HEPHY Institut für Hochenergiephysik

ÖAW Österreichische Akademie der Wissenschaften

Status of the IDM after Run-1 of the LHC

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(in collaboration with G. Bélanger, B. Dumont, B. Herrmann, S. Kraml, D. Sengupta, O. Stål)

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The Inert Doublet Model

One of the most “archetypical” DM models, the Inert Doublet Model

Desphande, Ma (1978)
Barbieri, Hall, Rychkov(2006)
Honorez, Nezri, Oliver, Tytgat (2006)
...

- Gauge + spacetime symmetries : as in the SM.

- Particle content : SM + one SU(2) doublet of complex (Lorentz) scalar fields.

$$H = \begin{pmatrix} G^+ \\ \frac{1}{\sqrt{2}}\left(v + h^0 + \mathrm{i}G^0\right) \end{pmatrix}, \quad \Phi = \begin{pmatrix} H^+ \\ \frac{1}{\sqrt{2}}\left(H^0 + \mathrm{i}A^0\right) \end{pmatrix}$$

- An extra Z_2 discrete symmetry that protects the lightest component of the extra doublet from decaying.

The Lagrangian reads :

$$\mathcal{L}_{\rm cov} = (D_\mu H)^\dagger (D^\mu H) + (D_\mu \Phi)^\dagger (D^\mu \Phi)$$

$$V_0 = \mu_1^2 |H|^2 + \mu_2^2 |\Phi|^2 + \lambda_1 |H|^4 + \lambda_2 |\Phi|^4 + \lambda_3 |H|^2 |\Phi|^2 + \lambda_4 |H^\dagger \Phi|^2 + \frac{\lambda_5}{2}\left[(H^\dagger \Phi)^2 + \mathrm{h.c.}\right]$$

Parameters and constraints

All in all, the IDM can be described by a set of 5 free parameters:

(+ λ_2 which is irrelevant here)

$$m_h, \quad m_{H^0}, \quad m_{A^0}, \quad m_{H^\pm}, \quad \lambda_L$$

- m_h → h mass
- $m_{H^0}, m_{A^0}, m_{H^\pm}$ → inert scalar masses
- λ_L → H^0 - H^0 - h coupling

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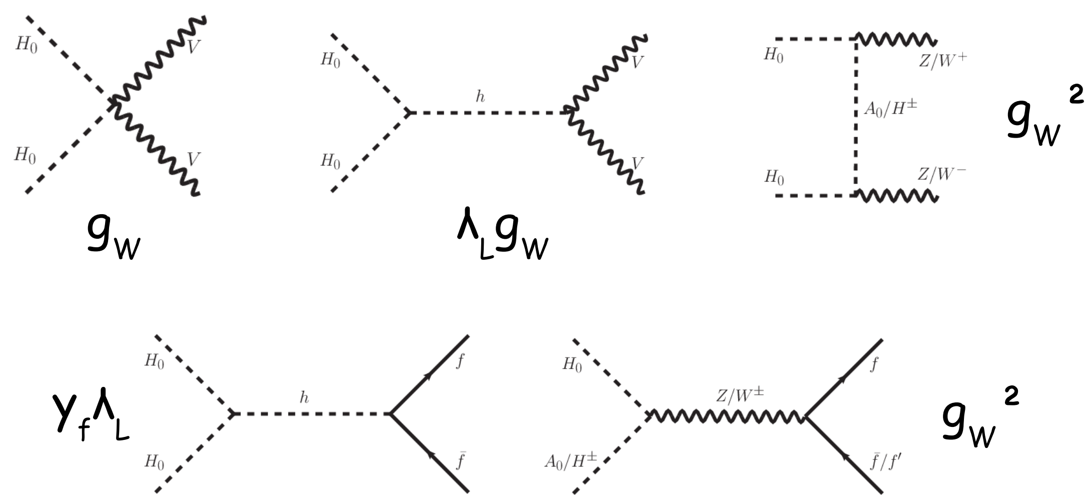

(+ h final states)

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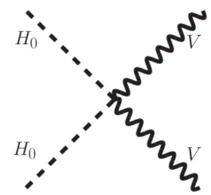
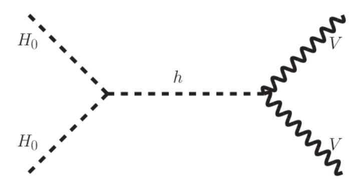
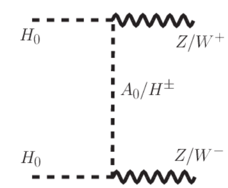


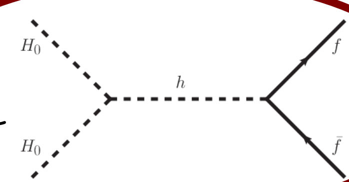
g_W



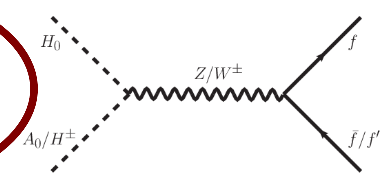
$\lambda_L g_W$



$g_W^{\;2}$



$y_f \lambda_L$ → Also controls DD



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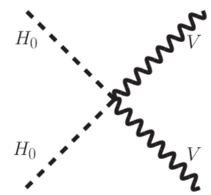

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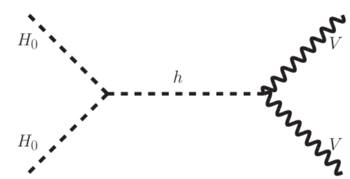
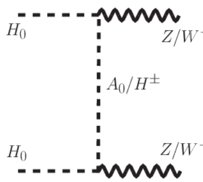
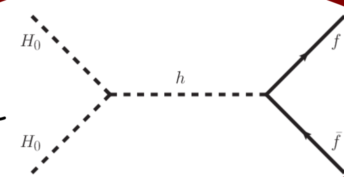


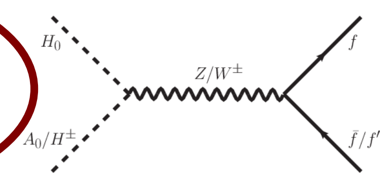
$\lambda_L g_W$



$g_W^{\ 2}$

Also controls DD ← $y_f \lambda_L$





$g_W^{\ 2}$

(+ h final states)

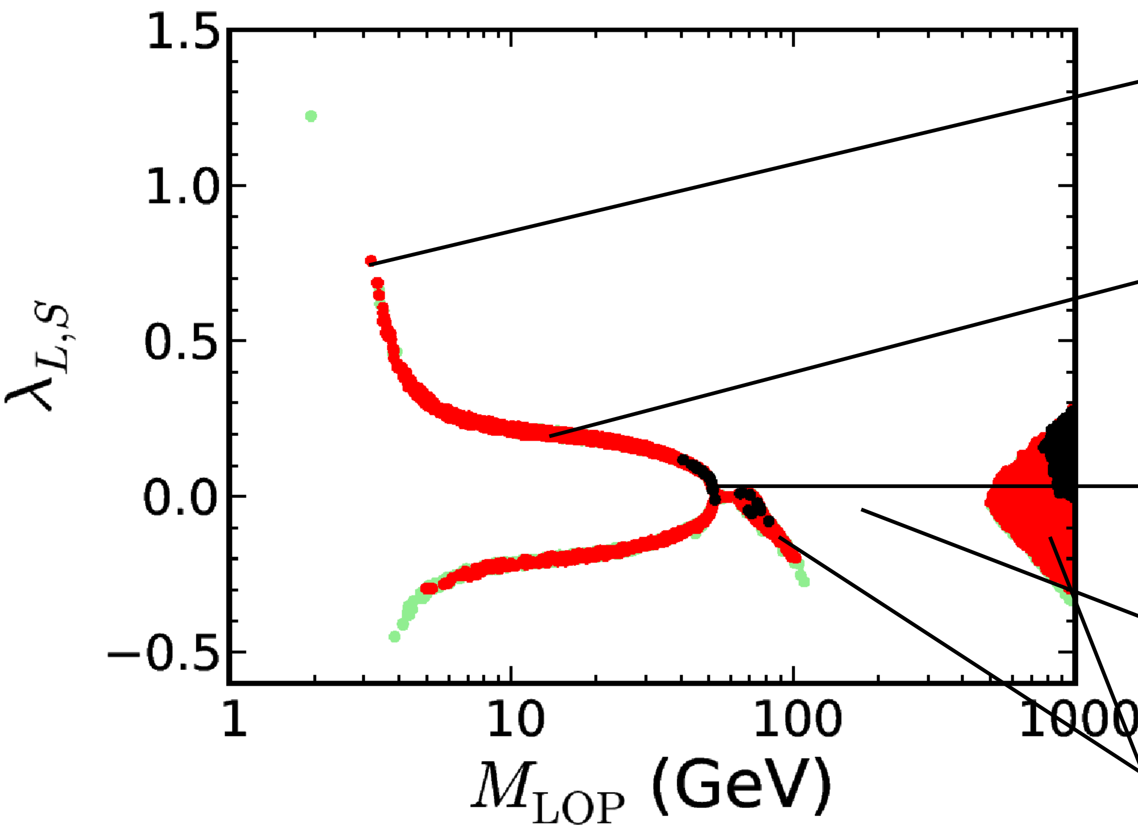
Further constraints come from:

- Vacuum stability, perturbativity, unitarity
- LEP-2 and EWPTs
- h (invisible) decays
- LHC SUSY searches

Long list of Refs, *cf e.g.* Ilnicka, Krawczyk, Robens (2015) for a recent summary

The relic density

Simple models allow us to understand all of the underlying physics. DM is OK in basically three regimes:



Annihilation primarily into τ's : small-ish Yukawa, large λ_L needed

Annihilation primarily into b's : $O(3)$ larger Yukawa, $O(3)$ smaller λ_L

Resonant Higgs/WW^* (gauge) contributions : tiny λ_L

WW channel open for good, relic density too small

This would have actually also been too small, but destructive interference

A different kind of destructive interference

A.G., B. Herrmann, O. Stal (2013)
(*cf* also Honorez, Nezri, Oliver, Tytgat (2006), Honorez, Yaguna (2010))

Connections: DD

We can easily establish a correspondence between the mechanisms producing the relic density and direct detection

A.G., B. Herrmann, O. Stal (2013)

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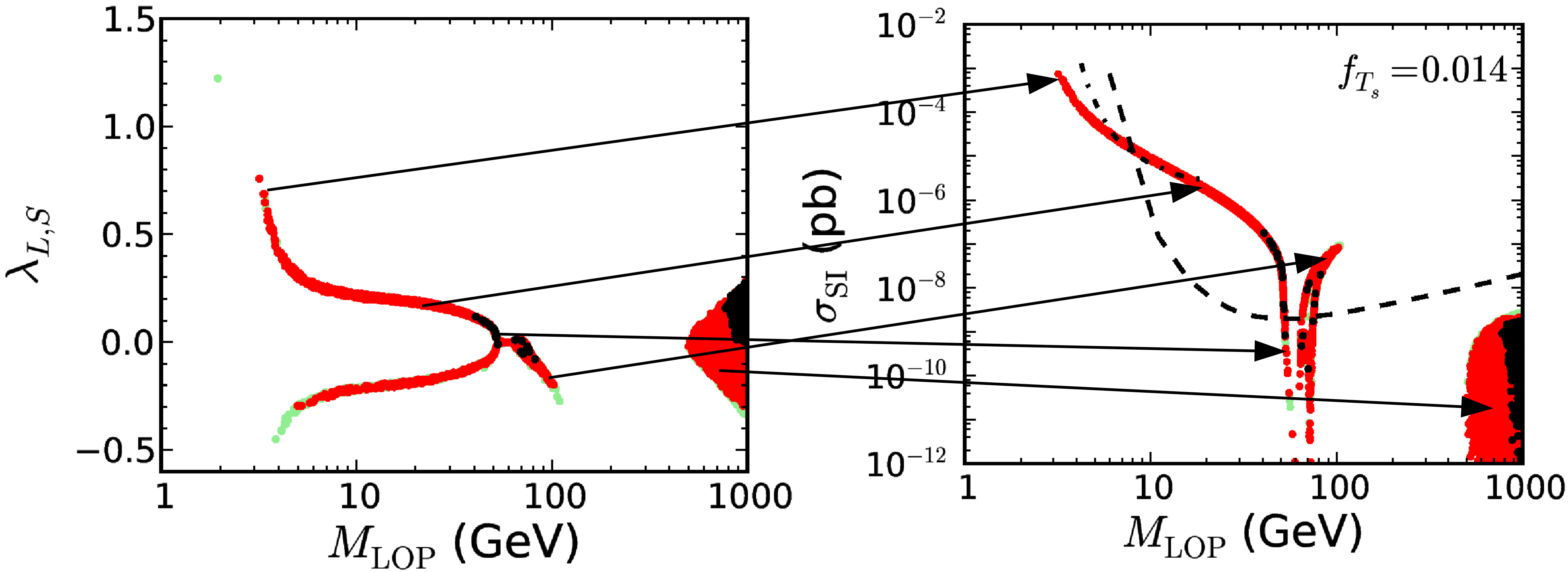
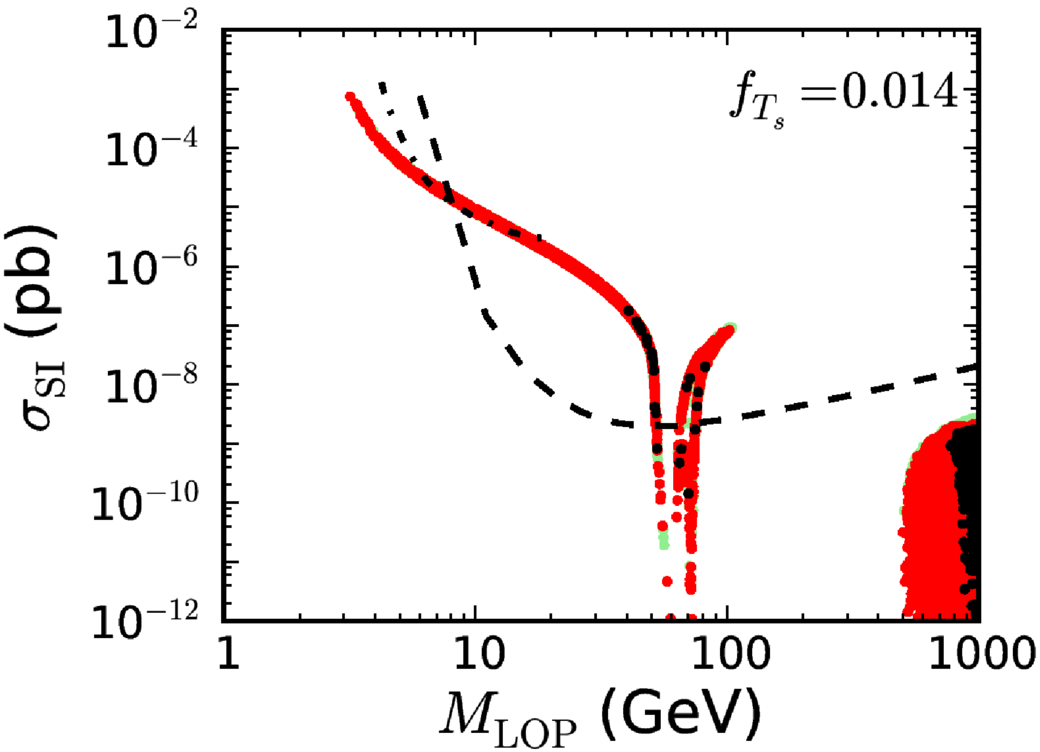


NB: this picture became *much* clearer after the Higgs boson discovery!

Connections: DD + BR(h → inv)

What's more, the Higgs boson properties *also* constrain the IDM

A.G., B. Herrmann, O. Stal (2013)



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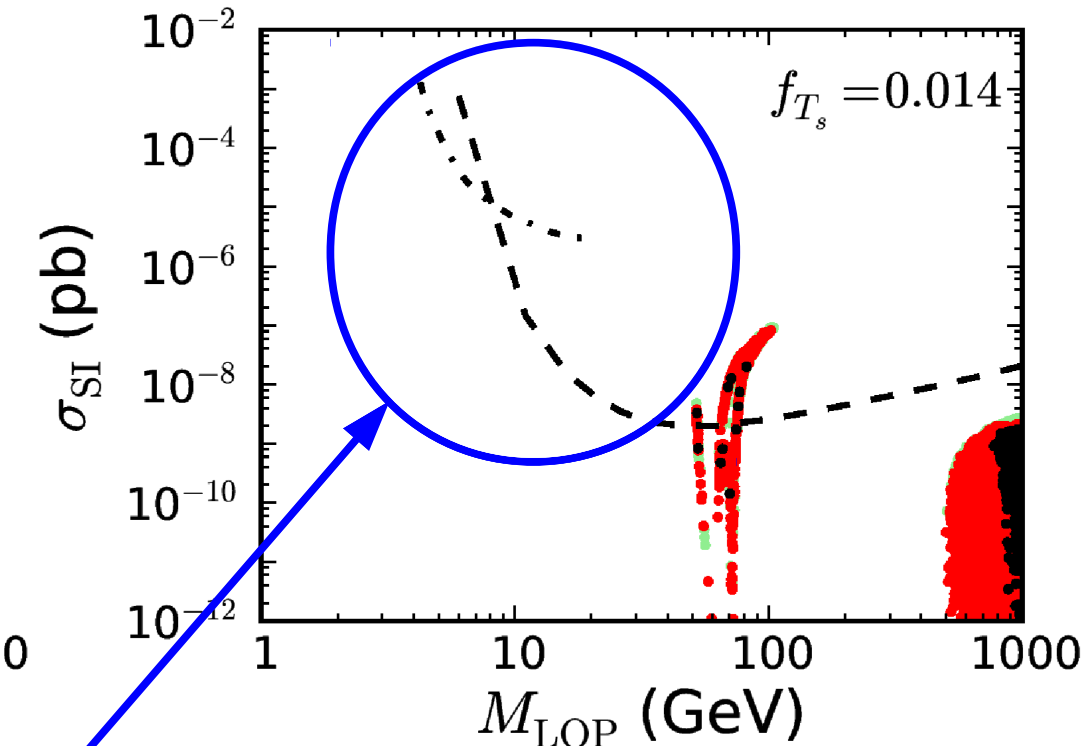

Impose BR(h → inv) < 0.65
(currently ~0.12)

A constraint that's clear of uncertainties, based on the *mediator* properties.

The "Higgs funnel"

Funnels are present in most s-channel DM models, corresponding to mediator being on-shell *in the early universe* → tiny couplings ($\lambda_L \sim O(10^{-3})$).

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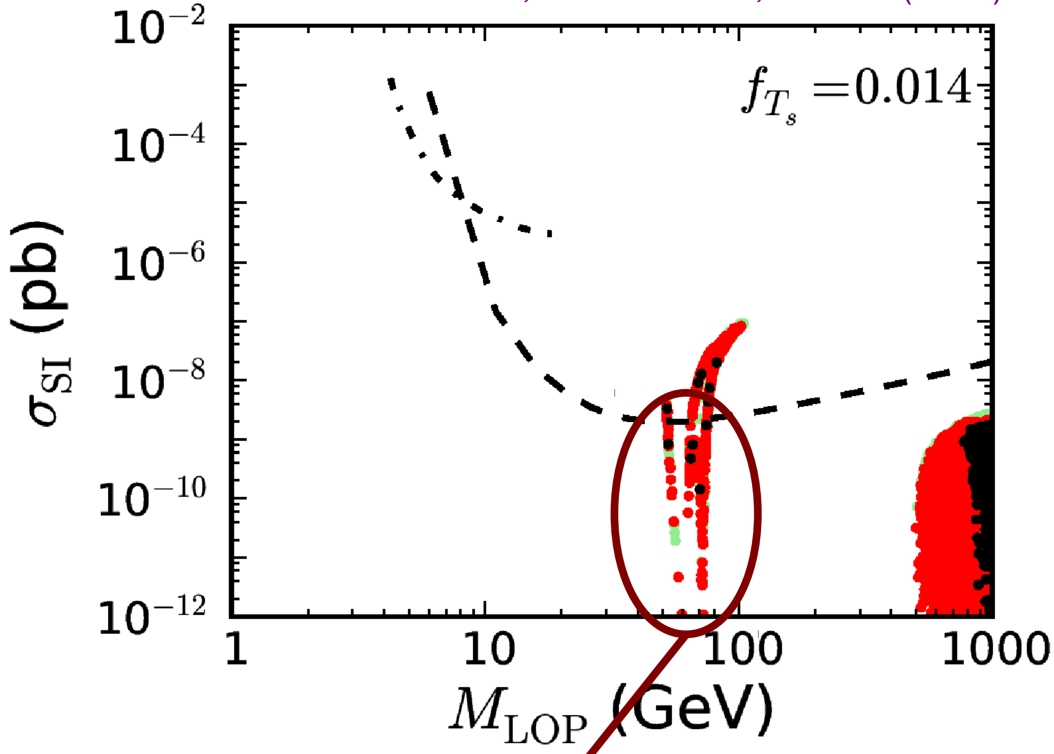

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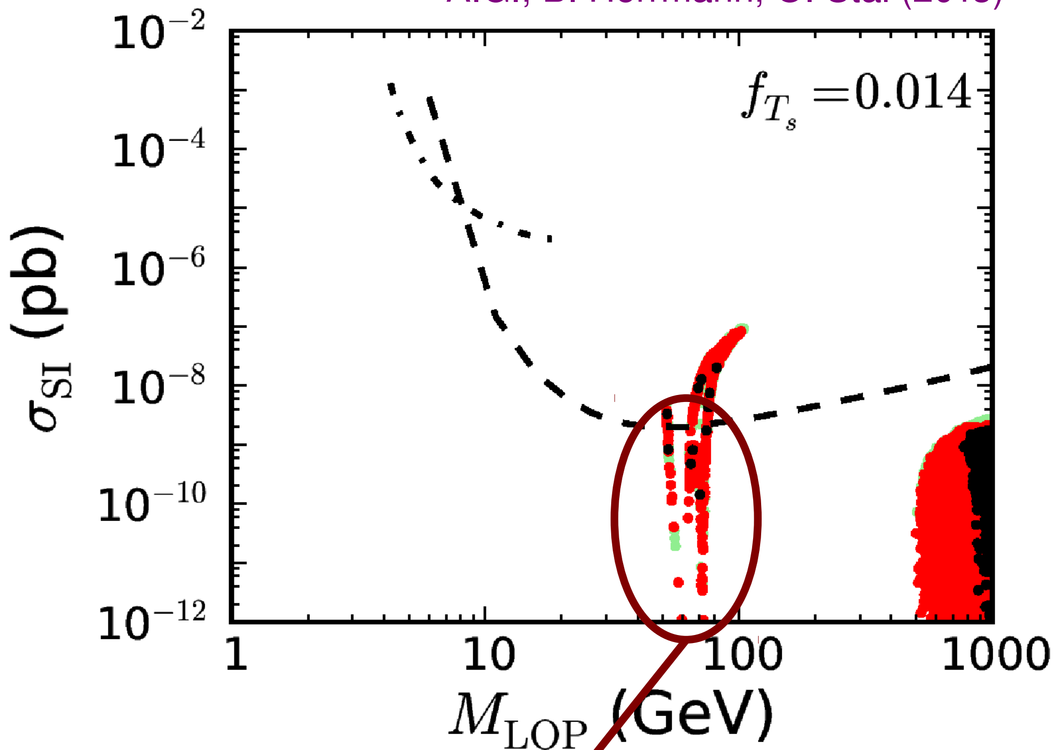

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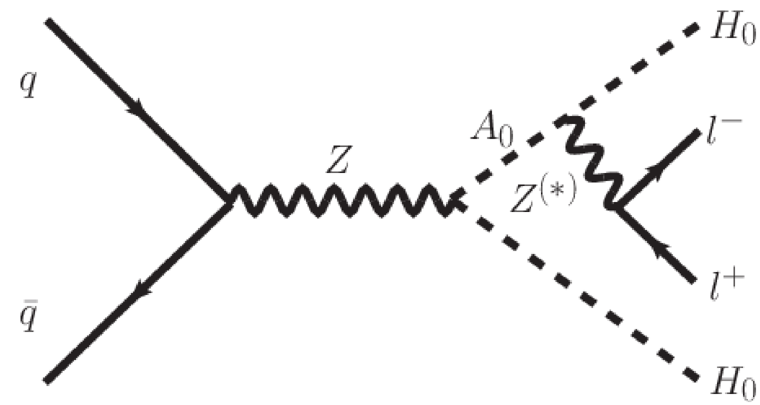
However, consider e.g.

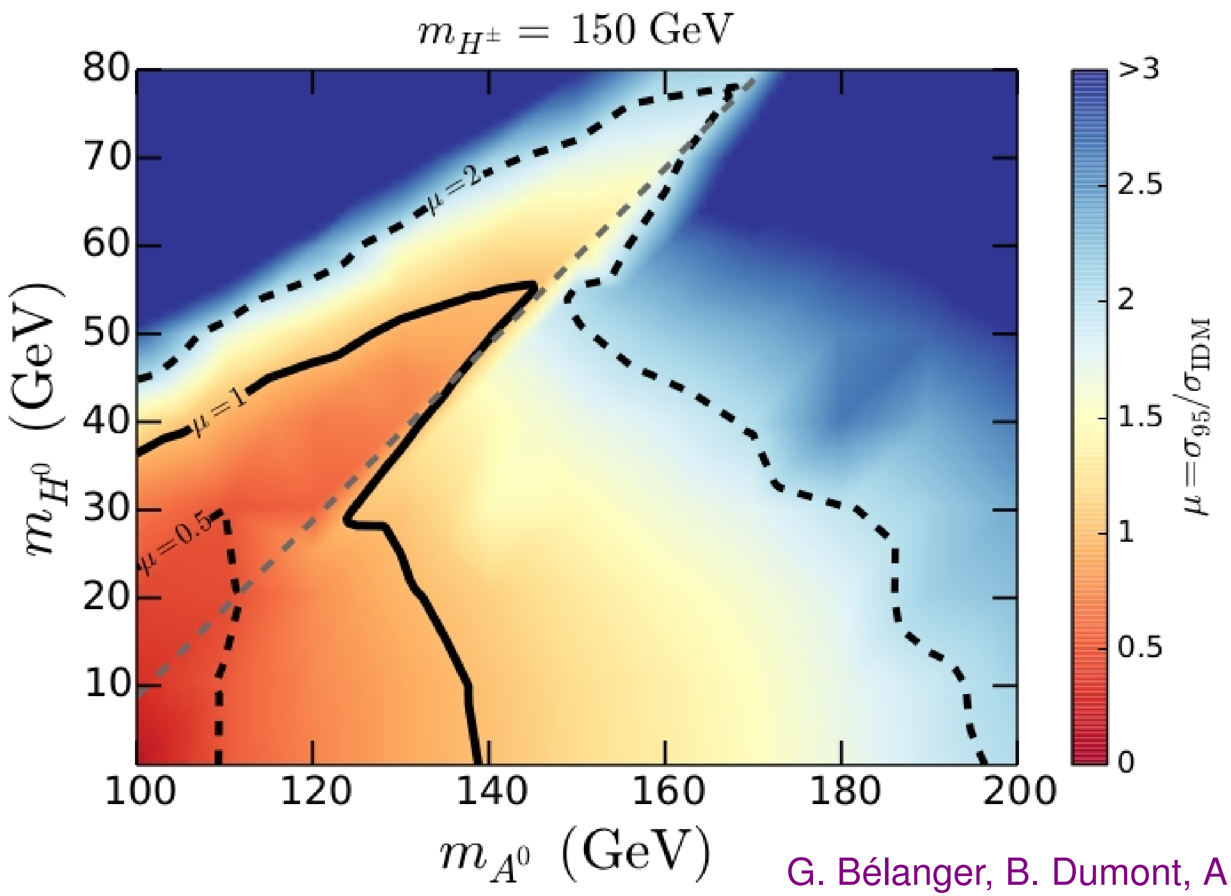


All couplings are gauge →
the h-DM-DM coupling is simply irrelevant!

+ Use dileptons + MET constraints from SUSY and h → inv searches

Probing the Higgs funnel in the IDM

The LHC Run 1 already yields really interesting constraints



- Results shown are for $m_{H^+} = 150$ GeV, but fairly insensitive to precise value.

- The constraints apply to the IDM as a DM model but don't depend on DM assumptions.

- Fairly generic signature in all DM models in which DM couples to a heavier state through a Z.

G. Bélanger, B. Dumont, A.G., B. Herrmann, S. Kraml, D. Sengupta (2015)

Run 2 will probe a large part of the funnel and we strongly encourage a dedicated search.

Summary

- The IDM is a very interesting dark matter (actually, generically BSM) model that predicts a rich phenomenology in all DM search channels.

- Three main regimes for DM:
  - Low ($m_{DM} < m_W$)
  - Intermediate ($m_{DM} \sim m_W$)
  - High ($m_{DM} > 500$ GeV)

  Low and Intermediate: Only h-funnel survives

  High: Basically unconstrained

- On the h-funnel:
  - in truly minimal models (*e.g.* singlet scalar), almost impossible to probe.
  - In "slightly" extended scenarios such as the IDM, try relying on the NLOP (*e.g.* through dilepton + MET searches).
  - Otherwise, look for resonances.

  For the last two points:
  - Apply to more generic funnels too.
  - Success *not* guaranteed, but still...

- Combining information is completely essential. No DM detection technique alone can give us conclusive evidence.

Thank you!

Theoretical constraints in the IDM

A.G., B. Herrmann, O. Stal (2013)