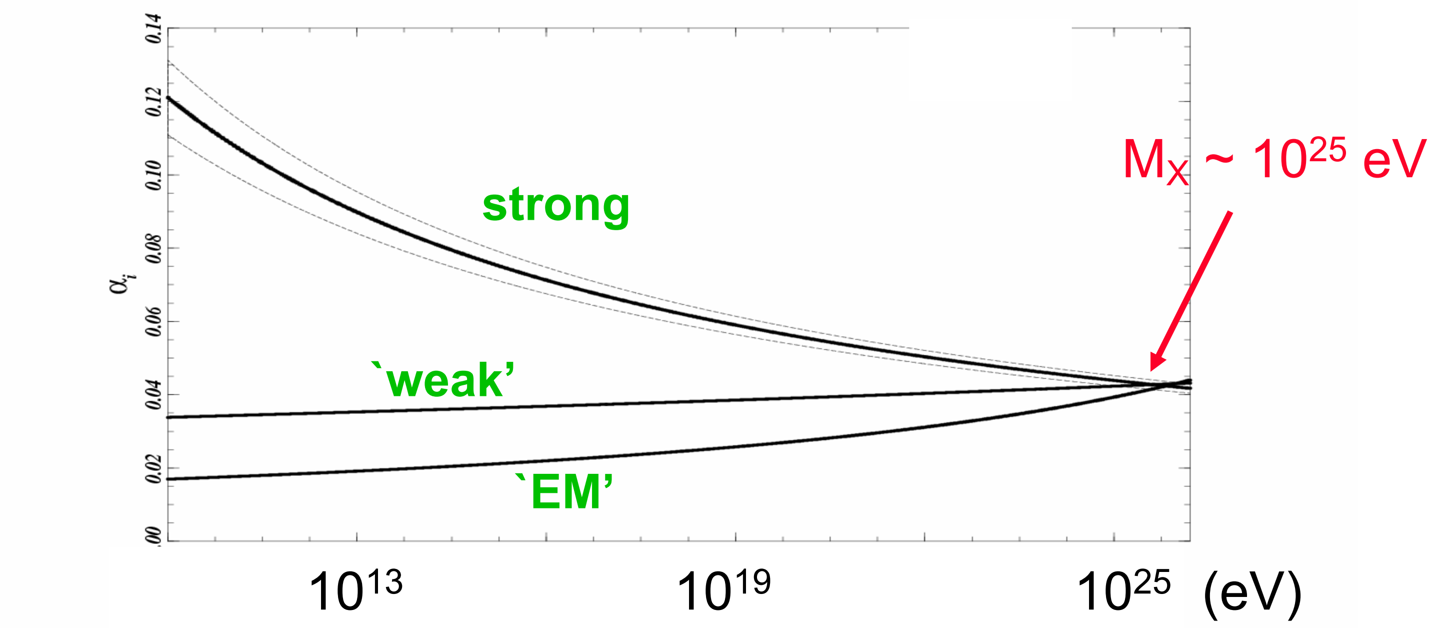
Neutrino Astronomy…
Particle Physics with a Petaton

David Saltzberg (UCLA), SLAC SUMMER INSTITUTE LECTURE,
AUGUST 2008

One Motivation for a Particle Physicist

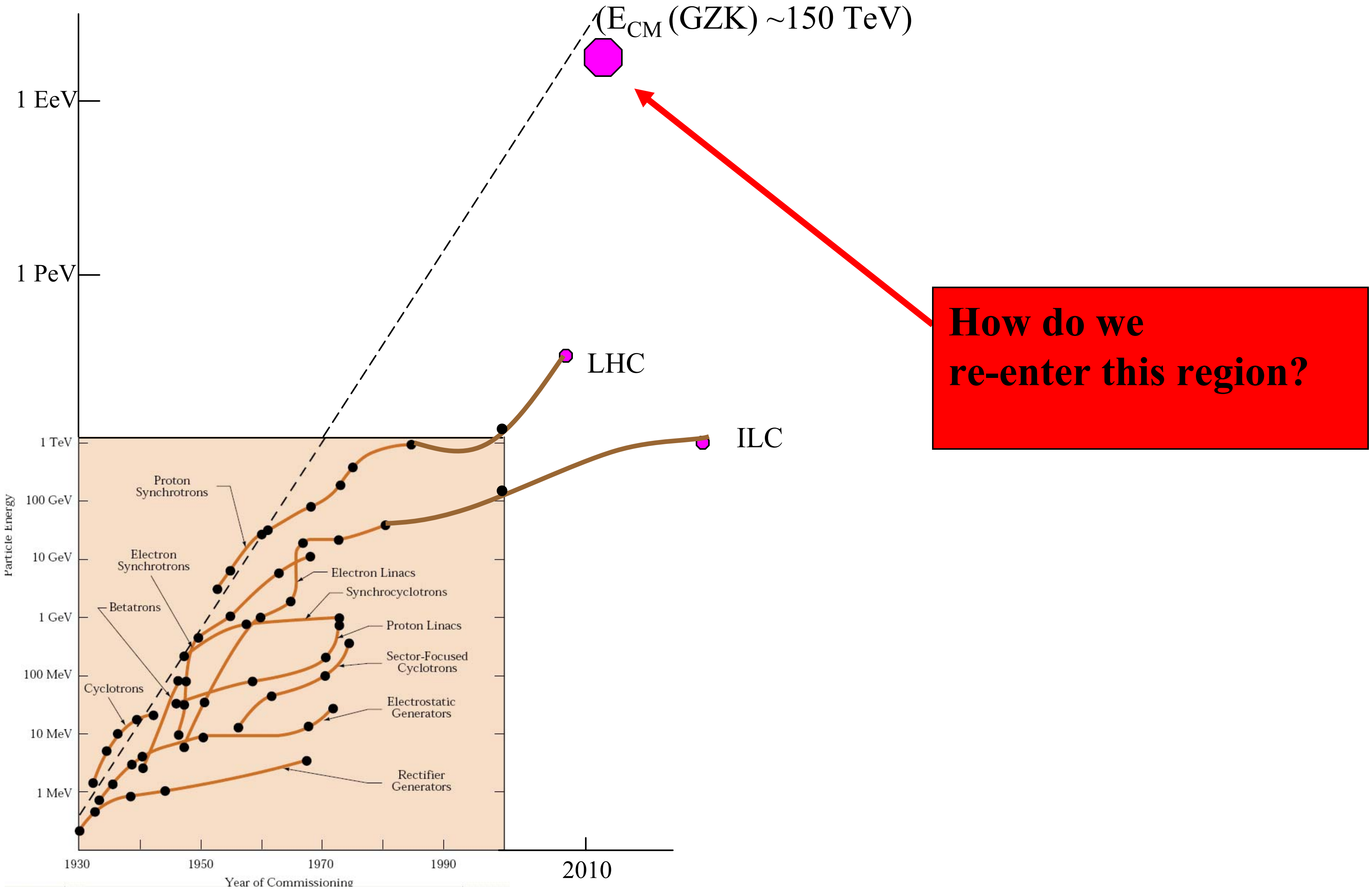
- Exotic Physics: UHECR would result from decays of super-heavy particles.
- Example: Grand Unified Supersymmetric Theories:



Is its lifetime comparable to age of universe or is it $\sim 10^{-40}$ sec?

Loophole—produce them continuously by "topological defects" (TD)

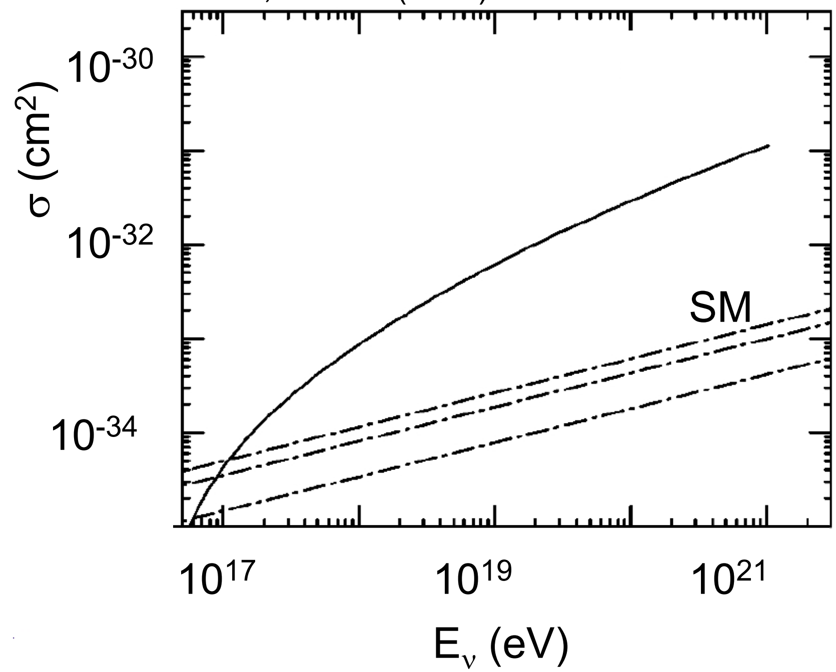
…for a particle physicist
Livingston Plot



Enhancement of UHE Neutrino Cross Section

Sample predictions for TeV scale quantum gravity

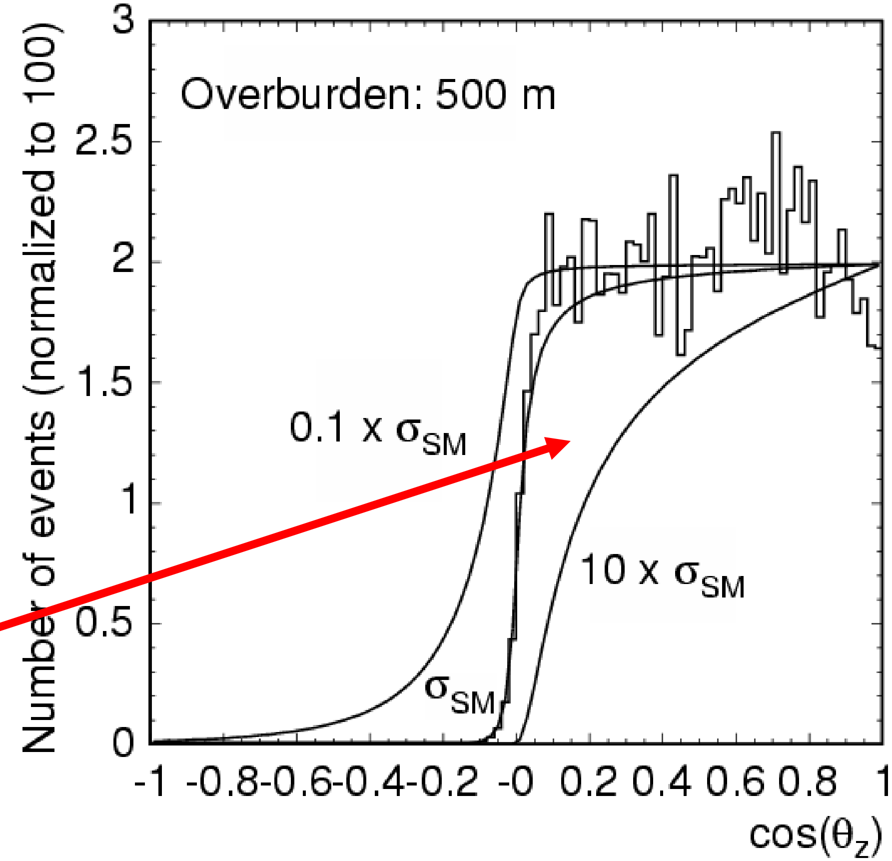
Anchordoqui,Feng,Goldberg,Shapere,
PRD65, 103002 (2002)



- UHE ν cross sections could be up to ~100$\mathcal{X}$ Standard Model
    - * would be invisible to UHECR interactions

Measuring ν cross section up to E_{CM}=150 TeV

- 30% Cross Section measurement with ground detector easily achievable using Earth as a filter near horizon
- Not dependent on GZK shape or absolute intensity
- Angular resolution even for non-contained events is sufficient.
- Anomalous cross sections from large extra dimensions etc. at E_{cm}=150 TeV would be clearly visible.



More Particle Physics:
z=1 is a VERY long baseline

- One experimental parameter: $(L/E)|_{experiment} \propto t^{\nu}_{proper}$
  - Determines (largely) the sensitivity to
    - Δm^2, <u>decays</u> (eg majoron emission) decoherence …

Order of magnitude:

type	L/E	$t_{proper} \sim (L/c)(m_\nu/E)$
CERN SpS/WANF	500 m/25 GeV	3 attoseconds
Stopped μ (LAMPF)	30 m/ 40 MeV	130 attoseconds
NUMI	735 km/ 4 GeV	30 femtoseconds
Reactor (KamLAND)	150 km/5 MeV	800 femtoseconds
Atmospheric	10,000 km/1 GeV	2 picoseconds
Sun	150,000,000 km/5 MeV	800 nanoseconds
GZK	1 Gpc/100 PeV	50 milliseconds
SN-1987a	50 kpc/15 MeV	1 hour

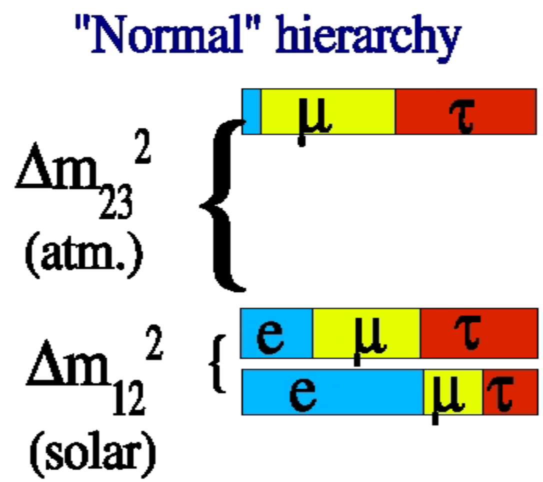
available

?

- **Decays alter flavor ratios:** **Beacom,Bell,Hooper,Pakvasa,Weiler, PRL 90,181301 (2003)**
  Recent review: Pakvasa, Phys. Atom. Nucl., 67, 1154 (2004)

Particle Physics in Neutrino Sector

- GZK neutrinos are the "longest baseline" neutrino experiment:
  - Longest L/E (proper time) for: extra ν admixtures & anomalous ν decays
    - SUN: L/E ~ 30 m/eV
    - GZK: L/E ~ 10^9 m/eV
- Measured flavor ratios of ν_e:ν_μ:ν_τ can identify non-standard physics at source



ν_e:ν_μ:ν_τ

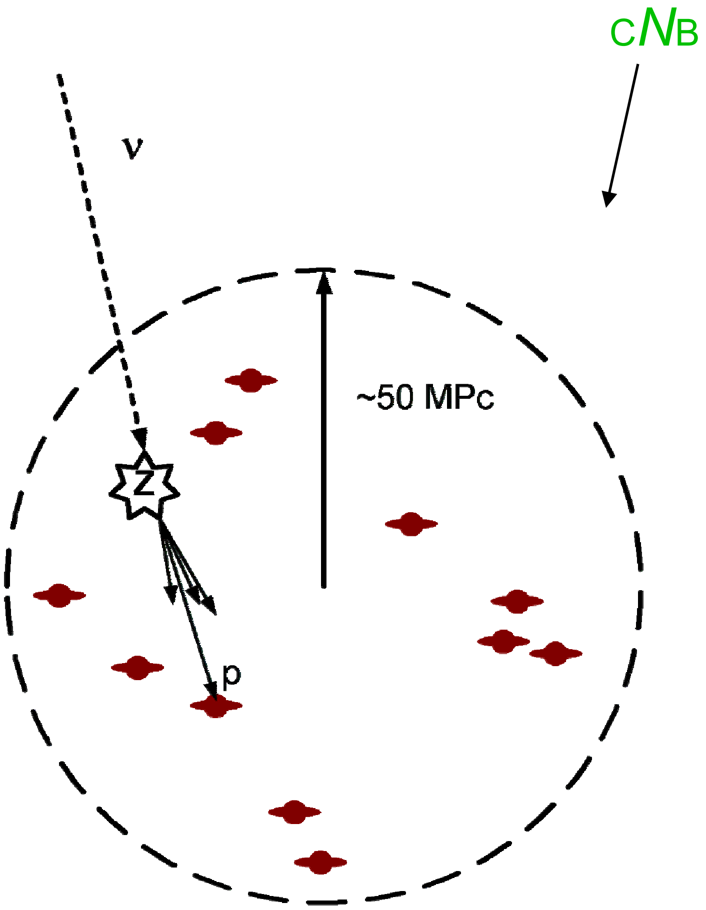
(1:1:1)$\rightarrow$ (5-6):1:1

Neutrino decay leaves a strong imprint on flavor ratios at Earth

Z-bursts?

If local enhancement of local CNB:

$$\sqrt{2m_\nu^{CNB}E_\nu^{UHECR}} = M_Z \sim 10^{11}\,eV$$

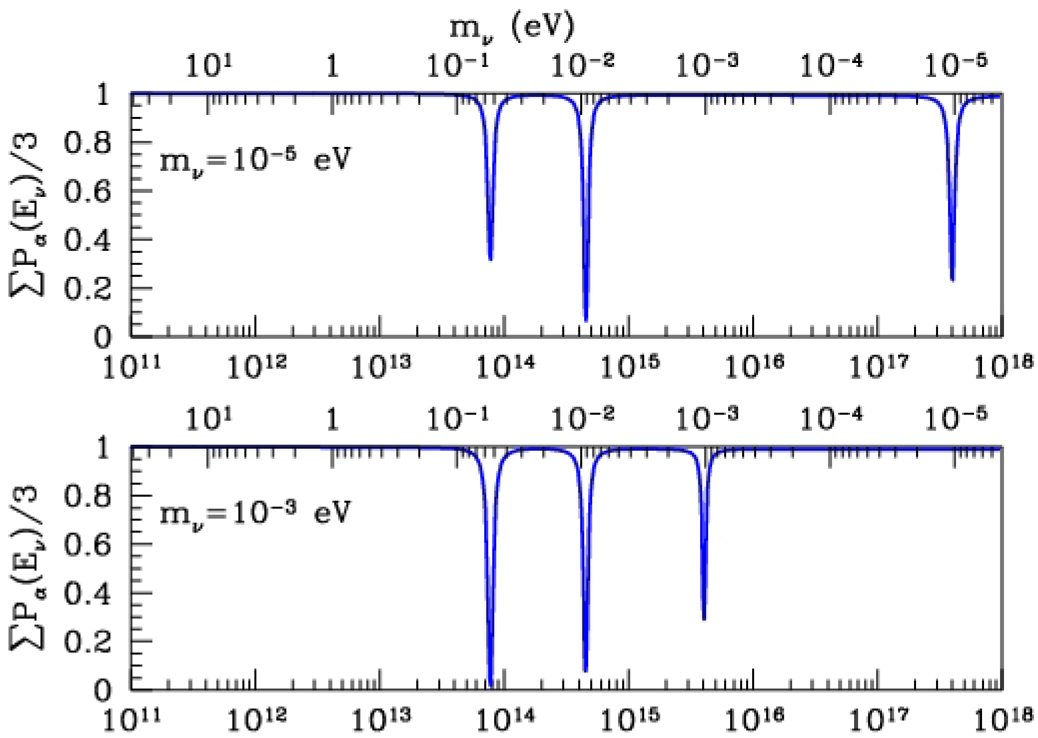


if $m_\nu^{CNB} \sim 0.05 - 0.5$ eV

$\Rightarrow E_\nu \sim 10^{22-23}$ eV

$\Rightarrow$ Would be a minimum flux of 10^{23} eV neutrinos

Z-burst neutrino
mass spectroscopy of CNB

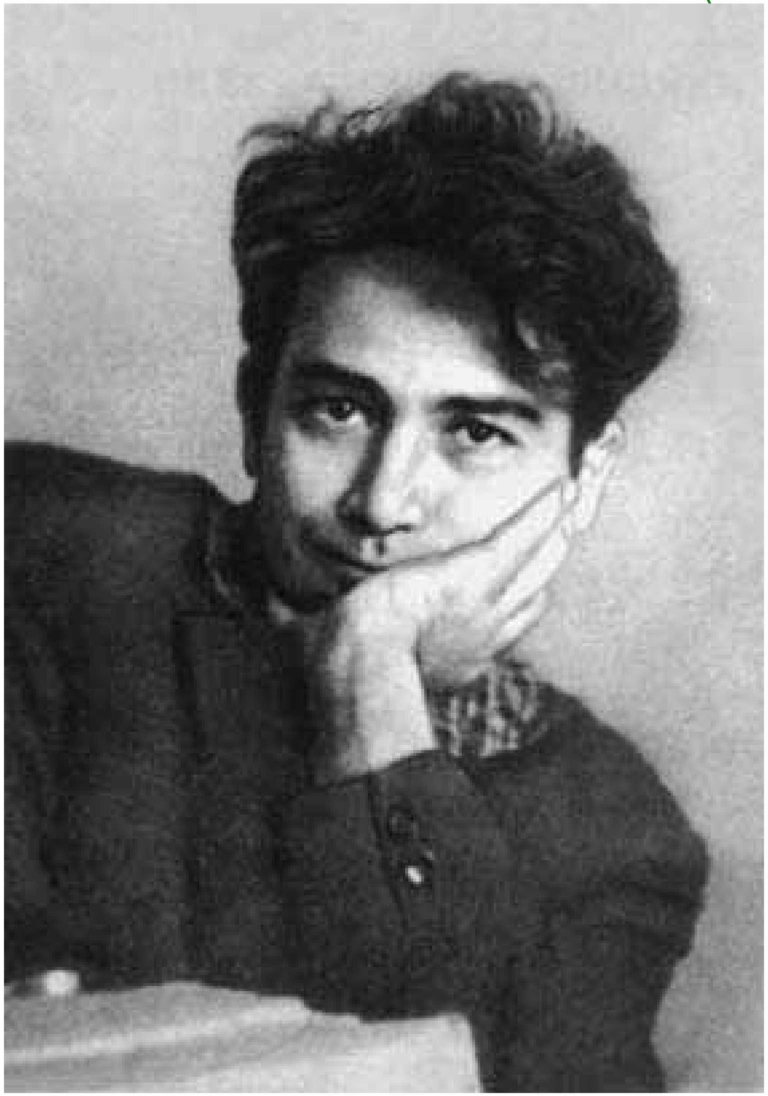


E_ν (GeV)

Barenboim, Requejo, Quigg, PRD71,083002 (2005)

Three Good ideas by Gurgen Askaryan

(1928-1997)



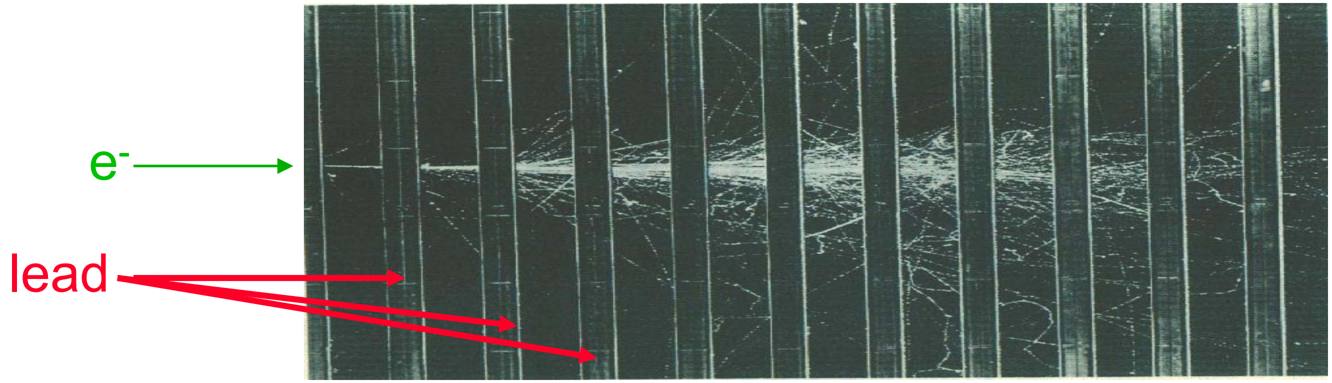
How to go beyond 10 km^3 neutrino detector?

Optical attenuation/scattering lengths ~ 100 m

km^3 and Beyond? Three Good Ideas by Gurgen Askaryan (I)

(1962)

UHE event will induce an e/γ shower:



In electron-gamma shower in matter, there will be ~20% more electrons than positrons.

Compton scattering: $\gamma + e^-_{\text{(at rest)}} \rightarrow \gamma + e^-$

Positron annihilation: $e^+ + e^-_{\text{(at rest)}} \rightarrow \gamma + \gamma$

Three Good Ideas by Gurgen Askaryan

Excess charge moving faster than *c/n* in matter emit Cherenkov Radiation

$$\boxed{\frac{dP_{CR}}{d\nu} \propto \nu d\nu}$$

Each charge emits field $|E| \propto e^{ik \cdot r}$ and Power $\propto |E_{tot}|^2$

In dense material $R_{Moliere} \sim 10$cm.

$\lambda \ll R_{Moliere}$ (optical case), random phases $\Rightarrow$ **$P \propto N$**

$\lambda \gg R_{Moliere}$ (microwaves), coherent $\Rightarrow$ **$P \propto N^2$**

Confirmed with Modern simulations + Maxwell's equations:
(Halzen, Zas, Stanev, Alvarez-Muniz, Seckel, Razzaque, Buniy, Ralston, McKay …)

Optical viewing ~ 100m, Radio viewing ~ 1km

Three Good Ideas by G. Askaryan (1962)

- **#3.** Can exploit this effect in large natural volumes transparent to radio (dry):

  pure ice, salt formations, lunar regolith

eg, "RICE" experiment

- ***Other ideas by Askaryan:

  Bubble chamber

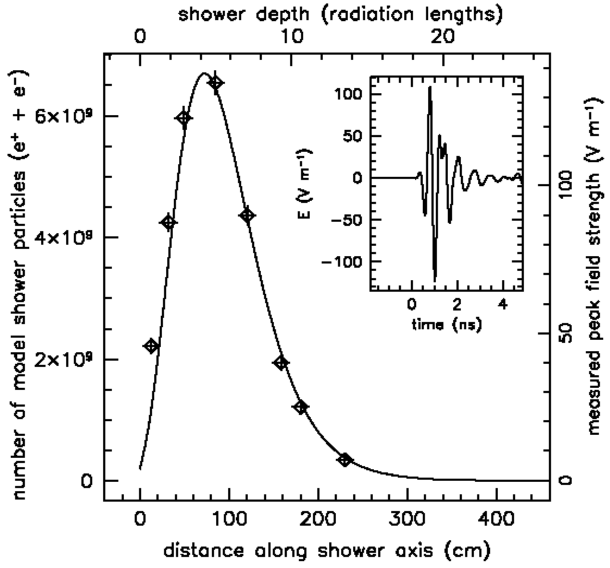
  Laser Ablation

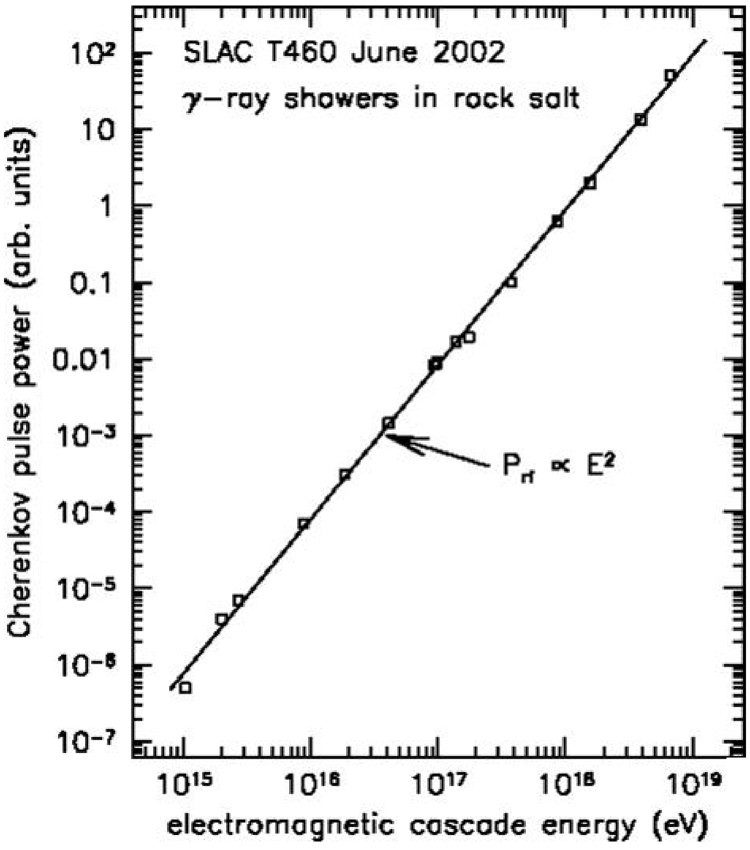
  Laser self-focussing

  Acoustic UHECR detection ...

The SLAC ``Kitty Litter'' box

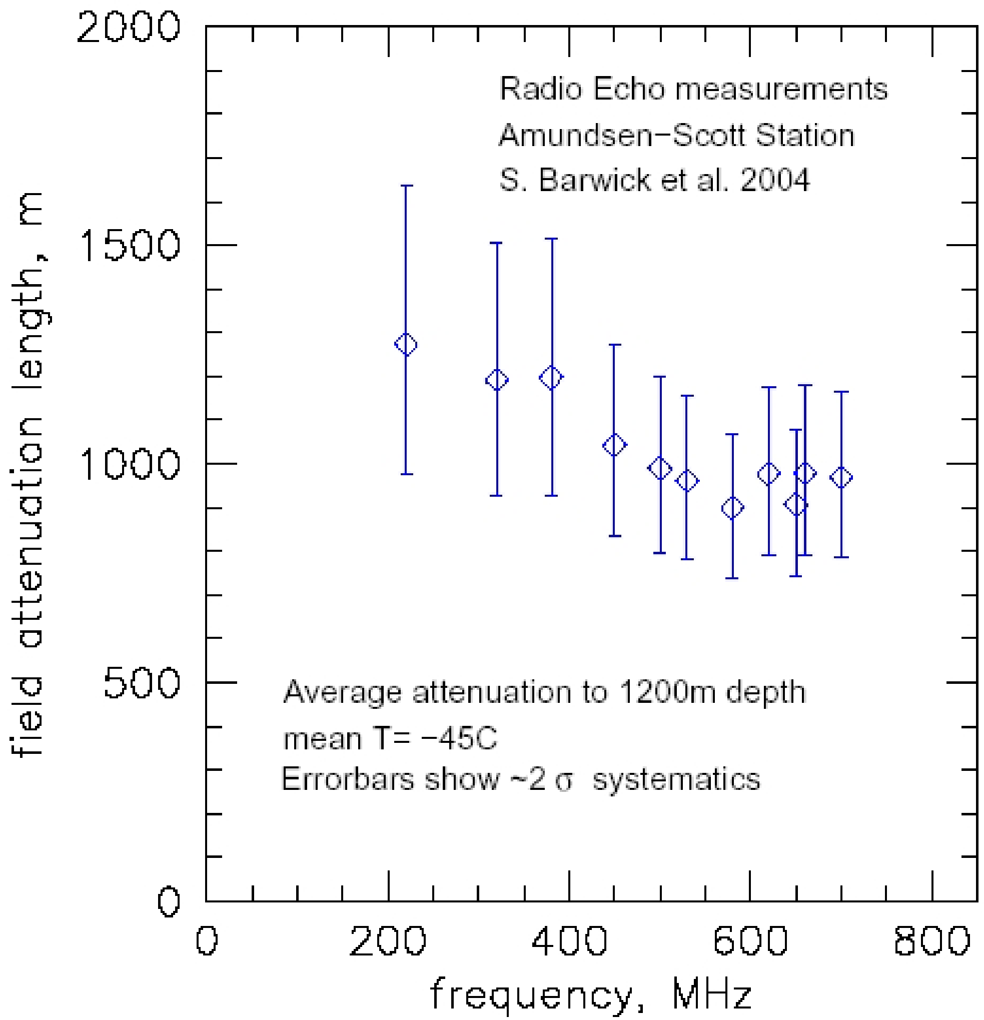
SLAC FFTB





- Amplitude expected
- 100% linearly polarized
- Cherenkov angle

South Pole Ice properties: RF attenuation



Thermal Fluctuations

Black Body Fluctuations:

<u>freq>>peak</u>:

$\delta(N_\gamma)=\sqrt{N_\gamma}$

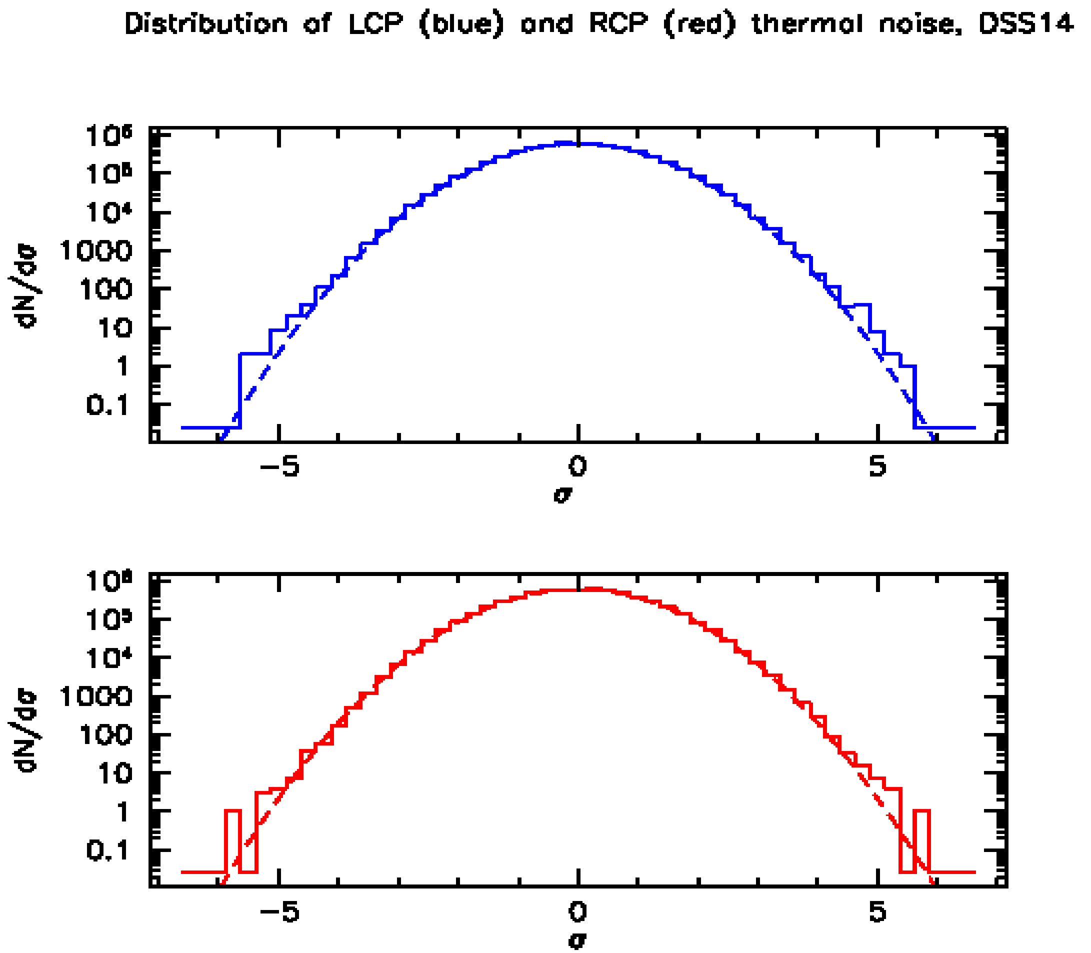
"shot noise"

<u>freq<<peak:</u>

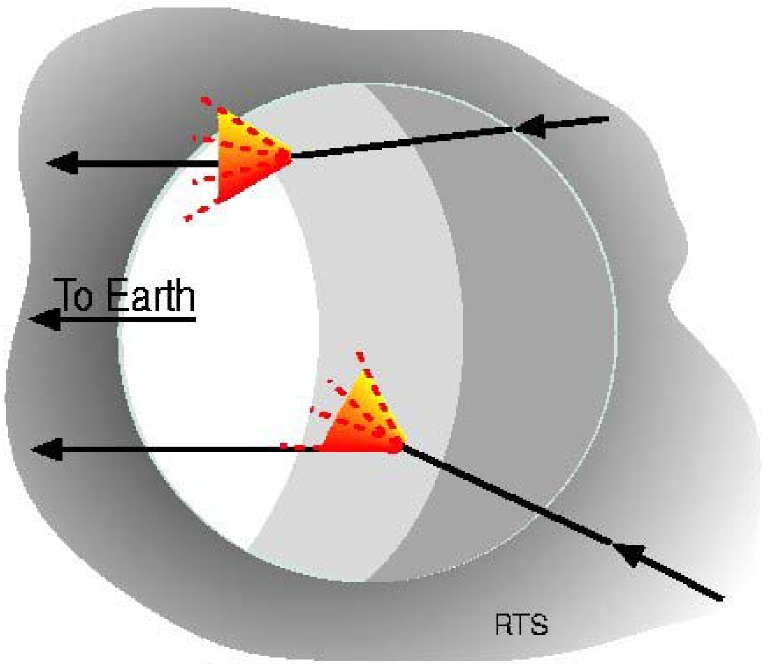
$\delta(N_\gamma)=N_\gamma$

S-band obs. of moon (far below peak)

V is Gaussian with σ=r.m.s.(V)



Using the Moon as a 200,000 km^3 Target



- Zheleznyk and Dagkesamanskii (1988)
  - 10^{20} eV ν produces ~1000 Jy at 2GHz

    (1Jy = 10^{-26} W/m^2/Hz)
  - brightest quasars ~25 Jy at this frequency band
  - Moon as blackbody: ~200 Jy

    → no need to go to the moon

    → use radiotelescopes

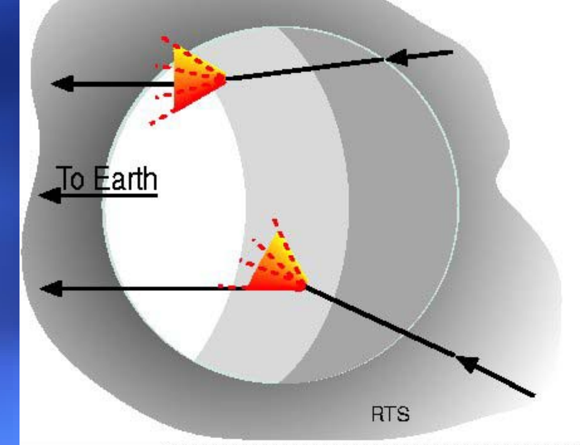
12 hrs using single Parkes 64m dish in Australia (1996)

Limitted by R.F.I.

T. Hankins *et al*., MNRAS 283, 1027 (1996)

Goldstone Lunar UHE Neutrino Search (GLUE)

P. Gorham *et al.*, PRL 93, 041101 (2004)

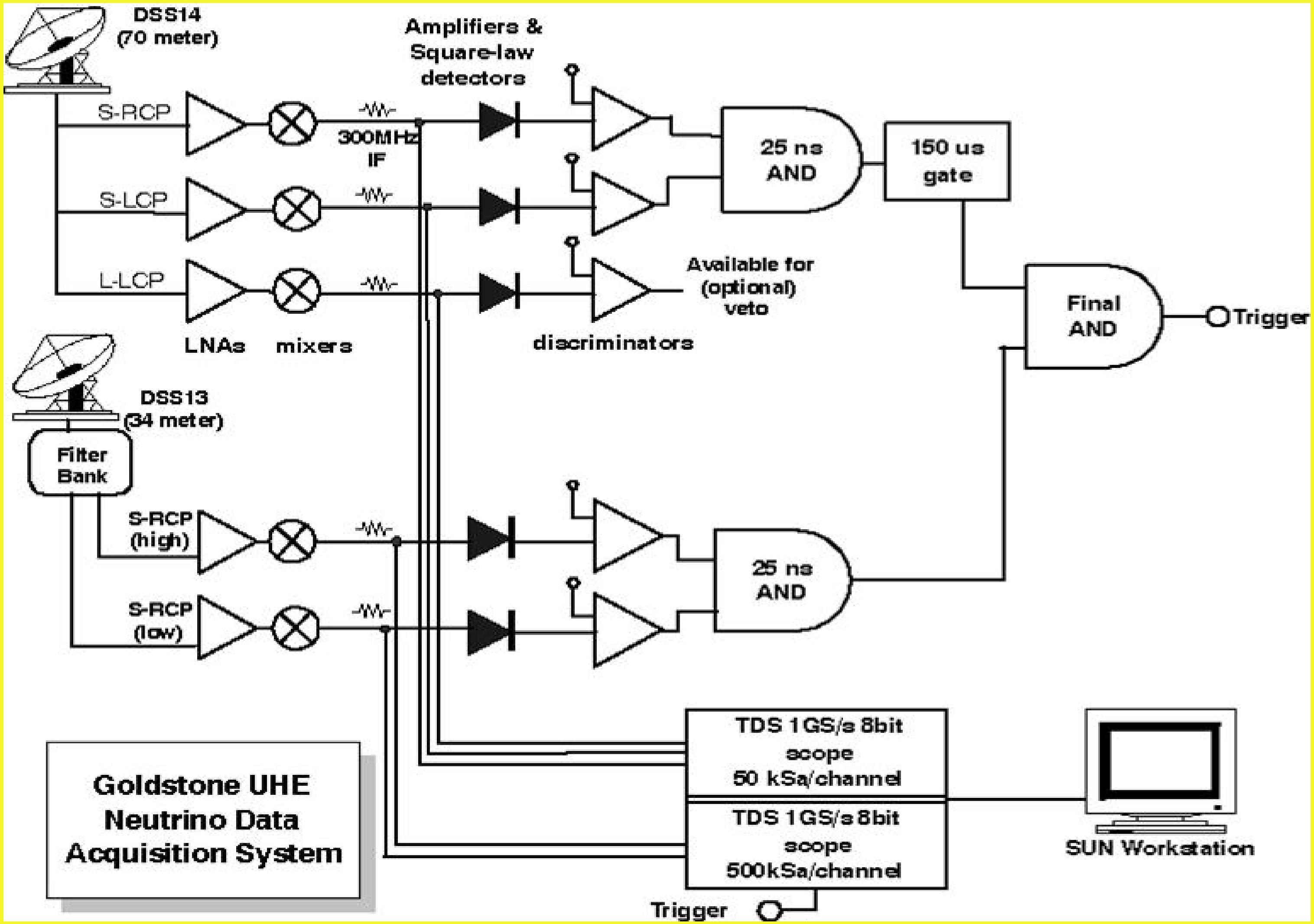


Two antennas at JPL's Goldstone, Calif. Tracking Station

- limits on $>10^{20}$ eV ν's
- regolith atten. len. ~20 m
- ~123 hours livetime
- $[V\Delta\Omega]_{eff}$~600 km^3-sr

➔**New experiment planned using Westerbork (NL) Antennas**

A more detailed view of GLUE
(since common to most radio detection)

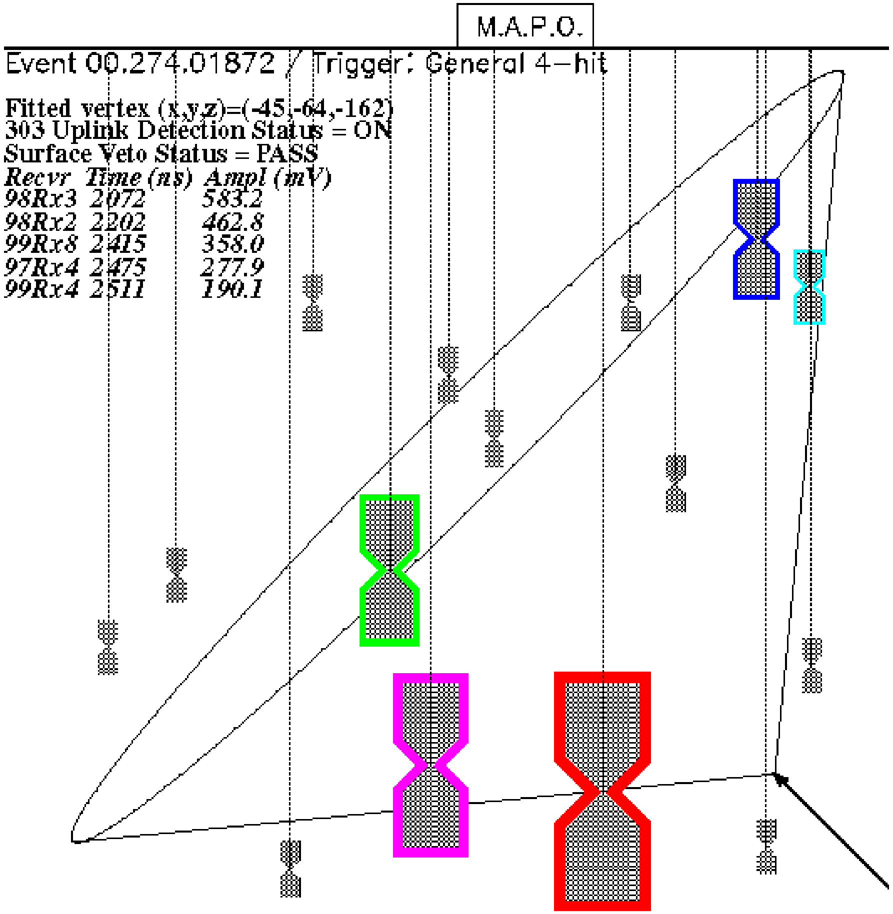


RICE Experiment

- "Radio in Ice Experiment"

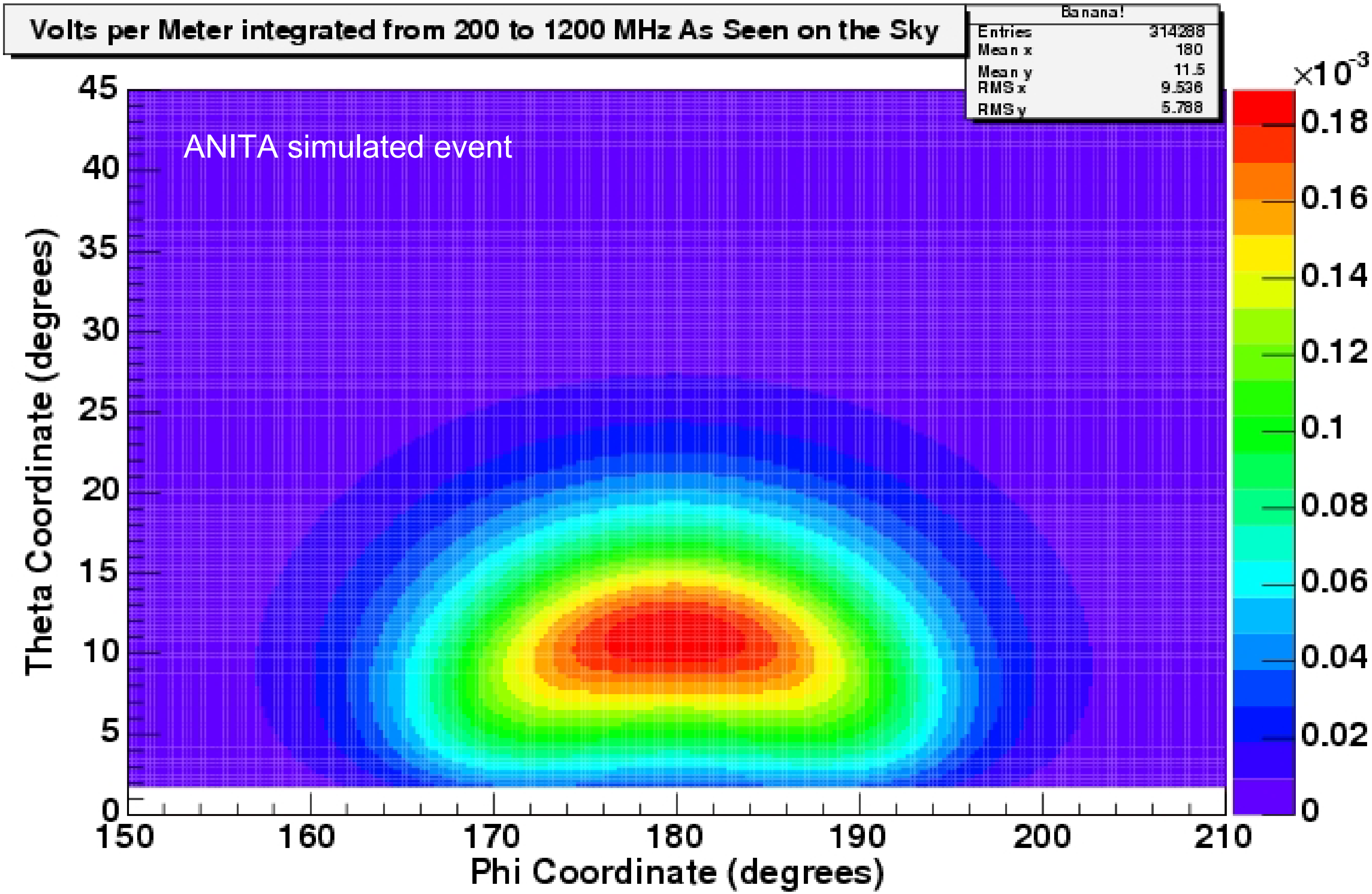
- Dipoles (250-1000 MHz) on AMANDA strings @ S Pole
- 200 x 200 x 200 meter array
- E_ν>~10^{17} eV
- $[V\Delta\Omega]\sim$ 10 km^3-sr

NEW 7 year result Kravchenko, *et al.*, PRD73,082002



Candidate event

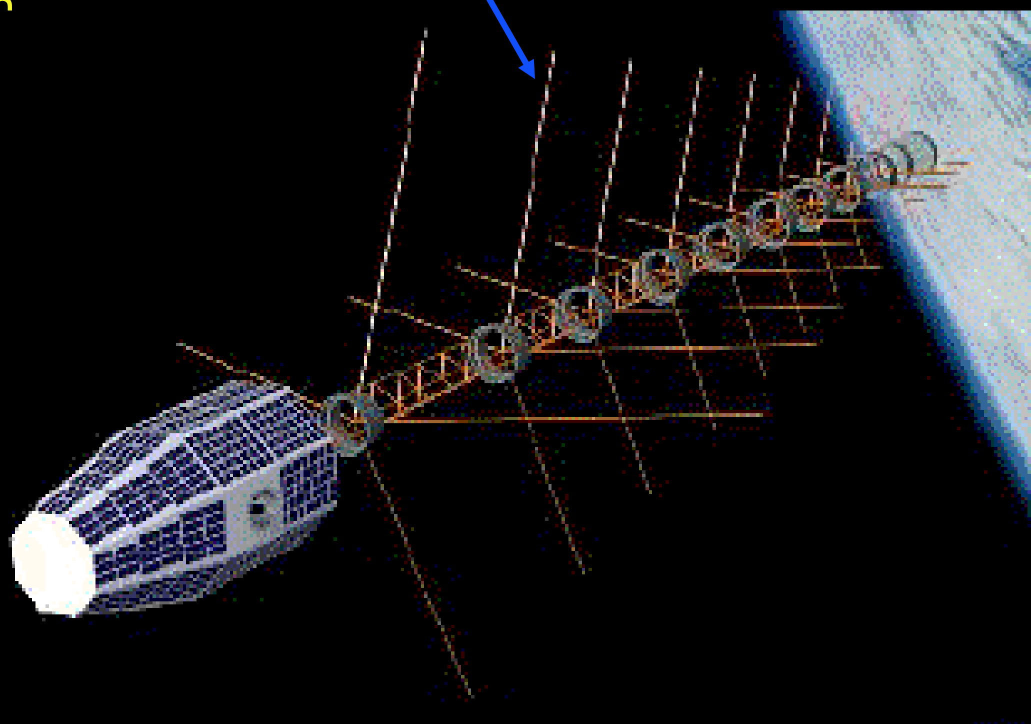
>100 km Cherenkov Ring in Air



FORTE satellite
(Fast On-orbit Recording of Transient Events)

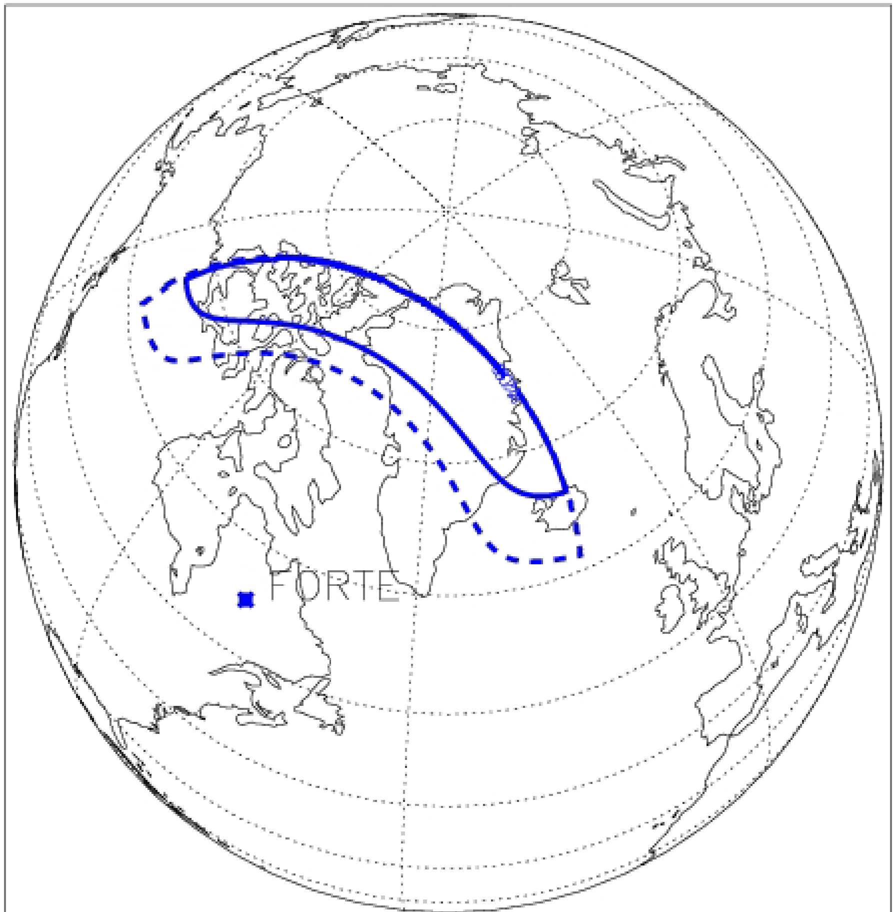
- Main mission: lightning
- Viewed Greenland ice with appropriate trigger (1997-99)
  - 1.9 MILLION km^3
  - 38 days at 6%
- Can self-trigger on transient events in 22MHz band in VHF band (from 30 300 MHz)
- Event characterization
  - polarization
  - ionospheric group delay and birefringence
  - timing

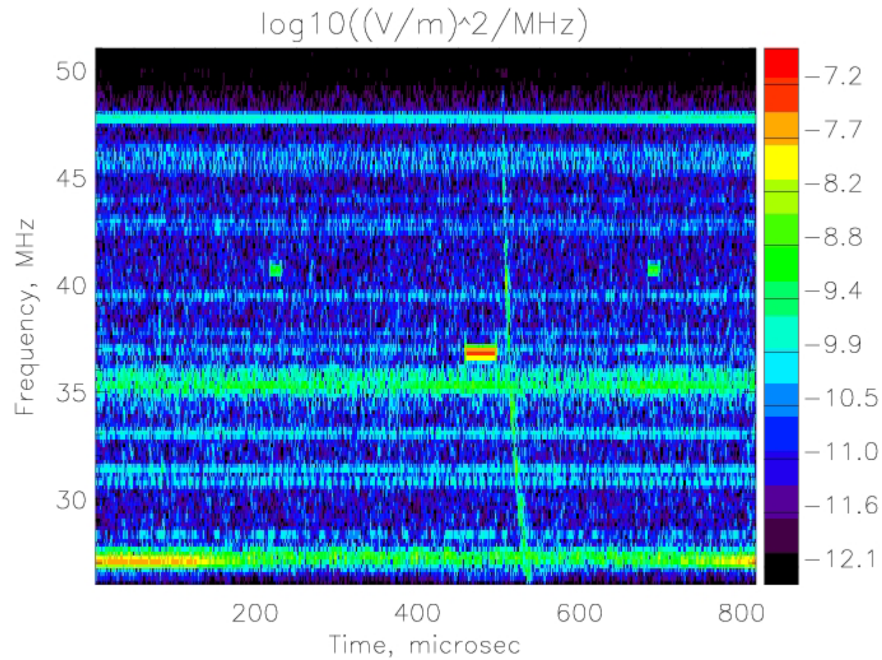
Log-periodic antennas



N. Lehtinen et al., PRD 69, 013008 (2004)

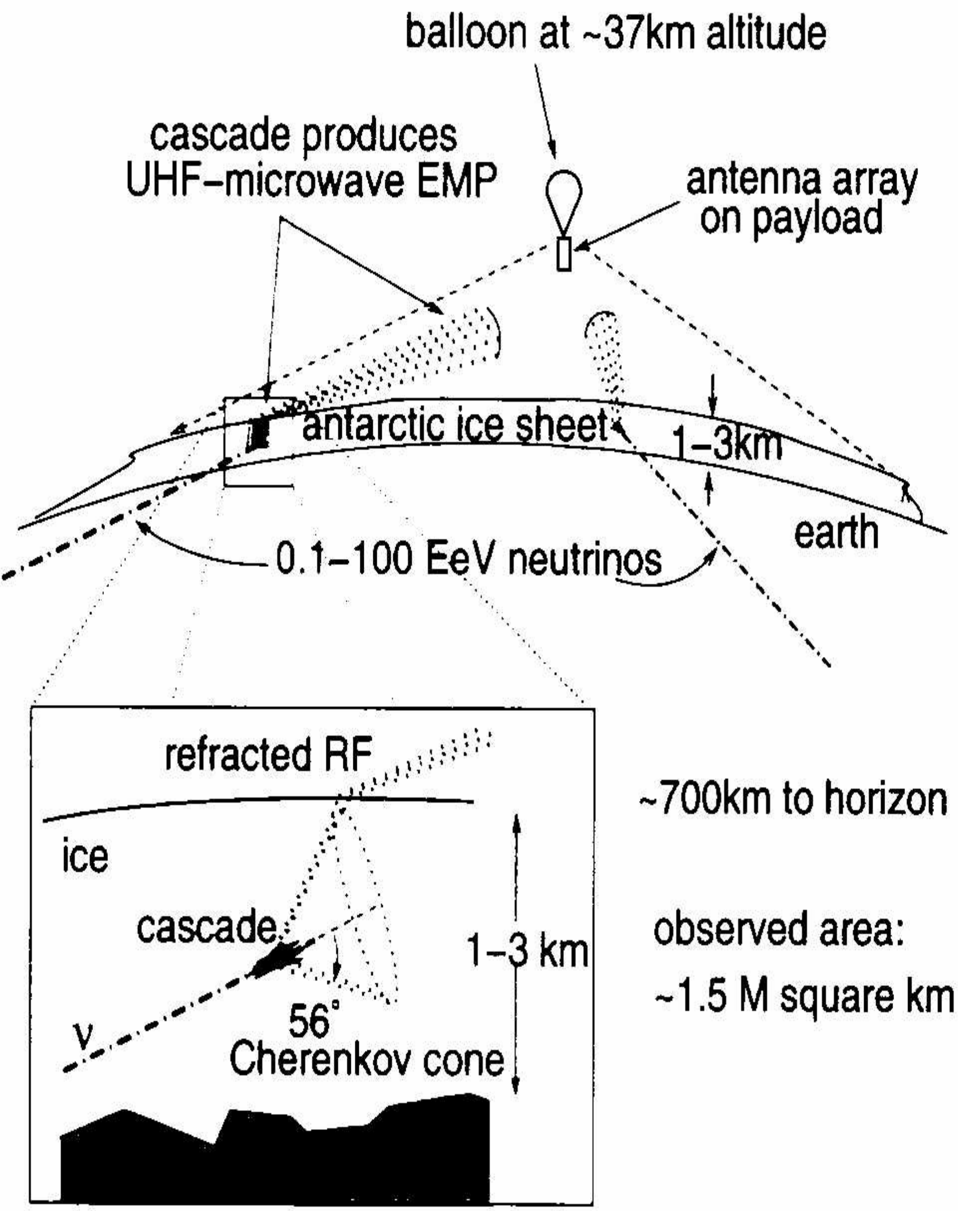
Example Forte Event





- $E_{\nu}^{thresh} \sim 10^{22}$ eV
- $[V\Delta\Omega] \sim 100{,}000\ km^3$ sr, but threshold extremely high.

ANITA



>1 million cubic km!

Plan 60 days in 3 flights

$E_\nu > 10^{17}$ eV

[VΔΩ]~20,000 km^3-sr

ANITA World Tour

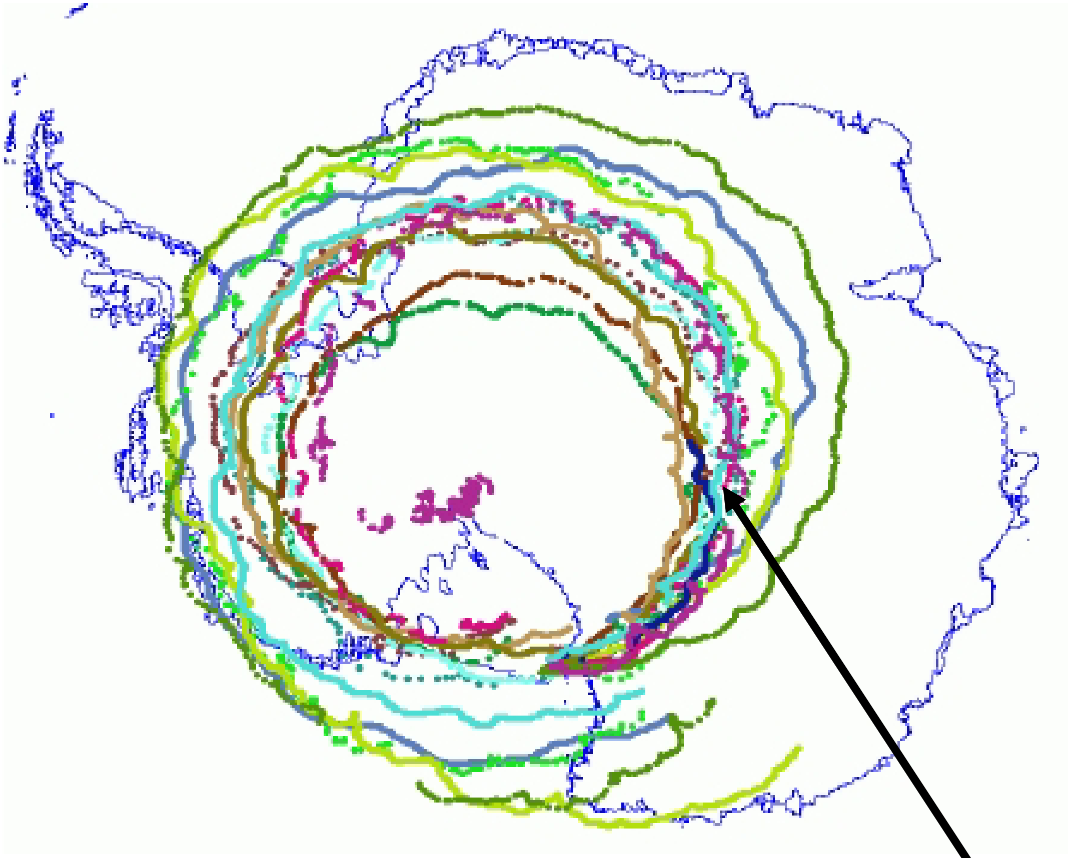
- December: 2003-04 Anita-lite
- June 2005 Test run at Ft. Sumner, NM
- June 2006 Full ANITA assembled
- June 2006 Testbeam with Ice target @SLAC
- July 2006 shipped to the ice…
- Dec 06-Jan 07 Flight!

photo: Jeff Kowalski

Anita collaboration list
available online

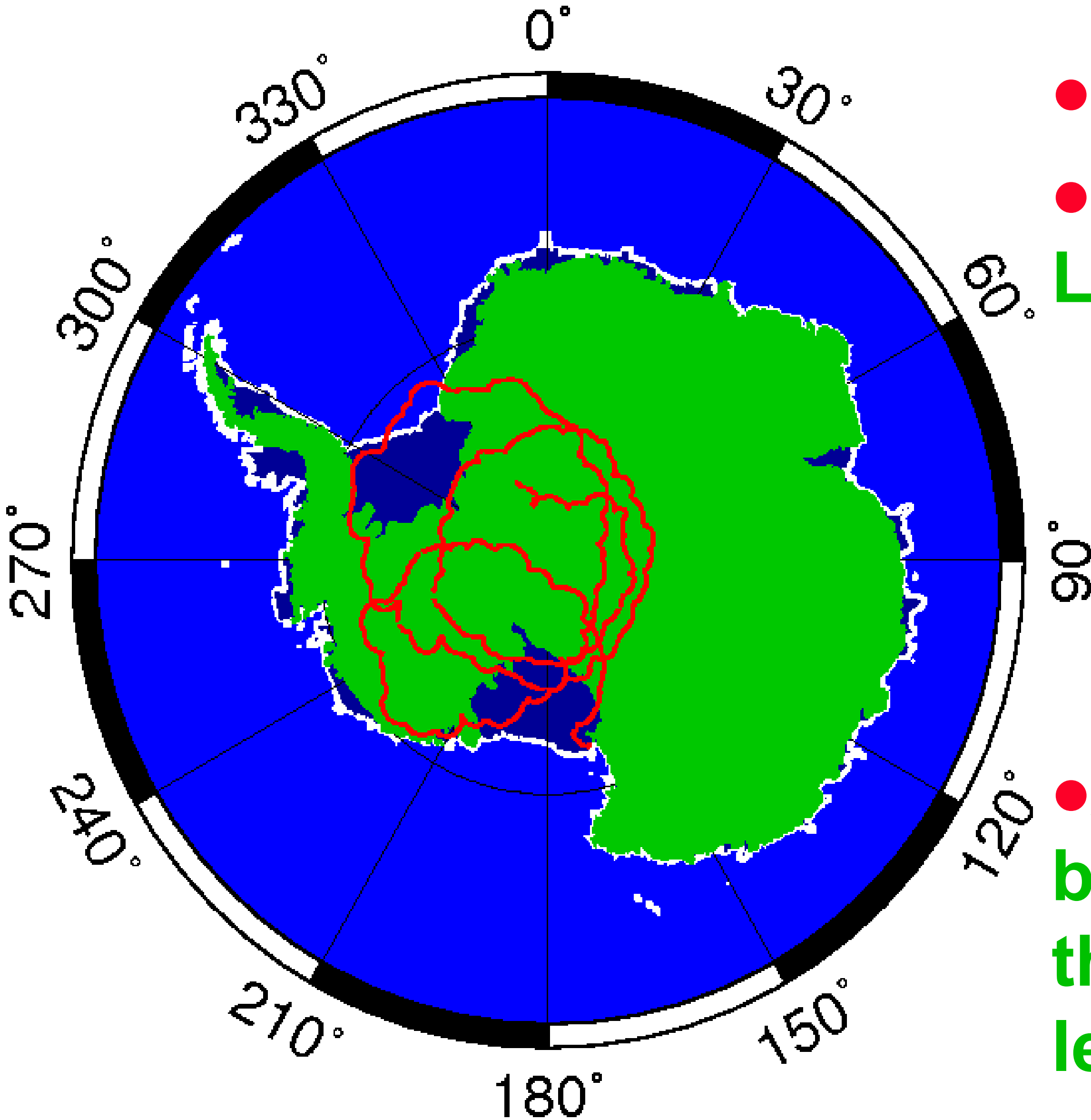

Show Movie…

Historic LDB Flight Paths

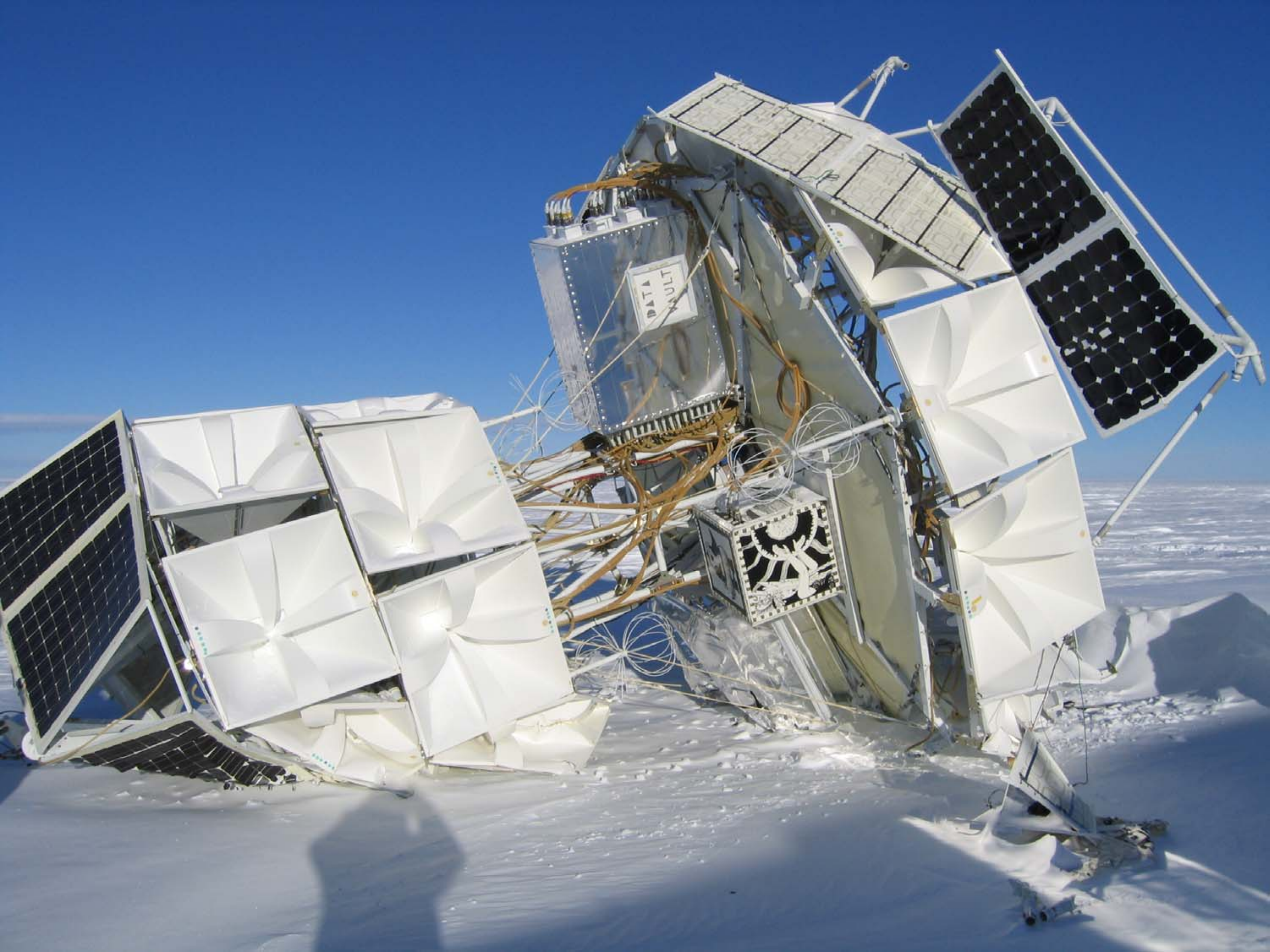


East Antarctica= Deepest Coldest Clearest Ice

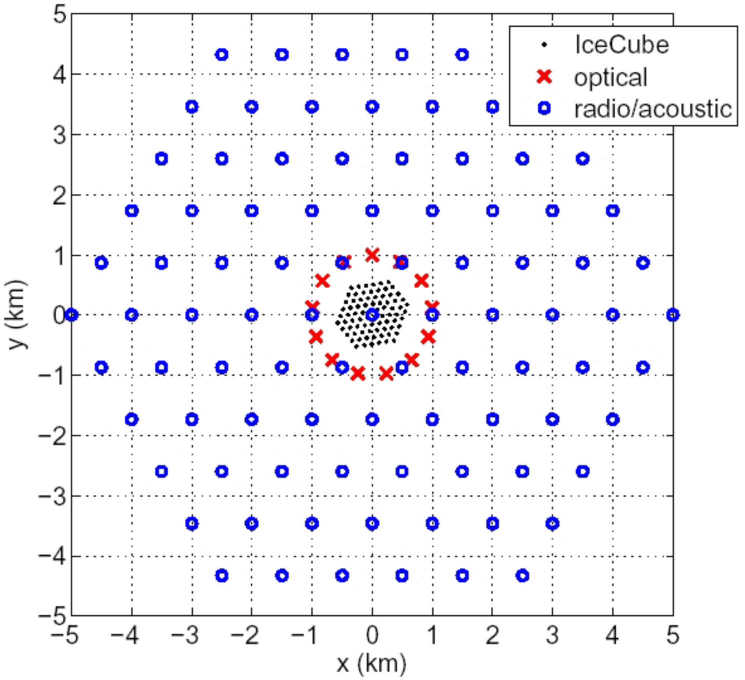
ANITA flight

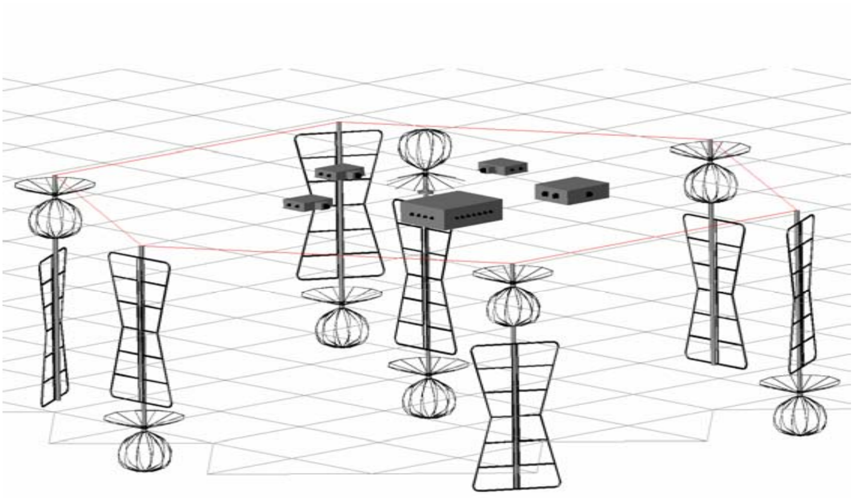


- 35 Days
- Second longest LDB flight
- Away from bases, saw thermal noise levels.


DATA

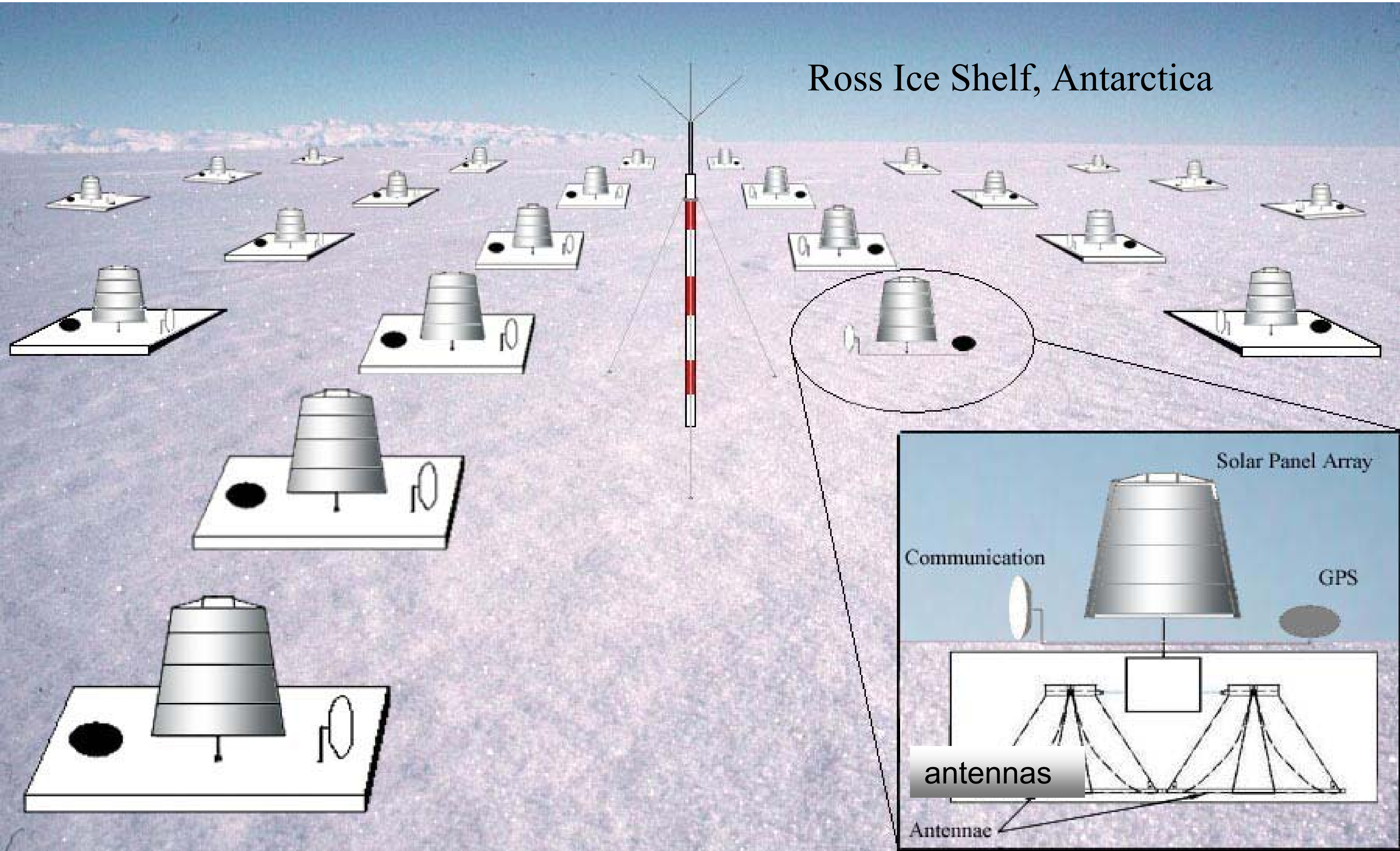
AURA & IceRay: Expanding Ice-Cube Hybrid Acoustic & Radio Techniques



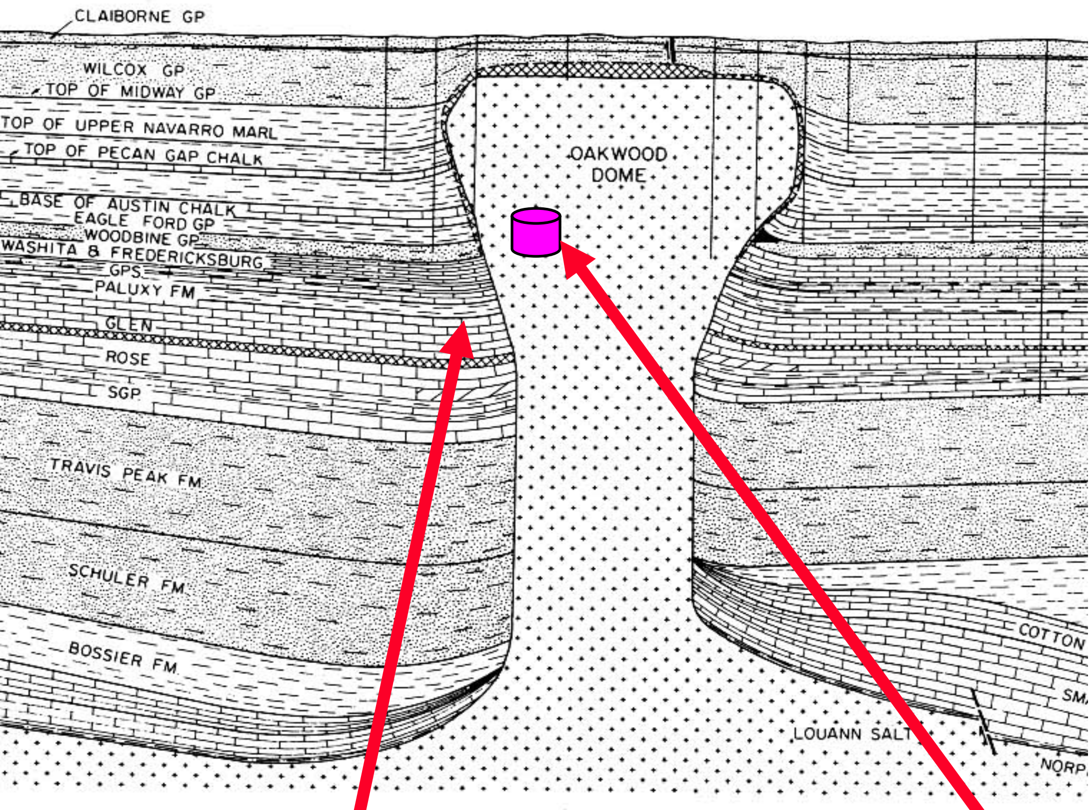


from J. Kelly presentation

ARIANNA: 100 x 100 station Array



SALSA:
A possible salt detector

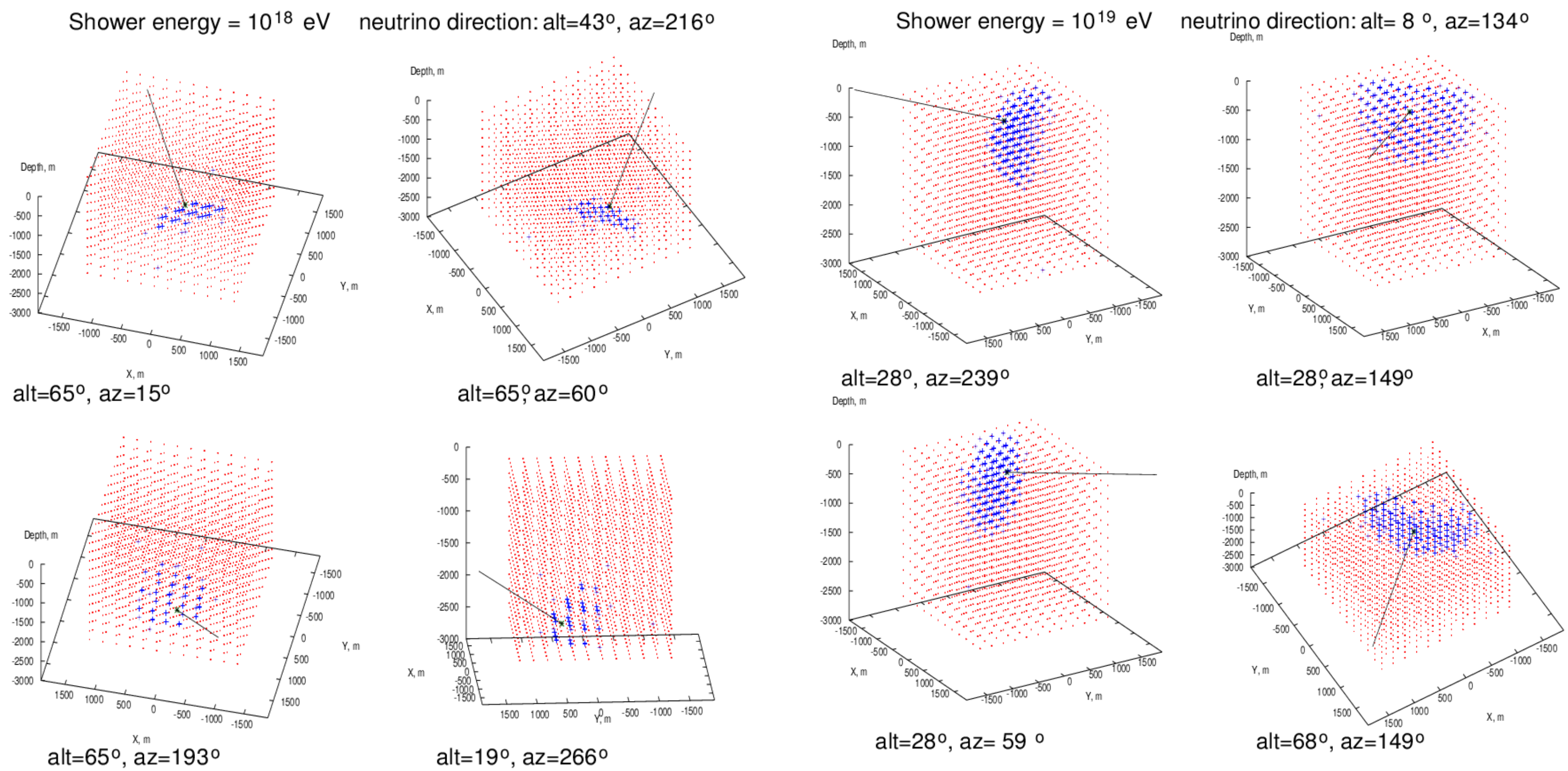


diapir action pushes out water

~1km^3 w.e.

- ~25km^3 in upper 3km of dome (75 km^3 water-equiv.)
  - >2$\mathcal{X}$ denser than ice
  - easier to deploy than S.Pole
- Calorimetric; large V,$\Delta\Omega$; Cherenkov polarization usable for tracking
- Good candidates in Texas and Louisiana, maybe Utah

SalSA simulations



- A 2.5 km^3 array with 225 m spacing, 12^2=144 strings, 12^3=1728 antenna nodes, 12 antennas per node, dual polarization ==> **$V_{eff}\,\Omega$ ~400 km^3 sr w.e. at 1 EeV**
- Threshold <10^{17} eV, few 100s antennas hit at 1 EeV, >1000 hits at 10 EeV
- **Rate: at least 20 events per year from rock-bottom minimal GZK predictions**


UCLA

Cote Blanche Salt Attenuation Lengths

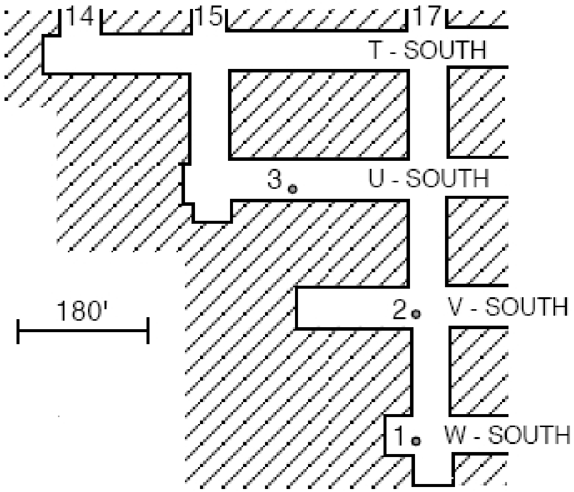
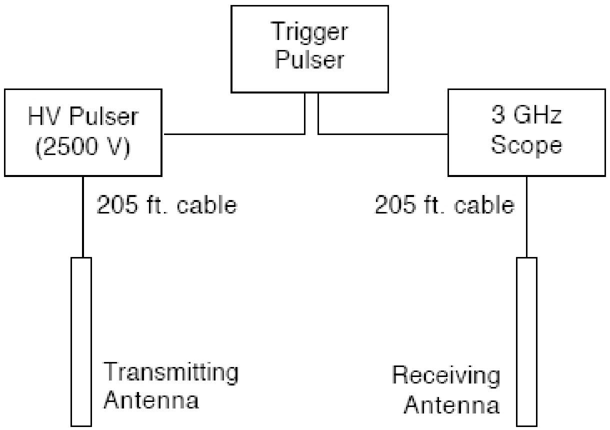
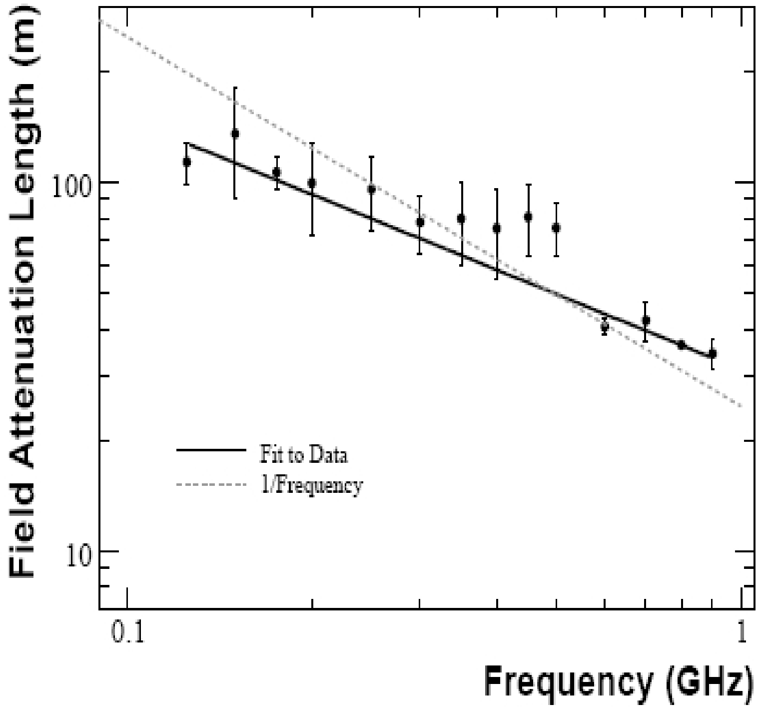
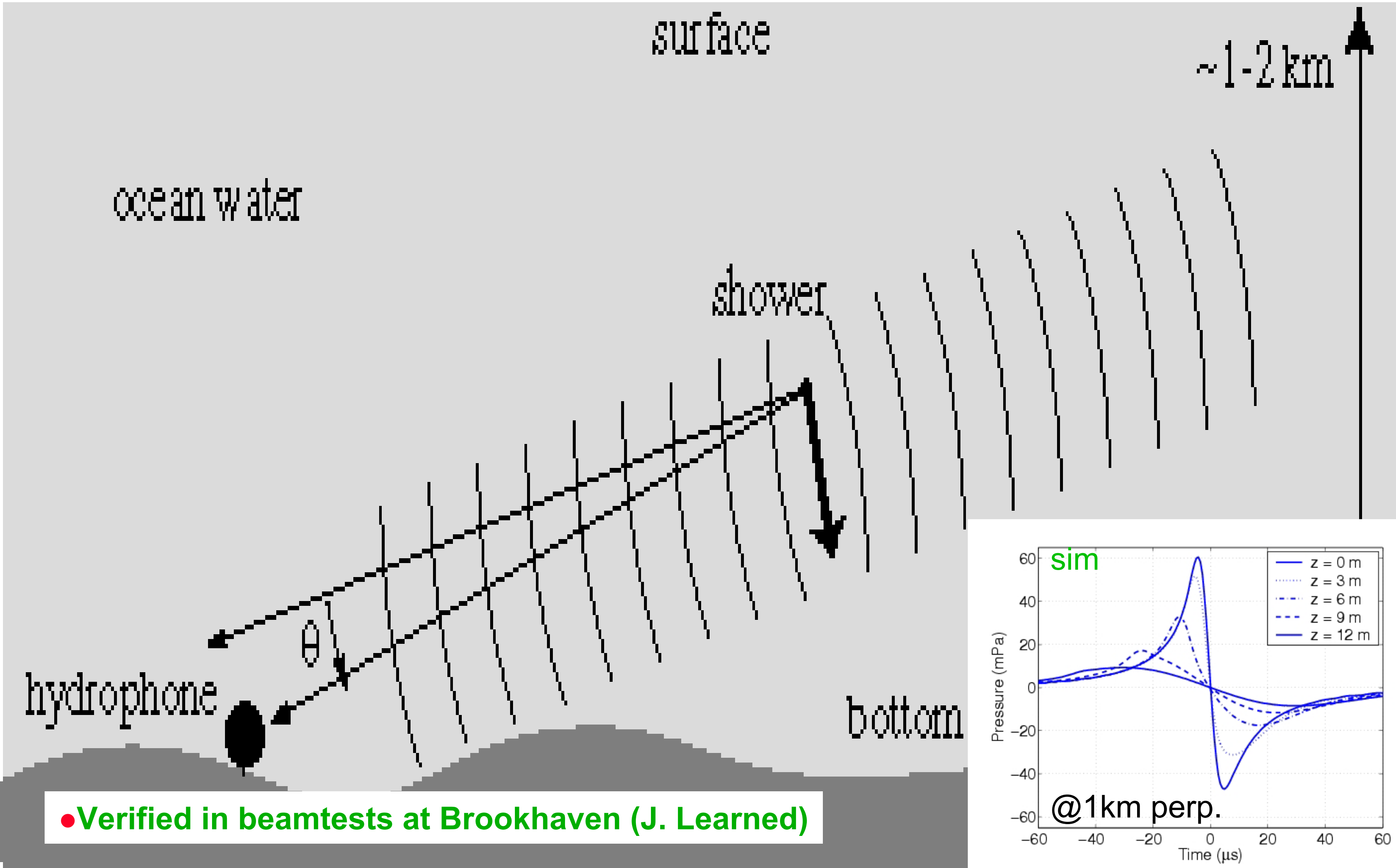


Fig. 1.



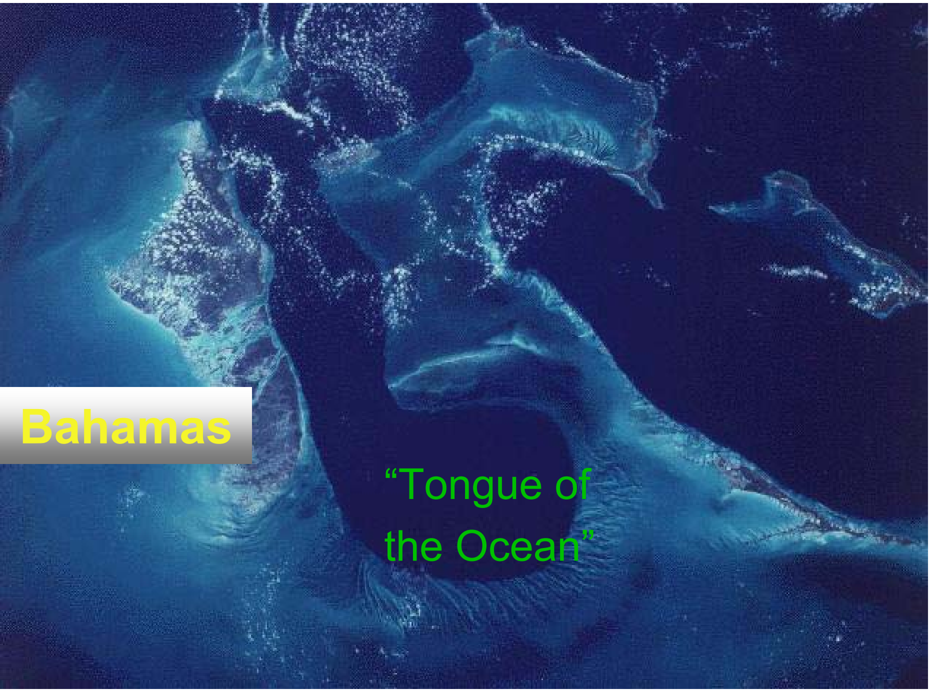


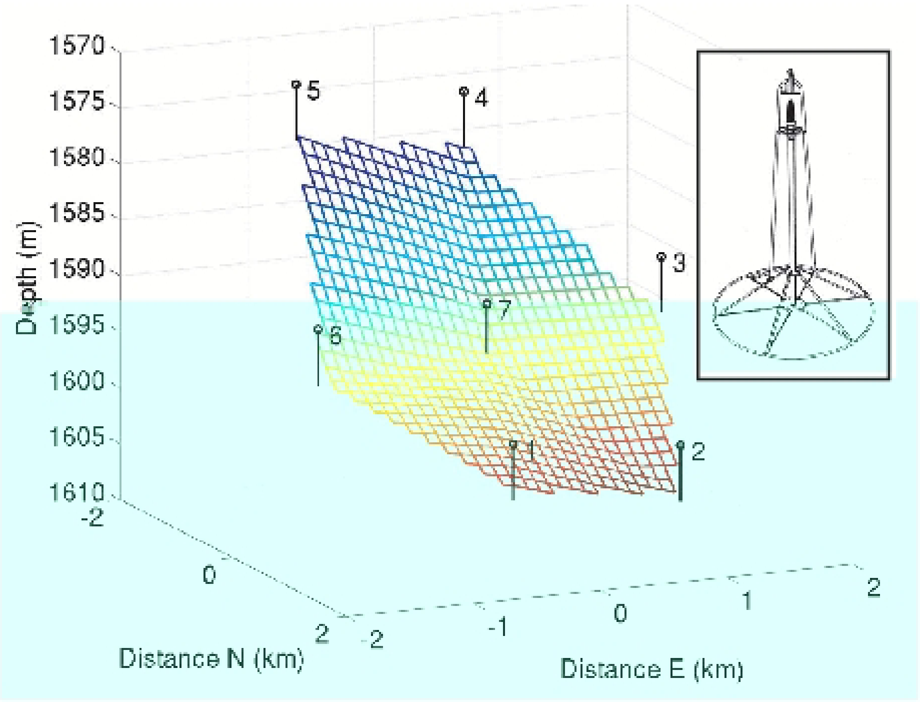
Another Good Idea from Askaryan (III): Acoustic Detection
(1957)



- **Verified in beamtests at Brookhaven (J. Learned)**

SAUND
(Study of Acoustic Underwater Neutrino Detection)

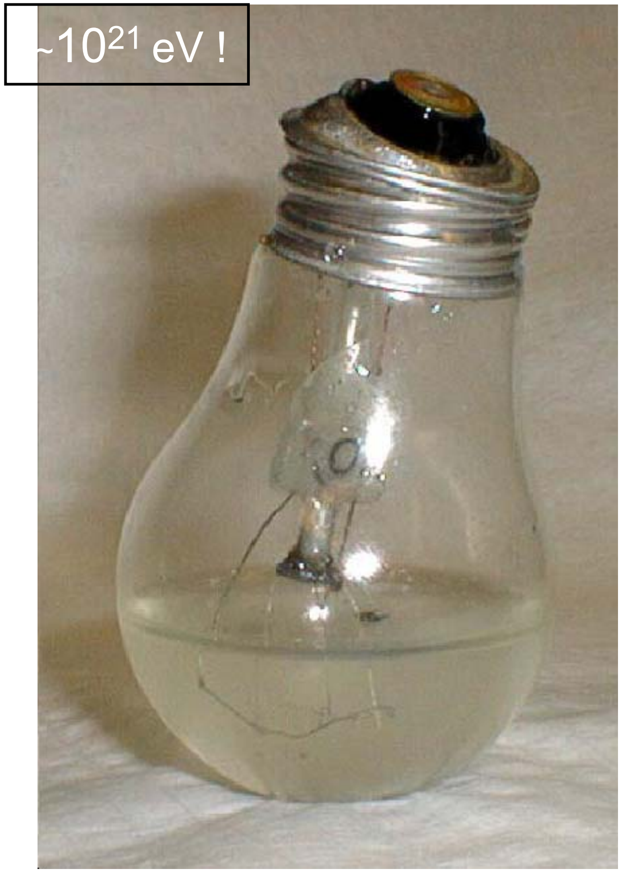


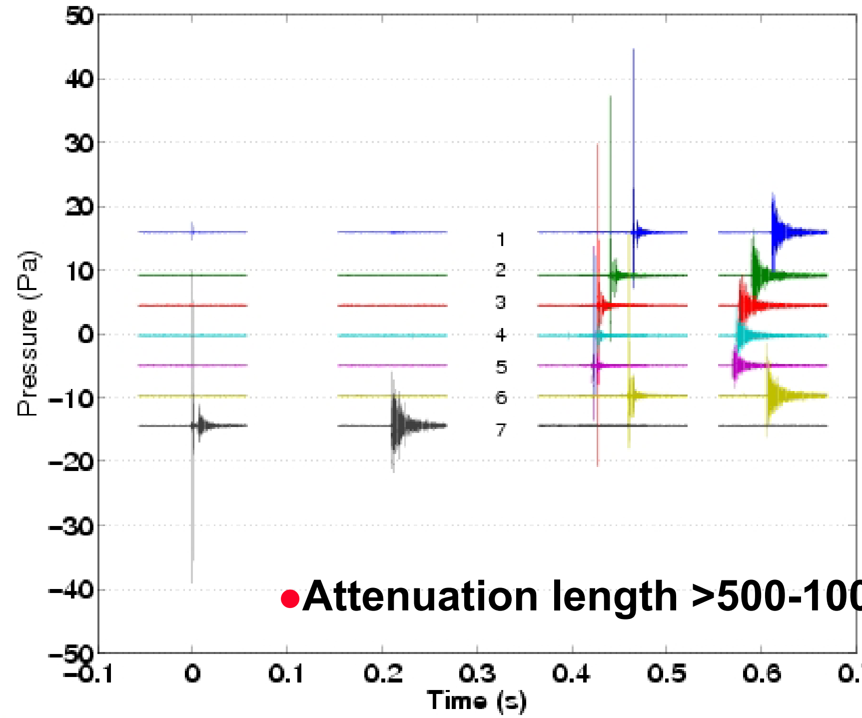


- 7 Hyrdophones, subset U.S. Navy array (AUTEC)
- Detection 7kHz to 50 kHz
- Noise floor $\nu^{-1.7}$, sets threshold ~ 10^{23} eV
- Physics run 195 days

J. Vandenbrouke *et al.*,Ap. J. 621, 301

SAUND Calibration





- **Attenuation length >500-1000m**

- E_ν ~ 10^{22} eV: too high for now.

  but salt domes may prove
  10× more signal and much
  less background

Acorνe

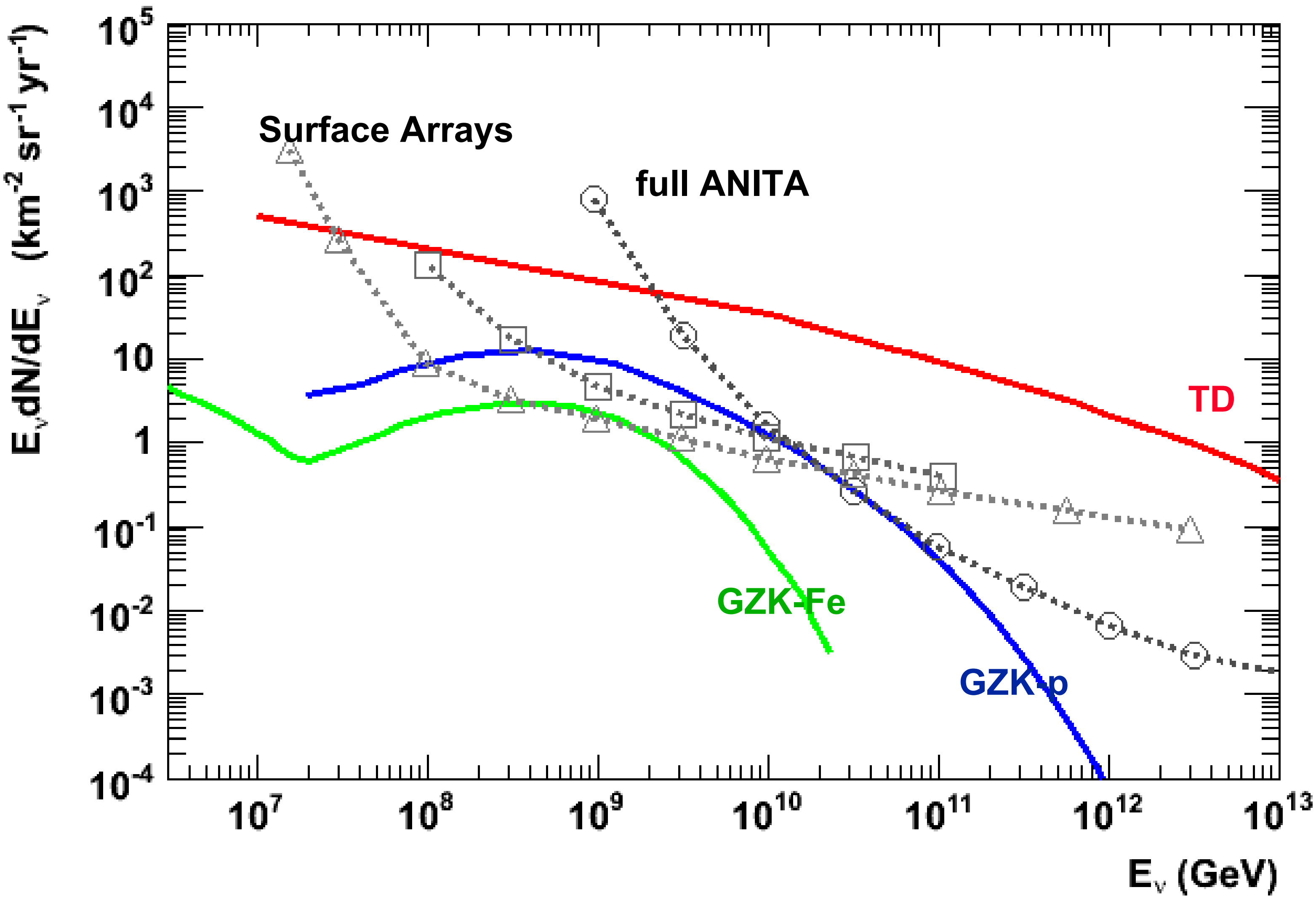
- Poster by your classmate, Simon!
- Array of Rona 8 hydrophones off of coast of Scotland
- Monitor at 140 kHz, digitize all
- No up-front hardware trigger needed.

Other Developing(?) Ideas

- Drone flights over deepest Antarctic Ice or
- View from a Mountainside
  - use the best ice: up to 4km deep
  - closer→ lower threshold
  - instrument can be maintained
  - 1 year/ year
- ANITA++
  - Phased array of balloon-borne deployable antennas
- Lunar or even Europa orbiter

There are more ideas than people to work on them

Reaching GZK sensitivity & Lowering the Theshold

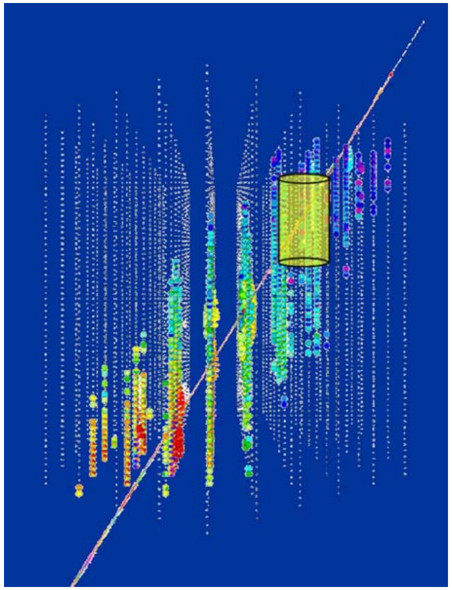


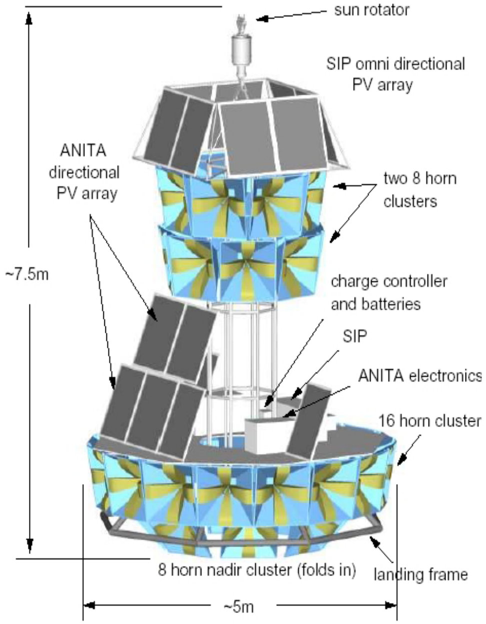
<u>Events</u>! even if UHECR are Iron

limits are for energy bin with E_{hi}/E_{lo}=e

Where we might be in just 2 years…

- IceCube
  - Discovery of bottom-up sources
  - Discovery of a few GZK neutrinos
- ANITA:
  Discovery of a handful of GZK neutrinos
- Auger
  - Discovery of a few GZK neutrinos ?





GZK Neutrinos are coming….Are you ready?

- Conclusion-II (for a particle physicist):
  - UHE ν may provide an HEP laboratory:
    - Probe total cross section & new physics at highest Ecm
    - The longest baseline available neutrinos– by far

"Enough storyboarding. Let's shoot something."