A large fiber sensor network for an acoustic neutrino telescope

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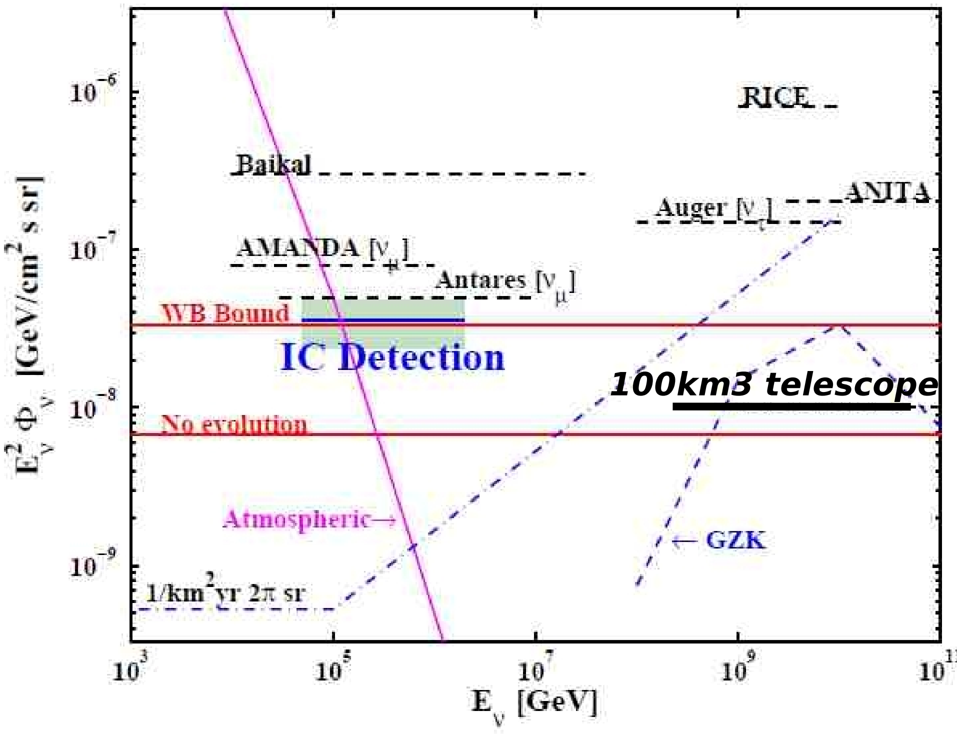
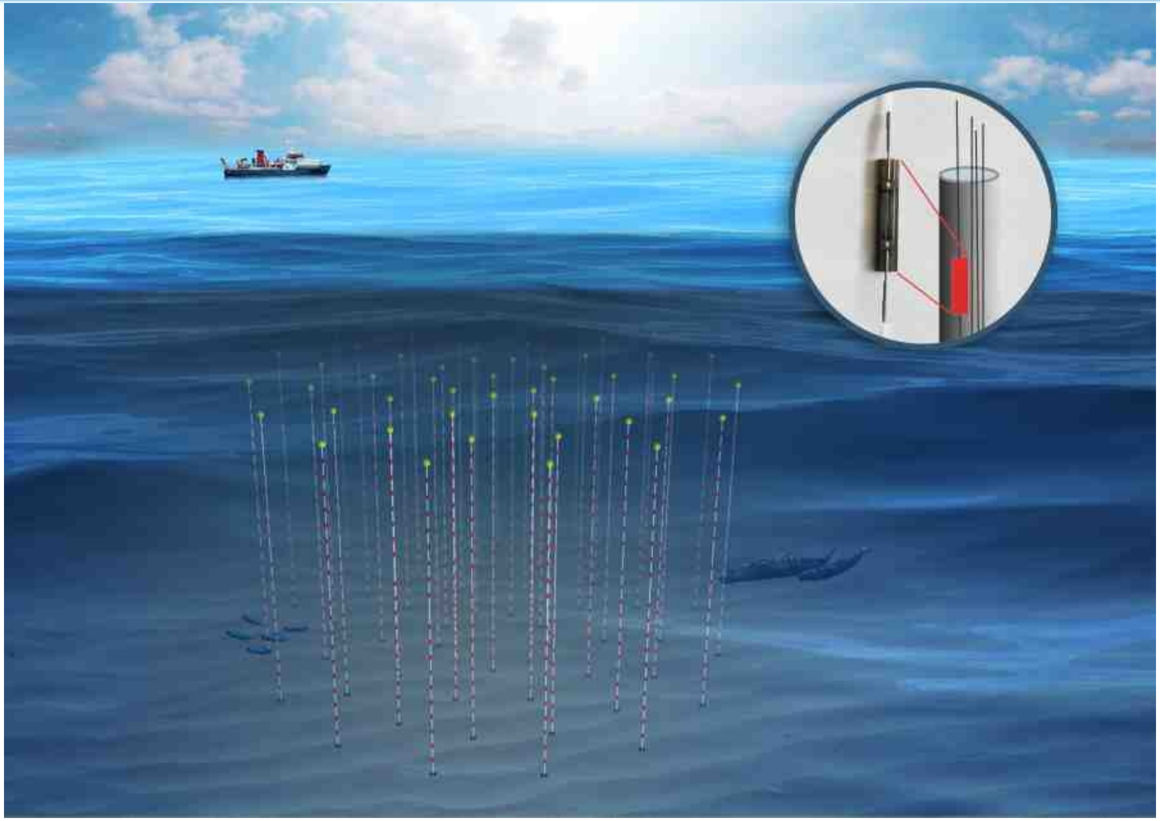
UHE neutrinos

- Scientific objectives: *GZK mechanism,* GRBs, superheavy dark matter
- Detecion of neutrino's with energy > EeV: Expected low fluxes
- ***Target detection volume 100 km3***

Waxman, Arxiv:1312.0558



Acoustic detection of cosmic neutrinos



- 3D geometry: > 100 strings
- or 2D geometry on seafloor

Required: > 1000 hydrophones

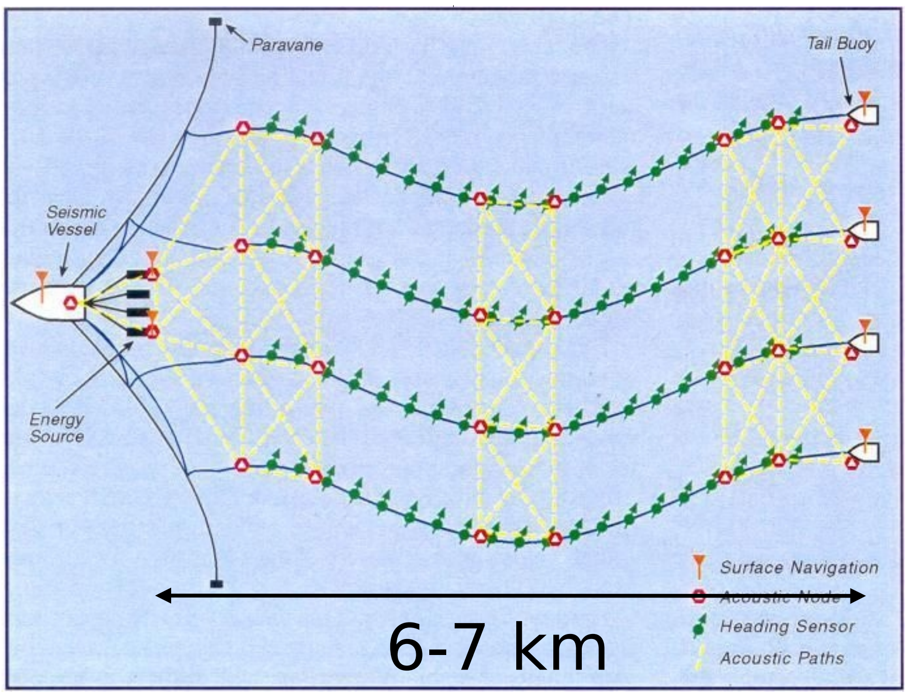
Hydrophone arrays in industry

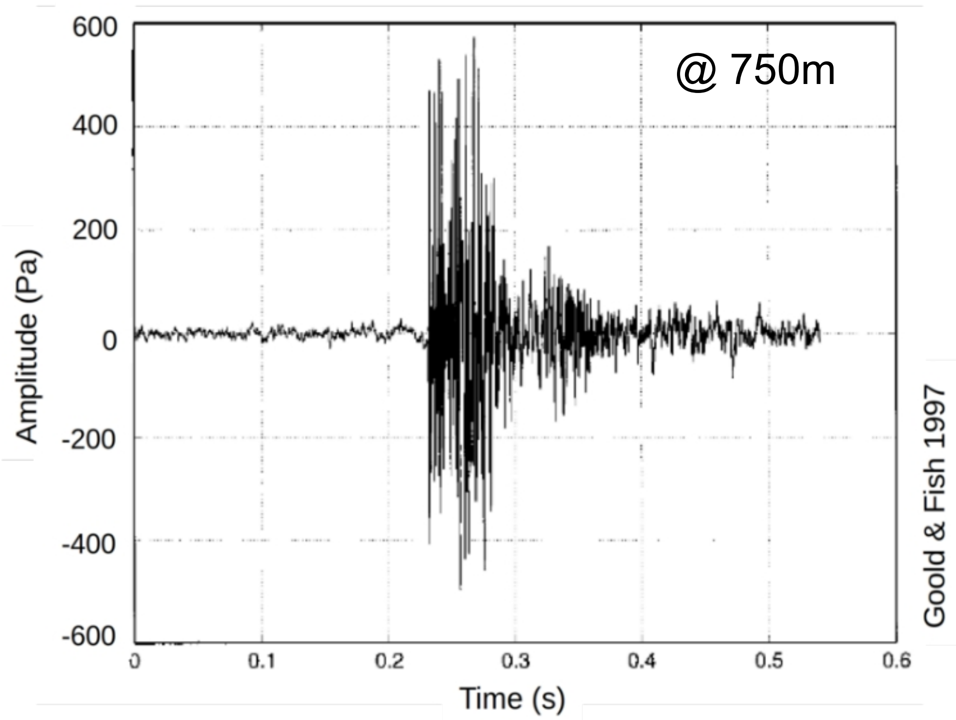
- Applications of hydrophones in the **oil&gas** industry

A towed neutrino telescope?

Hydrophone arrays in industry

- Applications of hydrophones in the **oil&gas** industry
- Air gun: signals with up to kPa amplitudes (!!)





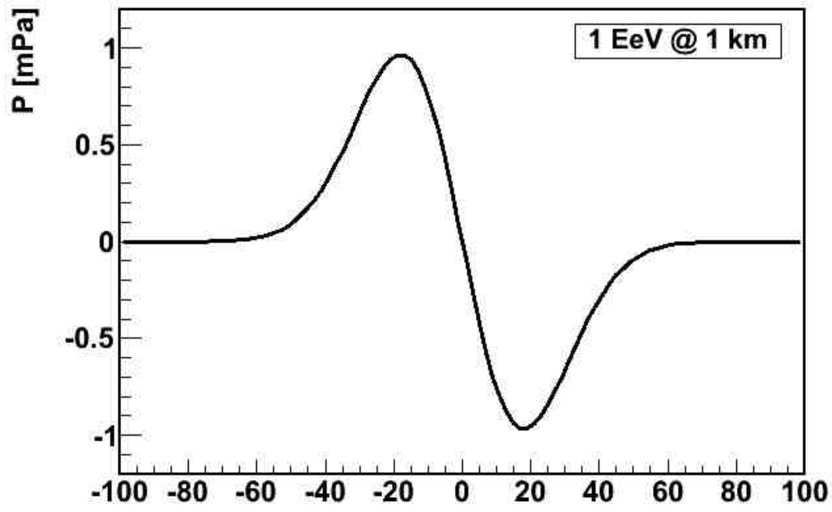
Hydrophone array for neutrinos

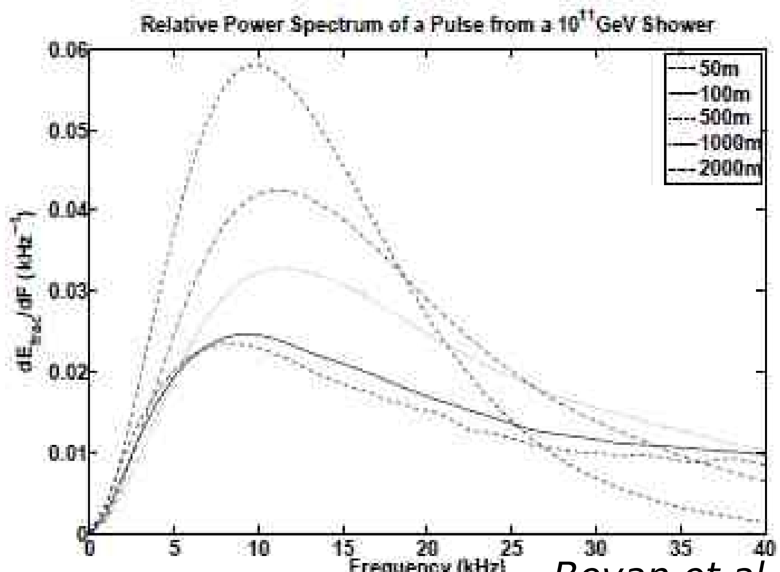
- New technology and dedicated development is needed for
  - Extreme small signals
  - And even larger arrays with high hydrophone density

- *Move to fiber optic technology*

Acoustic signals of neutrinos

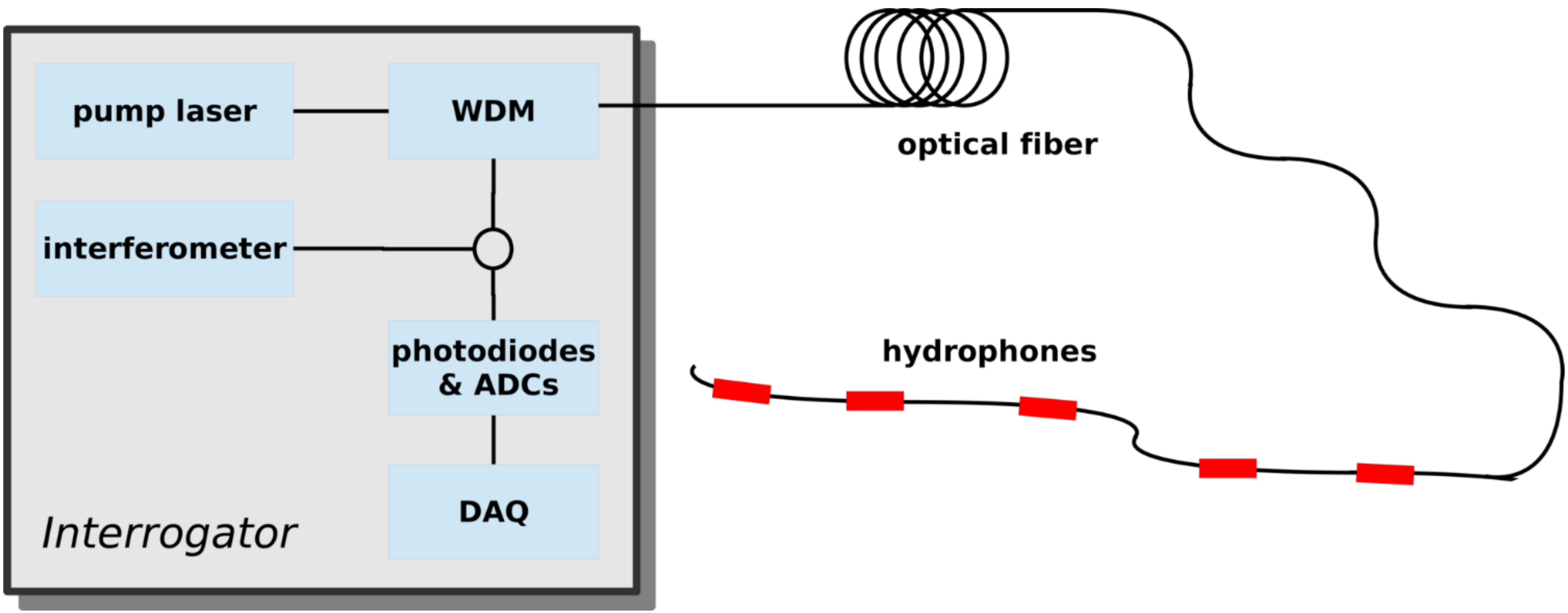
- Bipolar pulse, several mPa amplitude
- Frequency spectrum peaks at 5-10 kHz.
- Spectrum depends on the position of the hydrophones wrt to the source (both distance and angle).





Bevan et al 2007

Measurement concept



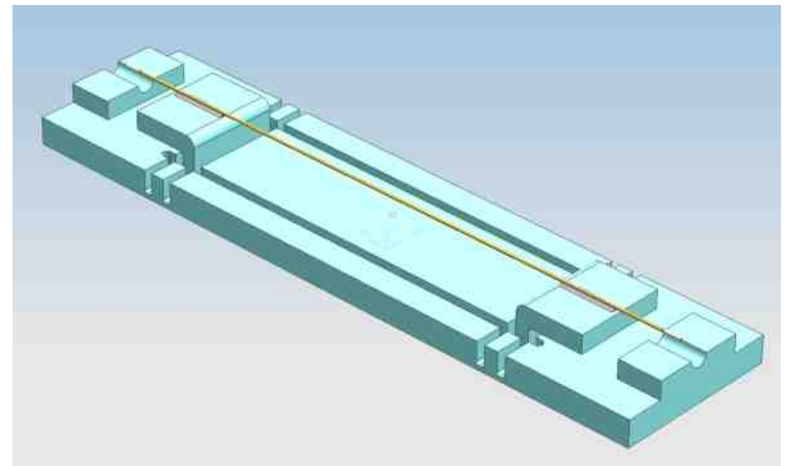
Three main components:
hydrophone sensor, *optical fiber* and *interrogator*

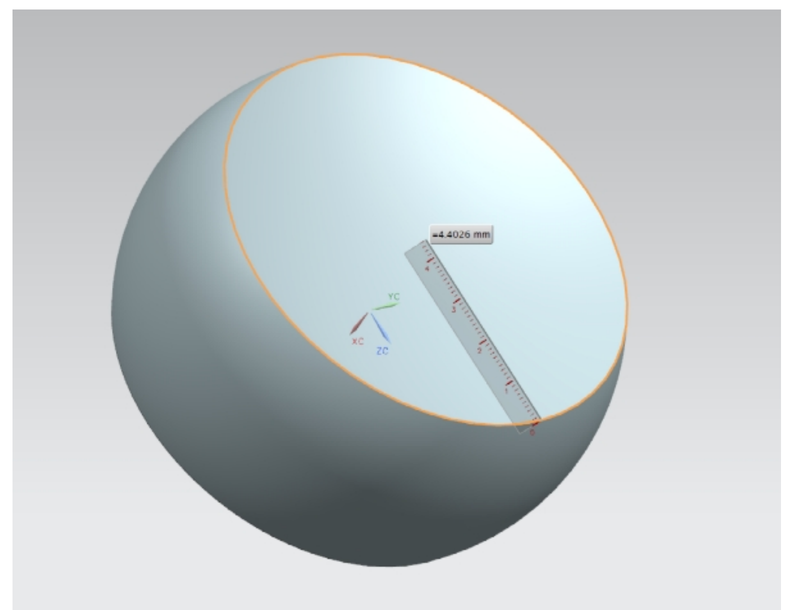
Sensor

- Sensor is a mechanical <u>transducer</u> that converts pressure in strain in the fiber
- Transducer should exhibit a large <u>strain sensitivity:</u>

  $\eta > 10^{-11}\ \varepsilon/\mathrm{mPa}$

- <u>Two type of sensors</u> have been produced at TNO
- Material: Aluminum
- Size is related to the acoustic wavelength





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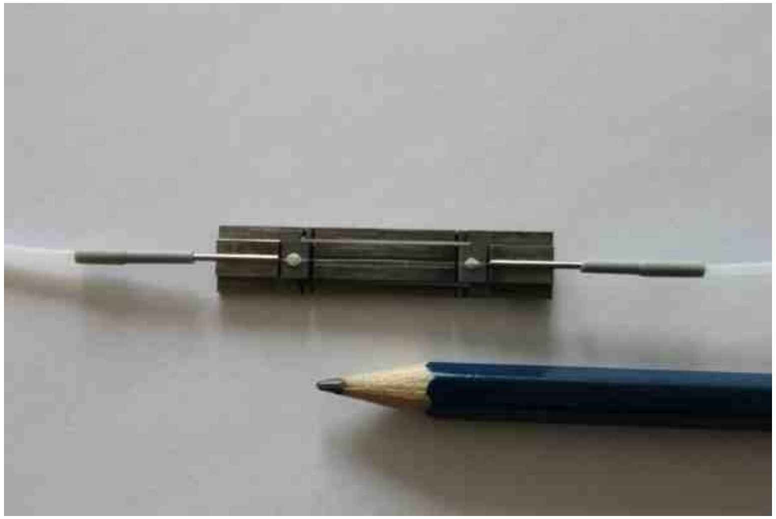
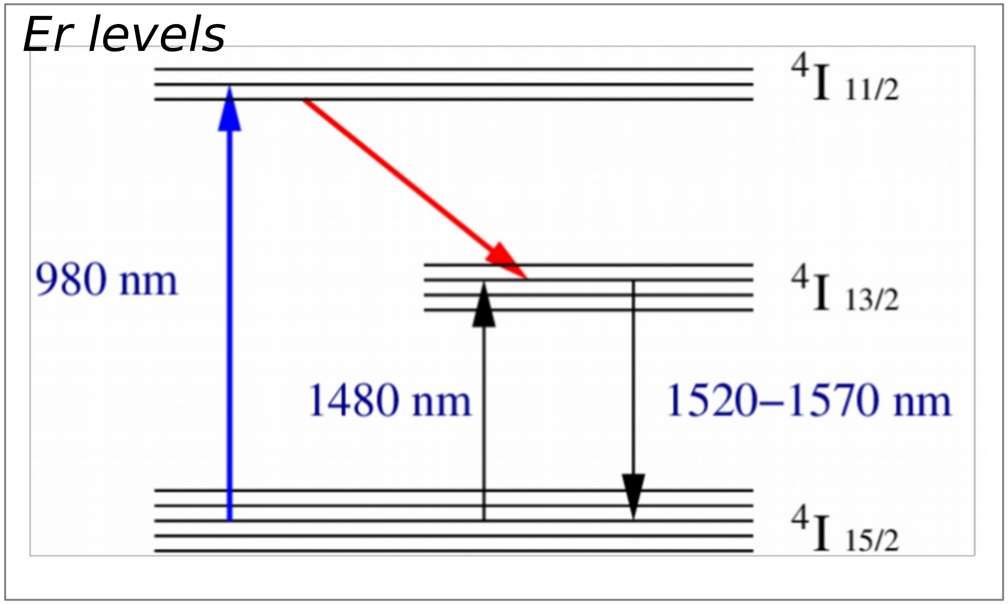
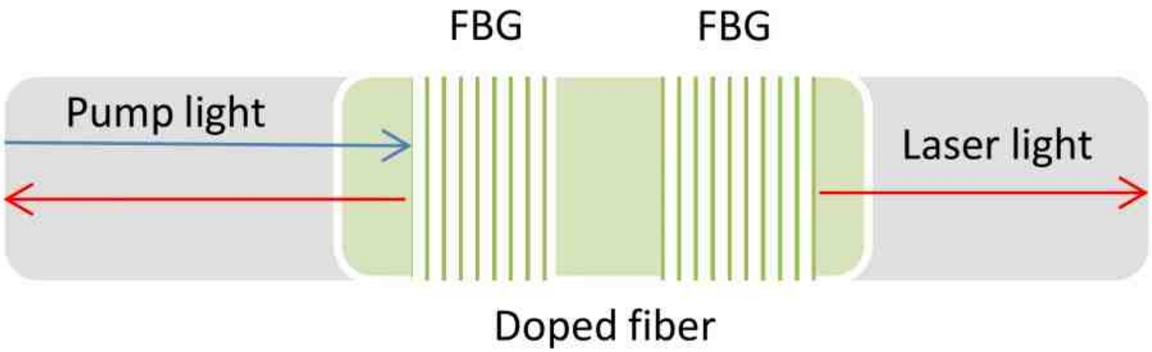


Fiber laser

- Optical fiber includes fiber lasers
- Optical lasers are based on *erbium doped fibers*
- Grating structure applied to create a laser



Pumping @ 980 or 1480 nm,
Laser source at 1520-1570 nm



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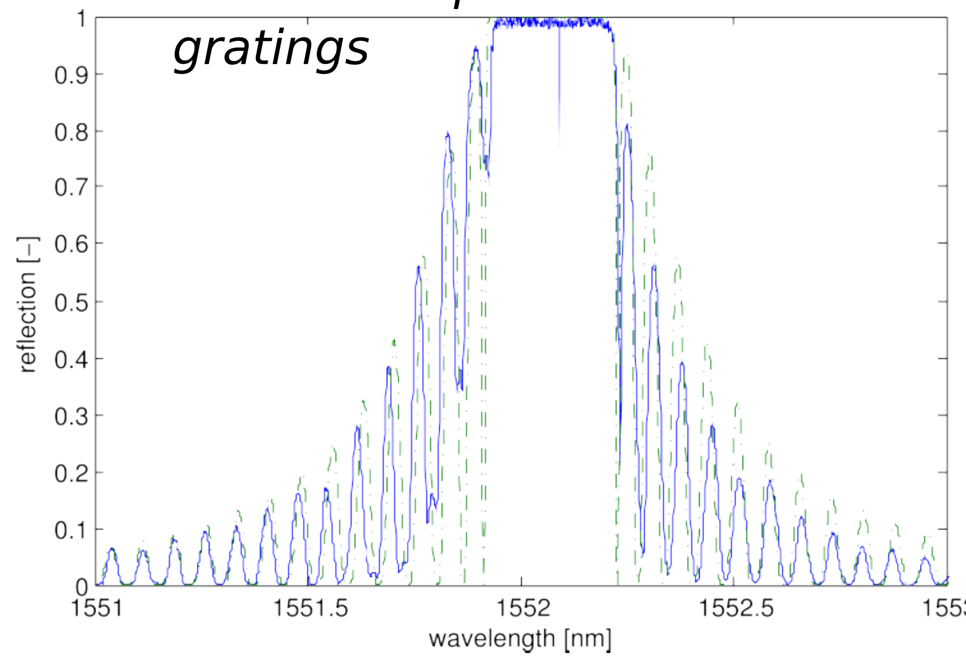
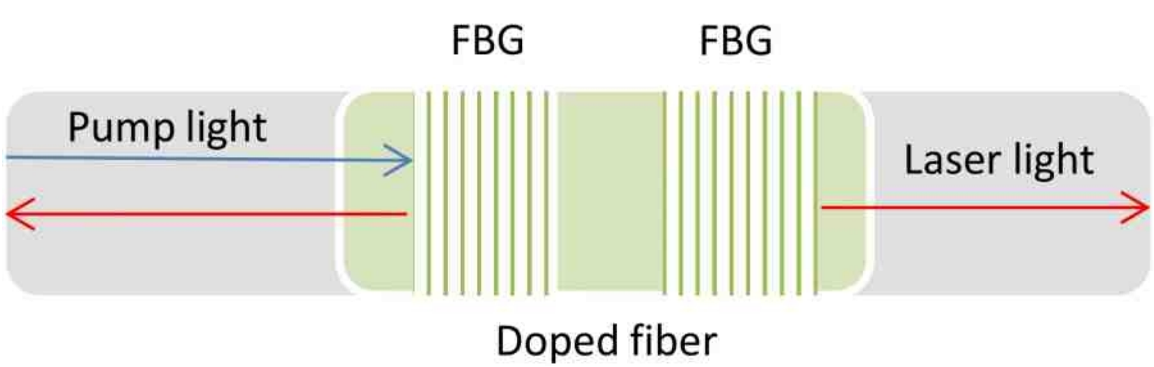
Reflection spectrum of the gratings





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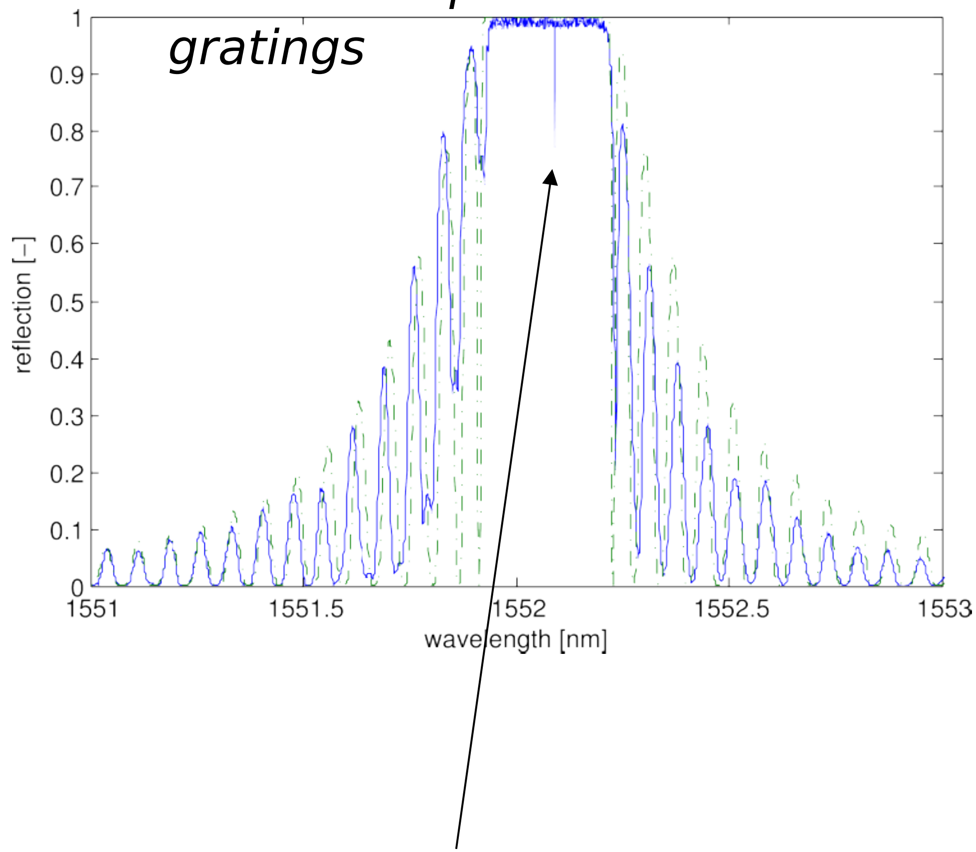
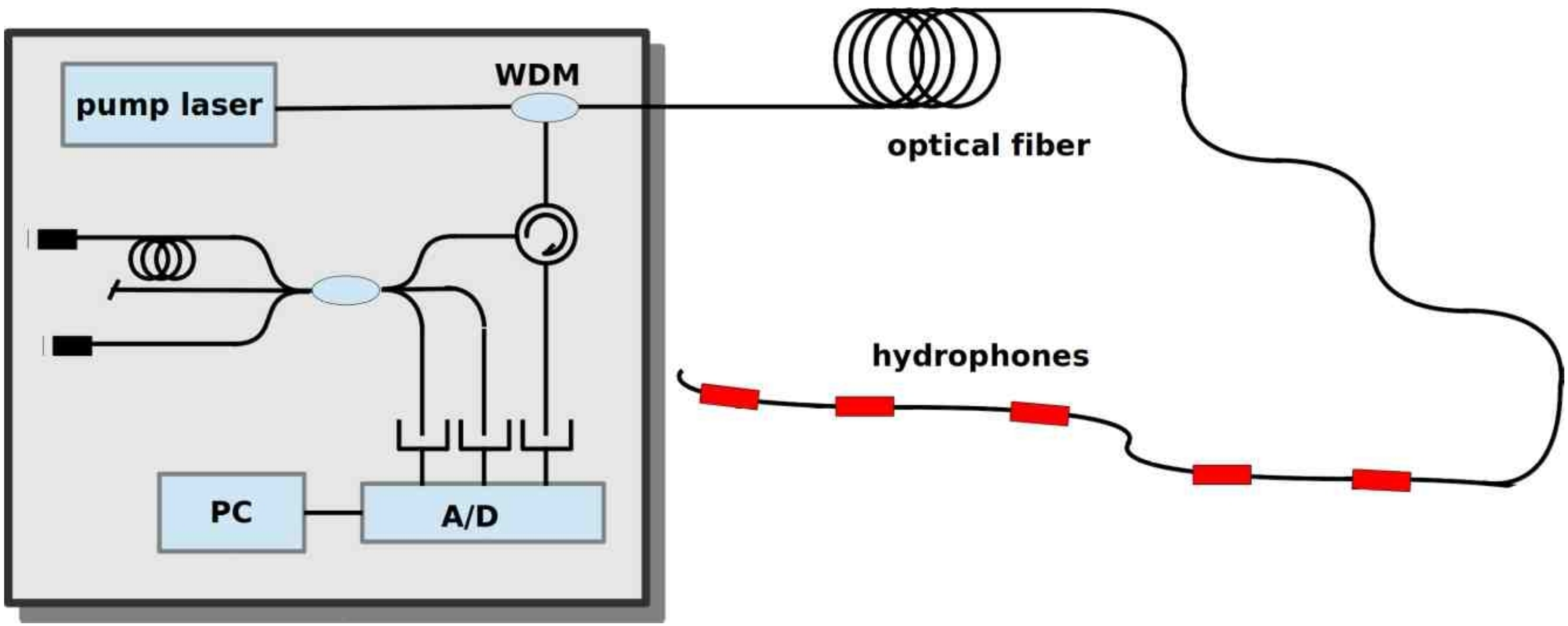


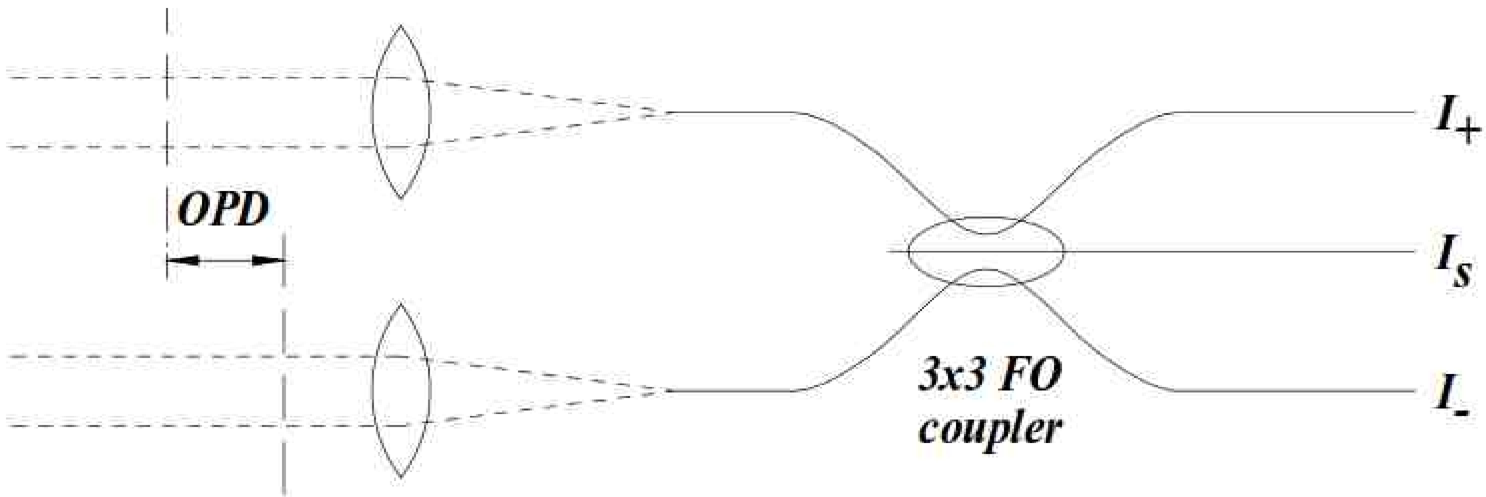
Coherent light source:
line width ~ 5kHz.

Interferometer



- 3x3 interferometer: *coupler* with fixed phase difference in output branches.
- Need 3 photodiodes per sensor
- Normalize each output

Interferometer



$$I_S(OPD) = A_0(1 + V\cos(\frac{2\pi}{\lambda}OPD)).$$

$$I_+(OPD) = A_0(1 + V\cos(\frac{2\pi}{\lambda}OPD + \frac{2\pi}{3})).$$

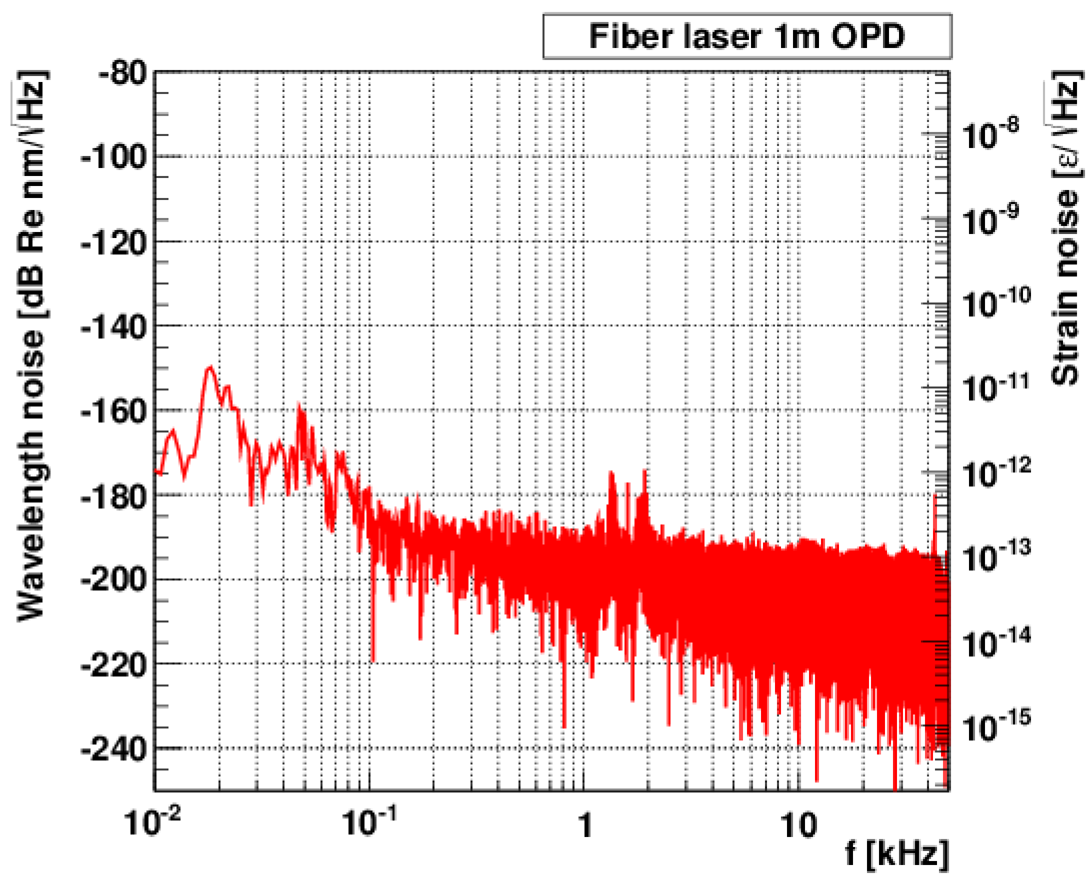
$$I_-(OPD) = A_0(1 + V\cos(\frac{2\pi}{\lambda}OPD - \frac{2\pi}{3})).$$

$$OPD = \frac{\lambda}{2\pi}\arctan\left(\sqrt{3}\frac{I_+ - I_-}{2I_s - I_+ - I_-}\right).$$

- 3x3 interferometer: *coupler* with fixed phase difference in output branches.
- Need 3 photodiodes per interrogator
- Normalize each output

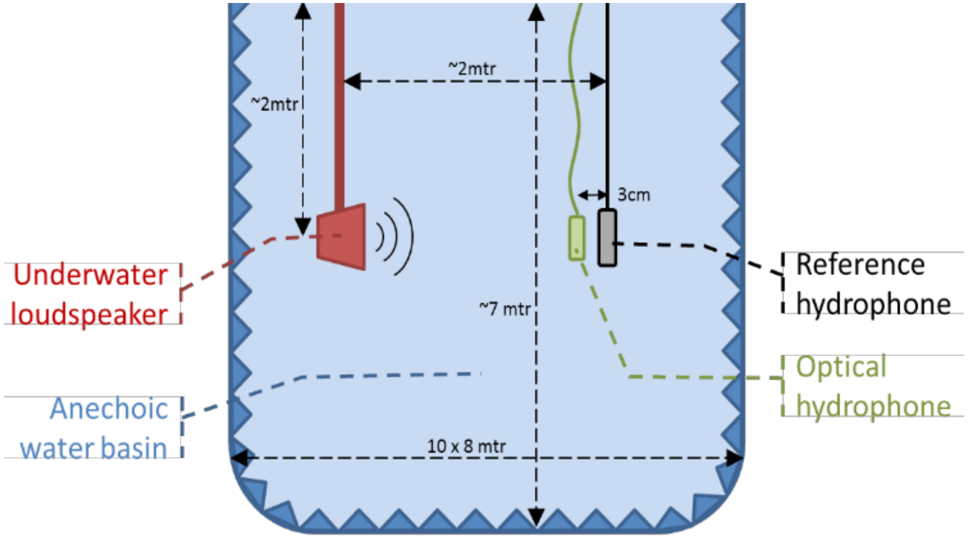
Interrogator

- Performance measured at an acoustically and vibration isolated environment.
- Good noise performance



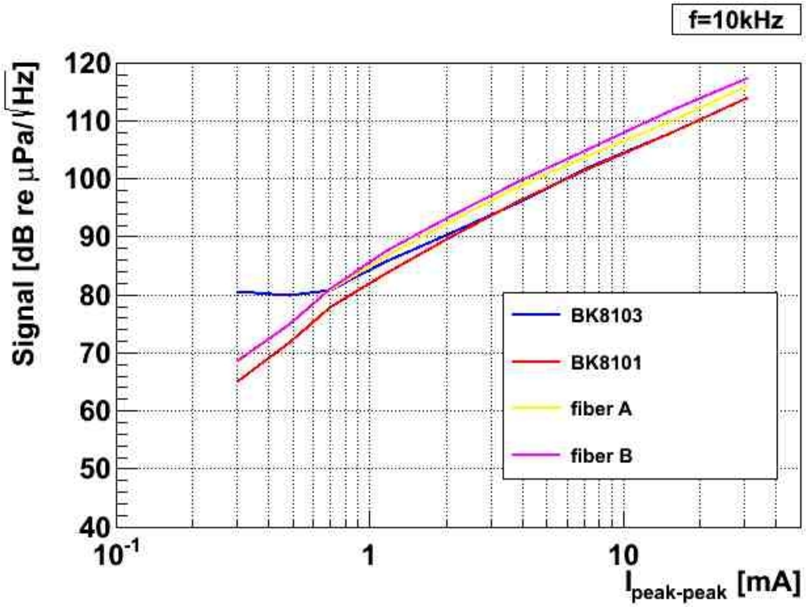
Experimental set-up

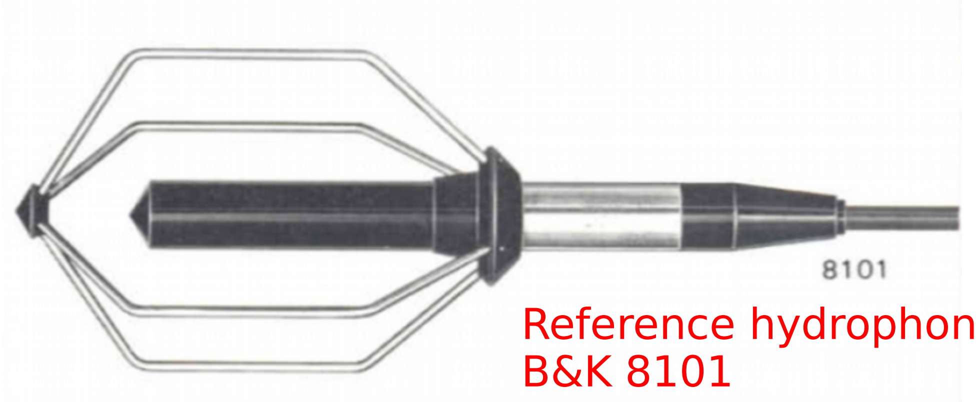
- Measurements carried out at the anechoic basin at TNO.
- Basin measures 8x10x7 m^3
- Using well calibrated reference hydrophones (BK types 8101, 8103)



Linearity measurements

- Response to a single tone (at given frequency) is measured as a function of the input current in to the projector.
- Output signal is measured for two reference hydrophones and 2 fiber laser hydrophones.
- Fiber laser hydrophones are linear down to levels compared to sea state 1

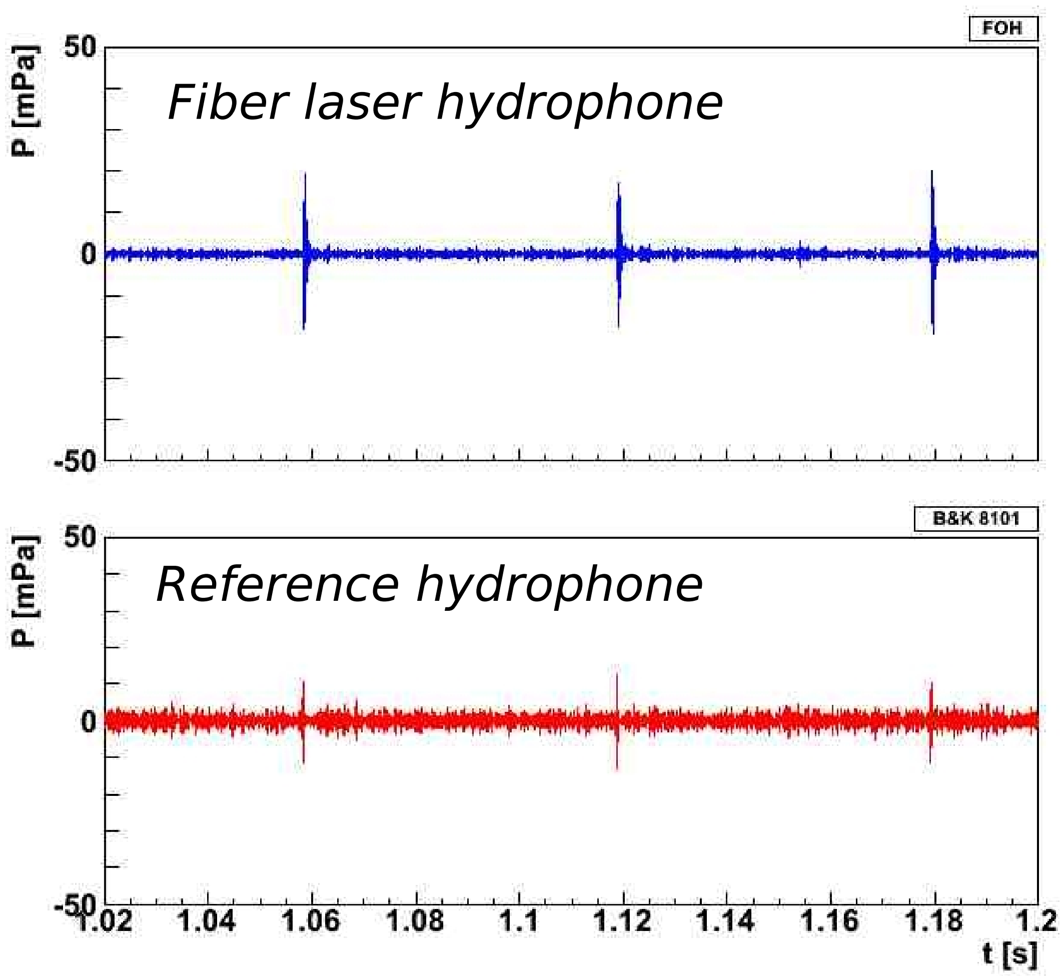




Reference hydrophone
B&K 8101

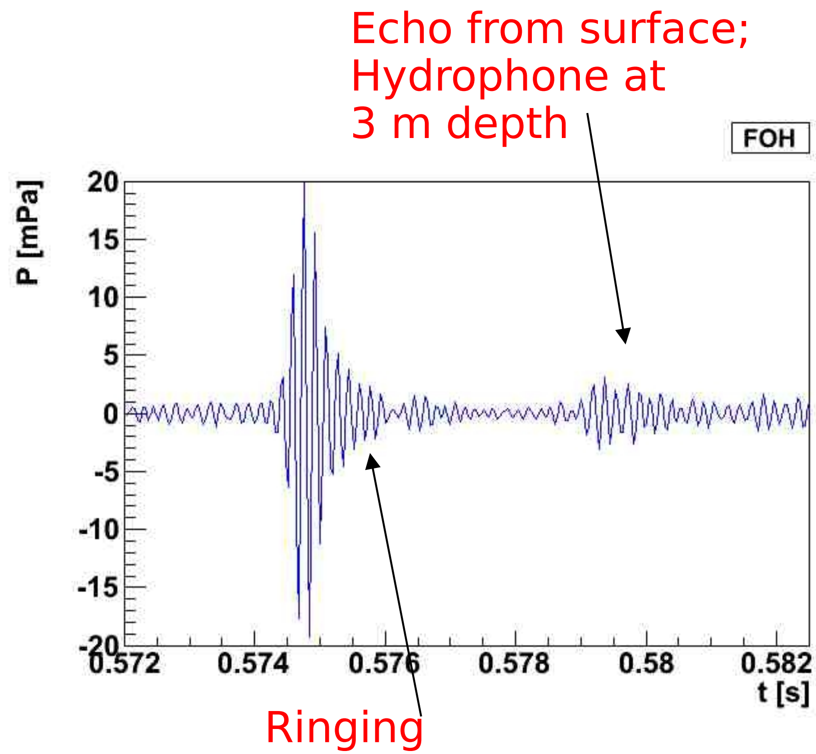
Pulse train measurements

- Study of individual pulses.
- Compared fiber laser hydrophone with reference
- Results are just raw data, no signal processing applied.



Pulse train measurements

- Pulse (and echo) stands above well above background
  - Sensitive to mPa pulses
  - Good noise performance of the basin



Summary and outlook

- Advantages of fiber optic hydrophone:
  - Proper sensitvity:_ *mPa pulses, sea state 0 sensitivity*
  - Cost-effective: *design for mass scale production*
  - *Passive system* (remote pumping and interrogation); easy deployment.
- Next:
  - Optimize fiber laser design, fiber diameters
  - Resonance peaks
  - Pressure compensation mechanism
  - Multiplexing

BACKUP SLIDES

Signal and background

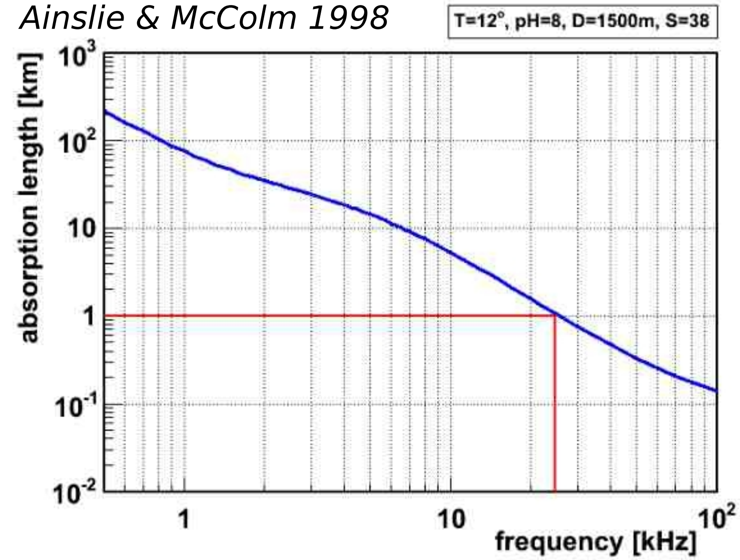
- Absorption length of sea water @ 25 kHz is ~ 1km

  -> *Large detection volumes*

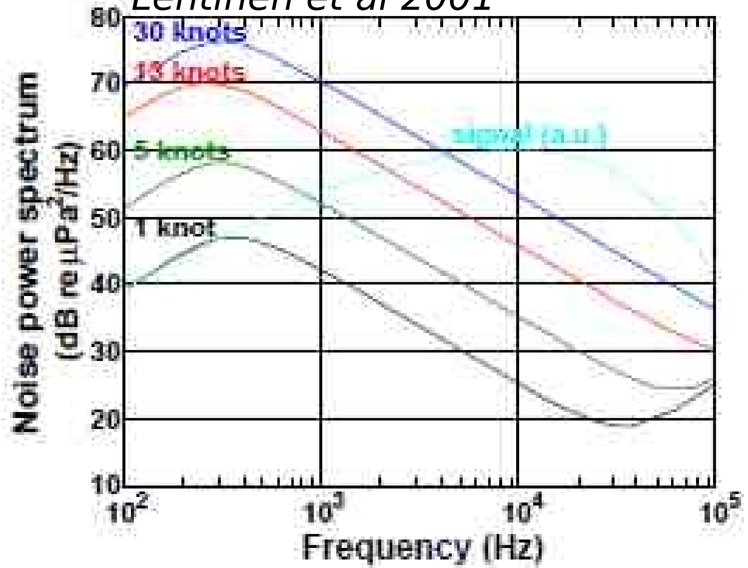
- Sea state noise: omnipresent noise due to the rain and waves at the surface.

- Signal measurements should include higher frequencies as well (up to 40-50 kHz).

Ainslie & McColm 1998



Lehtinen et al 2001



New sensor development

- Can we produce a cheap sensor (<100 euro/sensor)?
- .. and with the proper sensitivity?
- … and with a large reproducibility?

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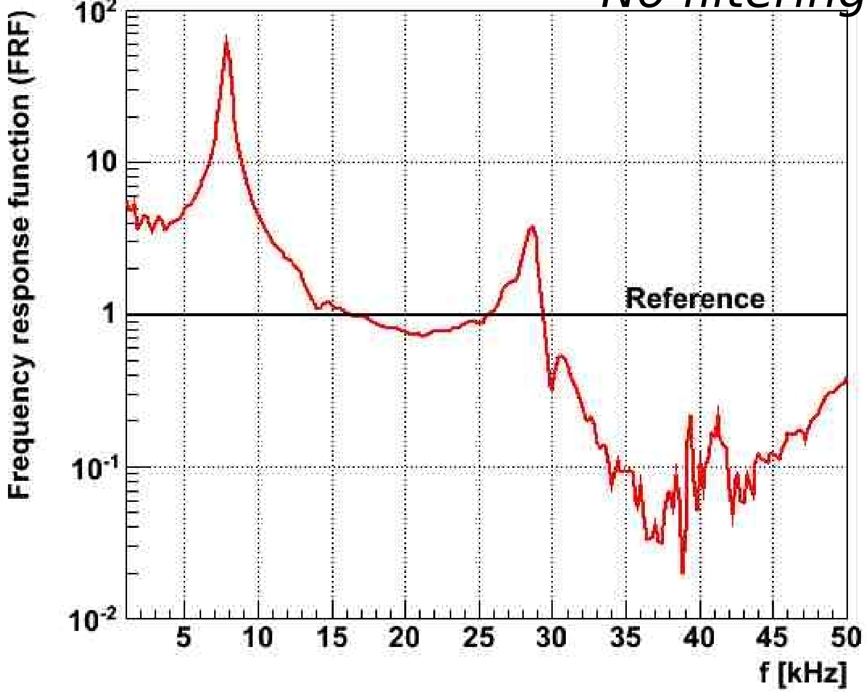
New sensor development

- New sensor developed:
  - Both *aluminum* and *stainless steel*
  - Used simple FBG fibres of both
    80 and 125 μm diameter

New sensor development

- First measurements: Response close to the reference hydrophone
- Resonance peaks due to cavity and fiber, can be removed by filtering.

No filtering



Filtering applied