Ultra-High Energy Neutrino Astronomy in Antarctica

Ryan Nichol

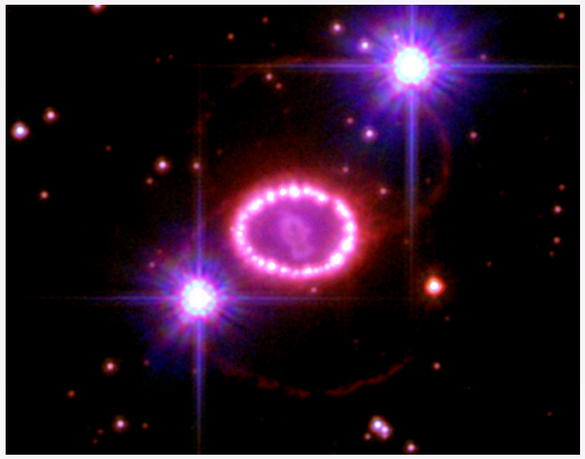
Outline

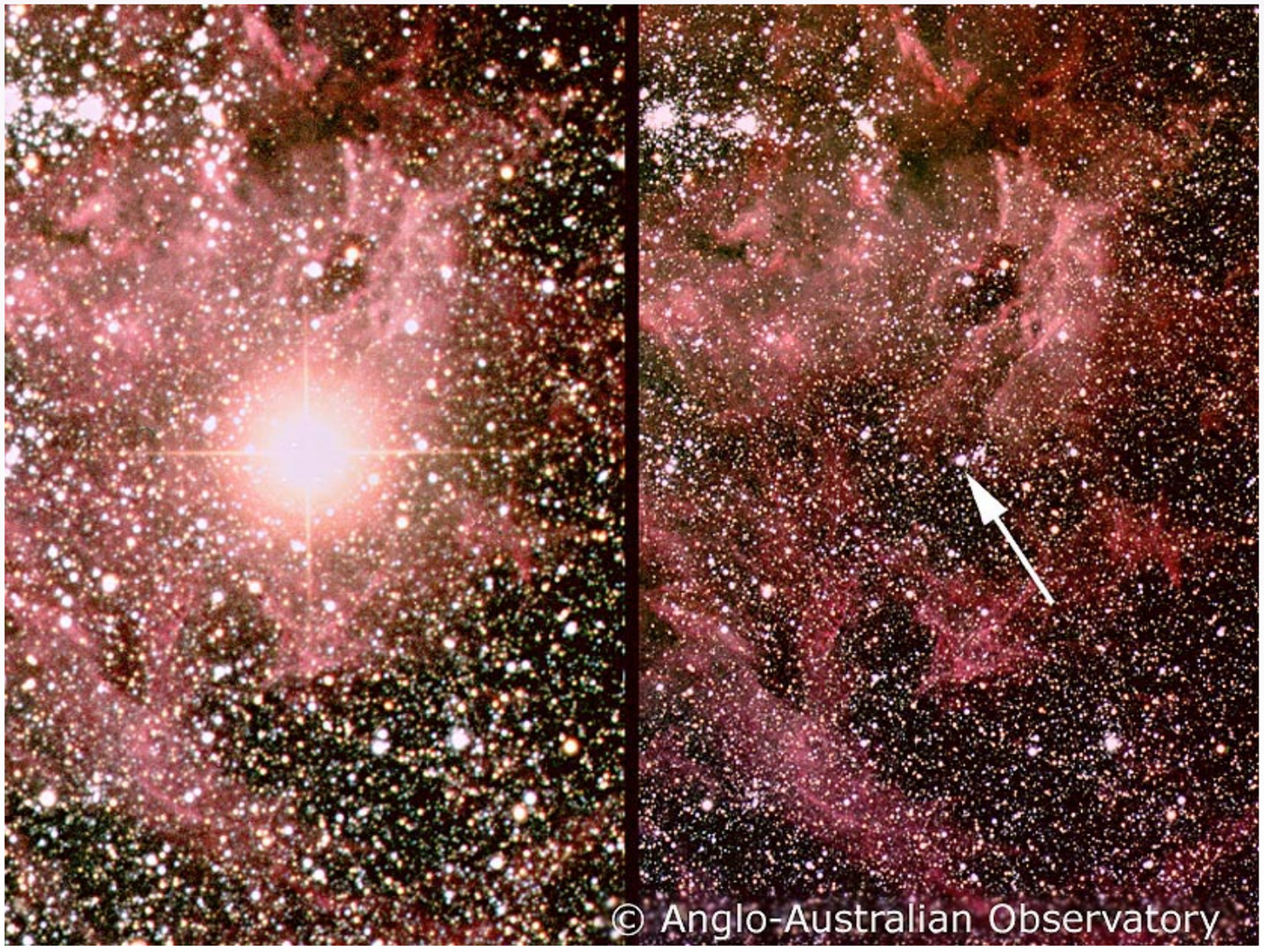
- Abbreviated History Lesson
- Motivation for Ultra-High Energy Neutrino Astronomy
  - For Astronomers, Astrophysicists and Particle Physicists
- Detection Methods
  - Radio
- Why Antarctica?
- Current Experiments
  - ANITA
- Proposed Experiments
  - ARIANNA, AURA, IceRay, etc.

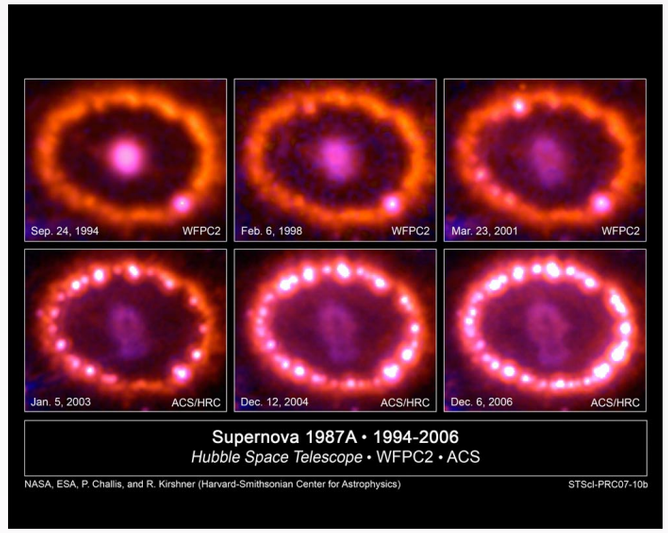
Why?

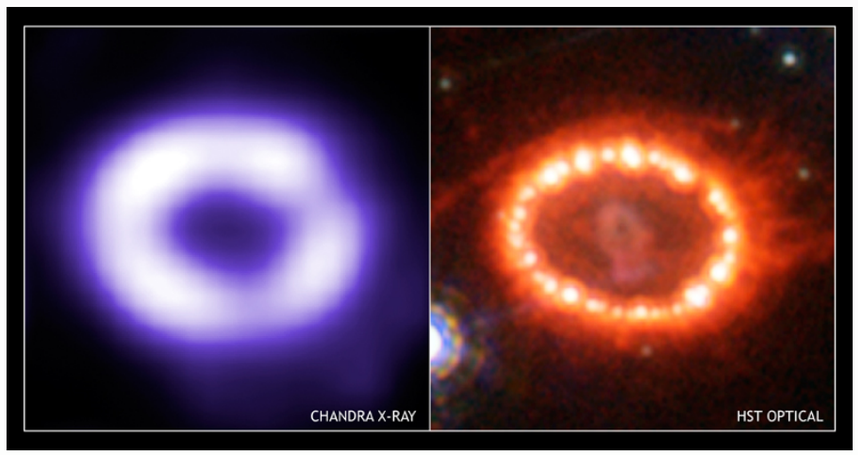
Skewed History Lesson

- Neutrino Astronomy started with a bang...



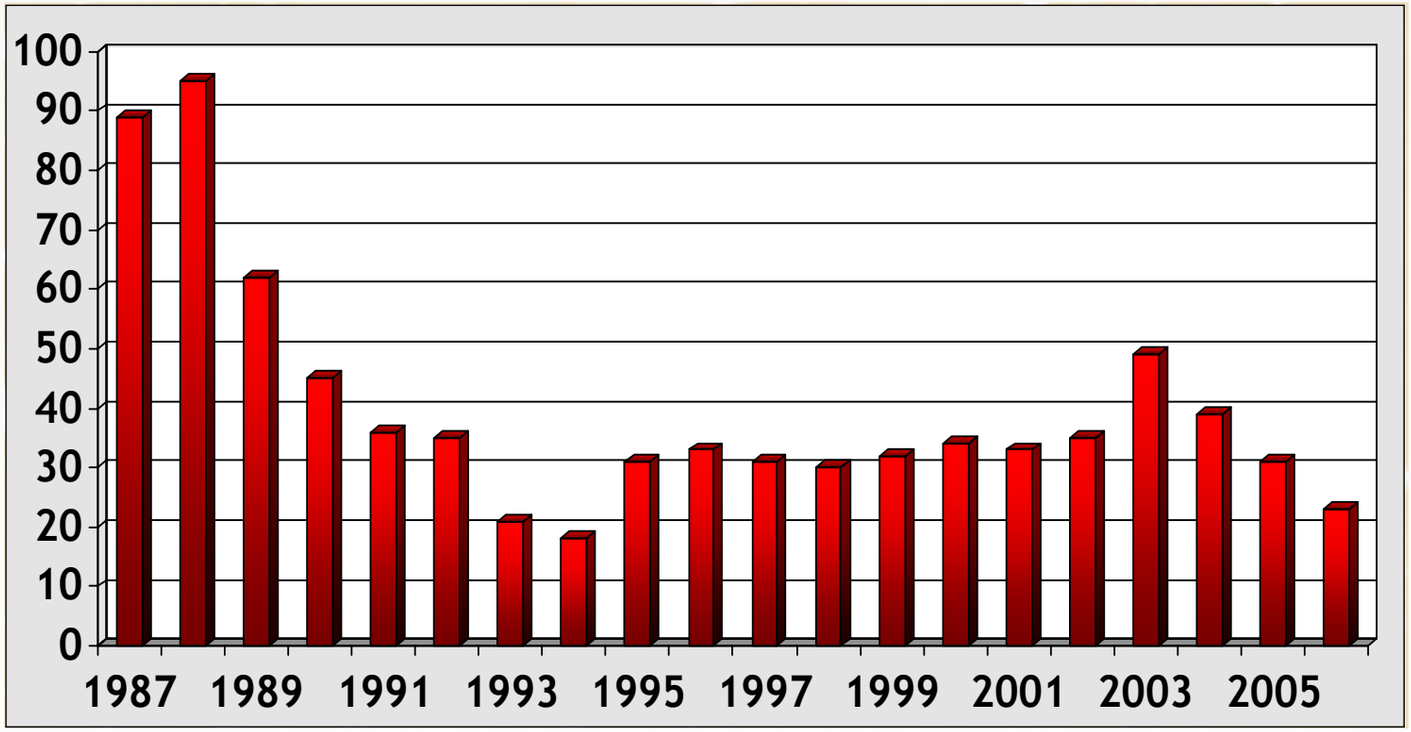




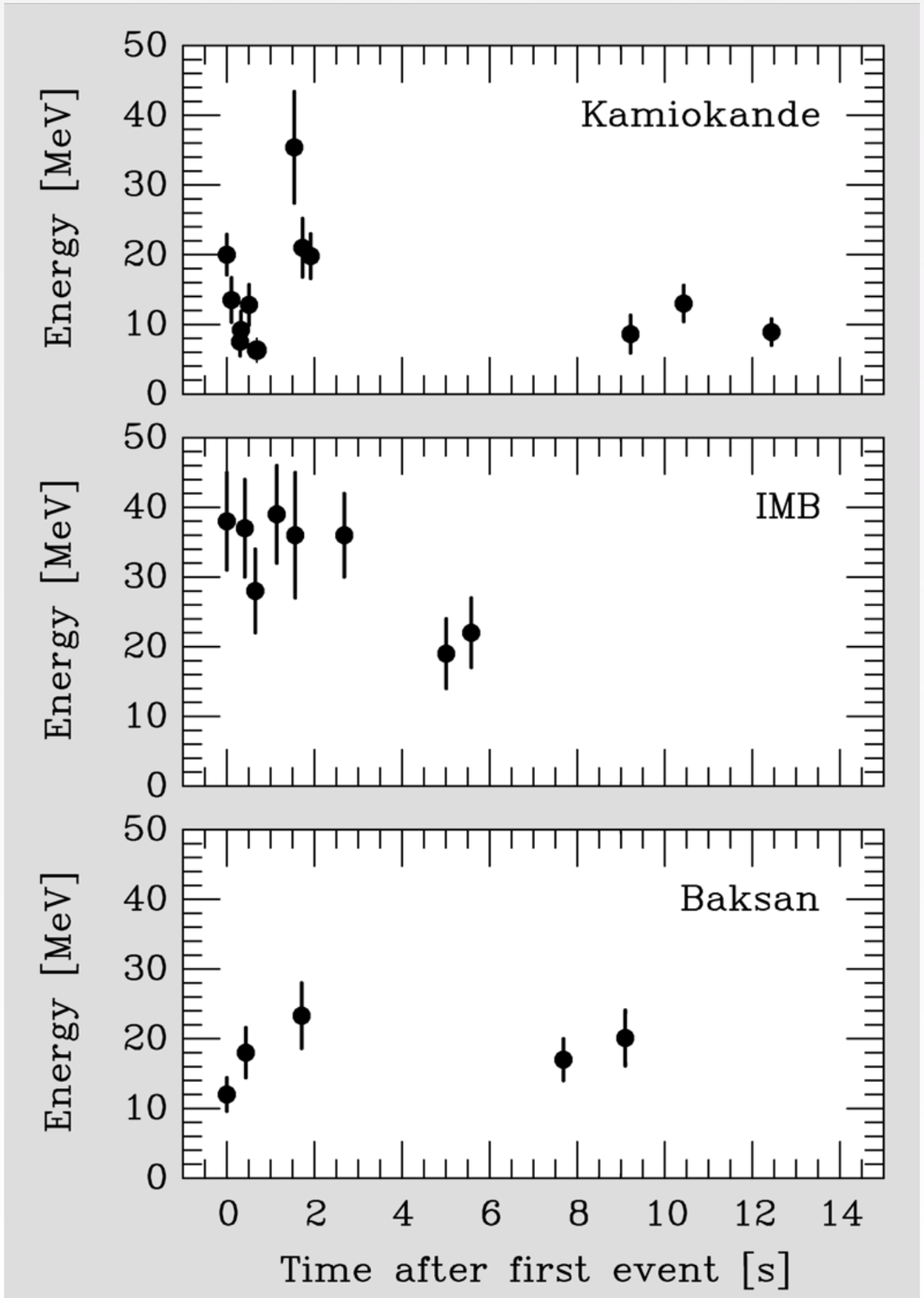


Pretty pictures from Hubble, Chandra (X-ray) and AAO

- ... and just a handful of neutrino events sparked a flurry of scientific interest



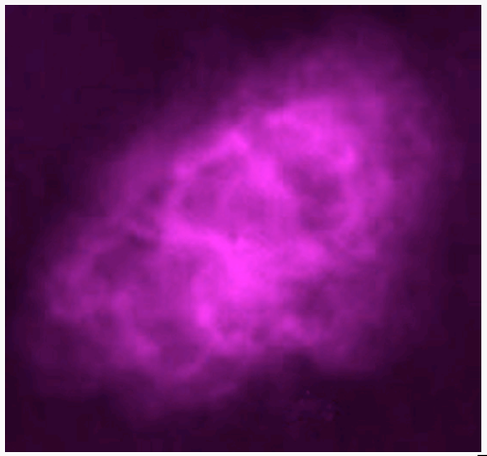
Annual Citations (from SPIRES) of SN 1987A Papers



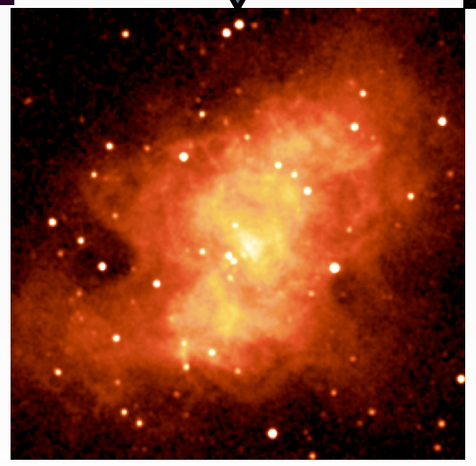
Plots stolen from Georg Raflett

Neutrino Astronomy for Astronomers

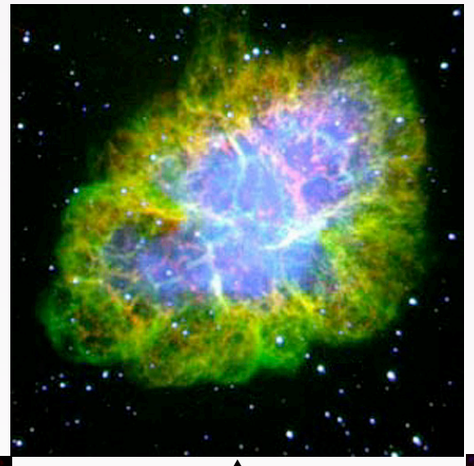
- Why is neutrino astronomy interesting?
  - The pretty pictures answer.



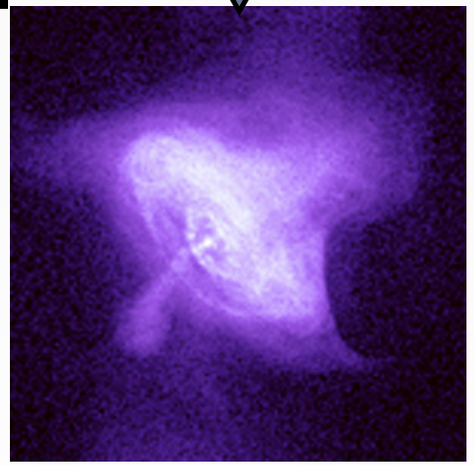
Radio



Infrared



Optical

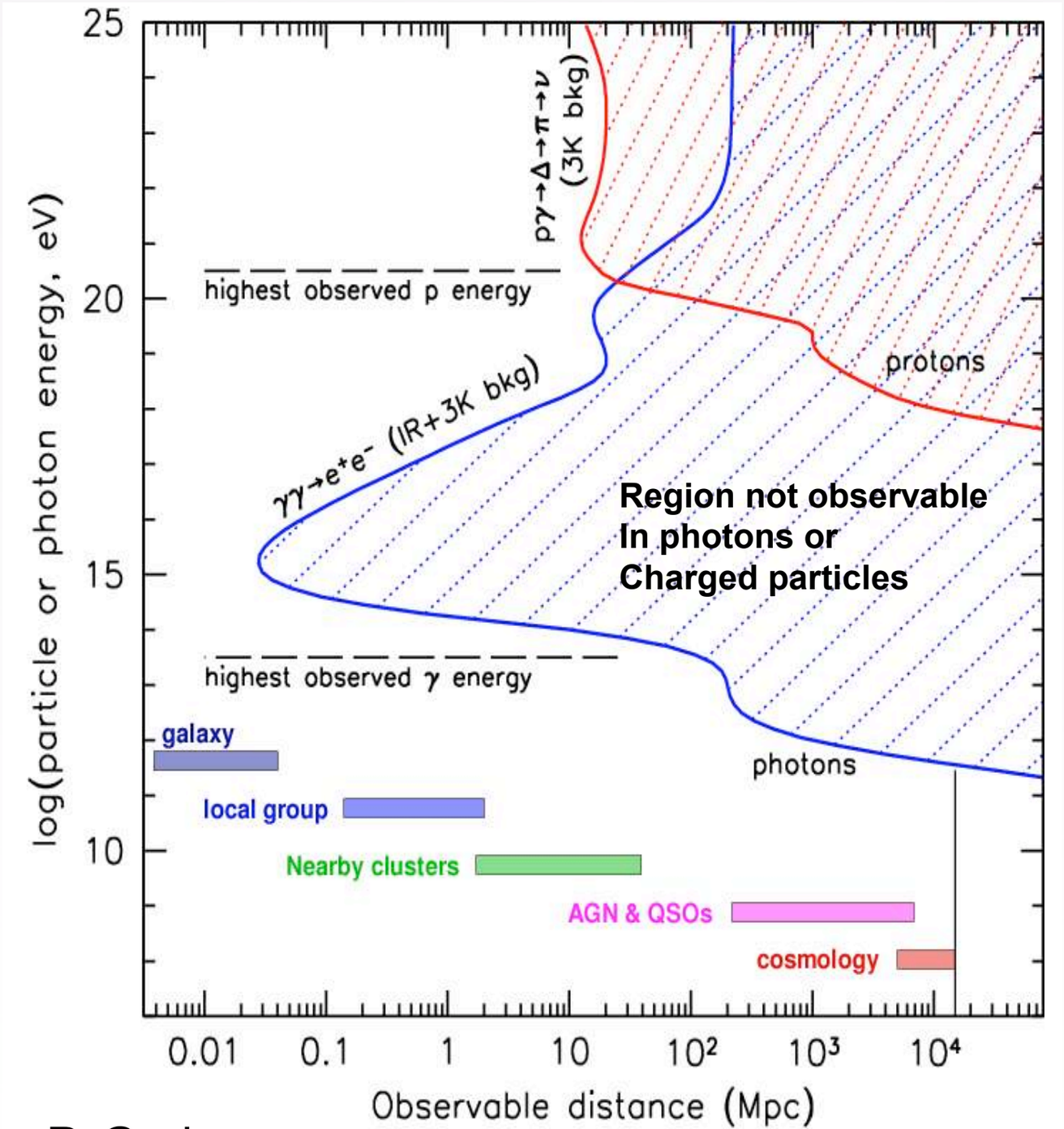


X-Ray

Neutrinos?

"The real voyage of discovery consists not in seeking new landscapes, but in having new eyes." **Marcel Proust**

Reaching the parts...



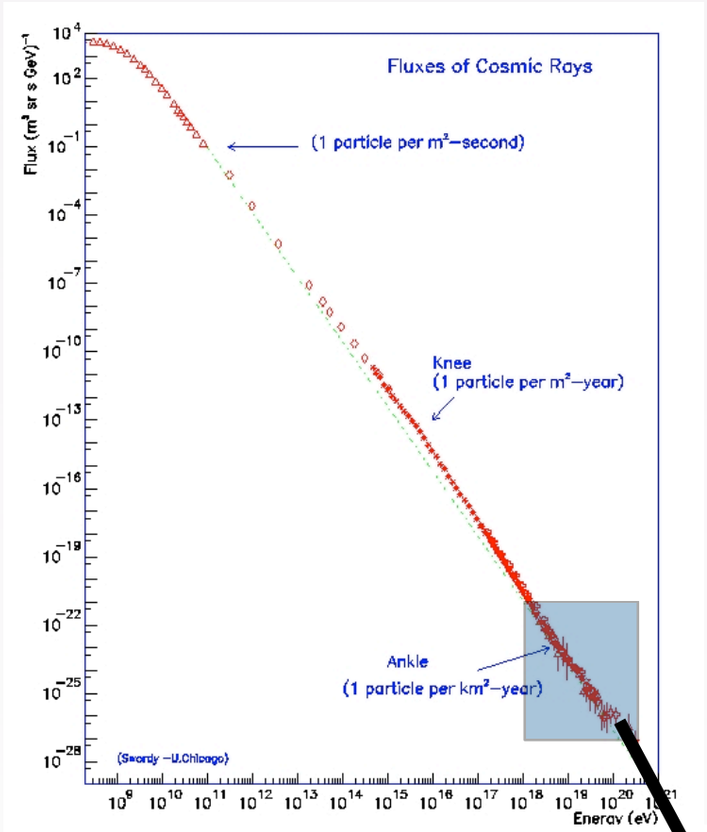
P. Gorham

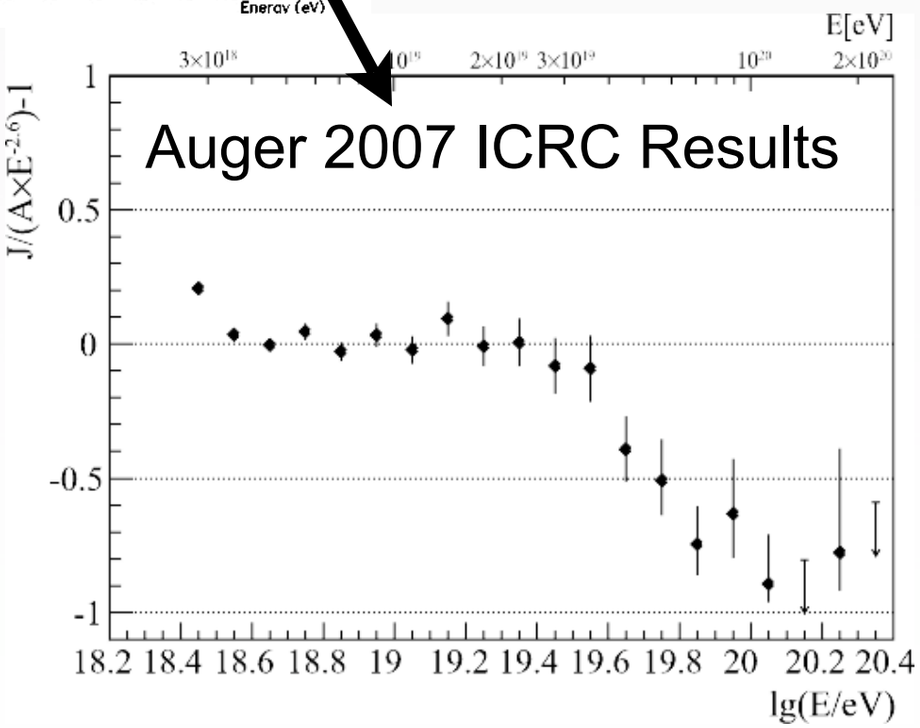
- Photons attenuated by:
  - Infrared Background
  - CMB
- Protons:
  - Deflected by magnetic fields
  - Attenuated by CMB
- Neutrinos:
  - Can reach the energies and distances that other particles can't.

The 

Particle

Proton's Bane...



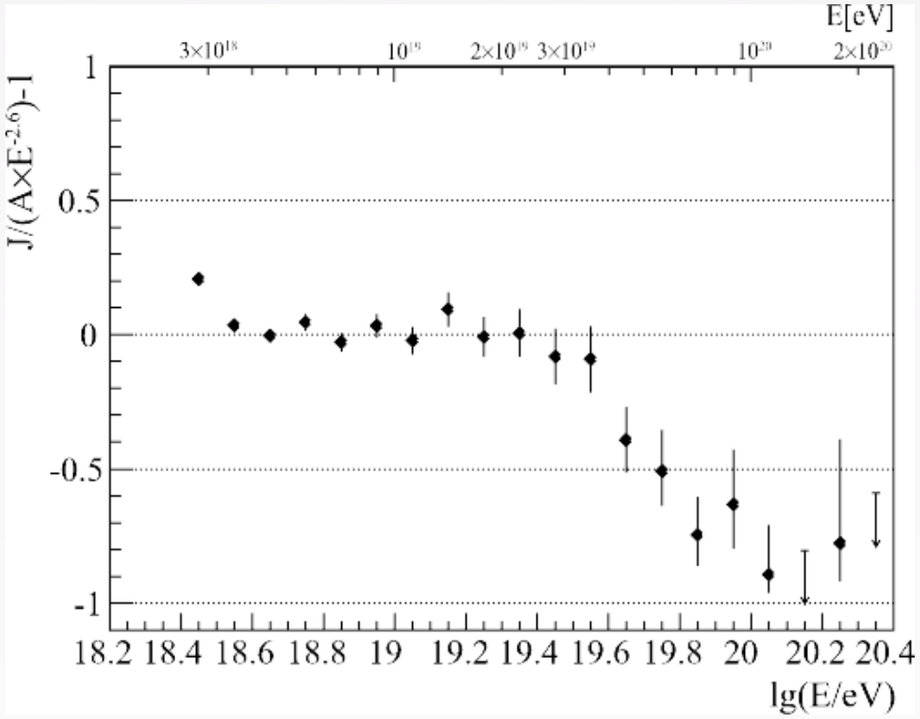


- Greisen-Zatsepin-Kuzmin (GZK) calculated cosmic rays above $10^{19.5}$eV should be slowed by CMB within 50MPc.

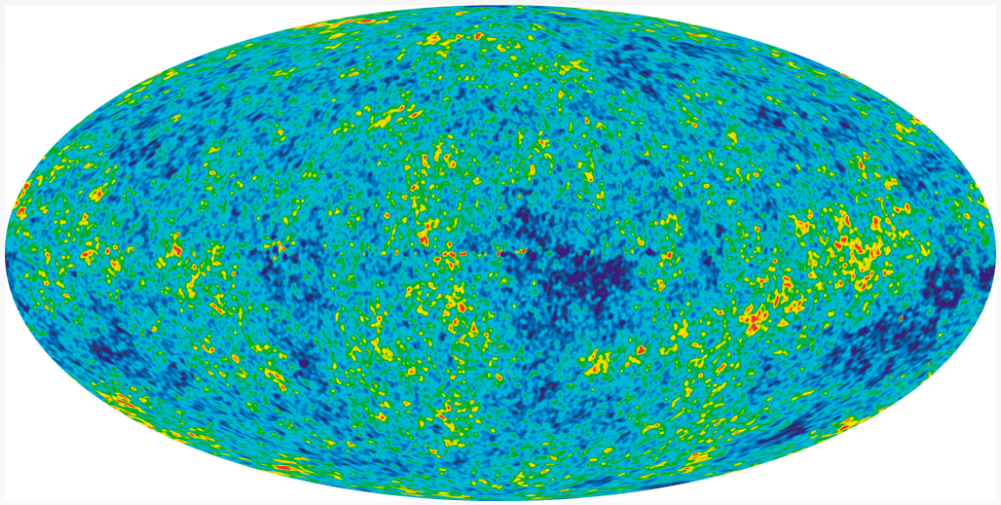
$$p + \gamma_{CMB} \rightarrow \Delta^* \rightarrow n + \pi^+$$
$$\searrow \mu^+ + \nu_\mu$$
$$\searrow e^+ + \overline{\nu}_\mu + \nu_e$$

- Have Auger detected the GZK cut-off?

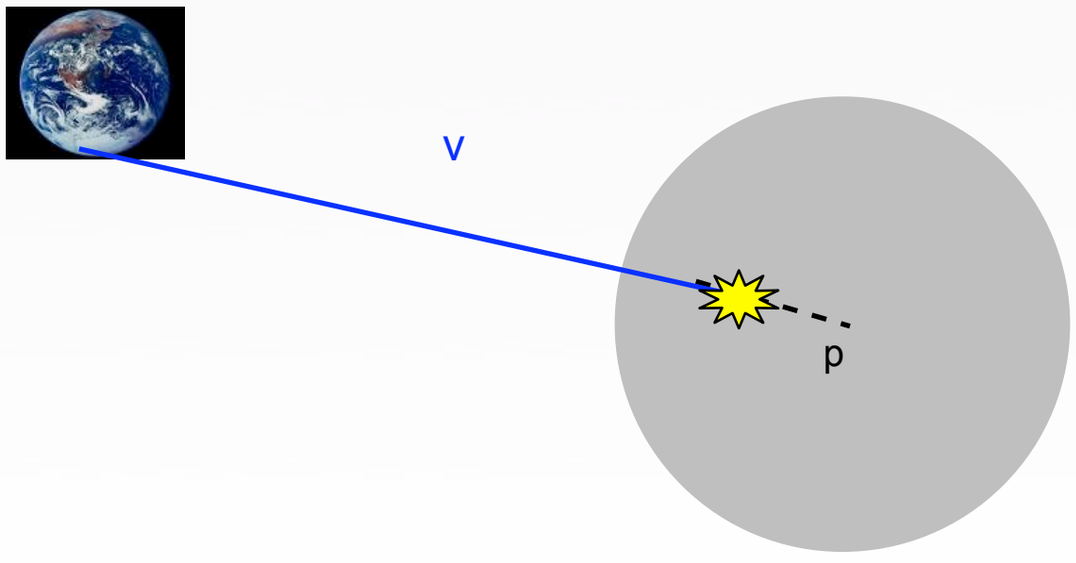
...is Neutrino's Boon



+



= "Guaranteed" Neutrino Beam!



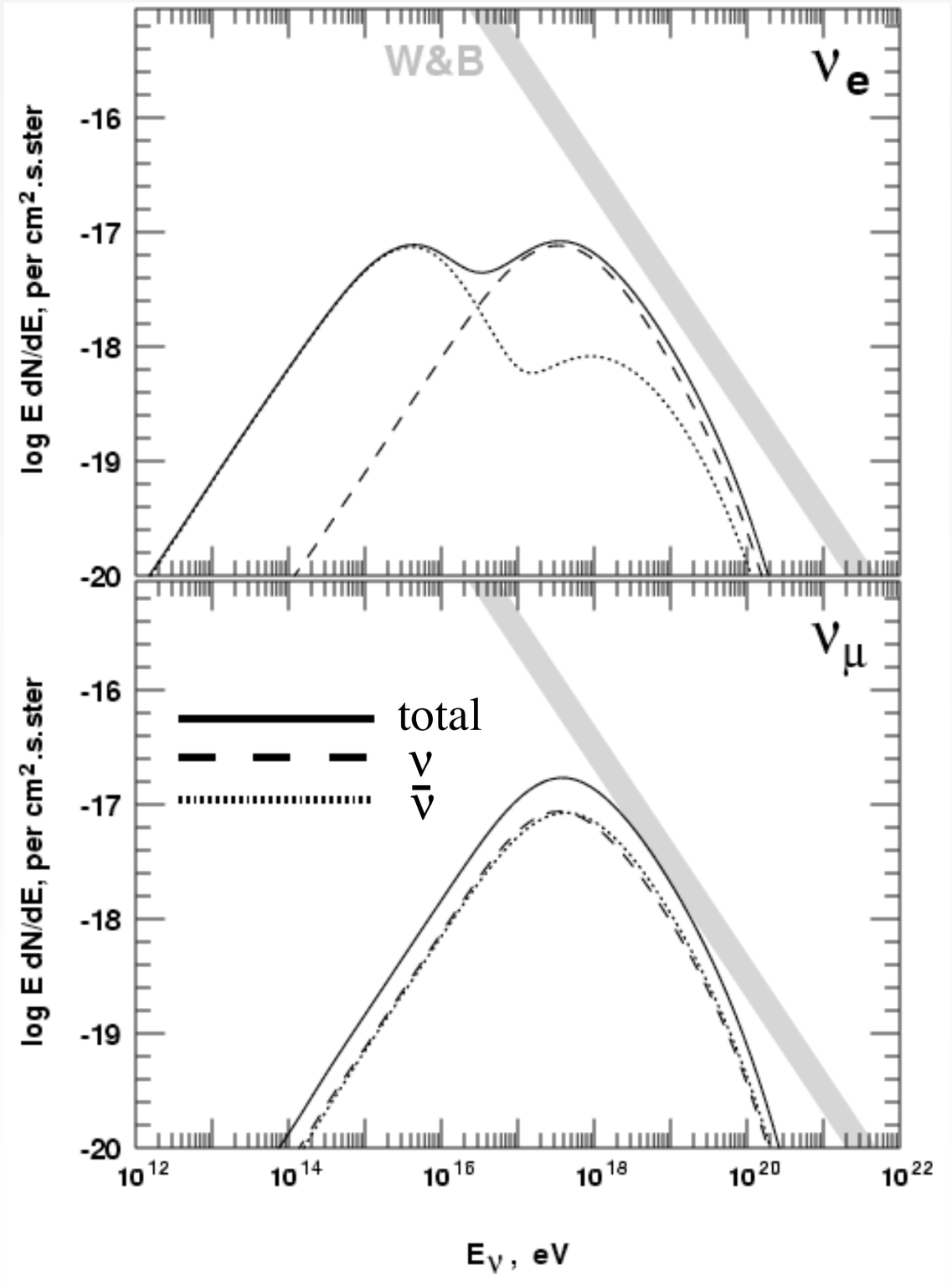
GZK Neutrinos Point Back to original proton source

GZK Flux

- Calculation contains many assumptions
  - Earth CR flux only
  - Injection Spectrum
  - Cosmological Evolution
  - Optical Density of Source

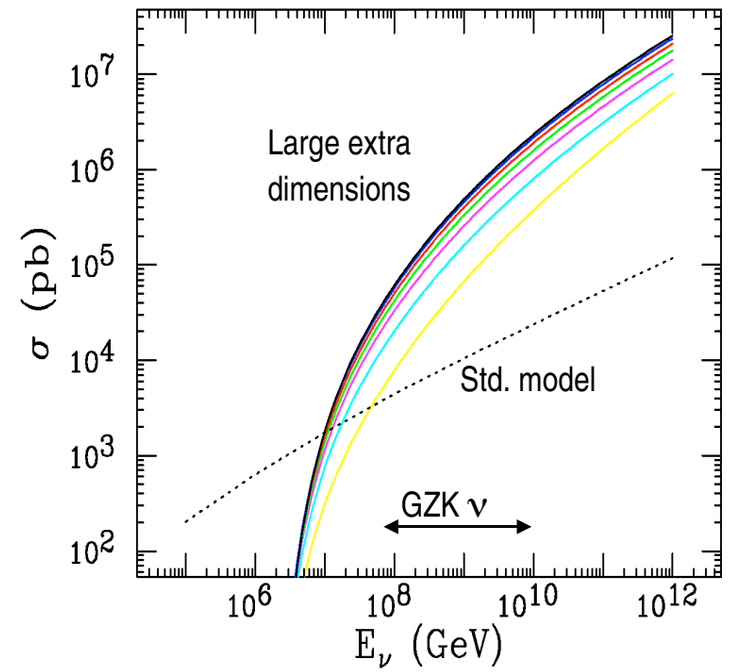
- Still ‘best known’ neutrino flux

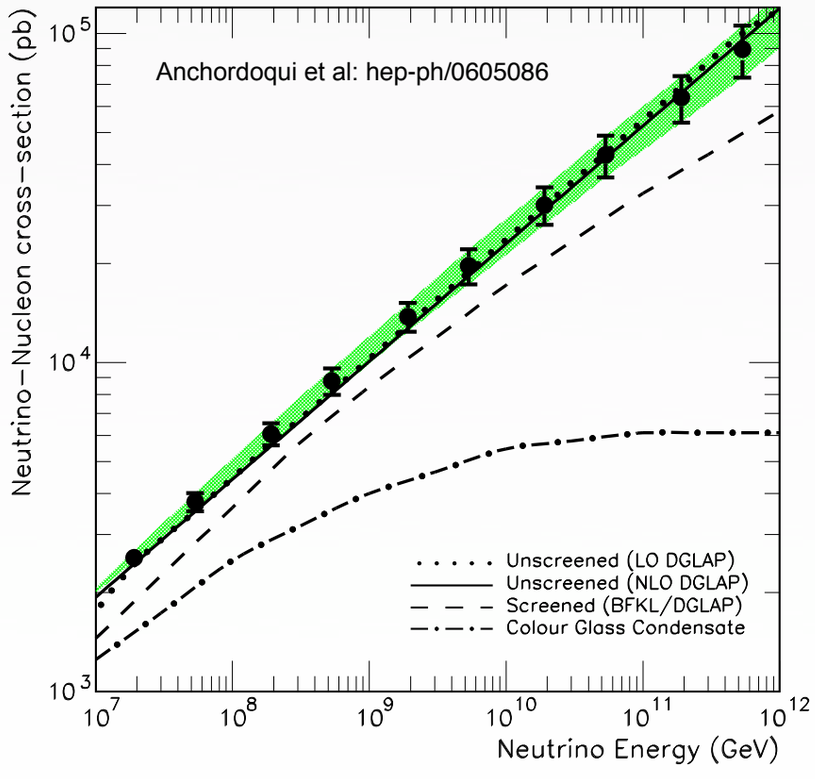
Engel, Seckel & Stanev



Particle Physics with 300TeV Neutrino Beam

- Neutrino-nucleon cross section in new regime
  - Large extra dimensions
  - Micro blackholes
- With flavour tagging can probe:
  - Neutrino Oscillations
  - Neutrino Decay/ Decoherence
- Other/Exotic:
  - Super heavy relics
  - Topological Defects
  - Magnetic Monopoles





How can you do it?

A Problem of Size

- Some Numbers:

  ~10 GZK neutrinos per km^2 per year

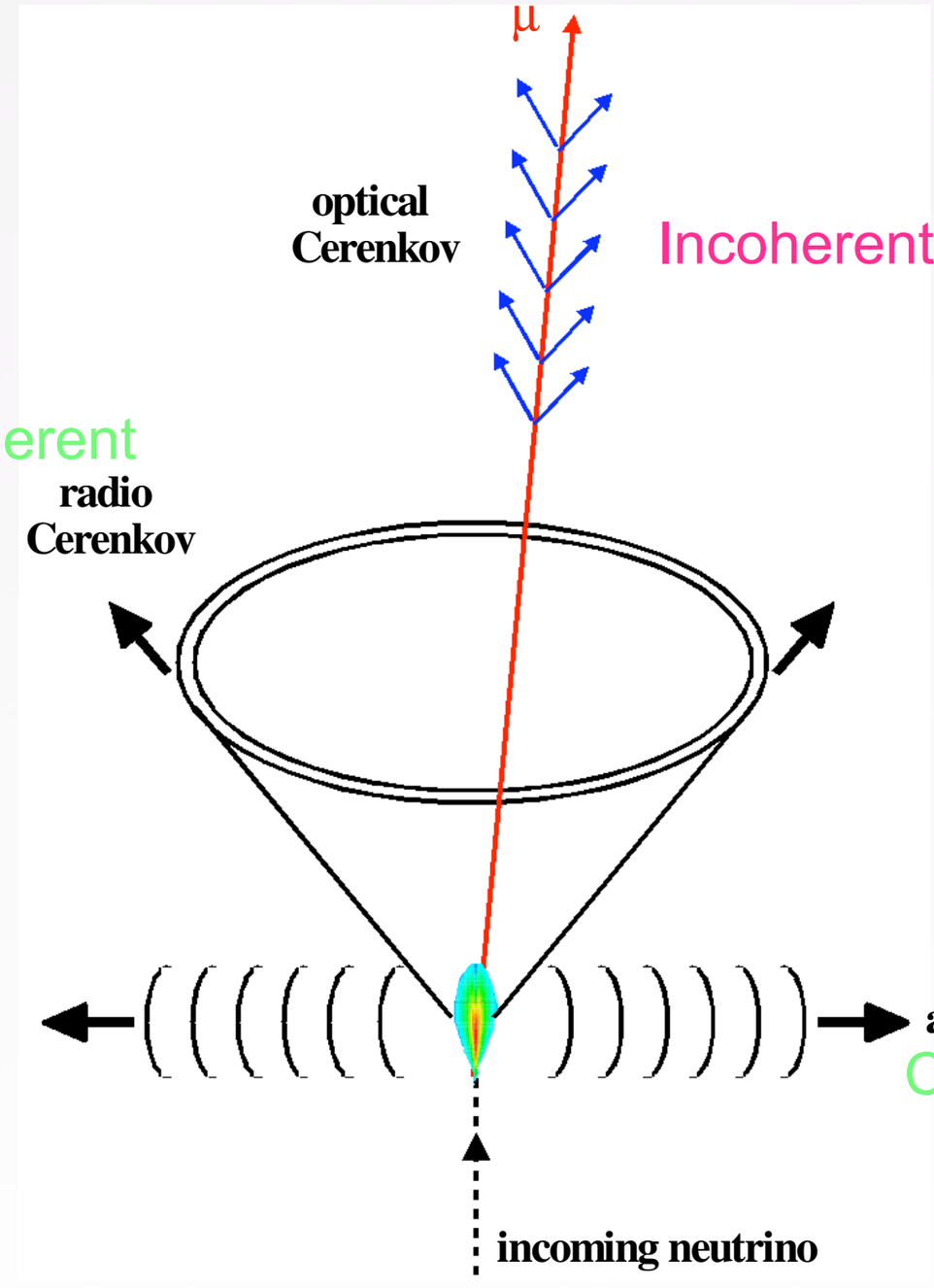
  @ 10^{18} eV the ν-N interaction length ~ 300km

  $\therefore$ 0.03 neutrino interactions per km^3 per year

- One needs a huge detector volume (>>10 km^3) in order to ensure a neutrino detection.
- Have to use a naturally occurring medium, possibilities are:
  - Air, Ice, Salt, Water, The Moon

Possible Detection Methods

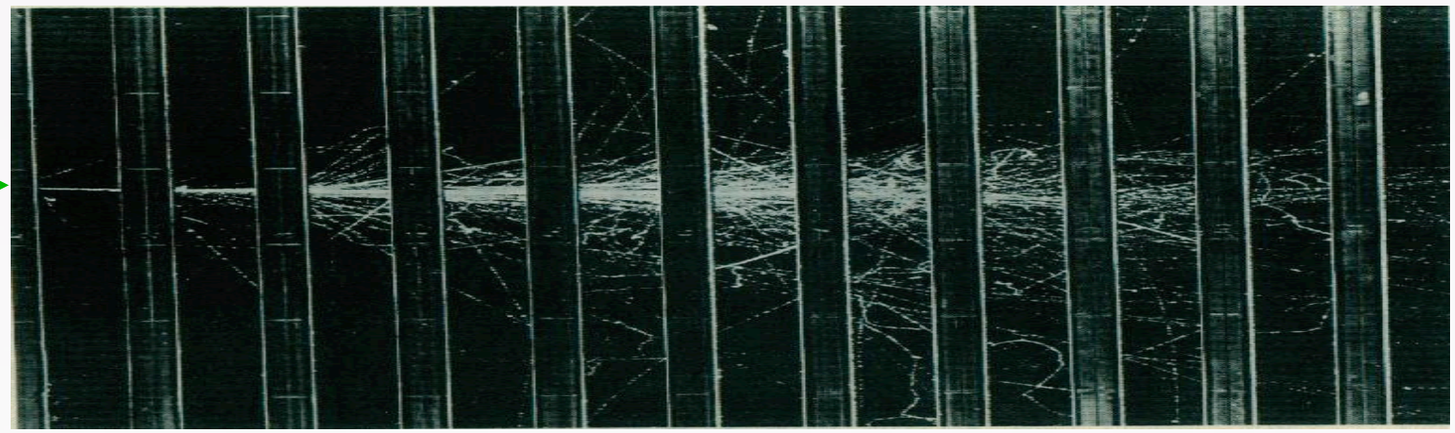
- Optical Cherenkov
  - Mature field but not scalable to huge volumes
- Radio Cherenkov
  - Active field best candidate for first detection
- Acoustic
  - Emerging field, with much R&D
- Other
  - Air showers



Askaryan Effect

- In 1962 Gurgen Askaryan hypothesized coherent radio transmission from EM cascades in a dielectric:

$e^{\pm}$ or γ →

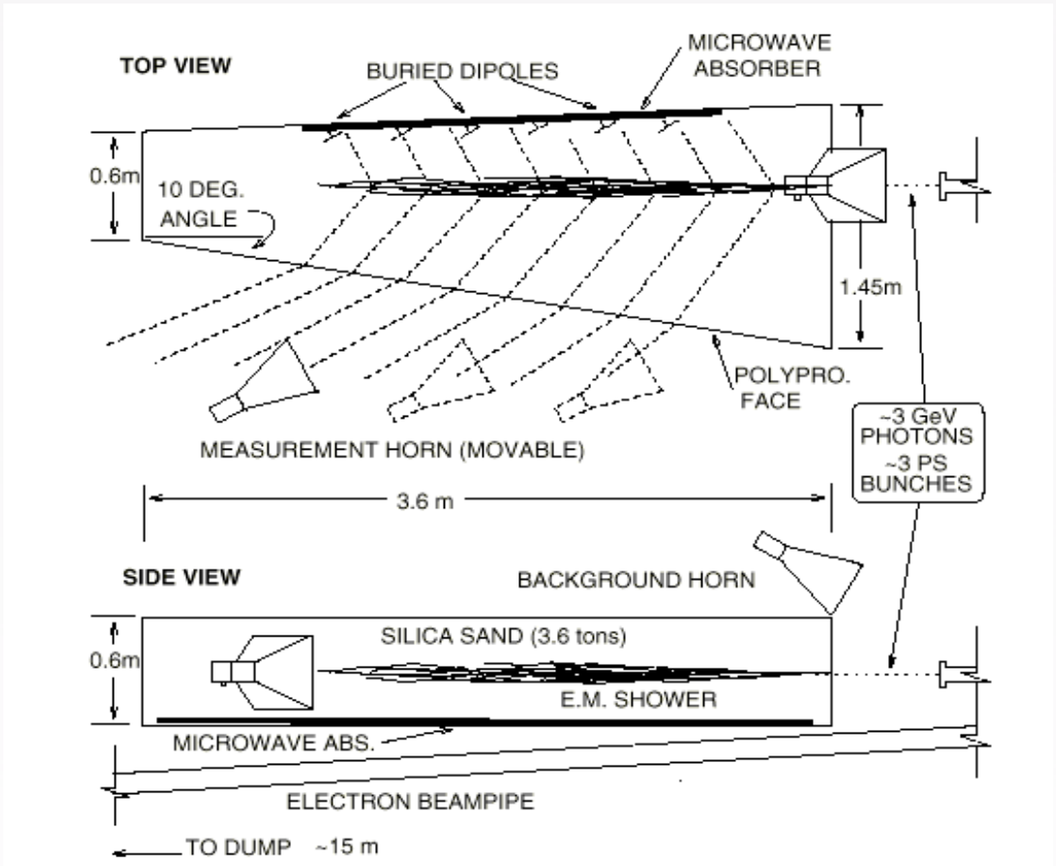


Typical Dimensions:
L ≈ 10 m
$R_{Moliere}$ ≈ 10 cm

  - 20% Negative charge excess:
    - Compton Scattering: $\gamma + e^-_{(rest)} \Rightarrow \gamma + e^-$
    - Positron Annihilation: $e^+ + e^-_{(rest)} \Rightarrow \gamma$
  - Excess traveling with, $v > c/n$
    - Cherenkov Radiation: $dP \propto \nu \, d\nu$
  - For $\lambda > R$ emission is coherent, so $P \propto E^2_{shower}$

Experimental Verification

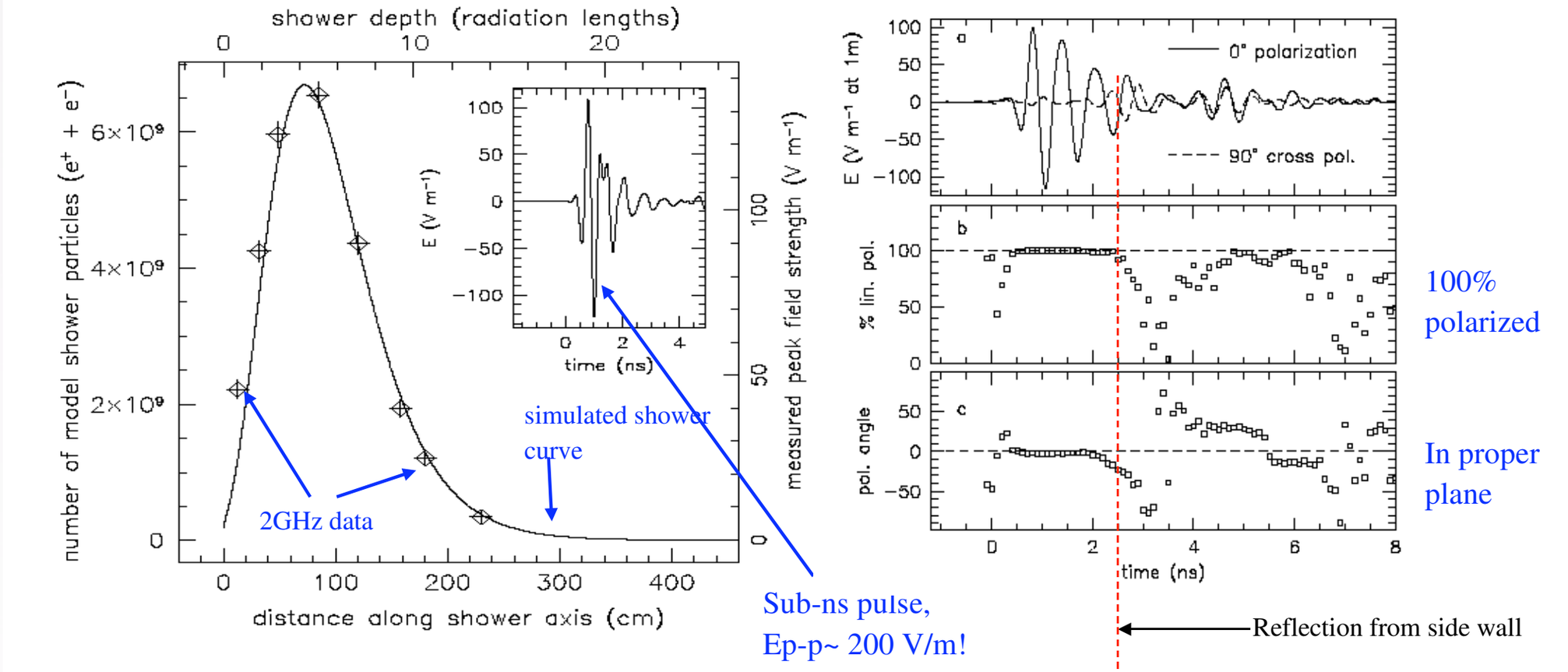
- Askaryan effect experimentally confirmed in 2000



From Saltzberg, Gorham, Walz et al PRL 2001

- Using 3.6 Tonnes of sand
  - (like a big cat's litter box)

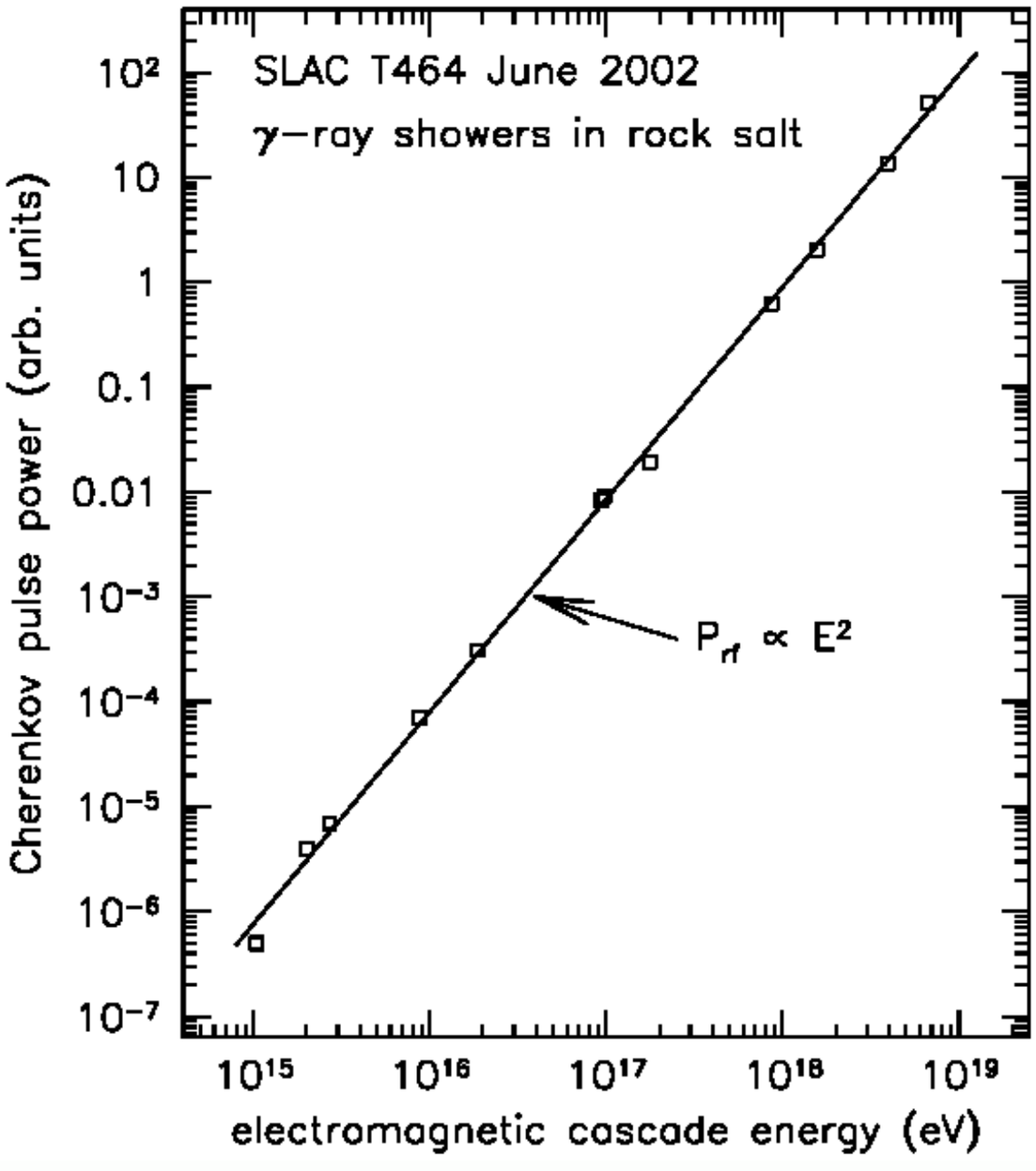
Results from Sand Box



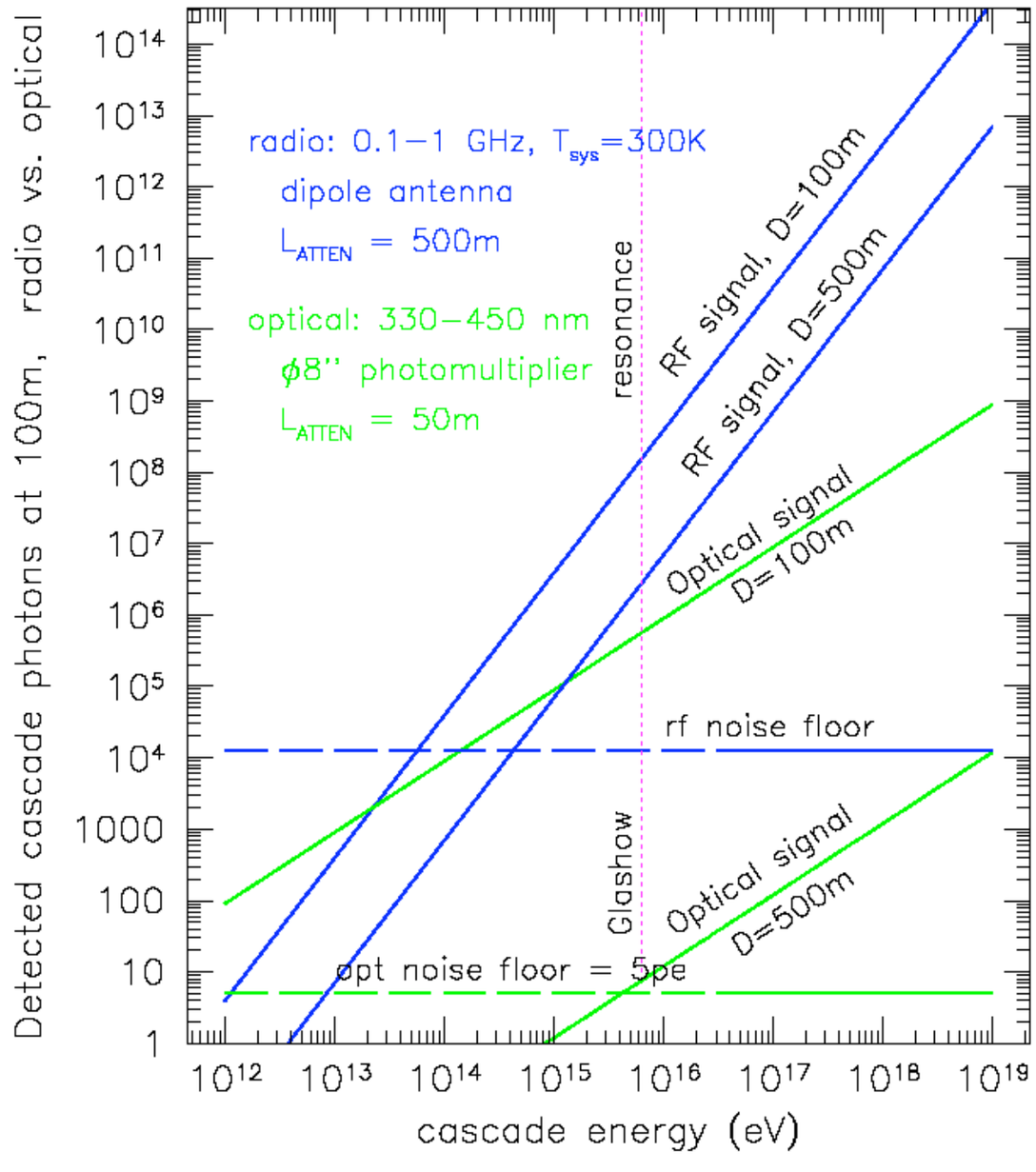
- Sub nanosecond pulse
- Excellent agreement between data and simulation of number of particles in shower
- Linearly polarised as expected
- Further measurements in 2002 with salt as the medium

Coherent Signal

Coherent signal over 4 orders of magnitude

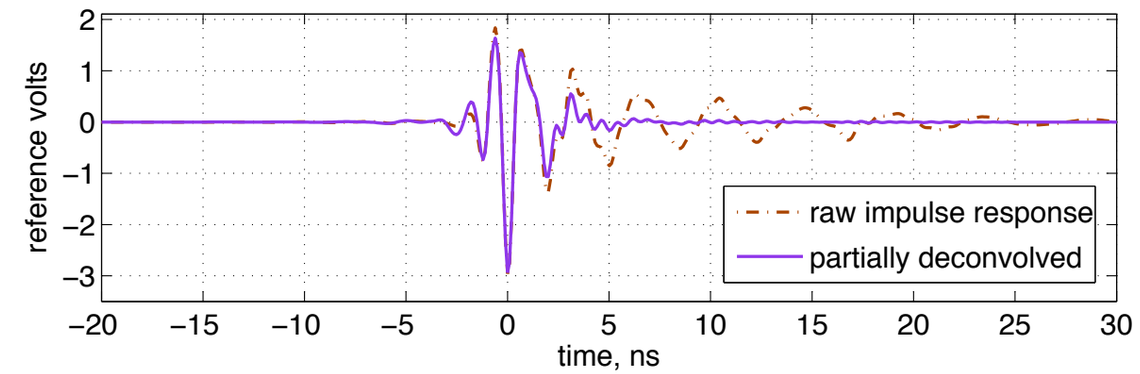


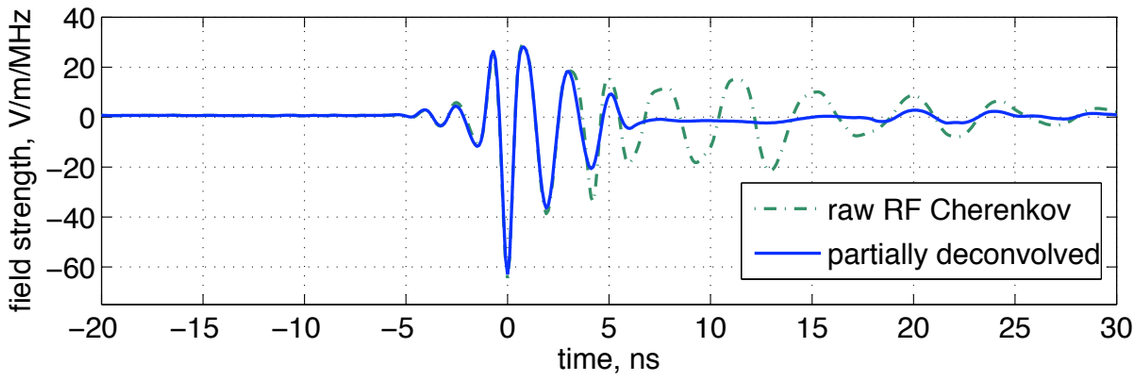
SNR dominant for E > 10 TeV

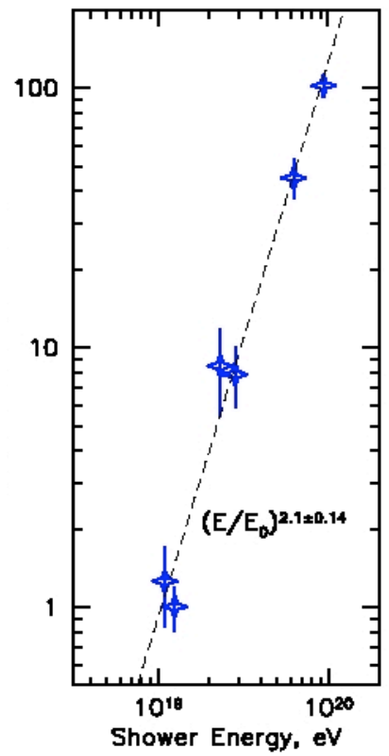


Also in Ice

- ...so we took it to SLAC in summer 2006.
- and built a 7.5 tonne block of ice





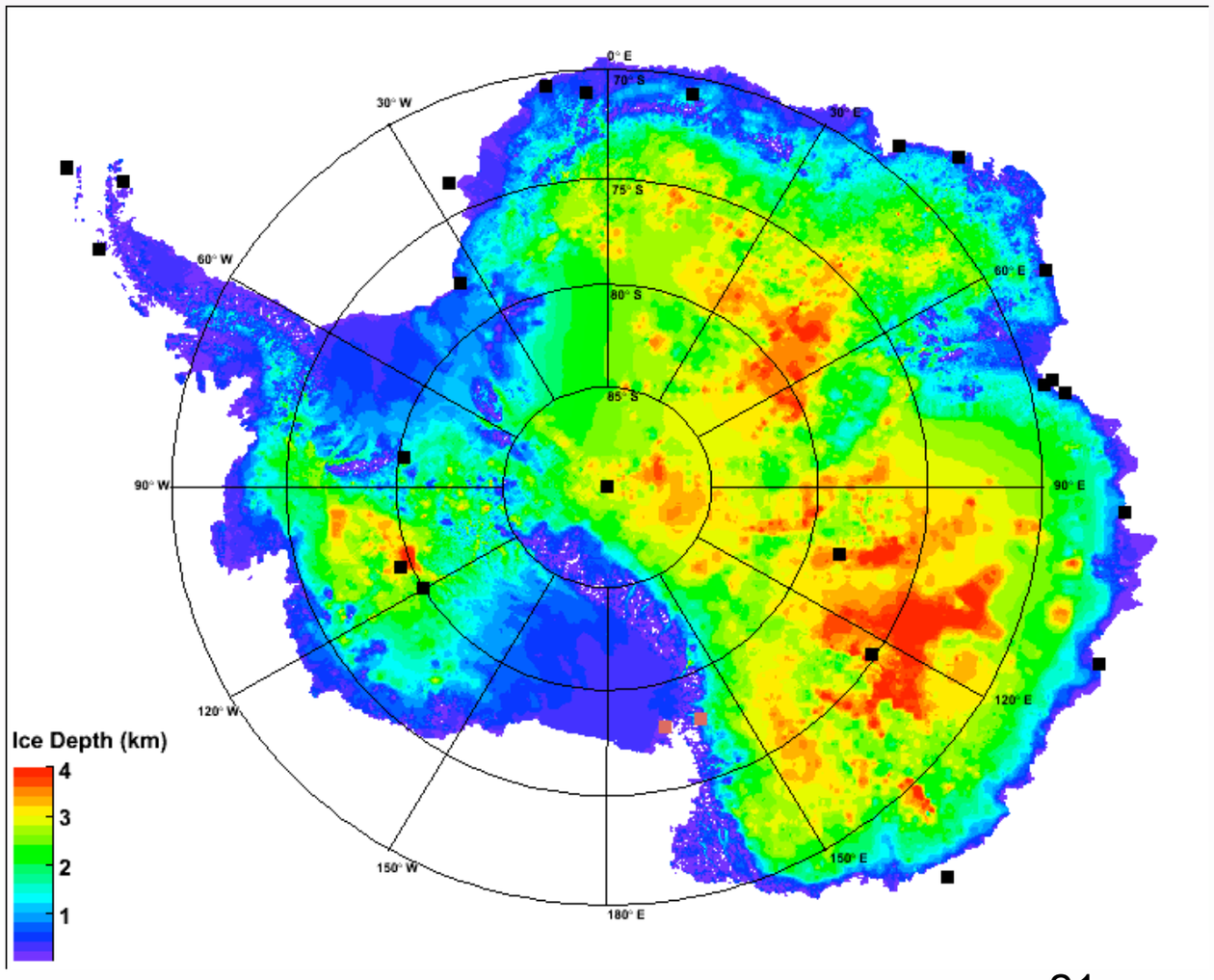


From: ANITA SLAC test beam paper submitted to Physics Review Letters

Where can you do it?

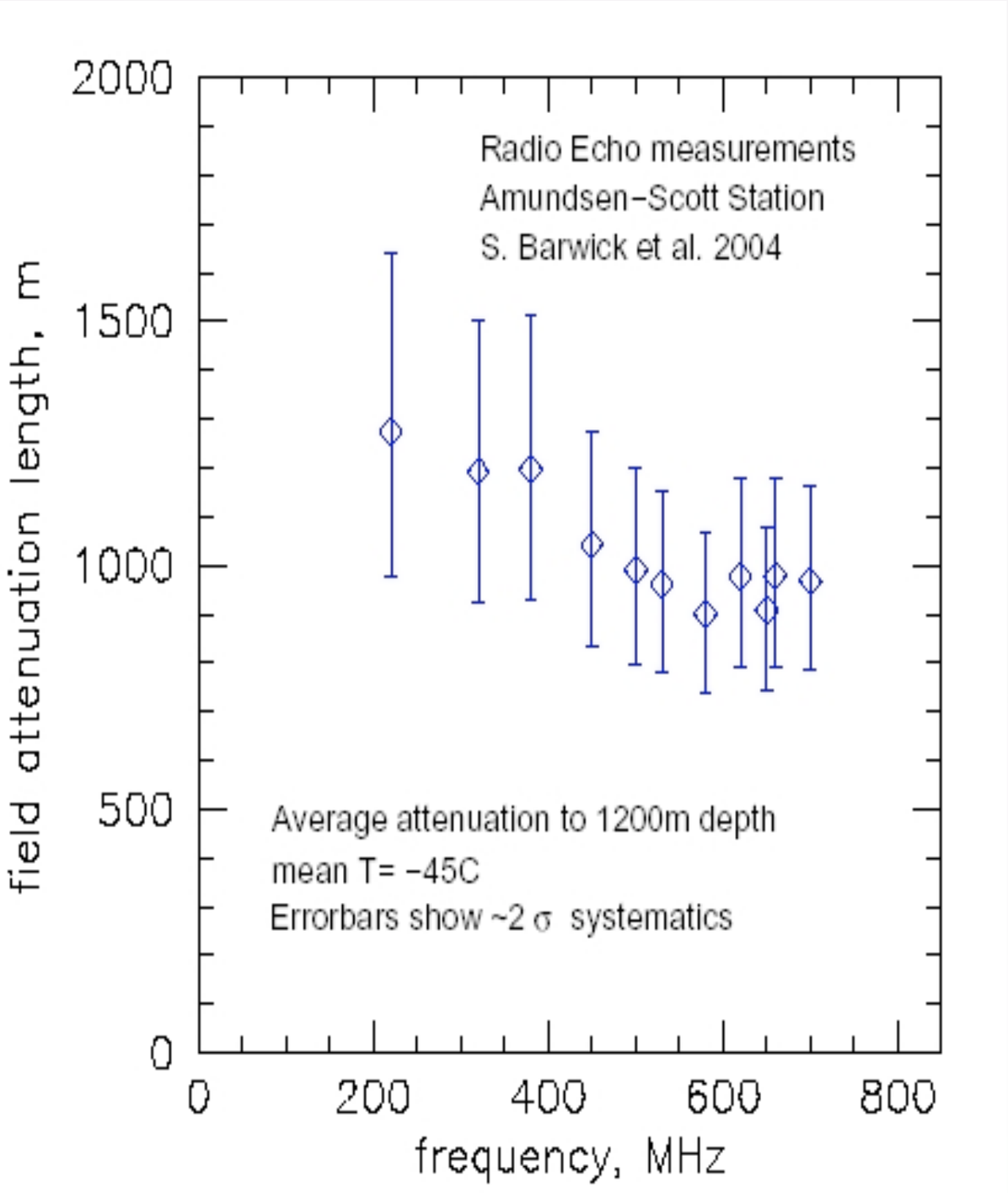
Antarctica

- The coldest, driest, windiest place on Earth!
  - Lots of Ice
    - Despite our best efforts
    - Over 4km thick in places
  - Also:
    - The only continent dedicated to scientific research
    - No indigenous (human) population
      - So relatively free of manmade noise



Long Radio Attenuation Lengths

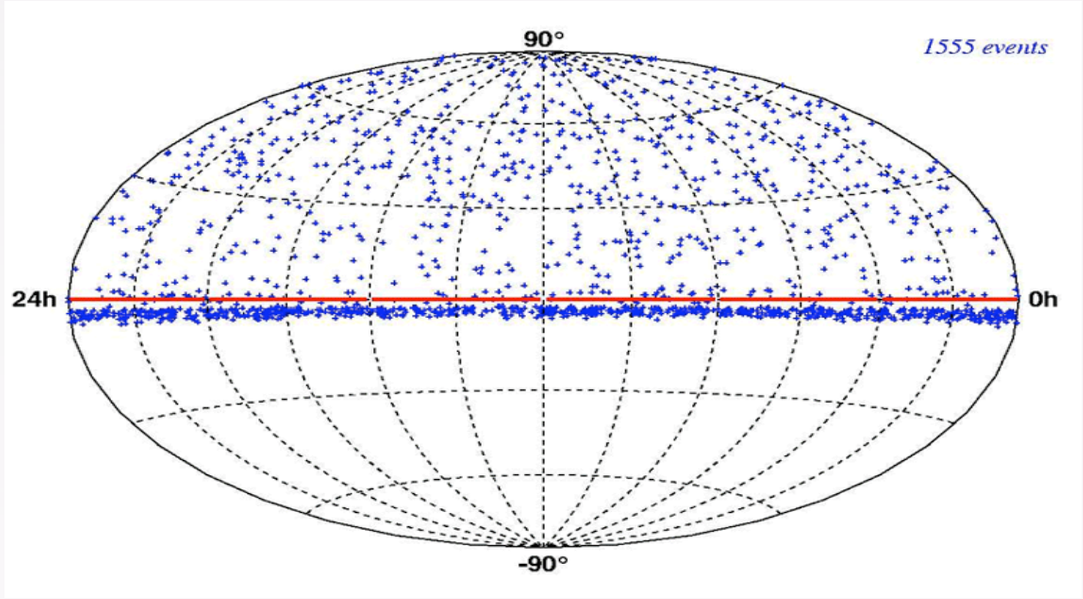
- There are numerous *in situ* measurements of the attenuation length of Antarctic ice, they show:
  - Attenuation length is greater than 1km
  - Limits set on the birefringence
  - Many GPR measurements also



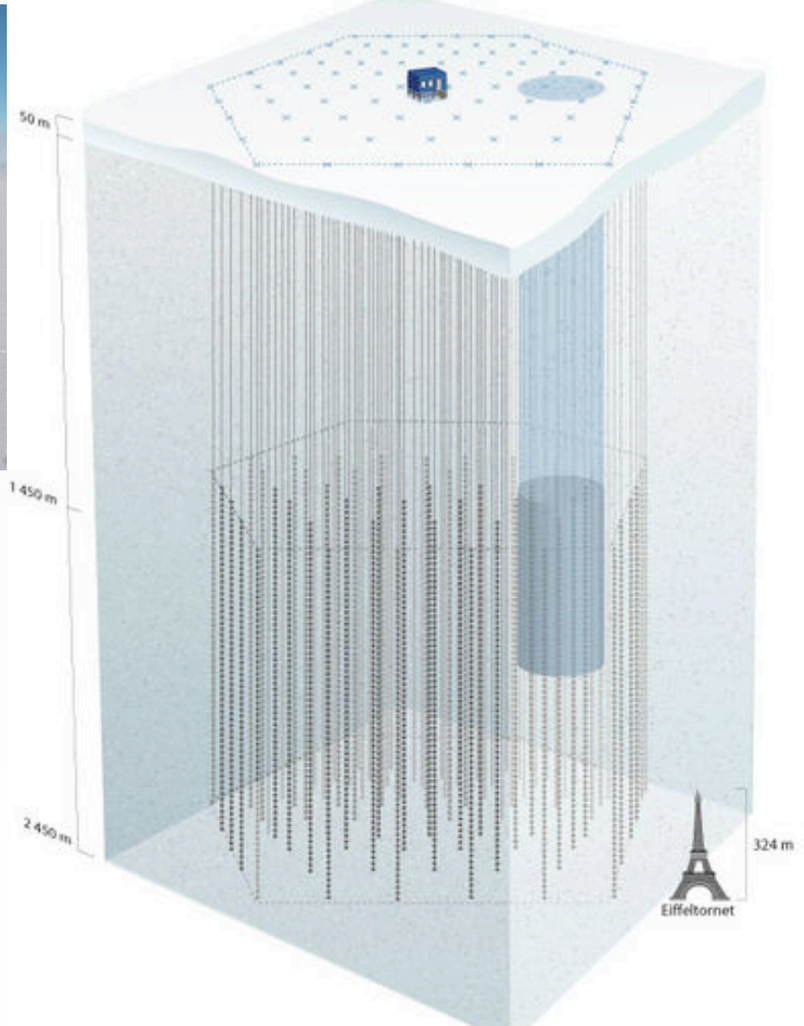
What with?

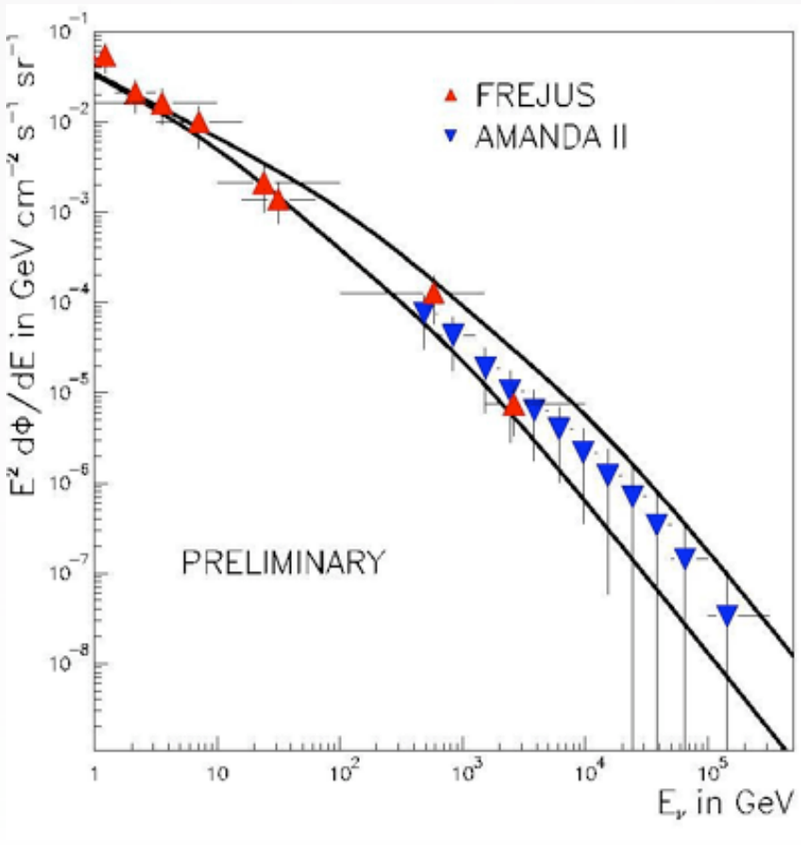
Amanda/IceCube

- Neutrino telescope at South Pole
  - Uses Optical Cherenkov method



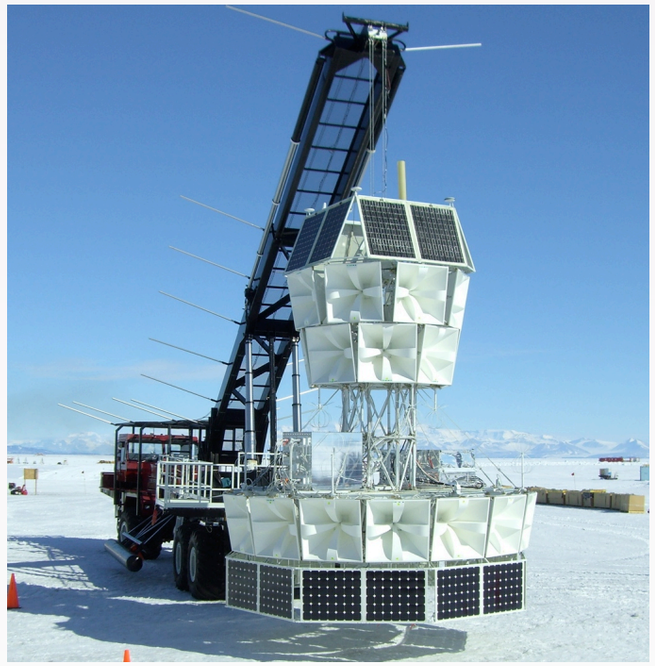
No excess above atmospheric neutrinos

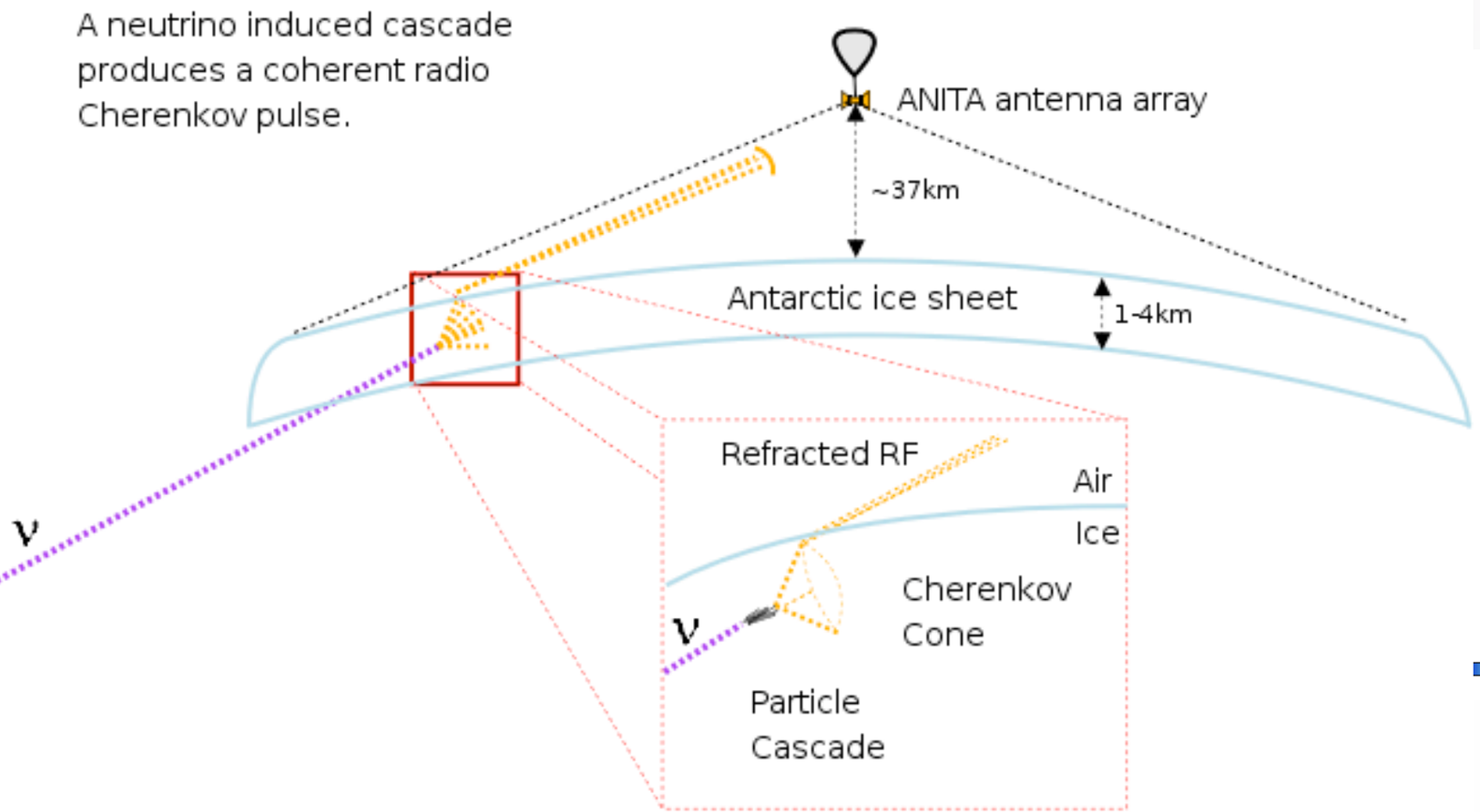


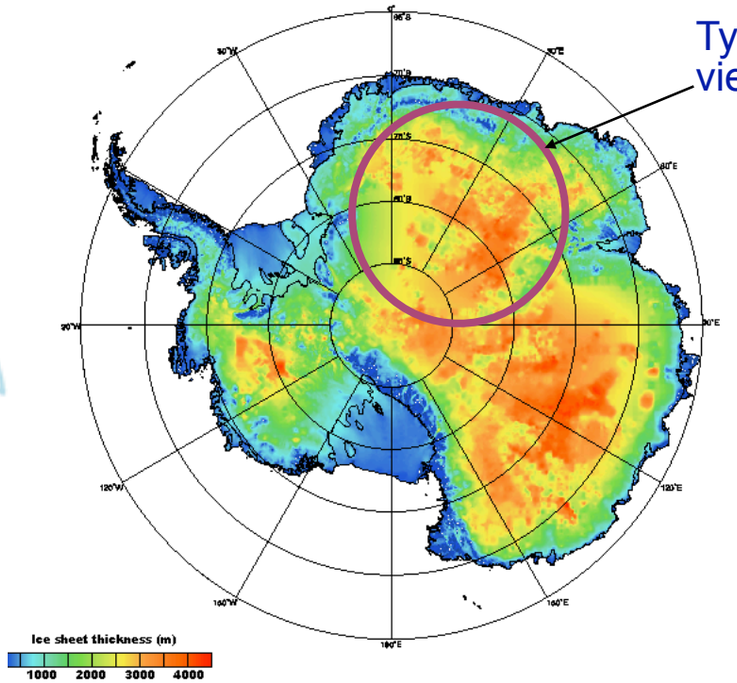


ANITA

- The ANtarctic Impulsive Transient Antenna
  - A more elegant solution?
  - A balloon borne experiment
    - 32 dual polarization antennas
    - Altitude of 37km
    - Horizon at 700km
    - Over 1 million km^3 of ice visible





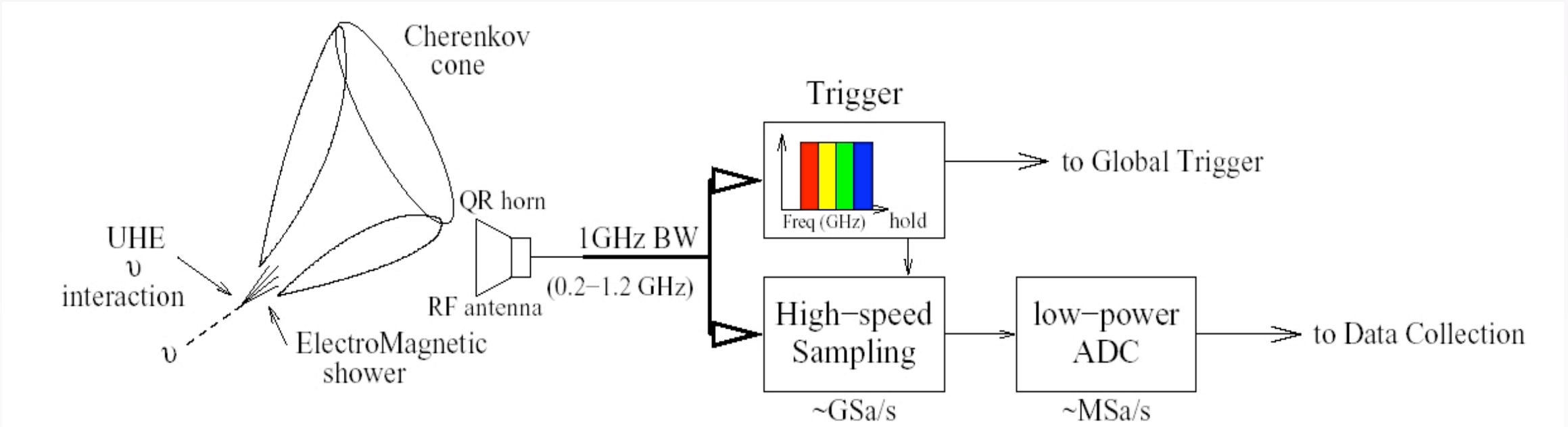


The ANITA Collaboration

- University of Hawaii at Manoa
  Honolulu, Hawaii, USA
- University of California at Irvine
  Irvine, California, USA
- University of California at Los Angeles
  Los Angeles, California, USA
- University College London
  London, UK
- University of Delaware
  Newark, Delaware
- Jet Propulsion Laboratory
  Pasadena, California, USA
- University of Kansas
  Lawrence, Kansas, USA
- University of Minnesota
  Minneapolis, Minnesota, USA
- The Ohio State University
  Columbus, Ohio, USA
- Stanford Linear Accelerator Center
  Menlo Park, California, USA
- National Taiwan University
  Taipei, Taiwan
- Washington University in St. Louis
  St. Louis, Missouri, USA

ANITA Electronics

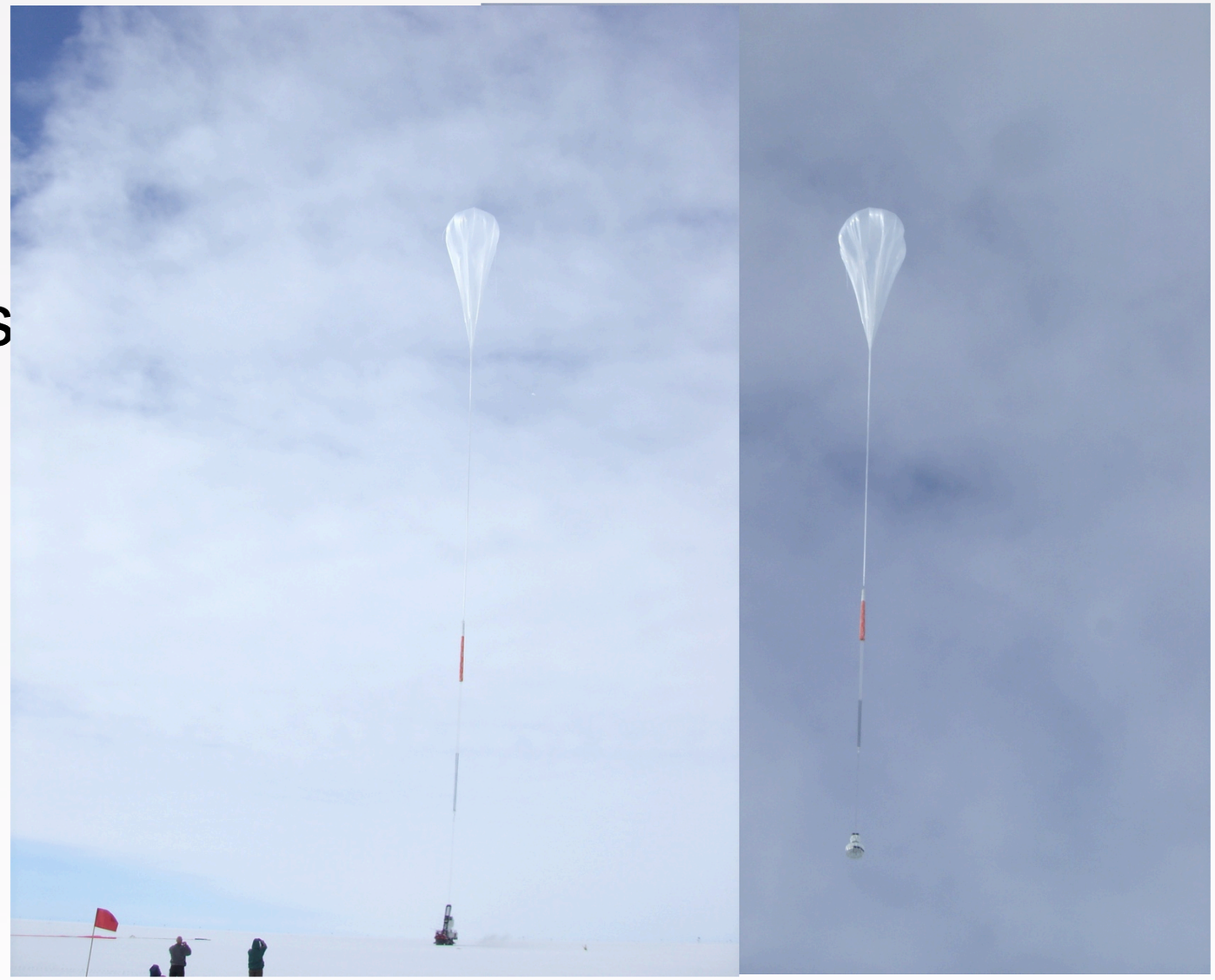
- Needed a low power (only solar energy), 90 channel, GHz bandwidth oscilloscope.

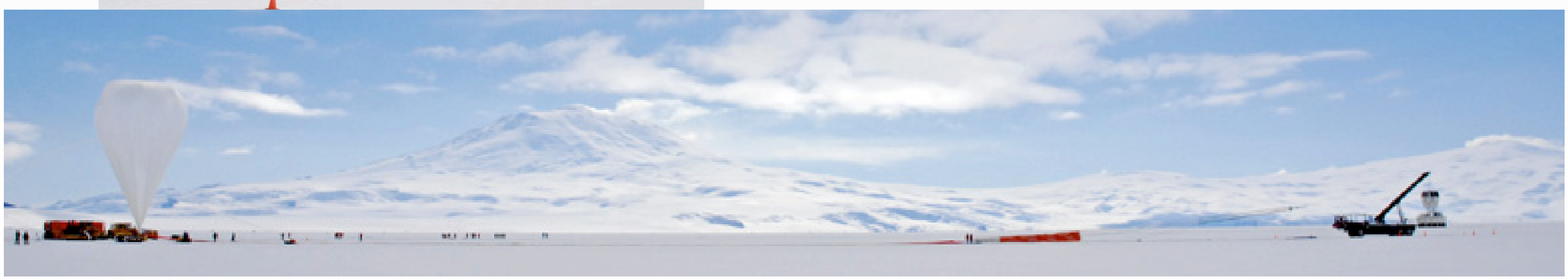


- Split trigger and waveform paths
- Use multiple frequency bands for trigger
- ‘Buffer’ waveform data in switched capacitor array
- Only digitise when we have a trigger

Up, up and away

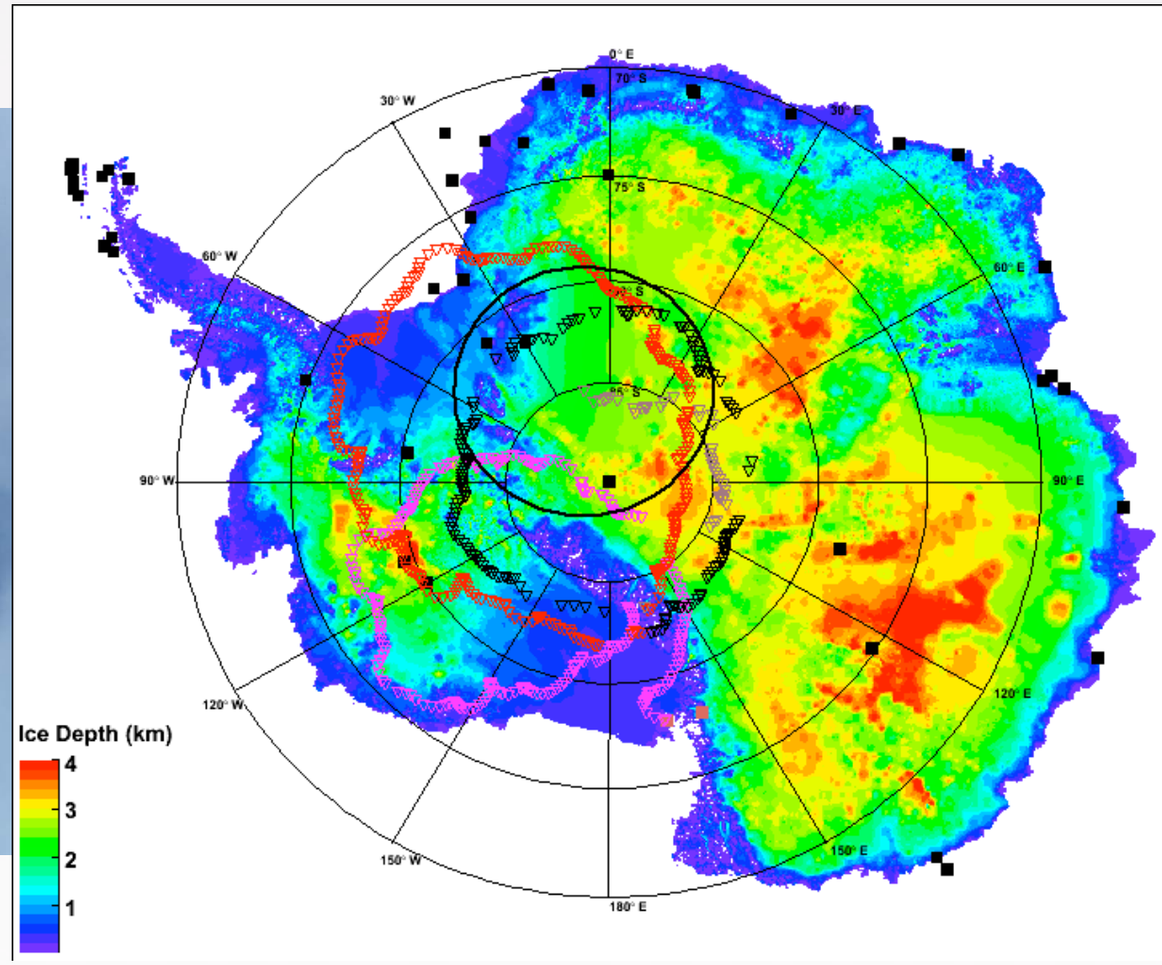
- The Balloon
  - Just 0.02mm thick
  - Takes 100 million litres of helium (and several hours) to fill



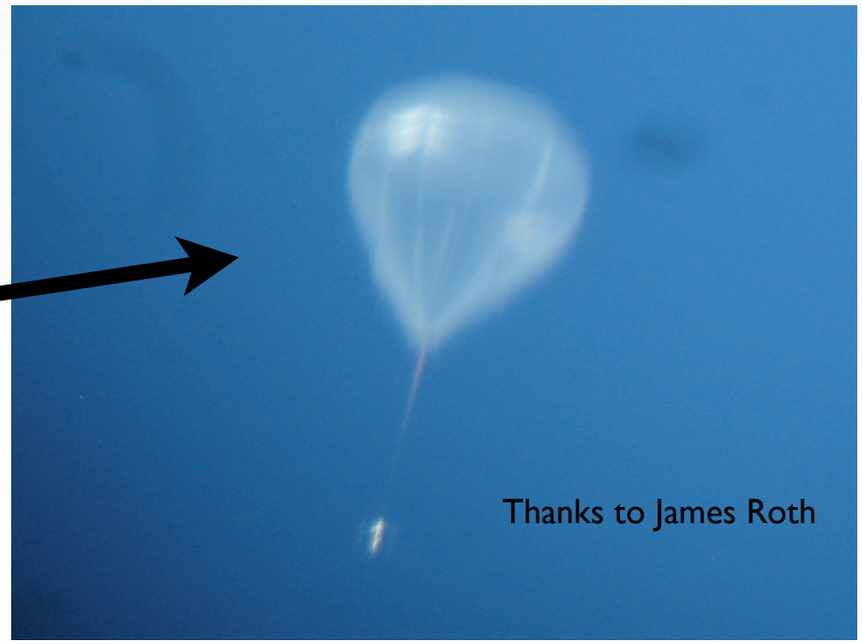


The Flight

- Lasted 35 days (record is 42)
  - Three and a half sort of polar orbits
  - Recorded over 8 million triggers
    - Maybe 1 or 2 neutrinos
- Flew so close to South Pole, someone took a photo

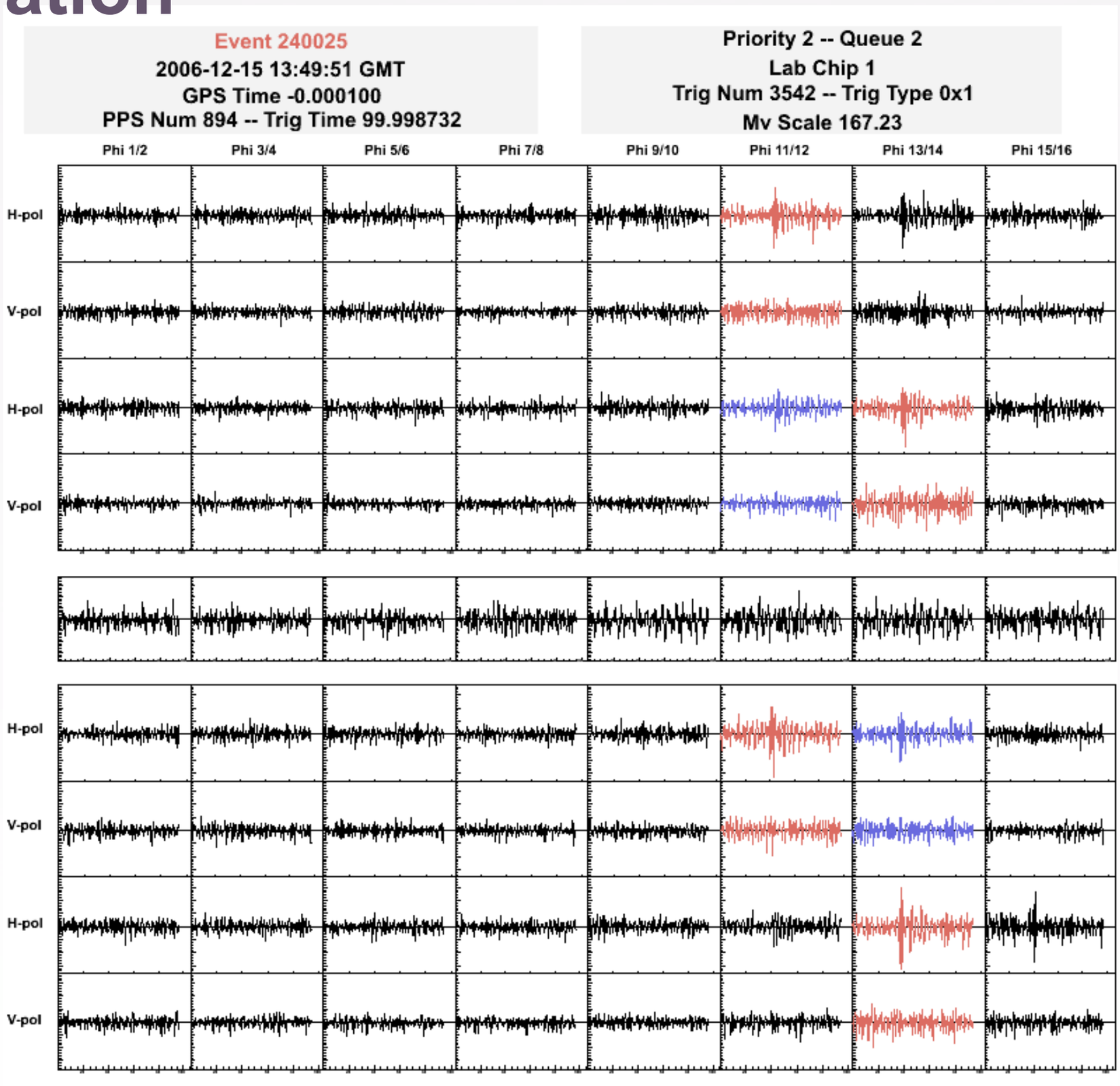


Fits inside the balloon at altitude

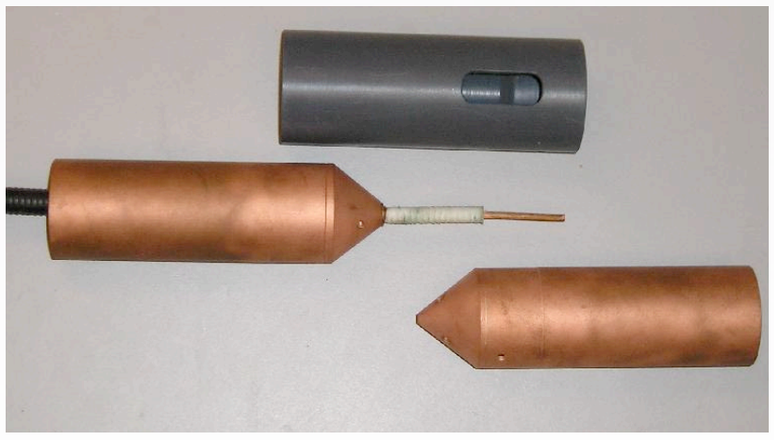


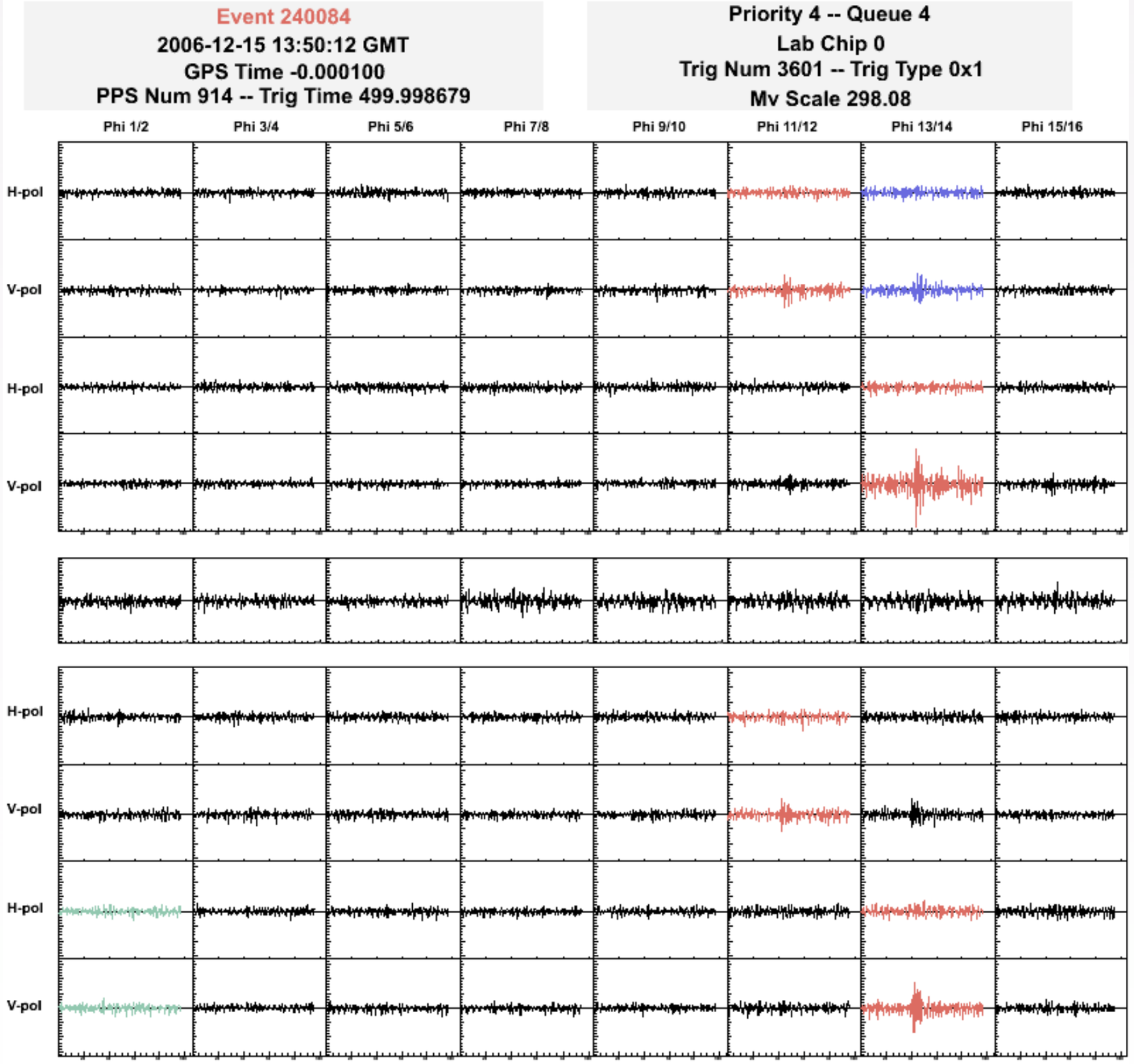
Thanks to James Roth

Ground Calibration



Borehole Calibration

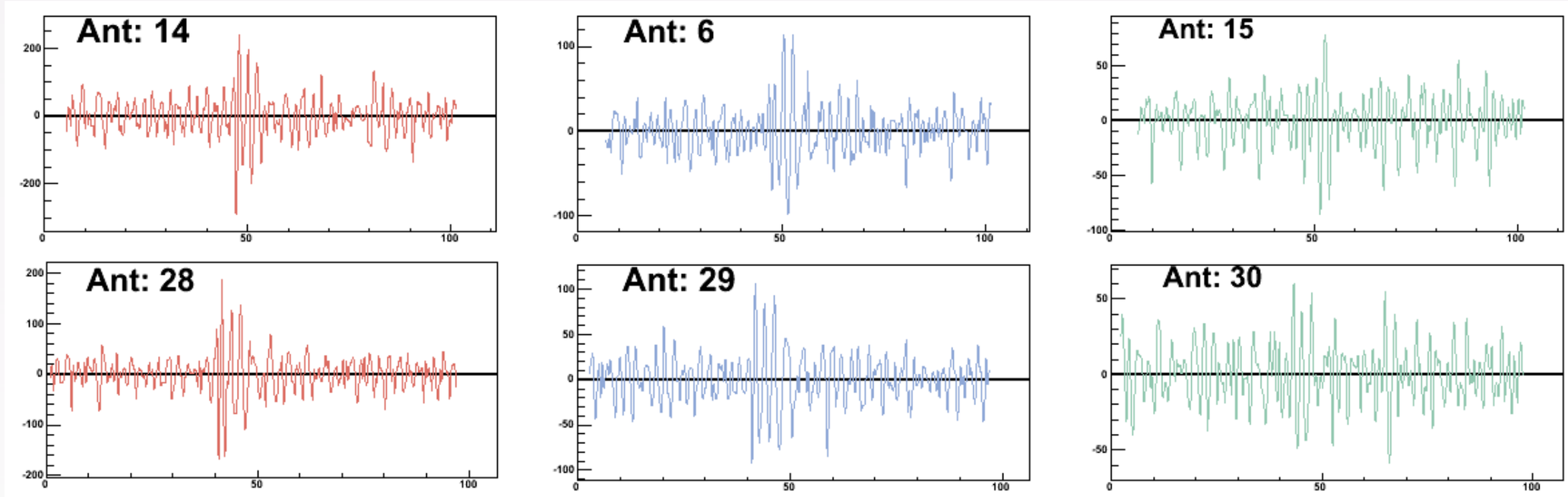




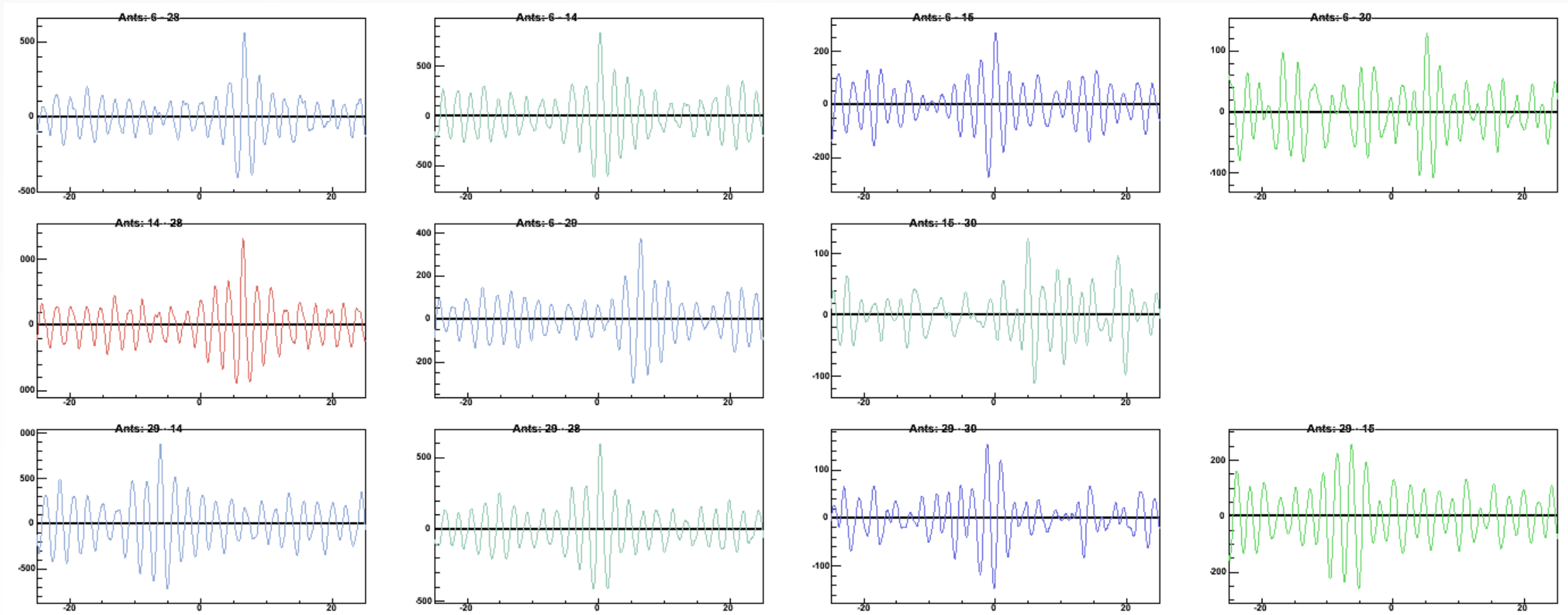
Event Reconstruction

Upper

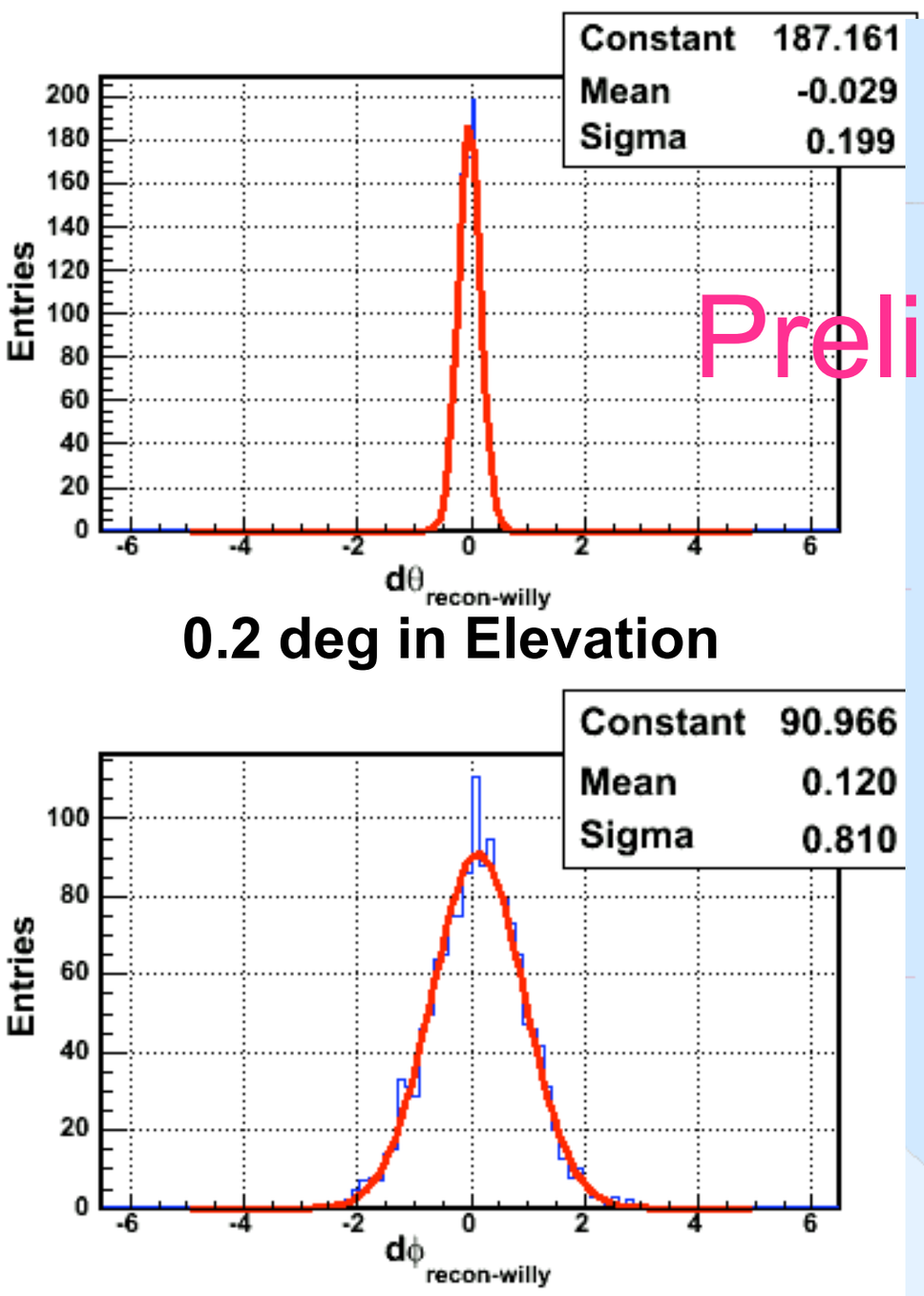
Lower



Measure Time Difference Between Antennas Using Cross-Correlations



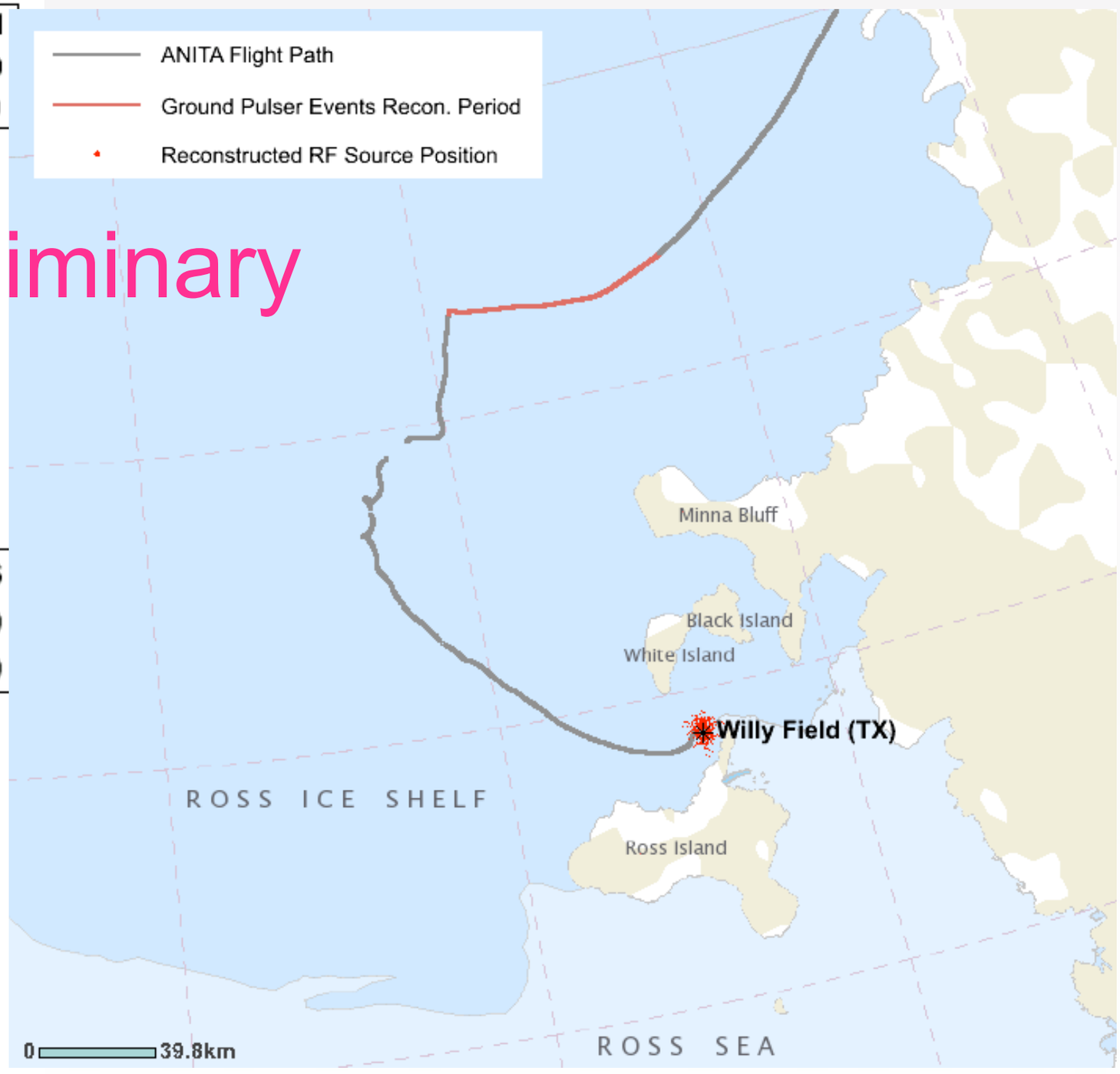
Angular Resolution -- From J. Nam



0.2 deg in Elevation

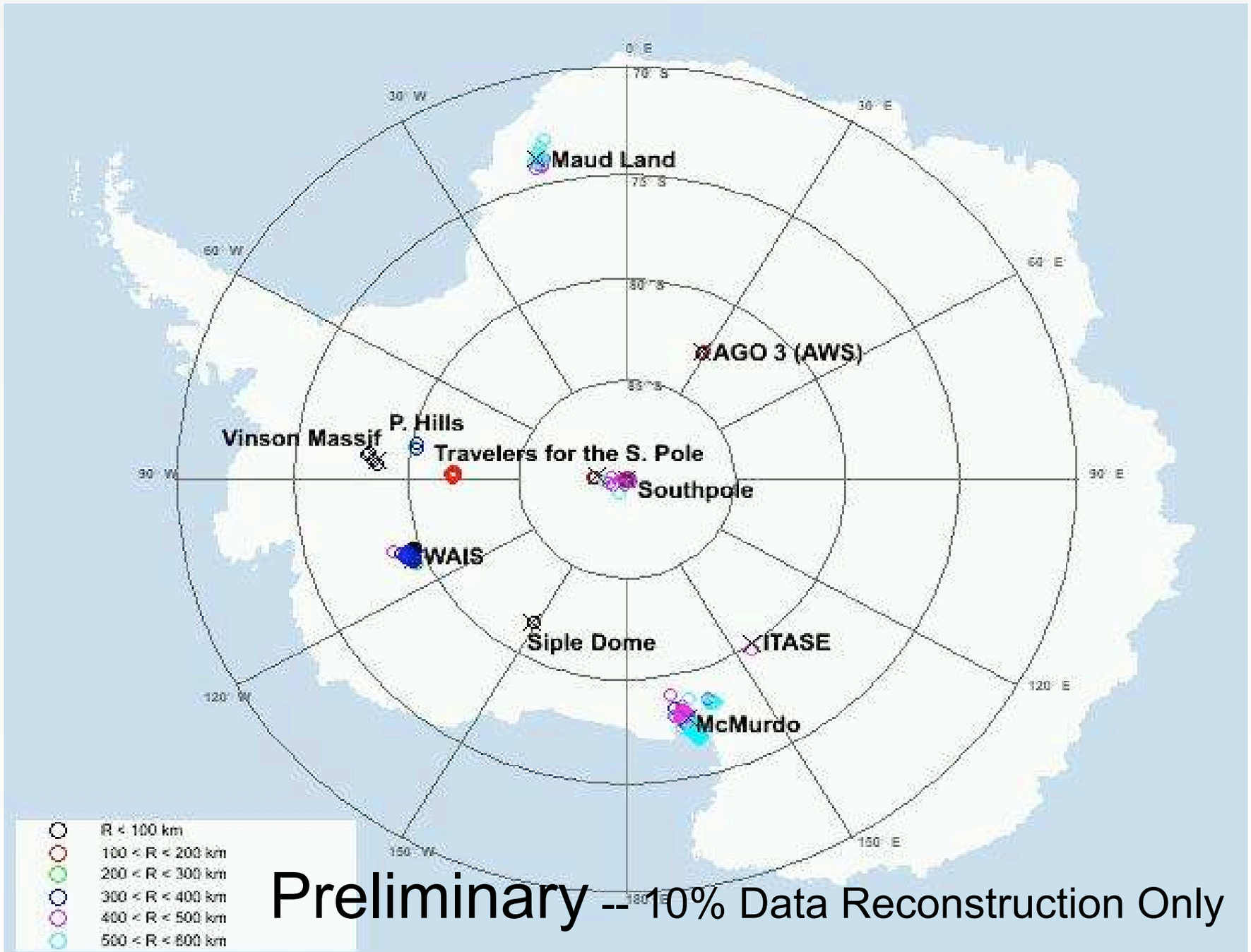
0.8 deg in Azimuth

Preliminary



A Glimpse at the Data -- (J. Nam)

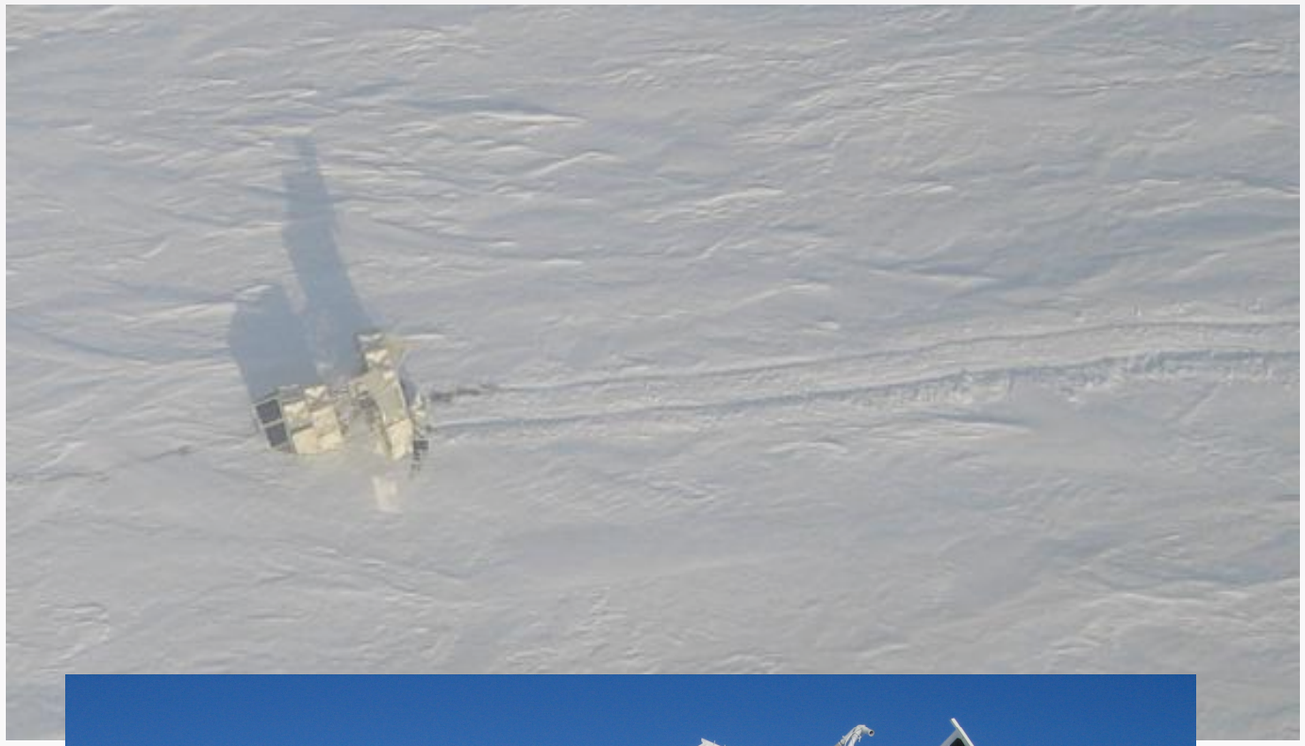
- Just using reconstruction (no signal cuts)

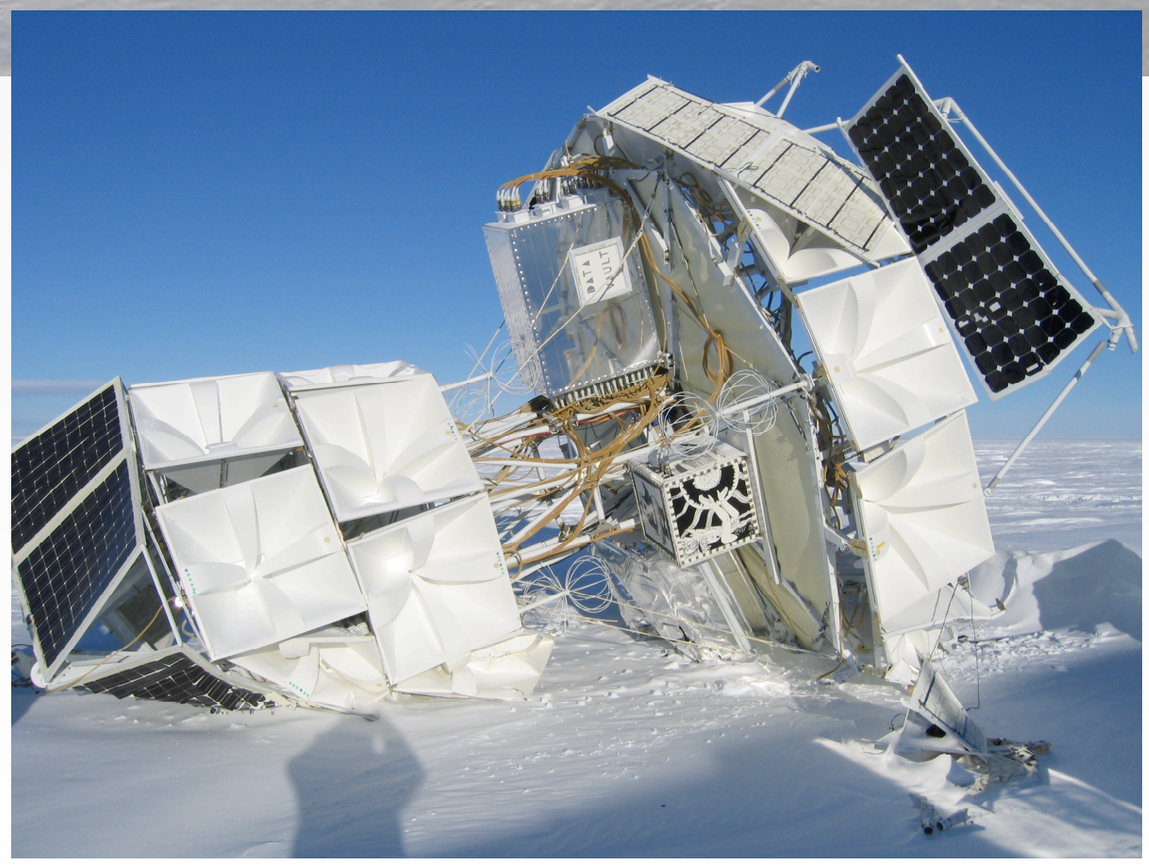


Preliminary -- 10% Data Reconstruction Only

What Goes Up...

- The Landing:
  - Initiated by detonating small explosive to separate from balloon
  - Descend gently on a parachute to the ground
  - Release parachute to prevent dragging
    - BLAST was dragged for 100 miles this year (ended in a crevice)
    - A few years ago one was dropped from 5000 feet

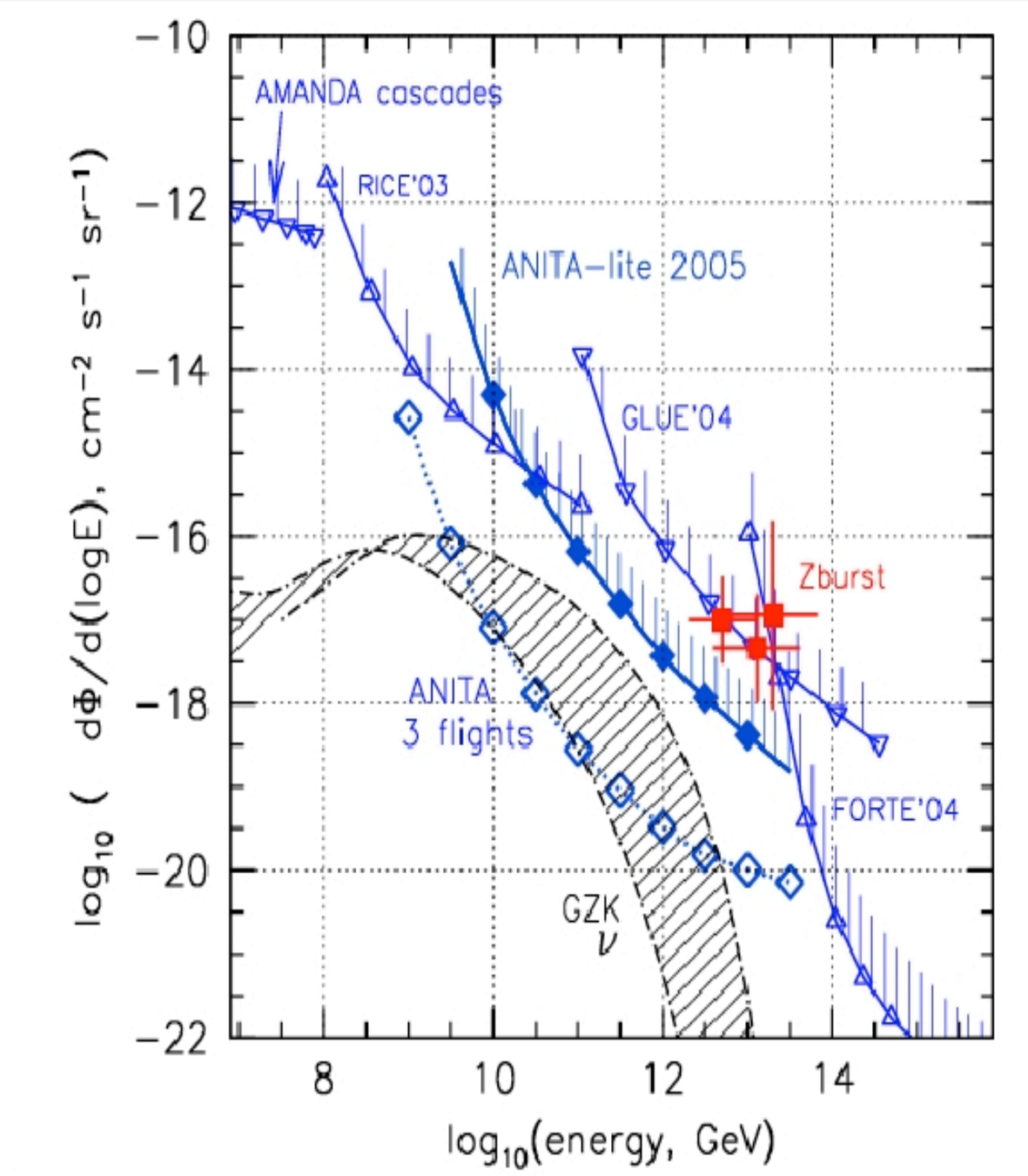




Photos from Dana Braun

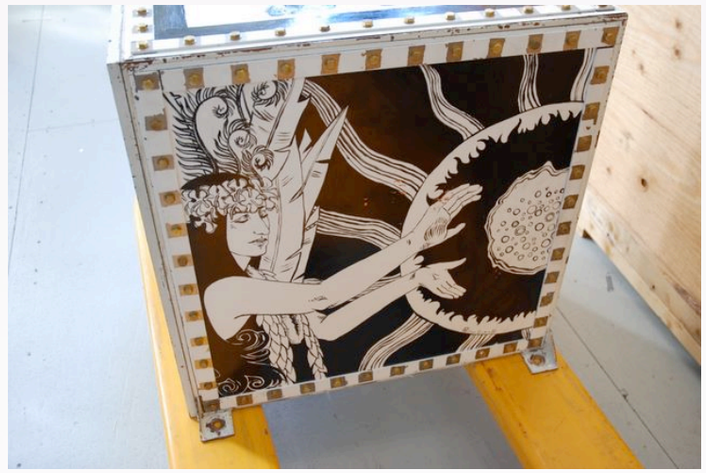
ANITA Prospects

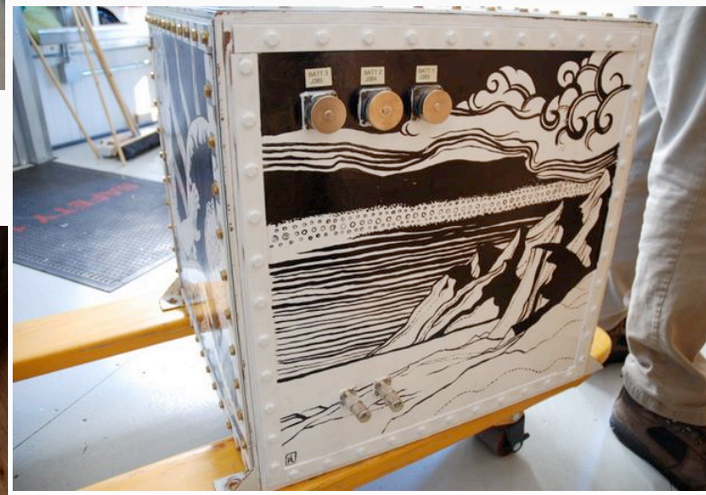
- Analysis is progressing
  - Are just now starting analysis of blind data sets.
- Expect to either detect UHE neutrinos or set the world's best flux limit.
- ANITA-lite, the ANITA prototype currently has the best limits over some of the range.



Battery Box

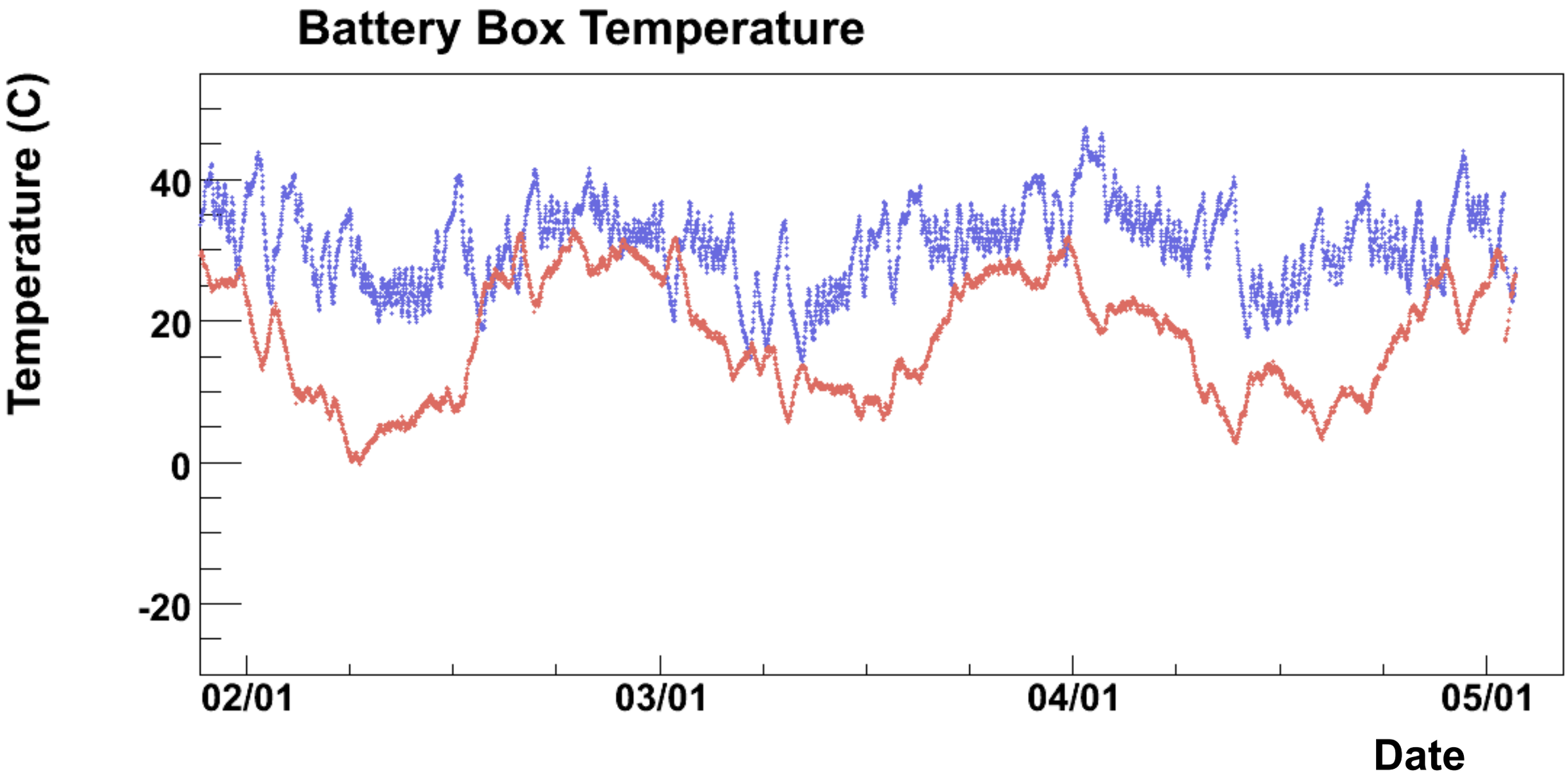
- Overheating is a major problem in Antarctica
  - At least at 37km
  - Paint everything white
- Battery box is like Goldilocks:
  - Not too hot
  - Not too cold
  - Need half black half white
- Antarctic Art Contest!





Thanks to the artists: Kai Smart, Dana Grant, Karen Joyce and ??? and Jeff Kowalski for the photographs

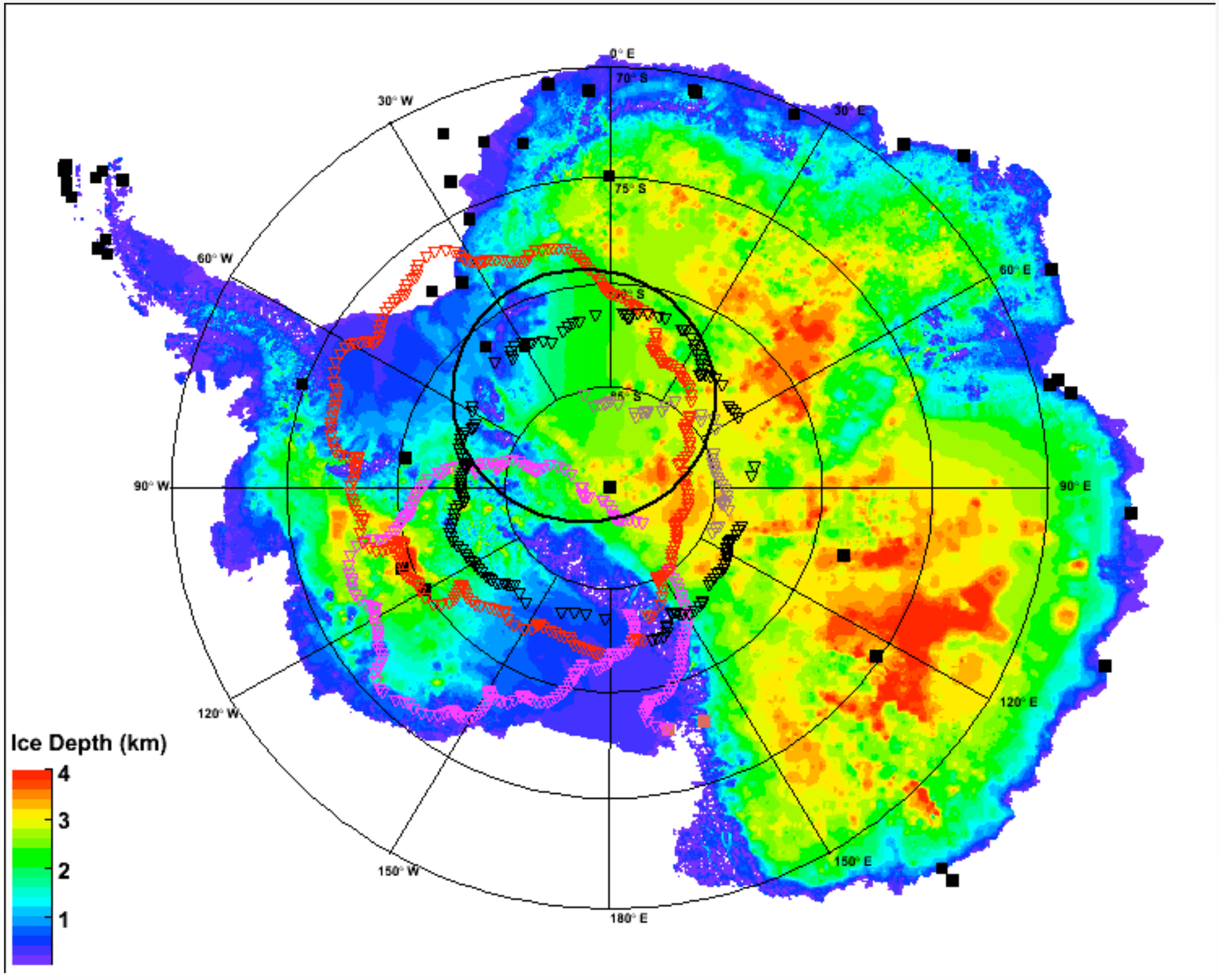
Paint Job Results



The Taylor Dome Tale

- Calibration Field Camp
  - 10 man weeks in a tent in the dry valleys
  - Waiting for balloon to fly over

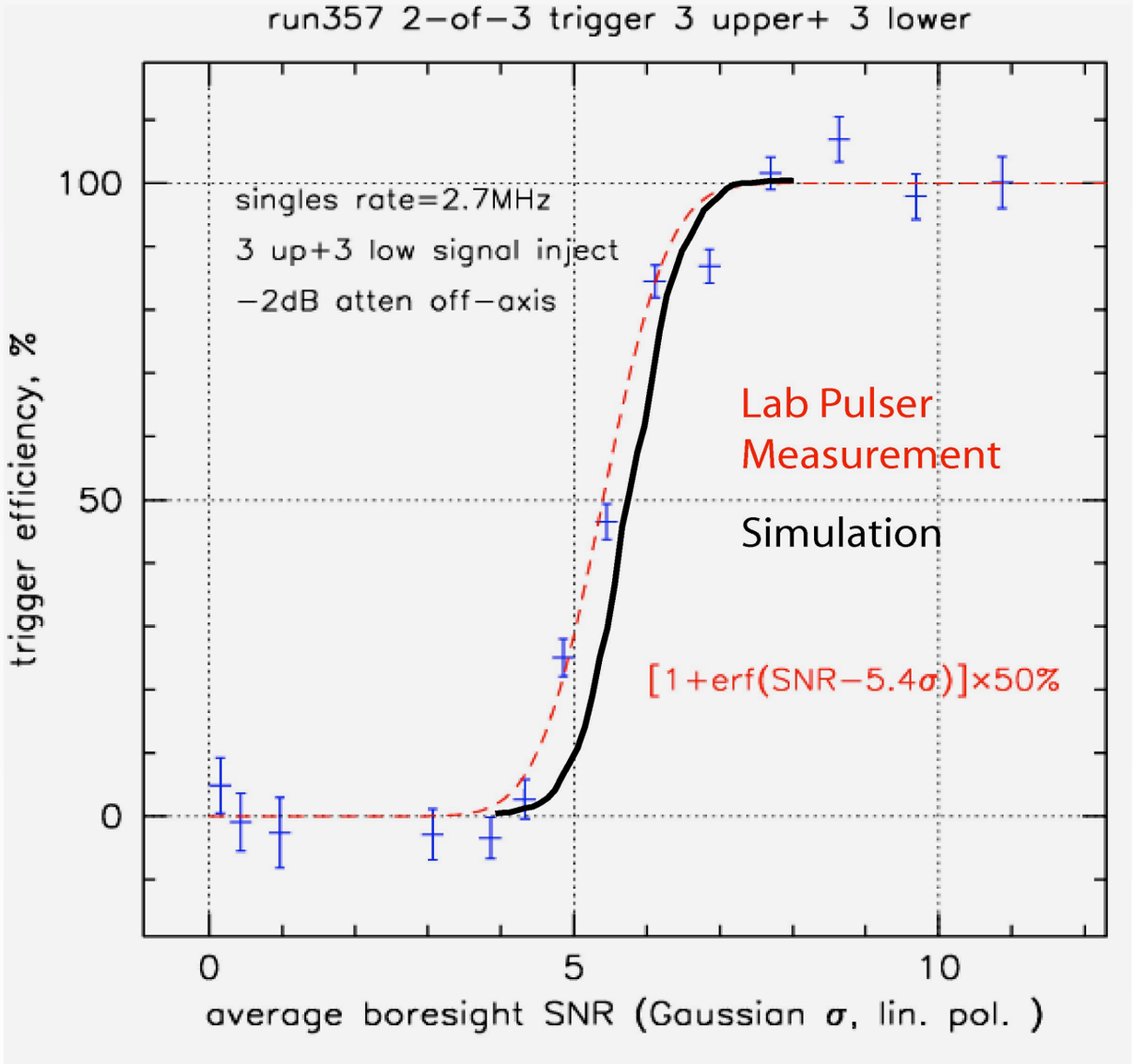
Maybe Next Time



If not now, when?

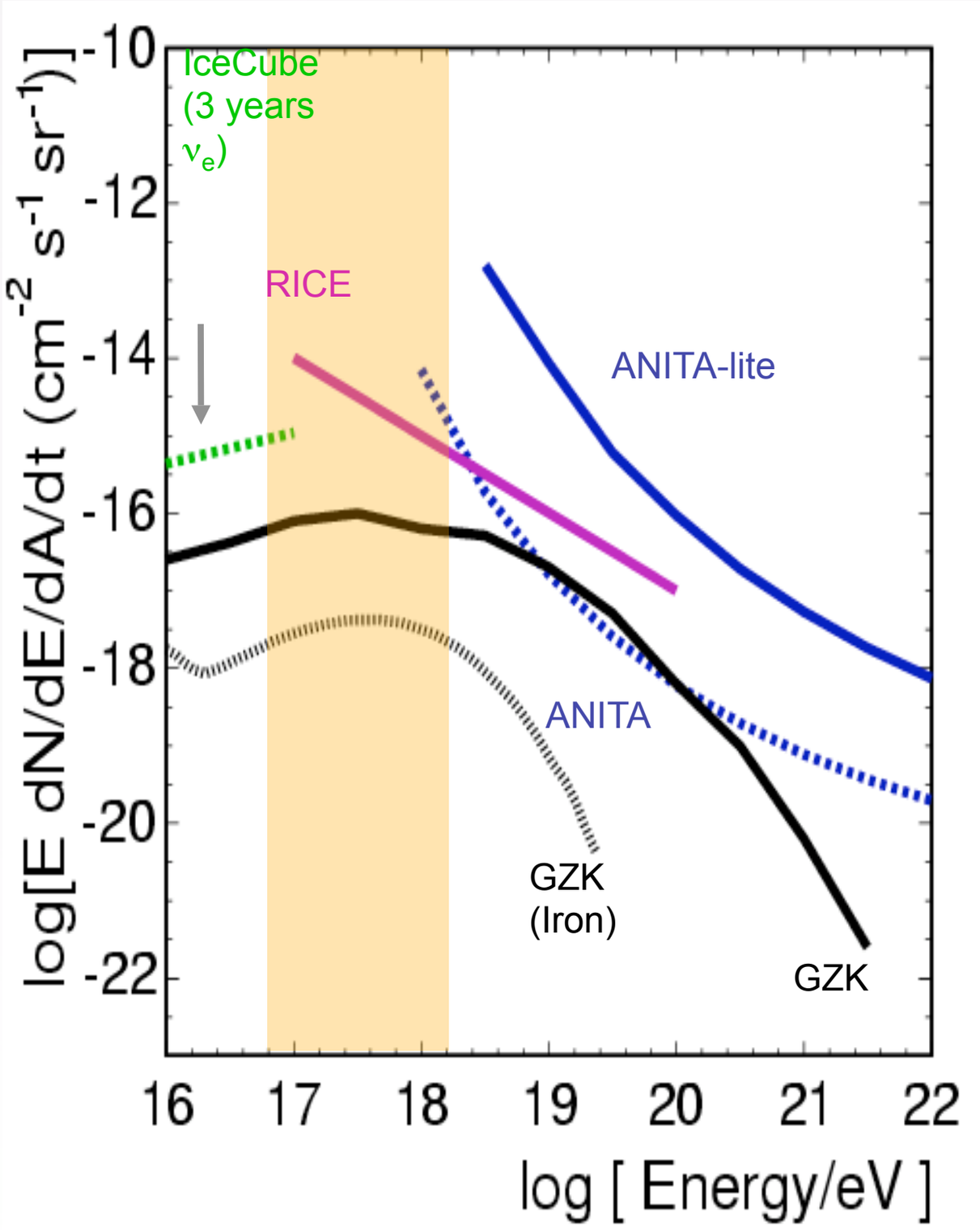
ANITA-II

- Second ANITA flight approved for 2008/9
- Plan to:
  - Add more antennas
  - Change trigger bands
  - V-Pol Trigger option
  - Implement software trigger
- Hope for:
  - Longer flight
  - Better flight path



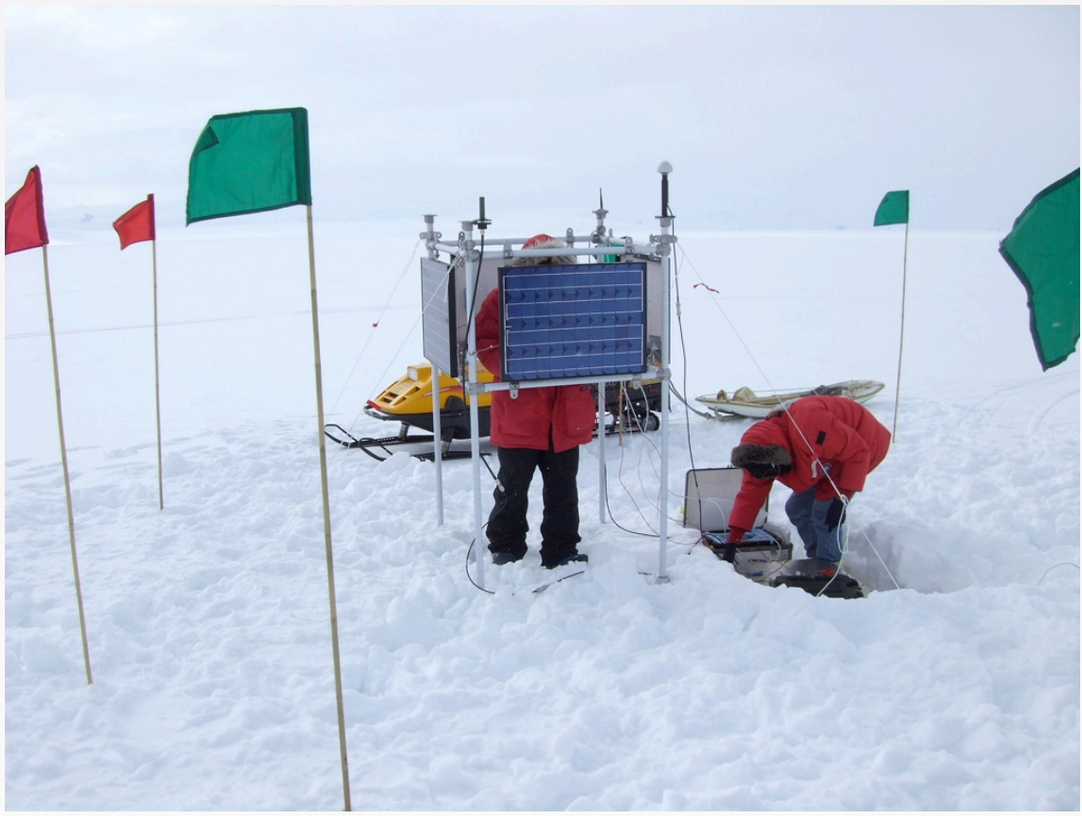
Embedded Detectors

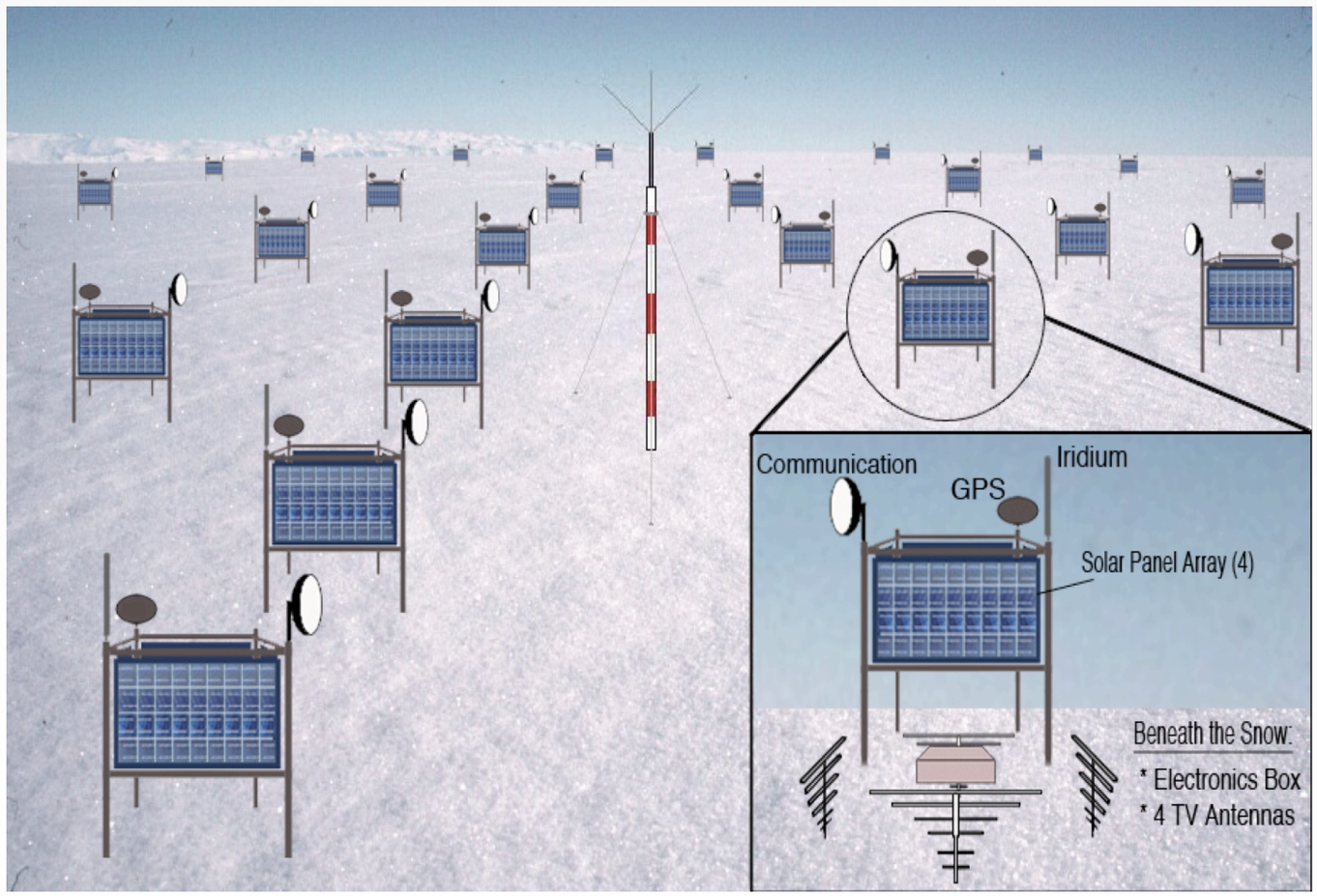
- Need embedded detectors to lower energy threshold
- Two of the ice-based candidates are:
  - ARIANNA
  - AURA/IceRay
- Also competition from:
  - Auger
  - SalSA
  - Lofar/SKA

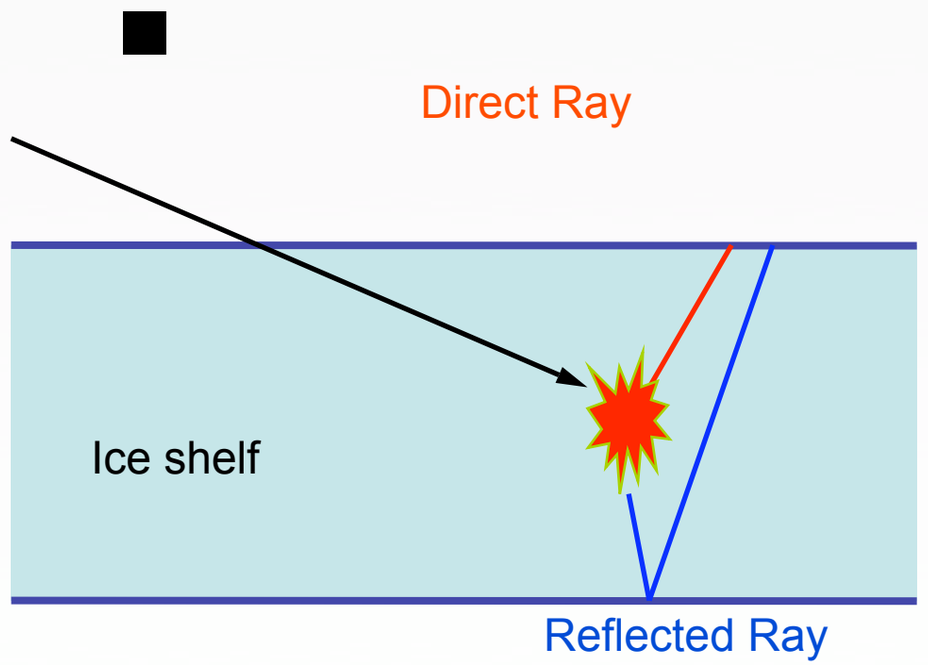


ARIANNA

- Prototype station deployed 2006/7
  - Communicated for two months with iridium modem

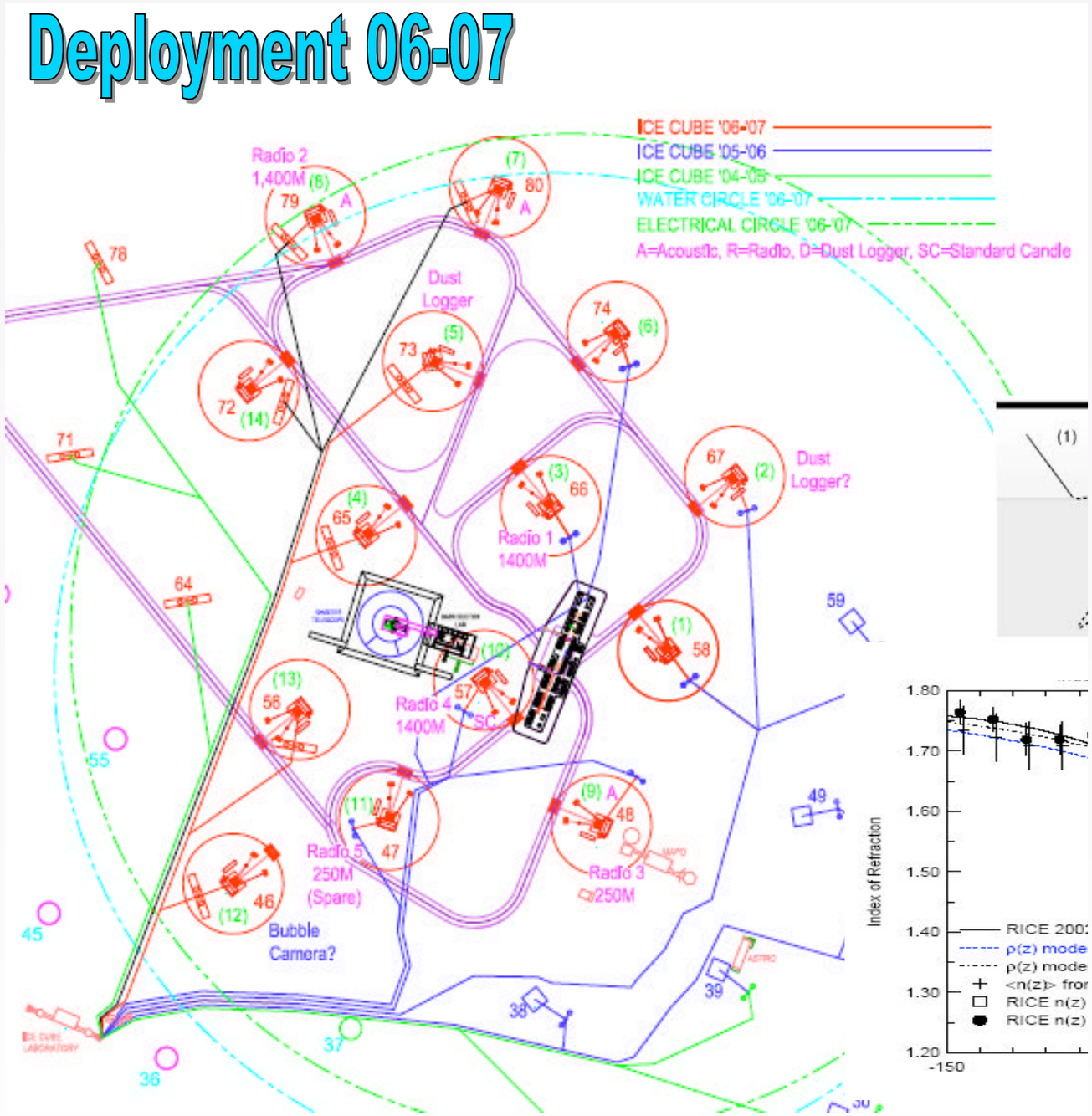






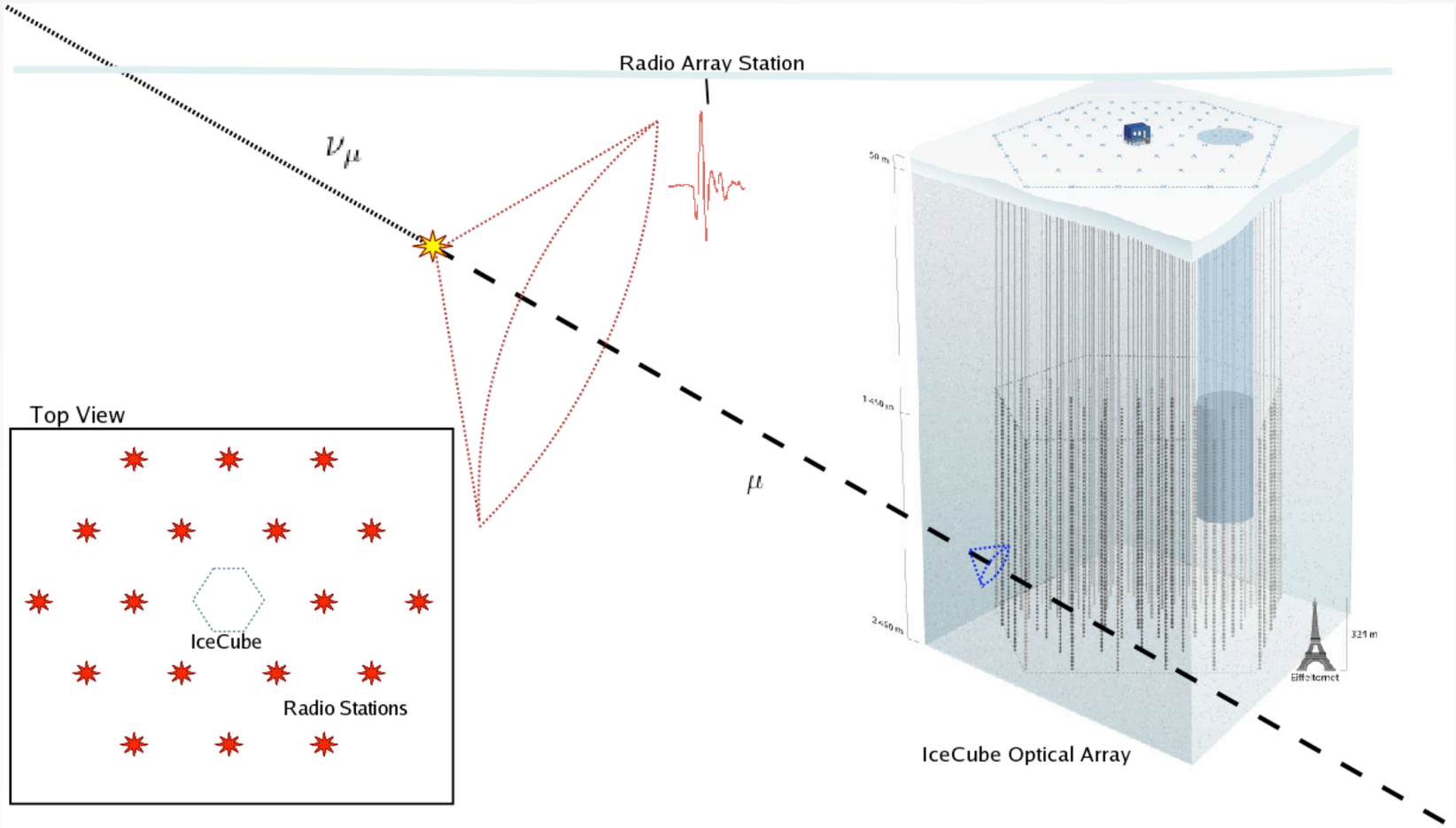
AURA/SPATS R&D

- Deploy acoustic and radio detectors in conjunction with IceCube
  - Possibility to measure neutrino with all three detection methods simultaneously
- Successor to the RICE experiment



IceRay/AURA

- An array of surface or just sub-surface antennas

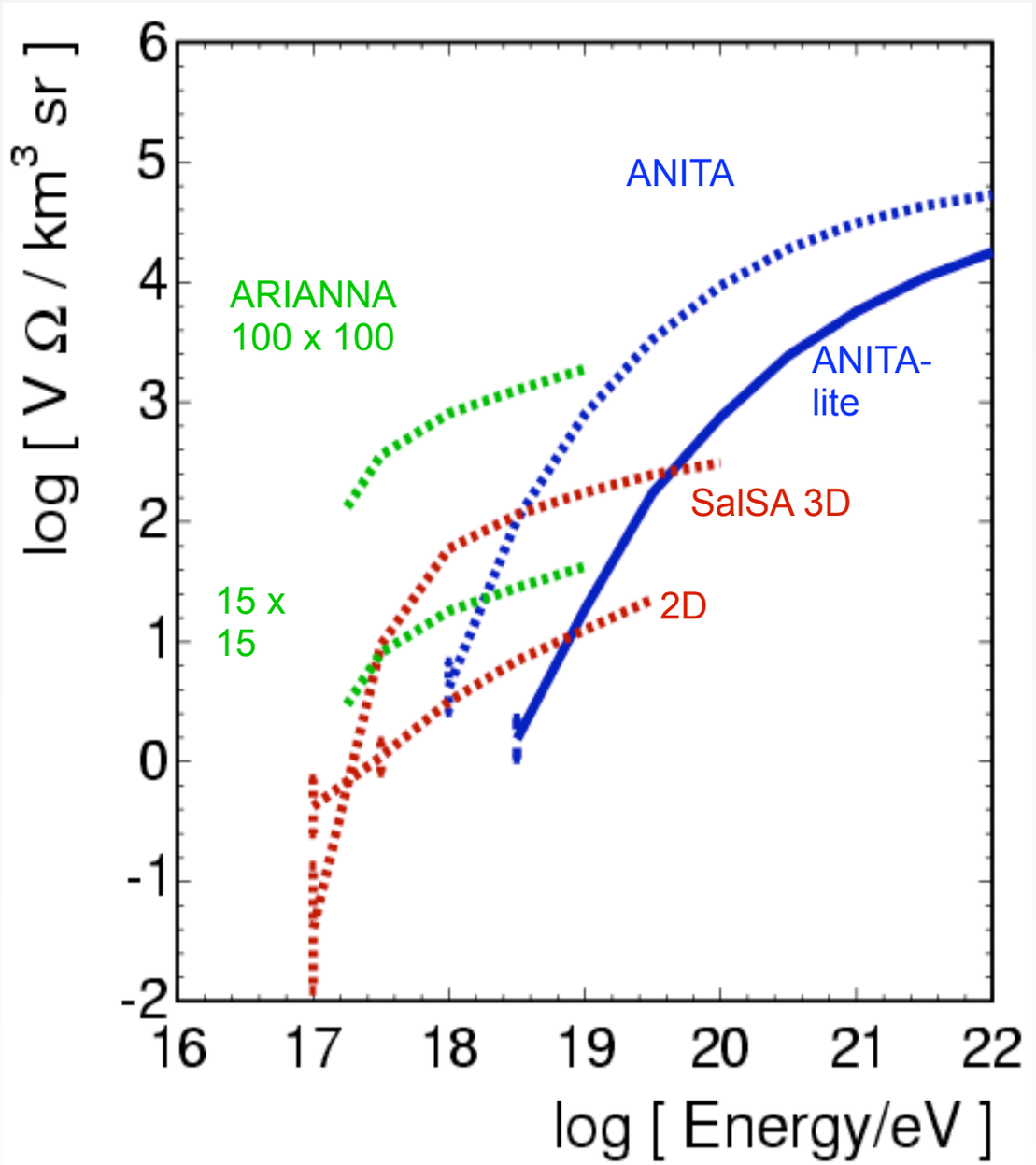


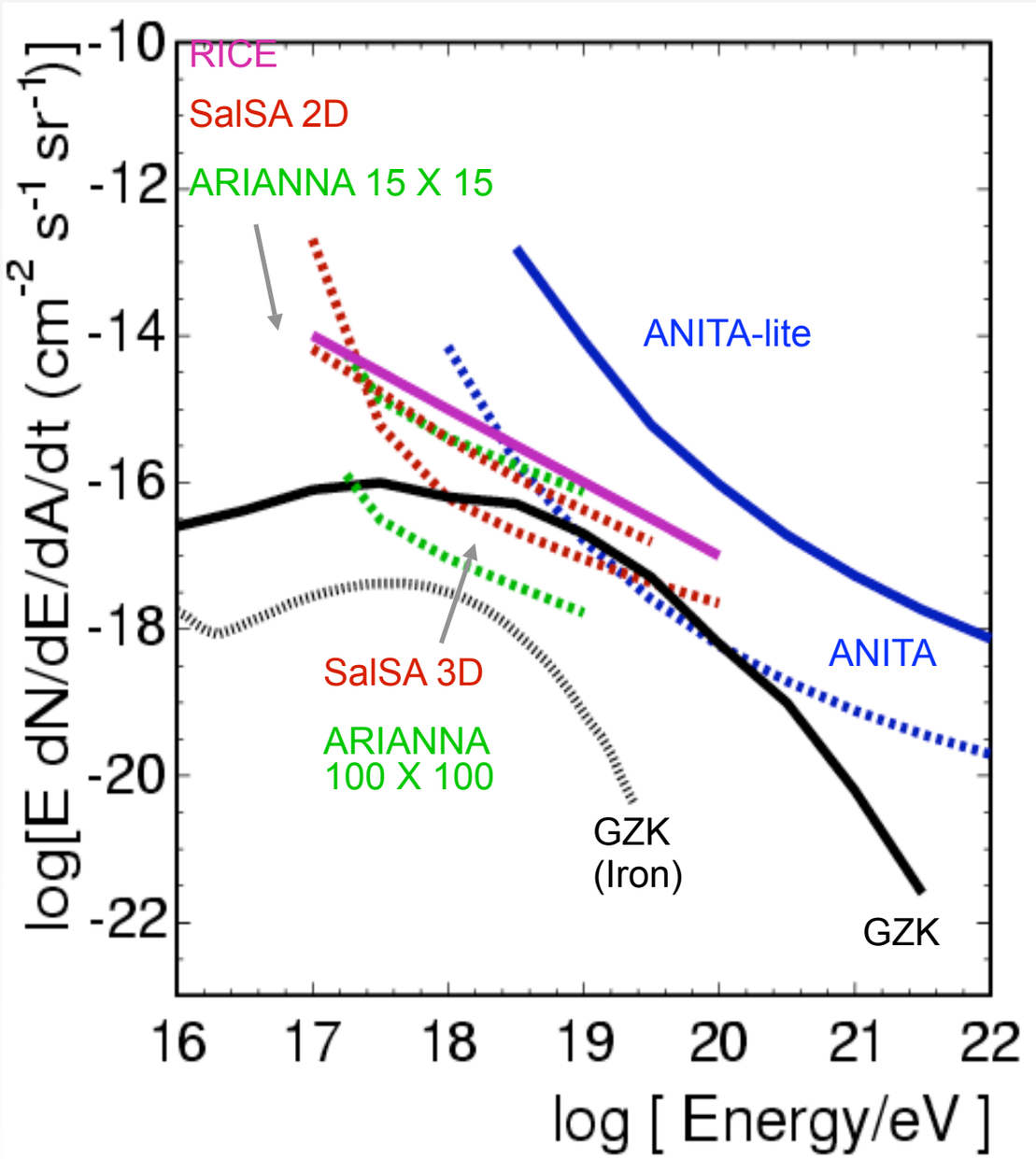
Preliminary Simulations:

- Array of 18-36 stations
- Detect 4-8 Neutrinos/yr
- Small fraction coincident with IceCube

- R&D work is ongoing
- An SOI has been submitted to STFC

Expected Sensitivities





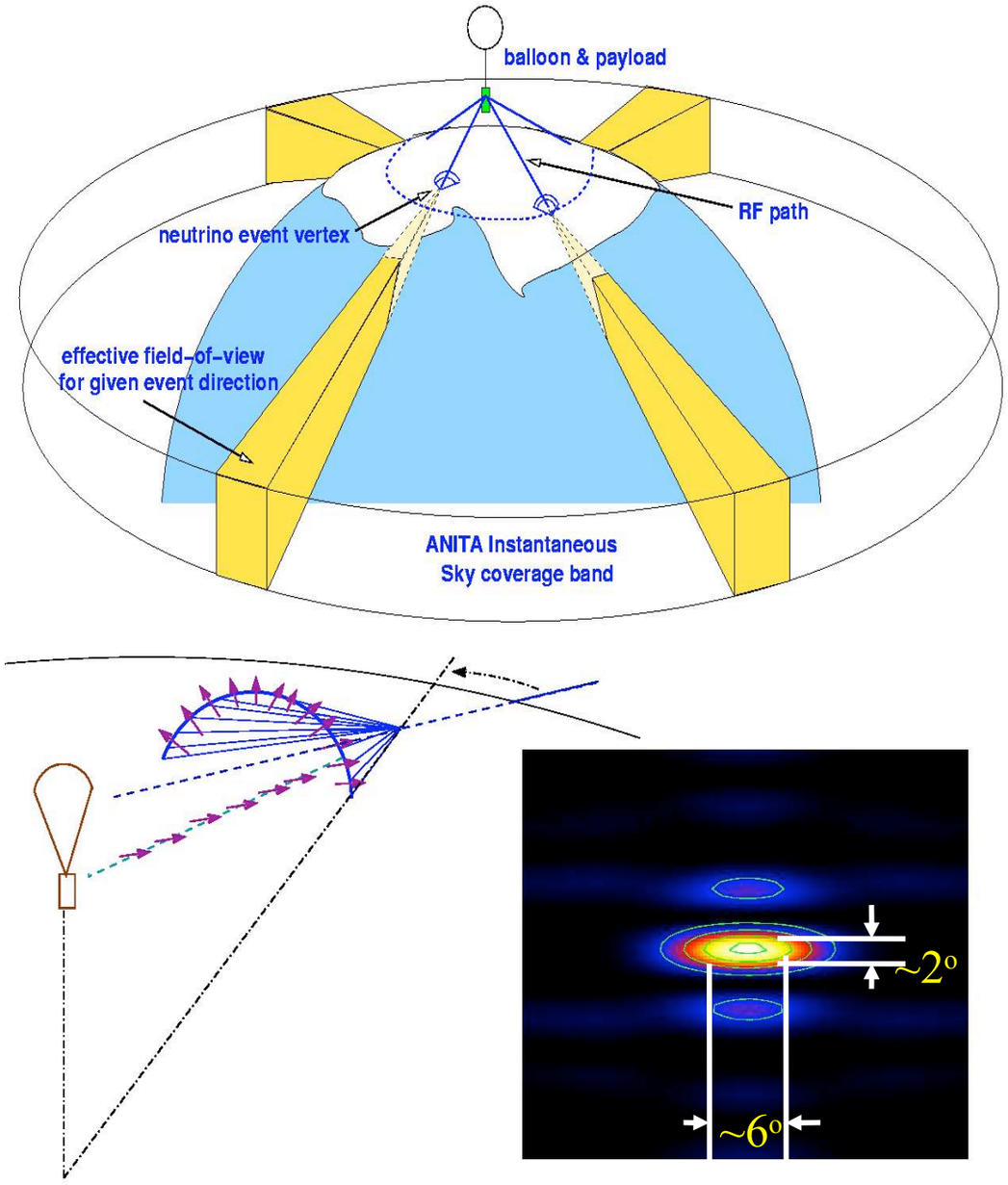
ANITA: 2 events expected (pre-flight) from reasonable proton GZK model
ARIANNA: 25 events / 6 months (100 x 100), 0.6 events / 6 months (15 x 15)
SalSA: 10-20 events / year (3D), 0.6 events / year (2D)

Summary

- Neutrino Astronomy is really frontier physics
  - Radio detection technique allows for vast detection volumes of >100km^3
- ANITA completed its first full flight and analysis is underway
  - Will either detect UHE neutrinos or set best limit
- The next generation of neutrino astronomy facilities may finally realise the ambition of probing the universe with “new eyes”
  - An ultra-high energy neutrino beam for studying fundamental physics
- Hopefully soon we will have the first detection of an UHE neutrino.

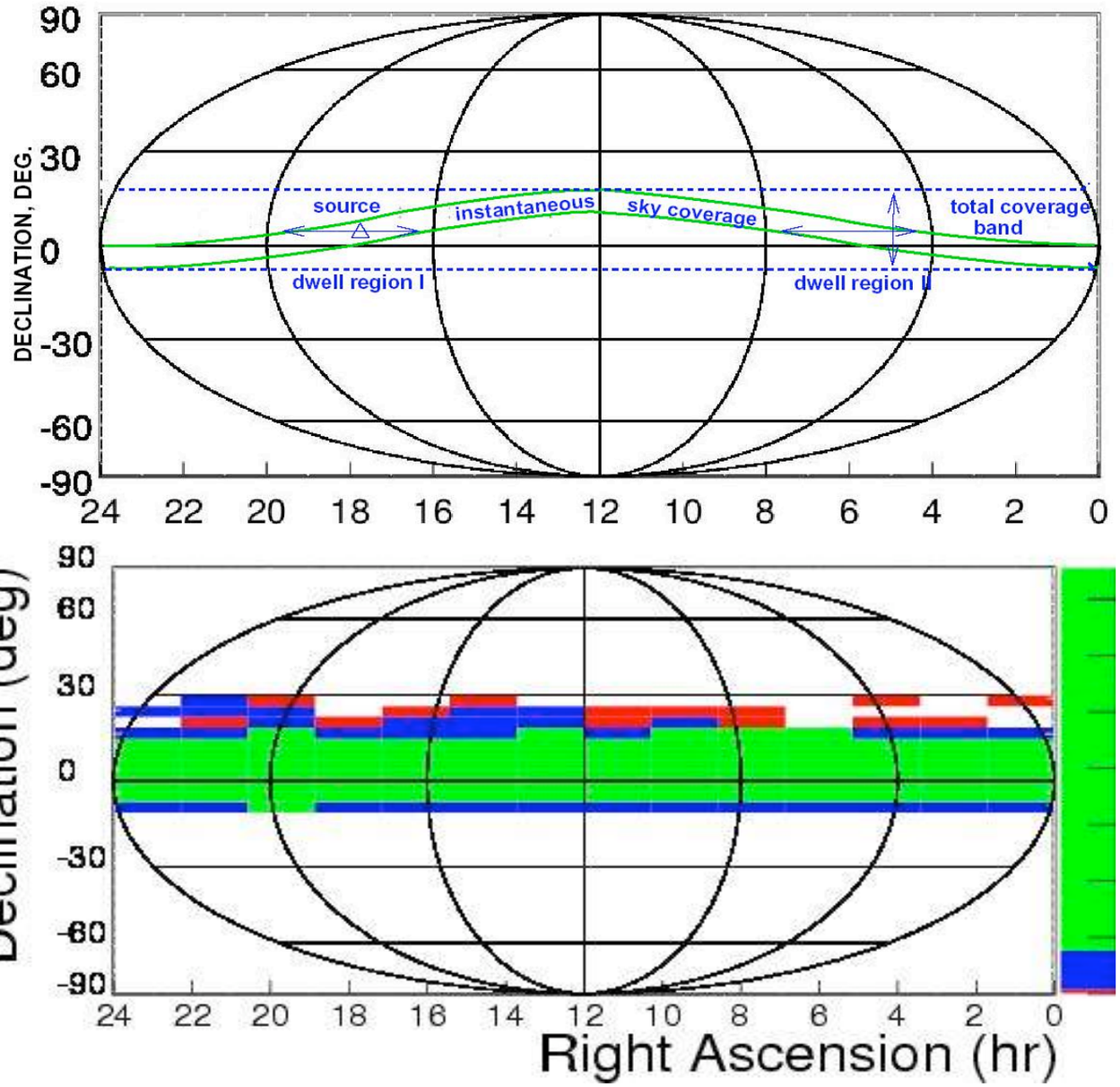
Backup Slides

- Angular Resolution



- Using signals from multiple antennas it is possible to measure the direction of arrival of radio pulse to ~0.5° in elevation and ~1.5° in azimuth (based on ANITA-lite calibration data)
- The neutrino direction can vary around radio pulse direction but is constrained to ~2° in elevation and by 3-5° in azimuth by polarization angle.

- Point Source Sensitivity



- ANITA is sensitive to sources with declination between -10 and 20 degrees.
- The actual dwell time over a particular source is less than the flight time.
  - So exposure for a point source is a factor 4-5 less than a diffuse source.

- Calorimeter

  - The observed voltage V_{obs} is proportional to the neutrino energy E_ν:

$$V_{obs} \sim E_\nu \, y \, h_{eff} \, R^{-1} \, exp\left(-\frac{\beta^2}{2\sigma_{\beta^2}} - \alpha d \right)$$

y is the fraction of neutrino energy in the cascade

h_{eff} is the effective height of the antenna (gain)

R is the range to the cascade

Gaussian in β from observer position on Cerenkov cone

(estimated from RF spectrum)

Exponential is attenuation in ice at depth d.

(estimated from RF spectrum and polarization effects)

Gives: $\Delta E_\nu / E_\nu \sim 1.9$ (60% of which is intrinsic from y)

Fun Slides

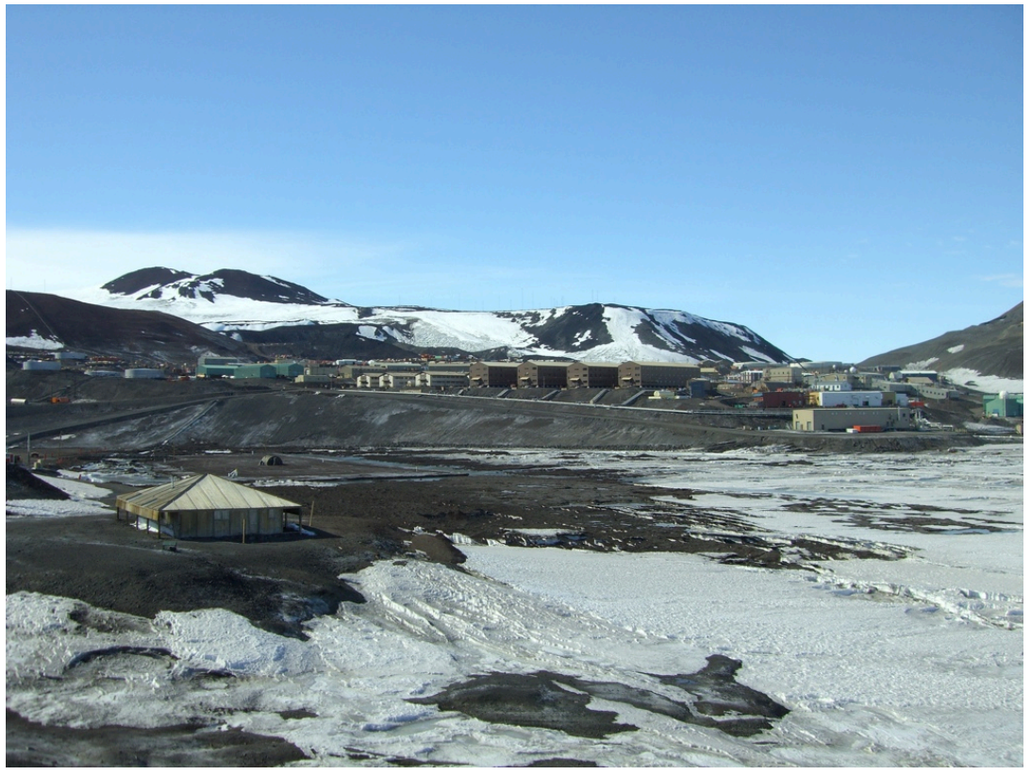
Ryan Nichol

- Alternative Titles:
  - “Call that an accelerator?”
    - Let me tell you about a real particle accelerator, just as soon as we work out where it is, how it works and what exactly it is accelerating.
  - “World’s largest scientific experiment?”
    - Our detector is the size of a continent, of course we haven’t actually detected anything yet (but hey, neither have you).
  - “Call that a long-baseline neutrino experiment?”
    - We measure our baseline in Mpc, or we will if we find one of the little blighters.
  - “Yet more stuff that might happen before the ILC”


PARKA, RED
CARHART, PARKA
CARHART, JACKET
JACKET, POLAR-FLEECE
PANT, POLAR-FLEECE
PANTS, WIND BIBBED
UNDERSHIRT EXPEDITION
UNDERDRAWER EXPEDITION
CAP, YAZOO
MITTEN, WIND
GLOVE, LEATHER
SOCK, WOOL
MITTEN, LEATHER
MITTEN, GAUNTLET
GOGGLES, SNOW
ATTENTION
WHEN RETURNING OR EXCHANGING CLOTHING YOU MUST BRING YOUR CLOTHING ISSUE FORM WITH YOU


UNITED STATES ANTARCTIC PROGRAM
PASSENGER TERMINAL


U.S. AIR FORCE
1103



- McMurdo Facts:
  - Established 1937
  - Takes its name from McMurdo Sound (named after Lieutenant Archibald McMurdo of the *Terror*
  - Near Scott's Hut
  - Food is inedible 363 days a year
    - Christmas
    - Thanksgiving

- Facilities:
  - Harbour (two weeks a year)
  - 3 Airfields
  - 1 bowling alley
  - 3 bars

- Williams Field Facilities
  - Own galley (so edible food)
  - Three payloads this year
  - No indoor plumbing though