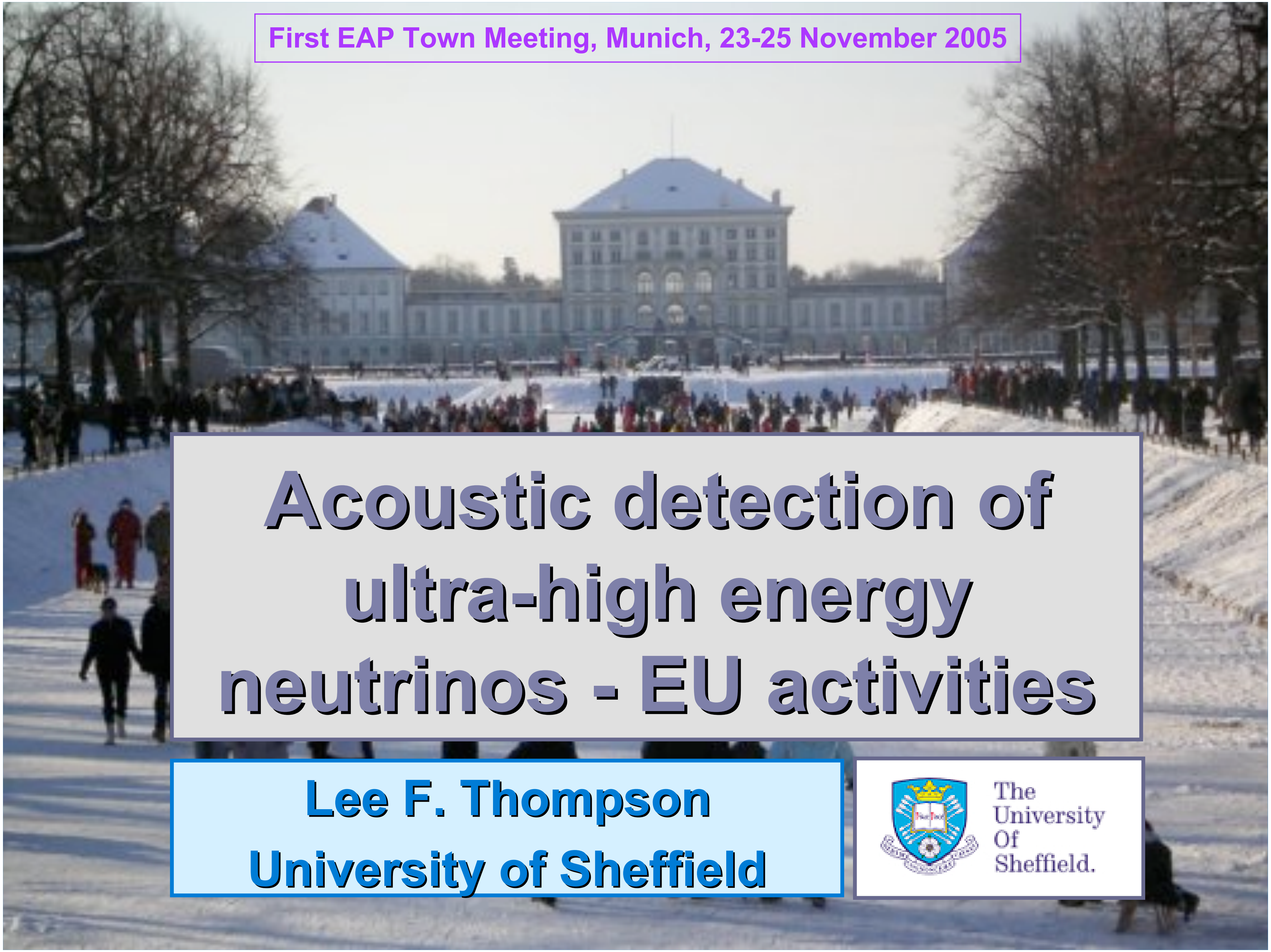


First EAP Town Meeting, Munich, 23-25 November 2005

# Acoustic detection of ultra-high energy neutrinos - EU activities

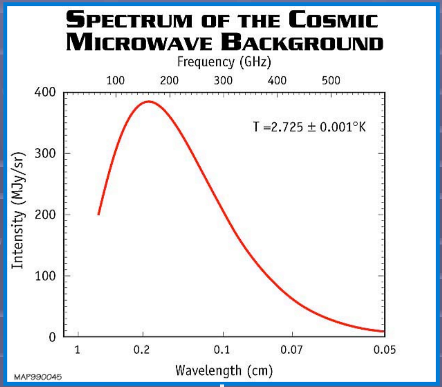
**Lee F. Thompson**

**University of Sheffield**

The University Of Sheffield.

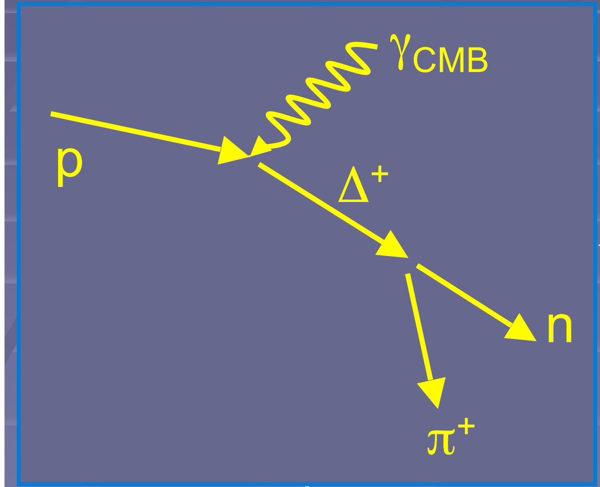
# So why are UHE neutrinos of interest?

- GZK threshold is approx. $6 \times 10^{19}$eV
- *Some pion production at lower proton energies due to HE tail of CMB spectrum*



The lack of a GZK cutoff poses problems for astrophysical explanations of UHECR

**Need to invoke New Physics**



**Does the GZK cut-off exist?**

**YES**

**NO**

$$\begin{aligned} &\qquad\qquad\qquad \hookrightarrow p + e^{-} \boxed{+ \bar{\nu}_{e}} \\ p + \gamma_{CMB} &\rightarrow \Delta^{+} \rightarrow n + \pi^{+} \\ &\qquad\qquad\qquad\quad \hookrightarrow \mu^{+} \boxed{+ \nu_{\mu}} \\ &\qquad\qquad\qquad\qquad \hookrightarrow e^{+} \boxed{+ \nu_{e}} \boxed{+ \bar{\nu}_{\mu}} \end{aligned}$$

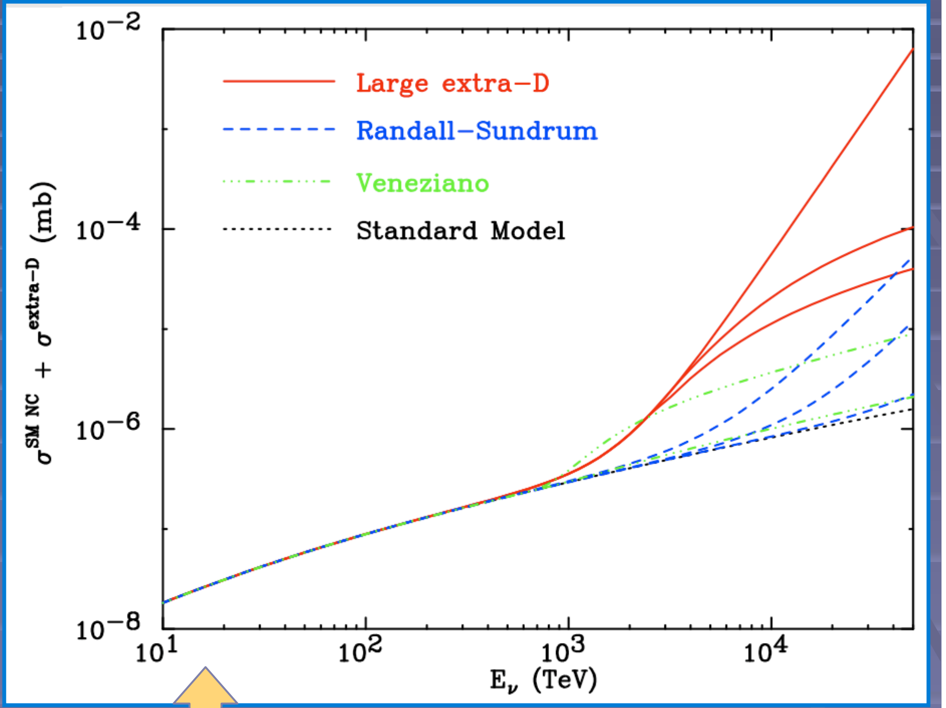
**UHE neutrinos from proton interactions with the CMB**

# What if there is no GZK cut-off?

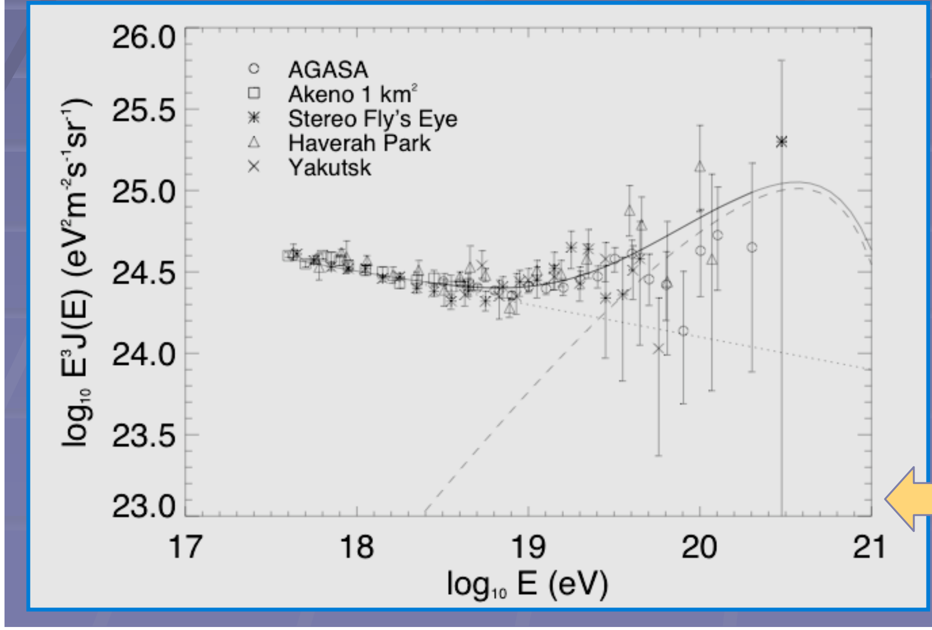
**If trans-GZK cosmic rays do exist need some new physics to explain them**

**Most of these “solutions” predict enhanced fluxes of UHE neutrinos**

- Strongly interacting neutrinos
- *New neutral primaries*
- Violation of Lorenz invariance
- *Decaying supermassive dark matter*

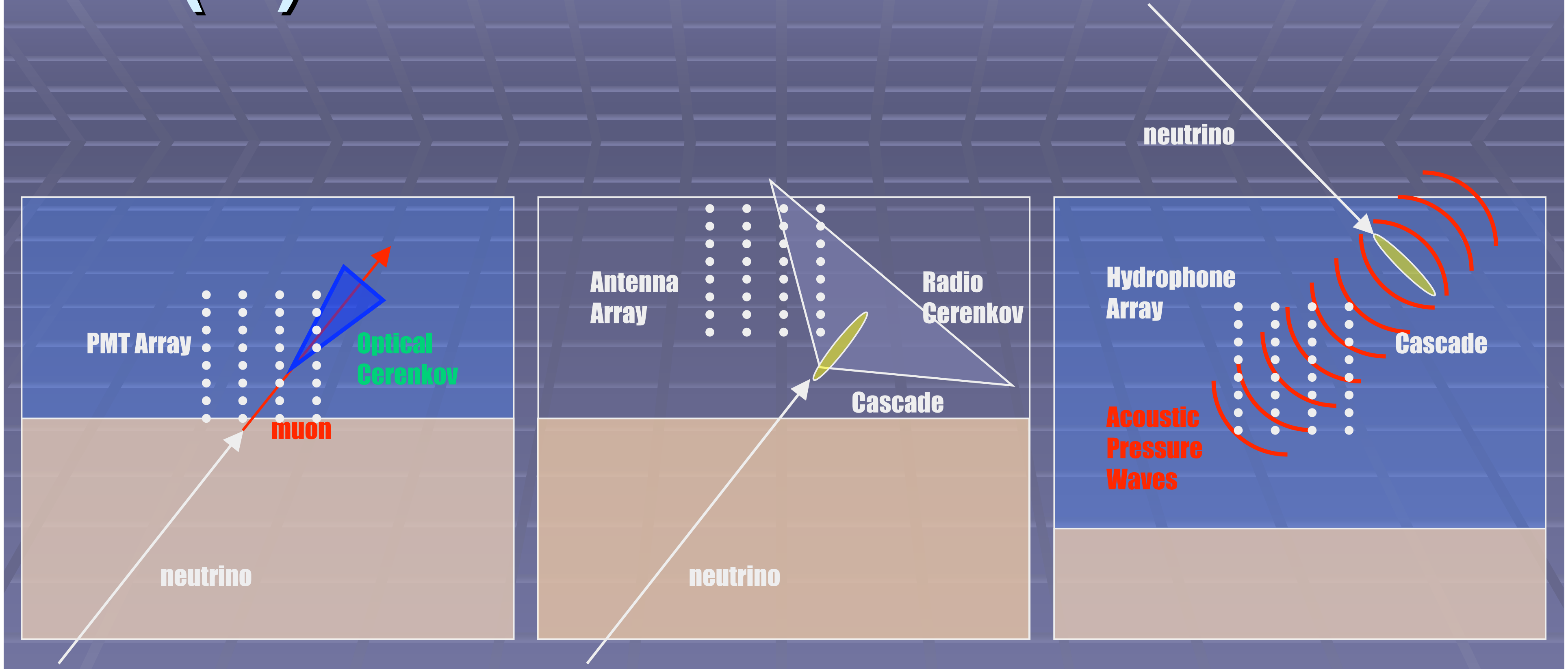


**Neutrino-nucleon cross-sections for low-scale models of quantum gravity involving e.g. extra dimensions**



**Fit to the UHECR spectrum beyond the “ankle” with a decaying supermassive dark matter particle with m=5x$10^{21}$eV (dashed line)**

# (U)HE ν Detection Methods



## Optical Cerenkov

Works well in water, ice

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

Most advanced technique

## Radio Cerenkov

Long (order km) attenuation lengths in ice and salt

First generation experiments proposed

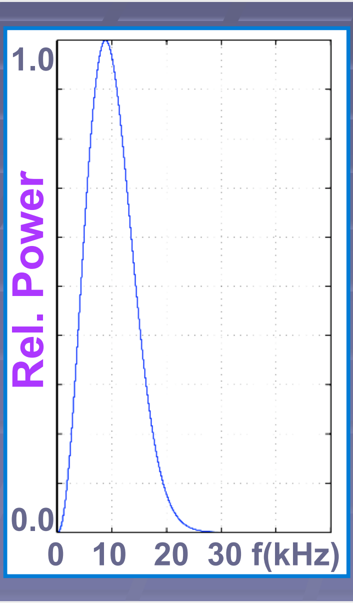
## Acoustic Detection

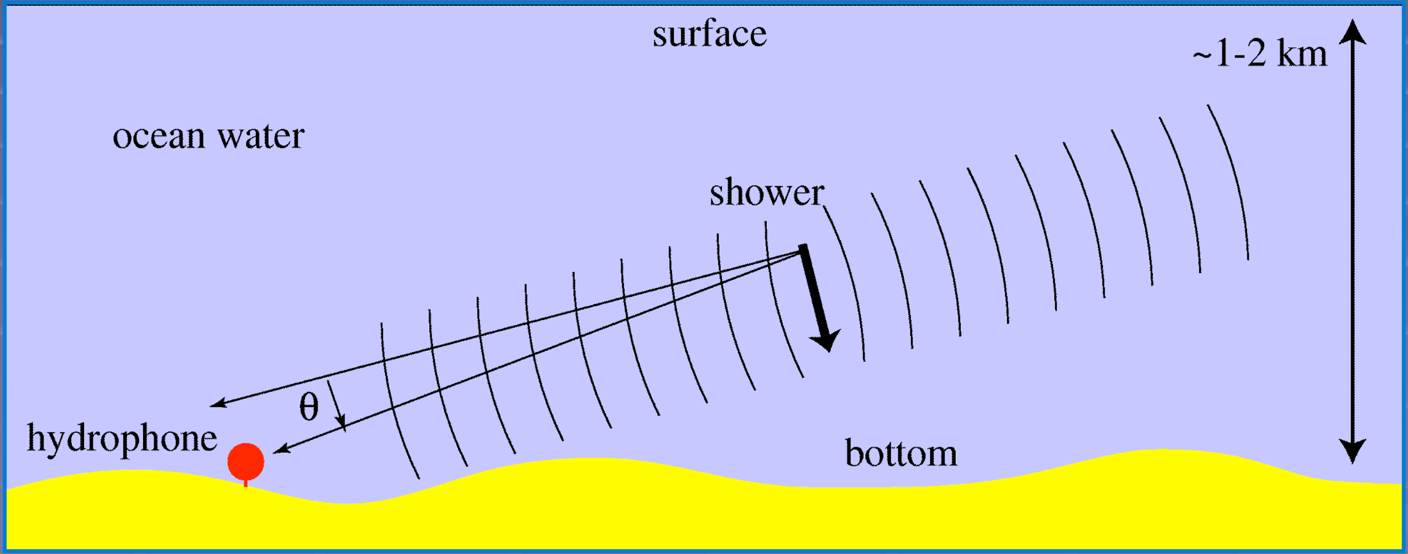
Very long attenuation lengths in water (order 10km), ice and salt

Huge effective volumes may be possible

# Acoustic detection of UHE neutrinos

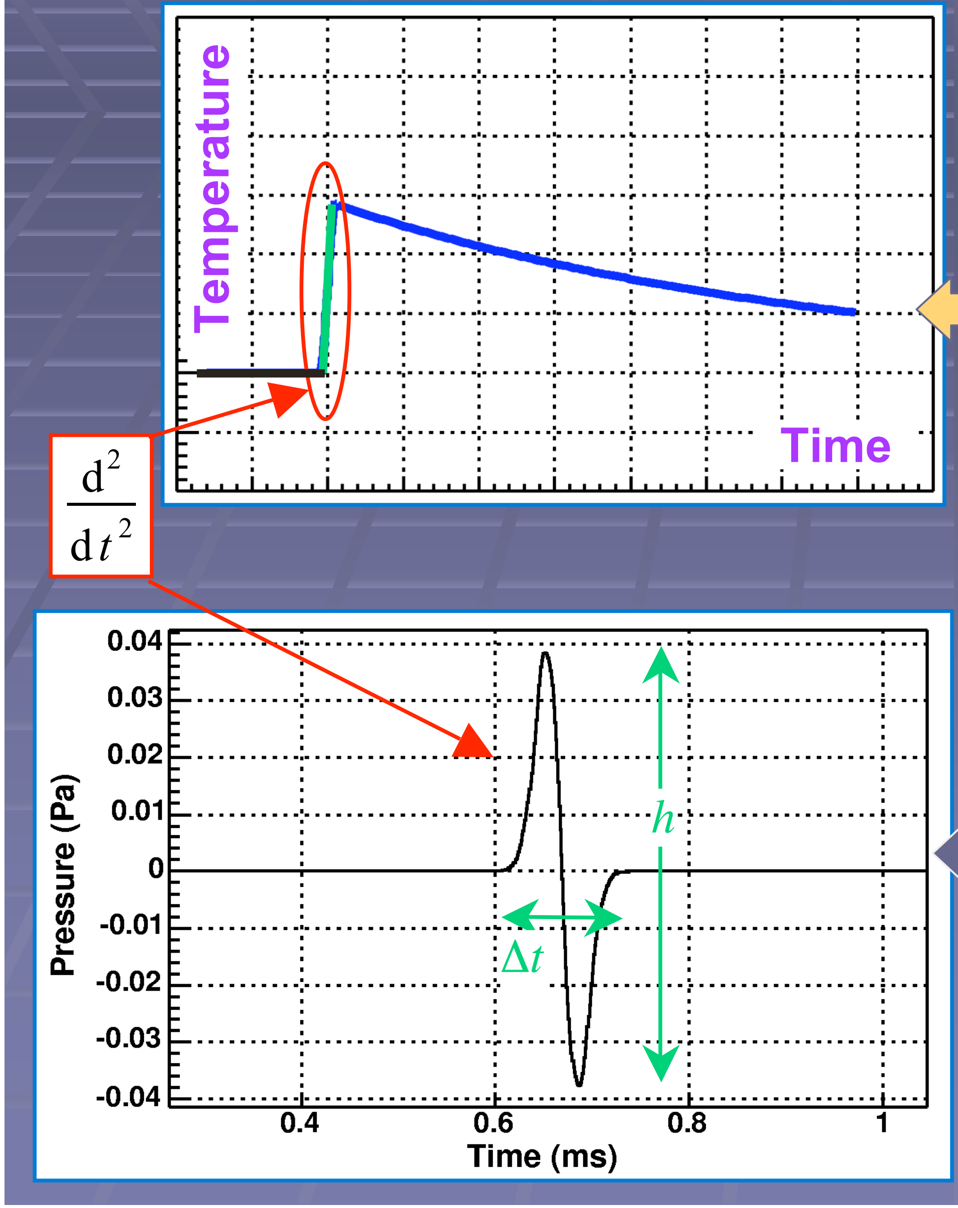
- When a UHE neutrino interacts with a medium such as water the subsequent hadronic and EM showers can deposit large amounts of ionization (thermal) energy in a small volume of a target such as sea water.
- *Thermal-acoustic coupling is weak but non negligible*
- This principle has been demonstrated in test beam experiments





- *At the expected frequencies the attenuation length in water is very long (kilometres)*
- Leads to the possibility of huge effective volumes for neutrino detection for a sparsely populated hydrophone array

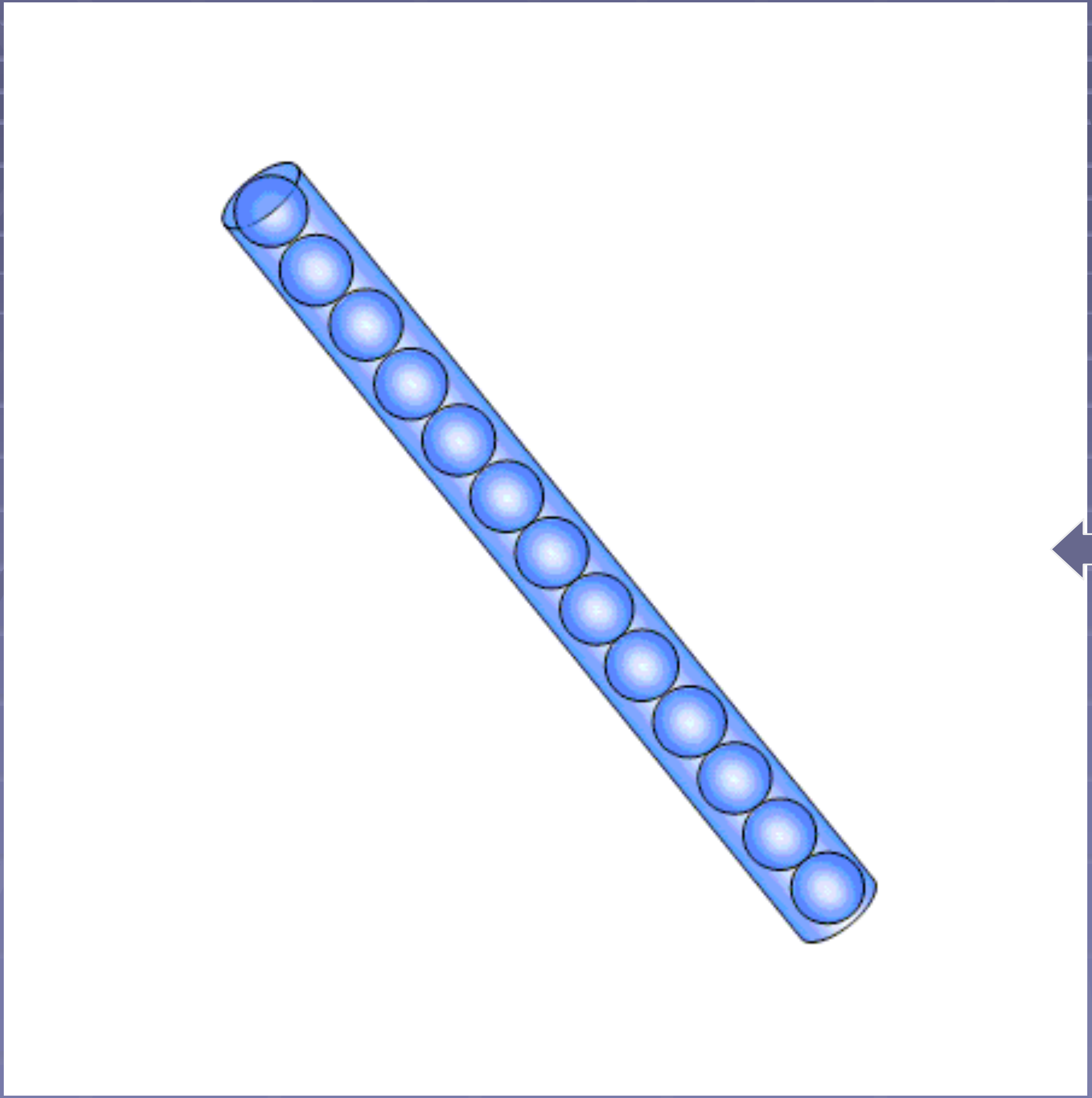
# Acoustic Detection Features



- *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 (essentially) 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 $\beta$ 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*

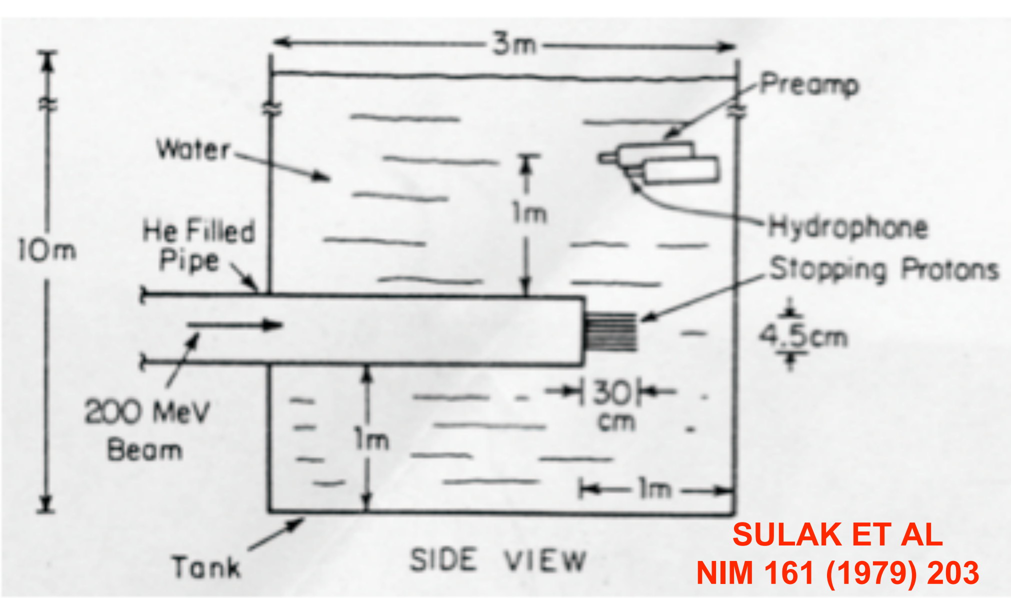
# Acoustic Detection Features



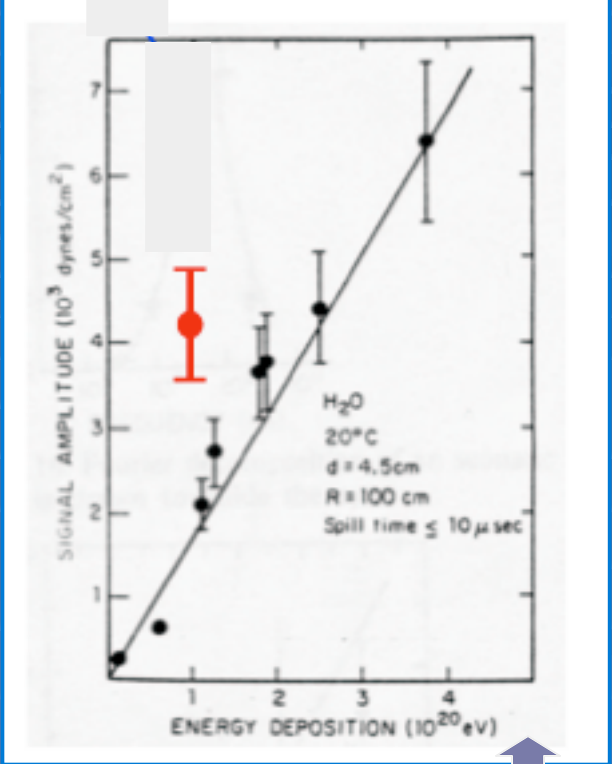
- Typical cylindrical volume over which the energy is deposited is 10m long by a few centimetres wide
- *The energy deposition is instantaneous with respect to the signal propagation*
- Hence the acoustic signal propagates in a narrow "pancake" perpendicular to the shower direction in analogy with light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

# Test beam experiments

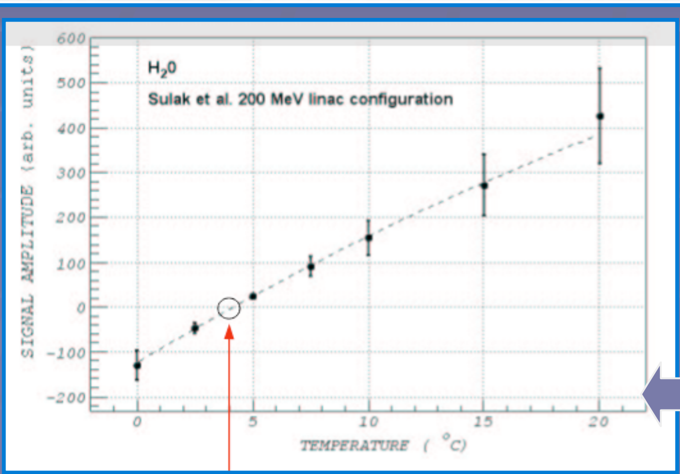
- Results from test beam experiments in late 1970’s confirming bi-polar acoustic pulse in a test beam



**SULAK ET AL**
**NIM 161 (1979) 203**



- Signal amplitude vs. energy deposition along with our prediction from first principle studies



- Signal amplitude vs. water temperature - warmer (or very cold) is better!

# EU activities

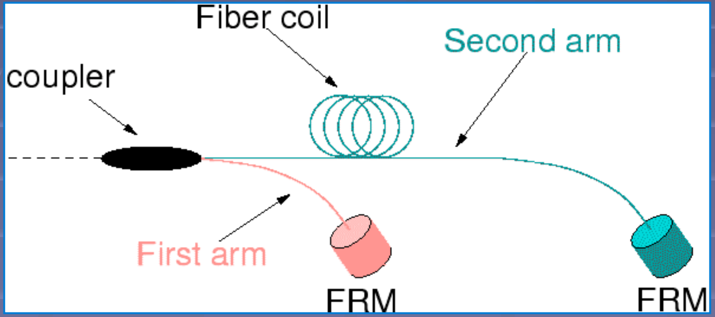
- Acoustic detection of UHE neutrinos is actively being researched in a number of European countries including
  - France
  - Germany
  - Italy
  - Sweden
  - United Kingdom
- Plus interest from countries such as
  - Belgium
  - Spain

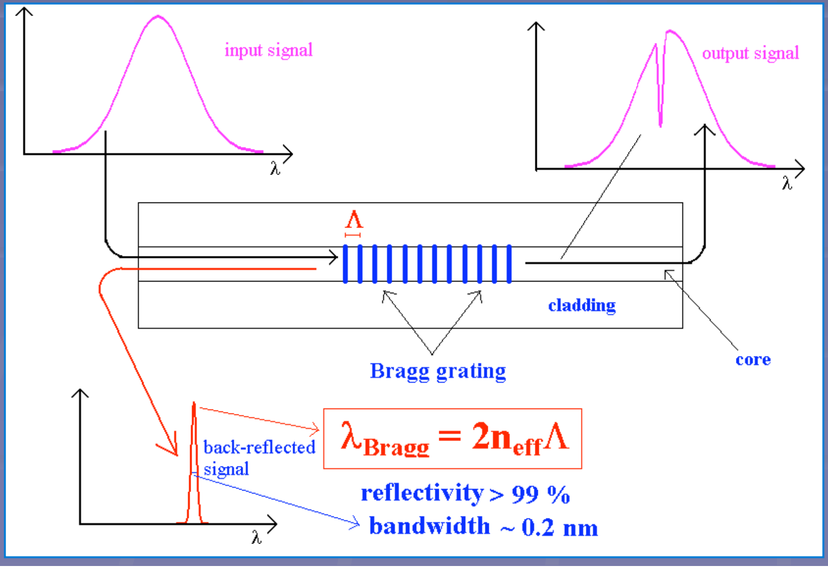
- Work in areas including
  - Hydrophone design and construction
  - Calibrator design and construction
  - Data taking at deep sea sites (for signal processing purposes)
  - Test setups
  - Simulation studies

# “Hydrophone” development

- Numerous activities taking place across Europe
- E.g.: design of cheap, robust sensors using ceramics

Phase mismatch gives the amplitude of the pressure wave





$\lambda_{Bragg} = 2n_{eff}\Lambda$

reflectivity > 99 %

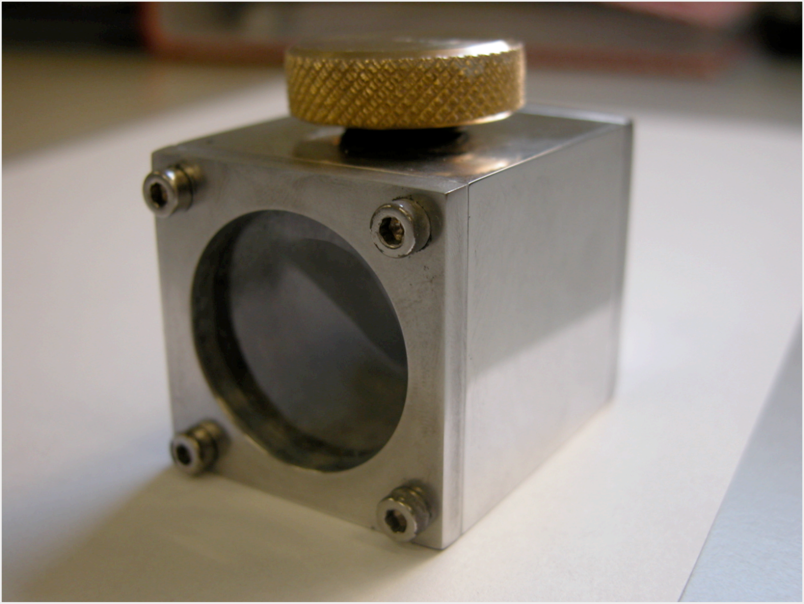
bandwidth ~ 0.2 nm

- Other developments include totally passive devices such as
  - Fibre Bragg Grating + Distributed Bragg Reflector Fibre Laser
  - Optical fibre coils plus interferometer
- Obvious benefits include:
  - No input power
  - No magnetic field perturbation
- Test work indicates sensitivities comparable with conventional hydrophones

# Towards a calibrator

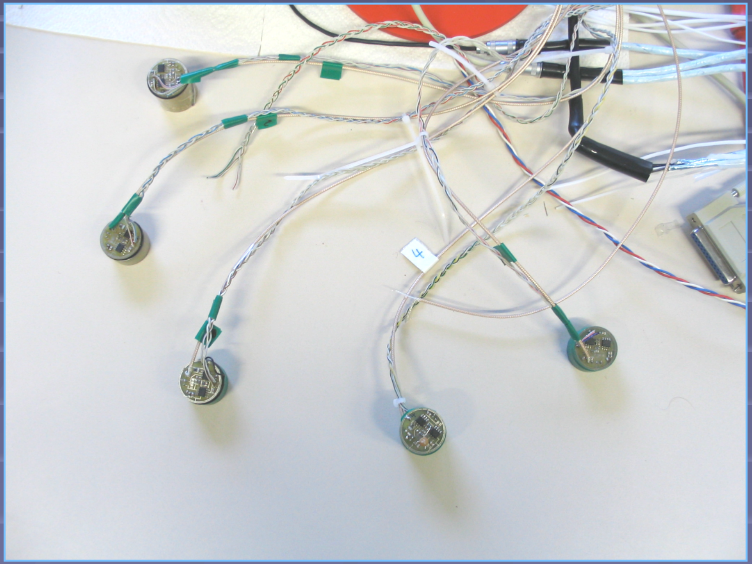
- UHE neutrinos dump > 1Joule in a small volume of water or ice quasi-instantaneously
- A tall order for a calibrator!
- Numerous technologies currently under consideration
  - Lasers
  - LEDs
  - Heated elements
  - Spark gaps
  - etc.

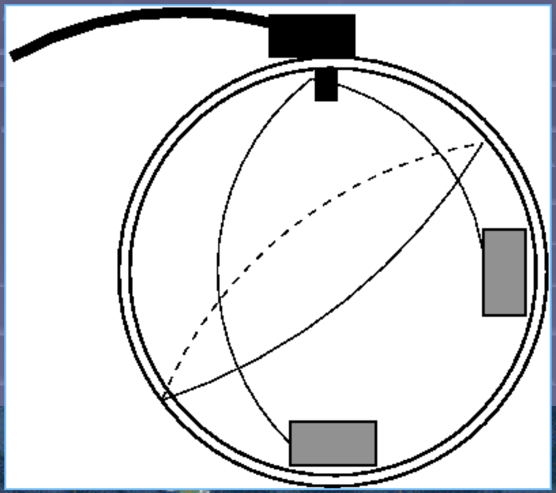
- Alternatively, if the thermal to acoustic coupling is well understood can used well-calibrated hydrophones

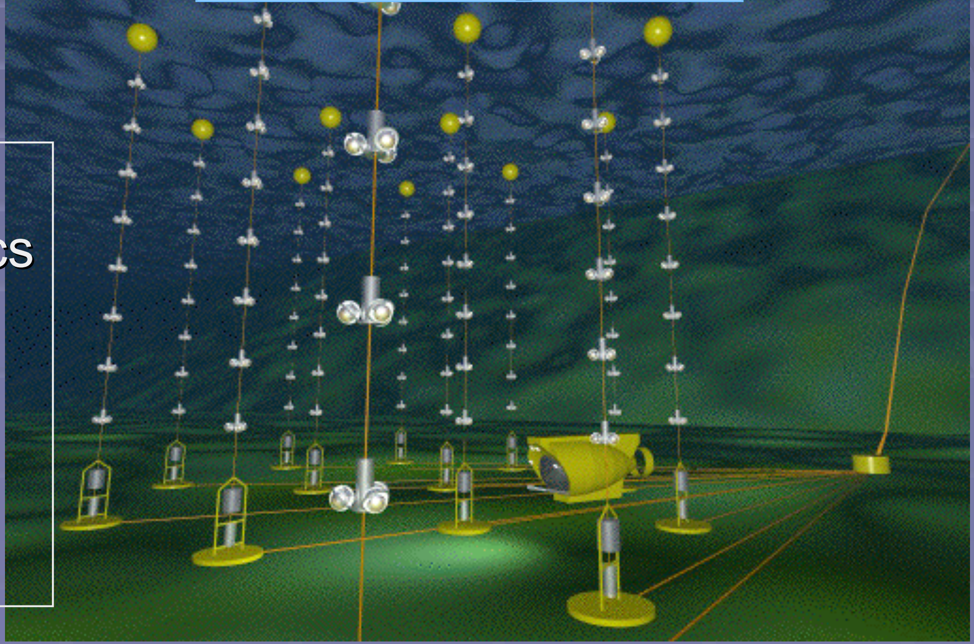


Example of an ink-filled box with mylar windows used in conjunction with laser

# Test Setup (ANTARES)



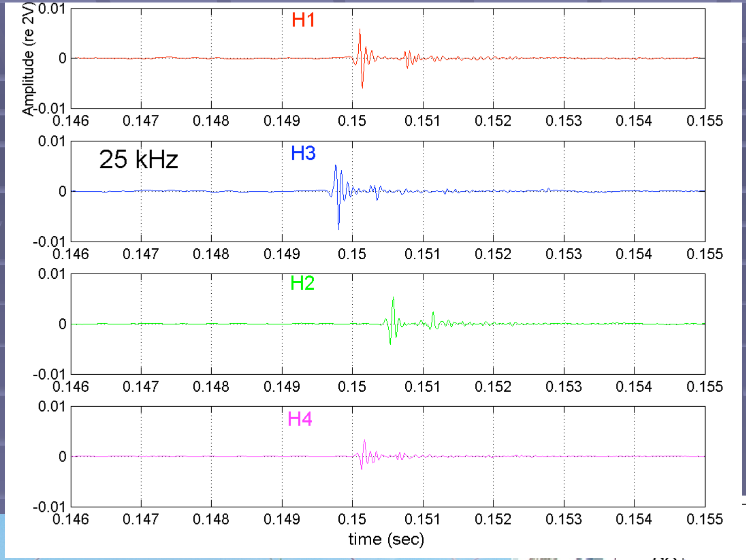




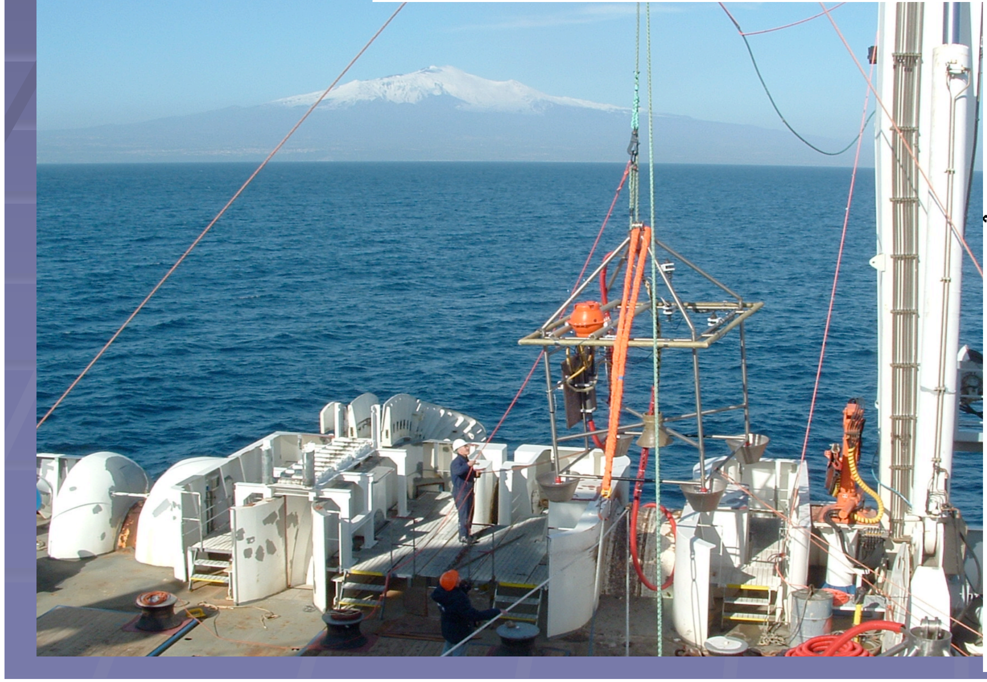
- Plans to build “acoustic modules” where piezoceramics are fixed to the insides of pressure spheres
- Deployment and readout at ANTARES site foreseen

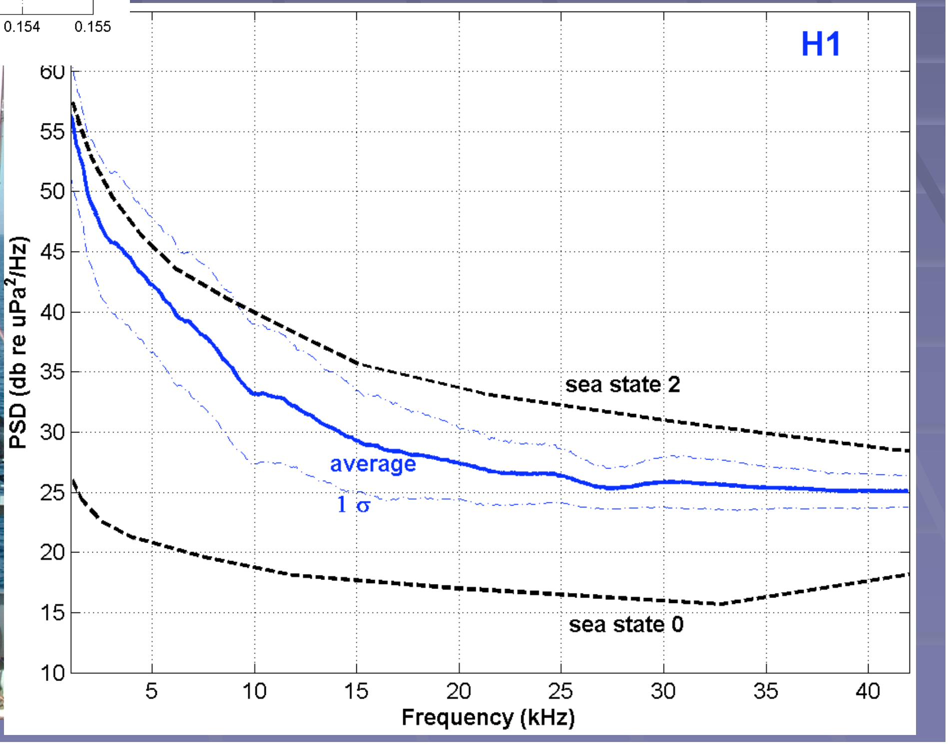
# Test Setup (Italy)

**Event recorded on May 1 at 19:00**

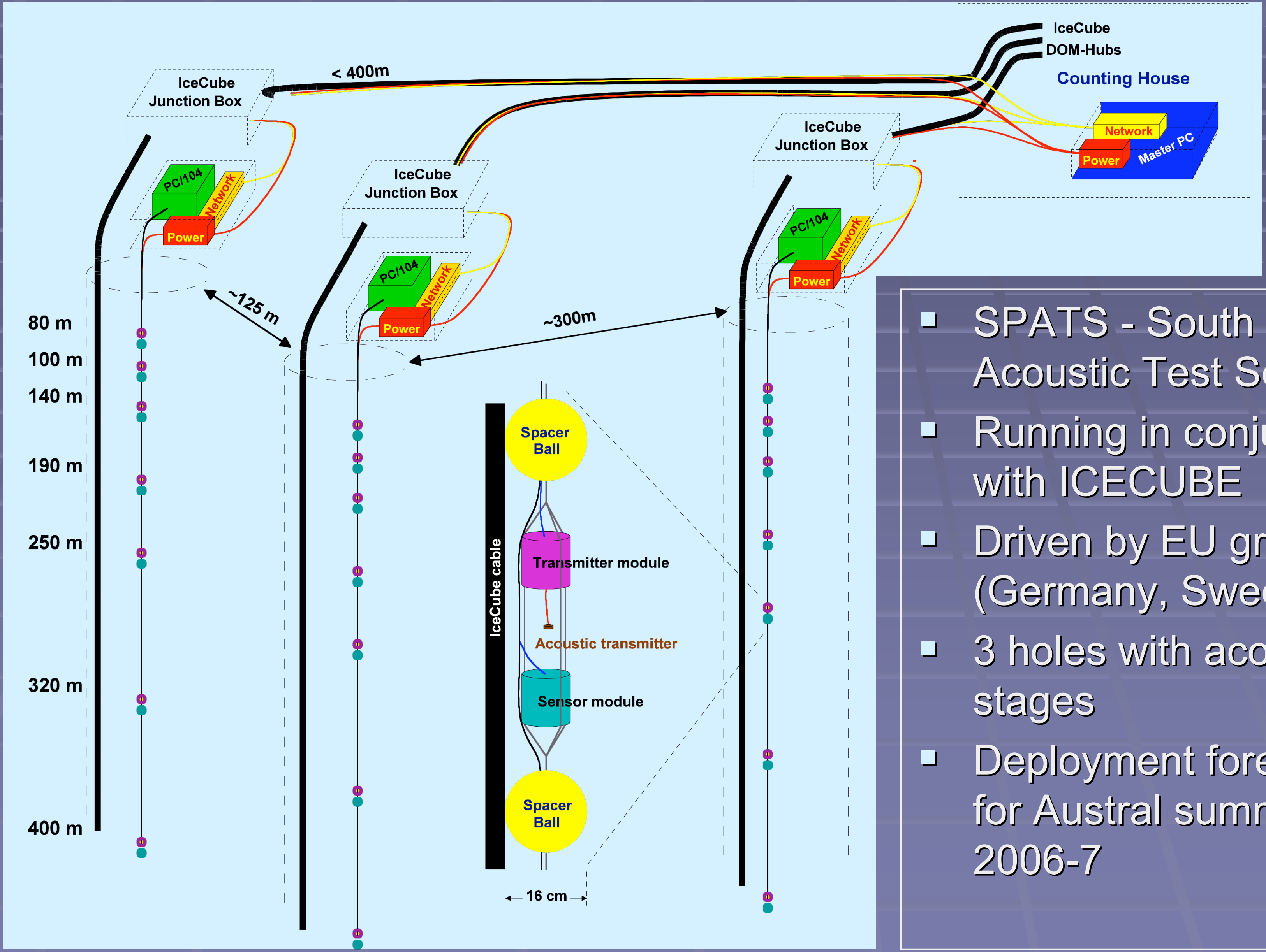


- Online monitoring from 4 hydrophones off Catania, Sicily
- Hydrophone sensitivities measured and well understood
- Several biological signals seen!



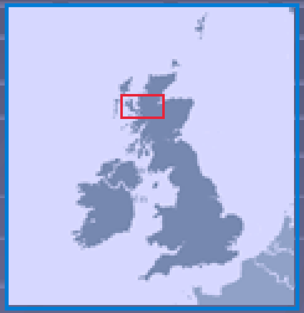


# Test Setup (South Pole)



- SPATS - South Pole Acoustic Test Setup
- Running in conjunction with ICECUBE
- Driven by EU groups (Germany, Sweden)
- 3 holes with acoustic stages
- Deployment foreseen for Austral summer 2006-7

# Test setup (UK)

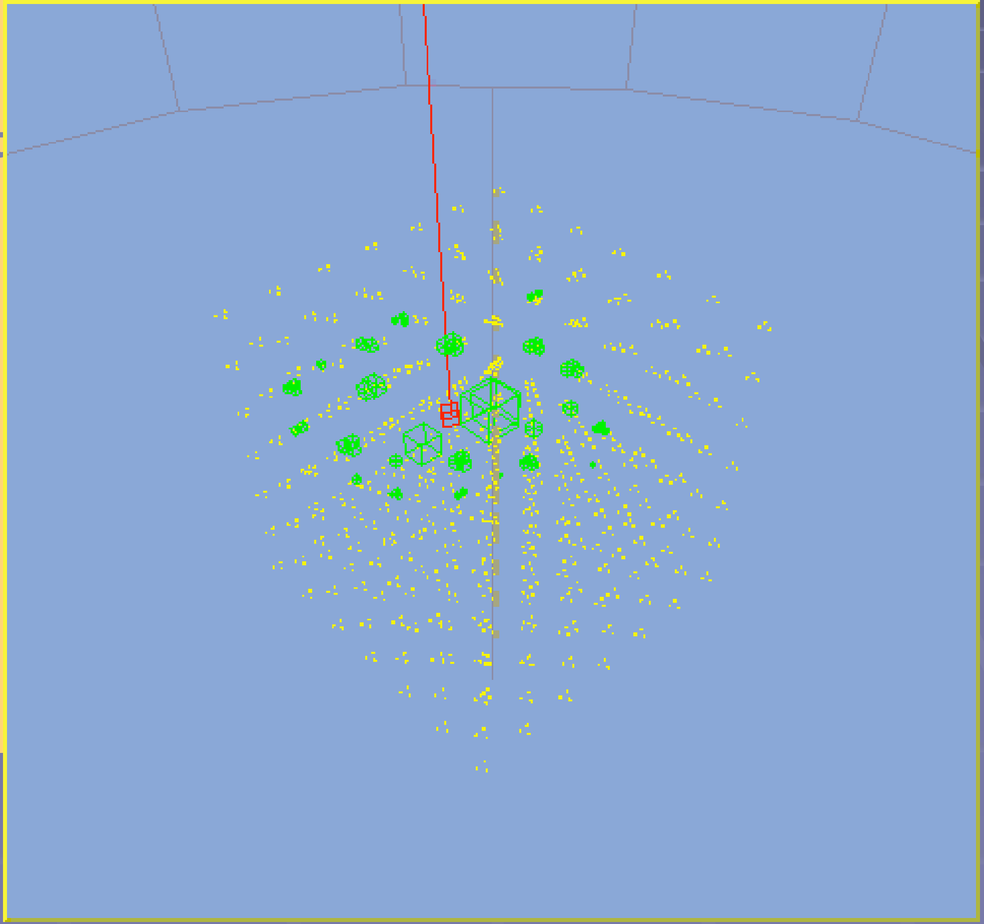


- Military facility in North West Scotland
- *An array of high sensitivity hydrophones with a frequency response appropriate to acoustic detection studies*
- Existing large-scale infrastructure including DAQ, data transmission, buildings, anchorage
- *PPARC/MoD funding for DAQ upgrade to permit several weeks' worth of <u>unfiltered</u> data to be recorded → deployment Dec'05*
- Provides an excellent testbed for any "calibrator"
- *Expect to also make use of a NATO "line array", enables phases to be tuned so that response in non-isotropic (well matched to "pancake" nature of expected signal)*

# Simulations and Sensitivity Studies

**One approach:**

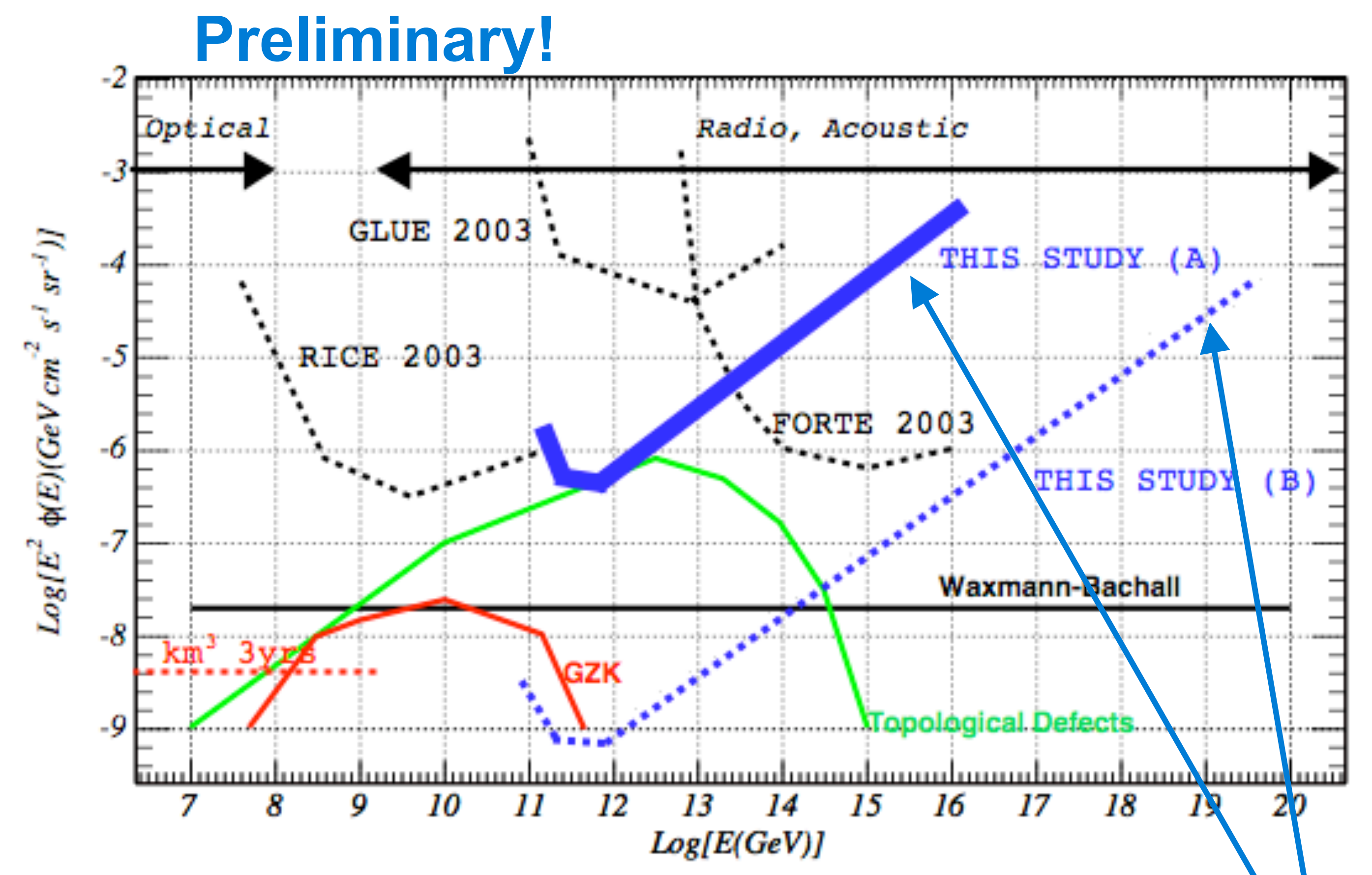
- Take a parametrised acoustic signal - amplitude is a function of incoming neutrino energy and direction
- **Calculate the expected signal at each hydrophone in the array taking into account attenuation, etc.**
- Place cuts at each hydrophone at a very conservative threshold that corresponds to **one false alarm per 10 years** according to the known sea state
- **Record only those hydrophones above threshold and within the plane of the acoustic "pancake"**
- NB: results of parametric simulation have been cross-checked against, e.g. GEANT, in appropriate energy domains



Example simulated event in a 1000 hydrophone array

# Sensitivity of the Technique

- Only suitably reconstructed events are subsequently used for the sensitivity calculations
- *NB: band of predicted sensitivities in study A is similar to that predicted by SAUND using similar, but not identical, assumptions*



**Preliminary!**

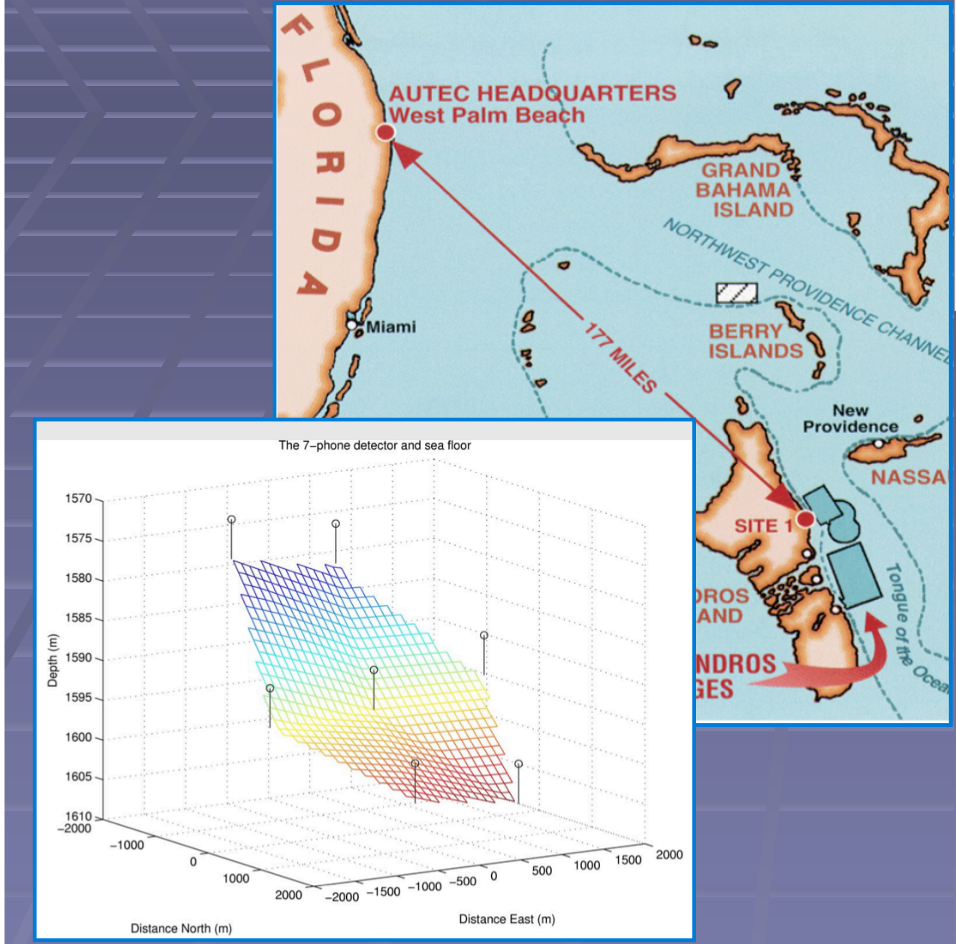
**Example calculated sensitivities for a different hydrophone arrays in the Mediterranean:**

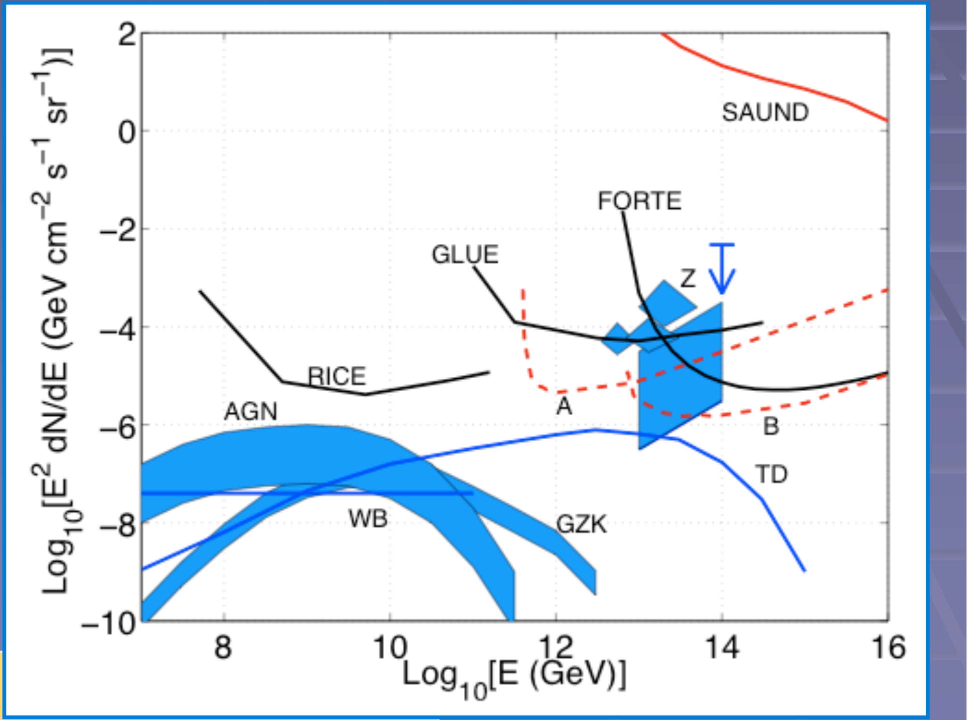
**A: 1000 hydros, 35mPa threshold, 1 yr**

**B: 5000 hydros, 5mPa threshold, 5 yrs**

# Non-EU Acoustic Activities

- The SAUND collaboration, operating the AUTEC hydrophone array in the Bahamas has published first results from the array in **astro-ph/0406105**





**7 hydrophones read out**
**Proposed increase to read out more sensors**
**Analysis method involves selecting 5-fold co-incidences**

# EU acoustic detection and KM3NeT / ICECUBE

- The next generation of very large volume optical Cerenkov telescopes in ice and water are well underway
- Clearly acoustic detection will benefit from this
- All optical Cerenkov telescopes require acoustics for positioning information on the optical sensors
- Necessary infrastructure for an optical Cerenkov telescope can be “piggy-backed’ by acoustic detection community providing power, data acquisition and enviroment for testing

# Summary

- Acoustic detection of UHE neutrinos is a promising technique that is complementary to traditional techniques such as optical Cerenkov telescopes
- *Energy range coincides with that of the highest energy cosmic rays, observation of UHE neutrinos at these energies would provide vital information on the origins and mechanisms responsible for UHECR*
- There is significant EU activity in this research field in a number of key areas including hydrophone developments and sensitivity studies
- Obvious overlap with other HE neutrino devices - optical Cerenkov, radio detection of UHE neutrinos
- *A field ideally matched for EU funding?*