Indirect detection, direct detection, and collider detection cross-sections for a 70 GeV dark matter WIMP

Bailey Tallman, Alexandra Boone, Caden LaFontaine, Trevor Croteau, Quinn Ballard, Sabrina Hernandez, Spencer Ellis, Adhithya Vijayakumar, Fiona Lopez, Samuel Apata, Jehu Martinez and Roland Allen

Physics and Astronomy Department, Texas A&M University
E-mail: allen@tamu.edu

Assuming a dark matter fraction $\Omega_{DM} = 0.27$ and a reduced Hubble constant $h = 0.73$, we obtain a value of 70 GeV/c$^2$ for the mass of the dark matter WIMP we have previously proposed. We also obtain a value for the annihilation cross section given by $\langle \sigma_{\text{ann}}v \rangle = 1.19 \times 10^{-26}$ cm$^3$/s in the present universe, consistent with the current limits for dwarf spheroidal galaxies. Both the mass and cross-section are consistent with analyses of the Galactic-center gamma rays observed by Fermi-LAT and the antiprotons observed by AMS-02 if these data are interpreted as resulting from dark matter annihilation. The spin-independent cross-section for direct detection in Xe-based experiments is estimated to be slightly above $10^{-48}$ cm$^2$, presumably just within reach of the LZ and XENONnT experiments with $\geq 1000$ days of data taking. The cross-section for production in high-energy proton collisions via vector boson fusion is estimated to be $\sim 1$ femtobarn, possibly within reach of the high-luminosity LHC, with $\geq 140$ GeV of missing energy accompanied by two jets.
cross-sections for a 70 GeV dark matter WIMP

Roland Allen

In earlier papers we proposed a new dark matter WIMP which has no interactions other than second-order interactions with W and Z bosons [1, 2]. This particle is unique among viable dark matter candidates in that it has a well-defined mass and couplings, with no free parameters, so that in principle precise predictions can be made for all experimental cross-sections. As described below, the mass is determined by adjusting it to yield the observed dark matter relic abundance, with both this quantity and the cross-section for annihilation in the present universe calculated using MicrOMEGAs [3]. The cross-sections for direct detection and collider detection are estimated from results for the inert doublet model [4, 5], by inferring the values in the limit that there is no Higgs coupling and that the masses of the particles other than the dark matter particle become extremely large: See Figs. 2 and 7 of Ref. [4], and Figs. 2 and 10 (plus Table 3) of Ref. [5]. (We have received communications from authors of these papers indicating that these estimates are reasonable. Now we are undertaking to replace the estimates by precise independent calculations.)

All cross-sections are relatively low, and thus consistent with current experimental and observational limits, because they result only from gauge interactions which are second-order.

In Fig. 1 we show representative diagrams for annihilation of the present dark matter candidate – the lowest-energy higgsion[1, 2] – if its mass $m_h$ is below the mass of the W boson. The currently preferred values of $\Omega_{DM} = 0.27$ and $h = 0.73$ imply that $\Omega_{DM} h^2 = 0.144$. The calculations with MicrOMEGAs yield $\Omega_{DM} h^2 = 0.134, 0.147, 0.162$ respectively for $m_h = 70.5, 70.0, 69.5$ GeV/c$^2$, so we conclude that $m_h \approx 70$ GeV/c$^2$ is required if the dark matter consists exclusively of this one component.

It should be mentioned, however, that the present theory includes supersymmetry at some energy scale, and a lightest supersymmetric partner, such as the lightest neutralino, can stably coexist with the lightest higgsion as a subdominant component, in a multicomponent scenario. Other components such as axions are also hypothetically possible, although such candidates have much more poorly defined masses and interactions.

Figure 1: Representative diagrams for annihilation of the present dark matter candidate.
cross-sections for a 70 GeV dark matter WIMP

Roland Allen

For a mass of 70 GeV/c², our calculations yield a cross-section given by \( \langle \sigma_{\text{ann}} \rangle = 1.19 \times 10^{-26} \) cm³/s for annihilation in the present universe. This value is consistent with the current limits from observations of dwarf spheroidal galaxies [7, 8].

Both the mass and cross-section are also consistent with the interpretation that (i) the Galactic-center gamma ray excess observed by Fermi-LAT and (ii) the antiproton excess observed by AMS-02 result from annihilation of these particles in the present universe. The detailed analyses are cited as Refs [34]-[43] in Ref. [1], and a more extensive discussion and set of references is given in a recent Snowmass review [9].
In Fig. 2 we show representative diagrams for direct detection as the dark matter particle $h^0$ collides with the quarks in a nucleus. Based on the results of Ref. [4], we estimate a cross-section which is slightly above $10^{-48}\text{ cm}^2$ in Xe-based experiments. This should be (barely) attainable within the next few years by LZ [10] and XENONnT [11]. In principle other direct-detection experiments, such as PandaX [12] and (a repurposed) SuperCDMS, should be able to observe this particle on a longer time scale.

Fig. 3 shows representative diagrams for collider detection of the present dark matter candidate. Based on the results of [5], we estimate the cross-section for production via vector boson fusion to be $\sim 1\text{ fb}$, which may be within reach of the high-luminosity LHC in 12-15 years, and other collider experiments on a longer time scale.

References

[1] Reagan Thornberry, Maxwell Throm, John Killough, Dylan Blend, Michael Erickson, Brian Sun, Brett Bays, Gabriel Frohau and Roland E. Allen, EPL [European Physics Letters] 134, 49001 (2021), arXiv:2104.11715 [hep-ph], and references therein.

[2] Caden LaFontaine, Bailey Tallman, Spencer Ellis, Trevor Croteau, Brandon Torres, Sabrina Hernandez, Diego Cristancho Guerrero, Jessica Jakisik, Drue Lubanski, and Roland E. Allen, Universe 7, 270 (2021), arXiv:2107.14390 [hep-ph].

[3] G. Bélanger, A. Mjallal, A. Pukhov, Eur. Phys. J. C81, 3 (2021), arXiv:2003.08621 [hep-ph], and references therein; http://lapth.cnrs.fr/micromegas/.

[4] Michael Klasen, Carlos E. Yaguna, and José D. Ruiz-Ávarez, Phys. Rev. D 87, 075025 (2013), arXiv:1302.1657 [hep-ph].

[5] Bhaskar Dutta, Guillermo Palacio, Diego Restrepo, and José D. Ruiz-Ávarez, Phys. Rev. D 97, 055045 (2018), arXiv:1709.09796 [hep-ph].

[6] Shin’ichiro Ando, Alex Geringer-Sameth, Nagisa Hiroshima, Sebastian Hoof, Roberto Trotta, and Matthew G. Walker, Phys. Rev. D 102, 061302 (2020), arXiv:2002.11956 [astro-ph.CO].

[7] A. Alvarez, F. Calore, A. Genina, J. Read, P. Dario Serpico and B. Zaldivar, J. Cosmol. Astropart. Phys. 09, 004 (2020), arXiv:2002.01229 [astro-ph.HE].

[8] Tracy R. Slatyer, SciPost Phys. Lect. Notes 53, 1 (2022), arXiv:2109.02696 [hep-ph], and references therein.

[9] Rebecca K. Leane et al., arXiv:2203.06859 [hep-ph].

[10] J. Aalbers et al. [LZ collaboration], arXiv:2207.03764 [hep-ex], and references therein.

[11] E. Aprile et al. [XENONnT collaboration], arXiv:2207.11330 [hep-ex], and references therein.

[12] Yue Meng et al. [PandaX-4T Collaboration] Phys. Rev. Lett. 127, 261802 (2021), arXiv:2107.13438 [hep-ex], and references therein.