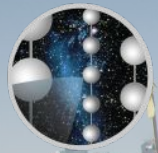

IceCube
South Pole Neutrino Observatory

KIT
Karlsruhe Institute of Technology

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Radio measurements of air-showers with an IceCube Surface Array station

Hrvoje Dujmović for the IceCube Collaboration

Acoustic & Radio EeV Neutrino Detection Activities

8.6.2022

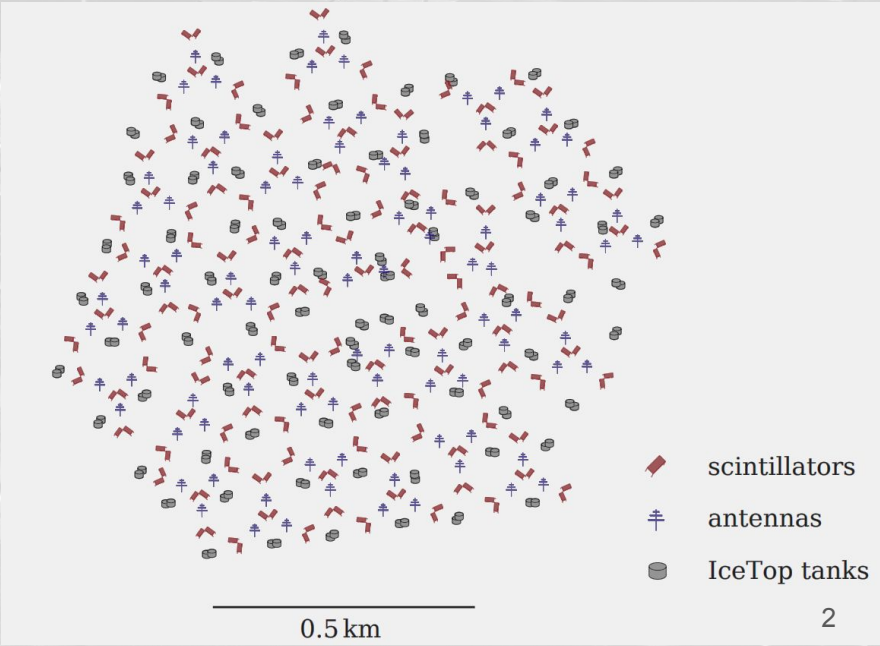
IceCube Surface Array

Current: IceTop

- 162 ice-Cherenkov tanks on the surface above IceCube
- Act as a veto against atmospheric backgrounds
- Used as a cosmic-ray detector for various studies
- Deteriorating performance due to snow accumulation

Future: Surface Array Enhancement

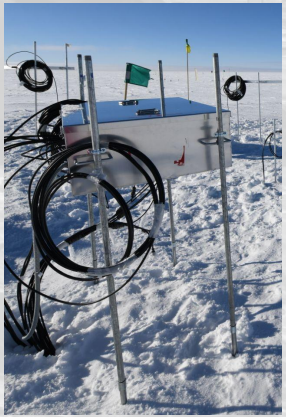
- The Surface Array Enhancement will consist of 256 Scintillator panels & 96 Radio antennas
- Understand the effects of the snow, reduce the threshold and unlock additional physics
- Unique opportunity to measure different shower components with radio, scint., IceTop, in-ice detectors

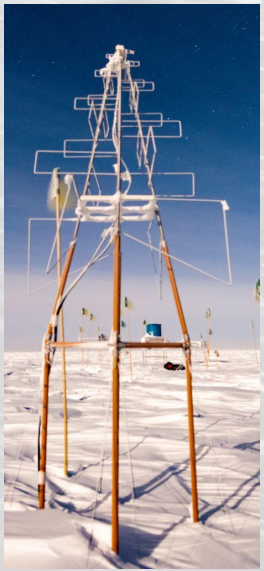


Surface Array prototype station

Prototype station deployed at South Pole in Jan. 2020

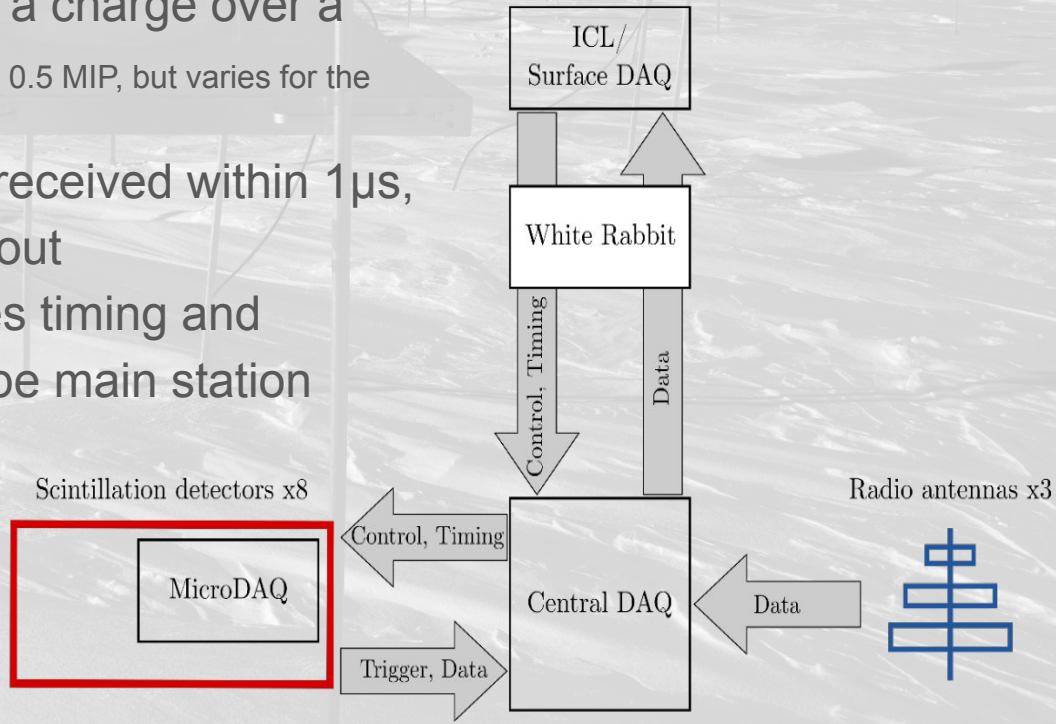
- 8 scintillators + 3 antennas + central DAQ
- Mostly same hardware that will be deployed for the full array
- Goals:
  - Test the hardware in Polar conditions
  - Acquisition of calibration data
  - Prove the design viability by measuring air showers
  - Use measured air-shower to develop reconstruction and analysis methods
  - Benchmark the novel 70-350 MHz radio band





Surface array data acquisition

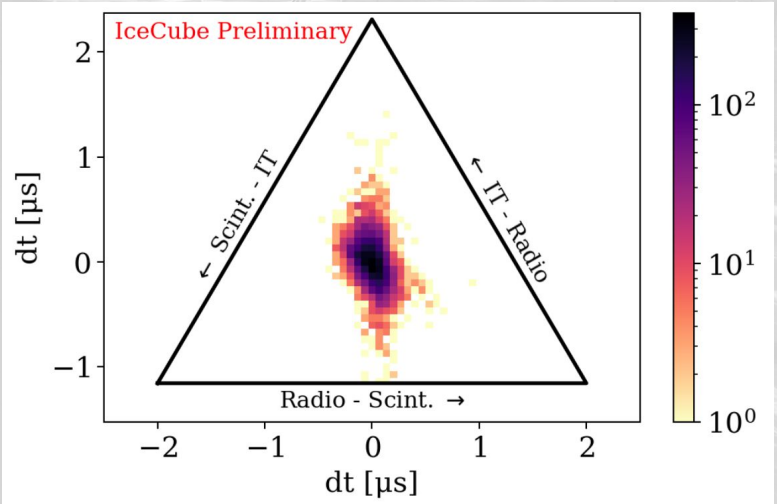
- Scintillation detectors send digitized signals and triggers to the central DAQ if a charge over a threshold is recorded (nominally 0.5 MIP, but varies for the prototype station)
- If triggers from 6 panels are received within 1μs, the radio antennas are read out
- White Rabbit system provides timing and communication to the IceCube main station



Radio data readout

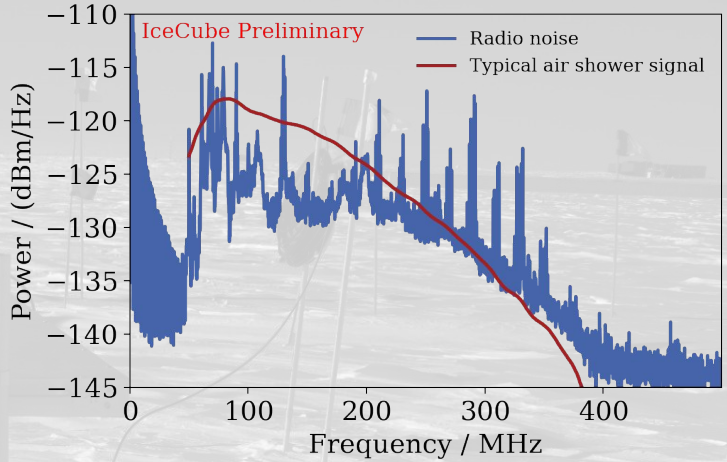
- Analogue radio signals are digitised by the central DAQ
- 3 antennas x 2 polarisations read out @1GHz
- Analogue bandpass filter 70-350 MHz
- Trace length of 1024/2048/4096 ns
- For short traces, can readout the same trace multiple times
  →averaging to suppress internal noise

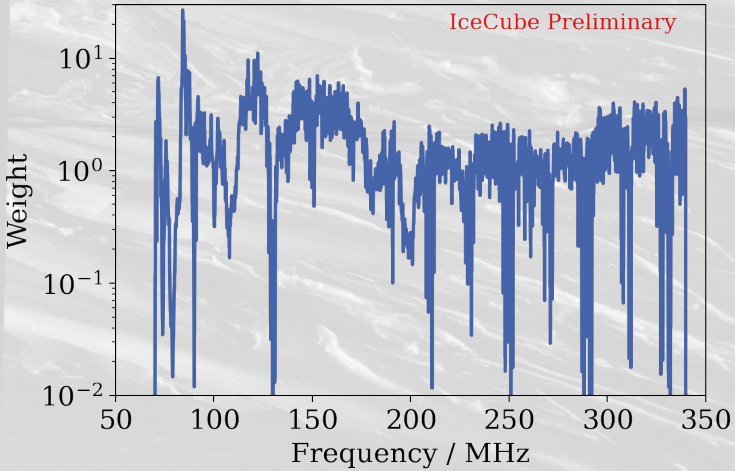
- Data streams from radio, scintillators and IceTop are merged offline:
  - If events are found in all three streams within 1μs from each other they are merged into a coincident event



Filtering

- Software-triggered background traces recorded every 30s
- Median background spectrum calculated for each polarisation & antenna in 8h intervals
- Typical air shower signal averaged over MC + detector response
- Frequency weighting applied to the data with W = S/N^2

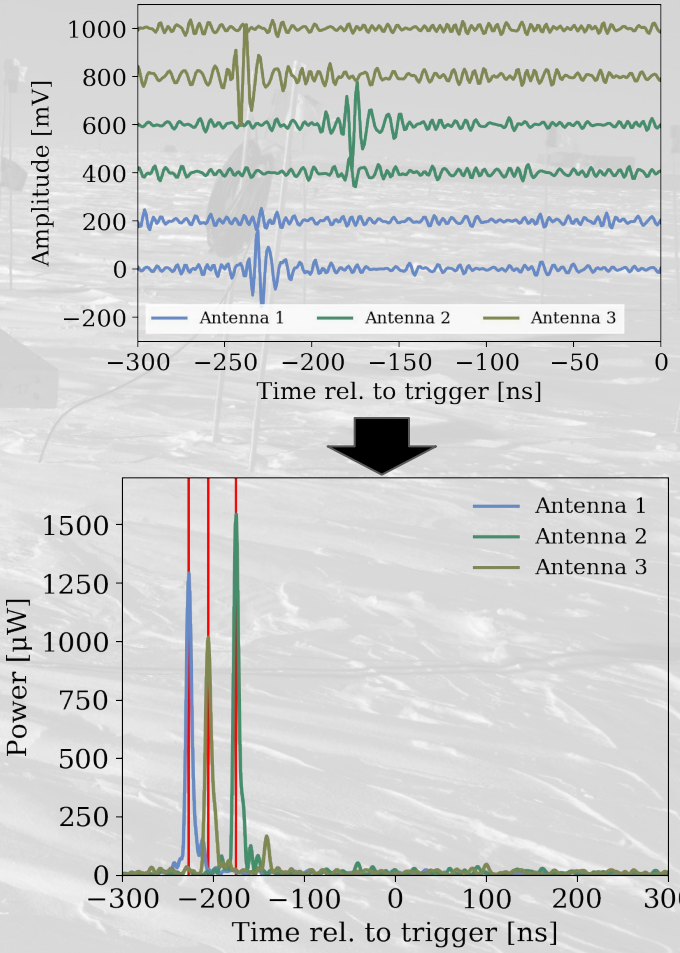




Event selection

- Data from 6.2020 - 3.2022 analysed
  - Due to a lot of testing and calibration runs: total lifetime ~6 months
- ~300’000 coincident events in total
- For each of the events:
  - Apply filtering
  - Combine the Hilbert envelopes from the two polarisations to get total power/antenna
  - (Peak power / median noise power) > 7 for each antenna
  - Peak position within 5ns of where expected based on IT reconstruction

→121 events with identified with clear radio pulses in all antennas



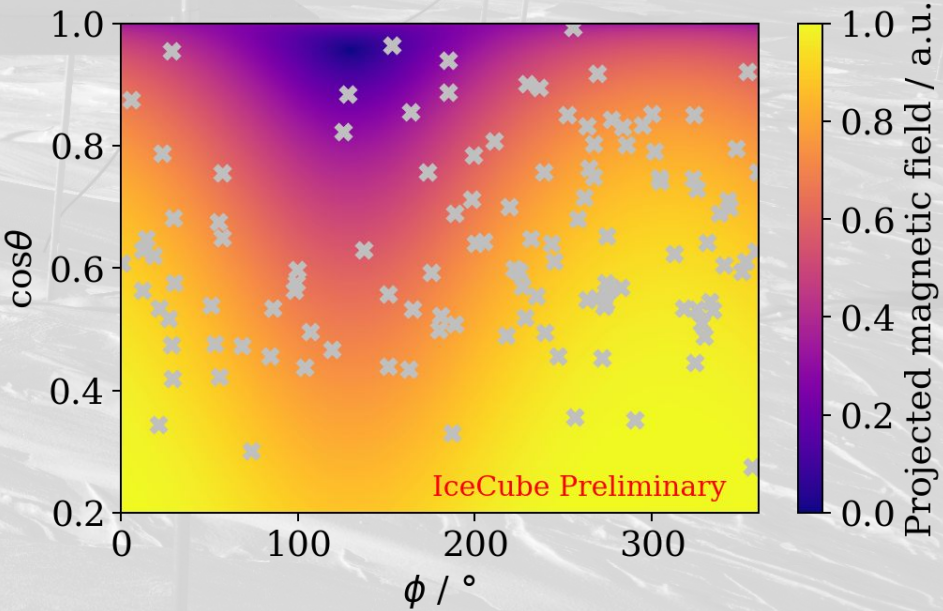
Same event selection applied to background data and scrambled IT data
→false positive rate <3%

Event reconstruction

- Position of the power peak in each antenna is taken as the signal timing
- Plane-wave approximation used to reconstruct the shower arrival direction
- More sophisticated reconstructions are under development

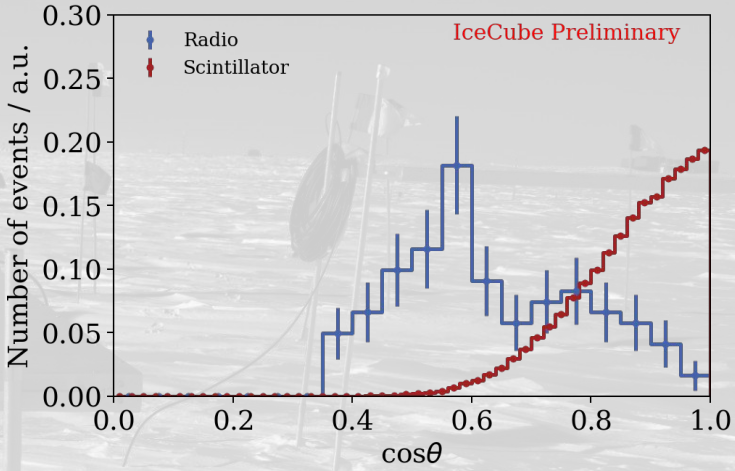
See talk by R.Turcotte tomorrow

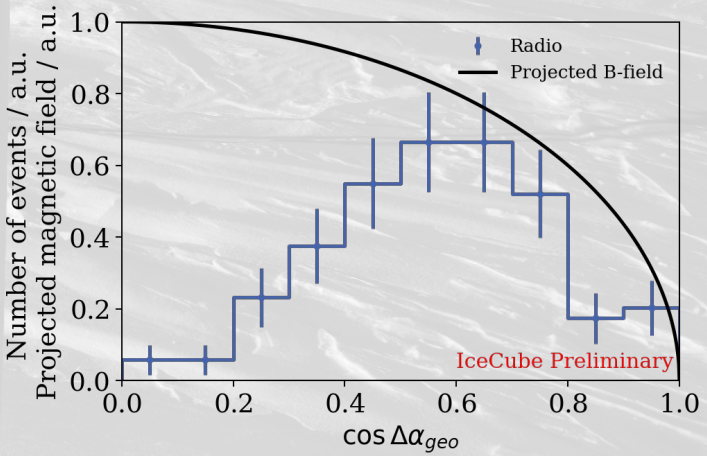
Energy threshold higher || B-field
→less events



Event arrival directions

- Event arrival direction taken from the IT reconstruction to get a more direct comparison
- For highly inclined showers the scintillator trigger becomes inefficient
- Vertical showers suppressed because of the nearly vertical magnetic field





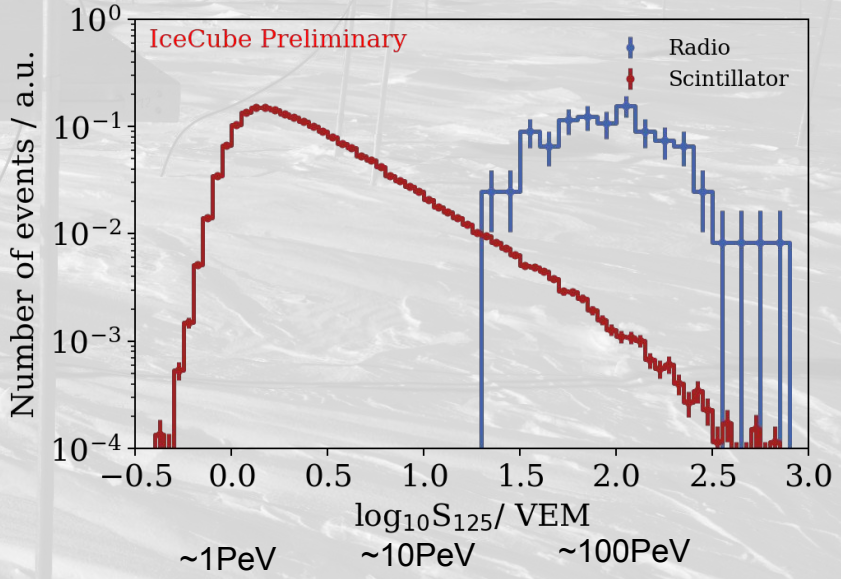
Shower energy distribution

- Radio and scintillator energy reconstruction still under development
- Standard IceTop energy calibration is only valid for showers with cosθ > 0.8

→Difficult to get accurate shower energy

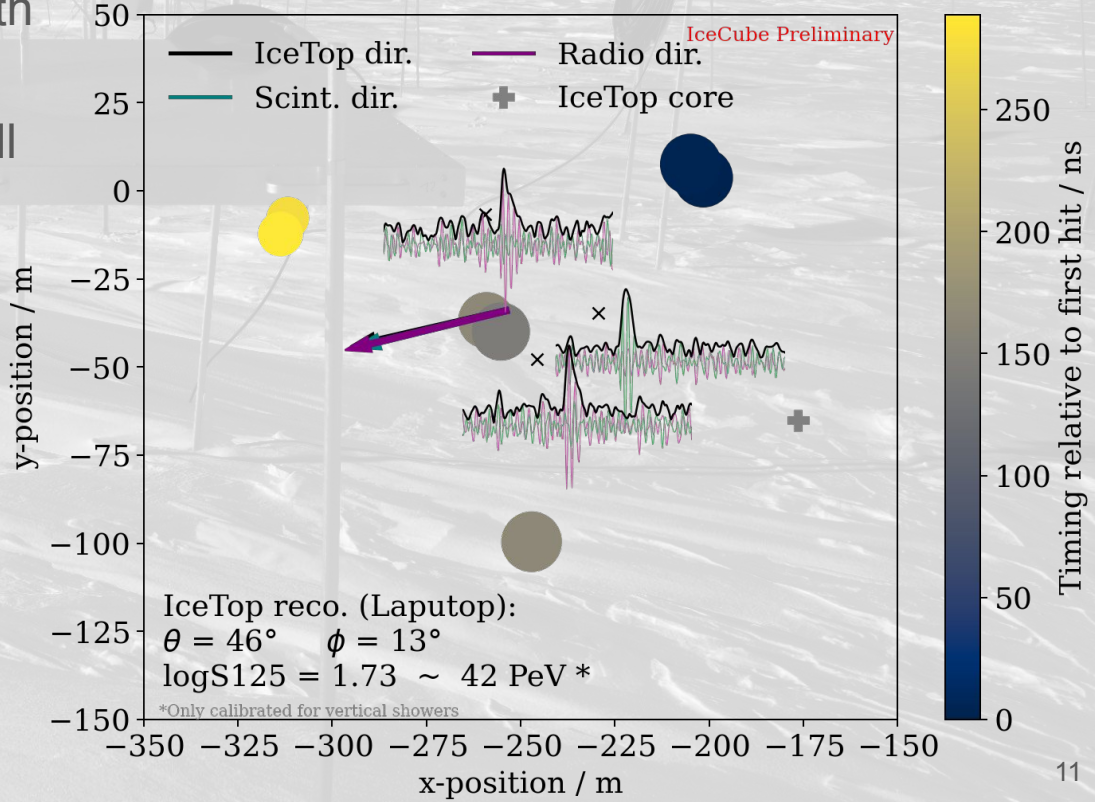
- S_{125} is an IT-reconstructed energy-proxy parameter

→Energy threshold for the radio showers seems to be around 20-30 PeV, consistent with simulations



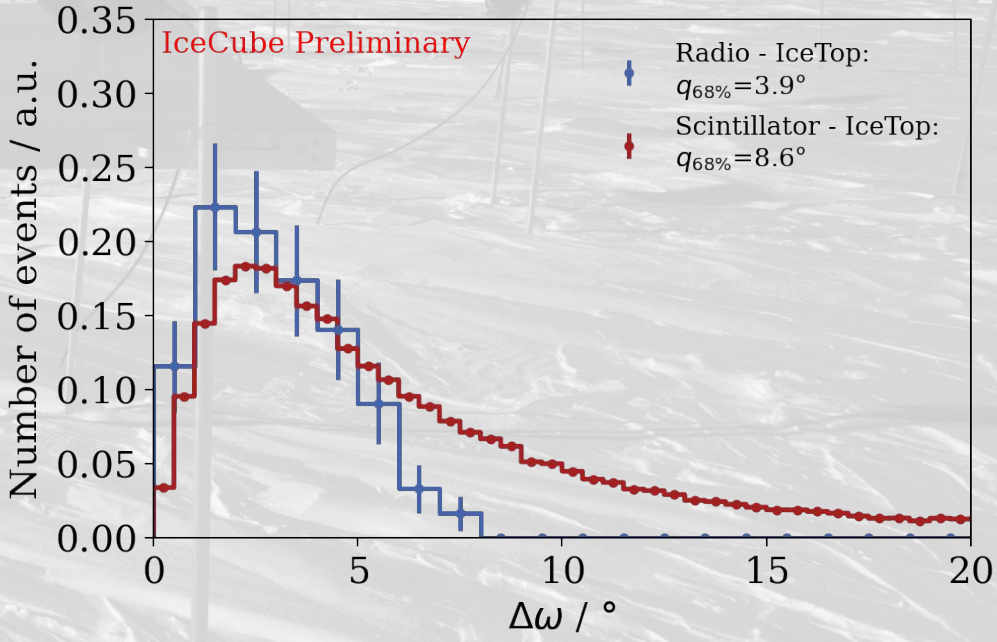
Coincident events

- 59 events reconstructable with radio, scintillators and IT
- All reconstructions match well



Reconstruction performance

- Reconstructed directions compared between IceTop and Radio/Scintillators
- Radio uncertainty as expected due to the short lever arm
- Scintillator data dominated by low energy events with larger IT uncertainties



Conclusions & outlook

- Prototype station for the IceTop surface enhancement deployed in Jan. 2020
- Use of the novel 70-350 MHz band for air-shower emission
- Cosmic-ray air-showers detected with the prototype station in coincidence with IceTop
- Basic event selection and reconstruction developed for the radio data
- Multiple cross-checks performed → data looks the way we'd expect it to

- More sophisticated reconstructions in development
  - Combined reconstruction could use information from radio + scintillators + IceTop
- Deployment of additional stations over the next years