Coloured spin-1 resonances from Composite Higgs Models

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Context

Underlying models: M1-12 (Ferretti et al) with two species of hyperquarks: electroweak ψ and coloured χ

Colour sector resonances:

- Spin-0: $\langle\chi\chi\rangle$: ubiquitous π_8 & $\pi_6^{4/3}$, $\pi_6^{-2/3}$ or $\pi_3^{2/3}$
- Spin-1: $\langle\chi\sigma^\mu\bar{\chi}\rangle = \mathcal{V}^\mu + \mathcal{A}^\mu$ with $\mathcal{V}^\mu \in H$, $\mathcal{A}^\mu \in G/H$

- Example SU(6)/SO(6):
  - $\pi : \pi_8, \pi_6$
  - $\mathcal{V}^\mu : \mathcal{V}_8^\mu, \mathcal{V}_3^\mu, \mathcal{V}_1$
  - $\mathcal{A}^\mu : \mathcal{A}_8^\mu, \mathcal{A}_6^\mu$

Hidden symmetry method

Consider two sectors:

$$\mathrm{SU}(6)_0 \times \mathrm{SU}(6)_1 \to \mathrm{SO}(6)_0 \times \mathrm{SO}(6)_1$$

where

- $\mathrm{SU}(6)_0$ is partly gauged by SM
- $\mathrm{SU}(6)_1$ is fully gauged by the heavy resonances

Mixing $\mathcal{V}_8^\mu \leftrightarrow G^\mu$

$$\mathcal{L} \supset \frac{f_K^2}{4}\tilde{g}^2\,\mathcal{V}_{8,\mu}^a\mathcal{V}_8^{a,\mu} + \frac{f_K^2}{4}\tilde{g}_s^2\,G_\mu^a G^{a,\mu} - \frac{f_K^2}{2}\hat{g}_s\tilde{g}\,G_\mu^a\mathcal{V}_8^{a,\mu}$$

Mass:

$$M_{\mathcal{V}_8} = \frac{f_K}{\sqrt{2}}\sqrt{\tilde{g}^2+\hat{g}_s^2}\,.$$

Mixing:

$$\begin{pmatrix} G_\mu^a \\ \mathcal{V}_{8,\mu}^a \end{pmatrix} \to \begin{pmatrix} \cos\beta_8 & -\sin\beta_8 \\ \sin\beta_8 & \cos\beta_8 \end{pmatrix}\begin{pmatrix} G_\mu^a \\ \mathcal{V}_{8,\mu}^a \end{pmatrix}, \qquad \tan\beta_8 = \frac{\hat{g}_s}{\tilde{g}} \lesssim 1\,.$$

Physical strong gauge coupling:

$$g_s = \hat{g}_s\cos\beta_8 = \tilde{g}\sin\beta_8 = \frac{\hat{g}_s\tilde{g}}{\sqrt{\hat{g}_s^2+\tilde{g}^2}}\,,$$

Phenomenology: production

Production channels:

- QCD pair production of $\mathcal{V}_8\mathcal{V}_8$, $\mathcal{V}_3\mathcal{V}_3^c$, $\mathcal{A}_8\mathcal{A}_8$, $\mathcal{A}_6\mathcal{A}_6^c$
- $\mathcal{V}_8$ single production via $q\bar{q}$-coupling

Phenomenology: spin-1 decays

Generically:

$$\mathcal{V} \to \pi\pi$$
$$\mathcal{A} \to \pi\pi\pi$$

In particular:

$$\mathcal{V}_8 \to q\bar{q},\ b\bar{b},\ t\bar{t},\ \pi_8\pi_8,\ \pi_6\pi_6^c$$
$$\mathcal{V}_3 \to \pi_8\pi_6$$
$$\mathcal{A}_8 \to \pi_8\pi_8\pi_8,\ \pi_8\pi_6\pi_6^c$$
$$\mathcal{A}_6 \to \pi_6\pi_8\pi_8,\ \pi_6\pi_6\pi_6^c$$

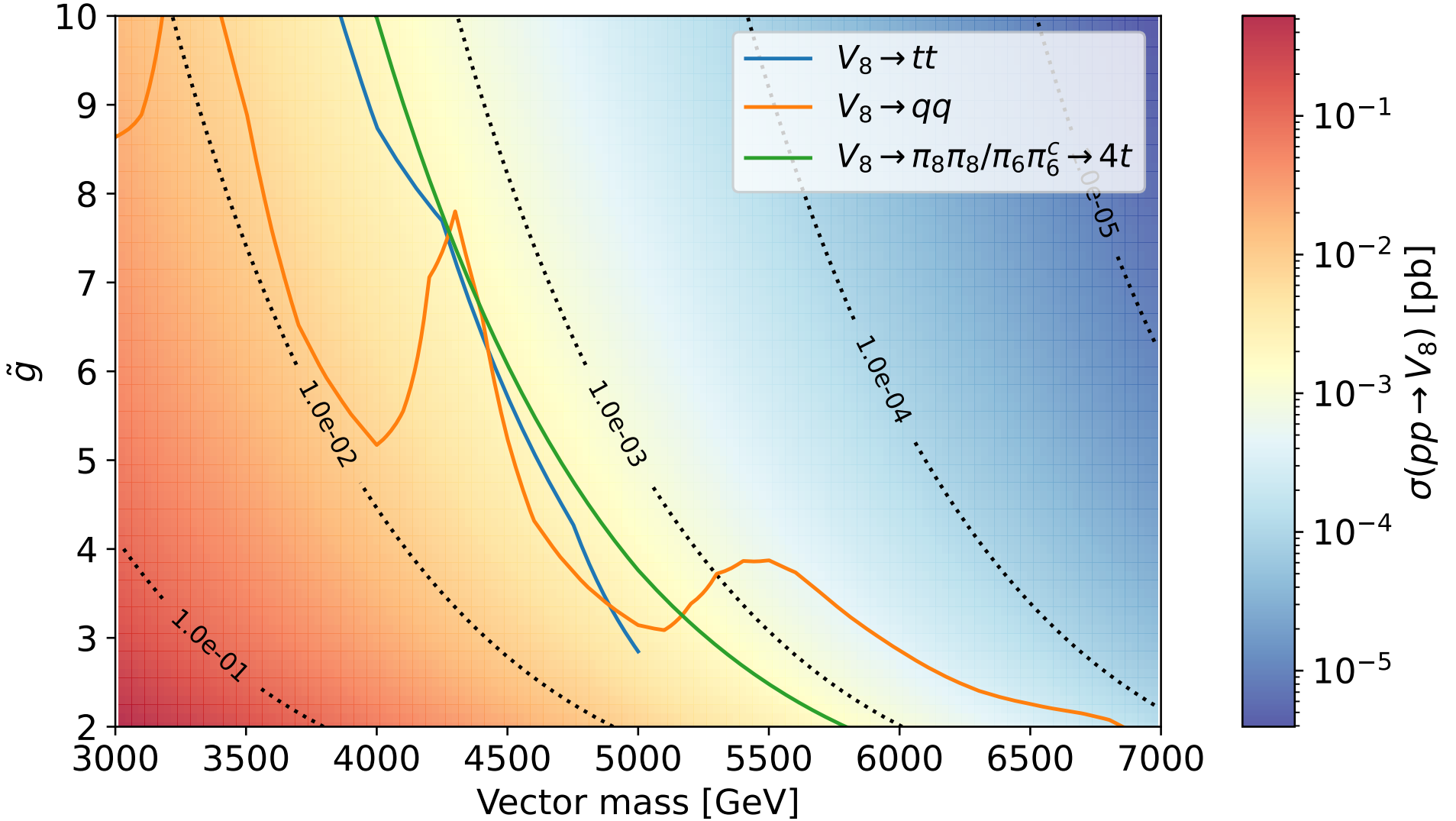
Phenomenology: spin-0 decays

$$\pi_8 \to t\bar{t},\ gg$$

$$\pi_6 \to tt \text{ or } bb$$

$$\pi_3 \to \bar{b}\bar{s} \text{ or } t\bar{\nu}, b\tau^+$$

Bounds


$V_8 \to tt$
$V_8 \to qq$
$V_8 \to \pi_8\pi_8/\pi_6\pi_6^c \to 4t$
1.0e-01
1.0e-02
1.0e-03
1.0e-04
1.0e-05
$\tilde{g}$
Vector mass [GeV]
$\sigma(pp \to V_8)$ [pb]

Large widths

Coupling $\mathcal{V}$-π-π is purely composite sector: $\mathcal{O}(1-5)$

Conclusion

Summary

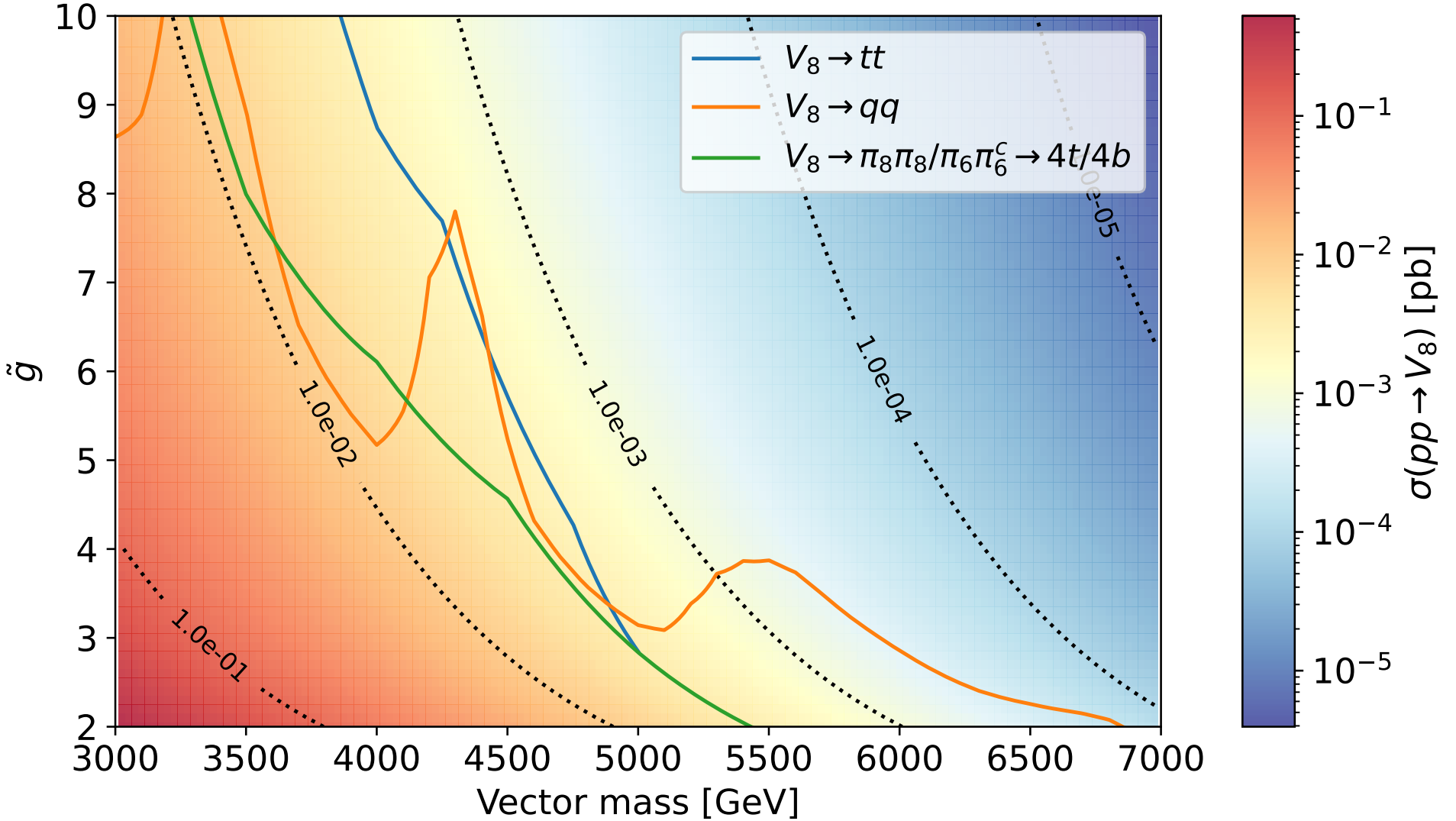
- At the LHC: Phenomenology of colored spin-1 resonances dominated by $\mathcal{V}_8$ single production
- Mass bounds of the order 5 TeV
- Technical difficulty: width is very large ($\Gamma/M > 50\%$) in large parts of the parameter space

Outlook

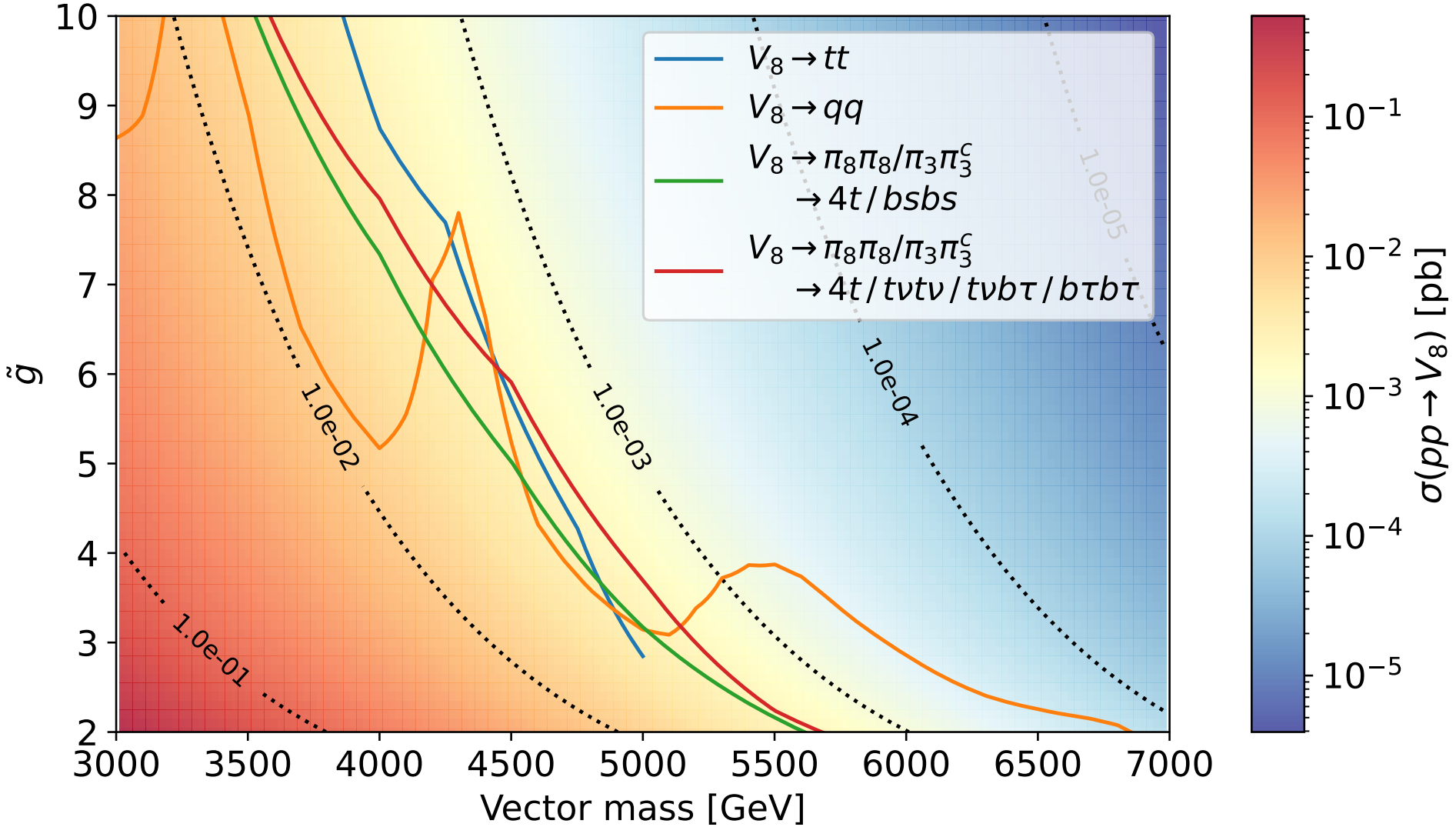
- Pair production offers very rich final states like $\mathcal{A}_8\mathcal{A}_8 \to 6\pi_8 \to 12t$ to explore at a future collider
- $pp \to \mathcal{V}_8 \to T\bar{t}$ might be dominant VLQ single production

Backup

Bounds


$V_8 \to tt$
$V_8 \to qq$
$V_8 \to \pi_8\pi_8/\pi_6\pi_6^c \to 4t/4b$
1.0e-01
1.0e-02
1.0e-03
1.0e-04
1.0e-05
$\tilde{g}$
Vector mass [GeV]
$\sigma(pp \to V_8 \to dd)$ [pb]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}

Bounds


$V_8 \to tt$
$V_8 \to qq$
$V_8 \to \pi_8\pi_8/\pi_3\pi_3^c \to 4t\,/\,bsbs$
$V_8 \to \pi_8\pi_8/\pi_3\pi_3^c \to 4t\,/\,t\nu t\nu\,/\,t\nu b\tau\,/\,b\tau b\tau$
1.0e-01
1.0e-02
1.0e-03
1.0e-04
1.0e-05
$\tilde{g}$
Vector mass [GeV]
$\sigma(pp \to V_8)$ [pb]

Hidden symmetry method: Lagrangian

$$
\begin{aligned}
\mathcal{L} \overset{\text{UG}}{=} & -\frac{1}{2\hat{g}_s^2}\,\mathrm{Tr}\,\mathbf{G}_{\mu\nu}\mathbf{G}^{\mu\nu} - \frac{1}{2\hat{g}'^2}\,\mathrm{Tr}\,\mathbf{B}_{\mu\nu}\mathbf{B}^{\mu\nu} - \frac{1}{2\tilde{g}^2}\,\mathrm{Tr}\,\boldsymbol{\mathcal{F}}_{\mu\nu}\boldsymbol{\mathcal{F}}^{\mu\nu} \\
& + \frac{f_0^2}{2}\,\mathrm{Tr}\,d_{0,\mu}d_0^{\mu} + \frac{f_1^2}{2}\,\mathrm{Tr}\,d_{1,\mu}d_1^{\mu} + r f_1^2\,\mathrm{Tr}\,d_{0,\mu}d_1^{\mu} \\
& + \frac{f_K^2}{2}\,\mathrm{Tr}\,e_{0,\mu}e_0^{\mu} + \frac{f_K^2}{2}\,\mathrm{Tr}\,e_{1,\mu}e_1^{\mu} - f_K^2\,\mathrm{Tr}\,e_{0,\mu}e_1^{\mu} \\
& + \mathcal{L}_{\text{fermions}}
\end{aligned}
$$