SEARCH FOR NUCLEARITES WITH THE KM3NET DETECTOR

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ABSTRACT

Strange quark matter (SQM) is a hypothetical type of matter composed of almost equal quantities of up, down and strange quarks. In [1], Edward Witten presented the SQM as a denser and more stable matter that could represent the ground state of Quantum Chromodynamics (QCD). Massive SQM particles are called nuclearites. These particles could have been produced in violent astrophysical processes, such as neutron star collisions and could be present in the cosmic radiation. Nuclearites with masses greater than 10^{13} GeV and velocities of about 250 km/s (typical galactic velocities) could reach the Earth and interact with atoms and molecules of sea water within the sensitive volume of the deep-sea neutrino telescopes. The SQM particles can be detected with the KM3NeT telescope (whose first lines are already installed and taking data in the Mediterranean Sea) through the visible blackbody radiation generated along their path inside or near the instrumented area. In this work the results of a study using Monte Carlo simulations of down-going nuclearites are discussed.

NUCLEARITES

Massive SQM particles with galactic velocities do not interact with atoms through direct nuclear interactions, because of the Coulomb repulsion. The relevant interaction mechanism of nuclearites with matter is through elastic and quasi-elastic collisions. In transparent media (such as water), a fraction of the energy emitted through the elastic and quasi-elastic collisions of these particles with the atoms encountered is dissipated as blackbody radiation in the visible spectrum. This fraction of energy, i.e. the luminous efficiency, is estimated in the case of water to be $\eta \approx 3 \cdot 10^{-5}$. This allows for the search of nuclearites using neutrino telescopes.

Energy loss →

$$\frac{dE}{dx} = -\sigma \rho v^2$$

ρ – density of the medium
v – velocity of the nuclearite
M – nuclearite mass
ρ_N – density of the nuclearite

[2]

Cross-section →

$$\sigma = \begin{cases} \pi (3M/4\pi\rho_N)^{2/3} & \text{for } M \geq 8.4 \cdot 10^{14} \text{ GeV} \\ \pi \cdot 10^{-16} \text{cm}^2 & \text{for lower masses.} \end{cases}$$

KM3NeT DETECTOR

The detector consists of two large volume photomultiplier (PMT) arrays, ARCA (Astroparticle Research with Cosmics in the Abyss) and ORCA (Oscillation Research with Cosmics in the Abyss), placed at the bottom of the Mediterranean Sea in Italy (3500 m) and France (2475 m), respectively (Fig. 1). Either configuration will be composed by 115 Detection Units (DUs), each DU containing 18 Digital Optical Modules (DOMs). A DOM consists of 31 PMTs distributed on the internal surface of a glass sphere, and several sensors. All the DUs are connected to Junction Boxes (JB) placed on the seabed and connected to the shore station through optical fibers.

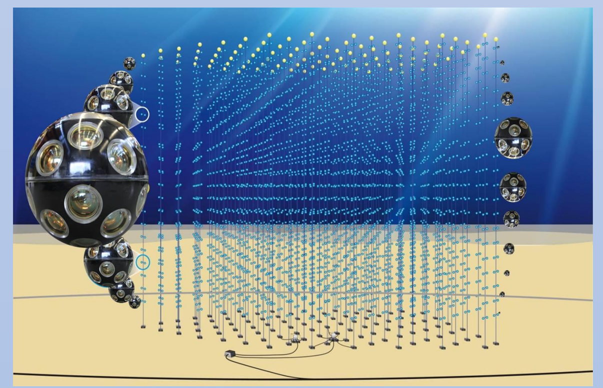


Fig. 1 – KM3NeT representation of a detection block.

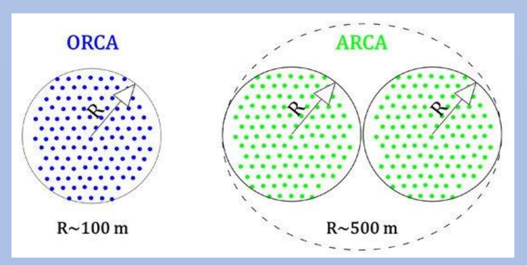


Fig. 2 – The geometries of the KM3NeT configurations.

Characteristics of the KM3NeT detectors.

	ORCA	ARCA
Depth (m)	2475	3500
Height (m)	~ 200	~ 700
Radius (m)	~ 100	~ 500
No. of DUs	115	115
No. of DOMs/DU	18	18
No. Of PMTs/DOM	31	31
Distance between DUs (m)	23	95
Distance between DOMs (m)	9	36

ANALYSIS

The Monte Carlo (MC) program used for this analysis is based on a previous code, developed for the ANTARES detector [3], and it is adapted to simulate the KM3NeT detector and the nuclearites propagation and interaction. The MC code simulates the full geometries of the KM3NeT detector and the characteristics of the PMTs. The algorithm considers an isotropic flux of downgoing nuclearites, which are uniformly distributed on a simulation hemisphere with the basis at the level of the seabed. The zenith and azimuth angles are described as follows: $\theta \in [0, \pi/2]$, $\phi \in [0, 2\pi]$. The initial velocity of the nuclearites at the entry in the Earth atmosphere (approximately 50 km above the sea level) is considered $\beta_0 \approx 10^{-3}$. The simulation hemisphere defines the sensitive volume of the detector. For ORCA and ARCA configurations, the radii of the sensitive volumes are: r_{hsf_ORCA} = 548 m, r_{hsf_ARCA} = 912 m, taking into account that the radii of the detectors are: r_{det_ORCA} = 100 m, r_{det_ARCA} = 500 m (see Fig. 2). The nuclearite events are propagated through the atmosphere and sea water until they reach the simulation hemisphere. From this point, the simulation code generates the initial coordinates of the entry point in the sensitive volume and proceeds in time steps of 50 ns. The propagation of the particle follows the relation [2]: $v(L) = v_0 e^{-\frac{\sigma}{M}\int_0^L \rho dx}$.

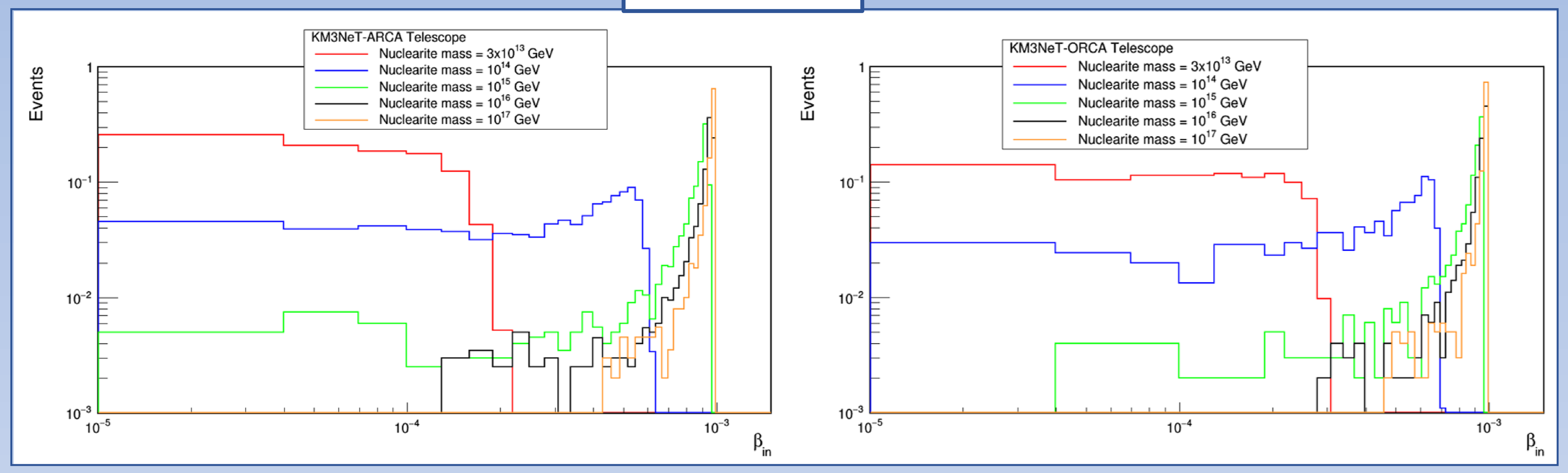
The algorithm searches for a luminous signal greater than 0.3 photo-electrons (pe), until the energy loss of the particle is less than 3 eV or the particle reaches the sea bottom or exits the sensitive volume. From the simulations, we obtain information such as the positions of the PMTs that saw the event, the time stamp of the event and the number of 'detected' photons. The background due to K40 and to bioluminescence is not simulated.

RESULTS

- This preliminary analysis uses simulated nuclearite events for masses in the range $3 \cdot 10^{13} - 10^{17}$ GeV, for both ORCA and ARCA configurations
- Only events with non-zero signal inside the detector were considered.
- Several distributions, relevant for the expected nuclearite signal at the KM3NeT depth, regarding the velocity at the entry in the simulation hemisphere, the number of hits and the signal duration inside the sensitive volume, are presented here.

Fig. 3 – Velocity distribution of the nuclearites at the entry in the simulation hemisphere: Events with higher masses (starting with 10^{15} GeV) have residual velocities at the entry in the sensitive volume approximately equal to their initial velocities at the entrance in the atmosphere.

$$v(L) = v_0 e^{-\frac{\sigma}{M}\int_0^L \rho dx}$$ [2]



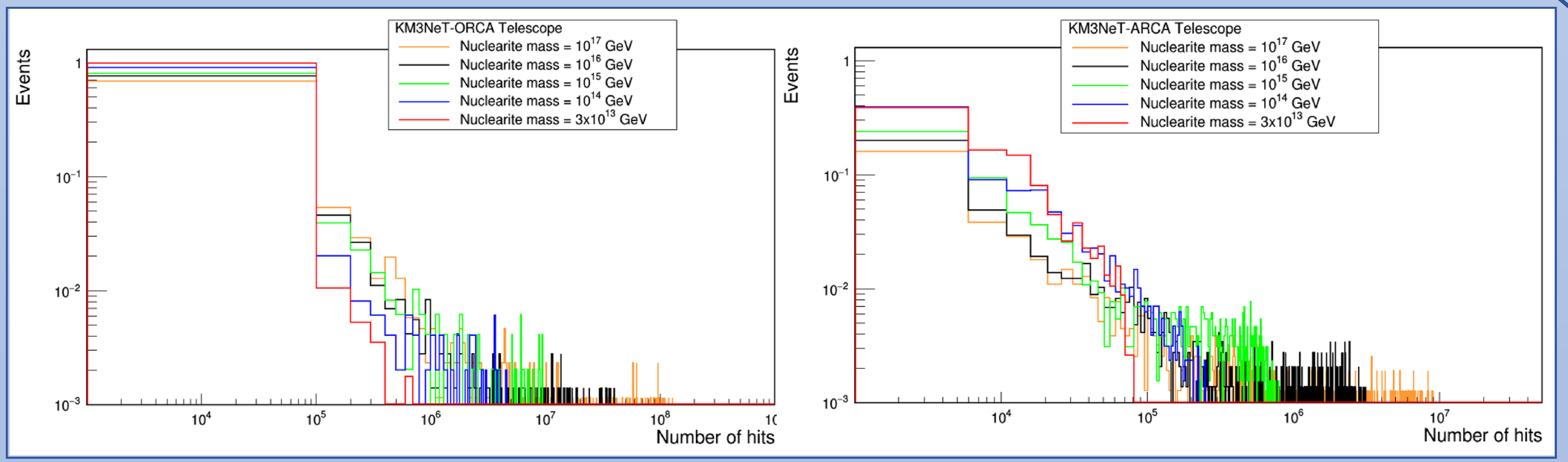


Fig. 4 – Distribution of the number of hits: The distributions show that the number of hits observed depend on the photomultiplier density of the detectors and also it increases with the nuclearite mass.

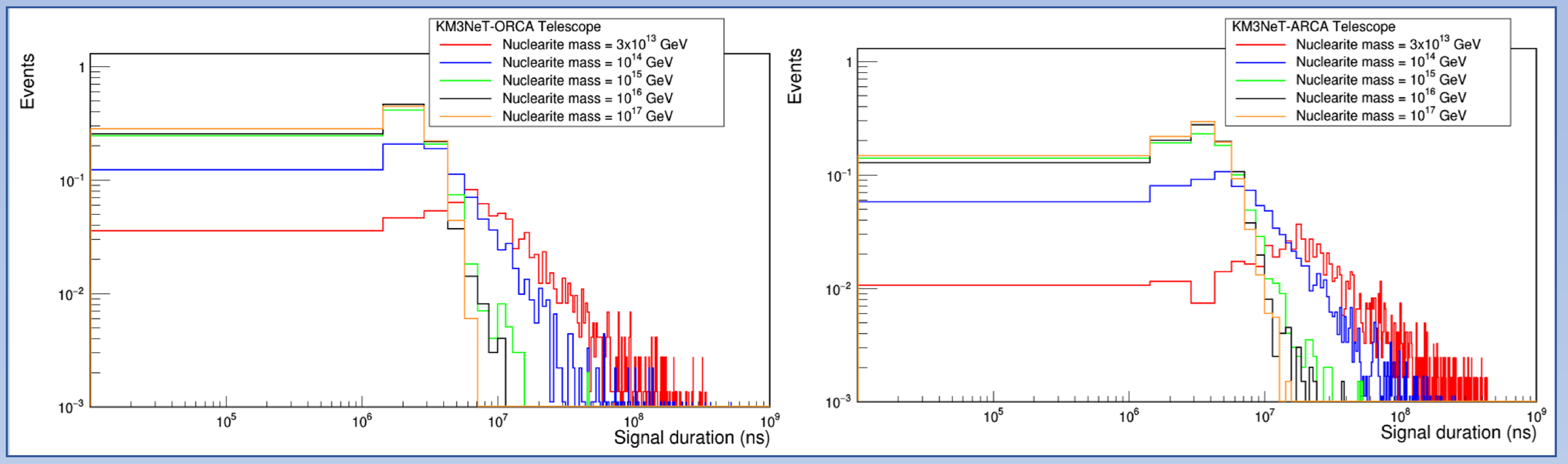


Fig. 5 – Signal duration: The duration of the signal is taken as the time interval between the first and the last hit. The nuclearite events with smaller masses (red and blue colors) have a larger span of the signal duration distribution in the detector, due to the small velocities at the entry in the sensitive volume.

CONCLUSIONS

This is a preliminary study of the expected signal at the KM3NeT detector depth for downgoing massive nuclearites. The distributions obtained show typical nuclearite events with a large number of hits and a large signal duration inside the detector (>1 ms). This is the signature of a nuclearite event that passes through underwater neutrino telescopes such as ANTARES and KM3NeT.

REFERENCES

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[3] G. Păvălaş (ANTARES Collaboration), POS(ICRC2015)1060