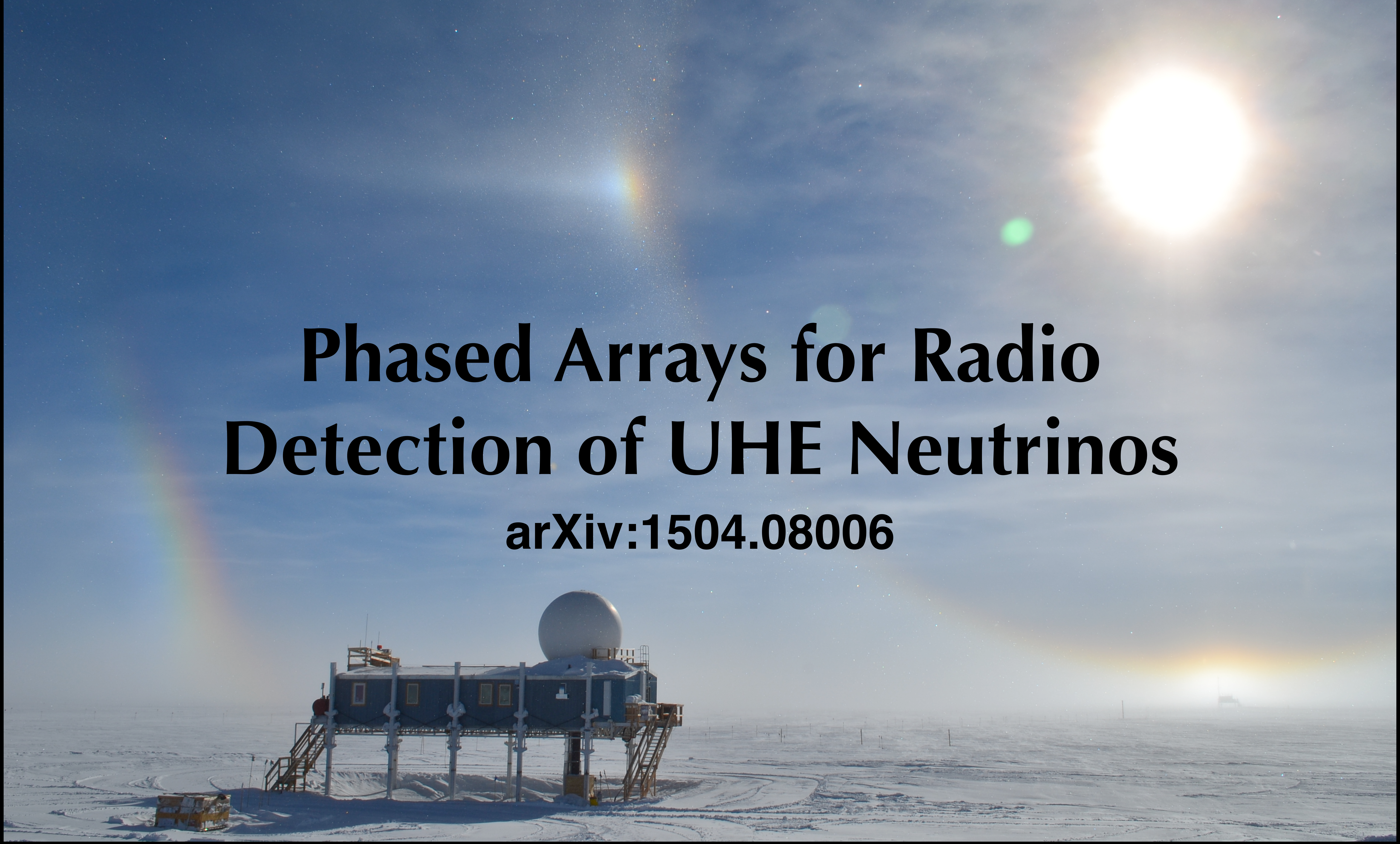
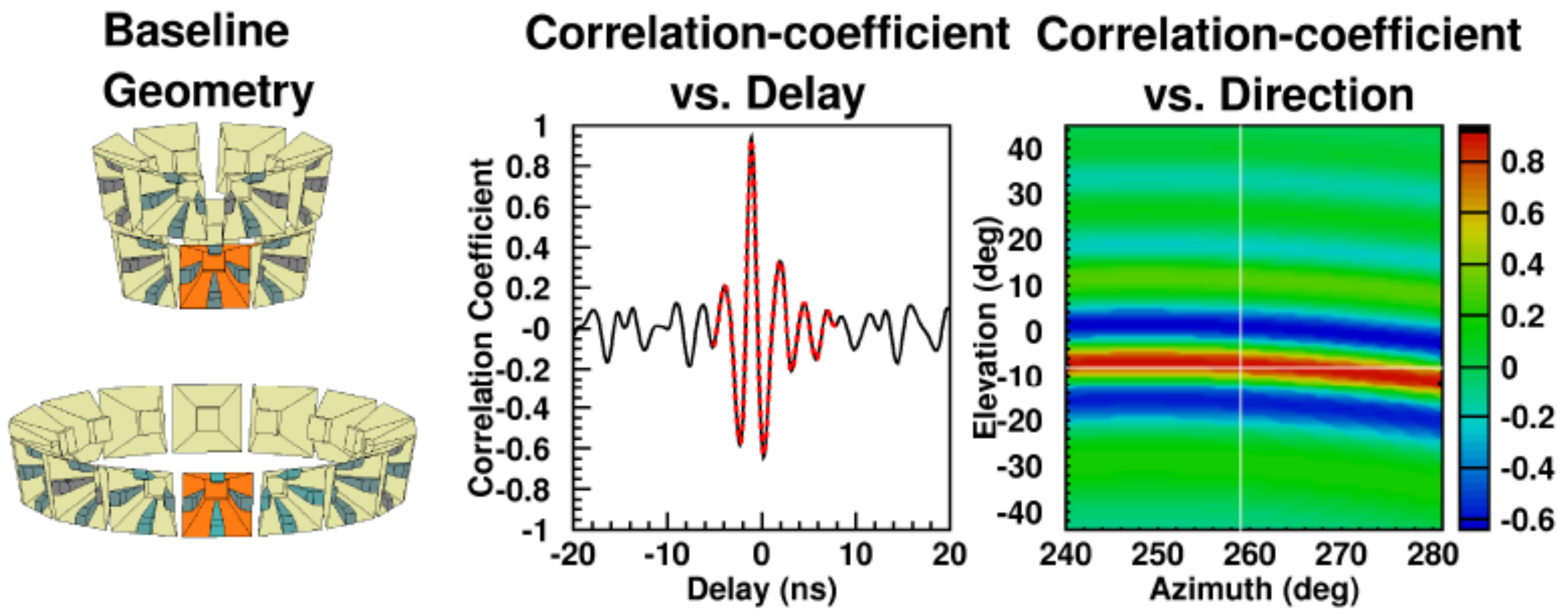
Phased Arrays for Radio Detection of UHE Neutrinos

arXiv:1504.08006



Keith Bechtol
w/ Abigail Vieregg and Andres Romero-Wolf
ICRC 31 July 2015
THE UNIVERSITY of WISCONSIN MADISON

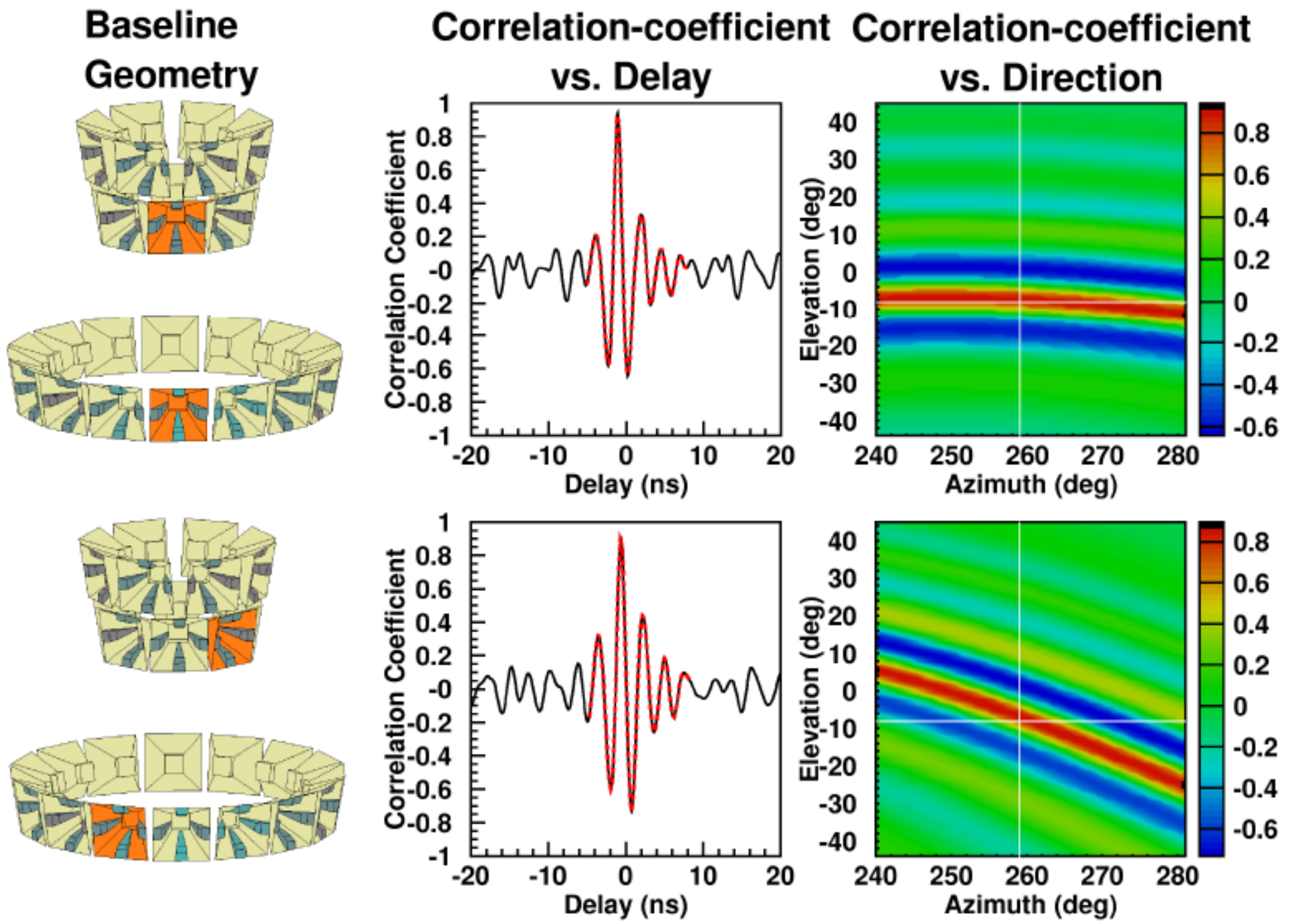
Interferometry



Waiting for a broadband (100 to 1200 MHz) impulsive (few ns) wavefront to cross the detector

Romero-Wolf et al. 2014

Interferometry



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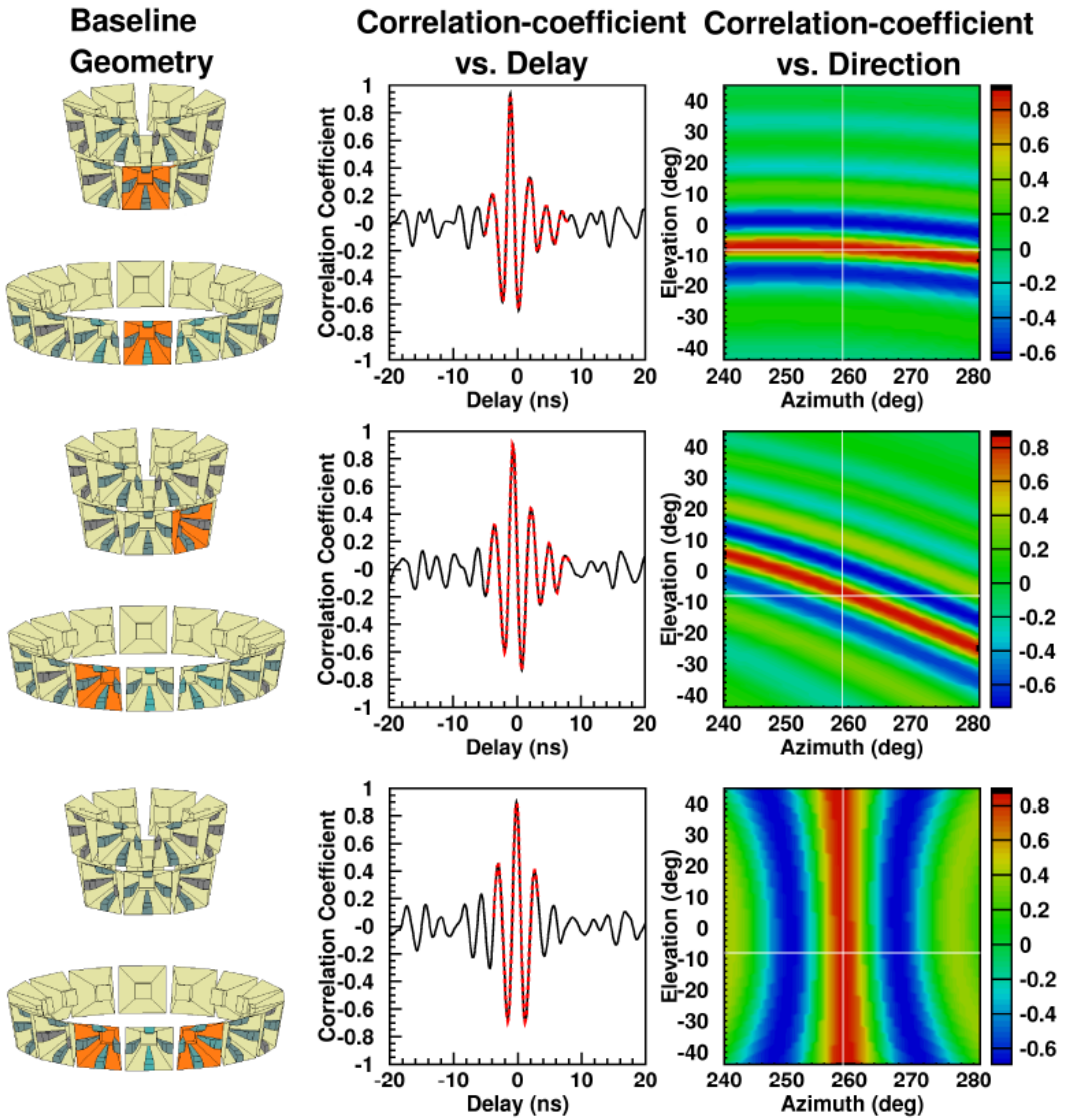
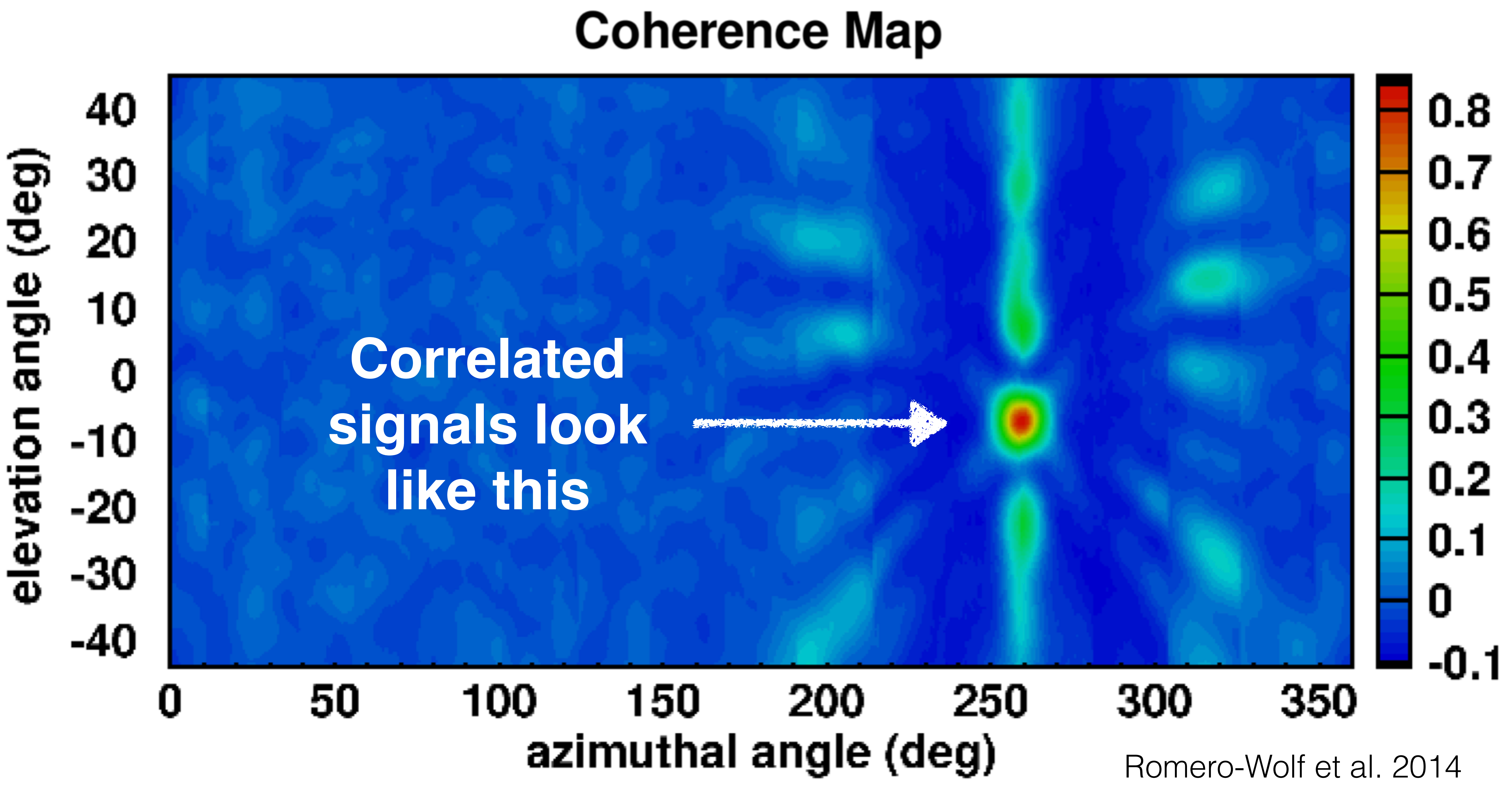


Waiting for a broadband (100 to 1200 MHz) impulsive (few ns) wavefront to cross the detector

Romero-Wolf et al. 2014

Interferometry

Trigger threshold is set by rate that data can be acquired
Most triggered events are uncorrelated thermal noise background



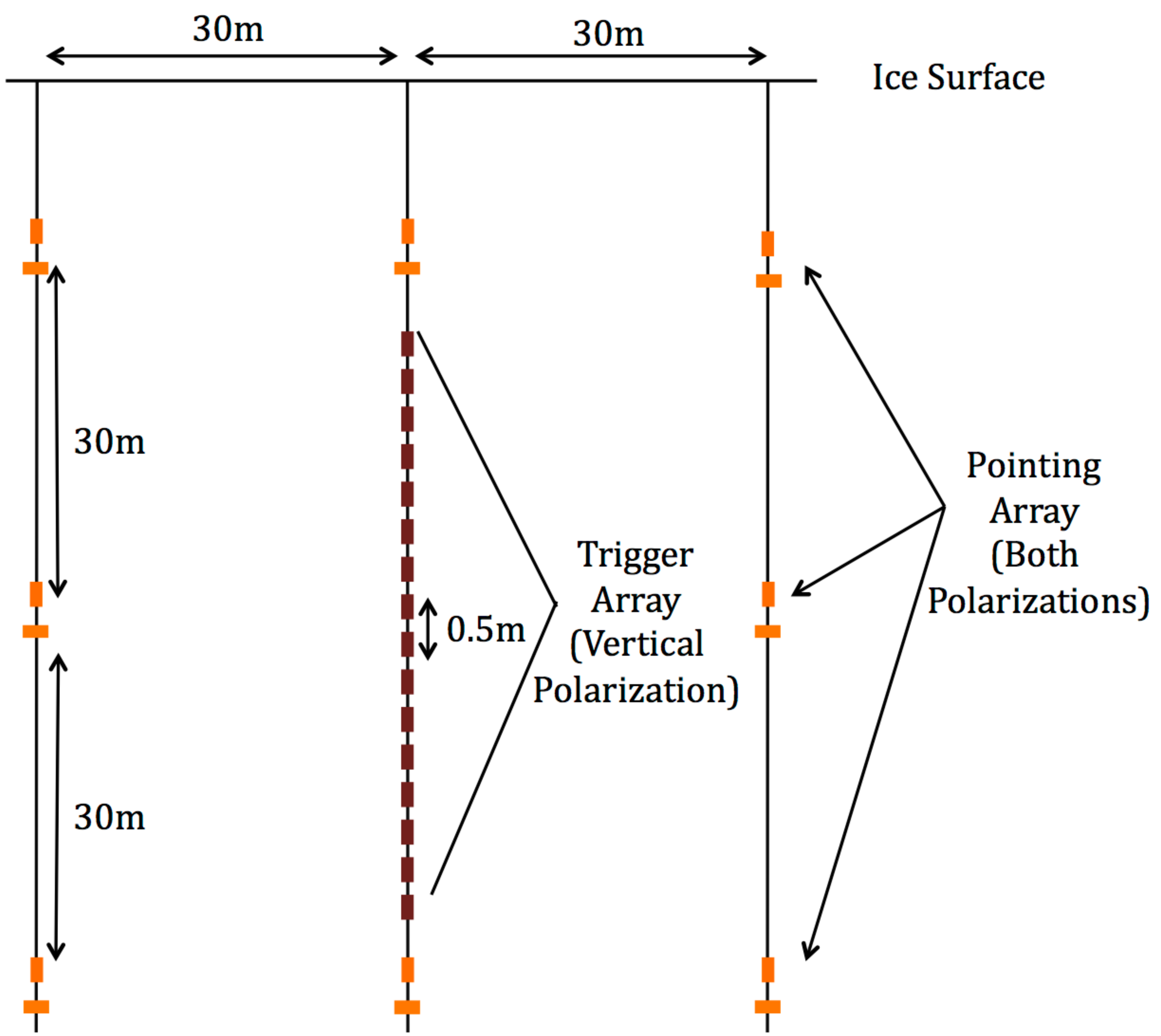
Romero-Wolf et al. 2014

Beam-forming in hardware might achieve a lower (more sensitive) trigger threshold relative to simple coincidence trigger

Phased Array Concept

16 antenna phased array example

Co-located but distinct “pointing” and “trigger”arrays



Phased Array Concept

16 antenna phased array example

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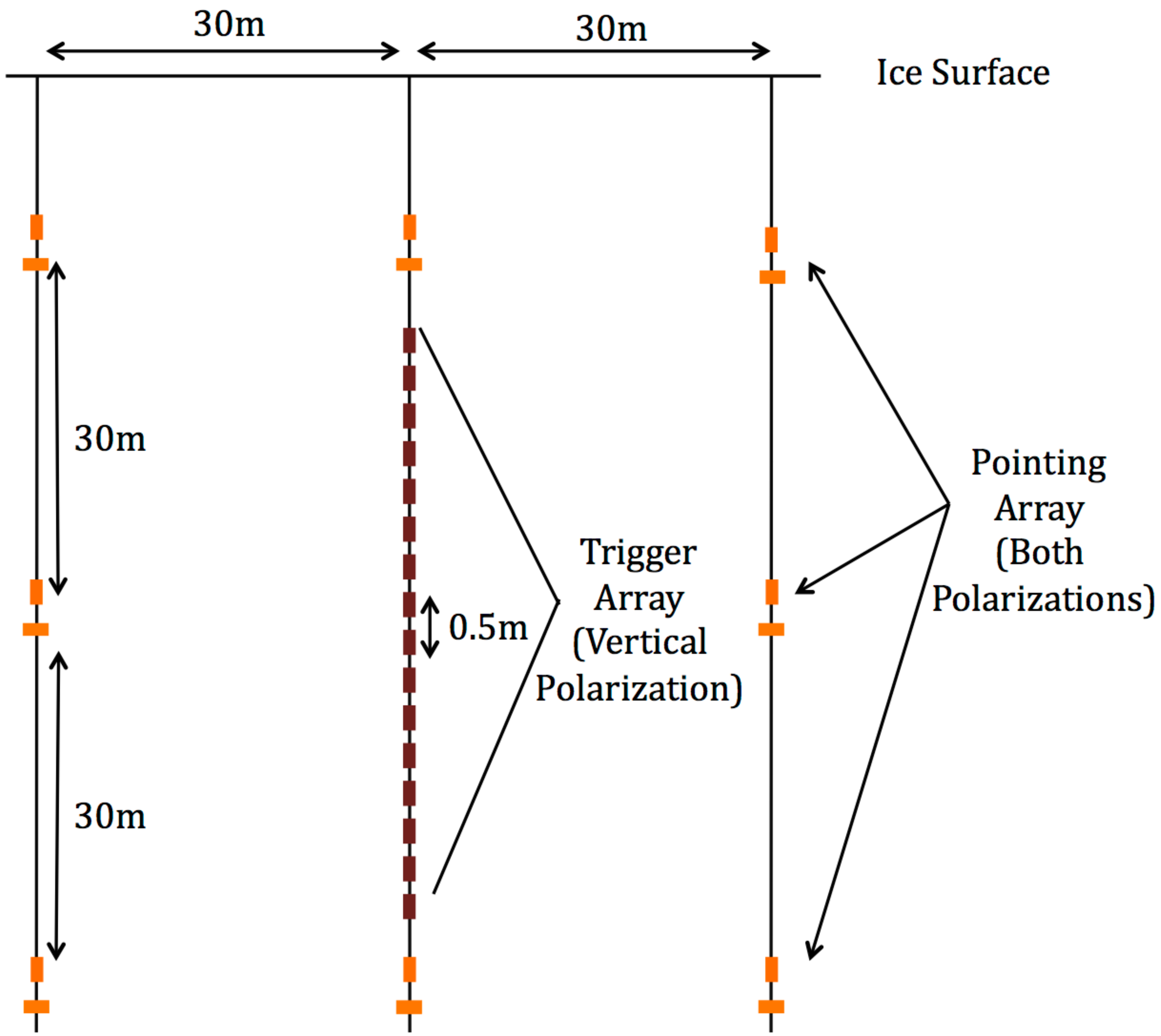
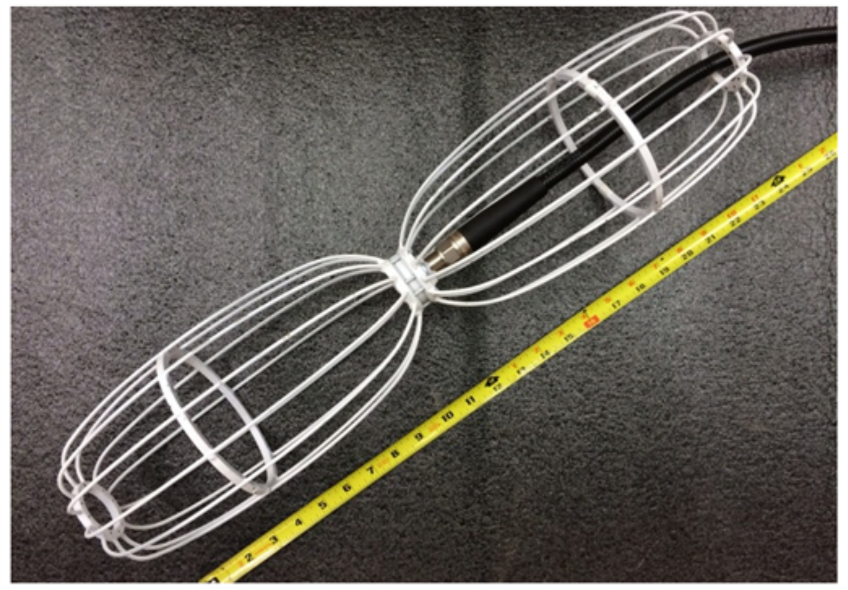
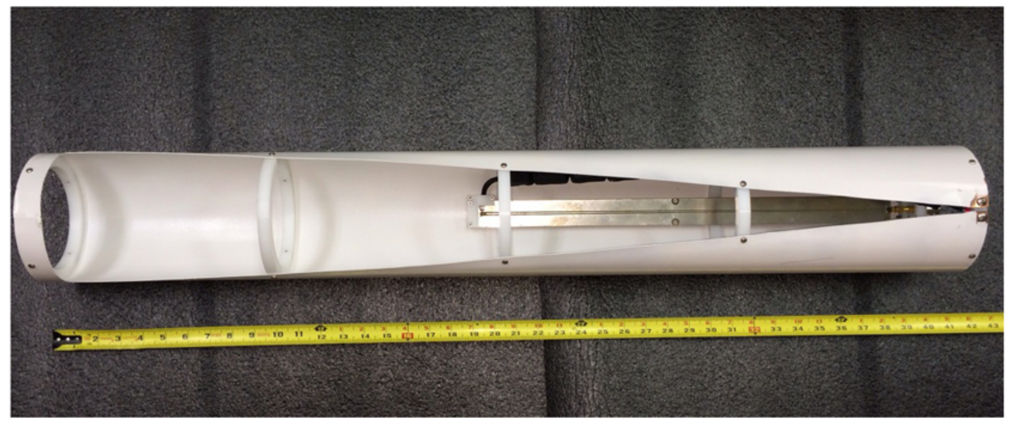


Construct an effective high-gain antenna by phasing multiple low-gain antennas

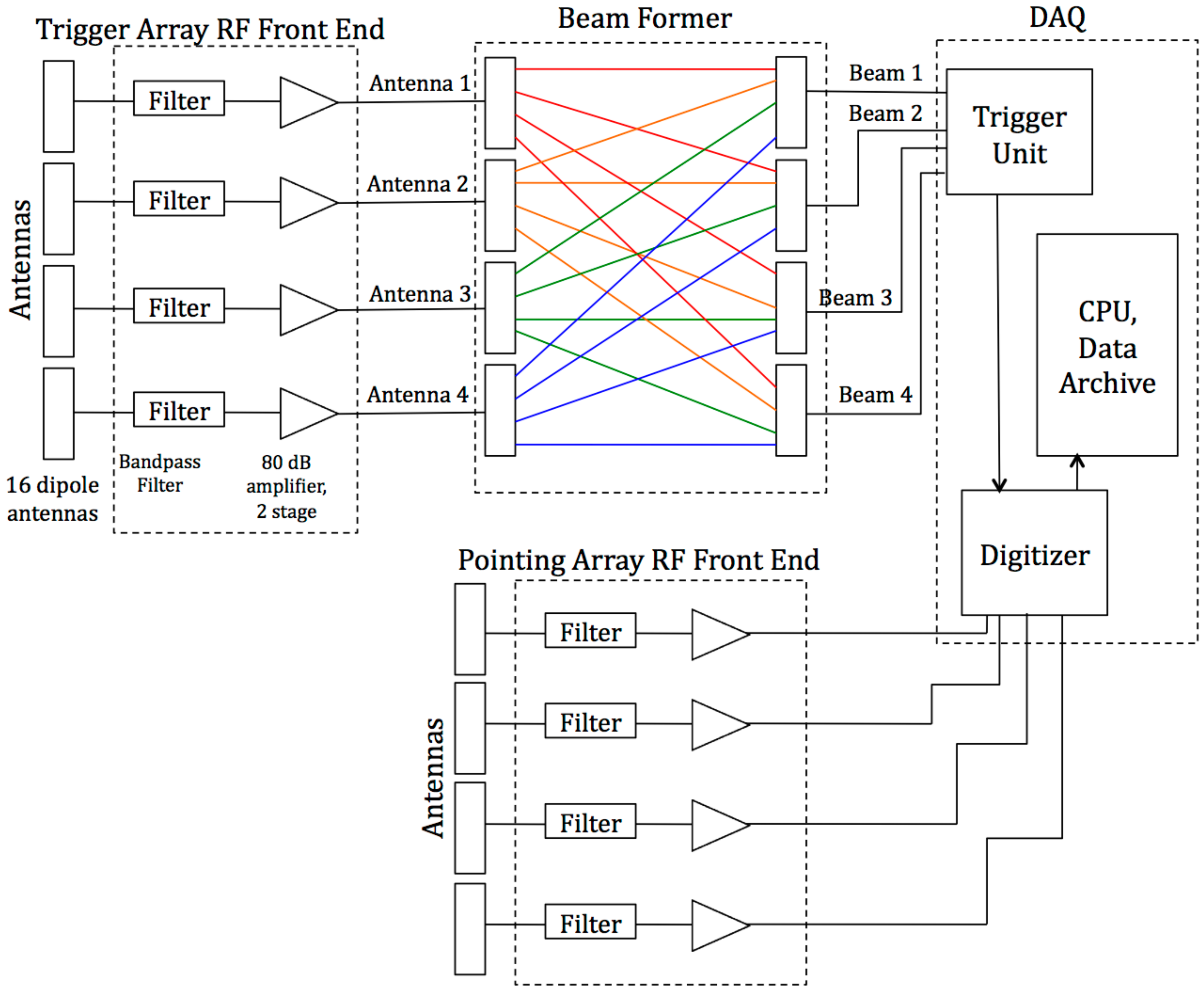
$$G_{eff} = 10\log_{10}(N \times 10^{G/10})$$





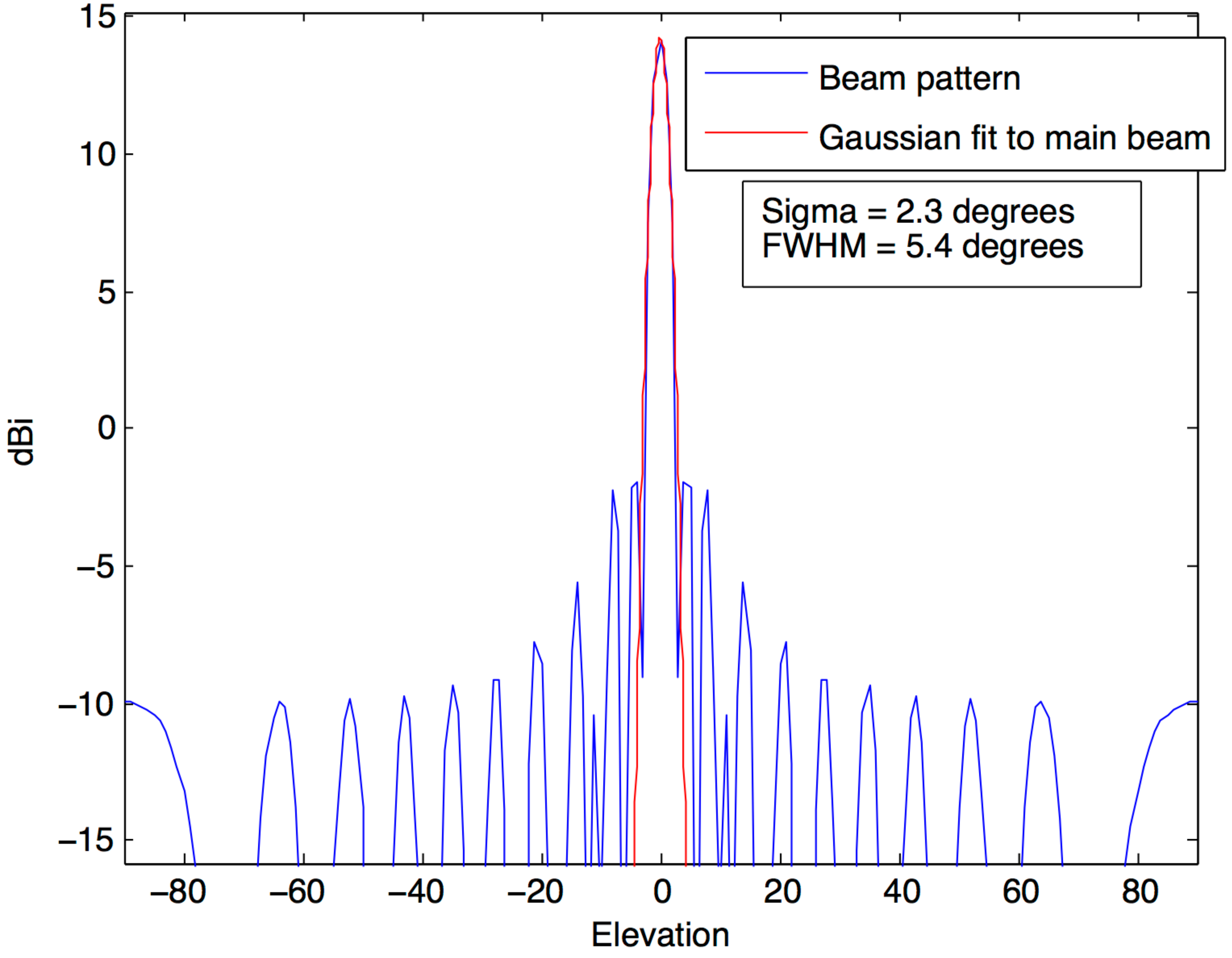
Phased Array Concept

Triggering on **beams** rather than waveforms from **individual antennas**



Phased Array Concept

Compact trigger array results in wide beams
Can attain good zenithal coverage with small number of trigger channels



Beam pattern for one trigger channel 200 MHz (16 antenna example)

Simulations

Consider 10 stations in Greenland as concrete example

For widely spaced stations, acceptance scales linearly with number of stations

Station Configurations

1. 16 antennas unphased (E-field threshold = 0.15 mV m^{-1}, 100 to 800 MHz)
2. 16 antennas phased (lower by factor 4)
3. 400 antennas phased (lower by factor 20)

Volumetric Acceptance

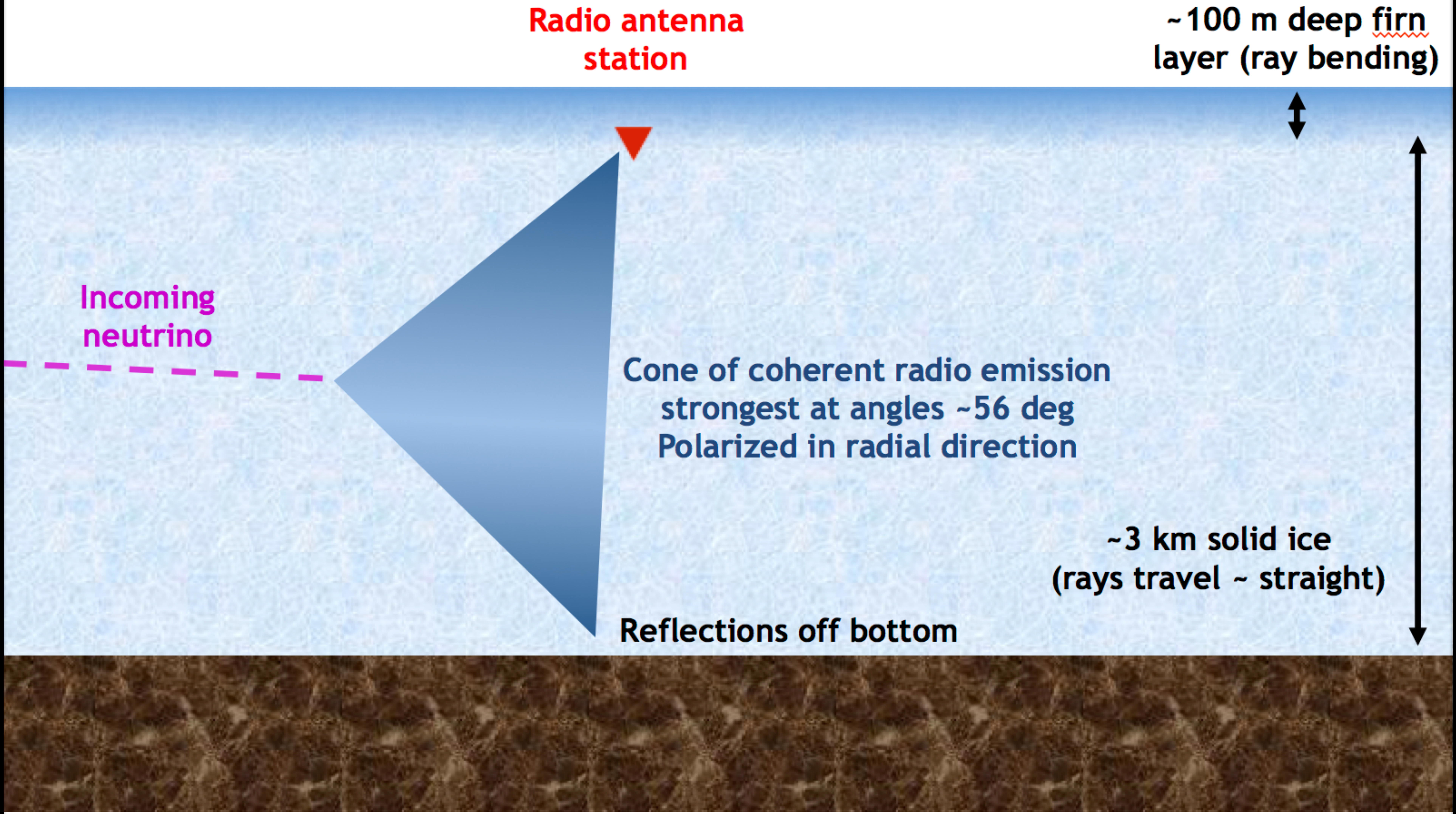
$$V\Omega = \frac{4\pi V_{\text{sim}}}{N} \times \sum_i \left(p_{\text{Earth},i} \times p_{\text{detect},i} \times \frac{\rho_i}{\rho_{\text{water}}} \right)$$

Areal Acceptance

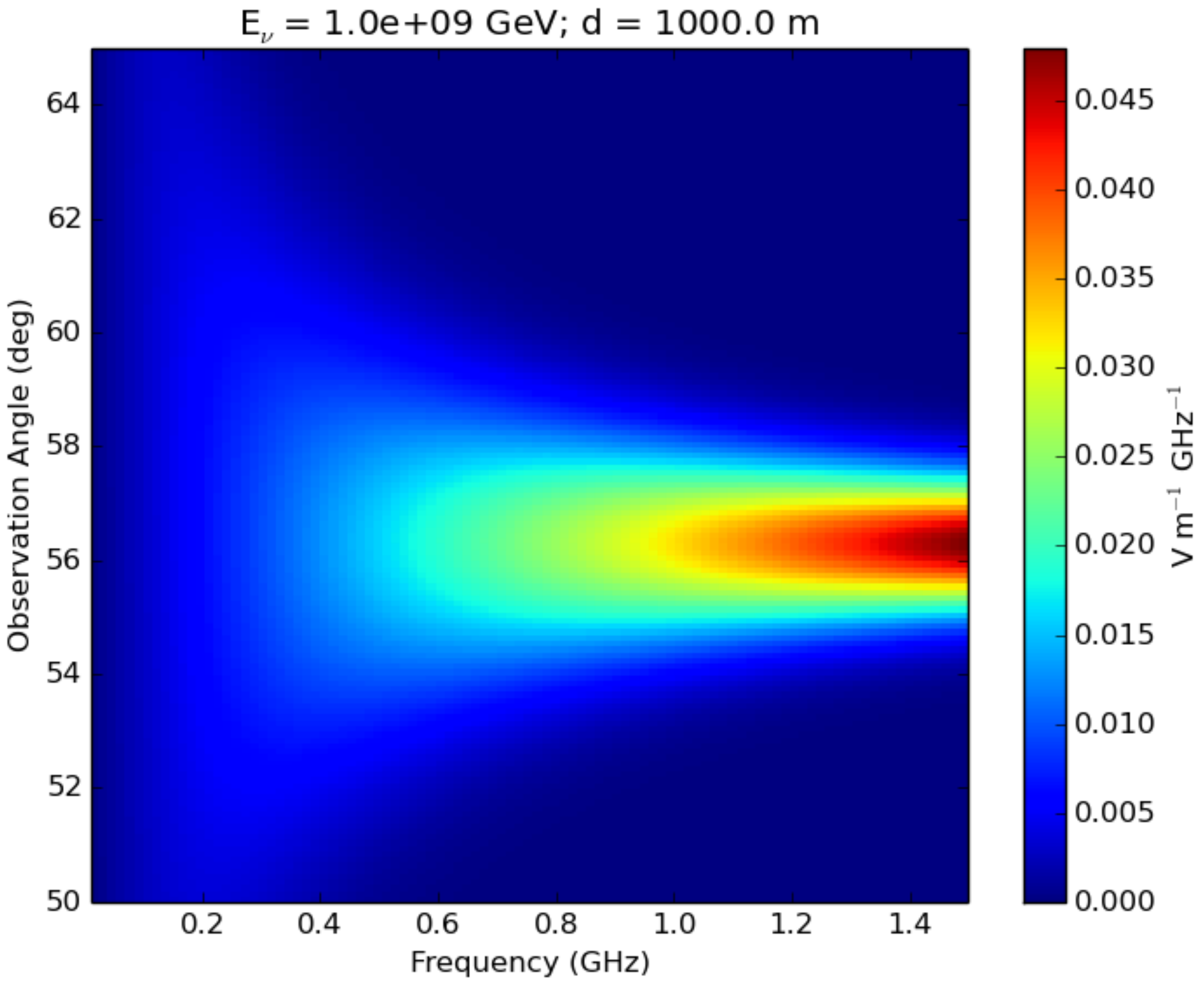
$$A\Omega = V\Omega / l$$

See appendix of arXiv:1504.08006 for details

Event Geometry Cartoon

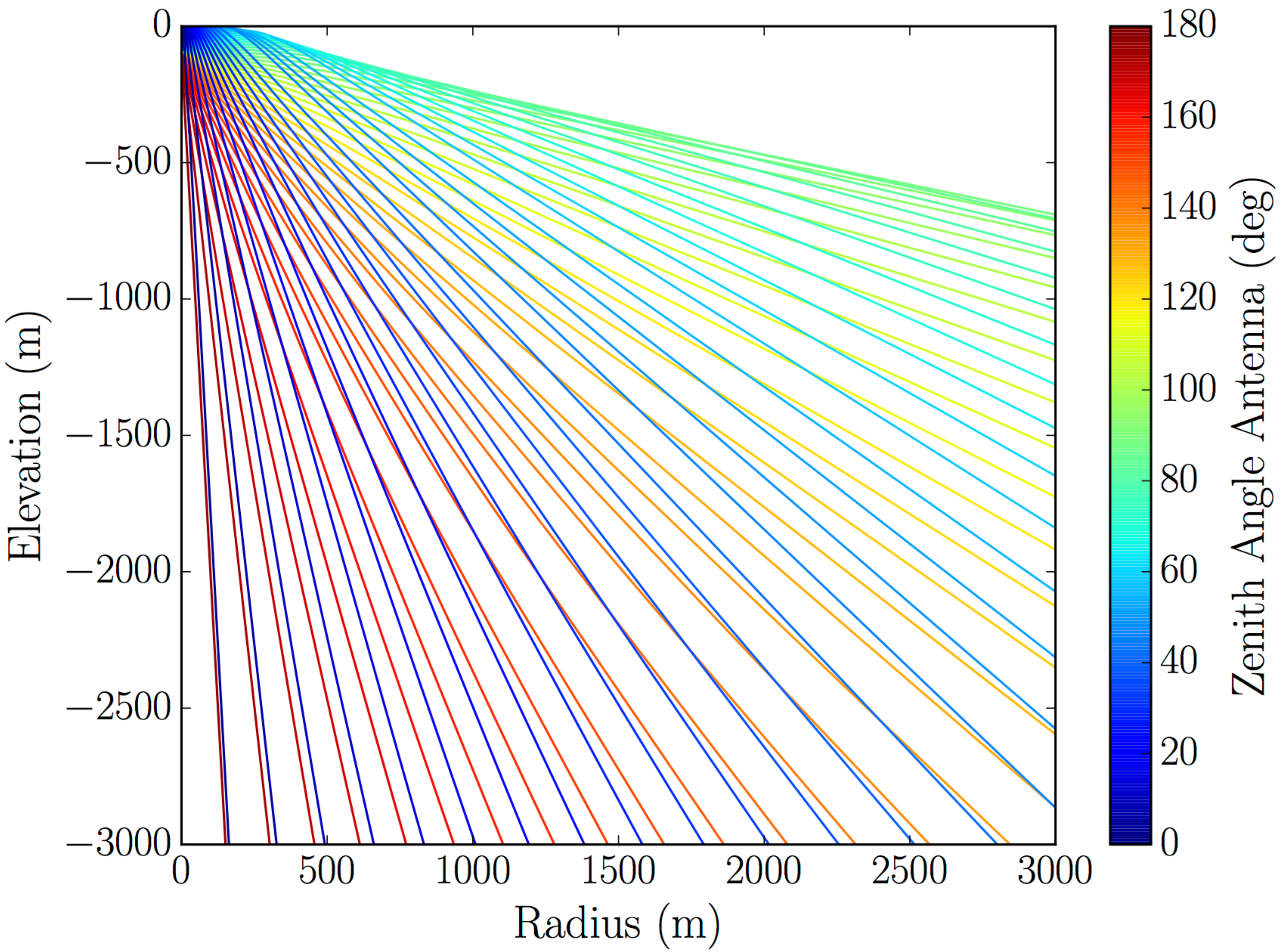


Askaryan Emission



Use simple analytic parametrization of Askaryan emission from Lehtinen et al. 2004

Ray-tracing Library



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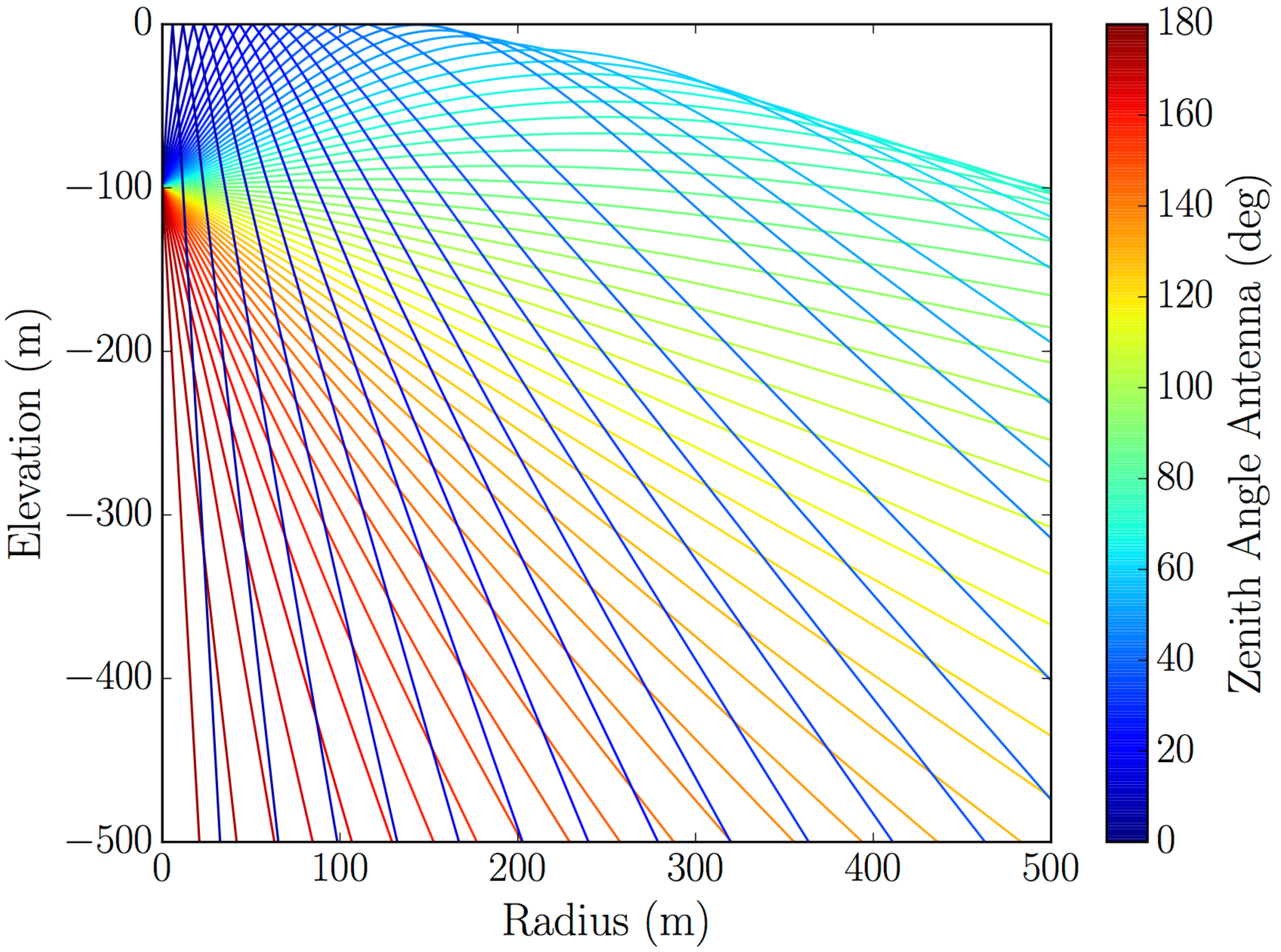
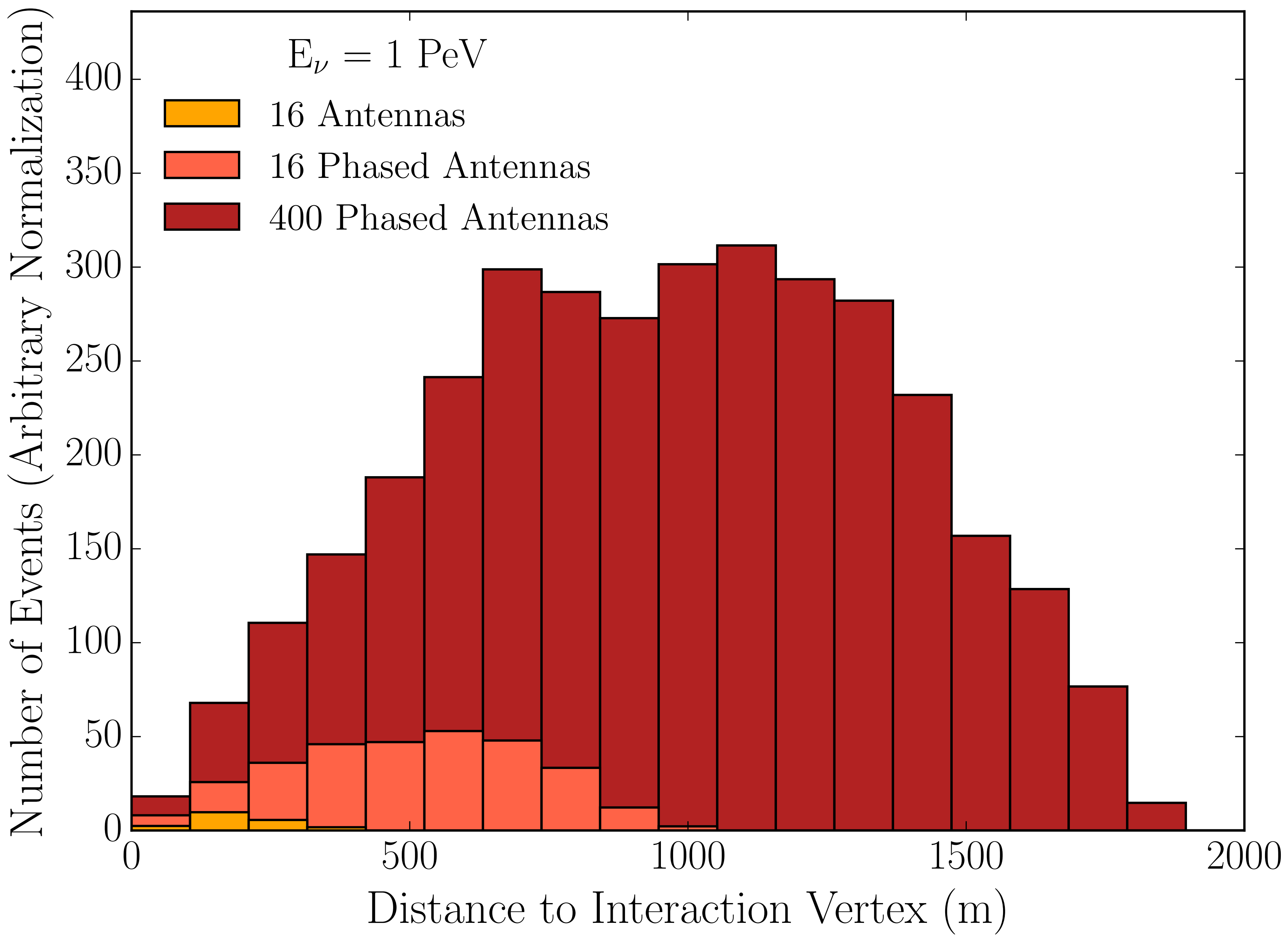
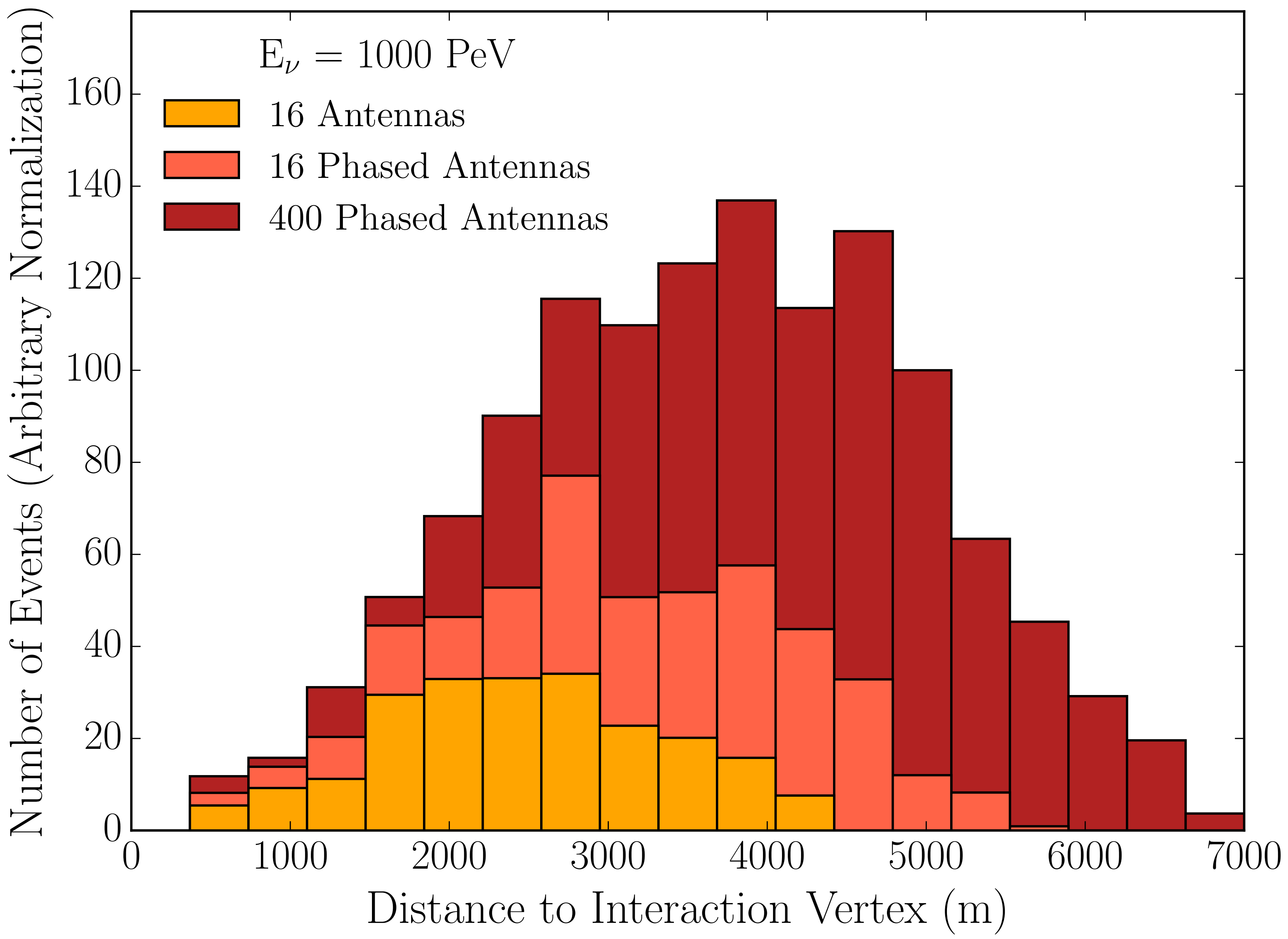


Distance to Interaction Vertex

Triggered events in three station configurations



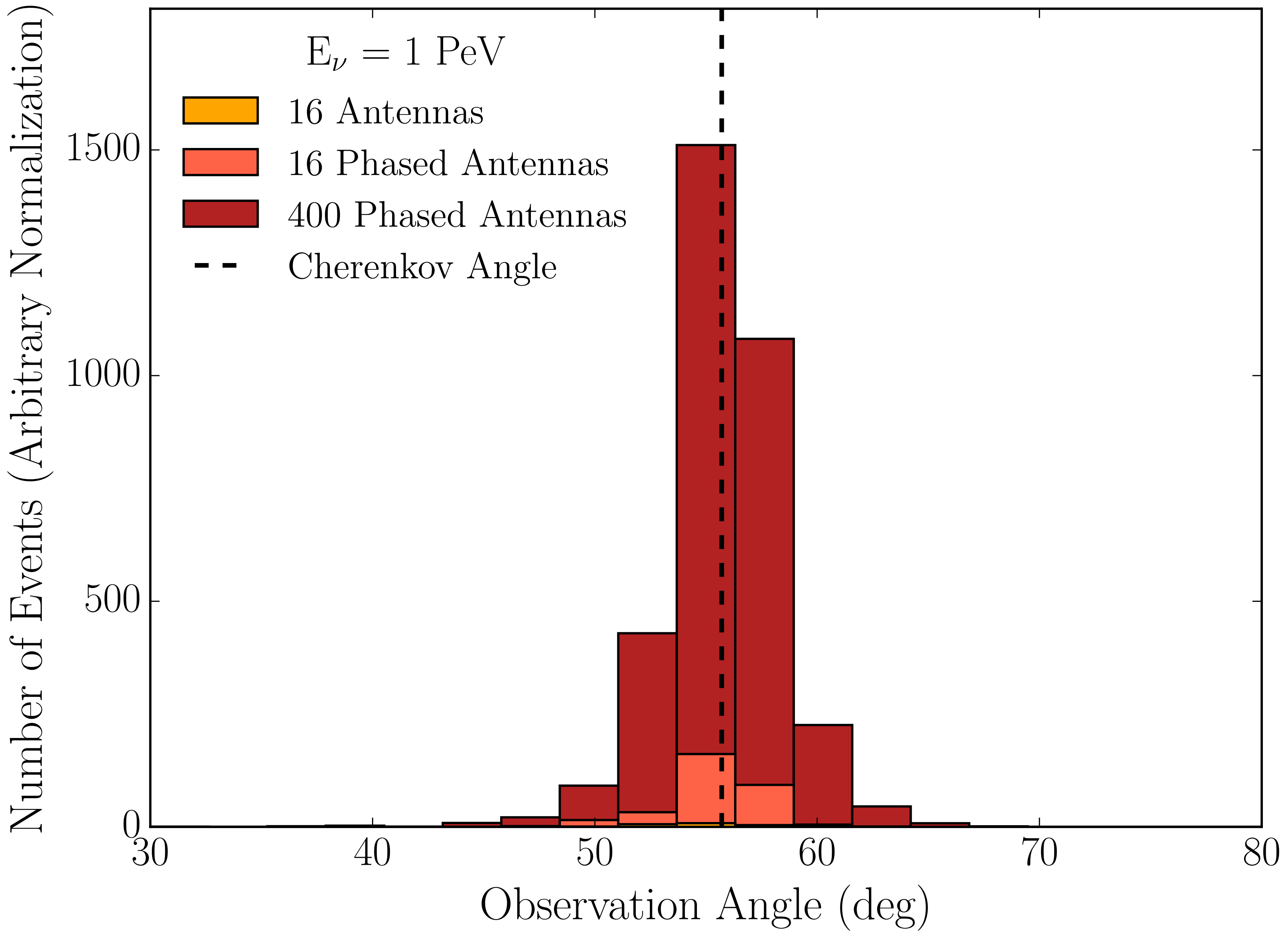
1 PeV



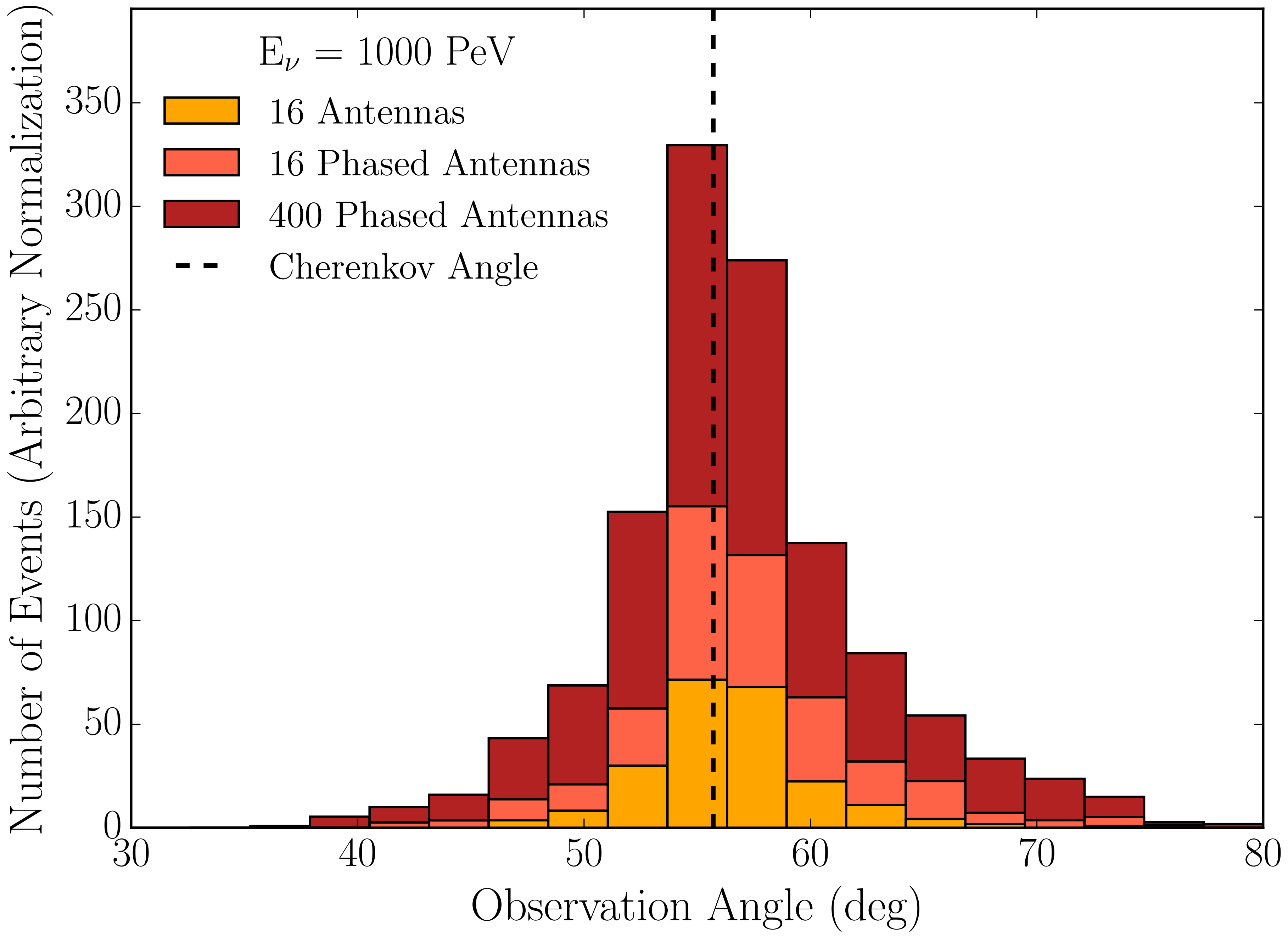
1000 PeV

Observation Angle

Triggered events in three station configurations



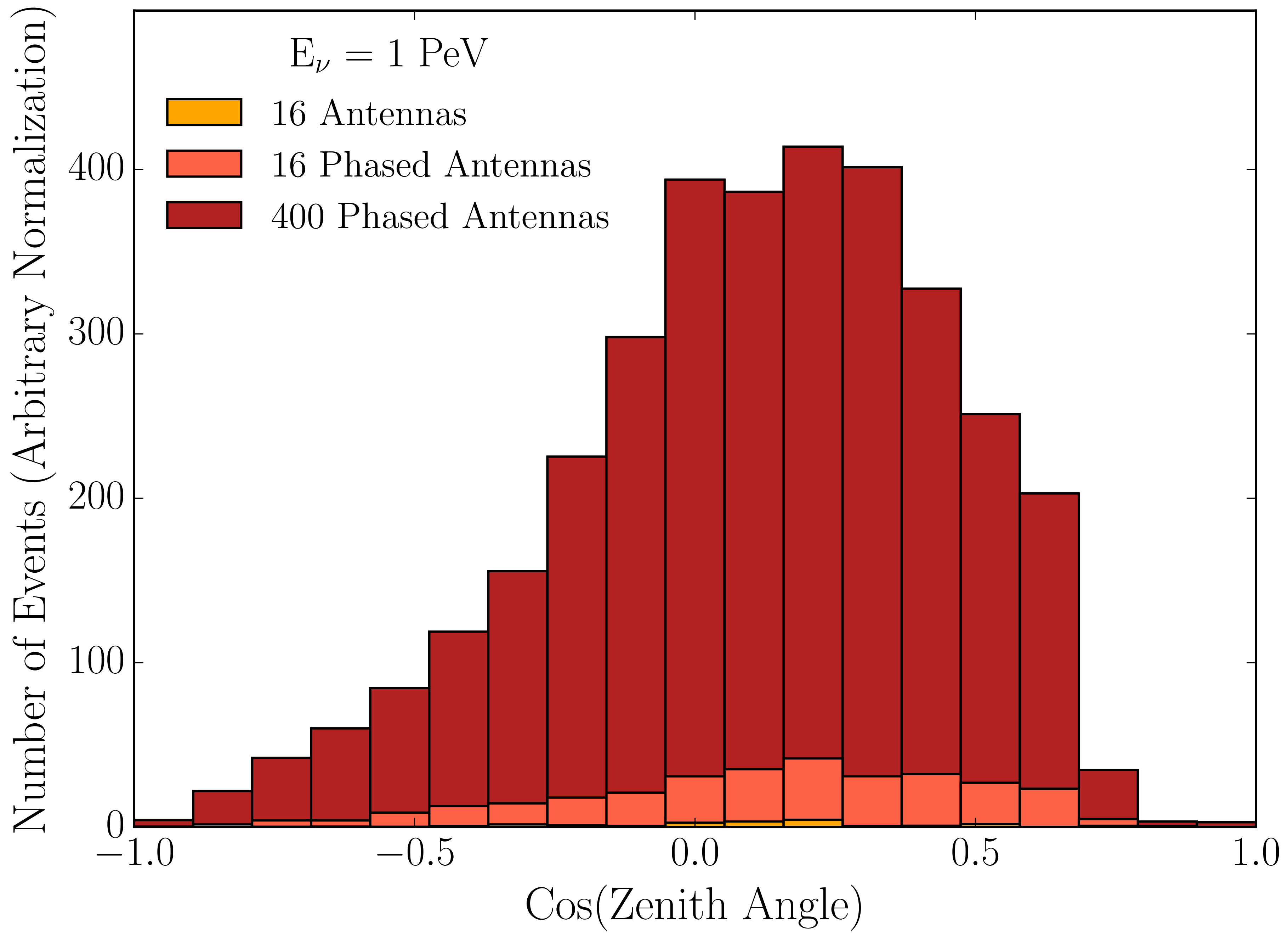
1 PeV



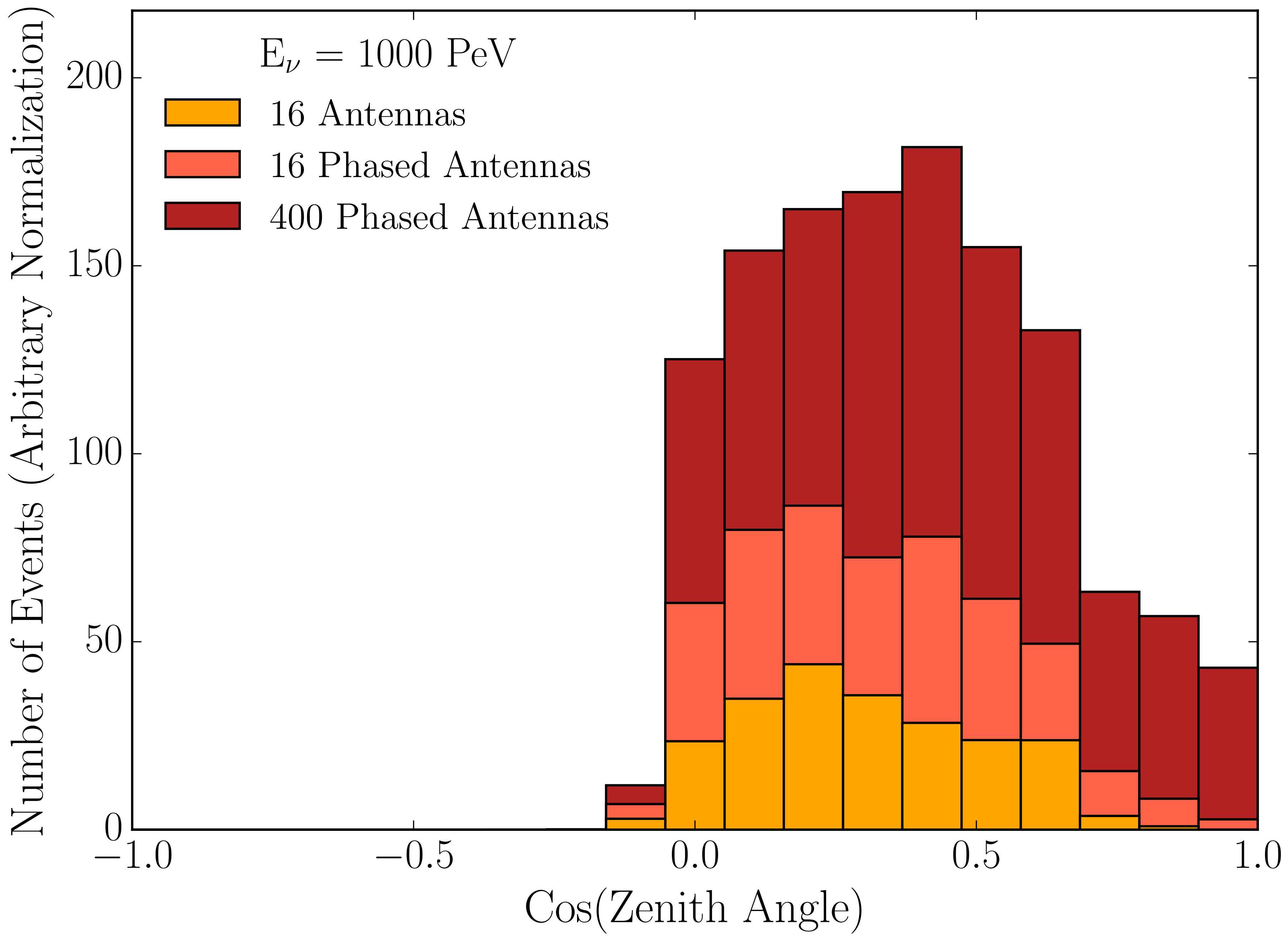
1000 PeV

Primary Neutrino Zenith Angle

Triggered events in three station configurations

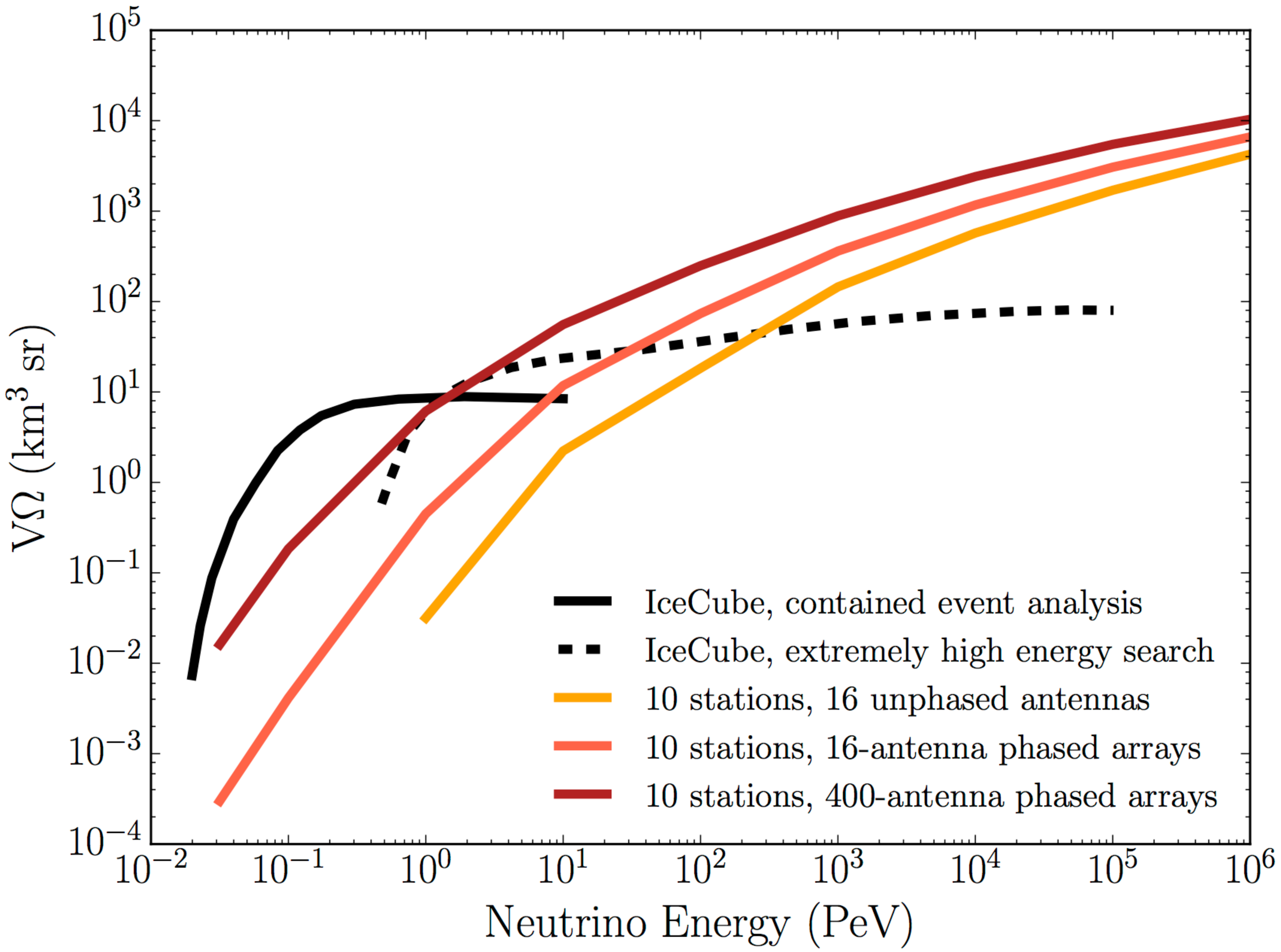


1 PeV



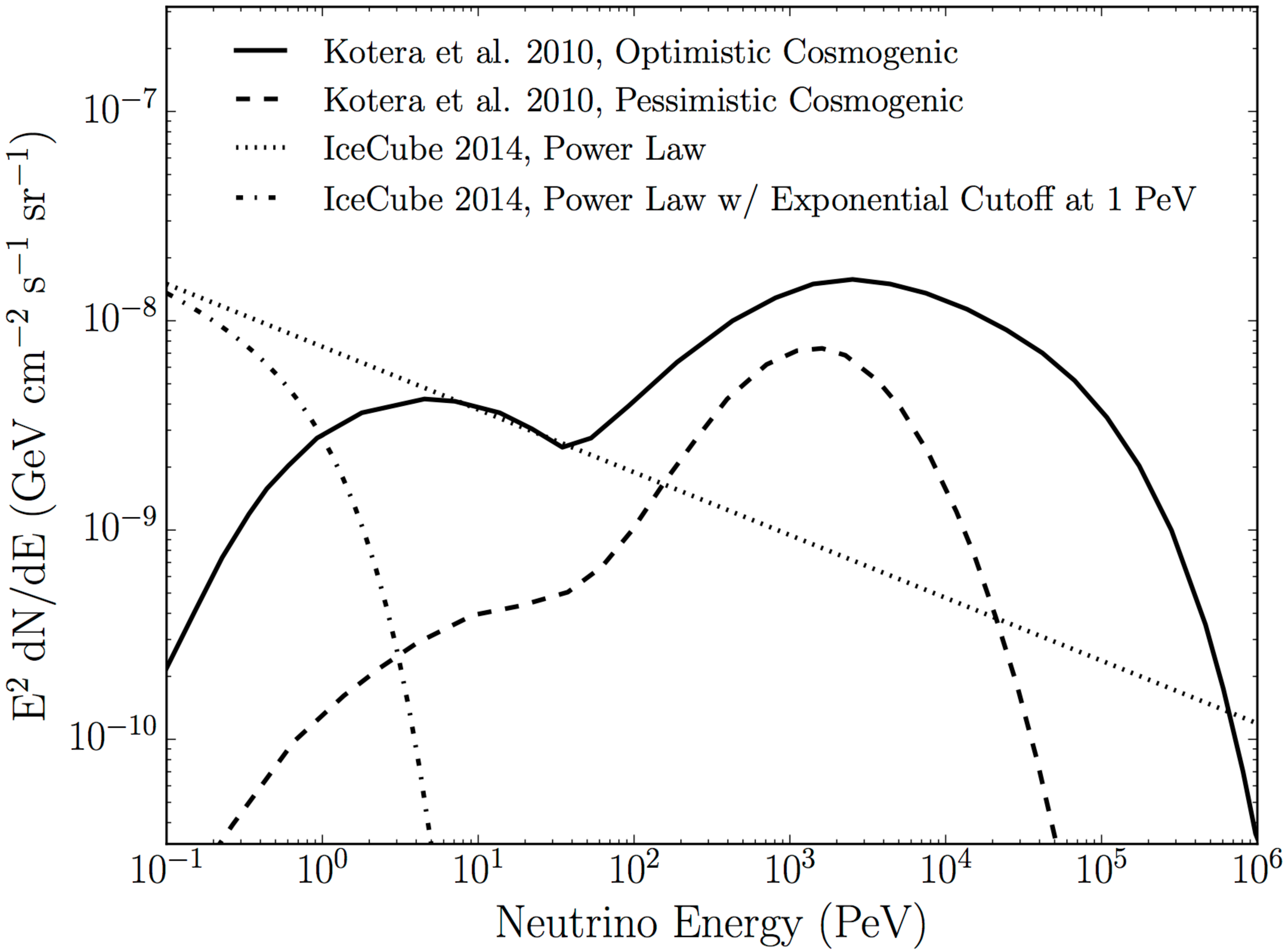
1000 PeV

Volumetric Acceptance

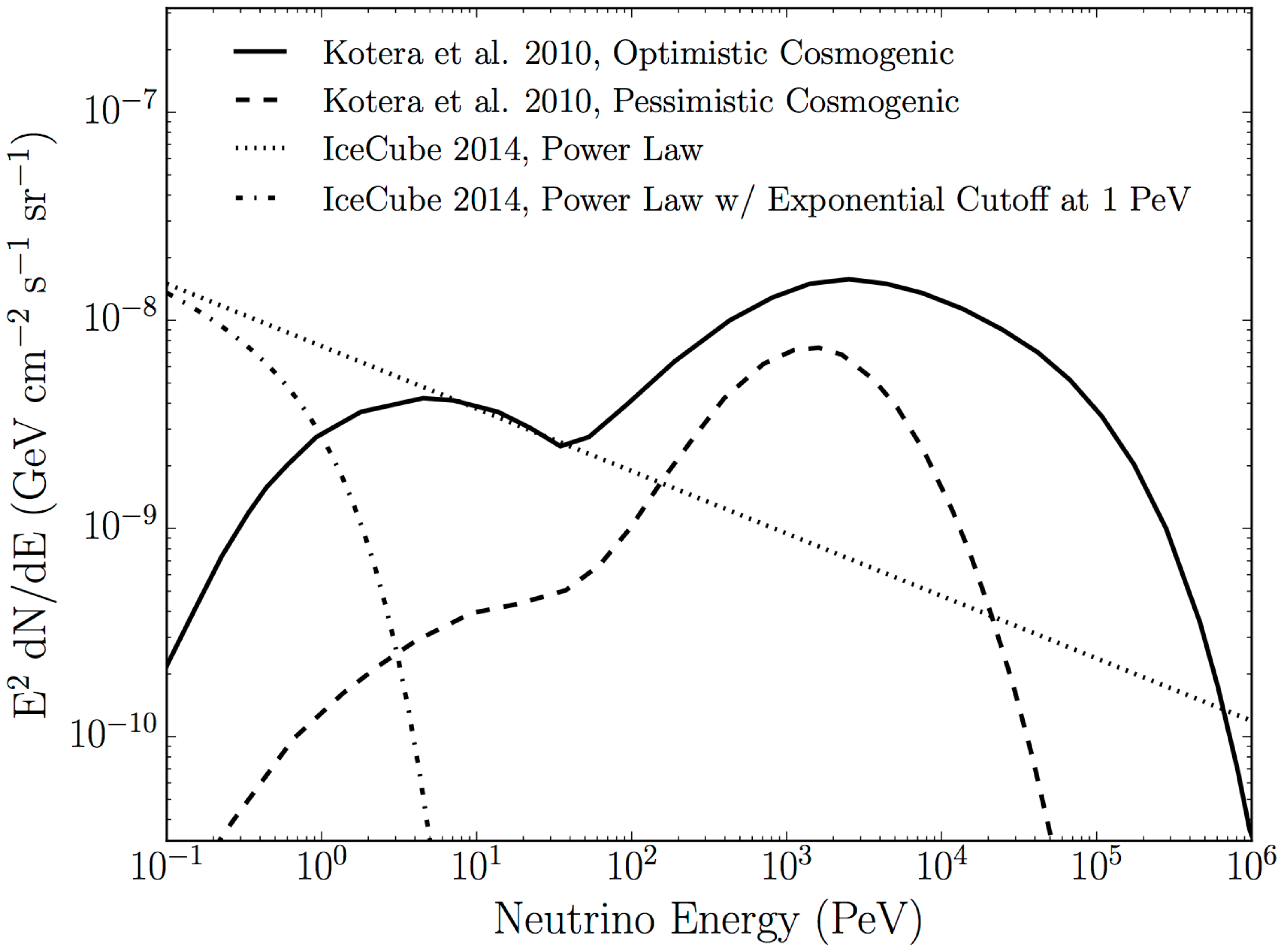


Acceptance for radio arrays at trigger level, IceCube acceptance at analysis level

Model Comparison

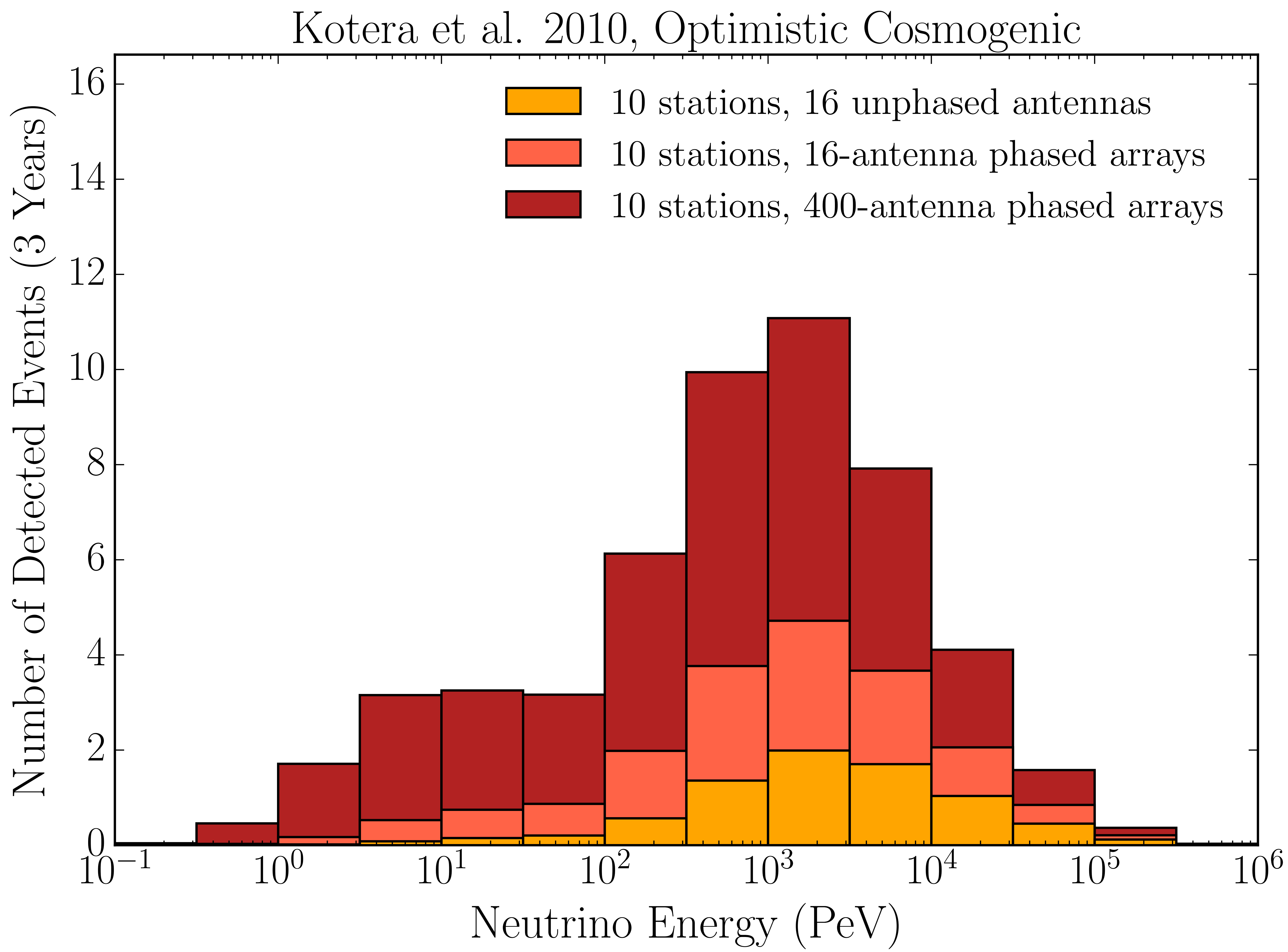


Model Comparison



Station Configuration	Power Law	Power Law with Cutoff	Optimistic Cosmogenic	Pessimistic Cosmogenic
16-antenna	0.9	0.0	7.7	2.3
16-antenna, phased	3.8	0.1	19.6	6.0
400-antenna, phased	18.4	2.2	52.9	15.6

Expected Events



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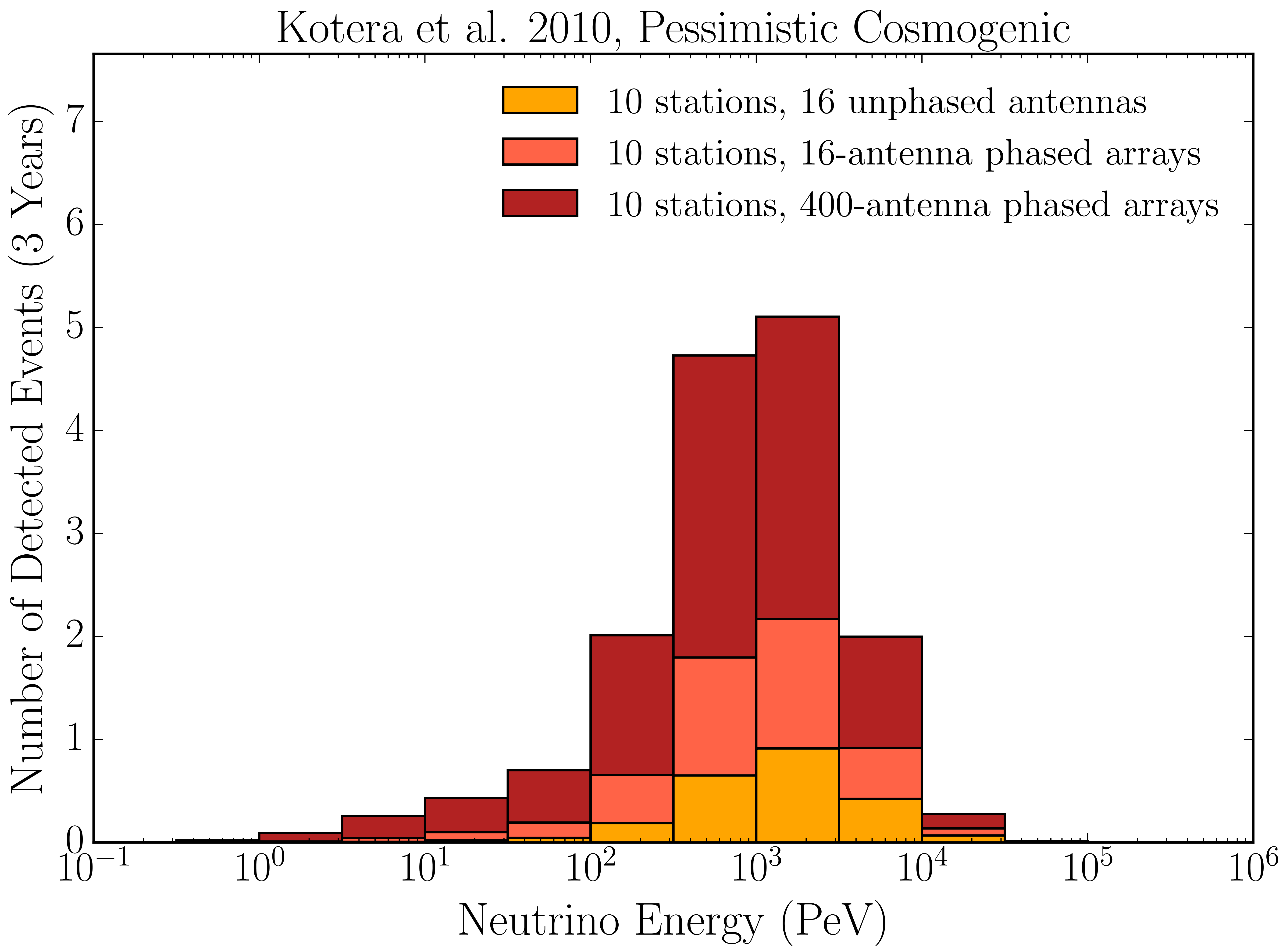

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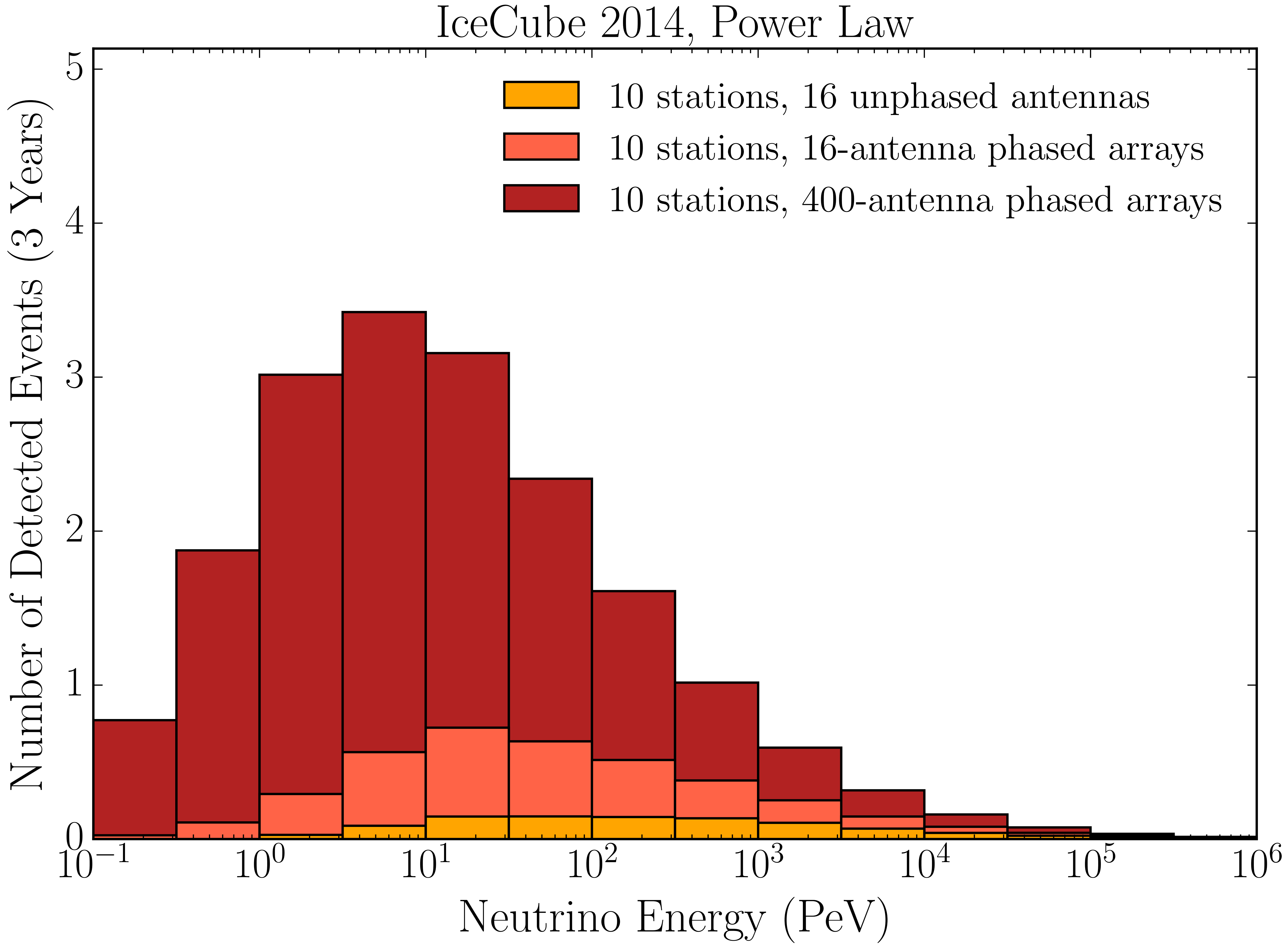

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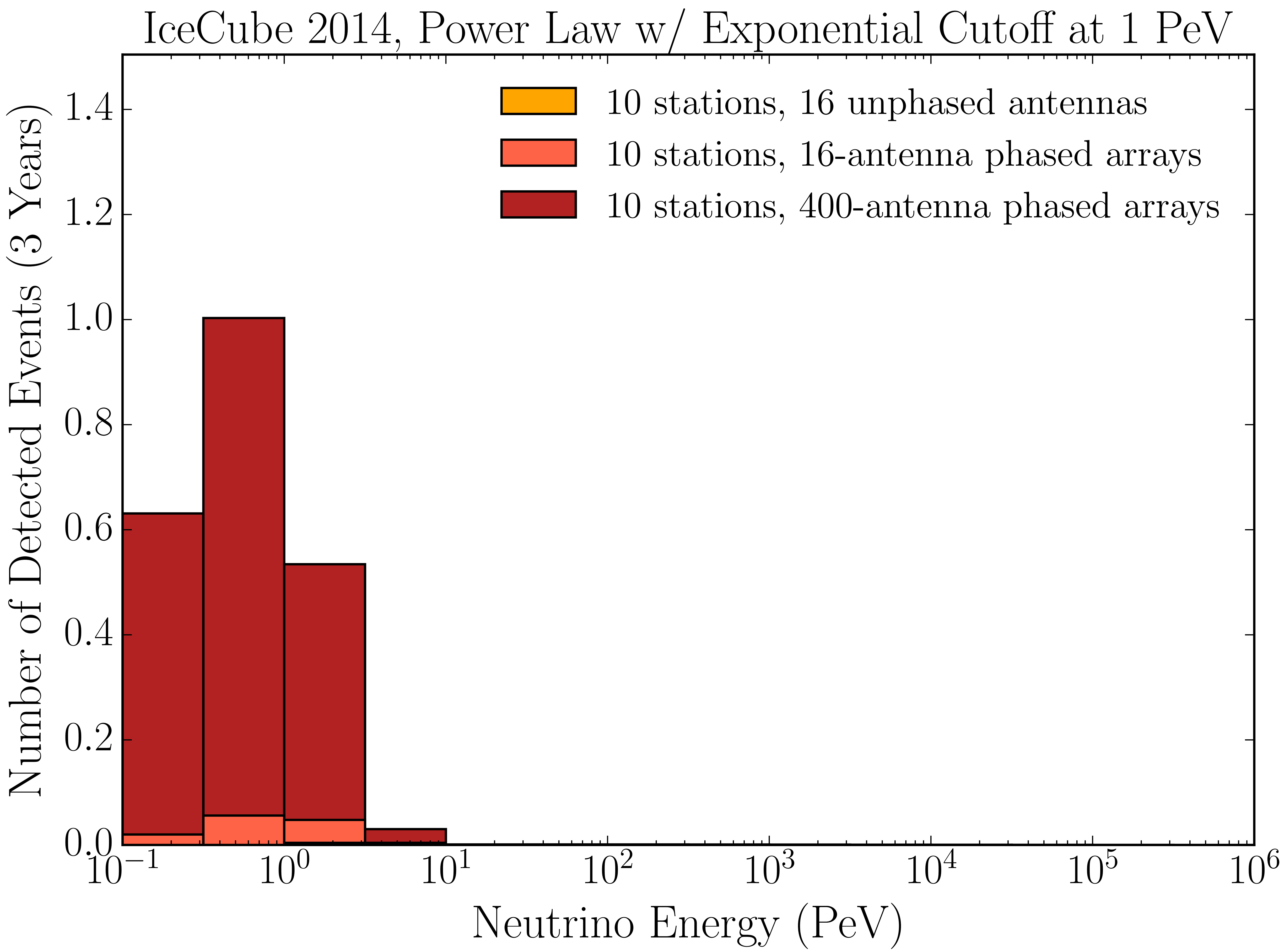


Key Points and Questions

Key Points

- Trigger and pointing arrays can be de-coupled (less sensitive to wavefront curvature, ice effects, etc.)
- Radio technique could potentially reach the PeV scale if a sufficient number of antennas are phased together
- Increase event rate over all energies with relatively modest hardware modifications (scalability of radio technique, energy calibration with optical Cherenkov techniques)

Open Questions

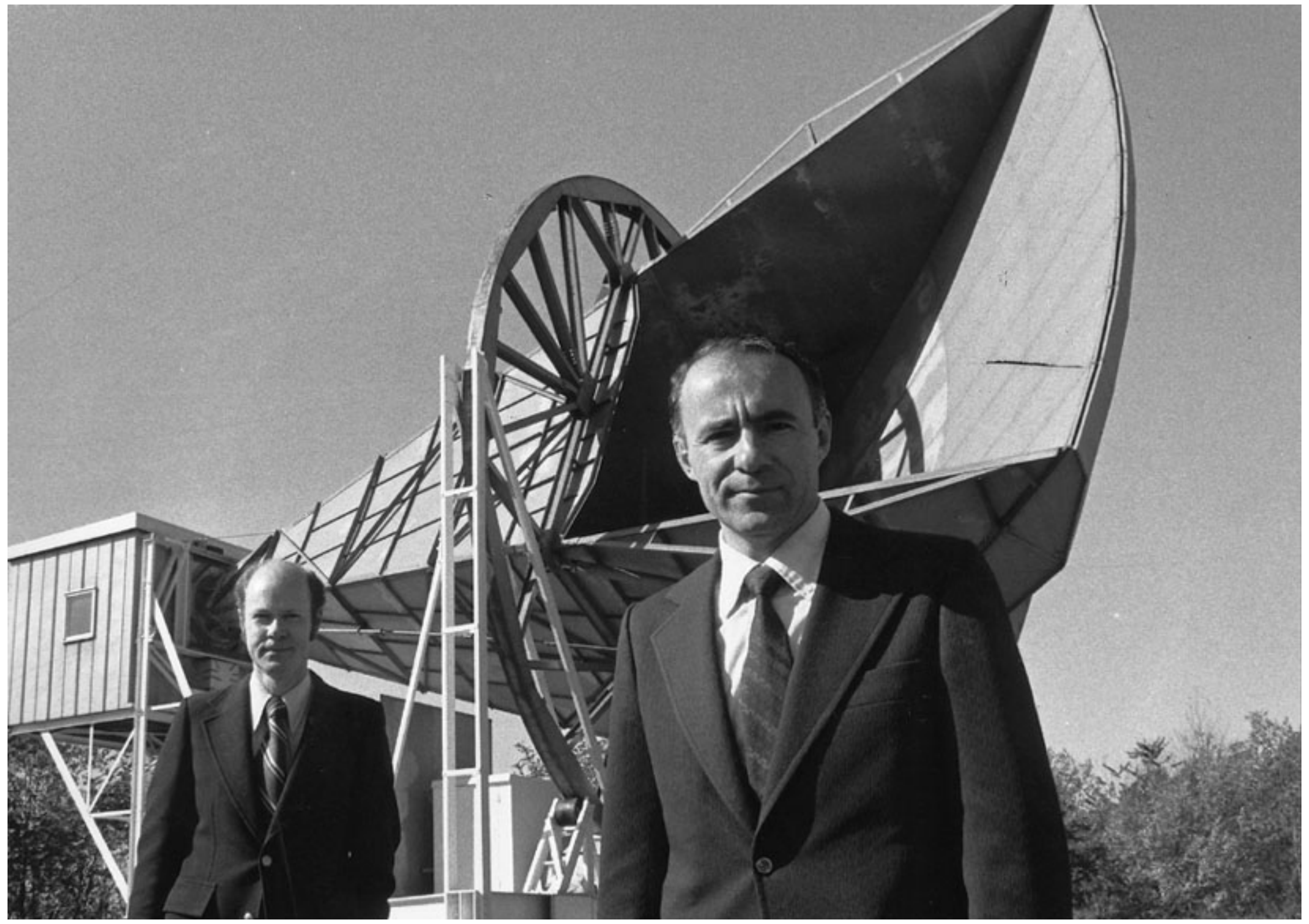
- Reconstructing events with lower signal-to-noise per antenna?
- When phasing more antennas, how would beams be distributed? More extensive hardware modifications?

See proceedings by Stephanie Wissel for tests of a prototype station in Greenland June 2015

UHE Neutrinos

UHECRs w/ E > 10^{20} eV

T = 2.7 K CMB



"Guaranteed" production of UHE neutrinos w/ E > 10^{18} eV
+ prompt emission at sources