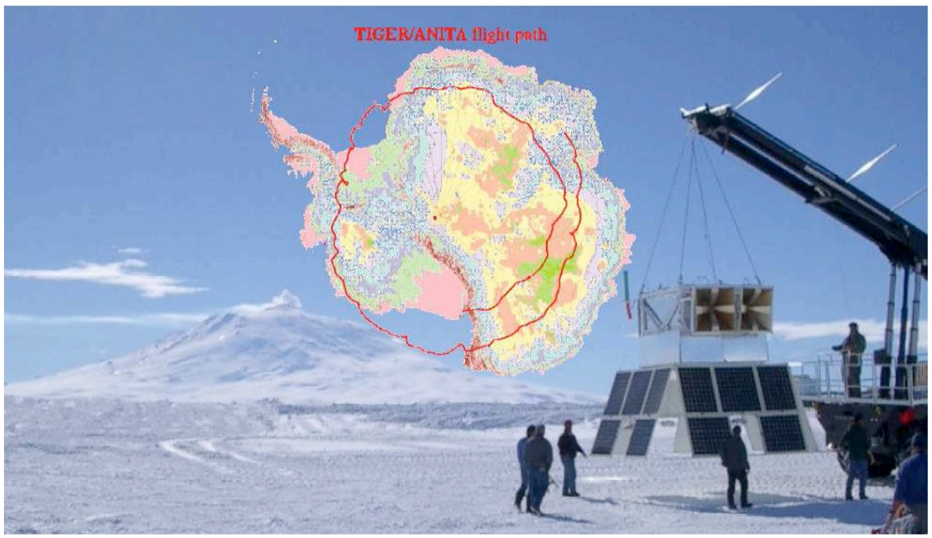
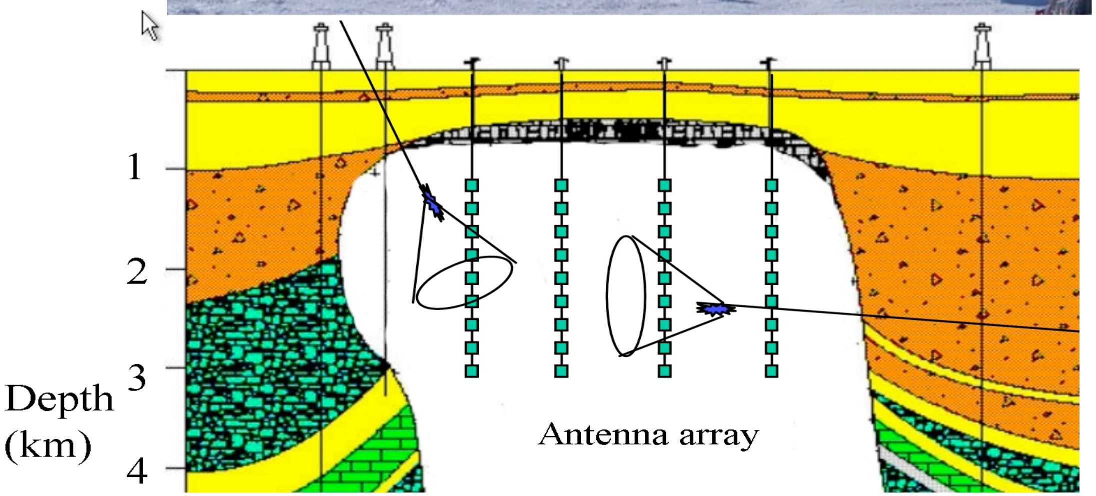
Searching for Ultra High Energy Neutrinos with ANITA and SalSA





Amy Connolly
for the
ANITA
and
SALSA
Collaborations

TeV Particle Astrophysics
13-15 July 2005

Motivation: The GZK Process

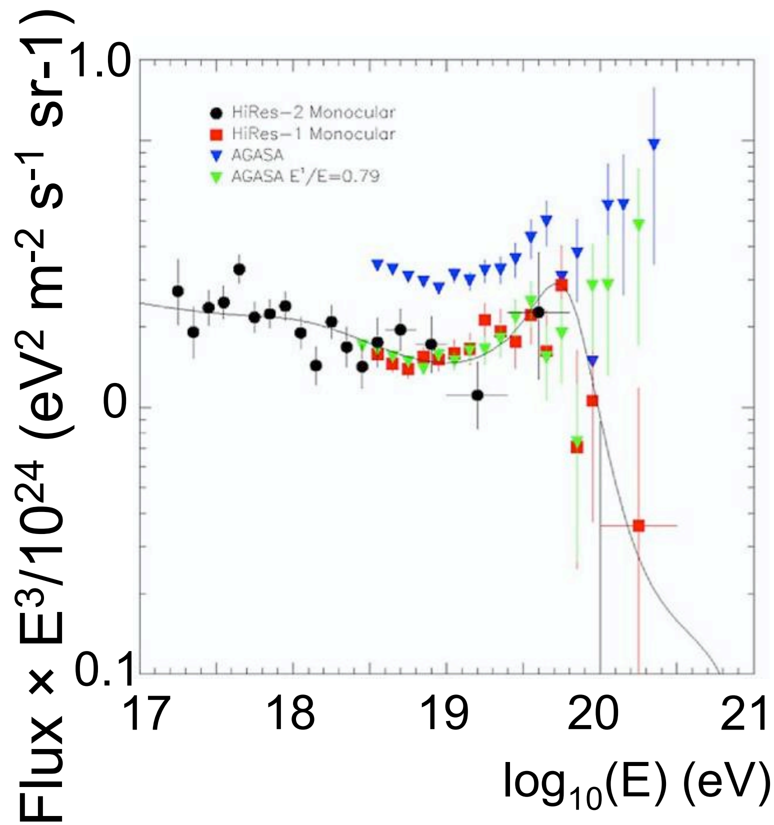
Greisen–Zatsepin–Kuzmin: Cosmic rays $>10^{19.5}$ eV from sources $\gtrsim$ 50 Mpc should not be detectable

$$p + \gamma_{cmb} \to \Delta^* \to p + \pi$$
$$\hookrightarrow \mu\nu$$
$$\hookrightarrow e\nu\nu$$

Yet: ~20 events observed $>10^{19.5}$ eV

Do not definitively point to any "local" known object(s)

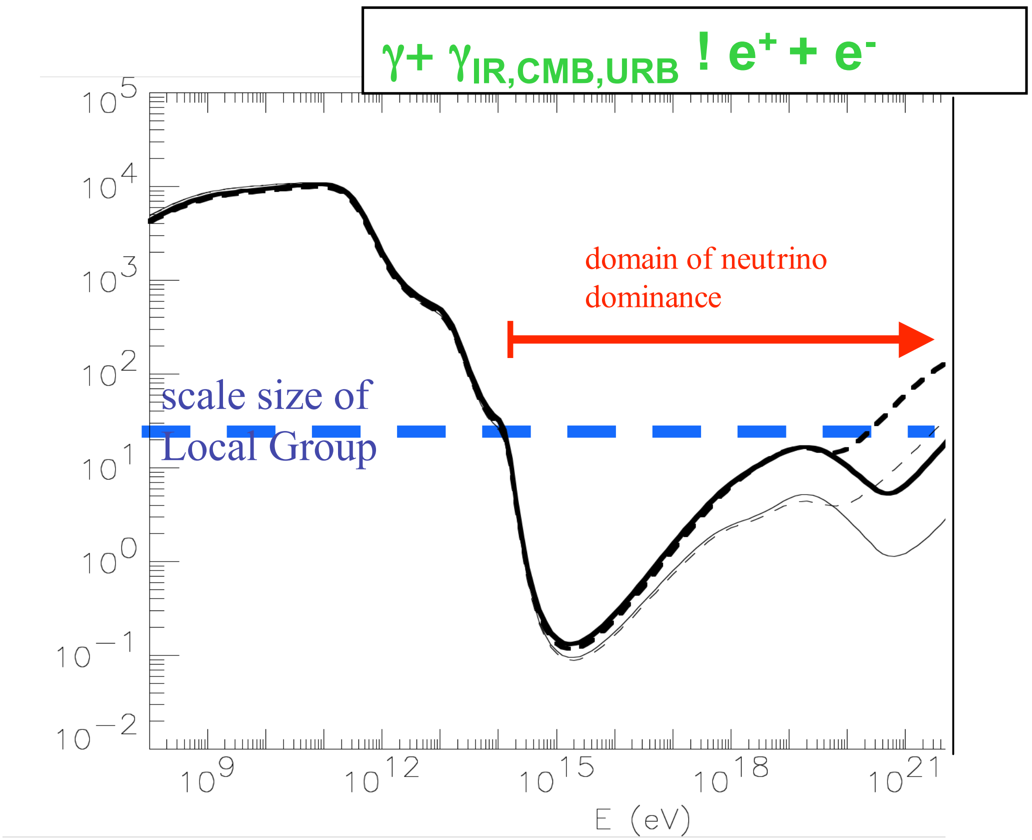
Do not expect significant bending in intergalactic fields at these momenta.



Expect neutrino flux in the UHE region: An important piece of the GZK puzzle.

Motivation (cont):
Only useful messengers >100 TeV: ν's

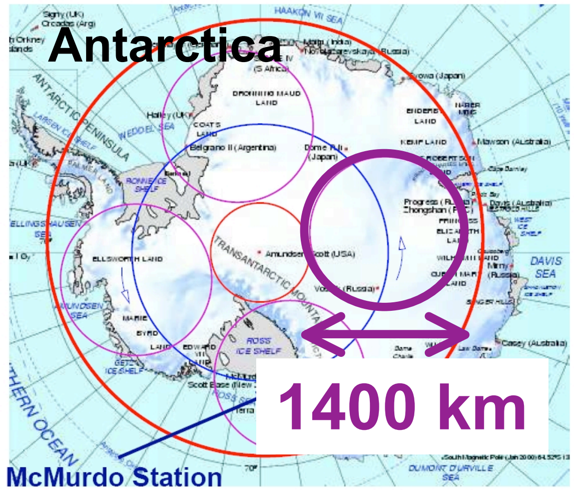
Every new energy band yields major discoveries

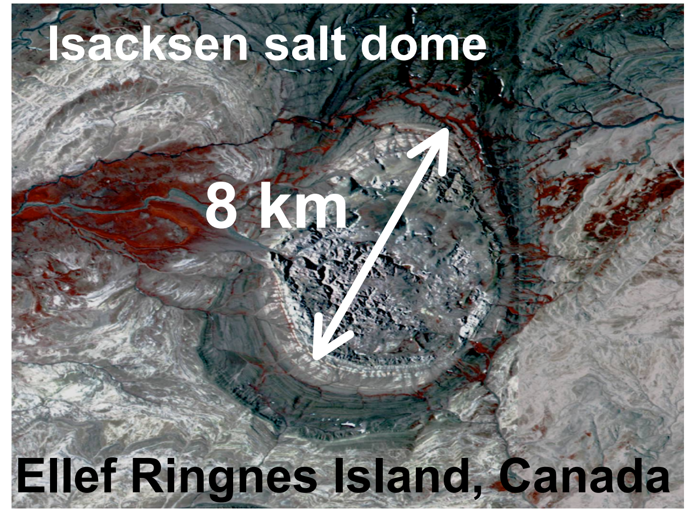


- **Photons lost above 30TeV:** pair production on IR & μwave background
- **Protons & Nuclei:**
  scattered by B-fields or GZK process at all energies
- But the sources extend to 10^{21} eV

Beyond km^3-Scale Detection Volume

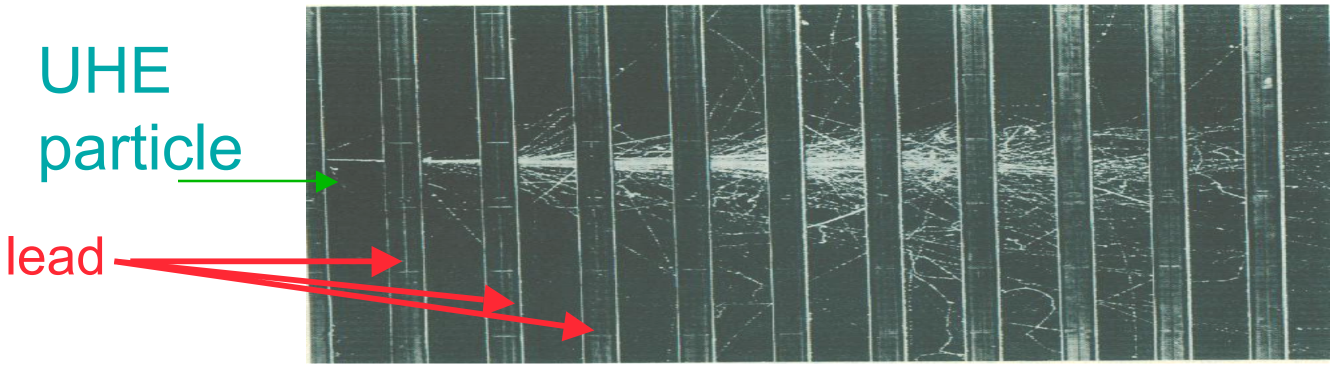
Rate of UHE cosmic rays is ~1/km^2/ century





	Ice Cube	ANITA	SalSA
Atten. length	>100 m	~km	~km
Threshold	> 1 TeV	10^{18} eV	10^{17} eV
Sensors	4800 PMT's	~40 antennas	~1000 antennas
$[V\Delta\Omega]_{eff}$ (w.e.)	1 km^3 sr	~ 10^4 km^3 sr	~10^2 km^3 sr
Livetime	years	weeks	years

Idea by Gurgen Askaryan (1962)



Bremsstrahlung:
$e^- \rightarrow e^- \gamma$
Pair Production:
$\gamma \rightarrow e^+e^-$
$\rightarrow$ EM Shower

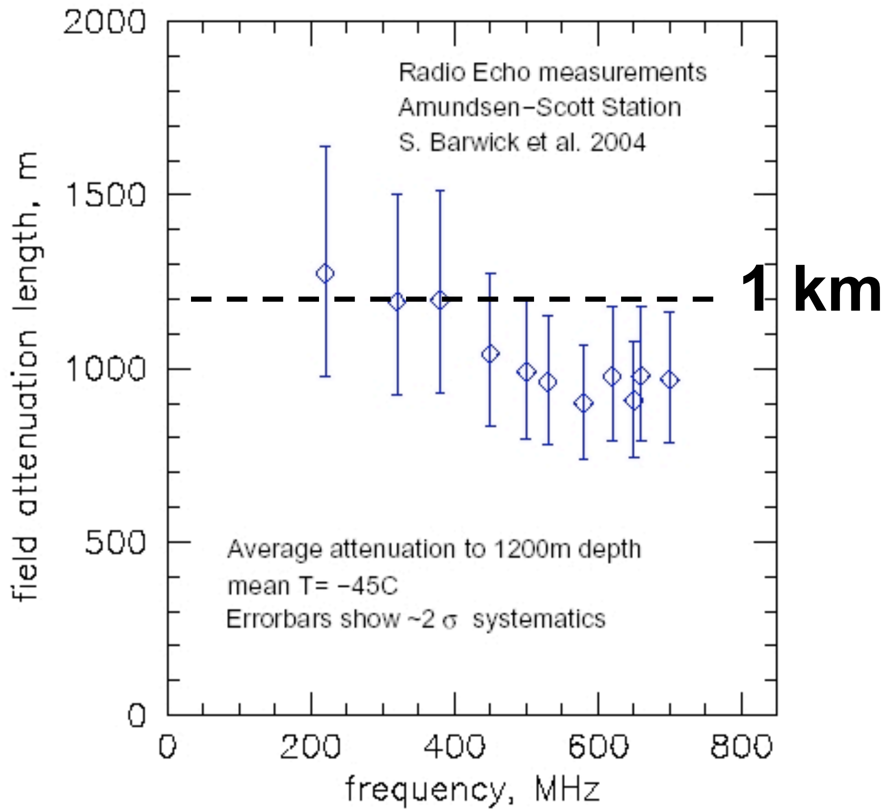
- A 20% charge asymmetry develops:
  - Compton scattering: $\gamma + e^-$(at rest) $\rightarrow \gamma + e^-$
  - Positron annihilation: $e^+ + e^-$(at rest) $\rightarrow \gamma + \gamma$
- Excess moving with v > c/*n* in matter

  $\rightarrow$ Cherenkov Radiation $dP \propto \nu\, d\nu$
- If $\lambda >> L \rightarrow$ **COHERENT EMISSION** $P \sim N^2$
- $\lambda \gtrsim L \rightarrow$ **RADIO/MICROWAVE EMISSION**

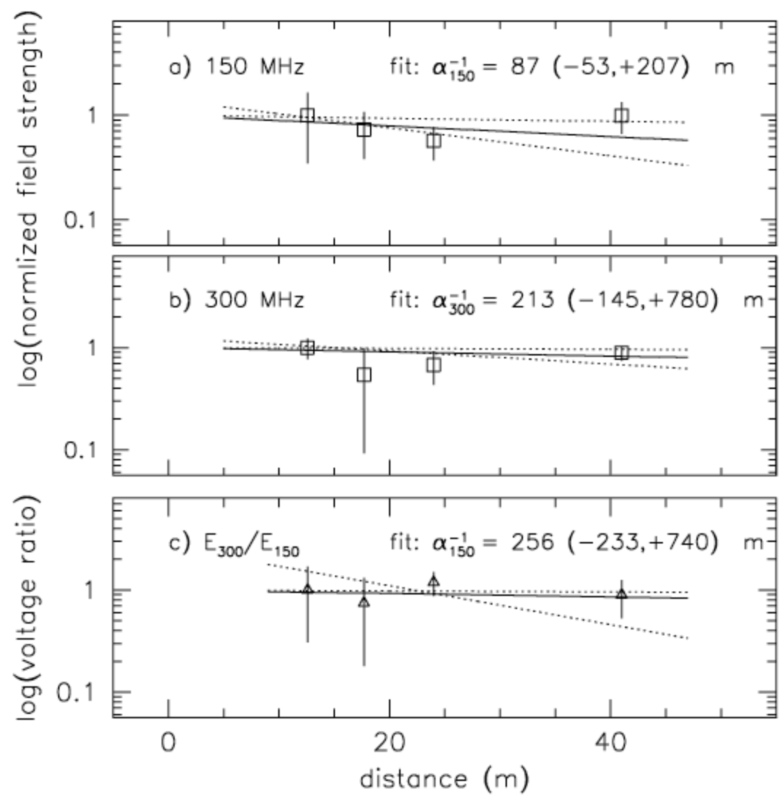
Macroscopic size: $R_{Moliere} \approx 10$ cm, L ~ meters

This effect was confirmed experimentally by Gorham, Saltzberg at SLAC in 2002

Long Attenuation Lengths in Radio in Ice, Salt, Sand



South Pole Ice

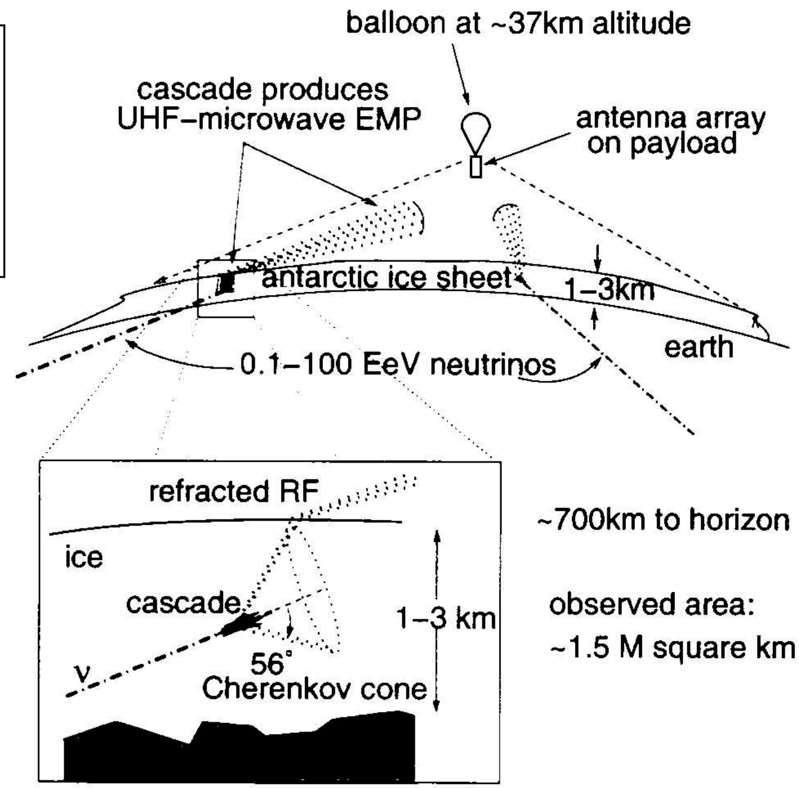


Hockley Mine near Houston, TX

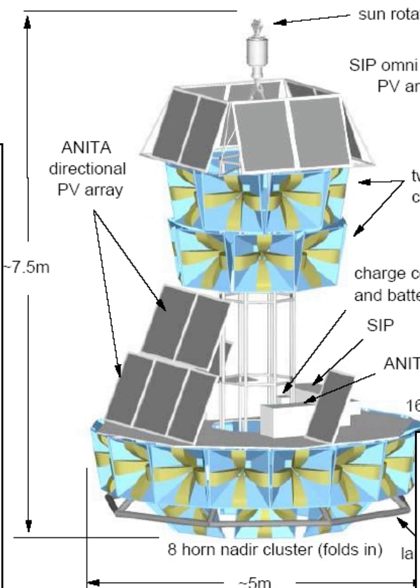
The GLUE experiment sought UHE neutrinos by observing the moon's regolith.

ANITA
(ANtarctic Impulsive Transient Antenna)

Each flight ~15 days – or more



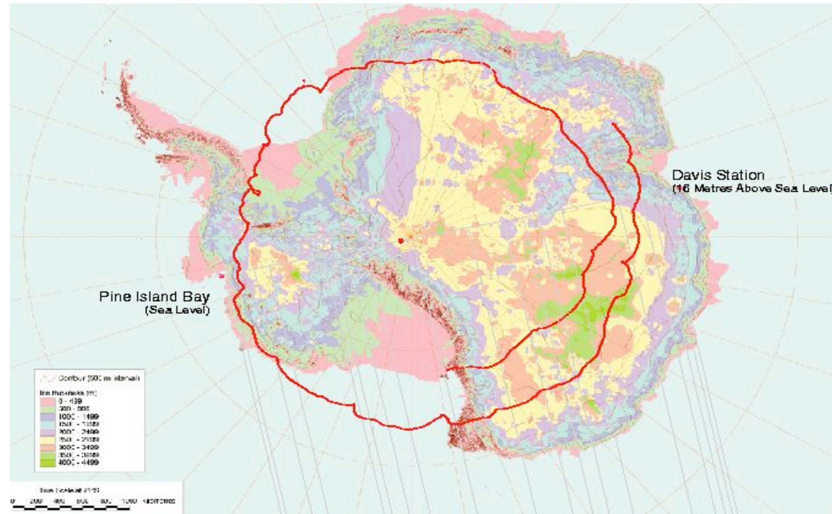
40 quad-ridged horn antennas, dual-polarization, with 10± cant

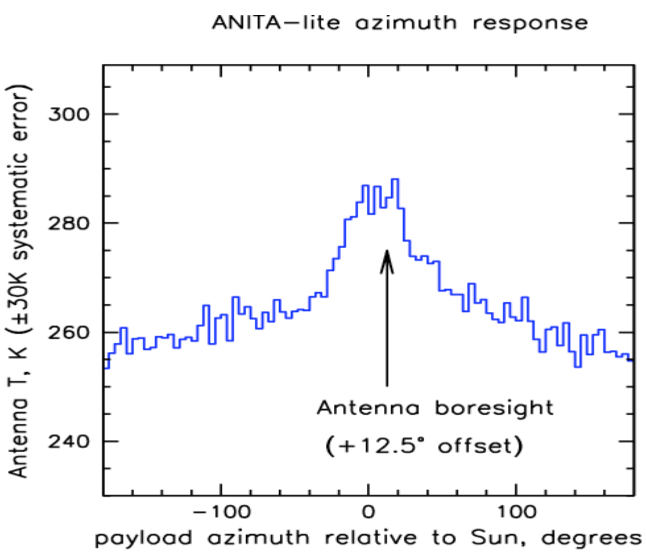


Downgoing - not seen by payload
Upcoming – absorbed in the earth
! ANITA sees "skimmers".

ANITA-lite 2003-2004

- Practice run with 2 antennas – piggybacked on TIGER
- 18 day flight
- Virtually every subsystem planned for ANITA tested
- Calibration pulses sent to payload from ~200 km away





Angular resolution measured:

ANITA-lite: $\sigma(\Delta t)=0.16$ ns ! $\sigma(\Delta\phi)=2.3^{\pm}$

ANITA: expect $\sigma(\Delta t)=0.1$ ns → $\sigma(\Delta\phi)=1.5°$, $\sigma(\Delta\theta)=0.5°$

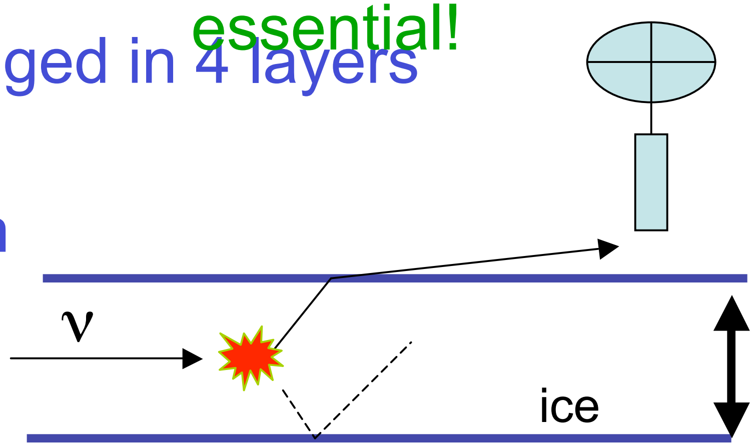
- Measured level of emission consistent with Galactic+Solar+$kT_{ice.}$ Spectrum also consistent with quiet sun model

Will show limits from ANITA-lite

Anita Simulation

- Ray tracing through ice, firn (packed snow near surface)
- Fresnel coefficients
- Attenuation lengths are depth and frequency dependent
- Include surface slope and roughness
- 40 quad ridged horn antennas arranged in 4 layers
- Bandwidth: 200 MHz-1200 MHz
- For now, signal in frequency domain
- Measured antenna response
- Secondary interactions included
- Weighting accounts for neutrino attenuation through Earth, etc.

Complementary simulations being developed – essential!

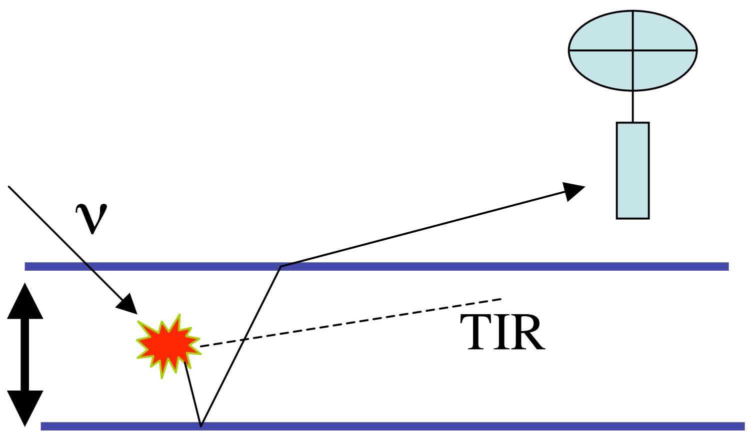


[S. Barwick]

Reflected Rays

Work by: S. Barwick, F. Wu from University of California at Irvine

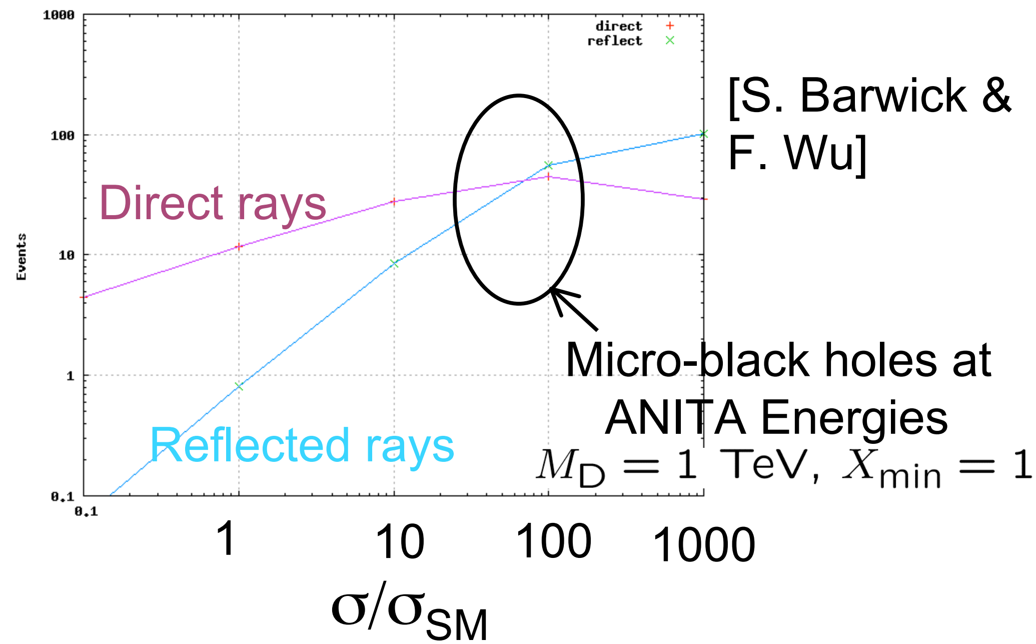
- ANITA could (possibly) detect events where a signal is reflected from ice-bedrock interface



[S. Barwick]

- Signals suffer from extra attenuation through ice and losses at reflection
- At SM σ 's, reflected rays not significant

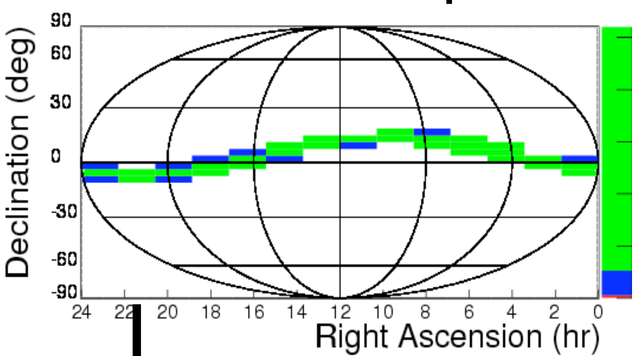
- At large cross-sections, short pathlengths → down-going neutrinos dominate ! reflected rays important

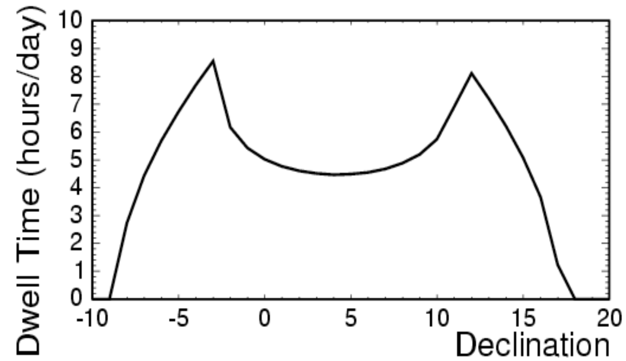


- Could measure cross section from relative rates of direct (far) to reflected (near).

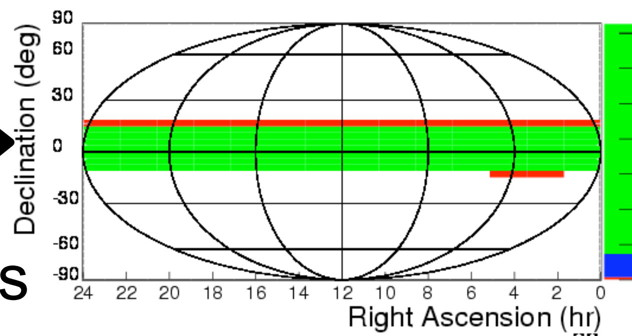
Skymaps

For each balloon position:



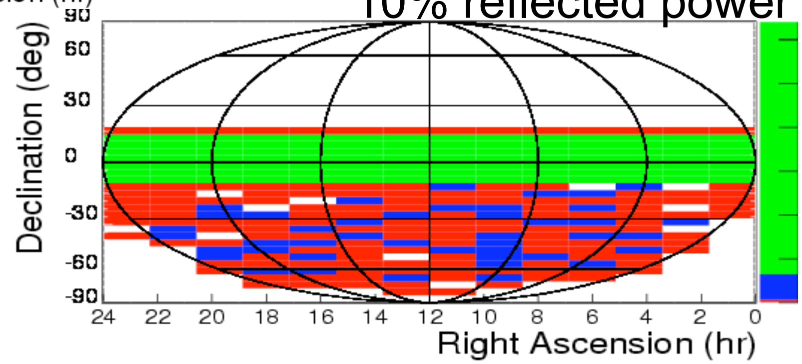


After a complete trip around the continent, cover all Right Ascensions



If we could observe reflected rays, could view more sky!

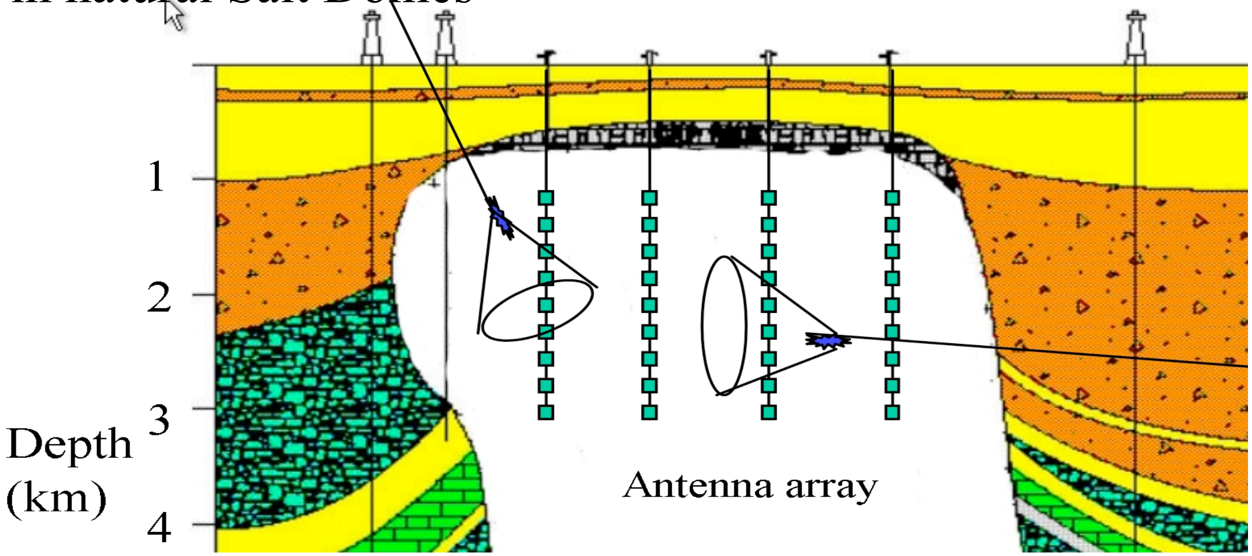
10% reflected power



Uncertainty at ice-bedrock interface being investigated: under-ice topologies, radar reflectivities, use Brealt code to study interfaces quantitatively

SalSA (Saltdome Shower Array)

A large sample of GZK neutrinos using radio antennas in a 12£ 12 array of boreholes in natural Salt Domes



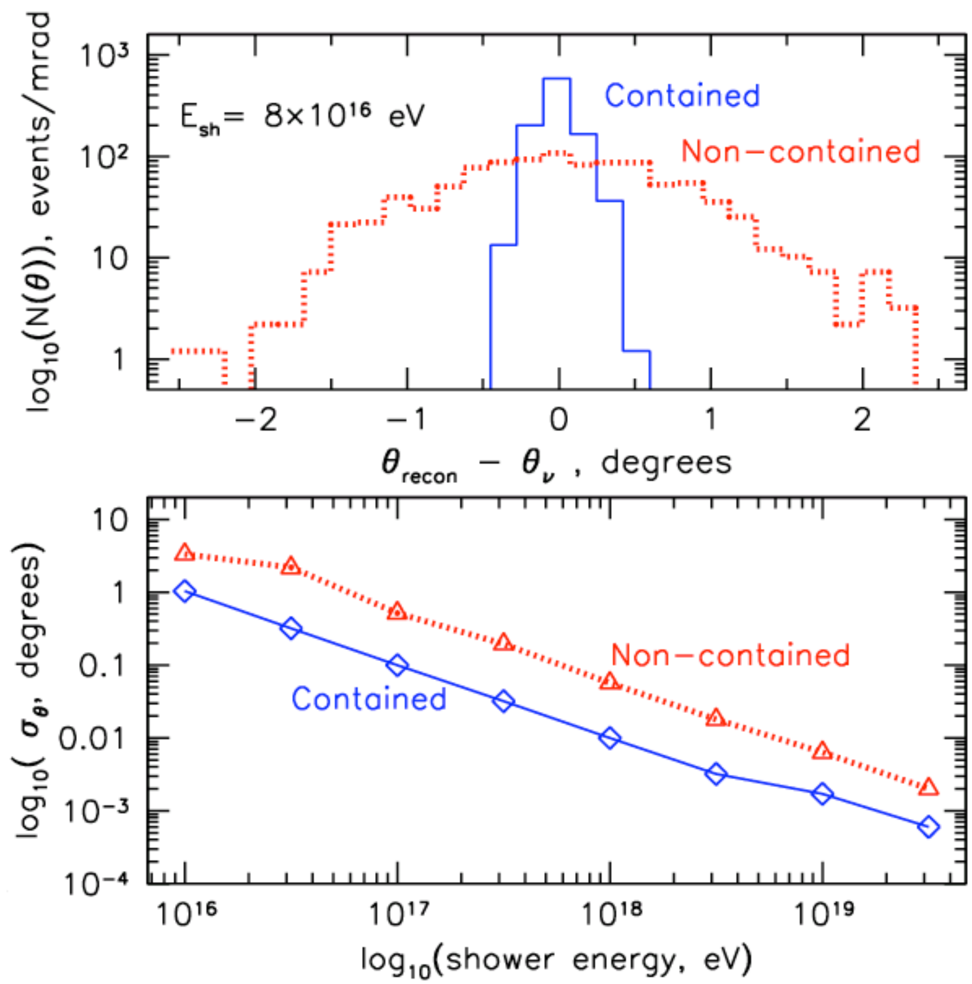
SalSA simulations being developed, building on experience modeling GLUE, ANITA

- ANITA sensitivity, 45 days:
  - ~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**

SalSA Angular Resolution

Work by: P. Gorham, University of Hawaii and Kevin Reil, SLAC

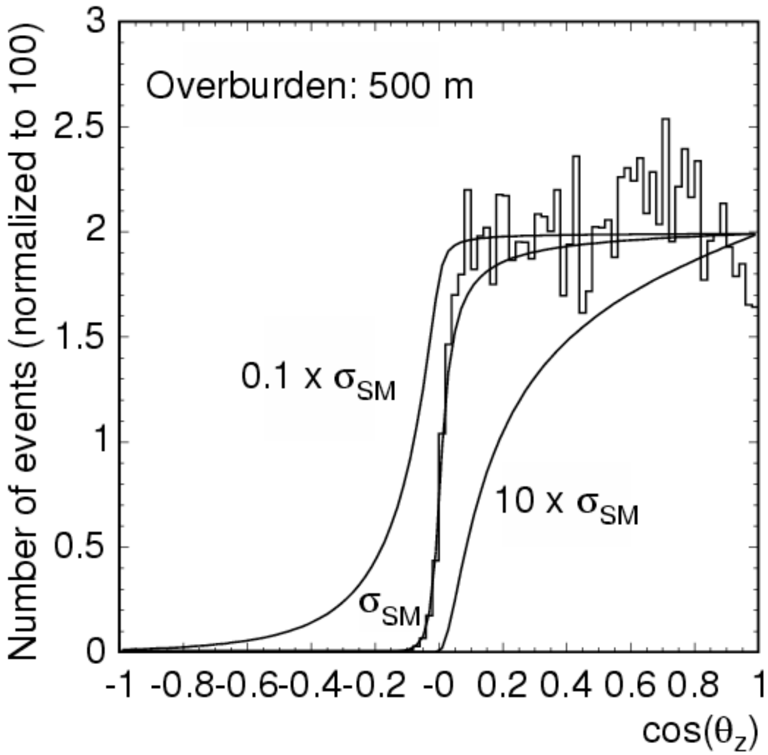
- Performed chi-squared analysis from two hadronic shower event types
  - Fully contained
  - Parallel to a face 250 m outside array
- Fit to
  - Amplitude of Cerenkov signal
  - Polarization
- At 8£10^{16} eV:
  - Contained: fraction of deg.
  - Non-contained: ~1 deg.
- Improves with energy



[P. Gorham]

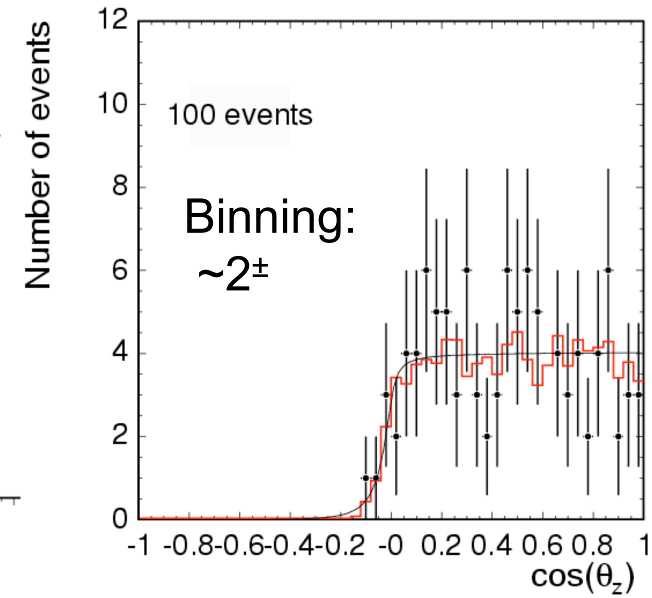
SalSA Cross Section Measurement

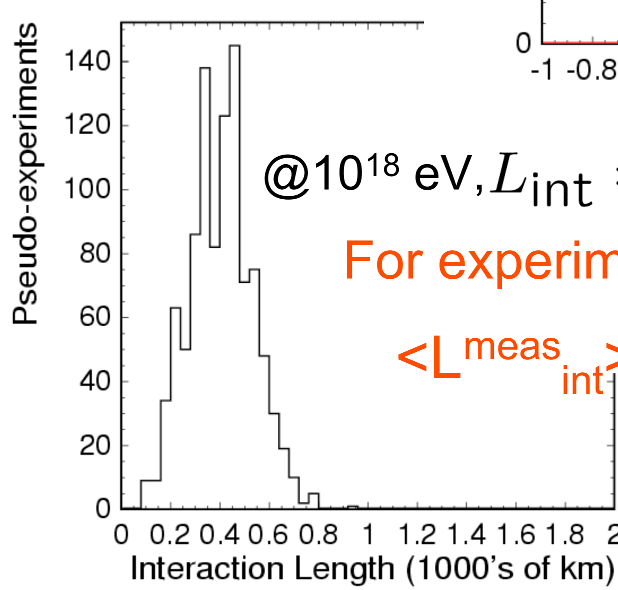
ν N cross section can be measured from $\cos\theta_\nu$ distribution



At SM σ, only 10% of events in sensitive region

Generate $\cos\theta_\nu$ distribution from simulation and throw dice for many pseudo-experiments





@10[18] eV, $L_{\text{int}} = 395\ \text{km(rock)}$

For experiments w/ 100 events

$\langle L^{meas}_{int} \rangle$=400 § 130 km

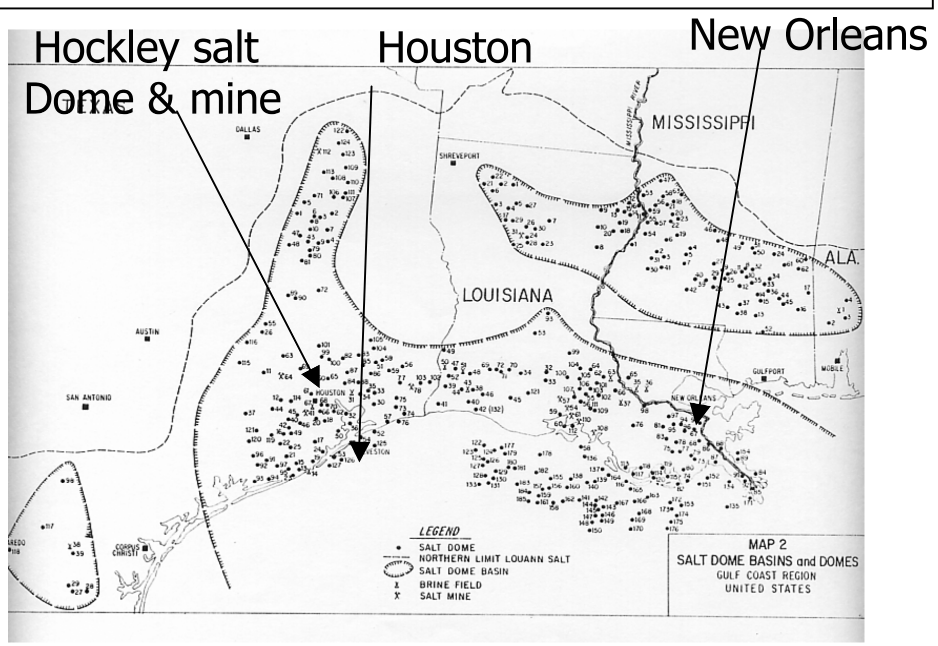
With 300 events $\rightarrow 410 \pm 80\ \text{km}$

Use Poisson likelihood

Salt Dome Selection: U.S. Gulf Coast Most Promising

- Salt origin: Shallow Jurassic period sea, 200-150M yrs old, inshore Gulf coast area dried ~150 Myrs ago
- Plasticity at 10-15km depth leads to ‘diapirism’ : formation of buoyant extrusions toward surface

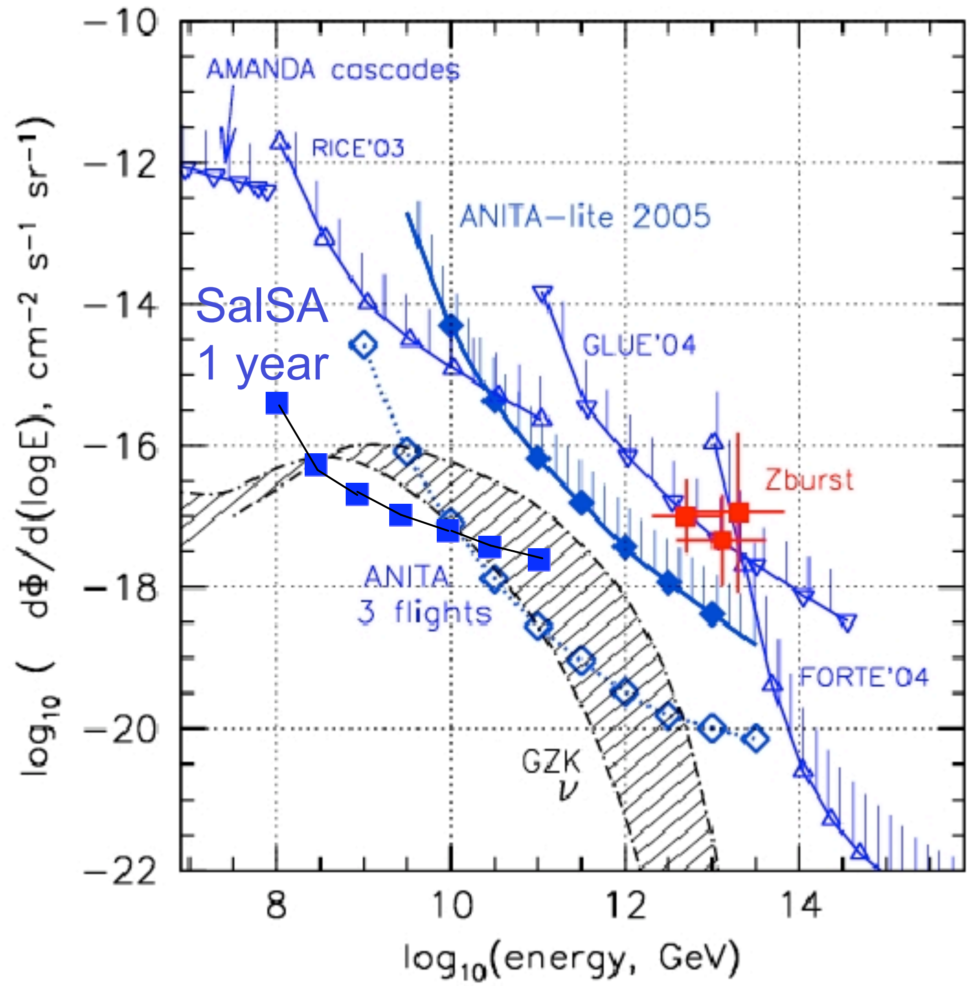
! Stable salt diapirs all over Gulf coast



- Studying surveys from 70’s, 80’s for Nuclear Waste Repository sites
  - Requirements have large overlap with SalSA, large, stable dome, near surface, with dry salt, no economic usage
  - Strong candidates:
    - Richdon (MS), Vacherie (LA), Keechie (TX)
  - We are visiting dome sites to explore feasibility of SalSA given local geography, infrastructure, politics

Sensitivities

- SalSA & ANITA
  - SalSA lower threshold
  - ANITA higher VΩ, shorter livetime
- Two independent simulations for each experiment give similar results for ES&S "baseline"
  - ANITA: handful of events
  - SalSA: ~13 events/year



ANITA Roadmap

- ANITA-lite PRL coming soon
- ANITA EM flight this summer
- First ANITA flight 2006-2007 Austral summer

SalSA Roadmap (In Tandem)

- Select 3-5 salt domes, drill a few holes
- Use chemical & loss-tangent measurements on core, plus borehole radar to assess initial salt quality
- Choose best of initial domes that meet requirements for three or four deep (3km) boreholes, to install a ‘Salsita’ (4 holes)
- 1-2 years’ operations to establish proof-of-concept, and discover or confirm small sample of GZK neutrino events, then propose full array

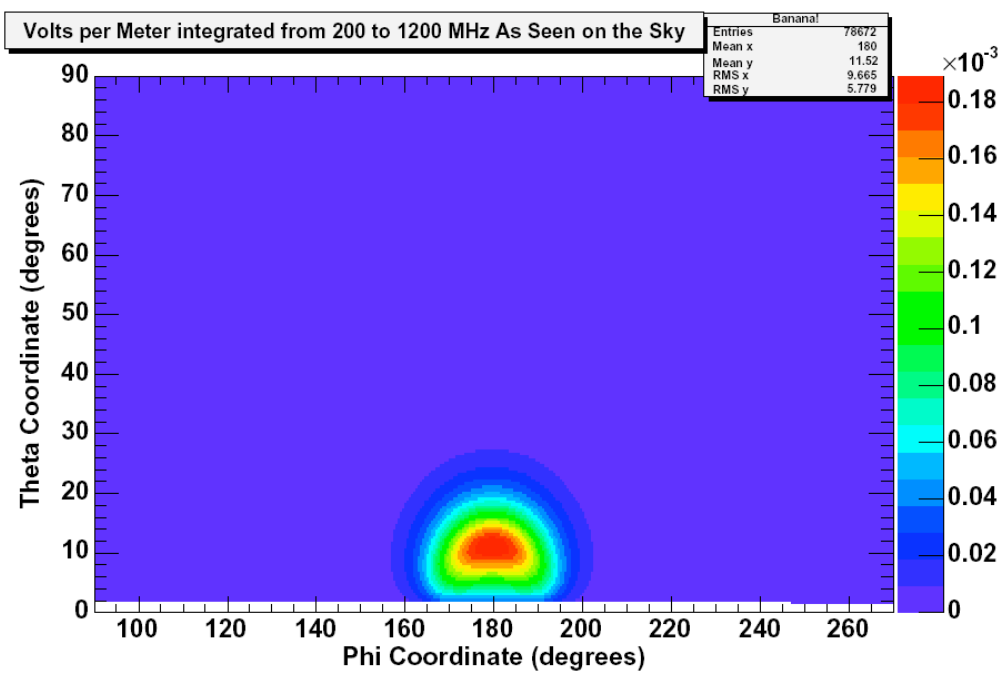
Salsita could be contemporary with ANITA, Auger, IceCube

Backup Slides

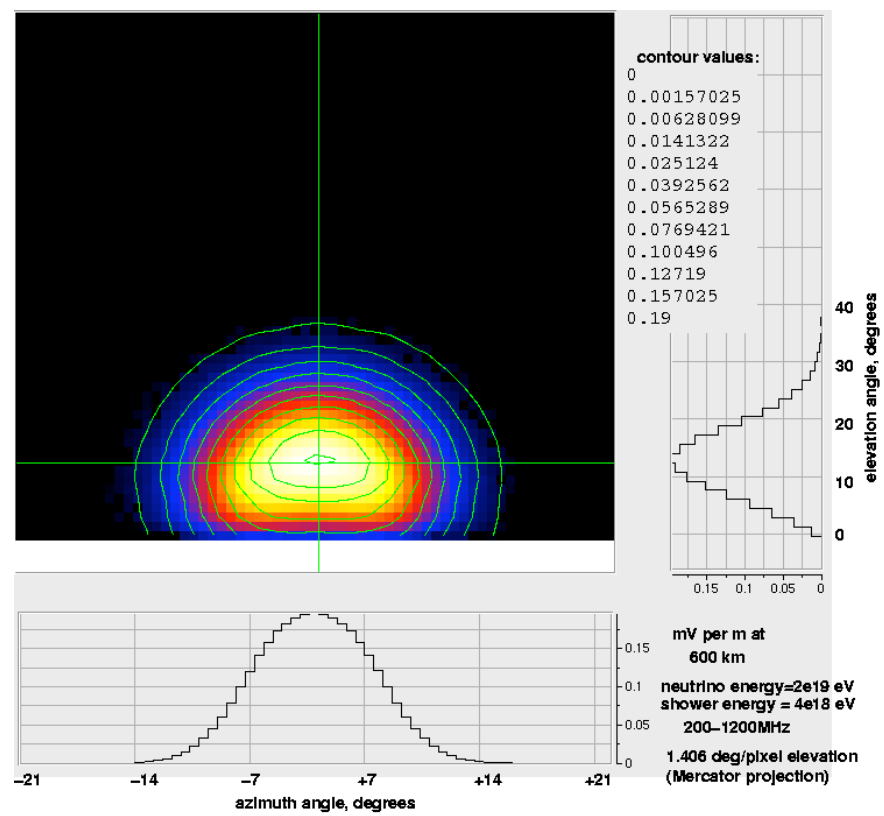
Validating our Simulations (cont)

ANITA

Projection of Askaryan signal onto the sky:



[S. Hoover]



pixel table near maximum

	63	64	65	66	67
11	0.157285	0.162721	0.165123	0.162927	0.157241
10	0.179696	0.184166	0.186041	0.183962	0.179579
9	0.19018	0.194548	0.195629	0.194356	0.190588
8	0.188091	0.190761	0.191335	0.190653	0.188149
7	0.174355	0.175214	0.17587	0.175493	0.17431

[P. Gorham]

SalSA: Benchmark Detector Parameters

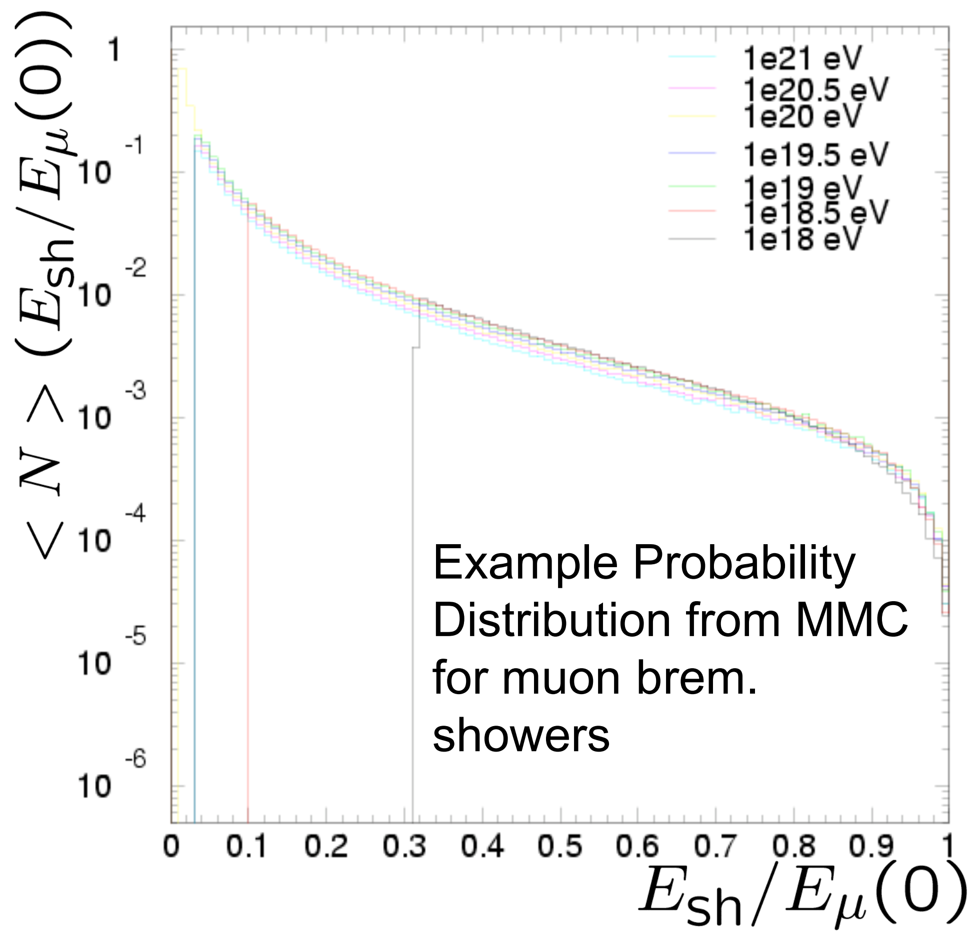
- Overburden: 500 m
- Detector
  - Array starts at 750 m below surface
  - 10 x 10 string square array, 250 m horiz. separation
  - 2000 m deep, 12 “nodes”/string, 182 m vert. separation
  - 12 antennas/node
- Salt extends many atten. lengths from detector walls
- Attenuation length: 250 m
- Alternating vert., horiz. polarization antennas
- Bandwidth: 100-300 MHz
- Trigger requires 5/12 antennas on node, 5 nodes to fire: $V_{signal}>2.8\ \sigma$ £ V_{RMS}
- Index of refraction=2.45
- Syst. Temp=450K=300K (salt) + 150K (receiver)

Impact of Salt Properties

- Track length L
  - X_0^{ice}=43 cm, X_0^{salt}=10.3 cm ! Expect L_{salt}/L_{ice}=0.26. Simulations show 0.34.
- Cerenkov index of refraction factor
- Cerenkov threshold
- Critical energy
- Coherence
- Angular scaling

Secondary Interactions

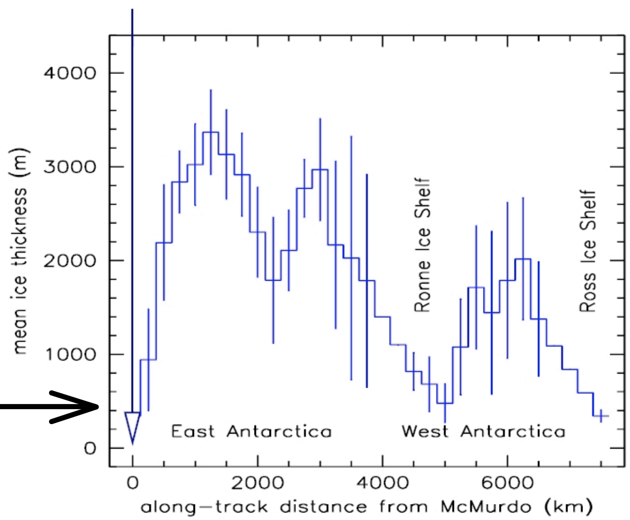
- Generate $d\sigma/dE_{\text{sh}}$ from MMC for each flavor, interaction type
- From MMC, also retrieve multiplicity of each type of sec. interaction
- Force neutrinos in our simulation to obey these distributions
- For now, consider interaction (primary or secondary) which contributes the strongest signal
- Critical for flavor ID



P. Miocinovic

Anita – Ice Properties

Use measured ice and crust layer thicknesses (model is Crust 2.0 based on seismic data)

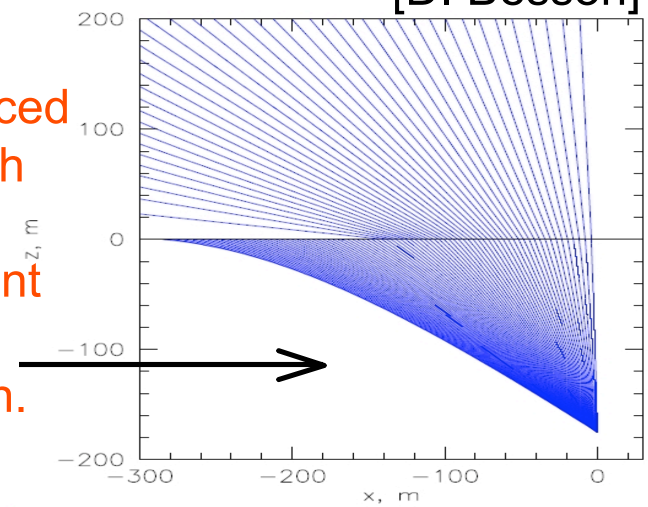


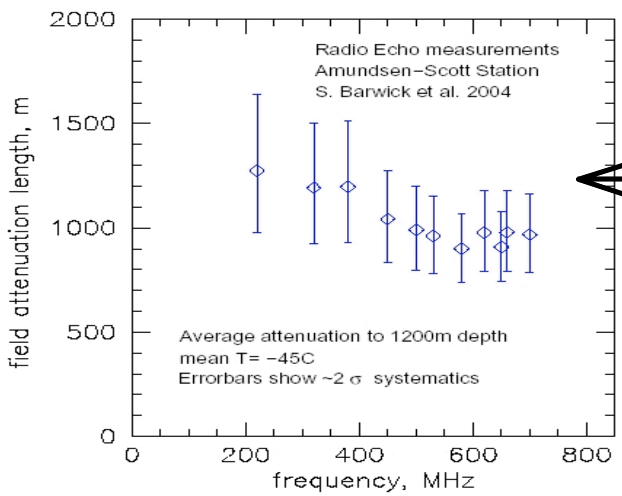
[P. Gorham]

n(z): 1.8 in deep ice
1.3 at surface

[D. Besson]

Rays traced in ice with depth-dependent index of refraction.





Use measured attenuation lengths (frequency dependent)

Temperature-dependence also included:
~few hundred m in warmest ice (in firn and near bedrock)
~1300 m at mid-depth