

Upper limits on the isotropic diffuse flux of cosmic PeV photons from Carpet-2 observations

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Submitted 2 December 2022

Resubmitted 15 December 2022

Accepted 16 December 2022

DOI: 10.31857/S1234567823030023, EDN: owefft

Isotropic diffuse gamma-ray flux in the PeV energy band is an important tool for multimessenger tests of models of the origin of high-energy astrophysical neutrinos [1] and for new-physics searches.

Gamma rays born jointly with neutrinos produce pairs on the cosmic microwave background [2] and are important to distinguish between Galactic and extragalactic scenarios [3–5]. Several Galactic models [6–11] and some new-physics scenarios [12, 13] (but see [14, 15]) can be tested. Anisotropic Galactic flux has been reported [16].

Carpet-2 is a surface air-shower array located at the Baksan Neutrino Observatory of INR RAS, see [17–24] and interpretation of the most recent result in [25, 26]. We use the effective number of relativistic particles N_e estimated by the surface detector and the number n_μ of muons recorded in the 175 m² area muon detector. For the purpose of this work, we use two data sets. The *Maximal-exposure* data set combines 1999–2011 events and 2018–2022 events with the cut $n_\mu > 1$ imposed in addition to the standard quality cuts [27]. The *Photon-friendly* data set includes the events recorded in 2018–2022 without the n_μ cut. Monte-Carlo (MC) simulations of photon-induced air showers and the Carpet-2 detector response are described in [27].

Air showers caused by primary gamma rays are poor in muons, and a low value of the ratio n_μ/N_e becomes a useful tracer of photon-induced events. Here, we develop and use a new statistical method to constrain the flux of primary photons, making use of the shapes of the distributions of electromagnetic and hadronic showers in n_μ/N_e , which are very different. The approach can

easily be generalized and applied to the data of other installations capable of detecting muons in air showers, e.g., Yakutsk [28], NEVOD [29] etc.

The results for the differential and integral fluxes are presented and compared to those published by other groups in Fig. 1.

Carpet-2 starts to operate with the extended muon detector of 410 m² in 2022 and will soon be upgraded to Carpet-3, covering a much larger surface area. With future large-scale installations, like LHAASO [37] and SWGO [38], the diffuse isotropic flux of PeV gamma rays might be eventually discovered.

This work was supported by Ministry of science and higher education of the Russian Federation under the contract 075-15-2020-778.

This is an excerpt of the article “Upper limits on the isotropic diffuse flux of cosmic PeV photons from Carpet-2 observations”. Full text of the paper is published in JETP Letters journal. DOI: 10.1134/S0021364022603244

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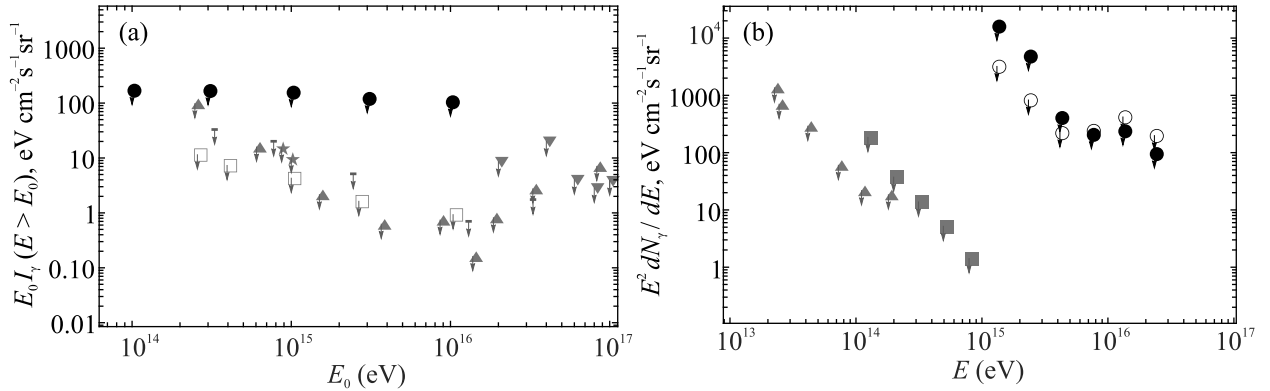


Fig. 1. 90% CL upper limits on the isotropic diffuse flux of high-energy photons. (a) – Integral flux. Black circles: Carpet-2, this work (strongest limits of the two data sets). Gray symbols – limits from other experiments (empty boxes – KASCADE [30], upward triangles – KASCADE and KASCADE-Grande [31], downward triangles – EAS-MSU [32], horizontal dashes – CASA-MIA [33], asterisks – EAS-TOP [34]). (b) – Differential flux. Black symbols: Carpet-2, this work (full circles – maximal-exposure data set, empty circles – photon-friendly data set). Gray symbols – limits from other experiments (triangles – HAWC [35], squares – analysis of Tibet-AS γ results by other authors [36])

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