Virtual Higgs portal to new particles in a natural scenario with both supersymmetric and non-supersymmetric WIMPs

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This talk is based on the following papers:

R. Thornberry, M. Throm, J. Killough, D. Blend, M. Erickson, B. Sun, B. Bays, G. Frohaug, and R. E. Allen, "A natural dark matter scenario with two coexisting stable WIMPs: neutralinos and Higgsons", submitted.

M. Throm, R. Thornberry, J. Killough, B. Sun, G. Abdulla, and R. E. Allen. "Two natural scenarios for dark matter particles coexisting with supersymmetry", Mod. Phys. Lett. A 34, 1930001 (2019).

R. E. Allen, "Saving supersymmetry and dark matter WIMPs—a new kind of dark matter candidate with well-defined mass and couplings", Phys. Scripta 94, 014010 (2019).

R. E. Allen and A. Saha, "Dark matter candidate with well-defined mass and couplings", Mod. Phys. Lett. A 32, 1730022 (2017).

R. E. Allen, "Predictions of a fundamental statistical picture", arXiv:1101.0586.

After decades of intense efforts, neither supersymmetry nor dark matter particles have been detected.

One should recall, however, that historically important discoveries typically require patient waits — 48 years for the Higgs boson, a century for gravitational waves, and almost two centuries for black holes.

There are still compelling motivations for seeking both of these proposed central features of nature:

Alternatives to dark matter have been rendered increasingly implausible by astronomical observations, and without SUSY it is hard to understand the unification of coupling constants at high energy or why the Higgs boson mass is not enormously increased by radiative corrections.

The pessimism regarding SUSY is in part due to experimental limits that now rule out the simplest models. But there was never any reason to believe that simplistic models like these would be quantitatively valid. They have primarily served to provide valuable guidance for the qualitative role of SUSY in various physical phenomena.

Another discouraging development was the finding that natural supersymmetric models have difficulty in predicting the observed relic abundance of dark matter, *if it is assumed that the dark matter consists entirely of supersymmetric partners* . But if this assumption is dropped, as in the scenario considered here, the tension between theory and observation is ameliorated.

Regarding dark matter searches, the cross-sections were always known to be small. The limits that have been established are consistent with either of the two scenarios discussed here. On the other hand, both neutralinos and the new particles discussed here can still lie within reach of the direct-detection experiments planned for the next few years, as well as an upgraded LHC, and the AMS and Fermi satellite experiments.

Multicomponent model of Baer, Barger, Sengupta, and Tata:

These authors have pointed out that a multicomponent dark matter scenario, with a significant admixture of neutralinos but some other particle dominating, relieves the tension between susy dark matter and the observed dark matter abundance:

H. Baer, V. Barger, J. S. Gainer, P. Huang, M. Savoy, H. Serce, and X. Tata, Phys. Lett. B 774, 451 (2017), arXiv:1702.06588.

In the present scenario the additional dark matter particle results from an extended Higgs sector.

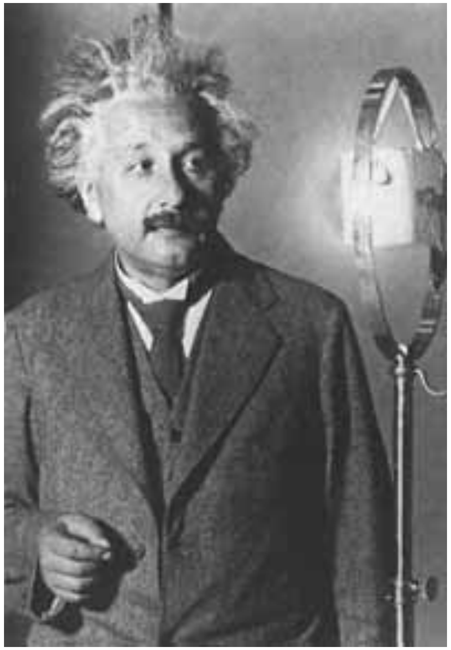
This scenario inevitably follows from a fundamental theory, but here we consider it simply as a postulated phenomenological model:

1. R. Thornberry, M. Throm, J. Killough, D. Blend, M. Erickson, B. Sun, B. Bays, G. Frohaug, and R. E. Allen, "A natural dark matter scenario with two coexisting stable WIMPs: neutralinos and Higgsons", submitted.
2. M. Throm, R. Thornberry, J. Killough, B. Sun, G. Abdulla, and R. E. Allen. "Two natural scenarios for dark matter particles coexisting with supersymmetry", Mod. Phys. Lett. A 34, 1930001 (2019), arXiv:1901.02781 [hep-ph].
3. R. E. Allen, """Saving supersymmetry and dark matter WIMPs—a new kind of dark matter candidate with well-defined mass and couplings", Phys. Scripta 94, 014010 (2019), arXiv:1811.00670 [hep-ph].
4. R. E. Allen and A. Saha, "Dark matter candidate with well-defined mass and couplings", Mod. Phys. Lett. A 32, 1730022 (2017), arXiv:1706.00882 [hep-ph].

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

In the present theory the lowest-energy neutralino is a stable dark matter particle, but so is the new particle predicted here (also with spin ½ and R-parity = -1). In the present theory, Higgs bosons are amplitude modes in an extended sector with spin ½ particles.

They are somewhat analogous to the Higgs/amplitude modes observed in superconductors: P. B. Littlewood and C. M. Varma, "Amplitude collective modes in superconductors and their coupling to charge density waves", Phys. Rev. B. 26, 4883 (1982).

In Mod. Phys. Lett. A 34, 1930001 (2019) we have called the new spin ½ particles (both neutral and charged) "Higgsons" *H*, to be distinguished from Higgs bosons *h* and the higgsinos of susy.

Their couplings to gauge bosons are either momentum-dependent or second-order, and therefore weak for direct or indirect detection of slowly moving dark matter particles.

But their effective coupling to Higgs bosons is comparable to that of a neutralino.

Also, their predicted mass is ≤ 125 GeV/c^2 .

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]:

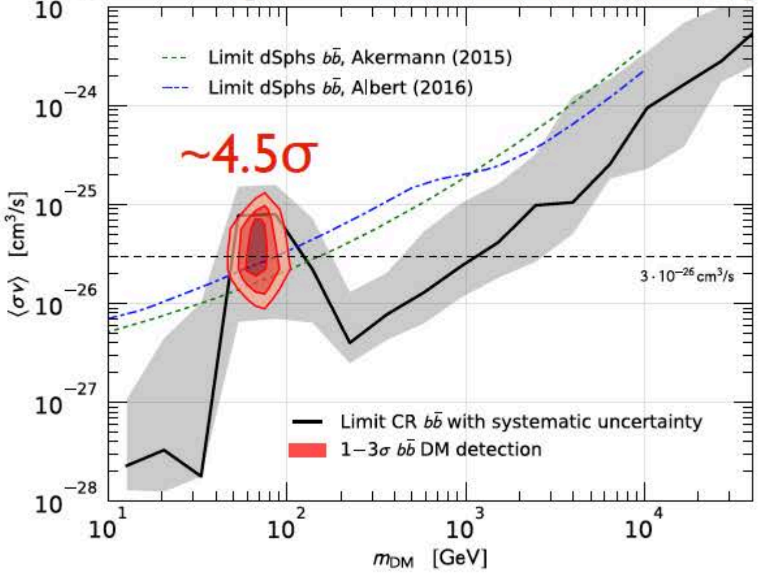
"… strong limits on heavy DM have been derived from global CR fits. At the same time, the data have also revealed a tentative signal of DM, corresponding to a DM mass of around 40–130 GeV …"

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

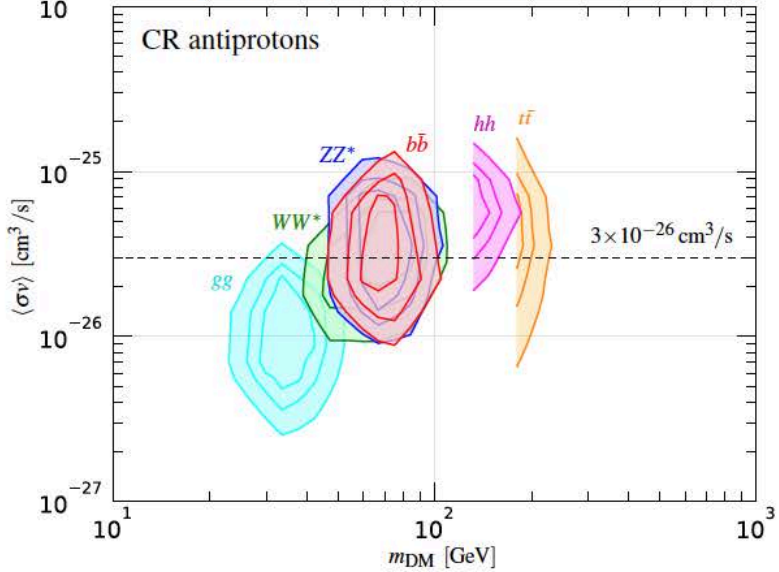
A mass of ≤ 125 GeV is required of the present dark matter candidate, whereas susy particles are commonly expected to have significantly larger masses.

Hint for 100 GeV-ish dark matter

[Cuoco, Krämer, Korsmeier, 2017]

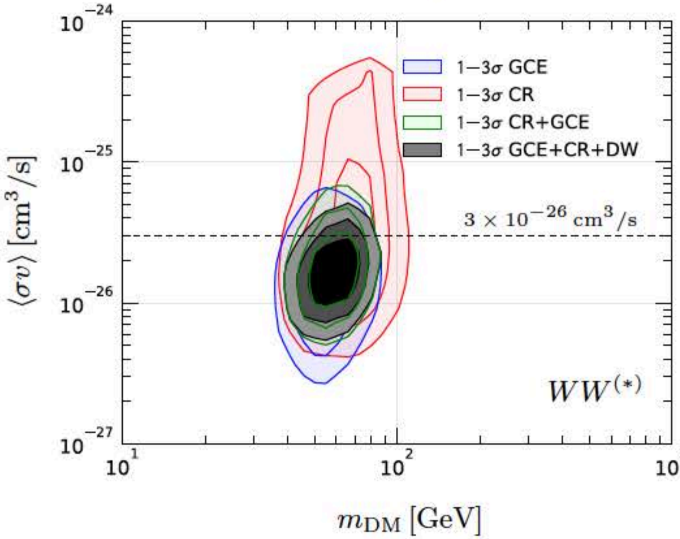


[Cuoco, JH, Korsmeier, Krämer 2017]

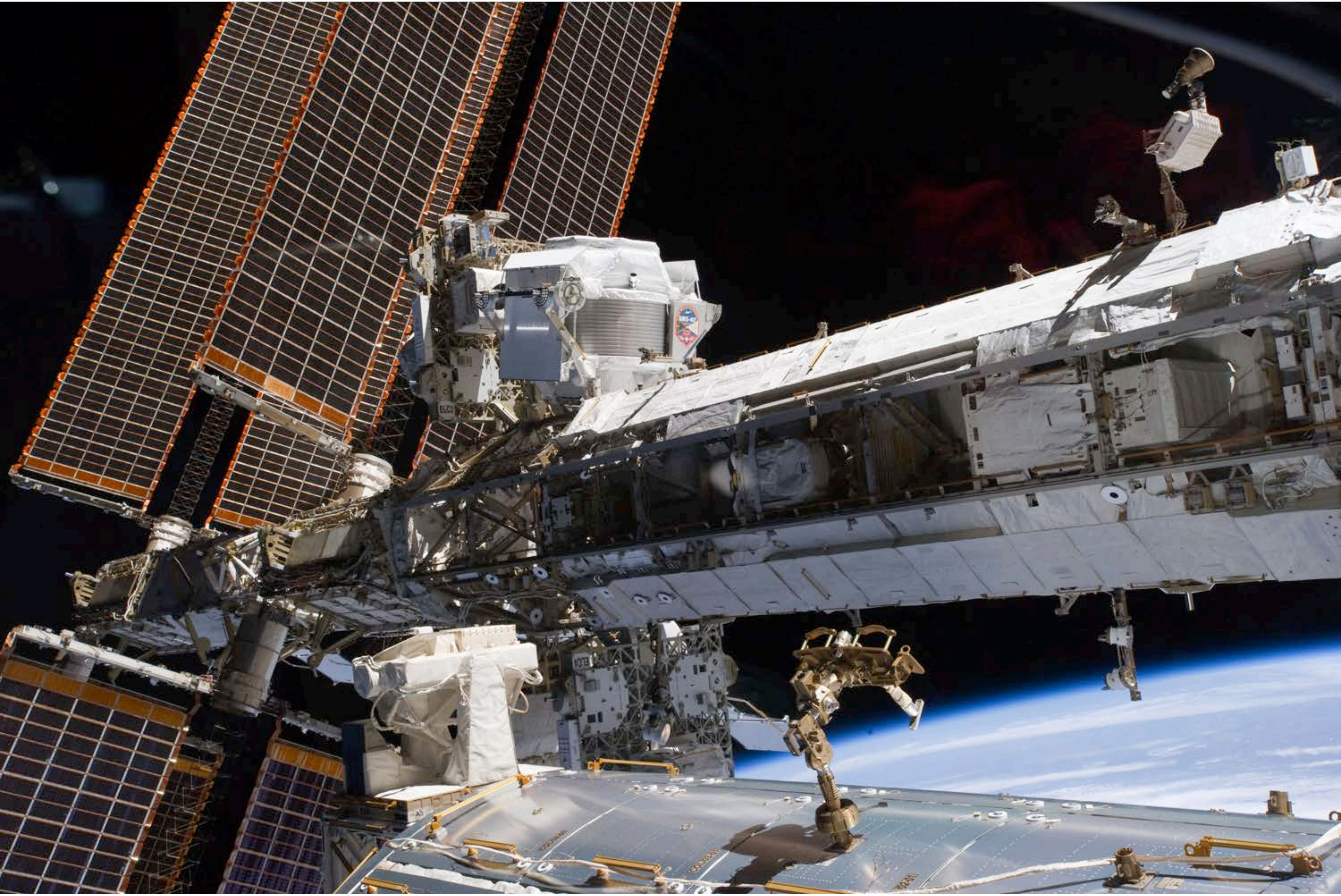


Compatible with Fermi-LAT gamma-ray Galactic center excess (GCE), dwarfs galaxies:

[Cuoco, JH, Korsmeier, Krämer 2017]



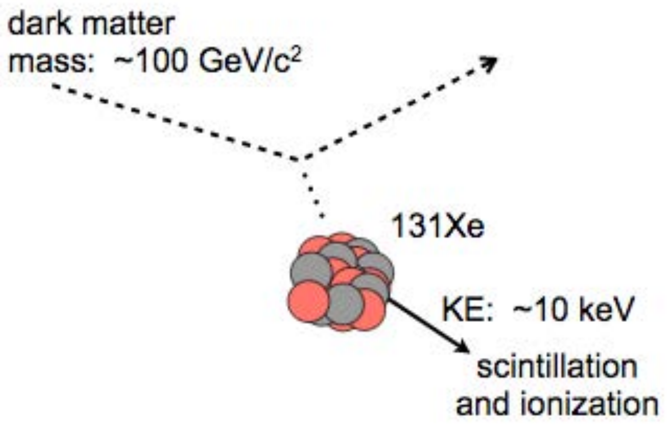
slide shown by Jan Heisig at the EPS HEP conference

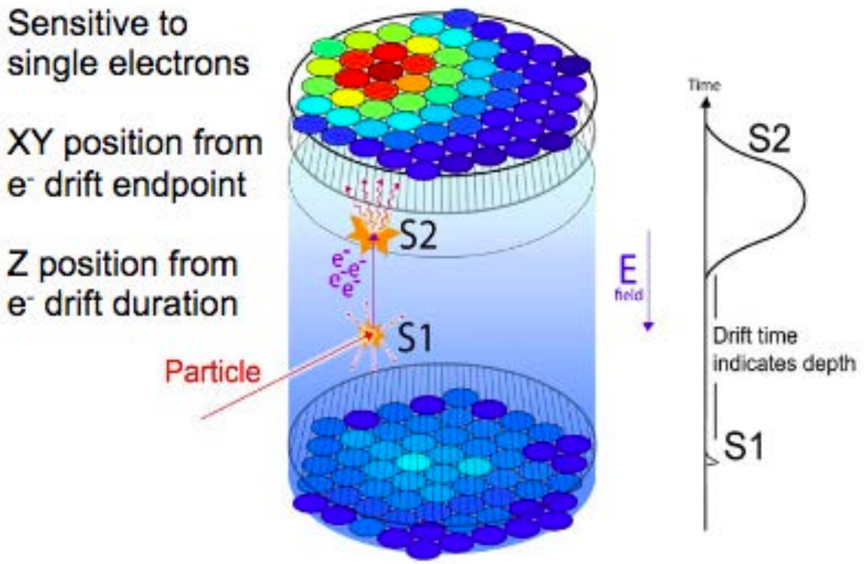


indirect detection − here AMS

LZ will be perfect for ~ 100 GeV/c^2 WIMPs

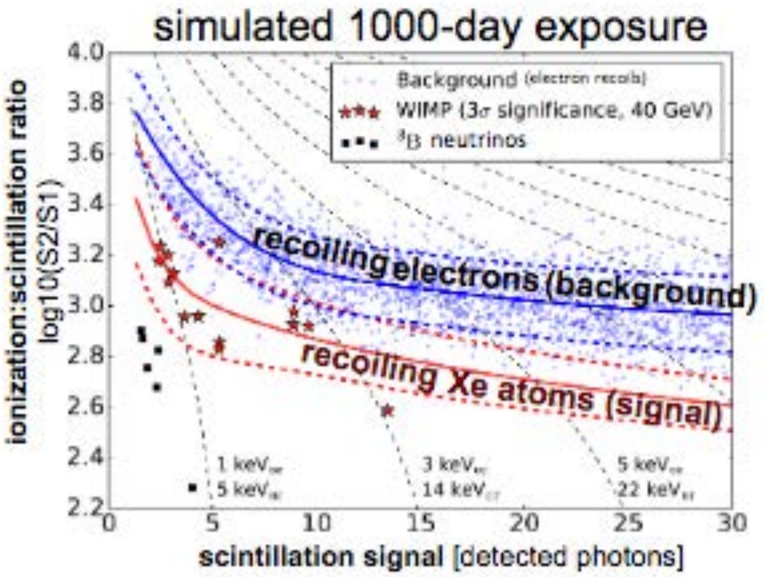
Credit: the Hertel Group --
https://www.physics.umass.edu/sites/default/files/attachments/page/20470/fie-hertel-lz.pdf




Sensitive to single electrons

XY position from e⁻ drift endpoint

Z position from e⁻ drift duration

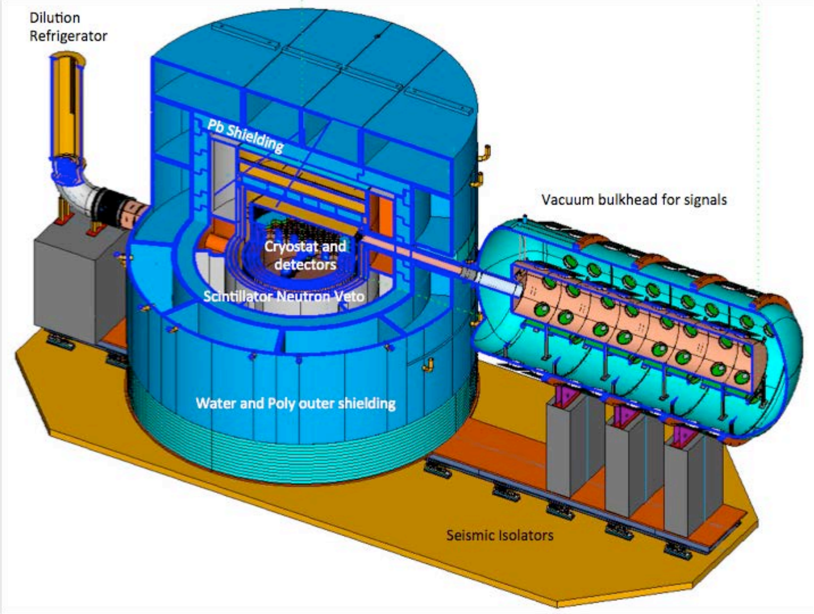



Davis Cavern before lab construction

But the Xenon experiment is equally good, and since we have shown only the inequality

$$m_H \leq 125\ \mathrm{GeV}/c^2$$

this particle is a candidate for observation in many experiments including those optimized for somewhat lower masses.



Cryogenic Dark Matter Search Experiment: Directly detect nuclear recoils from scattering of WIMPs off the nuclei of semiconducting crystals cryogenically cooled to 50 mK, using ionization and phonon detectors to perform simultaneous measurements of both signals.

collider detection – LHC

The Higgs-mediated couplings of these new particles H are relevant in all four scenarios – direct, indirect, and collider detection, and creation in the early universe – but the momentum-dependent (or second-order) gauge interactions will produce only very small cross-sections for slow-moving dark matter particles in the present universe, and are therefore relevant only for collider experiments and cosmological abundance.

The gauge couplings can play a significant role in determining the abundance of dark matter as it freezes out following annihilation in the early universe, where dark matter particles move with large momentum (at roughly 0.1-0.2 c).
The present dark matter candidate should then be produced in roughly the observed abundance (due to the usual "WIMP miracle"), but will not be ruled out by the current limits on direct or indirect dark matter detection.

Three "theorems":

1. Mass of lowest H^0 is ≤ 125 GeV/c^2 .

2. Naturalness implies that coupling of Higgson H^0 to Higgs h^0 is comparable to self-coupling of Higgs.

3. Both neutralino and Higgson are stable.

Although they both have an R-parity of -1, neither can decay into the other (or into other Standard Model and susy particles), for the reason given below, as demonstrated in the first paper on the title slide.

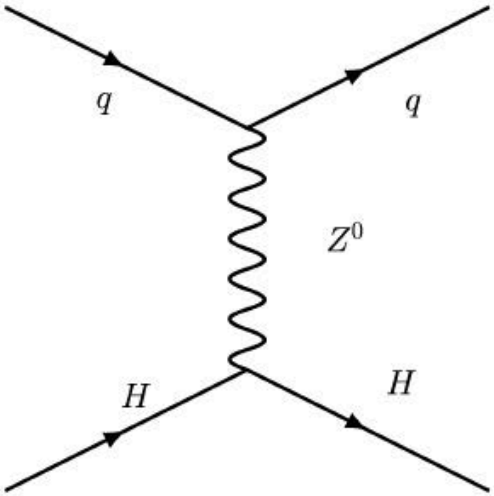
There are a number of experimental predictions of the present theory:

1. The present theory cannot even be formulated without supersymmetry.
2. The fundamental gauge group is necessarily SO(N), consistent with the fact that SO(10) is a leading candidate for gauge unification.
3. The theory cannot be formulated without the new spin ½ Higgsons, automatically providing an excellent dark matter candidate.
4. The theory predicts Lorentz invariance for all sectors that have been tested by experiment and observation up to the present – fermions, gauge bosons, scalar bosons, and gravity.
5. However, in this one new sector -- which should be observable at energies when these new particles are created in pairs above 250 GeV – there is not invariance under a Lorentz boost with respect to the cosmological frame. (Rotational invariance is exactly preserved, and the theory is consistent with the many existing tests of Lorentz invariance.)

One should recall that previously sacred symmetries have been found to be violated as experiments become increasingly sophisticated, with P, CP, and T violation observed in 1956, 1964, and 2012.

The spin-statistics theorem is based on Lorentz invariance, and it is the absence of complete Lorentz symmetry in this new sector that permits the spin ½ bosons *H* to exist.

The fact that the neutralinos are fermions and the Higgsons are bosons is the basic reason that the lowest mass versions of both are stable dark matter candidates.



Direct detection via Z^0 exchange with first-order momentum-dependent vertex.

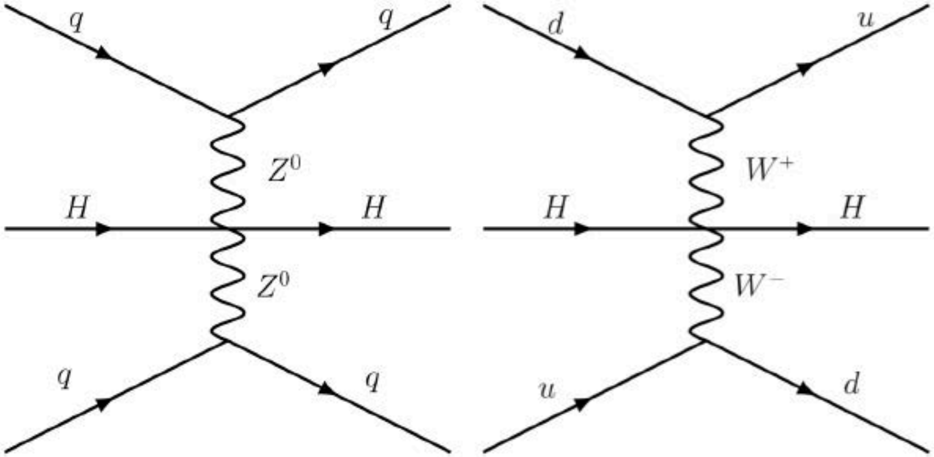


Fig. 2. Left: Direct detection via double Z exchange with second-order vertex. Right: Direct detection via double W exchange with second-order vertex

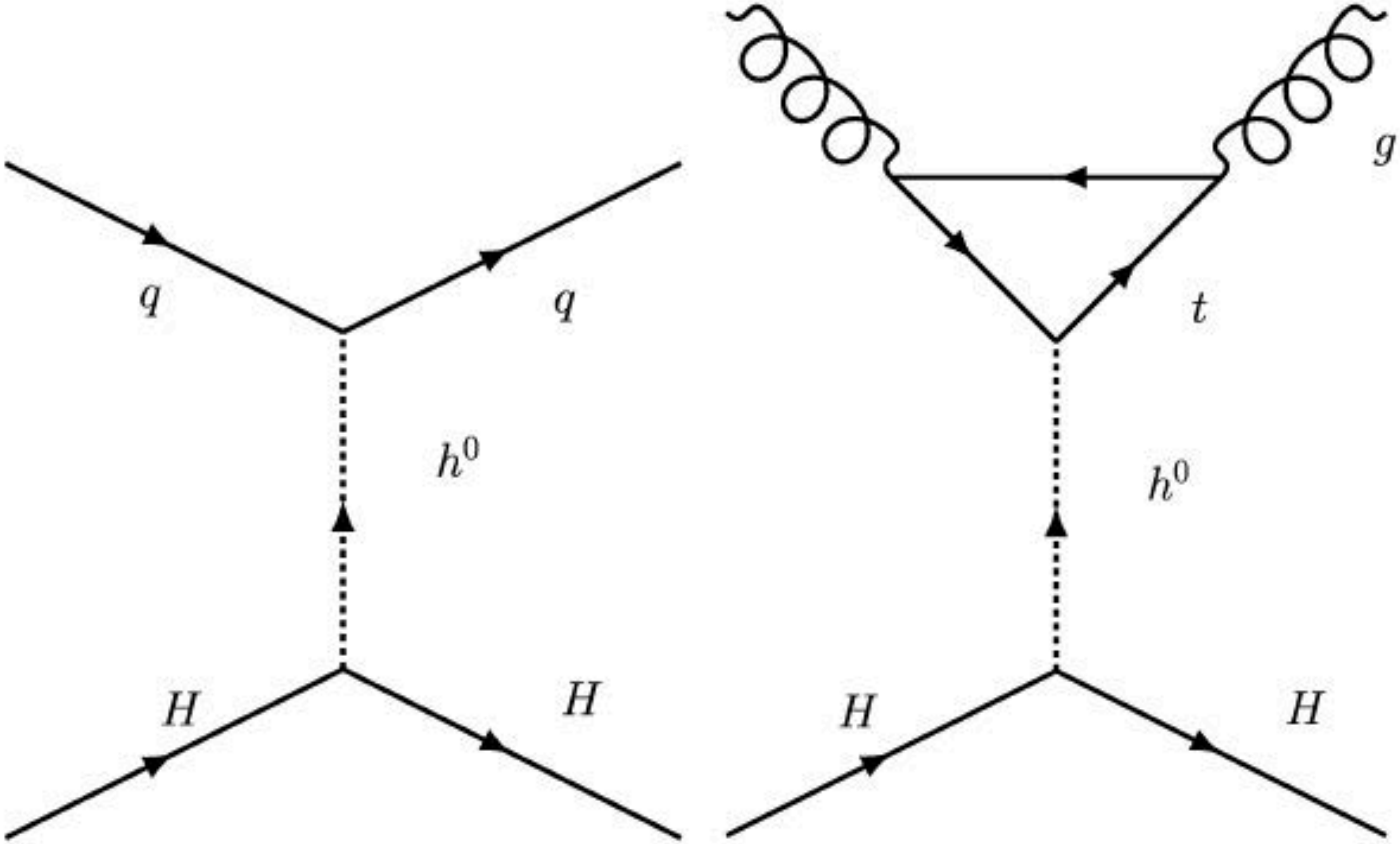


Fig. 3. Left: Direct detection via h^0 exchange with, e.g., strange quark. Right: Direct detection via h^0 exchange with top quark triangle coupled to gluons

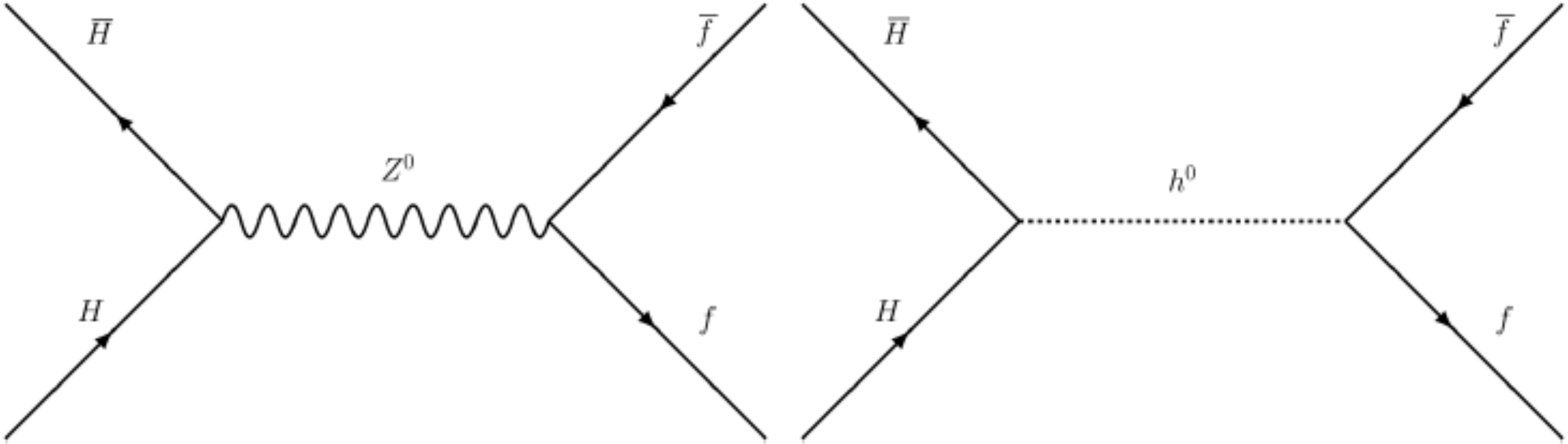


Fig. 4. Left: Indirect detection via Z^0. Right: Indirect detection via h^0.

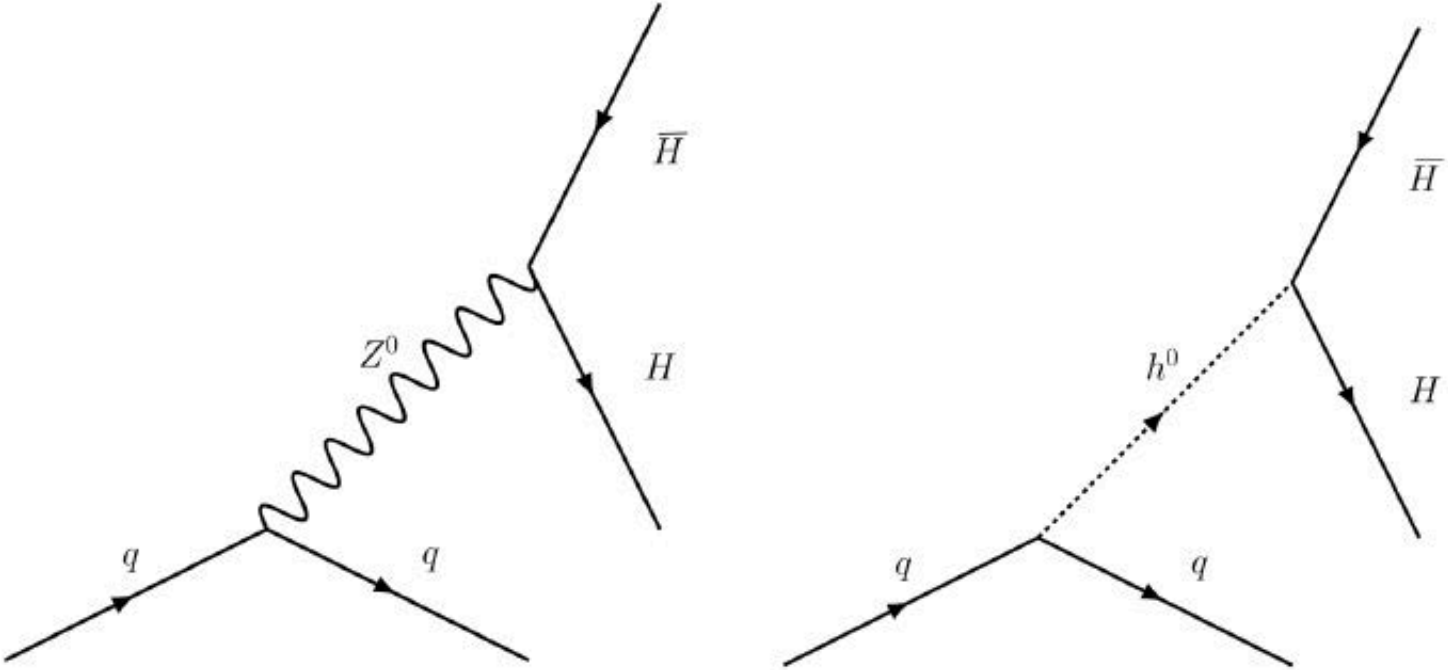
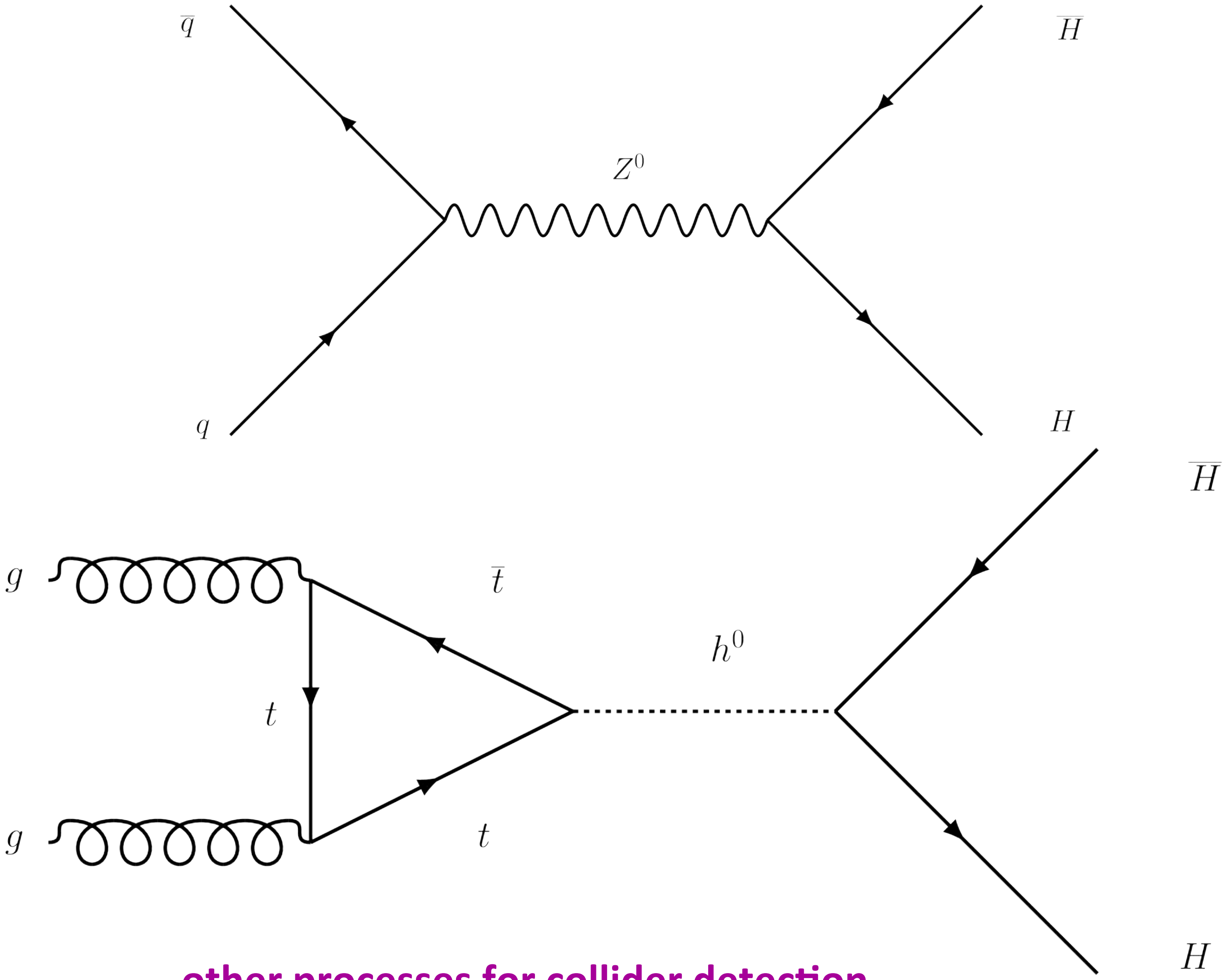


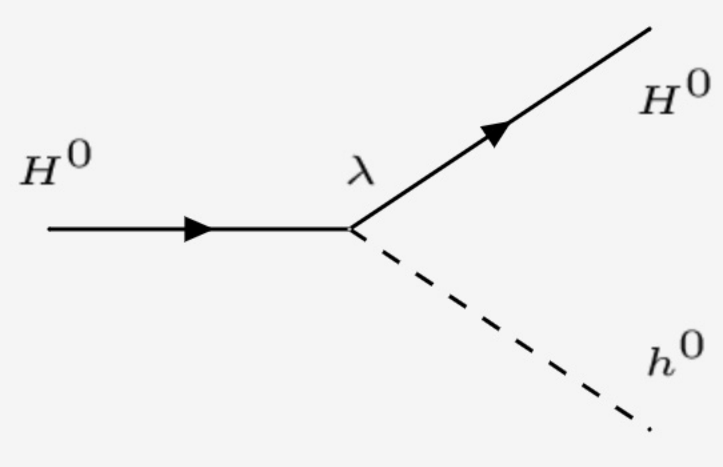
Fig. 5. Left: Collider production via Z^0. Right: Collider production via h^0.

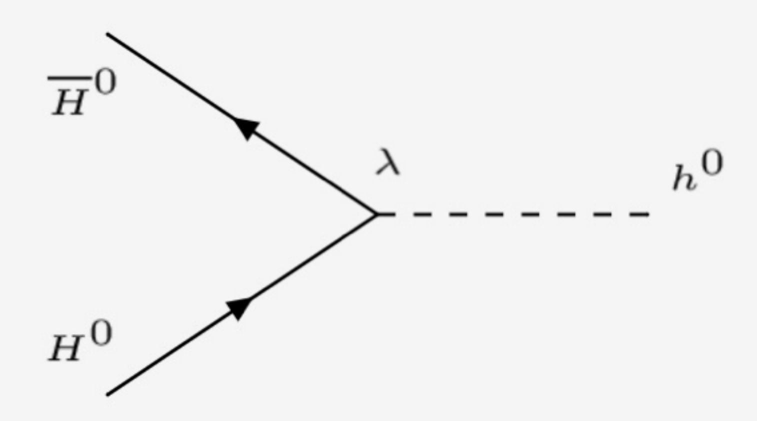


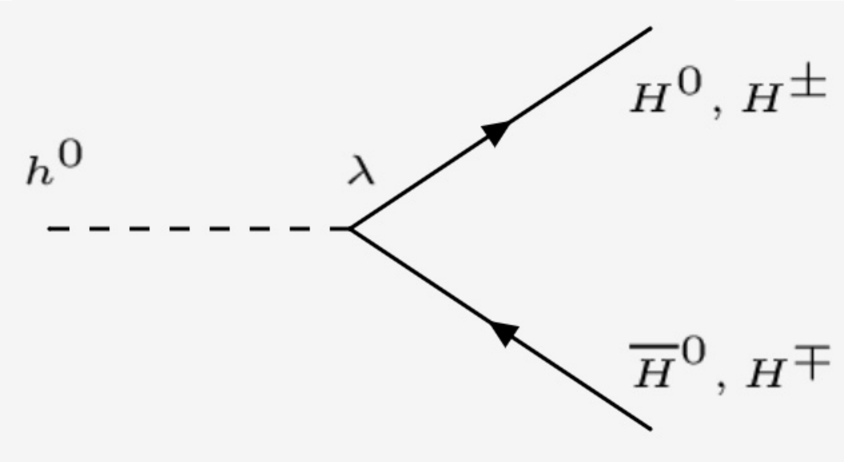
other processes for collider detection

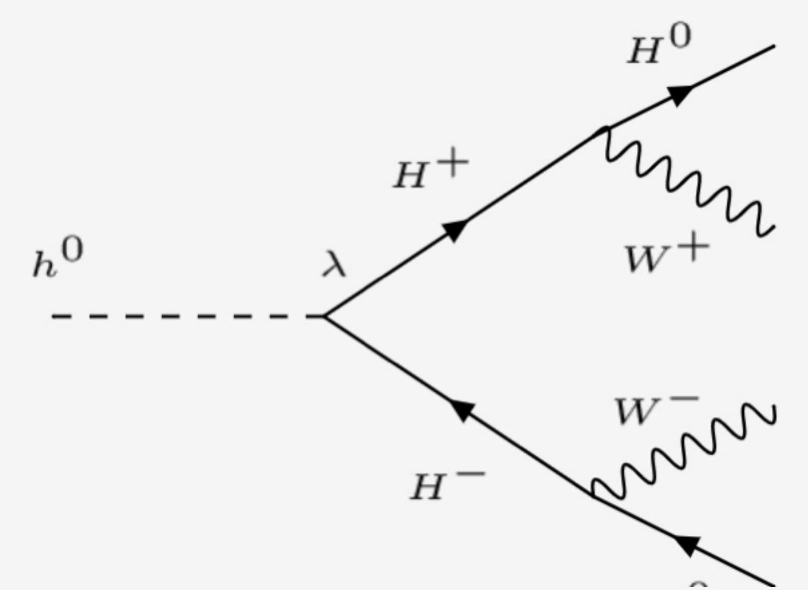
CMS and ATLAS have placed limits on production of dark matter particles via decay of a real (on-shell) Higgs, which means with particle masses below 125/2 ≈ 60 GeV/c^2 .

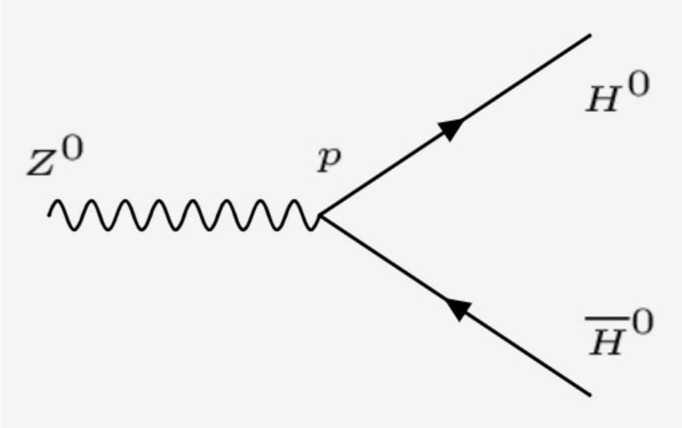
This is again favorable for the present candidate (which in the simplest version of the theory has a mass of 125 GeV/c^2).

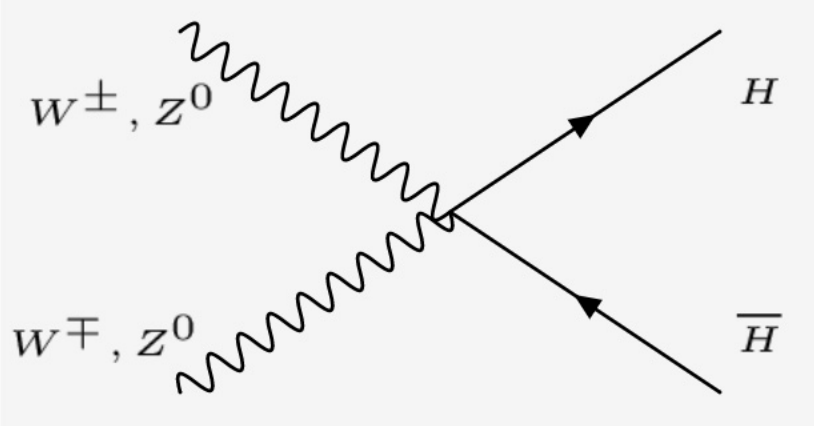

H^0
λ
H^0
h^0


$\overline{H}^0$
λ
h^0
H^0


h^0
λ
H^0, $H^\pm$
$\overline{H}^0$, $H^\mp$


H^0
H^+
W^+
h^0
λ
W^-
H^-


Z^0
p
H^0
$\overline{H}^0$


$W^\pm$, Z^0
H
$W^\mp$, Z^0
$\overline{H}$

In summary, with an R-parity of -1 (providing stability), a mass that is ≤ 125 GeV/c^2 , well-defined weak-interaction couplings, and a coupling to the Higgs that is comparable to that of well-studied susy (neutralino) candidates, the particle predicted here is in many respects an ideal dark matter candidate.

The theory that predicts these new particles -- which are associated with an extended version of the Higgs sector -- also unambiguously predicts supersymmetry.

The fact that susy has also not yet been observed is then attributed to a higher energy scale for superpartners than has been explored so far.

And the neutralino of susy remains a quite likely secondary component of the dark matter.

(There may be other constituents, such as axions, but these other candidates remain poorly characterized with respect to mass and abundance.)

Perhaps most important, the present theory predicts a plethora of new neutral and charged particles, and new physics, to be discovered at collider energies that could be available in the foreseeable future.

Thanks for your attention!