Composite PNGB Higgs at the LHC and Beyond

Oleksii Matsedonskyi

Naturalness workshop, DESY 2018

Outline

- Definition
- CH Landscape
- Phenomenology:
  - Direct production
  - Indirect probes at low and high energy

(bottom-up*) Definition

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* we identify the minimal number of necessary ingredients of the low-energy description, leaving aside possible UV completions

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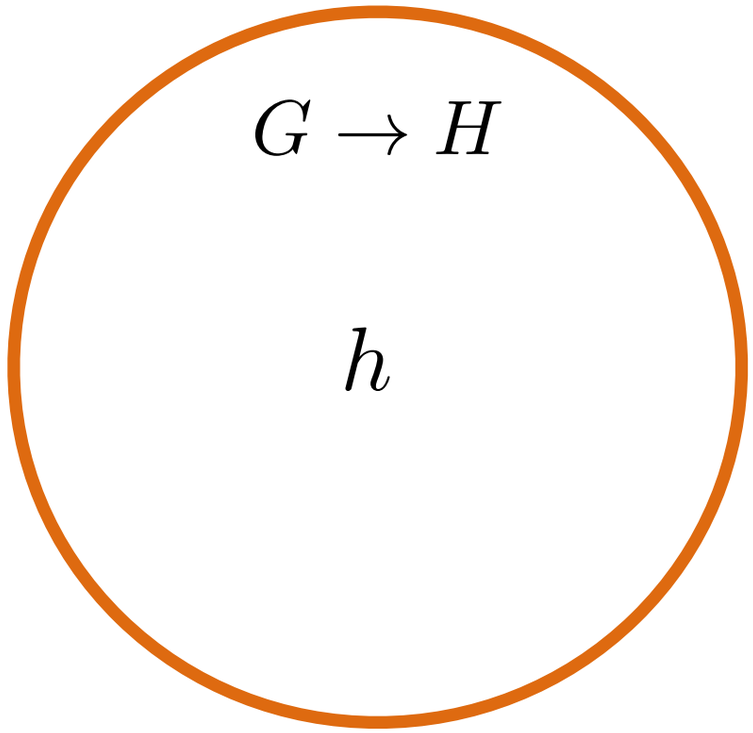

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- G/H gives ≥ 4 NGBs

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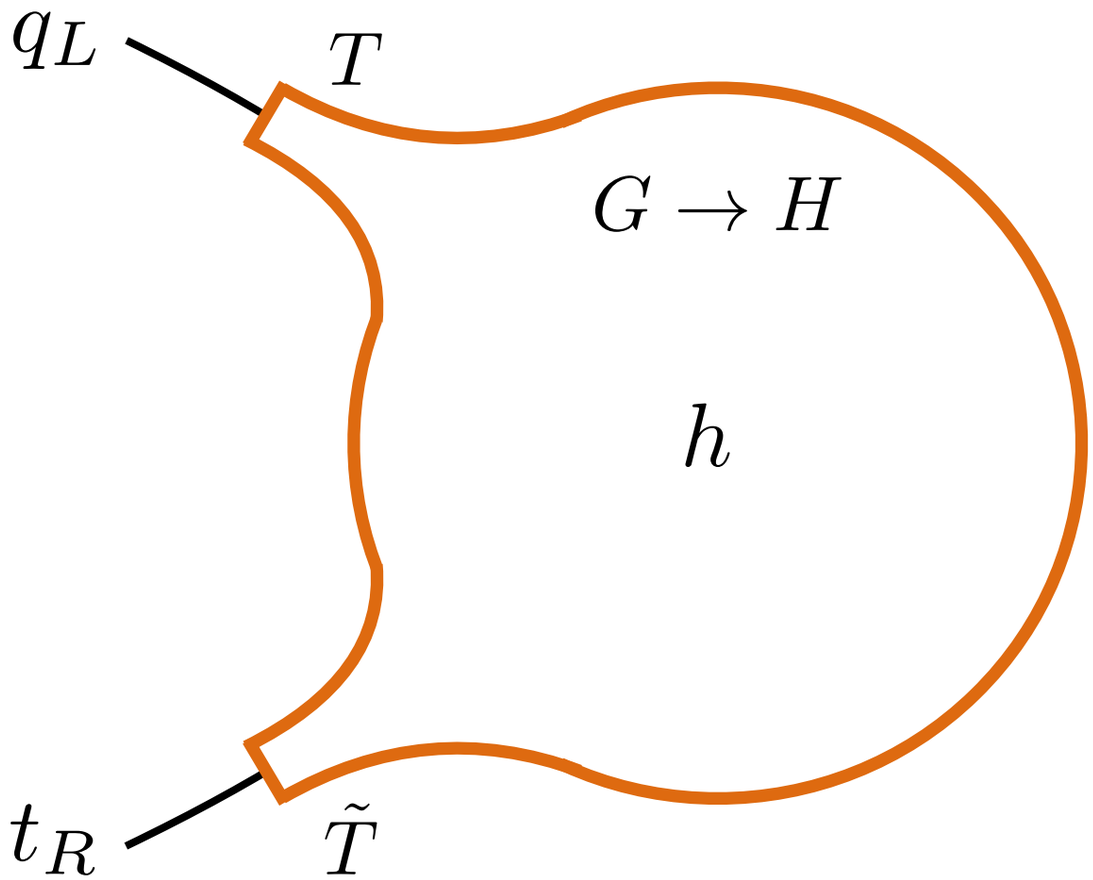

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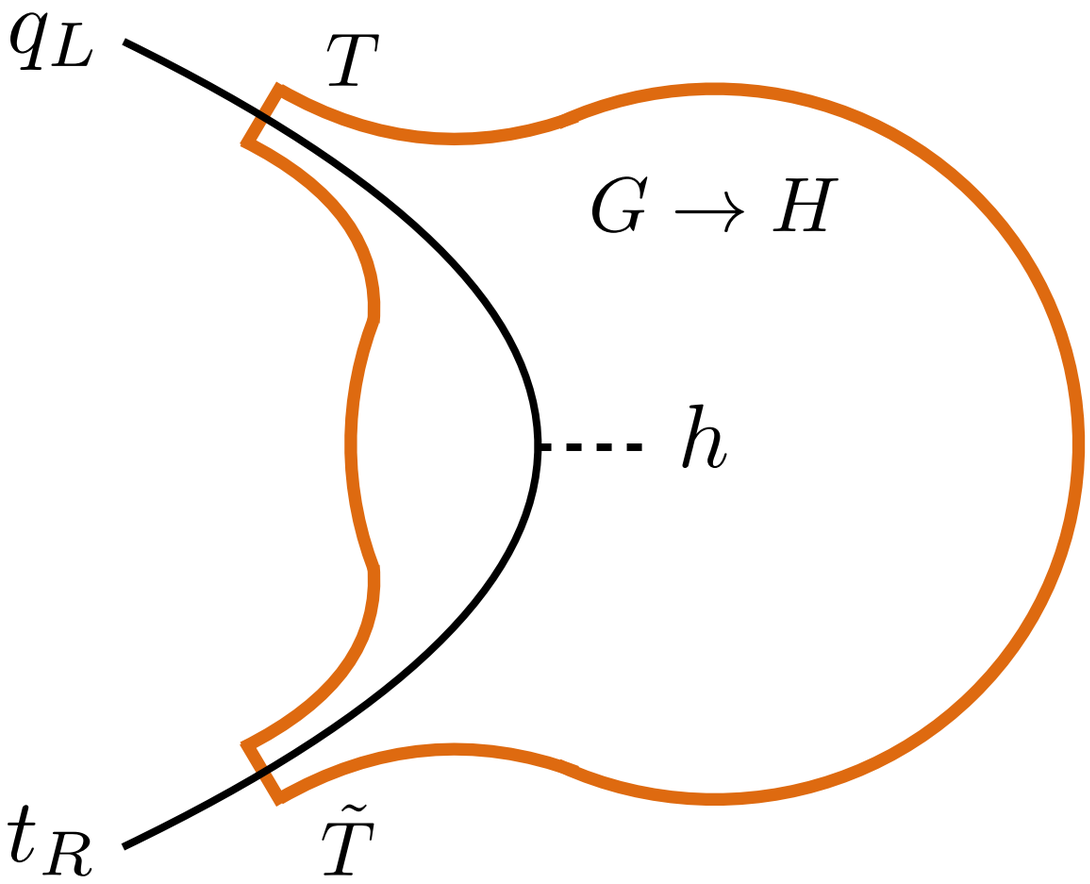

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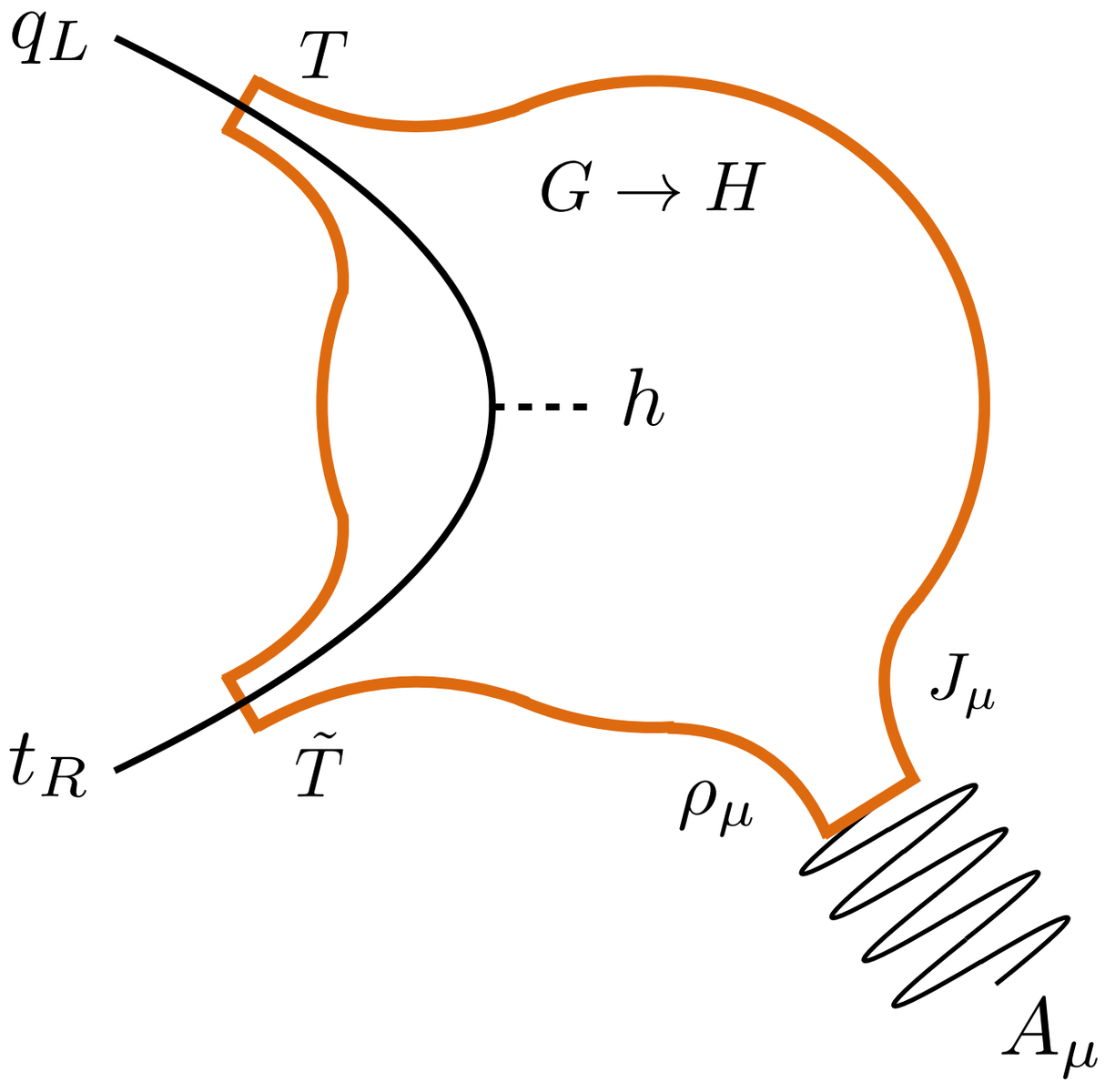

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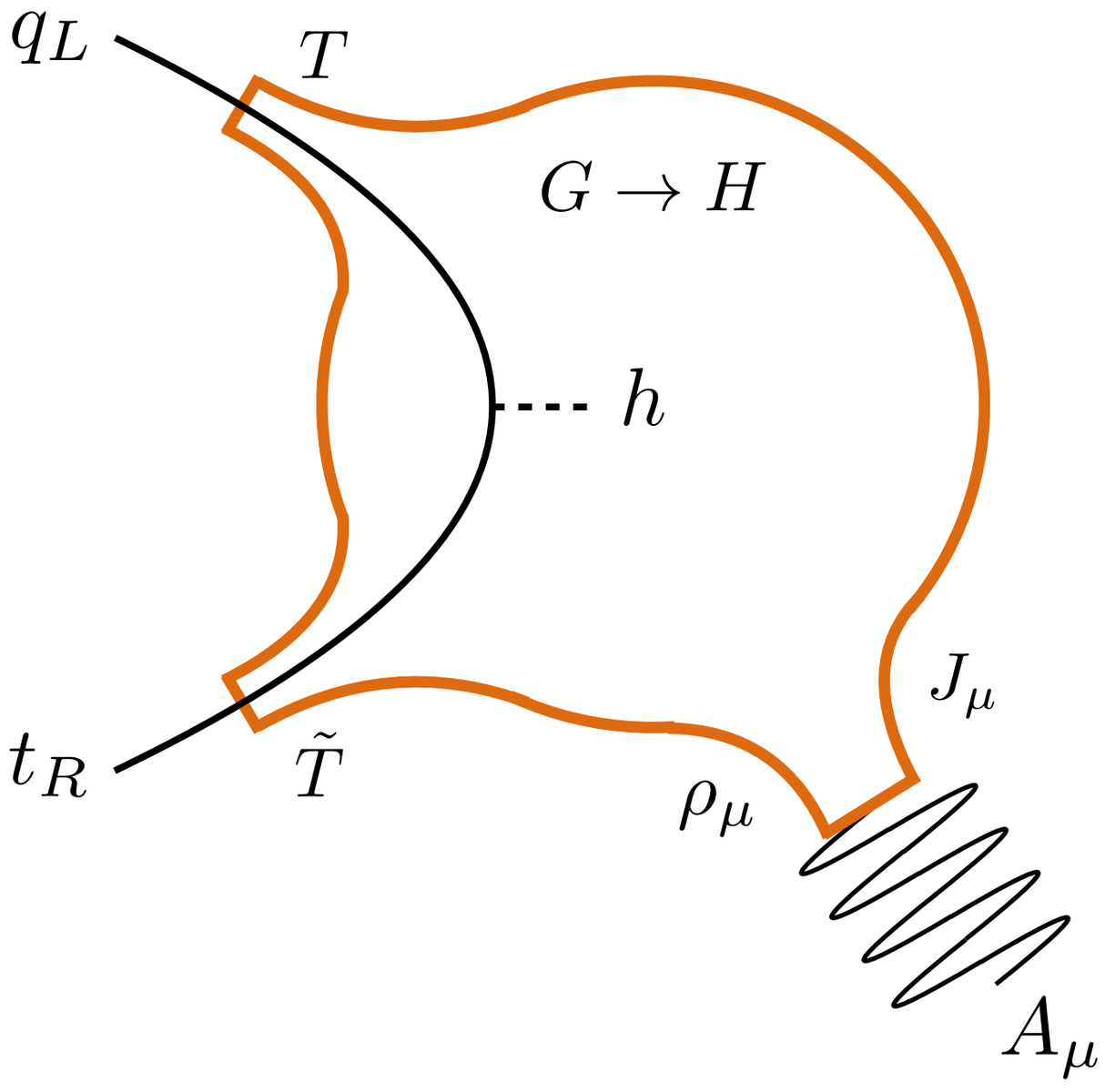

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- elementary - composite couplings break G

a few more features…

- custodial symmetry for T parameter
- custodial symmetry for Zb_Lb_L
- some flavour symmetry for ϵ_K?

- tuning for $v \ll f$
- more tuning or light partners for m_h

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- Origin of tuning(s)
  - Higgs potential

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  - to decrease β :
    - more tuning
    - since $\beta \propto \not{G}$, one can lower the elem-comp mixings Δ

$$\text{but} \quad m_t \sim \frac{\Delta^2}{m_T} \quad \text{hence} \quad m_T \text{ has to be low as well}$$

CH Landscape

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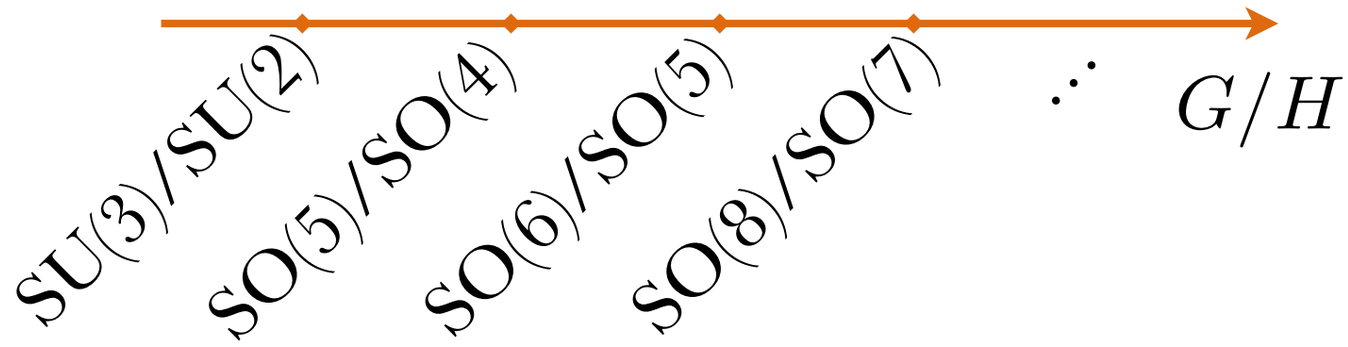

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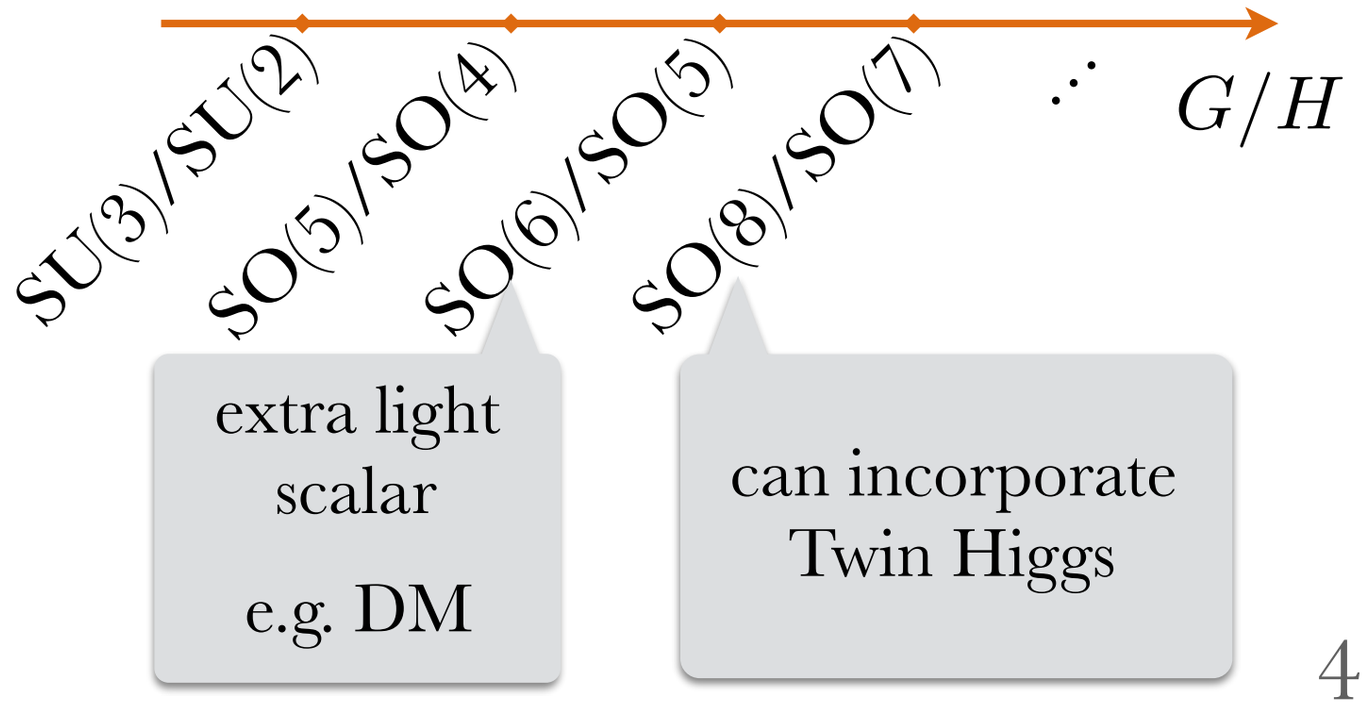

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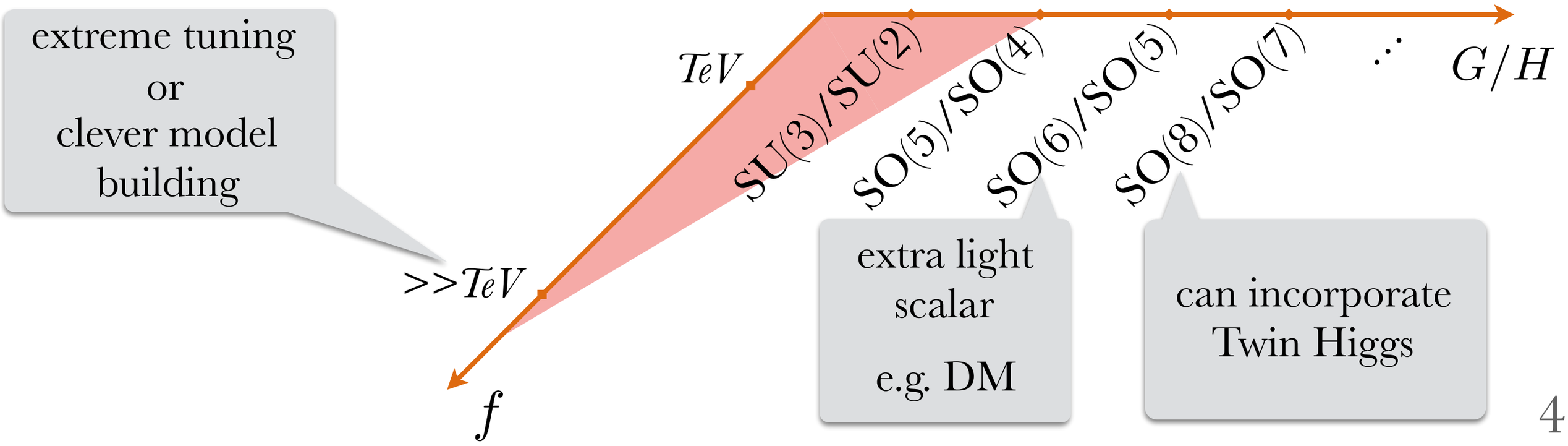

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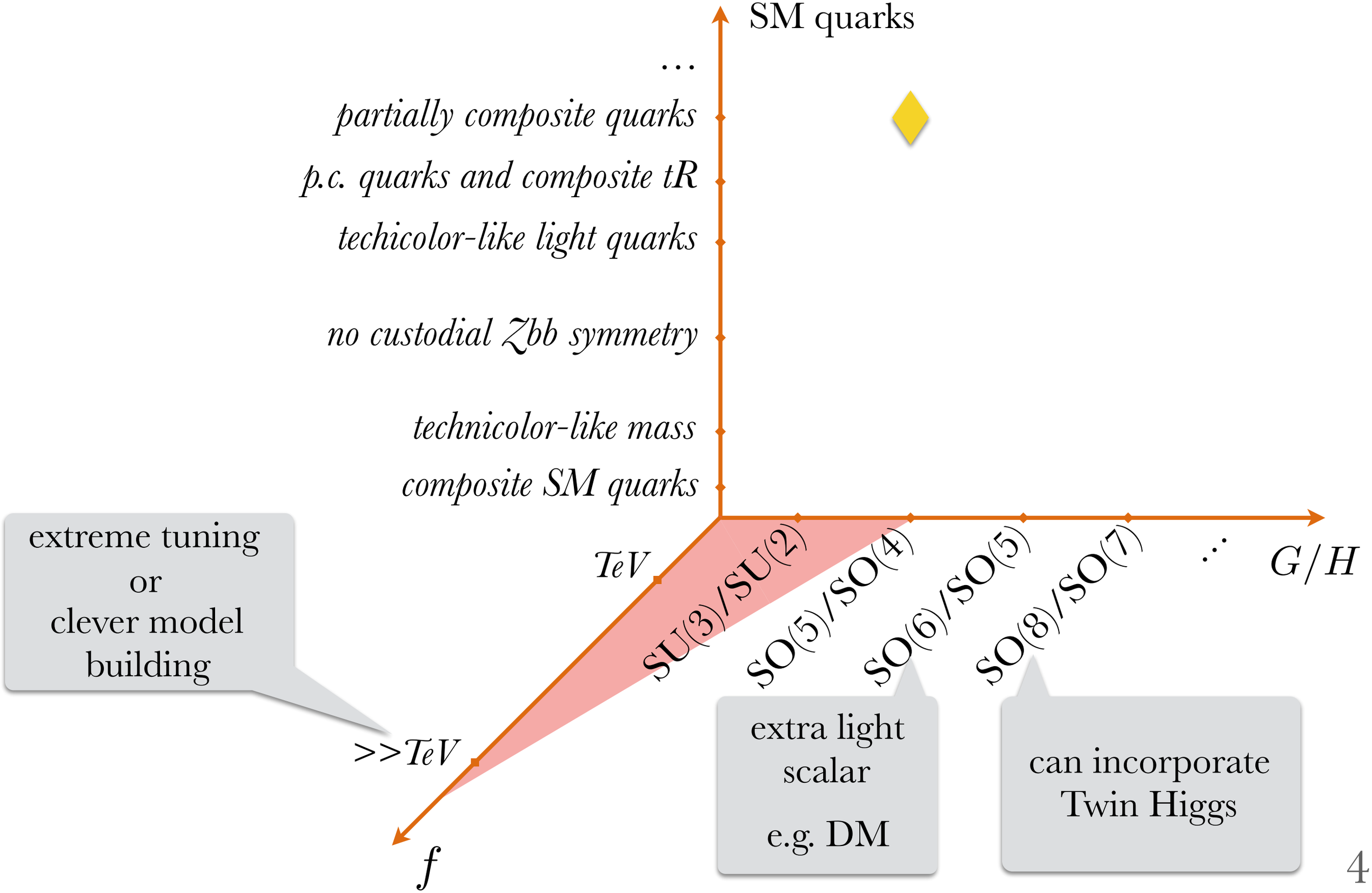

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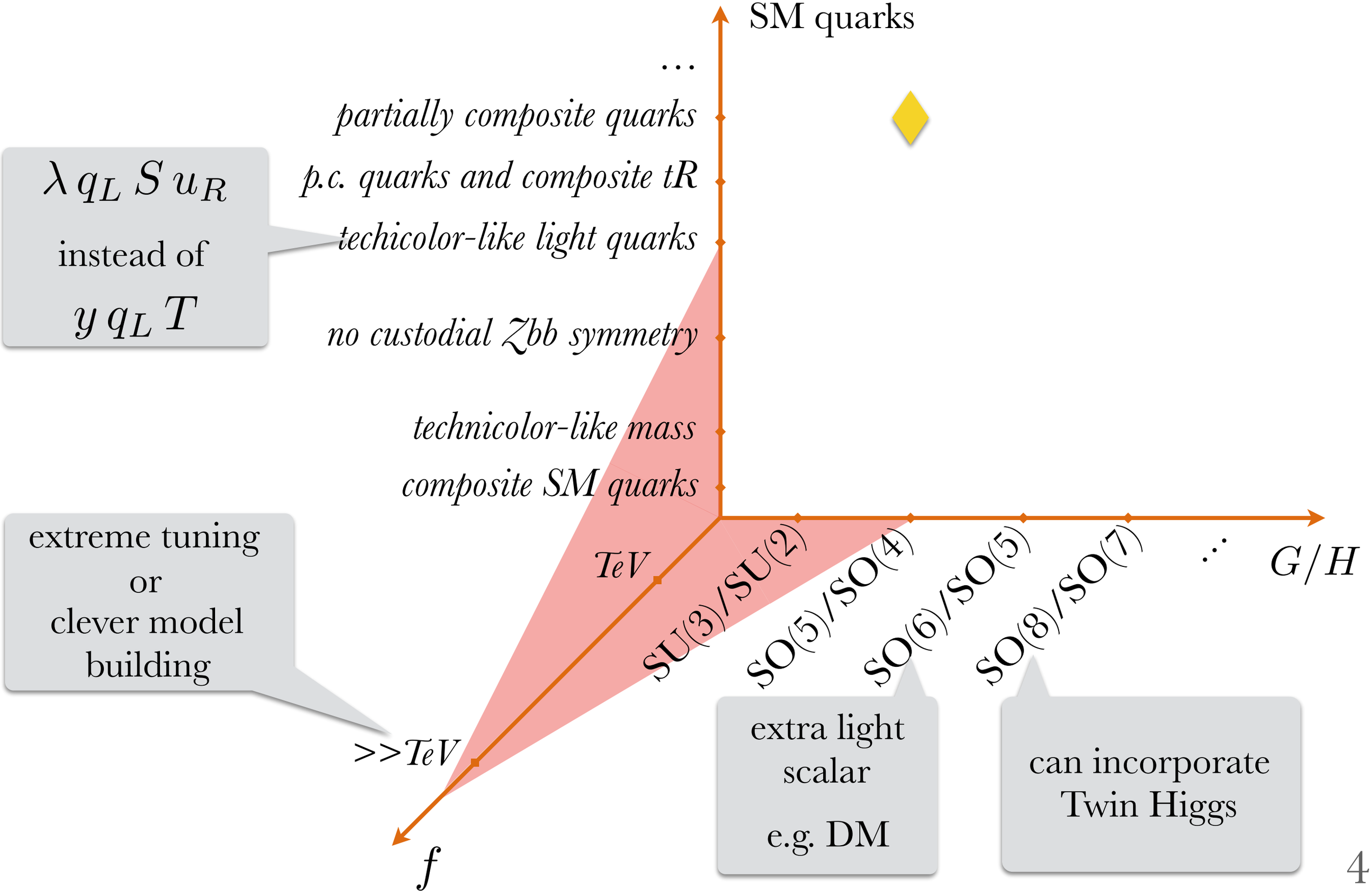

Phenomenology

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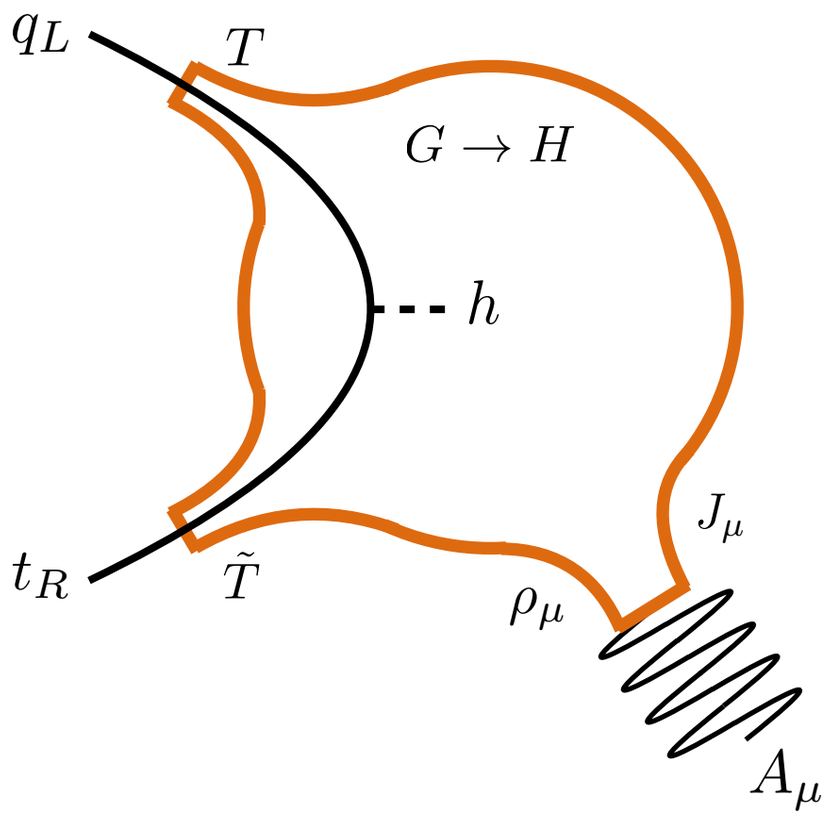
- observed quarks are partially composite

$$t_L = \cos\phi_L\, t_L + \sin\phi_L\, T_L$$

- *ffV couplings*
- *4f operators*
- *flavour physics*



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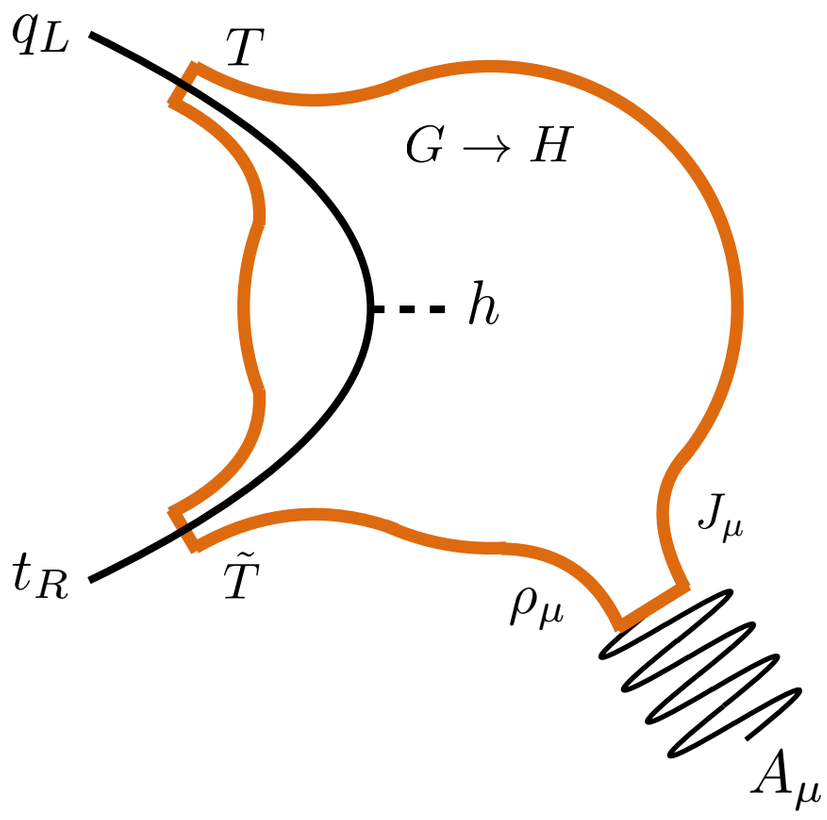

- new resonances: fermions, vectors and scalars

$$\tilde{T} \quad T \quad \rho_\mu$$

- *collider searches for new states*
- *Dark Matter*
- *cosmological phase transitions*
- *S,T parameters*

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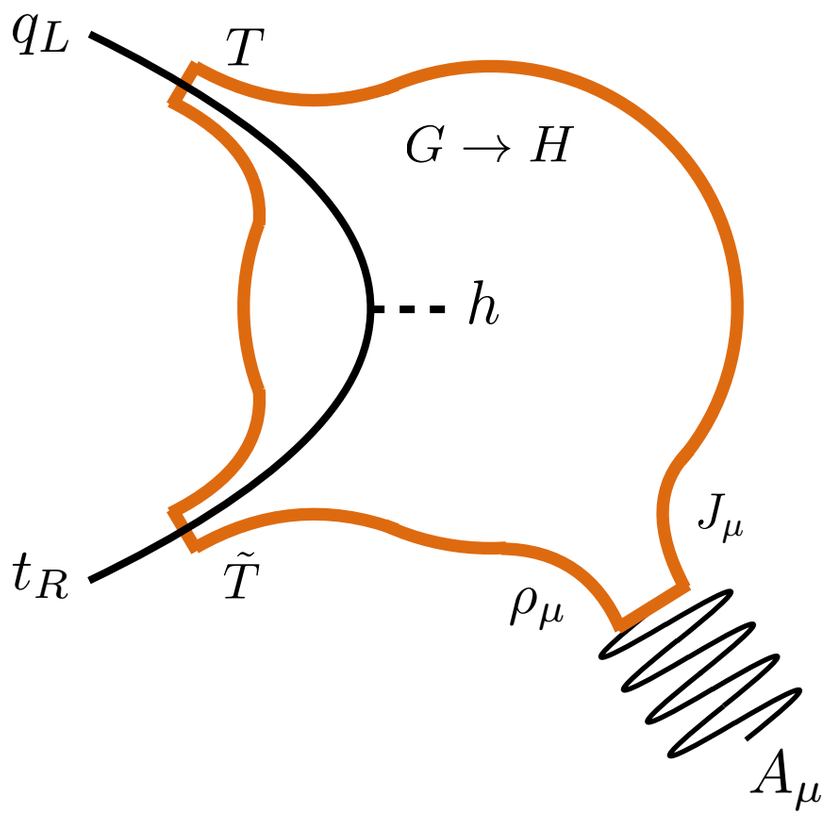

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$$h \to f \sin\frac{h}{f} = h - \frac{h^3}{6f^2} + \dots$$

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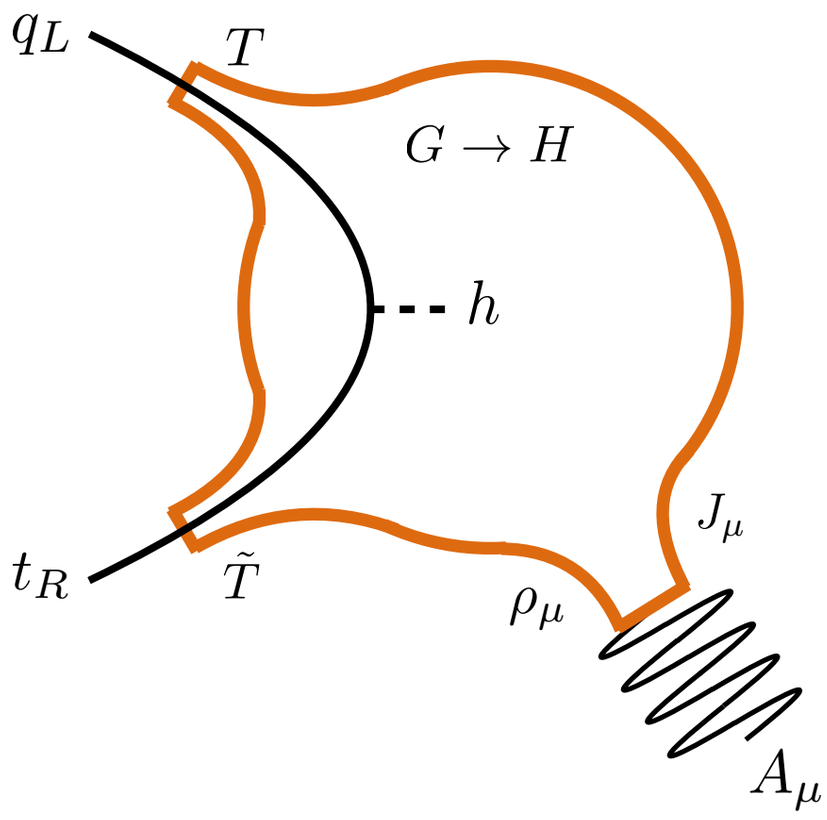

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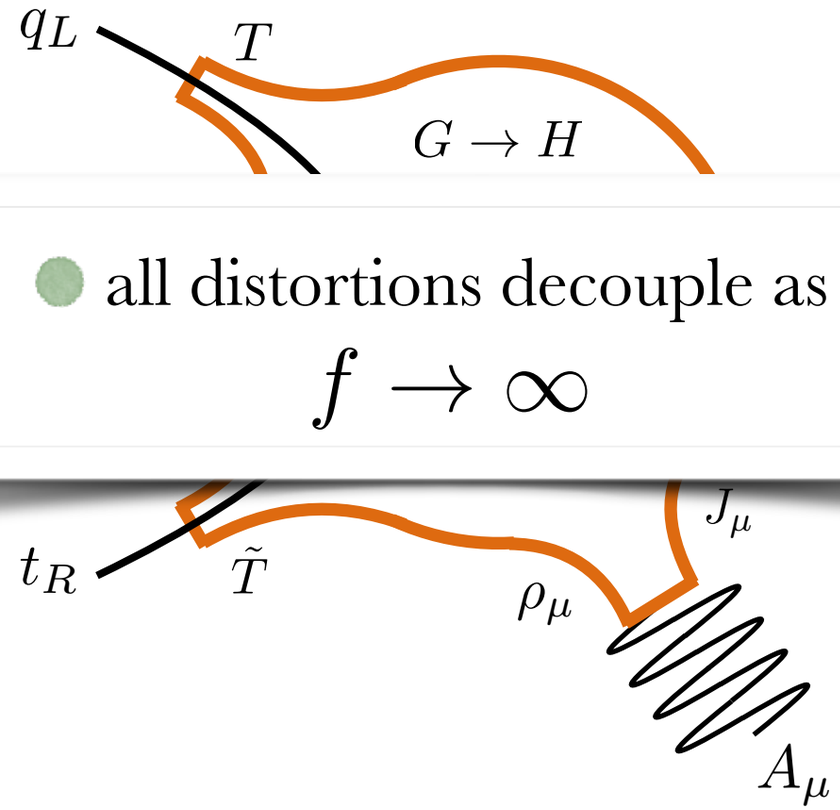

- all distortions decouple as

$$f \to \infty$$

- new resonances: fermions, vectors and scalars

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Direct production

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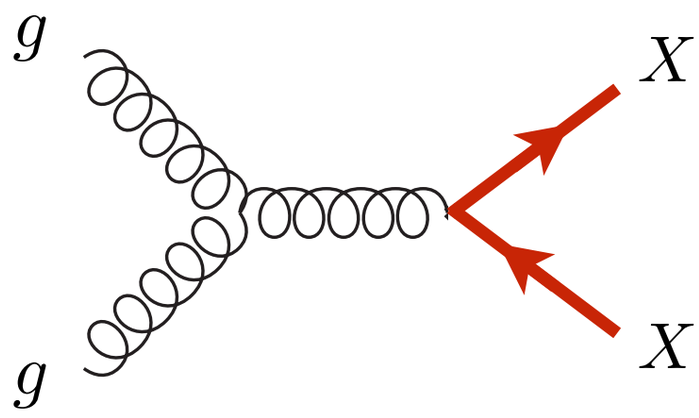
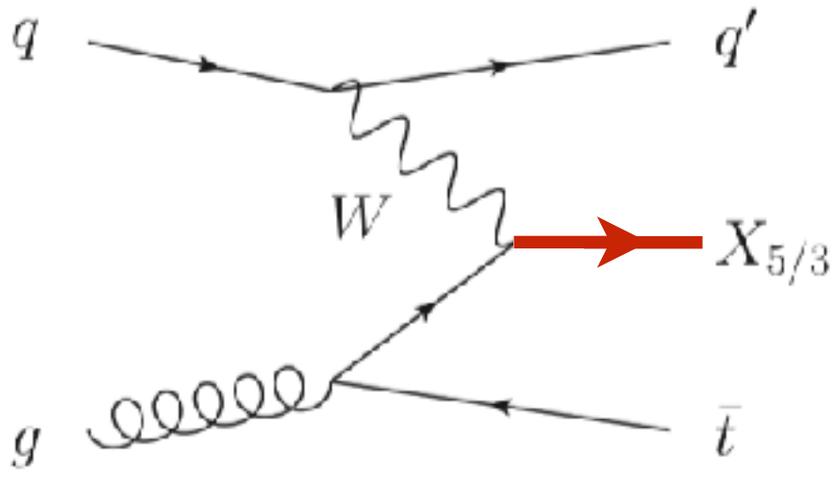
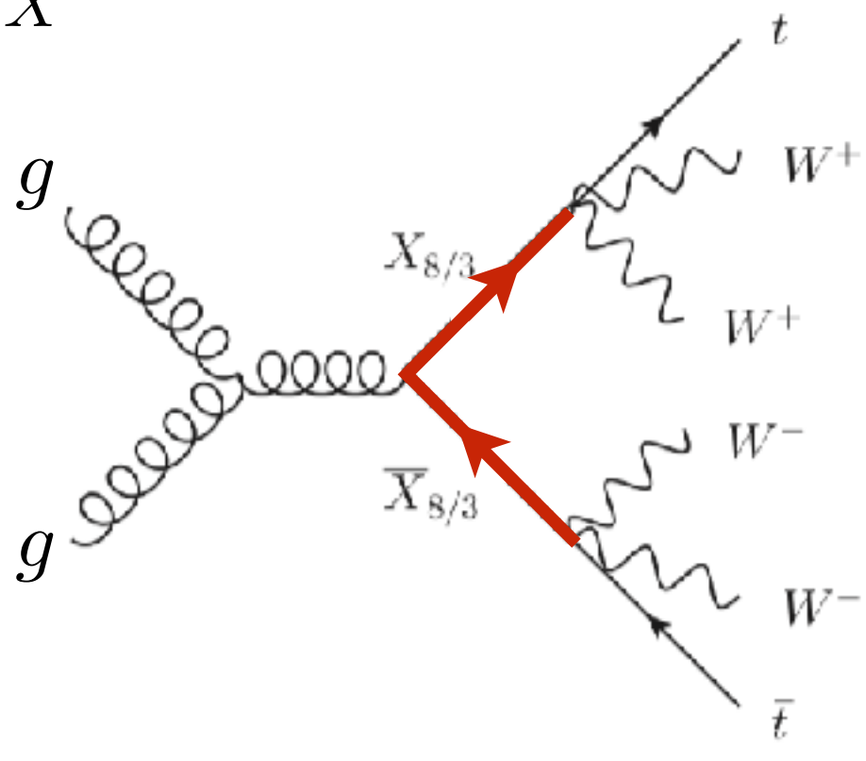
- Fermionic partners:
  - Have to be EW and QCD charged
  - Often predicted to be much lighter than other resonances



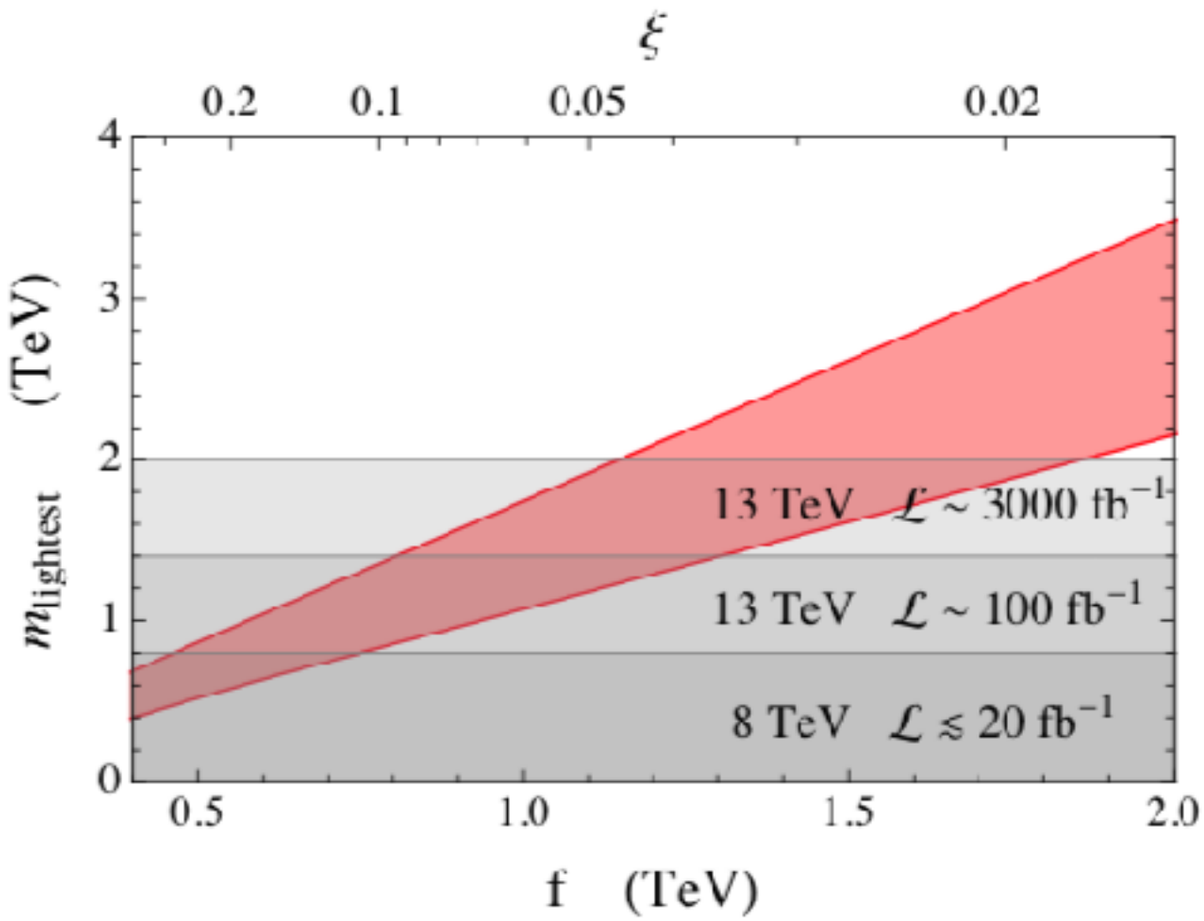




Direct production

- Current bound $m_X > 1.3$ TeV CMS-PAS-B2G-17-008

- Future LHC projections OM,Panico,Wulzer [1512.04356]



- FCC-hh $m_X > 6$ TeV (1ab^{-1}) Panico,Riembau,Vantalon [1712.06337]

Direct production

- EW-charged spin-1 resonances
  - couplings to mostly elementary SM states $\propto g_A/g_\rho$

$$\mathcal{L}_{mass} \sim g_\rho^2\, \rho_\mu^2 + g_\rho g_A\, \rho_\mu A^\mu$$

$$A_\mu \to A_\mu + (g_A/g_\rho)\rho_\mu$$

  - longitudinal g.b. (~composite states) have a larger coupling. To see this we can e.g. "undo" the Unitary gauge on g.b. only

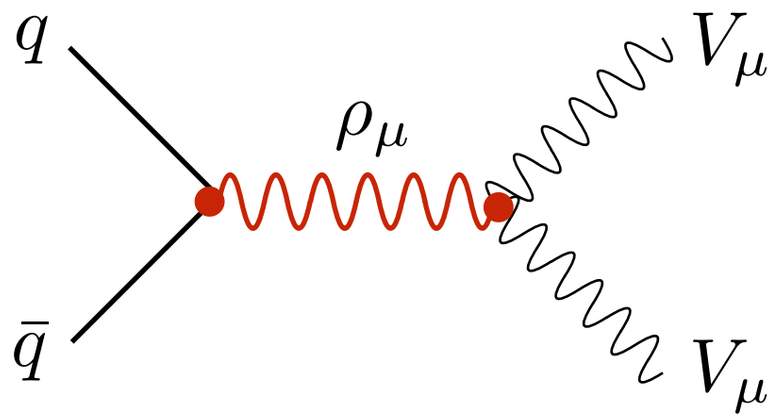
$$g_A A_\mu \to g_A A_\mu + \partial_\mu \pi$$

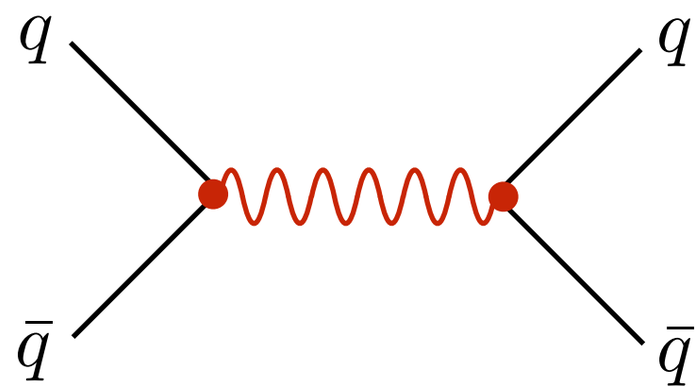
  - new interactions grow with energy and are not g_A suppressed

Direct production

- despite the previous enhancement, the LHC production is dominated by Drell-Yan due to low A_L luminosity

Falkowski,Grojean,Kaminska,Pokorski,Weiler[1108.1183]
Pappadopulo,Thamm,Torre,Wulzer[1402.4431]





- current bound $m_\rho \gtrsim 3\,TeV \;\; (g_\rho = 3)$

CMS[1708.05379]
ATLAS[1708.09638]

Higgs couplings

- LO Higgs couplings modifications wrt SM
  - come from the Higgs "geometric" origin.

$$h \to f \sin \frac{h}{f} = h - \frac{h^3}{6f^2} + \dots$$

  - are of order v^2/f^2
  - will be constrained to ~10% at the LHC and to ~1% at future lepton machines

Precision physics

- The leading operators affecting the **LEP** measurements are
  - universal

$$S \sim \Pi'_{BW_3}(0)$$
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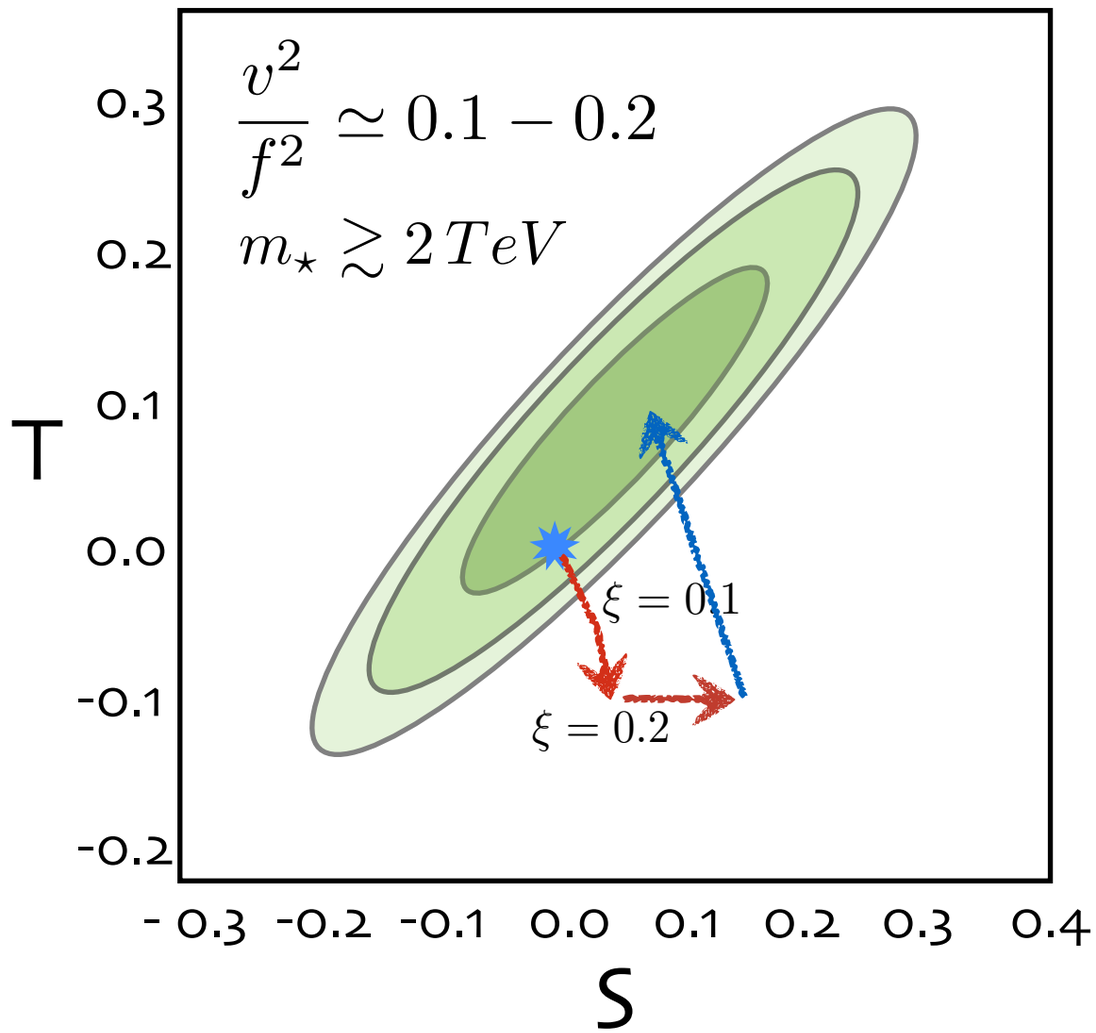

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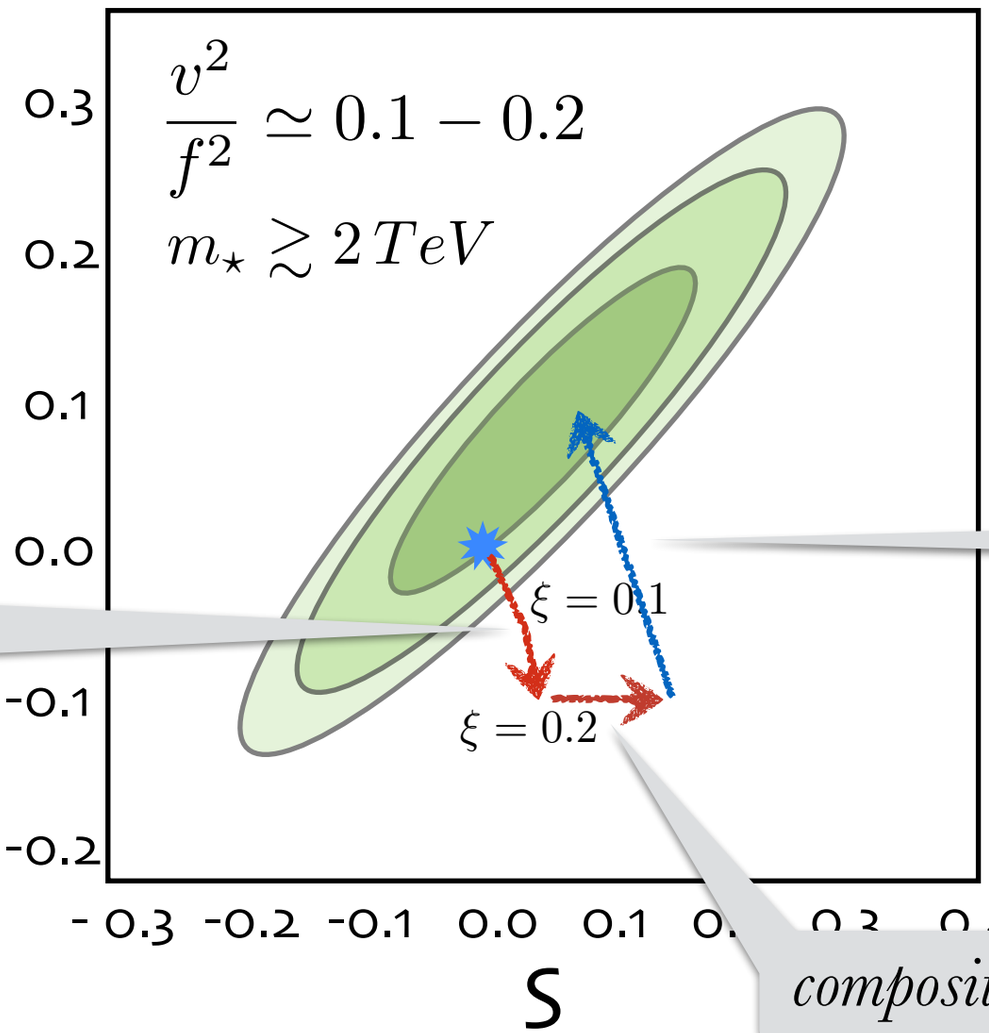

hVV coupling modification (reduction)
Barbieri et al [0706.0432]

composite fermions
Gillioz [08063450], Grojean,OM,Panico [1306.4655]

composite vectors

High-energy Precision physics

- in the same channels **LHC** will only slightly improve on S and T

High-energy Precision physics

- Any way to benefit from high c.o.m. energy @ **LHC**?
  - energy-growing operators in quark production

$$W, Y \sim (D_\mu F^{\mu\nu})^2 \sim p^4 A_\mu^2 \quad \text{vs} \quad S \sim (H D_\mu H)(D^\nu F^{\mu\nu}) \sim v^2 p^2 A_\mu^2$$

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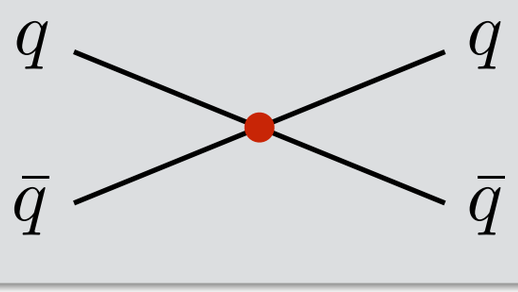

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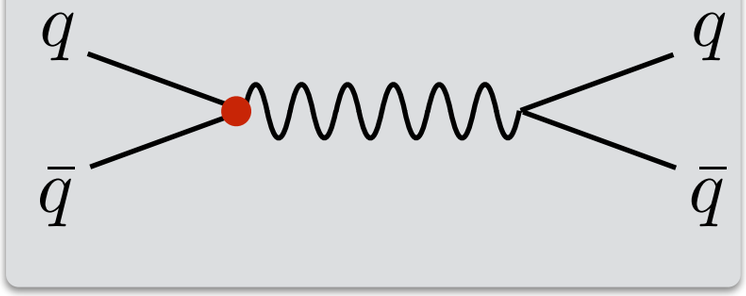

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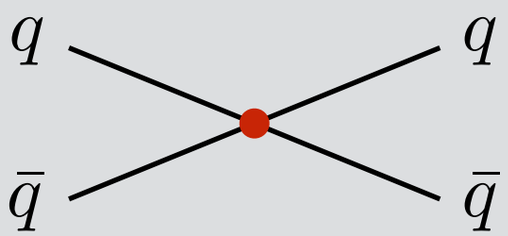

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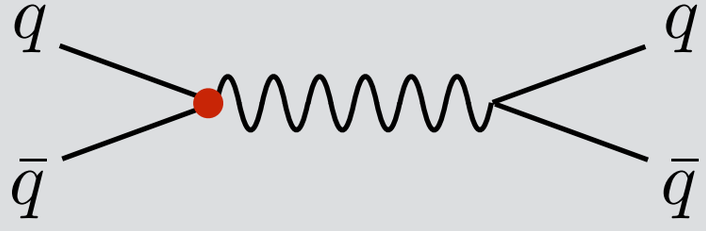
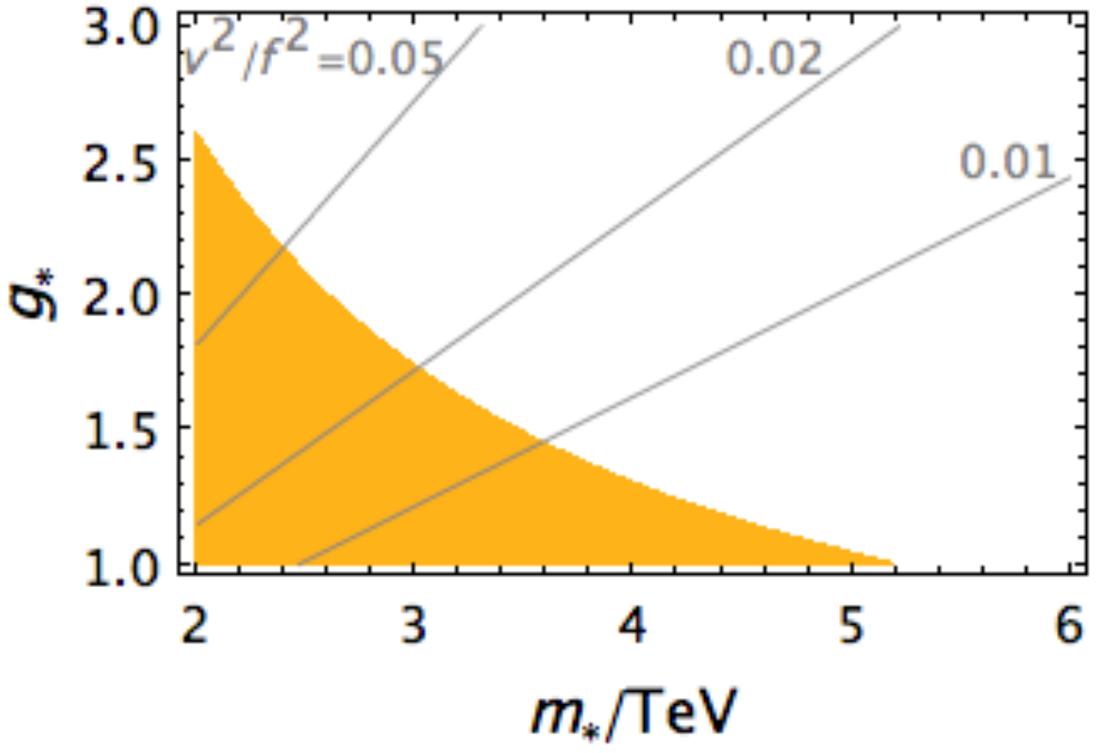


- HL-LHC reach
  Farina et al[1609.08157]

$$Y, W \lesssim 10^{-4}$$

- one more order of magnitude at CLIC

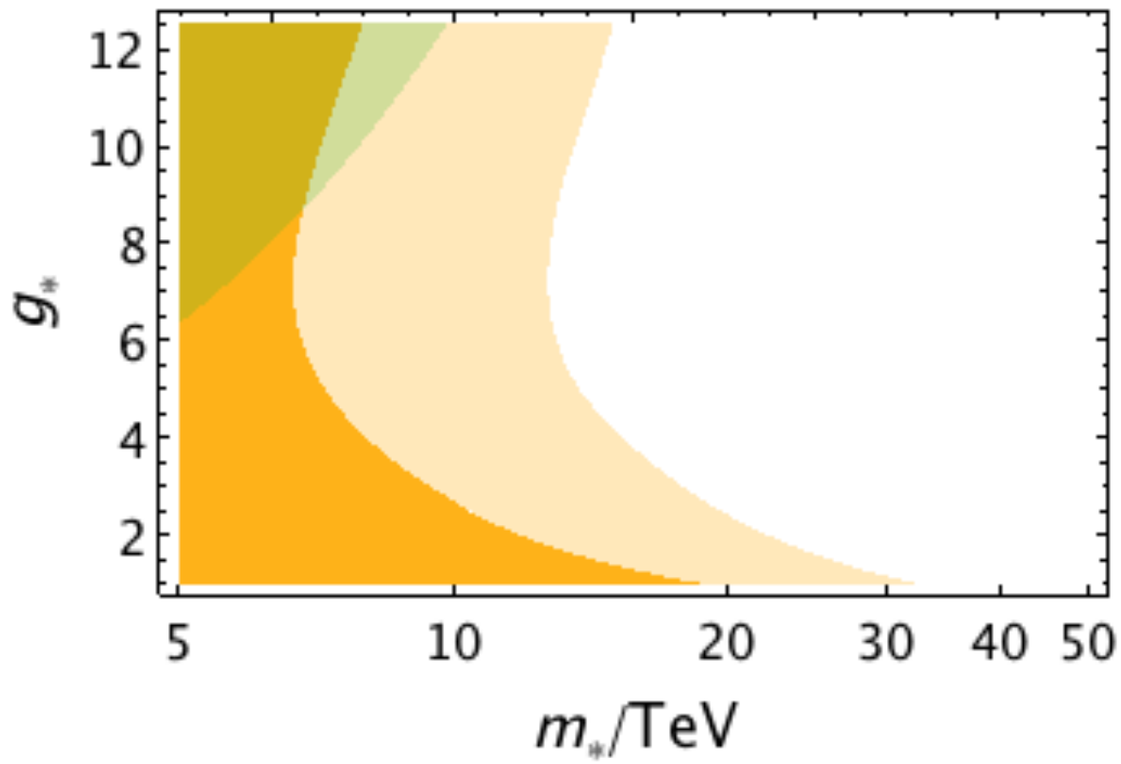


High-energy Precision physics

- Any way to benefit from high c.o.m. energy @ **LHC**?
  - 4-fermion (non-universal) operators, sensitive to top compositeness

$$\epsilon_q^2 g \frac{1}{m_\star^2} (\bar{q}\gamma_\mu q)(D_\nu F^{\mu\nu}) \quad \rightarrow \quad \epsilon_q^2 g^2 \frac{1}{m_\star^2}\ q^4$$

  - currently not very constraining, but can become important e.g. at **CLIC**



OM,G.Durieux

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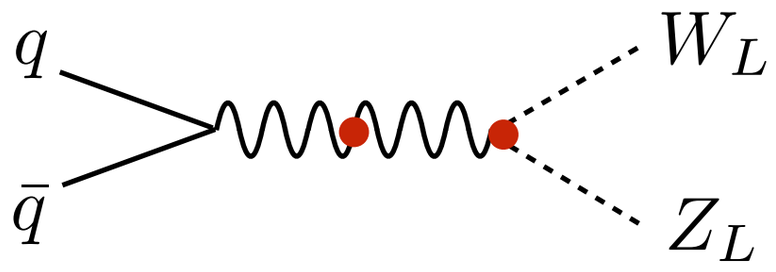
  - energy growth of SM-BSM interference terms with longitudinal g.b.



Franceschini et al [1712.01310]
DaLiu,Liao-Tao Wang [1804.08688]

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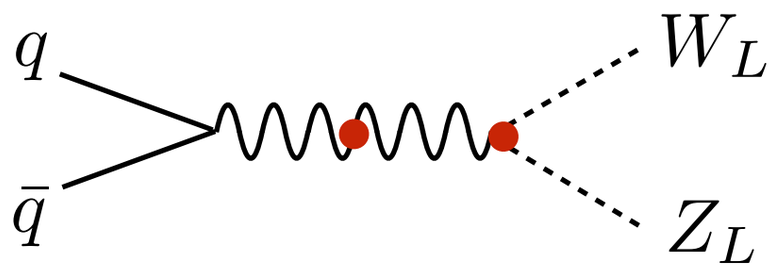

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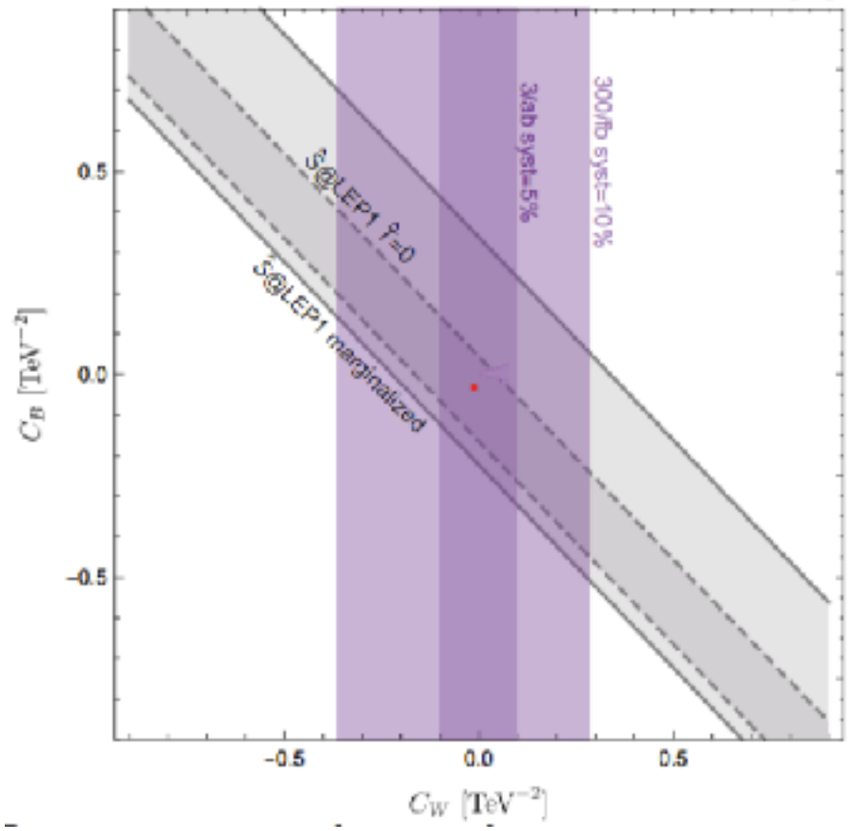
  - at HL-LHC can become comparable (and complementary) to LEP



Conclusion

- CH - one of the few ways to naturally explain EW scale …
- … up to a (not extreme) tuning.
- Gives a variety of currently testable predictions.
- High-energy machines offer new precision tests.
- So far no experimental signals, but can be nearby.