Two natural scenarios for dark matter particles coexisting with supersymmetry

Maxwell Throm, Reagan Thornberry, John Killough, Brian Sun, Gentill Abdulla, and Roland E. Allen

Physics and Astronomy, Texas A&M University

This talk is based on the following papers:

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 scenarios 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 possibly the AMS and Fermi satellite experiments.

First Scenario: the multicomponent model of Baer, Barger, Sengupta, and Tata

Recently it has been pointed out that a multicomponent dark matter scenario, dominated by e.g. axions, but with a significant admixture of neutralinos, 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.

This suggestion provides motivation for both the many weakly interacting massive particles (WIMPs) searches — including e.g. Xenon, LZ, and SuperCDMS — and the very different searches for axions.

Second Scenario: Supersymmetry coexists with an extended Higgs sector which accounts for the dark matter

This scenario inevitably follows from a fundamental theory which is an alternative to string theory, but here we consider it simply as a postulated phenomenological model:

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).

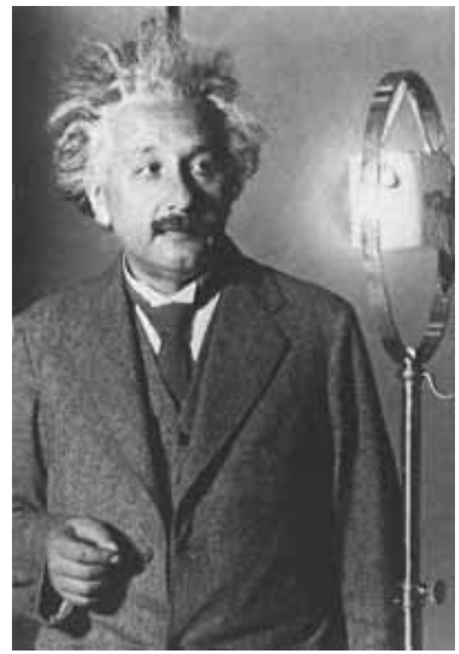
R. E. Allen, ""Saving supersymmetry and dark matter WIMPs—a new kind of dark matter candidate with well-defined mass and couplings", Phys. Scripta 94, 014010 (2019).

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

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 exists, but it loses its status as a dark matter candidate if the new particle predicted here (with spin ½ and R-parity = -1) has lower mass.

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, (1982).

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

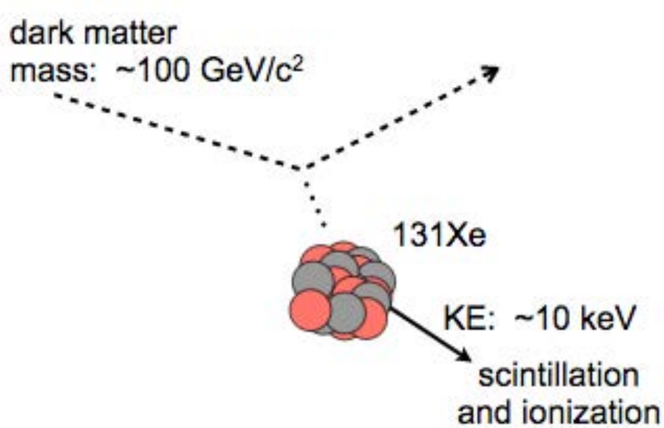
Their couplings to gauge bosons are either momentum-dependent or second-order, and therefore weak for direct or indirect detection of slowly moving dark matter particles.

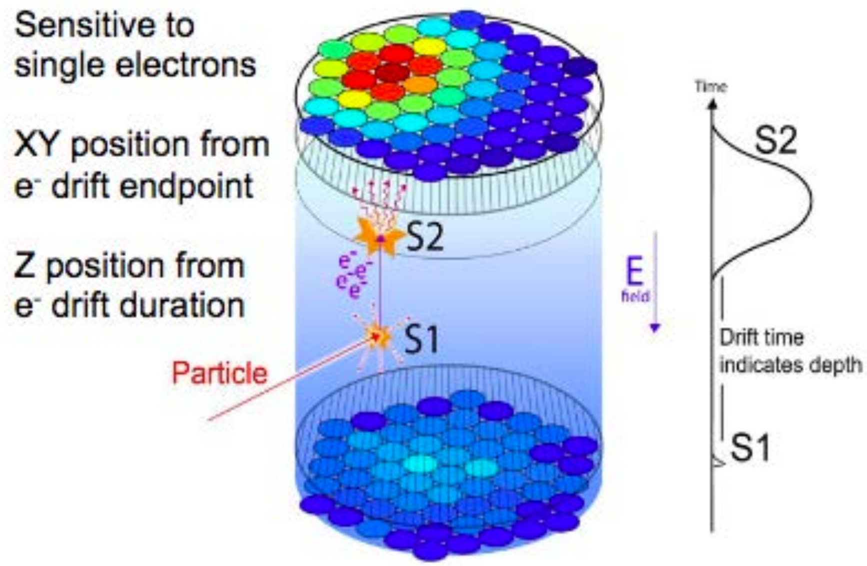
But their effective coupling to Higgs bosons is comparable to that of a neutralino.

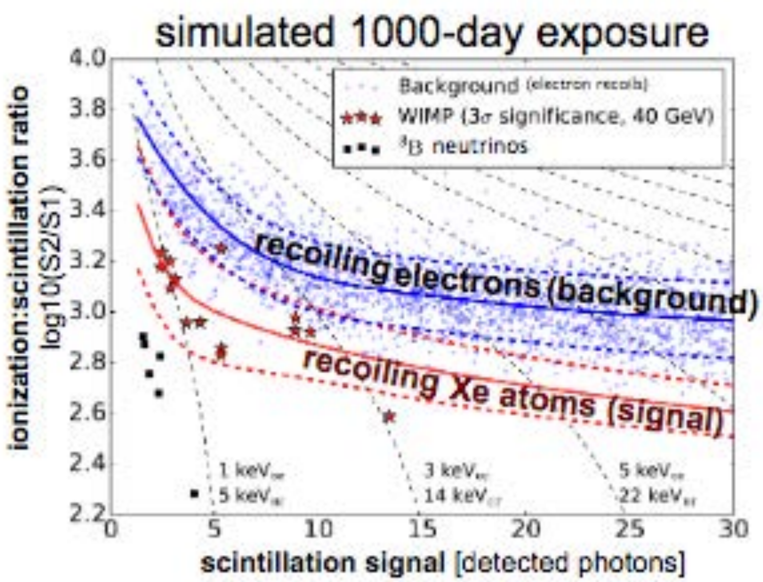
Also, their predicted mass is ≤ 125 GeV/c^2 .

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





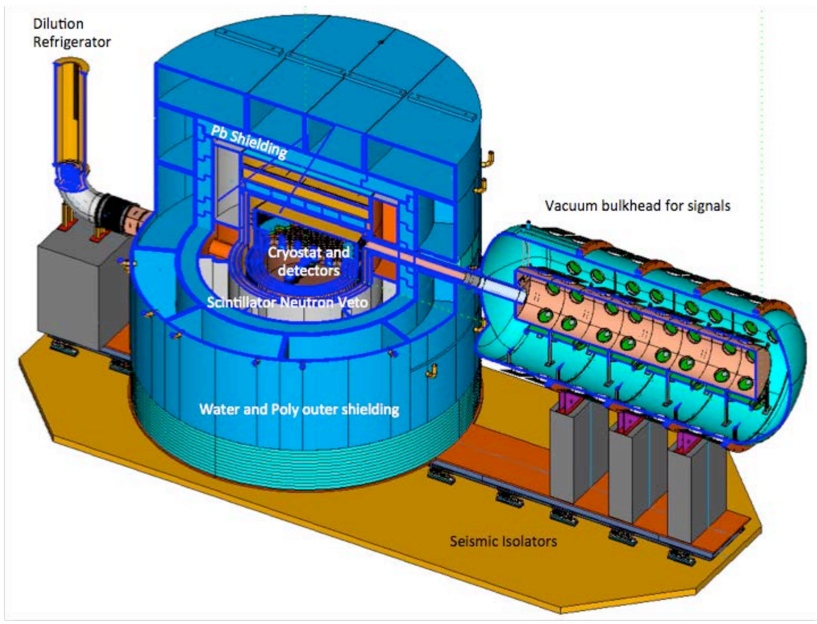


Davis Cavern before lab construction

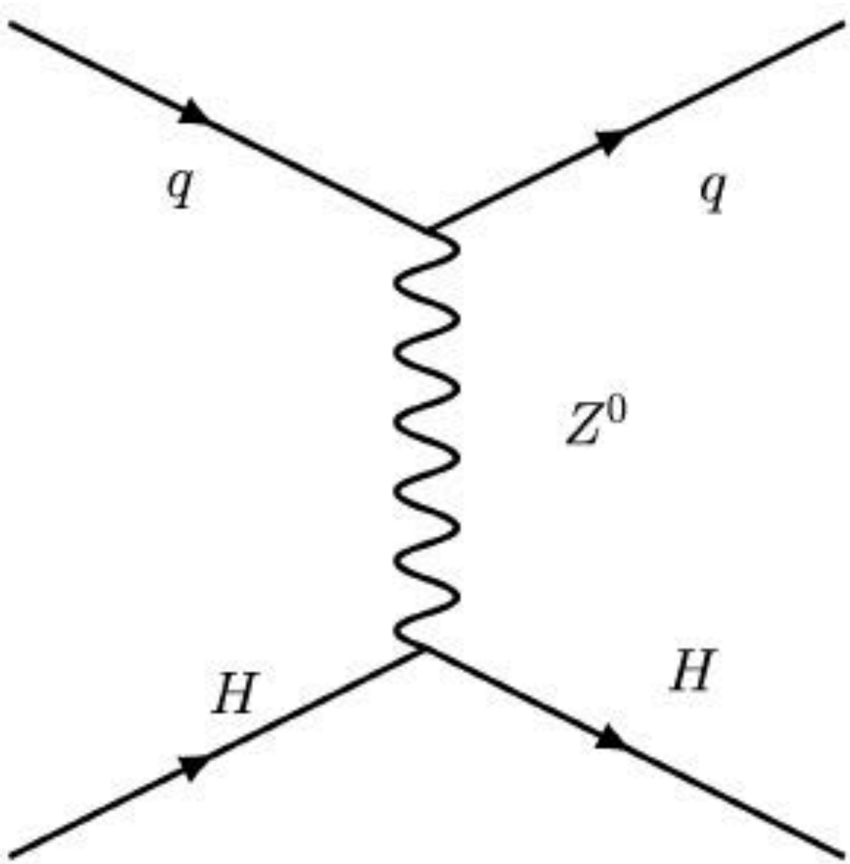
But the Xenon experiment is equally good, and since we have shown only the inequality

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

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.



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

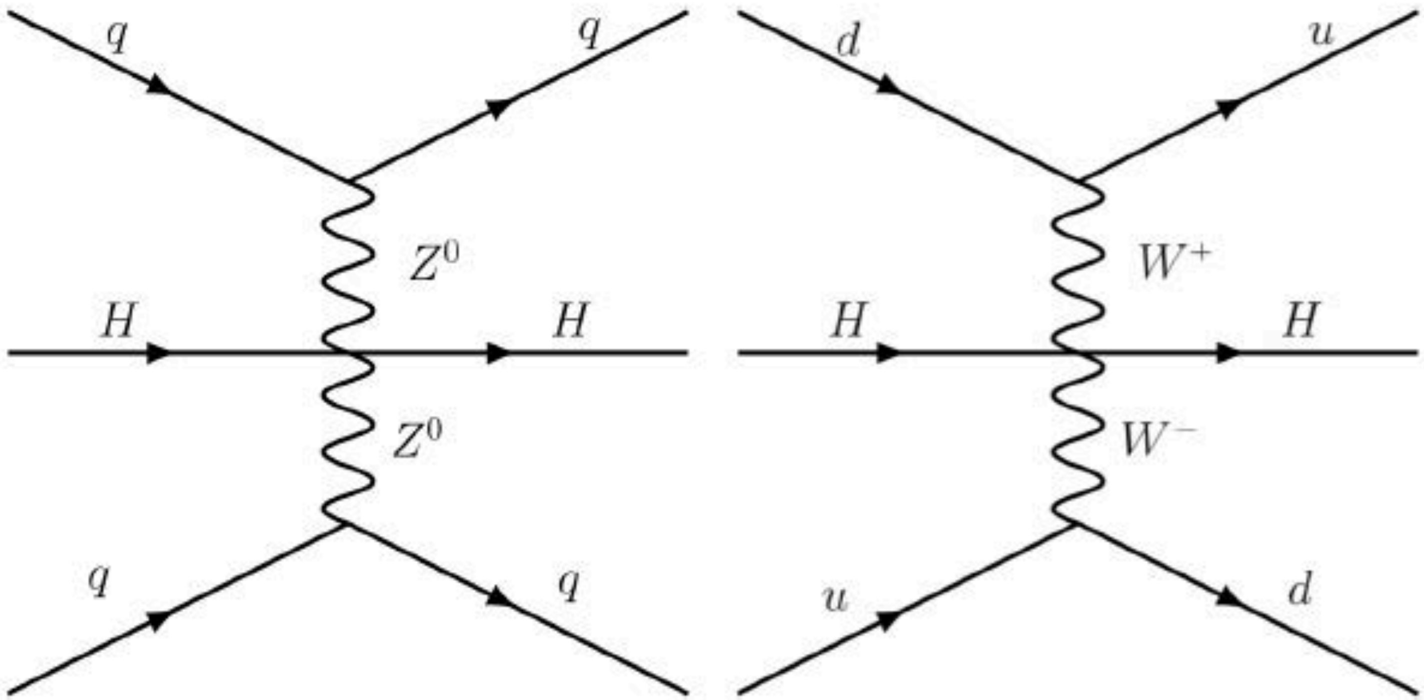


Fig. 2. Left: Direct detection via double Z exchange with second-order vertex. Right: Direct detection via double W exchange with second-order vertex

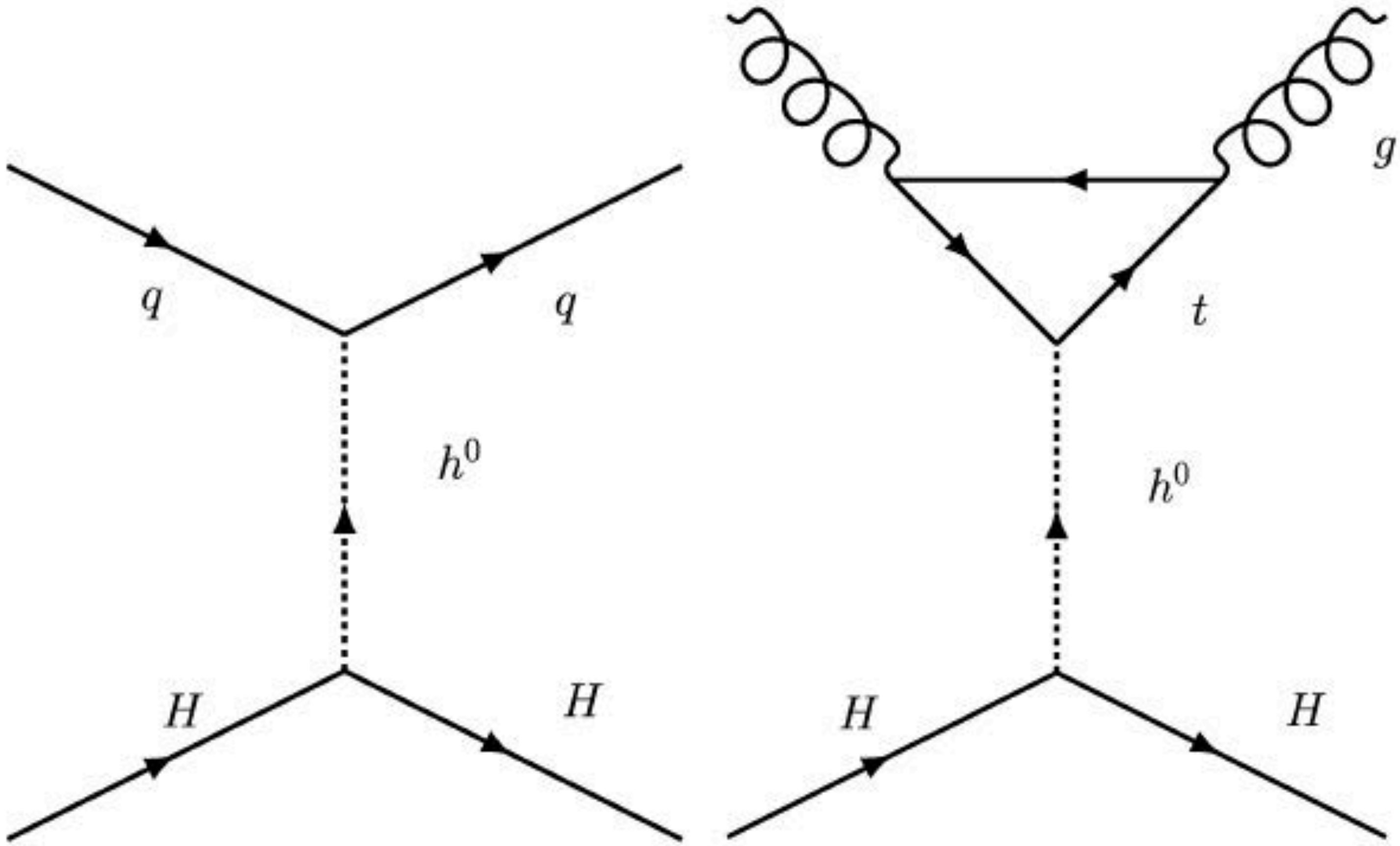
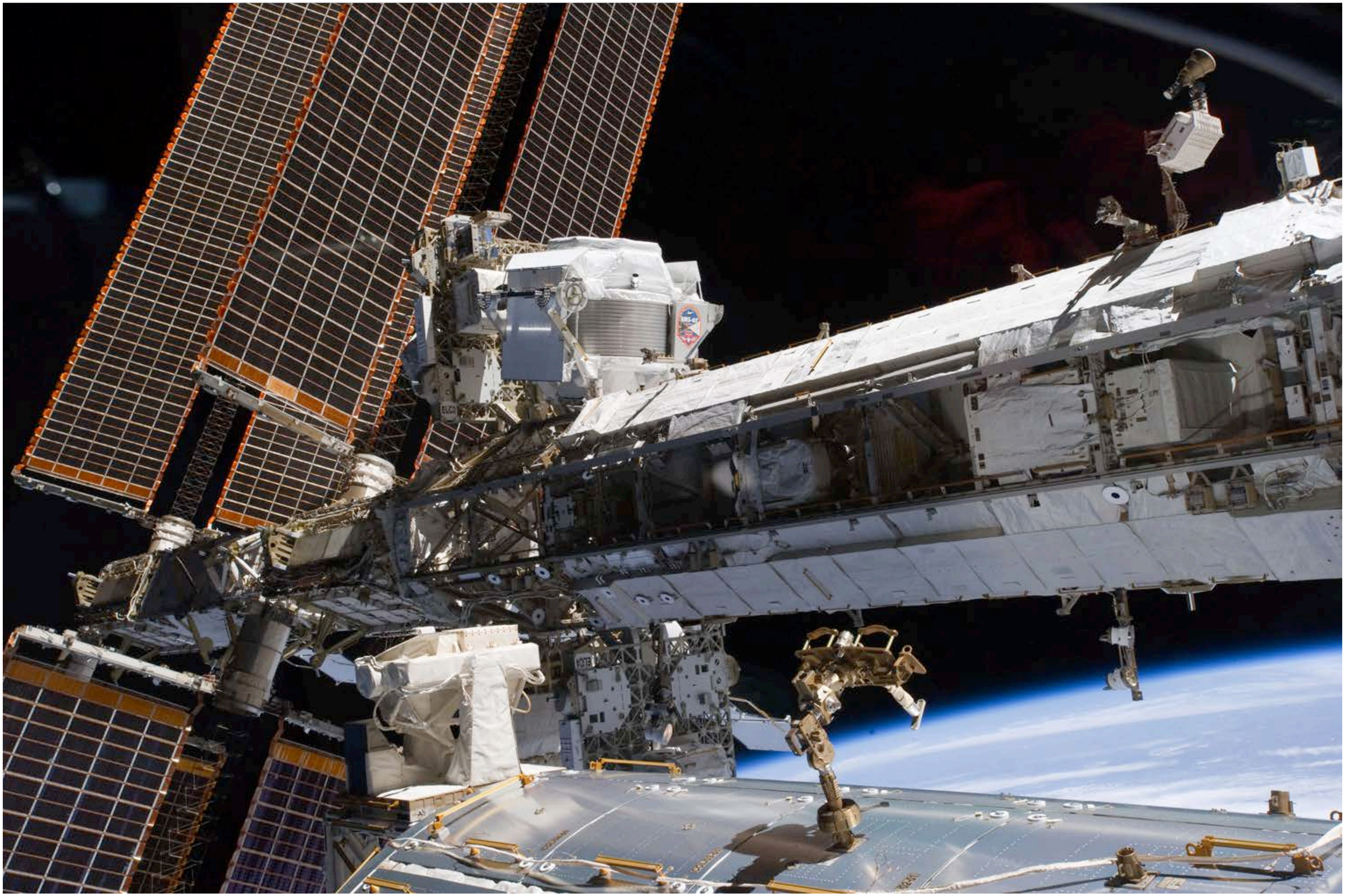


Fig. 3. Left: Direct detection via h^0 exchange with, e.g., strange quark. Right: Direct detection via h^0 exchange with top quark triangle coupled to gluons



Indirect detection − here AMS

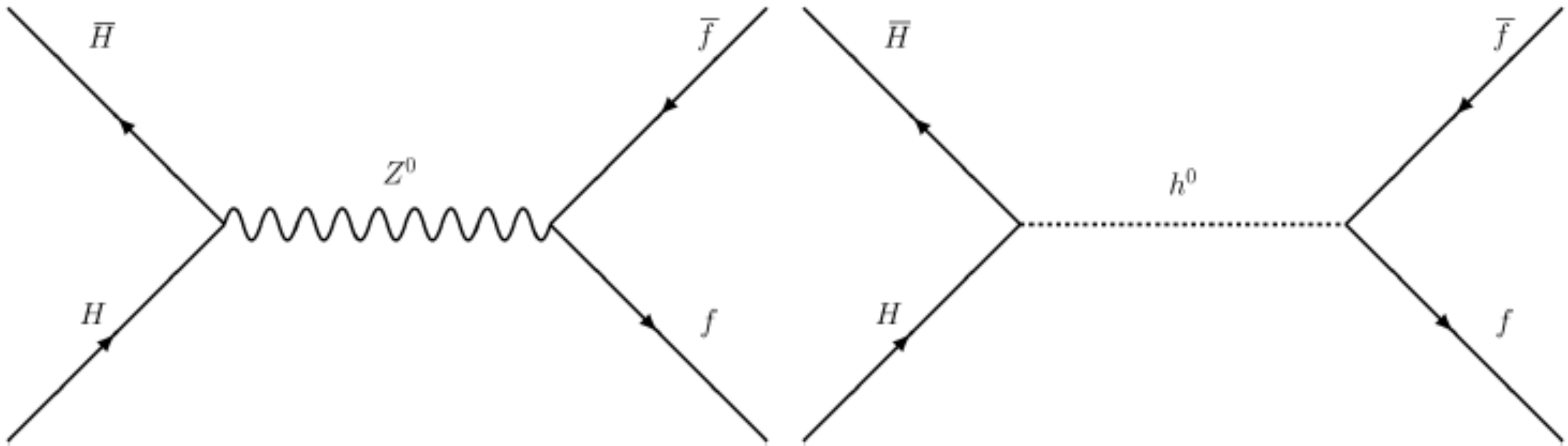


Fig. 4. Left: Indirect detection via Z^0. Right: Indirect detection via h^0.

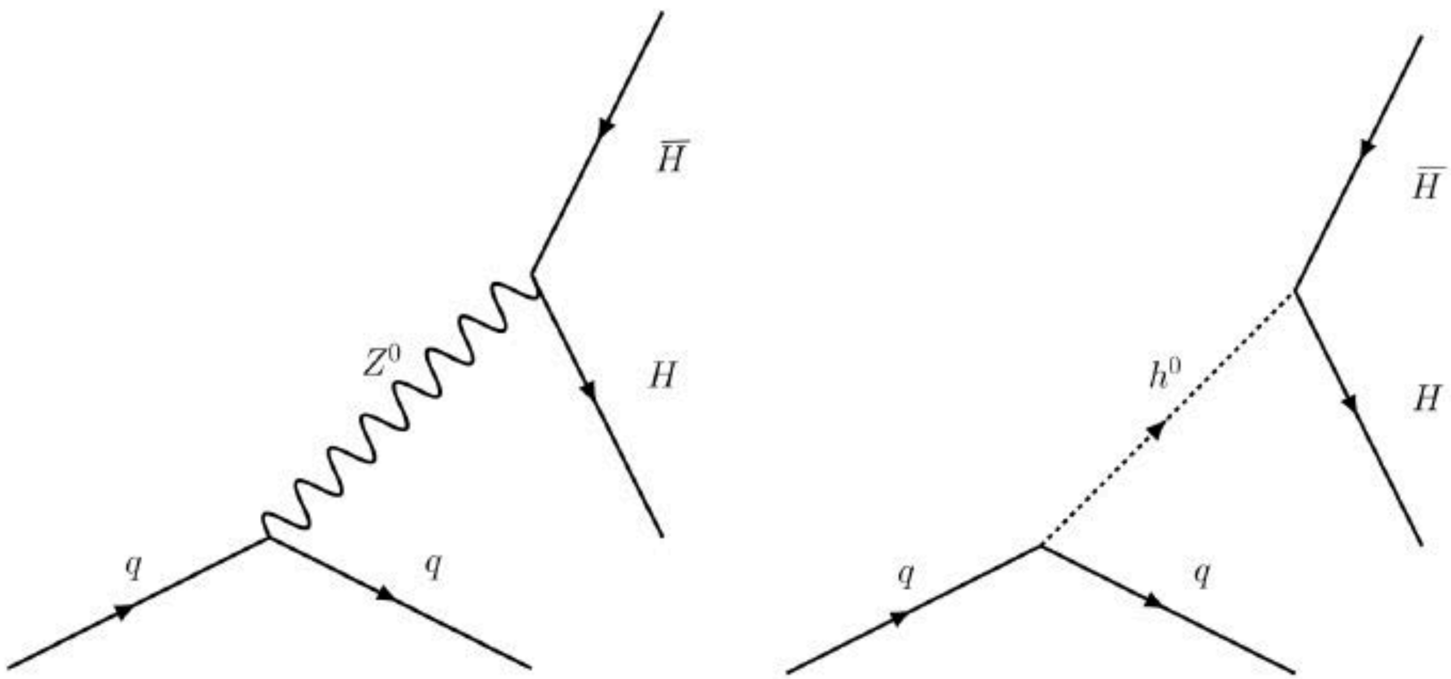
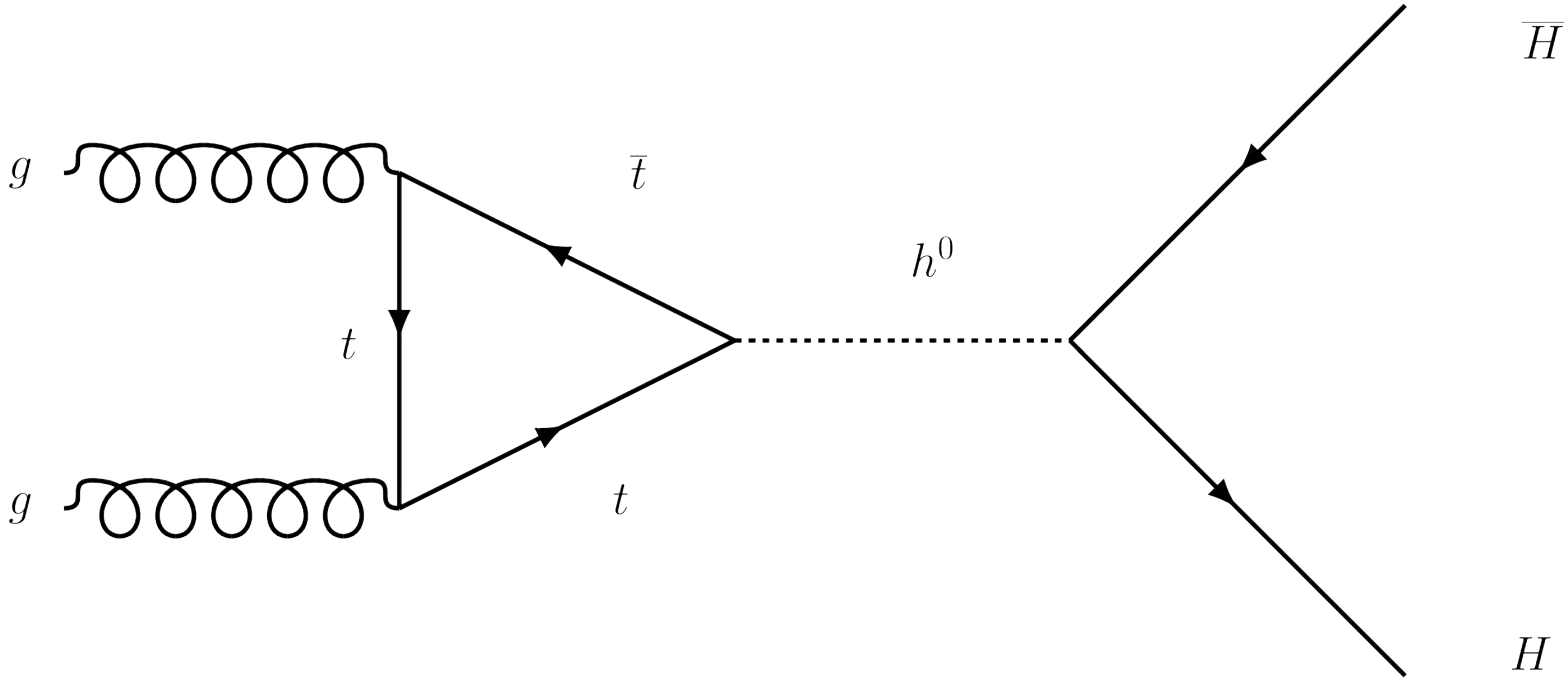
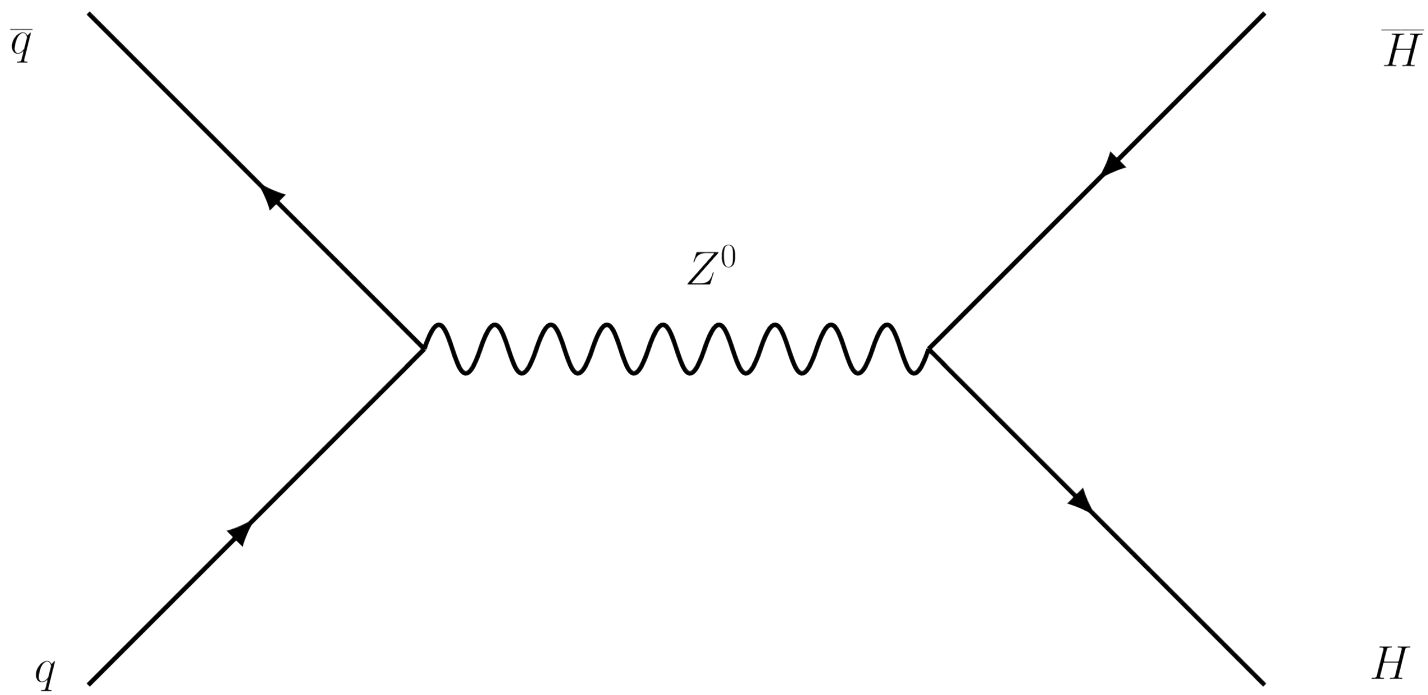


Fig. 5. Left: Collider production via Z^0. Right: Collider production via h^0.

collider detection


g
g
t
$\bar{t}$
t
h^0
$\overline{H}$
H


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

We conclude that the Higgson H^0 and the neutralino χ^0 should have comparable cross-sections for Higgs exchange. Since this is the dominant process for direct detection via spin-independent scattering, H^0 is in the same basic range of detectability as the neutralino.

The amplitudes can easily differ by an order of magnitude, however, and the cross-sections by two orders of magnitude, so quantitative calculations are needed. The mass of the H^0 is ≤ 125 GeV and its coupling constant λ_H is related to the quartic coupling constant of the Higgs (about 1/6), so better estimates are feasible.

In summary, with well-defined couplings, an R-parity of -1 (providing stability), and a mass that is ≤ 125 GeV/c^2 , 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.

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!