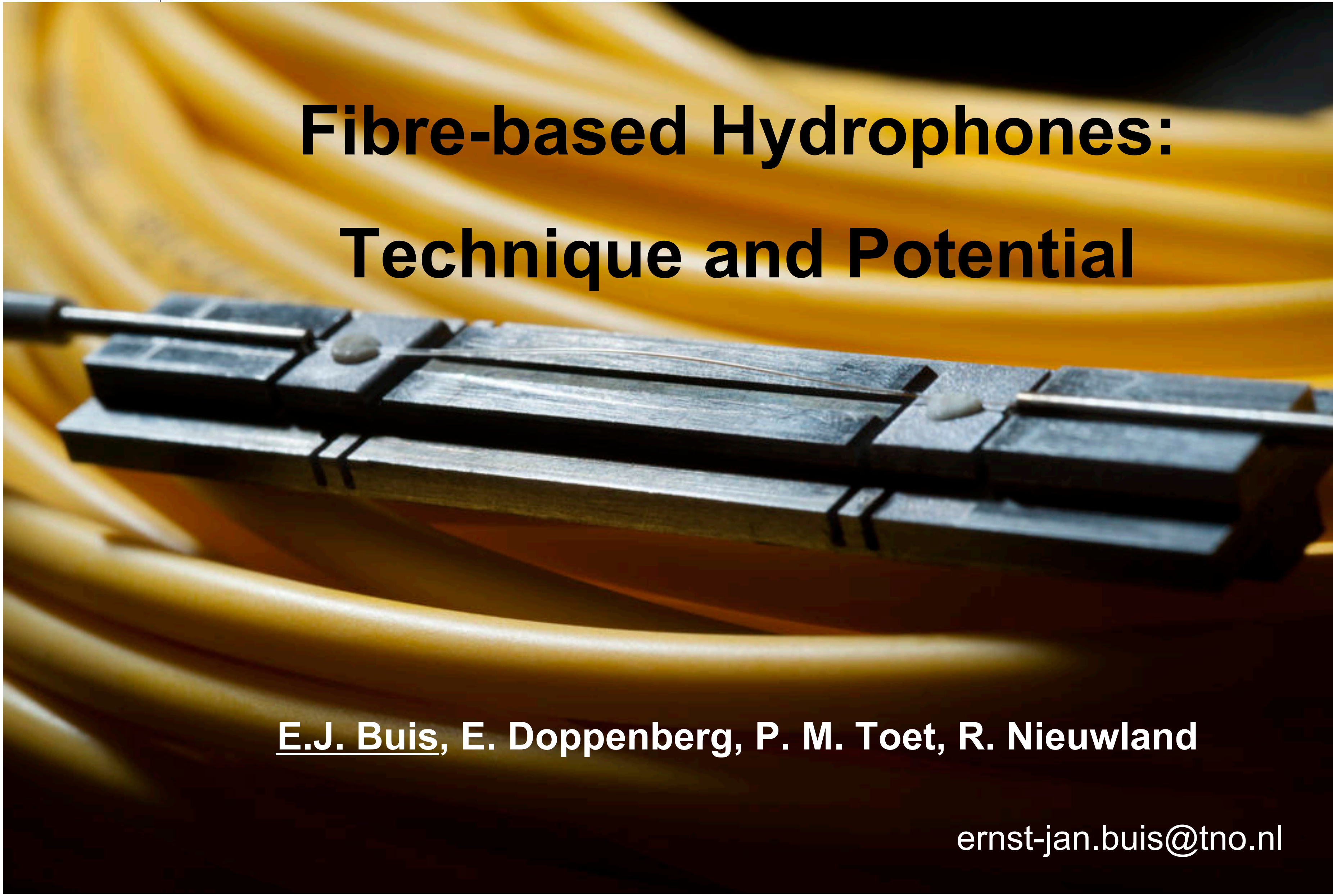

Fibre-based Hydrophones: Technique and Potential

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TNO and KM3NeT: a brief introduction

TNO: Netherlands organisation for applied scientific research

Independent research organisation, ~3800 employees

Working for various customers: governments, the SME sector, large companies, service providers and non-governmental organisations

Conducting research in various areas, among them: fiber-based hydrophones with applications in geology, oil & gas, port security

To investigate application of fiber-based hydrophones for neutrino detection, TNO joined KM3NeT in May 2014

Requirements on hydrophone system

- Sensitivity:
  - Detect pulses at the **mPa** level in the frequency range **5-30 kHz**
  - Sensitive to deep sea state zero
- Simple, robust and relative simple to integrate or deploy
- Price < 100 euro/sensor: as several hundred or even thousand

sensors are required.

Fibre hydrophones system

<u>Main components:</u>

1. Erbium doped fibres with a grating

2. Sensor

3. Interogator

Fibre hydrophones system

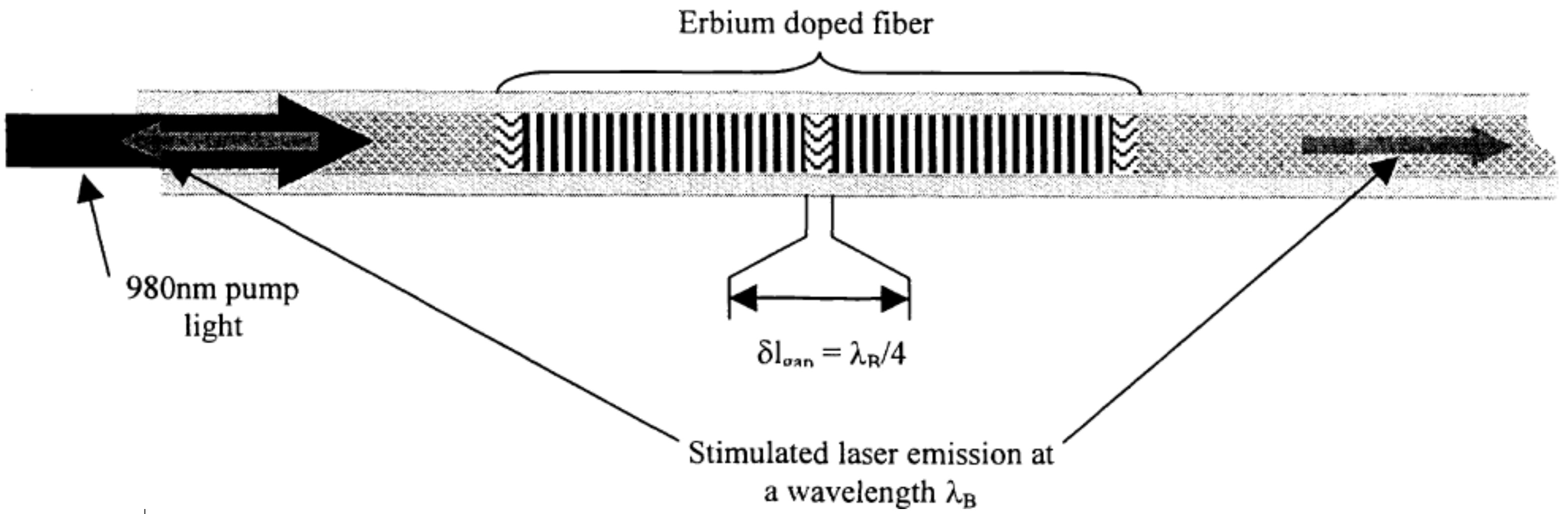
Main components:

1. Erbium doped fibres with a grating
2. Sensor
3. Interogator

oil filled hose or solid cable

1. Erbium doped fibres

- Pump laser λ=980 nm, Erbium induced emission light λ=~1550 nm.
- Fibres are locally doped with Erbium in a gratingstructure. This results in an extremely coherent light source in the fibre it self.



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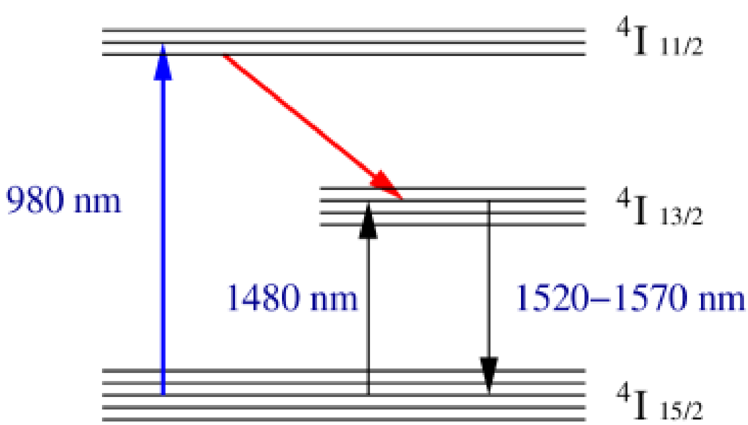
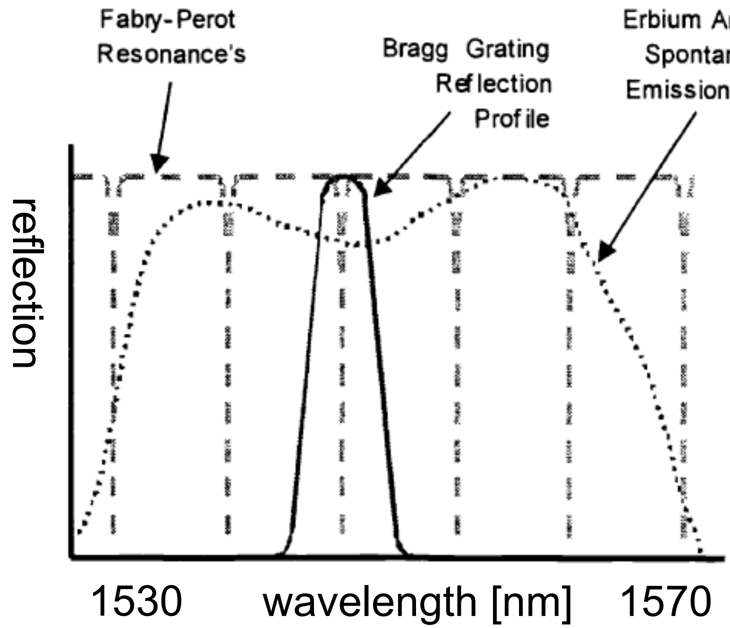
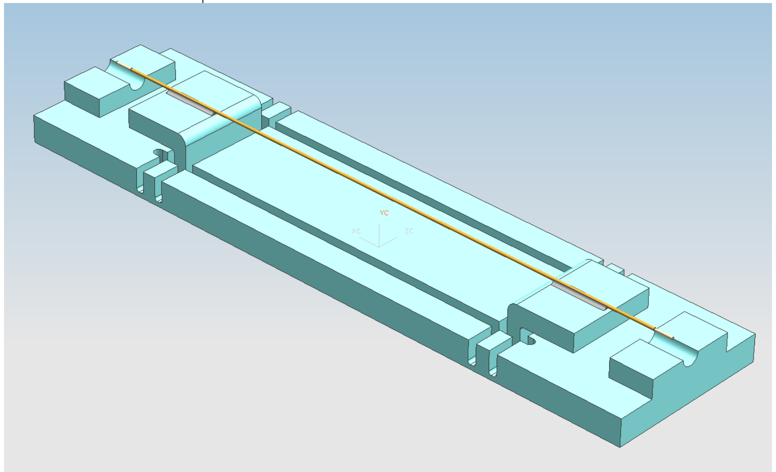




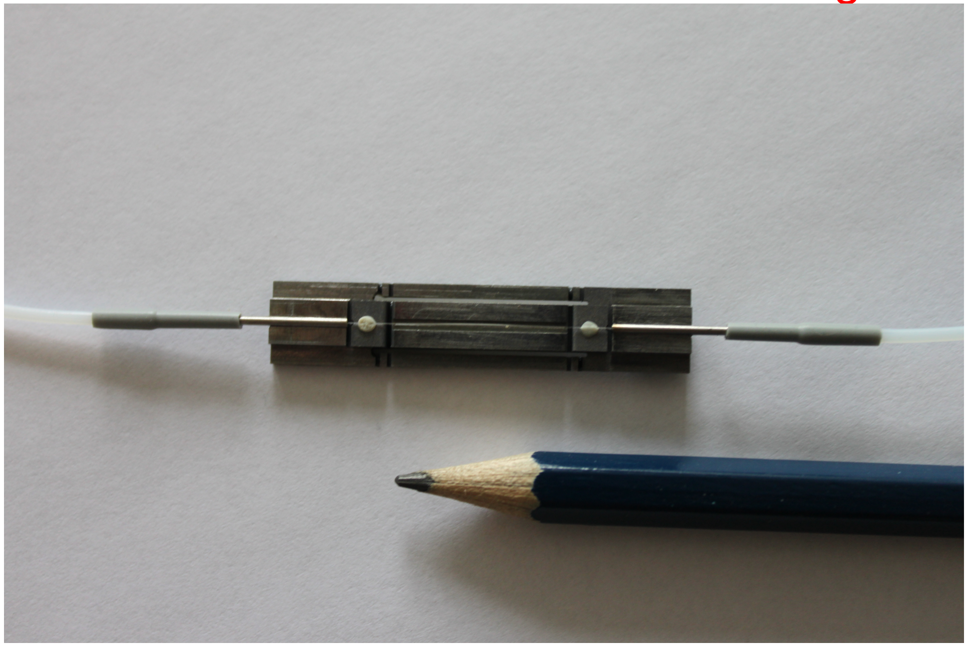
2. Sensor

- Convert presure pulse to a mechanical deformation of the fibre: strain
- Mechanical sensor determines the dynamical frequency range.
- Sensor material is aluminum

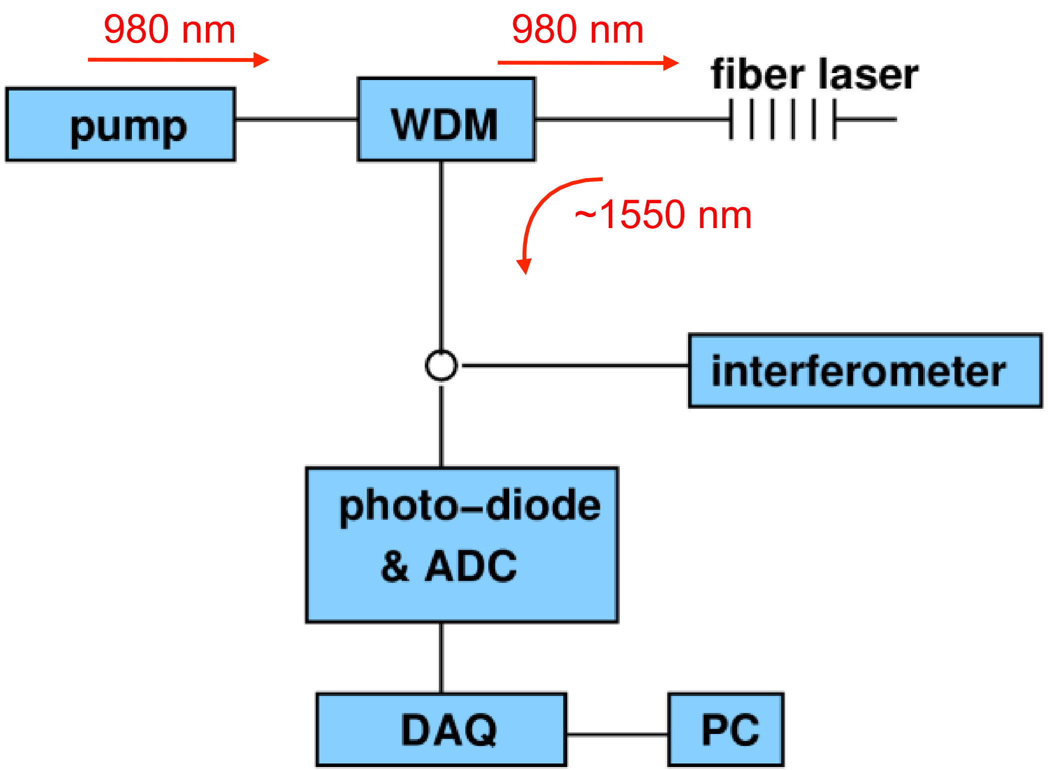


CAD model
Dimensions: 45x9 mm

Sensor with fibre glued

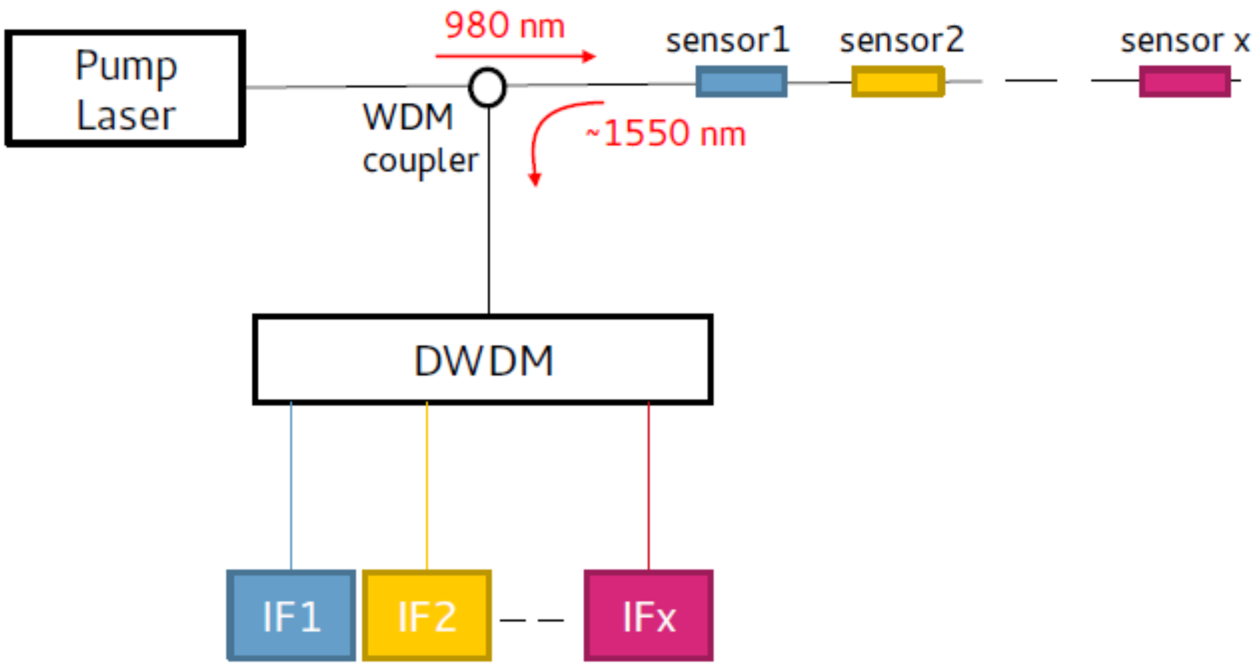


3. Interogation system



- A fibre is used to read out an interogator.
- Pump laser power ~100 mW
- Received power ~10 μW

3. Interogation system: multiplexing

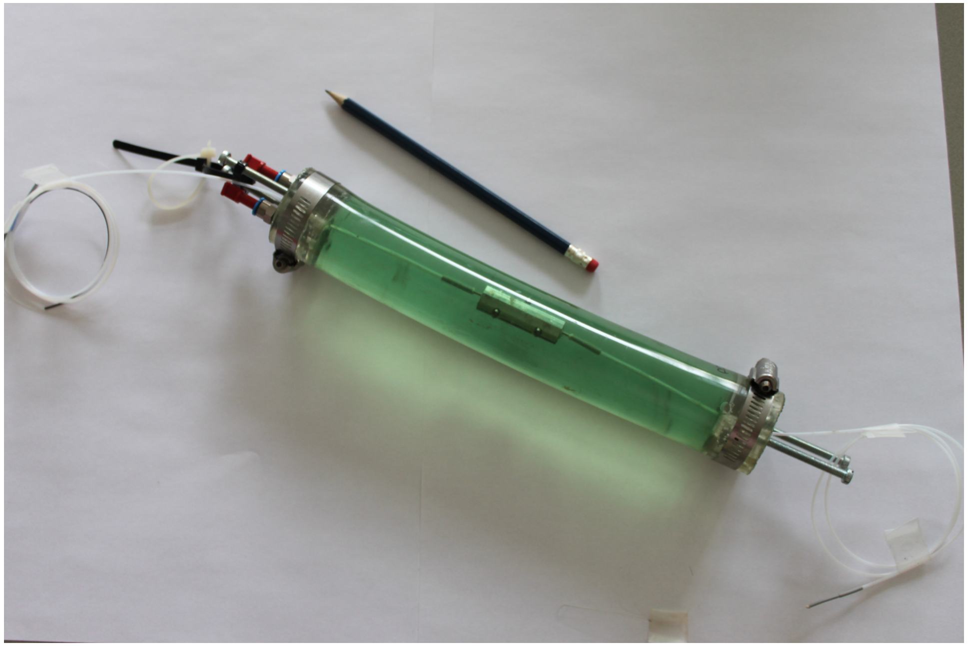


- Include multiple sensors with each a specific grating structure
- Multiplexing with up to 10 sensors/fibre.

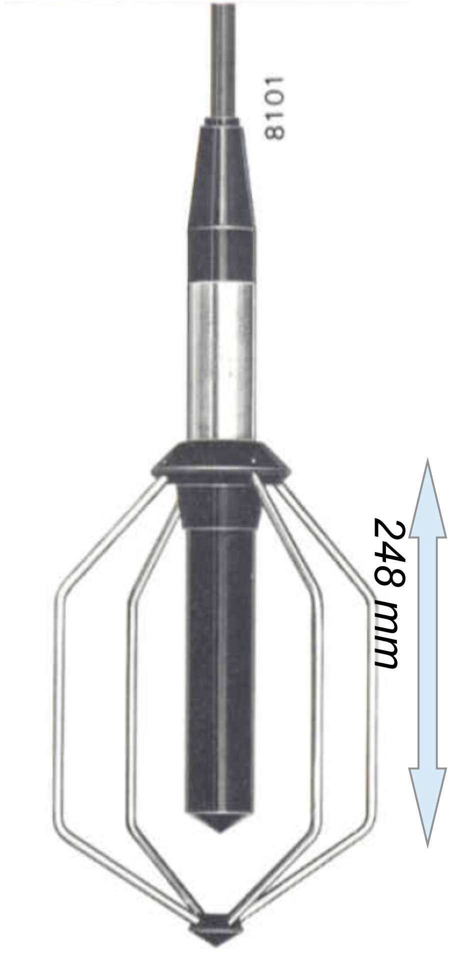
Hydrophone characterization

- Sensitivity, noise measurements.
- Linearity.
- Measurements in an oil filled hose.

Oil hose

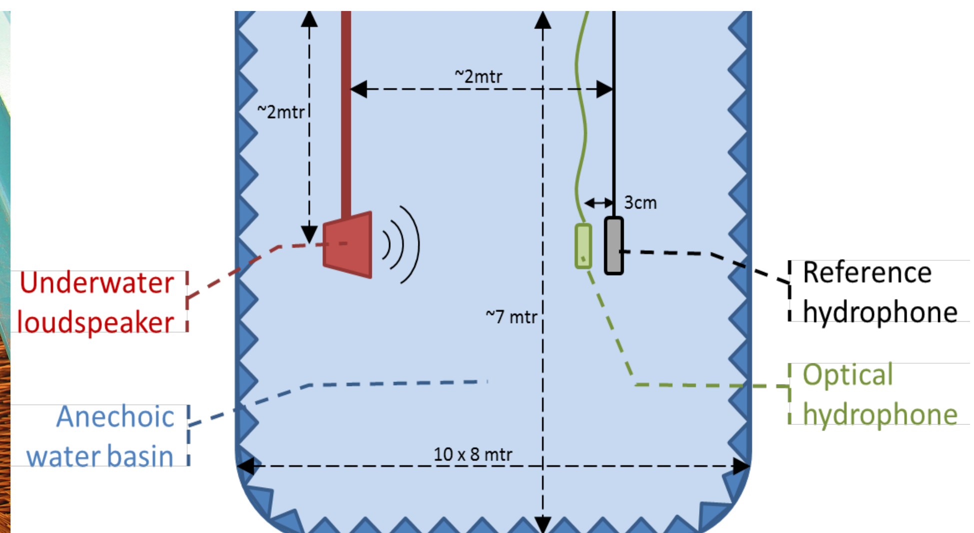


Reference hydrophone
B&K 8101



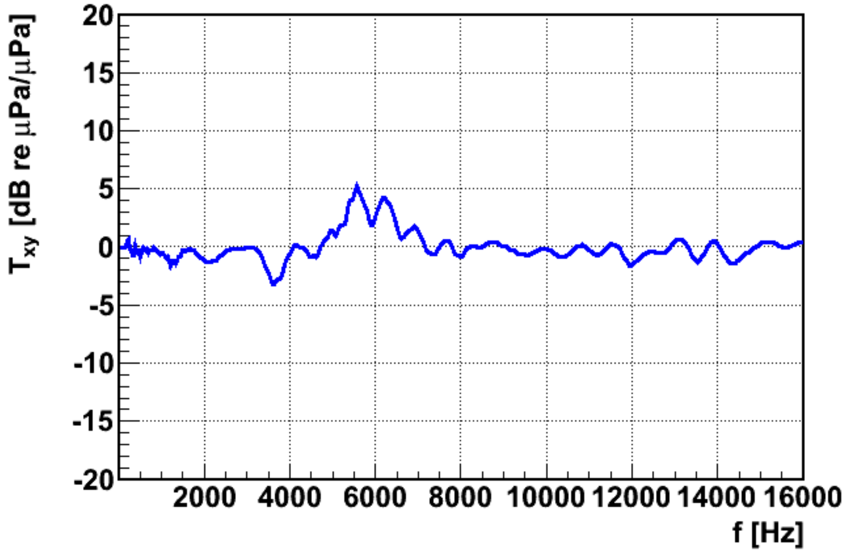
Experimental setup in basin

- Using an anechoic basin at TNO (Acoustically insulated).
- Dimensions of the basin 8x10x7m, (basin should be large to avoid mix of signal and echo).
- Compare to well-calibrated commercial hydrophone



Response function

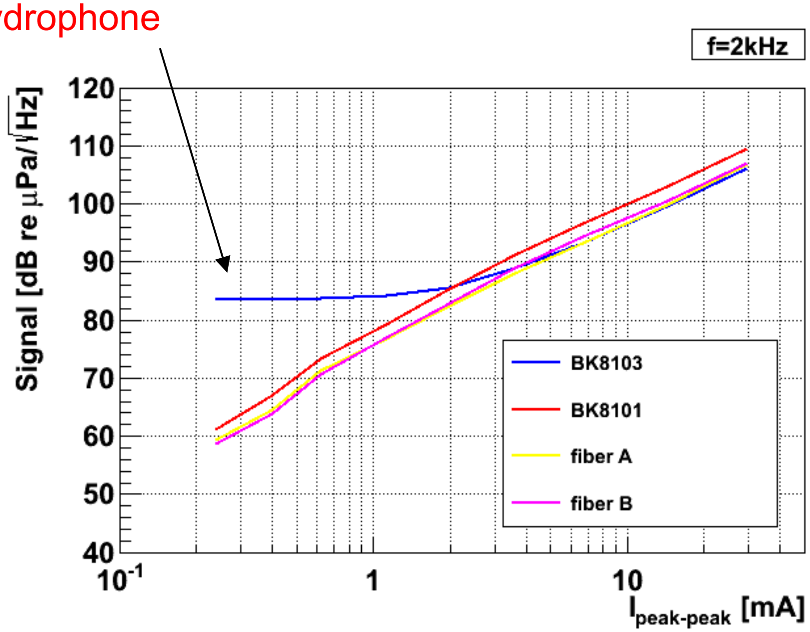
- Response function with respect to the (calibrated) reference hydrophone (B&K8101).
- Response curve is flat. Peak at 5.5 kHz is mechanical resonance.

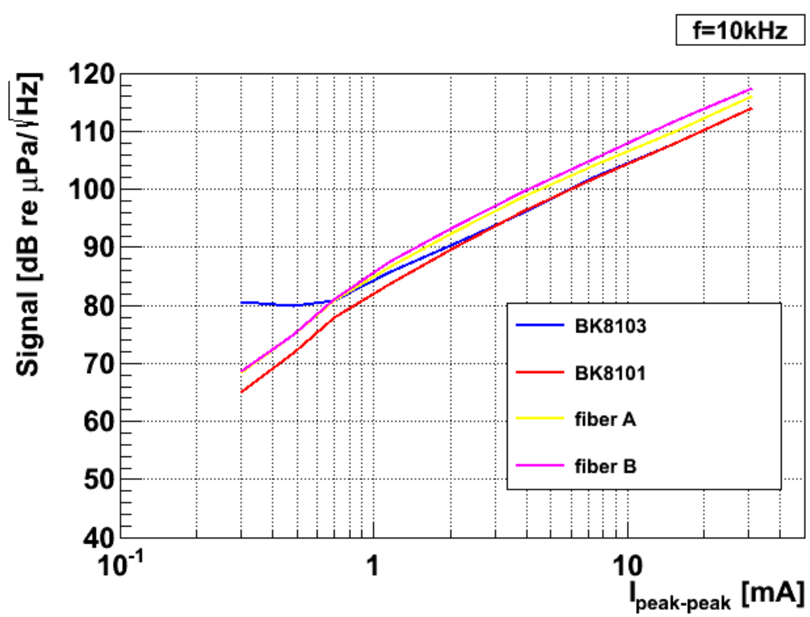


Linearity

- 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

Noise in B&K hydrophone



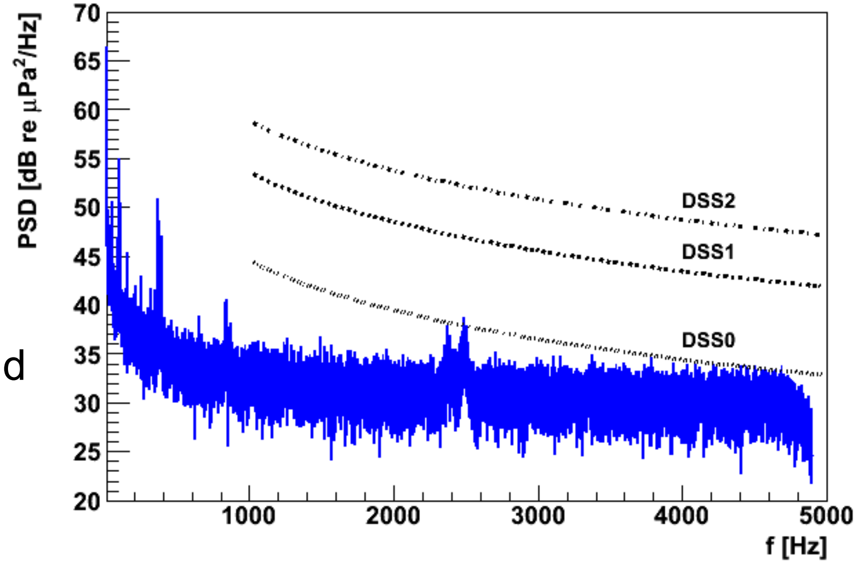


TNO innovation for life

Noise sources

- Noise sources:
  - Relative intensity Noise (RIN)
    - Self emission
    - Fluctuation in pump power
    - Shot noise
    - Thermal noise (both in fiber and electronics)
  - Phase Noise

“dry” measurement
in isolated environment



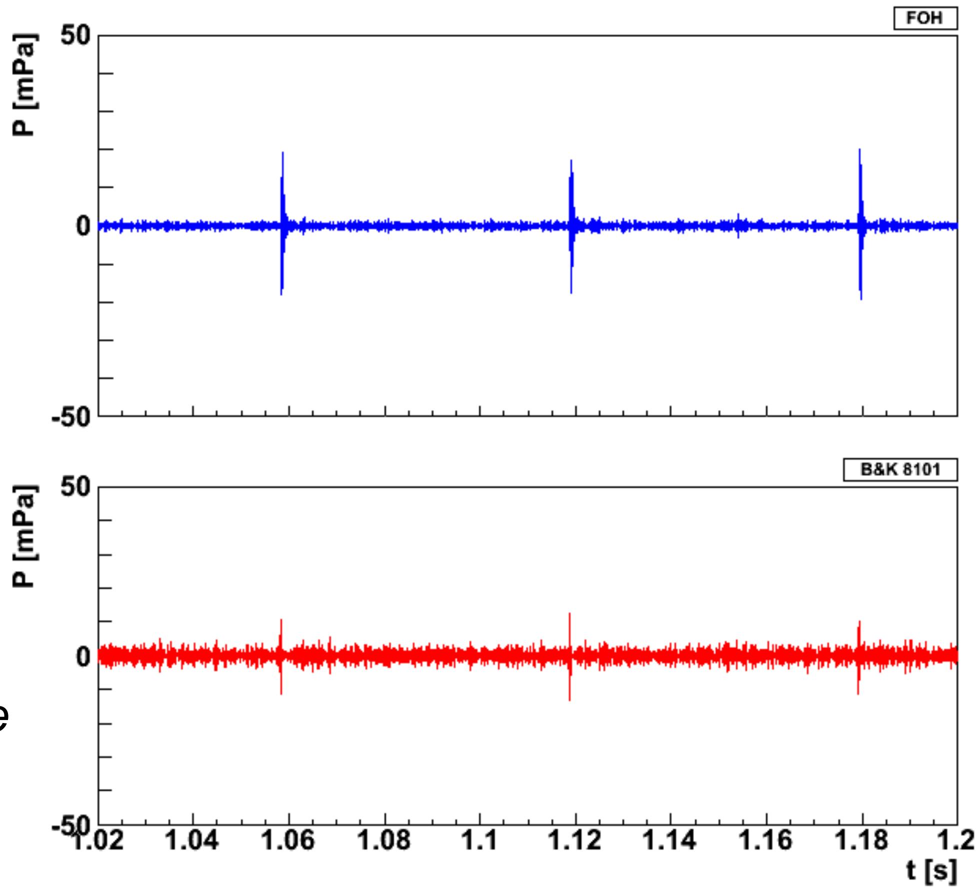
- Self noise measured in vibration shielded environment.
- (It is hard to get below DSS0 in the basin at the appropriate frequencies.)

Pulse reconstruction

- Pulse train was generated to detect individual pulses
- Simple passband filter was applied (4th order Butterworth)

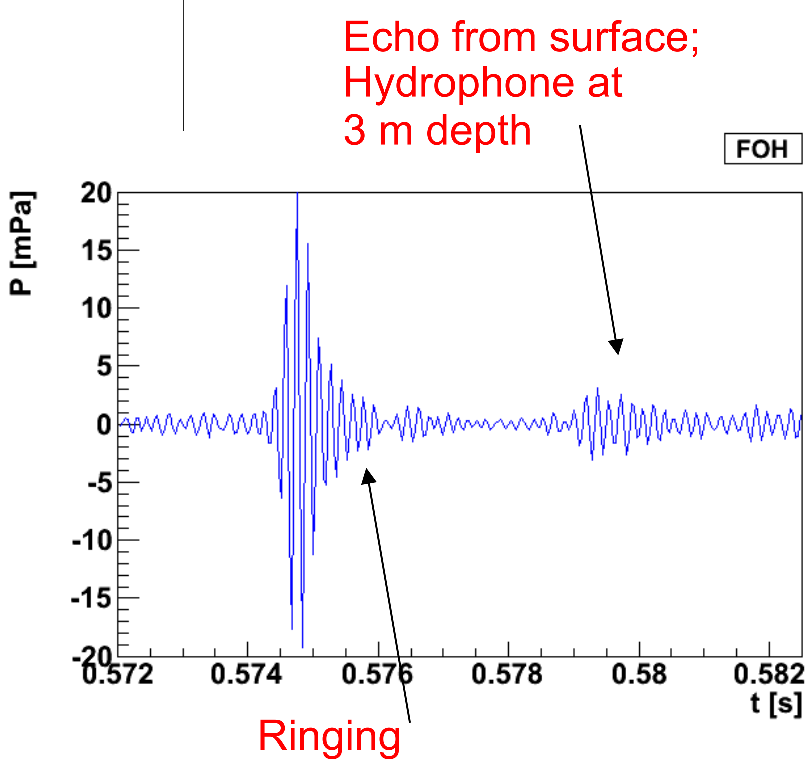
Fiber laser hydrophone

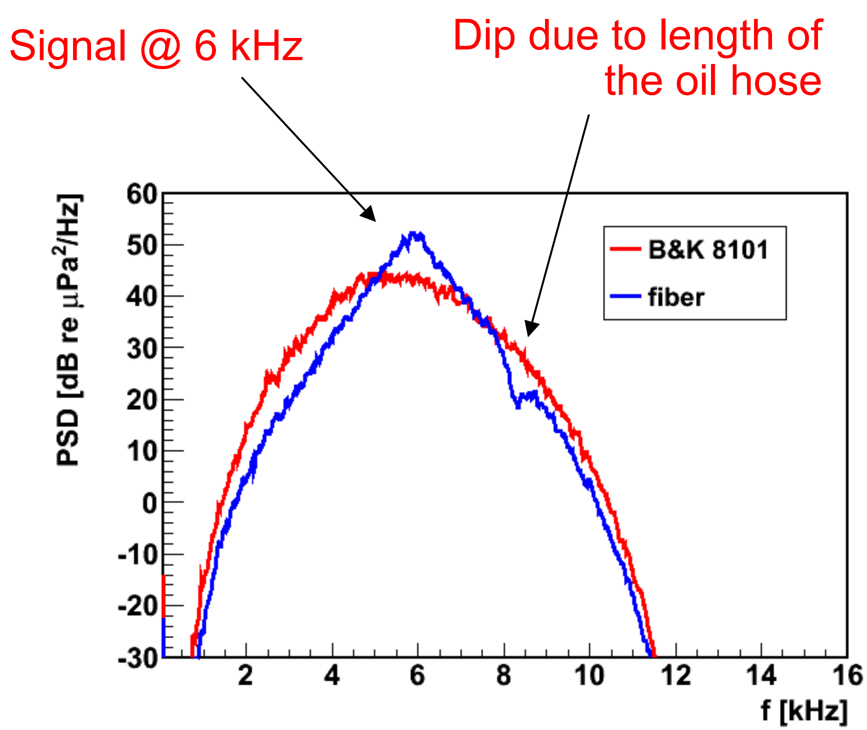
Reference hydrophone



Pulse reconstruction

- Pulse (also from echo) stands well above the noise.
- A power spectral density has been reconstructed from 100 pulses.
- Reconstructed pulse is as low as 1 mPa, the shape shows ringing.





Conclusions

- Acoustic detection provides a way to study neutrinos with ultra high energy.
- Fibre laser hydrophones are sensitive enough to detect (cosmic-ray induced) pulses at the mPa level in the frequency range 5-20 kHz. Acoustic measurement of cosmic rays can become ocean noise limited.
- Only small difference in performance when hydrophone is used in oil hose.
- Impulse events show ringing. To be investigated further.

- Implementation of fiber laser hydrophones have many advantages over piezo-hydrophones:
  - Sensitive, cheap and simple
  - No electronics X-talk, low power dissipation
- TNO has large experience/heritage in marine acoustic systems (next slides)
- More reading: arXiv:1311.7588 [astro-ph.IM]

Projects at TNO

For geology, oil & gas, port security.

- Sensor development
- DAQ and interogators
- Engineering
- Cable and streamers
- Data analysis

Optical streamers

Assembly table

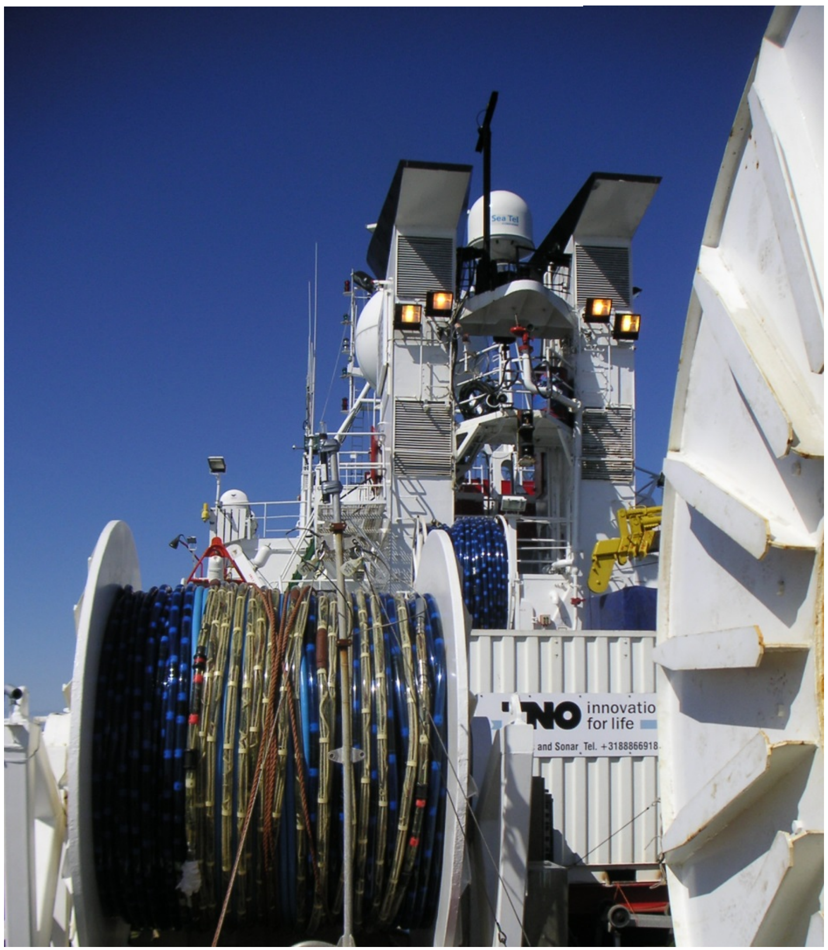
Tow cable assembly

Streamer calibration

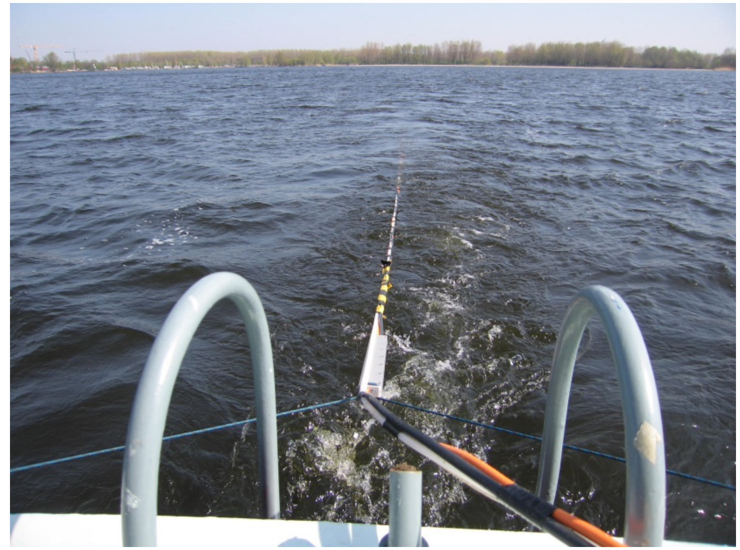
Assembled streamers on a roll are guided into the basin

River/sea trial

Off the coast of Scotland

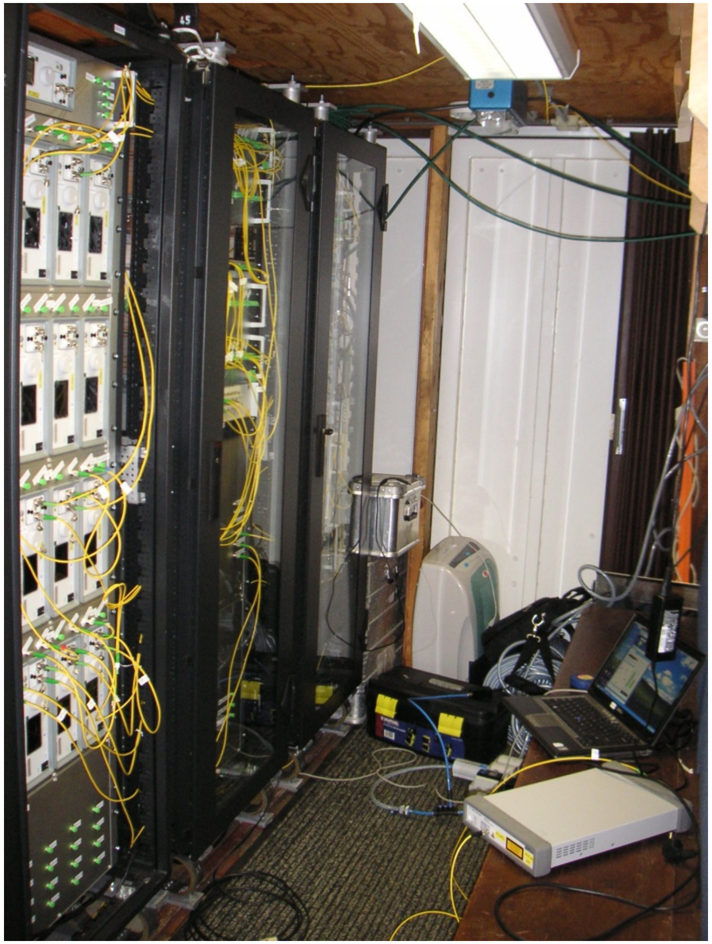


River in Holland



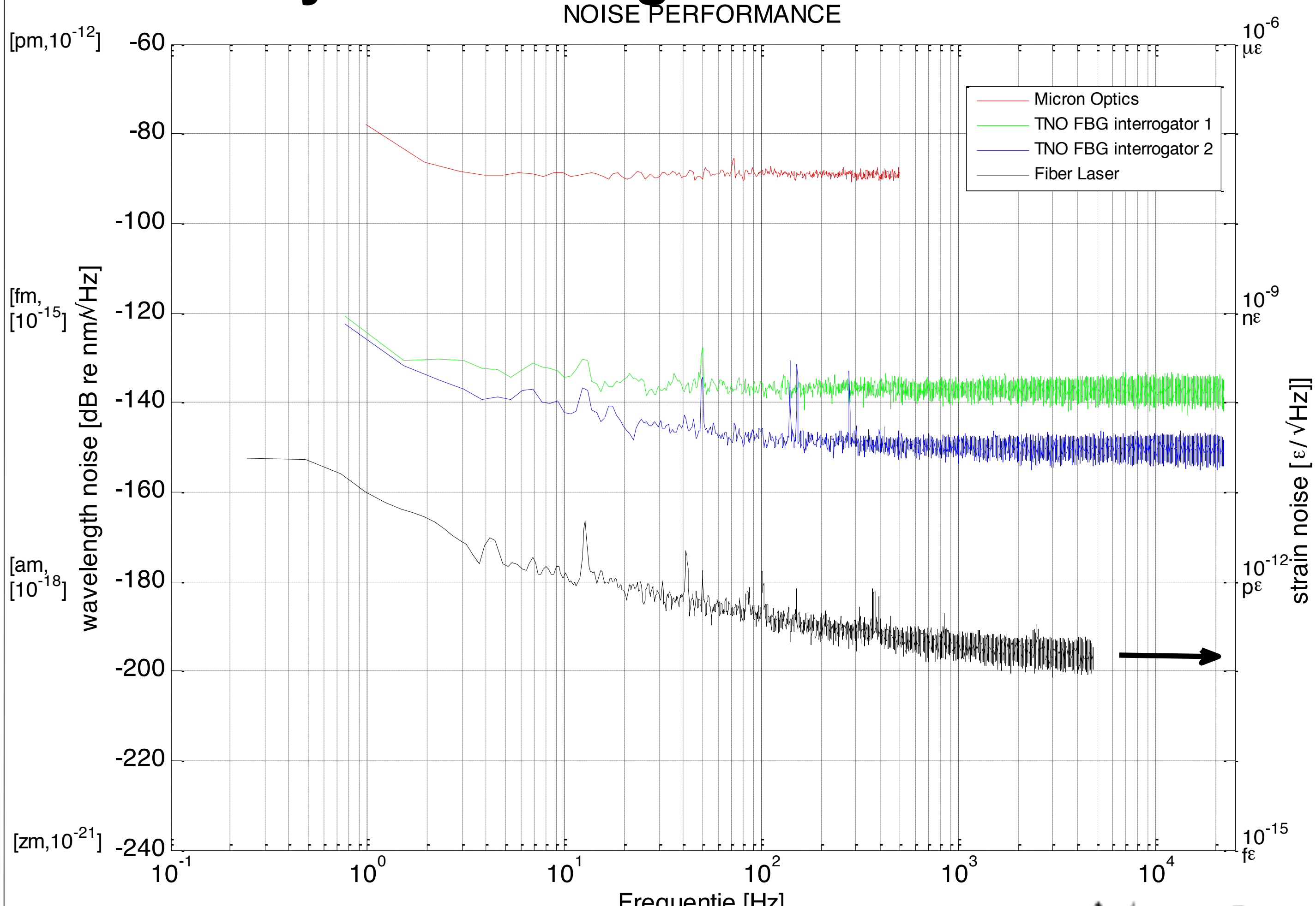
Electronics shed on deck

Interrogators and light sources to readout up to 10 k sensors (albeit time multiplexed)



backup

Sensitivity and interogators



$$\phi = \frac{2\pi}{\lambda} OPD \qquad \frac{\Delta\phi}{\Delta\lambda} = \frac{2\pi}{\lambda^2} OPD$$

Concept cosmic ray set up