ANTARES - Baikal-GVD Alerts Analysis

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Abstract

ANTARES and Baikal-GVD are both Cherenkov neutrino telescopes located in the Northern Hemisphere. As a consequence, their fields of view overlap allowing for a combined study of the sky (Fig: 1). Under a Memorandum of Understanding since December of 2018, Baikal-GVD received 38 alerts from ANTARES, and followed up a total of 32. While no prompt coincidence was found, a cascade mode search showed some events falling within an angular distance of less than 5° for the three of these alerts. The 4.5° angular resolution of Baikal-GVD allows for the possibility of these events to be spatially correlated so a dedicated analysis was performed to check the possible correlation between ANTARES and Baikal-GVD events.

In this poster we present the results of the analysis of these alerts after the addition of the latest ANTARES cascade dataset and the optimization of the search method with a novel Machine Learning Algorithm for background rejection. To navigate through the poster, read it left to right. Start with the boxes next to this for a presentation of ANTARES and Baikal-GVD. Continue with the Baikal-GVD follow up results. And end with the optimization and results of the analysis from the ANTARES side.

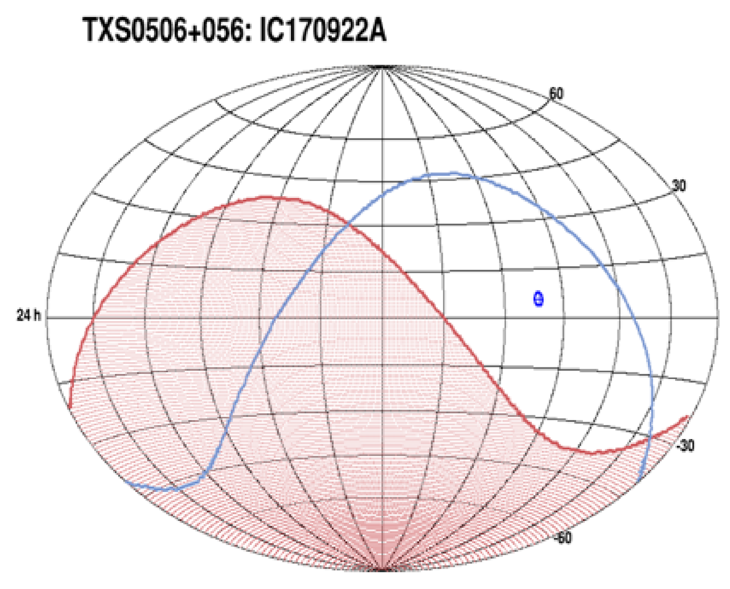

Fig. 1: Example of overlapping FoV in time of known neutrino alert IC170922A. Red for GVD and blue for ANTARES.

ANTARES Alerts

ANTARES is located in the Mediterranean sea, 40 km offshore of the coast of Toulon, France [1]. It is optimized for the detection of up-going neutrinos coming across the earth. It is able of real-time processing with delays below 10 seconds between detection and alert emission.

ANTARES sends alerts for **doublets of neutrinos**, neutrinos with $E > 1$ TeV and direction **close to local galaxies** (directional); and with **high energy** ($E > 7$ TeV) or **very high energy** ($E > 30$ TeV) neutrinos, HE and VHE respectively.

ID	Right Asc. [°]	Declination [°]	Trigger
Alert A7	151.1	-27.3	Dir.
Alert A15	280.4	1.0	HE
Alert A16	186.5	-4.2	HE

Baikal-GVD

The deep underwater neutrino telescope Baikal-GVD is under construction in Lake Baikal [2]. It is built in individual clusters, separated 300 m of each other. A cluster is composed of 288 optical modules divided in 8 strings. In season Apr 2018 - Feb 2019 three clusters were operational and were extended to five on Apr 2019, and to seven in Apr 2020. Detection is based on measuring the Cherenkov radiation emited by leptons produce in neutrino interactions.

Fig. 2: Pictures of the installation of cluster 7 in lake Baikal

Follow up of ANTARES neutrino alerts: 5° cone radius ± 1 day

Follow-up frame:

1. Search for events per cluster in different time windows of ±500 sec, ±1 hour and ±1 day around alerts inside a 5° cone radius.
2. Search for coincidence on two or more clusters within 6 μs for the first ±10 seconds and, in an extended interval, for the next ±1 hour around the trigger.

The next table summarizes the number of cascades detected, the detection time, and expected background. Coordinates are shown in Figure 3, 4 and 5.

Alert	# cascades	$\Delta T_{trigger}$ [h]	Bkg/(cluster·day)*
A7	3	+21.7, -3.2, -23.2	0.021
A15	2	+20.3, -0.6	0.054
A16	2	-14.8, -18.6	0.045

*Bacckground is computed from scrambled data from the 2018/19 season.

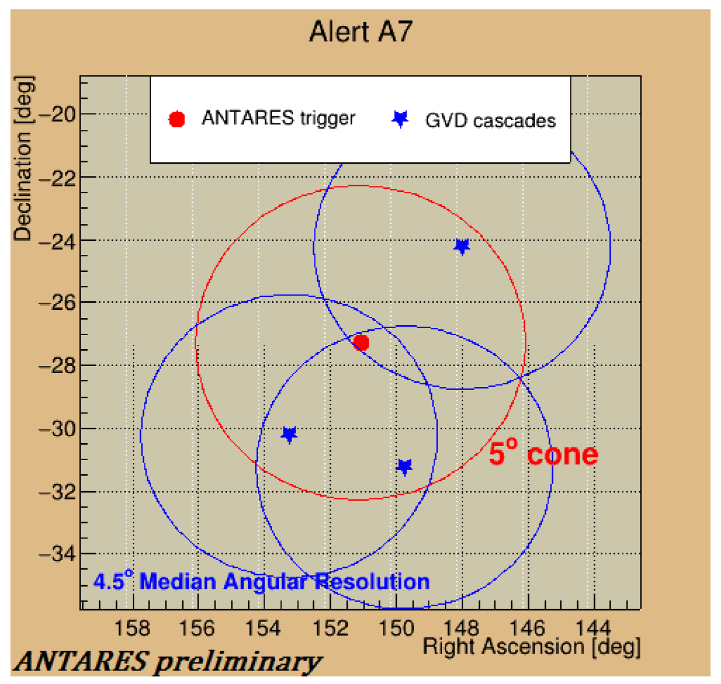

Fig. 3: Alert A7: A triplet of cascades was reconstructed around the ANTARES trigger in ±1 day time.

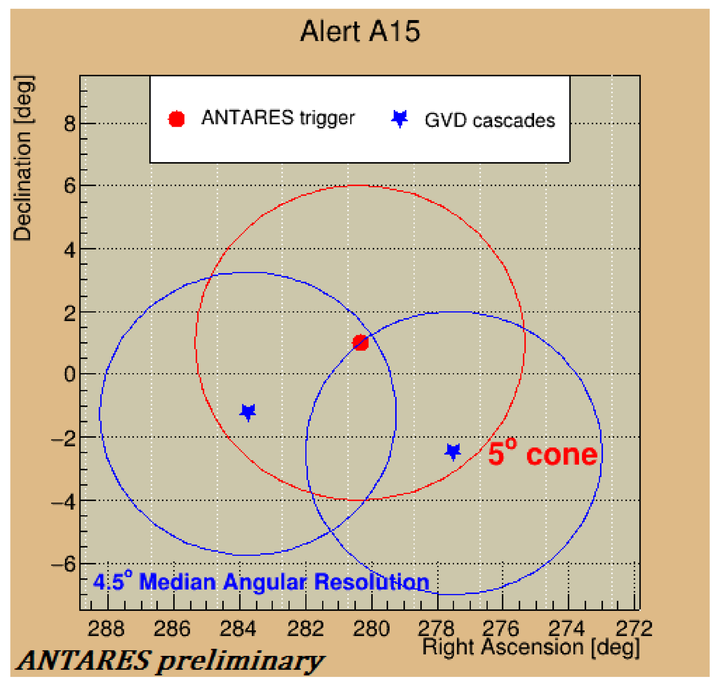

Fig. 4: Alert A15: Two cascades were reconstructed around the ANTARES trigger in ±1 day time.

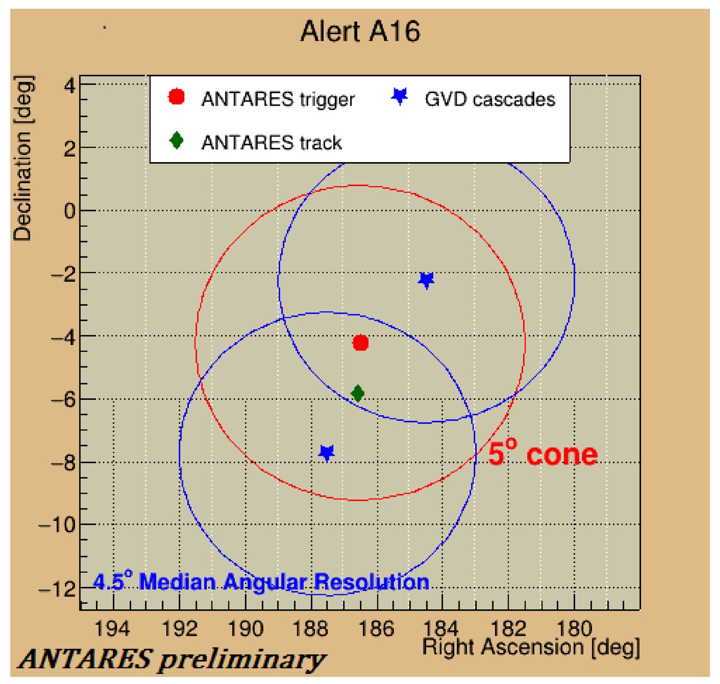

Fig. 5: Alert A16: Two cascades were reconstructed around the ANTARES trigger in ±1 day time. An additional track was found in ANTARES data 9 hours and 15 minutes after the alert within 2 degrees.

ANTARES follow-up with cascades on the Up-going Sky

ANTARES is looking for additional cascades events for these three alerts with associated GVD events in the same time window

We **optimized a set of cuts** so that a single detected event would allow us **to reject the background hypothesis at a 3σ level**. As a search window of 48 hours is used, the optimization is divided in the **up-going** (this poster) and the down-going sky. This analysis has been used also as a test bench to **compare two classification algorithms** widely used in the ANTARES collaboration:

a) A **Random Decision Forest** (RDF) used to discriminate between tracks (CC $\nu_\mu/\bar{\nu}_\mu$) and cascades(CC $\nu_e/\bar{\nu}_e$ and all NC) using pure hit information [3].

b) A newly developed **Boosted Decision Tree** (BDT), trained on basic reconstruction variables to find cascades produced by atmospheric neutrinos, but which can be extended to cosmic cascades with the proper cut selection.

Moreover, **the size of the Region of Interest (RoI) is also optimized and a cut on the likelihood ratio L_μ is aditionally used to further remove background** based on basic reconstruction information [4]. All posible (RoI size, BDT/RDF cut, L_μ cut) combinations are tested, and those setting the background level below the desired value are further evaluated for a reference flux $\phi \propto E^{-2}$ [a.u]. The cut for each classifier that yields the higher expected signal (ES) for every alert is selected and shown in the next table:

Alert	T. visible [h]	(RoI =, BDT>, L_μ>)	ES [a.u.]	(RoI =, RDF>, L_μ>)	ES [a.u.]
A7	31.7	(16°, 0, 44)	2.00	(11°, 0.20, 17)	1.93
A15	23.7	(12°, 0, 8)	1.39	(11°, 0.10, 14)	1.26
A16	25.2	(8°, 0, 6)	1.48	(10°, 0.10, 16)	1.46

The BDT rises as the best classifier for the up-going sky. This can be explained by the fact that, as shown in Figure 6, the BDT suffers less overlapping between the signal (green) and background (blue + red) distributions than the Dusj-RDF. However, by comparing the expected signal (ES) values on the table the improvement of the BDT over the RDF is, at most, around 10% for alert A15, and 3.6% and 1.4% for A7 and A16 respectively. Overall, **both classifiers have similar discrimination powers for the E^{-2} flux**.

The ANTARES **up-going data was unblinded** for the optimized cuts **and no event was detected for any of the alerts** so the computation of according limits is under way. However, this work serves as motivation to encourage further combined efforts between ANTARES and Baikal-GVD collaborations.

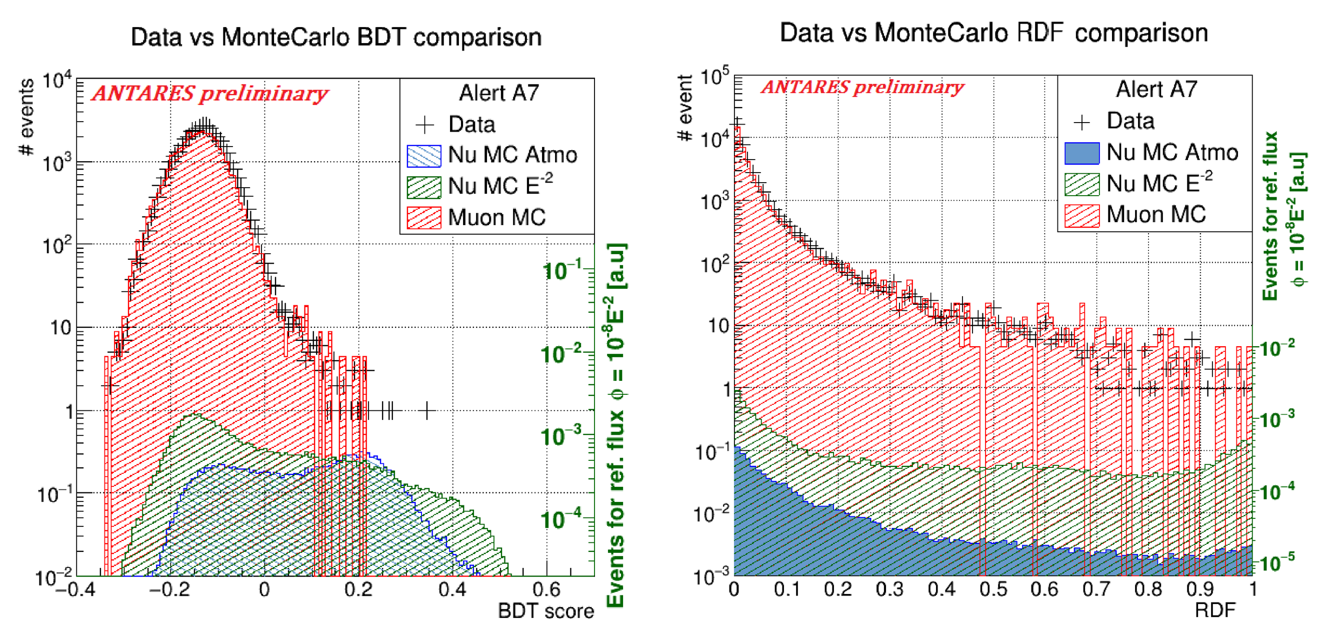

Fig. 6: Distribution for the output variables of the new BDT (left) and RDF (right) for data, MC generated atmospheric neutrino and muon background, and MC generated signal. The BDT can achieve a muon background free sample with a strict enough cut. However, a significant part of the astrophysical neutrino distribution (green) is left out. On the contrary, the RDF can not achieve such purities but it keeps in comparison more astrophysical events, even for strict cut values.

References:

[1] Ageron, M., et al. "ANTARES: the first undersea neutrino telescope." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 656.1 (2011): 11-38.

[2] Avrorin, A. D., et al. "The Baikal-GVD neutrino telescope: First results of multi-messenger studies." arXiv preprint arXiv:1908.05450 (2019).

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[4] A. Albert et al. , ANTARES Collaboration. The Astron. J.,154:275, 2017.

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