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IceCube-Gen2 Surface Array

Frank G. Schröder for the IceCube-Gen2 Collaboration

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KIT – The Research University in the Helmholtz Association

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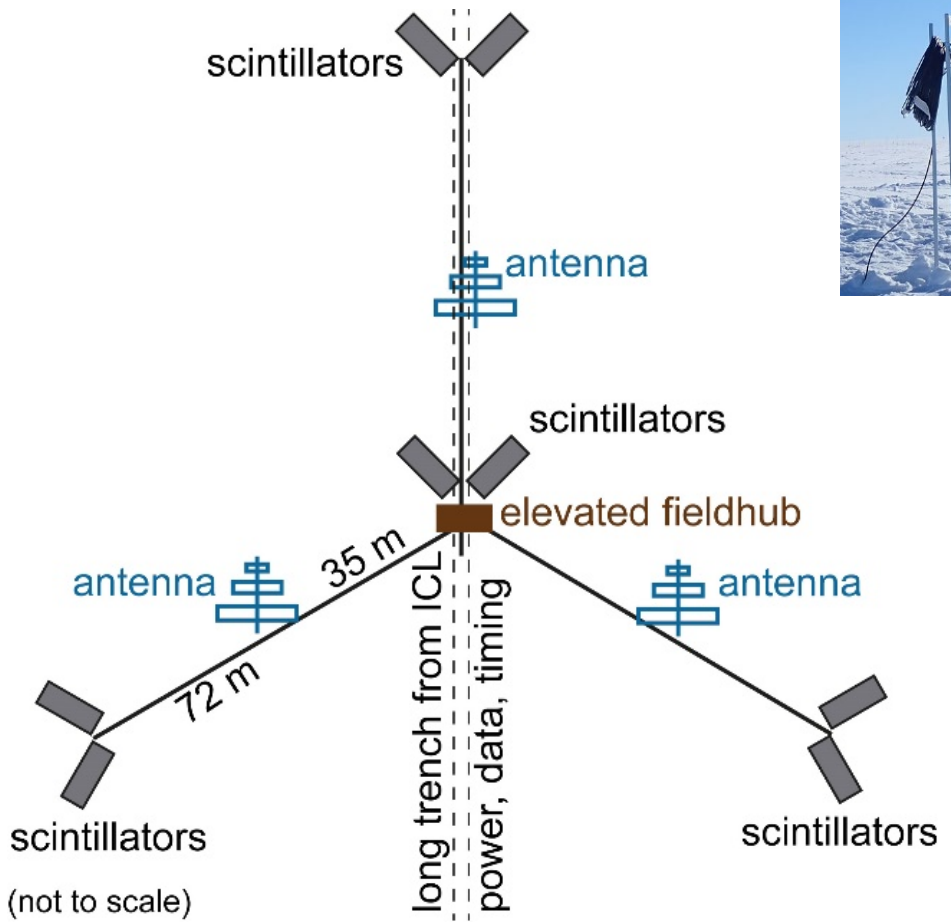
Baseline Design Follows Planned Enhancement of IceTop

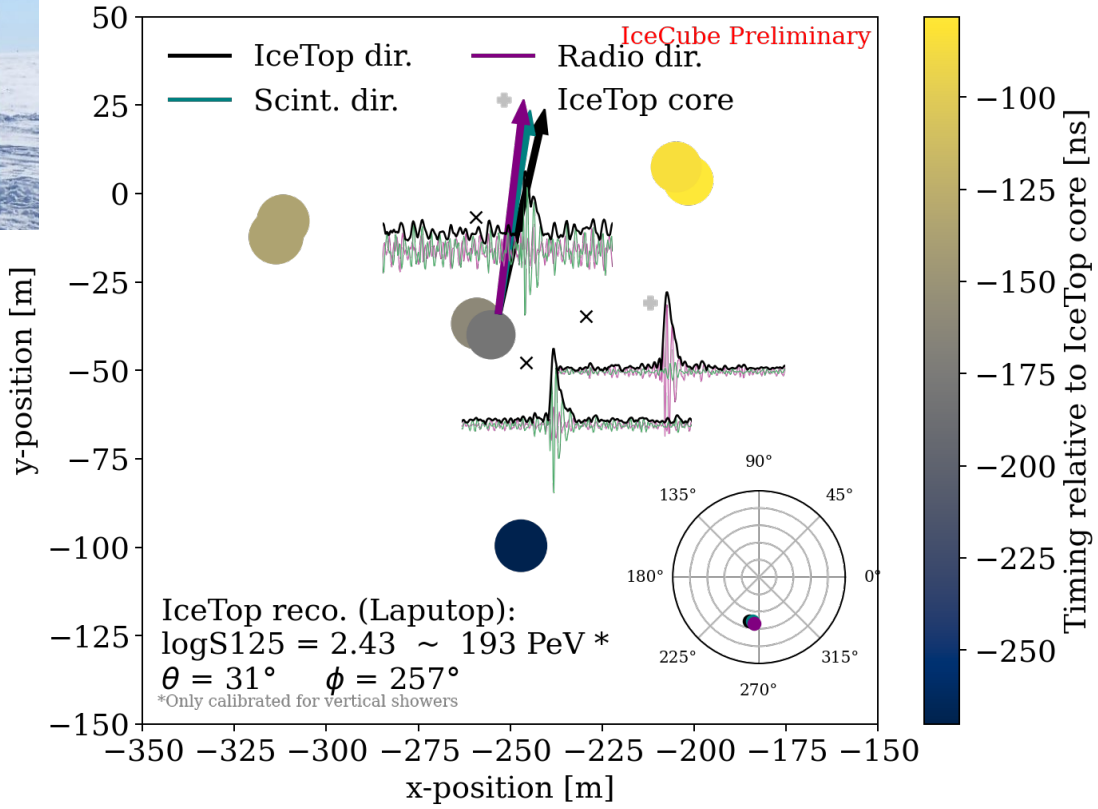
Station Design:

4 pairs of scintillators + 3 antennas



Complete prototype station since 2020:
scintillator + radio + IceTop coincidences

→ contributions PoS (ICRC2021) 225, 314, 317



Example event detected in coincidence with IceTop

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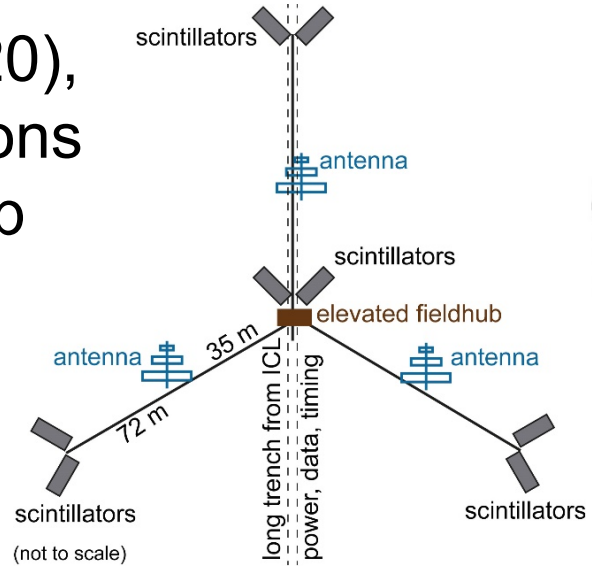
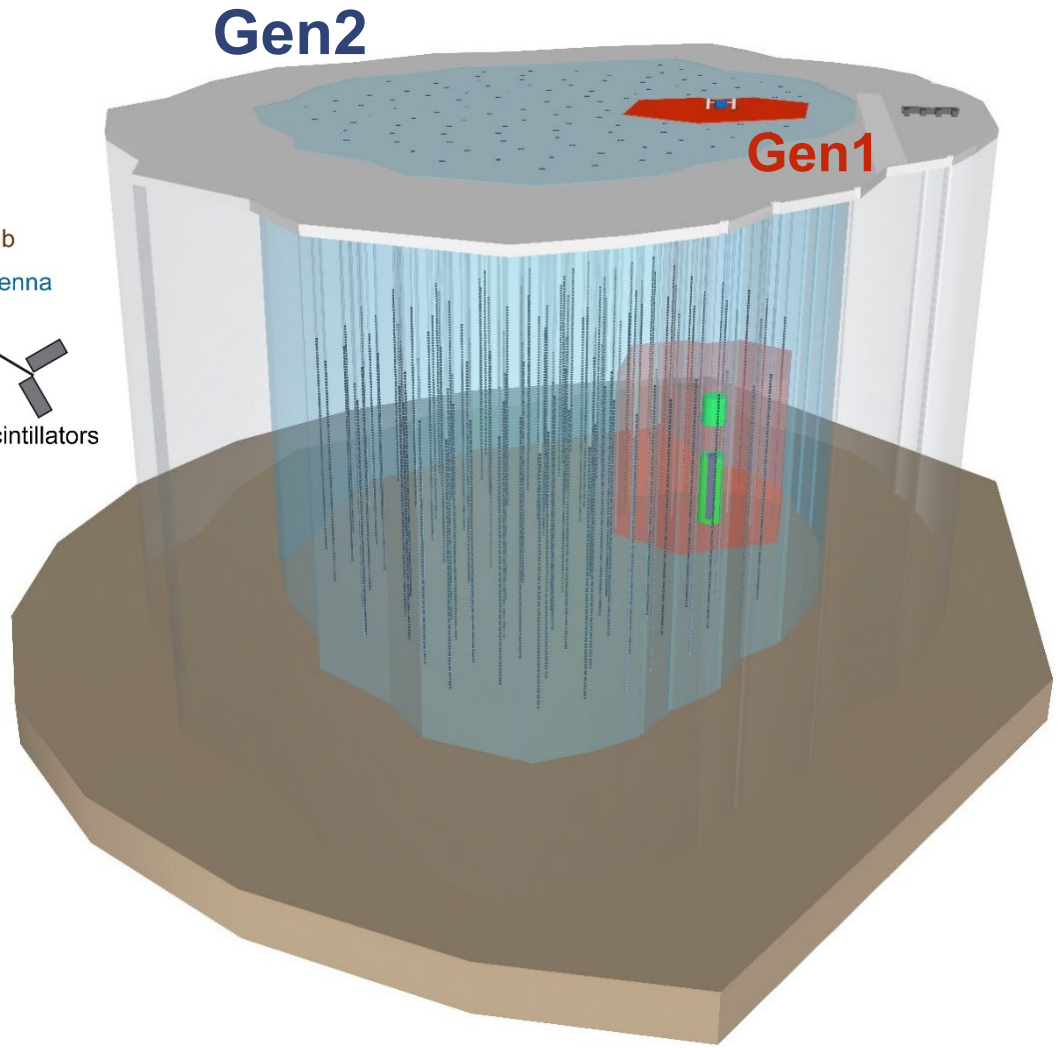
Baseline Design of Gen2 Surface Array

- 1 station per optical string (120), 240m spacing between stations extending 32 station of IceTop enhancement (Gen1)
  - + few extra stations in gap to Gen1 and for cross-calibration





- Higher aperture with increase in max. energy and accuracy for mass
  - 8−10× aperture surface only (> 6 km^2)
  - > 30× aperture for coincidences with optical in-ice array
- four IceAct stations as instrument for low-energy cosmic rays → PoS (ICRC2021) 276

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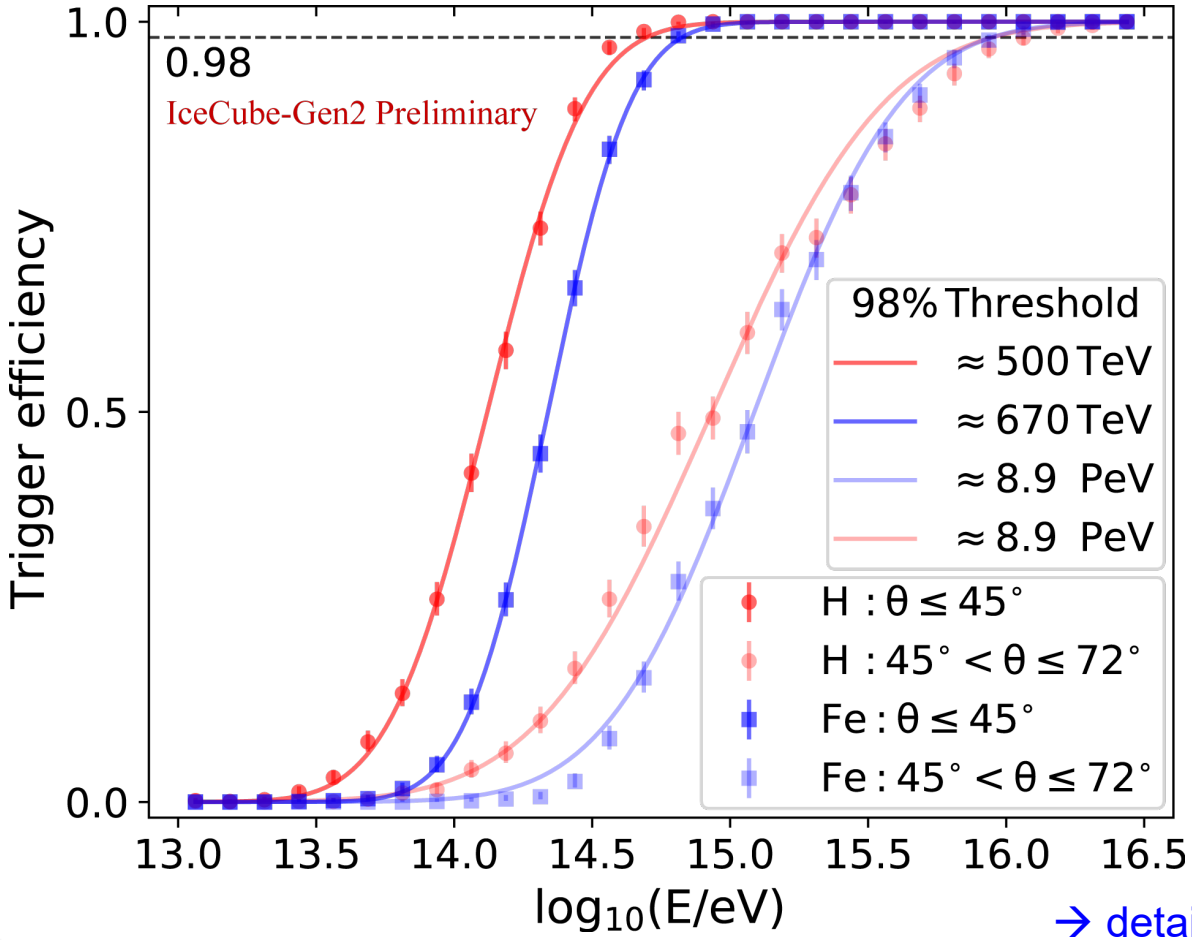
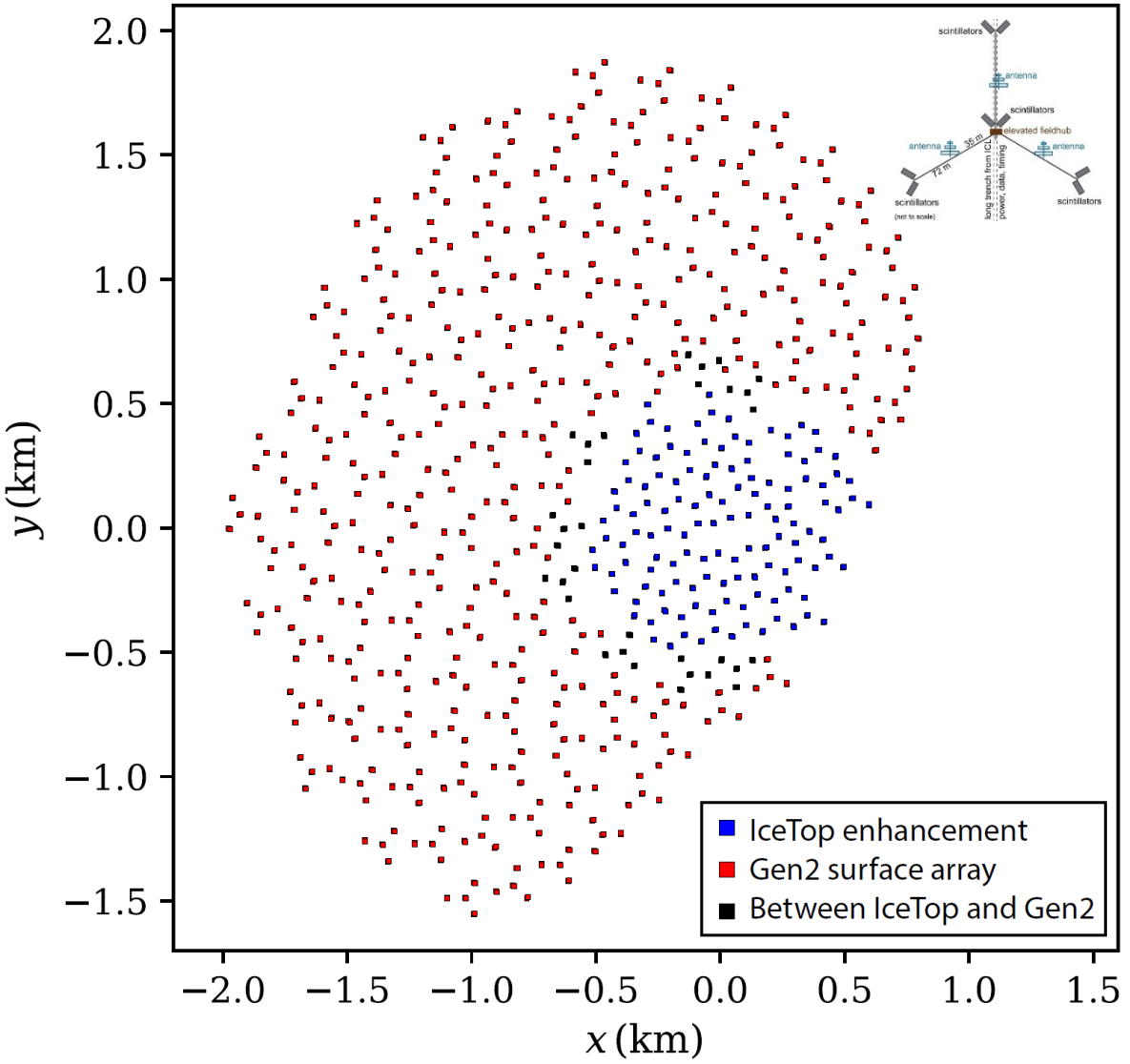
Simulation of Baseline Design

- Low threshold important for veto: expected threshold around 0.5 PeV





→ details in PoS (ICRC2021) 411

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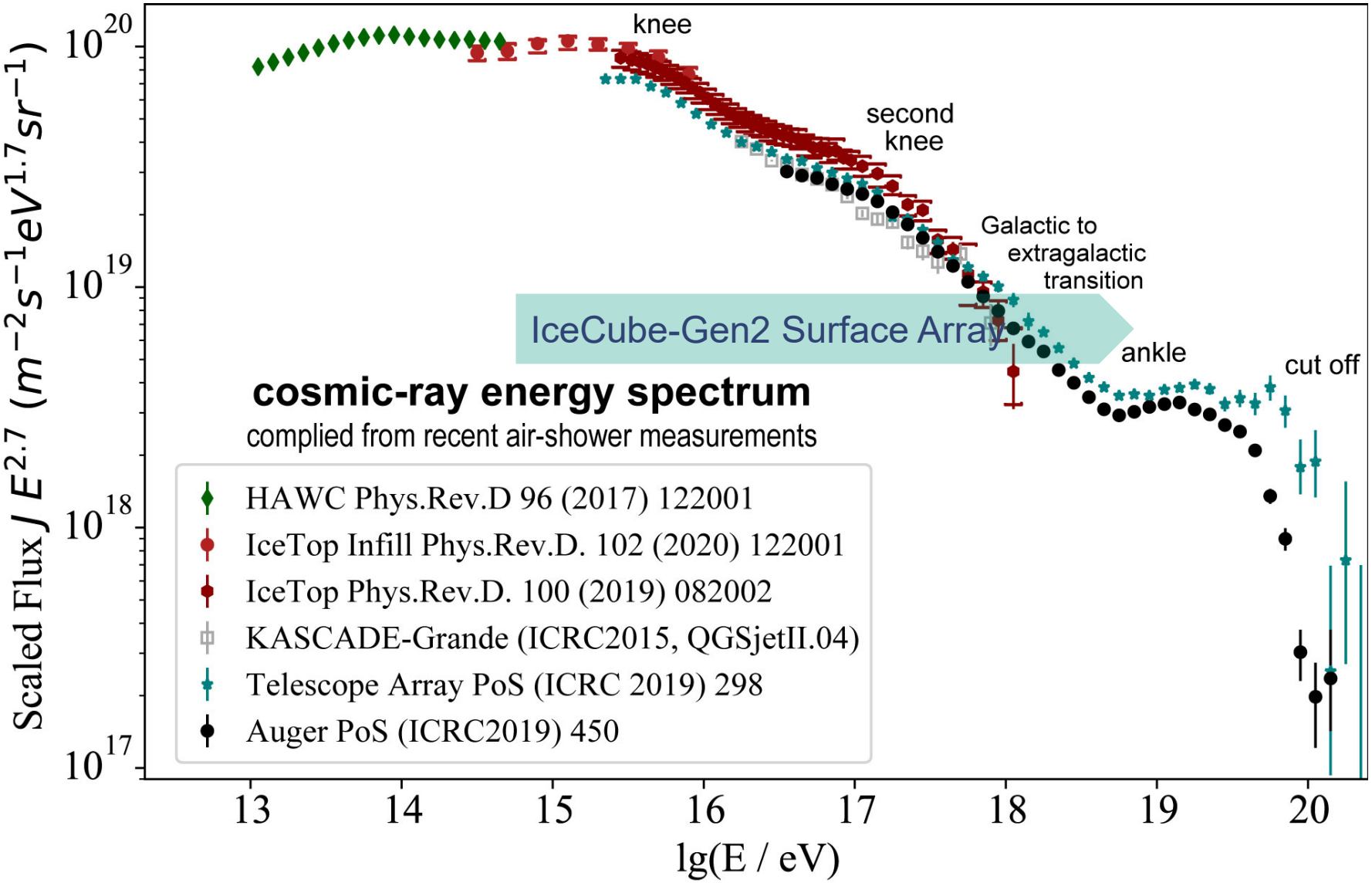
Energy reach until Ankle: Galacitc-to-extragalactic Transition



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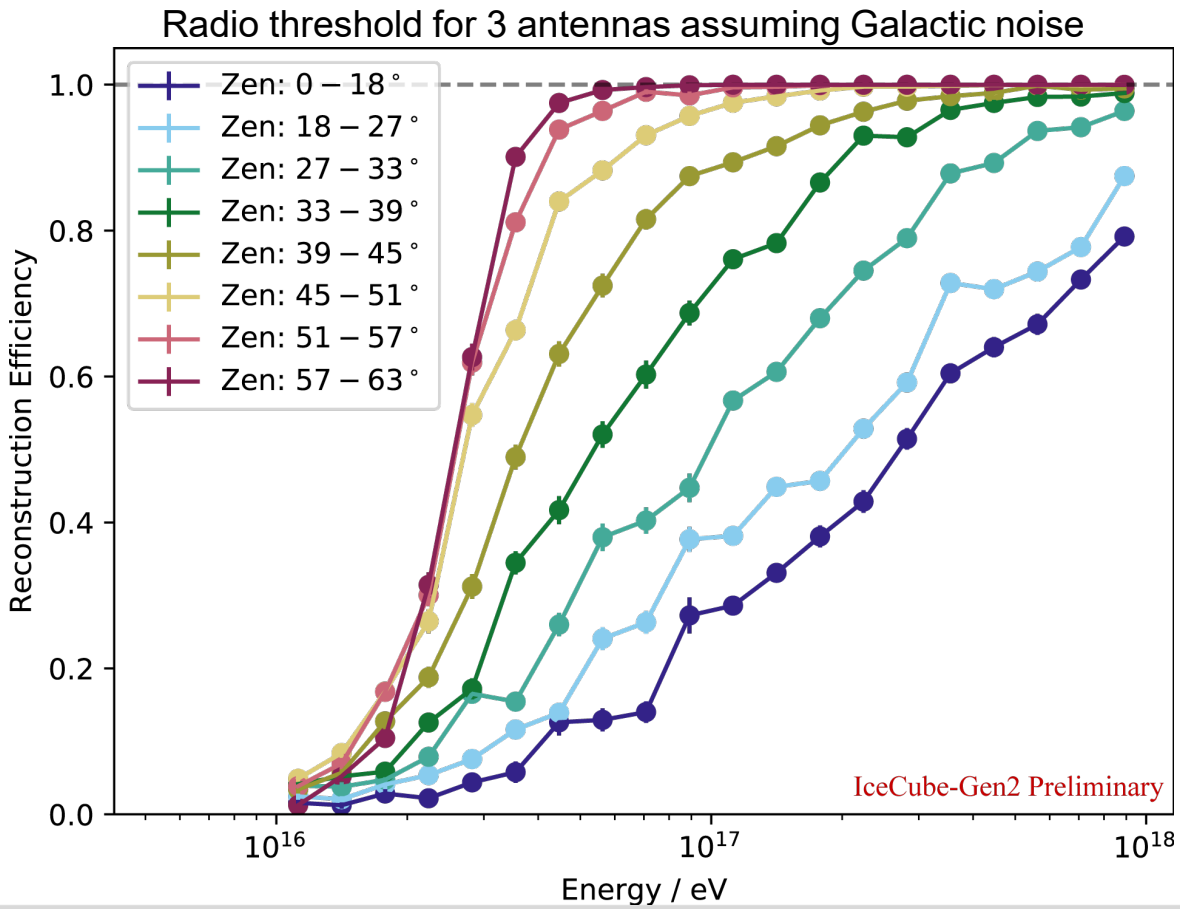
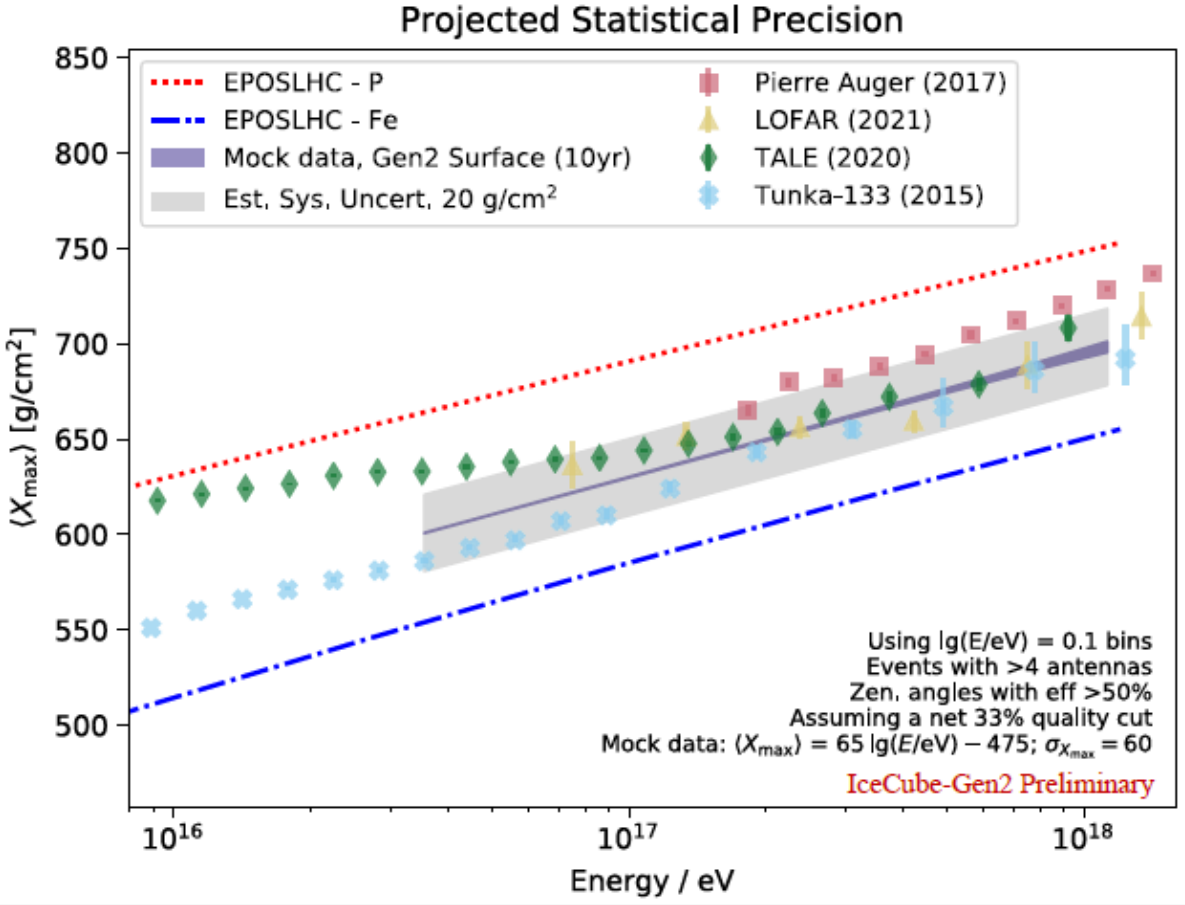
Radio antennas will increase accuracy above $10^{16.5}$ eV

- Assuming a precise X_{max} reconstruction with 5+ antennas, highest accuracy for mass composition is provided from $10^{16.5}$ eV to above 10^{18} eV → most energetic Galactic Cosmic Rays
- Combination with muon measurements will maximize accuracy for this important energy range





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Overview over Science Goals of Gen2 Surface Array

Science Goals	Scientific Measurements and Observables
Veto for neutrino detection	1) Check down-going real-time alerts. IceTop retracted 3 alerts in 2020 2) Veto for down-going events with increased solid angle compared to Gen1 3) Test potential of radio veto for very inclined air showers
Shower and CR physics using surface *and* in-ice detector	1) Prompt muons or more generally PeV forward muons 2) Hadronic interactions and mass composition using the in-ice detector 3) PeV photon search with surface array has discovery potential for Galactic sources
Other cosmic-ray physics	1) Hadronic interactions with the larger surface detector → overlap with AMIGA 2) Anisotropy, mass composition, energy spectrum, etc. with the surface detector
Calibration of in-ice detectors	1) Cross-calibration of in-ice radio antennas for energy scale and consistency 2) Physics calibration of the in-ice atmospheric leptons (prompt and regular atm. neutrinos + muons): in-situ calibration of the cosmic-ray flux 3) In-ice muons in coincidence with surface array as cross-check of optical calibration

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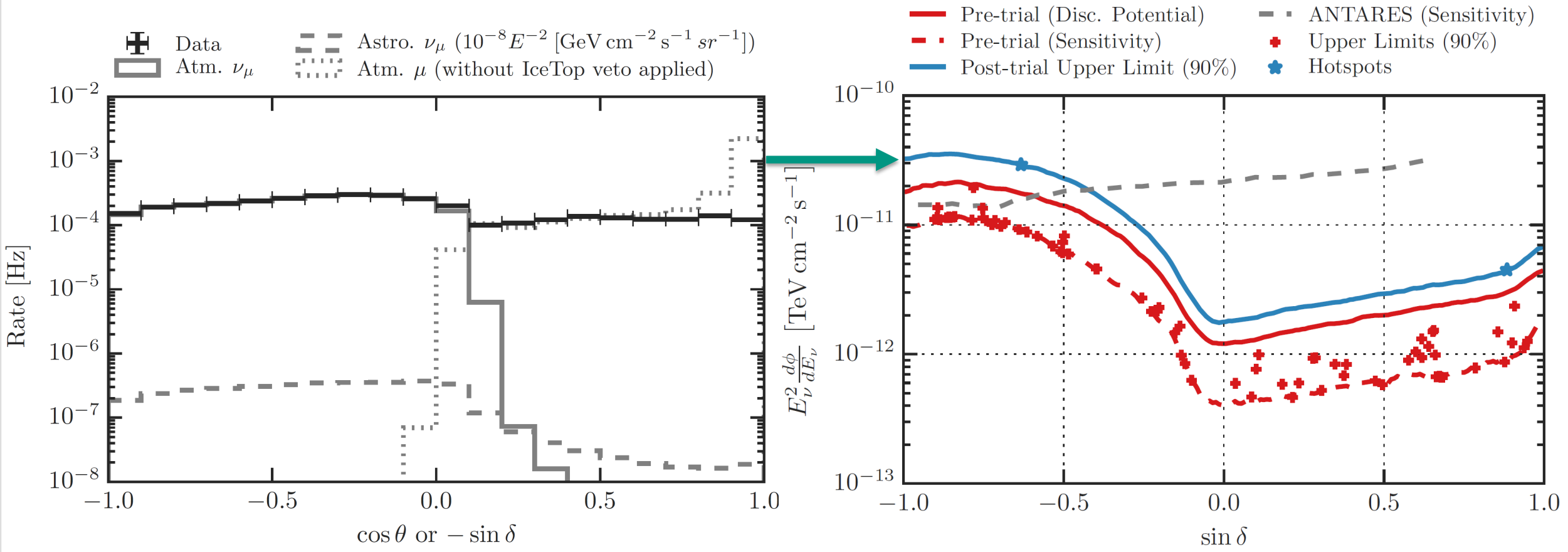
Example for Veto experience with IceTop (= Gen1)

IceTop has increased the sensitivity to downward neutrinos. The Gen2 Surface Array will provide the same functionality to the Gen2 optical array *and* cover a larger aperture.



IceCube Coll., Astrophys. J., 835 (2017) 151

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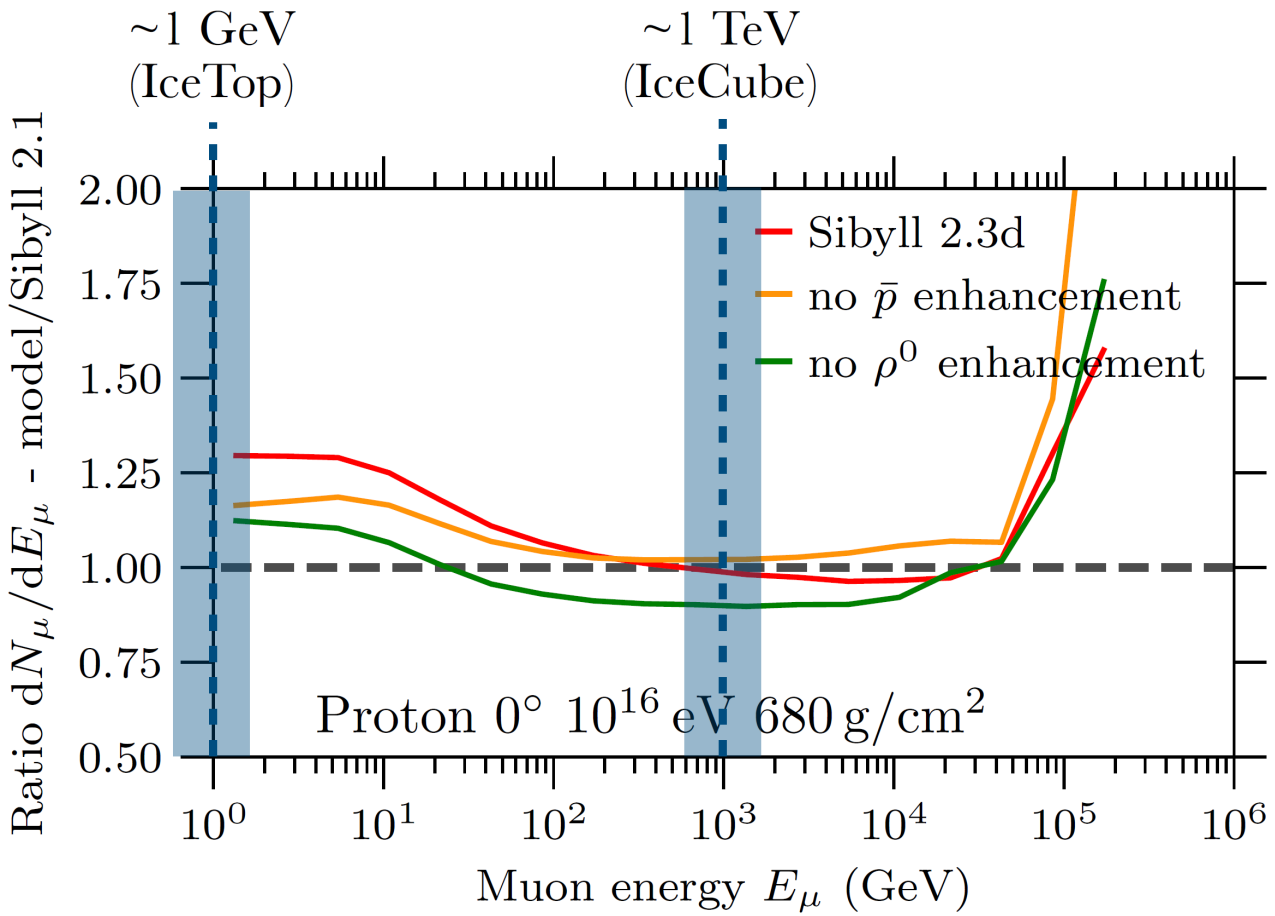
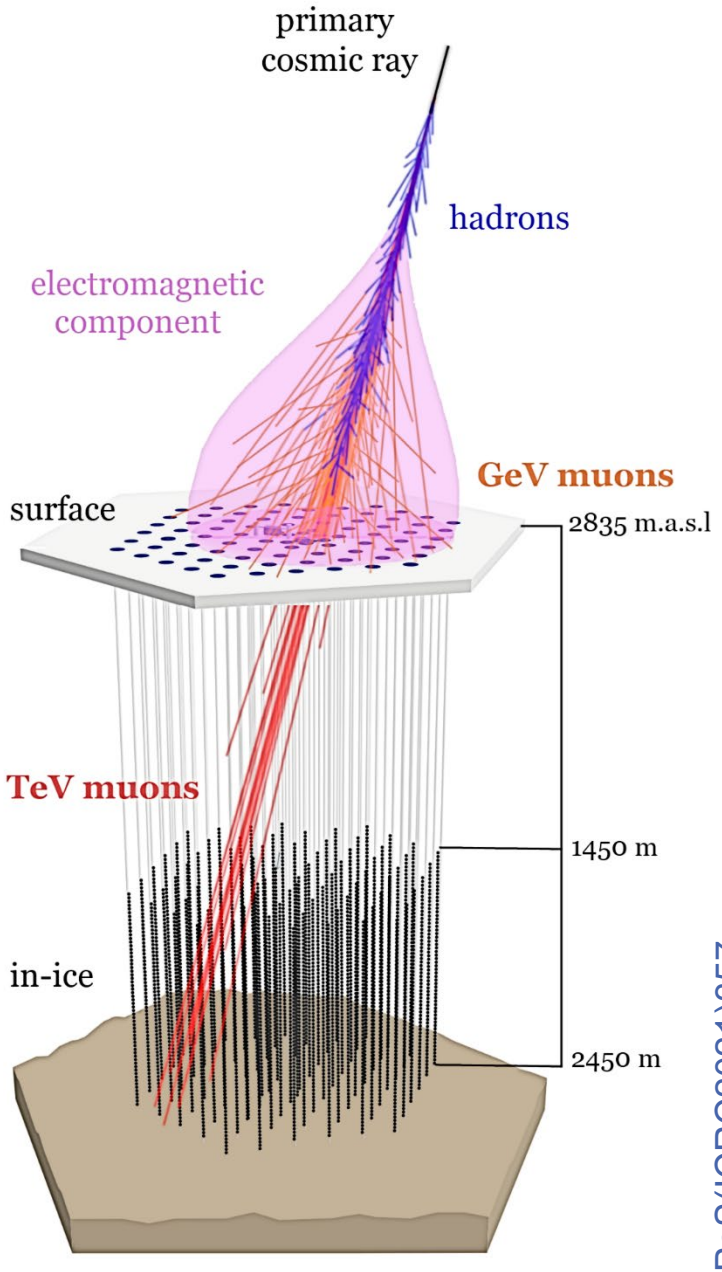
In-Ice Coincidences: Muon Spectrum

- scrutinize hadronic interaction models by *muon spectrum:*
  GeV muons at distant surface detectors + TeV muons in the ice
- possible with Gen1, but huge aperture increase (> 30×) in Gen2





F. Riehn et al, PRD 102 (2020) 063002

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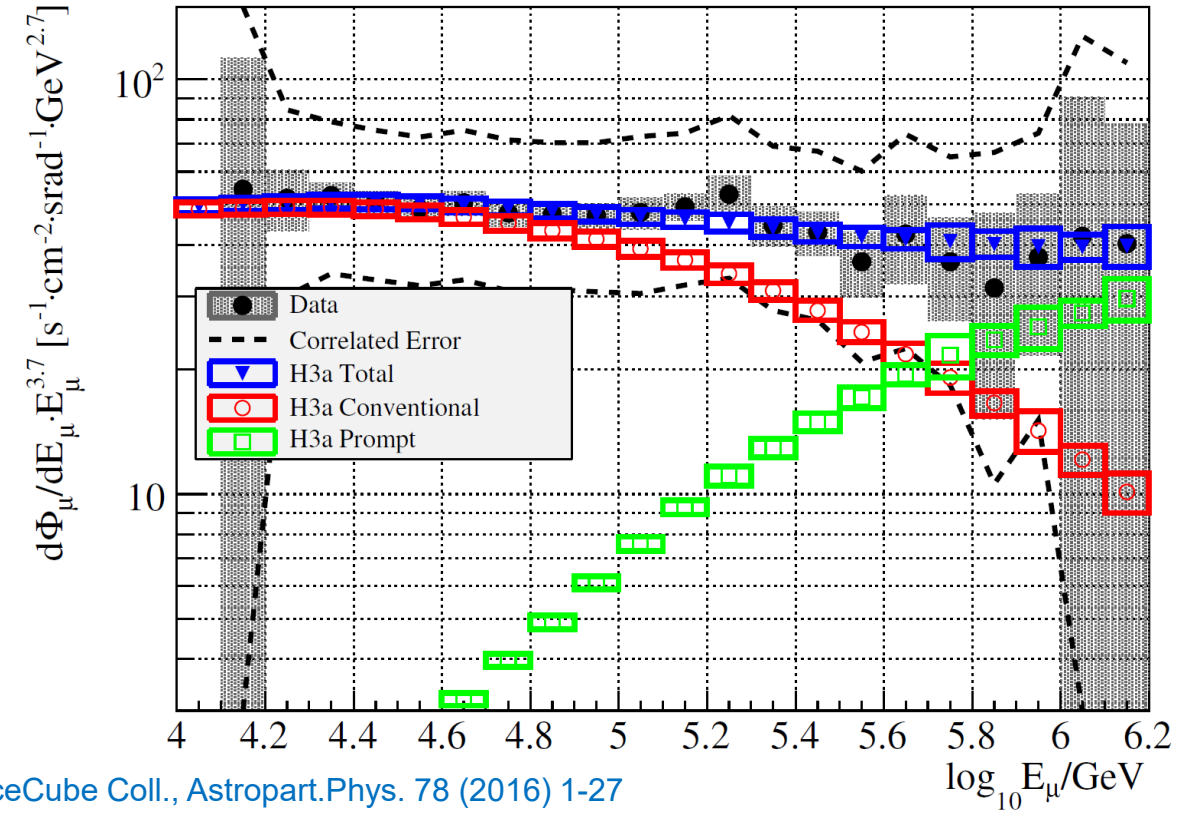
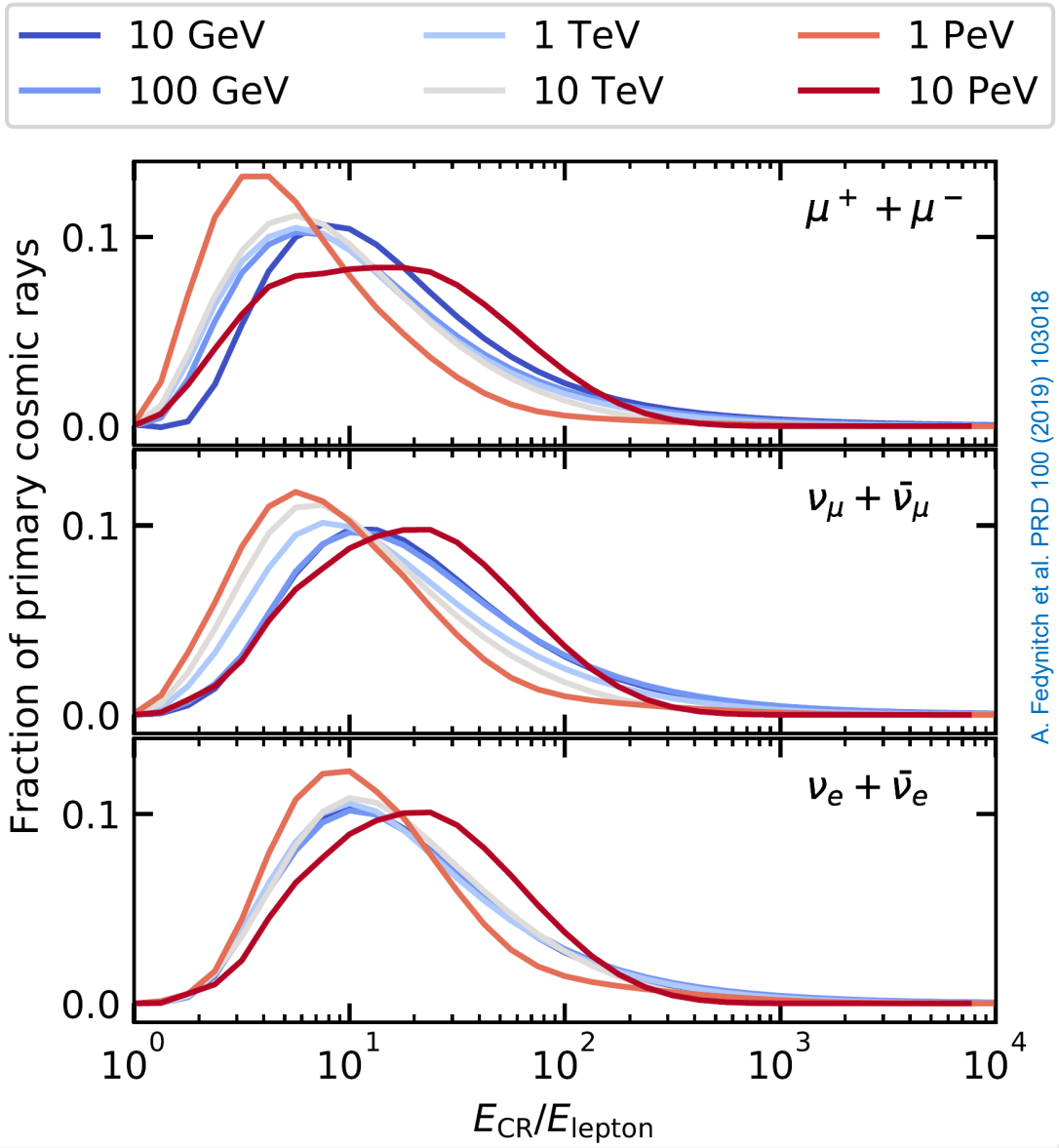
Prompt and conventional PeV forward muons

- Aperture increase in combination with 0.5 PeV threshold for protons enables to study transition from conventional to prompt muons

→ better understanding for important uncertainty



IceCube Coll., Astropart.Phys. 78 (2016) 1-27



A. Fedynitch et al. PRD 100 (2019) 103018

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Conclusion

Baseline Design

- Cover footprint of Gen2 optical array by an array of elevated scintillators and radio antennas
- Threshold of 0.5 PeV constantly provided by scintillation panels
- High accuracy (X_{max} + calorimetric energy) provided at high energies by radio antennas

→ IceCube-Gen2 will be a unique detector combining a surface array with a deep detector

Science Case

- Supporting neutrino detection of IceCube-Gen2 and enabling important cosmic-ray physics
- Combination of surface and in-ice detector enables unique science, e.g., regarding prompt muons
- IceCube-Gen2 will be the most accurate detector for the Galactic-to-extragalactic transition

→ Surface array supports and complements IceCube-Gen2's multi-messenger science mission

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