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

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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 $\langle \sigma_{ann} v \rangle = 1.19 \times 10^{-26}$ 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 $\gtrsim 1000$ days of data taking. The cross-section for production in high-energy proton collisions via vector boson fusion is estimated to be ~ 1 femtobarn, possibly within reach of the high-luminosity LHC, with ≥ 140 GeV of missing energy accompanied by two jets.

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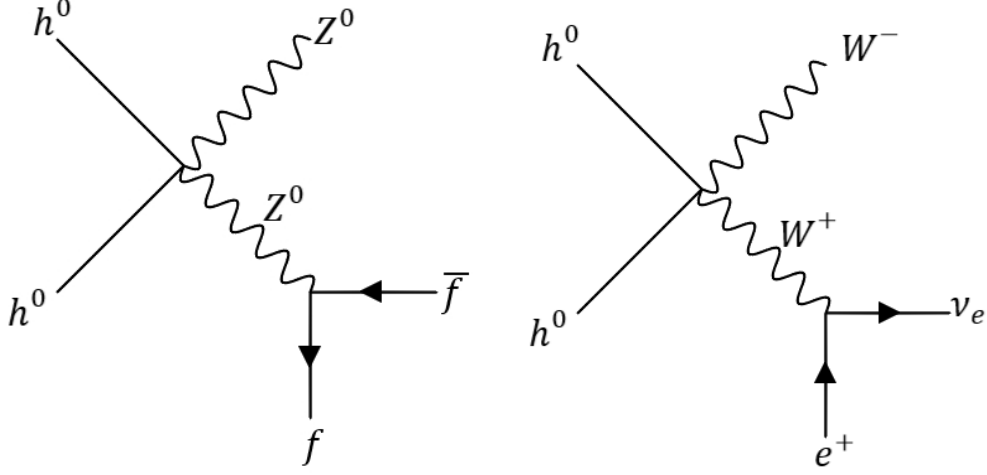*6-13 July, 2022*
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Figure 1: Representative diagrams for annihilation of the present dark matter candidate.

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 higgson[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 higgson 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.
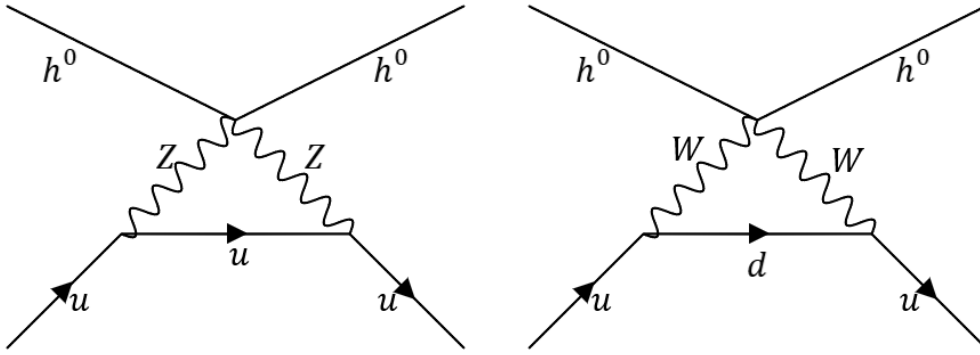
Figure 2: Representative diagrams for direct detection of the present dark matter candidate.
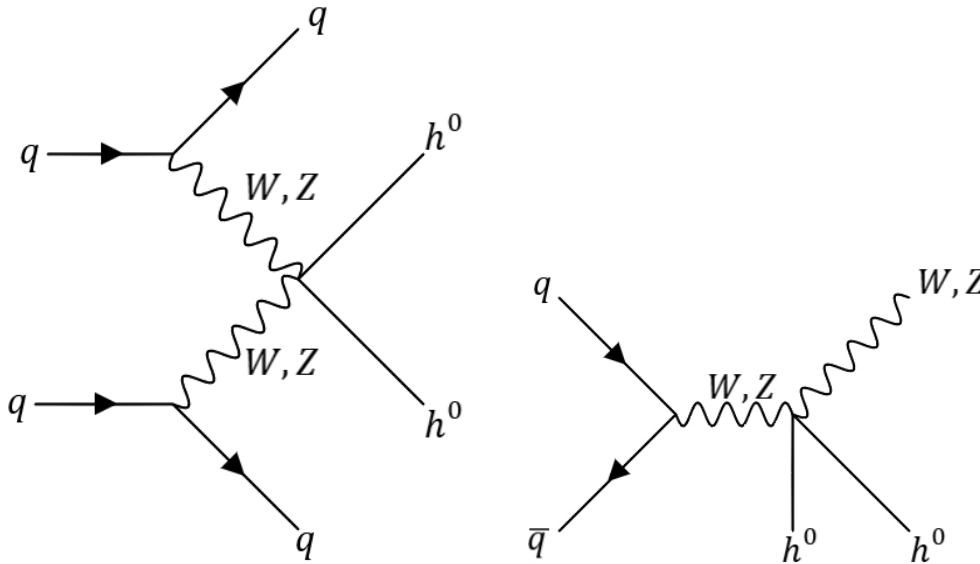

Figure 3: Representative diagrams for collider detection of the present dark matter candidate, with ≥ 140 GeV of missing energy accompanied by two jets in the more promising vector-boson fusion process.

For a mass of $70\,\text{GeV}/c^2$, our calculations yield a cross-section given by $\langle\sigma_{ann}v\rangle = 1.19\times10^{-26}$ cm^3/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} 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 ~ 1 femtobarn, which may be within reach of the high-luminosity LHC in 12-15 years, and other collider experiments on a longer time scale.

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