The Surface Array Enhancement of the IceCube Neutrino Observatory

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TeVPA 2022

picture credit: {Y.Makino), IceCube/NSF

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European Research Council
Established by the European Commission

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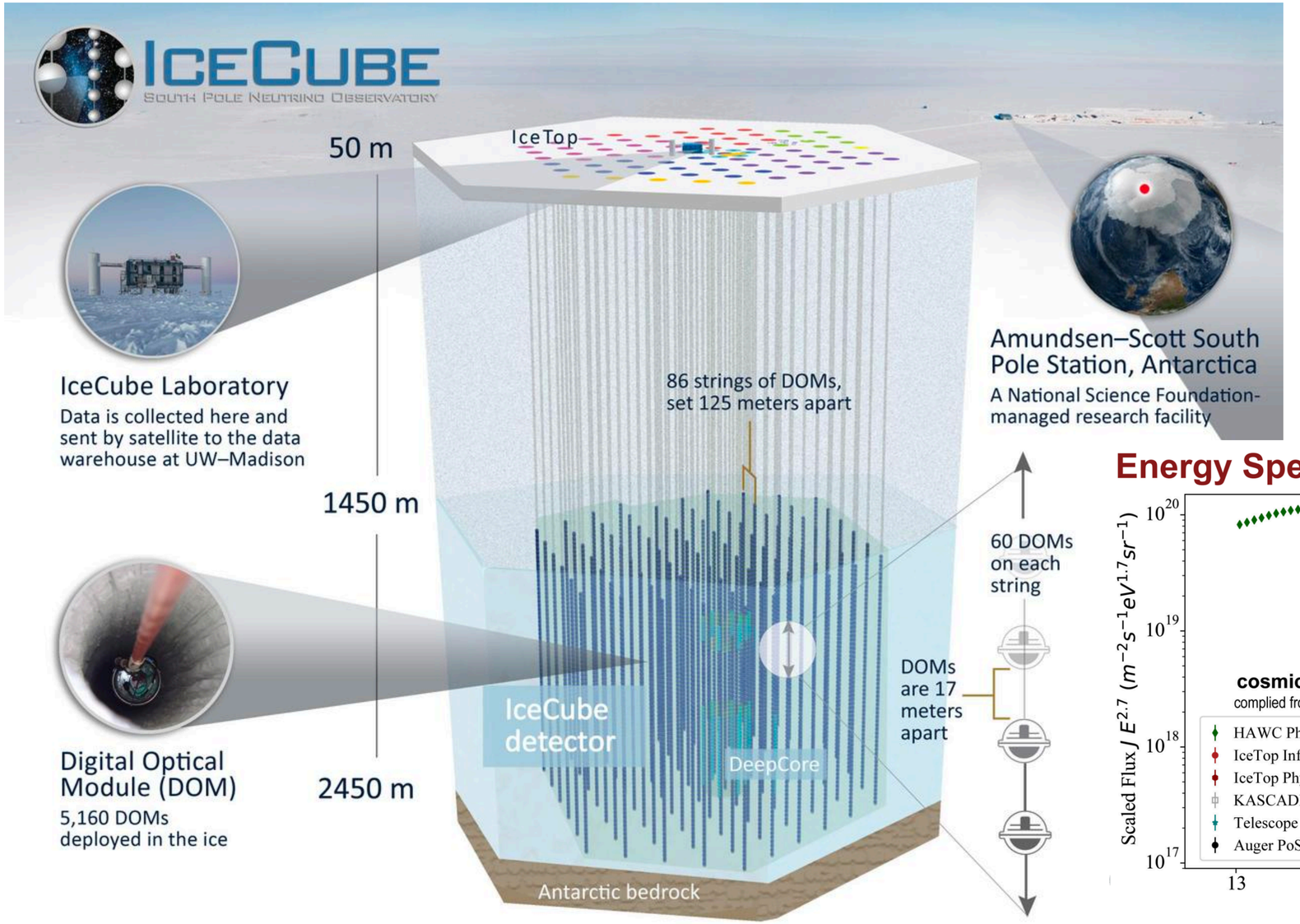
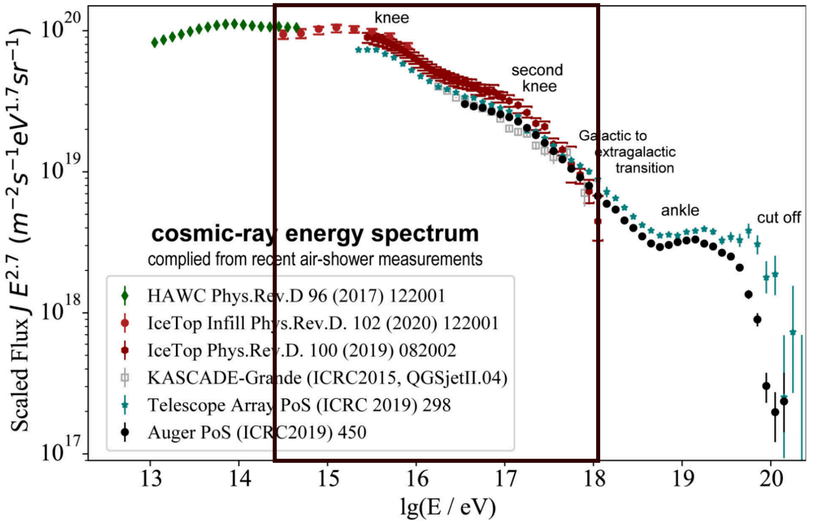
The IceCube Neutrino Observatory



Energy Spectrum of Cosmic Rays

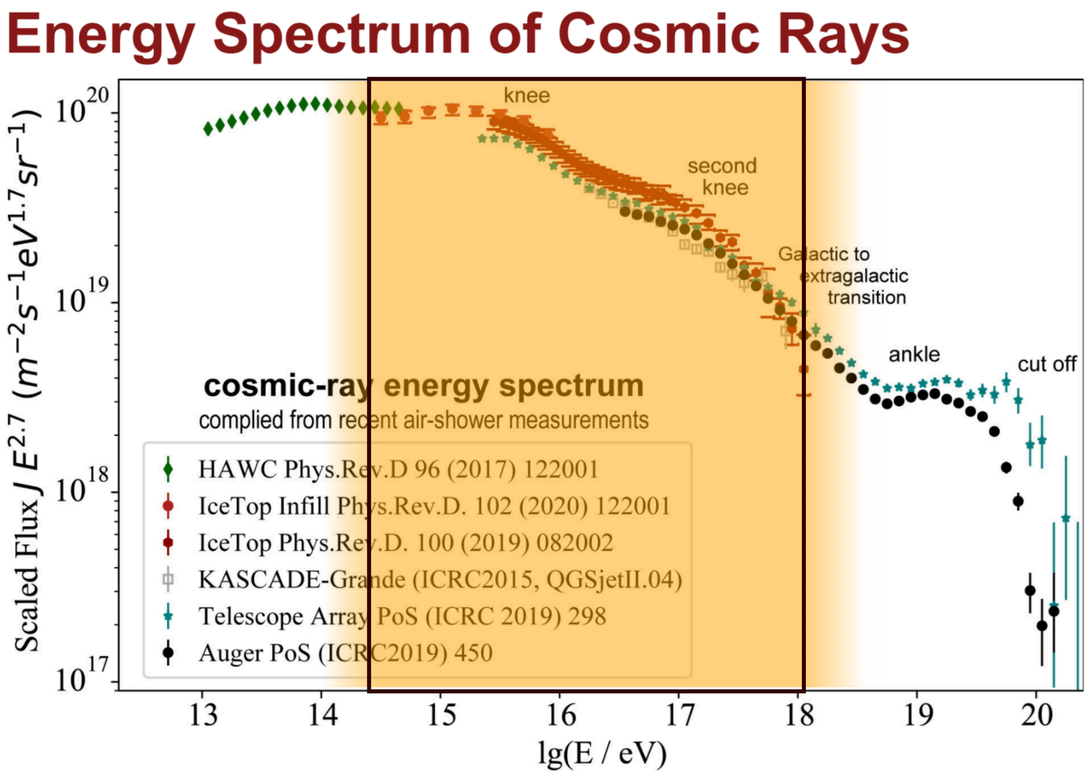


F.G. Schroeder, PoS(ICRC2019)030

Planned

Surface Array Enhancement

- Mitigate the **snow accumulation** on the IceTop tanks
- **Supporting IceCube's Neutrino mission**
  - Improving the **background veto** for IceCube
  - Improving the understanding of **atmospheric background**
- **Cosmic rays physics**
  - Extending the **energy range**
  - Adding independent measurements in the **~ PeV region**
  - Exploring the **galactic to extragalactic transition**
  - Increasing **mass composition** resolution
- **R&D for IceCube-Gen2 (surface)**



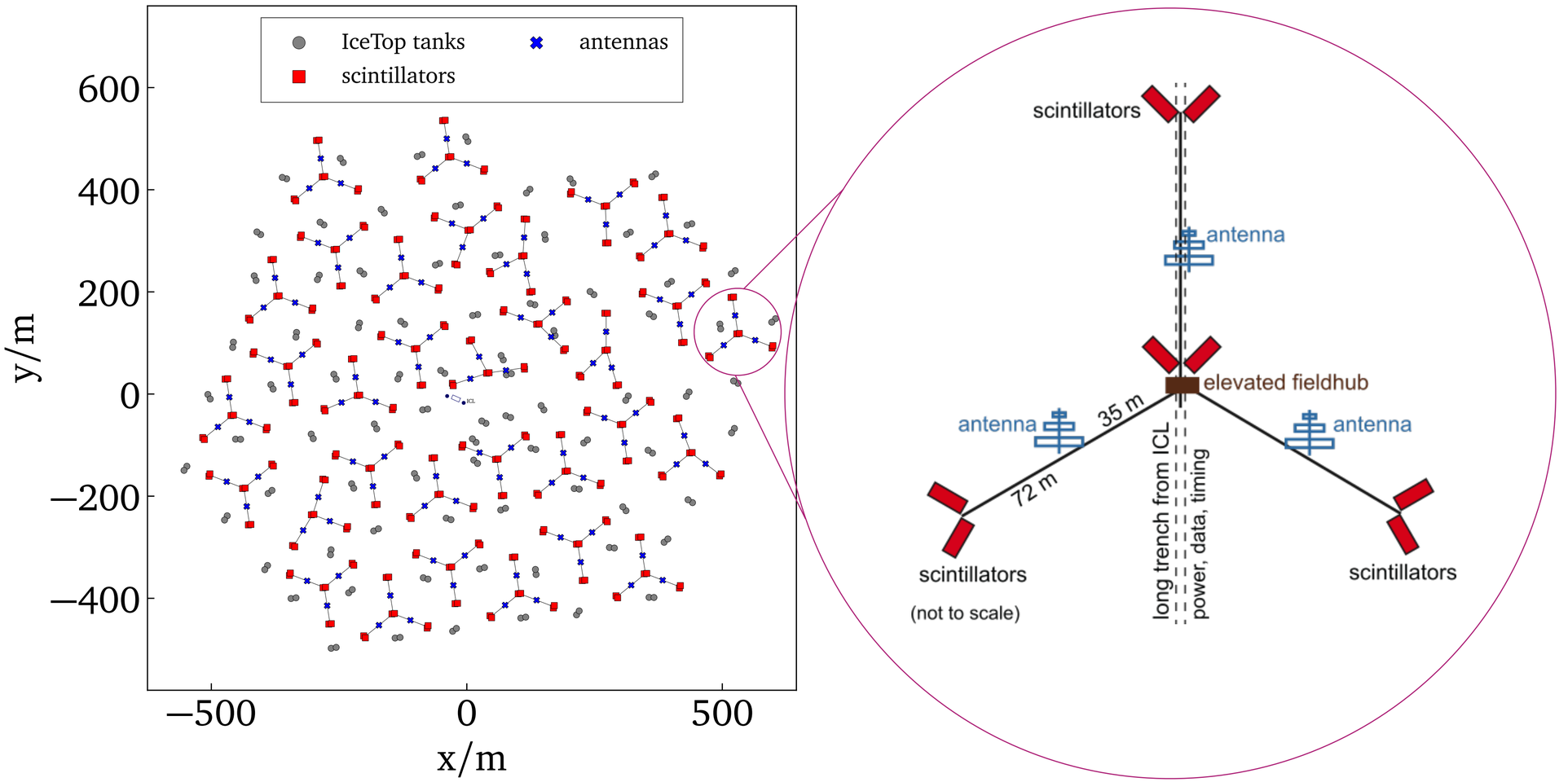
F.G. Schroeder, PoS(ICRC2019)030 (modified)

Planned

Surface Array Enhancement

32 Stations

- 8 scintillation panels
- 3 antennas

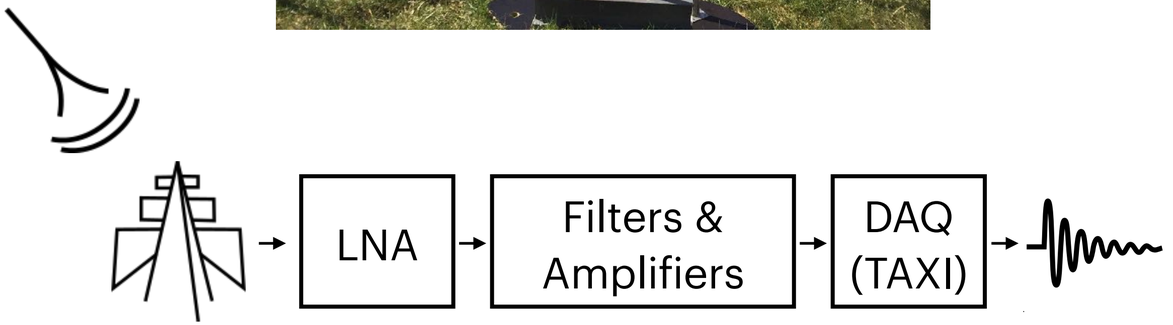


A. Leszczyńska, PoS(ICRC2019)332 (modified)

Elevated

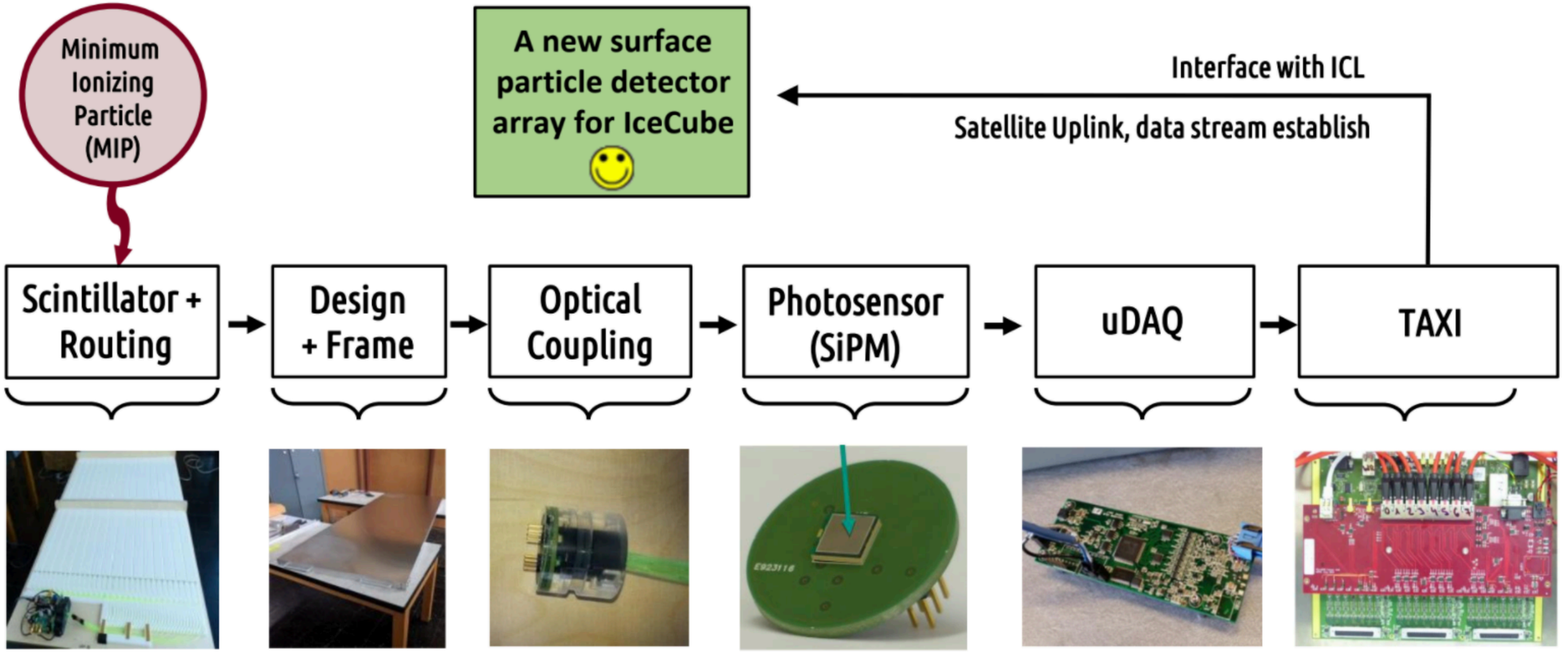
Radio Antennas

- SKALA-V2 **LPDA Antennas**
- Nominal bandwidth : **70MHz to 350MHz**
- Integrated LNAs with **high amplification and low noise** (40K)
- Custom made radio **pre-processing board** for additional **filtering and amplification**
- Omni-directional
- Good directivity for **± 60º from zenith**
- Low power
- **±0.5º uncertainty** on the levelling
- Low cross-polarisation
- Easy assembly in the field



Elevated

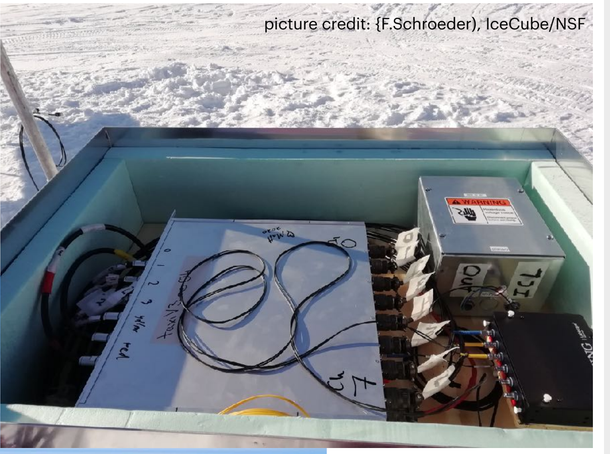
Scintillation Panels

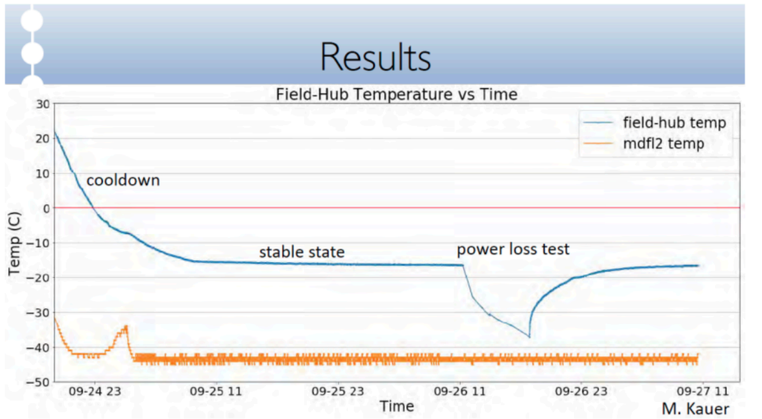


T. Huber

Elevated
Field Hub

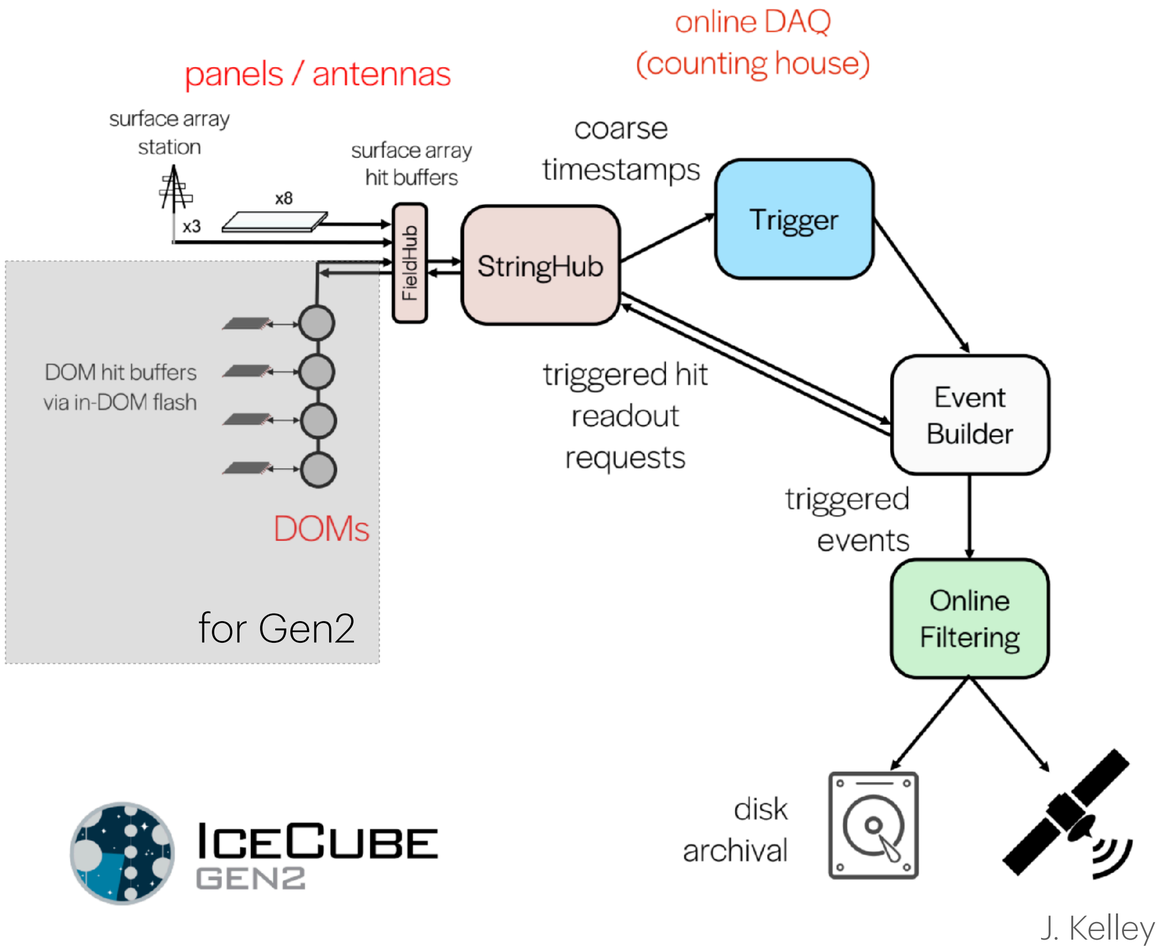
- Insulated container for electronics
  - Ensure a **higher and more stable temperature** for the electronics. Also provide a **slower cool-down** in case of power outage
- **Double shielding** to mitigate RFI
- Will have some **storage** for the **cable slack**
- Separated DC/DC converter box for safety





Infrastructure

- Communication
  - **Integrated** in the IceCube Infrastructure
  - Use of existing **satellites** for data transfer
- Data transfer and power routed via **cables** from/to ICL
- Future **trigger logic** planned with **in-ice coincidences**
- Power
  - **40-65 W** per station
    - Small fraction of IceCube power budget

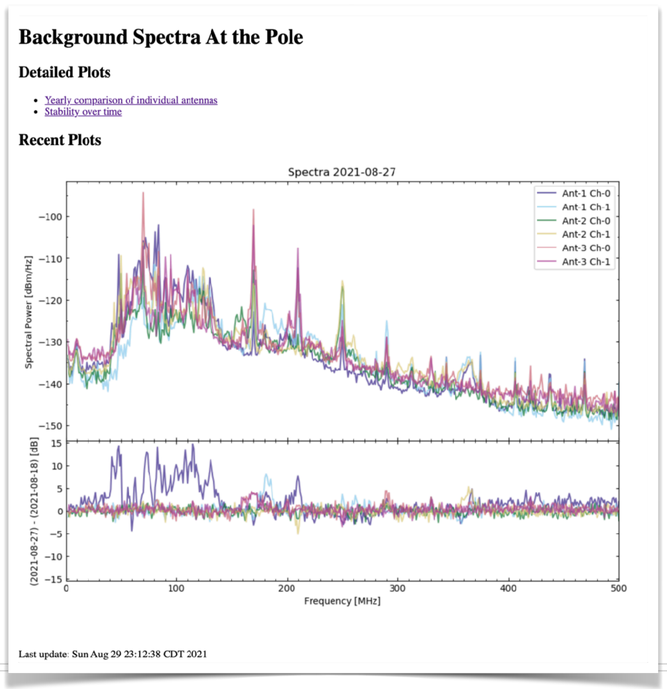


Maintenance

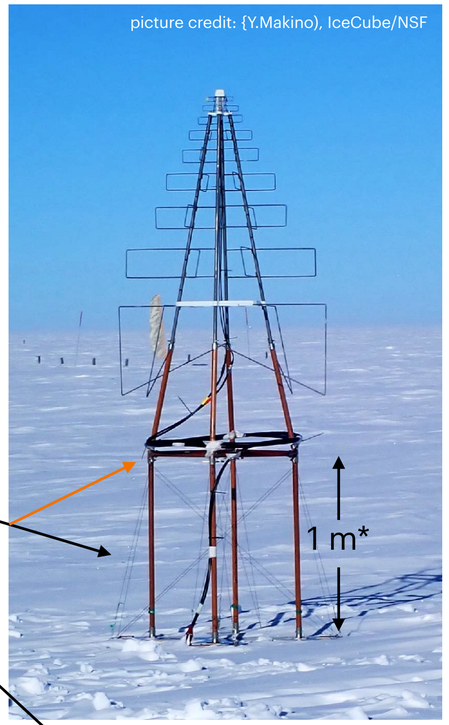
- Average of **20 cm/year** of **snow accumulation**
- **Raising** the individual detectors every **5 years.** The maintenance will naturally be staggered (with deployment)
- About **2 person for 2 weeks** every year for maintenance for full array

Monitoring

- Antennas' baseline monitoring already online, daily trigger rates
- **Alerts** sent when abnormal behavior
- Will be extended (e.g. scintillators' gain, DAQ temperature, etc)



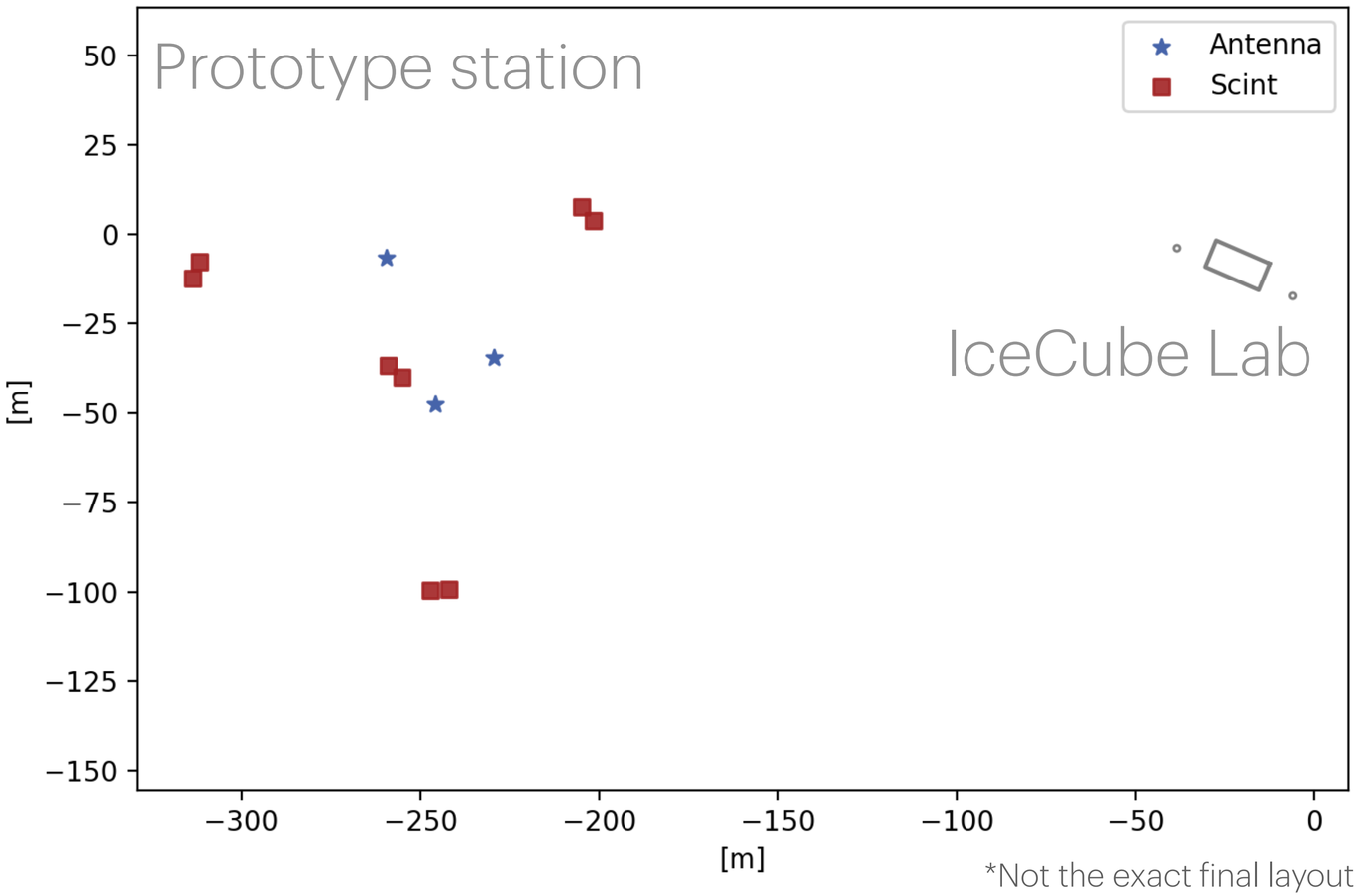
Extendable structure
Cable slack (20 years)



*The final version has 1.20 m

Prototype Station

- Deployed in **January 2020**
  - 8 scintillator panels
  - 3 radio antennas
- **Continuously recording** (background and event data)
- **Air showers recorded**! (next slides...)
- Further analyses on-going



*Not the exact final layout

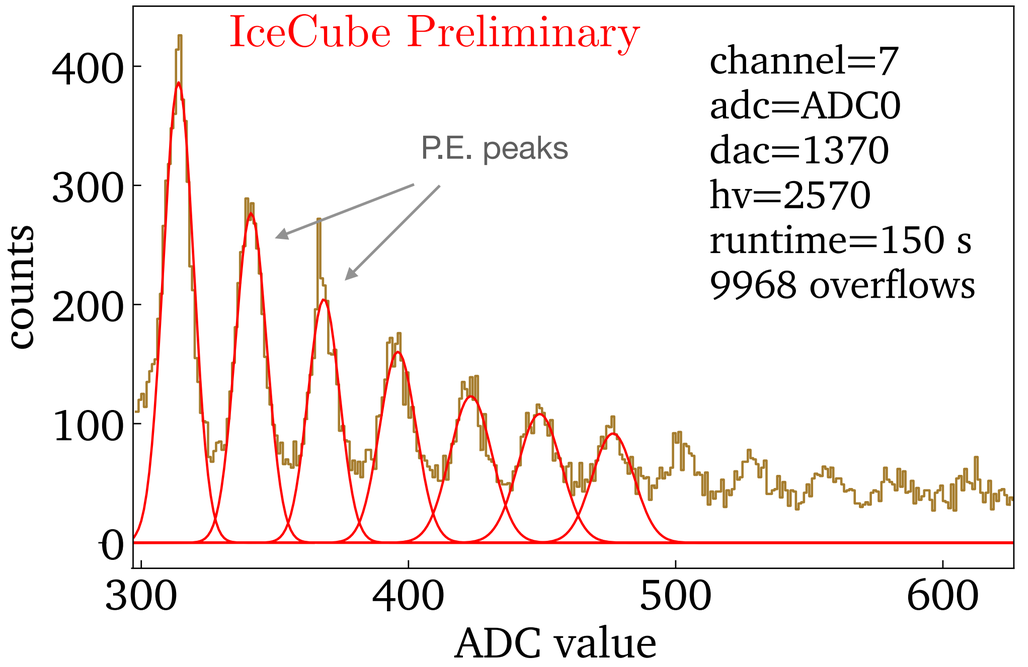
Raw data and background

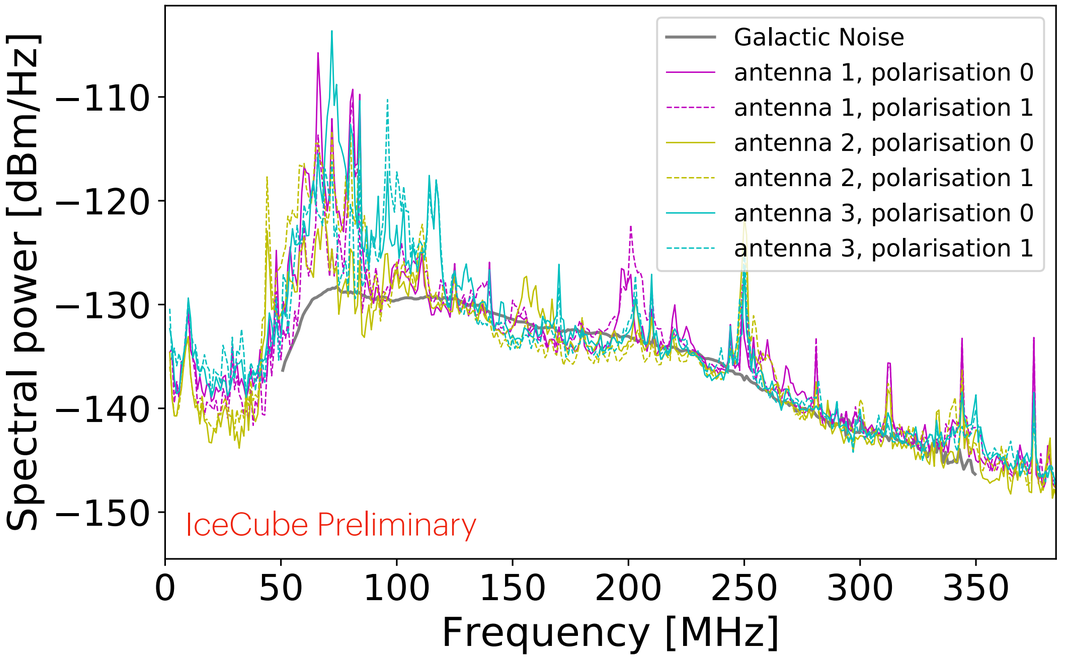
Scintillator panels:

- Example of a **charge histogram** (high gain)

Radio antennas:

- **Median spectrum** (04/17/2020) compared with **galactic noise** (Cane model) and **thermal noise** (40K) in gray





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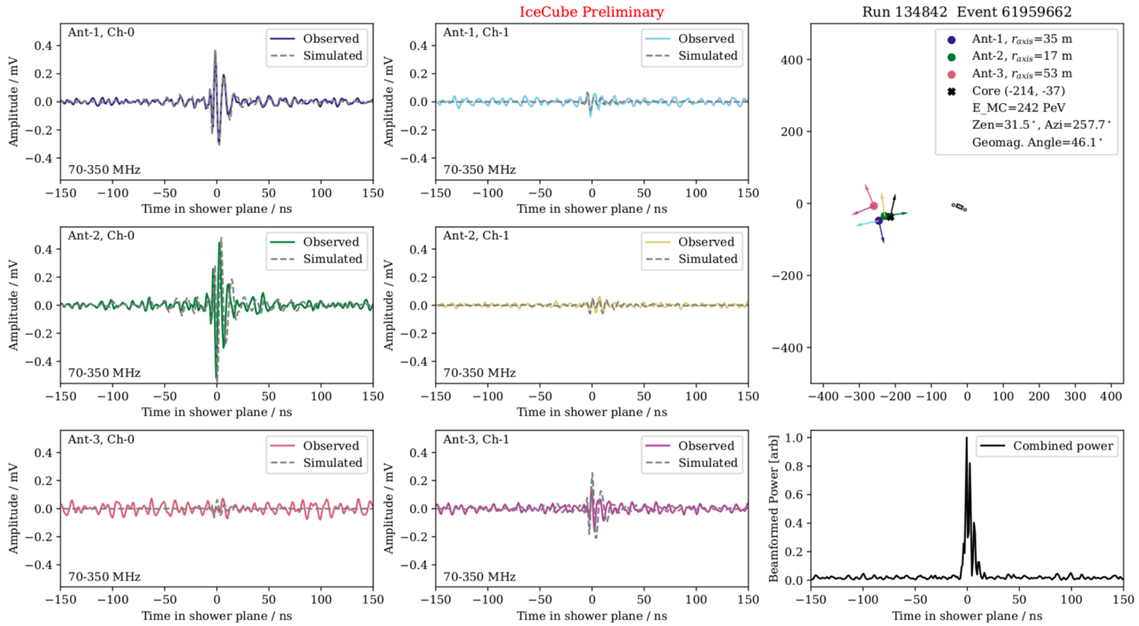
Detection of air showers!

Example of an **air-shower recorded** (full lines) by the antennas and compared with **simulation** (dashed lines)



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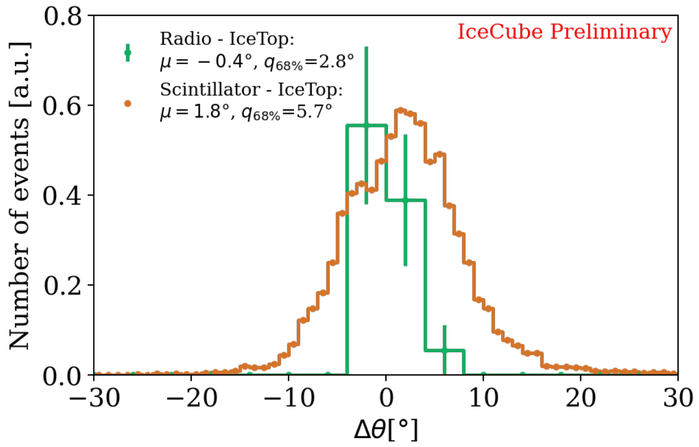

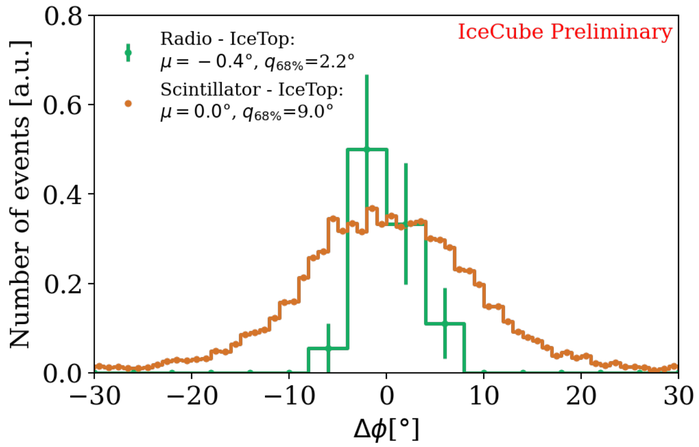

Arrival directions compared to IceTop (plane wavefront assumed)

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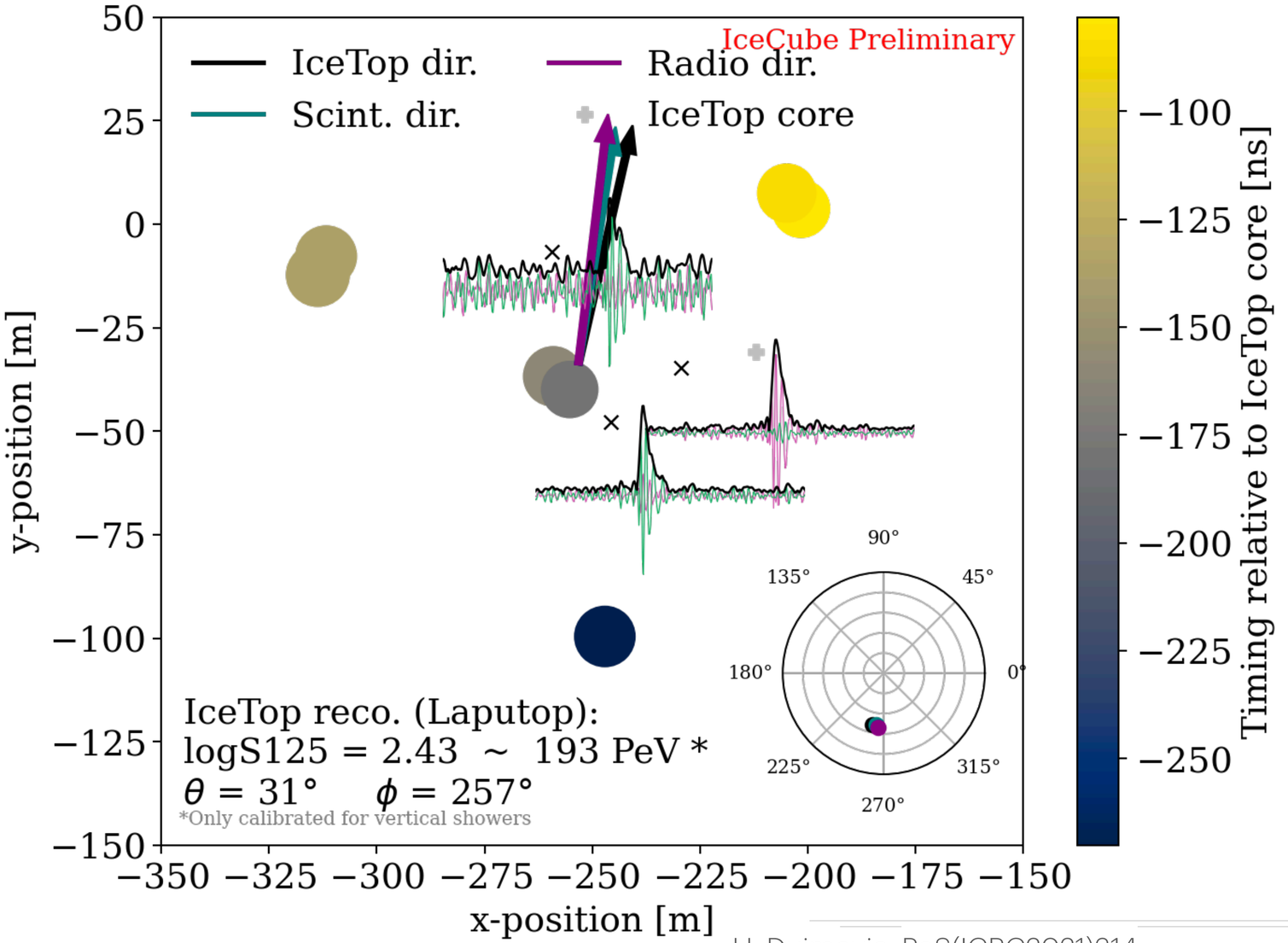
Triple coincidences



Scintillators
Size -> charge deposited
Color -> time

Antennas
Filtered waveforms,
Summed envelopes

Reconstructed direction

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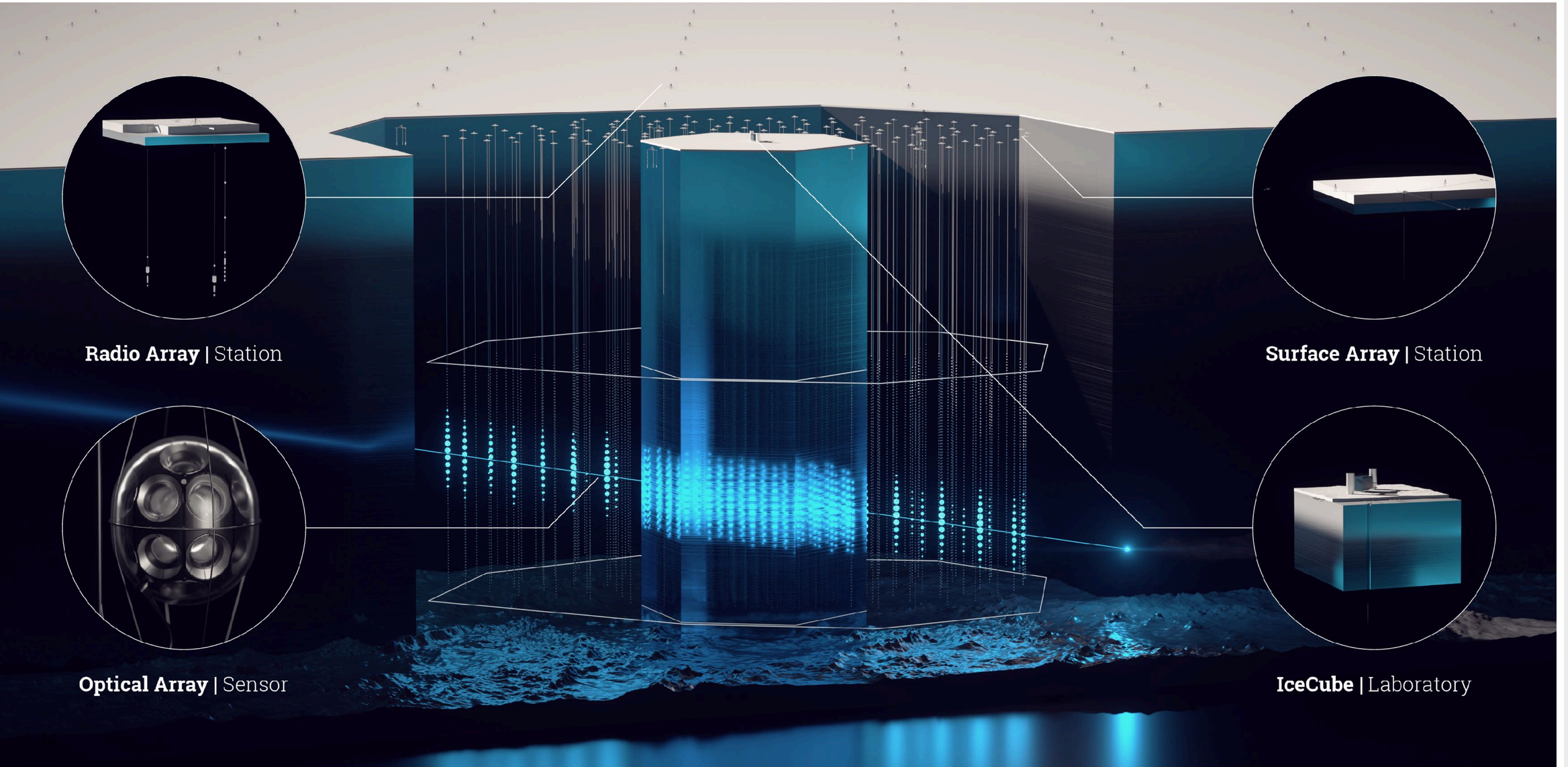
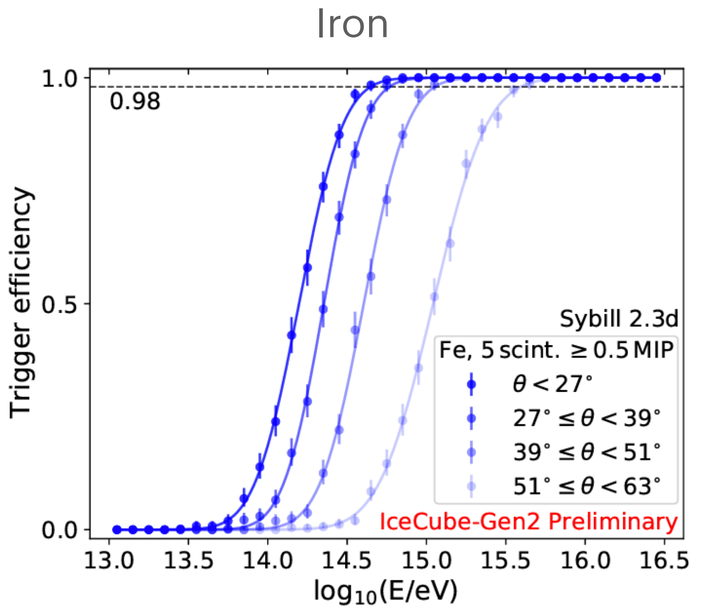
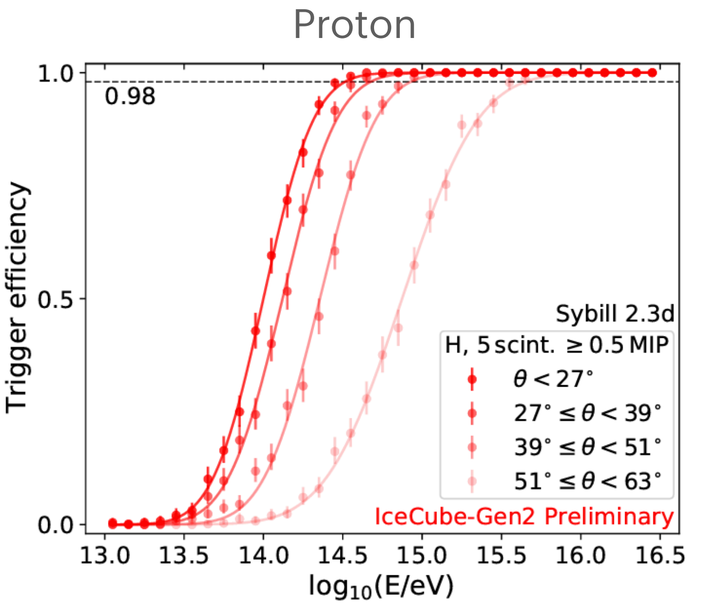
Outlook into the future - IceCube Gen2



A look into the future

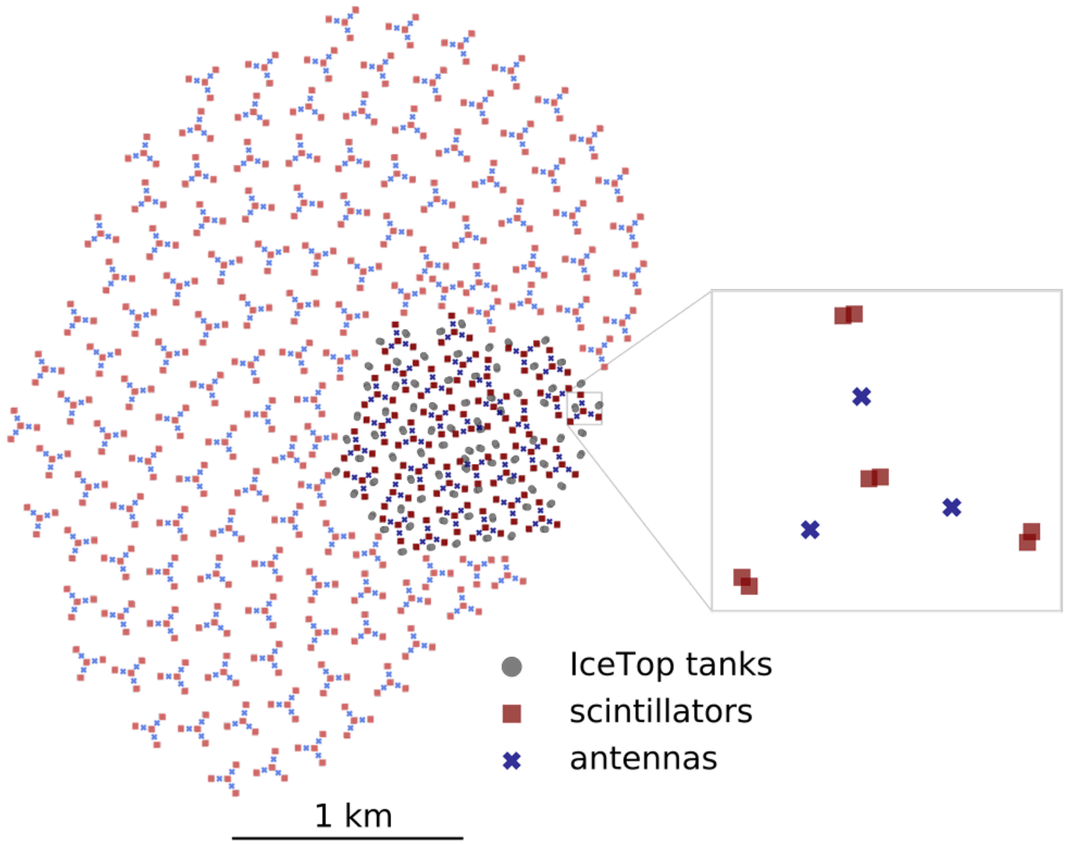
- **Veto the background** for the in-ice detector (Gen2)
- **Extending the energy range** by a factor of 3 (fully covering the *predicted* transition region from galactic to extra-galactic CRs)
- 8-10x geometric aperture but **30x** for **in-ice coincidences aperture**
- Observing the **transition** from **conventional to prompt muon** (0.5-1 PeV)
- Threshold of **~0.5 PeV**

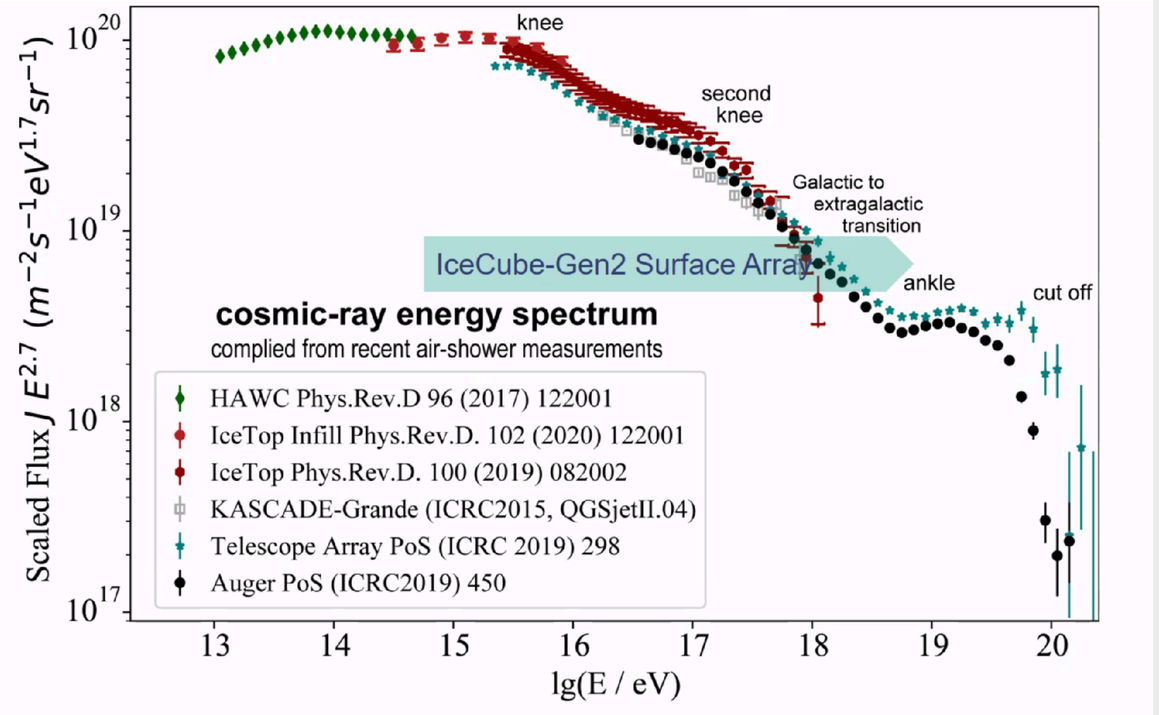




A. Leszczynska, M. Weyrauch, PoS(ICRC2021)411

Outlook in the future - IceCube Gen2





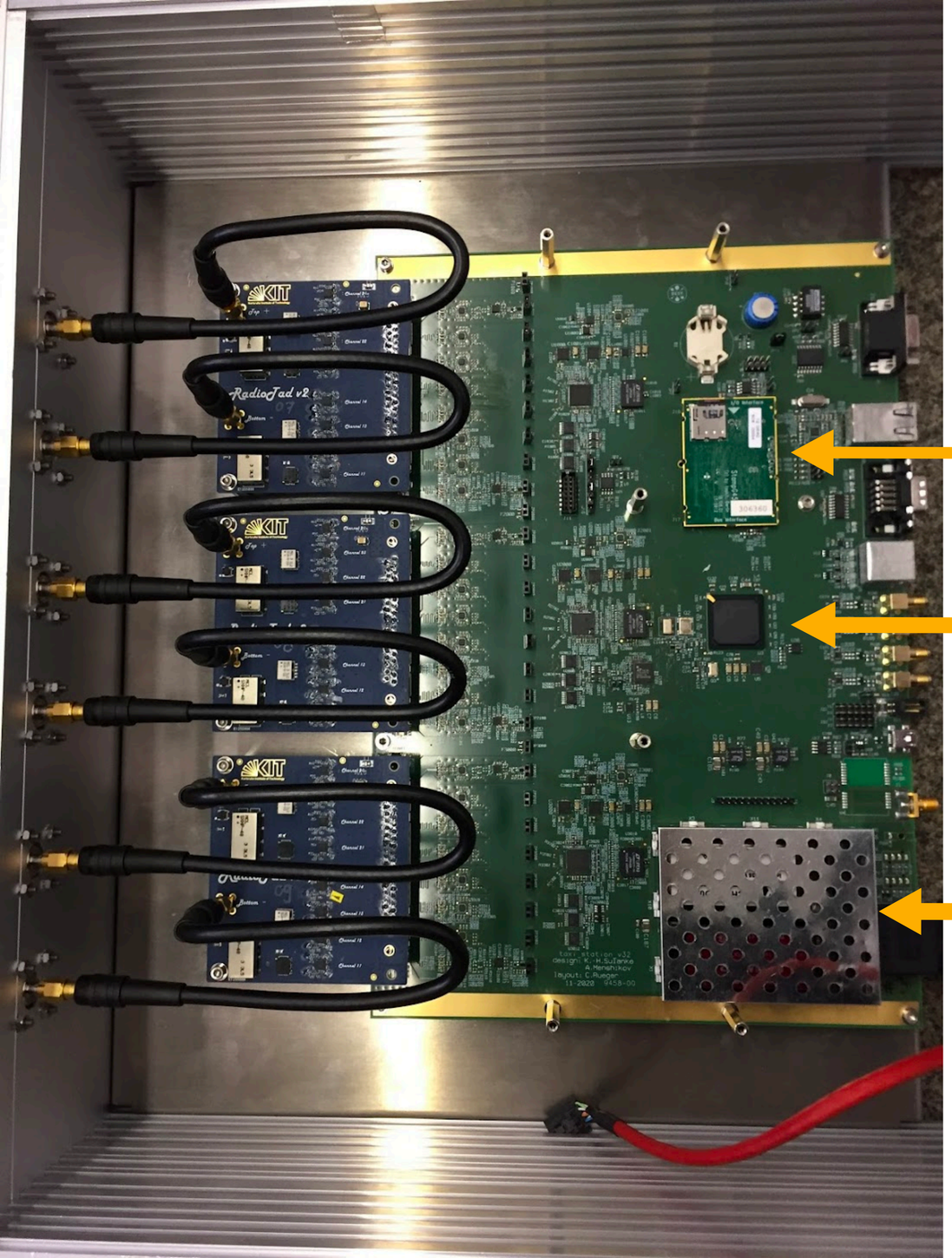
F.G. Schroeder, PoS(ICRC2019)030 (modified)

Conclusions

- We developed a **hybrid detector** combining **elevated scintillation detectors** and **elevated radio antennas** to complement the already existing ice-Cherenkov tanks.
  - This will **mitigate** the continuously **increasing detection threshold** of IceTop due to snow.
- A **prototype station** was deployed in January 2020 and as expected **records air-showers** and the **direction reconstruction agrees** between all detector types.
- The **enhanced array** covering **1 km²** planned to be **deployed in the coming years**
- **Planning and development** starting from the experience gained is on-going for the bigger **IceCube-Gen2 surface array**
- Stay tuned for more results of these future cosmic ray detectors

Back-up slides

TAXI



Embedded Linux
(Stamp)

FPGA

Shielded DC/DC
converters

SKALA LNA

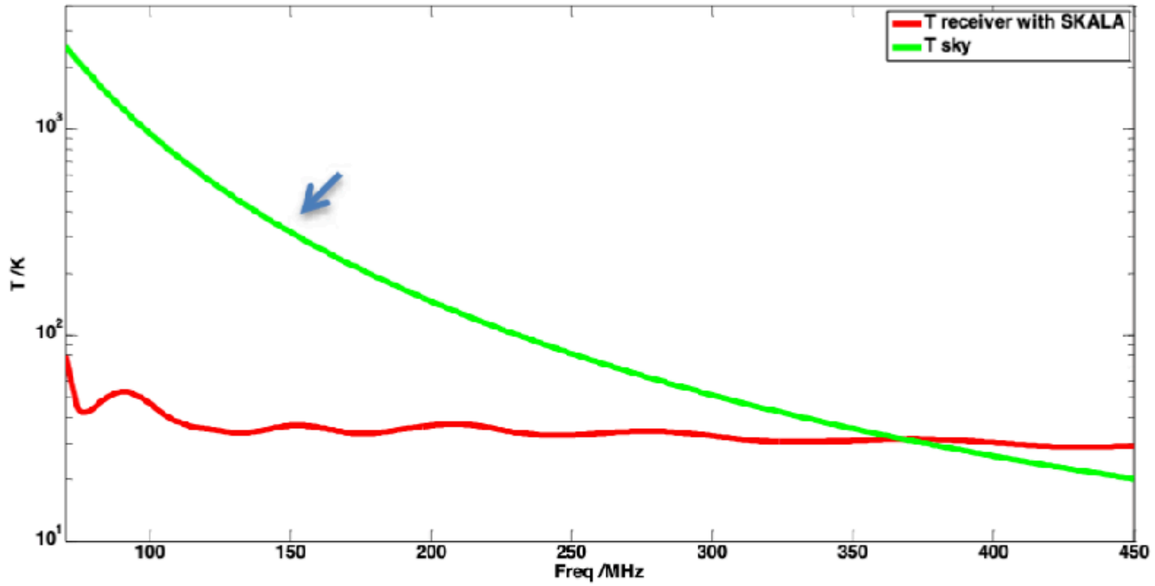
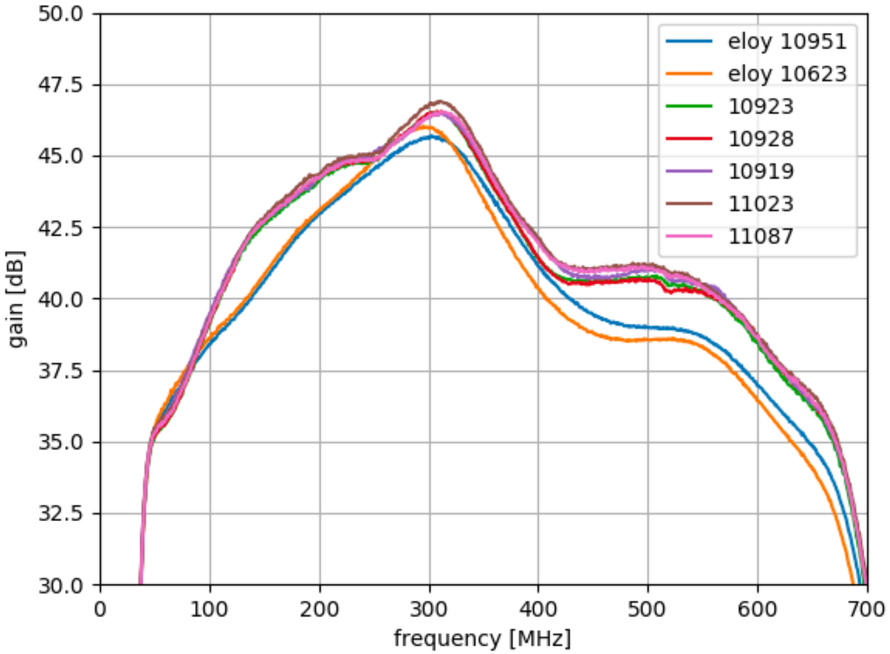


Fig. 9. Receiver noise temperature versus sky noise.

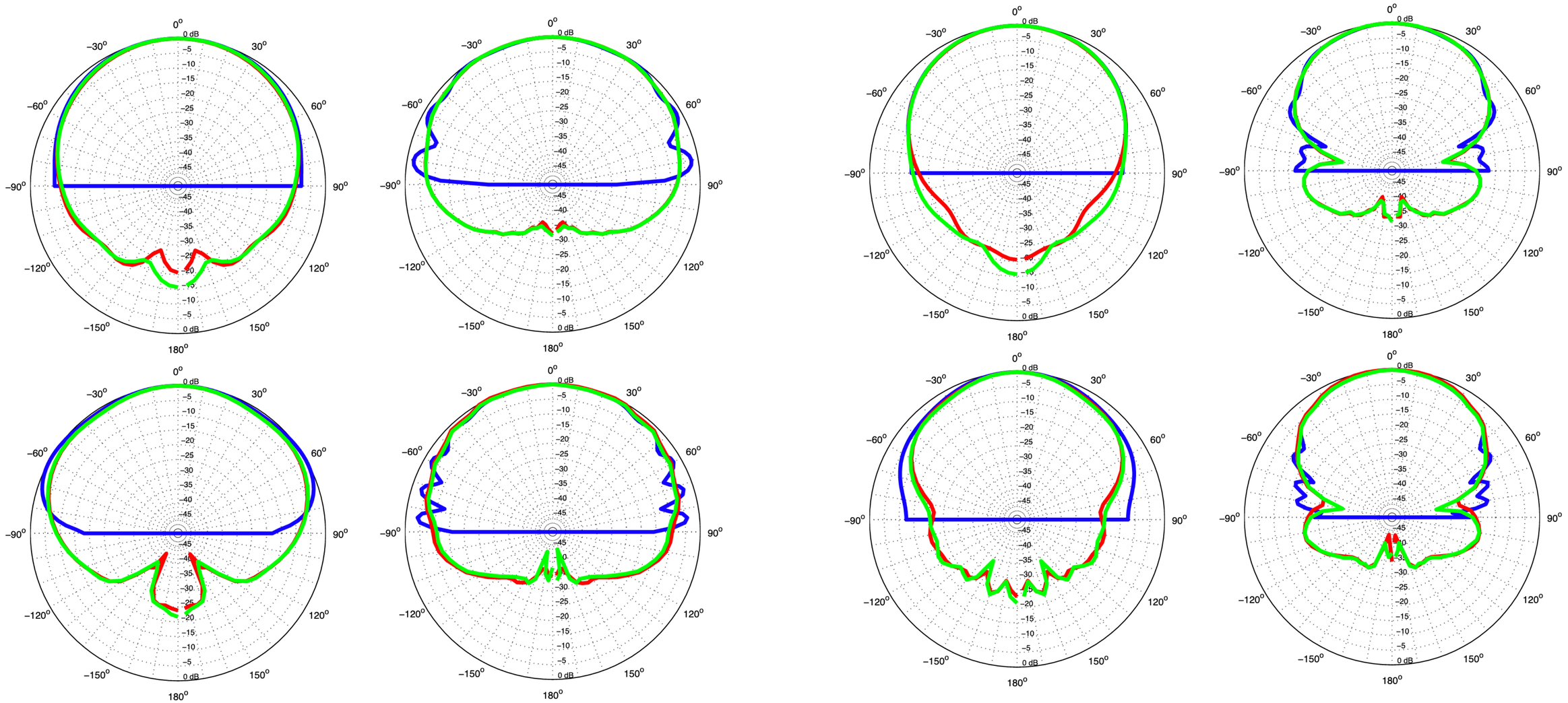


E. de Lera Acedo, N. Drought, B. Wakley and A. Faulkner, "Evolution of SKALA (SKALA-2), the log-periodic array antenna for the SKA-low instrument," *2015 International Conference on Electromagnetics in Advanced Applications (ICEAA)*, 2015, pp. 839-843, doi: 10.1109/ICEAA.2015.7297231.

H-plane cut

E-plane cut

SKALA2 Gain

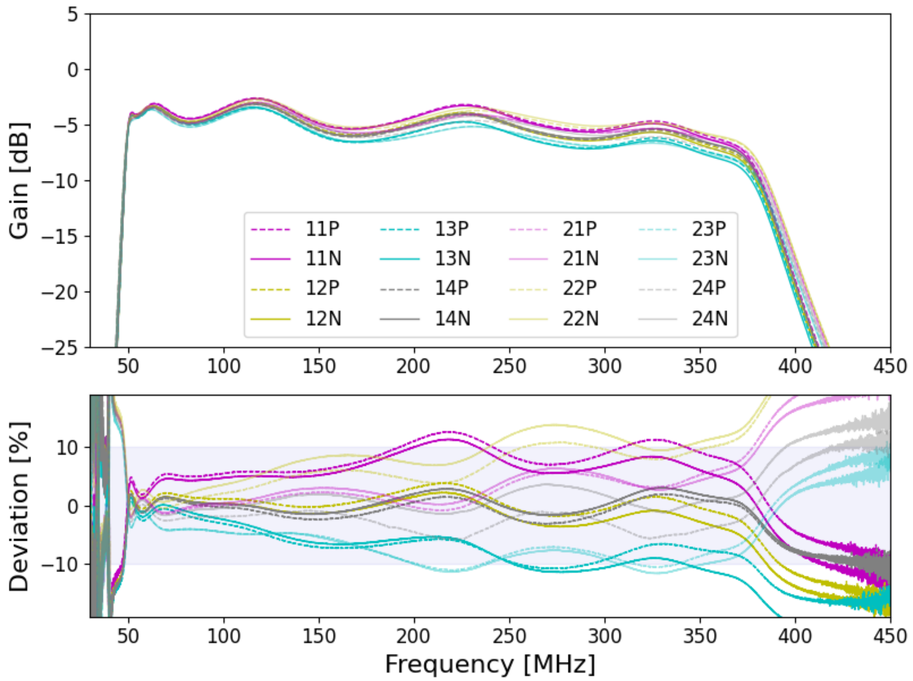


Inf. GND Soil Mesh over Soil

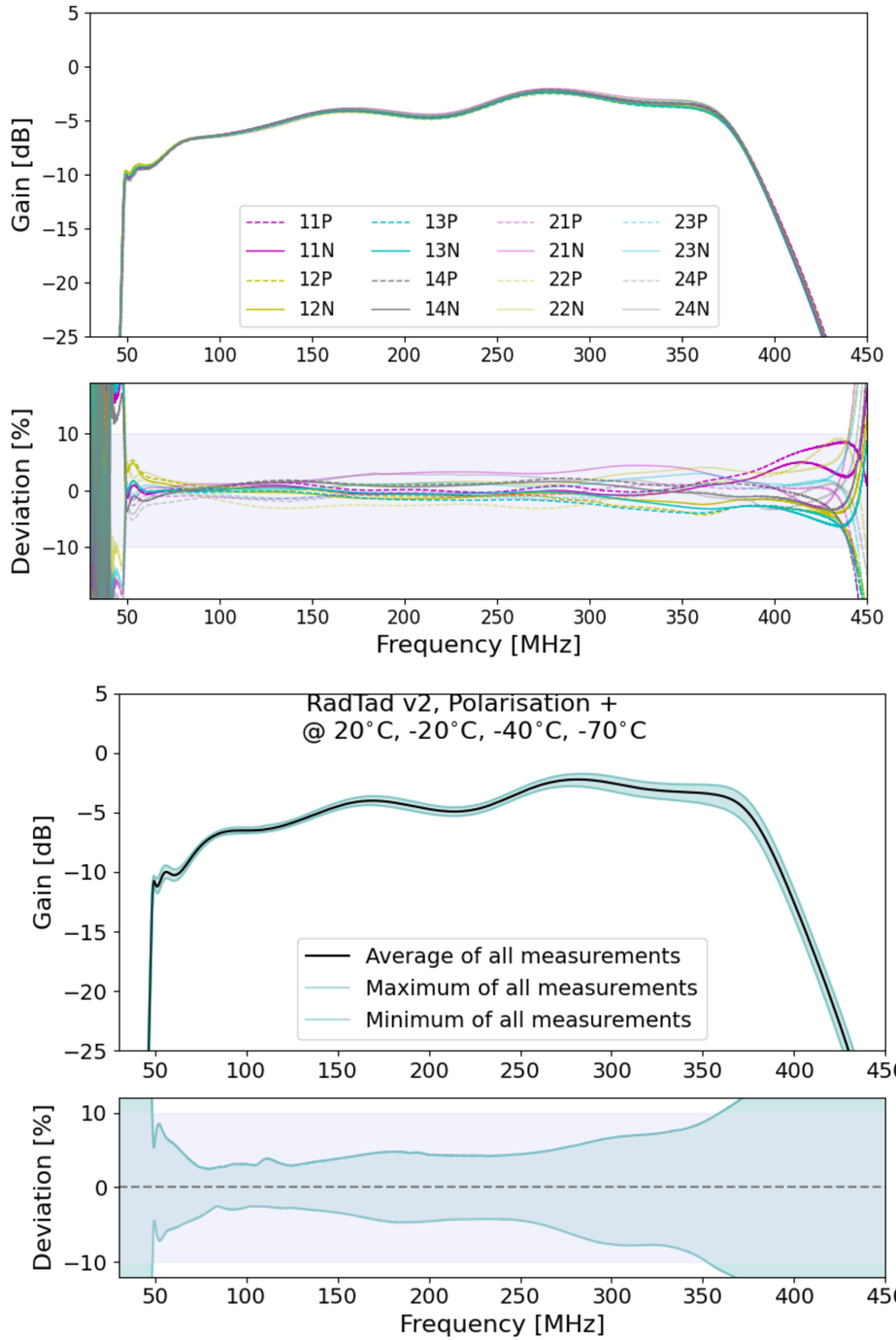
E. de Lera Acedo, N. Drought, B. Wakley and A. Faulkner, "Evolution of SKALA (SKALA-2), the log-periodic array antenna for the SKA-low instrument," *2015 International Conference on Electromagnetics in Advanced Applications (ICEAA)*, 2015, pp. 839-843, doi: 10.1109/ICEAA.2015.7297231.

RadioTad

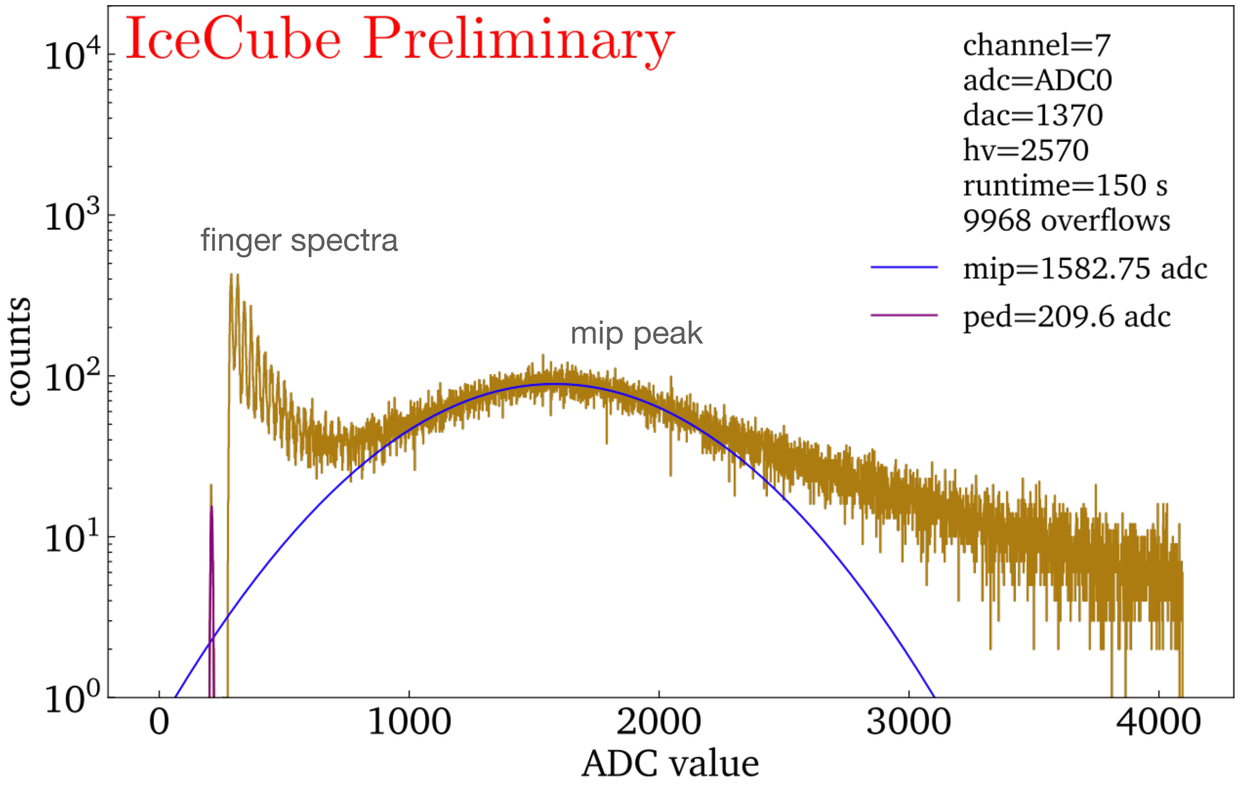
Gain RadioTad v1



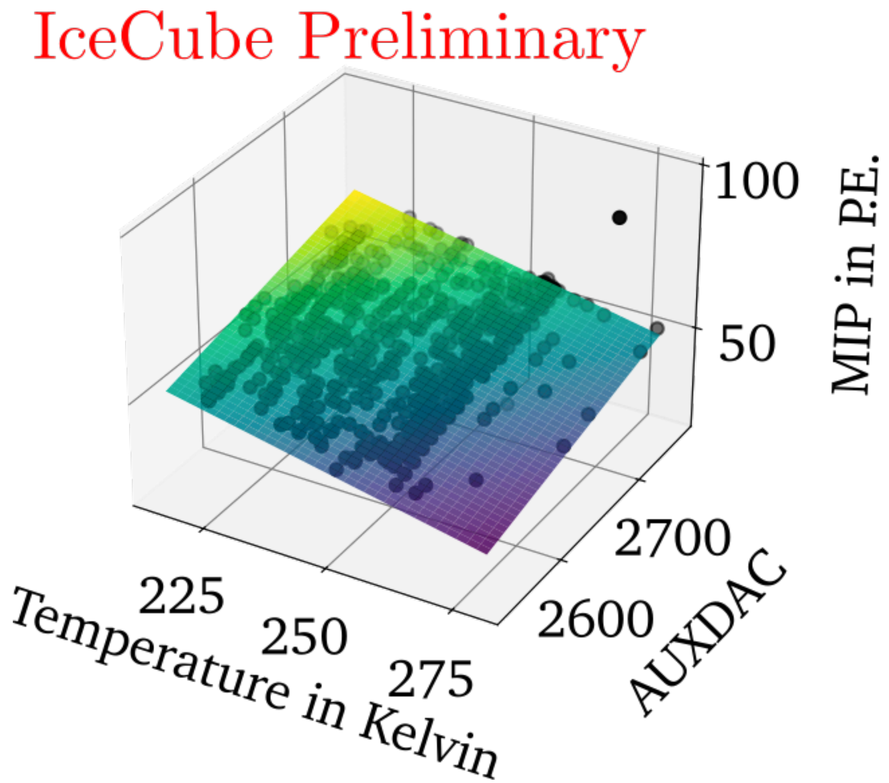
Gain RadioTad v2



Scintillators



Temperature and voltage versus gain. The gain can be maintained constant by varying the voltage according to the temperature



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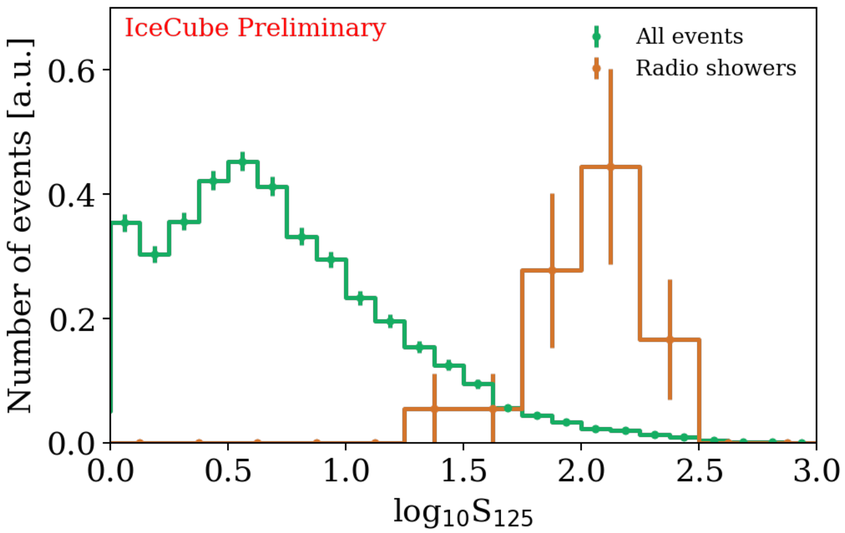
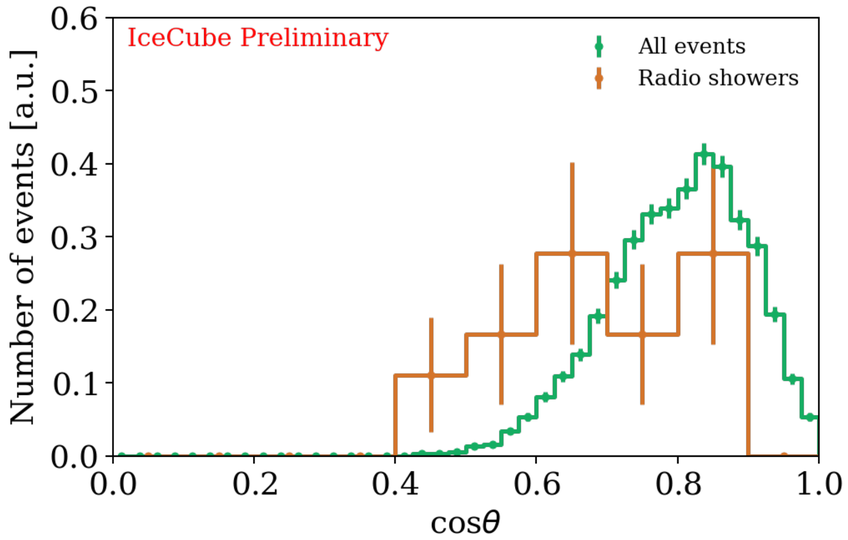
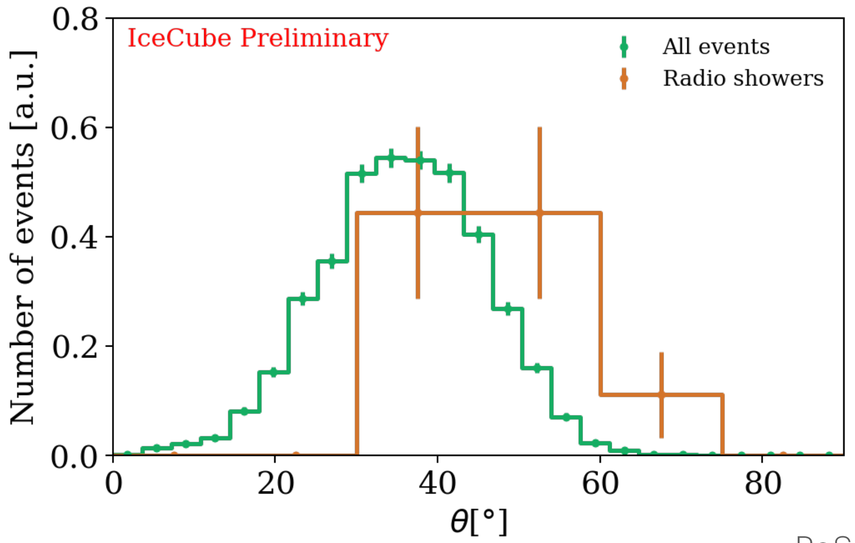
Air showers reconstruction







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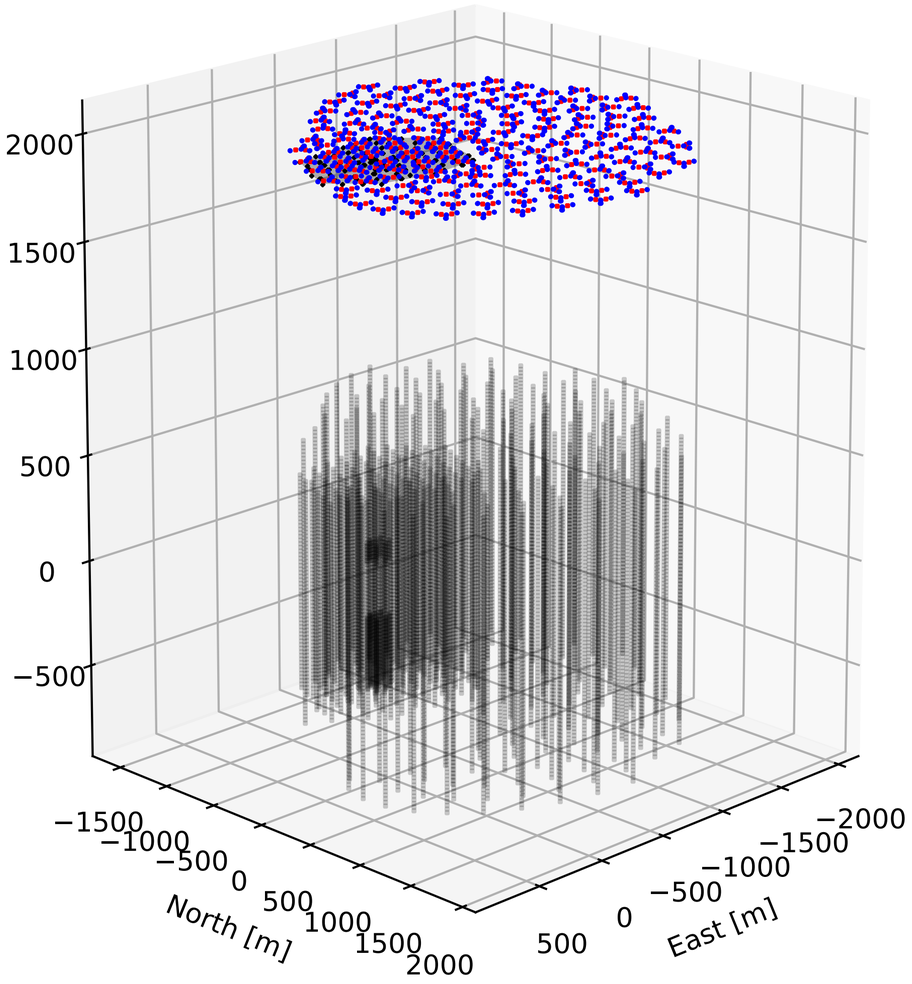
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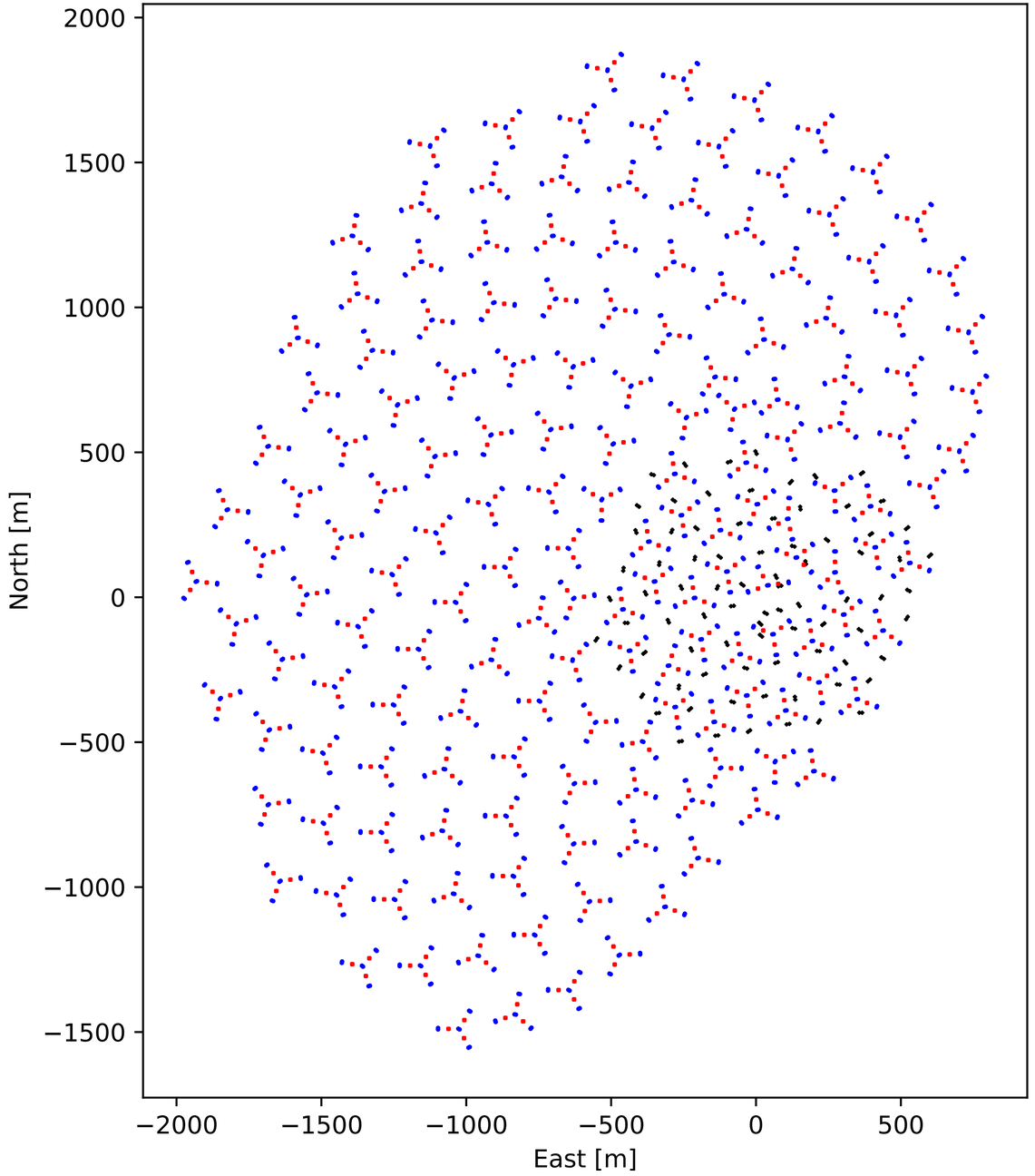
East [m]


2000
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North [m]
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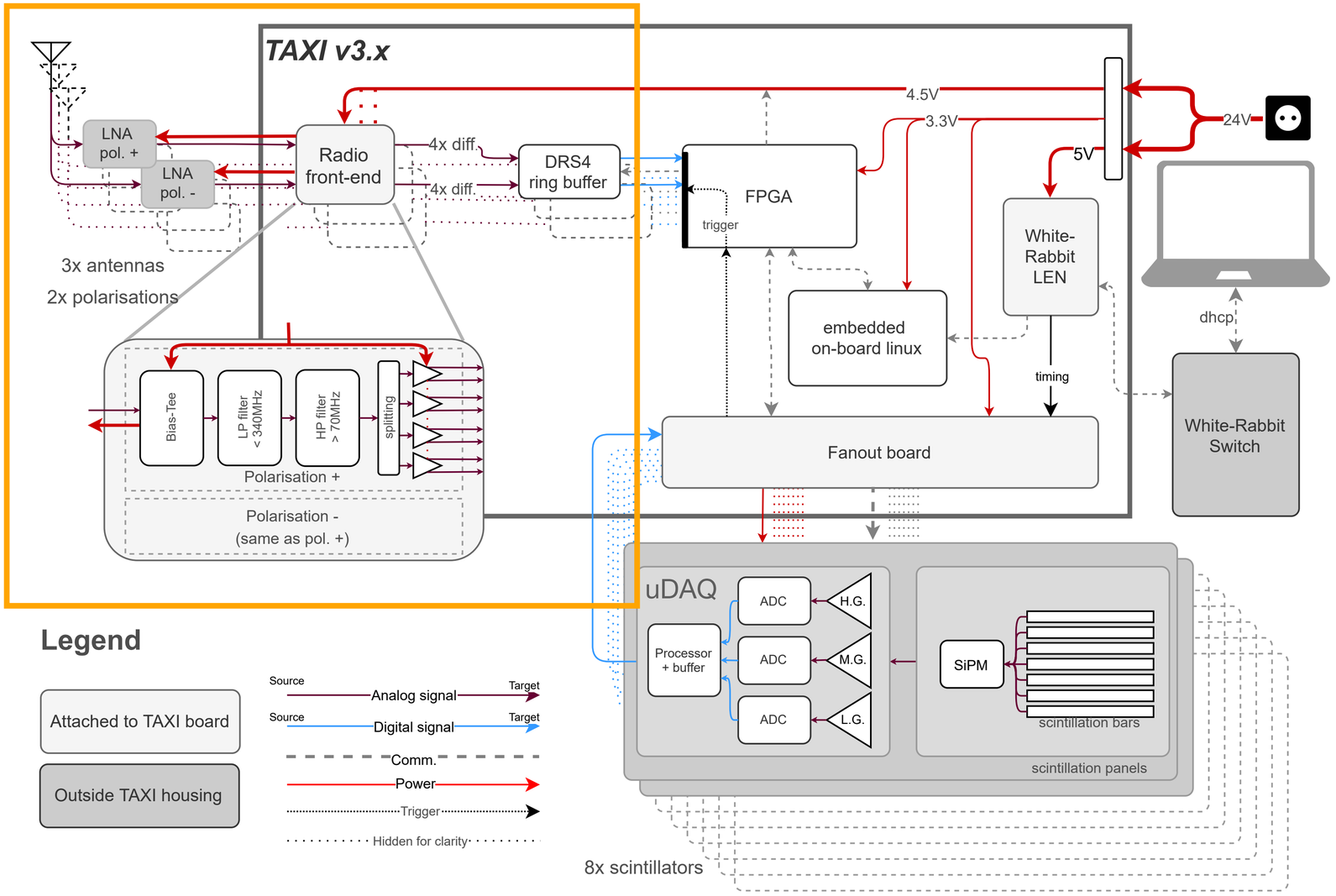
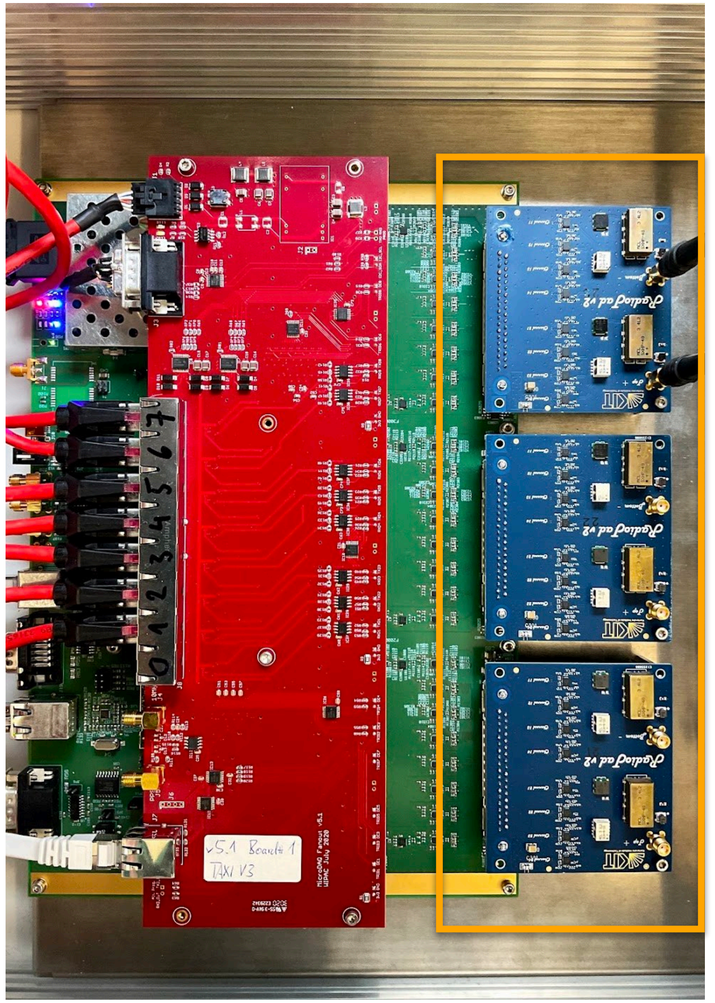
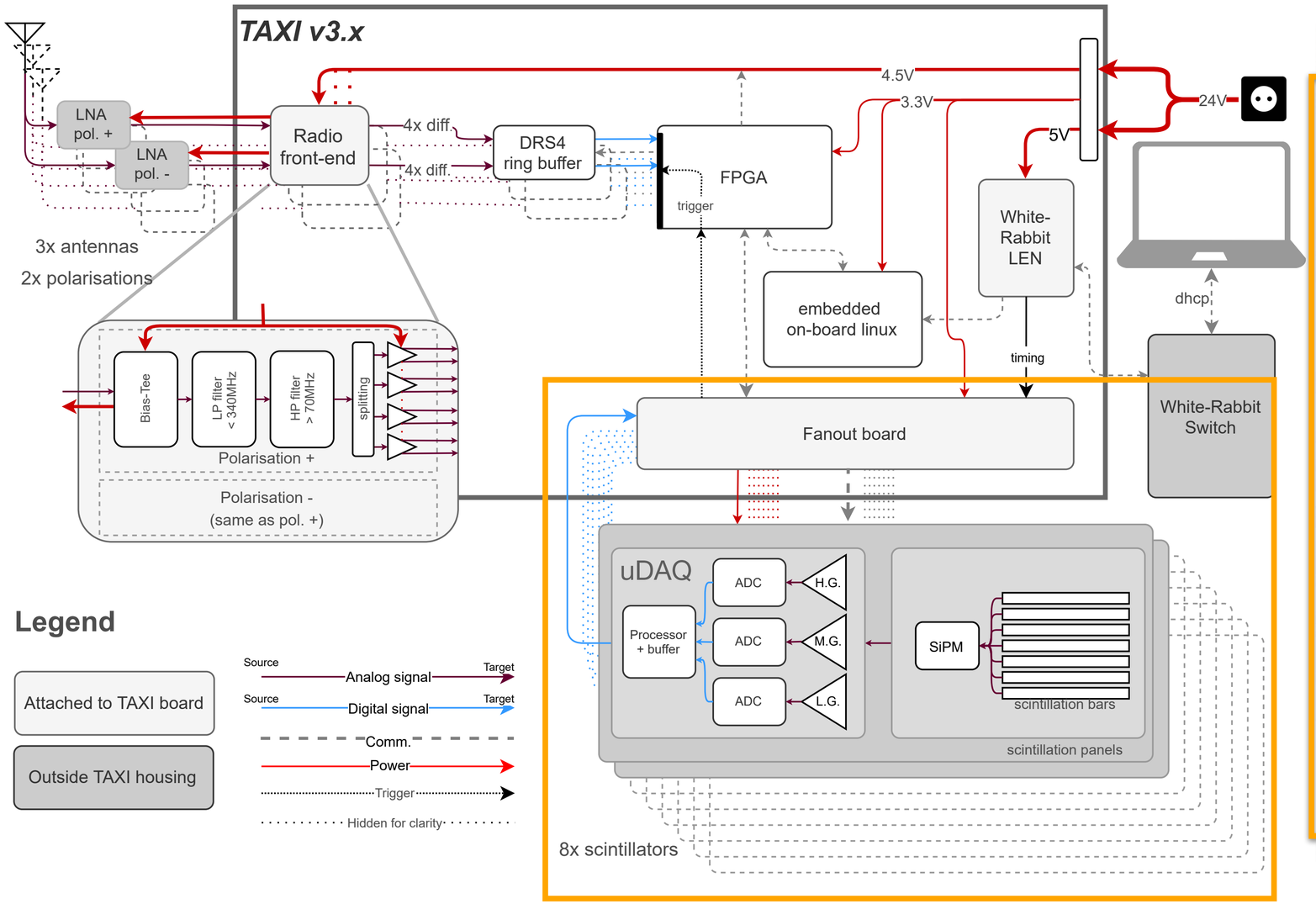
East [m]

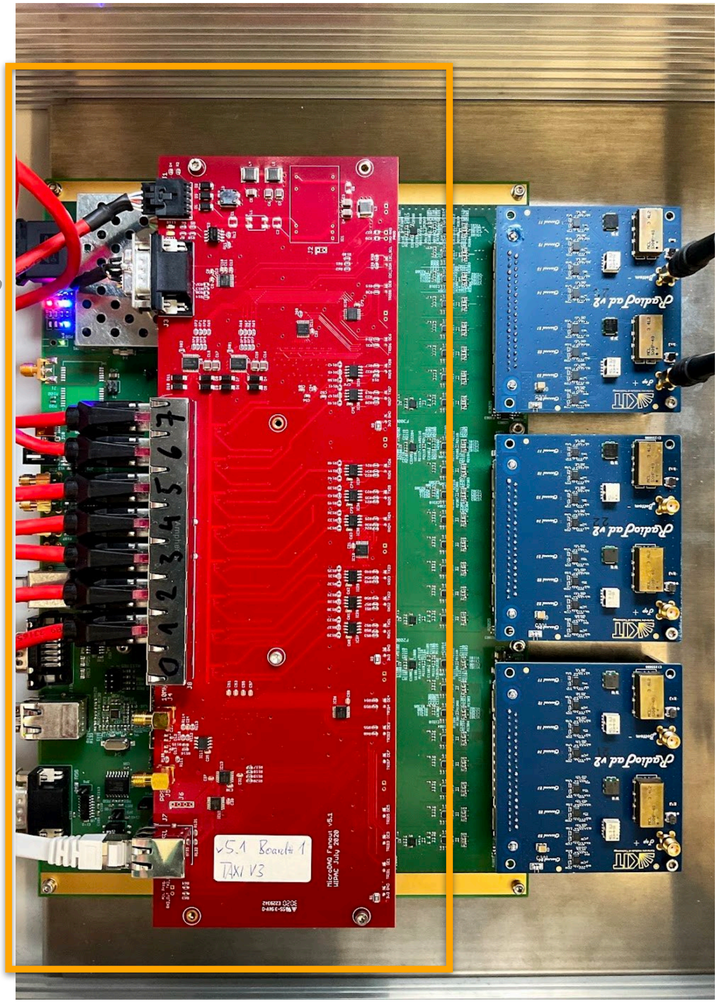
DAQ and related components





DAQ and related components





DAQ and related components