Dark matter in SO(10) GUT

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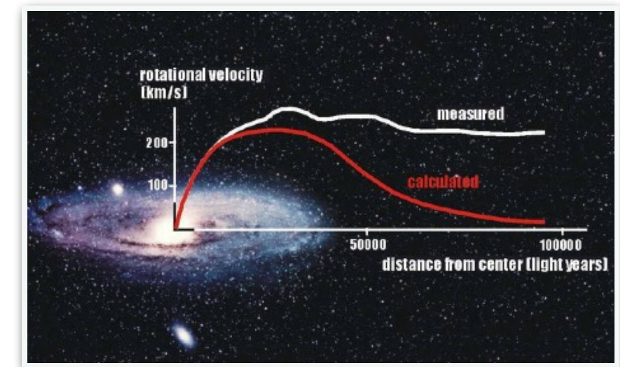
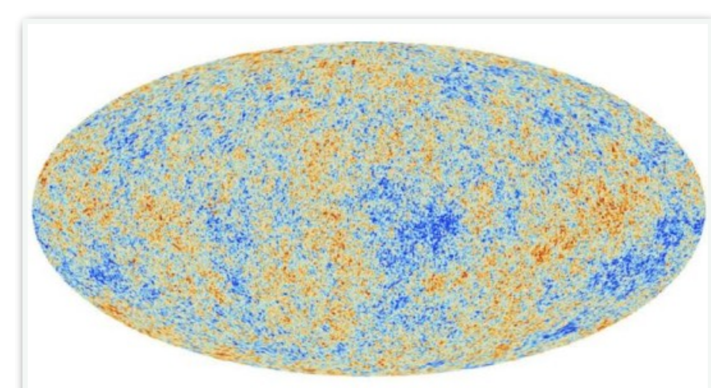
There exists a wide array of evidence for a nonbaryonic, clustering component of the Universe. Most likely new particle(s).

Acceptable candidates are very feebly interacting with SM, reproduce observed abundance, cold-ish, and very stable!



DM should be at least older than the Universe. If it emits cosmic rays the lifetime may become orders of magnitude larger:

$$\tau_{\rm DM} \gtrsim 10^{26}\,\mathrm{s}$$



From HEP viewpoint, stability points to a new preserved symmetry. A guide for model-building!

Straightforward solution is to impose a parity by hand.

However, less ad-hoc solutions are welcome. If stability results from new symmetry connected to SM, non-trivial interplay and constraints would emerge, e.g.,

- A new (unbroken) gauge group;
- Global flavour symmetry;
- SO(10) GUT

SO(10)-based Grand Unified Theories offer many nice features:

Automatic anomaly cancelation

Electric charge quantization

Gauge and matter unification

Neutrino masses

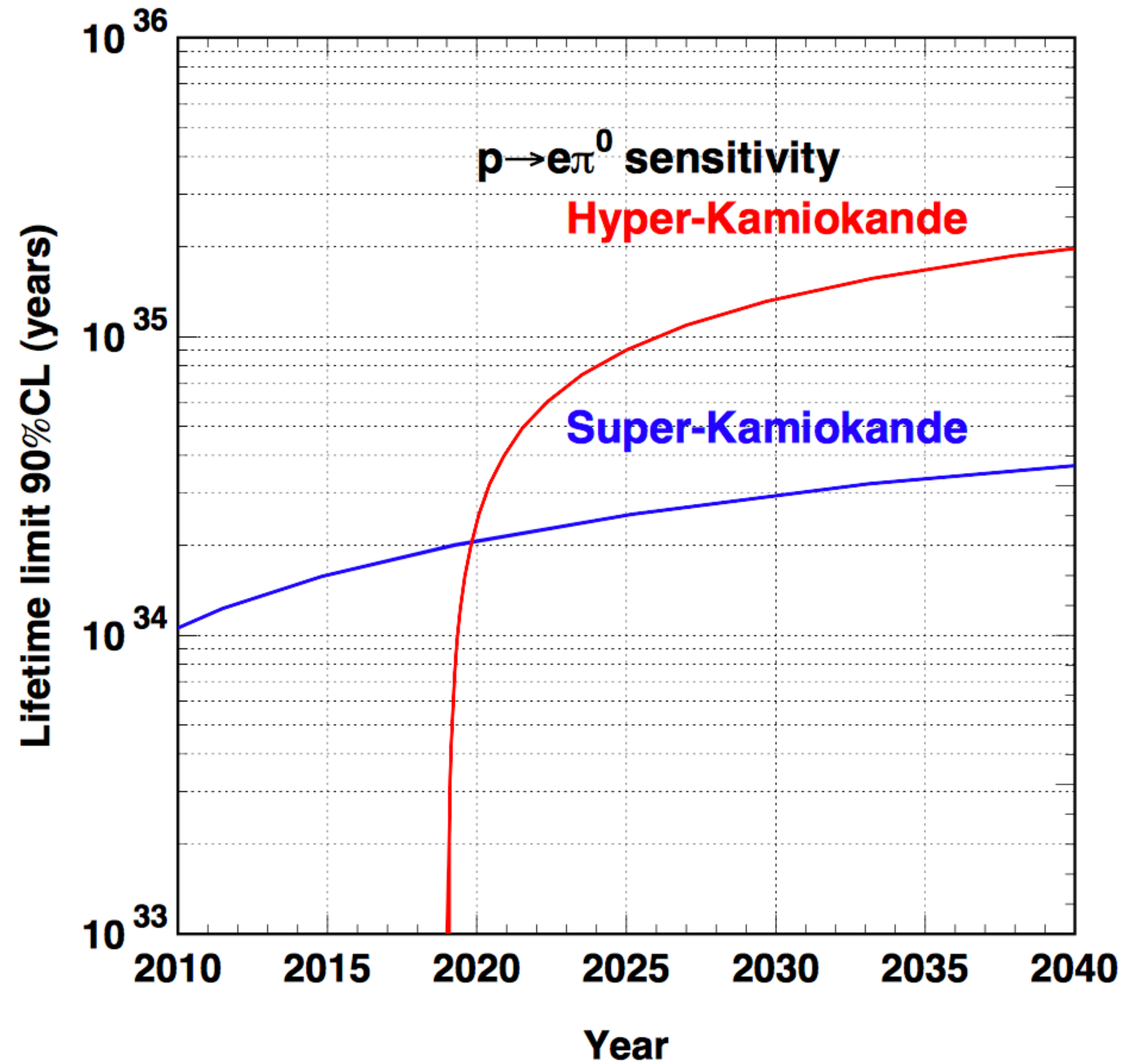
Baryogenesis

New physical scales (e.g., LR)

Elegant inclusion of axions

Elegant inclusion of inflation

…



[Letter of Intent for Hyper-K experiment]

SO(10)-based Grand Unified Theories offer many nice features. In particular, a stabilizing symmetry!

SO(10) has a Z_4 center. Its irreps. can be partitioned into 4 congruence classes.

$$
\begin{array}{lcccc}
\mathcal{Z} & : & \psi & \to +i & \psi \\
 & : & \overline{\psi} & \to -i & \overline{\psi} \\
 & : & \phi_{2n+1} & \to - & \phi_{2n+1} \\
 & : & \phi_{2n} & \to + & \phi_{2n}
\end{array}
\quad \longrightarrow \quad
\boxed{
\begin{array}{lcccc}
\mathcal{Z}^2 & : & \psi & \to & -\psi \\
 & : & \phi & \to & +\phi
\end{array}
}
$$

[Kibble, Lazarides, Shafi '82; O'raifeartaigh '86]

If no SO(10) spinor takes vev: remnant parity.

Non-SUSY SO(10) GUT provide a nice motivation from top for WIMPs in the form of various (admixtures of) multiplets.

	SO(10) reps.	DM candidates (SM)	$\mathbb{Z}_2$
Fermions	**10,**	**(1,2,**1/2**)**	
	45, 54, 210	**(1,1,**0**)+(1,3,**0**)** [Frigerio, Hambye '09]	**+**
	126	**(1,1,**0**)**	
	...		
Scalars	**16, 144**	**(1,1,**0**)** [Kadastik, Kannike, Raidal '09]	**-**
	...		

Why not the simplest possibility, 10, and have a doublet DM?

Due to the rich gauge structure of the GUT, the low-energy doublet interacts with new gauge bosons — saving it from direct detection limits.

Enhanced phenomenological predictions and broader DM parameter space.

Plan

The Model

Pheno & Results

Summary

[SB, Nardi, Krauss ’16]

Let's consider a simple setup

We consider a minimal SO(10) fields content: 3 generations of fermion in **16**, and scalars in **126**, **45**, and a complex **10**.

$$
\begin{array}{rclr}
SO(10) & \longrightarrow & SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L} & (\mathbf{45}_H) \\
 & \longrightarrow & SU(3)_C \times SU(2)_L \times U(1)_Y & (\overline{\mathbf{126}}_H) \\
 & \longrightarrow & SU(3)_C \times U(1)_Q & (\mathbf{10}_H)
\end{array}
$$

Arguably, the most economical chain. Abandoned due to tachyonic instabilities, then resuscitated after inclusion of quantum corrections.

[Bertolini, di Luzio, Malinsky ’10]

Now, we add our would-be DM in a fermonic 10

The **10** contains new VL quarks;

$$\mathbf{10}_{\mathcal{L},\mathcal{R}} \supset \xi_{\mathcal{L},\mathcal{R}} = \begin{pmatrix} \xi & \xi^+ \\ \xi^- & \xi^c \end{pmatrix}_{\mathcal{L},\mathcal{R}}$$

$$\begin{aligned} \mathbf{10} &= (\mathbf{1},\mathbf{1},\mathbf{6}) + (\mathbf{2},\mathbf{2},\mathbf{1}) \quad \text{(PS)} \\ &= (\mathbf{1},\mathbf{1},\mathbf{3},-\frac{1}{3}) + (\mathbf{1},\mathbf{1},\overline{\mathbf{3}},\frac{1}{3}) + (\mathbf{2},\mathbf{2},\mathbf{1},0) \quad \text{(LR)} \end{aligned}$$

To split the multiplet, we connect it to **45**:

$$\mathcal{L}_{DM} \supset y\, \mathbf{10}_{\mathcal{L}}.\mathbf{45}_H.\mathbf{10}_{\mathcal{R}} + h.c.$$

45 breaks the group (first stage to LR), and splits the **10**'s thanks to its vev structure:

$$\langle \mathbf{45}_H \rangle \propto (B-L) = \mathrm{diag}(a,a,a,b,b) \otimes i\sigma_2$$

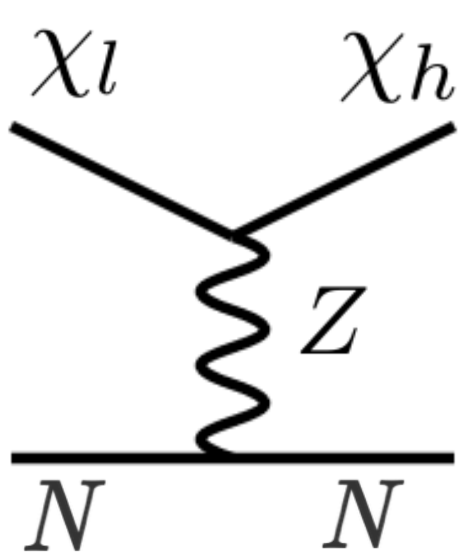
~GUT ~TeV

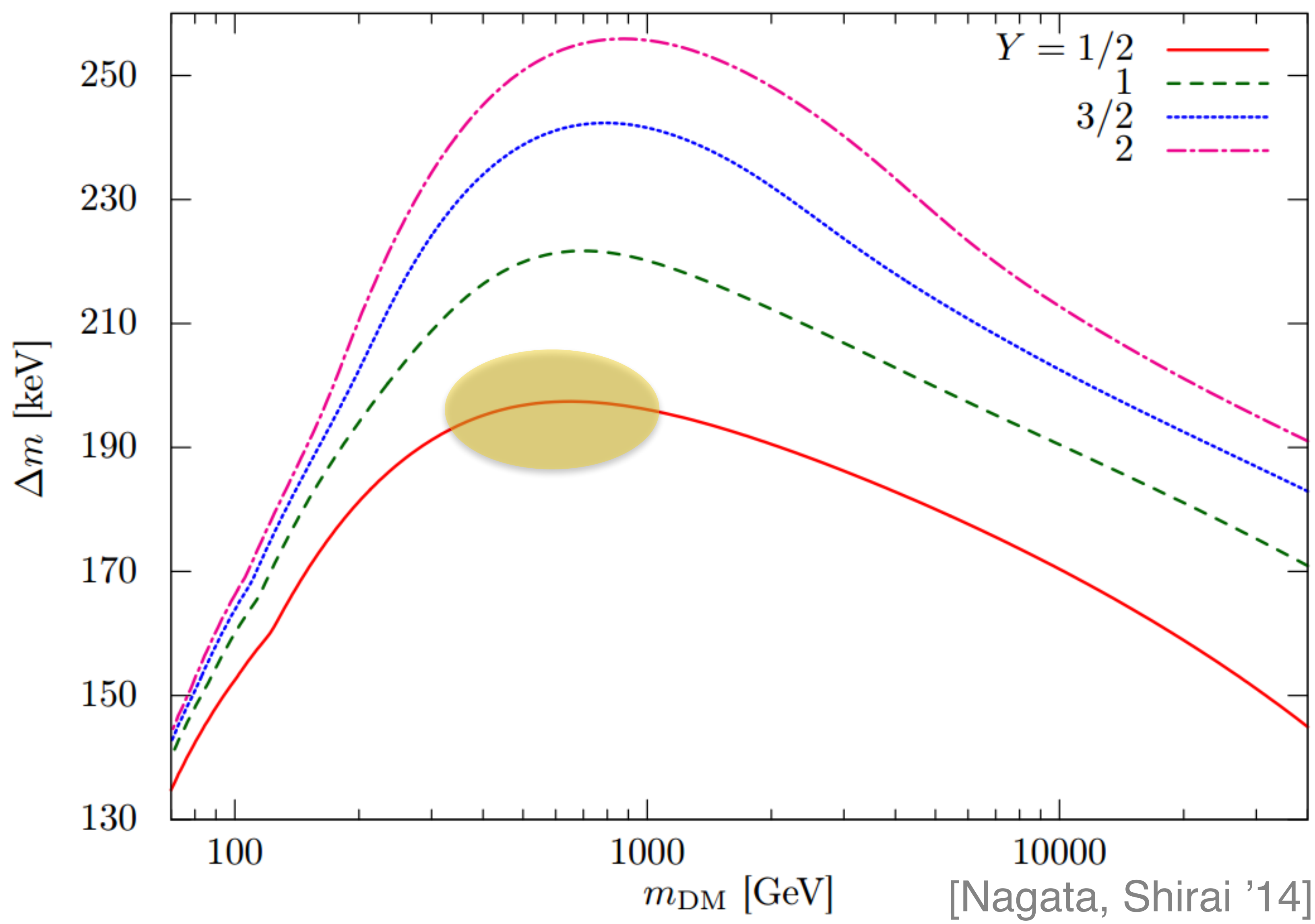
[Dimopoulos, Wilczek '81]

A pure hyper-charged DM is ruled out by direct detection exps!

Solution: Split the Dirac state to two Majorana; or
Make Z interactions off-diagonal.

Only a small splitting is needed!





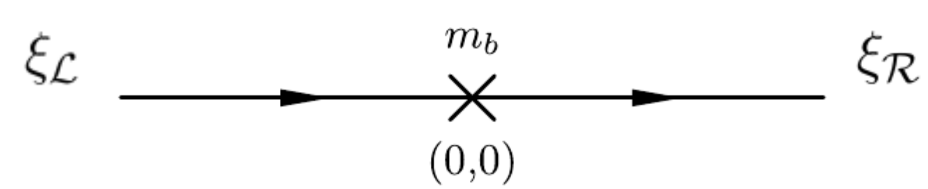
[Nagata, Shirai '14]

Our DM obtains two mass contributions

We have the typical Dirac ‘’off-diagonal’ terms

$$y\,\mathbf{10}_{\mathcal{L}}.\mathbf{45}_{H}.\mathbf{10}_{\mathcal{R}} \rightarrow m_b \xi^{\dagger}_{\mathcal{L}} \xi_{\mathcal{R}} + \ldots$$

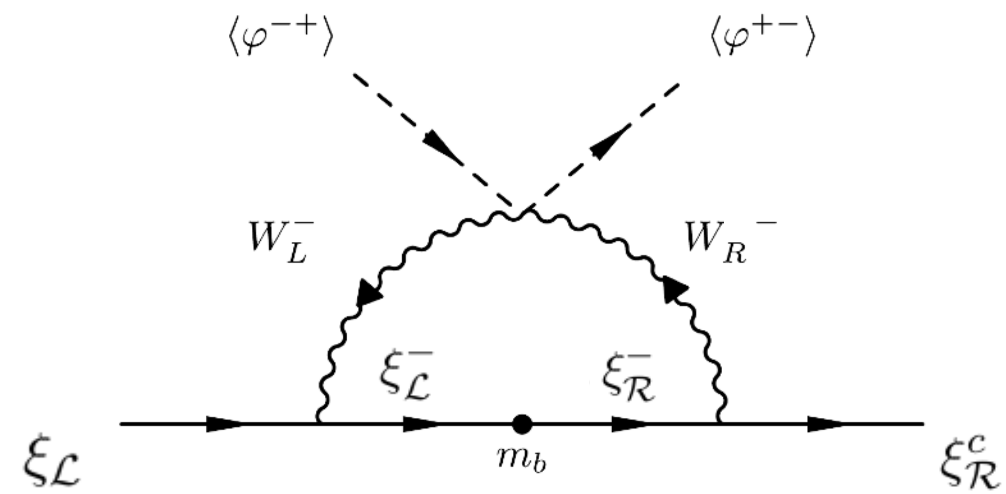
$$\begin{pmatrix} \xi & \xi^{+} \\ \xi^{-} & \xi^{c} \end{pmatrix}_{\mathcal{L}} \qquad \begin{pmatrix} \xi & \xi^{+} \\ \xi^{-} & \xi^{c} \end{pmatrix}_{\mathcal{R}}$$



$$y\,\mathbf{10}_{\mathcal{L}}.\mathbf{45}_{H}.\mathbf{10}_{\mathcal{R}} \rightarrow m_b \xi^{-\dagger}_{\mathcal{L}} \xi^{-}_{\mathcal{R}} + \ldots$$

As well as a new contribution due to WR

$$\begin{pmatrix} \xi & \xi^{+} \\ \xi^{-} & \xi^{c} \end{pmatrix}_{\mathcal{L}} \qquad \begin{pmatrix} \xi & \xi^{+} \\ \xi^{-} & \xi^{c} \end{pmatrix}_{\mathcal{R}}$$



Interestingly, we obtain an upper-bound on W′ masses from DM!

After diagonalizing the mass matrices, we obtain two neutral Dirac fermions with masse:

$$m_{h,l} = \underset{\substack{\uparrow \\ \text{45h}}}{m_b} \pm \underset{\substack{\uparrow \\ \text{loop}}}{\delta_m}$$

The radiative contributions is readily calculable:

$$\frac{1}{2}\delta_m \sim \frac{g_L^2 g_R^2}{16\pi^2}\frac{v_u v_d}{M_{W_R}^2} m_b$$

The neutral current are now off-diagonal.

Demanding that the splitting exceeds the kinetic energy of DM implies:

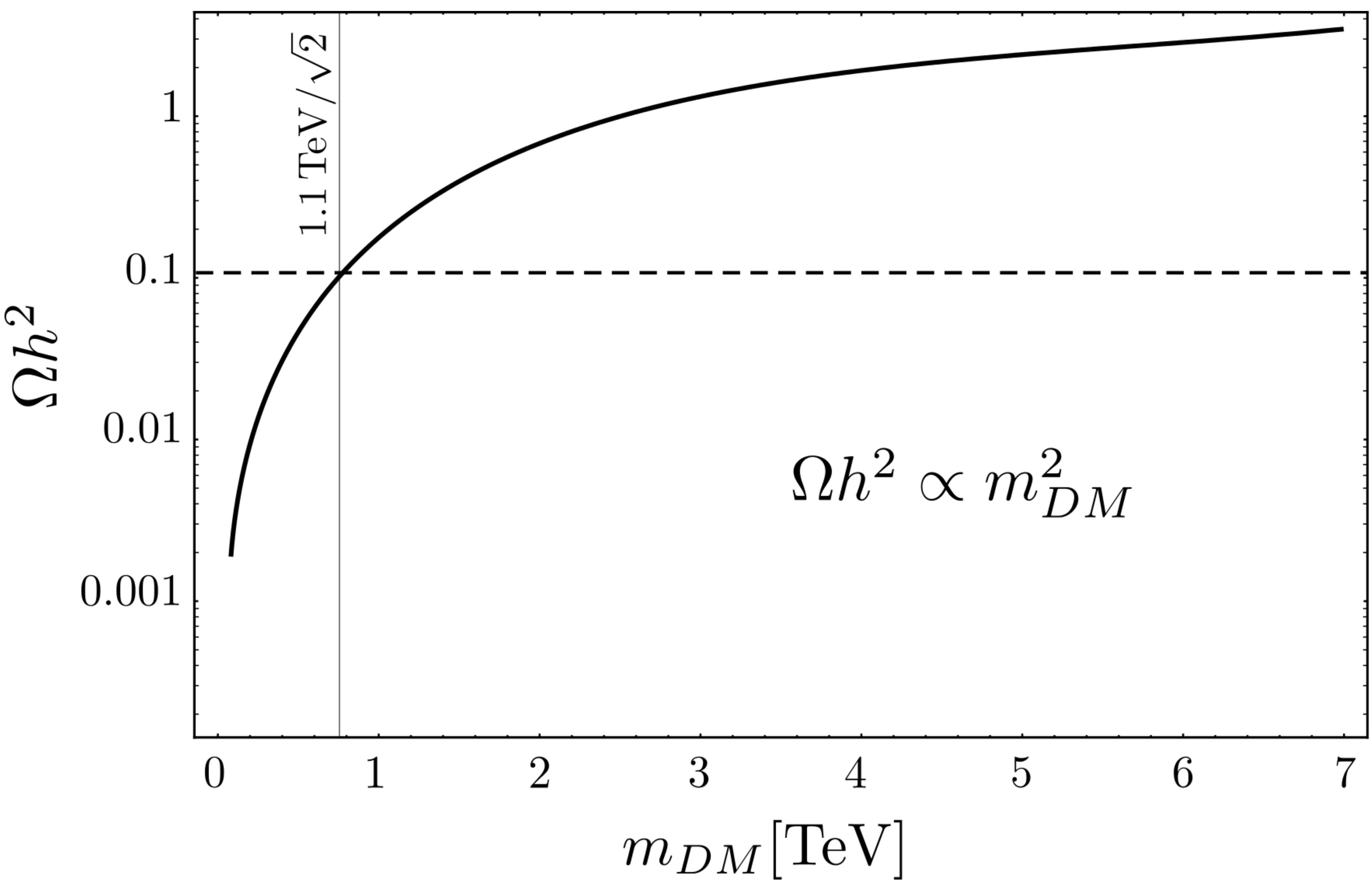
$$M_{W_R} \lesssim 25 \left(\frac{m_b}{\text{TeV}}\right)^{1/2}$$

Phenomenology of the bi-doublet Dark matter.

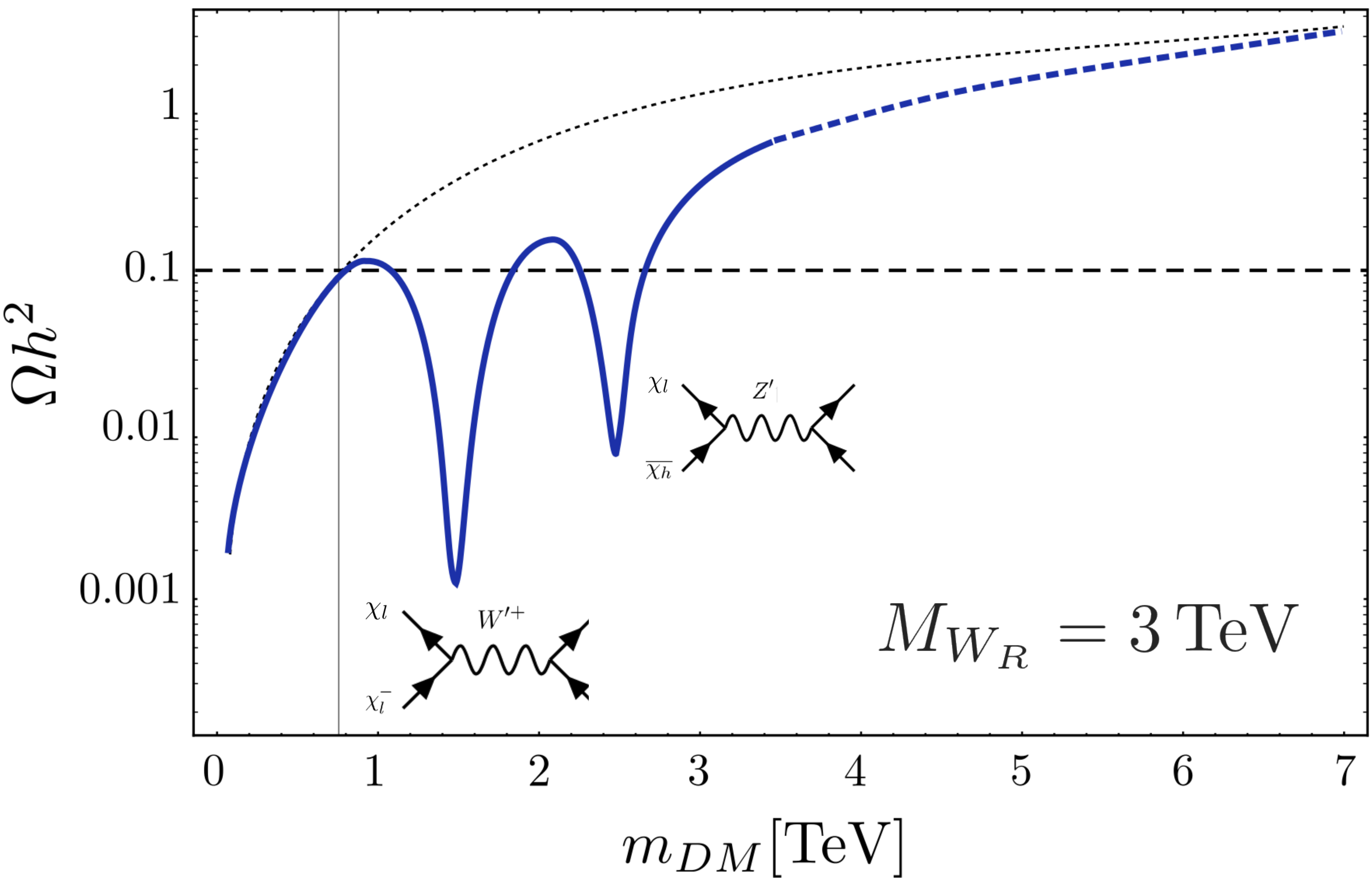
At low energy the model can be viewed as a minimal left-right, gauge theory augmented with a stable bi-doublet DM.

At the level of the SM this results in 2 fermionic doublets.

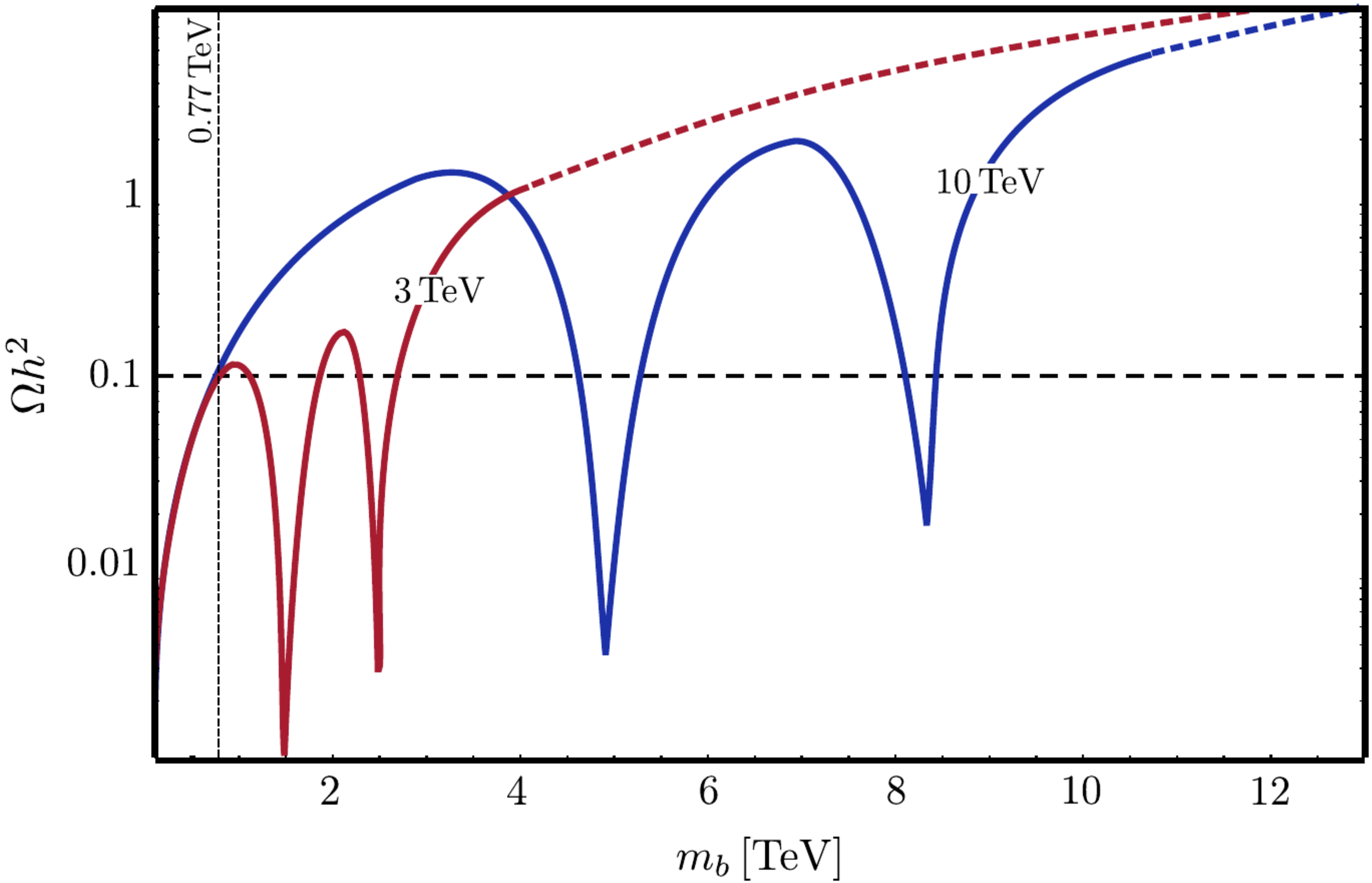
We can study its pheno without worrying of what happens at the GUT scale.



$1.1\,\mathrm{TeV}/\sqrt{2}$
1
0.1
0.01
0.001
Ωh^2
$\Omega h^2 \propto m_{DM}^2$
0
1
2
3
4
5
6
7
$m_{DM}[\mathrm{TeV}]$



Ωh^2
1
0.1
0.01
0.001
0
1
2
3
4
5
6
7
m_{DM}[TeV]
χ_l
Z'
$\overline{\chi_h}$
χ_l
W'^+
χ_l^-
$M_{W_R} = 3\,\mathrm{TeV}$



0.77 TeV
1
0.1
0.01
Ωh^2
3 TeV
10 TeV
2
4
6
8
10
12
m_b [TeV]

Indirect detection

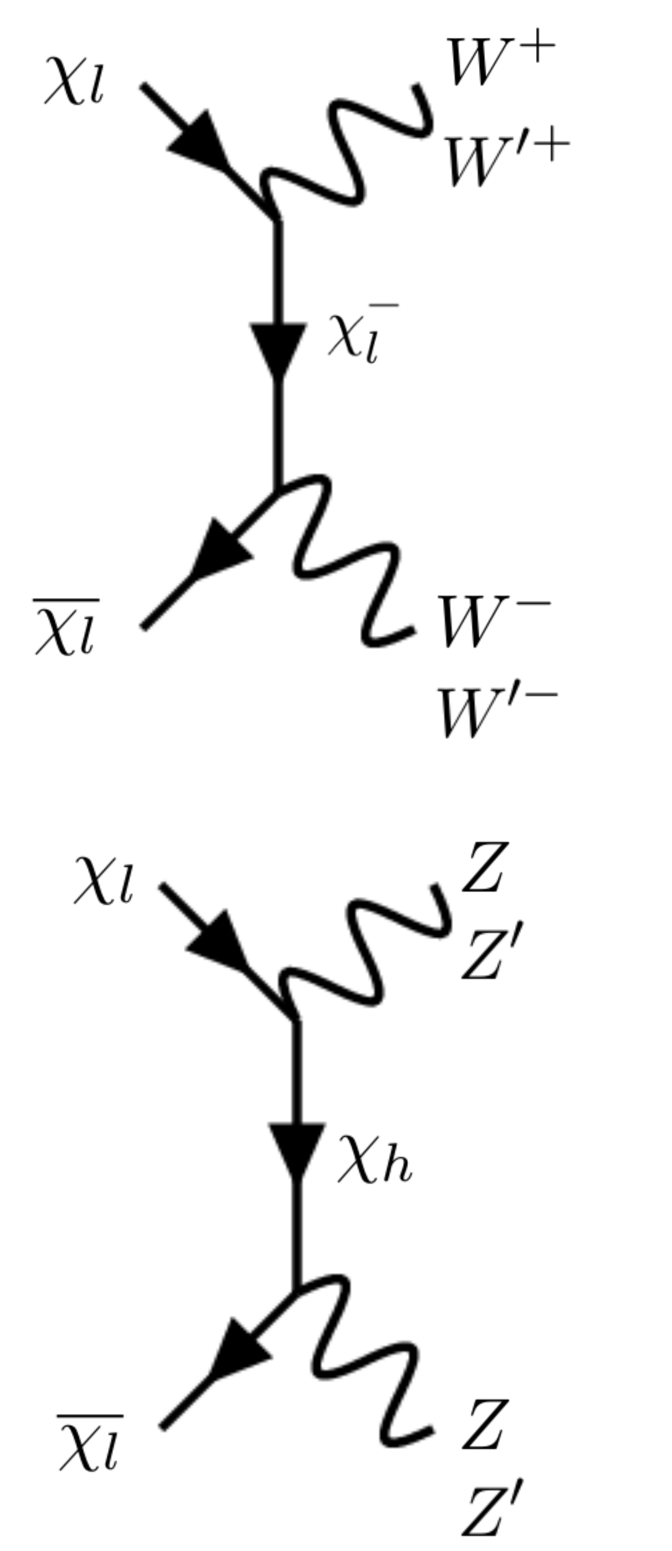
The leading annihilation channel for indirect detection searches is into diboson states.

The signal remains below current limits:

$$\langle \sigma v \rangle \approx 10^{-1.5} \left(\frac{2\,\mathrm{TeV}}{m_{\chi_l}} \right)^2 \langle \sigma v \rangle_{\mathrm{FERMI}}$$

Future observatories like CTA could soon probe some of the allowed regions.

Collider pheno similar to quasi-degenerate Higgsino in split-susy



To conclude …

Non-SUSY **SO(10)** provides a natural framework to motivate WIMP DM. The pheno is rich with possible interplays with neutrino masses, BAU, unification, inflation, and new mass scales.

Simplest possibility consists of adding a **10**-plet, leading to a Left-Right bi-doublet DM.

Direct detection bounds force the LR scale to be low: testable scenario. Interplay DD/LHC.

The leading annihilation channel for indirect detection searches is into diboson states. Interesting for future ID observatories.

Back-up

Decay of the exotic quarks

We consider a minimal **SO(10)** fields content: 3 generations of fermion **16**, and scalars in **126**, **45** and complex **10**.

The exotic D quarks have to decay before BBN. With **SO(10)** gauge bosons we can estimate:

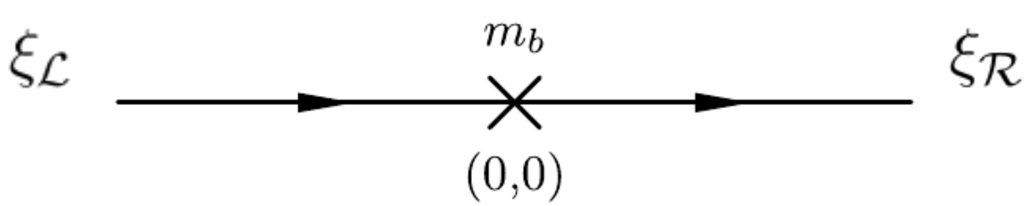
$$D \to \overline{e_L^c}\, Q_L \chi$$

$$\tau_D \approx \frac{8\pi}{g^4} \frac{M_X^4}{M_D^5} \Longrightarrow M_D \gtrsim 1.75 \times 10^8\, g^{-4/5} \left(\frac{M_X}{10^{16}\,\mathrm{GeV}} \right)^{4/5} \mathrm{GeV}$$

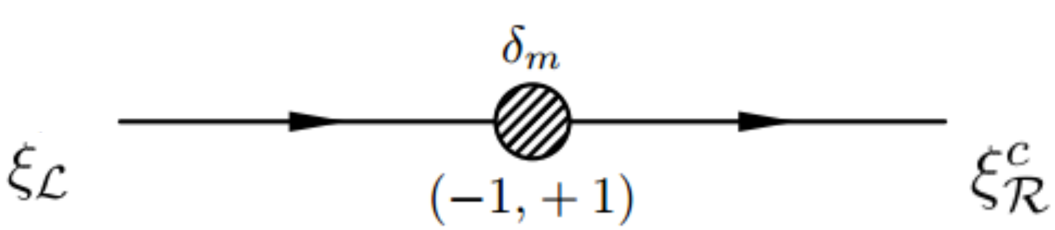
This is the fermionic version of the doublet-triplet splitting and the **45** helps resolving it.

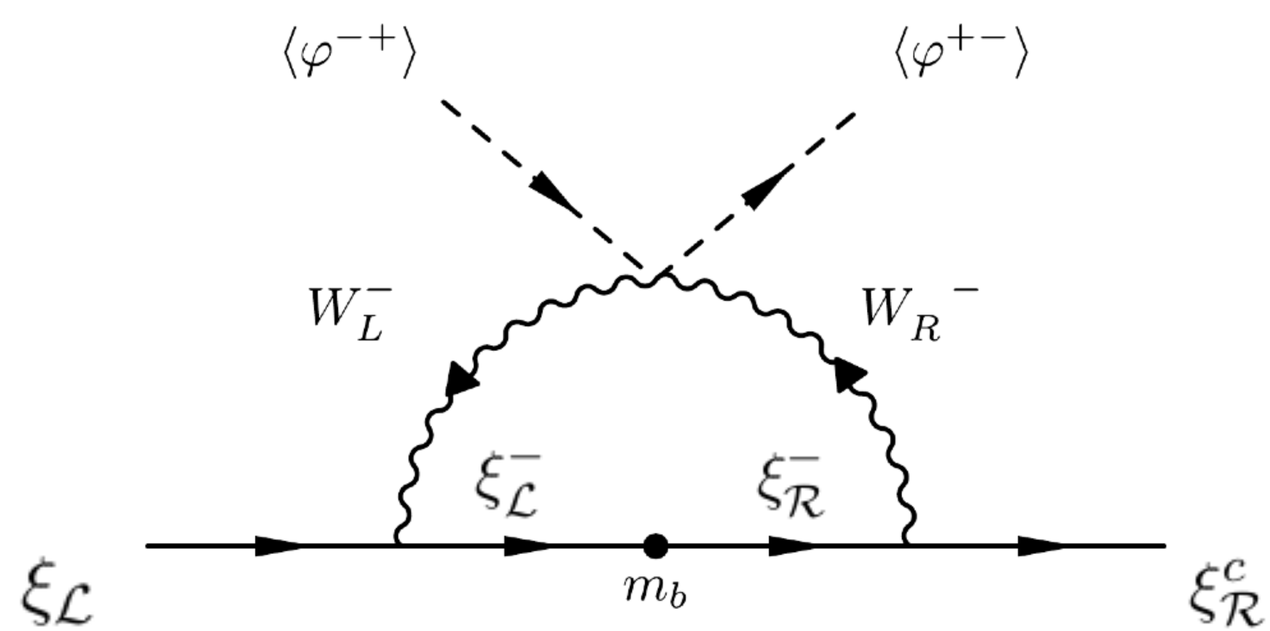
Our DM obtains two mass contributions.

The ''off-diagonal' terms are isospin neutral contributions — aligned with gauge interactions.

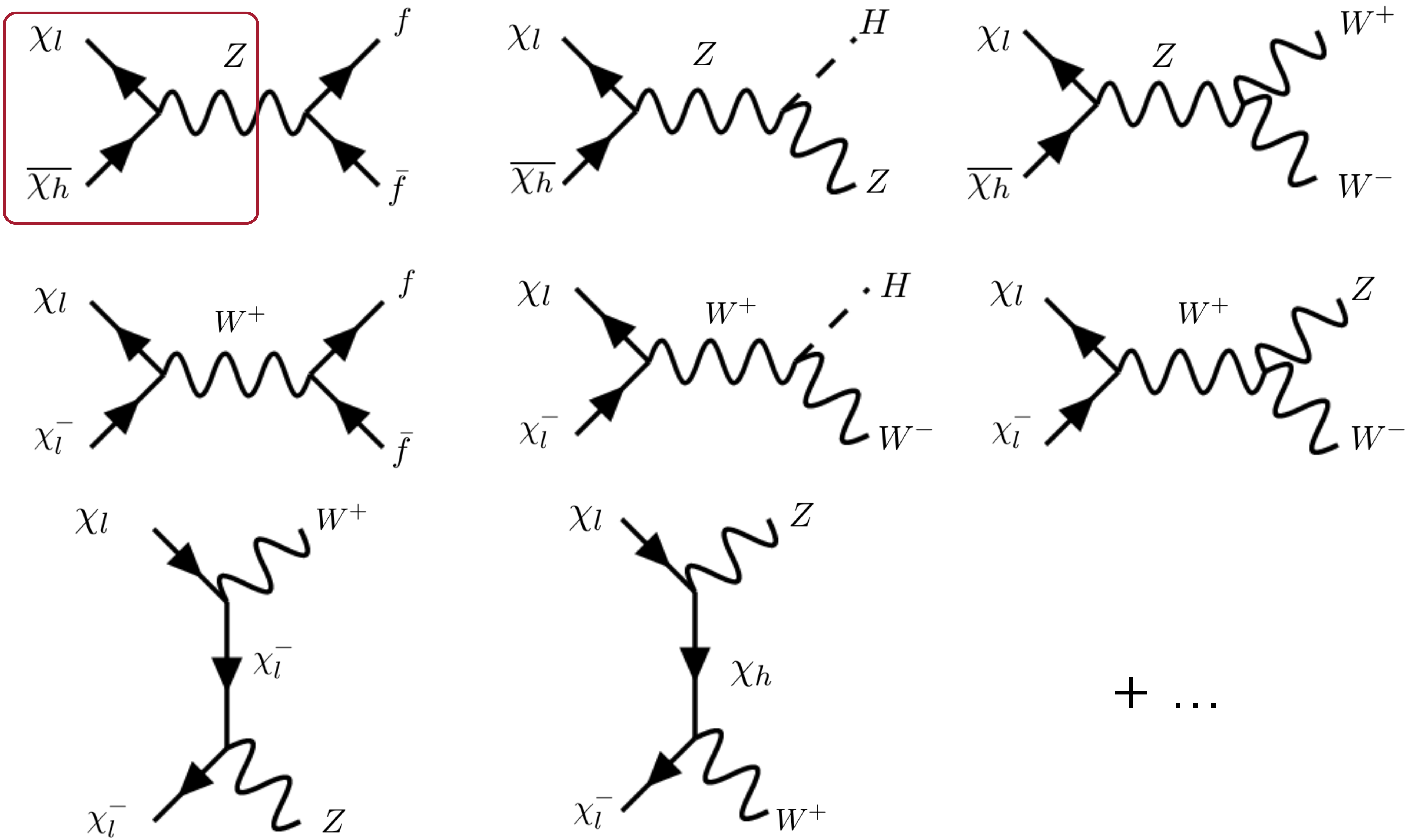


The isospin violating contribution requires an object transforming as a bi-triplet. We can generate it: (**2**,**2**)x(**2**,**2**)=(**3**,**3**)+.. and **10**x**10**=**54**+ …

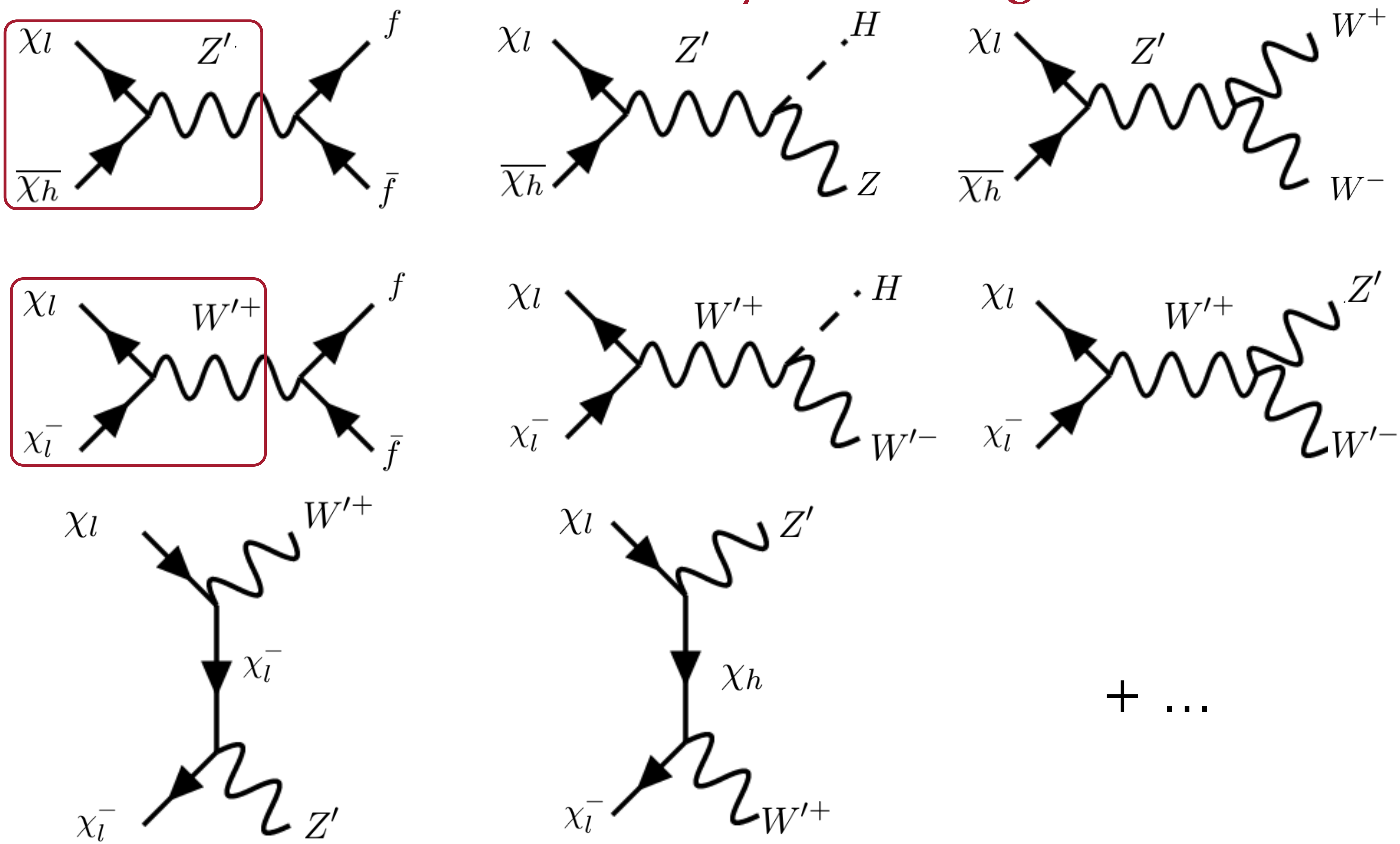




Our Bi-doublet DM has off-diagonal neutral currents



Our Bi-doublet DM has off-diagonal neutral currents … and many more diagrams



Two kinds of splitting

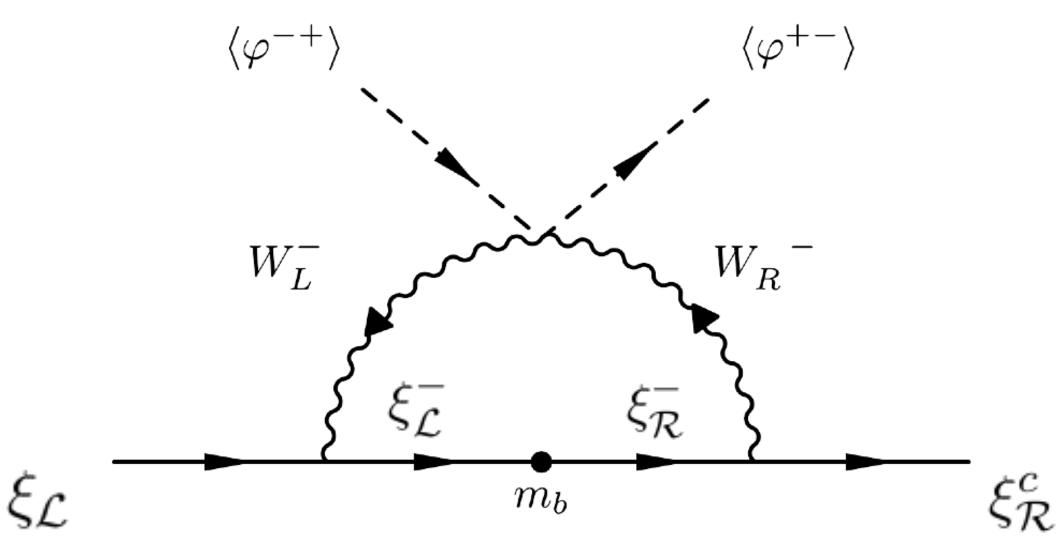
DIRAC

$$\boxed{-\mathcal{L}_{DM} = y\,\mathbf{10}_{\mathcal{L}}\,.\,\mathbf{45}_H\,.\,\mathbf{10}_{\mathcal{R}}}$$

$$y\,\overline{\mathbf{10}_{\mathcal{L}}}.\mathbf{45}_H.\mathbf{10}_{\mathcal{R}} \supset m_b(\overline{\xi_{\mathcal{R}}}\xi_{\mathcal{L}} + h.c.)$$

$$\begin{pmatrix} \xi & \xi^+ \\ \xi^- & \xi^c \end{pmatrix}_{\mathcal{L}} \qquad \begin{pmatrix} \xi & \xi^+ \\ \xi^- & \xi^c \end{pmatrix}_{\mathcal{R}}$$

W_L W_R



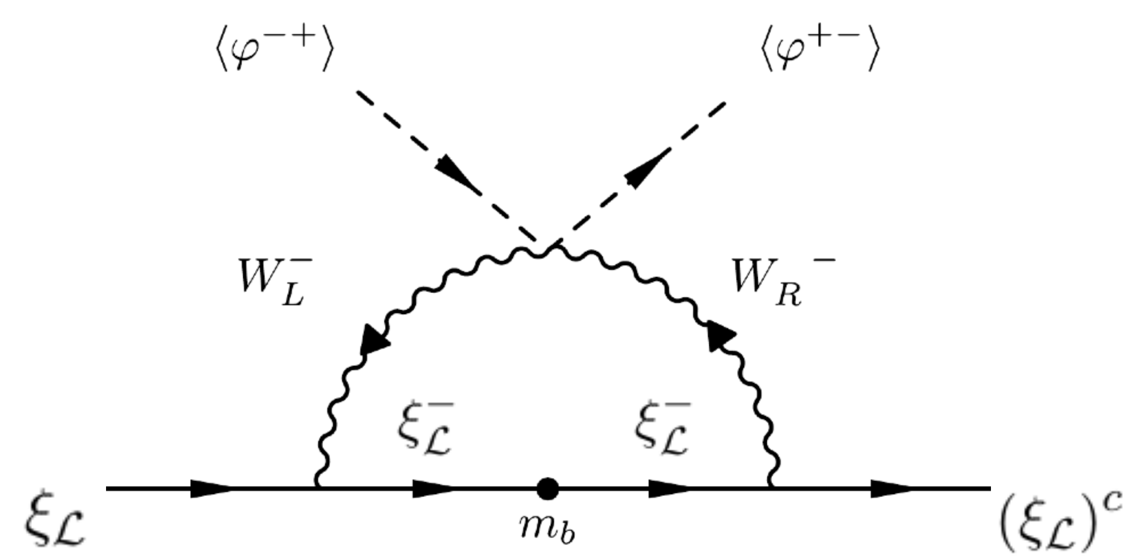
MAJORANA

$$\boxed{-\mathcal{L}_{DM} = m_b\,\mathbf{10}_{\mathcal{L}}\,.\,\mathbf{10}_{\mathcal{L}}}$$

$$m_b\,\mathbf{10}_{\mathcal{L}}^T C\mathbf{10}_{\mathcal{L}} \supset m_b(\xi_{\mathcal{L}}^{cT} C\xi_{\mathcal{L}} + h.c.) = m_b(\overline{\xi_{\mathcal{R}}}\xi_{\mathcal{L}} + h.c.)$$

W_R W_L

$$\begin{pmatrix} \xi & \xi^+ \\ \xi^- & \xi^c \end{pmatrix}_{\mathcal{L}}$$



Two kinds of splitting

DIRAC

$$-\mathcal{L}_{DM} = y\,\mathbf{10}_{\mathcal{L}}\,.\,\mathbf{45}_H\,.\,\mathbf{10}_{\mathcal{R}}$$

- 2 Dirac neutral fermions
- 2 Charged fermions
- Exotic Quarks naturally decoupled

MAJORANA

$$-\mathcal{L}_{DM} = m_b\,\mathbf{10}_{\mathcal{L}}\,.\,\mathbf{10}_{\mathcal{L}}$$

- 2 Majorana fermions
- 1 Charged fermion

In both cases:

$$m_{h^-,l^-} \approx m_{h,l} + 340\,\mathrm{MeV}$$

$$m_{h,l} = m_b \pm \delta_m$$

$$\boxed{J_\mu^{NC} \propto \chi_h \gamma_\mu \chi_l}$$