Despite overwhelming cosmological and astronomical evidence, the nature of dark matter (DM) remains unknown \cite{1,2}. The masses of the possible DM particle candidates can span tens of orders in magnitude. The conventional channel for the direct detection of DM uses nuclear recoil to search for the elastic scattering between DM and target nucleus \cite{3}. This approach is sensitive to DM with masses above GeV/$c^2$, but insensitive to the
sub-GeV DM due to insufficient recoil energy to surpass the detection threshold. The big bang nuclear synthesis (BBN), on the other hand, puts constraints for DM mass less than $\mathcal{O}(1)\text{ MeV}/c^2$ [4], although with quite some model dependence. The combination of direct detection and BBN leaves open a very large mass range from $\text{MeV}/c^2 \lesssim m_\chi \lesssim \text{GeV}/c^2$. Within such a mass range, the cosmic microwave background (CMB) [5] and large-scale structures [6] can only put a lower limit on DM-nucleon cross section of $\sim 10^{-29}$ cm$^2$. In addition, the supernova SN1987A data can exclude some parameter space in between $10^{-47}$ and $10^{-40}$ cm$^2$ [7].

To explore the sub-GeV DM, various new approaches have been proposed and utilized, via e.g., accessing the electron recoil (ER) channel [8–16], lowering the nuclear recoil (NR) detection threshold [17–21], and utilizing the so-called Migdal effect [22–28]. It has also been realized that certain processes could boost the kinetic energy of the Galactic DM, leaving detectable energy in the detector [29–38]. In particular, the detectability of the cosmic ray boosted dark matter (CRDM) has been widely recognized since the upscattering of the DM would be inevitable were there finite DM-nucleus interactions [4,39–47].

Recently it was pointed out in Ref. [47] that due to the directionality of the Galactic cosmic rays and the Earth rotation, the detected rate and recoil energy spectra of CRDM would exhibit a sidereal diurnal modulation. Utilizing this signature, the PROSPECT collaboration has realized CRDM would exhibit a sidereal diurnal modulation. Utilizing this signature, the PROSPECT collaboration has performed the first experimental search for CRDM [48] using a liquid scintillator anti-neutrino detector with a 6.4 tonne-day surface data set, probing a DM mass region from keV/c$^2$ to GeV/c$^2$ and a DM-nucleon cross section from $10^{-28}$ cm$^2$ to a few $10^{-26}$ cm$^2$, with the sensitivity floor limited by both the exposure and detector background. In this study, we perform a CRDM search using the full data set from the PandaX-II experiment [49–51]. With a 100 tonne-day exposure and a much lower background in PandaX-II, this analysis advances the search by three orders in interaction strength which was previously unexplored experimentally.

The prediction of CRDM signals includes calculations of the upscattered DM flux by cosmic rays (CRs), the attenuation in the Earth and the scattering in the detector. For the treatment of the first component, we adopt the procedure in Refs. [38–47], in which the Galactic CRs distribution is simulated with the GALPROP code [52], traversing through a Navarro-Frenk-White [53] Galactic DM distribution. Since the CRs are primarily protons and helium nucleus, the upscattered DM flux is connected with DM-proton cross section $\sigma_{\chi p}$ under the assumption of an isospin-independent, spin-independent interaction between the DM particle and nucleon, but modified by a so-called dipole form factor (see later). The form factor softens the upscattered spectrum, which in turn limits the acceleration effect particularly for massive DM particles. As shown in Ref. [47], the energy spectrum and angular distribution of the CRDM flux reaching the Earth can be treated as uncorrelated. Due to matter attenuation, the CRDM flux arriving at the detector varies with experimental sites. The China Jinping Underground Laboratory (CJPL) [54–55], where the PandaX-II experiment resides in, is located at 28.18°N and 101.7°E (Earth coordinates), 1580 m in elevation above the sea level, accessed by a 17 km long horizontal tunnel from both sides of the Jinping mountain. The rock overburden is about 2400 m. In our calculation, the Jinping mountain profile is extracted from the NASA SRTM3 data set [55–56] within an area of about 50×50 square kilometer.

The Earth attenuation is often calculated with the “ballistic trajectory” (BT) approximation [38–40,42–45,47], i.e. the DM travels strictly along a straight line but with an energy loss related to the DM scattering cross section. The average energy transfer per length $dx$ is

$$\frac{dT}{dx} = -\frac{\rho_A}{m_A} \int_0^{T_{\text{max}}} \frac{d\sigma(A)}{dT_{\text{r}}} T_{\text{r}} dT_{\text{r}},$$

in which $T_{\text{x}}$ and $T_{\text{r}}$ are the kinetic energy of the incoming DM and the outgoing nucleus, $\rho_A$ and $m_A$ are the Earth matter density and the nuclear mass, taken to be $\rho_A = 2.8$ [55], 4, and 11 g/cm$^3$ and $m_A = 24$, 24, and 54 GeV/c$^2$ [47] in the crust, mantle and core, respectively. $T_{\text{max}} = T_{\text{x}} (T_{\text{x}} + 2 m_\chi) / (T_{\text{x}} + m_\mu)$ is the maximum nuclear recoil energy, where $m_\chi$ is the DM mass, and $m_\mu = (m_\chi + m_\mu)^2 / 2 m_A$ is the reduced mass of the two-body system. $d\sigma(A)/dT_{\text{r}}$ is the recoil energy-dependent DM-nucleus differential cross section, which is related to the DM-proton cross section $\sigma_{\chi p}$ as

$$\frac{d\sigma(A)}{dT_{\text{r}}} = \frac{\sigma_{\chi p} A^2}{T_{\text{r}} T_{\text{max}}} \left[ m_A (m_\chi + m_\mu) / m_p (m_\chi + m_A) \right]^2 \frac{G_A(Q^2)}{Q^2},$$

where $m_p$ is the proton mass. In this equation, $G_A(Q^2) = 1/(1 + Q^2 / A_A^2)$ is the dipole nuclear form factor, where $A_A = 0.22$ and 0.18 GeV/c for the mantle (crust) and core, respectively [57–58], and $Q = \sqrt{2 m_A T_{\text{r}}}$ is the 4-momentum transfer. The attenuation of CRDM flux in a given direction is obtained by numerically integrating Eqn. [1] along the line-of-sight through the Earth to CJPL, and is repeated for all solid angles.

The BT approximation ignores the angular deflection of the DM after scattering, which could be significant when the number of scatterings is large. To set the scale, the DM mean-free-path in the mantle is approximately 170 m if $\sigma_{\chi p} = 10^{-30}$ cm$^2$ when $G_A = 1$. The deflection after each scattering is driven by Eqn. [4] due to the scattering angle dependence of $Q^2$. An independent Monte Carlo (MC) simulation is developed to
incorporate details of the scatterings using similar approaches as in Refs. [41, 45, 48, 52]. The CRDM particles are randomly generated on the Jinping mountain surface (50 km×50 km) according to their sky distribution at a given sidereal time, with energy above 1 GeV truncated to avoid inelastic contributions [39, 48]. Only the CRDM flux with DM momentum pointing below the earth horizon are selected - contribution from other angles would have to penetrate and be deflected by the bulk of the Earth, therefore conservatively omitted [60]. The DM-nucleus collisions inside the mountain are simulated, with collision steps randomly sampled using the total DM-nucleus cross section (integral of Eqn. (2) over recoil energy). The outgoing DM angle is uniformly sampled in the center-of-mass frame, but weighted by Eqn. (2) for proper angular dependence. Clearly, the angular deflection becomes large for lower energy CRDM. Such stepping process is repeated until the DM reaches the CJPL site, exits the mountain, or stops completely. The attenuated CRDM flux using the BT and full MC are overlaid in Fig. 1 at two fixed sidereal hours for DM mass $m_\chi = 0.1 \text{ GeV/c}^2$ and cross section $\sigma_{\chi p} = 10^{-30} \text{ cm}^2$. The event rate induced by CRDMs varies with sidereal time due to the rotation of the Earth [47], peaking around $t_{\text{sid}} \sim 18 \text{ hr}$ when the Galactic center appears on the same side of the Earth as CJPL, and reaching the minimum around $t_{\text{sid}} \sim 6 \text{ hr}$ when they are on opposite sides. As expected, the full MC simulation gives a more conservative underground flux, and will be used in the CRDM search in the rest of this paper.

PandaX-II utilizes a 580 kg dual-phase xenon time projection chamber to search for scattering of the DM off xenon atoms, where the prompt scintillation photons ($S_1$) and the delayed proportional electroluminescence photons ($S_2$) are collected by photomultiplier arrays to reconstruct the energy and position of events. Details on the experiment and data-taking are described in previous PandaX-II analyses [49, 51, 61]. This analysis uses the full PandaX-II data sets, including Runs 9, 10, and 11 [51]. The electron equivalent energy of each event is reconstructed as $E_{ee} = 13.7 \text{ eV} \times (S_1/\text{PDE} + S_2/\text{EEE/SEG})$, where PDE, EEE and SEG represent the photon detection efficiency, electron extraction efficiency, and single electron gain, respectively, with values taken from Ref. [51]. The NR energy is connected with $E_{ee}$ via the so-called Lindhard quenching factor [62]. The same data quality and selection cuts as in Ref. [51] are adopted. The radial selection is set at $R^2 < 55,000 \text{ mm}^2$, resulting in negligible surface background contribution [63]. The corresponding fiducial mass is 250.5 ± 9.6 kg and the total exposure is 100 tonne-day. The reconstructed energy range is required to be less than 25 keV$_{ee}$, which is approximately 100 keV NR energy. In total, there are 2111 events selected, with distribution in log$_{10}(S_2/S_1)$ vs. $S_1$ is shown in Fig. 2a.

The ER and NR signal response models in the PandaX-II detector are constructed under the NEST 2.0 prescription [64], with parameters fitted from calibration data [65]. Our background model includes tritium, $^{85}$Kr, $^{127}$Xe, $^{136}$Xe, the so-called “flat ER” (including detector material radioactivity, radon, and neutrinos), neutrons and accidental events. The estimate of each component’s contribution and distribution in $(S_1,S_2)$ is described in Ref. [65]. For our signal model, the NR spectrum produced by CRDM is calculated based on the attenuated CRDM energy spectrum for a given $m_\chi$, $\sigma_{\chi p}$, and $t_{\text{sid}}$ (c.f. Fig. 1) [39], and the standard Helms form factor [66]. To purify CRDM candidates, a further cut is decided in the $(S_1, \log_{10}(S_2/S_1))$ space, utilizing the discrimination power of the NR signal against the ER background in PandaX-II. A figure-of-merit $\epsilon_S/\sqrt{B}$ scan is made, where $\epsilon_S$ is the NR signal efficiency estimated based on the $^{241}$Am-Be neutron calibration data and $B$ is the remaining background under the cut. The optimal cut is found to be at the NR median line, which maintains roughly 50% of the DM NR signal efficiency and excludes approximately 99% of the ER background. The expected background under this cut is summarized in Table I with a mean value of 26.6 events and an overall uncertainty of 17%.

The NR median lines, slightly different in Run 9 and Runs 10/11 due to varying run conditions, are overlaid in Fig. 2a. For all three runs, 25 candidate events are found below the NR median lines. Our search is performed based on their reconstructed energy $E_{ee}$ and $t_{\text{sid}}$, with corresponding one-dimensional projections shown in Figs. 2b and 2c. To fit the data, a standard unbinned likelihood function is constructed. The distribution of

![Fig. 1: Attenuated CRDM flux at CJPL at sidereal hours 6 (red) and 18 (blue), where the solid and dashed lines denote results obtained with the full MC and BT methods, respectively.](image-url)
TABLE I: Expected background events in Run 9, 10 and 11, after the below-NR-median signal selection cut.

| Item             | Run9 | Run10 | Run11 | Total |
|------------------|------|-------|-------|-------|
| Tritium          | 0    | 0.83  | 3.91  | 4.74 ± 1.90 |
| $^{86}$Kr        | 2.14 | 0.45  | 8.49  | 11.08 ± 3.32 |
| $^{127}$Xe       | 0.96 | 0.06  | 0     | 1.02 ± 0.23 |
| $^{136}$Xe       | 0    | 0.01  | 0.04  | 0.05 ± 0.01 |
| Flat ER          | 0.72 | 1.17  | 5.61  | 7.50 ± 2.25 |
| Neutron          | 0.31 | 0.17  | 0.64  | 1.12 ± 0.56 |
| Accidental       | 0.34 | 0.17  | 0.60  | 1.11 ± 0.33 |
| **Total**        | 4.47 | 2.86  | 19.29 | 26.62 ± 4.49 |
| **Data**         | 10   | 1     | 14    | 25    |

background events in $t_{\text{sid}}$ is assumed to scale with the data taking live time in each bin. This assumption is validated using the 2086 events above the NR median, in which the rate vs. $t_{\text{sid}}$ is flat using a binned likelihood fit with a goodness-of-fit p-value of 36%. No significant CRDM signal is found above background.

A profile likelihood ratio approach is used to set the CRDM signal exclusions [67], comparing fits to the data with pseudo-data sets produced at different values of $m_\chi$ and $\sigma_{\chi p}$. Since the distributions of background and CRDM signal in ($t_{\text{sid}}$, $E_{\text{ee}}$) depend on their distributions in S1 and S2, our ER and NR model uncertainties [68] have to be properly incorporated. For illustration, the 90% contours of the ER and NR medians obtained through the calibration data [65] are overlaid in Fig. 2a. Therefore, our pseudo-data sets are generated by sampling the signal and background models within the allowed ranges. The 90% C.L. exclusion of the CRDM parameter space is shown in Fig. 3 (red region), together with the ±1σ sensitivity band obtained from the background-only pseudo-data. Our lower exclusion boundary lies within the sensitivity band, confirming that our data are consistent with background-only hypothesis. At the lower exclusion boundary, about a few $10^{-32}$ cm$^2$, the Earth shielding effect is negligible, therefore the limit is driven by the product of the flux of CRDM and its detection probability. For comparison, the sensitivity for the lower boundary weakens by 10% or so if the sidereal hour information is omitted from the analysis. The upper exclusion boundary at around $10^{-26}$ cm$^2$ is driven by the shielding from the Jinping mountain. The mass range of CRDM signals are limited to about 1 GeV/$c^2$, beyond which the acceleration by CRs becomes inefficient kinematically, and the CRDM energy spectrum is further softened by the form factor. For comparison, the recent result from PROSPECT [43], and constraints from cosmological and astrophysical observables [44] are overlaid in Fig. 3. Our data cover a large region from MeV/$c^2$ to GeV/$c^2$ and between few $10^{-32}$ cm$^2$ and $10^{-29}$ cm$^2$ in cross section, which was not constrained previously neither experimentally nor by cosmological and astrophysical probes. It is notewor-

FIG. 2: (a) $\log_{10}(S2/S1)$ vs. $S1$ distribution for all 2111 events in PandaX-II with equal-NR-energy lines in Run 11 indicated by the grey curves. The red and blue bands are the 90% contours of the ER and NR medians in Run 11. Larger circles are the final 25 candidates used in this search. (b) energy distribution of the final candidates, overlaid with the nominal background (blue) and the CRDM signals at (0.1 GeV/$c^2$, $10^{-30}$ cm$^2$) (red dashed) and (10$^{-4}$ GeV/$c^2$, $10^{-31}$ cm$^2$) (purple dashed); (c) $t_{\text{sid}}$ distribution, overlaid with the same CRDM signals in (b) and the nominal background.
thy that our upper exclusion boundary is similar to that from PROSPECT, a surface detector with only shielding from the atmosphere. The reason lies in the fact that our mean-free-path in the mountain is calculated using Eqn. [3], with the form factor included as suggested by Ref. [45], whereas in the PROSPECT’s treatment, the form factor suppression in the mean-free-path is conservatively omitted [68]. For illustration, the exclusion contour adopting the same treatment as PROSPECT is shown as the dashed blue curve in Fig. 3, significantly weakening the upper exclusion. Nevertheless, since our curve (red) is more self-consistent in applying the form factor, we quote it as our official result. On the other hand, we adopt the 1 GeV cut-off in the CRDM energy to avoid incoherent and inelastic contributions, leading to a more conservative Earth shielding evaluation as compared to Ref. [43].

In summary, we report a sensitive search for the CRDM using 100 tonne-day full data set from PandaX-II. The sidereal diurnal modulation in rate and energy spectrum are used in this analysis. No significant dark matter signals are identified above the expected background. A new exclusion limit is set on the DM-nucleon scattering cross section with nucleon within $10^{-25}$ cm$^2$ to $10^{-26}$ cm$^2$. More sensitive searches can be carried out using the upcoming data from PandaX-4T [69] and other multi-ton DM experiments [70][72].

We thank C. V. Cappiello and Yufeng Zhou for helpful discussion. This project is supported in part by Office of Science and Technology, Shanghai Municipal Government (grant No. 18JC1410200), a grant from the Ministry of Science and Technology of China (No. 2016YFA040301), grants from National Science Foundation of China (Nos. 12005131, 11905128, 12090061, 12090064, 11775141), and Shanghai Pujiang Program (20PJ1407800). QY acknowledges the support by the Key Research Program of the Chinese Academy of Sciences (No. XDBP15) and the Program for Innovative Talents and Entrepreneur in Jiangsu. We thank supports from Double First Class Plan of the Shanghai Jiao Tong University. We also thank the sponsorship from the Chinese Academy of Sciences Center for Excellence in Particle Physics (CCEPP), Hongwen Foundation in Hong Kong, and Tencent Foundation in China. We strongly acknowledge the CJPL administration and the Yalong River Hydropower Development Company Ltd. for indispensable logistical support and other help.

FIG. 3: 90% exclusion region with the full MC method (red region), together with constraints from PROSPECT [48] (yellow), CMB [5] (gray) and Cosmology [4, 6] (brown). The green band is the ±1σ sensitivity band. The dashed blue curve represents limits obtained with the mean-free-path in the mountain computed assuming $G_A = 1$, consistent with the treatment in Ref. [48]. Phenomenological interpretations of the experimental data [35][41] are omitted from the figure, for visual clarify.

*Spokesperson: jianglai.liu@sjtu.edu.cn
†Corresponding author: nzhou@sjtu.edu.cn
‡Corresponding author: yuanq@pmo.ac.cn

[1] G. Bertone, D. Hooper, and J. Silk, Phys. Rept. 405, 279 (2005) [arXiv:hep-ph/0404175 [hep-ph]]
[2] G. Bertone and D. Hooper, Rev. Mod. Phys. 90, 045002 (2018)
[3] J. Liu, X. Chen, and X. Ji, Nature Phys. 13, 212 (2017) [arXiv:1709.00688 [astro-ph.CO]]
[4] G. Krnjaic and S. D. McDermott, Phys. Rev. D 101, 123022 (2020)
[5] W. L. Xu, C. Dvorkin, and A. Chael, Phys. Rev. D 97, 103530 (2018)
[6] K. K. Rogers, C. Dvorkin, and H. V. Peiris, (2021), [arXiv:2111.10386 [astro-ph.CO]]
[7] W. DeRocco, P. W. Graham, D. Kasen, G. Marques-Tavares, and S. Rajendran, Phys. Rev. D 100, 075018 (2019) [arXiv:1905.09284 [hep-ph]]
[8] R. Essig, J. Mardon, and T. Volansky, Phys. Rev. D 85, 076007 (2012) [arXiv:1108.5383 [hep-ph]]
[9] T. Emken, R. Essig, C. Kouvaris, and M. Sholapurkar, JCAP 09, 070 (2019) [arXiv:1905.06348 [hep-ph]]
[10] R. Essig, A. Manalaysay, J. Mardon, P. Sorensen, and T. Volansky, Phys. Rev. Lett. 109, 021301 (2012) [arXiv:1206.2644 [astro-ph.CO]]
[11] R. Essig, M. Fernandez-Serra, J. Mardon, A. Soto, T. Volansky, and T.-T. Yu, JHEP 05, 046 (2016) [arXiv:1509.01586 [hep-ph]]
[12] P. Agnes et al. (DarkSide), Phys. Rev. Lett. 121, 111303 (2018) [arXiv:1802.00998 [astro-ph.CO]]
[13] D. W. Amaral et al. (SuperCDMS), Phys. Rev. D 102, 091101 (2020) [arXiv:2005.14067 [hep-ex]]
[14] L. Barak et al. (SENSEI), Phys. Rev. Lett. 125, 171802 (2020) [arXiv:2004.11378 [astro-ph.CO]]
[15] A. Aguilar-Arevalo et al. (DMIC), Phys. Rev. Lett. 128, 181802 (2019) [arXiv:1907.12628 [astro-ph.CO]]
[16] C. Cheng et al. (PandaX-II), Phys. Rev. Lett. 126, 211803 (2021) [arXiv:2101.07479 [hep-ex]]
[17] S. Pirro and P. Mauzskopf, Ann. Rev. Nucl. Part. Sci. 67, 2021
[18] A. Abdelhameed et al. (CRESST), Phys. Rev. D 100, 102002 (2019).
[19] M. Mancuso et al. (CRESST), J. Low Temp. Phys. 199, 547 (2020).
[20] E. Aprile et al. (XENON Collaboration), Phys. Rev. Lett. 123, 251801 (2019).
[21] P. Agnes et al. (DarkSide Collaboration), Phys. Rev. Lett. 121, 081307 (2018).
[22] M. Ibe, W. Nakano, Y. Shoji, and K. Suzuki, JHEP 03, 194 (2018), arXiv:1707.07258 [hep-ph].
[23] D. Baxter, Y. Kahn, and G. Krnjaic, Phys. Rev. D 101, 076014 (2020), arXiv:1908.00012 [hep-ph].
[24] R. Essig, J. Pradler, M. Sholapurkar, and T.-T. Yu, Phys. Rev. Lett. 124, 021801 (2020), arXiv:1908.10881 [hep-ph].
[25] D. S. Akerib et al. (LUX), Phys. Rev. Lett. 122, 131301 (2019), arXiv:1811.11241 [astro-ph.CO].
[26] E. Armengaud et al. (EDELWEISS), Phys. Rev. D 99, 092003 (2019), arXiv:1901.03588 [astro-ph.GA].
[27] Z. Z. Liu et al. (CDEX), Phys. Rev. Lett. 123, 161301 (2019), arXiv:1905.00354 [hep-ex].
[28] E. Aprile et al. (XENON Collaboration), Phys. Rev. Lett. 123, 241803 (2019).
[29] L. Necib, J. Moon, T. Wongjirad, and J. M. Conrad, Phys. Rev. D 95, 075018 (2017).
[30] T. Emken, C. Kouvaris, and N. G. Nielsen, Phys. Rev. D 97, 063007 (2018).
[31] C. Kouvaris, Phys. Rev. D 92, 075001 (2015).
[32] M. Aoki and T. Toma, JCAP 10, 020 (2018), arXiv:1806.09154 [hep-ph].
[33] G. F. Giudice, D. Kim, J.-C. Park, and S. Shin, Phys. Lett. B 780, 543 (2018), arXiv:1712.07126 [hep-ph].
[34] H. An, M. Pospelov, J. Pradler, and A. Ritz, Phys. Rev. Lett. 120, 141801 (2018).
[35] C. Kachulis et al. (Super-Kamiokande Collaboration), Phys. Rev. Lett. 120, 221301 (2018).
[36] B. Fornal, P. Sandick, J. Shu, M. Su, and Y. Zhao, Phys. Rev. Lett. 125, 161804 (2020).
[37] W. Wang, L. Wu, J. M. Yang, H. Zhou, and B. Zhu, JHEP 12, 072 (2020), Erratum: JHEP 02, 052 (2021), arXiv:1912.09904 [hep-ph].
[38] K. Bondarenko, A. Boyarsky, T. Bringmann, M. Hufnagel, K. Schmidt-Hoberg, and A. Sokolenko, JHEP 03, 118 (2020), arXiv:1909.08632 [hep-ph].
[39] T. Bringmann and M. Pospelov, Phys. Rev. Lett. 122, 171801 (2019), arXiv:1810.10543 [hep-ph].
[40] Z.-H. Lei, J. Tang, and B.-L. Zhang, (2020), arXiv:2008.07116 [hep-ph].
[41] C. V. Cappiello and J. F. Beacom, Phys. Rev. D 100, 103011 (2019).
[42] C. Xia, Y.-H. Xu, and Y.-F. Zhou, Nucl. Phys. B 969, 115470 (2021), arXiv:2009.00353 [hep-ph].
[43] C. Xia, Y.-H. Xu, and Y.-F. Zhou, (2021), arXiv:2111.05559 [hep-ph].
[44] Y. Ema, F. Sala, and R. Sato, Phys. Rev. Lett. 122, 181802 (2019).
[45] J. B. Dent, B. Dutta, J. L. Newstead, and I. M. Shoemaker, Phys. Rev. D 101, 116007 (2020).
[46] C. V. Cappiello, K. C. Y. Ng, and J. F. Beacom, Phys. Rev. D 99, 063004 (2019).
[47] S.-F. Ge, J. Liu, Q. Yuan, and N. Zhou, Phys. Rev. Lett. 126, 091804 (2021).
[48] M. Andriamirado et al. (PROSPER Collaboration), Phys. Rev. D 104, 012009 (2021).
[49] X. Cui et al. (PandaX-II Collaboration), Phys. Rev. Lett. 117, 121303 (2016).
[50] X. Wang et al. (PandaX-II), Chin. Phys. C 44, 125001 (2020), arXiv:2007.15469 [astro-ph.CO].
[51] A. W. Strong and I. V. Moskalenko, Astrophys. J. 509, 212 (1998), arXiv:astro-ph/9807150.
[52] J. F. Navarro, C. S. Frenk, and S. D. M. White, Astrophys. J. 490, 493 (1997), arXiv:astro-ph/9611107.
[53] K. J. Kang, J. P. Cheng, Y. H. Chen, Y. J. Li, M. B. Shen, S. Y. Wu, and Q. Yue, J. Phys. Conf. Ser. 203, 012028 (2010).
[54] Z. Guo et al. (JNE), Chin. Phys. C 45, 025001 (2021), arXiv:2007.15925 [physics.ins-det].
[55] T. G. Farr et al., Rev. Geophys. 45, 207 (2007).
[56] C. F. Perdrisat, V. Punjabi, and M. Vanderhaeghen, Prog. Part. Nucl. Phys. 59, 694 (2007), arXiv:hep-ph/0612014.
[57] I. Angell, [Atom. Data Nucl. Data Tabl. 87, 185 (2004).
[58] Z. Z. Liu et al., (2021), arXiv:2111.11243 [hep-ex].
[59] The effect of the diurnal modulation under this assumption is verified to be essentially the same as the BT method for the cross section considered here.
[60] A. Tan et al. (PandaX-II Collaboration), Phys. Rev. D 93, 122009 (2016).
[61] B. Lenardo, K. Kazka, A. Manalaysay, J. Mock, M. Szydagis, and M. Tripathi, IEEE Trans. Nucl. Sci. 62, 3387 (2015), arXiv:1412.4417 [astro-ph.IM].
[62] X. Zhou et al. (PandaX-II), Chin. Phys. Lett. 38, 109902 (2021), arXiv:2008.06485 [hep-ex].
[63] M. Szydagis et al., "Noble Element Simulation Technique v2.0", (2018).
[64] B. Yan et al. (PandaX-II), Chin. Phys. C 45, 075001 (2021), arXiv:2102.09158 [physics.ins-det].
[65] C. Savage, K. Freese, and P. Gondolo, Phys. Rev. D 74, 043531 (2006), arXiv:astro-ph/0607121.
[66] D. Baxter et al., (2021), arXiv:2105.00599 [hep-ex].
[67] C. V. Cappiello, “private communication,”.
[68] Y. Meng et al. (PandaX-4T), (2021), arXiv:2107.13438 [hep-ex].
[69] E. Aprile et al. (XENON), JCAP 11, 031 (2020), arXiv:2007.08796 [physics.ins-det].
[70] D. S. Akerib et al. (LZ), Nucl. Instrum. Meth. A 953, 163047 (2020), arXiv:1910.09124 [physics.ins-det].