The role of vector boson fusion in the production of heavy vector triplets at the LHC and HL-LHC

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Based on arXiv:2207.05091

THE UNIVERSITY OF MELBOURNE

The LHC: Beyond the Standard Model

- 27km ring of superconducting magnets
- Oppositely-travelling proton beams collide at 0.99999999c
- 14 TeV centre-of-mass energy

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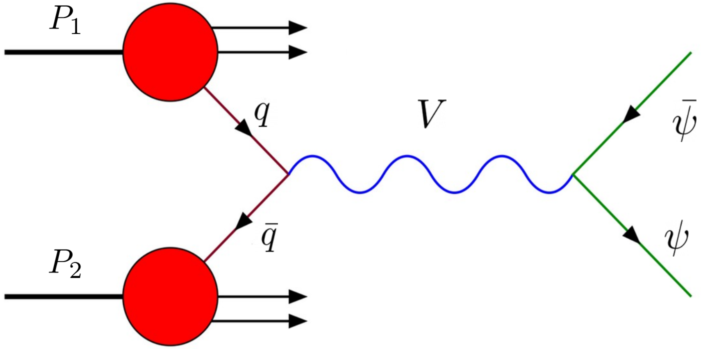

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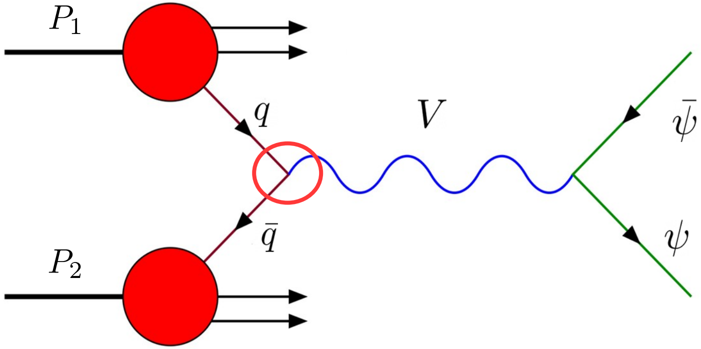

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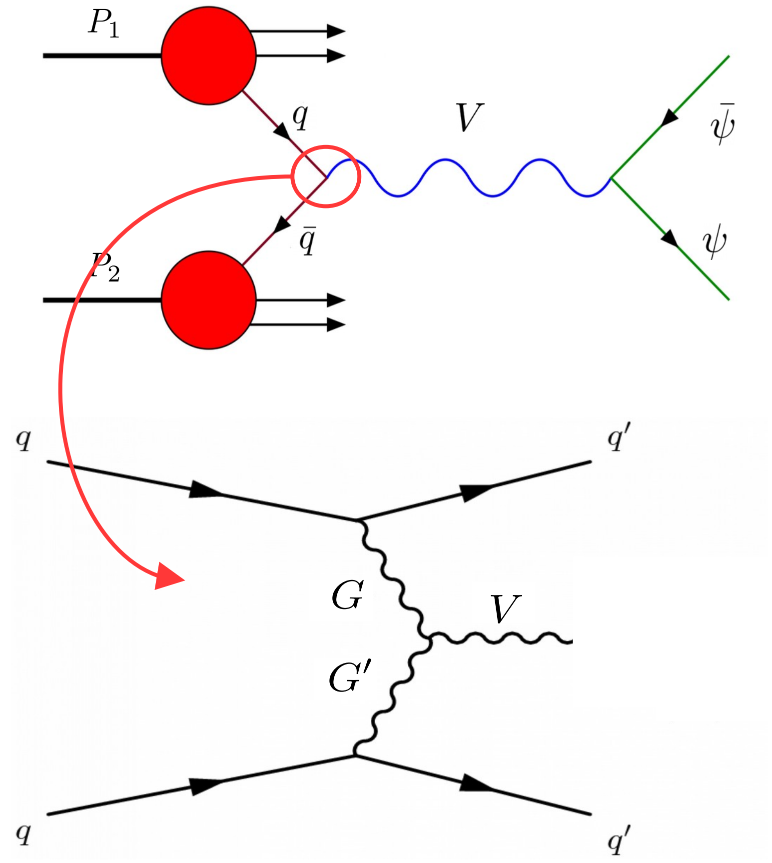

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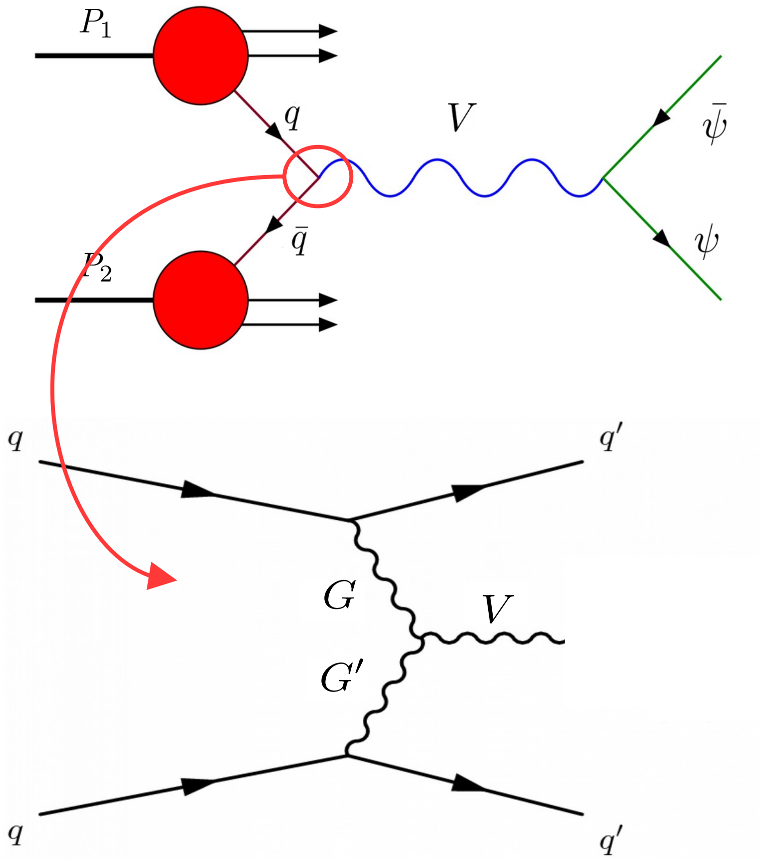
-- Parton luminosity
-- Parton-level cross section



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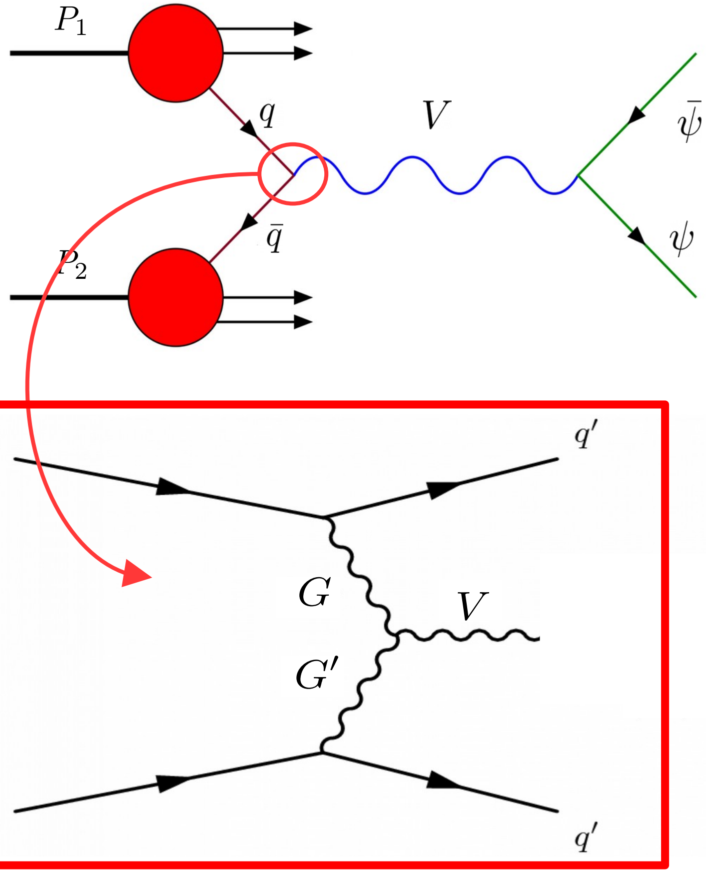

A simplified model of heavy vector triplets

Simplified models are a useful framework for connecting a variety of BSM theories with experimental data. We introduce the vector

$$V^a \sim (\mathbf{1}, \mathbf{3}, 0),\ a = 1,\ 2,\ 3$$

- Mass eigenstates V^0 and $V^\pm$
- Phenomenological Lagrangian describes interactions with the field content of the Standard Model:

$$\mathcal{L}_V \supset -\frac{1}{4} D_{[\mu} V^a_{\nu]} D^{[\mu} V^{\nu]\,a} + \frac{m_V^2}{2} V^a_\mu V^{\mu\,a} + i\, g_V c_H V^a_\mu H^\dagger \tau^a \overleftrightarrow{D}^\mu H$$
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$$\sigma \times BR \propto c^2_{q,H} \times c^2_{q,H,\ell}$$

Production cross section

Is there a region in the simplified parameter space where VBF is the dominant production mode?

$$\sigma(pp \to V + X) \quad = N_{\rm DY} \sum_{q,\bar{q}' \in p} \frac{\Gamma_{V \to q\bar{q}'}}{M_V} \frac{dL_{q\bar{q}'}}{d\hat{s}}\Big|_{\hat{s}=M_V^2} + N_{\rm VBF} \sum_{G,G' \in p} \frac{\Gamma_{V \to GG'}}{M_V} \frac{dL_{GG'}}{d\hat{s}}\Big|_{\hat{s}=M_V^2}$$

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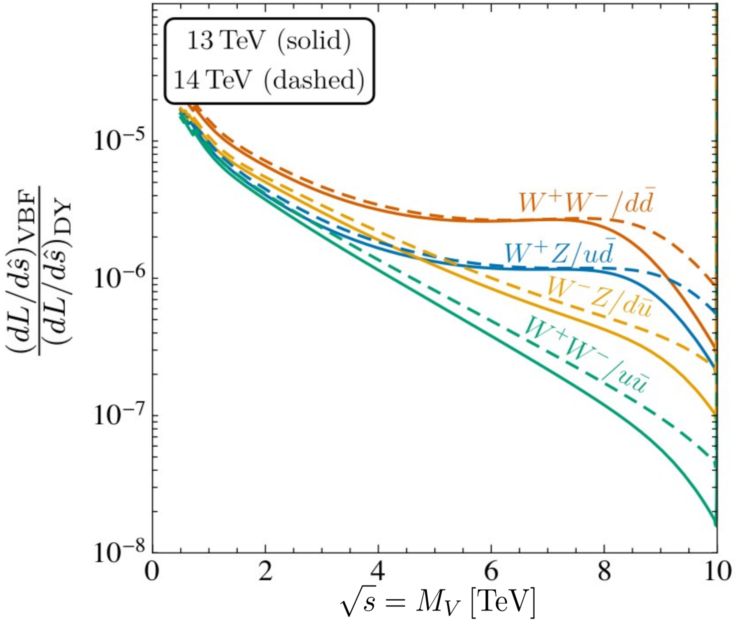

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Decay widths and c_q, c_H

The relationship between c_q and c_H determines VBF's viability

$$\Gamma_{V^\pm \to W_L^\pm Z_L} \simeq \Gamma_{V^0 \to W_L^+ W_L^-} \simeq \Gamma_{V^\pm \to W_L^\pm h} \simeq \Gamma_{V^0 \to Z_L h} \simeq \frac{g_V^2 c_H^2 M_V}{192\pi}$$

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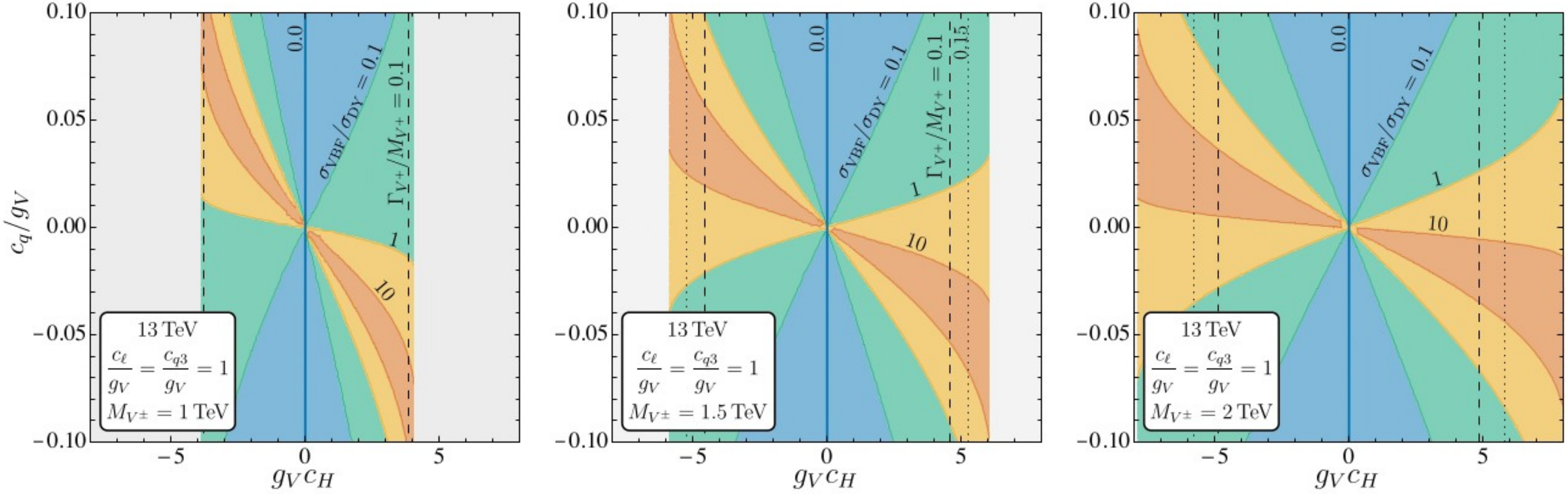
Order one for $g_V \sim c_H \sim c_q \sim 1$

- For VBF to overcome DY (whilst still satisfying the narrow width approximation), we require that

$$c_q / g_V \lesssim 0.05$$

VBF production can dominate



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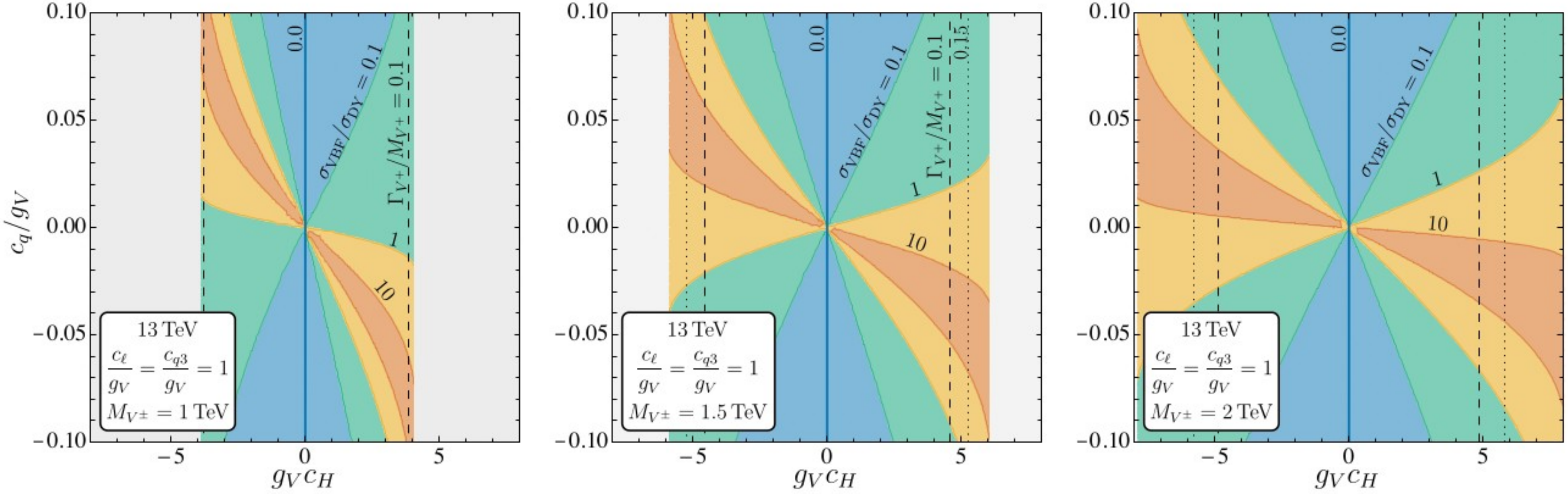

Viable area increases with resonance mass

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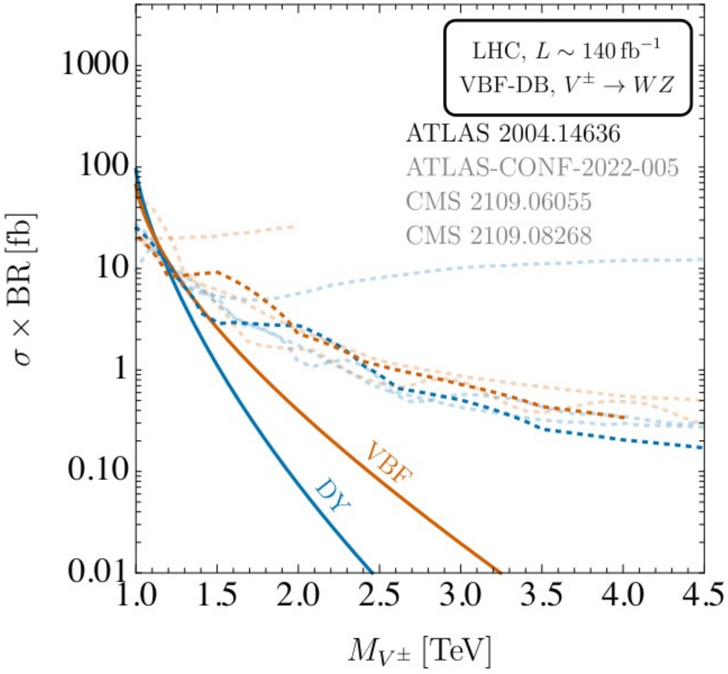
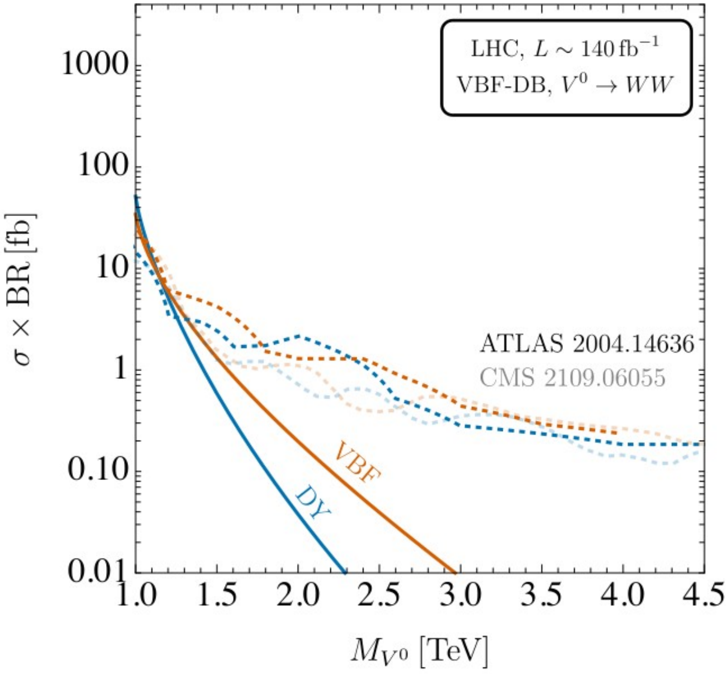
Experimental limits on the cross section are given for some final state. For a given resonance mass, what parameter combinations are not ruled out?





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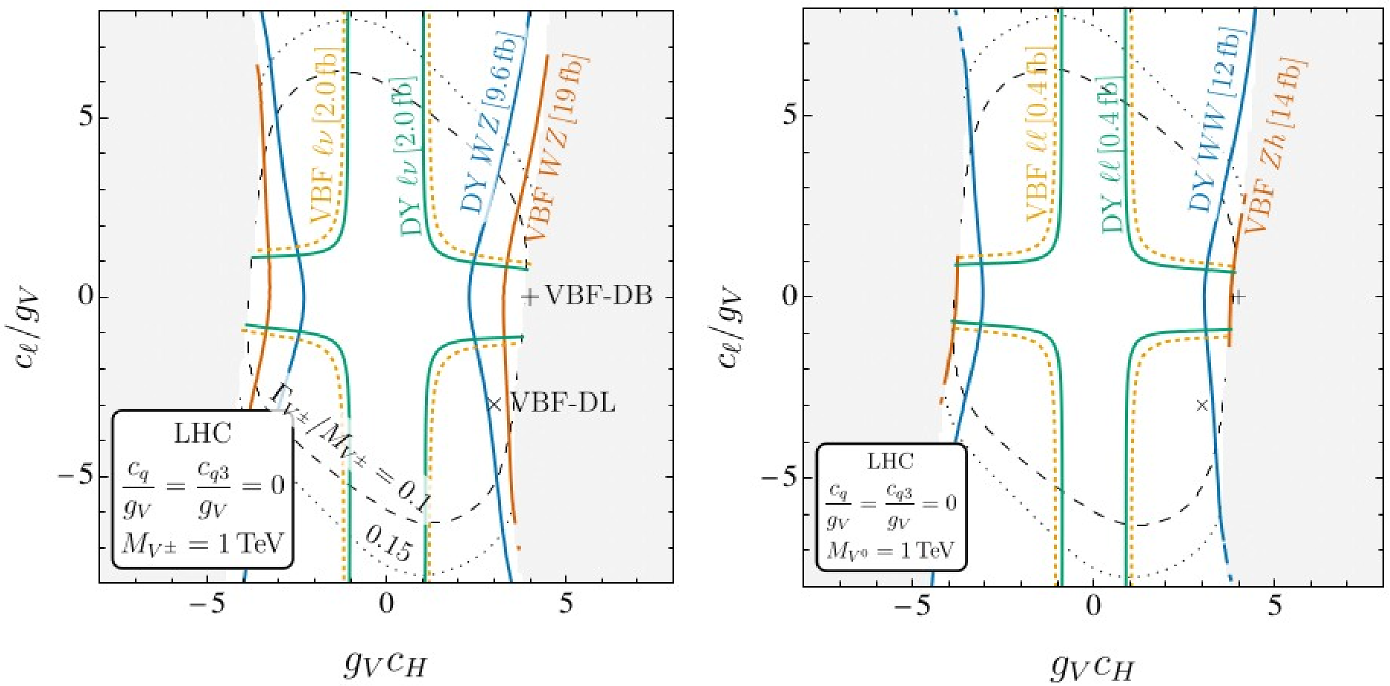

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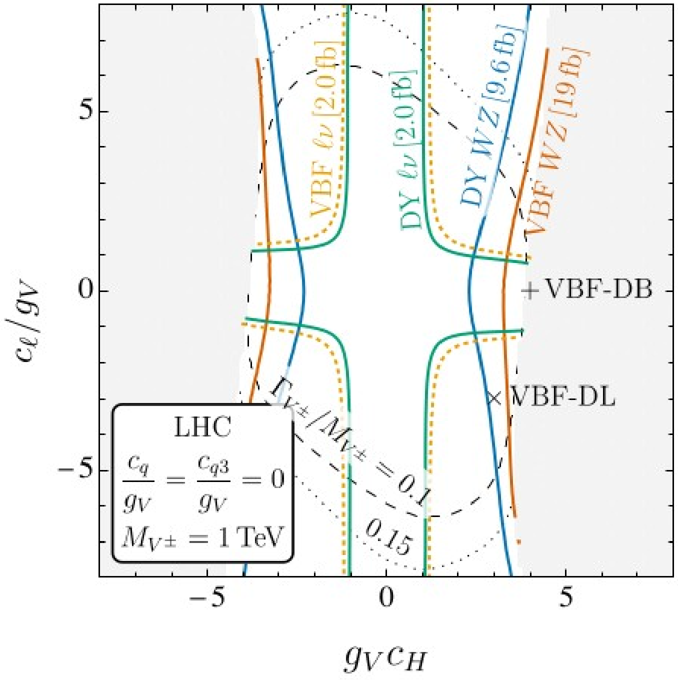

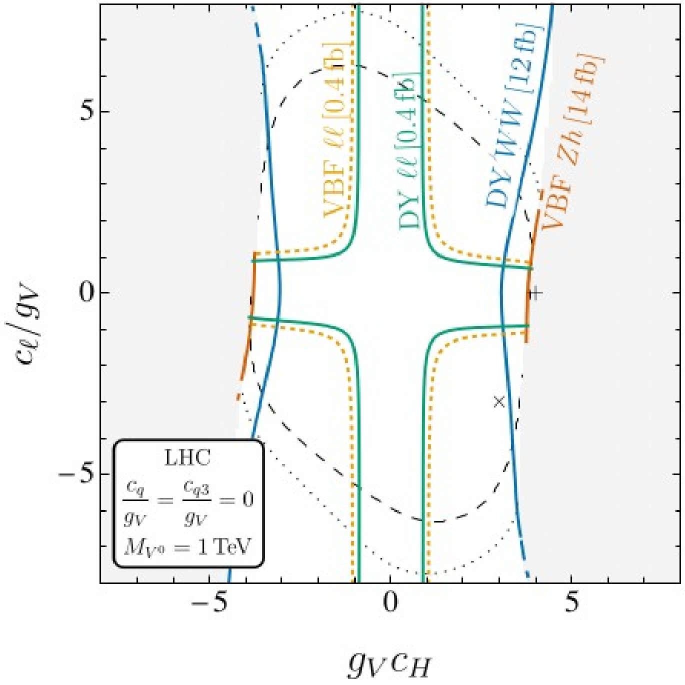

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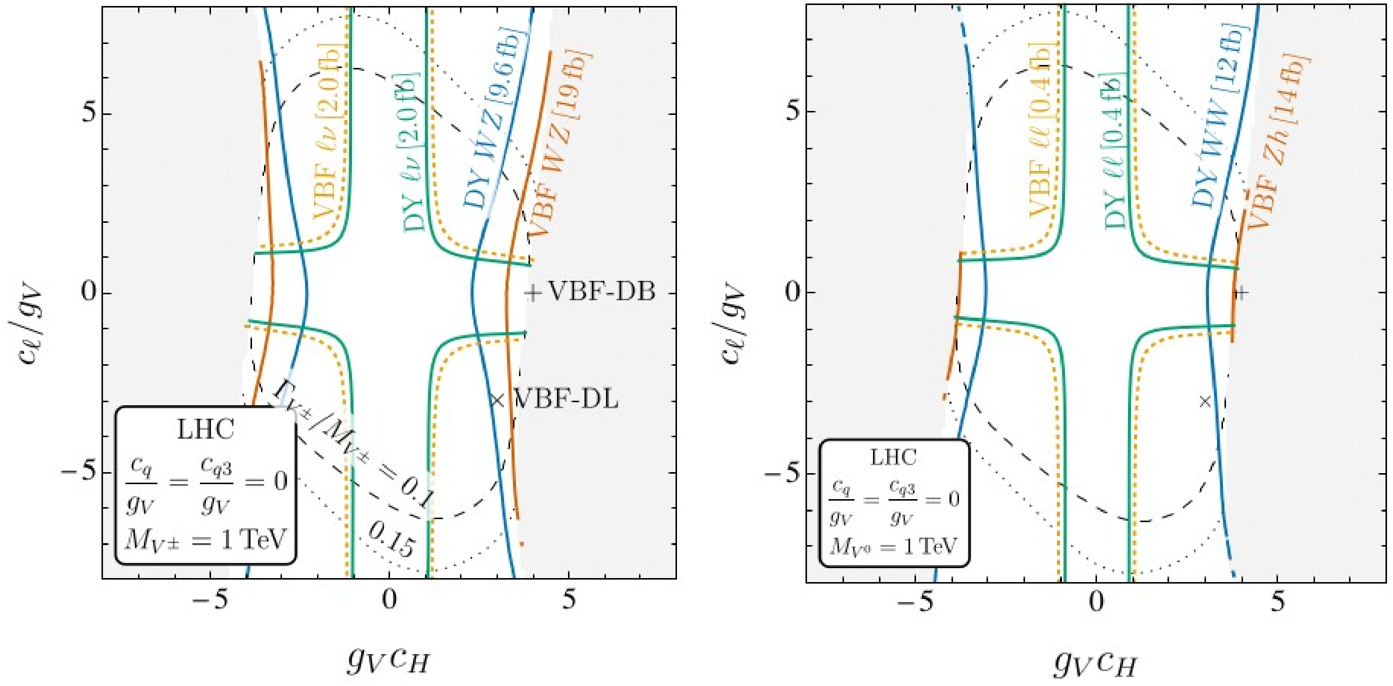

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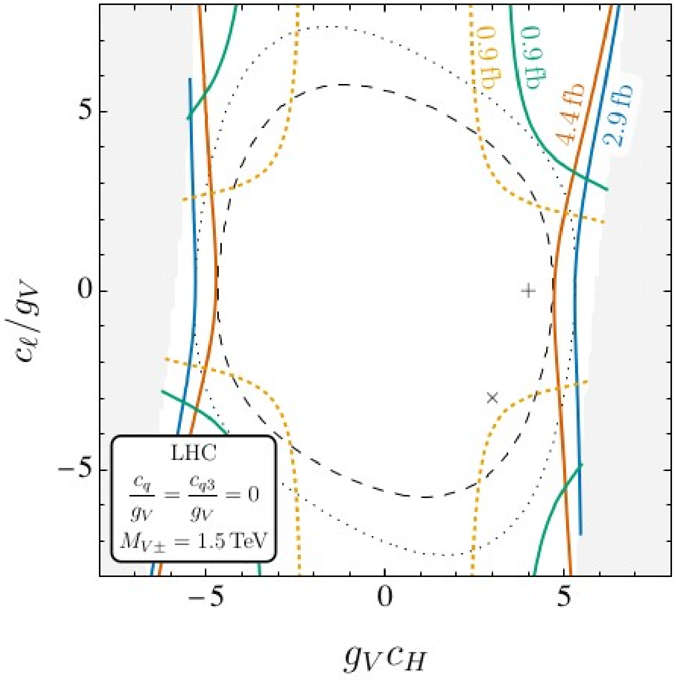

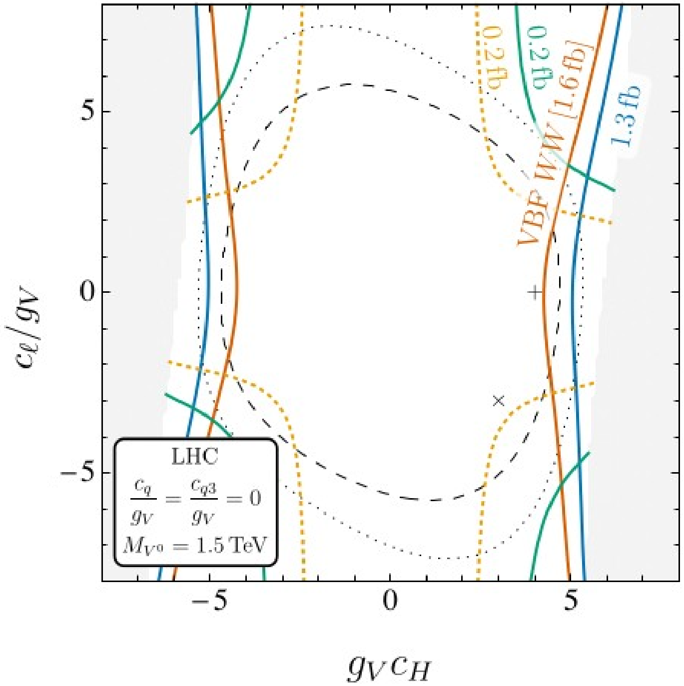

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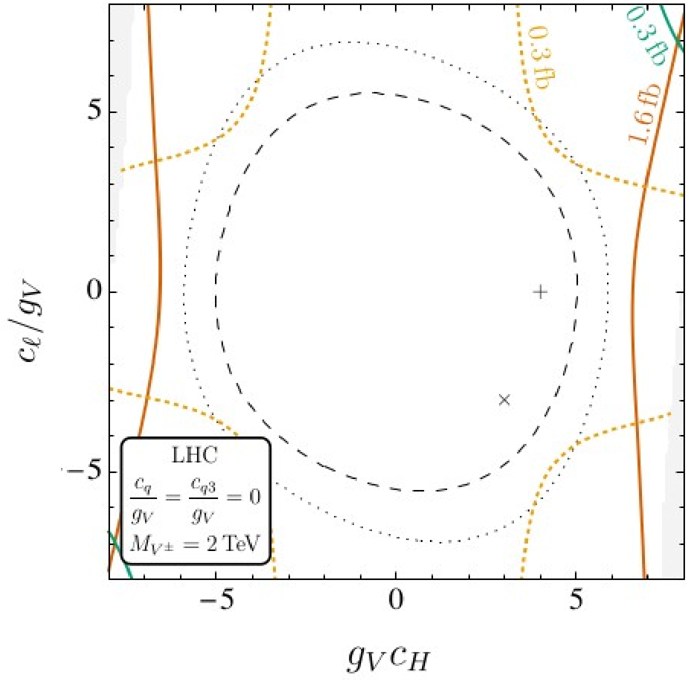

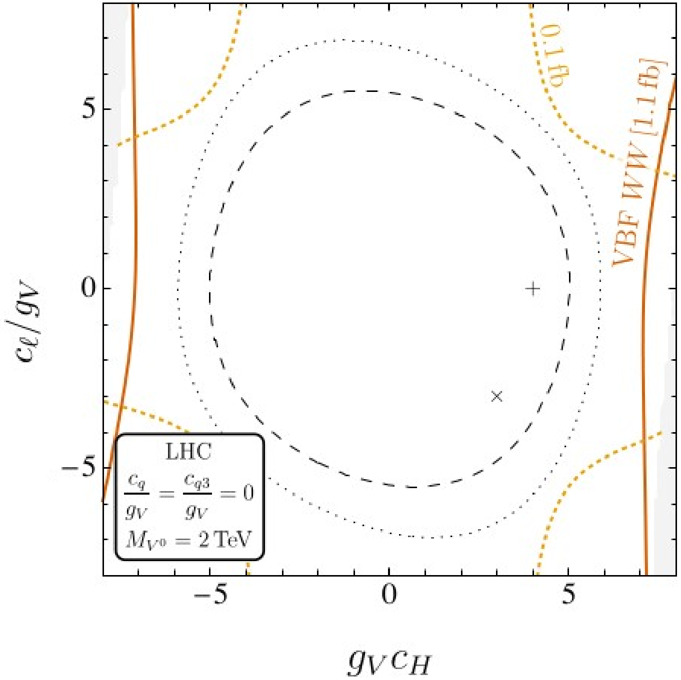

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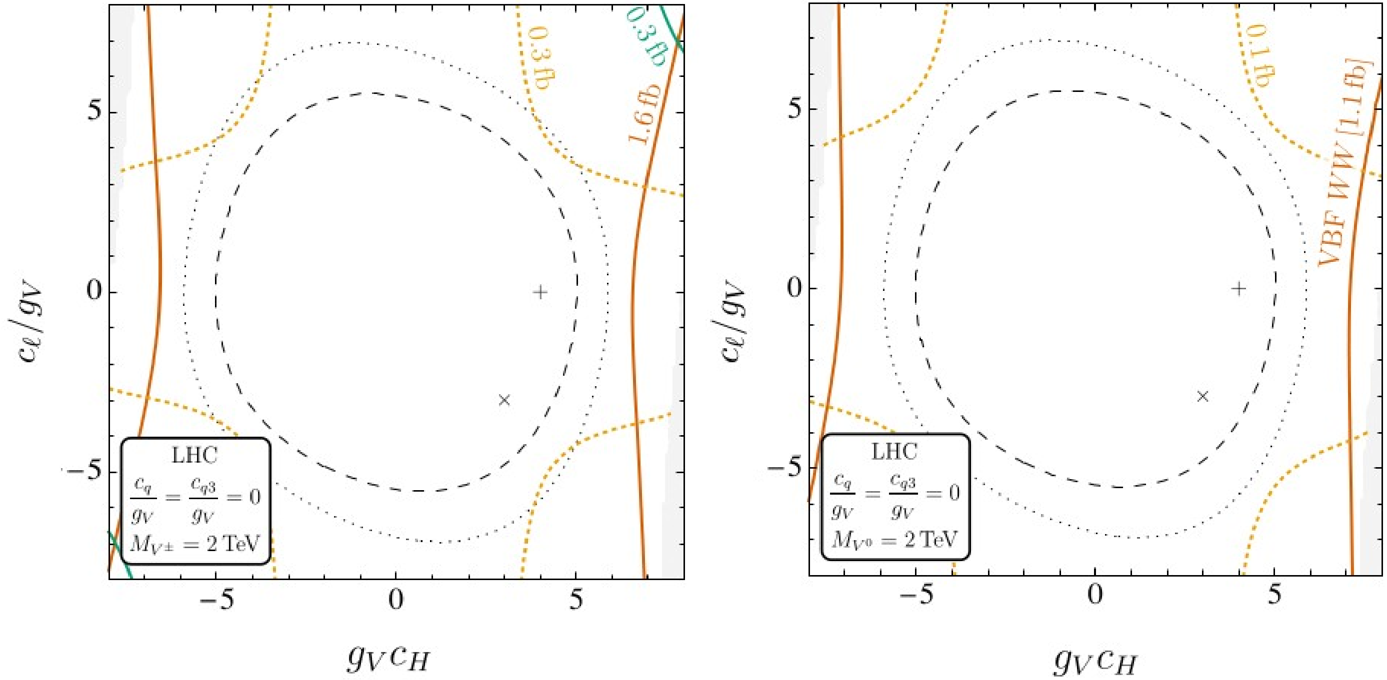

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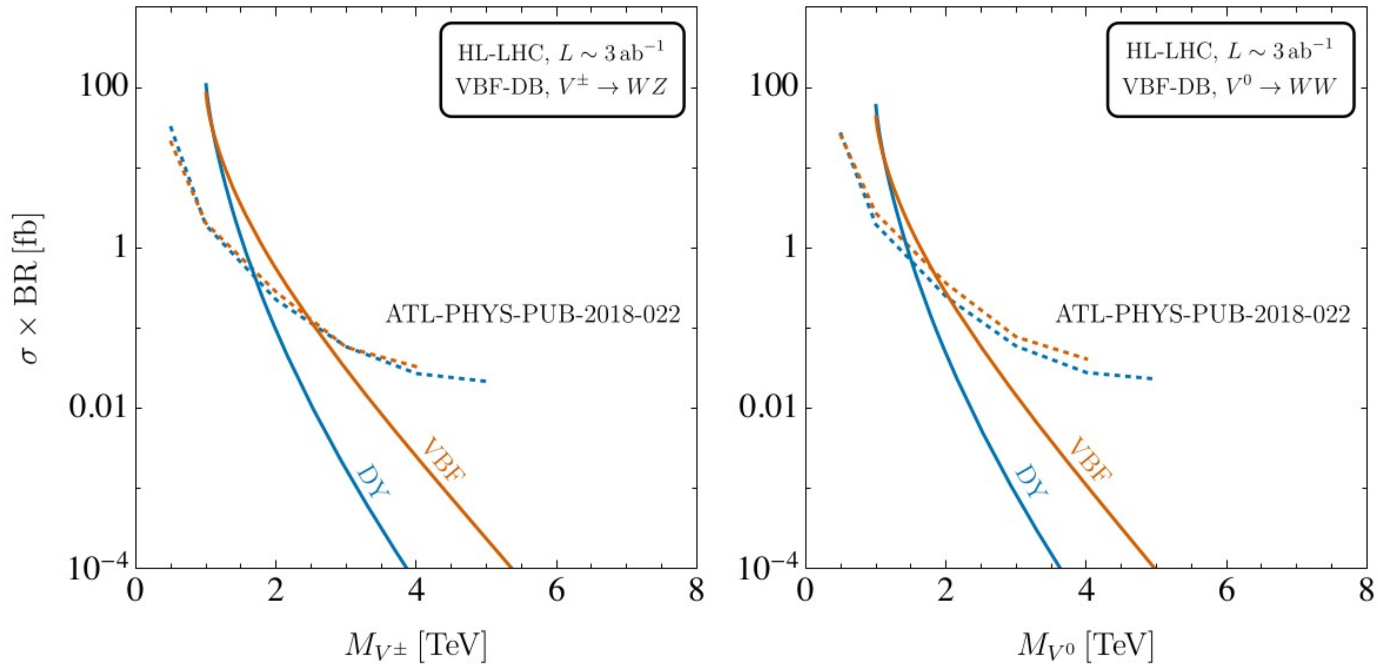
As resonance mass increases, DY drops off and VBF becomes most constraining

Projected limits to the HL-LHC

In future, the LHC is well-placed to further leverage the dominant VBF production mode present in certain regions of the HVT parameter space. Look to HL-LHC:



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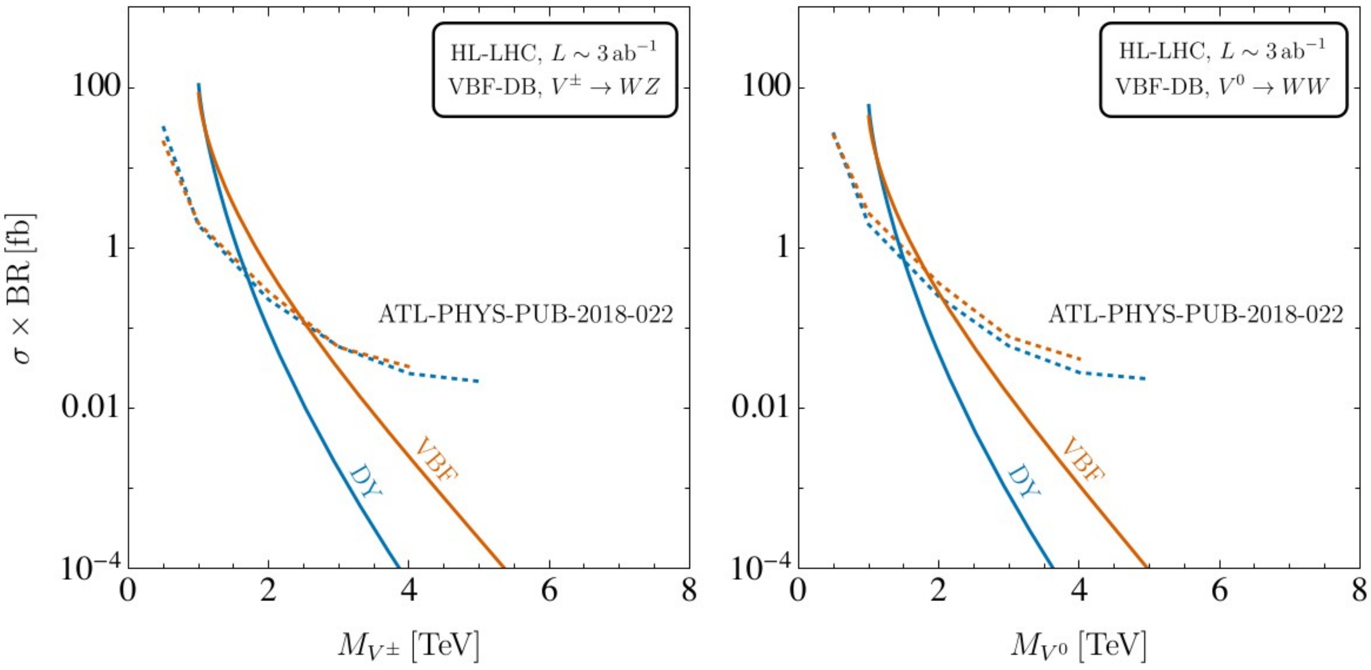

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No VBF di-lepton projections yet, but similar bound expected

Projection to 27 TeV HE-LHC?
100 TeV future circular collider?
We leave this to future work.

Summary

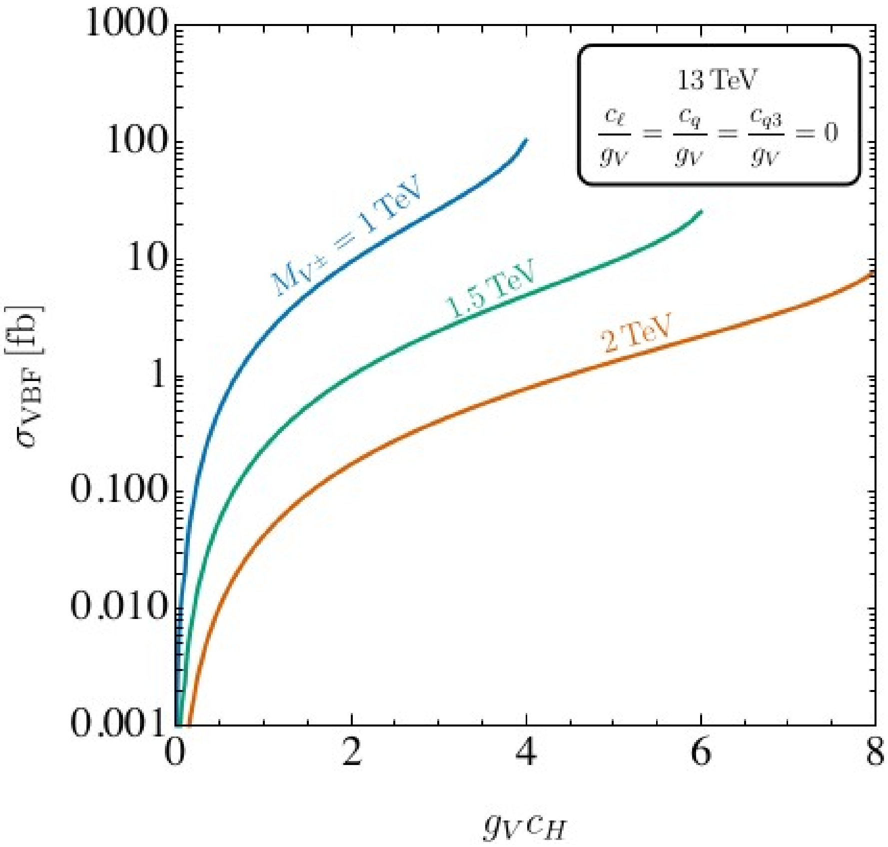
Vector boson fusion is relatively unexplored at the LHC, yet current experimental capabilities place it as a competitive production mode. A simplified model of heavy vector triplets highlights how VBF may be valuable to future searches.

- Heavy vectors with very small couplings to light quarks may be produced predominantly via VBF
- In this region of parameter space, LHC searches in the VBF production mode have a higher mass reach than those for DY at resonance masses above 1 TeV
- HL-LHC projections have an even higher mass reach for VBF

Next steps: How would VBF production fare at the HE-LHC or the FCC?

Thank you

Higher masses

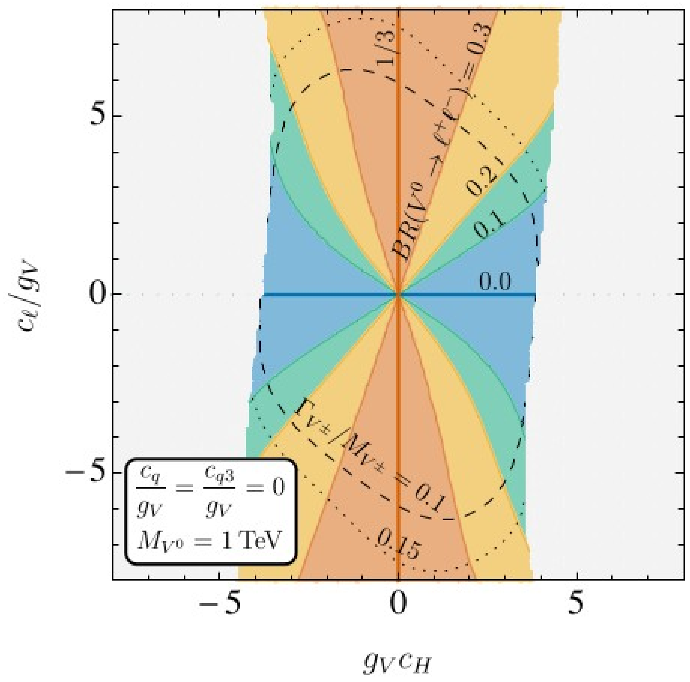


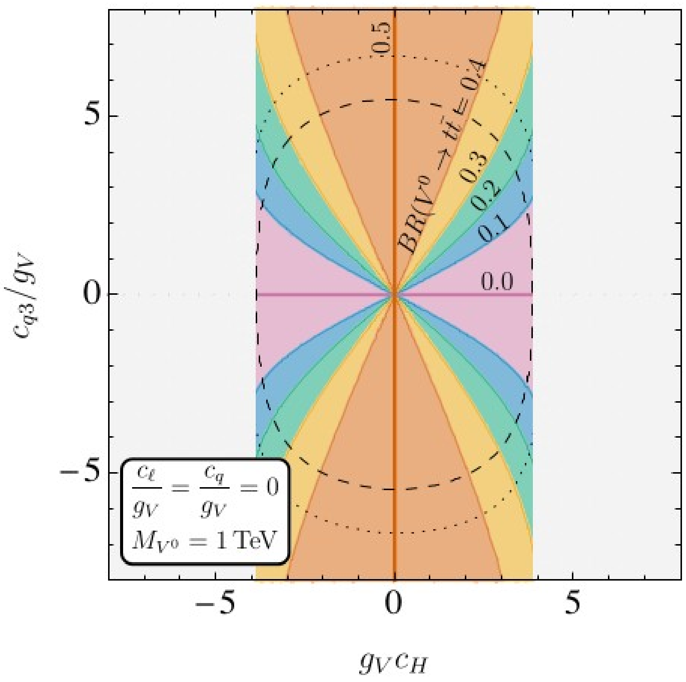
The area for which $\sigma_{VBF}/\sigma_{DY} > 1$ increases with resonance mass, but σ_{VBF} also decreases

- Parton luminosities decrease rapidly
- VBF searches will eventually lose sensitivity
- $g_V c_H \ll 1$ also difficult to probe

Valuable decay channels

Now that we know the relevant region of parameter space, what is the relative importance of each decay channel?





- Decays into di-jets generally irrelevant for VBF studies
- c_{q3} can be different to light quark couplings
- Di-lepton/ heavy di-quark decays can dominate over di-boson in certain regions of parameter space