Coloured spin-1 resonances in composite Higgs models

Manuel Kunkel
in collaboration with Giacomo Cacciapaglia, Aldo Deandrea, and Werner Porod

supported by

Studienstiftung des deutschen Volkes

GRK 2994

DFG

PLANCK 2025

Why Composite Higgs?

Naturalness problem:

Elementary Higgs $\Rightarrow$ large radiative corrections to Higgs mass

$\Rightarrow$ massive cancellations necessary to obtain $m_h = 125$ GeV

Possible solution: Higgs as a pseudo Nambu-Goldstone bound state of two fermions: $h \sim \langle \Psi\Psi \rangle$

CH model: hyperquarks Ψ charged under a new asymptotically free gauge group G_{HC} which induces a spontaneous $G \to H$ global symmetry breaking when it condenses

Besides the Higgs, CHMs typically contain further pNGBs and also spin-1 resonances

Ferretti models

Name	G_{HC}	ψ	χ	Coset
M1	SO(7)	$5 \times \mathbf{F}$	$6 \times \mathbf{Spin}$	$\frac{SU(5)}{SO(5)} \frac{SU(6)}{SO(6)}$
M2	SO(9)	$5 \times \mathbf{F}$	$6 \times \mathbf{Spin}$	$\frac{SU(5)}{SO(5)} \frac{SU(6)}{SO(6)}$
M3	SO(7)	$5 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$\frac{SU(5)}{SO(5)} \frac{SU(6)}{SO(6)}$
M4	SO(9)	$5 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$\frac{SU(5)}{SO(5)} \frac{SU(6)}{SO(6)}$
M5	Sp(4)	$5 \times \mathbf{A}_2$	$6 \times \mathbf{F}$	$\frac{SU(5)}{SO(5)} \frac{SU(6)}{Sp(6)}$
⋮	⋮	⋮	⋮	⋮
M12	SU(5)	$4 \times (\mathbf{F}, \bar{\mathbf{F}})$	$3 \times (\mathbf{A}_2, \bar{\mathbf{A}}_2)$	$\frac{SU(4)^2}{SU(4)} \frac{SU(3)^2}{SU(3)}$

Ferretti et al, 1312.5330, 1604.06467, 1610.06591

Coloured pNGBs

$$\pi_8 \quad \text{and/or} \quad \pi_6^{4/3} \text{ or } \pi_6^{-2/3} \text{ or } \pi_3^{2/3}$$

with decays

$$\begin{aligned} \pi_8 &\to t\bar{t} \\ \pi_6^{4/3} &\to tt \\ \pi_6^{-2/3} &\to bb \\ \pi_3^{2/3} &\to \bar{b}\bar{s} \quad \text{or} \quad t\nu, b\tau^+ \end{aligned}$$

and we take $m_\pi = 1.6$ TeV in the following to lie above current recasting bounds

Coloured spin-1 resonances

$$\chi\sigma^\mu\bar{\chi} = \mathcal{V}^\mu + \mathcal{A}^\mu \quad \text{with } \mathcal{V}^\mu \in H,\ \mathcal{A}^\mu \in G/H$$

where $H \supset \mathrm{SU}(3)_c \times \mathrm{U}(1)_X$ and X is the hypercharge for these states

Hidden symmetry approach

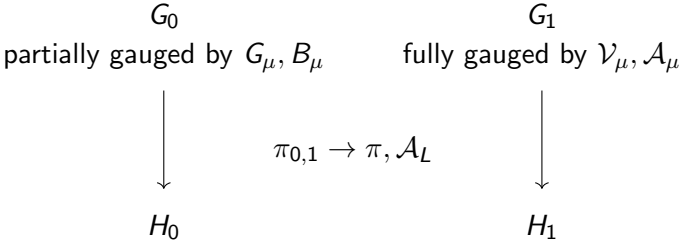
G

Hidden symmetry approach

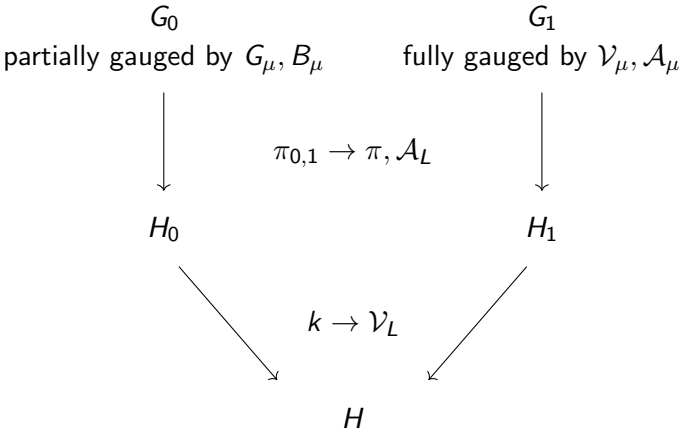
G_0
partially gauged by G_μ, B_μ

G_1
fully gauged by $\mathcal{V}_\mu, \mathcal{A}_\mu$

Hidden symmetry approach



Hidden symmetry approach

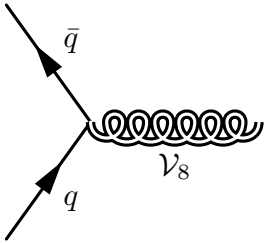


Coloured spin-1 resonances

- Ubiquitous $\mathcal{V}_8, \mathcal{V}_1, \mathcal{A}_8$
- Depending on the coset $\mathcal{V}_3, \mathcal{V}_6, \mathcal{A}_3, \mathcal{A}_6$

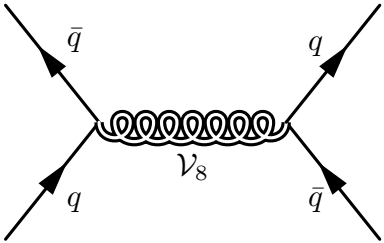
Coloured spin-1 resonances

- Ubiquitous $\mathcal{V}_8, \mathcal{V}_1, \mathcal{A}_8$
- Depending on the coset $\mathcal{V}_3, \mathcal{V}_6, \mathcal{A}_3, \mathcal{A}_6$
- $\mathcal{V}_8$ mixes with gluon
  $\Rightarrow$ single production channel



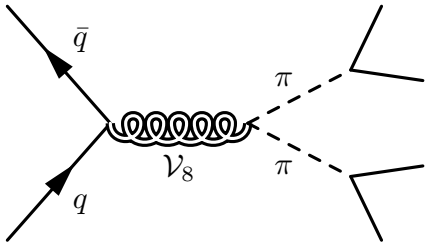
Coloured spin-1 resonances

- Can calculate
  - $\mathcal{V}_8 \to q\bar{q}$



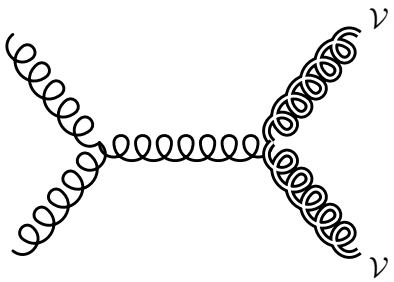
Coloured spin-1 resonances

- Can calculate
  - $\mathcal{V}_8 \to q\bar{q}$
  - $\mathcal{V}_8 \to \pi\pi$



Coloured spin-1 resonances

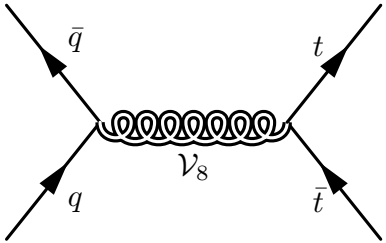
- Can calculate
  - $\mathcal{V}_8 \to q\bar{q}$
  - $\mathcal{V}_8 \to \pi\pi$
  - Couplings to gluons, $c_{\mathcal{V}_8 gg} = 0$



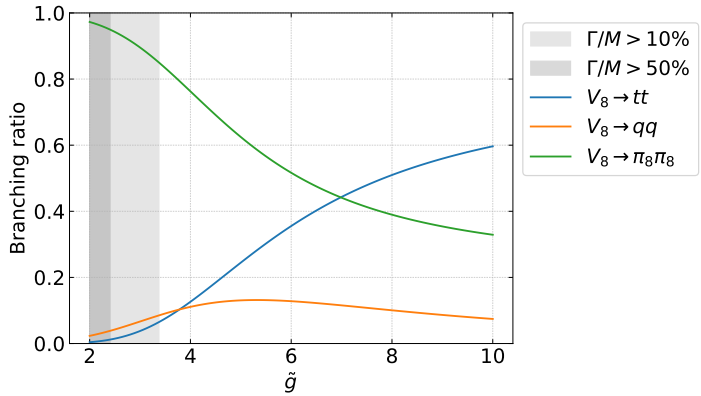
Coloured spin-1 resonances

- Can calculate
  - $\mathcal{V}_8 \to q\bar{q}$
  - $\mathcal{V}_8 \to \pi\pi$
  - Couplings to gluons, $c_{\mathcal{V}_8 gg} = 0$
- Missing: couplings c_{tt} from partial compositeness

$$\bar{T}\,\not{\mathcal{V}}_8\,T \to \bar{t}\,\not{\mathcal{V}}_8\,t$$

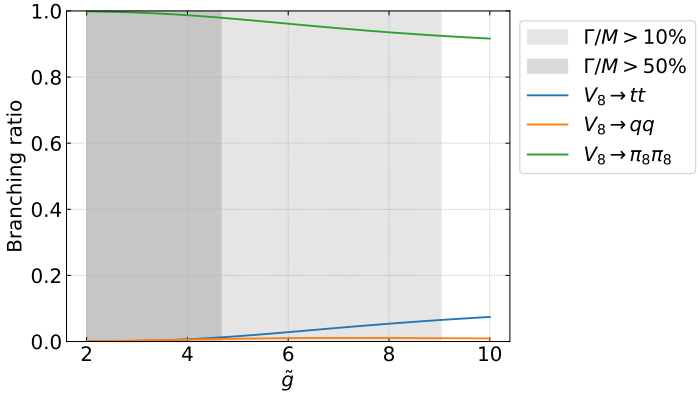


Decays of $\mathcal{V}_8$



for the $SU(3)^2/SU(3)$ coset

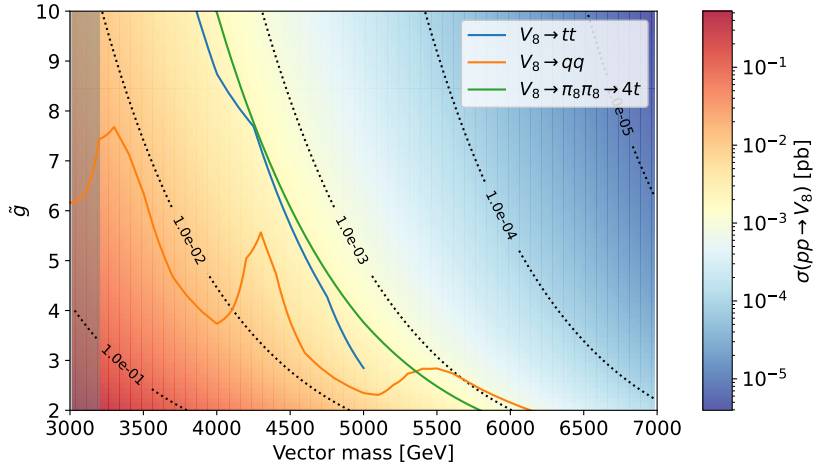
Decays of $\mathcal{V}_8$



for the $SU(3)^2/SU(3)$ coset

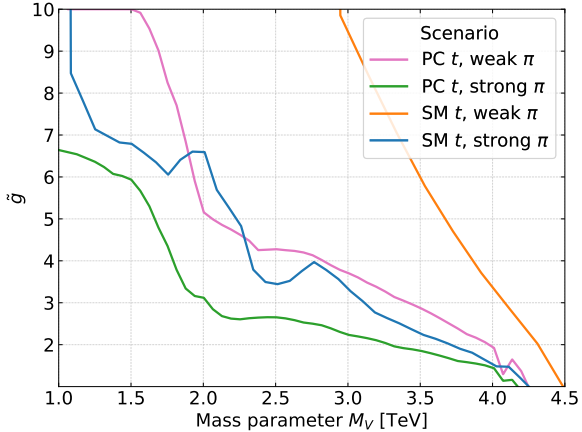
Bounds on $\mathcal{V}_8$ single production

pub. in JHEP 06 (2024) 092



Outlook: Electroweak spin-1 resonances

The same can be done for EW spin-1 states which mix with the EW gauge bosons:



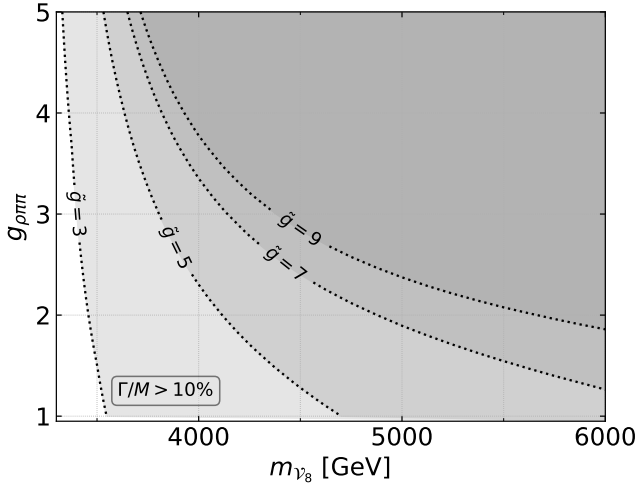
Conclusions

- Composite Higgs models predict coloured spin-1 resonances
- Among them is always an octet $\mathcal{V}_8$ that mixes with the gluon
- LHC phenomenology dominated by $\mathcal{V}_8$ single production
- Mass bounds up to 5 TeV
- Technical difficulty: width is very large ($\Gamma/M > 50\%$) in parts of the parameter space

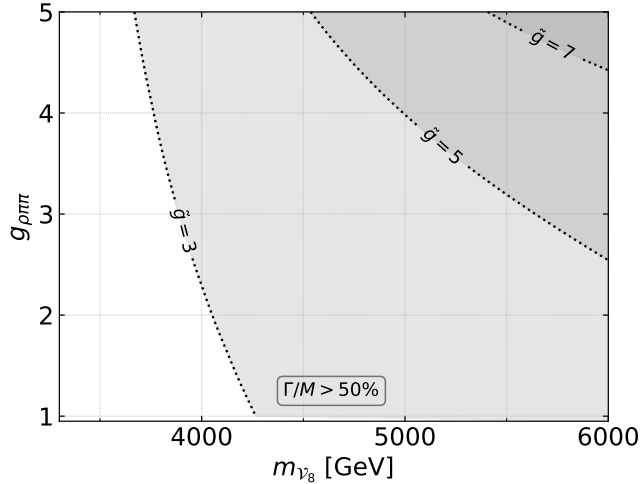
For more details, see 2404.02198 for the coloured and 2412.08720 for the electroweak vectors

Backup

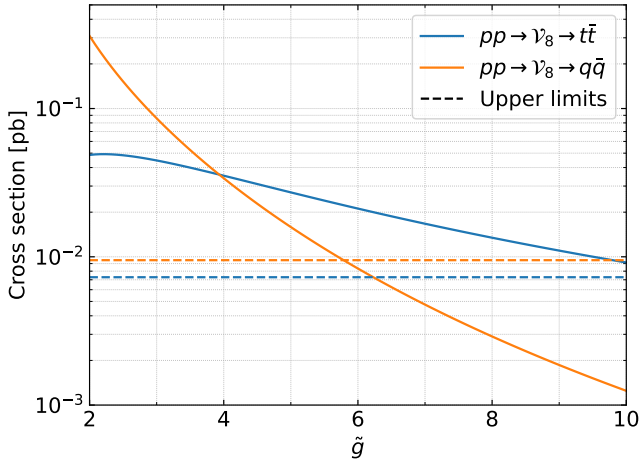
Coloured spin-1 resonances: broad resonance



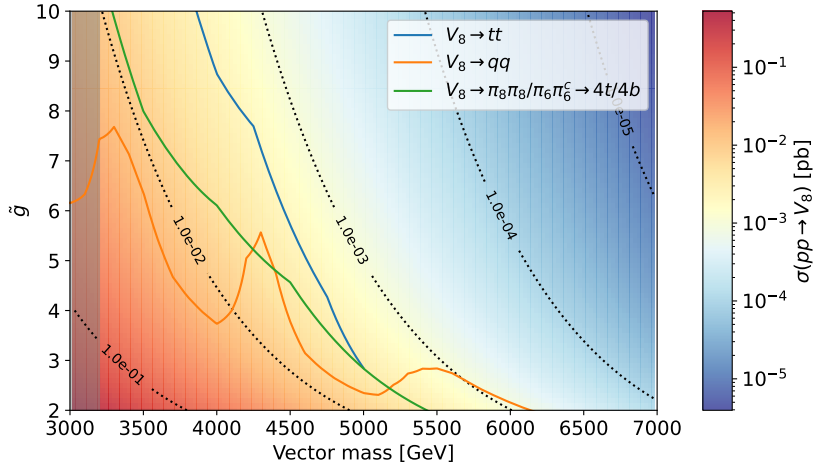
Coloured spin-1 resonances: broad resonance



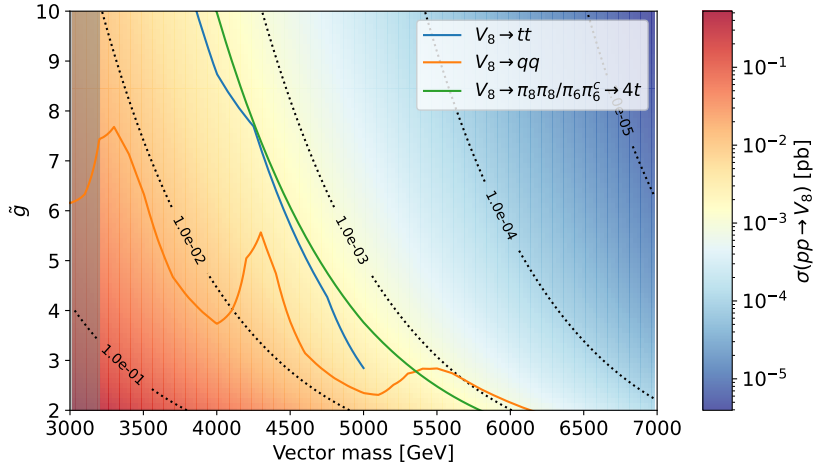
Coloured spin-1 resonances: bounds for $m_{\mathcal{V}_8} < 2m_\pi$



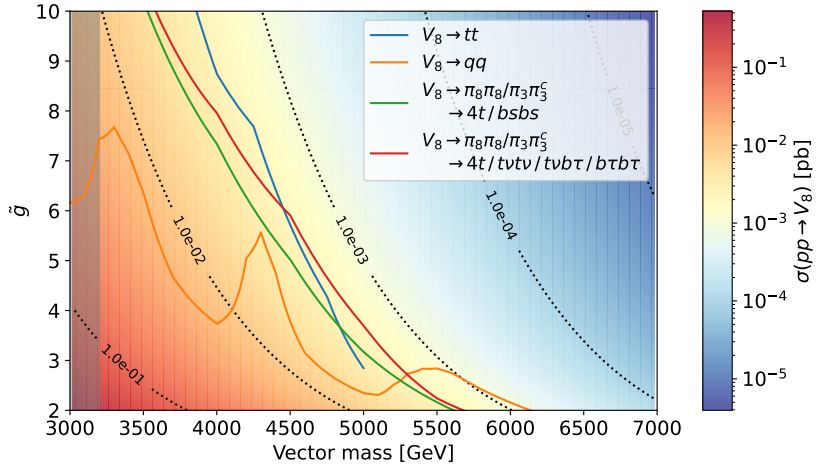
Coloured spin-1 resonances: bounds for $m_{\mathcal{V}_8}$



Coloured spin-1 resonances: bounds for $m_{\mathcal{V}_8}$



Coloured spin-1 resonances: bounds for $m_{\mathcal{V}_8}$



Coloured spin-1 resonances: bounds for $m_{\mathcal{V}_8}$