Search for strange matter particles with the ANTARES detector

Gabriela Emilia Păvălaş

Institute of Space Science, Bucharest-Magurele

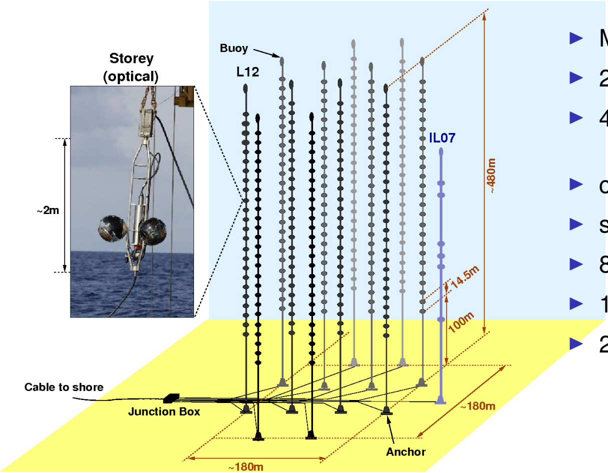
25th European Cosmic Ray Symposium, 4-9 September 2016

Introduction

- lumps of strange quark matter (SQM) formed in a quark hadron phase transition in the Early Universe were predicted by Witten (1984)
- composed of up, down and strange quarks in approximately equal proportions, with a mass range spanning from heavy nuclei ($\gtrsim 250$ GeV) up to neutron stars $\sim 10^{57}$ GeV
- SQM particles would be stable and neutral and could contribute to the dark matter content in the Universe
- nuclearites - massive cosmic SQM particles ($M_N \gtrsim 10^{10}$ GeV) reaching the Earth with velocities of ~ 250 km s^{-1}
- no experimental or astrophysical evidence for nuclearite existence so far
- MACRO and SLIM experiments set upper limits on the downgoing nuclearite flux at $5.4 \cdot 10^{-16}$ cm^{-2} s^{-1} sr^{-1}, for $M_N \geq 10^{14}$ GeV and $1.3 \cdot 10^{-15}$ cm^{-2} s^{-1} sr^{-1}, for $M_N \geq 10^{10}$ GeV
- ANTARES neutrino telescope is sensitive to the signal of non-relativistic nuclearites

The ANTARES detector

- primarily dedicated to the search for high energy neutrinos

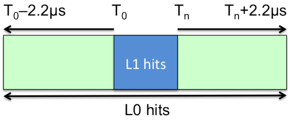


- Mediterranean Sea
- 2500 m depth
- 40 km from Toulon

- completed in May 2008
- surface area 0.1 km^2
- 885 photomultipliers
- 12 lines
- 25 storeys/line

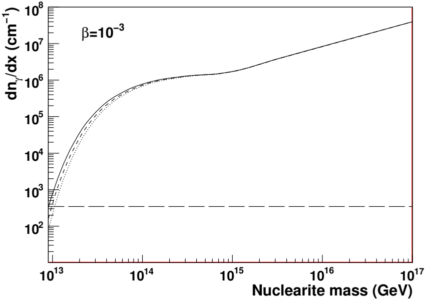
The ANTARES detector - data acquisition

- data acquisition strategy: ' all-data-to-shore' concept
  - L0 hits - basic charge and time information of the PMT signal, with amplitude above 0.3 photoelectrons - raw data
  - L1 hits - hits with large amplitude (> 3 pe) or coincidences on the same storey within 20 ns
  - raw data is organized in frames of $\sim$ 104 ms
- standard physics triggers:
  - directional trigger (3N) - 5 L1 hits correlated in space and time
  - cluster trigger (T3) - two clusters of two L1 hits in adjacent and next-to-adjacent storeys, within a 2.2 μs window
  - event information collected in an extended time window called snapshot, that typically amounts to $\sim$6 μs for atmospheric muons



Nuclearite characteristics

- slow massive particles, $\beta \sim 10^{-3}$
- interact mainly through elastic and quasi-elastic collisions
- in water they produce a thermal shock wave, emitting a large amount of black-body radiation at visible wavelengths
- nuclearite typical crossing time of the ANTARES detector $\sim$ 1ms



- flat line: # of Cherenkov photons/cm emitted by muons with $\beta \sim 1$

Analysis: Input

Blinding strategy & ANTARES data selection

- search strategy established using Monte Carlo simulations
- validation of the MC atmospheric muon simulation on a fraction of the available data
- sample of 2009 and 2010 data, containing runs ending in "0" ($\sim$ 24 days)

Monte Carlo simulations

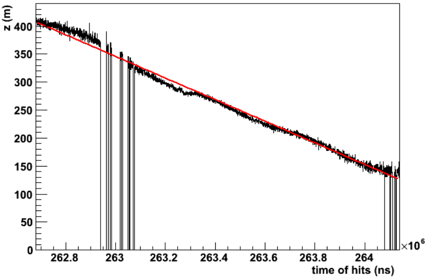
- downgoing nuclearites in the mass range 10^{14} - 10^{17} GeV
- downgoing atmospheric muons produced with MUPAGE program
- MC samples processed with 3N and T3 triggers, using background from raw data files
- most of the triggered nuclearite events result in a series of connected snapshots of variable duration, from a few μs up to few ms

Bioluminiscence background

- luminous flashes produced by living organisms, mostly bacteria
- causes sporadic peaks in the singles rates of up to several MHz for a few seconds or less, that mimic at a certain extent the nuclearite signal
- these bursts can be identified by using the event display, programs that provide the counting rate on a small time scale

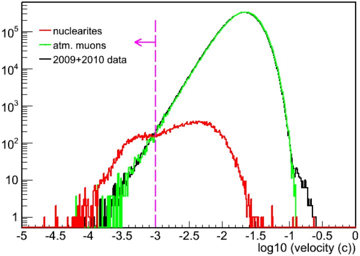
Analysis: Track reconstruction method

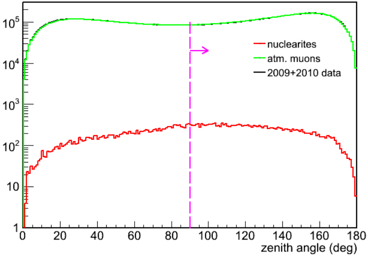
- linear fit of the charge barycenter distribution vs time of hits
- hits with q>0.3 p.e. selected and distributed in 500 ns time histograms
- $v = \sqrt{(v_x^2 + v_y^2 + v_z^2)}$, $dv = \frac{1}{v}\sqrt{(v_x \cdot dv_x)^2 + (v_y \cdot dv_y)^2 + (v_z \cdot dv_z)^2}$
- $\theta = arccos(\frac{v_z}{v})$, $d\theta = \frac{1}{\sqrt{1-(\frac{v_z}{v})^2}} \cdot \sqrt{(\frac{dv \cdot v_z}{v^2})^2 + (\frac{dv_z}{v})^2}$



Analysis: First level cuts

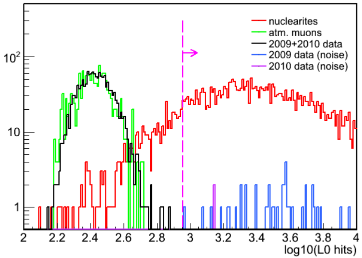
- $v < 10^{-3}c$ & $\theta > 90^\circ$
- snapshot distribution for nuclearites

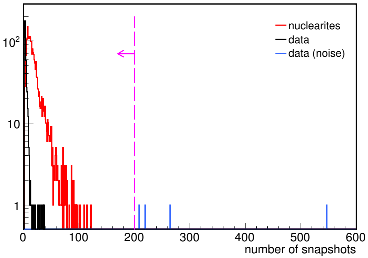




Analysis: Second level cuts

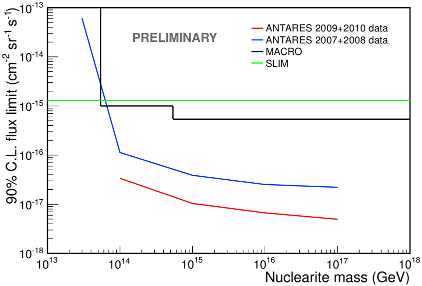
- best discriminant: distribution of logarithmic #L0 hits
- discrepancy between MC muon and data distributions
  - a few snapshots with large # L0 hits found in runs 39360, 39680, from 2009 and run 51720 from 2010 can be attributed to bioluminiscence
  - comparison between nb. of snapshots/frame in data and nb. of snapshots per nuclearite event lead to cut C2a: nb. of snapshots/frame < 200
  - a snapshot with large # L0 hits found in run 46030 is consistent with a muon bundle, applying a cut characteristic for nuclearite events, C2b: multiple snapshots within 1 ms around the selected snapshot are required, and the newly reconstructed trajectory to comply with first level cuts
- optimised cut C2c: # L0 hits > 900





ANTARES preliminary sensitivity for down-going nuclearites

- the final step in the candidate event identification is the reconstruction of the events using all snapshots around the surviving ones in a time window of $\sim$ 1 ms
- sensitivity was computed using the Feldman-Cousins prescription, for $\sim$ 300 days of data taken in 2009 and 2010
- the ANTARES upper limit for a downgoing nuclearite flux obtained from 2007 and 2008 data in a previous analysis is shown for comparison



6. Conclusions

- ANTARES detector is sensitive to strange matter particles
- these particles would emit a large amount of light in a time interval up to few ms, making the signal easily recognizable
- although bioluminescence background may mimic the nuclearite signal, the selection criteria presented here are capable of rejecting it
- the result can be further improved with more ANTARES data