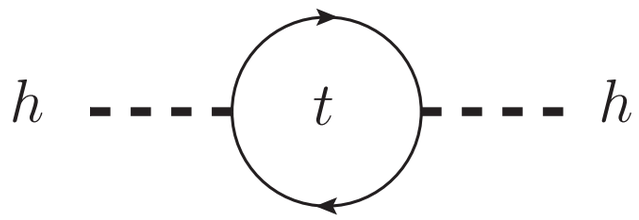
Higgs as a Composite PNGB

Oleksii Matsedonskyi

Nov. 2015

Introduction: The Hierarchy Problem

- Higgs mass is unstable under radiative corrections



$$\delta m_h^2 \simeq \frac{g^2}{16\pi^2}\,\Lambda^2$$

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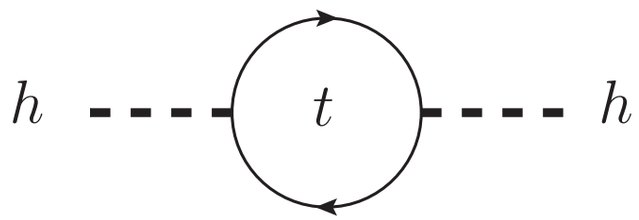

$$\delta m_h^2 \simeq \frac{g^2}{16\pi^2}\,\Lambda^2$$

$$\Lambda \sim M_{Planck}$$

$$\text{tuning} \sim \frac{M_{Planck}^2}{m_h^2} \sim 10^{32}$$

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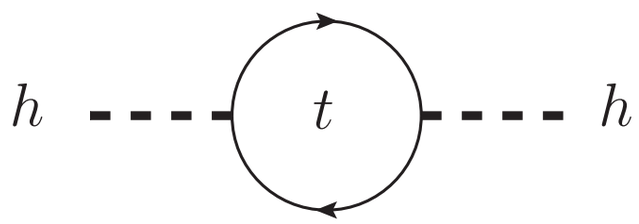

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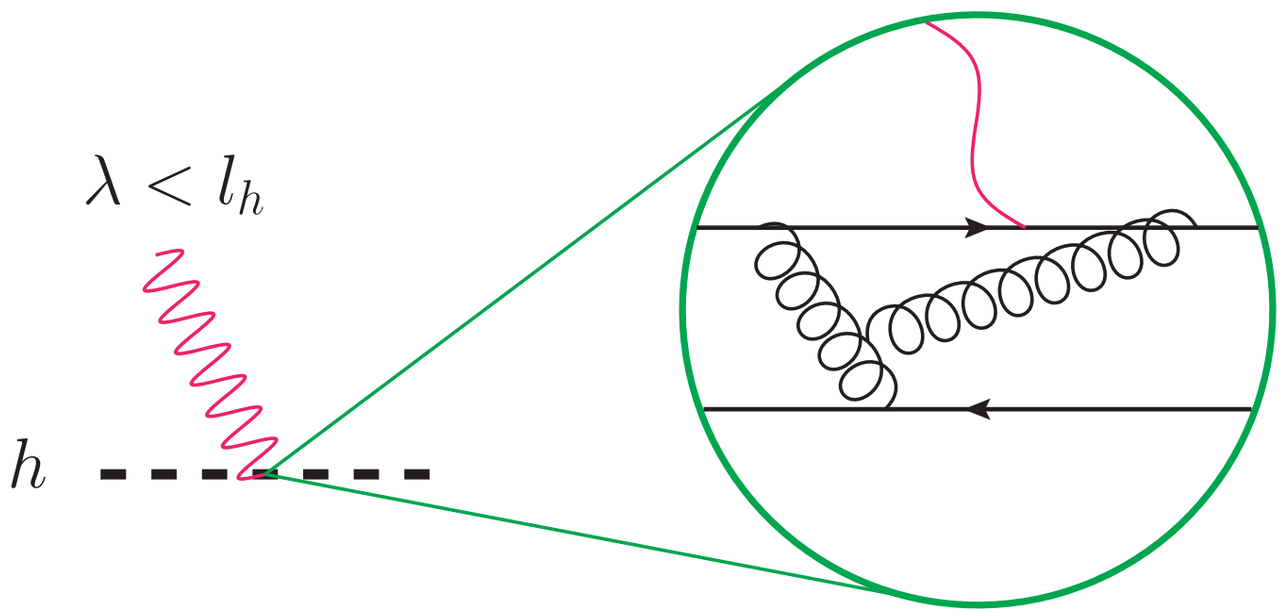
- UV can be screened by TeV scale

New Physics

CH

$\lambda < l_h$



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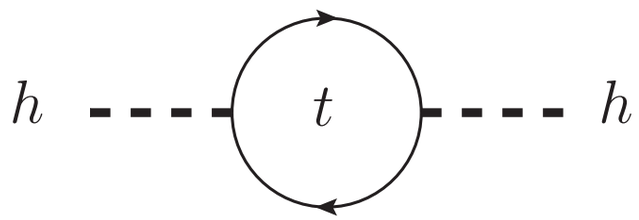

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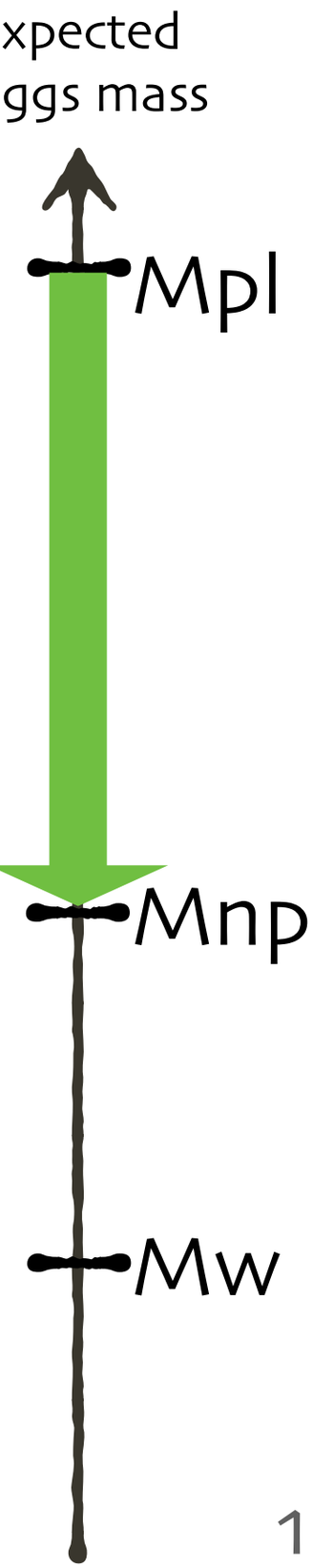

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$$\delta m_h^2 \simeq \frac{1}{l_h^2} \simeq m_\rho^2$$

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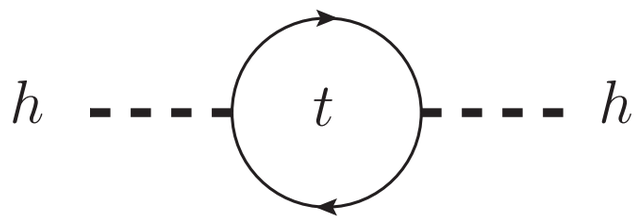

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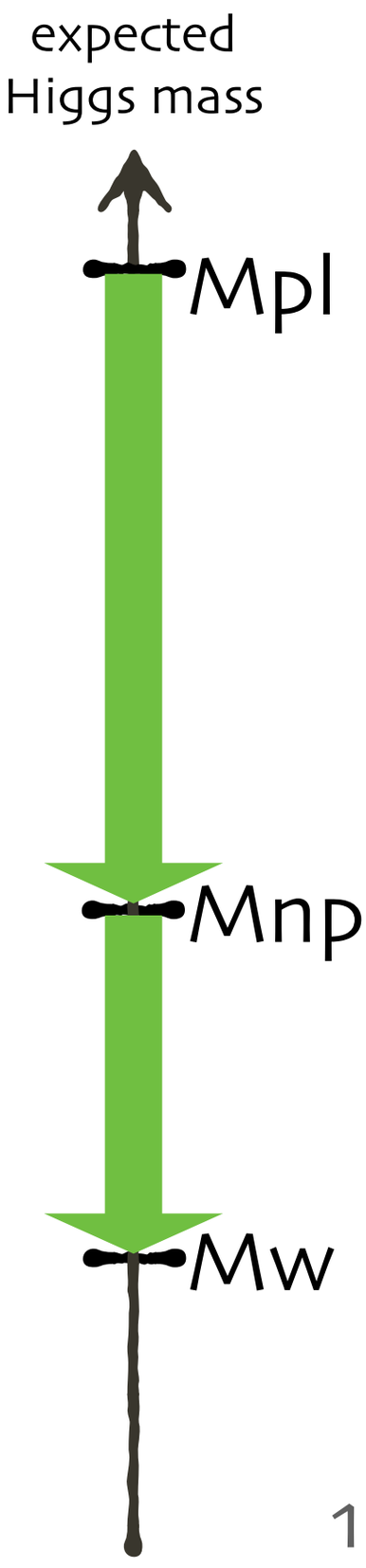

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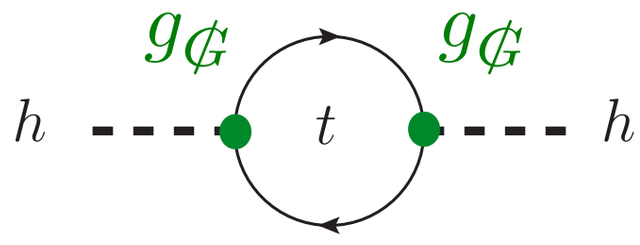
New Physics

$$\delta m_h^2 \simeq \frac{1}{l_h^2} \simeq m_\rho^2$$

- Higgs realized as a Goldstone boson

can be naturally light



$$\delta m_h^2 \simeq \frac{g_{\not G}^2}{16\pi^2}\,m_\rho^2$$

[Georgi,Kaplan;Contino,Nomura,Pomarol]

Composite Goldstone Higgs

<u>composite sector</u>

SO(5) → SO(4) at a scale f >>Mz

(analogous to SU(2)L x SU(2)R → SU(2)V in QCD)

[Kaplan'91;Agashe,Contino,Pomarol'05]

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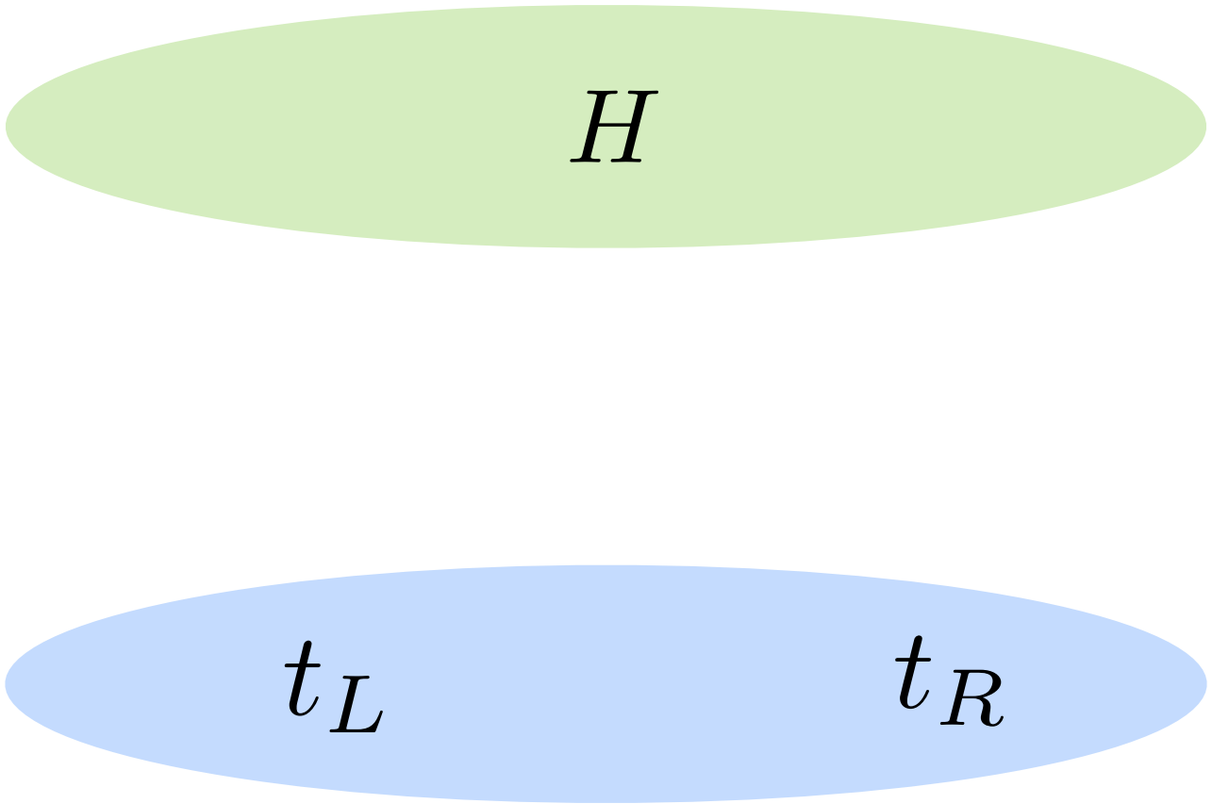

<u>elementary sector</u>

SM without Higgs

[Kaplan'91;Agashe,Contino,Pomarol'05]

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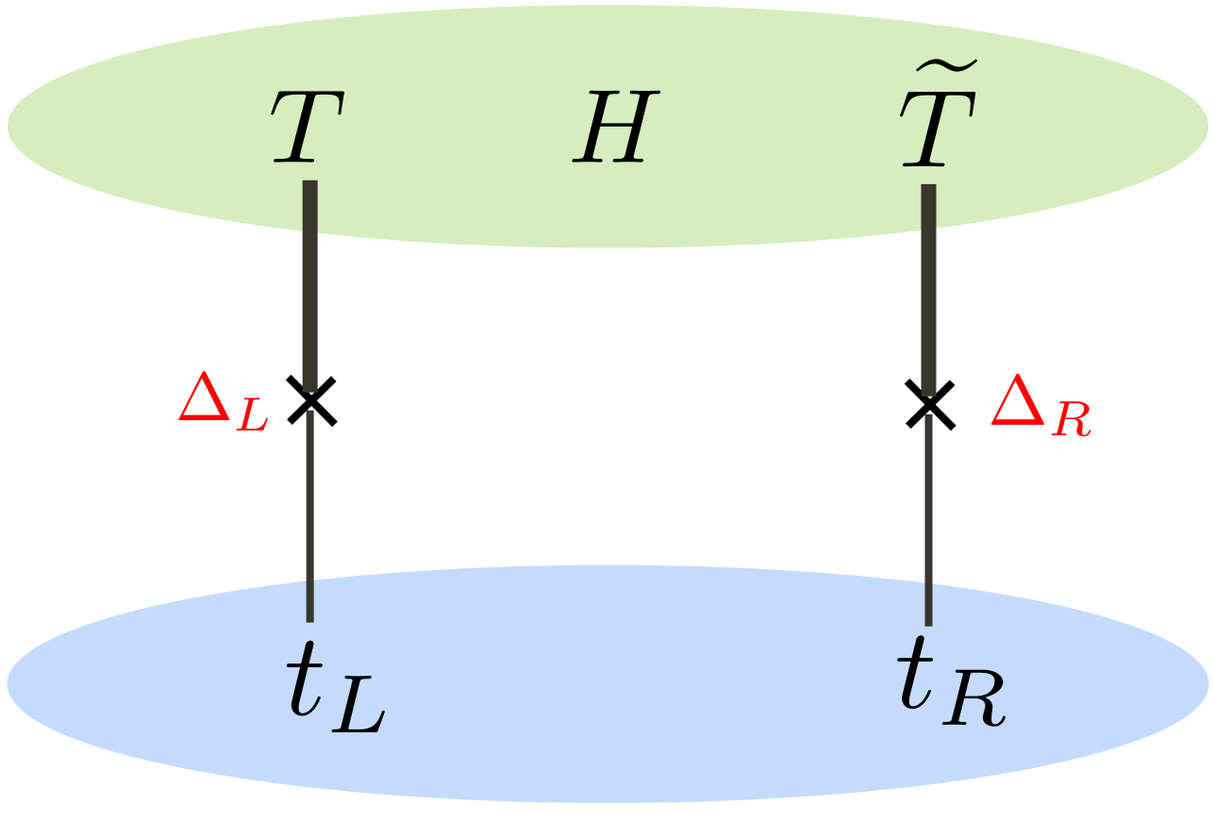

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SM fermions become partially composite

$$t_L^{\grave{}} = \cos\phi_L\, t_L + \sin\phi_L\, T_L$$

$$\sin\phi_L \simeq \frac{\Delta_L}{M_T}$$

<u>elementary sector</u>

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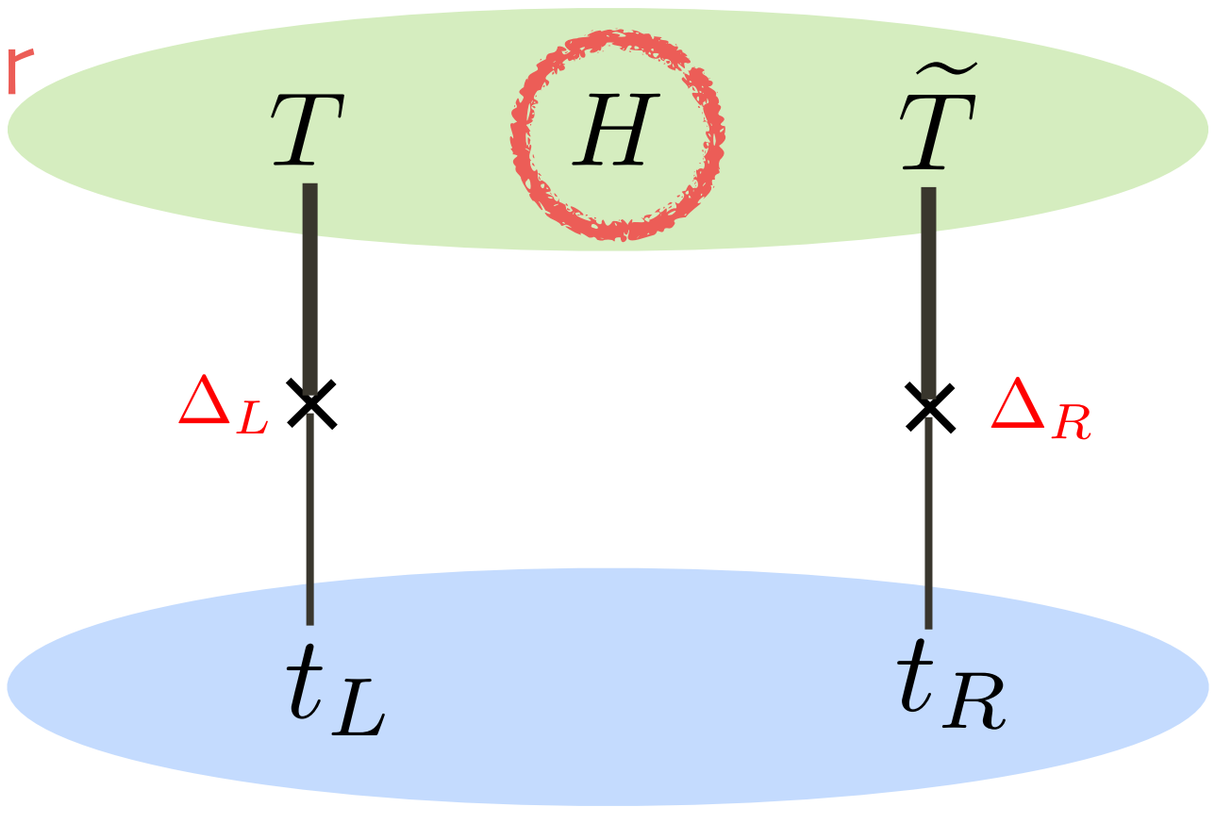
✦ Higgs self-inter



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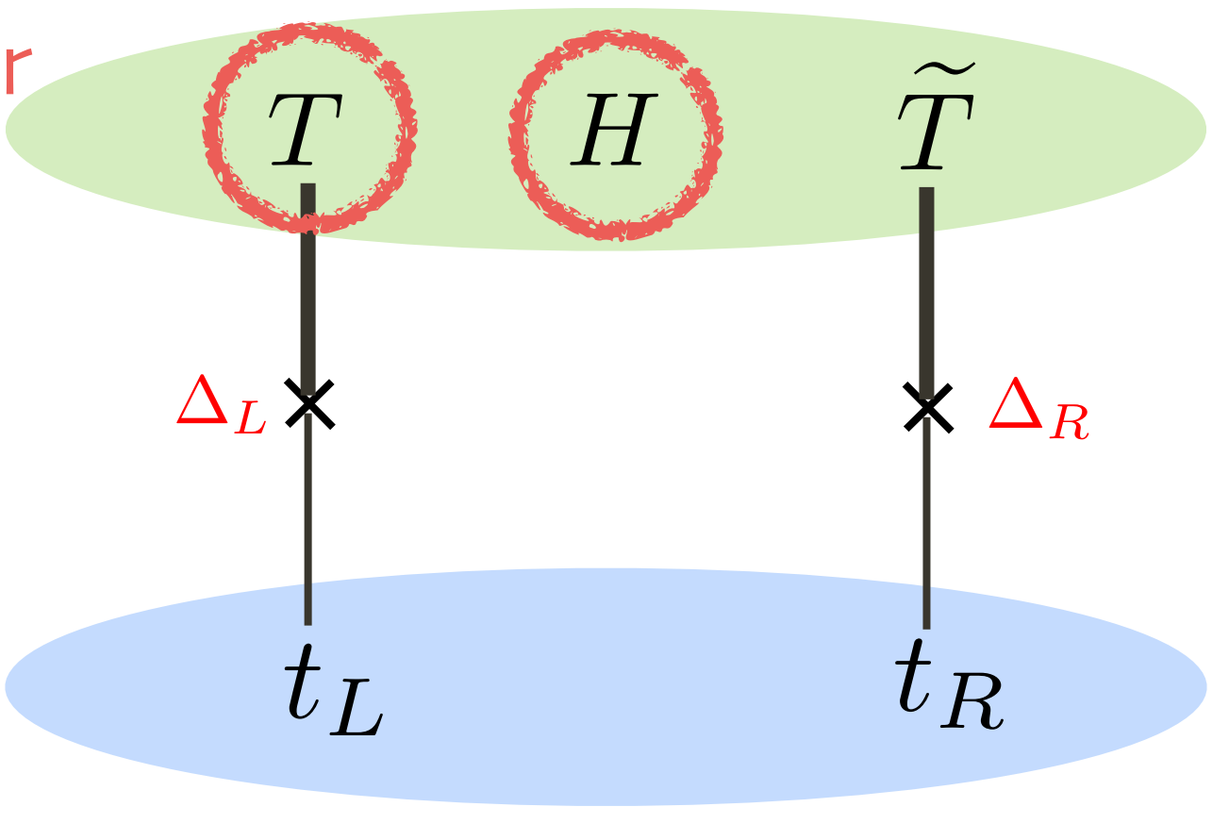
- ✦ Higgs self-inter
- ✦ direct searches



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Composite Goldstone Higgs

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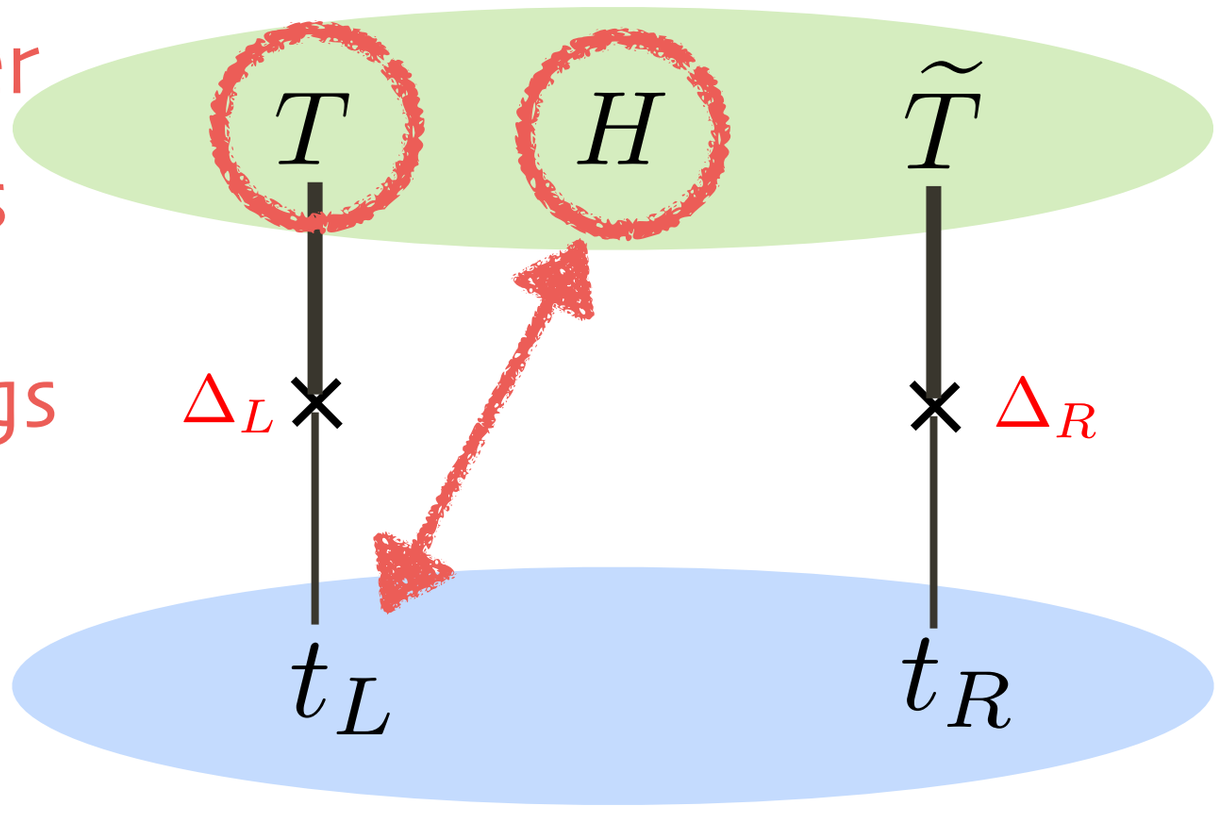
- ✦ Higgs self-inter
- ✦ direct searches
- ✦ Higgs couplings



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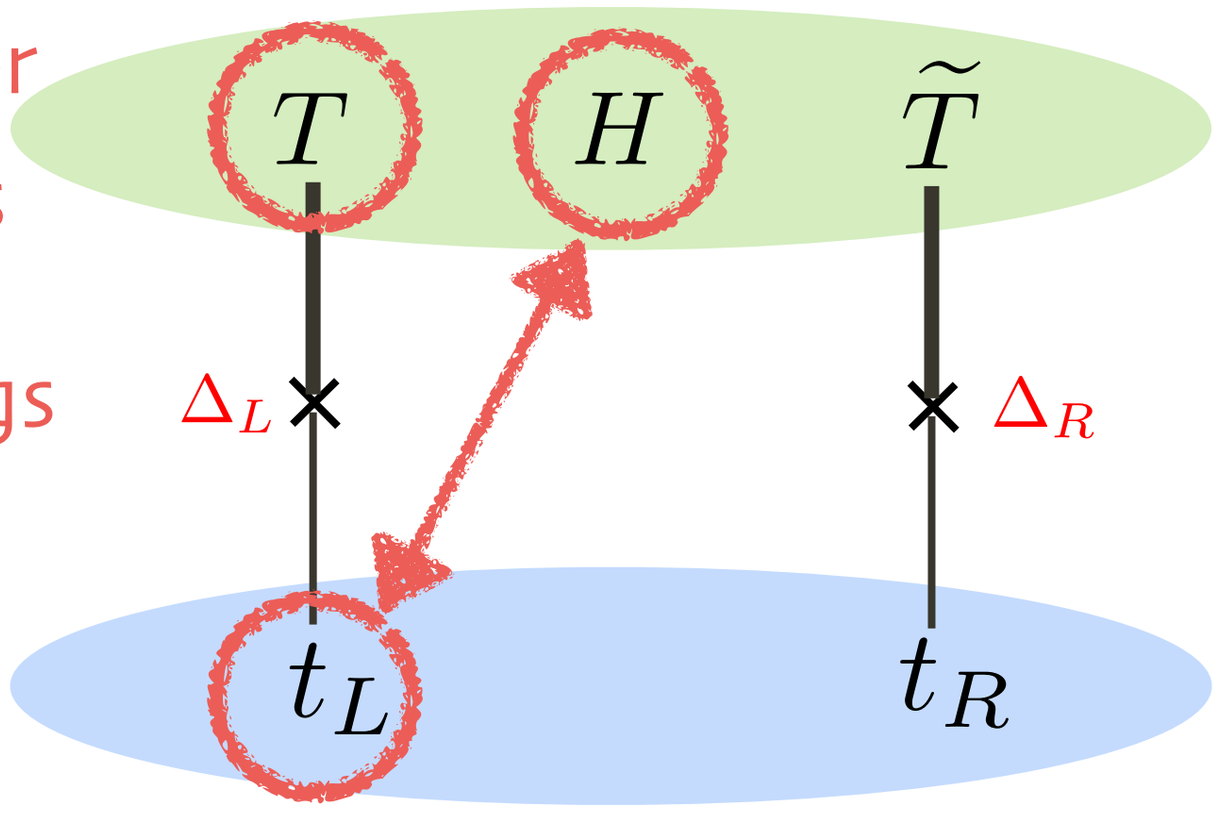
- ✦ Higgs self-inter
- ✦ direct searches
- ✦ Higgs couplings
- ✦ EWPT
- ✦ flavour



<u>elementary sector</u>

SM without Higgs

[Kaplan'91;Agashe,Contino,Pomarol'05]

Mass Spectrum

- f sets all the mass scales of the theory
- masses are proportional to f and the strength of coupling to it:

NP: $m_\rho \sim g_\rho f$

SM: $m_{\rm SM} \sim g_{\rm SM}\, v_{\rm SM}$

$v_{\rm SM} \ll f$

extra scale separation from tuning

$$\xi = \left(\frac{v}{f}\right)^2$$

possible since Gsm can be embedded into SO(4)

currently

$\xi \lesssim$ **0.1**

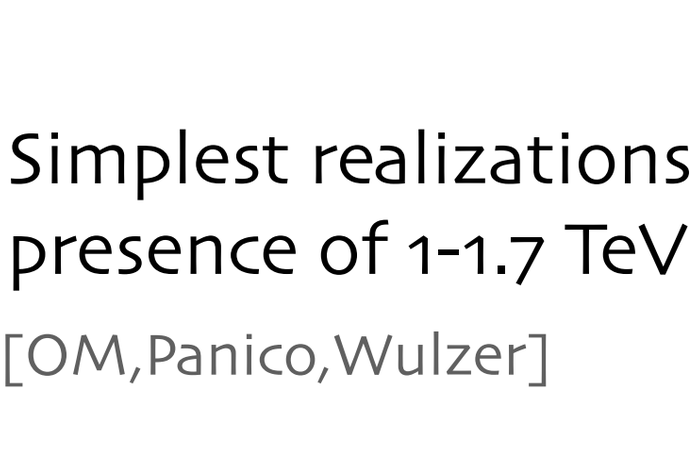
$f \gtrsim$ **800** GeV

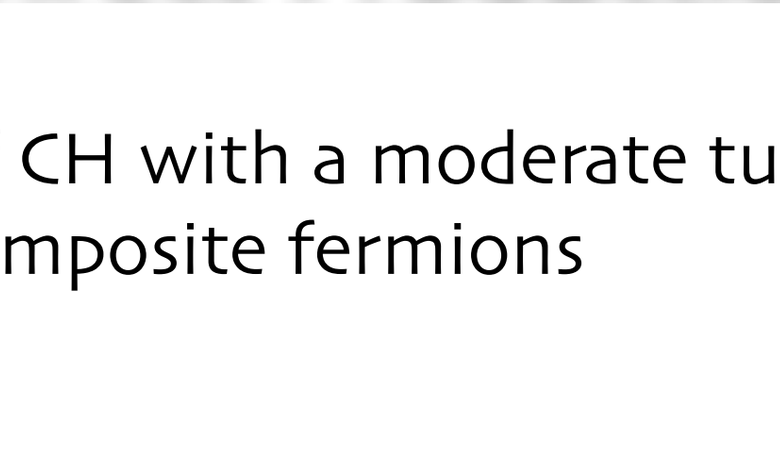
Direct Production

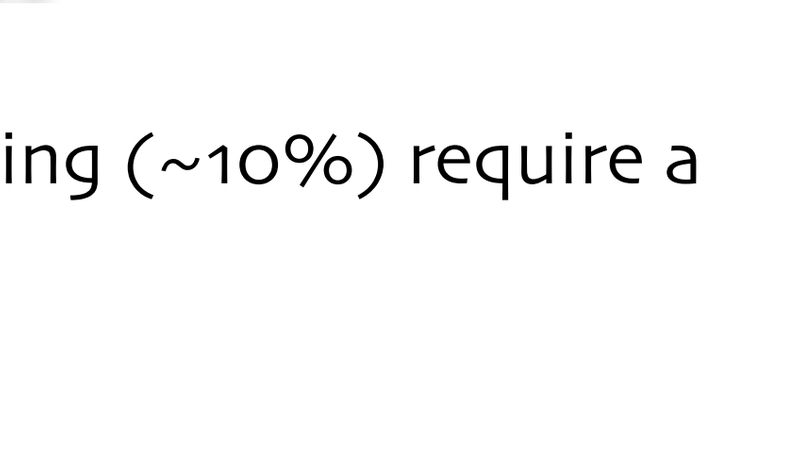
Simplest realizations of CH with a moderate tuning (~10%) require a presence of 1-1.7 TeV composite fermions

[OM,Panico,Wulzer]

Pair Production	Single Production	
	with a top quark	with a bottom





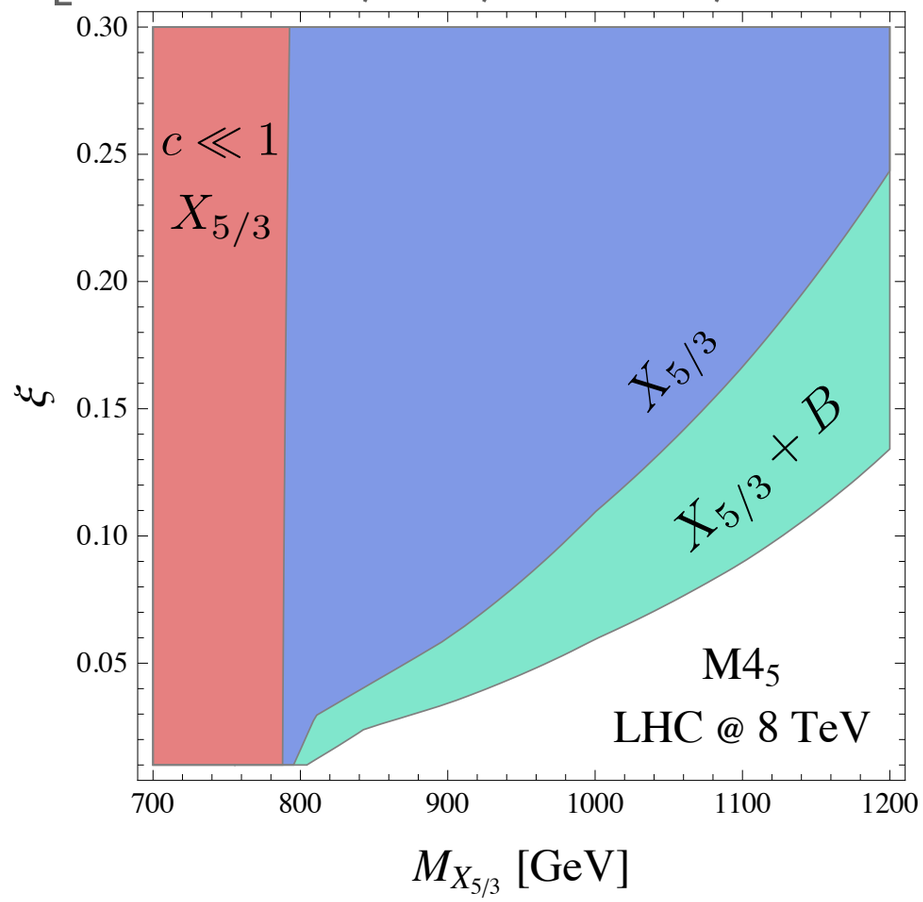


[Contino,Servant;Mrazek,Wulzer]

Direct Production

Direct searches can bound the degree of CH models naturalness

[De Simone,OM,Rattazzi,Wulzer]



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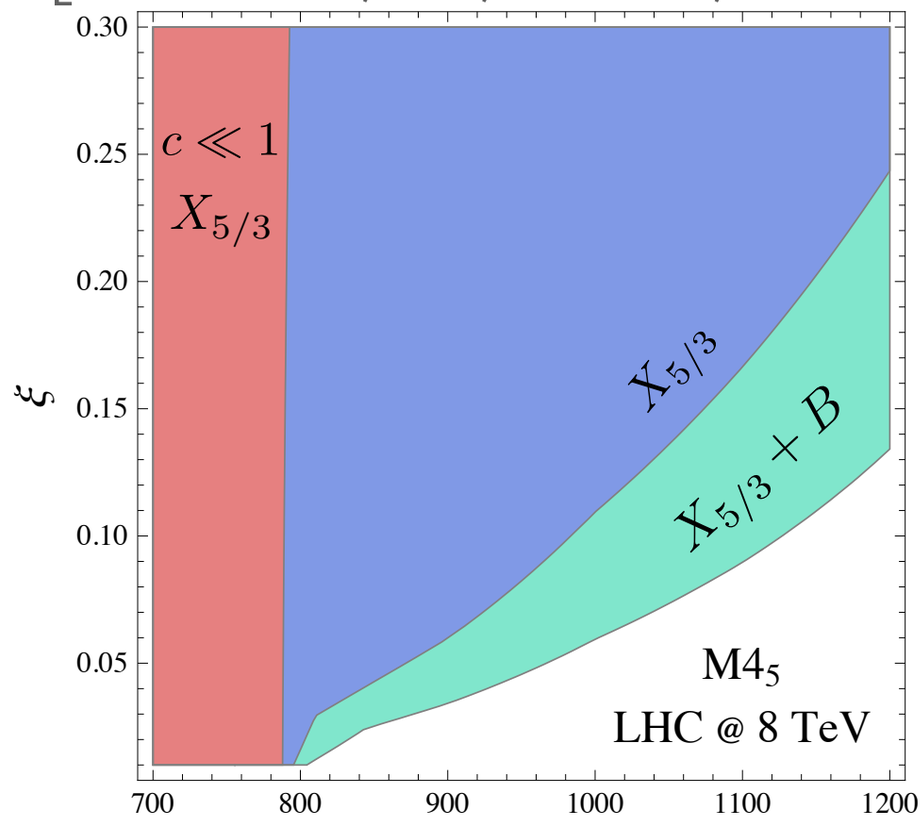
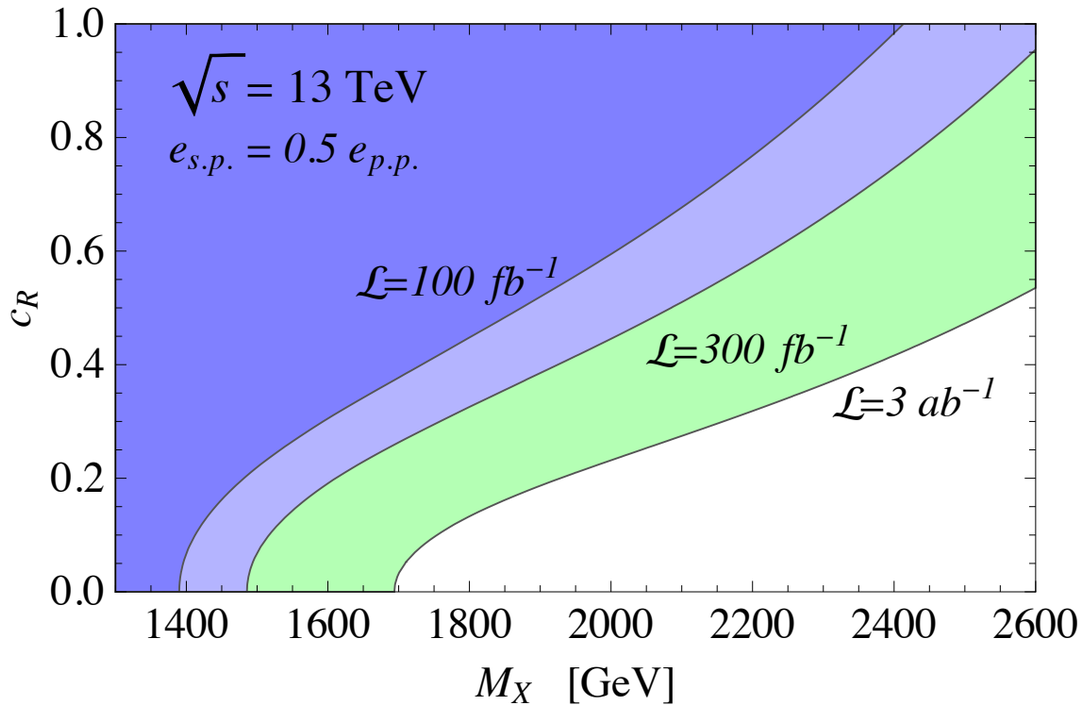




Growth of single production at 13TeV requires a universal parametrization of experimental analyses output

$$\sigma_{\rm sing}(X\bar{t}) = \left(c_R^2 + c_L^2\right)\sigma_{Wt}(m_X) + 2\,c_R\,c_L\left(\frac{m_t}{m_X + m_t}\right)\sigma'_{Wt}(m_X)$$

[OM,Panico,Wulzer]

Higgs Couplings Deformation

- Higgs as NGb generically induces non-renormalizable interactions

$$H \to f \, \exp i\frac{H}{f} \; = f + iH - \frac{H^2}{2f} - \frac{iH^3}{6f^2} + \cdots$$

- e.g. HVV coupling $\quad g^2\, v_{\rm SM}\, h\, W^2 \to g^2 \left(1 - \frac{1}{2}\xi + \cdots\right) v_{\rm SM}\, h\, W^2$

- one expects NP in higher order operators $\quad \frac{g_\rho^2\, v^2}{m_\rho^2} \; \sim \xi$

- this is generic to strongly coupled resonances, but the Goldstone symmetry imposes additional constraints on the deviations

$$g_{\rm SM} \to g_{\rm SM}(1 + c\,\xi)$$

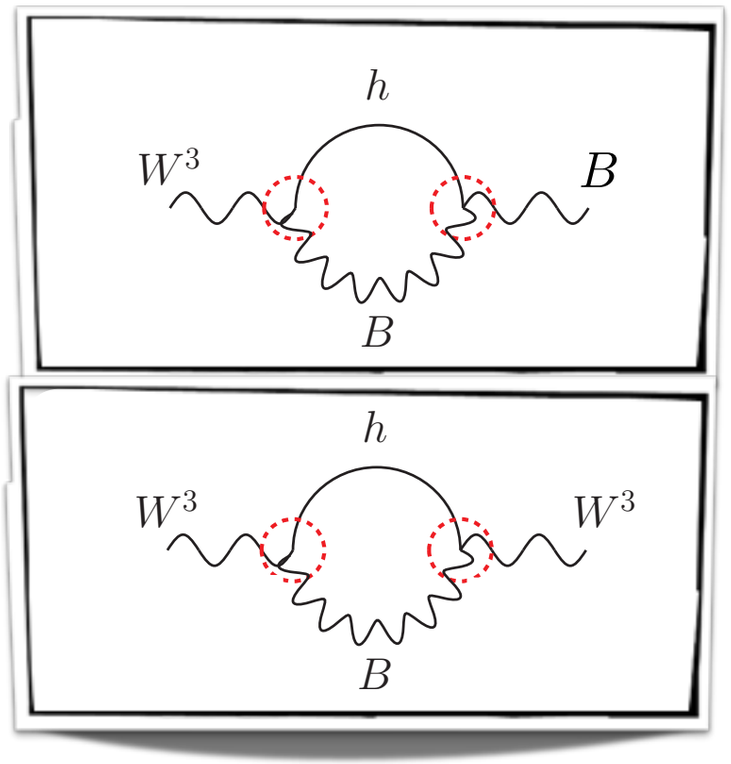
EWPT

strong constraints on NP scenarios by LEP measurements:

$$S \sim \Pi'_{BW_3}(0)$$
$$T \sim \Pi_{W^\pm}(0) - \Pi_{W_3}(0)$$

- generic for CH models

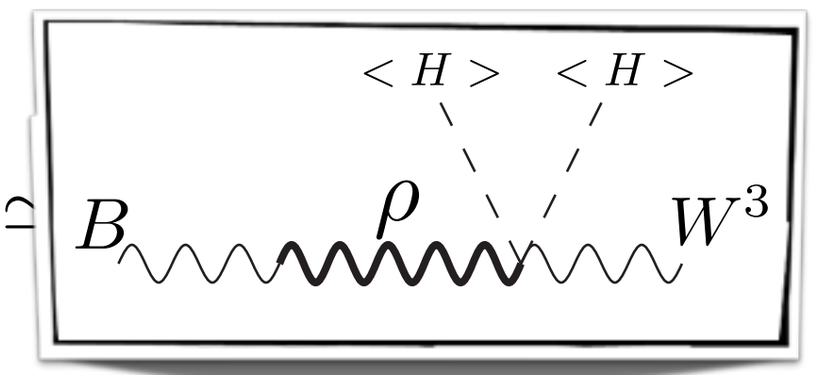
$\Delta S =$

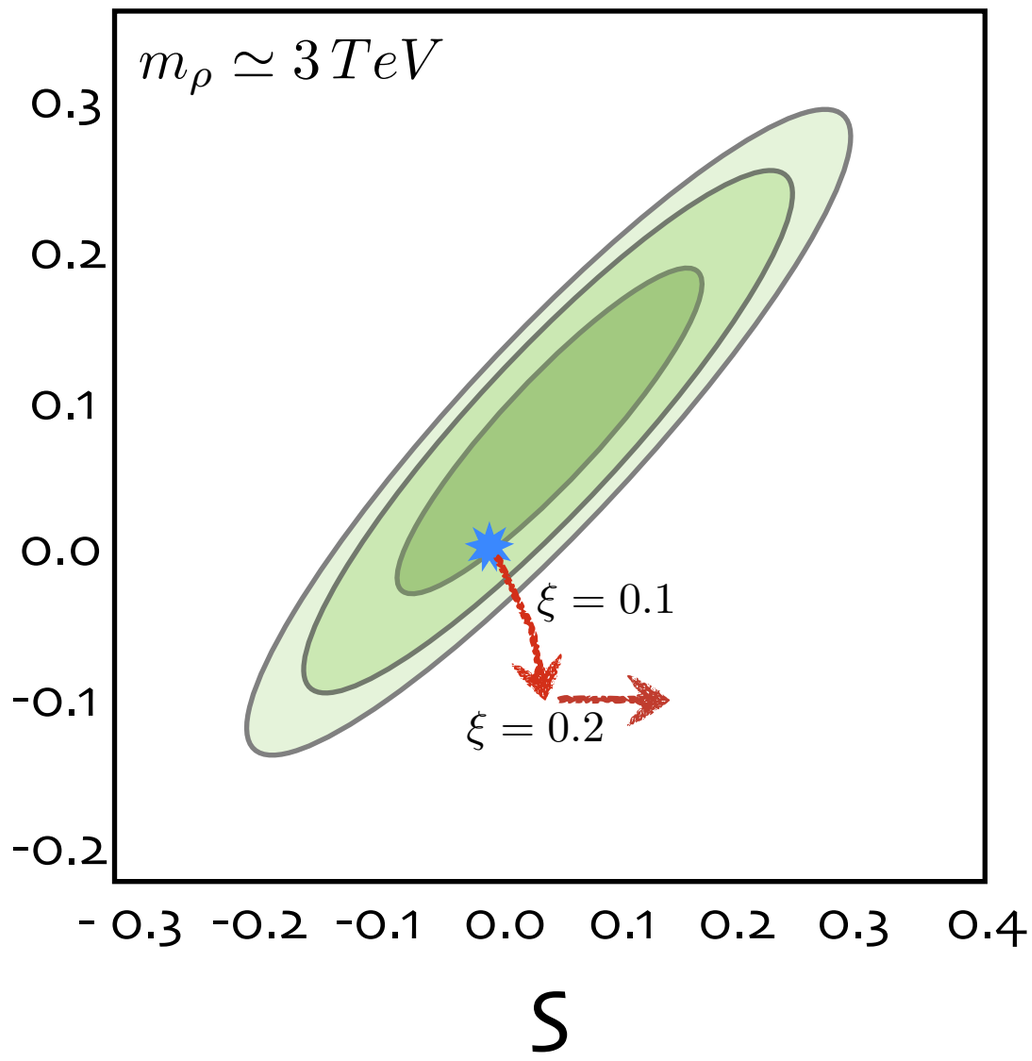


$\Delta T =$

- vector resonances

$\Delta S \simeq$





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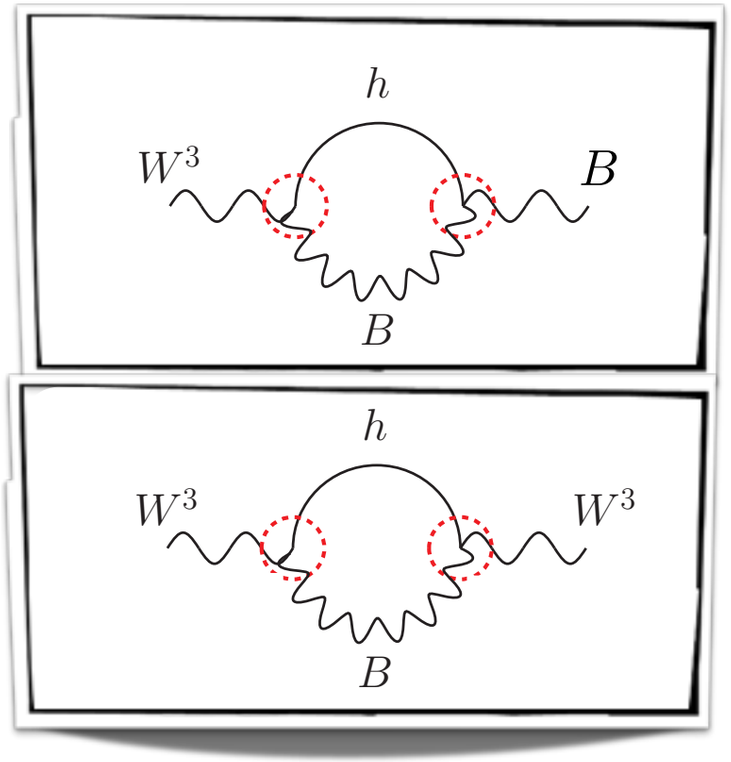
$\Delta S =$ 

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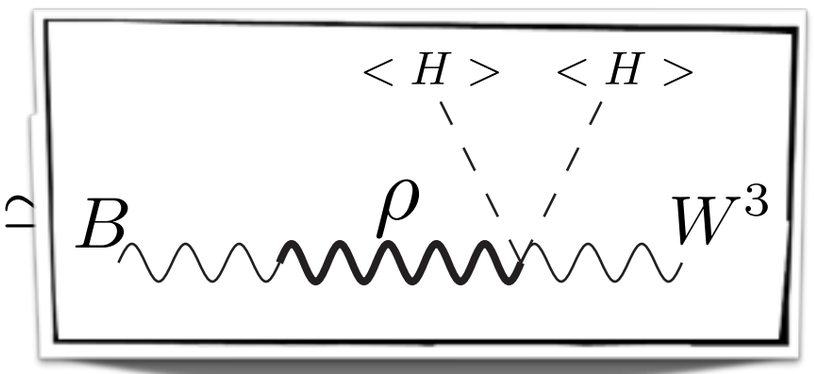
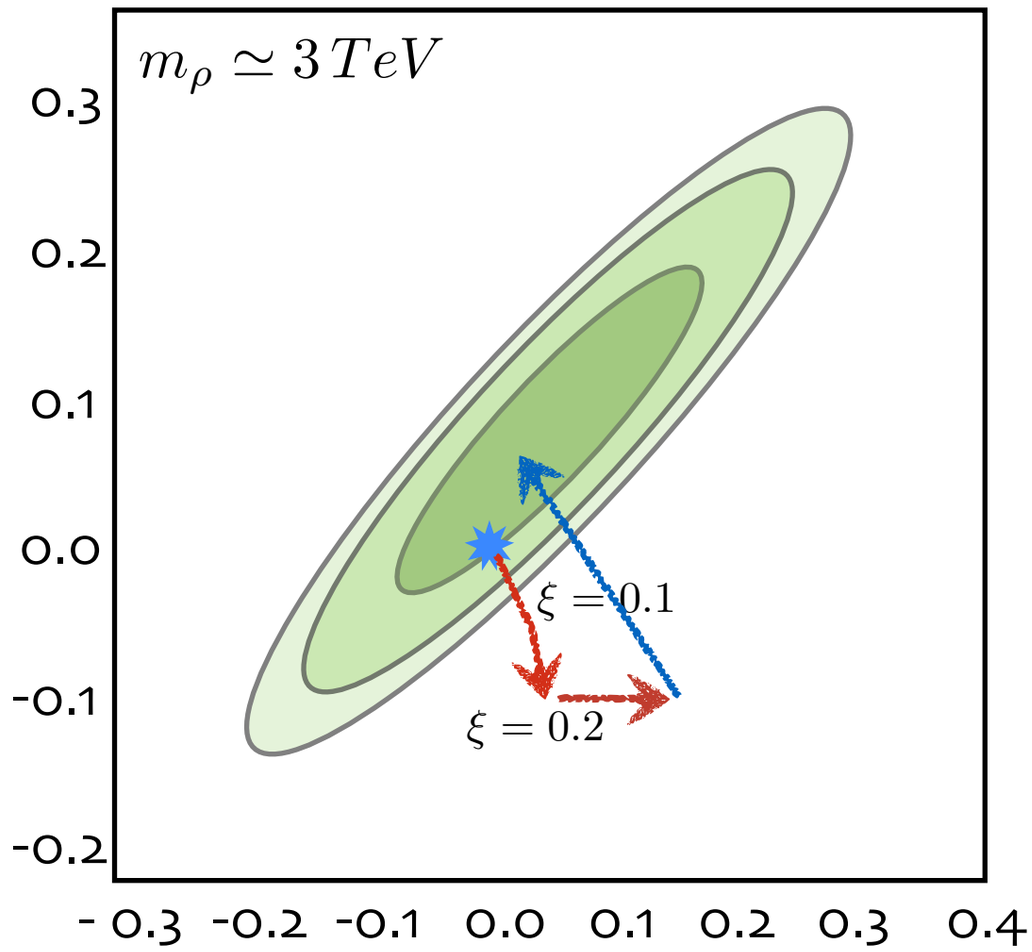
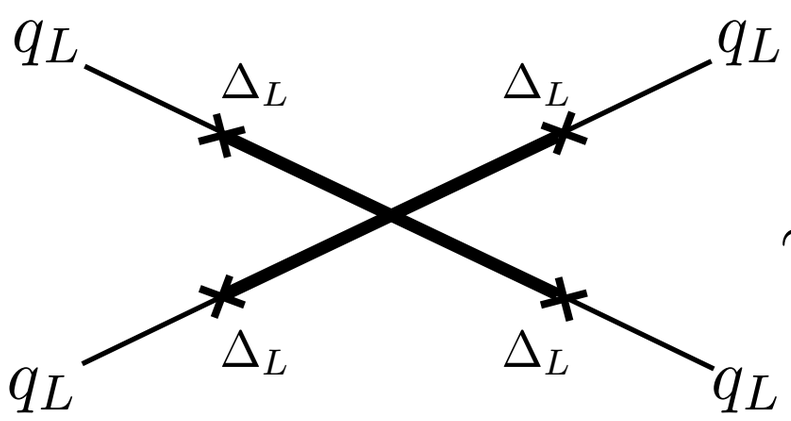
$\Delta S \supset$ 



$$\Delta S \simeq \pm \xi \, \log\left(\frac{m_\rho^2}{m_4^2}\right)$$

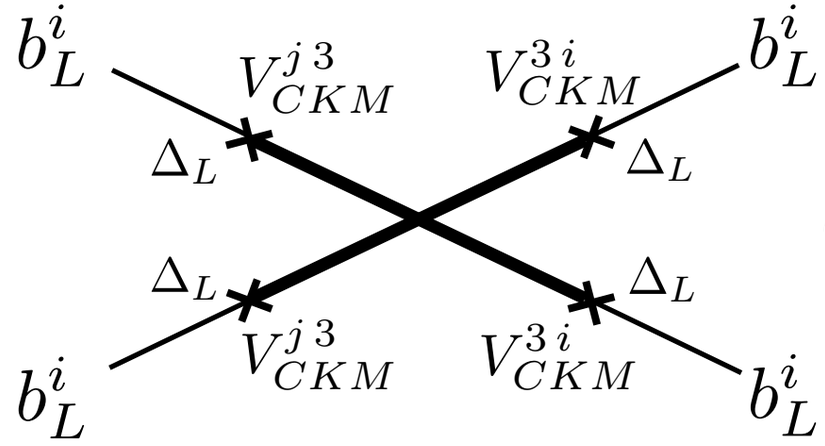
[Grojean,OM,Panico]

Flavour



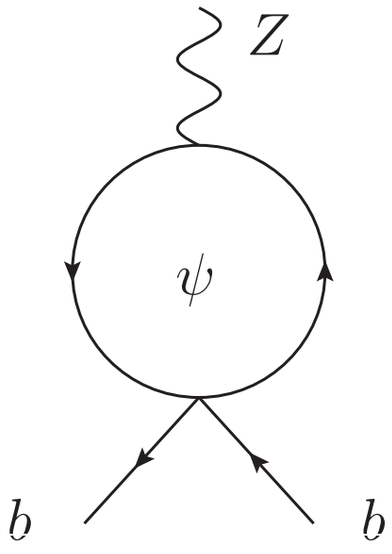
$$\sim \frac{\sin^4 \phi_L}{f^2}$$

dijets



$$\sim \frac{\sin^4 \phi_L}{f^2} \xi_{ij}^2$$

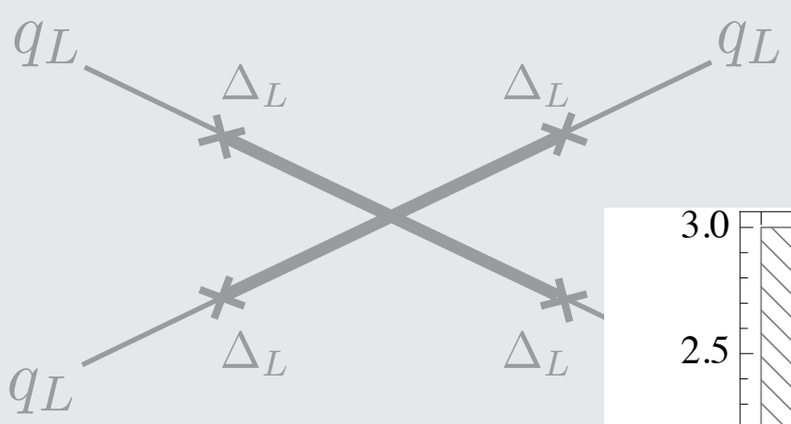
$\Delta F = 2$



Z width,
Zbb coupling

. . .

Flavour



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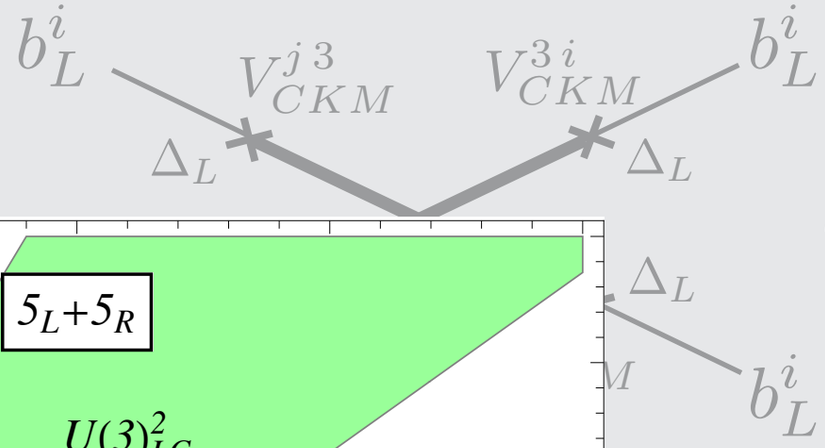

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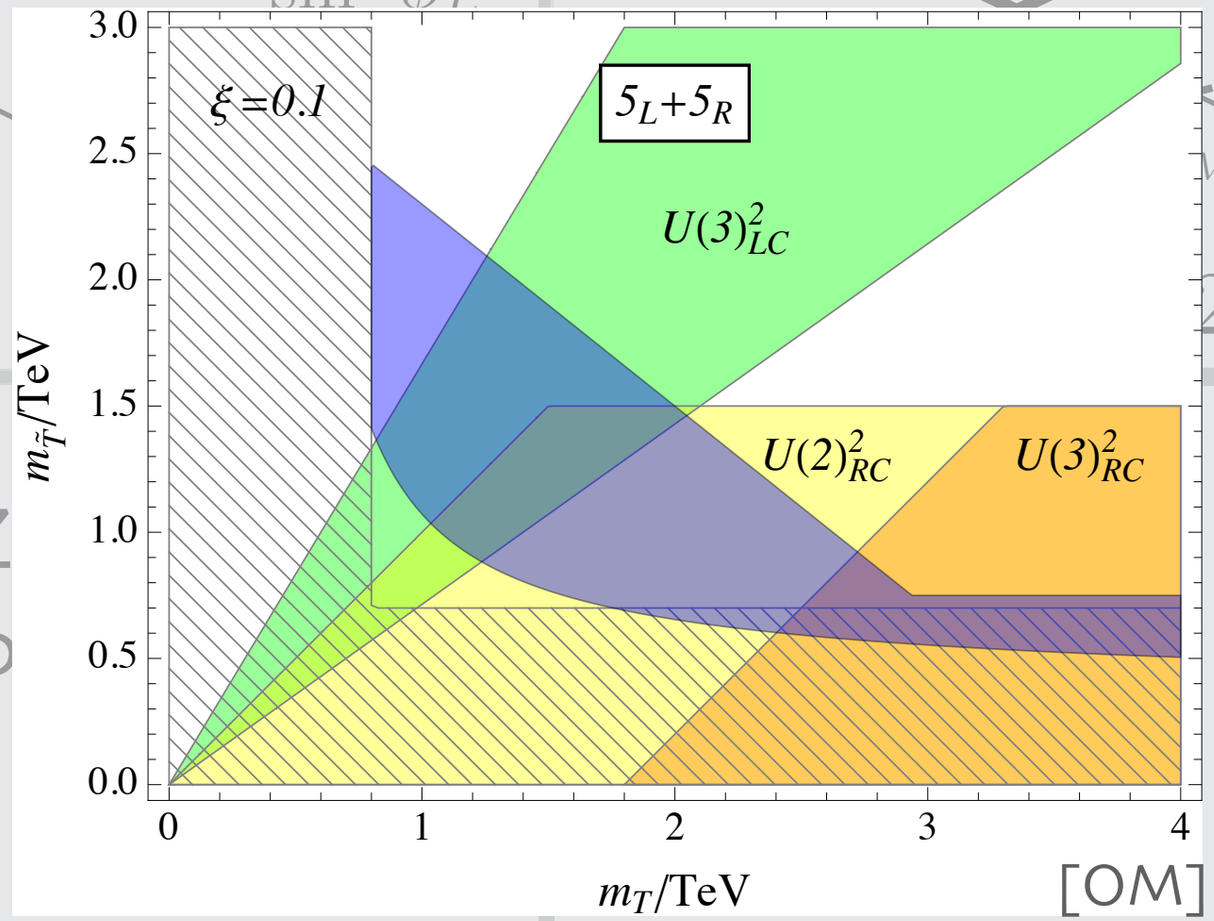
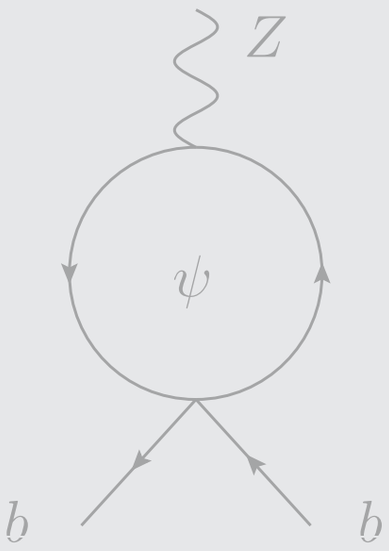


[OM]

Z

Zbb



Summary

CH can address both large and (with ~10% tuning in the simplest models) little hierarchy problems

The simplest CH realizations require 1-2TeV composite resonances

Besides that, deviations from the SM can show up in many other observables