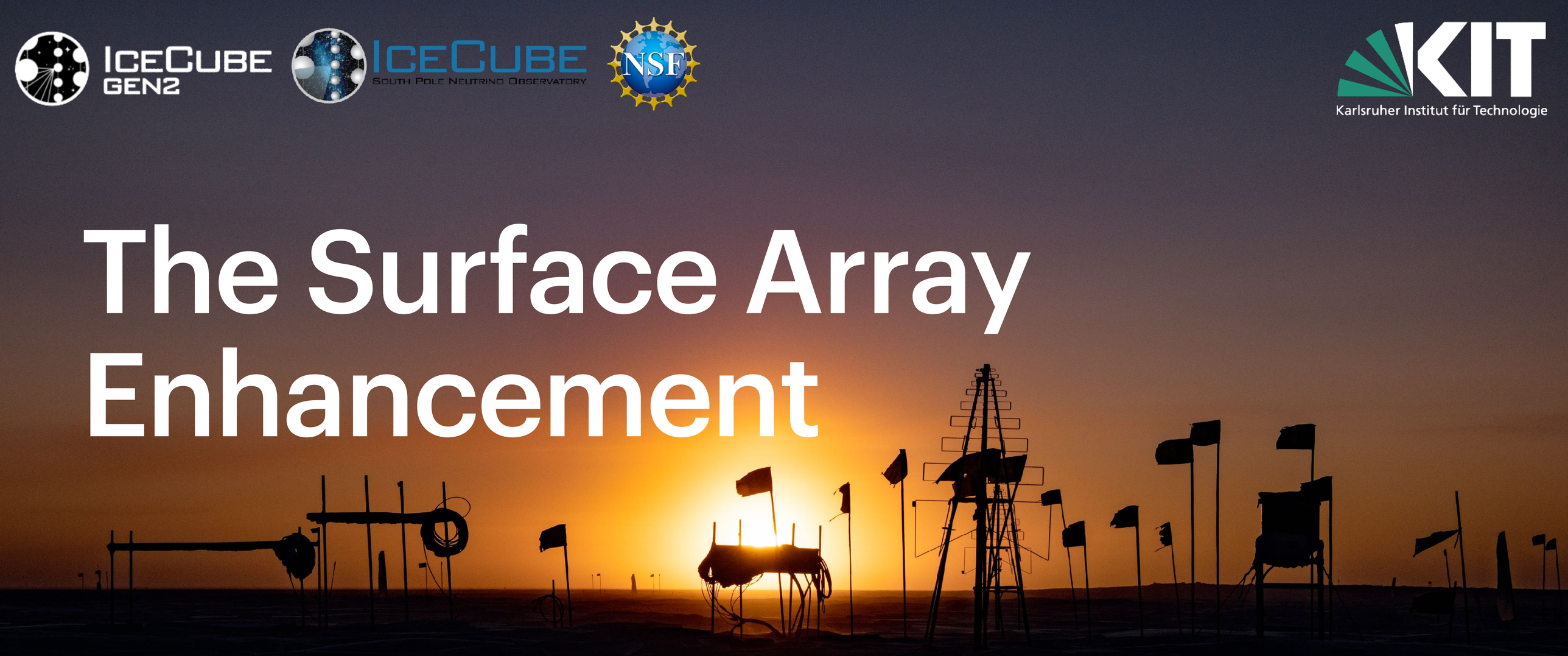
The Surface Array Enhancement



A comprehensive overview of the planned cosmic-ray surface detector at the South Pole

Roxanne Turcotte on behalf of the IceCube Collaboration

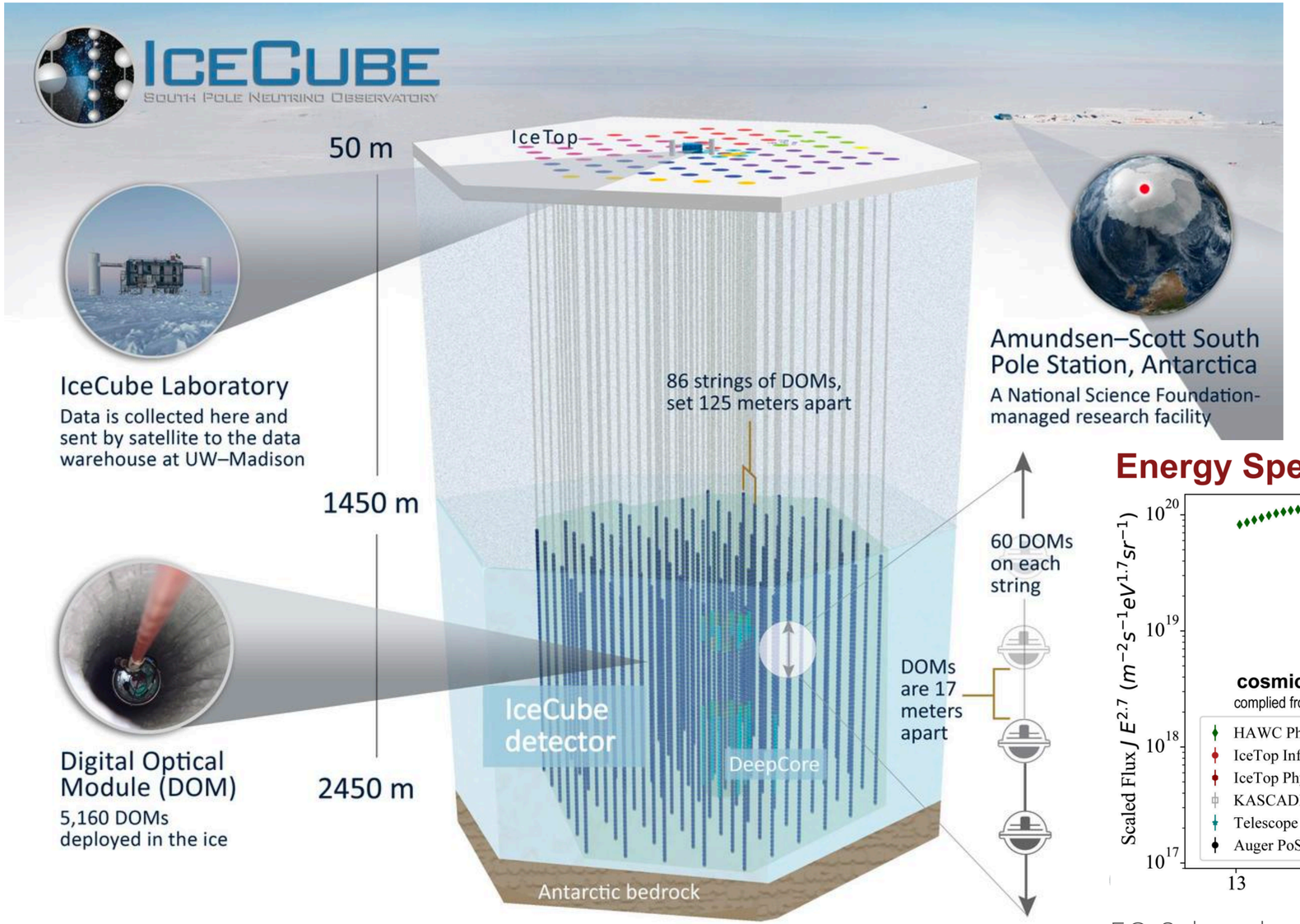
at the SCAR AAA Workshop

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

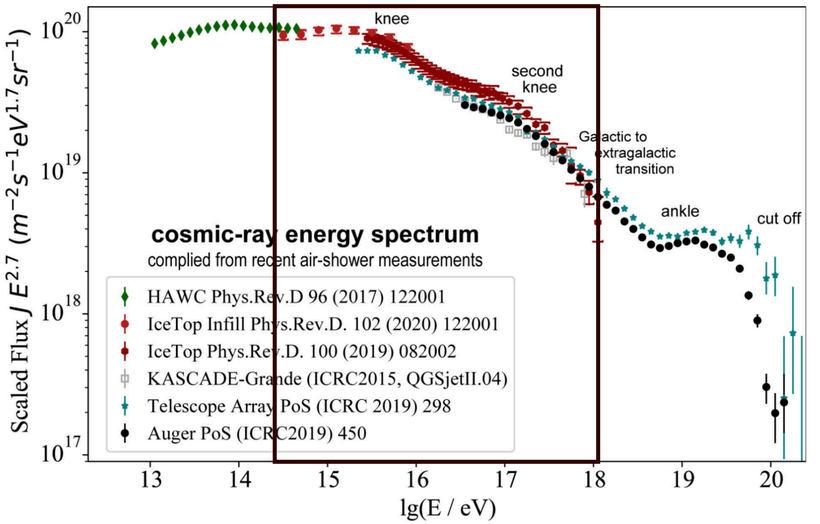
09.09.2021

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 802729).

The IceCube Neutrino Observatory



Energy Spectrum of Cosmic Rays



F.G. Schroeder
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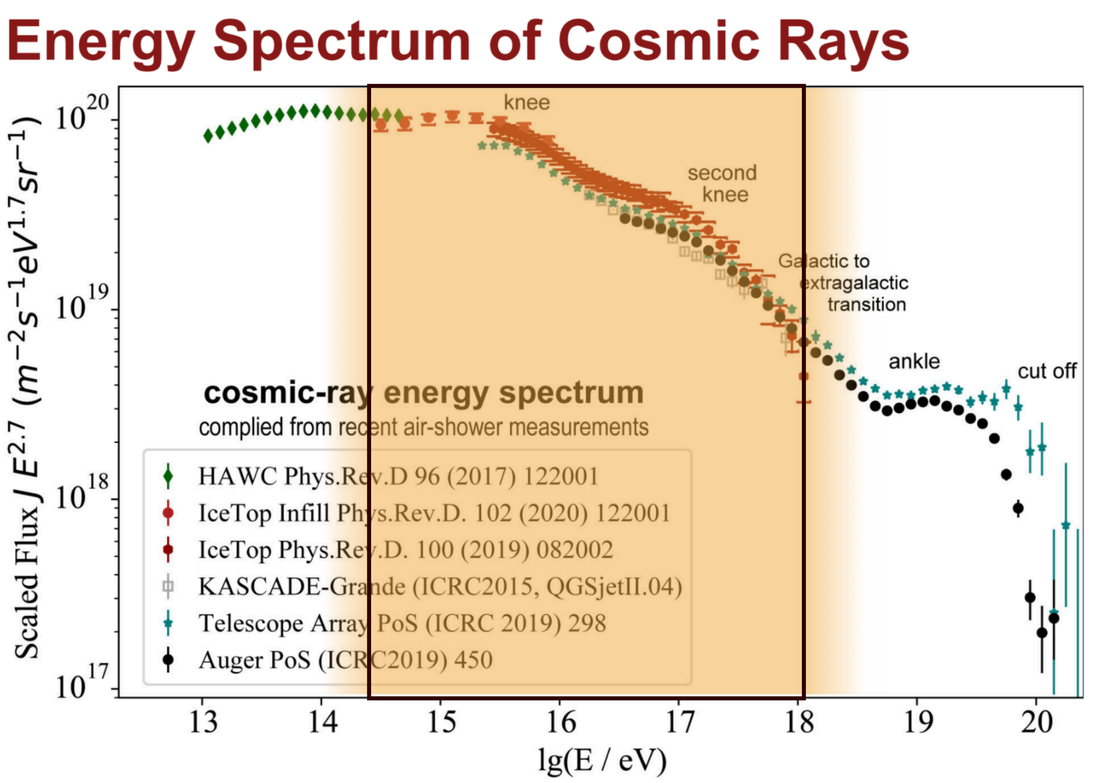
Planned

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 (modified)

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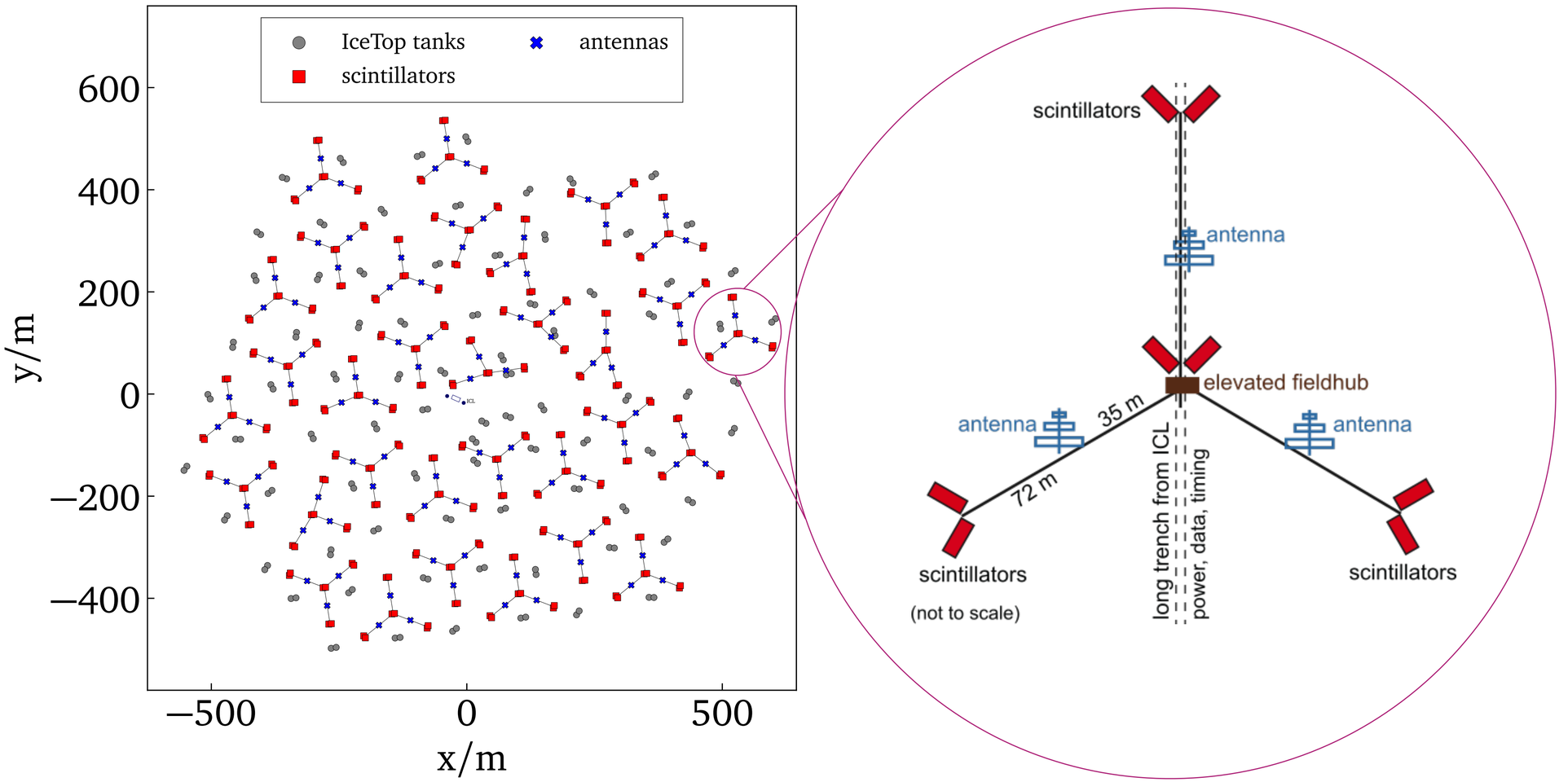
Planned

Surface Array Enhancement

32 Stations

- 8 scintillation panels
- 3 antennas



PoS(ICRC2019)332 A. Leszczyńska (modified)

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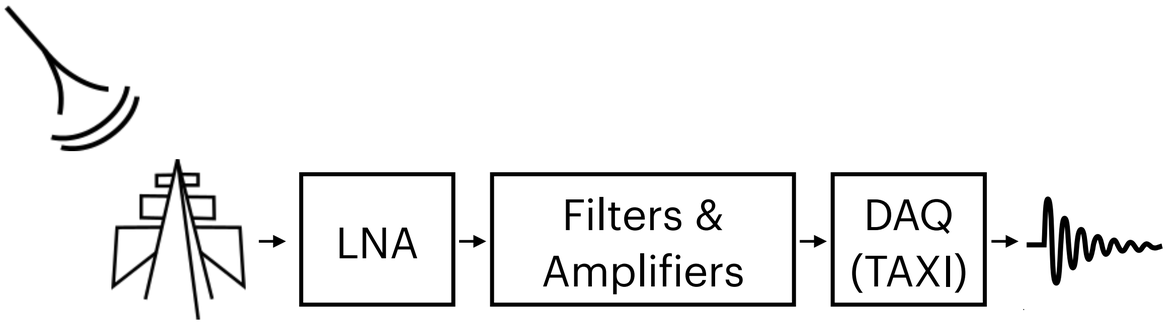
Elevated
Radio Antennas

- 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 **± 60° from zenith**
- Low power
- **±0.5° uncertainty** on the levelling
- Low cross-polarisation
- Easy assembly in the field



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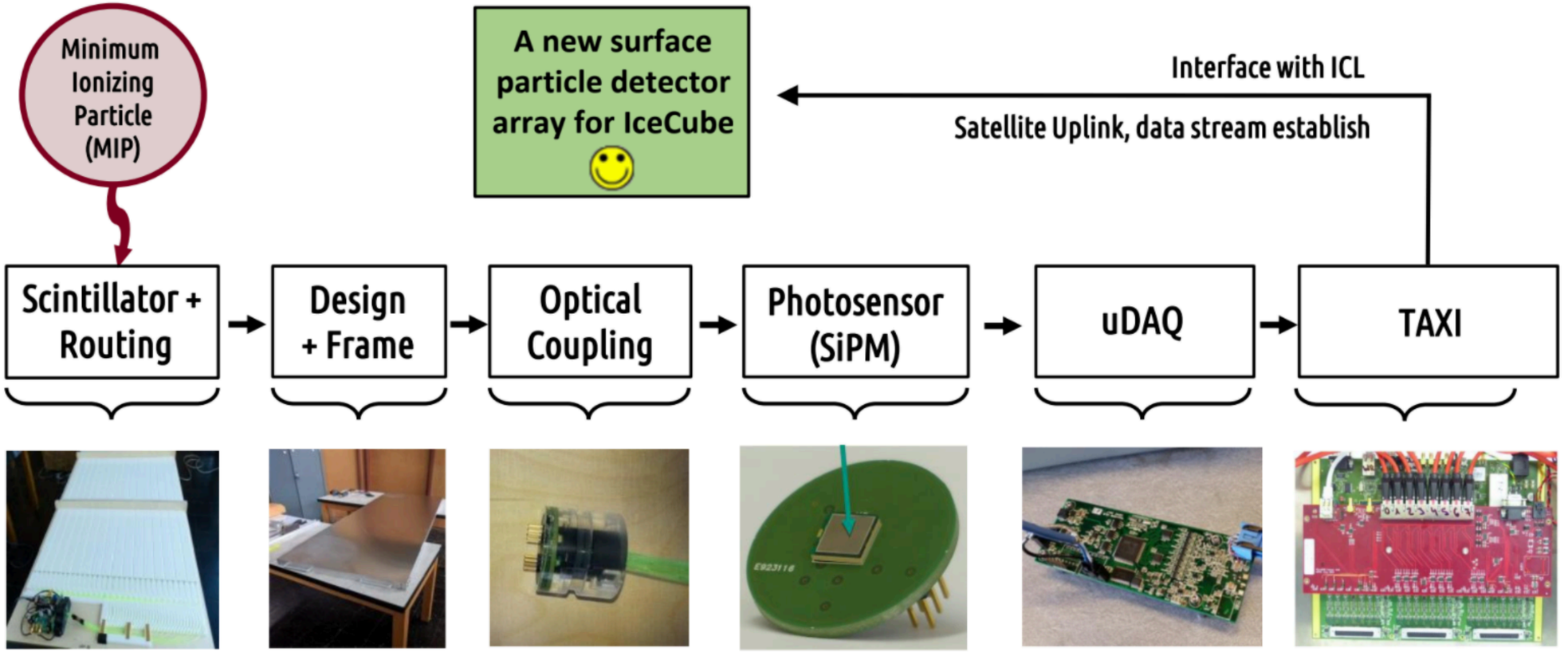
Elevated
Scintillation Panels



T. Huber

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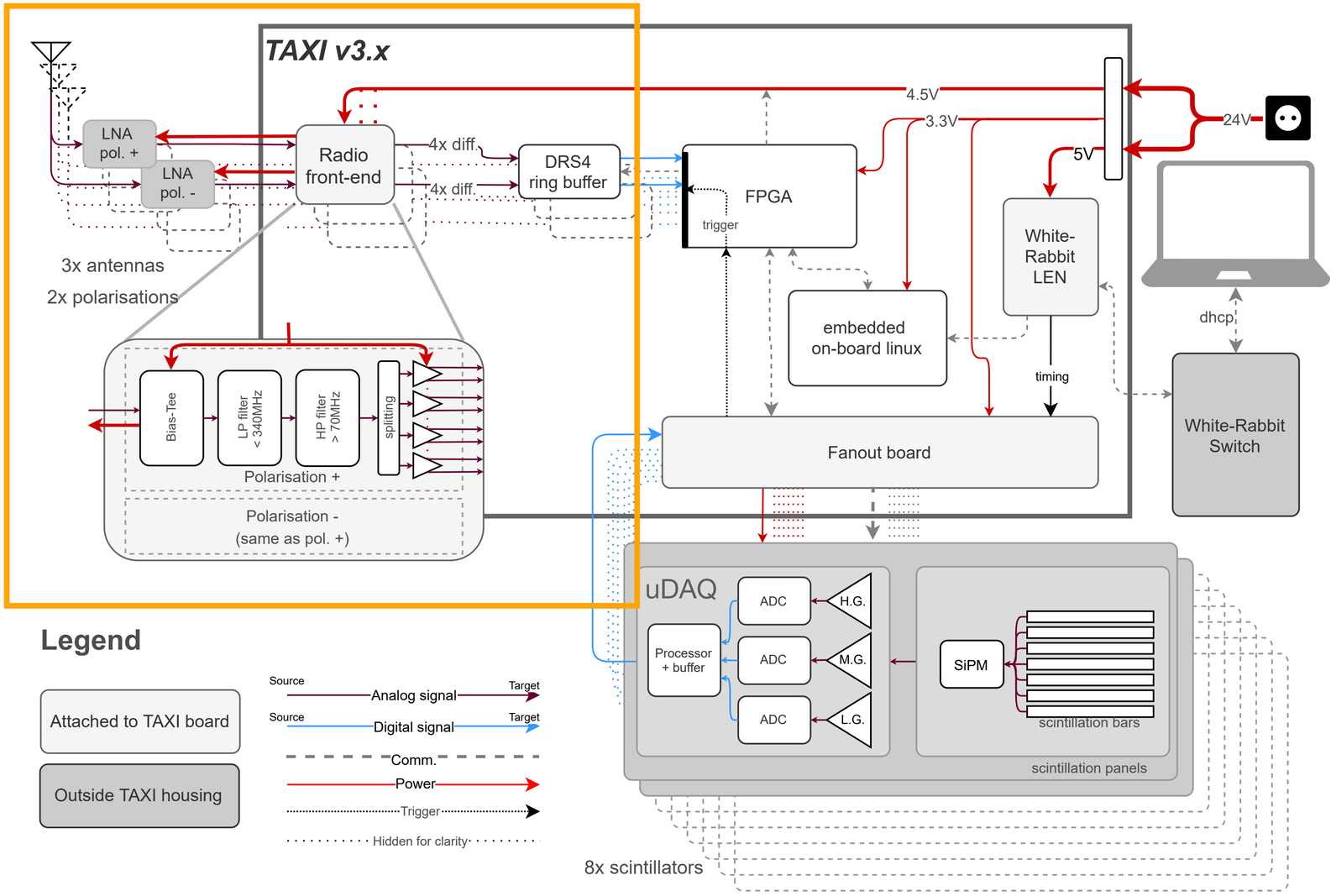
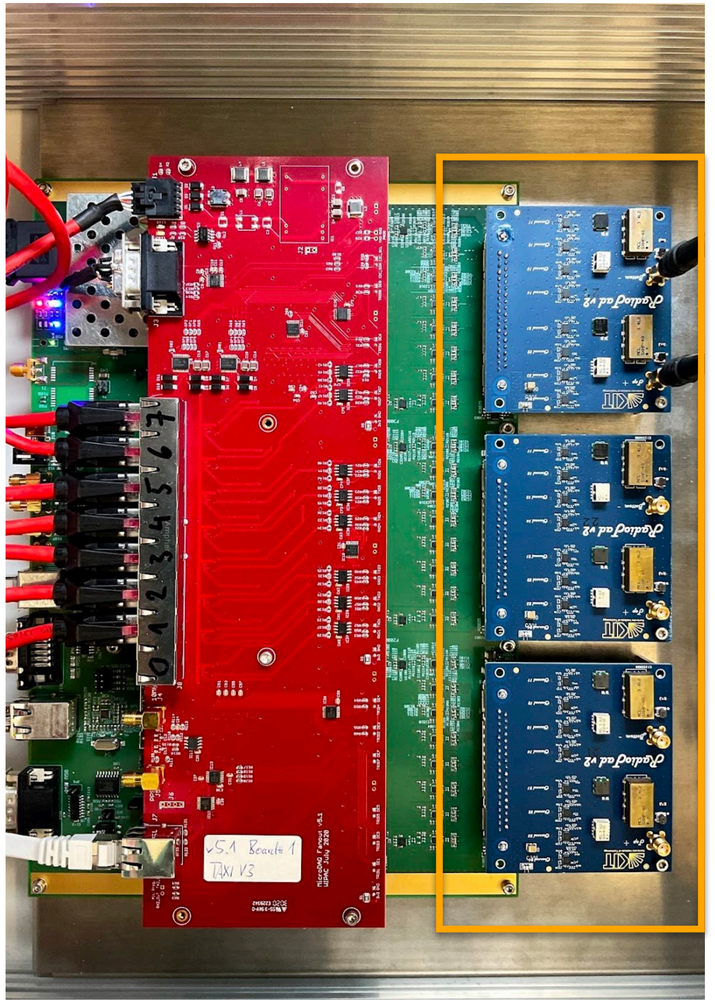
DAQ and related components





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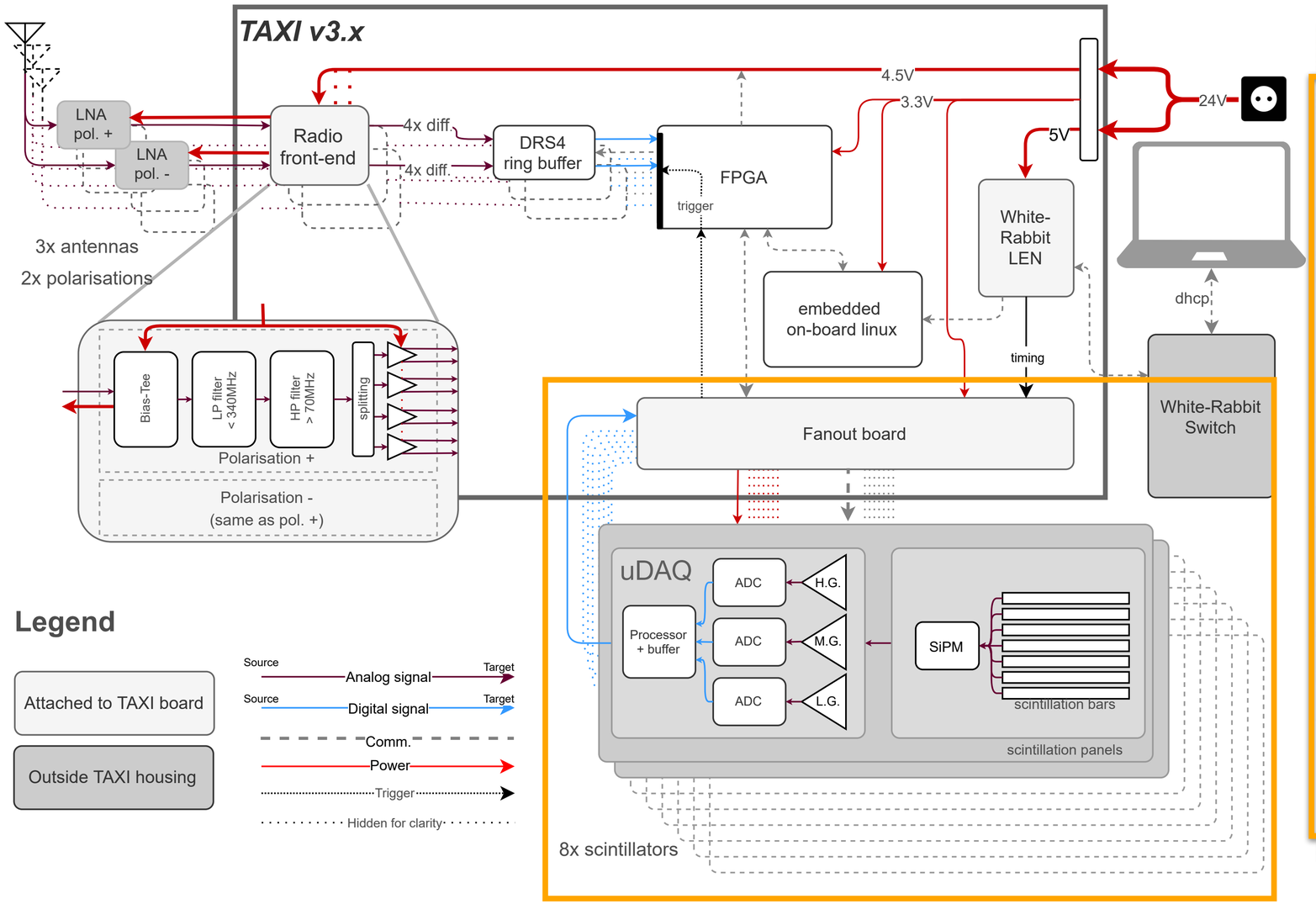
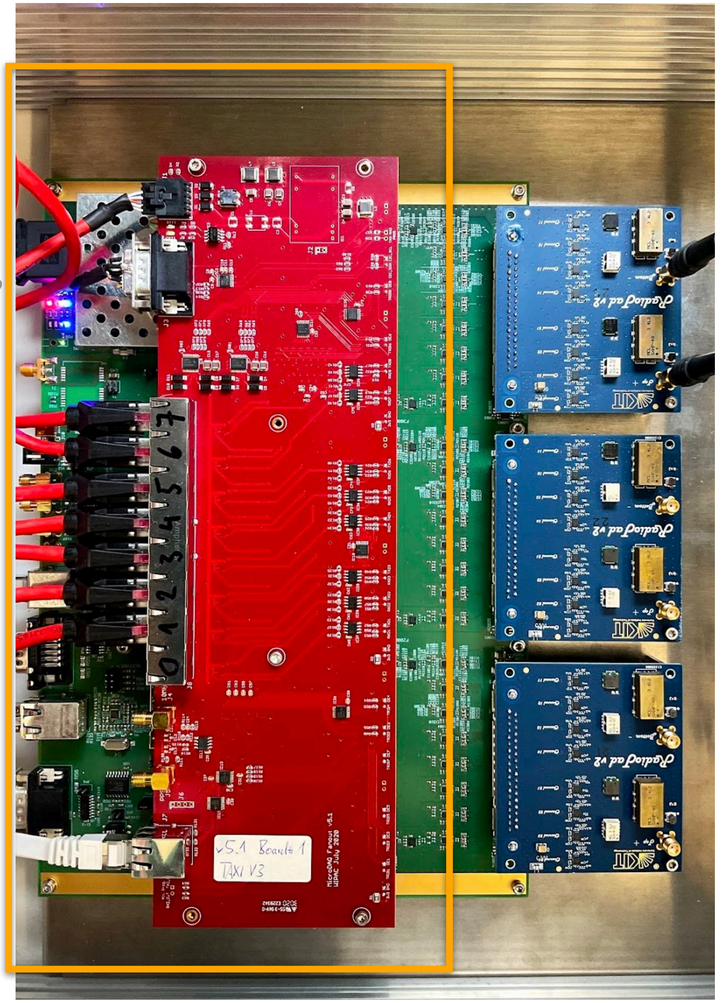
DAQ and related components





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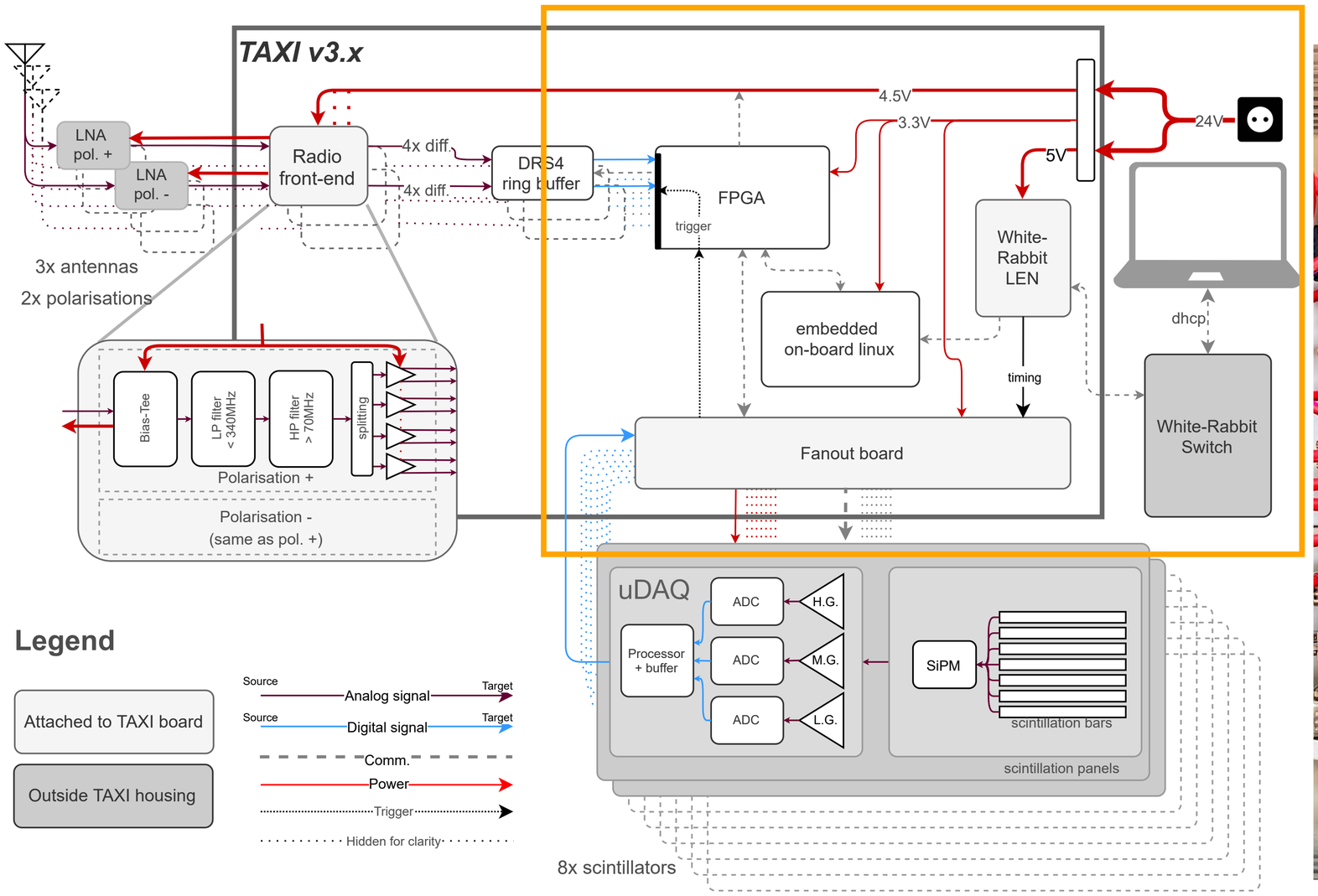
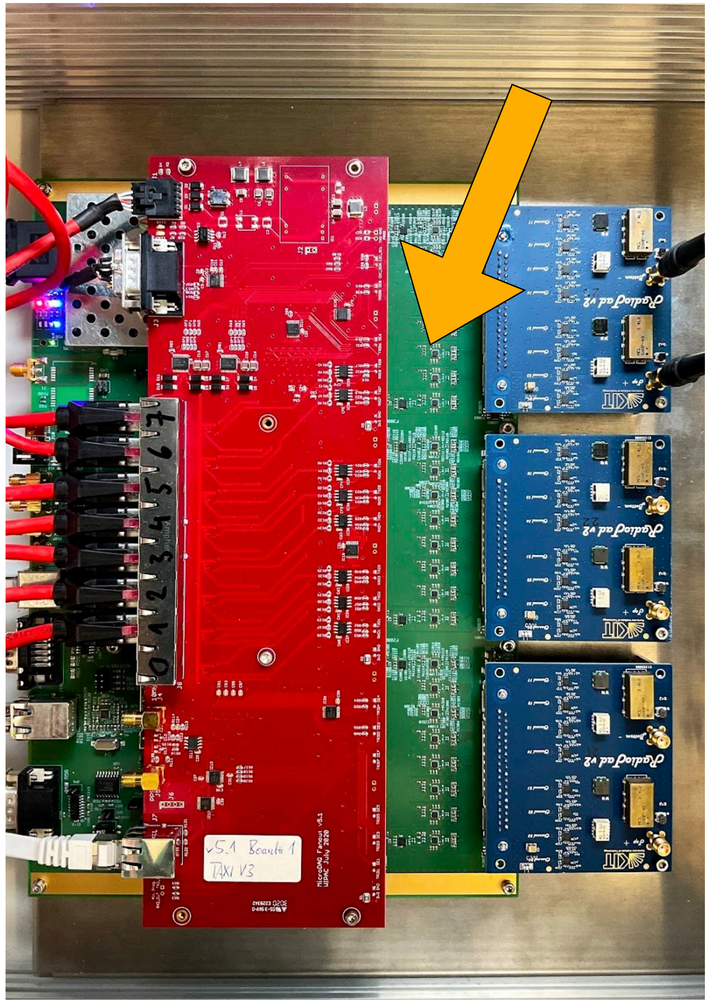
DAQ and related components



Legend



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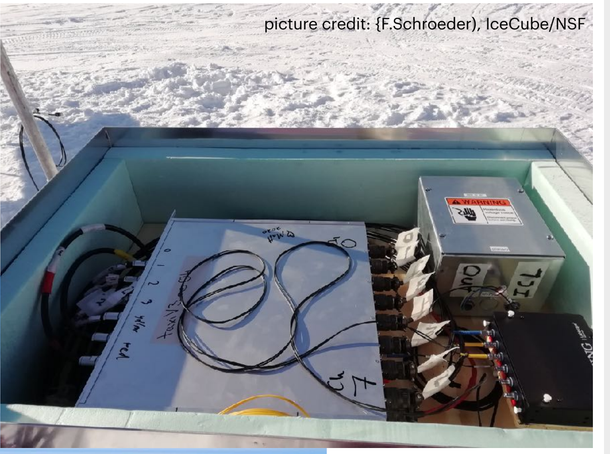
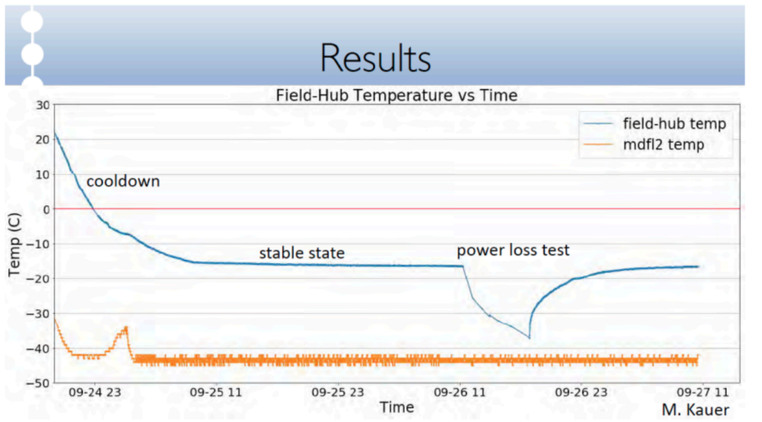
Elevated
Field Hub

- 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


picture credit: {F.Schroeder), IceCube/NSF


picture credit: {F.Schroeder), IceCube/NSF



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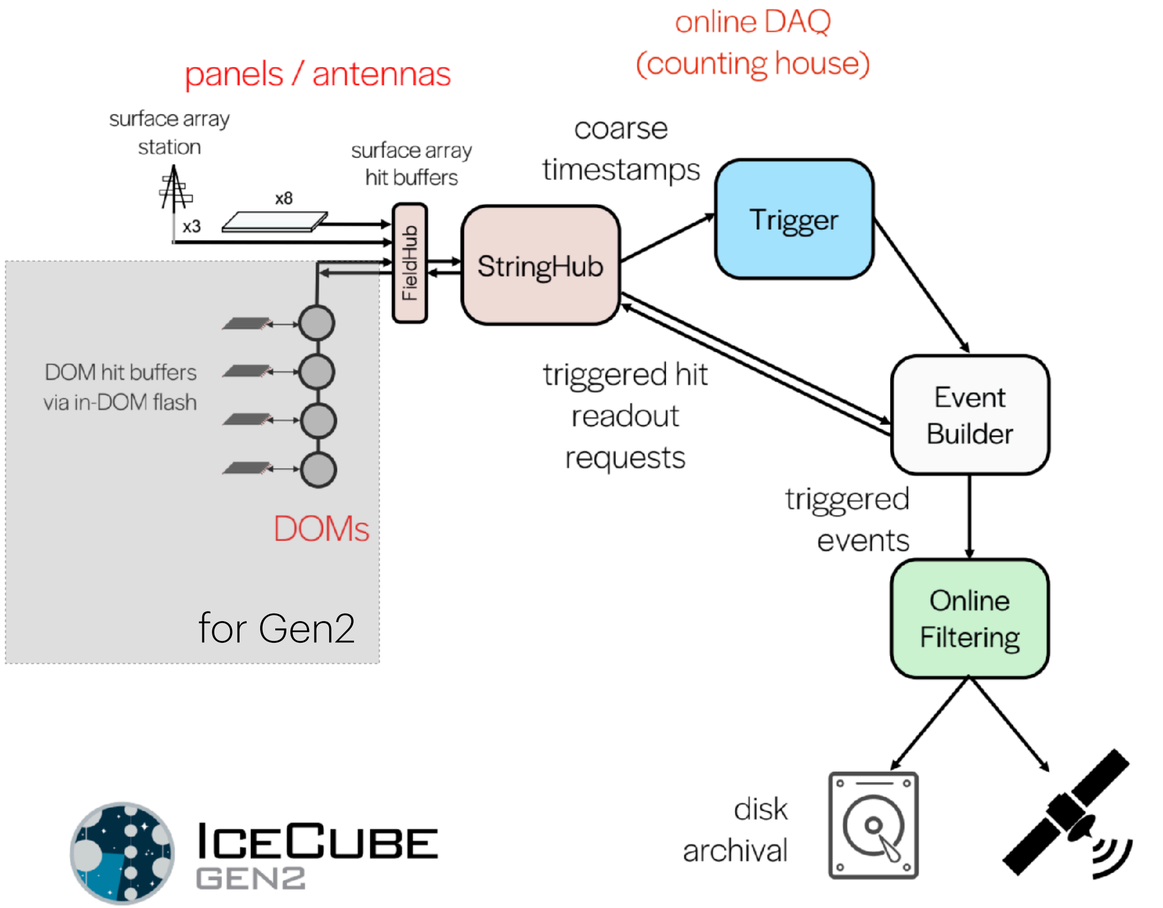
Infrastructure

- 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



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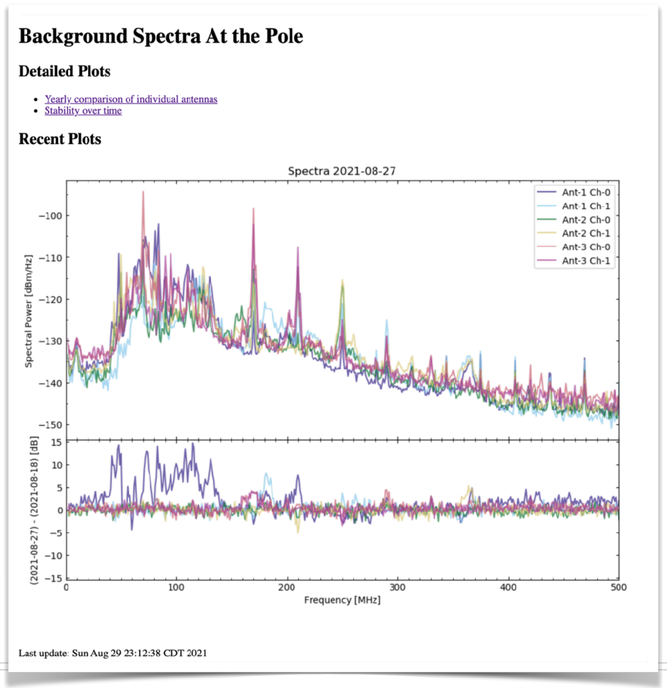
Maintenance

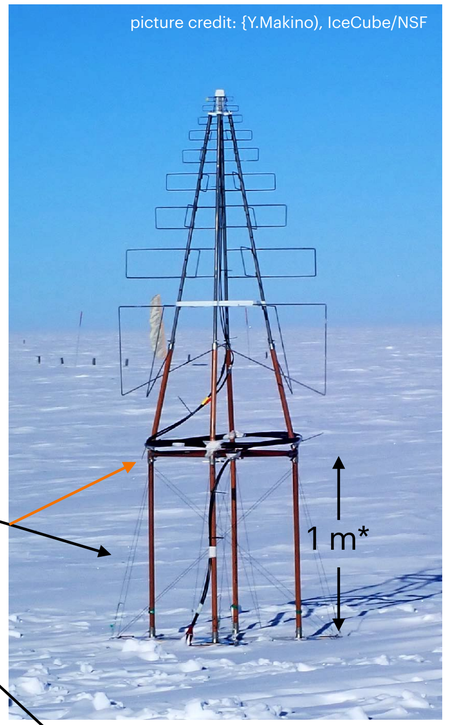
- Average of **20 cm/year** of **snow accumulation**
- **Raising** the individual detectors every **5 years.** The maintenance will naturally be staggered (with deployment)
- About **2 person for 2 weeks** every year for maintenance for full array

Monitoring

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



Extendable structure
Cable slack (20 years)



*The final version has 1.20 m

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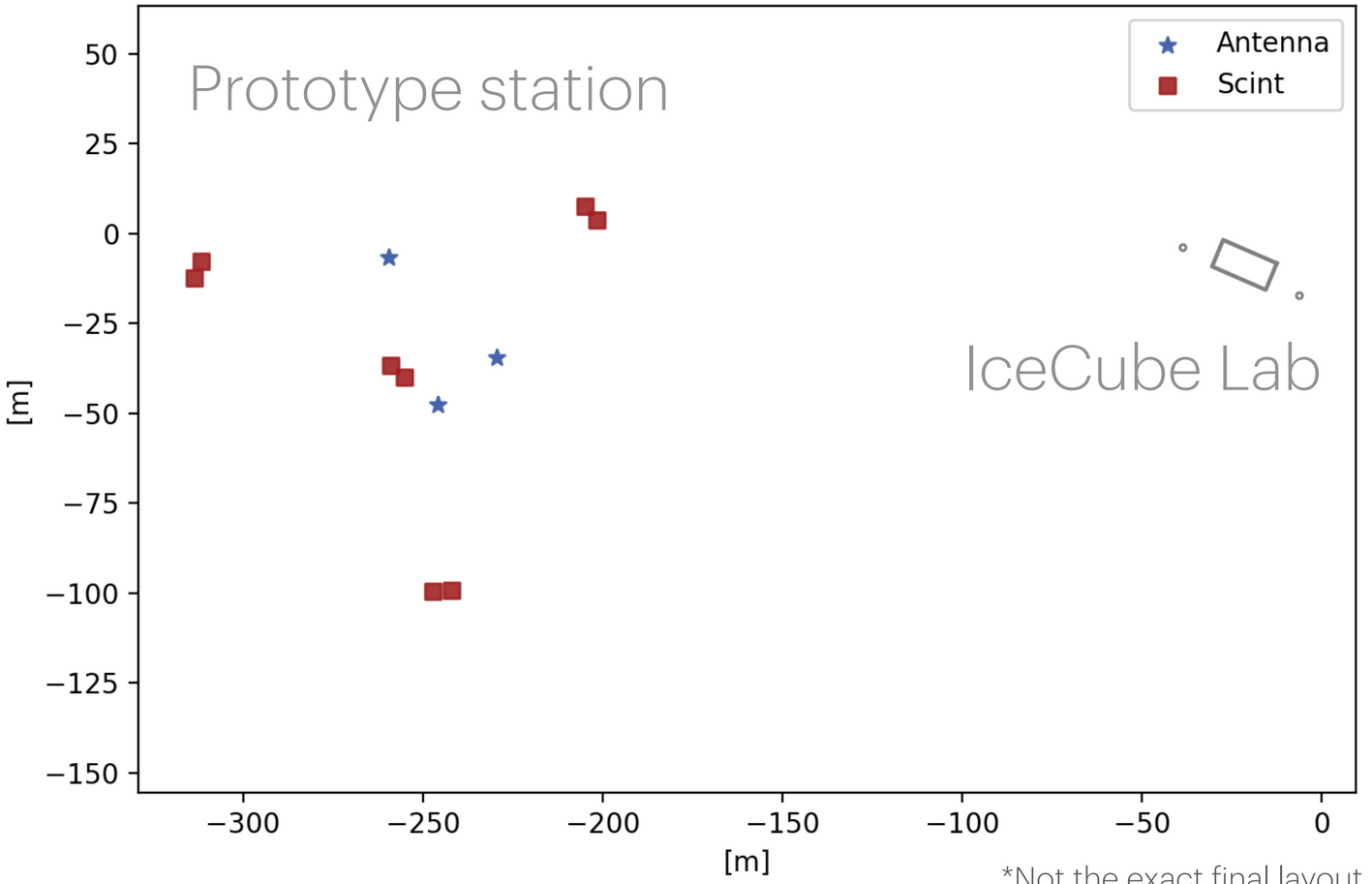
Prototype Station

- 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

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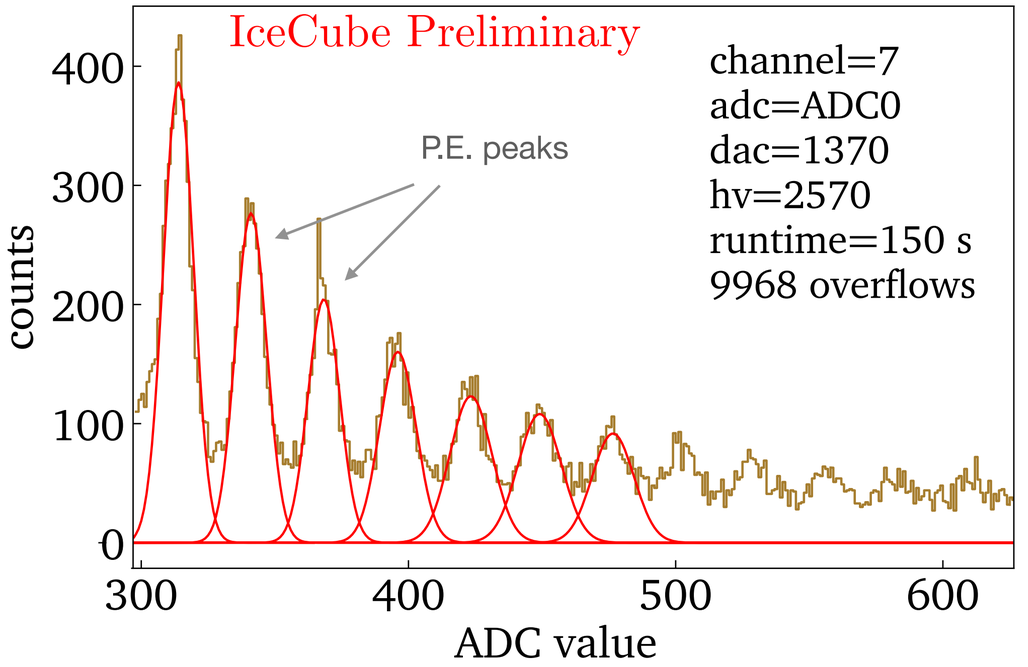
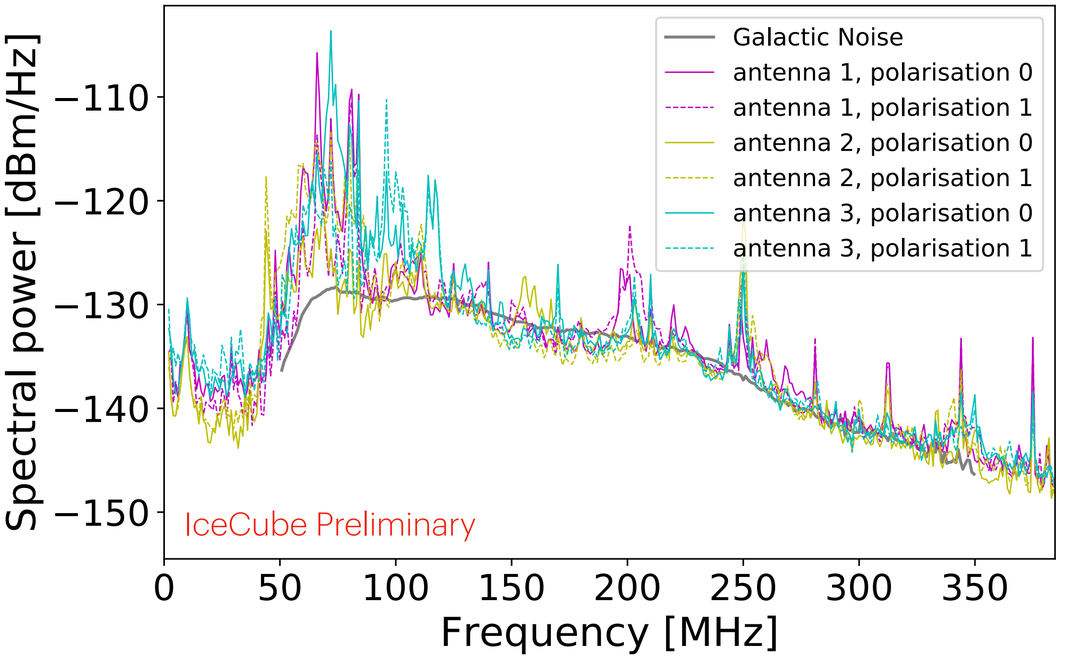
Raw data and background

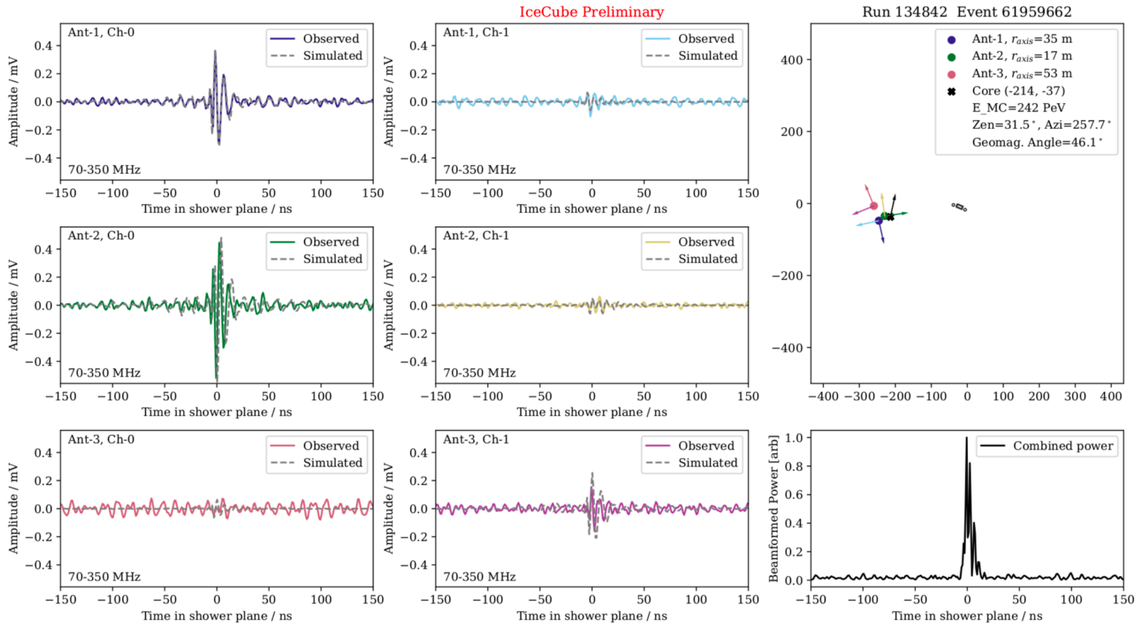
- Example of a **charge histogram** (high gain)
- **Median spectrum** (17.04.2020) compared with **galactic noise** (Cane model) and **thermal noise** (40K) in gray



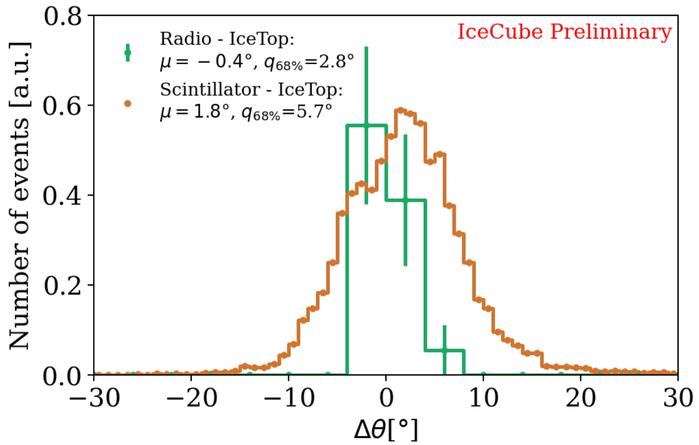


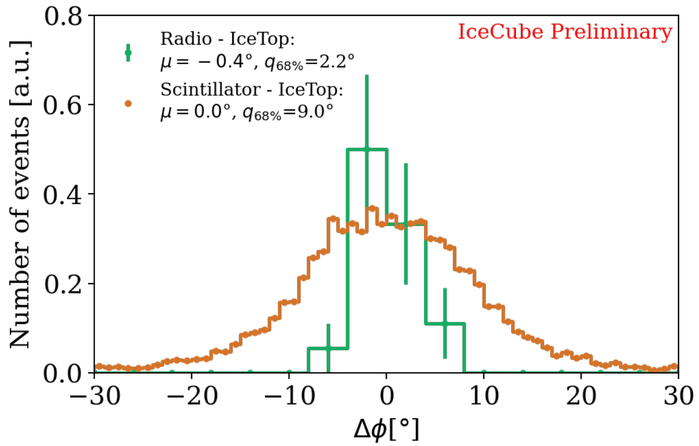
Detection of air showers!

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



PoS(ICRC2021)317 (A. Coleman)





Arrival directions compared to IceTop

(plane wavefront assumed)

PoS(ICRC2021)314 (H. Dujmovic)

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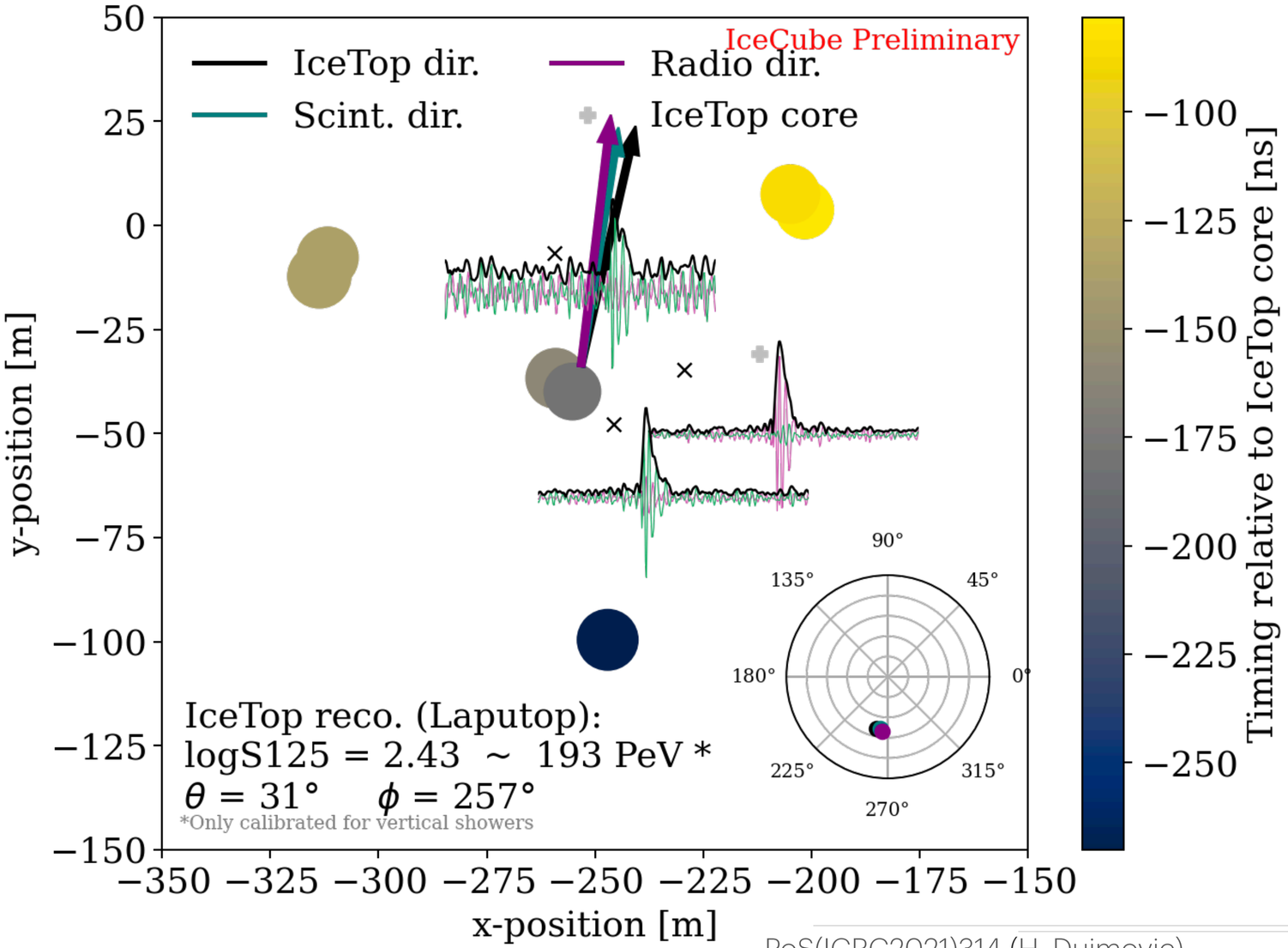
Triple coincidences

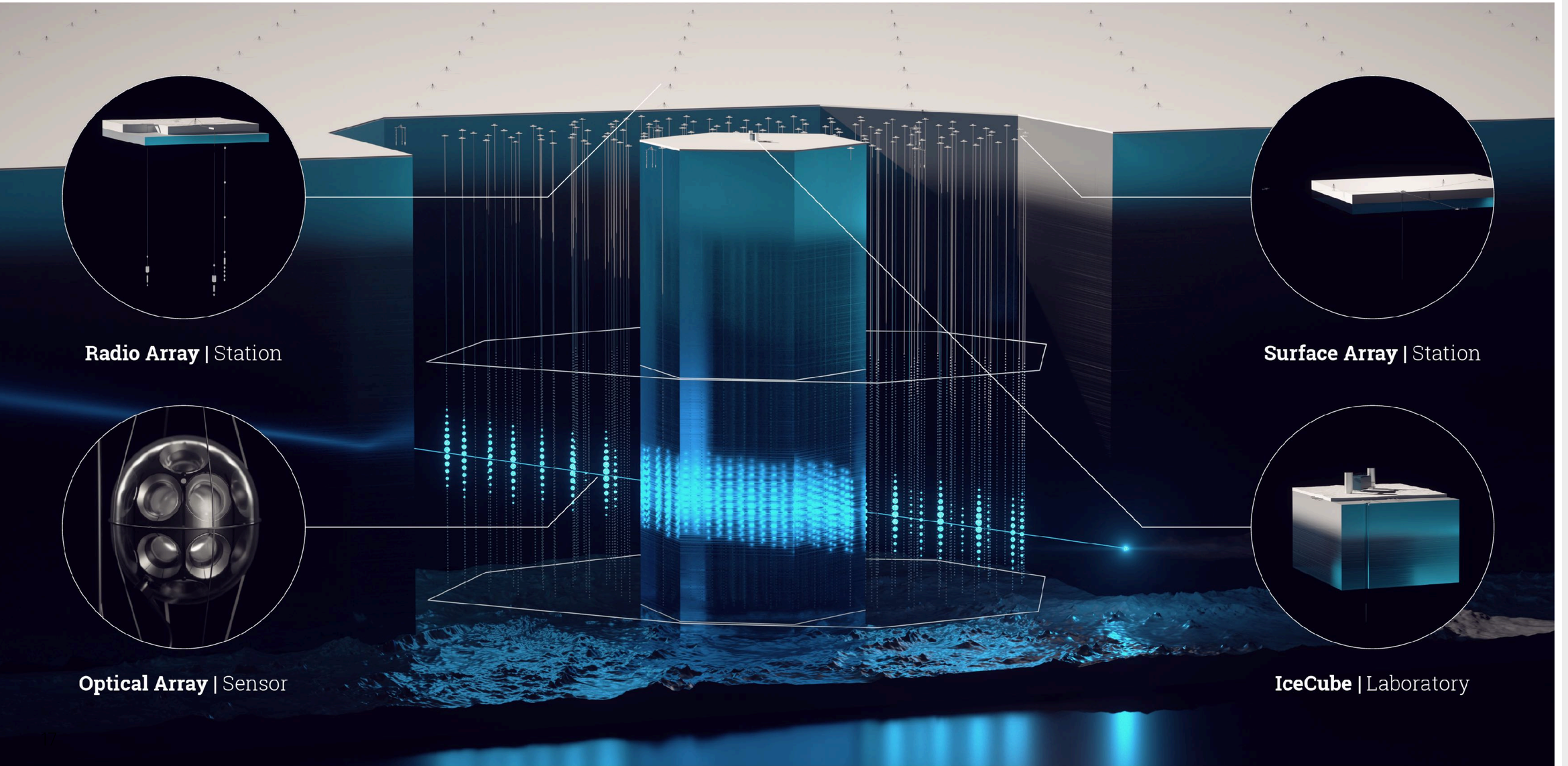


Scintillators
Size -> charge deposited
Color -> time

Antennas
Filtered waveforms,
Summed envelopes

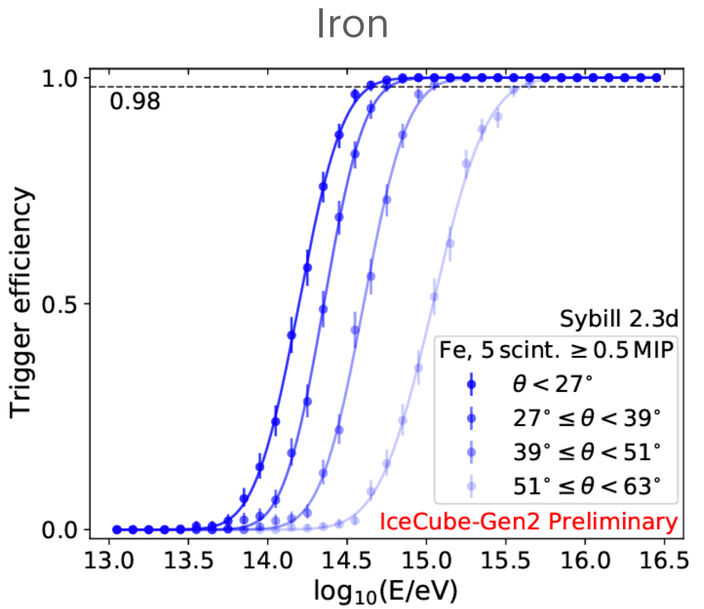
Reconstructed direction

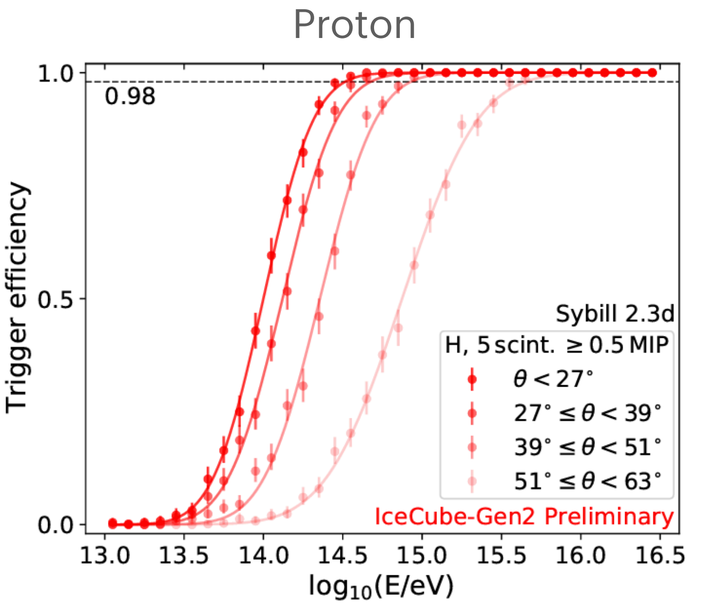
Outlook in the future - IceCube Gen2



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**





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

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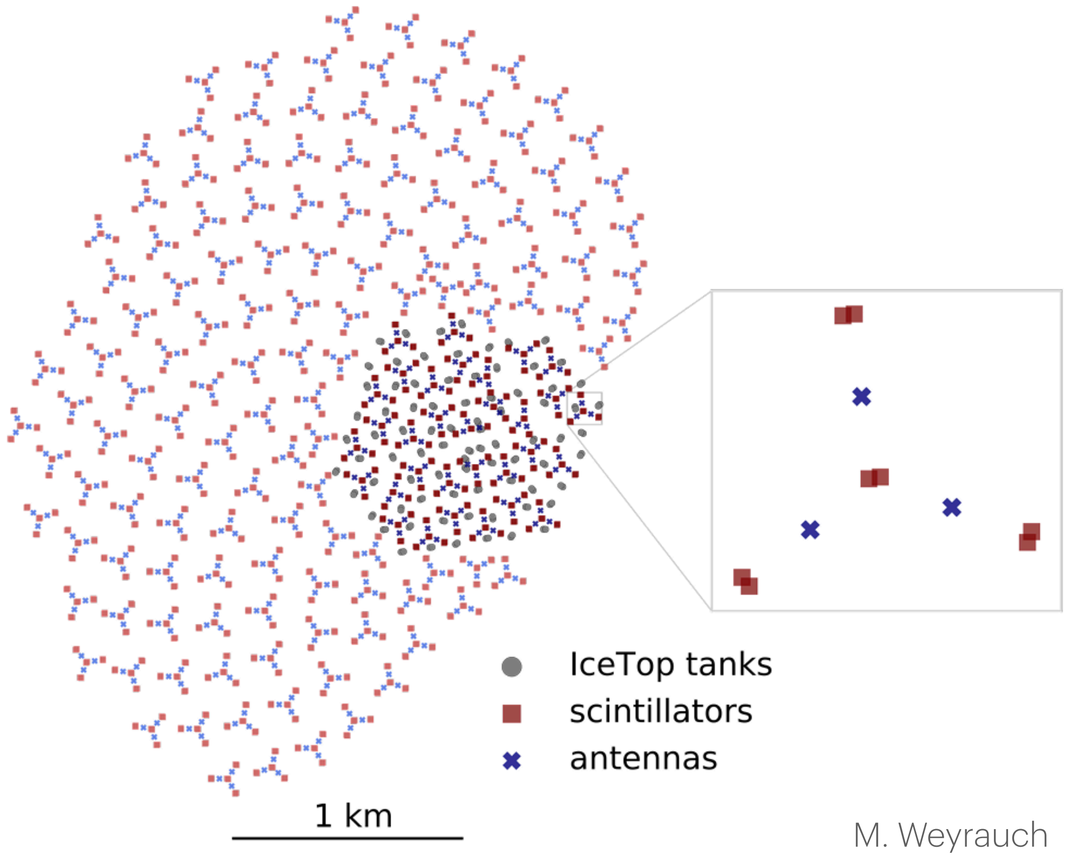
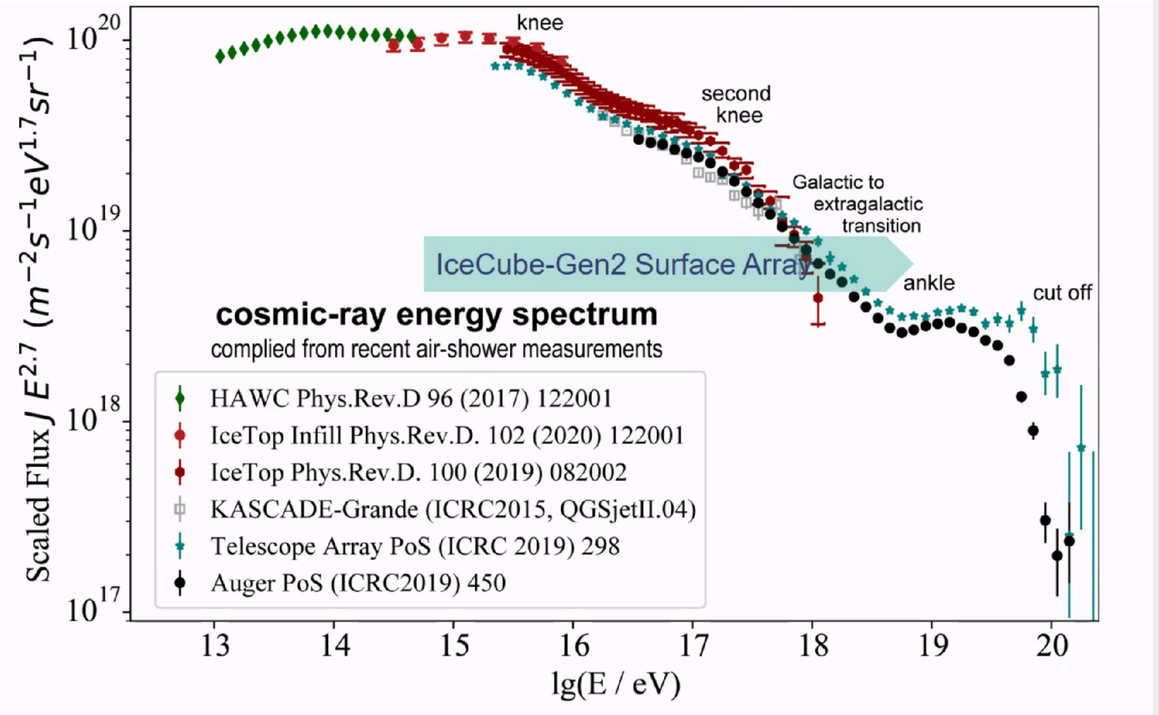
Outlook in the future - IceCube Gen2



M. Weyrauch



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Conclusion

- 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 :)

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