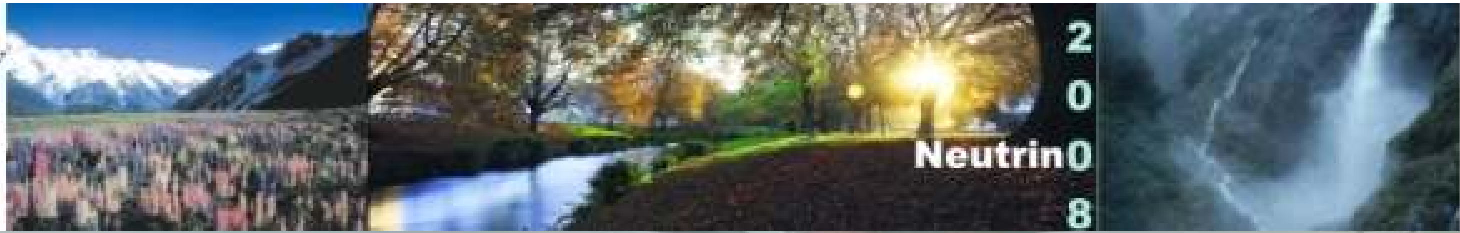


Acoustic Detection

Giorgio Riccobene
INFN-LNS

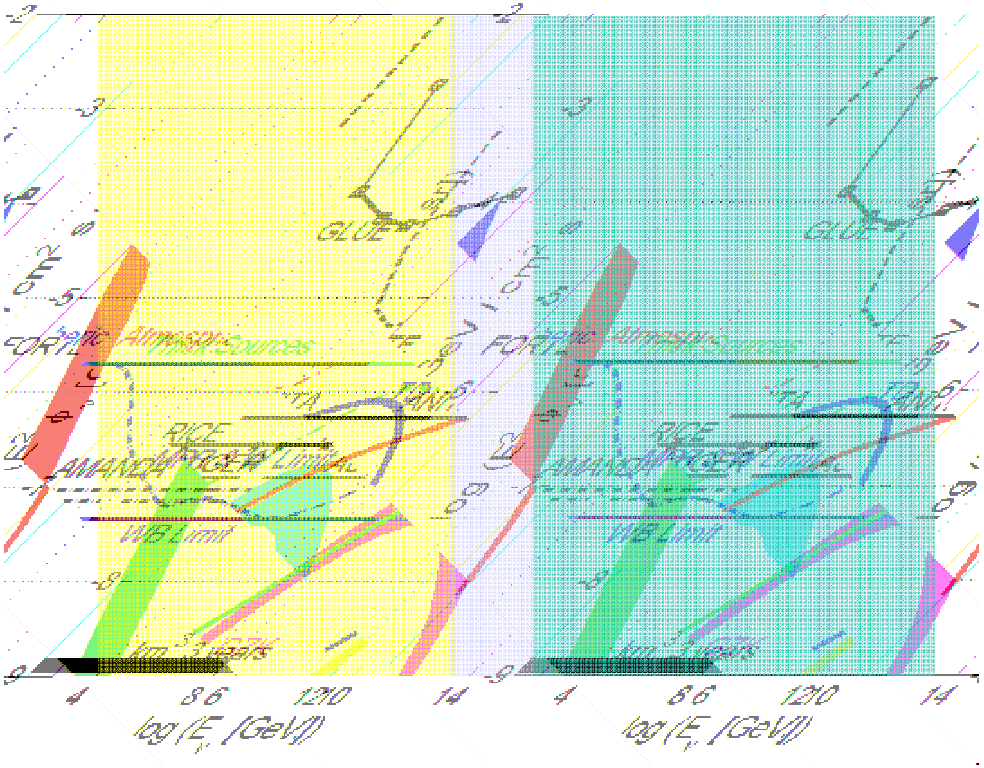
Motivations

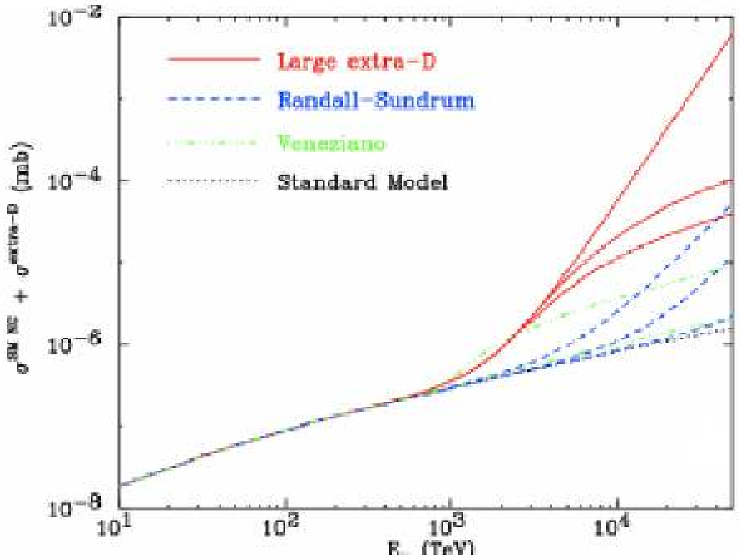
UHE neutrino fluxes

Neutrino cross section at extreme enegy

High Energy Neutrinos: What We (don't) Know

Optical Cherenkov Radio Radio and Acoustic





Extending the neutrino observation to extreme energies

astrophysics UHECR origin, GZK neutrinos

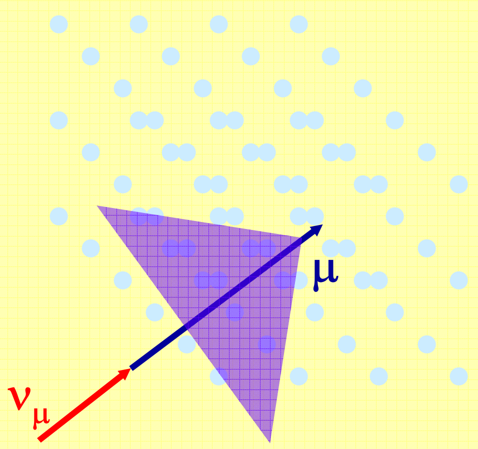
cosmology decay of Plank scale massive particles, Topological Defects,…

particle physics study neutrino cross section

Large Area Detectors for HE neutrinos

1 TeV — 100 PeV — 1000 ZeV

Optical Detection (ICECUBE-KM3NeT)



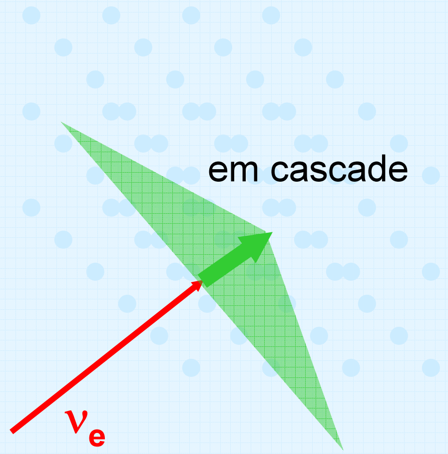
Medium: Seawater, Polar Ice

ν_μ (throughgoing and contained)
$\nu_{e,\tau}$ (contained cascades)

Carrier: Cherenkov Light (UV-visible)
Attenuation length: 100 m

Sensor: PMTs
Instrumented Volume: 1 km^3

Radio Detection (RICE, SALSA)



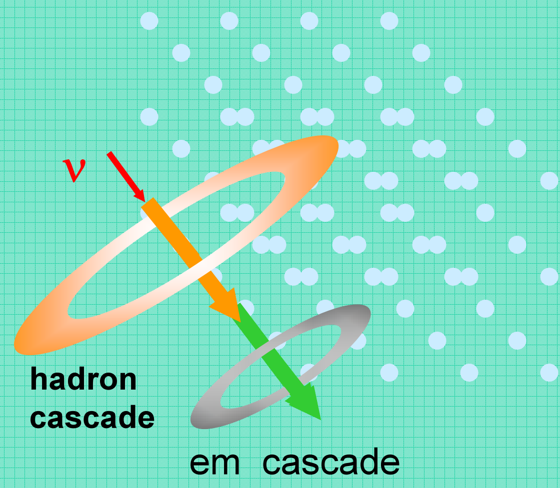
Medium: Salt domes, Polar Ice

ν (cascades)

Carrier: Cherenkov Radio
Attenuation length: 1 km

Sensors: Antennas
Instrumented Volume: >1 km^3

Acoustic Detection (Prototypes)



Medium: Seawater, Polar Ice, Salt Domes

ν (cascades)

Carrier: Sound waves (tens kHz)
Attenuation length: ~ 10 km

Hydro(glacio)-phones
Instrumented Volume: >100 km^3

A Short Summary of Activities on Acoustic Detection

1957	Askaryan
	Markov Zeleznyk
1979	Learned
	BNL, Harvard, SLAC - Beam Experiments
’80s	DUMAND
	Kamchatcka
’90	SADCO

2000’s	BAIKAL (ITEP, MSU, Irkutsk)
	ANTARES (Erlangen, Marseilles, Valencia)
	SAUND (Stanford, US Navy)
	ACORNE (Imperial College, Lancaster, Northumbria, Sheffield, UCL)
	SPATS (DESY Zeuthen, Berkeley, Gent, Stockholm, Uppsala,…)
	NEMO (LNS, Roma, Pisa, Genova)

Beam Experiment, Simulation, R&D, deep sea measurements
thanks to neutrino telescopes’ infrastructures and military facilities
after the end of cold war

Basic Theory

Beam Test Experiments

Neutrino Acoustic Detection

Basics of thermo-acoustics mechanism

A pressure wave is generated instantaneous following a sudden deposition of energy in the medium (neglecting absorption: O(10 km) at 10 kHz)

Istantaneous deposition of heat through ionization

$$t_{deposition} \approx D / c \approx 10^{-7} : 10^{-8} \ sec$$

Thermo-acoustic process:

increase of temperature (specific heat capacity C_p), expansion (expansion coeff β)

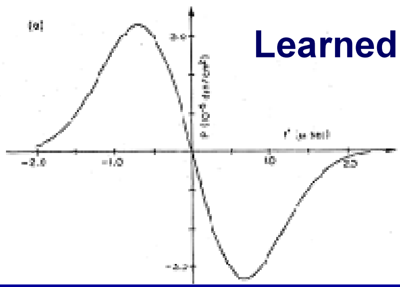
$$t_{expansion} \approx 10^{-5} \ sec >> t_{deposition}$$

$$\nabla^2 \mathbf{p} - \frac{1}{\mathbf{c_s}^2}\ddot{\mathbf{p}} = -\frac{\beta}{\mathbf{c_p}} \cdot \frac{\partial \varepsilon(\mathbf{r},\mathbf{t})}{\partial \mathbf{t}}$$

For a point like source (micropulse):

$$\mathbf{p}(\mathbf{r},\mathbf{t}) \propto \frac{\mathbf{E}_0 \beta}{4\pi \mathbf{c_p}} \frac{\partial}{\partial \mathbf{t}} \frac{\delta\left(\mathbf{t} - \frac{\mathbf{r}}{\mathbf{c_s}}\right)}{\mathbf{r}}$$

Bipolar pulse
spherical expansion



Learned

For a shower heating a volume of matter (macropulse):

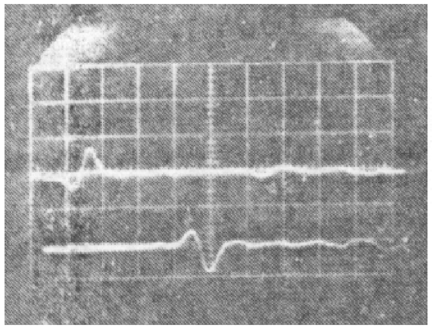
$$\mathbf{p}(\mathbf{r},\mathbf{t}) \propto \frac{\beta}{4\pi \mathbf{c_p}} \frac{\partial}{\partial \mathbf{t}} \int \frac{1}{\mathbf{r}} \varepsilon \ \mathbf{dV}$$

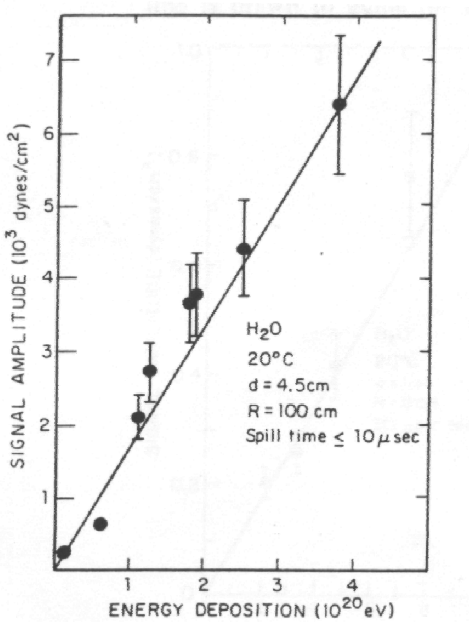
Sum of pointlike sources: wavefront and signal shape depend on the energy density distribution

Accelerator Experiments: results and open questions

Brookhaven NL (Harvard, SLAC) 1979

200 MeV proton beam (LINAC)
Spill time 3 to 20 us
Beam diameter 4.5 cm
Energy deposited in water $10^{19} \rightarrow 10^{21}$ eV
Bipolar pulses observed
Dependency on C_p, T and on beam diameter confirmed (about 10% uncertainty)



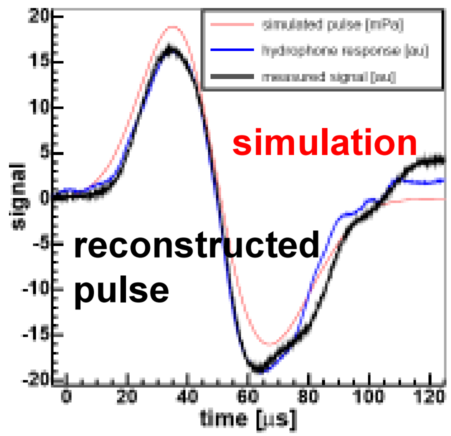


Recent measurements (2000's)

Uppsala: 177 MeV p
E= $10^{16} - 10^{17.5}$ eV
Bipolar pulse observed
Unclear dependence on temperature
Other contibution to observed pulses ?

ITEP Synchrotron: 100, 200 MeV p
E= $10^{15} - 10^{20}$ eV
Measured pressure increses linearly with E

Erlangen Laser Nd-YaG
E= $10^{17} - 10^{19}$ eV
Dependence on C_p confirmed



Neutrino Acoustic Detection Principle

→ Neutrino Interaction (strong Earth absorption: look upward !)

→ Hadronic shower formation at interaction vertex (ν_e e.m. shower)

→ H shower carries (on average) ¼ E_ν

→ Shower Development (LPM must be taken into account for EHE)

→ Sudden deposition of heat through ionization

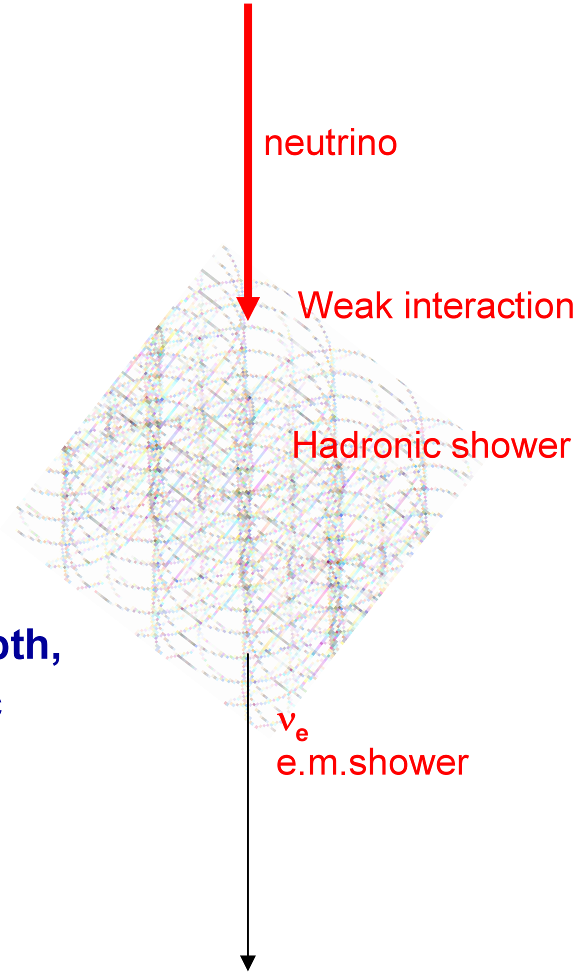
→ Thermo-acoustic process: Increase of temperature (C_p), Volume Expansion (β)

→ The "pen shaped" energy deposition region (20 m depth, 10 cm diameter) produces a pancake shaped acoustic wave peak wavelength

$$\lambda \approx 2d \qquad f = \frac{c_s}{2d} \approx \mathbf{10\ kHz}$$

→ Acoustic wave propagation in the medium: near field

$$p_{max}(r) \propto 1/\sqrt{r}$$



Acoustic pulse amplitude in Salt, Water, and Ice

Conversion of ionization energy into acoustic energy

	Med Sea	S.P. ice	NaCl
T [ºC]	14º	-51º	30º
c_s [m s^{-1}]	1545	3920	4560
β [K^{-1}]	25.5x10^{-5}	12.5x10^{-5}	11.6x10^{-5}
C_P [J kg^{-1} K^{-1}]	3900	1720	839
$\gamma = c_s^2 \frac{\beta}{C_p}$	0.12:0.13	1.12	2.87

Gruneisen coefficient

$$p_{max} \approx E_\nu \times \frac{1}{4} \times \gamma \approx 6 \cdot 10^{-21} E_\nu \left[\frac{\text{Pa}}{\text{eV}}\right]$$

in water

The Size of Neutrino Acoustic Detectors

$E_\nu = 10^{20}$ eV

in water: p = 0.6 Pa @ 1 km → 20 mPa (neglecting attenuation)

in Ice : p = 6 Pa @ 1 km → 200 mPa (neglecting attenuation)

Underwater Cherenkov detectors
Upgoing events – 100 TeV

$$P_{\nu\mu}\left(E_\nu, E_\mu^{min}\right) = R_\mu^{eff}\sigma_{CC}N_A = 10^{-4}$$

$$\frac{N}{A_{eff}\cdot T} = \Phi_\nu P_{\nu\mu} 2\pi e^{-D(N_A \sigma_{Tot} \rho_{Earth})} \approx 100 \frac{events}{km^2 y}$$

WB flux

Underwater Acoustic detectors
Downgoing events – 10^{20} eV

$$P_{det}(E_\nu, p_{min}) = H_{det}^{eff}\sigma_{Tot}N_A \approx 10^{-3}$$

$$\frac{N}{A_{eff}\cdot T} \approx 10^{-3} \frac{events}{km^2 y}$$

Sound absorption length in ocean O(10 km), noise O(10 mPa)

Several groups developing and improving simulation codes for large acoustic detectors
What we can do with 1 km^3 filled with hydrophones ?

Study of Medium Properties

Study of the Medium Acoustic Properties : Water

Complex but well characterized by several military studies

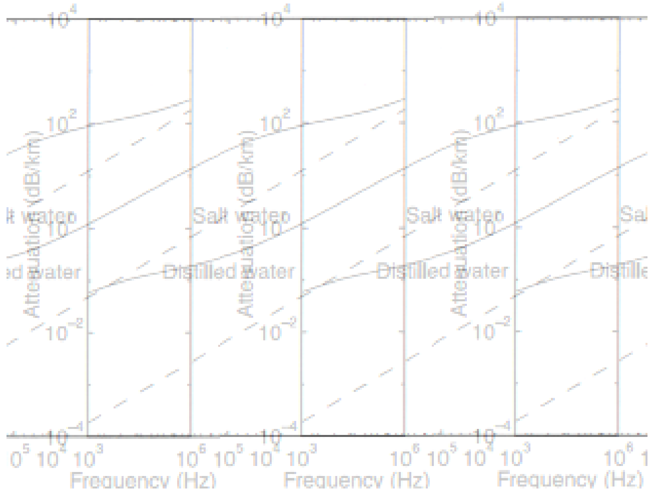
Absorption is mainly caused by chemical relaxation:

$B(OH)_3$ 50 Hz - 5 kHz

$MgSO_4$ 5 kHz – 500 kHz

$$a_{sound} = \left(\frac{8\pi^2 \kappa}{3\rho\, c_s^3} \right) f^2$$

$L_a \approx 10$ km (at 10 kHz)



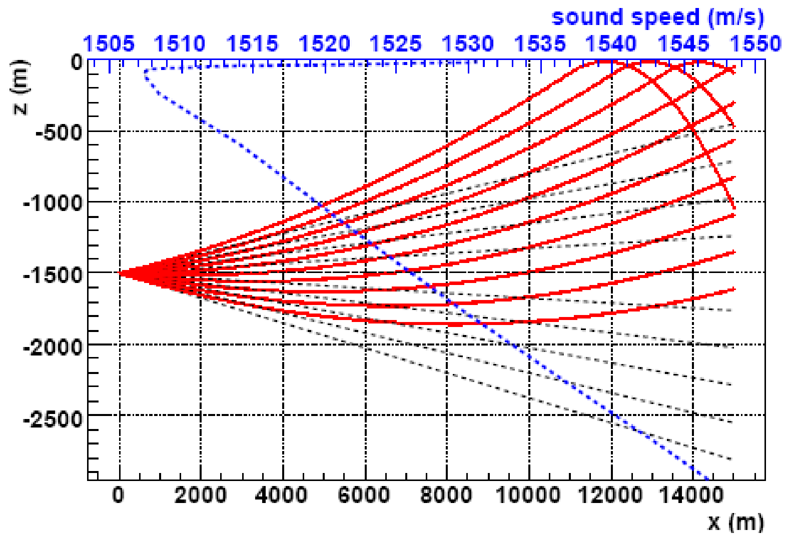
Sound velocity in water changes as a function of depth, tempeature and salinity

at surface (T,S) dominated at large depth (increases linearly with pressure)

$$c_s = 1545 \text{ m/s} \qquad \frac{\Delta c_s}{\Delta z} = 1.65 \text{ cm/s/m}$$

→ refraction

pancake shape modification

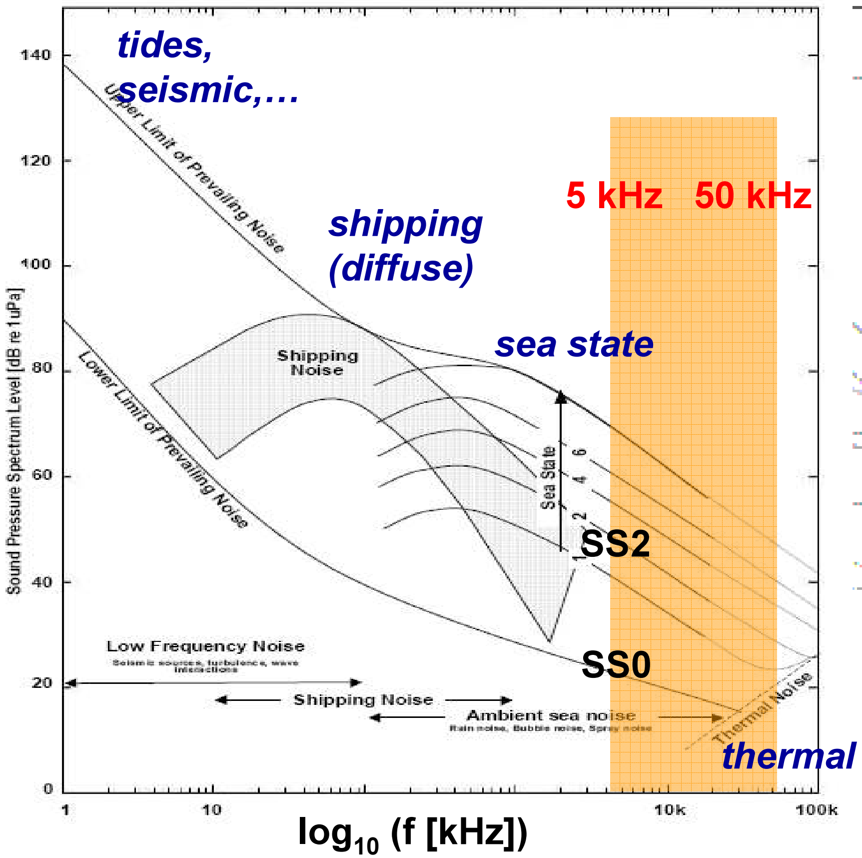


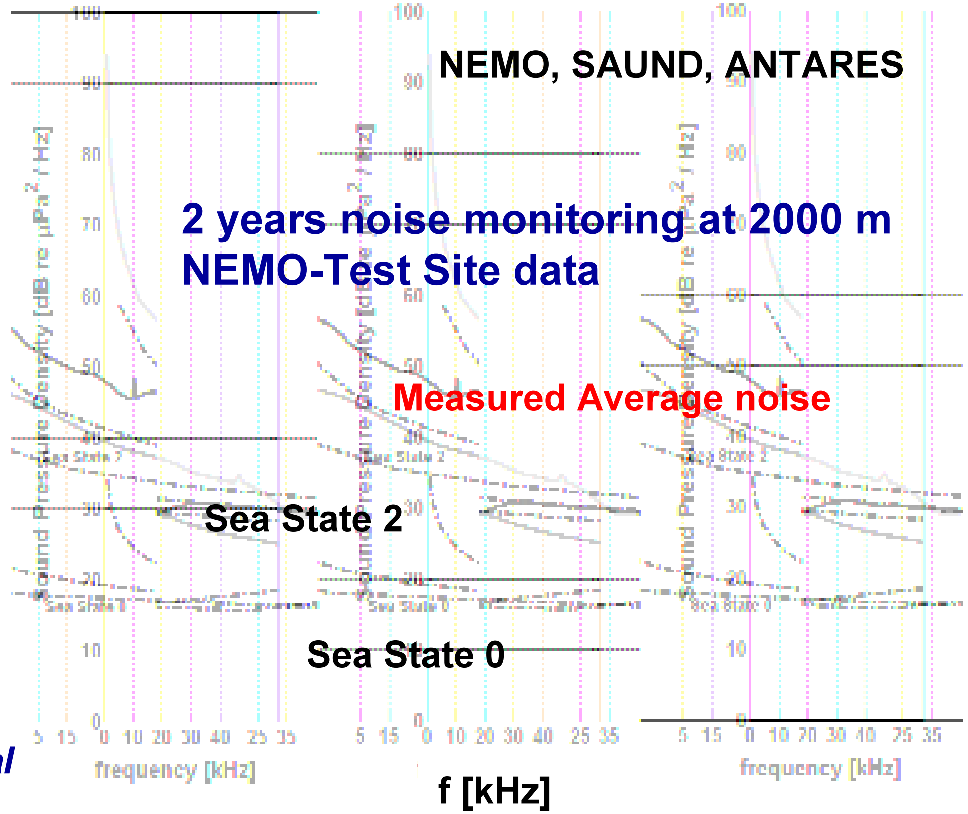
Acoustic Noise in Water

Diffuse noise: Seismic, surface waves (wind), rain, thermal noise

Impulsive noise: Cetaceans, man made shipping (also diffuse!) and instrumentation

Man made noise is increasing (1 dB/year in densely inhabitated seas)





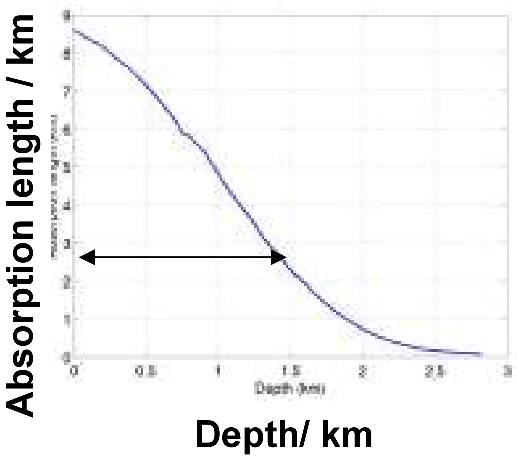
Knudsen's Formula

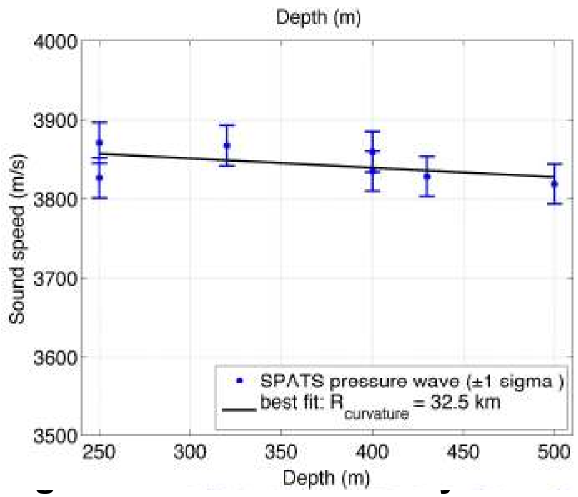
$$P(f_{Hz}, SS) = 94.5 - 10 \log f^{5/3} + 30 \log(SS + 1)$$

Study of the Medium Acoustic Properties : Polar Ice

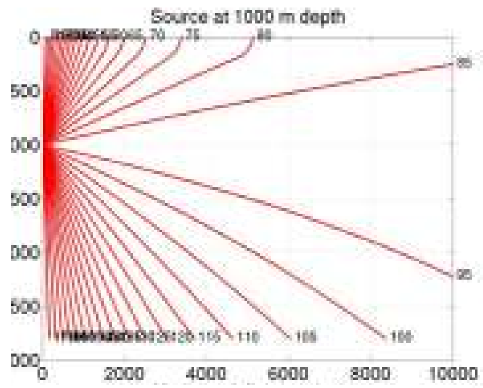
Not a well known medium…Need accurate in situ measurements !

scattering	absorption	speed of sound
Rayleigh scattering at crystal boundaries →crystal size →frequency $\lambda_s \sim a^3 \times f^4$ theory: λ_s(10 kHz) = 800 km λ_s(100 kHz) = 0.2 km	molecular reorientation → energy loss in relaxation temperature dependent crystal size dependent South Pole: λ_a(200m) = 8 km λ_a(2000m) = 0.8 km	weak temperature dependence strong density dep. →signal refraction important in firn pressure waves: v_s = 3900 m/s shear waves: v_s = 2000 m/s





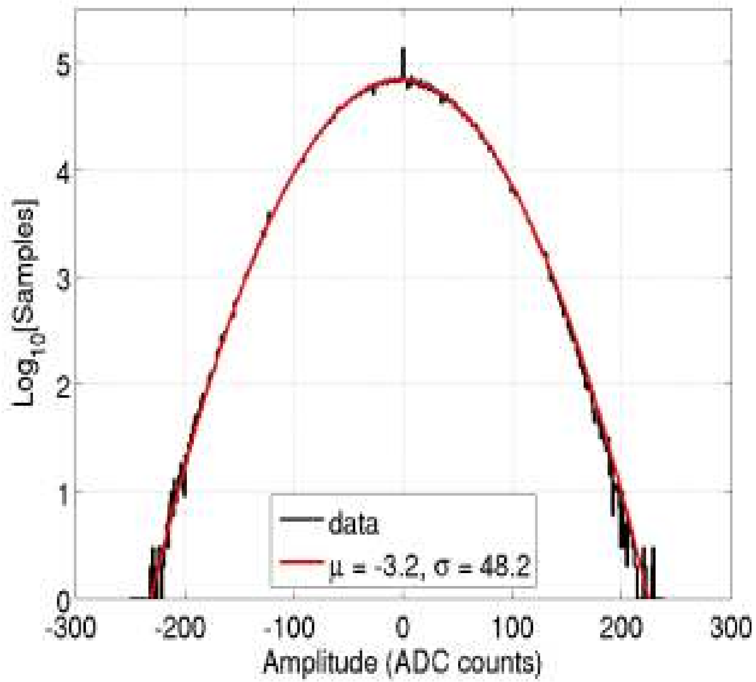
New results from SPATS



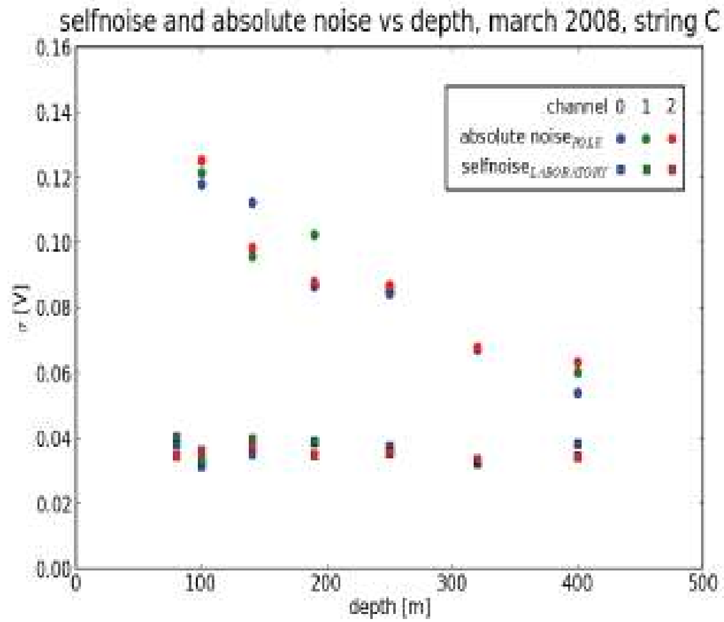
Acoustic Noise in Ice

SPATS Measurements:

Noise is stable
Gaussian
Independent on weather conditions
No seasonal variation observed



Changes as a function of depth



Absolute value determination is not possible now due to change of glaciophone sensitivity with pressure and temperature.

Needs in situ calibration

Acoustic Neutrino Event Simulation

Event Reconstruction

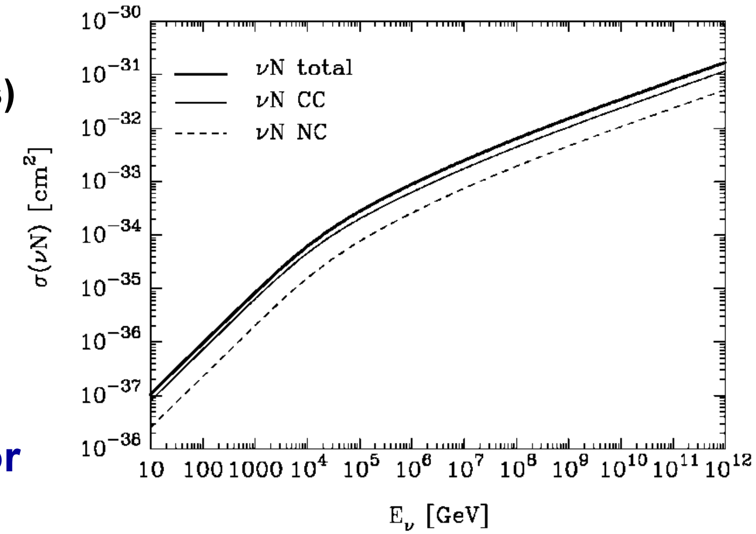
Expected Effective Volume and Sensitivity

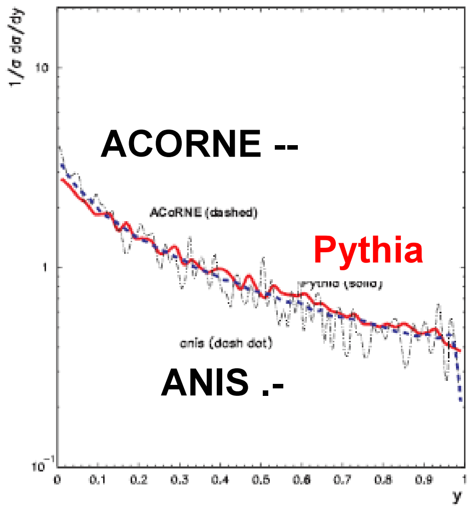
Simulations of neutrino interaction and shower propagation

Neutrino Interaction

ANTARES(Erlangen,Marseilles)
SAUND
Ghandi et al.

ACORNE
ANIS (from Amanda)
HERWIG+CORSIKA
neutrino shower simulator



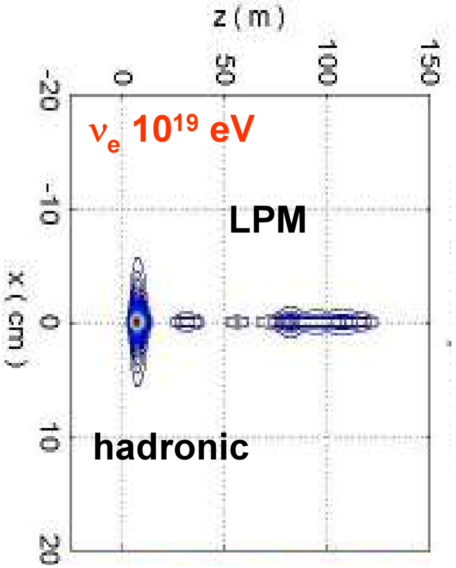


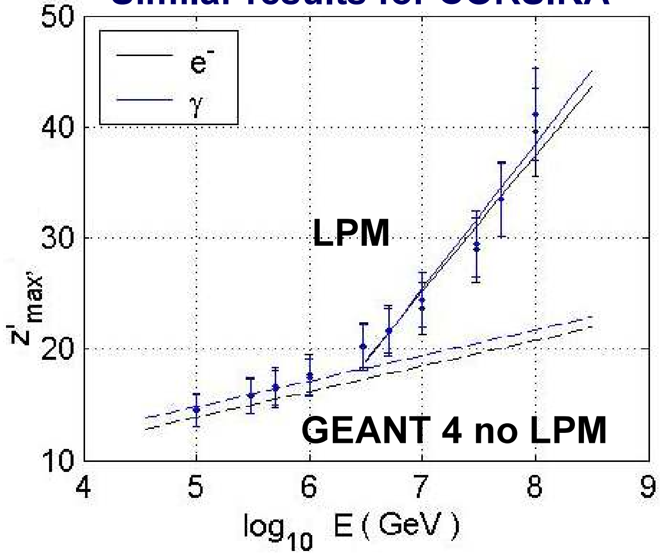
Shower development

Zheleznyk and Dedenko
(e.m. shower including LPM)

SAUND
hadronic
Alvarez Muniz-Zas

ANTARES (Marseilles)
Hadronic + e.m.
GEANT 4 +LPM





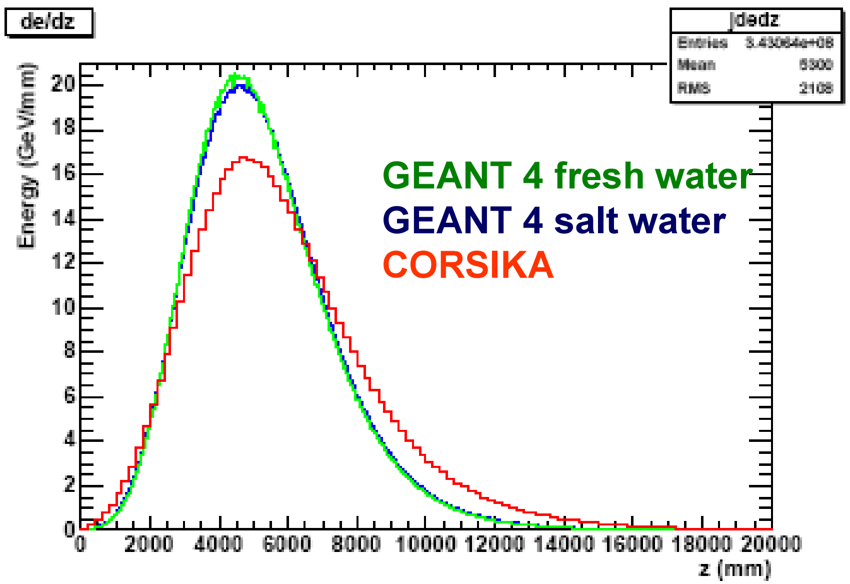
Simulations of neutrino interaction and shower propagation

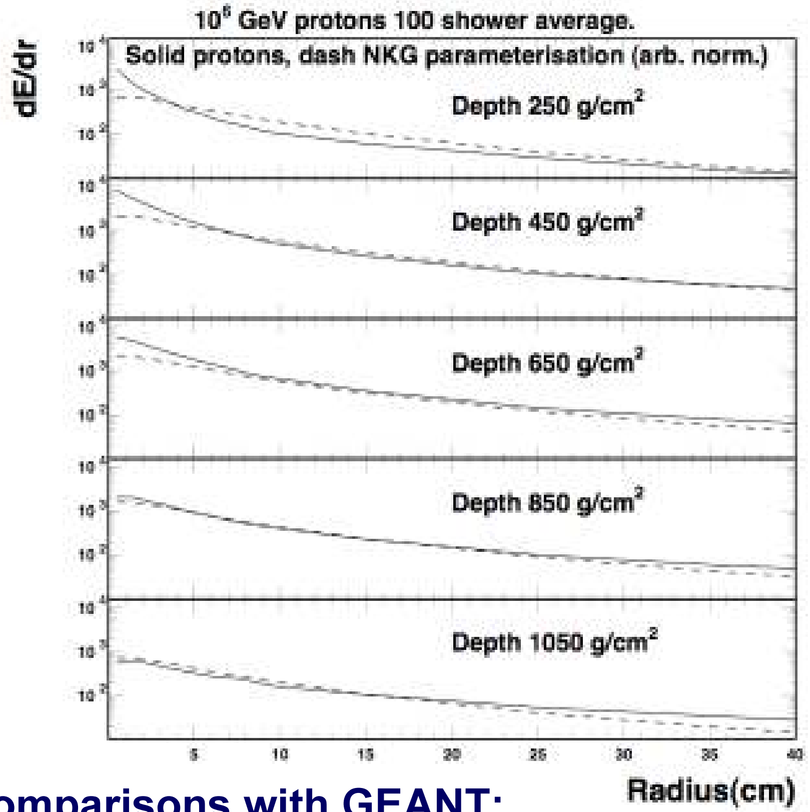
Shower development

ACORNE:

CORSIKA modified for water

transverse and longitudial energy deposits have been parameterized for fast simulations





Astropart Phys V28 3 (2007) 366

Comparisons with GEANT:

- ~ 10% lower at peak
- Showers broader

Comparison with NKG:

- less energy at smaller radii
- low frequency contribution enhanced)

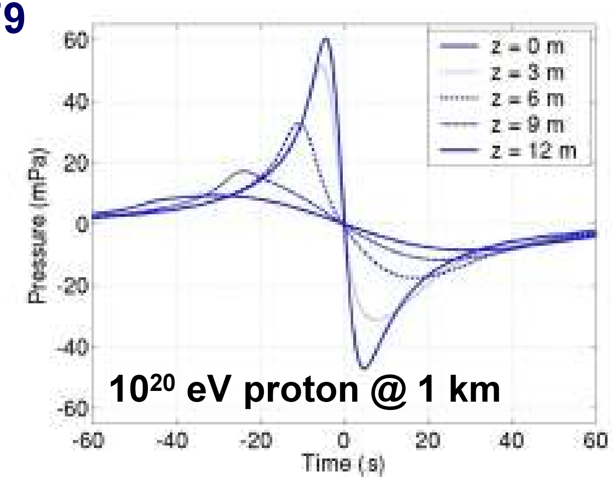
Acoustic Wave Propagation in Water and Ice

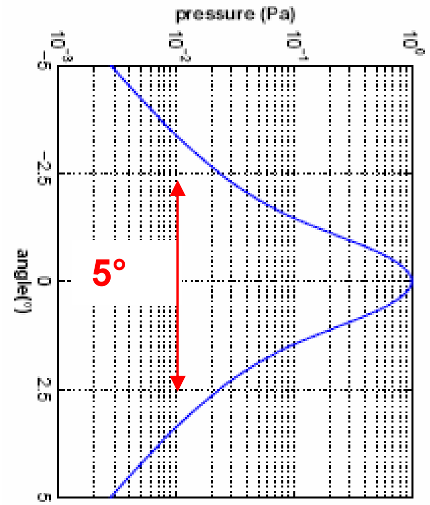
Based on the Learned paper 1979

Thermoacoustic model +
sound waves interference

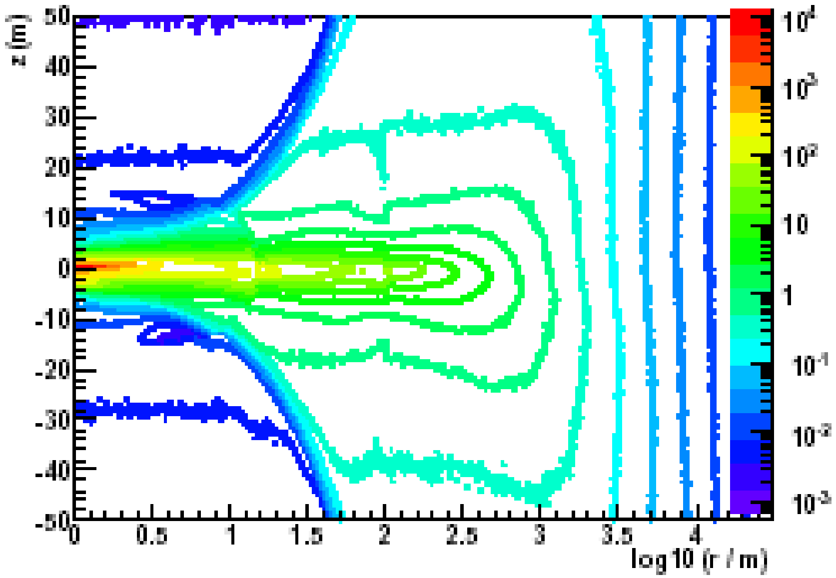
p_{max} **~ 6 · 10^{-21} Pa/eV**
pancake shaped wavefront

ACORNE, SAUND,
ANTARES (Erlangen, Marseilles)

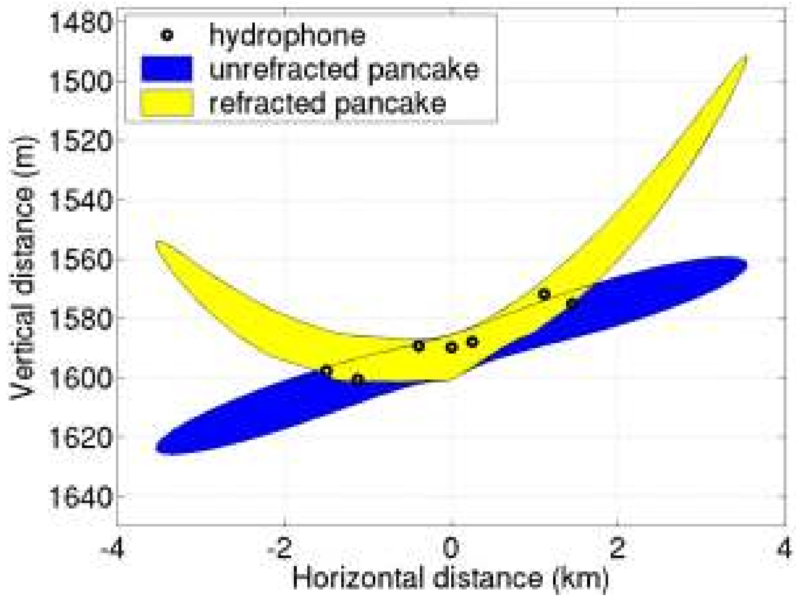




Sonic pancake **mPa/EeV**



Sound velocity grandient : wave refraction



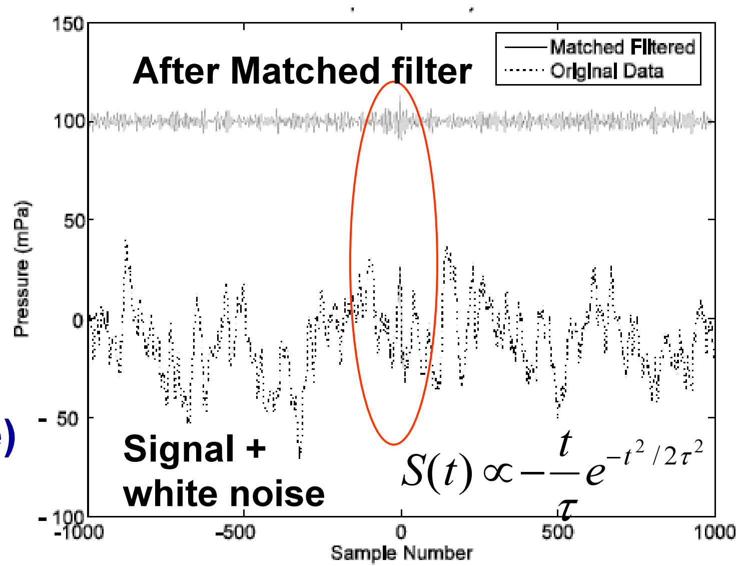
Event Detection and Reconstruction

Event trigger: ACORNE, SAUND

Matched filter on signal
(factor 3 improvement SNR)
Caveat : signal is different at different angles:
a number of matched filters should be applied
(ACORNE)

Threshold 35 mPa
(1 False alarm over 10 years for calm sea noise)

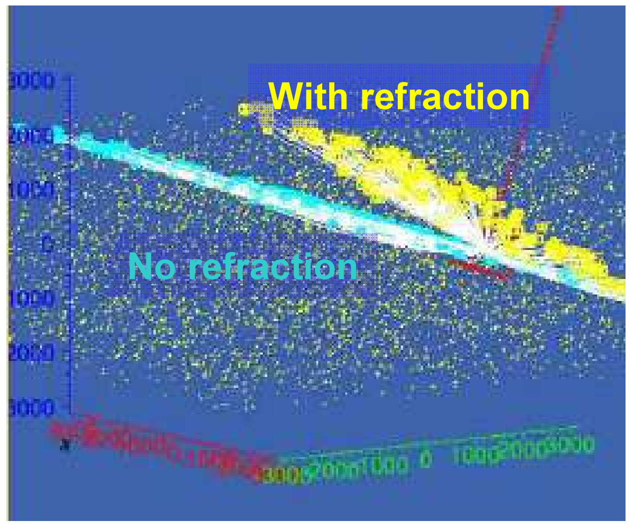
Beamforming
gain √(NHydros) for white noise



ACORNE, SAUND

Vertex Reconstruction:

At least 4 hydrophones required
Homogeneous medium: Exact analytical solution
Real Case (Sound Velocity Profile) : Ray Tracing
Caveat: refraction and surface/bottom reflections



Event Energy reconstruction:

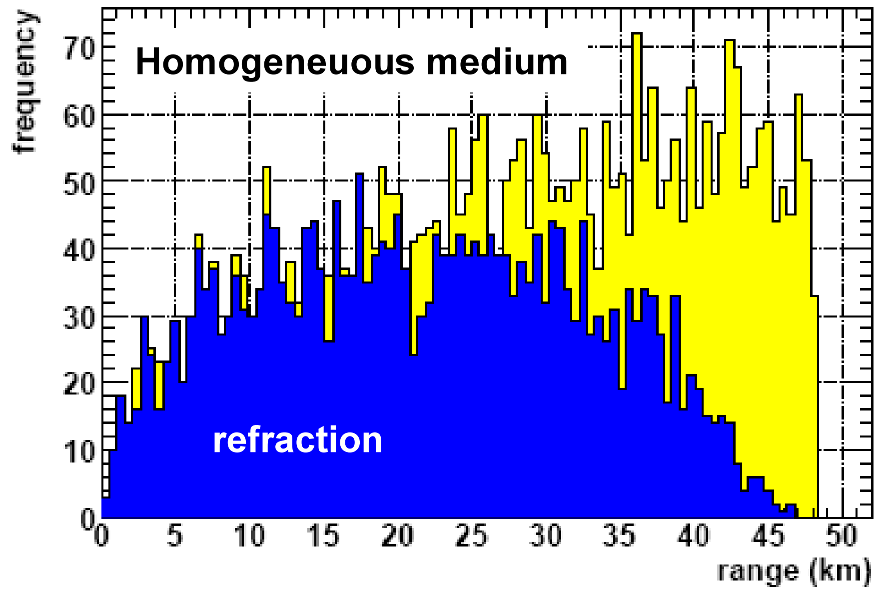
Estimate energy from reconstructed distance and wavefront shape and amplitude

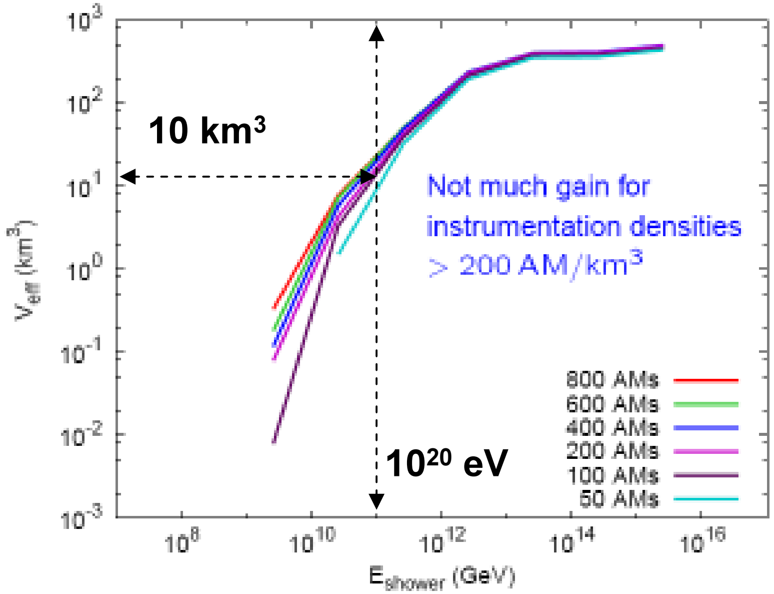
Acoustic Detector Effective Volume

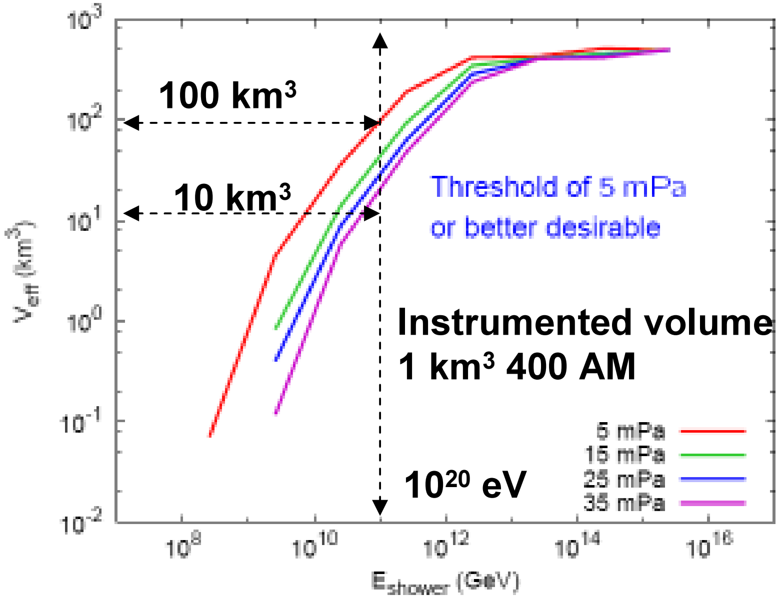
ANTARES (Erlangen, Marseilles) , ACORNE

Effective volume: $$V_{eff} = \frac{N_{det}}{N_{gen}} V_{gen}$$

Generation volume is limited due to wave refraction and reflections on surface/bottom







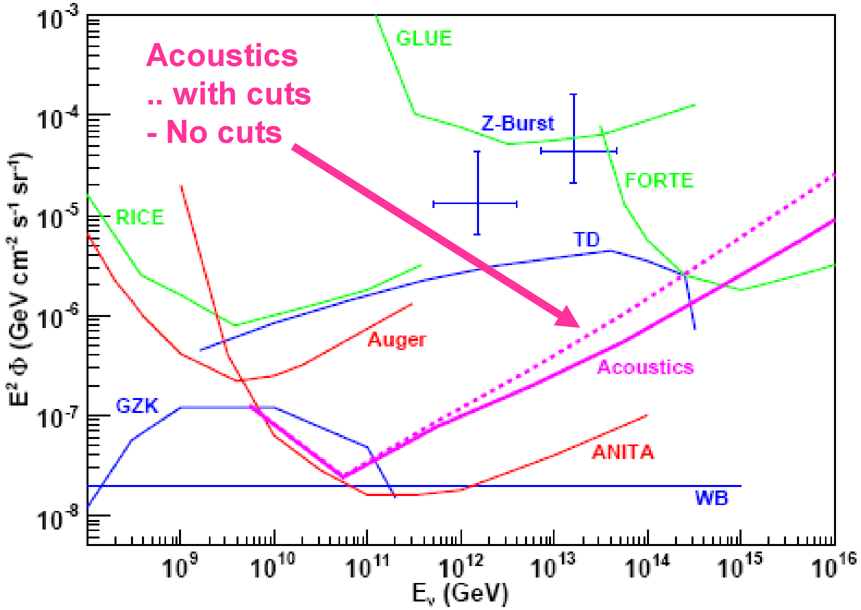
Sea State 0 noise < 2 mPa [10kHz to 50 kHz]

Not realistic for long term measurements

Sea State 2 noise ~ 10 mPa [10: 50 kHz]

Acoustic Detector Sensitivity

ANTARES (Marseilles, Erlangen)

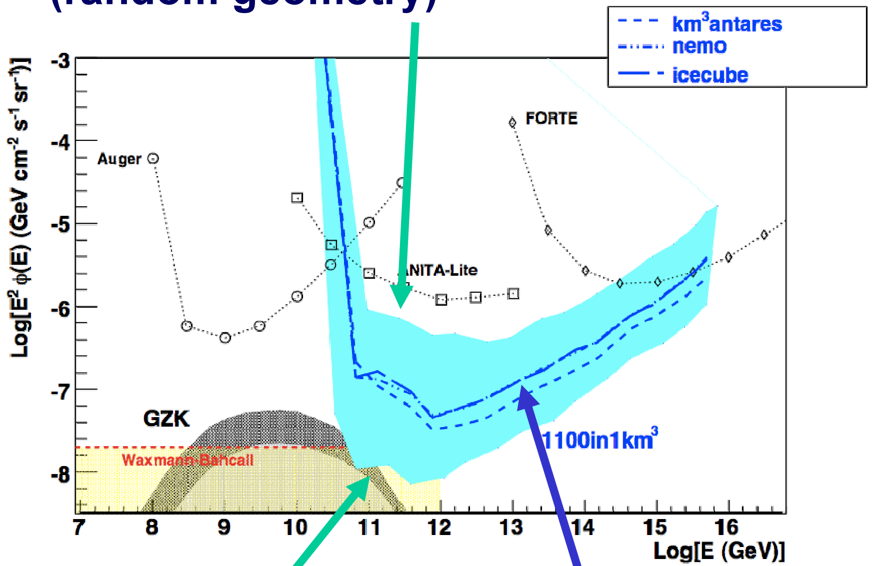


1500 km^3 , 200 hydros per km^3
5 years
threshold 5 mPa

ACORNE

1100 hydros in 1 km^3

1 year, threshold 35 mPa, 95% CL (random geometry)

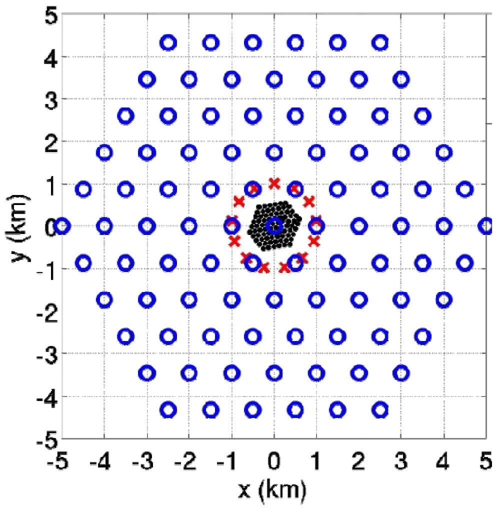


km^3 regular geometries
5 years, 15 mPa, 95% CL

10 years, threshold 5 mPa, 90% CL (random geometry)

A “complementary” km^3-scale detector ?

Hybrid detector in Ice

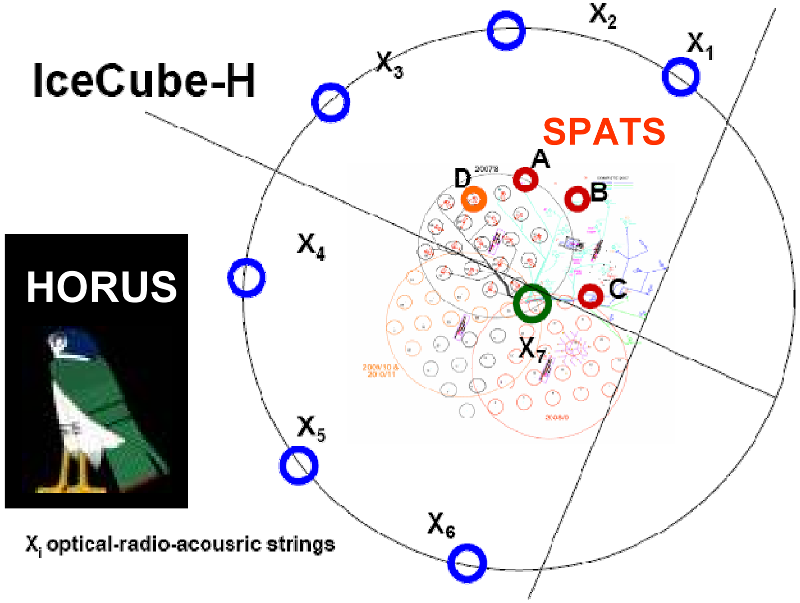


Optical:

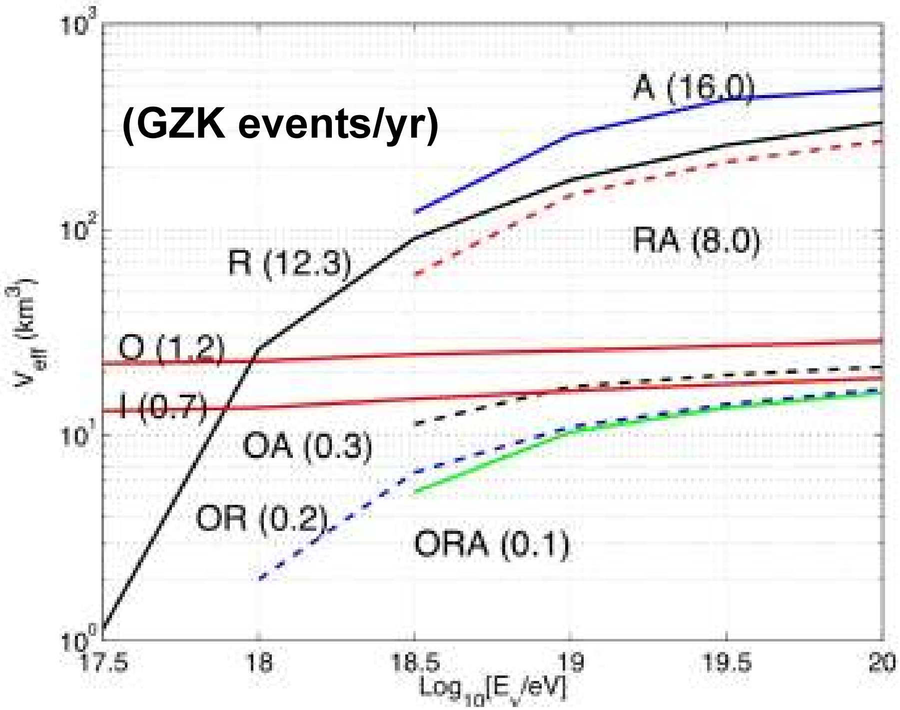
- ■ - 80 IceCube
- X - 13 IceCube-Plus holes at 1 km radius (2.5 km deep)

Radio/Acoustic:

- O - 91 holes, 1 km spacing, 1.5 km deep



X_i optical-radio-acousric strings



Coincident effective volumes + event rates for IceCube (I), an optical extension (O), and combinations with surrounding A + R arrays

Technological R&D

Transducers

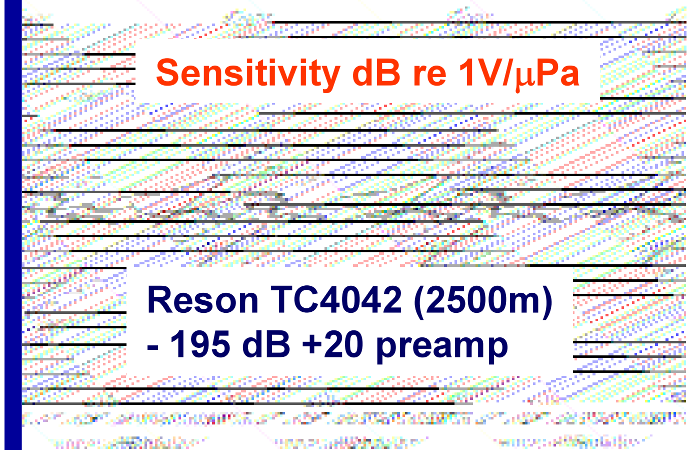
- piezo hydrophones
- glaciophones
- fiber optic hydrophones

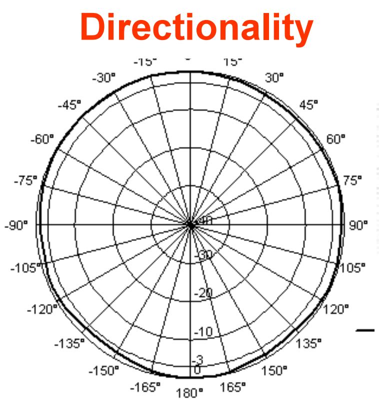
Calibrators

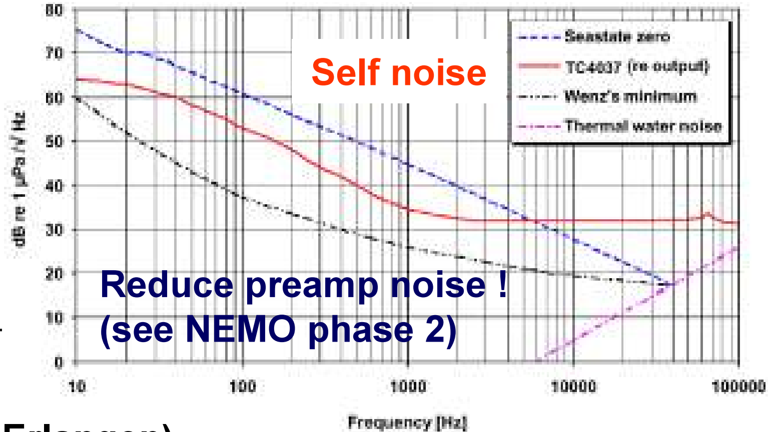
Transducers: Piezo Hydrophones

Commercial Piezo Hydrophones (for deep sea)

There is a good number of companies expert in developing hydrophones for military and navigation instrumentation.
Also ceramic available on the market to build hydrophones







NEMO, ANTARES(Erlangen)

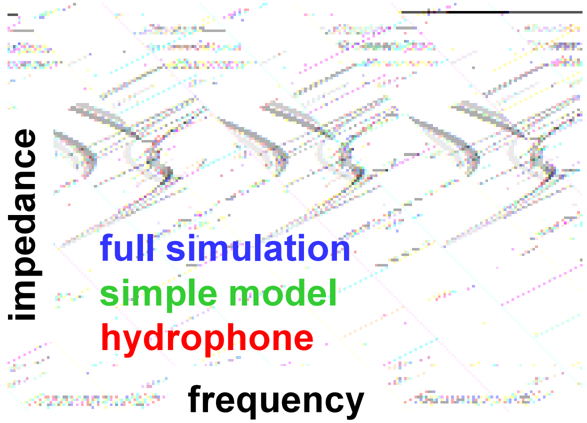
Custom Piezo hydrophones (for deep sea)

acoustic sensors with performance well-matched to expected signal

Microscopic model of piezo and coupling
Solved using Finite Element Analysis

Results predictions using equivalent circuits

BAIKAL, ANTARES (Erlangen)



Transducer Amplitude Calibrations

Commercial Hydrophones

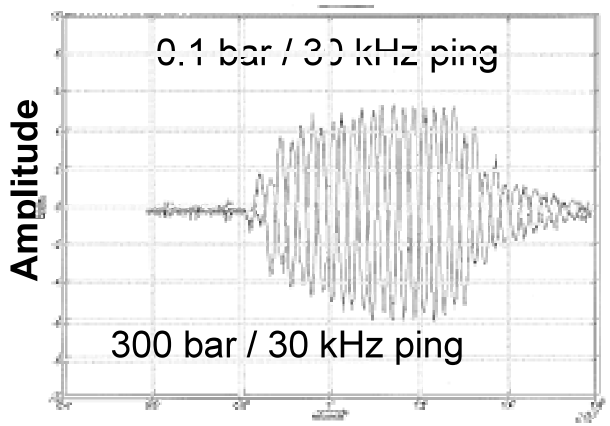
factory calibrated:

→ piston test at 250 Hz, water pool test > 5 kHz (typical)

→ directionality pattern

sensitivity often changes with pressure

(about 10 dB less at 3500 m)



High pressure Tests :

NEMO and NURC (NATO Undersea Research Centre)

developing a standard procedure for relative calibration under pressure

Hydrophone response at 0.1 and 300 bar (after several cycles)

SMID/NURC hydrophone for NEMO Phase 2

Self made hydrophones / glaciophones

Calibration at low depth

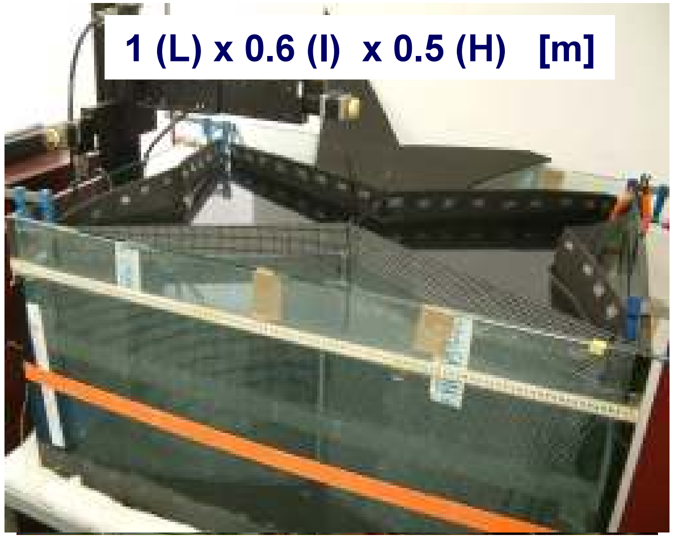
in large or phono-absorbant pools

NEMO and CNR Corbino (4.5 x 6 x 5.5 m^3 pool)

SPATS 78 x 10 x 5 m^3 pool

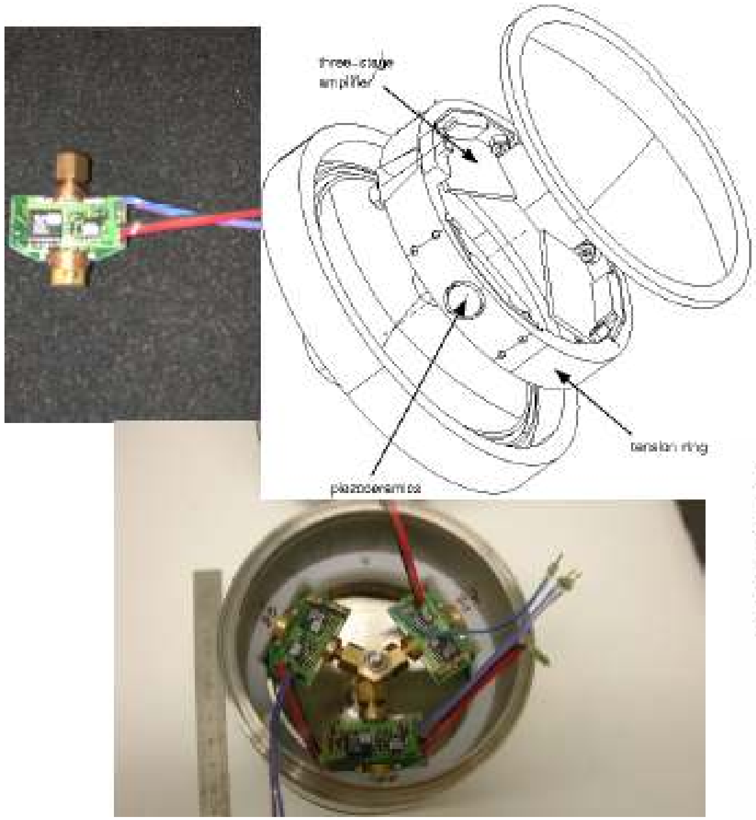
ANTARES (Erlangen) 14 m^3 tank, T controlled tank

ANTARES (Valencia) butterfly shaped small tank



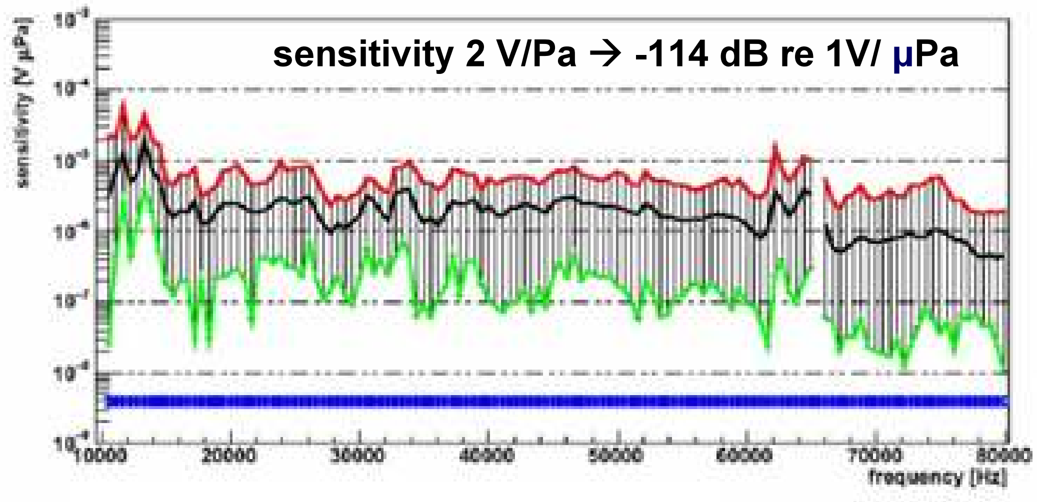
1 (L) x 0.6 (l) x 0.5 (H) [m]

Transducers: Glaciophones



The SPATS Module:

3 channels
- **Piezoceramic**
- **Low noise preamplifier**
- **Precalibrated screw**

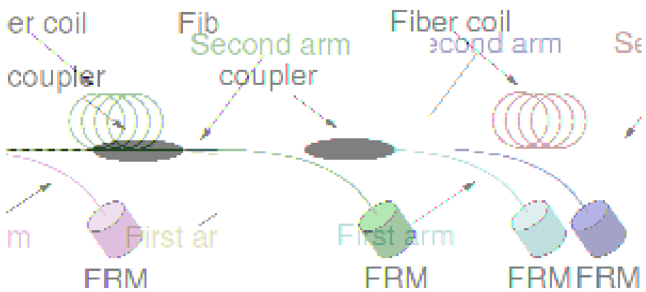


Mass production, typical calibration (in water pool)
Reference hydrophone: Sensortech SQ03: -163.3±0.3 dB re 1V/µPa

Transducers: Fiber Optic Hydrophones

Optical fibre hydrophones are very interesting:
1) they're cheap **2) could be used to produce 1 km height vertical arrays**

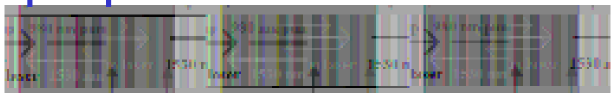
INFN Genova: Fibre optic coiled on an (air) mandrel. Fibre attenuation proportional to Pa.
Good sensitivty upto 5 kHz, low resonance frequency (10 kHz).
Under study: moulding and pressure tests, increase mandrel diameter



INFN Pisa: Herbium doped fibres between Bragg gratings.
Pump at λ_p=980 nm → λ_L = 1530 nm laser.
Pressure produce change of cavity length and n. Change of λ_L measured with M-Z i.m.

980 nm pump

Bragg gratings



1530 nm laser

Erbium doped fiber

1530 nm laser

Mach-Zender interferometry

$$\Delta\varphi_{Mach-Zender} = \frac{2\pi \cdot D}{\lambda^2}\Delta\lambda$$

for SS0 (20 dB re 1 μPa/√Hz)
$\Delta\lambda$= 10^{-12} nm
Requires D= 300 m
$\Delta\varphi$ = 1 μrad
Hard but feasible

"Neutrino Pulse" Calibrators

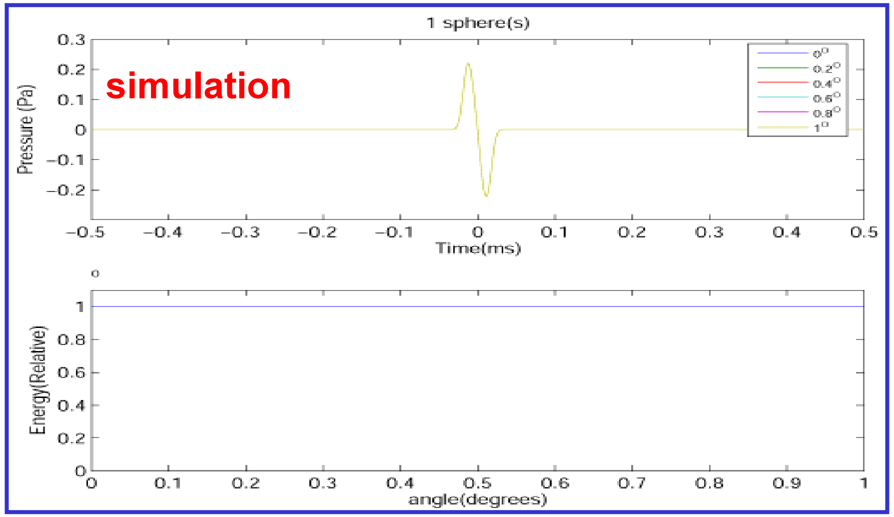
Reliable neutrino signal calibrator: test array capability in reconstructing the ν event

ACORNE

Hydrophone excitation to produce bipolar signal (achieved)

Coherent signal from several hydros to get pankake shape (under development)

Portable Laser calibrator under study



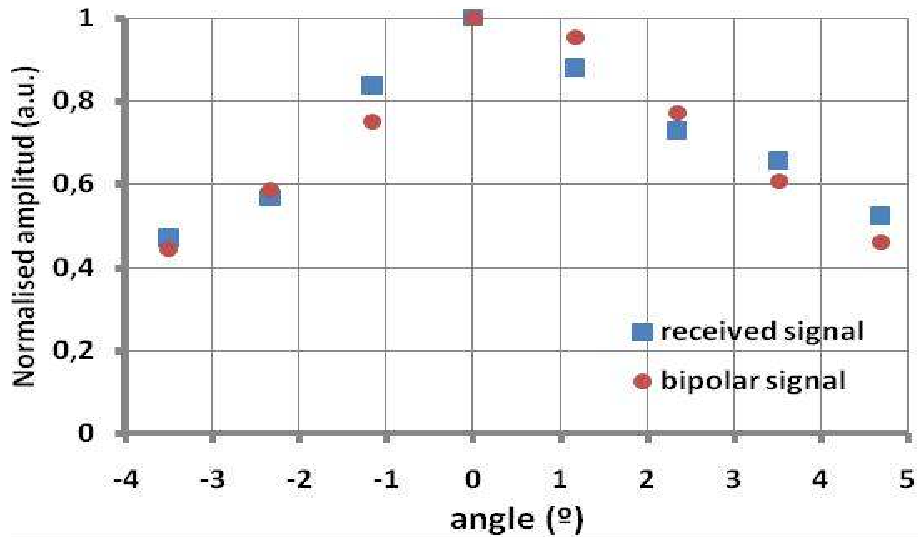
ANTARES (Valencia)

Parametric Calibrator

Transducers excited with 2 ~1 MHz waves

Non linear effect of ceramic

Bipolar kHz pulse proportional to V^2
Signal confined in narrow angles



Test Experiments

Ice:

- SPATS

Sea:

- SAUND
- ACORNE
- AMADEUS
- NEMO-OnDE

Lake:

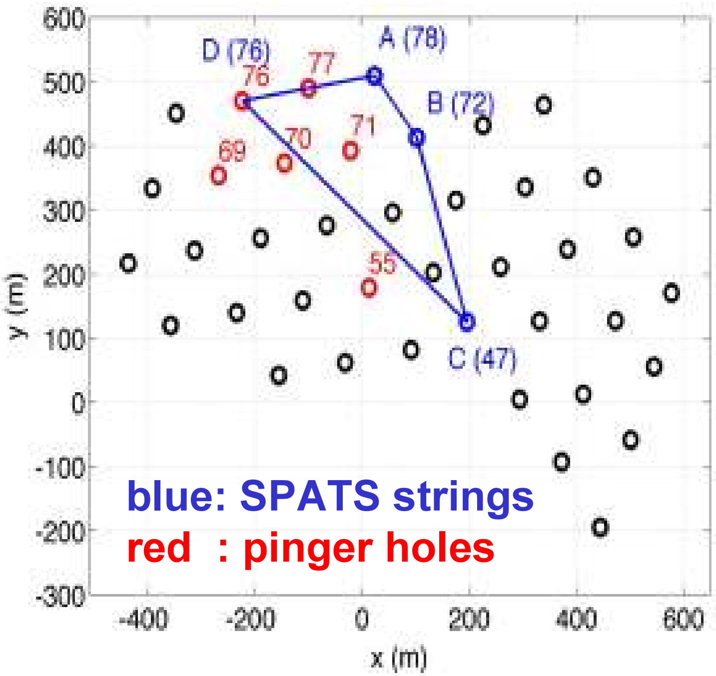
- Baikal

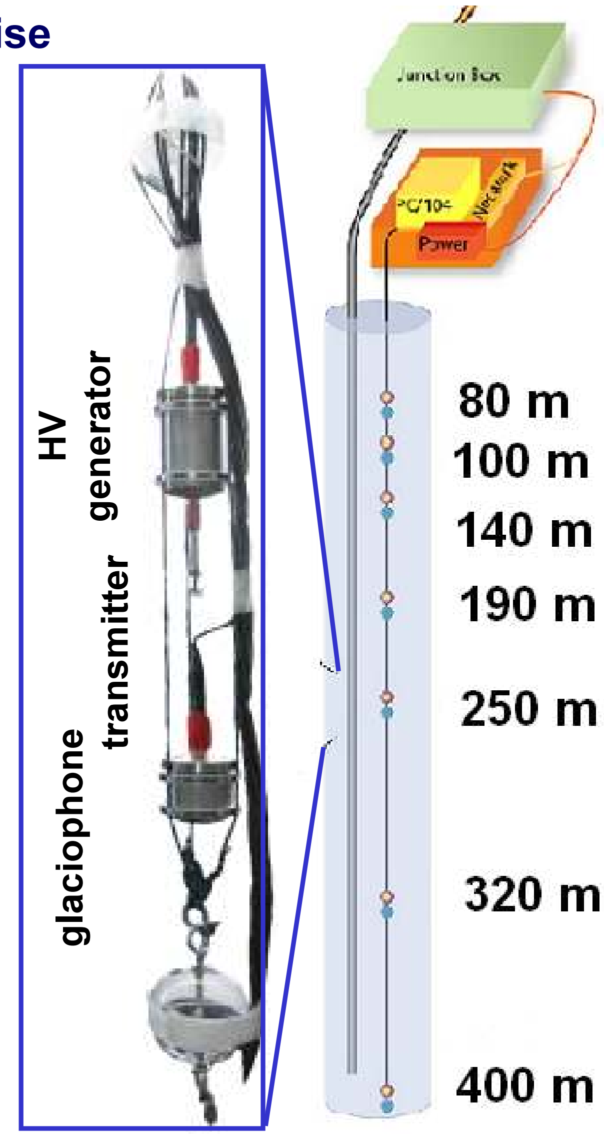
SPATS in ICECUBE Deployment and Operation

Measure ice properties :
attenuation length, wave refraction, noise

3 strings in IceCube holes 72, 78 47
7 stages per string
stage = 1 transmitter + 1 sensor

surface digitization (200 / 400 kHz)
GPS phased array





String-D
100 m longer

Improved glaciophones

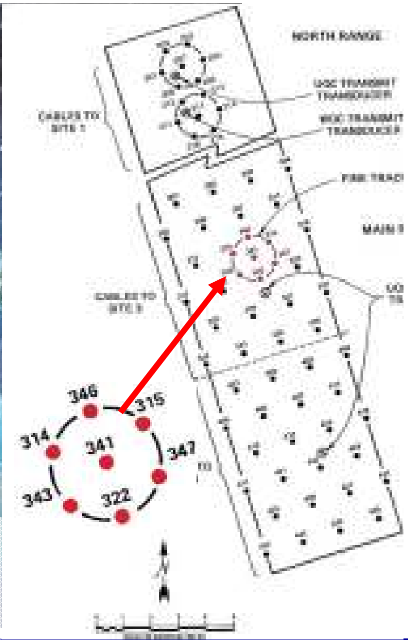
Improved transmitters

New HADES glaciophone

Pinger tests: movable transmitter used in 6 holes (water filled)

AAL to meausre sound velocity (Aachen)

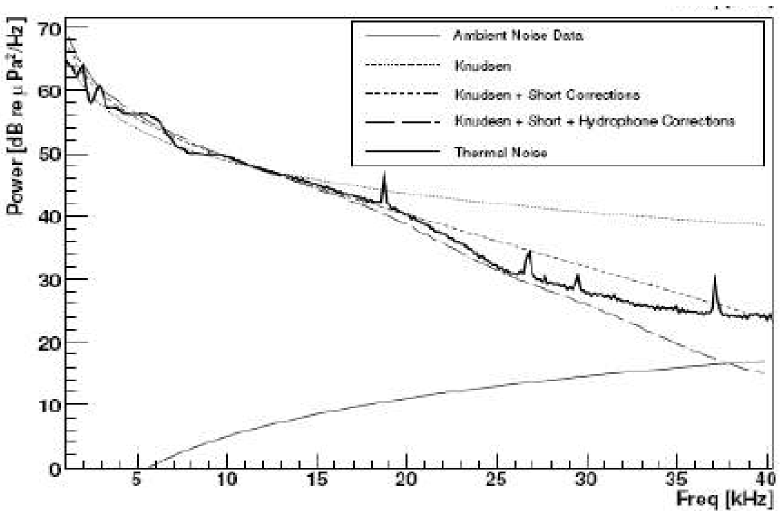
SAUND: Study of Acoustic Ultra-high-energy Neutrino Detection



1100 m depth, hydrophones on seabed

SAUND 1: 6 Hydrophones - 7 km^2
(signals digitized on shore 100 kHz, 12 bits)
15 days free run
SAUND 2: 56 Hydrophones - 1000 km^2
(underwater digitization)
120 days DAQ (target 1 year)
Phased onshore. Sensitivity -186 (+50 gain) dB

Event vertex and energy reconstruction
Test with imploding light bulbs (proven !)

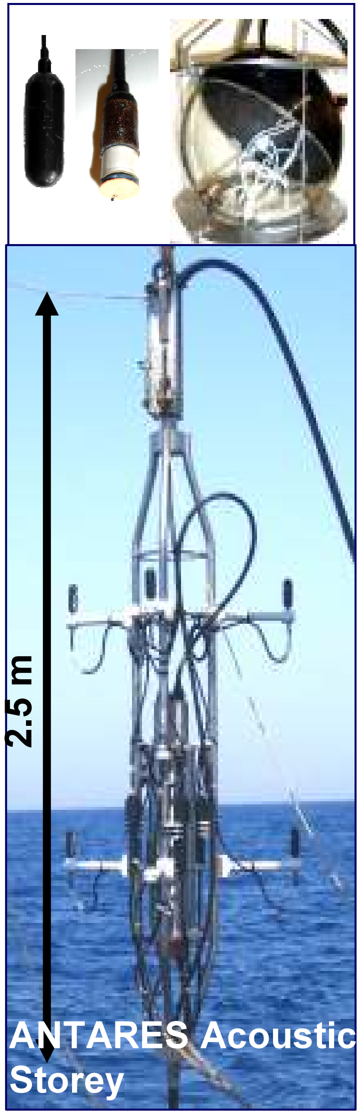


SAUND 2

Ambient noise measured every minute
(input for adaptive matched filter)
Accurate background noise studies
Sea state contribution well separated

Triggered event analysis under study

AMADEUS: ANTARES Modules for Acoustic Detection Under the Sea



3 Acoustics storeys installed on ANTARES Instrumentation Line 07

3 Acoustic storeys installed on ANTARES Line 12 (connected)

IL 07 - Deployment: July 2007 Start data taking: December 2007

Each storey has 6 hydrophones. Spacing between storeys 1 to 300 m

Two storeys of commercial hydros. One storey of self-made hydros

Sampling (underwater) 200 ks/s 16 bits. ANTARES data transmission

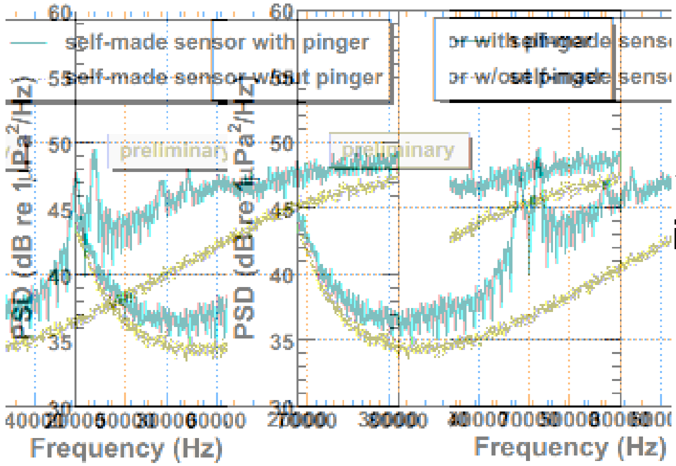
Clock system for synchronisation of all acoustic sensors

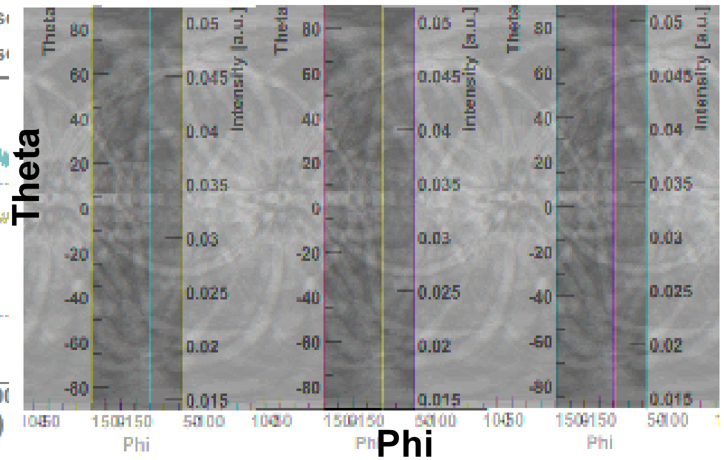
Measure background noise

Cross check with the ANTARES acoustic positioning system

Test for detection and event reconstruction algorithms

Studies of hybrid detection methods (optic and acoustic)





ACORNE: Acoustic Cosmic Ray Neutrino Experiment

QinetiQ /UK Navy facility at Rona (NW Scotland)
Low depth, noisy environment . Test for trigger and reconstruction

Depth: 230 m   Area: 1.5 km x 200m
8 hydrophones ITC8201 (10 Hz : 65 kHz, -158 dB re 1V / μPa)
Sampling (onshore): 140 kHz, 16 bits

Hydrophone gain and sensitivity well balanced (proven with noise spectra)
Source reconstruction difficult (hydrophones movements not continuously monitored)

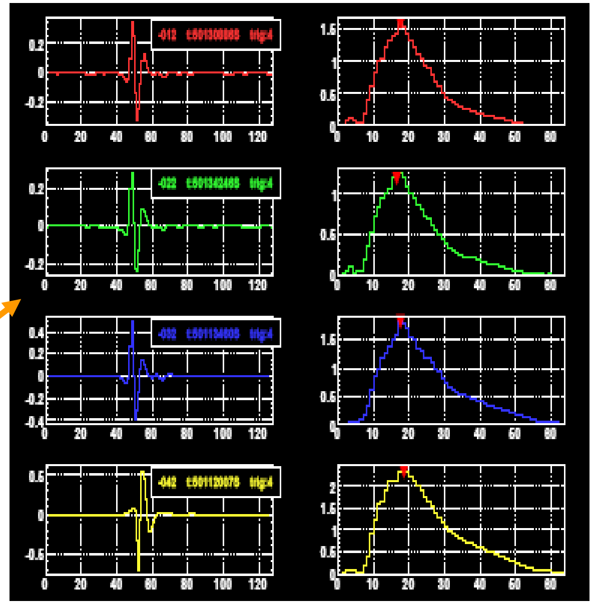
Raw data acquistion 15 days in ‘05, several weeks ‘06

Raw Data Reduction: (230,000 events)
4 triggers: p, dp/dt, d^2p/dt^2, Matched Filter

Data analysis: (3500 events)
35 mPa threshold, 4 fold coincidences

Signal classification:
ringing, sinusoidal, high frequency, bipolar, impulse

Neural network approach in progress



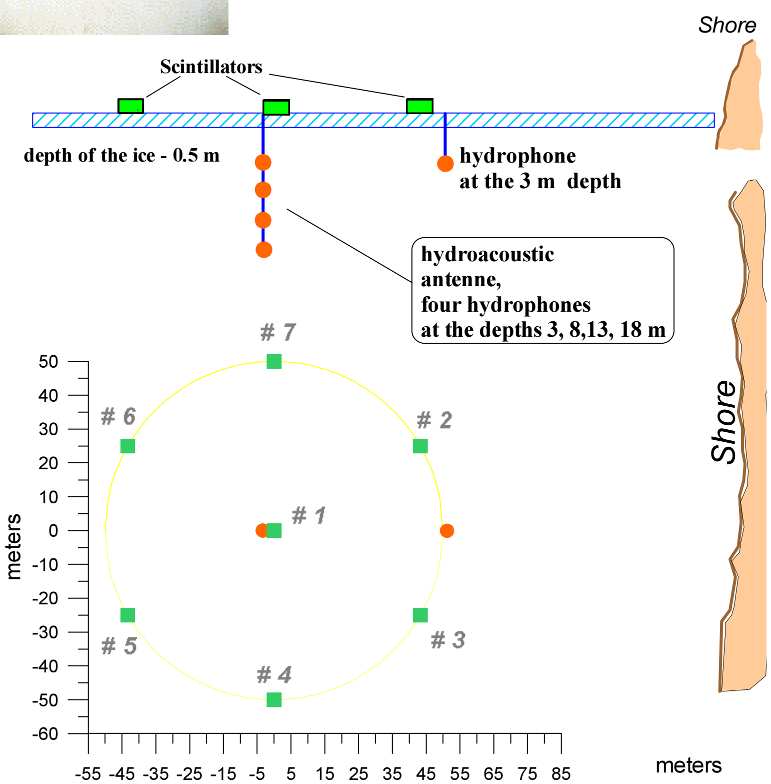
BAIKAL

Infrastructure: BAIKAL NT200+ telescope and surface EAS scintillator array

ITEP antenna / surface EAS array

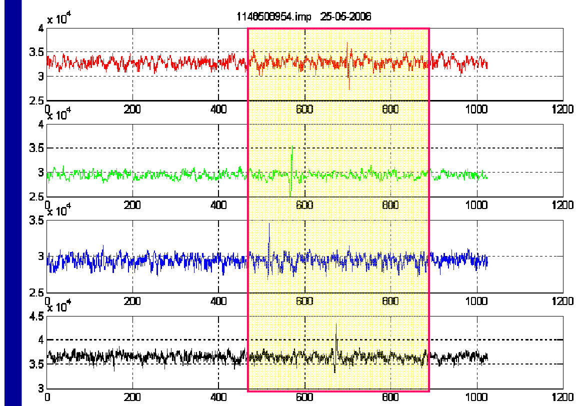
Sensitivity -135 dB re V/ μPa

Events sample dominated by surface Background

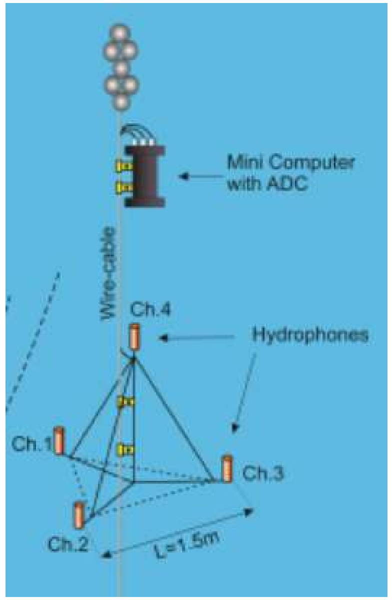


Thetrahedral antenna / NT200+

Deployed at 100m
Noise studies
Event search

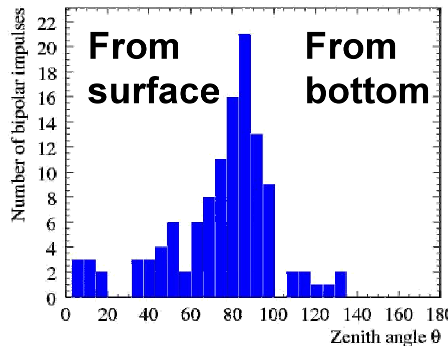


1 msec

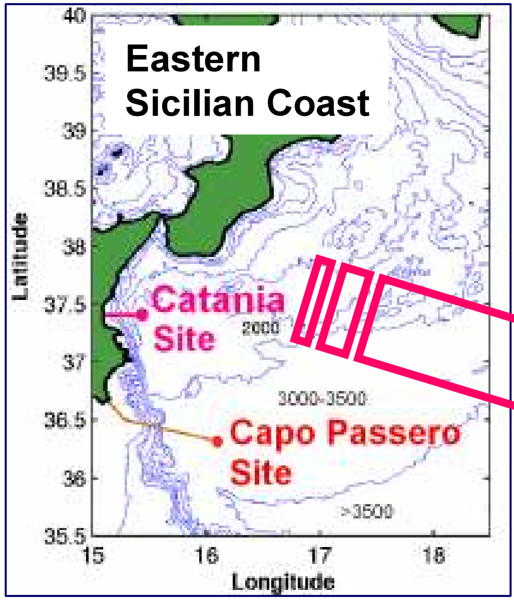


Bipolar pulse on 4 hydrophones

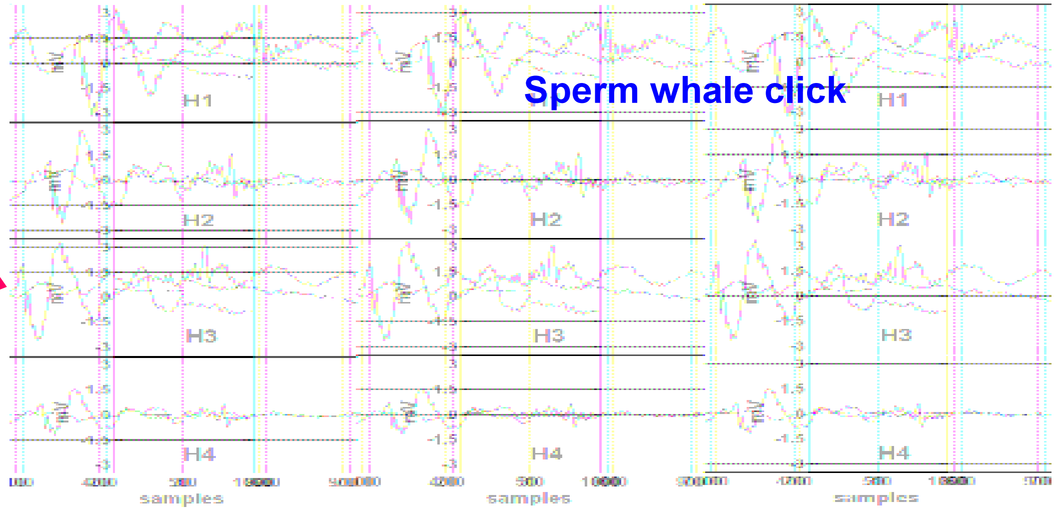
Angular distribution of bipolar pulses for 2 months data acquisition



NEMO-OnDE: Ocean Noise Detection Experiment



Deployed at the NEMO Test Site 2000 m depth, 25 km offshore Catania. Next deployment end of 2008, in the framework of ESONET-LIDO demo mission. There is a Deep Sea Test Site facility available for R&D !



Thetrahedral antenna (1m size):

4 Reson TC4042 hydrophones (special production for 2500 m depth).

Low cost professional audio electronics (96 kHz, 24 bit sampling, $\Delta\Sigma$)

Hydrophones synchronised and phased.

On-line monitoring and recording on shore. Recording 5’ every hour

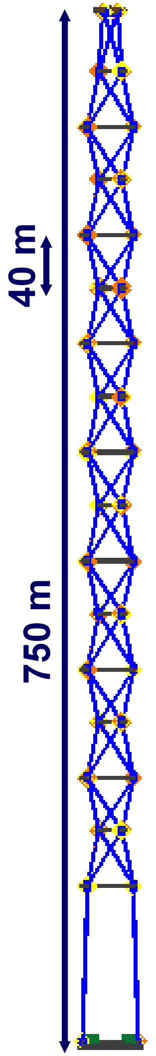
Data taking from Jan. 2005 to Nov. 2006 (NEMO Phase 1 deployed).

Sea Noise measurement and modelling (presently under study)

Bioacoustics: study of sperm whales population in the East Med Sea

Test of triggers and reconstruction (limited size: 1m) algorithms under test (using also ACORNE software tools)

NEMO Phase II – Acoustic Positioning and Acoustic Physics



NEMO Tower

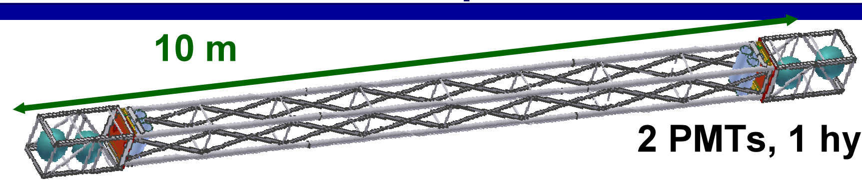
NEMO Phase II: Installation and operation of a "full scale" tower in Capo Passero
16 floors, 64 Optical Modules, 750 m total height

Same electronics and DAQ and DAT as NEMO Phase I:
OM data synchronised and phased (about 1 ns resolution)

34 hydrophones for Acoustic Positioning …And for Acoustic Physics / Biology

→ Reduce costs and improve reliability of the tower acoustic positioning system
→ 750 m long antenna for feasibility studies on acoustic detection
→ Optical and acoustic data in the same data stream with the same time
   All signals are phased !
   A viable solution for KM3Net (?)

Hydrophones (SMID-NURC)	30 (-207 dB) + 4 (-201 dB)	Tested for 3500 m
Preamp (SMID-NURC)	32 dB gain, 0.8 nV/ √Hz input noise	
ADC-board	24 bits, 192 kHz sampling, 3 dB gain	
FCM	Optical Transmission to shore + GPS time stamp	

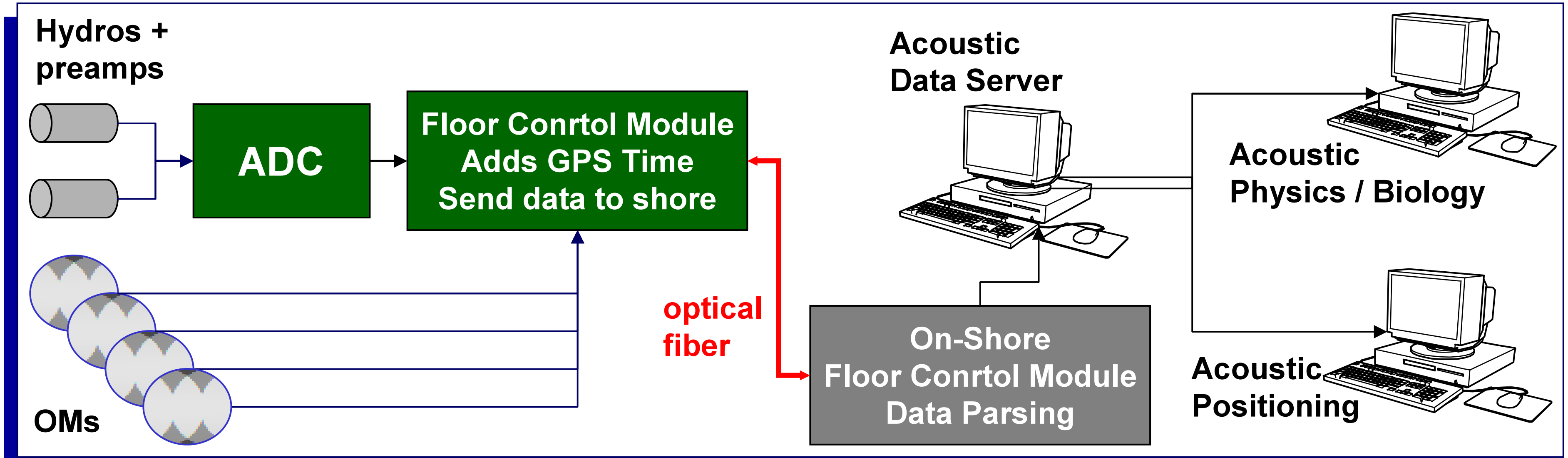


NEMO Floor

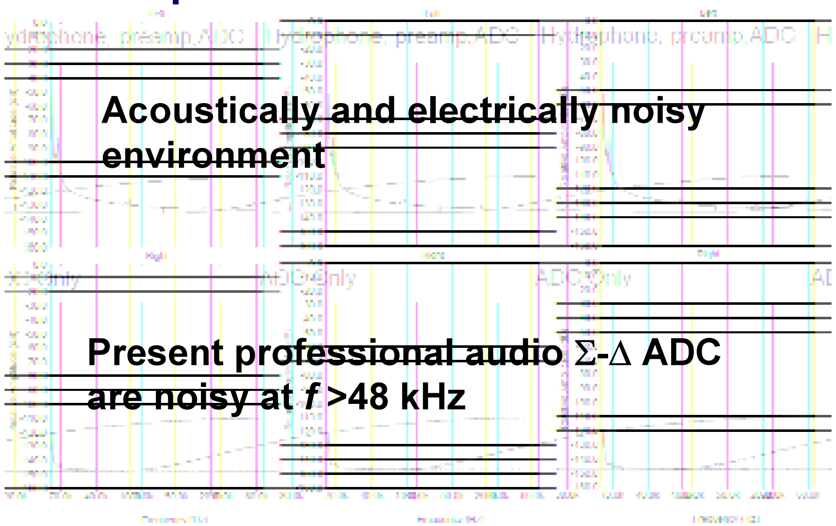
NEMO Phase II – “Acoustic” Electronics Chain

“All data to shore” philosophy

data payload: 2 Hydros = 1 OM, fully sustainable

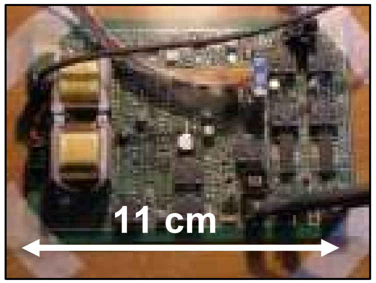


Complete DAQ chain tested



Acoustically and electrically noisy environment

Present professional audio Σ-Δ ADC are noisy at *f* >48 kHz



NEMO Phase II “Acou-Board”

Dynamic range > 90 dB [0 : 96 kHz] (to be improved)

Excellent for acoustic positioning signals

Equivalent self noise

(-207 dB hydro) 35 dB re 1 μPa/√Hz [1:48 kHz]

(-201 dB hydro) 29 dB re 1 μPa/√Hz [1:48 kHz]

Summary

Simulations

Several reliable codes available for neutrino interactions and EAS in water / ice, and for acoustic wave formation

Medium properties (acoustic wave propagation, noise)

Water: well known, a deep sea site for a large installation would require further studies

Ice: requires better investigation

Other : Salt, Permafrost (R. Nahnhauer) interesting to investigate

Event trigger and reconstruction

Available, require further improvements

Technological R&D:

Hydrophones (ceramics) available, present costs about 1000€ (could be reduced)

Tune custom hydrophones for neutrino pulse range ? Improve sensitivity for high depth

Amplitude calibration required for high pressure (and low temperature in ice)

"Synthetic neutrino pulse" emitters soon availale

Dedicated DAQ or "cheap" professional audio electronics (with improvements) ?

Test Sites:

Opportunity to test technology / software

Acoustic detection using the km^3 Cherenkov telescope infrastructure:

Acoustic positioning system is required in water, use it also for acoustic physics

Performances could be competitive with a small effort… KM3Net ? …

Personal Comments

There are lots of improvements in the UHE neutrino acoustic detection field

Small groups applying for a common EU FP7 JRA on Acoustics (thanks to L. Thompson)

ARENA Conferences were and are a great opportunity for discussion

Workshop on acoustic detection 2003	**Stanford**
ARENA 2005	**Zeuthen**
ARENA 2006	**Newcastle**
ARENA 2008	**Roma, Next June 25-28**

Final Note

Dolphins use sound !

They're the second most evoluted species on Planet Earth

… Mankind is only the third !