1st Pan-African Astro-Particle & Collider Physics Workshop
21 - 23 March 2022

Search for nuclearites in nine years of ANTARES data

M. Bouta[1], J. Brunner[2], A. Moussa[1] , G. E. Pavalas[3], and Y. Tayalati[4]

[1] Mohammed First University, in Oujda, Morocco

[2] Centre de Physique des Particules de Marseille

[3] Institute of Space Science, Romania

[4] University Mohammed V in Rabat, Morocco

Université Mohammed V
Faculté des Sciences
Rabat

Outlines

- Introduction
- ANTARES neutrino telescope
- Nuclearites signal
- Nuclearites simulation in ANTARES
- Analysis
- Conclusion

Introduction

SQM

Hypothetical form of matter, strongly interacting

- 1971 Bodmer, first discussion of SQM
- 1984 Witten, SQM is absolutely stable
- 1984 Farhi & Jaffe, bag model and Fermi gas

A form of matter in which quarks up, down and strange are confined in the same stable structure.

SQM classification

According to their size, SQM objects are divided in three types

Strangelets : $A < 10^7$
Nuclearites : $10^7 < A < 10^{22}$
Strange stars : $A > 10^{22}$

Nuclearites Sources

Hadronization process in the early universe

Collision of binary compact stars

Type II supernovae

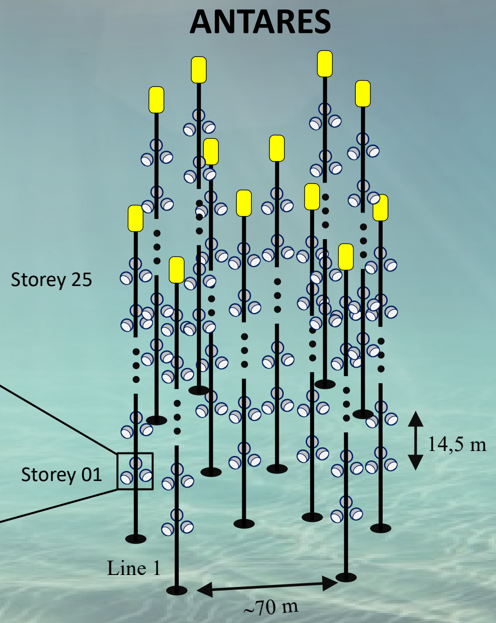
ANTARES neutrino telescope

- 12 lines, 25 storeys/line
- 3 PMTs/storey looking 45° downwards
- Deployment completed in 2008
- ~2,5 km depth in the Mediterranean sea
- 40km offshore from Toulon, France

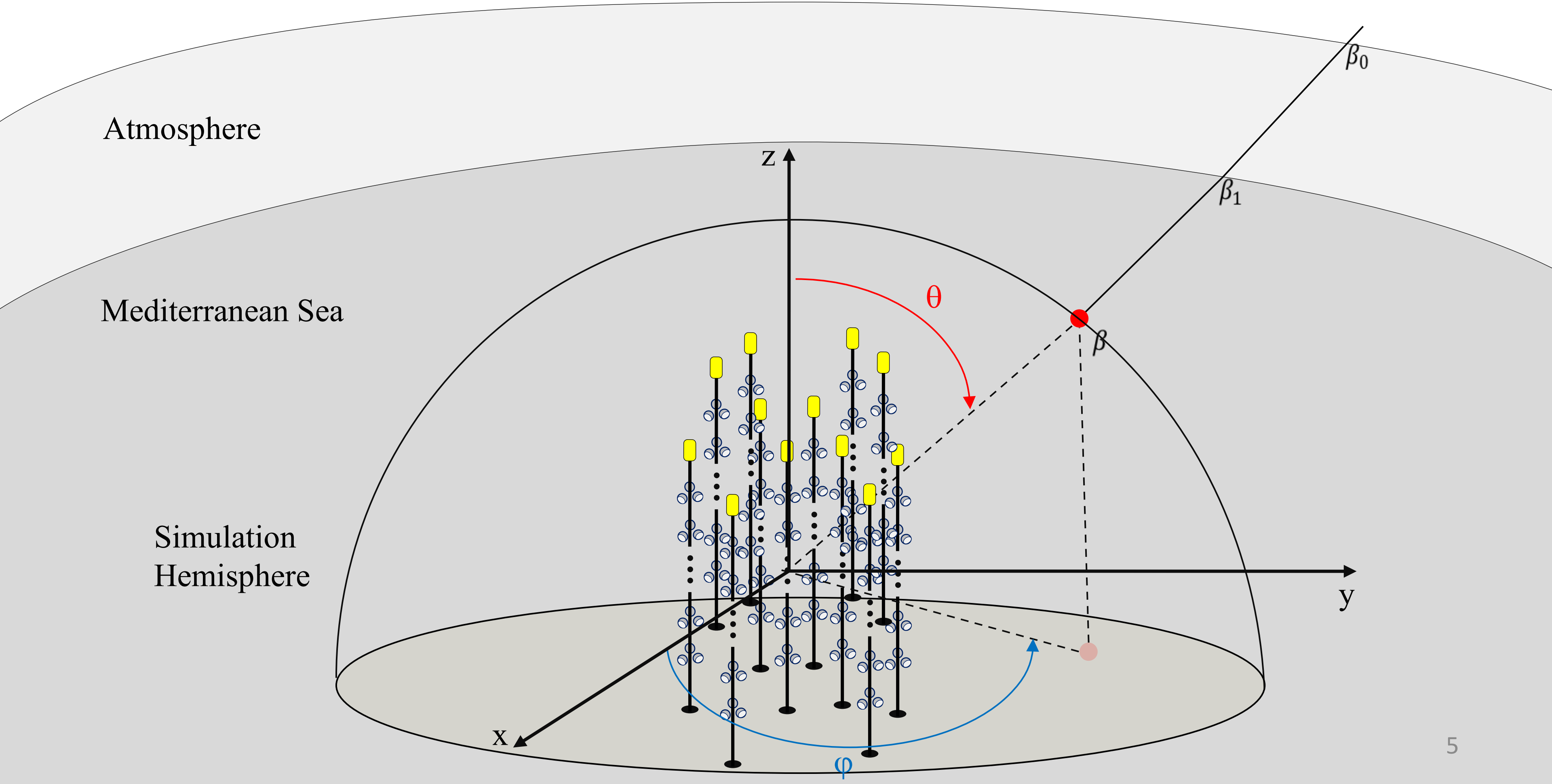
More than 12 years of data taking

Mediterranean sea

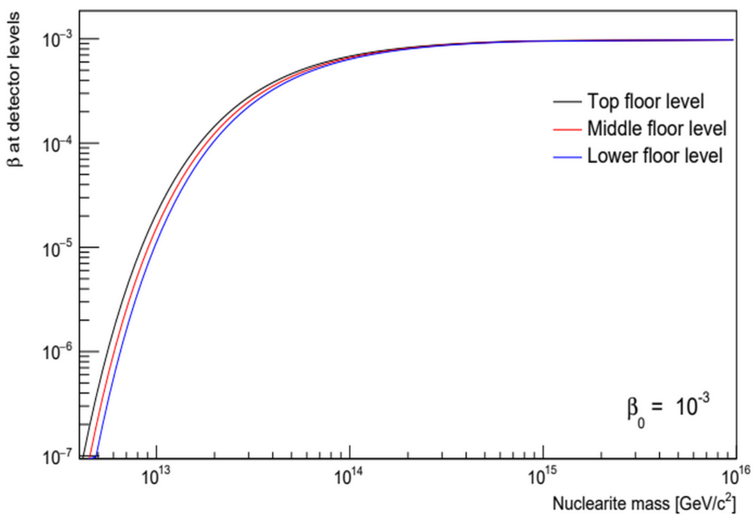
2,5 Km

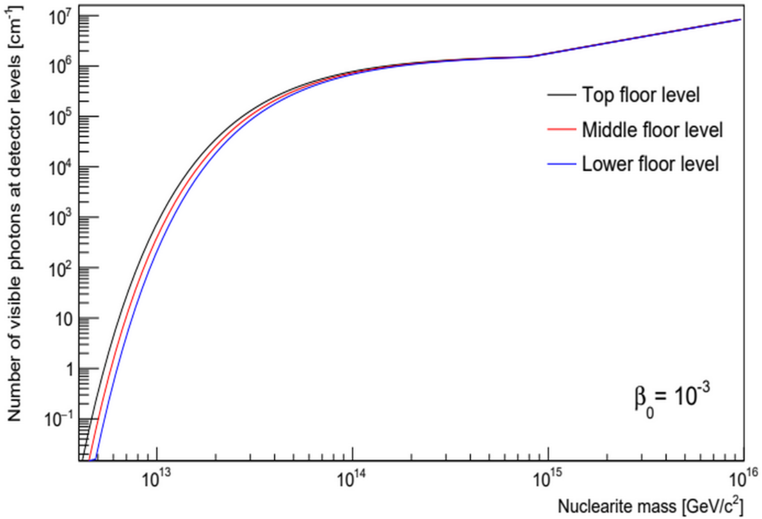


Nuclearites simulation in ANTARES



Nuclearites signal





$$\beta(L) = \beta_0 \cdot \exp\left(-\frac{\sigma}{M_N}\int_0^L \rho(x)dx\right)$$

$$\frac{dN_\gamma}{dx} = \frac{\eta}{\pi} \cdot \frac{dE/dx}{eV}$$

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

$$\sigma(cm^2) = \begin{cases} \pi \cdot 10^{-16} & \text{if} \quad M_N < 8.4 \cdot 10^{14}\ \text{GeV}/c^2 \\ \pi \cdot (\frac{3M_N}{4\pi\rho_N}) & \text{if} \quad M_N \geq 8.4 \cdot 10^{14}\ \text{GeV}/c^2 \end{cases}$$

Analysis

Blind analysis

(fraction of 10% of the experimental data, 0-ending runs from 2009-2017)

→ Define and optimize the selection criteria for nuclearites events

RbR strategy

MC simulation follow a run-by-run processing

→ Taking into account the real acquisition conditions for each run

Only events strictly triggered by one or both of the two standard muon triggers were selected :

- T3 Trigger : Occurrence of at least two L1 hits in three consecutive storeys within 100ns or 200ns.
- 3D Trigger : 5 L1 hits within 2.2 μs.

L1 hit : cluster of hits that occur within 20 ns in different PMTs of the same storey, or a single hit with a charge greater than 3 photo electrons.

Analysis - Run selection and cuts flow

- period of analysis : 2009-2017
- Using RbR v4

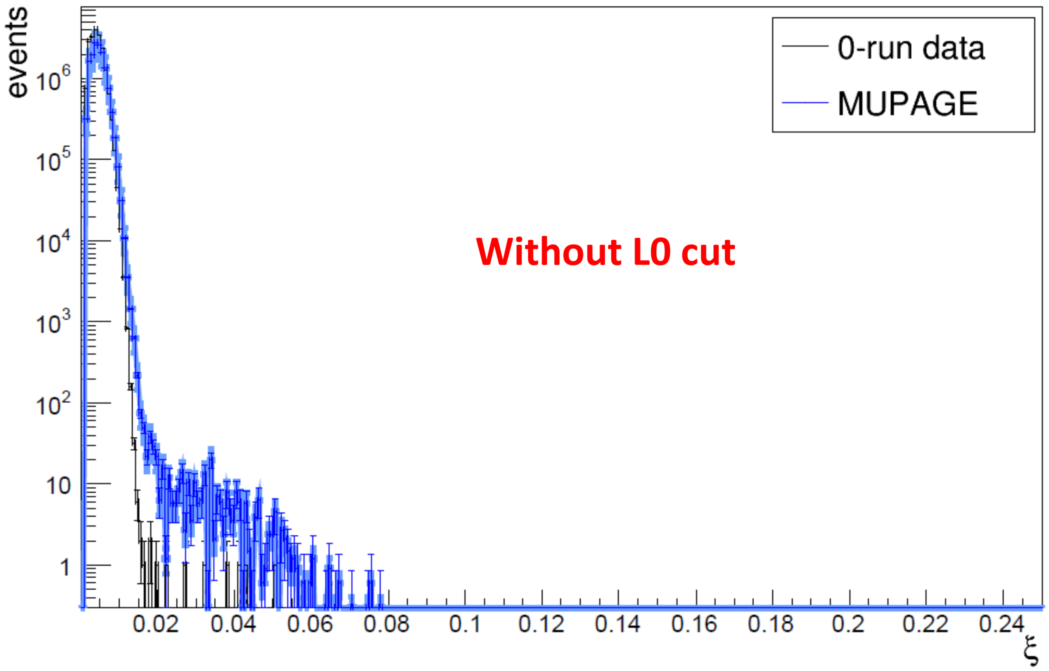
- Silver runs
  - QB >= 3 (QualityBiolum = 4 for 2013 and up)
  - No SCAN
  - No sparking runs

❑ For Nuclearites :
- Masses : 4×10^{13} threshold detection mass, 10^{14}, 10^{15} and 10^{16} GeV/c^2 with $\beta_0 = 10^{-3}$ at the top of the atmosphere
- Generating 100 events for each run

❑ Muons :
- MUPAGE files v4

Trigger Condition : T3 or 3D or (T3 and 3D))

Analysis - Data & MC

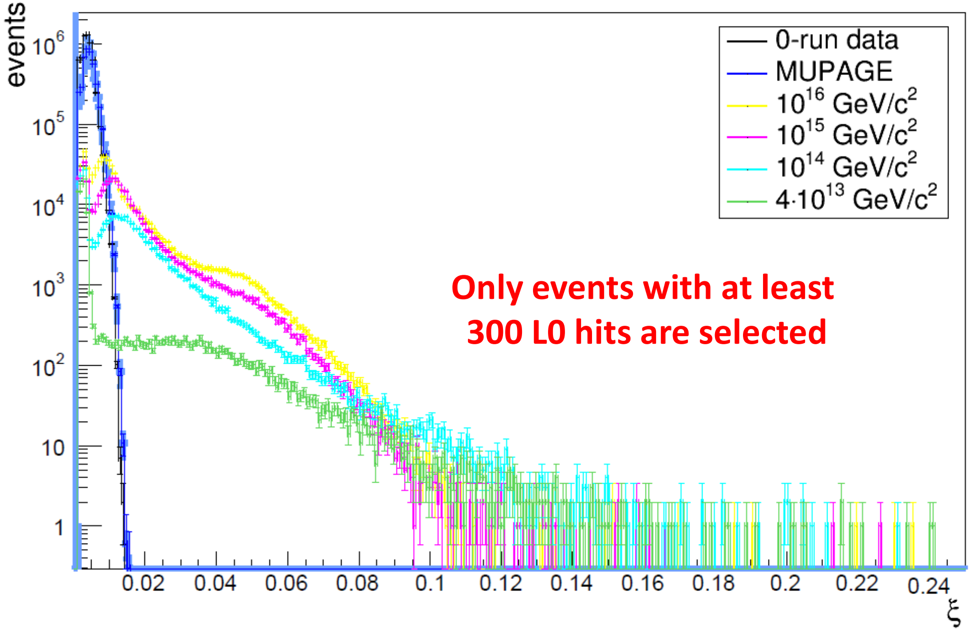


ξ = log10(nhits3)/nfloor distributions, it refers to the luminous weight of the event in the detector.

Where, for a given event, **nhits3** represents the number of hits with charge >= 3 p.e. and **nfloor** the number of storeys that recorded the hits.

Analysis - Discrimination variables

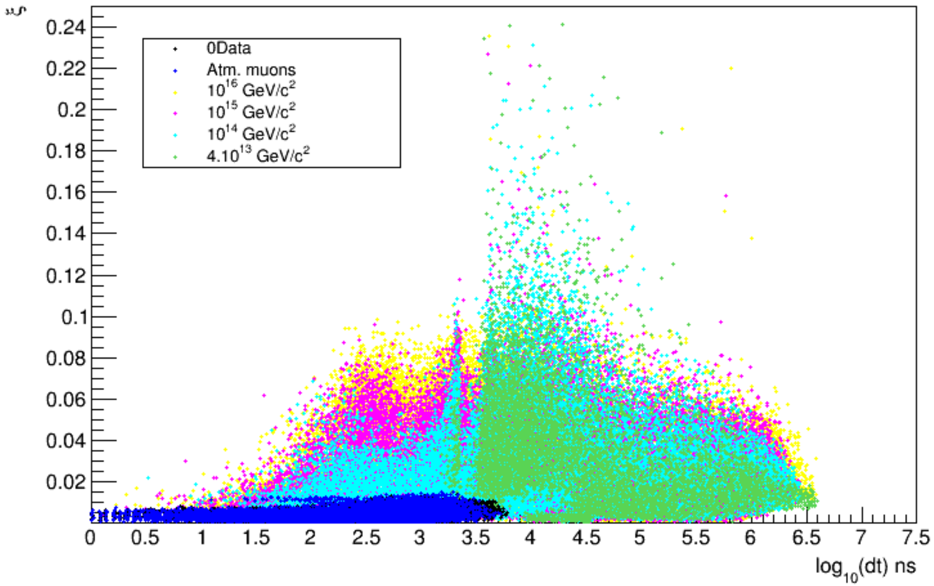
With L0 cut



Only events with at least 300 L0 hits are selected

By applying a cut on the number of L0 hits, we manage to clean the distributions and separate our signal.
ξ Parameter helps in distinguishing our signal from other forms of backgrounds.

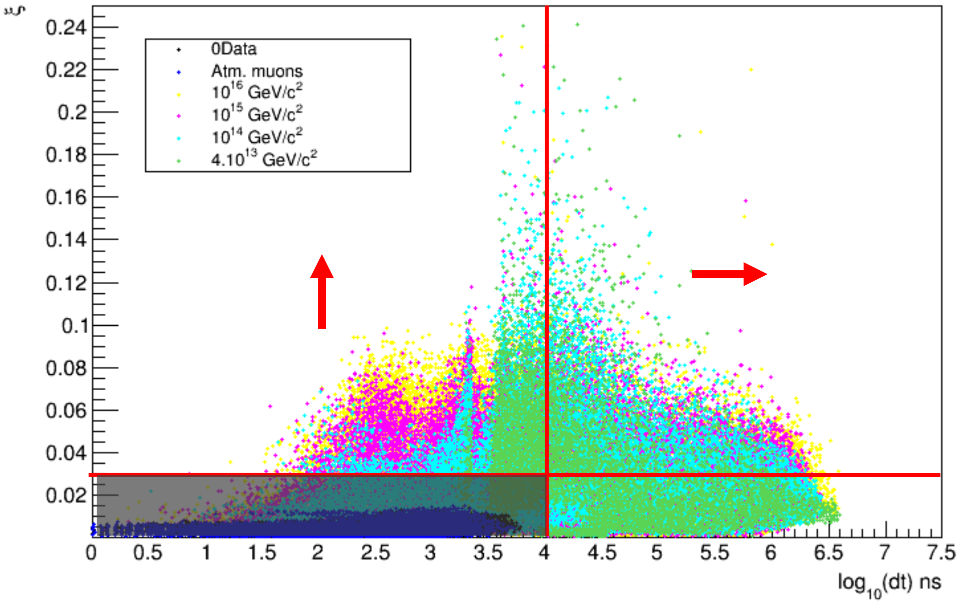
Analysis - Isolation



2D plot showing the $\log_{10}$(nhits3)/nfloors versus $\log_{10}$(dt).

Nuclearites are well isolated in a wide region, either for the snapshot duration (dt) or for ξ

Analysis - Isolation



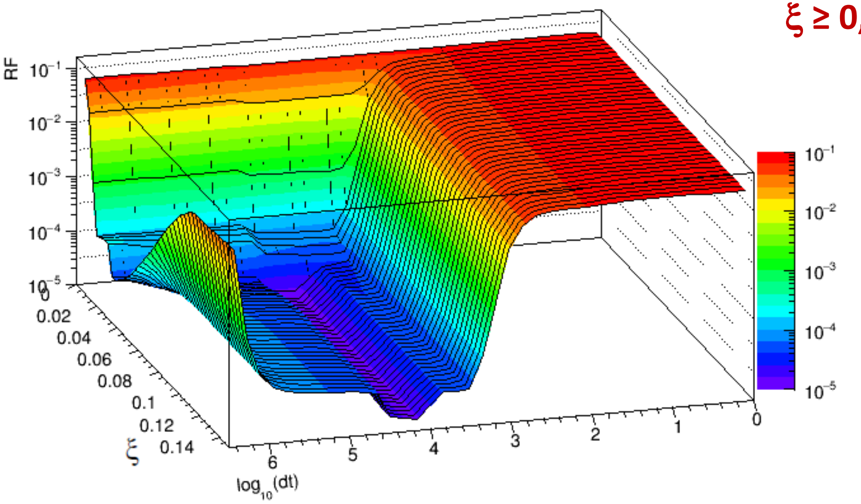
2D plot showing the $\log_{10}$(nhits3)/nfloors versus $\log_{10}$(dt).

By applying the optimal cuts on these two variables, we can easily separate nuclearites from the background

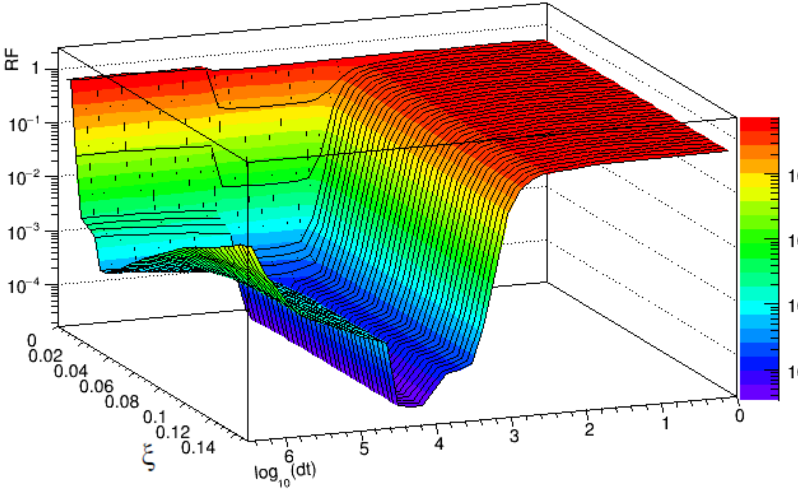
Analysis - Rejection Factor

The Model Rejection Factor has been used to look for the best cuts on dt and ξ.

L0 ≥ 300 - quality cut
Log10(dt) ≥ 4,125
ξ ≥ 0,029

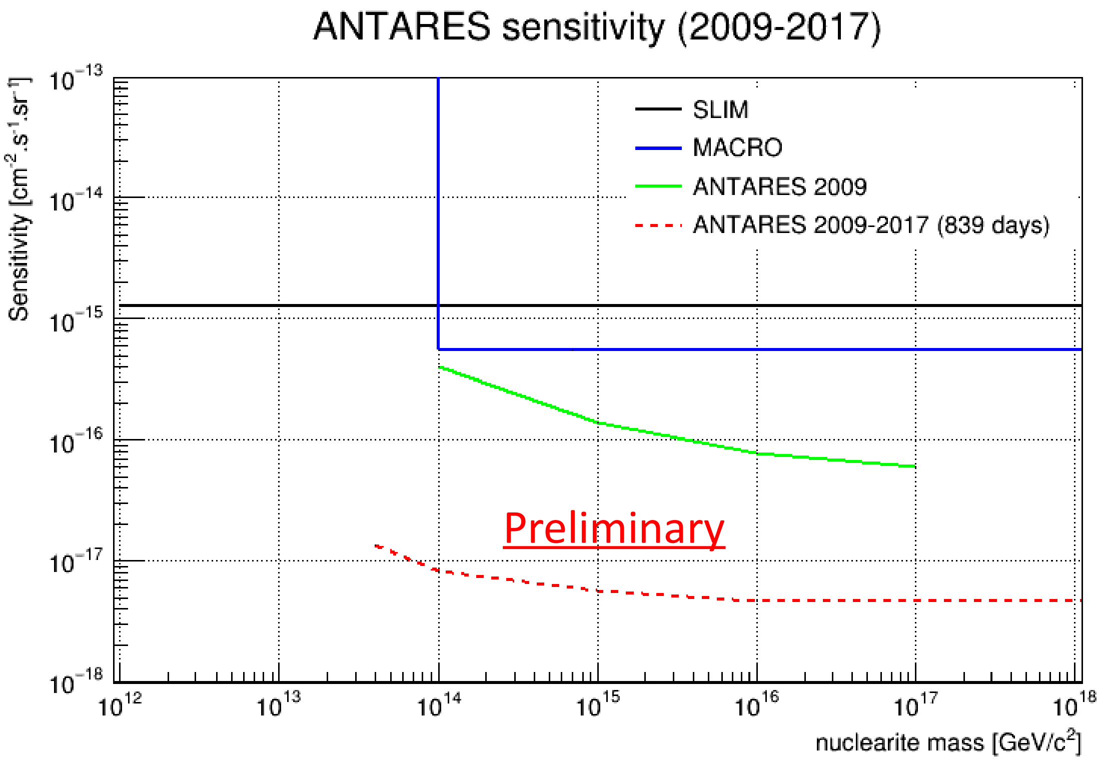


Rejection factor for mass 10^{16} GeV/c^2



Rejection factor for mass 4×10^{13} GeV/c^2

Analysis - Sensitivity



Sensitivity of ANTARES to nuclearites using 839 days of data taken in the period 2009-2017.

The first results of the sensitivity are improving the limit on the flux reported by SLIM and MACRO.

Conclusion

- The signal of nuclearites in ANTARES were simulated and it reflects the nuclearite behavior in the detector.
- Our discrimination variables are helping in isolating nuclearites signal.
- The preliminary results of sensitivity are showing a significant improvement.

We improved the limit on the flux reported by SLIM and MACRO by more than one order of magnitude, and also, the sensitivity obtained by ANTARES during period 2009.

Thank You For Your Attention