Study of acoustic neutrino detection in OvDE-2 raw acoustic data

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The 10th International Workshop on Acoustic and Radio EeV Neutrino Detection Activities (ARENA 2024)

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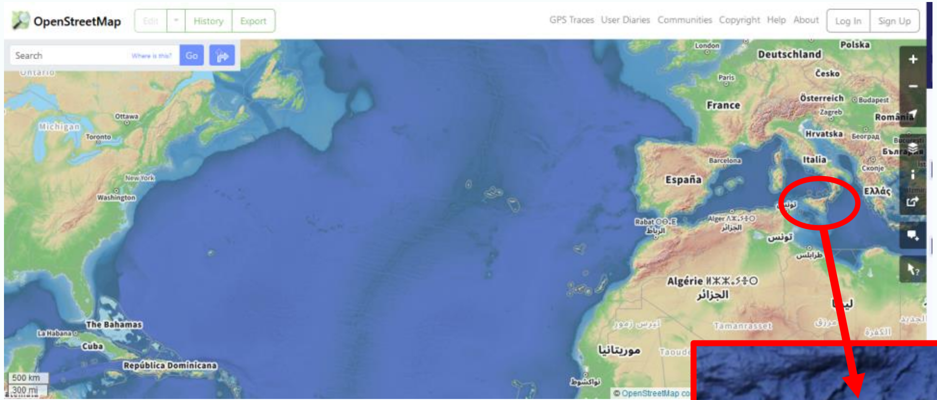
INTRODUCTION

OvDE-2

The aim of this presentation: Test an acoustic neutrino detector (presented at ARENA22) in another environment.
The data is provided by a hydrophone in OvDE-2 (2100 m depth).



Why OvDE-2 data?

OvDE-2 is a marine station with four SMID TR-401 hydrophones + preamplifiers (synchronized by a GPS signal)
f_s: $192\ kHz$ (24 bits)

First studies for the experimental acoustic neutrino detection in the Ionian Sea has been done by the former NEMO Collaboration with the deployment of OvDE (Ocean Noise Detection Experiment).

The construction of OvDE-2 has represented a test-bench for the SMO (Submarine Multidisciplinary Observatory) project.

INTRODUCTION

OvDE-2

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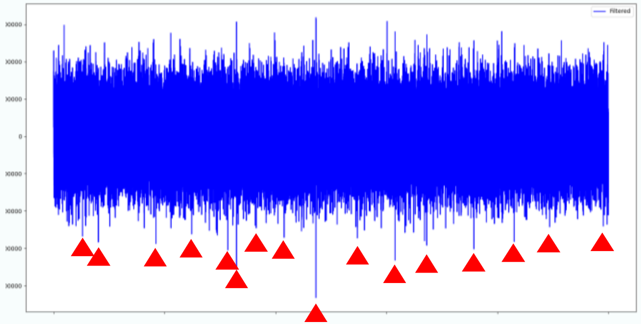
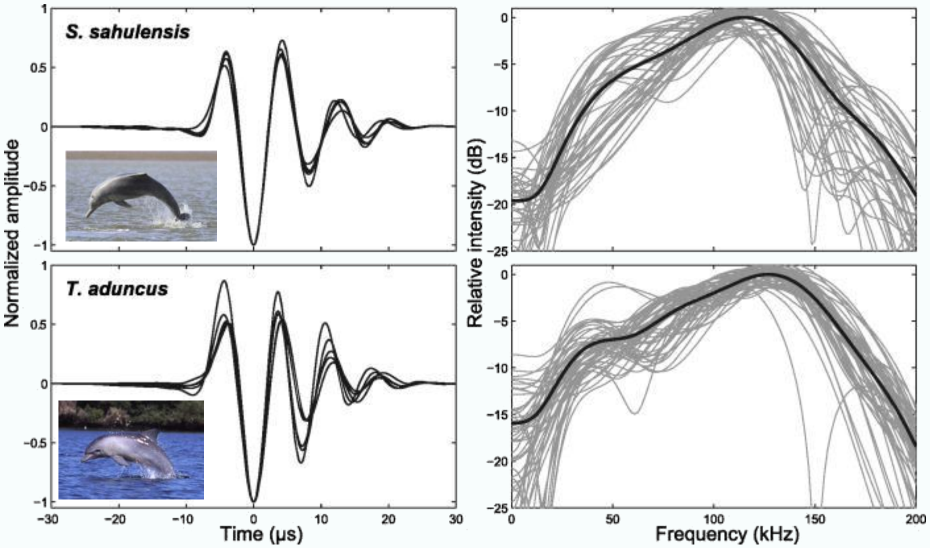


▲ The worst case: a lot of bioacoustics clicks!

We want to test the acoustic neutrino trigger in a critical case environment: 24H recorded by OvDE-2 with a lot of bioacoustics clicks for the marine mammals' echolocation.

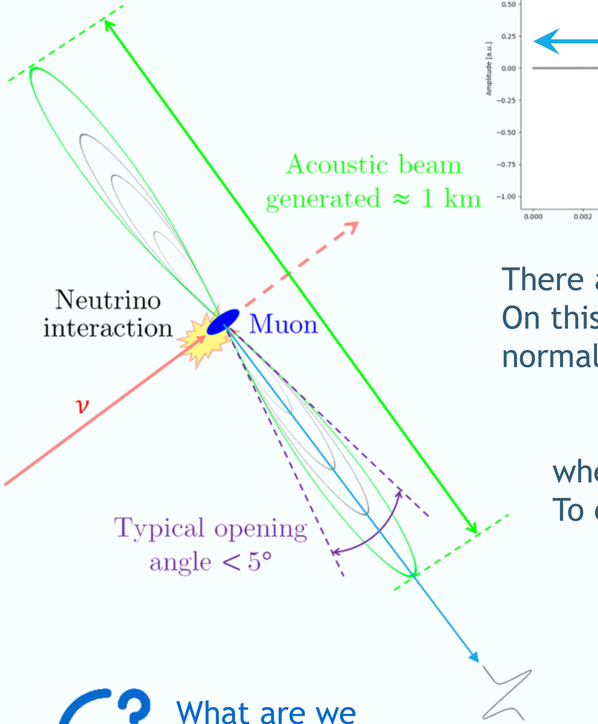
How sensitive is the detector to these clicks?



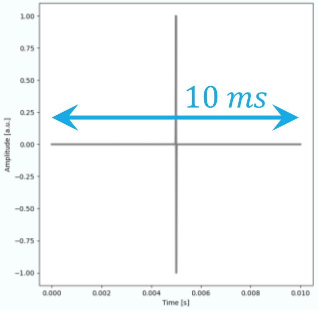
[M.. De Freitas, et.al Echolocation parameters of Australian humpback dolphins (Sousa sahulensis) and Indo-Pacific bottlenose dolphins (Tursiops aduncus) in the wilde. *The Journal of the Acoustical Society of America*. **2015**, 137, 3033–3041. DOI: 10.1121/1.4921277]

INTRODUCTION

Neutrino Induced Bipolar Pulse



BP generation at 1 MHz



UHE Neutrinos (peak):

- $10^{12}\ GeV \approx 1.25\ Pa$
- $10^{11}\ GeV \approx 123.9\ mPa$
- $10^{10}\ GeV \approx 12.33\ mPa$
- …

[**S. Bevan, et.al** 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]

OvDE-2 $f_s = 192\ kHz$

There are several equations to simulate a BP from the interaction of a neutrino in fluid. On this occasion, it has been chosen to simplify the generation of a BP (t): by deriving a normal distribution $g\ (t)$

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

where the σ represents the standard deviation at a confidence interval of ~68%. To control the width of the BP, the inter-peak value Λ should be equivalent to 2σ:

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

$$\Lambda = 2\sigma$$

$$BP(t) = \frac{-4t}{\Lambda^2}\cdot e^{-2\left(\frac{t}{\Lambda}\right)^2}$$

Λ represents the BP inter-peak time distance

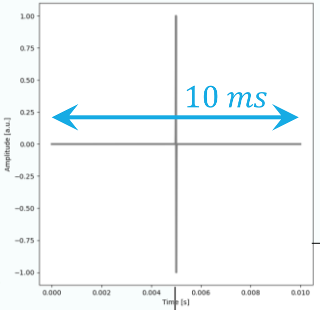
What are we looking for?

The acoustic neutrino signature is an **exotic signal** that contains a range of low frequencies (< 100 kHz) and it is propagated in a very narrow beam (< 5º)

INTRODUCTION

NEUTRINO INDUCED BIPOLAR PULSE

BP generation at 1 MHz



UHE Neutrinos (peak):

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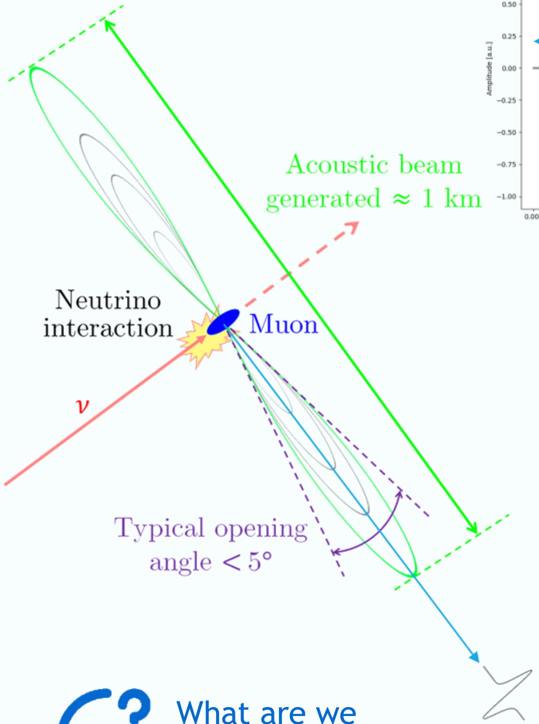
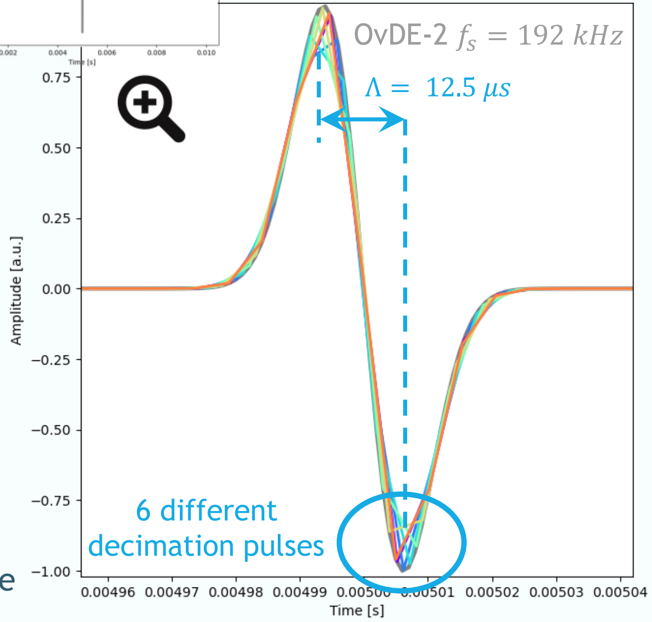
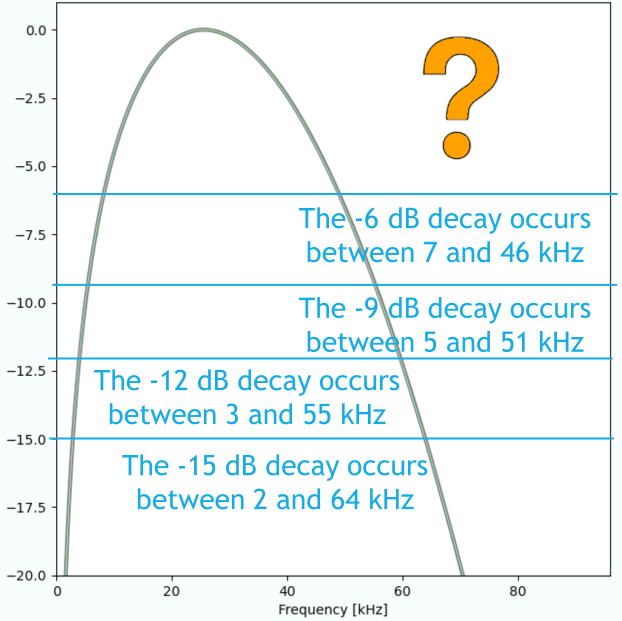


Bipolar Pulse (BP)





What are we looking for?

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

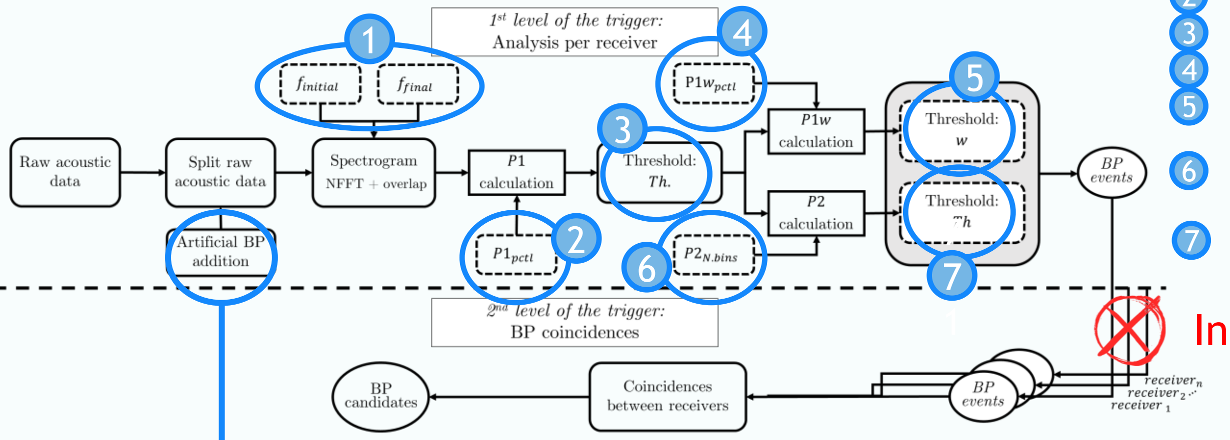
ACOUSTIC NEUTRINO DETECTION

ACOUSTIC NEUTRINO DETECTION

WORKFLOW

The proposed acoustic neutrino detector at ARENA22 studies 3 parameters (cut-off) provided by the spectrogram analysis:

- $P1$ (to control the BP intensity): Mean PSD value between the BP frequency range
- $P1w$ (to control the BP duration): Width to $P1_{\mathrm{pctl}}$% of the $P1$ peak
- $P2$ (to control de BP duration): Difference between $P1$ value of 1 bin ($\sim 50\ \mu s$) and the $P1$ value of the $\pm$ 50 samples surrounding it ($\sim$ 5 ms)



Parameters set-up:

1. $f_{initial} + f_{final}$: Frequency range
2. $P1_{pctl}$: Percentile for the P1 calculation
3. $P1_{Th}$: Threshold of P1 to detect BP events
4. $P1w_{pctl}$: Percentile for the P1w calculation
5. $P1w_{Th}$: Threshold of P1w to detect BP events
6. $P2_{N.bins}$: Bins surrounding the candidate for the P2 calculation
7. $P2_{Th}$: Threshold of P2 to detect BP events

In this study, we are using a single hydrophone

The artificial BP is added in a ToA randomly in each split data

ACOUSTIC NEUTRINO DETECTION

Artificial BP in OvDE-2 Raw Data

The inserted BP is at random time of the raw acoustic data

Which neutrinos are "visible" in OvDE-2?

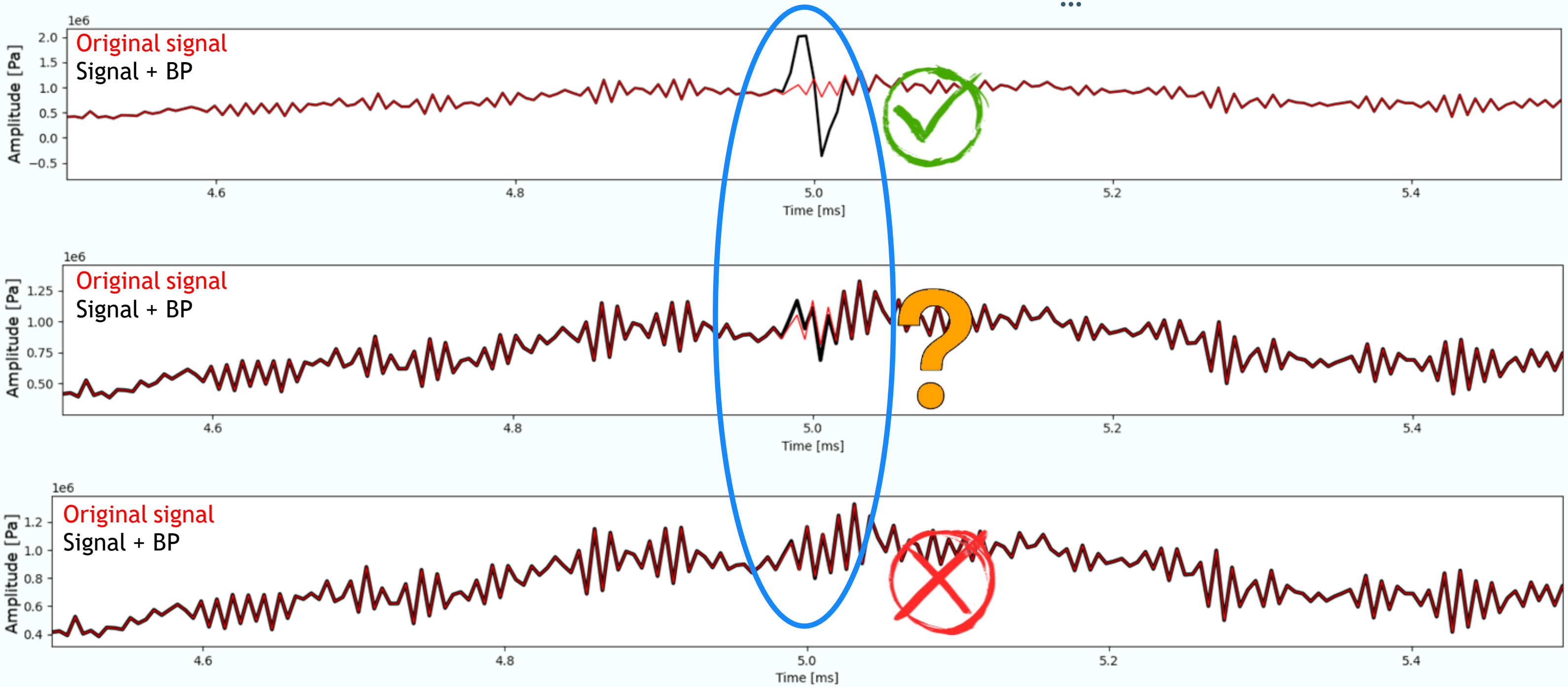
UHE Neutrinos (peak):

- $10^{12}\ GeV \approx 1.25\ Pa$
- $10^{11}\ GeV \approx 123.9\ mPa$
- $10^{10}\ GeV \approx 12.33\ mPa$
- …

$10^{12}\ GeV$ ν

$10^{11}\ GeV$ ν

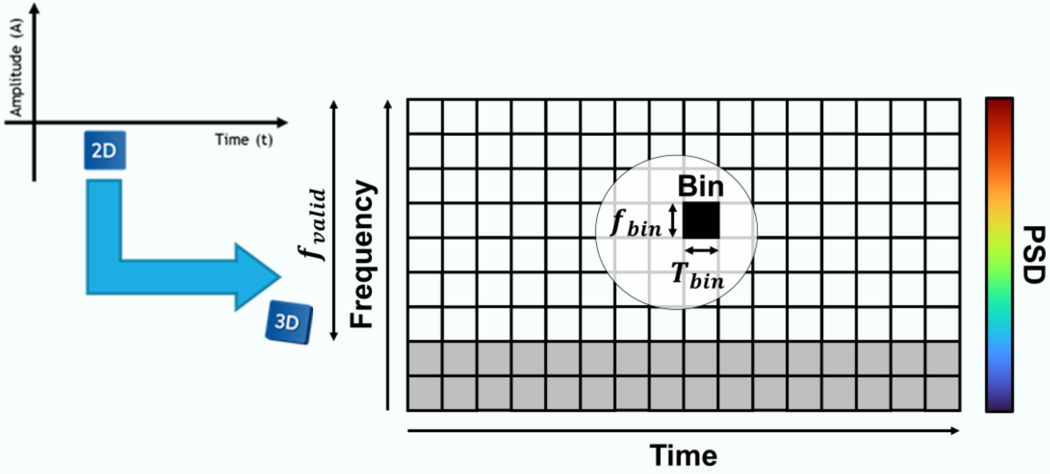
$10^{10}\ GeV$ ν



The spectrogram analysis is proposed because the detection depends more on energy than BP shape

ACOUSTIC NEUTRINO DETECTION

SPECTROGRAM CONFIGURATION



$P1$: Mean PSD value between the BP frequency range

$P1w$: Width to $P1_{\mathrm{pctl}}\%$ of the $P1$ peak

$P2$: Difference between $P1$ value of 1 bin and the $P1$ value of the $\pm$ 50 bins surrounding it

f_s: $192\ kHz$

Compromise between f_{valid}, T_{bin}, f_{res} and f_s

$$T_{bin} = \frac{NFFT}{f_s}(1 - overlap)$$

$$f_{bin} \geq \frac{f_s}{NFFT}$$

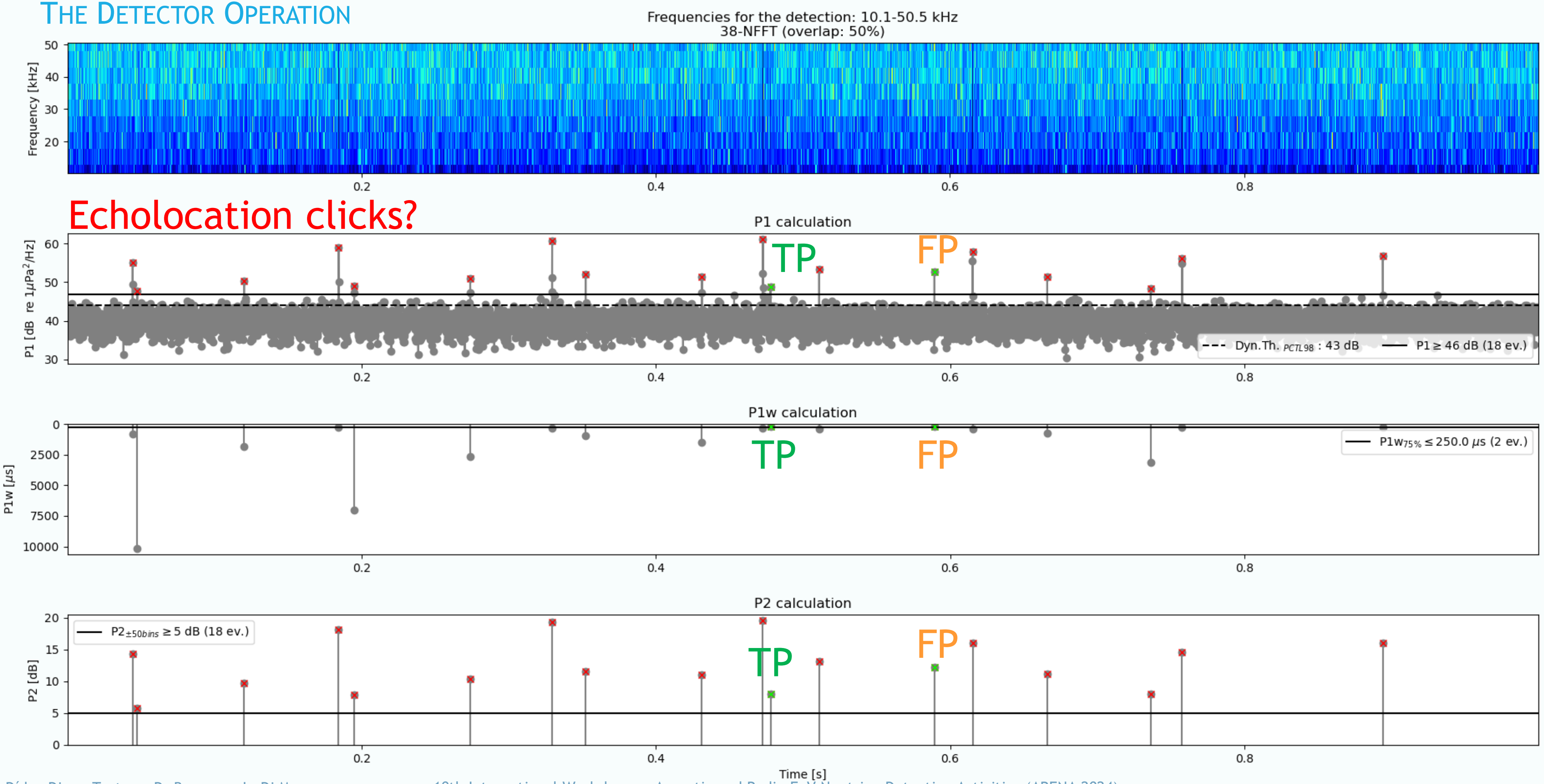
$$f_{valid} \geq \frac{2f_s}{NFFT}$$

NFFT	T_{bin} [µs] Objective $\lesssim 100$	f_{bin} [kHz] Objective $\lesssim 5$	f_{valid} [kHz] Objective $\lesssim 10$
32	83.33	6.00	12.00
38	**98.96**	**5.05**	**10.10**
64	166.67	3.00	6.00

ACOUSTIC NEUTRINO DETECTION

THE DETECTOR OPERATION

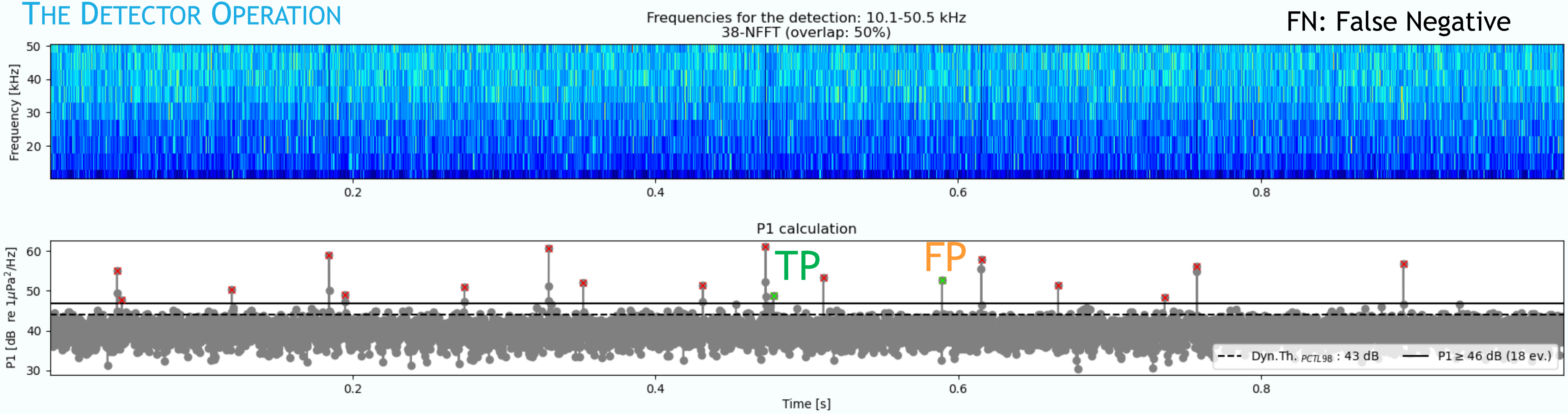
TP: True Positive
FP: False Positive

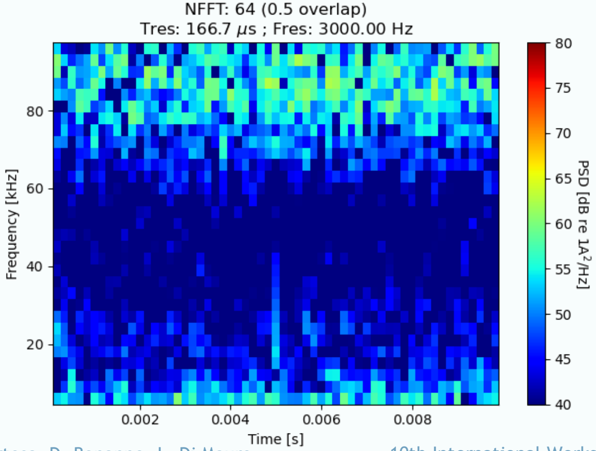


ACOUSTIC NEUTRINO DETECTION

THE DETECTOR OPERATION

TP: True Positive
FP: False Positive
FN: False Negative





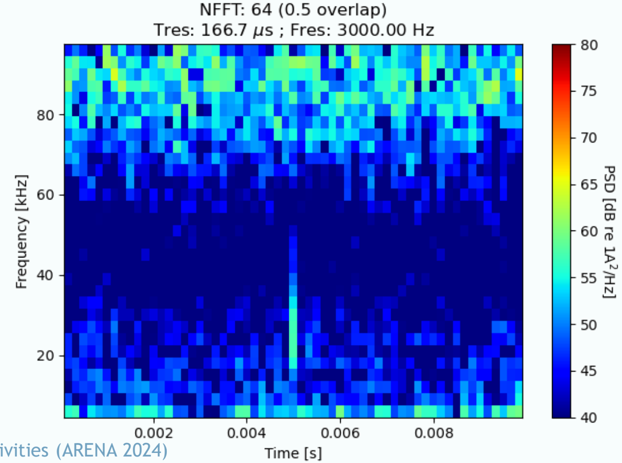
TP

FP

Powerful and short clicks pass the algorithm as a BP

$$Precision = \frac{TP}{TP + FP}$$

$$Recall = \frac{TP}{TP + FN}$$

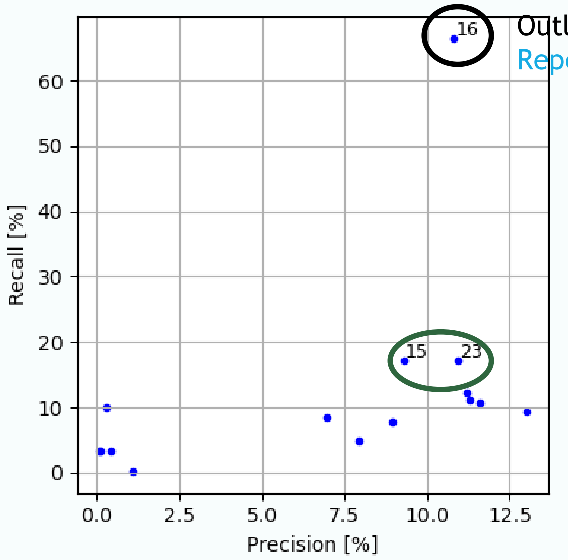


ACOUSTIC NEUTRINO DETECTION

THE DETECTOR CONFIGURATION

Different tests have been carried out to identify the optimal detector configuration. A random hour of the total 24H sample has been used.

We proceeded to test different frequency ranges, different values for the parameters calculation, and different thresholds.



Outlier:
Repeated in the 23rd

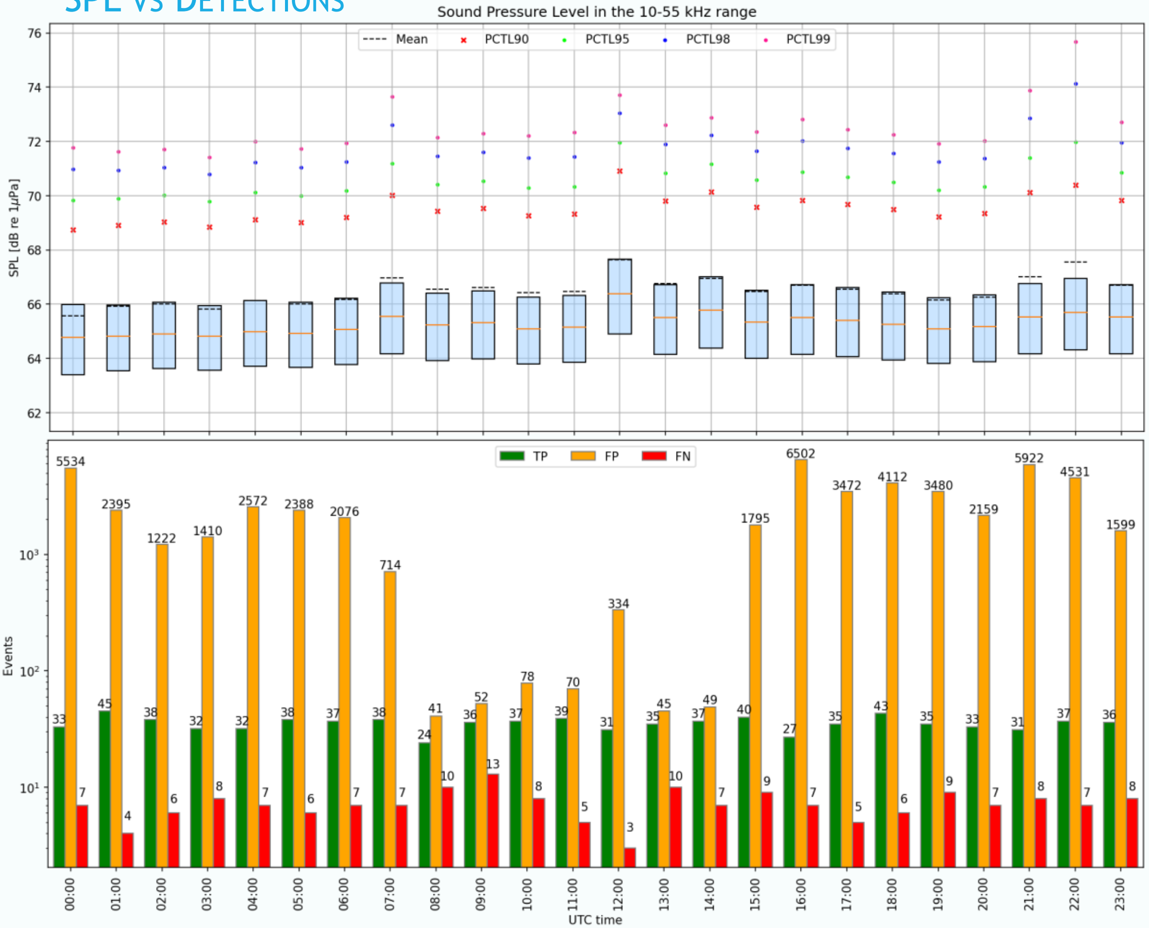
$10^{11}\ GeV$
ν

Index	Frequency range		P1 [dB re 1μPa²/Hz]		P1w [s]		P2 [dB]		Precision [%]	Recall [%]
	Initial [kHz]	Final [kHz]	Percentile [%]	Threshold [dB]	Percentile [%]	Threshold [μs]	Number of bins [± samples]	Threshold [dB]		
15	10	50	98	3	80	250	50	5	9.30	17.22
16	10	55	98	3	75	275	50	5	10.82	66.52
23	10	55	98	3	75	275	50	5	10.92	17.22
...										

RESULTS

RESULTS

SPL vs Detections



Is the background noise in the raw data affecting the BP detector?

10^{12} GeV

ν

TP detections: Constant

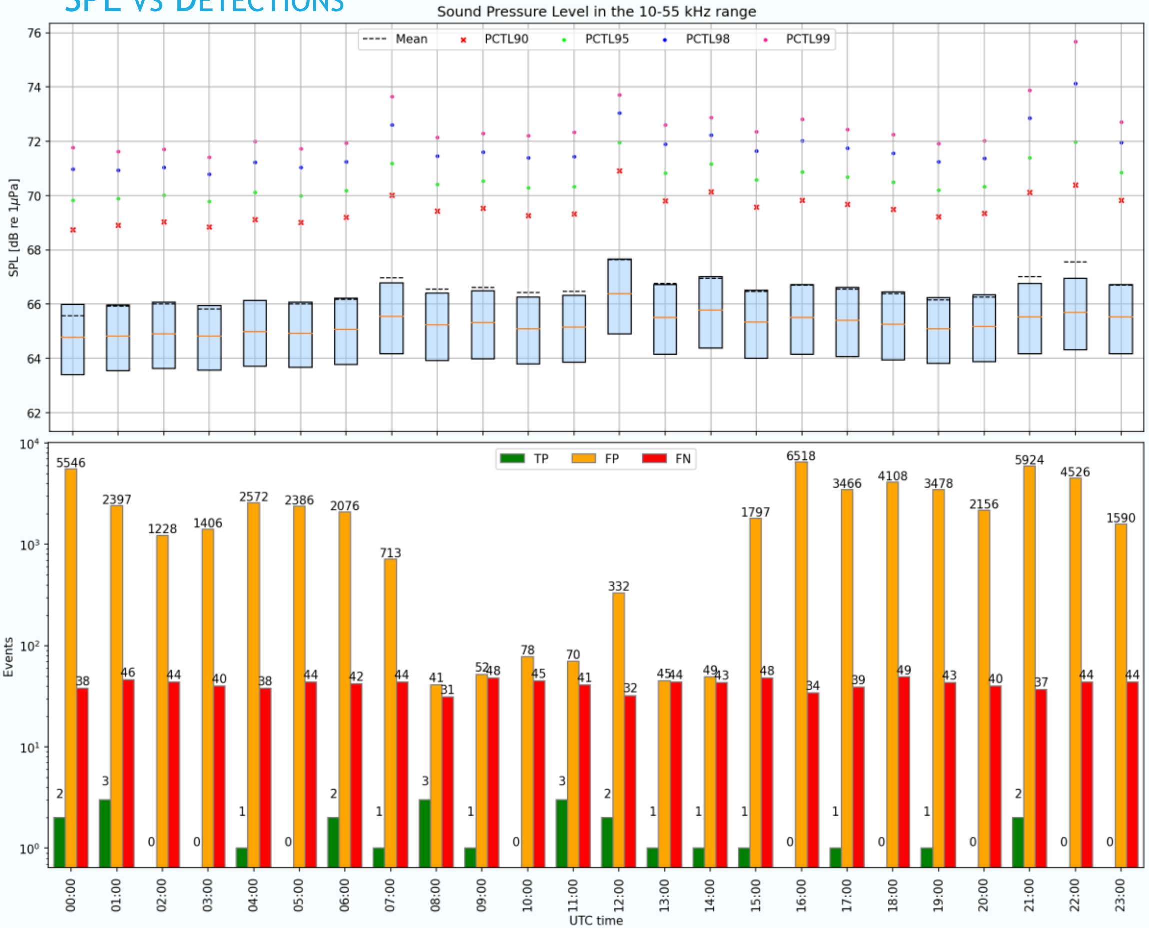
FP detections: $+\mathrm{SPL} \rightarrow -\mathrm{FPs}$

Precision: 1.59 %

Recall: 82.99 %

RESULTS

SPL VS DETECTIONS



Is the background noise in the raw data affecting the BP detector?

10^{11} GeV ν

TP detections: Constant?

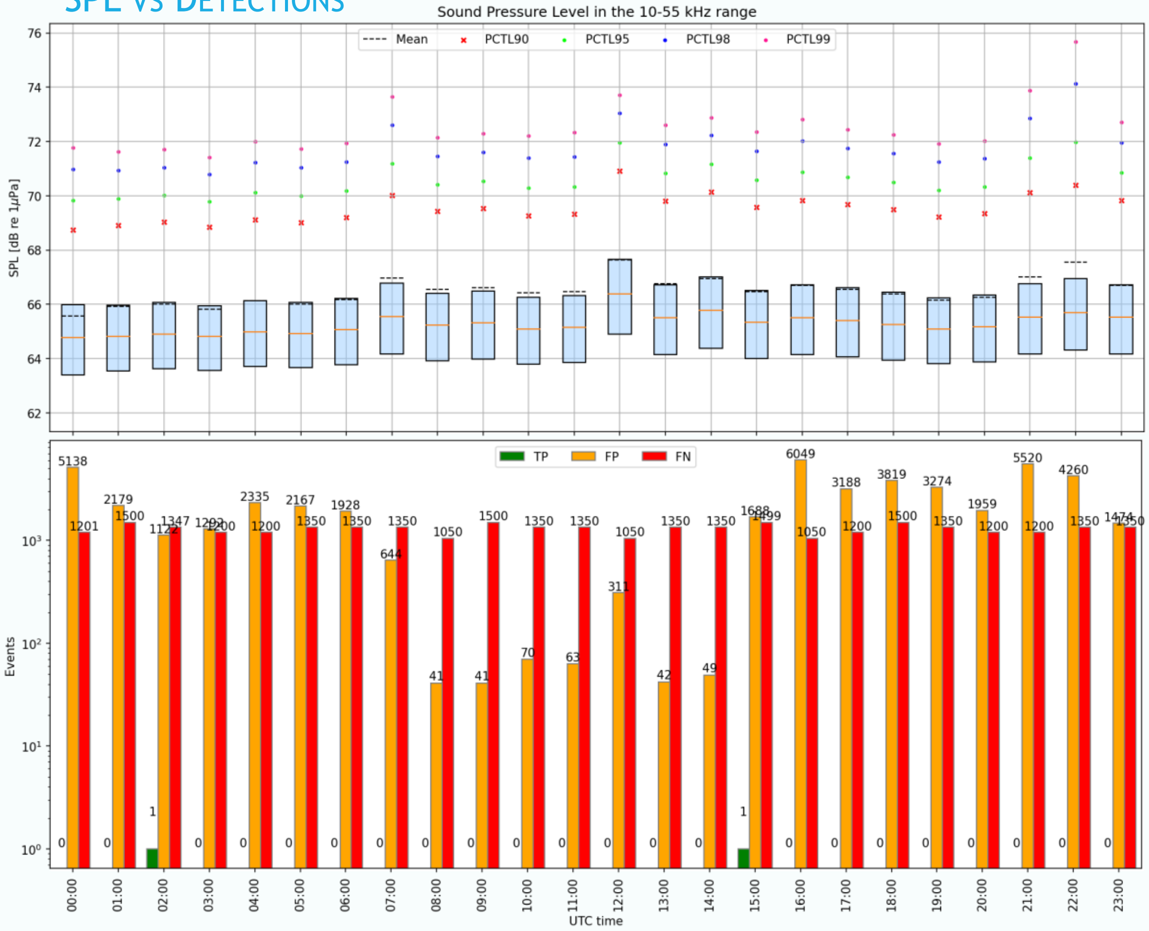
FP detections: $+\text{SPL} \rightarrow -\text{FPs}$

Precision: 0.5 ‰

Recall: 2.44 %

RESULTS

SPL vs Detections



10^{10} GeV ν

Is the background noise in the raw data affecting the BP detector?

TP detections: 2

FP detections: $+\mathrm{SPL} \rightarrow -\mathrm{FPs}$

Precision: 0.041 ‰

Recall: 0.064 ‰

RESULTS

DETECTIONS

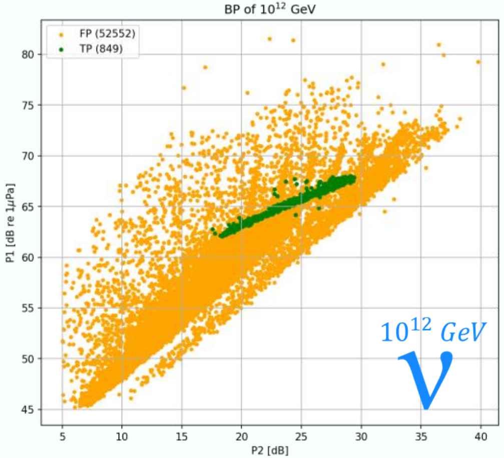
Energy [GeV]	Artificial BPs	BP detections	True Positive (TP)	False Positive (FP)	False Negative (FN)	Precision [%]	Recall [%]
10^{12}	1023 (1/min)	53401 (0.86/s)	849	52552	174	1.59	82.99
10^{11}	1023 (1/min)	52579 (0.84/s)	25	52554	998	0.05	2.44
10^{10}	1023 (1/min)	0 (0.00/s)	0	0	1023	0.00	0.00
10^{10}	31199 (30/min)	48655 (0.78/s)	2	48653	31197	0.0041	0.0064

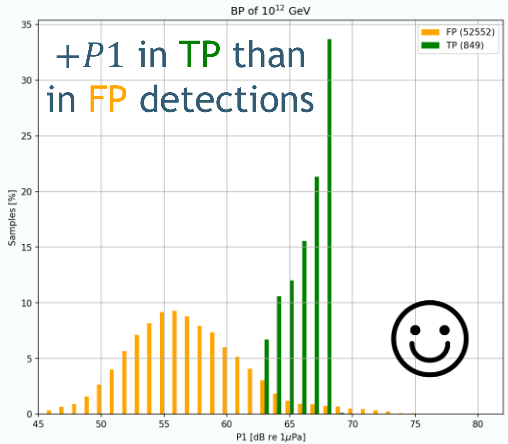
Objective < 1/s

RESULTS

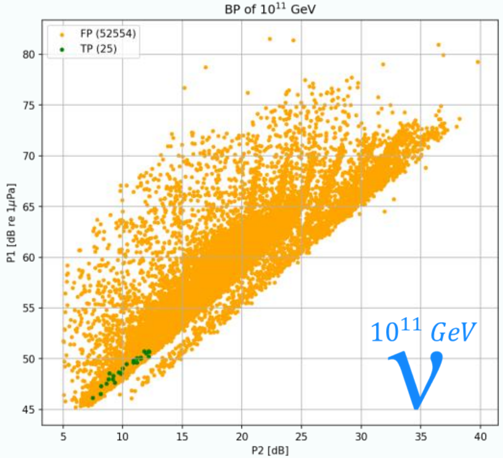
DETECTIONS

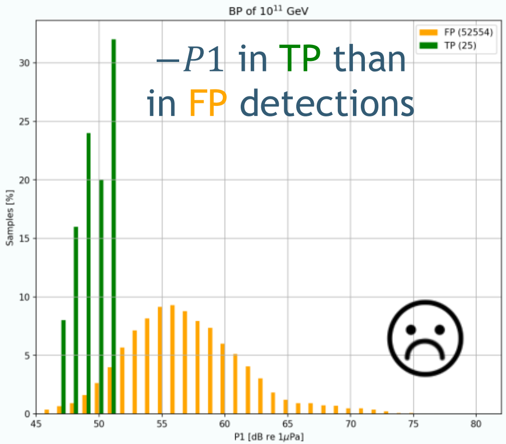
Precision: 1.59%
Recall: 82.99%



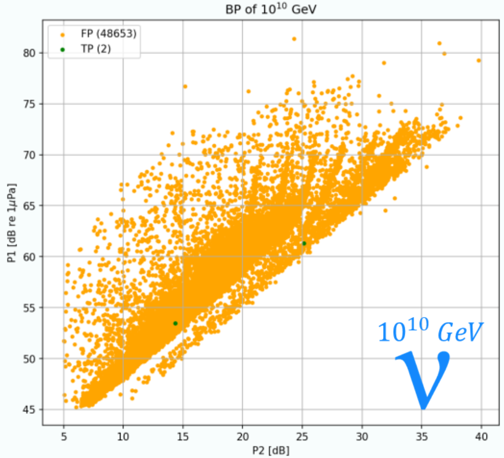


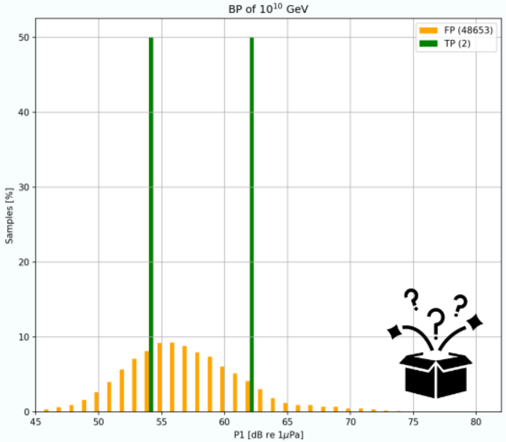
Precision: 0.05%
Recall: 2.44%





Precision: 0.0041%
Recall: 0.0064%





SUMMARY AND CONCLUSIONS

- The algorithm proposed in ARENA22 has been tested in another environment (critical case full of bioacoustics echolocation clicks).
- Neutrinos of energy 10^{12} GeV we are above background noise (FPs).
- OvDE-2 data requires a different kind of detector (scalogram analysis?).
- Testing the second step of the algorithm (coincident events at different receivers) is expected to reduce the number of FPs.
- Research should be undertaken to develop detectors for lower energy neutrinos.
- This kind of detector can also be useful for other signals, for example for bioacoustics echolocation clicks.

Thanks for your attention

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Backup slides

The 10th International Workshop on Acoustic and Radio EeV Neutrino Detection Activitie (ARENA 2024)

ACOUSTIC NEUTRINO DETECTION

THE DETECTOR OUTPUT

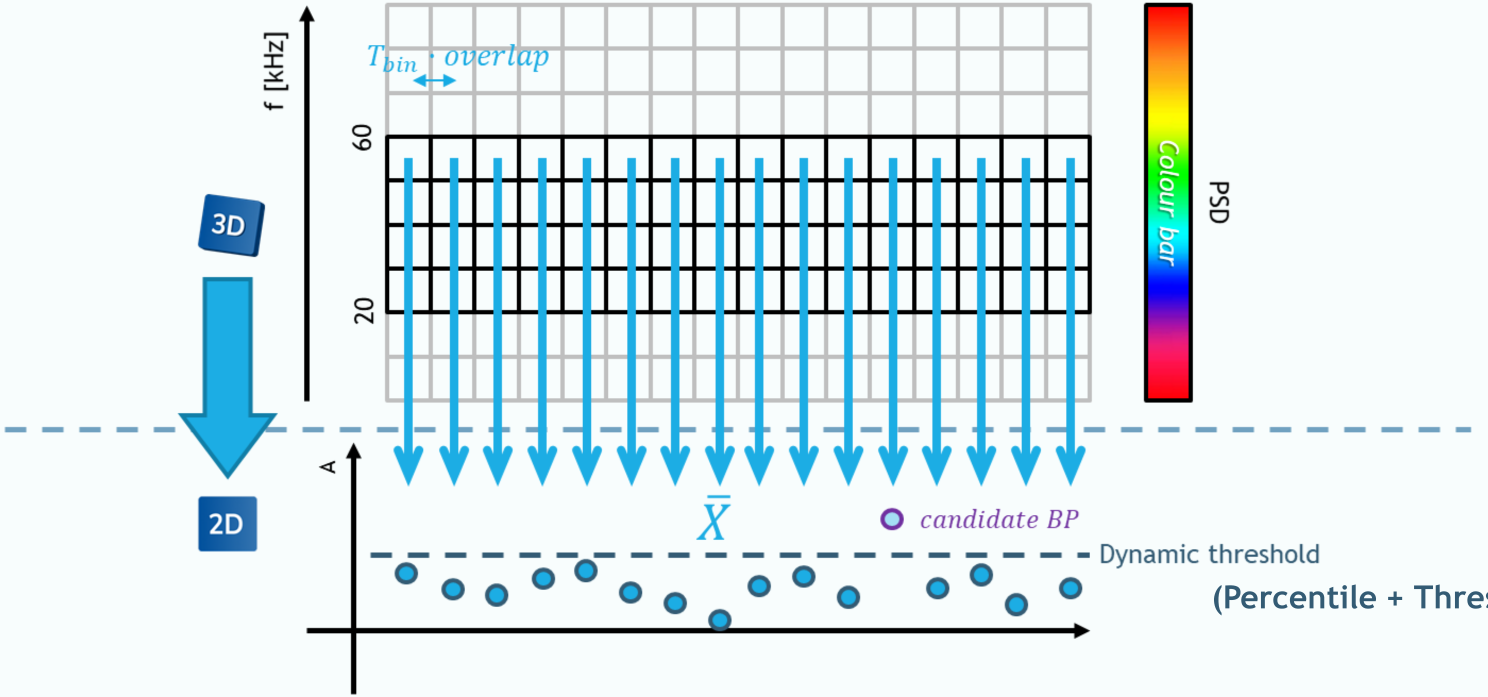
File name	ToA [unixtime]	Is an artificial BP?	P1 [dB re $1\mu Pa^2/Hz$]	P1w [s]	P2 [dB]	N.P1	N.P1w	N.P2	SPLs [dB re $1\mu Pa$]
…	Detection time	True/False	Detection values			Number of events that have passed the cut-off threshold			SPL in the analyzed split

ACOUSTIC NEUTRINO DETECTION

The Spectrogram as a Signal Detector

$P1$ calculation:

Trigger alert of candidate BP using a spectrogram in KM3NeT:



(Percentile + Threshold)