Development of a Trigger for Acoustic Neutrino Candidates in KM3NeT

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The 9th International Workshop on Acoustic and Radio EeV Neutrino Detection Activities (ARENA 2022)

CONTENTS

KM3NeT

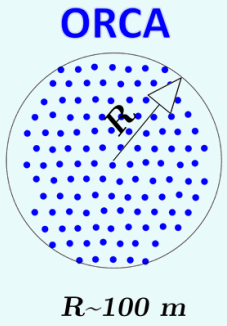
The Detector Framework

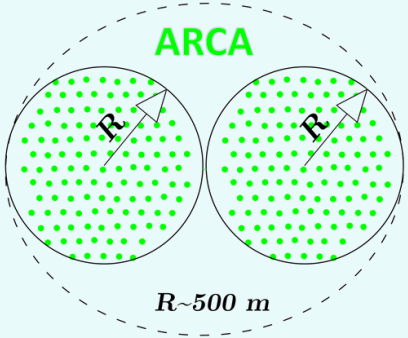
- Two sites:

  ARCA (Capo Passero, Italy) → Astronomy Research with Cosmics in the Abyss

  ORCA (Toulon, France) → Oscillations Research with Cosmics in the Abyss

- Three nodes with 115 Detection Units each one: 2 in ARCA + 1 in ORCA





KM3NeT

The Detector Framework

- Two sites:

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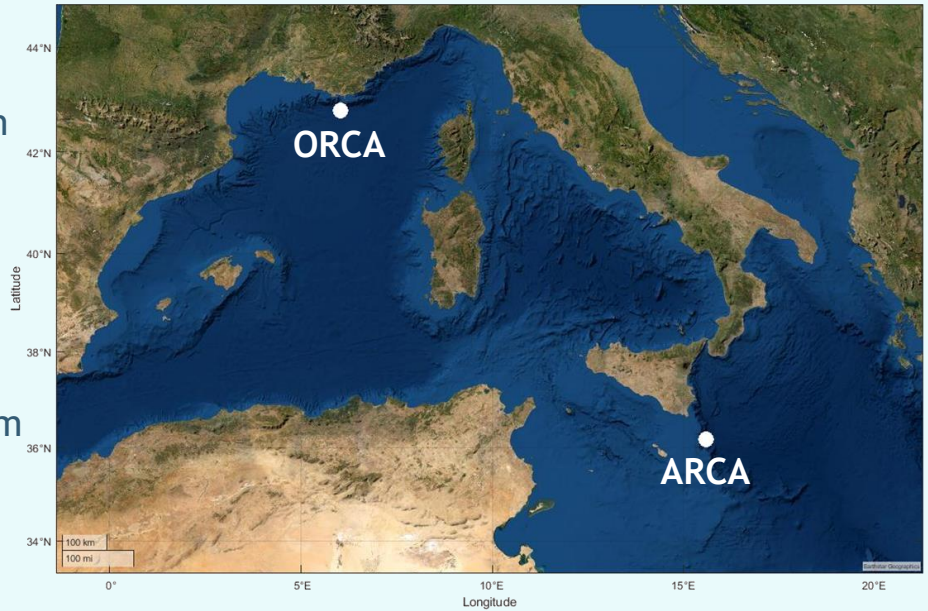
- Three nodes with 115 Detection Units each one: 2 in ARCA + 1 in ORCA

ARCA

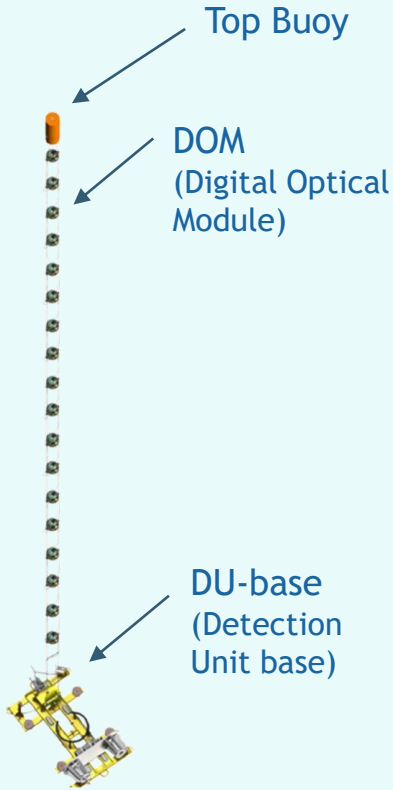
- 18 DOMs / DU
- Depth sea bed ~3400 m
- DUs height ~700 m
- DOMs distancing ~36 m
- Volume ~1 km3

ORCA

- 18 DOMs / DU
- Depth sea bed ~2500 m
- DUs height ~200 m
- DOMs distancing ~9 m
- Volume ~0.018 km3

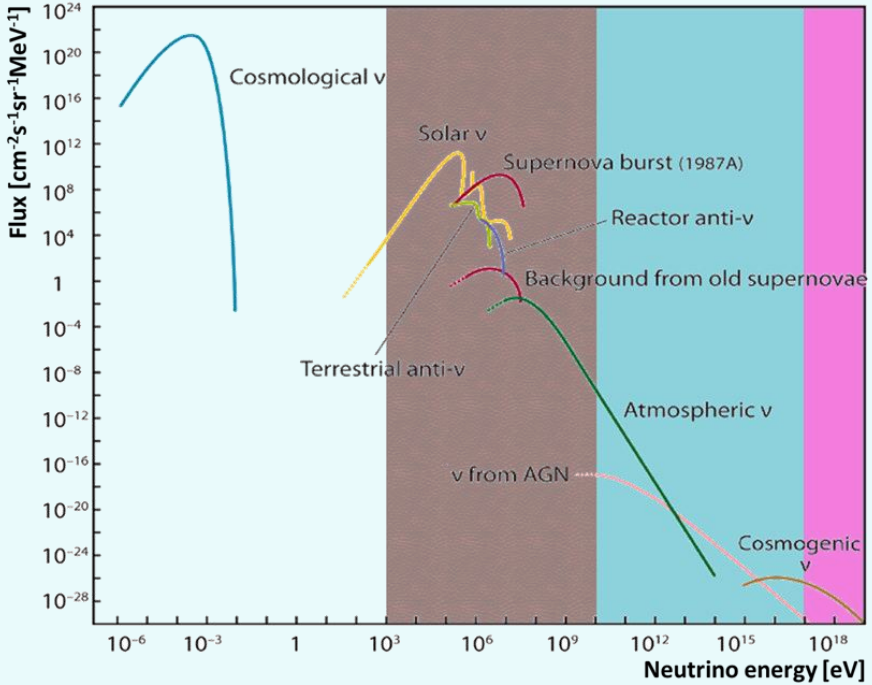


Detection Unit



KM3NeT

Acoustic Sensors



[**Spiering, C. Towards** High-Energy Neutrino Astronomy. A Historical Review. *Eur. Phys. J. H* **2012**, 37, 515–565. arXiv:astro-ph.IM/1207.4952. DOI: 10.1140/epjh/e2012-30014-2]

Underground detectors

Cherenkov detectors in water/ice → KM3NeT

Huge detector volumes with:

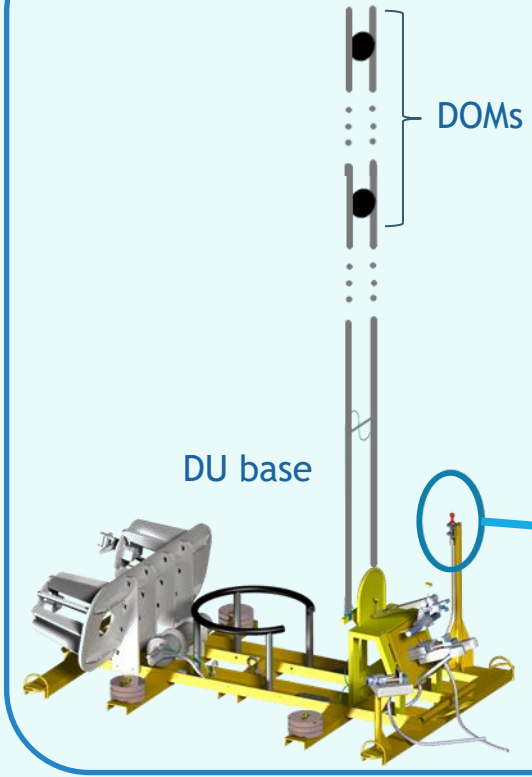
- **Acoustic detection** → KM3NeT ??
- Radio detection
- Detection via air showers

Is it possible to increase the neutrino detection range in KM3NeT?

KM3NeT
ACOUSTIC SENSORS

Motivation: the establishment of a trigger of interesting events is crucial to study the background and efficiencies, thus to see the feasibility of the technique.

Digital Acoustic Receivers



Piezoceramic sensors
(dynamic + internal)

Hydrophones
(fixed + external)

RVR: −160 ± 6 dB (re 1 V/µPa at 1 m) in the 10–70 kHz range

This study starts to analyse raw acoustic data from the hydrophones

RVR: −156 dB (re 1 V/µPa at 1 m) in the 5-90 kHz range

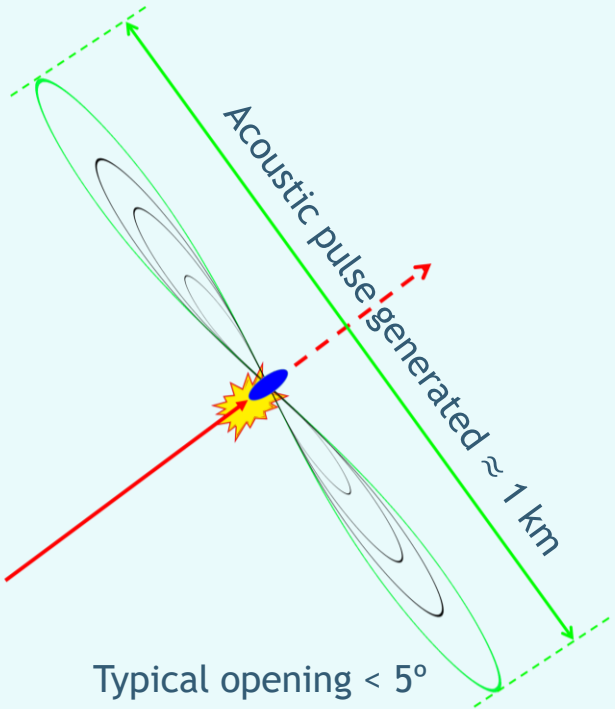
Why hydrophones to start?

- Fixed
- Known (and flat) frequency response
- + Frequency range
- + Sensitivity

ACOUSTIC NEUTRINO DETECTION

BIPOLAR PULSE

* ↑*temporal resolution* : ↓*frequency resolution*



Typical opening < 5º

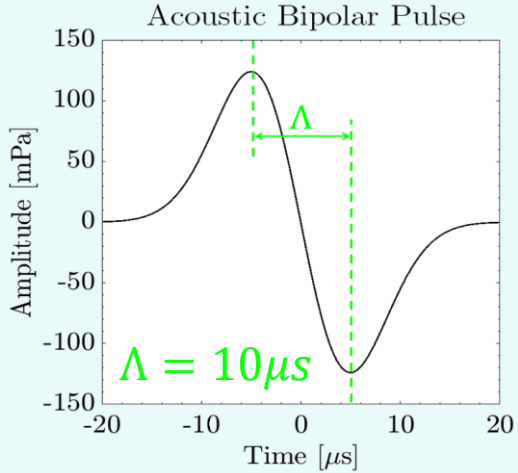
Acoustic neutrino interaction

The generation of a BP: by deriving a normal distribution

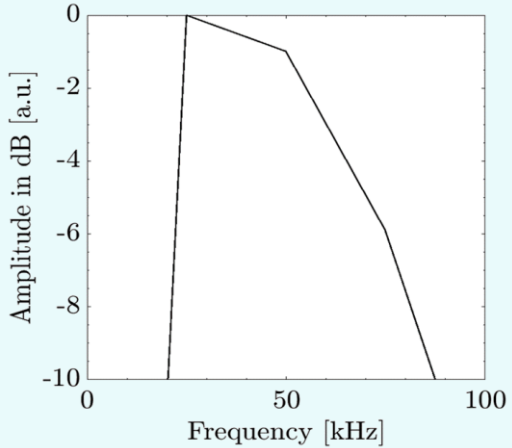
What are we looking for?

Bipolar Pulse (BP) simulation

UHE neutrino: 10^{20} eV



The -3 dB decay occurs between 20 and 60 kHz



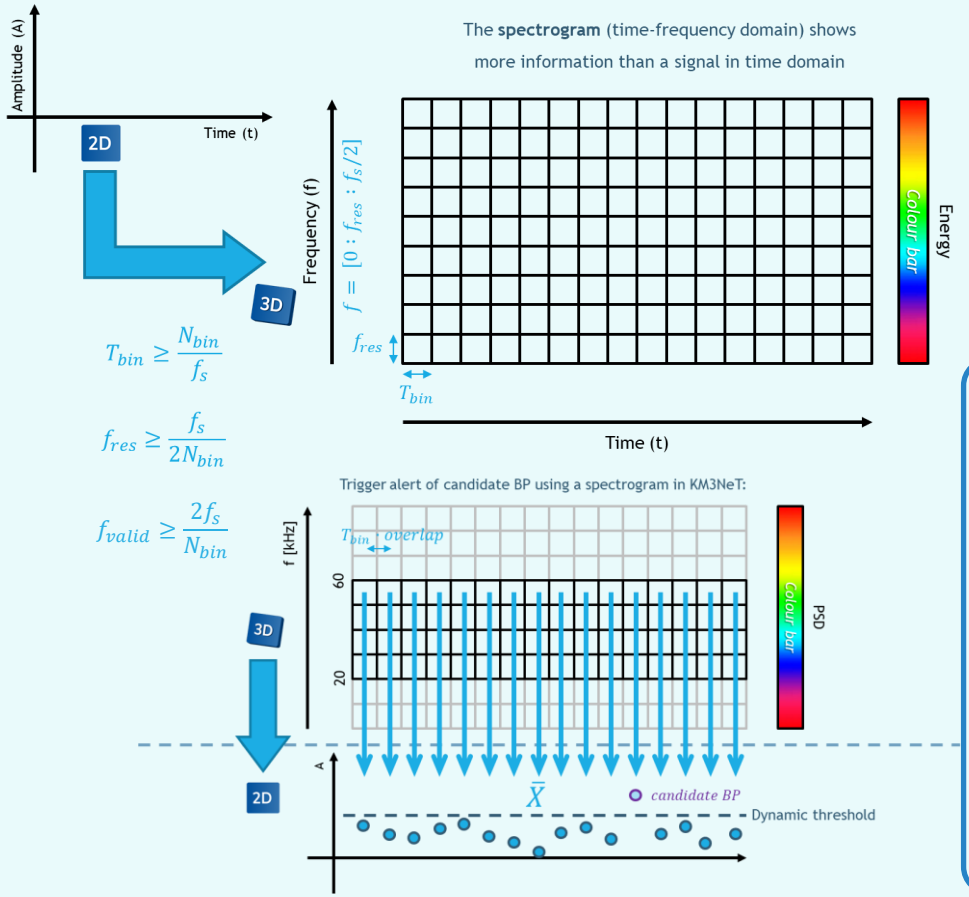
[**Waters, D**. Study of the acoustic signature of UHE neutrino interactions in water and ice. *Nucl. Instrum. Methods Phys. Res., Sect. A* **2009**, 607, 398–411. DOI: 10.1016/j.nima.2009.05.009]

Simulated BP at 0º (hydrophone ⊥ pancake) and 1km

BP of 123.9 mPa amplitude → 1.97 mV amplitude in the hydrophone (RVR conversion)

ACOUSTIC NEUTRINO DETECTION

THE SPECTROGRAM AS A SIGNAL DETECTOR



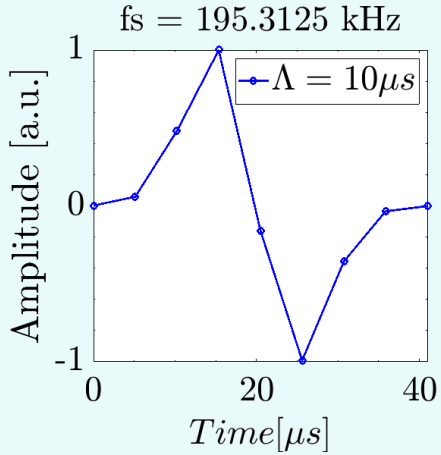
* ↑*temporal resolution* : ↓*frequency resolution*

Spectrogram analysis for acoustic neutrino detection is proposed:
The detection depends more on energy than BP shape

<u>Set-up</u>:

- Time resolution: 50 μs (Tbin 100 μs + 50% overlap): Nbin = 20 samples
- Frequency resolution: 5 kHz
- Frequency down limit: 20 kHz

Bipolar Pulse simulation (artificial BP)



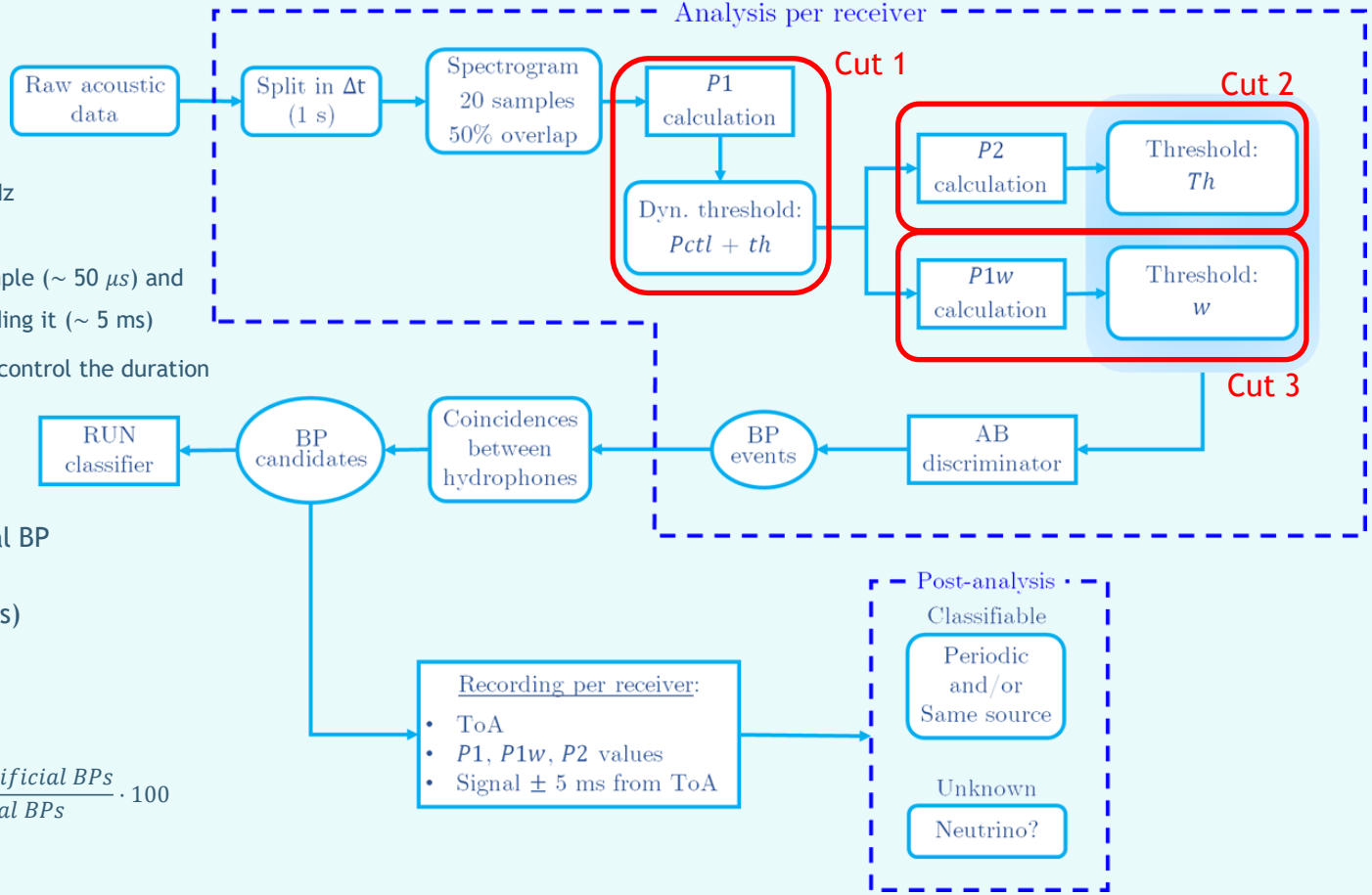
KM3NeT is working with f_s of 195312.5 Hz:
9 samples in 40 μs

ACOUSTIC NEUTRINO DETECTION

TRIGGER ALERT PROPOSAL

- $P1$: Mean PSD value between 20 and 60 kHz
- $P1w$: Width to 80% of the $P1$ peak
- $P2$: Difference between $P1$ value of 1 sample ($\sim 50\ \mu s$) and the $P1$ value of the $\pm$ 50 samples surrounding it ($\sim$ 5 ms)

$P1$: to control the intensity ; $P2$ + $P1w$: to control the duration



Evaluating the trigger for an artificial BP of 10^{20} eV detection:

- 1 $artificial\ BPs$ / minute (0.02 ev/s)
- Efficiency → $Recall$
- Background → ev/s

$$Recall\ [\%] = \frac{TP}{TP + FN} \cdot 100 = \frac{detected\ artificial\ BPs}{artificial\ BPs} \cdot 100$$

$BP\ candidates\ [ev/s] < 1$??

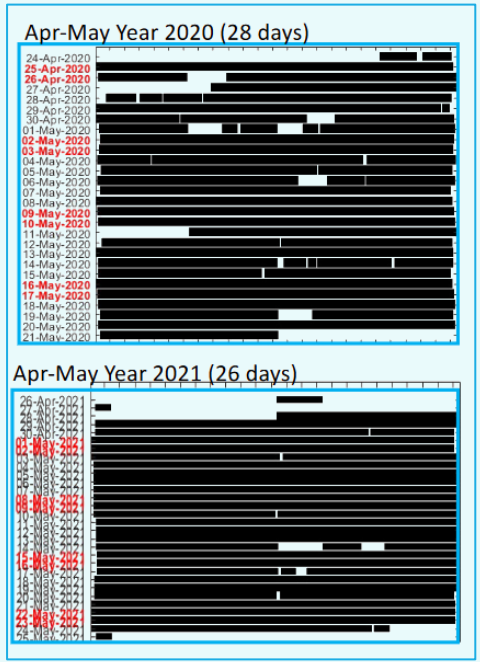
TESTING EXPERIMENTAL DATA

THE RAW ACOUSTIC DATA FROM ORCA

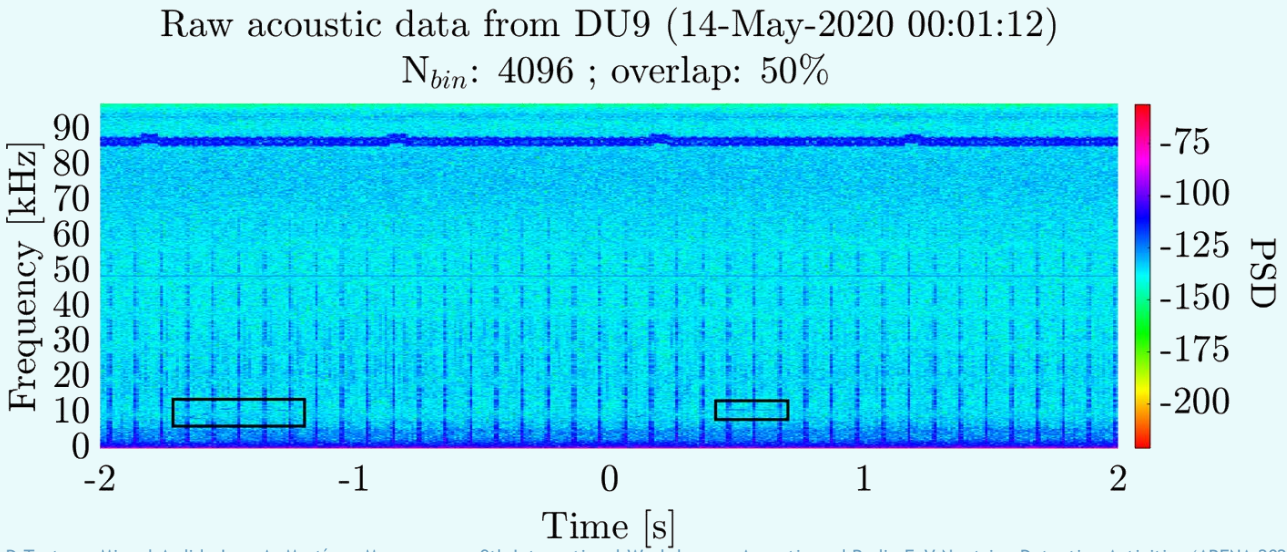
- Electricity network signal of 50 Hz (and its harmonics)
- Acoustic Beacons (ABs)
- Digital Penetrations (DPs)
- Bioacoustics
- Ships, sonars, environmental …

Hydrophones to study:
DU2, DU3, and DU9

There are more than 25 days in the same period recorded during two consecutive years by 3 hydrophones



All these noises (background) are noticeable in the spectral analysis:

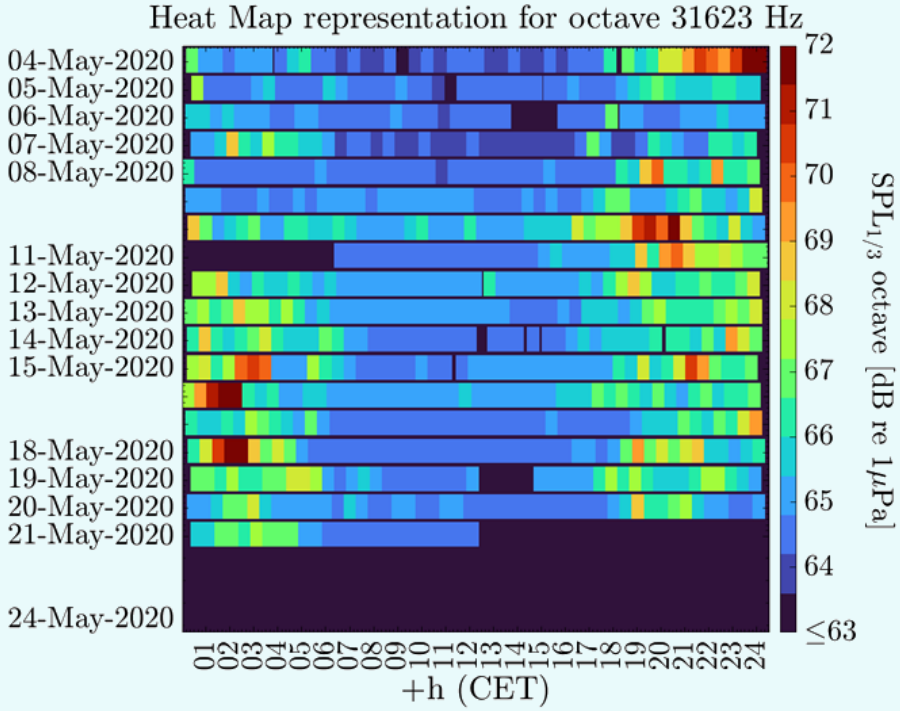


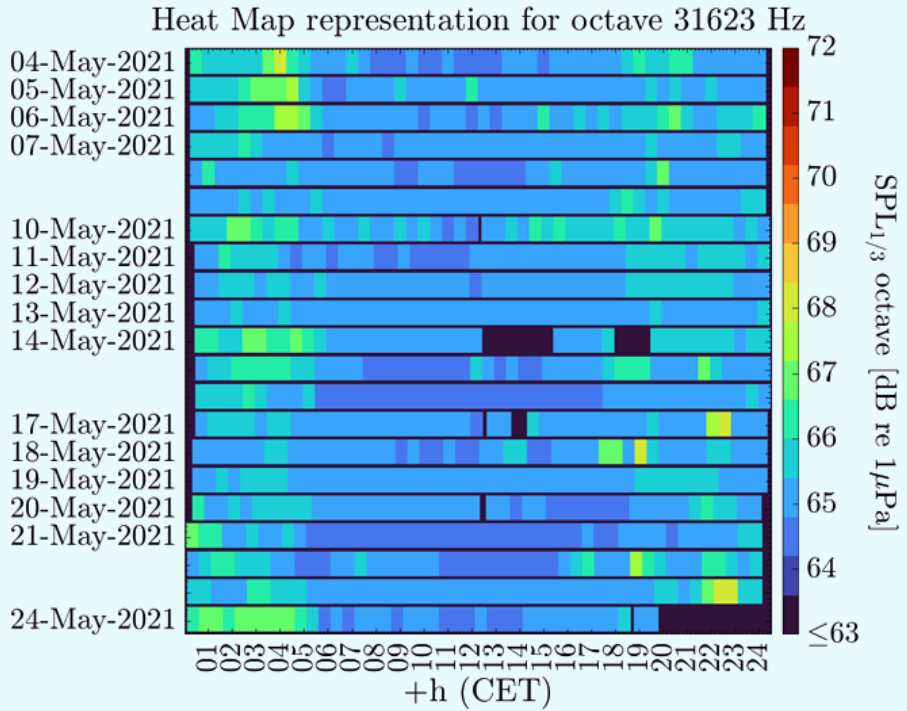
TESTING EXPERIMENTAL DATA

THE RAW ACOUSTIC DATA FROM ORCA

Hydro-DU3:

SPL on the 1/3 octave of 30 kHz





Heatmaps calculated to large temporal visualization:

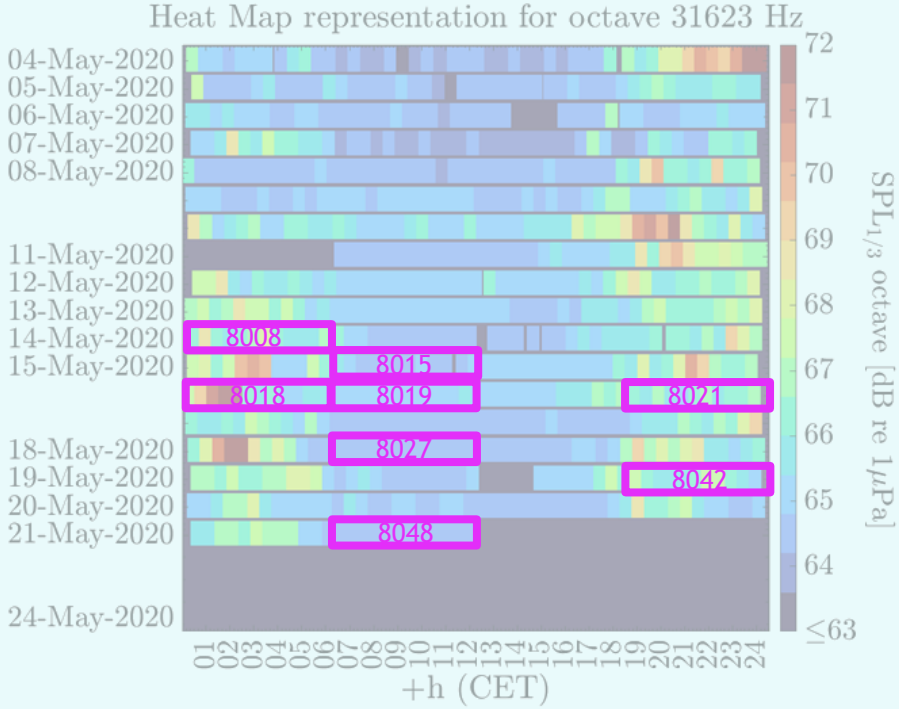
[**Miralles, R.; Lara, G.; Gosalbez, J.; Bosch, I. & León, A.** Improved visualization of large temporal series for the evaluation of good environmental status. *Applied Acoustics* **2019**, 148, 55–61. DOI: 10.1016/j.apacoust.2018.12.009]

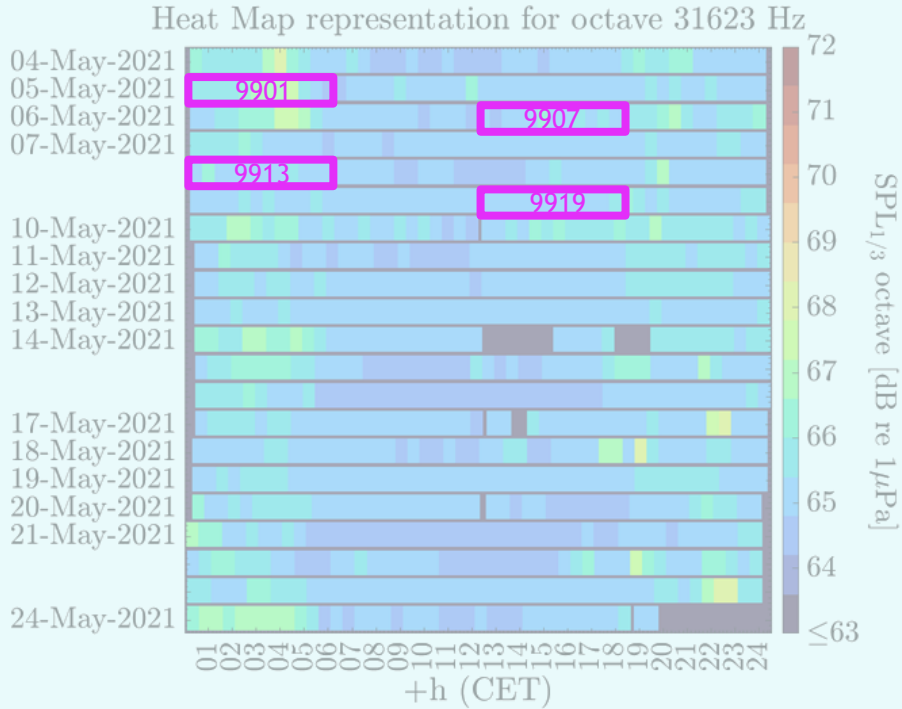
TESTING EXPERIMENTAL DATA

THE RAW ACOUSTIC DATA FROM ORCA

Hydro-DU3:

12 RUNs selected to the analysis (6H/RUN)





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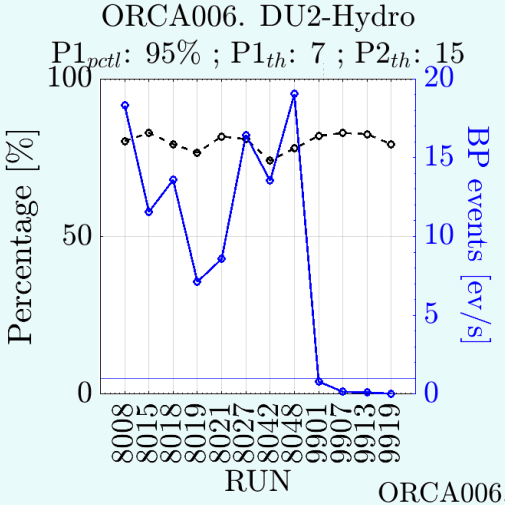
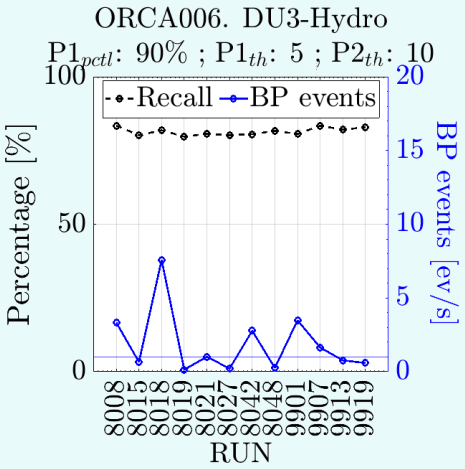
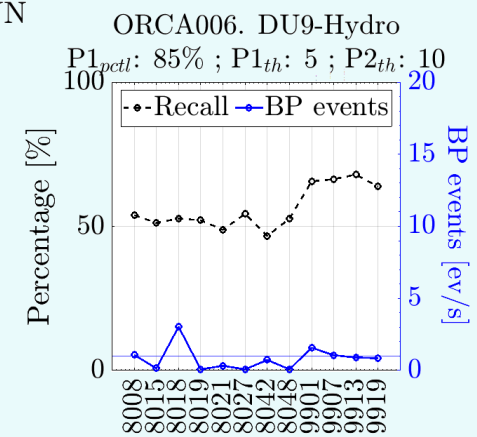
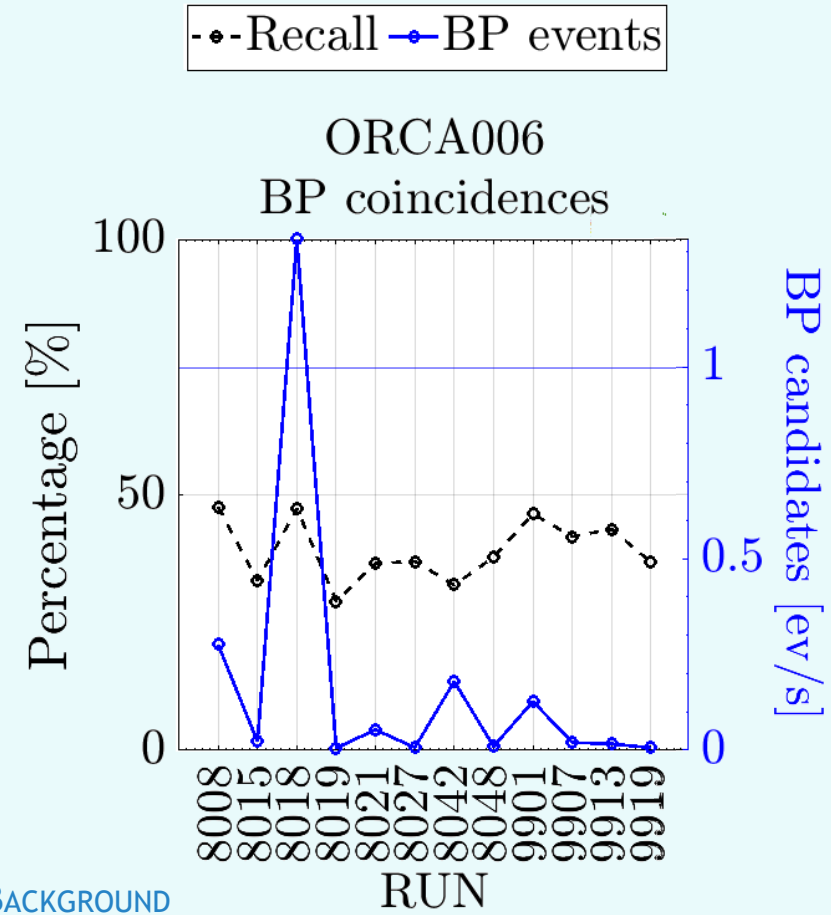
TESTING EXPERIMENTAL DATA

RESULTS





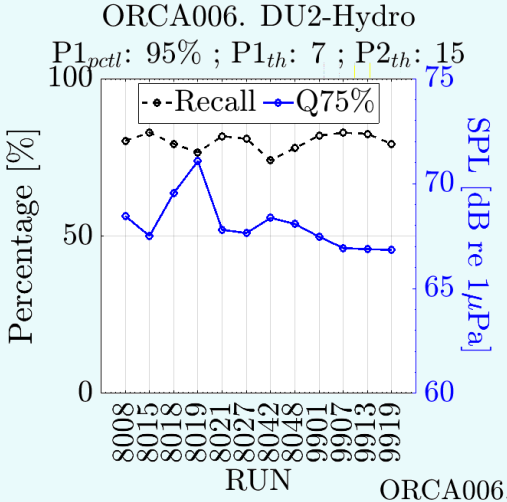


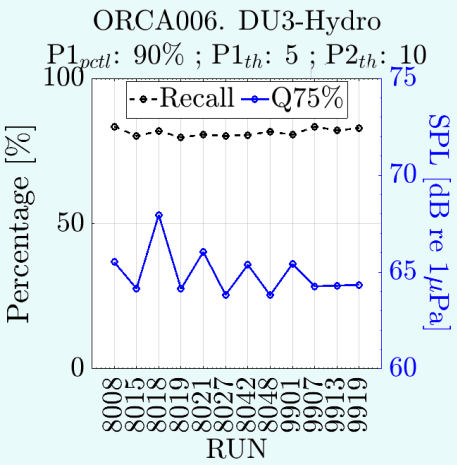


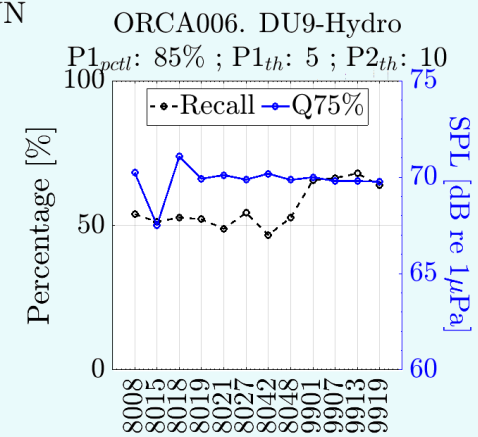
EFFICIENCY VS BACKGROUND
(RECALL VS EV/S)

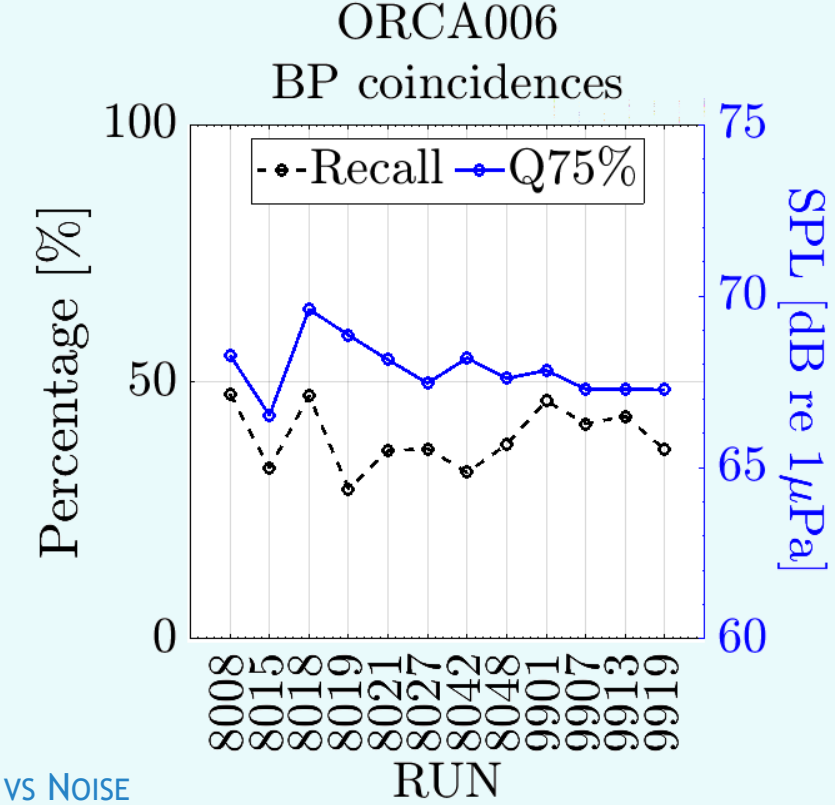
TESTING EXPERIMENTAL DATA

RESULTS







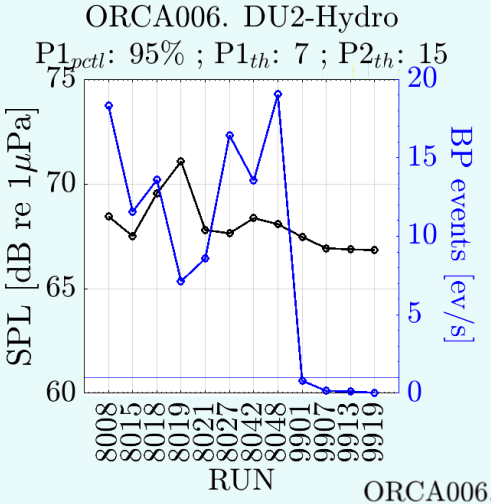


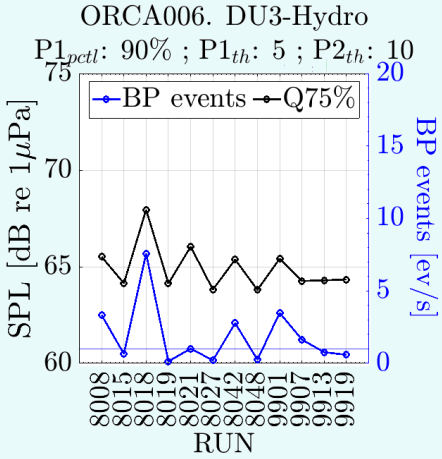
EFFICIENCY VS NOISE
(RECALL VS SPL)

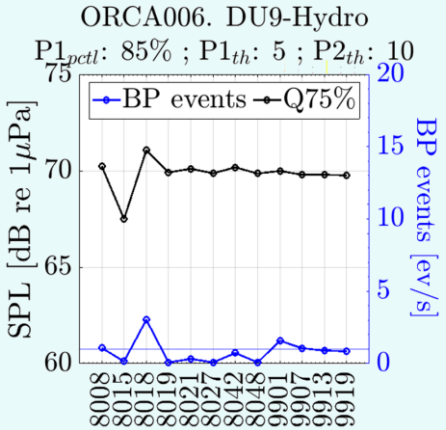
Mean(SPL $_{25\text{-}50\ kHz}$ dB re 1μPa)

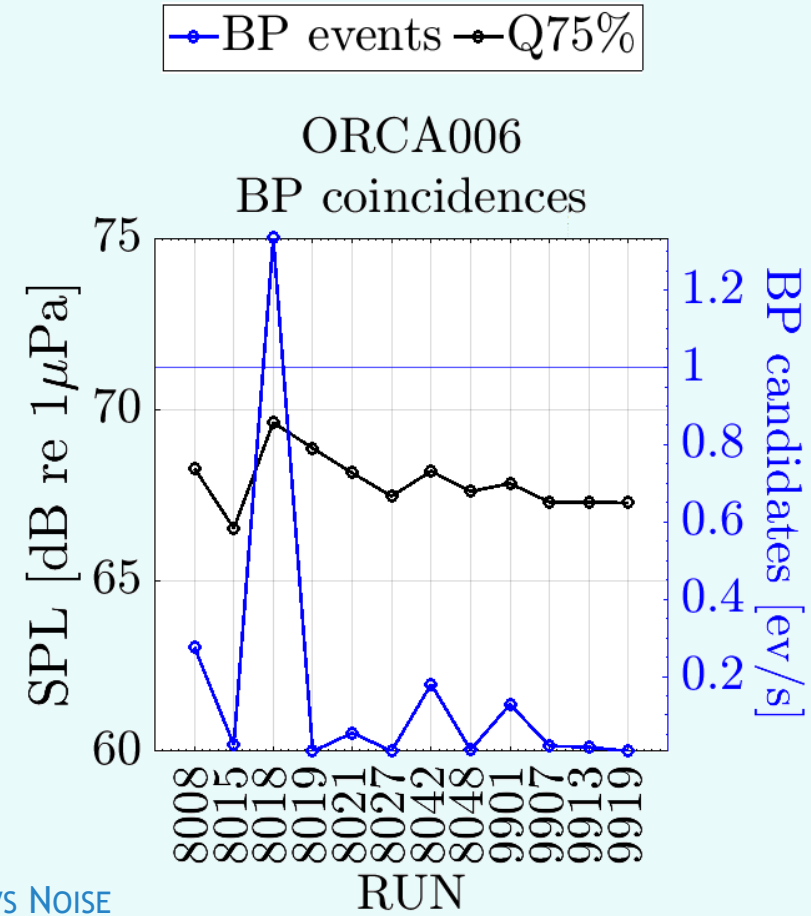
TESTING EXPERIMENTAL DATA

RESULTS









BACKGROUND VS NOISE
(EV/S VS SPL)

Mean(SPL $_{25\text{-}50\ kHz}$ dB re 1μPa)

SUMMARY AND CONCLUSIONS

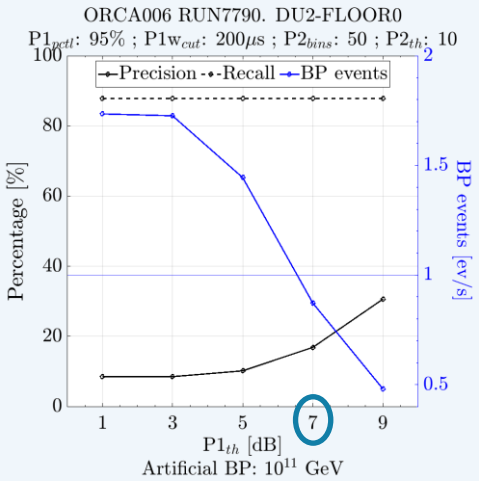
- Acoustic raw data of hydrophones have been analysed. Reference neutrino-induced BP acoustic signals have been added.
- The detection of these signals and the background has been studied
- A proposal of trigger for a BP detector, based on the spectrogram, is proposed.
- The performance of the trigger has been shown.
- The limit of the f_s and the distance between hydrophones in KM3NeT is invariant, but for this type of experiments it could be optimized.
- This trigger will allow to record interesting events and to do systematic studies that will allow to study the feasibility of the technique.
- The trigger can also be useful for other signals, for example for bioacoustics.

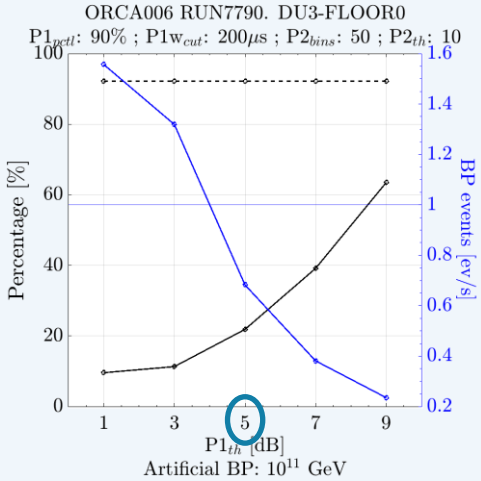
Thanks for your attention

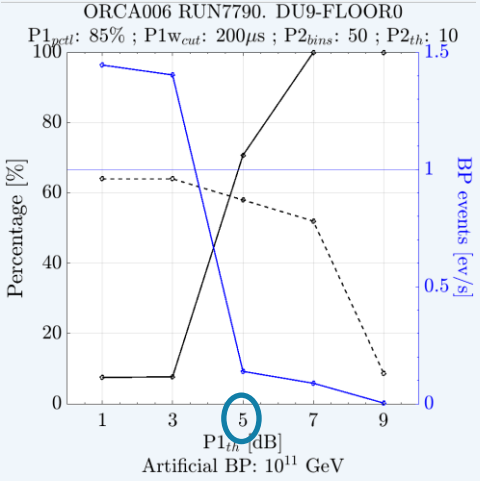
Backup slides

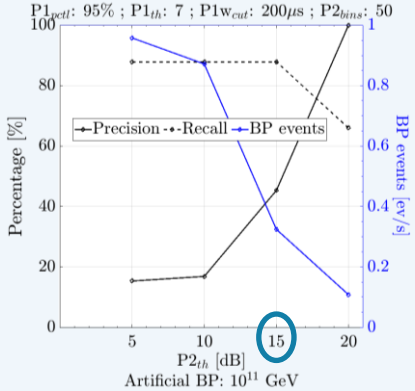
BACKUP SLIDES

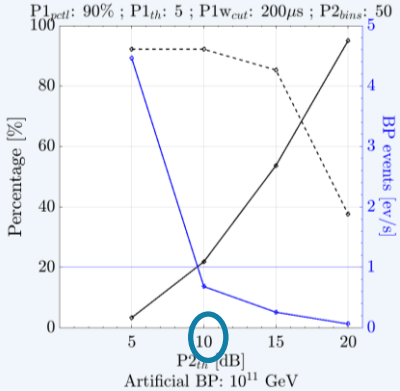
HYDROPHONE THRESHOLD SELECTION

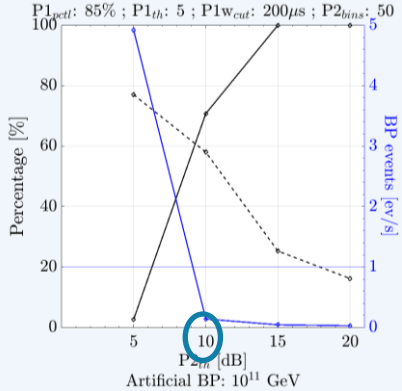










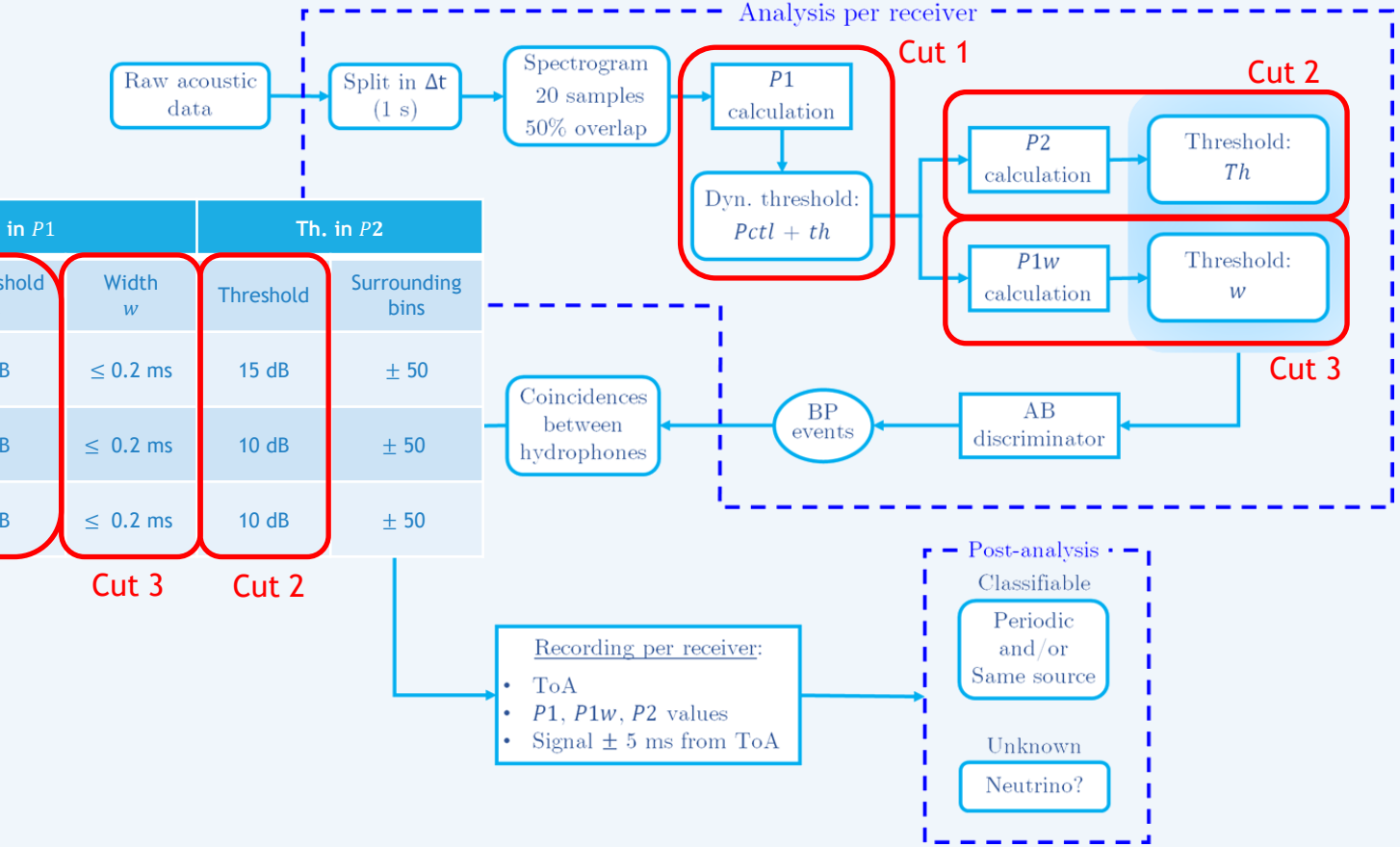


BACKUP SLIDES

SELECTED THRESHOLD

Hydrophone	Dyn. Th. in $P1$			Th. in $P2$	
	Percentile $PCTL$	+ Threshold th	Width w	Threshold	Surrounding bins
DU2	95 %	7 dB	≤ 0.2 ms	15 dB	± 50
DU3	90 %	5 dB	≤ 0.2 ms	10 dB	± 50
DU9	85 %	5 dB	≤ 0.2 ms	10 dB	± 50

Cut 1 Cut 3 Cut 2

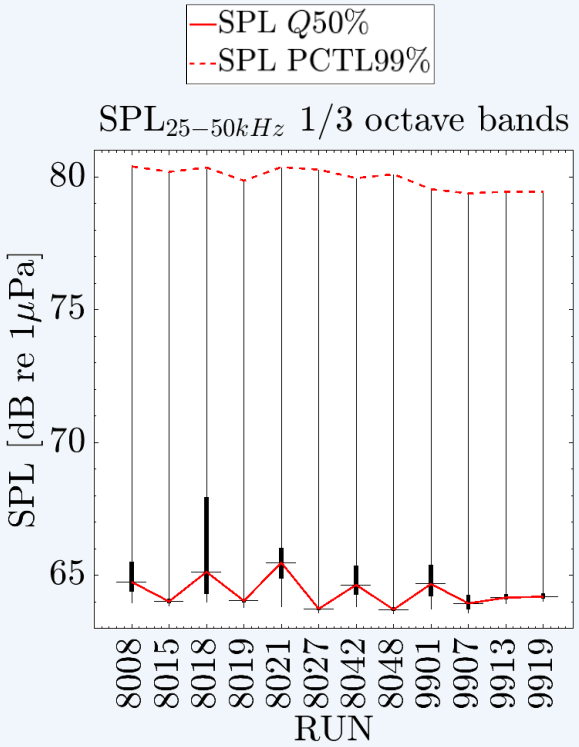


BACKUP SLIDES

SPL ON THE RAW ACOUSTIC DATA

Hydro-DU3

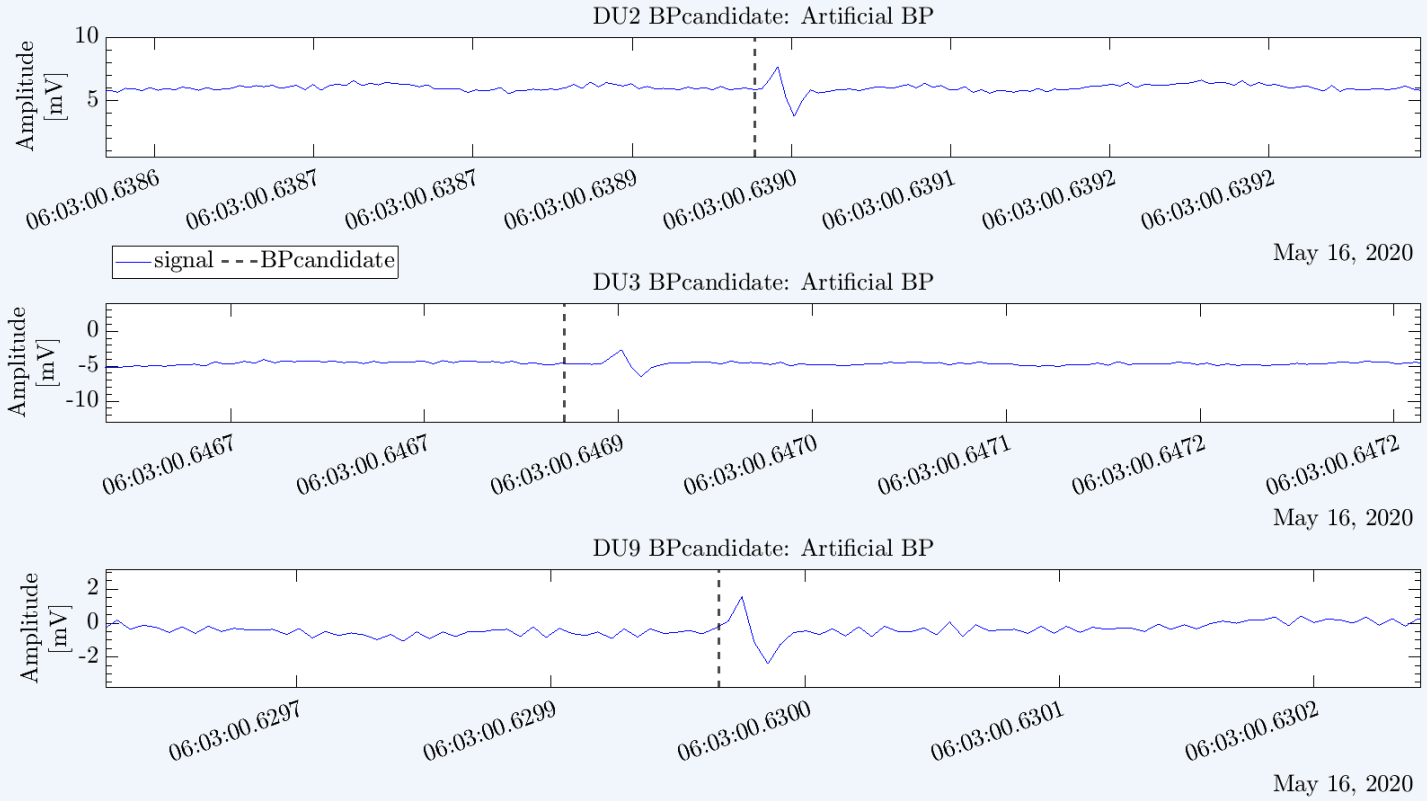
RUN	Date + 6H	$SPL_{25-50\,kHz}$ [dB re 1µPa]			
		Q25%	Q50%	Q75%	PCTL99%
8008	14/05/2020 0:01	64.4	64.8	**65.5**	80.4
8015	15/05/2020 6:01	64.0	64.0	**64.1**	80.2
8018	16/05/2020 0:01	64.3	65.1	**68.0**	80.4
8019	16/05/2020 6:01	64.0	64.0	**64.1**	79.9
8021	16/05/2020 18:01	64.9	65.5	**66.0**	80.4
8027	18/05/2020 6:01	63.7	63.7	**63.8**	80.3
8042	19/05/2020 18:01	64.3	64.7	**65.4**	80.0
8048	21/05/2020 6:01	63.7	63.7	**63.8**	80.1
9901	05/05/2021 0:00	64.2	64.7	**65.4**	79.5
9907	06/05/2021 12:00	63.7	64.0	**64.3**	79.4
9913	08/05/2021 0:00	64.1	64.2	**64.3**	79.5
9919	09/05/2021 12:00	64.1	64.2	**64.3**	79.5



BACKUP SLIDES

BP SIMULATED ON THE EXPERIMENTAL DATA

A BP source is simulated one km from the hydrophones in a random position every minute of the raw data and is added to it:



BACKUP SLIDES

BP SIMULATED ON A SPECTROGRAM

Spectrogram of an artificial BPs in the raw acoustic data: