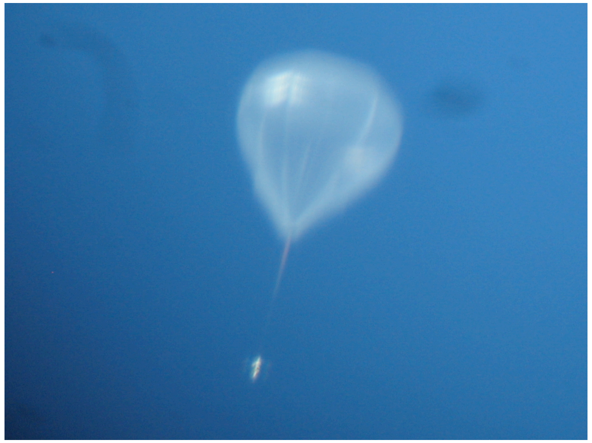
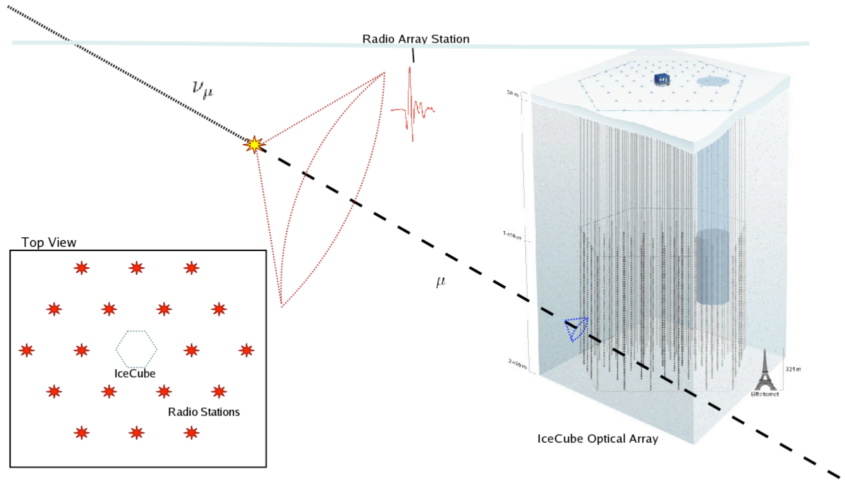
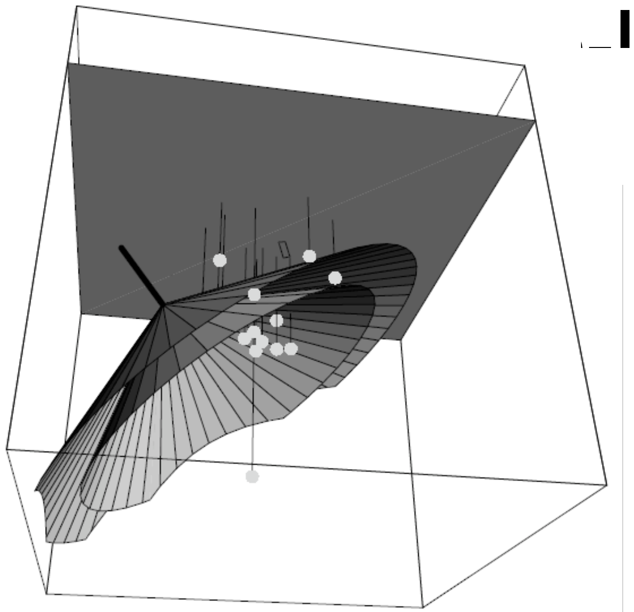
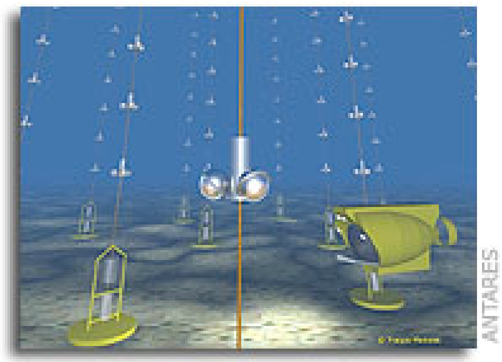
High Energy Neutrino Experiments



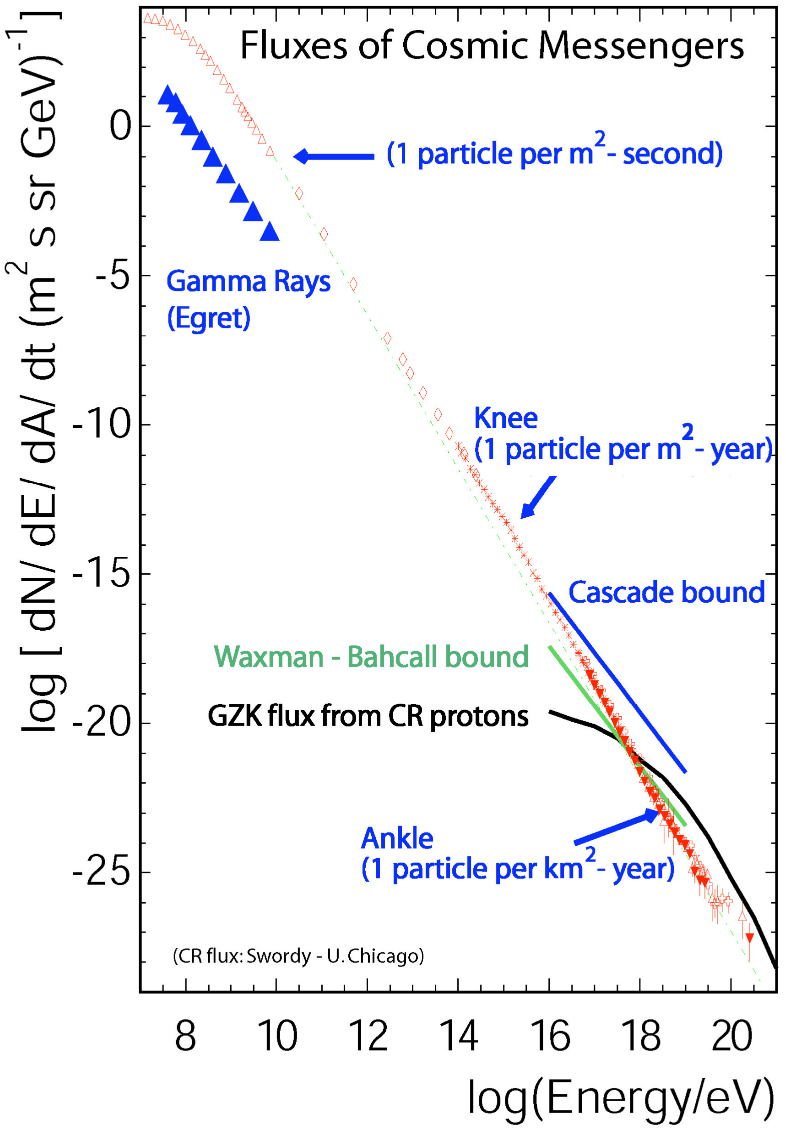






Amy Connolly
University College London
Neutrino Horizons in the 21st Century
18 April, 2008

Cosmic Messengers



- Only cosmic messengers observed so far are (charged) cosmic rays and gamma rays
- Neutrinos would
  - Point back to their source
  - Travel cosmological distances unattenuated
  - Extend beyond CR cutoff
- Expect neutrinos from:
  - Gamma Ray Bursts
  - Active Galactic Nuclei
  - CR interactions with CMB
- I will discuss experiments searching for cosmic neutrinos above $\sim 10^{12}$ eV

The only extraterrestrial neutrinos seen: The Sun and SN1987a

Each source has:

1. Had a important impact on particle physics

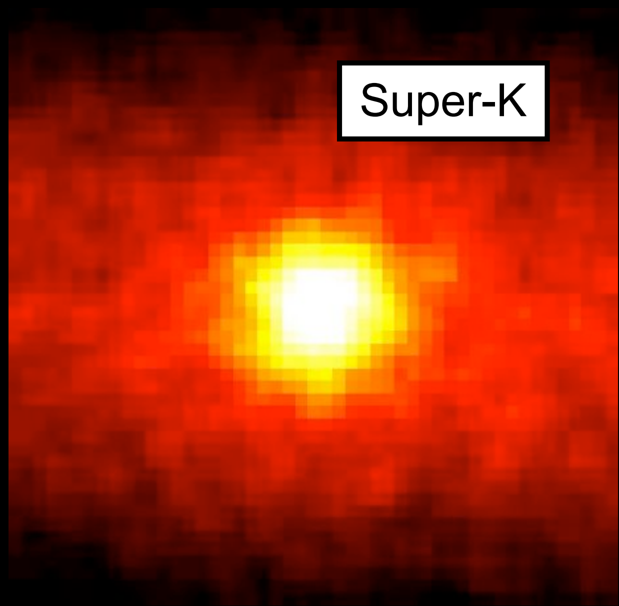
2. Looked deeper into the source than otherwise possible

The Sun

Weak eigenstates ≠ mass eigenstates

→ neutrinos have mass

Supernova 1987a



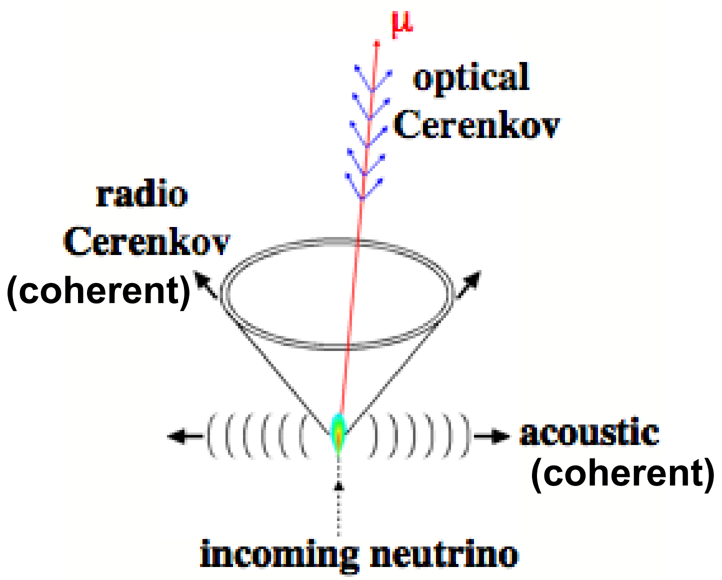
Lack of dispersion
→ mass limits

High Energy Neutrino Detection Techniques

- High energy neutrinos can be detected through: air showers**, optical***, radio* and acoustic*

  *** Observed from neutrinos
  ** Observed from a natural process (CR's)
  * Observed in beam tests

For example:
$\nu_\mu + p \rightarrow \mu$ + hadronic shower



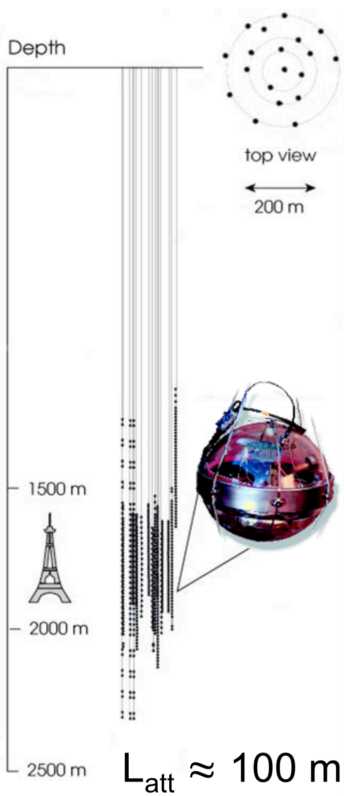
Attenuation Lengths

	Attenuation Length		
	water	ice	salt
EM optical (Cerenkov)	~ 50 m	~ 100 m	? (large)
EM radio (0.1-1.0 GHz)	~ 0	~1 km	~few 100 m?
Acoustic (10 kHz)	~ 10 km	? (large)	? (large)

- Steeply falling spectrum → larger volumes needed to reach higher energies
- Optical: 10^{11} - 10^{18} eV
- Radio: > 10^{18} eV
- Acoustic: Above 10^{18} eV, under investigation

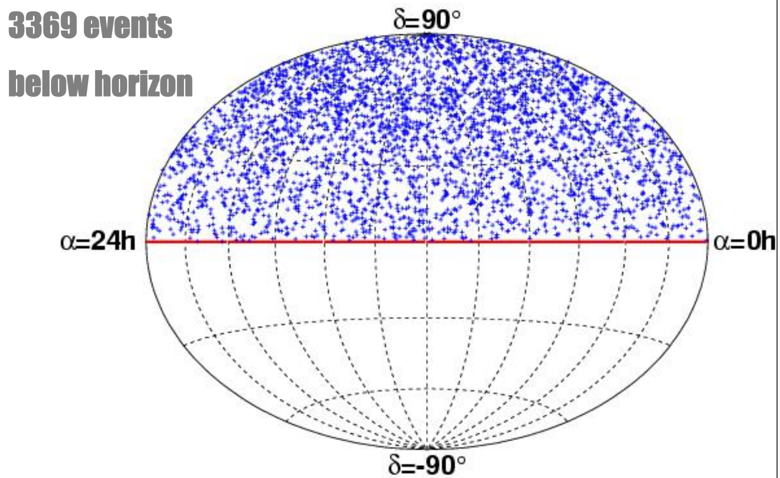
Amanda II

USA, Germany, Sweden, Belgium, Venezuela



$L_{att} \approx 100$ m

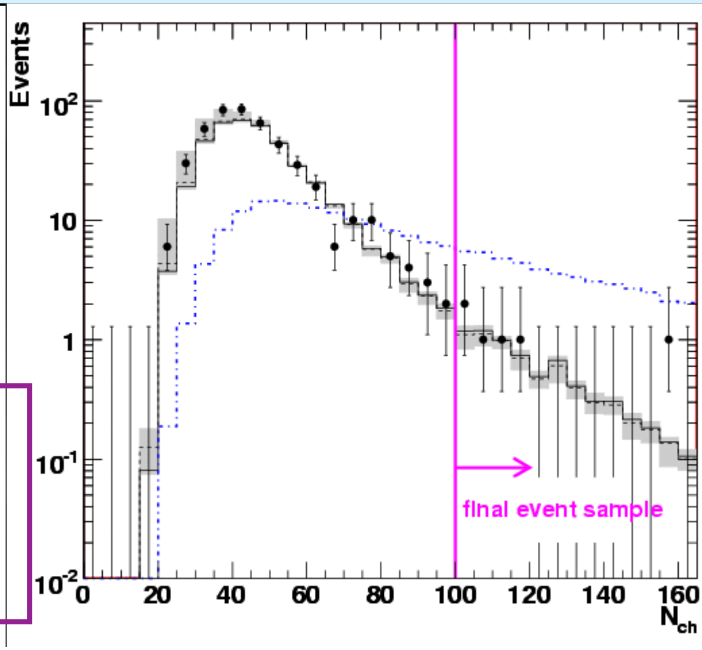
- Photomultiplier tubes (PMT's) deployed along strings
- Detect blue Cerenkov light from muons and particle tracks in showers induced by neutrino interactions in ice



Using earth as a filter, search for ***upgoing neutrinos***

Largest background from CR interactions in atmosphere: ***atmospheric neutrinos***

AMANDA II: 19 strings 1500-2000 m (1997 – present)



No excess observed over atmospheric neutrino expectation

No cosmic diffuse ν flux observed

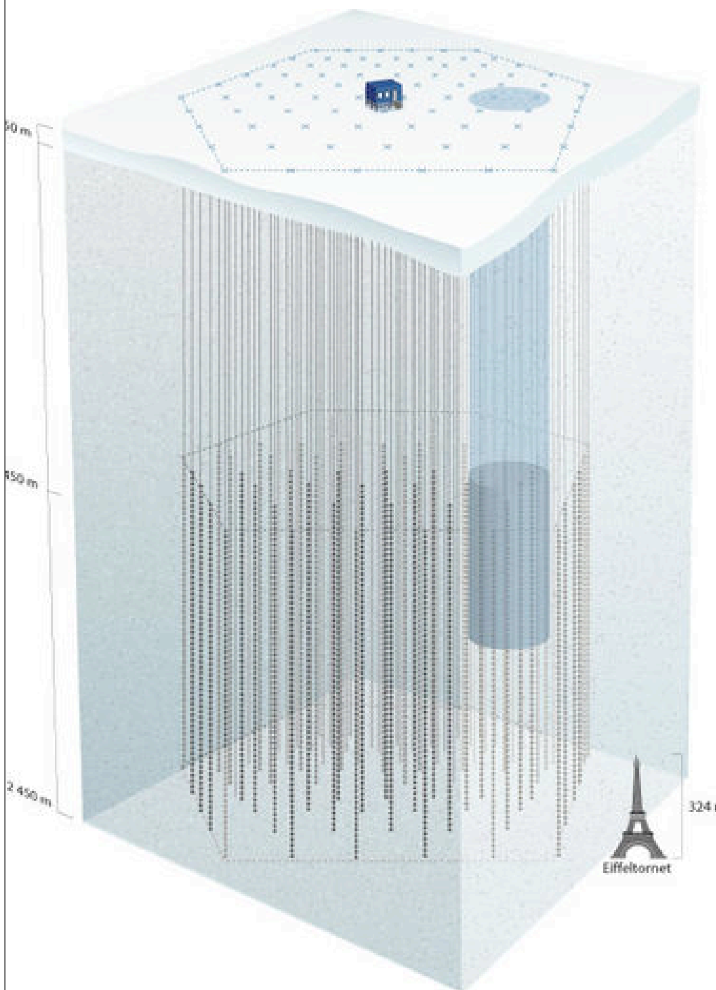
Observed neutrinos show no significant deviation from isotropic

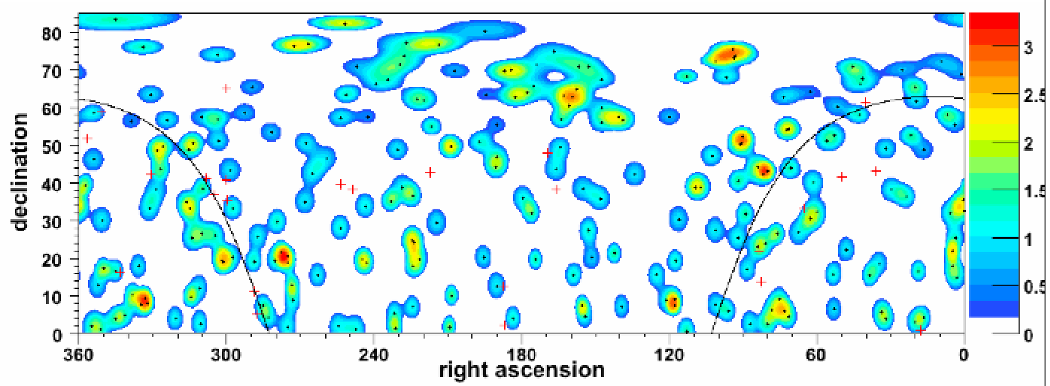
No point sources observed

IceCube

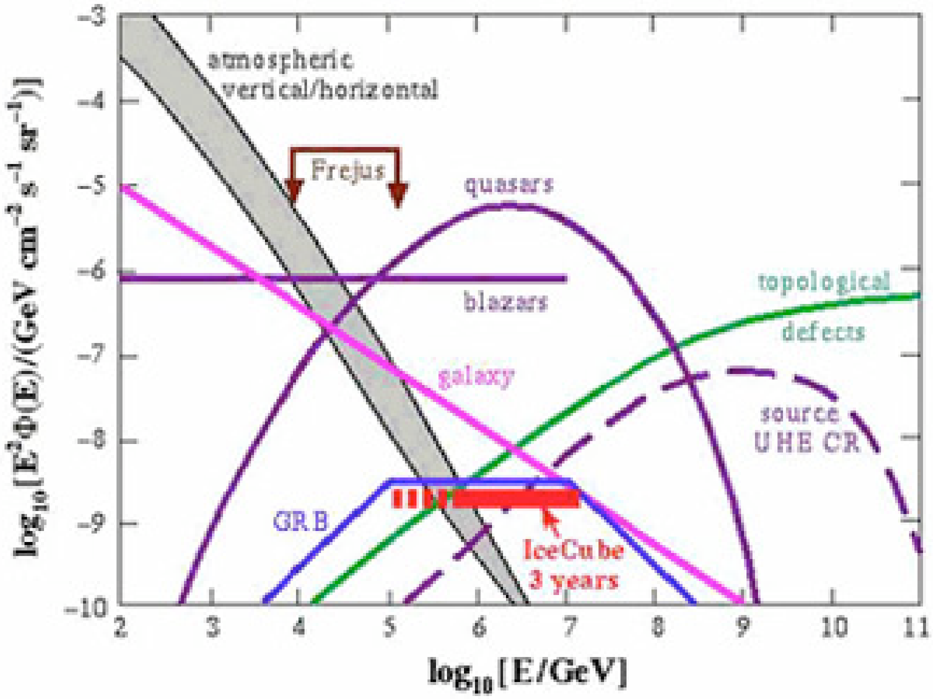
USA, Germany, Sweden, Belgium,
UK, New Zealand, The Netherlands, Venezuela

70 strings 1500-2500 m deep
160 tanks (IceTop)
(40 strings, 80 tanks are deployed)





Construction to be completed in 2011
70× the size of Amanda II



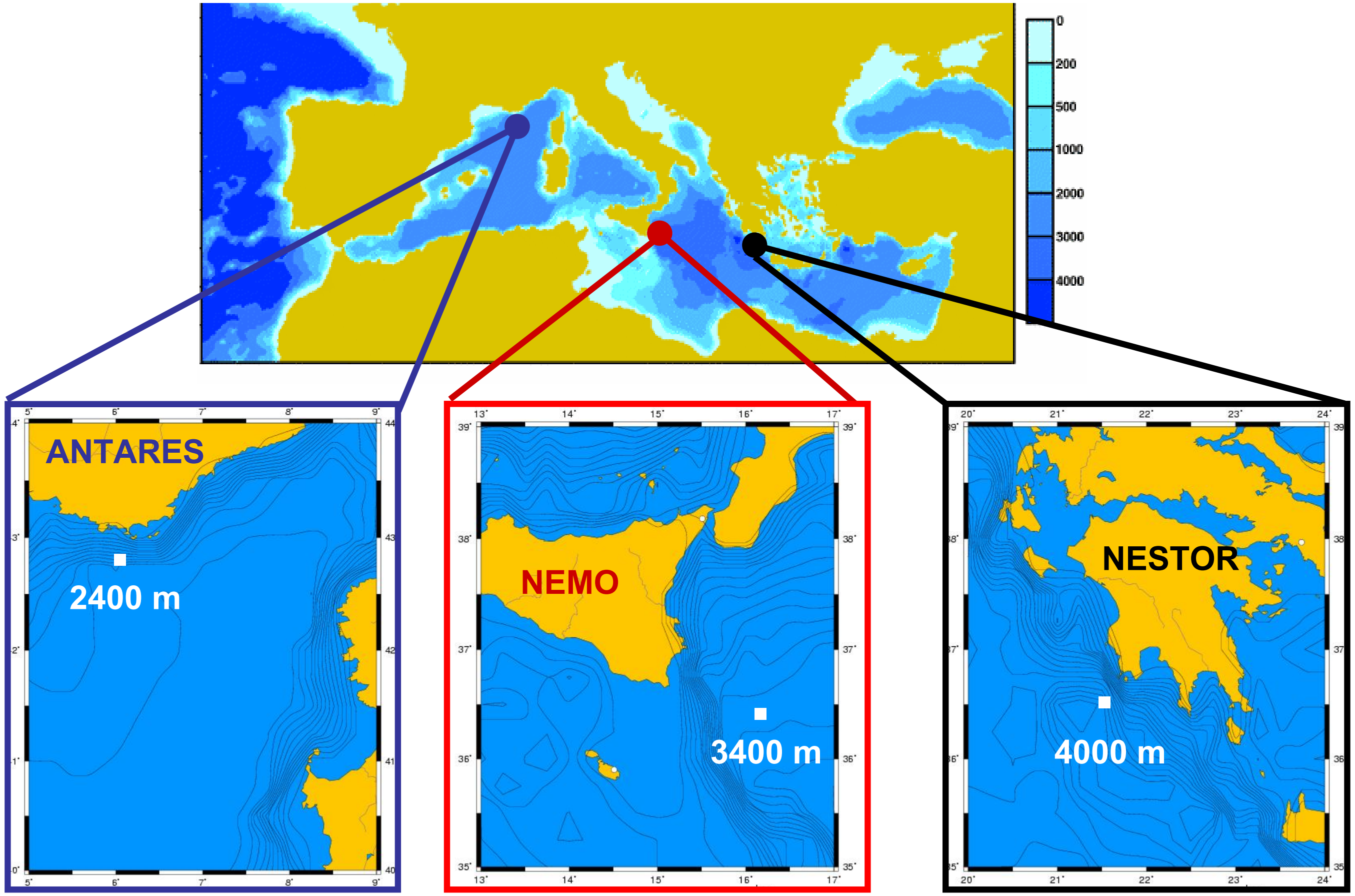
Optical Technique: Ice and Water

- Advantages of Ice as Medium
  - Established hole-drilling and infrastructure at South Pole
  - No bioluminescence
  - No biology "muddying waters"
  - No currents
- Advantages of Water as Medium
  - Less scattering, better angular resolution (<0.3° vs. 1°)
  - View region of sky that includes galactic center
  - More pleasant places to work!

DUMAND: First deep sea neutrino telescope - 4.8 km deep off coast of Hawaii 1980-1995

BAIKAL: Bottom (1100 m deep) of Siberian freshwater lake
NT200: 8 cables with 192 optical modules (OM's) 1998
Constrained diffuse cosmic ν flux, WIMPs, Mag. Monpls., point sources
Funding for R&D towards 1 km^3 detector: TDR 2008, deployment 2010

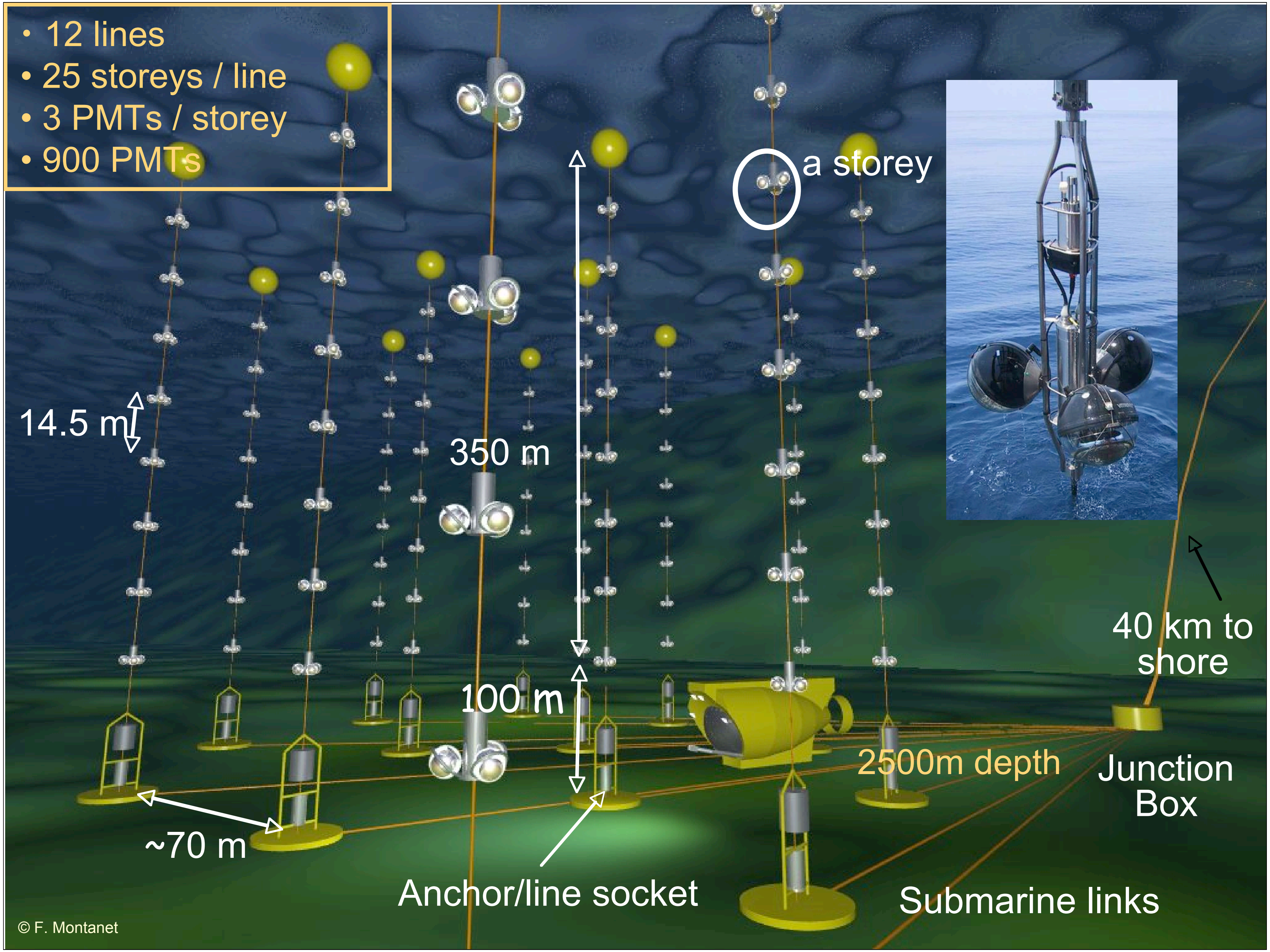
Current Underwater Neutrino Experiments in the Mediterranean



Germany
Spain
Russia
Romania
France
The Netherlands
Italy

Italy

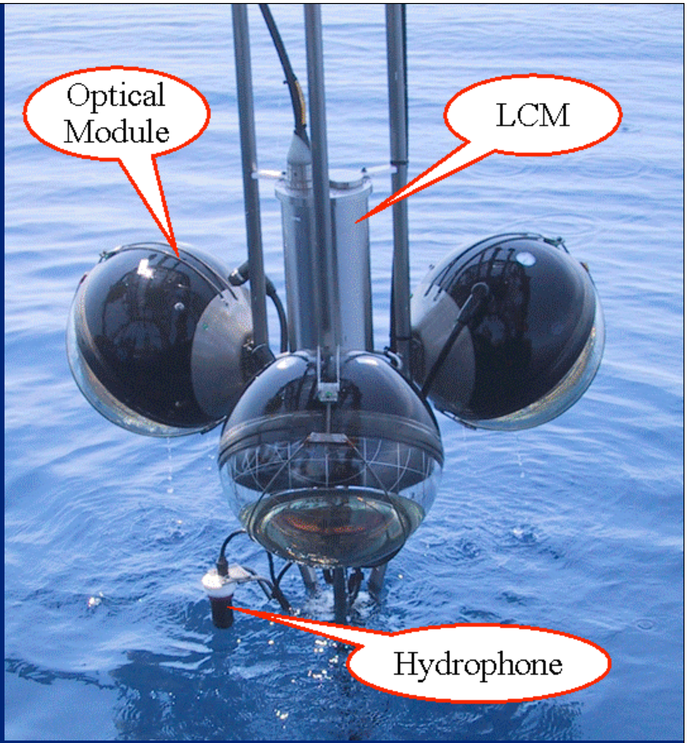
Germany
Greece
Russia
Switzerland
USA

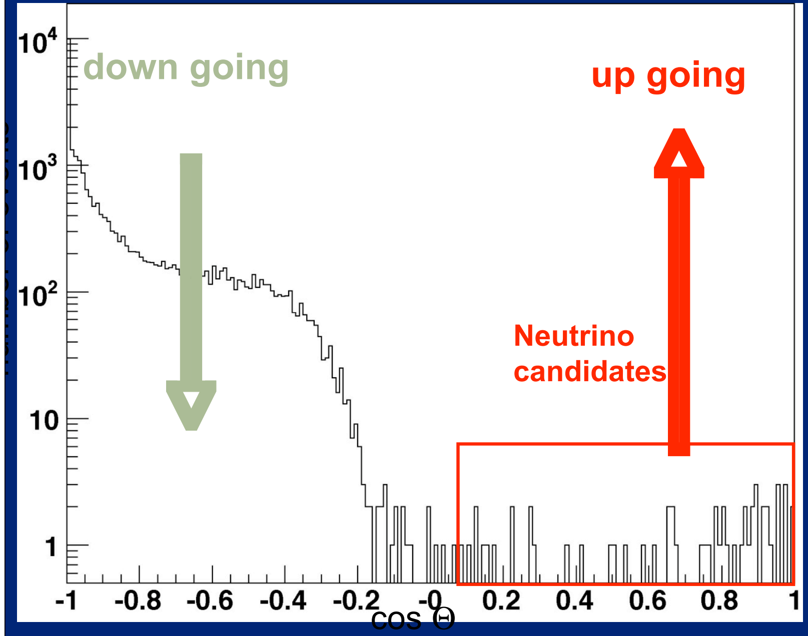


• 12 lines
• 25 storeys / line
• 3 PMTs / storey
• 900 PMTs
a storey
14.5 m
350 m
100 m
~70 m
Anchor/line socket
2500m depth
Submarine links
Junction Box
40 km to shore
© F. Montanet

ANTARES

- 10 out of 12 lines installed
- + 1 instrumentation line
  - Environmental sensors, light emitters, video cameras
  - 18 hydrophones over 3 storeys
- Last 5+1 installed in 2007





- Reconstructed events from data taken Feb-May 2007
- Steep fall at cosθ=0.2 expected from cosmic ray muons
- Upward going events are neutrino candidates

KM3NeT

- A Consortium of 40 institutes from 10 European countries

\+ \+ \+ . . .

- **Cyprus:** Univ. Cyprus Nicosia
- **France:** CEA/Saclay, CNRS/IN2P3 (APC Paris, CPP Marseille, IReS Strasbourg), Univ. Haute Alsace/GRPHE, IFREMER
- **Germany:** Univ. Erlangen, FTZ (Univ. Kiel)
- **Greece:** HCMR Anavissos, HOU Patras, NCSR Athens, NOA/Nestor Athens, Univ. Athens
- **Ireland:** DIAS Dublin
- **Italy:** CNR/ISMAR, INFN (Univs. Bari, Bologna, Catania, Genova, Napoli, Pisa, Roma-1, LNS Catania, LNF Frascati), INGV, Tecnomare SpA
- **Netherlands:** NIKHEF/FOM Amsterdam, Univ. Amsterdam, Univ. Utrecht, KVI (Univ. Groningen)
- **Romania** ISS Bucharest
- **Spain:** IFIC (CSIC) Valencia, Univ. Valencia, UP Valencia
- **UK:** Oceanlab (Univ. Aberdeen), Univ. Leeds, Univ. Liverpool, Univ. Sheffield

Particle/Astroparticle institutes (32) – Sea science/technology institutes (7) – Coordinator

KM3NeT DESIGN REPORT

- Design Study supported by the European Union with 9 M€, overall budget ~20 M€.
- Started on Feb. 1, 2006; will run for 3 years

Objectives

- Design a cost effective neutrino telescope with:
  - Effective volume >1 km^3
  - Angular resolution for muons (E_ν>10 TeV) 0.1°
  - Energy threshold: few 100 GeV. When pointing ~100 GeV
  - Sensitivity to all neutrino flavours, CC/NC reactions
  - Field of view close to 4π for high energies

Deliverables

- Conceptual Design Report by Fall 2007
- Technical Design Report by the end of 2008

Site choice will depend on:

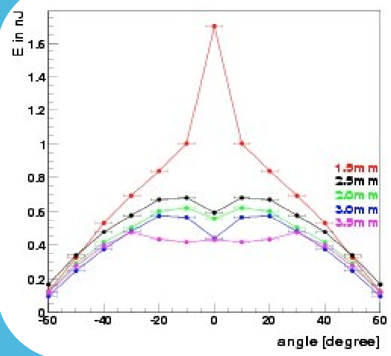
- Depth
- Distance from shore
- Bioluminescence rate
- Sedimentation
- Biofouling
- Sea currents
- Earth quake profile
- Access to on-shore facilities

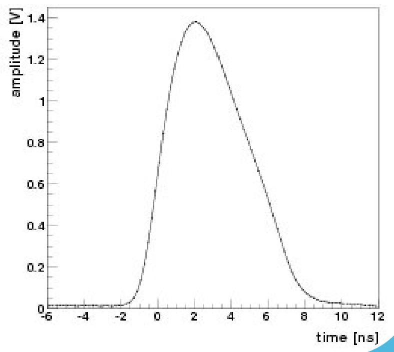
KM3NeT
Opens a new window on our universe

KM3NeT-UK Activities
The University of Sheffield
LED Beacon Pulser Assembly

The University Of Sheffield.

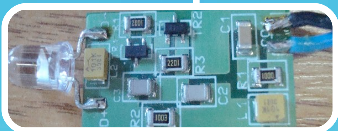
L. Thompson, J. Perkin, O. Veledar





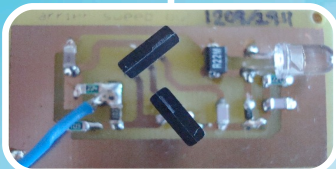
The relative time offset of Optical Modules in ANTARES is measured using a system of LED based optical beacons [arXiv:astro-ph/0703355]

Rise times of the optical pulse are typically 2-3ns with an energy of 150pJ or $4\text{x}10^8$ photons per pulse



Using a new circuit design [doi:10.1088/0957-233/18/1/016] and current LED technologies the following developments are being researched:

- Increase pulse-pulse stability
- Increase pulse amplitude
- Remove need for ext. trigger
- Drive multiple LEDs from 1 board
- Preserve ns timing of pulses



KM3NeT

Opens a new window on our universe

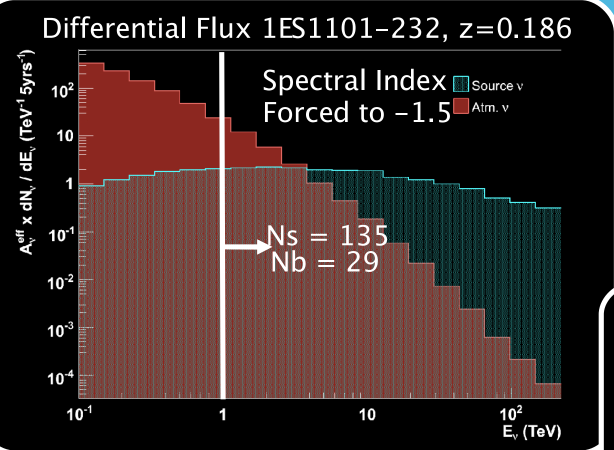
KM3NeT-UK Activities

The University of Leeds

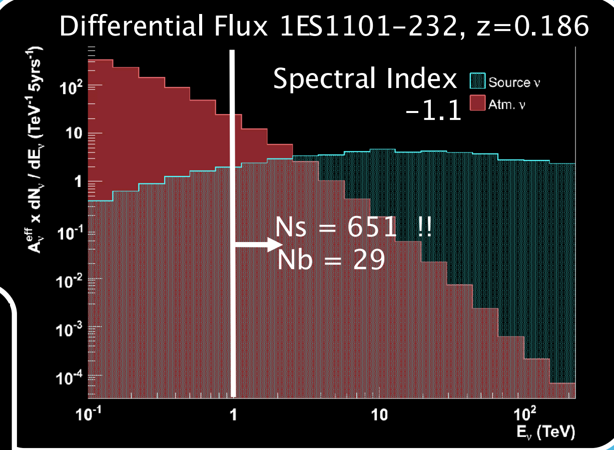
KM3NeT sensitivity to BLAZERs

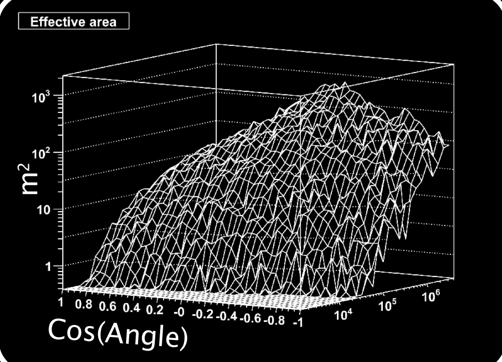
UNIVERSITY OF LEEDS

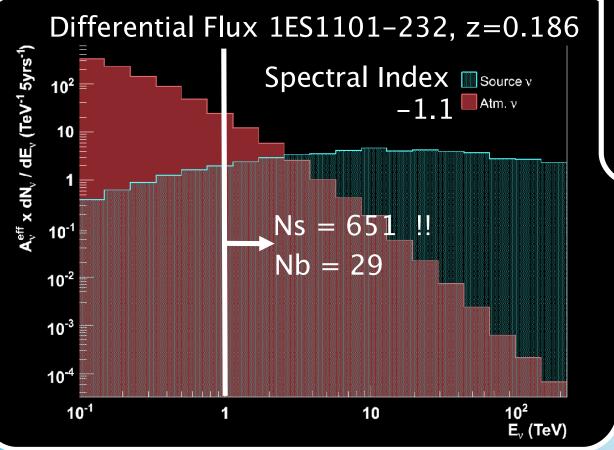
- Upper limits obtained for several southern hemisphere blazars
- Heavily EBL dependent
- Even with lowest EBL model some limits exceed background



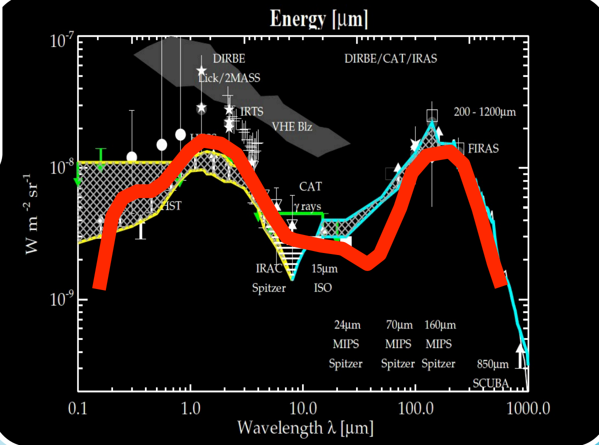
- Based on a neutrino effective area (geometry independent)







S. Bradbury,
J. Rose,
R. White



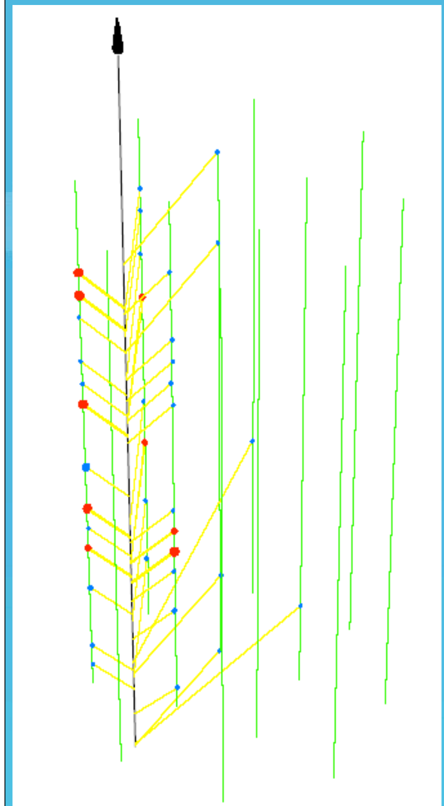
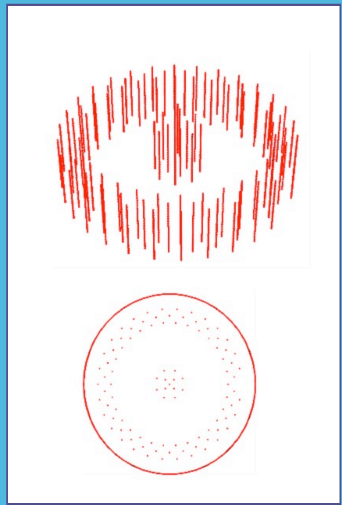
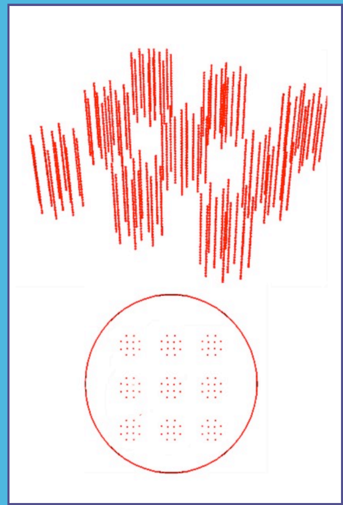
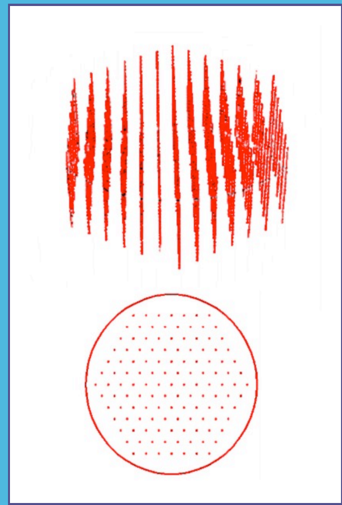
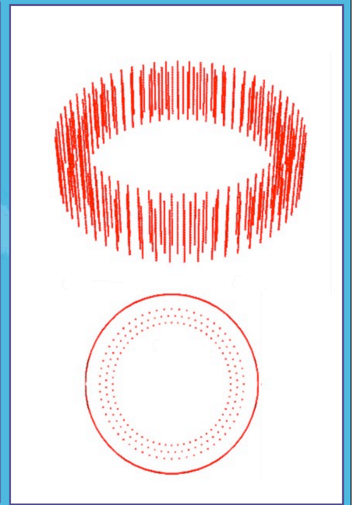
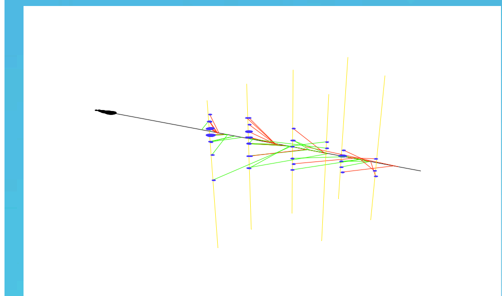
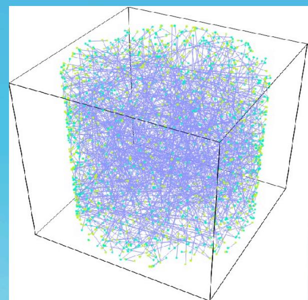
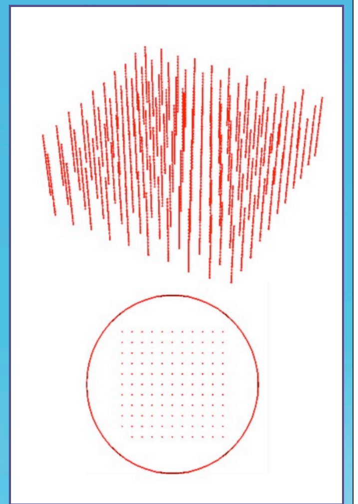
See ICRC 2007 procs.

KM3NeT
Opens a new window on our universe

KM3NeT-UK Activities
The University of Liverpool
KM3NeT Geometry Evaluation

UNIVERSITY OF LIVERPOOL

C. Touramanis, F. Jouvenot

A complete detector simulation framework exists for the *fast* evaluation of different KM3NeT geometries

arXiv:0711.2139v1 [astro-ph]

UHE Neutrinos (>10^{18} eV):
Need for Detection Volume Beyond km^3

~ 10 GZK neutrinos / km^2 / year

10^{18} eV: ν N interaction length ≈ 300 km

→ 0.03 neutrinos / km^3 / year

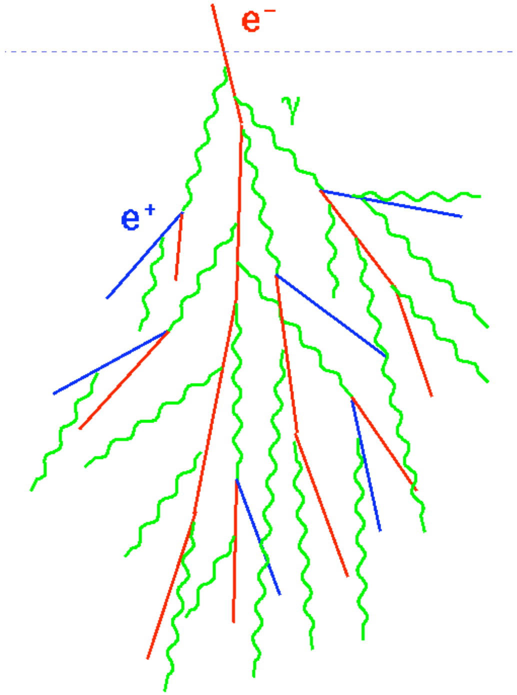
At most, we see 1/2 the sky

→ 10^{-2} neutrinos / km^3 / year

To be assured sensitivity to "guaranteed" GZK neutrino flux, we need >>10^2 km^3 detection volume

Radio Technique: Gurgen Askaryan (1962)

- Coherent Cerenkov signal from net "current," instead of from individual tracks
- A ~20% charge asymmetry develops:
  - Compton scattering: γ + e-(at rest) → γ + e-
  - Positron annihilation: e+ + e-(at rest) → γ + γ
- Excess moving with v > c/n in matter
- → Cherenkov Radiation dP ∝ ν dν
- If $\lambda >> R_{Moliere}$ → Coherent Emission $P \sim N^2 \sim E^2$
- $\lambda > R_{Moliere}$ → Radio/Microwave Emission

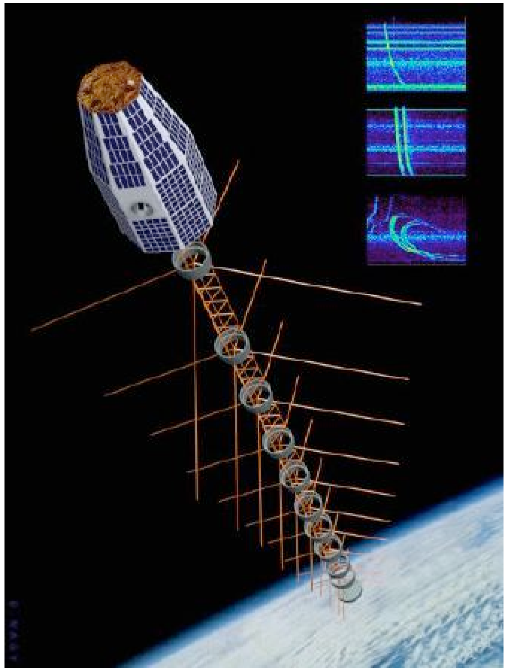


Long radio attenuation lengths in ice, salt, sand

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

Pioneering Radio Cerenkov Experiments

FORTE



FORTE 97-99
Greenland Ice
Log periodic antenna,
20-300 MHz
$A=10^5\ km^2.sr$

GLUE

GLUE/Goldstone 99:
In Lunar regolith
~2 GHz
$A=6.10^5\ km^2.sr$

RICE

RICE 1999-present
Antennas on
AMANDA strings
100-1000 MHz dipoles
$V\sim10\ km^3.\ sr$
Data up to 2005
published

Radio Ice Cerenkov Experiment

MIT, Whitman College, U. of Delaware, U. of Canterbury, University of Kansas, University of Kansas Design Laboratory

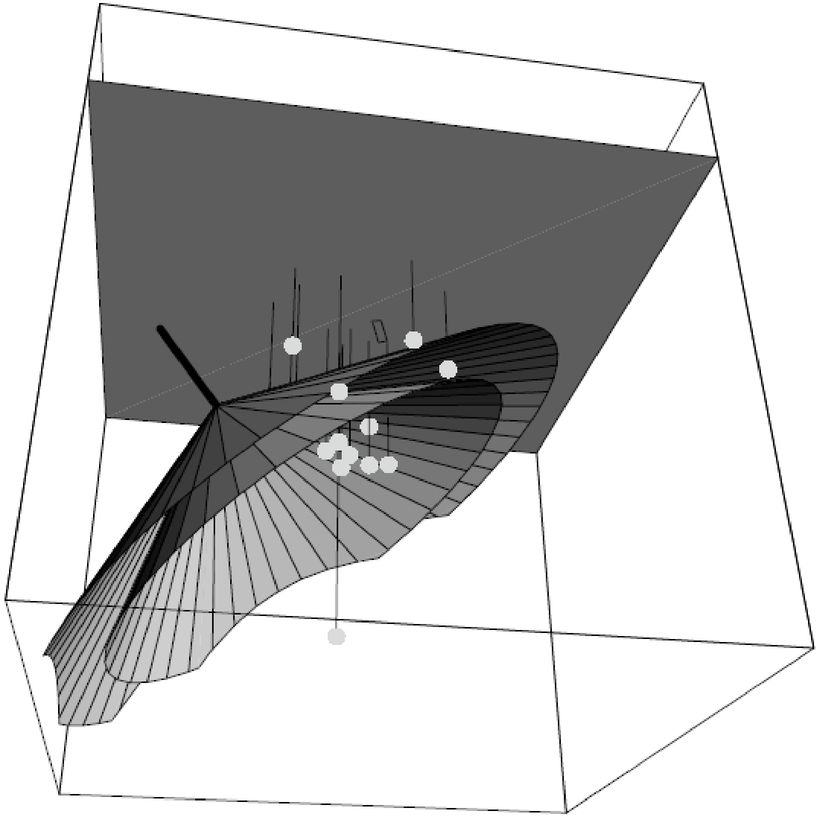
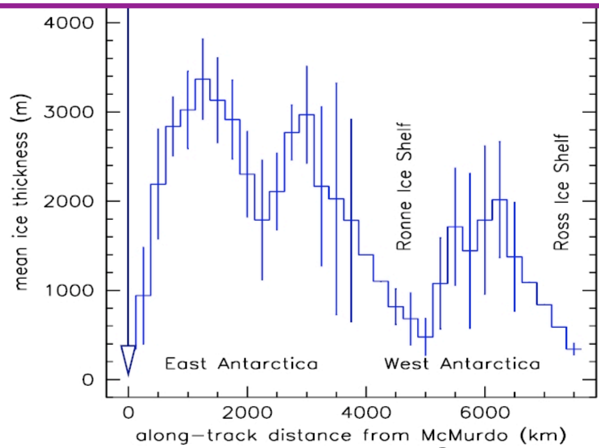


Figure Credit: Kravchenko et al., 2003

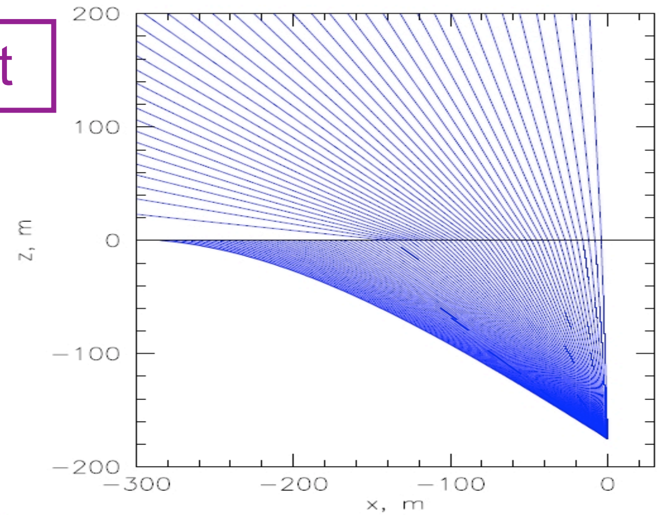
- Martin A. Pomerantz Observatory
  - 1 km from S. Pole
- 16 buried radio receivers in 200 m x 200 m x 200 m area
- Detects Cerenkov radiation in 0.2 GHz to 1 GHz frequency range

Antarctic Ice Properties

Ice thicknesses across continent



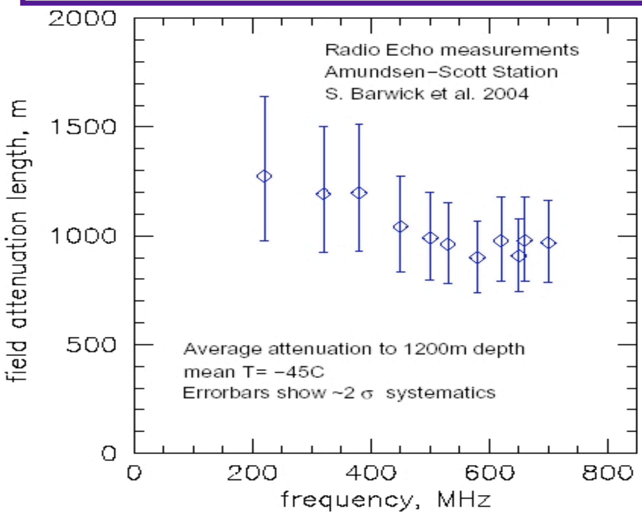
[P. Gorham]



[D. Besson]

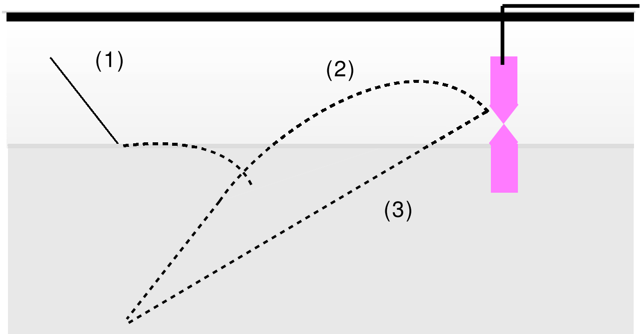
Ray paths near surface with depth-dependent index of refraction.

Depth of South Pole Ice: 2.5 km



Attenuation lengths measured at the South Pole

n(z): 1.78 in deep ice
1.33 at surface

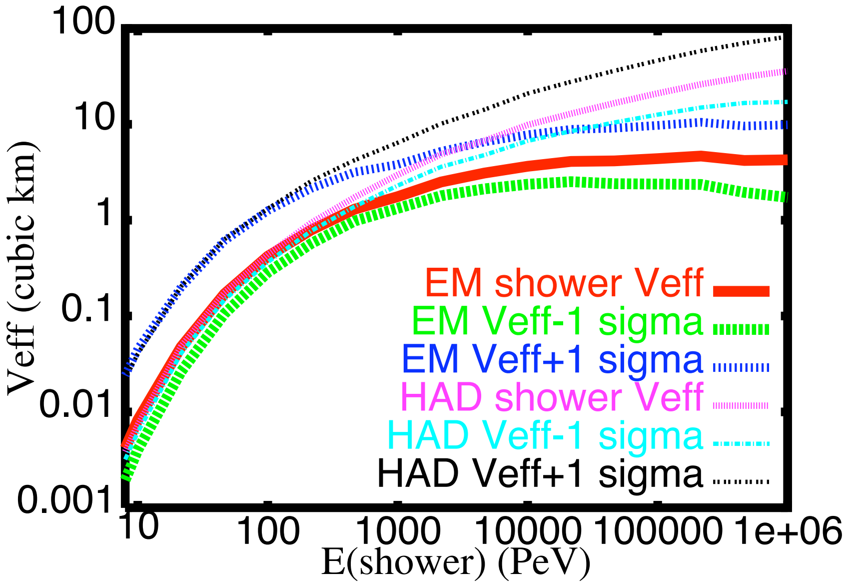


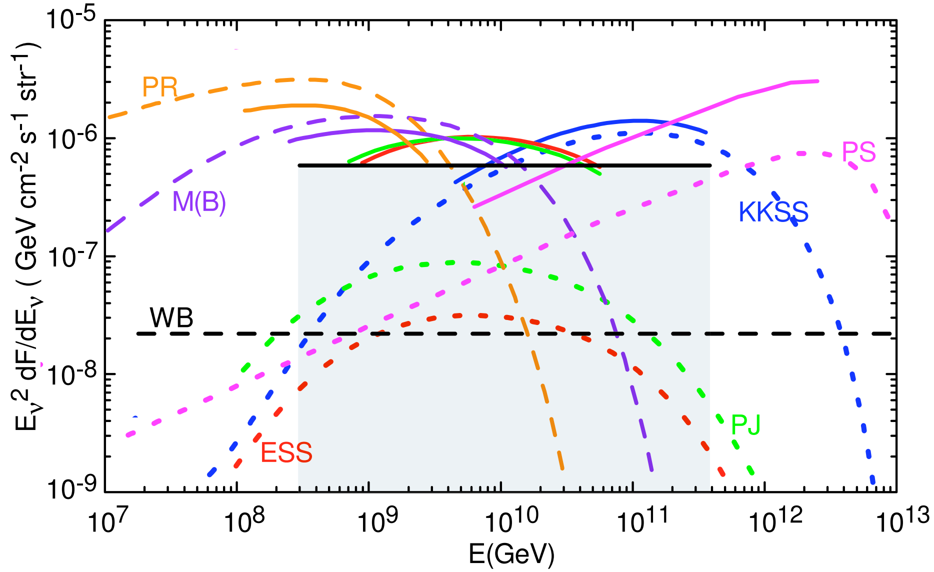
I. Kravchenko, et al., 2006

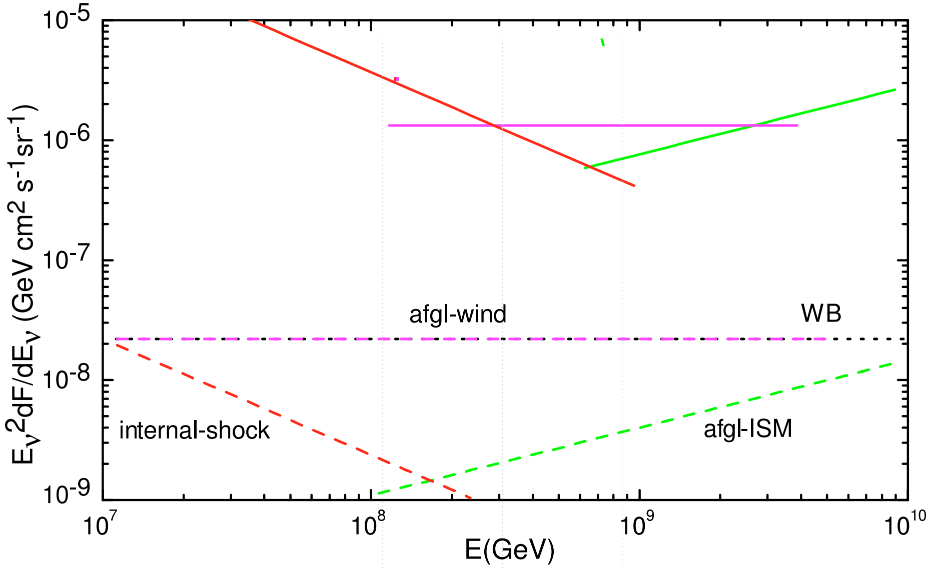
RICE Results

I. Kravchenko et al., 2006

- 2001-2005: No neutrinos detected in 1.85 years of livetime.







RICE rules out the most intense neutrino flux model predictions

RICE Limits on Magnetic Monopoles

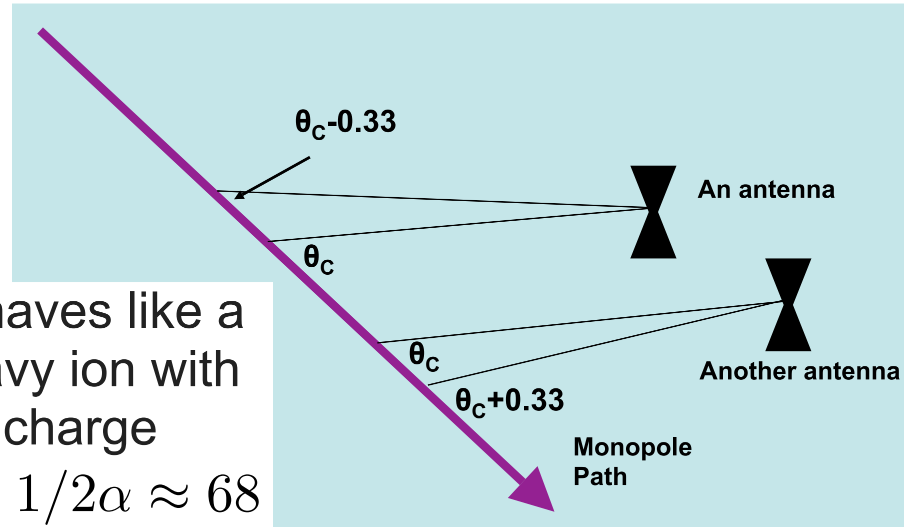
Daniel Hogan, Kansas University, RICE Collaboration

- (Wick et al. '03) Monopole mass < 10^{14} GeV

➡ relativistic

- Energy ~ 10^{16} GeV
- Relativistic monopoles cause EM showers in ice

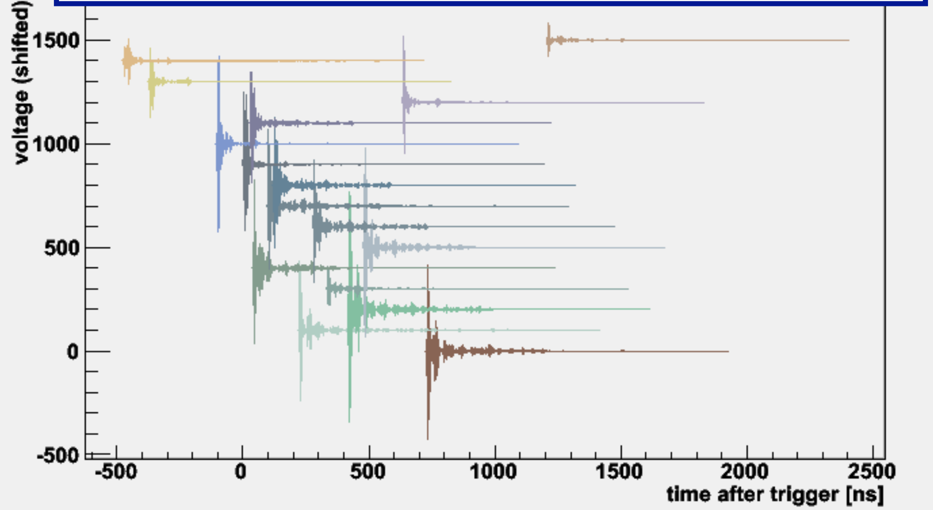
➡ Cerenkov signal

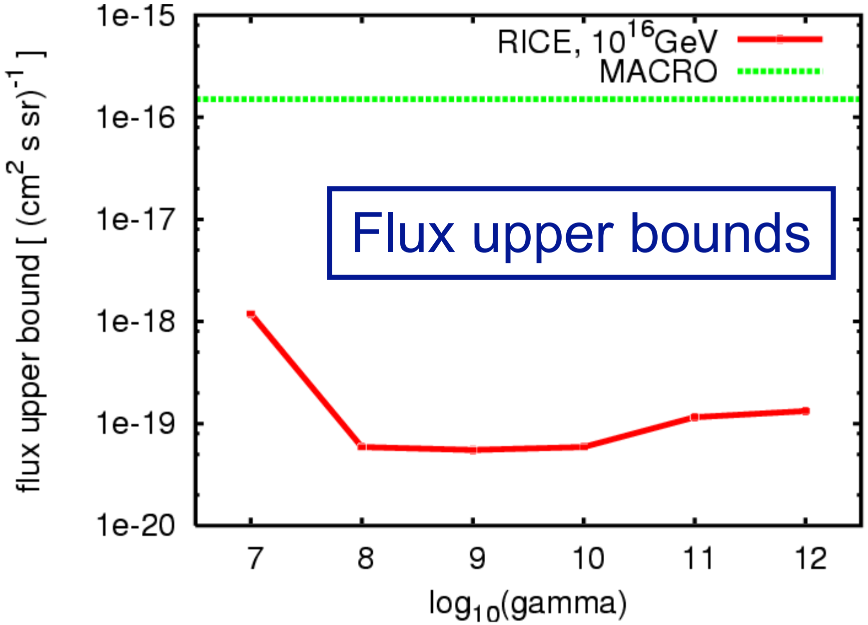


Behaves like a heavy ion with charge

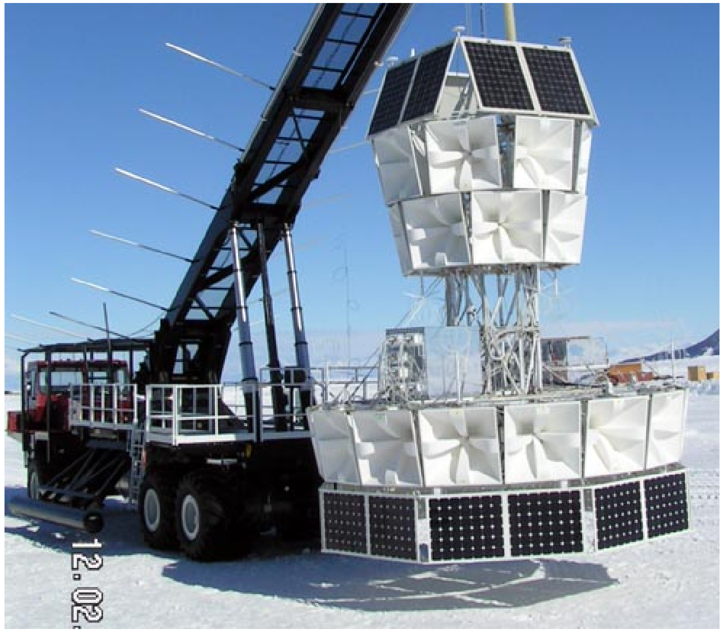
$$Z = 1/2\alpha \approx 68$$

A typical simulated voltage profile

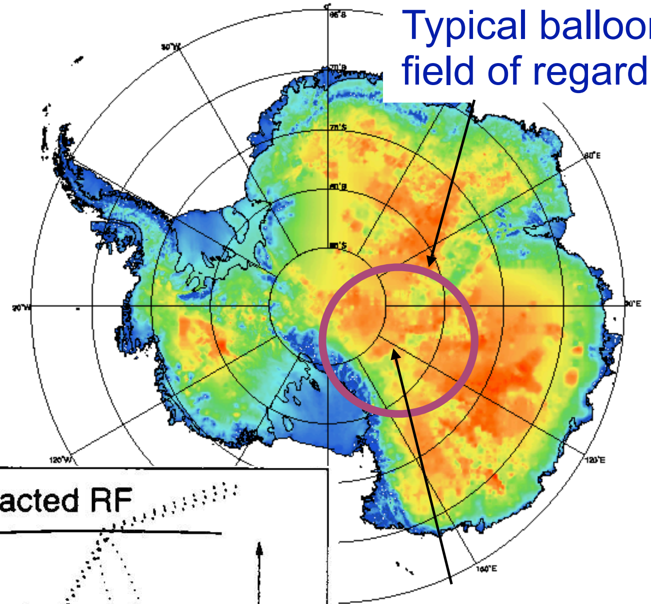




ANITA
(ANtarctic Impulsive Transient Antenna)

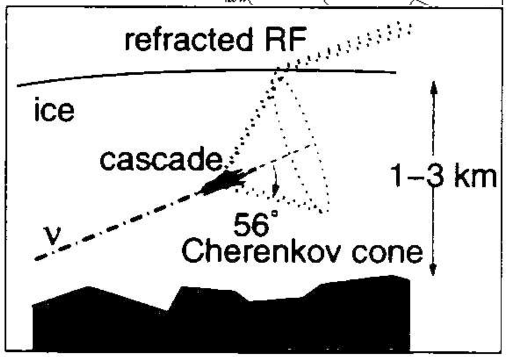


First full physics flight: Dec. 15th 2006 – Jan 18th 2007!



Typical balloon field of regard

~4km deep ice!



32 quad-ridged horn antennas, dual-polarization, 200-1200 MHz, 10° cant

Balloon flies 37 km above the ice

Balloon operations by the Columbia Scientific Balloon Program (NASA)

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

Observes ~1.5 x 10^6 km^2 of ice at once!

The ANITA Collaboration

USA UK (UCL) Taiwan

University of Hawaii at Manoa
Honolulu, Hawaii

University of California at Irvine
Irvine, California

University of California at Los Angeles
Los Angeles, California

University College London
London, England

University of Delaware
Newark, Delaware

Jet Propulsion Laboratory
Pasadena, California

University of Kansas
Lawrence, Kansas

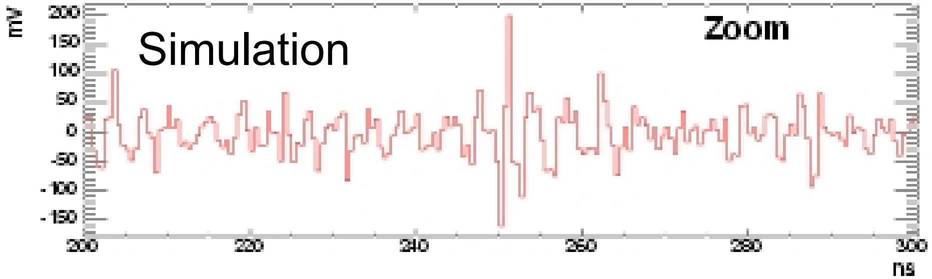
Ohio State University
Columbus, Ohio

Stanford Linear Accelerator Center
Pasadena, California

National Taiwan University
Taiwan

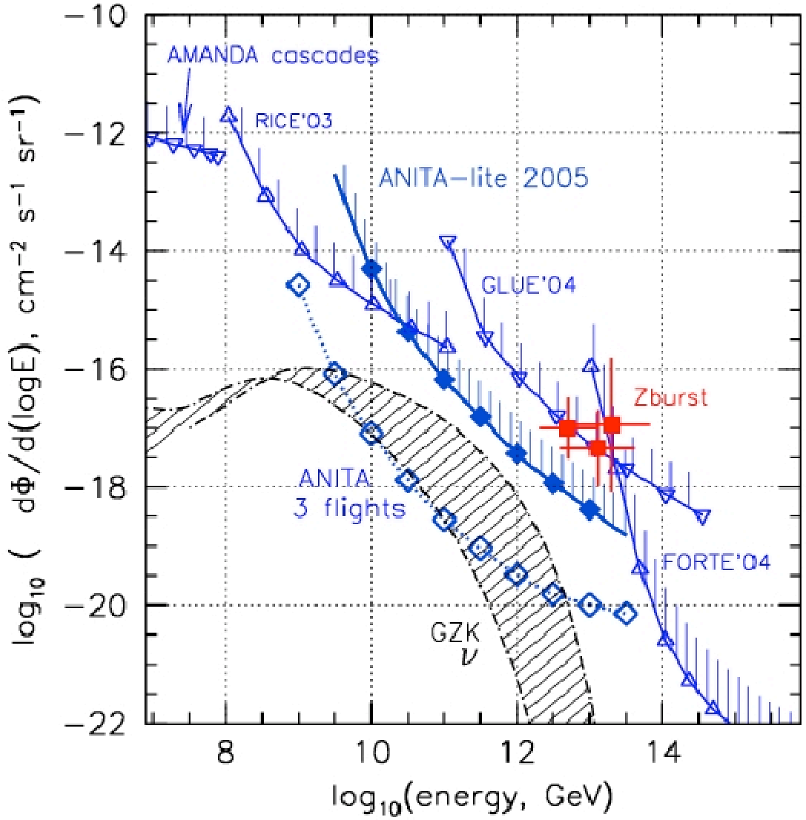
Washington University in St. Louis
St. Louis, Kansas

Anita-lite: 2 antennas, 2003-2004 Season



- Designed cuts to select Askaryan-like events
  - # cycles in a waveform
  - Integrated power
  - Time coincidence between channels
- Reduce noise with cross-correlation analysis
- Both analyses find analysis efficiency ~50%
- ANITA-lite ruled out Z-burst models

- Two independent analyses modeled time dependent pulse on measured noise



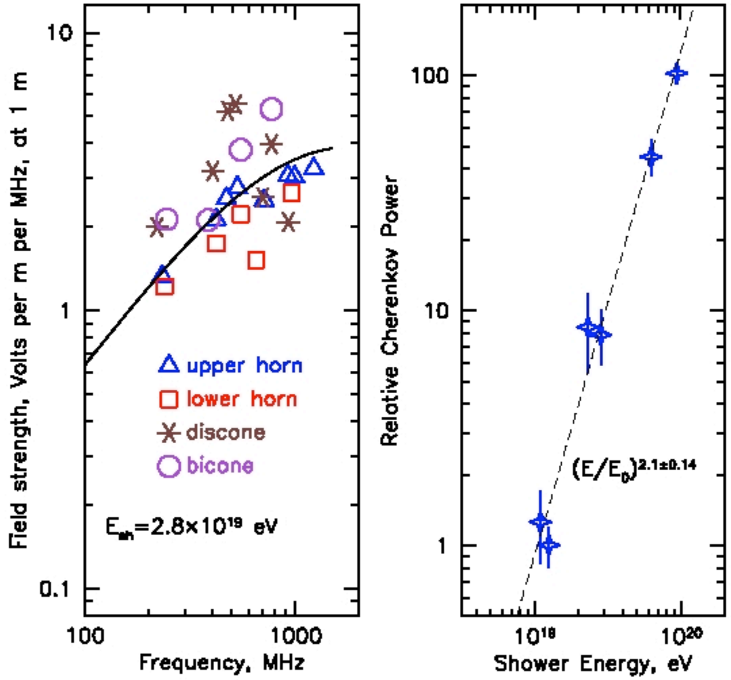
ES&S baseline (min)
Kalashev, *et al.*, saturate all bounds (max)

ANITA Calibration at SLAC: June 2006

Produced Askaryan pulses in ice from a 28.5 GeV electron beam at SLAC

$\sim 10^9$ particles per bunch

$\rightarrow 10^{19}$- 10^{20} eV showers

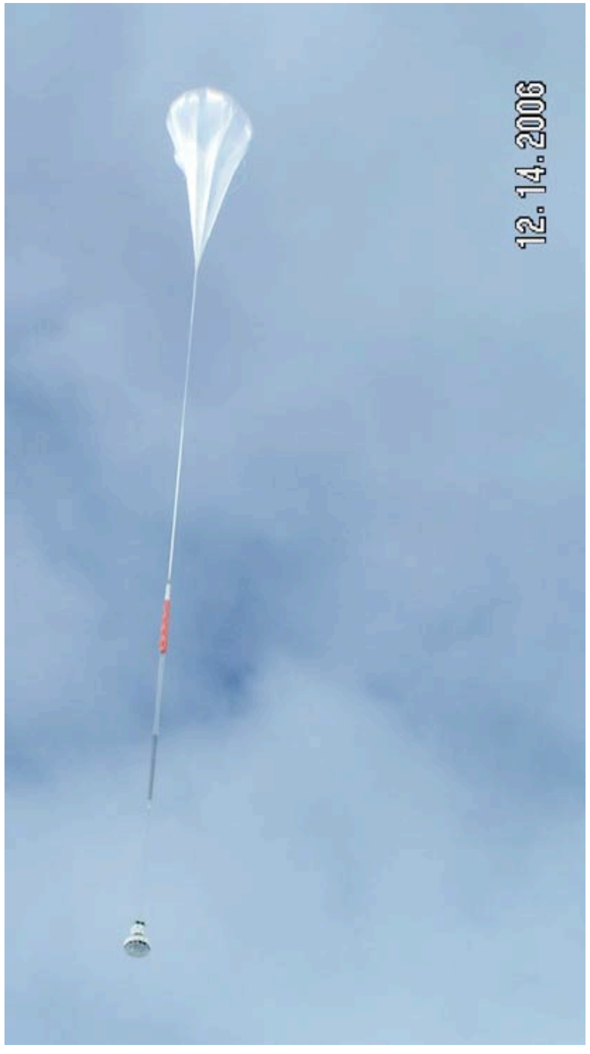


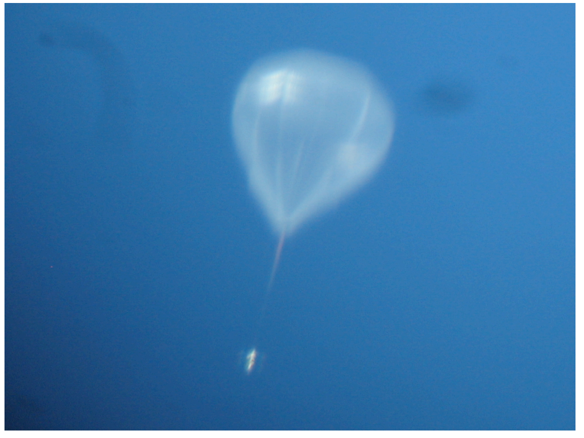
ANITA Collaboration (P.W. Gorham et al.) hep-ex/0611008

From there, ANITA was off to Antarctica…

ANITA Flight

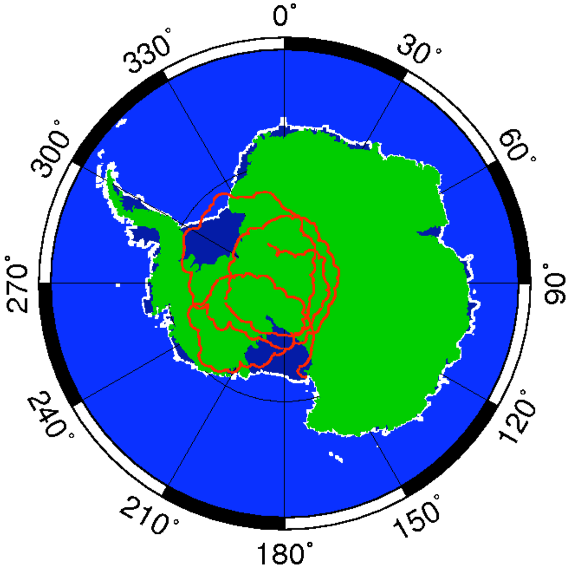
- ANITA launched on Dec. 15th
- Took 3.5 trips around Antarctica
- In flight for 35 days
- Terminated on Jan 18th
- Full recovery completed
- Analysis is underway
- Expect to either be the first to discover UHE neutrinos or set world's best limits





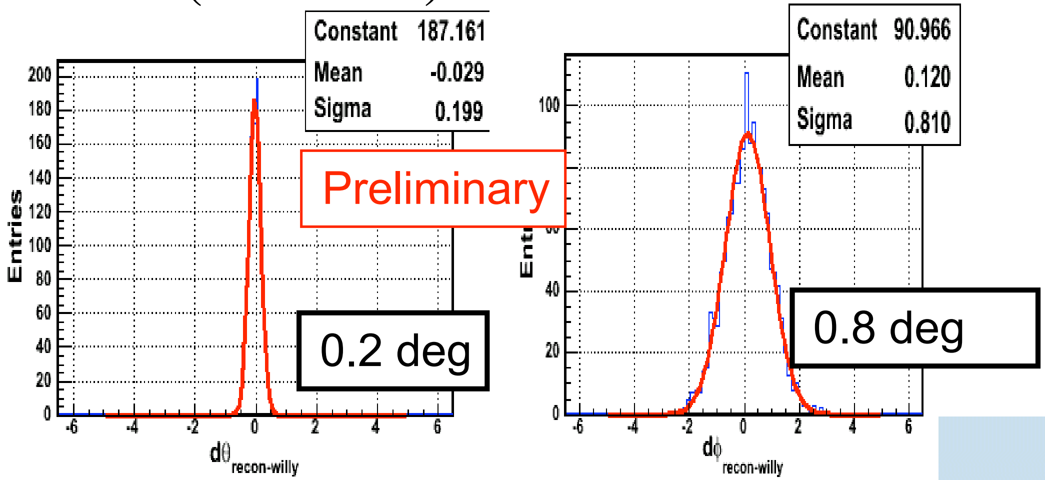
View of ANITA from the South Pole

Picture taken by James Roth



ANITA Event Reconstruction

Data (Borehole)

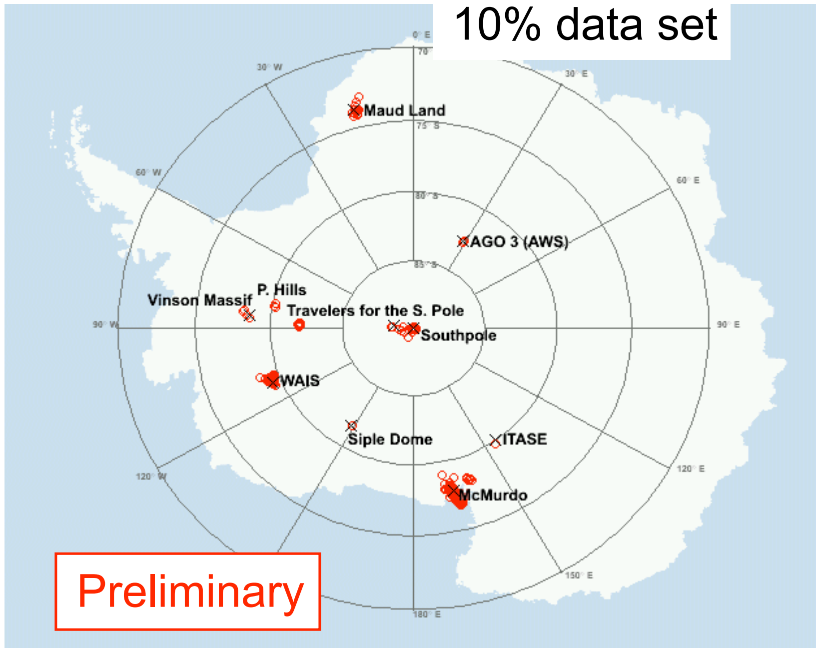


up-down

left-right

- Calibration pulses sent to the payload while ANITA was in view of McMurdo
- From the surface and from borehole

- Preliminary analysis with 10% data set
- V>3sigma
- Establish angular reconstruction, select good events
- Time profile, FFT consistent with expectation
- All associated with camps, travelers, automatic weather stations

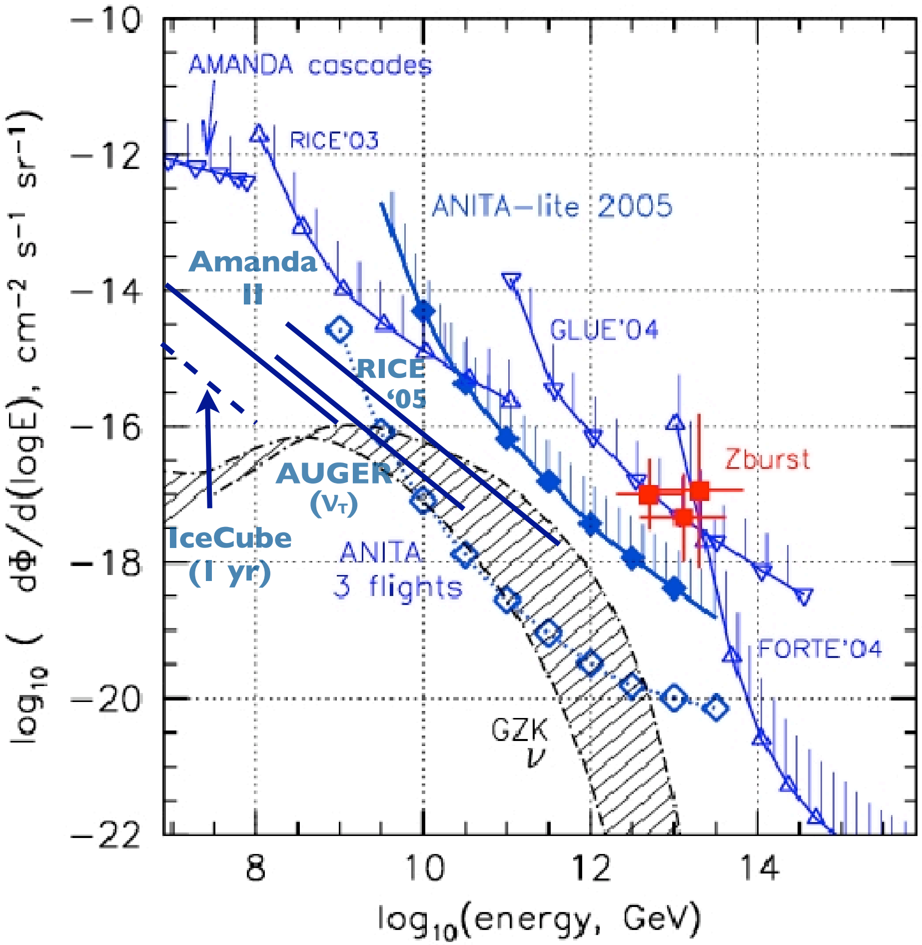


Haven't looked at remaining 90%

ANITA II approved - flight 2008-2009

Embedded Radio Detectors Designed to Target Energy Gap

- Detectors embedded in the interaction medium have lower threshold
- Variety of embedded radio detector projects being studied or plannec
- Antarctic ice and salt
- Goal of any next-generation experiment: 100 GZK neutrinos/yeaı
- Cross section measurement possible



Limit curves from Barwick et al., Phys.Rev.Lett 96:171101,2006 and references therein, (RICE '06) I. Kravchenko et al., 2006, Phys.Rev.D73:082002,2006, and (AUGER) L.Anchordoqui et al., ICRC Proceedings 2007

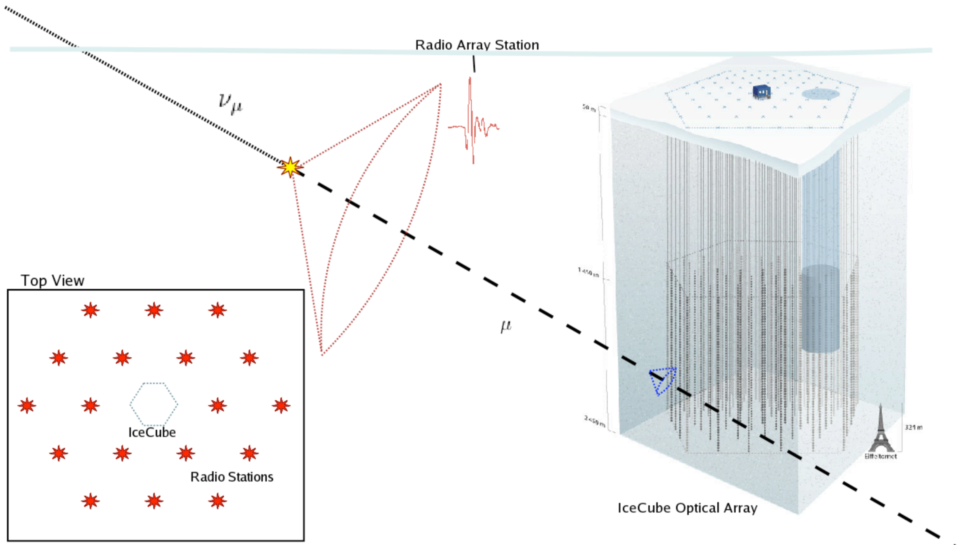
IceRay / AURA

USA, UK (UCL)

A next-generation array could deploy antennas:

- On surface (IceRay)
- Deep (AURA):
  - On existing IceCube strings
  - On strings in dedicated radio boreholes

Ice is the only medium that is feasible for all three: optical, radio and acoustic techniques



Preliminary simulations:

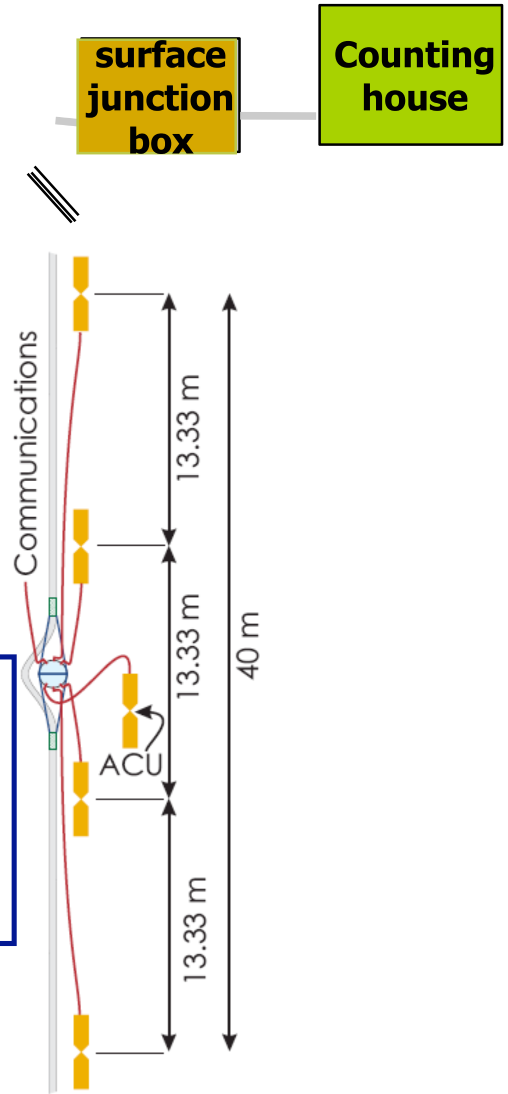
- An array of 18-36 stations that could be built by ~2012 could detect 4-8 GZK neutrinos/year
- Pre-curser to larger array that would detect 100 GZK neutrinos/year

A fraction of events could be measured in both radio and optical instruments

AURA
Askaryan Under ice Radio Array

Information on AURA slides from Hagar Landman (Wisconsin) for the IceCube Collaboration

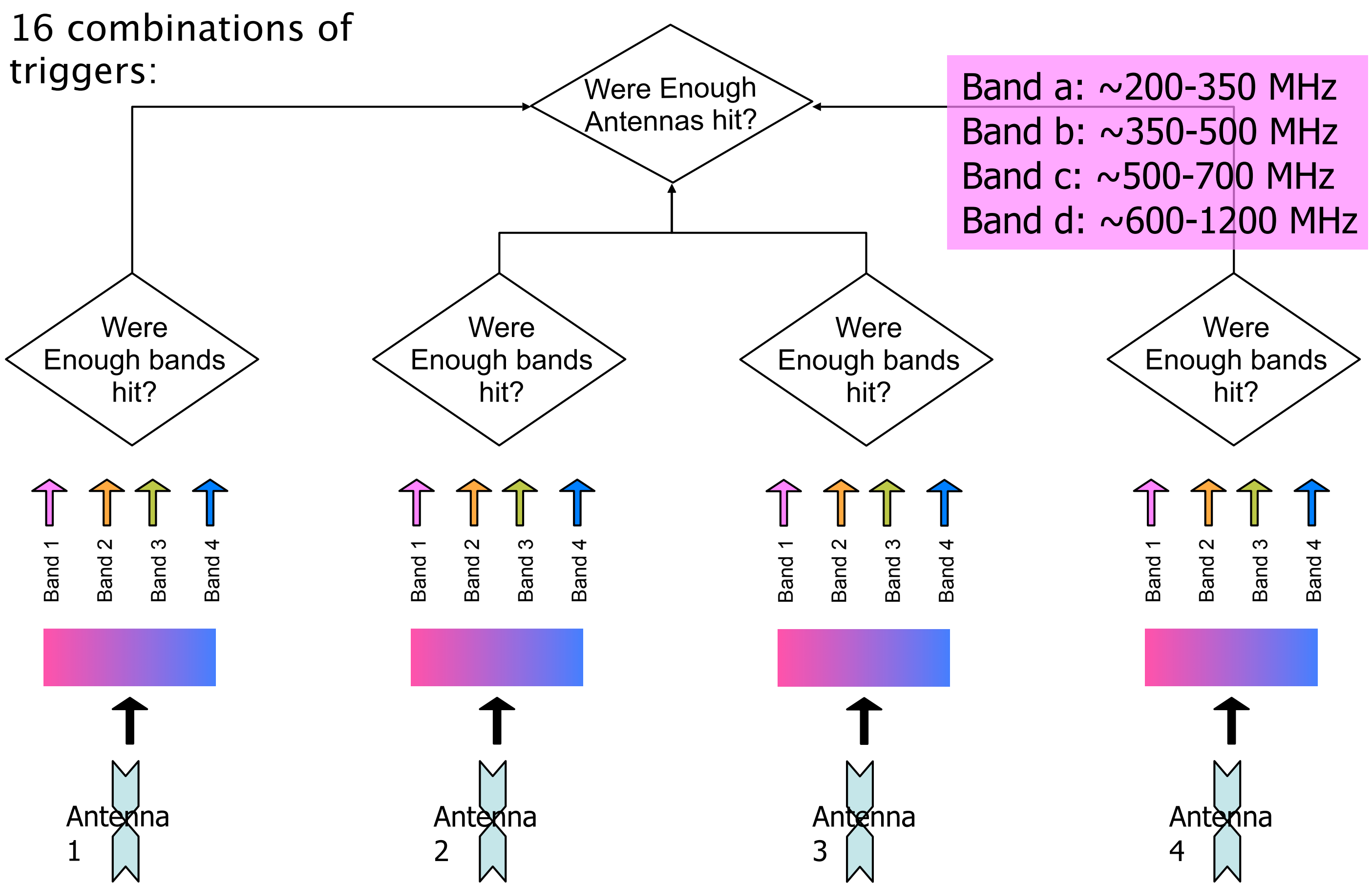
- Utilize existing infrastructure and technology for Radio Frequency neutrino detector at the South Pole
  - RICE - Antennas, electronics and control
  - ANITA – Digitizer and triggering
  - IceCube- Main board, DAQ, holes, cables



AURA Cluster
- Digital Radio Module (DRM) – Electronics
- 4 Antennas
- 1 Antenna Calibration Unit (ACU)

3 Radio clusters were deployed in the 06-07 polar season at the South Pole

AURA Triggering

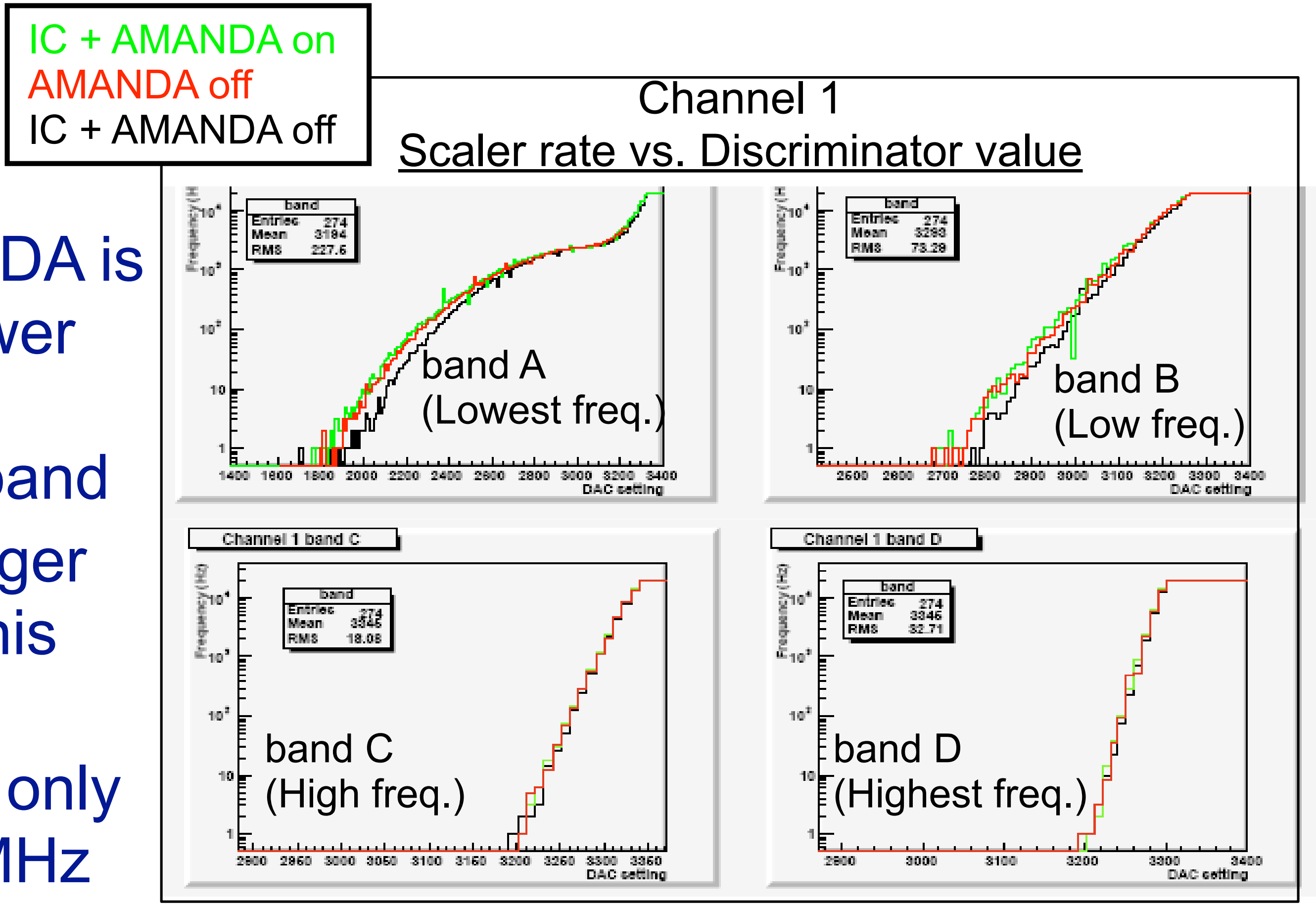


- Antennas: Broad band dipole, centered at 400 MHz
- Front end electronics: 450 MHz Notch filter, 200 MHz High pass filter ~50dB amplifiers (+20 dB in DRM)
- Each antenna sampled using two 1 GHz channels to total of 512 samples / 256 ns (2 GSPS)

Suitability of IceCube environment for AURA

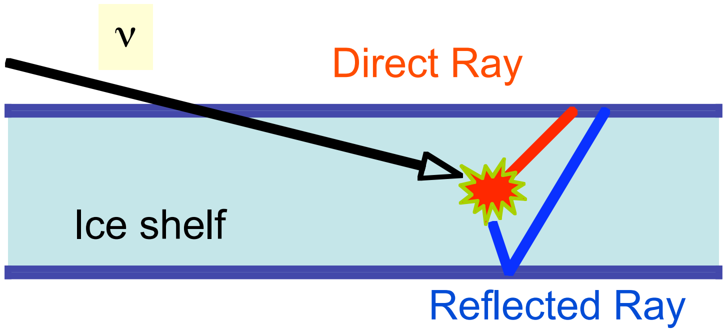
- Channel and cluster trigger rates were compared when IceCube/AMANDA were idle and when taking data.

- Noise from IceCube/AMANDA is enhanced in lower frequency on a given channel/band
- Combined trigger reject most of this noise
- Measurement only down to ~200 MHz

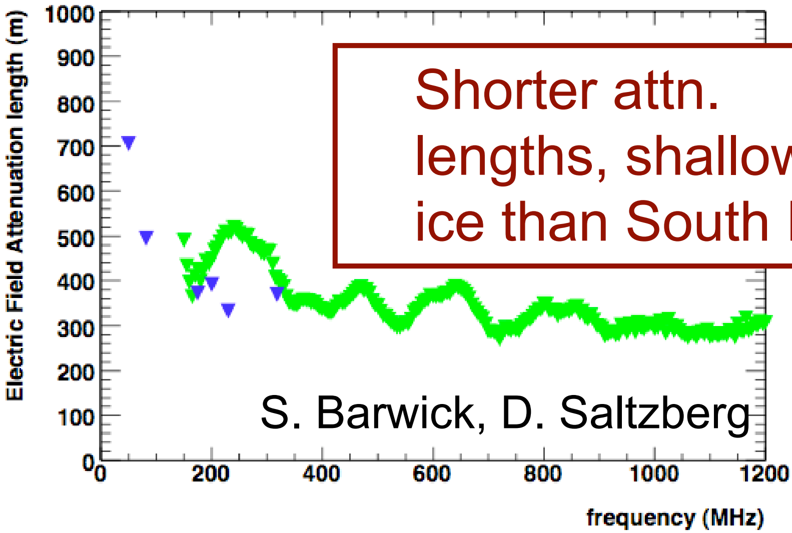


Ross Ice Shelf Array (ARIANNA)

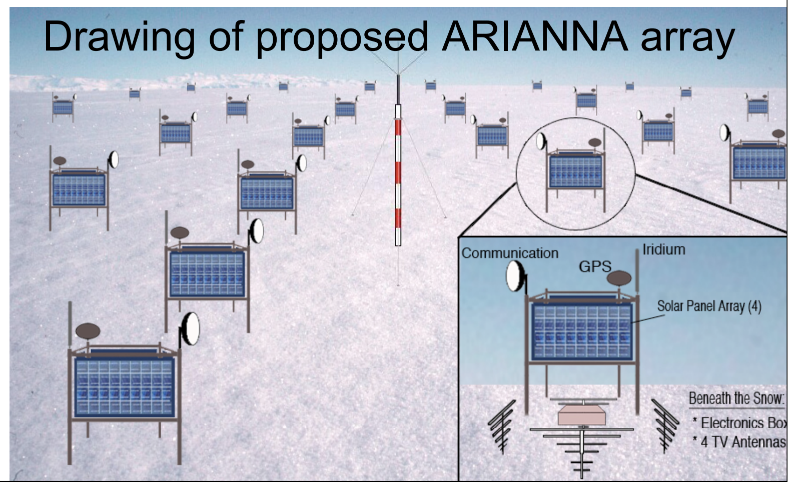
An array could also be deployed on the surface of the Ross Ice Shelf



- Highly reflective surface at interface with seawater
- Could observe reflections -> more solid angle

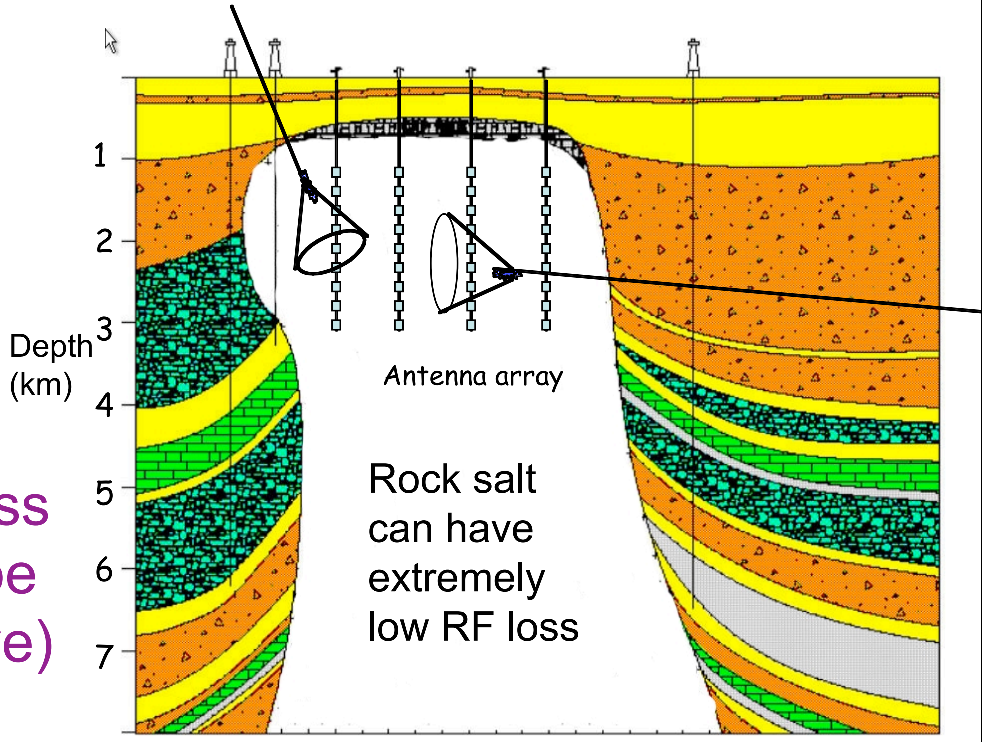


Shorter attn. lengths, shallower ice than South Pole

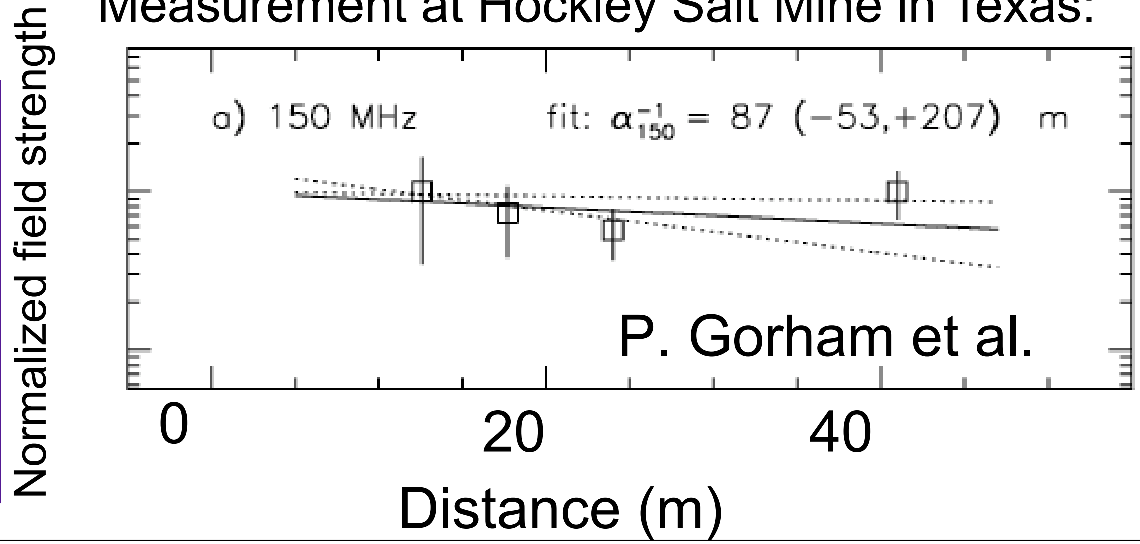


SalSA

- Salt formations can extend several km's wide x 10 km deep
- Salt domes can be very pure
- Ground penetrating radar (GPR) has shown very low loss
- Askaryan array in salt could be drilled from surface (expensive) or laid along floors of a salt mine



Measurement at Hockley Salt Mine in Texas:



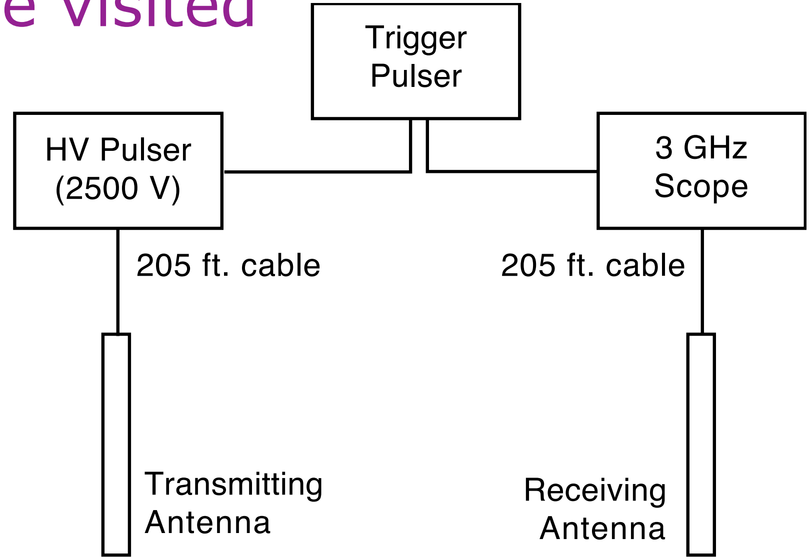
Before a SalSA experiment can proceed, long attenuation lengths for radio in salt need to be confirmed

Attenuation Length Measurements in Salt

Cote Blanche Salt Mine, Louisiana, USA

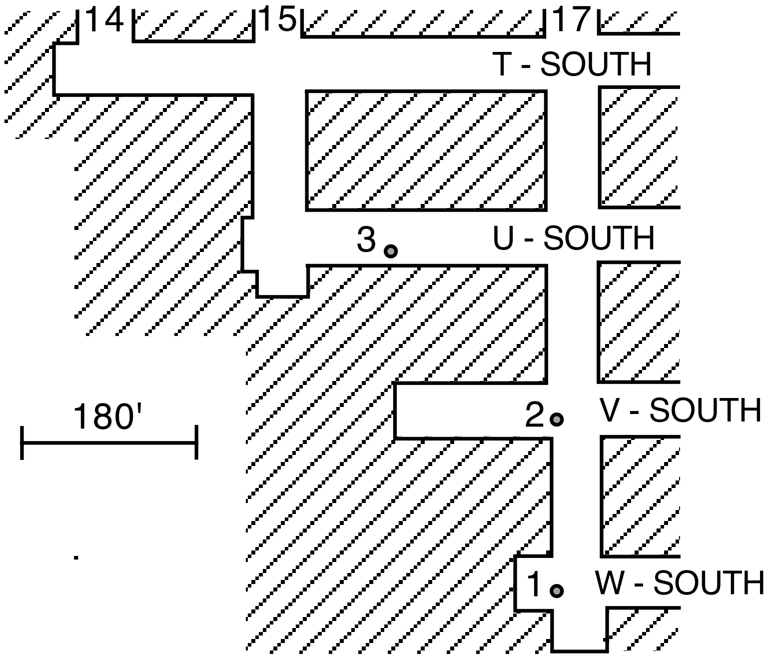
A. Connolly (UCL) ,A. Goodhue (UCLA),
R. Nichol (UCL), D. Saltzberg (UCLA),
M. Cherry (LSU), J. Marsh (LSU)

- Visited Cote Blanche salt mine to measure radio attn. lengths in salt
- Ground penetrating radar (GPR) experts saw lowest loss in any mine visited

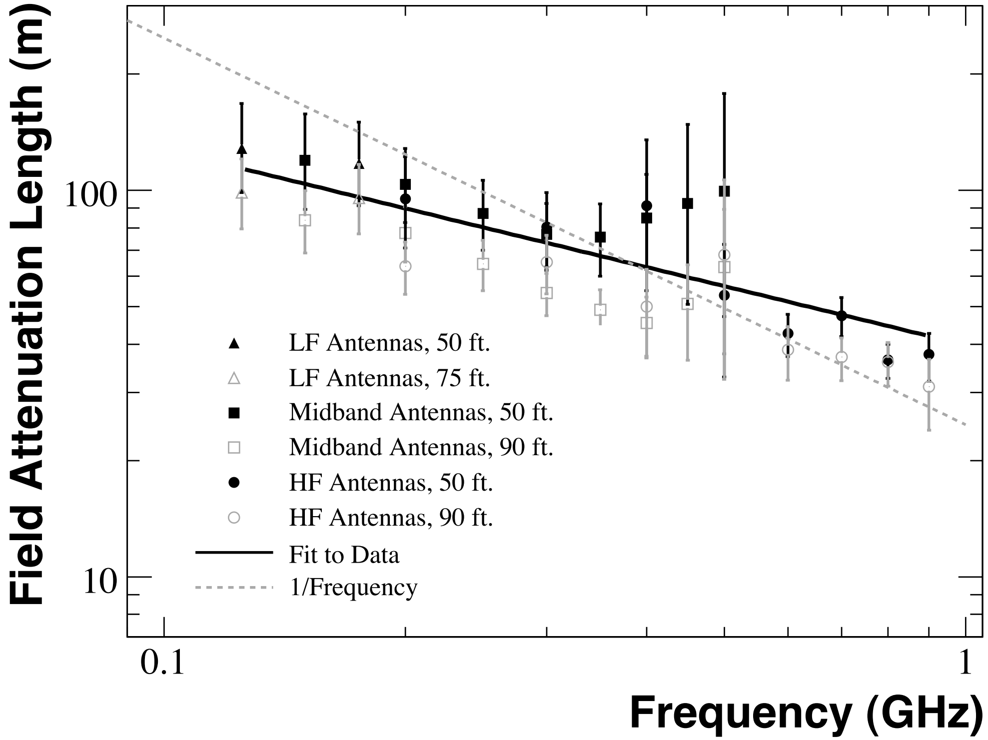


Attenuation Length Measurements in Salt

Cote Blanche Salt Mine, Louisiana, USA



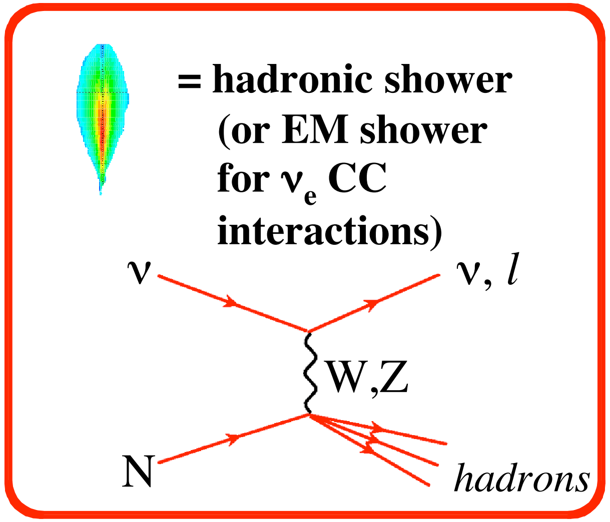
3 holes - maximum distance 168 m
depths 30-60 m

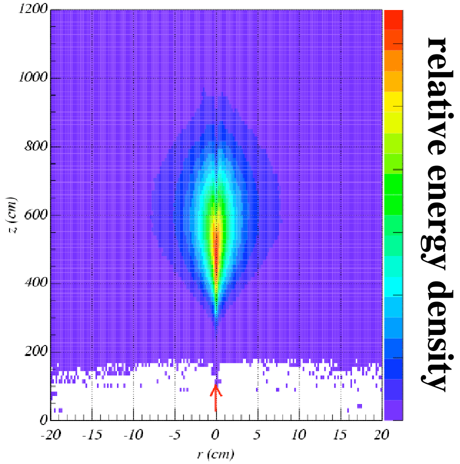


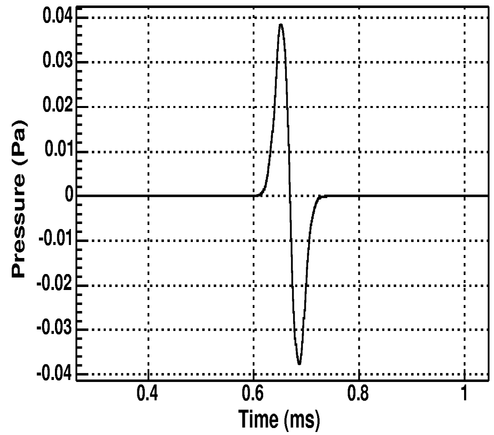
Will be difficult for salt to compete with Antarctic ice in volume, but like deep water experiments, SalSA could provide alternate view of northern sky

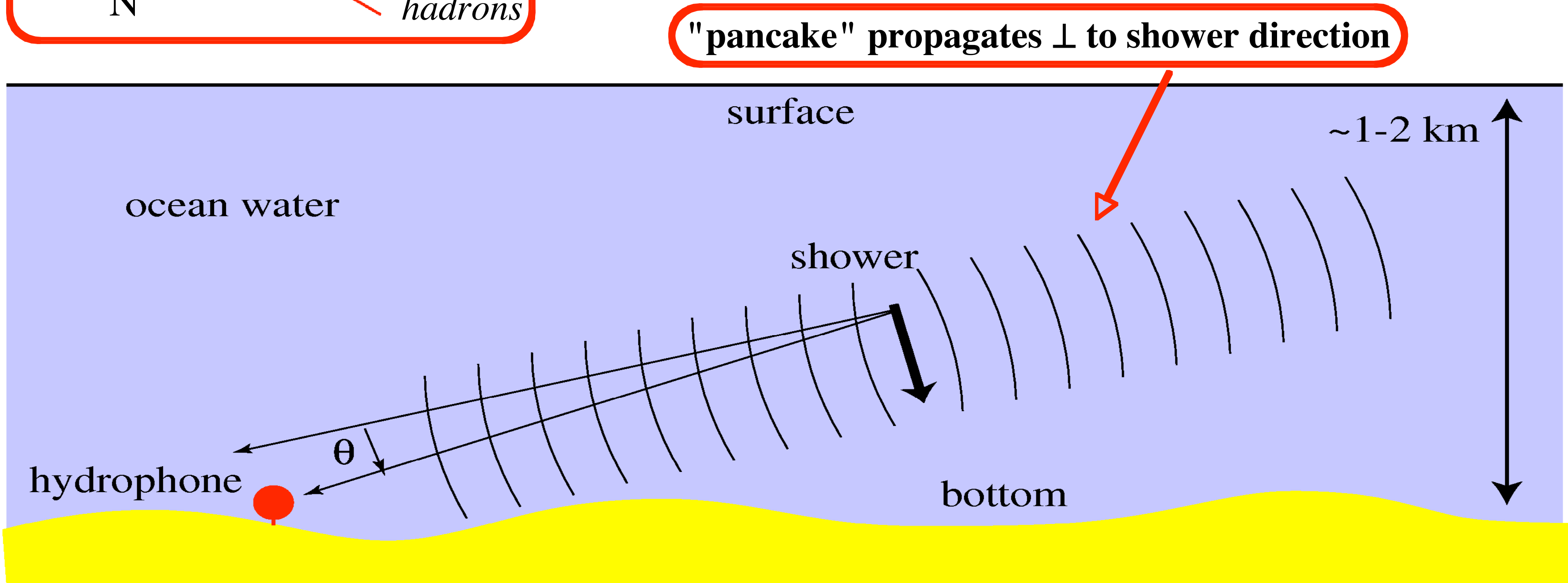
- ~100 meter attn. lengths observed
- Difficult to reconcile with long transmission in GPR results
- There may be clearer salt yet to be seen

Detection of Acoustic Neutrinos



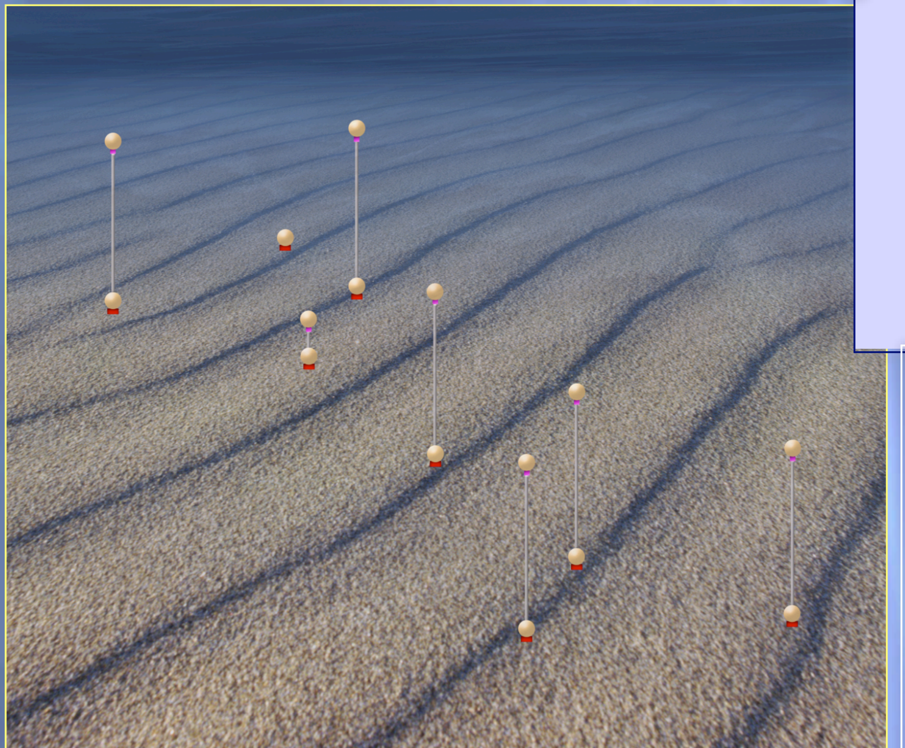


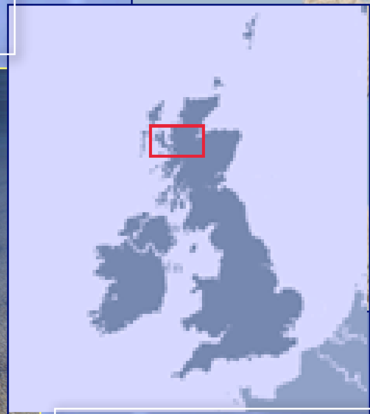




The ACoRNE project

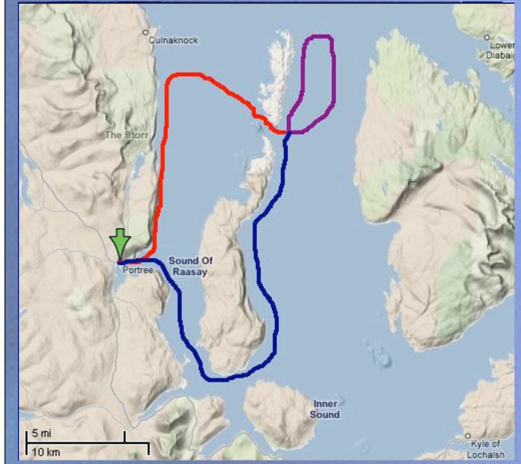
- Collaboration of scientists from Sheffield-Lancster-IC-Northumbria-UCL
- 3 years funding via Joint Grants Scheme (50-50 STFC and MOD)



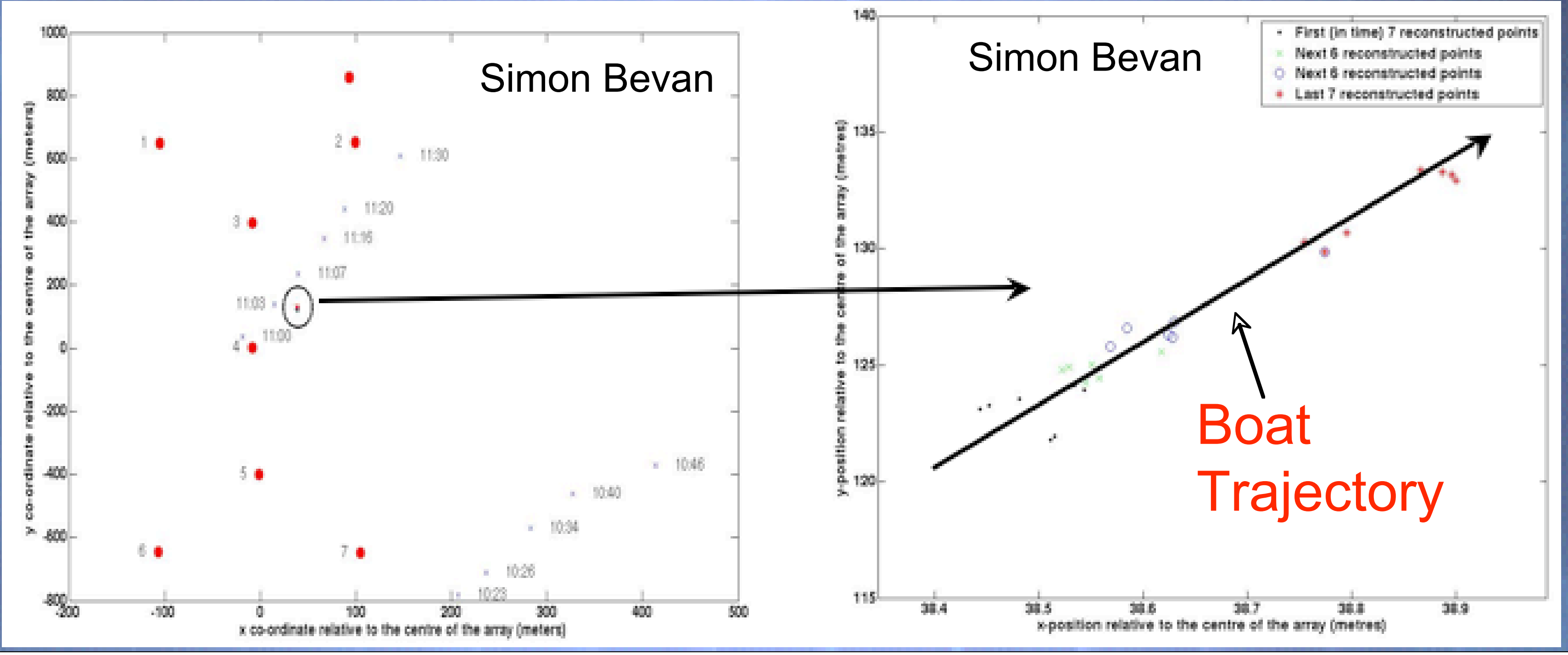


- The Qinetic underwater acoustic range, a hydrophone array off Rona in North-West Scotland used by the ACORNE collaboration
- 7 hydrophones read out quasi-continuously at 16bits,140kHz - a total of (~26Tb uncompressed) data taken to date (since December 2005)

Rona Field Trip August

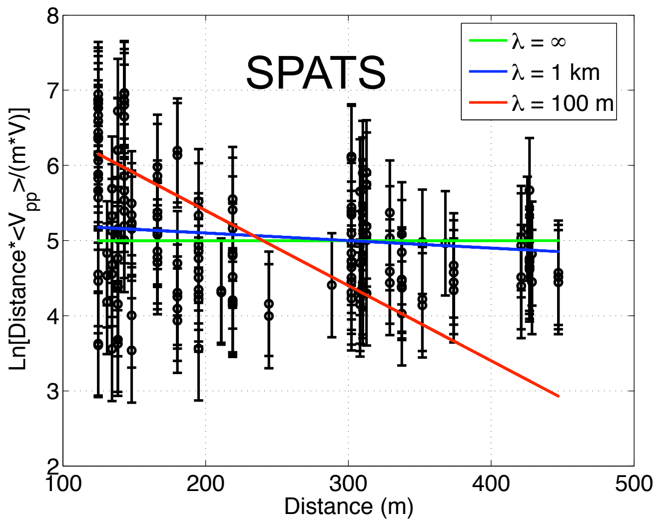


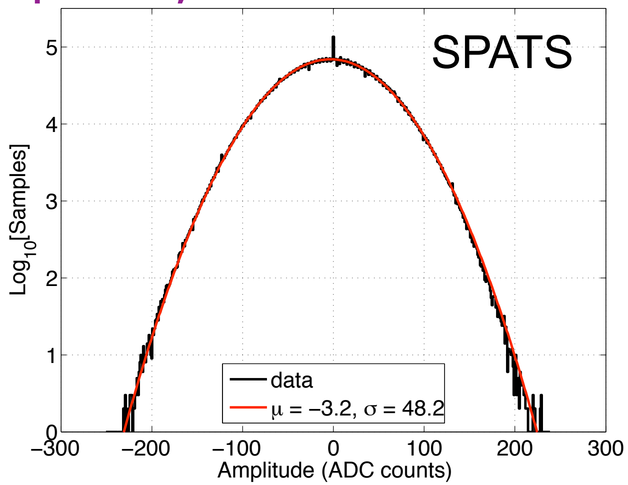
- In August 2007 Rona team injected a number of different pulse types and amplitudes directly above the Rona array
- Analysis is underway
- Boat position, and drift, successfully reconstructed
- One step closer to reconstructing a neutrino!



South Pole Acoustic Test Setup (SPATS)

- 3 string deployed in IceCube holes Jan 2007
- 4th string deployed Jan. 2008
- Goal to measure acoustic properties of ice
- Each string - 7 acoustic "stages" (Rx, Tx)
- IceCube Hole 78 includes optical, radio and acoustic





AMADEUS

- 3 acoustic storeys on Instrumentation line of ANTARES
- 3 more planned for another line

OvDE

- Acoustic sensors deployed on NEMO strings in Jan. 2005

Summary

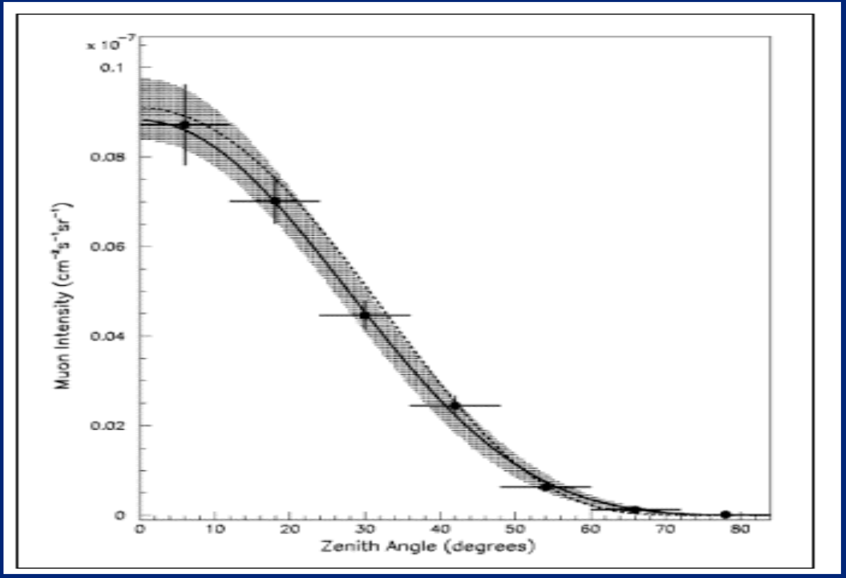
- Visible technique for neutrino detection is well established with IceCube (completion 2011) and KM3NeT (TDR end of this year) set to dig into mainstream models for neutrinos from astro sources
- Radio detection technique brings neutrino astronomy to >100's km^3 detection volumes - ice best medium foreseeable future
  - Radio technique setting important constraints
- Acoustic detection holds potential for larger volumes, R&D still needed and much is underway
- Development of next-generation projects is ongoing, and the field is finding the best path forward based on
  - Experience with existing projects
  - Site selection studies
  - Ever maturing simulations
- We (UCL) are looking for UK collaborators on IceRay project
  - Ice is only medium where visible, radio, acoustic are all possible
  - South pole only place where all three techniques being developed

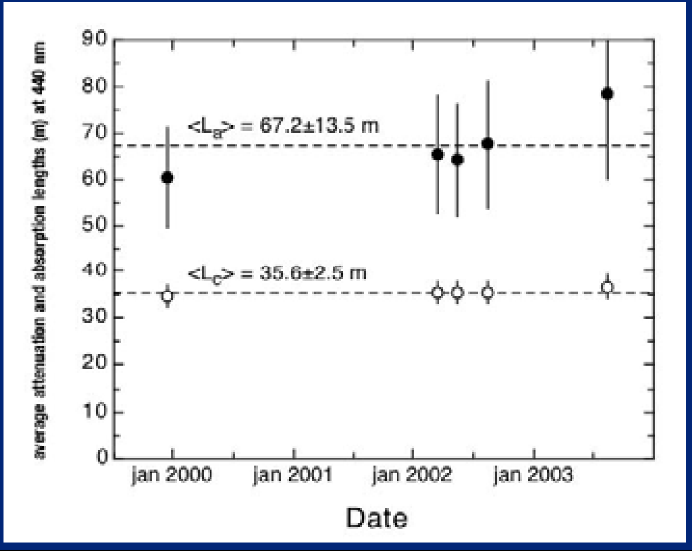
The race is on for cosmic neutrino detection!

Backup Slides

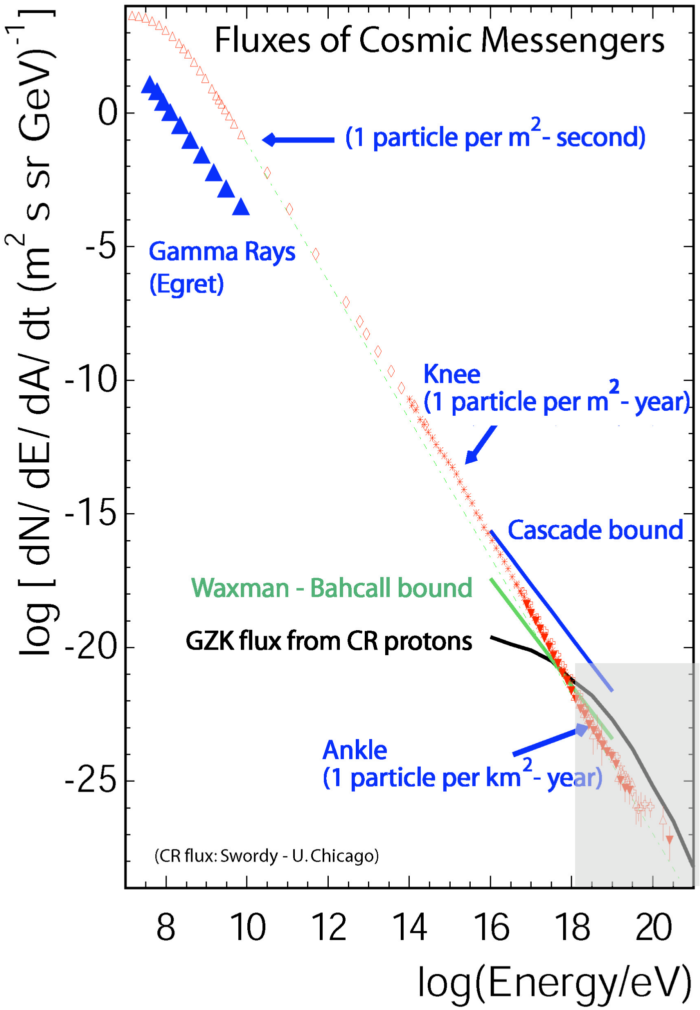
NESTOR	NEMO

• 15 km from Greek coast
• 4100 m depth
• Deploy from floating platform →avoid expensive subs
• Star-shaped storeys
• March 2003 data - 1 storey
• NuBE-NESTOR km^3 GRB detector planned
	• Off coast of Sicily
	• Since 1998: 30 sea campaigns
	• Phase 1 completed (test site)
	  • 4 - 15m-long storeys
	  • Separated by 150 m
	  • Currently taking data
	• Phase 2 underway
	  • Preferred site
	  • Full: 9 x 9 - 1 km towers



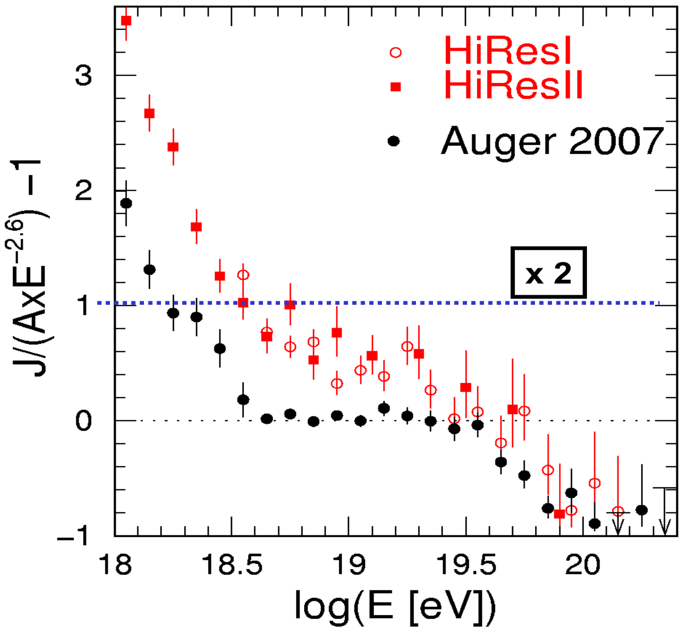


The Highest Energy Cosmic Messengers



- Greisen-Zatsepin-Kuzmin (GZK):
  Above $10^{19.5}$ eV:

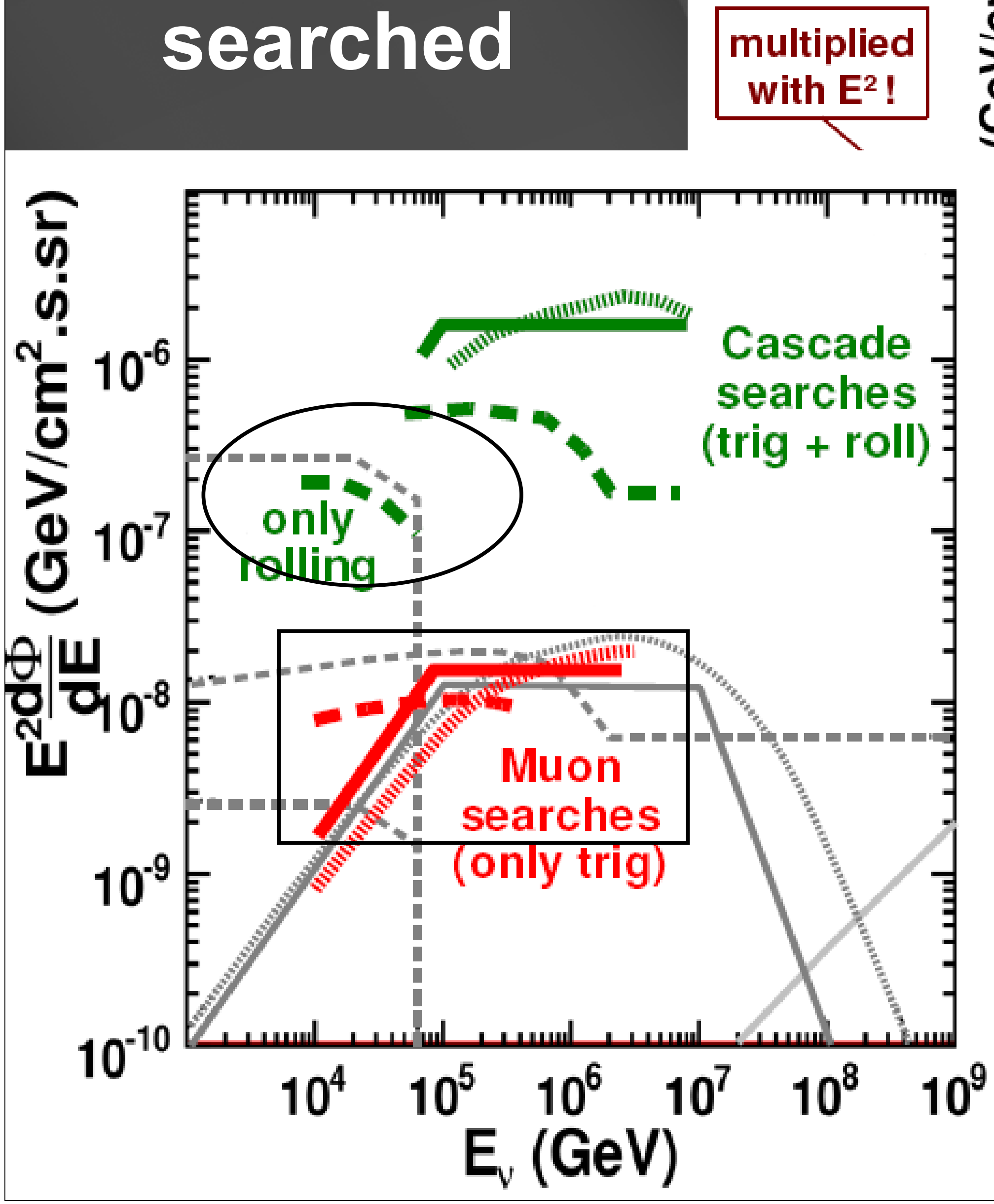
$$\mathbf{p}\ \gamma_{\mathbf{CMB}} \rightarrow \mathbf{\Delta}^{*} \rightarrow \mathbf{n}\ \pi^{+} \rightarrow \mathbf{n}\ \mathbf{e}^{+}\ \nu_{\mu}\ \nu_{\mathbf{e}}\ \bar{\nu}_{\mu}$$

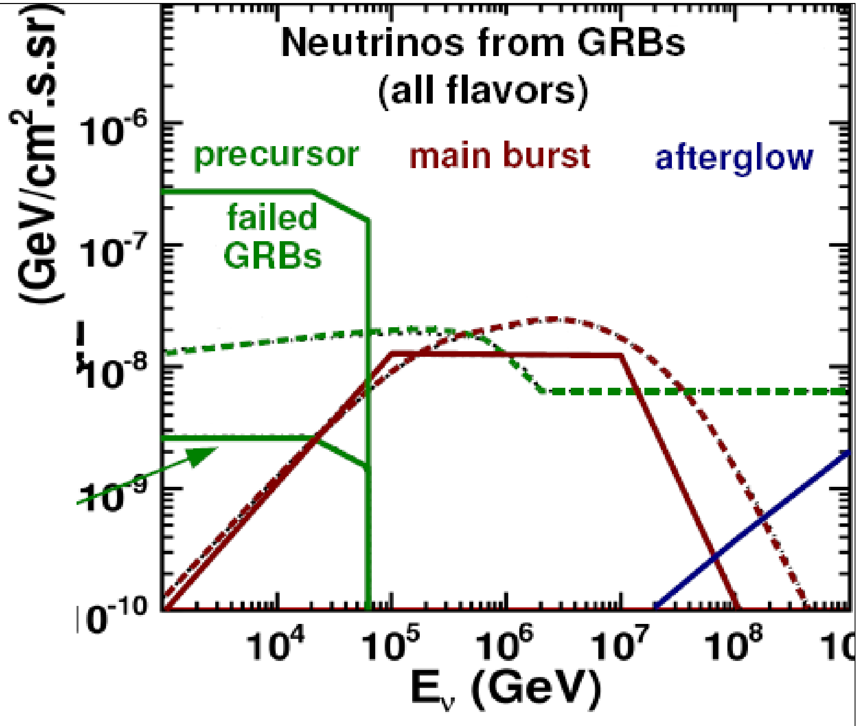


Expect ultra-high energy (UHE) neutrinos from GZK process

And from any photo-hadronic interactions producing CR’s

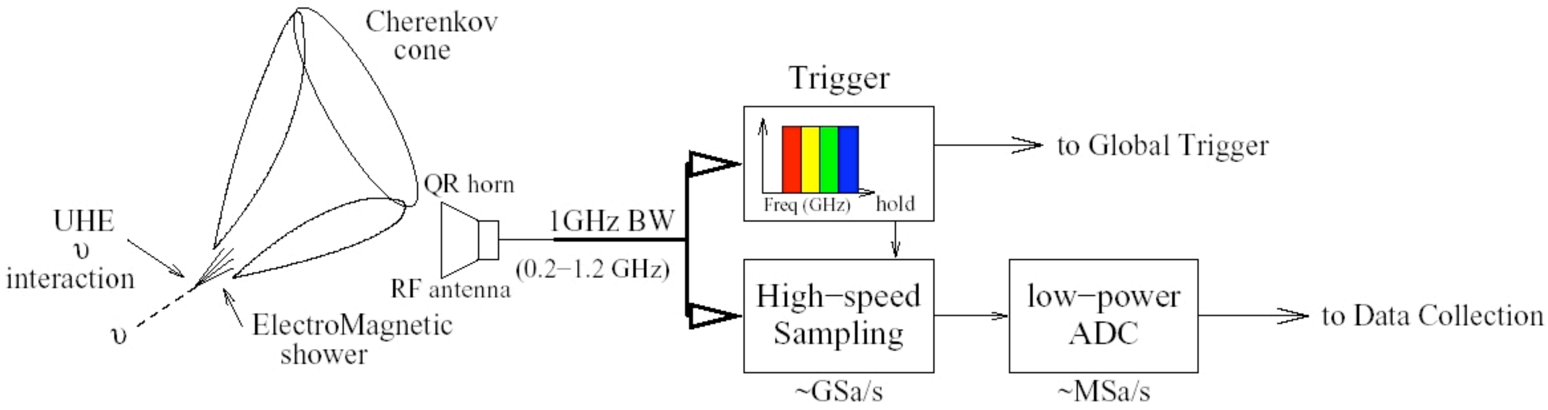
420 GRB searched





- AMANDA starts to exclude models
- IceCube will reach 70 times the instrumented volume in 2009

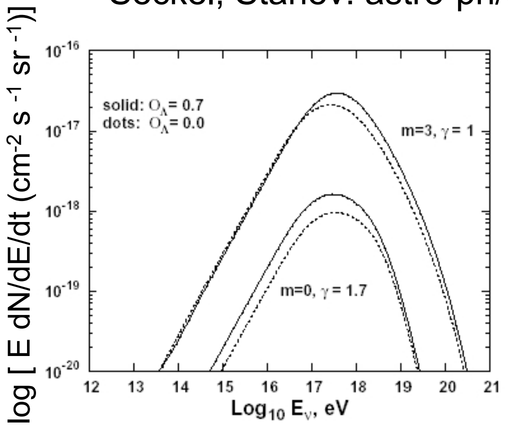
ANITA Signal Acquisition



- Trigger: Signal divided into frequency sub bands (channels)
  - Powerful rejection against narrow bandwidth backgrounds
  - Multi-band coincidence allows better noise rejection
- 8 channels/ antenna
- Require 3/8 channels fire for antenna to pass L1 trigger
- Global trigger analyzes information across antennas
- For Anita-lite, no banding: 4 channels, require 3-fold coincidence

What Messages Will UHE Neutrinos Carry

Seckel, Stanev: astro-ph/0502244



Source distribution, spectrum

γ (CMB)

GZK process

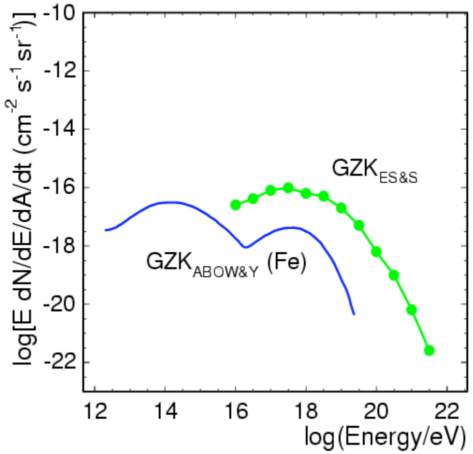
p, Fe

Cosmic ray composition

Universe expansion
Λ (subtle)

ν

Point back to the source

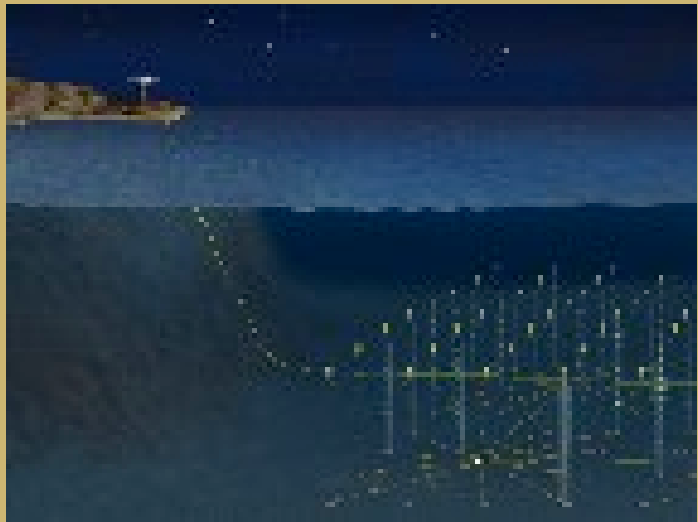


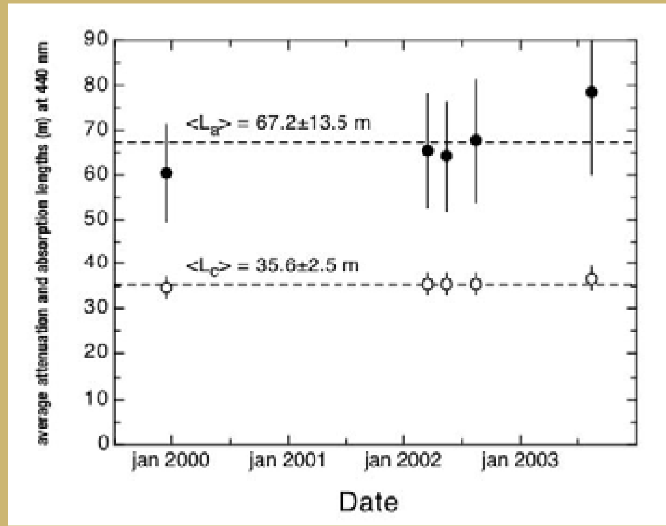
Center of mass energies > LHC !

Physics potential of UHE neutrinos spans particle physics and astrophysics

BAIKAL

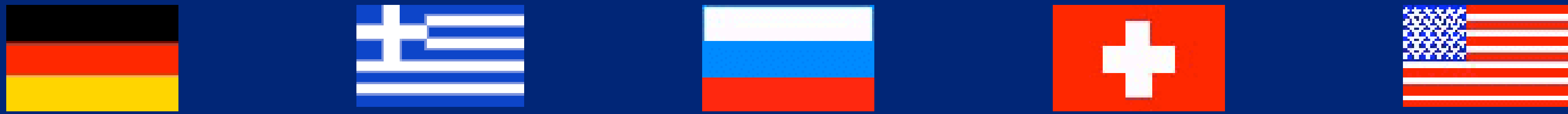
NEMO



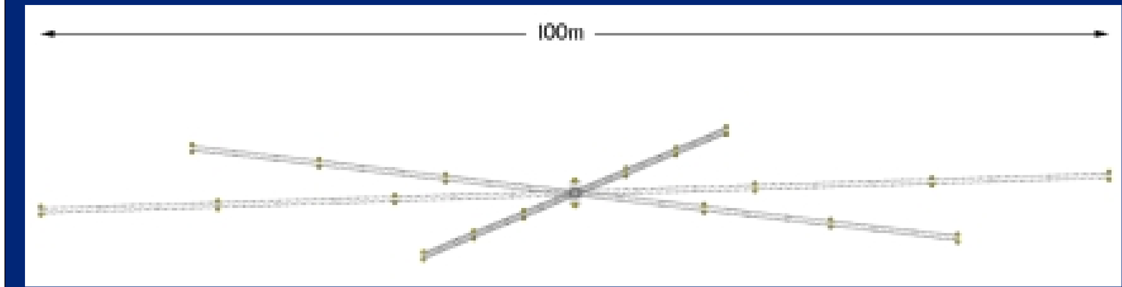


- Full array would be km^3 scale, ~5000 OM's on 64 towers
- NEMO - Phase 1 completed
  - Construction, deployment, operation of all key elements of test site (2031 m deep, closer to shore)
  - 4 storey tower separated by 150 m, 15 m long storeys
  - Currently taking data
- NEMO - Phase 2
  - Work on preferred site (further, deeper) begun

NESTOR

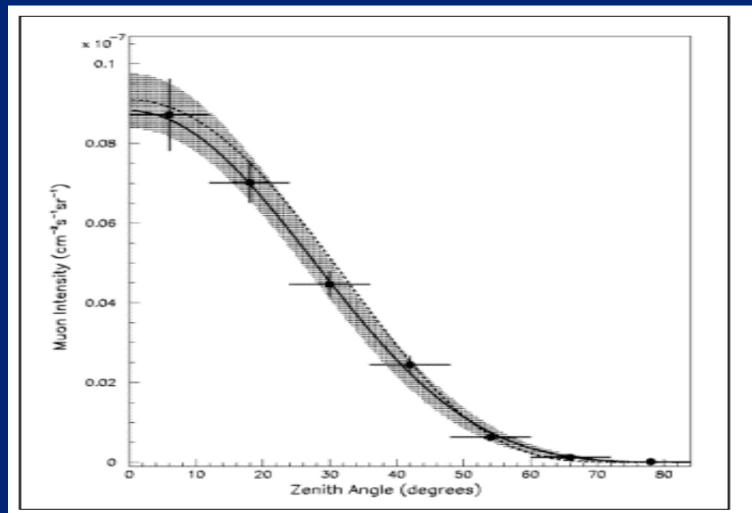


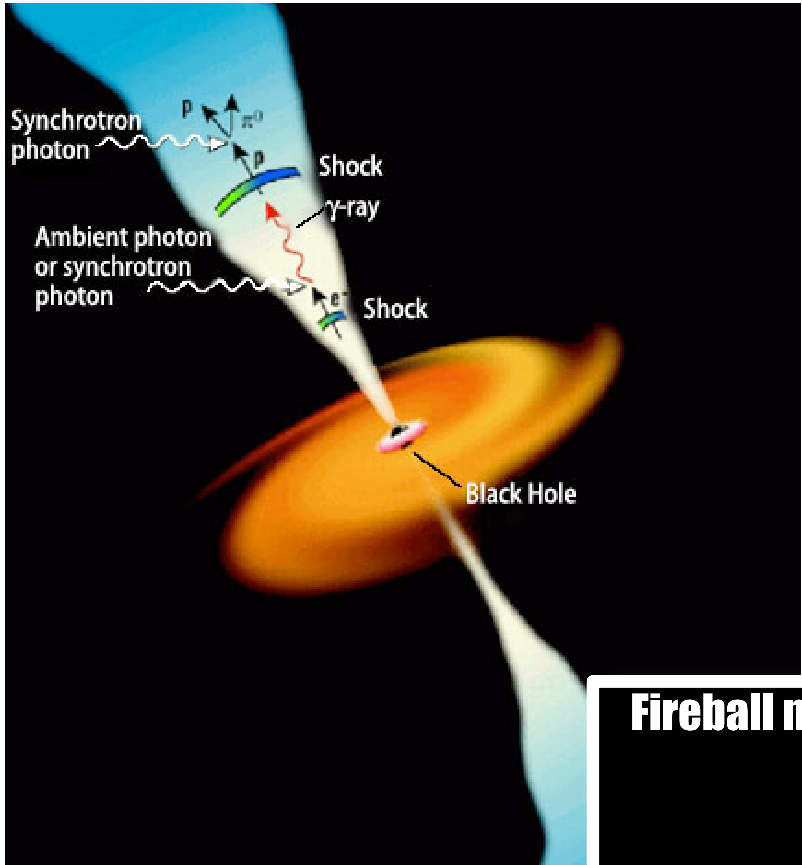
- 15 km from Greek coast
- 4100 m depth

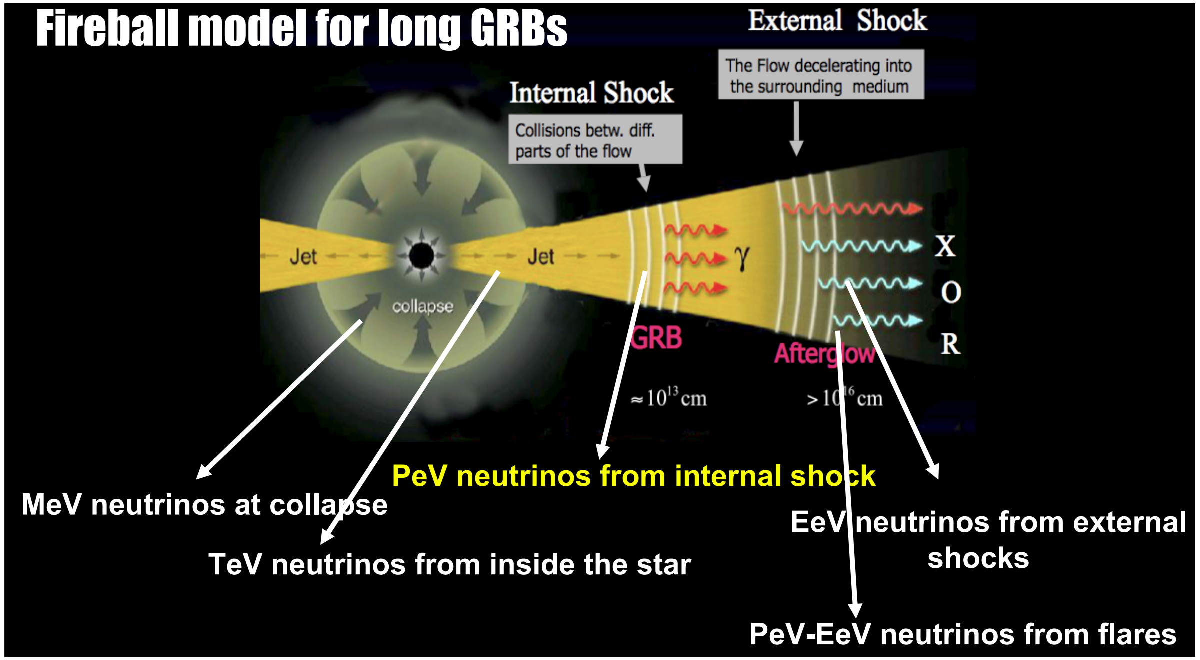


- Deploy from floating platform →avoid expensive subs
- Star-shaped storeys
- 2 OM's each point: one ↑, one ↓
- Plan to repair cable, deploy 4–storey prototype tower

- March 2003 prototype detector connected
- Problem with cable one month later
- Measured ν flux

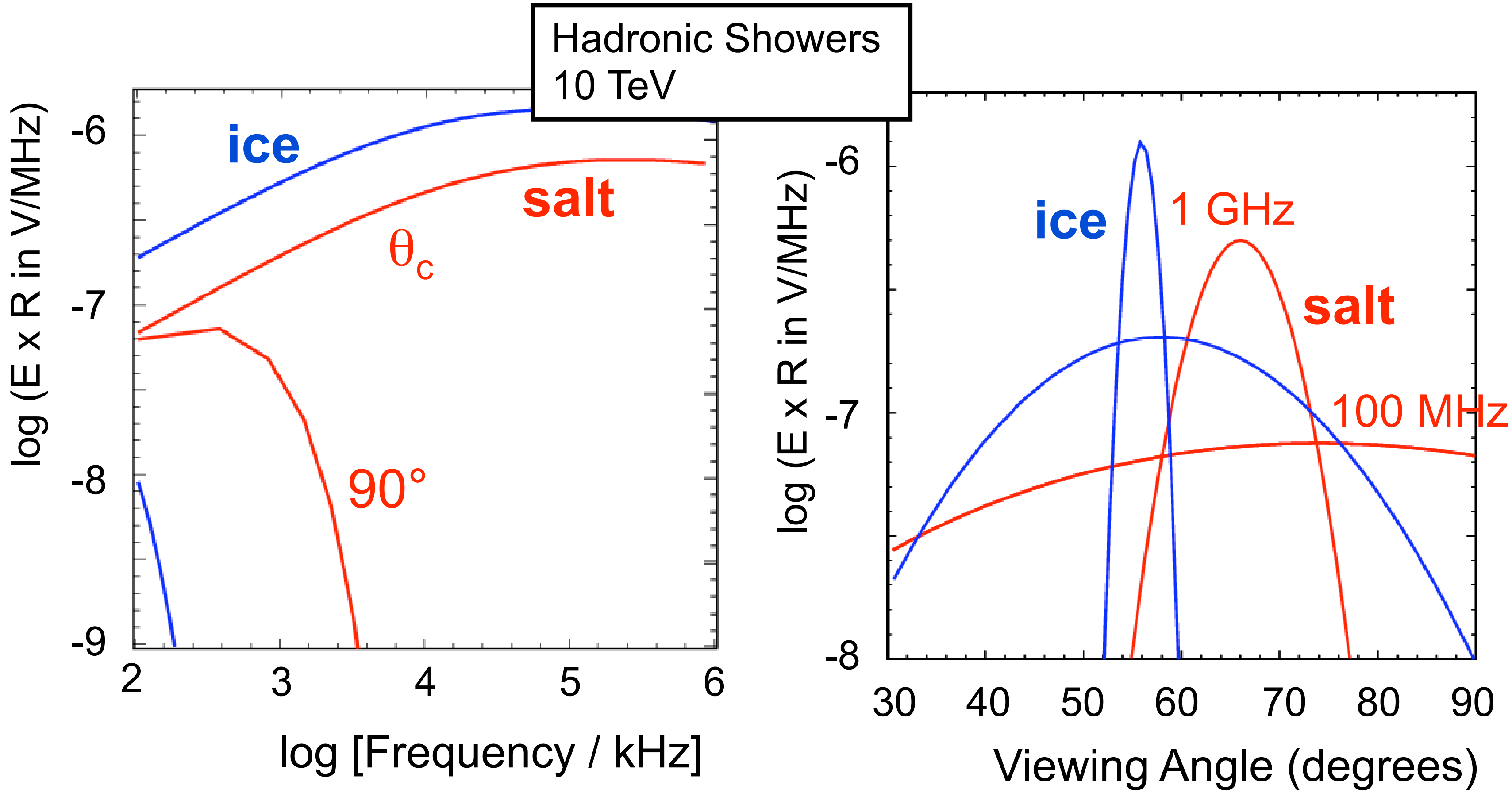



Synchrotron photon
p
π^0
p
Shock
γ-ray
Ambient photon or synchrotron photon
e
Shock
Black Hole


Fireball model for long GRBs
External Shock
The Flow decelerating into the surrounding medium
Internal Shock
Collisions betw. diff. parts of the flow
Jet
Jet
collapse
γ
X
O
R
GRB
Afterglow
≈10^{13}cm
>10^{16}cm
PeV neutrinos from internal shock
MeV neutrinos at collapse
EeV neutrinos from external shocks
TeV neutrinos from inside the star
PeV-EeV neutrinos from flares

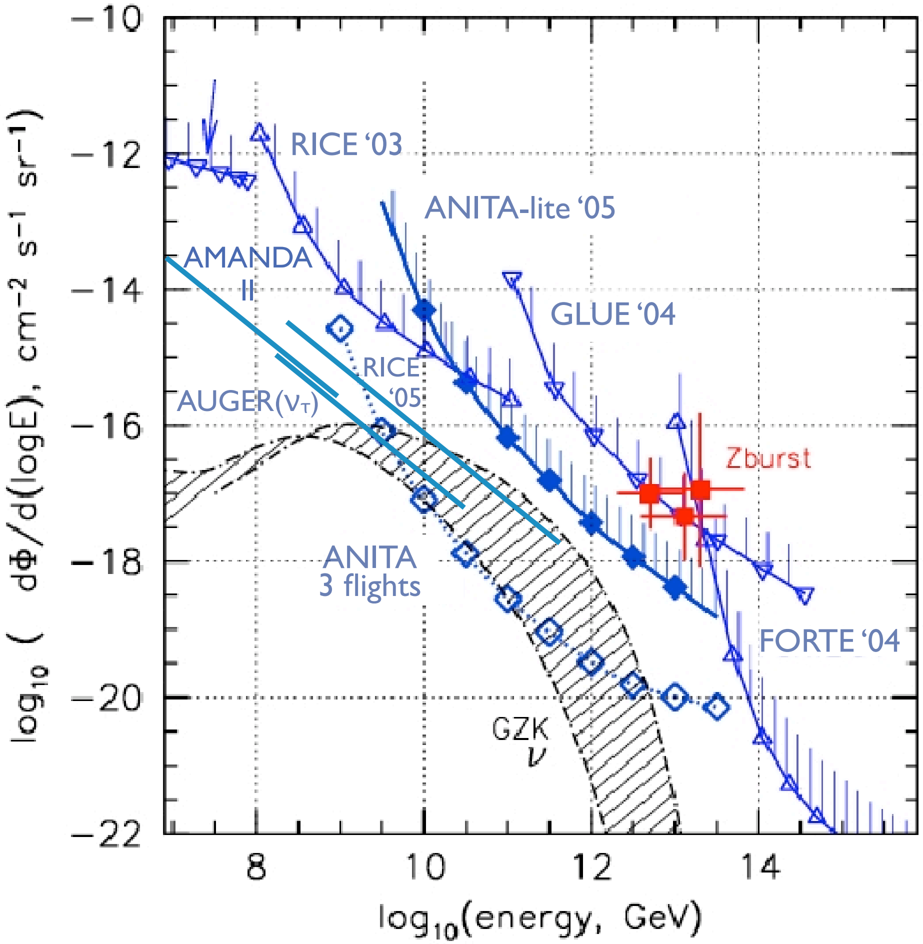
Comparing Askaryan Signal in Ice and Salt

Parameterization in the simulation from J. Alvarez-Muniz astro-ph/0512337:

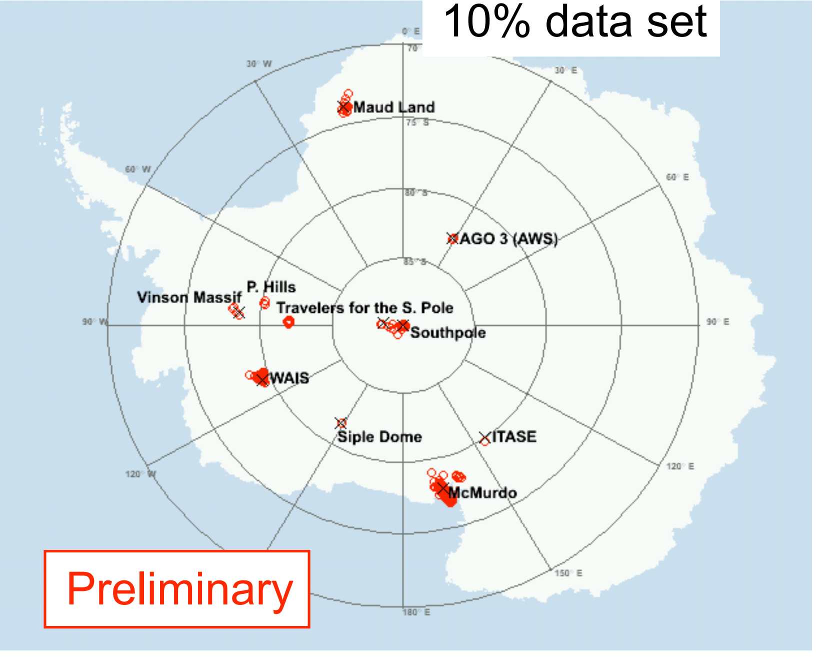


Electric field α shower energy

Electromagnetic showers narrow beyond ~ 10 PeV due to LPM effect



RICE '03
ANITA-lite '05
AMANDA II
GLUE '04
RICE '05
AUGER(ν_τ)
Zburst
ANITA 3 flights
FORTE '04
GZK ν
$\log_{10}$ ($d\Phi/d(\log E)$, cm^{-2} s^{-1} sr^{-1})
$\log_{10}$(energy, GeV)
−10
−12
−14
−16
−18
−20
−22
8
10
12
14

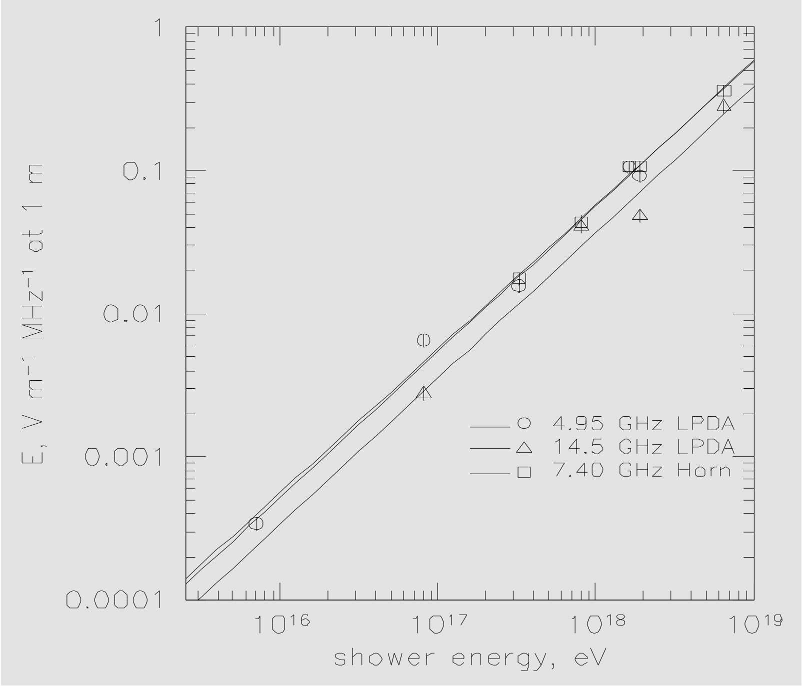

10% data set
Maud Land
AGO 3 (AWS)
P. Hills
Vinson Massif
Travelers for the S. Pole
Southpole
WAIS
Siple Dome
ITASE
McMurdo
Preliminary

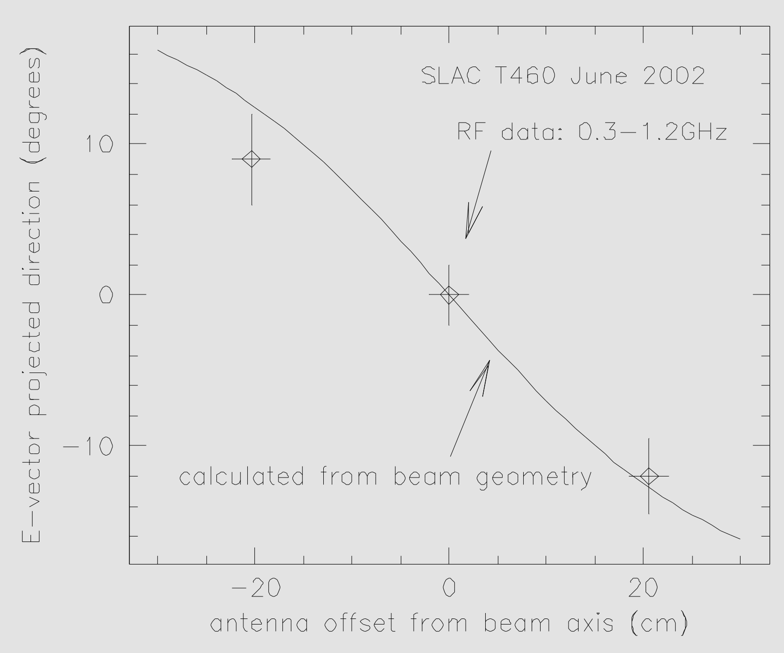
Accelerator Measurements of Askaryan Signal

Argonne: P. Schoessow, JPL: G. Resch
SLAC: C. Field, R. Iverson, A. Odian, D. Walz
UCLA: D. Saltzberg, D. Williams
UH Manoa: P. Gorham, E. Guillian, R. Milincic

Beam measurements at SLAC using photon beam incident on

- Sand (2000)
- Salt (2002)

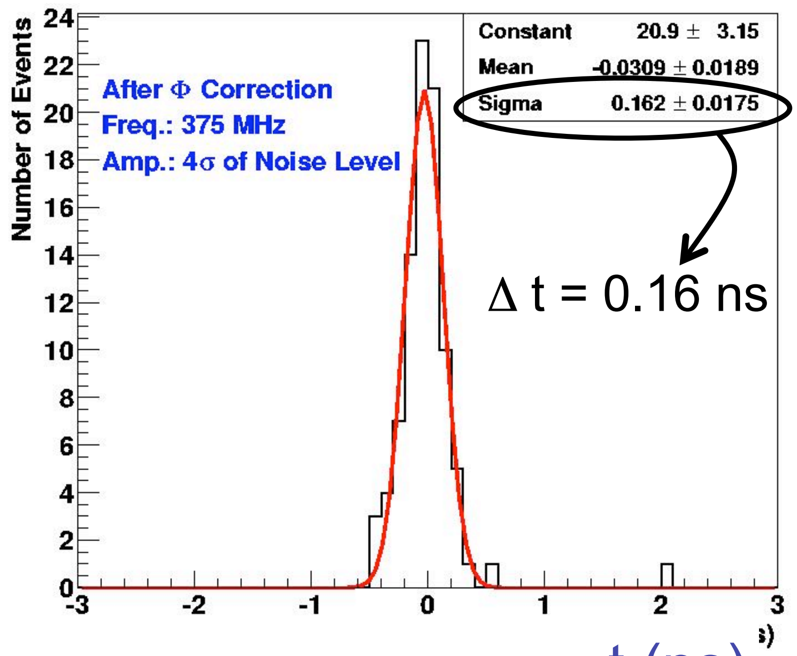




Anita-lite (cont)

- Flying two antennas with angular separation 22° allowed us to measure ANITA's angular resolution
- Compare time of arrival of calibration pulses

Angular resolution measured:
ANITA-lite: $\sigma(\Delta t)$=0.16 ns → $\sigma(\Delta\phi)$=2.3±
Full ANITA: expect $\sigma(\Delta t)$=0.1 ns → $\sigma(\Delta\phi)$=1.5°, $\sigma(\Delta\theta)$=0.5°

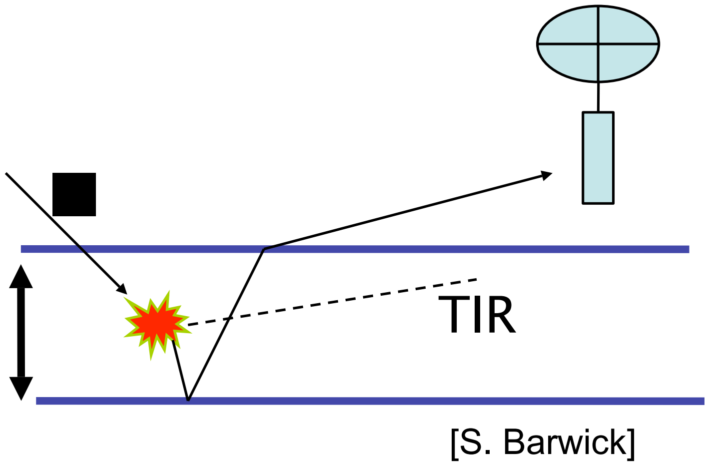


Remember that this is resolution on *RF direction*

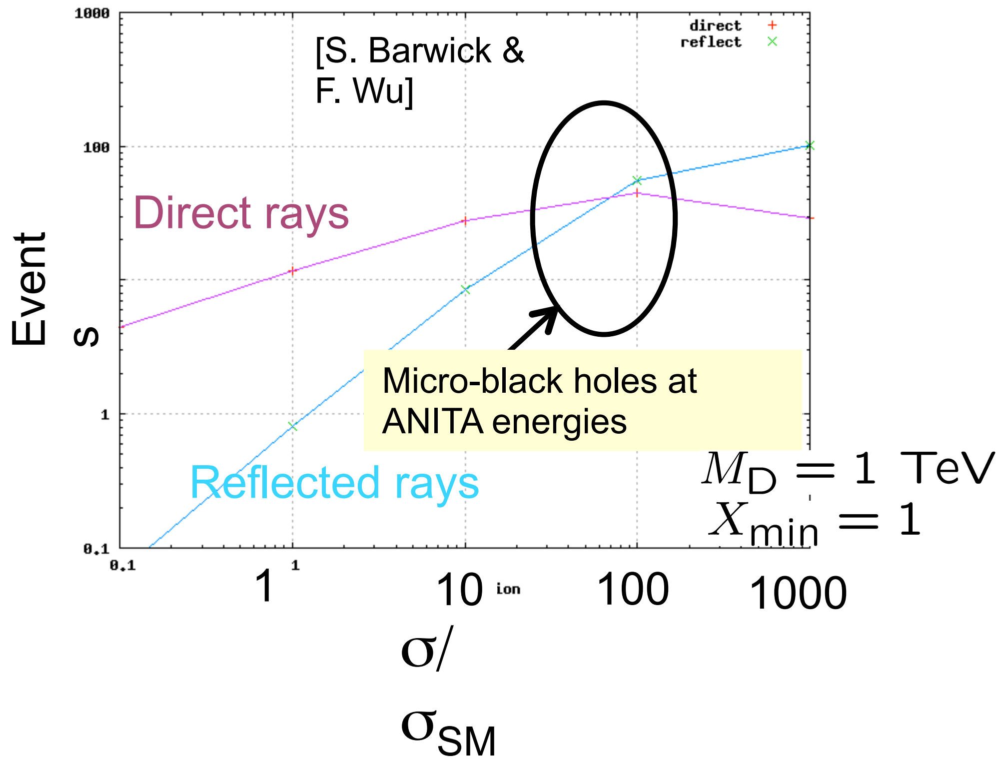
- Could verify that a signal comes from the ice
- Help discern near, far events → for energy measurement, for example

Reflected Rays

- ANITA could (possibly) detect events where a signal is reflected from ice-bedrock interface
- At SM σ's, reflected rays not significant
- At large cross-sections, short pathlengths → down-going neutrinos dominate ! reflected rays important



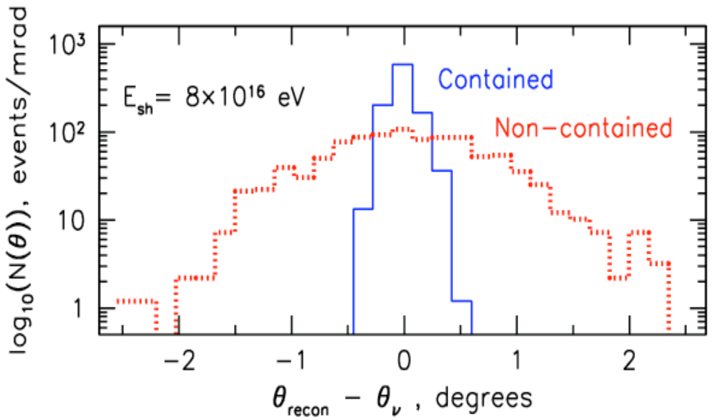
Signals suffer from extra attenuation through ice and losses at reflection



Angular Resolution of SalSA / ARIANNA

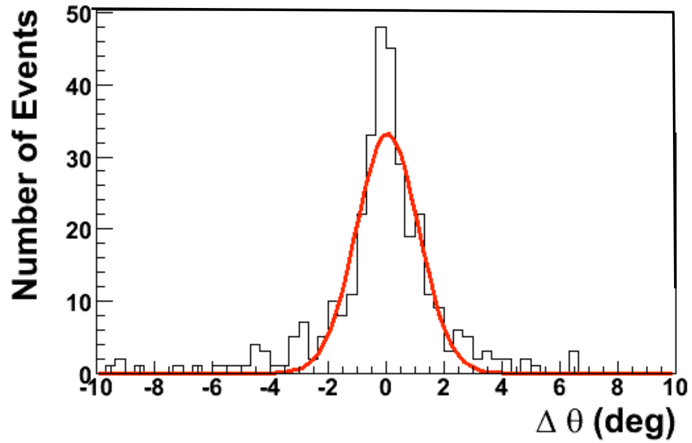
- Two complementary SalSA simulations also developed, UCLA (Connolly) and Hawaii (Gorham)
- Mainland simulation is a general "embedded detector" sim.
  - –Also models ARIANNA with different choice of inputs
- Antennas arranged in nodes of antennas
- Multilevel trigger requires coincidences between antennas within nodes, coincidence between hit nodes

SalSA 3D array



P. Gorham, University of Hawaii
and Kevin Reil, SLAC

ARIANNA 2D array



F. Wu and S. Barwick, UCI

$\Delta\,\theta$ ~ fraction of a degree (contained)

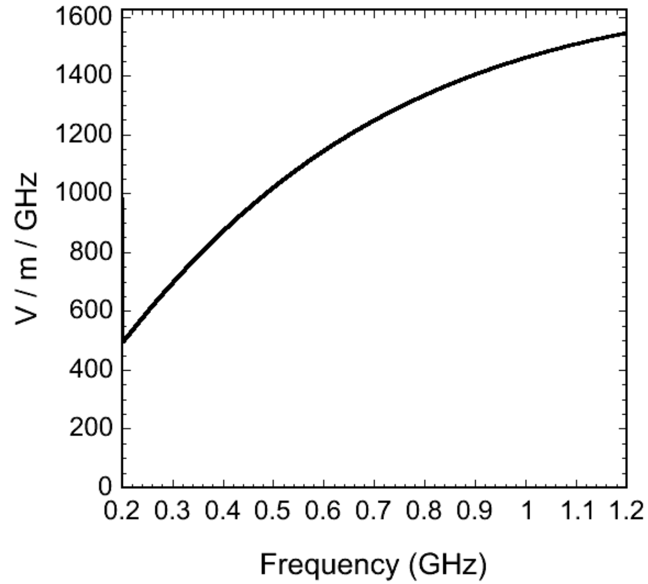
$\Delta\,\theta$ ~ 1 deg

This is the angular resolution on the *neutrino* direction!

Moving Trigger Simulation from Frequency Domain to Time Domain

- Currently, simulations model the signal strength by integrating the frequency profile
- Noise contribution is selected from a Gaussian
- Compare that signal + noise to threshold
- True system integrates power in time domain
- Thermal noise is our largest background ! essential that our system's response to noise is well understood

(J. Alvarez-Muniz, *et al.*, Phys.Rev.**D62**:063001,2000; J. Alvarez-Muniz, *et al.*, Phys.Lett.**B411**:218-224,1997)



- Need to model channel dependent thresholds from ANITA flight

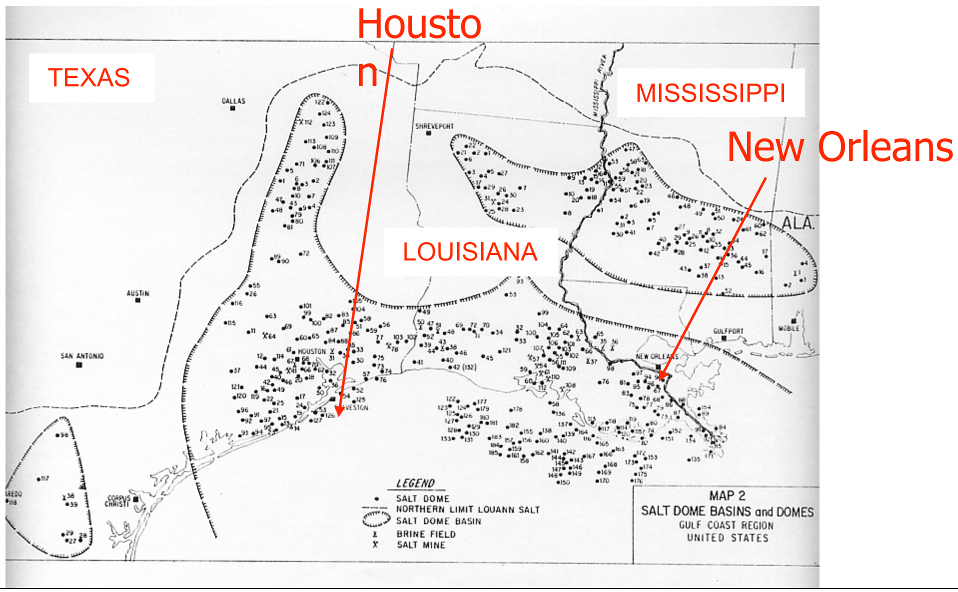
We have built the tools for a time domain simulation

Salt Dome Selection:

U.S. Gulf Coast Most Promising

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

Stable salt diapirs all over Gulf coast



- Studying surveys from 70's, 80's by DOE 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)
  - Visited dome sites to explore feasibility of

Visit to Vacherie Dome

near Shreveport, Louisiana

Visit to Vacherie Dome

ANITA Calibration at SLAC: June 2006

- Went to SLAC for 2 weeks of beam time in End Station A during June 2006
- Full-up system calibration with actual Askaryan impulses from Ice

GOALS

- Produce Askaryan pulses in ice from a 28.5 GeV electron beam
- Self-trigger on pulses from full ANITA payload
- Record data at many positions to map out Cherenkov cone

10 ton Ice Target

- ~10 ton ice target
- Ironed sides of ice blocks to minimize gaps between blocks
- Ice blocks were assembled into a target   2.0 m x

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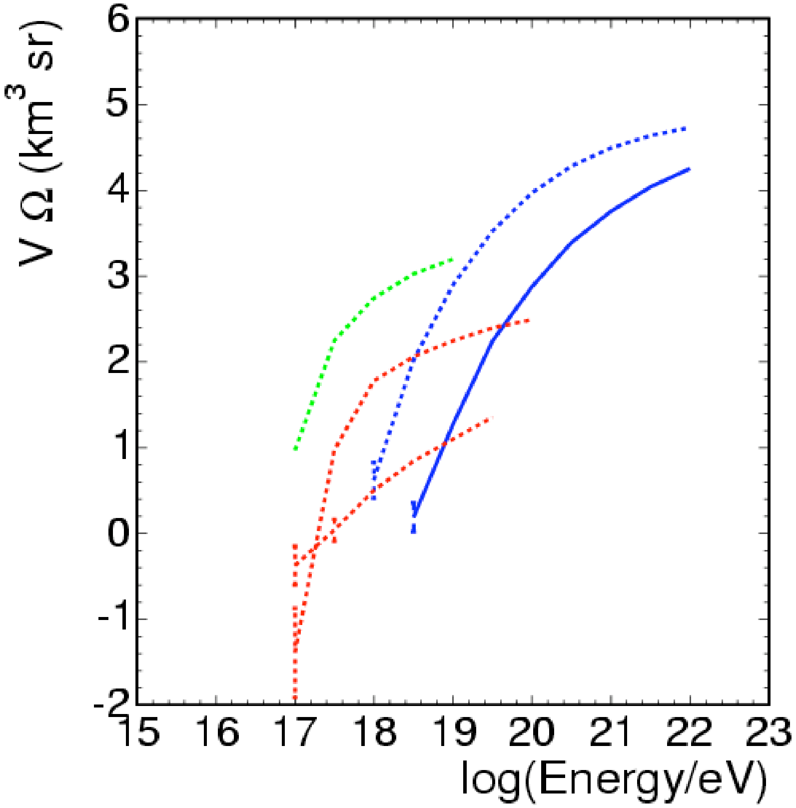
Volume * str



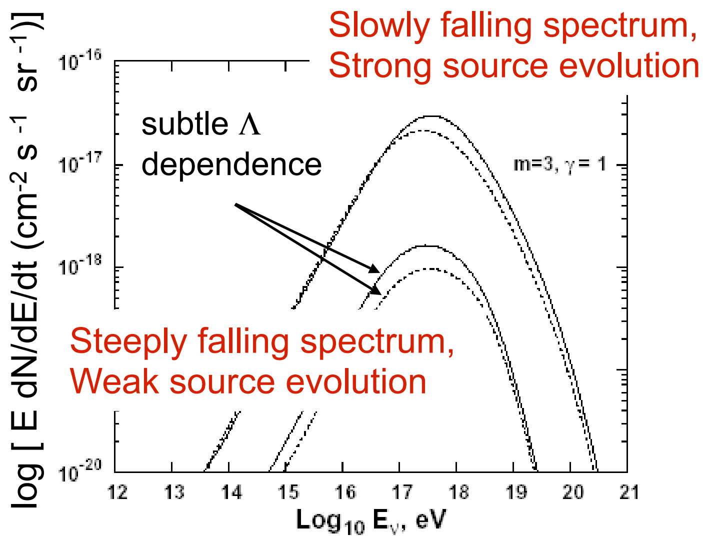
What Messages Will Neutrinos Carry

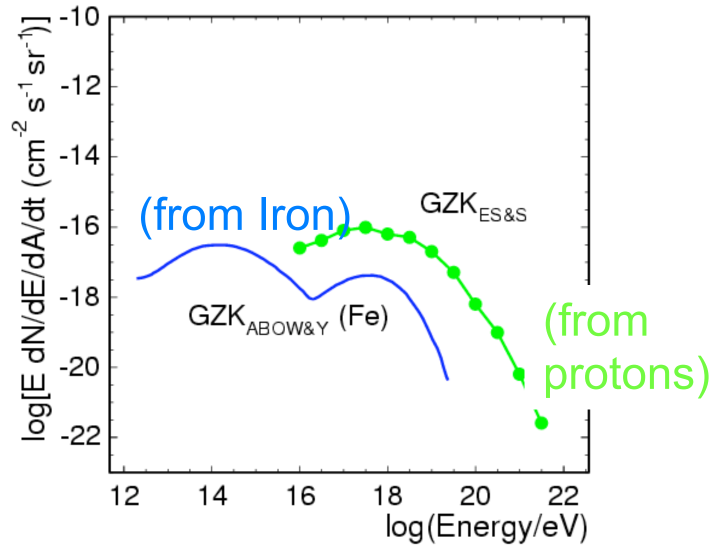
- Could point to new sources
- Neutrinos carry information about cosmic rays and their sources
  - Flux could reveal clues about the nature of CR sources
    - Spatial distribution
    - Injection spectra
  - Cosmological constant (subtle)
  - Composition of the CR's
- Center of mass of a 10^{17} eV neutrino incident on a nucleon is 14 TeV

→Beyond typical LHC energies

Potential for new physics

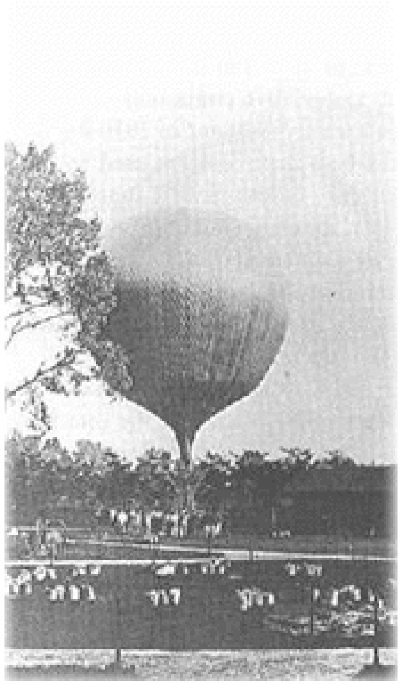
Seckel, Stanev: astro-ph/0502244





Cosmic Origin of Radiation

1912 Austrian Victor Hess boarded a balloon with a radiation counter
Went to 17,500 ft. altitude
Radiation increased with altitude
Established “cosmic” origin of natural radiation



Observations of cosmic particles have led to many groundbreaking discoveries:

- Particle physics: discovery of many subatomic particles (e^+, π^+, μ^+, K , …)
- Astrophysics: Discovery of new objects, insights into engines inside them

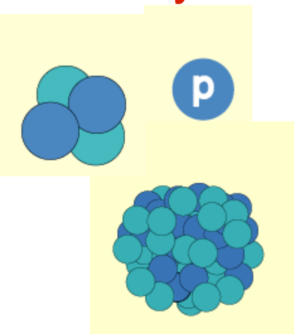
Ballooning remains an important means for probing the cosmos

I will describe how we are looking for a new class of cosmic radiation from a balloon at 120,000 ft. by looking “down” instead of “up”

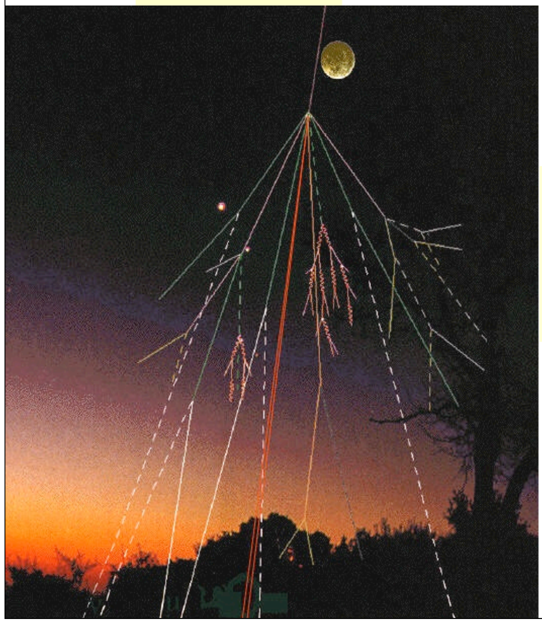
Types of Cosmic Radiation

Ordinary Matter

Protons and Heavy Nucleii



- Over 99% of cosmic radiation
- Positively charged
- Detected through ionization (high altitude) or showers of π, μ, γ in atmosphere



Electrons

- Only 1% of cosmic radiation

Photons

γ

- Less than 0.1% of cosmic radiation
- Detected directly with telescopes (high altitude) or showers of e,γ in atmosphere

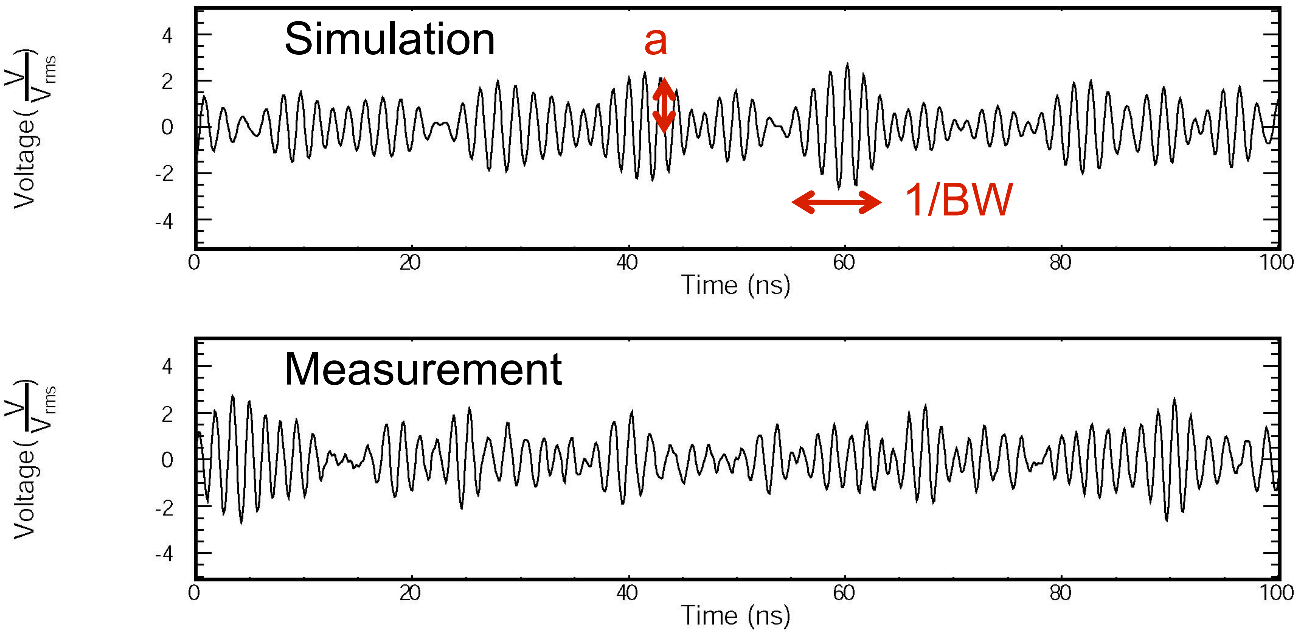
Neutrinos

ν

- Only extraterrestrial neutrinos observed from Sun, Supernova 1987a
- Only observed through weak interactions

Building Tools for Time Domain Trigger Simulation

Noise only (no signal) in the band from 550 to 750 MHz (Band 3):



Simulated by summing sin waves flat in frequency within the band, with random phases

Voltages distributed by a Gaussian:
$P(V)\,dV = 1/(\sqrt{2\pi}\,\sigma)\exp(-V^2/2\sigma^2)$

Raleigh:
$P(a)\,da = a/\sigma^2 \exp(-a^2/2\sigma^2)da$

- Essentially, the noise (at ~center frequency f_0) is acting as a carrier, to the “signal” (the bandwidth)
- Envelope magnitudes a following a Raleigh distribution

Consider a Power Integrator

Integration Time Δt: 1 oscillation

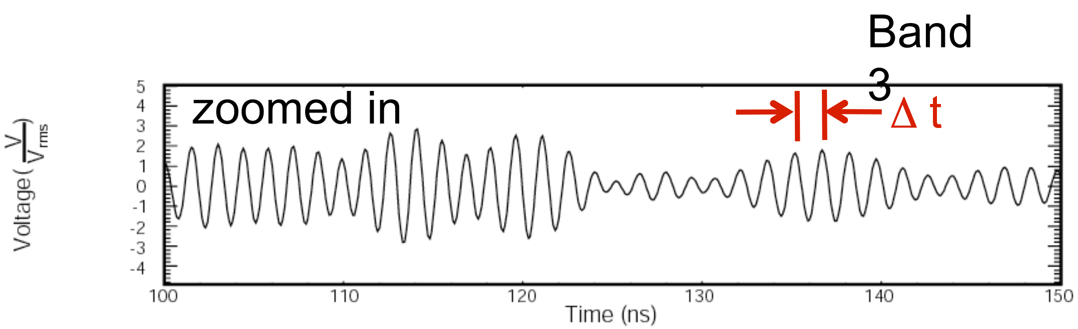
Within the window,

$V(t) \approx a \sin(2\pi f_0 t)$

$P(t) \approx a^2 \sin^2 (2\pi f_0 t)$

$\int P(t)\, \Delta t = a^2 / 2$

→ samples power envelopes $a^2=J$

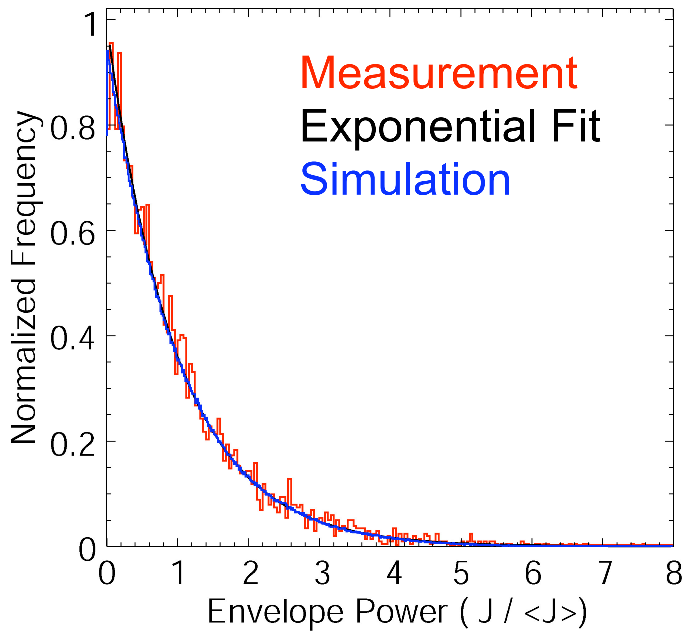


$$P(a)\, da = a/\sigma^2 \exp(-a^2/\sigma^2)\, da$$

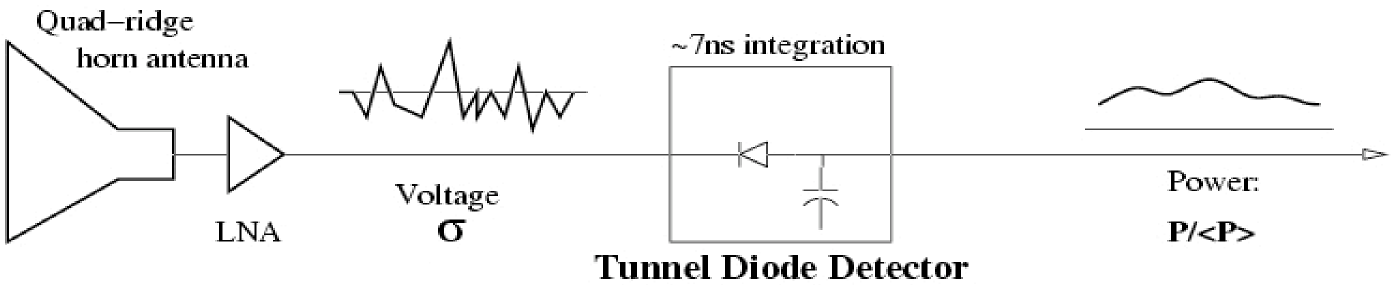
$$2\, a\, da = dJ$$

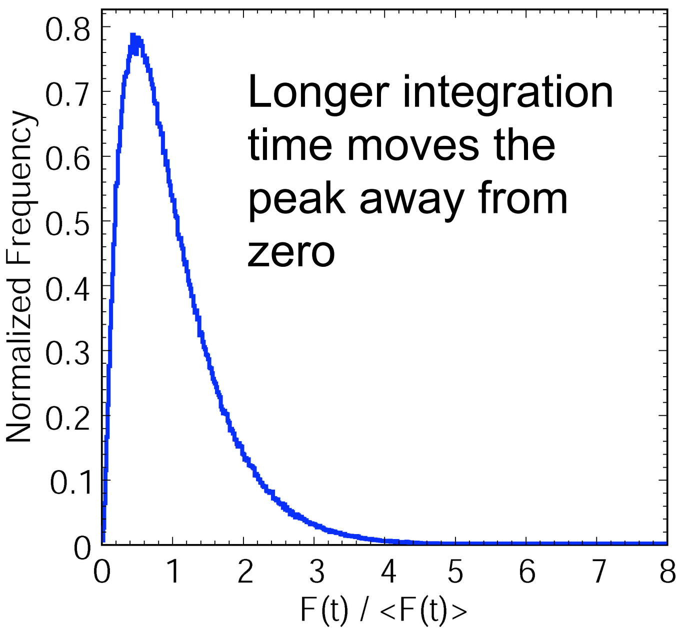
$$P(J) = 1/(2\sigma^2) \exp(-J/\sigma^2)\, dJ$$

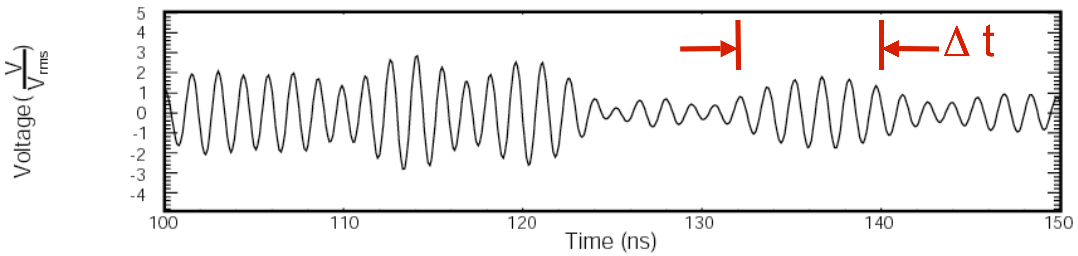
→ result is an exponential distribution



ANITA's Single-Channel (Level 1) Trigger Is





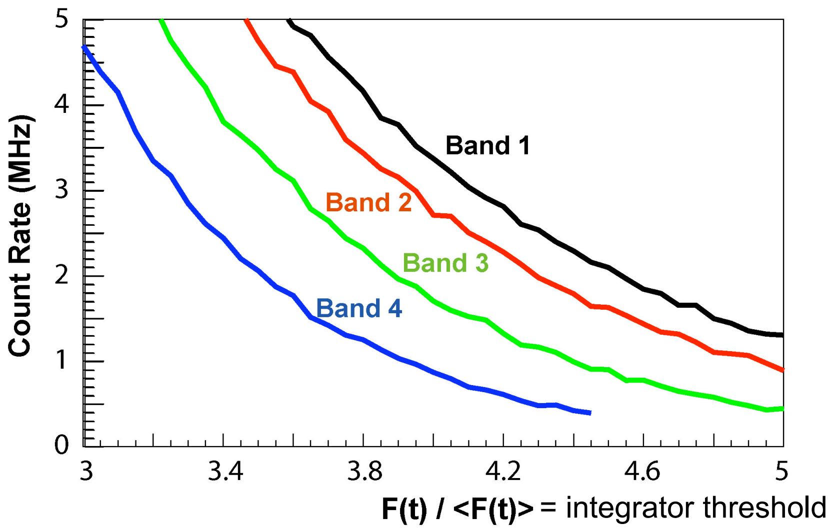


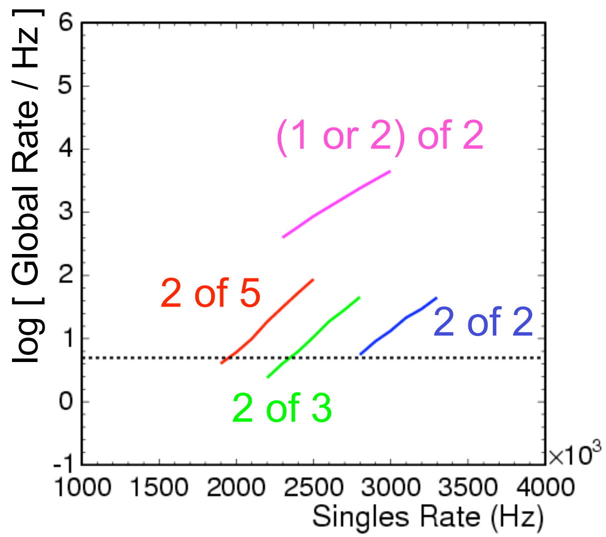
Band 3

- Model the tunnel diode as an integrator
  - Integration time $\Delta t = 7$ ns
  - Exponential response $\tau = 5$ ns
- Deadtime once a trigger is generated is 12 ns

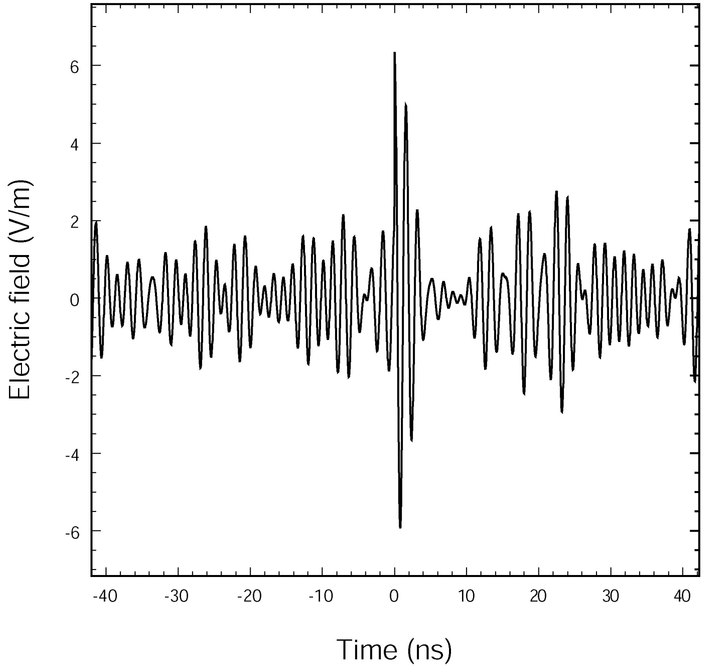
Trigger Rates

- Using our L1 trigger model, we calculate single-channel trigger rates
- Global trigger requires
  - L2: Coincidence between 2/3 neighboring antennas
  - L3: Coincidence in ϕ between L2 hits
- We calculate Global trigger rates with toy MC
- This analysis was used to guide
  - Choice of L2 trigger parameters
  - Trigger parameters during flight





Adding in Signal



- Add FFT of signal parameterization onto simulated noise
- Calculate a global trigger efficiency vs. S/N

- Compare with lab measurement from a pulser with similar bandwidth
- Agreement looks very promising!
- Will be used to assess ANITA sensitivity with in-flight parameters