LHAASO telescope sensitivity to diffuse gamma-ray signals from the Galaxy

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We estimate the sensitivity of LHAASO telescope for the large angular scale diffuse γ-ray flux in multi-TeV—multi-PeV energy range. We discuss possible sources of the signal in this energy range including the guaranteed flux from cosmic ray interactions in the interstellar medium and possible flux from decaying dark matter. We show that LHAASO will be able to detect the diffuse cosmic ray induced γ-ray flux up to high Galactic latitude regions thus providing firm identification of the Galactic cosmic ray component of the astrophysical neutrino signal detected by IceCube and clarification of the nature of the knee feature of the cosmic ray spectrum. Comparing the diffuse flux sensitivity with the diffuse γ-ray flux expected from the dark matter decays, we show LHAASO will be able to detect the γ-ray signal from dark matter particles of PeV–EeV mass decaying on the time scale up to 3×10^{29} s.

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I. INTRODUCTION

Diffuse γ-ray flux from cosmic ray interactions in the Milky Way galaxy provides the strongest γ-ray signal on the sky [1–3]. This signal is measured up to the energy $\sim$3 TeV all across the Galactic plane, in the mid and high Galactic latitude regions by Fermi/LAT telescopes [1,2,4]. Its spectrum at the highest energies is consistent with a powerlaw $dN_\gamma/dE \propto E^{-\Gamma_\gamma}$ with the slope $\Gamma_\gamma \simeq 2.4$, with no signature of high-energy cut-off.

The main source of Galactic γ-rays in the multi-TeV energy band is decays of pions resulting from interactions of cosmic rays in the interstellar medium. Other diffuse flux components, such as the extragalactic γ-ray flux and inverse Compton emission from cosmic ray electrons are suppressed in this energy range. The extragalactic photons could not reach the Earth because of the pair production on the extragalactic background light (EBL) [5,6]. The inverse Compton flux is suppressed because of suppression of the scattering cross section in the Klein-Nishina regime of Compton scattering of the interstellar radiation field photons [7,8] and due to the high-energy cutoff in the spectrum of cosmic ray electrons [9].

The pion decay photons carry on average a fraction $E_\gamma \sim \kappa E_p$, $\kappa \simeq 0.04 \ll 1$ of the parent proton energy E_p [10,11]. This suggests that the Galactic diffuse emission spectrum is expected to ultimately have a high-energy softening at the energy by a factor κ lower of the limiting energy at which cosmic ray protons (and atomic nuclei) could not anymore be retained by the Galactic magnetic field [12]. If this characteristic energy is in the range of the “knee” of the cosmic ray spectrum at 1–10 PeV, the spectrum of the cosmic-ray generated diffuse γ-ray flux is expected to have a soften in the energy range 10–100 TeV. Measurement of such softening at different locations across the Galaxy is, in principle, possible with γ-ray telescopes sensitive in the TeV–PeV energy range. Such measurement would provide an important step toward understanding of the mechanism of propagation of cosmic rays through the interstellar medium and escape of cosmic rays from the Milky Way.

Apart from the conventional cosmic ray induced γ-ray flux, the TeV–PeV band diffuse emission might contain new types of contributions, which at the same time can explain high level of diffuse neutrino flux in 10–100 TeV energy range observed by IceCube [13–15]. Soft spectrum of neutrino signal in this energy range is inconsistent with conventional extragalactic source modelling [16]. Both large scale diffuse neutrino and gamma-ray fluxes can come from new types of Galactic sources like decaying dark matter (DM) [17–20], cosmic rays injected by nearby recent supernovae interacting with walls of local bubble [20–23] or from large-scale cosmic ray halo around the Milky Way [24–26].

In what follows we explore the sensitivity of LHAASO telescope [27] for the diffuse γ-ray flux distributed over large angular scales. We compare the sensitivity with the expected levels of the diffuse emission from cosmic ray interactions in the interstellar medium and from the DM decays. We show that LHAASO will provide detailed mapping of the cosmic ray induced γ-ray flux at all Galactic latitudes, in the energy range overlapping with that of IceCube astrophysical neutrino signal [13]. This will provide an identification of the Galactic component of the astrophysical neutrino flux first predicted by Berezinskii and Smirnov [12]. It will also reveal the characteristic energy at which the diffusion regime of cosmic ray changes [28] and they ultimately start to free-stream, rather than diffuse, out of the Galaxy. Finally, diffuse flux measurements will provide up to two orders of magnitude improvement of sensitivity for the search of decaying DM consisting of particles with masses in the PeV-EeV range.

II. LHAASO SENSITIVITY FOR DIFFUSE γ-RAY FLUX

The main obstacle for the measurements of large scale diffuse γ-ray flux with ground-based γ-ray telescopes is high level of residual charged cosmic ray background. Contrary to the γ-rays coming from isolated point sources, extensive air showers (EAS) produced by diffuse γ-rays could not be distinguished from the EAS produced by background charged cosmic rays based on directional information. Still the diffuse γ-ray flux varies as a function of the right ascension and declination, while the residual charged particle background rate depends mostly on zenith and azimuth angles. This difference provides a possibility for the measurements of the diffuse γ-ray flux even in the presence of much stronger charged cosmic ray background.

Imaging Atmospheric Cherenkov telescopes (IACT) can suppress the charged particle background down to the "minimal possible" level of the cosmic ray electron flux [9,29–31]. This opens a possibility of the study of the diffuse γ-ray flux in multi-TeV energy range where the cosmic ray electron flux decreases to the level comparable to the diffuse γ-ray flux [31].

This minimal possible charged particle background could not be reached with water Cherenkov detectors such as HAWC [32] and Water Cherenkov Detector Array (WCDA) of LHAASO [27] for which the background suppression techniques provide moderate efficiency in the energy range below 10 TeV, based on the imaging of the lateral distribution of particles in the EAS. Comparison of the background levels of HAWC, LHAASO with the minimal possible background level in $E < 20$ TeV energy range is shown in Fig. 1.

In the energy range above 20 TeV the background rejection performance of LHAASO rapidly improves due to the possibility of detection of the muon component of the EAS with the km2a array [27,33]. The level of the residual background of cosmic ray nuclei (protons) achieved with these technique reaches $\sim 10^{-5}$ of the cosmic ray flux in the energy range $E \sim 100$ TeV (Fig. 1).

The level of the residual charged particle background flux F_B determines the sensitivity for the diffuse γ-ray flux from a sky region within the field-of-view of a solid angle Ω for a telescope with effective collection area A in a given exposure time T: the minimal detectable flux should be much higher than the statistical fluctuations of the background:

$$F > 5\sqrt{F_B/(\Omega T A)} \tag{1}$$

The exposure $\Omega T A$ of LHAASO is compared to that of HAWC in Fig. 2. The annual exposures are calculated using the information on the effective collection areas at zenith angles $\Theta_z < 30°$.

For comparison we show in the same picture the exposure of the HAWC analysis of the Fermi Bubble region estimated based on the information given in Ref. [35]. Note in both HAWC nor LHAASO systematic uncertainties of modeling and measurement of the residual cosmic ray background preclude the possibility of the measurement of isotropic diffuse gamma-ray flux with

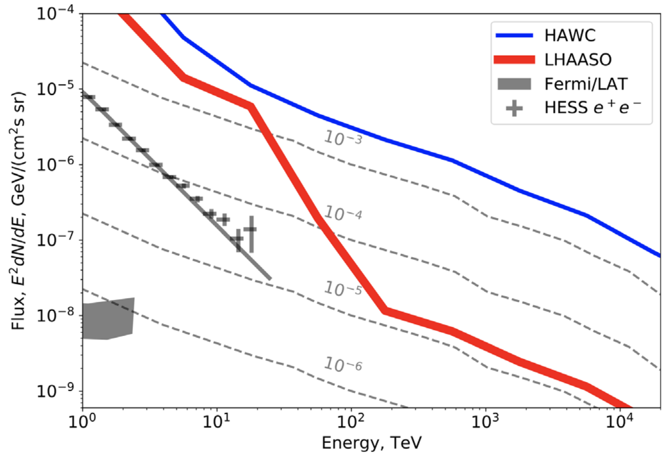

FIG. 1. Residual charged cosmic ray backgrounds for the diffuse γ-ray detection in Fermi/LAT [2], HESS (electron spectrum analysis) [9], HAWC [32], and LHAASO [33]. Grey dashed lines with markers show the fractional levels of the overall cosmic ray flux (from 10^{-6} to 10^{-3}).

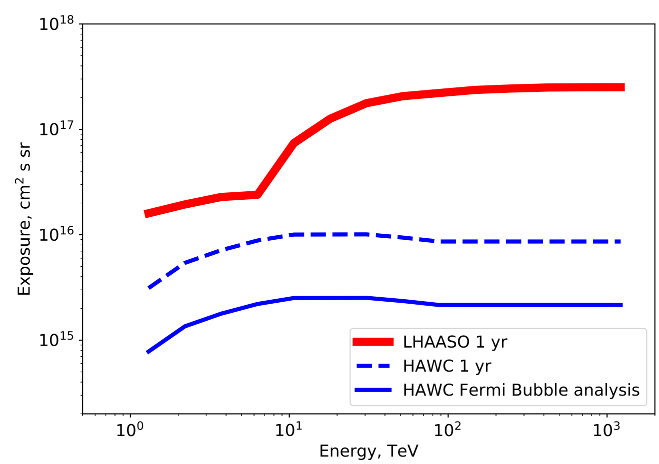

FIG. 2. Comparison of one-year exposures of HAWC [32] and LHAASO [33] of a sky revion within the telescope field-of-view with the HAWC exposure of the Fermi Bubble region considered for the dark matter decay signal search by Abeysekara *et al.* [34,35].

spatial morphology indistinguishable from that of the residual background. Nevertheless, is still possible to detect diffuse emission components with well defined spatial features, like an excesses around the Galactic plane, at low Galactic latitude and deficit at high Galactic latitude, excess in the direction of Fermi bubbles, or the characteristic excess around the Galactic center produced by the dark matter decays. Comparing diffuse signal + residual cosmic ray background fluxes from different parts of the sky provides a possibility to cancel the systematic uncertainty of the residual cosmic ray background modeling. In what follows we assume this approach for detection of the diffuse emission flux.

To calculate the sensitivity for the all-sky diffuse γ-ray flux we follow standard approach for the differential sensitivity estimate in γ-ray astronomy. We calculate the minimal detectable flux in individual energy bins (we choose the energy binning homogeneous in logarithm of energy, with two bins per decade, given moderate energy resolution of the water Cherenkov detectors). Apart from relation (1), we require that the detectable flux should be at least larger than 10^{-3} of the residual charged particle background, i.e., higher than the flux levels at which dipole anisotropy of the cosmic ray background is detected [36]. We also require that the flux should be high enough to produce at least 10 event counts in a given exposure. The residual cosmic ray flux has smaller angular scale anisotropies at the level of $\geq 10\%$ of the dipole [37]. The small scale anisotropy of the cosmic ray background is well measured by the combination of IceTop and HAWC data. It is possible to use this measurement as a template for the anisotropy of the residual background for the diffuse γ-ray study and hence to distinguish features of the diffuse γ-ray emission from those of the residual cosmic ray background. Nevertheless, the small scale anisotropy of the residual cosmic ray backgorund will inevitably introduce a systematic error in the measurement of the diffuse gamma-ray flux, at the level of $\sim 10\%$ of the residual cosmic ray background.

The resulting sensitivity is shown in Fig. 3. We have verified our sensitivity calculation via comparison of the estimate of sensitivity obtained with the method described above for HAWC Fermi Bubble exposure with the results on flux upper limits reported by HAWC Abeysekara *et al.* [35] we find a good agreement. This comparison is shown in Fig. 3. A discrepancy at the lowest energy is due to the face what we adopt a conservative assumption that the minimal detectable flux is at the level of the dipole anisotropy of the residual cosmic ray background, while the analysis of Ref. [35] reaches lower level via dedicated modeling of the dipole and smaller scale anisotropies.

Practical implementation of the measurement of the diffuse flux can rely on comparison of the flux levels integrated over the entire instantaneous field-of-view of LHAASO (a cone with opening angle about 45°).

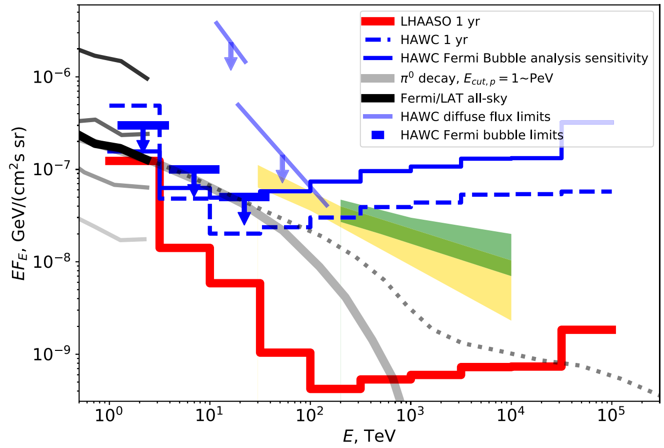

FIG. 3. Comparison of the sensitivity LHAASO and HAWC with model predictions of gamma-ray flux from cosmic ray interaction in the interstellar medium. Thin grey thin shaded levels in 0.3–3 TeV energy range show the measurements of diffuse Galactic γ-ray flux with Fermi/LAT, in the sky regions $|l| < 30°$, $|b| < 2°$; $150° < l < 210°$, $|b| < 2°$; $10° < |b| < 30°$; $|b| > 50°$ (from top to bottom), reported by Neronov and Semikoz [2]. Black thick line shows the all sky averaged flux level [20]. Grey thick line shows a model of pion decay emission produced by proton power law spectrum with cutoff at $E_{p,\mathrm{cut}} = 1$ PeV. Grey thick dotted line shows the spectrum without a high-energy cutoff but modified by the effect of $\gamma\gamma$ pair production on cosmic microwave background photons. Yellow and green butterflies show the measurements of the astrophysical neutrino spectrum by IceCube [15,38]. HAWC limits on the flux from Fermi Bubble region are from Ref. [35]. Limits on diffuse flux are from [39].

The lowest diffuse flux regions in the direction of the Galactic poles span approximately this angular size. Flux in the fields of view in the direction of regions at lower Galactic latitudes can be compared to the Galactic pole flux levels and the difference in the flux levels is then attributed to the diffuse γ-ray emission. A more refined approach would be to analyze simultaneously all the observable Northern sky, e.g., via a likelihood fitting of different diffuse and isolated source flux components, possibly using predefined templates for the spatial morphology of the signal. The likelihood fitting would also be appropriate for subtraction of resolved point and extended sources, necessary to for isolation of the diffuse flux component.

III. γ-RAY SIGNAL FROM COSMIC RAY INTERACTIONS

From Fig. 3 one can see that the sensitivity limit of LHAASO is well below the expected level of diffuse γ-ray flux from the sky in $E \gtrsim 10$ TeV energy range [2,20] in all sky segments. Only in the high Galactic latitude regions, $|b| > 50°$ the diffuse sky flux could possibly be marginally detectable by LHAASO, if its spectrum extends as a power law to 10–100 TeV energy range [2].

The cosmic ray spectrum in the local Galaxy has a pronounced "knee" softening feature of unknown origin at energy around 3 PeV in all particle spectrum (see discussion of both observations and interpretations of knee in recent review [40]). It is possible that the spectral softening at the knee is due to the change of regime of propagation of cosmic rays in the interstellar medium [41–43]. Lower energy cosmic rays are efficiently scattered off inhomogeneities of the turbulent component of Galactic magnetic field. Higher energy cosmic rays diffuse faster along the ordered magnetic field lines [44–46]. The exact energy of such regime change depends on the structure of magnetic field [47]. The Galactic magnetic field varies across the Galactic disk and the energy of the knee feature should therefore also vary. It is, however, not possible to observe such variability with the direct cosmic ray measurements which are available only on the Earth location.

Interactions of cosmic rays with energies in the PeV range result in production of γ-rays with energies in the 10–100 TeV range. A feature in the PeV cosmic ray flux induces a feature in the diffuse γ-ray flux. Therefore, measurements of the 10–100 TeV diffuse γ-ray flux from different parts of the Galaxy provide a possibility to measure the position of the knee of cosmic ray spectra at different locations of the Galaxy. Details of the changes in the gamma-ray spectrum in 10–100 TeV band are determined by the specific of the mechanism of the change of diffusion regime of cosmic rays in the knee energy range. Comparison of LHAASO sensitivity with the sky-average flux model of pion decay emission generated by a cut-off power law distribution of protons with cut-off energy $E_{p,\mathrm{cut}} = 1$ PeV, calculated based on the parameters of Ref. [10], is shown in Fig. 3. LHAASO sensitivity for the diffuse γ-ray flux is largely sufficient for detection and mapping of the position of high-energy suppression of the γ-ray flux induced by the knees of cosmic ray spectra at different locations all along the Galactic plane. This is clear from the comparison of the sky averaged flux measurement by Fermi/LAT in the TeV range (shown by the thick black line) with the diffuse emission flux levels in the inner and outer Galactic plane regions [2] shown by two top thin grey lines in the TeV energy range in Fig. 3.

An alternative model for the origin of the knee is that it represents high-energy cutoff in the injection spectrum of Galactic cosmic rays from dominant component of cosmic ray sources [48–51]. If there are no sources in the Galaxy able to accelerate protons to the energies much above PeV, the Galactic component of the cosmic ray flux would have a high-energy cutoff. Given that the escape time of PeV cosmic rays from the Galaxy is relatively short, only a small number of individual cosmic ray sources contributes to the cosmic ray content of the Galaxy in the PeV range at any given moment of time. In particular, only one nearby source can dominate cosmic ray flux around knee [52–54]. Such source could be e.g., Vela supernova, which also can be responsible for large fraction of diffuse neutrino flux [22,23].

Similarly to the escape model of the knee, it is not possible to test cutoff model with direct cosmic ray measurements. The test is possible only with γ-ray observations. Contrary to the escape model of the knee, variations of the knee positions across the Galactic disk are not expected to correlate with the variations of the structure of Galactic magnetic field in this "source spectral cutoff" model. This provides a possibility for the test of both models with LHAASO observations in different sky directions.

It is possible that some Galactic cosmic ray sources produce cosmic rays with energies well above the knee. In this case one expects to observe the diffuse emission spectrum without a high-energy cut-off in the 10–100 TeV range from a sky region around such sources. This possibility is shown by the thick dotted grey line in Fig. 3. Even in the absence of the cutoff in the emission spectrum, the spectrum of γ-rays from a source in the Galactic center region is expected to show strong deviation from a power law. The "dip" spectral feature visible in this spectrum in the PeV energy range is due to the effect of $\gamma\gamma$ pair production on cosmic microwave background photons [5]. This type of features in the spectra of isolated sources and diffuse emission is also detectable by LHAASO.

The diffuse γ-ray flux from cosmic ray interactions is accompanied by the neutrino flux with comparable spectral characteristics. Therefore, measurement of the diffuse γ-ray flux from all over the sky in the energy band 10 TeV–10 PeV by LHAASO will "nail down" the Galactic part of the astrophysical neutrino signal found by IceCube [13–15] (shown in Fig. 3), thus providing at least a partial resolution of the problem of the origin of astrophysical neutrinos.

The overall anisotropy of the astrophysical neutrino flux does not reveal strong excess toward the Galactic plane or the Galactic center direction. This suggests that either the Galactic component does not dominate the astrophysical neutrino flux or that there is a new Galactic flux component which appears in the multi-TeV energy range and is distributed all over the sky, rather than concentrated toward the Galactic plane. Such new component could be due to interactions of cosmic rays from nearby sources [20,22,23] or emission from the large scale cosmic ray halo around the Milky Way [24,26]. Predictions for γ-ray fluxes in these models are shown in Fig. 4. Both the local source and the large scale halo fluxes are bound to be at most at the level of the high Galactic latitude γ-ray flux in the TeV energy range.

The large scale halo cosmic ray spectrum is close to the E^{-2} power law which is determined by the injection spectrum of cosmic rays from Galactic sources. The halo spectrum has a cut-off at the energy is the characteristic maximal energy attainable in the Galactic cosmic ray sources. The γ-ray spectrum of the halo follows the powerlaw of the parent proton spectrum (close to E^{-2} and has a cutoff at the energy by a factor $\sim$30 below the

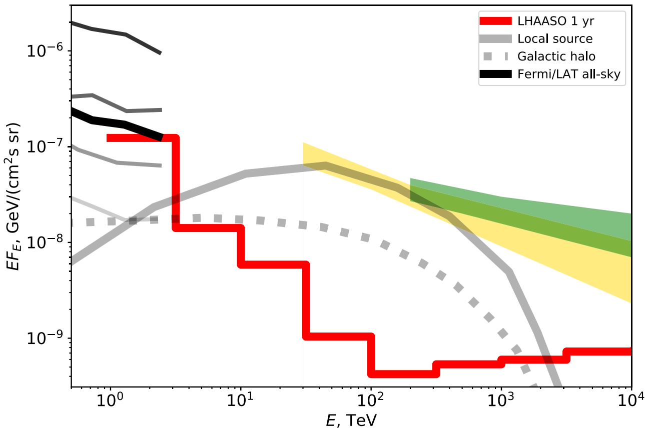

FIG. 4. Comparison of the sensitivity LHAASO and HAWC with predictions of the local source (thick grey solid line) and large-scale cosmic ray halo (thick dotted grey line) models. Thin grey shaded levels in 0.3–3 TeV energy range show the measurements of diffuse Galactic γ-ray flux with Fermi/LAT, in the sky regions $|l| < 30°$, $|b| < 2°$; $150° < l < 210°$, $|b| < 2°$; $10° < |b| < 30°$; $|b| > 50°$ (from top to bottom), reported by Neronov and Semikoz [2]. Thick black line is the sky average diffuse flux measurement [20]. Yellow and green butterflies show the measurements of the astrophysical neutrino spectrum by IceCube [38].

cutoff energy of the parent proton spectrum, because the characteristic energy of the pion decay γ-rays is much below the energy of the parent protons [10].

The spectrum diffuse emission from the cosmic ray halo around a local source is harder than E^{-2} because low energy cosmic rays are still retained in the source region and could not escape to the interstellar medium. As a result, the γ-ray and neutrino flux levels could reach the level of the IceCube neutrino flux in the 100 TeV energy range. The local source spectrum also has a cutoff at the energy determined by the maximal energy of cosmic rays accelerated in the source [20,22,23].

IV. γ-RAY SIGNAL FROM THE DECAYING DARK MATTER

Cosmic ray interactions in the interstellar medium provide a guaranteed source of neutrinos and γ-rays with energy range above 10 TeV. Apart from this guaranteed source, other "unexpected" sources might appear on the sky, like the DM decay signal. It has unique spectral and imaging properties and could be readily distinguished from the diffuse flux from cosmic ray interactions.

The best strategy for the indirect search of the decaying DM is best performed with telescopes providing the largest "grasp" $G = A\Omega$ [55–57]. HAWC and LHAASO are the detectors with the largest grasp in the very-high-energy γ-ray band and are therefore well suited for the DM search.

The signal from the Galactic DM halo is

$$\frac{dF_{\rm DM}}{d\Omega} = \frac{\kappa\Gamma_{\rm DM}}{4\pi}\int_{\rm los}\rho_{\rm DM}(r)dl \qquad (2)$$

where $\rho_{\rm DM}(r)$ is the DM density as a function of the radius from the Galactic center, κ is the fraction of the rest energy of the DM particles transferred to γ-rays and $\Gamma_{\rm DM} = 1/\tau_{\rm DM}$ is the decay width which is inverse of the DM decay time $\tau_{\rm DM}$. Typical variations of the DM column density $\int_{\rm los}\rho_{\rm DM}dl$ across the sky directions are within a factor of 2 around the sky-average value. In our estimates we use the DM column density calculation for the Navarro-Frenk-White (NFW) density profile

$$\rho_{\rm DM} = \frac{\rho_0}{(r/r_0)(1+r/r_0)^2} \qquad (3)$$

with $\rho_0 = 0.2\ {\rm GeV/cm^3}$ and core radius $r_0 = 21.5$ kpc [55,58].

The cosmological contribution to the DM decay signal is suppressed in the γ-ray band due to the pair production of the photons of the extragalactic background light (EBL) [6]. This is not the case for the neutrino signal, which still has the cosmological (isotropic) component. This component reduces the scale of variations of the signal across the sky in the neutrino channel.

Different strategies for the search of the DM decay signal are possible. HAWC analysis [34] has adopted an approach in which stronger signal from the directions around the Galactic center (more precisely, the region of Fermi bubble) is searched and the rest of the sky is considered for the background estimate. An alternative possibility is to search for somewhat weaker (by a factor of two, on average) signal across the entire sky. An advantage of the latter approach is larger exposure available for the full-sky search. Assuming that the Fermi Bubble region analyzed by Abeysekara *et al.* [34] spanned an angle $\Theta_{\rm FB} \lesssim 0.5$ sr, while the full sky available for HAWC is a strip within declination range from $-25°$ to $65°$, with total $\Omega \simeq 7.3$ sr, one finds that the exposure of the Fermi bubble region is a fraction $\Omega_{\rm FB}/\Omega \simeq 7\%$ of the HAWC annual exposure. The signal-to-noise ratio scales as a square root of time, and the full-sky exposure would provide an increase of the DM signal-to-noise ratio by a factor of $\simeq$2 on one-year observation time span, compared to the Fermi bubble region exposure, in spite of the lower average flux.

Use of the full-sky exposure, rather than of limited sky region around the Galactic center is important also in the view of uncertainties of the Galactic diffuse γ-ray emission unrelated to the DM decay flux. This Galactic diffuse emission provides a background on top of which the DM decay signal is detected. Even though this background is possibly subdominant compared to the residual charged particle background in γ-ray telescopes, it might still be stronger than the DM decay signal.

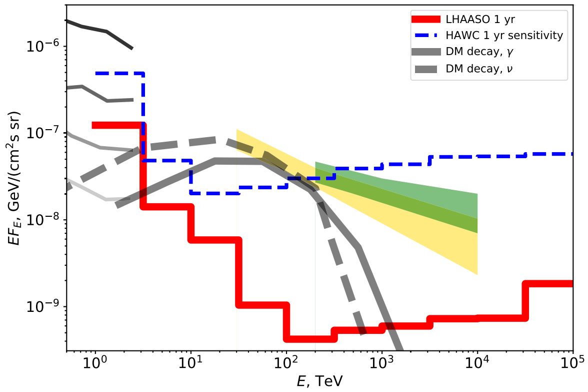

FIG. 5. Comparison of the sensitivity LHAASO and HAWC with the expected sky-averaged multimessenger signal from decaying DM with $\tau_{DM} = 3 \times 10^{27}$ s, and DM particle mass $m_{DM} = 5$ PeV, which could explain the IceCube astrophysical neutrino flux [20]. Thin grey shaded levels in 0.3–3 TeV energy range show the measurements of diffuse Galactic γ-ray flux with Fermi/LAT, in the sky regions $|l| < 30°$, $|b| < 2°$; $150° < l < 210°$, $|b| < 2°$; $10° < |b| < 30°$; $|b| > 50°$ (from top to bottom), reported by Neronov and Semikoz [2].

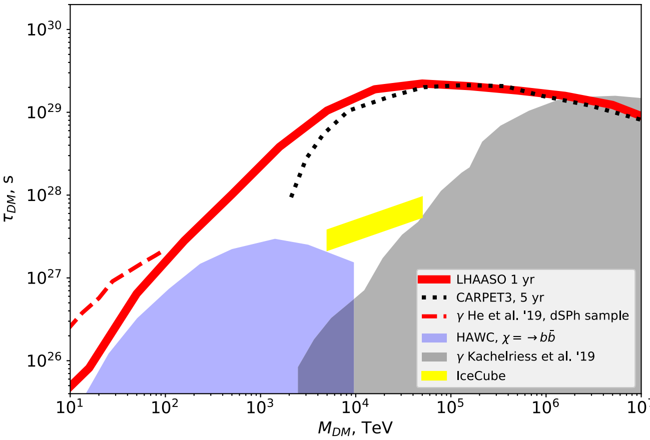

FIG. 6. Sensitivity of LHAASO for the measurement of dark matter decay time (for DM decaying into quarks). Yellow band shows the range of decay times for which DM decays give sizeable contribution to the IceCube neutrino signal [20]. Blue and grey shaded regions show the existing bounds imposed by HAWC [34] and ultrahigh-energy cosmic ray experiments [59]. and dashed curves are from the HAWC search of the DM decay signal in the Fermi bubble regions [34]. Dashed red line shows an estimate of LHAASO sensitivity for decaying DM from the analysis of a sample of dwarf spheroidal galaxies from Ref. [60].

Figure 5 shows a comparison of sensitivity of LHAASO with the model predictions for the γ-ray and neutrino fluxes for the DM with mass $m_{DM} = 5$ PeV decaying into quarks on the time scale $\tau_{DM} = 3 \times 10^{27}$ s [20]. The decay time is chosen so that the neutrino flux level is comparable to the IceCube astrophysical neutrino flux. From this figure one can see that LHAASO sensitivity for the diffuse γ-ray flux will be sufficient for the detection of the γ-ray signal in such DM decay model.

To estimate LHAASO sensitivity reach for the decaying DM search, we follow the approach of Ref. [34] to estimate the significance of detection of the DM decay signal sampled from all sky in the field-of-view. In each energy bin we compare the DM decay flux levels for different values of m_{DM}, τ_{DM} with the residual charged particle background levels and calculate by how much is the χ^2 of the fit of the signal + background data is inconsistent with the background-only model in all energy bins. In this way we find the minimal detectable DM decay flux as a function of the DM mass for the model of Ref. [20] of DM decaying into quark-antiquark pair. We then convert the estimate of the minimal detectable flux into the estimate of the maximal measurable DM decay time using Eq. (2). The result is shown in Fig. 6. From this figure one could see that LHAASO will explore the range of DM decay times up to $\tau_{DM} \sim 3 \times 10^{29}$ s over a wide DM mass range $m_{DM} > 10$ PeV. In the mass range 10 TeV $< m_{DM} <$ 10 PeV LHAASO will provide a factor of 3-to-10 improvement of sensitivity compared to HAWC. In any case, LHAASO will fully test a model in which non-negligible fraction of the astrophysical neutrino flux is generated by the DM decays. Comparing LHAASO sensitivity with the limits imposed by the nondetection of γ-ray signal by ultrahigh-energy cosmic ray experiments [59] we find that the LHAASO will mostly provide better sensitivity in the DM mass range below EeV.

Figure 5 also shows a comparison of the sensitivity of the DM decay signal search using the DM halo of the Milky Way with the sensitivity which can be reached based on observations of a sample of isolated sources, dwarf spheroidal galaxies (dSph).

V. CONCLUSIONS

We have explored the potential of LHAASO for the study of diffuse γ-ray emission signals in the TeV–PeV energy range. We find that its sensitivity will be largely sufficient for the measurement of Galactic diffuse γ-ray flux generated by interactions of cosmic rays with energies up to the knee (Figs. 3, 4). LHAASO study of the diffuse γ-ray flux will provide a clue for solution of the problem of the nature of the knee feature of the cosmic ray spectrum. It will also nail down the Galactic component of the astrophysical neutrino flux, including possible contributions from the local bubble and Galactic halo. LHAASO will provide a major improvement of sensitivity for the search of the γ-ray signal from decaying heavy DM particles with masses in the TeV–EeV range (Fig. 6). This improvement will be sufficient for the full test of a model of the IceCube astrophysical neutrino signal in which a sizeable fraction of the neutrino flux originates from DM decays in the Galactic halo and in the distant Universe.

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