



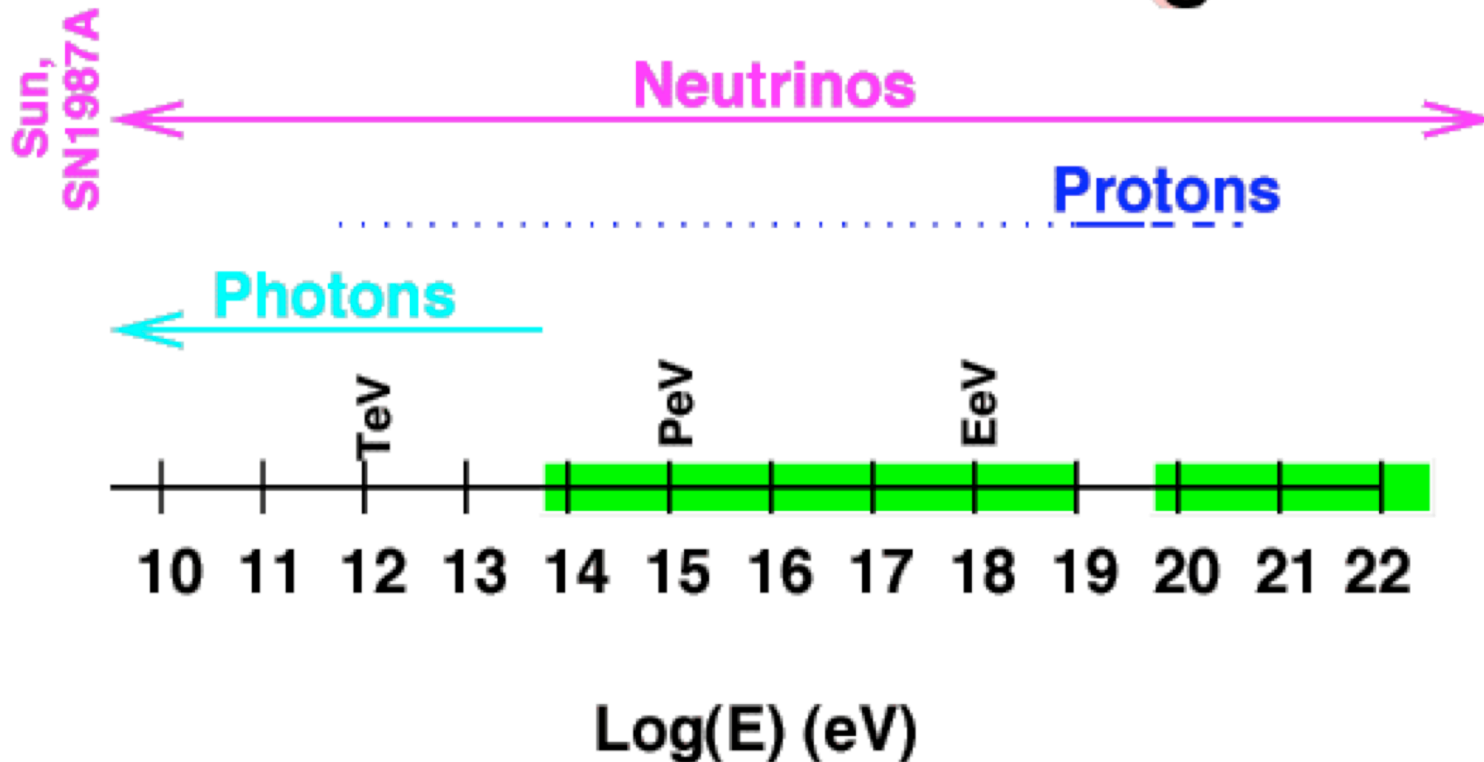
# ANtarctic Impulsive Transient Antenna



Using the very highest energy astrophysical neutrinos to probe physics beyond the standard model

Steve Barwick, UCI  
ISMD, LBL 2007

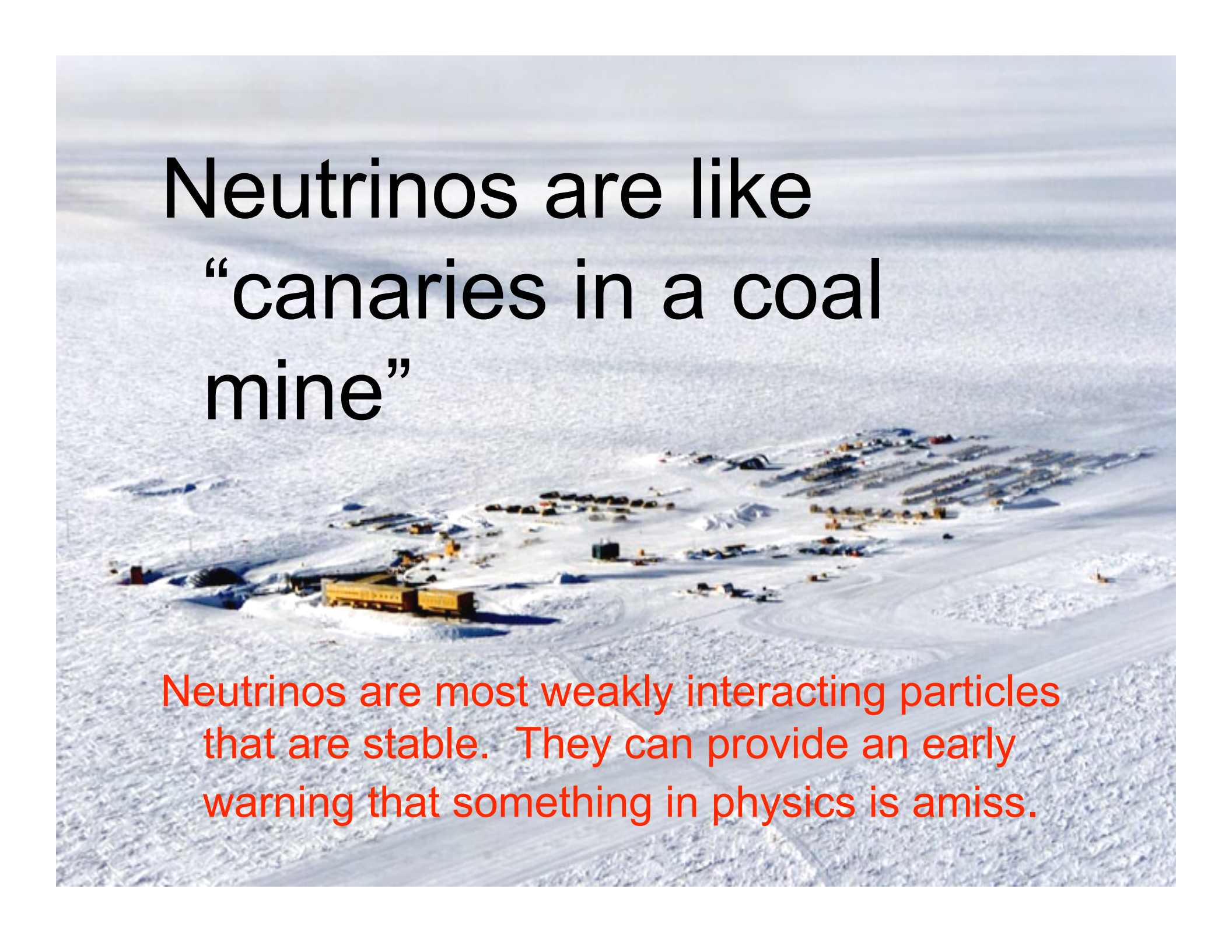
# Astronomical Messengers



**PHOTONS:** not deflected, but: reprocessed in sources, absorbed in IR (100 TeV), and CBR

**PROTONS:** deflection in magnetic fields, GZK cutoff

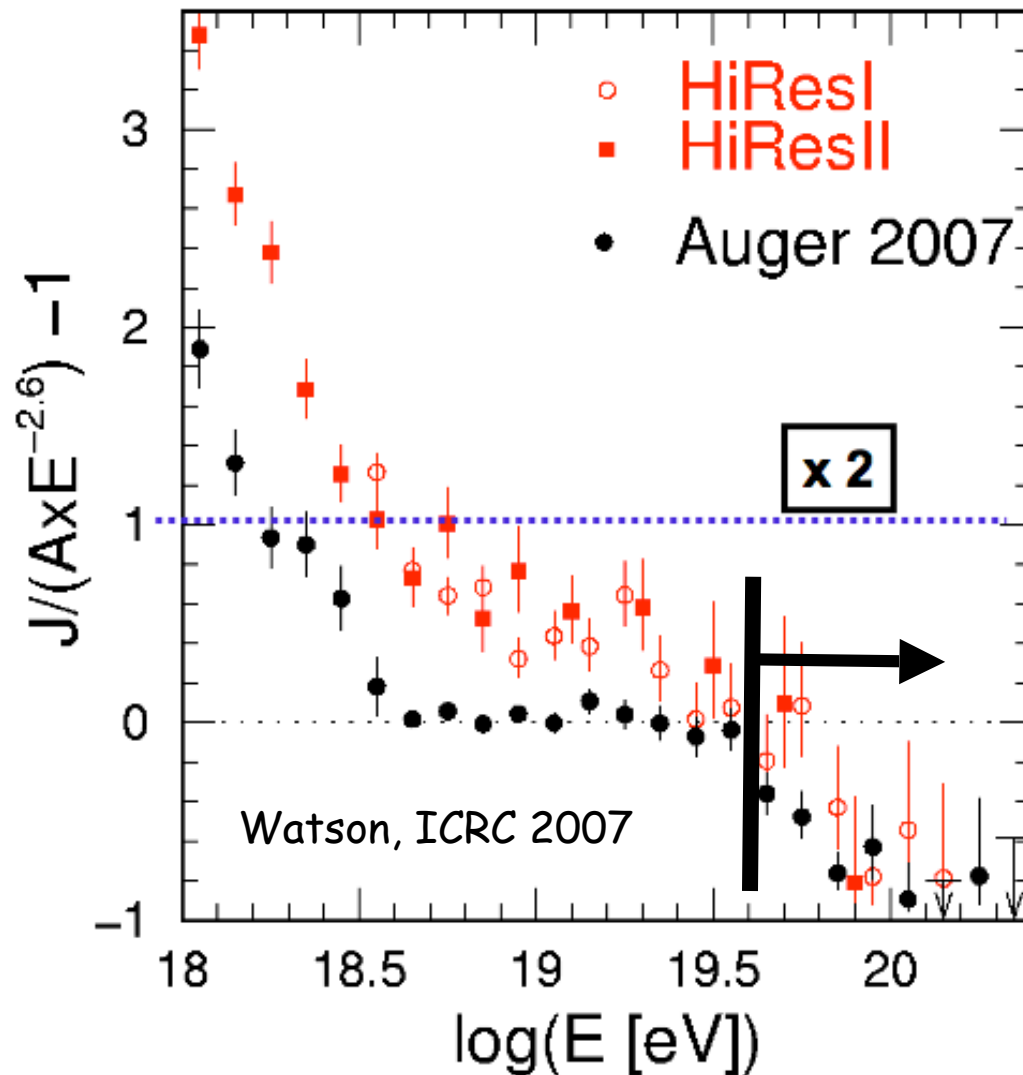
**NEUTRINOS:** not absorbed or deflected, hard to see

An aerial photograph of a snowy, mountainous landscape. In the center, there is a small settlement or research station with several buildings, including a prominent yellow structure. The terrain is covered in snow, with some tracks and paths visible. The sky is overcast and grey.

Neutrinos are like  
“canaries in a coal  
mine”

Neutrinos are most weakly interacting particles that are stable. They can provide an early warning that something in physics is amiss.

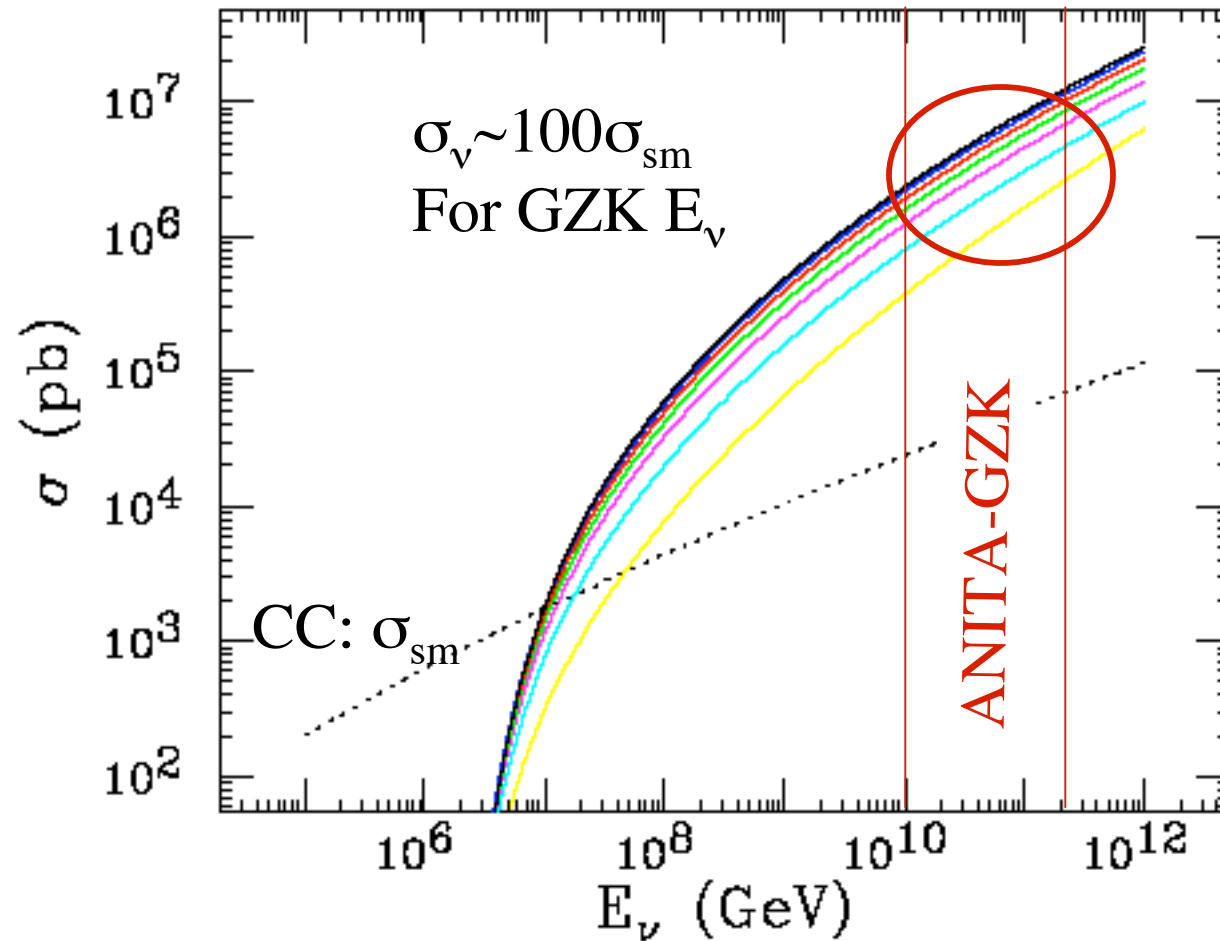
# “GZK” suppression exists!



Both HiRes and  
AUGER see  
suppression  
@  $E \sim 10^{19.5} \text{ eV}$



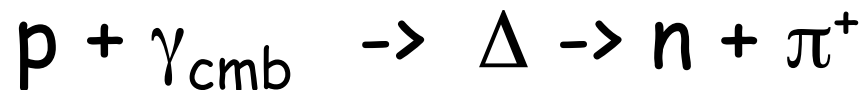
# EHE Neutrinos Explore Higher Dimensions



(Anchordoqui, et al, hep-ph/0307228)

# Cosmogenic (or GZK) Neutrinos

Predictions are secure:



$n \rightarrow$  lower energy protons

$\pi \rightarrow \mu + \nu$

However,  $\nu$ -Flux Calculations depend on:

1. Elemental composition (p, Fe, mixed)
2. Cosmology ( $\Lambda=0.7$ )
3. Injection Spectra,  $E^{-\gamma}$  and  $E_{\text{max}}$
4. Evolution of sources with redshift,  $(1+z)^m$ 
  - Star formation, QSO, GRB, little or no

# **ANITA**

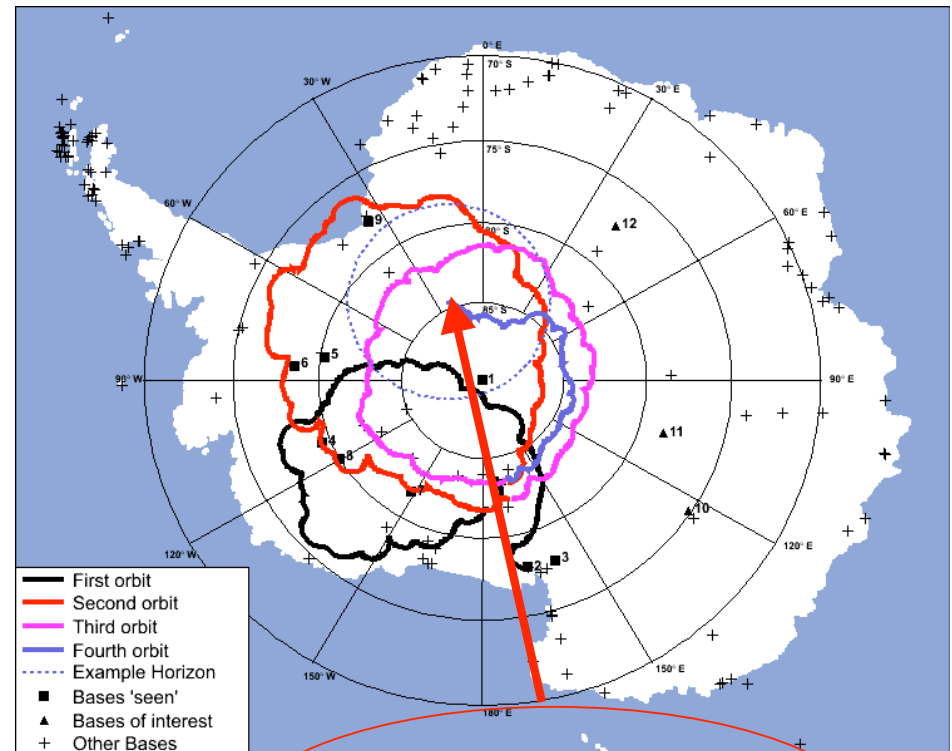
## **EeV astronomy**

UCI, UHawaii (P. Gorham - PI), UCLA, OSU, JPL,  
WashU, UMinn, UKansas, UDelaware, SLAC



# ANtarctic Impulsive Transient Antenna

[www.ps.uci.edu/~anita](http://www.ps.uci.edu/~anita)



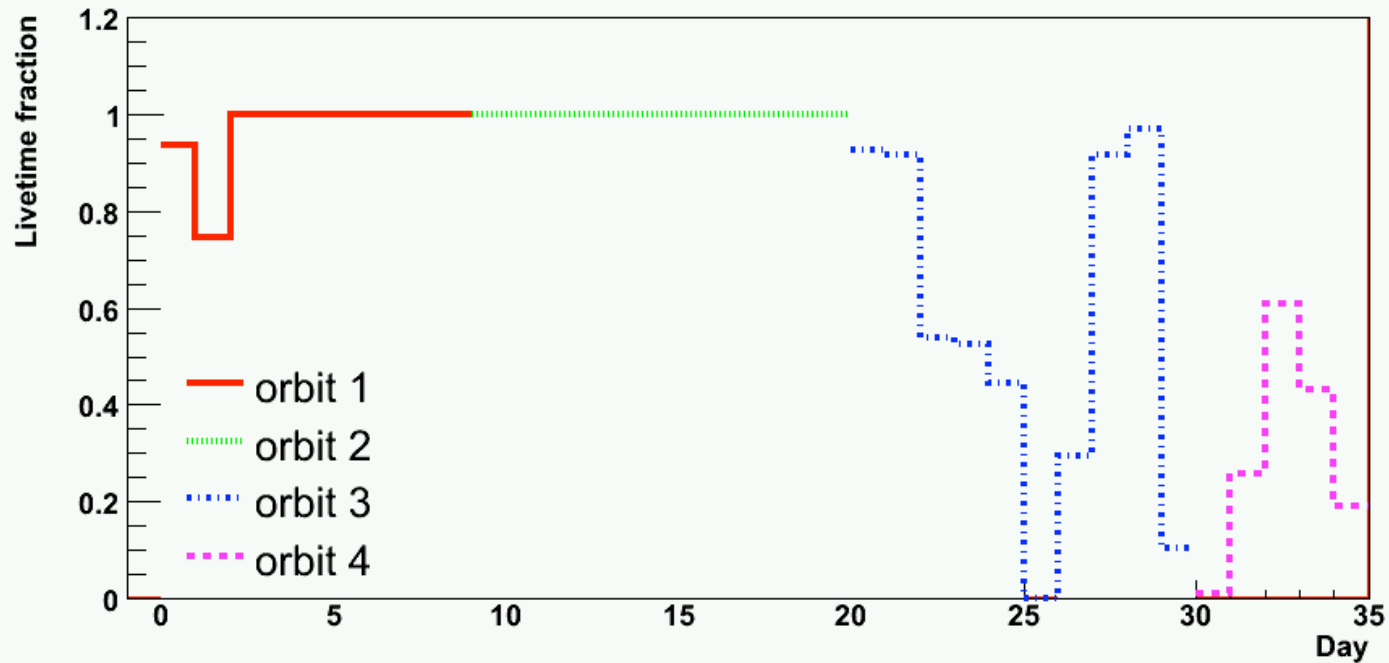
600 km radius,  
1.1 million km<sup>2</sup>

- ANITA launched on Dec 15, 2006 and remained aloft for 35 days





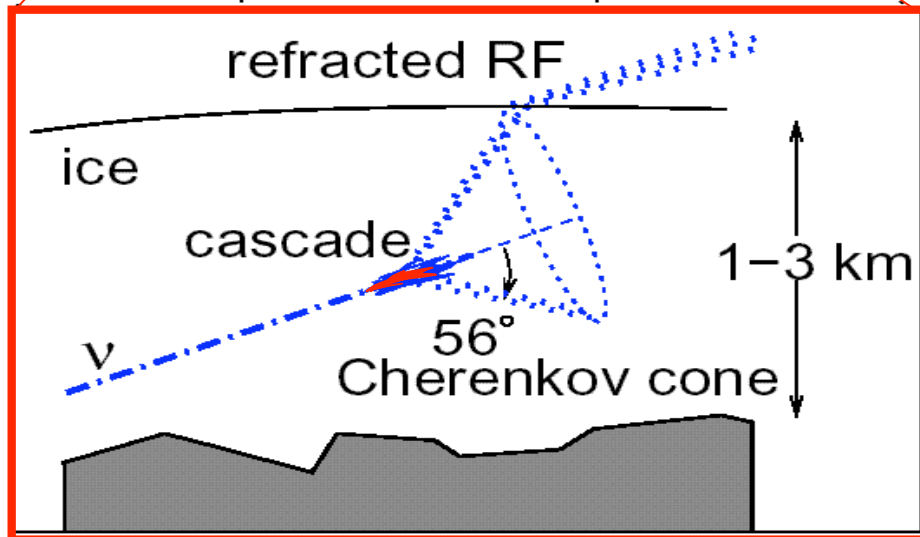
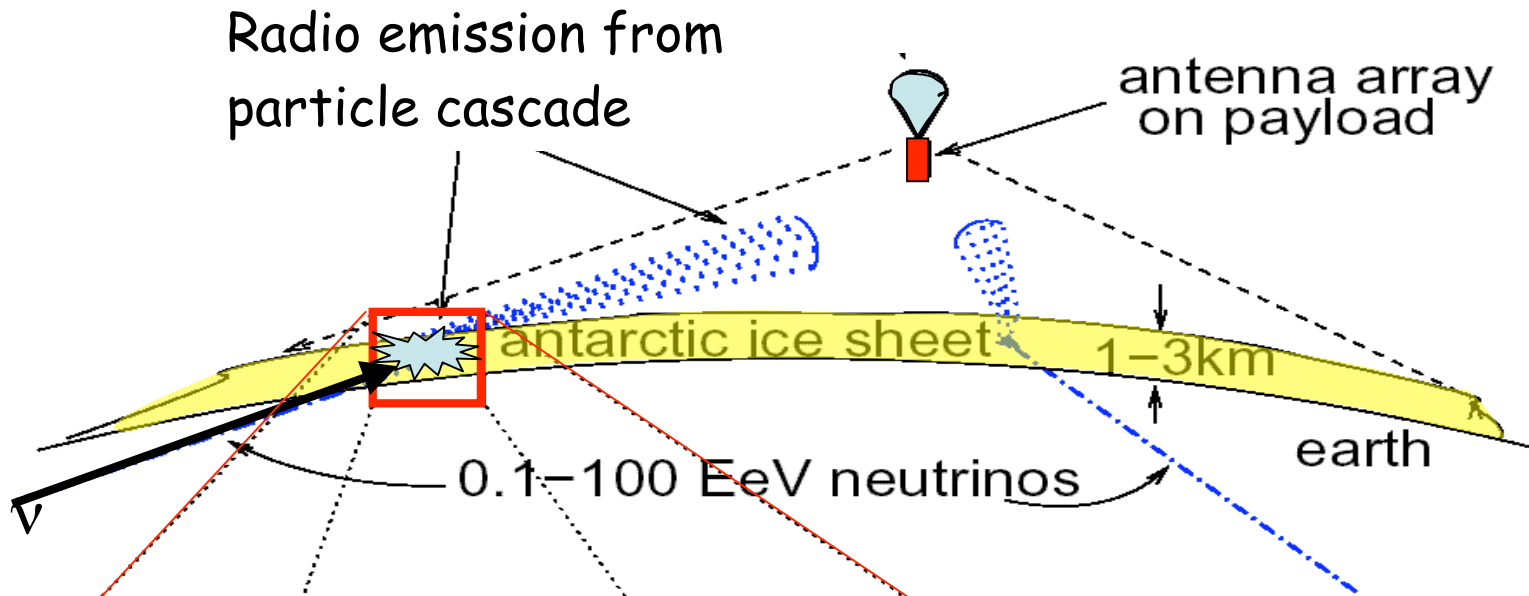
## Livetime



Despite unusual flight path, and instrumental issues that reduced livetime for last 12 days of flight, ANITA-1 represents dramatic leap forward



# ANITA concept



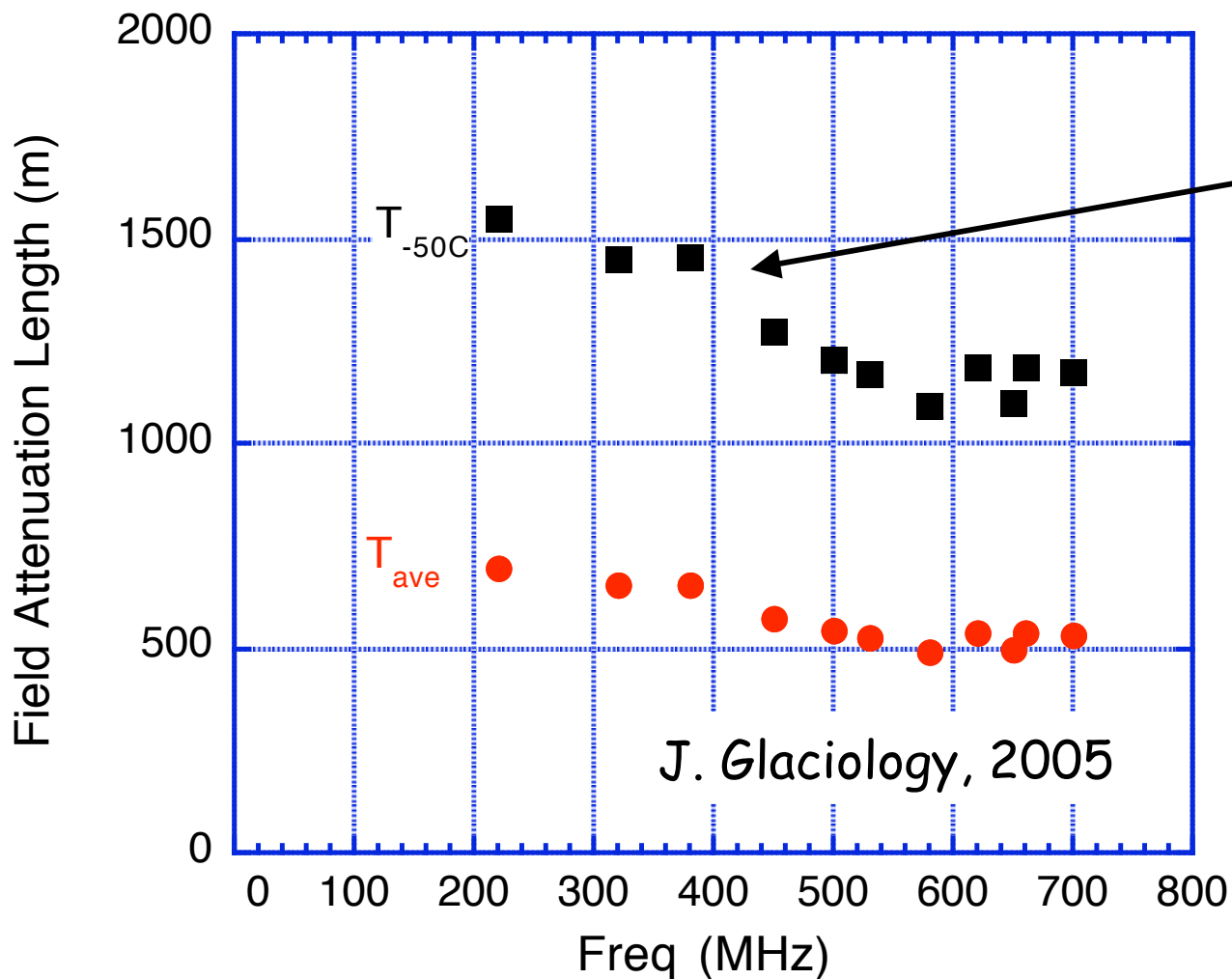
P. Gorham



# Ice Attenuation at South Pole

- from 200MHz to 700MHz

Reflection studies @S.Pole, Jan. 2004 - S. Barwick



Most of Antarctic ice is -50C!

Excellent transparency, compare to ~100 meter for light, it is 10x larger

*J. Glaciology, 2005*

# Calibration Chain

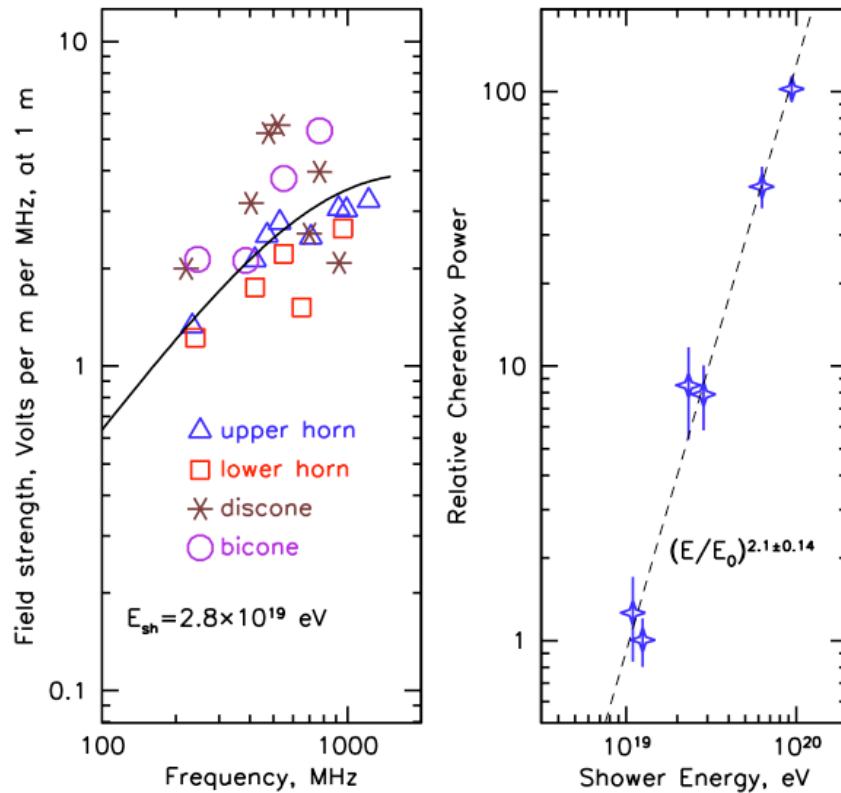
- |                                |                            |
|--------------------------------|----------------------------|
| 1. Signal Strength, cone width | SLAC beam                  |
| 2. Propagation and Surface     | Borehole TRX               |
| 3. Angular Resolution          | Borehole/Surface TRX       |
| 4. Detector Operation          | Thermal/Sun/Galactic Noise |



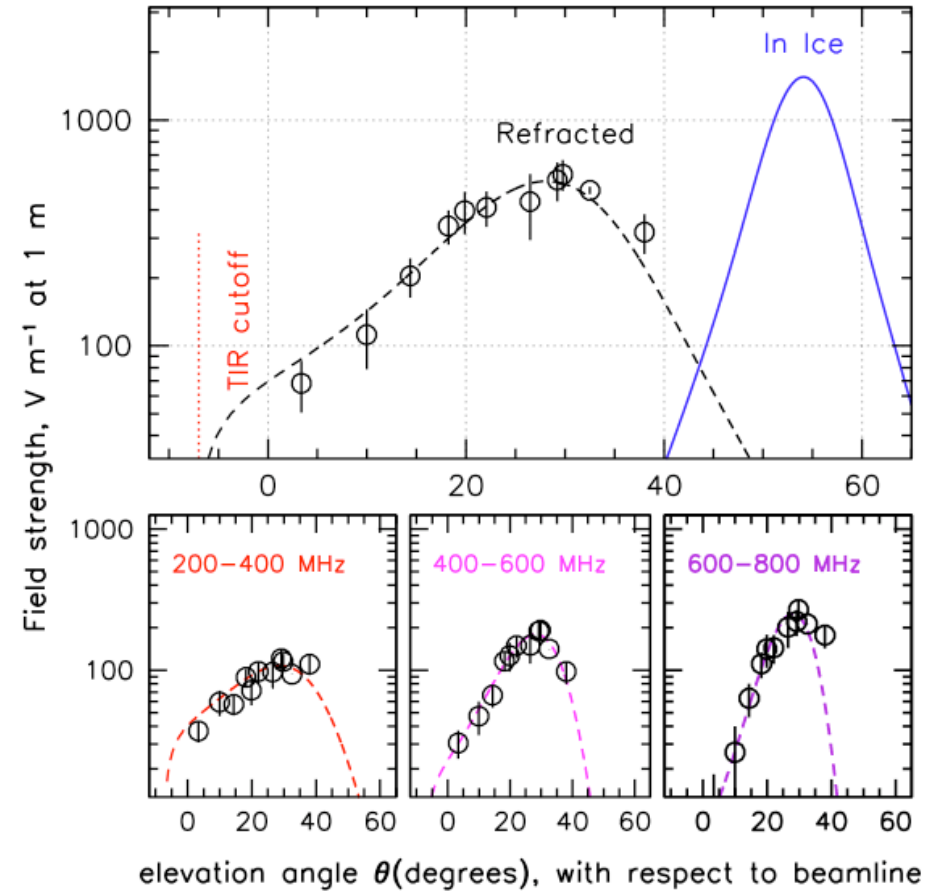


# SLAC beam tests on Ice Target

Gorham, Barwick, et al., astro-ph/0611008



Absolute RF power and frequency dependence confirmed

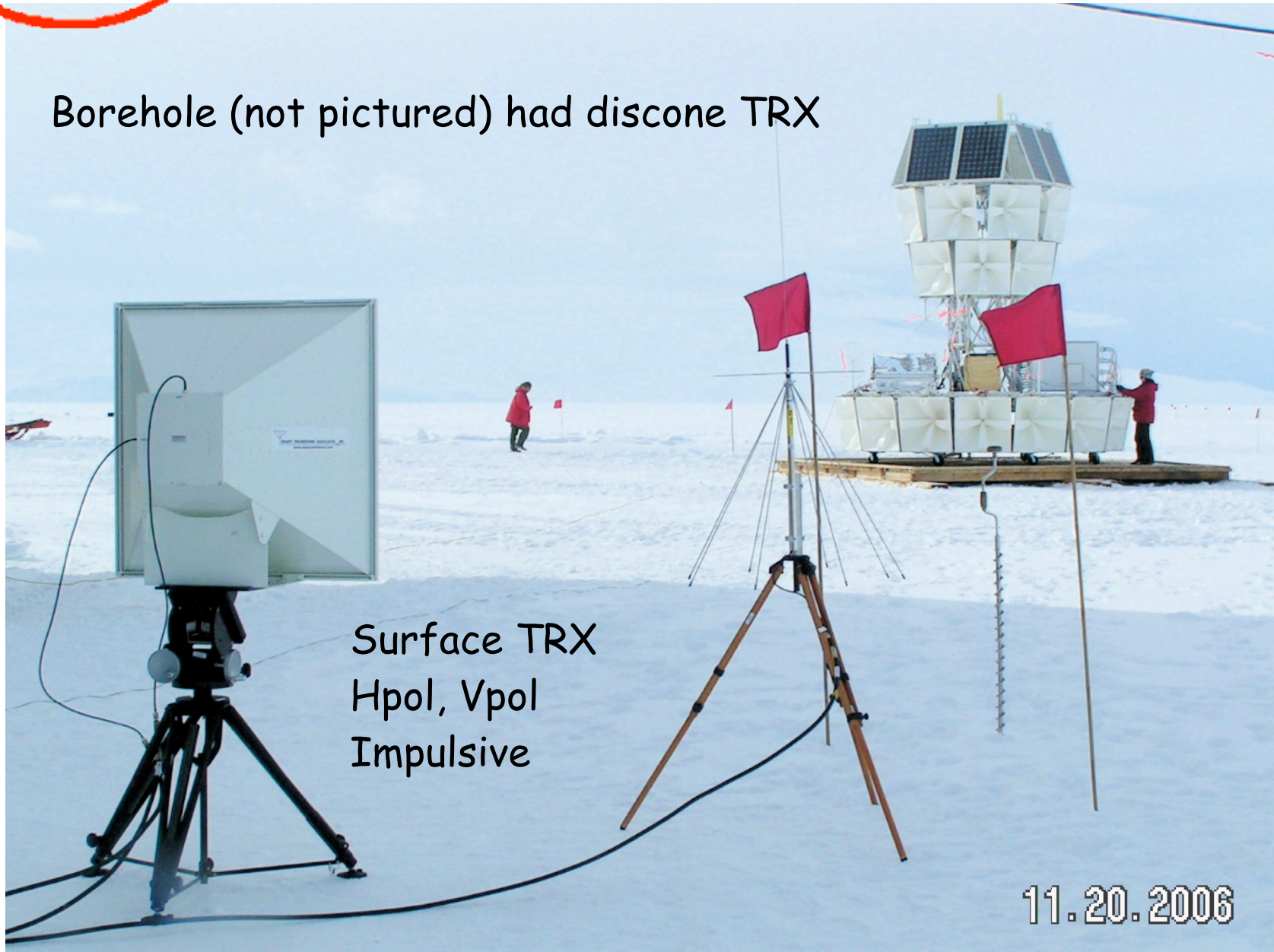


Width of cherenkov cone and frequency dependence confirmed



## Surface Calibration

Borehole (not pictured) had discone TRX

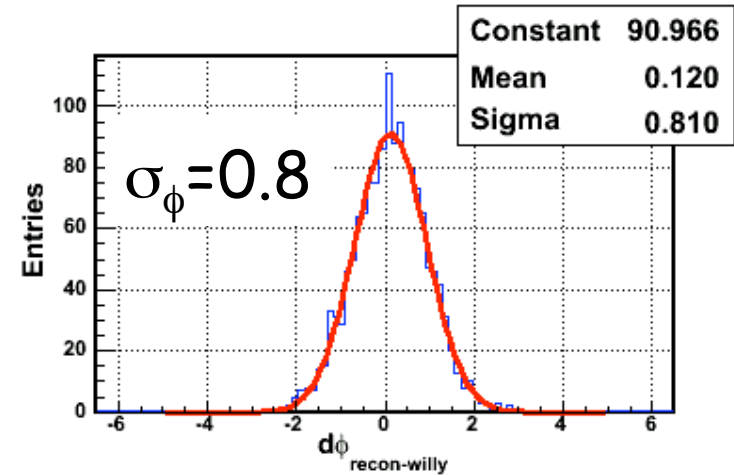
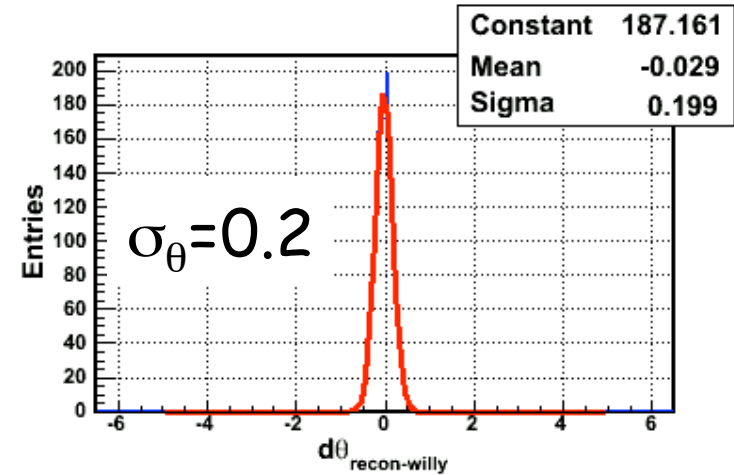


Surface TRX  
Hpol, Vpol  
Impulsive

11.20.2006



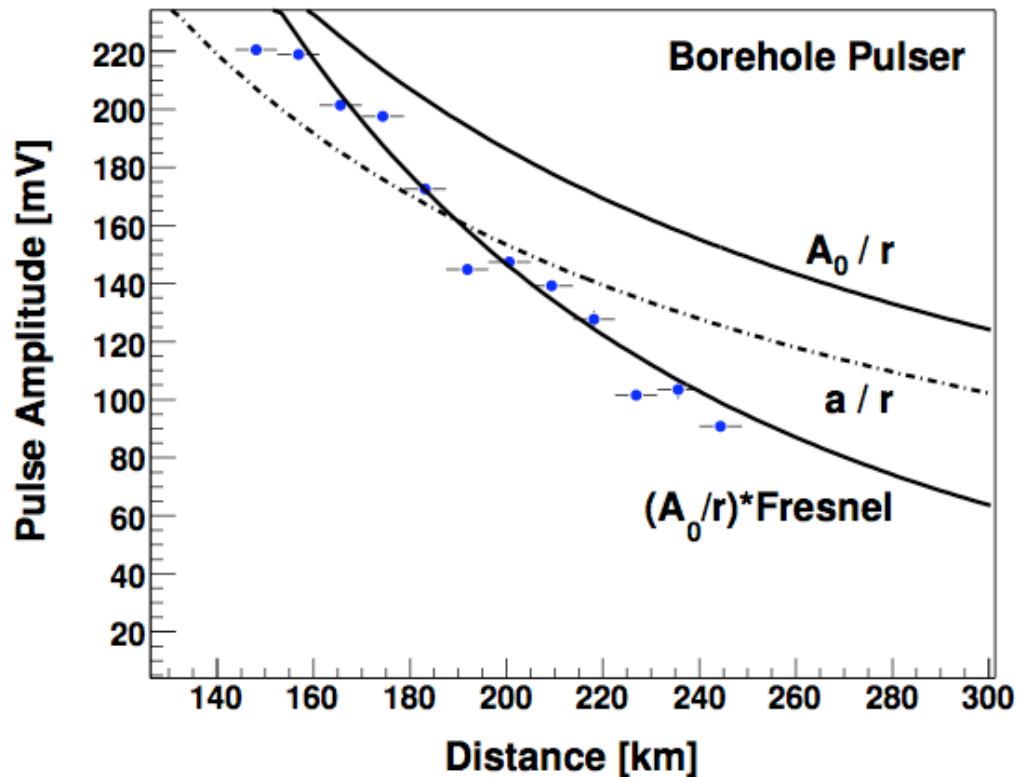
# In Situ Angular Resolution



Excellent timing and angular resolution

# ANITA Calibration using Borehole Pulser

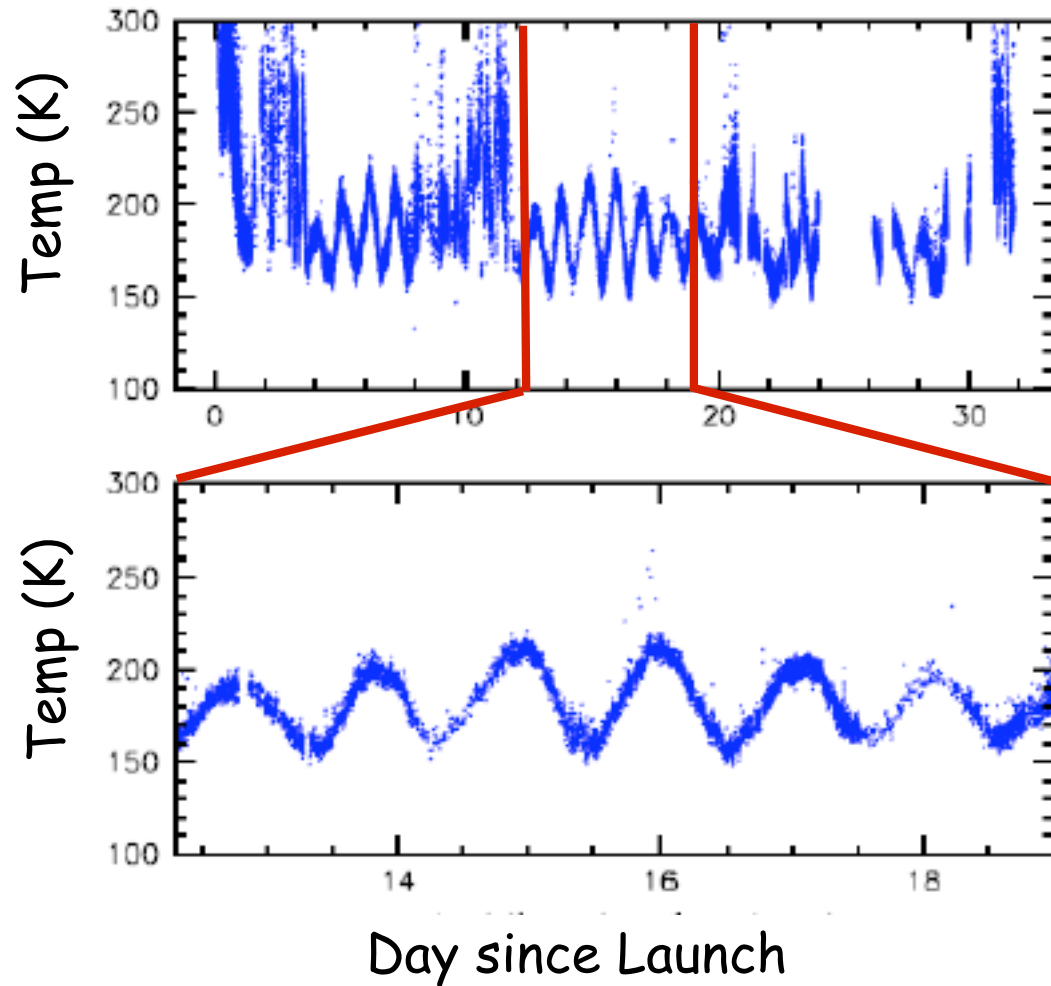
Goldstein, ICRC 2007



- Absolute Amplitude,  $A_0$ , of radio signal is confirmed
- Fresnel effects from ice-air boundary properly modeled



# Thermal/Solar/Man-made Noise

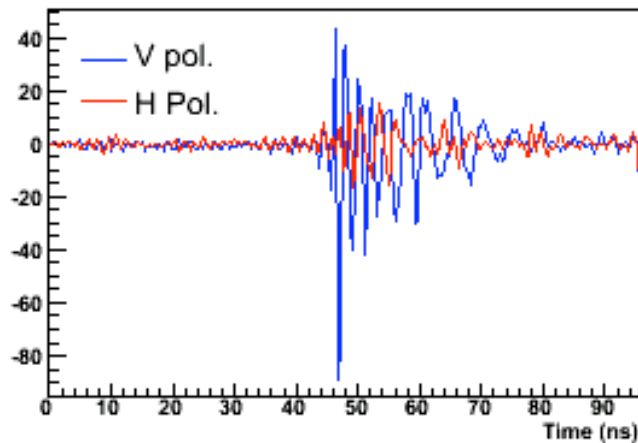


Variation due to  
sun-angle

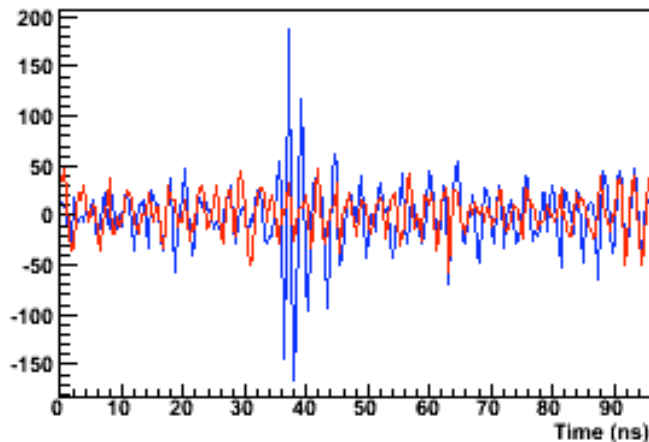


## Analysis Strategy

SLAC Beam Test Data



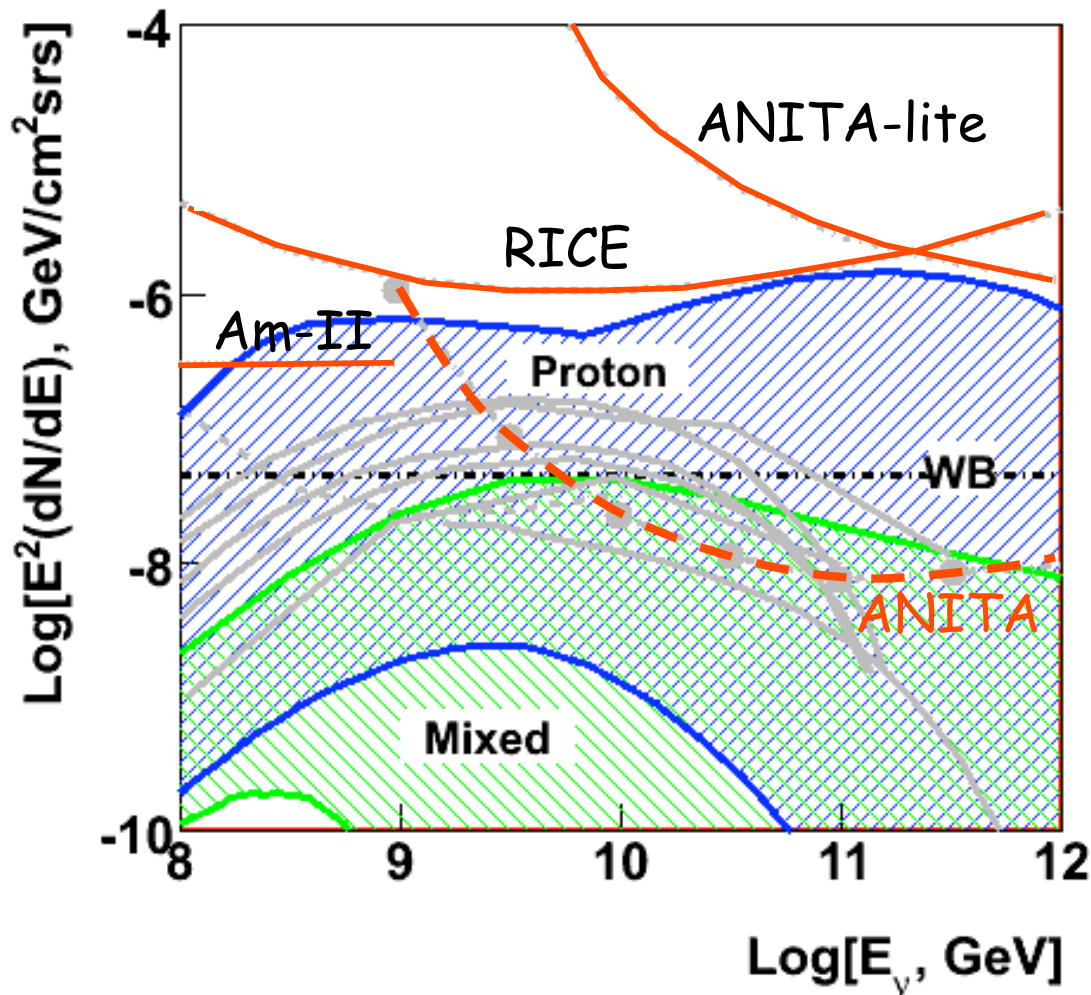
Willy Ground Pulser Data



1. 3 ant top, 3 ant bot  $>3.5V_{\text{rms}}$  in  $V_{\text{pol}}$
2. Good reconstruction
3. Vpol and Hpol compatible with  $\nu$  expectation
4. Time profile of waveforms consistent with SLAC and GP
  - a) Not too long or short
  - b) Bandwidth limited charact.
5. FFT consistent with uniform power at all frequencies, no strong lines of RFI
6. Temporally isolated from similar events
7. Avoid "known" sources of RFI



# Projected Sensitivity



ANITA sensitivity  
[Barwick et al, PRL 96(2006)]

- based on 45 days
- assume that no neutrino events are found

Fluxes are for  
sum of all  $\nu$  flavors

# Measuring or Constraining Neutrino Cross-section w/ ANITA

Fenfang Wu, Steve Barwick, for the ANITA Collaboration  
ICRC, 2007



# Event Rates depend on $\sigma$

- $d^2N/dEdt \sim 2\pi N_A \rho V_{\text{eff}} F_{\nu} \sigma_{\nu N}$

Where:

$N_A$  = Avogadro's number

$\rho$  = density of medium

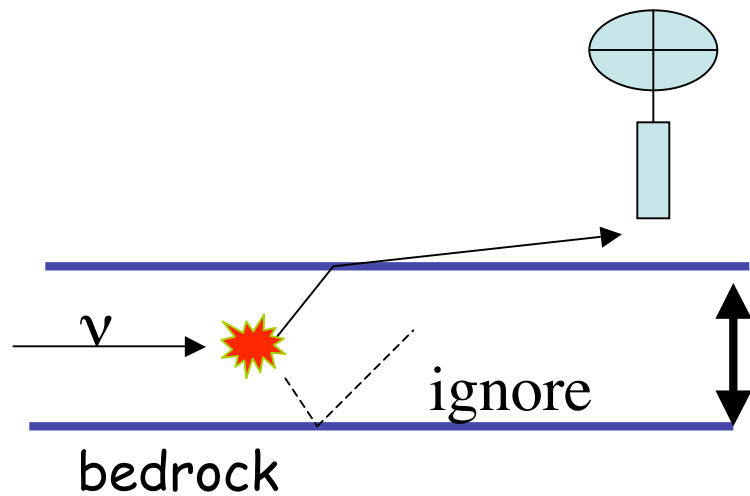
$V_{\text{eff}}$  = effective volume of detector

$F_{\nu}$  = differential neutrino flux per solid angle

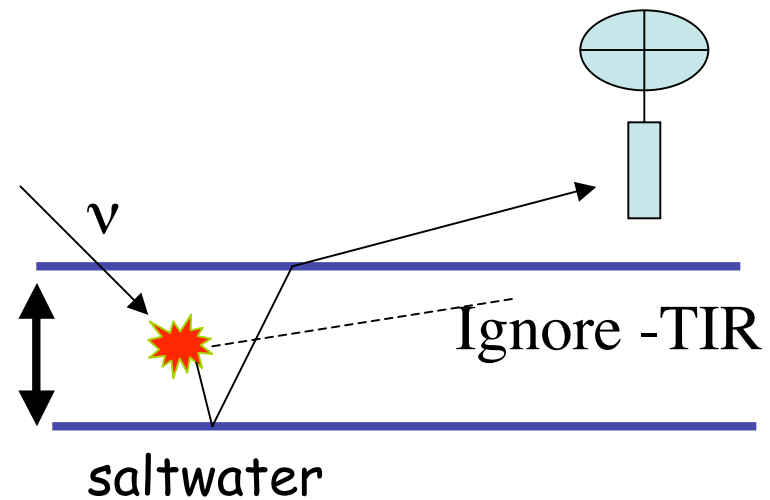
$\sigma_{\nu N}$  = neutrino-nucleon cross-section

$$= \sigma_{\text{cc}} + \sigma_{\text{nc}} \text{ where } \sigma_{\text{cc}}/\sigma_{\text{nc}} \sim 2 \text{ for } E_{\nu} > 10^{18} \text{eV}$$

# Reflected and Direct Events



**Direct**

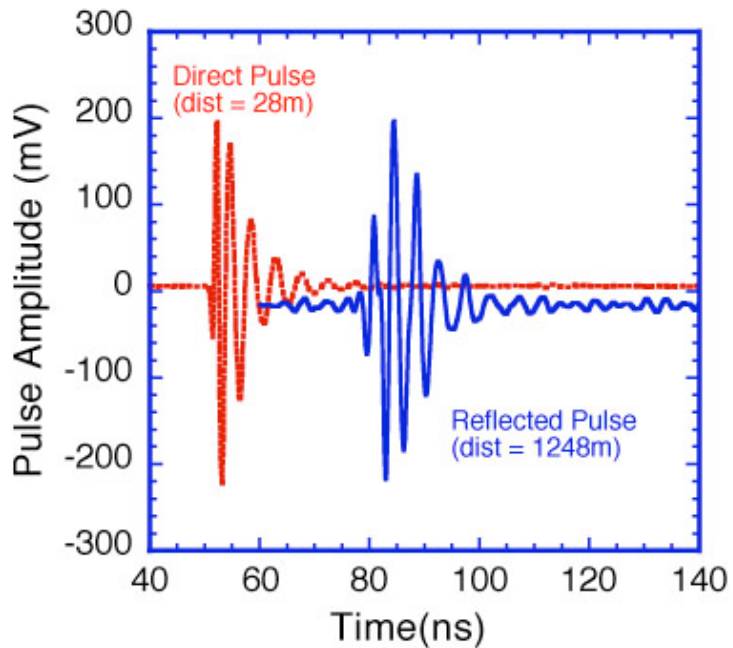


**Reflected**

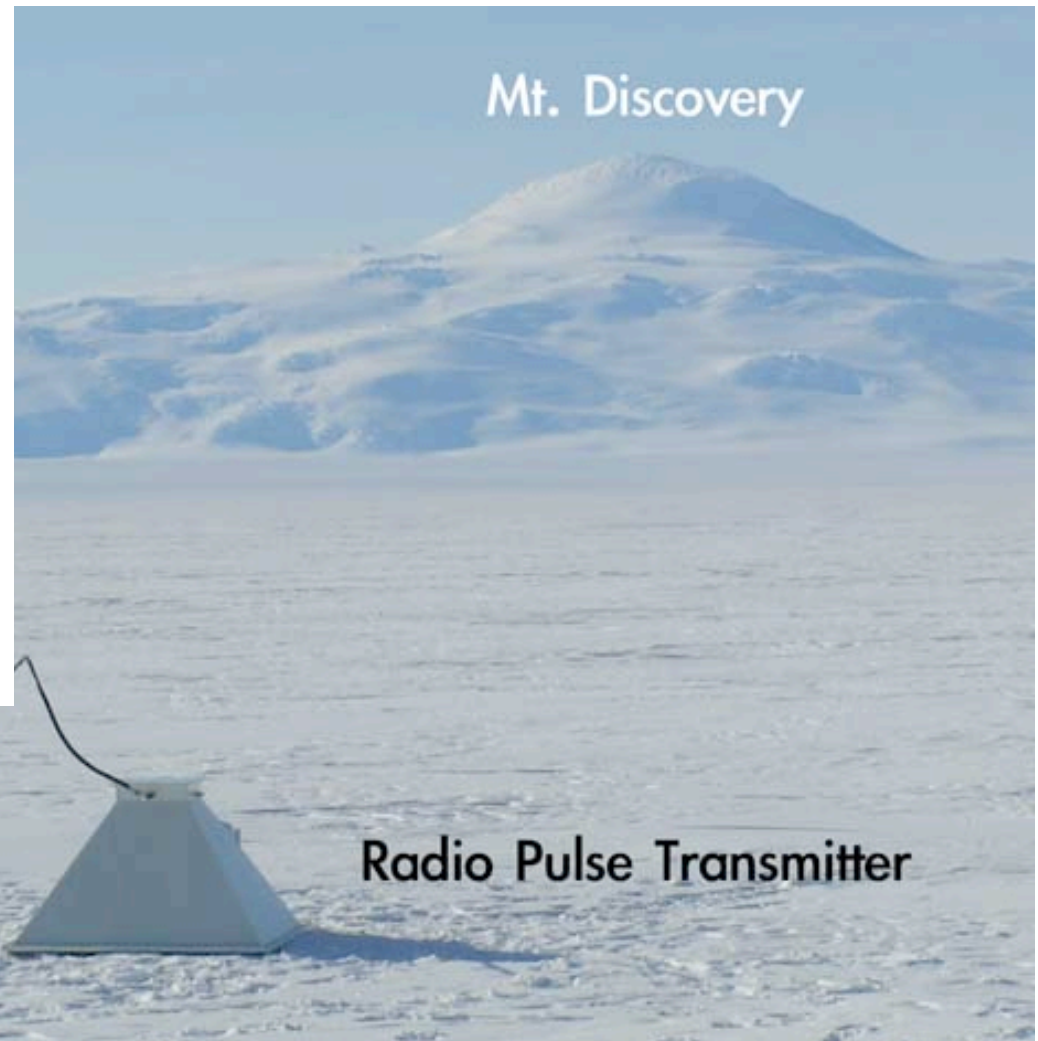
# Camping at Moore's Bay Site



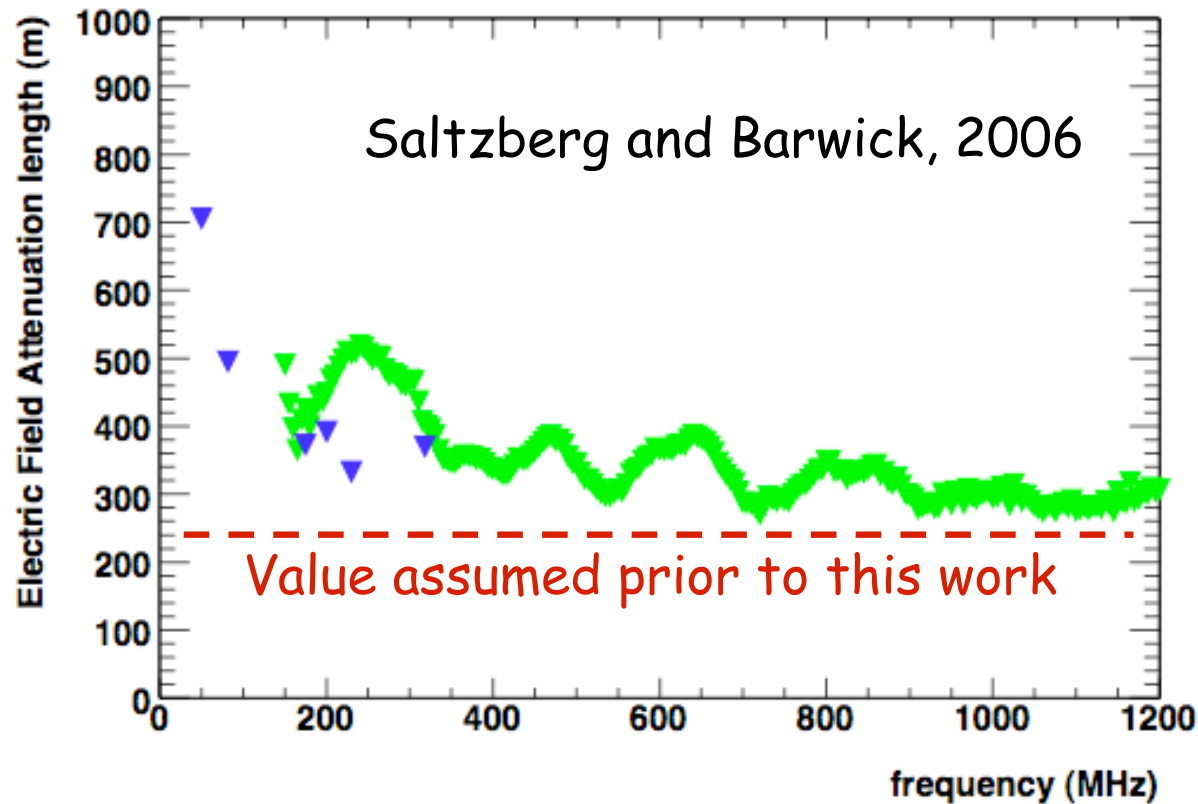
# Moore's Bay Site Studies



Amazing fidelity of reflected pulse from sea-water bottom -behaves as nearly flawless mirror



# 1-way Field Attenuation- Moore's Bay

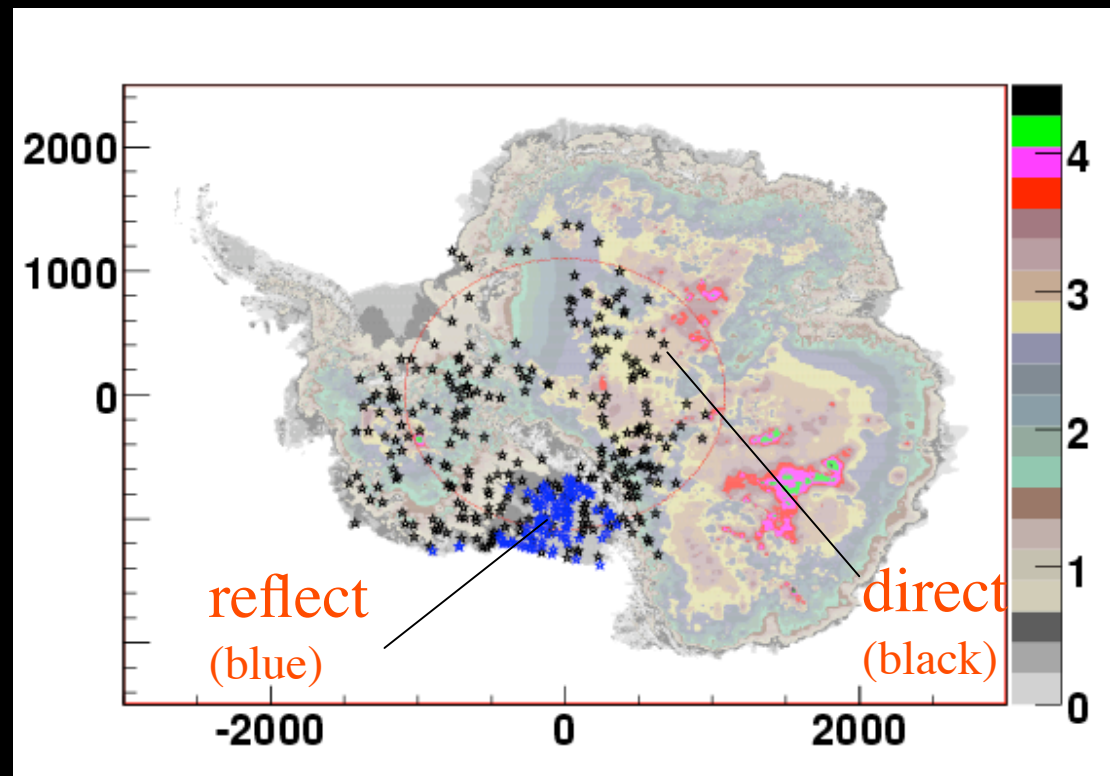
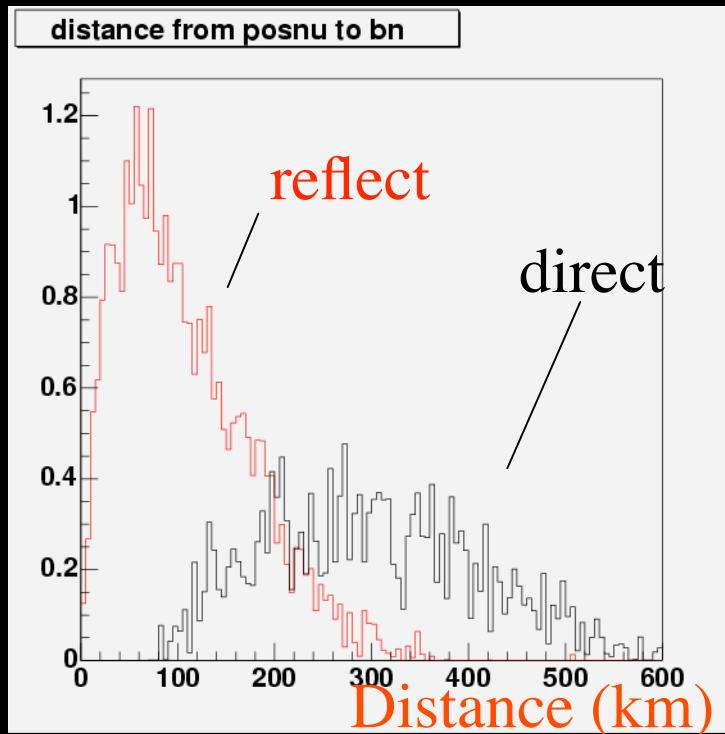


Preliminary

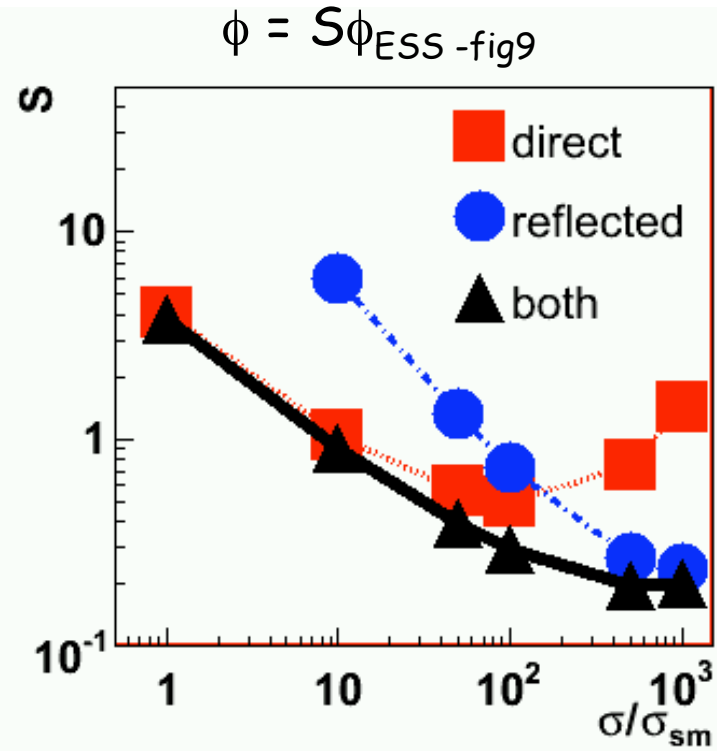
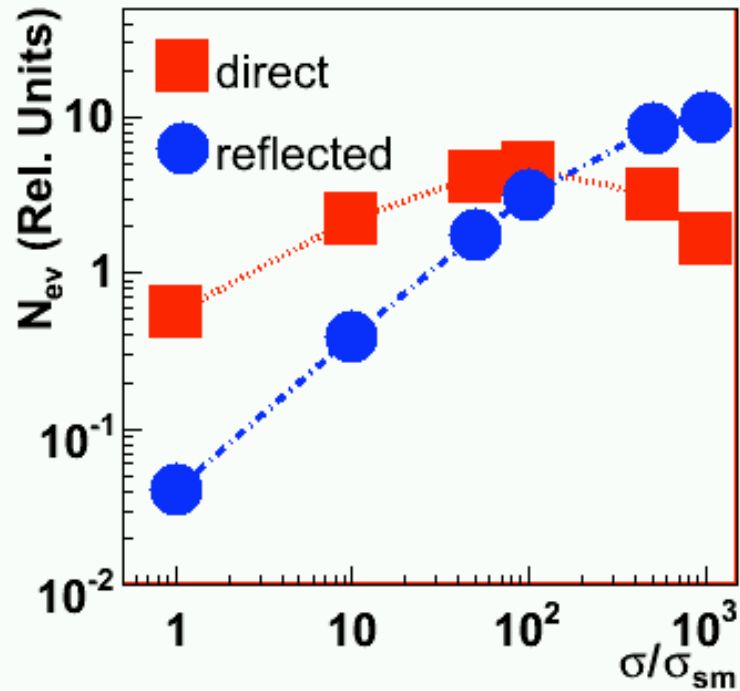
# Event ID : Reflected or Direct?

- Based on Topology and distance
- Develop likelihood function to separate reflected from direct events

$$E_v = 10^{20} \text{ eV}, R_{\text{ross}} = -3\text{dB}, \sigma = 100\sigma_{\text{sm}}$$



# Direct and Reflected Event Rates

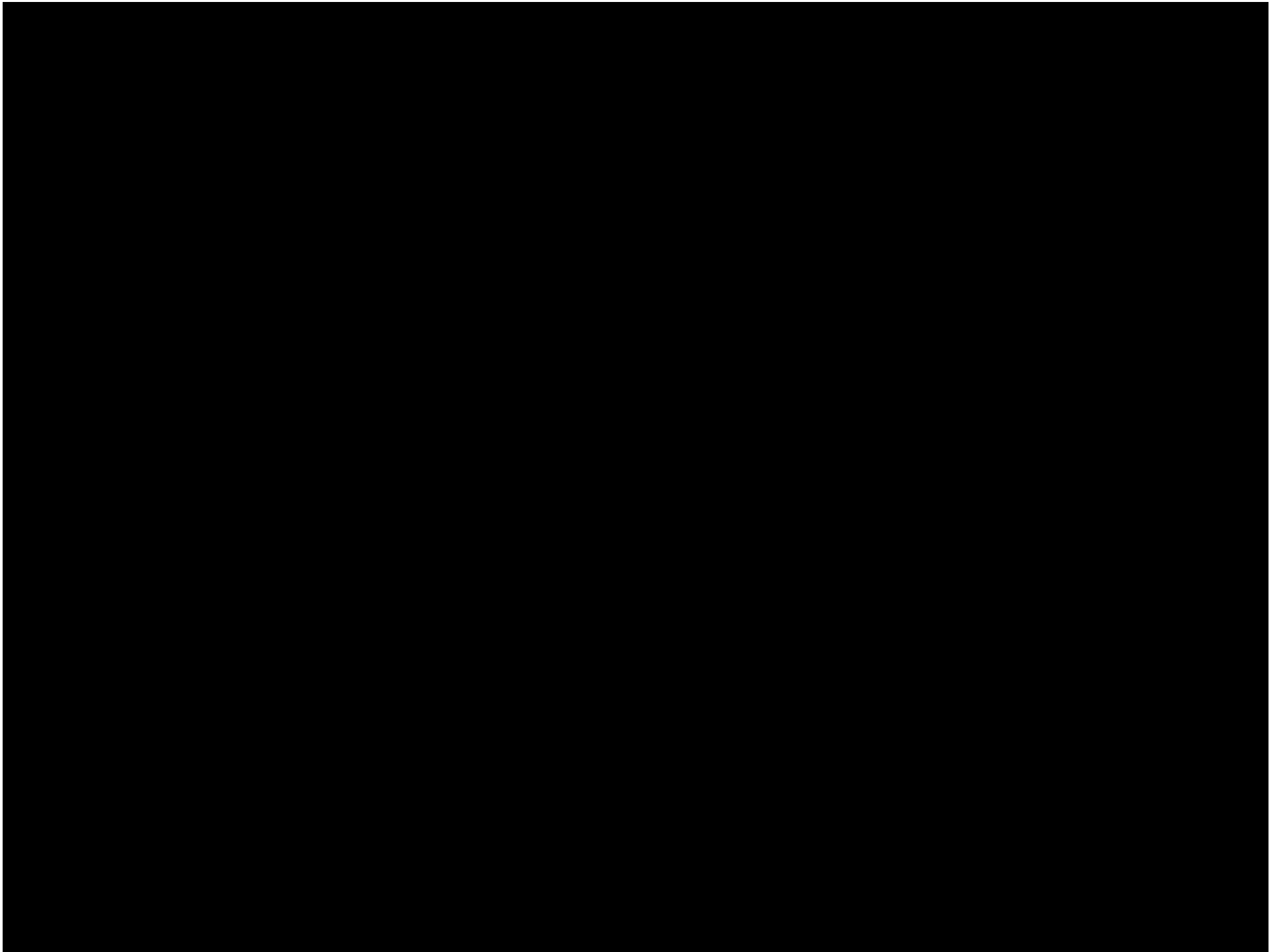


For scenario  $N_\nu=0$



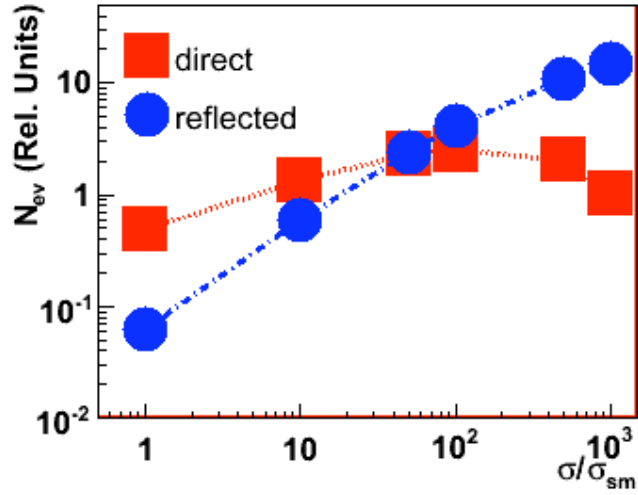
# Outlook

- With **AMANDA-II**, the requisite tools to inaugurate **multi-messenger astronomy** are available -> IceCube continues this technique.
- To probe the **neutrino fluxes** and **physics** at highest energies, new techniques are being developed based on **radio cherenkov** detection.
- **ANITA** extends search volume to  **$10^6 \text{ km}^3$** 
  - Launched from McMurdo Dec 15, 2006, and remained aloft 35 day
- **ARIANNA** spans the impending energy gap
  - Ice studies in Nov' 06 astonishingly good, but not the only contender (SALSA, AURA, Auger, acoustic detection)
  - MRI proposal submitted Jan 2007 for 200 station Phase A

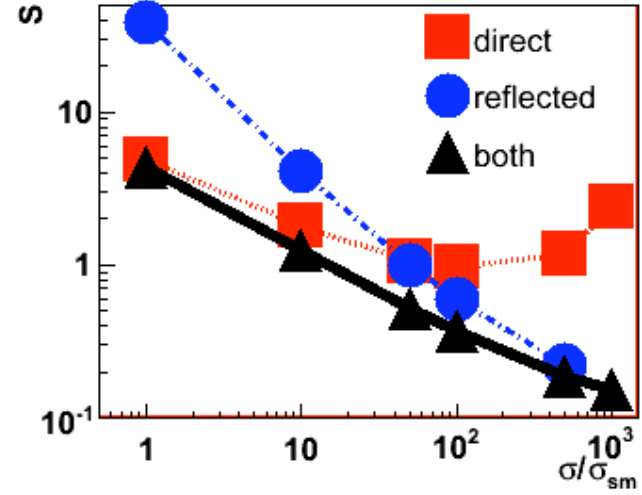


S.pole

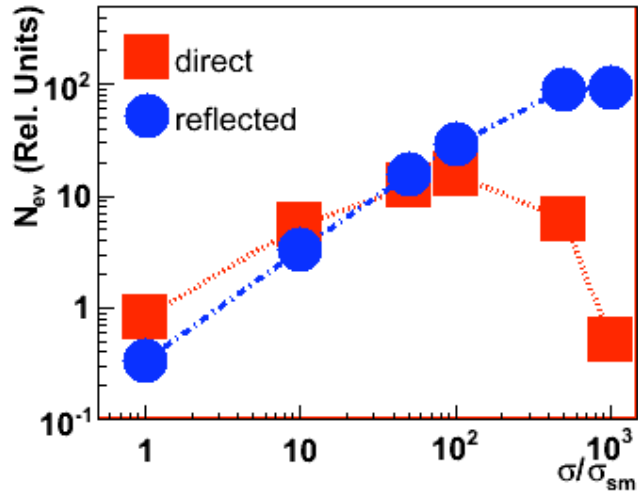
ESS\_Fig9



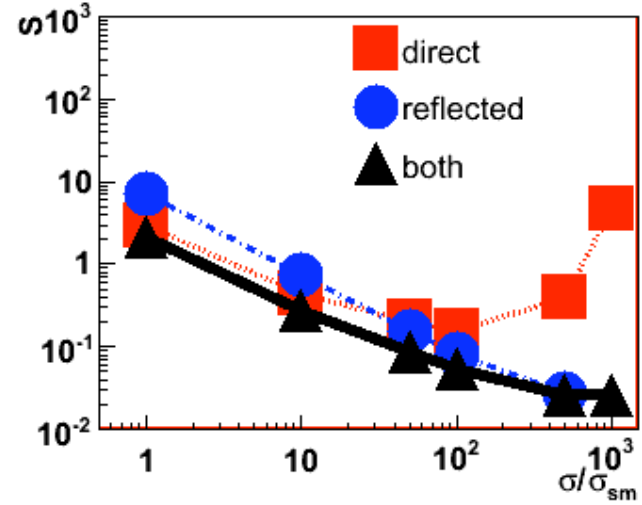
$$\phi = S\phi_{ESS\text{-fig9}}$$



E-2



$$\phi = S\phi_{E^{-2}}$$



# Ideas to measure $\sigma_\nu$ at UHE

- Kusenko and Weiler, PRL 88 (2002)161101
  - Use Hor. Air Sh and upward-going leptons
- Anchordoqui, et al. , PRL 96 (2006)021101
  - Earth skimming to downward going  $\nu$  in buried detectors like AMANDA
- Anchordoqui, et al. , hep-ph/0410136v2
  - Use RICE limits and assumed flux
- Hussain and McKay, hep-ph/0510083v2
  - Use RICE limits and assumed flux
- Barger, Huber and Marfatia, hep-ph/0606311
  - Use RICE limits and derived neutrino flux



Representative List

ANITA probes with improved sensitivity at  $E > 10^{19} \text{eV}$