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Neutrinos from galactic sources

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The HAWC telescope has recently revealed new spectra for gamma-ray sources in the Galactic plane. We will consider, with particular emphasis, the 2HWC J1825-134 source. Amongst the HAWC sources, it is indeed the most luminous in the multi-TeV domain and therefore is one of the first that should be searched for with a neutrino telescope in the northern hemisphere. We will show the prospects to detect this source at the KM3NeT detector and comment on the possibilities for others neutrino telescopes.

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One of the most important problems in high energy astrophysics is the origin of galactic cosmic rays [1, 2]. During the acceleration of cosmic rays, the production of gamma rays is expected. These could be produced from hadronic interactions with the interstellar medium, or from leptonic processes.

The identification of the origin of the gamma-ray emission, specifically if leptonic or hadronic, is thus one of the most important goals in gamma-ray astronomy. In case cosmic rays lose part of their energy in hadronic processes, then, from the decay of charged pions, a flux of high energy neutrinos is expected. Neutrino telescopes are, for this reason, able to provide important information on the production mechanisms of cosmic rays and on the nature of the gamma-ray emission, as the detection of neutrinos from a gamma-ray source would imply that the emission is hadronic.

Gamma-ray data are necessary to make correct estimation of neutrino fluxes from point-sources. For this reason, a multi-messenger search is mandatory for the identification of the origin of cosmic neutrinos. To search for PeVatrons, a gamma-ray experiment with detection sensitivity up to about 100 TeV is of fundamental importance. Indeed, the characteristic gamma-ray feature of a PeVatron include an hadronic, hard spectrum that extends until at least several tens of TeV.

The High Altitude Water Cherenkov Observatory (HAWC) is a gamma-ray observatory sensitive in the multi-TeV energy domain. The HAWC observatory has reported new data on galactic sources in recent years, see e.g. [3, 4]. Among these sources, the eHWC J1825-134 source, located in the southern sky, has been detected with an hard spectrum that extends up to multi-TeV energies. This source represents thus a possible PeVatron source. Moreover, this is the brightest source detected by HAWC in the multi-TeV domain. A kilometer-cube detector in the northern hemisphere will see the events from this possible PeVatron source as muon events, for which a good angular resolution is feasible and it could use all its volume for the point sources search.

1. The eHWC J1825-134 source

The source eHWC J1825-134, analysed in Ref. [4], is located in the southern sky with a right ascension of 276.40° and a declination of −13.37°. The spectrum can be described by a power law with an exponential cut-off:

$$\frac{dN_\gamma}{dE_\gamma} = \phi_0 \left(\frac{E_\gamma}{10\ \text{TeV}}\right)^{-\alpha_\gamma} \exp\left(-\frac{E_\gamma}{E_{cut,\gamma}}\right) \tag{1}$$

where $E_{cut,\gamma}$ is the cut-off energy of the gamma-ray spectrum, α_γ the spectral index and ϕ_0 the flux normalized, see the values reported in Table 1. The spectrum is plotted in Fig. 1 with blue thick data points.

Source	σ_{ext}	ϕ_0	α_γ	$E_{cut,\gamma}$
eHWC J1825-134	0.53 ± 0.02	2.12 ± 0.15	2.12 ± 0.06	61 ± 12

Table 1: Extension of the source in degrees, flux ϕ_0 normalized to 10^{-13} TeV^{-1} cm^{-2} s^{-1}, spectral index α_γ and cut-off energy $E_{cut,\gamma}$ in TeV.

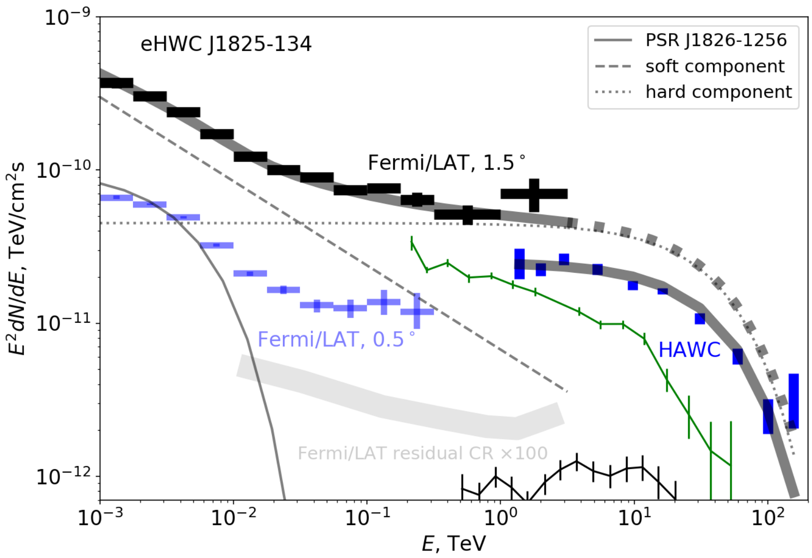

Figure 1: Spectrum of eHWC J1825-134 region measured by Fermi/LAT compared to the HAWC and HESS spectral measurements. Blue thin data points show the spectrum extracted from a circular region of radius 0.5° around the position of the HAWC source, while black thick data points are extracted from a 1.5° radius region. Dashed, dotted and thin solid curves show the spectral fit components. The normalization of the hard component (dotted line) is found from the fit to the Fermi/LAT data. The spectrum for the HESS J1825-137 source is denoted with green thin data points, while the one for the HESS J1826-130 source with black thin data point. The Fermi/LAT residual cosmic-ray background, rescaled, by hundred, is denoted by the gray band.

2. The neutrino flux and the KM3NeT/ARCA effective area

The event rate at a neutrino telescope can be described by the following expression [5]:

$$N_{\rm ev} = \epsilon_\theta \epsilon_\nu \, t \int_{E_\nu^{\rm th}} dE_\nu \, \frac{dN_\nu(E_\nu)}{dE_\nu} \times A_\nu^{\rm eff} \,, \tag{2}$$

where it is implicit a sum over neutrino and antineutrino. The parameter $\epsilon_\nu = 0.57$ is the visibility of the source, while $\epsilon_\theta = 0.72$ is a reduction factor present if the source morphology is assumed to be a Gaussian of standard deviation $\sigma_{\rm ext}$. As angular resolution of the KM3NeT/ARCA detector, we have considered $\sigma_{\rm res} \sim 0.1°$ [6]. The number of neutrino events $\frac{dN_\nu(E_\nu)}{dE_\nu}$ has been calculated starting from the gamma-ray spectrum reported in the eHWC catalog and considering the expressions given in Ref. [7].

As for the effective area, we considered the Letter of Intent of the KM3NeT collaboration [6], assuming in particular an effective area optimized for energies above 1 TeV, see left panel of Fig. 2.

The expected atmospheric muon neutrinos is then integrated over an opening angle equal to $\Omega = \pi\sigma_{\rm eff}^2$, where $\sigma_{\rm eff}$ takes into account the extension of the source and the resolution of the detector.

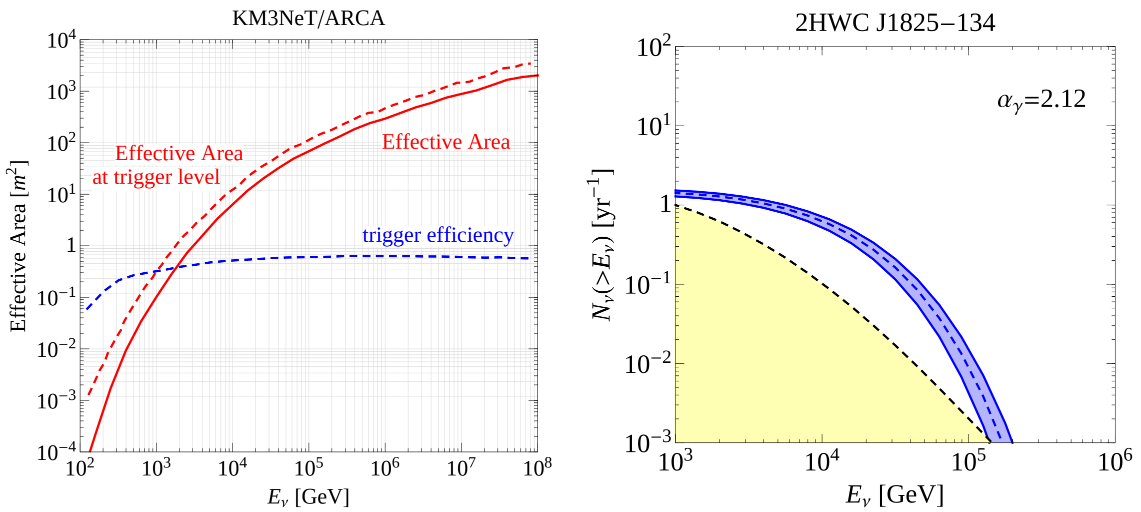

Figure 2: Left panel: Effective area used in the analysis (red solid line), effective area at trigger level (red dashed line), and trigger efficiency (blue dashed). The latter is used to obtain an effective area optimized for energies above 1 TeV. Right panel: Number of events expected for the atmospheric background (yellow area) and for the source, for the best-fit value of α_γ and values of $E_{cut,\gamma}$ within the statistical errors (blue band).

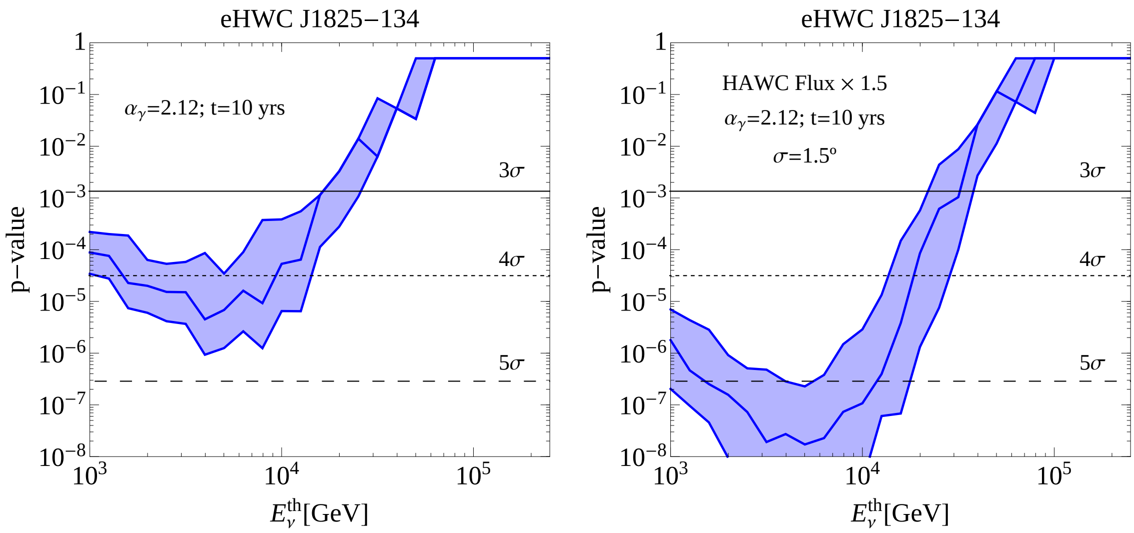

Figure 3: Left panel: p-value for the best-fit value of α_γ and values of $E_{cut,\gamma}$ within the statistical errors, for 10 years of running of the KM3NeT detector. The normalization is fixed to the best-fit value and the extension of the source is fixed to 0.53°. Left panel: p-value for the extended region. The HAWC flux has been multiplied by 1.5, as provided by the information from the Fermi/LAT analysis, and an opening angle of 1.5° has been considered.

3. Results

3.1 Fermi/LAT observations

The results of the Fermi/LAT spectral analysis, which is based on the aperture photometry approach, are shown in Fig. 1. The black data points show the source spectrum extracted from the region which encompasses the ∼ 1 TeV emission as observed by Fermi/LAT. The flux level measured by Fermi/LAT, in the TeV range, is higher than the one measured by the HAWC collaboration. Note, however, that the HAWC analysis assumes a Gaussian source morphology convolved with the HAWC point spread function, which does not match the complex morphology seen by Fermi/LAT. In the figure, we report also the data points for the HESS J1825-137 source considering an opening angle of 0.8° [8] and for the HESS J1826-130 source [8].

The 1.5° region extracted from the Fermi/LAT analysis, includes, apart from the HAWC extended source itself, also the pulsar PSR J1826-1256 and the diffuse emission from the Galactic disk in front/behind the source. For the pulsar, we considered the spectrum reported in the Fermi 4FGL catalog [9]. The spectrum of the diffuse emission from the inner Galactic disk is, instead, modelled with a power law spectrum with a slope $\Gamma \simeq 2.5$ [10, 11]. The high-energy hardening is modelled adding a cut-off power law component to the spectral model.

Fitting together the sum of these three components, we find that the normalisation of the cut-off power law is by factor of 1.5 higher for the Fermi/LAT as compared to the HAWC spectral fit. The discrepancy between these two spectra at energy around 1 TeV could be possibly ascribed either to the source morphology assumed to extract the HAWC flux, or to the difficulty of estimation of the cosmic ray background in the source region [12], or to possible systematic errors [4]. For a more detailed discussion about the analysis of the Fermi/LAT data from this region, we refer to [13].

3.2 Neutrino event rate from the eHWC J1825-134 source and extended region

The neutrino even rate from the eHWC J1825-134 source at the KM3NeT detector, as well as the background events, are reported in the right panel of Fig. 2. In the left panel of Fig. 3, instead, we show the results for the p-value as a function of the neutrino energy threshold for 10 years of running time of the KM3NeT detector. We found that for an energy threshold of the order of $E_\nu^{\rm thr} \lesssim 10$ TeV, a minimum in the p-value is present. In general, in 10 years of running of the KM3NeT detector, the significance is well above 3σ as long as the energy threshold is less than about 10 TeV.

We then estimated the neutrino event rate at KM3NeT considering the more extended region of 1.5° radius. In this case, we take the Fermi/LAT flux as reference and we set $\epsilon_\theta = 1$ (i.e. we do not assume a Gaussian morphology). In the right panel of Fig. 3, the p-value is shown. In this scenario, the statistical significance reaches 5σ in the case of 10 years running time and for an energy threshold of the order of about 10 TeV.

4. Conclusions

We have calculated the expected number of events at the KM3NeT detector from the source eHWC J1825-134, using data provided by the HAWC collaboration, as well as information derived by analysis of the Fermi/LAT data. We found that, after 10 years of running, a statistical significance between 4 and 5 σ has to be expected, depending on the actual extension and diffuse emission of the source.

The discovery potential for the eHWC J1825-134 source at the BAIKAL-GVD detector [14] in Baikal Lake will be similar to the one found for the KM3NeT detector.

The IceCube detector, instead, has an optimal sensitivity for sources located in the northern sky, but it is less sensitive to sources located in the southern sky, using tracks events. However, the use of cascades events, coming from interactions of neutrino of all flavours, and the use of the DeepCore sub-arrays improve the sensitivity to the sources in the southern celestial hemisphere [15]. Thus, the cascade channel represents the most promising way to discover this source with the IceCube detector.

Moreover, we want to add that possible combined analyses between tracks and cascades channels, or between data coming from different neutrino telescopes could improve the sensitivity to this source, respect of using only the upgoing muons at the KM3NeT detector.

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References

[1] S. Gabici, C. Evoli, D. Gaggero, P. Lipari, P. Mertsch, E. Orlando, A. Strong, A. Vittino, Int. J. Mod. Phys. D 28 (15) (2019) 1930022. arXiv:1903.11584.

[2] M. Kachelriess, D. Semikoz, Prog. Part. Nucl. Phys. 109 (2019) 103710. arXiv:1904.08160.

[3] A. U. Abeysekara, et al., Astrophys. J. 843 (1) (2017) 40. arXiv:1702.02992.

[4] A. Abeysekara, et al., Phys. Rev. Lett. 124 (2) (2020) 021102. arXiv:1909.08609.

[5] A. Kappes, J. Hinton, C. Stegmann, F. A. Aharonian, Astrophys.J. 656 (2007) 870–896. arXiv:astro-ph/0607286.

[6] S. Adrian-Martinez, et al., J. Phys. G43 (8) (2016) 084001. arXiv:1601.07459.

[7] F. L. Villante, F. Vissani, Phys. Rev. D78 (2008) 103007. arXiv:0807.4151.

[8] H. Abdalla, et al., Astron. Astrophys. 621 (2019) A116. arXiv:1810.12676.

[9] S. Abdollahi, et al., Astrophys. J. Suppl. 247 (1) (2020) 33. arXiv:1902.10045.

[10] A. Neronov, D. Malyshev, arXiv:1505.07601.

[11] R. Yang, F. Aharonian, C. Evoli, Phys. Rev. D93 (12) (2016) 123007. arXiv:1602.04710.

[12] A. Neronov, D. Semikoz, Astron. Astrophys. 633 (2020) A94. arXiv:1907.06061.

[13] V. Niro, A. Neronov, L. Fusco, S. Gabici and D. Semikoz, arXiv:1910.09065.

[14] A. D. Avrorin, et al., arXiv:1908.05427.

[15] M. Aartsen, et al., Astrophys. J. 886 (2019) 12. arXiv:1907.06714.