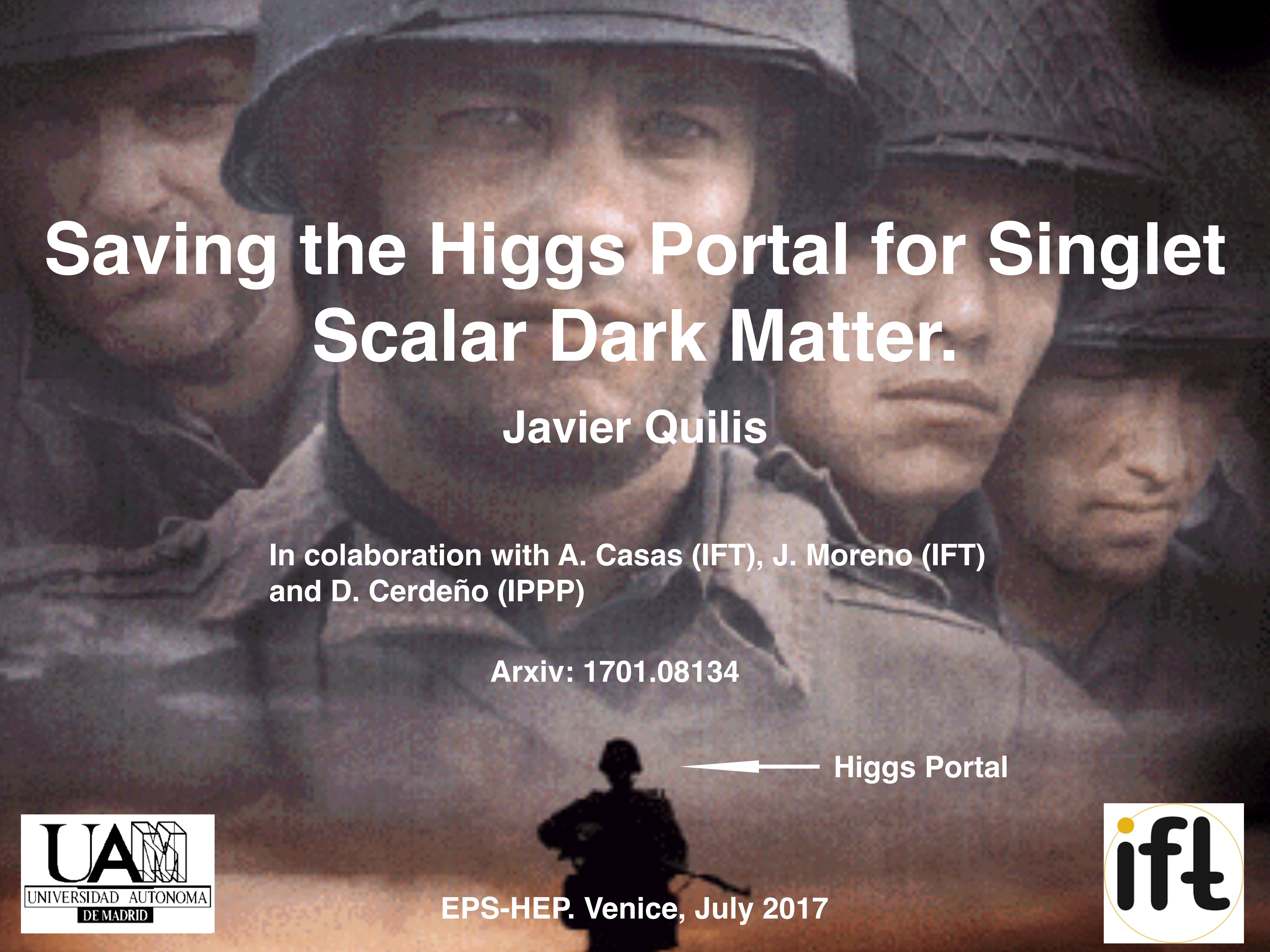

Saving the Higgs Portal for Singlet Scalar Dark Matter.

Javier Quilis

In colaboration with A. Casas (IFT), J. Moreno (IFT) and D. Cerdeño (IPPP)

Arxiv: 1701.08134

Higgs Portal

UNIVERSIDAD AUTONOMA DE MADRID

EPS-HEP. Venice, July 2017

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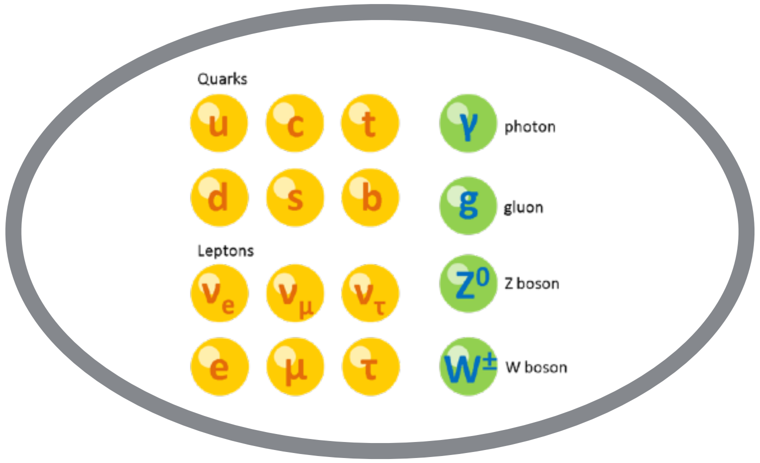
- Higgs portal with a Real Singlet Scalar DM
- Higgs portal with two Real Singlet Scalars
- Summary

Introduction

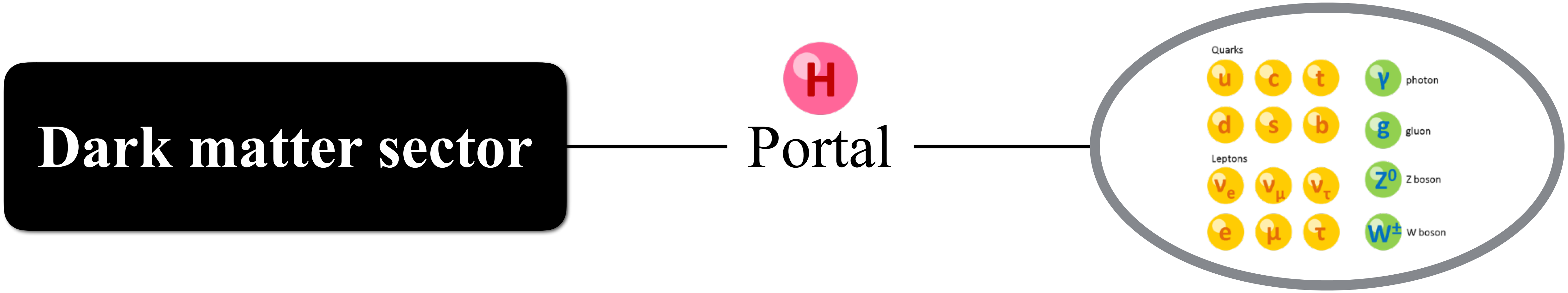
DM, portals and models

Relation between Dark sector and SM

Dark matter sector



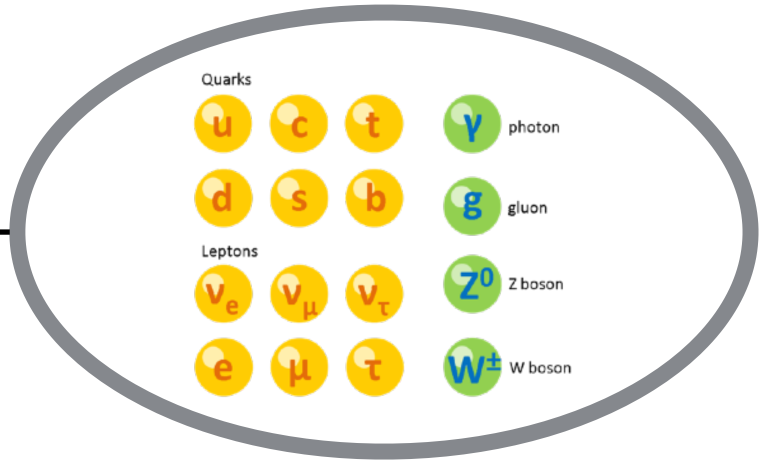
Relation between Dark sector and SM



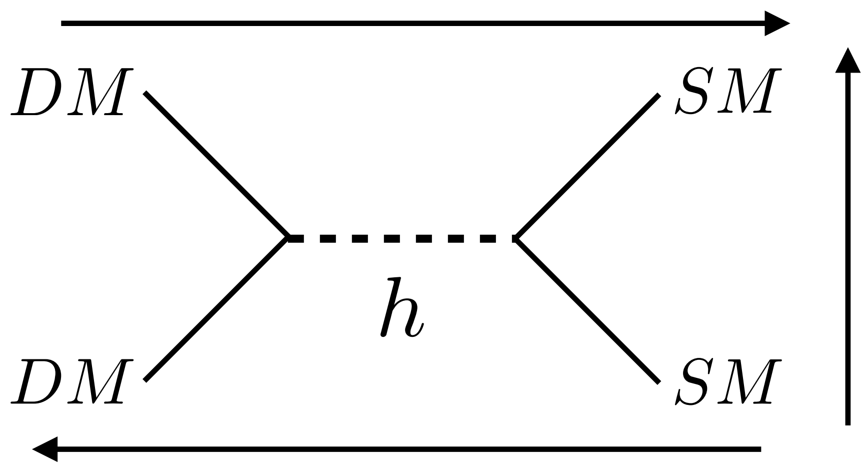
DM, portals and models

Relation between Dark sector and SM

Dark matter sector —— 

Portal —— 

Indirect detection



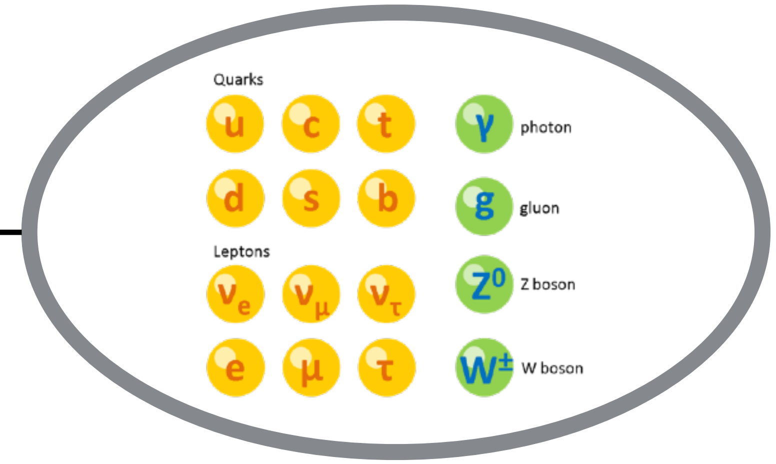
Direct detection

DM production

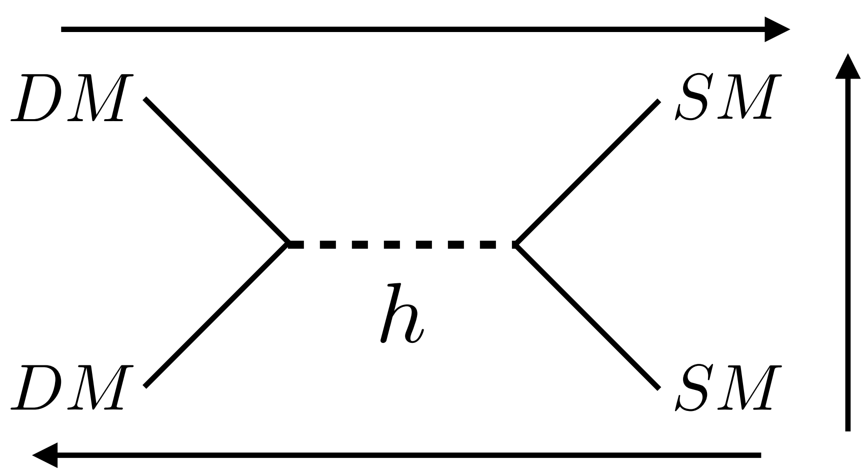
DM, portals and models

Relation between Dark sector and SM

Dark matter sector — Portal —



Indirect detection



Direct detection

DM production

Many candidates

Singlet, Doublet…

Scalar, fermionic…

Simplest:

Real singlet scalar DM

Higgs portal with a Real Singlet Scalar DM

Higgs portal with a Real Singlet Scalar DM

Z_2 symmetry

$$S \to -S \quad SM \to SM$$

Higgs portal with a Real Singlet Scalar DM

Z_2 symmetry

$S \to -S \quad SM \to SM$

<u>Lagrangian</u>

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

Renormalizable

Higgs portal with a Real Singlet Scalar DM

Z_2 symmetry

$S \to -S \quad SM \to SM$

Lagrangian

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

Renormalizable

After EWSB

$$\mathcal{L}_{\rm HP} = \mathcal{L}_{\rm SM} + \frac{1}{2}(\partial_\mu S \partial^\mu S - m_S^2 S^2) - \frac{1}{2}\lambda_S v h S^2 - \frac{1}{4}\lambda_S h^2 S^2 - \frac{1}{4}\lambda_4 S^4$$

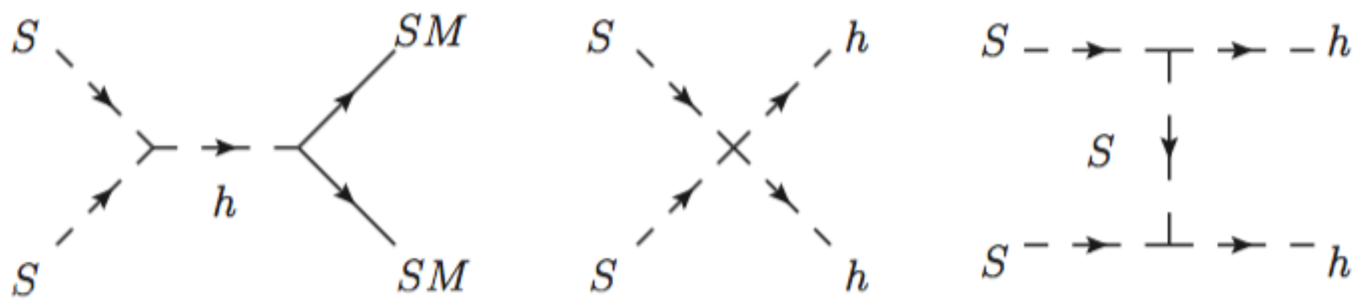
$(v = 175 \text{ GeV})$

Higgs portal with a Real Singlet Scalar DM

After EWSB

$$\mathcal{L}_{\rm HP} = \mathcal{L}_{\rm SM} + \frac{1}{2}(\partial_\mu S \partial^\mu S - m_S^2 S^2) - \frac{1}{2}\lambda_S v h S^2 - \frac{1}{4}\lambda_S h^2 S^2 - \frac{1}{4}\lambda_4 S^4 \qquad (v = 175 \text{ GeV})$$

Processes DM-SM

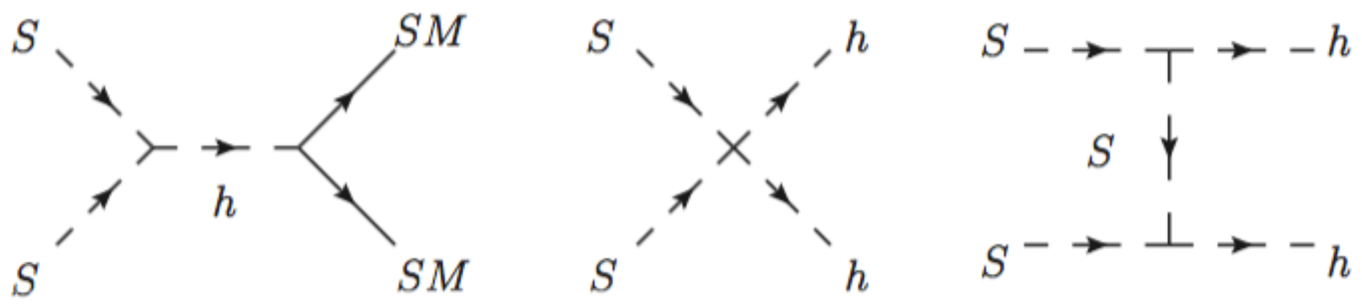


Higgs portal with a Real Singlet Scalar DM

After EWSB

$$\mathcal{L}_{\rm HP} = \mathcal{L}_{\rm SM} + \frac{1}{2}(\partial_\mu S \partial^\mu S - m_S^2 S^2) - \frac{1}{2}\lambda_S v h S^2 - \frac{1}{4}\lambda_S h^2 S^2 - \frac{1}{4}\lambda_4 S^4 \qquad (v = 175 \text{ GeV})$$

Processes DM-SM



relevant parameters $m_S \; \lambda_S$

Higgs portal with a Real Singlet Scalar DM

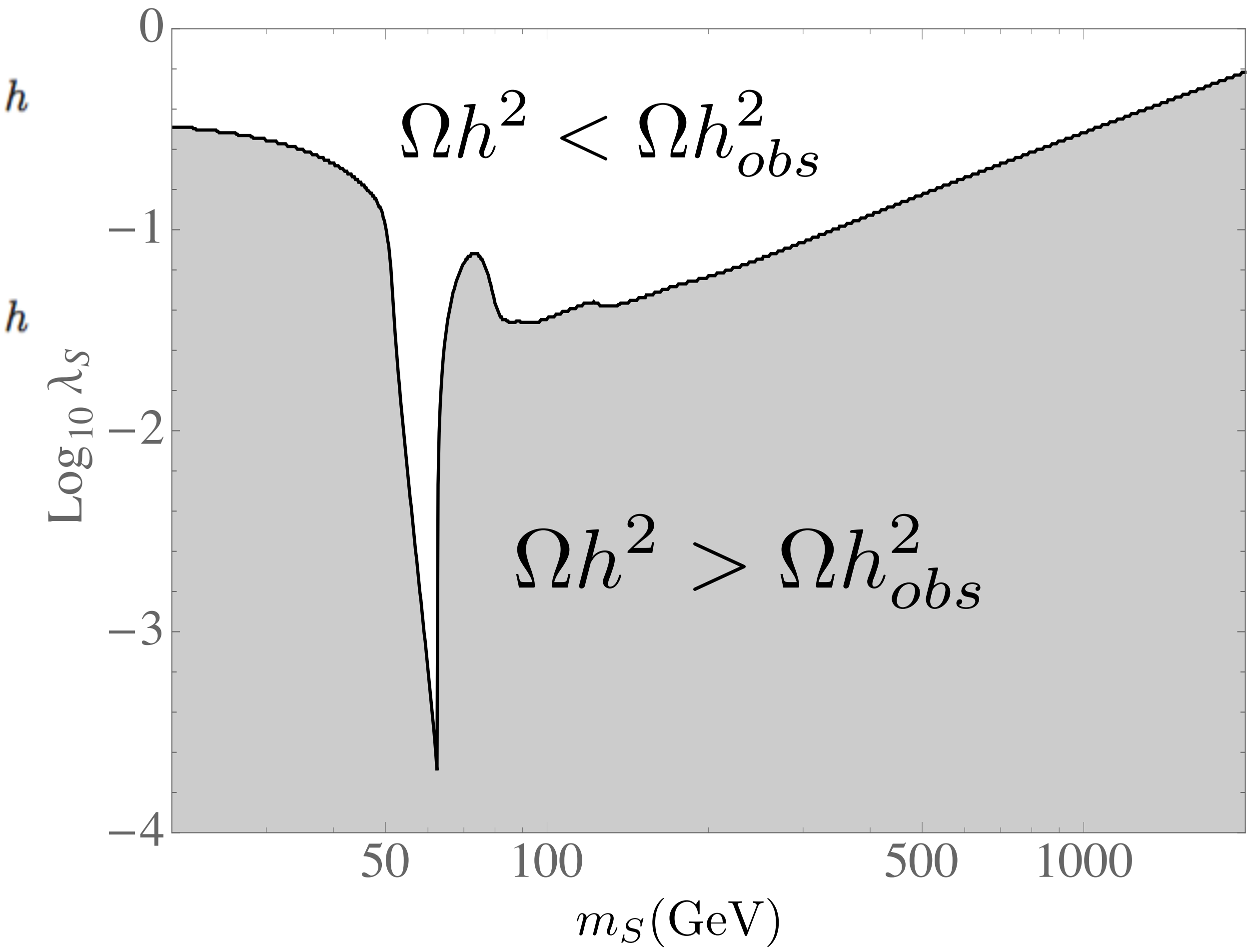
After EWSB

$$\mathcal{L}_{\rm HP} = \mathcal{L}_{\rm SM} + \frac{1}{2}(\partial_\mu S \partial^\mu S - m_S^2 S^2) - \frac{1}{2}\lambda_S v h S^2 - \frac{1}{4}\lambda_S h^2 S^2 - \frac{1}{4}\lambda_4 S^4 \qquad (v = 175 \text{ GeV})$$

Processes DM-SM

relevant parameters $m_S \ \lambda_S$

Relic density, Ωh^2



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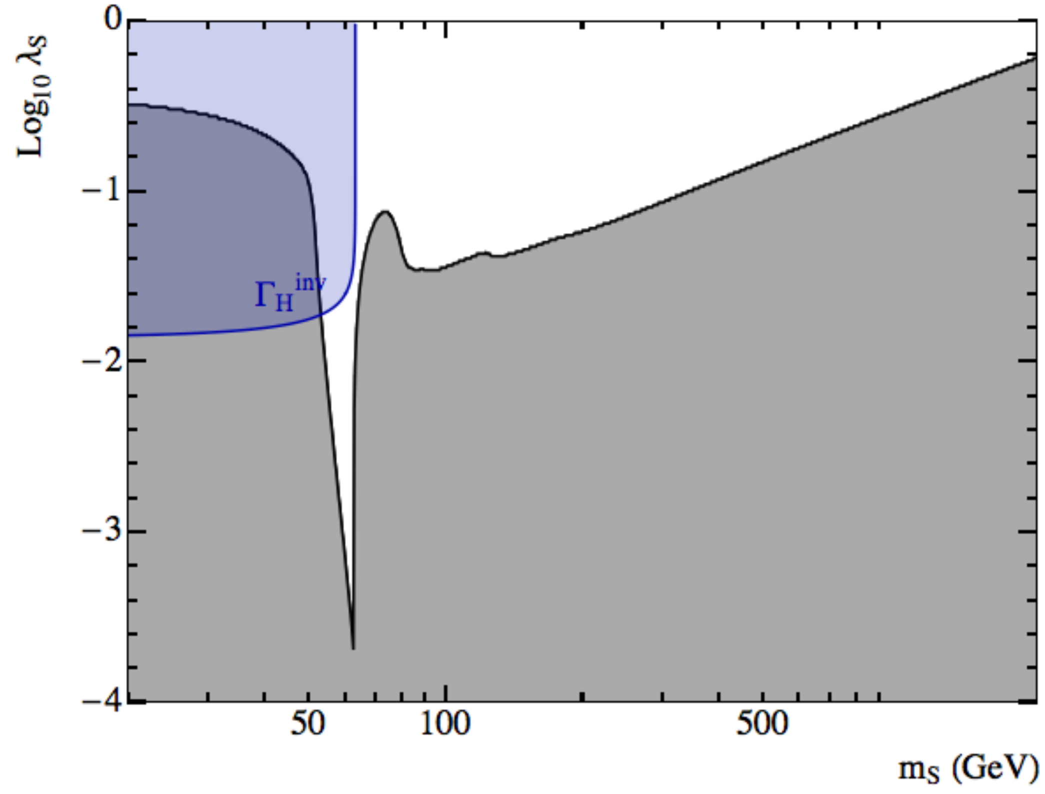
and many more….

Direct, indirect and Higgs Invisible Width constraints

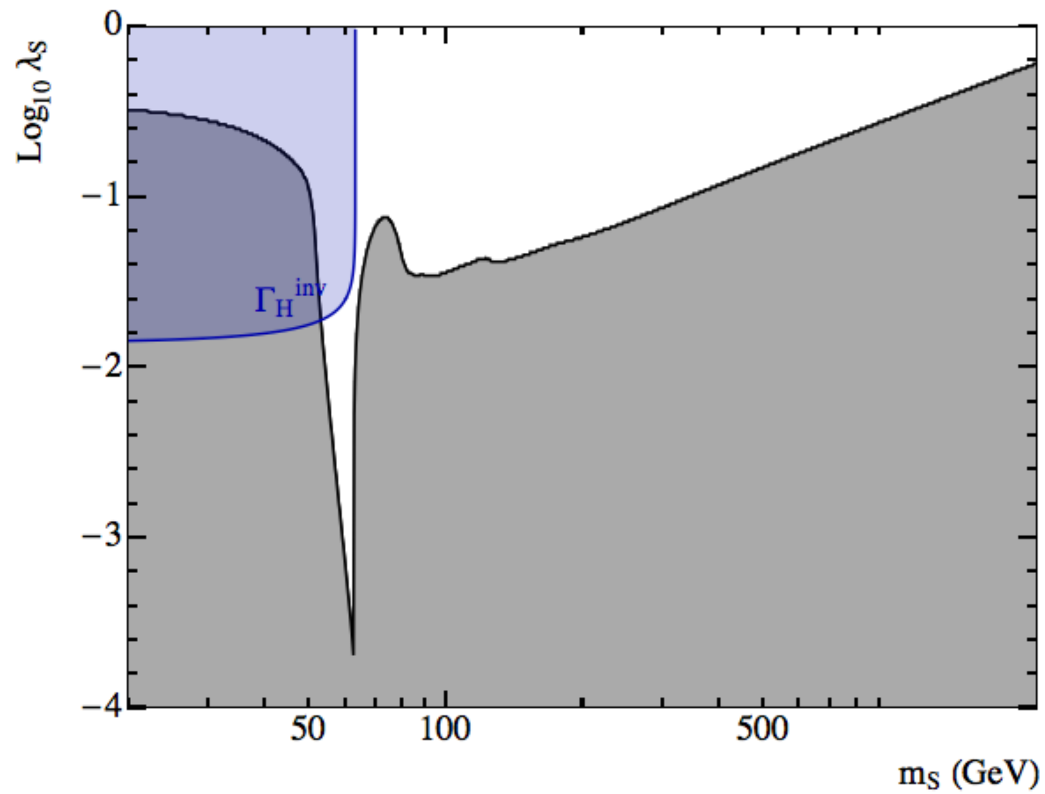
Direct, indirect and Higgs Invisible Width constraints

Γ_H^{inv}

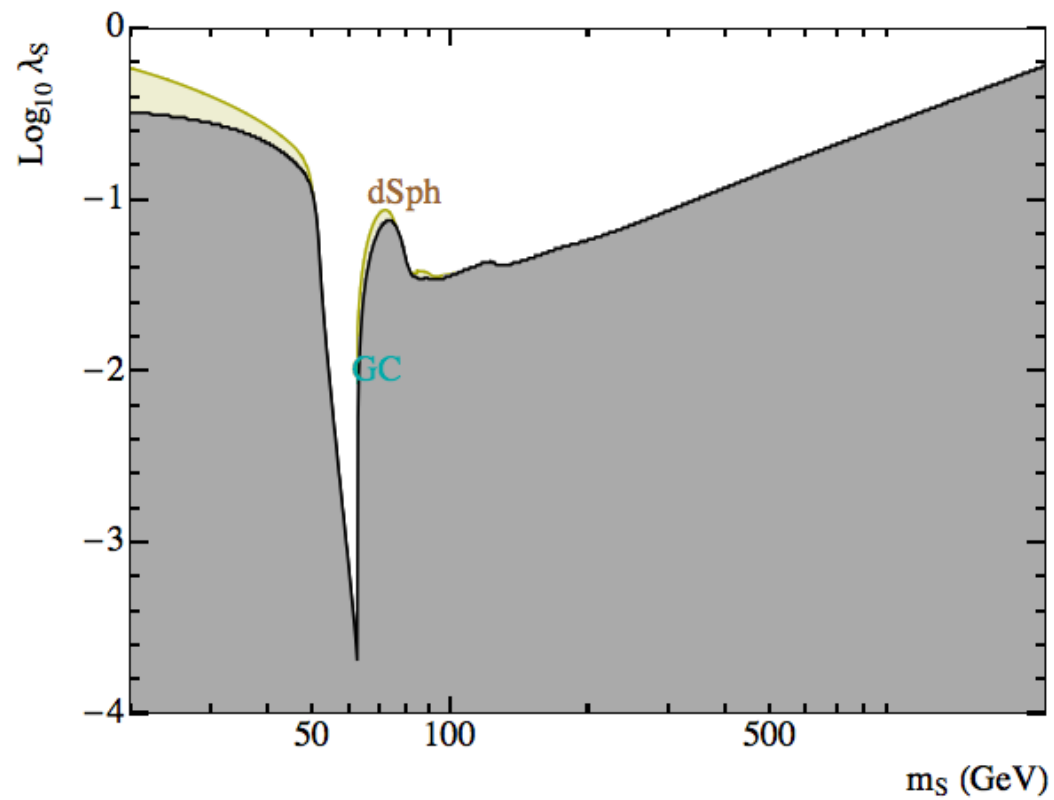


Direct, indirect and Higgs Invisible Width constraints

Γ_H^{inv}

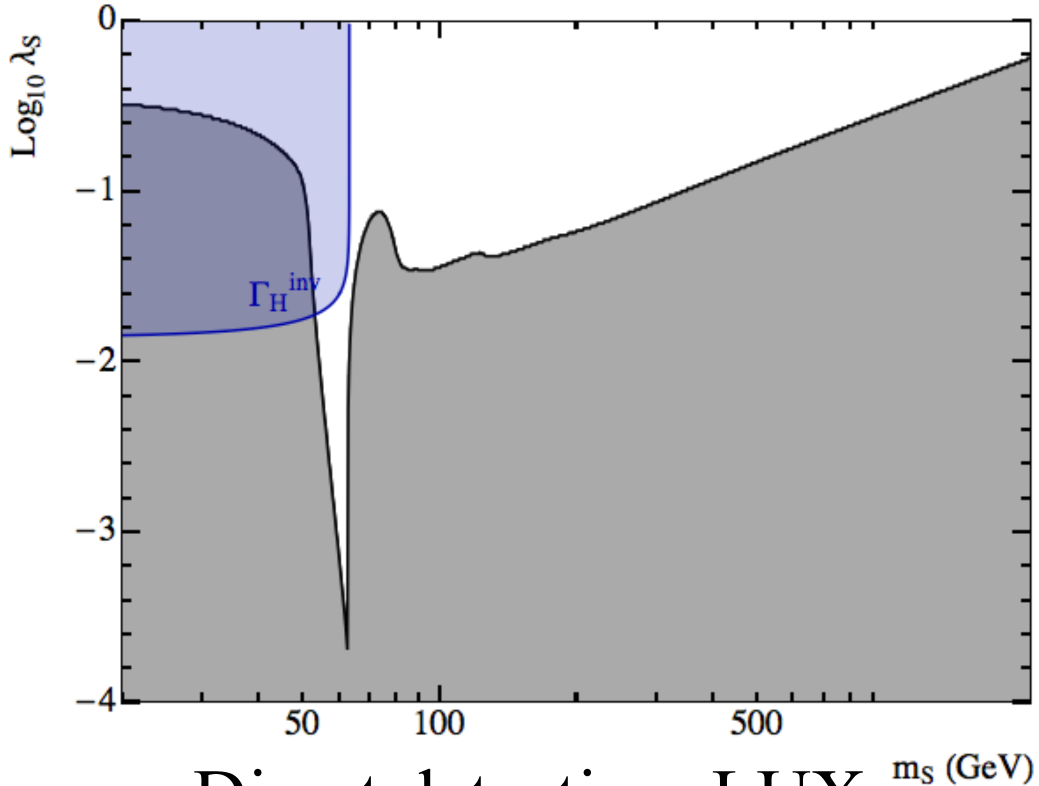


Indirect detection

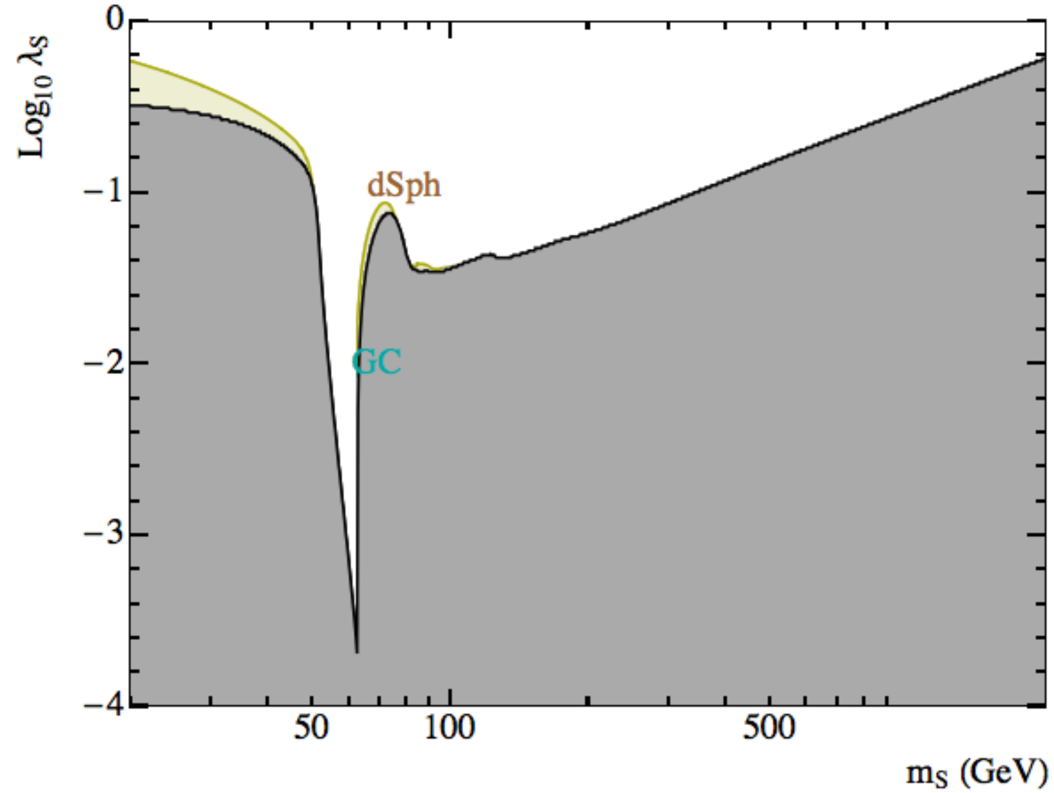


Direct, indirect and Higgs Invisible Width constraints

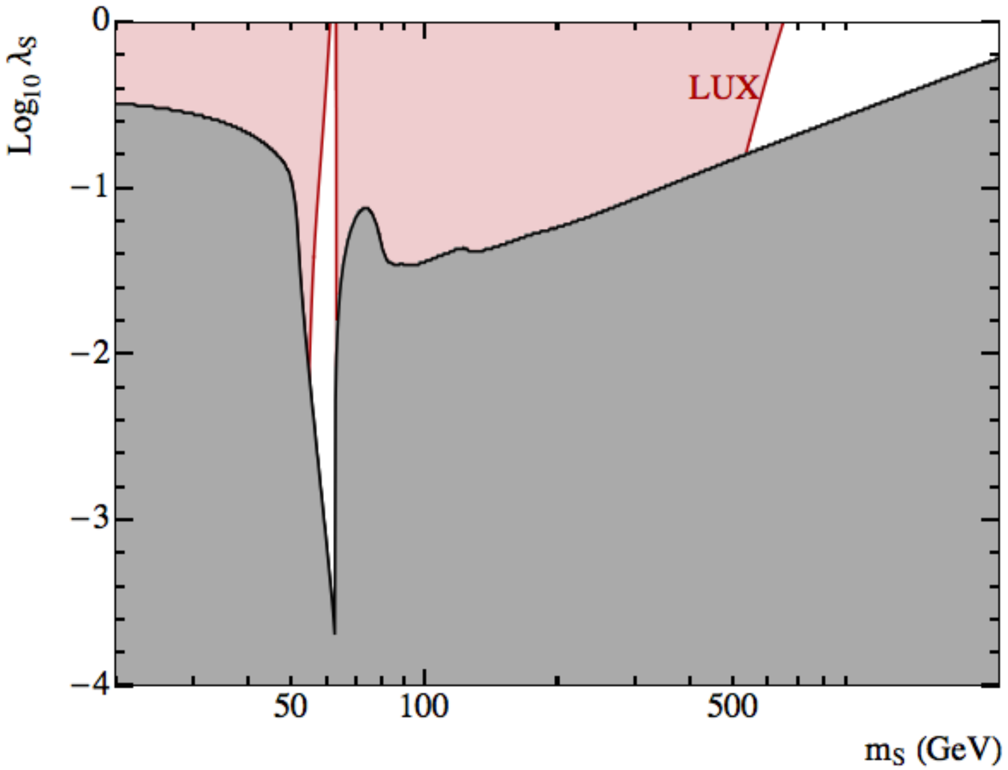
Γ_H^{inv}



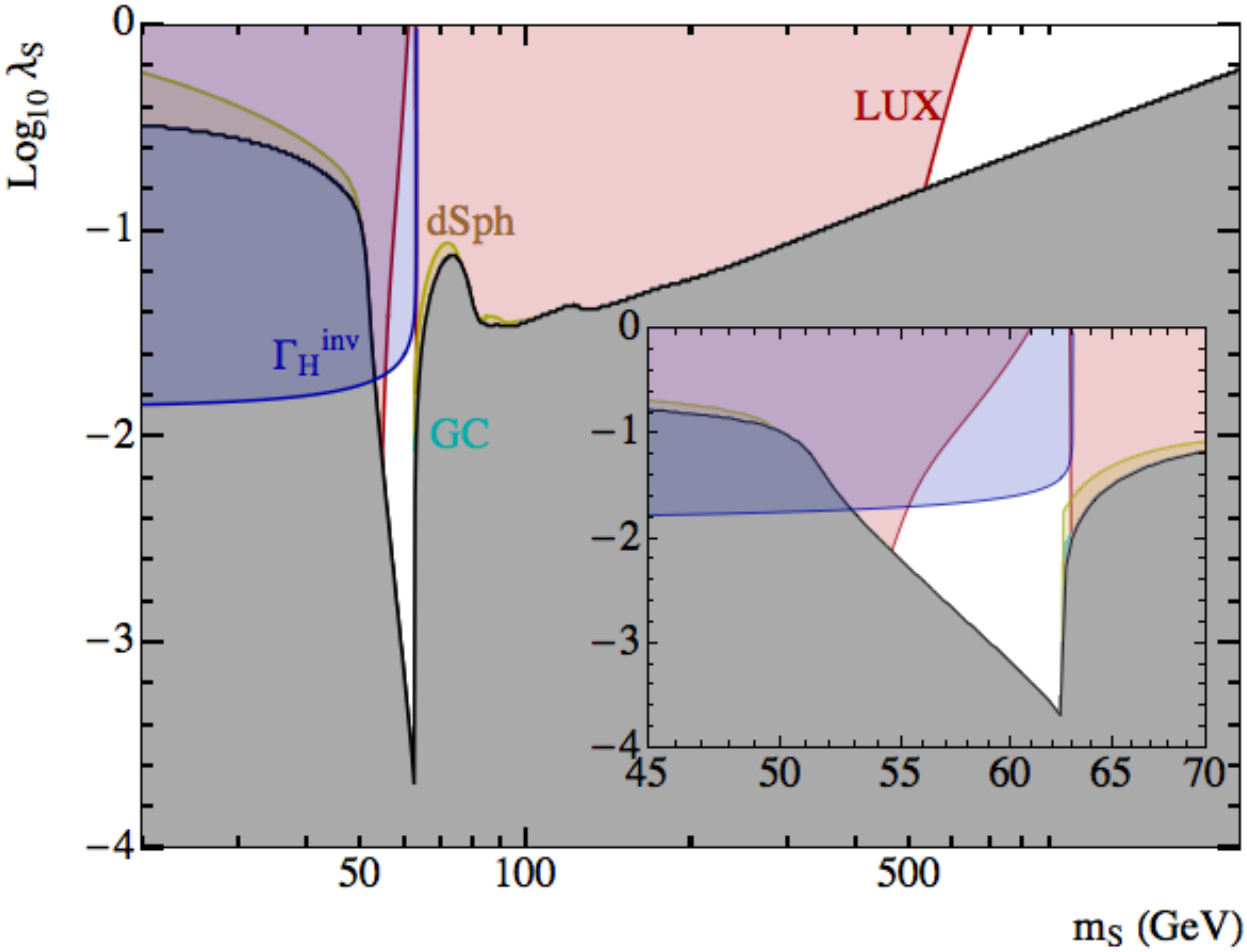
Indirect detection



Direct detection: LUX



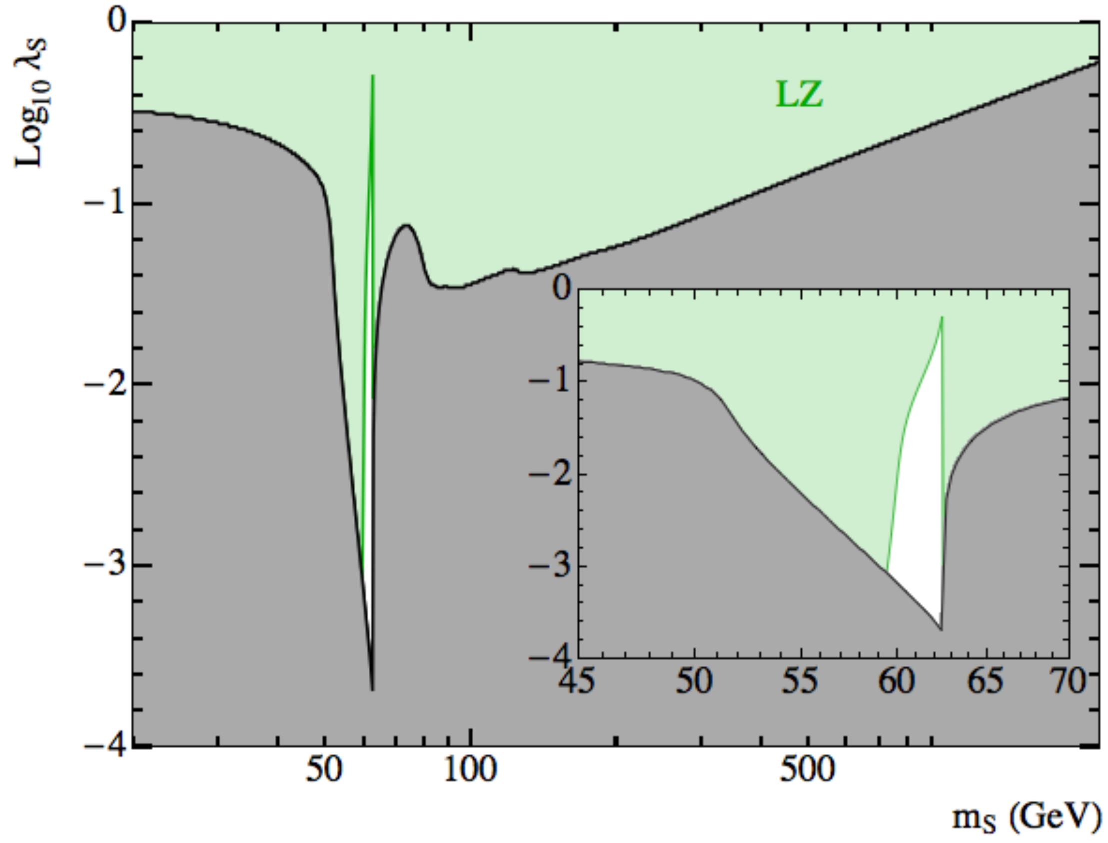
Direct, indirect and Higgs Invisible Width constraints



- **Masses over 500 GeV are allowed**
- **Small window in the resonance allowed**

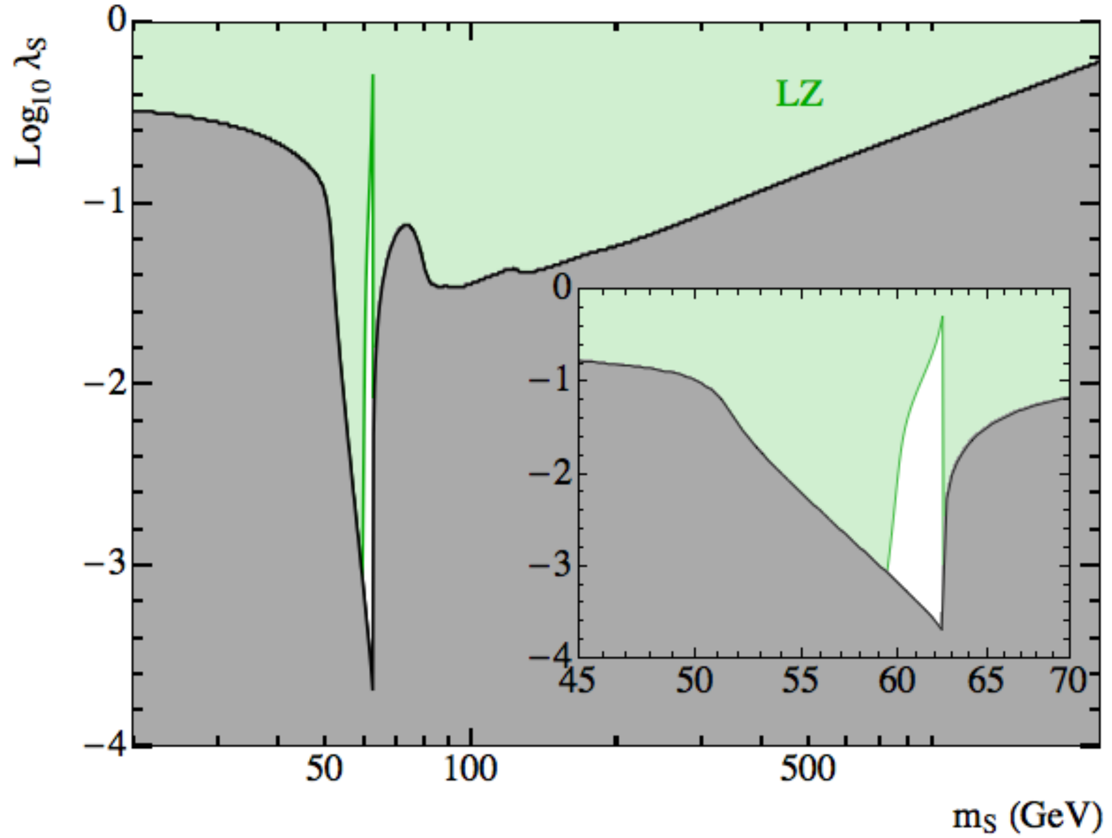
Future constraints

Future Direct Detection: LZ



Future constraints

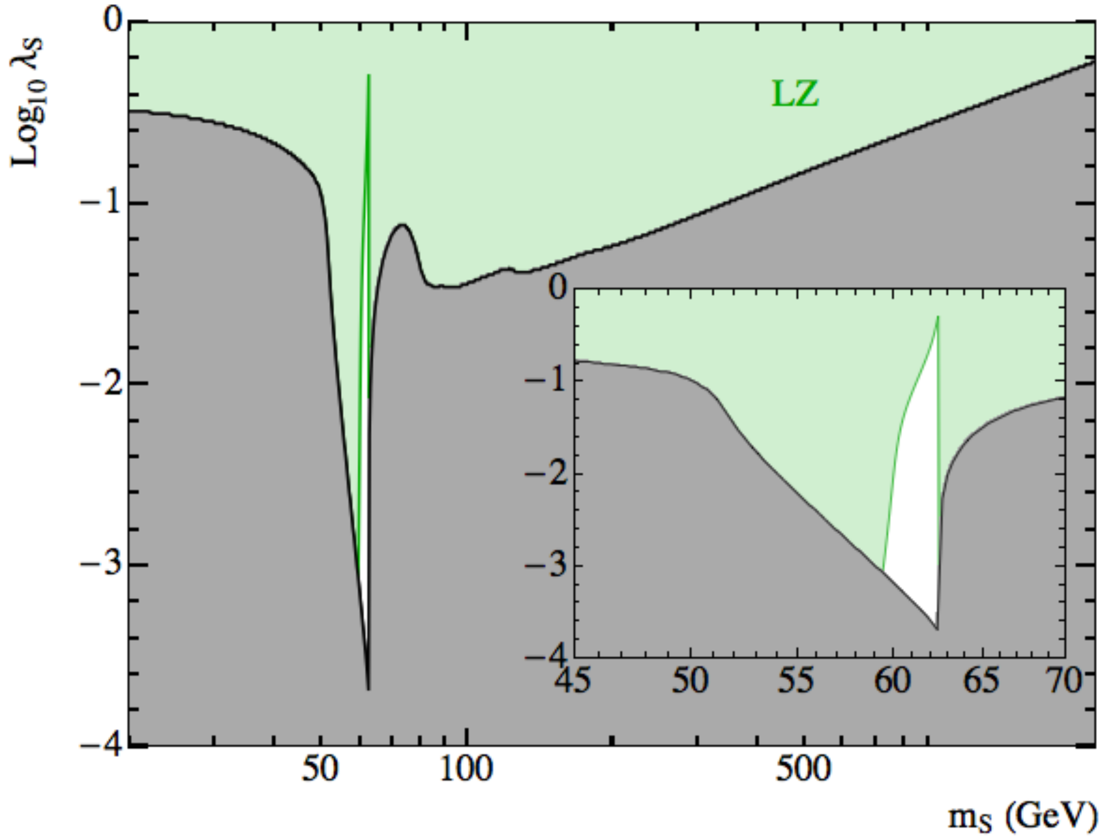
Future Direct Detection: LZ



The only zone remaining will be the window in the **resonance**

Future constraints

Future Direct Detection: LZ



The only zone remaining will be the window in the **resonance**

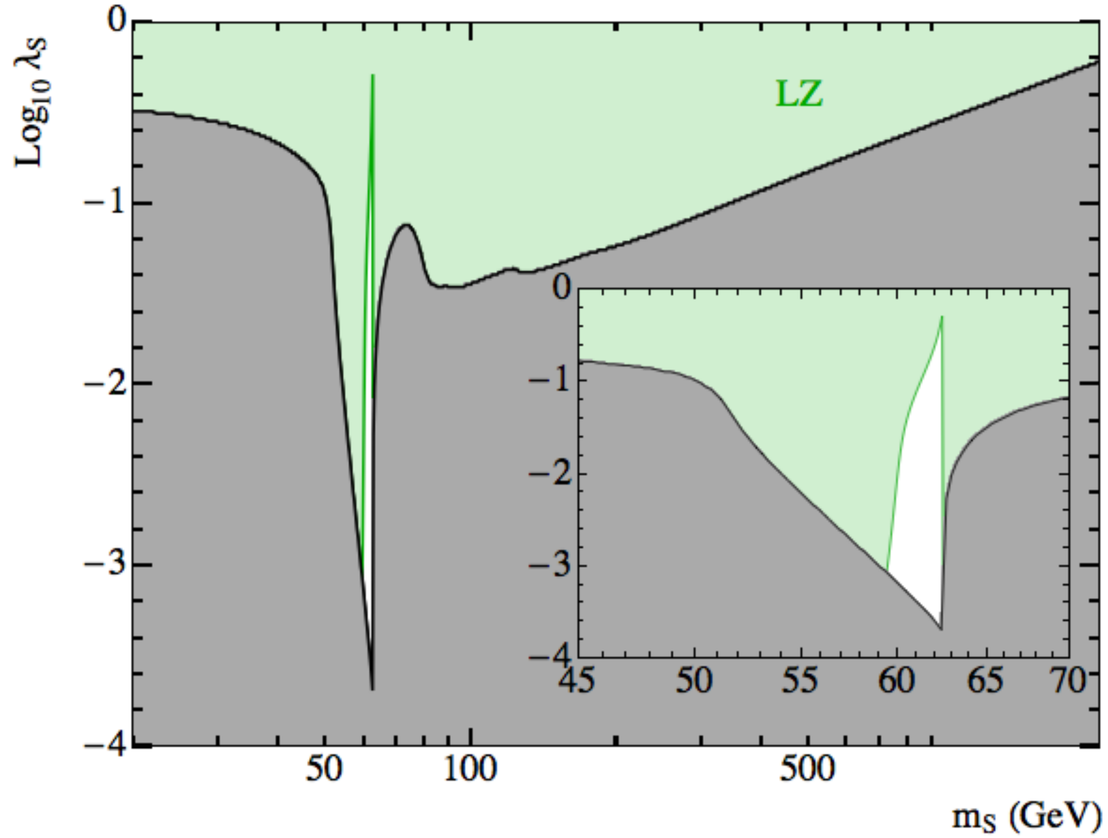
- We expect **indirect detection** experiments to explore that remaining window.

Feng et al: arXiv 1412:1105

Duerr et al: arXiv 1509.04282

Future constraints

Future Direct Detection: LZ



The only zone remaining will be the window in the **resonance**

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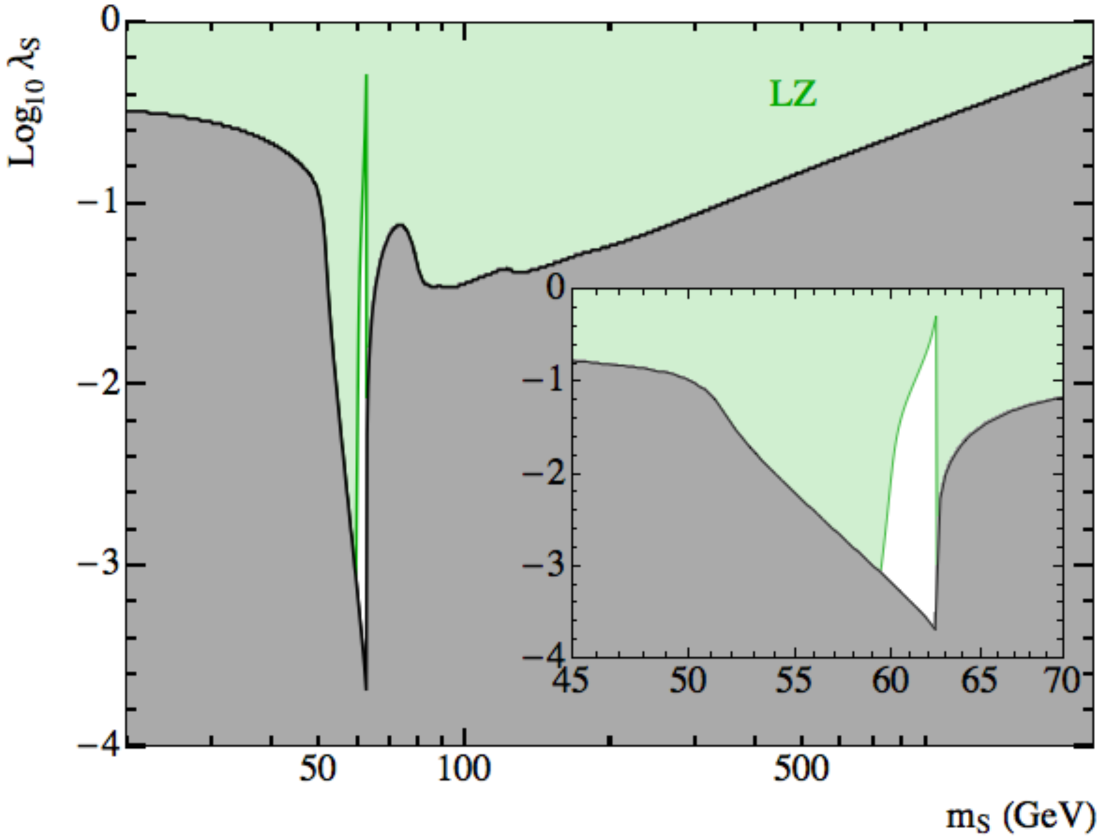
Feng et al: arXiv 1412:1105
Duerr et al: arXiv 1509.04282

No positive detection

Future constraints

Future Direct Detection: LZ



The only zone remaining will be the window in the **resonance**

- We expect **indirect detection** experiments to explore that remaining window.

Feng et al: arXiv 1412:1105

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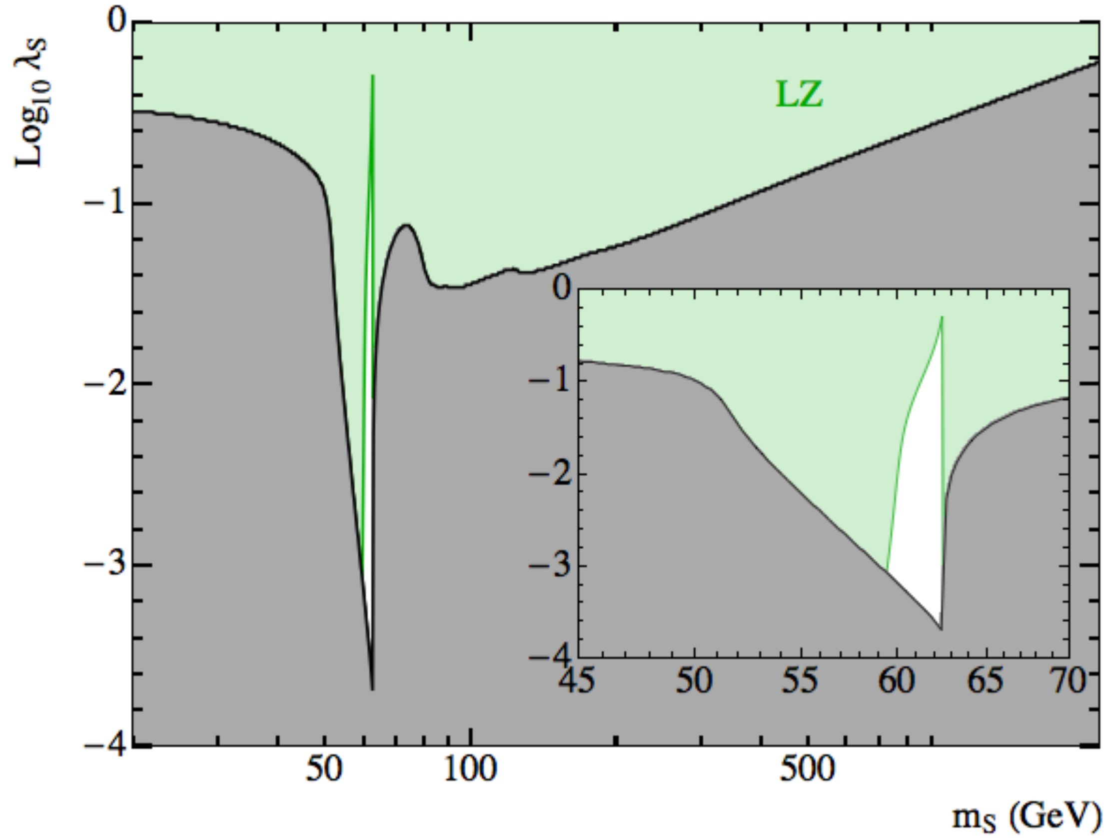
No positive detection → Scalar Higgs portal

Future constraints

Future Direct Detection: LZ



The only zone remaining will be the window in the **resonance**

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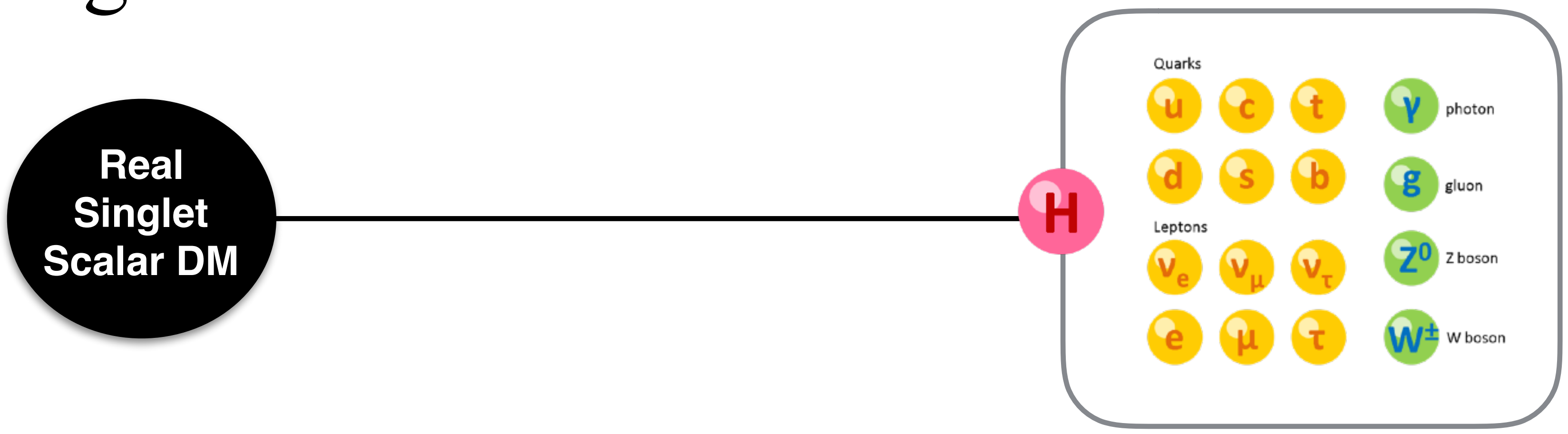
Feng et al: arXiv 1412:1105

Duerr et al: arXiv 1509.04282

No positive detection → ~~Scalar Higgs portal~~

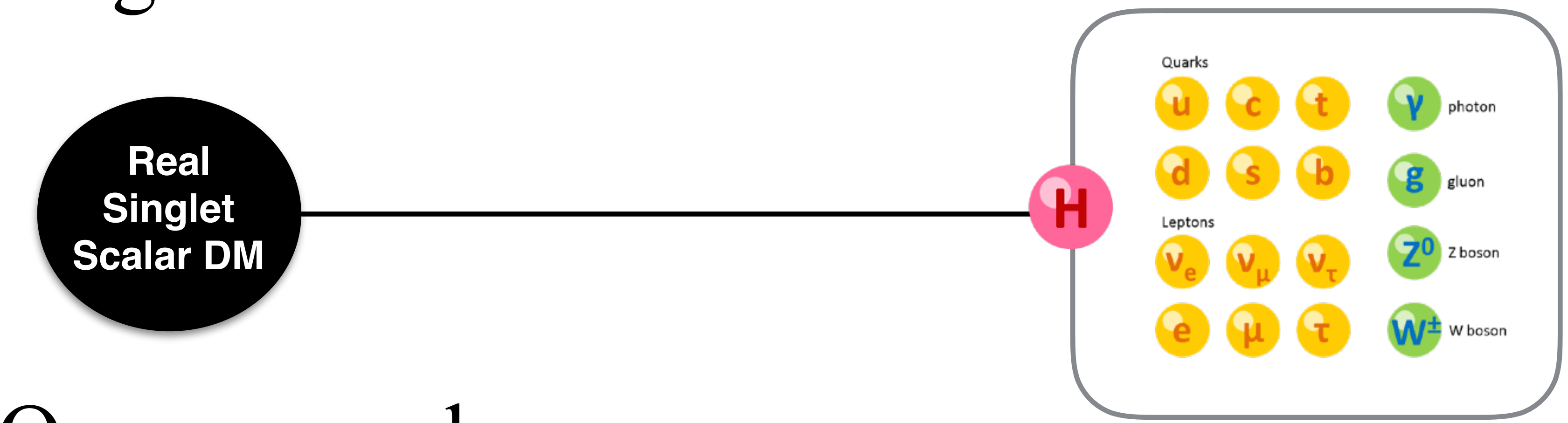
“Rescuing” the Higgs portal

Original model

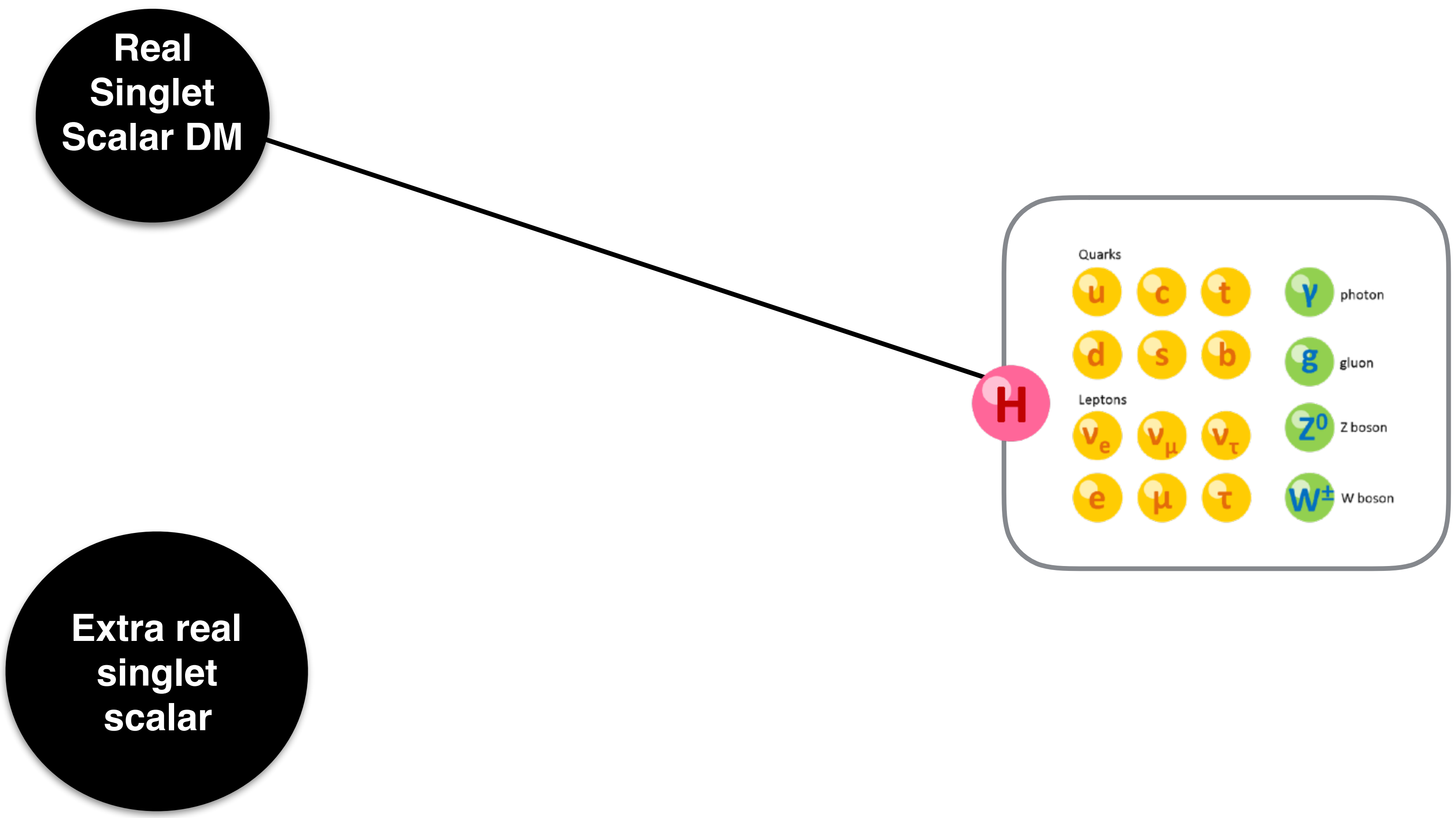


“Rescuing” the Higgs portal

Original model



Our proposal



"Rescuing" the Higgs portal

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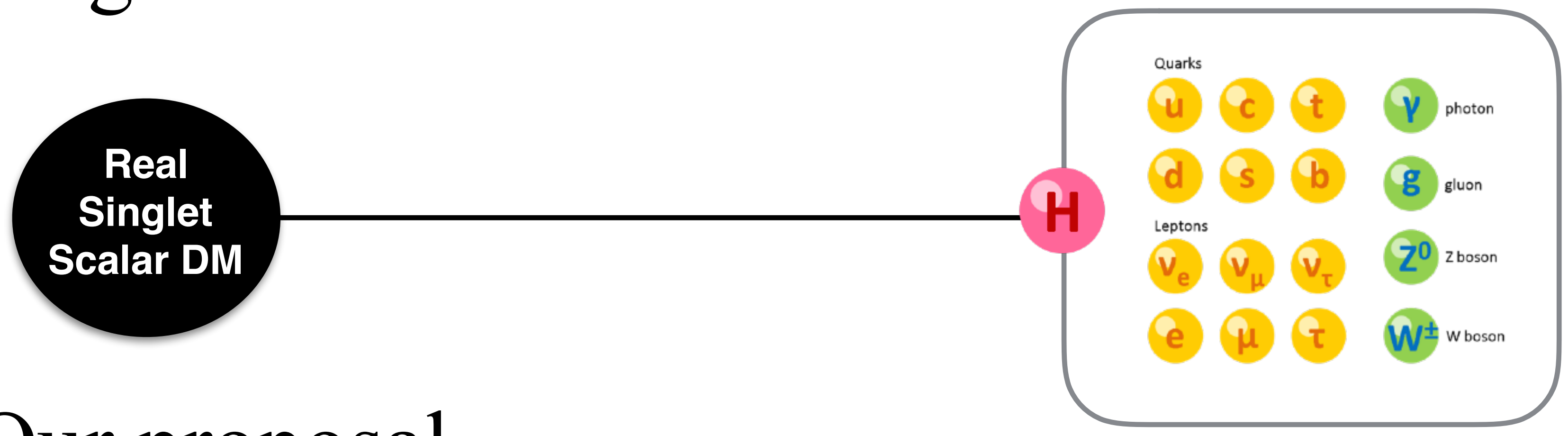

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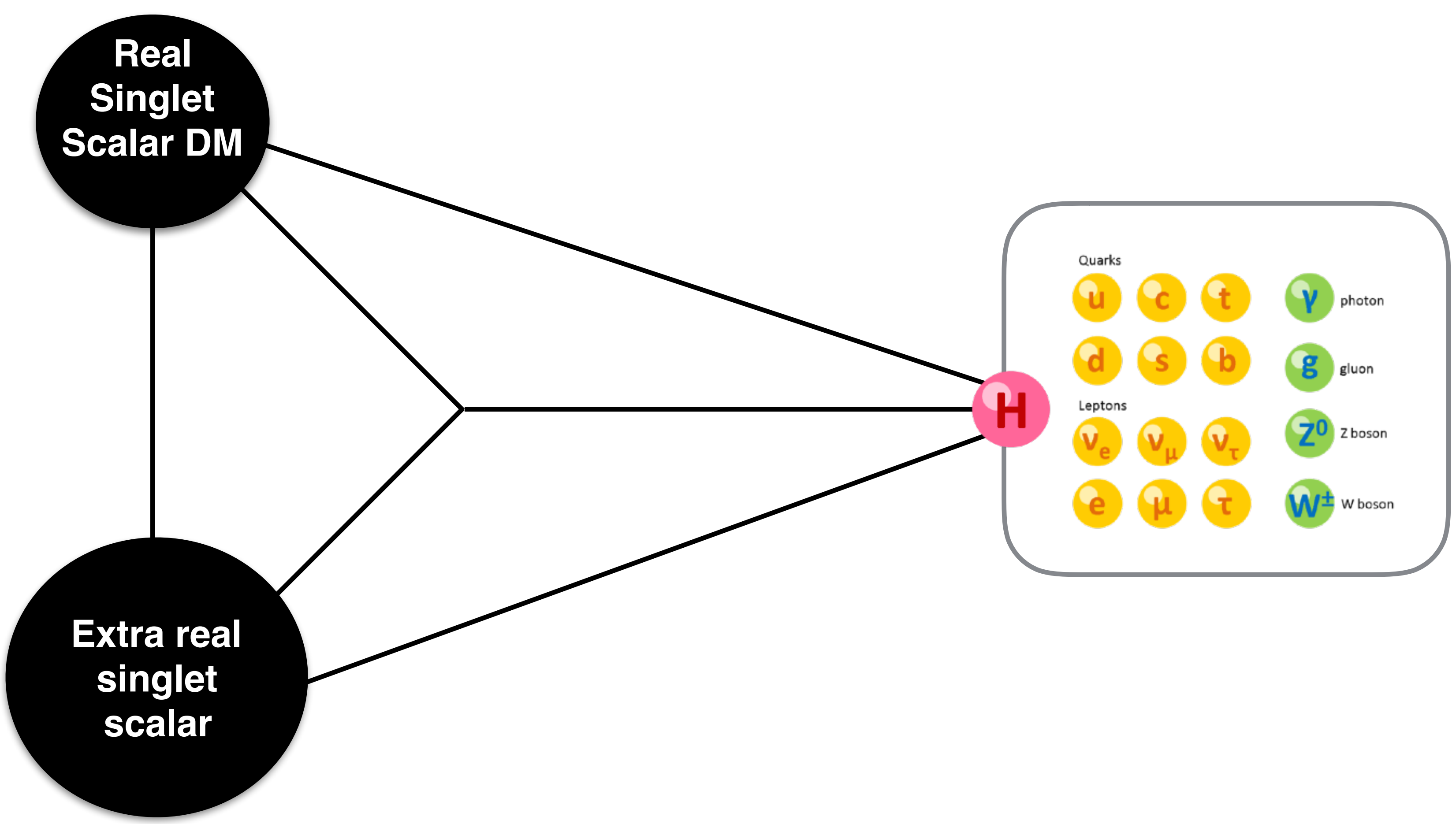

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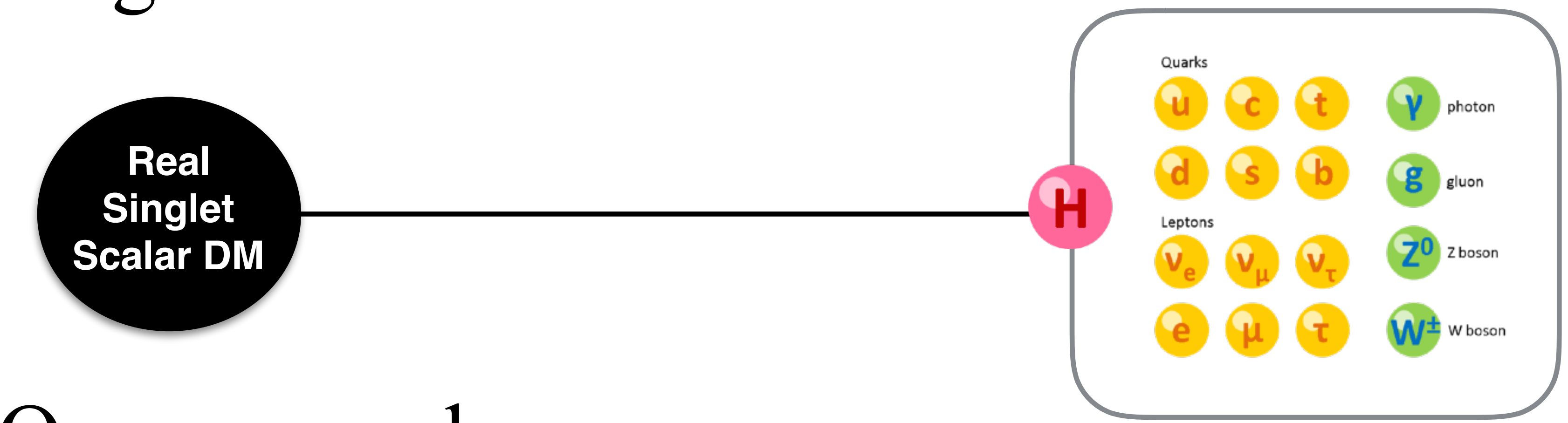

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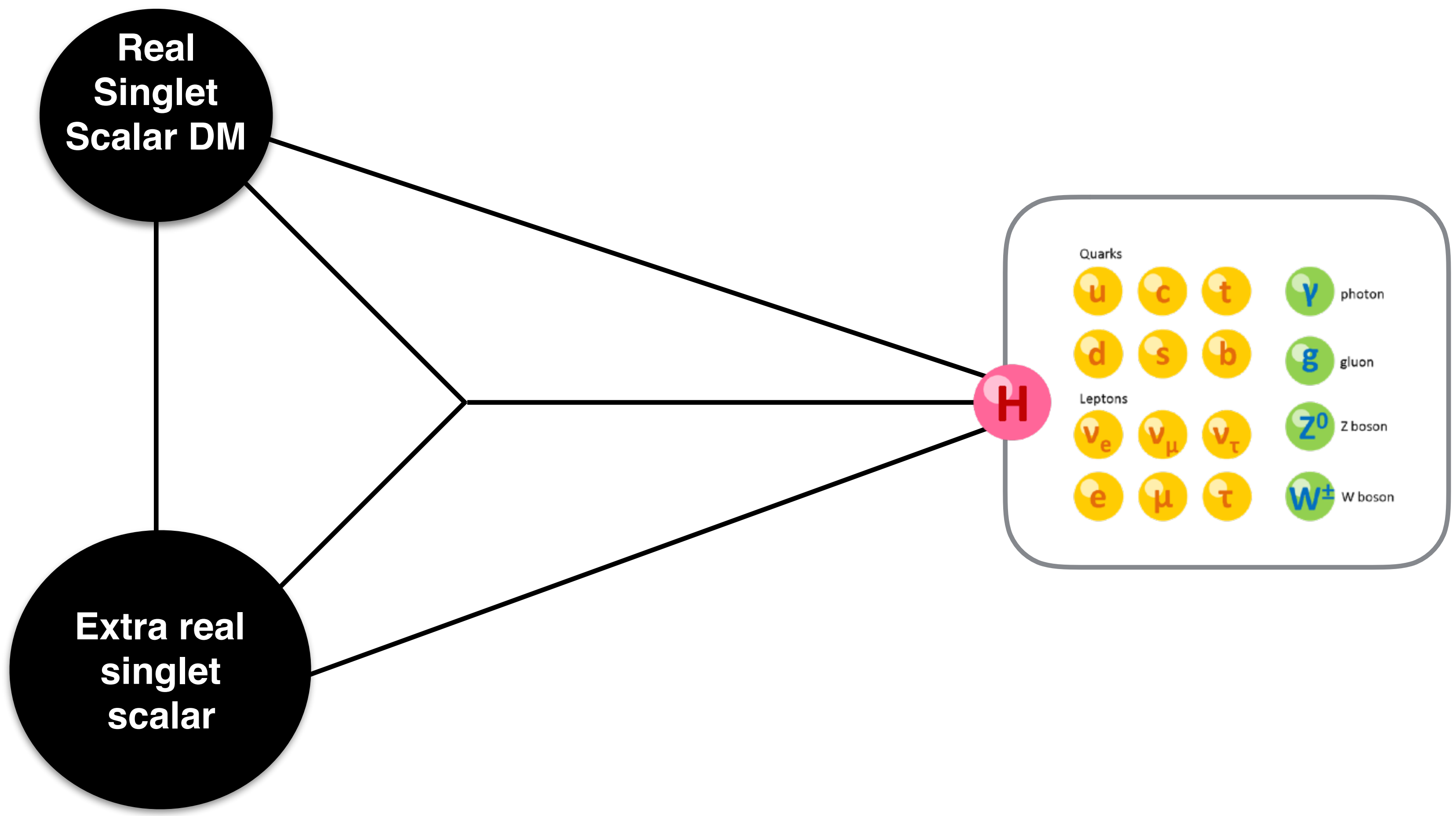
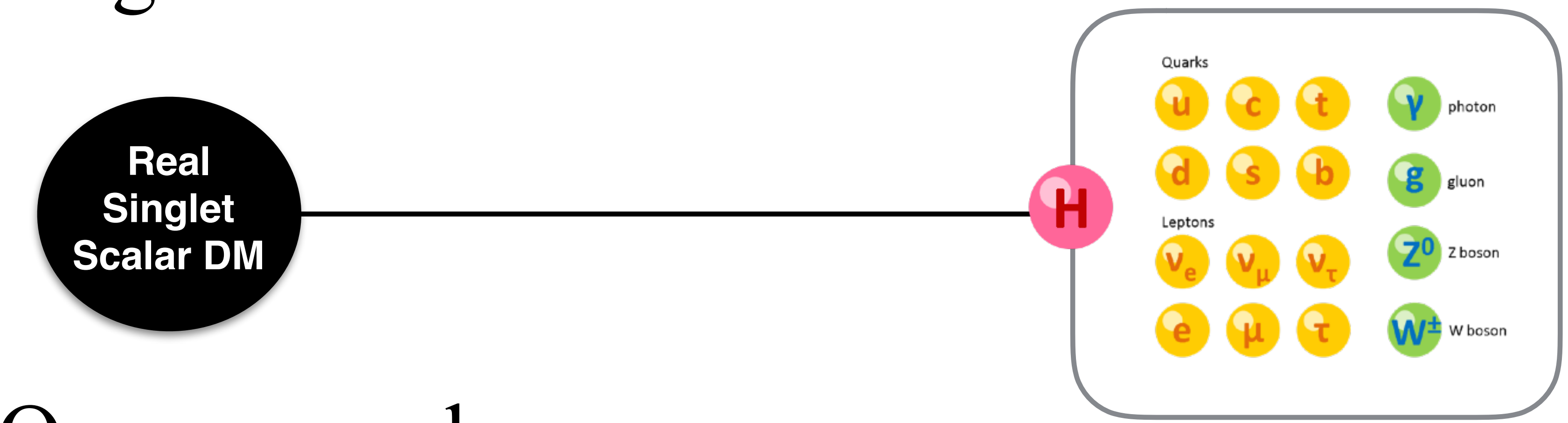


New scalar

- Heavier
- Decaying

“Rescuing” the Higgs portal

Original model



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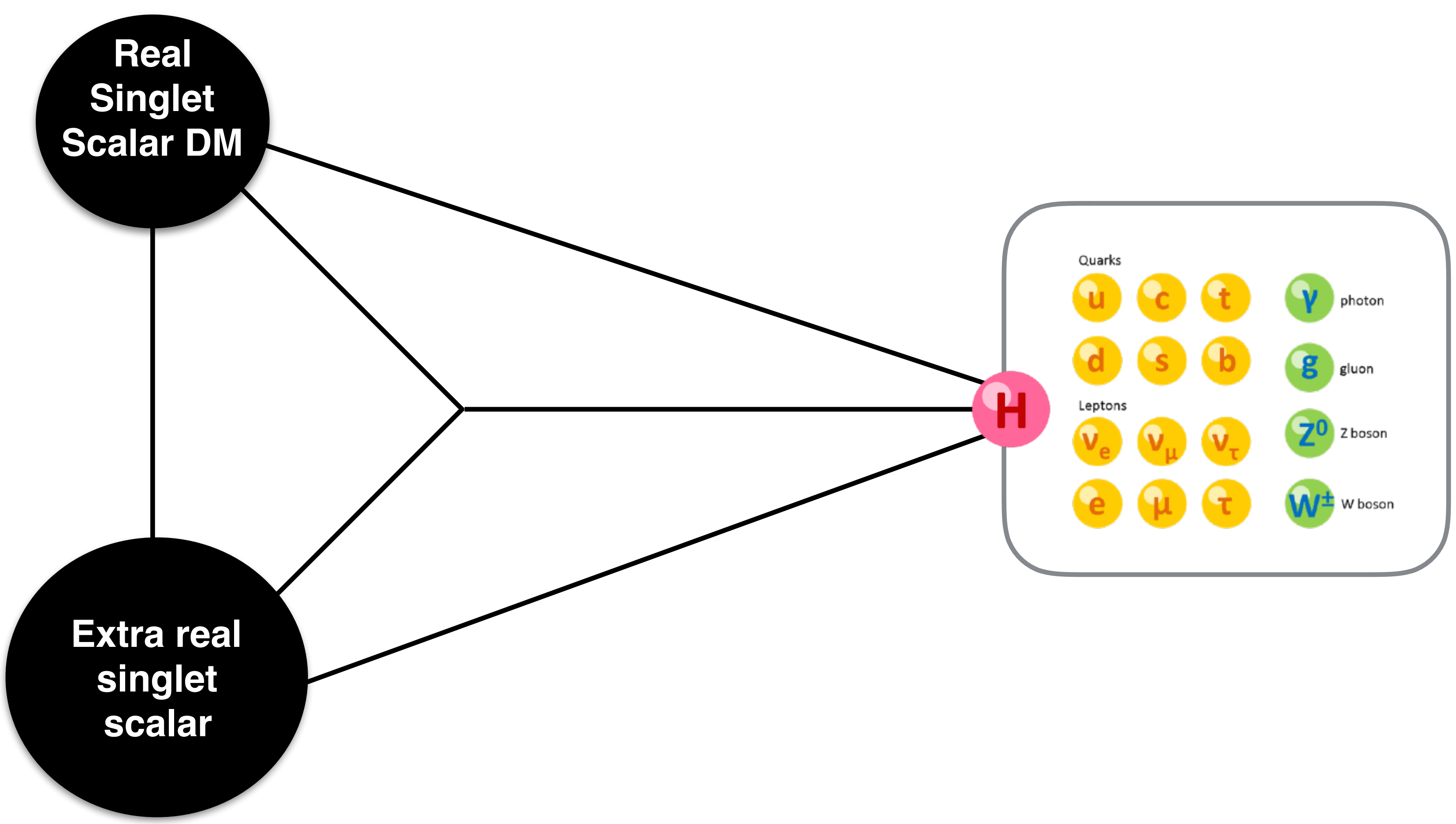

New scalar

- Heavier
- Decaying

Only
Singlet Scalar 1
remains

Higgs portal with two Real Singlet Scalars

Higgs portal with two Real Singlet Scalars

Global Z_2 symmetry

$$S_1 \to -S_1 \quad S_1 S_2 \to S_1 S_2$$

$$S_2 \to -S_2 \quad SM \to SM$$

S_1 DM candidate

S_2 Heavier scalar

Higgs portal with two Real Singlet Scalars

Global Z_2 symmetry

$S_1 \to -S_1 \quad S_1 S_2 \to S_1 S_2$

$S_2 \to -S_2 \quad SM \to SM$

S_1 DM candidate

S_2 Heavier scalar

Lagrangian

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

$$- \frac{1}{2}\lambda_1 S_1^2 |H|^2 - \frac{1}{2}\lambda_2 S_2^2 |H|^2 - \lambda_{12} S_1 S_2 \left(|H|^2 - \frac{v^2}{2}\right)$$

Renormalizable

Higgs portal with two Real Singlet Scalars

Global Z_2 symmetry

$$S_1 \to -S_1 \quad S_1 S_2 \to S_1 S_2$$

$$S_2 \to -S_2 \quad SM \to SM$$

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$$-\frac{1}{2}\lambda_1 S_1^2 |H|^2 - \frac{1}{2}\lambda_2 S_2^2 |H|^2 - \lambda_{12} S_1 S_2 \left(|H|^2 - \frac{v^2}{2}\right)$$

Renormalizable

After EWSB

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

$$-\frac{1}{2}\lambda_1 v S_1^2 h - \frac{1}{2}\lambda_2 v S_2^2 h - \lambda_{12} v S_1 S_2 h - \frac{1}{4}\lambda_1 S_1^2 h^2 - \frac{1}{4}\lambda_2 S_2^2 h^2 - \frac{1}{2}\lambda_{12} S_1 S_2 h^2$$

$$(v = 175 \text{ GeV})$$

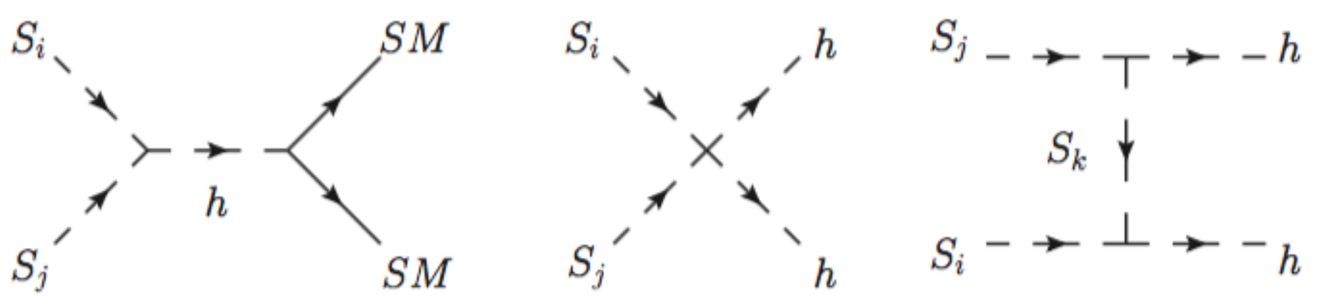
Higgs portal with two Real Singlet Scalars

After EWSB

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{2}\sum_{i=1,2}\left[(\partial_\mu S_i)^2 - m_{S_i}^2 S_i^2 - \frac{1}{12}\lambda_{i4}S_i^4\right] - \frac{1}{6}\lambda_{13}S_1S_2^3 - \frac{1}{6}\lambda_{31}S_1^3S_2 - \frac{1}{4}\lambda_{22}S_1^2S_2^2$$

$$-\frac{1}{2}\lambda_1 v S_1^2 h - \frac{1}{2}\lambda_2 v S_2^2 h - \lambda_{12} v S_1 S_2 h - \frac{1}{4}\lambda_1 S_1^2 h^2 - \frac{1}{4}\lambda_2 S_2^2 h^2 - \frac{1}{2}\lambda_{12} S_1 S_2 h^2 \qquad (v = 175 \text{ GeV})$$

Processes DM-SM



$i, j, k = 1, 2$

Coannihilation and eff. operator

To avoid constraints we need low values of λ_1

$$-\frac{1}{2}\lambda_1 v S_1^2 h - \frac{1}{4}\lambda_1 S_1^2 h^2$$

Higgs portal with two Real Singlet Scalars

Coannihilation and eff. operator

To avoid constraints we need low values of λ_1

$$-\frac{1}{2}\lambda_1 v S_1^2 h - \frac{1}{4}\lambda_1 S_1^2 h^2$$

To test coannihilation effects we are imposing low values of λ_2

$$-\frac{1}{2}\lambda_2 v S_2^2 h - \frac{1}{4}\lambda_2 S_2^2 h^2$$

Coannihilation and eff. operator

To avoid constraints we need low values of λ_1

$$-\frac{1}{2}\lambda_1 v S_1^2 h - \frac{1}{4}\lambda_1 S_1^2 h^2$$

To test coannihilation effects we are imposing low values of λ_2

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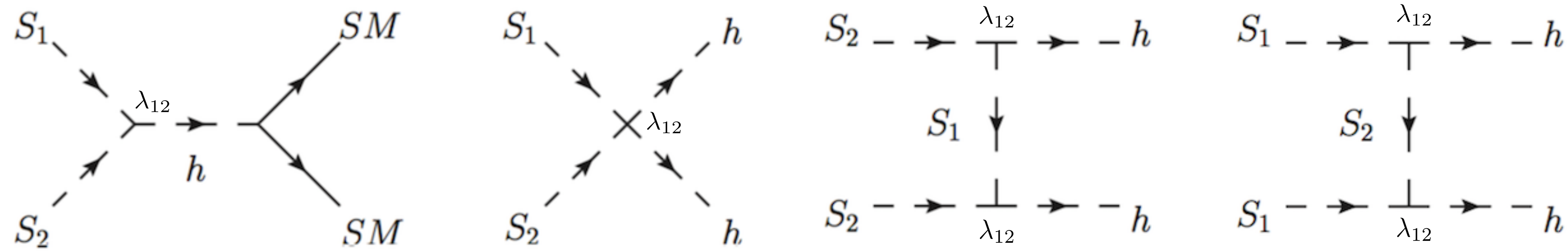
For low values of λ_1, λ_2 the coupling λ_{12} becomes relevant. $-\lambda_{12} v S_1 S_2 h - \frac{1}{2}\lambda_{12} S_1 S_2 h^2$



Coannihilation and eff. operator

To avoid constraints we need low values of λ_1

$$-\frac{1}{2}\lambda_1 v S_1^2 h - \frac{1}{4}\lambda_1 S_1^2 h^2$$

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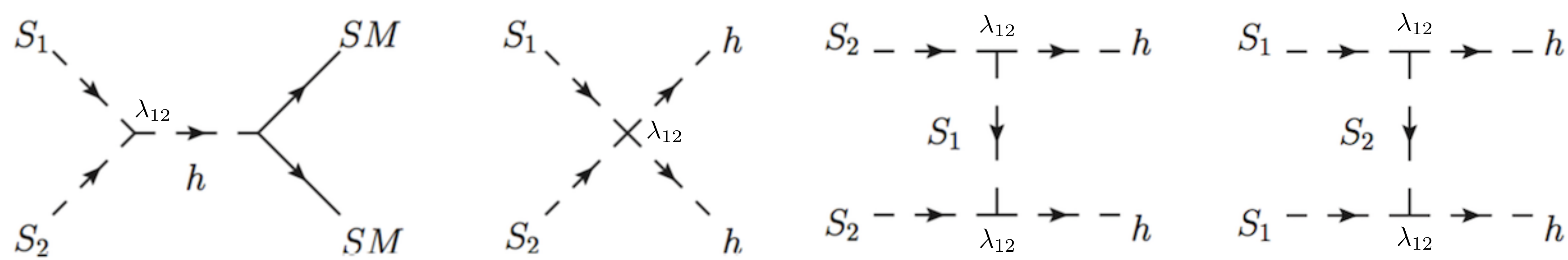
$$-\frac{1}{2}\lambda_2 v S_2^2 h - \frac{1}{4}\lambda_2 S_2^2 h^2$$

For low values of λ_1, λ_2 the coupling λ_{12} becomes relevant. $-\lambda_{12} v S_1 S_2 h - \frac{1}{2}\lambda_{12} S_1 S_2 h^2$



To analyze the effect of the coannihilation and effectives operators we set λ_1, λ_2 to

$\lambda_1 = \lambda_2 = \frac{\lambda_{12}^2}{(4\pi)^2}$ (radiative corrections), and we study the relevance of the coupling λ_{12}

Higgs portal with two Real Singlet Scalars

Coannihilation and eff. operator

$$\lambda_1 = \lambda_2 = \frac{\lambda_{12}^2}{(4\pi)^2}$$

The coupling λ_{12} is in charge of the annihilation of DM

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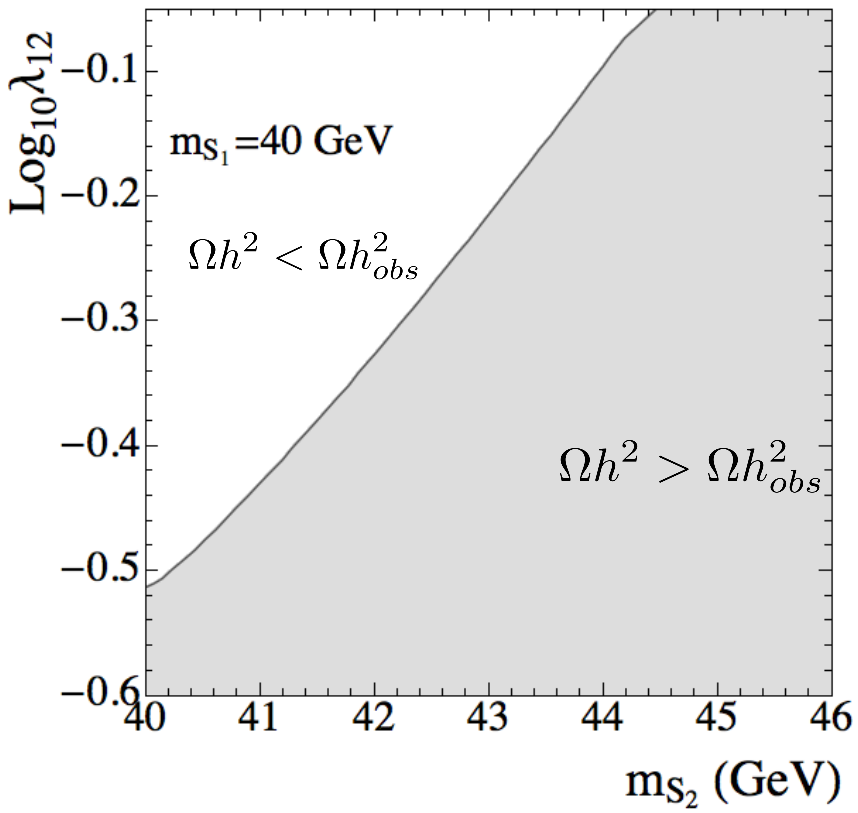

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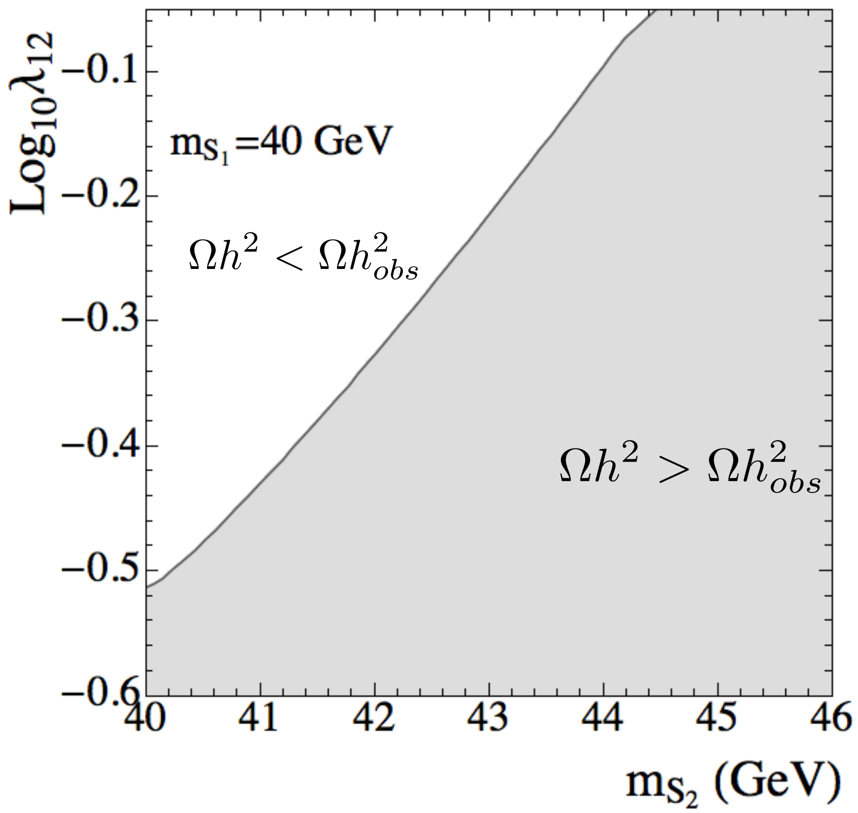

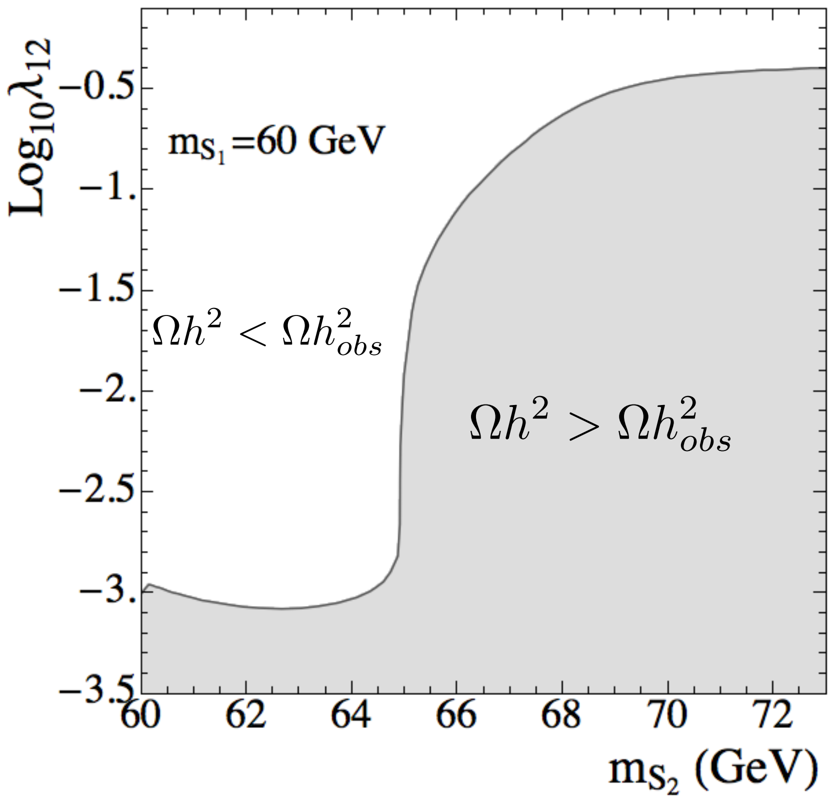

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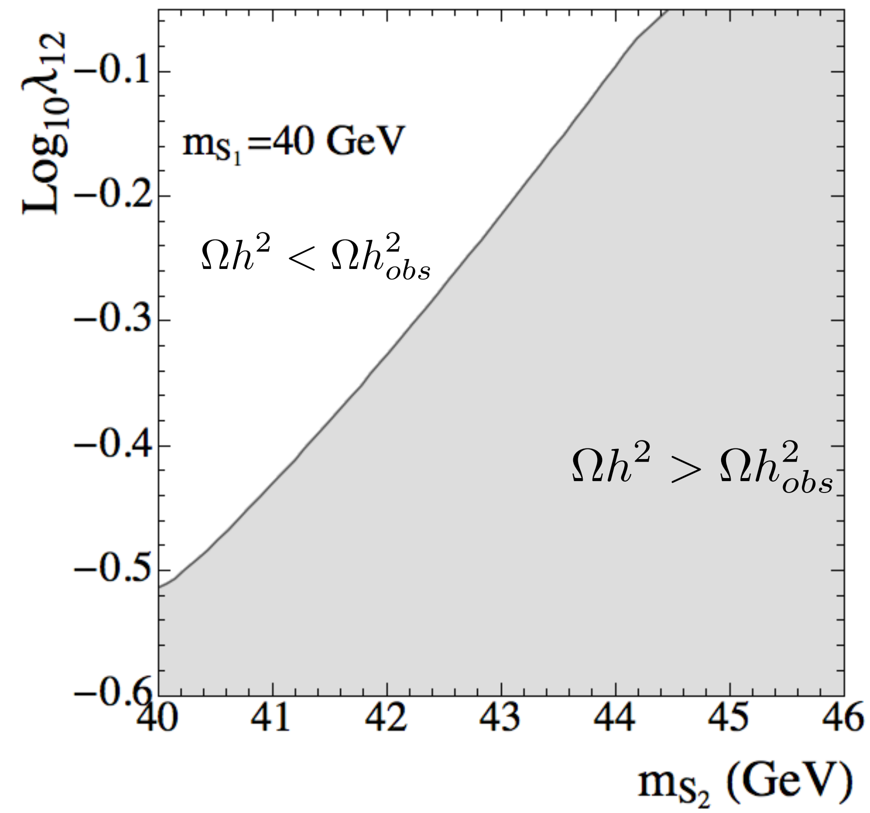

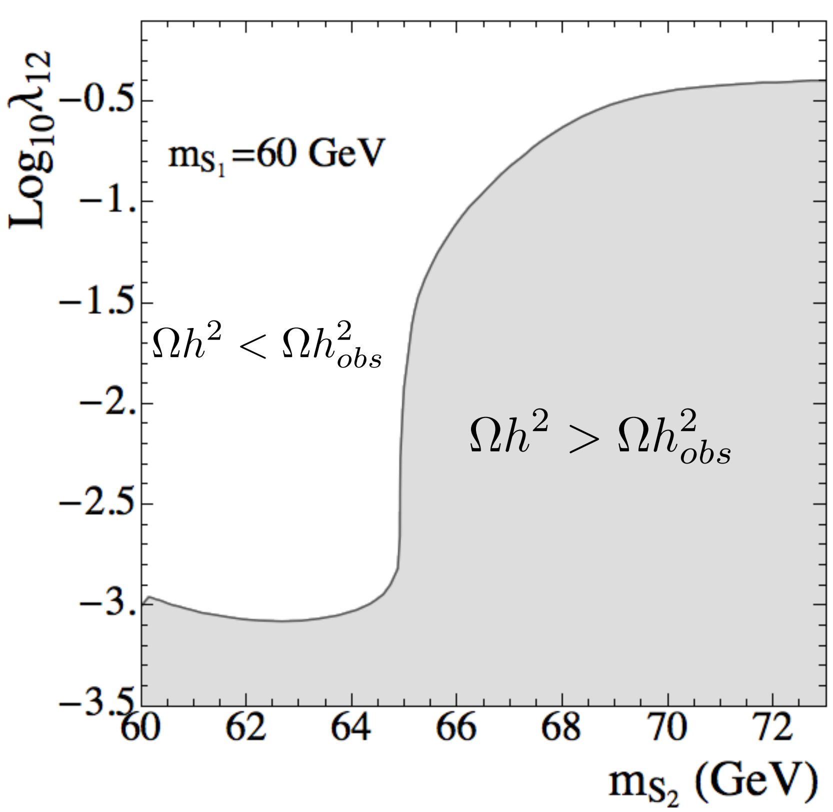

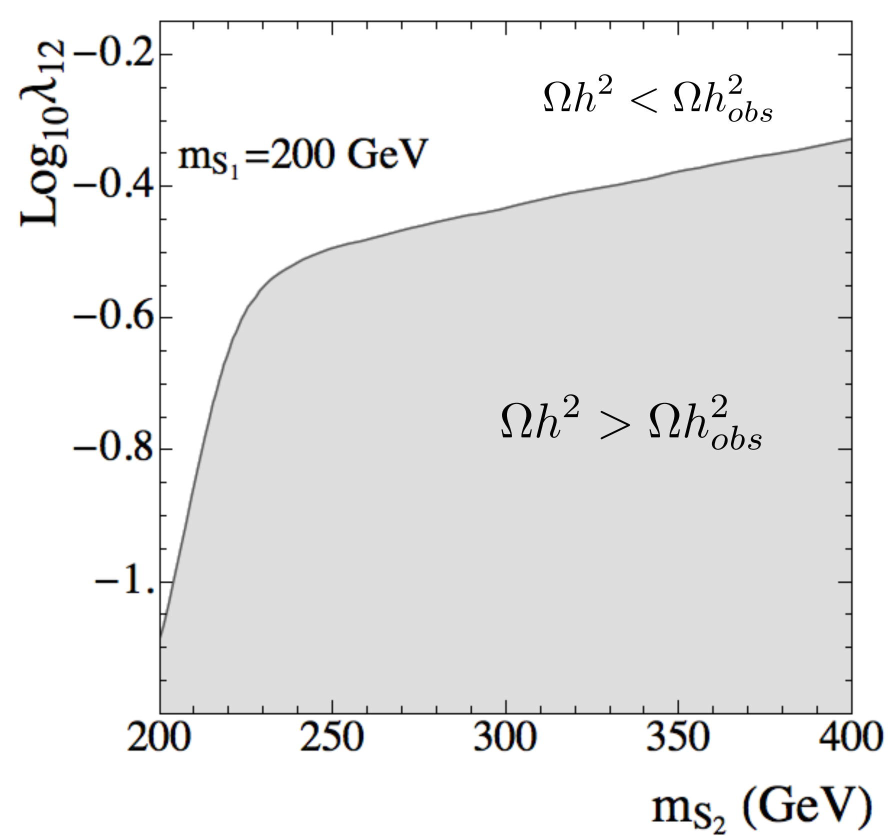

Parameter space of the new model

Random scan: $m_{S_1},\ m_{S_2},\ \lambda_1,\ \lambda_{12}$

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Higgs portal with two Real Singlet Scalars

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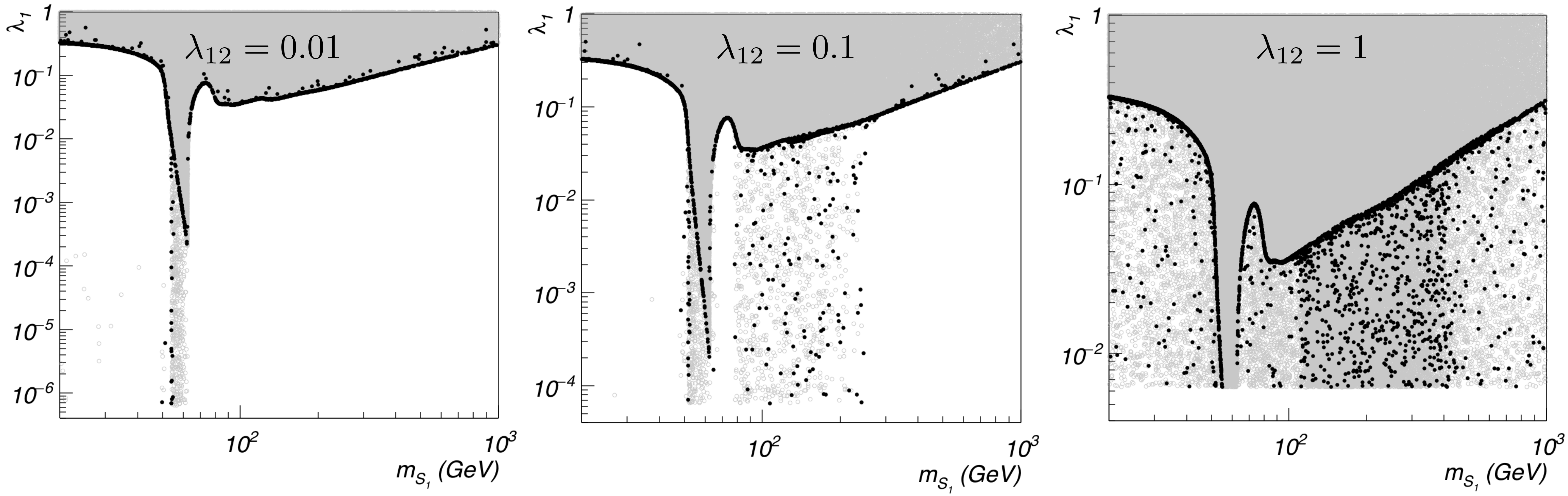

○ $0.116 > \Omega h^2$

● $0.116 < \Omega h^2 < 0.122$

Higgs portal with two Real Singlet Scalars

Constraints

- $\tau_{S_2} < 1s$ (BBN)
- LUX
- Γ_H^{inv}
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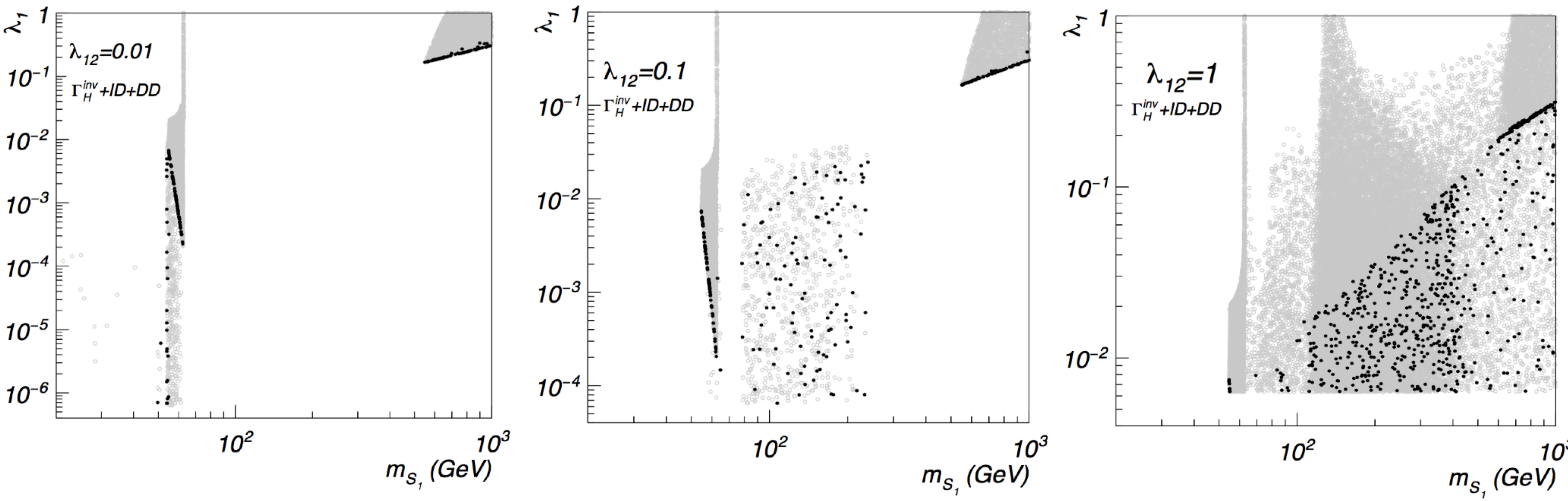

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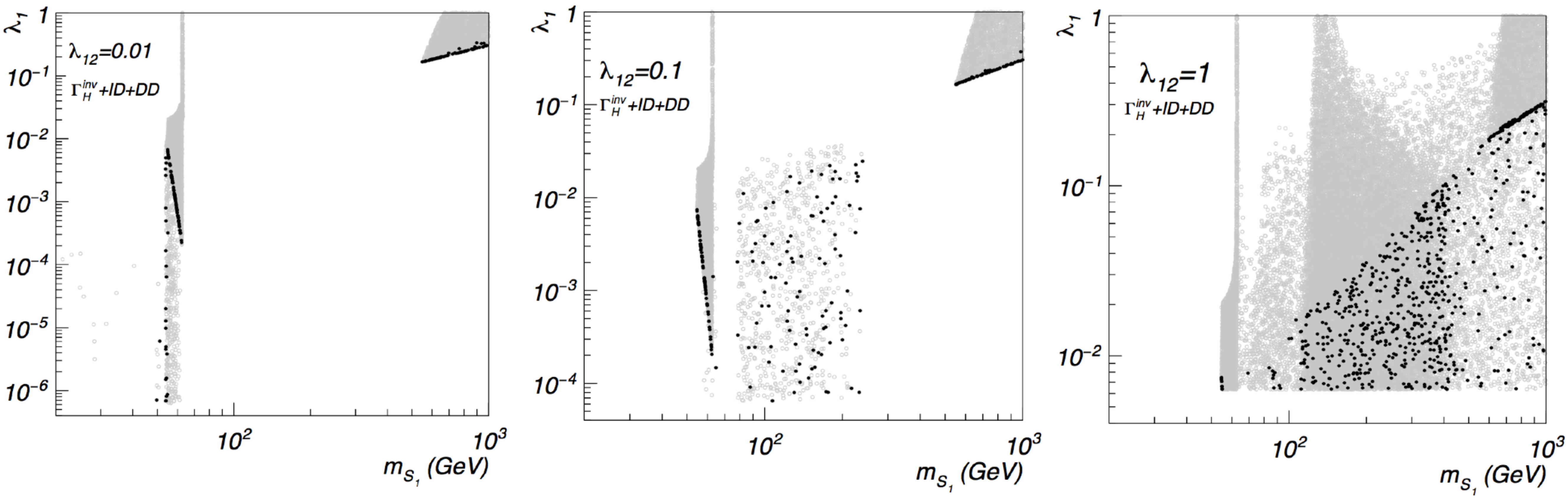

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For masses above 50 GeV we can find values of $m_{S_2},\ \lambda_1,\ \lambda_{12}$ with the correct relic density that survive all the constraints

Future DD constraints (LZ)

Higgs portal with two Real Singlet Scalars

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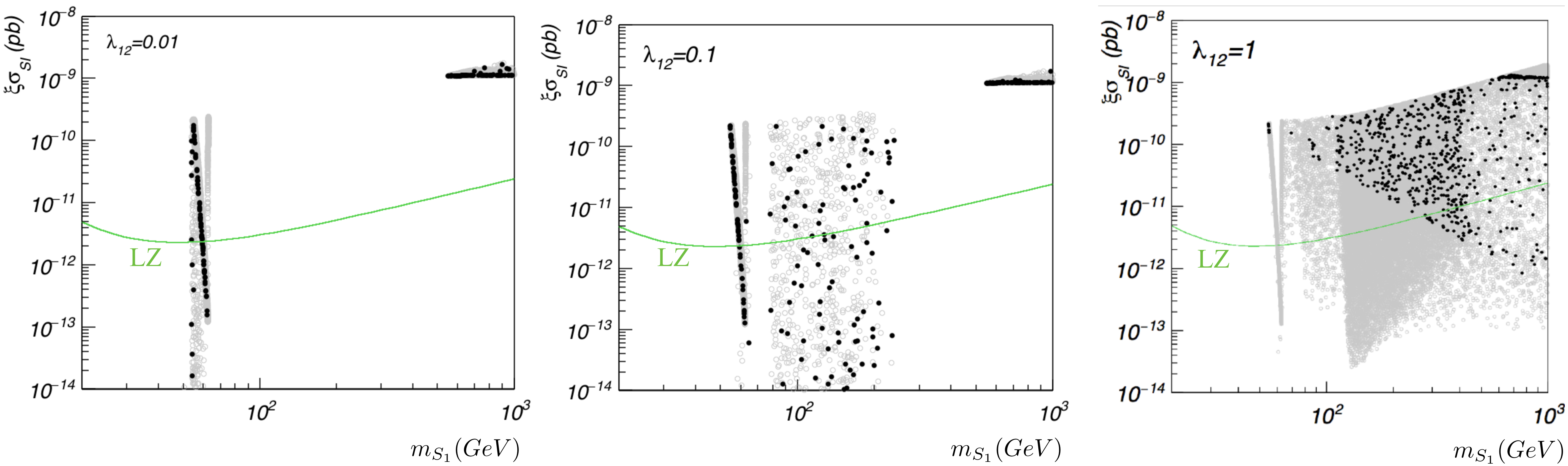

$$\xi = \Omega h^2/\Omega h^2_{obs}$$

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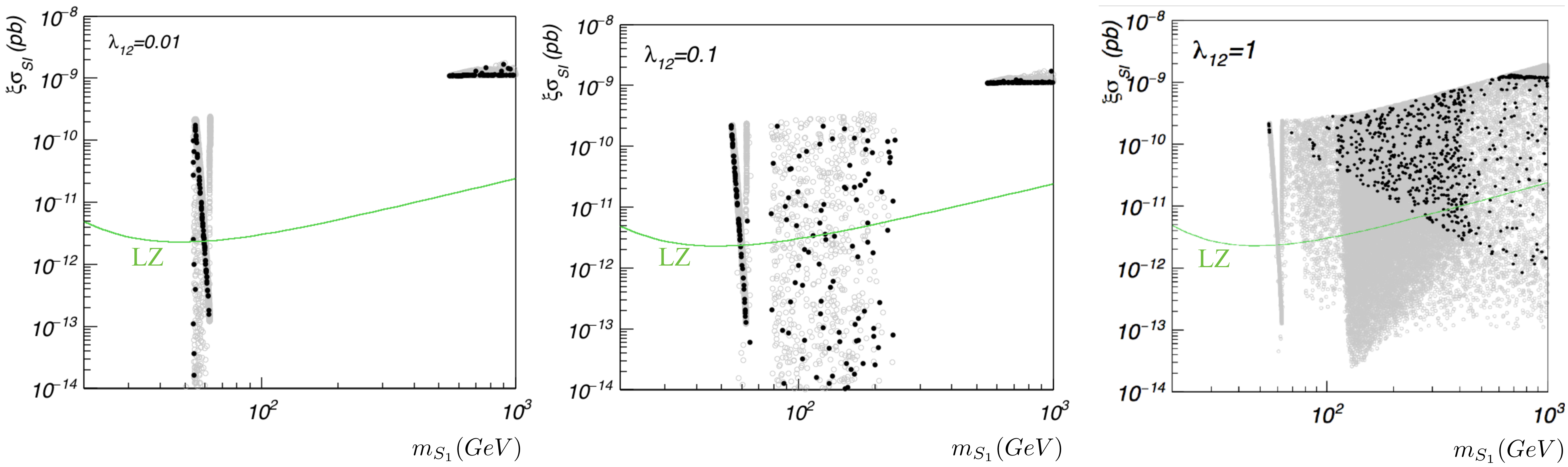

$\xi = \Omega h^2 / \Omega h^2_{obs}$

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There are points in the parameter space that avoid also future LZ constraints

Summary

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- 1 real scalar singlet Higgs portal has been almost completely explored
- Future DD and ID experiments will finish exploring the model
- A DM sector with two scalars can enlarge the allowed region in the parameter space
- If there is a positive detection in a zone where there would be more DM than the observed in the model with one scalar, could be allowed in this new model
- If the model with one scalar is completely ruled out by future DD and ID detection, the Higgs portal can live in this minimal extended version
- The model with 2 scalars is the most economical way to rescue the real singlet scalar model, which is the simplest model and renormalizable


Thanks for your attention!