Acoustic sensors for the new mDOM

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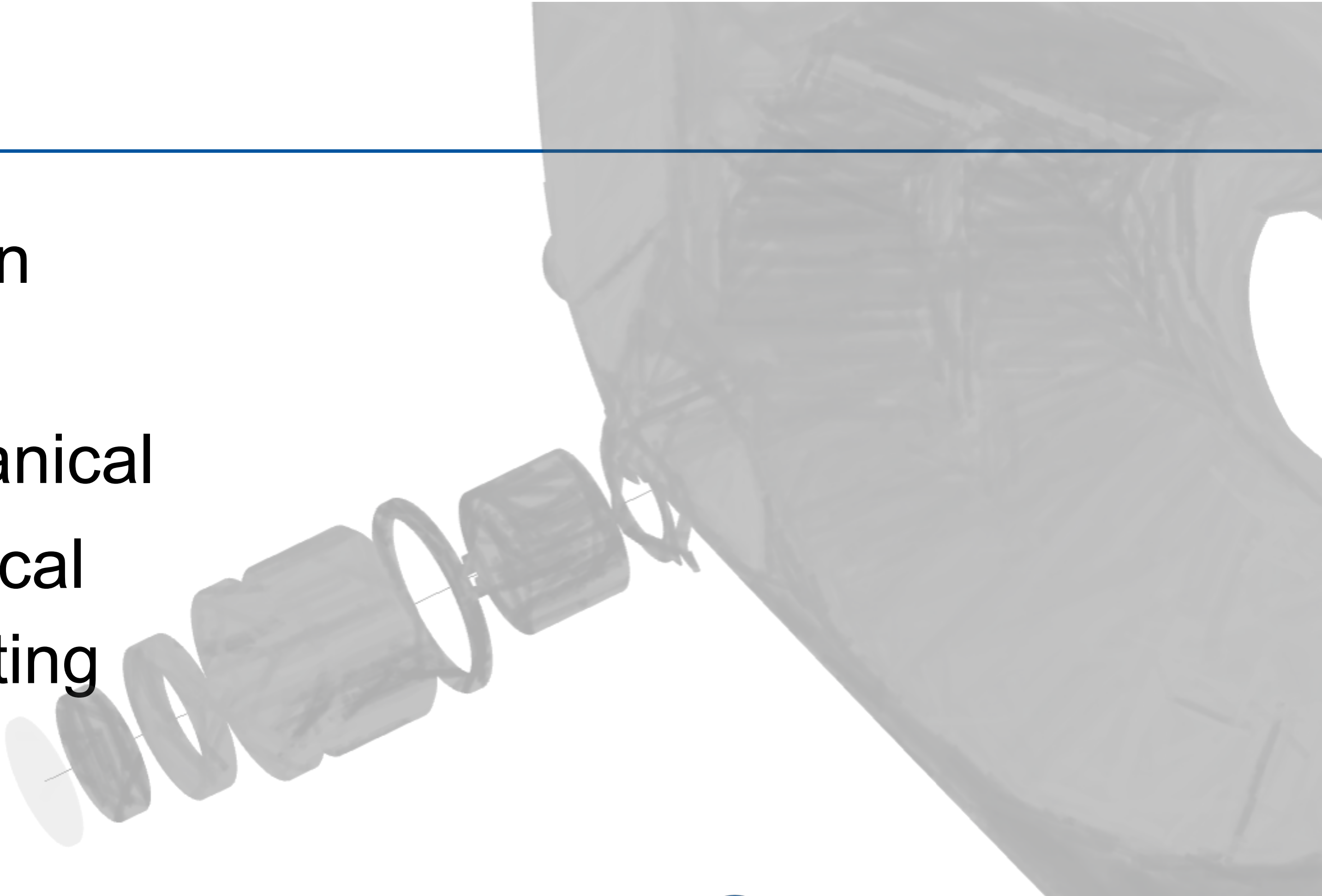
Lars Weinstock, Simon Zierke, Peter Linder

Plan

- Motivation
- Design
  - Mechanical
  - Electrical
- Pool Testing



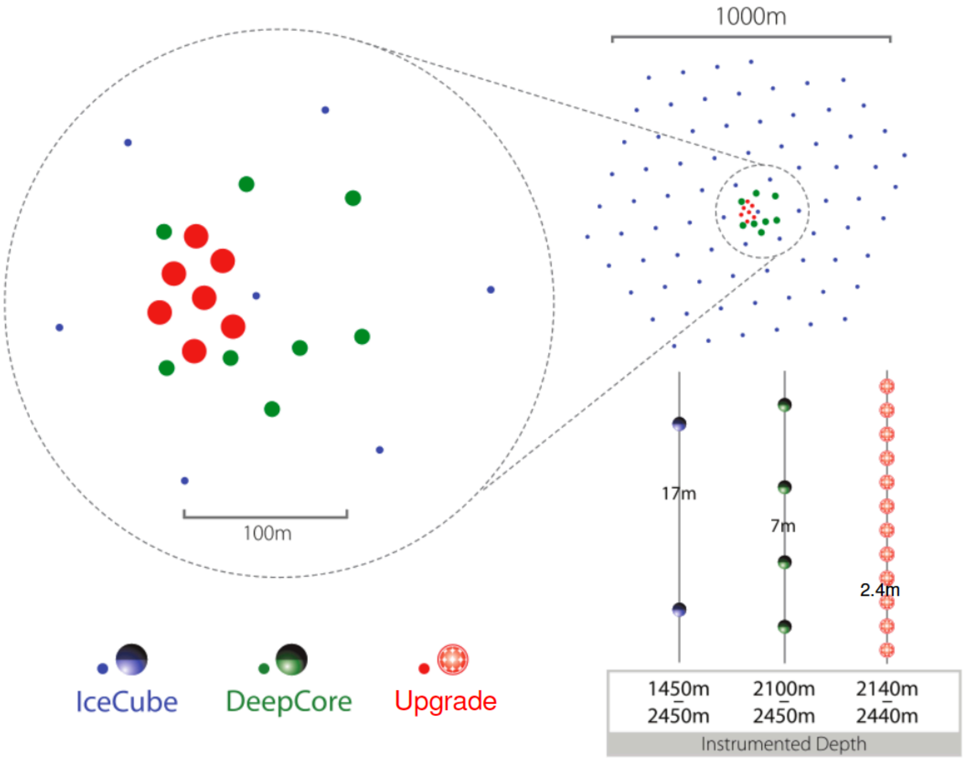
IceCube upgrade towards IceCube Gen2

IceCube Upgrade

- First step toward Gen2
- Deployment of 7 strings with 125 OM each, inside DeepCore
- Low energy and oscillation physics / Ice characterisation

IceCube Gen2

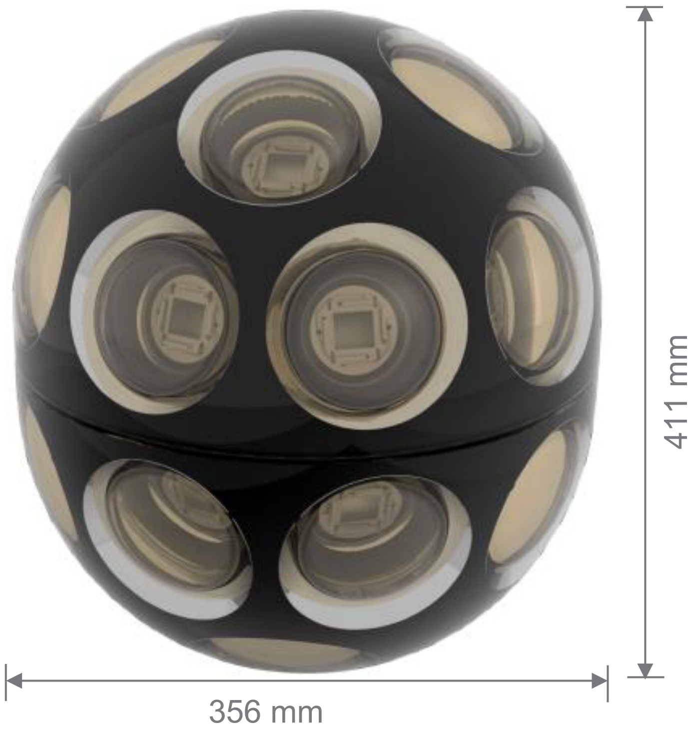
- Detection of EHE events
- Volume desired of 100km^3
- Large distances between the OM



mDOM and other components

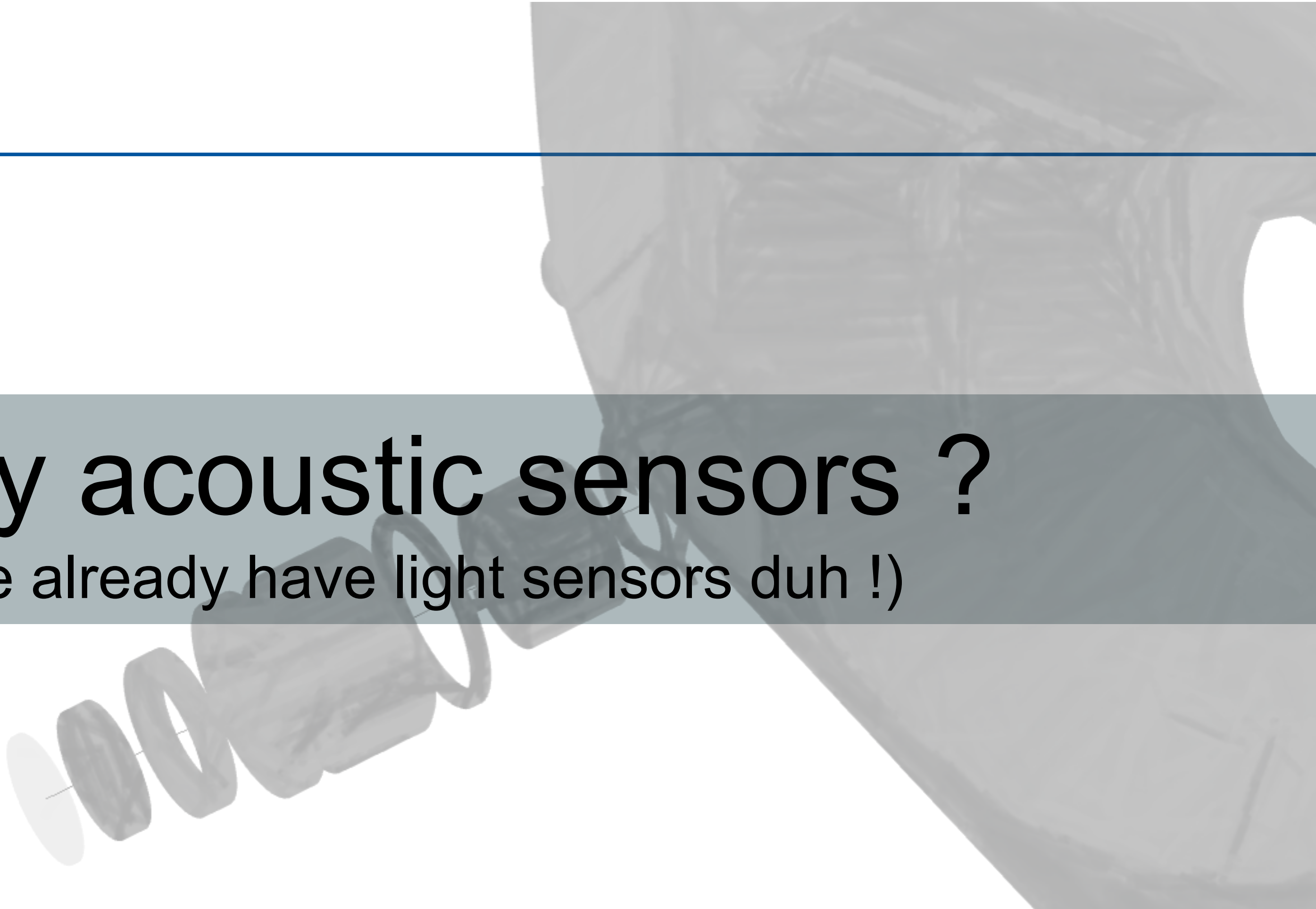
Calibration devices

- Camera system
  - 3 or 4 images sensor board
  - Hole ice / Freeze process
  - Geometry calibration
- Flasher LEDs
  - Up to 9
  - Ice scattering/absorption
  - Geometry calibration
  - Known emplacement in mDOM



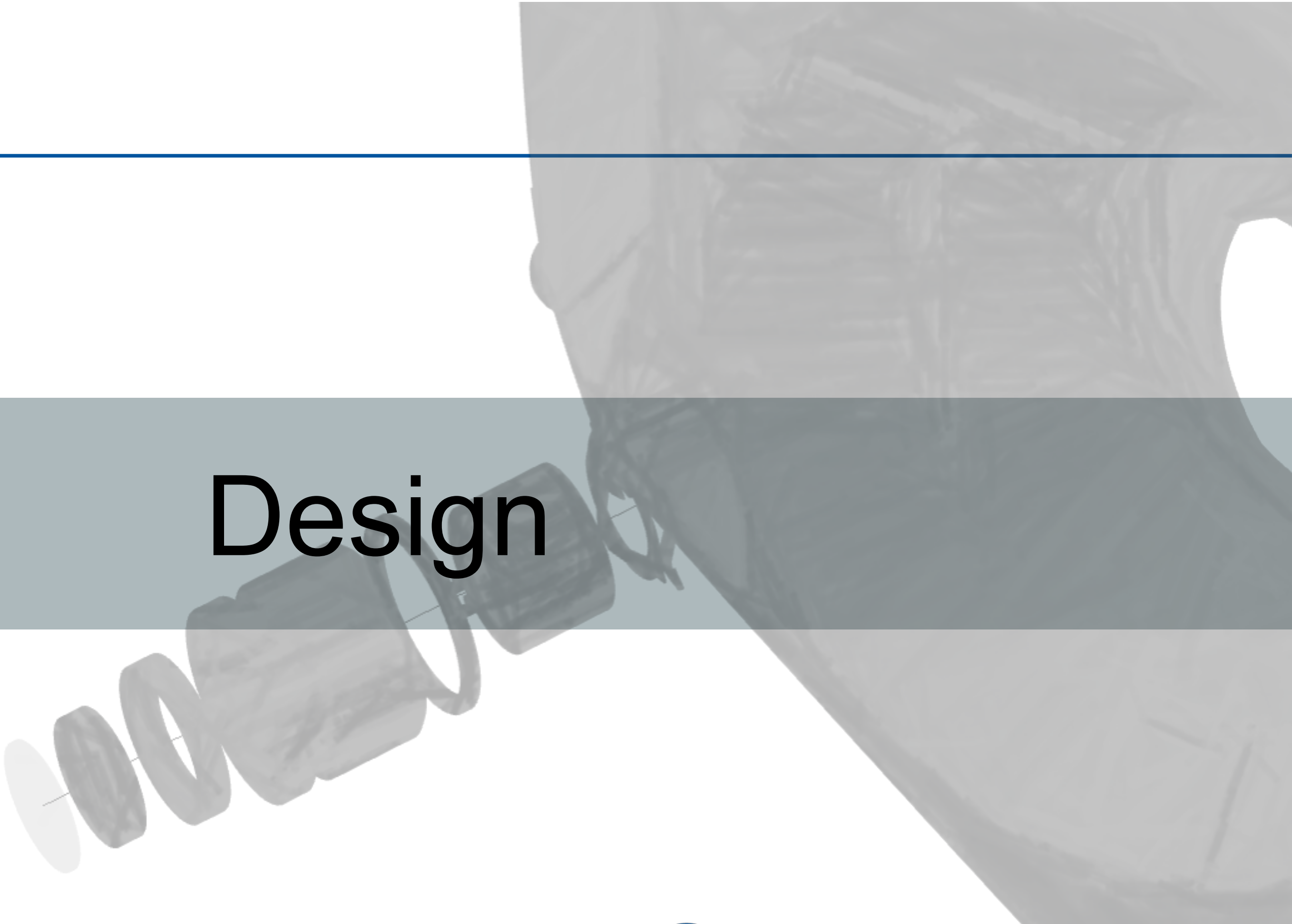
Why acoustic sensors ?

(we already have light sensors duh !)



Goals

- Increased distance between optical modules
  - OM positioning and orientation independent from optical devices (<1m)
- Glaciology
  - Detection crevasses, air bubble, dust, etc.
  - Long-term movement in ice and sheer
  - Characterizing the re-icing of the holes
- Hybrid detection of EHE neutrinos



Design

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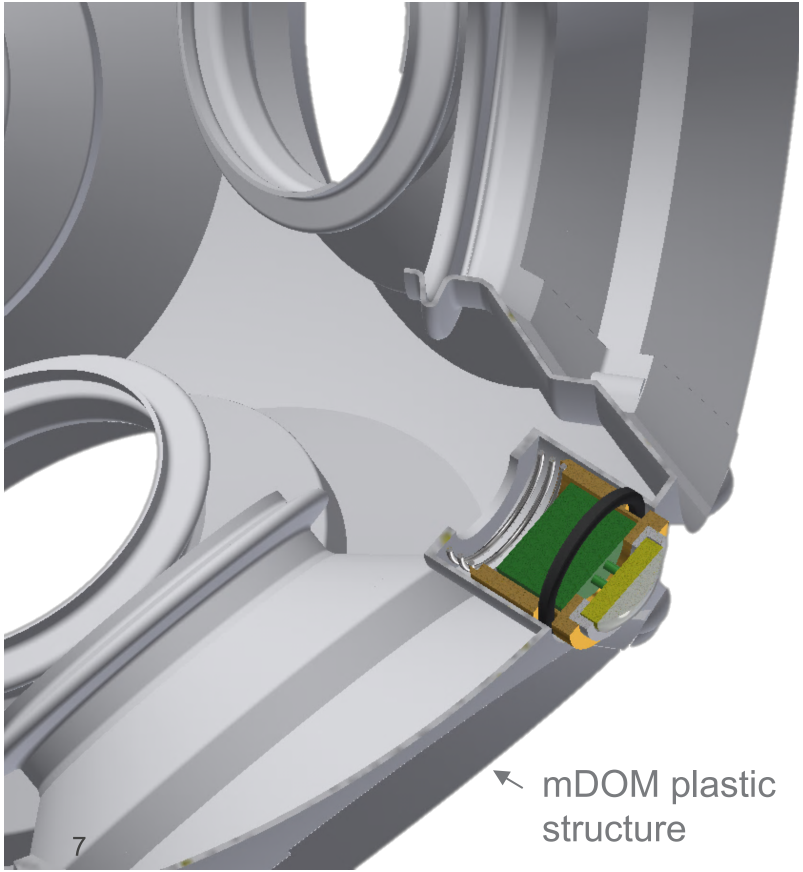
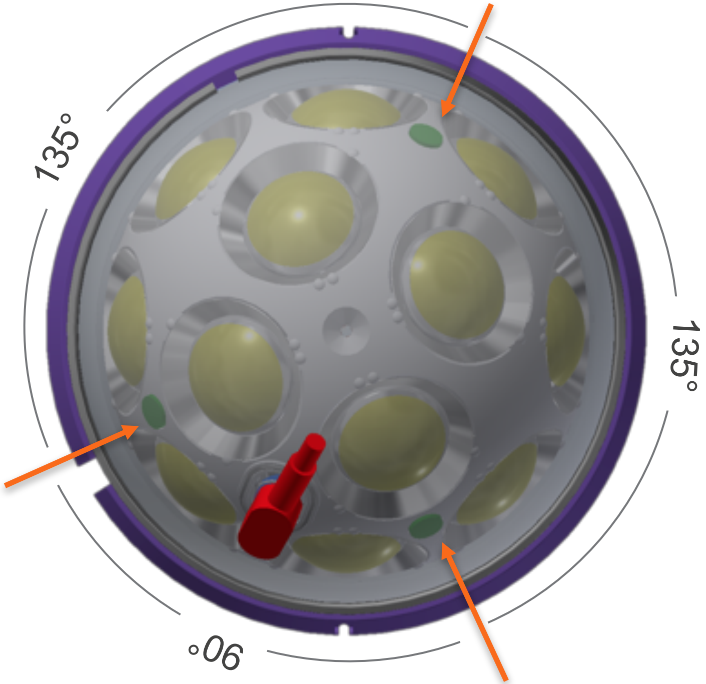
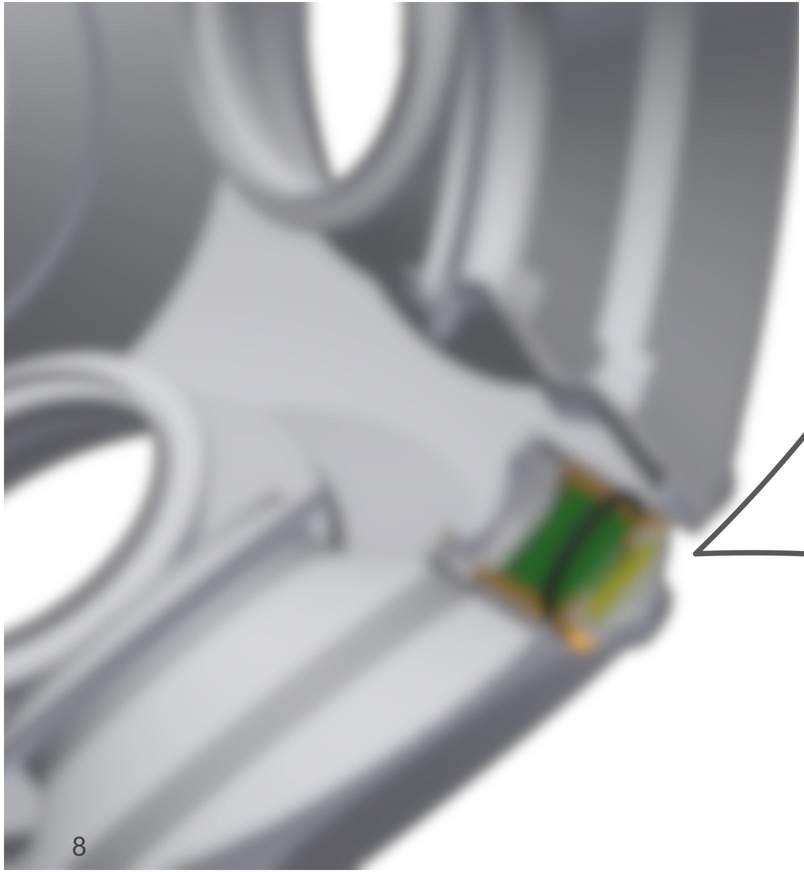
Design

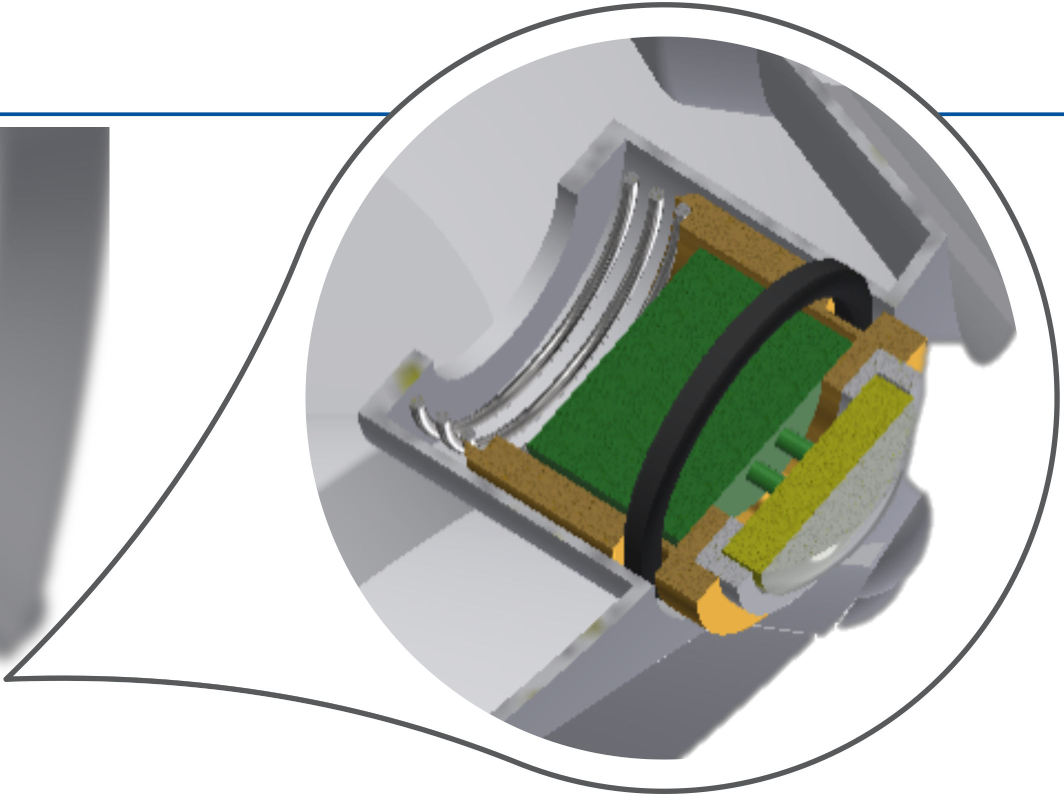


Top view of the mDOM

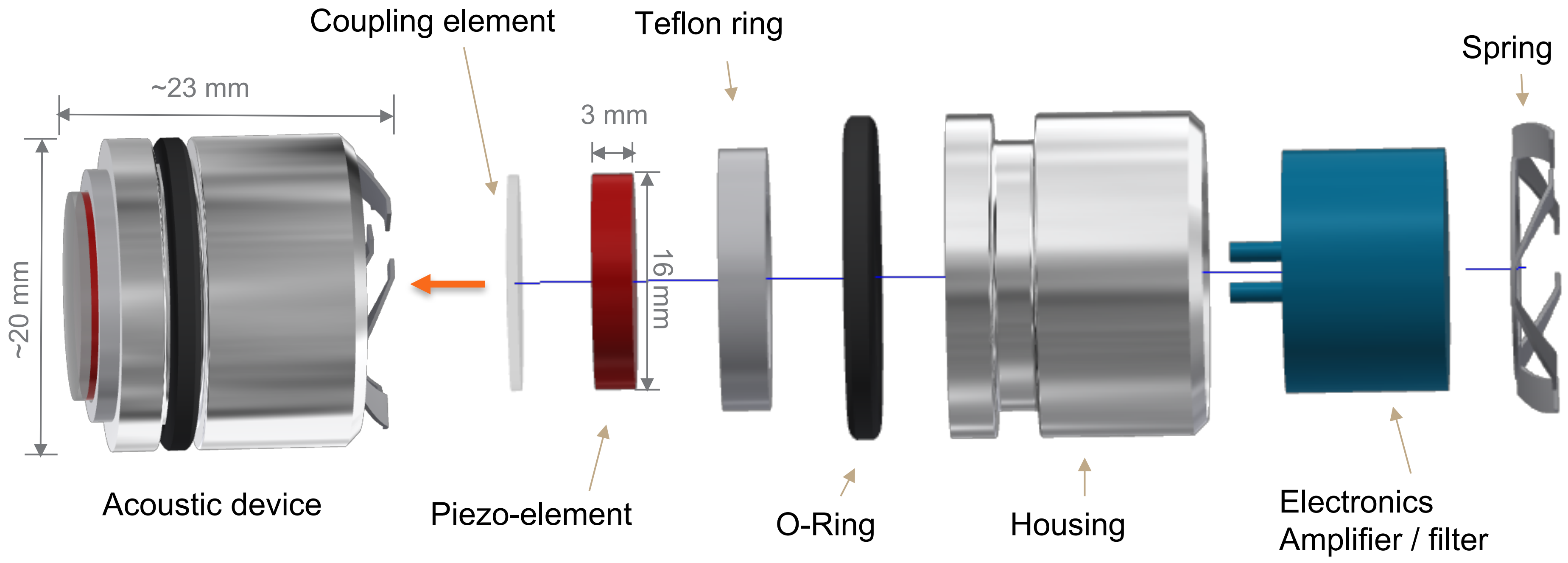


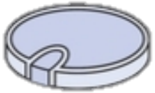
Design





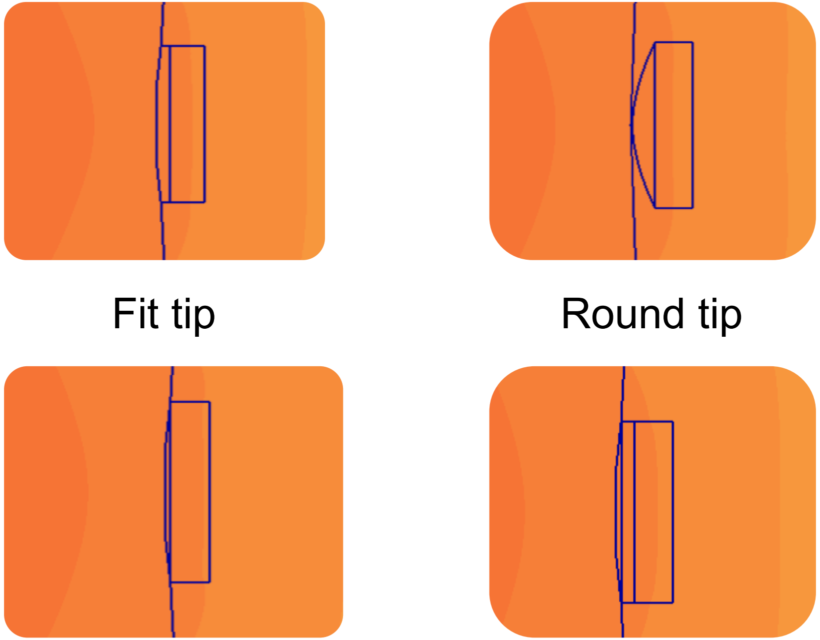
Design



Piezo wrap-around configuration : 

Coupling - Simulation

Material	Speed V_L	Density ρ	Impedance Z_L
	[mm/μs]	[g/cm^3]	[MRayl]
Silicone gel	1.05	1.00	1.10
Glass (silica)	5.90	2.20	13.00
Brass	4.70	8.64	40.60
Aluminium	6.38	2.73	17.41
Steel	5.9	7.8	46.00
Epoxy	2.61	1.23	3.21
PZT	4.00	7.800	31.2

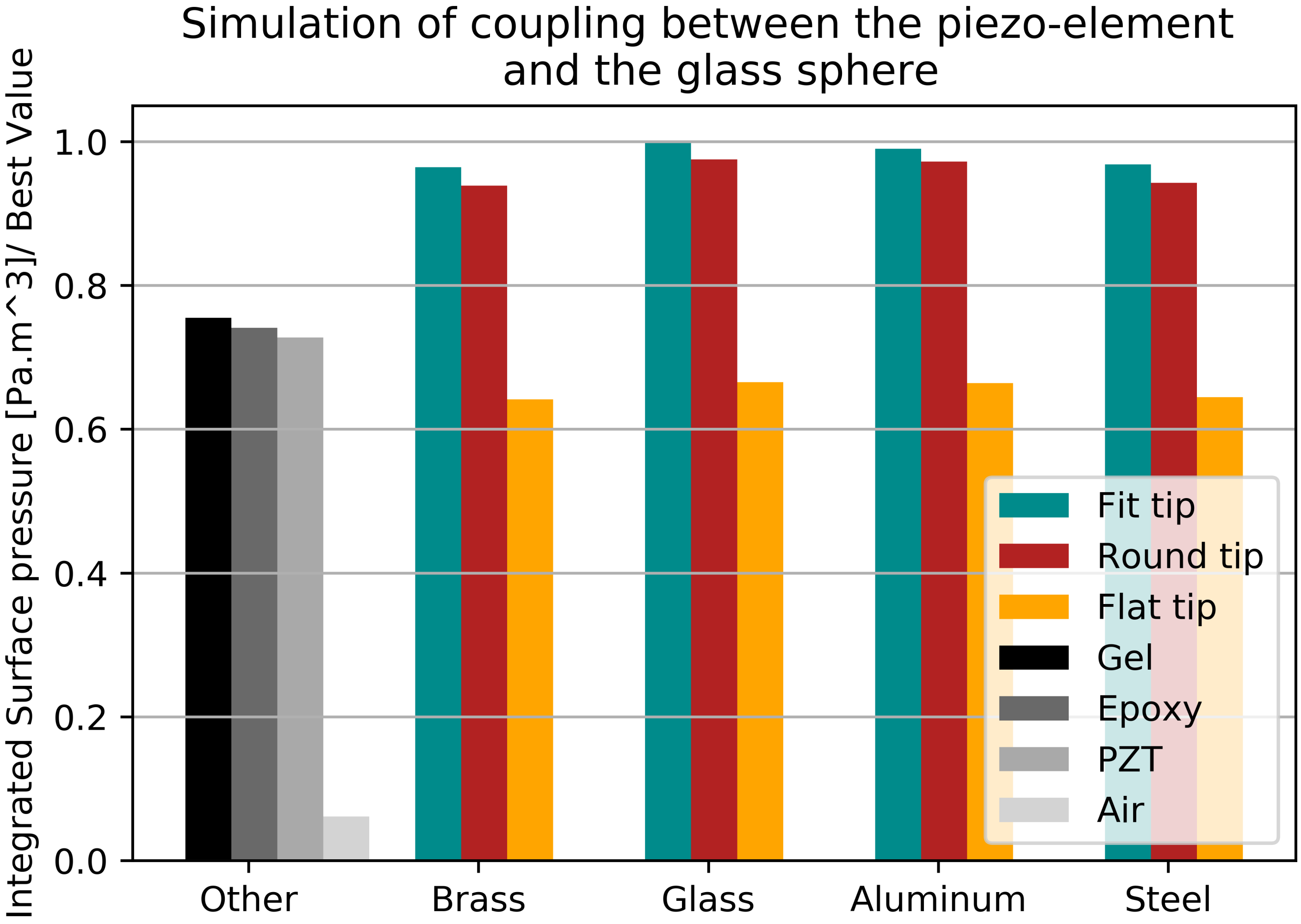


Fit tip

Round tip

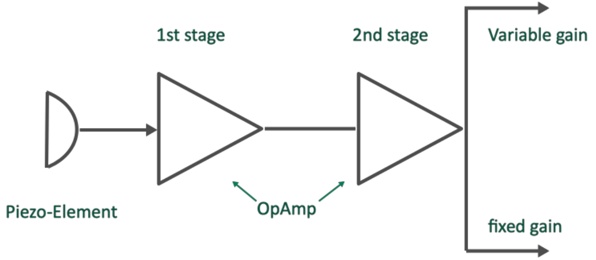
PZT, gel, epoxy

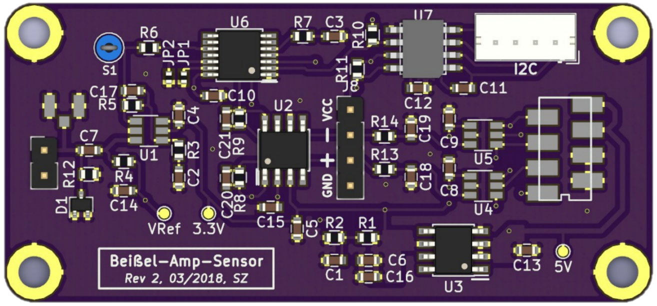
Flat tip


Simulation of coupling between the piezo-element
and the glass sphere
Integrated Surface pressure [Pa.m^3]/ Best Value
1.0
0.8
0.6
0.4
0.2
0.0
Other
Brass
Glass
Aluminum
Steel
Fit tip
Round tip
Flat tip
Gel
Epoxy
PZT
Air

Electronics

- 2 channels :
  - Narrow bandwidth around 10kHz for the positioning
  - Broader bandwidth for neutrino detection (10-100kHz)
- For now using the most recent Enex-Range electronics with improved S/N
  - Passband of 2-30 kHz
- Power consumption of one sensor is app. 71 mW (21,2mW OpAmp + microcontroller 49,5 mW)
- DATA-rate: typ. 100 kHz @ 12bit per channel





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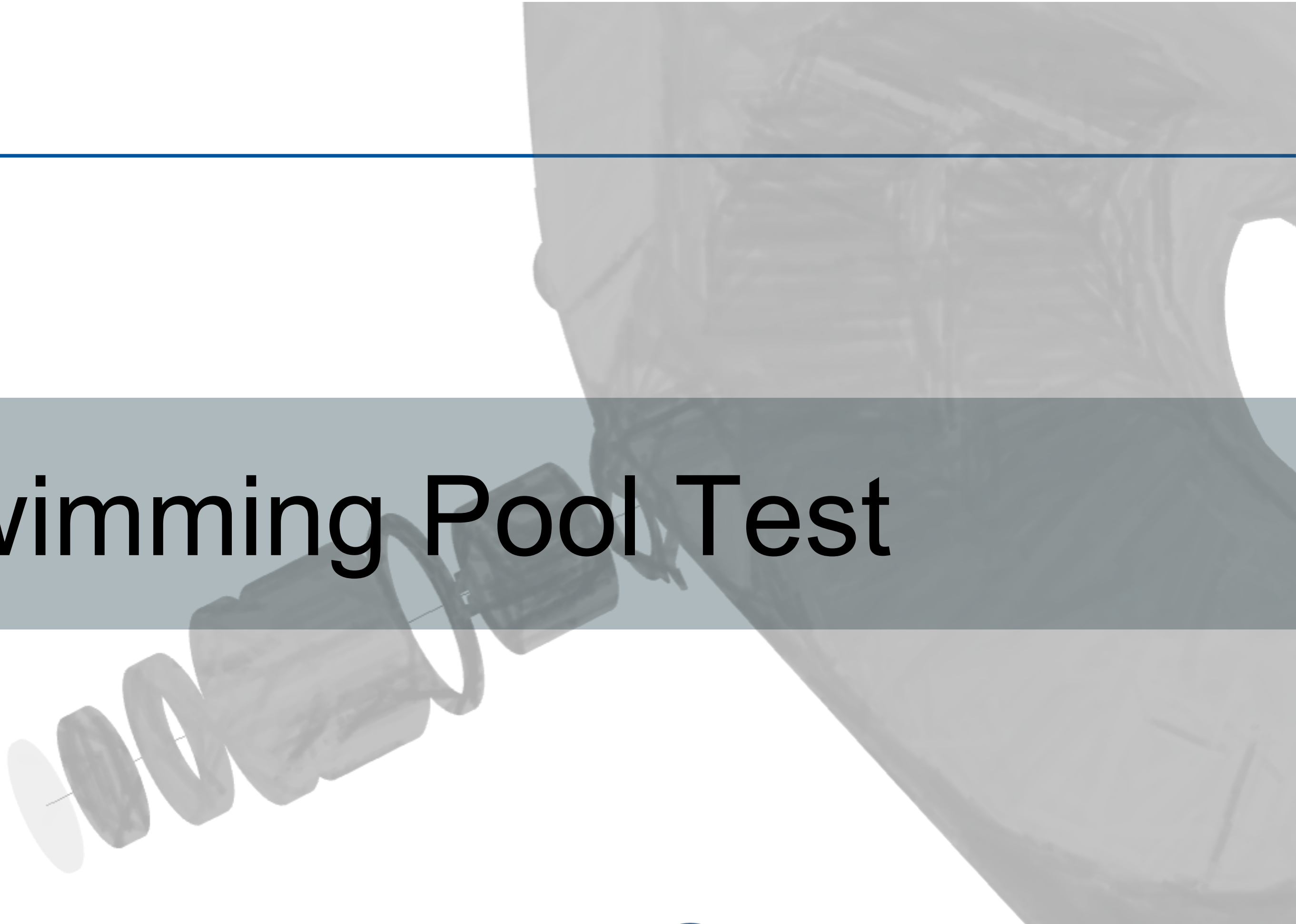
Swimming Pool Test



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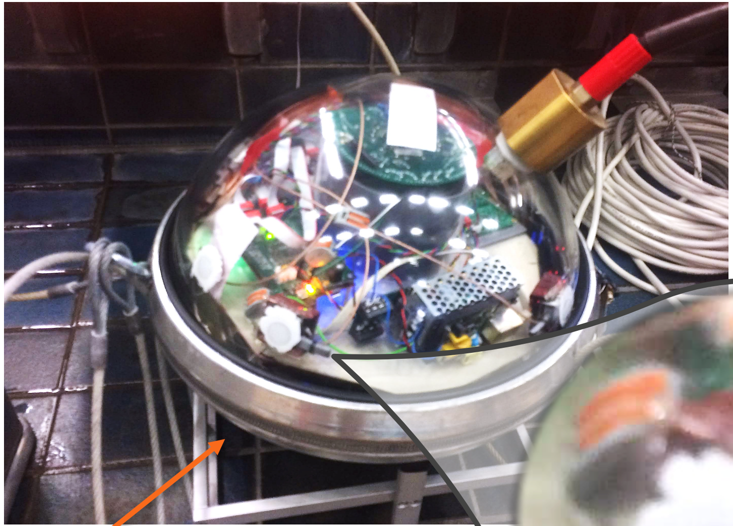
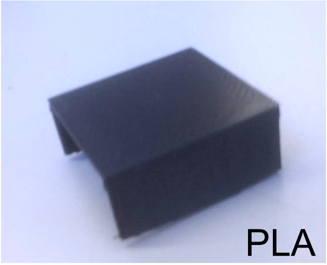
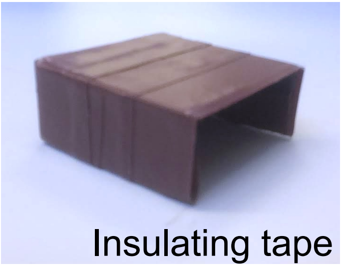
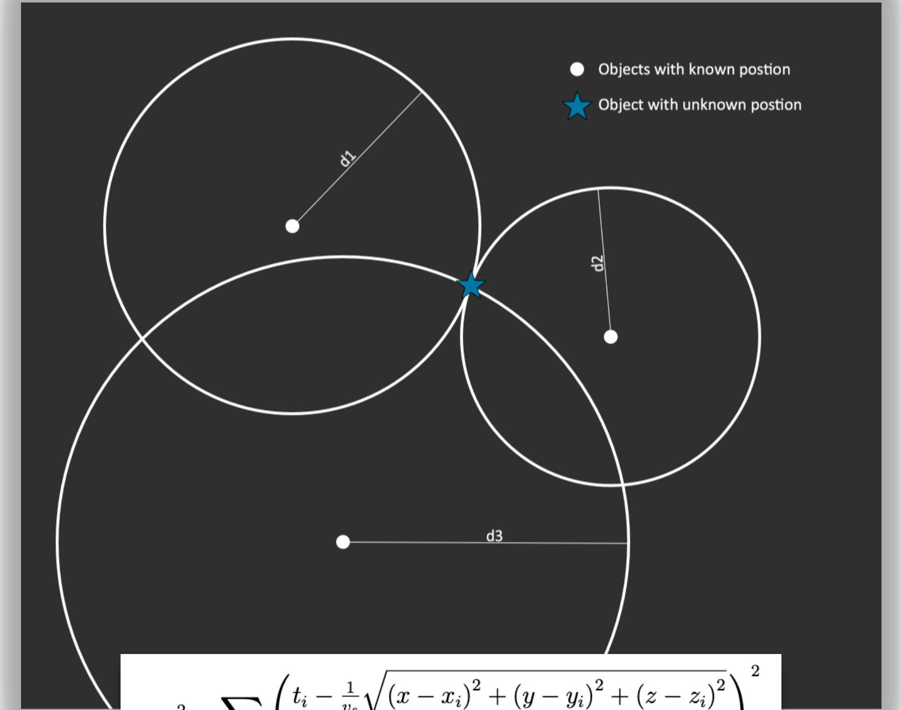
Piezo mounting



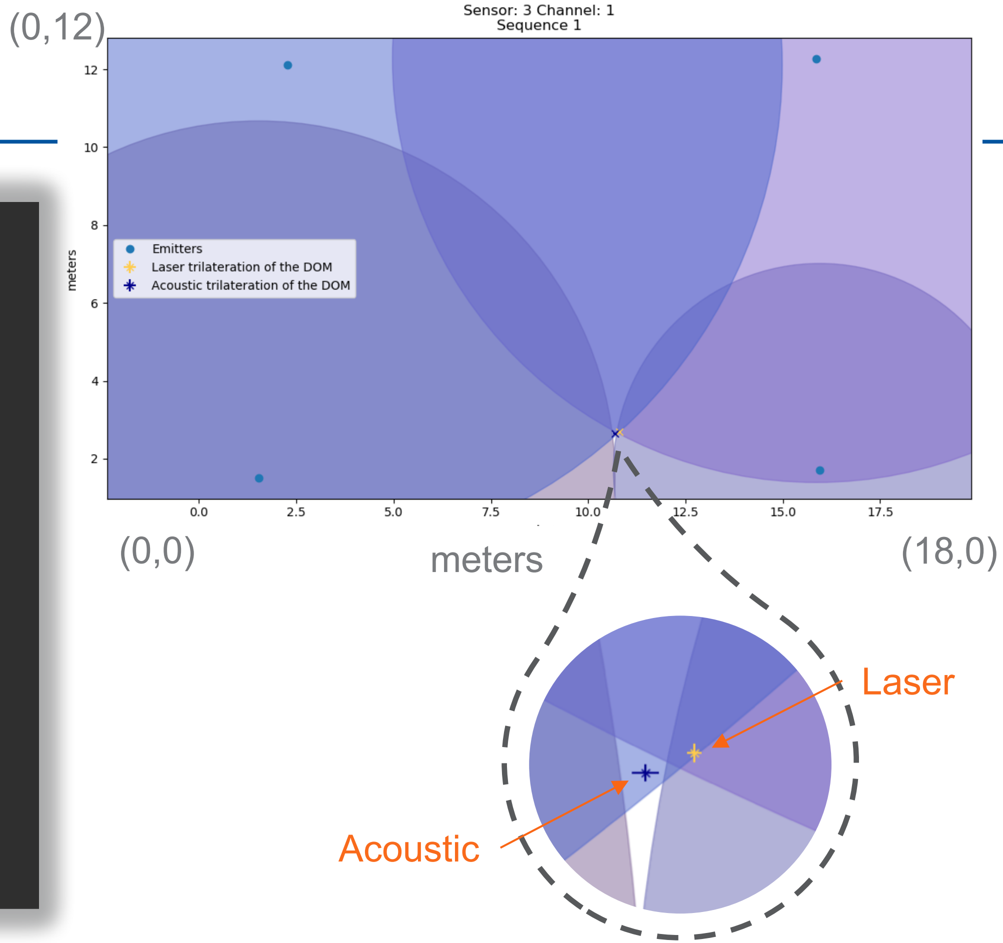




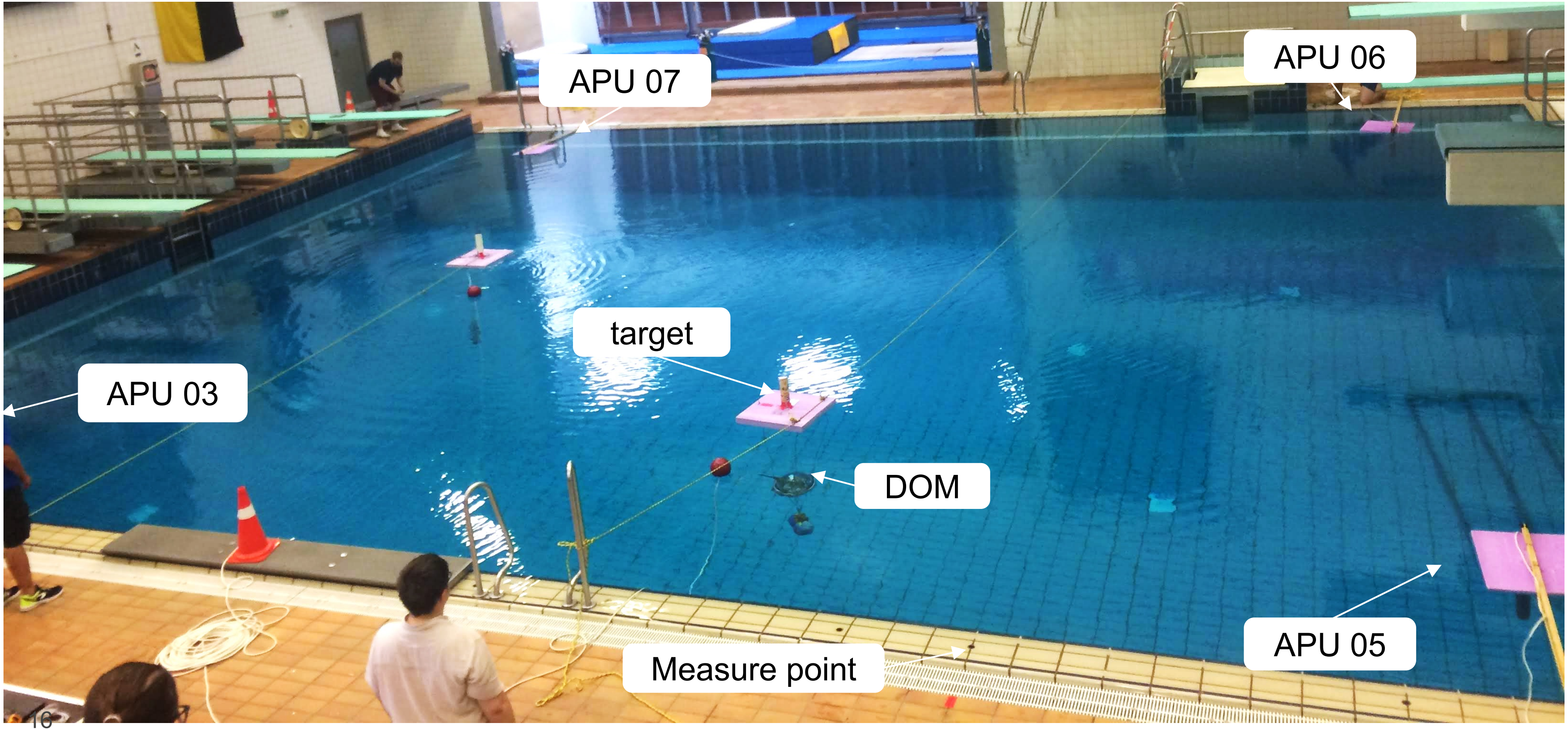
Trilateration



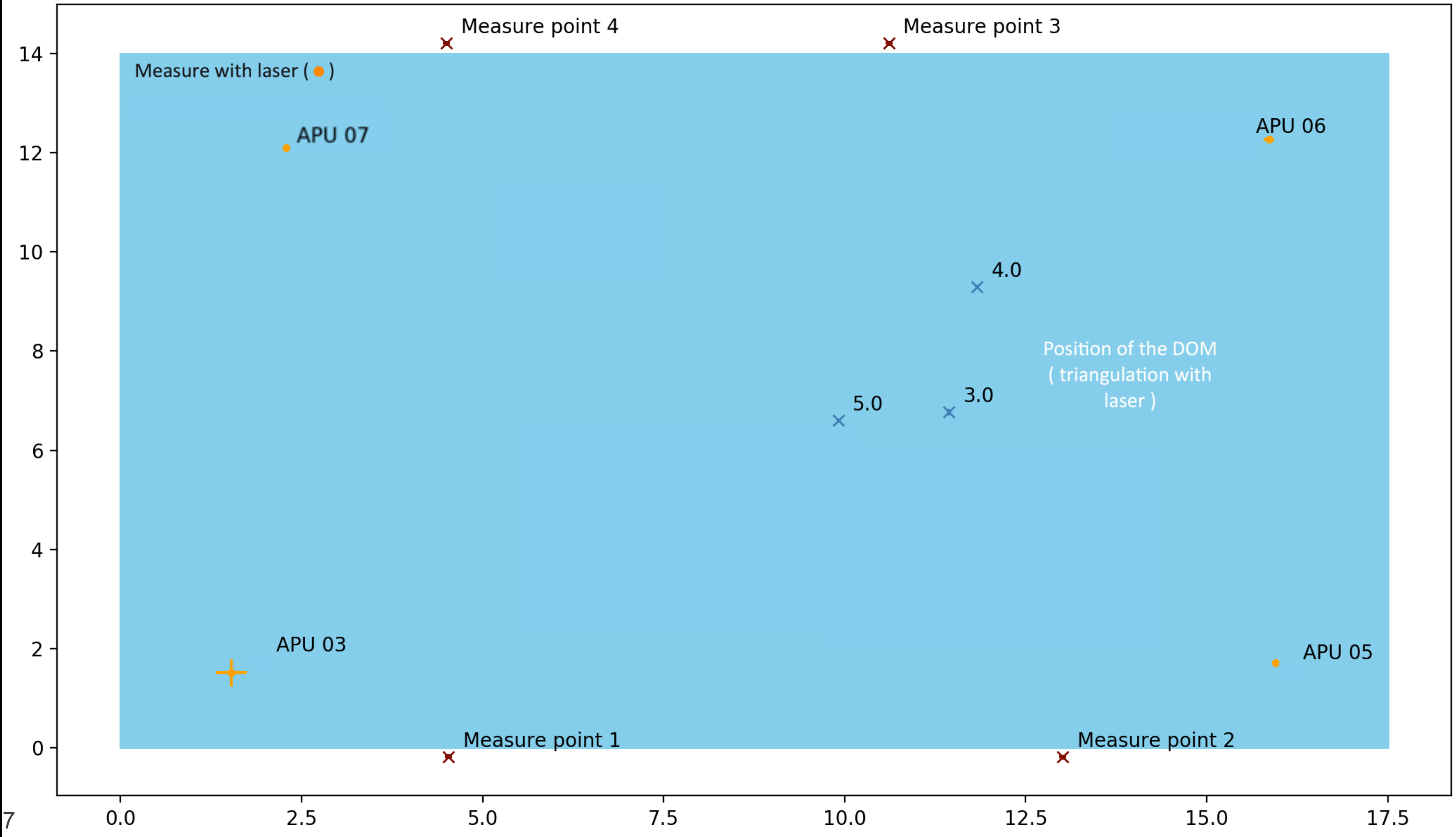
$$\chi^2 = \sum_i \left(\frac{t_i - \frac{1}{v_s}\sqrt{(x-x_i)^2 + (y-y_i)^2 + (z-z_i)^2}}{\sigma_i} \right)^2$$



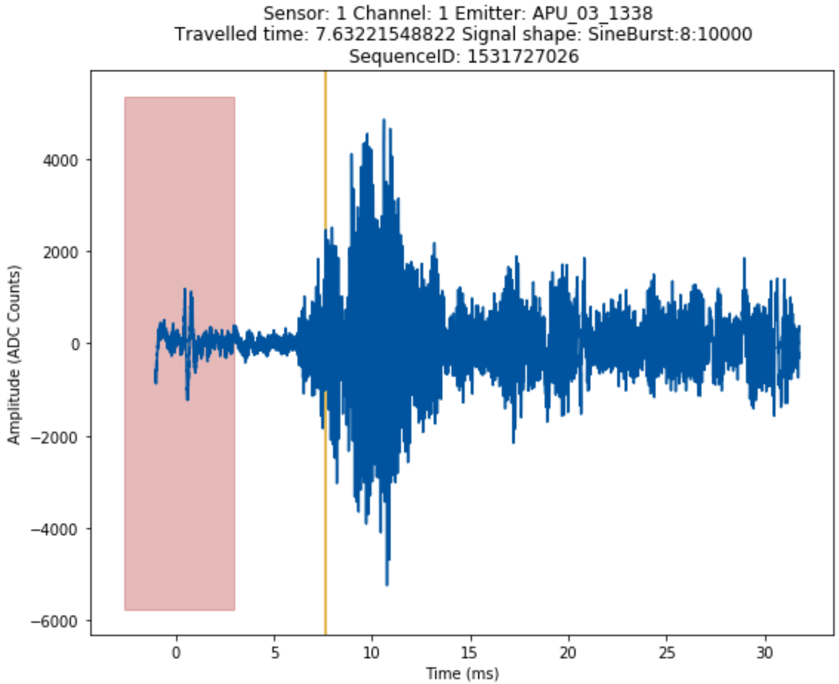
Swimming pool test - 16th July 2018

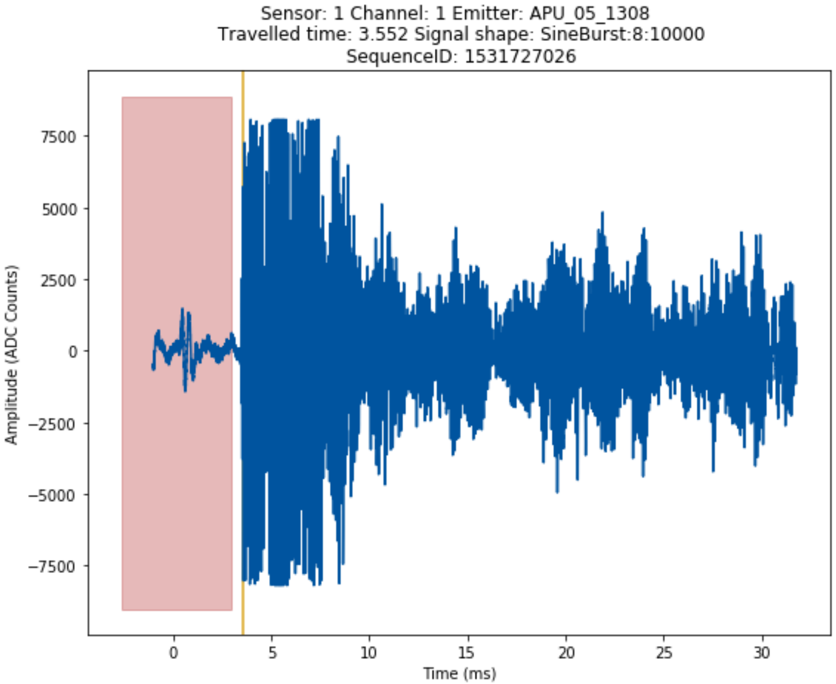


Position calibration with laser odometer



Unfiltered – Waveform differences





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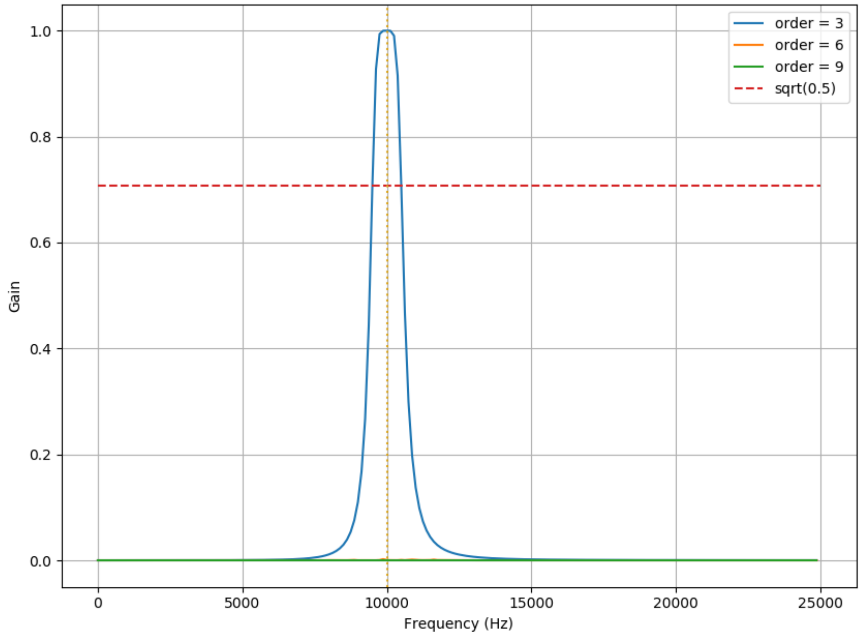
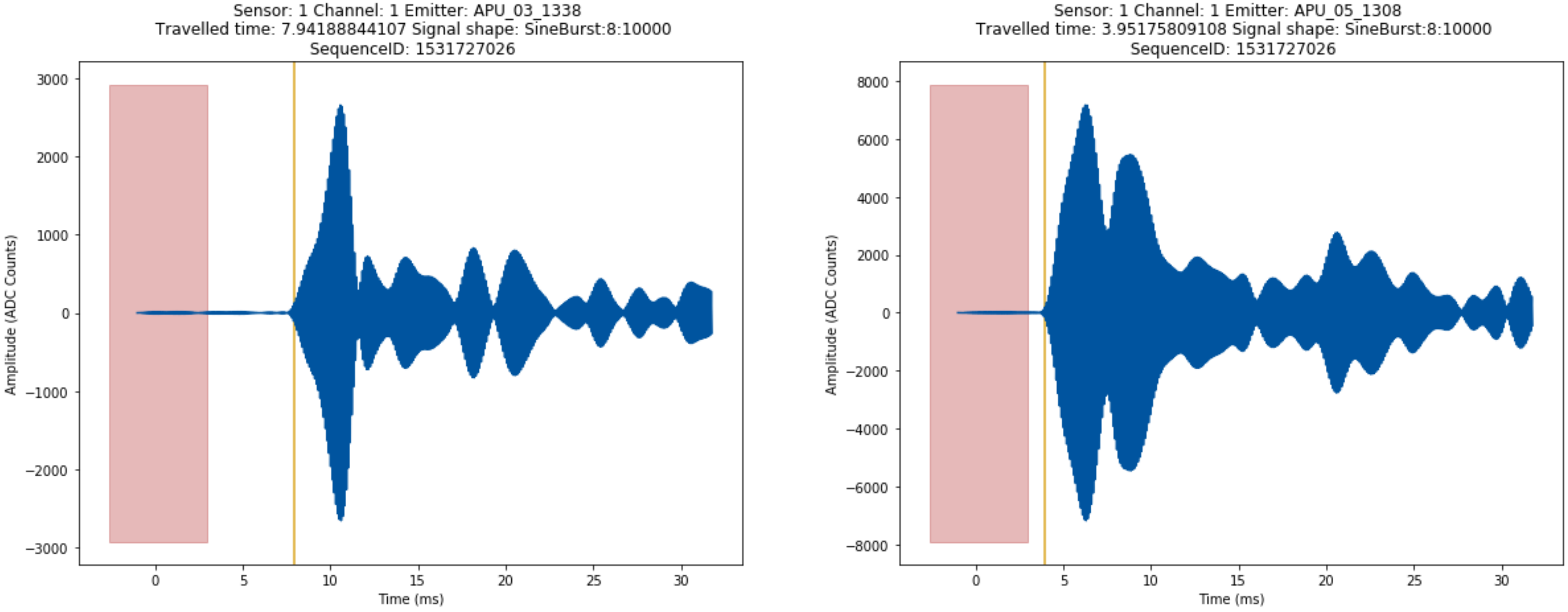
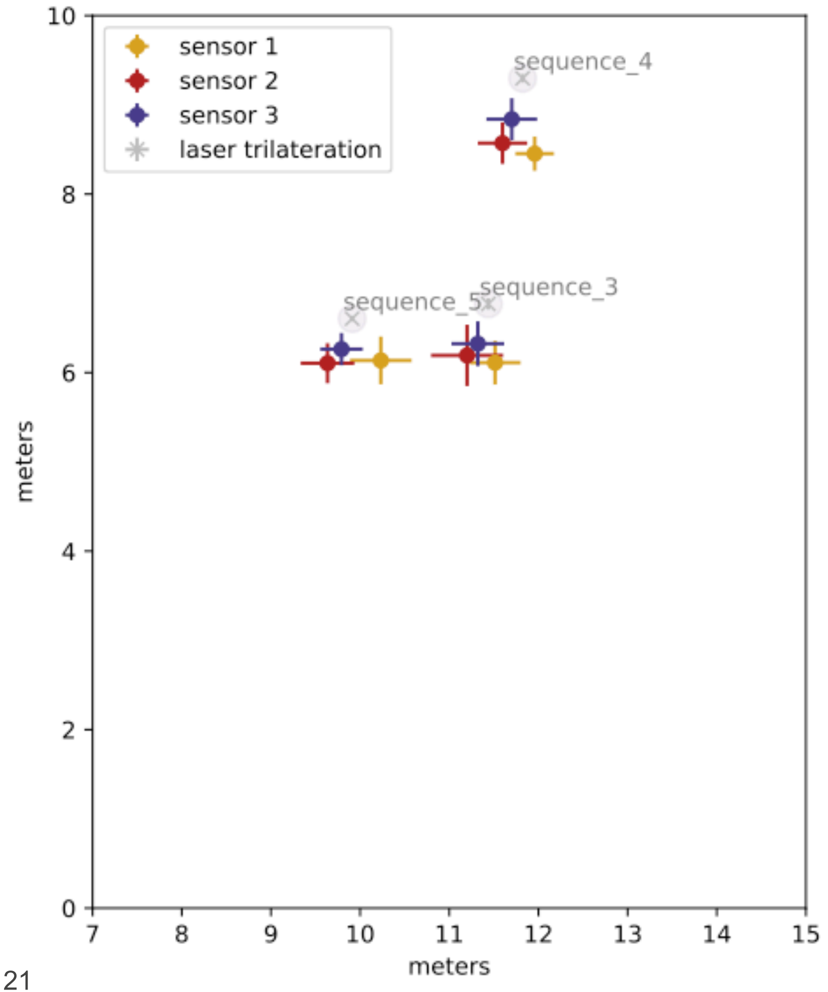
Butterworth bandpass Filter

- Aimed frequency : 10 kHz
- Low band frequency : 9.7 kHz
- High band frequency : 11.3 kHz
- Order used : 3



Filtered – Waveform differences





Filtered trilateration

- Sensor emplacement are accurate with their position in the Dom
- Still have to find why the position is shifted down
- Orientation is good

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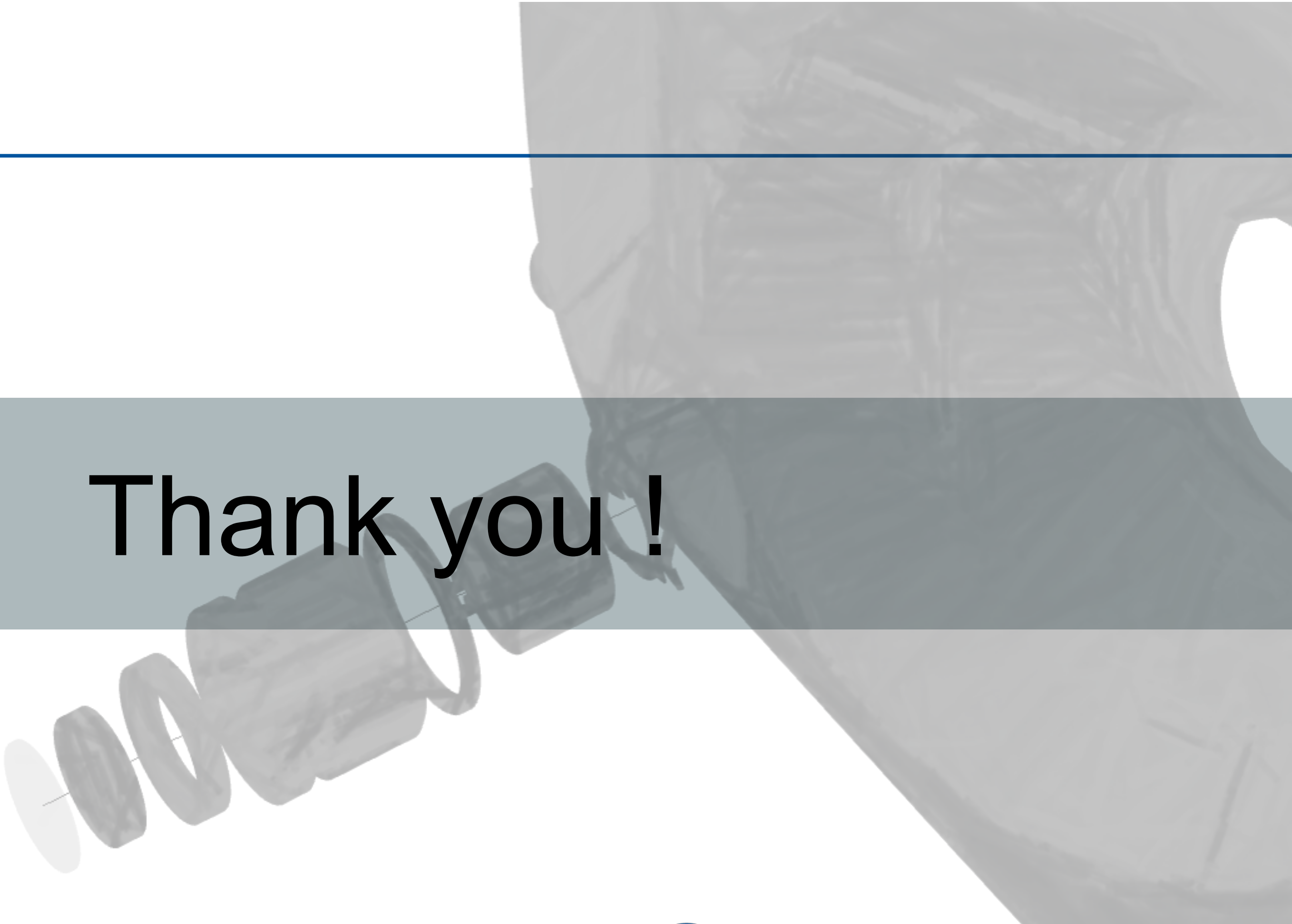
Summary and outlook

Summary

- Presentation of a concept for mechanical integration
- Performed pool test on positioning performance based on EnEx sensors

Outlook

- Analysis of the pool test data
- Angular dependence
- Signal amplitude with coupling-elements



Thank you !

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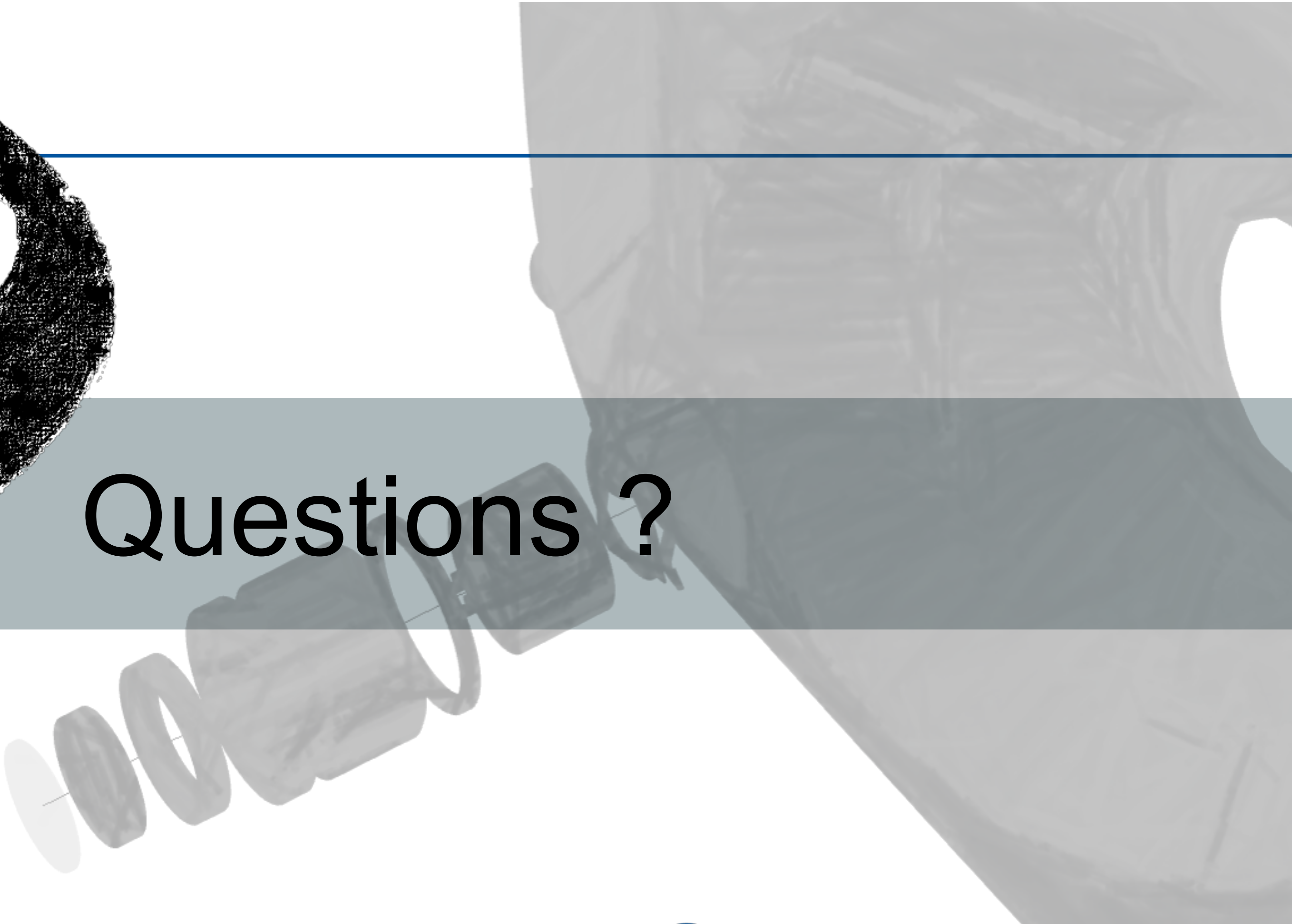
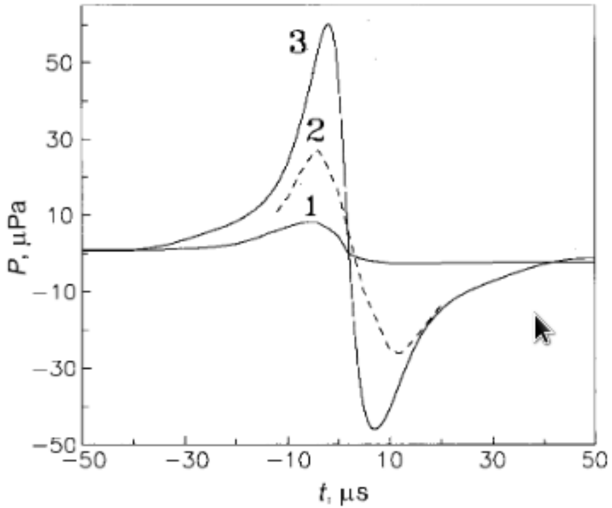
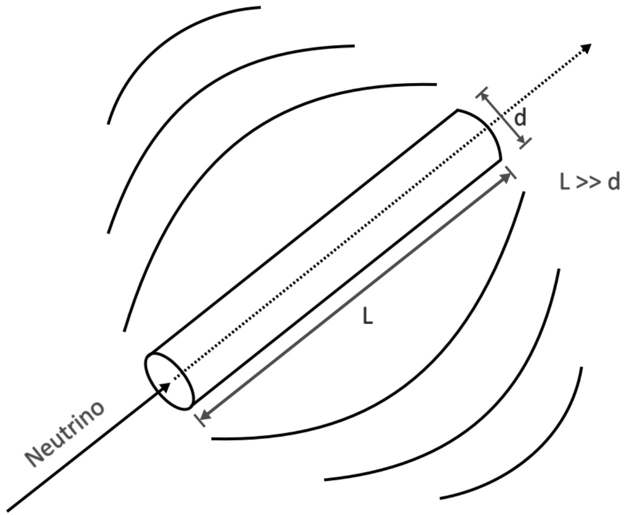


Questions ?

Acoustic emission by neutrinos

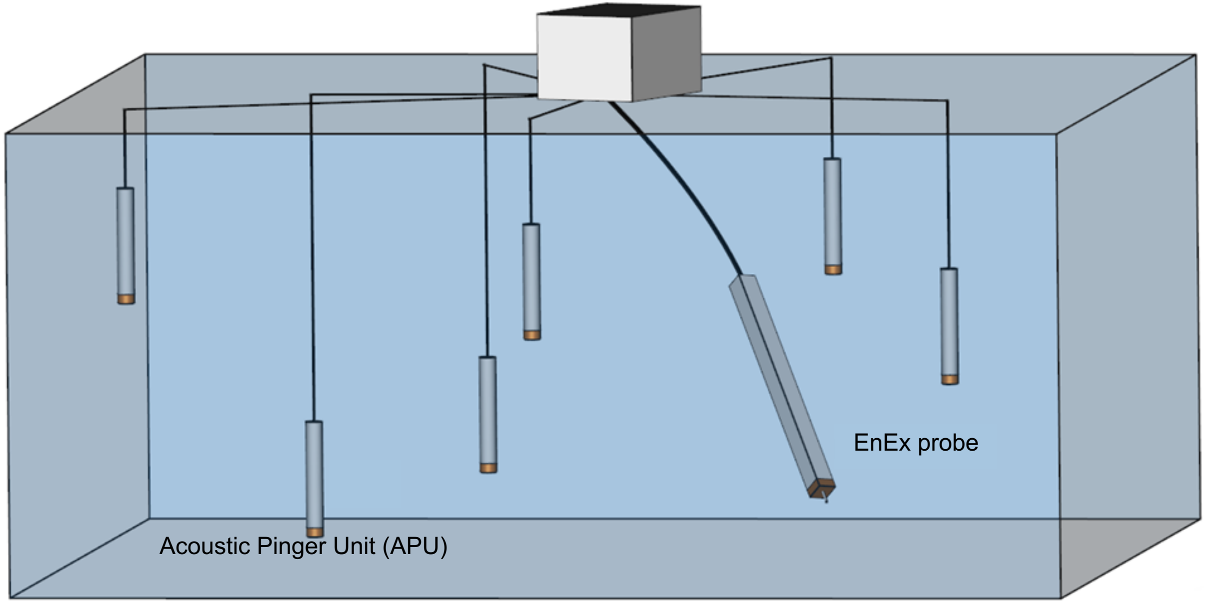
- Thermo-acoustic model
- Characteristic bi-pulse
- Emission in a plane perpendicular to neutrino direction





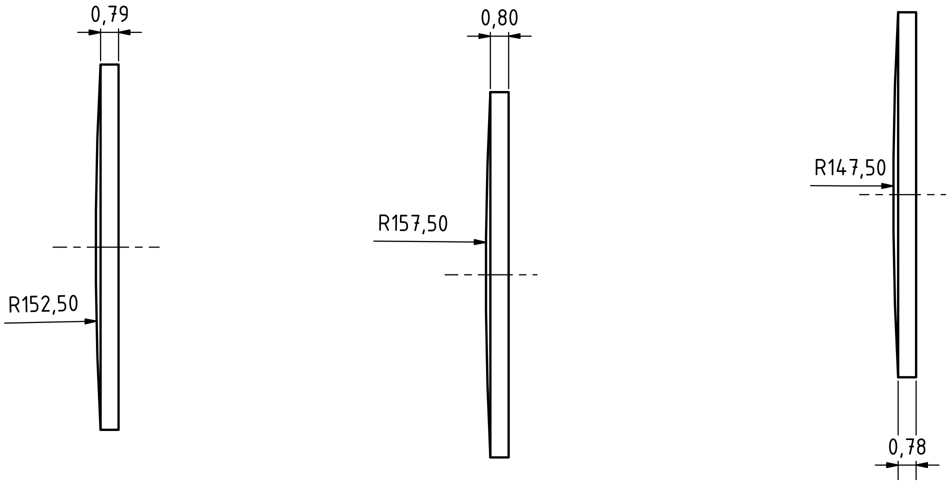
EnEx RANGE contribution

- Array of pingers (APU) emitters used to position an object (IceMole) in ice
- Knownledge carried from EnEx into IceCube



Type of coupling

- The coupling is important in acoustic waves
- The glass sphere shrinks under pressure
- Impossible to have a perfect coupling in all DOMs (different deepness = different pressure)



$R_{tip} = R_{sphere}$ $R_{tip} > R_{sphere}$ $R_{tip} < R_{sphere}$

∅

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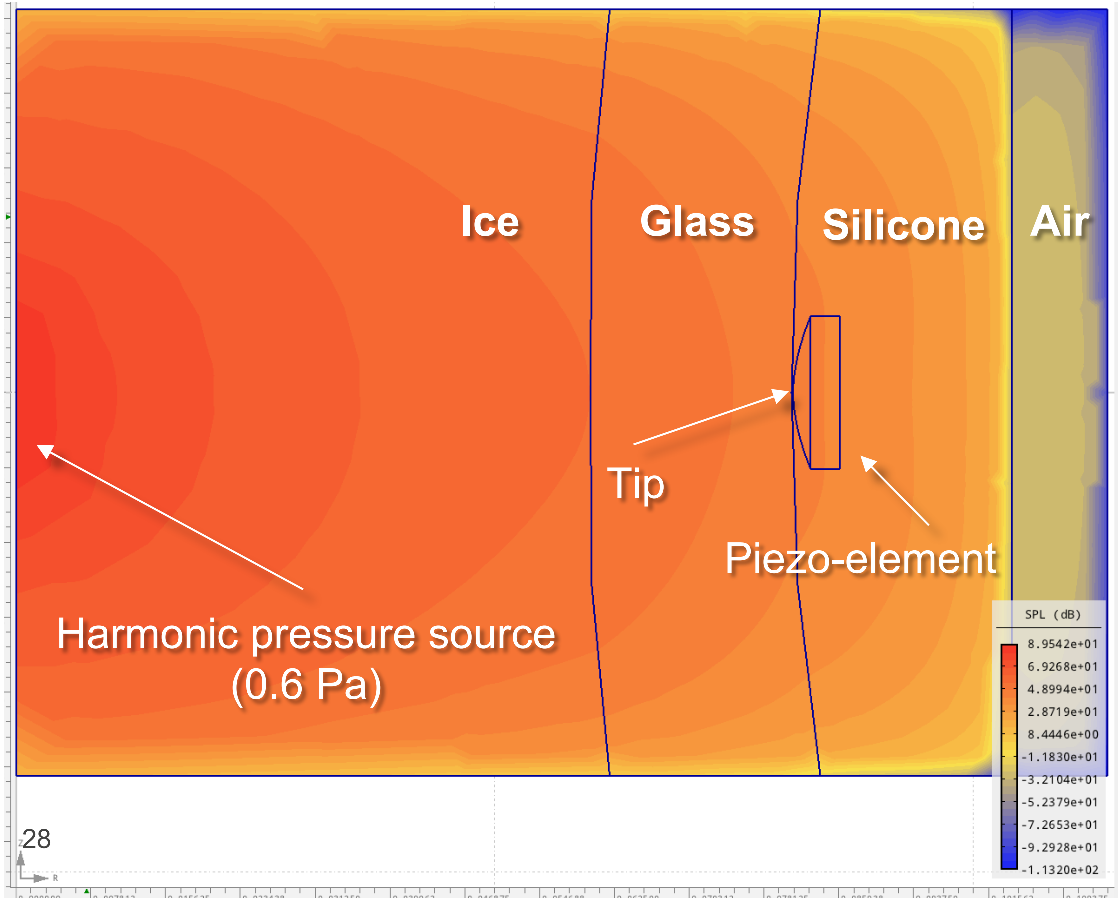
Coupling - Simulation



Methodology

- Harmonic wave with a pressure of 0,6 Pa
- 4 different coupling
  - Round (simulate $R_{tip} < R_{sphere}$)
  - Flat (simulate $R_{tip} > R_{sphere}$)
  - Perfect with thickness
  - No tip
- Different materials
  - Brass, Glass, Aluminum, Steel
- Transmission calculated from impedance

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Coupling - Simulation

Material	Speed V_L	Density ρ	Impedance Z_L
	[mm/μs]	[g/cm^3]	[MRayl]
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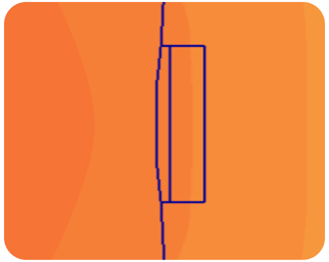
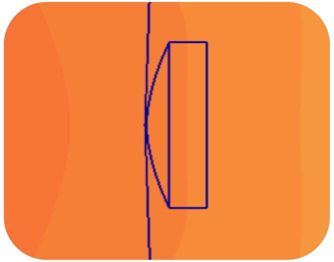
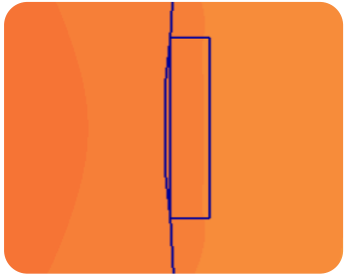


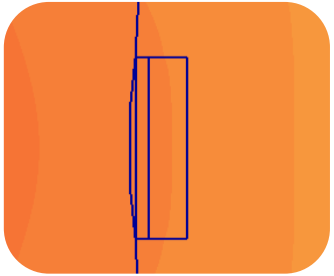
Fit tip



Round tip



PZT, gel, epoxy



Flat tip

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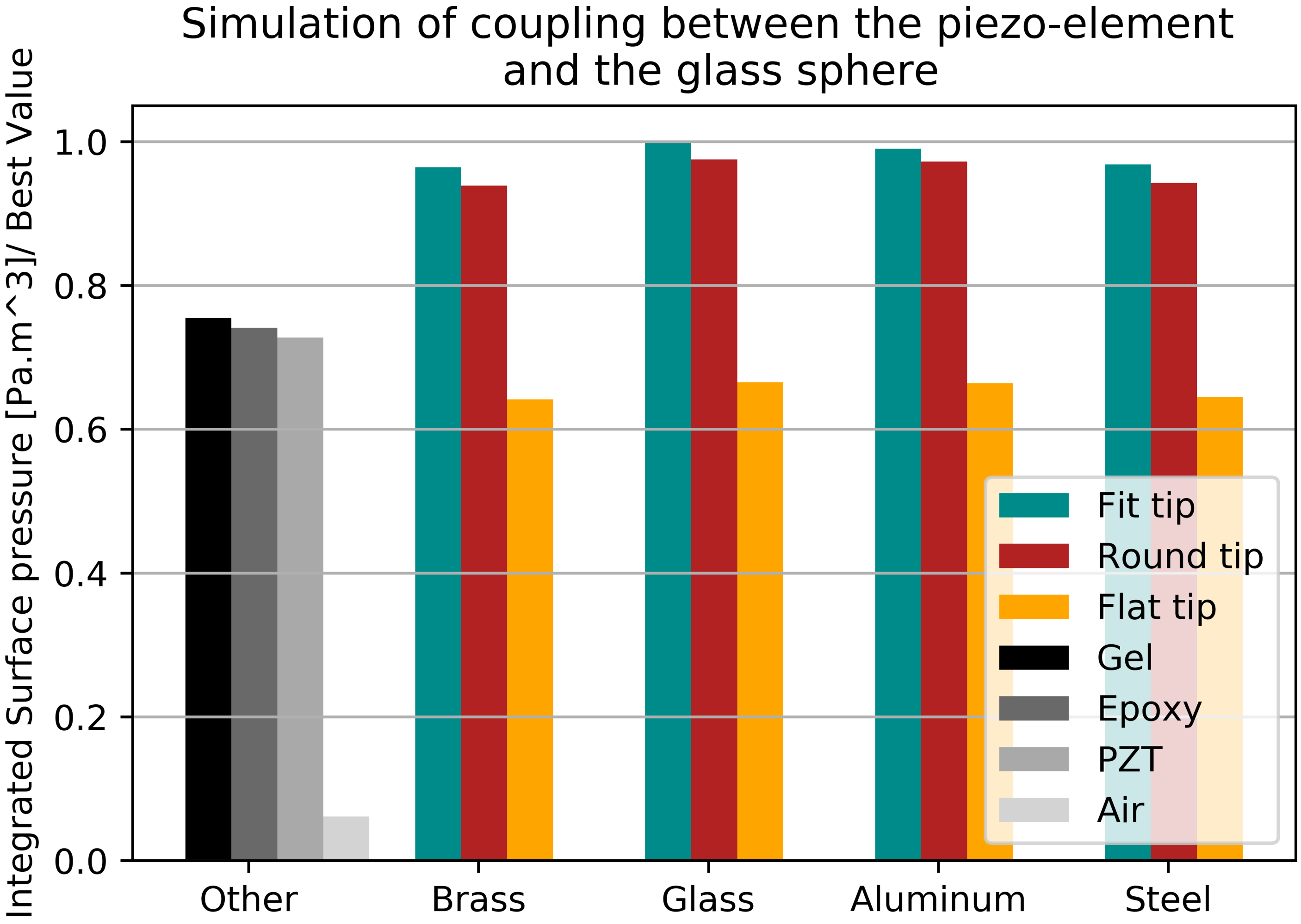
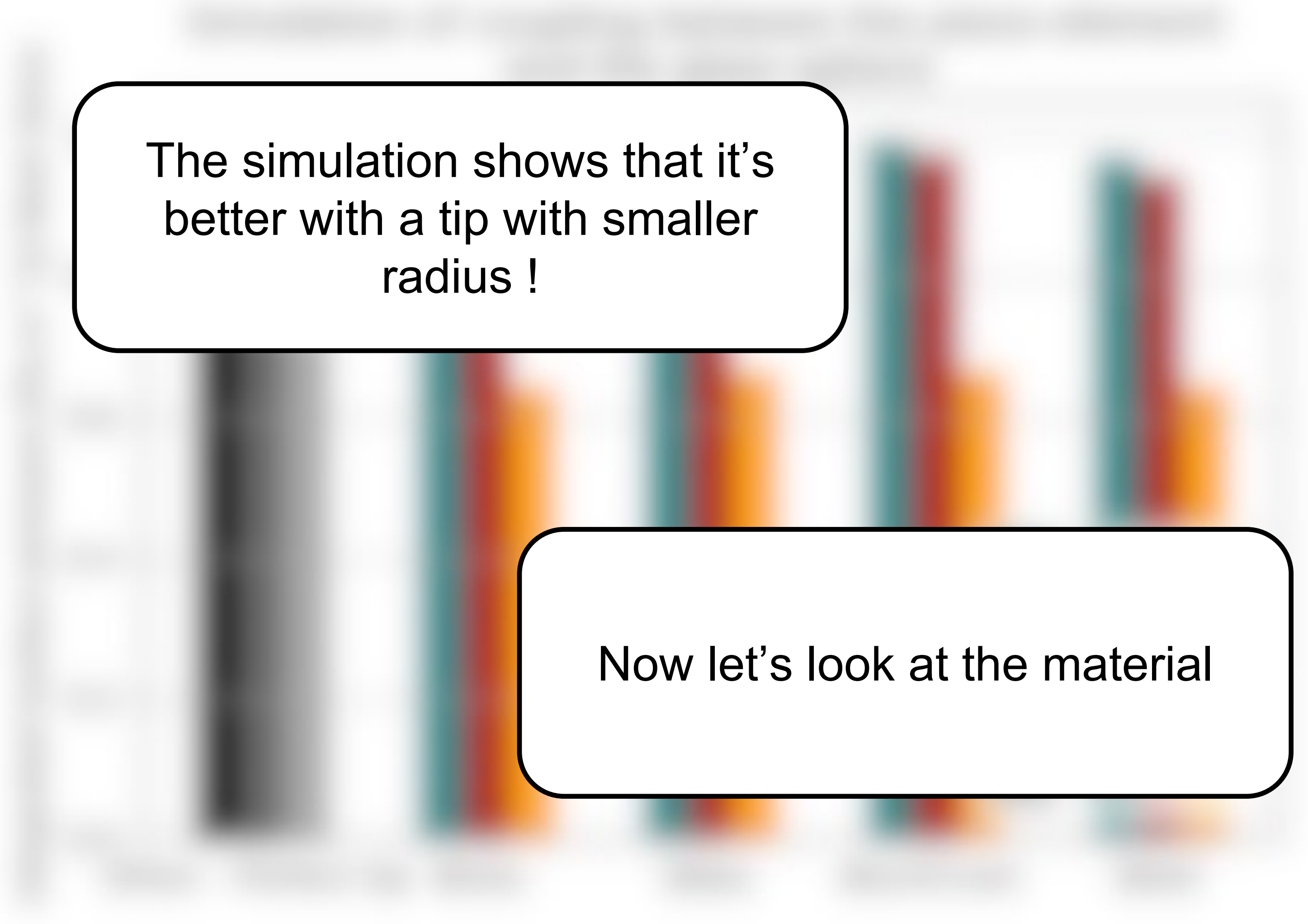
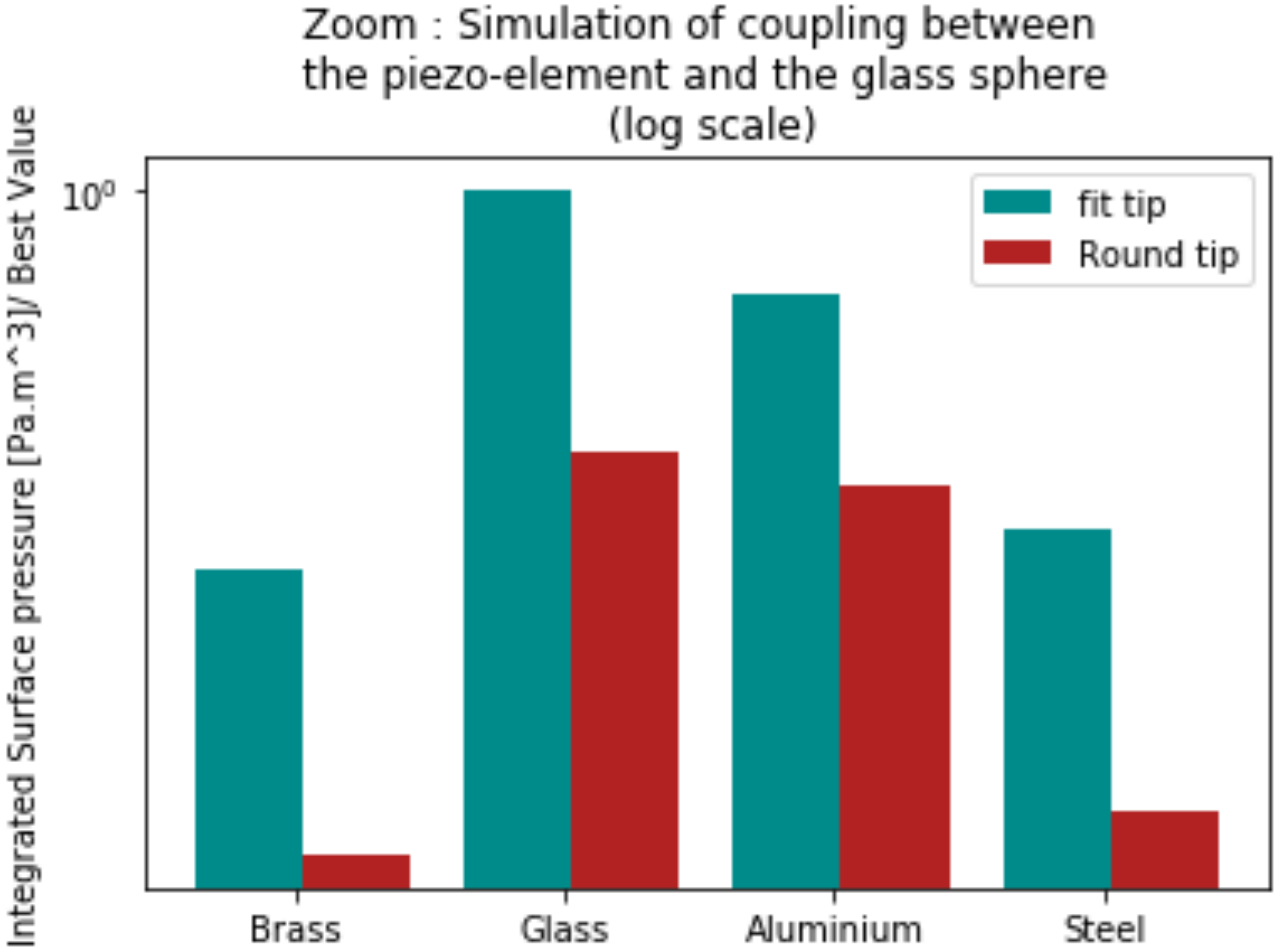


Simulation of coupling between the piezo-element and the glass sphere
Integrated Surface pressure [Pa.m^3]/ Best Value
1.0
0.8
0.6
0.4
0.2
0.0
Other
Brass
Glass
Aluminum
Steel
Fit tip
Round tip
Flat tip
Gel
Epoxy
PZT
Air



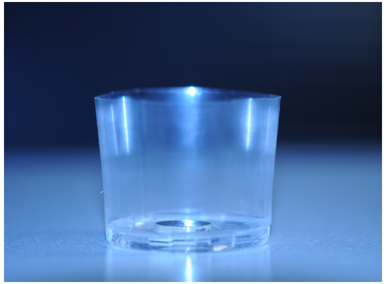
The simulation shows that it’s better with a tip with smaller radius !

Now let’s look at the material

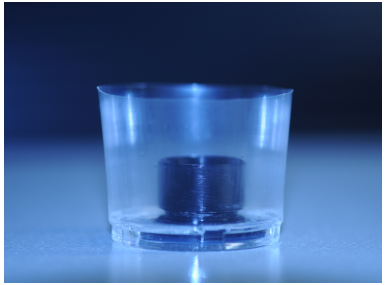

Zoom : Simulation of coupling between the piezo-element and the glass sphere (log scale)
Integrated Surface pressure [Pa.m^3]/ Best Value
10^0
fit tip
Round tip
Brass
Glass
Aluminium
Steel

Compatibility

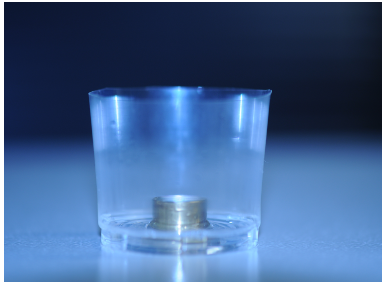
Aluminium



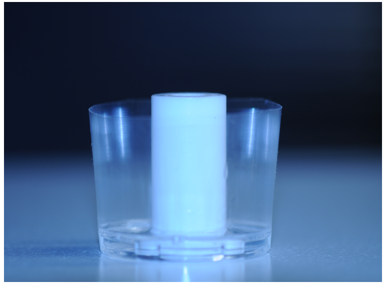
Piezo-element



Plastic PLA
(for the testing setup)



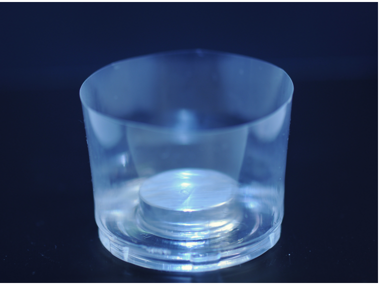
Brass



Teflon

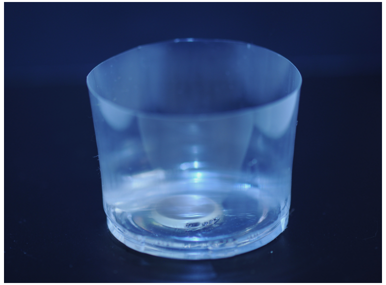
Chemical compatibility test

- Mix gel with material
- Visual inspection for optical degradation
- More tests required ?



Aluminum

✓

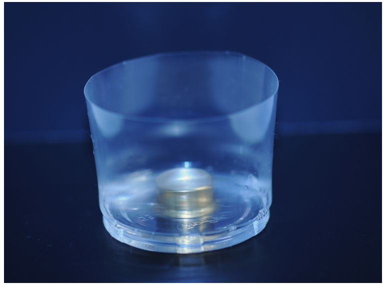


Piezo-element

✓

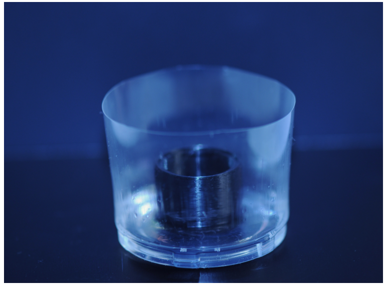
Teflon

✓



Brass

✓

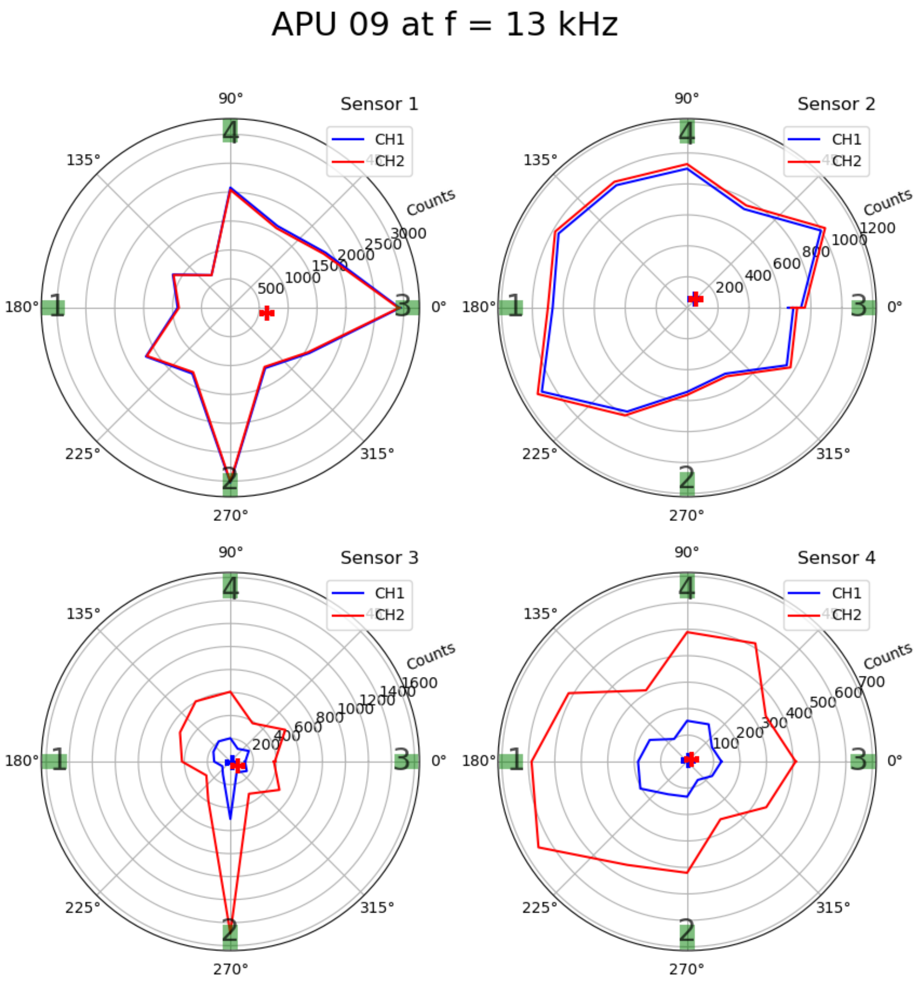


Plastic PLA
(for the testing setup)

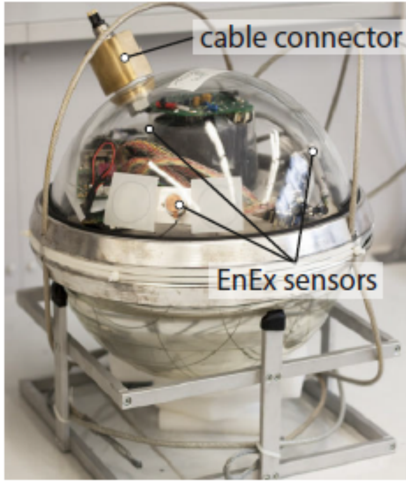
✓

Angular dependency

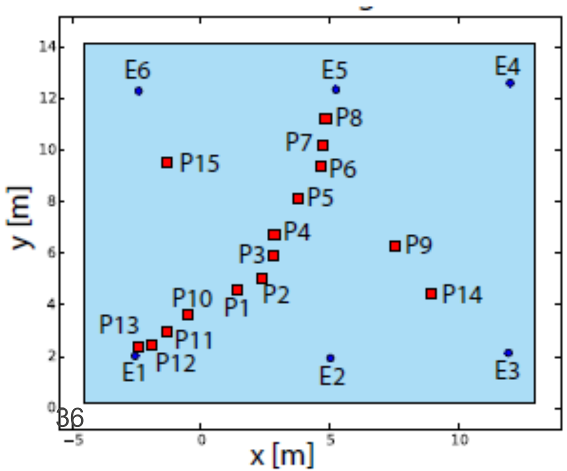
- Strong angular dependence for only one sensor (sensor 3)
- The angular coverage seems good with 3 sensors

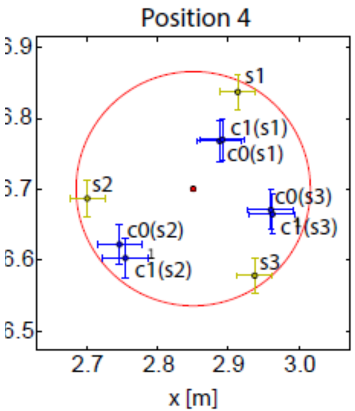


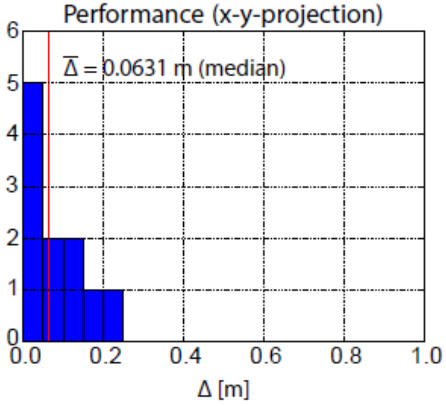
Pool performance - Hopefully

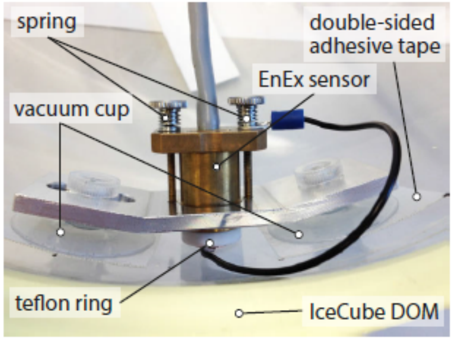


- 1. ch. 16 kHz to 20 kHz - Positionning
- 2. ch. 10 kHz to 100 kHz – Neutrino
- 50 mW (idle), 75 mW (digitalizing)
- Performance in water pool: [DOI: 10.1051/epjconf/2017135, ARENA 2016]









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