



Tau neutrino search with the MAGIC telescope

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Abstract: The MAGIC telescope located on the Roque de los Muchachos on the Canary Island La Palma at a height of 2200 m a.s.l. is able to point to the sea. This permits a search for air shower signatures induced by particles coming out of the Earth. An analytical approximation results in ν_τ effective areas from $\sim 10^3 \text{ m}^2$ (at 100 TeV) to 10^5 m^2 (at 1 EeV) for an observation angle of about 1° below the horizon, rapidly diminishing with further inclination. Taking into account the huge effective area, this configuration was investigated for its suitability to search for ultra-high energy (UHE) tau-neutrino signatures. The outcome of simulations for tau-neutrino signatures will be presented, models for astrophysical neutrino sources reviewed, and estimated event rates in MAGIC are shown.

Introduction

Although optimized to detect electromagnetic air showers produced by gamma ray primaries, the MAGIC telescope [1] (2200 m a.s.l., 28.45°N , 17.54°W) is also sensitive to hadronic showers. When the telescope turns down, this background diminishes until almost vanishing at the horizon. The telescope can look down to a maximum of about 10° below the horizontal plane, the Sea is visible in an azimuthal range covering about 80° (see fig. 1). Only a small light contamination from continuous scattered star light and from scattered Cherenkov light initiated by air showers will then be observed.

We investigated the possible response of the MAGIC telescope to upwards moving showers initiated by UHE τ -particles originating from a ν_τ collision with the Sea or underneath rock.

The ν_τ channel has several advantages with respect to the ν_e or ν_μ channel. First, the majority of the possible τ decay modes leads to an (observable) air shower or a combination of showers. Only 17.4% decays to a muon and neutrinos, considered to be unobservable for the effective areas of interest here. Moreover, the boosted τ lifetime ranges

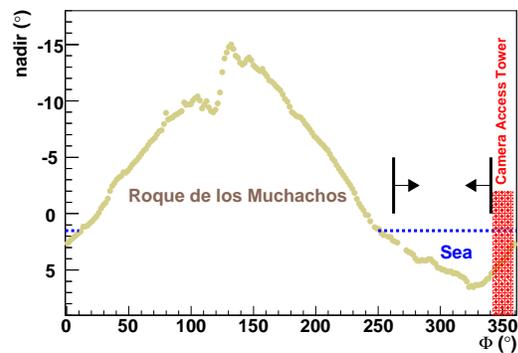


Figure 1: Horizon seen from the MAGIC Telescope. The region $\Phi = [262^\circ, 340^\circ]$ can be used to point toward the Sea.

from ~ 50 m at 1 PeV to almost hundred kilometers at EeV energies [2, 3], only slightly affected by energy losses in matter.

The production of UHE neutrinos in astrophysical shocks is expected in the case of hadronic models, where accelerated protons interact with photons via the Delta resonance. This process leads to the coincident production of neutrinos and TeV photons, since charged pions have neutrinos as

decay products while π^0 mesons decay into two photons. Alternatively, proton-proton interactions lead to a similar output of neutrinos. The production ratio of the different flavors of neutrinos is $(\nu_e : \nu_\mu : \nu_\tau)_{\text{source}} = (1 : 2 : 0)$. Neutrino oscillations will equalize their rates, so that ν_e , ν_μ and ν_τ should be detected in equal fractions even though they are not emitted as such.

Expected effective τ -neutrino areas

In order to estimate the effective areas of an Imaging Air Cherenkov telescope looking down to the Sea from 2200 m altitude, a small simulation was written for the case of a ν_τ entering the Earth, creating a τ -particle there (or in the Sea) and exiting the Sea towards the telescope. Also the case of a two-, three- and four-fold interaction-decay sequence was simulated. The τ subsequently decays and gives rise to an energetic air shower in 82.6% of the cases. Only mean interaction lengths were simulated (in a similar way as found in [4, 5]), and we assume a shower opening angle of 1.4° and an effective trigger area of 2° of the MAGIC camera. Above $2 \cdot 10^8$ GeV shower energy, the full 2° field-of-view was taken as effective shower opening angle, due to the contribution of the fluorescence light. The depth of the Sea was assumed to be constantly 3 km throughout the observed area, with standard rock underneath. The τ -particle range was assumed to be equal to its lifetime (up to an energy of 10^8 GeV), above this energy, energy losses in the parameterization of [2] (formula 16) were computed.

Under these assumptions, we obtained energy and zenith angle dependent effective areas as shown in fig. 2. One can see that basically a range of zenith angles around 91.5° to maximally 92.5° yields reasonable effective areas, reaching $5 \cdot 10^5$ m² at energies around 100 EeV. The traversed distance in Earth amounts then to about 100 km, an optimal value also obtained in the literature [6, 7, 8, 3].

Determination of the Energy Threshold

When the telescope looks down to the Sea from a mountain of 2200 m height, the horizon is seen under a zenith angle of $\sim 91.5^\circ$, at a distance of

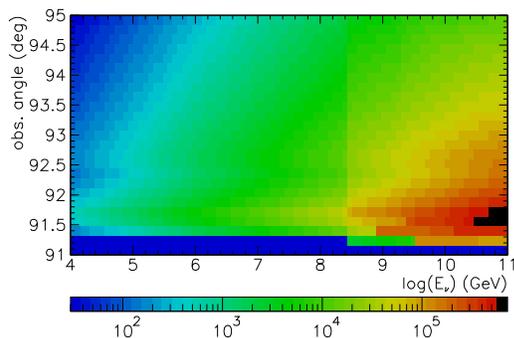


Figure 2: Effective tau neutrino areas (in m²).

~ 165 km. Moving down to 94° , the surface of the Sea is still ~ 32 km away. These numbers have to be compared with the typical position of a shower maximum at 10 km height, obtained when the telescope looks directly upwards and observes showers at the trigger energy threshold of 50 GeV.

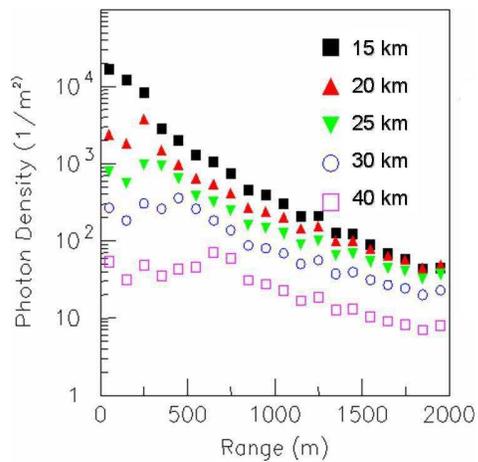


Figure 3: Photon densities of Cherenkov light from a 1 PeV shower, observed at different distances.

Fig. 3 shows the simulated (observable) photon densities for an electromagnetic shower of 1 PeV injection energy, seen from various distances along the surface of the Earth. The MAGIC telescope has an effective mirror area of 236 m², with a photo-conversion efficiency of about 15% at green to reddish wavelengths. Applying an analysis threshold of about 200 photo-electrons per image, a minimum Cherenkov photon density of about 7 photons/m² has to be required. For observations

at 94° zenith angle, this limit translates directly into an energy threshold of about 40 TeV. At 92° (91.7°), the threshold becomes 300 (500) TeV.

This condition does not yet include the possible confusion with residual backgrounds from cosmic rays which will probably raise the thresholds further.

According to [9], muon bundles should penetrate to the telescope in two thirds of the cases, already below the threshold energies. However, we consider here the possibility to separate these signals from stray muons from cosmic rays extremely difficult, and do not predict any possibility to lower the thresholds even further.

Model Predictions

Since the lower energy threshold for neutrino detection with MAGIC lies at $E_{\min} \sim 50$ TeV, the detection of galactic neutrinos can be excluded, since sources like microquasars have typical maximum energies of around $E_{\max} \sim 100$ TeV, see e.g. [10]. In this section, we review extragalactic sources suitable for observation with the MAGIC telescope.

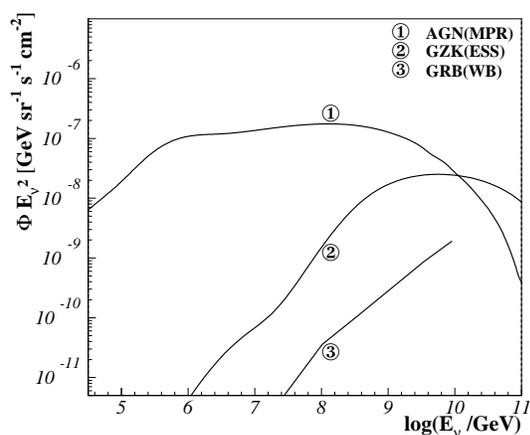


Figure 4: Isotropic neutrino flux prediction from extragalactic sources. With MAGIC, the observation of single sources is done in the case of GRBs and AGNs. With the observation of the strongest sources, a higher flux than average can be expected.

Neutrinos from AGNs

The observation of TeV photons from Active Galactic Nuclei are one indicator that also neutrinos can originate from these sources, assuming that the TeV photons come from π^0 -decays. In the case of optically thick sources, keV-GeV emission can also point to neutrino emission, if the UHE photon emission is a cascaded TeV signal. Prediction (1) in fig. 4, labeled *AGN(MPR)*, shows the maximum contribution from GeV blazars as derived in [11]. There is a significant contribution up to energies of $E \sim 10^{11}$ GeV, making it possible to test the model by observing the most luminous GeV sources with MAGIC. In particular, 1ES 1959+650 is a good candidate for neutrino emission. In 2004, an orphan flare, i.e. TeV emission with no X-ray counterpart, has been detected from this source, pointing to a partially hadronic origin of the radiation [12]. The neutrino emission from such a flaring state has been calculated in [13]. This model will also be used for the calculation of expected event rates.

GZK neutrinos

UHE protons originating from extragalactic sources interact effectively with the Cosmic Microwave Background via the Delta resonance above energies of $\sim 10^{19.5}$ eV [14]. This process yields a neutrino flux at energies of around $\sim 10^8 - 10^{11}$ GeV. Such a flux is presumably present permanently and isotropically. As an estimate, the prediction from [15] is shown as model (2) in fig. 4, labeled *GZK(ESS)*.

GRB afterglow neutrinos

The prompt gamma-ray emission of Gamma Ray Bursts is typically followed by an afterglow of X-ray, optical and radio radiation, which can be associated to an UHE neutrino flux as pointed out in [16]. Assuming neutrino production via the Delta-resonance, the photon and proton energies are correlated as $E_\gamma \cdot E_p \sim 0.2 \text{ GeV}^2 \cdot \Gamma^2$ with the boost factor of the shock $\Gamma > 100$. With a typical afterglow photon energy of ~ 100 eV, the produced neutrinos will have energies around 10^9 GeV. Thus, such a flux is well-suited to be

investigated with MAGIC. The average neutrino spectrum from GRB afterglows is shown as model (3) in fig. 4, labeled *GRB(WB)*. However, GRB spectra can in some cases deviate from the mean spectrum.

Results

Based on the above models, we estimated typical observable event rates from the AGN 1ES1959 [13], a GRB located at a redshift of $z = 1$ [16] and the observation of the diffuse GZK neutrinos [15], displayed in figure 5. Only the observation of a GRB at small distance seems to give event rates that are potentially observable. Several strong bursts per year can be expected, possibly with a neutrino flux much higher than assumed in the figure. These bursts can be observed by the MAGIC telescope using an online trigger from GRB satellites once the GRB occurs in the field of view of MAGIC neutrino observations.

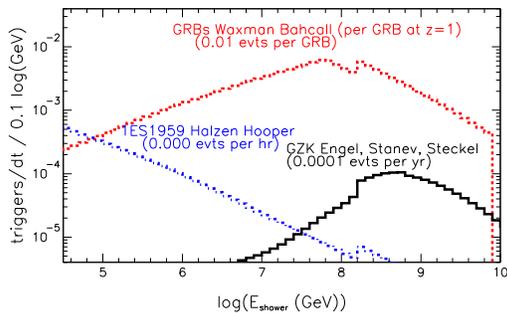


Figure 5: Expected visible shower event rates from investigated neutrino models

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