



Search for Neutrino Emission from the Fermi Bubbles with the ANTARES Telescope

Simone Biagi

University of Bologna and INFN
on behalf of the ANTARES Collaboration

The search for neutrinos from the Fermi Bubbles (FBs) using ANTARES data collected in the period 2007-2010 is presented.

The Fermi Bubbles are extended regions that cover ~ 0.8 sr in the sky, centered around the Galactic Center and almost symmetrical with respect to the Galactic Plane (Fig. 1). The FBs are characterized by gamma emission with a spectrum $\propto E^{-2} \cdot e^{E/E_c}$, with a relatively constant intensity all over the region [1]. According to a proposed hadronic mechanism for gamma ray emission [2], the Fermi Bubbles can be a source of high-energy neutrinos. From the measured gamma flux it is possible to derive the neutrino flux [3]:

$$\begin{aligned} \text{Neutrino flux} &\sim 0.4 \text{ Gamma flux} \\ \text{Energy cutoff} &\sim 1/20 \text{ Cosmic Rays knee} \end{aligned} \quad \rightarrow \quad \begin{aligned} d\Phi_\nu/dE &= 1.2 \times 10^{-7} E^{-2} \text{ GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \\ 50 \text{ TeV} &\leq E_c \leq 500 \text{ TeV} \end{aligned}$$

1. The ANTARES neutrino telescope

ANTARES is the largest neutrino telescope in the Northern hemisphere [4]. Anchored in the Mediterranean Sea, 40 km off-shore Toulon at a depth of about 2500 meters, it is composed of a 3D array of 885 optical modules mounted on 12 strings (Fig. 2). The main scientific goal is the search for cosmic neutrinos coming from galactic and extragalactic sources. Neutrinos are detected through the Cherenkov light emitted along the path of charged particles produced in neutrino interactions inside or in the vicinity of the detector. ANTARES is sensitive to all flavors though it is optimized for muon neutrinos. Data taken in 2007-2010 with different configurations are used in this analysis: half of the detector was active for ~ 170 days and 9-12 line detector acquired data for ~ 420 days (equivalent live-times).

Ratio	Data	MC
1 to 2	0.97 ± 0.04	0.97 ± 0.07
2 to 3	0.98 ± 0.04	1.12 ± 0.07
3 to 1	1.05 ± 0.04	0.92 ± 0.07

Table 1. Ratio of events in the OFF zones for data and MC. Events with $\Lambda > 6$ and $N_{hit} > 60$.

Cutoff [TeV]	MRF	Sensitivity
no cutoff	2.75	3.30
500	3.79	4.55
100	5.74	6.89
50	7.58	9.09

Table 2. MRF and sensitivity to a neutrino flux $\propto E^{-2}$ (in units of $10^{-7} \text{ GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$) for different energy cutoffs. Λ and N_{hit} cuts are optimized to get the best sensitivity.

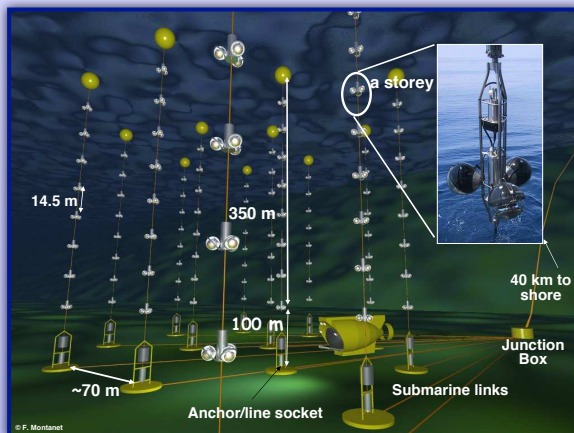


Figure 2. The ANTARES neutrino telescope is a three-dimensional array of 885 photomultipliers distributed over 12 lines installed in the Mediterranean Sea.

2. ON/OFF zones approach

To properly estimate the amount of background in the FBs zone it is useful to define different zones in the sky with the same coverage and visibility. The shape of FBs reported in [1] is approximated as in Fig. 3.

In local coordinates, the FBs move in the sky. A zone with the same position but shifted in time follows the FBs zone. A proper choice of the time shift avoids an overlapping of the zones, allowing an unambiguous definition of the "OFF zones". In this analysis, three OFF zones (Fig. 1) are identified corresponding to 6, 12 and 18 hours time shifts from the Fermi Bubbles (ON zone).

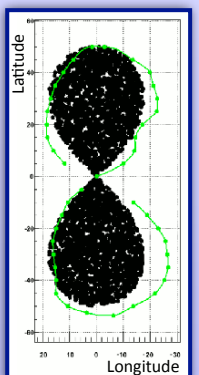


Figure 3. FBs shape (green line) and approximation (black dots) in g.c.

3. Data/MC comparison

Background in this analysis is estimated directly from data. The optimization of the analysis cuts is done using MonteCarlo (MC) simulations in order to maximize the sensitivity to a FBs neutrino signal and to reject atmospheric muons and atmospheric neutrinos (blinded analysis). Cuts are optimized according to the prescriptions of the Model Rejection Factor (MRF) procedure [5]. The reconstruction quality parameter Λ and the number of hits used in reconstruction (the simplest energy estimator) are the main parameters. Neutrino tracks reconstructed with only one line and with an angular error greater than 1° are rejected.

The ratios between the OFF zones for data and MC (see Table 1) have to be compatible with 1 to confirm the uniformity of the zone visibility. A conservative systematic error of 3% is evaluated to account for different visibilities of the zones.

The rejection of downward-going atmospheric muons is achieved cutting on the Λ parameter (Fig. 4); an energy estimator, like the number of hits (Fig. 5), can provide a discrimination between atmospheric and signal neutrinos.

The Feldman and Cousins method is used to calculate the MRF at 90% C.L. [6]. The corresponding sensitivity for the considered energy cutoffs is reported in Table 2.

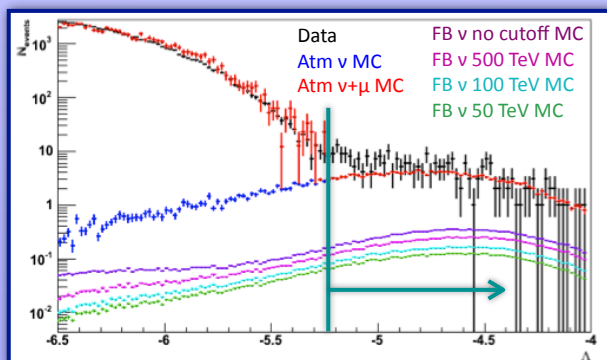


Figure 4. Reconstruction quality parameter Λ distribution for data and MC. Events with the best N_{hit} are selected.

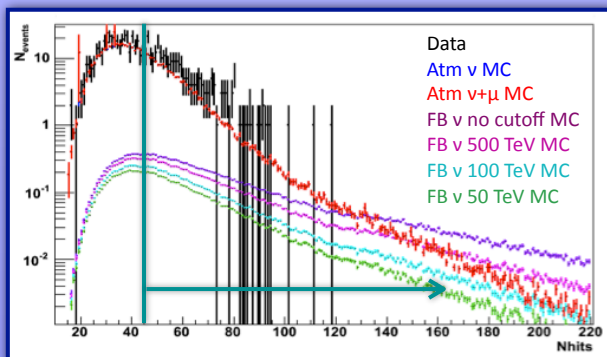


Figure 5. Number of hits distribution for data and MC. Even in this case, the cut on Λ is already applied.

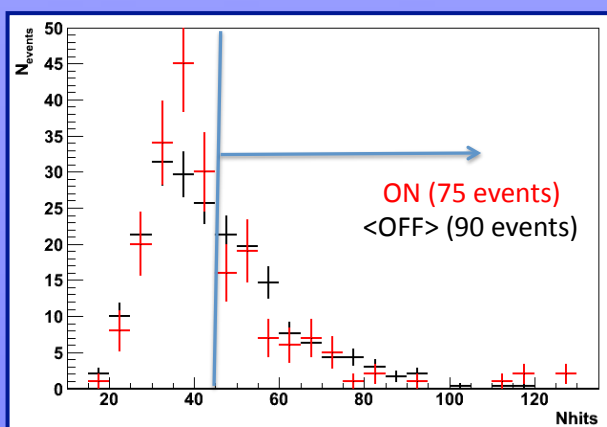


Figure 6. N_{hit} distributions for the ON zone and the average of the OFF zones. After the final cut ($\Lambda > 5.24$ and $N_{hit} > 44$) 75 events remain in the ON zone and 90 in the $\langle \text{OFF} \rangle$ zone.

4. Unblinding and results

Data are unblinded in the ON region searching for an excess of events in comparison to the expected background. 75 events are observed in the ON region with $90 \pm 5(\text{stat}) \pm 3(\text{sys})$ background events evaluated through an average of the OFF regions (Fig. 6).

No evidence of a neutrino signal from the Fermi Bubbles region is found.

Upper limits at 90% C.L. are computed using the Feldman and Cousins recipe with 75 observed events and 90 background events. In addition, a systematic error of +15% -6% for data/MC comparison is taken into account in the limit calculation. Due to a negative fluctuation of background in the ON zone, the quoted upper limits are lower than the ANTARES sensitivity to neutrino fluxes.

A comparison of these limits with the assumed theoretical models is in Fig. 7; the limits for the most optimistic cutoffs are very close to the expected fluxes.

Soon, data collected in 2011-2012 will be considered to increase the statistical significance of the analysis. Furthermore new and more efficient energy estimators will be used.

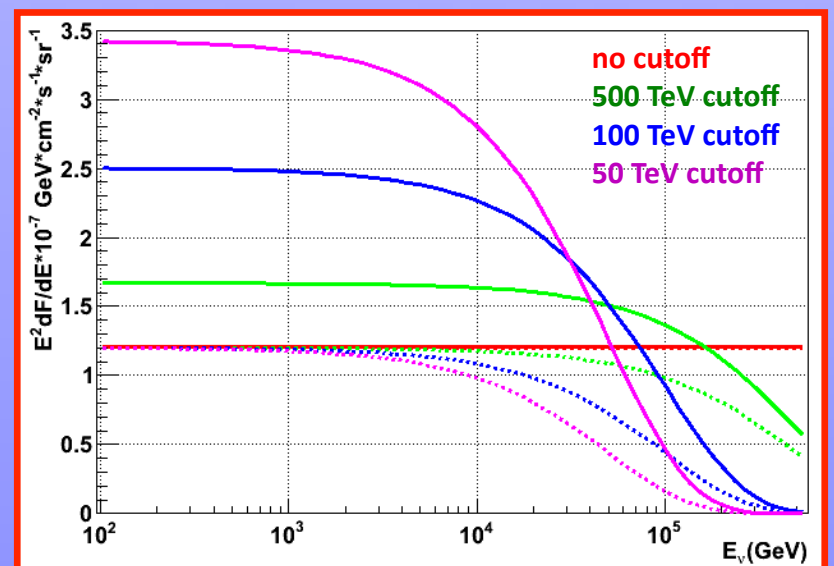


Figure 7. ANTARES upper limits (90% C.L.) for a E^{-2} neutrino flux from Fermi Bubbles with different energy cutoffs. Theoretical prediction are plotted with dotted lines.

References

- [1] M. Su, T.R. Slatyer, and D.P. Finkbeiner, arXiv:1005.5480.
- [2] R.M. Crocker and F. Aharonian, Phys. Rev. Lett. 106 (2011) 101102.
- [3] F.L. Villante and F. Vissani, Phys. Rev. D 78 (2008) 103007.
- [4] M. Ageron et al., Nucl. Instrum. Meth. A 656 (2011) 11-38.
- [5] G.C. Hill and K. Rawlins, Astrop. Phys., 19 (2003) 393-402.
- [6] G.J. Feldman and R.D. Cousins, Phys. Rev. D 57 (1998) 3873-3889.