Acoustic Detection of Ultra-High Energy Neutrinos

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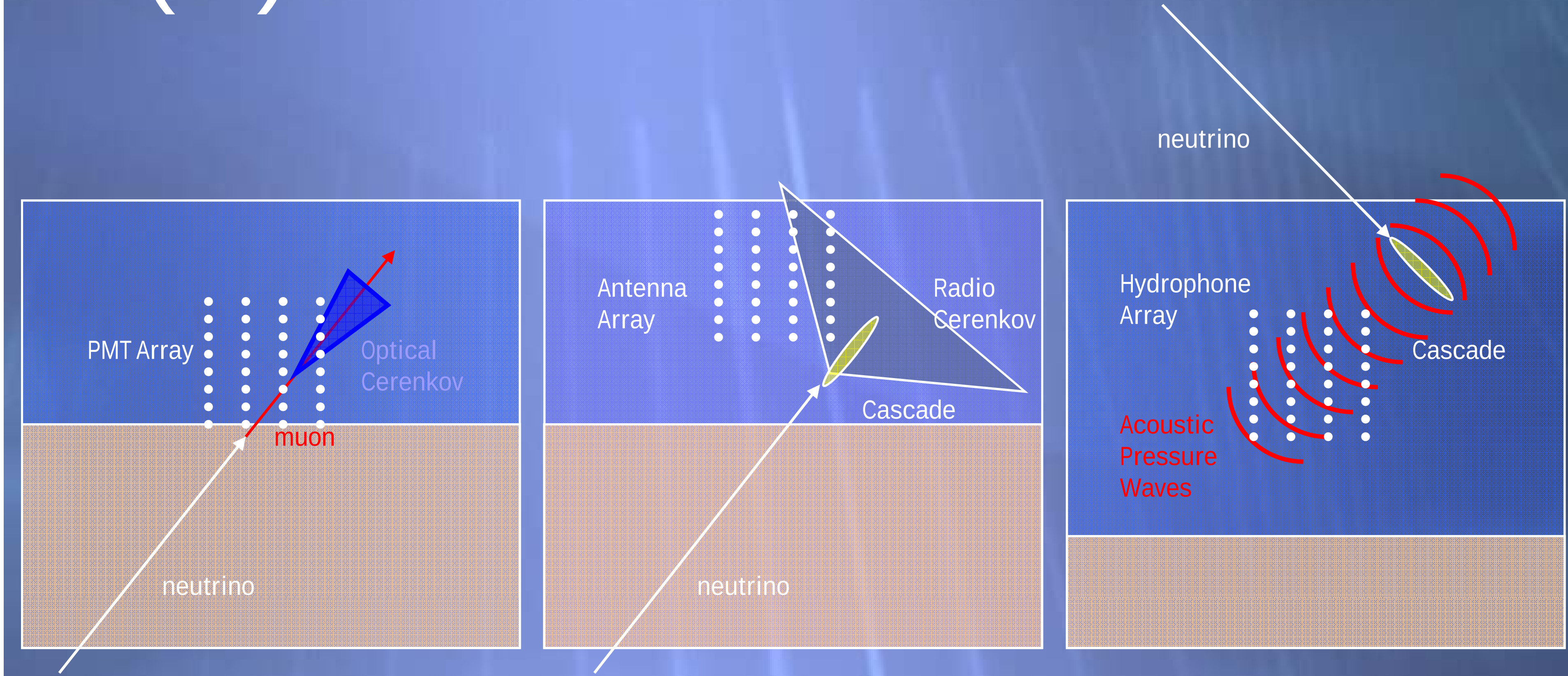
(U)HE ν Detection Methods



<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

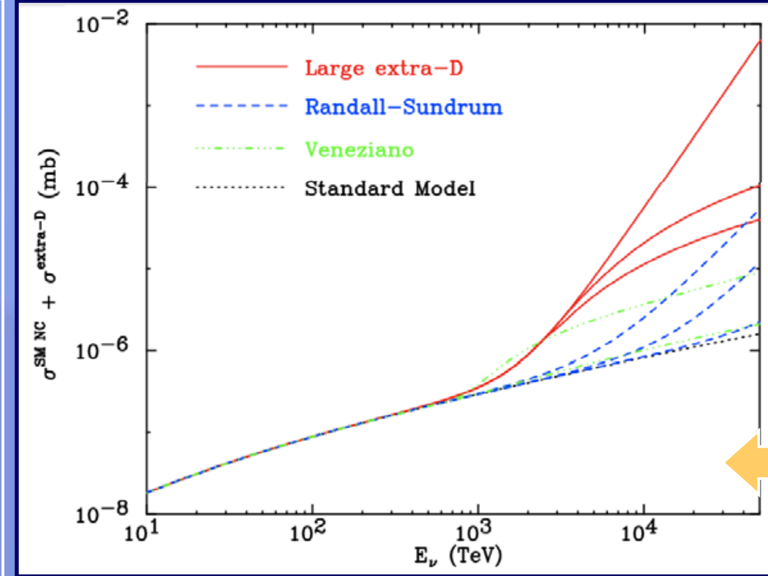
<u>Acoustic Detection</u>

3D array of hydrophones

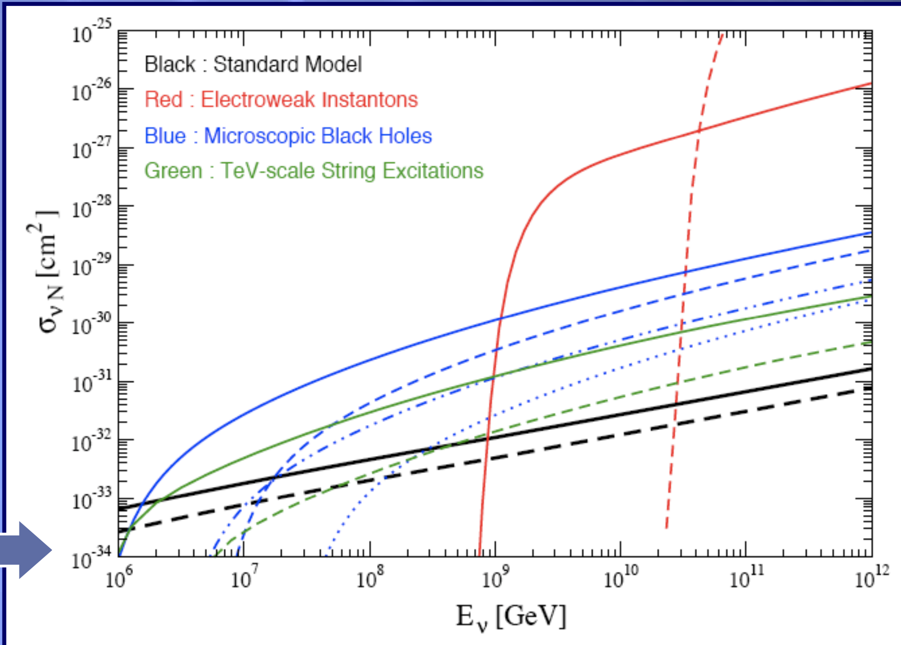
Very long attenuation lengths (order 10km) in water, ice and salt

Motivation

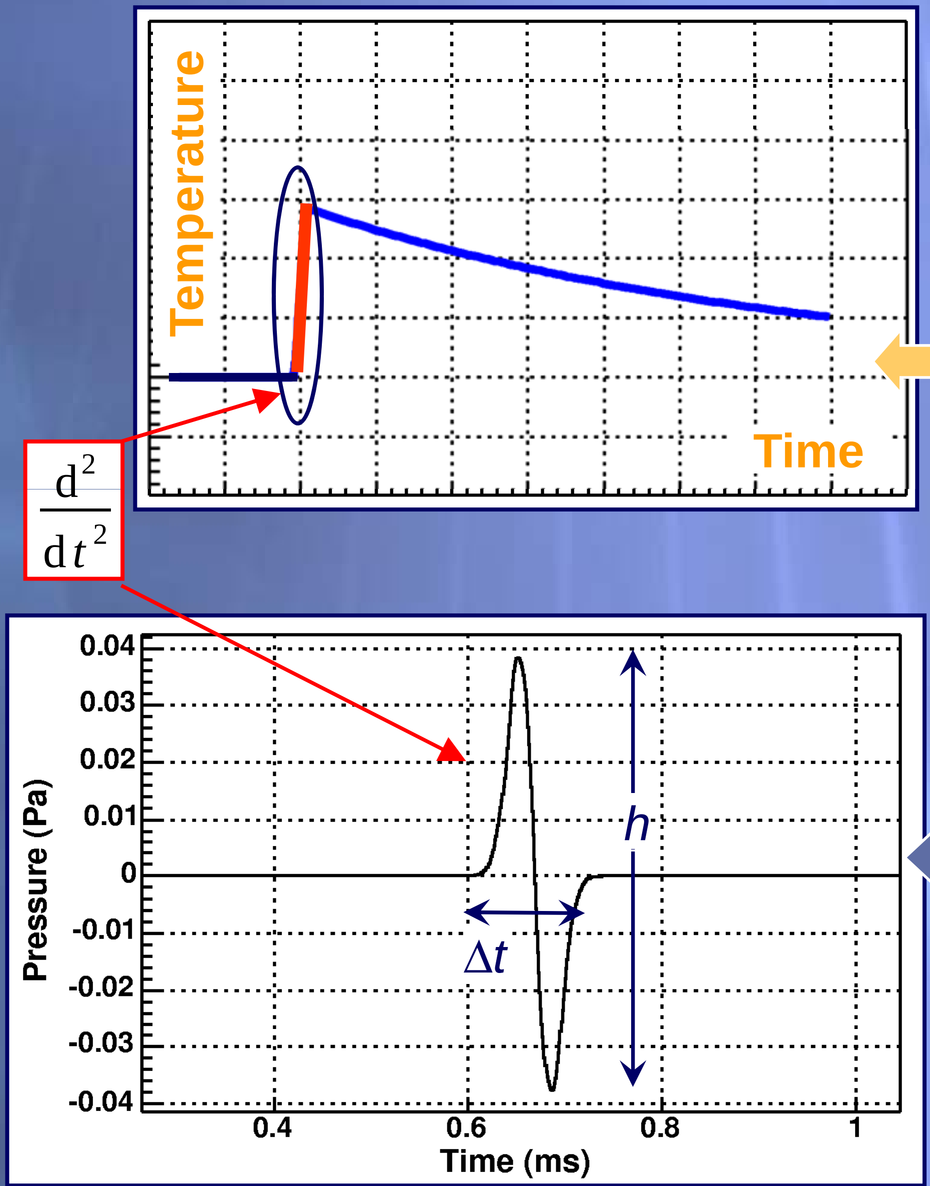
- Probing Ultra High Energies with neutrinos
- *In addition to cosmogenic neutrinos other theories such as:*
  - Strongly interacting neutrinos
  - *New neutral primaries*
  - Violation of Lorenz invariance
  - *Decaying supermassive dark matter*
  - Instantons, excitons
  - *etc...*
- Many of these 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



Acoustic Detection Principle



- Fast thermal energy deposition (followed by slow heat diffusion)
- *Results in a quasi-instantaneous temperature increase and expansion of the medium leading to "acoustic shock" sound pulse*

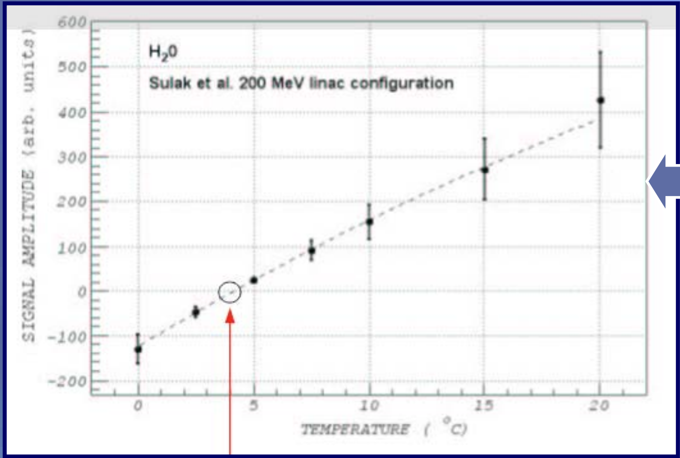
- Double derivative leads to classic bipolar pulse shape
- *Pulse width Δt is related to the* ***transverse*** *shower spread*
- Pulse height h is defined by the medium: $h \propto \beta / C_p$ where b is the co-efficient of thermal expansivity and C_p is the specific heat capacity

Acoustic Detection Principle

QuickTime™ and a
GIF decompressor
are needed to see this picture.

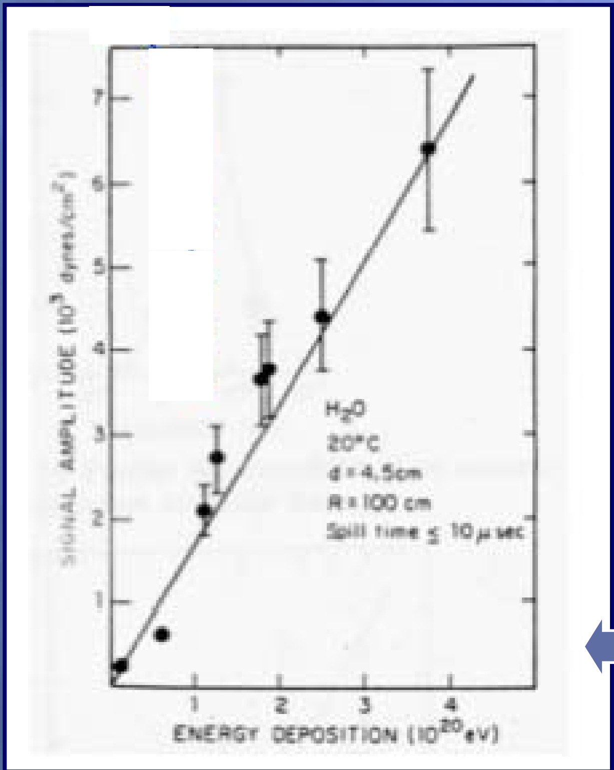
- Cylindrical volume over which the hadronic energy is deposited is typically 10m-20m long and a few centimetres wide
- *In analogy with light diffraction through a slit the acoustic signal propagates in a narrow "pancake" perpendicular to the direction of the shower*

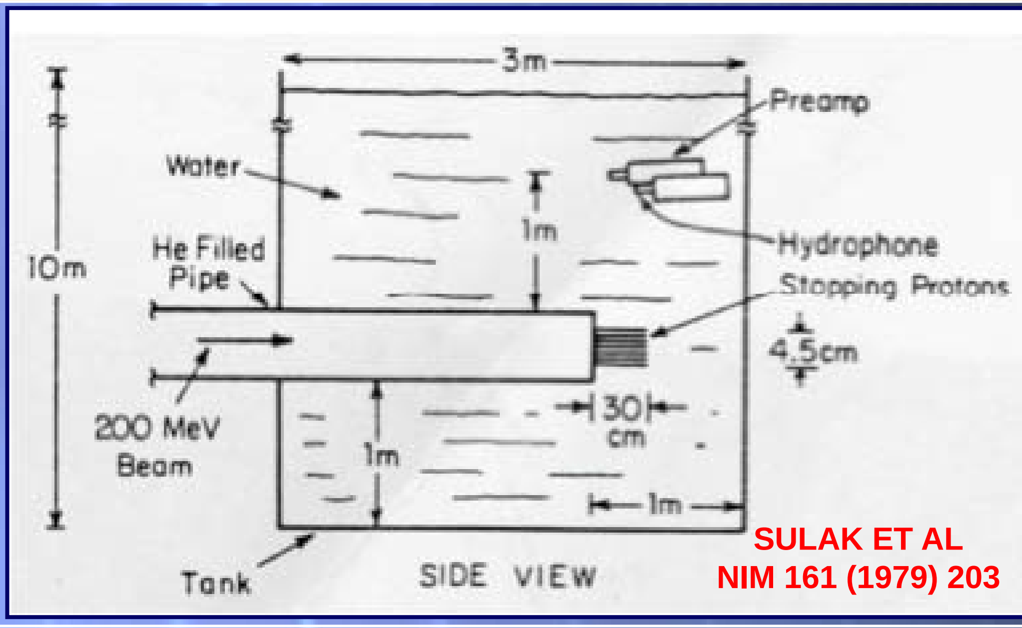
Confirmation of Technique



- Signal amplitude vs. water temperature - warmer is better!
- P proportional to β(T) - thermo-acoustic origin

- Results from experiments in late 1970s confirmed bi-polar acoustic pulse in a test beam at Brookhaven





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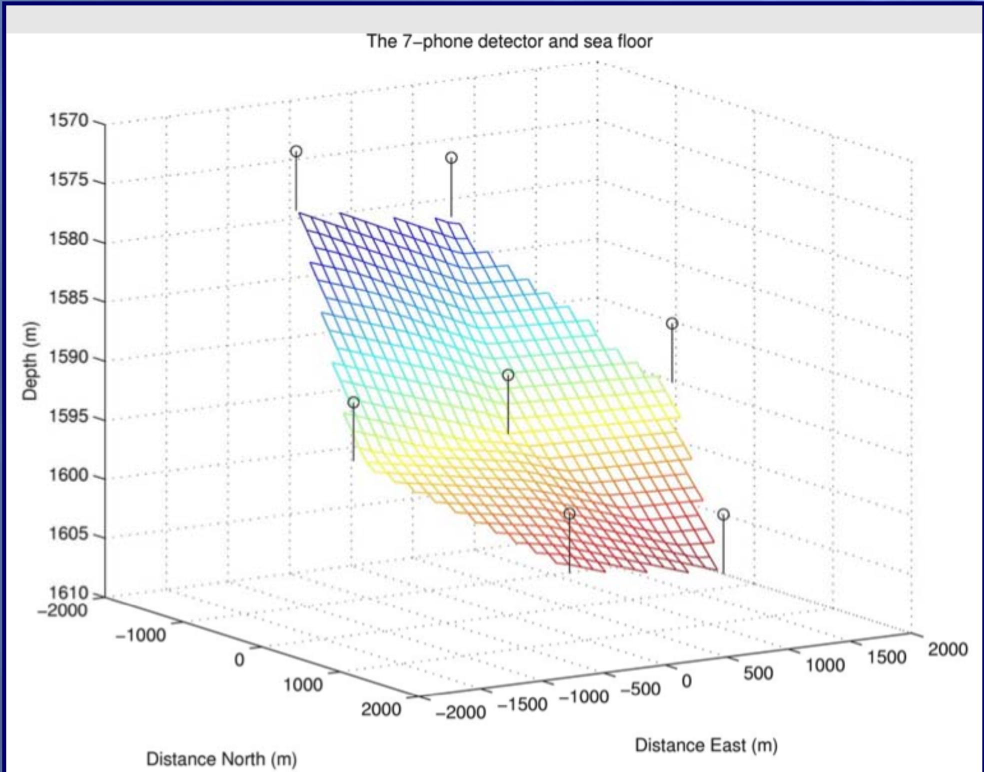
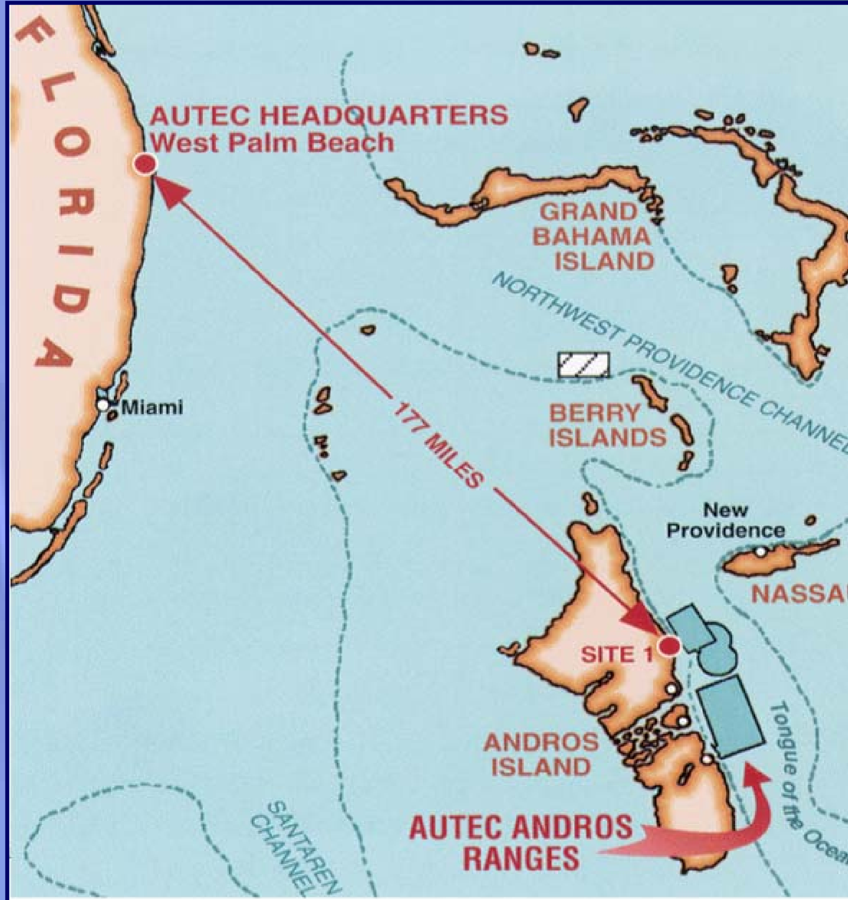
- Signal amplitude vs. energy deposition
- Pressure proportional to Energy - proves predicted coherent effect

Stanford Acoustic Underwater Neutrino Detector (SAUND)

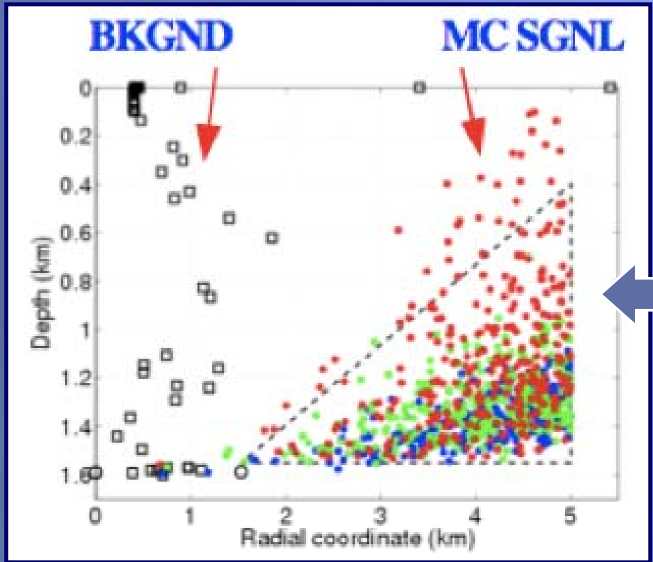
- The SAUND experiment
- *Stanford based venture using the AUTEC array, naval hydrophones in the Bahamas*





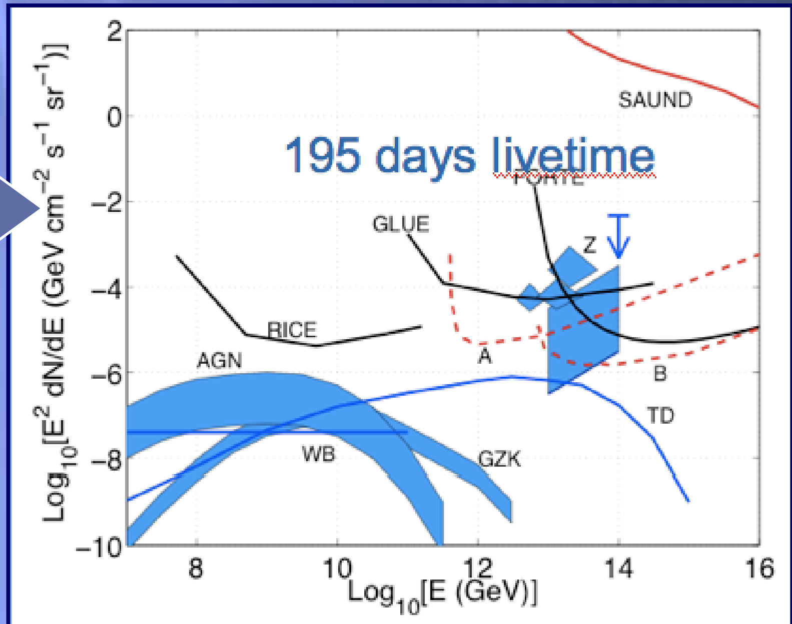
- SAUND I: 7 hydrophones read out
- *Raw data filtered before acquisition*

SAUND

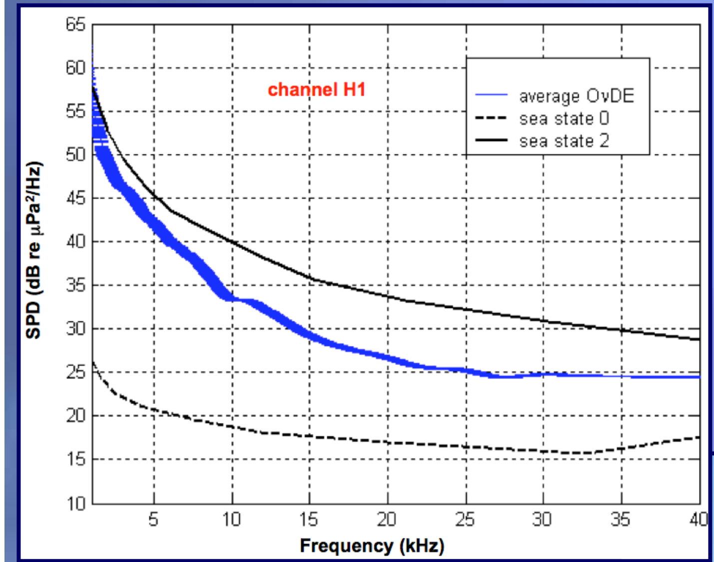


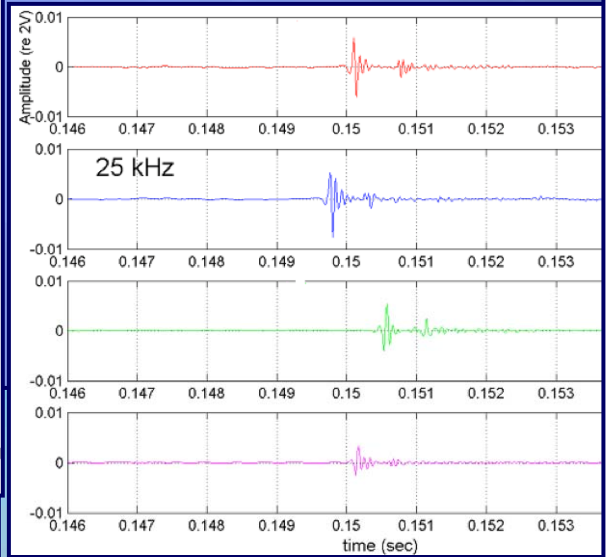
- SAUND analysis requires multi-phone co-incidences and fiducial cuts to remove the remaining multi-polar backgrounds

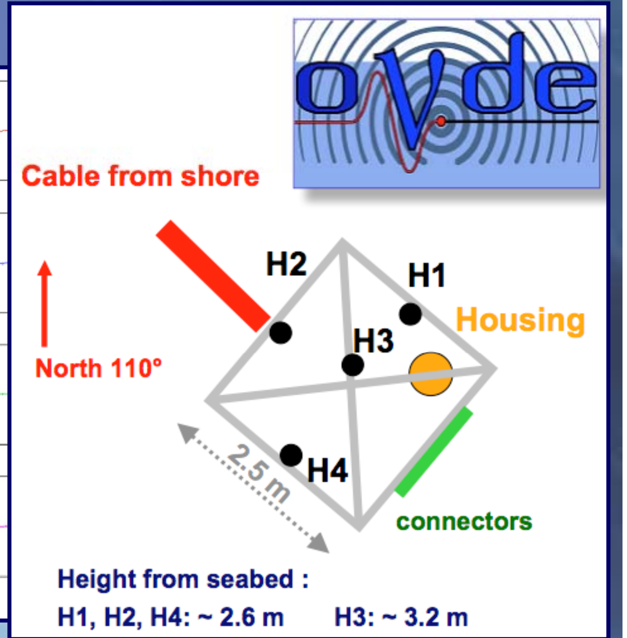
- Published sensitivity for 195 days of data with SAUND I
- SAUND II is reading out ~56 hydrophones and started data taking in summer 2006



Ocean Noise Detection Experiment (ONDE)

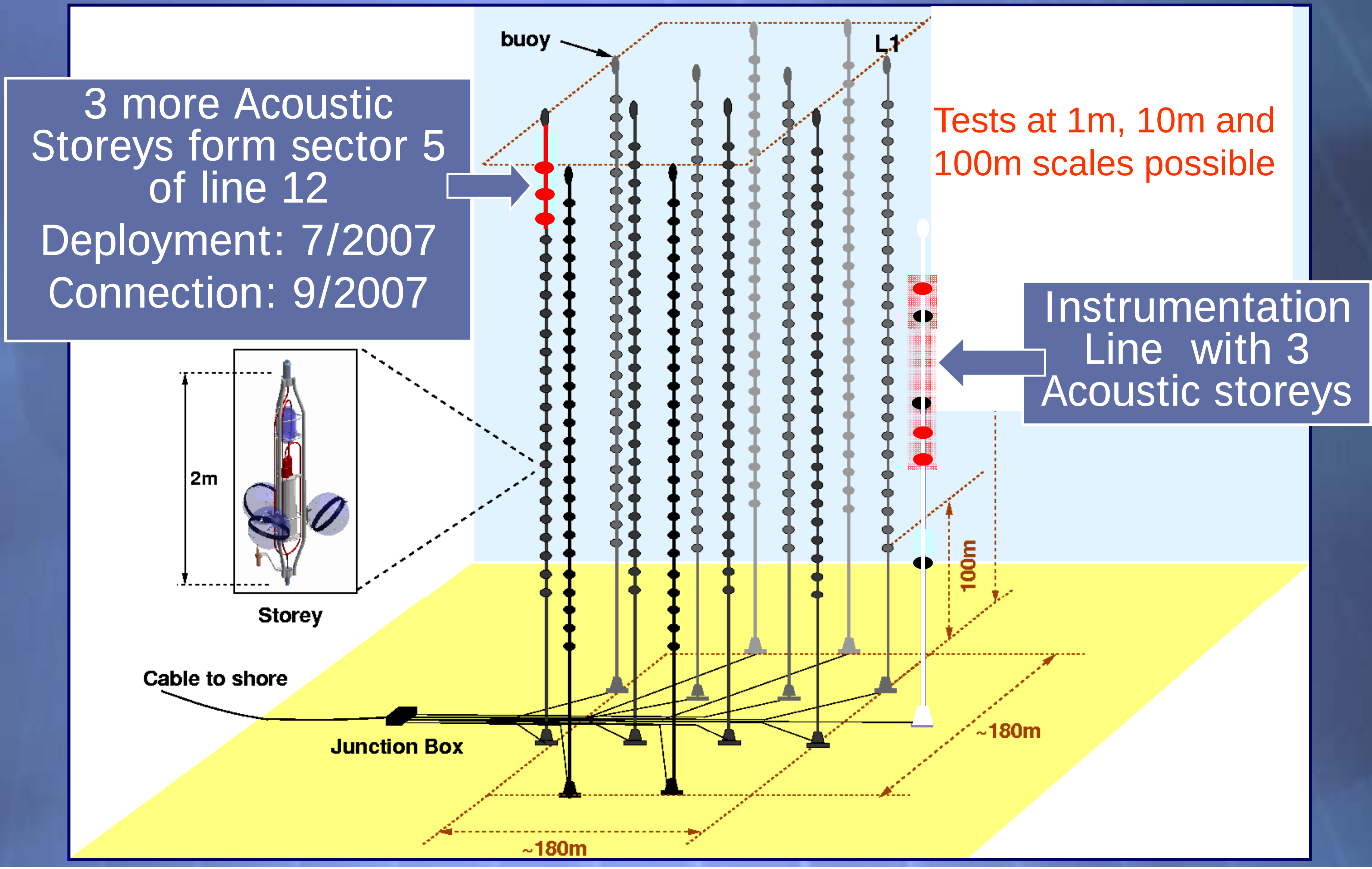






- ONDE was deployed in January 2005 at the NEMO Test Site in Sicily
- *4 hydrophones werer read out (5' per hour) for ~2 years*
- Full analysis of noise (by hour, month, etc.)
- *Bio coincidences seen*

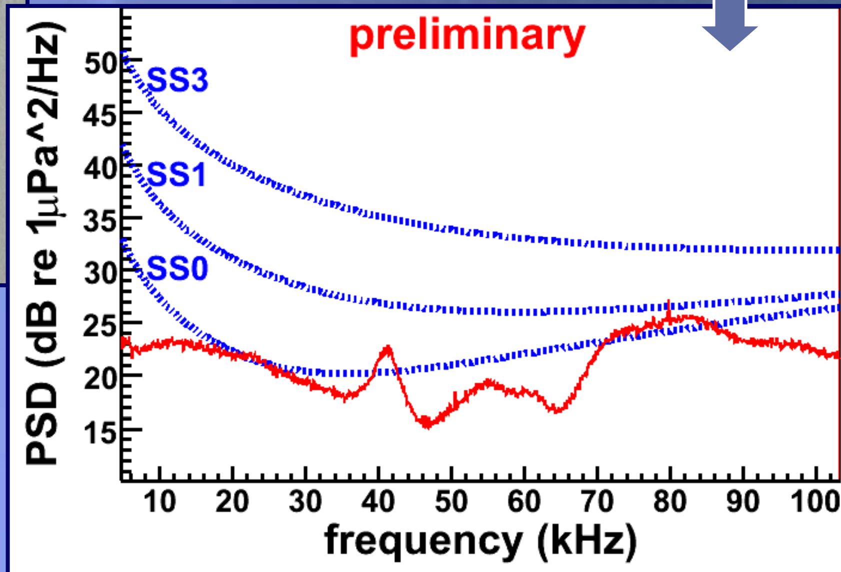
Antares Modules for Acoustic Detection Under the Sea (AMADEUS)



AMADEUS

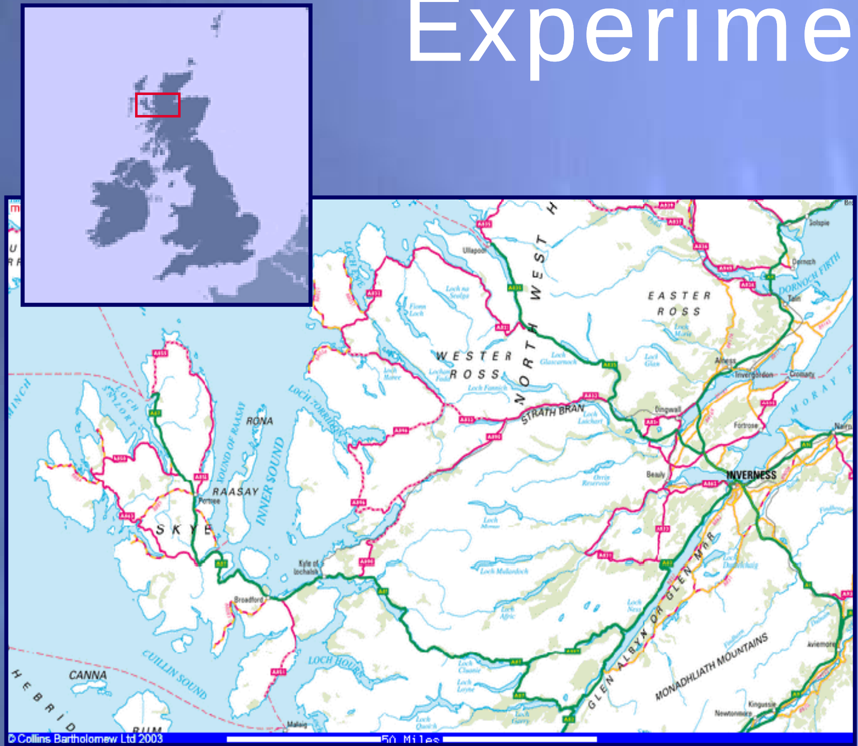
Hydrophone:
Piezo element with pre-amplifier and filter in PU coating

- Acoustic system in connection with ANTARES
- *2 lines instrumented with acoustic sensors*
- Intrinsic sensor noise measured



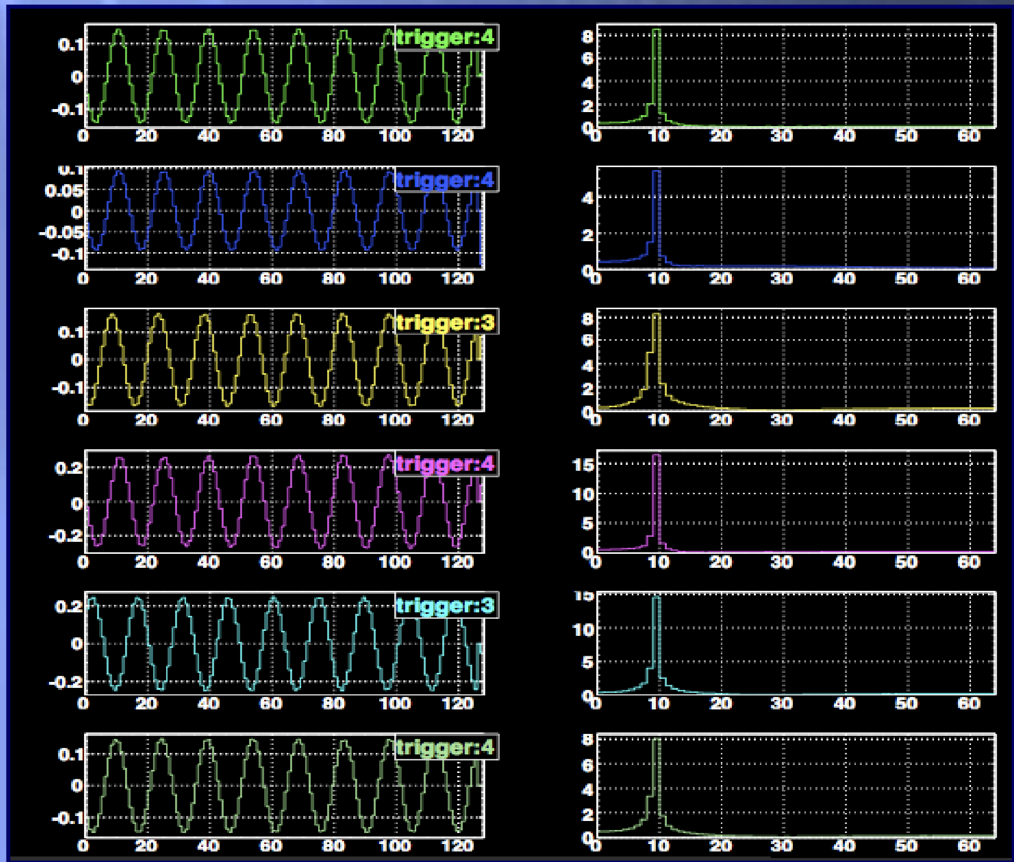
These studies will be extended to KM3NeT

Acoustic Cosmic Ray Neutrino Experiment (ACORNE)



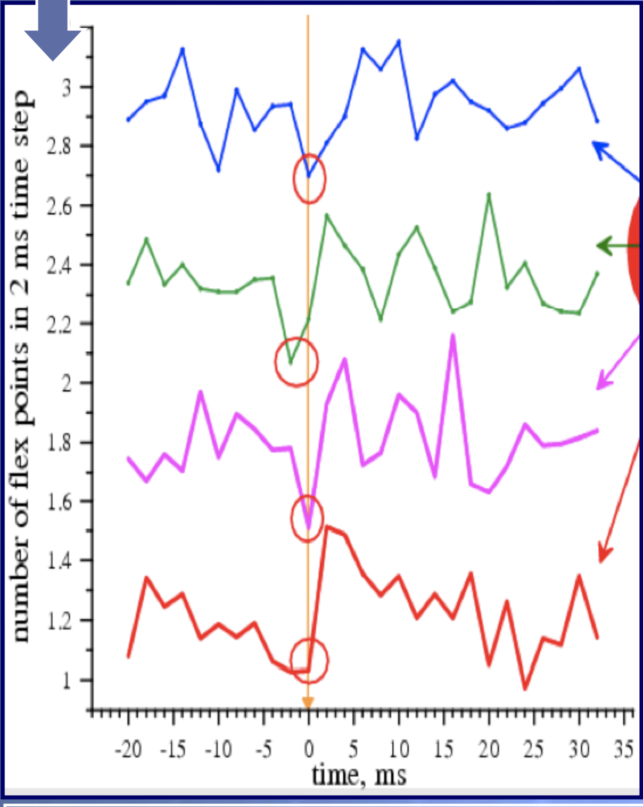
- Rona hydrophone array, a military array in Scotland used by the ACORNE collaboration
- *2 weeks of unfiltered data taking in December 2005, quasi-continuous since September 2006*

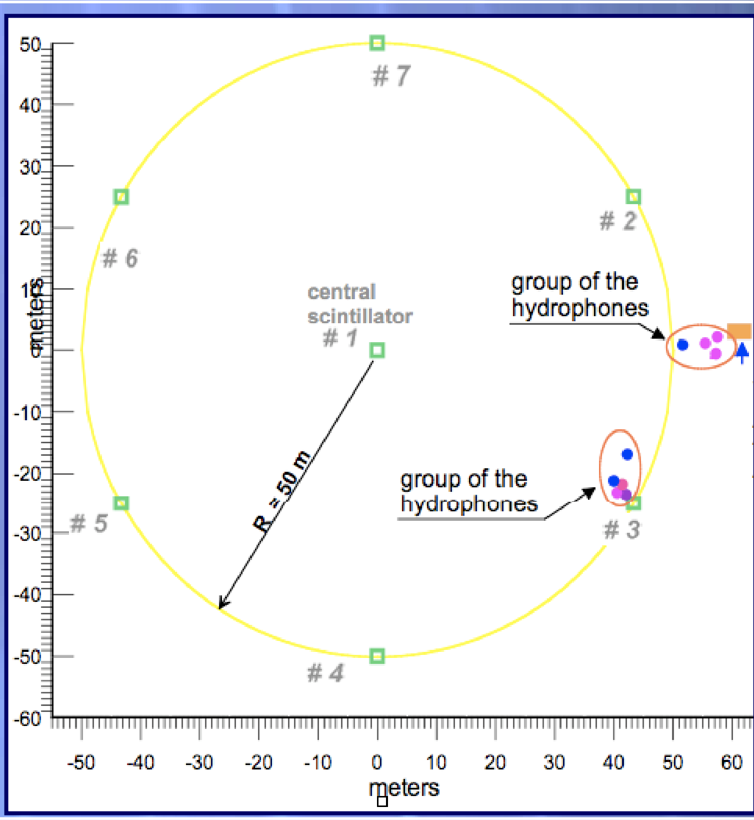
- 8 hydrophones read out continuously at 16bits,140kHz - a total of (~15Tb)
- *Average spectra show hydrophones are well-balanced*

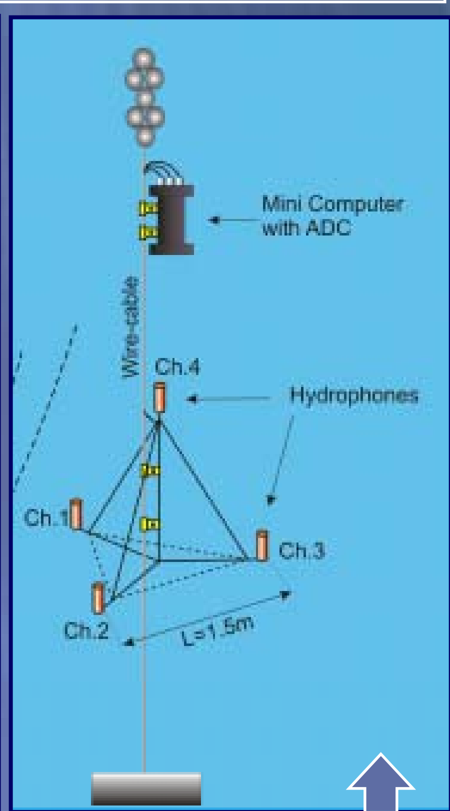


Lake Baikal

- Co-incidence of surface (ice) based scintillators and hydrophones
- *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



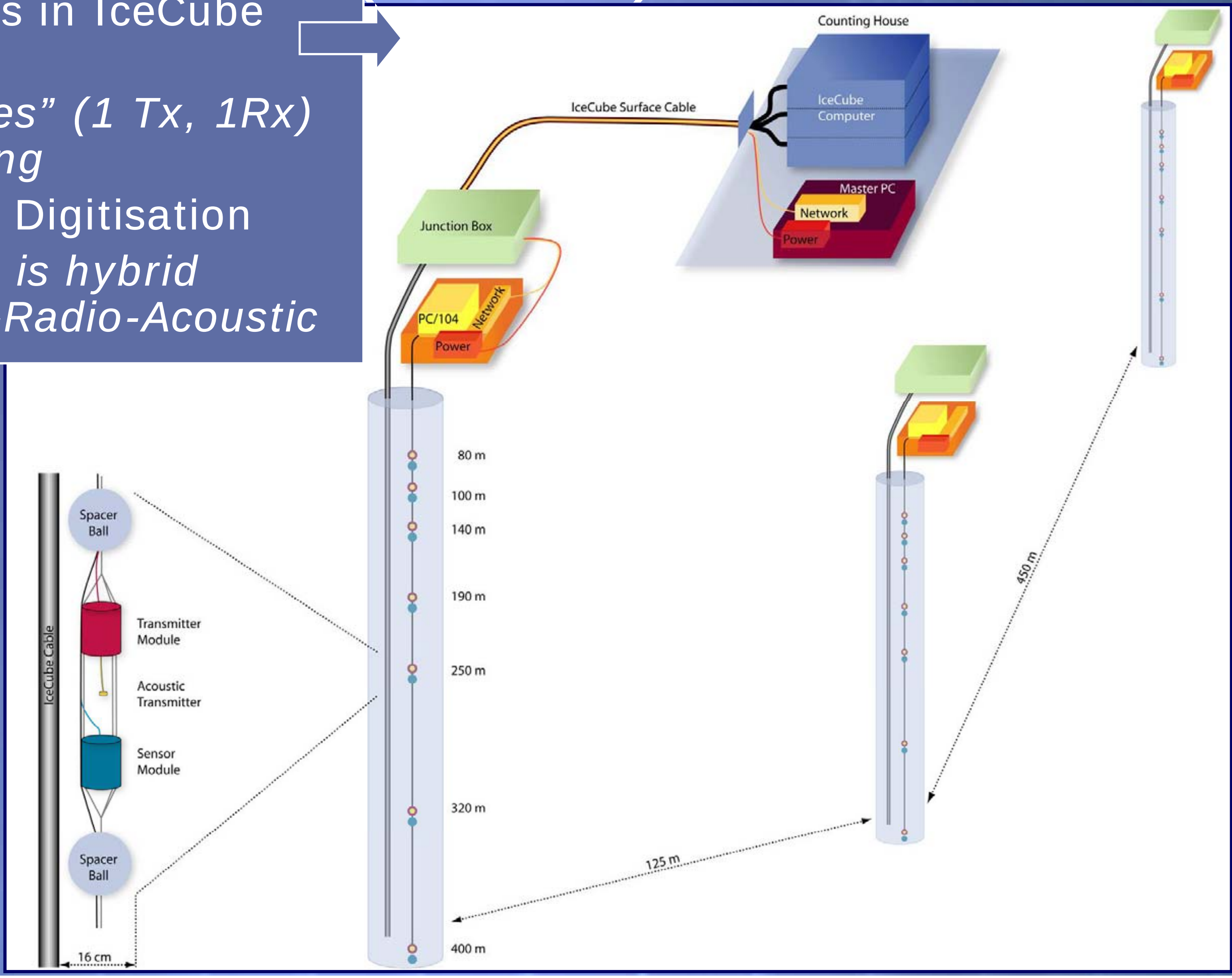




- New acoustic module with 4 hydrophones deployed in April 2006
- *100m, autonomous, self-triggered, on-detector processing*
- First results to be presented at ICRC conference

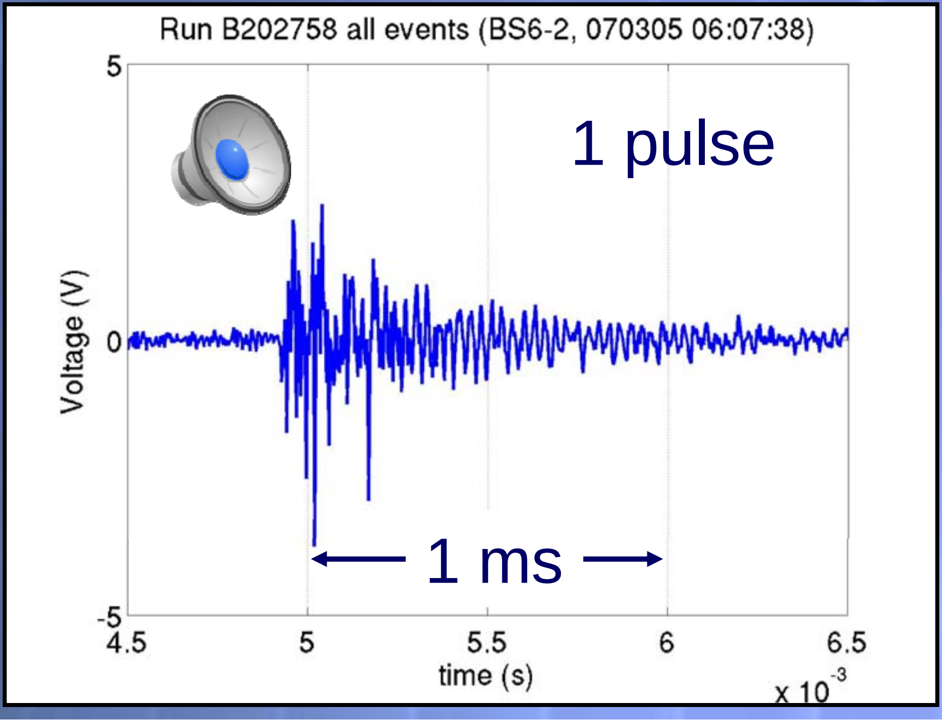
South Pole Acoustic Test Setup (SPATS)

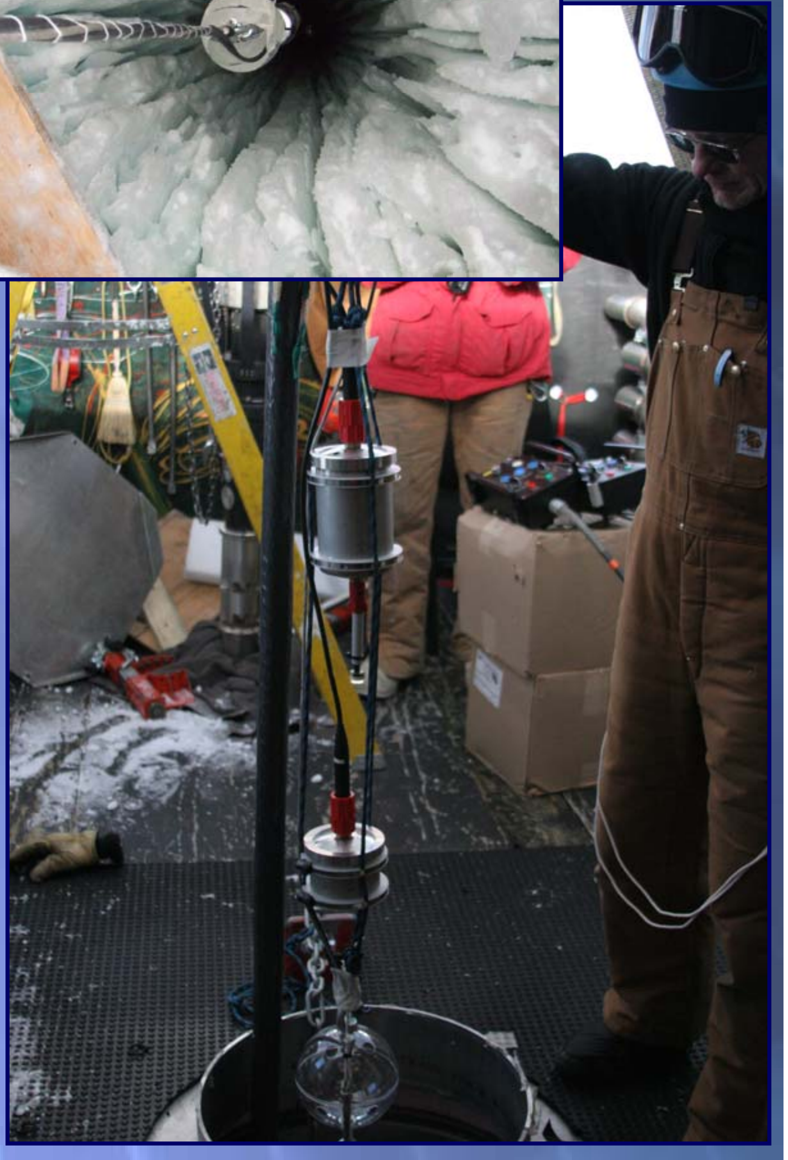
- 3 strings in IceCube holes
- *7 “stages” (1 Tx, 1Rx) per string*
- Surface Digitisation
- *1 string is hybrid Optical-Radio-Acoustic*



SPATS

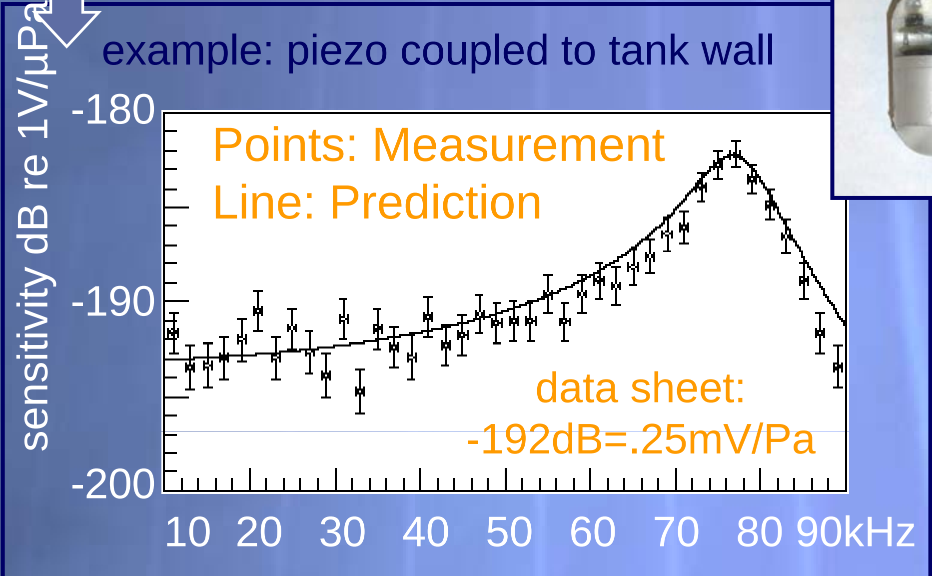
- Almost continuous data-taking since Feb ‘07:
  - *threshold/forced background runs*
  - inter-string Tx-Rx tests
  - *min-max distances:125m-529m*

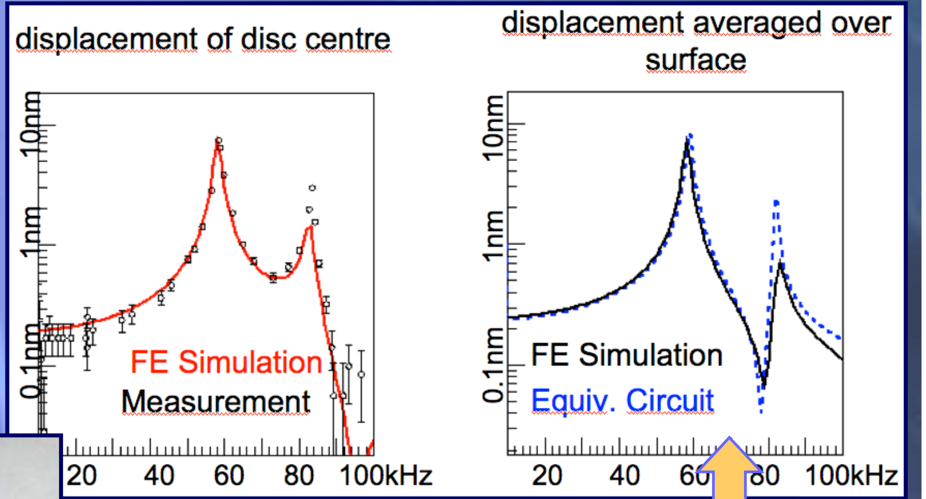




Sensor Development

- 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





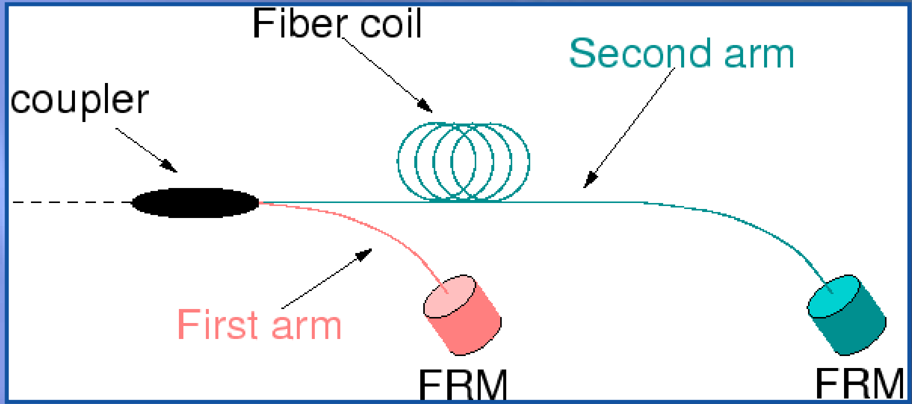
Further detailed understanding of piezos is under study

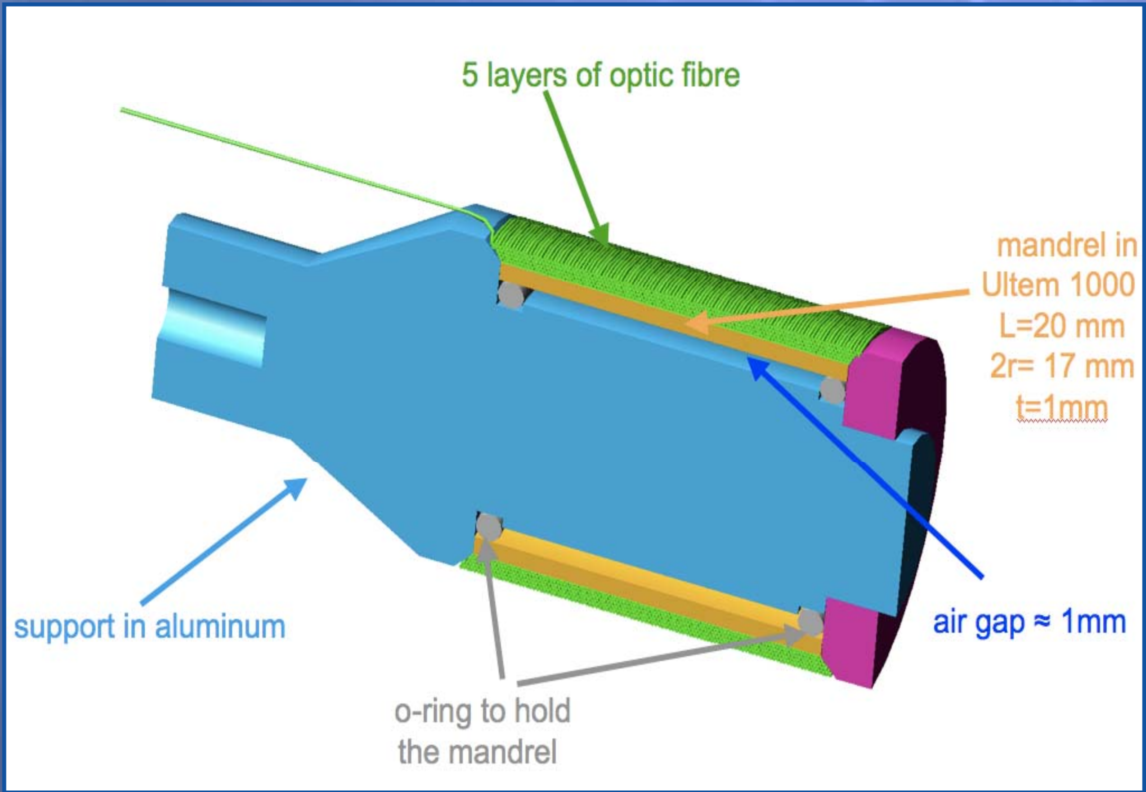
*At the **microscopic** level piezos can be modelled using PDEs for an anisotropic material*

- Solve using Finite Element Analysis
- *Use Laser Interferometry to compare results*

Sensor Development

- Development of novel hydrophone designs
- *From Genova: an air-backed mandrel hydrophone*
- Incorporates a Bragg grating, interferometer and laser

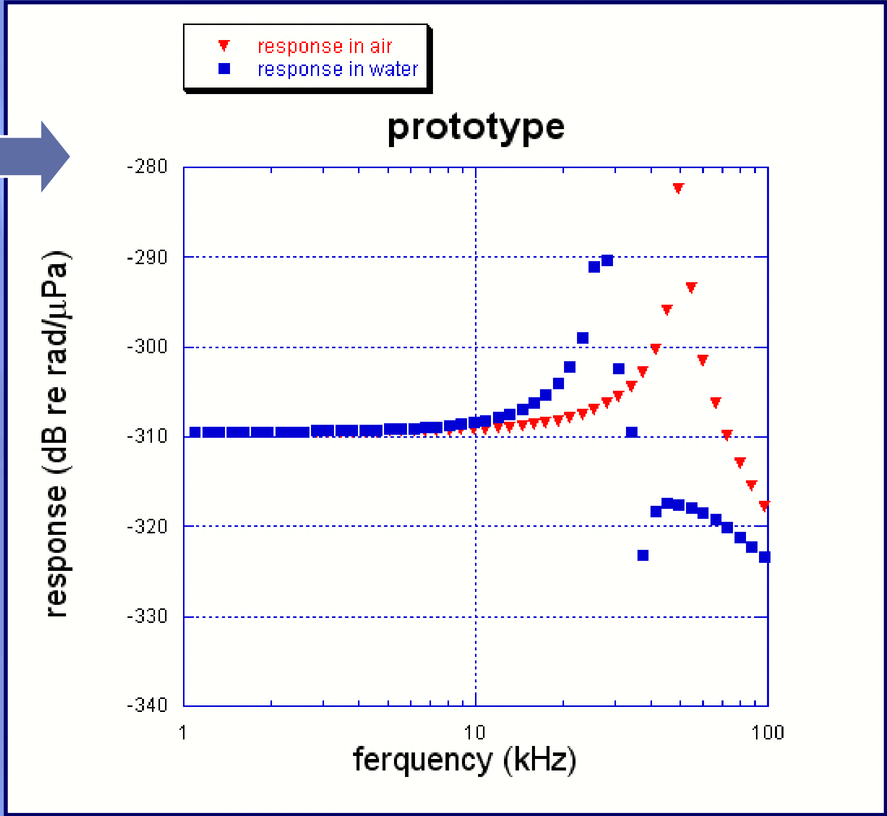


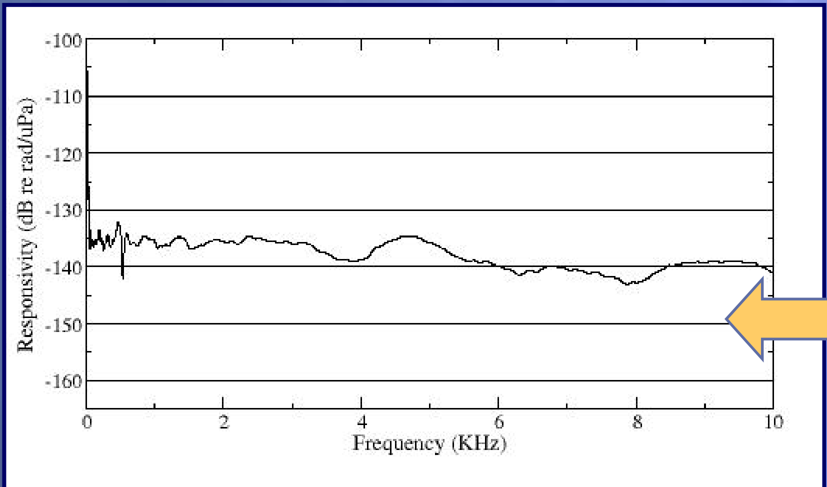


- Advantages include:
- *(Relative) ease of fabrication*
- Immune from EMI
- *No need for ADC*
- Could be arranged in large arrays using multiplexing

Sensor Development

- Prototypes developed and characterised
  Main challenges:
  - *to improve response in 20kHz-30kHz region*
  - Improve operating depth

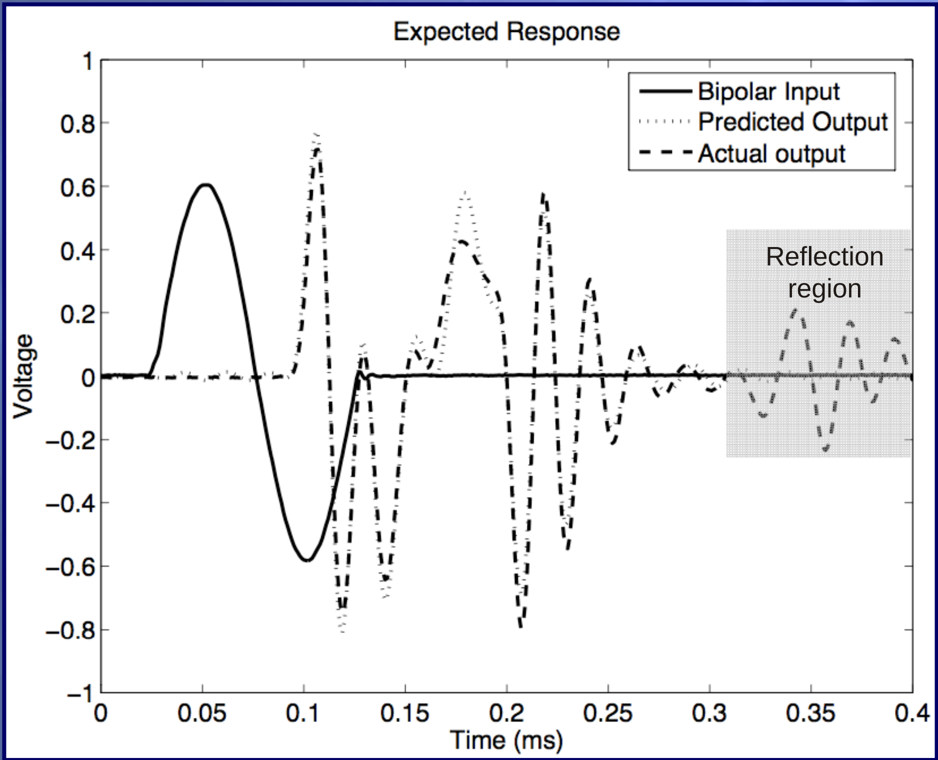


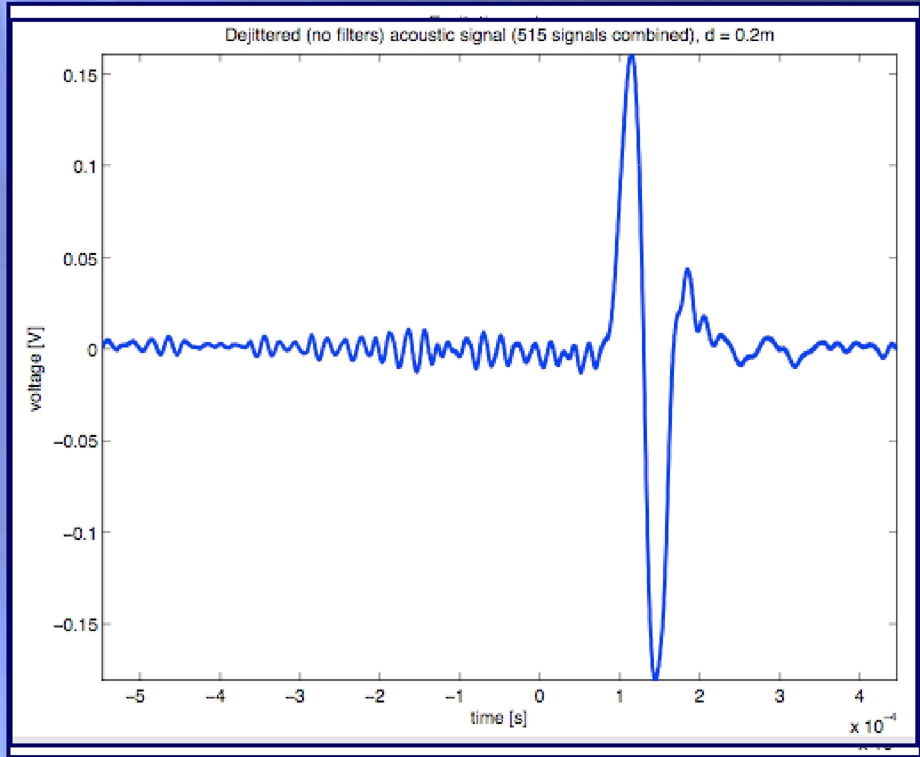


- Minimum detectable signal at 5kHz is 450µPa
- *Promising technique*

Acoustic Calibration

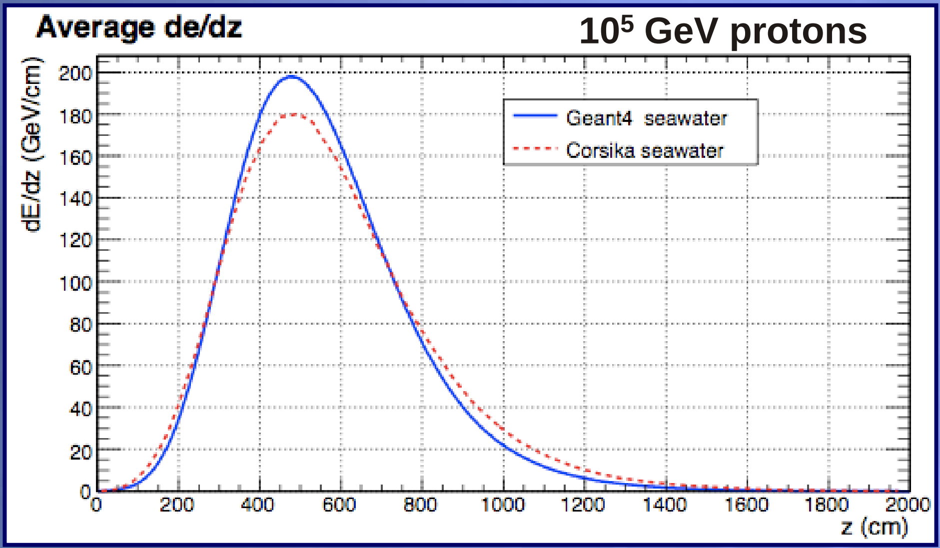
- Work done by the ACORNE collaboration
- Using signal processing techniques (including equivalent circuits - able to very accurately characterise a hydrophone in both phase and amplitude

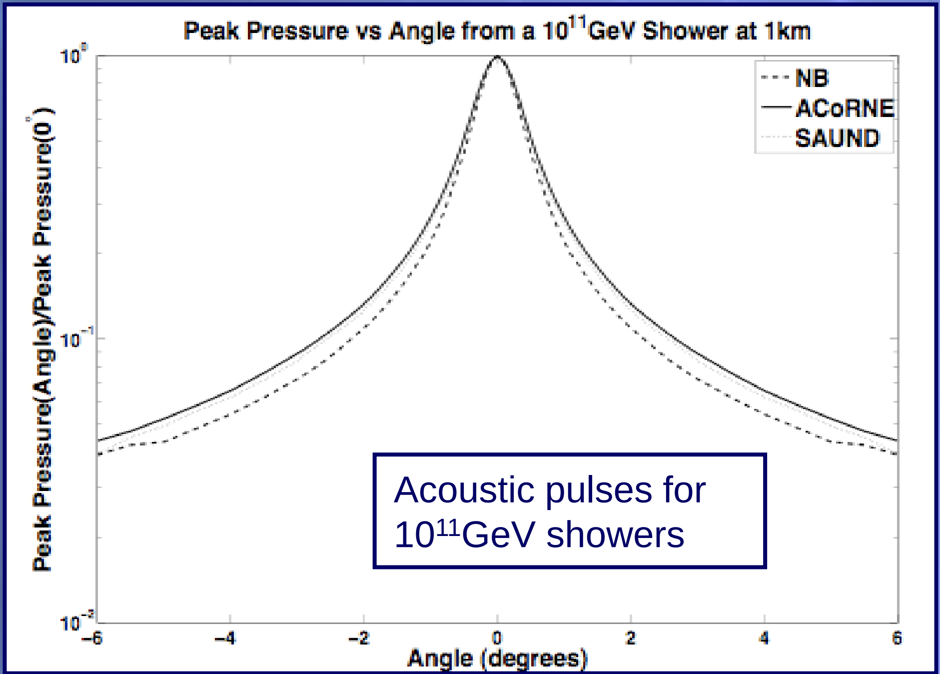


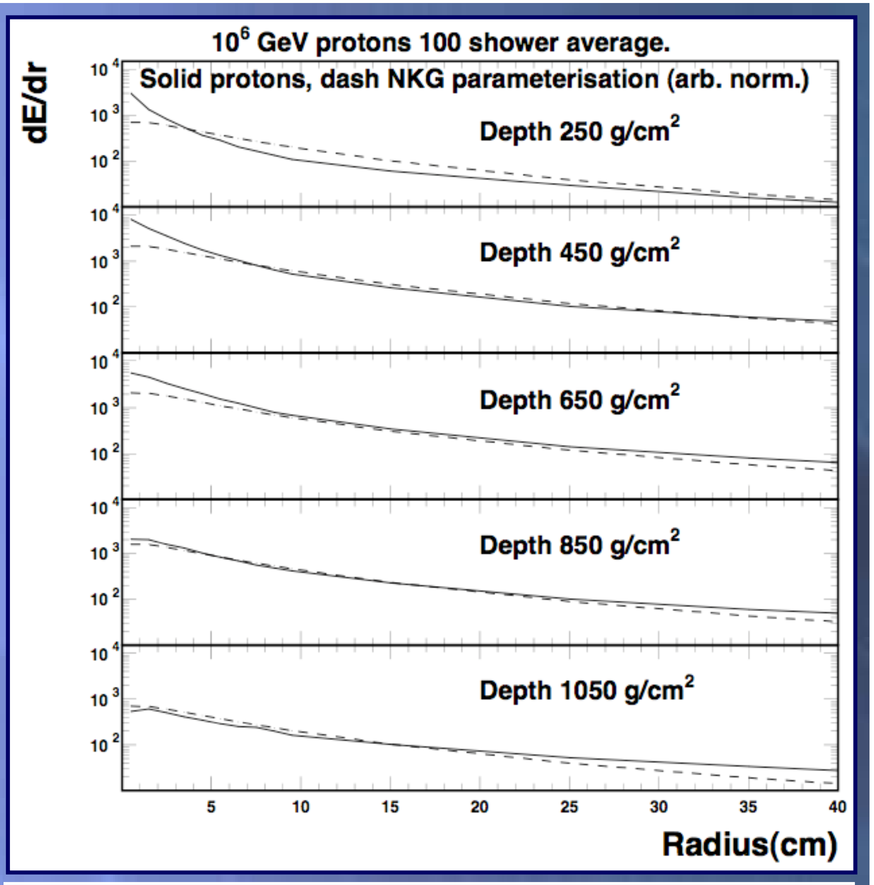


- ACORNE group are now using this technique to transmit accurate bipolar pulses
- Will be done above the Rona array in early August

Simulation Work

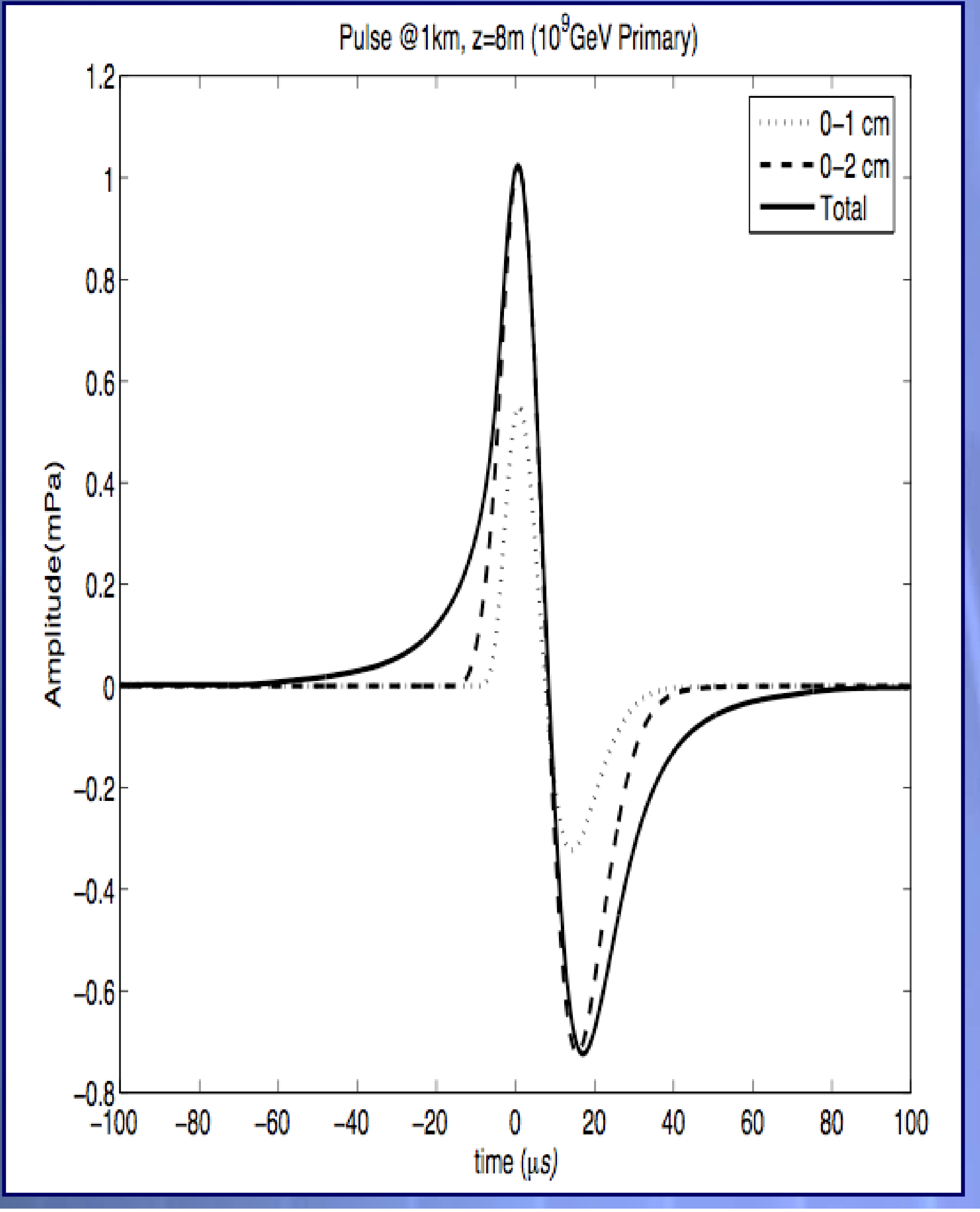






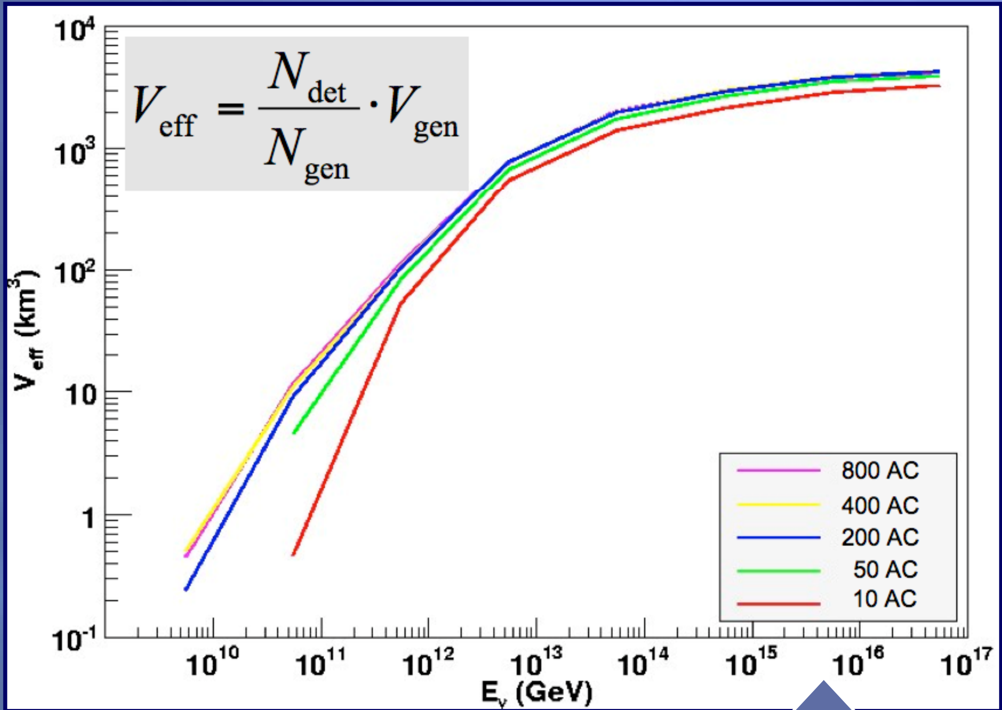
- The acoustic signal is very sensitive to the core of the hadronic cascade
- *CORSIKA has been modified to make it work in water*
- Cross-checks with GEANT4
- *Avoids extrapolating low energy Toolkits such as GEANT4*

Simulation Work



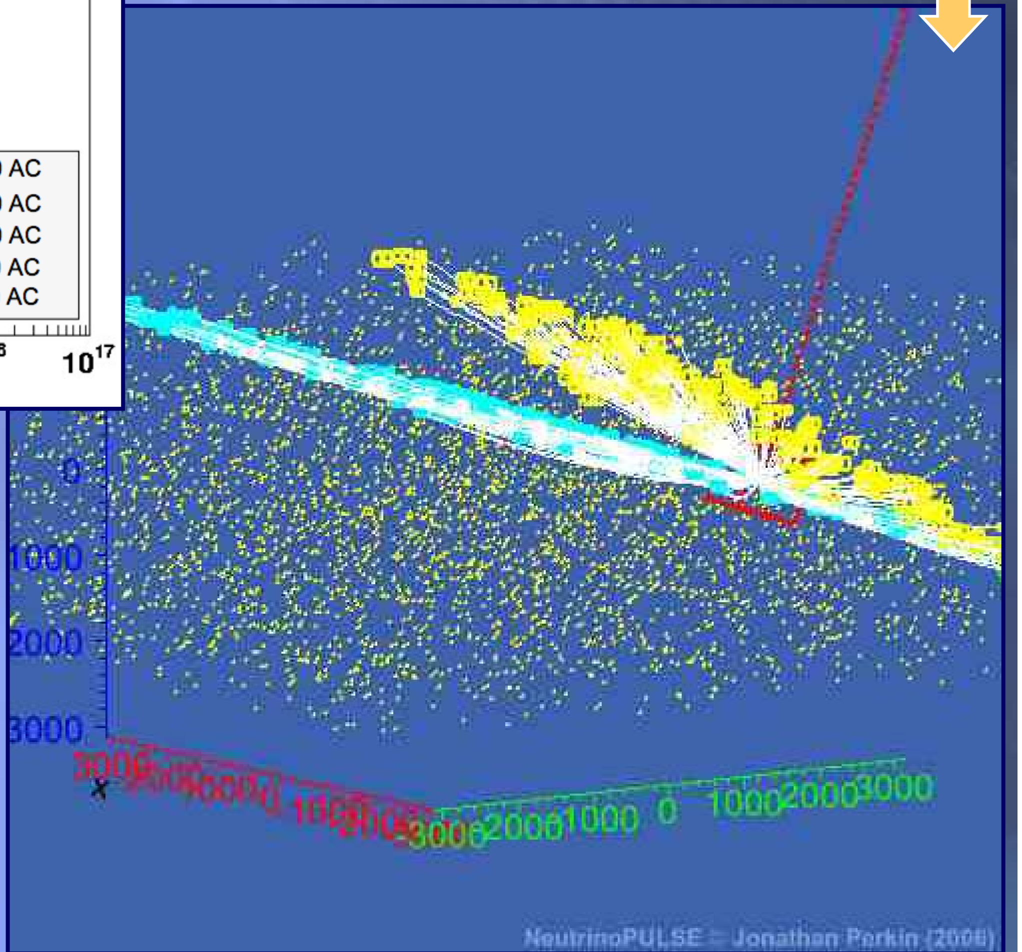
- Generated acoustic pulses using CORSIKA parameterisations
- The acoustic signal 1km from shower axis in the pancake plane
- Average of 100 CORSIKA showers at 10^9 GeV in water
- See arXiv:0704.0125 [astro-ph] for further information

Sensitivity Calculations



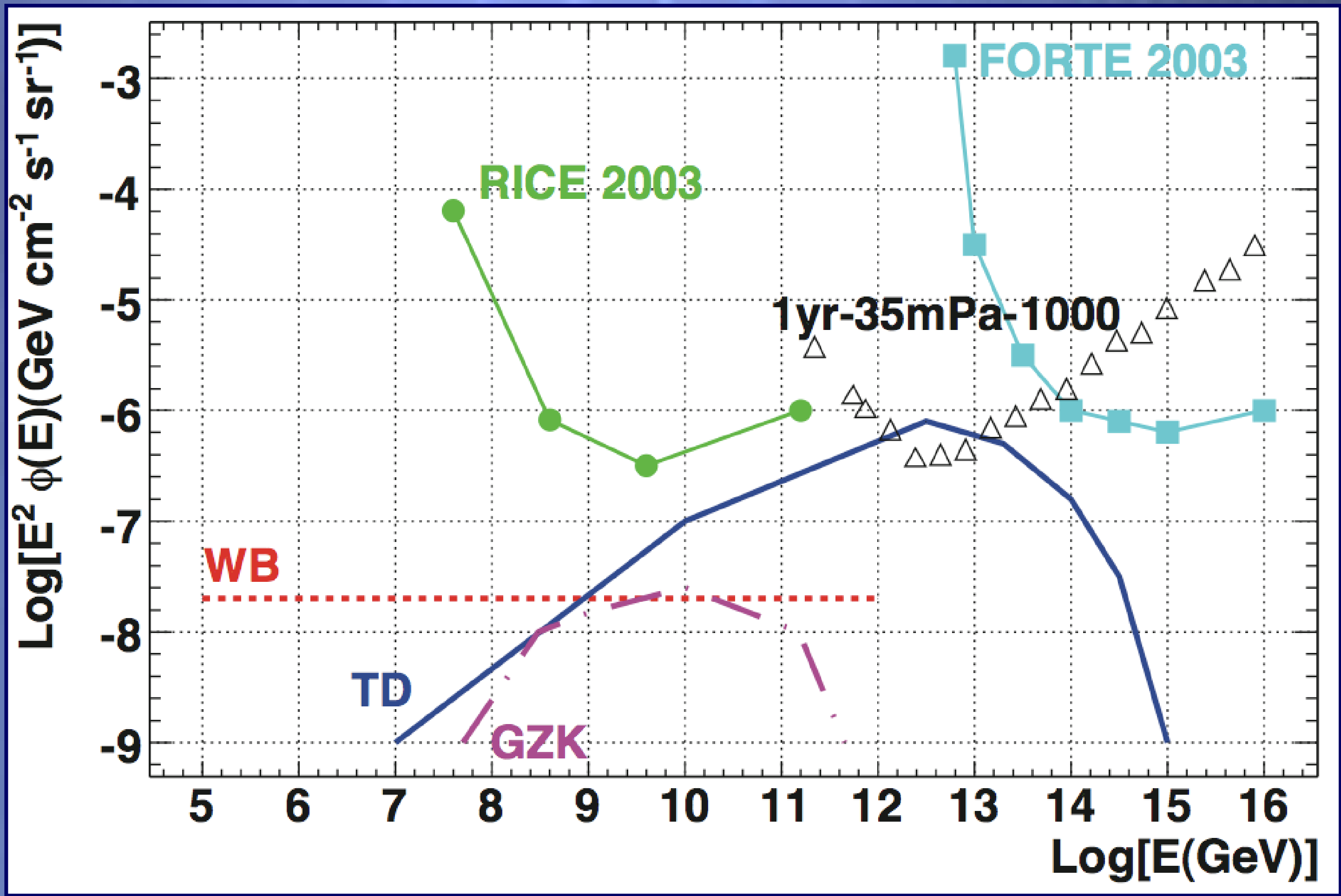
- Effective volume for a 1 km^3 array instrumented with different numbers of ANTARES-style *acoustic storeys*
- *No improvement in effective volume above 200AC/km^3*
- Detection threshold 5mPa

- Current studies are concentrating on the effects of refraction
- *Linear Sound Velocity Profile (SVP) distorts the acoustic pancake into a hyperbola*

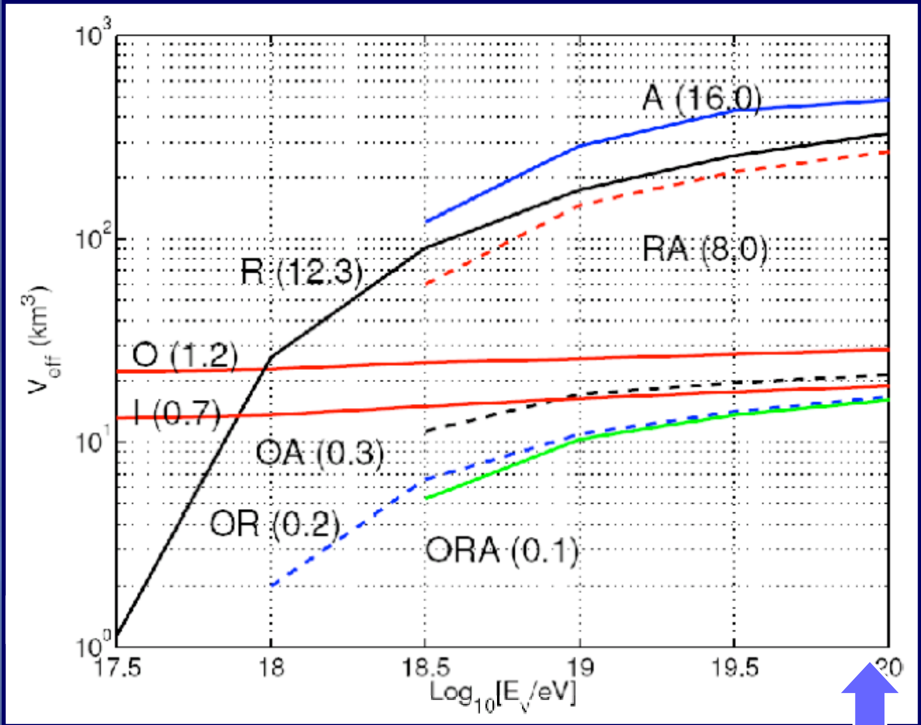


Sensitivity Calculations

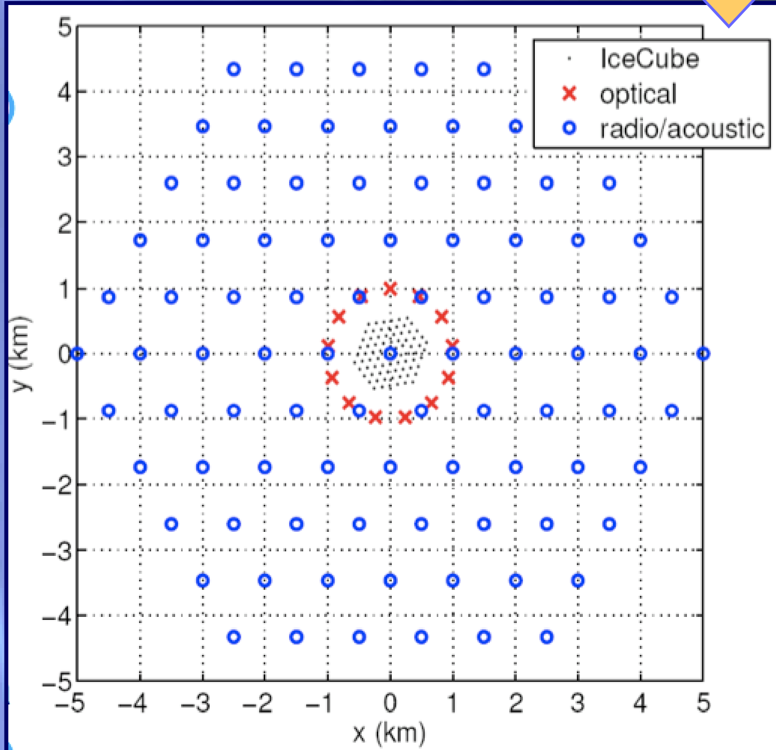
- Example curve for 1 year, 1000 hydros in a volume of 1 km^3 with 35mPa hydrophone threshold



Sensitivity Calculations



- ✦ Considering Hybrid arrays incorporating optical, radio and acoustic technologies
- ✦ *Cross-calibration between technologies should be possible*
- ✦ Yields up to 20 events per year



- ✦ Effective volume for hybrid arrays involving extending beyond IceCube with strings of radio and acoustic sensors
- ✦ *IceCube plus 5x2 radio and 300 acoustic sensors per string*
- ✦ See D. Besson, astro-ph/0512604

Summary

- *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 be in parallel with the infrastructure of first and second generation optical Cerenkov neutrino telescopes
- *This is already starting to happen (ANTARES-AMADEUS, IceCube-SPATS-AURA)*
- Multi-messenger observations of astrophysical objects clearly provide valuable information, this is also true at ultra high energies

ARENA Workshops

- Acoustic and Radio detection EeV Neutrino Activities
- DESY (2005) and Newcastle (2006)
- *Follow on from RADHEP (2000), Stanford workshop (2003)*
- ARENA 2008 will be in Rome!