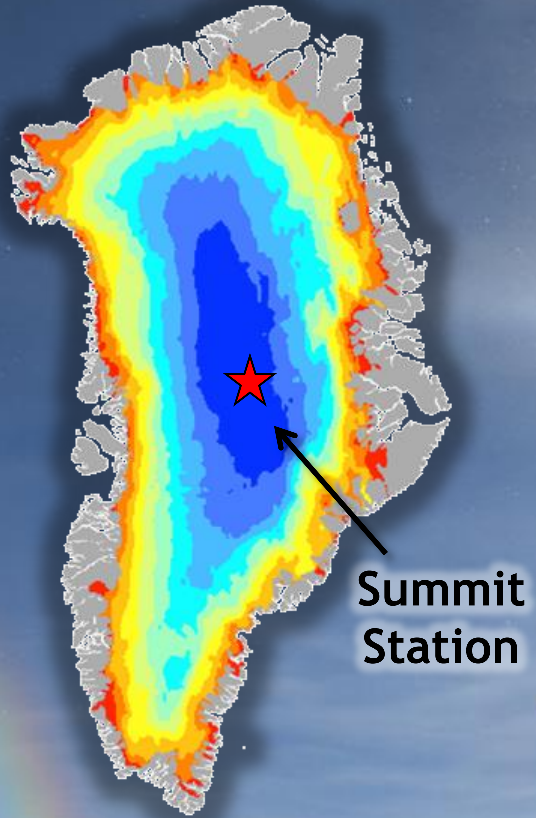
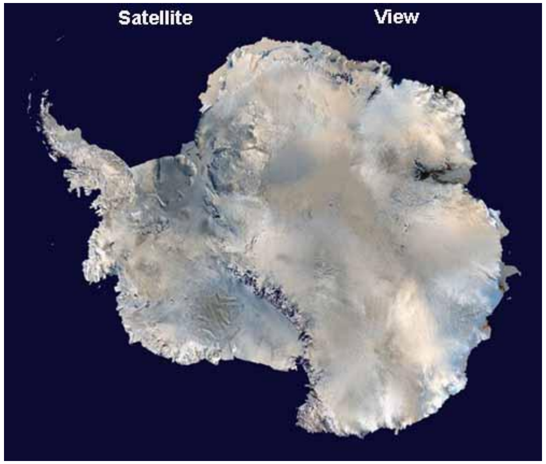


Greenland Neutrino Observatory

Keith Bechtol for the GNO Collaboration
KICP / University of Chicago
12 June 2014

GNO Concept

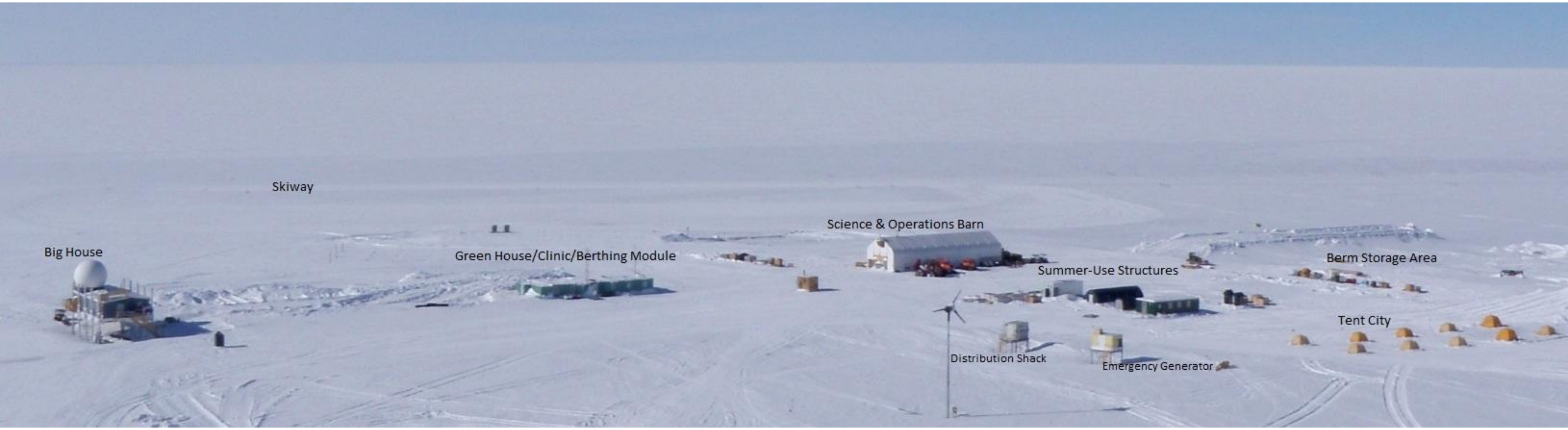


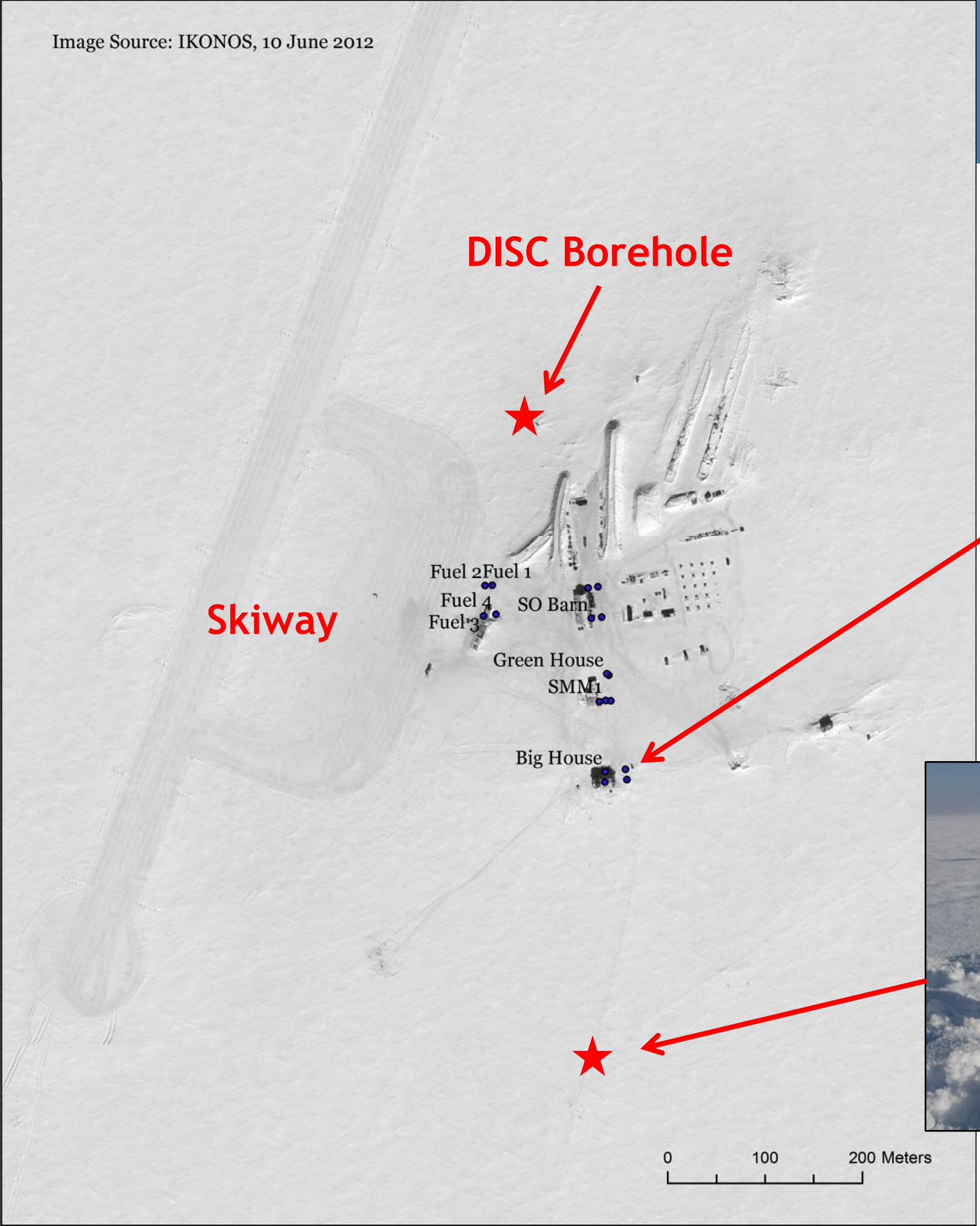
Antarctica and Greenland both have sufficient volumes ($>100\ km^3$) of radio-transparent ice

- In-ice radio detector array for UHE neutrinos
  - Very similar scientific goals and methods to ARA and ARIANNA
- Exploring **central Greenland** as candidate site for array of ~100 stations
- Investigating logistics, optimizing design, and preparing to deploy surface testbed station in spring 2015

Summit Station, Greenland

- NSF research station operated year round
- **Deepest ice of any reasonable site in Greenland**
  - ~3000 m, water layer at bottom (reflections add to effective volume)
  - South Pole ~2700 m
- Sunlight 10 months per year → solar power option, long summer
- Access:
  - LC-130 flights, annual overland traverse, flight from NY to Greenland
- Plans for a new “Isi” station with construction beginning 2014





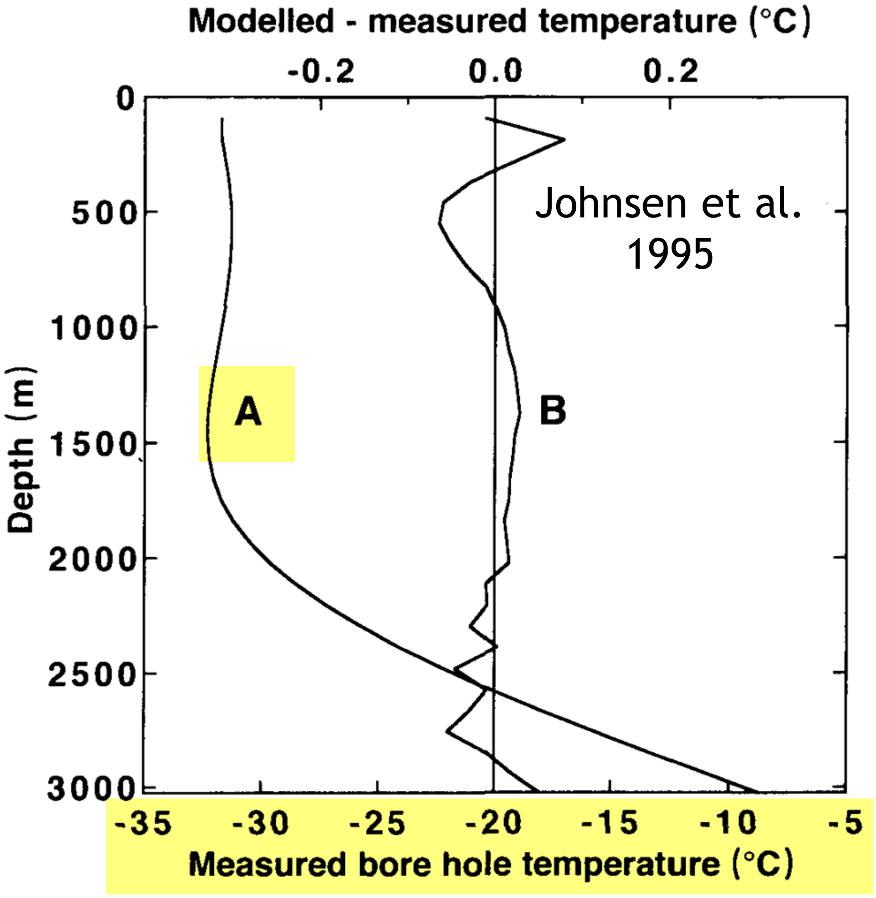
Big House

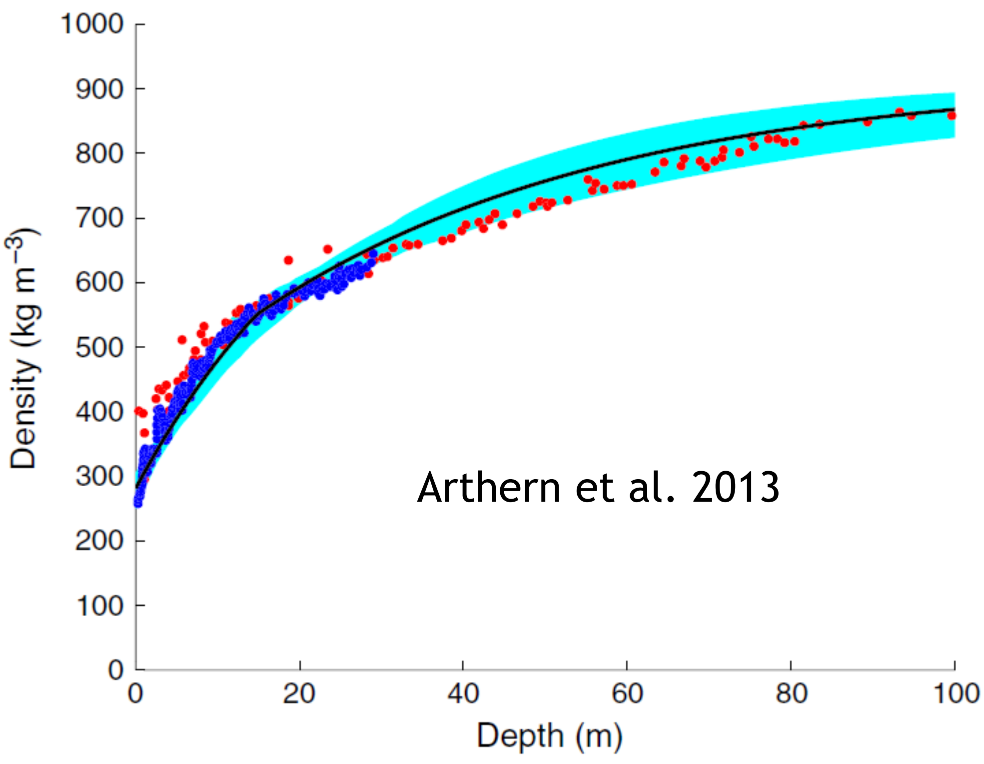
GISP2 Borehole

Summit Station, Greenland

Summit Station was site of Greenland Ice Sheet Project Two (GISP2) deep ice coring effort, completed 1993

→ Excellent data on ice properties already available





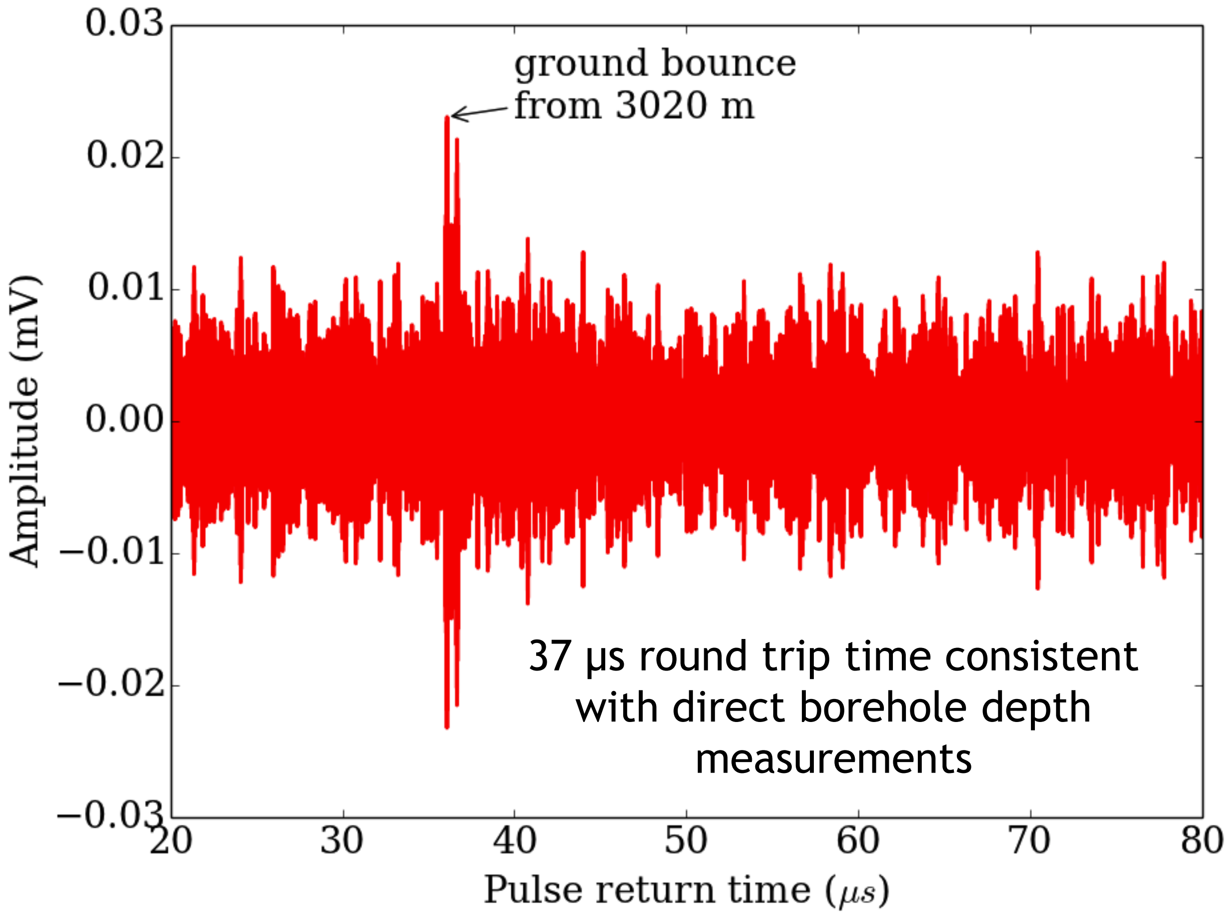
Site Characterization

Visited Summit Station in June 2013 to evaluate ice properties

- Attenuation length
- Calibration pulser down borehole
- Ambient RF background measurements

Using ground bounce to measure attenuation length

Attenuation Length



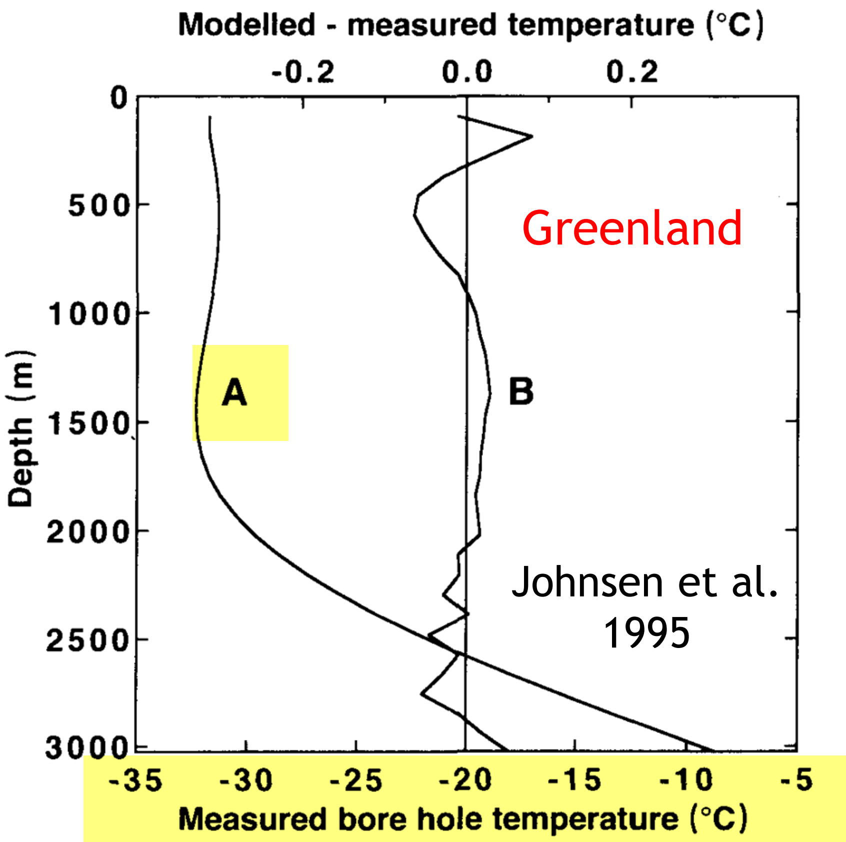
Filtered to 70-80 MHz

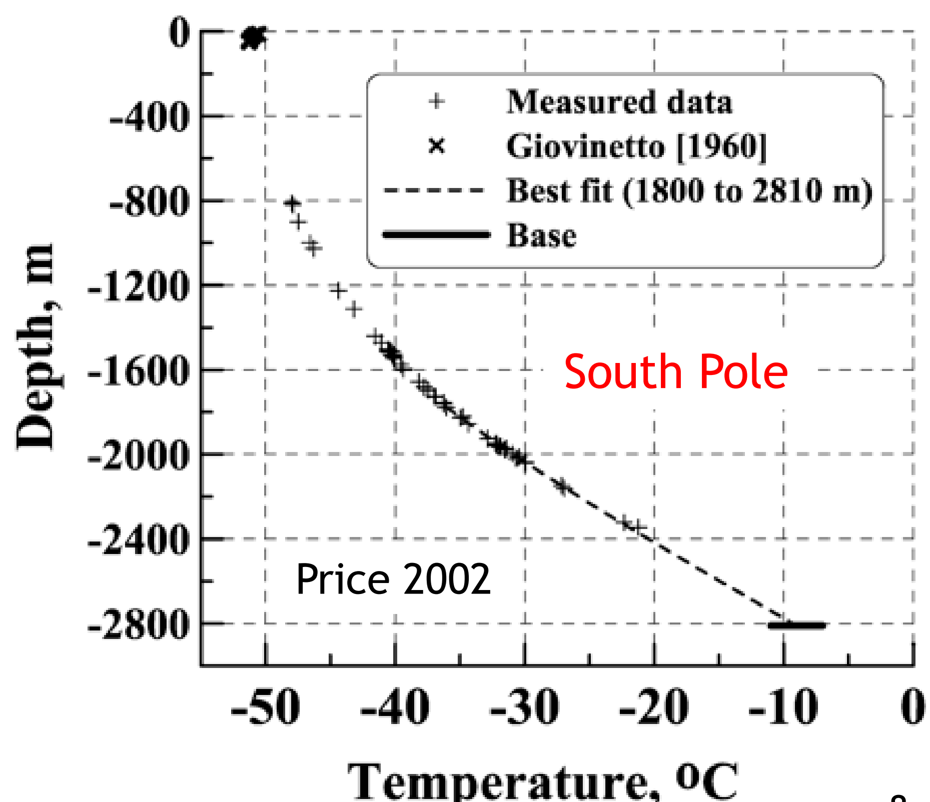
$$959^{+149}_{-127}\,\mathrm{m} \;@\; 75\,\mathrm{MHz}\;(\text{average over all depths})$$

Attenuation Length

Attenuation length varies with temperature (longer in colder ice) and frequency (longer at lower frequencies)

Greenland ice not as cold as South Pole

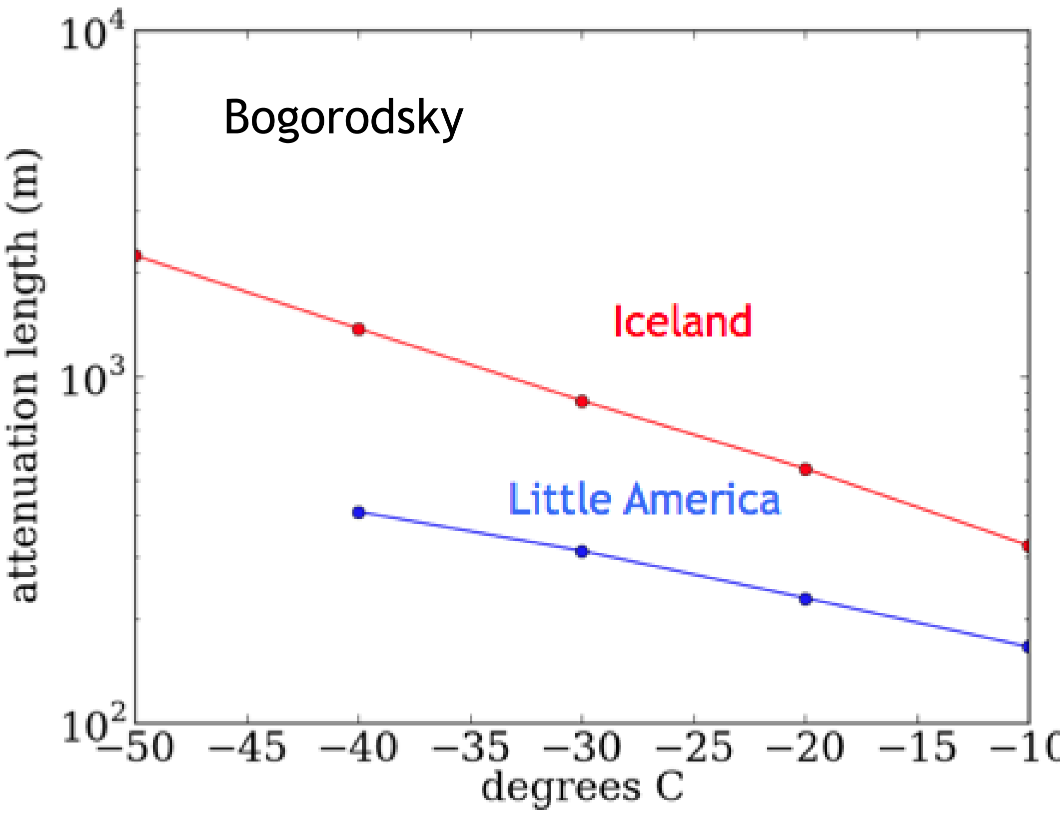




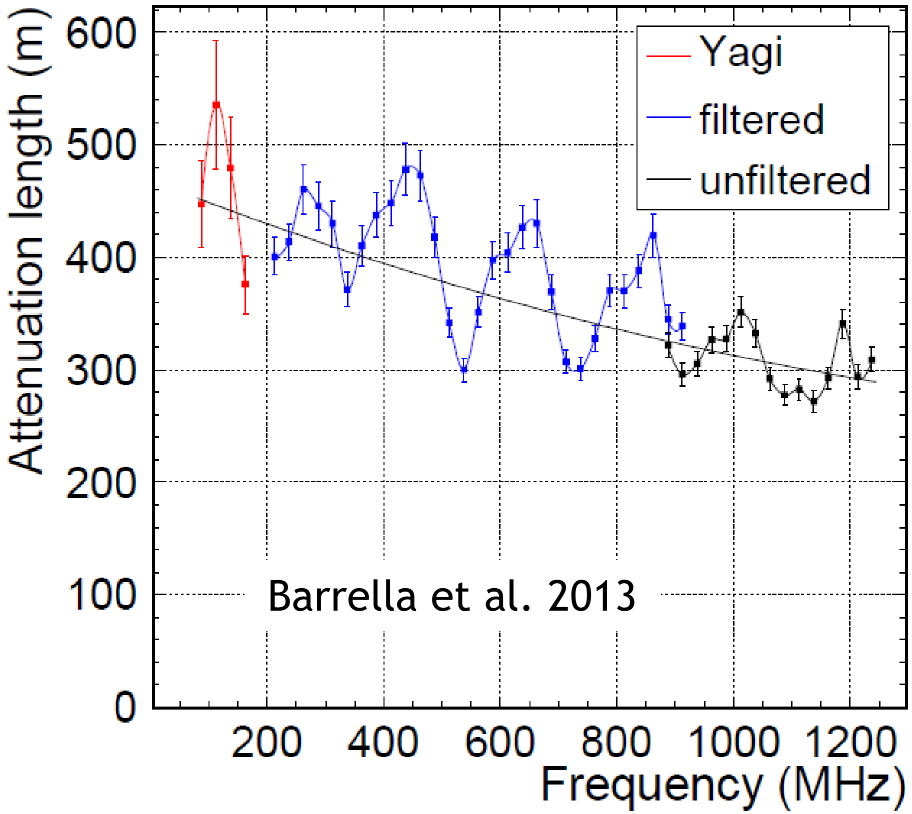
Attenuation Length

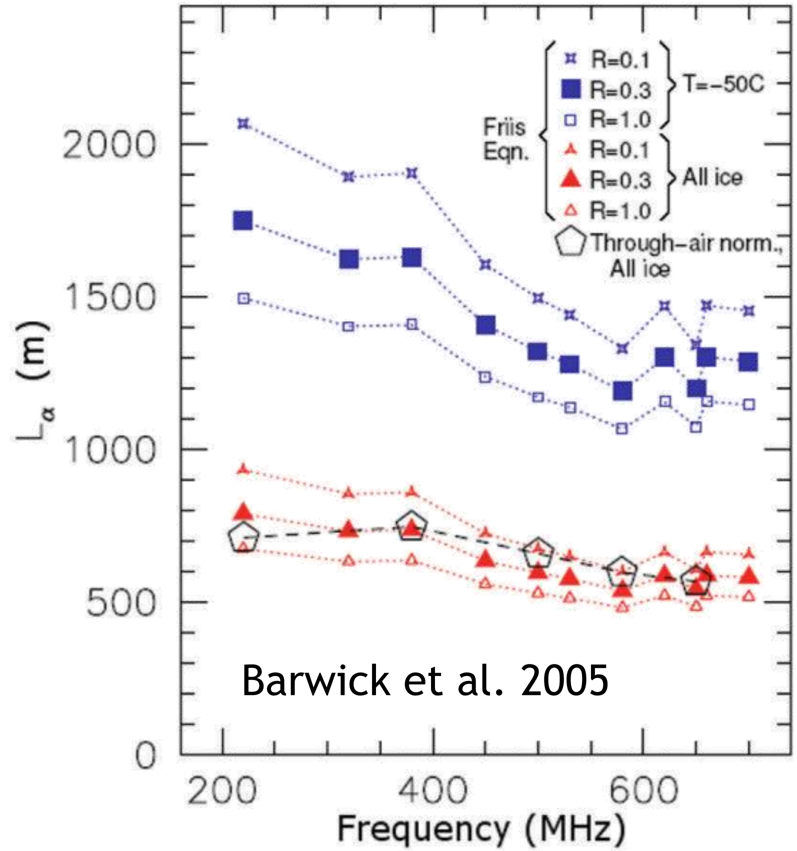
Attenuation length varies with temperature (longer in colder ice) and frequency (longer at lower frequencies)

Greenland ice not as cold as South Pole (-32C vs. -47C)



Attenuation Length



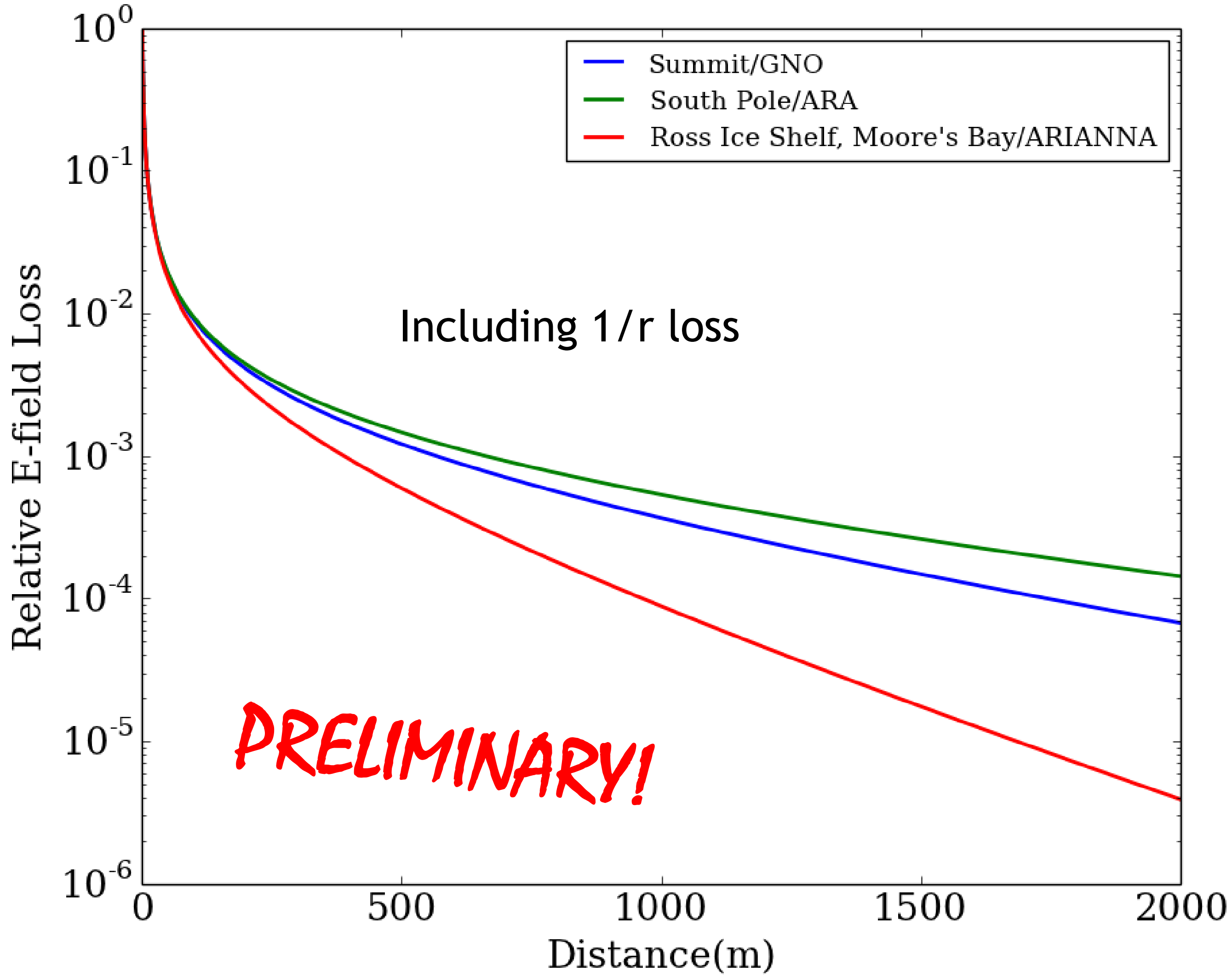


Frequency dependence measured directly at South Pole and Ross Ice Shelf

- Attenuation length falls off slower than 1/frequency

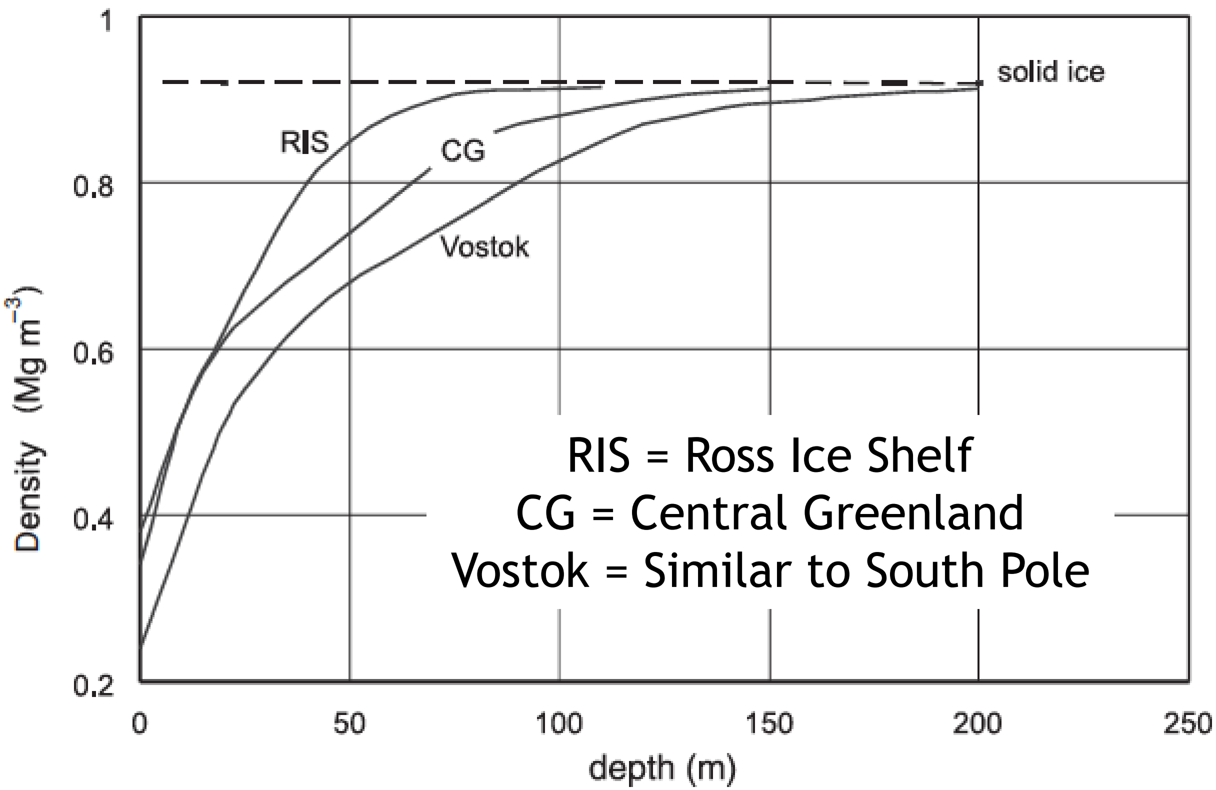
Preliminary Estimate: $997 \pm 150\,\mathrm{m} @ 300\,\mathrm{MHz} (\mathrm{upper}\ 1500\,\mathrm{m})$

Attenuation Length



Firn Layer Comparison

Depth of firn layer affects balance between cost of drilling deep and time for station deployment vs. increasing effective volume (more on this later)

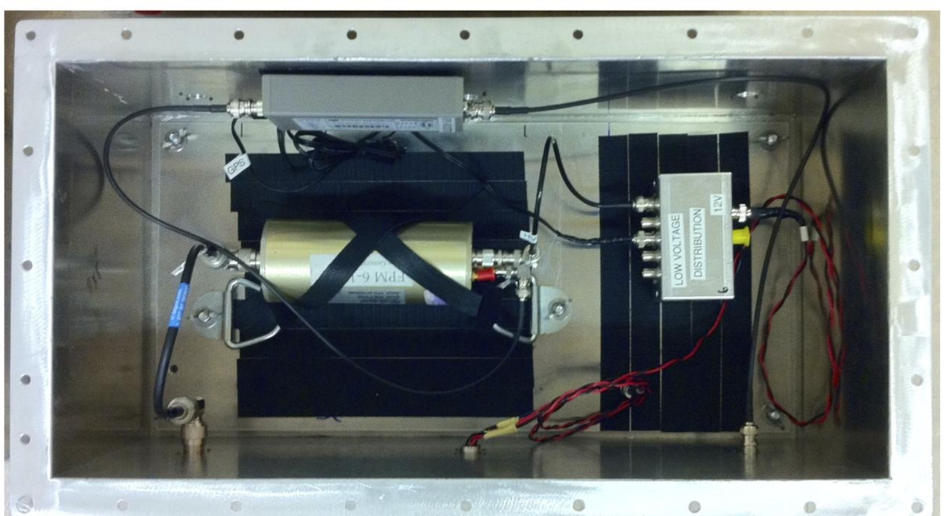


Thinner firn layer in central Greenland relative to South Pole

Summit Station: DISC Borehole

Deep Ice-Sheet Coring (DISC) borehole all the way to bedrock (3053 m) available for our use

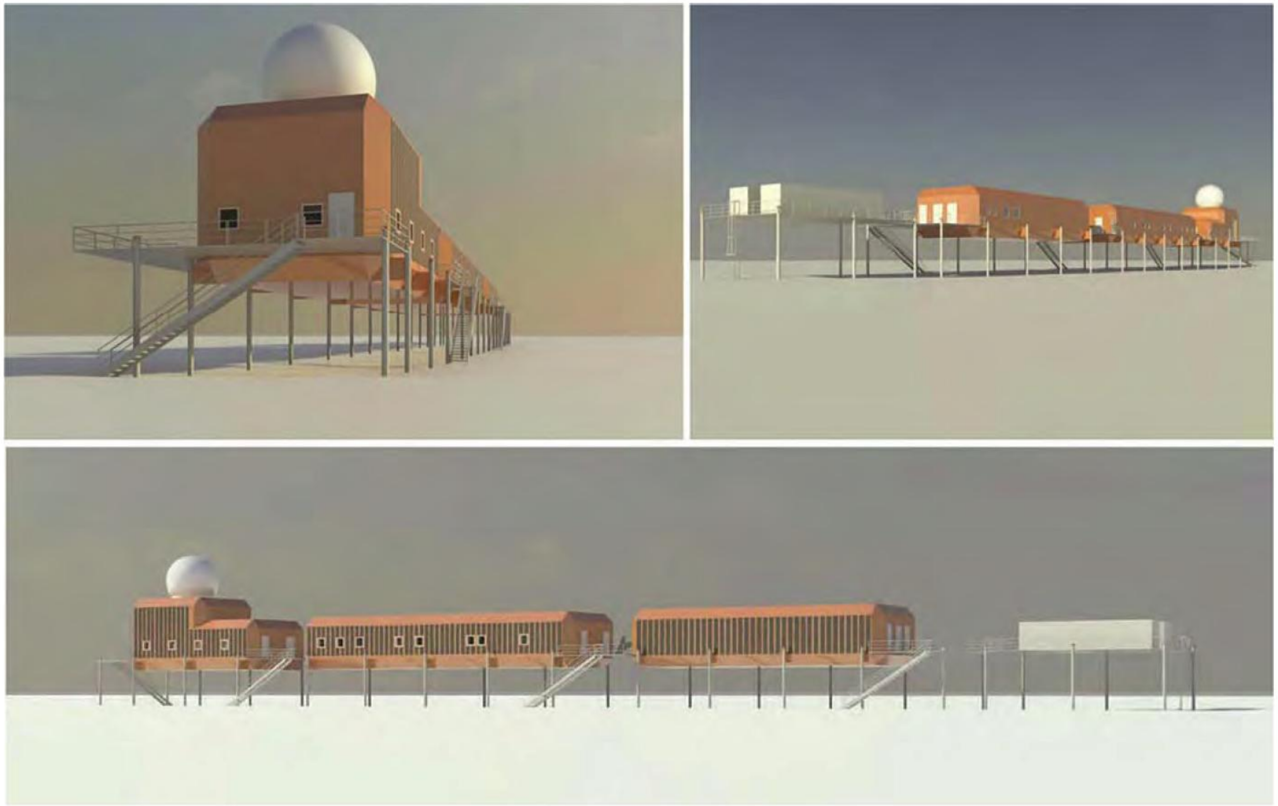
Calibration pulser system includes GPS receiver, high voltage pulser, and transmitting antenna.



Planning to test at many depths and install two such systems at 500 m and 1000 m down borehole

Isi Station

- Gradual transition from existing Summit Station facilities to new Isi facilities between now and 2020
- Population in 2018: 15 minimum over winter, 60 max in summer



Residence, dining, power plant / emergency power plant, lab / balloon inflation, garage

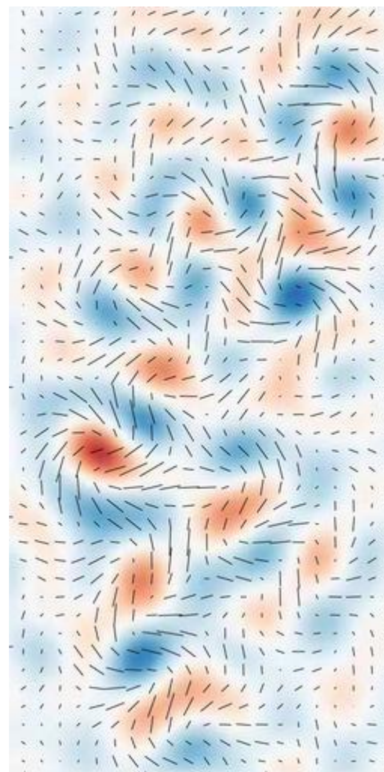
Atmospheric Watch Observatory

Isi Station

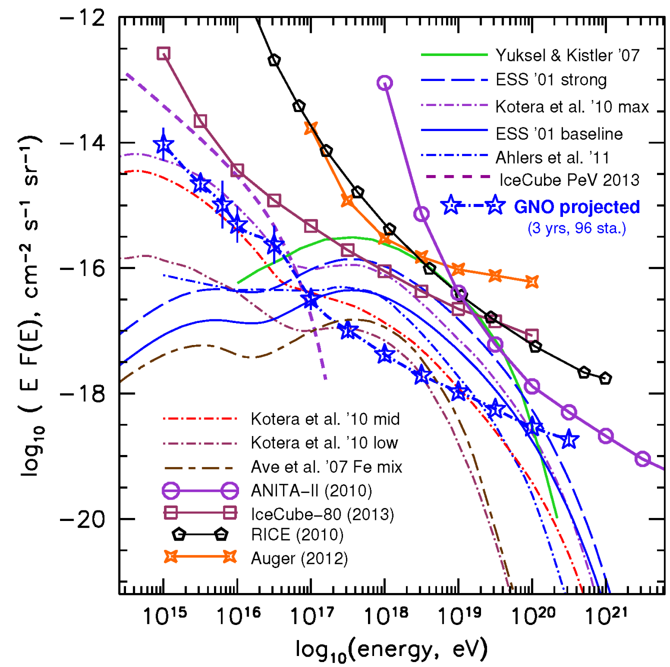
Astrophysics and cosmology experiments feature prominently among expected science anchor tenants at Isi Station

12 m telescope part of VLBI network

CMB Telescopes



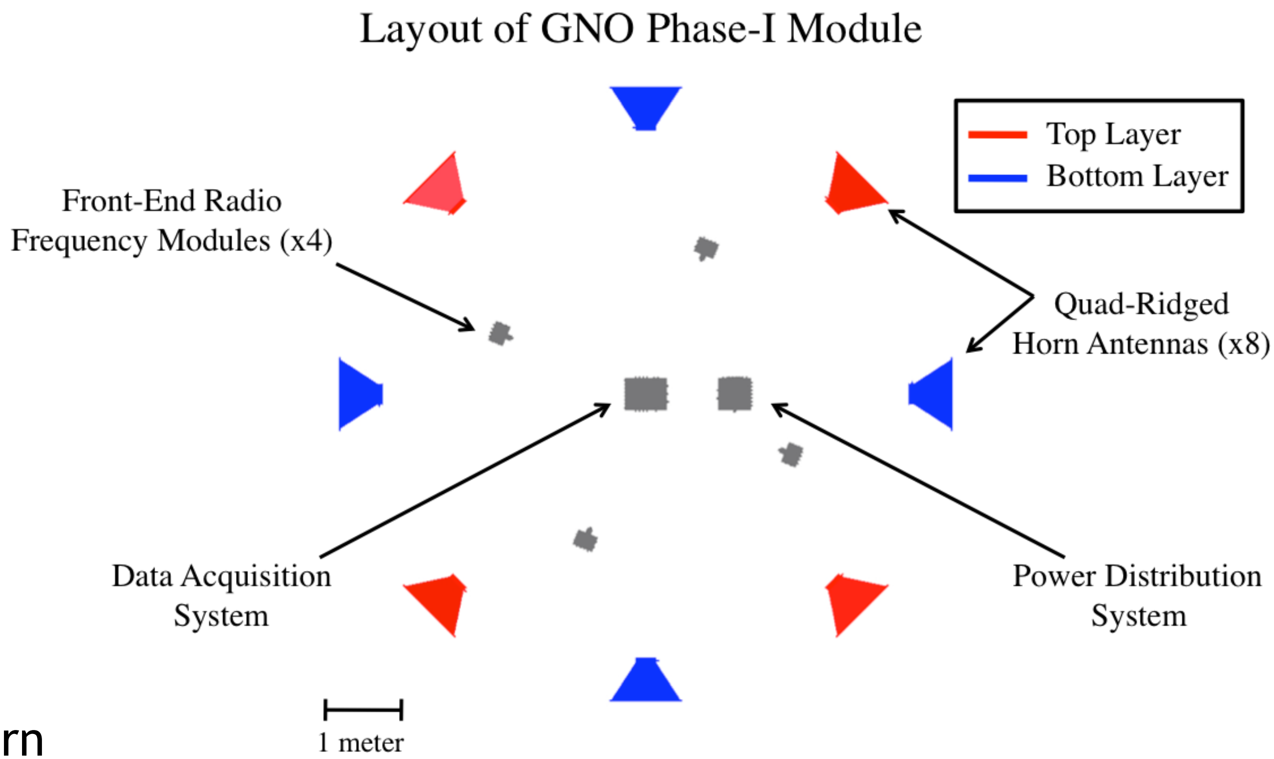
Greenland Neutrino Observatory



Deploy Testbed Station Spring 2015

- Near-surface antennas (1-2 meters deep)
- Run off summit station power first winter, then develop solar power

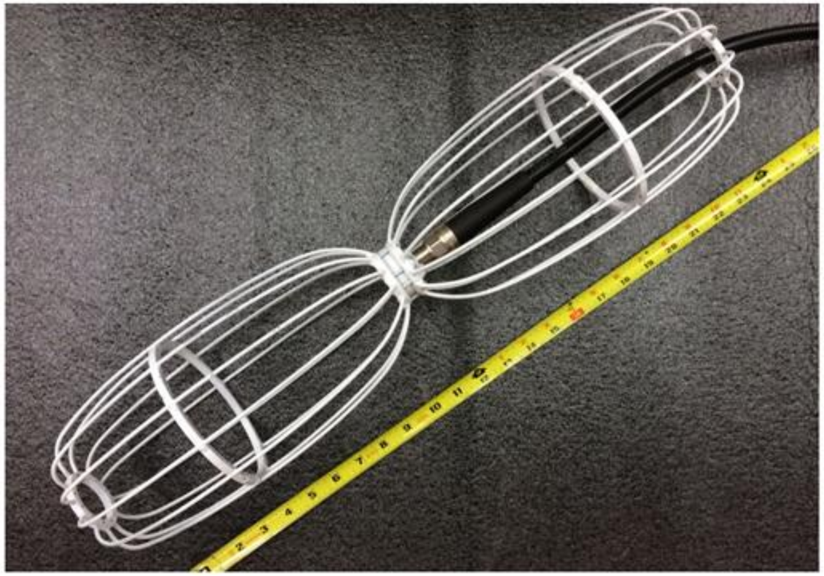
High-gain, quad-ridged horn antenna planned for use in first station (same as ANITA), or log-periodic antennas



8 vertical + 8 horizontal polarization channels

Season 2 Testbed Station

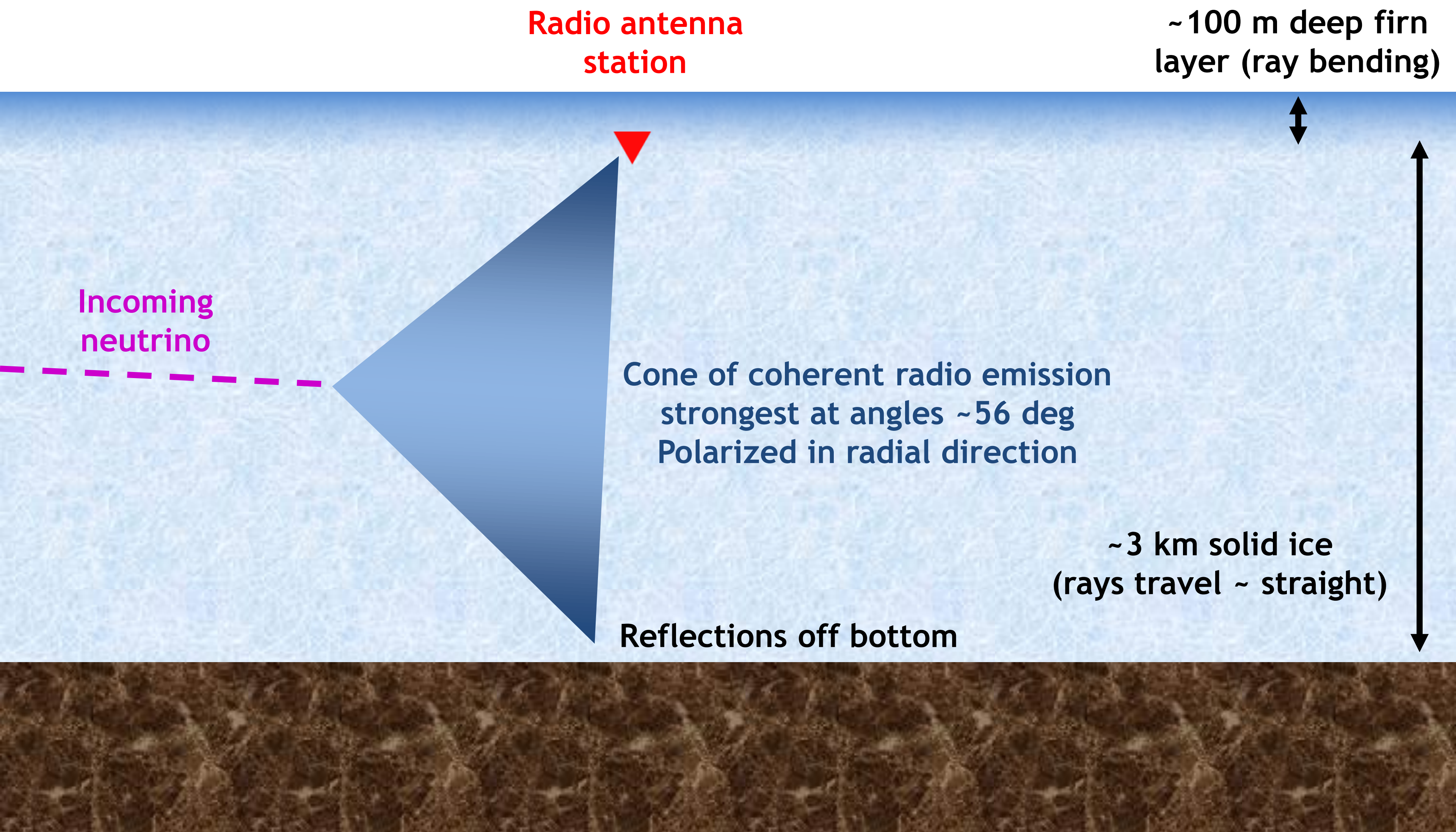
Planning to deploy station at 100 m depth in second season to directly test performance gain relative to surface station



Vertically polarized down-borehole antenna

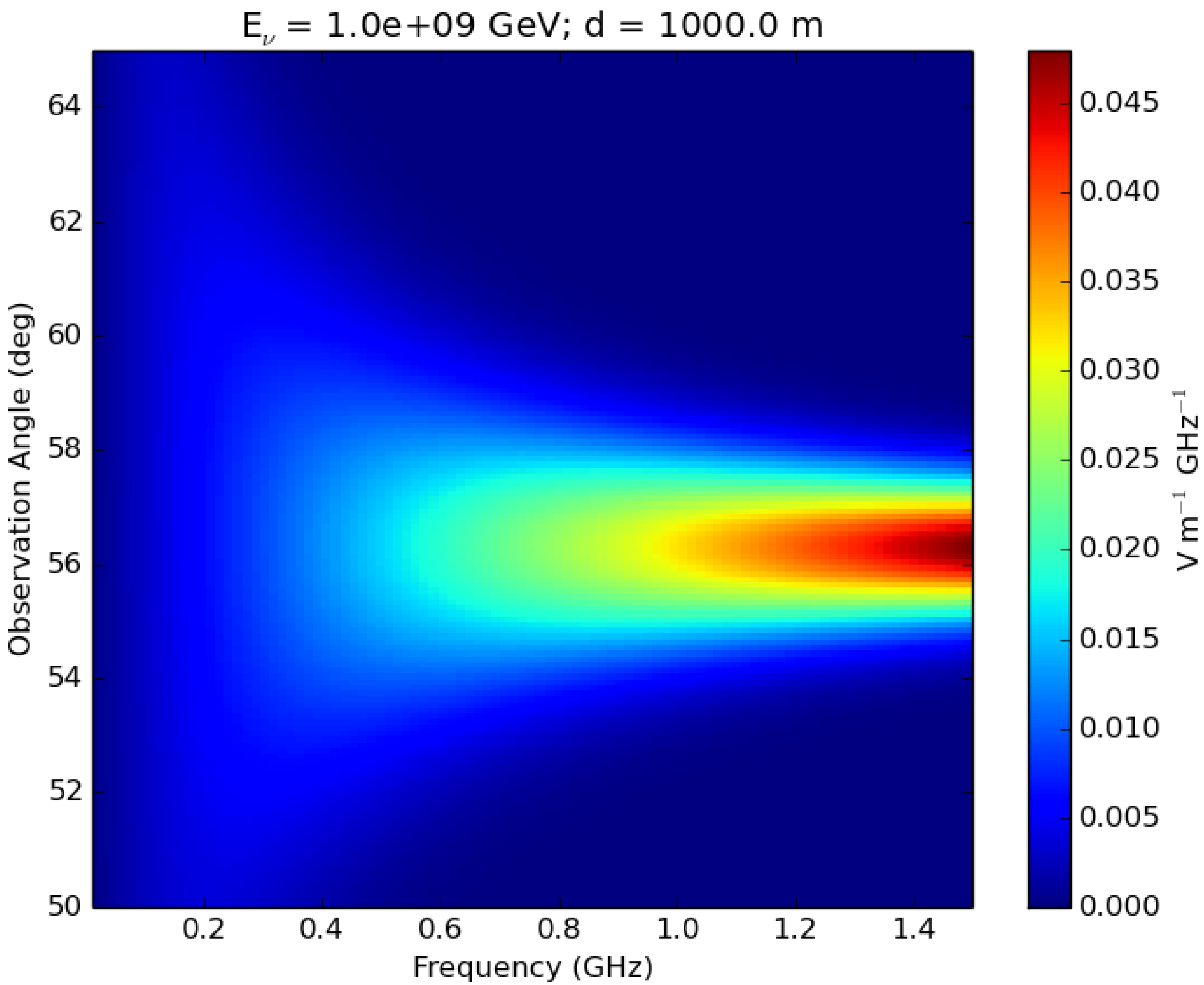
Horizontally polarized down-borehole antenna

Event Geometry



Radio Cherenkov Emission

Using parameterization of Lehtinen et al. 2003 based on Zas et al. 1992



Simulations Framework

- Precompute ray-tracing solutions using boundary condition that rays must intersect antenna
  - i.e., shoot rays "backwards" from antenna to interaction vertex
- Throw neutrinos randomly in target volume and with uniformly distributed arrival directions in solid angle
  - Interaction probability weighted by local ice density
- Calculate electric field at antenna using interpolation of ray-tracing solutions around interaction vertex

Simulations Framework

V_{sim} = simulated target volume

Density ratio

Volumetric acceptance (km^3 sr water equivalent)

$$V\Omega = \frac{4\pi \times V_{\text{sim}}}{N} \times \sum_{i \in \text{Detected Events}} \left(P_{\text{Earth},\, i} \times \frac{\rho_i}{\rho_{\text{water}}} \right)$$

N = Total # of simulated events

P_{Earth} = Prob neutrino survives Earth traverse

Acceptance (m^2 sr)

$$A\Omega = \frac{V\Omega}{\langle l \rangle}$$

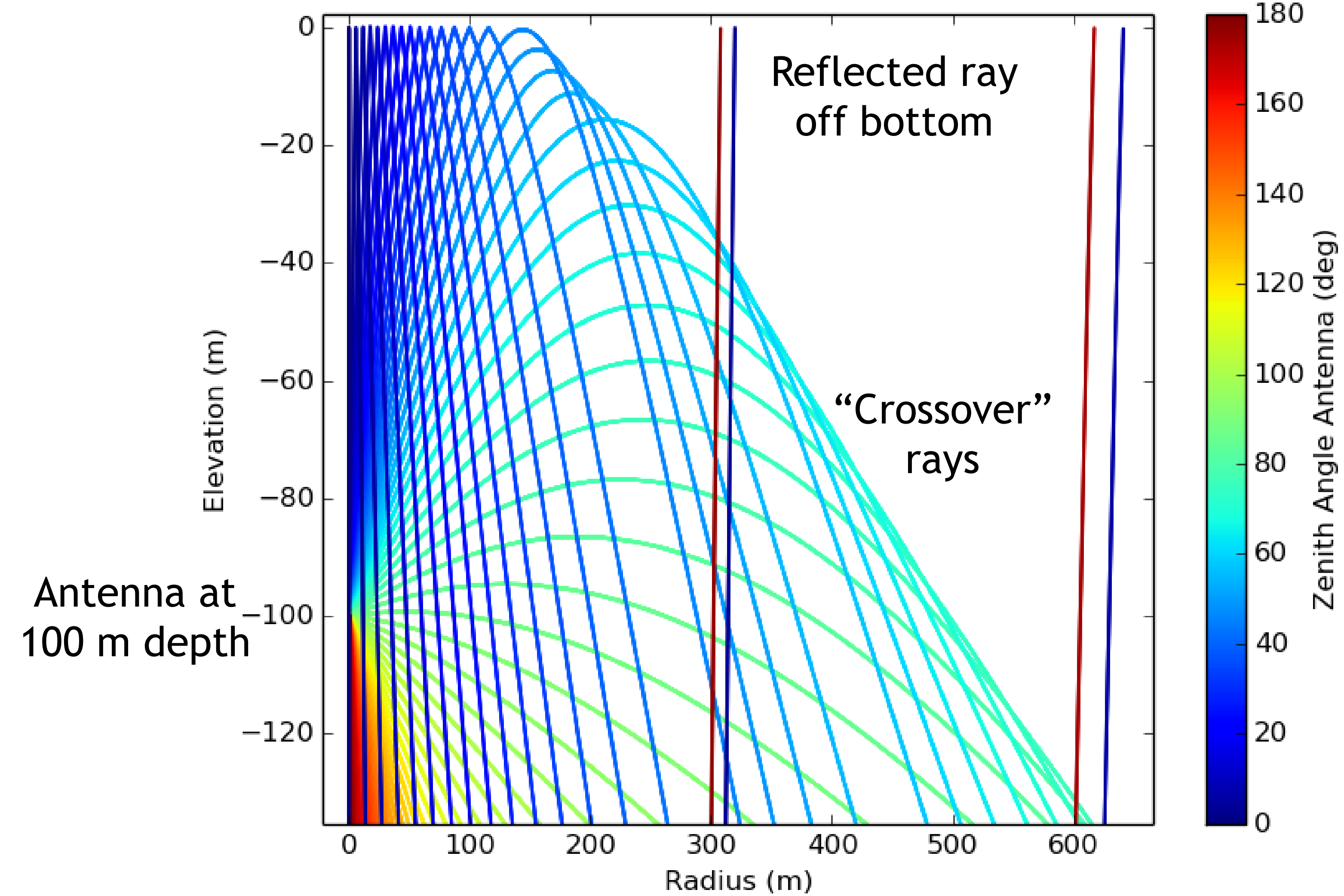
Expectation value of interaction length (m)

$$\langle l \rangle = \sigma \times \rho_{\text{water}}$$

Volumetric acceptance computed in water-equivalent units

Ray-Tracing Solutions

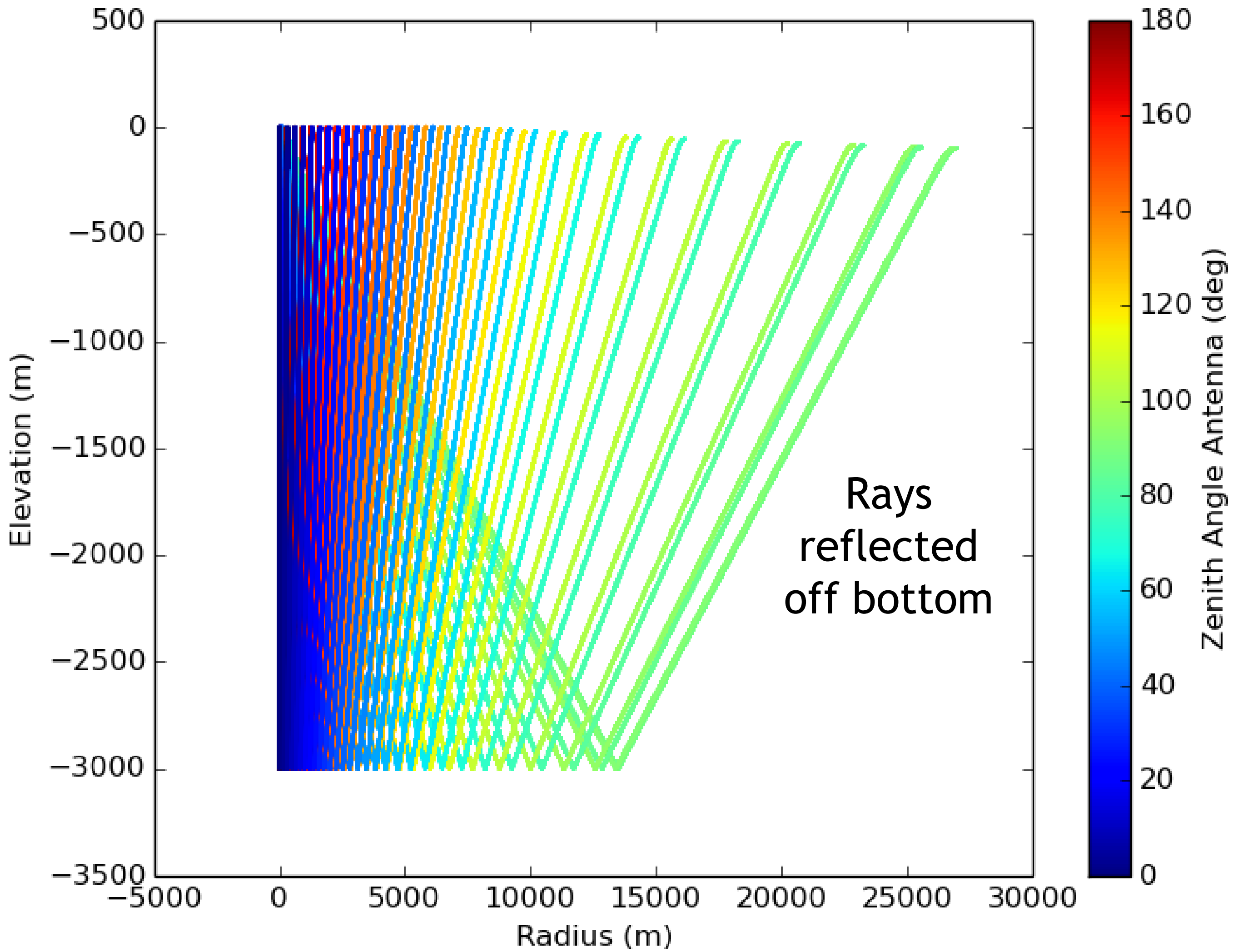
Reflections off ice-air interface



Shooting rays "backwards" from antenna to interaction vertex

Ray-Tracing Solutions

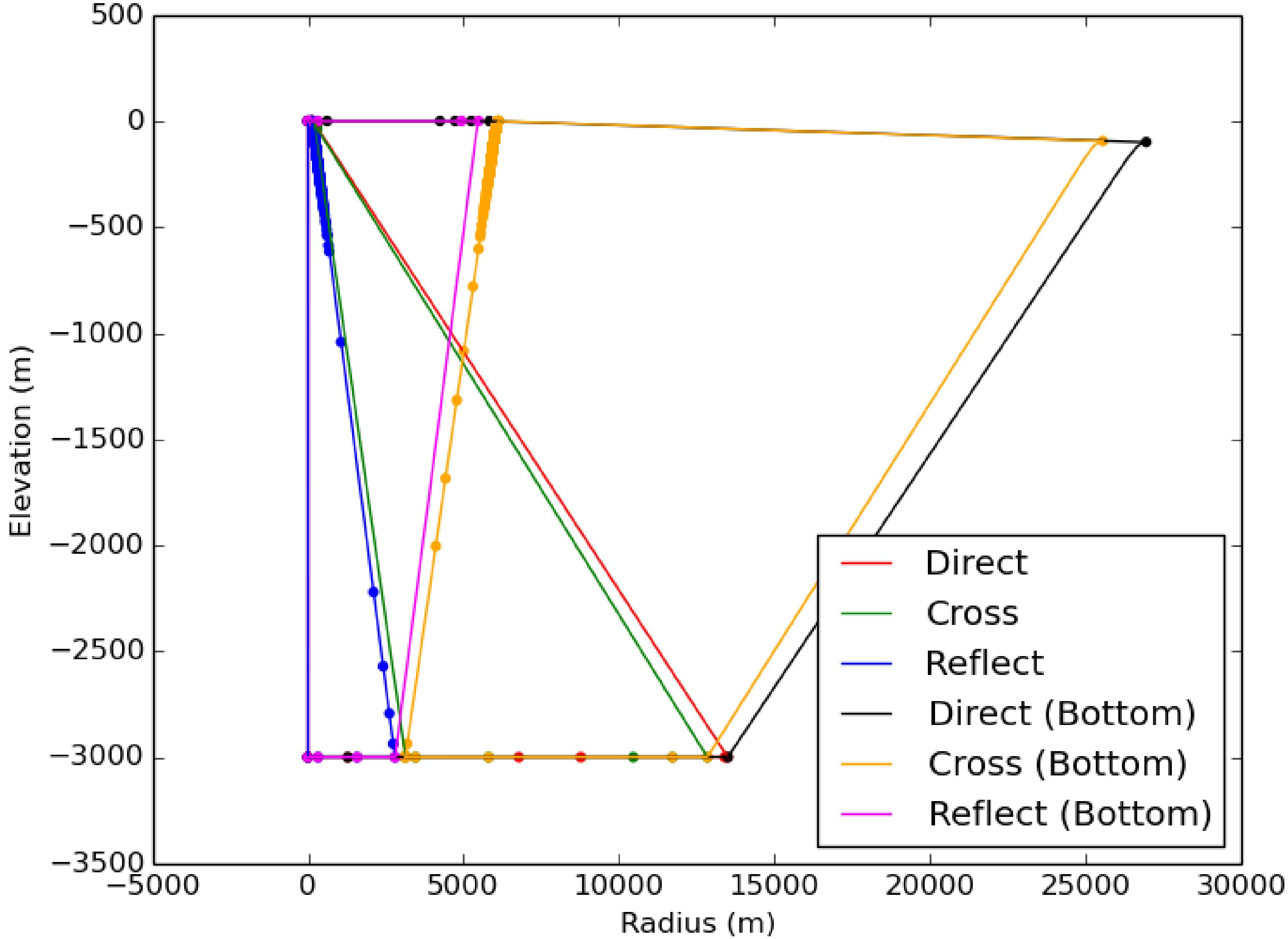
Zooming out from previous figure



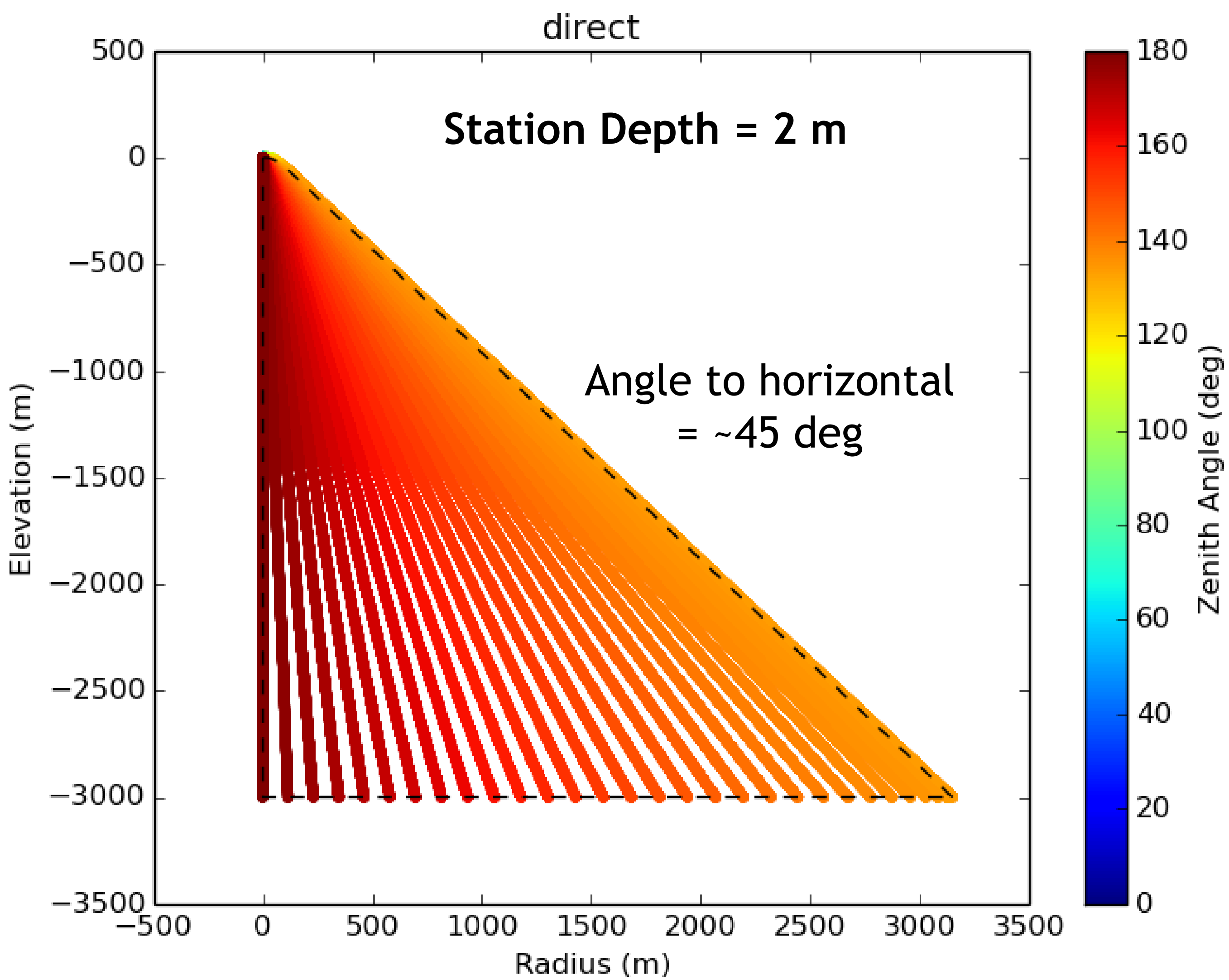
Ray-Tracing Solutions

6 ray-tracing solution regions in depth-volume space

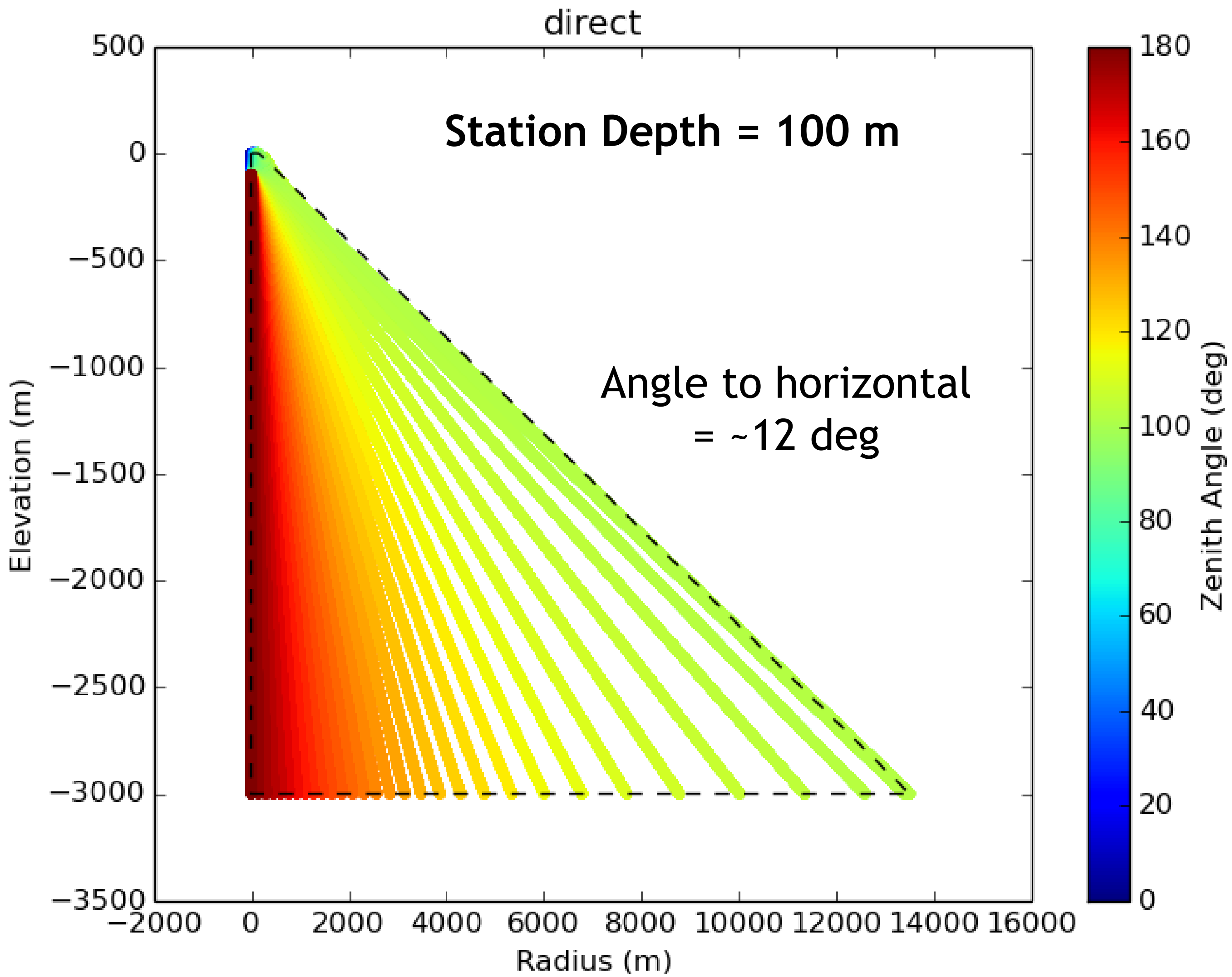
including reflections off bottom and top of ice sheet



Surface vs. Deep Configuration



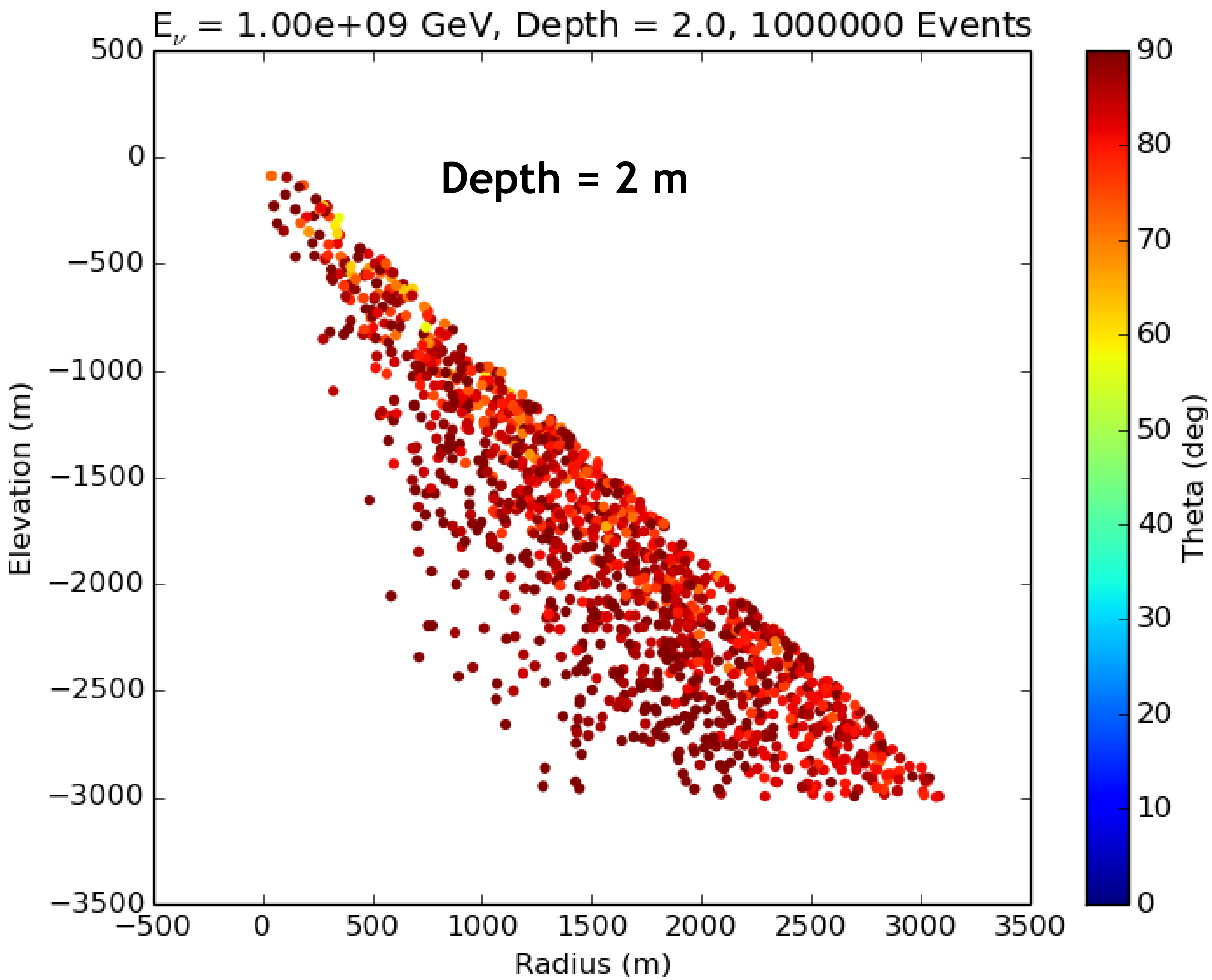
Surface vs. Deep Configuration



Note different horizontal scale

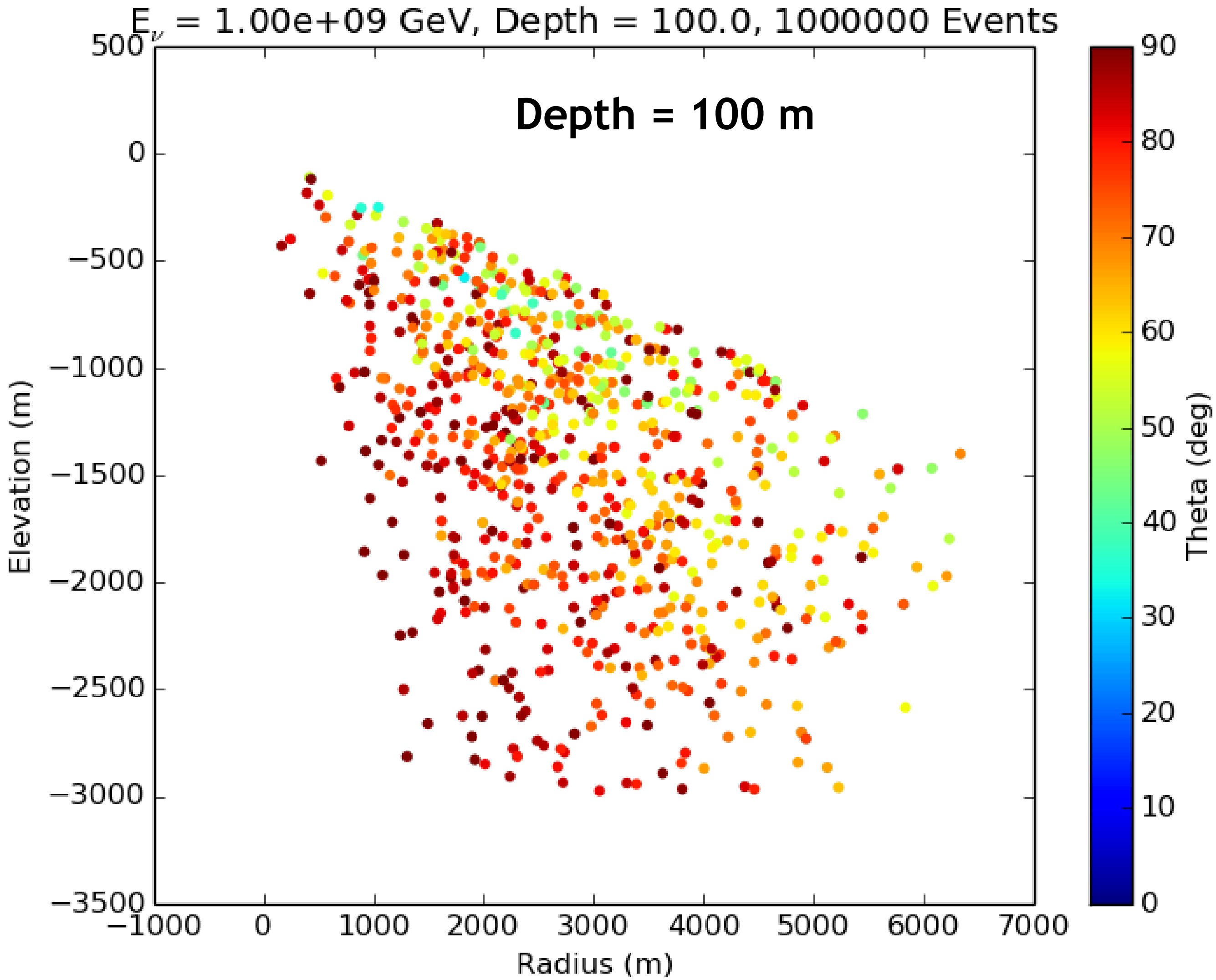
Surface vs. Deep Configuration

Interaction vertices of detected neutrino events, color-coded by zenith angle of neutrino arrival direction



Surface vs. Deep Configuration

Interaction vertices of detected neutrino events, color-coded by zenith angle of neutrino arrival direction



Simulation Caveats

PRELIMINARY!

- Currently using simplistic trigger criterion
  - 100% efficiency for events producing an electric field at antenna exceeding some threshold
- Not yet attempting to include multi-station effects
  - Limit of widely spaced stations
- Not yet attempting to account for differences in antenna response between various designs
- Increasing fidelity of detector response is major upcoming simulation effort

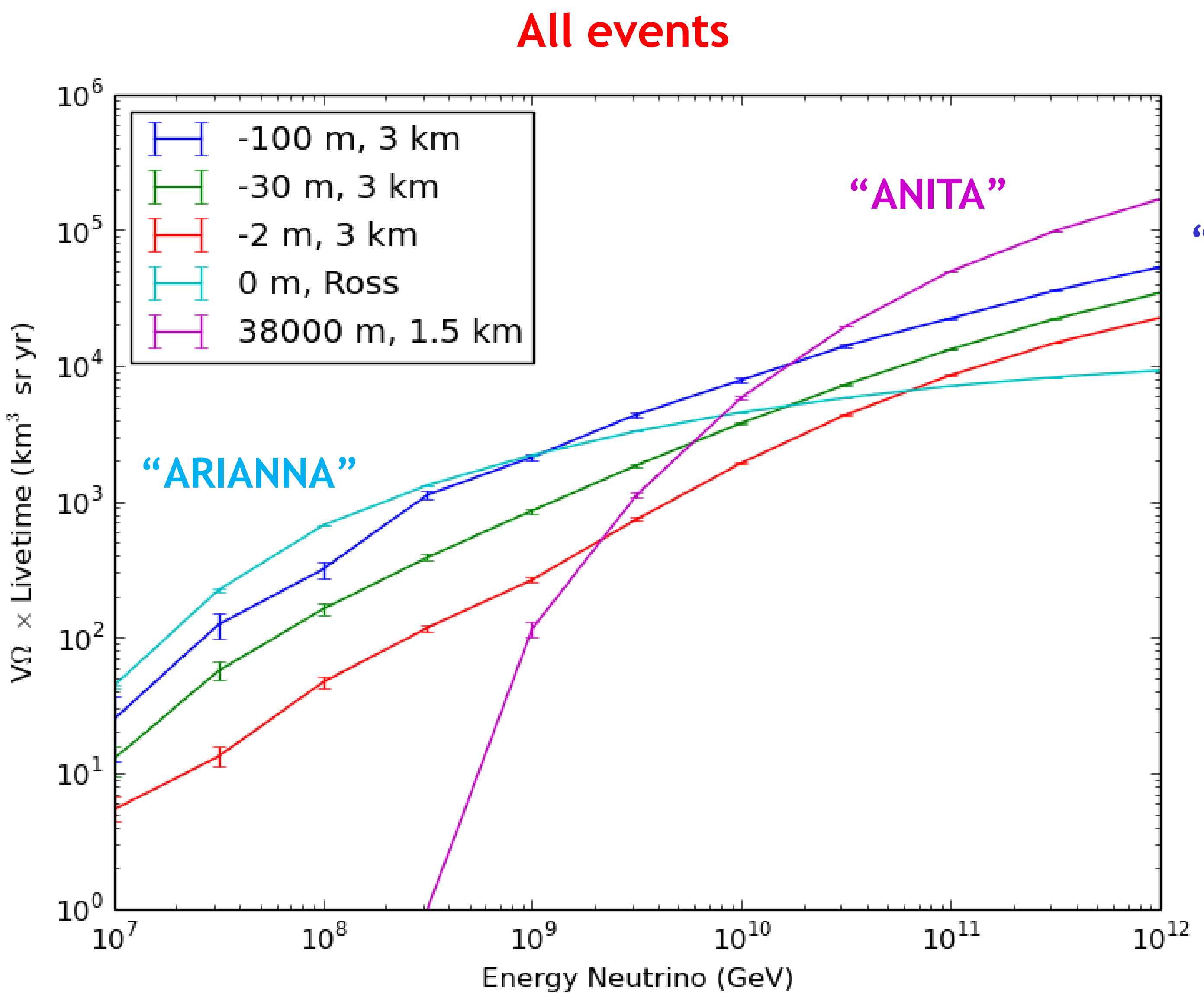
Simulated Detector Configurations

GNO-like configurations shaded red

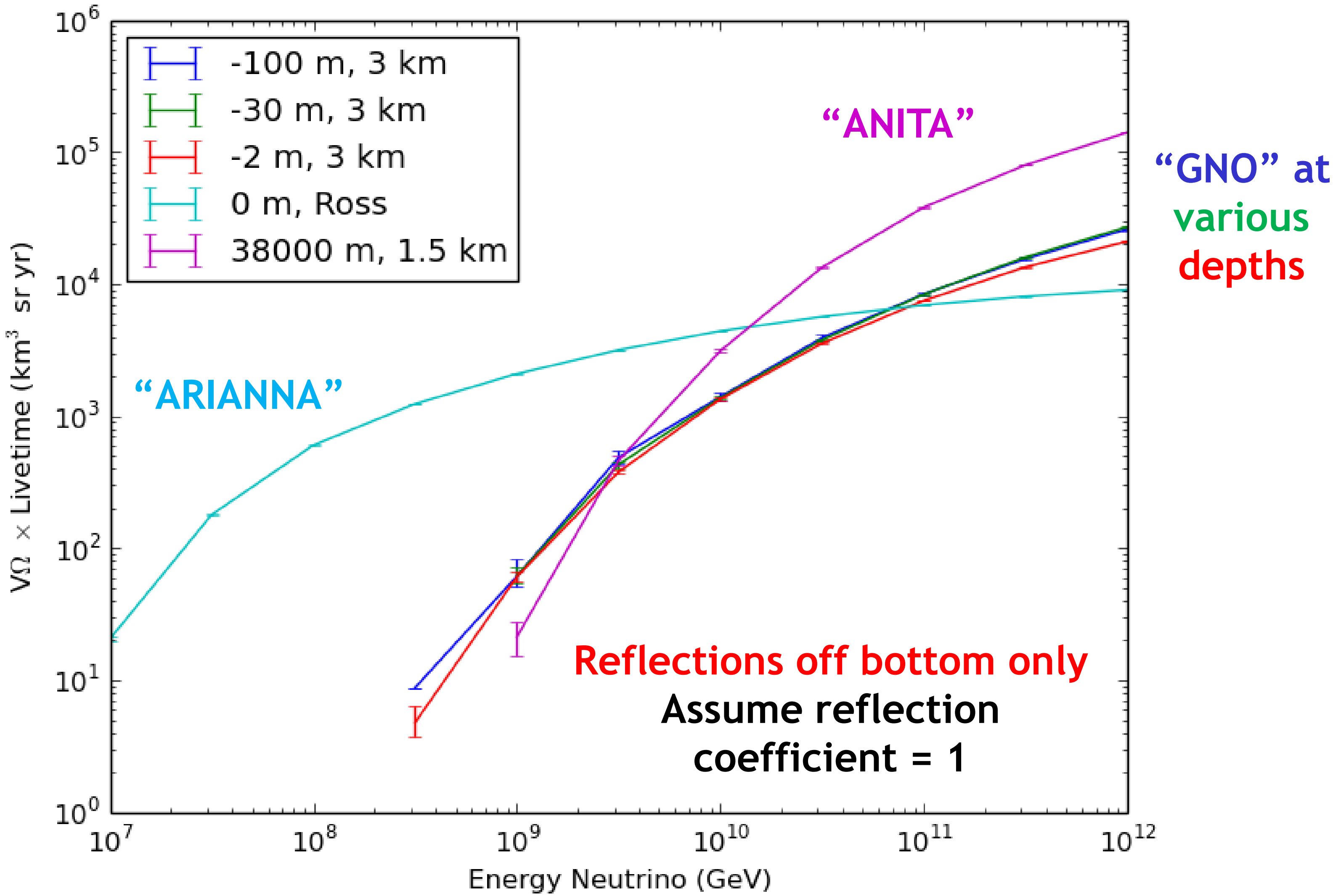
As a check of the simulation tools, consider other configurations, some similar to other proposed or existing experiments

Elevation (m)	Ice Depth (m)	Attenuation Length at 300 MHz (m)	Bandwidth (MHz)	# Stations	Livetime (yr)
38000	1500	1000	100 - 800	1	0.1
0	500	400	100 - 800	961	3
-2	3000	1000	100 - 800	37	3
-30	3000	1000	100 - 800	37	3
-100	3000	1000	100 - 800	37	3

Volumetric Acceptance Comparison

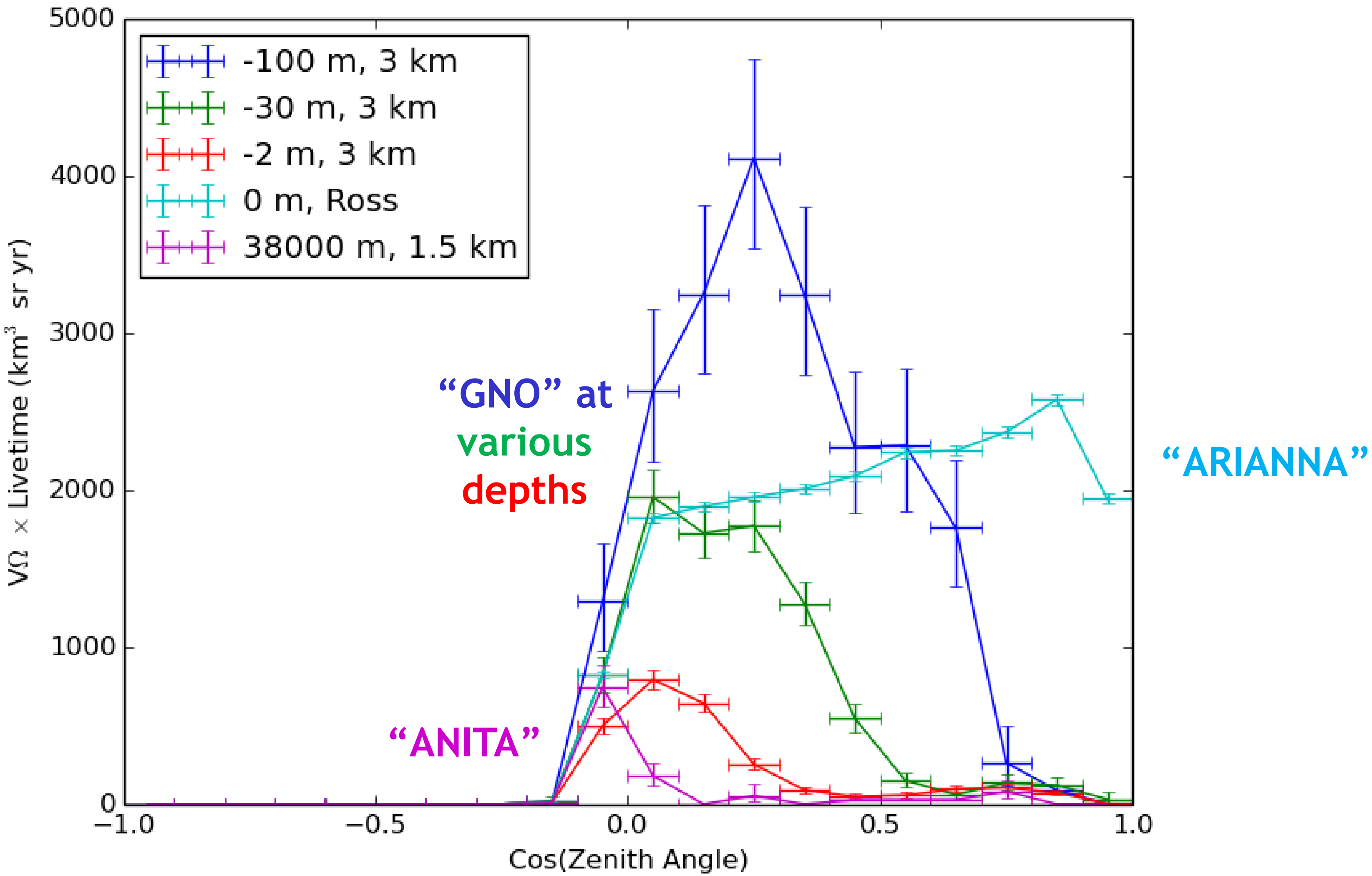


Volumetric Acceptance Comparison



Volumetric Acceptance Comparison

Neutrino Energy = 10^9 GeV



GNO Collaboration

- **University of Chicago**
  - Abigail Vieregg (PI)
  - Keith Bechtol
  - Rhys Povey
  - Jessica Avva
  - Christopher Hughes
- **UCLA**
  - David Saltzberg
  - Stephanie Wissel
- **Jet Propulsion Laboratory**
  - Andres Romero-Wolf
- **University of Hawaii**
  - Peter Gorham
  - Gary Varner
- **University College London**
  - Ryan Nichol

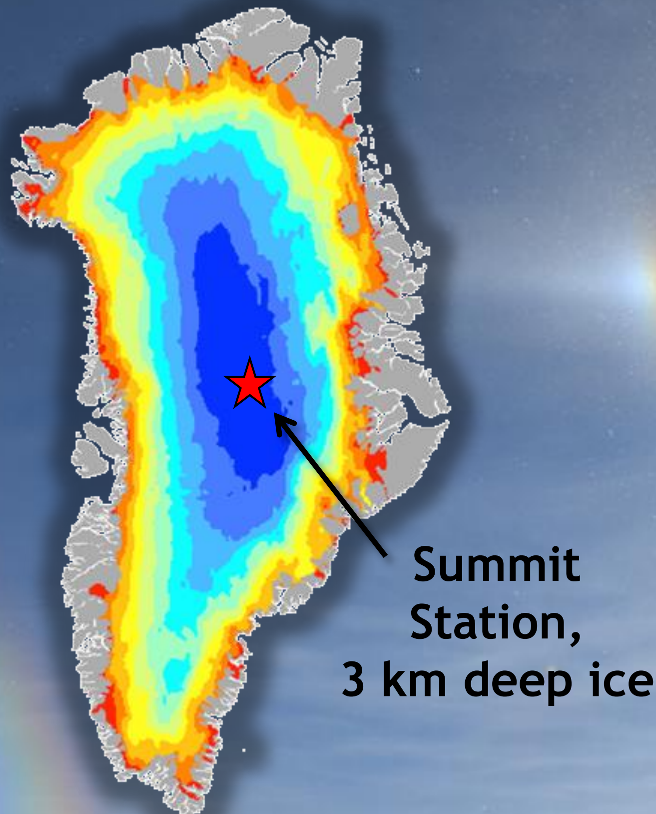
GNO Current Status and Outlook

- Central Greenland has potential to host a world-class UHE neutrino observatory
- Existing infrastructure of Summit Station and promising outlook for Isi Station
  - Relatively easy access for much of the year
- Configuration trade studies and hardware development for prototype station under way – stay tuned!

Greenland Neutrino Observatory

Backup Slides

Greenland Neutrino Observatory

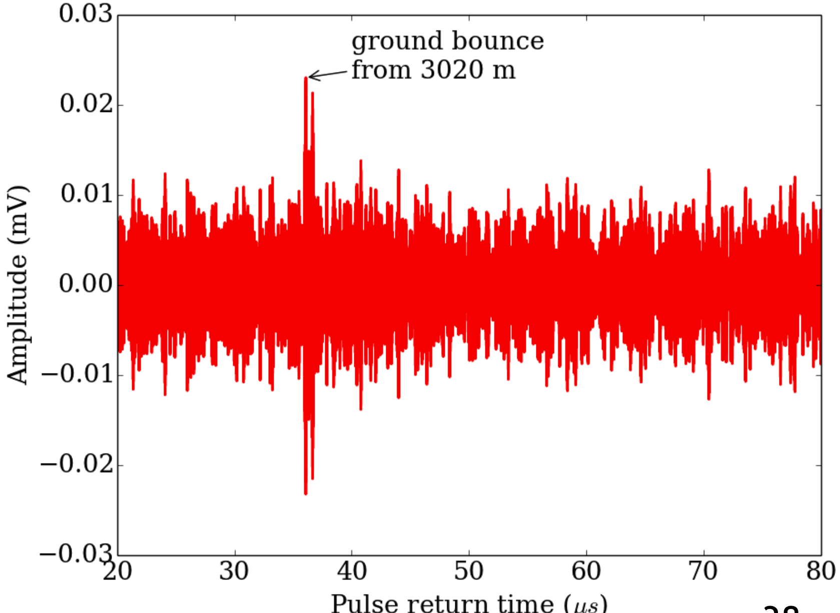


Investigating central Greenland as site of UHE neutrino detector array of radio antennas with >100 km^3 effective volumetric acceptance

GNO Site: Summit Station, Greenland

Site Characteristics
- Year-round NSF research station
- 10 months of sunlight
- Access by C-130s, annual overland traverse, direct flights from NY
- Plans for expanded “Isi Station”
- Full-depth borehole available for our use

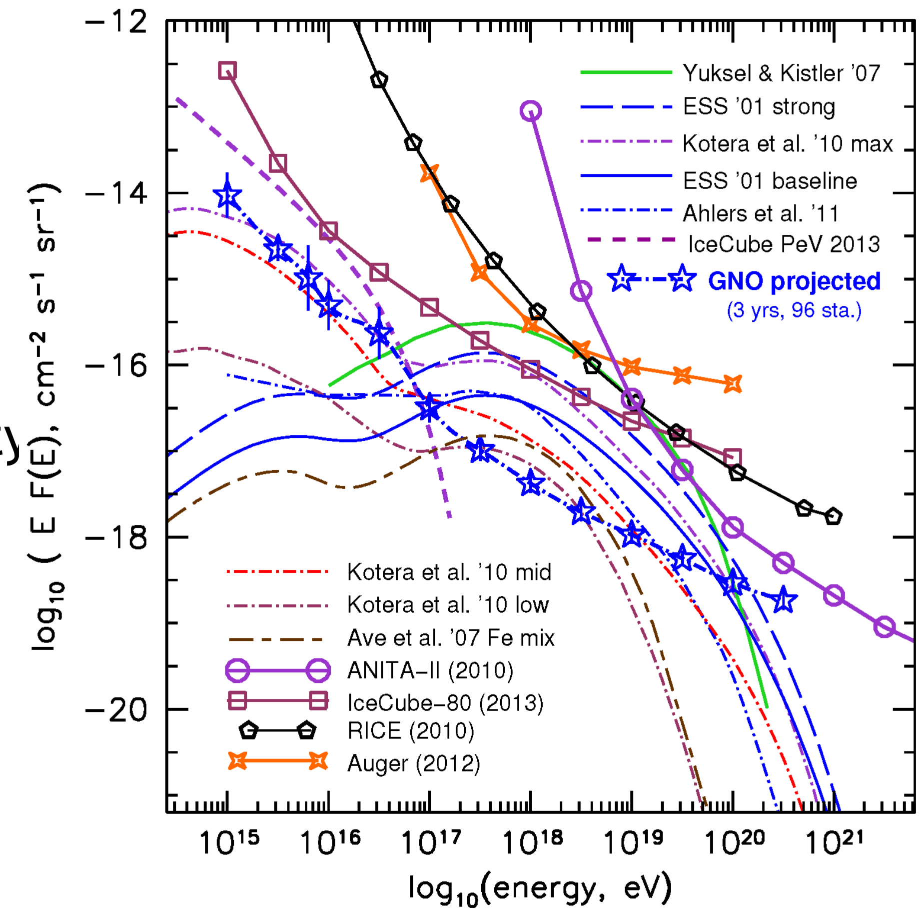
Site characterization visit in June 2013



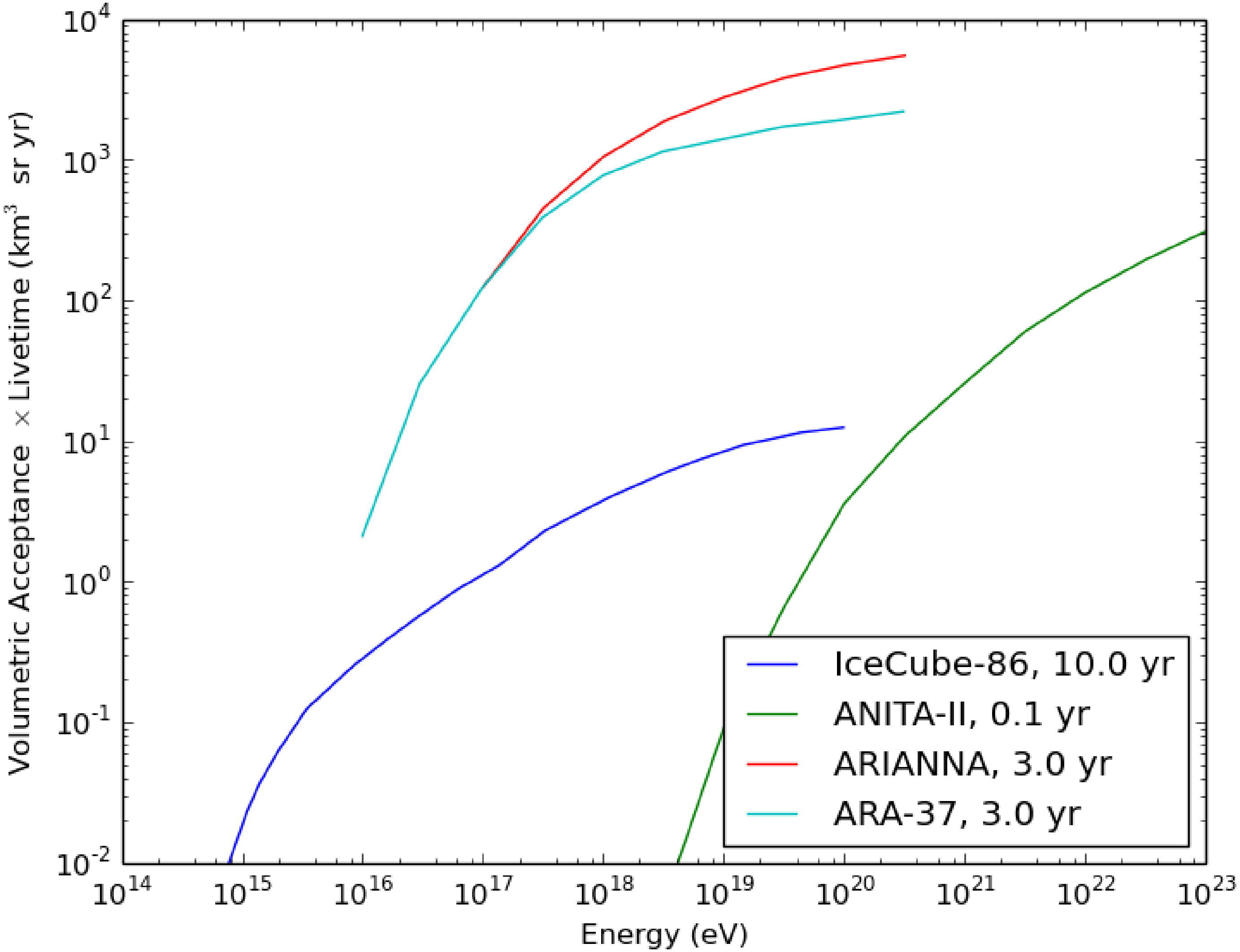
Ice Properties
- Site of GISP2 deep ice coring effort
- 3 km deep ice
- 997 +/-150 m attenuation length in top 1.5 km at 300 MHz
- Firn layer ~100 m deep

GNO Current Activities

- **Deploy testbed station in spring 2015**
  - Near-surface station of high-gain antennas, planning 8 vertical + 8 horizontal polarization channels, running off station power
  - Hardware development at University of Chicago
- **Optimizing station design and full array configuration**
  - Goal sensitivity to detect multiple UHE neutrinos per year even in lowest flux cosmogenic scenarios
  - Developing simulation tools



Comparison to Literature



Sources:

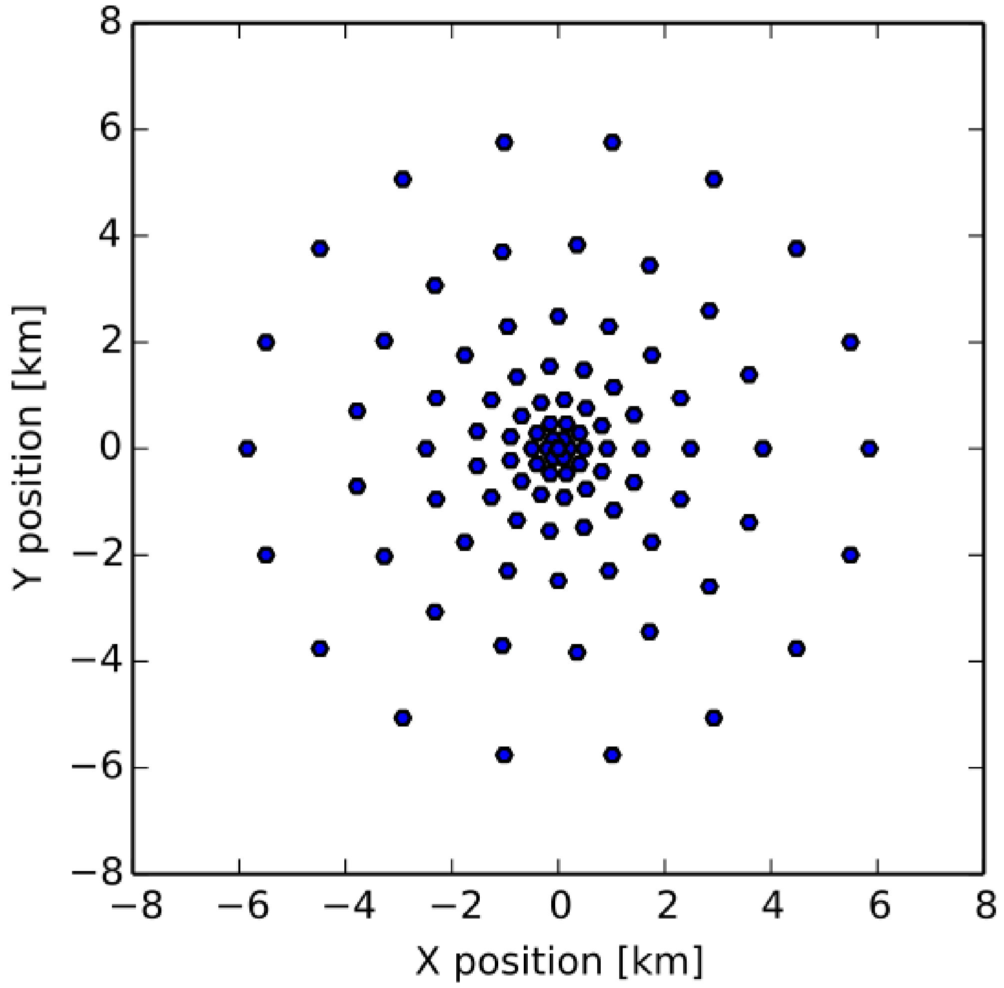
IceCube-86
Aartsen et al. 2013

ANITA-II
Gorham et al. 2012

ARIANNA
Hanson Dissertation 2013

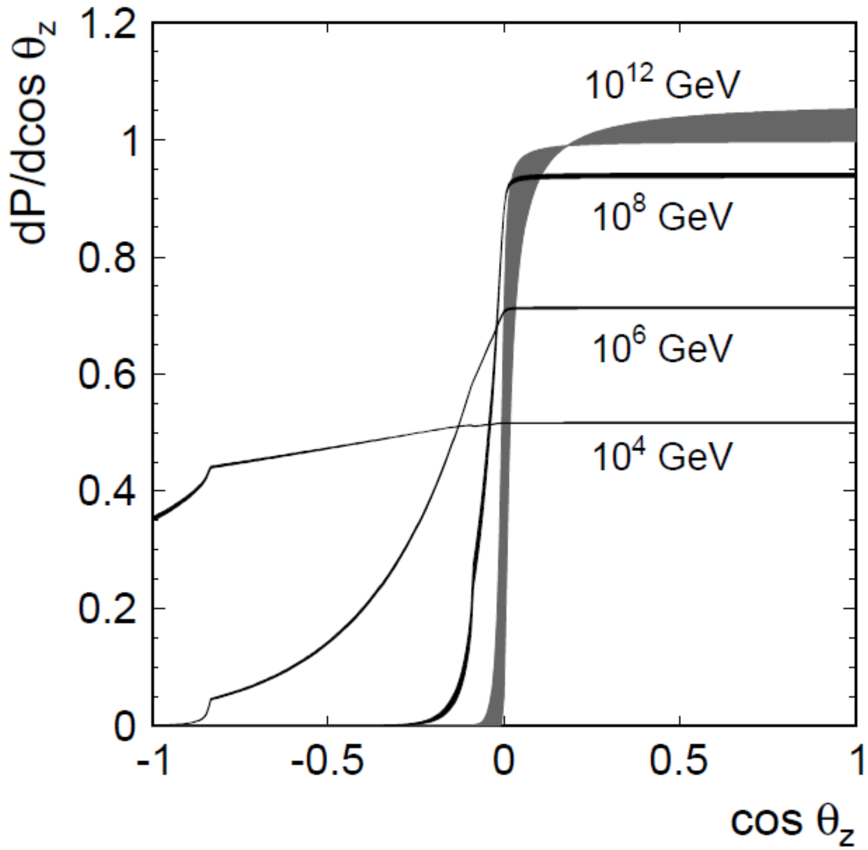
ARA-37
Allison et al. 2012

Expanding to Full Array



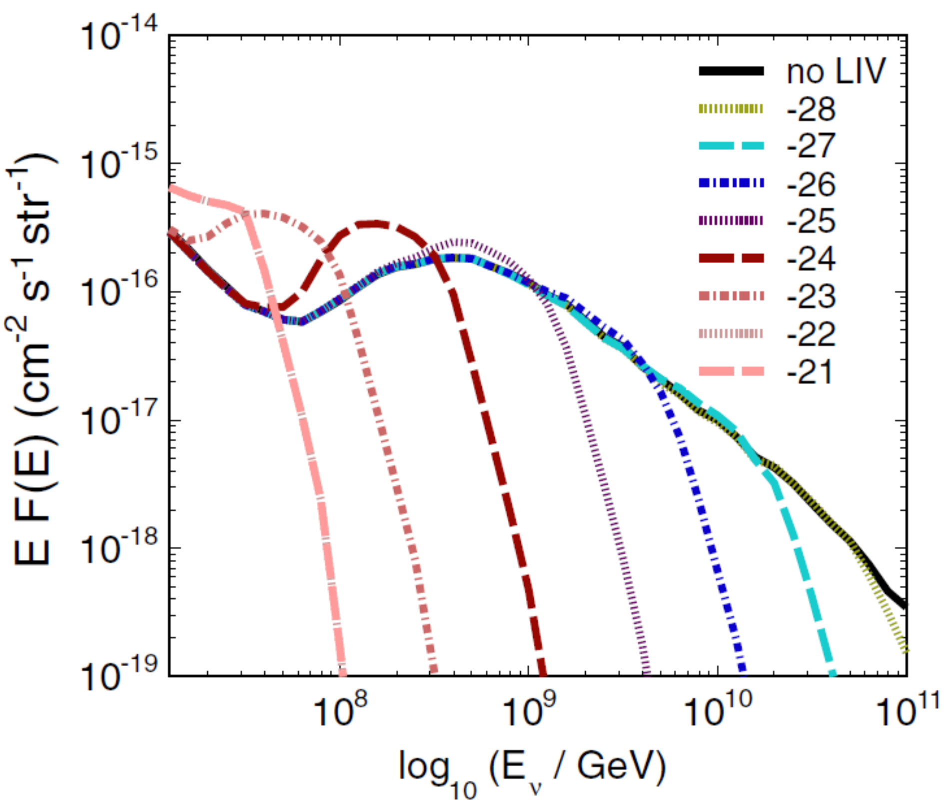
Neutrino Properties

Neutrino interaction cross section



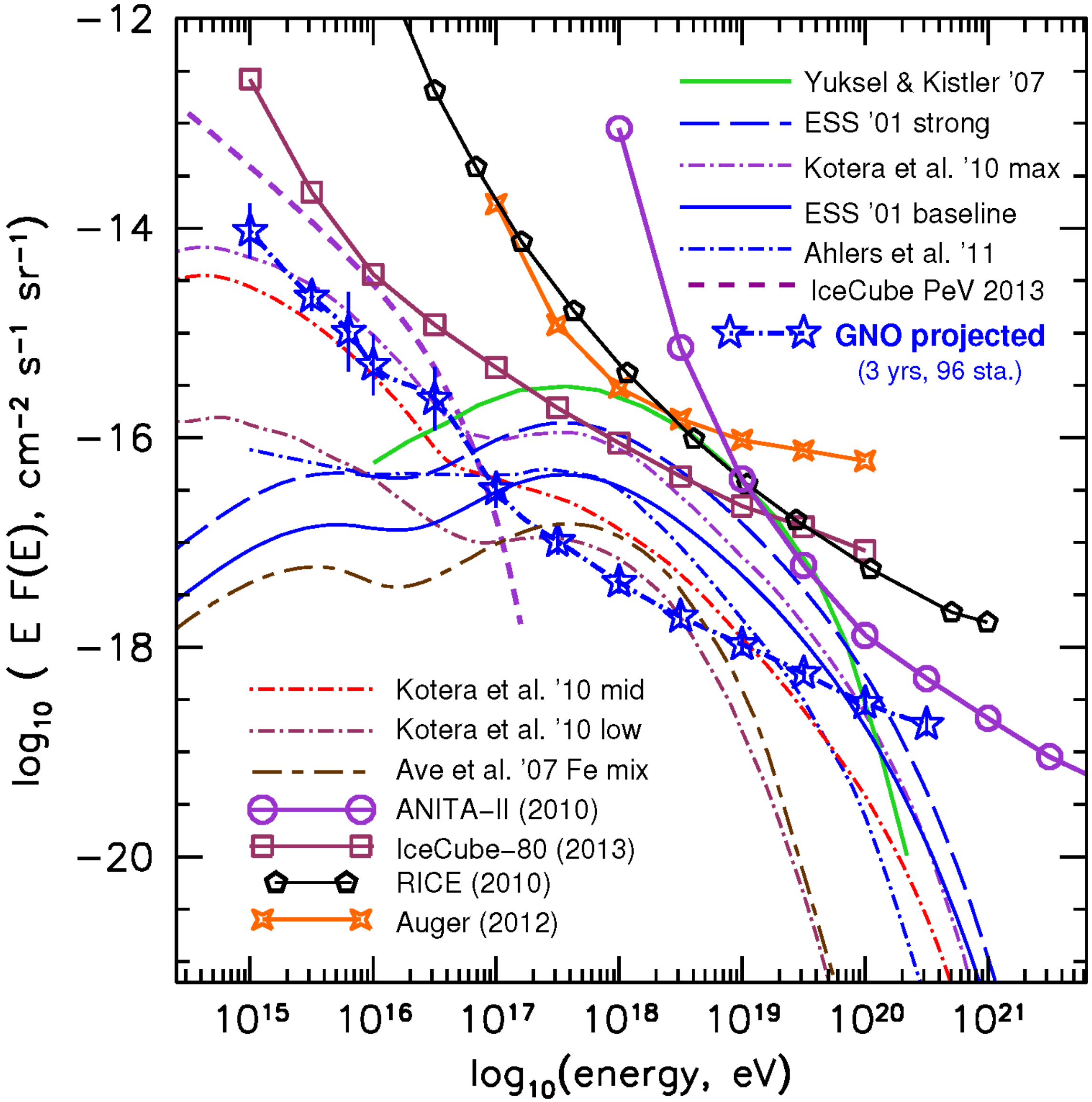
Connolly et al. 2011

Search for Lorentz invariance violation in neutrino sector



Gorham et al. 2012

Evolution of UHECR Sources



Distant UHECR sources

UHECR composition

Processes deep within opaque sources

Prompt emission at accelerators in addition to BZ process

Design array with sensitivity to explore range of cosmogenic theory scenarios