Towards a hybrid optical-acoustic deep-sea neutrino detector

M. Ardid; S. Ardid; D. Diego-Tortosa; V. Espinosa; A. Herrero;
C. D. Llorens; C. A. Quiroz-Rangel

mardid@fis.upv.es ; sardid@fis.upv.es; vespinos@fis.upv.es;
didac.diegotortosa@lns.infn.it; aherrero@mat.upv.es; cdavid@upv.es; carquira@upv.es

UNIVERSITAT POLITÈCNICA DE VALÈNCIA
CAMPUS DE GANDIA

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Contents Overview

Neutrino Properties

Almost no mass.

Extremely light particles, barely interacting with matter.

No electric charge.

Not deviated by magnetic fields in space.

Cosmic Messengers.

Travel cosmological distances, providing insights into distant phenomena.

Optic Detection Principle

1 **Neutrino Interaction**

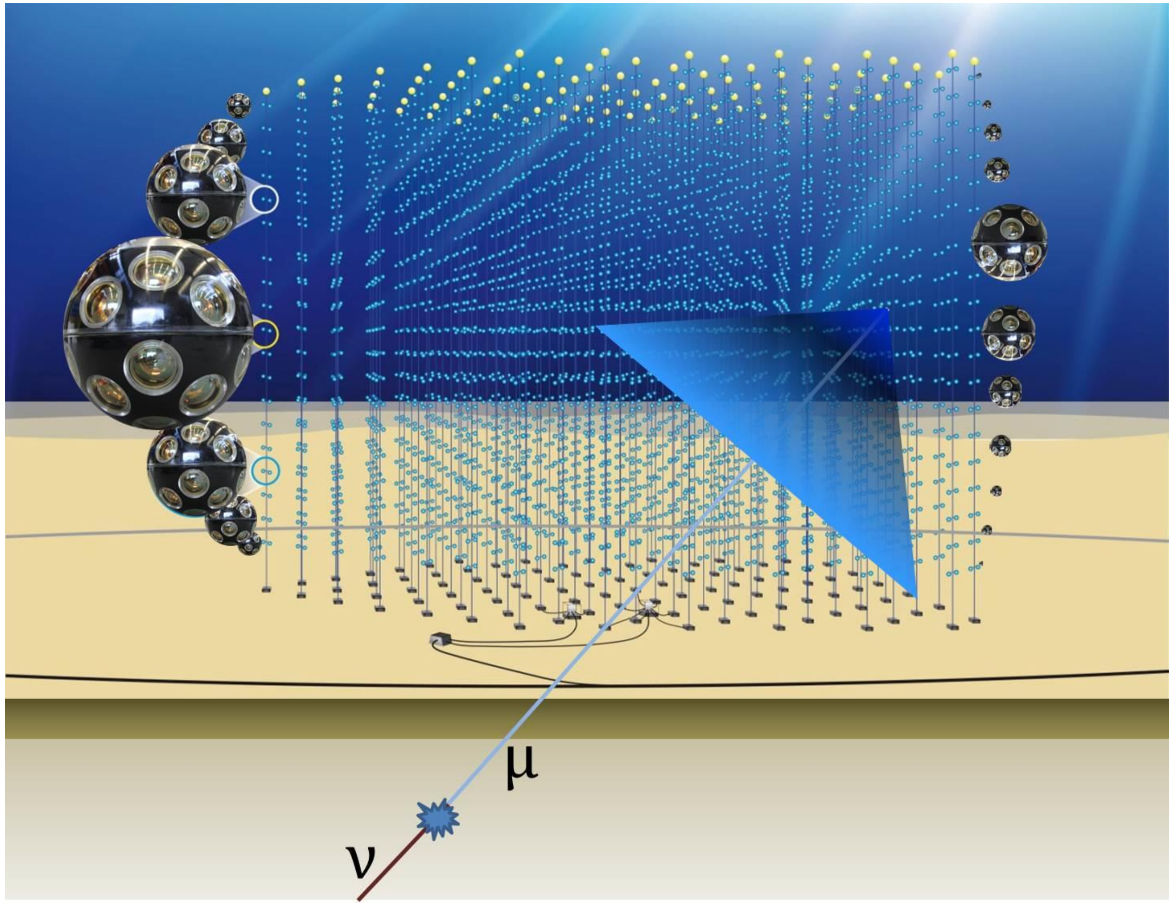
Neutrino ν collides with matter in detector volumen.

2 **Charged Particle Production**

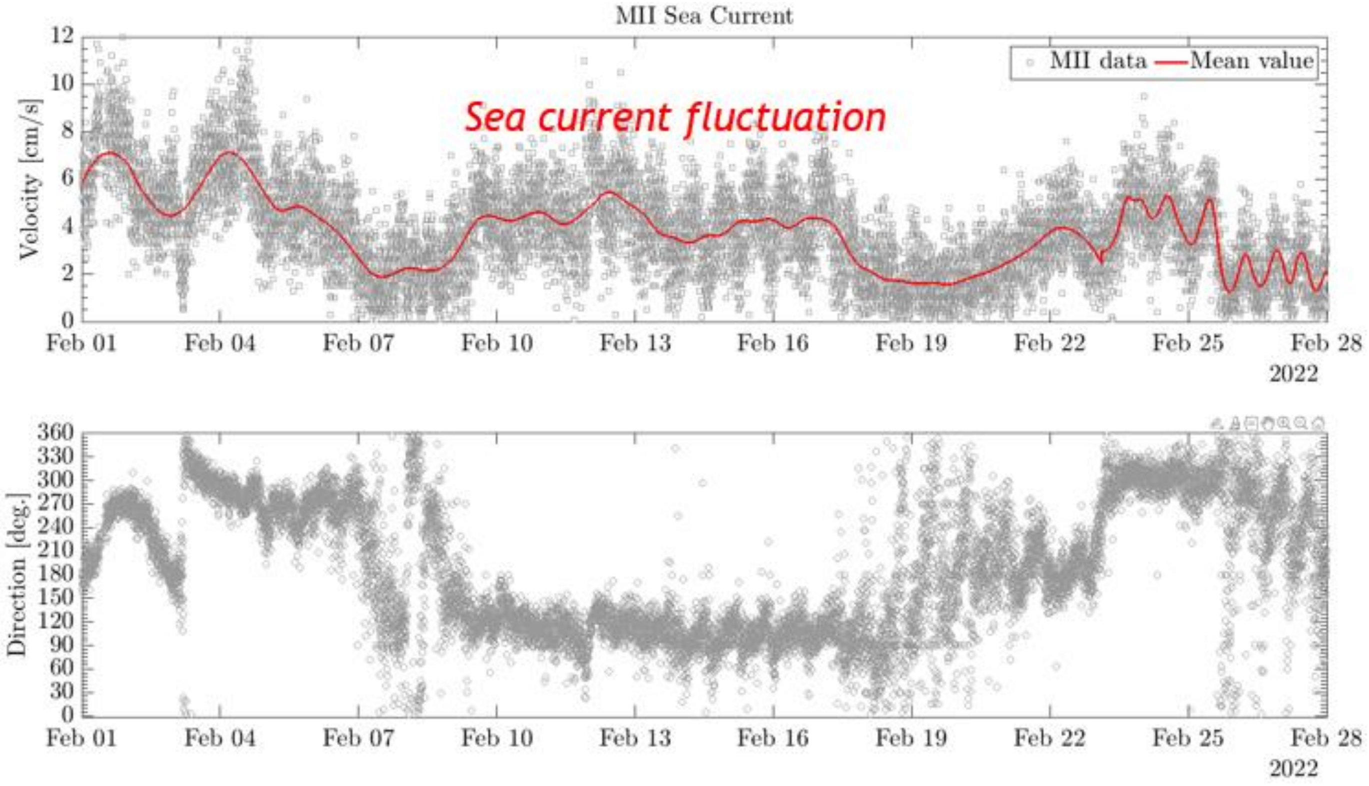
Interaction produces charged particles, e.g. muon μ.

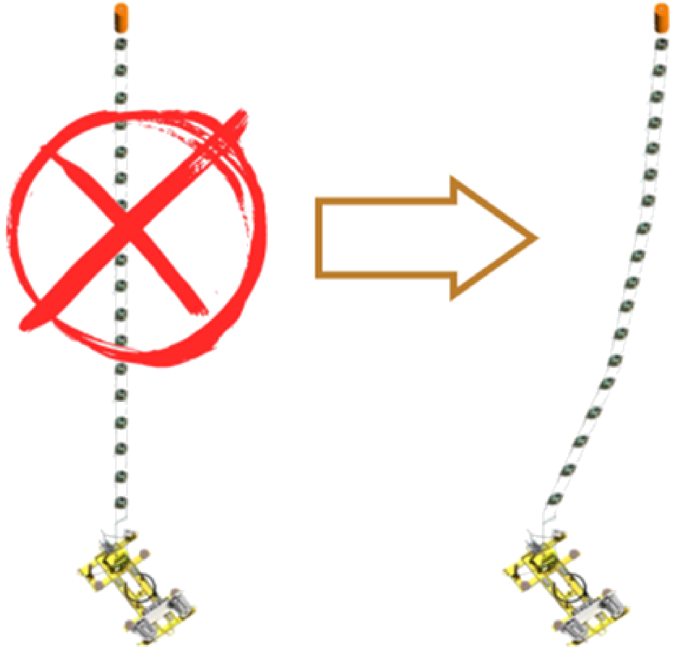
3 **Cherenkov Radiation**

Particles emit Cherenkov light, detected by PMTs.



KM3NeT - Acoustic Positionig System



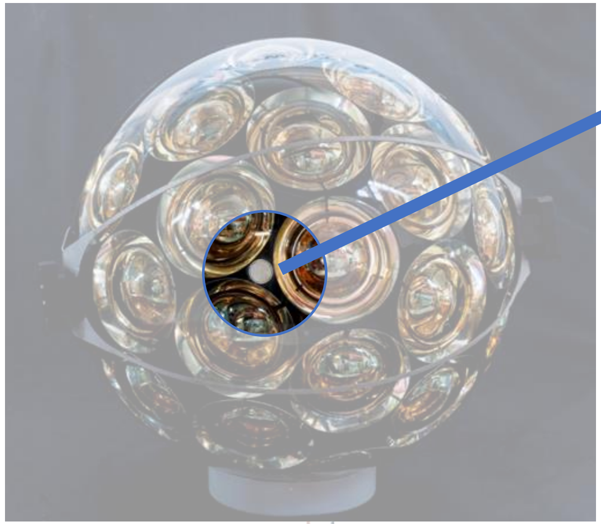


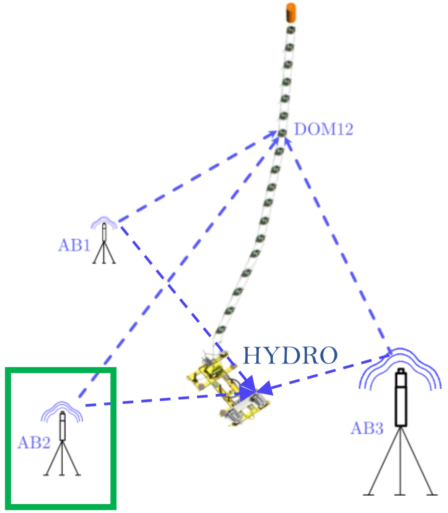
KM3NeT - Acoustic Positioning System (APS)

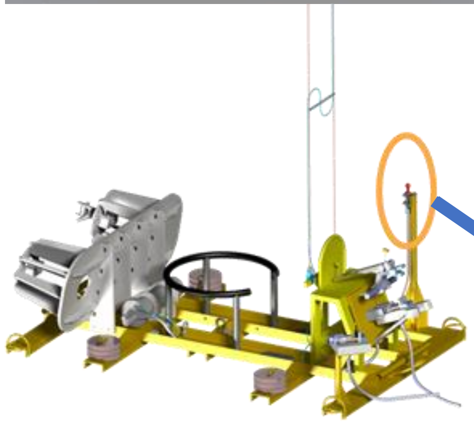
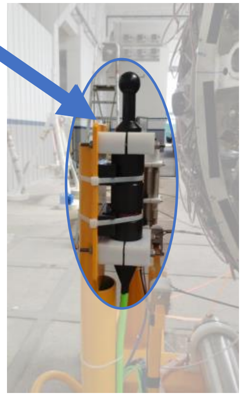
Emitters
- Acoustic Beacons – DU Bases and Tripods.
  20 kHz – 60 kHz.

Receivers
- Piezoceramic sensor (DOM)
  10 kHz - 60 kHz.
- Hydrophone (DU base)
  5 Hz – 90 kHz.

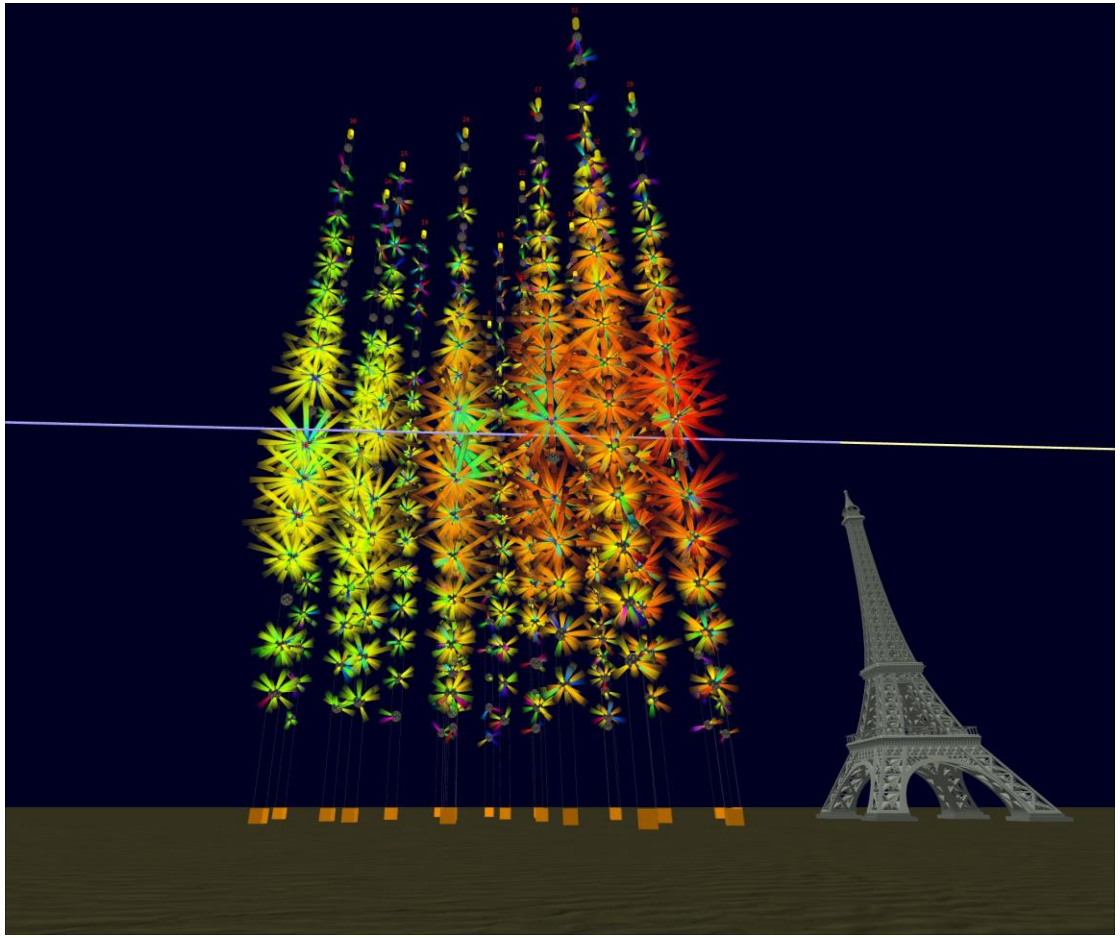
Synchronization of time of arrival of acoustic signals emitted allows positioning





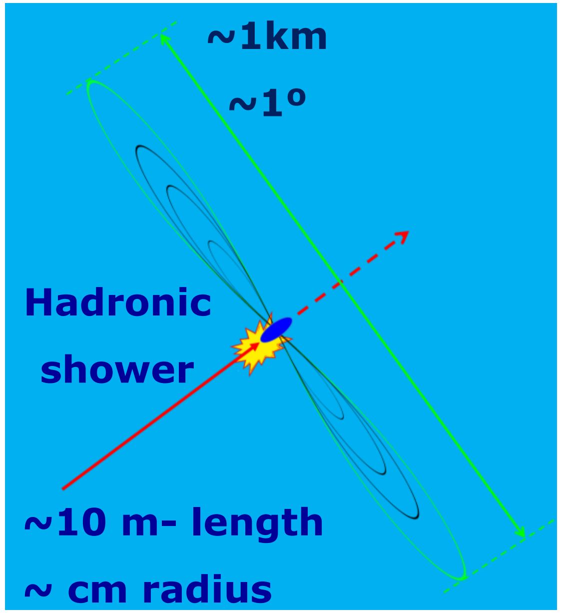

Ultra-High-Energy Cosmic Neutrino



A record-breaking discovery….

On February 13, 2023, the KM3NeT team recorded a neutrino event unlike any other. Named KM3-230213A, the neutrino's energy was estimated to be an astonishing 220 peta- electronvolts (PeV) – roughly a billion times 100 million times the energy of visible light photons and about 30 times the highest neutrino energy previously detected..

Acoustic Detection Principle



"[Development of a trigger for acoustic neutrino candidates in km3net". *PoS(ARENA2022)*].

Mechanism

Thermo-acoustic effect from particle interaction.

Signal

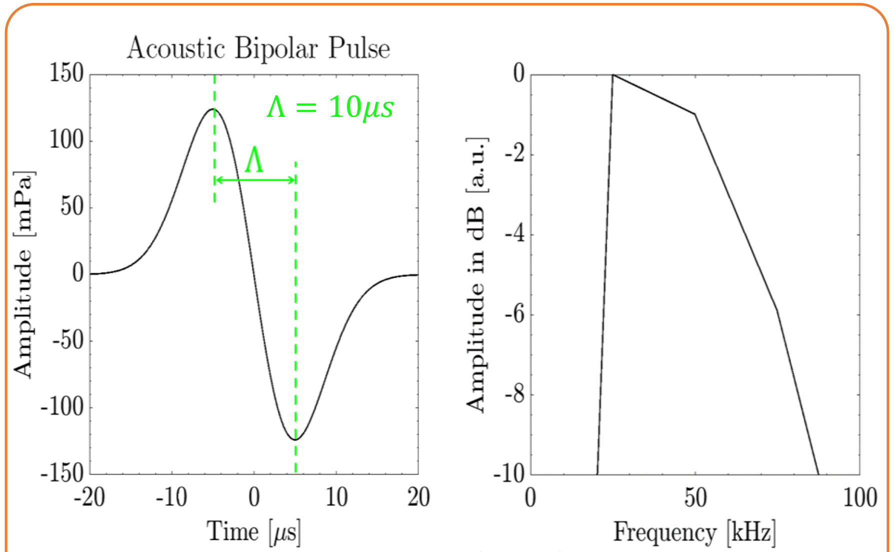
Bipolar acoustic pulse.

Frequency

~ 10 kHz - 90 kHz range.

Directionality

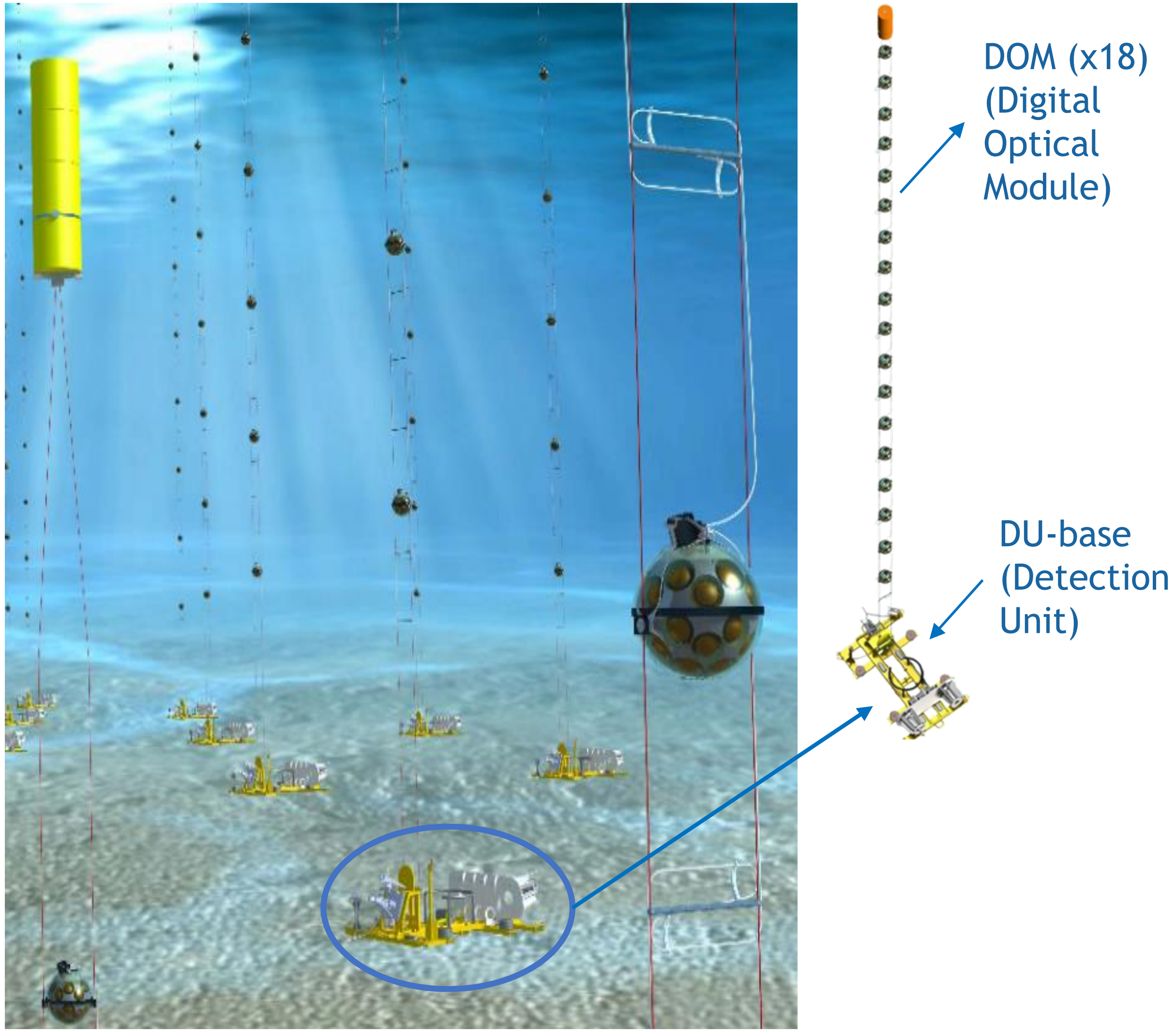
Narrow beam, typically < 5° opening angle.

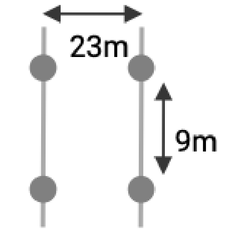


Acoustic Bipolar Simulation

[**Waters, D**. Study of the acoustic signature of UHE neutrino interactions in water and ice. *Nucl. Instrum. Methods Phys. Res., Sect. A* **2009**, 607, 398–411.

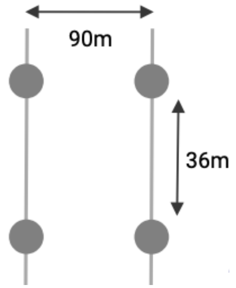
KM3NeT APS adapted for acoustic detection?





ORCA

- Depth ~2500 m
- One block of 115 DUs
- **Distance between DUs ~23 m**
- **Vertical dist. between DOMs ~9 m**



ARCA

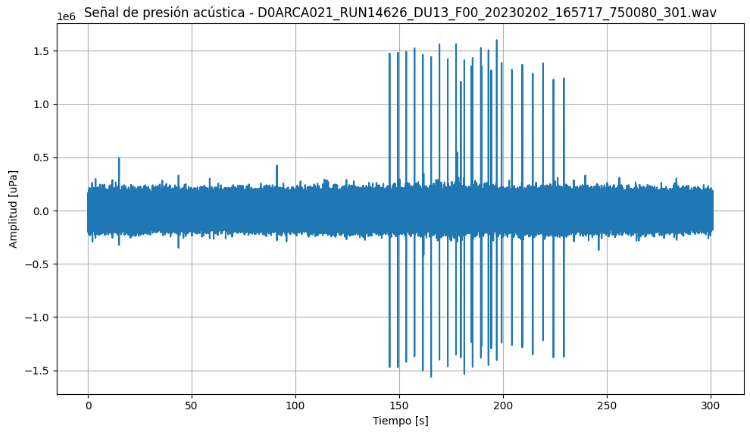
- Depth ~3500 m
- Two blocks of 115 DUs each one
- **Distance between DUs ~90 m**
- **Vertical dist. between DOMs ~36 m**

- The APS software is not designed to identify signals with bipolar pulse characteristics.
- Difficulties for identifying spatial-temporal coincidences due to distance between receivers and low speed of sound

Towards an acoustic trigger - Methodology

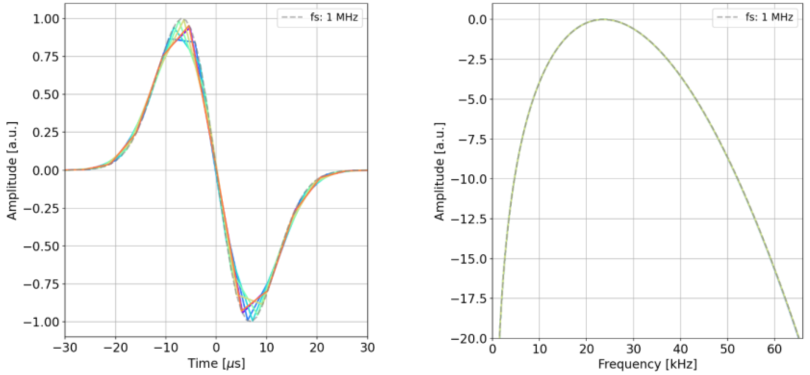
Signal Processing by Spectogram analysis.

1. Raw acoustic data (monitoring the site).



2. Add simulated BP into raw acoustic data.

$$\sigma = 12{,}5^{-6} (width\ BP).$$
$$GeV = 1e^{10}, 1e^{11}, 1e^{12}.$$
$$P_{max} = \frac{10^{(1{,}0021 * \log_{10} GeV)}}{10^{11{,}93}} [Pa].$$
$$BP_{scaled} = BP * P_{max} * 1e^{6} [\mu Pa].$$



$$g(t) = e^{-\frac{1}{2}\left(\frac{t}{\sigma}\right)^2} = e^{\frac{-t^2}{2\sigma^2}}$$

$$BP(t) = \frac{dg}{dt} = -\frac{t}{\sigma^2} \cdot e^{\left[\frac{-t^2}{2\sigma^2}\right]} \quad \xrightarrow{\Lambda = 2\sigma} \quad BP(t) = \frac{-4t}{\Lambda^2} \cdot e^{-2\left(\frac{t}{\Lambda}\right)^2}$$

https://arxiv.org/html/2409.04472v1#S1

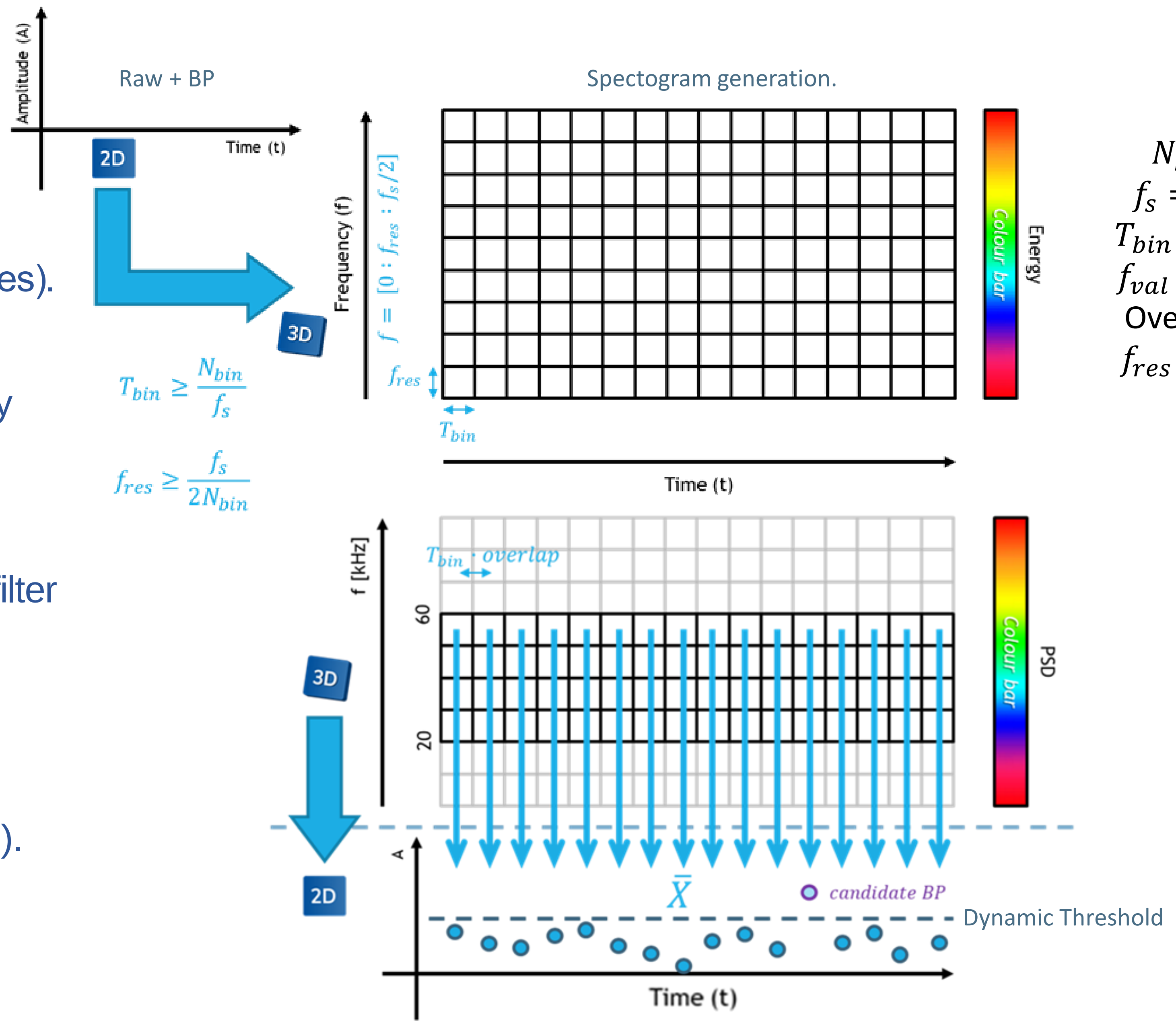
3. Detection phase (Trigger) and ToAref.

•Define a bin size (number of samples).

•Compute the power spectral density (PSD) over relevant frequencies.

• Define PSD-based parameters to filter the data.

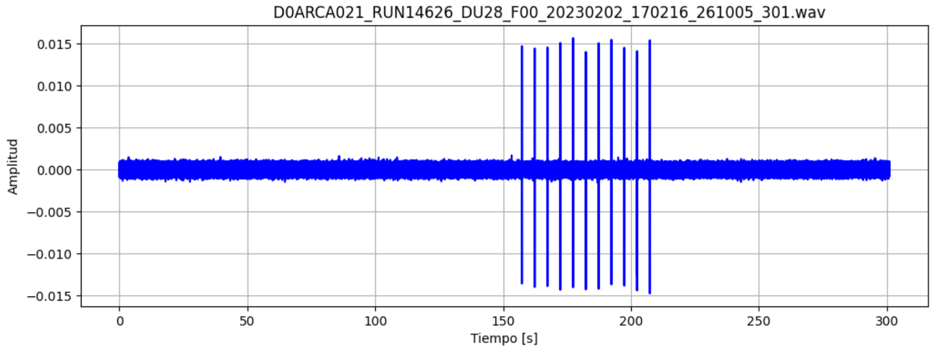
•Parameters can be tuned for each receiver (sensitivity, RVR, SNR, etc.).

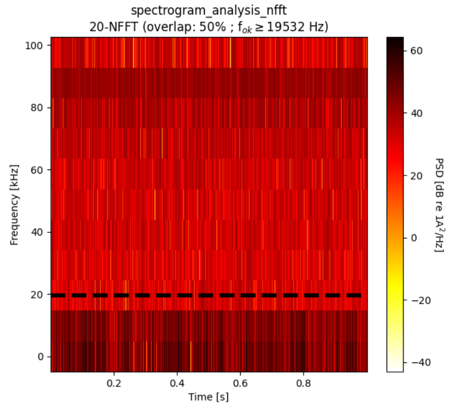


$N_{bin} = 20$
$f_s = 195132$
$T_{bin} = \sim 100\mu s$
$f_{val} = \sim$20 kHz
Overlap = 50%
$f_{res} = \sim 5\ kHz$

1

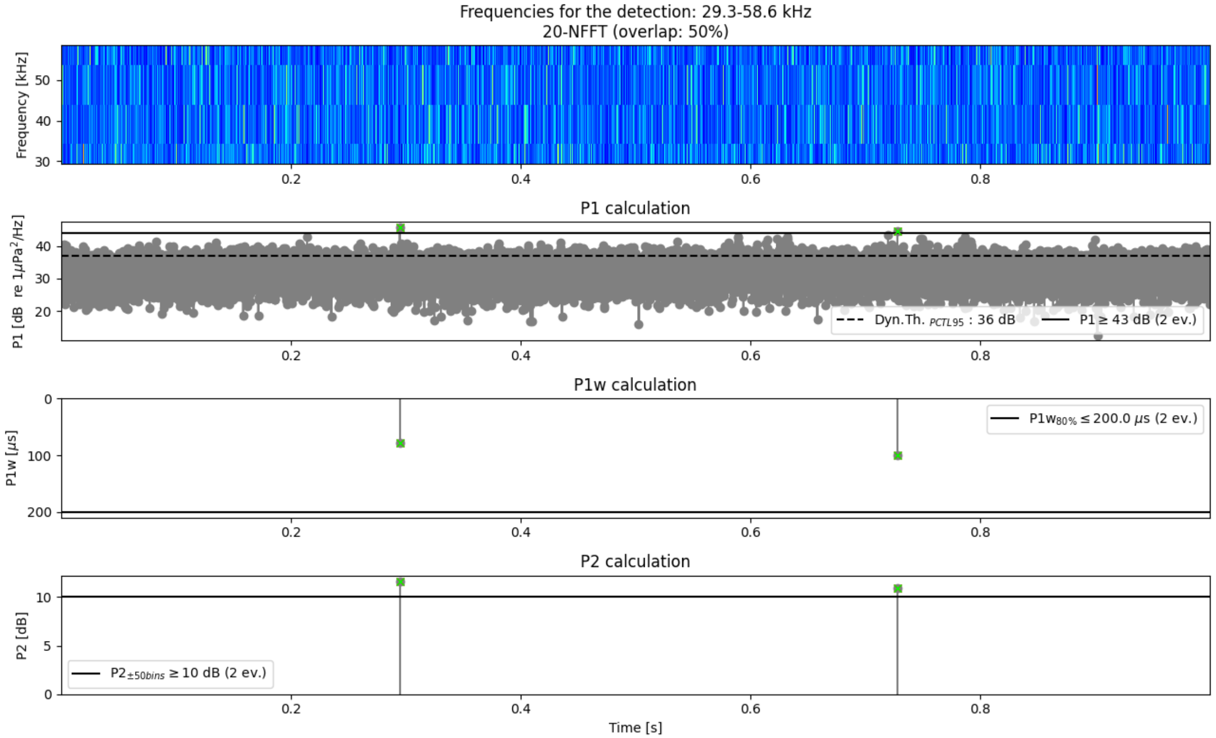
Raw data





2

Spectrogram



3

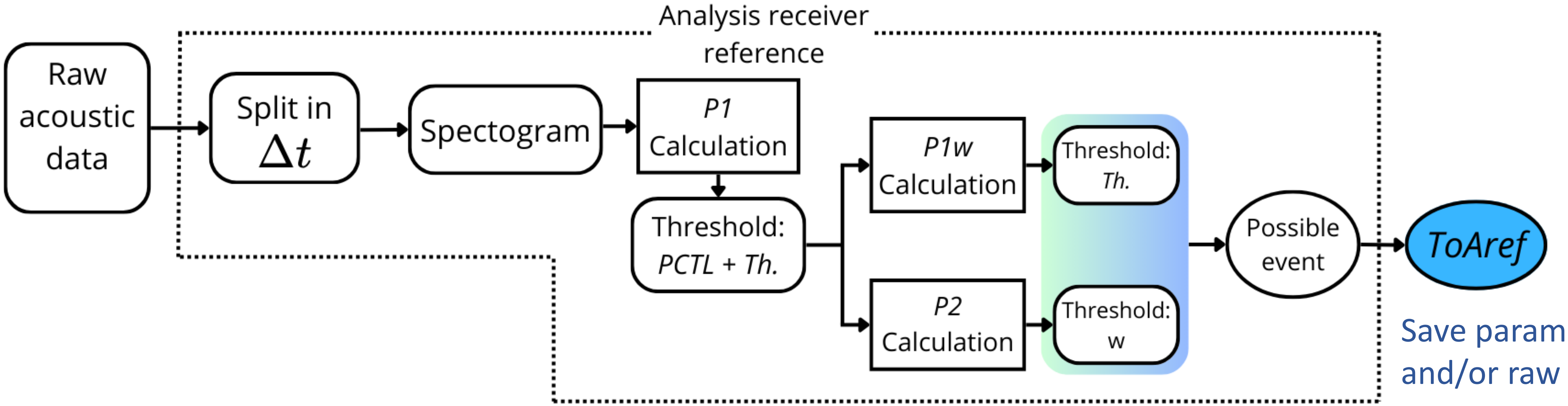
Computing (P1, P1w, P2)

- Intensity vs. freq.
- Time width

4

Filtering

Triggering interesting acoustic events.

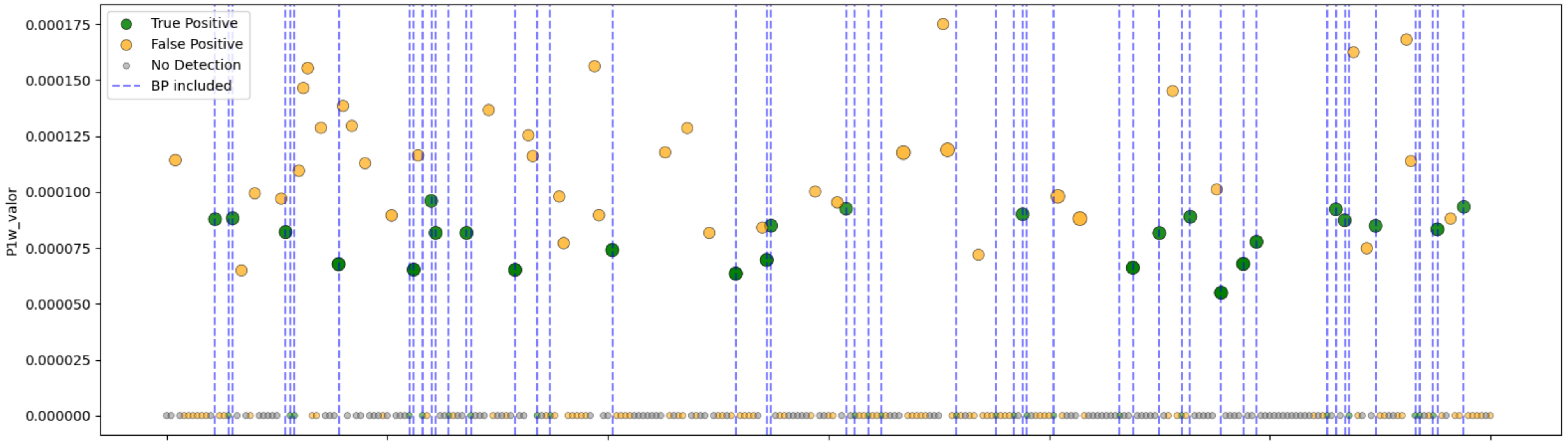


Save parameters and/or raw data

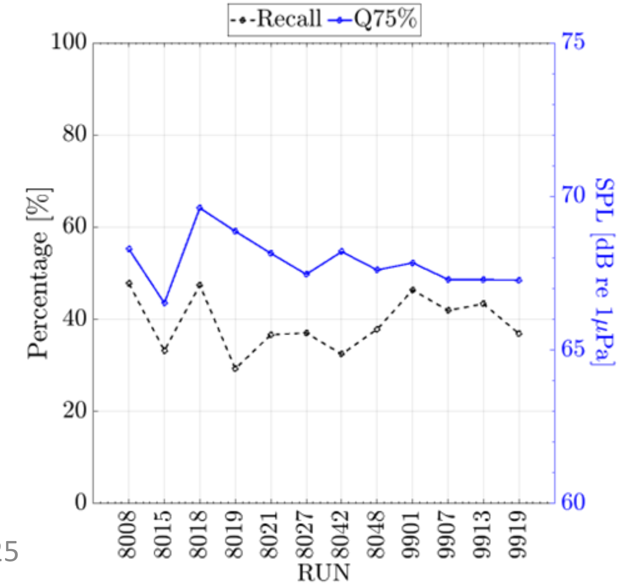
"Development of a trigger for acoustic neutrino candidates in km3net". *PoS(ARENA2022)* .

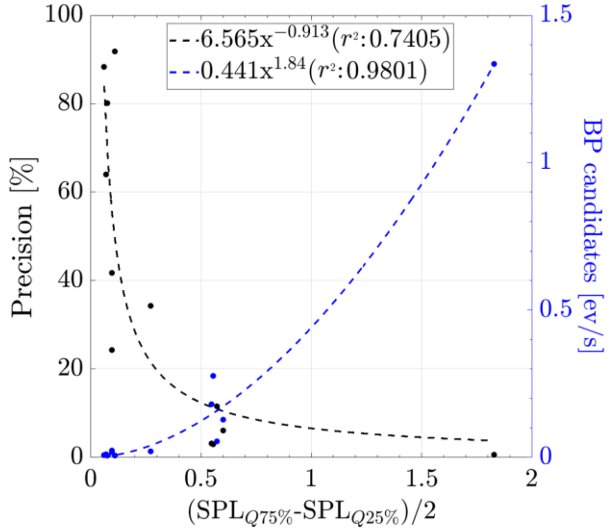
Simulations - Example of file analysed (10^{20} eV @ 1km 0º orientation - ARCA site)

Analysis ongoing



ORCA site Study: Efficiency/Background vs. Noise

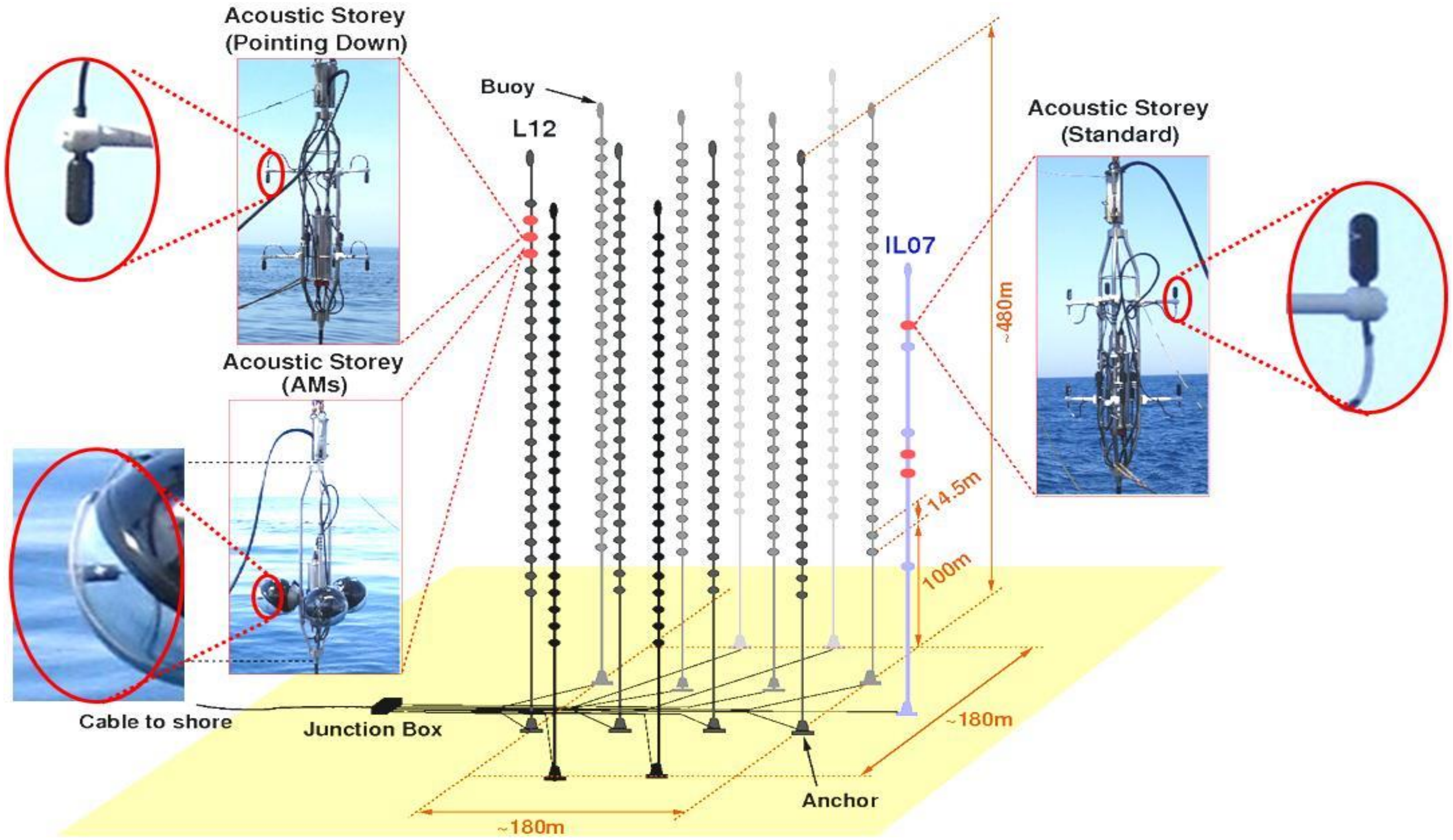




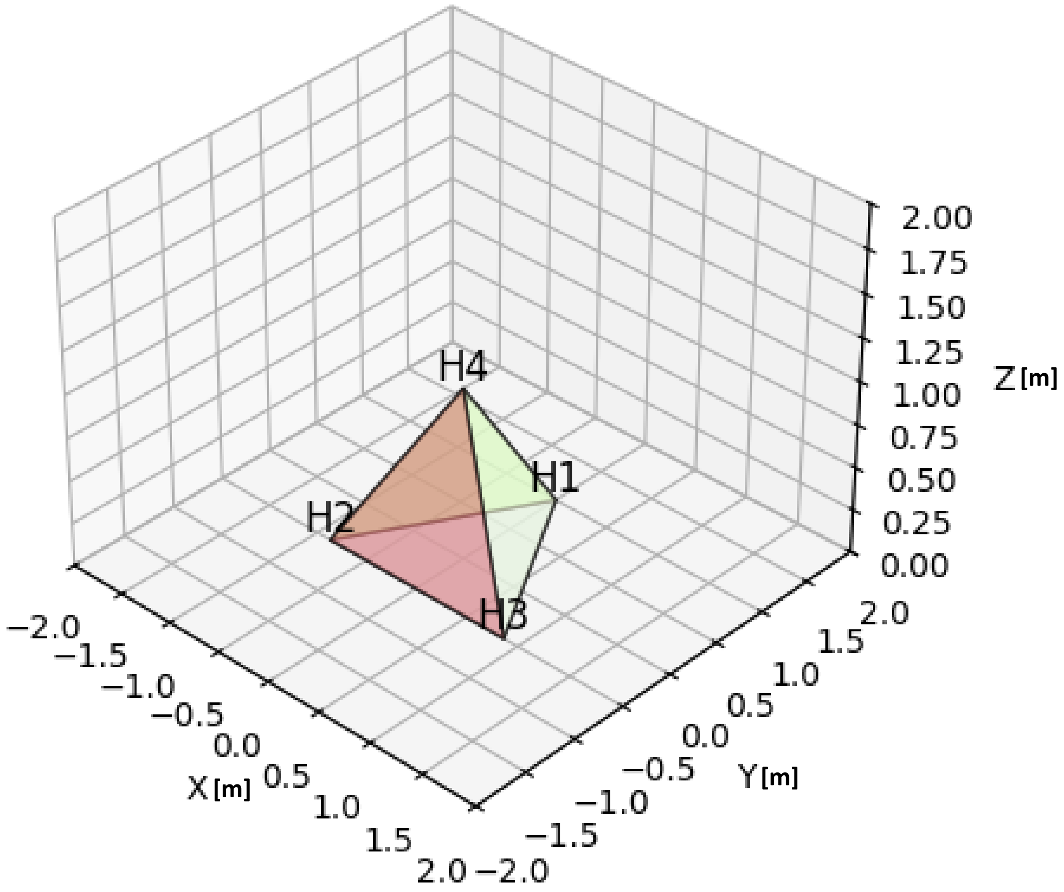
D. Diego-Tortosa PhD thesis

Towards an Acoustic Antenna

- Distance between hydrophones in KM3NeT (> 10 m) is large for acoustic distances: difficulties for setting coincident events
- Previous experience: AMADEUS/ANTARES with ~1 m distance between hydrophones.



Proposal Acoustic Antenna



Hydrophones Spacing

~ 1-meter intervals for optimal spatial resolution of triggering events.

Frequency Range

10Hz-100 kHz to capture neutrino-induced acoustic signals and other underwater acoustic phenomena within this range.

Synchronization

Connected to a ground station timing system for precise measurements.

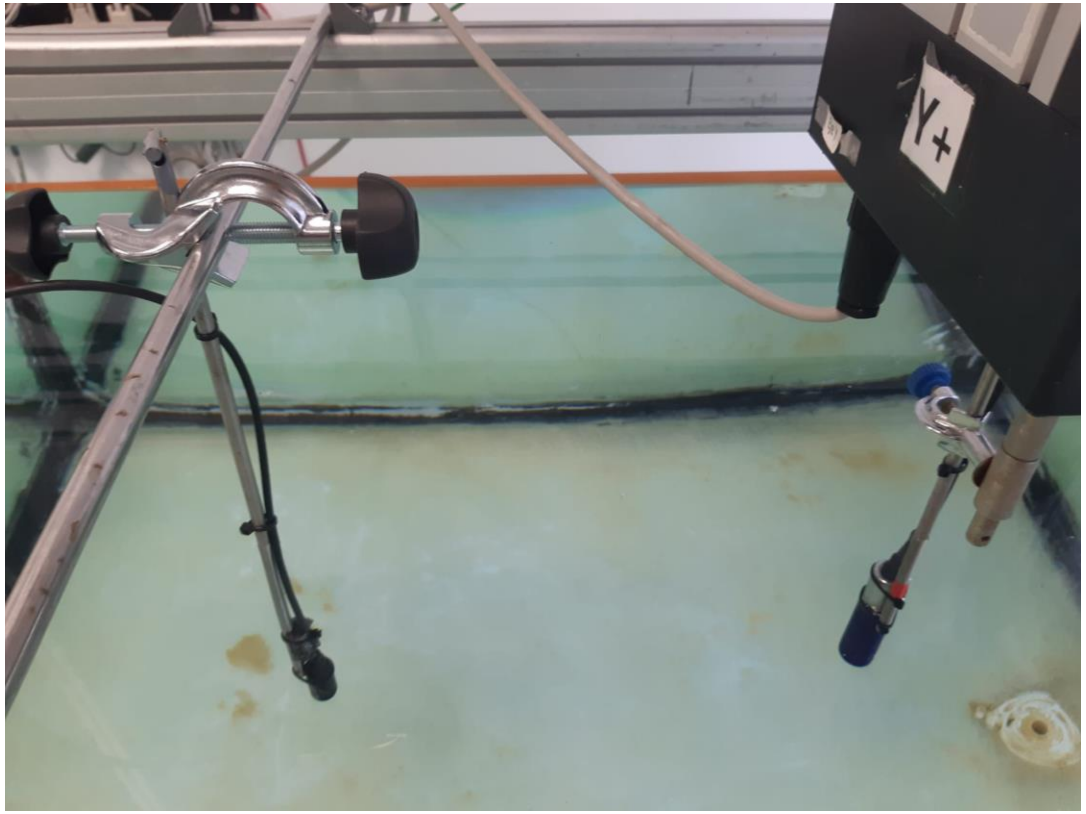
Signal Processing

Event triggering designed to identify sharp, broadband acoustic pulses.

Work in progress….

Proposal Acoustic Antenna

Characterization and comparison of hydrophones.



Conclusions and future work

- We have presented the idea of a hybrid optical-acoustic deep-sea neutrino detector to extent these detectors to ultra-high energies, ≥ 1 EeV.
- The acoustic system of KM3NeT could be used for this purpose, but some aspects need to be improved:
    1. A dedicated acoustic trigger to register interesting events: a method using spectrogram analysis has been proposed.
    2. Complement the system with an acoustic antenna, so to help in coincidence searches: the ongoing work for the design of the array has been presented.
- Once the R&D is complete, we aim to implement it in KM3NeT.

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