Prospect for dark matter signatures from dwarf galaxies by
LHAASO

Dong-Ze He\textsuperscript{1}, Xiao-Jun Bi\textsuperscript{2,3}, Su-Jie Lin\textsuperscript{2}, Peng-Fei Yin\textsuperscript{2}, and Xin Zhang\textsuperscript{1,4}

\textsuperscript{1}Department of Physics, College of Sciences, Northeastern University, Shenyang 110819, China
\textsuperscript{2}Key Laboratory of Particle Astrophysics, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China
\textsuperscript{3}School of Physical Sciences, University of Chinese Academy of Sciences, Beijing 100049, China and
\textsuperscript{4}Center for High Energy Physics, Peking University, Beijing 100080, China

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Large High Altitude Air Shower Observation (LHAASO) is a next generation observatory for high energy gamma-rays and cosmic rays with wide field of view. It will observe gamma-rays with unprecedented sensitivity in the energy range between 300 GeV to 1 PeV. Therefore it is promising for LHAASO to search for the high energy gamma-rays induced by dark matter (DM) annihilation in dwarf spheroidal satellite galaxies (dSphs), which are ideal objects for the DM indirect detection. In this work, we investigate the LHAASO sensitivity to DM annihilation signatures for nineteen dSphs and take the uncertainty of the $J$-factors of dSphs into account. We perform a joint likelihood analysis for the nineteen dSphs and find that the LHAASO sensitivity to the DM annihilation cross section will reach $\mathcal{O}(10^{-24}) \sim \mathcal{O}(10^{-25})$ cm$^3$ s$^{-1}$ at the mass scale above TeV for several annihilation modes.
I. INTRODUCTION

A lot of compelling astrophysical and cosmological observations have indicated the existence of non-baryonic cold dark matter (CDM), which constitutes nearly 25% of the energy budget of the universe [1]. DM is essential in the evolution of Universe and the formation of large-scale structures. However, in spite of the acknowledged existence of DM, we still have a poor understanding about its fundamental properties as an elementary particle, and do not know its interaction with the Standard Model particles other than gravity. In order to reveal these mysteries, many new physics models have been proposed in the literature, among which a popular kind of the DM candidate is the weakly interacting massive particles (WIMPs) [2–4].

WIMPs could either annihilate or decay in astrophysical systems today, and then produce steady and energetic Standard Model particles, such as protons/antiprotons, electrons/positrons, neutrinos, and photons. One kind of the mainstream DM identification methods, namely the indirect DM detection, is just to search for such non-gravitational signals and to further reveal the physical properties of DM particles. Particularly, the observations of high-energy gamma-ray emissions produced by DM annihilation, either monoenergetic (from direct annihilation) or with a continuum of energies (through the cascade decays or final state radiations), are of great interest and importance, because the propagation process of gamma-rays is not deflected by the interstellar magnetic field and can naturally trace back to the sites where DM annihilations occur. As the DM annihilation rate is proportional to the square of DM density distributions, these gamma-ray signatures would be preferentially generated in the DM dominated regions, and then can be detected by terrestrial and satellite experiments.

Hitherto, quite a number of works have been performed to study the gamma-ray signatures from DM annihilation in many different dark-matter-rich astrophysical objects, such as galaxy clusters [5], galactic halo [6–12], galactic DM substructures [13–15], etc. Since there is no significant gamma-ray excess to date that has been confirmed, the stringent upper limits on the DM annihilation cross section have been reported in the literature [16–26]. Among these astrophysical objects, the dwarf spheroidal satellites (dSphs) of the Milky Way, known as large galactic substructures predicted by the CDM scenario, are considered to be the most promising and ideal laboratories for the indirect DM detection. Firstly, the mass-to-light ratios in dSphs can be of very large order of magnitude, which suggests that they are significantly DM dominated systems. Secondly, dSphs are also expected to be relatively free of gamma-ray emission from other astrophysical sources, since they have little or no recent star formation activity and detected ionized gas [27, 28]. These outstanding advantages could extremely simplify the interpretation of a gamma-ray excess potentially detected in the direction of a dSph.

During the past twenty years, the achievements in Gamma Ray astronomy either in the GeV range with space-borne instruments or in the TeV region with ground-based detectors,
produced extraordinary advances in high energy astrophysics. However, for the gamma-ray sky in the energy range above a few tens of TeV, the past and present telescopes can only record few photons, which makes this energy region almost completely unexplored. Under this circumstance, a strong interest is addressed to the development of next-generation instruments, which are able to make more precise observations in a more extended energy range with a high sensitivity. Currently, the most sensitive detectors for very high energy (VHE) gamma-rays are imaging air Cherenkov telescopes (IACTs), such as H.E.S.S [29], VERITAS [30] and MAGIC [31]. But the sensitivity of IACTs would be limited by their small field of view (FOV) and short operation duty cycle. The ground-based air shower particle detectors, such as Tibet-AS\γ and ARGO-YBJ may overcome those disadvantages of IACTs, but the poor background rejection power still limits their sensitivities. One of the reasonable methods to improve the sensitivity of the ground-based array detectors is to detect muons in the shower, such as the Muon Detector of Tibet-AS\γ experiment. Besides, the water Cherenkov detectors Milagro and high altitude water Cherenkov (HAWC) also take advantage of the muon information to discriminate photons from cosmic rays.

Most importantly, the under-construction large high altitude air shower observatory (LHAASO) project [32, 33], will become a continuously-operated gamma-ray telescope at energies from $\sim 300$ GeV to 1 PeV and open a new window for the gamma-ray detection. LHAASO is designed to maintain a high sensitivity as well as a strong background rejection power ($\sim 1\%$) and a large FOV ($\sim 2$ sr) simultaneously. Therefore, through the VHE gamma-ray observation from dSphs by LHAASO, it is very promising to detect the DM annihilation signatures or set strong limits on the properties of heavy DM. From such a point of view, we investigate the prospects for detecting the DM annihilation signature by the LHAASO observations of nineteen dSphs. We also take the uncertainties of the $J$-factor of dSphs into account [34, 35], and study the impact of these uncertainties on the LHAASO sensitivity. In order to derive a reasonable sensitivity, the simulated data of LHAASO considering the background rejection power are also used.

This paper is organized as follows. In Sec. II, we give a brief introduction to the LHAASO experiment. In Sec. III, we discuss the calculation of gamma-ray flux from DM annihilation and introduce the methods of simulating the gamma-ray observation and of calculating the limits on DM annihilation cross section. We show the LHAASO sensitivities to the DM annihilation cross section and make comparison with other experimental results in Sec. IV. Finally, the conclusion is given in Sec. V.

II. LHAASO OBSERVATORY

LHAASO is a hybrid cosmic ray and gamma-ray observatory located at 4410 m above sea level near Daocheng, Sichuan province, China (100°.01E, 29°.35N). LHAASO experiment is composed of a square kilometer particle detector array (KM2A), a water Cherenkov detector
array (WCDA), a wide field Cherenkov telescope array (WFCTA), and a high threshold shower core detector array (SCDA).

KM2A is primarily designed for the detection of very high energy gamma-rays ($E \gtrsim 10$ TeV). The surface array consists of 5195 scintillator electron detectors with 1 m$^2$ each and a spacing of 15 m. The large effective area of $\sim$ km$^2$ of the surface detectors could provide enough exposure for the photons with high energies. With the purpose of rejecting the cosmic ray background, 1171 underground muon detectors with 36 m$^2$ each and a spacing of 30 m will be built under the surface detector array, with the total active area being up to 40000 m$^2$. For the energies above 50 TeV, KM2A will achieve a background free detection of photons and make LHAASO become the most sensitive observatory around the world.

WCDA, located at the center of KM2A array, is attributed to the gamma-ray detection in the lower energy range $\lesssim 10$ TeV. It is comprised of four water pools with $150 \times 150$ m$^2$ each, and the total active area is 90000 m$^2$ which is 4.5 times larger than that of HAWC. In addition, WFCTA and SCDA are dedicated to measure the cosmic ray spectra of individual composition, providing a multi-parameter measurement in order to better distinguish between different compositions. Thereinto, WFCTA can detect the longitude evolution of a cosmic ray shower, and SCDA can detect the shower components near the core.

The gamma-ray sensitivity of LHAASO to a Crab like source is shown in Fig. 1 [33]. In this figure, the exposure time is one year for air shower array experiments and 50 hours for IACTs. It is shown that for energies above 20 TeV, LHAASO will be the most sensitive gamma-ray experiment in the world. The three major goals of LHAASO are: (1) surveying the very high energy gamma-ray sky with a sensitivity of $\sim 1\%$ of the Crab Nebula flux, (2) precisely measuring the cosmic ray spectrum of individual composition at the knee region and beyond, and (3) exploring the new physics frontiers. For the layout of the detectors and a more detailed description of the experiment, we refer the reader to Refs. [32, 33].

The most relevant detectors for gamma-ray detection of LHAASO are KM2A and WCDA. Thanks to the large area of the array KM2A and the high capability of background rejection, LHAASO can reach sensitivities for gamma-rays with energies above $\sim 30$ TeV, about 100 times higher than that of current experiments, offering the possibility to monitor the gamma-ray sky up to 100 TeV for the first time, and thus is preferably effective for the detection of gamma-rays from Galactic source. The threshold energy of WCDA can be as low as $\sim 300$ GeV and thus it could be effective for the extragalactic sources. As it is still under-construction, in this paper we exclusively focus on the discussion about the prospects of searching for heavy annihilating DM particles above TeV from the LHAASO gamma-ray observation of dSphs.
FIG. 1. Simulated integral sensitivity of LHAASO for a Crab-like source, compared with the sensitivities of other experiments [33, 36]. The observation times are 1 year and 50 hours for wide field of view detectors and IACTs, respectively.

III. ANALYSIS METHOD

A. Gamma-ray fluxes from DM annihilation in dSphs

The expected gamma-ray flux from DM annihilation is calculated with the utilization of not only the astrophysical properties of the potential DM distribution, but also the properties of the initial and final state particles in different annihilation channels. For self-conjugate DM particles, the gamma-ray integral flux from pair annihilation in a dSph (point-like source) can be given by

\[ \Phi = \frac{1}{4\pi} \frac{\langle \sigma v \rangle}{2m^2}\int_{E_{\text{min}}}^{E_{\text{max}}} \frac{dN_\gamma}{dE_\gamma} dE_\gamma \times J, \]  

(1)

where \( m_\chi \) is the DM mass, \( \langle \sigma v \rangle \) is the thermal average velocity-weighted DM annihilation cross section, \( \frac{dN_\gamma}{dE_\gamma} \) is the differential spectrum of prompt photons resulting from DM annihilation, and the integration is for each energy bins between \( E_{\text{min}} \) and \( E_{\text{max}} \). Note that \( \frac{dN_\gamma}{dE_\gamma} \) should be a sum of all the photons from any possible DM annihilation final states according to the DM model. However, in this analysis we only hypothesize the gamma-ray contribution from a certain annihilation channel through the use of the PPPC4DM package [37, 38].

In Eq. (1), \( J \) represents the astrophysical “J-factor”, which is the integral of the DM density squared along the line of sight (l.o.s) distance \( x \) in the region of interest (ROI)

\[ J = \int_{\text{source}} d\Omega \int_{\text{l.o.s}} dx \rho^2(r(\theta, x)), \]  

(2)
where $\Omega$ denotes the solid angle of the observation region over which the $J$-factor is calculated, and can be expressed as $\Delta\Omega = 2\pi \times [1 - \cos \alpha_{\text{int}}]$, where $\alpha_{\text{int}}$ is the integration angle. The density profile $\rho(r)$ describes how the density of a astrophysical system varies with the distance $r$ from its center, which is given by

$$r(\theta, x) = \sqrt{R^2 - 2xR \cos \theta + x^2},$$

where $R$ is the distance from the Earth to the source center, and $\theta$ is the angle between the orientation to the center of source and the line of sight.

The DM density profile of dSphs can be derived from the kinematic observation of stellar velocities through the use of the Jeans equation (see e.g. Refs. [39–41]). There are several systematic and statistical uncertainties in the determination of the DM density profile and $J$-factor. For instance, the stellar surface brightness and velocity anisotropy profiles are required in the Jeans analysis, but these profiles have not been uniquely determined. For the ultra-faint dSphs with large $J$-factors which are of interest to the indirect detection, the lack of kinematic data would also induce large statistical uncertainties in the $J$-factor. In this work, we take the calculated mean values of $J$-factor and their statistical uncertainties of nineteen dSphs in Table I, which are calculated assuming a NFW density profile [34, 35]. Note here that these $J$-factors are integrated over a cone with the integration angle $\alpha_{\text{int}} = \min\{\theta_{\text{max}}, 0.5^\circ\}$. This is because in order to decrease the background event counts which will be calculated in next subsection, we are supposed to keep the integration angle as small as possible. The discussions on the systematic uncertainties in the $J$-factor of dSphs can be found in Refs. [42, 43] and the references therein.

### B. Events at LHAASO

The ground-based experiment LHAASO is impinged by secondary particles from the Extensive Air Shower (EAS) induced by cosmic rays. By monitoring the generated Cherenkov light in the water Cherenkov detectors (WCDs), one can estimate the cosmic particles’ energy and determine the orientations from which the initial cosmic particles arrived. Different kinds of initial cosmic particles (hadron/gamma) would lead to different energy distributions in the WCDs across the Array. For example, a gamma-ray shower results in a smoother energy distribution, whereas a hadron shower leads to a clumped distribution across the WCDs. Using this feature, we can discriminate the gamma signals from the backgrounds induced by the primary incoming cosmic-ray particles. Since LHAASO is still under-construction, at present we could only make a mimic observation.

The procedure is as follows: Firstly, we calculate the expected counts of background event resulting from the incoming cosmic ray particles. Then we assume that there is no significant signals from DM annihilation, and make a Gaussian sampling around the background event counts $B$ to get a mimic total observational counts $N$. 

TABLE I. The astrophysical properties of nineteen selected dSphs within the LHAASO FOV. The name, right ascension (RA.), declination (DEC.), maximum angular radius ($\theta_{\text{max}}$), and $J$-factor of the dSphs are listed below. The $J$-factor and $\theta_{\text{max}}$ of the dSphs are taken from Ref. [34]. However, for the four dSphs marked with asterisks whose $J$-factors are not given in Ref. [34], we utilize the calculated results from Ref. [35].

| Source          | RA. (deg) | DEC. (deg) | $\theta_{\text{max}}$ (deg) | $\log_{10} J_{\text{obs}}$ (GeV$^2$cm$^{-5}$) |
|-----------------|-----------|------------|-----------------------------|---------------------------------|
| Boötes I        | 210.02    | 14.50      | 0.47                        | 18.2 ± 0.4                     |
| Canes Venatici I| 202.02    | 33.56      | 0.53                        | 17.4 ± 0.3                     |
| Canes Venatici II| 194.29   | 34.32      | 0.13                        | 17.6 ± 0.4                     |
| Coma Berenices  | 186.74    | 23.90      | 0.31                        | 19.0 ± 0.4                     |
| Draco           | 260.05    | 57.92      | 1.30                        | 18.8 ± 0.1                     |
| Draco II*       | 238.20    | 64.56      | −                           | 18.1 ± 2.8                     |
| Hercules        | 247.76    | 12.79      | 0.28                        | 16.9 ± 0.7                     |
| Leo I           | 152.12    | 12.30      | 0.45                        | 17.8 ± 0.2                     |
| Leo II          | 168.37    | 22.15      | 0.23                        | 18.0 ± 0.2                     |
| Leo IV          | 173.23    | −0.54      | 0.16                        | 16.3 ± 1.4                     |
| Leo V           | 172.79    | 2.22       | 0.07                        | 16.4 ± 0.9                     |
| Pisces II*      | 344.63    | 5.95       | −                           | 16.9 ± 1.6                     |
| Segue I         | 151.77    | 16.08      | 0.35                        | 19.4 ± 0.3                     |
| Sextans         | 153.26    | −1.61      | 1.70                        | 17.5 ± 0.2                     |
| Triangulum II*  | 33.32     | 36.18      | −                           | 20.9 ± 1.3                     |
| Ursa Major I    | 158.71    | 51.92      | 0.43                        | 17.9 ± 0.5                     |
| Ursa Major II   | 132.87    | 63.33      | 0.53                        | 19.4 ± 0.4                     |
| Ursa Minor      | 227.28    | 67.23      | 1.37                        | 18.9 ± 0.2                     |
| Willman 1*      | 162.34    | 51.05      | −                           | 19.5 ± 0.9                     |

The background events $B$ can be calculated by

$$B = \int_{E_{\text{min}}}^{E_{\text{max}}} \int_{\Delta \Omega} \zeta_{\text{cr}} \cdot \Phi_p(E) \cdot A_{\text{eff}}^p(E) \cdot \varepsilon_p(E) d\Omega dE \times T,$$

(4)

where $\Phi_p(E)$ is the flux of protons in the primary cosmic rays described by a single power-law spectrum, which is best-fitted by the observational datasets of experiments ATIC [44], CREAM [45] and RUNJOB [46]. As the abundance of the rest particles in the cosmic ray is about 10% of the proton’s abundance, we introduce an additional factor $\zeta_{\text{cr}} = 1.1$ to take the contributions of other particles into account. The effective area $A_{\text{eff}}^p$ is derived from a interpolation calculation in the Science White Paper of LHAASO, which is a function of energy and zenith angle [47]. With regard to the survival ratio $\varepsilon$ in the $\gamma/p$ discrimination, we performed a rough simulation on WCDA, and find that $\varepsilon_p$ is $\sim 0.278\%$ when we keep $\varepsilon_{\gamma}$ equal to $\sim 40.13\%$ [48]. The observational time $T$ is taken to be one year. The integration is calculated in all the energy bins within a cone which is defined as $\Delta \Omega = 2\pi \times [1 - \cos(\max\{\alpha_{\text{int}}, \theta_c\})]$, where $\theta_c$ is the energy dependent angular resolution of LHAASO.
Similarly, the signal event $S$ can be expressed as
\[
S = \epsilon_{\Delta \Omega} \int_{E_{\text{min}}}^{E_{\text{max}}} \Phi_{\gamma}(E) \cdot A_{\text{eff}}(E) \cdot \varepsilon_{\gamma}(E)dE \times T,
\]
where $\epsilon_{\Delta \Omega} = 0.68$ is the fraction of observed event counts within the angular resolution of the instrument. Here, we assume that all the dSphs are point-like sources, as the energy dependent angular resolution of LHAASO is always larger than the typical angular radius scale of the inner region of the dSph, where DM annihilations have the most important contribution to the gamma-ray flux. The effective area $A_{\text{eff}}$ is derived from the same procedure as that in Eq. (4) and $\Phi_{\gamma}(E)$ is the flux of gamma photons from DM annihilation as described in Eq. (1).

C. Statistic analysis

In order to quantify the gamma-ray excess in a particular sky region, we perform a likelihood ratio test, which is determined by the ratio of the likelihoods under two hypotheses. The test statistic (TS) is calculated by
\[
\text{TS} = -2 \ln \left( \frac{L_{0,\text{max}}}{L_{\text{max}}} \right),
\]
where $L_{0,\text{max}}$ is the maximal likelihood under the null hypothesis without DM contribution, and $L_{\text{max}}$ is the maximal likelihood under the alternative hypothesis with DM contribution, evaluated at the value of the cross section which maximizes the likelihood. The factor of two in the definition is for the purpose of causing the distribution of TS values to asymptotically approach a $\chi^2$ distribution. Both likelihoods are taken to be Poisson distribution
\[
\mathcal{L}(S|B, N) = \prod_i \frac{(B_i + S_i)^{N_i} \exp[-(B_i + S_i)]}{N_i!},
\]
where $i$ denotes the $i$-th energy bin, $S_i$ is the sum of expected number of signal counts corresponding to a DM annihilation cross section, $B_i$ is the number of expected background counts, and $N_i$ is the number of total observed counts. Since the value of $S_i$ is physically restricted to be positive, for the sources within the under-fluctuations of the background (i.e., $S_i < 0$), the value of $S_i$ maximizing the likelihood is expected to be zero, being consistent with no gamma-rays from DM sources. In this case, we can get $L_0 = L_{\text{max}}$, leading to a TS value of zero for the under-fluctuations.

We also consider the statistical uncertainty in $J$-factor determination as a nuisance parameter in the likelihood formulation, following the approach in Refs. [25, 42]. The likelihood
in all energy bins for the \( j \)-th dSph can be written as

\[
\mathcal{L}_j = \prod_i \mathcal{L}_{ij}(S_{ij}|B_{ij}, N_{ij}) \times \mathcal{J}(J_j|J_{\text{obs},j}, \sigma_j),
\]

(8)

where \( i \) and \( j \) represent the \( i \)-th energy bin and \( j \)-th dSph, respectively. The \( J \)-factor likelihood term for the \( j \)-th dSph is assumed to be a Gaussian term

\[
\mathcal{J}(J_j|J_{\text{obs},j}, \sigma_j) = \frac{1}{\ln(10) J_{\text{obs},j} \sqrt{2\pi \sigma_j}} \times e^{-\left[\log_{10}(J_j) - \log_{10}(J_{\text{obs},j})\right]^2/2\sigma_j^2},
\]

(9)

where \( \log_{10}(J_{\text{obs},j}) \) and \( \sigma_j \) are the observed mean values and corresponding standard deviations. In the practical calculation, the \( \log_{10}(J_j) \) is chosen to maximize the \( \mathcal{L}_j \) for given \( \langle \sigma v \rangle \) and \( m_\chi \).

For a \( \chi^2 \)-distributed TS, in order to set a one-side 95% confidence level limit, we expect to derive the decreasing likelihood with increasing number of photons emitted from a potential DM source. We optimize \( \Delta \text{TS} = \text{TS} - \text{TS}_{95} = 2.71 \) corresponding to an alternative hypothesis excluded at 95% C.L. \[49\]

\[
-2 \ln \left( \frac{\mathcal{L}_{0,\text{max}}}{\mathcal{L}_{\text{max}}} \right) + 2 \ln \left( \frac{\mathcal{L}_{0,\text{max}}}{\mathcal{L}_{95}} \right) = 2 \left( \ln \mathcal{L}_{\text{max}} - \ln \mathcal{L}_{95} \right) = 2.71.
\]

(10)

Then we can set 95% C.L. upper limit on the DM signature flux by requiring that the corresponding log-likelihood has decreased by \( 2.71/2 \) from its maximum. After deriving the allowed amount of signal counts \( S_{95} \) at 95% C.L., we impose Eqs. (1) and (5) to derive the corresponding values of \( \langle \sigma v \rangle_{95} \).

For the joint likelihood analysis of many dSphs, the analysis procedure is similar to the single dSph analysis. The combined likelihood of all dSphs becomes

\[
\mathcal{L}^\text{tot} = \prod_j \mathcal{L}_j.
\]

(11)

By adjusting the number of \( \langle \sigma v \rangle \), we can get \( \langle \sigma v \rangle_{95} \) satisfying \( 2 \left( \ln \mathcal{L}_{\text{max}} - \ln \mathcal{L}_{95} \right) = 2.71/2. \)

IV. LHAASO SENSITIVITIES

In this section, we describe the LHAASO sensitivity to the DM annihilation cross section through the gamma-ray observation towards dSphs. The simulated integral flux sensitivity curve of LHAASO project to a Crab-like sources is shown in Fig. 1; the sensitive curves for other projects are also shown in the same figure for comparison \[33\]. We can clearly see that LHAASO is more sensitive at high energy range above \( \sim 10 \) TeV than other ground-based projects. This implies that LHAASO will have a better capability to explore the property
of heavy DM particles.

We select nineteen dSphs inside the FOV of LHAASO, whose mean values and uncertainties of the $J$-factor are listed in Table I. These dSphs are chosen for their favored declination angle for LHAASO and have well studied dark matter contents. Due to the large FOV of LHAASO (defined in the declination range $-11^\circ < \delta < 69^\circ$), we involved four more dSphs (Draco II, Leo V, Pisces II and Willman 1) in the analysis, compared with the observation of HAWC [50]. In light of the simulated gamma-ray observation of LHAASO, we calculate the sensitivities to the DM annihilation cross section for five annihilation channels $b\bar{b}$, $t\bar{t}$, $\mu^+\mu^-$, $\tau^+\tau^-$ and $W^+W^-$, as shown in Fig. 2. The individual sensitivities for each dSph are considered. In addition, the combined sensitivities resulting from a joint likelihood analysis for all the selected dSphs are also exhibited. For the sake of improving the research comprehensiveness, we take the statistical uncertainty of the $J$-factors into account, which would more or less loosen the sensitivity to the gamma-ray signature from dSphs. In spite of this issue, our result is still better than the current upper limit set by HAWC [50] by a factor of $2 \sim 5$.

We find that the combined sensitivity is dominated by the influence of three dSphs with large $J$-factors and favorable locations in the FOV of LHAASO, including Segue 1, Ursa Major II and Triangulum II. Since LHAASO is located at the latitude of $\sim 29^\circ$, it would be more sensitive than HAWC to the high-latitude sources such as Ursa Major II. Although Triangulum II with almost the largest $J$-factor among all the selected dSphs is very close to the center of the LHAASO FOV, it is not utterly dominant over the combined sensitivity. This is because the statistical uncertainty of the $J$-factor of Triangulum II is large due to the lack of kinematic observational data. Including the uncertainty of the $J$-factor into the joint likelihood analysis would alleviate the overestimation of the combined sensitivity to a great extent. The remaining 16 dSphs do not significantly impact on the combined sensitivity. Despite that some of them are relatively close to the center of the LHAASO FOV, those dSphs have so small $J$-factors that LHAASO is not sensitive enough to them.

In order to consider the statistic fluctuation in the analysis, we repeat 500 mimic observations under the null hypothesis considering the Poisson fluctuation on the expected event count. Then we calculate the median combined sensitivity and the two-sided 68% and 95% containment bands as shown in Fig. 3. In this figure, we also displayed the comparison of the LHAASO sensitivity to the constraints from another five dSph gamma-ray observations, including the HAWC combined limit [50], Fermi-LAT combined dSph limit [24], HESS combined dSph limit [51], VERITAS Segue 1 limit [52] and MAGIC Segue 1 limit [53].

Broadly speaking, the most strong LHAASO sensitivity to the DM annihilation cross section comes from the $\tau^+\tau^-$ annihilation channel, which is nearly close to $10^{-24} \text{ cm}^3 \text{ s}^{-1}$, for all the DM masses considered here. For the $b\bar{b}$ channel, the MAGIC observation sets the most stringent constraint up to $\sim 8 \text{ TeV}$. Above $\sim 8 \text{ TeV}$, LHAASO is more sensitive to this channel. Besides, with regard to the $\tau^+\tau^-$ and $W^+W^-$ channels, LHAASO are more sensitive beyond $\sim 2 \text{ TeV}$ and $\sim 3 \text{ TeV}$, respectively, compared with the current limits set
FIG. 2. The projected sensitivities to the DM annihilation cross section $\langle \sigma v \rangle$ at 95% confidence level for nineteen dSphs within the LHAASO FOV of one year for the $bb$, $tt$, $\mu^+\mu^-$, $\tau^+\tau^-$, $W^+W^-$ annihilation channels. The solid blue line represents the combined sensitivity resulting from a joint likelihood analysis, considering the observations of all dSphs.
FIG. 3. The LHAASO median combined sensitivities (red solid lines), and related two-sided 68% (yellow bands) and 95% (green bands) containment bands of one year for the $b\bar{b}$, $t\bar{t}$, $\mu^+\mu^-$, $\tau^+\tau^-$, and $W^+W^-$ annihilation channels. The HAWC combined limits [50], Fermi-LAT combined limit [24], VERITAS Segue 1 limit [52], HESS combined dSph limit [51] and MAGIC Segue 1 limit [53] are also shown for comparison.
by other experiments. For the $t\bar{t}$ and $\mu^+\mu^-$ channels, LHAASO has great sensitivities for the almost whole mass range from 1 TeV to 100 TeV. Therefore, we can conclude that LHAASO will be able to set stringent constraints on the property of heavy DM particles, especially for those heavier than $\sim 10$ TeV.

V. CONCLUSION AND DISCUSSION

LHAASO is a newly planed under-construction wide FOV observatory to research on VHE gamma-ray astronomy with unprecedented sensitivity. Considering the fact that LHAASO will carry out its preliminary operation at the end of this year, it is timely to predict the physical perspective of LHAASO based on the simulated experimental data. In this paper, we investigate the LHAASO sensitivity to the DM annihilation cross section for five DM annihilation channels by the gamma-ray observation of dSphs. We calculate the individual sensitivities for nineteen dSphs within the LHAASO FOV using a likelihood ratio analysis method. In order to make the analysis more comprehensive and reliable, the statistical uncertainty of the $J$-factor is also incorporated as a nuisance parameter in the likelihood formulation. In addition, we also calculate the combined sensitivity from a joint likelihood analysis of overall dSphs with the purpose of enhancing the statistical power in the calculation. These are the first simulated LHAASO sensitivity to the DM annihilation cross section using the mimic observation data.

Our calculation shows that the LHAASO combined sensitivity is dominated by the influence of the three dSphs with large $J$-factors: Segue 1, Ursa Major II and Triangulum II. Furthermore, we compare the LHAASO sensitivities with the current limits set by other five gamma-ray experiments, including HAWC, Fermi-LAT, VERITAS, HESS and MAGIC. The results manifest that the LHAASO sensitivities are better than the current limits above $\sim 2$, 5 and 8 TeV for the $\tau^+\tau^-$, $W^+W^-$ and $b\bar{b}$ channels, respectively. For the $t\bar{t}$ and $\mu^+\mu^-$ channels, LHAASO has great sensitivities in the large mass range from 1 TeV to 100 TeV.

It is worthwhile to mention several systematic uncertainties arising from the determination of the $J$-factor of dSphs would contribute a factor of several on the uncertainty of the final sensitivity. In spite of the existence of these uncertainties, our results still shows that the LHAASO gamma-ray researches of dSphs would be a promising way of the DM indirect detection. It is believed that LHAASO will greatly enrich our knowledge about heavy DM particles above $\mathcal{O}$(TeV).

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