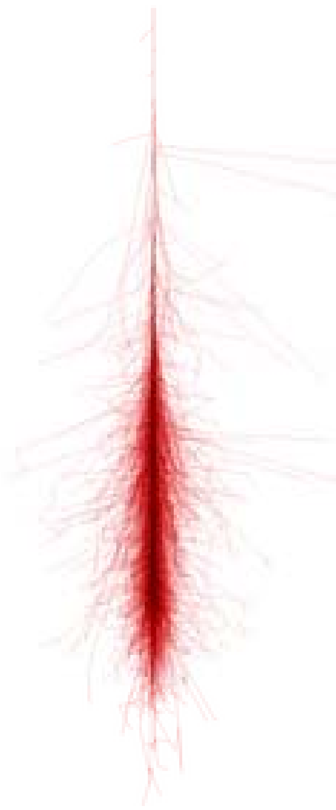
Radiowave shower detection

Basic parameters:

1) Radio transparency ~ L_{atten}~2 km vs. 40 m ice/water for optical
2) Radio 'coherence' ➔ quadratic growth of signal power at >20 cm wavelengths (vs. linear for optical/PMT)
3) Now extensive experience in situ (RICE) + 3 beam tests at SLAC by GLUE/ANITA groups



$R_{Moliere}$

Forest through trees

- Radio detection (+acoustic) are techniques!
- In principle, accesses very broad scientific programme:
  - UHE neutrinos (point+diffuse [GRB’s], e.g.)
  - Micro-black holes & LSG
  - Standard model (and non-SM) cross-sections
  - Magnetic Monopoles
  - Exotics+…

Comment

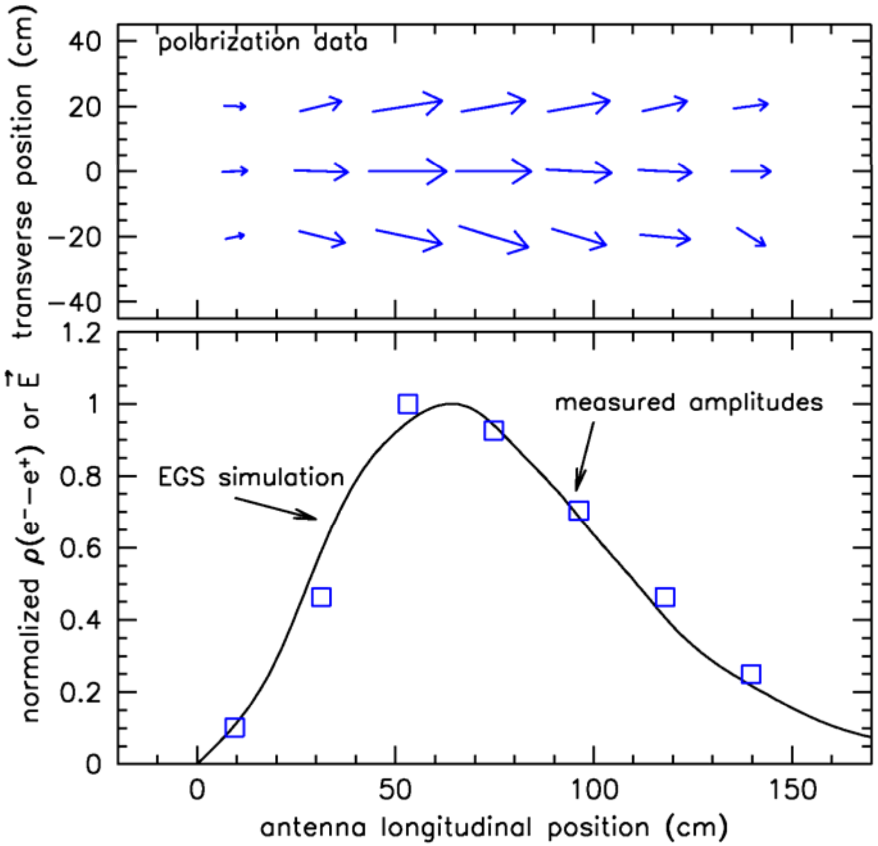
- UHE neutrino detection probes universe in redshift/energy space inaccessible to UHECR or Gamma-Ray astronomy.
- Prior experience→not unlikely we will find a new source out there…
- UHECR's probe out to 10^{-8} of Hubble Volume!
- Only sources from last 20 Myr!
- Also – for 4π coverage of night sky, would like both a northern observatory (to view northern sources) and a southern observatory (to view southern sources)

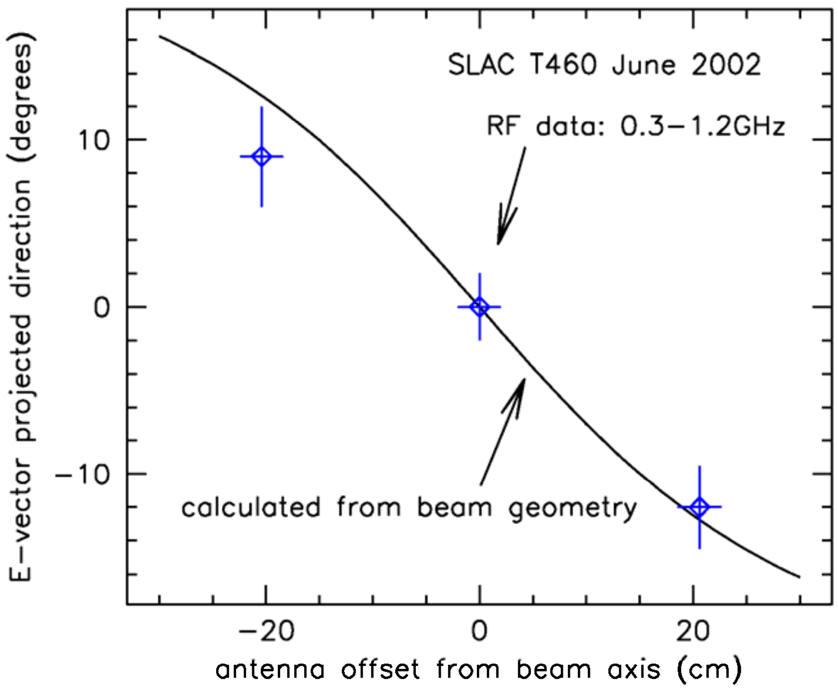
In-Progress Efforts

Expt	Threshold	N(element)	Comment
RICE	100 PeV	20 (dipole)	1999-, small
ANITA	10^4 PeV	36 (dual-pol horn)	06-07 flite, systematix?
nuMoon, GLUE, FORTE, PRO	1000 PeV	1 BIG dish	Livetime?
AURA	100 PeV	2 cluster x 4/cluster	Initial data-analysis
SALSA	100 PeV	14000	Salt props?
ARIANNA (Ross Ice Shelf)	10 PeV	10000 horn	Start-up $ - 12/06 msrmnt
LOPES/LOFAR/ CODALEMA	100 PeV	~10-20	Large RFI backgrounds

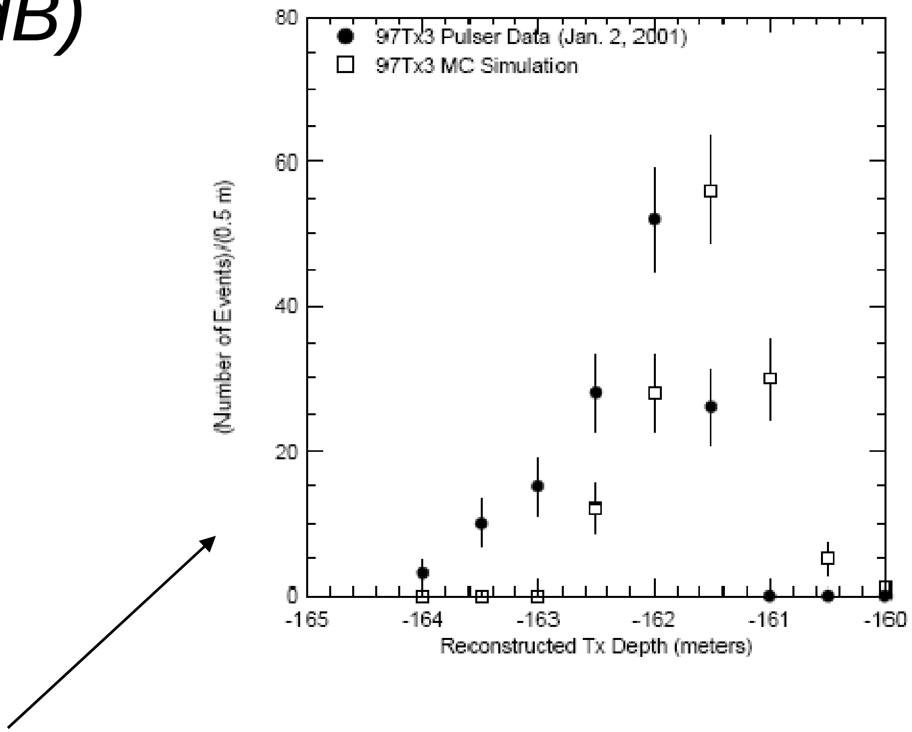
Why believe radio?

- Attenuation length *in situ* data-measured SP
- Test beam data consistent➔coherence→GHz





- *In situ* absolute system gain calibration (~dE/E) using calibrated radio sources
  - *RICE (gain error~3 dB)*
  - *ANITA (~ 0.5 dB)*

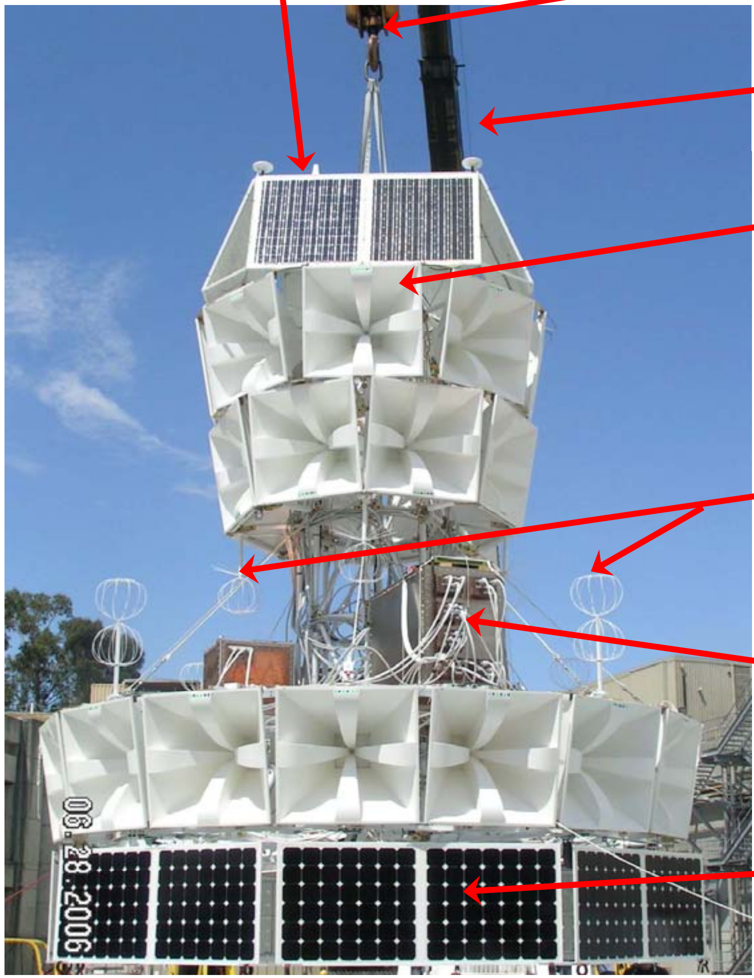


- *In situ* reconstructed radio sources (Tx)
- Observation of λ=10 m radio coherence in coincidence w/ EAS (LOPES/KASCADE)
  - Signal strength~Allen formula (from 60's)

TESTBEAM VERIFICATION (ANITA)

Power for CSBF systems

Connection to balloon (here a crane hook)



GPS antennas

32 Quad-ridge horn antennas
- Sensitive from 200 to 1200 MHz
- 10 degree cant to view distant ice

8 Veto antennas
- Record local interference to prevent triggering on self-generated noise

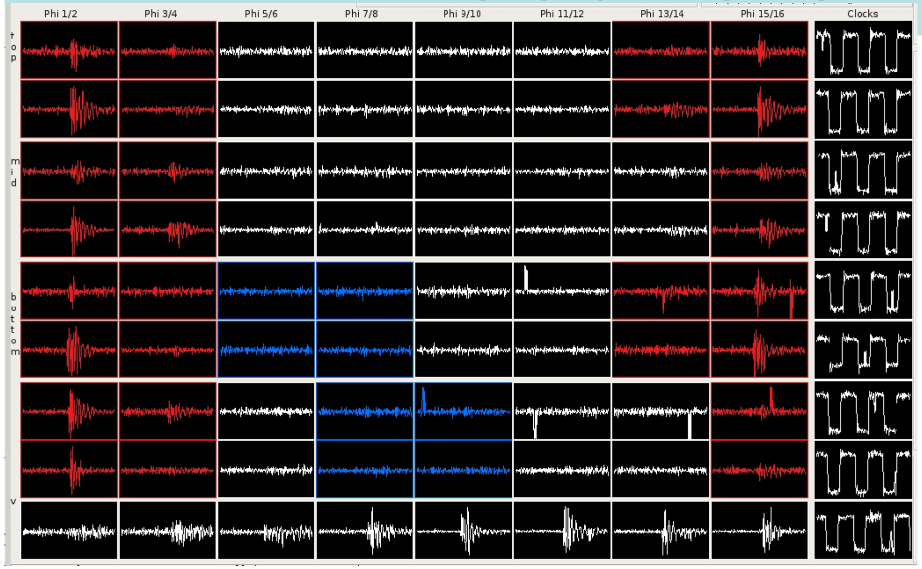
Electronics

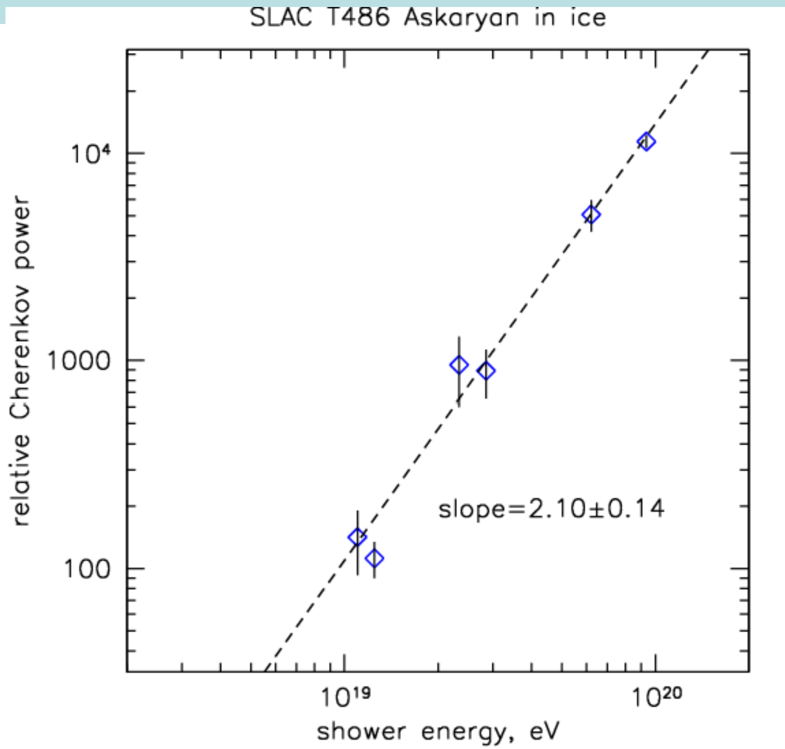
Omni-directional PV array
- Provides power for science mission

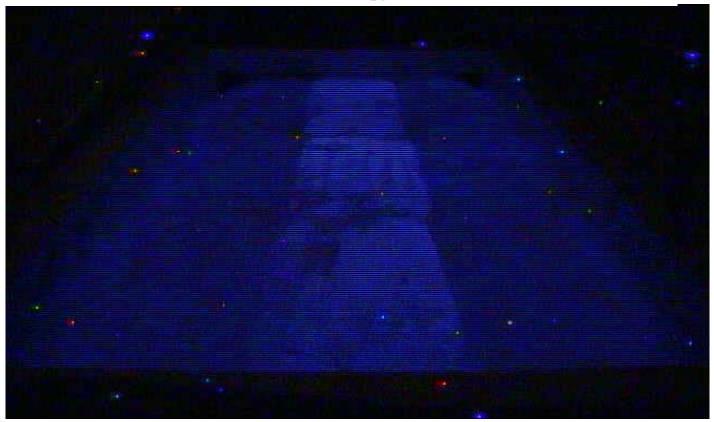
SLAC Calibration

- Instrument calibration using electron beam at SLAC
- ~10 ton ice target
  - Used payload to detect Askaryan radiation from $10^{19} – 10^{20}$ eV particle showers in ice
- 1

Results of SLAC T-486





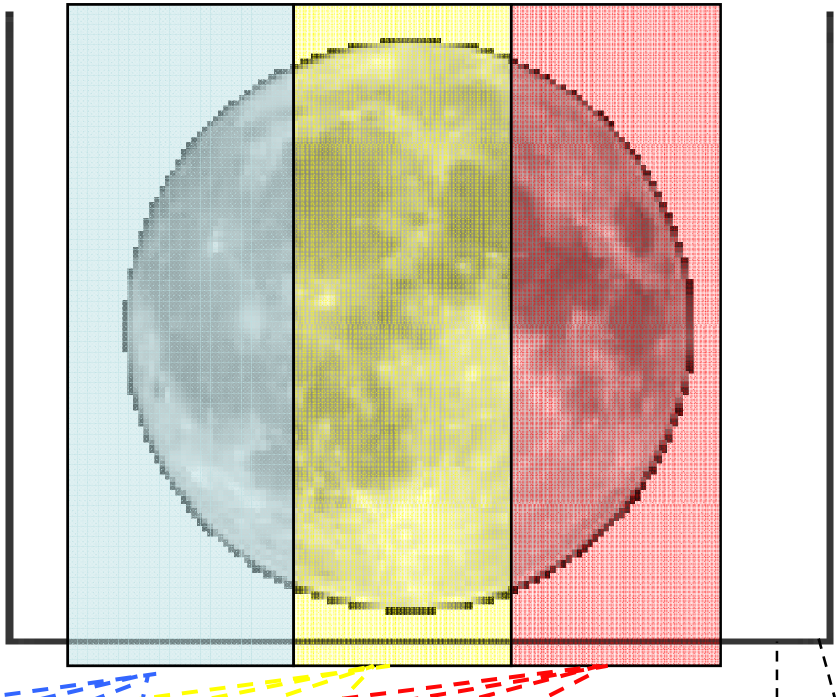


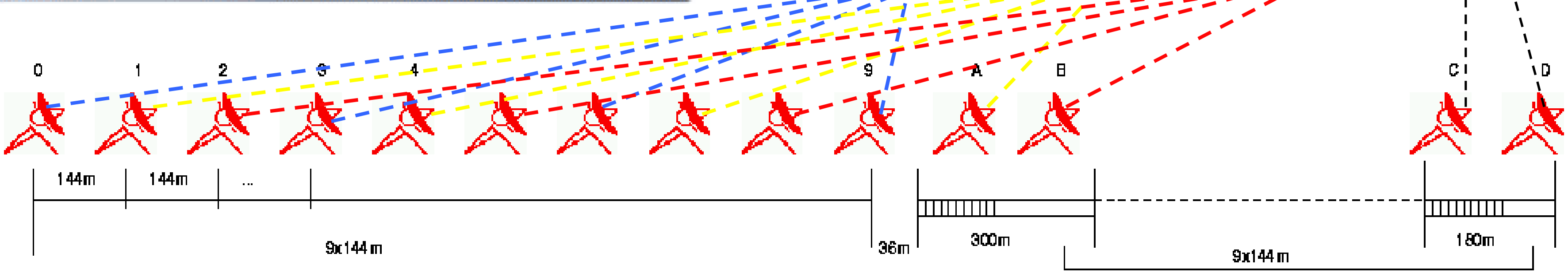
- All channels working
- Payload is self-triggering on Askaryan pulses from ice
- Lots of recorded RF to analyze verifies:
  - Instrument response
  - Timing resolution

Rubber meets road: Exptl. efforts

NuMoon Experiment @ WRST

Use Westerbork radio observatory

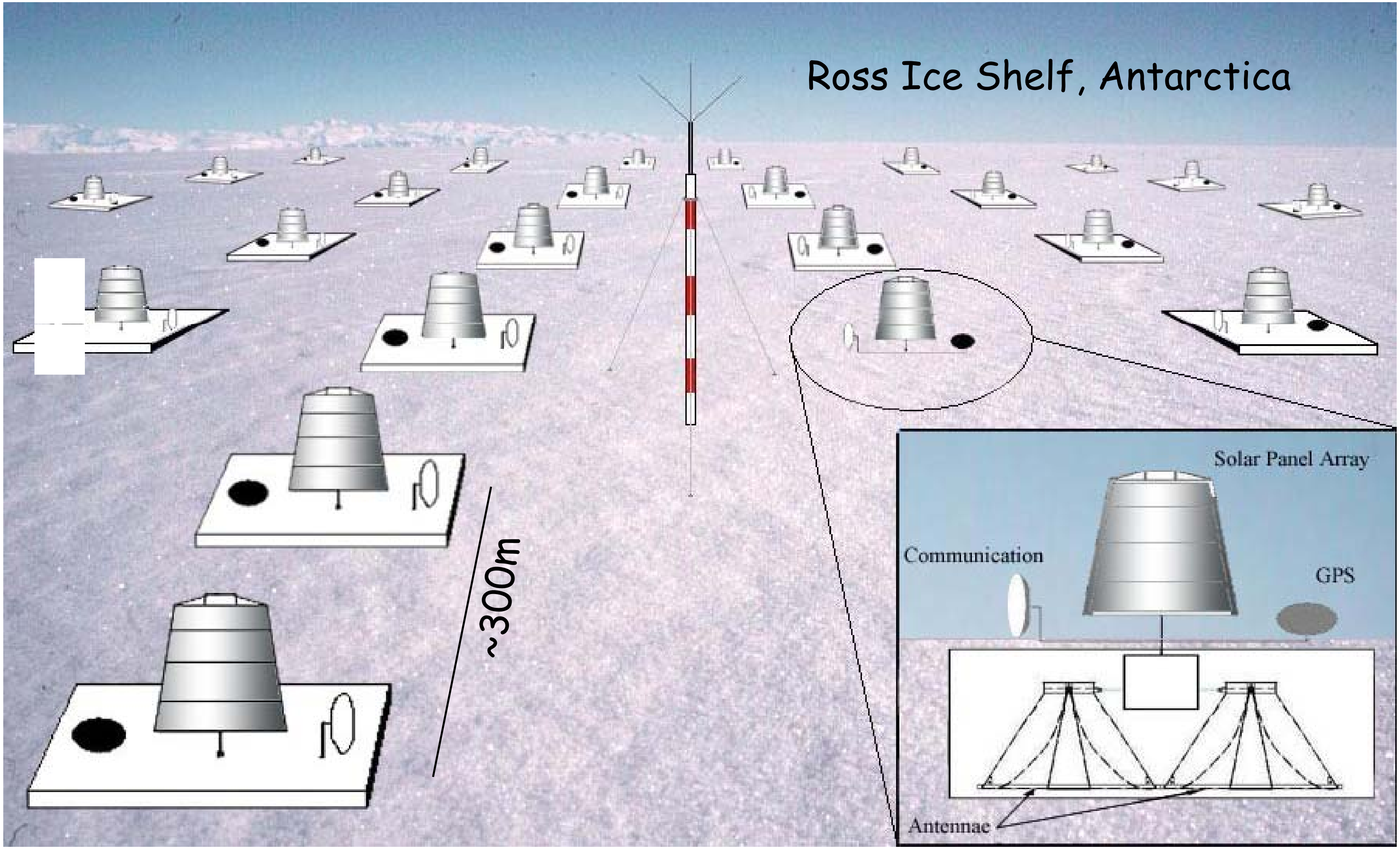




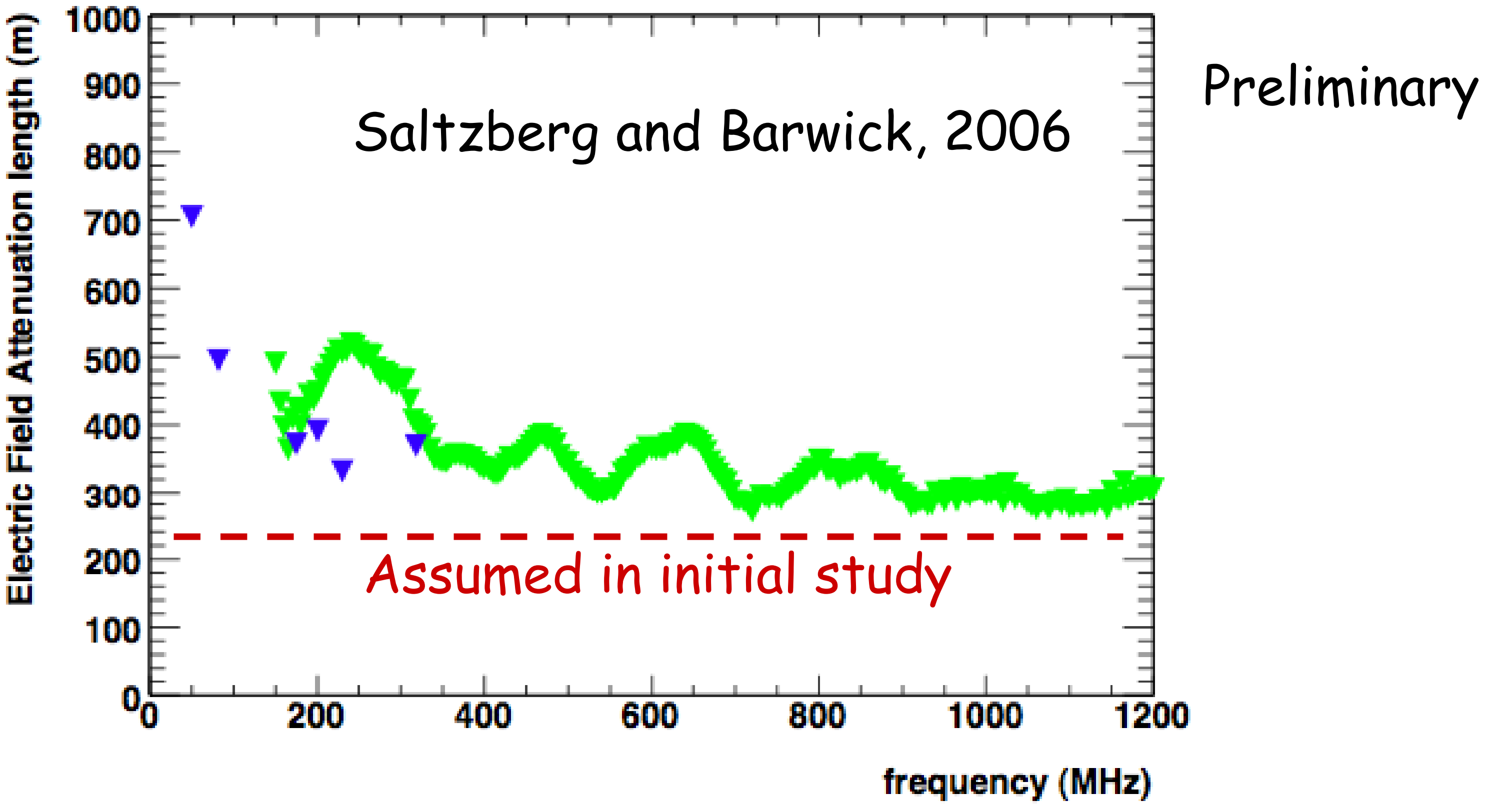
Target low-frequency➔GZK sensitivity in ~month

ARIANNA Concept

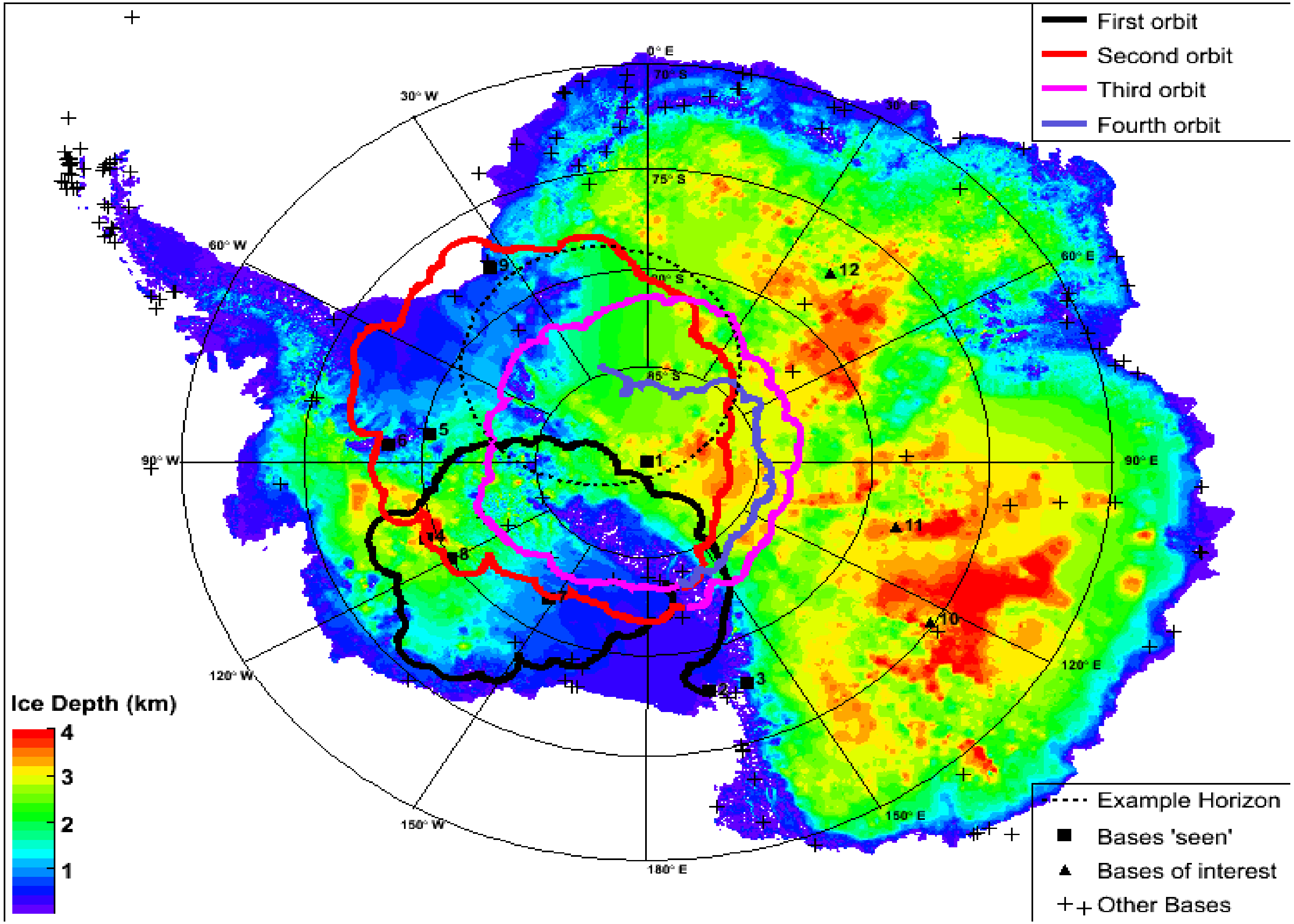
100 x 100 station array



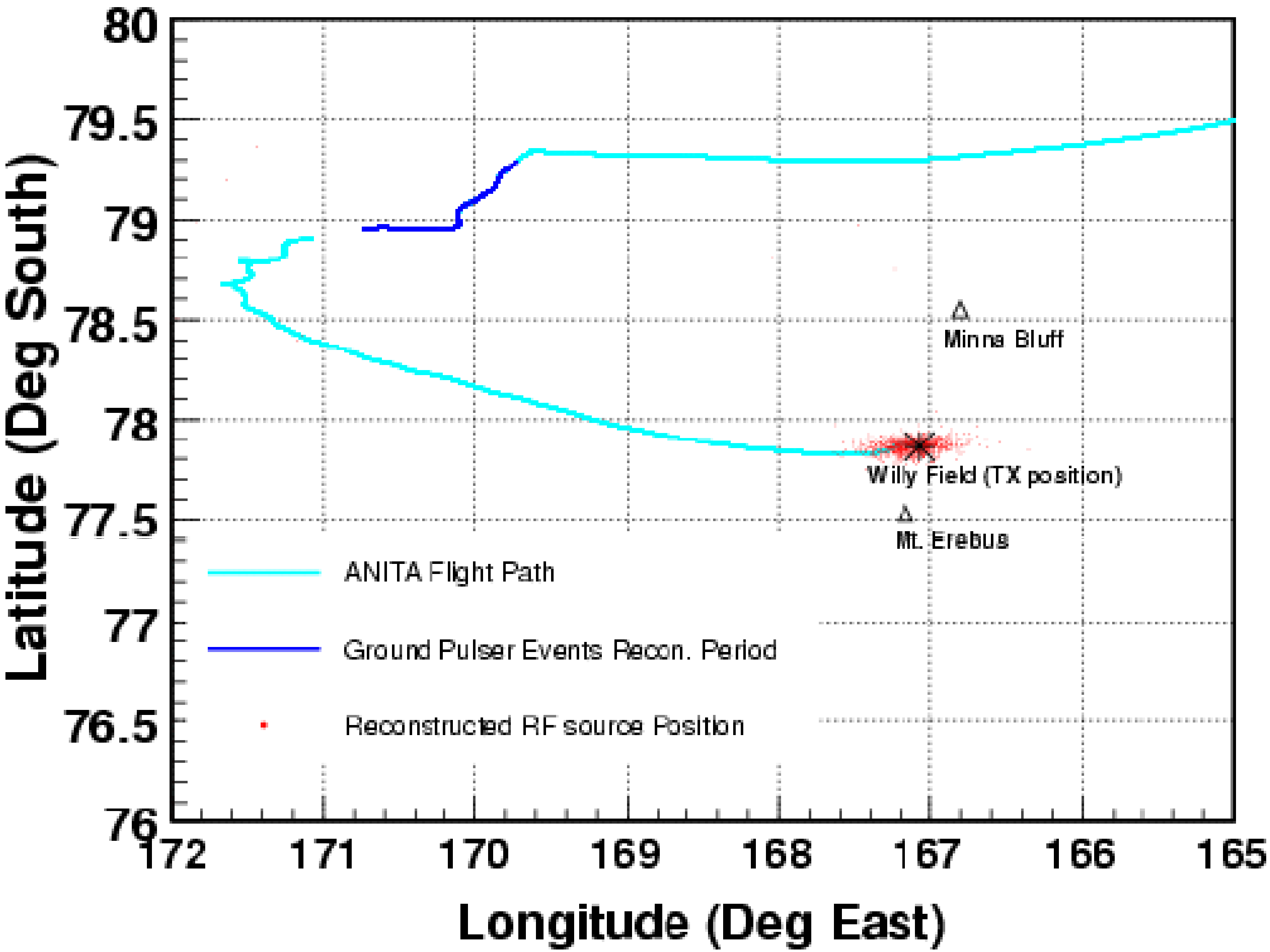
1-way Field Attenuation-Moore's Bay



ANITA – 36-day flight (12/06-1/07)

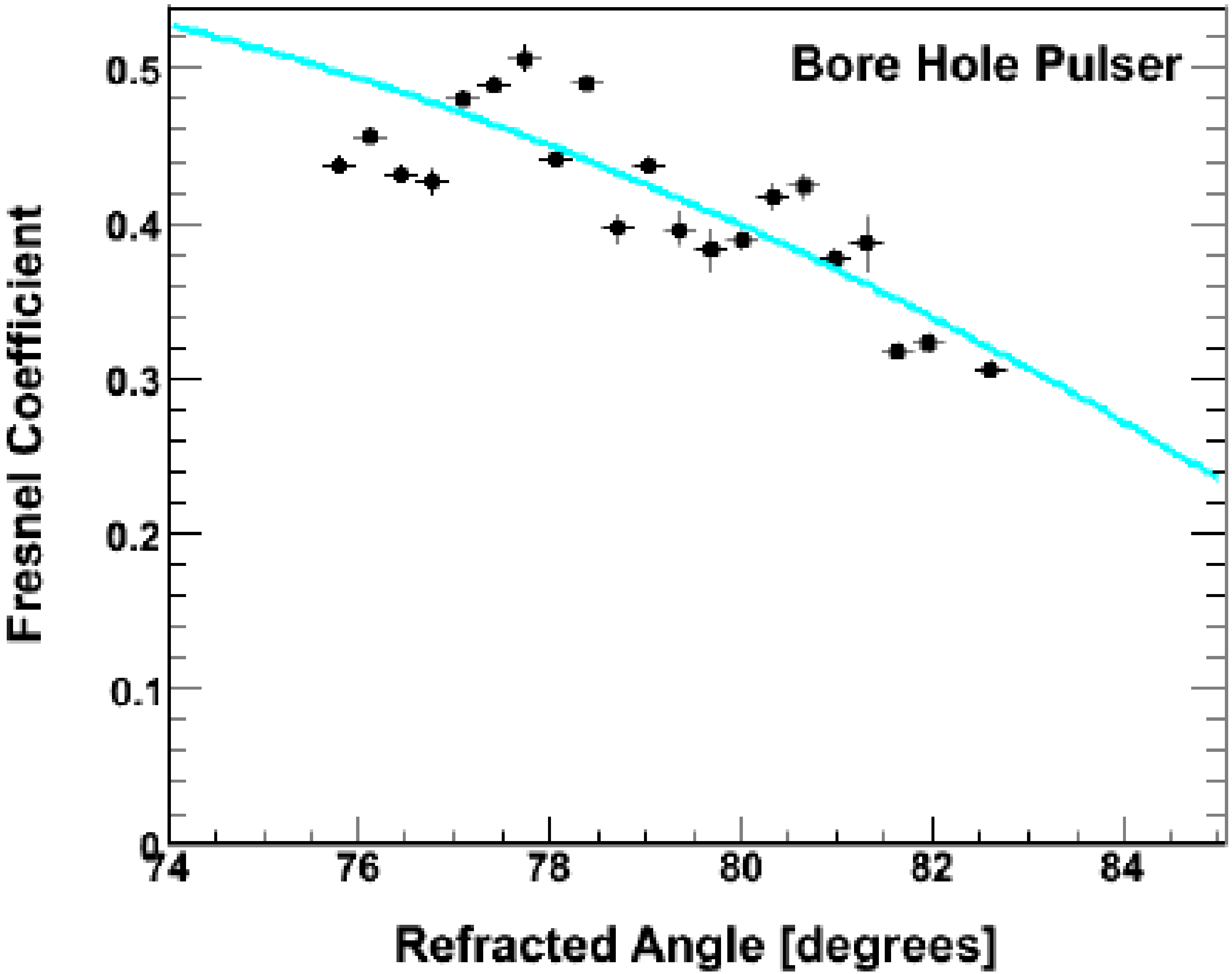


ANITA calibration



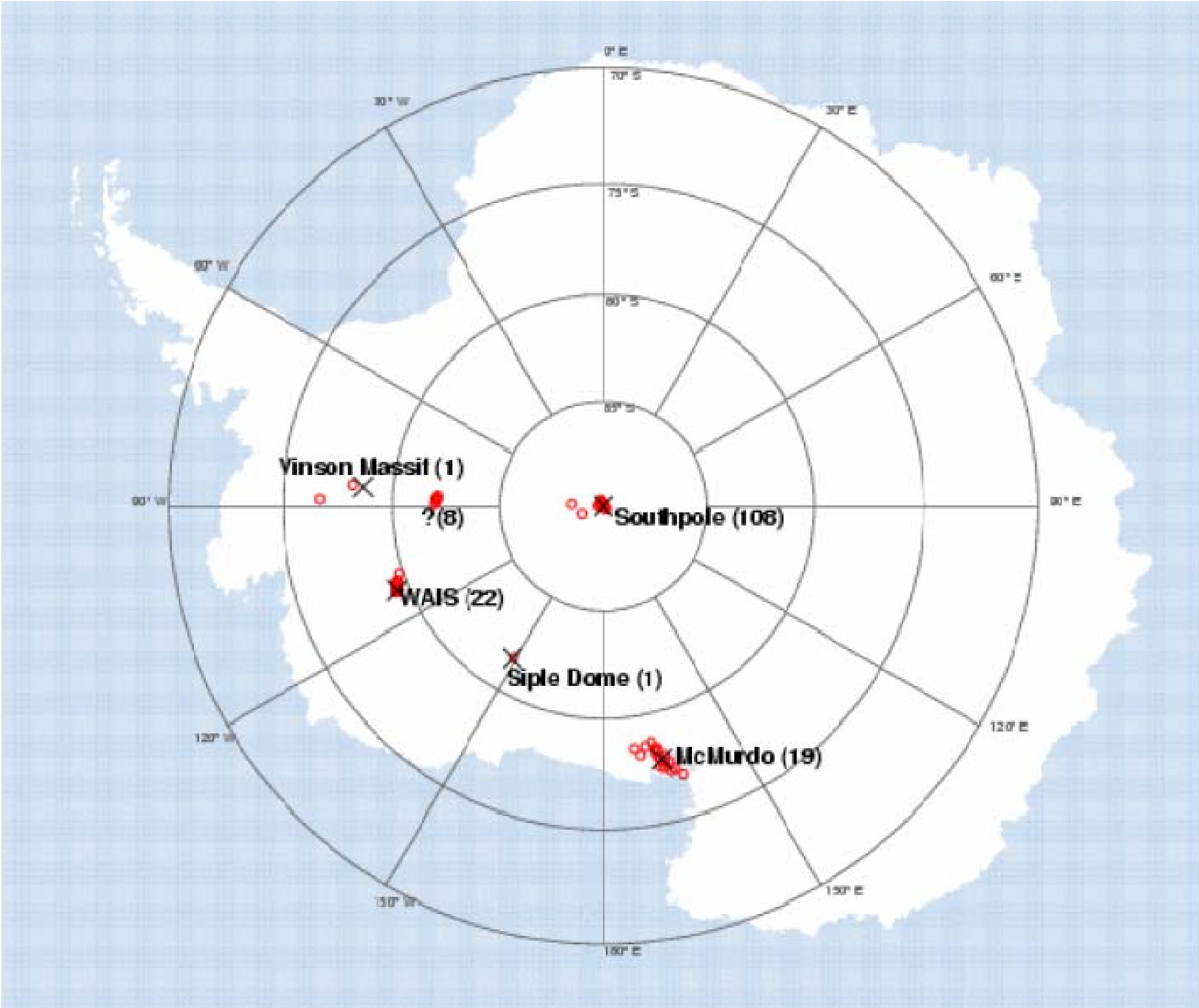
backward=(corr. signal amp. [Volts])*(4/h_eff)/(syst. gain)/(eff. BW)*(dist.)

forward=(discone volt. [Volts])/(eff. BW)*(ice atten.)*(4/h_eff)/(dist. to surface)



Source locations

RF Source Map for the initial 10% Data

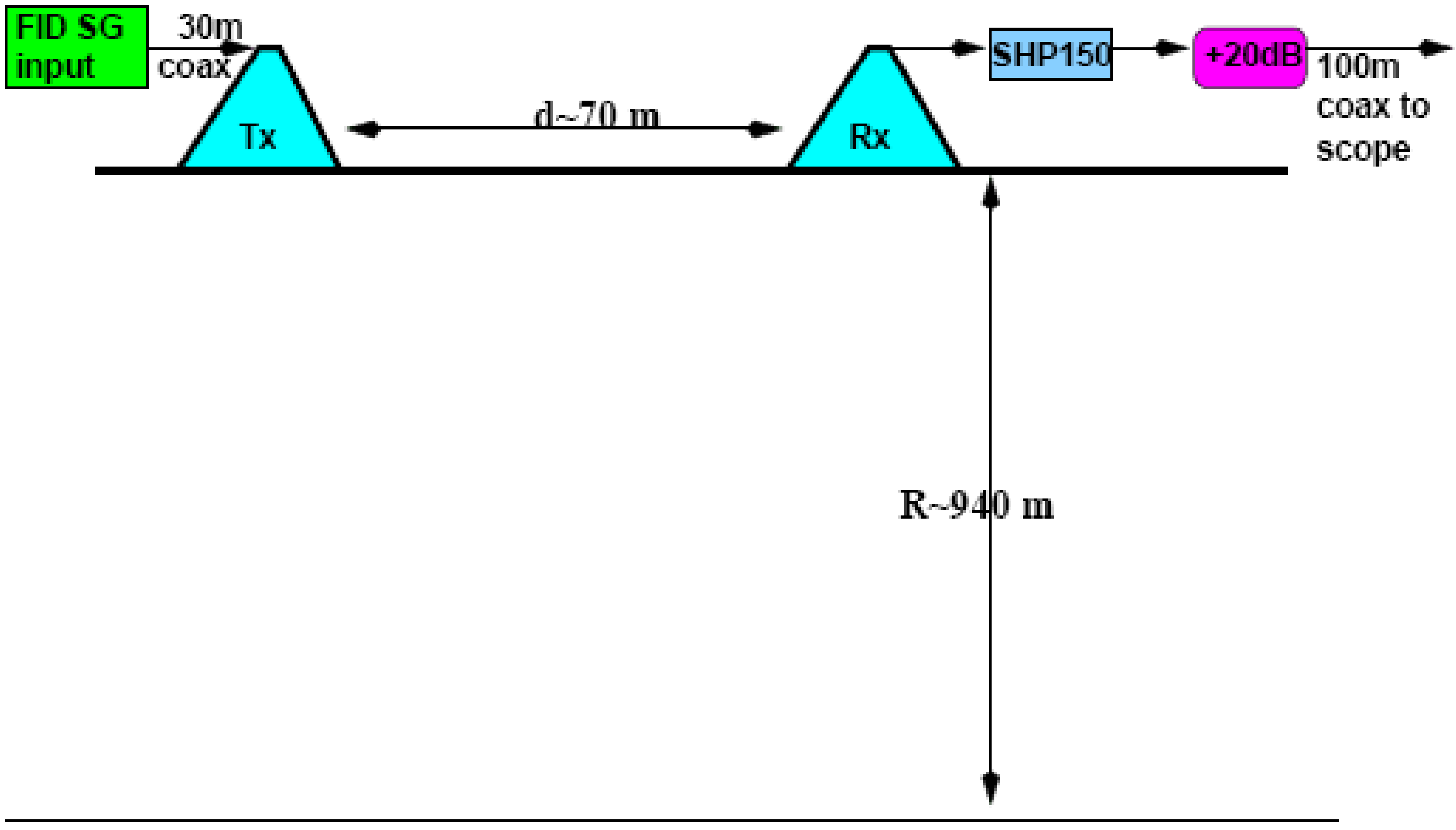


Data-taking underway, can only show Projected sensitivities

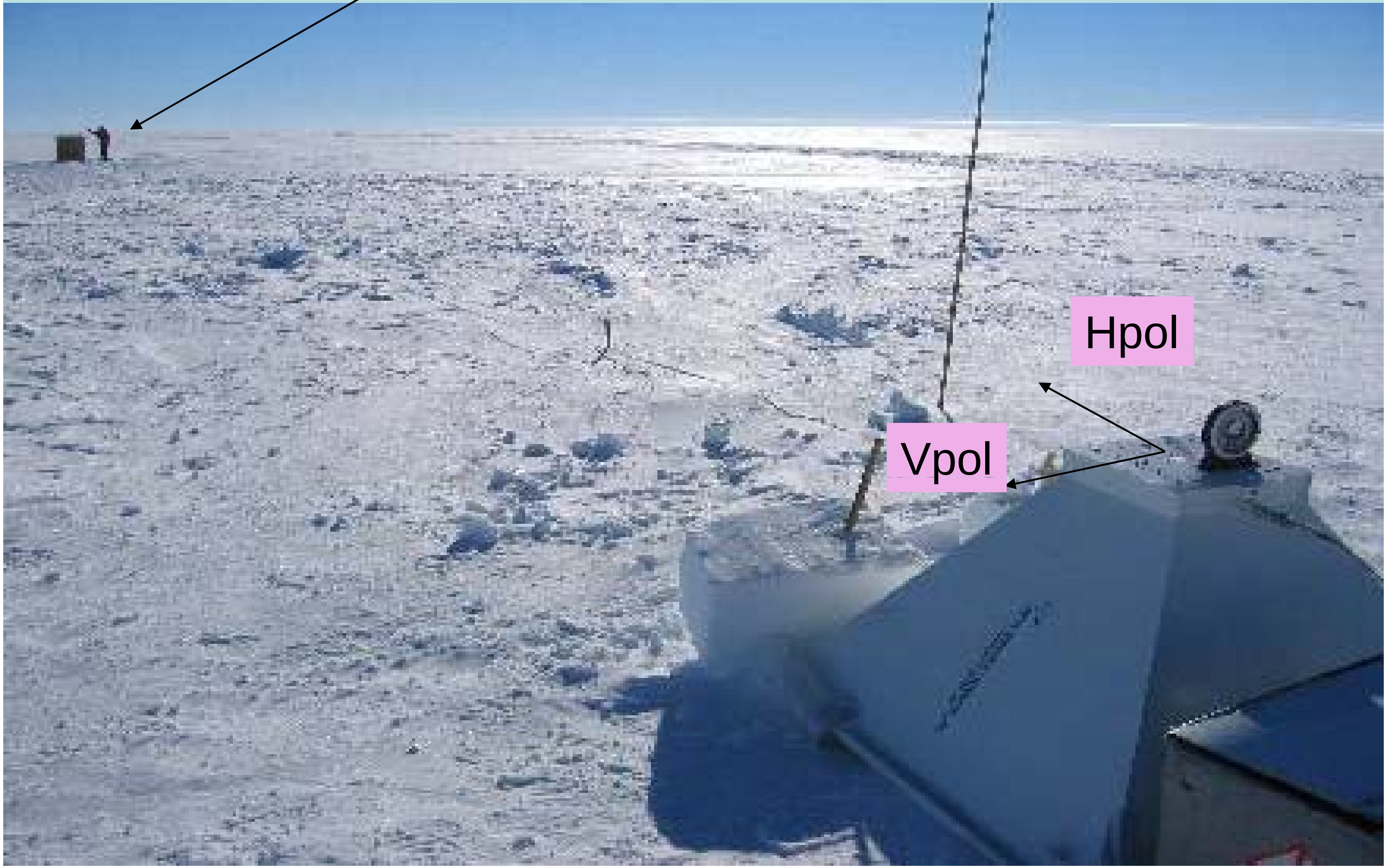
Table 1: *Expected numbers of events from a full range of GZK neutrino models for the total exposure of our 2006-2007 flight, and our proposed 2nd flight if it achieves the same duration but with improved efficiency, and improved energy threshold as per our proposed augmentations. The last column indicates the confidence level for model exclusion if no events are observed.*

GZK neutrino models	*Events, 1st flight*	*Events, 2nd flight*	*Total Events*	*Exclusion CL, 0 events*
All-iron UHECR [34]	0.01	0.02	0.03	—
Minimal, no evolution [33, 29, 30]	0.5-0.8	1.1-1.8	1.6-2.6	80-93%
$\Omega_m = 0.3, \Omega_\Lambda = 0.7$, Standard model [33]	0.8-1.3	1.6-1.7	2.4-3.0	91-95%
GRB UHECR-sources [65]	2.1	5.0	7.1	99.92%
Strong source z-evolution [33, 30, 28]	2.2-4.4	4.9-9.6	7.1-14	99.92-100%
Maximal, saturate all bounds [28, 30]	29-35	58-69	87-104	100%

Ice Properties Studies



Soul on Ice



In-air broadcasts

Taylor Dome attenuation lengths

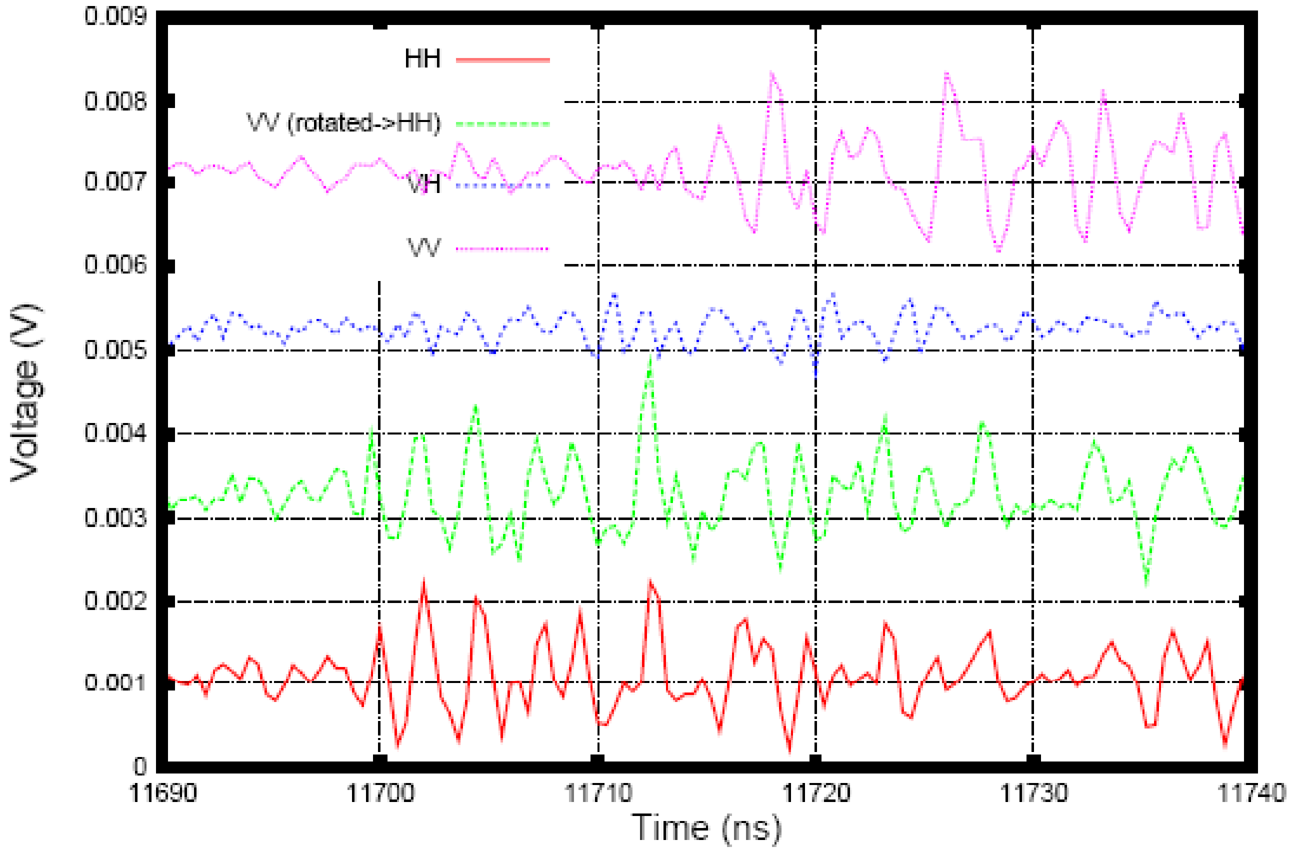
TABLE III: Summary of attenuation length measurements, under various assumptions for the reflection coefficient and the coherence characteristics of the underlying bedrock. Values shown are averaged over multiple measurements. Errors represent statistical spread of calculated values only.

Assumed Reflection Coeff.	Signal Normalization	Assumed Basal Scattering	Integrated Reflected Signal	Calculated $\langle L_{atten} \rangle$
1.0	In-air	Coherent	10 ns	340 ± 15 m
1.0	In-air	Coherent	50 ns	351 ± 15 m
1.0	In-air	Coherent	250 ns	616 ± 32 m
1.0	In-air	Incoherent	10 ns	441 ± 25 m
1.0	In-air	Incoherent	50 ns	458 ± 26 m
1.0	In-air	Incoherent	250 ns	1055 ± 95 m
1.0	Absolute	Incoherent	250 ns	628 m
0.3	Absolute	Incoherent	250 ns	1051 m

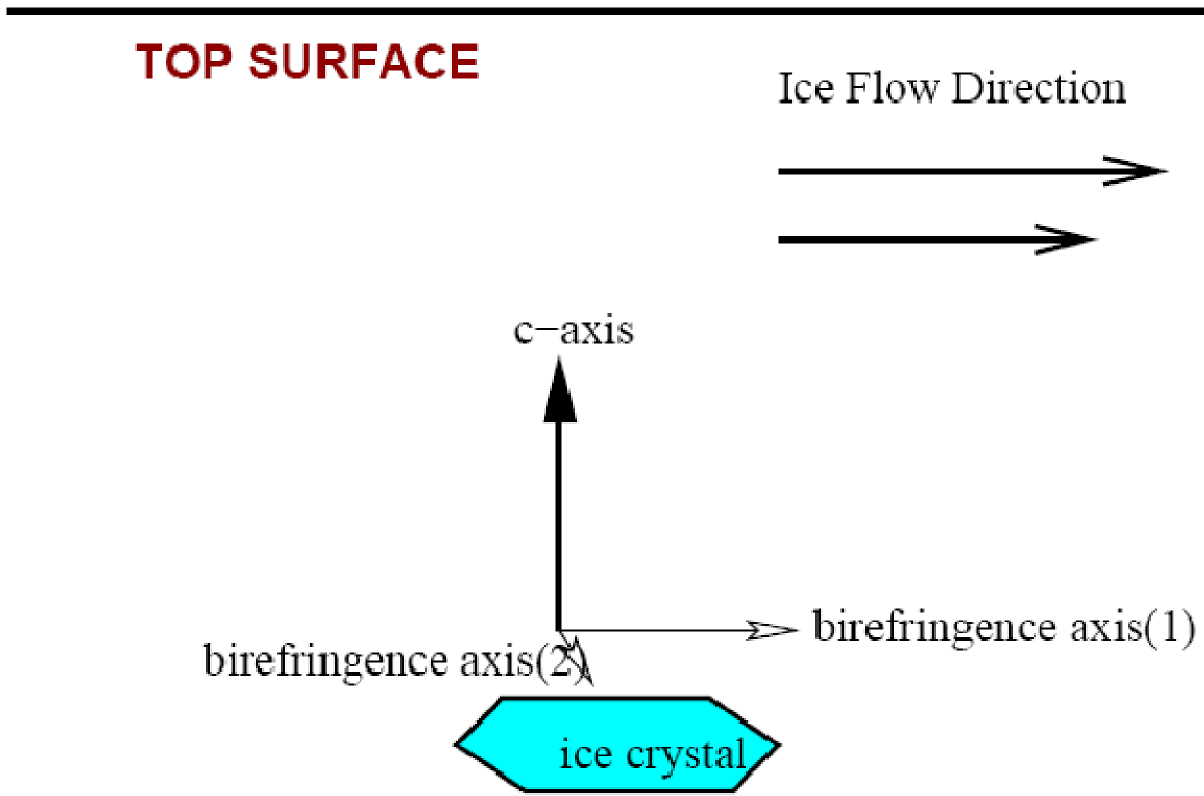
Compare: ~650 m at South Pole (averaged), 1650 m for T=-50 C

~200 m on West Antarctic Ice Sheet (WAIS)

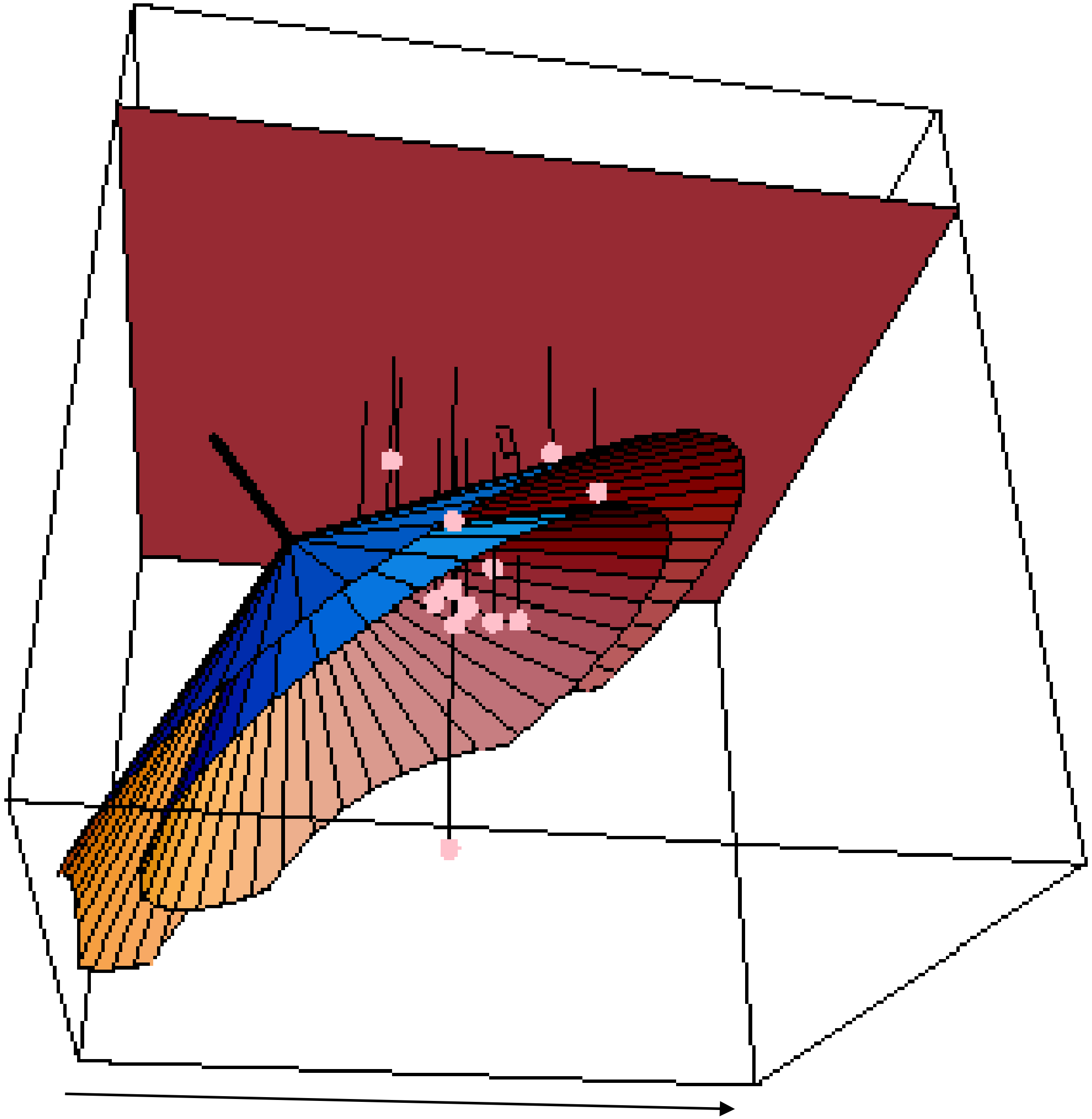
Birefringence! (0.12%)



Dielectric asymmetry due to COF

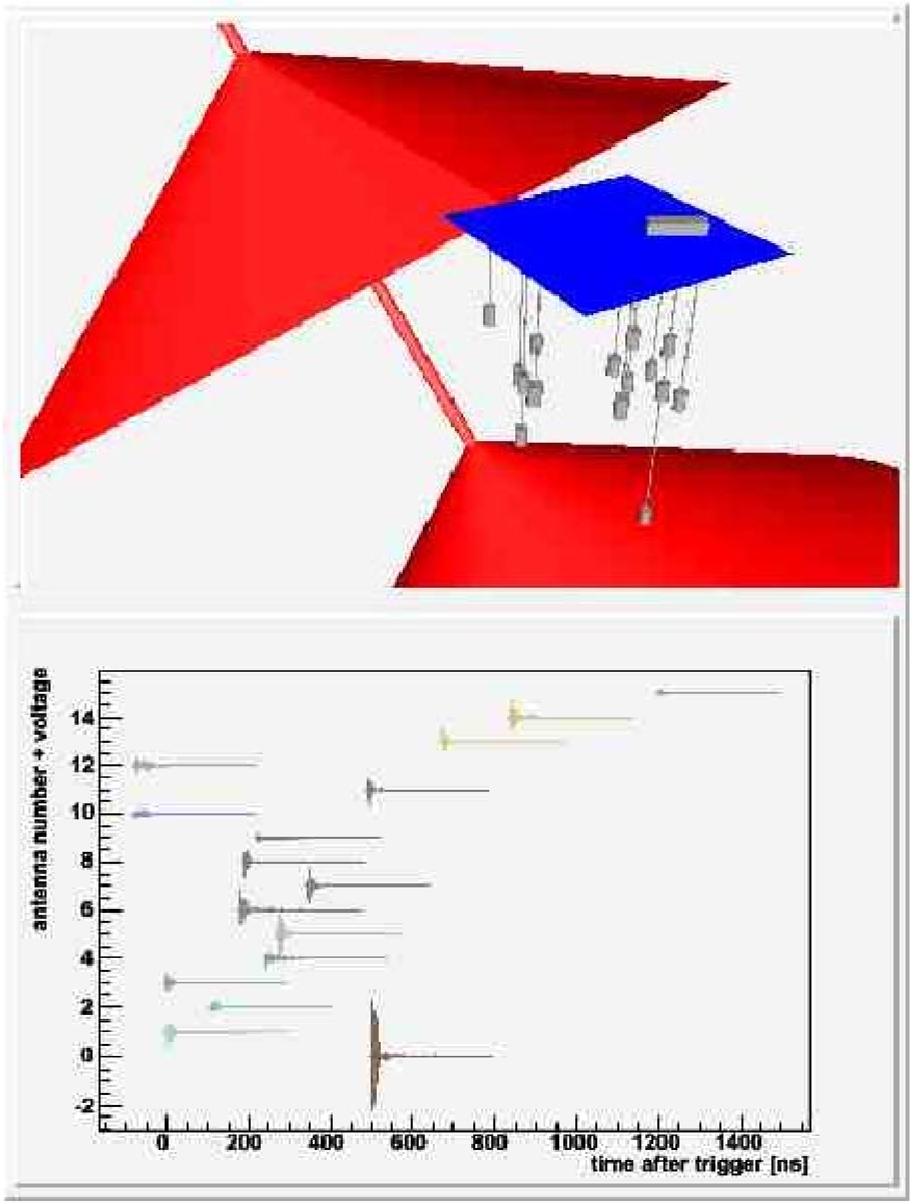


RICE, to-scale



400 meters

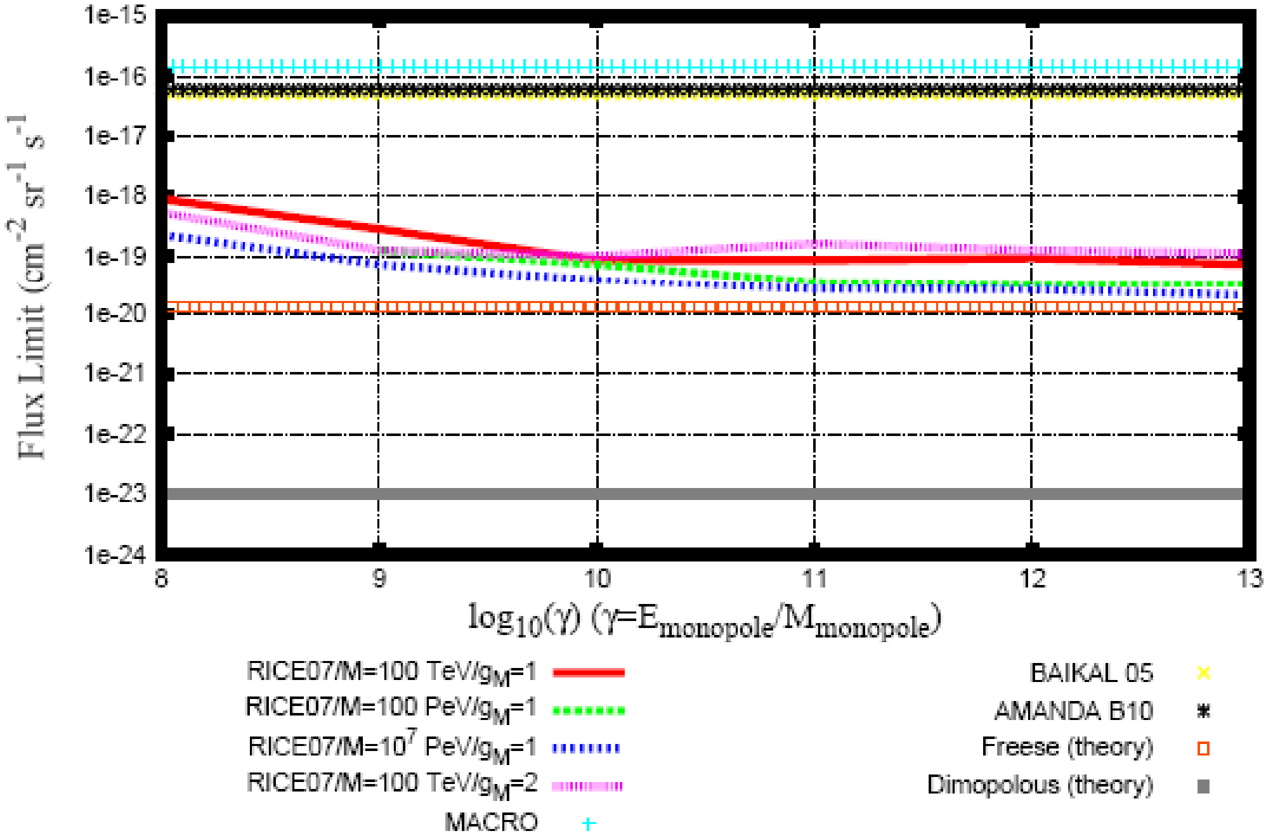
RICE monopole search



In-ice experiments have good sensitivity to ionization trail left by q=68.5e magnetic monopole. (Wick, Weiler et al, 2000).

Over kinematic region of interest here, photonuclear interactions dominate. (Note apparent error in original Wick et al calculation, however.)

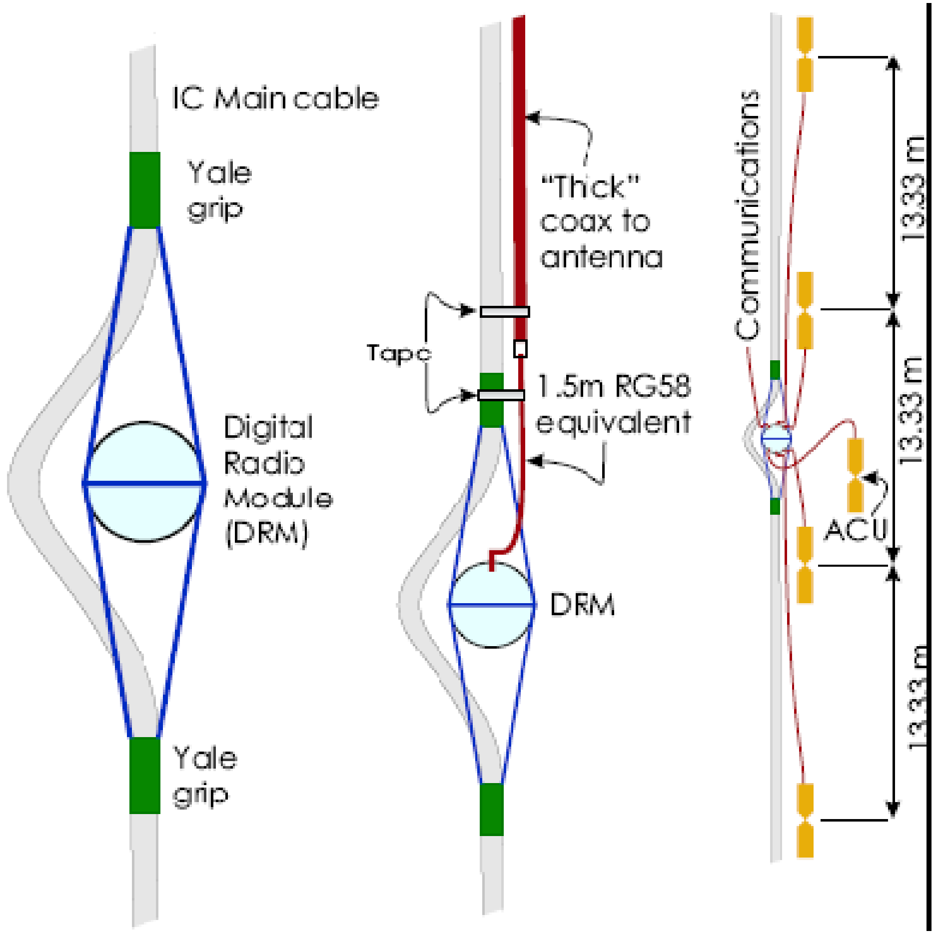
Monopole UL (RICE)



RICE plans: x2 sensitivity (end ’08)

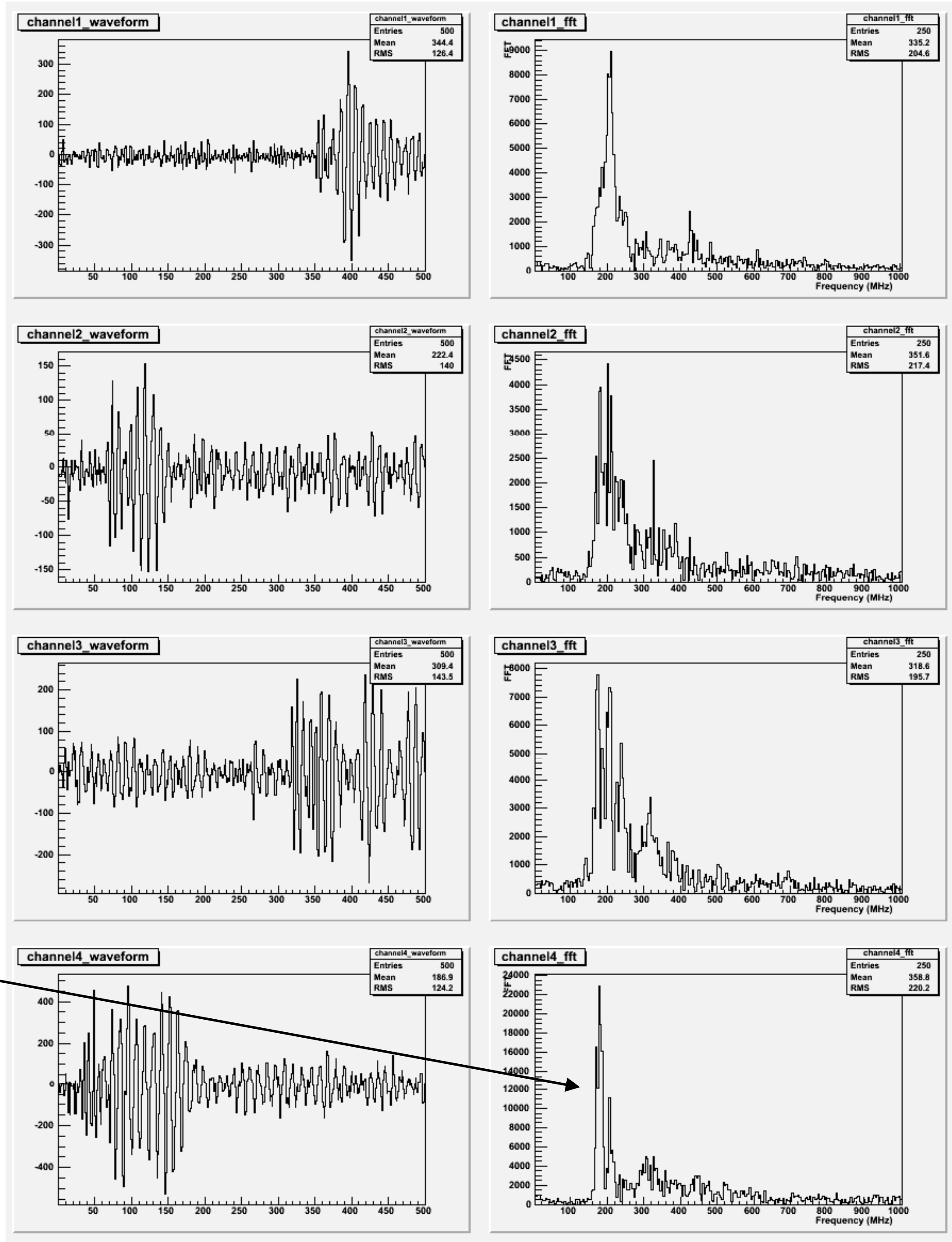
	1999	2000	2001	2002	2003	2004	2005	99-05	**06-07**
Total RunTime (10^6 s)	0.18	22.3	4.6	19.9	24.5	11.6	18.3	98.2	**27.2**
Total LiveTime (10^6 s)	0.10	15.7	3.3	13.6	17.1	9.4	15.5	74.1	**23.6**
DeadTime (303 ON) (10^6 s)	0.03	3.7	1.0	4.1	5.6	1.1	0.0	15.5	-
$\geq$4-hit General Triggers ($\times 10^4$)	0.26	30.6	6.0	16.9	13.8	9.4	26.5	103.5	**11.5**
Unbiased Triggers ($\times 10^4$)		3.3	1.3	3.5	4.4	2.5	4.0	19.0	**5.4**
AMANDA-coincidences ($\times 10^4$)	0.064	1.9	2.4	0.016	0.056	0.075	0.002	4.51	**0.03**
SPASE-coincidences ($\times 10^4$)		0.48	0.003	0.47	0.021	0.001	0.067	1.04	**0.02**
Veto Triggers ($\times 10^6$)	0.012	111.8	3.17	129.7	31.5	1.42	4.71	282.4	**250.2**

AURA (jan. 07 deployment)

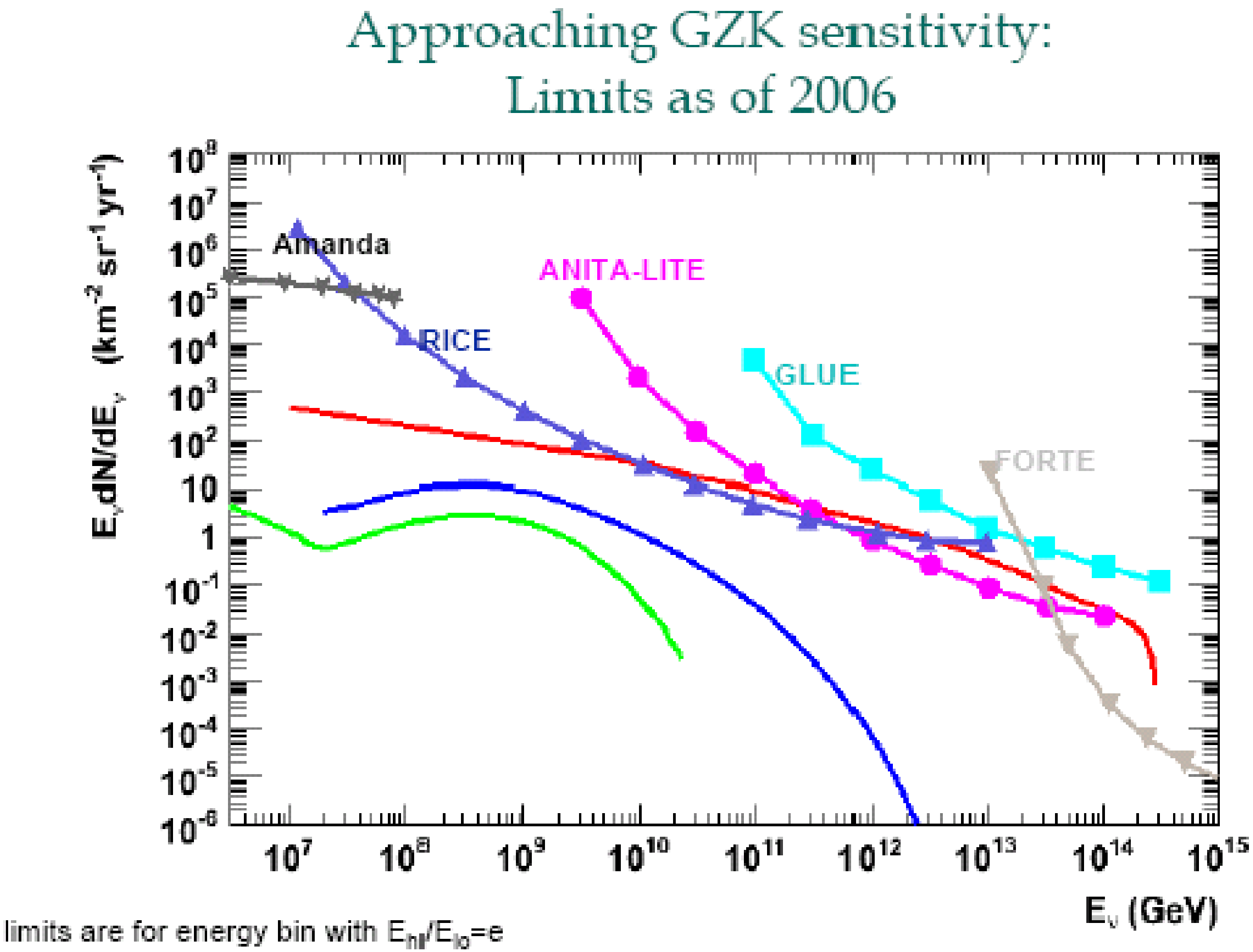


AURA: Received pinger signal / Transmitter at center of cluster

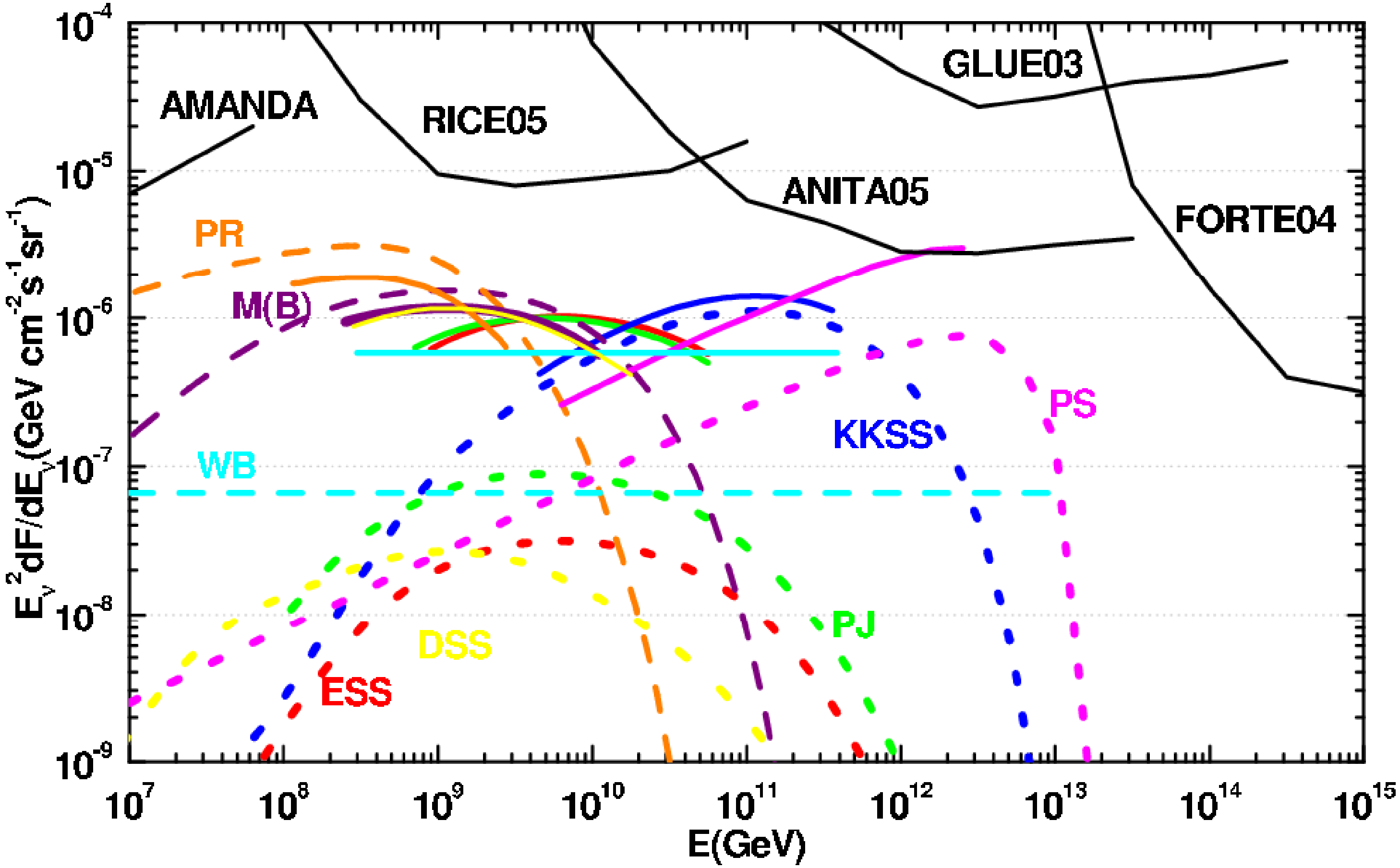
DRM-generated noise?



Upper limits (Saltzberg)



Upper limits (Hussain)



Cautions: 1) presented upper limits can `float' horizontally (no energy resolution), 2) different model parameters used for different modes, 3) 90% vs. 95% C.L. limits, 4) results depend on binning

Acoustic compared to Radio

+)~10 km L_{atten} in ice?

+) 20 khz-50 khz digitization and signal transmission➔can do all triggering/DAQ on surface with no high-frequency signal losses

+) Ray tracing insulates acoustic waves produced at surface from interior

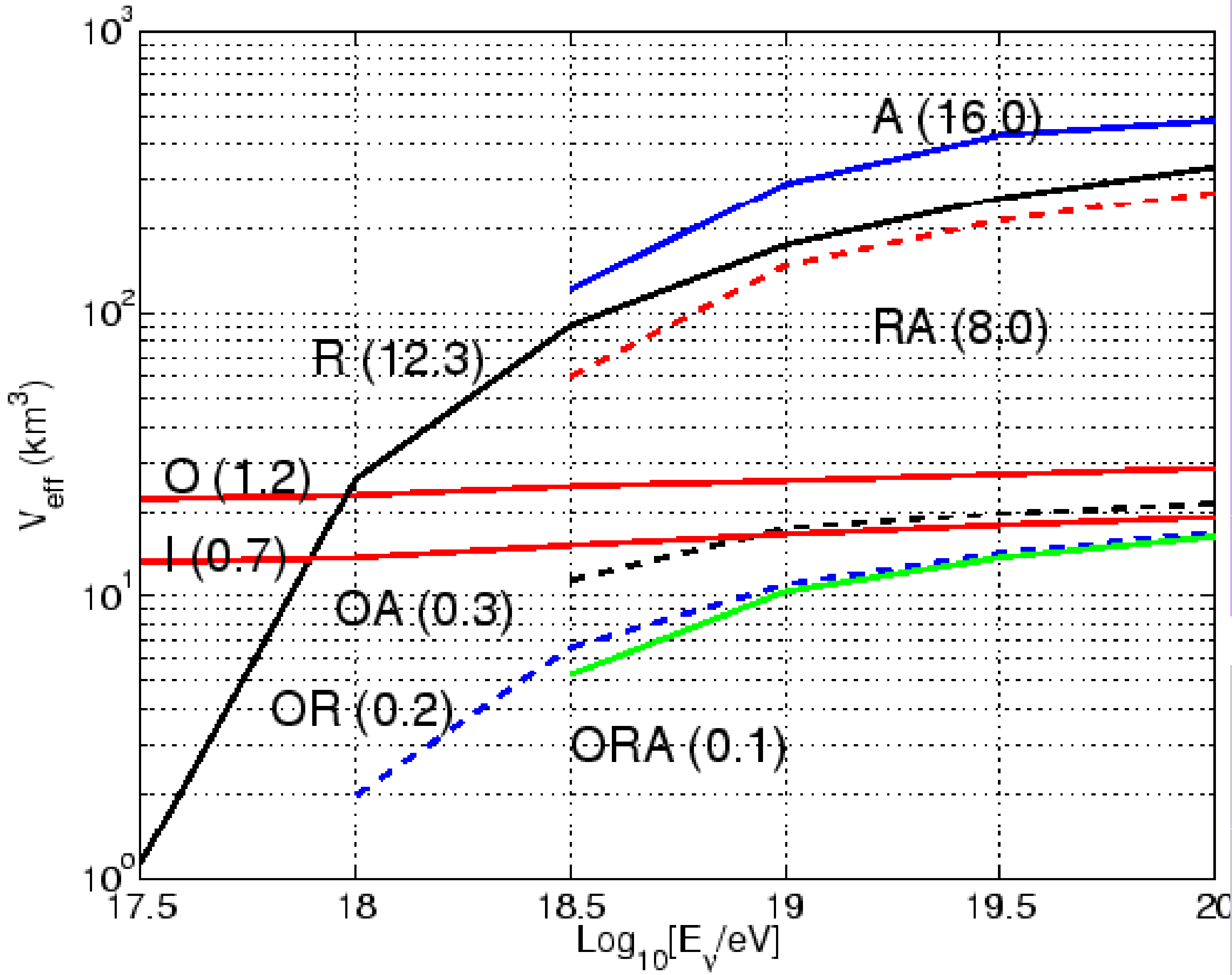
+) No battle with RF backgrounds

0) both polarizations

-) 1/f noise forces threshold up to 10^{19} eV

BEST IF YOU CAN DO BOTH!

Secular* Grail: Simultaneous obs.! GZK evts / hybrid dector (c. 2010)



N.B: coincidences offer lower thresholds (50%?), enhanced event reconstruction (Justin Vandenbrouke WG talk tomorrow)

*(an obscure reference to local KS politics; not crucial to understanding talk as a whole)

Conclusions (mine)

- Simulations are mature
- Testbeams have demonstrated coherence effects
- Sampling, signal transmission, and DAQ hardware has been extensively developed➔
- Expect maturation of initial round of experiments (1st generation - ANITA, LOFAR, AURA, e.g.) in next 3-5 years, with possible first indications of UHE neutrinos
- As we get closer to theoretical predictions, systematics will grow in importance..
- Community & interest will continue to grow over next 5 years.

Conclusions (mine, cont.)

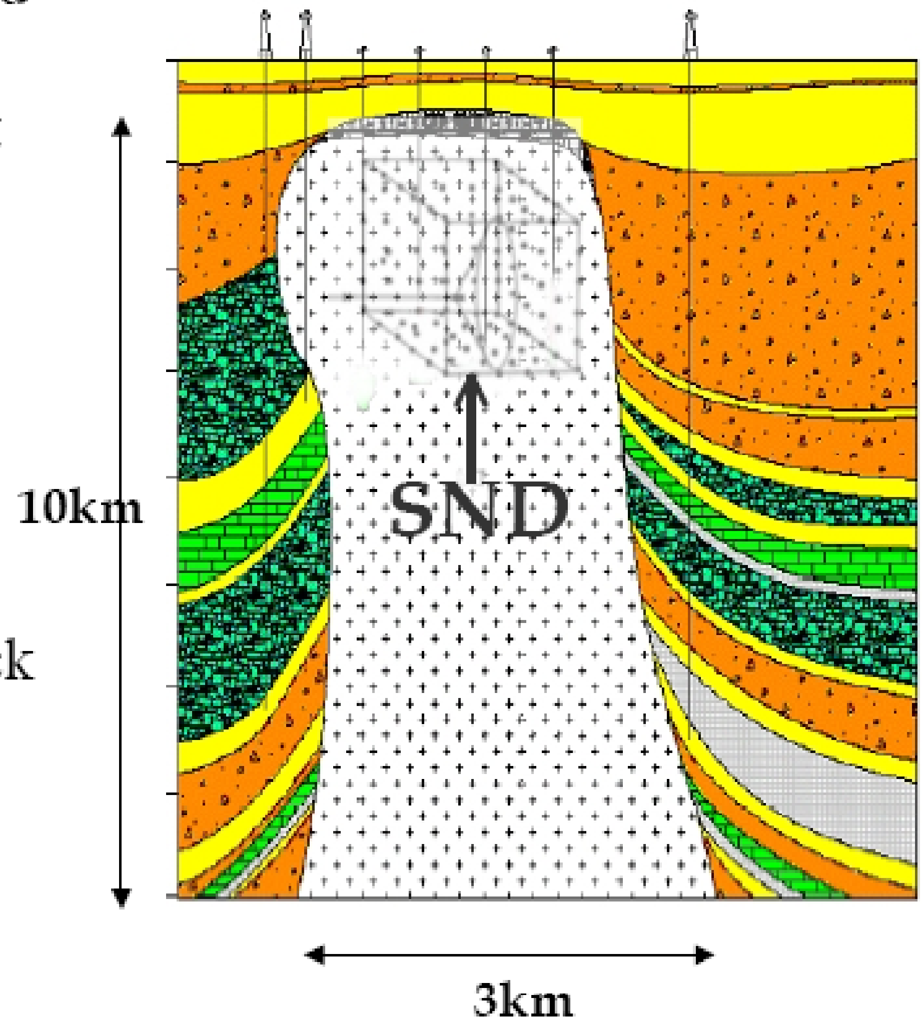
- The science is compelling for construction of a large-scale array.
- To convince the `community' will require either:
  - Tens-hundreds of GZK 'solid' neutrinos measured in one experiment, OR:
  - Couple-few GZK 'solid' neutrinos measured in each of >1 experiment, OR:
  - 1-2 GZK 'solid' neutrinos measured in conjunction with an already-demonstrated (e.g., PMT) technology.
- To do all the science we'd like will require >1 detector (one north, one south), each with 100 km^2-2π-10^8 sec sensitivities. (ILC era)

	Hardware cost	Reach/ thrshold		X-factor
NuMoon	$0	10^{20} eV		Averaging over lunar surface / had/ν separat.
LOPES LOFAR	$0	10^{15} eV		Effective area per receiver ~ 100m x 100m
Salt	$7K/Rx (14K Rx)	10^{16} eV		$1M/drilled hole, hole-to-hole variations
Ice, in situ	$7K/Rx (2K Rx)	10^{18} eV		RFI is fundamental! South Pole, e.g.
Ice, on situ	$3K/Rx (10K Rx)	10^{16} eV		Imaging source difficult; 50% deadtime (dark)
over situ	$10M (total)	10^{20} eV		Averaging over lots o' ice; only see surface

Salt Neutrino Detector Installed in a Salt Dome

1. Rock salt is free from liquid and gas permeation• petroleum or natural gas are likely to deposit around a salt dome.
2. Free from water permeation leads good radio wave transparency in a salt dome.
3. Covered soil prevents surface radio wave to penetrate.
4. Conceivable background is black body radiation in salt dome.

Dow Earth Sciences, Geol: J.Hertzing

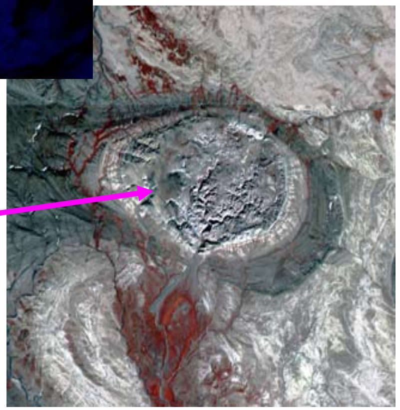


M.Chiba

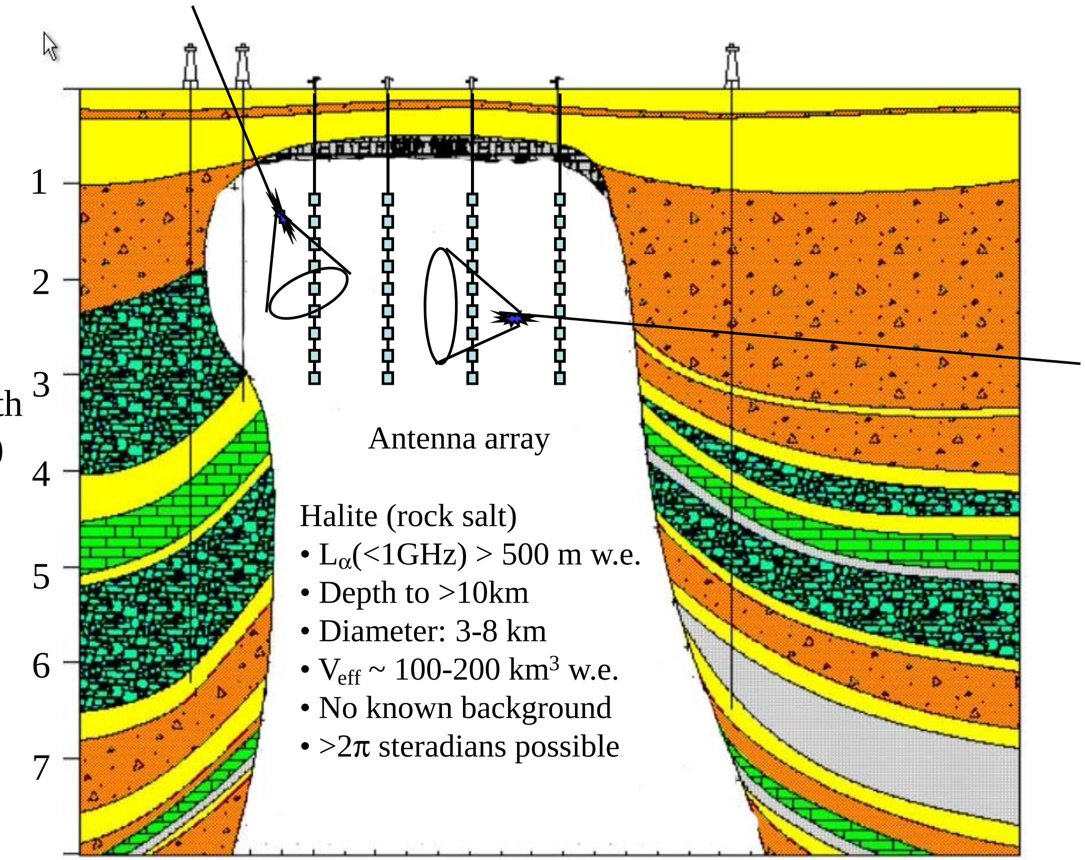
Saltdome Shower Array (SalSA) Concept

Salt domes: found throughout the world

Qeshm Island, Hormuz strait, Iran, 7km diameter

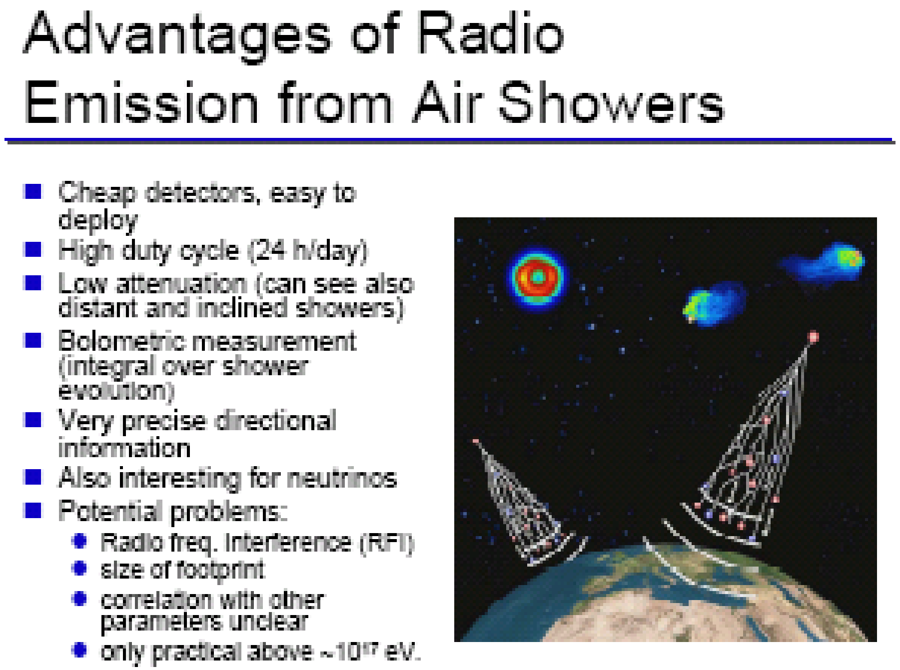


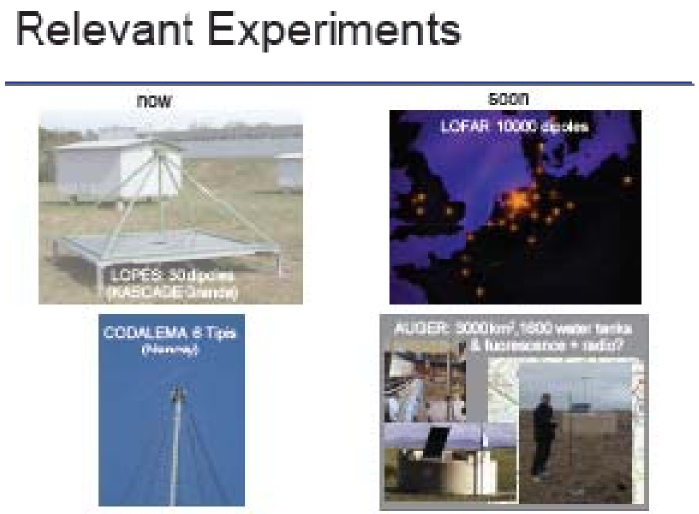
Isacksen salt dome, Elf Ringnes Island, Canada 8 by 5km

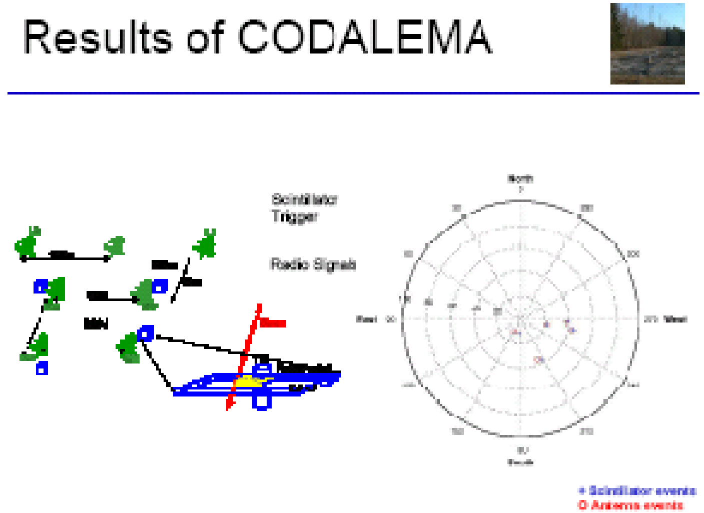


- Rock salt can have extremely low RF loss: ➔ as radio-clear as Antarctic ice
- ~2.4 times as dense as ice
- typical: **50-100 km^3** water equivalent in top ~3km ==>**300-500 km^3 sr possible**

Air shower detection of EAS (Heino Falcke, plenary)





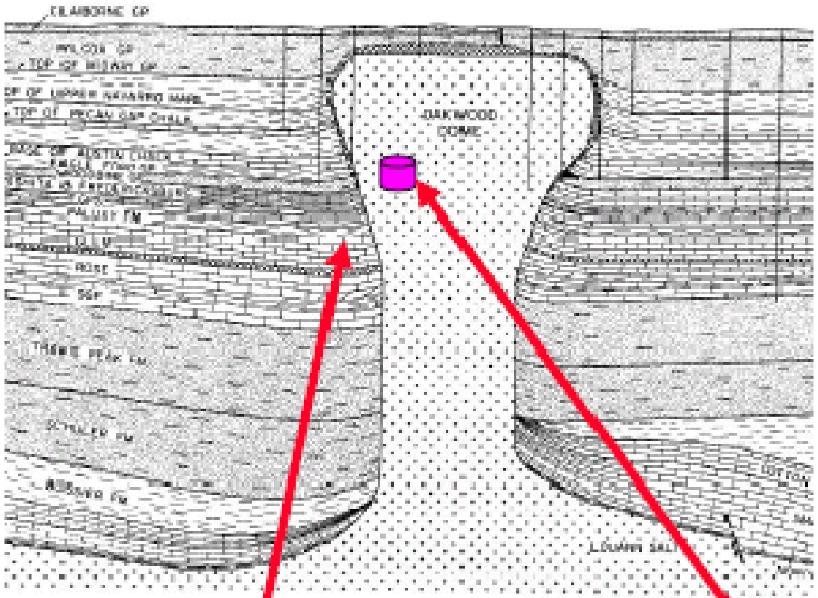


Threshold~100 PeV, LOPES must be externally triggered by ground detectors.

5 highly inclined events in 2004 data.

SALSA

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× denser than ice
  - easier to deploy than S.Pole
- Calorimetric; large V,ΔΩ; Cherenkov polarization usable for tracking
- Good candidates in Texas and Louisiana, maybe Utah
- Dutch investigating sites as well

Salt

- Experimental site on continental US?
- Surface layer+water ➔ ‘insulating barrier’, but:
- Uncertain salt properties, site-to-site
- Lab measurements encouraging but not fully fleshed out (L_{atten}~50 m → 1 km)
- High Drilling Costs
  - (~1M/hole vs. 50K/12 cm, 1 km deep hole at Pole)

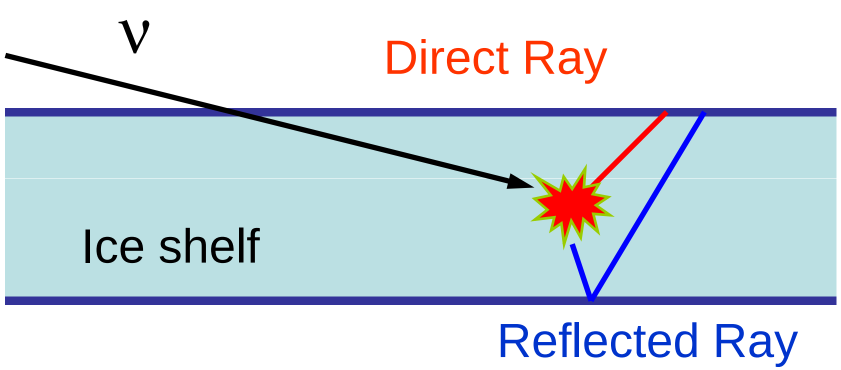
NuMoon Experiment @ LOFAR

- Total collecting area 0.5 km^2
- Cover whole moon,
- Sensitivity 25 times better than WSRT.
- Bands:
  - 30-80 MHz (600 Jy)
  - 115-240 MHz (20 Jy)

ARIANNA (proposed)

(Antarctic Ross Ice shelf ANtenna Neutrino Array)

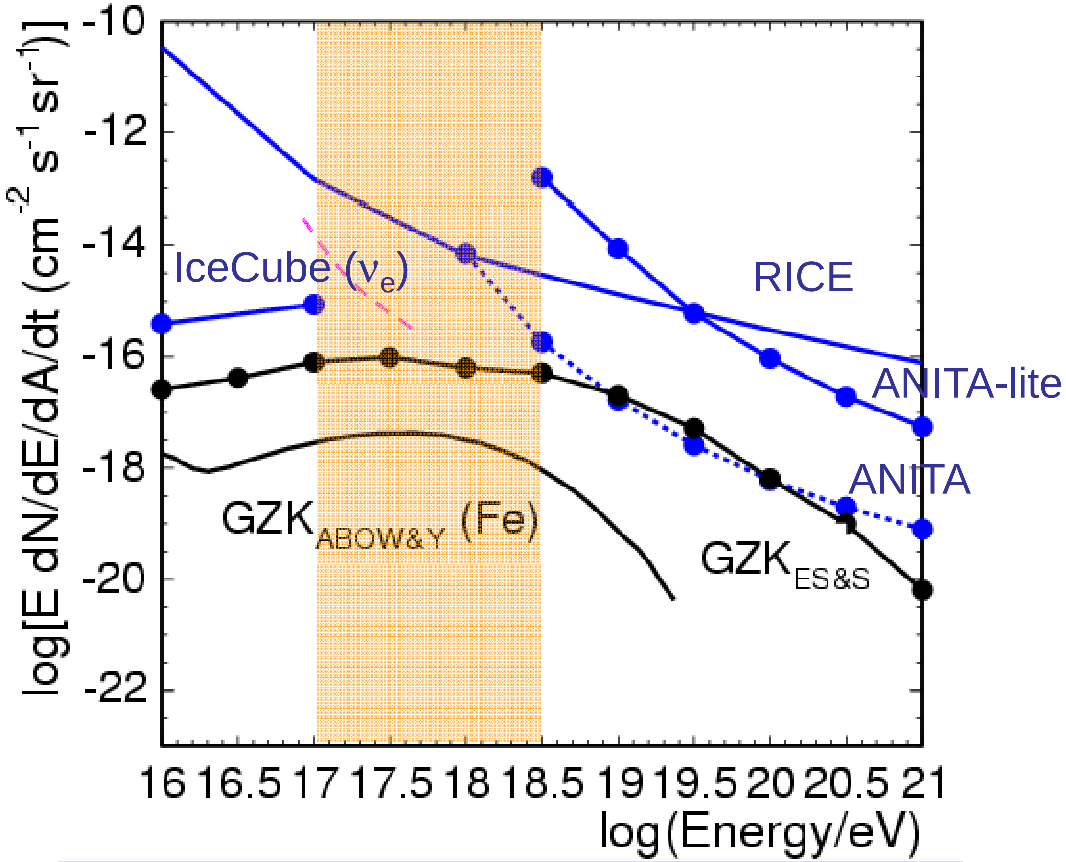
- Combining
  - SalSA's low threshold and large solid angle
  - "Accessibility" of Antarctic Ice compared to drilling in salt domes
  - Detection of reflected rays being developed for ANITA
- Array of antennas atop the Ross Ice Shelf looking down
  - No deep holes
  - Very competitive predicted sensitivity



Cosmic rays shower in the atmosphere, before reaching the ice

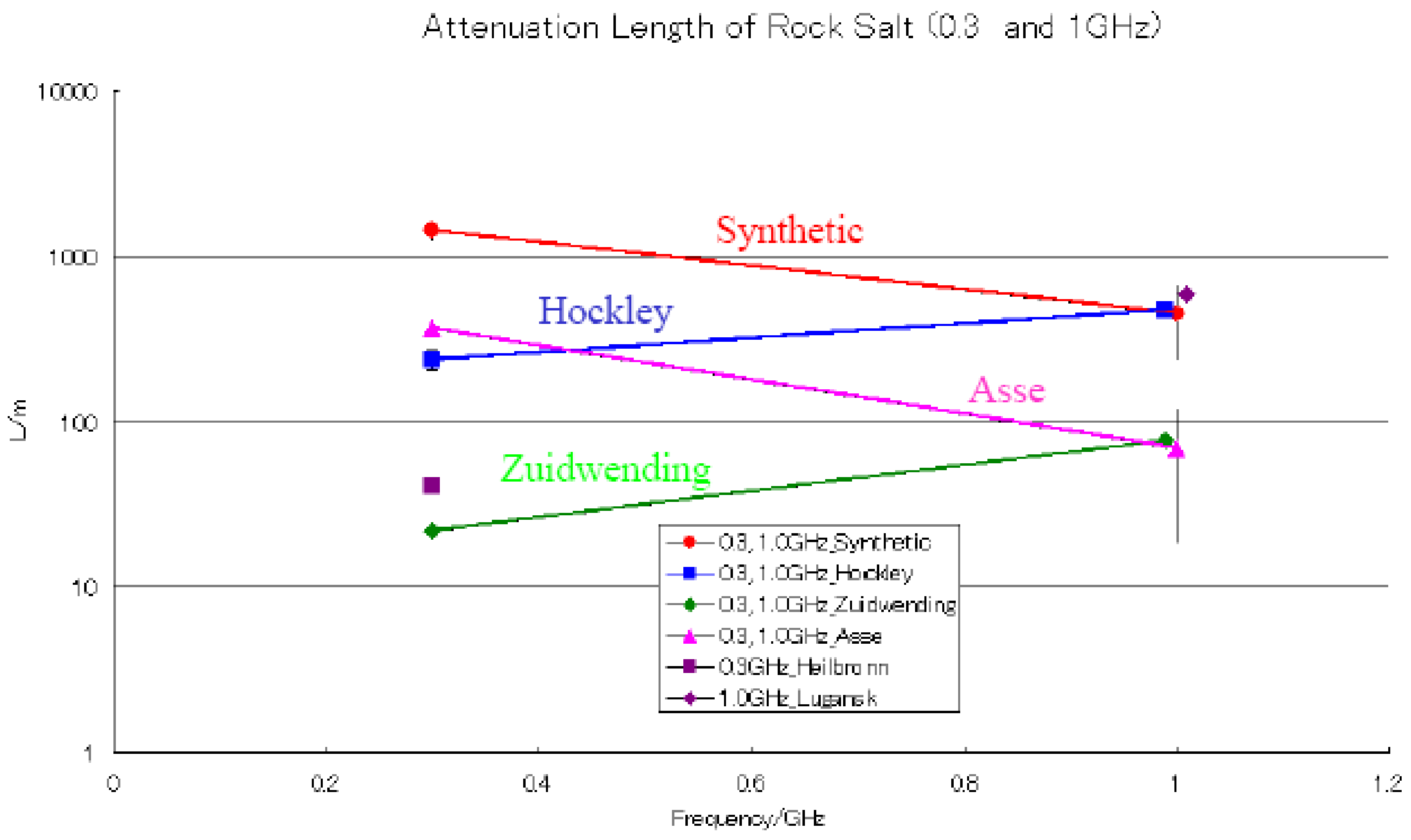
Embedded Detectors Designed to Span the Energy Gap (<GZK)

- Detectors embedded in the interaction medium have lower energy threshold compared to ANITA, GLUE, FORTE
- SalSA, ARIANNA
- Other embedded detectors (AURA, acoustic experiments) are also aiming for a similar region in parameter space



ARIANNA, SalSA both aim to measure a large sample ~100 of EeV neutrinos

Two types of Frequency Dependence (Preliminary)



Do we need multiple radio expts?

- Threshold~experimental scale (coincidence trigger requirement)
  - 10^{13} eV threshold (10^4 elements, 20 m spacing, surface array [Greenland]) viewing upcoming Sgr*A neutrinos
  - 100 m spacing←→Dense packed expt (RICE, e.g.); showers typically several km distant→10^{17} eV
  - 38 km height; showers typically 100 km distant→10^{19} eV threshold (ANITA)