A simplified model of heavy vector singlets at the LHC and future colliders

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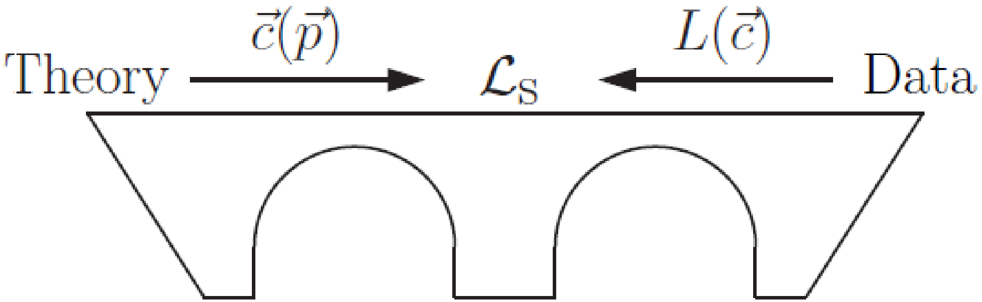
May 16

Simplified models

Simplified models provide a model-independent framework for doing collider physics phenomenology:

- Only consider one or two new particles/interactions
- Incredibly useful for direct searches of BSM physics



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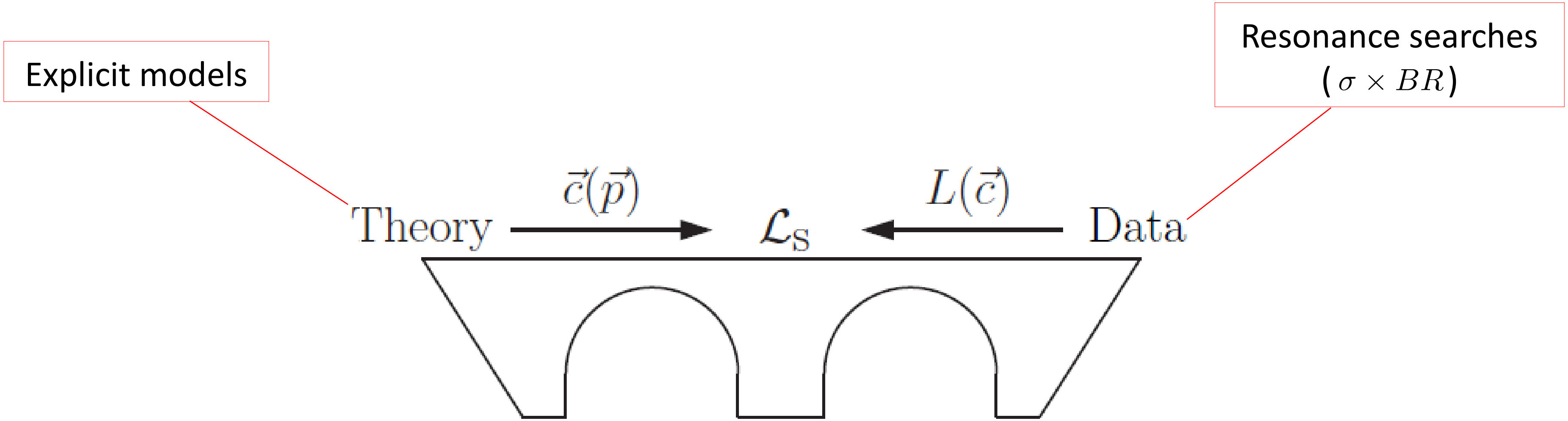

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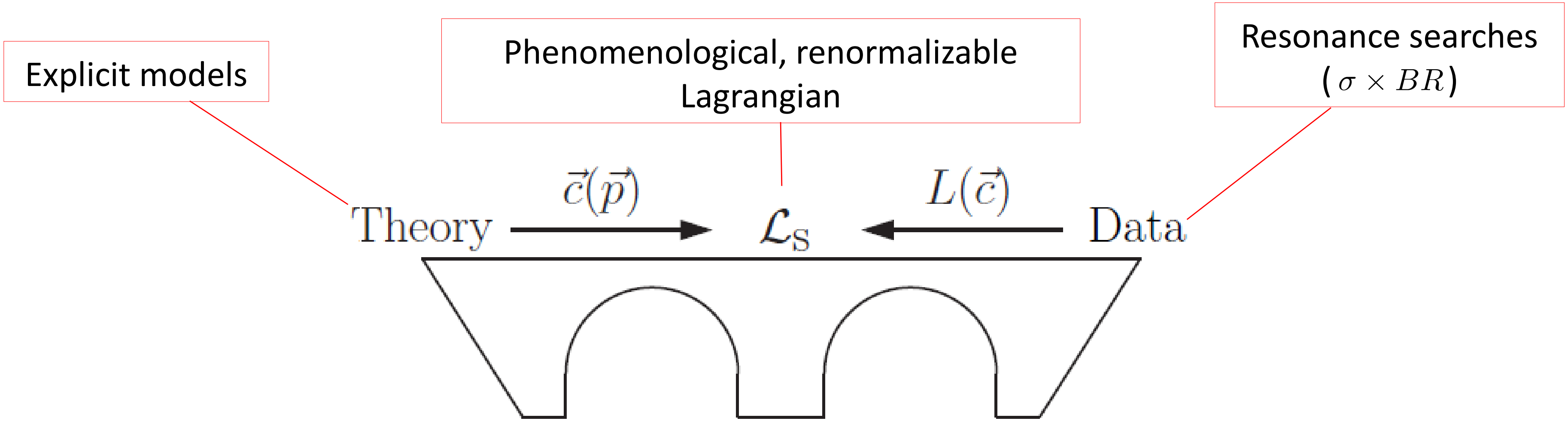

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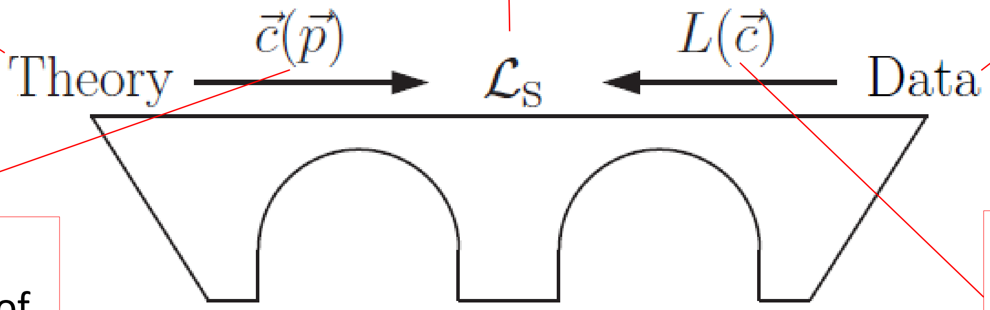
Explicit models

Phenomenological, renormalizable Lagrangian

Resonance searches ($\sigma \times BR$)



Simplified parameters expressible as functions of explicit model parameters

Experimental limits converted into limits on simplified parameters

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Heavy vector singlets

Introduce two new vectors that transform as

$$V^0 \sim (\mathbf{1}, \mathbf{1}, 0) \qquad \mathcal{L}_{V^0} \supset i\frac{g_V}{2} c_H^0 V_\mu^0 H^\dagger \overleftrightarrow{D}^\mu H + \frac{g_V}{2} c_\Psi^0 V_\mu^0 J_\Psi^\mu$$

$$V^\pm \sim (\mathbf{1}, \mathbf{1}, \pm 1) \qquad \mathcal{L}_{V^+} \supset i\frac{g_V}{\sqrt{2}} c_H^+ V_\mu^+ H^\dagger \overleftrightarrow{D}^\mu \tilde{H} + \frac{g_V}{\sqrt{2}} c_q^+ V_\mu^+ J_q^\mu$$

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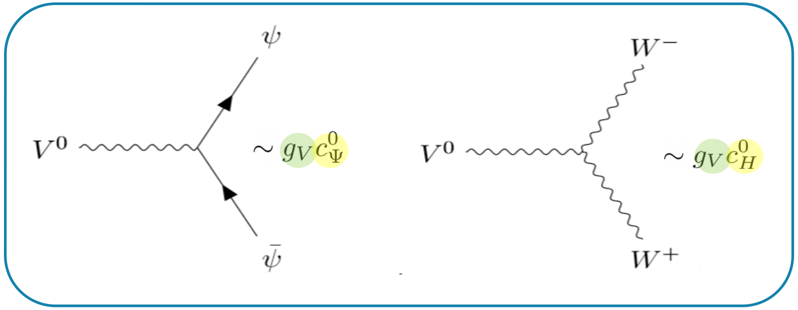

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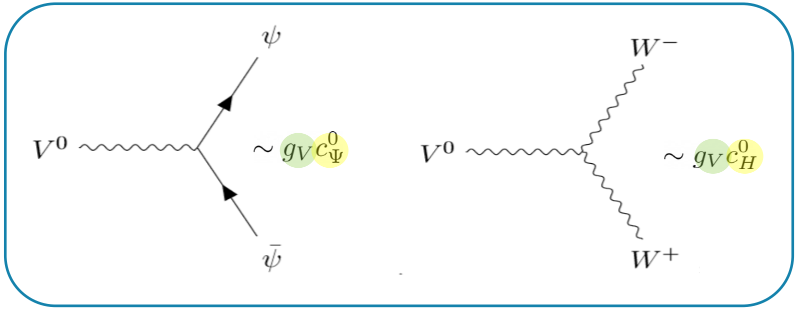

The combinations $g_V c_X$ parameterise decay rates and cross sections

$$\sigma \times BR \propto (g_V c_X)^2 \times (g_V c_Y)^2$$

These "simplified" parameters provide a bridge between experiment and UV complete models, with very broad applicability to BSM theories

Two-body final states

Many decay channels are open to exploration under the simplified model, and it is easy to combine searches. For heavy vector singlets, the neutral vector decays to leptons/quarks/bosons, and the charged vector decays to quarks/bosons:

Channel	$V^0 \in (\mathbf{1},\mathbf{1})_0$	$V^+ \in (\mathbf{1},\mathbf{1})_1$
ll	✓	✗
$l\nu$	✗	✗
$l\nu_R$	✗	✓
jj	✓	✓
tb	✗	✓
tt	✓	✗
WW	✓	✗
ZZ	✗	✗
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$W\gamma$	✗	✓
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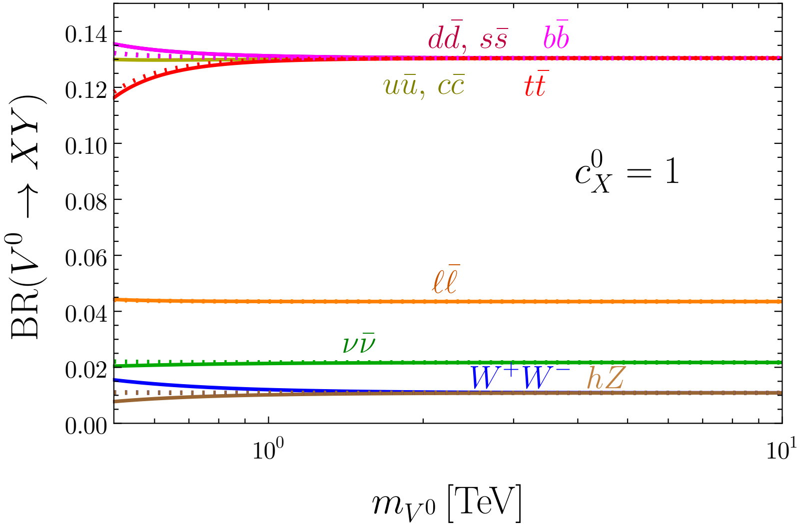

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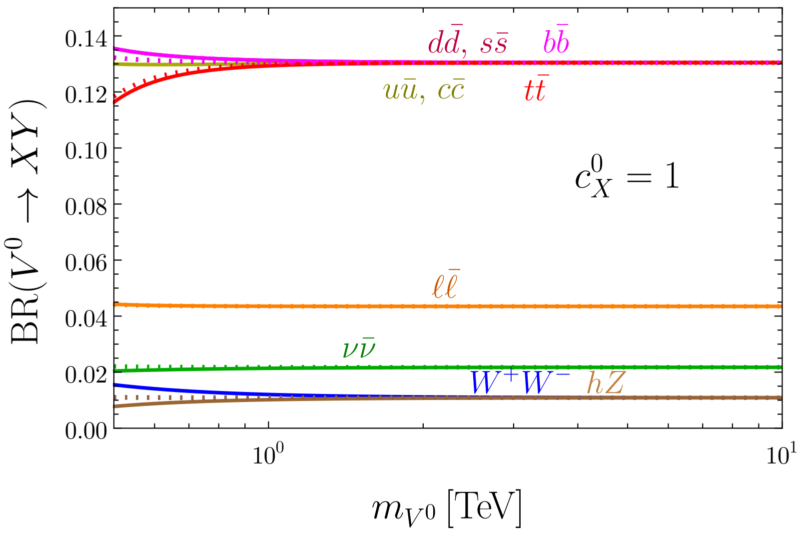

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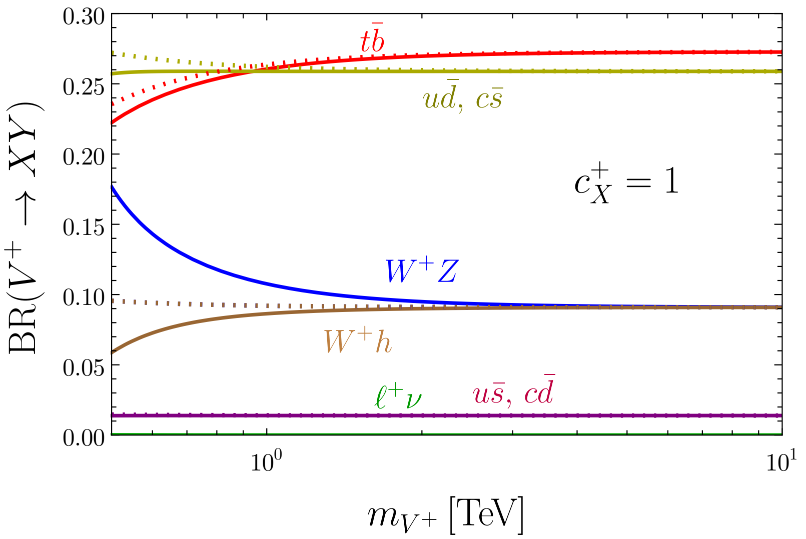

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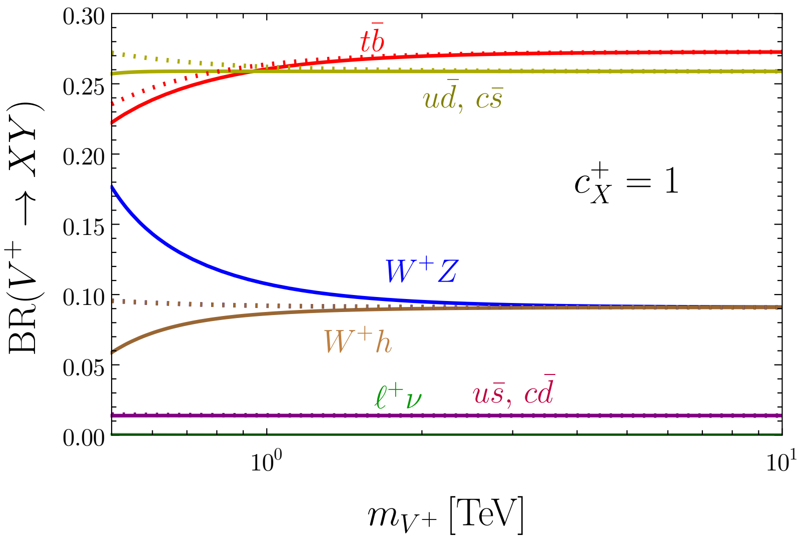
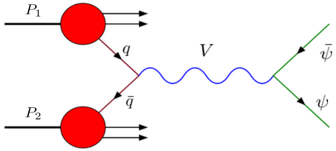


Limits on σ: current and future colliders

Under the narrow width approximation, the DY production cross-section goes as the (inverse partial widths) x (parton luminosities):



$$\sigma \propto \Gamma_{V\rightarrow q\bar{q}'}\frac{dL_{q\bar{q}'}}{d\hat{s}}$$

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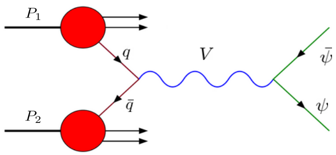

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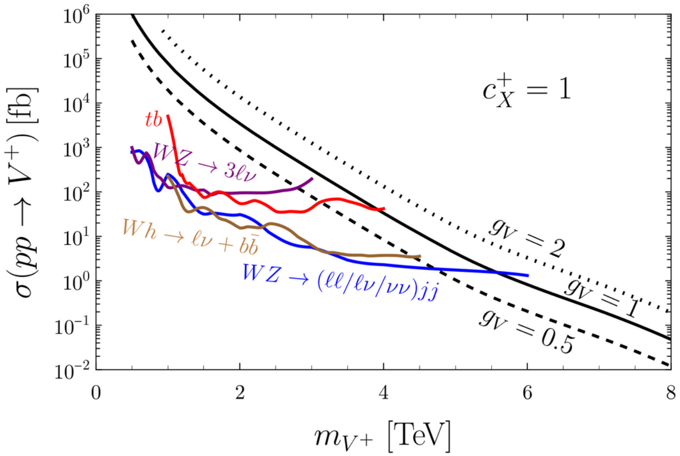

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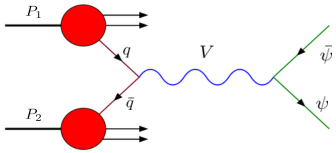

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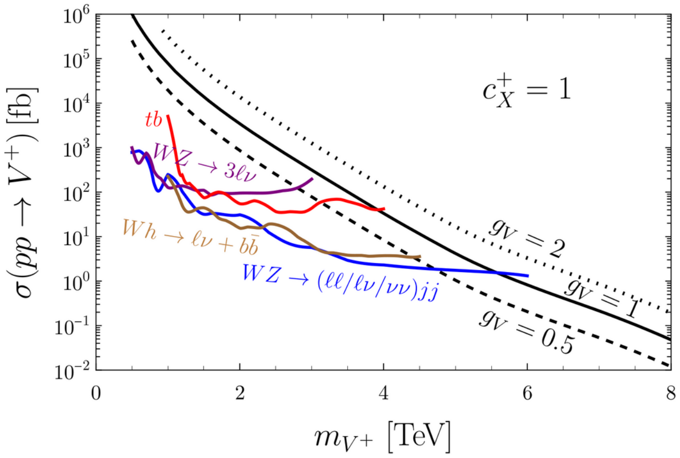

We can extrapolate to future colliders of energy S and luminosity L. Only need to know the parton luminosities at appropriate CoM energy.

A. Thamm, R. Torre, A. Wulzer: 1502.01701

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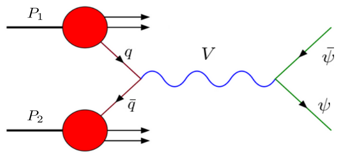

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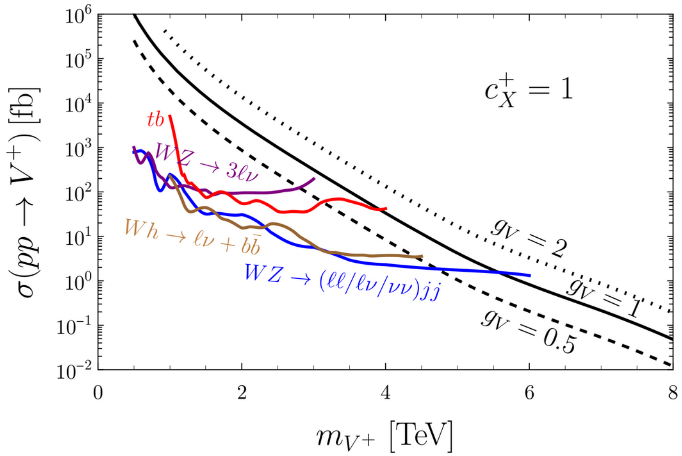

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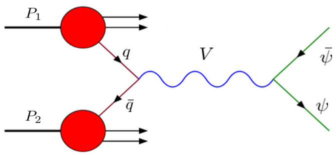

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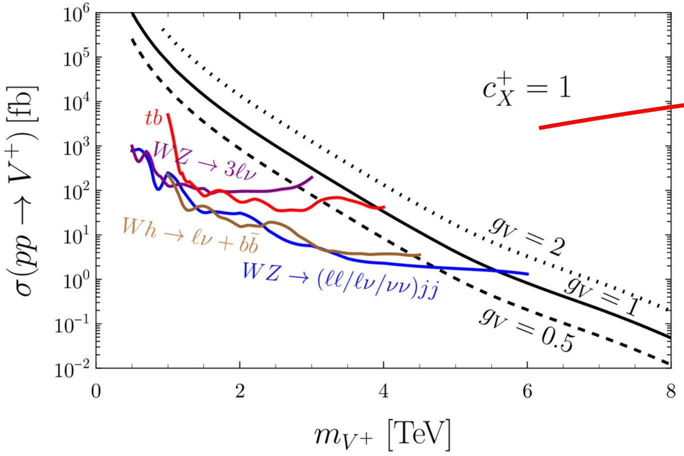
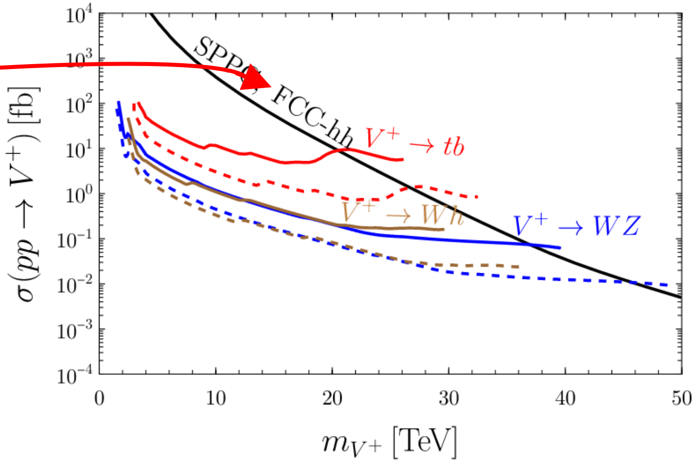
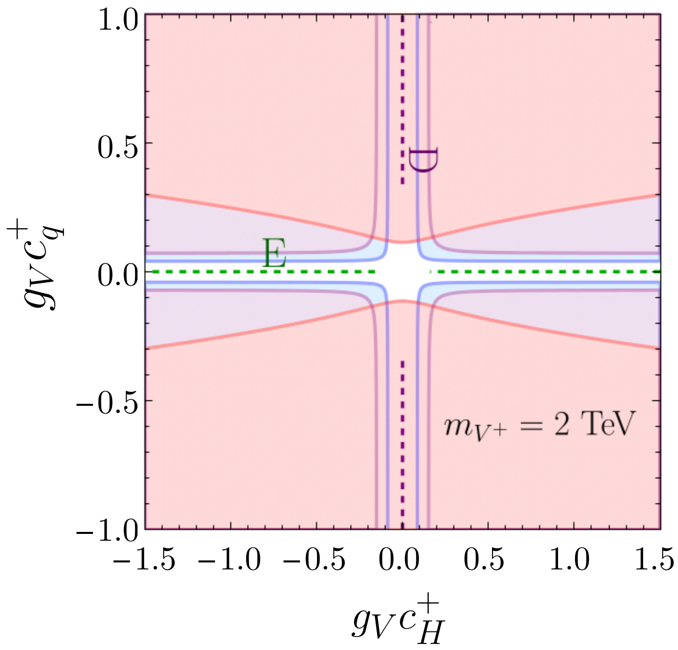


~Order of magnitude higher mass reach than the LHC!



Limits on the simplified model

Experimental limits on the cross-section times branching ratio are readily converted into limits in the simplified parameter space:



Shaded regions correspond to various ATLAS & CMS searches

Explicit models easily mapped onto this space:

- Model D – weakly coupled gauge extension
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Zero quark coupling in model E → inaccessible to Drell-Yan

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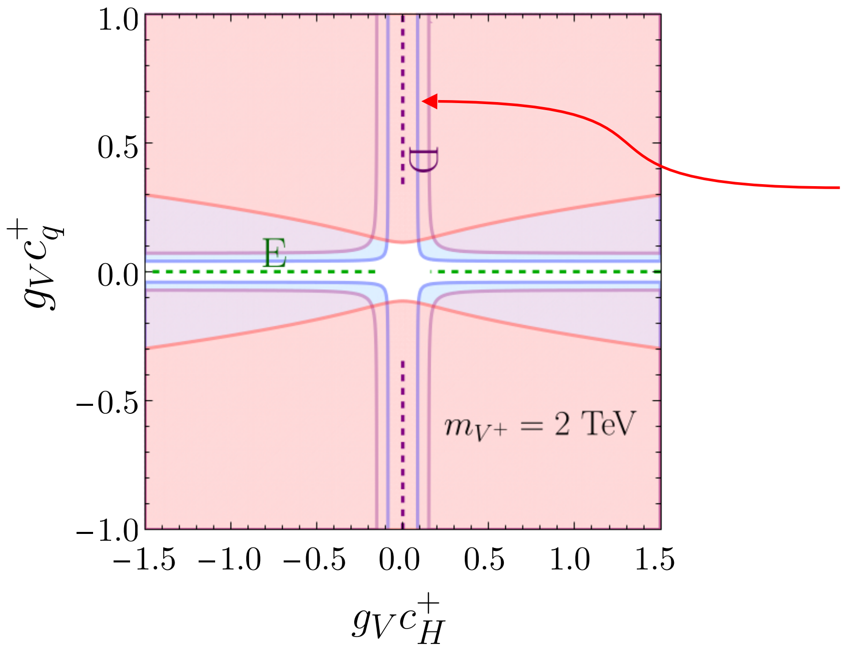

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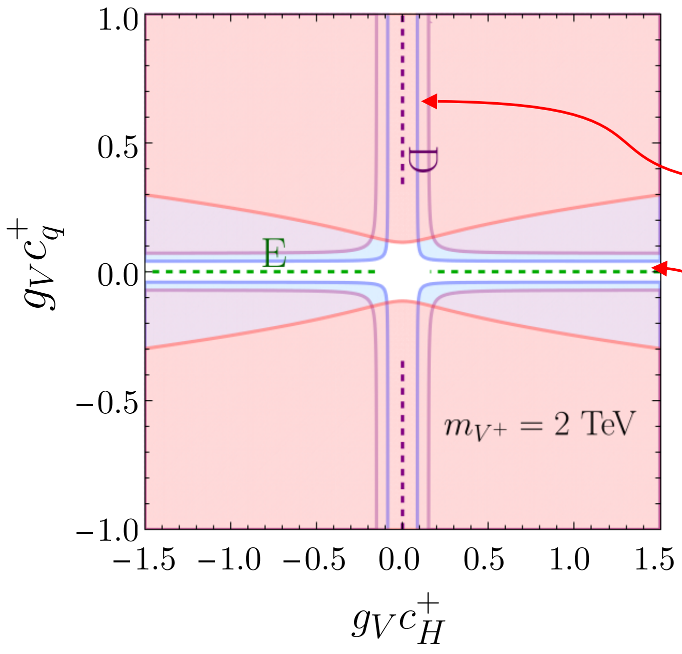

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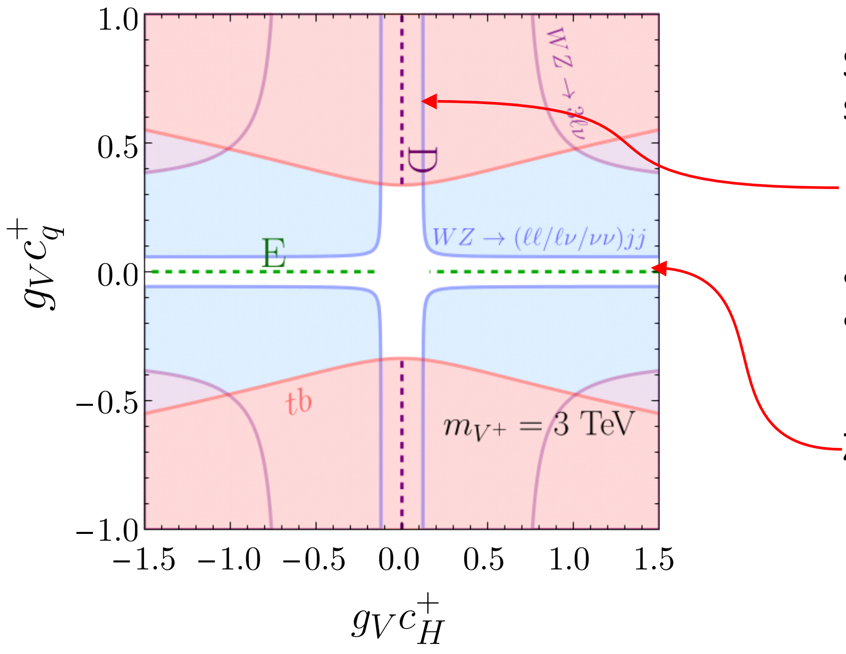

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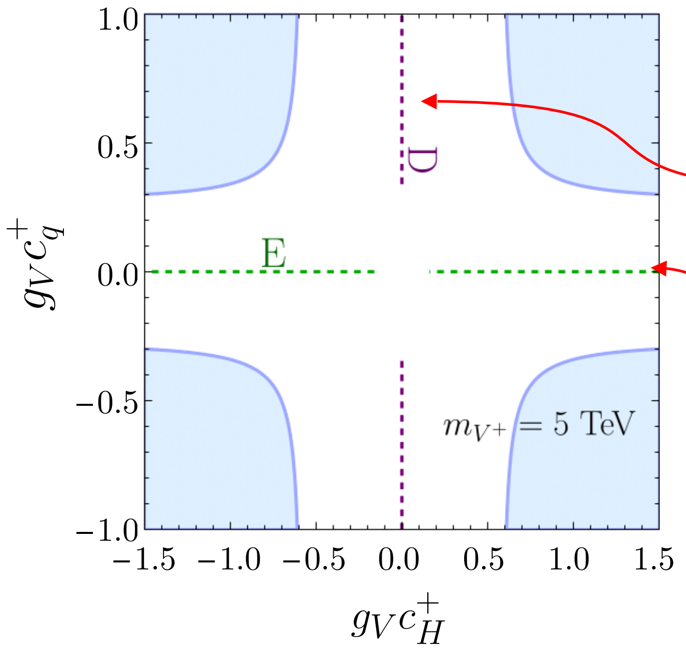

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	Model C			Model D	Model E
	$U(1)_{B-xL}$	$U(1)_R$	$U(1)_{q+xu}$	$SU(2)_R \times U(1)_X$	$SO(5)/SO(4)$
g_V	g_X	g_X	g_X	g_R	g_ρ
$m_{\mathcal{V}^0}$	$m_{\mathcal{V}^0}$	$m_{\mathcal{V}^0}$	$m_{\mathcal{V}^0}$	$\frac{g_V v_R}{2k_V}$	$\frac{m_\rho}{k_V}$
c_Q^0	$\frac{2}{3}$	0	$\frac{2}{3}$	$-2Y_Q\frac{g'^2}{g_V^2 k_V}$	$2Y_Q\frac{g'^2}{g_V^2 k_V}$
c_U^0	$\frac{2}{3}$	$-\frac{2}{3}$	2x/3	$\frac{1}{k_V} - 2Y_U\frac{g'^2}{g_V^2 k_V}$	$2Y_U\frac{g'^2}{g_V^2 k_V}$
c_D^0	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2(2-x)}{3}$	$-\frac{1}{k_V} - 2Y_D\frac{g'^2}{g_V^2 k_V}$	$2Y_D\frac{g'^2}{g_V^2 k_V}$
c_L^0	$-2x$	0	-2	$-2Y_L\frac{g'^2}{g_V^2 k_V}$	$2Y_L\frac{g'^2}{g_V^2 k_V}$
c_E^0	$-2x$	$\frac{2}{3}$	$-\frac{2(2+x)}{3}$	$-\frac{1}{k_V} - 2Y_E\frac{g'^2}{g_V^2 k_V}$	$2Y_E\frac{g'^2}{g_V^2 k_V}$
c_H^0	0	$-\frac{2}{3}$	$\frac{2(x-1)}{3}$	k_V	$-\frac{1}{k_V}\left(a_\rho^2 - \frac{g'^2}{g_V^2}\right)$
c_{VVHH}^0	0	$\frac{4}{9}$	$\frac{4(x-1)^2}{9}$	$\frac{k_V^2}{4}$	$-\frac{g'^2}{2g_V^2 k_V^2}\left(a_\rho^2 - \frac{g'^2}{2g_V^2}\right)$

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g_V	g_X	g_X	g_X	g_R	g_ρ
$m_{\mathcal{V}^+}$	∞	∞	∞	$\frac{g_V v_R}{2}$	m_ρ
c_q^+	-	-	-	1	0
c_H^+	-	-	-	0	$-\frac{a_\rho^2}{2}$
c_{VVHH}^+	-	-	-	$\frac{1}{4}$	0
c_{VVB}^+	-	-	-	1	1
c_{VVV}^0	-	-	-	k_V	$-k_V$
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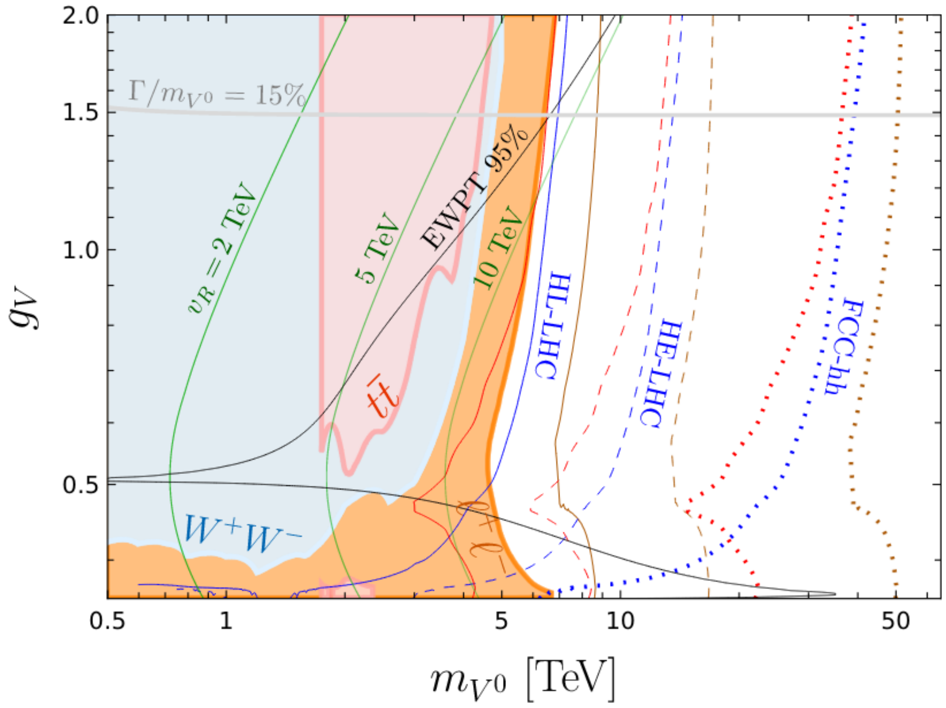
<u>Model D</u>: $SU(2)_R \times U(1)_X$

Asymmetric left-right gauge extension



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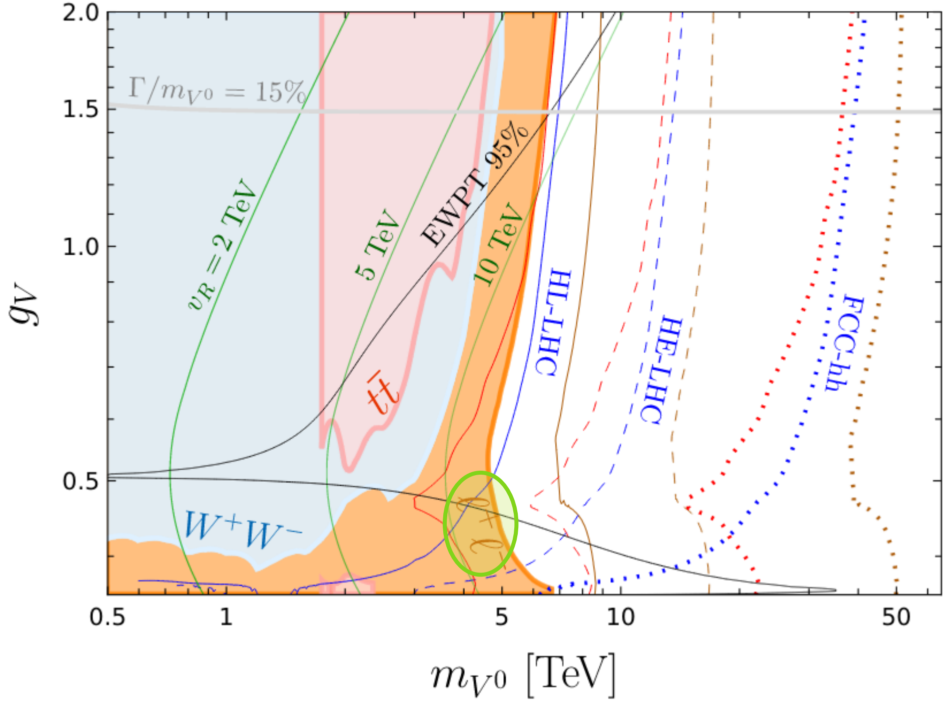

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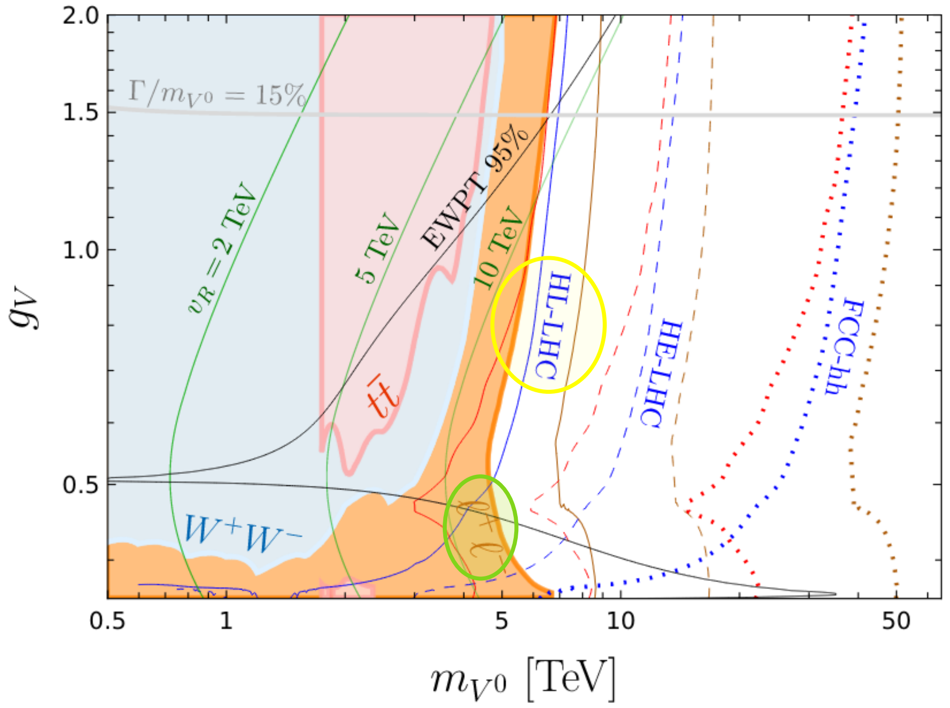

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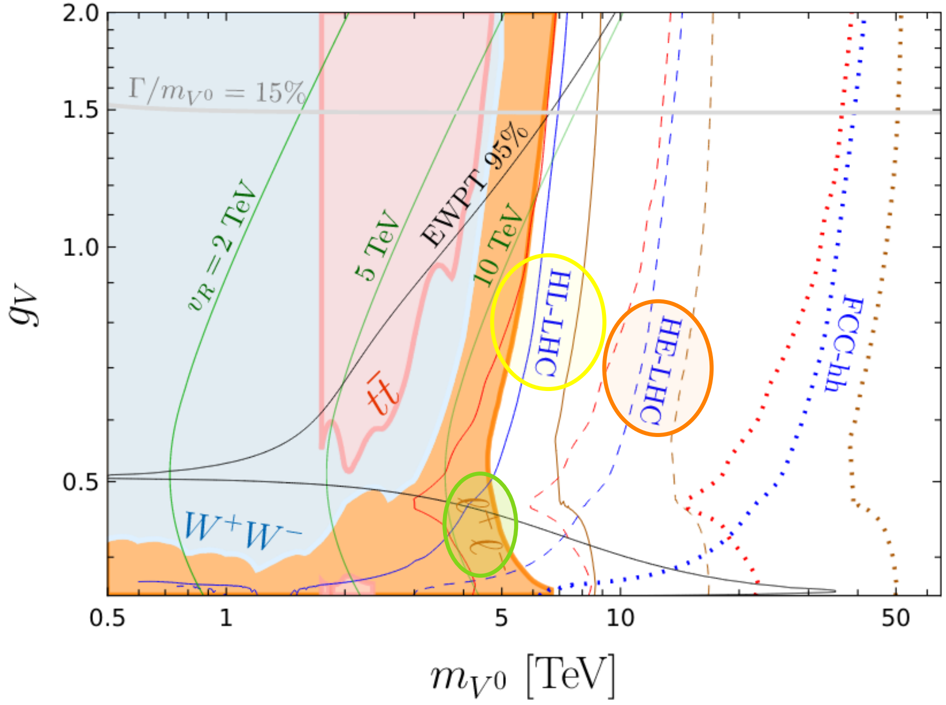

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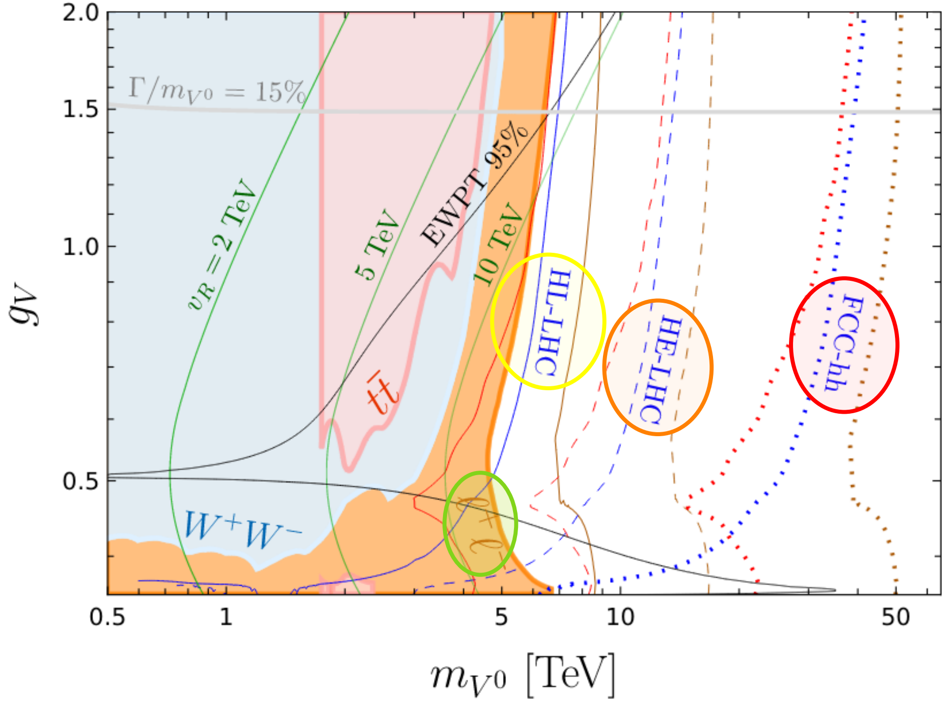

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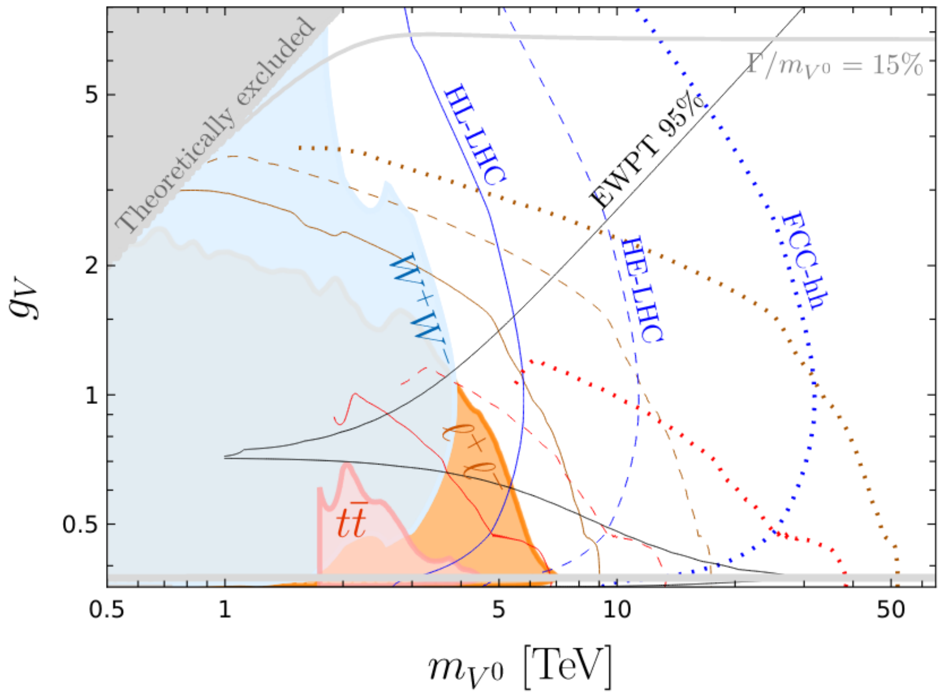
<u>Model E</u>:

Composite Higgs (strongly coupled)



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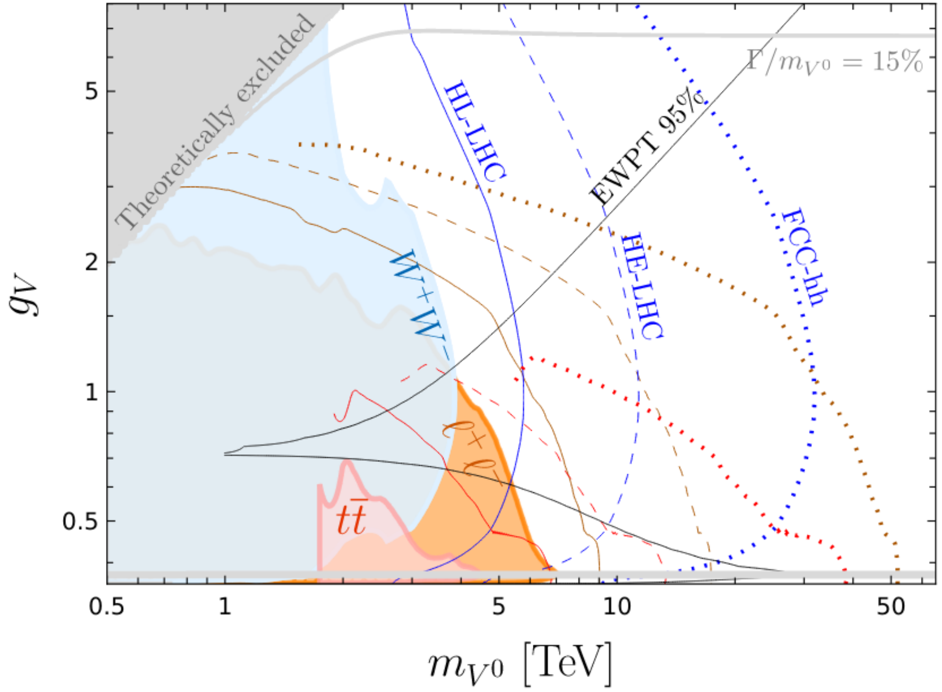

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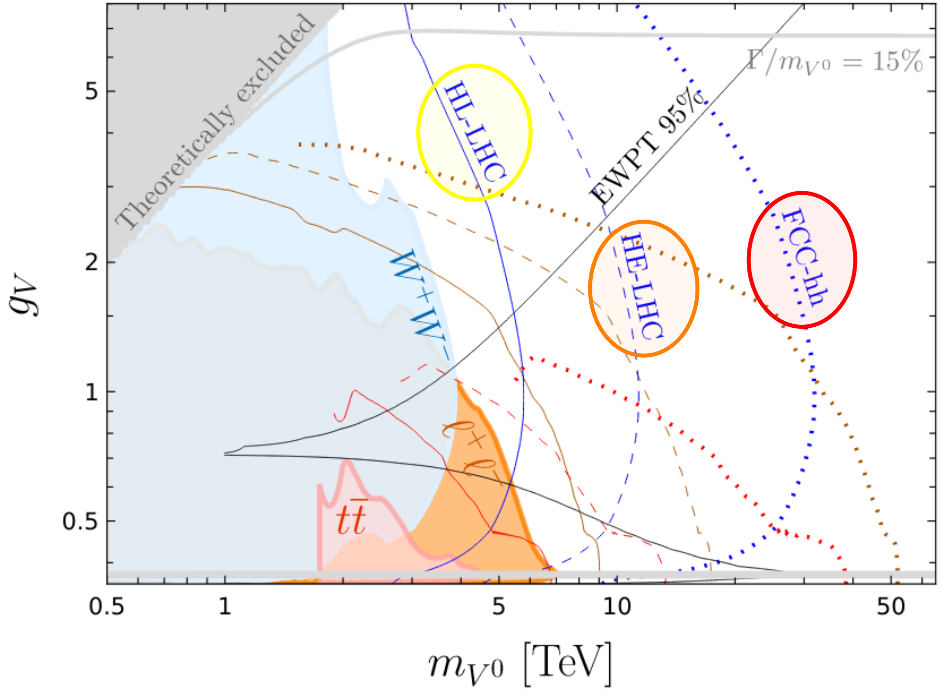
- Future:

  14 TeV HL-LHC - 9 TeV
  27 TeV HE-LHC - 17 TeV
  100 TeV FCC-hh - 50 TeV



Summary

Model-independent analyses are essential tools to bridge the theoretical world of model building and the experimental world of resonance searches

- Simplified models are heavily used in collider phenomenology, allowing for a quick and easy comparison with many explicit models
- Vector singlets are a common prediction of BSM theories (weakly coupled gauge extensions, composite Higgs), and we can determine which of these theories the current LHC can probe/rule out
- We can easily project current limits to future colliders of higher energy/luminosity for a rough sense of their reach
- The energy frontier remains key in exploring the wide range of BSM physics theories