Sub-TeV superpartners may be observable, with reduced cross-sections and modified experimental signatures

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Why have susy and dark matter WIMPs not yet been seen?

According to the theory at 2302.10241 and 2307.04255, it is not possible to form the usual sfermions of supersymmetry – but there are redefined sfermions which have only second-order gauge and Higgs couplings.

They still protect the Higgs mass in the usual way, but will be harder to produce and observe than is currently expected. The same is true of gauginos and higgsinos via processes which also involve sfermions.

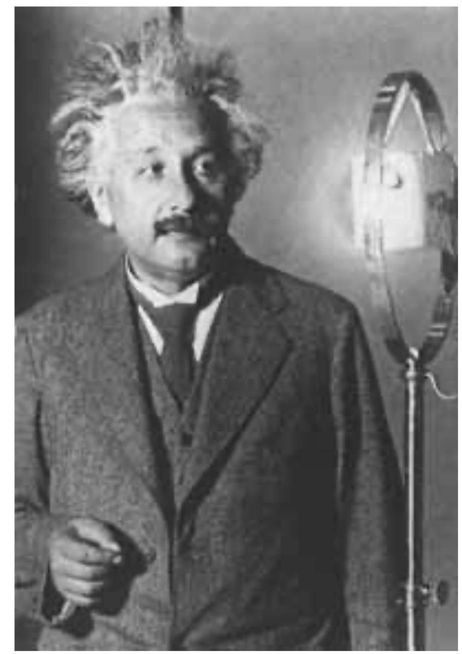
The result is a modified version of supersymmetry -- with reduced cross-sections and modified experimental signatures.

This same general result – a reinterpretation of all scalar boson sectors – also leads to the ideal dark matter candidate discussed in our earlier papers and talks, so this is a unified answer to both questions above.

The history of spin 1/2 fermions begins with the discovery of the electron in 1897 by J. J. Thomson.

The history of spin 1 gauge bosons begins with the 1905 paper of Einstein which introduced the photon.

A spin 0 boson is something new (2012), and surprises may *again* lie ahead!



Picture credits: phy.cam.ac.uk/history/electron, spaceandmotion.com, CERN

The present theory cannot even be formulated without SO(10) grand unification and a form of susy. But it has two unconventional aspects:

=> (1) A reinterpretation of all scalar boson fields.

Initial primitive fields must be joined in pairs to satisfy Lorentz invariance.

There are two ways to do this, which respectively lead to complex Higgs-like fields ϕ (which are conventional) and real fields φ that have only 2nd order couplings (and are therefore quite unconventional).

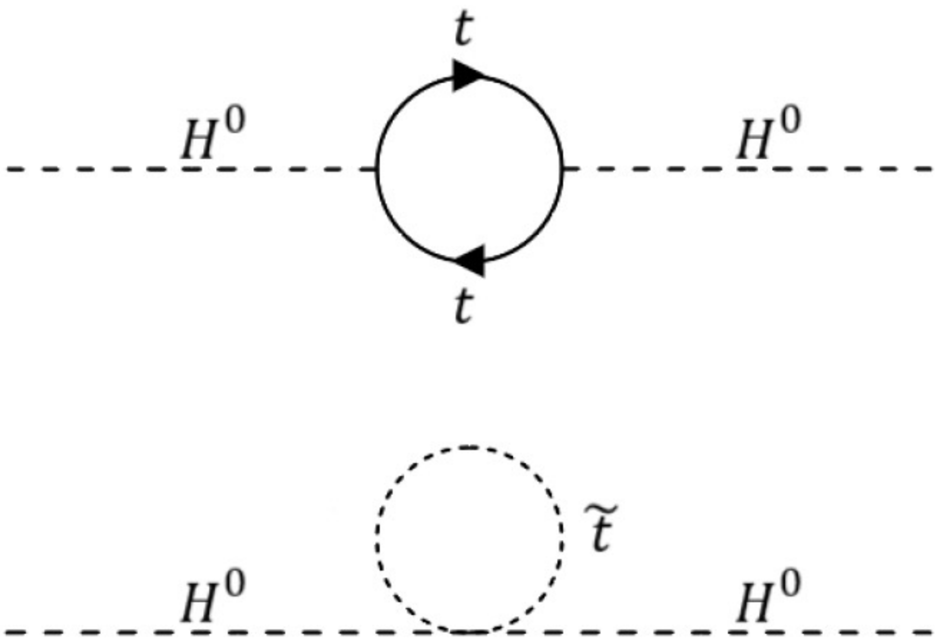
Our dark matter candidate (lowest energy higgson*) and our redefined sfermions belong to the second category.

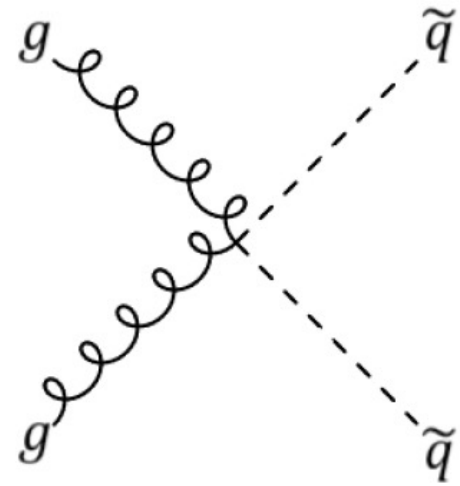
But in order to achieve Lorentz invariance we have broken supersymmetry.

This need to join two primitive fields in forming a mass eigenstate, in order to satisfy symmetry requirements, is not unprecedented: The real and imaginary parts of an ordinary charged scalar field must be joined to achieve gauge invariance, and left-and right-handed Weyl fields must be joined to form a Dirac or Majorana field in order to achieve Lorentz invariance.

$\Rightarrow$ (2) There are fermions belonging to the full $16 + \overline{16}$ fundamental spinorial representation of SO(10) (not equivalent because all fields are initially left-handed), rather than just the conventional 16.

*As defined and named in our many earlier papers on the dark matter candidate.





Left panel: Representative diagrams for contributions of a fermion and sfermion – in this case top quark and top squark – to radiative corrections of Higgs mass-squared. According to the Higgs coupling shown on the next slide, the unconventional sfermions defined here will still provide the standard susy cancellation of quadratric divergences, provided that all fermions and (redefined) sfermions have masses $\lesssim$ a few TeV.

There are 4 real (redefined) sfermions per Dirac fermion, equivalent in their effect to the usual 2 complex sfermions.

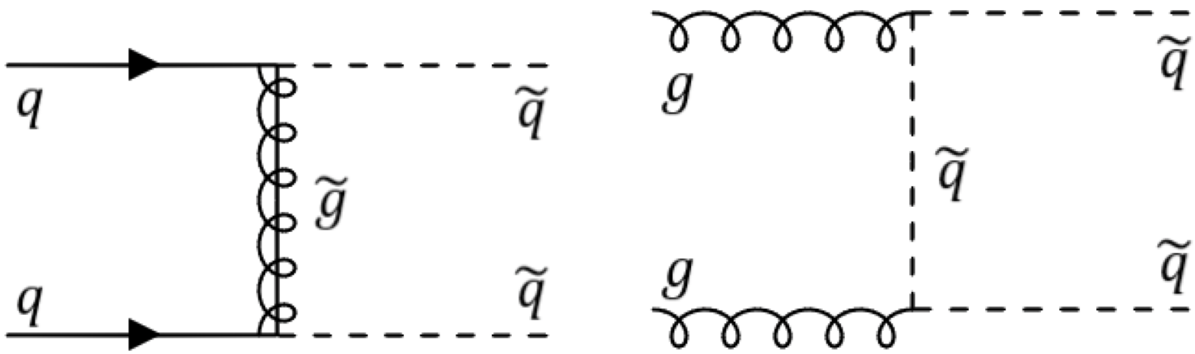
Right panel: Most squark production processes are not allowed in the present description, because they would require first-order interactions, but production by gluon fusion is still possible.

$$\overline{\mathcal{L}}_{\alpha}^{QCD} = -\frac{g_s^2}{6}\,\varphi_{\alpha}^{\dagger}\,\mathcal{A}^{\mu i}\mathcal{A}_{\mu}^{i}\,\varphi_{\alpha} \quad , \quad \overline{\mathcal{L}}_{\alpha}^{EM} = -\,(Qe)^2\,\varphi_{\alpha}^{\dagger}\,\bar{A}^{\mu}\bar{A}_{\mu}\,\varphi_{\alpha}$$

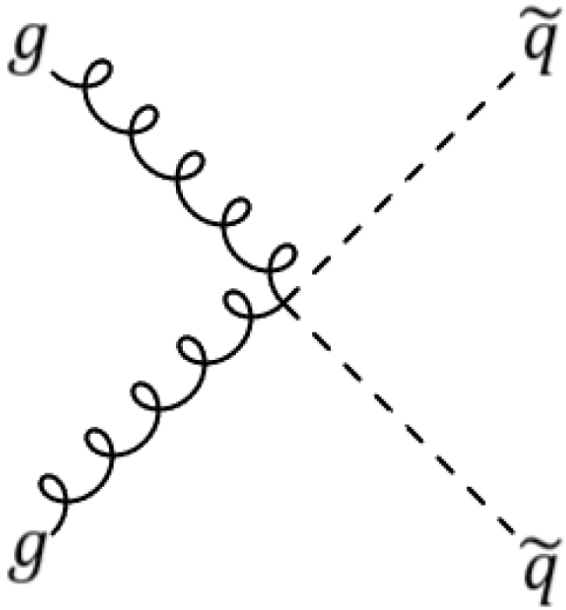
$$\overline{\mathcal{L}}_{\alpha}^{W} = -\frac{g^2}{2}\,\varphi_{\alpha}^{\dagger}\,W^{+\mu}W_{\mu}^{-}\,\varphi_{\alpha} \quad , \quad \overline{\mathcal{L}}_{\alpha}^{Z} = -\frac{g_Z^2}{4}\,\varphi_{\alpha}^{\dagger}\,Z^{\mu}Z_{\mu}\,\varphi_{\alpha}$$

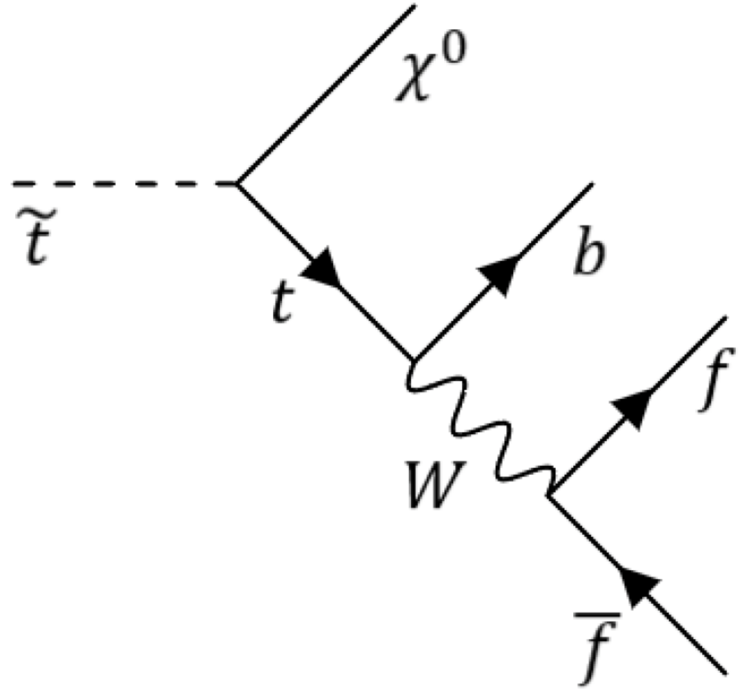
$$\overline{\mathcal{L}}_{\alpha}^{H} = -y_{\alpha}^2\,\varphi_{\alpha}\,H^{\dagger}H\,\varphi_{\alpha}$$

Strong, electromagnetic, weak, and Higgs interactions are all 2nd order.



With the present interpretation of sfermions, squarks $\tilde{q}$ cannot be produced in processes like these, involving quarks q and gluons g in colliding protons, since each vertex (i.e. interaction) in a physical process must involve two squark fields and two other bosonic fields.

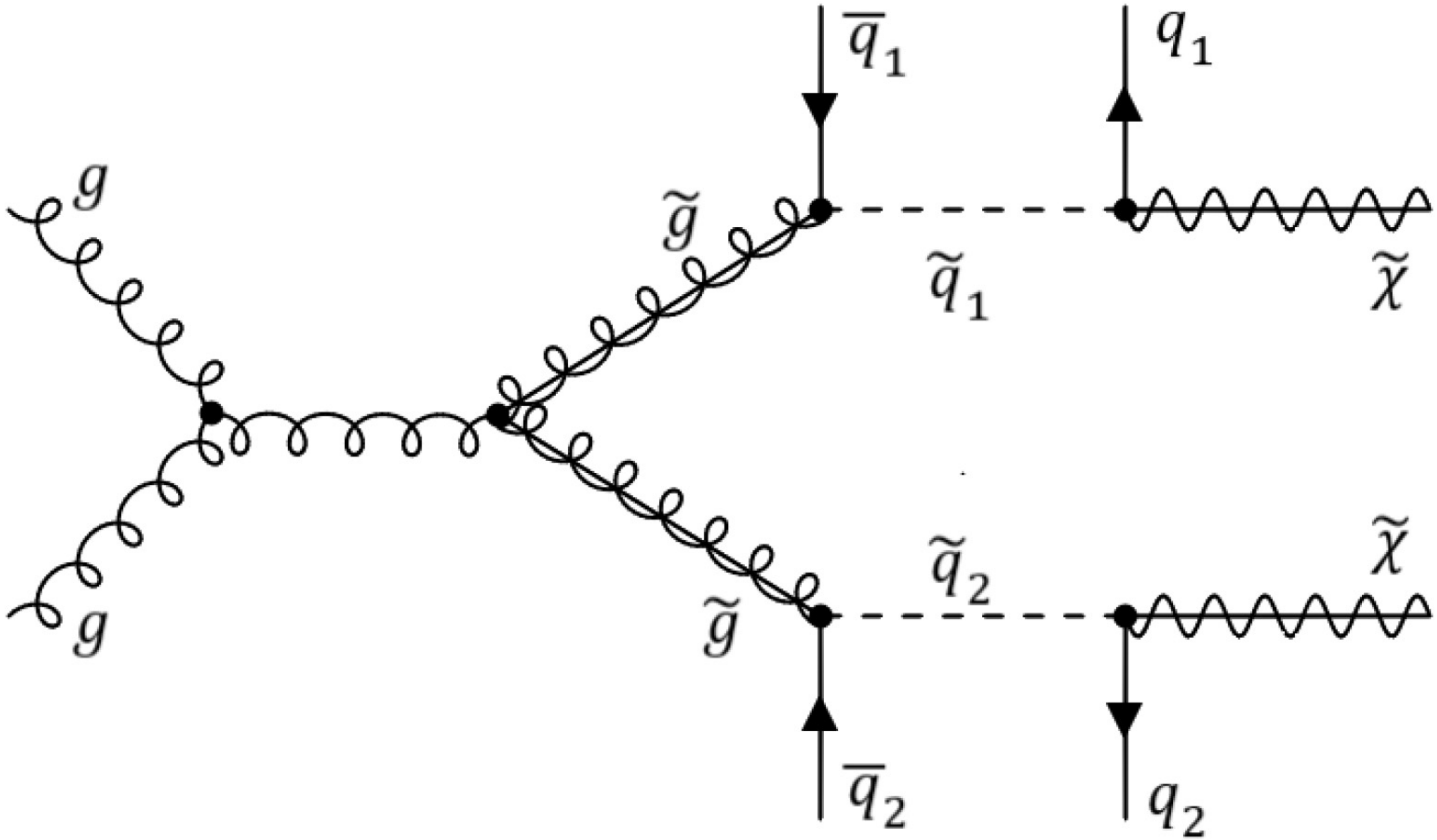




All sfermion decay processes, like the one shown here, do not exist (again because each vertex in a physical process must involve two sfermion fields and two other bosonic fields).

The standard schemes for detecting squarks rely on their being produced in collisions through processes that mostly do not exist in this new interpretation, and then decaying through processes that are entirely disallowed in this interpretation.

This implies that new detection schemes are required, and that squarks with masses of $\lesssim 1$ TeV may exist even though they have not previously been identified.



Example of a gluino decay process that will not be seen in the present scenario, because it requires first-order squark vertices.

So the experimental signatures for gluinos etc. will also be modified.

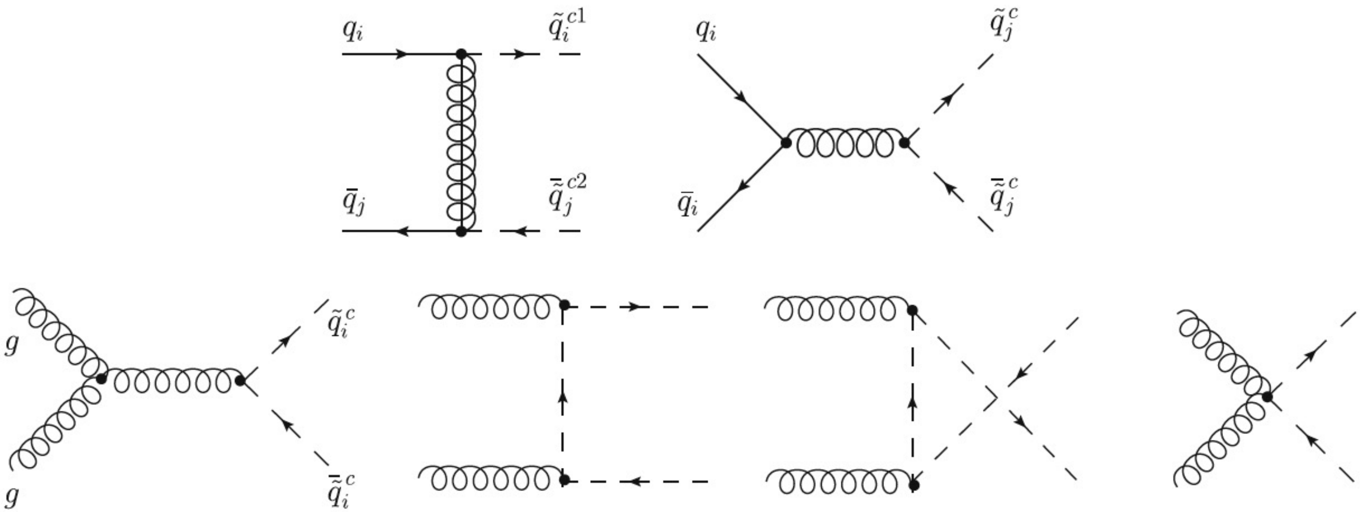
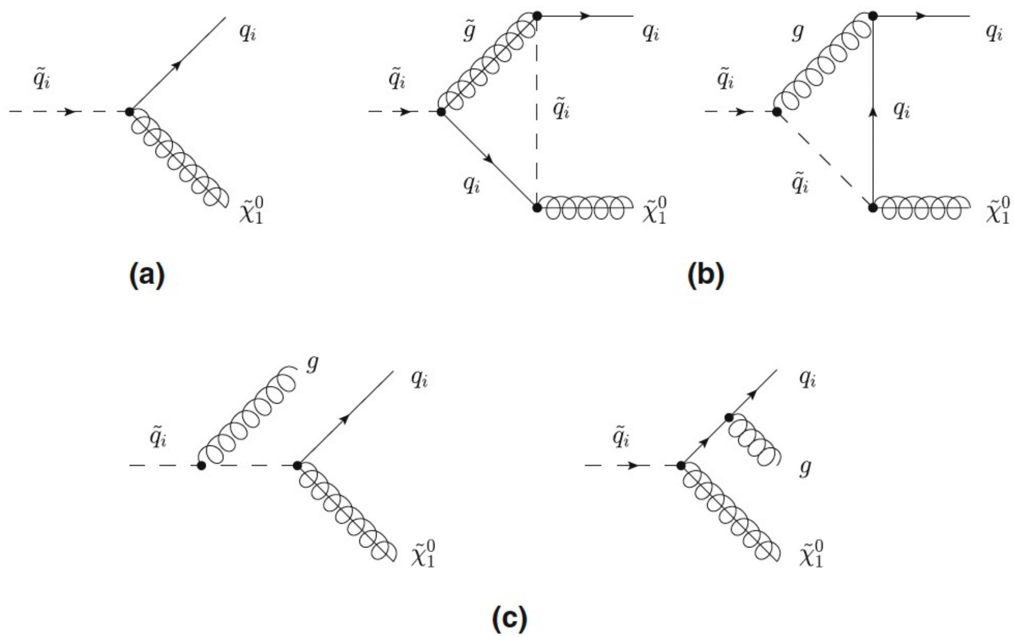


Fig. 1 Feynman diagrams contributing to squark–antisquark production at LO

Fig. 5 Feynman diagrams contributing to the decay $\tilde{q}_i \rightarrow q_i \tilde{\chi}_1^0$ at LO (**a**) and at NLO: virtual corrections (**b**) and real gluon radiation (**c**)

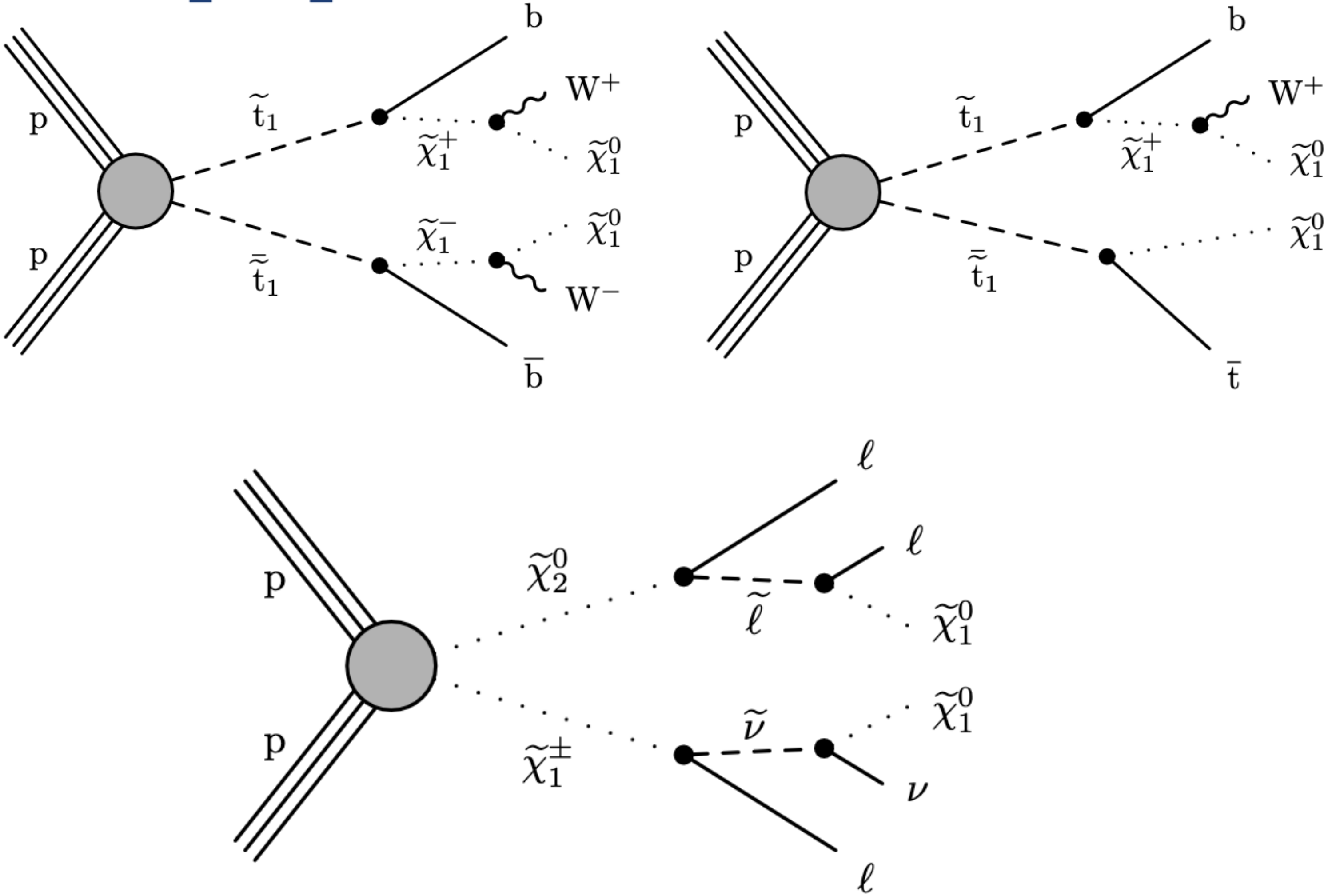


Credit: R. Gavin, C. Hangst, M. Krämer, M. Mühlleitner, M. Pellen, E. Popenda, M. Spira, "Squark production and decay matched with parton showers at NLO", Eur. Phys. J. C 75, 29 (2015) .

From talk by Costas Vellidis, Monday, July 17:

SUSY/BSM related searches and hints/anomalies in CMS

Top squarks "in the corridor"



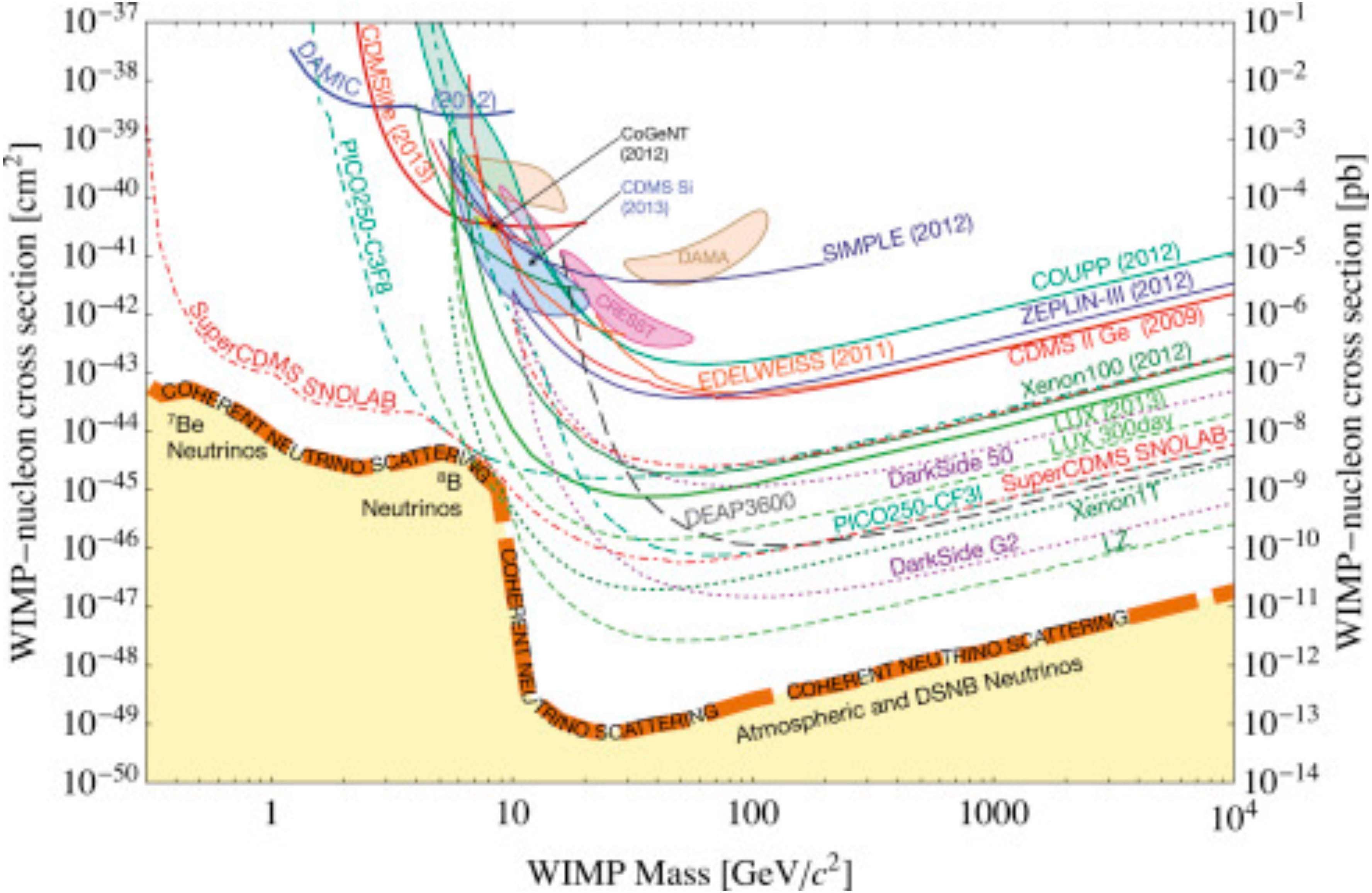
The same theory leads to a very promising dark matter candidate, as discussed in our previous papers [1-4]:

We estimate the WIMP-nucleon cross-section to be ~ 10^{48} cm^2. Both XENONnT and LZ anticipate a sensitivity that extends to 1.4 × 10^{-48} cm^2. So direct detection may be possible within ~ 5 years.

With a collider production cross-section (via vector boson fusion) estimated to be ~ 1 femtobarn, this particle may be observable at the high-luminosity LHC in ~ 12-15 years.

Its mass and annihilation cross-section are consistent with analyses of the gamma rays observed by Fermi-LAT and antiprotons observed by AMS-02, interpreted as evidence of dark matter annihilation, so it may already have been detected.

[1] Reagan Thornberry, Maxwell Throm, John Killough, Dylan Blend, Michael Erickson, Brian Sun, Brett Bays, Gabriel Frohaug, and Roland E. Allen, "Experimental signatures of a new dark matter WIMP", EPL [European Physics Letters] 134, 49001 (2021), arXiv:2104.11715 [hepph], and references therein.
[2] Caden LaFontaine, Bailey Tallman, Spencer Ellis, Trevor Croteau, Brandon Torres, Sabrina Hernandez, Diego Cristancho Guerrero, Jessica Jaksik, Drue Lubanski, and Roland E. Allen, "A Dark Matter WIMP That Can Be Detected and Definitively Identified with Currently Planned Experiments", Universe 7, 270 (2021), arXiv:2107.14390 [hep-ph].
[3] 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, "Indirect detection, direct detection, and collider detection cross-sections for a 70 GeV dark matter WIMP", proceedings of the 41st International Conference on High Energy Physics, ICHEP 2022, arXiv:2210.05380 [hep-ph].
[4] Bailey Tallman, Alexandra Boone, Adhithya Vijayakumar, Fiona Lopez, Samuel Apata, Jehu Martinez, and Roland Allen, "Potential for definitive discovery of a 70 GeV dark matter WIMP with only second-order gauge couplings", Letters in High Energy Physics LHEP-342 (2023), arXiv:2210.15019 [hep-ph].



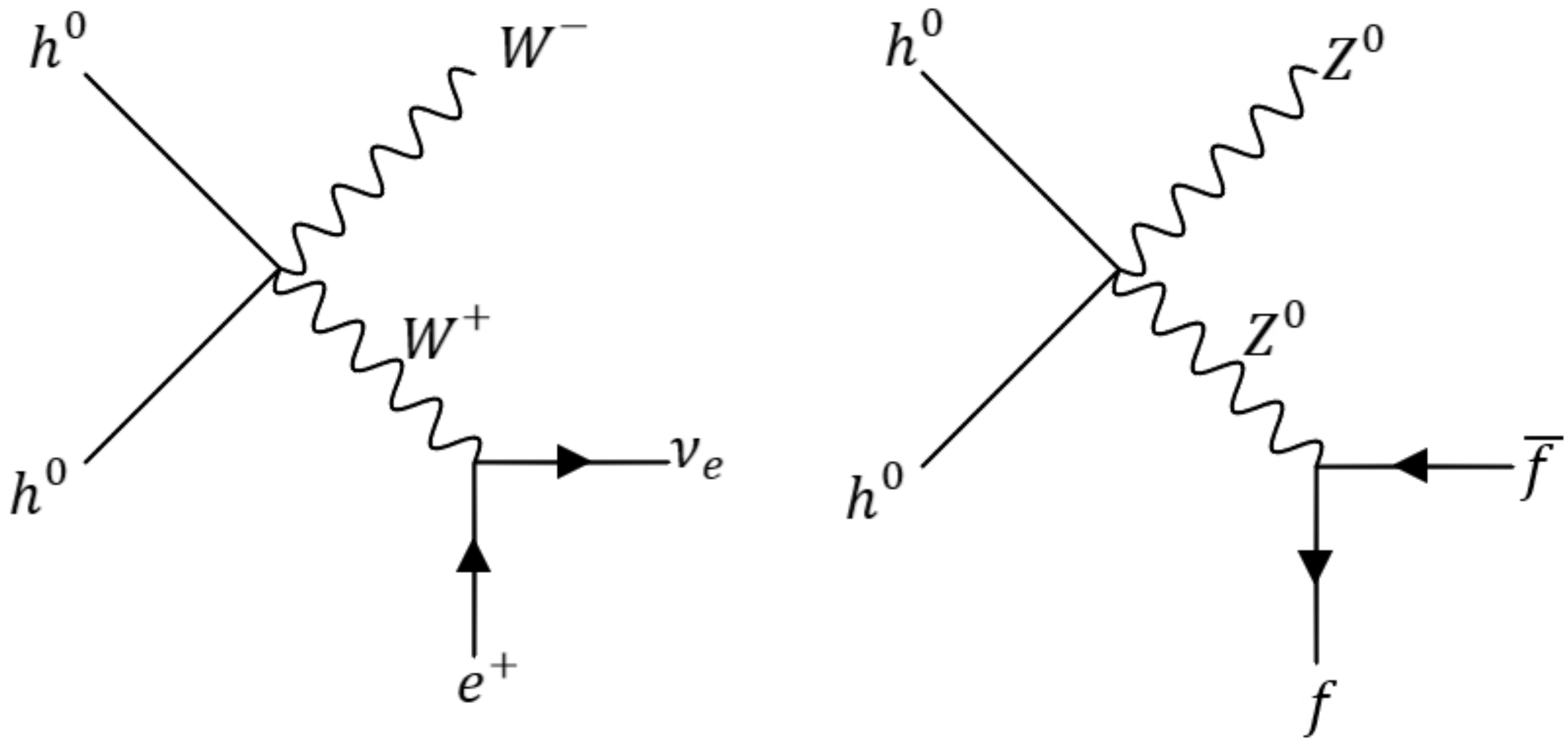
A cross-section for direct detection ~ 10^{-48} cm² at 70 GeV/c² is above the neutrino floor (or fog) and may be accessible to LZ and XENONnT, plus ultimately PandaX and other experiments.

Credit -- J. Billard, L. Strigari, E. Figueroa-Feliciano, Phys. Rev. D, 89, 023524 (2014), arXiv:1307.5458 ,

If the mass of h^0 were above the mass of a W boson, annihilation into real W and Z pairs would have a large cross-section, and result in a severe underabundance of dark matter.

If the mass of h^0 were far below the mass of a W boson, annihilation into a real W or Z and a virtual one would have a small cross-section, and would result in a severe overabundance of dark matter.

But for a mass of about 70 GeV the relic abundance is in agreement with observation.

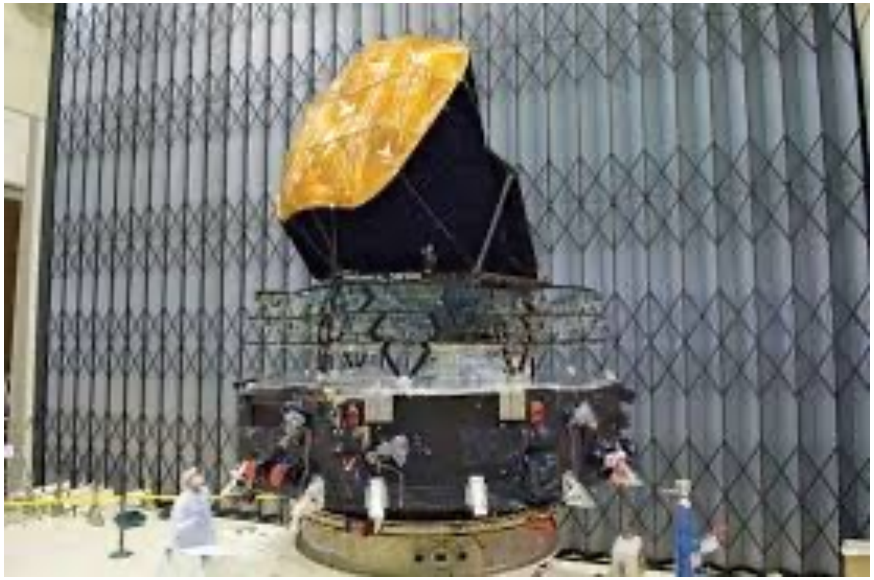


Three of the space-based studies of astrophysical phenomena:

Fermi-LAT

AMS-02

Planck



Christopher Karwin, Simona Murgia, Tim M. P. Tait, Troy A. Porter, and Philip Tanedo, Phys. Rev. D 95, 103005 (2017), arXiv:1612.05687 [hep-ph]:

"The center of the Milky Way is predicted to be the brightest region of γ-rays generated by self-annihilating dark matter particles. Excess emission about the Galactic center above predictions made for standard astrophysical processes has been observed in γ-ray data collected by the Fermi Large Area Telescope.

It is well described by the square of a Navarro, Frenk, and White dark matter density distribution. Although other interpretations for the excess are plausible, the possibility that it arises from annihilating dark matter is valid."

"… its spectral characteristics favor a dark matter particle with a mass in the range approximately from 50 to 190 (10 to 90) GeV … for pseudoscalar (vector) interactions."

Rebecca K. Leane and Tracy R. Slatyer, "Revival of the Dark Matter Hypothesis for the Galactic Center Gamma-Ray Excess", Phys. Rev. Lett. 123, 241101 (2019), arXiv:1904.08430 [astro-ph.HE]:

"… we conclude that dark matter may provide a dominant contribution to the GCE after all."

Intriguing results from two careful analyses of AMS-02 observations of antiprotons and Fermi-LAT observations of gamma rays from the Galactic Center

Ilias Cholis, Tim Linden, and Dan Hooper, "A Robust Excess in the Cosmic-Ray Antiproton Spectrum: Implications for Annihilating Dark Matter", Phys. Rev. D 99, 103026 (2019); arXiv:1903.02549 [astro-ph.HE]:

"This excess is well fit by annihilating dark matter particles, with a mass and cross section in the range of $m_\chi \approx$ 46-94 GeV ..."

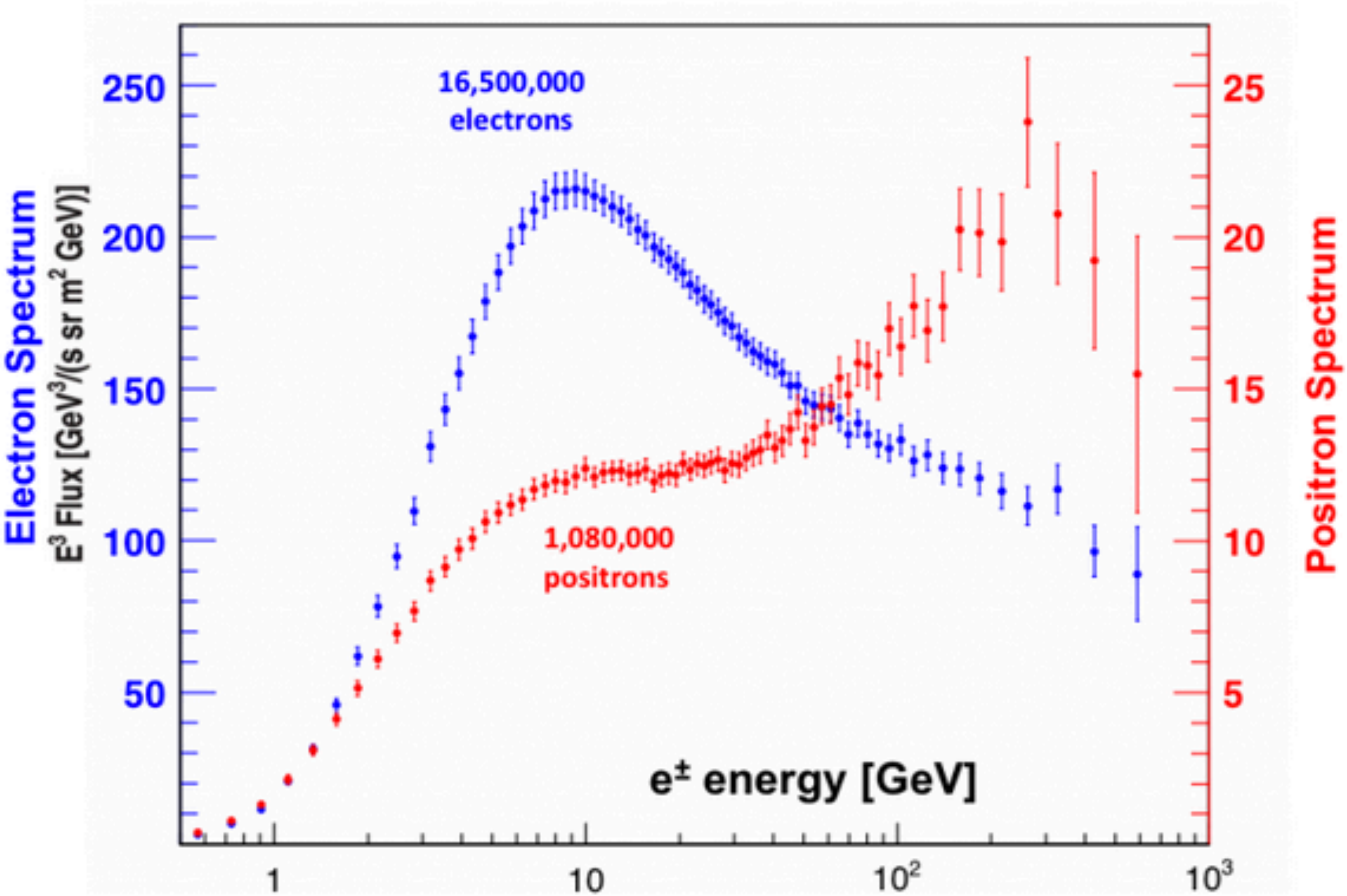
"… it is particularly intriguing that the range of dark matter models that can accommodate the antiproton excess is very similar to those which could generate the excess of GeV-scale gamma rays observed from the Galactic Center…"

Alessandro Cuoco, Jan Heisig, Lukas Klamt, Michael Korsmeier, and Michael Krämer, "Scrutinizing the evidence for dark matter in cosmic-ray antiprotons", Phys. Rev. D 99, 103026 (2019); arXiv:1903.01472 [astro-ph.HE]:

"… strong limits on heavy DM have been derived from global CR fits. At the same time, the data have also revealed a tentative signal of DM, corresponding to a DM mass of around 40–130 GeV …"

"This signal, if confirmed, is compatible with a DM interpretation of the Galactic center γ-ray excess …"

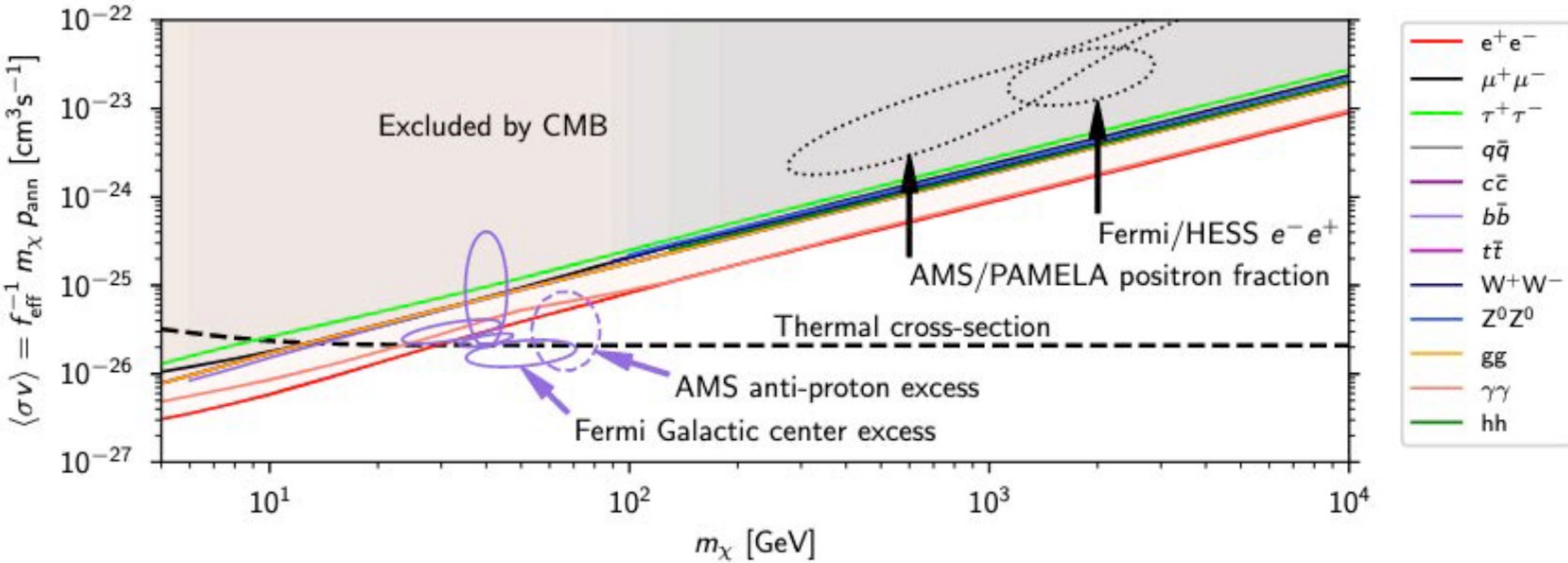
The inferred masses and cross-sections in the analyses are consistent with those for the present dark matter candidate – e.g., a mass about 70 GeV/c^2.



AMS has observed that the electron flux and positron flux display different behaviors both in their magnitude and in their energy dependence.

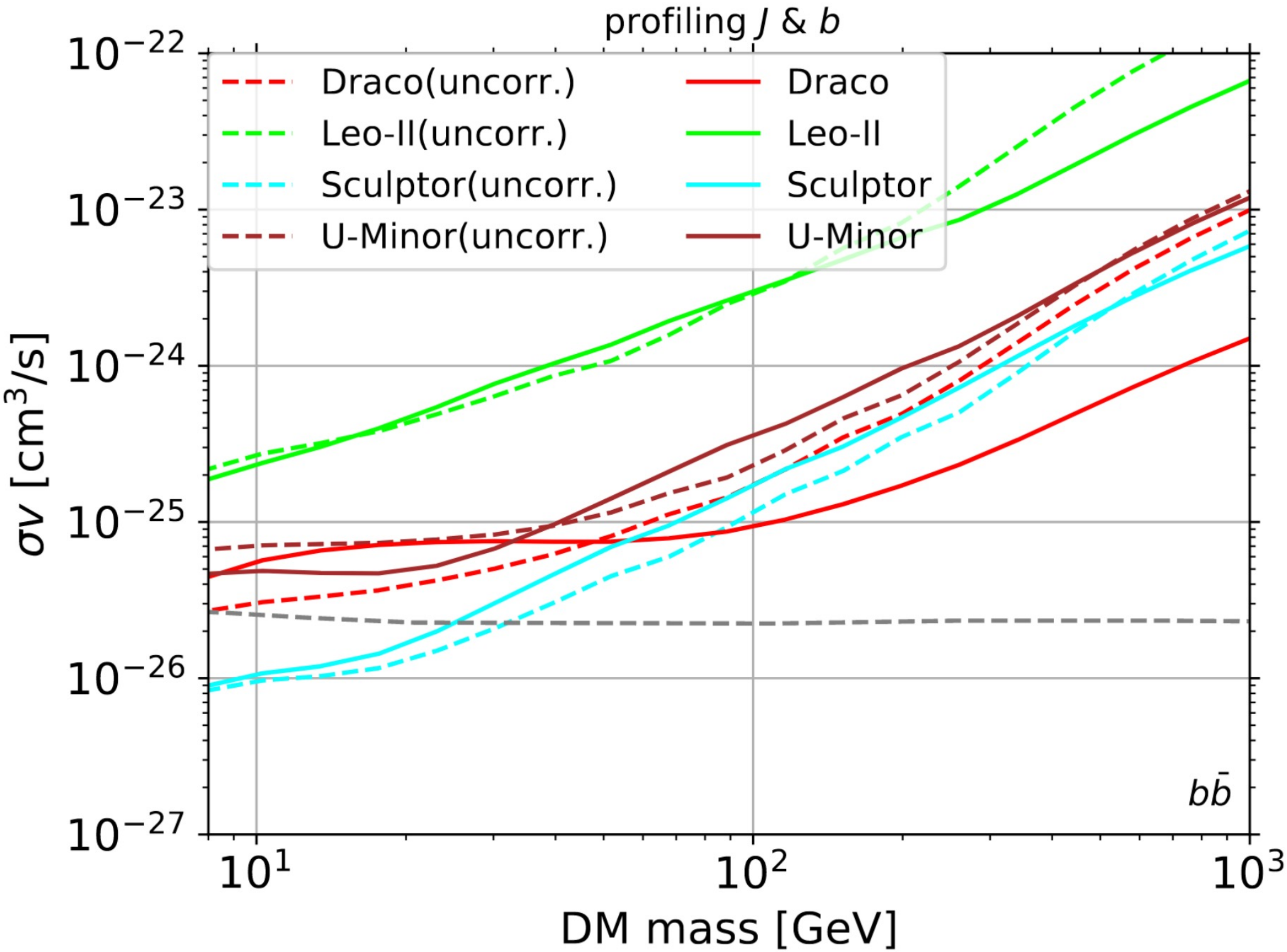
But the dark matter annihilation interpretation is now disconfirmed by Planck.

http://www.ams02.org/2016/12/the-first-five-years-of-the-alpha-magnetic-spectrometer-on-the-international-space-station/

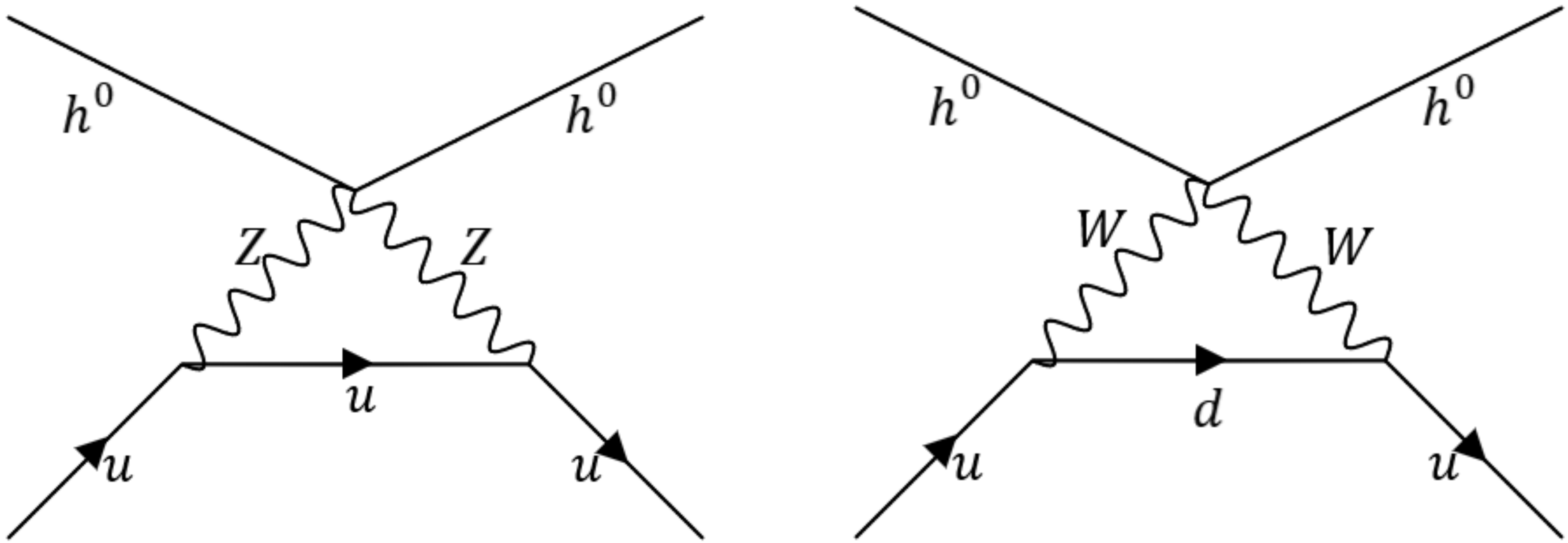


"*Planck* 2018 constraints on DM mass and annihilation cross-section. Solid straight lines show joint CMB constraints on several annihilation channels (plotted using different colours) … We also show the 2σ preferred region suggested by the AMS proton excess (dashed ellipse) and the Fermi Galactic centre excess according to four possible models with references given in the text (solid ellipses) … We additionally show the 2σ preferred region suggested by the AMS/ PAMELA positron fraction and Fermi/H.E.S.S. electron and positron fluxes … Assuming a standard WIMP-decoupling scenario, the correct value of the relic DM abundance is obtained for a 'thermal cross-section' given as a function of the mass by the black dashed line."

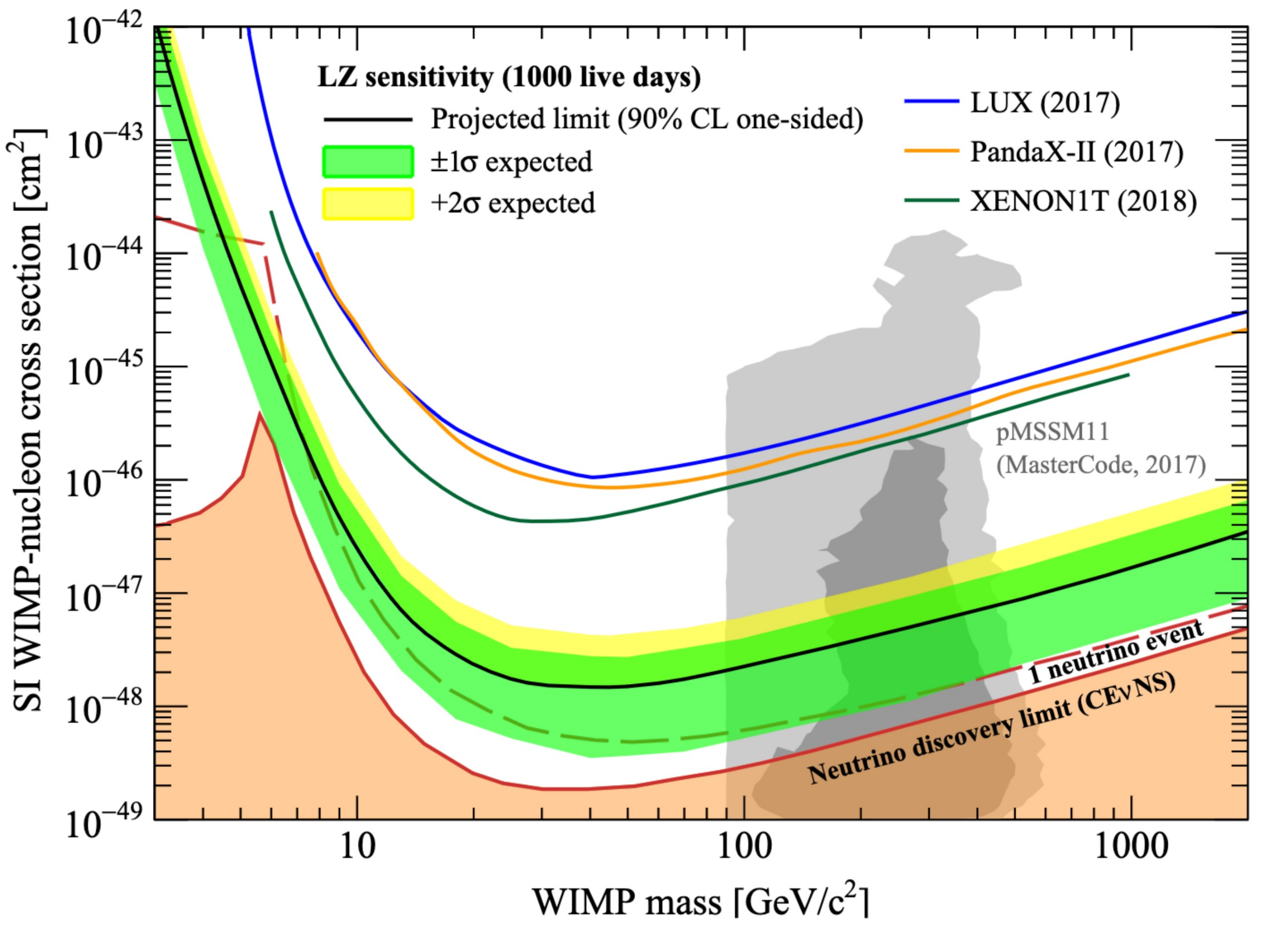
"CMB anisotropies are sensitive to energy injection in the intergalactic medium that could be a consequence, for example, of dark-matter (DM) annihilation … The current CMB sensitivity to the annihilation cross section of weakly-interactive massive particles (WIMPs) is competitive with and complementary to that of indirect DM search experiments."



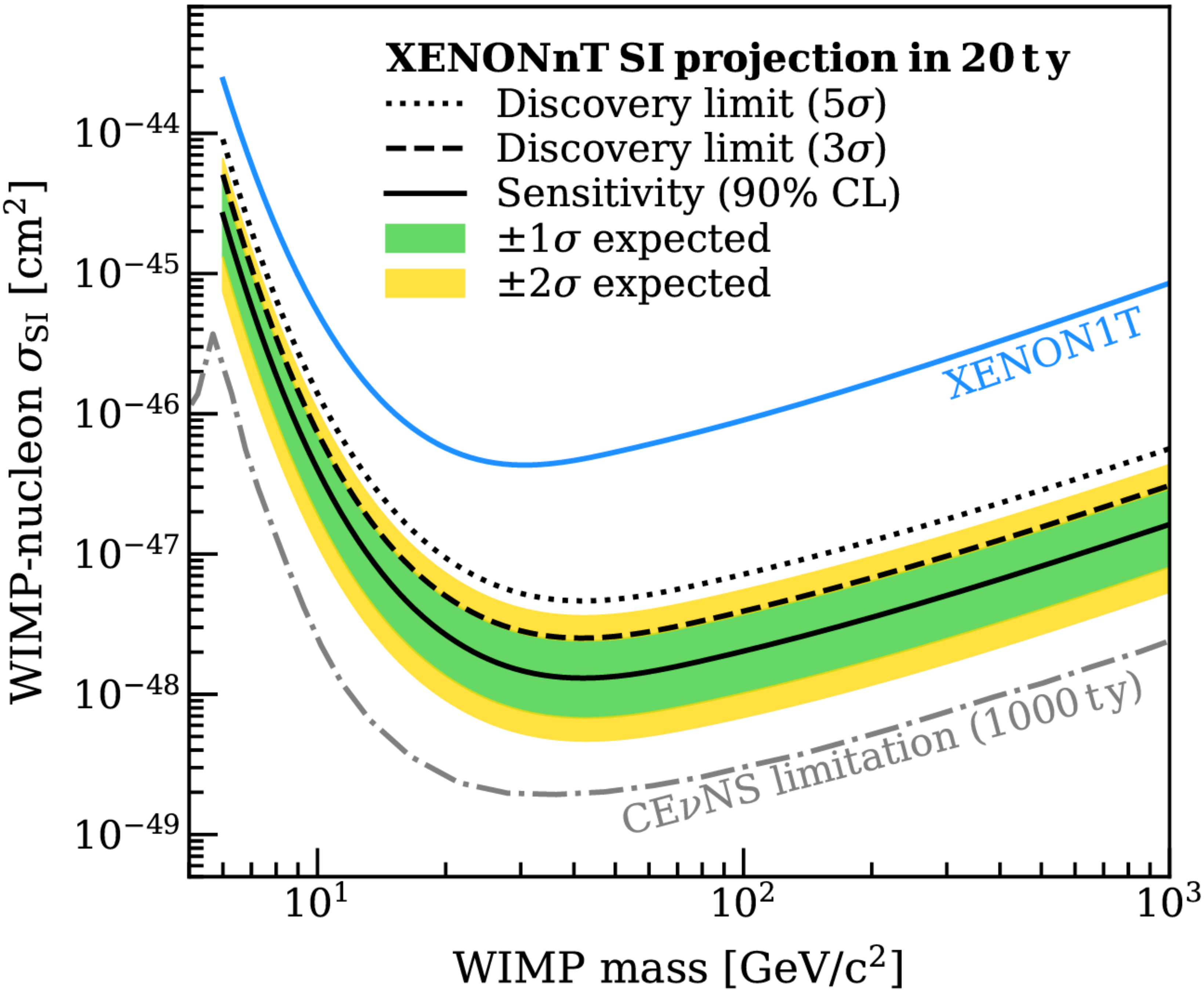
Our calculated annihilation cross-section of $\langle\sigma_{ann}v\rangle \approx 1.2\times10^{-26}$cm³/s at 70 GeV is consistent with the current limits: Alexandre Alvarez, Francesca Calore, Anna Genina, Justin Read, Pasquale Dario Serpico, and Bryan Zaldivar, "Dark matter constraints from dwarf galaxies with data-driven J-factors", JCAP 09, 004 (2020), arXiv:2002.01229 [astro- ph.HE].



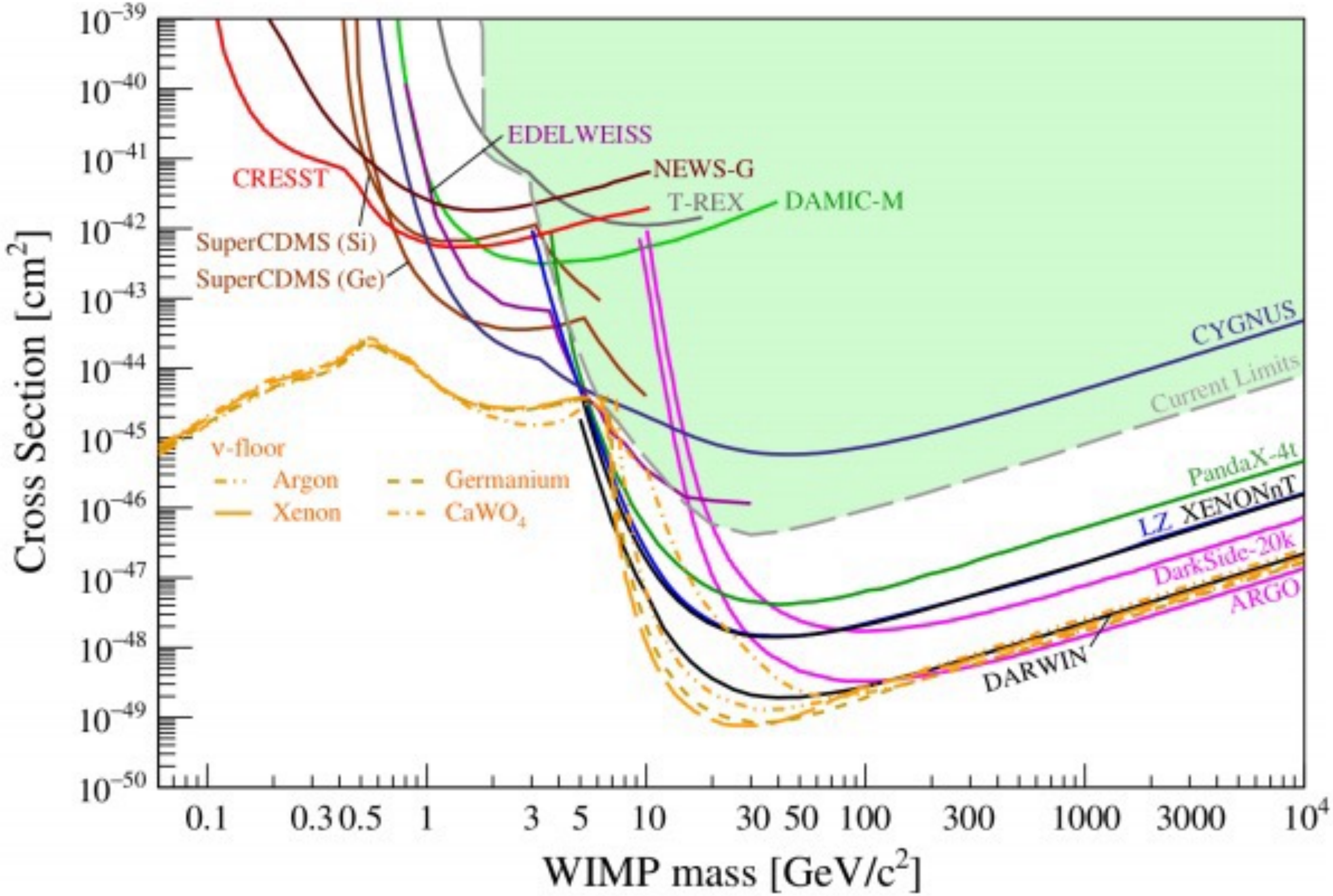
Gauge-mediated one-loop interactions like these appear to be the best prospect for direct detection, with WIMP-nucleon cross-section estimated to be $\sim 10^{-48}$ cm^2.



LZ sensitivity (1000 live days)
Projected limit (90% CL one-sided)
±1σ expected
+2σ expected
LUX (2017)
PandaX-II (2017)
XENON1T (2018)
pMSSM11
(MasterCode, 2017)
1 neutrino event
Neutrino discovery limit (CEνNS)
SI WIMP-nucleon cross section [cm^2]
WIMP mass [GeV/c^2]
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
10
100
1000

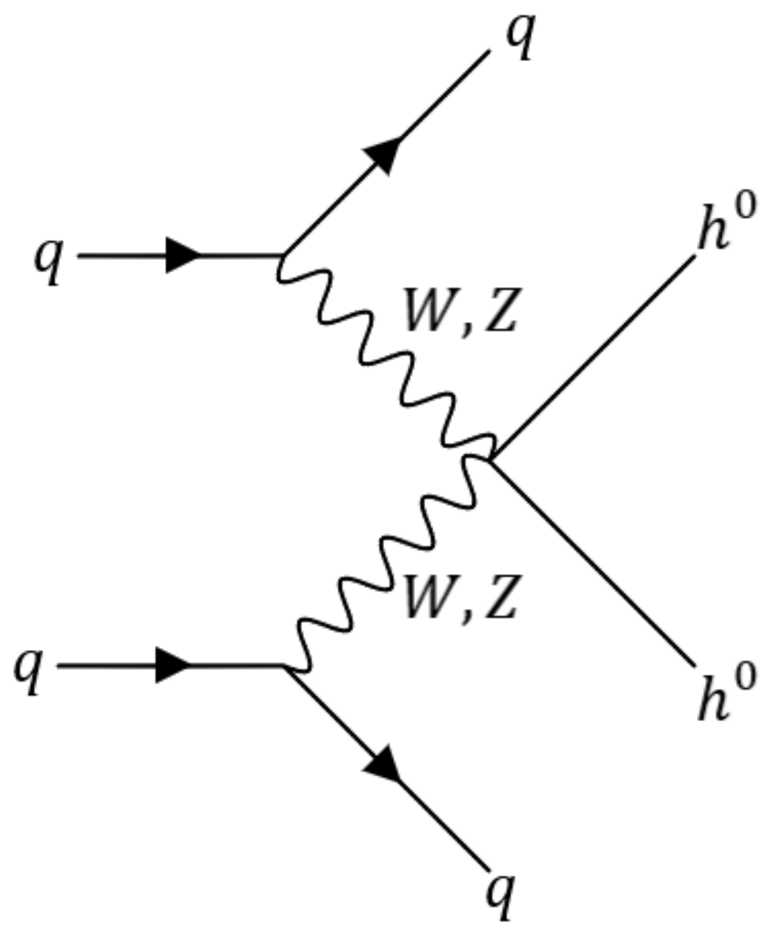


XENONnT SI projection in 20 t y
Discovery limit (5σ)
Discovery limit (3σ)
Sensitivity (90% CL)
±1σ expected
±2σ expected
XENON1T
CEνNS limitation (1000 t y)
WIMP-nucleon σ_{SI} [cm^2]
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
10^1
10^2
10^3
WIMP mass [GeV/c^2]



Again: A cross-section for direct detection ~10^{-48} cm^2 at 70 GeV/c^2 should be within reach of current or planned direct detection experiments.

Credit: Francis Villatoro@emulenews, https://twitter.com/emulenews/status/1383019854140170244



Vector boson fusion appears to be the best prospect for collider detection, with an estimated cross-section of ~ 1 fb possibly within reach of the high-luminosity LHC if it can attain 3000 fb^{-1}.

The signature is ≥ 140 GeV of missing energy and two jets.

The present theory leads to several predictions that are testable within the foreseeable future:

- ***the dark matter candidate, with well-defined mass and detection cross-sections***

- ***a new phenomenology for squarks, sleptons, gauginos, and higgsinos (and their linear combinations), providing a potential explanation of the fact that superpartners have not yet been identified***

- ***a large number of new fermions with masses not far above 1 TeV, which result from the full fundamental*** **spinorial** $16 + \overline{16}$ ***representation of SO(10) being physically realized, rather than just the conventional 16***

Thanks for your attention!