



**UNIVERSITÄT
HEIDELBERG**
ZUKUNFT
SEIT 1386

Singlet-Triplet Higgs Portal Dark Matter

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Based on work with Susanne Westhoff, to appear

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Higgs portal for fermionic dark matter

$$\mathcal{L}_{int} \supset \frac{\lambda}{\Lambda} (\bar{\psi}_{DM} \psi_{DM}) (H^\dagger H)$$

Higgs portal for fermionic dark matter

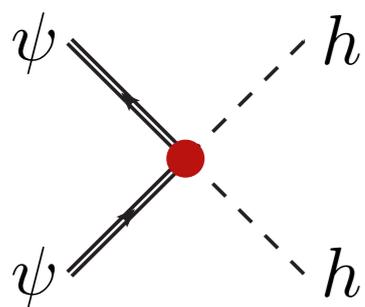
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- $H^\dagger H$ is one of two lowest-dimensional gauge-invariant operators in SM.
- Provides WIMP candidate.
- Can be tested on current colliders.

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Pure electroweak singlet, doublet, triplet.

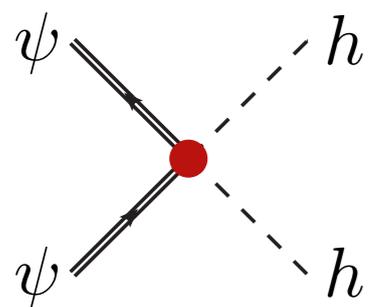
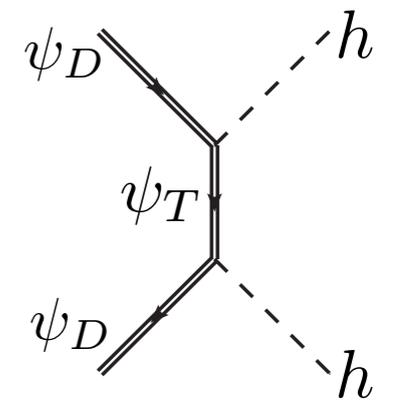
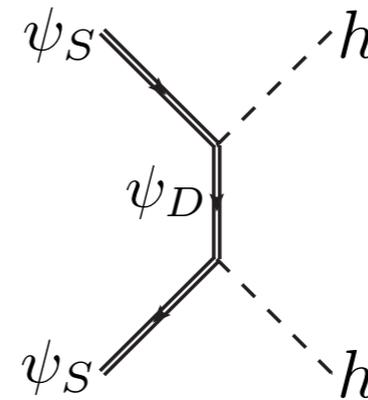
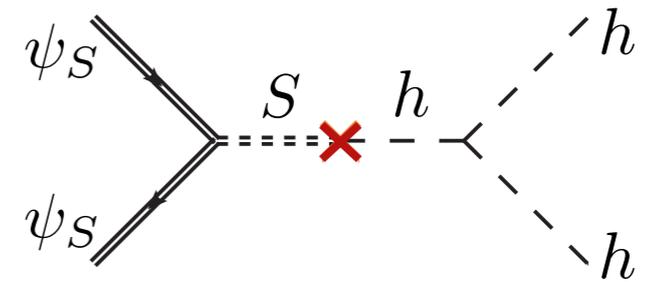
Dark matter candidate **only at Higgs threshold** or **too heavy for colliders.**

[Benival et al., 1512.06458] [Cirelli et al., 1507.05519]

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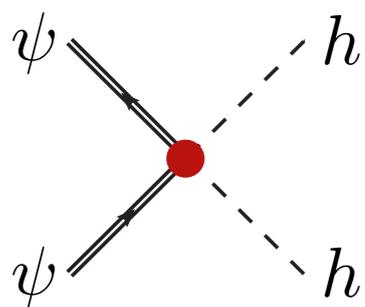
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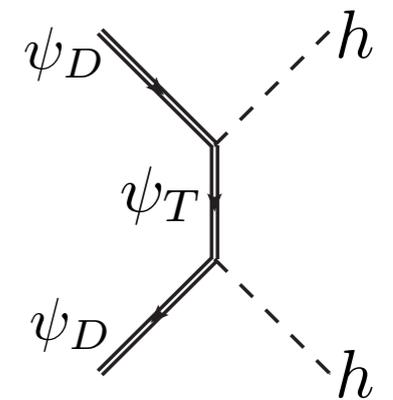
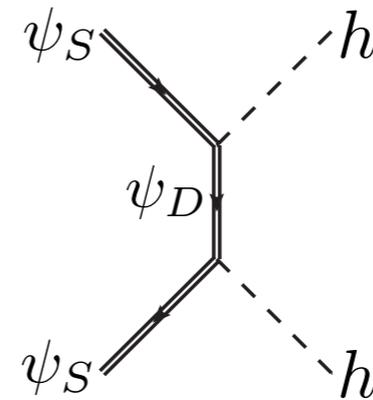
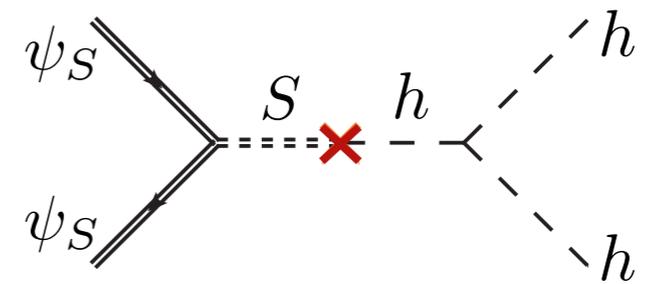
- $H^\dagger H$ is one of two lowest-dimensional gauge-invariant operators in SM.
- Provides WIMP candidate.
- Can be tested on current colliders.
- Searches for mediators.



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Minimal renormalizable extensions:
singlet-singlet, singlet-doublet,
doublet-triplet.

Tiny portal coupling: **naturalness?**

[Freitas, Westhoff, Zupan, 1506.04149]

[Lee et al., 0803.2932] [Dedes, Karamitros, 1403.7744]

[Mahbubani, Senatore, hep-ph/0510064]

Singlet-triplet scenario

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2 majorana fields: $SU(2)$ singlet ψ_S and triplet ψ_T

$$\mathcal{L}_{\text{eff}} \supset -\frac{m_T}{2} \text{Tr}(\bar{\psi}_T \psi_T) - \frac{m_S}{2} \bar{\psi}_S \psi_S + \frac{\lambda}{\Lambda} \left[(H^\dagger \bar{\psi}_T H) \psi_S + \bar{\psi}_S (H^\dagger \psi_T H) \right]$$

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Mass states are admixtures of ψ_S and ψ_T

Mixing angle:

$$\theta \simeq \frac{\mu}{m_T - m_S}$$

$$\mu = \lambda v^2 / \sqrt{2} \Lambda$$

Spectrum (tree-level structure):

$$m_T - m_S \left(\begin{array}{c} \psi_h \\ \psi_+ \\ \psi_l \end{array} \right) \frac{\mu^2}{m_T - m_S}$$

Couplings of dark fermions

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Two physical scenarios, depending on parameters of the theory:

Scalar case:

Couplings $\propto 1, \gamma_\mu$

Pseudo-scalar case:

Couplings $\propto \gamma_5, \gamma_\mu \gamma_5$

Couplings of dark fermions

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Pseudo-scalar case:

Couplings $\propto \gamma_5, \gamma_\mu \gamma_5$

Connected through
chiral rotation:

$$\psi_l \rightarrow i\gamma_5 \psi_l$$

- Changes the sign of the mass term:

$$-m_l \bar{\psi}_l \psi_l \rightarrow m_l \bar{\psi}_l \psi_l$$

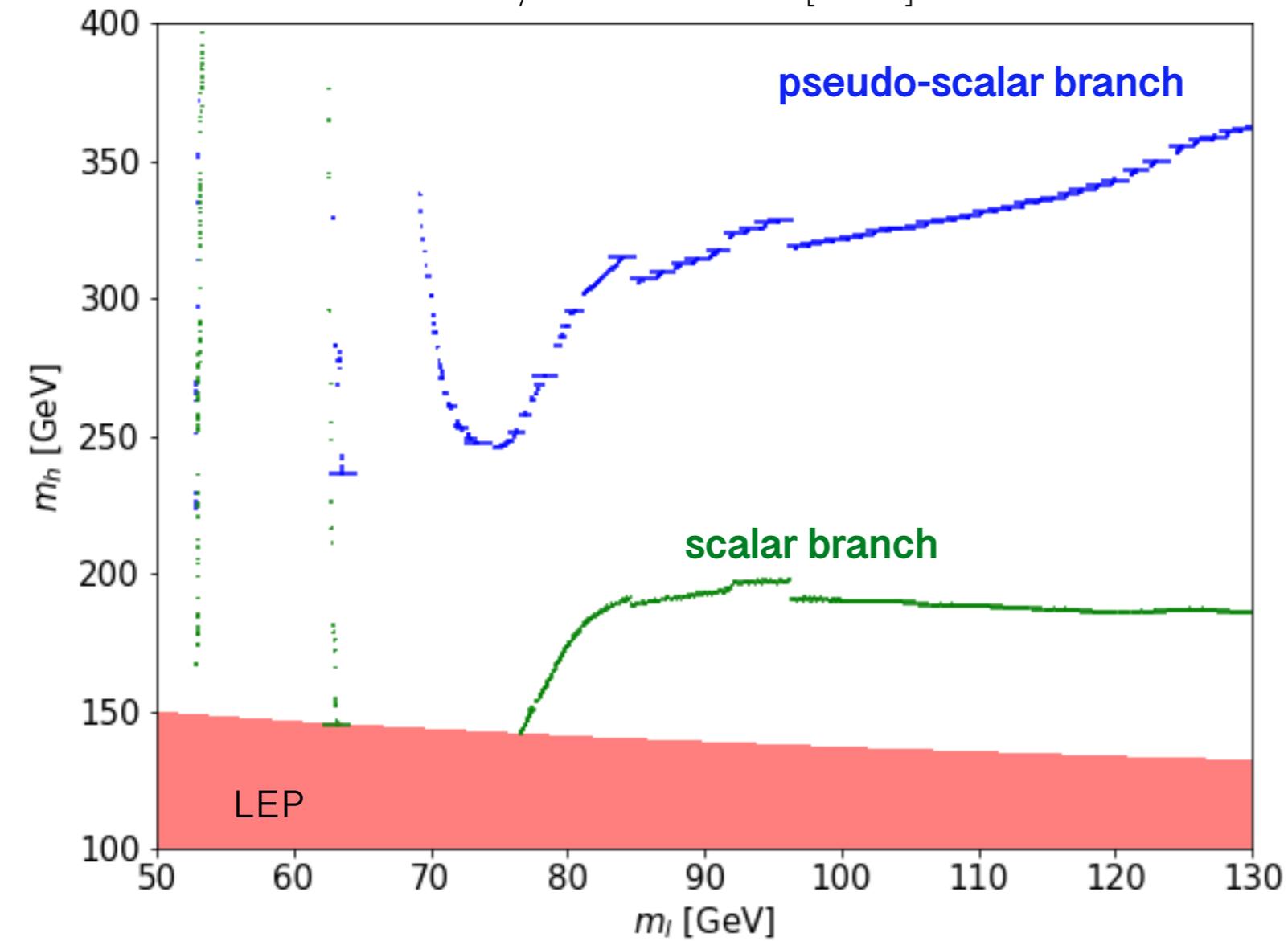
- Leads to pseudo-scalar (axial-vector) interactions:

$$\bar{\psi}_h \gamma_\mu \psi_l \rightarrow i \bar{\psi}_h \gamma_\mu \gamma_5 \psi_l$$

Relic density

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$$\lambda/\Lambda = 2 \times 10^{-3} [\text{GeV}]^{-1}$$

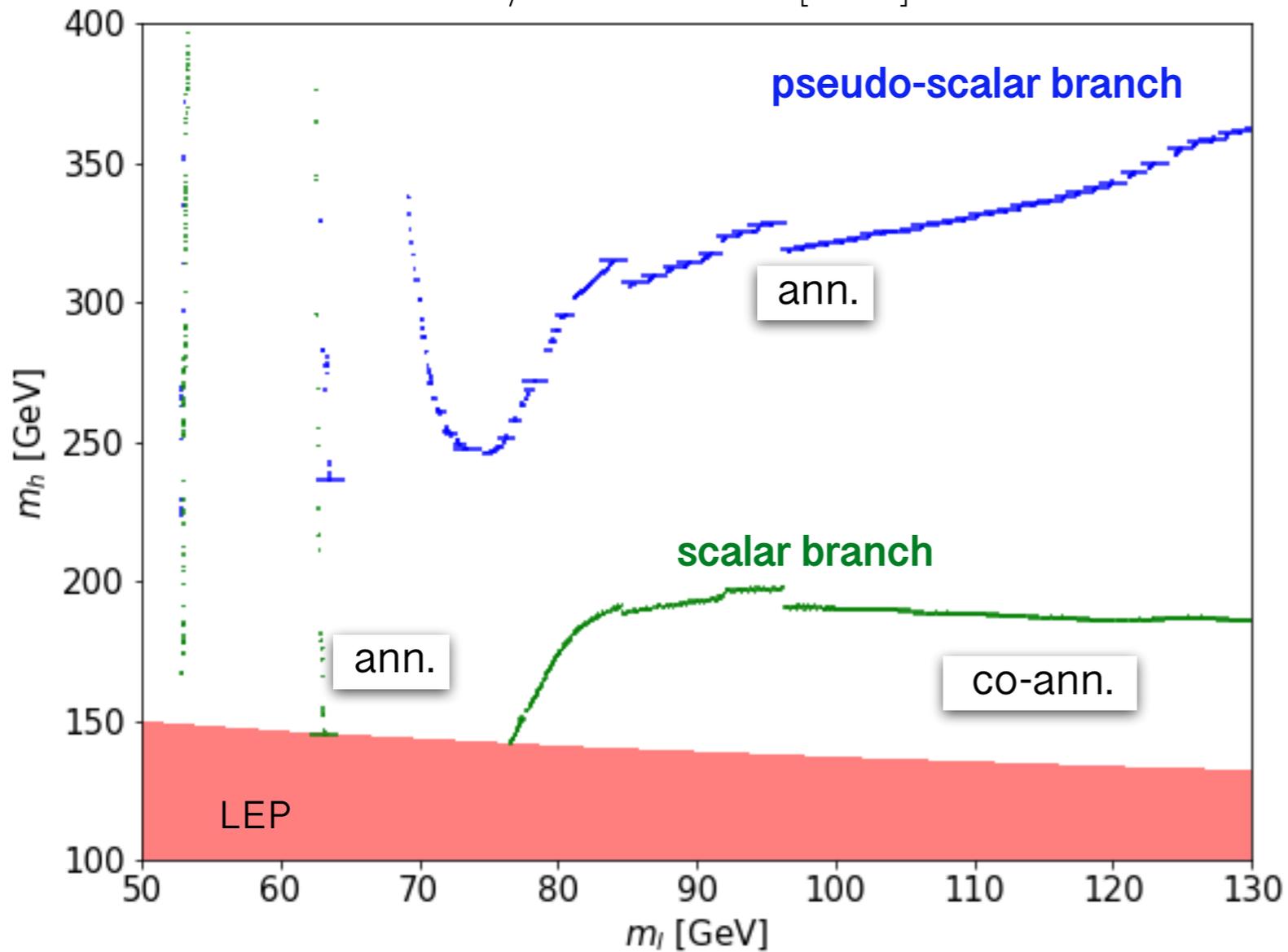


Blue/green: $\Omega_\psi h^2 = 0.1199 \pm 0.0022$

[Planck coll., 1502.01589]

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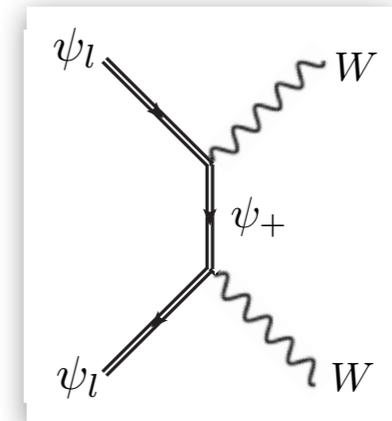
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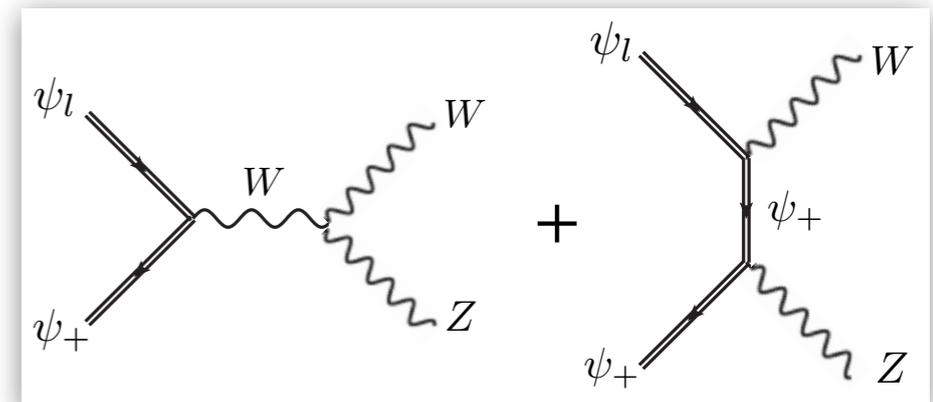
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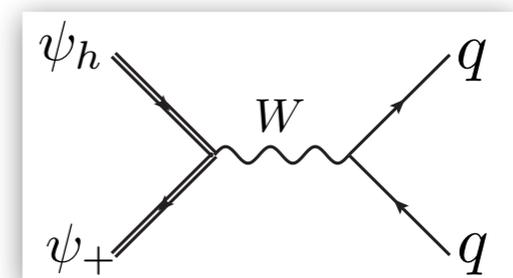
Annihilation



Co-annihilation

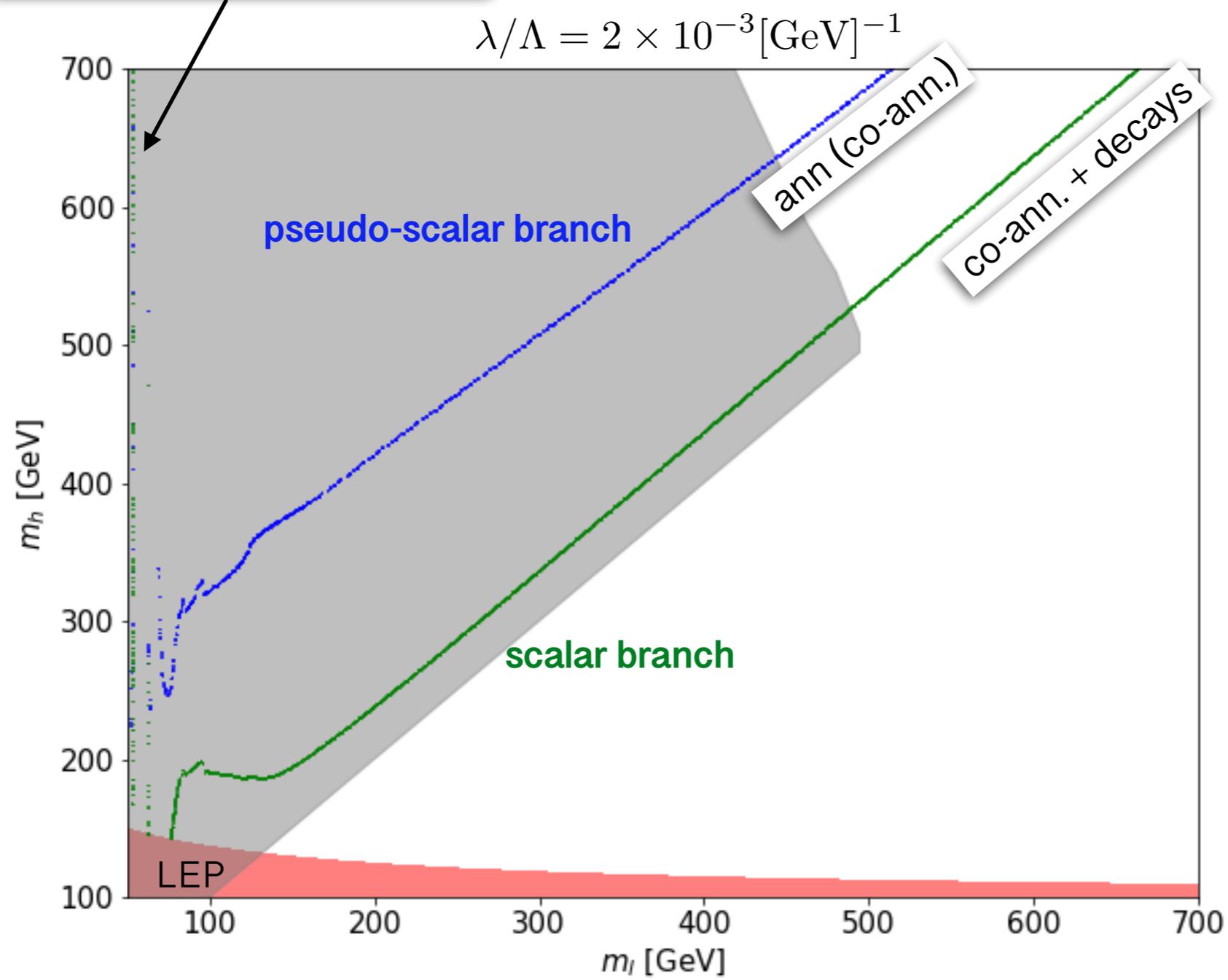


Co-annihilation
+ further decay to ψ_l



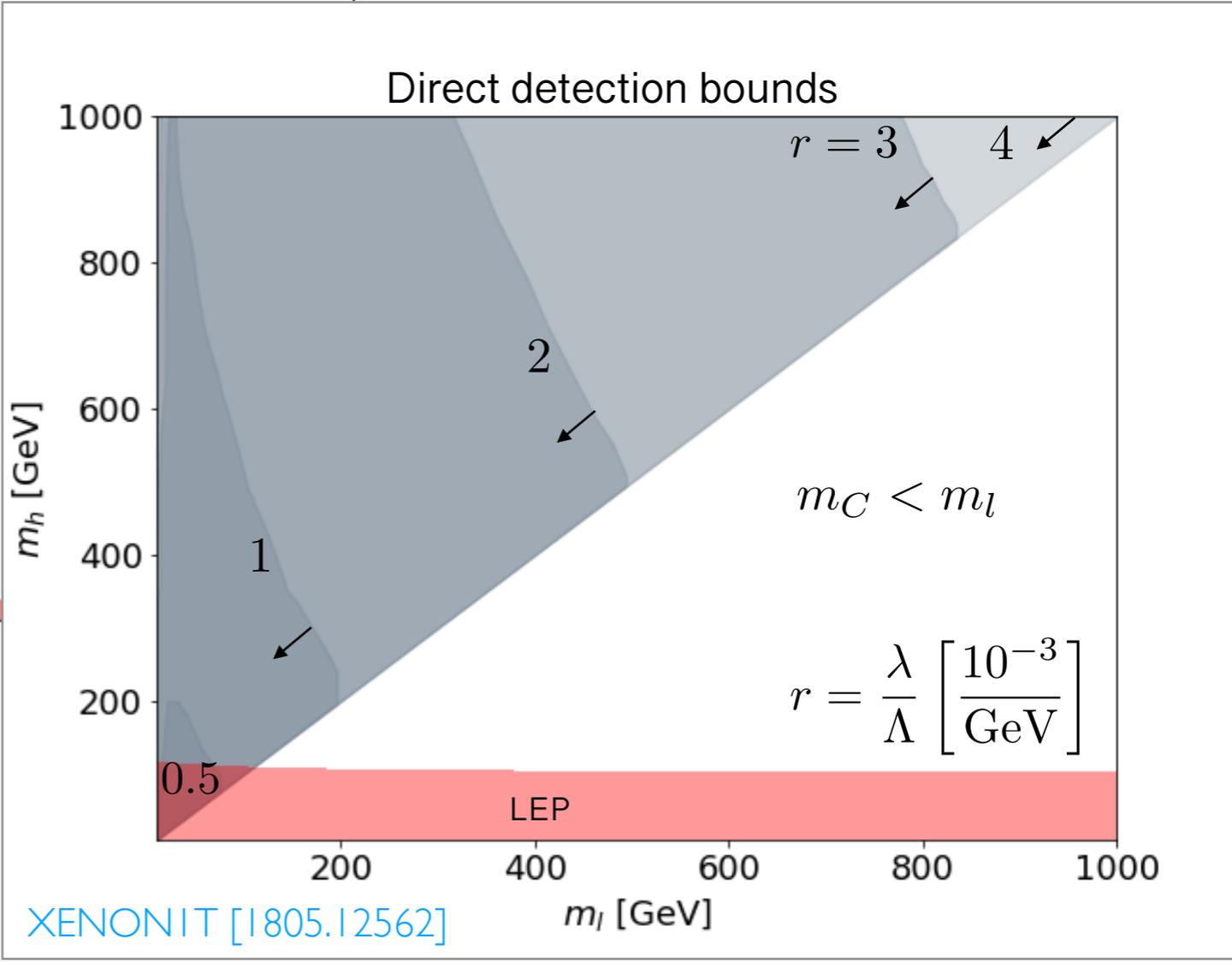
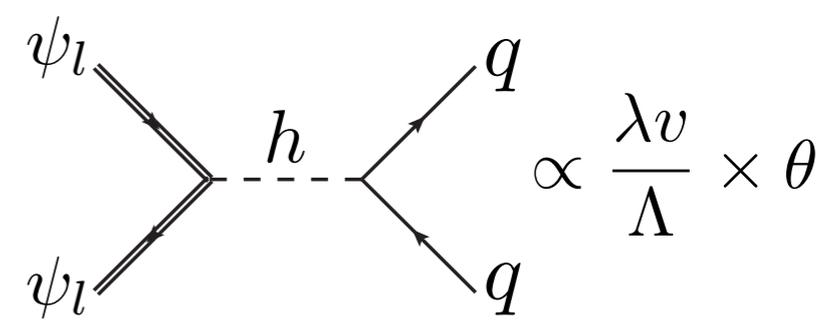
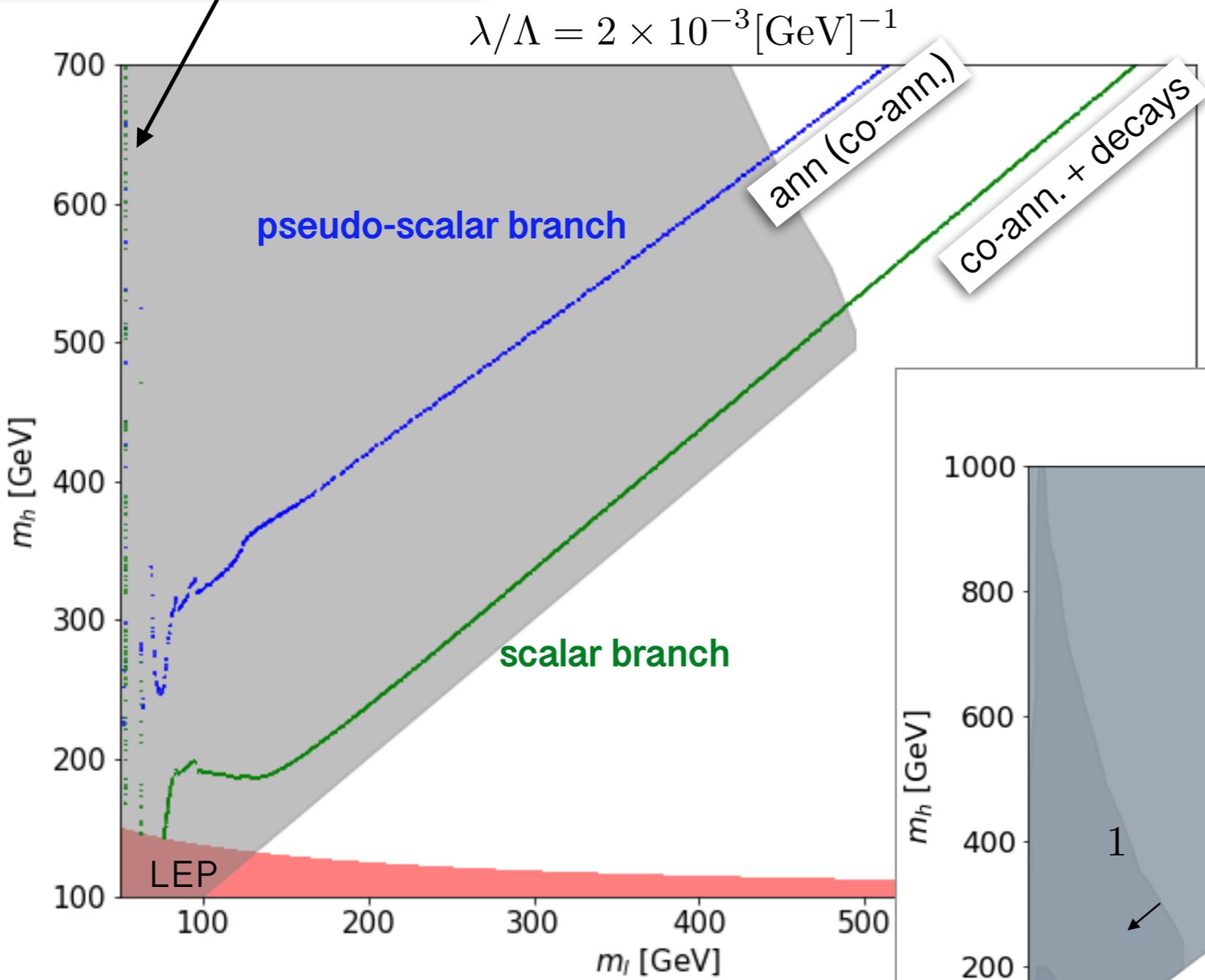
Direct detection

(ann. from higgs resonance)

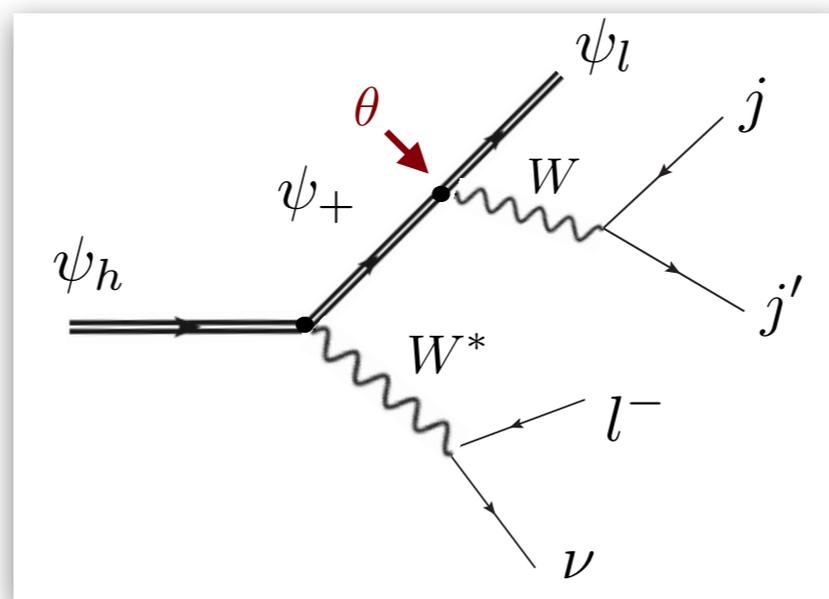
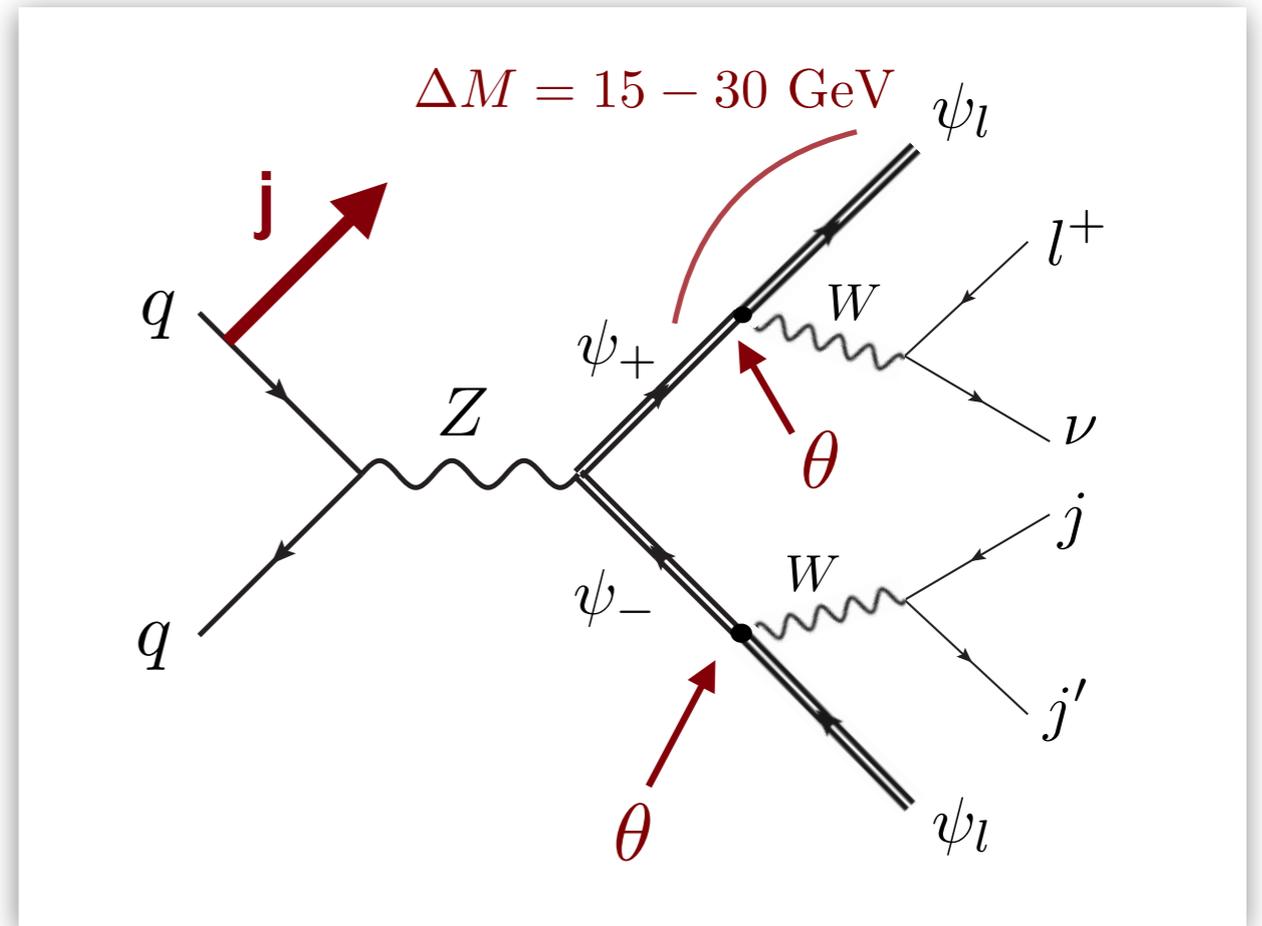
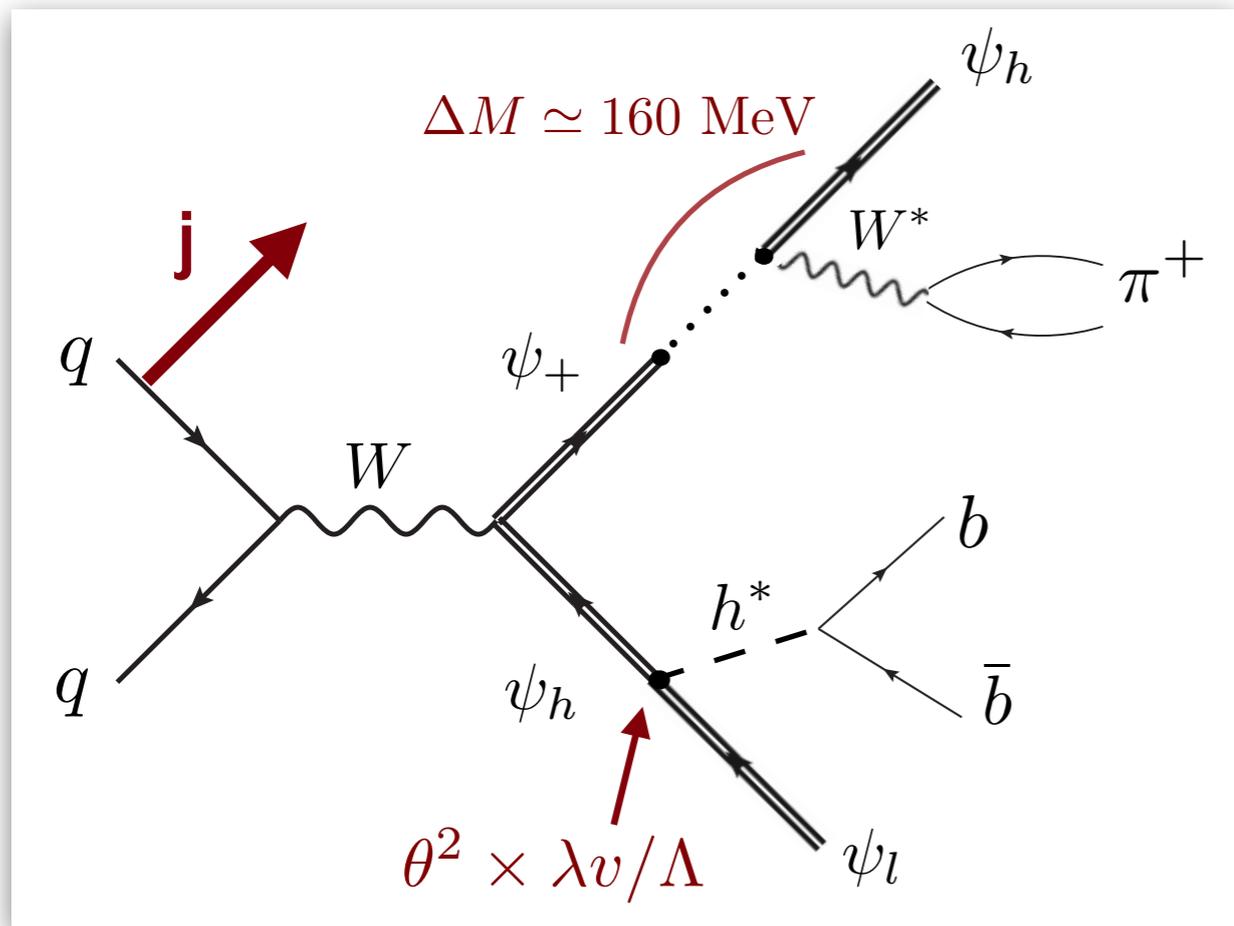


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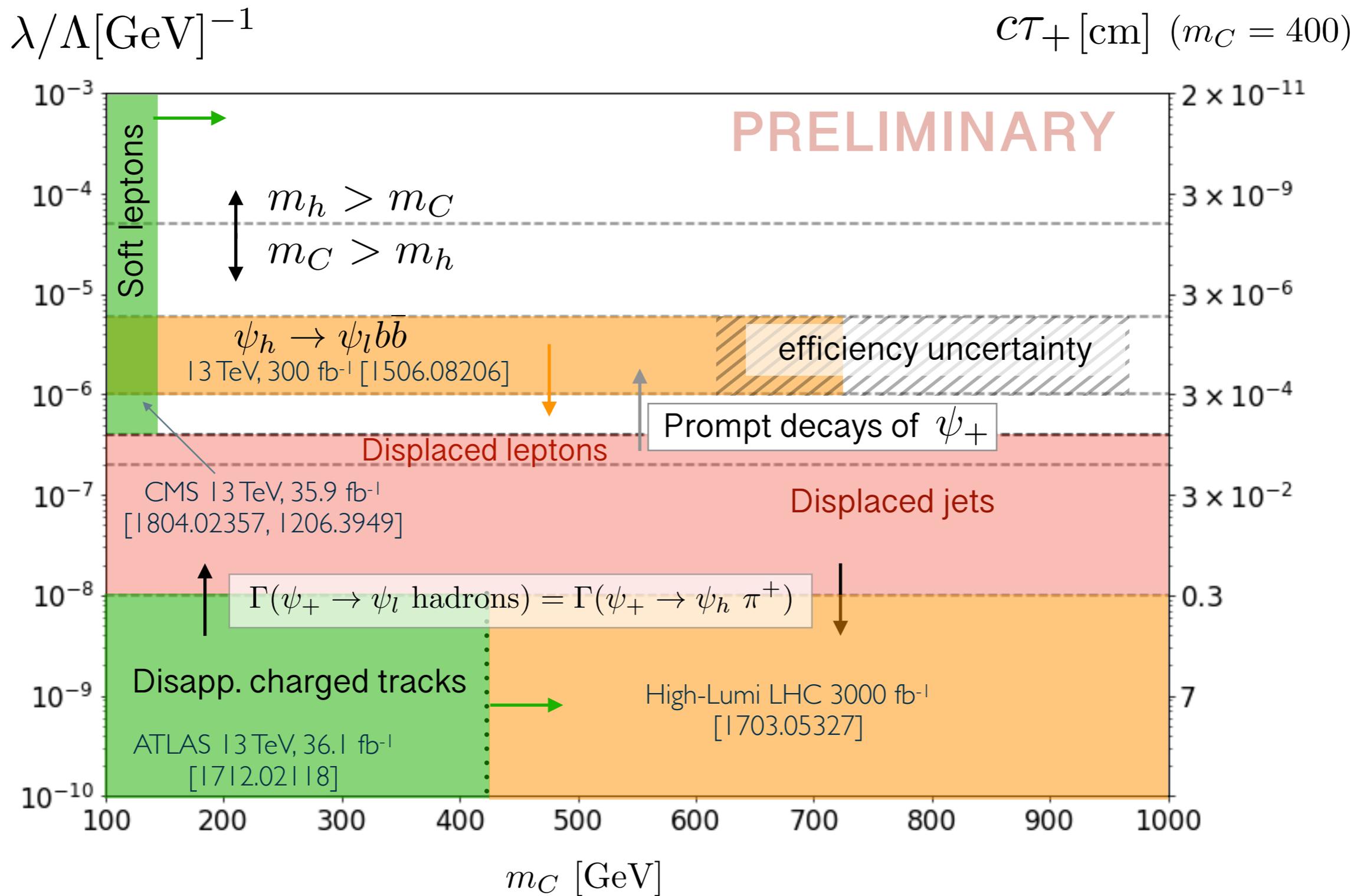
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LHC searches: long-lived states



Collider searches



Summary

- Singlet-triplet Higgs portal is a minimal fermionic extension to the SM weak sector with a naturally small coupling.
- There are two physical scenarios in this model: with scalar (vector) and pseudoscalar (axial-vector) couplings to Higgs (W bosons).
- The most promising collider signatures involve displaced particles. They probe very small portal couplings.
- New searches are needed to conclusively test this scenario: displaced jets and soft leptons, appearing tracks, etc.

Backup slides

Mixings & spectrum

$$\mathcal{L}_{\text{eff}} \supset -\frac{m_T}{2} \text{Tr}(\bar{\psi}_T \psi_T) - \frac{m_S}{2} \bar{\psi}_S \psi_S + \frac{\lambda}{\Lambda} \left[(H^\dagger \bar{\psi}_T H) \psi_S + \bar{\psi}_S (H^\dagger \psi_T H) \right]$$

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$$\left. \begin{aligned} \theta &\simeq \frac{\mu}{m_T - m_S} \\ \mu &= \lambda v^2 / \sqrt{2} \Lambda \end{aligned} \right\} \begin{pmatrix} \psi_l \\ \psi_h \end{pmatrix} = \begin{pmatrix} \sin \theta \psi_T + \cos \theta \psi_S \\ \cos \theta \psi_T - \sin \theta \psi_S \end{pmatrix}$$

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$$m_{l,h} = \frac{1}{2} \left(m_T + m_S \mp \sqrt{(m_T - m_S)^2 + 4\mu^2} \right), \quad m_C = m_T$$

Tree-level structure:

$$m_T - m_S \begin{pmatrix} \psi_h \\ \psi_+ \\ \psi_l \end{pmatrix} \frac{\mu^2}{m_T - m_S}$$

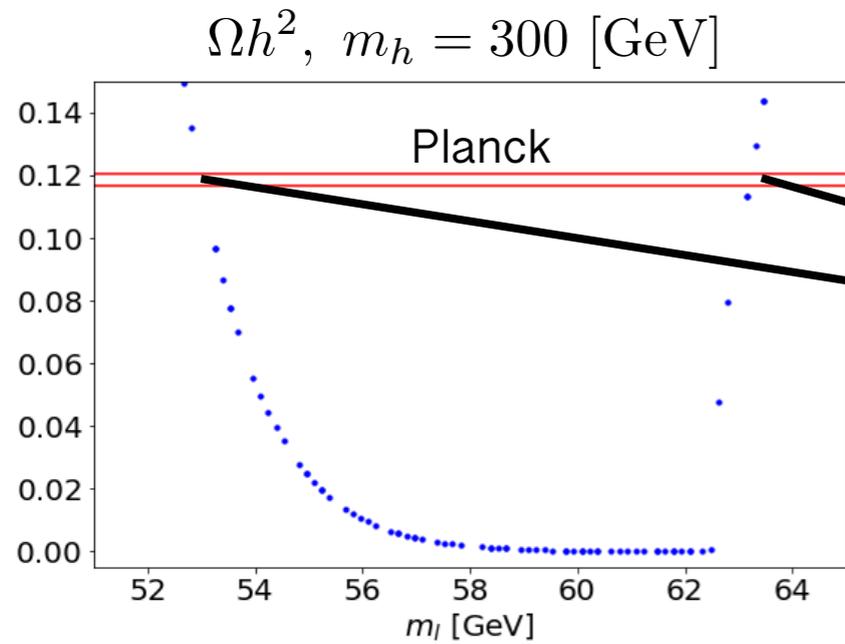
Electroweak splitting:

$$\begin{array}{c} \psi_h \\ \psi_+ \\ \dots \\ \psi_l \end{array} \quad \begin{array}{c} \uparrow \\ \text{approx.} \\ 160 \text{ MeV} \end{array}$$

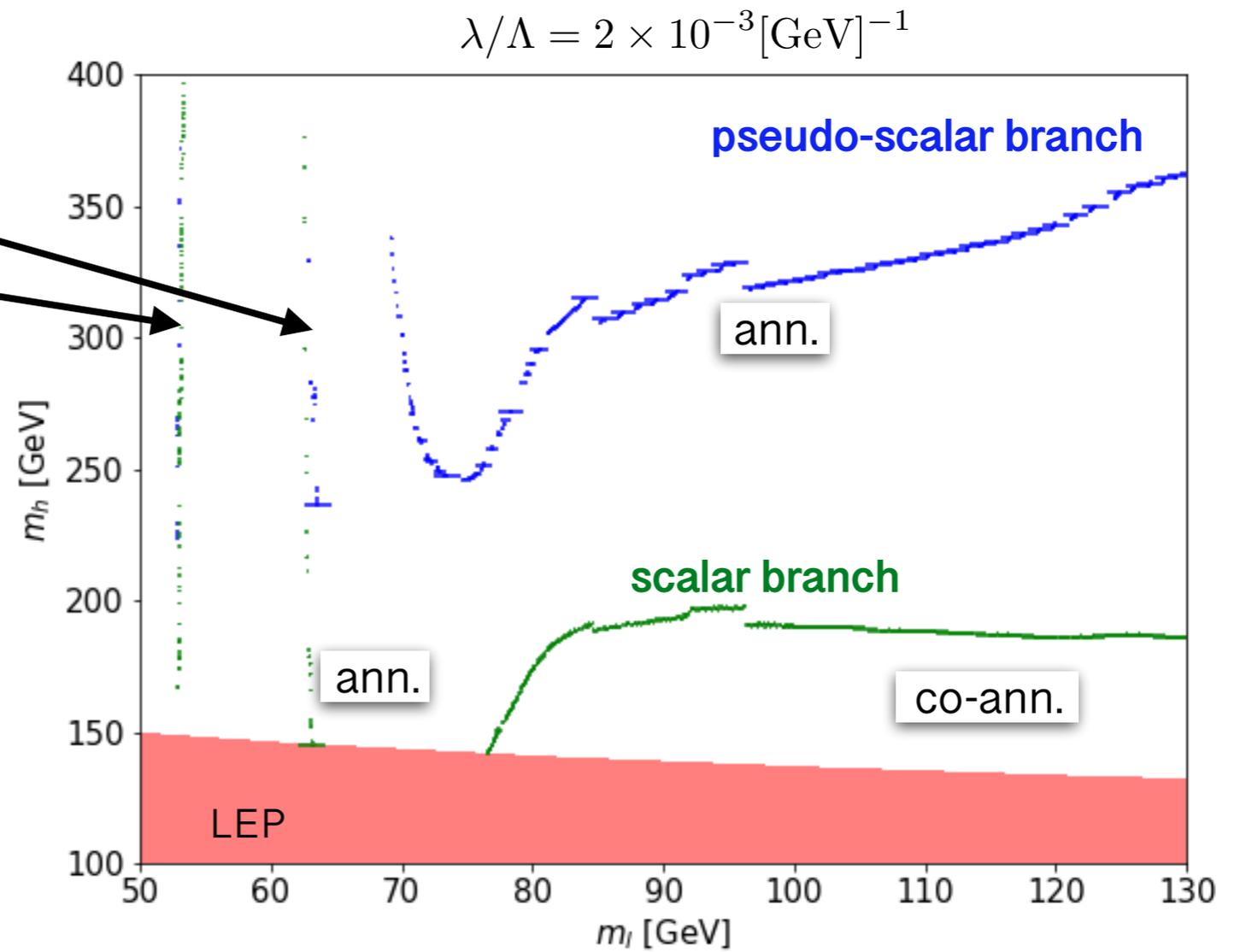
Small μ :

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