Scotogenic mechanism from a 3221 symmetry

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GENERALITAT VALENCIANA
Conselleria d'Educació, Universitats i Ocupació

The scotogenic model

From ancient greek

Σκότος : Darkness
Γένος : Kin, generation

- Take the SM and **add a Z_2 symmetry**

$$SU(3)_C \times SU(2)_L \times U(1)_Y \times Z_2$$

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$$\eta \sim (\mathbf{2}, 1/2, -) \quad N^\sigma \sim (\mathbf{1}, 0, -)$$

- The η_0 VEV is zero, so that **Z_2 is exact**

$$\langle \eta_0 \rangle = 0 \rightarrow Z_2 \text{ does not break}$$

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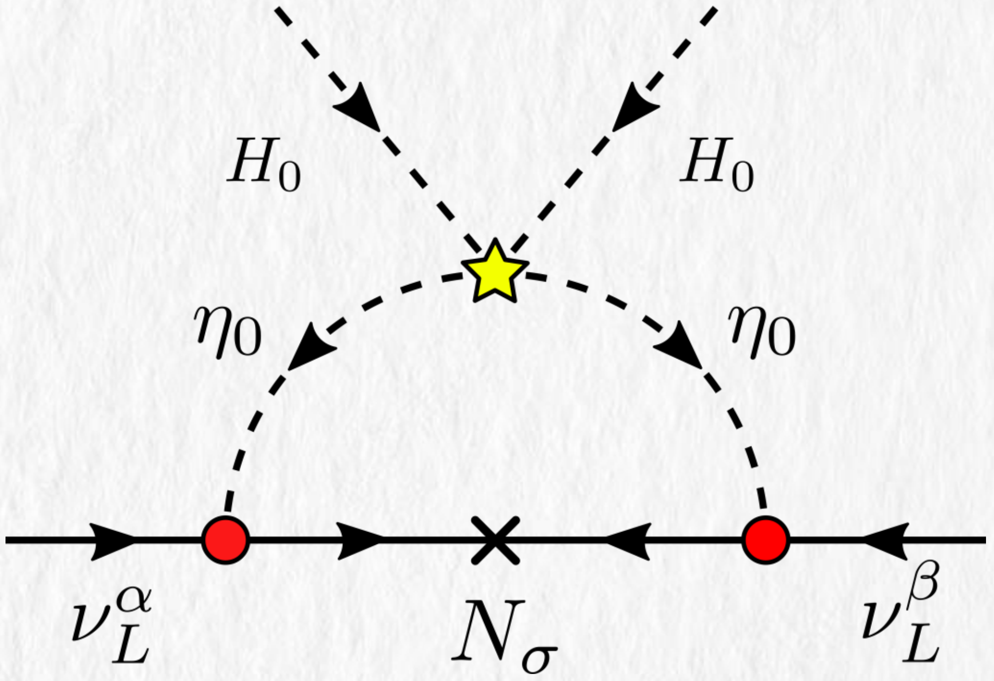

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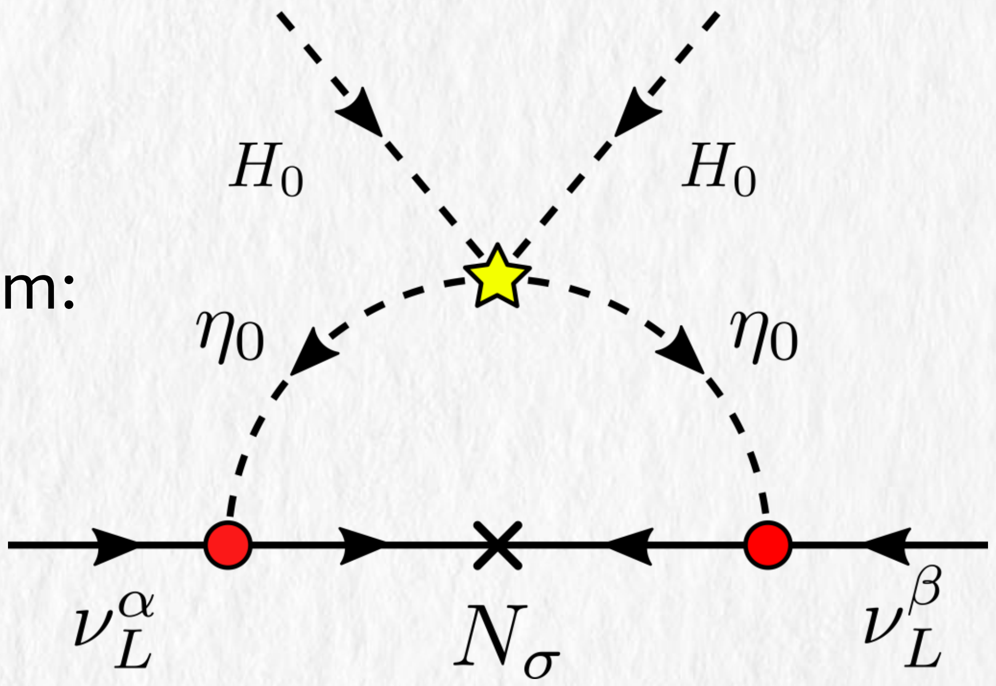
Radiative Majorana neutrino masses at 1-loop LO

Neutrino masses!

- The neutrino mass loop is generated from:



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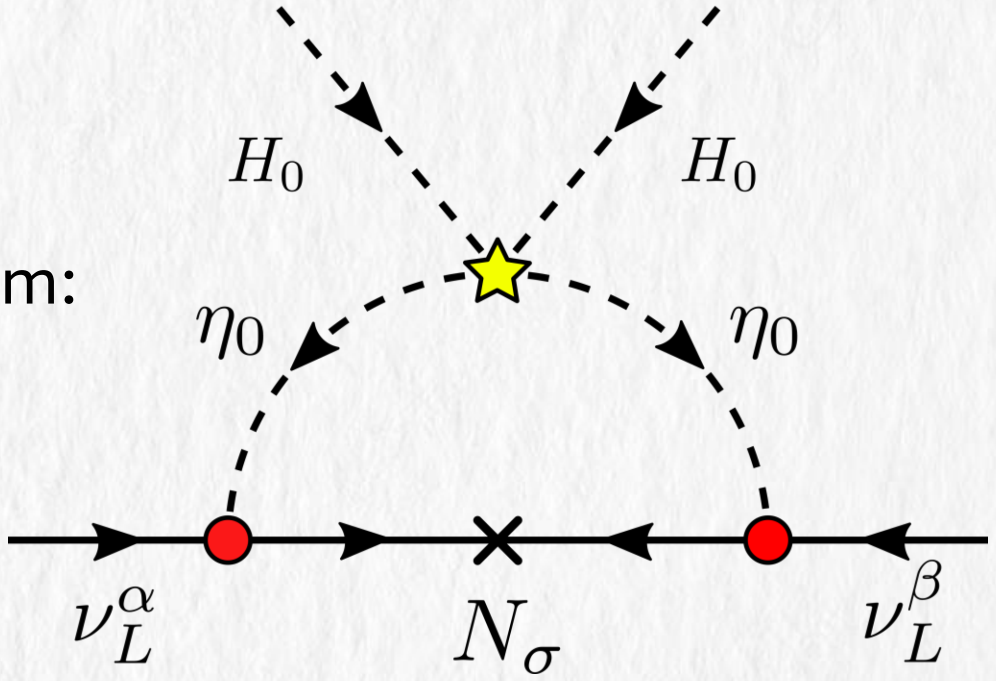
- A **Yukawa interaction**:

🔴 $Y^{\alpha\sigma}\left(\tilde{\eta}^{\dagger} L^{\alpha} \overline{N}^{\sigma}\right) + h.c.$



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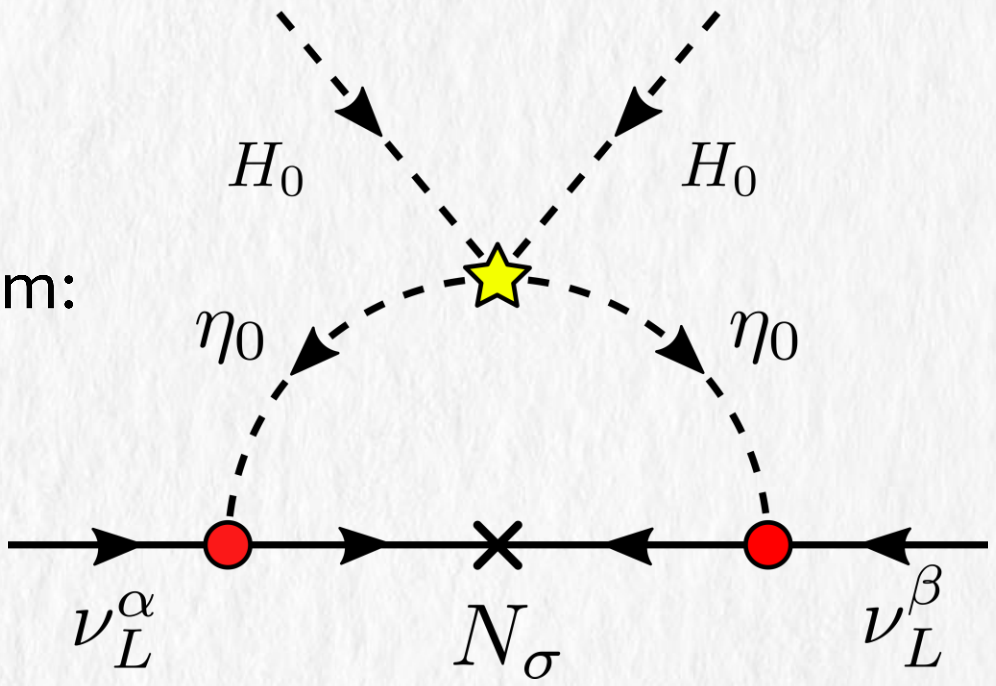

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⭐ $$\frac{1}{2}\lambda_5\left[\left(H^\dagger \eta\right)^2 + h.c.\right]$$

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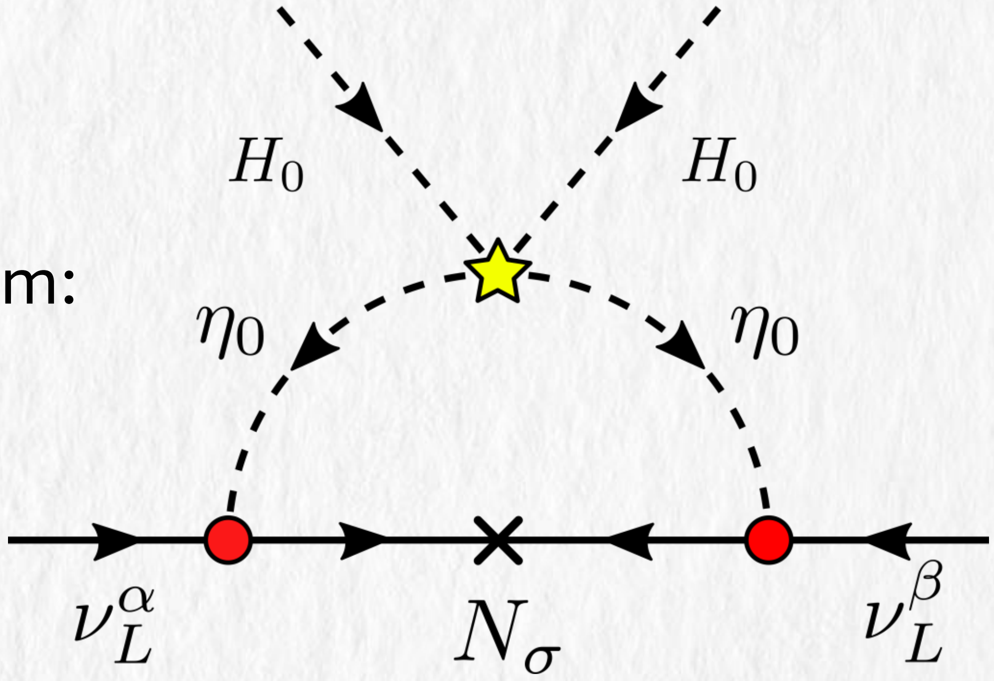

$$m_\nu^{\alpha\beta} \propto \frac{\lambda_5\, v^2\, Y^2}{16\pi^2 M}$$

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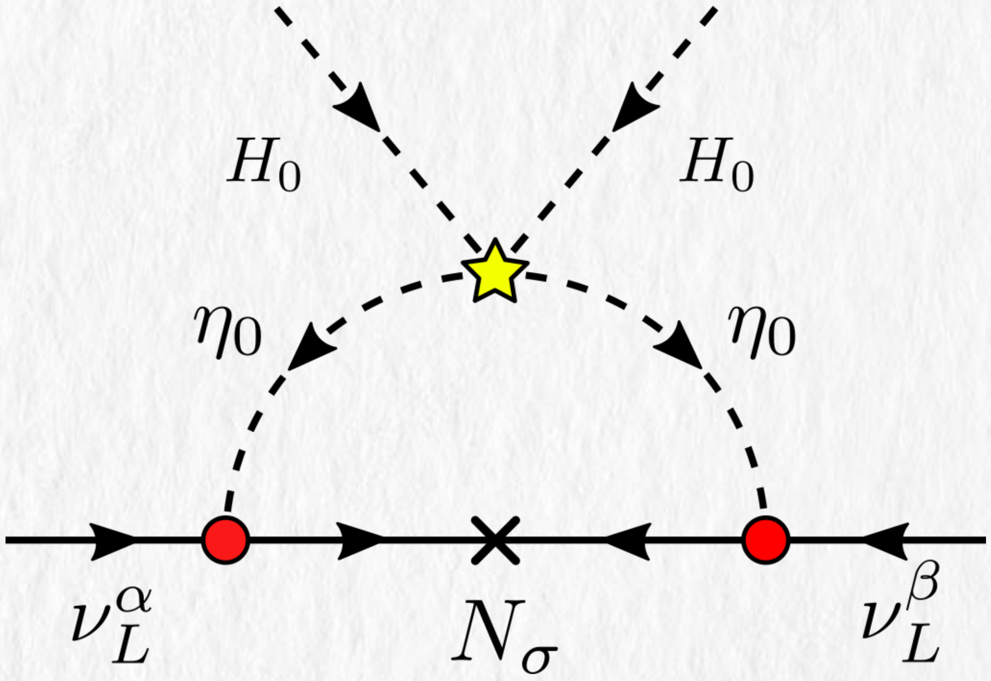
- We can get **neutrino masses ~ eV** with **loop masses M ~ 1 TeV** if:

$$\lambda_5 \, Y^2 \sim 10^{-8}$$



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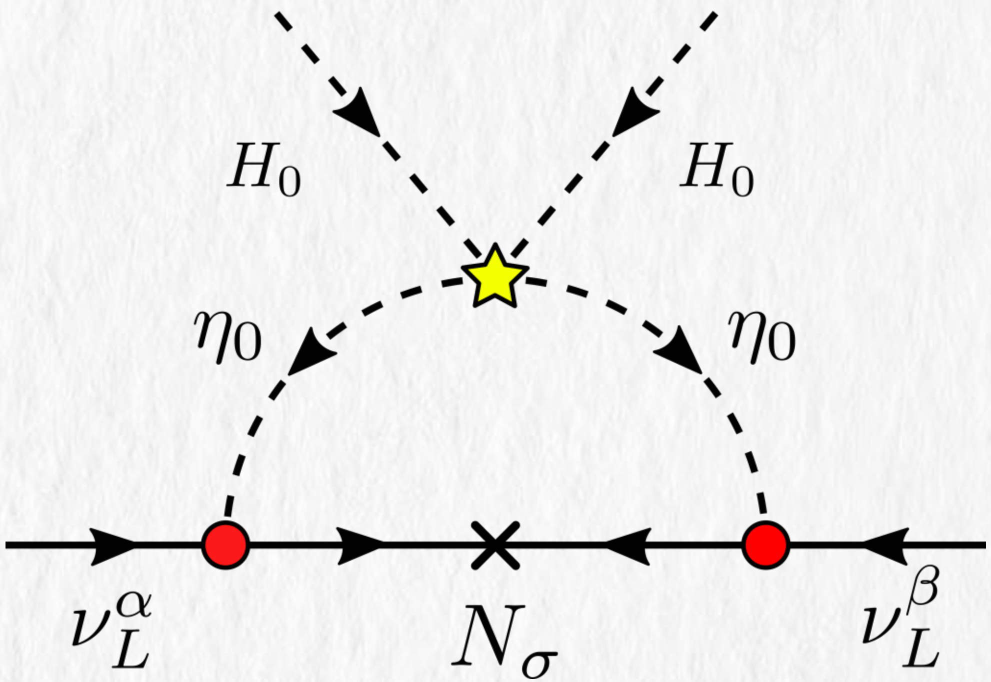

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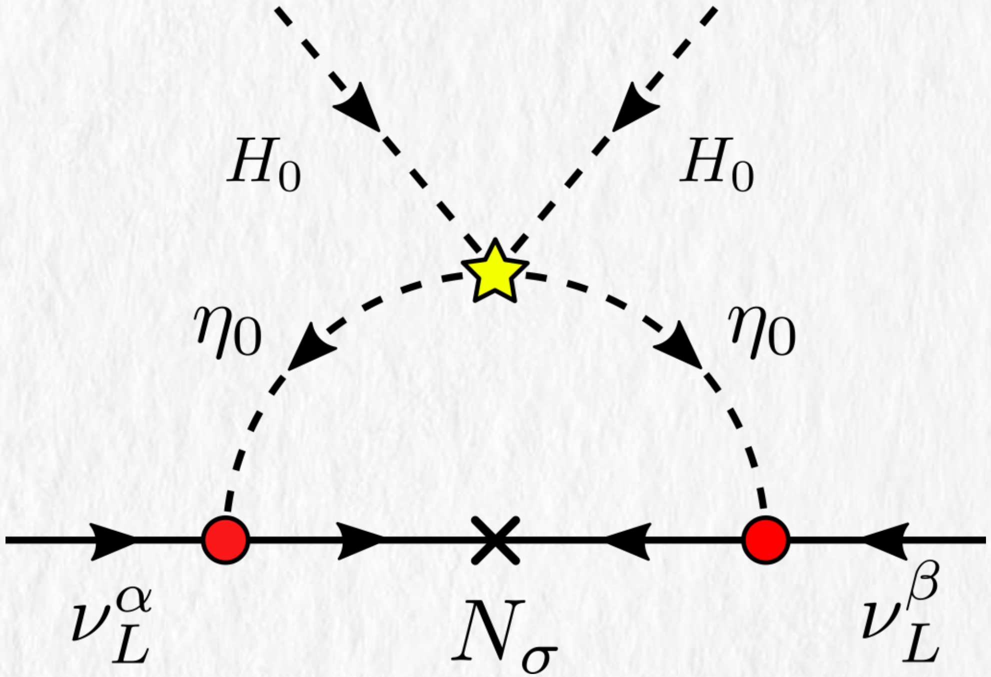
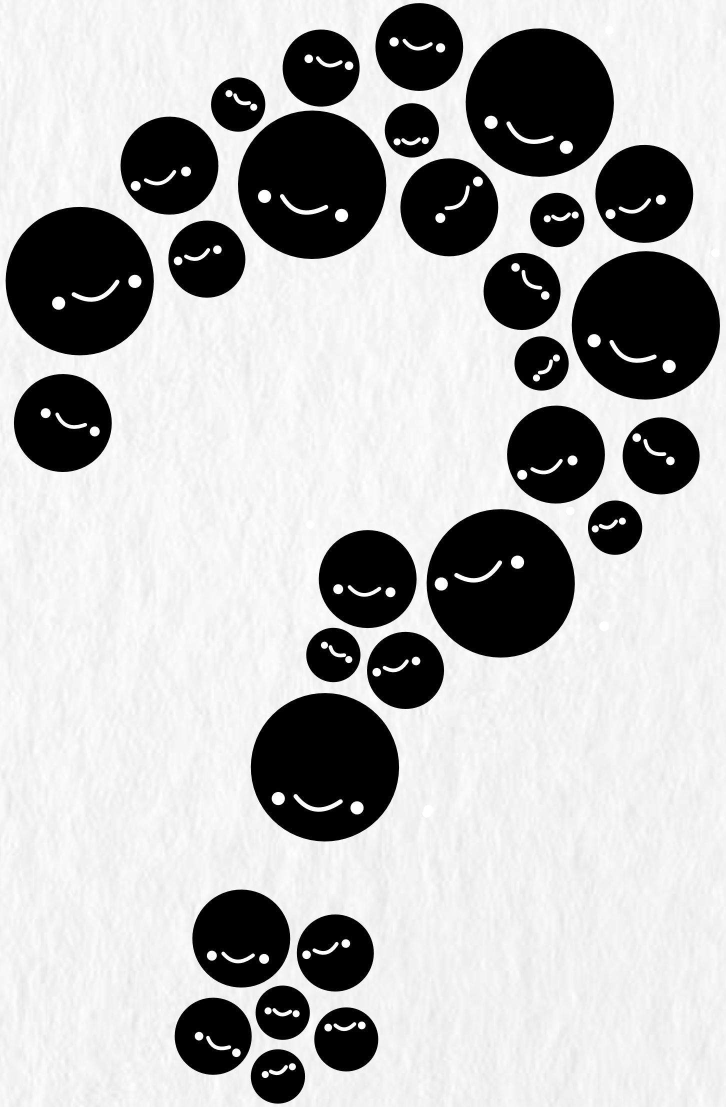
☆ But why's λ_5 small?



$$m_\nu^{\alpha\beta} \propto \boxed{\frac{\lambda_5 \, v^2 \, Y^2}{16\pi^2 M}}$$

There is always a bigger fish

- We want to build a SM extension that includes the **Scotogenic at low energies**…



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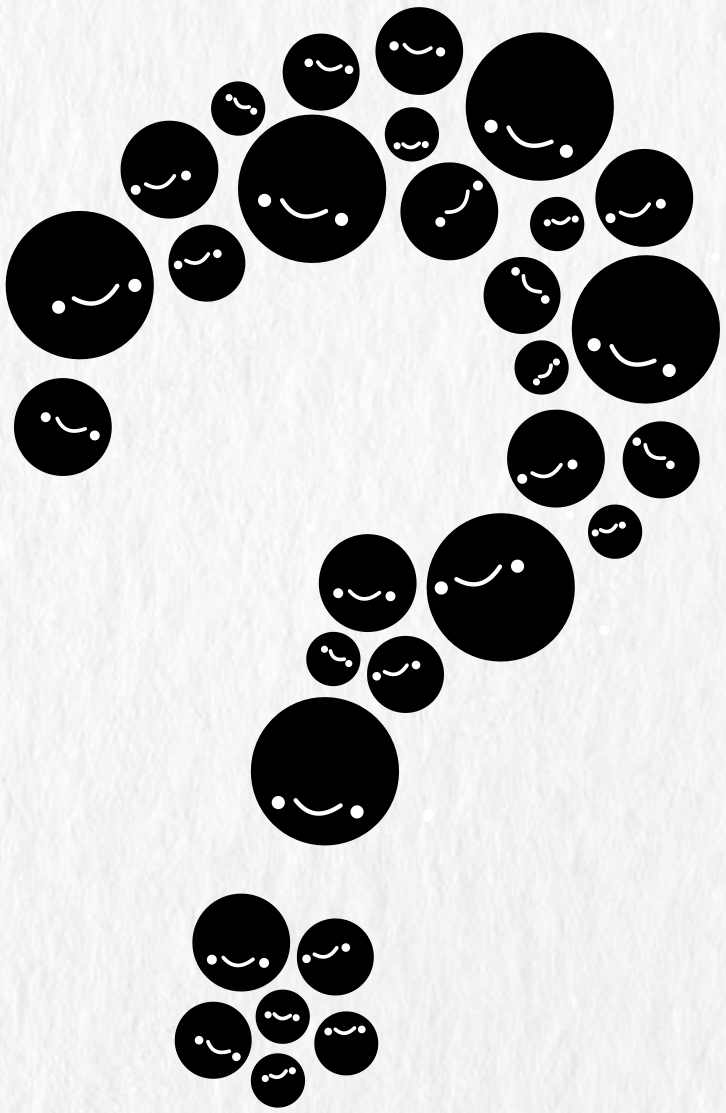
- ... with the added benefit of generating **λ_5's smallness naturally**



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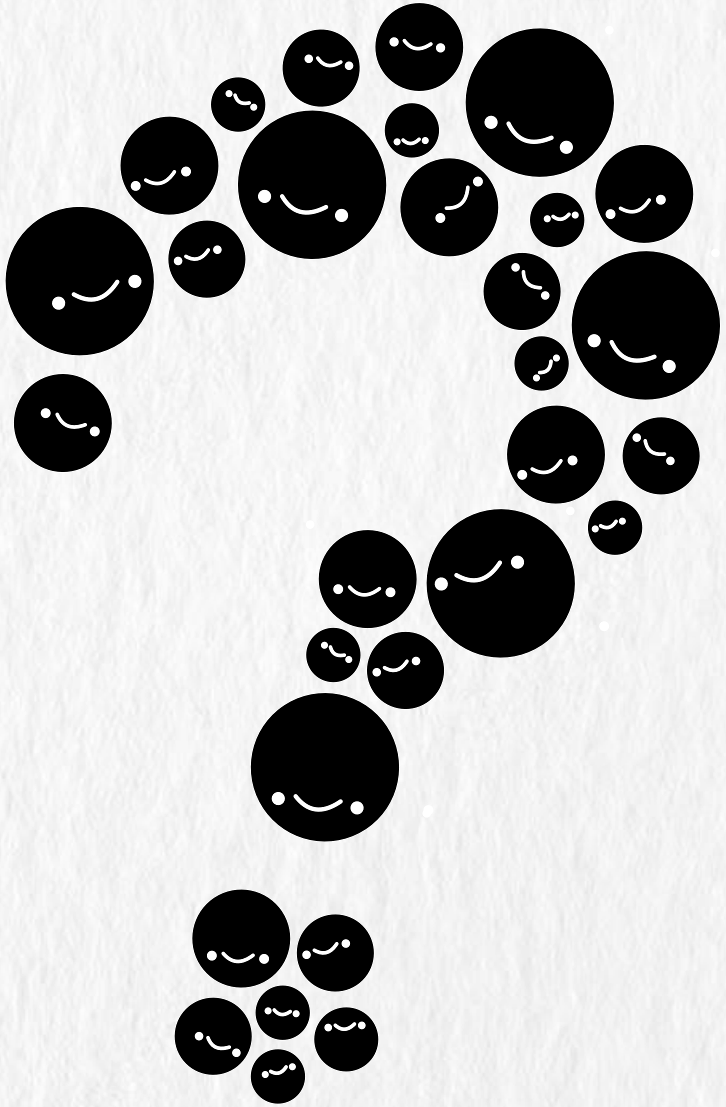
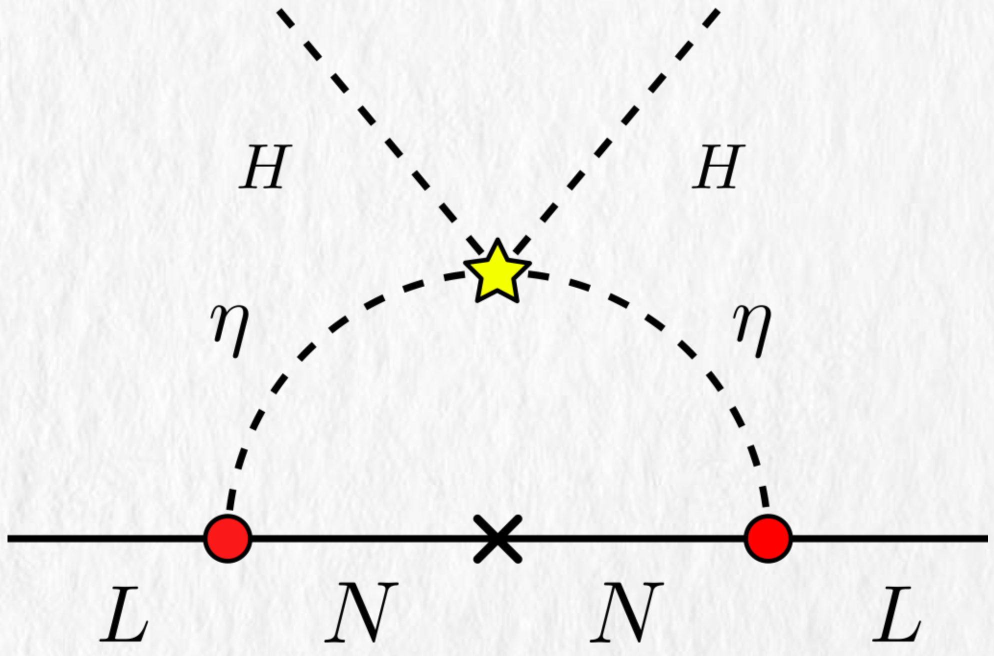
- ... with the added benefit of generating **λ_5's smallness naturally**

- We will also **generate Z_2 as an accidental symmetry**



How to model build

$SU(3)_C \times SU(2)_1 \times SU(2)_2 \times U(1)_Y$

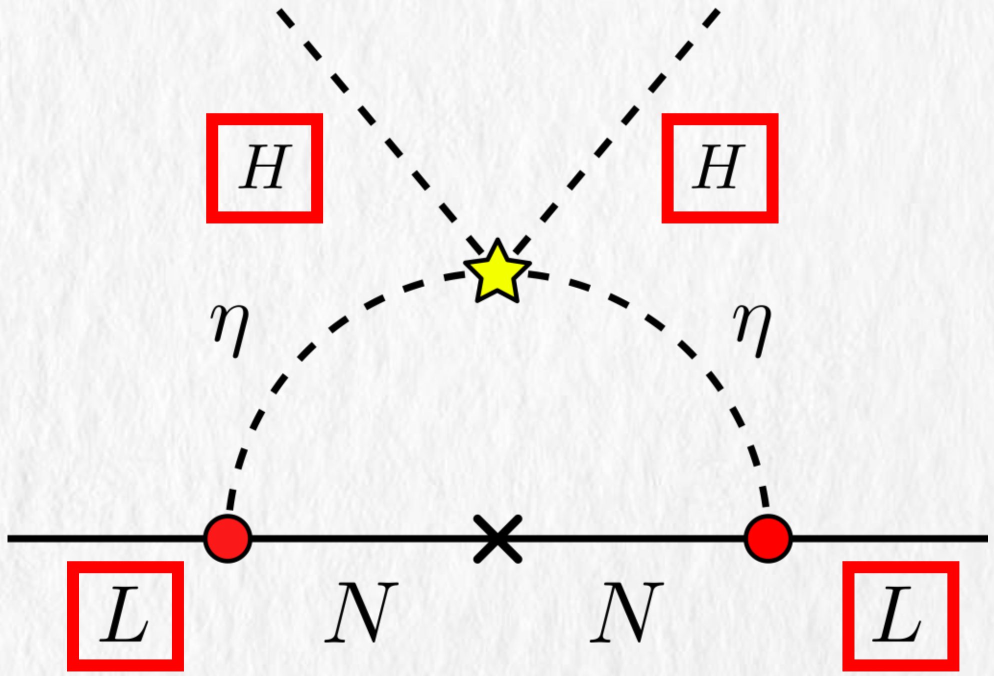


How to model build

The usual SM representations

$$SU(3)_C \times SU(2)_1 \times SU(2)_2 \times U(1)_Y$$

L	$\mathbf{1}$	$\mathbf{2}$	$\mathbf{1}$	$-1/2$
H	$\mathbf{1}$	$\mathbf{2}$	$\mathbf{1}$	$+1/2$

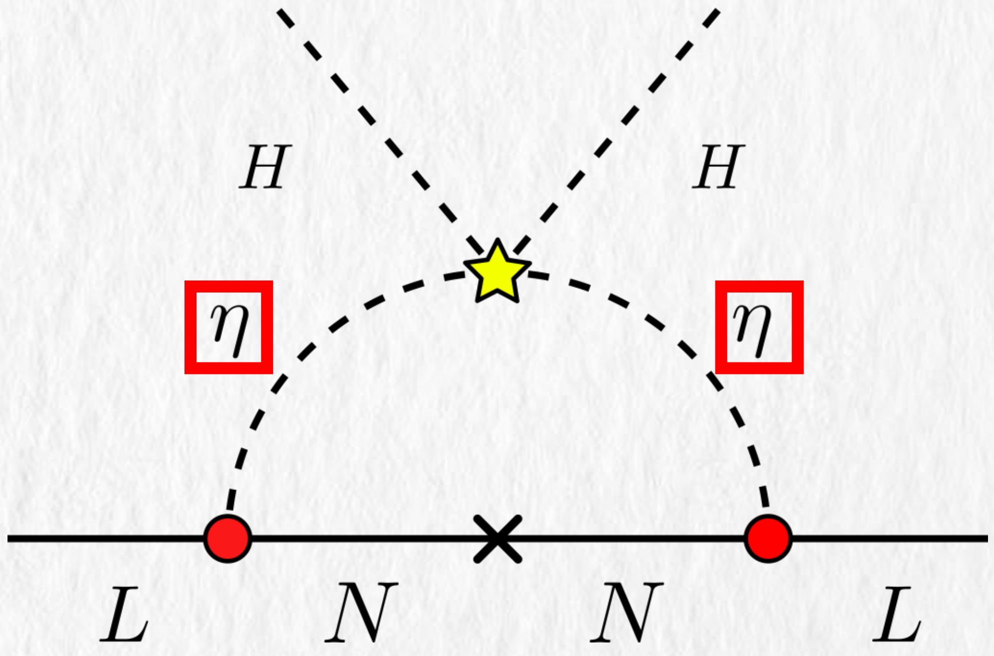


How to model build

The scotogenic scalar doublet

$$SU(3)_C \times SU(2)_1 \times SU(2)_2 \times U(1)_Y$$

L	$\mathbf{1}$	$\mathbf{2}$	$\mathbf{1}$	$-1/2$
H	$\mathbf{1}$	$\mathbf{2}$	$\mathbf{1}$	$+1/2$
η	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{2}$	$+1/2$



How to model build

This vertex is now messed up

$$SU(3)_C \times SU(2)_1 \times SU(2)_2 \times U(1)_Y$$

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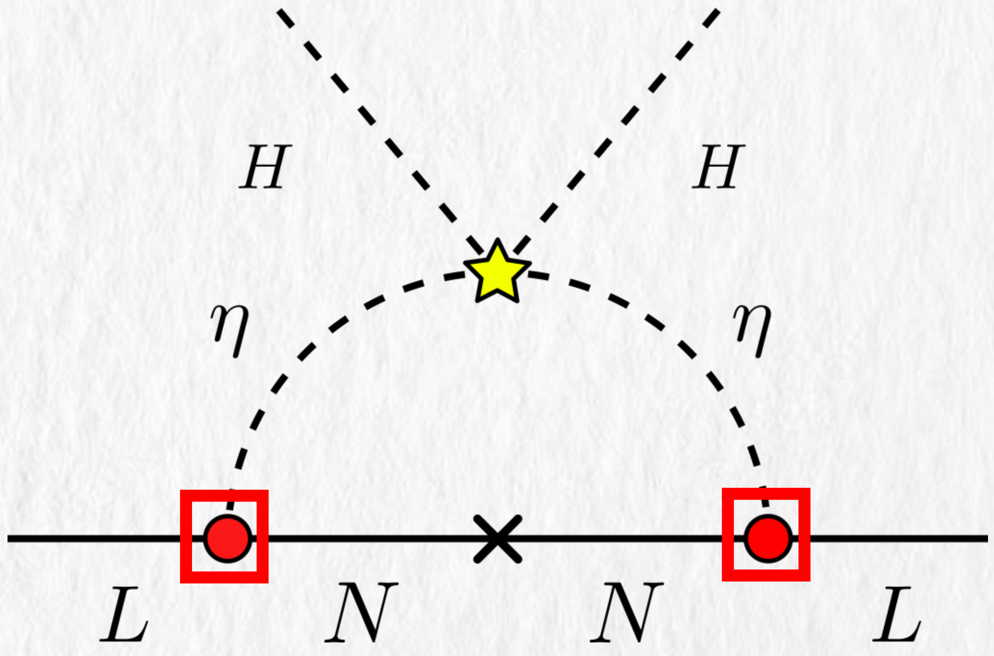


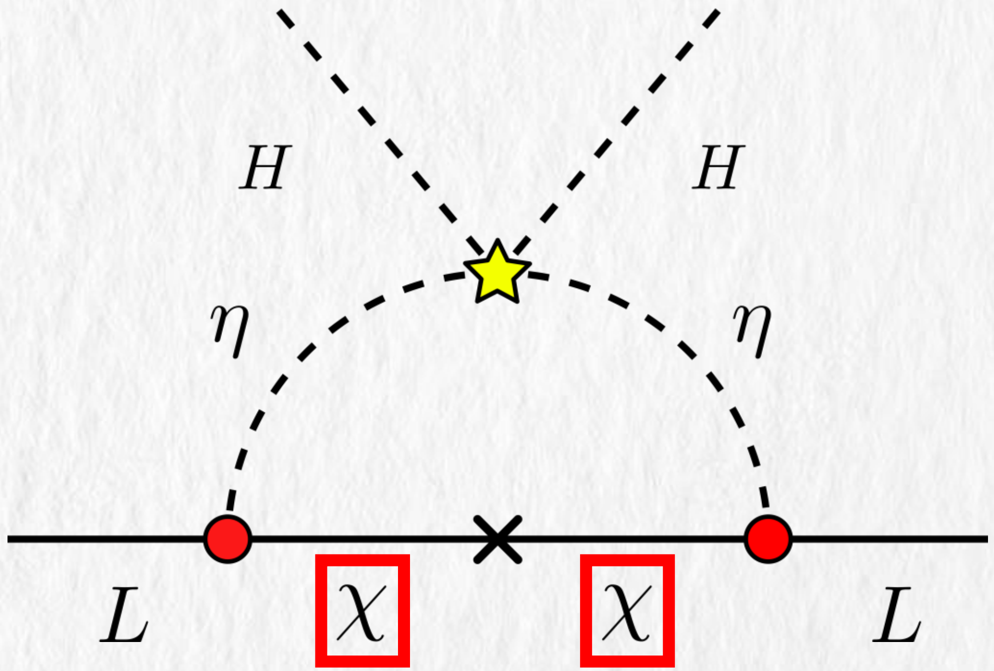
$$(\mathbf{2},\mathbf{1}) \times (\mathbf{1},\mathbf{2}) \times (\mathbf{1},\mathbf{1}) \not\supset (\mathbf{1},\mathbf{1})$$

How to model build

Change the singlet for a bidoublet

$$SU(3)_C \times SU(2)_1 \times SU(2)_2 \times U(1)_Y$$

L	$\mathbf{1}$	$\mathbf{2}$	$\mathbf{1}$	$-1/2$
H	$\mathbf{1}$	$\mathbf{2}$	$\mathbf{1}$	$+1/2$
η	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{2}$	$+1/2$
χ	$\mathbf{1}$	$\mathbf{2}$	$\overline{\mathbf{2}}$	0

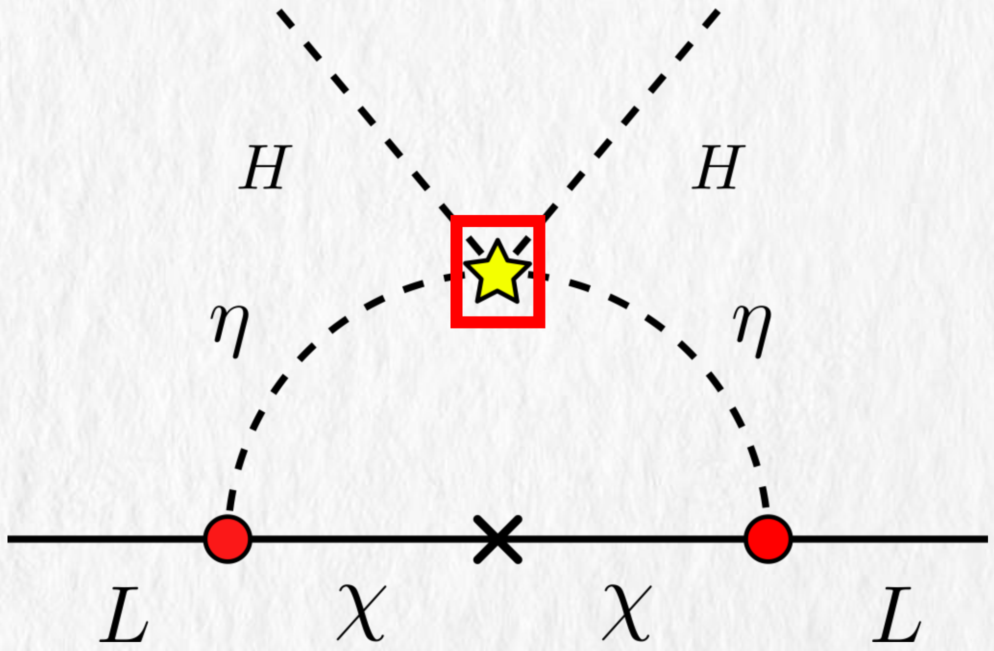


$$(\mathbf{2},\mathbf{1}) \times (\mathbf{1},\mathbf{2}) \times (\mathbf{2},\mathbf{2}) \supset (\mathbf{1},\mathbf{1})$$

How to model build

This vertex is messed up too

	$SU(3)_C$	$\times\, SU(2)_1$	$\times\, SU(2)_2$	$\times\, U(1)_Y$
L	$\mathbf{1}$	$\mathbf{2}$	$\mathbf{1}$	$-1/2$
H	$\mathbf{1}$	$\mathbf{2}$	$\mathbf{1}$	$+1/2$
η	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{2}$	$+1/2$
χ	$\mathbf{1}$	$\mathbf{2}$	$\overline{\mathbf{2}}$	0



$$(\mathbf{2},\mathbf{1})^2 \times (\mathbf{1},\mathbf{2})^2 \not\supset (\mathbf{1},\mathbf{1})$$

How to model build

Just add a scalar triplet, all good

	$SU(3)_C$	$\times SU(2)_1$	$\times SU(2)_2$	$\times U(1)_Y$
L	$\mathbf{1}$	$\mathbf{2}$	$\mathbf{1}$	$-1/2$
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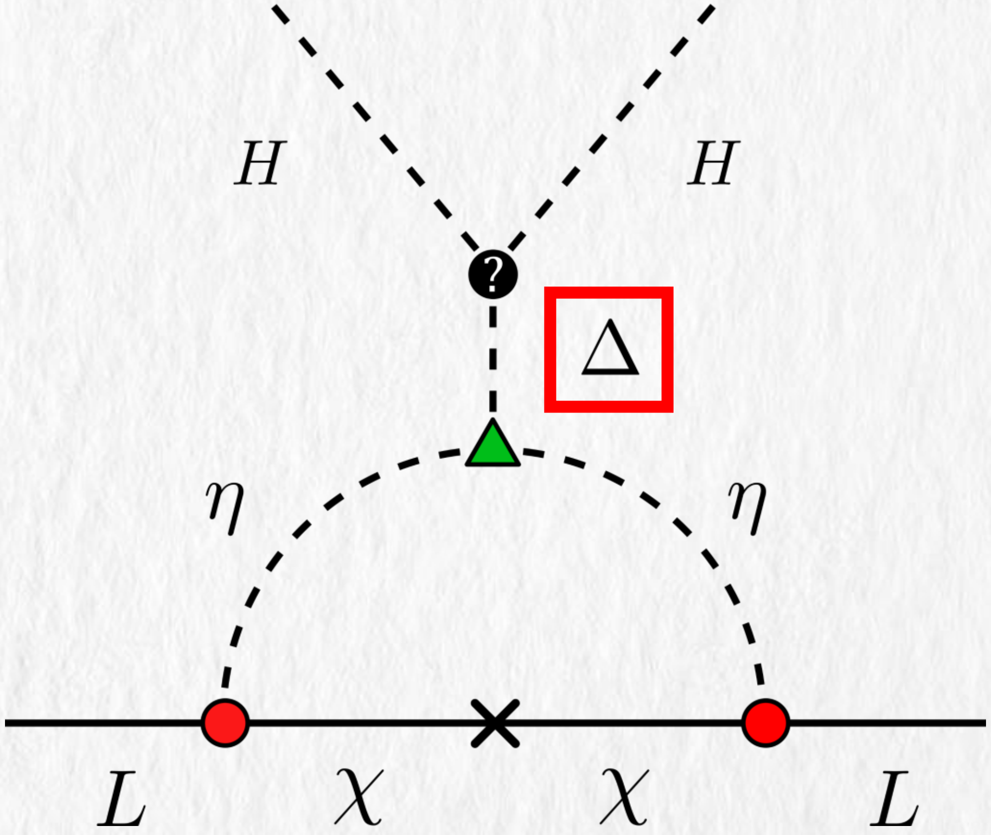
η	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{2}$	$+1/2$
χ	$\mathbf{1}$	$\mathbf{2}$	$\bar{\mathbf{2}}$	0
Δ	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{3}$	$+1$



$$(\mathbf{1},\mathbf{2})^2 \times (\mathbf{1},\mathbf{3}) \supset (\mathbf{1},\mathbf{1})$$

How to model build

$SU(3)_C \times SU(2)_1 \times SU(2)_2 \times U(1)_Y$

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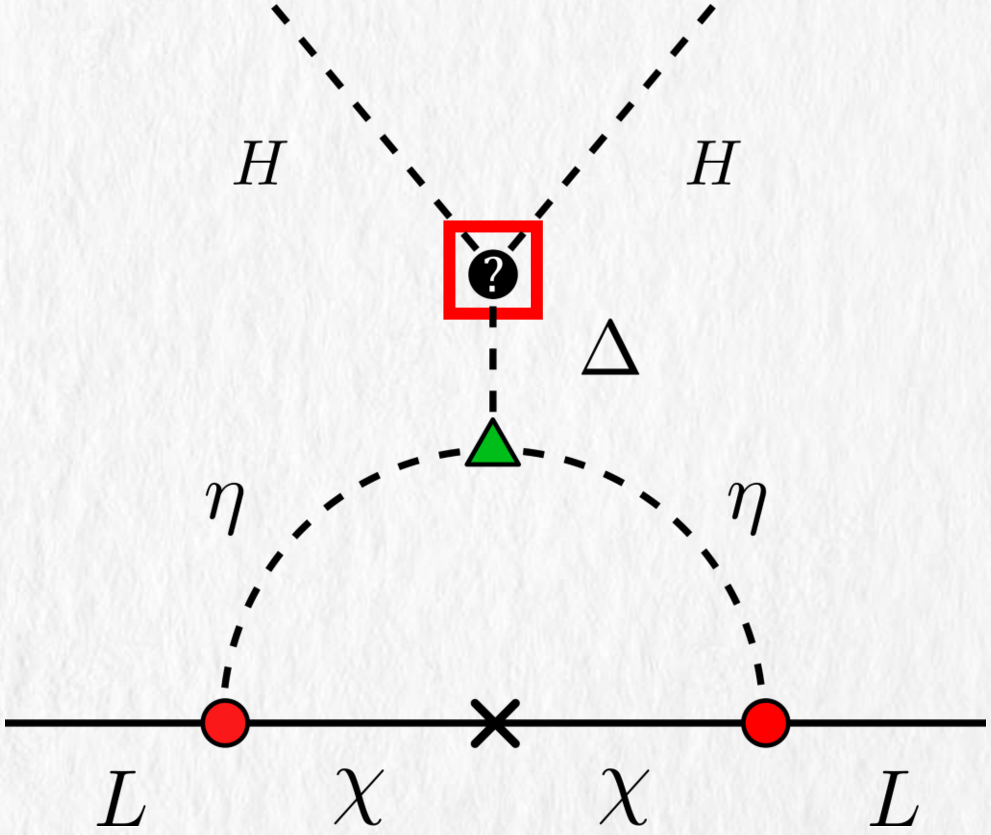
χ	$\mathbf{1}$	$\mathbf{2}$	$\overline{\mathbf{2}}$	0
Δ	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{3}$	$+1$

And this last vertex...



$$(\mathbf{2},\mathbf{1})^2 \times (\mathbf{1},\mathbf{3}) \not\supset (\mathbf{1},\mathbf{1})$$

How to model build

	$SU(3)_C$	$\times SU(2)_1$	$\times SU(2)_2$	$\times U(1)_Y$
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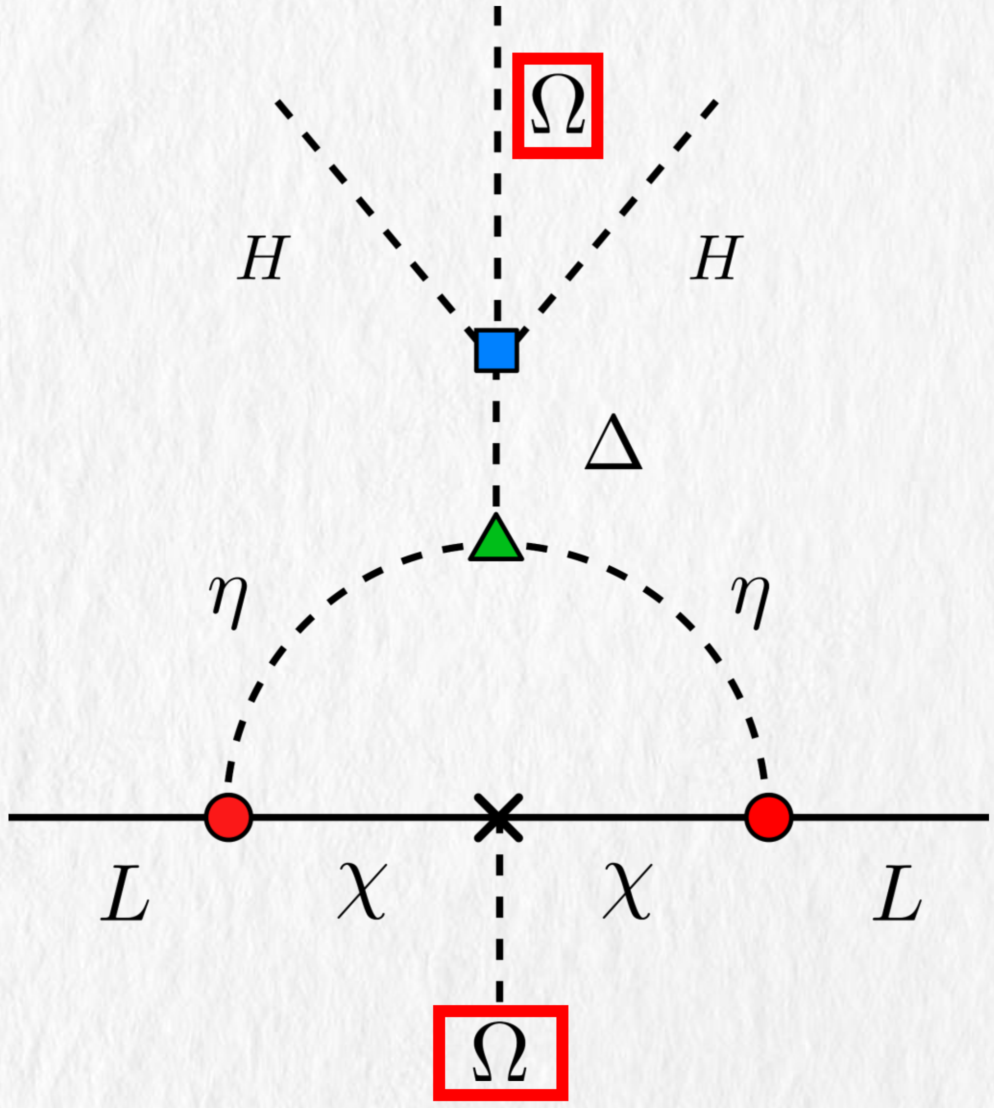
Δ	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{3}$	$+1$
Ω	$\mathbf{1}$	$\mathbf{3}$	$\overline{\mathbf{3}}$	0

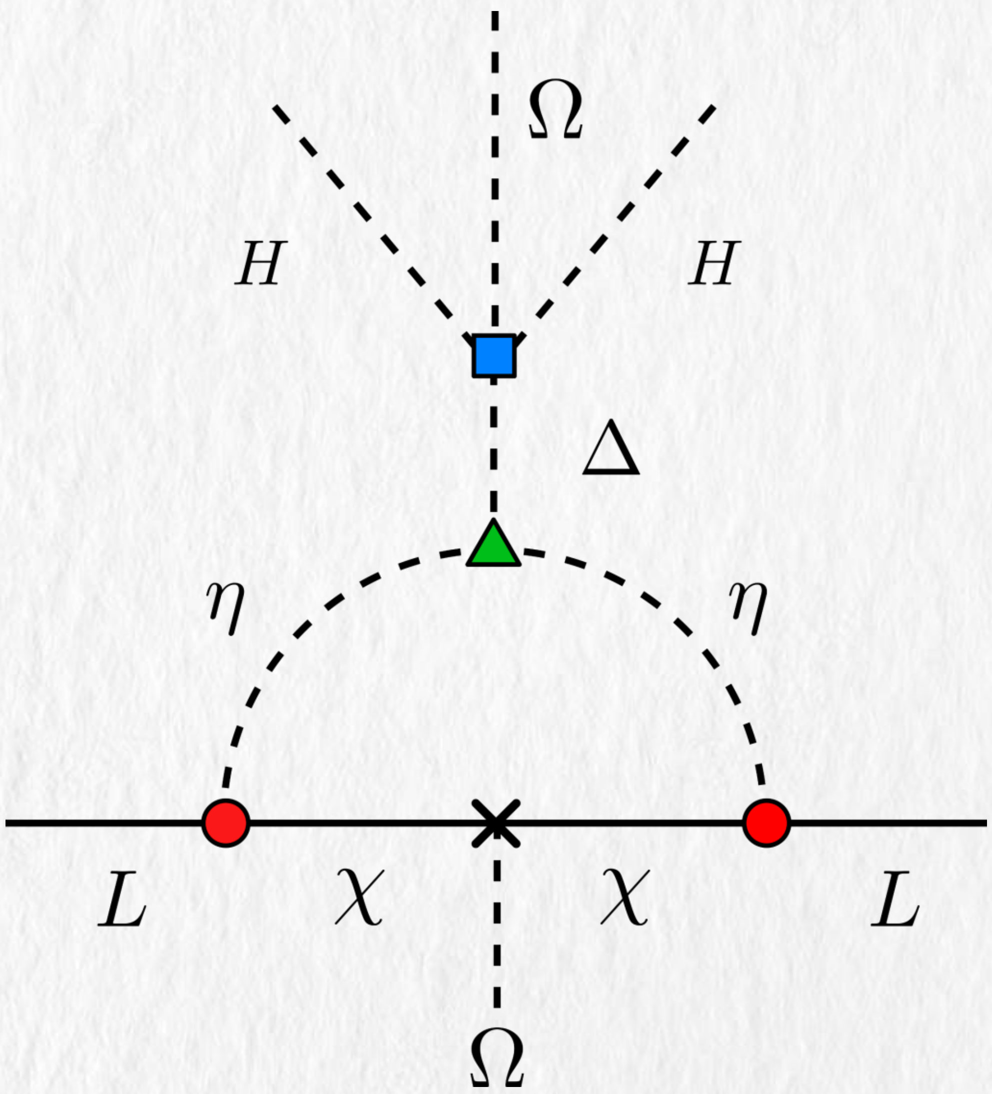
...is fixed by a scalar bitriplet



$$(\mathbf{2},\mathbf{1})^2 \times (\mathbf{1},\mathbf{3}) \times (\mathbf{3},\mathbf{3}) \supset (\mathbf{1},\mathbf{1})$$

Going down the ladder

- How do we **return to the scotogenic's diagram?**



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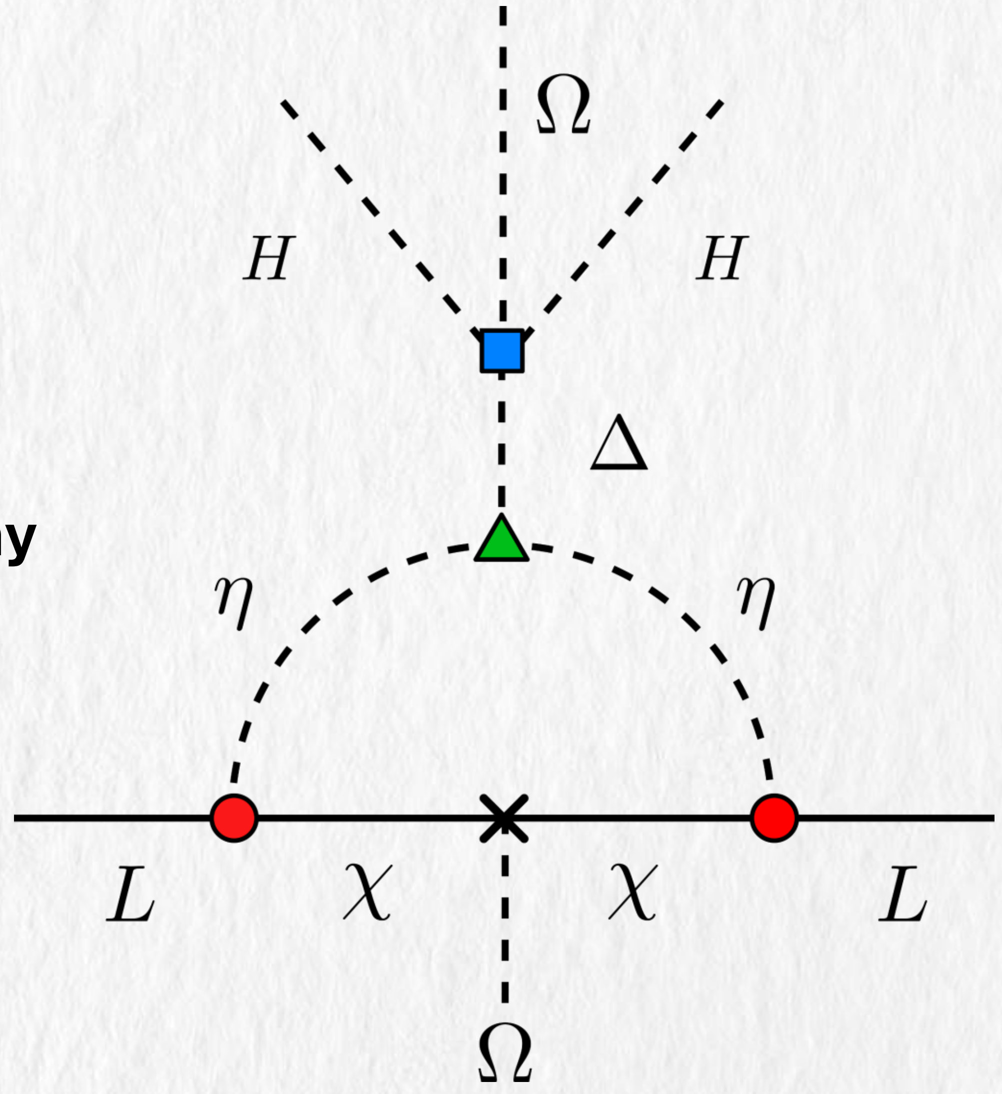
- How do we **return to the scotogenic's diagram?**

- Consider the following **VEVs and hierarchy**

$$\langle \Omega \rangle \propto \begin{pmatrix} v_\Omega & 0 & 0 \\ 0 & v_\xi & 0 \\ 0 & 0 & v_\Omega \end{pmatrix} \qquad \langle \Delta \rangle \propto \begin{pmatrix} 0 \\ 0 \\ v_\Delta \end{pmatrix}$$

$$\langle H \rangle \propto \begin{pmatrix} 0 \\ v_H \end{pmatrix} \qquad v_\Omega, v_\xi \gg v_H \gg v_\Delta$$



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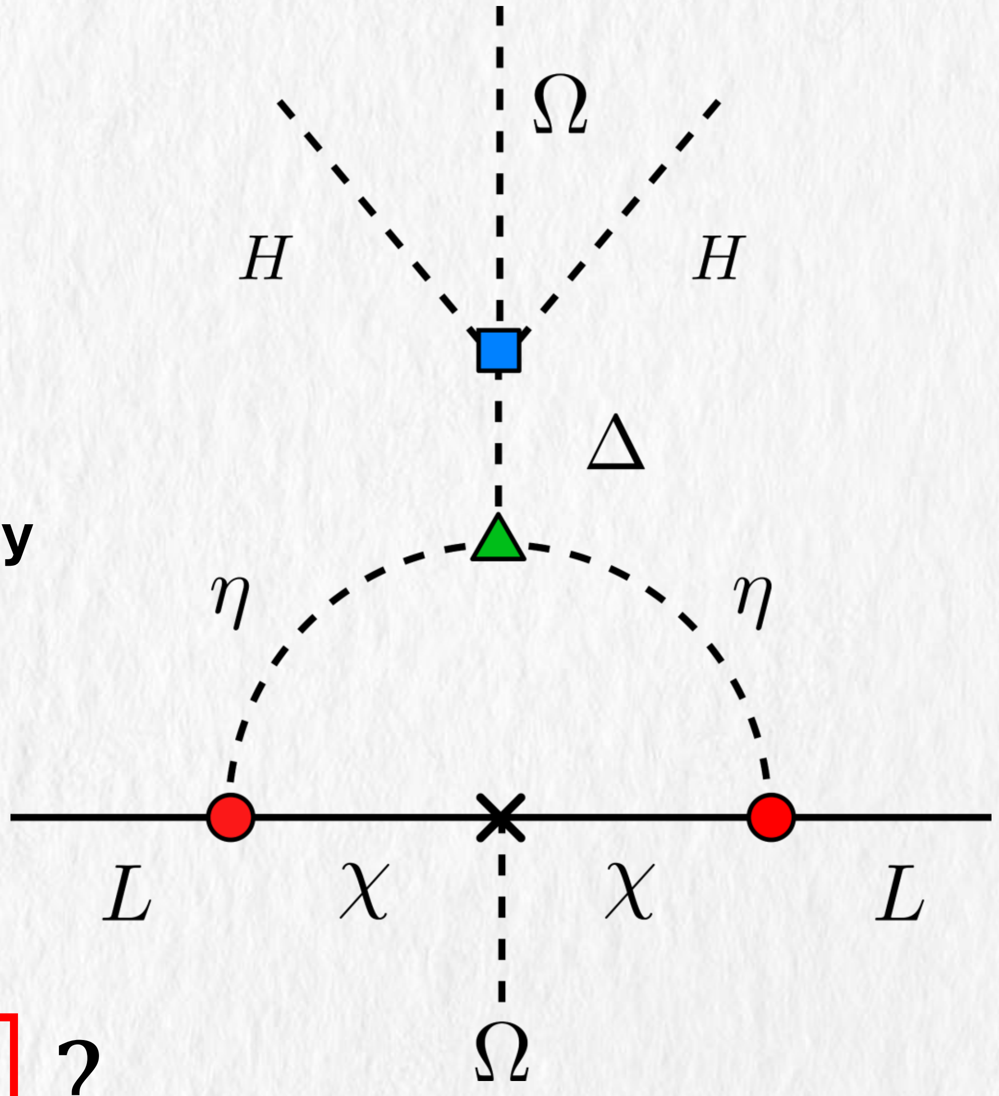
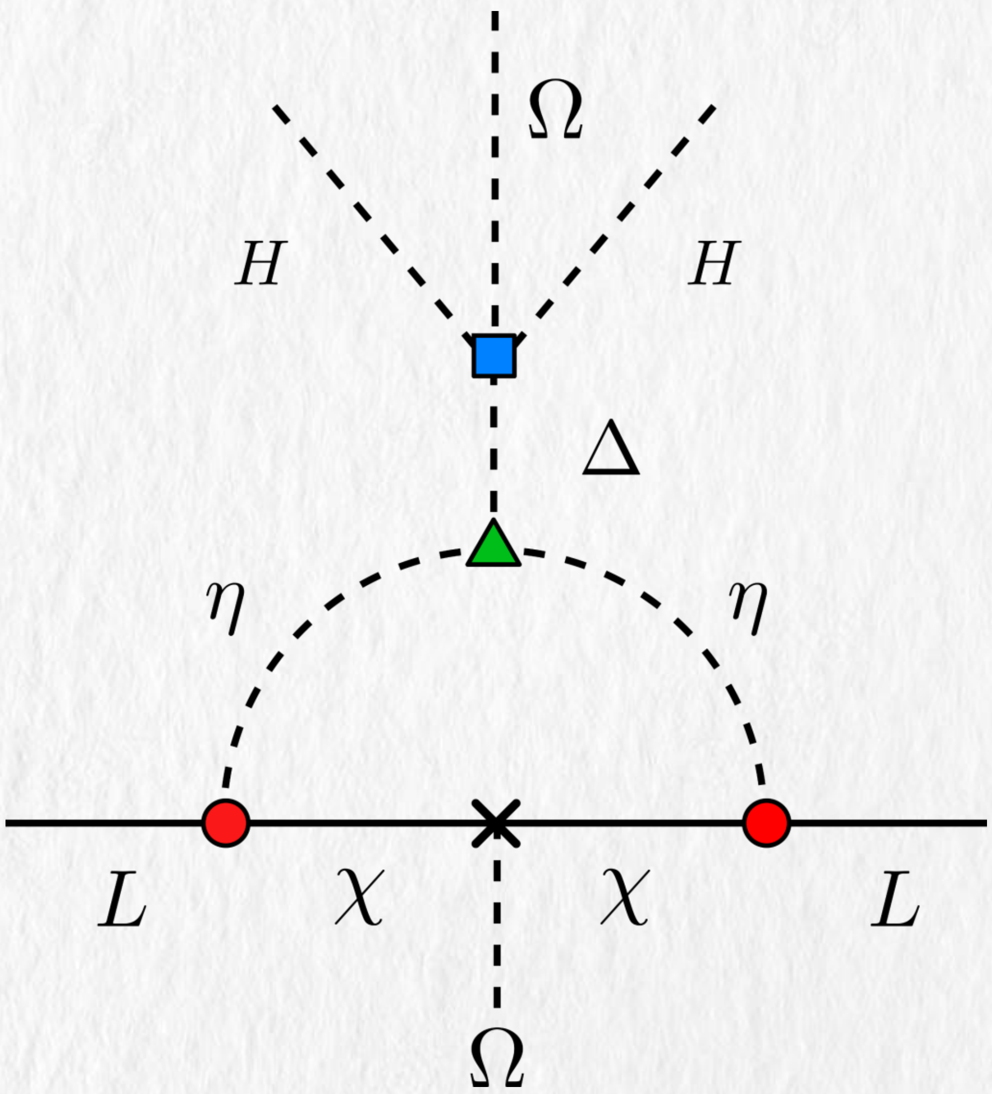
$$v_\Omega, v_\xi \gg v_H \boxed{\gg v_\Delta} \; ?$$



Why is v_Δ the smallest?

- The **smallness of λ_5** comes from it being **an effective operator after Δ is integrated out.**



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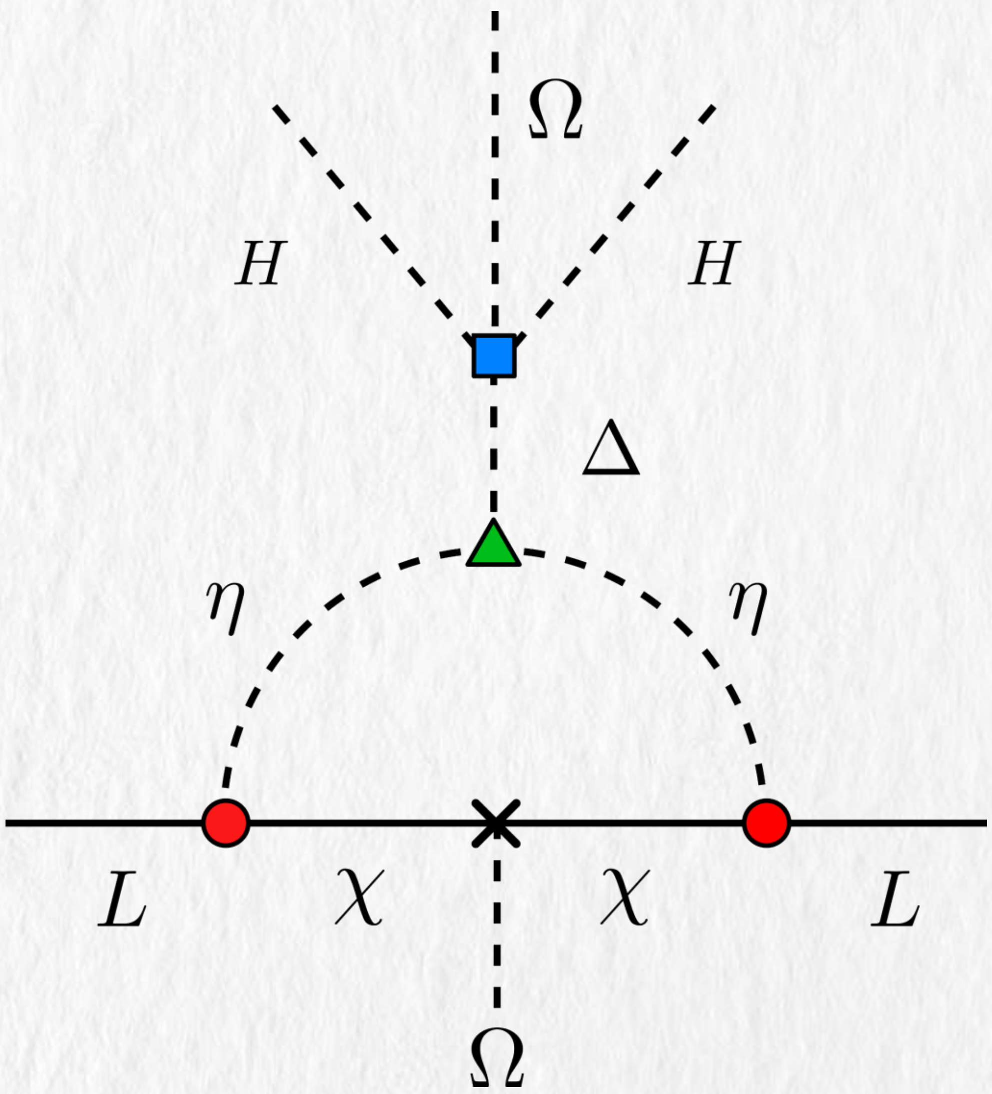

Why is v_Δ the smallest?

Effective theory!

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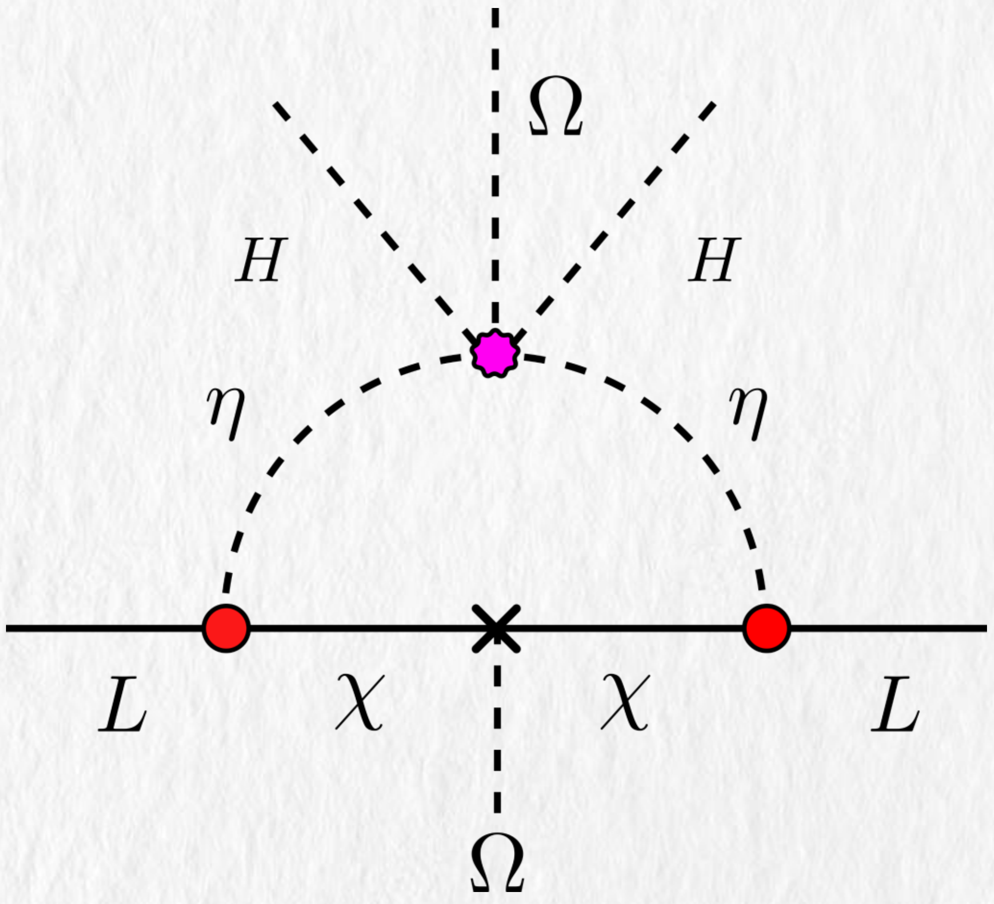
- Therefore we need $\boldsymbol{m_\Delta} \gg$ **any other mass scale**

- From the tadpole equations, **this forces small v_Δ**

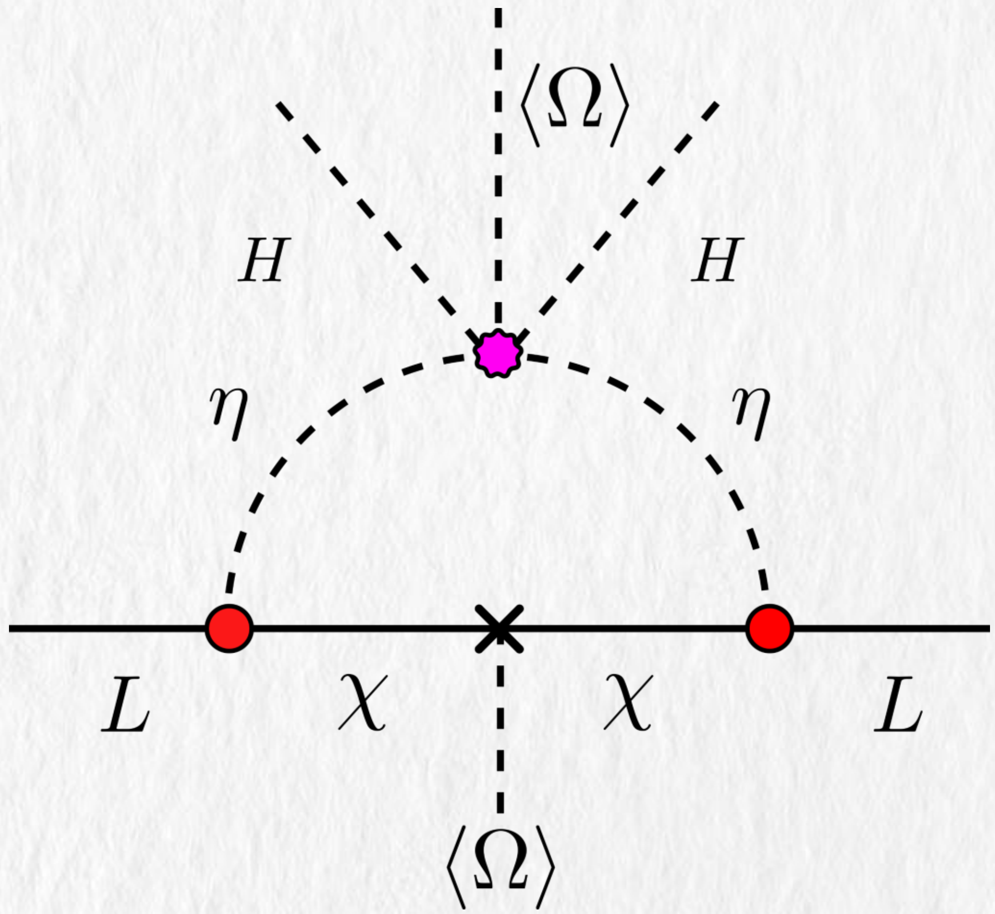
$$v_\Delta \propto \frac{v_H^2 v_\Omega}{m_\Delta^2}$$



Symmetry breaking

- The **first symmetry breaking step** comes from $\boldsymbol{v_\Omega}$ **and** $\boldsymbol{v_\xi}$

$$v_\Omega, v_\xi \gg v_H \gg v_\Delta$$



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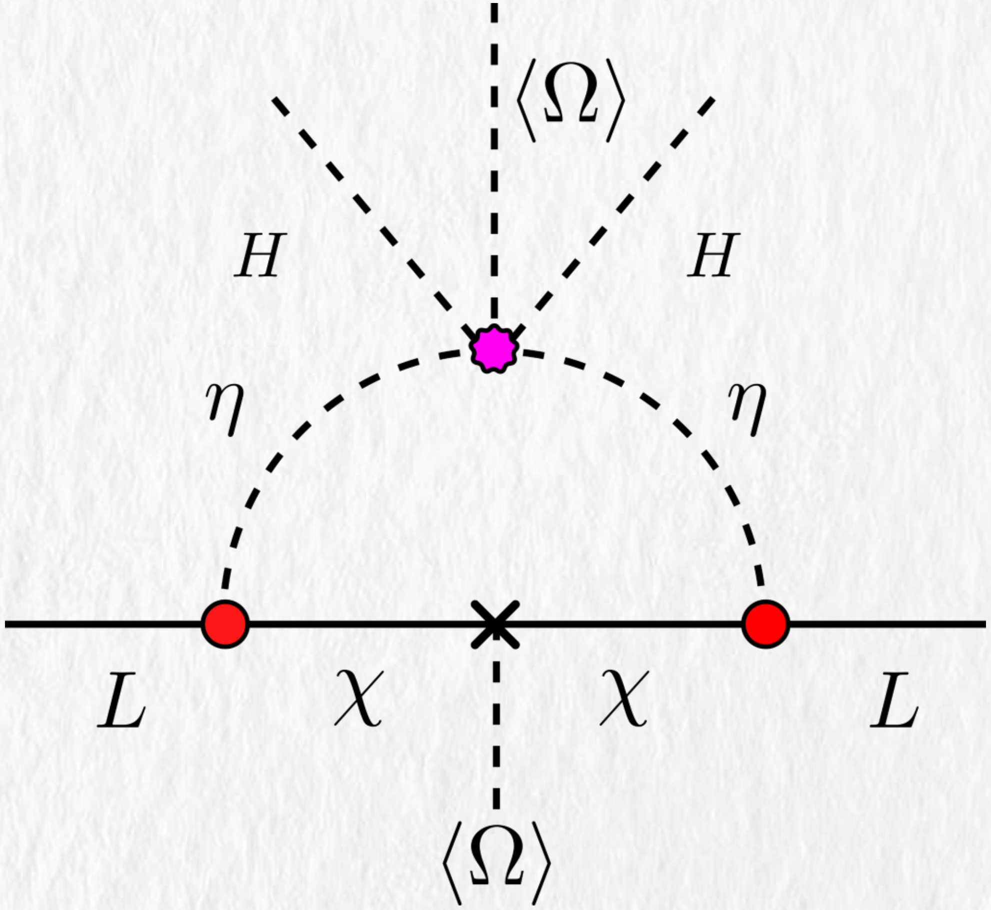
$$SU(2)_1 \times SU(2)_2 \xrightarrow{v_\Omega\,,\,v_\xi} SU(2)_L$$



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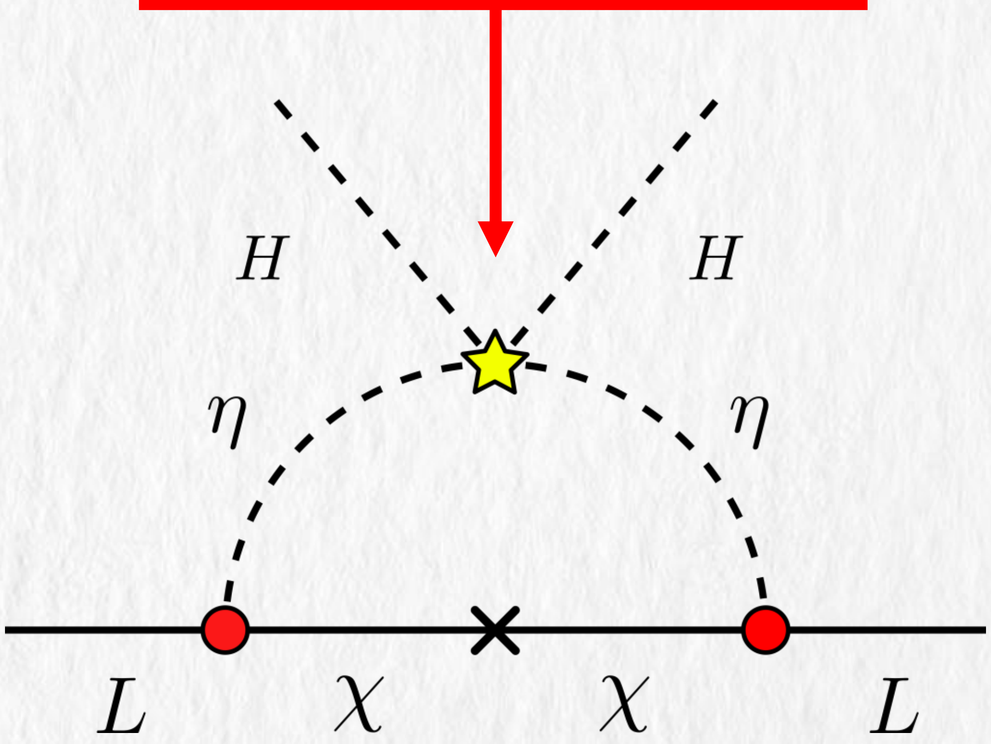

Symmetry breaking

$$\lambda_5 = \frac{v_\Omega \, \mu_2 \, \lambda_{H\Delta\Omega}}{4m_\Delta^2}$$ **Small!**

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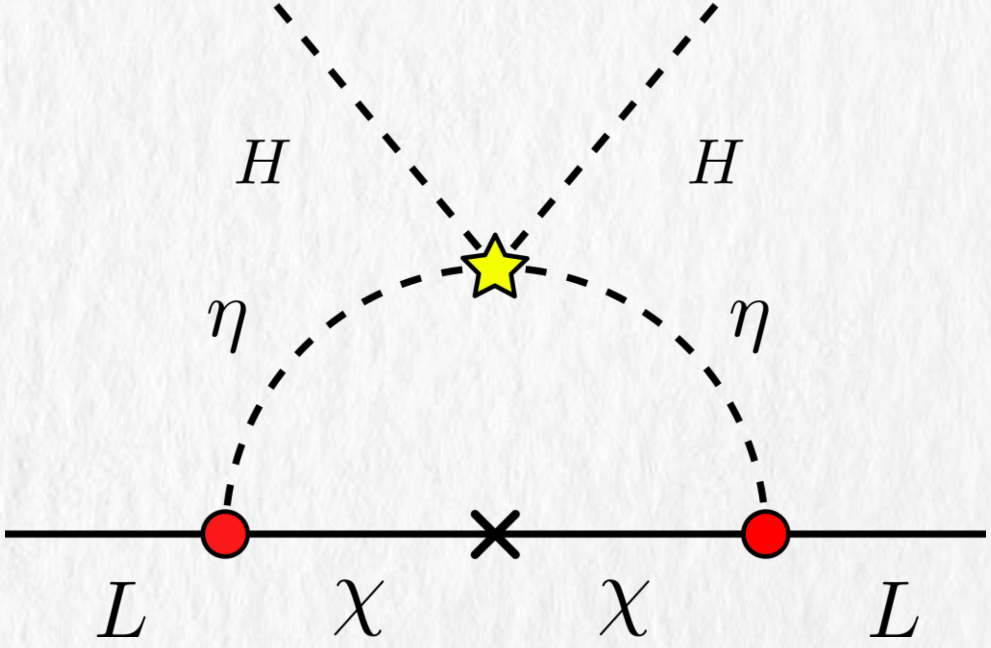

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- The **scotogenic fields always appear in pairs** within the lagrangian

$$\eta \sim (\mathbf{1}, \mathbf{2}) \xrightarrow{SU(2)_L} \boxed{\mathbf{2}} \quad \eta!$$

$$\chi \sim (\mathbf{2}, \overline{\mathbf{2}}) \xrightarrow{SU(2)_L} \mathbf{3} \oplus \boxed{\mathbf{1}} \quad N!$$

Is Z_2 two $SU(2)$ in a trenchcoat?

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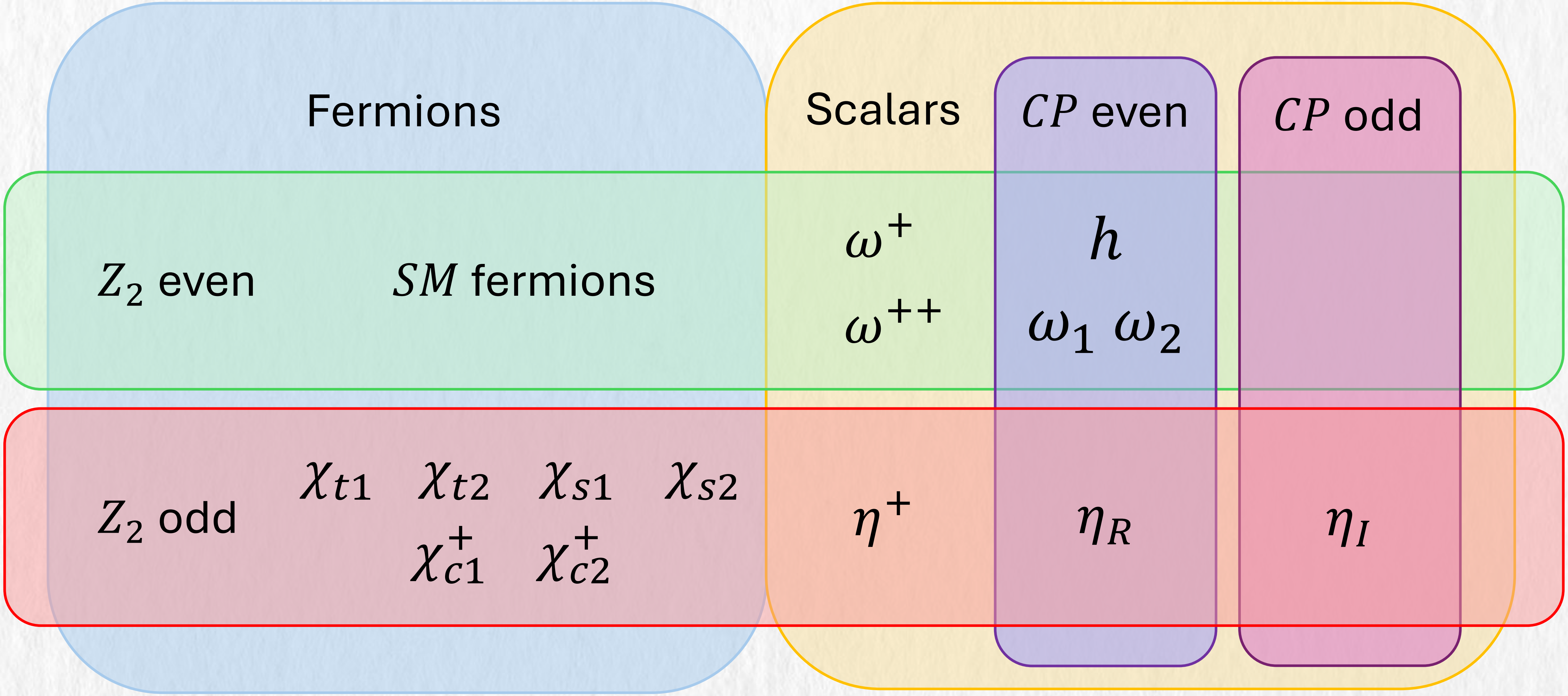
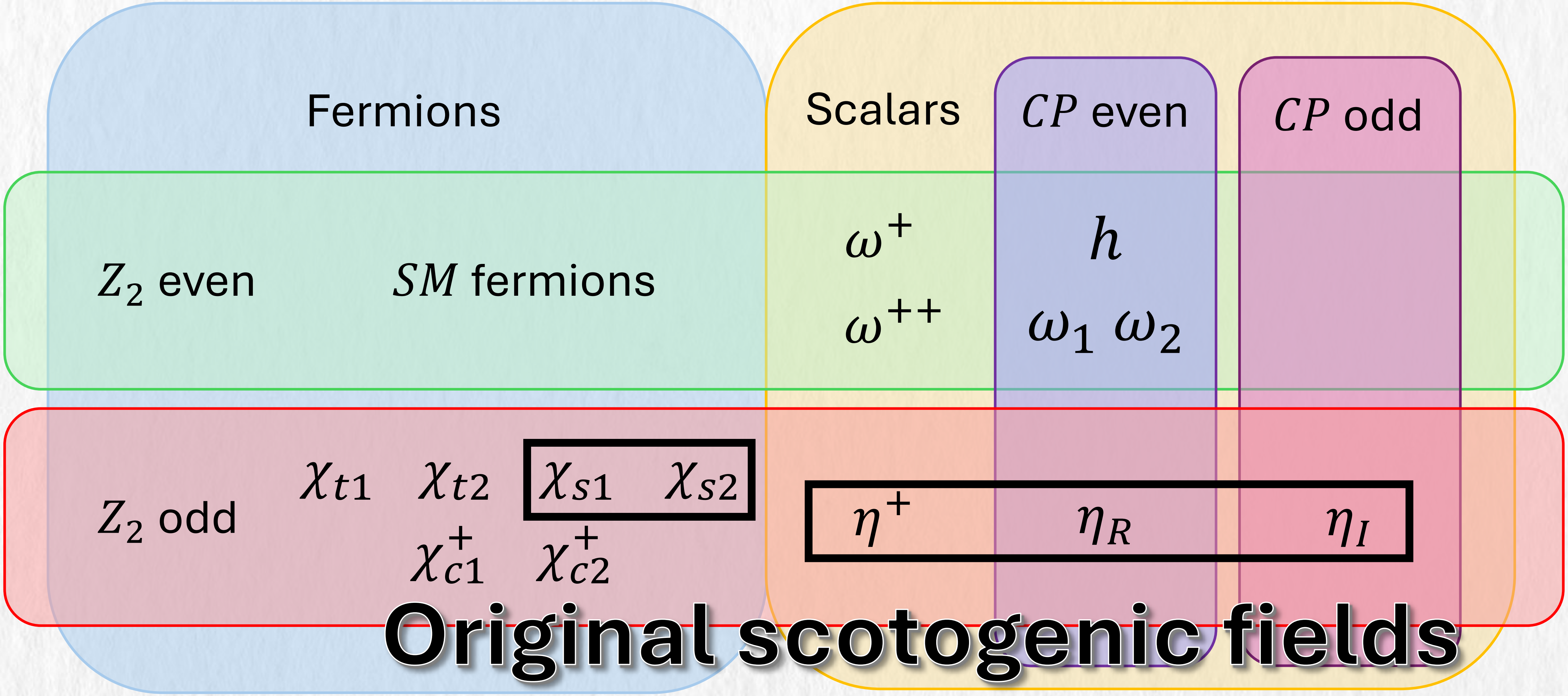
*Artist's rendition



All BSM masses have contributions from v_Ω



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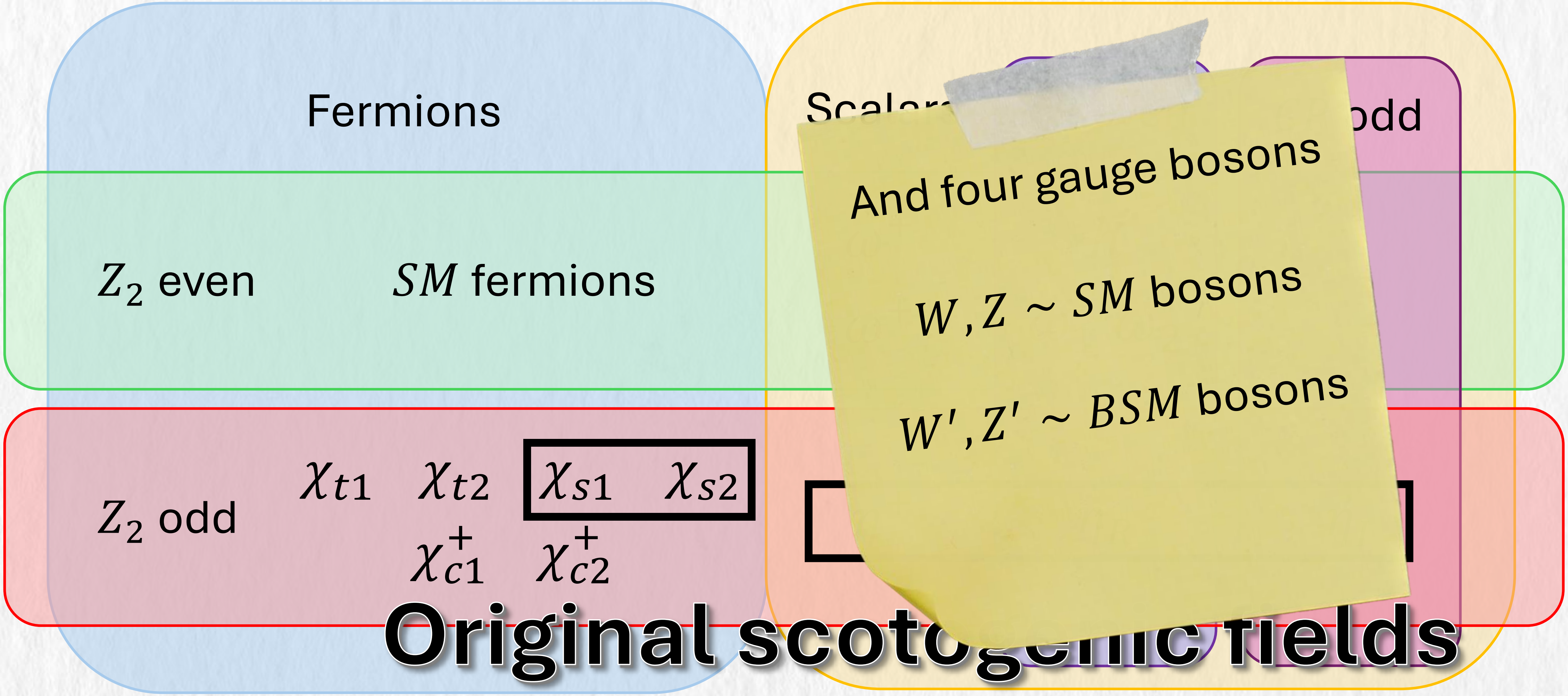

All BSM masses have contributions from v_{Ω}

We did some pheno too

- Very important!

Scotogenic mechanism from an extended $SU(2)_1 \times SU(2)_2 \times U(1)_Y$ electroweak symmetry

We propose an extension of the electroweak sector of the Standard Model in which the gauge group $SU(2)_L$ is promoted to $SU(2)_1 \times SU(2)_2$. This framework naturally includes a viable dark matter candidate and generates neutrino masses radiatively à la Scotogenic. Our scenario can be viewed as an

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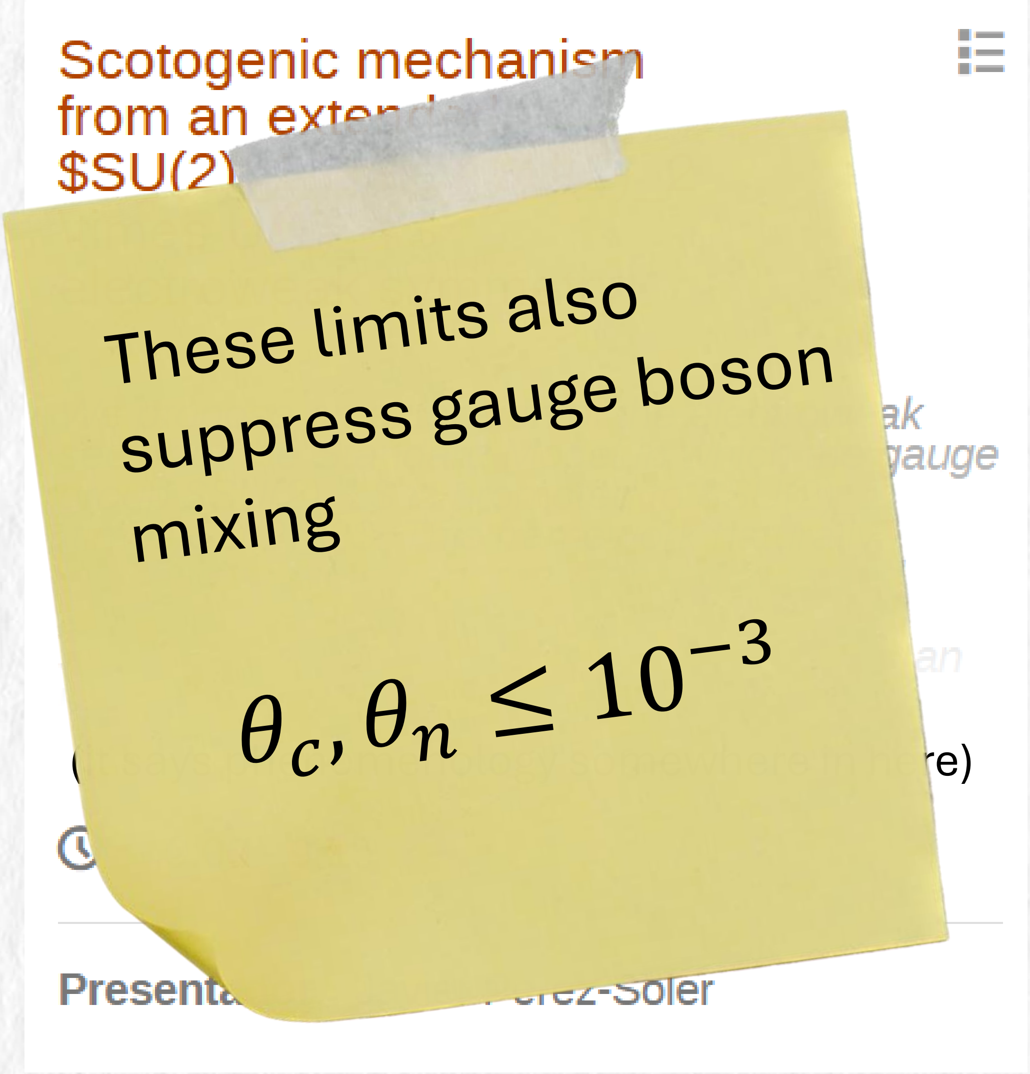

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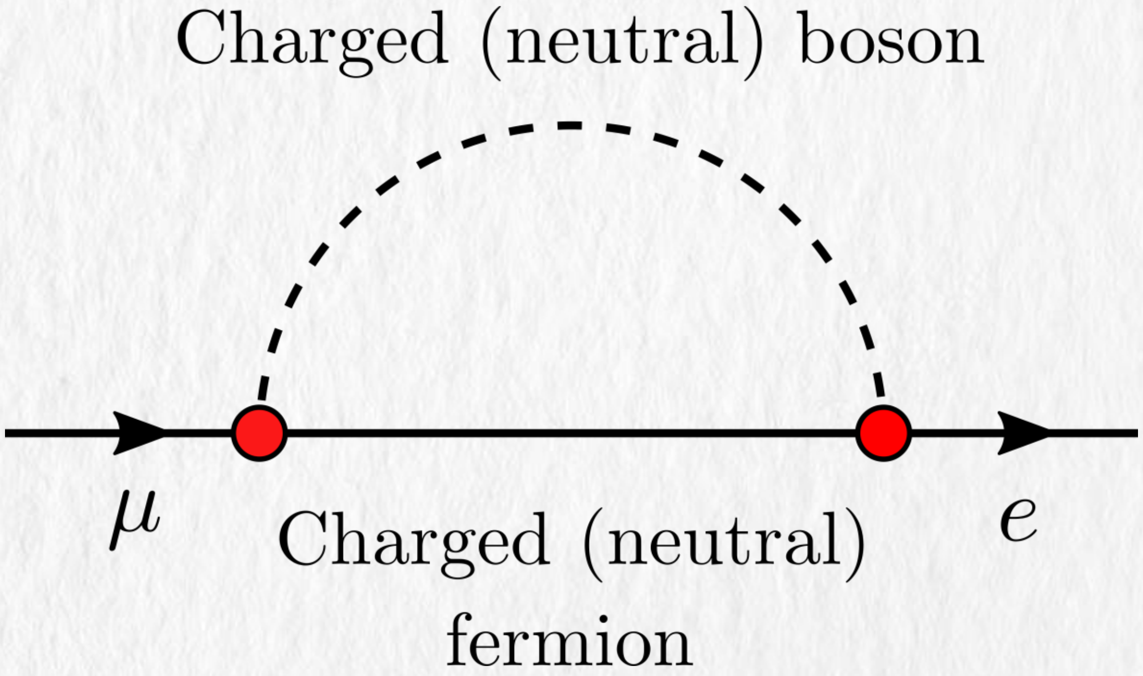
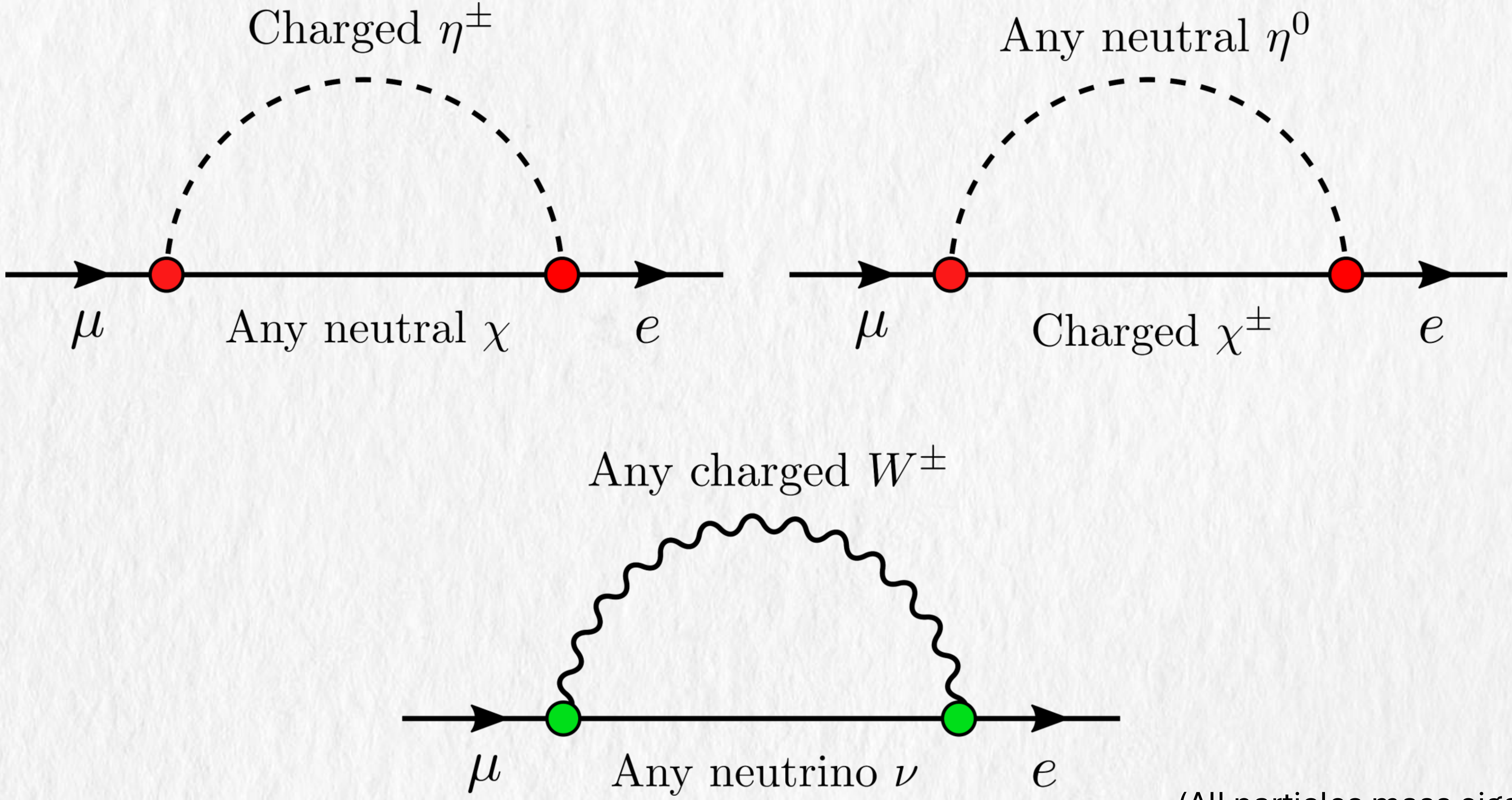
- $\mu \to e + \gamma$ is a classic choice

- $\mathrm{BR}(\mu \to e + \gamma) < 1.5 \cdot 10^{-13}$

(90% CL, MEG II 2021-2022)



(All particles mass eigenstates)



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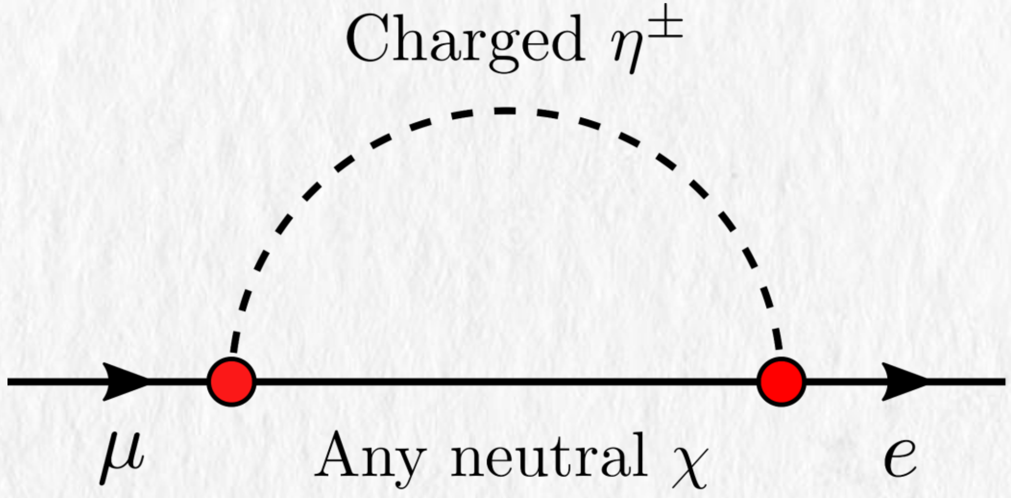
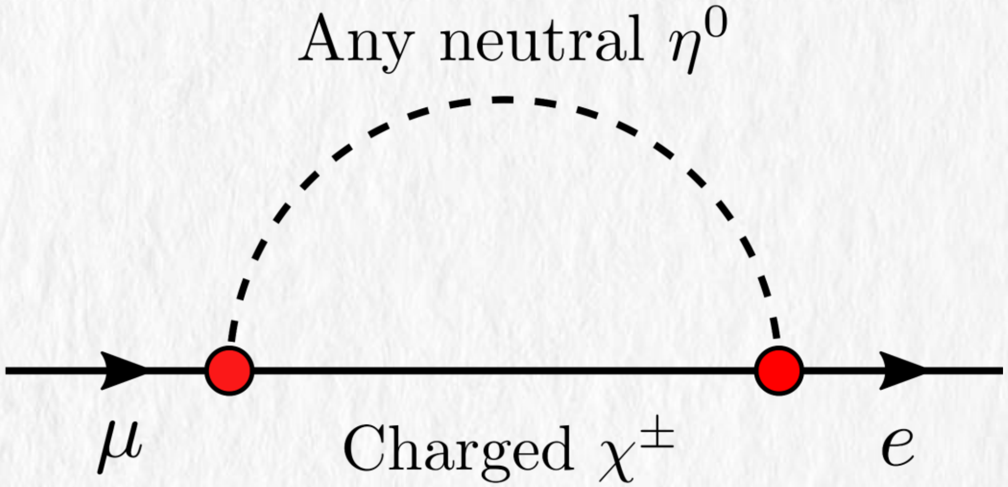
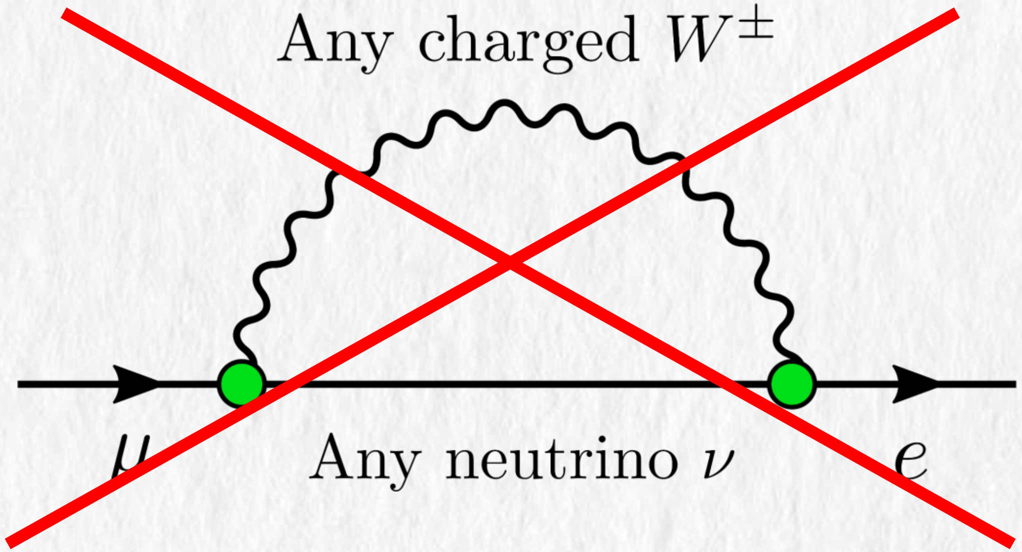




Mega suppressed

$$\sim \left(\frac{m_\nu}{m_W}\right)^4$$



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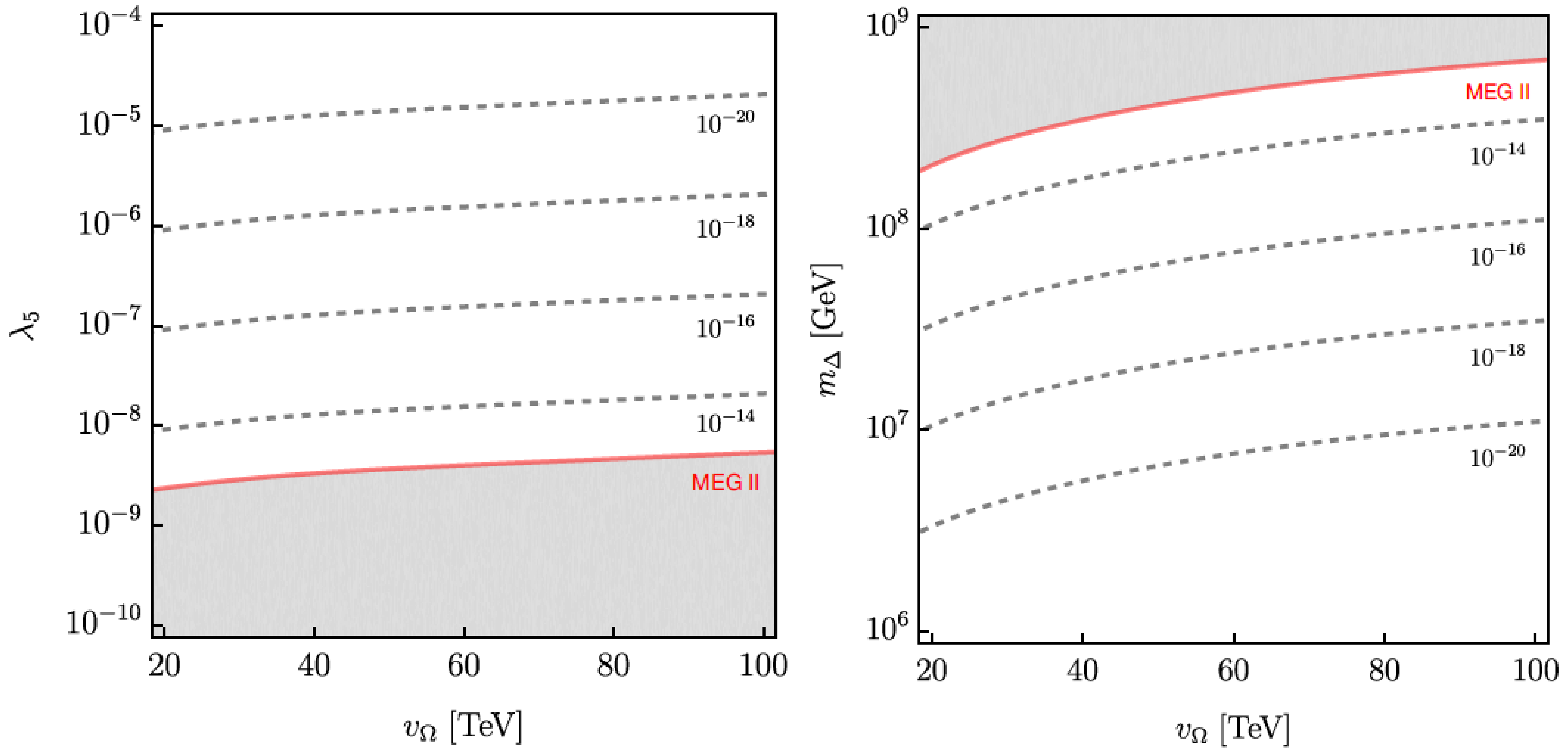

10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
λ_5
10^{-20}
10^{-18}
10^{-16}
10^{-14}
MEG II
20
40
60
80
100
v_Ω [TeV]
10^{9}
10^{8}
10^{7}
10^{6}
m_Δ [GeV]
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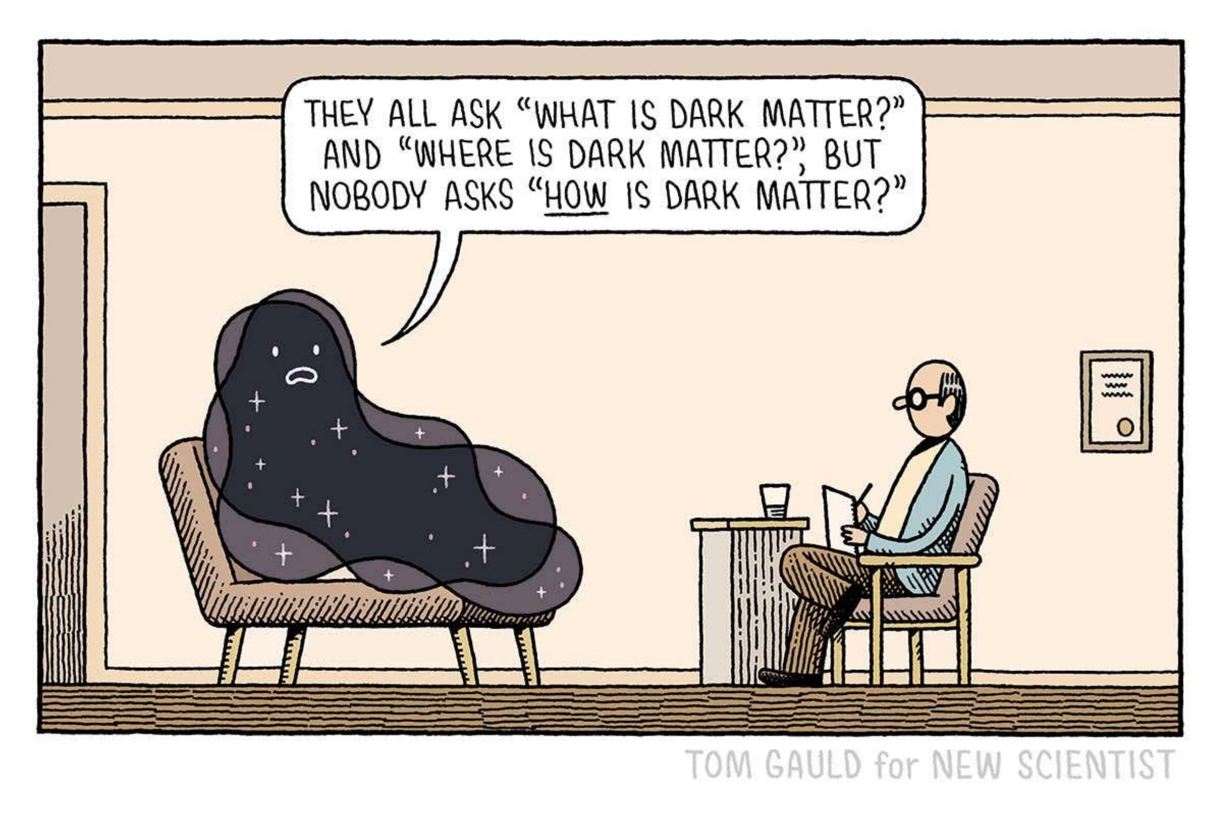
Final point: Dark matter

- We have a bunch of **stable DM candidates thanks to Z_2**



Actual picture displayed on the door to my office

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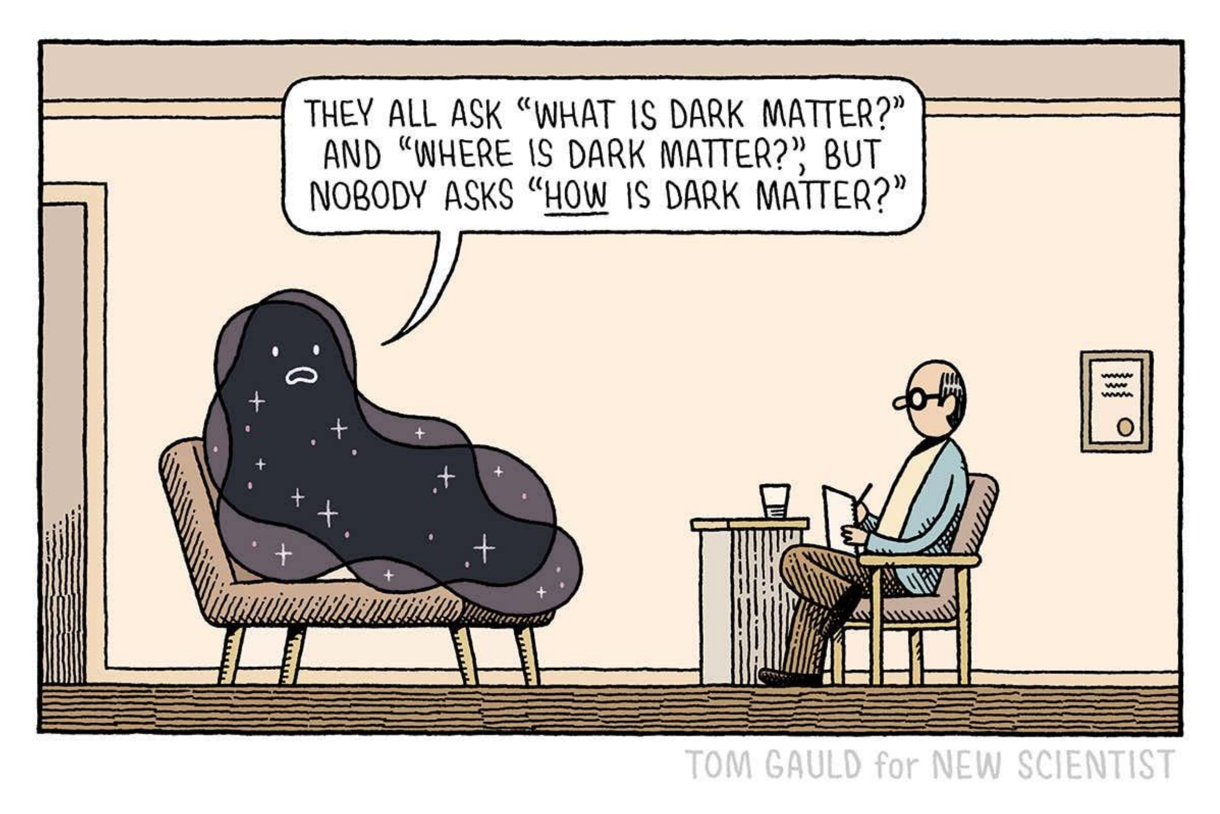

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Final point: Dark matter

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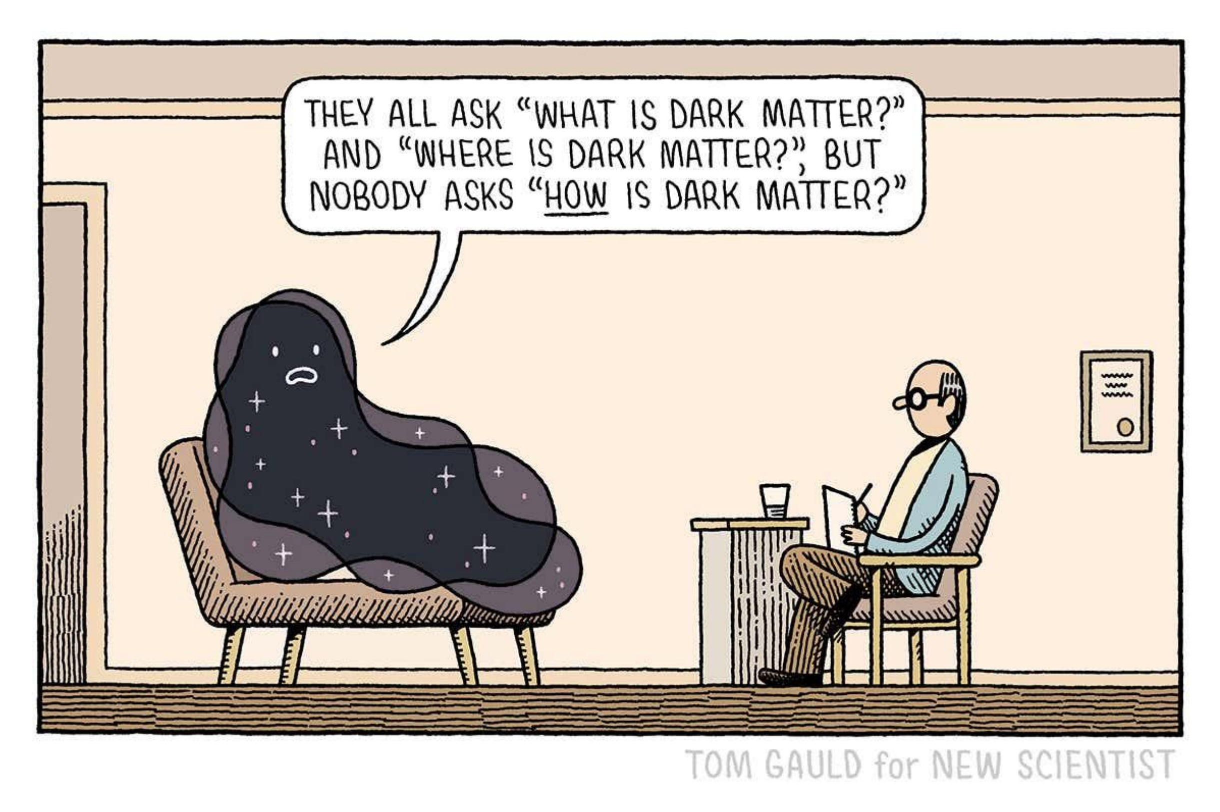
- **For scalars**, it's the **scotogenic guys η_R and η_I**
- **For fermions, we have two**, χ_{t1} and χ_{s1} ; coming from the neutral components of

$$\chi \to \mathbf{3} \oplus \mathbf{1}$$



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Summary of the summary

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- Can get **BSM phenomenology at the TeV scale**

Thanks!

r/Physics

Posted by u/[redacted] • 1

What to do if i have theories?

Question

I contacted a college and they ignored me

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The other picture displayed on the door to my office