Status of Acoustic Detection

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TeV Particle Astrophysics II
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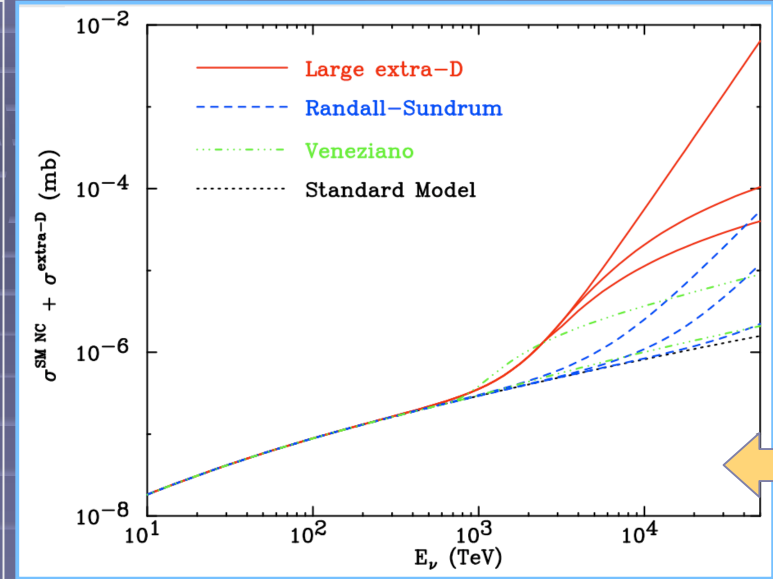
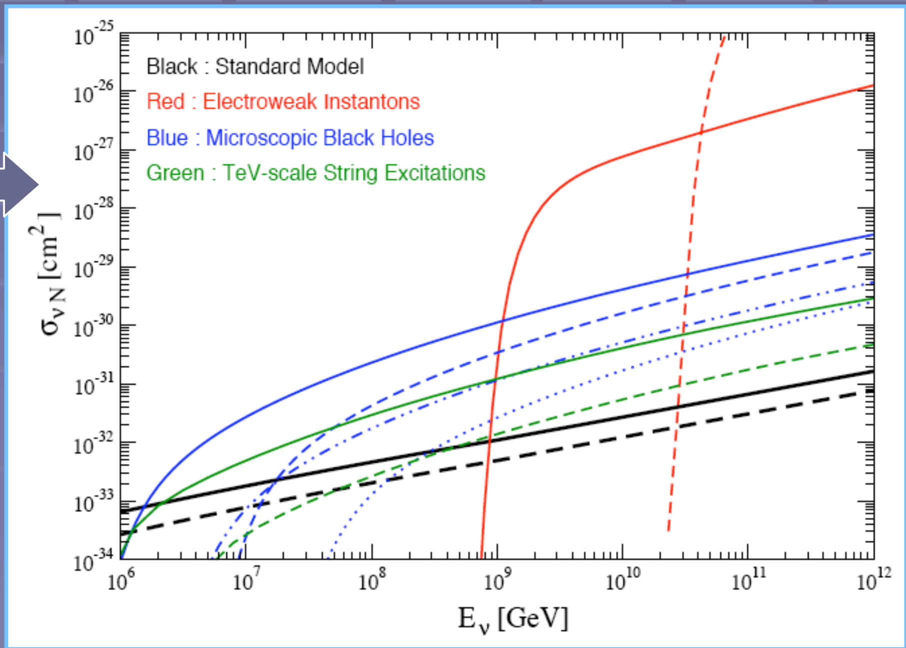
Motivation

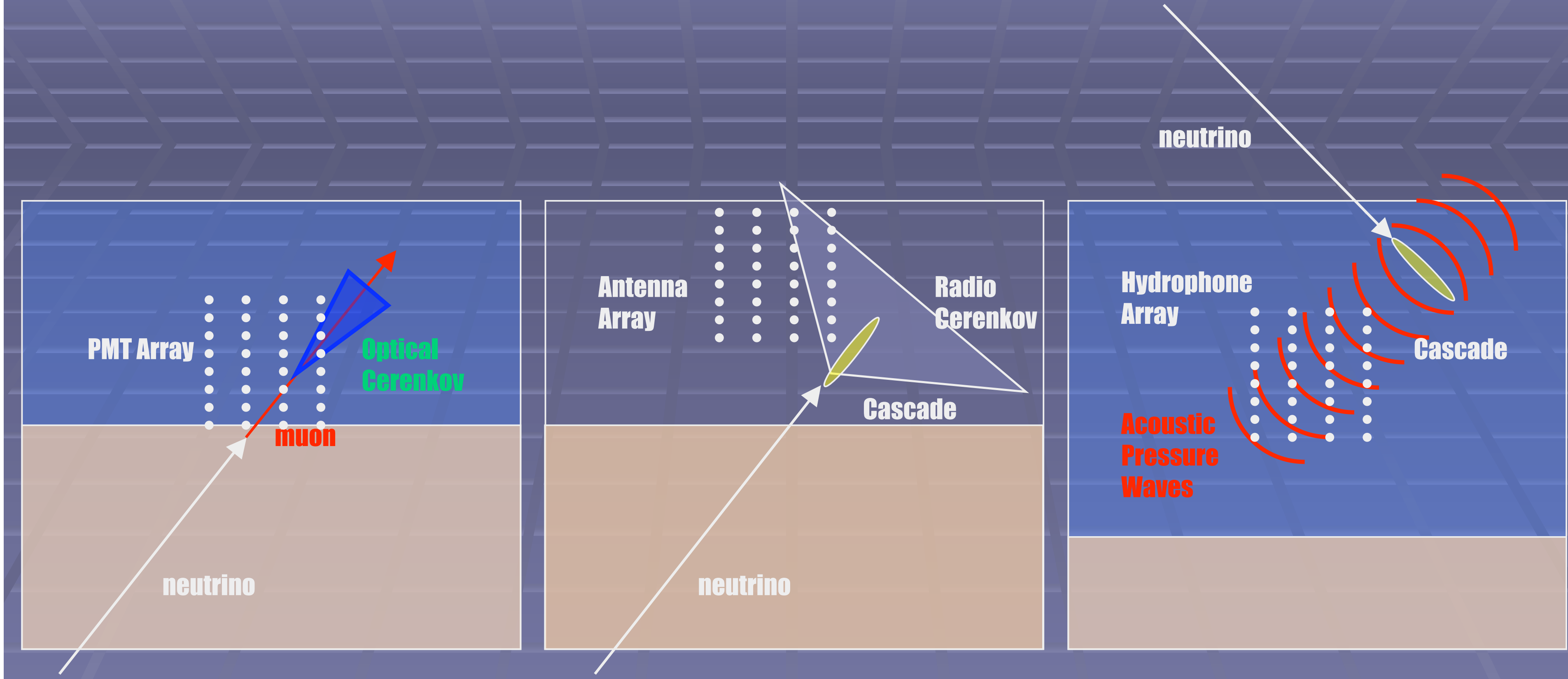
- If GZK cut-off exists then observation of GZK neutrinos is important
- *If not then some kind of top-down model is necessary, e.g.*
  - Strongly interacting neutrinos
  - *New neutral primaries*
  - Violation of Lorenz invariance
  - *Decaying supermassive dark matter*
  - Instantons, excitons
  - *etc…*
- Many of these models predict, e.g. enhanced neutrino cross-sections at ultra high energies



Neutrino-nucleon cross-sections for low- scale models of quantum gravity involving e.g. extra dimensions



(U)HE ν Detection Methods



<u>Optical Cerenkov</u>

3D array of photosensors

Works well in water, ice

Attenuation lengths of order 50m to 100m (blue light)

<u>Radio Cerenkov</u>

3D array of antennae

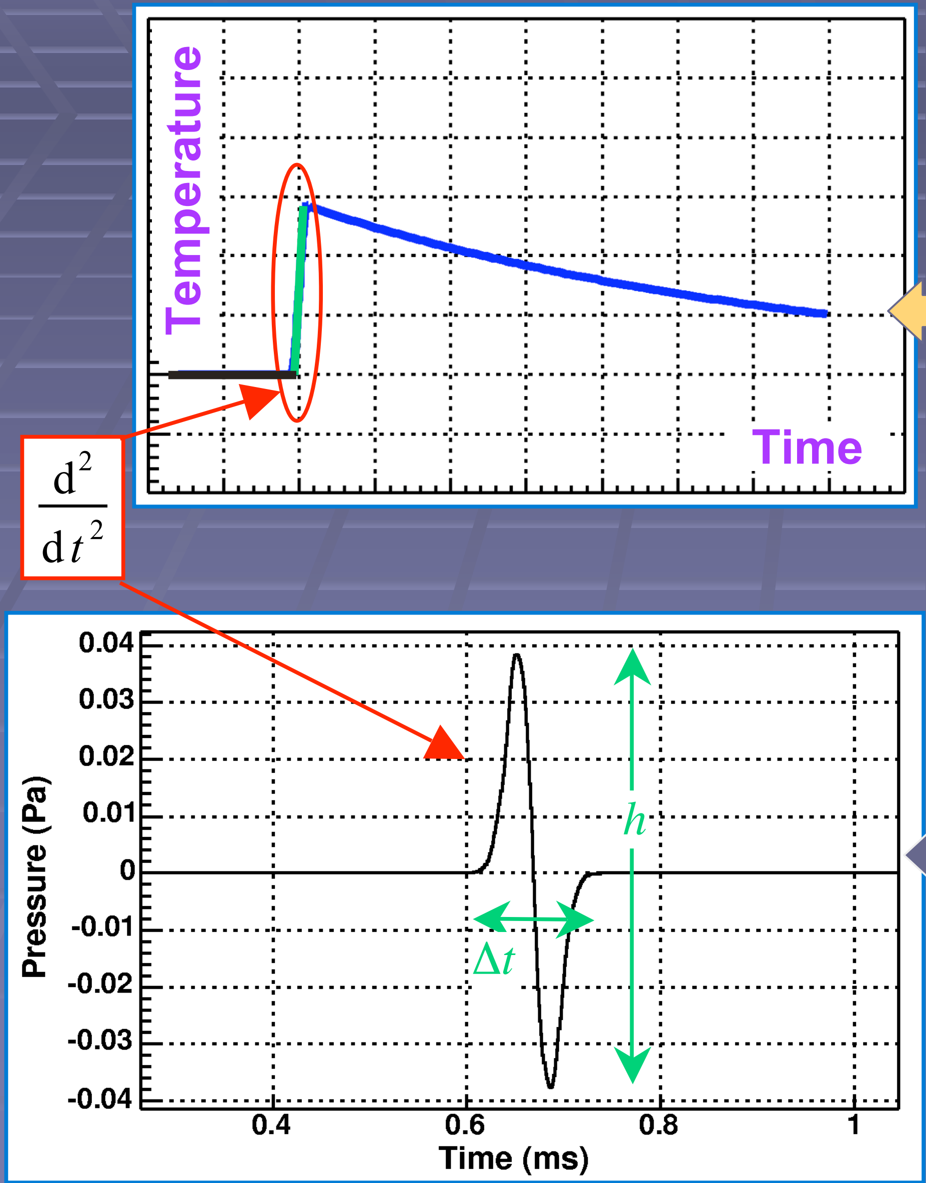
Long (order km) attenuation lengths in ice and salt

<u>Acoustic Detection</u>

3D array of hydrophones

Very long attenuation lengths in water (order 10km), ice and salt

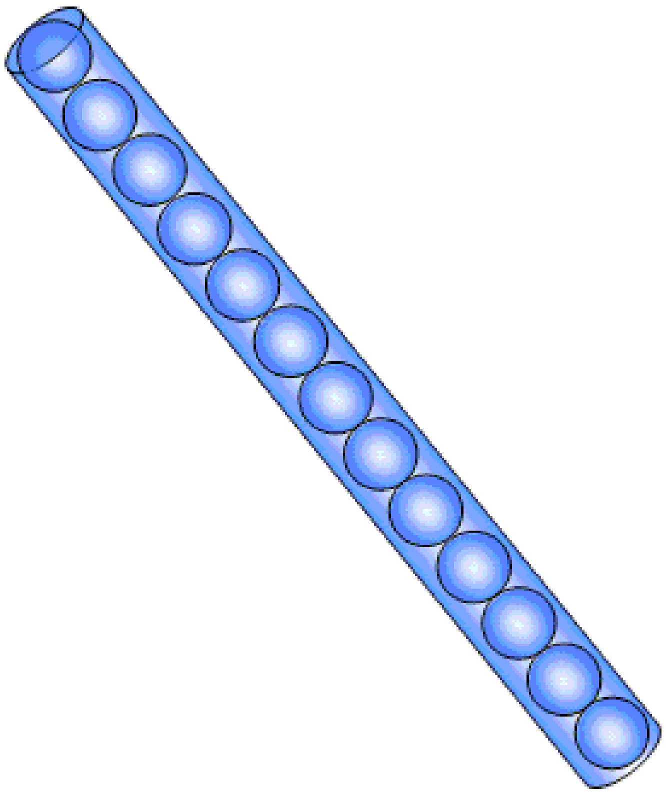
Acoustic Detection Principle



- ***Fast thermal energy deposition*** *(followed by* ***slow heat diffusion****)*
- ***Results in a near-instantaneous temperature increase and material expansion giving rise to an "acoustic shock" sound pulse***

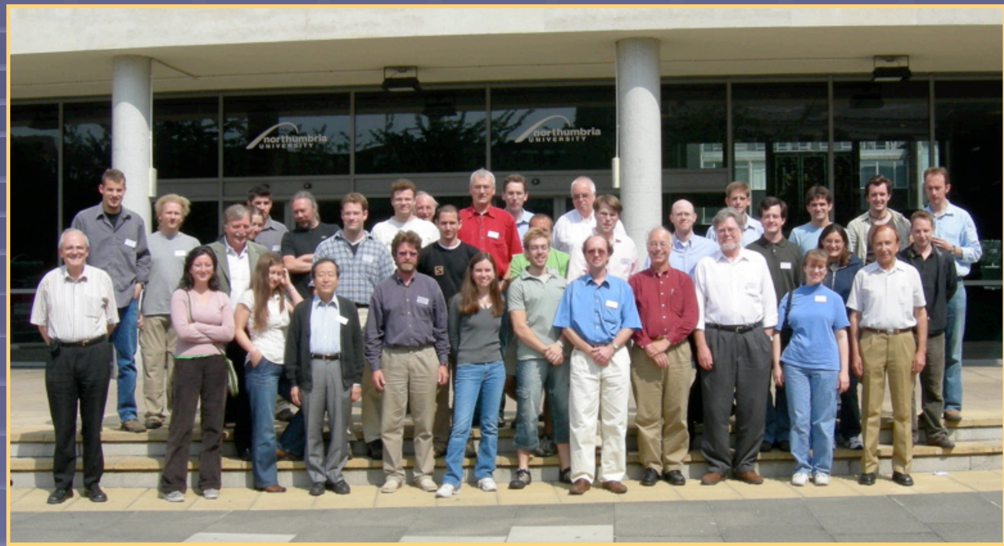
- This pressure pulse is related to the double derivative of the Heaviside step function of the temperature rise and leads to a characteristic expected bipolar pulse shape
- *h* is defined by the properties of the medium:
  - $h \propto \beta / C_p$ where β is the co-efficient of thermal expansivity and C_p is the specific heat capacity
- Δt is defined by the transverse spread of the shower

Acoustic Detection Features



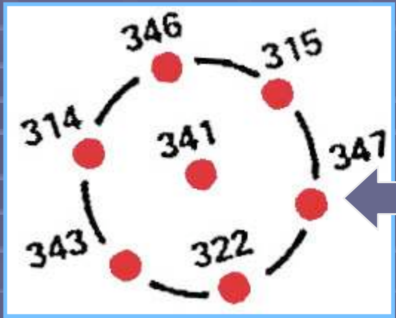
- Typical cylindrical volume over which the hadronic energy is deposited is 10m long by a few centimetres wide
- *The energy deposition is instantaneous with respect to the signal propagation*
- Hence the acoustic signal propagates in a narrow "pancake" perpendicular to the shower direction in analogy with light diffraction through a slit

ARENA 2006

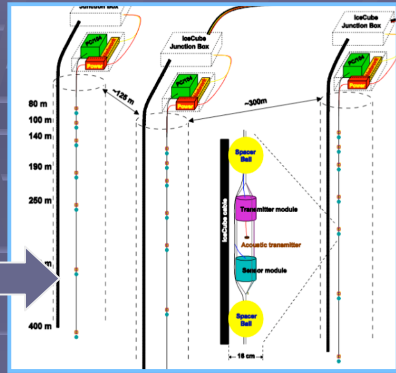


- Acoustic and Radio detection EeV Neutrino Activities
- *June 2006, Newcastle UK*
- ~50 participants
- *For presentations see www.shef.ac.uk/physics/arena*
- Follow on from RADHEP (2000), Stanford workshop (2003) and ARENA 2005 (DESY)

Contents

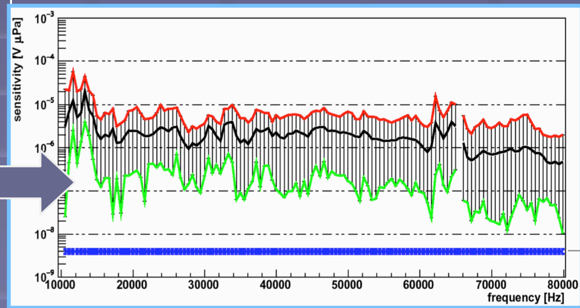


- Current Acoustic Sites

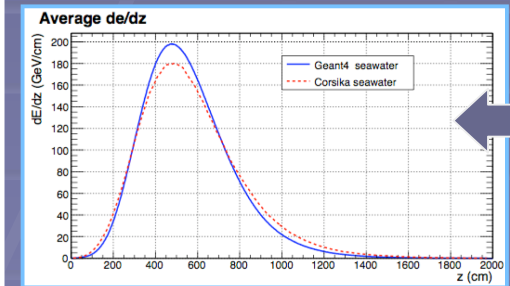


- *Future Projects*

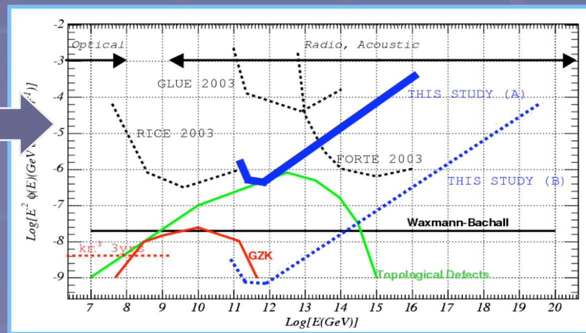
- Sensor development



- *Calibration*

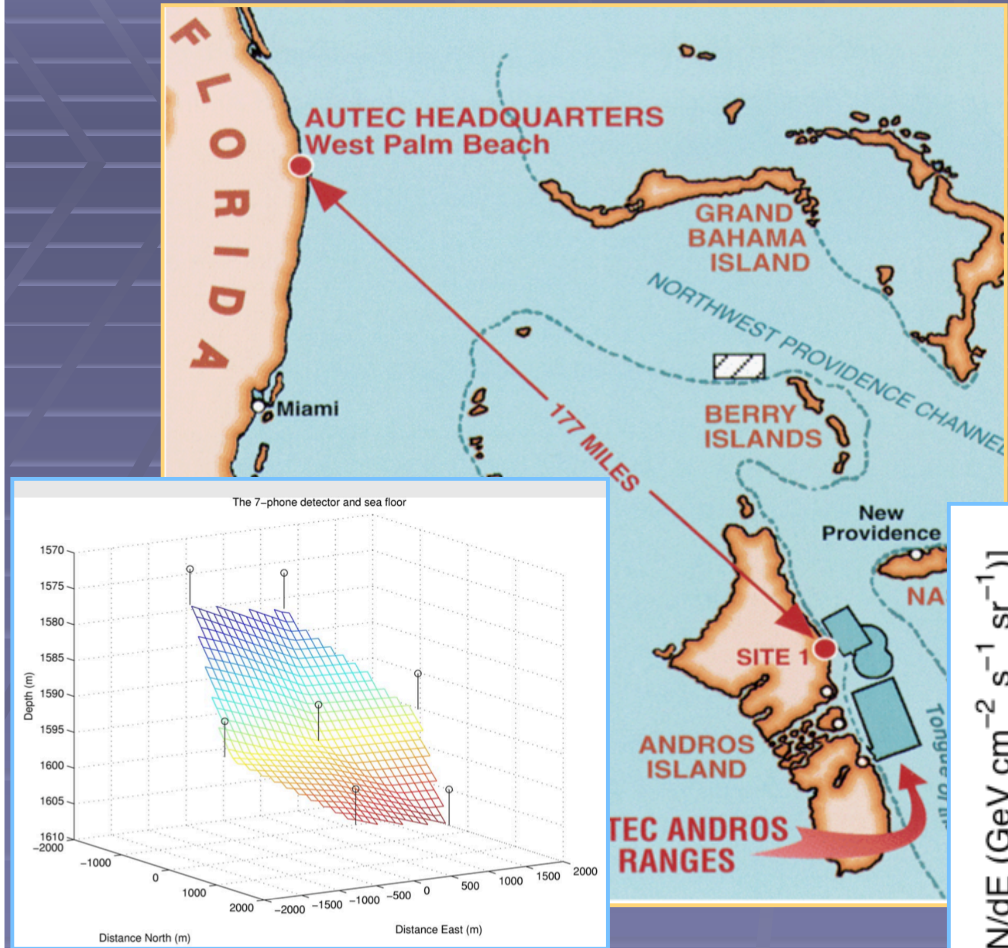


- Simulations



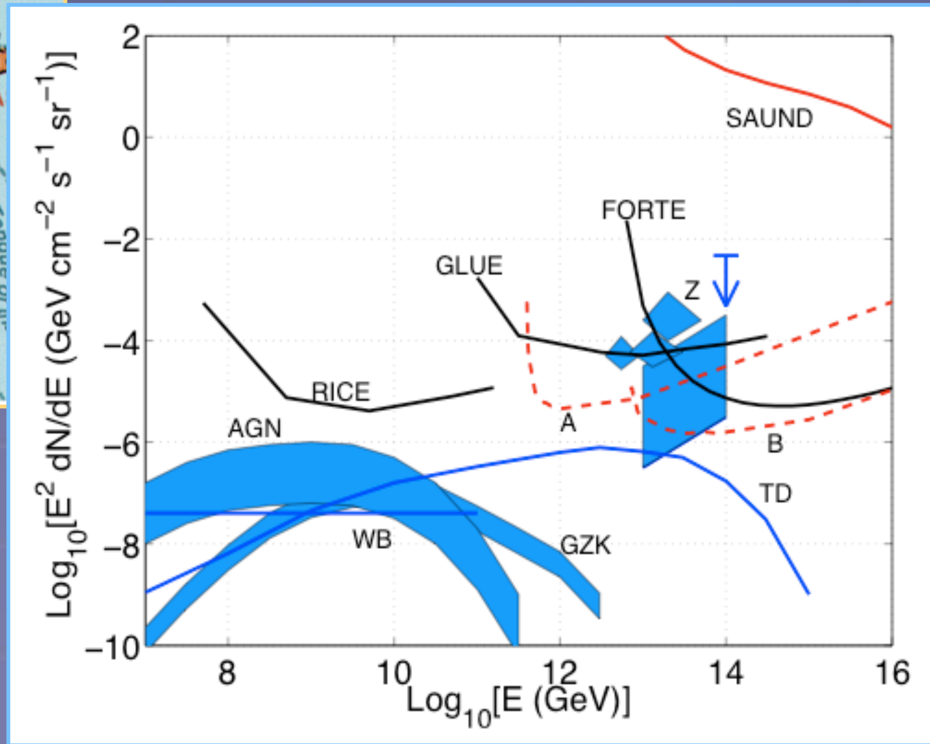
- *Sensitivity Calculations*

Existing Acoustic Sites



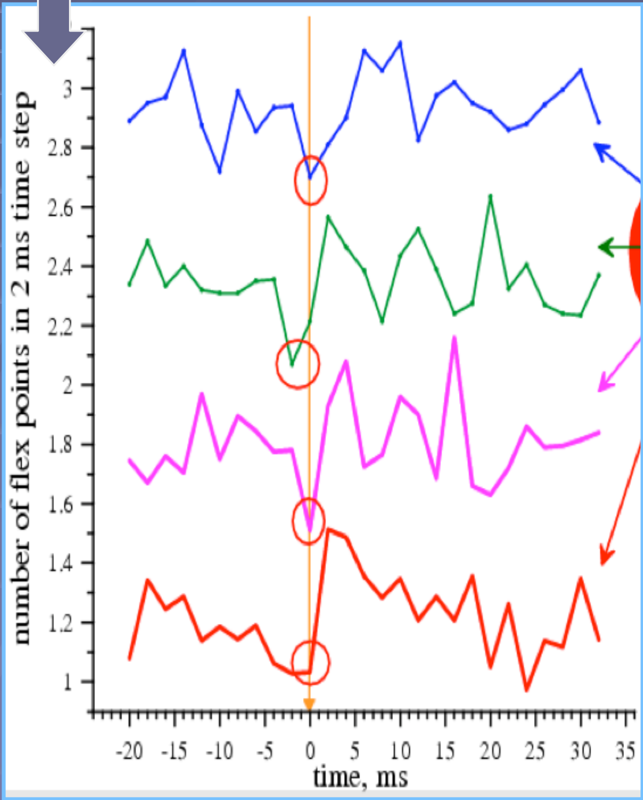
- The SAUND experiment
- *Stanford based venture using the AUTEC array, naval hydrophones in the Bahamas*
- First limit paper published based on 195 days reading out 7 hydrophones
- *See astro-ph/0406105*

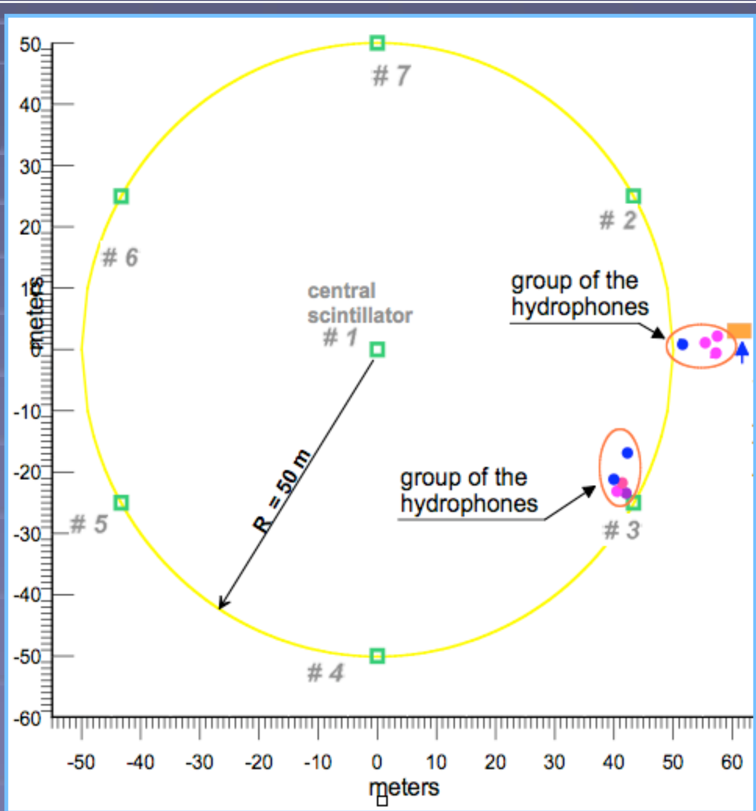
- **SAUND II funding approved**
- ***Move from 7 to ~56 hydrophones***
- **Area to be read out is ~1000 km^2**
- ***Mean sensor spacing is 4km***
- **Data taking started in June**

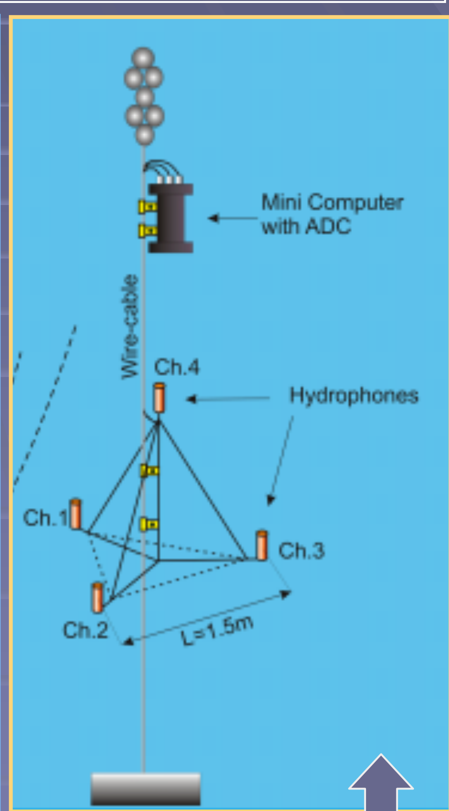


Existing Acoustic Sites

- Co-incidence of surface (ice) based scintillators and hydrophones deployed in water and ice
- *Data taken at the Lake Baikal NT-200 site during spring ice cover 2002 and 2003*
- Analysis in progress looking for features in acoustic signals in coinc. with EAS

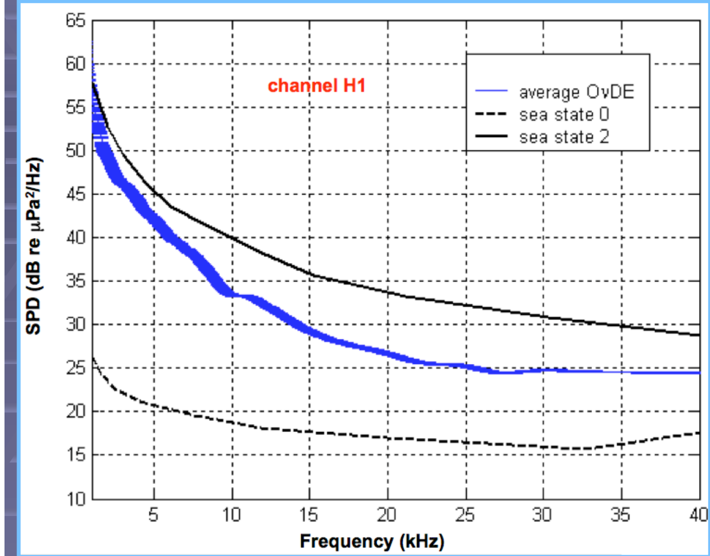


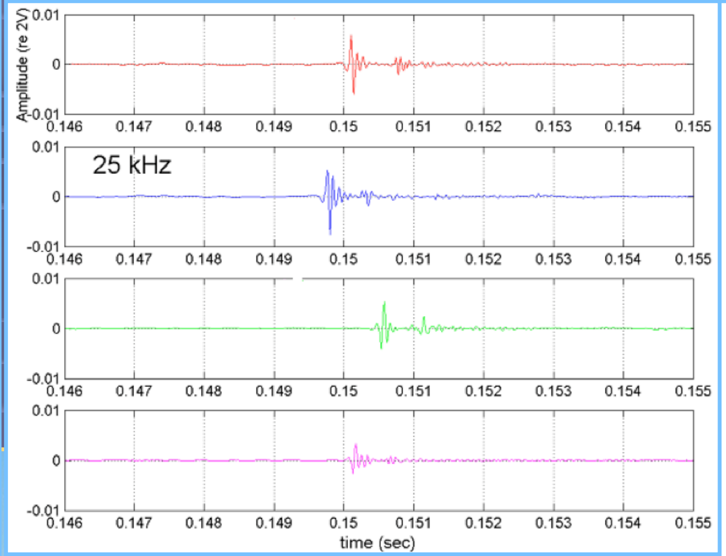


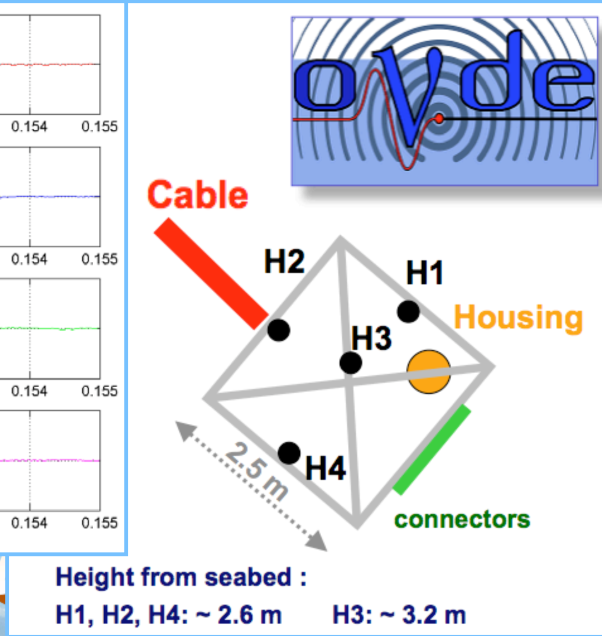


- New acoustic module with 4 hydrophones deployed in April 2006
- *100m, autonomous, self-triggered, on-detector processing*

Existing Acoustic Sites

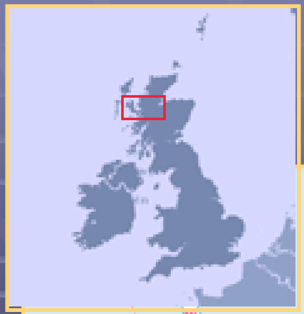


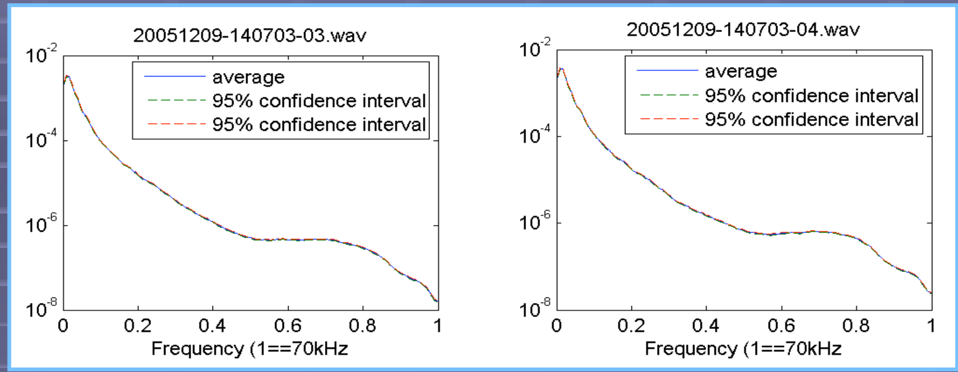


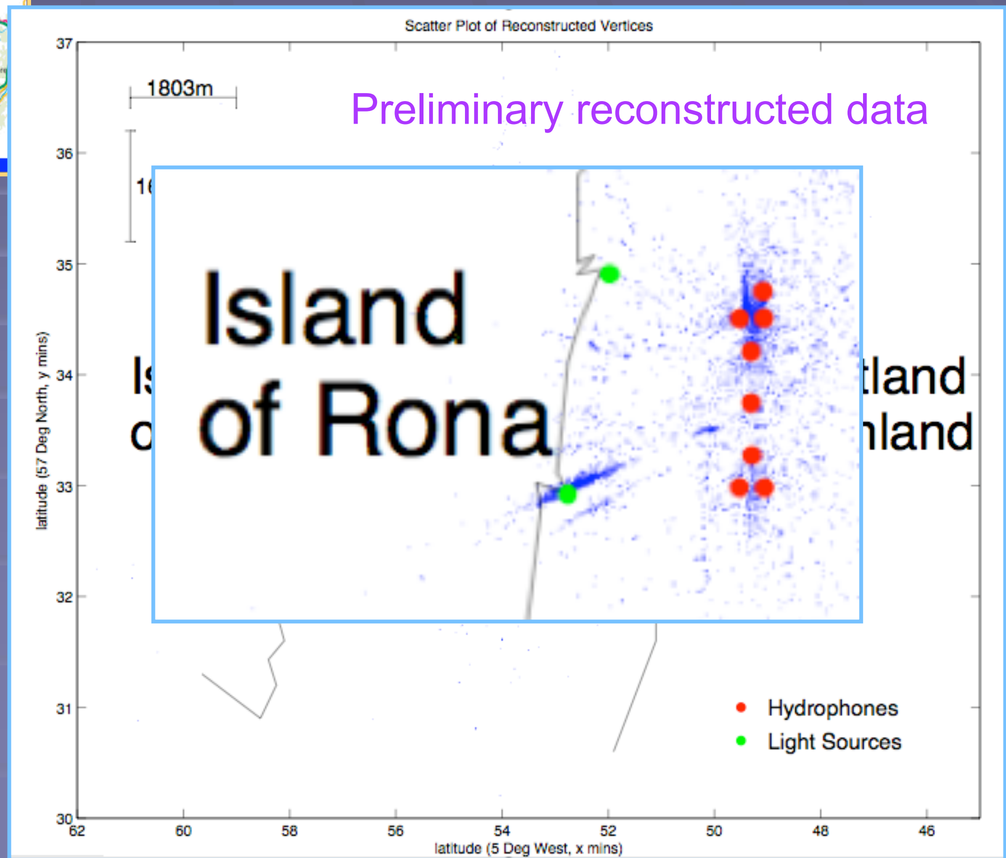


- ONDE - the Ocean Noise Detection Experiment was deployed in January 2005 at the NEMO Test Site in Sicily
- *4 hydrophones read out (5' per hour) since early 2005*
- Full analysis of noise (by hour, month, etc.)
- *Bio coincidences seen*
- See poster by Giorgio Riccobene for more information

Existing Acoustic Sites

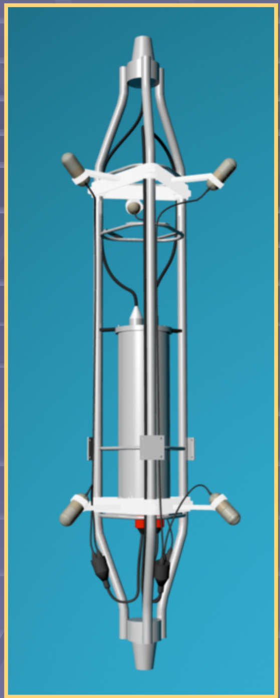




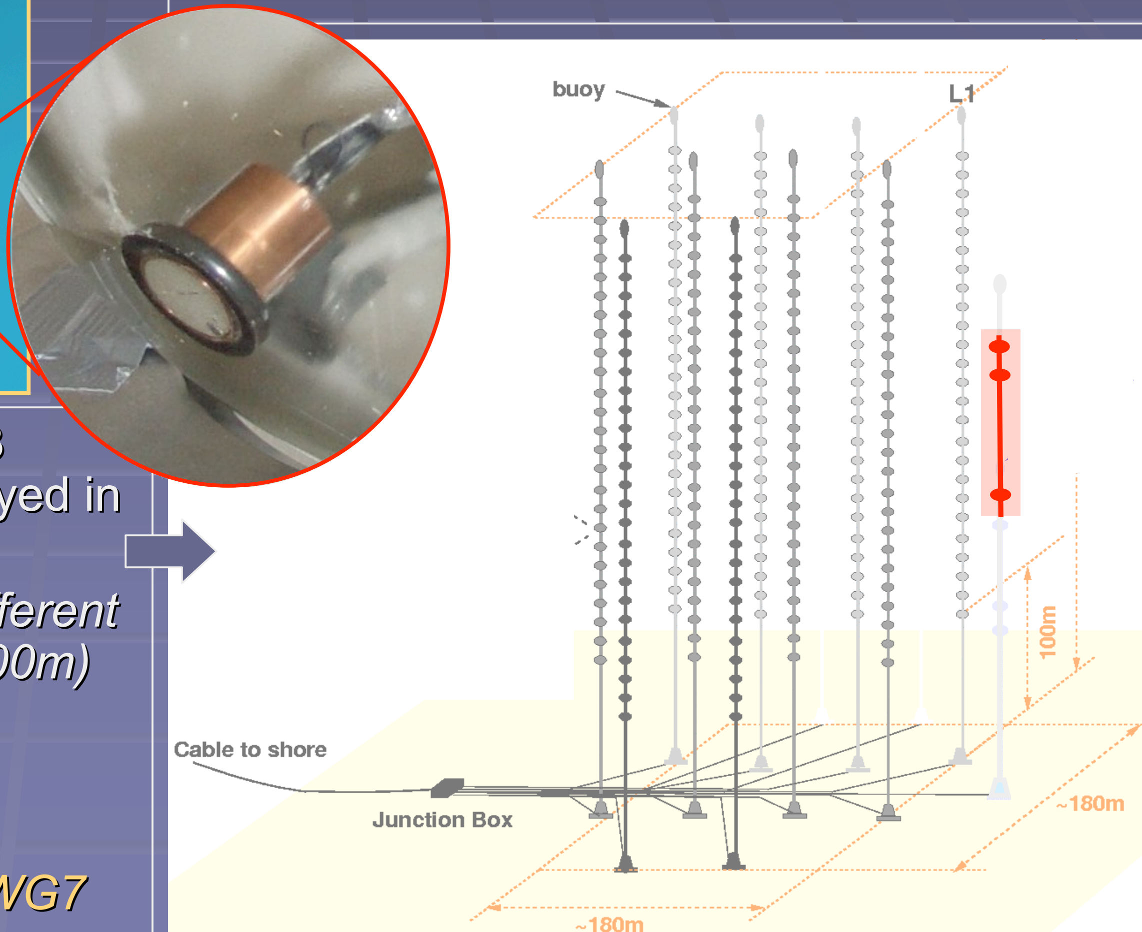


- Rona hydrophone array, a military array in Scotland used by the ACORNE collaboration
- *2 weeks of unfiltered data taking in December 2005*
- 8 hydrophones read out continuously at 16bits,140kHz - a total of (2.8Tb)
- *Data are passed through a number of triggers including a matched filter prior to analysis*
- Average spectra show hydrophones are well-balanced

Future Projects



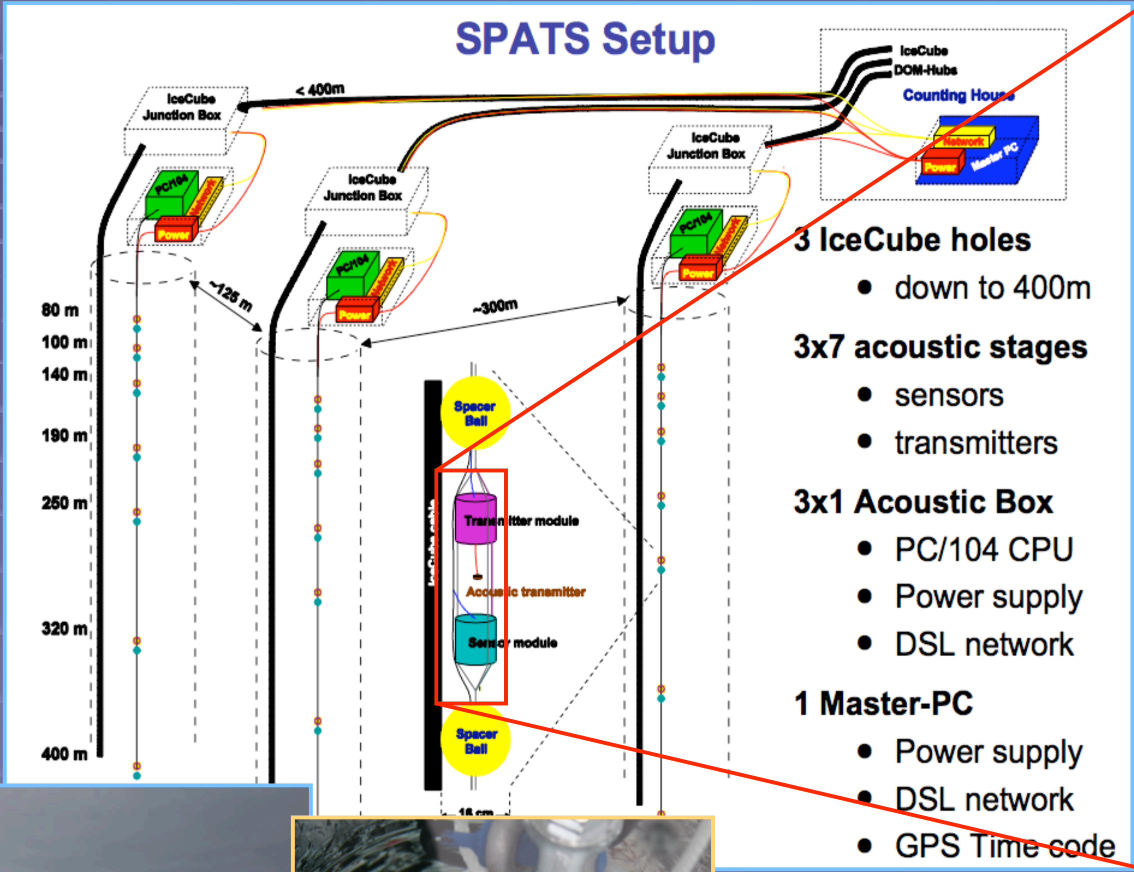
- Deployment of acoustic sensors in the ANTARES optical Cerenkov neutrino telescope
- *2 different acoustic storeys under consideration*

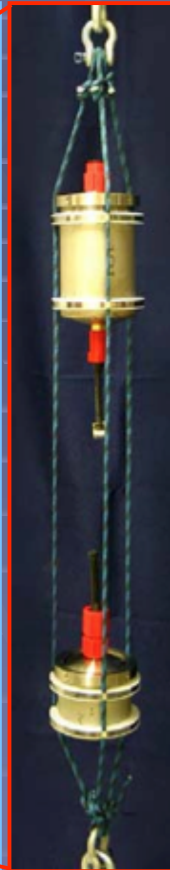


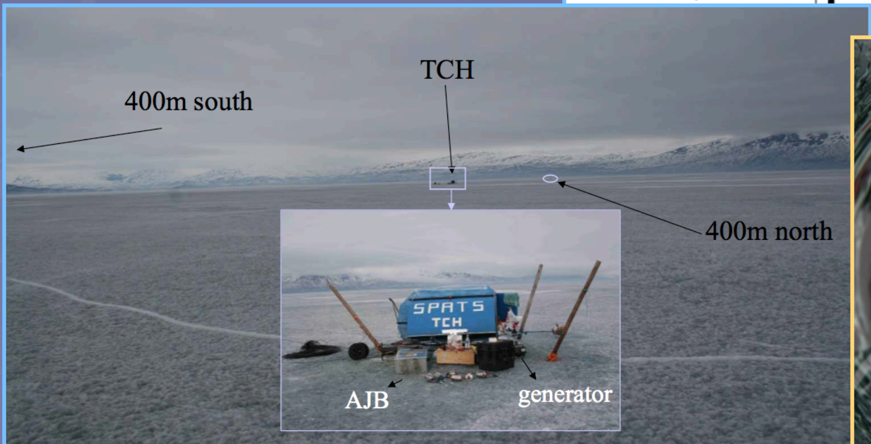
- “Instrumentation Line” with 3 acoustic storeys to be deployed in the first half of 2007
- *Look for co-incidences at different distance scales (1m, 10m,100m)*
- Also use existing acoustic transceivers to test 3D reconstruction
- *More in talk by Kay Graf in WG7*

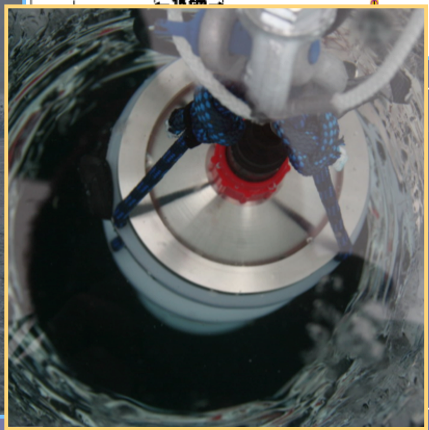
Future Projects

- IceCube is a natural place to extend the infrastructure of an optical array to incorporate radio and acoustic sensors
- *SPATS the South Polar Acoustic Test Setup is designed to test acoustic sensors in ice parallel with IceCube deployment*
- Planned sensors in 3 IceCube holes







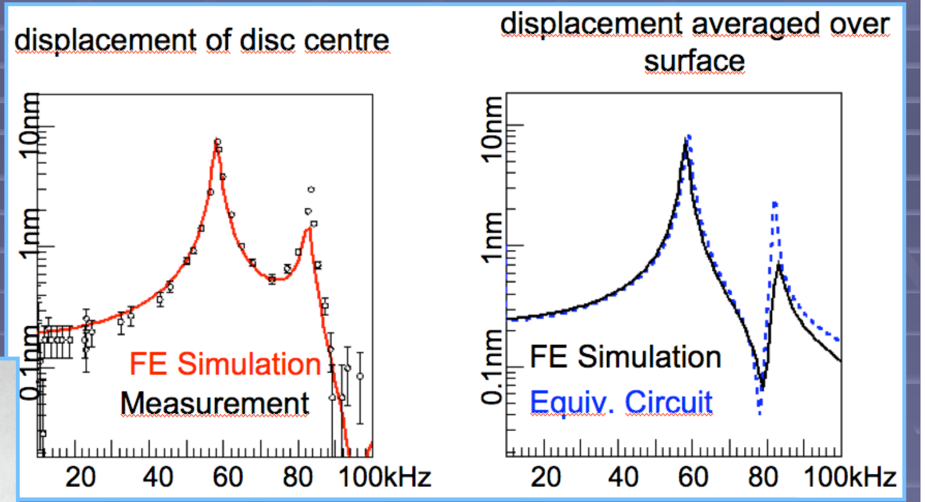


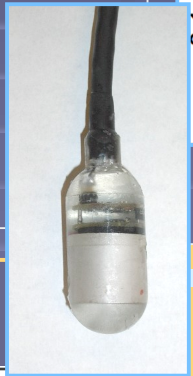
Successful long range (800m) tests of the system have take place at a frozen lake at Abisko, Sweden

More in parallel session talk by Stefan Hundertmark

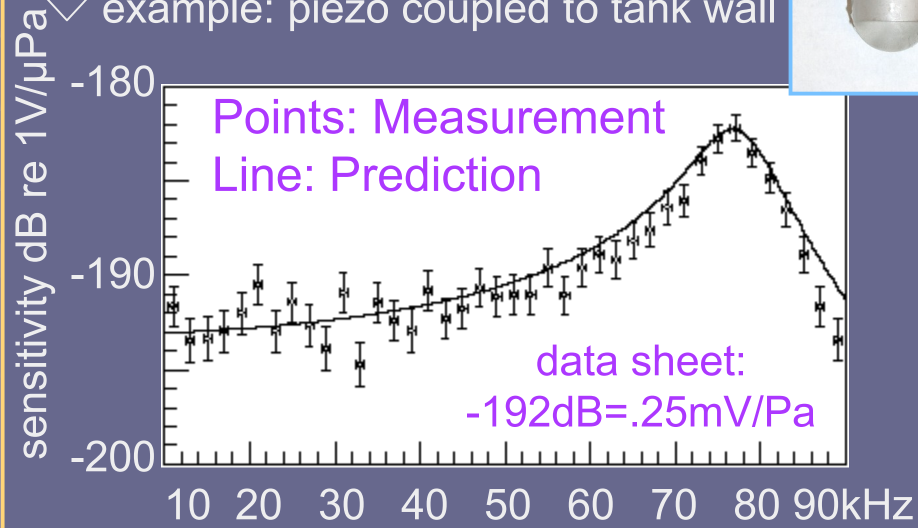
Sensor Development

- Can we design and build bespoke acoustic sensors with performance well-matched to expected signal?
- *Requires a good theoretical model of piezo and the coupling*
- Predictions using equivalent circuits





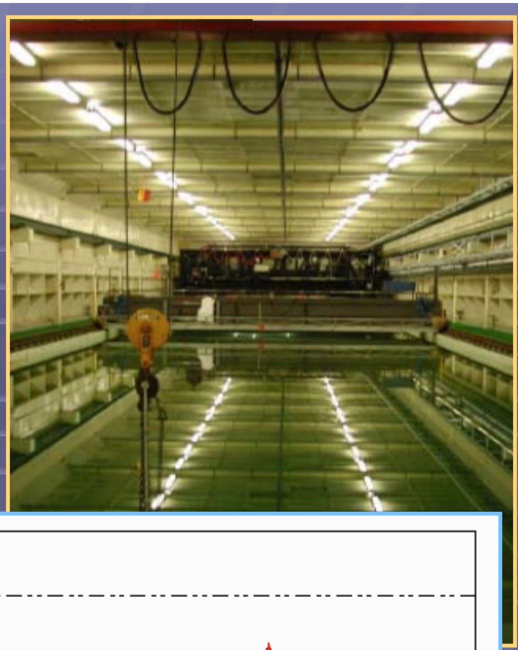
example: piezo coupled to tank wall

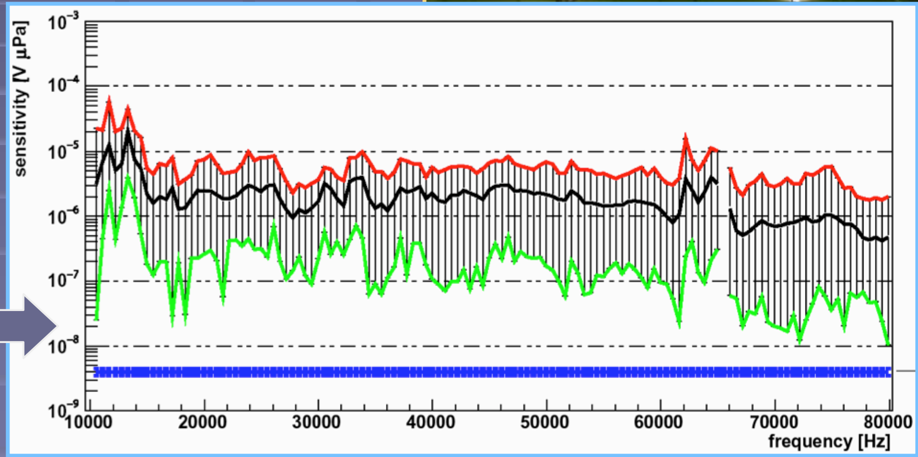


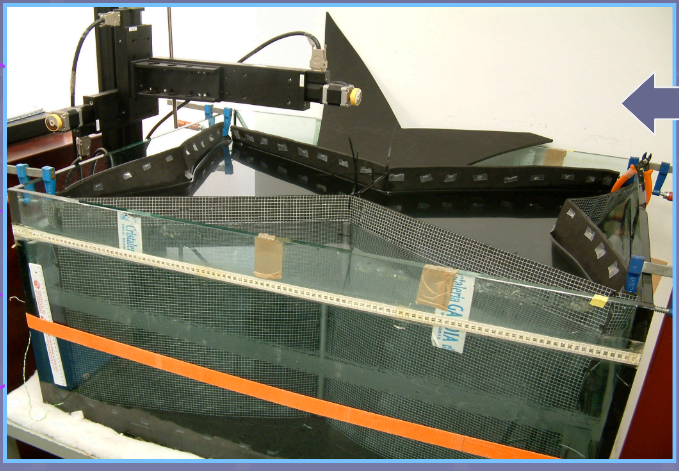
- Further detailed understanding of piezos is under study
- *At the **microscopic** level piezos can be modelled using PDEs for an anisotropic material*
- Solve using Finite Element Analysis
- *Use Laser Interferometry to compare results*

Sensor Calibration

- The SPATS team have calibrated their sensors using
  - a large water volume (78m x 10m x 5m)
  - *a fully calibrated reference hydrophone*
  - a broadband transmitter
- *A total of 75 sensors have been calibrated in water*
- Plot shows a summary of the measured sensitivities of all SPATS sensors





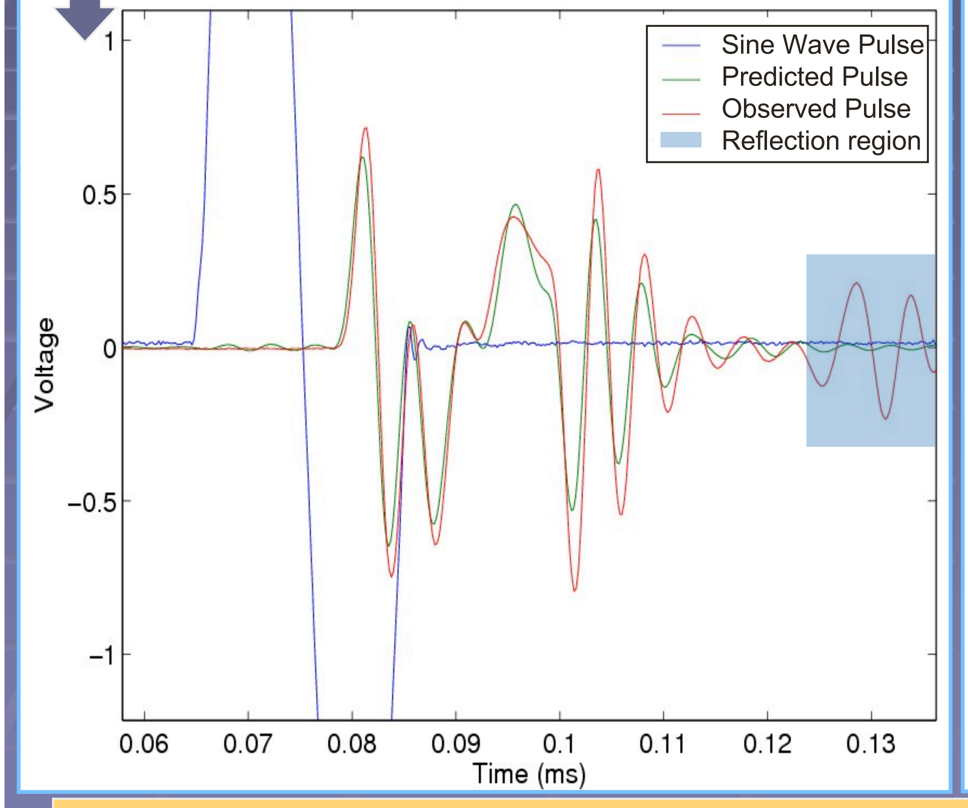


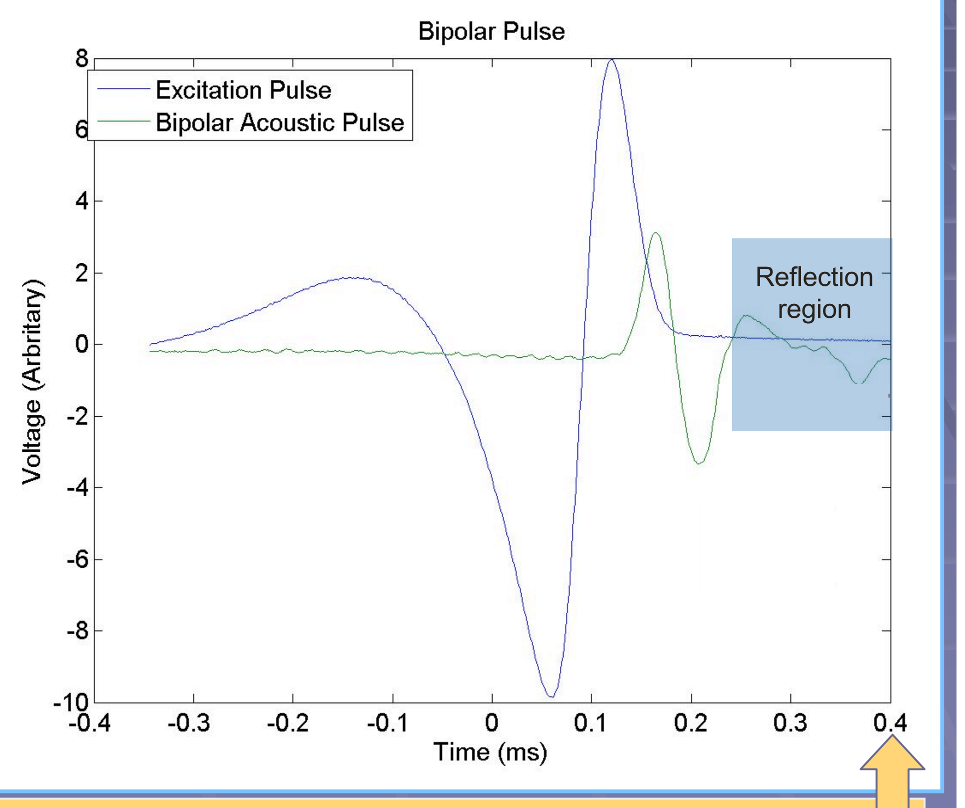
(Ardid, UPV, KM3NeT)

- Where this is not possible other techniques are also available to perform accurate and absolute calibration of acoustic sensors
- *These include the <u>reciprocity method</u> using 4 measurements with 3 <u>uncalibrated</u> hydrophones ideally in free field (butterfly baffle kills reflections) (Ardid et. al, UPV)*

Acoustic Calibration

- Aim: to apply an electrical impulse to a hydrophone that will result in a bipolar pulse being created in a body of water
- *First evaluate the hydrophone response using signal processing techniques*
- Predicted (5th order LRC model) and measured response for single cycle sine wave

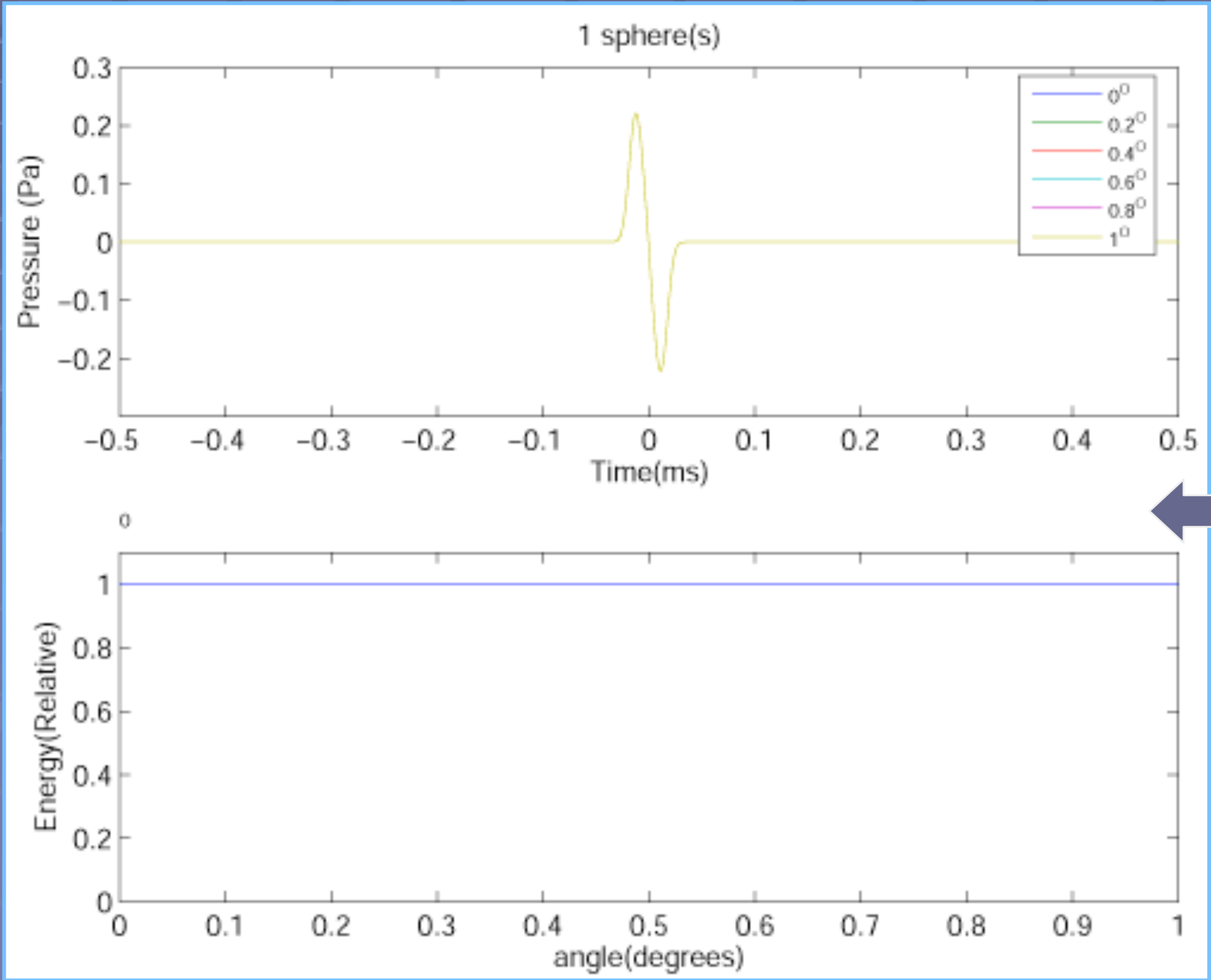




- Excitation and response pulses required to generate bipolar pulse using this method
- *Plans to use an acoustic calibration system based on this method at Rona*

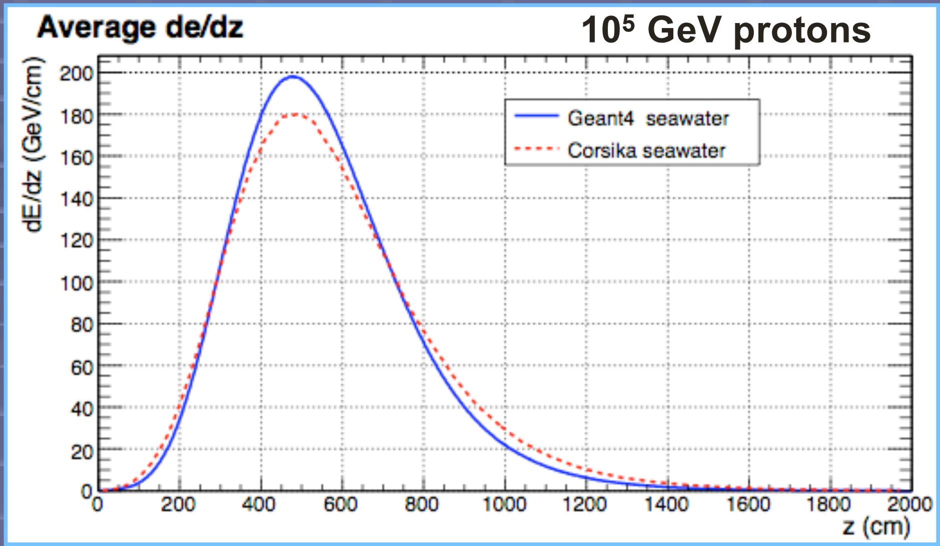
Acoustic Calibration

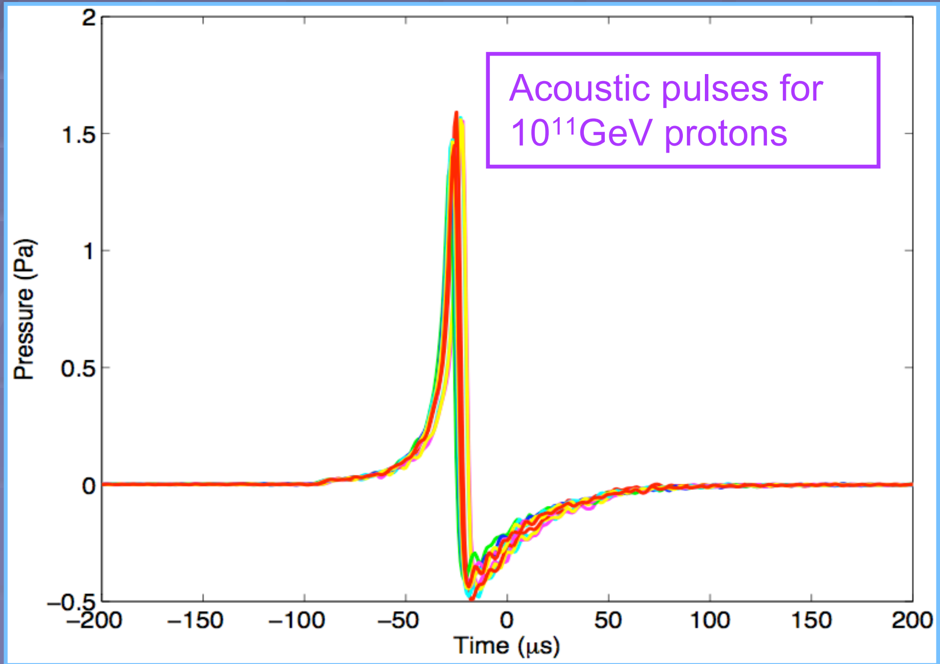
- Previous study uses a single source
- *However, as we have seen, a neutrino is a line source*
- Question: how many bipolar sources are needed to generate a suitable pancake?

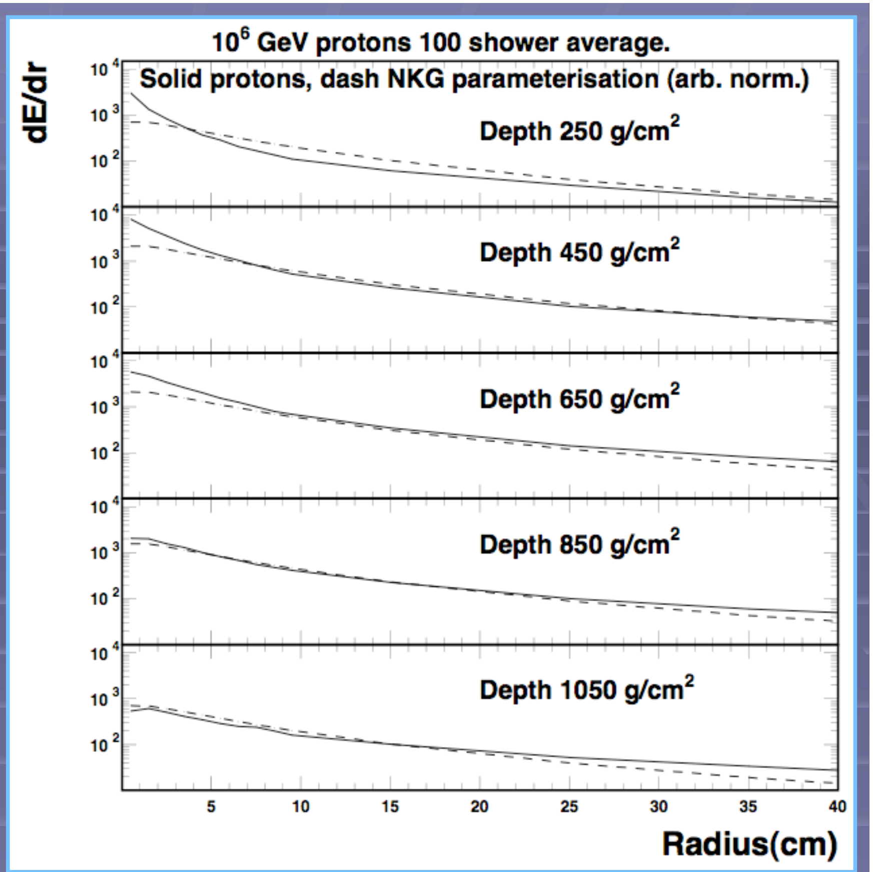


- $1.2x10^{20}$eV pulse simulated
- *1km from source*
- N sources deployed over 10m with (10/N)m spacing
- *Study the angular profile as a function of the number of sources*
- Of the order of 6 to 10 hydrophones (minimum) are needed

Simulation Work



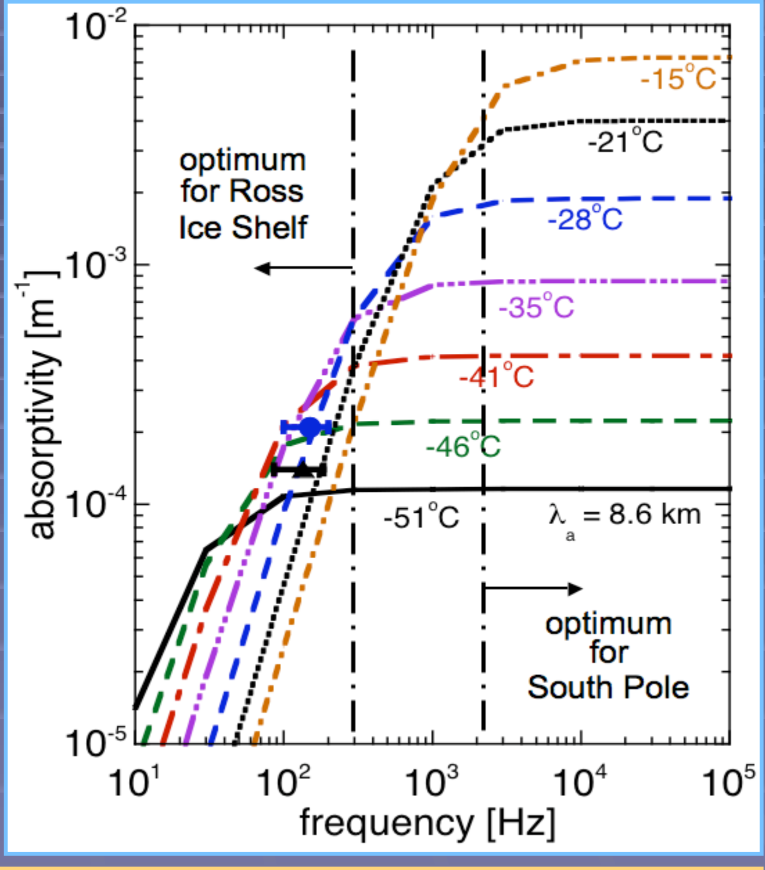




- CORSIKA has been modified to make it work in water
- *Comparisons with GEANT*
  - *~ 10% lower at peak*
  - *Showers broader*
- NKG parametrisation gives less energy at smaller radii - may be important for acoustic/radio
- *Developing a CORSIKA neutrino pulse simulator*

Material Properties

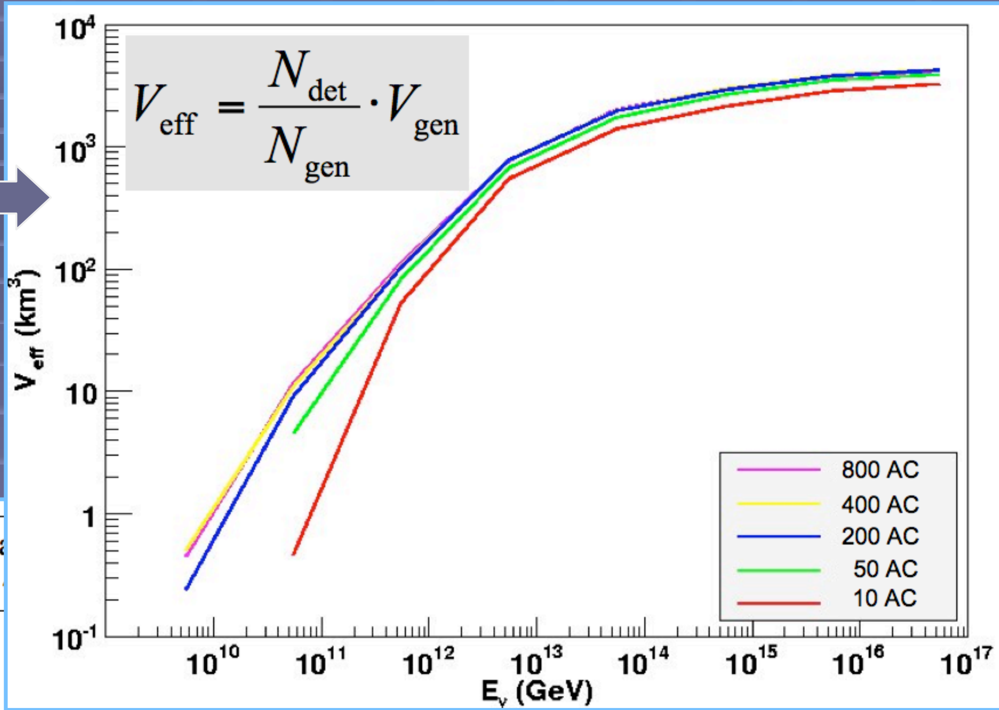
- *Also developing a fuller understanding of propagation of acoustic waves in salt and ice*
- Many things to consider including:
  - Cost of drilling
  - Scattering (gets worse as grain size increases) better for ice
  - Noise
  - Conditions are temperature dependant - not all ice is the same!
- *More information in WG7 talk by Buford Price*

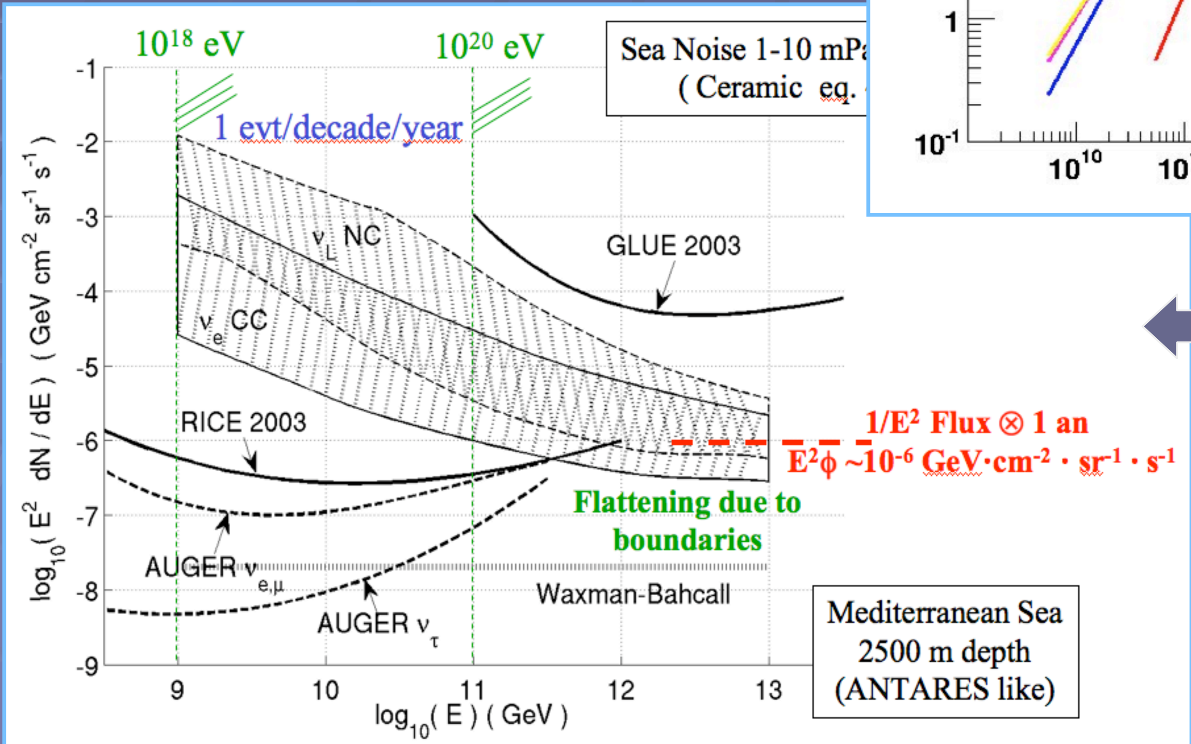


	grain size	λ_{scatt} 10^4 Hz	λ_{scatt} 3x10^4 Hz	λ_{abs} 10^4 Hz	λ_{abs} 3x10^4 Hz
Ice	0.2 cm	1650 km	20 km	8-12 km	8-12 km
NaCl	0.75 cm	120 km	1.4 km	3x10^4 km	3300 km

Sensitivity Calculations

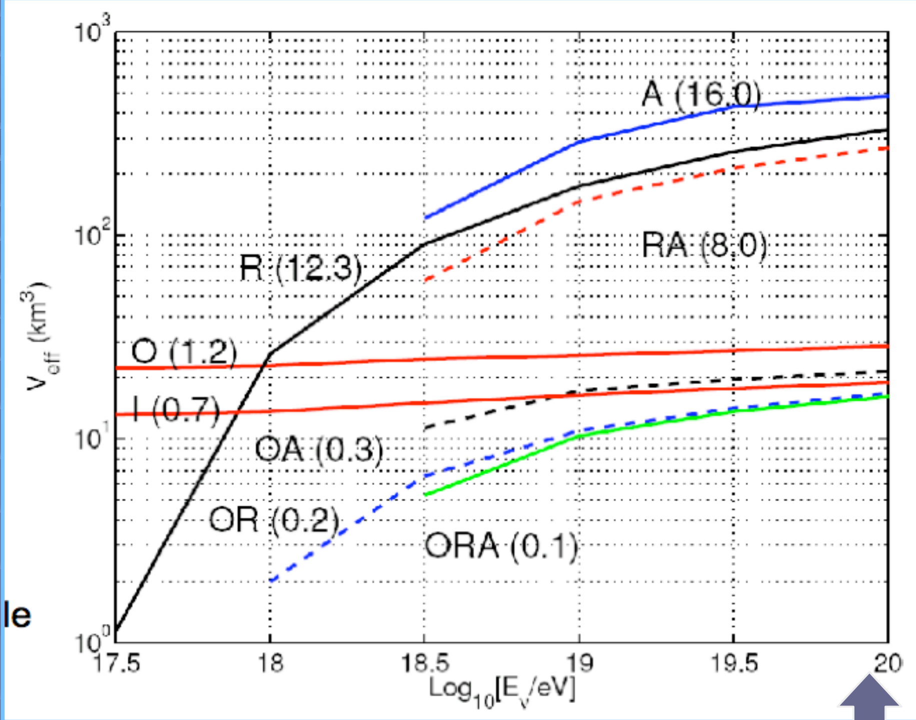
- Effective volume for a 1 km^3 array instrumented with different numbers of ANTARES-style *acoustic storeys*
- *No improvement in effective volume above 200AC/km^3*
- Detection threshold 5mPa



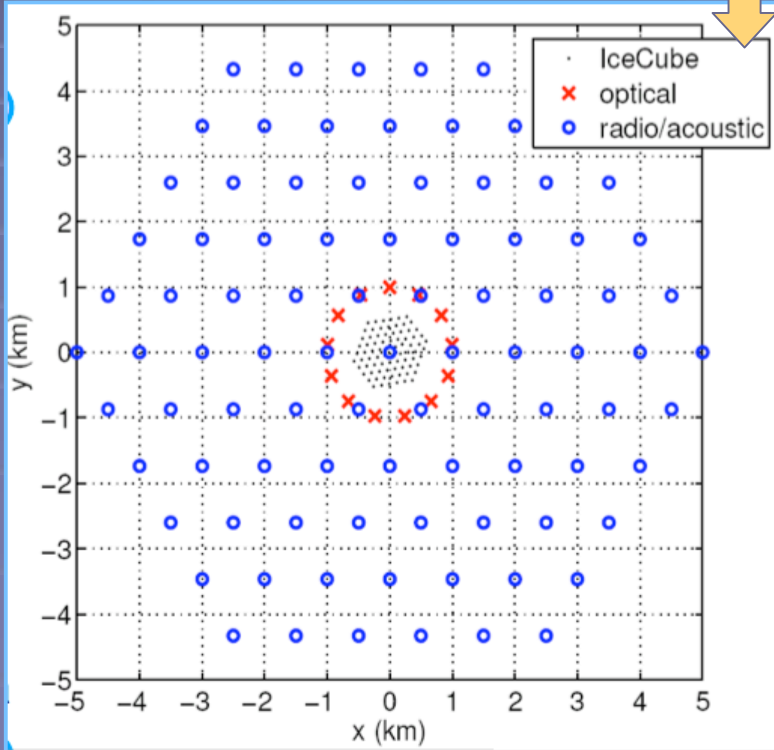


- Detailed acoustic simulation in the Med.
- *Sensitivity of a single hydrophone to the EM part of the cascade*
- Includes effects of complex attenuation
- *See astro-ph/0512604*

Sensitivity Calculations

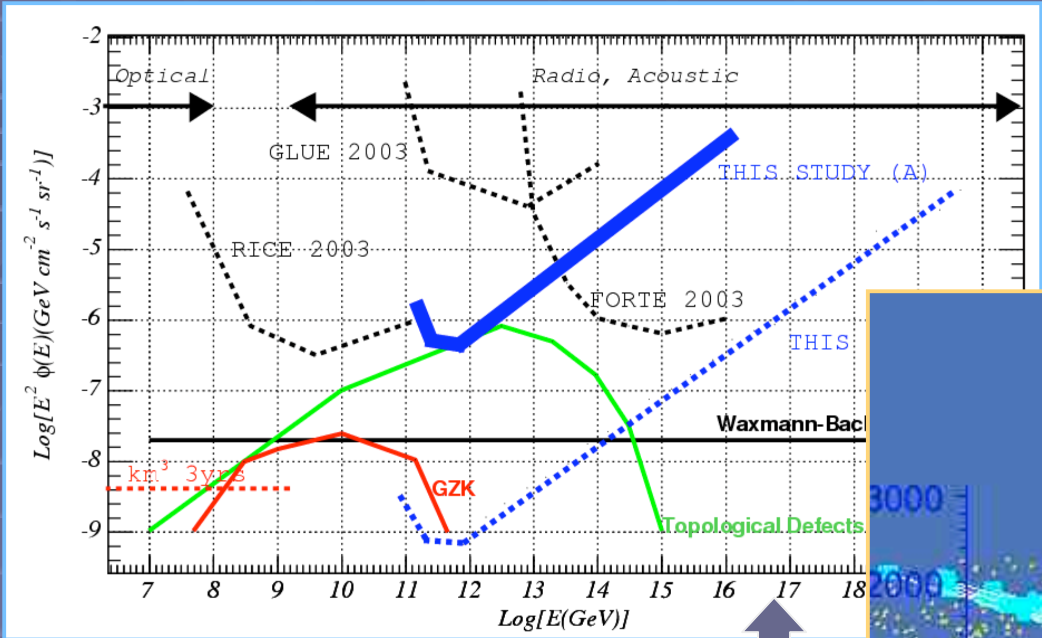


- Hybrid arrays: optical, radio and acoustic technologies
- *5x2 radio and 300 acoustic sensors per string + IceCube*
- Yields 20 events per year
- *Cross-calibration possible*

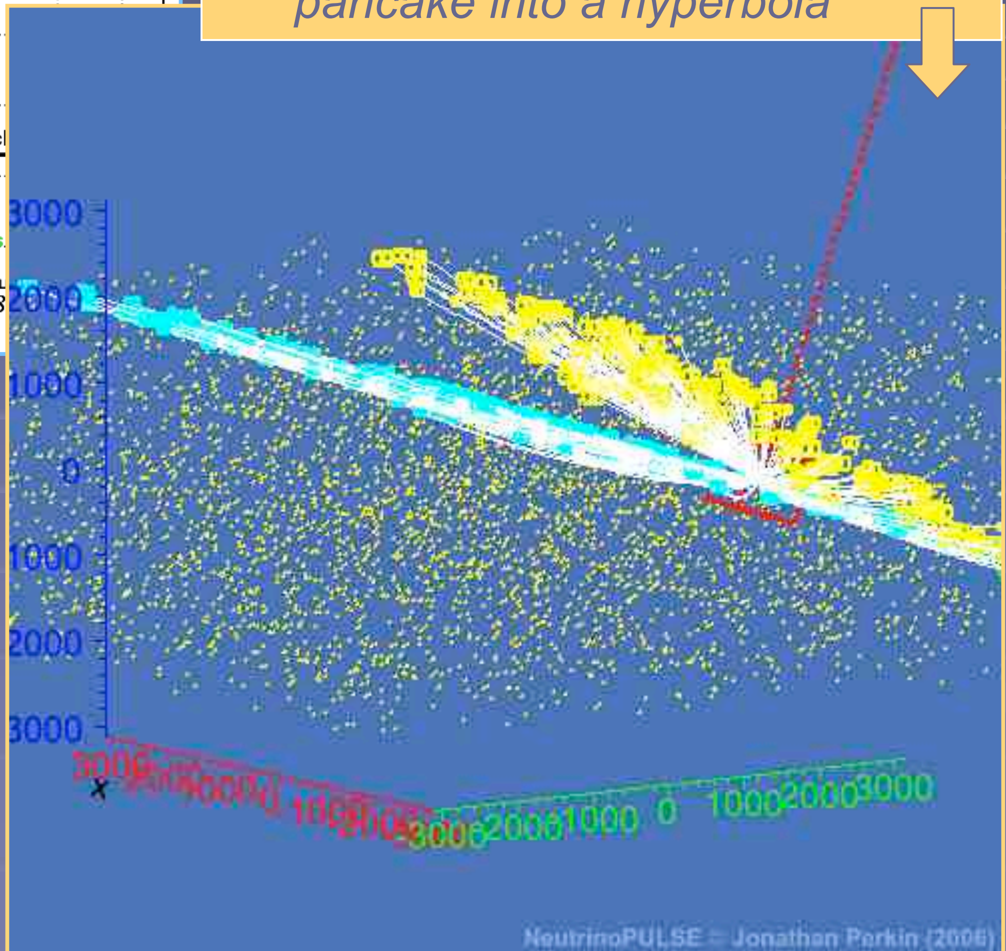


- Effective volume for hybrid arrays involving extending beyond IceCube with strings of radio and acoustic sensors
- *See astro-ph/0512604*
- See talk in parallel session by Justin Vandenbroucke

Sensitivity Calculations



- Current studies are concentrating on the effects of refraction
- *Linear SVP distorts the acoustic pancake into a hyperbola*



- Sensitivity of a large acoustic array to the hadronic component of neutrino induced cascades
- *200 acoustic sensors per km^3*
- 5 years of operation
- *5mPa sensor threshold applied*
- Dotted line: huge volume (50km x 30km x 1km)
- *NB no refraction in here*

Current Activities

From Rolf Nahnhauer
ARENA 2006 Summary Talk

group	experiment	activities
Stanford	SAUND	data taking, signal processing, calibration , simulation
INR1	AGAM, MP10	signal processing, calibration , simulation
INR2, Irkutsk	Baikal	signal processing, noise studies, in-situ tests at Baikal
ITEP	Baikal, ANTARES	detector R&D, accel. tests, in-situ tests at Baikal, signal proc., noise st.
Marseille	ANTARES	detector and installation R&D, calibration, noise studies, simulation,
Erlangen	ANTARES, KM3NET	detector R&D, accel. tests, calibration, simulation, noise studies, in-situ test measurements
Pisa, Firenze, Genova	KM3NET	detector R&D
Rome, Catania	NEMO	installation R&D, noise studies, simulation
Lancaster, IC, UNN, UCL, Sheffield	ACORNE, KM3NET	simulation, signal processing , calibration
U. Texas	Salt Dome	detector R&D, attenuation studies, material studies
Berkeley, DESY, Stockholm, Uppsala	IceCube	detector R&D, accel. tests, material studies, simulation, noise studies, in- situ test measurements (SPATS)

new results at ARENA 2006

Summary

- Multi-messenger observations of astrophysical objects clearly provide valuable information, this is also true at ultra high energies
- *The acoustic detection of UHE neutrinos is a promising technique that would complement high energy neutrino detection using the optical and radio techniques*
- It is likely that any development of a large volume acoustic sensor array would "piggy back" the infrastructure of first and second generation optical Cerenkov neutrino telescopes
- *This is already starting to happen (ANTARES, SPATS-IceCube)*
- Much activity in the field in many different areas