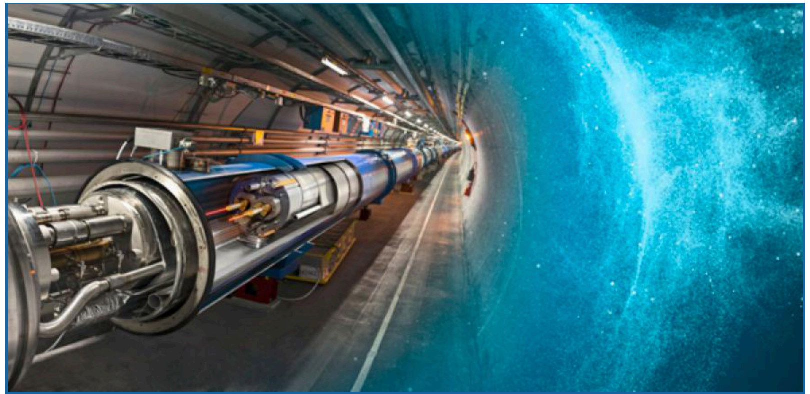
# Search for Magnetic Monopoles with ten years of ANTARES data

**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**



First Pan-African Astro-Particle and Collider Physics Workshop

# *Outline*

- 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 symmetrize 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/$c^2$.

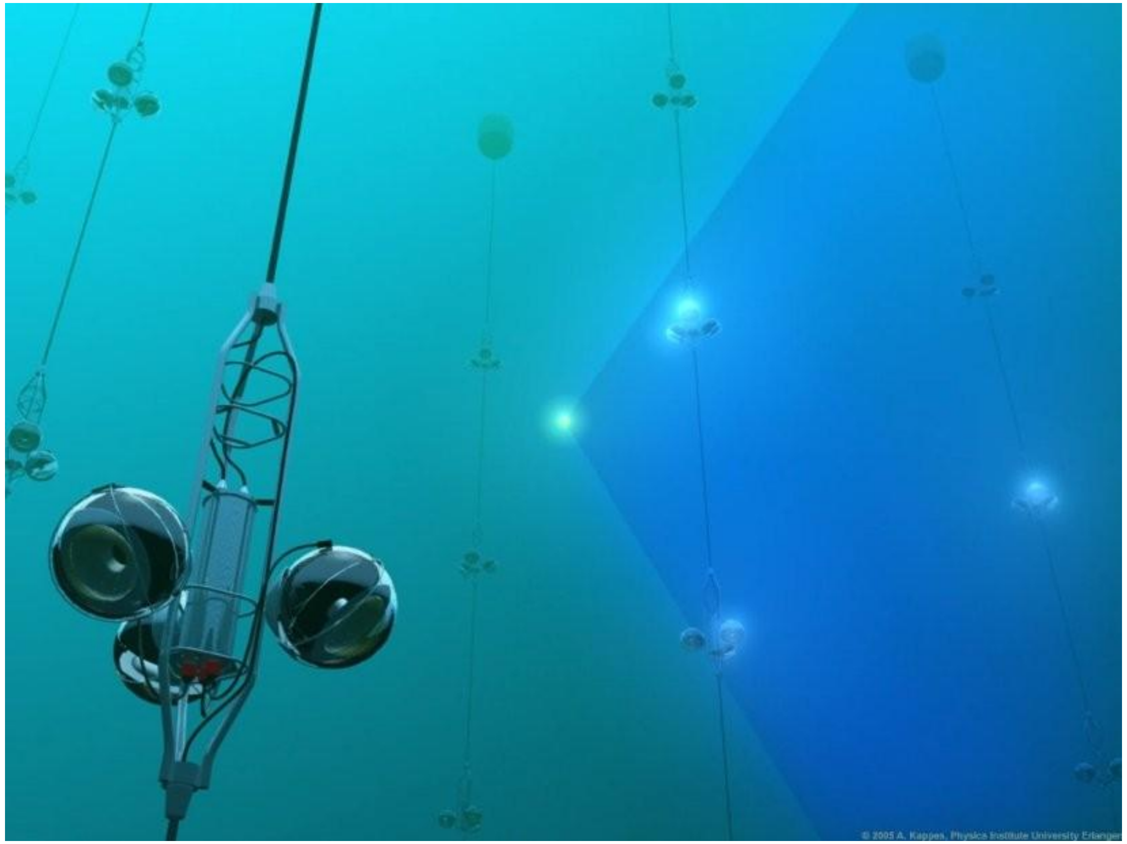
- The rarity of GUT MM is a motivation to the scenario of inflation.

- MM would only be expected as upgoing 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 range $\lambda \sim [300,600]$nm



# Magnetic Monopole analysis

- The simulations include 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 $\beta = v/c = 1$ and for $\beta$ variable.

- All productions are based on RBR V4 simulation which is a Monte Carlo 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 $\beta = v/c$ [0.55 , 0.995] split into 10 equally distant intervals.

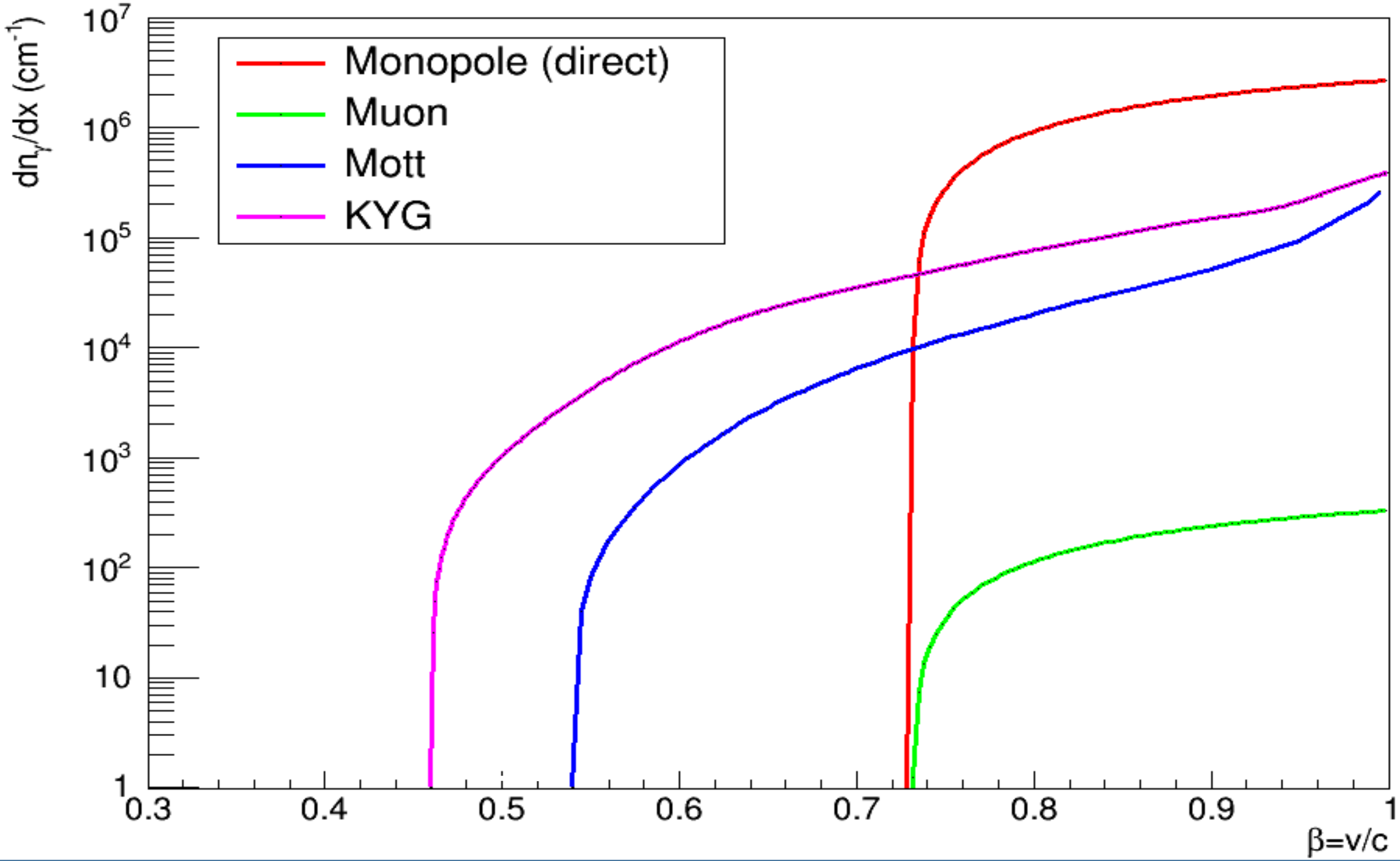
- Data considered are collected by the ANTARES telescope between January 2008 to December 2017.

# *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 muon passage in the detector.
- The main programs in the package used for MM simulation are named ***Genmon*** and ***Geamon***.
- 500 events were generated per run, around 16000 runs per β range were considered in this analysis.

# *Light yield*

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

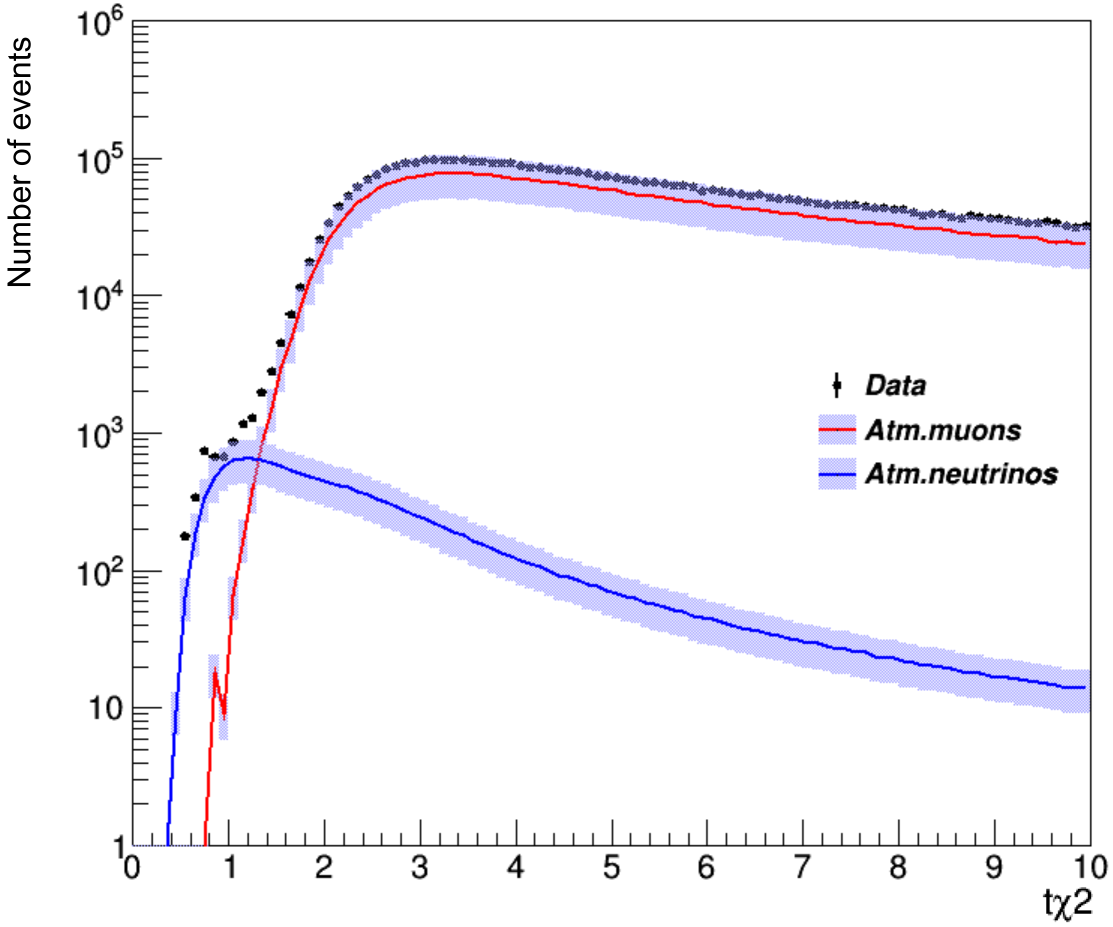



The new simulation of MM relies on the KYG model for the emission of delta-rays giving a higher amount of light with respect to the Mott model of cross section (***Ahlen, S.P., 1976. Monopole track characteristics in plastic detectors. Phys. Rev. D 14, 2935–2940***)

# *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 Data/MC comparison plots for atmospheric events.

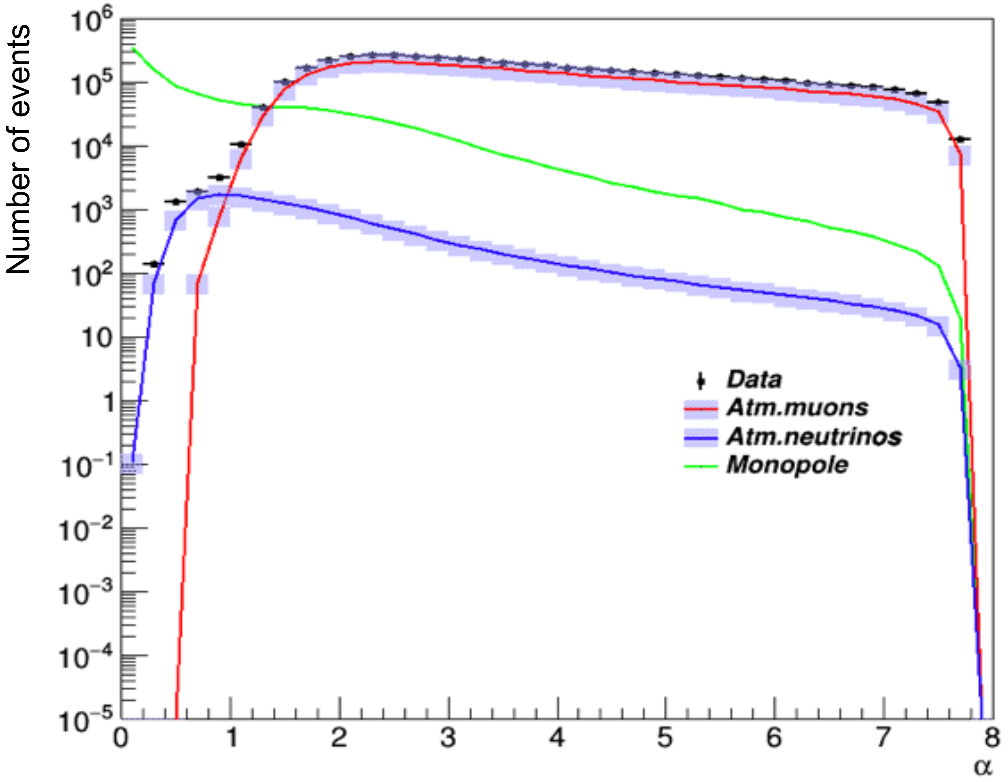
# *Other plots*

***Initial cuts :***

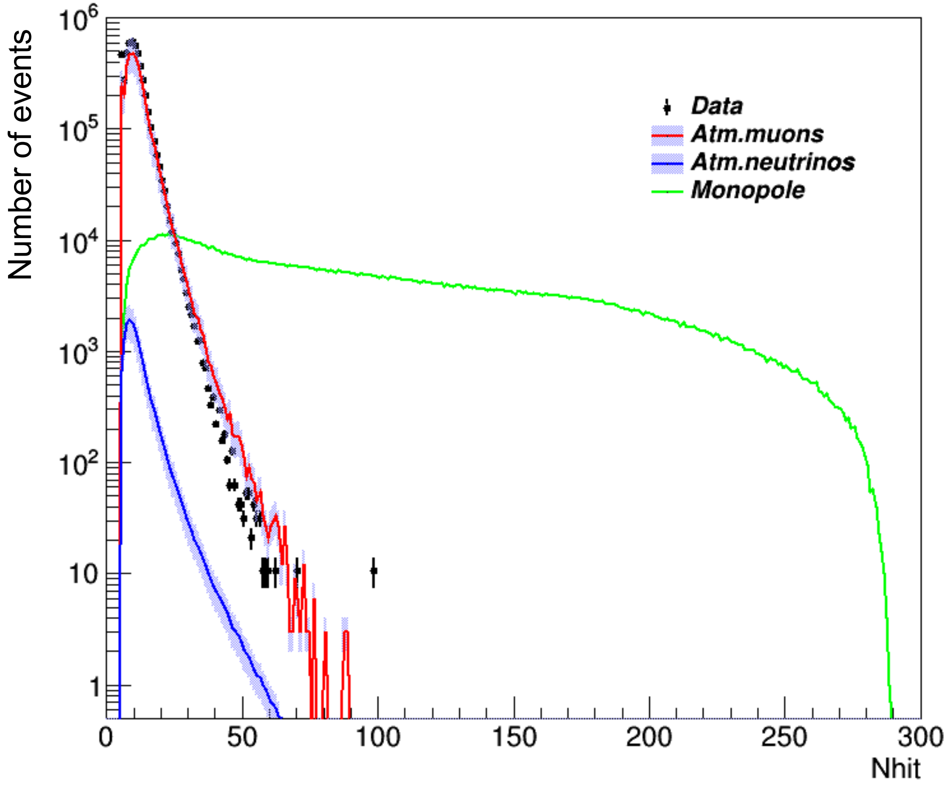
***nlines ≥ 2 & zenith ≤ 90 & tχ2 < 10***

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

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



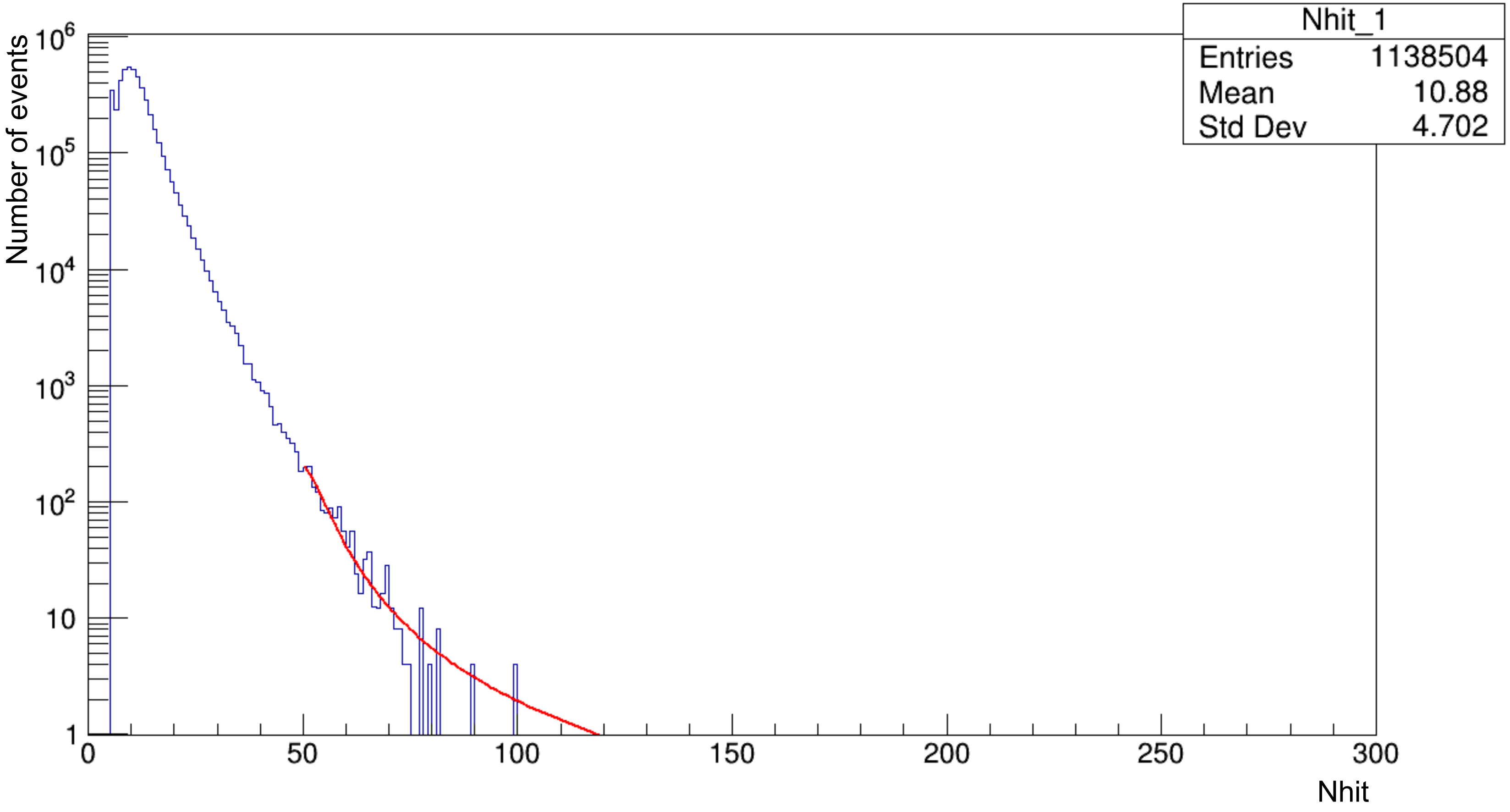

**Nhit : Number of floors with the chosen track hits (detected photons)**




β=[0.8615 , 0.906]

# Extrapolation of muon distribution

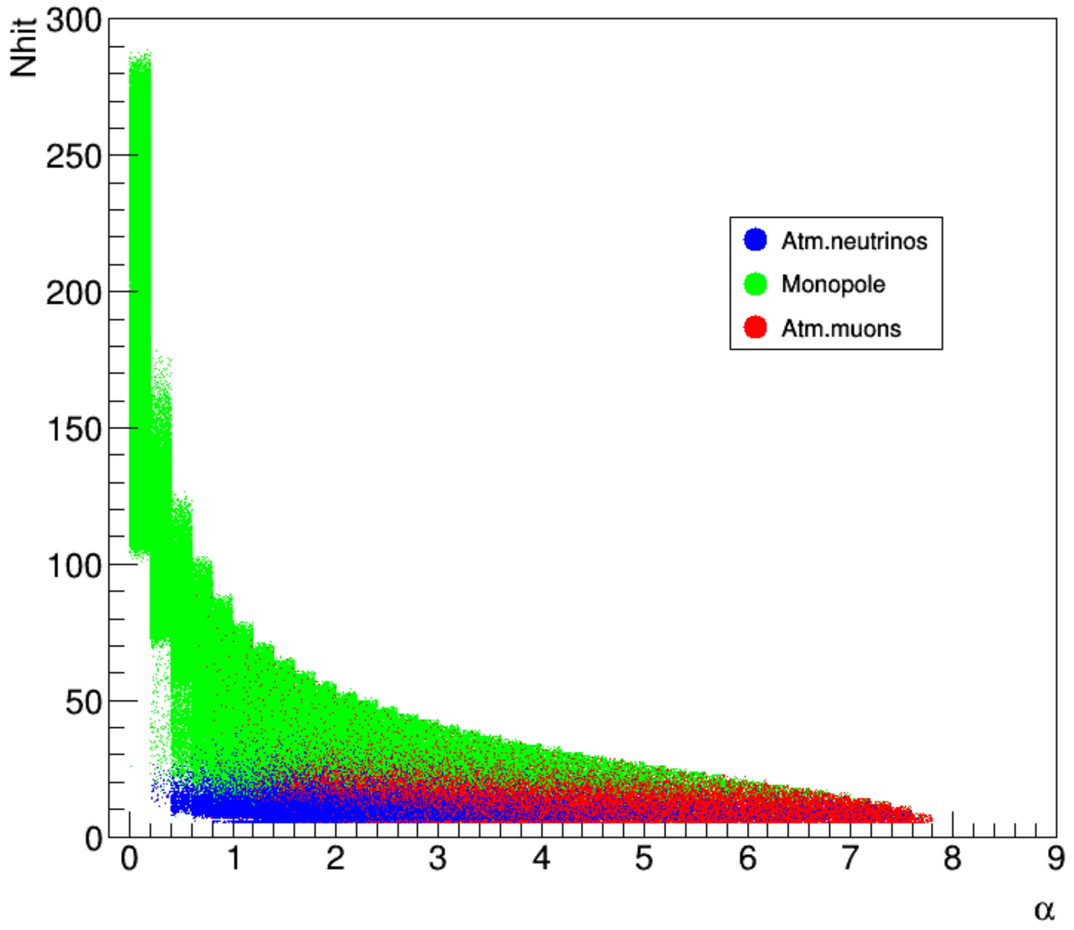
In order to compensate for the lack of statistics in the Nhit distribution for muons an extrapolation has been made in the signal region




A Landau type function has been used

# *Alpha_Nhit plots*

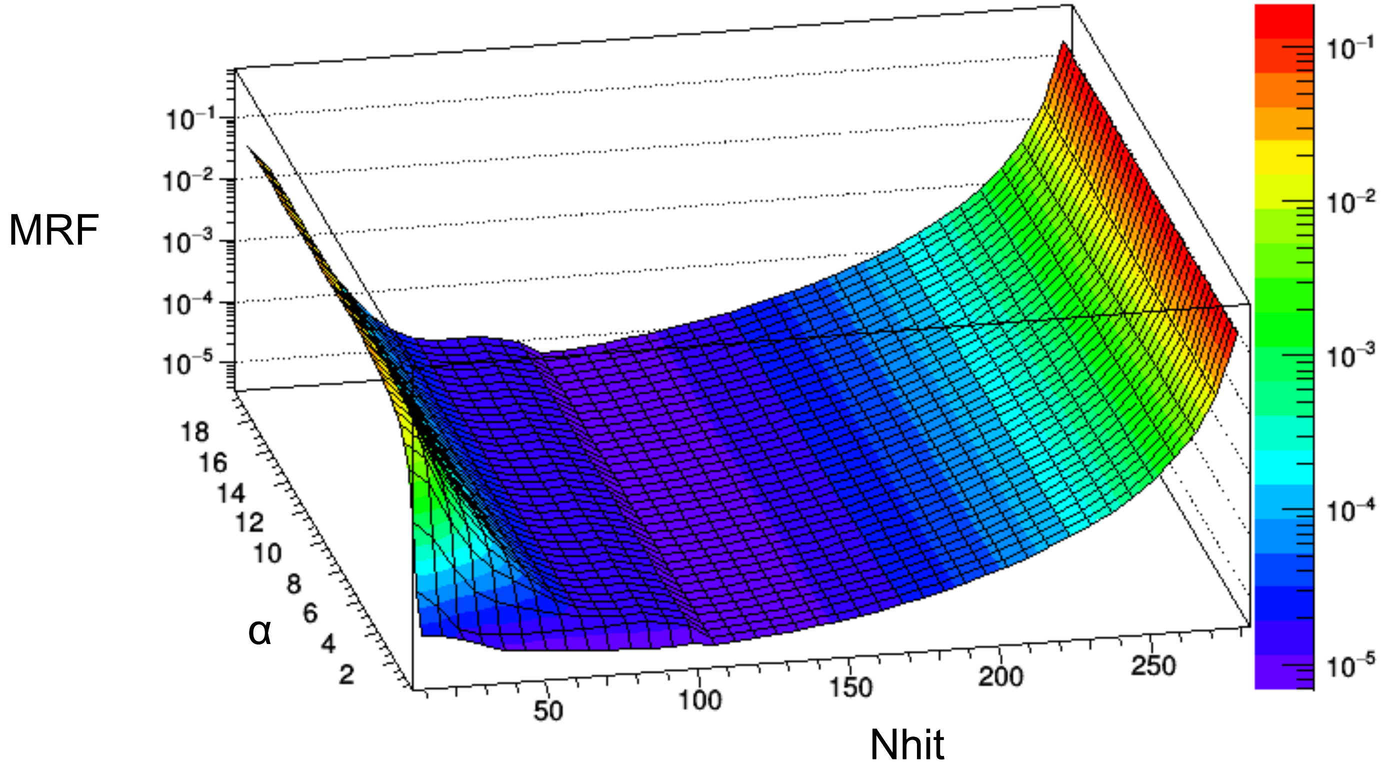
- A couple of cuts on Nhit and α isolates the signal from the background




β=[0.8615 , 0.906]

# *MRF optimization*

➢The Model Rejection Factor technique consists in varying the cuts until the minimum flux of Rejection Factor (RF) is found, which coincides with the best sensitivity.




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*

- $\beta$ reconstructed variable
- Monopole simulated $\beta$ : 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 $\alpha$ :

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

- As $\beta$ 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 a modified version of the reconstruction algorithm with free beta. This eliminates additional spurious atm. muon background. By construction this additional cut has no impact on the high velocity analysis.

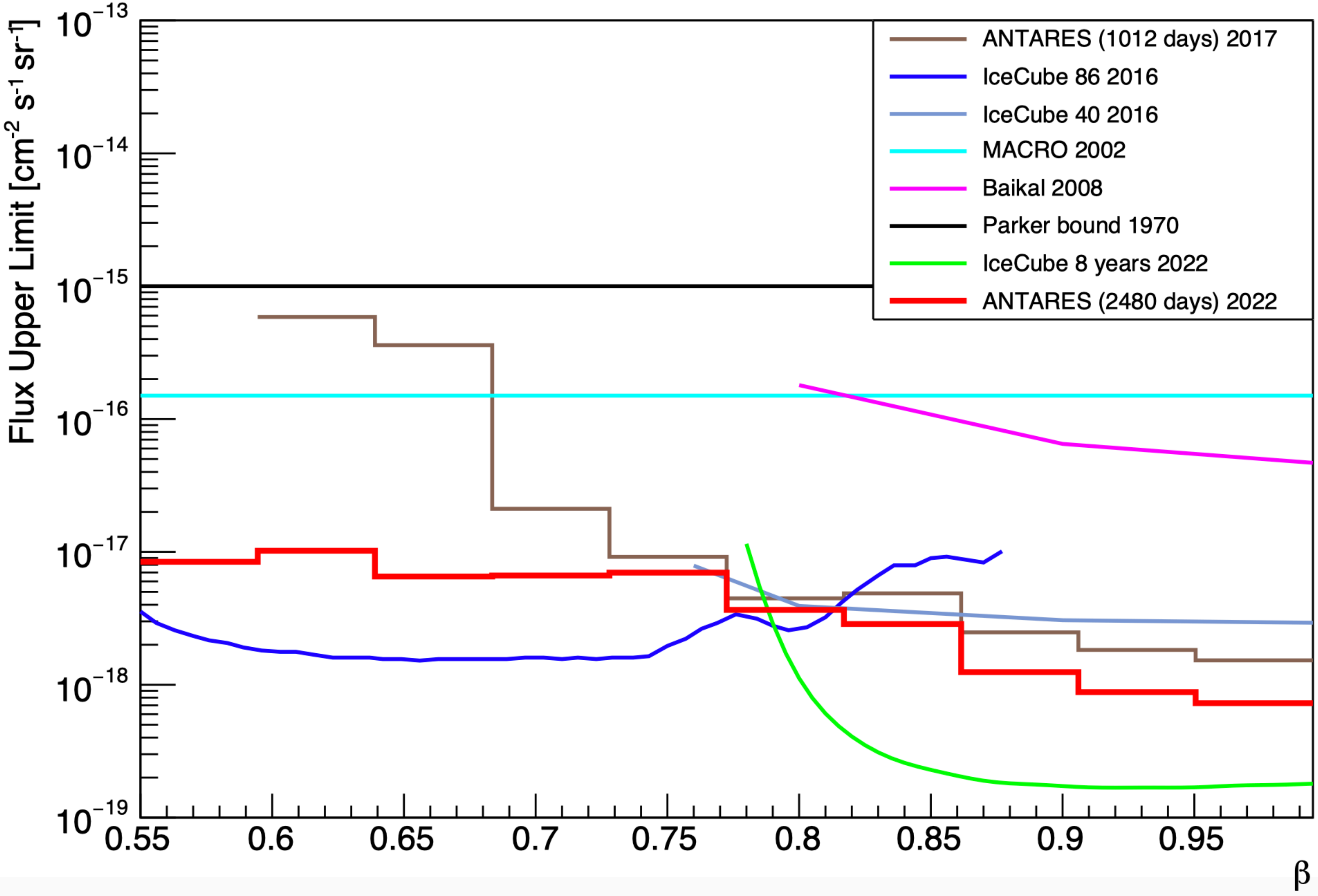
# Sensitivity results

➢ 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.

# ANTARES upper limit for MMs



# Conclusion

- The limit for the Magnetic Monopole found in this analysis (2480 days) presents a good improvement compared to the last limit found by the ANTARES Detector (1012 days), .

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

- A paper of this work was recently published (March 18th 2022) in the ***Journal of High Energy Astrophysics***:

Arxiv: https://arxiv.org/abs/2202.13786
DOI: https://doi.org/10.1016/j.jheap.2022.03.001