Extending a minimal DM Model

.. and its consequences for DM Searches at the LHC

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Main message

- The complementarity among the different DM-problem approaches (direct detection, indirect detection, collider searches,..) is crucial to probe any particular DM scenario.

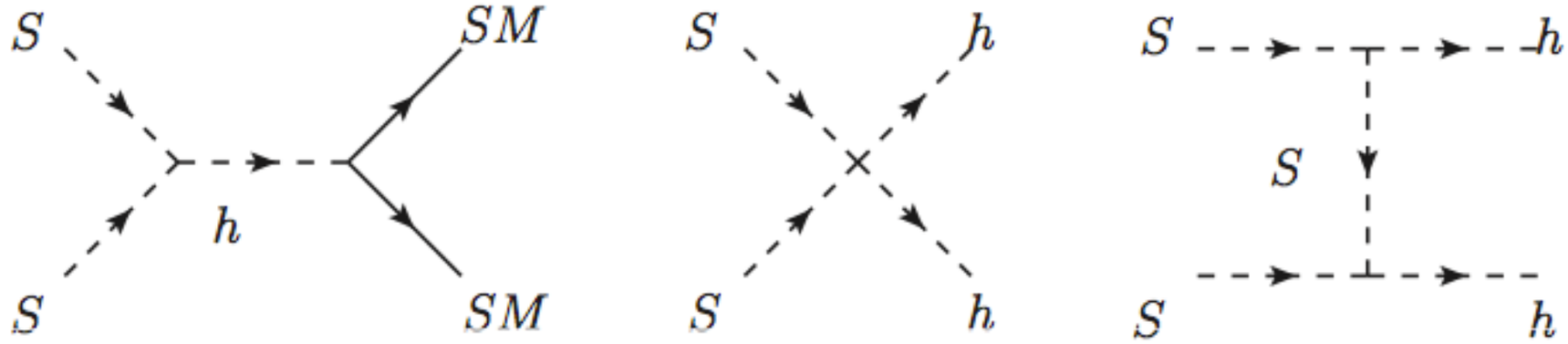
- In minimal scenarios (e.g. Higgs portal) direct detection bounds tend to push the model to parameter space regions where the observation of DM particles at the LHC is very challenging.

- Models constrained by present LHC DM searches typically include extra mediators / interactions.

- Effective Field Theory interactions provide a good description but his validity for LHC DM searches has to be checked when dealing with a particular UV completion.

The singlet-scalar Higgs portal (SHP)

$$\mathcal{L}_{\rm SHP} = \mathcal{L}_{\rm SM} + \frac{1}{2}\partial_\mu S \partial^\mu S - \frac{1}{2}m_0^2 S^2 - \frac{1}{2}\lambda_S |H|^2 S^2 - \frac{1}{4!}\lambda_4 S^4$$



Annihilation processes of the DM candidate, S

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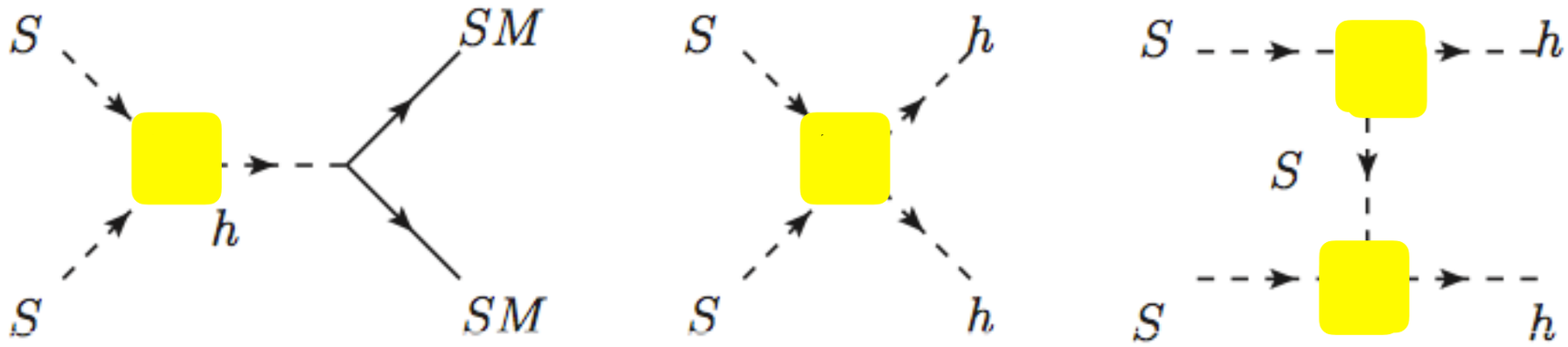

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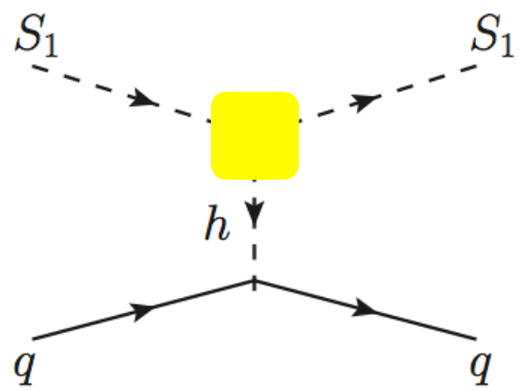
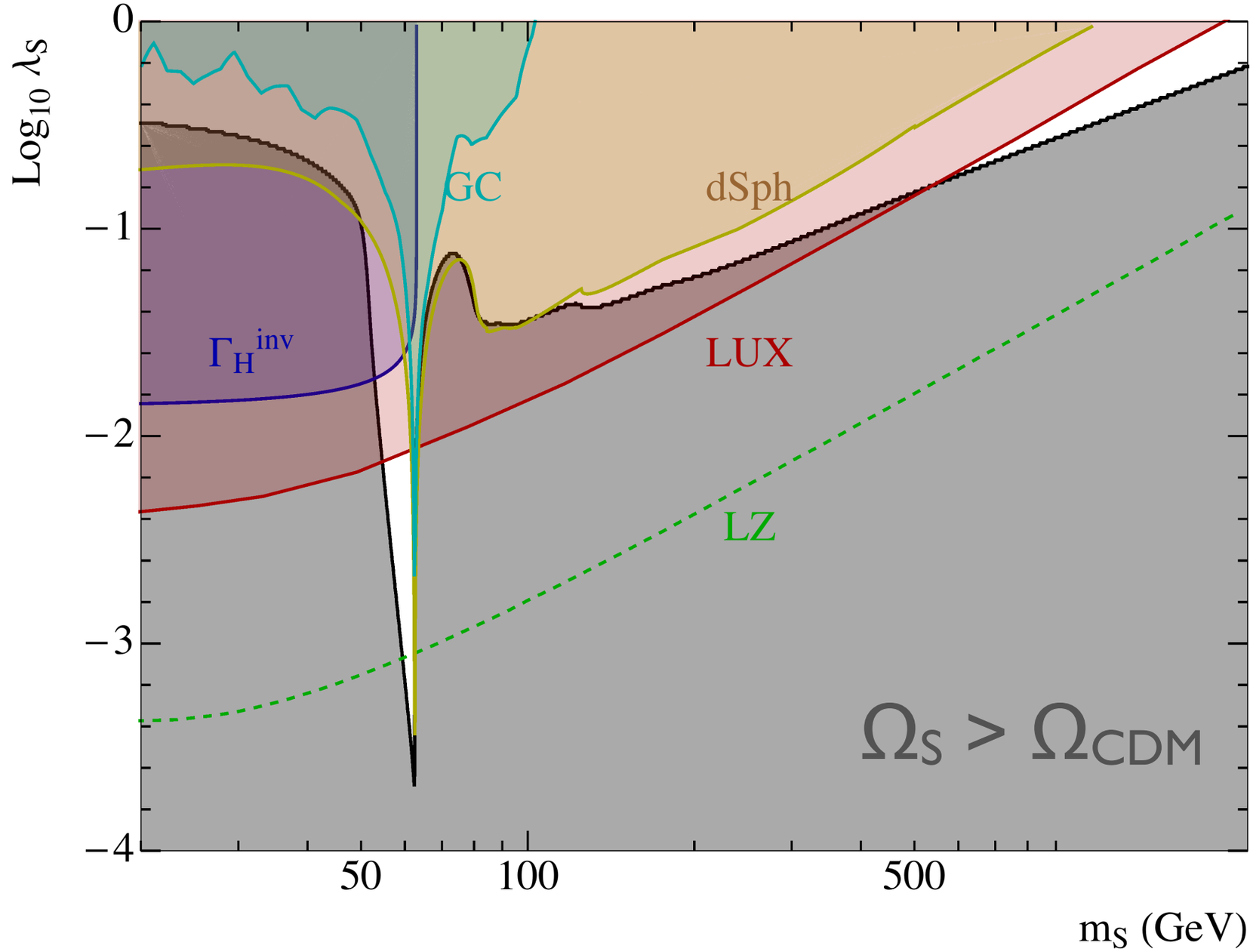


Direct detection interaction

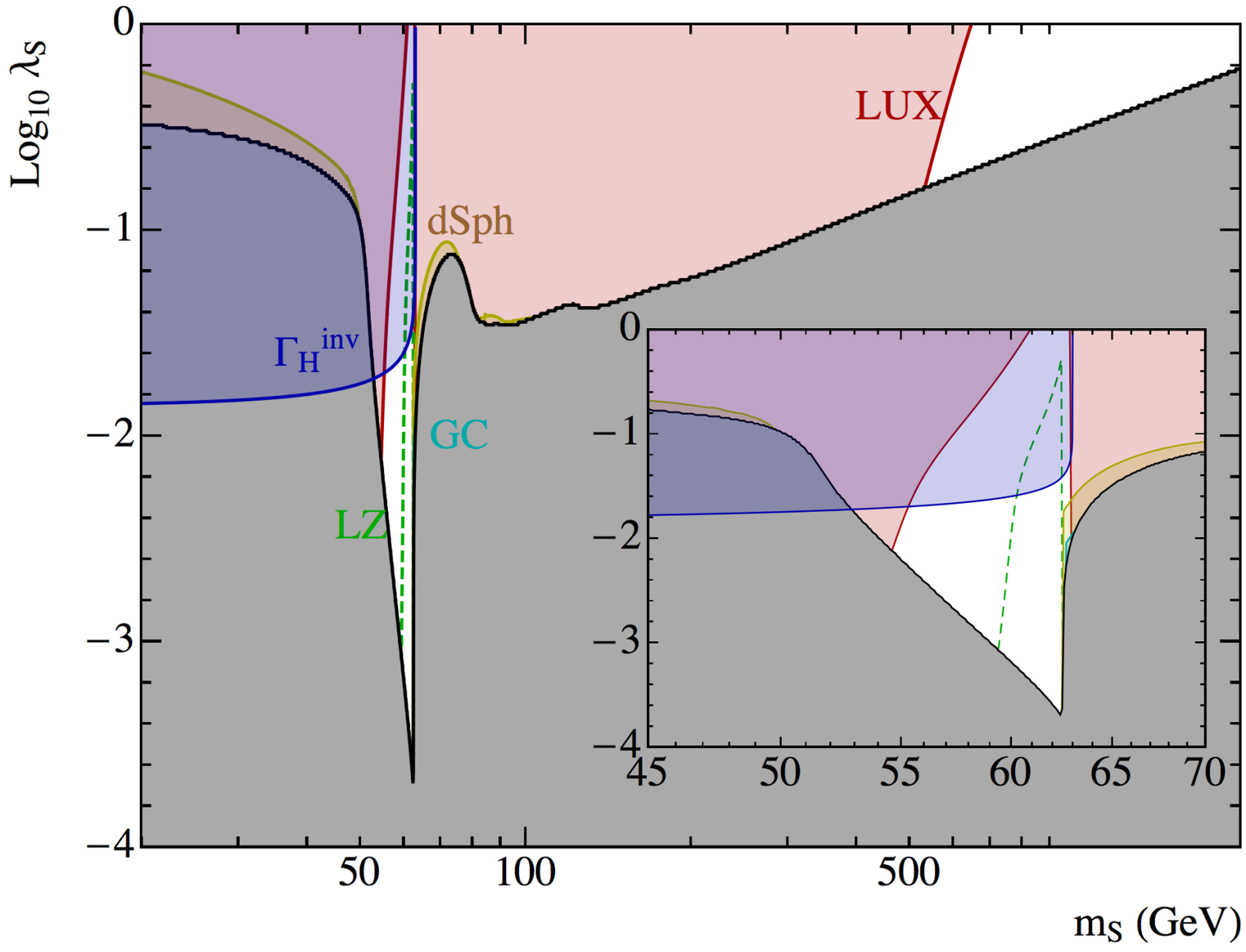
The singlet-scalar Higgs portal (SHP)

Parameter space of the SHP



The singlet-scalar Higgs portal (SHP)

Taking into account the rescaling of the density in regions where $\Omega_S < \Omega_{CDM}$



LHC constraints on Singlet Higgs Portal

<u>Below threshold</u>
($m_S < m_h/2$)

The model is efficiently probed (constrained) by the Higgs invisible width, implying $|\lambda_S| \lesssim 10^{-2}$

<u>Above threshold</u>

Very challenging! The cross section of process

$$pp \rightarrow h^* + X \rightarrow S\,S + X$$

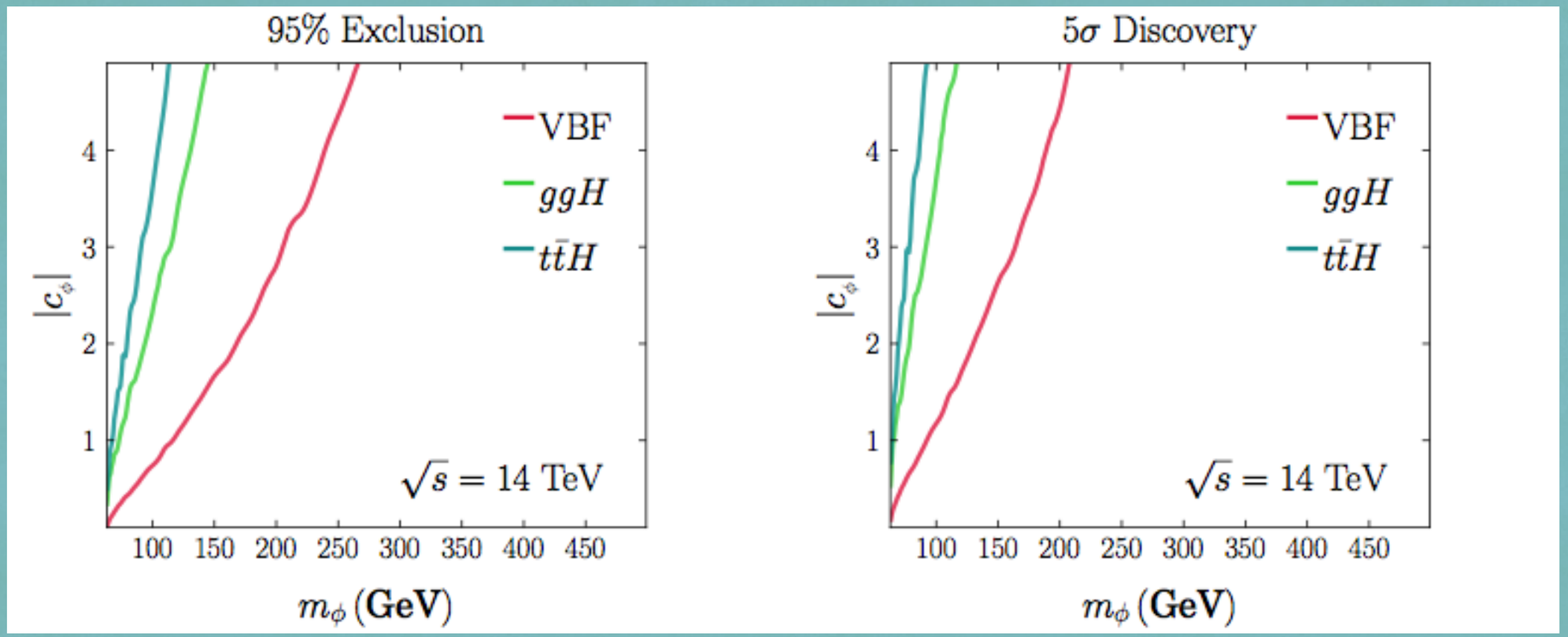
is suppressed by $|\lambda_S|^2$ and by two-body phase space

Possible channels:

include $\not{E}_T$ in association with monojet, tt,

VBF , mono H

Craig et al, 1412.0258



$\mathcal{L} = 3\ ab^{-1}$

Some ATLAS & CMS Mono-X searches @ 13 TeV

- **Monojet**

  ATLAS PRD 94 (2016) 032005,
  CMS arXiv:1703.01651

- **Mono-Higgs**

  ATLAS-CONF-2016-056
  CMS PAS EXO-16-011 — diphoton

  ATLAS Phys. Lett. B 765 (2017)
  CMS PAS EXO-16-012 — bb

  See Nicolo Trevisani's talk

- **tt**

  CMS PAS-EXO-16-005
  PAS-EXO-16-028

  ATLAS-CONF-2016-077
  ATLAS-CONF-2016-050
  ATLAS-CONF-2016-076

  See Jonatan Piedra's talk

- .. and many others

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- tt — CMS PAS-EXO-16-005, PAS-EXO-16-028; ATLAS-CONF-2016-077, ATLAS-CONF-2016-050, ATLAS-CONF-2016-076
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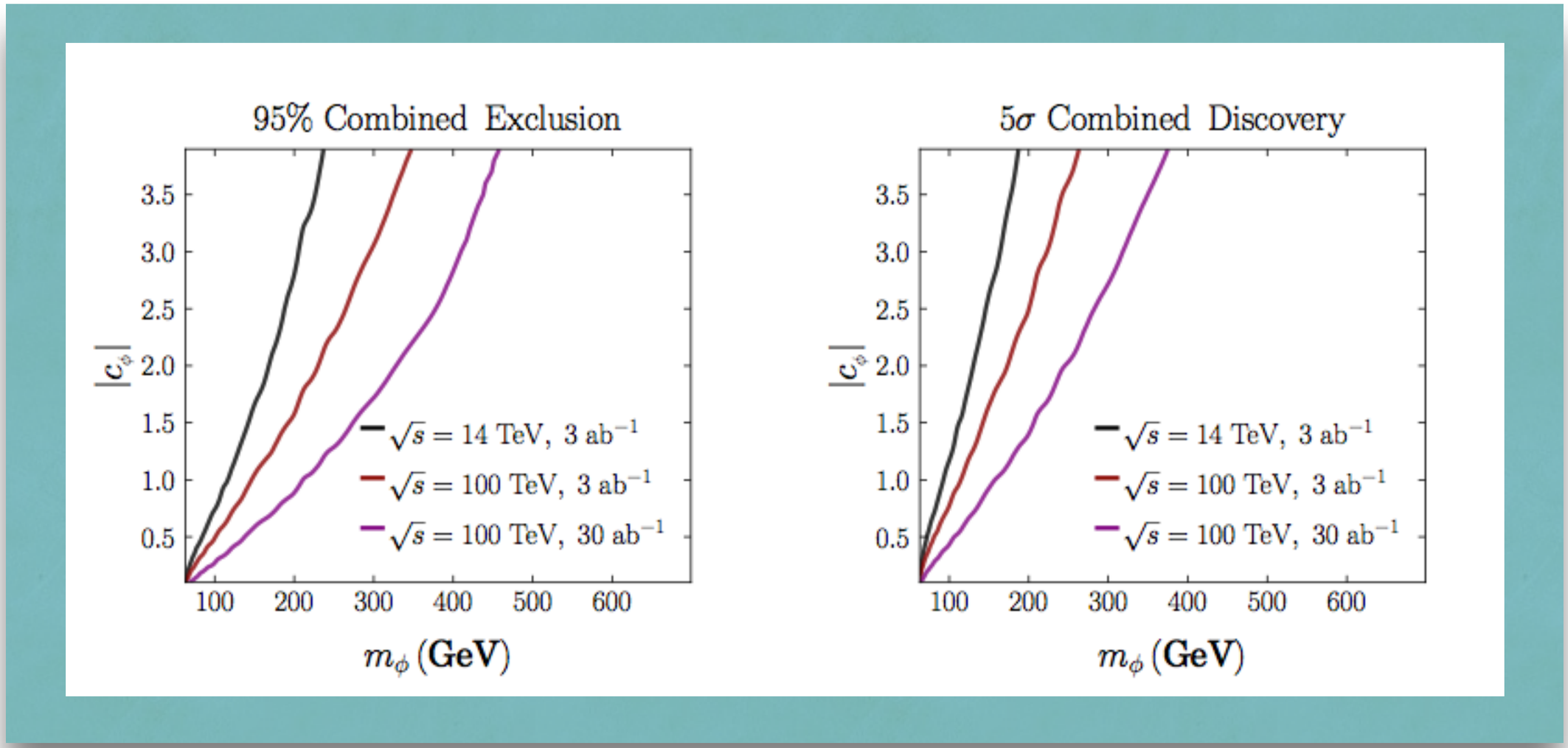
No significant evidence for dark matter particle production has been observed.

Results are usually interpreted in terms of models with **additional mediators (Z', Higgses, etc)**

Craig et al, 1412.0258



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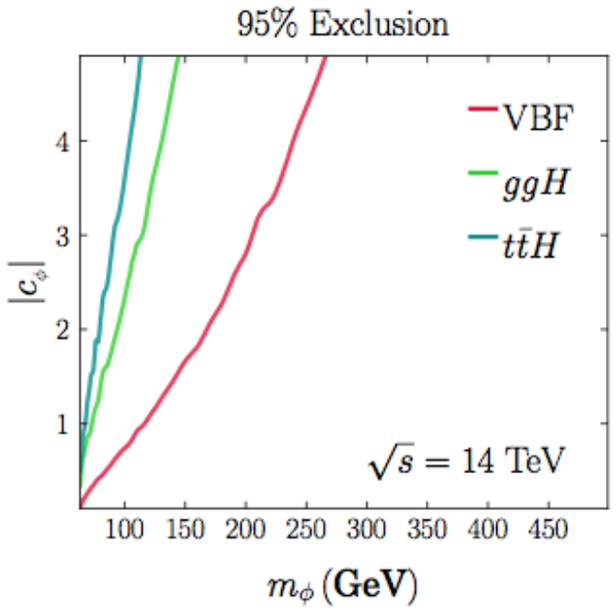

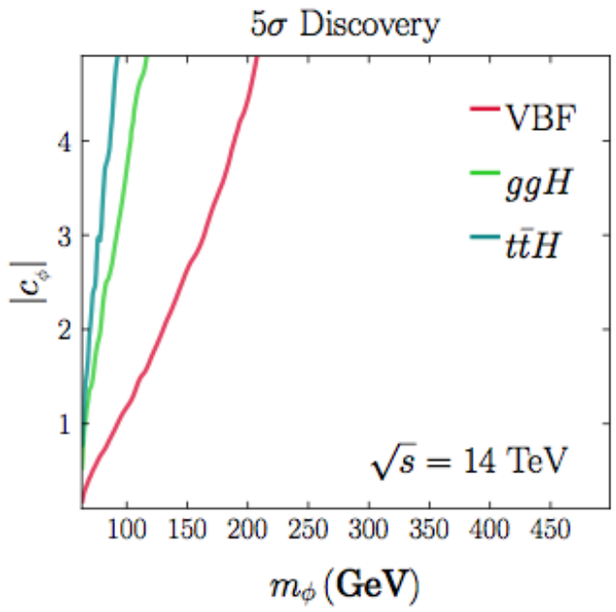

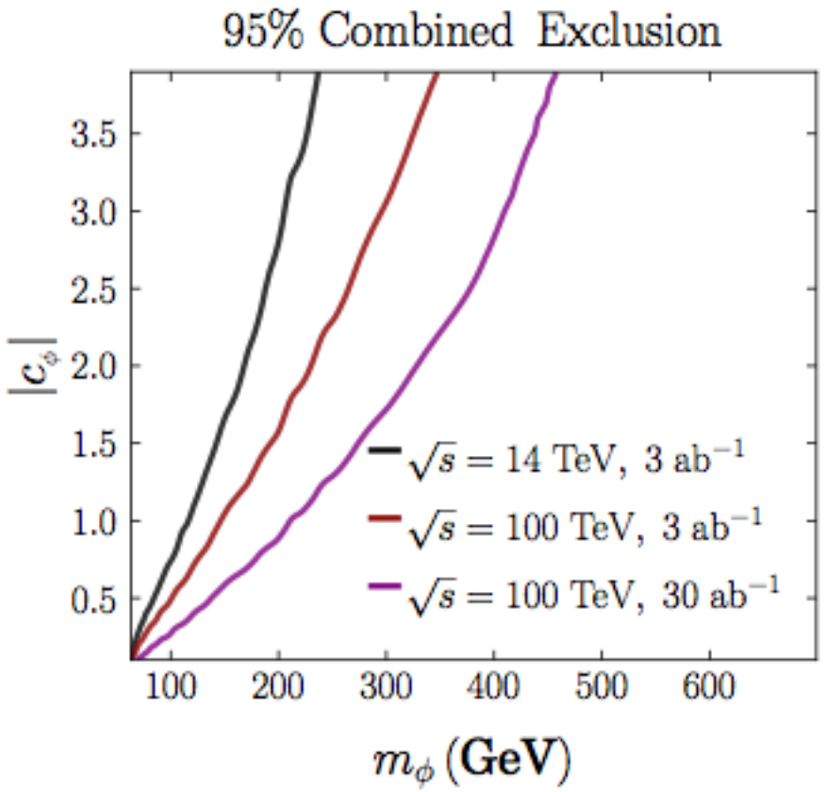

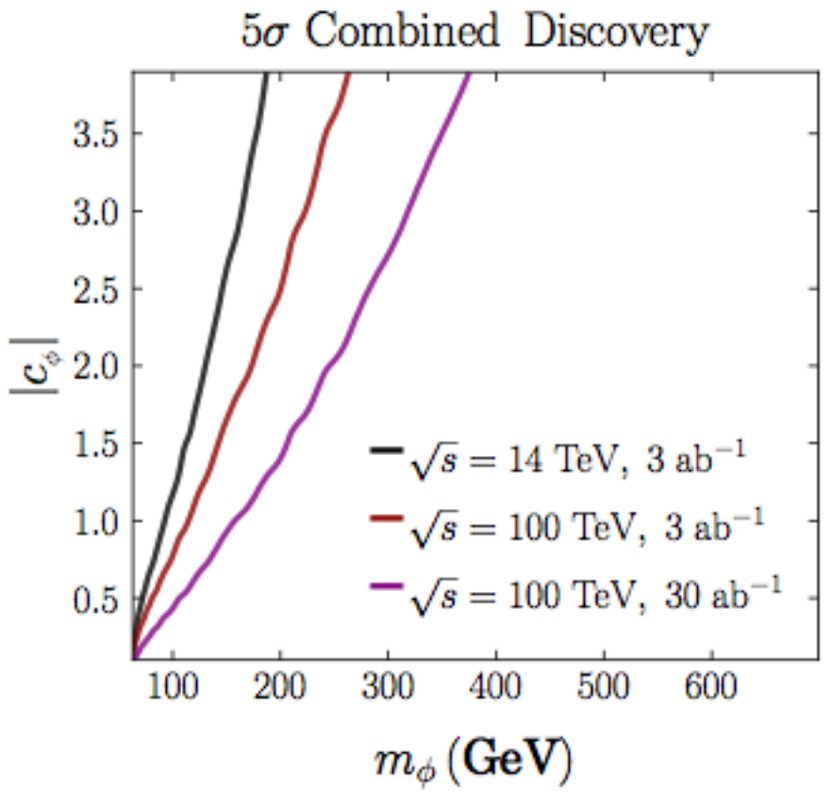

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- Reason: minimality. There is a unique coupling (λ_S) controlling all the processes (annihilation, direct detection, production at the LHC , etc)

WAY OUT:

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To extend the model

- Including higher dimensional effective operators

  - Linear Effective Higgs Portal
  - Non-linear Effective Higgs Portal

- Extending the mediator sector (ej, new Higgses, Z' bosons, etc)

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- Extending the mediator sector (ej, new Higgses, Z' bosons, etc)

- Extending the dark sector

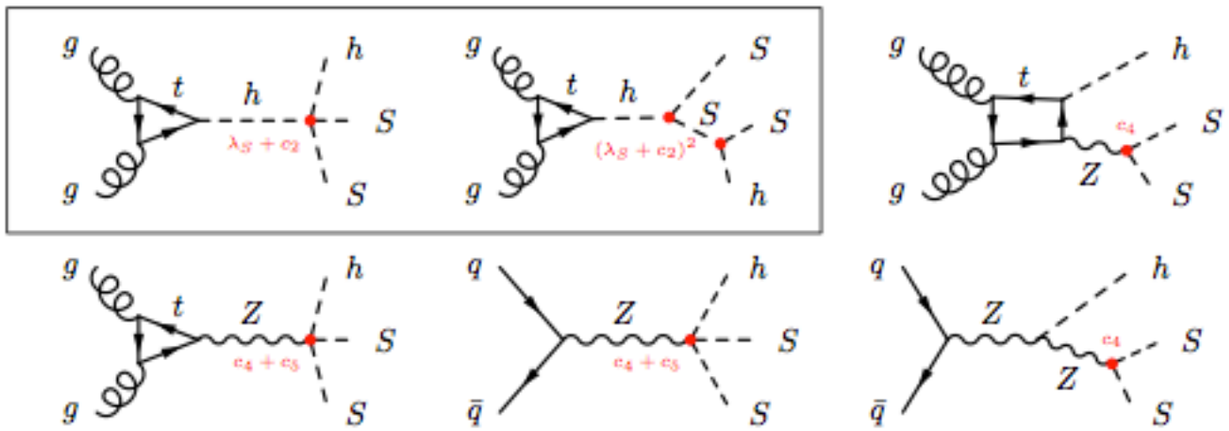
- .....

BONUS: **LHC signatures could be enhanced in these extensions !!!**

Two examples having a mono-Higgs enhancement

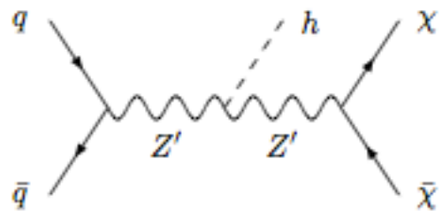
- Non-linear Higgs portal

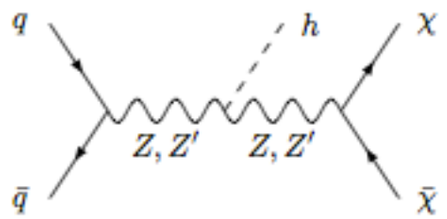
I. Brivio, M.B. Gavela, L. Merlo, K. Mimasu, J.M. No, R. del Rey ,V. Sanz



- Z' mediator

L. Carpenter, A. DiFranzo, M. Mulhearn, C. Shimmin, S. Tulin, D. Whiteson





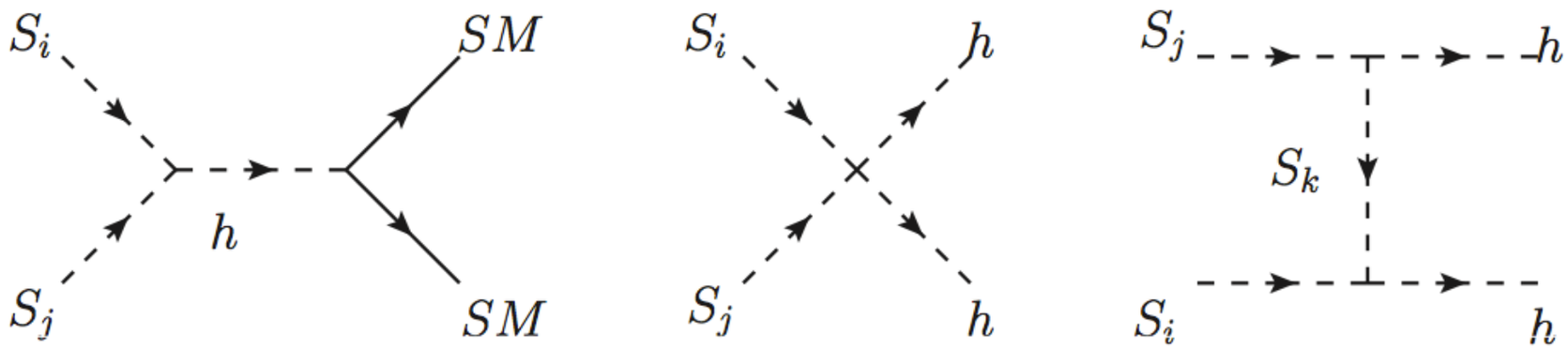
The simplest extension of the Scalar Higgs Portal

J.A. Casas, D.G. Cerdeño, JMM, J. Quilis

$$\mathcal{L}_{\rm ESHP} = \mathcal{L}_{\rm SM} + \frac{1}{2}\sum_{i=1,2}\left[(\partial_\mu S_i)^2 - m_i^2 S_i^2 - \frac{1}{12}\lambda_{i4} S_i^4\right] - \frac{1}{6}\lambda_{13} S_1 S_2^3 - \frac{1}{6}\lambda_{31} S_1^3 S_2 - \frac{1}{4}\lambda_{22} S_1^2 S_2^2$$
$$-\frac{1}{2}\lambda_1 S_1^2 |H|^2 - \frac{1}{2}\lambda_2 S_2^2 |H|^2 - \lambda_{12} S_1 S_2 \left(|H|^2 - \frac{v^2}{2}\right)$$

We assume $m_{S1} < m_{S2}$

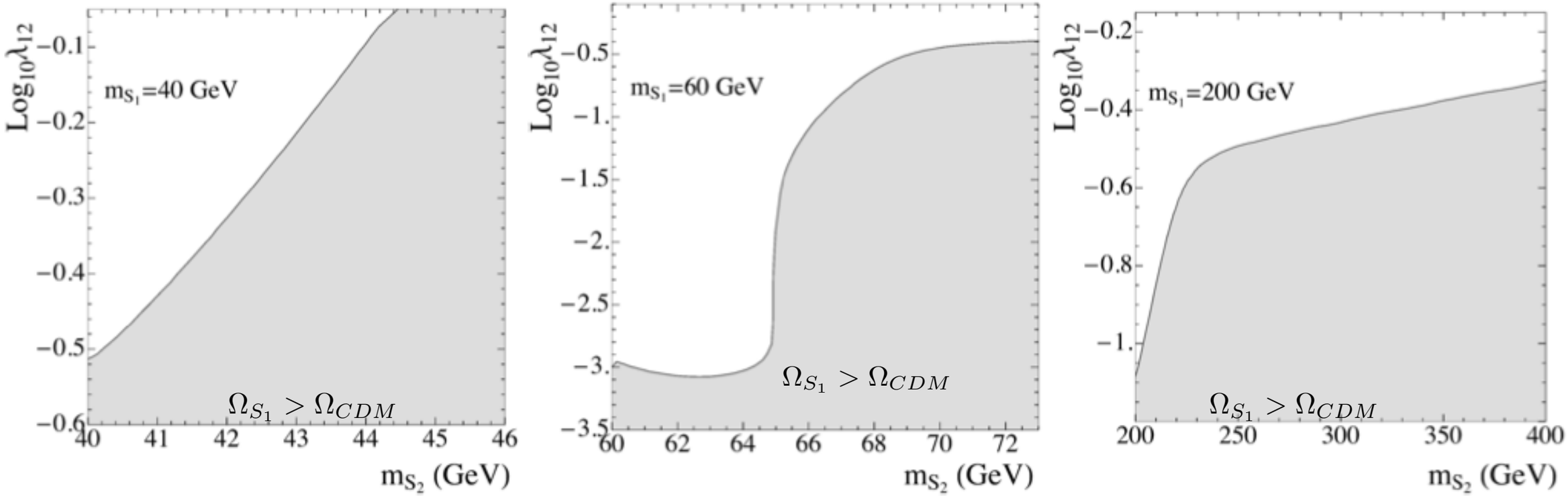
Notice that λ_{12} induces new (co)annihilation processes



that could get ride of the excess of DM in the low λ_1 region,

that is safe from direct DM constraints, enlarging the parameter space.

- DM density for small λ_1 values . We assume $\lambda_1 = \lambda^2_{12}/(4\pi)^2$



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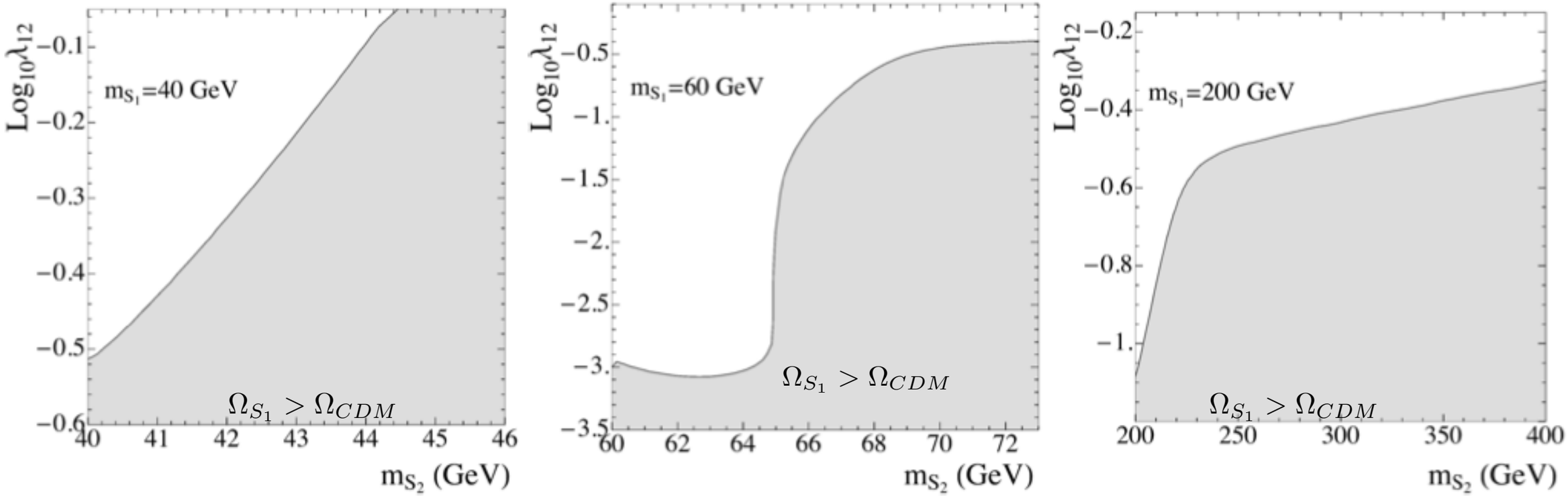
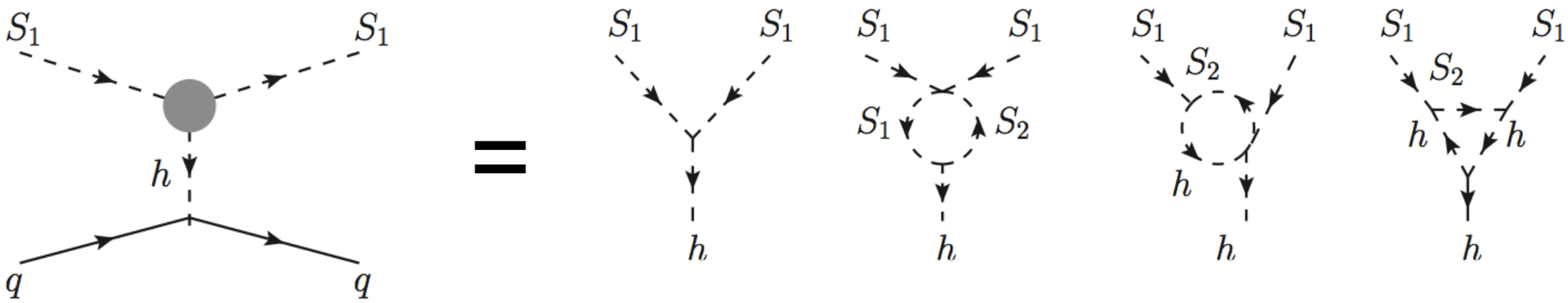
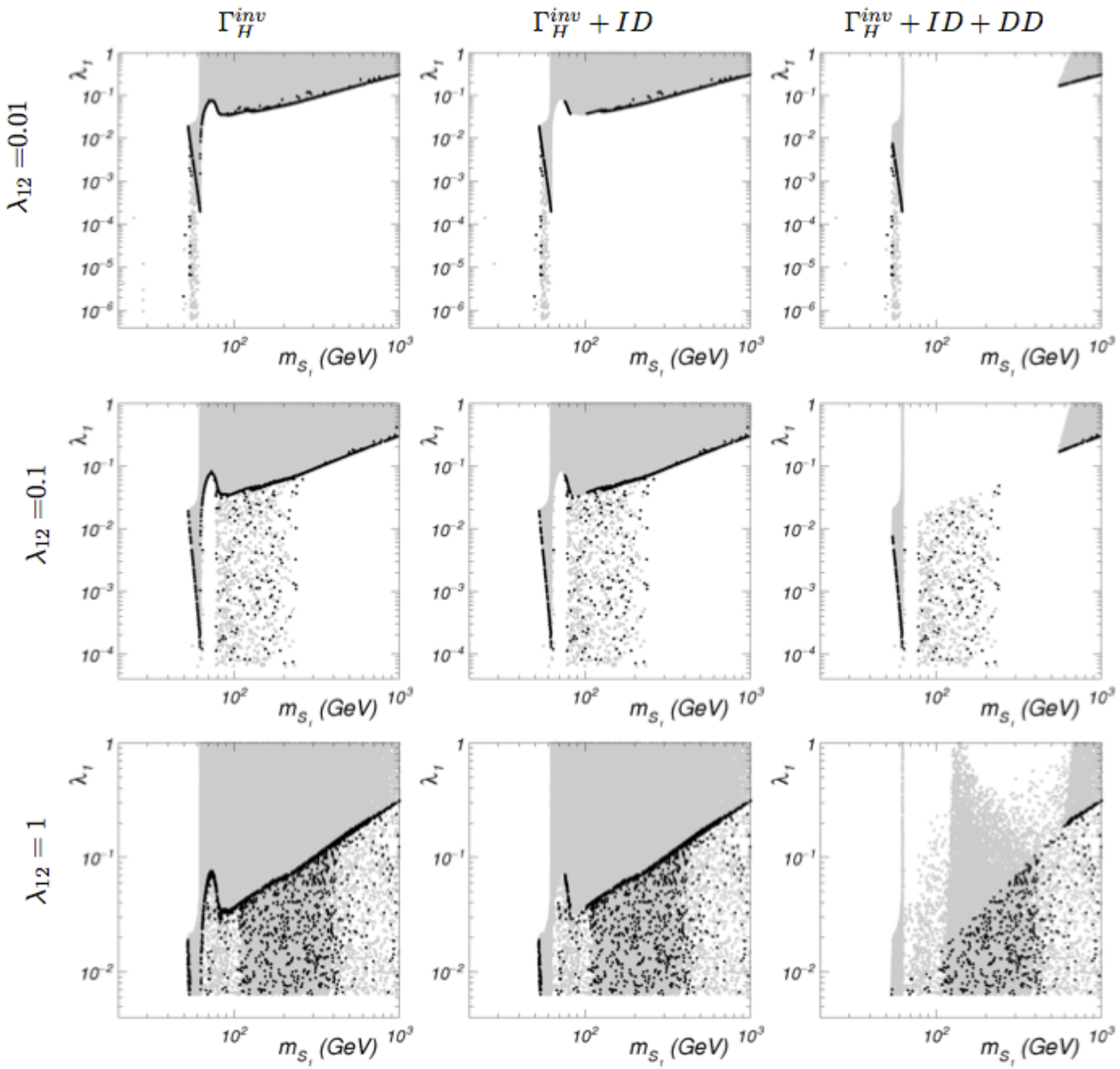
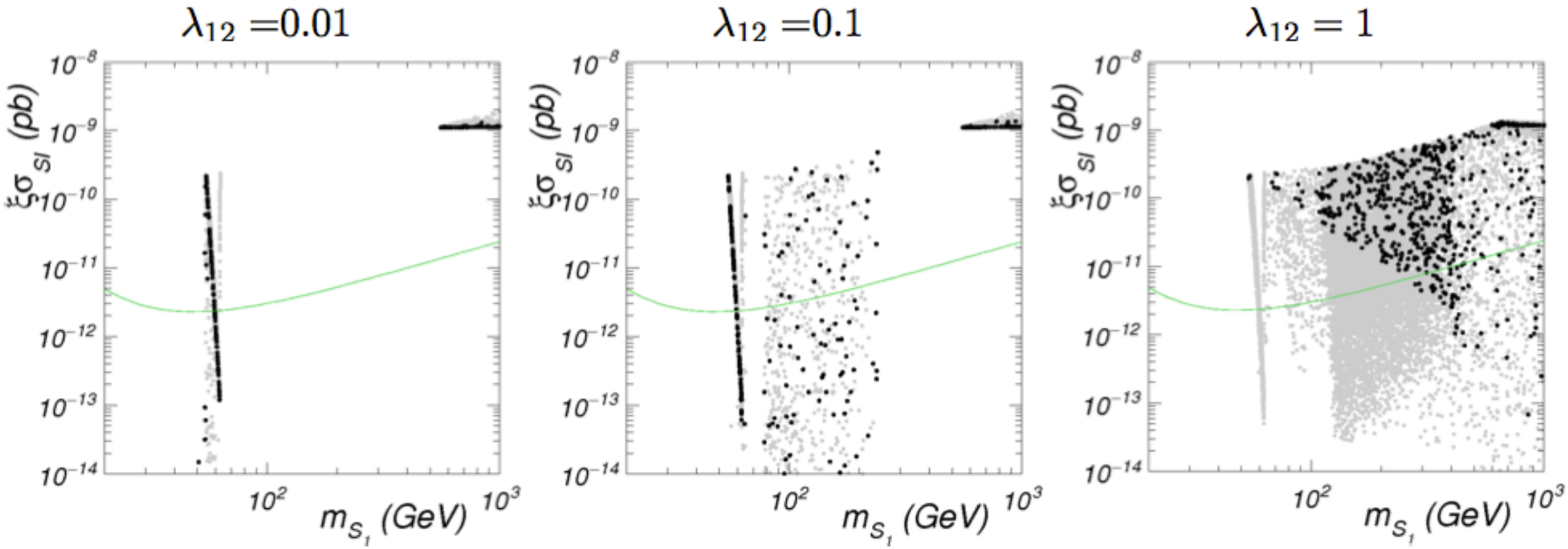


- Warning: radiative corrections to DM direct detection could be potentially large in the evaluation of the bounds




Γ_H^{inv}
$\Gamma_H^{inv} + ID$
$\Gamma_H^{inv} + ID + DD$
λ_{12} =0.01
λ_{12} =0.1
$\lambda_{12} = 1$
λ_1
m_{S_1} (GeV)

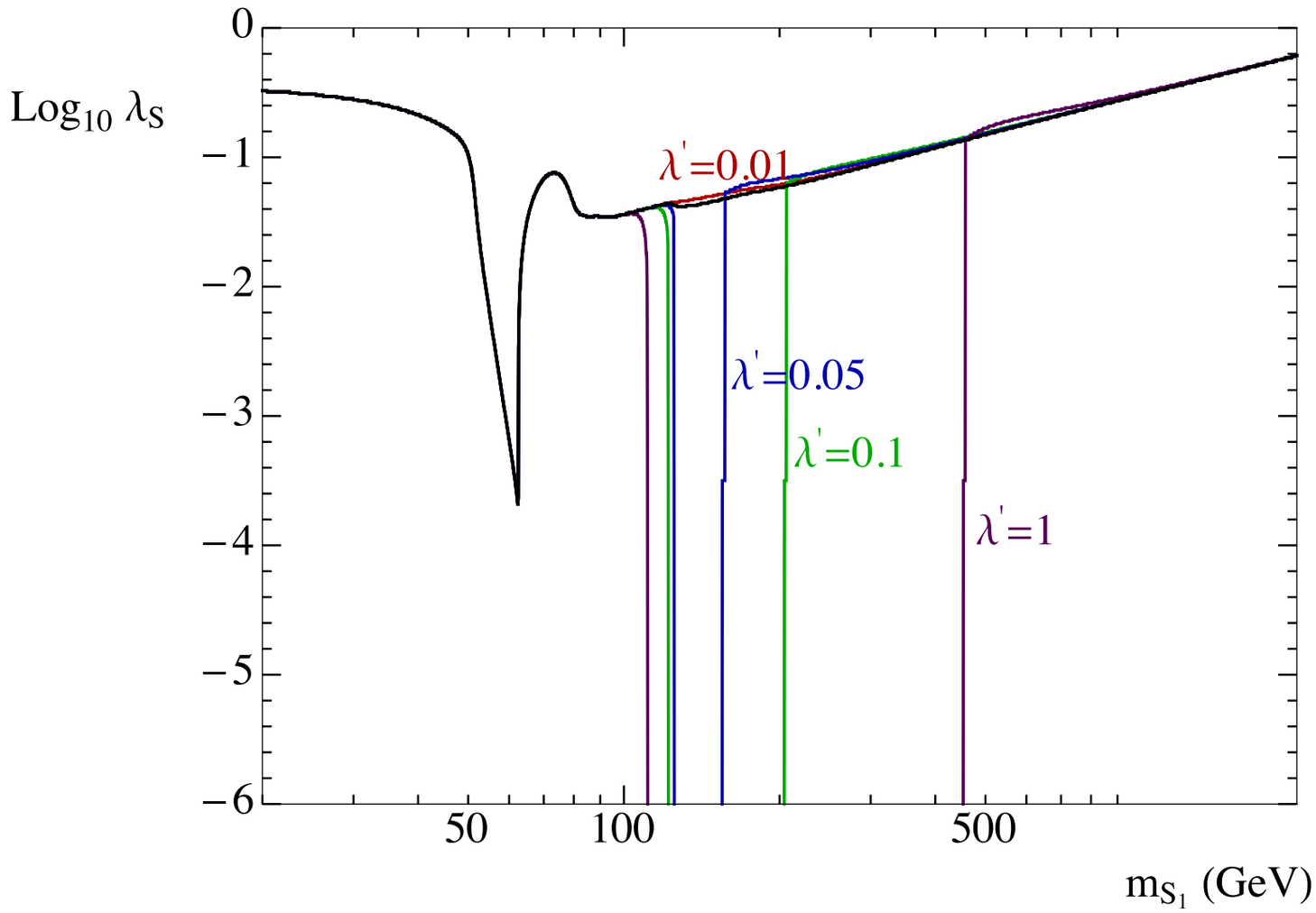
✓ Large regions of the Scalar Higgs Portal parameter space are now recovered, even for moderate values of λ_{12}



The results can be nicely understood in terms of the Singlet Higgs portal + 1 effective operator

$$\Delta\mathcal{L}_{\rm eff}(S_1,H) = \frac{1}{2}\frac{\lambda_{12}^2}{m_{S_2}^2}\, S_1^2\left(|H|^2-\frac{v^2}{2}\right)^2 + \cdots .$$

$$\mathcal{L}_{\rm SHP}^{'} = \mathcal{L}_{\rm SHP} + \frac{1}{2}\frac{\lambda'}{m_{S_1}^2}\, S_1^2\left(|H|^2-\frac{v^2}{2}\right)^2$$



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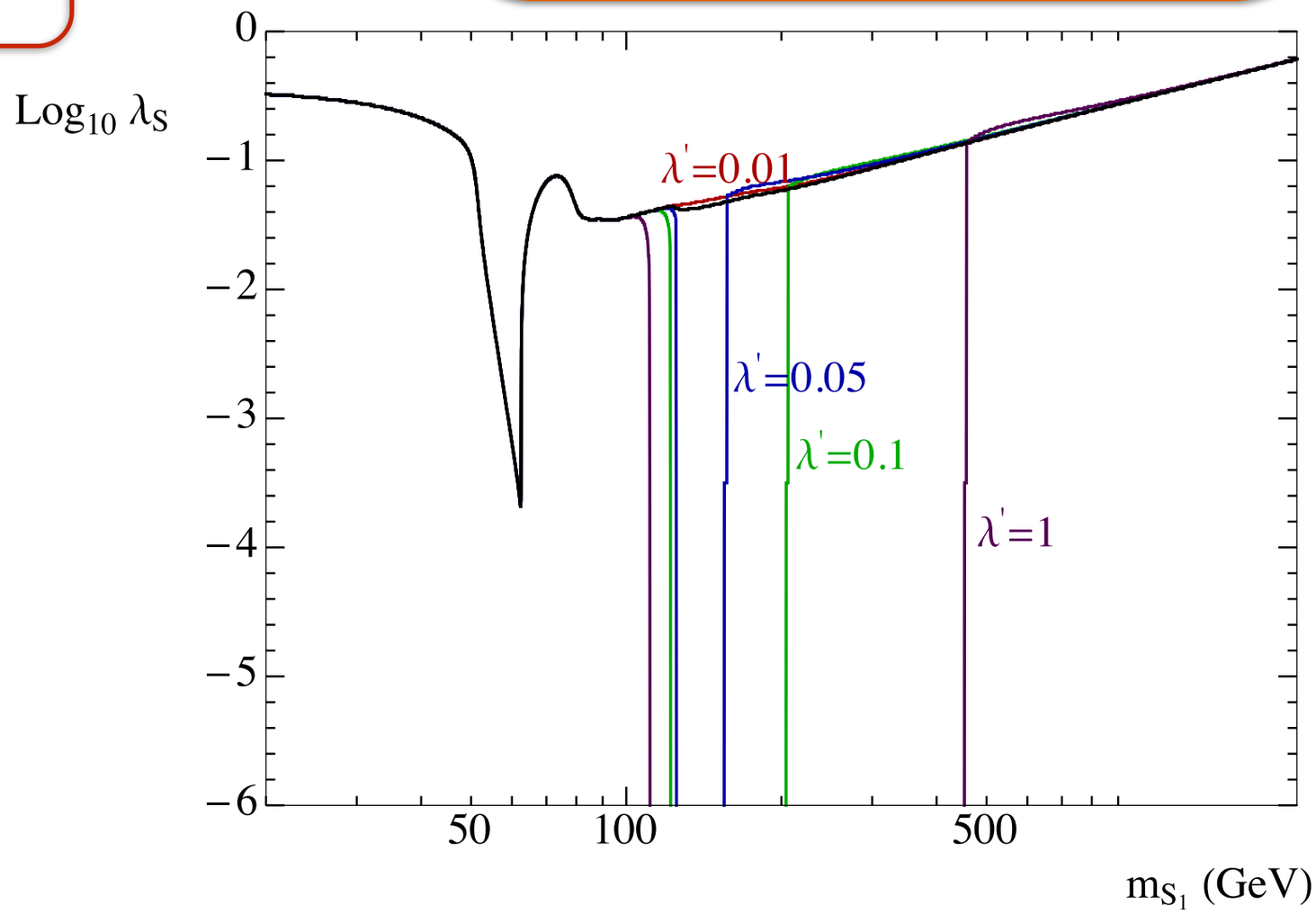
Intermediate O(100-300 GeV) m_{S1} values are now allowed



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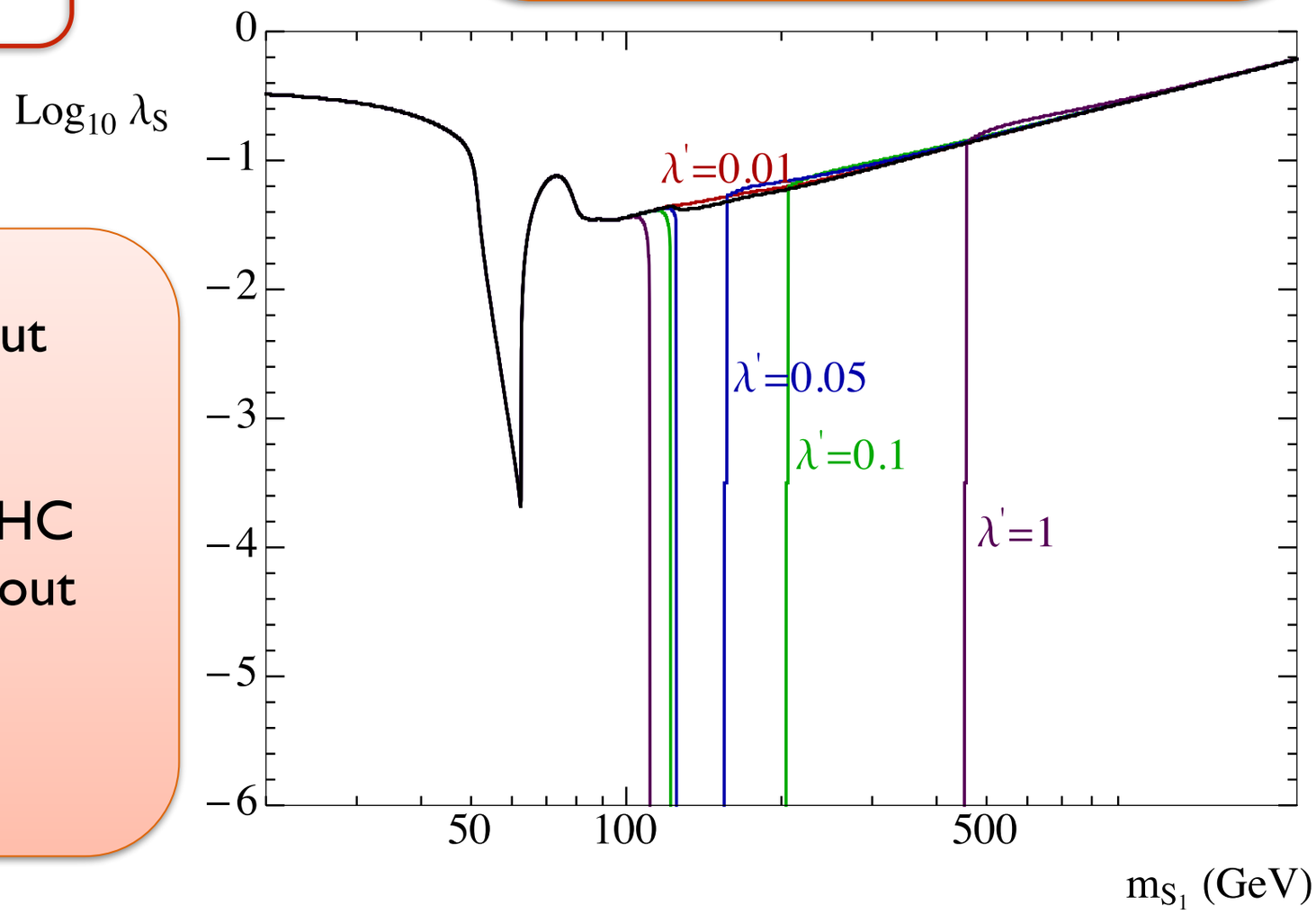

- Enlarges the hhSS vertex without increasing the hhS one
- Could enhance DM signals @ LHC (ej mono-Higgs signatures) without being in conflict with DM direct detection bounds

.. and again

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