# Search for relativistic Magnetic Monopoles with ANTARES

**J. Boumaaza [1]**, J. Brunner [2], A. Moussa [3], Y. Tayalati [1]

1 Mohammed V University, Rabat, Morocco
2 Centre de Physique des Particules de Marseille
3 Mohammed I University, Oujda, Morocco

**On behalf of the Antares collaboration**

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# *Outlines*

- Introduction
- Antares Neutrino Telescope
- Magnetic Monopole analysis
- Conclusion

# ***Introduction***: *Magnetic Monopoles*

- Particles with one magnetic pole : the magnetic counterparts of electric charges.

- MM discovery would symmetrise Maxwell's equations.

- Quantization of the electric charge (Dirac in 1931).

- Grand Unification Theories : MM would be created after the Big Bang (during the phase transition of symmetry breaking).

- There are also MM with lower masses resulting from Electroweak transition.

- The mass of GUT MM could exceed $10^{14}$ GeV/$c^2$.

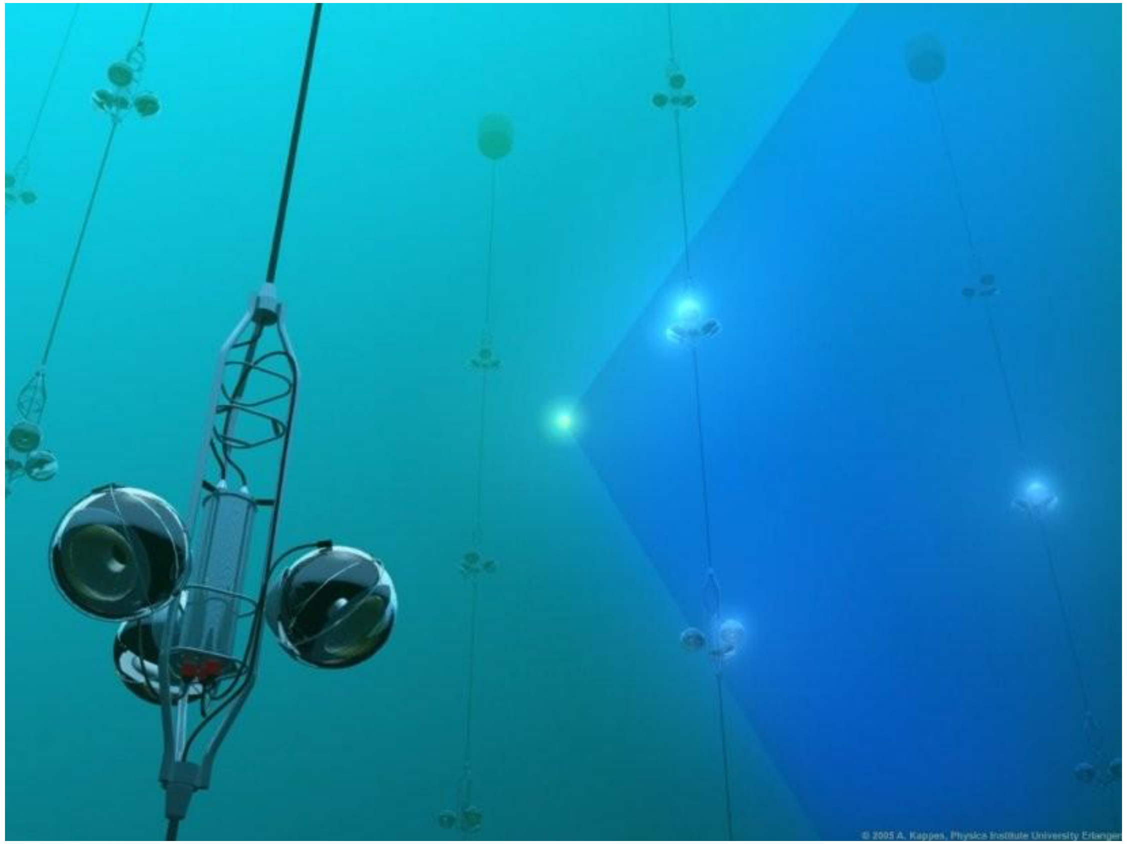
- The rarity of GUT MM is a motivation to the scenario of inflation.

- MM would only be expected as up going events in neutrino telescopes if their mass :

$$M \lesssim 10^{14}\ \mathrm{GeV}/c^2$$

# Antares Neutrino Telescope

- Antares :Astronomy with a Neutrino Telescope and Abyss environmental RESearch:
- Cherenkov based neutrino telescope
- 2475 m below the surface of the Mediterranean Sea
- 40km offshore from Toulon (France)
- 12 detection lines of about 350m each
- Each line has 25 floors with 3 optical modules sensitive to the wavelength region λ~[300,600]nm,



# Magnetic Monopole analysis

- The simulations includes magnetic monopoles, atmospheric muons and neutrinos (latest MC production).

- The simulation based on Kasama, Yang and Goldhaber (KYG) model of cross section (***Y. Kazama et al. Scattering of a Dirac particle with charge Ze by a fixed magnetic monopole, Phys. Rev. D 15 (1977) 2287***), of magnetic monopoles has been performed for β =v/c = 1 and for β variable.

- All productions are based on RBR V4 simulation which is a MonteCarlo simulation that follows a run-by-run processing taking into account the real acquisition conditions for each run including the degradation of the optical modules efficiency.

- Magnetic Monopoles were simulated in the range of β =v/c [0.57 , 0.995] split into 10 equaly distant intervals.

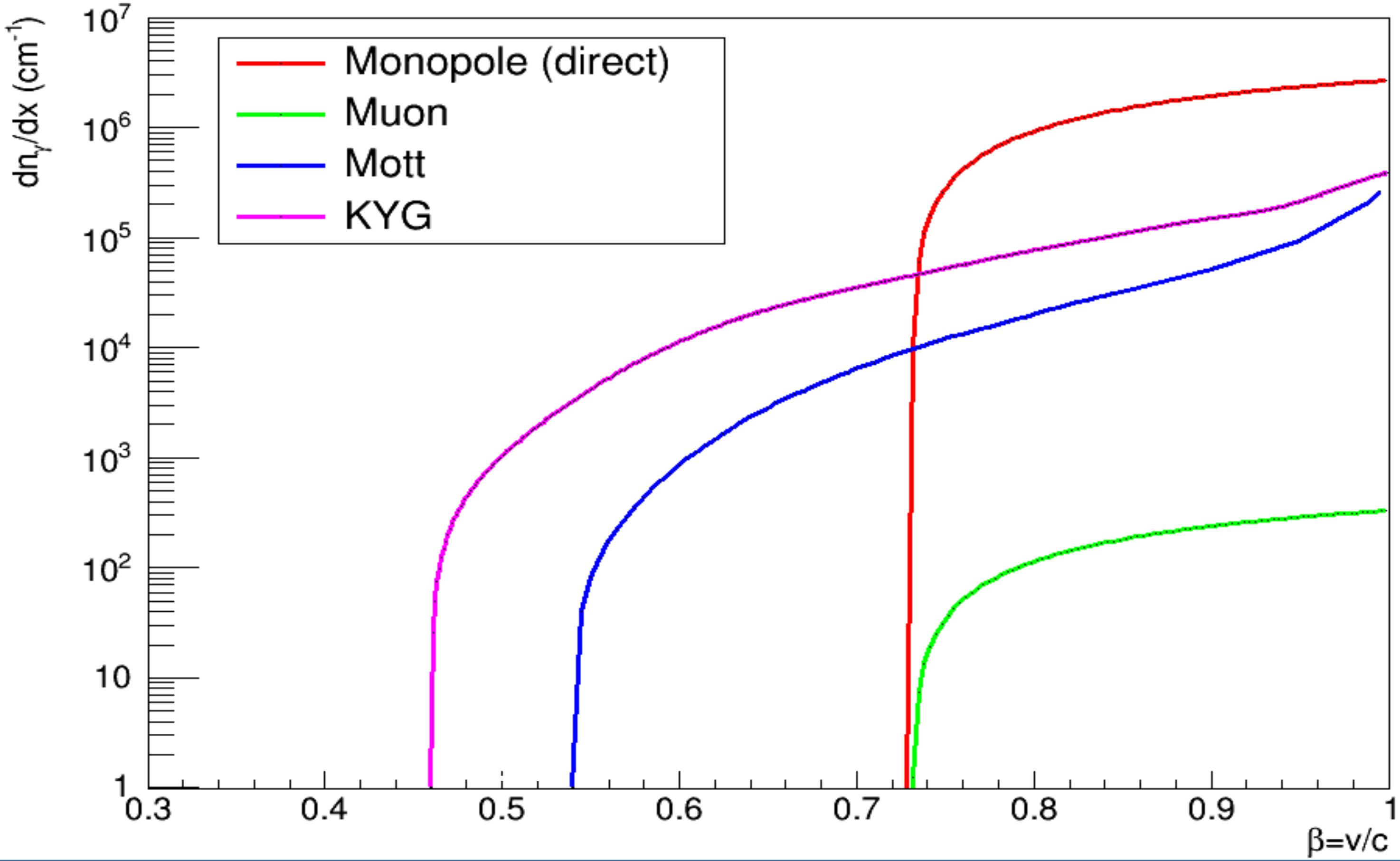
- Data considered are collected by the ANTARES telescope between January 2008 to December 2017.

# *Magnetic Monopole simulation*

- The MM simulation relies on the package **Simon** provided by the Antares collaboration.
- It is based on the ***genneu*** and ***geasim*** Monte Carlo generators used to simulate muons passage in the detector.
- The main programs in the package used for MMs simulation are named ***Genmon*** and ***Geamon***.
- 500 events were generated per run simulated as tracks.

# Light yield

- Number of Cherenkov photons emitted per cm in the sea water

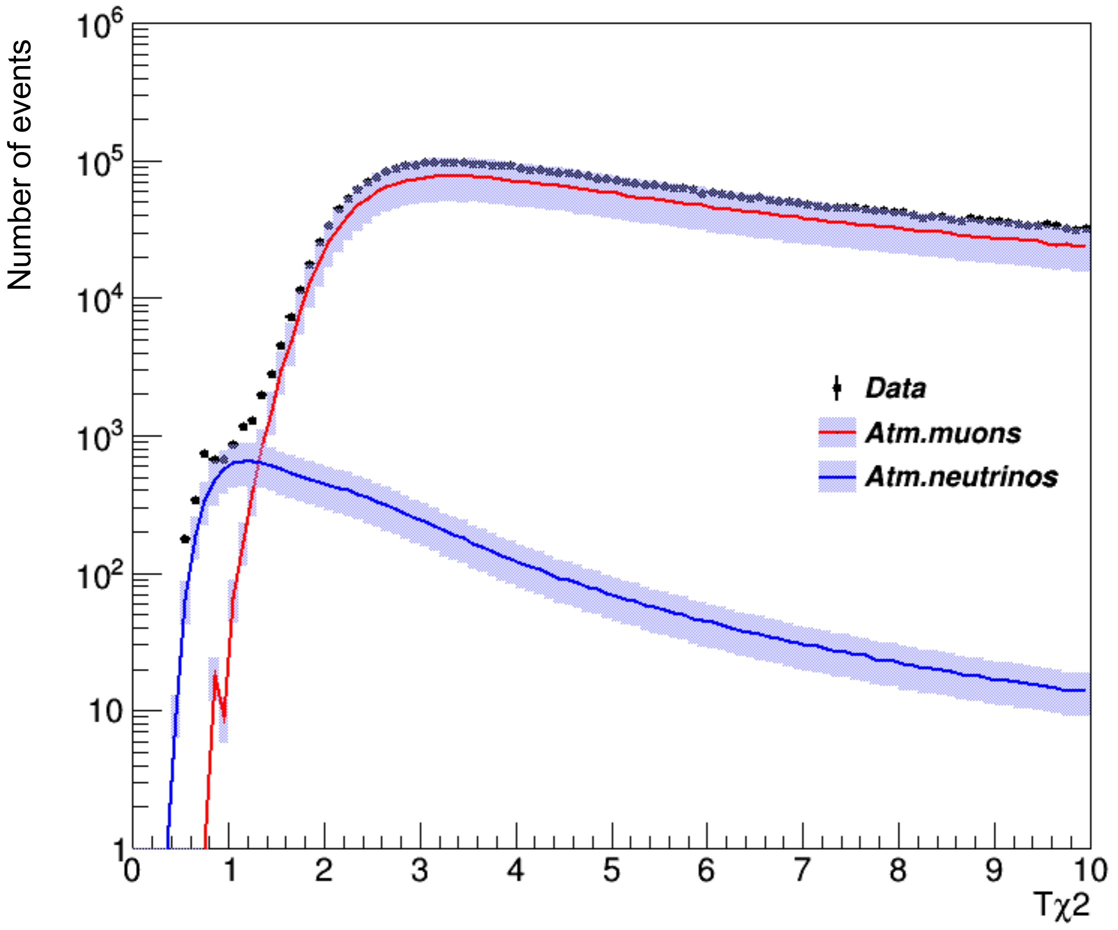



The new simulation of MM relies on KYG model for the emission of delta-rays giving a higher amount of light with respect to the Mott model of cross section

# *Part 1 : High velocity ranges*

- **β reconstructed = 1**
- **Monopole simulated β : in the range [0.817 , 0.995] split into 4 intervals**

# Agreement plots




***Initial cuts :***

***nlines ≥ 2 & zenith ≤ 90 & tχ2 < 10***

**In the first cut we require only events reconstructed with at least 2 lines of the detector**

**The second one is applied on the Zenith angle, it must be less than 90° and it aims to select only upgoing events**

**The last primary cut chosen is that the quality of reconstructed tracks is inferior to 10,**

**tχ2 : Quality of reconstructed tracks**

We are considering only 10% of the Data taken by the telescope in the agreement plots

# Other plots

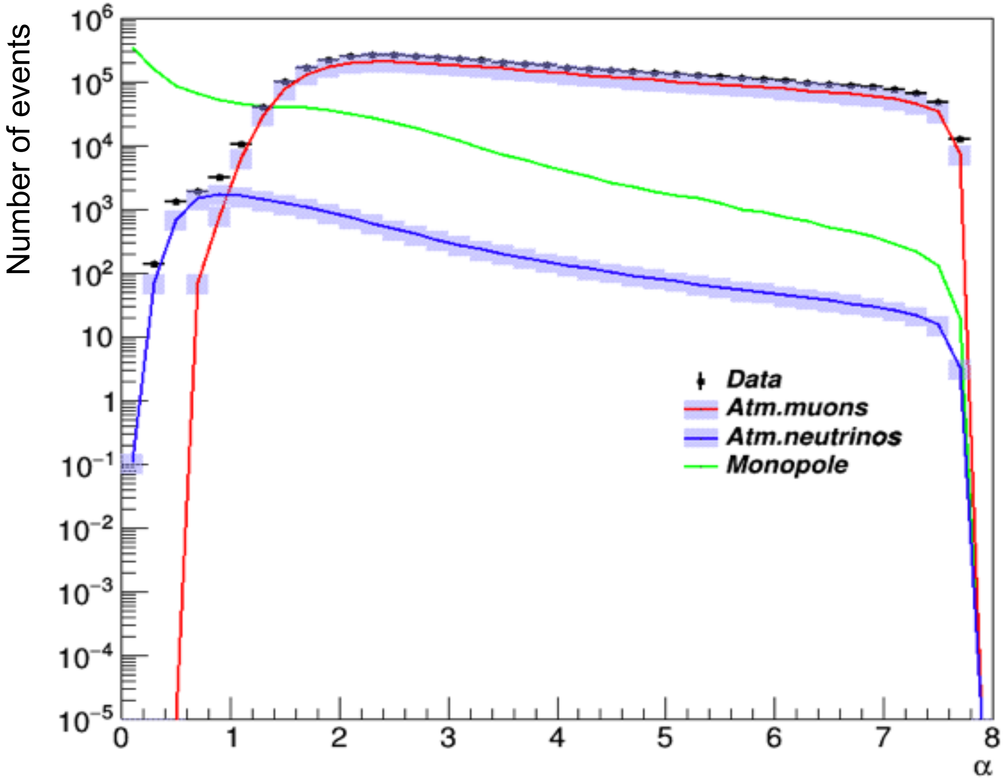
**Initial cuts :**

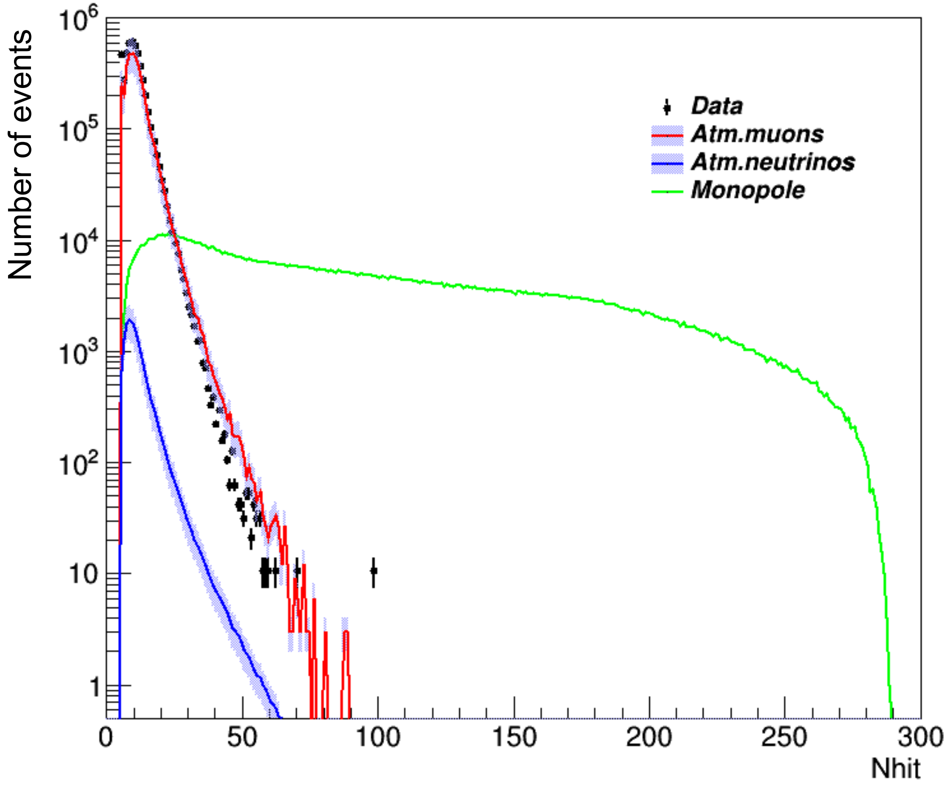
**nlines ≥ 2 & zenith ≤ 90 & tχ2 < 10**

**α = tχ2 / (1.3+(0.04×(Nhit-5)) 2 )**

**Nhit : Number of floors with the chosen track hits**

**Reconstruction quality taking into account the brightness of the event**

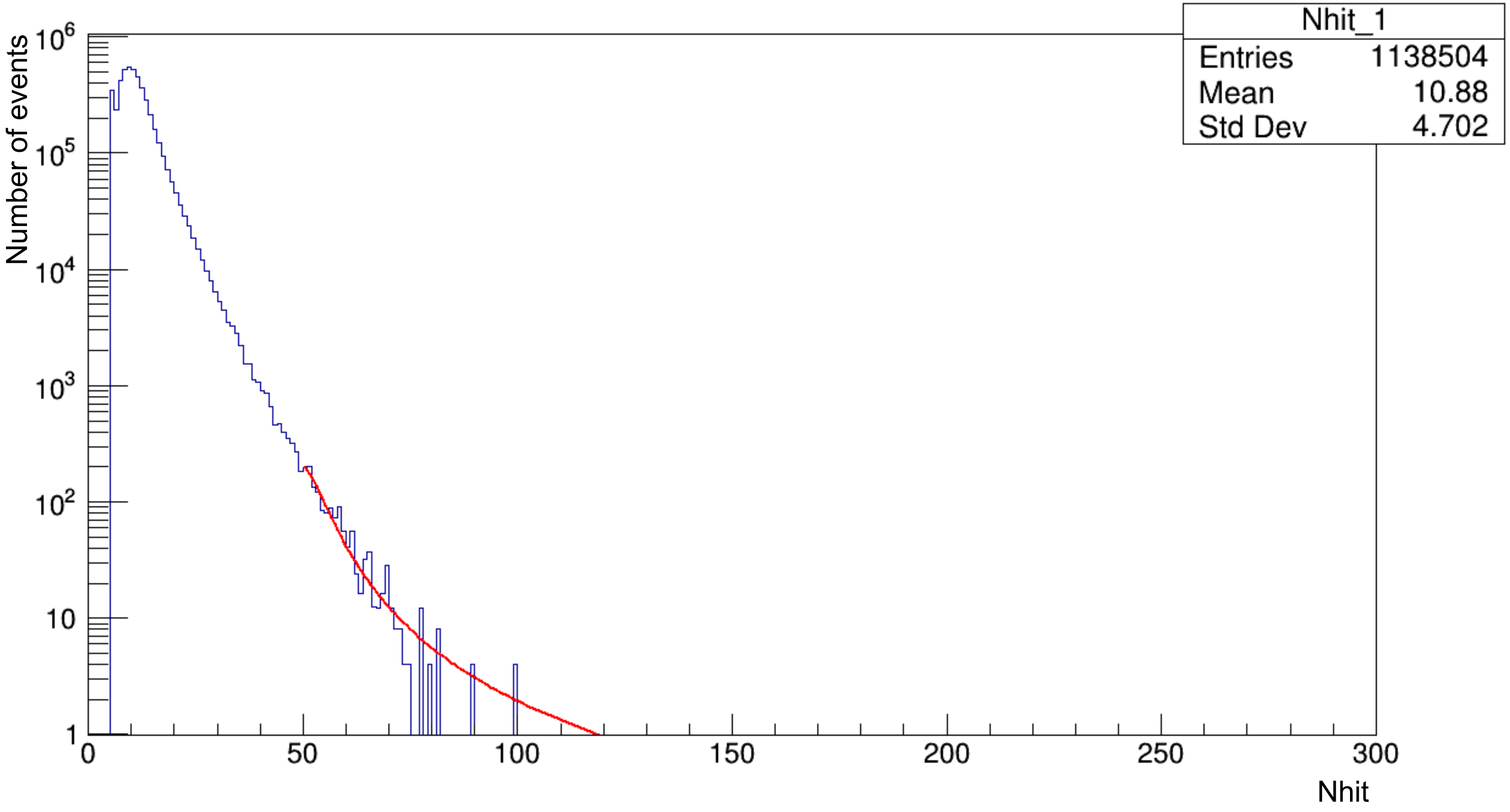



β=[0.8615 , 0.906]

# Extrapolation of muon distribution

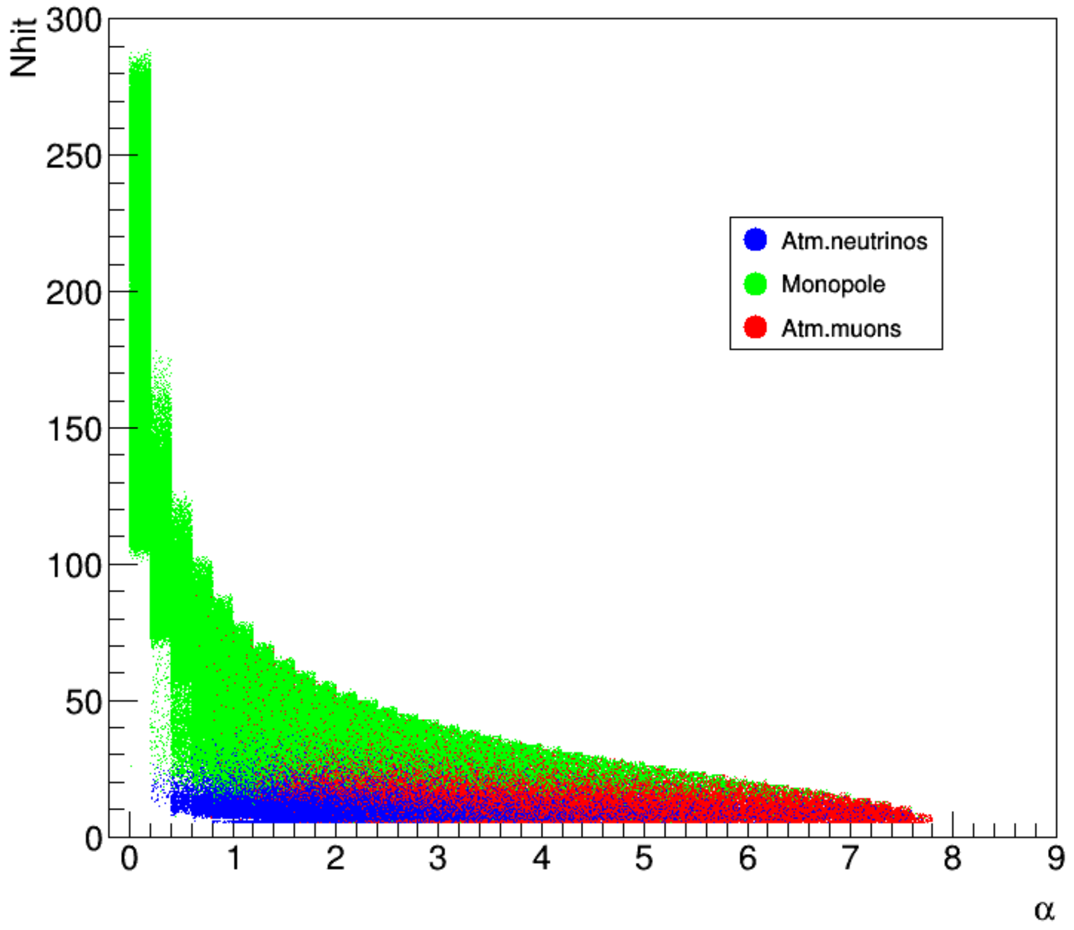
In order to compensate for the lack of statistics in the Nhit distribution for muons an extrapolation has been made in the region of signal




A Landau type function has been used

# *Alpha_Nhit plots*

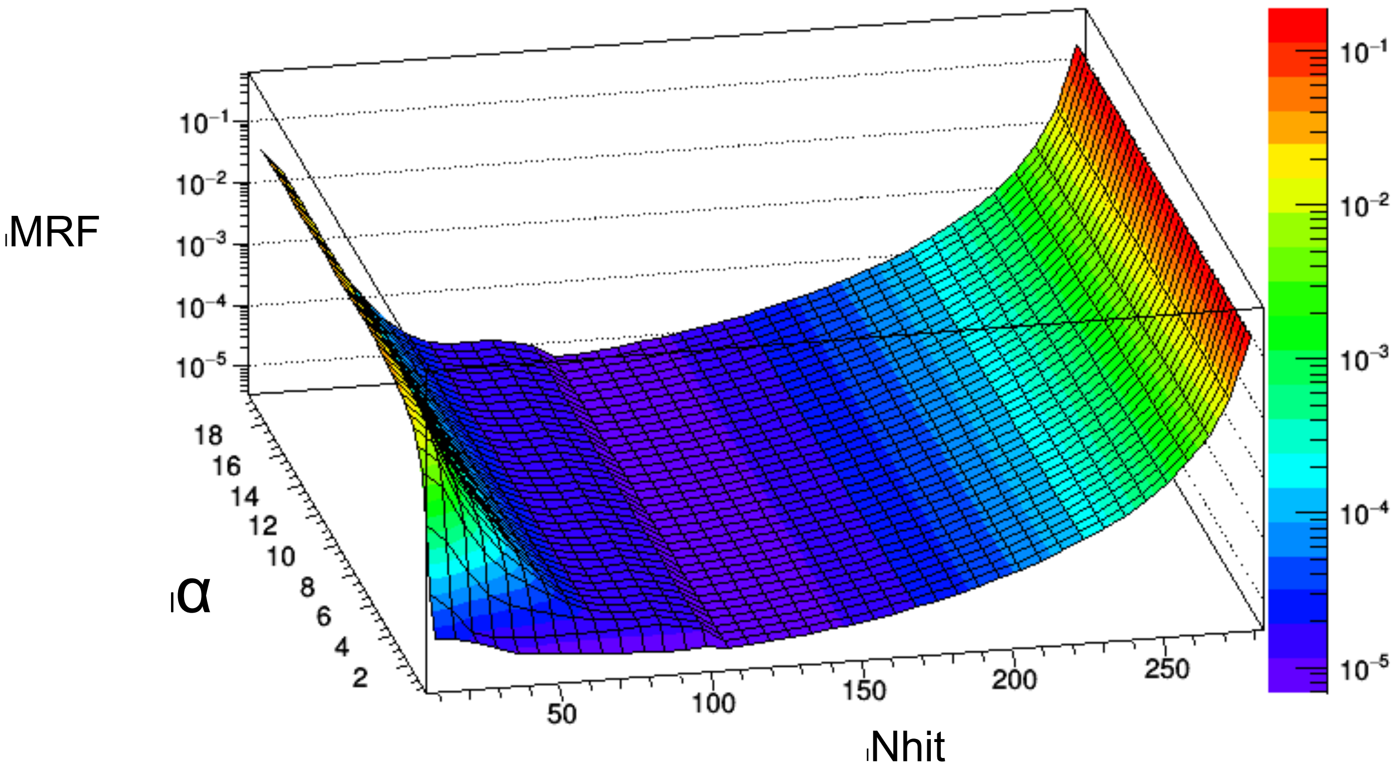
- A couple of cuts on Nhit and Alpha isolates the signal from the background




β=[0.8615 , 0.906]

# *MRF optimization*

➢ To obtain the best sensitivity we optimize the Model Rejection Factor for each velocity interval, by playing on α and Nhit cuts.




β = [0.8615 , 0.906]

# Sensitivity results

➢ The following table presents the optimized cuts, the expected number of background events remaining after cuts and the sensitivity obtained in each β range at high velocities

| β interval | α cut | Nhit cut | Background events remaining | Sensitivity (cm-2.sr-1.s-1) | Events remaining after unblinding |
|---|---|---|---|---|---|
| **[0.9505 , 0.995]** | **< 0.3** | **≥ 105** | **0.18** | **7.3e-19** | **0** |
| **[0.906 , 0.9505]** | **< 0.3** | **≥ 105** | **0.18** | **8.8e-19** | **0** |
| **[0.8615 , 0.906]** | **< 0.3** | **≥ 105** | **0.18** | **1.2e-18** | **0** |
| **[0.817 , 0.8615]** | **< 0.6** | **≥ 102** | **0.3** | **2.9e-18** | **0** |

After unblinding, no event survived the optimal cuts for the studied region of β.

# *Part 2 : “low” velocity ranges*

- **β reconstructed variable**
- **Monopole simulated β : in the range [0.57 , 0.817] split into 6 intervals**

# *“low” velocity ranges*

- The same analysis was followed with a change in the expression of α :

$$\alpha = t\chi 2 / (1.3+(0.04\times(Nhit-6))^2 )$$

- As β is variable in this region, it was used as primary cut to further isolate the signal from the background, knowing that the velocity of atmospheric muons and neutrinos is the velocity of light.

- An additional cut has been included in the optimization in this region of low velocities: zenith(beta=1)<90°, where "zenith" is calculated from the modified BBfit with free beta. This eliminates additional spurious atm. muon background. By construction this additional cut has no impact on the high velocity analysis.

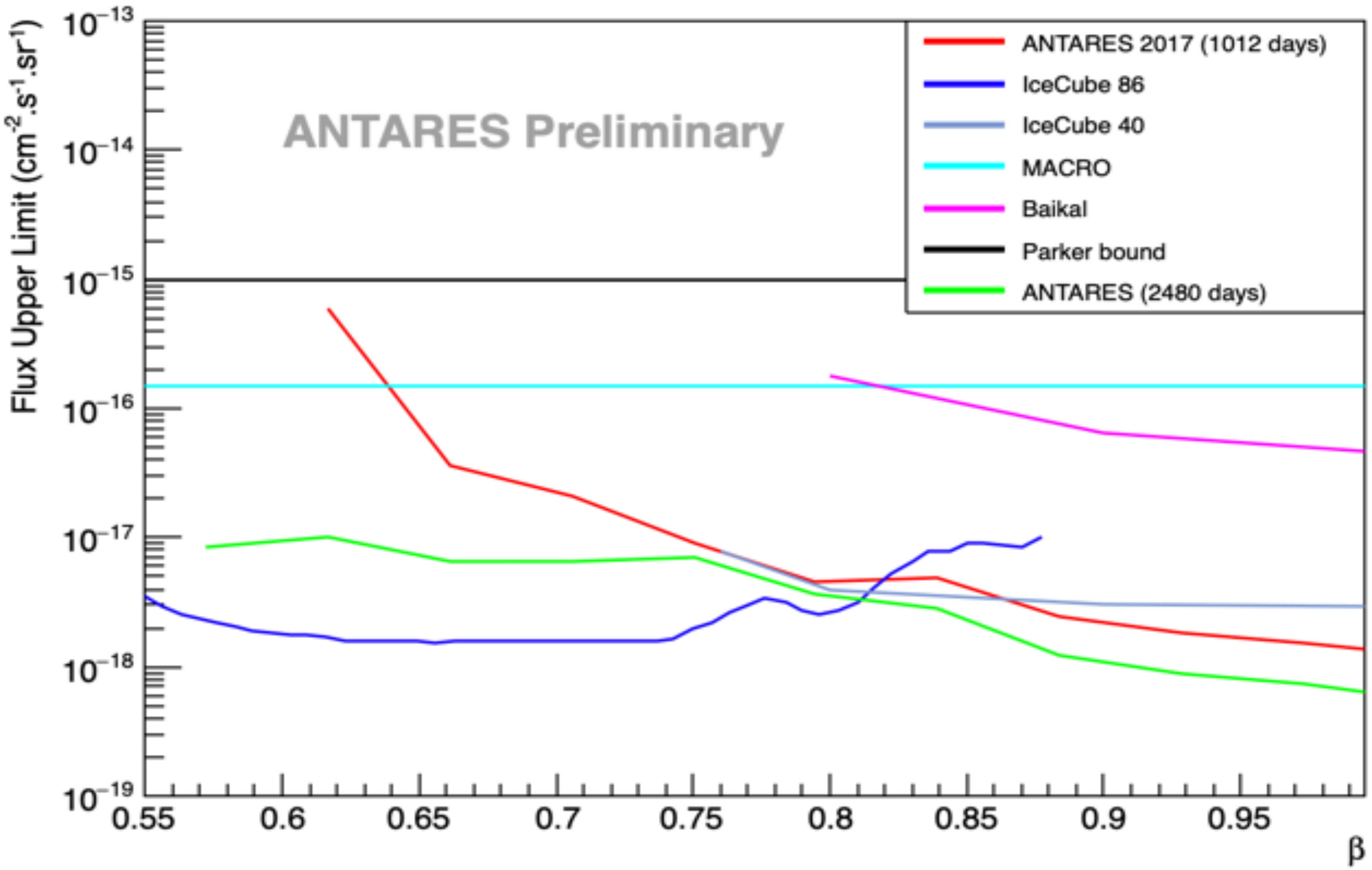
# *Sensitivity results*

➢ The following table presents the optimized cuts, the expected number of background events remaining after cuts and the sensitivity obtained in each β range at low velocities

| β interval | α cut | Nhit cut | Background events remaining | Sensitivity (cm-2.sr-1.s-1) | Events remaining after unblinding |
|---|---|---|---|---|---|
| **[0.7725, 0.817]** | **< 2.6** | **≥ 86** | **7.82E-04** | **3.66E-18** | **0** |
| **[0.728, 0.7725]** | **< 3.6** | **≥ 85** | **4.88E-04** | **6.98E-18** | **0** |
| **[0.6835, 0.728]** | **< 5.2** | **≥ 68** | **1.54E-04** | **6.64E-18** | **0** |
| **[0.639, 0.6835]** | **< 8.8** | **≥ 51** | **2.45E-04** | **6.53E-18** | **0** |
| **[0.5945, 0.639]** | **< 10.8** | **≥ 45** | **2.12E-05** | **1.02E-17** | **0** |
| **[0.55, 0.5945]** | **<12.4** | **≥ 41** | **5.34E-05** | **8.42E-18** | **0** |

After unblinding, no event survived the optimal cuts for the region of β.

# *Preliminary Antares upper limit for MMs*



# Conclusion

- The limit for the Magnetic Monopole found in this analysis presents a good improvement compared with the last limit found by the Antares Detector.

- The improvement in the Upper limit on the flux for low velocities, with respect to ANTARES previous result, is mainly due to the extra cut applied in his region, which led to a better background rejection.