The ANITA Cosmogenic Neutrino Experiment

Peter Gorham
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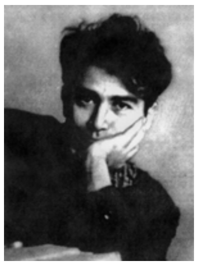
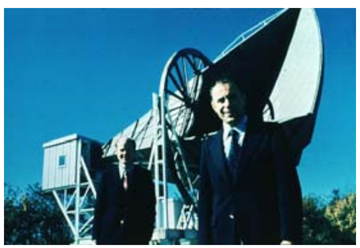
Science roots: the 60's





1. **1961: First 10^{20} eV cosmic ray air shower observed**
   – John Linsley, Volcano Ranch, near Albuquerque, NM
2. **1962: G. Askaryan predicts coherent radio Cherenkov from showers**
   – His applications? Ultra-high energy cosmic rays & neutrinos
3. **1965: Penzias & Wilson discover the 3K echo of the Big Bang**
   – (while looking for bird dung in their radio antenna)
4. **1966: Cosmic ray spectral cutoff at $10^{19.5}$ eV predicted**
   – K. Greisen (US) & Zatsepin & Kuzmin (Russia), independently
   – Cosmic ray spectrum *must end* close to ~10^{20} eV

$$p, \gamma + \gamma(3K) \longrightarrow \text{pions, e+e-} \longrightarrow \text{GZK neutrinos}$$

"GZK cutoff" process

END TO THE COSMIC-RAY SPECTRUM?

Kenneth Greisen

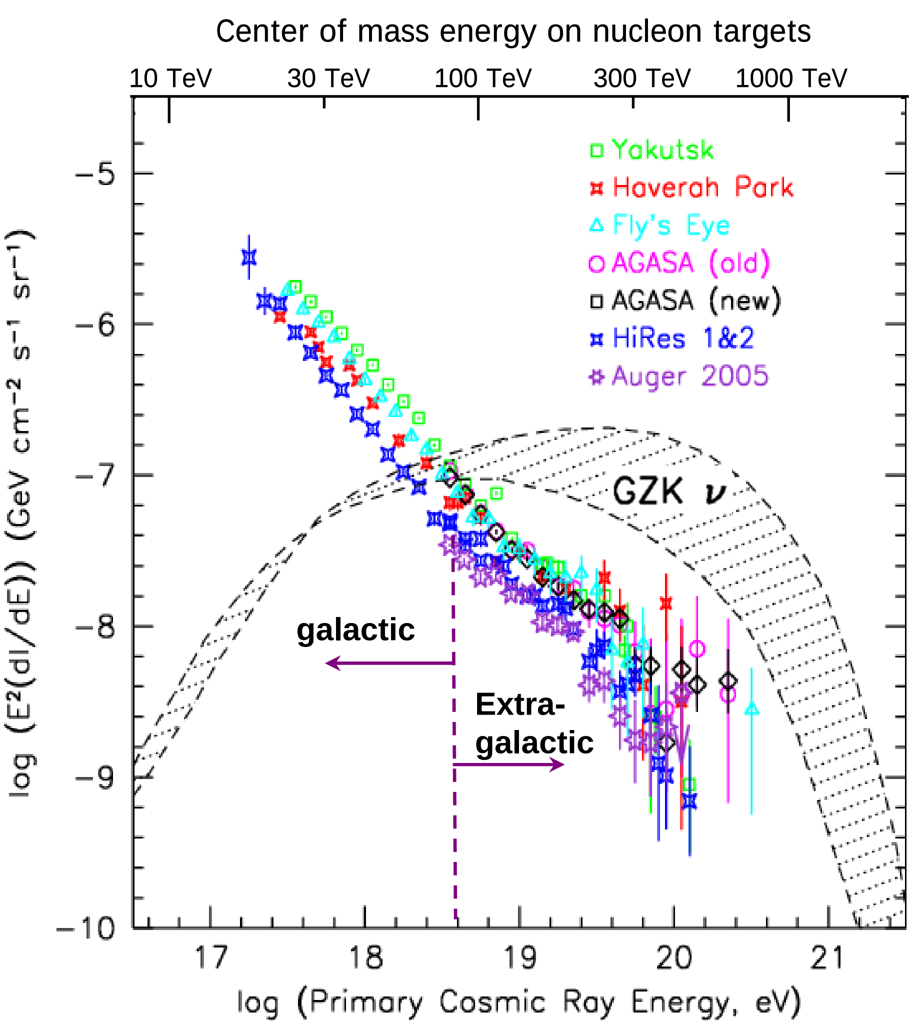
Cornell University, Ithaca, New York
(Received 1 April 1966)

(Ultra-)High Energy Physics of Cosmic rays & Neutrinos

- Neither origin nor acceleration mechanism known for cosmic rays above 10^{19} eV, **after 40 years!**

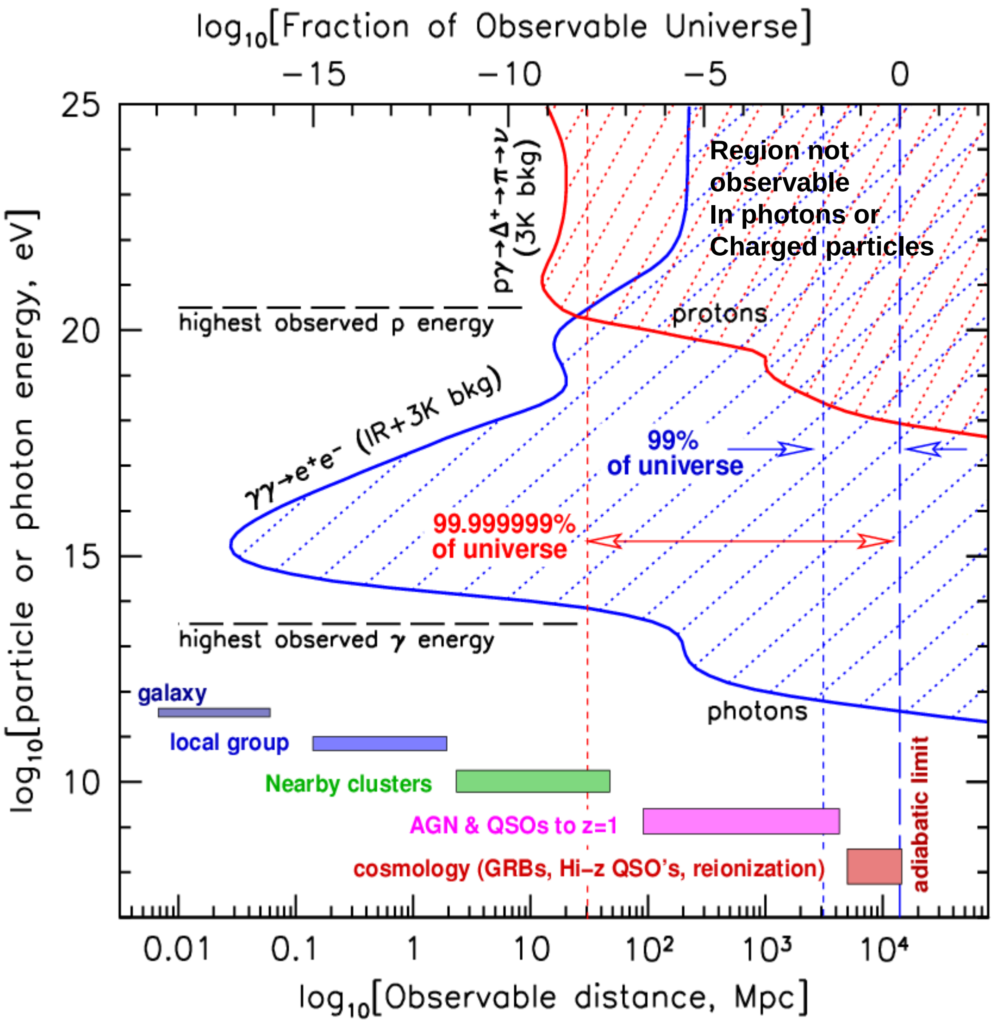
- A paradox:
  - No nearby sources observed
  - distant sources excluded due to GZK process

- **Neutrinos** at $10^{17\text{-}19}$ eV **required** by standard-model physics* through the GZK process--observing them is crucial to resolving the GZK paradox



* Berezinsky et al. 1971.

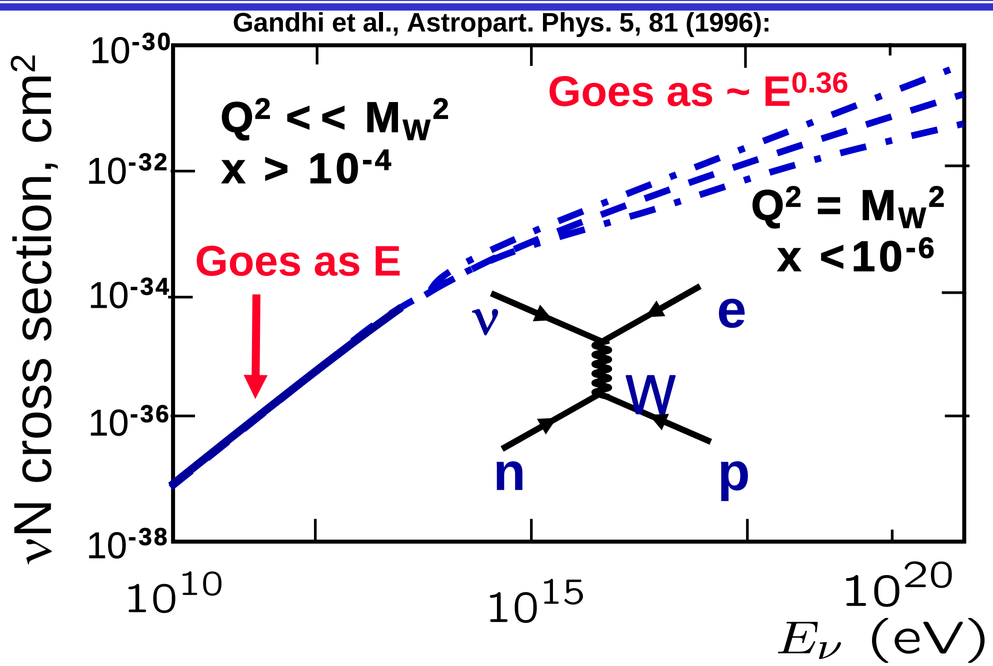
Neutrinos: The only long-range messengers at PeV energies and above

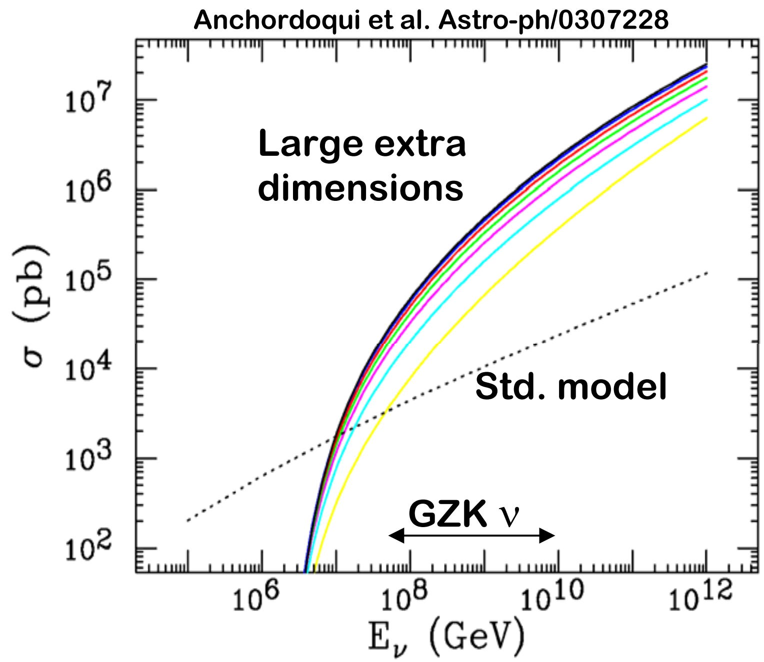


- **Photons lost above 30 TeV:** pair production on IR & μwave background
- **Charged particles:** scattered by B-fields or GZK process at all energies
- BUT: Sources known to extend to 10^9 TeV, maybe further if limited only by GZK

- => Study of the highest energy processes and particles throughout the universe *requires* PeV-ZeV neutrino detectors

Particle Physics: Energy Frontier & Neutrinos

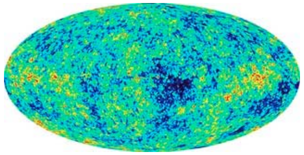




- Well-determined GZK ν spectrum becomes a useful neutrino beam
  - 10-1000 TeV center of momentum weak-interaction particle physics
  - study large extra dimensions at scales beyond reach of LHC
  - ν Lorentz factors of $\gamma=10^{18-21}$ assuming 0.01 eV masses
- Measured flavor ratios $\nu_e:\nu_\mu:\nu_\tau$ --deviations from 1:1:1 are interesting!
  - identify non-standard physics at sources (GRBs: Kashti & Waxman astro-ph/0507599)
  - Sensitive to sterile ν admixtures & anomalous ν decays (eg. Beacom et al PRL/PRD 2003)

GZK ν Particle Astrophysics/Cosmology

- Cosmic ray sources & maximum acceleration energy
  - Most of GZK ν flux is from $z > 1$, sources several Gpc away; every GZK neutrino effectively points to a GZK cosmic ray source!
- UHECR flux vs. redshift to $z = 15$-20, eg. WMAP early bright phase, re-ionization



- Independent sensitivity to dark energy density
  - GZK Source function depends on Ω_Λ, probes larger range of z than other tracers
- Exotic (eg. Top-down) sources; GUT-scale decaying relics or topological defects

What is needed for a GZK ν detector?

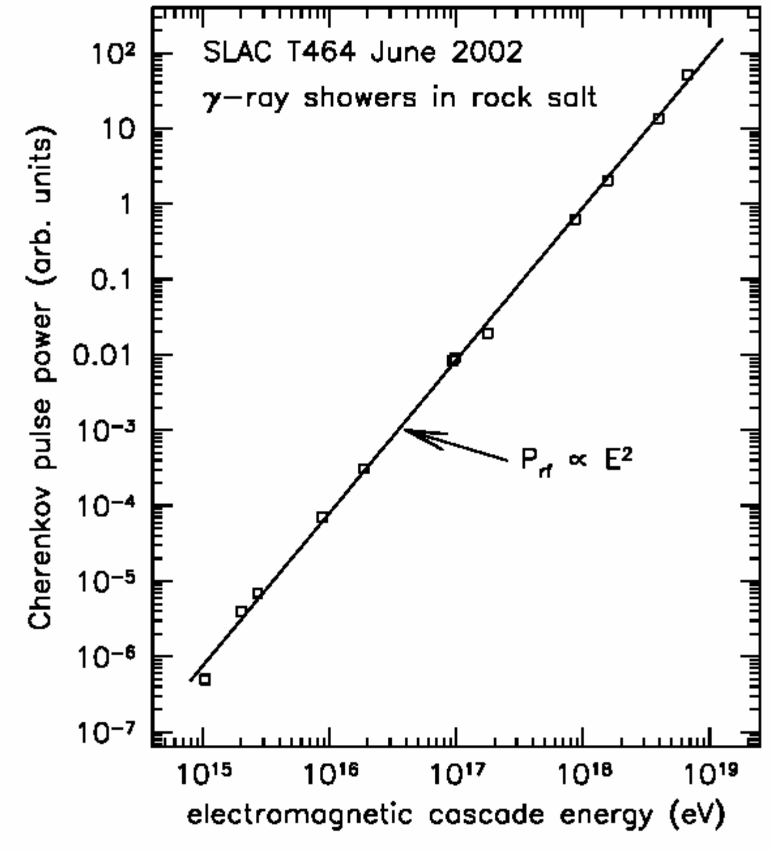
- Standard model GZK ν flux: <1 per km^2 per day over 2π sr
  - Interaction probability per km of water = 0.2%
  - Derived rate of order 0.5 event per year per cubic km of water or ice

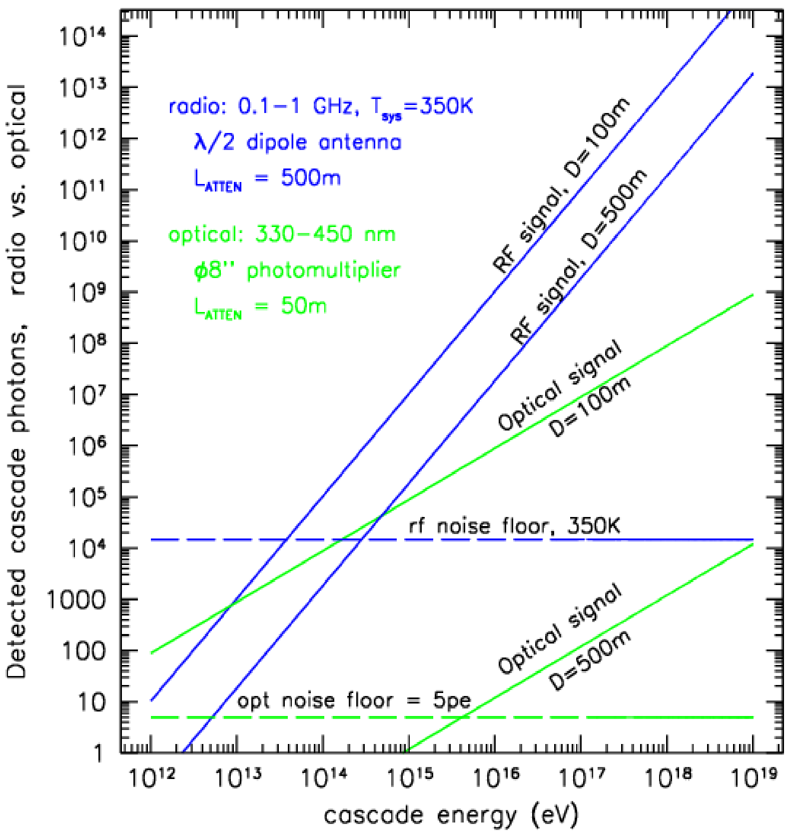
➔ **A teraton (1000 km^3 sr) target is required!**

Problem: how to scale up from current water Cherenkov detectors

- One solution: Askaryan effect: coherent radio Cherenkov emission
  - Particle showers in solid dielectrics yield strong radio impulses
  - Neutrinos can shower in many radio-clear media: air, ice, rock-salt, etc.
  - Economy of scale for radio (antenna array + receivers) is very competitive for hypergiant detectors

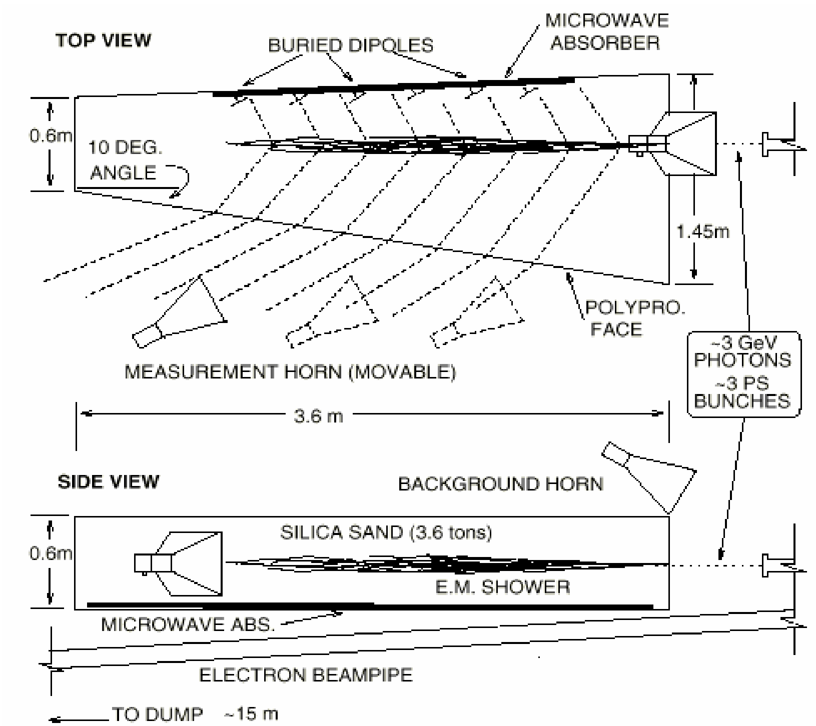
Radio vs. optical Cherenkov detection

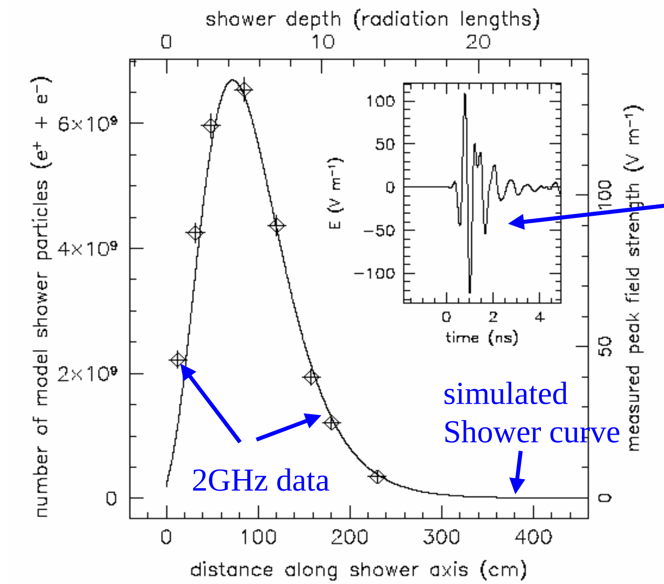




- RF signal grows quadratically with shower energy, dominates above PeV
- Both RF & optical have high SNR at E>PeV, but transmissivity of target materials (ice, salt, etc.) is much higher in RF ==> RF owns HE regime

Askaryan Effect: SLAC T444 (2000)





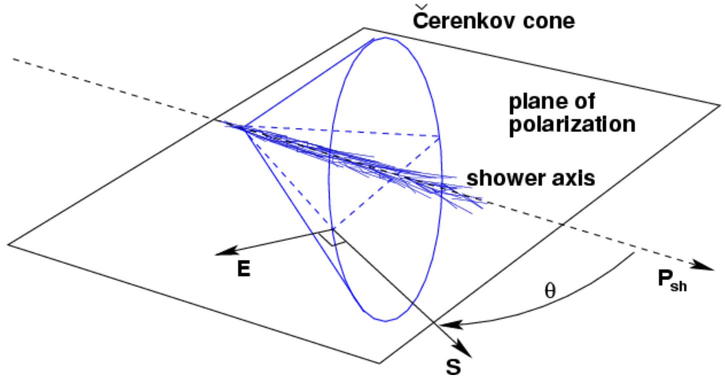
Sub-ns pulse,
Ep-p~ 200 V/m!

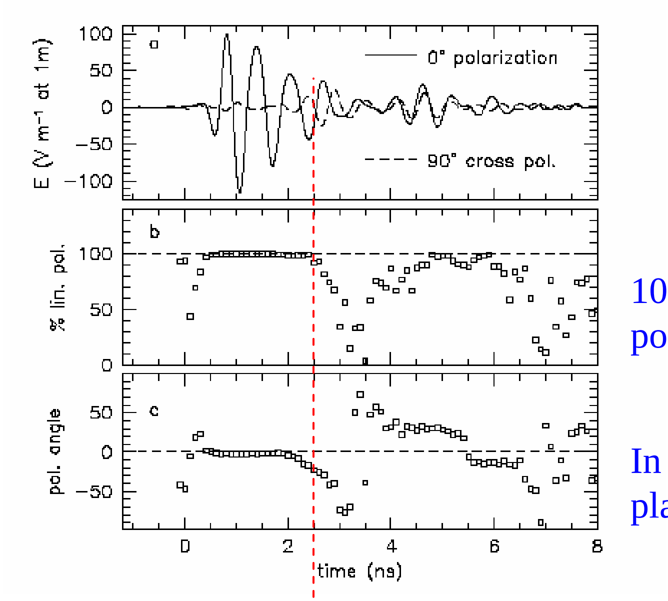
From Saltzberg, Gorham, Walz et al PRL 2001

- Use 3.6 tons of silica sand, brem photons to avoid any charge entering target
  ==> avoid RF transition radiation
- RF backgrounds carefully monitored
  - but signals were much stronger!

Cherenkov polarization tracking

Emission 100 % linearly polarized in plane of shower





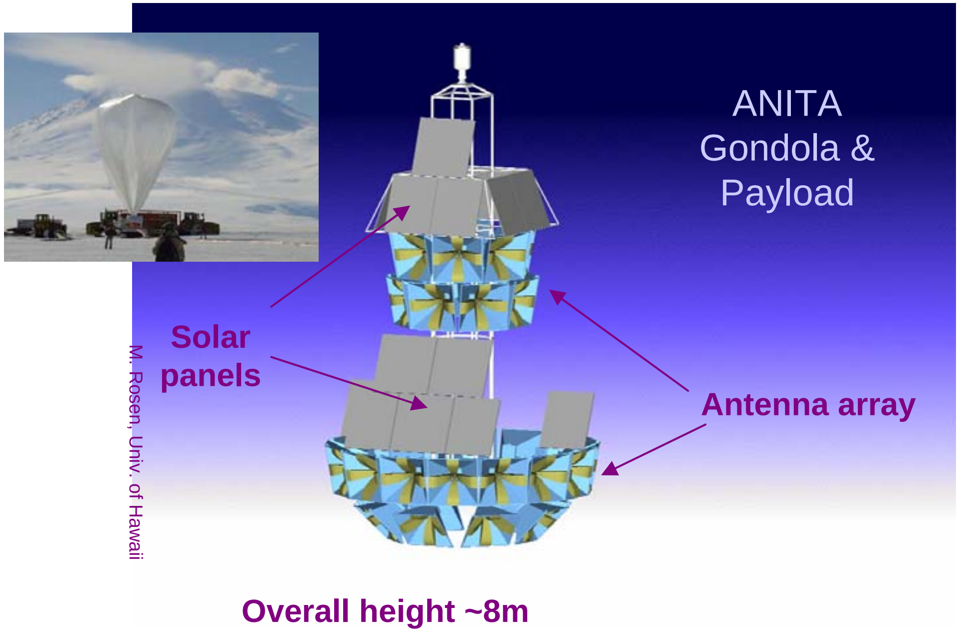
100% polarized

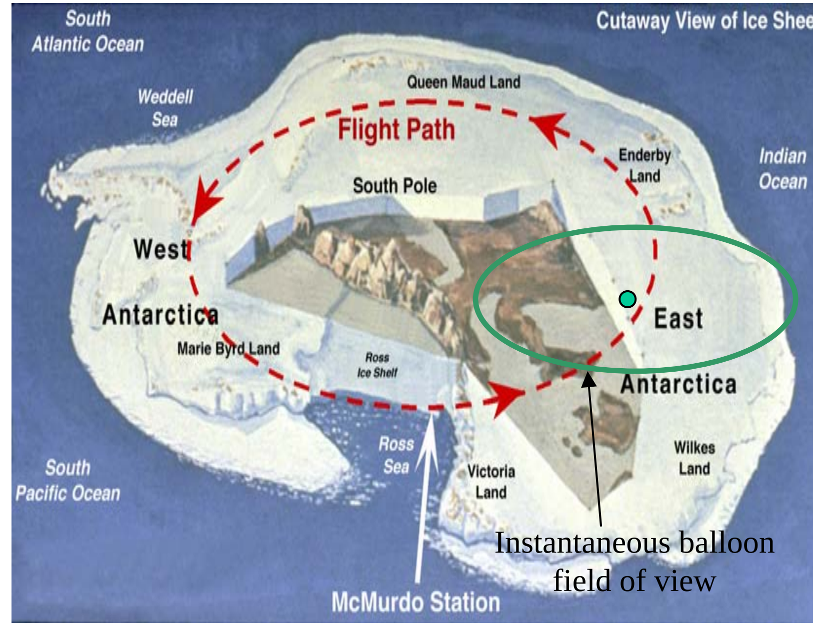
In proper plane

Reflection from side wall

- Radio Cherenkov: polarization measurements are straightforward
- Two antennas at different parts of cone will measure different projected plane of E, S
- **Intersection of these planes defines shower track**

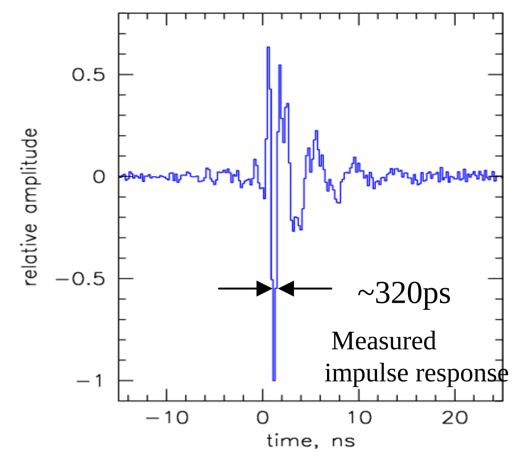
Antarctic Impulsive Transient Antenna--ANITA



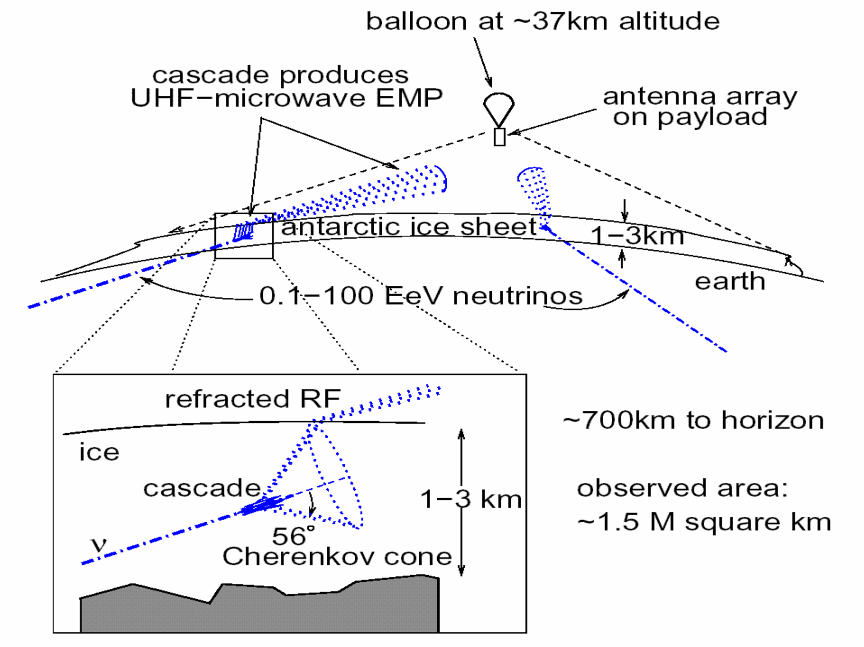


- NASA start in 2003, first LDB launch in '06-07
- Ultra-broadband antenna array, views large portion of ice sheet looking for Askaryan impulses

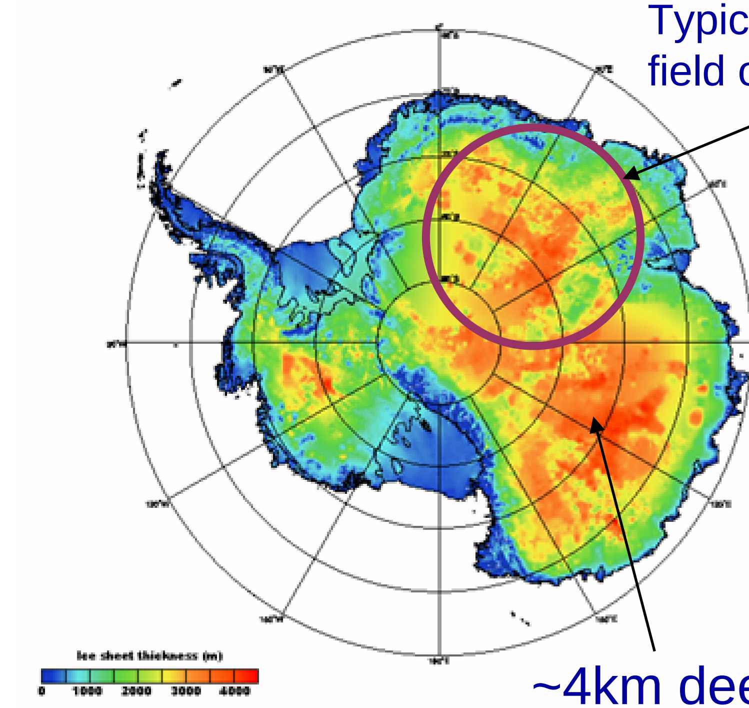
Quad-ridged-horn dual-pol antenna



ANITA concept

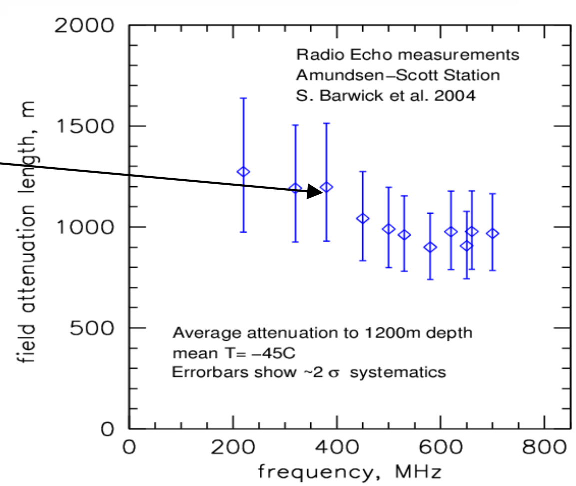


Typical balloon field of regard



~4km deep ice!

Ice RF clarity: 1.2 km(!) attenuation length

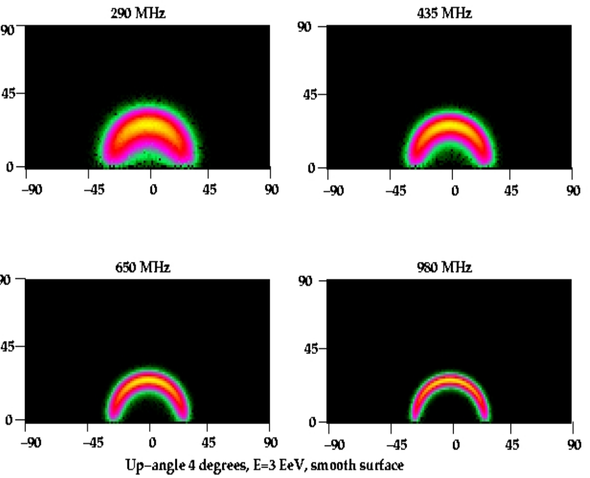


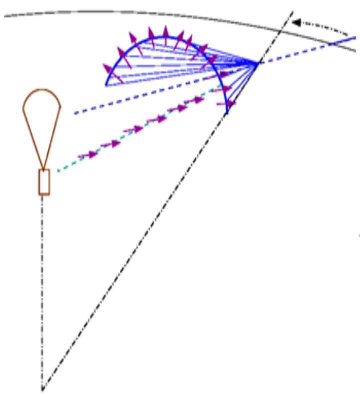
Effective "telescope" aperture:

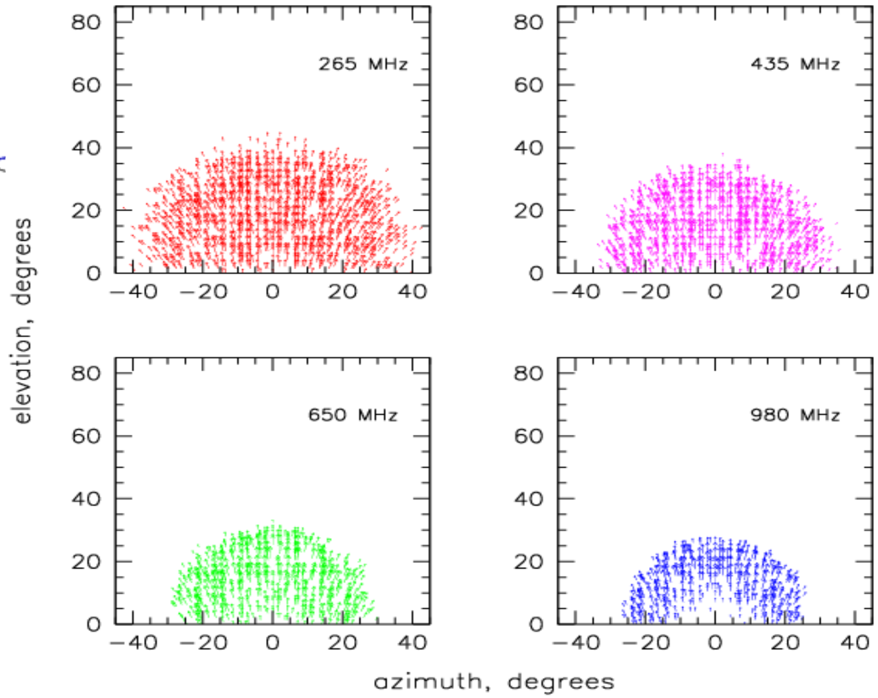
- ~250 km^3 sr @ 10$^{18.5}$ eV
- ~10^4 @ km^3 sr 10^{19} eV

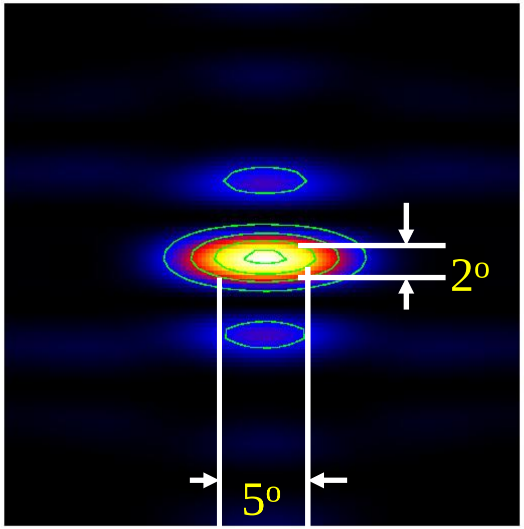
Area of Antarctica ~ area of Moon!

ANITA as a neutrino telescope



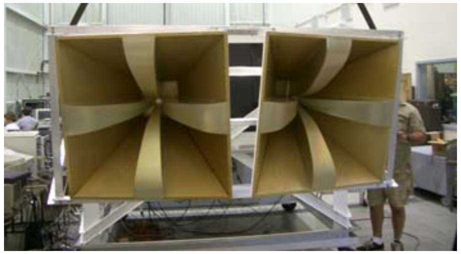


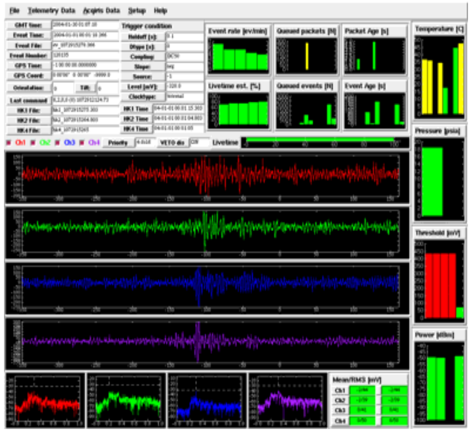




- Pulse-phase interferometer (150ps timing) gives intrinsic resolution of <1° elevation by ~1° azimuth for **arrival direction** of radio pulse
- **Neutrino direction** constrained to ~<2° in elevation by earth absorption, and by ~3-5° in azimuth by polarization angle

ANITA-lite Prototype flight 2004

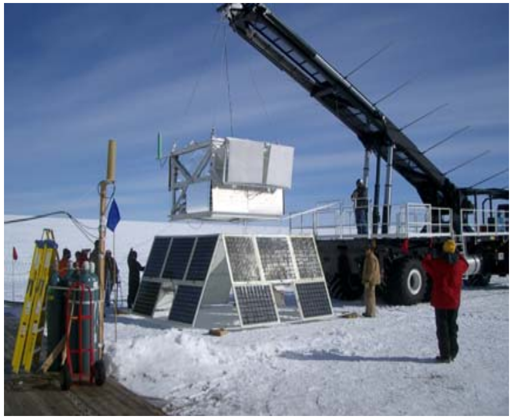


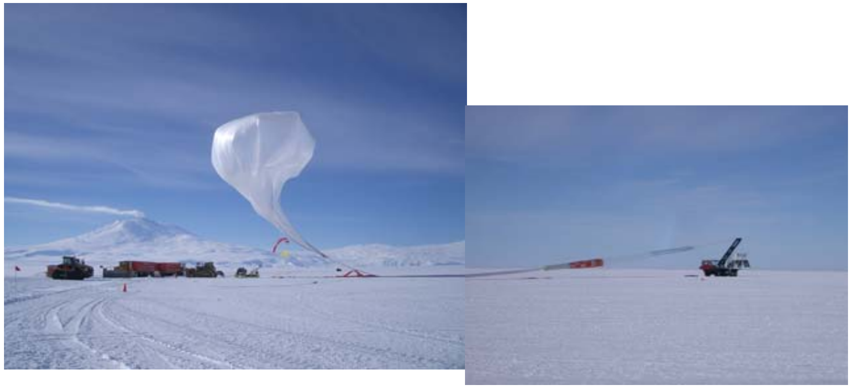


- Piggyback Mission of Opportunity on the 03-04 TIGER* flight, completed mid-January 04
- ANITA prototypes & off-the-shelf hardware used
  - 2 dual-pol. ANITA antennas w/ low-noise amps
  - 4 channels at 1 GHz RF bandwidth, 2 GHz sampling
- 18.4 days flight time, 40% net livetime due to slow (4sec per event) GPS time readout

*Trans-Iron Galactic Element Recorder

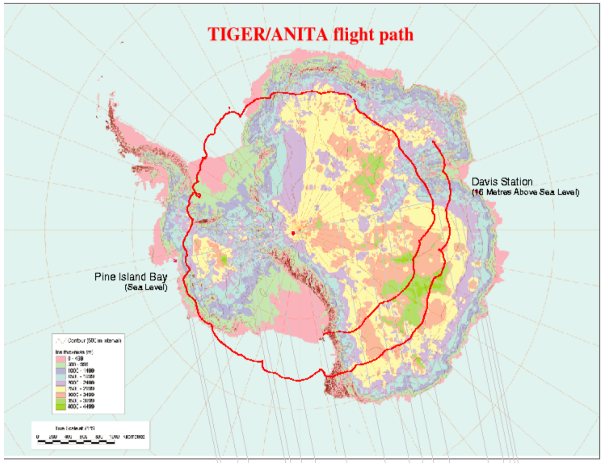
TIGER/ANITA-lite launch…



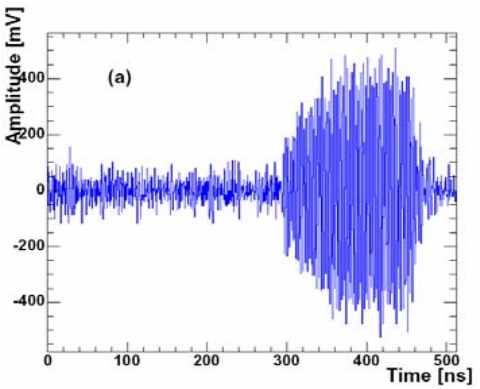


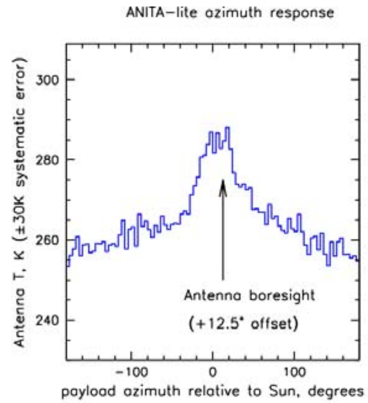
….flight…

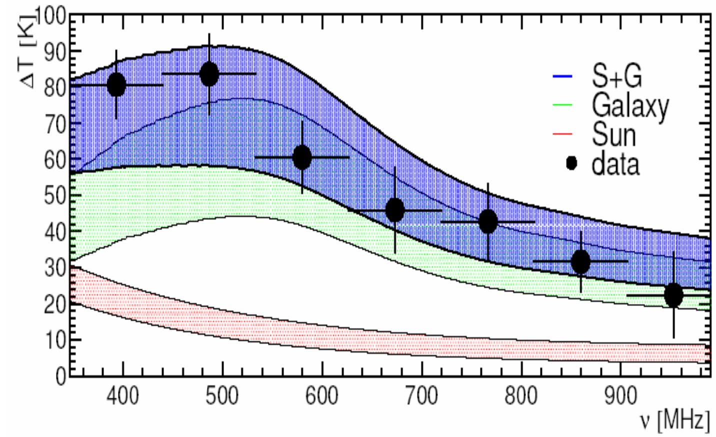
… & landing!



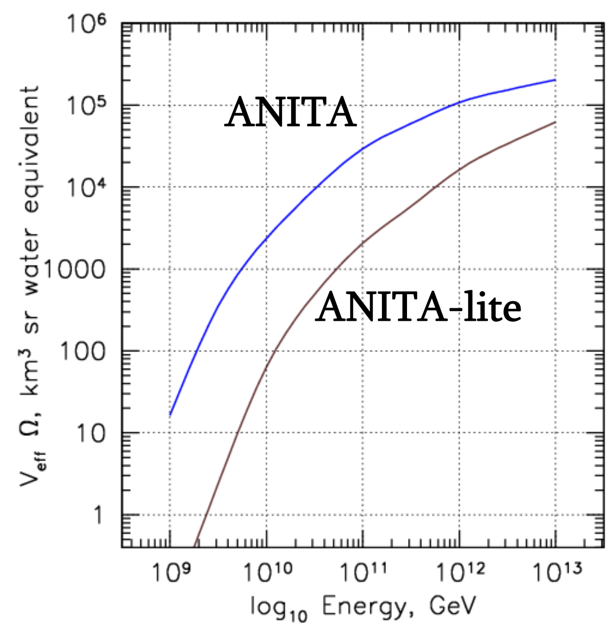
ANITA-lite sensitivity calibration





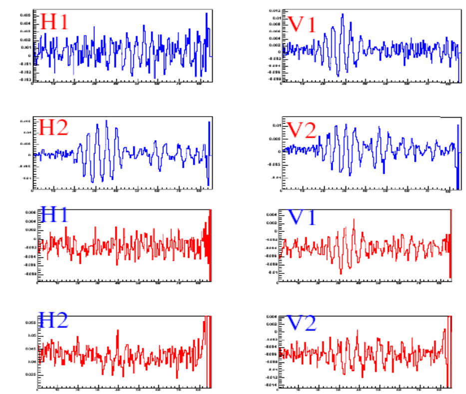


- Ground RF pulser used with GPS synch out to 200-300 km from McMurdo station

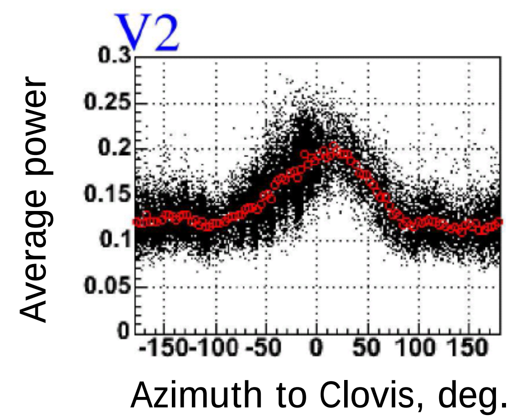


- Galactic Center & solar thermal & non-thermal RF emission provided realtime antenna sensitivity, along with onboard noise diodes for gain calibration
- Aperture estimate by Monte-Carlo using ice thickness data & balloon trajectory

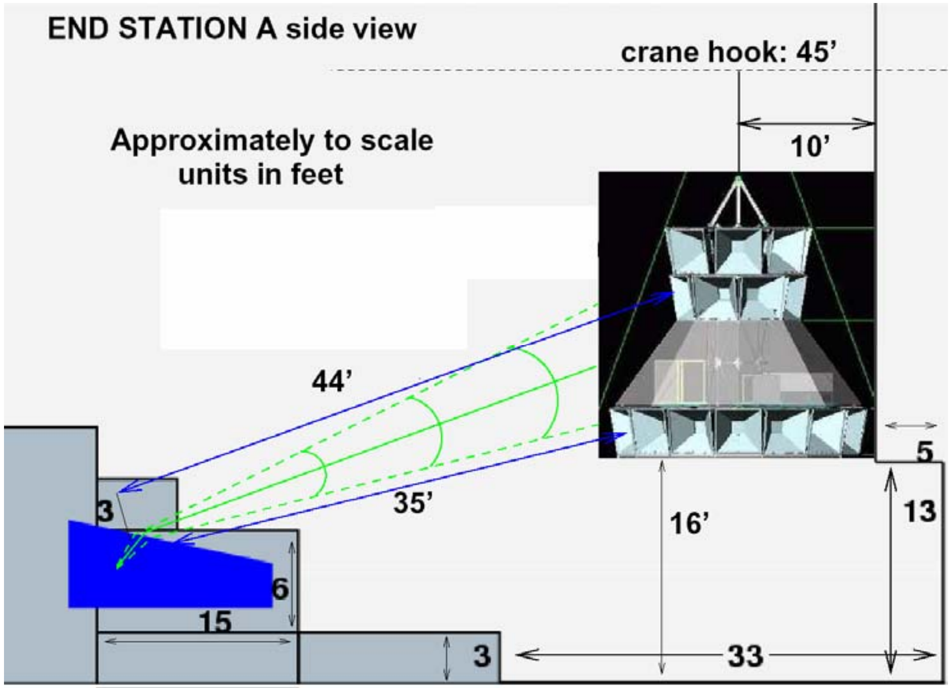
ANITA Engineering Flight, August 2005

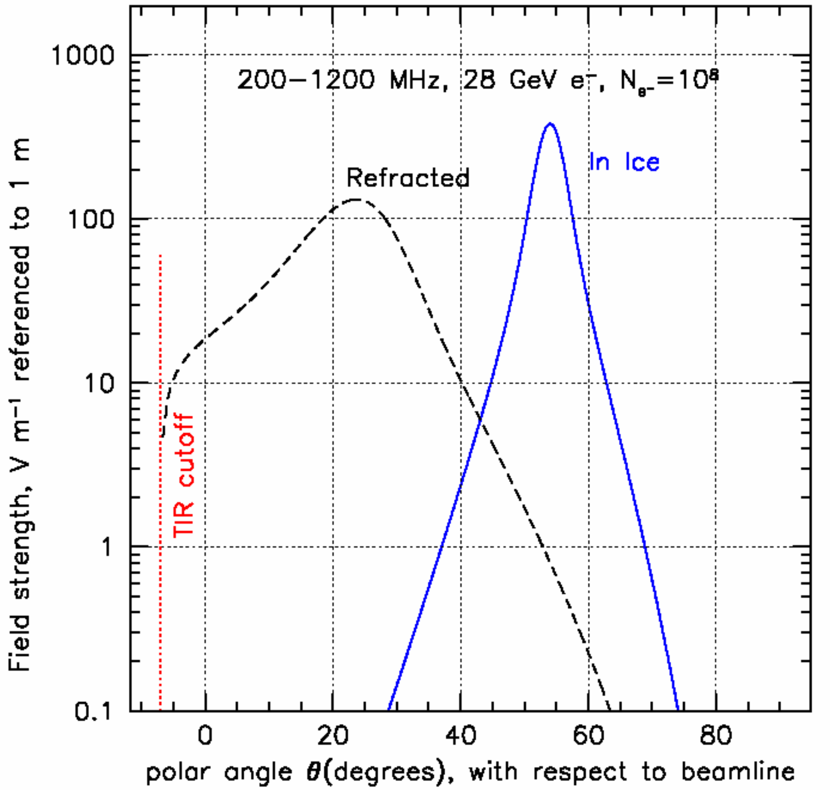


- August 29,2005, Ft. Sumner New Mexico
  - All subsystems represented (two dual-pol. antennas only, to limit landing damage)
  - 8 m tall Gondola performed perfectly
  - No science possible due to EMI (Cannon AFB in nearby Clovis), but waveform recording worked well
  - Full ANITA payload now cleared for Antarctica



SLAC T486 (June 2006): Askaryan on ice

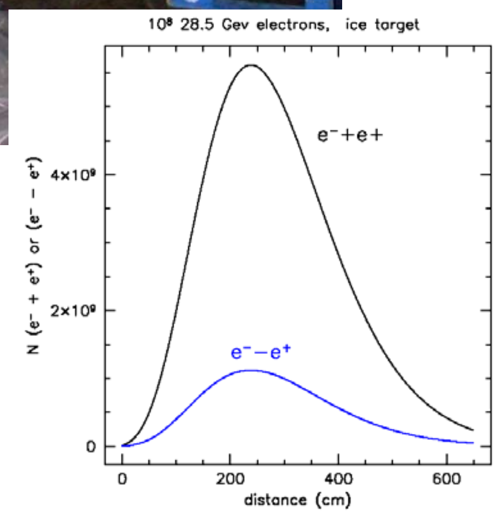


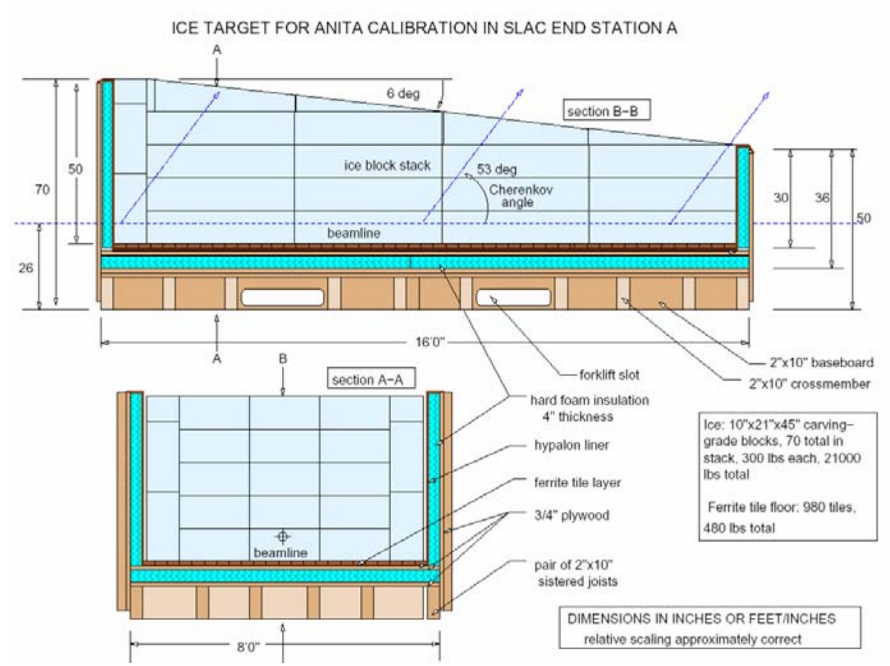


- Askaryan effect not yet verified in ice (though we shouldn't doubt that it works…)
- ANITA requires extraordinary validation of its sensitivity if no signals are observed--eg. "How can you be sure you would have seen the events if they were really there?"
- Answer: SLAC T486 in End Station A: use 12 tons of ice, SLAC electron bunches, and a very large hall

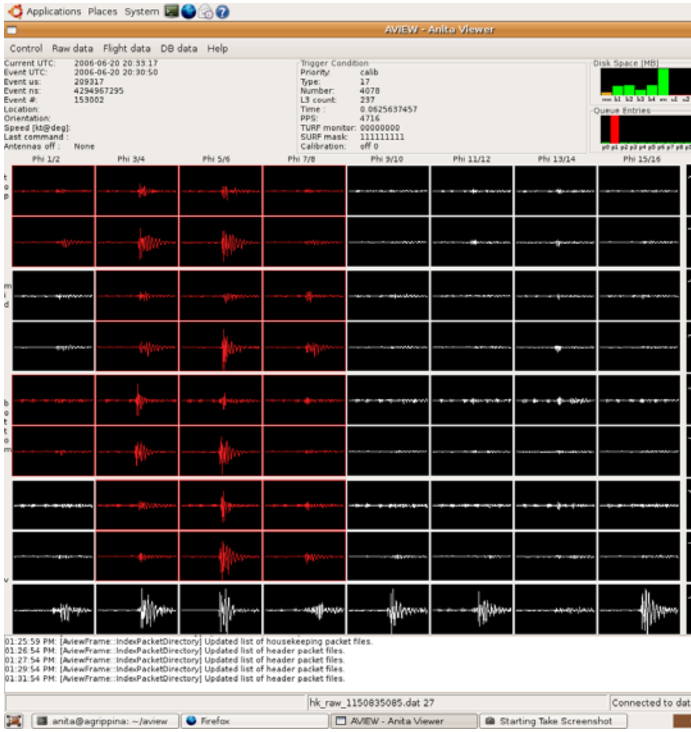
T486: ice target

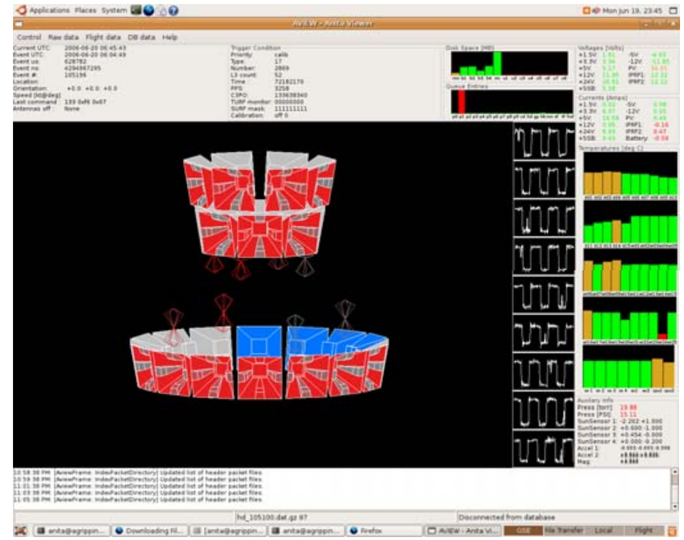
- Carver-grade ice, very pure
- 300 lb blocks, about 70 used to make target with >0.6 λ (in ice) at >200MHz in all directions around beam axis
- Target length: 12 radiation lengths=5 m of ice

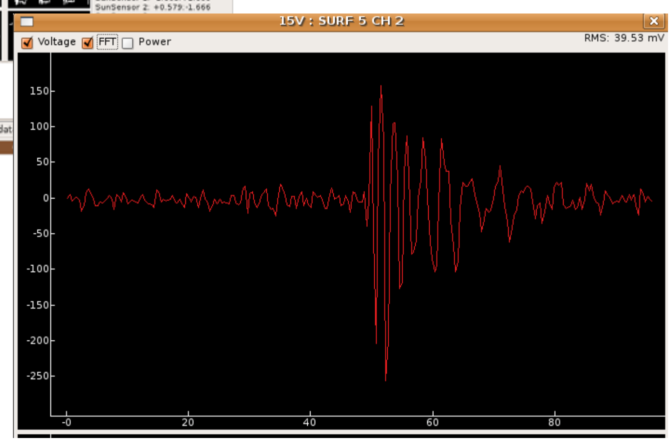


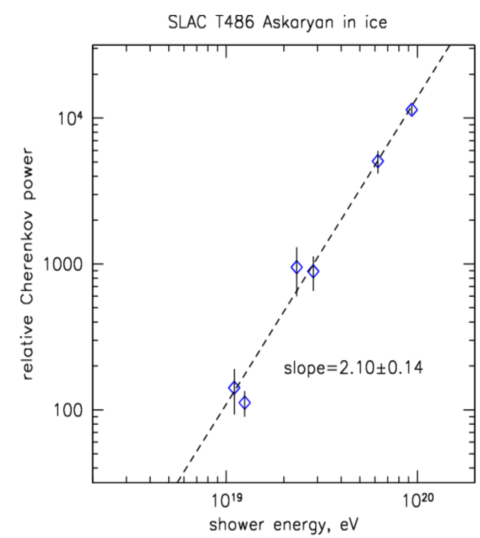


First Askaryan-in-ice data (this week)



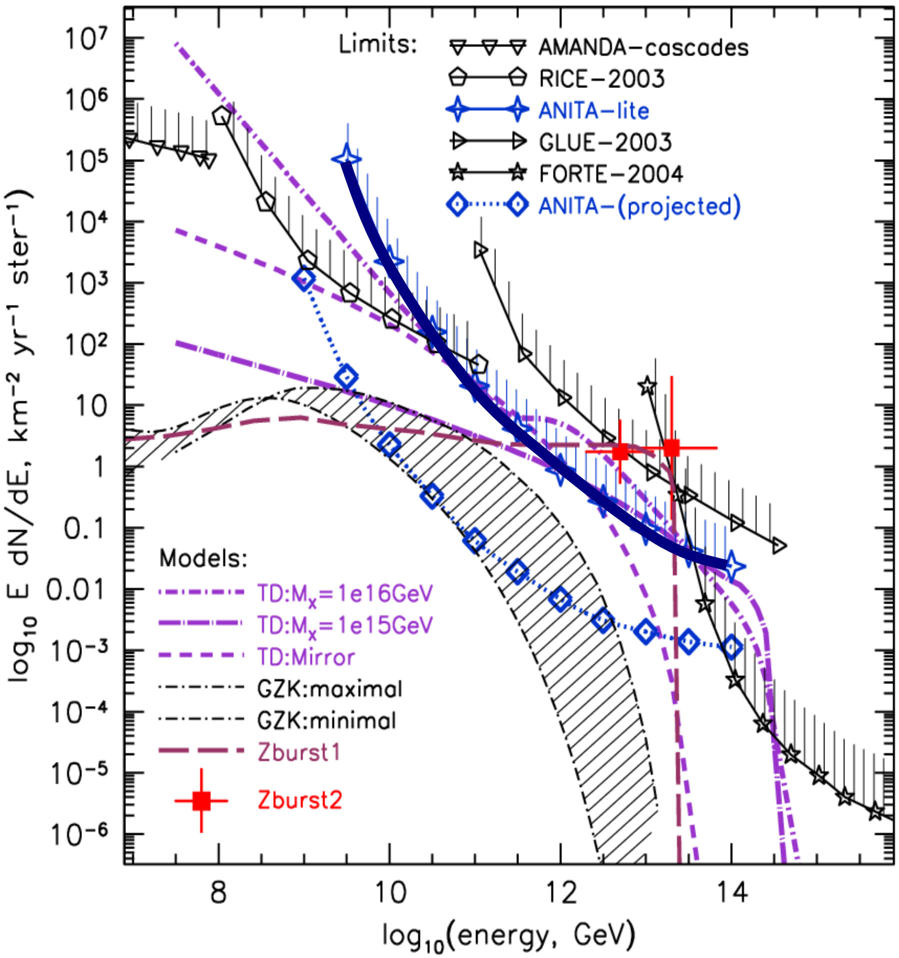






- Impulses are band-limited, highly polarized, as expected
- Very strong--need 20dB pads on inputs (eg, -95dB compared to Antarctic configuration)

Current UHE neutrino limits & projections



Strongest limits: all radio

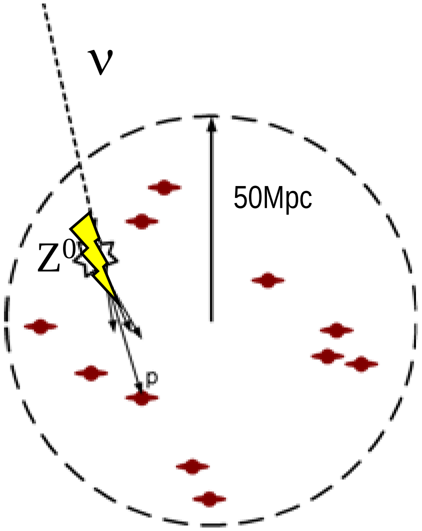
- **RICE** limits for 3500 hours livetime
- **GLUE** limits 120 hours livetime
- **FORTE** limits on 3.8 days of livetime

- **ANITA-lite**: 18.4 days of data, net 40% livetime with 60% analysis efficiency for detection
  - No candidates survive
  - Z-burst UHECR model ($\nu\nu$ annihilation -->hadrons) excluded:
    - we expect 6-50 events, see none
  - Highest Toplogical defect models also excluded

- **ANITA projected sensitivity:**
  - ν_e ν_μ ν_τ included, full-mixing assumed
  - **1.5-2.5 orders of magnitude gain!**

The Z-burst model

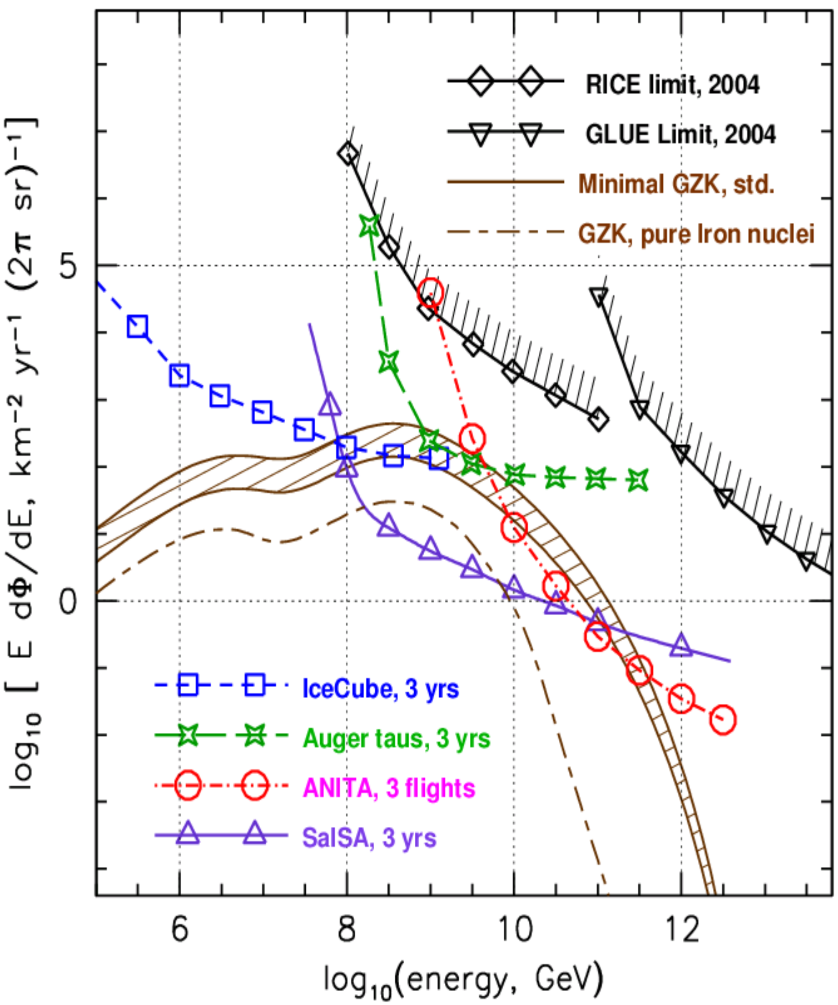
- Original idea, proposed as a method of Big-bang relic neutrino detection via resonant annihilation (T. Weiler PRL 1986):
  - 10^{23} eV $\nu + 1.9\text{K}\ \bar{\nu} \longrightarrow Z_0$ produces a dip in a cosmic neutrino source spectrum with a location dependent on the ν mass ,
  - *IF one has a source of 10^{23} eV neutrinos!*



- More recently: Z_0 decay into hadron secondaries gives 10^{20+} eV protons to explain any super-GZK particles, again
  - *IF there is an appropriate source of neutrinos at super-mega-GZK energies*
- (Many authors including Weiler have explored this revived version)

- The Z-burst proposal had the virtue of solving three completely unrelated (and very difficult) problems at once:
  - **relic neutrino detection AND ~~super-GZK cosmic rays~~ AND neutrino mass**
  - **==> " Nobel^3 " physics…. ? (No, but Nobel^2 still possible!)**

Existing Neutrino Limits and Future Sensitivity



- RICE limits for 3500 hours livetime
- GLUE limits 120 hours livetime
- ANITA sensitivity, 45 days total:
  - ~5 to 30 GZK neutrinos
- IceCube: high energy cascades
  - ~1.5-3 GZK events in 3 years
- Auger: tau neutrino decay events
  - ~1 GZK event per year?
- SalSA sensitivity, 3 yrs live
  - 70-230 GZK neutrino events

Summary

- ANITA has a good chance to detect GZK neutrinos within the next 8 months!
- First step in developing a rich potential for particle physics/ particle astrophysics
- Next generation ring imaging Cherenkov detectors (eg. SalSA) can begin to do particle physics with cosmogenic neutrinos
  - 10-1000 TeV CM weak (or strong?!) interactions