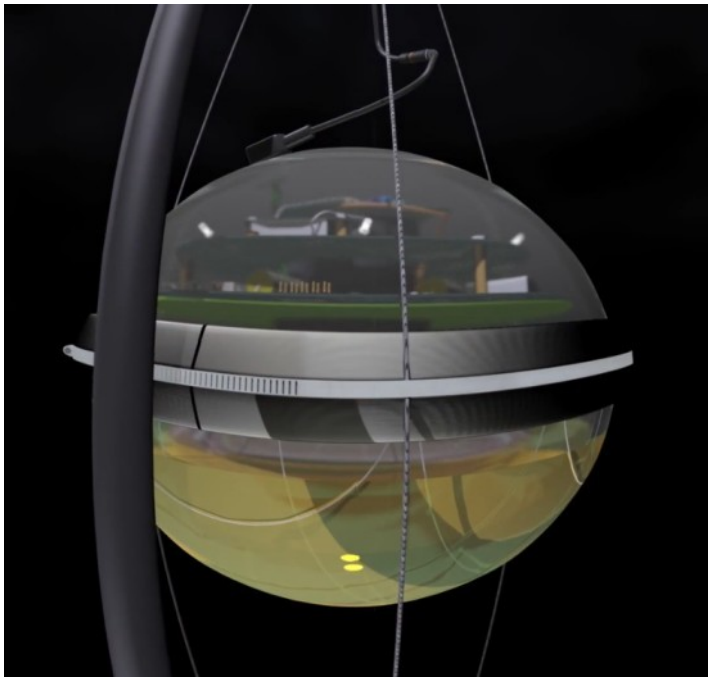
IceCube Sensors

DOMs (Digital optical Modules)
- Readout eletronic and Photo Multiplier



Movie #3:



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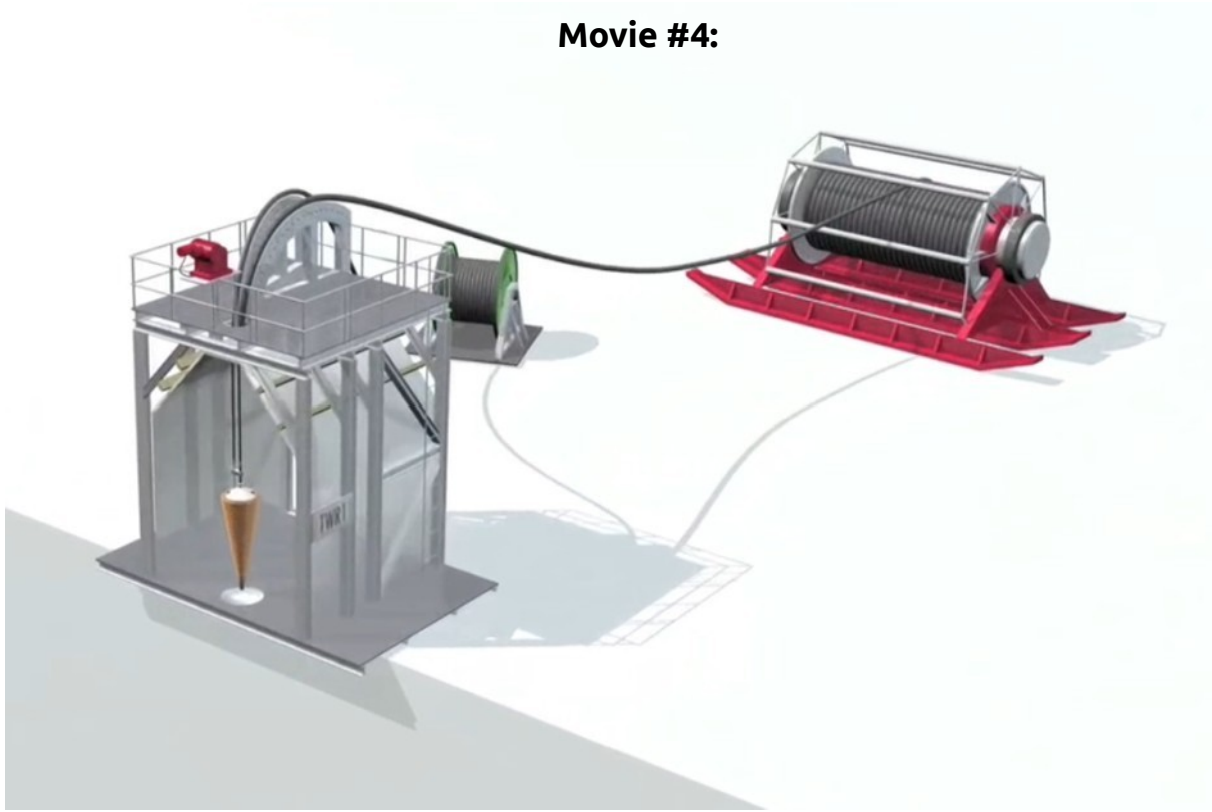
How to build IceCube

Movie #4:



"Deep Ice drill"

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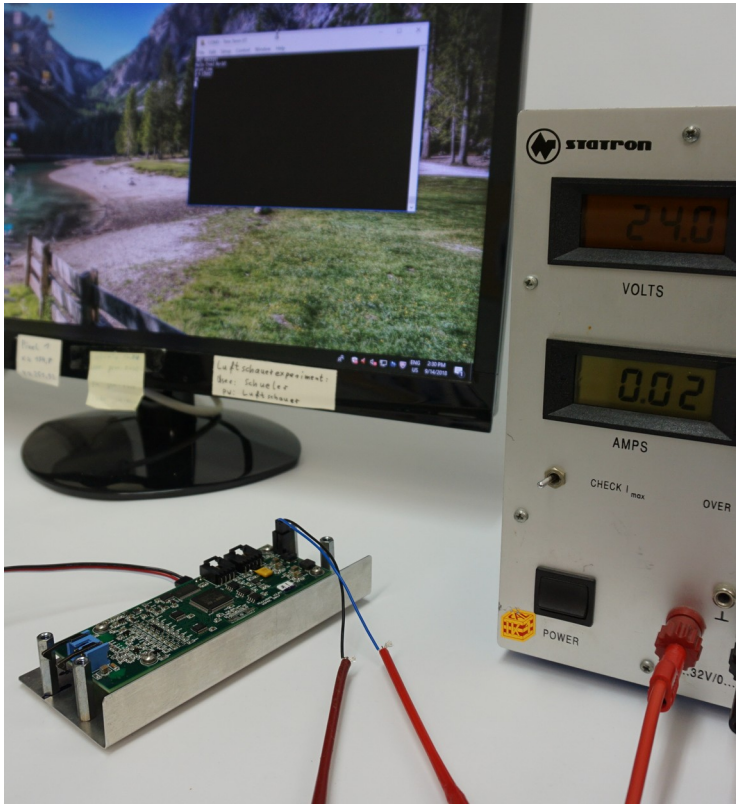
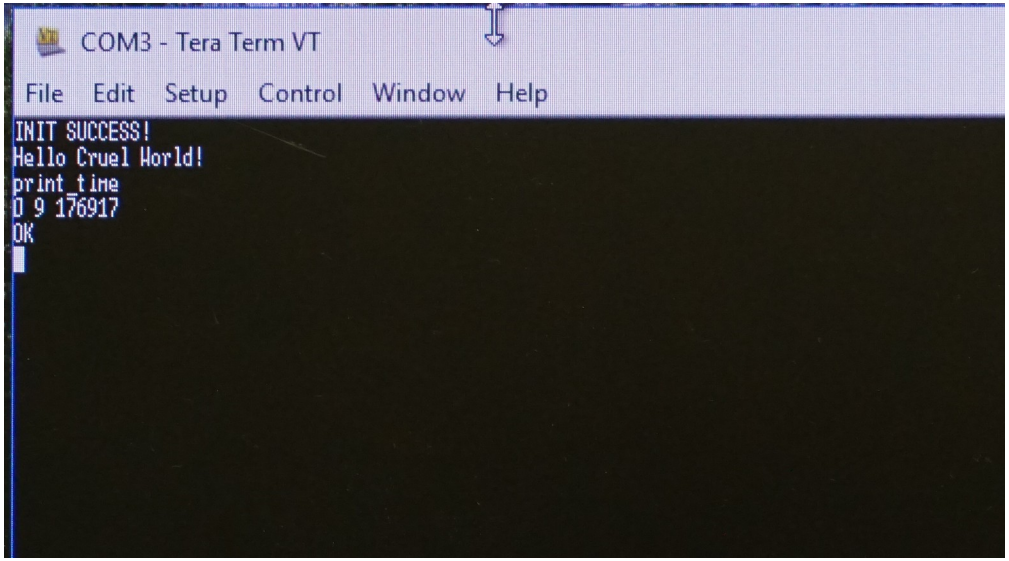
µDAQ at KIT

- Survived the transport Madison ↔ Karlsruhe



uDAQ



"Hello world" test

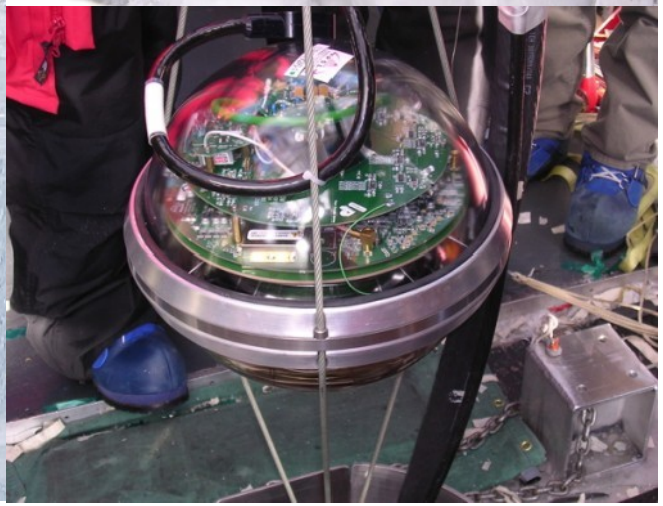
Next steps:

- SiPM calibration with uDAQ readout at KIT calibration setup (SPOCK)
- Include uDAQ in a scintillator at KIT
- Benchmark uDAQ vs TAXI

Marie Oehler (new PhD student), KIT-IKP will mainly work on that: marie.oehler@kit.edu

thomas.huber@kit.edu

How to build IceCube



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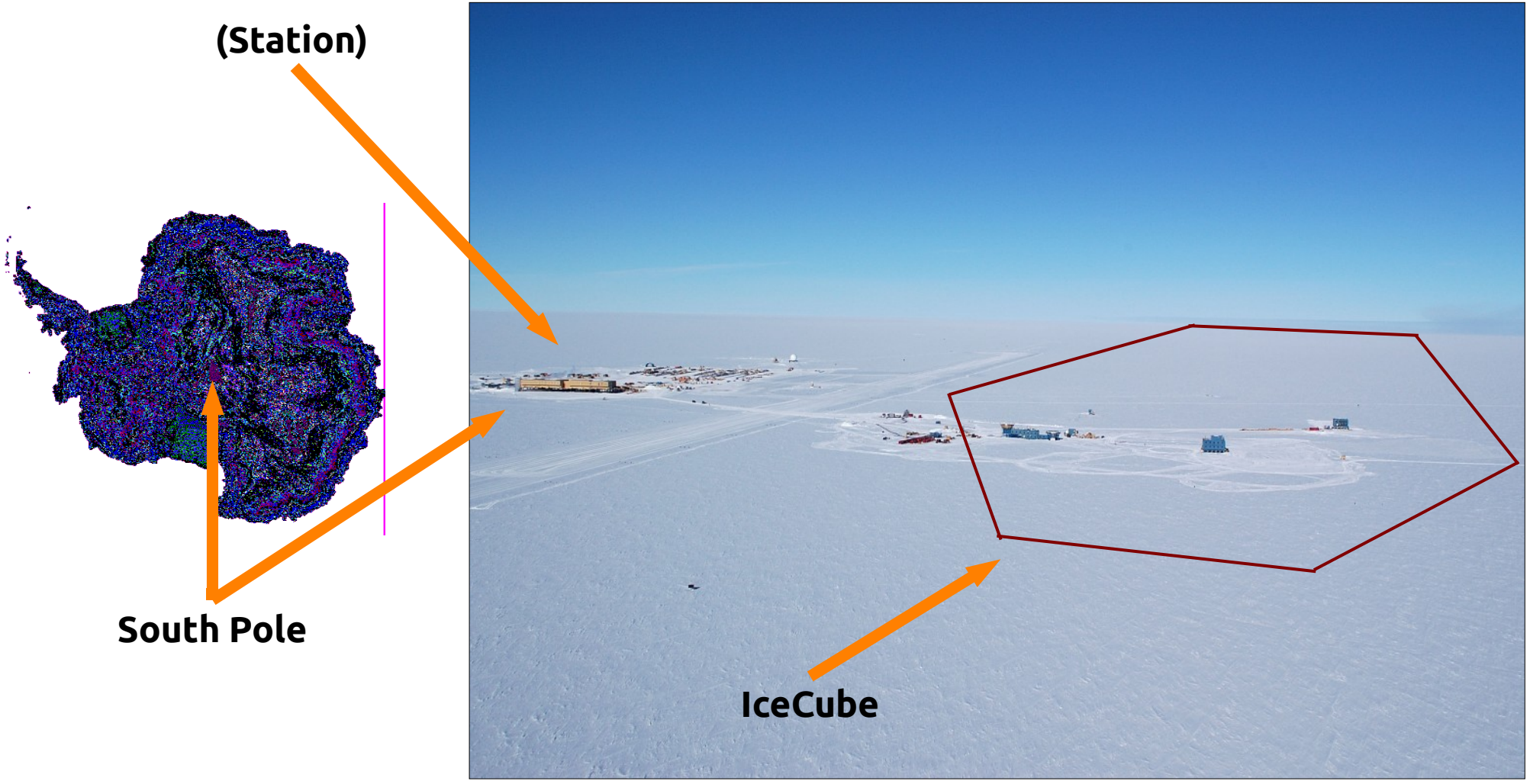
The IceCube Observatory



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