KM3NeT detection capability for high-energy neutrinos from the Fermi bubbles.

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Abstract: The Fermi Bubbles are two large areas, located above and below the Galactic center, emitting high energy gamma-rays with high intensity and a shape consistent with a E^{-2} law. If an hadronic mechanism is responsible for the emission of the gamma-ray flux the Fermi bubbles are also a source of high energy neutrinos. Thanks to its large detector volume and its location in the Mediterranean sea the KM3NeT neutrino telescope will be the ideal instrument to detect neutrinos from Fermi bubbles. In this paper the number of years required for the discoveries of neutrinos from Fermi bubbles as a function of the total light sensitive detection area is reported.

Keywords: Neutrino telescope, Fermi bubbles, KM3NeT

1 Introduction

In 2010 a dedicated analysis of sky maps constructed out of 20 months of Fermi LAT data, based on sophisticated background subtracting technique, has revealed the existence of two well defined areas emitting high energy gamma-rays [1]. These regions extend up to 50 degrees above and below the Galactic center. The gamma-ray spectrum, measured from about 1 GeV to about 0.1 TeV, is compatible with a power-law spectrum described by $E^2\, d\Phi_\gamma/dE \approx 3-6\times 10^{-7}\,\mathrm{GeV\,cm^{-2}\,s^{-1}\,sr^{-1}}$. No spatial variation in the spectrum shape or gamma-ray intensity inside the two bubbles has been observed. Moreover, the analysis has been further extended to 50 months of Fermi LAT data by the Fermi collaboration and the analysis, performed with two different fitting methods for Galactic foreground modeling, confirms a E^{-2} spectrum that extends up to 0.5 TeV with an intensity of about $5-6\times 10^{-7}\,\mathrm{GeV\,cm^{-2}\,s^{-1}\,sr^{-1}}$ [2]. The edges of the bubbles seem to be correlated with ROSAT Xray maps at $1.5-2$ keV, while the inner parts are correlated with the hard-spectrum microwave excess known as WMAP haze. Recently, also a linearly-polarized radio lobes emission in the Fermi bubble region emanating from the Galactic center has been measured [3]. The origin of the emission of high energy gamma rays and of the associated counterparts is still not clearly understood and many explanations, invoking both the hadronic [4, 5, 6] and leptonic mechanisms [1, 5, 7, 8] , have been suggested but none of them has been able to explain all the gamma and the counterparts features.

The detection or not detection of neutrinos from the Fermi bubble region could be a key information to shed light on the formation mechanism of the Fermi bubbles. The future KM3NeT neutrino telescope [9], whose construction is starting in the Mediterranean sea, will be the ideal instrument for the detection of high energy neutrinos from the Fermi bubbles. In fact, from its location the full southern sky and a large part of the northern sky, including most of the Galactic plane, can be explored. In particular, the Fermi bubble region is visible in a high percentage of observation time (58% for the Northern bubble and 80% for the southern bubble for a detector located at a latitude of $36^\circ\ 16'$N).

A complete description of the simulations and the analysis to evaluate the detection capability of the KM3NeT neutrino telescope for neutrino from the Fermi bubbles is reported in [10].

In this work the detection capability has been investigated as a function of the total sensitive detector area in terms of the number of observation years required to discover neutrinos from Fermi bubble. In fact, one of the key parameters in the design of a neutrino detector is the light detection capability that depends on the sensitivity area (photomultiplier photocathode area) of the detector. The detection capability estimate is based on Monte Carlo simulations and on the assumption that the mechanism responsible for the emission of the high energy gamma-ray is fully hadronic.

2 Simulations and results

The detection of Cherenkov light emitted by secondary particles produced in the neutrino interaction occurring in the volume inside or around the detector volume is the detection principle of the detector. The detector consists of an array of Optical Modules (OM) attached to vertical structures, called Detection Units (DU). The DUs are anchored to the sea floor and kept vertical by buoys and are connected to shore by an electro-optical cable. An array of DUs will constitute a detector building block. Many building blocks will be installed in the depth of the Mediterranean sea in one or more installation sites. The OM consists in 31 photomultipliers (PMTs), with a photocathode area of 3 inches and QE of 30% at 380nm of photon wavelength, housed inside a pressure resistant glass sphere: 19 PMTs are oriented downwards and the remaining 12 upwards [9].

Each DU consists a three-dimensional structure made of horizontal bars, 10m length, equipped with two OMs, one at each end (towers). Adjacent bars are oriented orthogonally to each other by means of a system of ropes. The distance between bars is of 40m. The distance between DU is about 180m, arranged in a circular pattern. The geometry used for this work is different from the one actually adopted by the collaboration that is based on vertical string like structures (strings). However, simulations have proven that the performances of a 154 DU detector based on tower are very similar to a 310 DU detector based on strings [9].

In this work the detection capability of detectors for Fer-

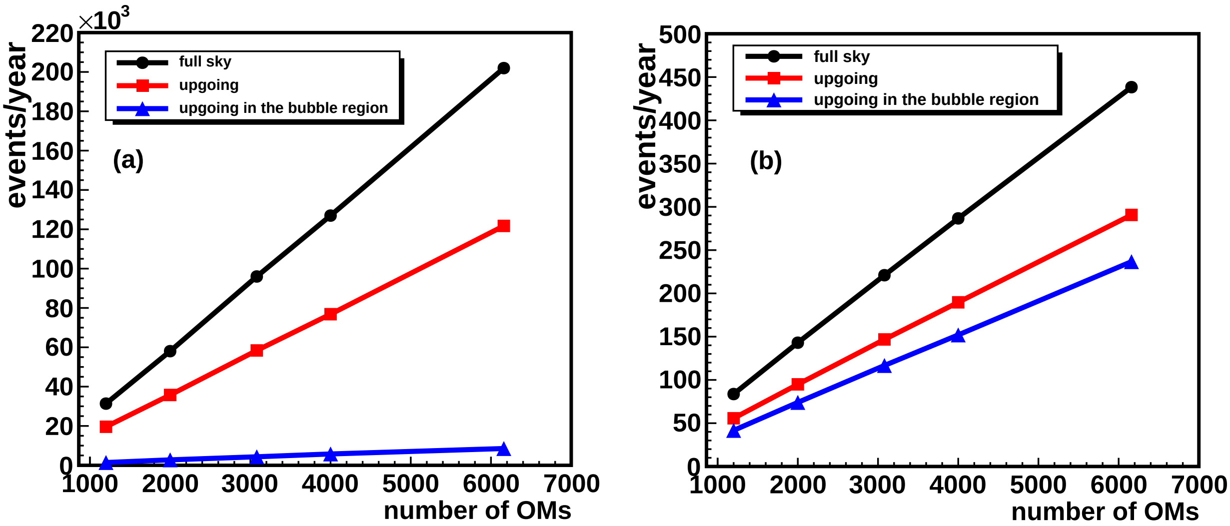

Fig. 1: Number of reconstructed atmospheric neutrino events per year (a) and reconstructed neutrino events per year from the Fermi bubbles (b) as a function of the number of OMs in the full sky (black circles), up-going (red squares) and in 19° around the bubble centers (blue triangles).

mi bubble has been investigated for an increasing number of OMs.

The neutrino spectrum can be estimated from the gamma spectrum following the prescription described in [11]. In the hypothesis that the source is transparent to gamma-ray emission and that the process responsible for the gamma emission is fully hadronic it is possible to estimate the neutrino flux from the measured gamma-ray flux. In particular assuming a gamma spectrum described by

$$E^2\phi_\gamma = 6\times 10^{-7} GeV cm^{-2} s^{-1} sr{-}1 \quad (1)$$

considering that the solid angle of the two simulated bubbles is 0.69 sr and assuming that a cutoff of 100 TeV, consistent with the knee in the Cosmic Ray spectrum, is present we estimated a neutrino flux of

$$\frac{d\phi_\nu}{dE} = 1\times 10^{-7}\cdot E^{-2}\cdot e^{-E/100TeV}\, GeV^{-1} cm^{-2} s^{-1} \quad (2)$$

The Monte Carlo simulation consists of different algorithms based on the ANTARES software [12] and modified for a km^3-scale detector and using KM3NeT OM properties. The algorithm chain accounts for: the generation of neutrinos from Fermi bubbles, the generation of atmospheric neutrino background, the neutrino interaction in the rock under the detector and in the sea water inside and above the detector volume, the propagation of the muon in the rock and in water, the generation of Cherenkov light, the ^{40}K optical background simulation. The PMT characteristics and optical water properties are also taken into account. The effect of ^{40}K optical background has been implemented, as estimated from a complete GEANT4 simulation, as a 5 kHz rate of single photon hits on each PMT and a 500 Hz of double coincidences between couples of PMTs in the same OM.

The algorithm that reconstructs the muon track direction from the PMT signals and position is based on the differences between the expected arrival times of the Cherenkov photons at the optical modules and the measured arrival time of the photons on the PMTs. In addition to the positions and track directions, a number of selected hits ($N_{\rm hit}$) and a track fit quality parameter (Λ) are given as output. The Λ parameter is used to reject badly reconstructed events. The $N_{\rm hit}$ parameter is correlated with the muon energy and a threshold on this parameter is used to increase the signal background ratio.

Muon neutrinos from the Fermi bubbles were generated homogeneously within two circular regions of 19° radius around two positions in the sky at the equatorial coordinates declination $\delta = -15°$ and right ascension $\alpha = 243°$ for the northern bubble and $\delta = -44°$ and $\alpha = 298°$ for the southern bubble. The simulated neutrino energy is between 10^2 and 10^8 GeV. The event were weighted to reproduce the spectrum (2).

Cosmic rays entering the atmosphere produce a large number of secondary particles. The production of pions and kaons and their subsequent decay chains produce a large flux of atmospheric neutrinos that together with high energy muons, produced in the extensive air showers, constitute the background for the detection of neutrinos of cosmic origin. The atmospheric neutrinos and antineutrino background was generated in the energy range 10^2 and 10^8 GeV and over the full solid angle. For atmospheric neutrinos the reference conventional flux considered was the Bartol model [13] and for the prompt contribution the recombination Quark Parton Model (RQPM) [14].

Only events reconstructed as up-going and located within 19° around the centre of each Fermi bubble were considered. In Fig. 1 for the full KM3NeT detector the number of events per year of neutrino background (left panel) and of neutrino from Fermi bubbles (right panel) reconstructed in the full sky, as up-going and in a wide region around the Fermi bubble north and south (19°) are reported as a function of the number of OM. No quality cuts are applied to these events.

A source is considered as discovered if the number of detected events in a given detector live time has a probability of $\alpha = 2.85\times 10^{-7}$ or less to originate purely from background in $1-\beta = 50\%$ of all experiments. This

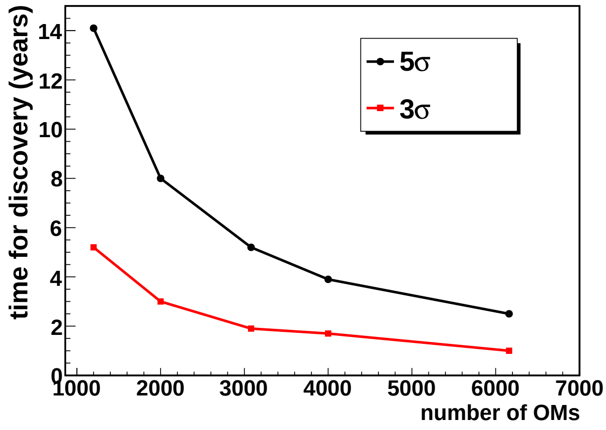

Fig. 2: Time for discovery at 5σ of significance, 50% probability, and 3σ of significance, at 50% probability, as a function of the number of OM for a spectrum with a 100 TeV cutoff.

corresponds to a significance of 5σ (area of the one-sided Gaussian tail).

In order to determine the number of observation years for the discovery, the cuts on Λ and N_{hit} were varied and the discovery flux that correspond to the Fermi bubble flux was estimated applying the Model Discovery Potential (MDP) method, described in [10]. In Fig. 2 the number of years required to have a signal from bubbles at 3σ and 5σ of significance, at 50% of probability, is shown as a function of the number of OM. While a linear trend is observed in the number of reconstructed events a similar trend is not observed in the number of observation years. The time for discovery shows a saturation trend for high number of OMs.

Simulation results reported in this work and in [10] has shown that the Fermi bubbles are, together with the Galactic sources discussed in [15], one of the most promising source of neutrinos for KM3NeT.

In fact, assuming the observed gamma rays are of hadronic origin and the spectrum extends to the multi-TeV range with a E_ν^{-2} spectrum with an exponential cutoff at 100 TeV, this analysis shows that in about 2.5 years a detector made of 6000 OM can detect this neutrino flux at a significance of 5σ with 50% probability. Since neutrino telescopes have a modular design and therefore an increasing science capabilities the detection power of the telescope to detect neutrinos from the Fermi bubbles has been explored as a function of the increasing number of OM showing that a significance of 3σ with 50% probability can be reached after 3 years of observation time with a smaller detector made of about 2000 OM.

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References

[1] Meng Su et al., Astrophys. J. 724 (2010) 1044.
[2] A. Franckowiak, D. Malyshev on behalf of the Fermi-LAT Collaboration from "The Fermi bubbles: Theory and Observations" Workshop 11-12 April 2013 - SLAC National Accelerator Laboratory, Menlo Park, California http://kipac.stanford.edu/kipac/events/fermi-bubbles-theory-and-observations.
[3] E. Carretti et al., Nature 493(2013) 66. doi:10.1038/nature11734.
[4] R. Crocker and F. Aharonian, Phys. Rev. Lett. 106 (2011) 101102.
[5] B. C. Lacki, ArXiv:1304.6137 - 23 April 2013.
[6] S. Thoudam, ArXiv:1304.6972 - 25 April 2013.
[7] D. O. Chernyshov et al., ICRC2011 proceedings, ArXiv:1109.2619.
[8] P. Mertsch and S. Sarkar, Phys. Rev. Lett. 107 (2011) 091101.
[9] KM3NeT Technical Design Report, available on http://www.km3net.org/TDR/TDRKM3NeT.pdf (ISBN 978-90-6488-033-9).
[10] S. Adrián-Martínez et al., Astrop. Phys. 42 (2013) 7-14.
[11] F.L. Villante and F. Vissani, Phys. Rev. D 78 (2008) 103007; F. Vissani and F.L. Villante, Nucl. Inst. Meth. A588 (2008) 123; F. Vissani, Astropart. Phys. 26 (2006) 310.
[12] J. Brunner et al., proceedings of the first VLVnT Conference, Amsterdam, Oct. 2003; A. Margiotta, proceedings of VLVnT11 conference, Erlangen, Germany, Oct. 2011.
[13] G.D. Barr et al., Phys. Rev. D70 (2004) 023006.
[14] E.V. Bugaev et al., Phys. Rev. D 58 (1998) 054001.
[15] A. Trovato et al., for KM3NeT collaboration "KM3NeT discovery potential for galactic point-like sources" - ICRC 2013 proceeding.