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

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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 $175\,\mathrm{m}^2$ 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 m^2 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.

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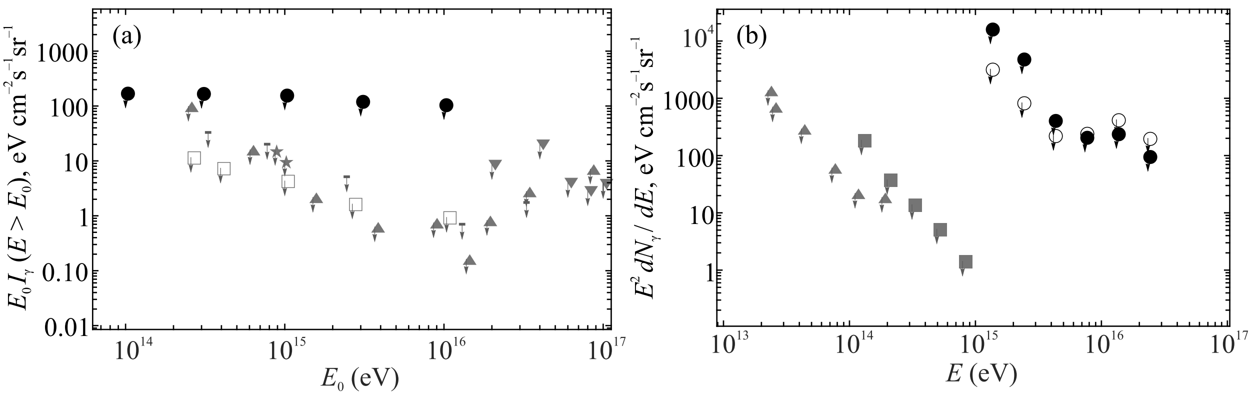

Fig. 1. 90% CL upper limits on the isotropic diffuse flux of high-energy photons. (a) – Integral flux. Black circles: Carpet-2, this work (strongest limits of the two data sets). Gray symbols – limits from other experiments (empty boxes – KASCADE [30], upward triangles – KASCADE and KASCADE-Grande [31], 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-ASγ results by other authors [36])

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