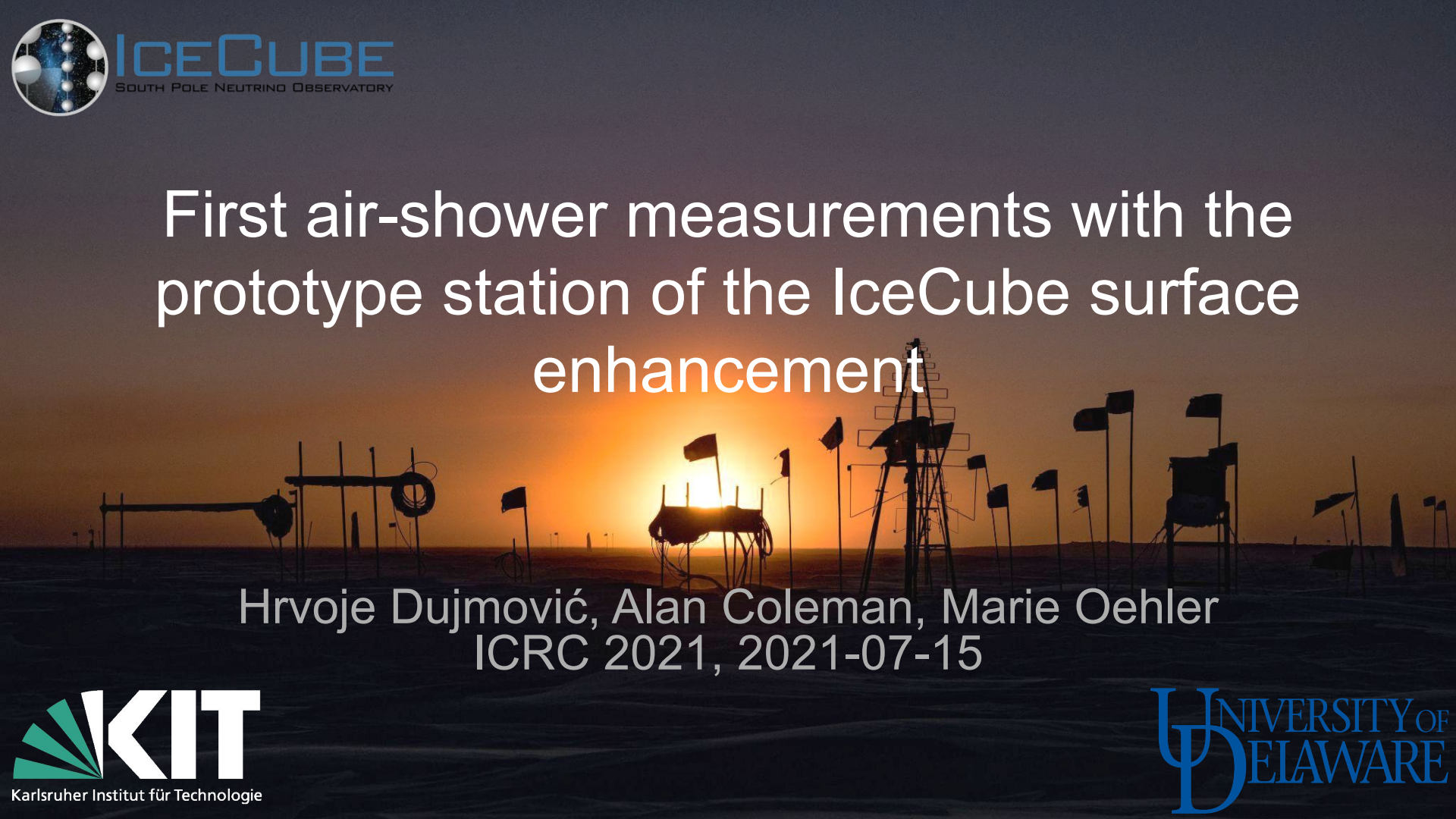

First air-shower measurements with the prototype station of the IceCube surface enhancement

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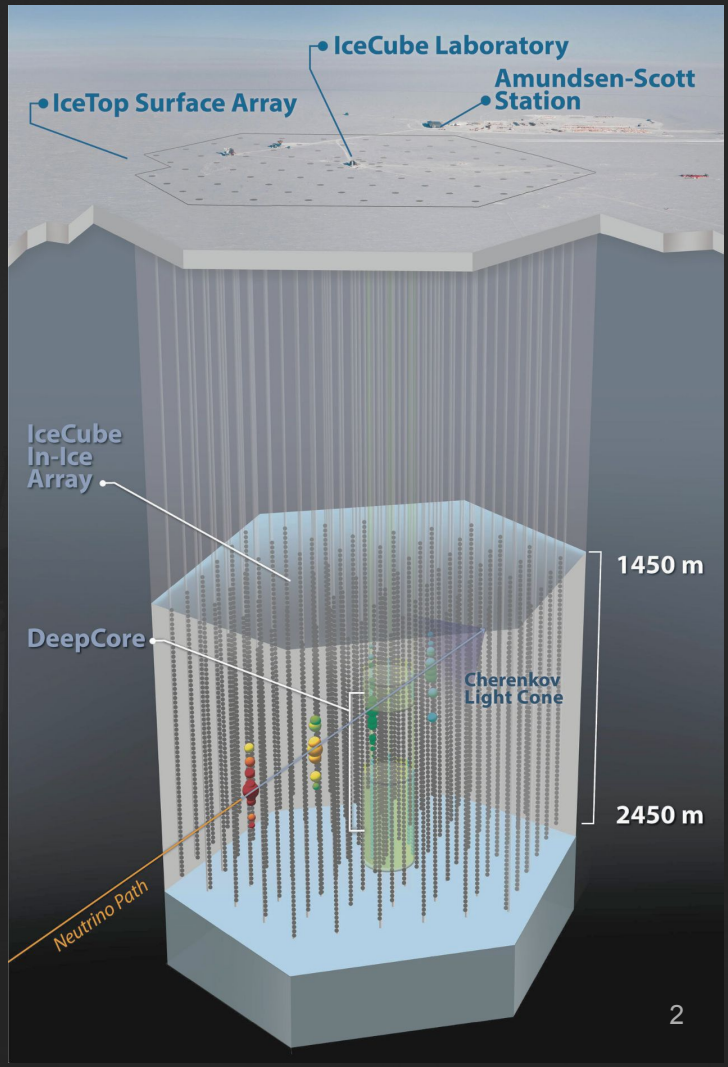
The IceCube Neutrino Observatory

- 5160 subsurface ice-Cherenkov modules
  - Used for detecting high energy neutrinos
  - Can measure TeV muons from air-showers

- 162 ice-Cherenkov tanks on the surface (IceTop, IT)
  - Act as a veto against atmospheric backgrounds
  - Used as a cosmic-ray detector for various studies

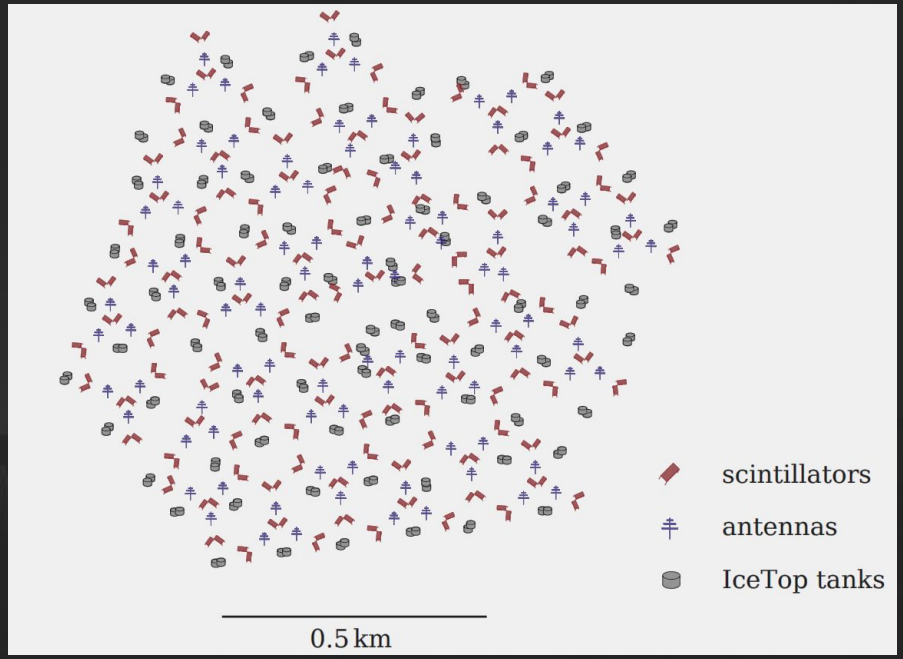


IceCube Surface Array Enhancement

- IT covered by snow → increased threshold
- Understand the effects of the snow, reduce the threshold and unlock additional physics by adding new surface detectors
  - Unique opportunity to measure different shower components with:
    Scintillators + **radio**
    + Ice-Cherenkov tanks + in-ice optical modules

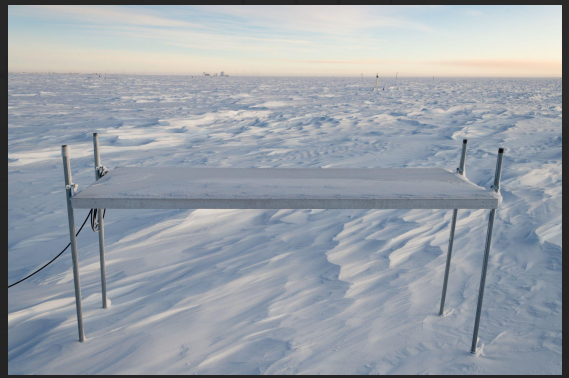
The Surface Array Enhancement will be deployed over the next ~5 years and consist of:

- 32 stations, each with:
  - 8x Scintillator panels
  - 3x Radio antennas
  - Central hub for DAQ, power and comms



Surface Array Enhancement prototype station

- Single prototype station deployed at South Pole in Jan.2020
  - 8 scintillators + 3 antennas + central DAQ
  - 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



For more details on prototype station hardware, see poster [646]

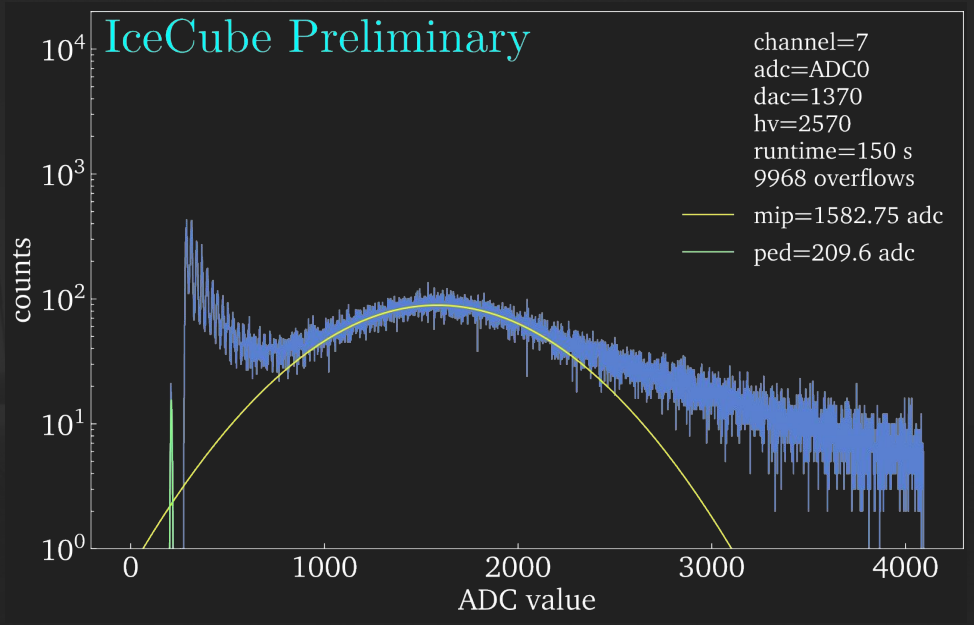
Pictures by: Y. Makino, IceCube/NSF

Scintillator data acquisition and processing

- If a panel sees a charge over threshold a hit is recorded
- Detector gain highly temperature dependent

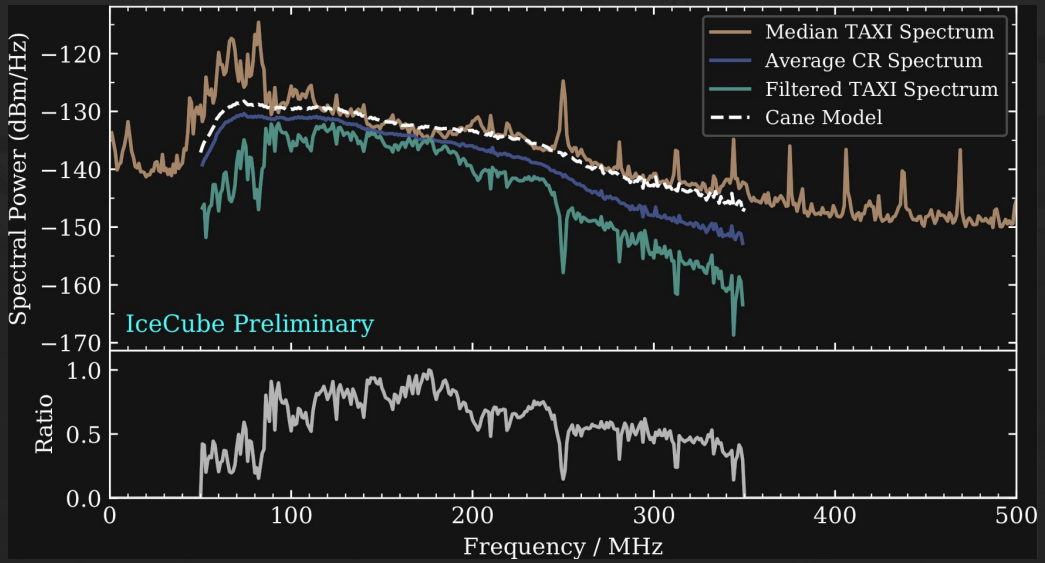
  → Low-threshold calibration runs are performed to convert the charge ADC → MIP

- Threshold varies between 0-few MIP
- Bias-voltage temperature corrections will be used in the future to stabilise both, the gain and the threshold



Radio data acquisition and processing

- Radio data acquisition triggered if 6 panels see a hit within 1μs
- SNR filtering scheme used to suppress frequencies with high RFI
- Peak-finder looks for pulses in the radio trace → timing, amplitude, SNR
- Strong cuts on SNR and relative pulse timing to only select obvious radio air showers



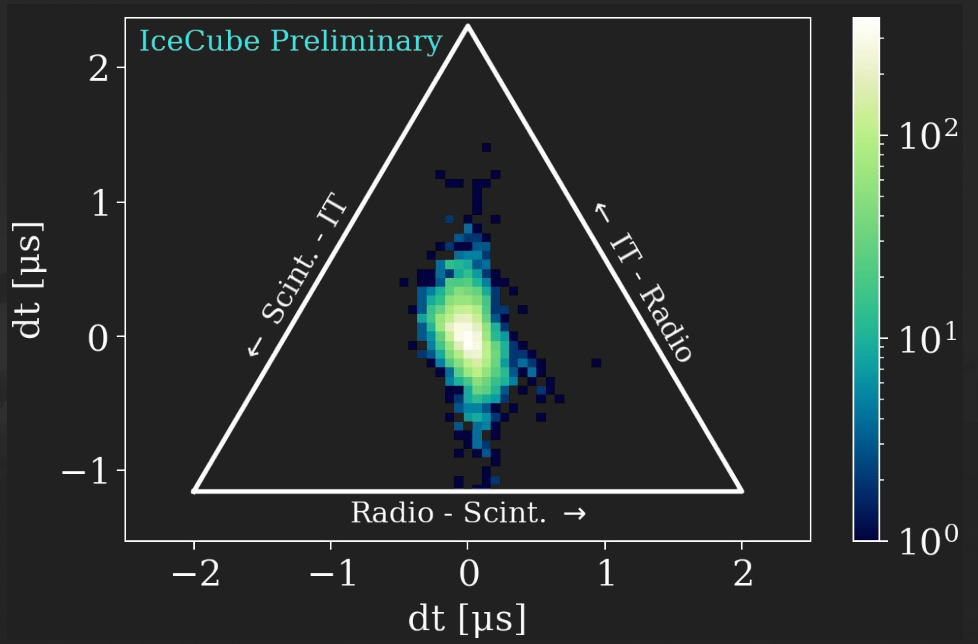
For more detail on radio data analysis and MC, see poster [611]

Timing coincidences

- Separate data streams:
  - IceTop data
  - Radio data
  - 8x individual scintillator panels

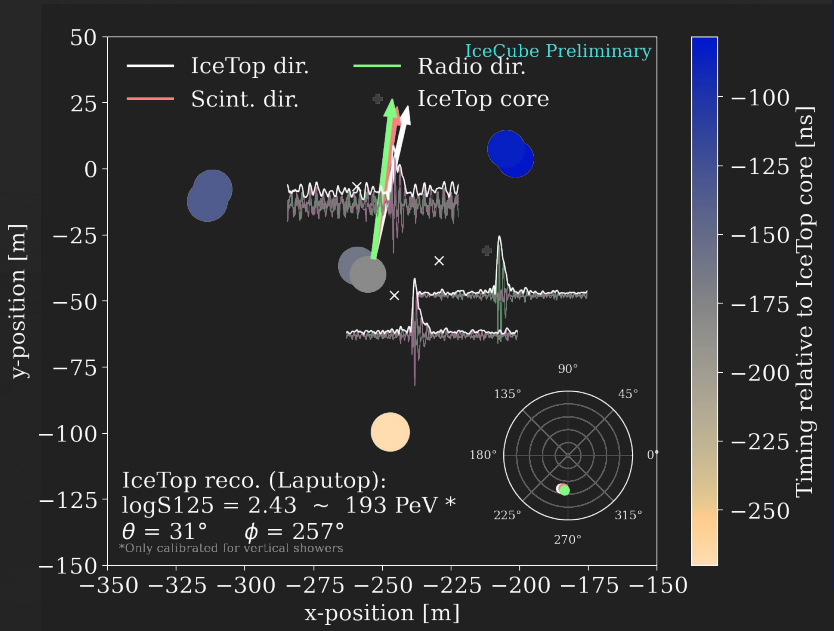
- 3+ scintillator hits within 1μs
  → Scintillator event

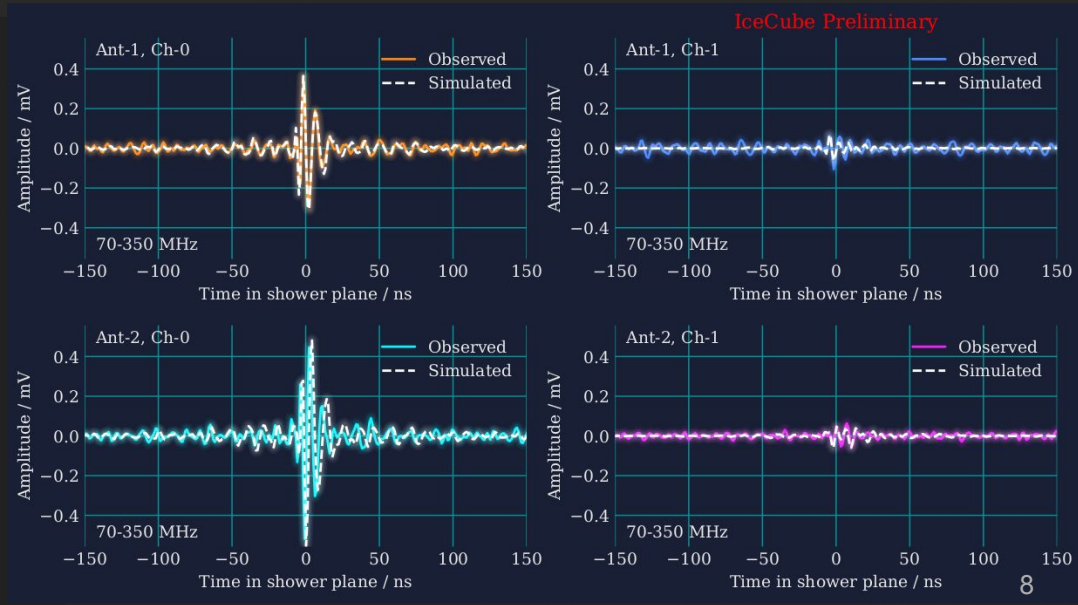
- Events from all three detectors within 2μs
  → (Triple) coincidence event



Shower reconstruction

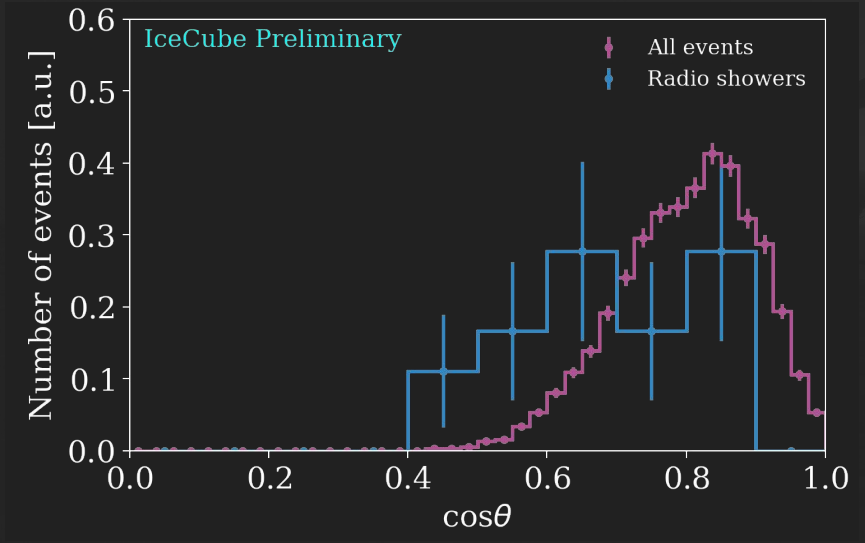
- IceTop: standard reconstruction (Laputop)
- Scintillator & radio: Only directional reconstructions assuming a plane shower front
- Shape of radio waveforms cross-checked with simulations based on IceTop reconstruction

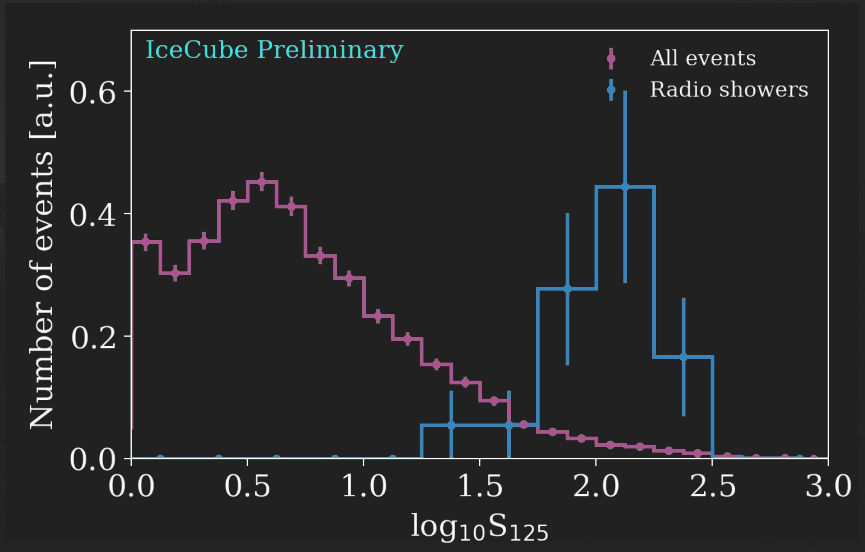




Event distributions

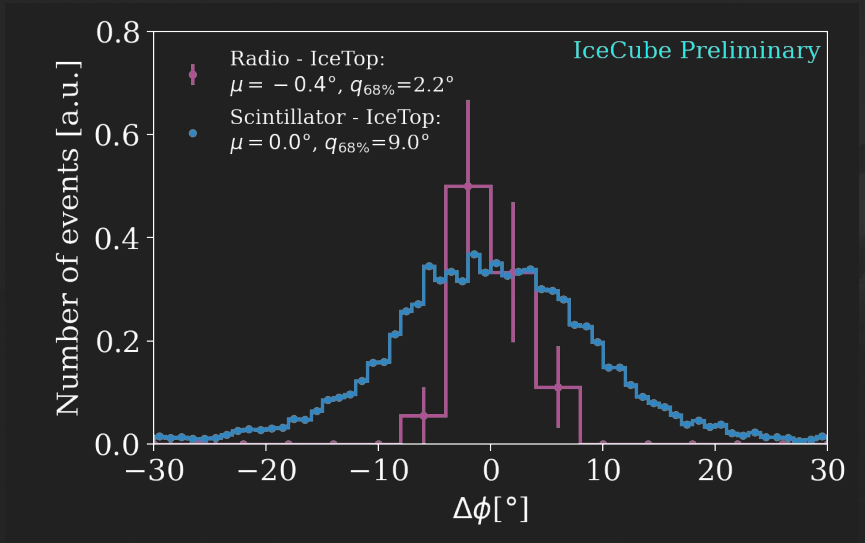
- Vertical events missing due to the high single-panel threshold
- Fraction of events with detectable radio signals increases with zenith
  → partially a magnetic field effect
- S_{125} energy proxy from IceTop → Radio threshold significantly higher than scintillators

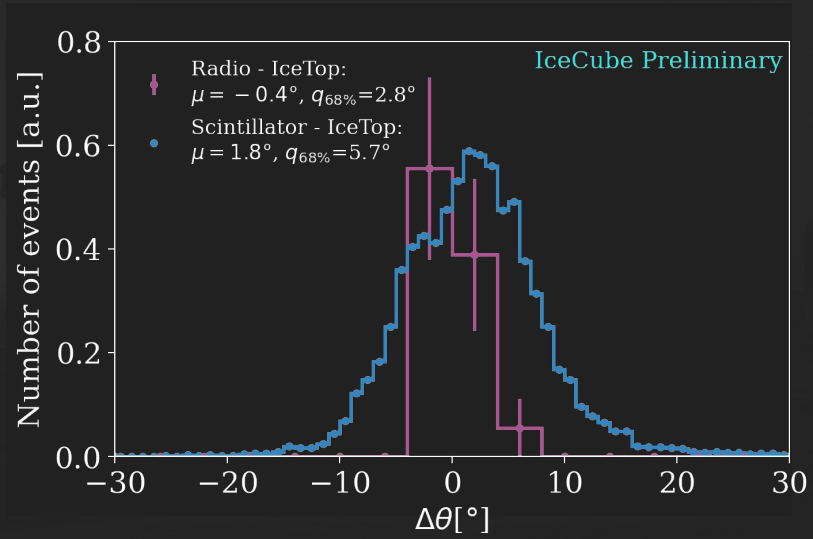




Reconstruction performance

- Reconstructed event directions generally agree between IceTop - Scintillators - Radio
- Direction accuracy somewhat limited by the small footprint of the prototype station





Conclusions & outlook

- Prototype station for the IceTop surface enhancement deployed in Jan. 2020
- First cosmic-ray air-showers detected with the prototype station in coincidence with IceTop
- Basic reconstructions developed for the surface enhancement data
- Multiple cross-checks performed → data looks the way we'd expect it to based on simulations

- Update firmware to allow a more consistent single-panel threshold
- More sophisticated reconstructions in development
  - Combined reconstruction could use information from all 3 detector components
- Additional comparisons to simulation to get a more detailed picture of the detector performance

Picture by: Y. Makino, IceCube/NSF