Search for nuclearite with ANTARES

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Summary

ANTARES is a Cherenkov underwater neutrino telescope, its building was completed in 2008. Even though optimised for the search of cosmic neutrinos, this telescope is also sensitive to nuclearites (massive nuggets of strange quark matter [1]) trough the black body radiation emitted along their path [2].

We discuss here the possible detection of non-relativistic down-going nuclearites with the ANTARES telescope and present the results of an updated analysis using data collected from 2009 to 2017.

The ANTARES detector

ANTARES (Astronomy with a Neutrino Telescope and Abyss environmental RESearch) is a Cherenkov based neutrino telescope deployed at a depth of 2450 m in the Mediterranean Sea, 42 km offshore from Toulon in France. It consists of [3]:

- 12 detection lines of about 450 m length.
- 25 floors separated by 14.5 m for each line.
- 3 optical modules per floor, each one contains 10 inch photomultiplier tube (PMT).

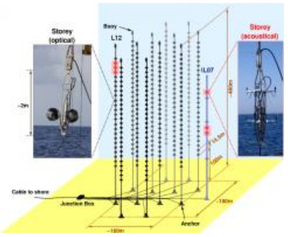

Figure 1. Schematic view of ANTARES.

Analysis

The analysis aims to separate nuclearites from any others particles that could reach the ANTARES detector. We use a Monte Carlo simulation of nuclearites, where for each mass and run number we simulate 100 events assuming an initial velocity at entrance of atmosphere of $\beta = 10^{-3}$. The signal is characterized by:

- a large number of fired PMTs ;
- many hits with large amplitude , ≥ 3 photoelectrons (nhits3);
- many detector floors (nfloor) crossed ;
- a long transit time (dt) in the detector;

A significant amount of low-energy background events is removed by applying the cut L0 ≥ 300 (i.e.L0 hits are hits with charge of at least 0,35 photo-electrons). After this pre-cut, Figure 2 shows the distributions of the discrimination variables for real data in black, atmospheric muons in blue and for the signal (nuclearites with four different masses).

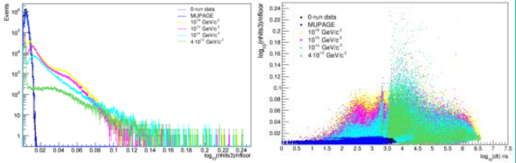

Figure 2. on the left, distribution of log10(nhits3)/nfloor, on the right, a 2D distribution of log10(nhits3)/nfloor versus dt.

Optimization

We extrapolate the discrimination variables to compensate for the lack of statistics in the distribution tails due to the contribution of the optical background in the real data. The extrapolation has been made using a Landau type function.

The optimisation of the cuts on the discrimination variables is made by minimizing the rejection factor (RF). This is performed by scanning the 2D distribution in figure 2, with small steps.

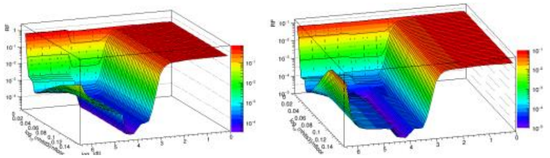

Figure 3. on the left, example of the RF for nuclearites with mass $4{\times}10^{13}$ GeV/c^2, and for 10^{16} GeV/c^2 on the right.

Results and discussions

The sensitivity at 90% of confidence level (C.L.) noted S90 is computed using the Feldman-Cousins formula assuming events with a Poissonian distribution.

$$S_{90}(cm^{-2}\cdot sr^{-1}\cdot s^{-1}) = \frac{\bar{\mu}_{90}(n_b)}{S_{eff}((cm^2\cdot sr)\times T(s)}$$

$$\bar{\mu}_{90}(n_b) = \sum_{n_{obs}=1}^{\infty} \mu_{90}(n_{obs}, n_b)\cdot \frac{n_b^{n_{obs}}}{n_{obs}!}\cdot e^{-n_b} \quad \text{and} \quad S_{eff} = \frac{n_{Nuc}}{\phi_{Nuc}}$$

Where T is the duration of data taking corresponding to 2009-2017 period in seconds. n_{Nuc} represent the number of nuclearites remaining after applying the optimized cuts and ϕ_{Nuc} represent the flux of generated Nuclearites.

For masses higher than 10^{16} GeV/c^2, nuclearites events must be more energetic and they would emit more light. Therefore, the limit of the last test point can be taken as a conservative limit also for larger nuclearites masses.

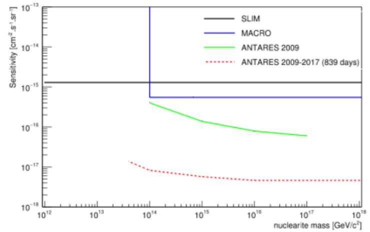

Figure 4. ANTARES sensitivity for nuclearites by using 839 days livetime of data at 90% of C.L. [4-6]

If no candidate found in the forthcoming analyses, the new flux limit will improve the MACRO and SLIM upper limits.

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