Acoustic detection of high energy showers in water

*introduction

*activity in Italy

*perspectives, possible collaborations

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Genova

Workshop on the Russian-Italian
Cooperation in the cosmic Ray Physics and
Astroparticle physics
Moscow 17-20 october 2005

First evidence

О. Л. Песков, В. И. Кротов, Н. Д. Сергеев. Большую работу по обработке экспериментального материала выполнили инженер З. Ф. Дерюгина и техник Н. А. Гущина.

Поступило в редакцию 22 II 1957 г.

ЛИТЕРАТУРА

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4. W. H. Jens, Mech. Eng. 76, 981—986 (1954).
5. В. С. Чиркин, В. П. Юркин, ЖТФ, 26, 1542—55 (1956).

Гидродинамическое излучение от треков ионизирующих частиц в стабильных жидкостях

Г. А. Аскарьян

Прохождение ионизирующих частиц в жидкостях сопровождается увлечением молекул среды расталкивающимися скоплениями одноименно заряженных ионов и микровзрывами при локальных нагревах, создаваемых вблизи треков частиц. Эти процессы могут привести к образованию локальных пустот и зародышей паро-газовой фазы. (Превращение этих зародышевых полостей в пузырьки види-

рующей частицы, и через C—совокупность начальных параметров создания ионных рывков или образования полостей (например, начальные характеристики ионных скоплений или локальных нагревов), однозначно характеризующую процесс излучения. Тогда в широком интервале скоростей частиц

$$dn = n(Z, \beta, C)\, dC \simeq \frac{Z^2}{\beta^2}\, n_1(C)\, dC,$$

G.A Askarian: hydrodinamical emission in tracks of ionizing particles in stable liquids. 1957

and later....

G.A.Askarian, B.A.Dolgoshein, A.N.Kalinovsky, N.A.Mokhov: Acoustic detction of high energy particle showers in water. Nucl. Inst. and Meth., 164 (1979), 267.

"... All this gives good reason to believe that the acoustical method of particle detection may find applications both at accelerators of the new generation and for detection of cosmic neutrinos in the Ocean"

experimentally confirmed by

L.Sulak, et al. :
Experimental studies of the acoustic signature of proton beams traversing fluid media", Nucl. Inst. and Meth., 161 (1979),203

Neutrinos from where?

Production mechanism

1. **Emission of jets**

2. **Fermi acceleration mechanism** →

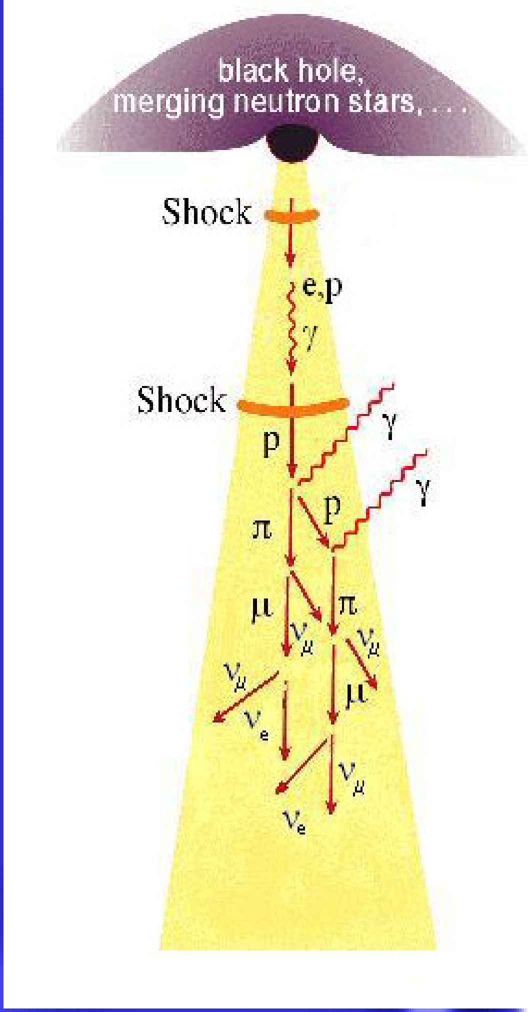
   proton spectrum: $dN_p/dE \sim E^{-2}$

3. **p+p → p + N + π**

→Neutrinos from succcesive π and μ decay

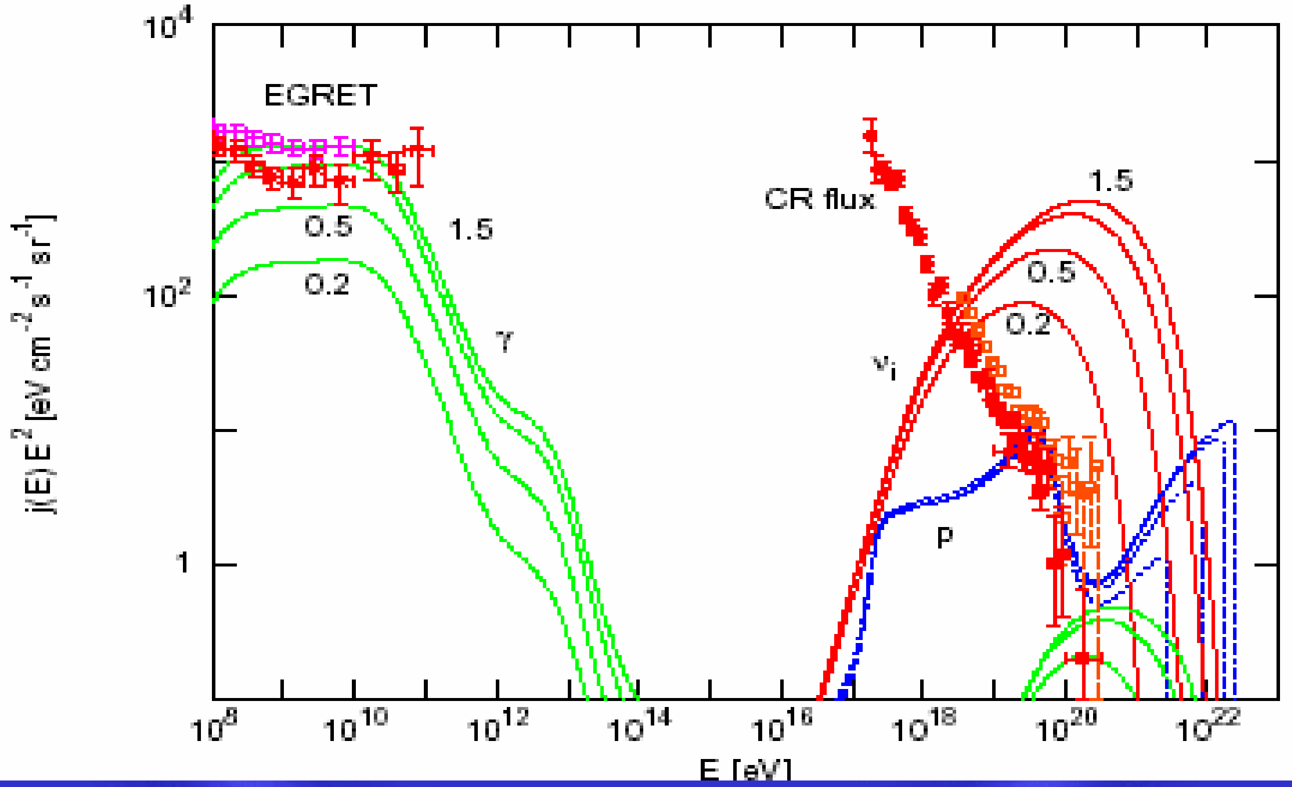
4. **Another mechanism: from π decay produced in the interaction of p with CMB at energies above ~ 10^{19} eV**

Cosmic source



An exemple: the ‘cosmogenic neutrino flux’

created by decaying charged pions produced in interaction of primary nucleons of energy above $5x10^{19}$ eV with CMB photons, the Greisen-Zatsepin-Kuzmin effect(D.Semikoz, G. Sigl, hep-ph/0309328 29 sep 2003)



Why acoustic detection ?

•High energy neutrinos interact via DIS with matter (1% probability in 1 km of water at 10^{20}eV).

•Energy is shared between a quark ad a lepton; on the average 80% to the lepton and 20% to the hadronic shower (≈ Joule for 10^{20}eV neutrinos) .

•The hadronic shower is confined (typically a 2 cm. Radiux x 20 m length cylinder) and produces detectable pressure waves.

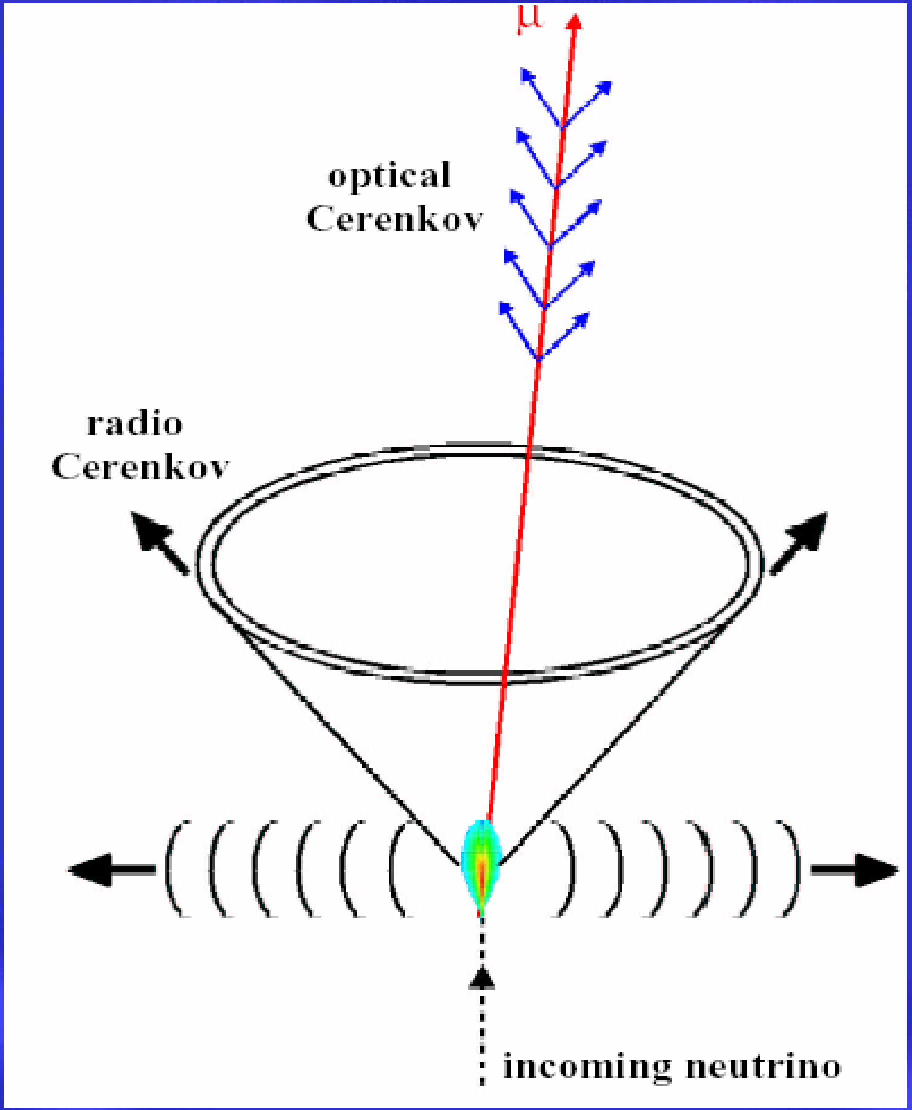
• the acoustic front has a typical disk shape('pancake'), the pressure wave is bipolar, ≈ 50 μs period, amplitude ≅ mPa or higher depending on the initial energy and distance

•The signal propagates for several km (attenuation lenght of 1km at 20 kHz)

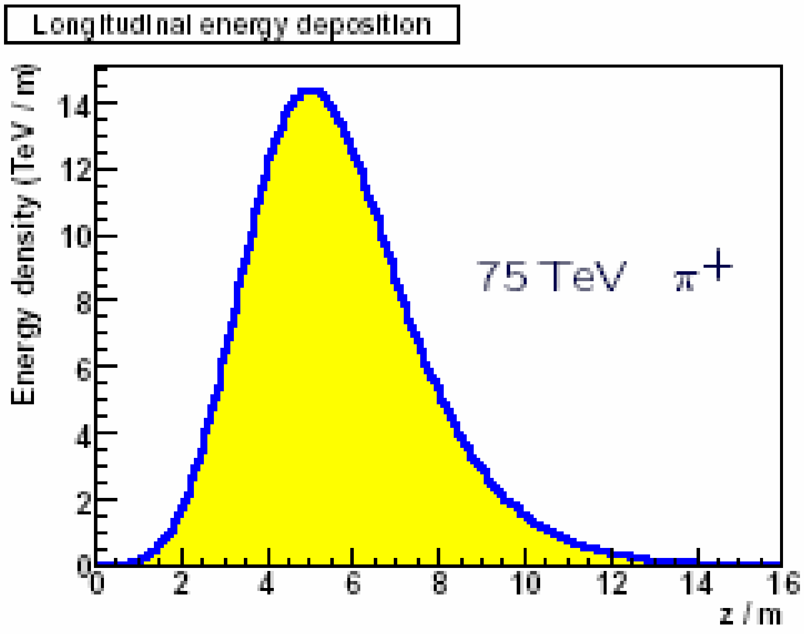
→

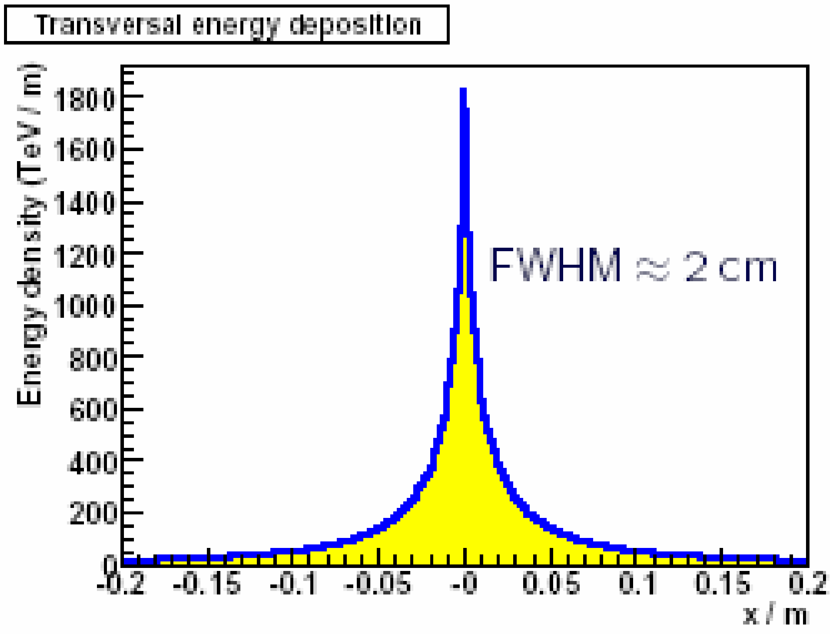
at high energies (≥ 10^{18}eV) the acoustic detection may be an alternative to Cerenkov light detection (attenuation lenght ≅ 50 m)

The production mechanism

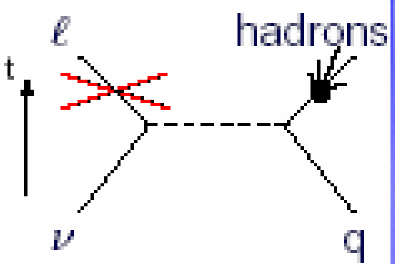


Hadronic Showers





- neglect primary electromagnetic showers due to LPM effect
- full 3D simulation of the energy deposition with GEANT4
  - shower extension (nearly) independent of energy
  - ⇒ energy density scales linearly with energy
- numeric integration of energy density gives bipolar acoustic signal $p(\vec{r}, t)$



The acoustic signal

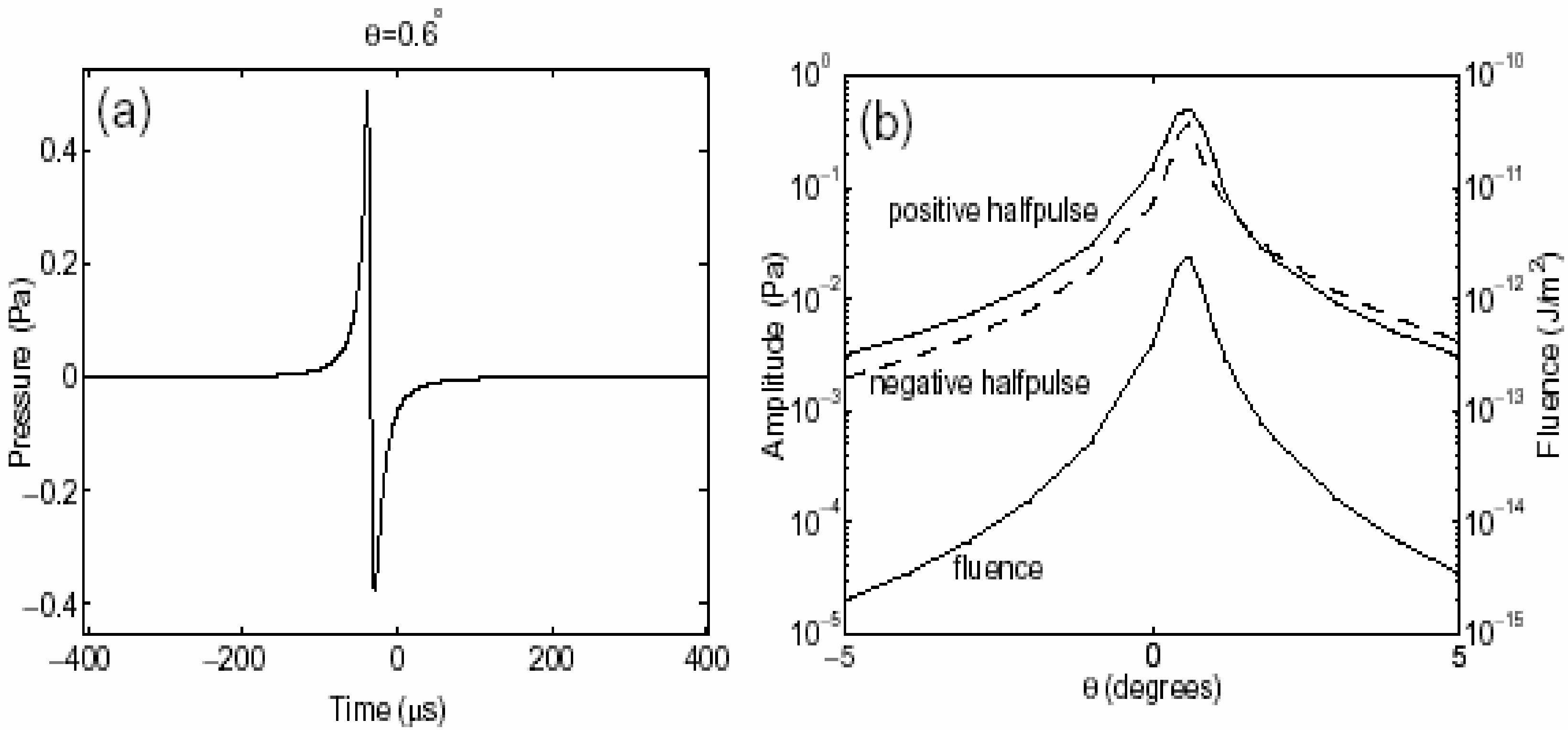
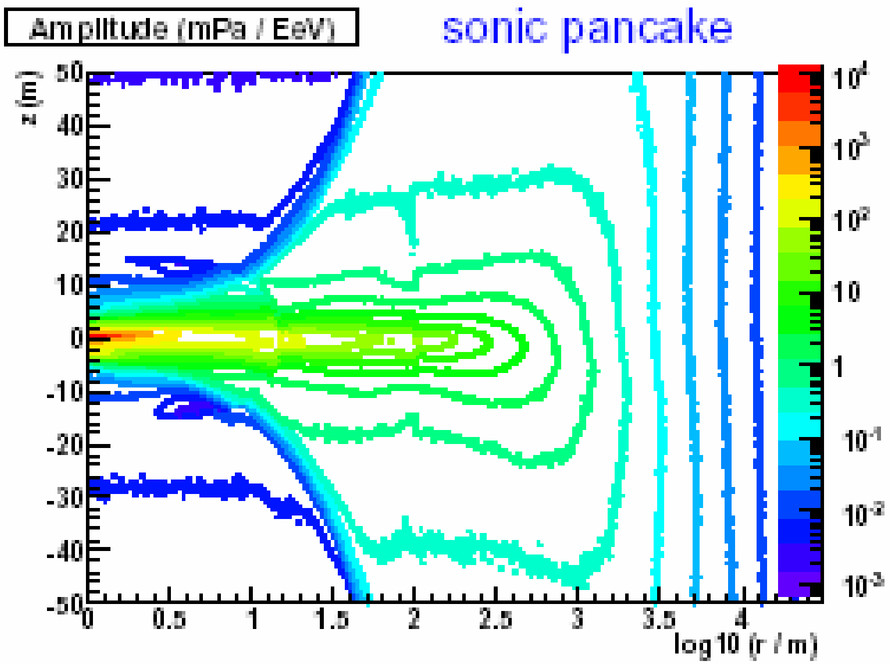


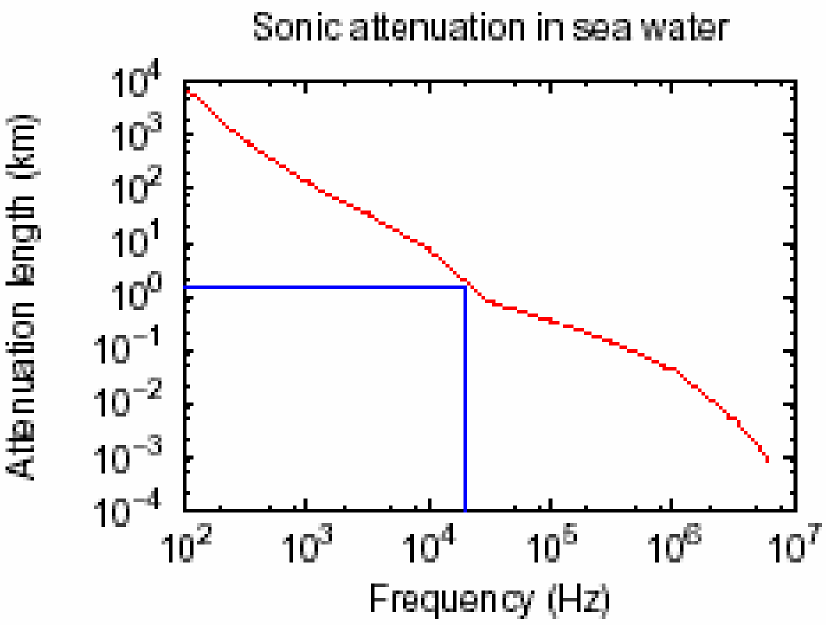
FIG. 4: Results of calculations of the acoustic signal from the hadronic part of the neutrino-induced shower [38], at the distance of 1000 m from the shower axis, for a primary hadronic energy of 10^{20} eV: (a) the pulse shape at the observation angle of $\theta = 0.6^{\circ}$, where the amplitude is maximal; (b) the pressure amplitude of the pulse and the total energy fluence in the pulse, $(\rho c)^{-1} \int_{-\infty}^{+\infty} p^2\, dt$. These last two quantities are plotted as functions of observation angle as defined in Figure 3.

Signal Propagation

- attenuation length
  strongly frequency dependent
- central frequency of signal ≈ 20 kHz

⇒ attenuation length ≈ 1 km





- sonic disc well collimated
  for distances up to 1 km
- diffraction is neglected
  (for the moment...)

Acoustic detection activity in Italy

GENOVA (University and INFN): prototype of an hydrophone based on the interference of light in optic fibres.

PISA (University, INFN, IFAC-CNR): Developement of an Erbium doped fiber laser as a deep sea hydrophone.

LNS (INFN) Ocean noise Detection Experiment

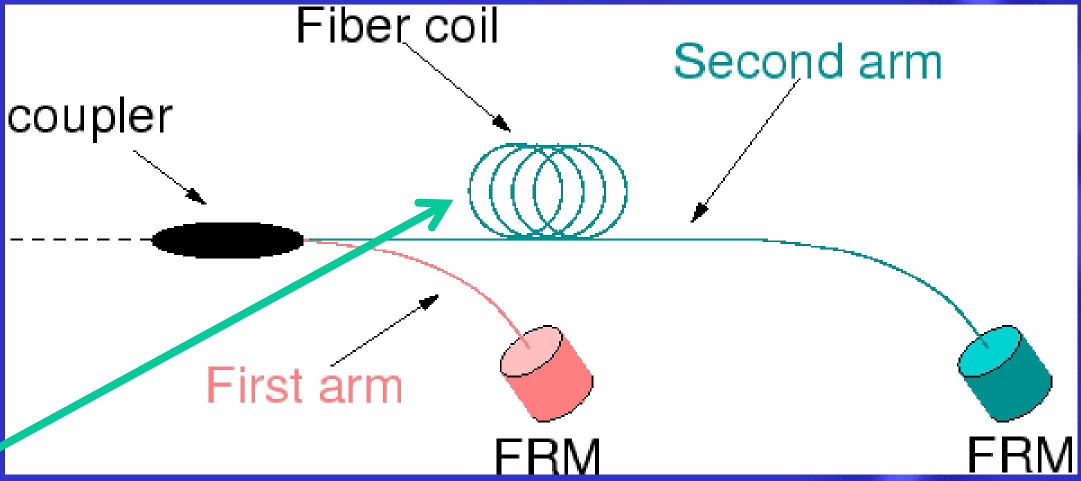
ITEP-ROMA : hydrophones calibration using a 100 and 200 MeV proton beam

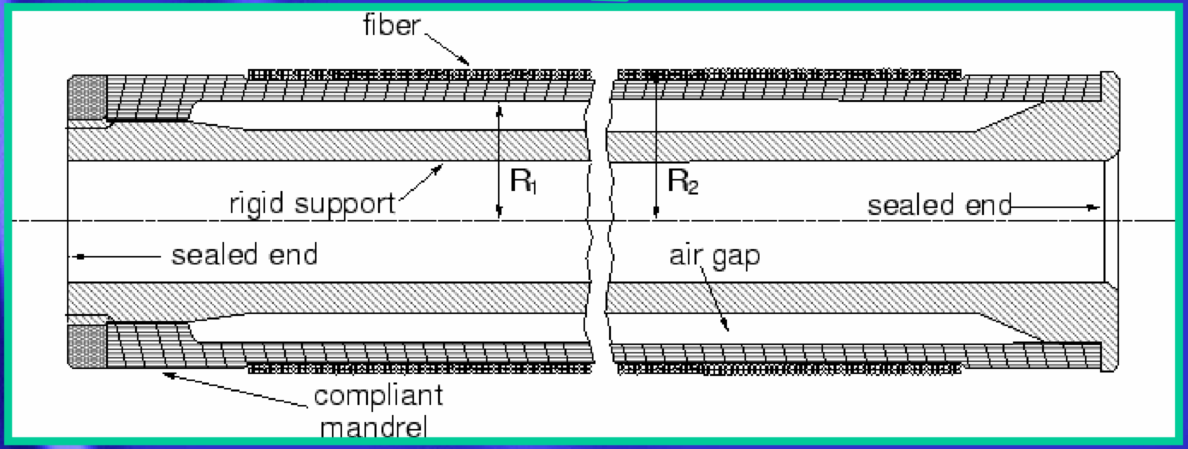
The Hydrophone in Genova

Dipartimento di Fisica

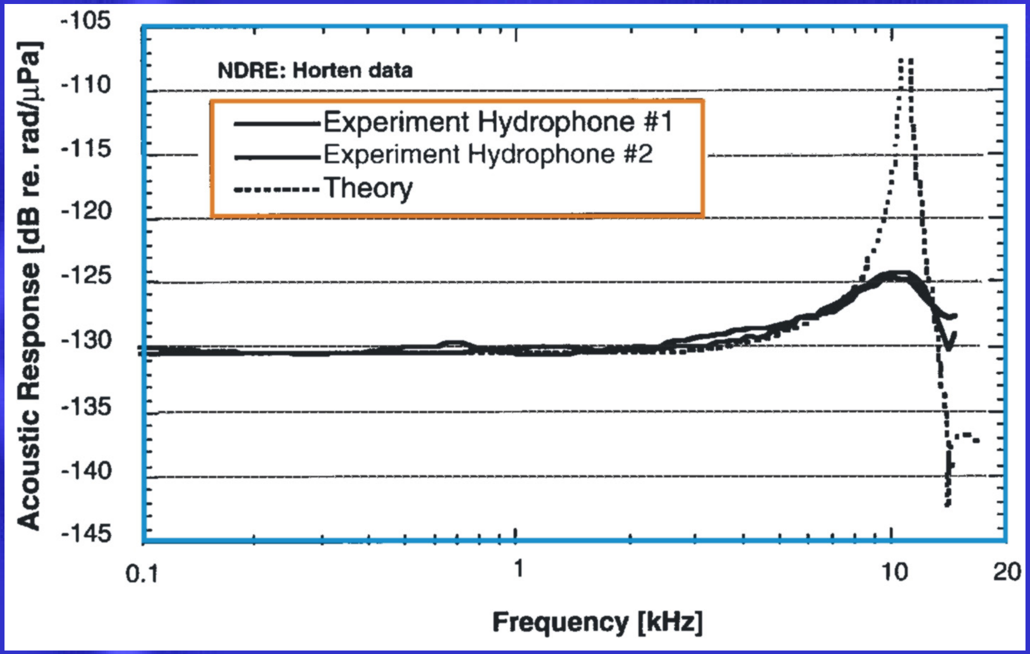
Università di Genova

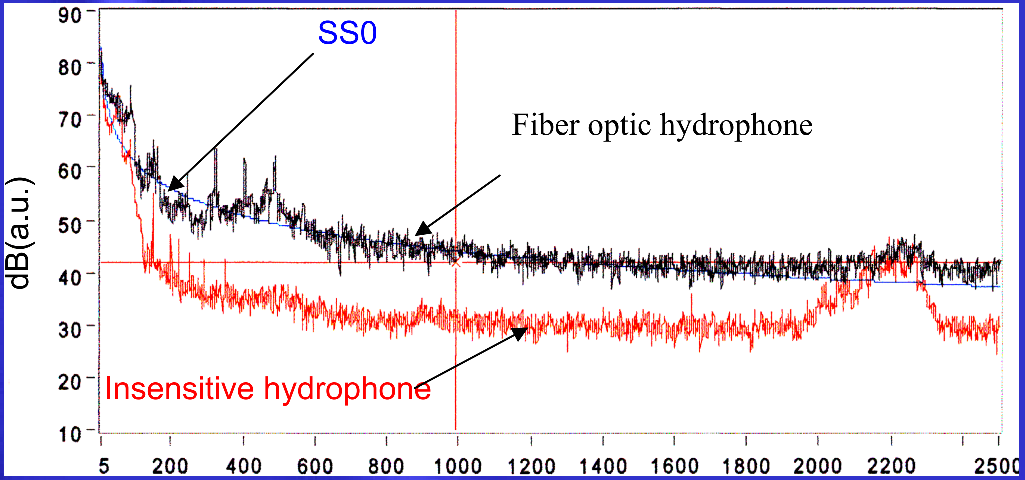
M.Anghinolfi
S.Cuneo
M.Ivaldi
L.Repetto





Present configuration





∅ = 22 mm, L=25 mm, fibre ∅ =125 µm, resonance freq. ≈ 10 kHz in air

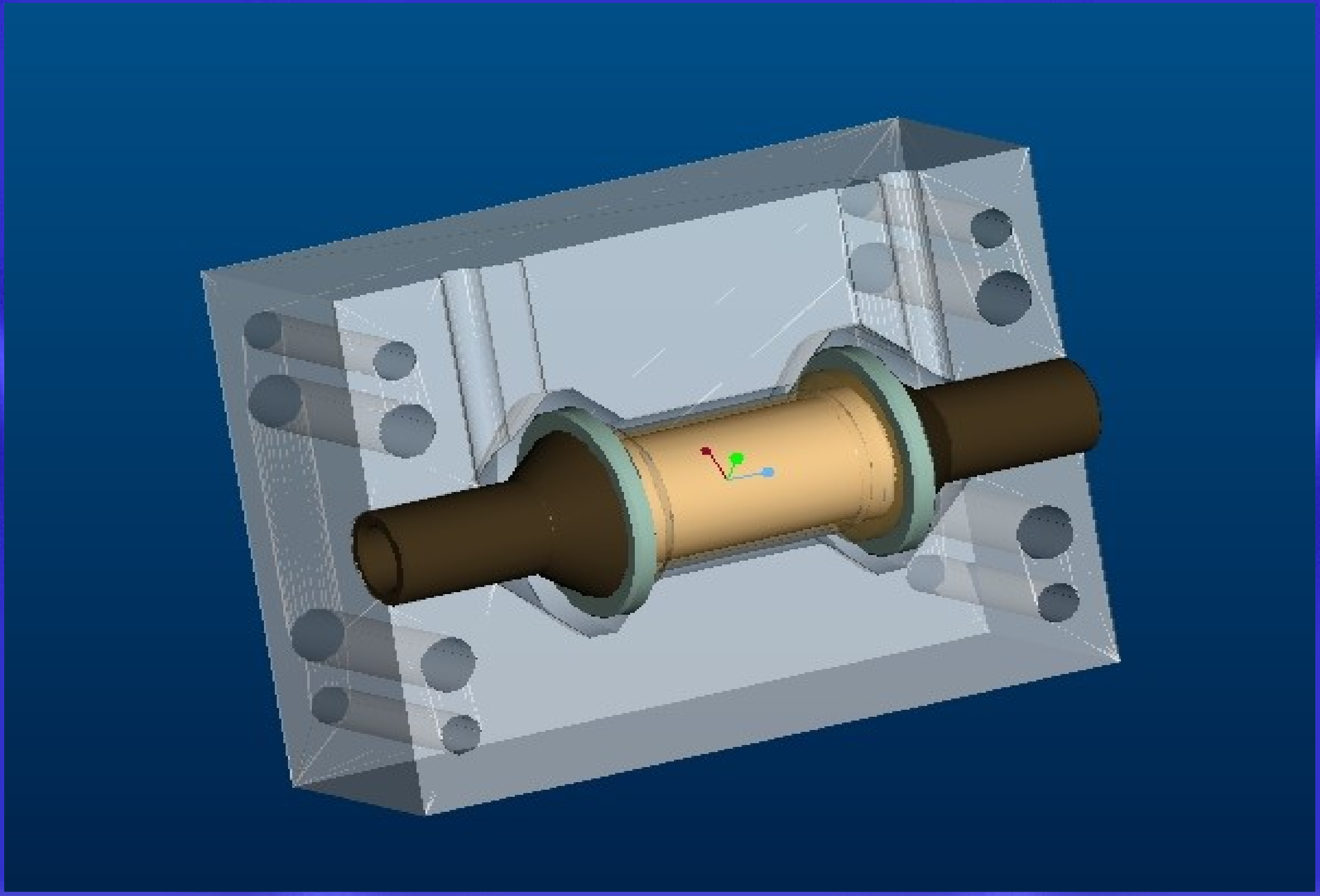
Response in air

..and in the sea

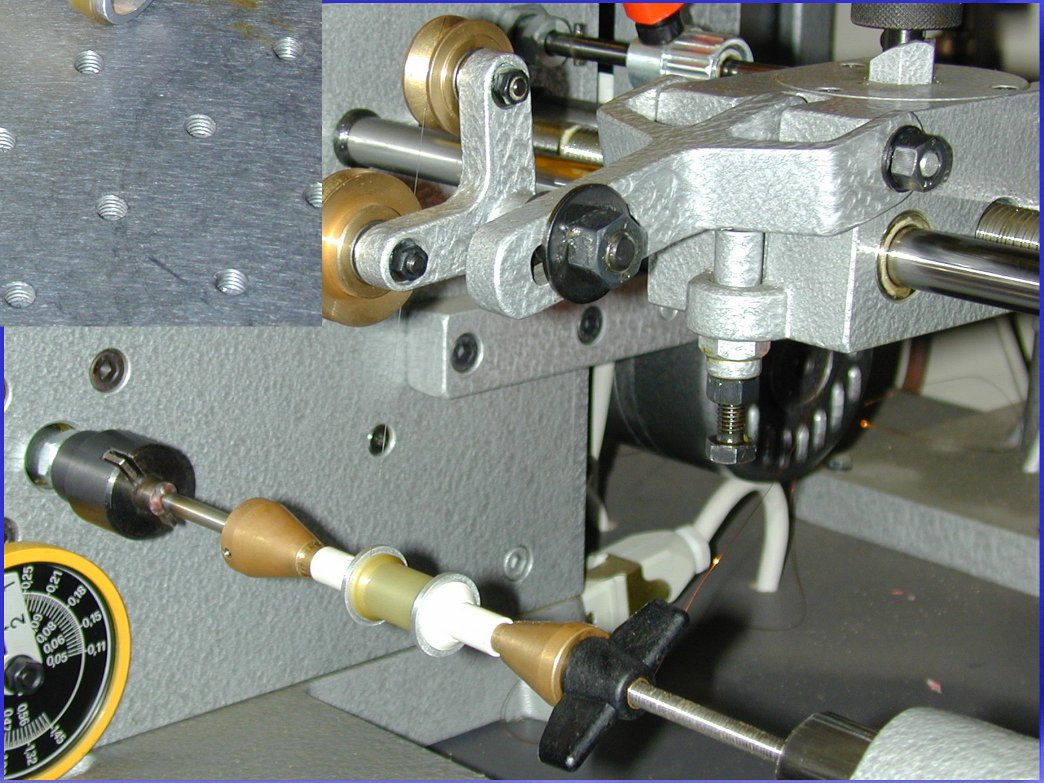
Next step: increase resonance frequency

∅: 22→15 mm, L:25→20 mm, fibre ∅ :125 → 80 μm

Expected resonance frequency in water ≈ 20 kHz



Production starts



The hydrophone in PISA

DIPARTIMENTO DI FISICA "Enrico Fermi"
Università di Pisa

IFAC

INFN

DEVELOPMENT OF AN ERBIUM-DOPED FIBER LASER AS A DEEP SEA HYDROPHONE

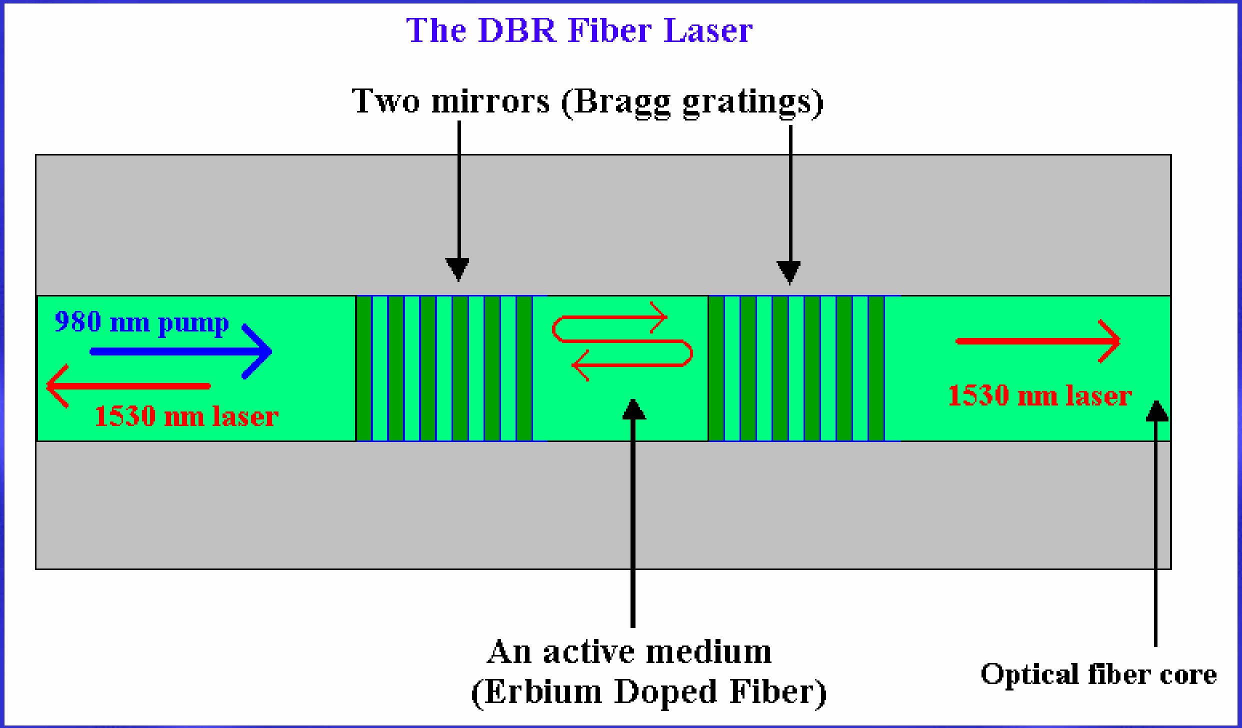
P.E.Bagnoli[1,2], N.Beverini[2,3], R.Falciai[4], E.Maccioni[2,3]
M.Morganti[2,3], F.Sorrentino[3], F.Stefani[1], C.Trono[3,4]

[1]Dipartimento di Ingegneria dell'Informazione, University of Pisa, Italy
[2]Istituto Nazionale di Fisica Nucleare, Pisa, Italy
[3]Dipartimento di Fisica, E.Fermi", University of Pisa, Italy
[4]Istituto di Fisica Applicata " Nello Carrara", IFAC-CNR, Firenze, Italy

THE DISTRIBUTED BRAGG REFLECTOR FIBER LASER (DBR-FL)

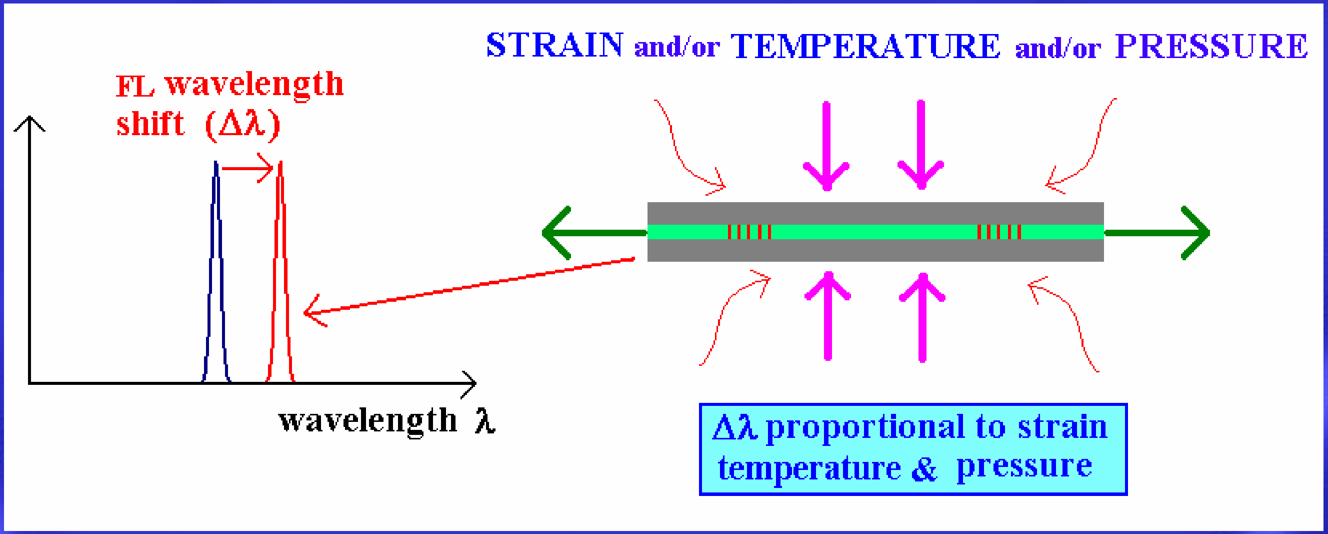
Two Bragg gratings with identical reflection wavelength are directly inscribed on the core of an erbium doped (active medium) optical fiber.

This structure forms a laser cavity which, when pumped at 980 nm, lases with emission peak at ~1530 nm



FIBER LASER SENSORS

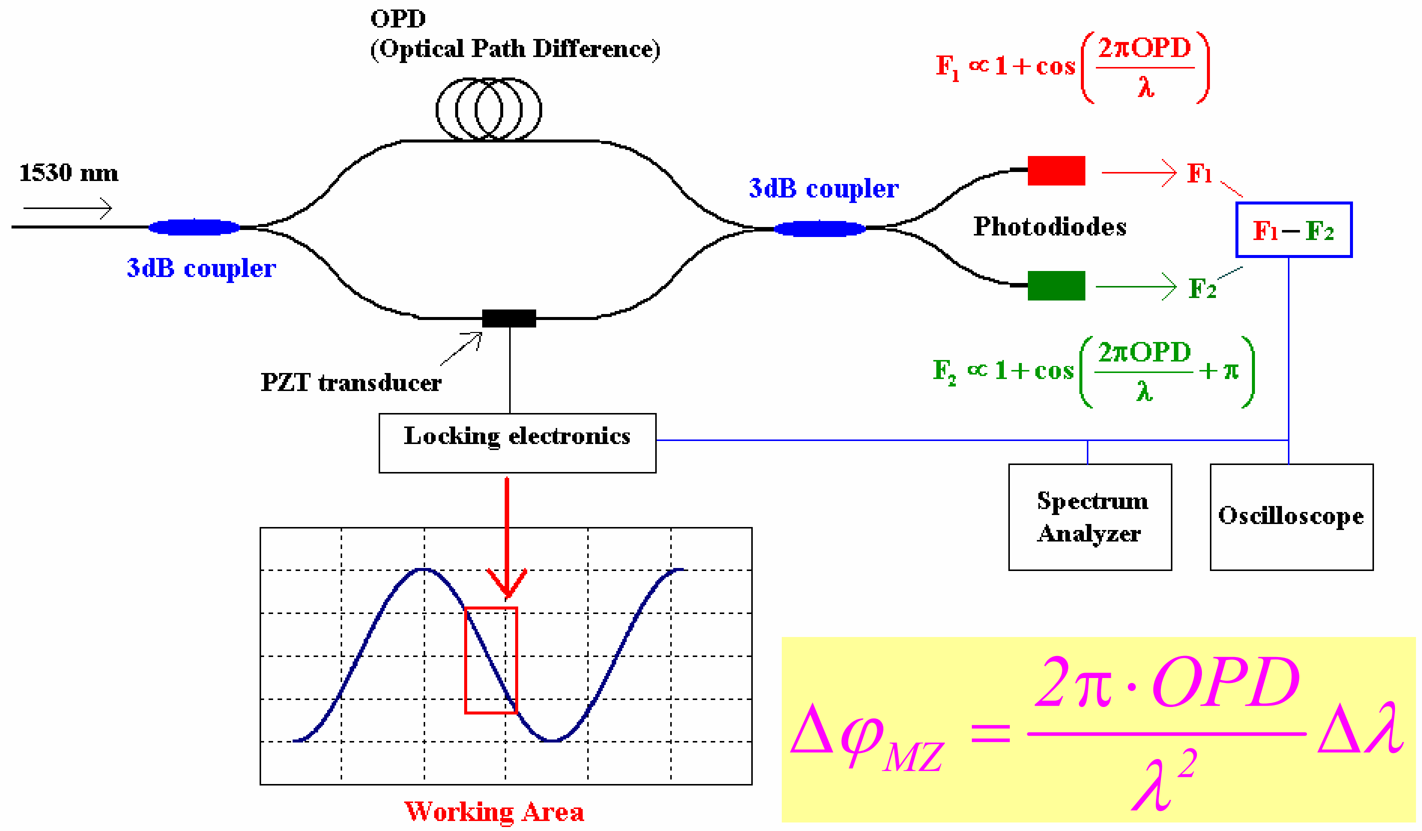
Physical elongation (**strain**), **temperature** and **pressure** variations, which changes the cavity length and fiber refractive index n_{eff}, produce a shift in the fiber laser emission line.



TYPICAL SENSITIVITIES FOR A BARE FIBER LASER

STRAIN [ε]	TEMPERATURE	PRESSURE
~1.2 pm/με @ 1550 nm	~ 10 pm/°C @ 1550 nm	~ -3.6 pm/MPa @ 1550 nm

MACH-ZENDER INTERFEROMETER (MZI)



$$\Delta\varphi_{MZ} = \frac{2\pi \cdot OPD}{\lambda^2}\Delta\lambda$$

For deep-sea applications, hydrophone sensitivity goal is the so-called Deep Sea State Zero (DSS0). At 1 kHz, the DSS0 level is 100 µPa/Hz$^{1/2}$, which corresponds to a $\Delta\lambda=10^{-12}$ nm.This requires an OPD of 300 m and a $\Delta\varphi_{MZ} \approx 1$ µrad, which is hard to gain, but realistic with the present technology.

DBR FIBER LASER

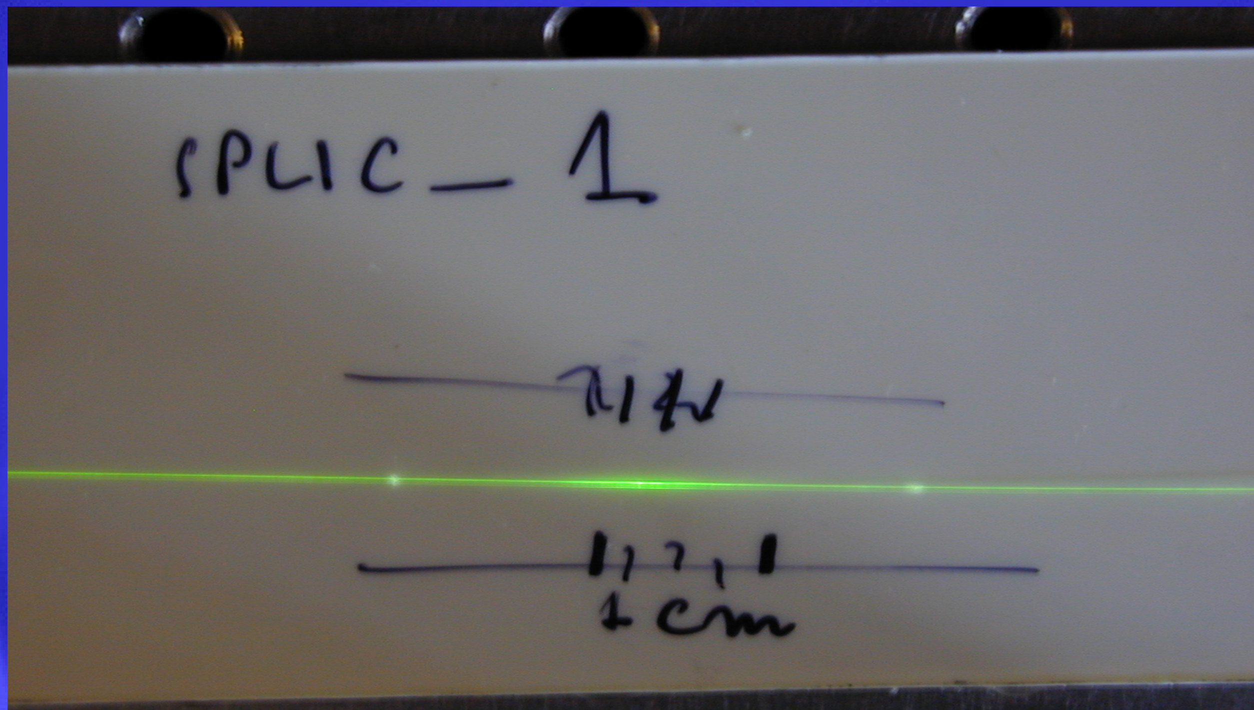


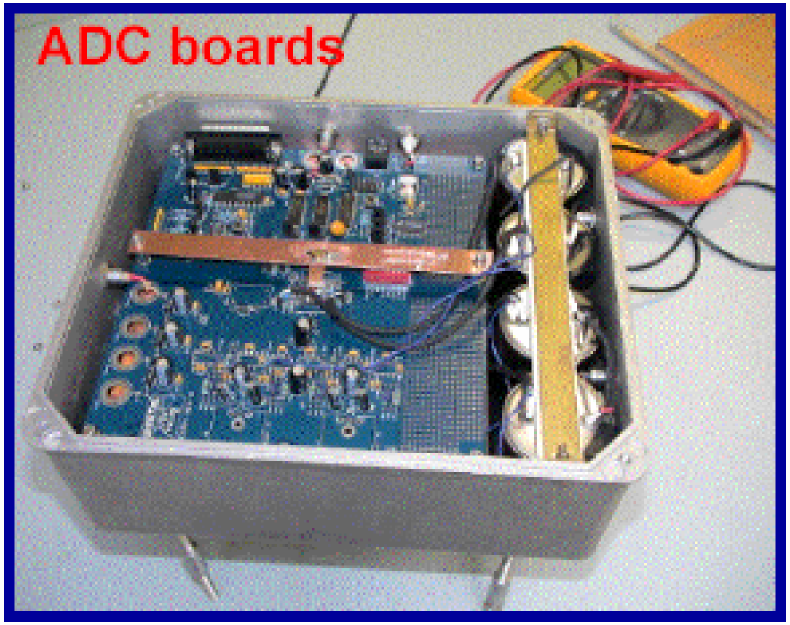
Photo of one of several DBR lasers realized. The green light is due to "up conversion" of pump laser radiation

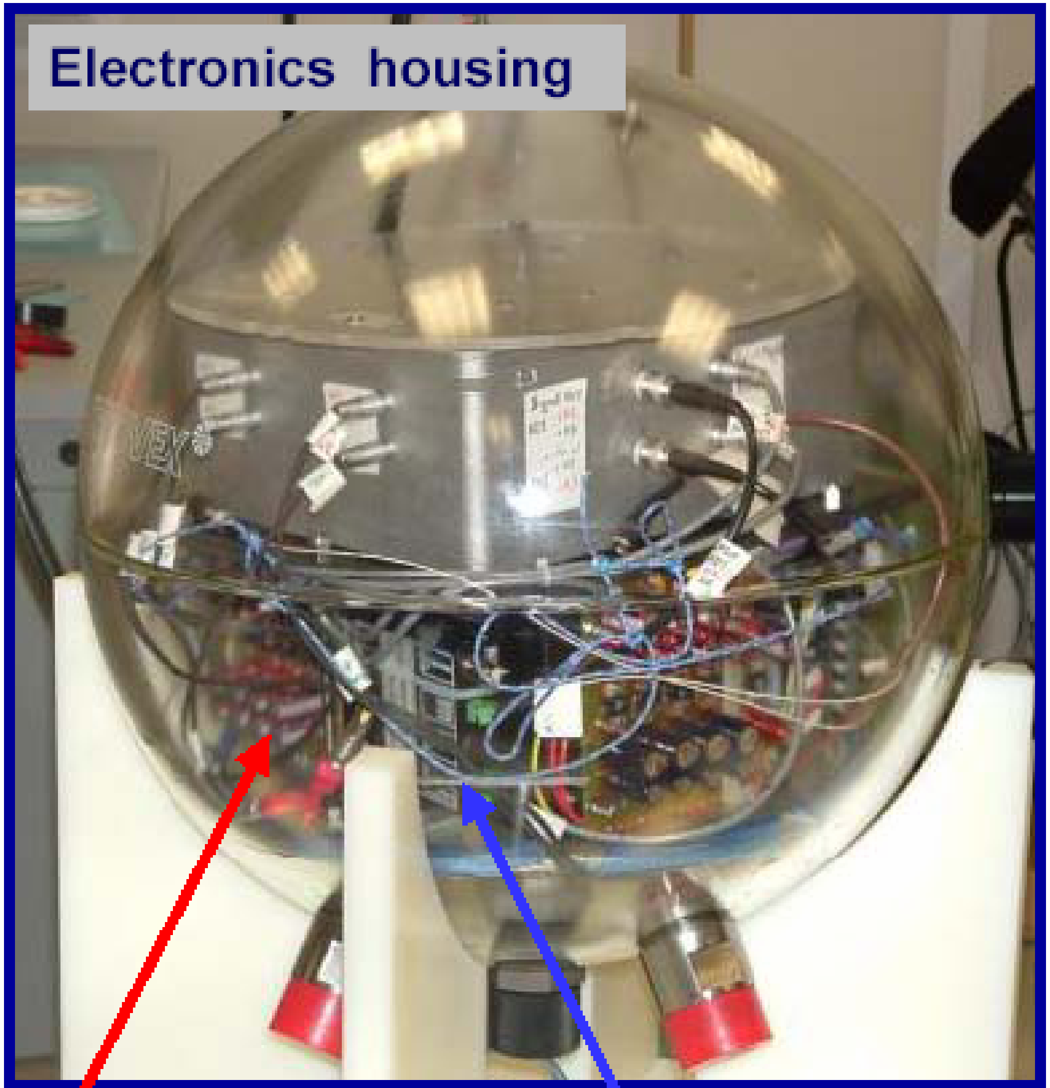
The ED fiber is cut and spliced to a standard fiber (low loss <0.3 dB/Km) very close to the cavity.

The hydrophone in Catania - LNS

First activities at the NEMO test site:
On line monitoring of underwater acoustic background from 2000 m depth

Experimental Apparatus

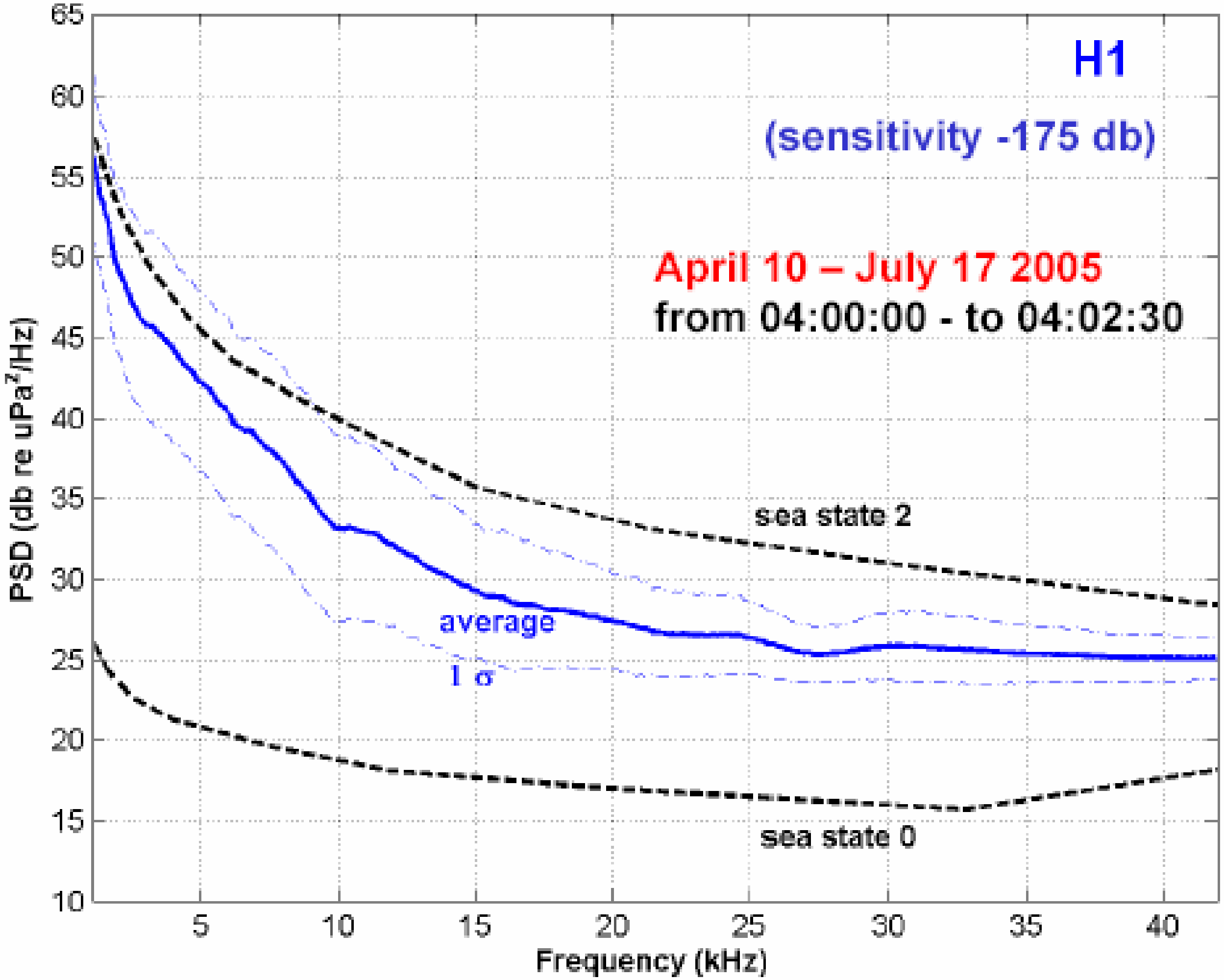




Power:
transformers and
regulators

Electro/Optical
Modem

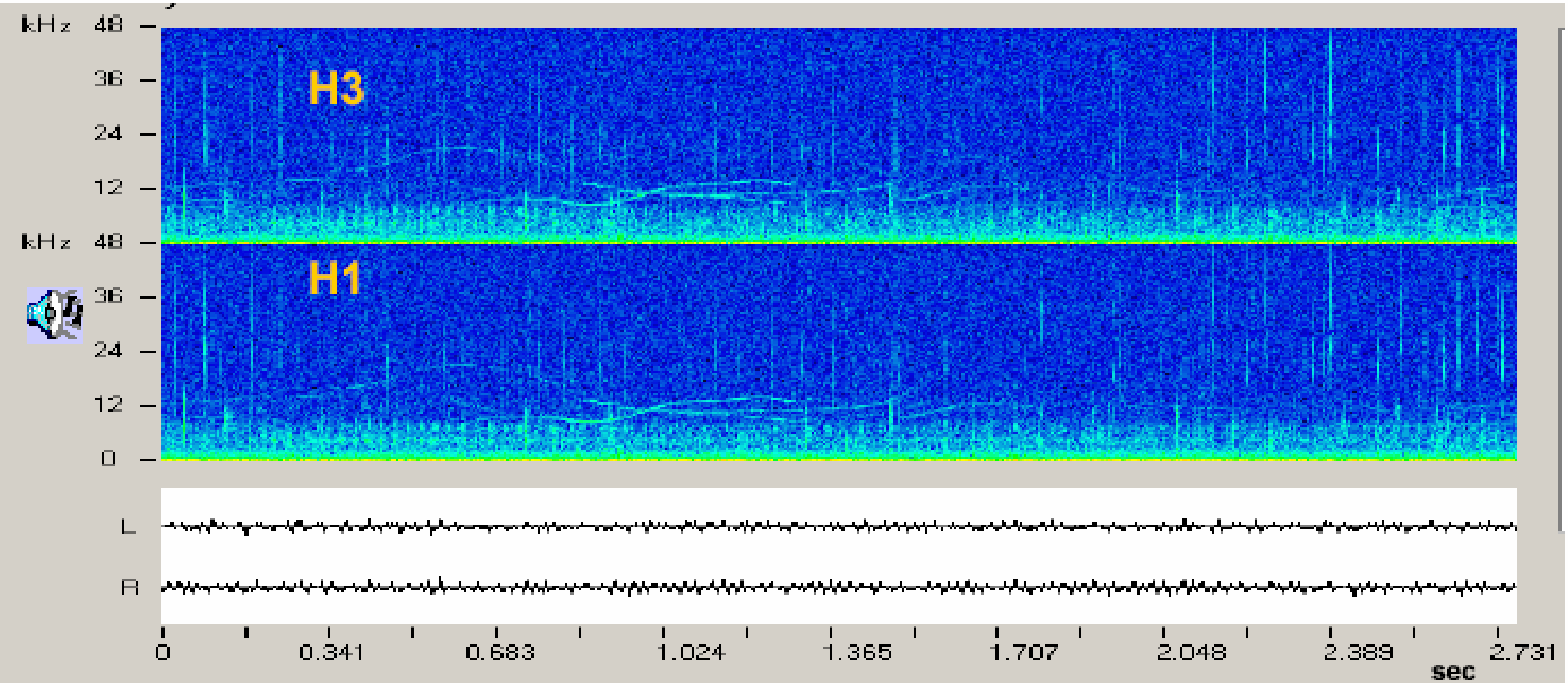
Average Noise Power Spectral Density



Fluctuations of noise level are strong below 20 kHz.

At higher frequency PSD = 25±2 db re ($\mu Pa^2/Hz$)

Search for Cetaceans in the Gulf of Catania



The detection of such sounds **indicates presence of marine mammals more frequent than previously believed.**

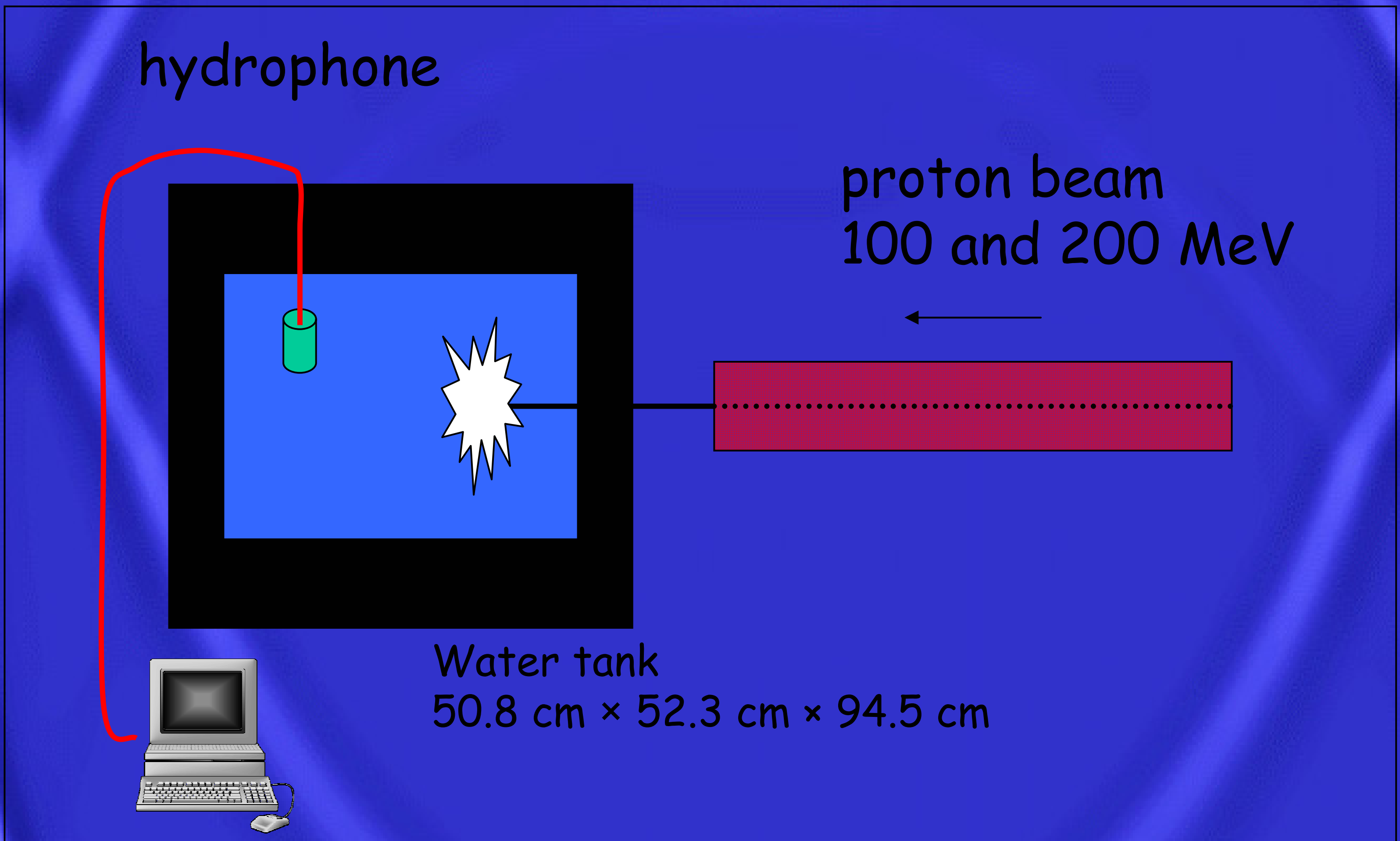
Long term observation and signal tracking will allow the determination of their presence and seasonal routes.

By analyzing sperm whale "click" details it is possible to assess the size and the sex of the animals.

INFN and CIBRA

Hydrophone Calibration at ITEP

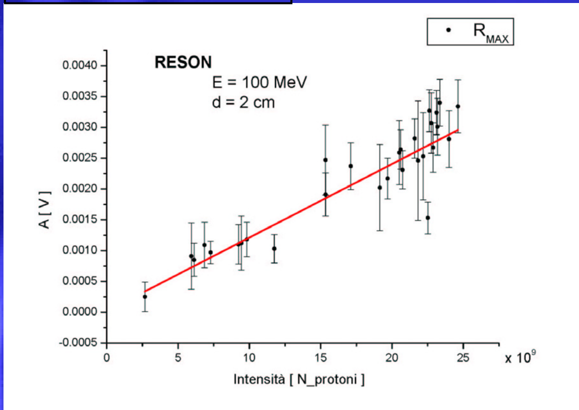
ITEP :V.Lyashuk, V.Lykiashin, A. Rostovstev
ROMA (University) :T.Capone,T.Chiarusi, C.De Bonis, R.Masullo

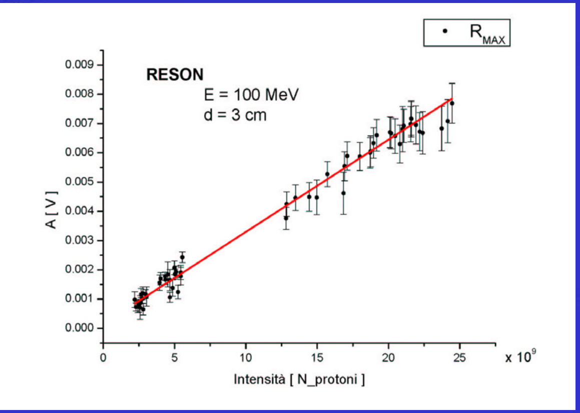


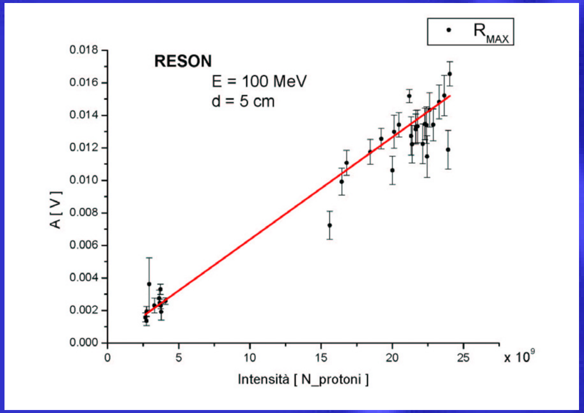
Signal amplitude vs beam current

RESON Hydrophone

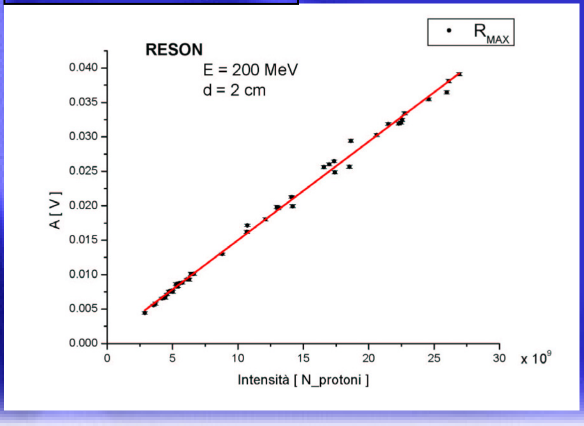
E = 100 MeV

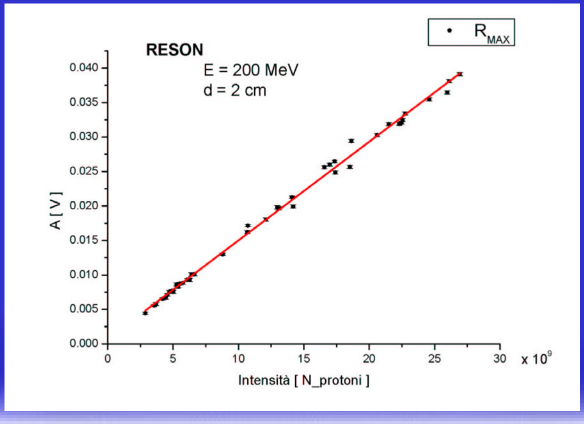


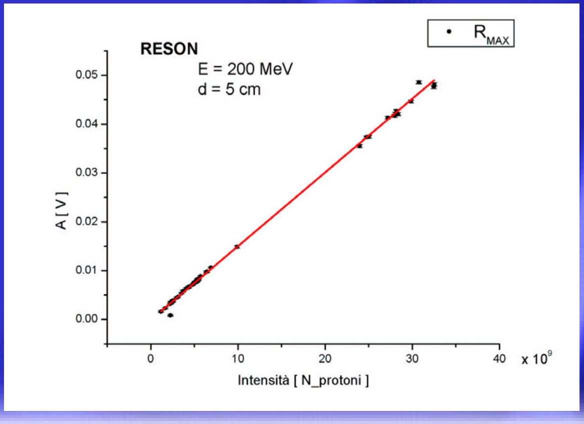




E = 200 MeV



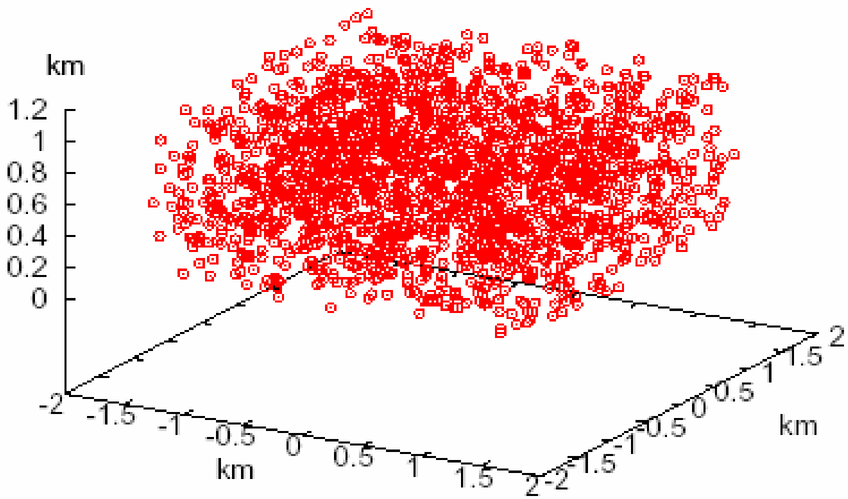




MC simulation

Detector Simulation

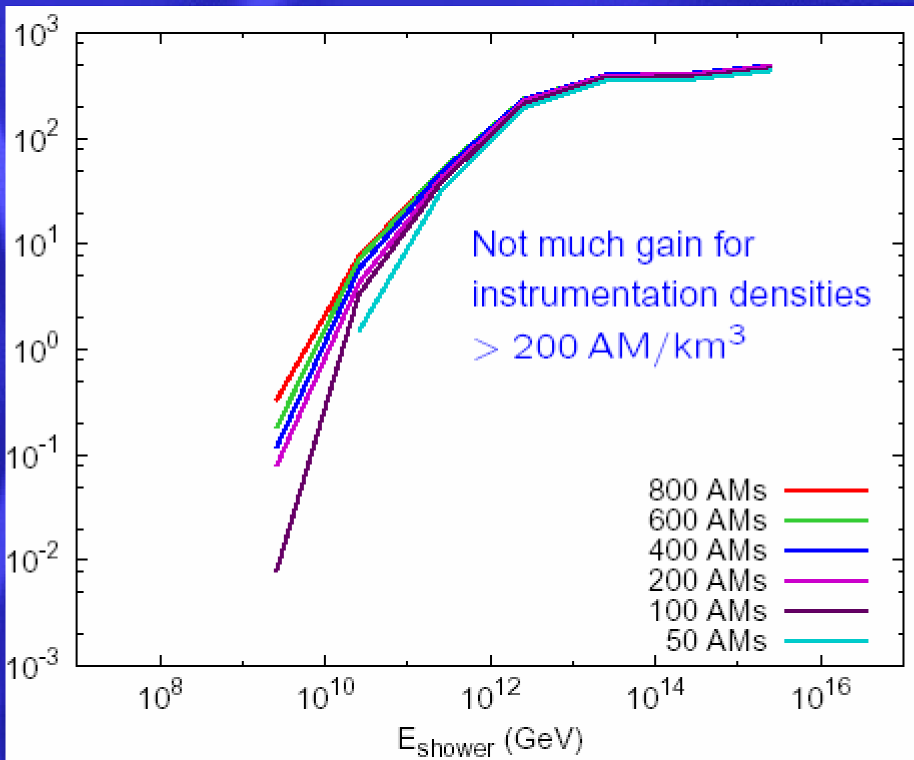
- Homogenous, but randomized, AM distribution to avoid geometry effects.
- Generate showers with a given energy spectrum
  and 2π sr angular distribution inside the can volume.
- Each AM records arrival time and amplitude of signals above a given threshold.
- A trigger in $\geq$ 4 AMs forms an event.



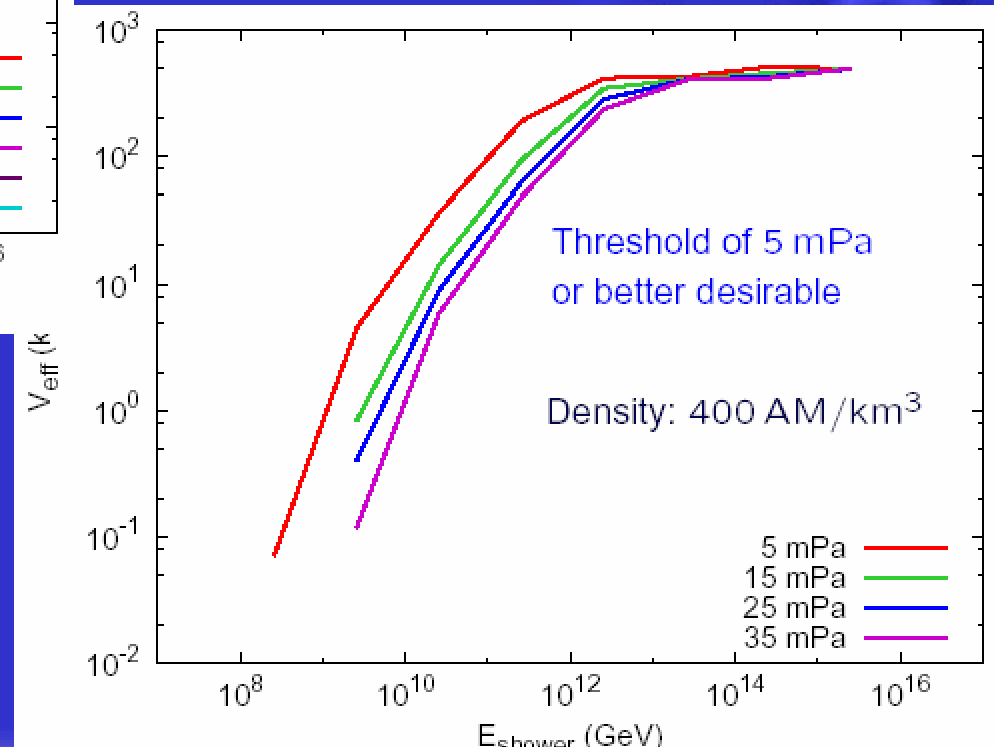
Example detector:

- instrumented volume: $10\,\mathrm{km}^3$
- density: $200\,\mathrm{AM/km}^3$
- precision:
  - AM-position: 10 cm
  - time: $10\,\mu s$
    (sampling: 100 kHz)
  - amplitude: 2 mPa

Effective volume



$$V_{\text{eff}} = \frac{N_{\text{det}}}{N_{\text{gen}}} V_{\text{gen}}$$



T.Karg
U.Erlangen
ARENA 2005

Signal processing

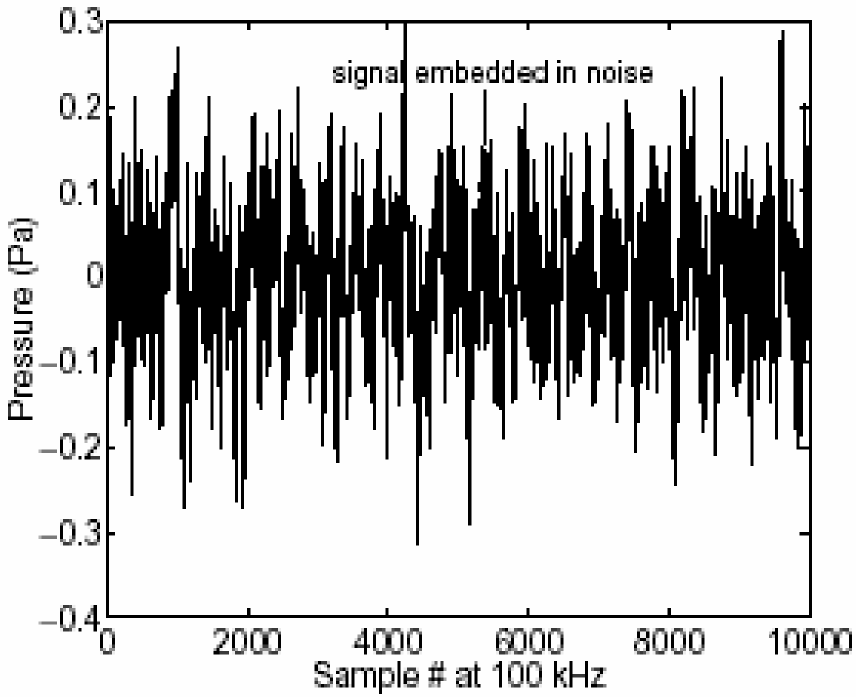


FIG. 8: The signal from 2×10^{19} eV hadronic shower artificially embedded in the noise sample of length $M = 10000$ at position $k_0 = 5000$. The noise is simulated using the spectrum for wind speed of 13 knots. The time interval of this sample is 0.1 s.

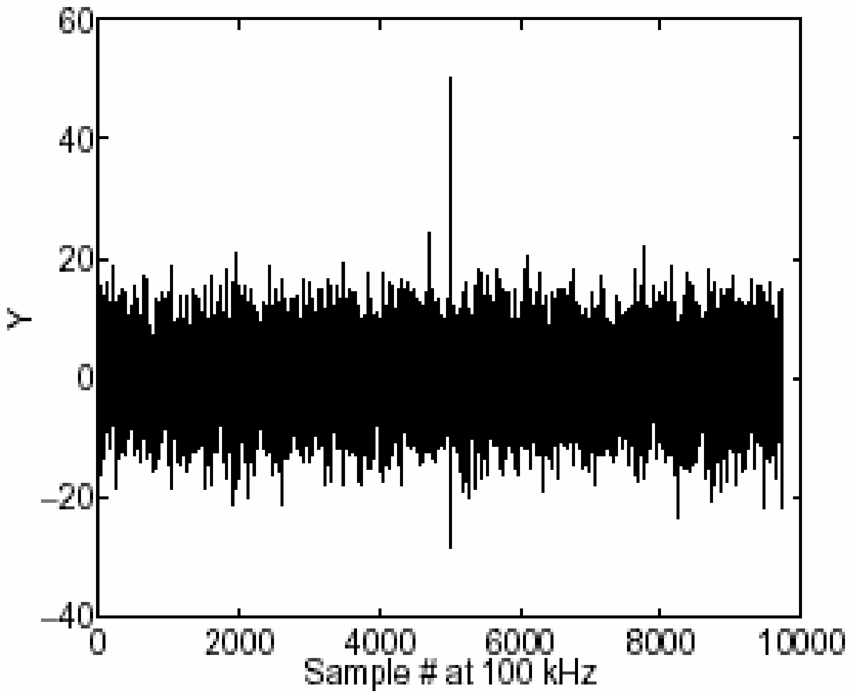


FIG. 9: The variable Y discussed in the text and computed in detail in Appendix (see equation A3) for the time series shown in Figure 8. A prominent peak at the correct location of $k_0 = 5000$ is clearly visible.

Nikolai G. Lehtinen et al. for the AUTEC hydropone array

Still many things to do...

MC simulation:

- generation of the signal, propagation in real media (attenuation, reflection)
- Reconstruction algorithms
- Evaluation of effective volume as a function of energy and geometrical configuration

Signal processing

- Algorithms to improve signal/noise
- Time correlations
- Detailed measurement of the environmental noise

Hydrophones

- Calibration with known sources (proton beam, sparks, implosion of small vessels)
- Tests in water tanks
- Developement of the present fiber optic hydrophones

• • • • • •

... and in particular

Genova: **read out electronics; extension of the single hydrophone configuration to a multiple array**

LNS: **data analysis from a small (4) set of hydrophones; signal Processing; noise reduction**

Pisa : **signal processing; laser expert; read out electronics**

Roma: **R&D for absolute calibration of an hydrophone in the open sea**

CONCLUSIONS

- Extremely high energy neutrinos ($E \approx 10^{18 \div 20}$ eV) are a challenging probe to study the exotic phenomena in the Universe.

- The hadronic shower produced in their interaction with water can be detected with hydrophones.

- A lot of activity is underway...but still a lot of R&D is needed.

- COLLABORATION usefull !!

Hydrophone:
Realization of one prototype; test in air using the present read out configuration (A. Plotnikov).

Upgrade of the read out electronics: new ADC board (already available but not used); extension to an array of hydrophones (signal multiplexing)

Test of the Hydrophone in water (poliurethane coating, test on water tank , test in open sea)

Simulation of the acoustic propagation; reconstruction algorithms, effective volume in different hydrophone configuration, ...

KM3net:
Relization of a module of an ANTARES string (5 modules) to be located at the NEMO site.