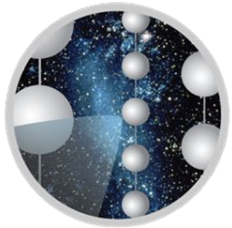
Karlsruher Institut für Technologie

Improving air-shower observations with the Surface Array Enhancement - Results from a Prototype Station

Megha Venugopal for the IceCube Collaboration

ARENA 2024, Chicago



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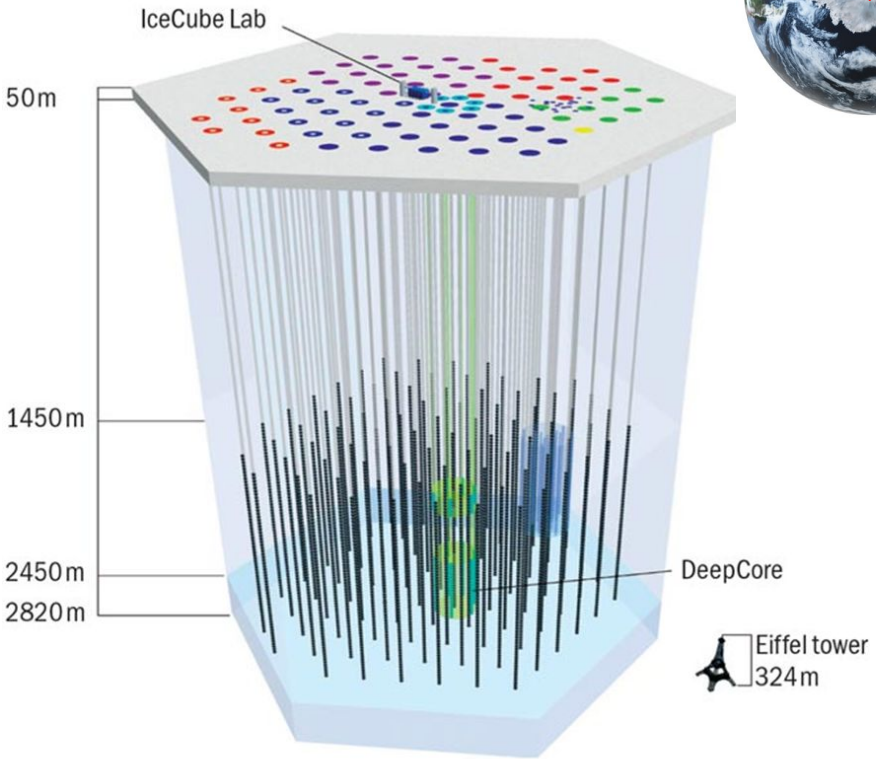
IceCube and IceTop

- IceCube is a km^3 detector in ice detecting neutrinos and atmospheric muons
- IceTop is a km^2 surface array for cosmic ray research and also serves as a veto for IceCube neutrino research.



Deployment of an IceTop tank

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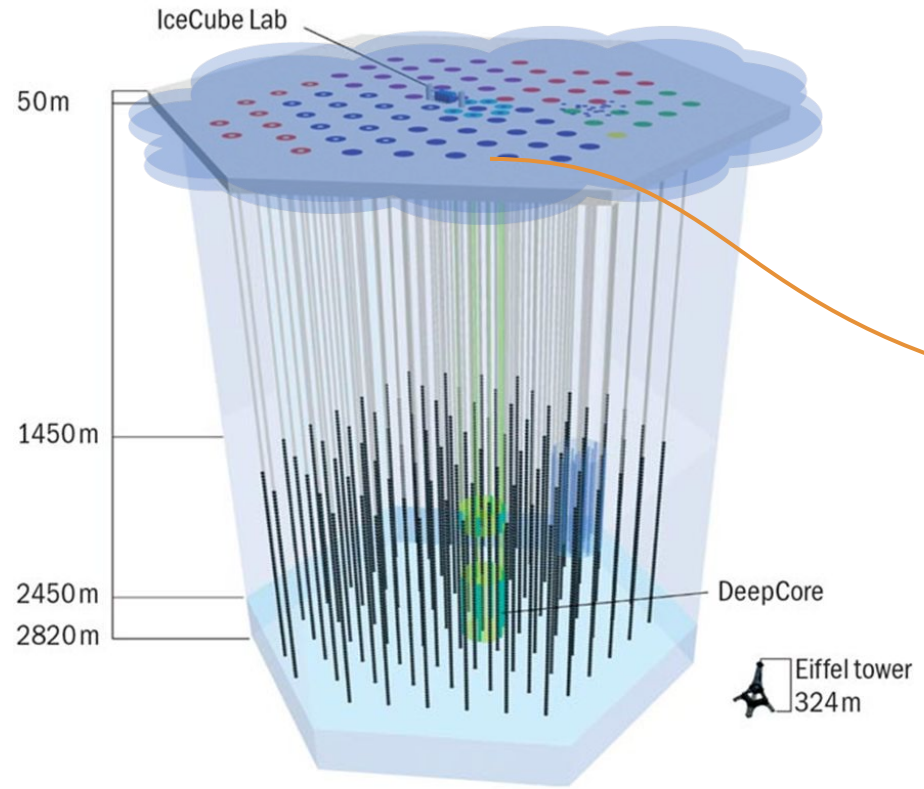
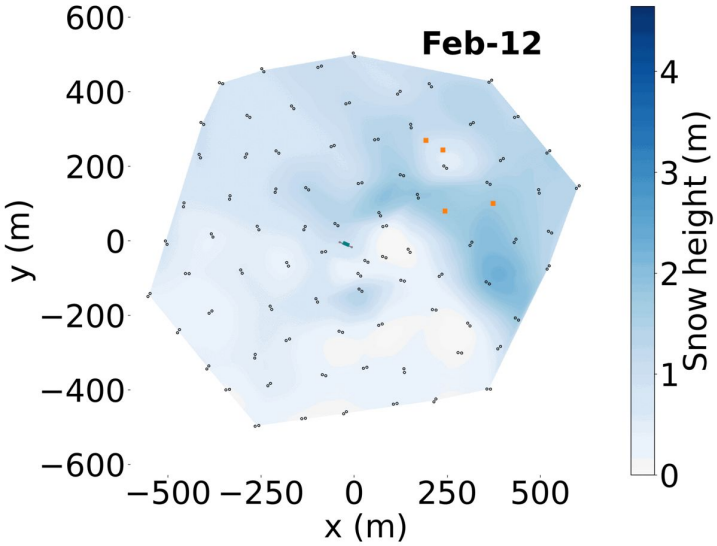
IceTop





Plot credit: J. Saffer

Snow accumulation over time on IceTop

Rising **snow accumulation** driven by winds

- Reduced efficiency detecting low energy cosmic rays
- Higher uncertainty in air-shower reconstruction

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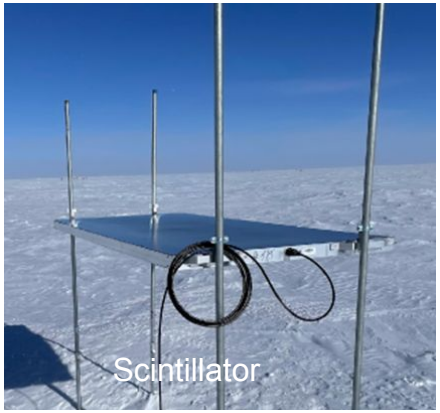
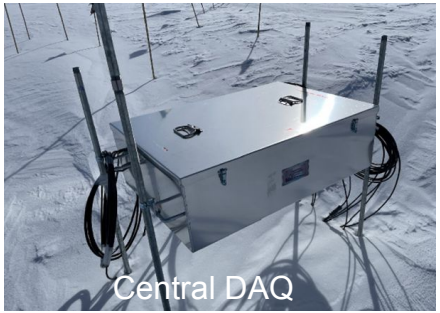
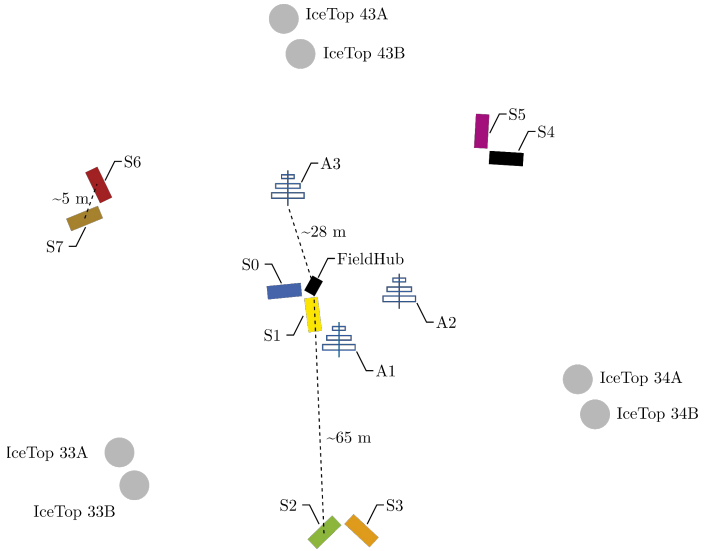
The prototype station of the Surface Array Enhancement







Layout of the Prototype Station

- 2 types of detectors -
  - 3 antennas and 8 scintillation detectors per station
  - Easy to elevate and cost-effective
- Radio operational band 70-350 MHz
- Deployed in 2020, upgraded in 2023

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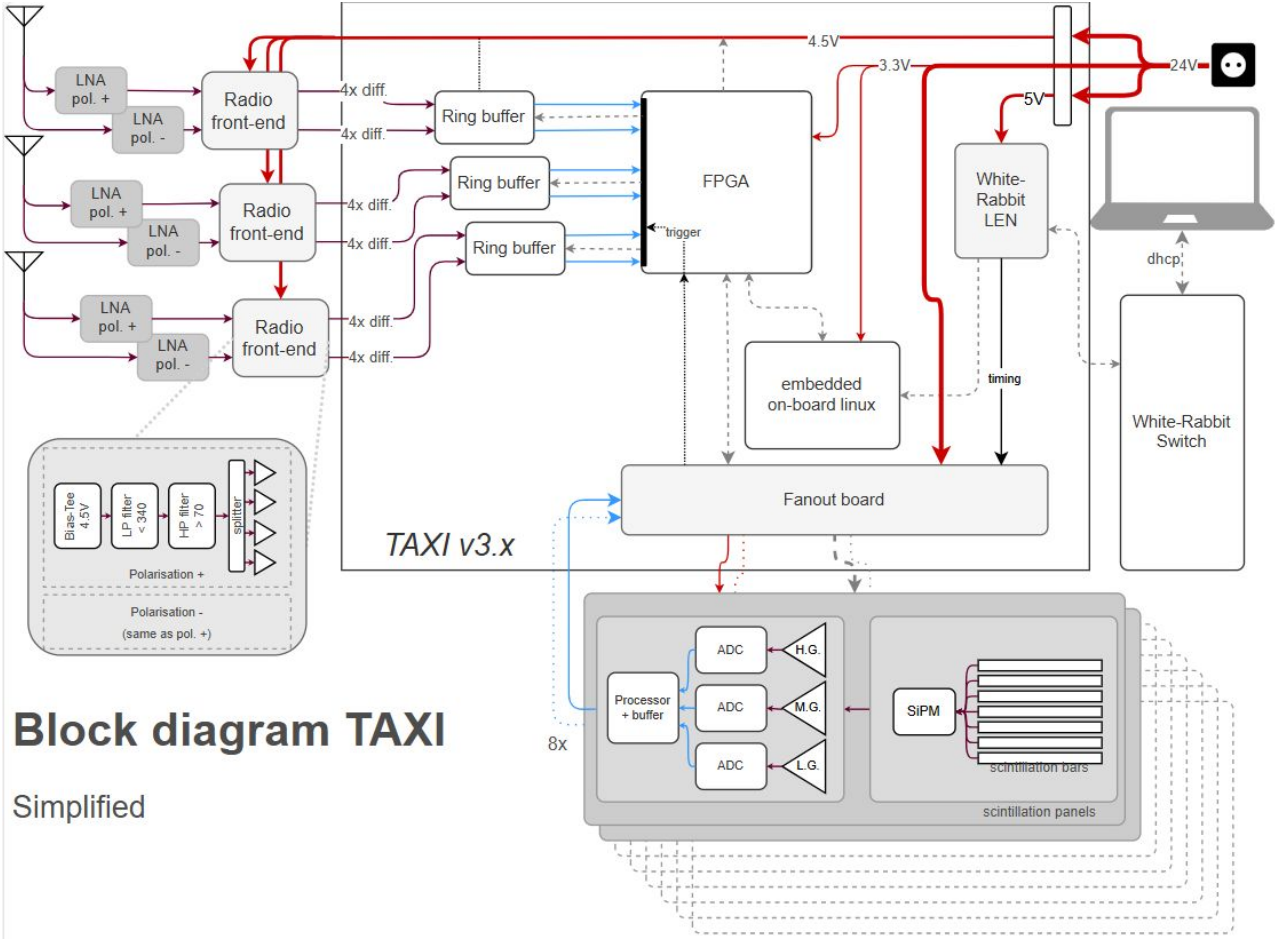
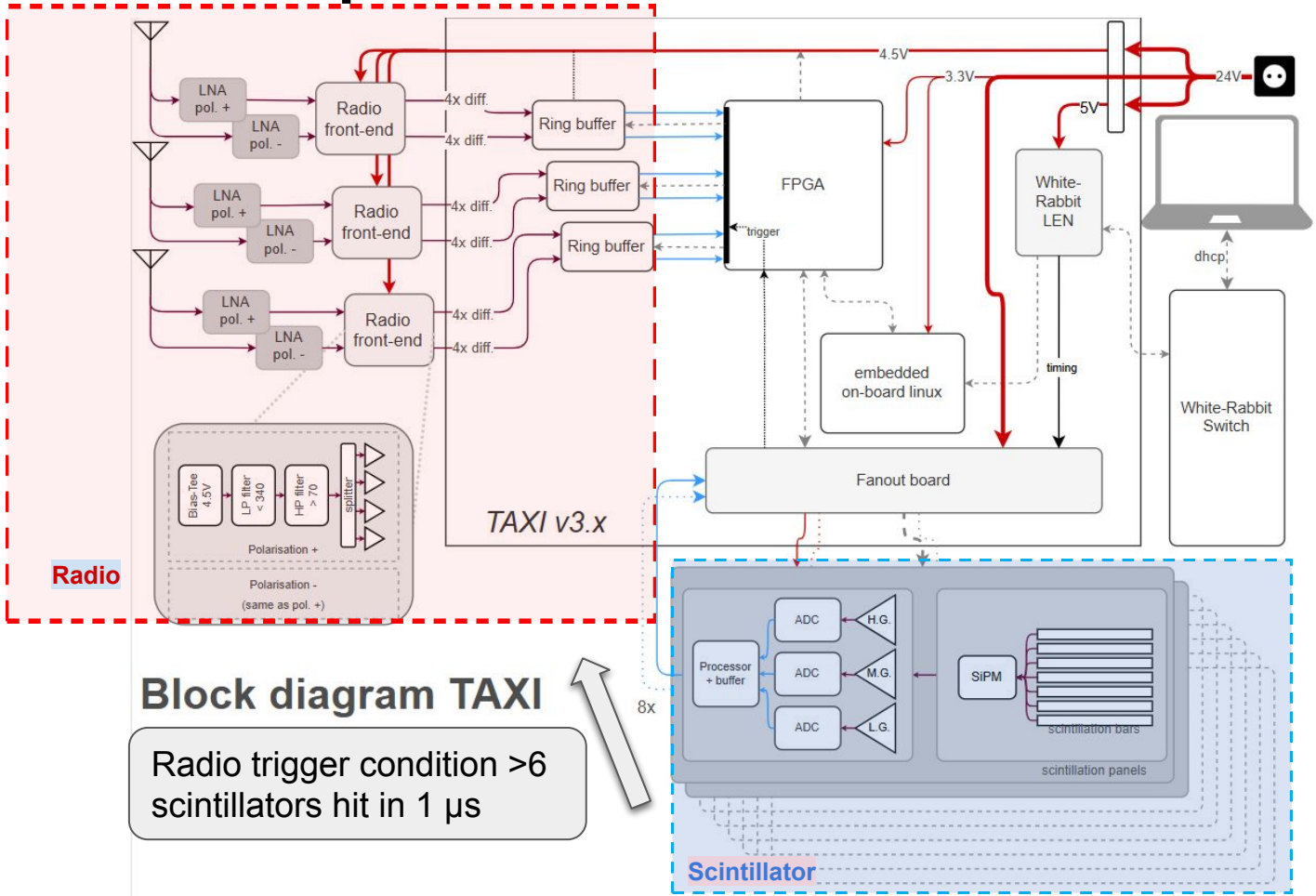
The Data Acquisition of the SAE



Block diagram TAXI

Simplified

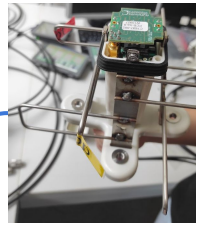
The Data Acquisition of the SAE



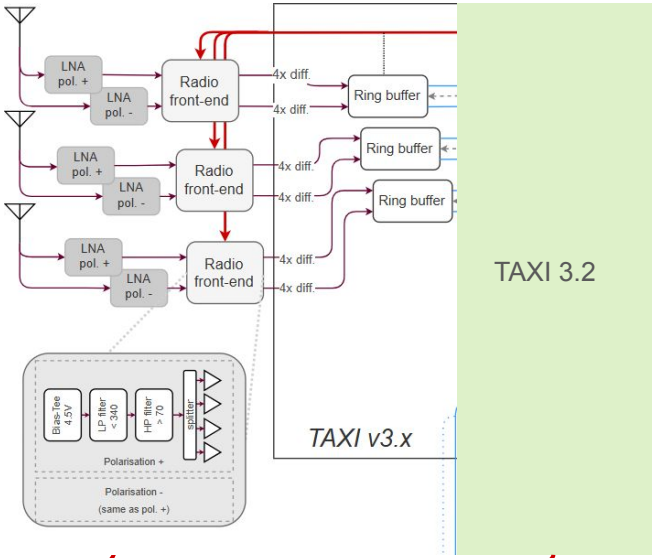
Block diagram TAXI

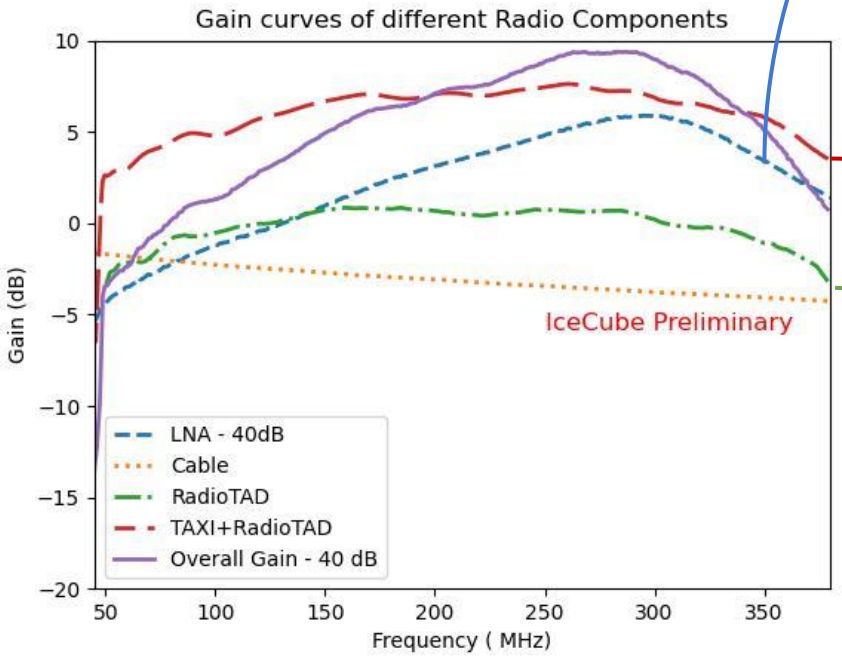
Radio trigger condition >6 scintillators hit in 1 µs

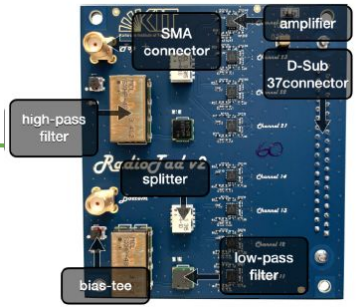
Radio signal chain



Low-Noise Amplifier







RadioTAD

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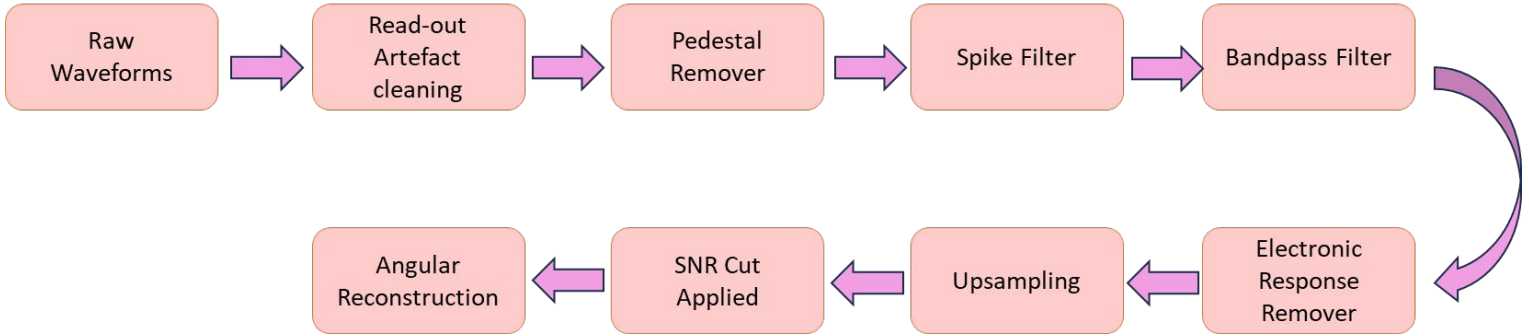
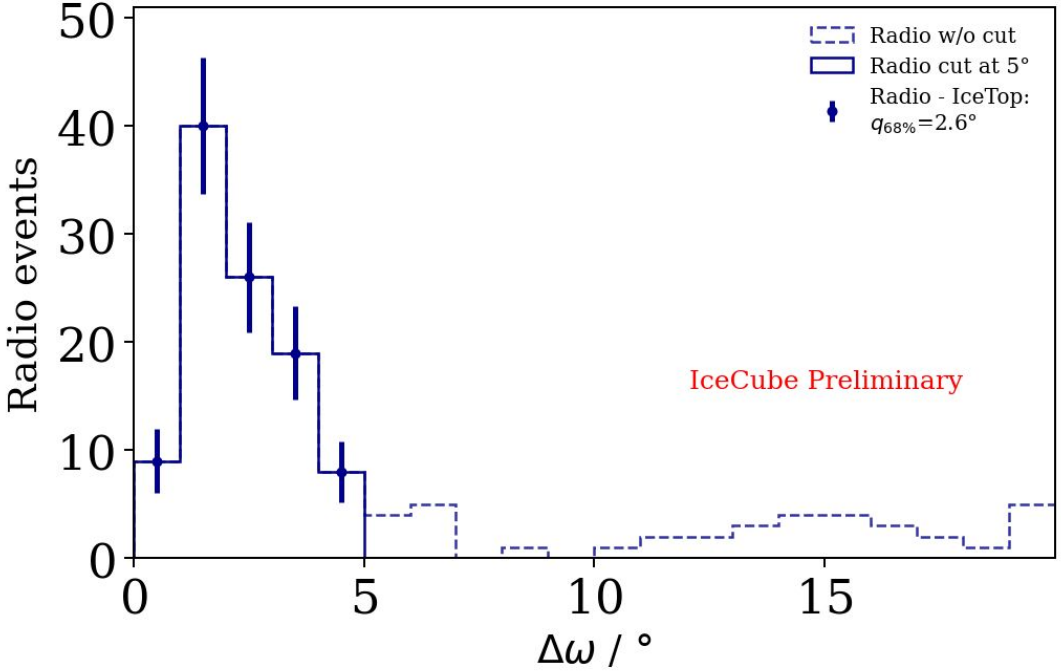
Air shower identification with the Prototype Station

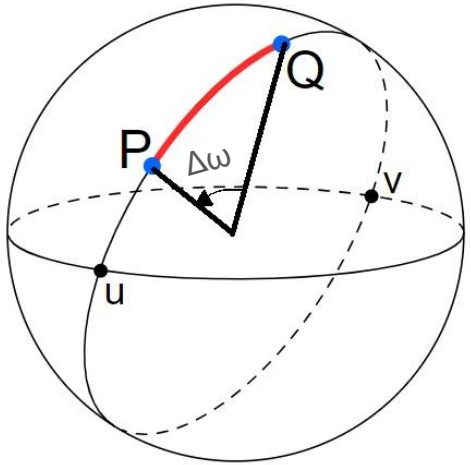
- Dataset : Jan - Jun 2022 (4 months considered) due to differences in data taking
- Radio coincidence identified with IceTop and scintillation panels - in a 2μs window during processing.
- Cleaned for artefacts and RFI, filtered to 100-230 MHz, electronic response removed
- SNR cut computed from background data to reject 95% background per antenna
- Signal required in all 3 antennas

Background is recorded with a fixed rate trigger.
95% of background for each antenna is rejected by checking the SNR distribution.



Difference in opening angle w.r.t IceTop





- Cut when opening angle between the direction reconstructed by IceTop and radio Δω ≥ 5°
- Total number of events after cut with the SNR method= 104 (341 total identified events after SNR cut.)

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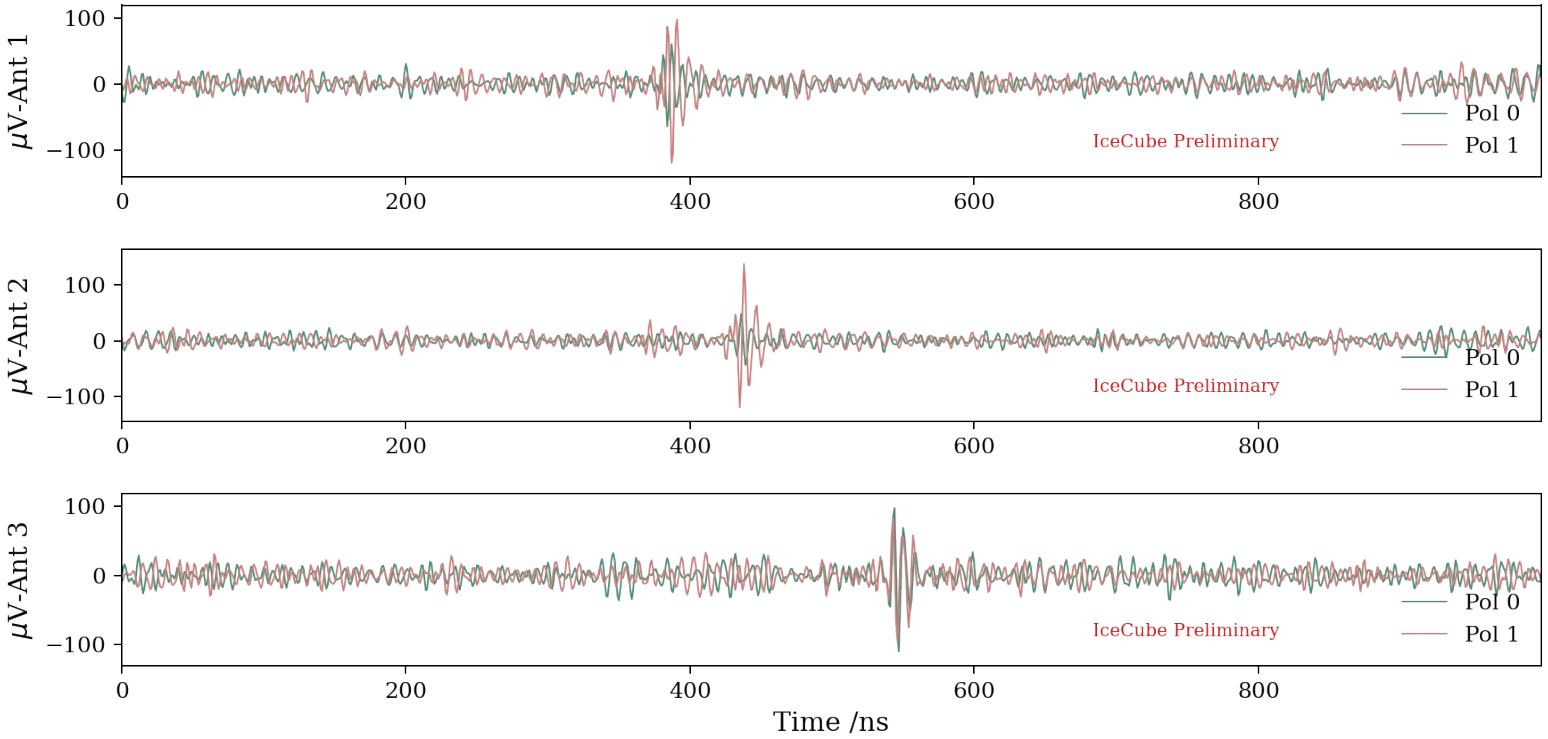
Example air-shower event in radio



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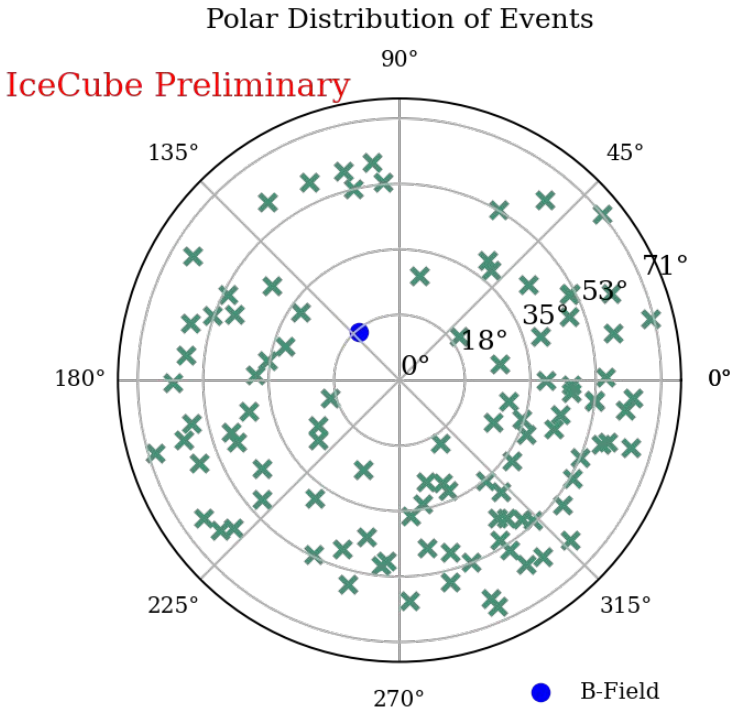
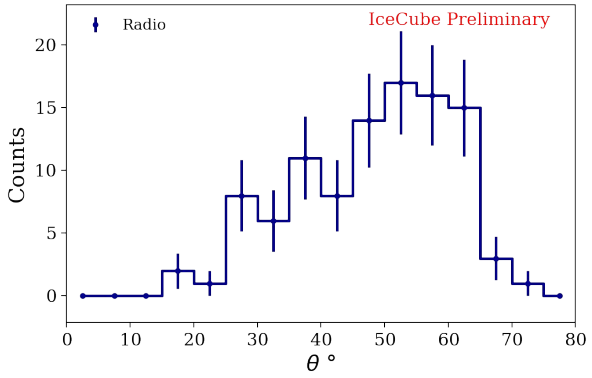
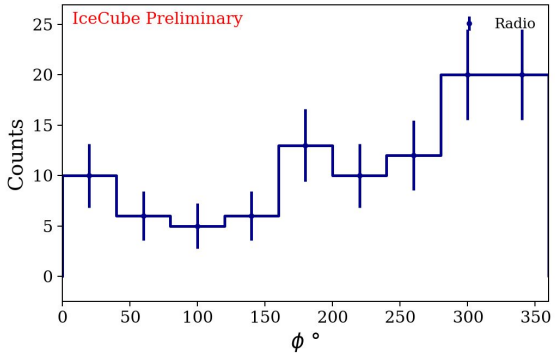
Distribution of all radio events in the sky







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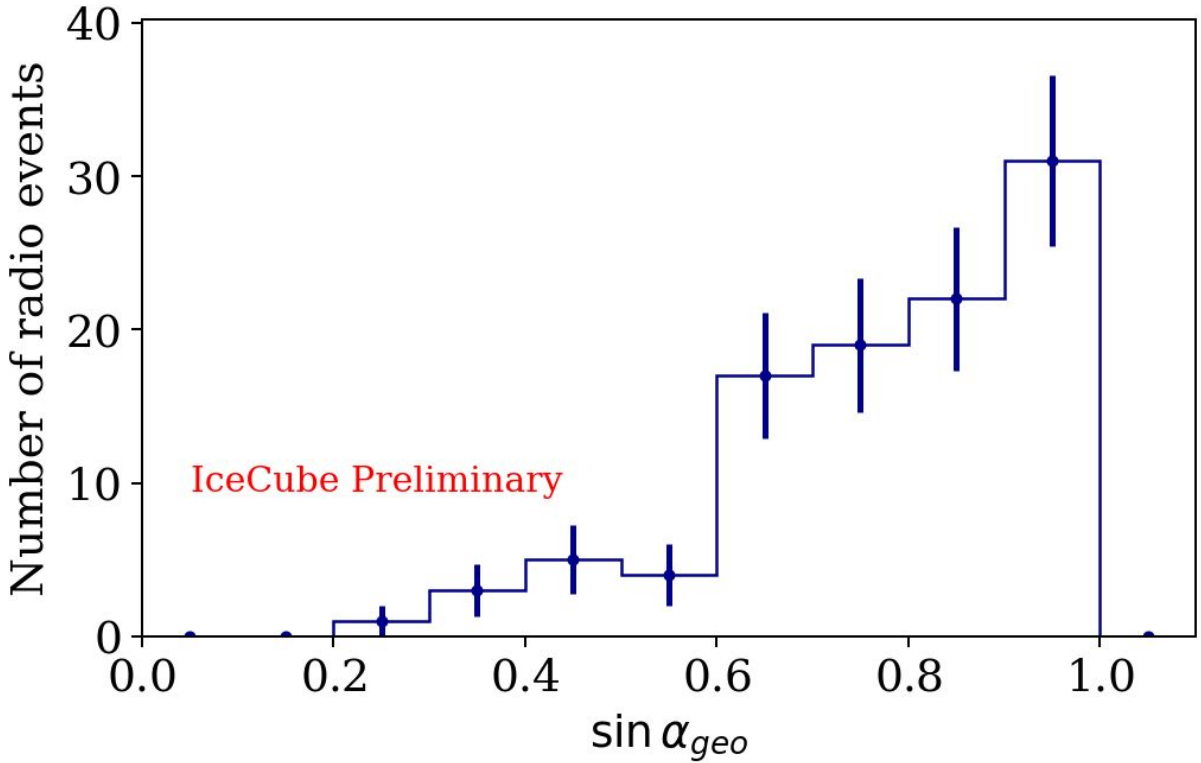
Scaling of radio events with the geomagnetic angle



- Larger radio signal with increasing geomagnetic angle - we see more events as expected;

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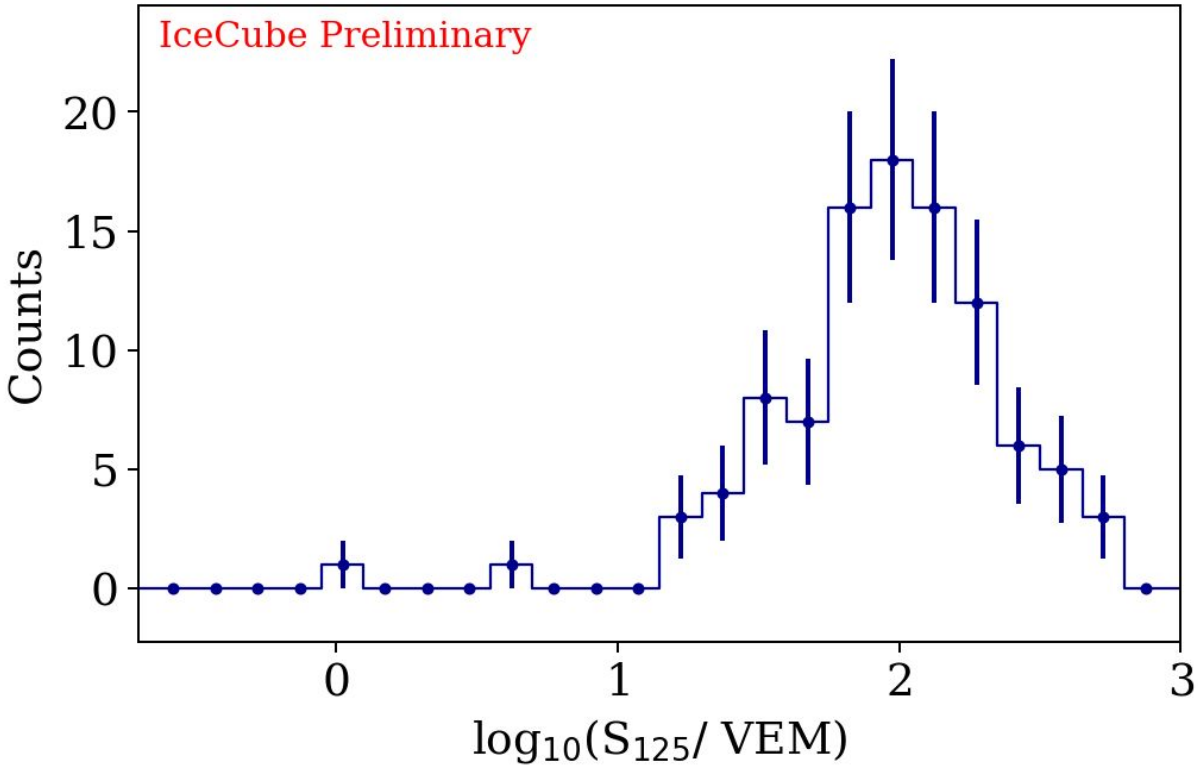
S125 Distribution of all events



- S_{125} - energy proxy for IceTop
  - Calibrated for quasi-vertical showers
  - 1 VEM ~ 1PeV
- S_{125} corresponds to an LDF value taken at the reference distance of 125 m from the shower axis.

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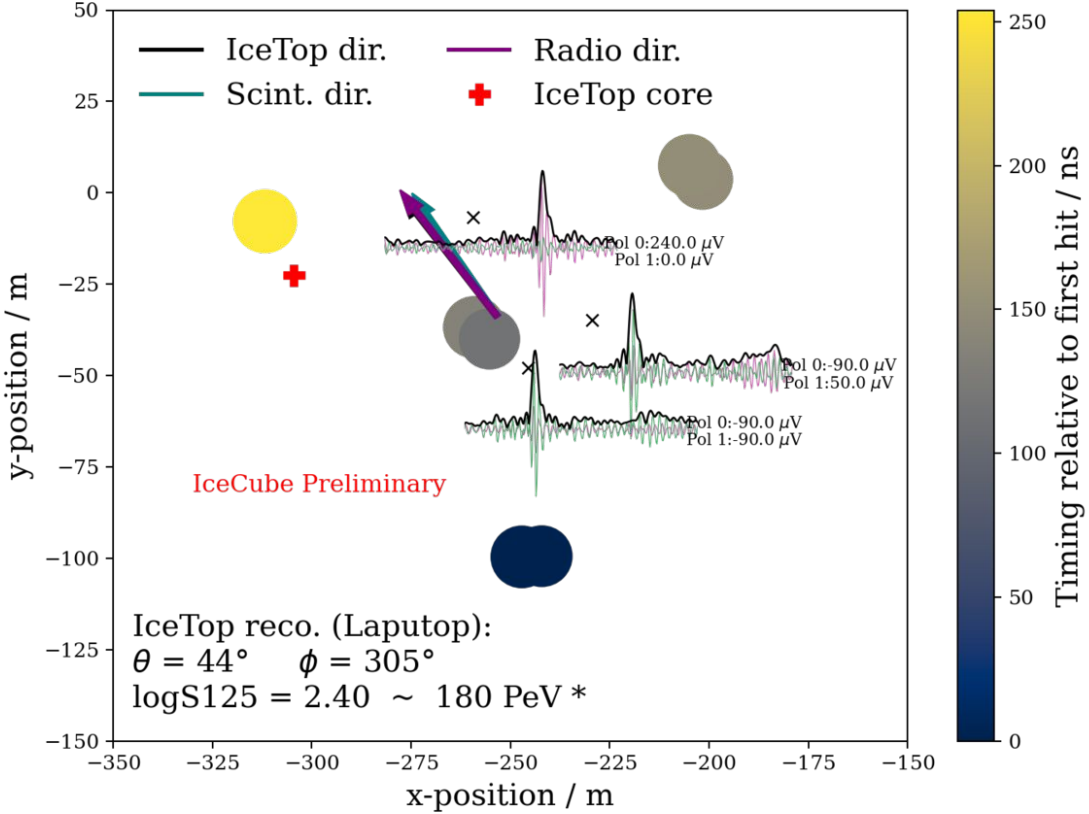
Example 3-fold coincidence events with core reconstructed in IceTop footprint



- Blobs show scintillator charge and timing
- Arrows indicate reconstructed directions by different detectors
- Red plus sign indicates core reconstructed with IceTop.

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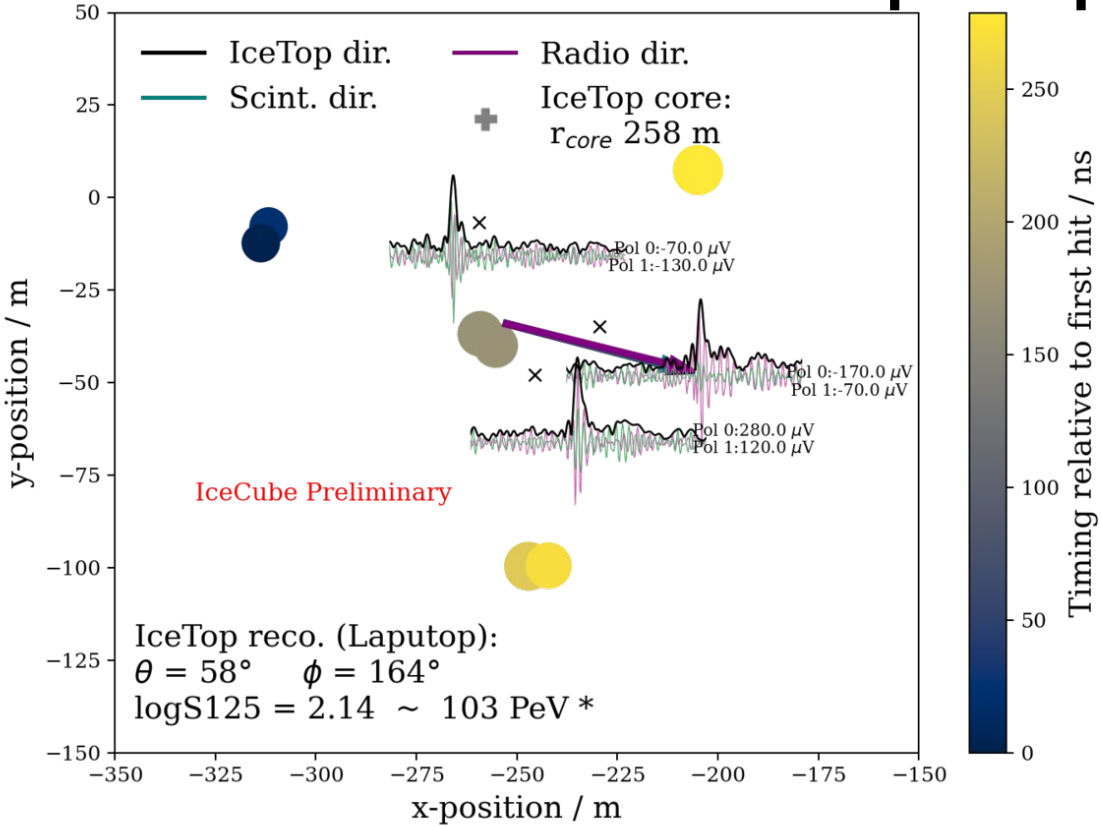
Example 3-fold coincidence events with core reconstructed outside IceTop footprint



- Blobs show scintillator charge and timing
- Arrows indicate reconstructed directions by different detectors
- Grey plus sign indicates core reconstructed with IceTop lying outside IceTop footprint..

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Conclusion

- The antennas at the Pole are the first operating in a 70 - 350 MHz and the analysis is carried out in the 100 - 280 MHz.
- The radio antennas of the prototype station at the Pole are fully functional and detecting air showers continuously with energies starting from 10 PeV.
- We have detected over 100 events in a 4 month time period.

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Outlook

- The surface enhancement will be a unique detector capable of giving insights into cosmic ray science with its multi-detector systems.
- The station layout is used in the design of the IceCube-Gen2 surface array with a footprint increase by a factor of 8 over IceTop.

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Thank you!

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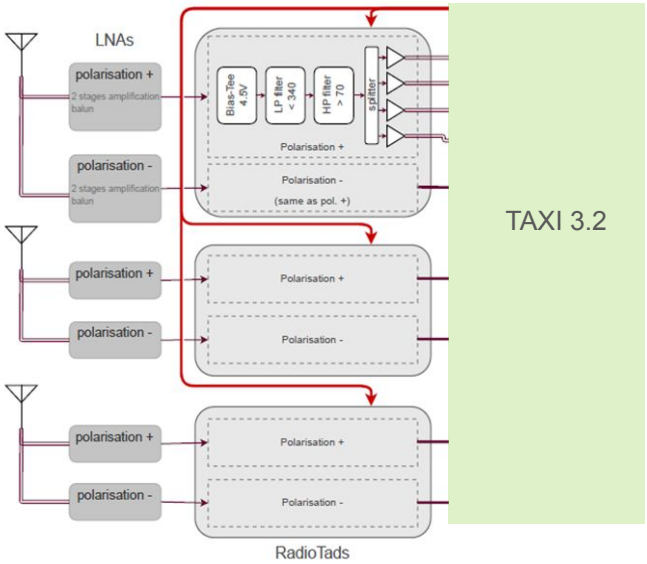
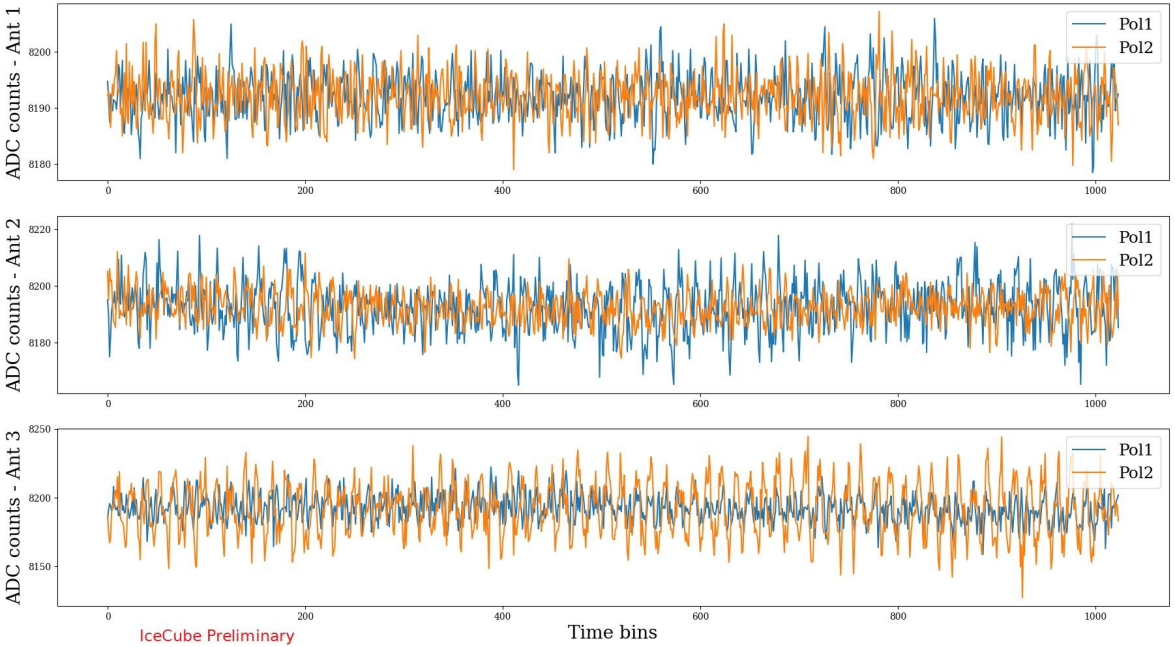
Average background traces as measured by the DAQ





- Measured in 3 antennas over 2 polarizations
- Averaged over one day

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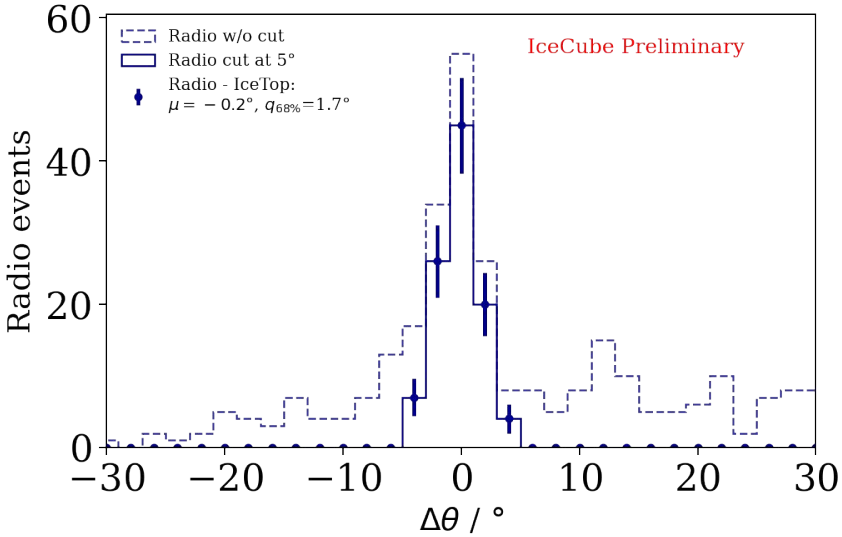
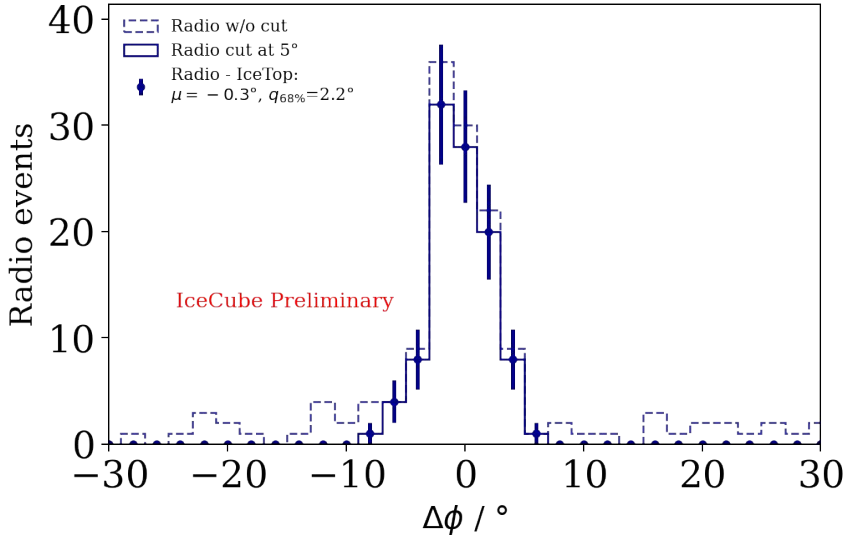
Difference in reconstructed zenith and azimuth w.r.t IceTop





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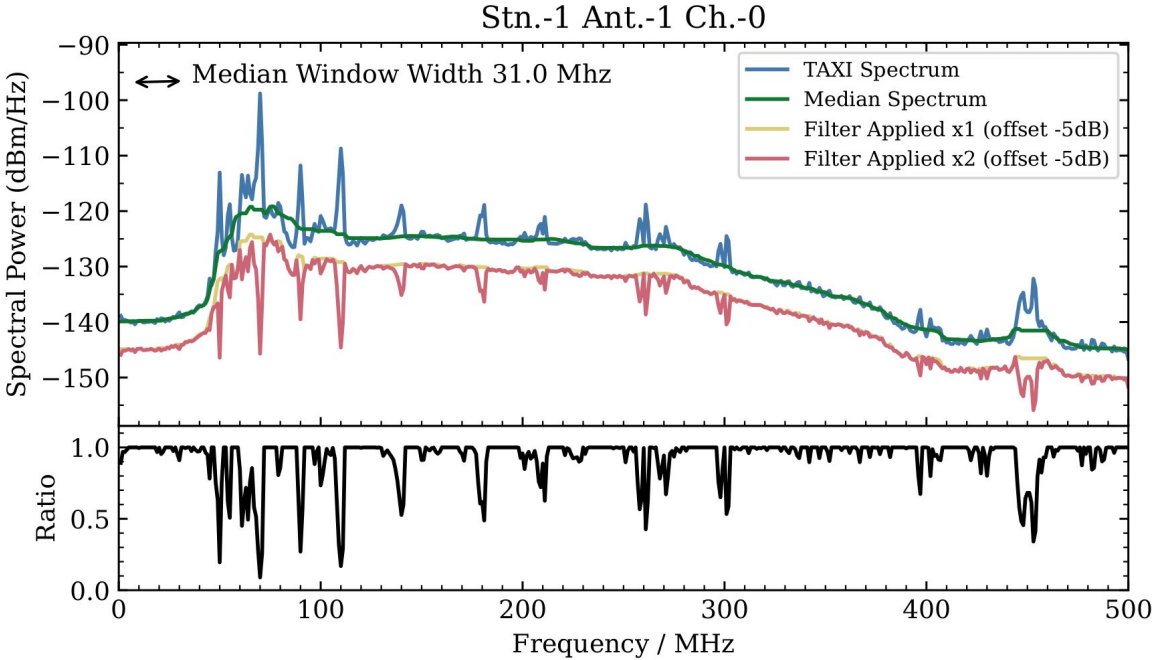
Spike Filter for RFI cleaning



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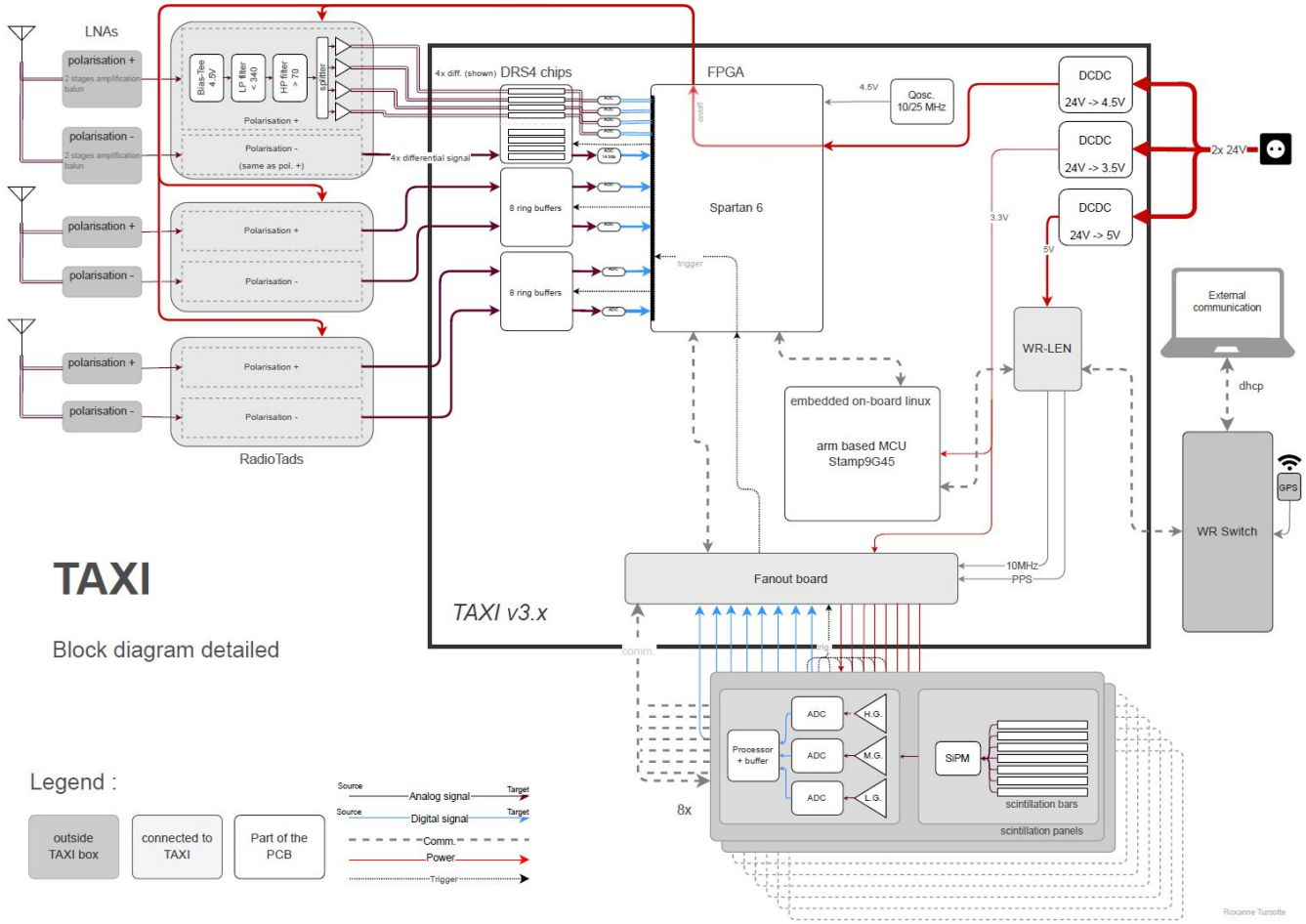
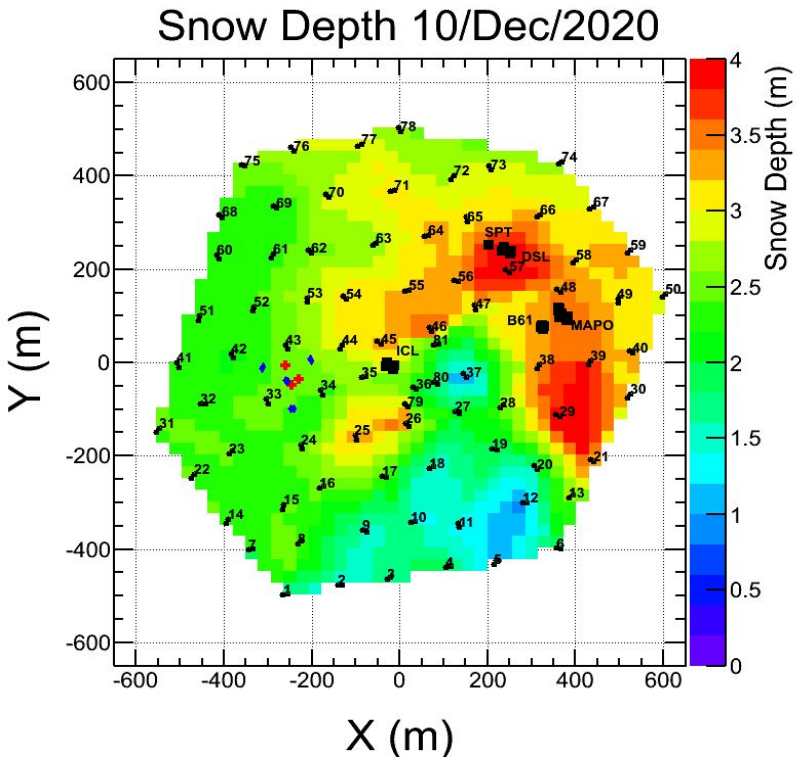
The Data Acquisition of the SAE (detailed)



Snow accumulation and the location of the prototype station



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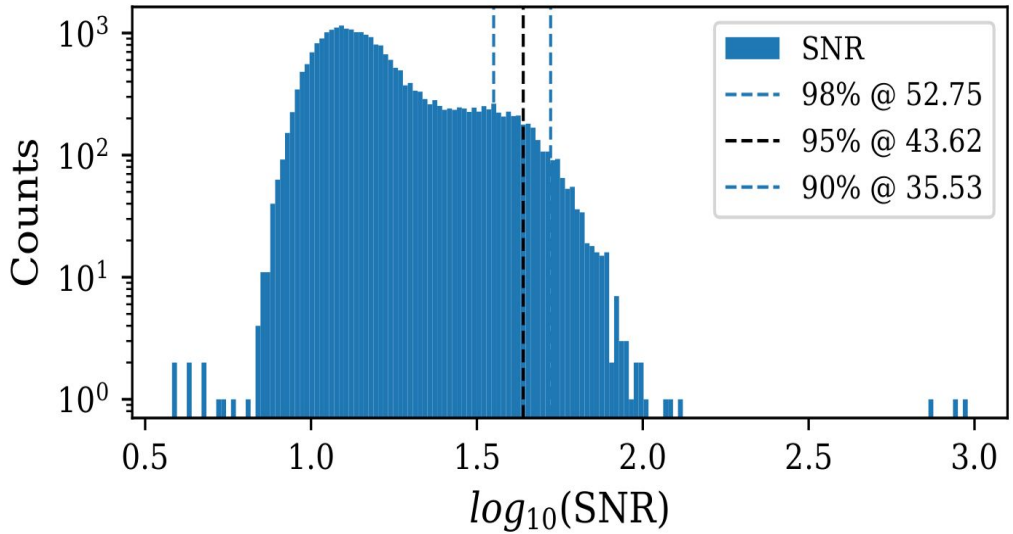
SNR distribution of Antenna 1



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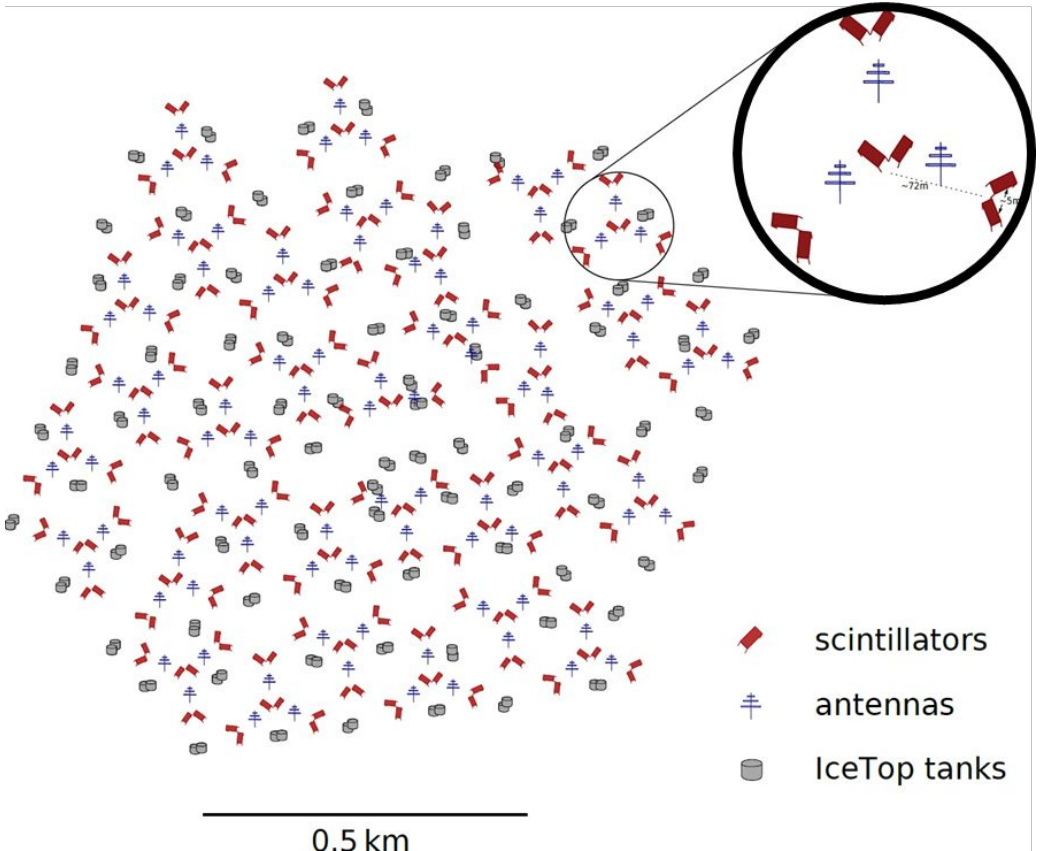
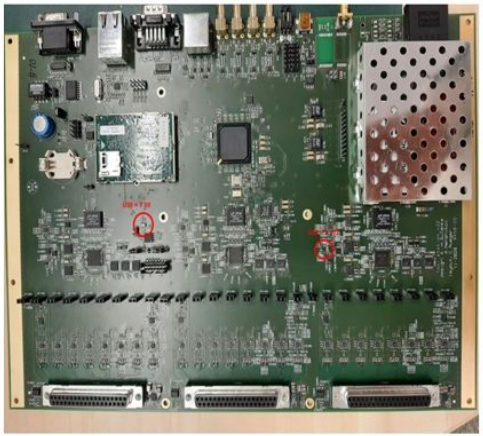
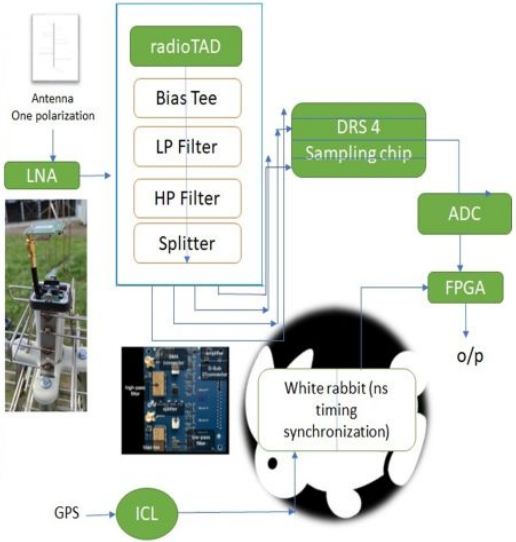
Actual proposed layout of the enhancement and a single station

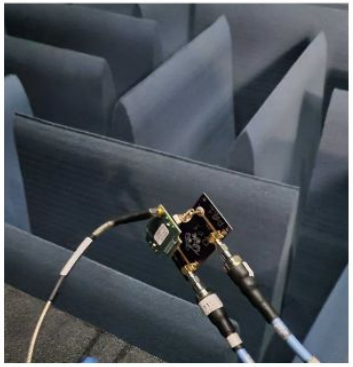


Methods of calibration of different components

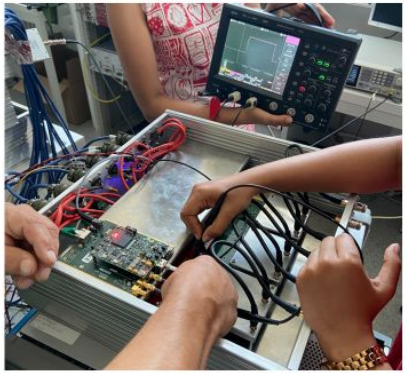




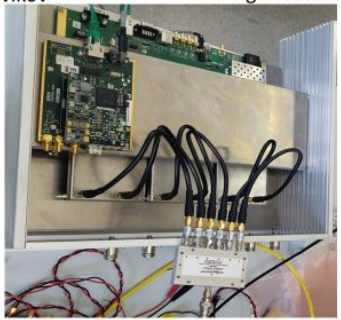
Taxi Board (Left) and Schematics of the radio signal chain in the TAXI (Right)



Calibration of LNA in an anechoic chamber
Picture Credit: Sasha Novikov



Checking the udaq signal during timing measurements



Gain characterization for the radio signal across the TAXI board with a known input signal

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