Direct and Indirect Constraints on Composite Higgs Models

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SCUOLA NORMALE SUPERIORE PISA

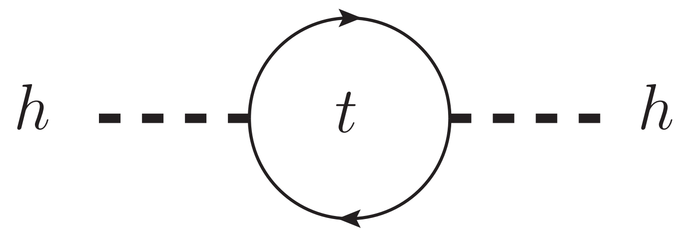
FCC-ee 2015, SNS Pisa

- Intro:
  - Higgs as composite NGB
  - Higgs potential saturation
  - SM couplings deformation
- Direct Searches
- Precision Physics
  - EWPT
  - Higgs couplings
  - VFF
- Summary: Precision/Discovery

1. Higgs as Composite NGB

Higgs as Composite NGB

- Higgs mass is unstable under radiative corrections



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

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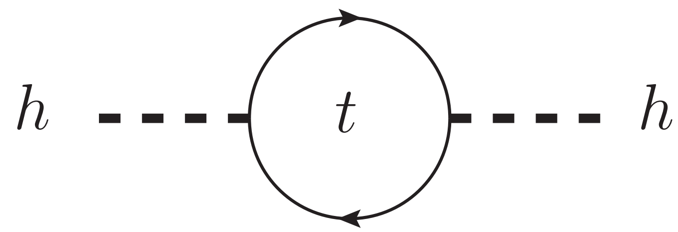
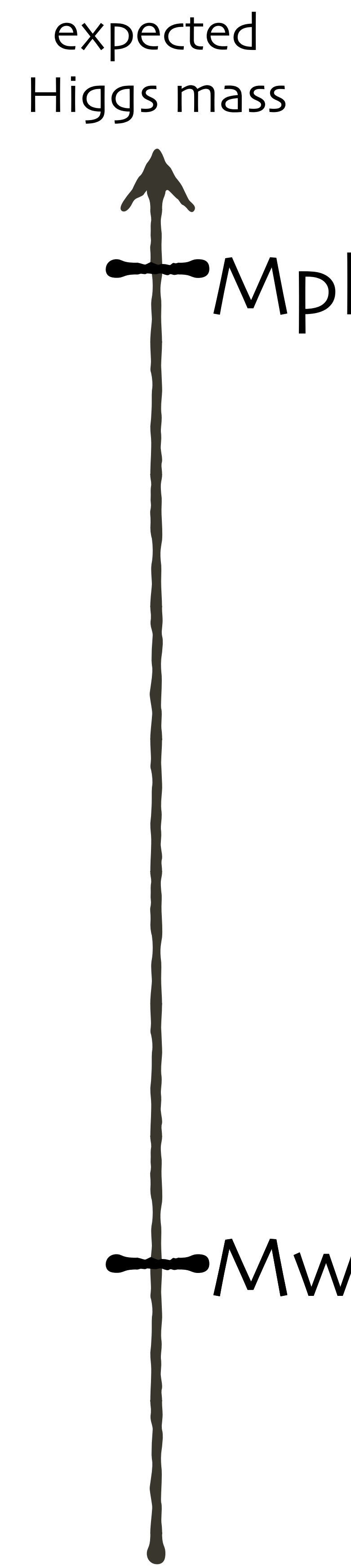


$$\delta m_h^2 \simeq \frac{g^2}{16\pi^2} \Lambda^2$$

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

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



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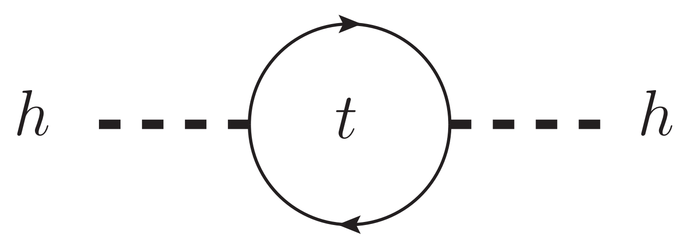

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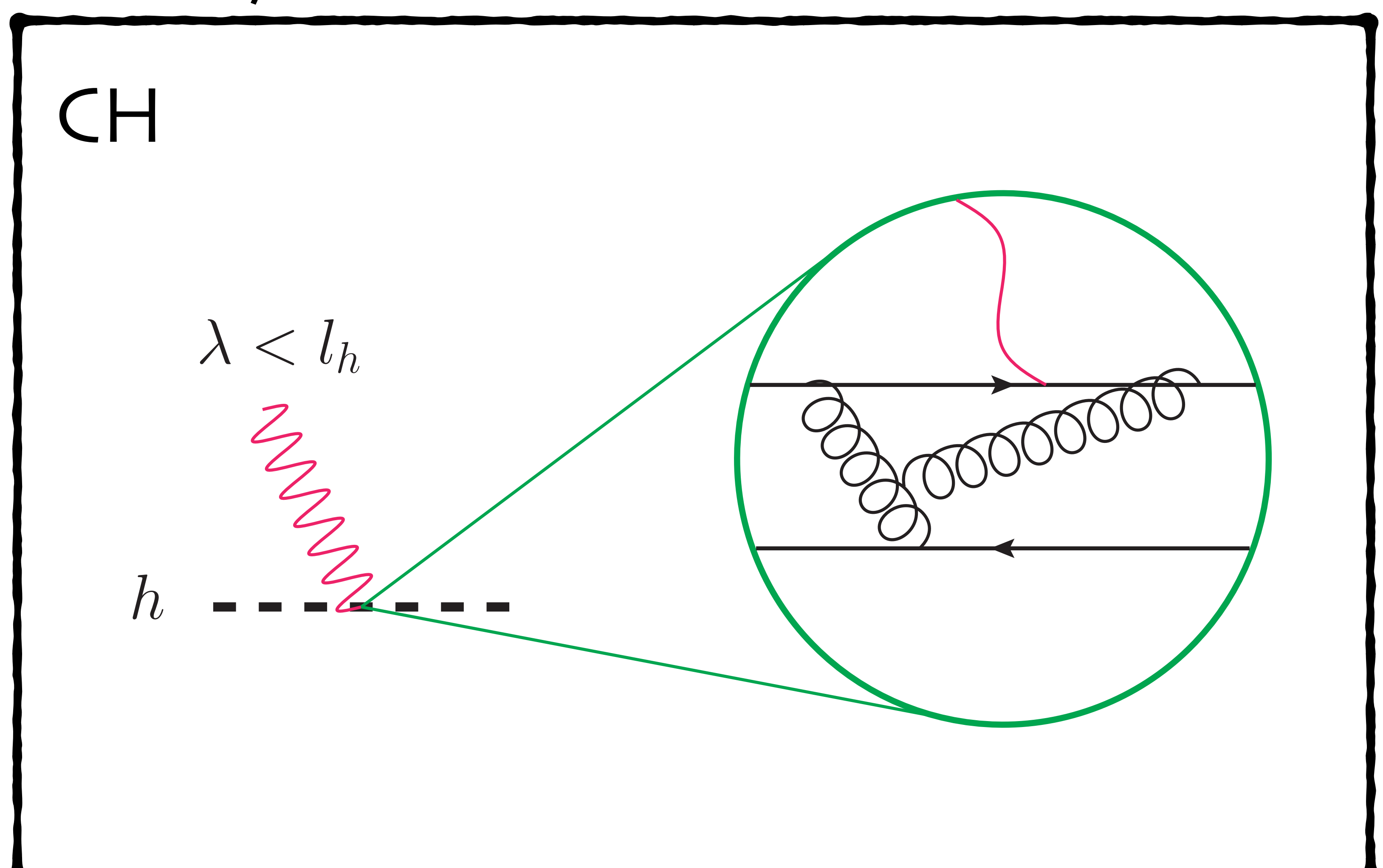
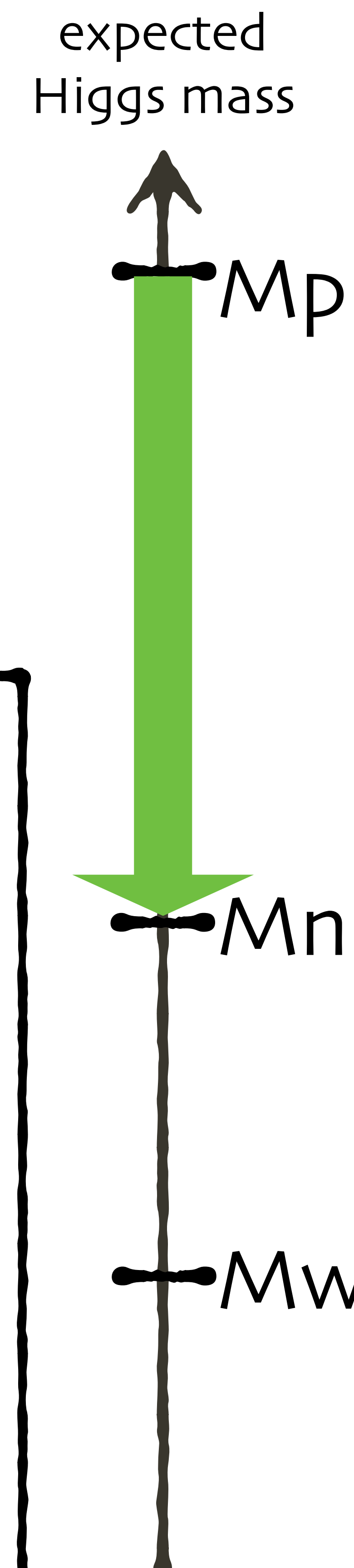
- UV can be screened by TeV scale New Physics





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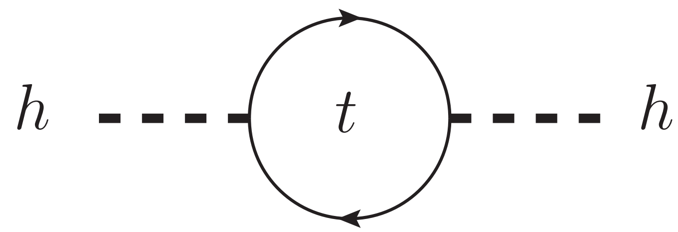

$$\delta m_h^2 \simeq \frac{g^2}{16\pi^2}\Lambda^2$$

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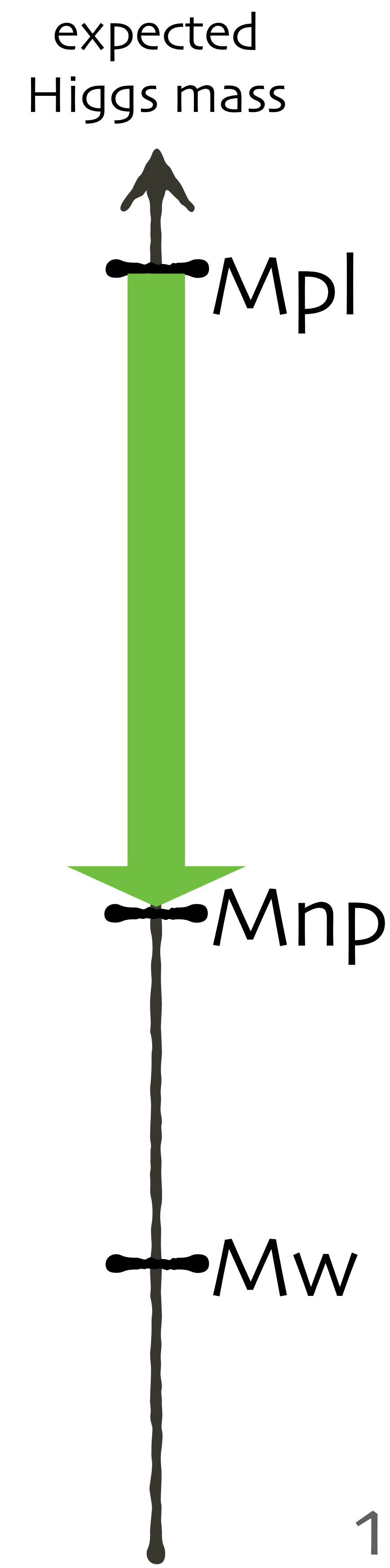
$$\delta m_h^2 \simeq \frac{1}{l_h^2} \simeq m_\rho^2$$



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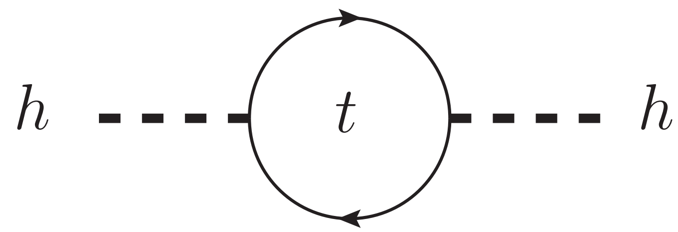

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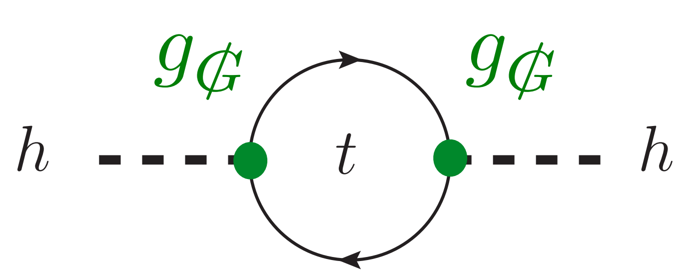
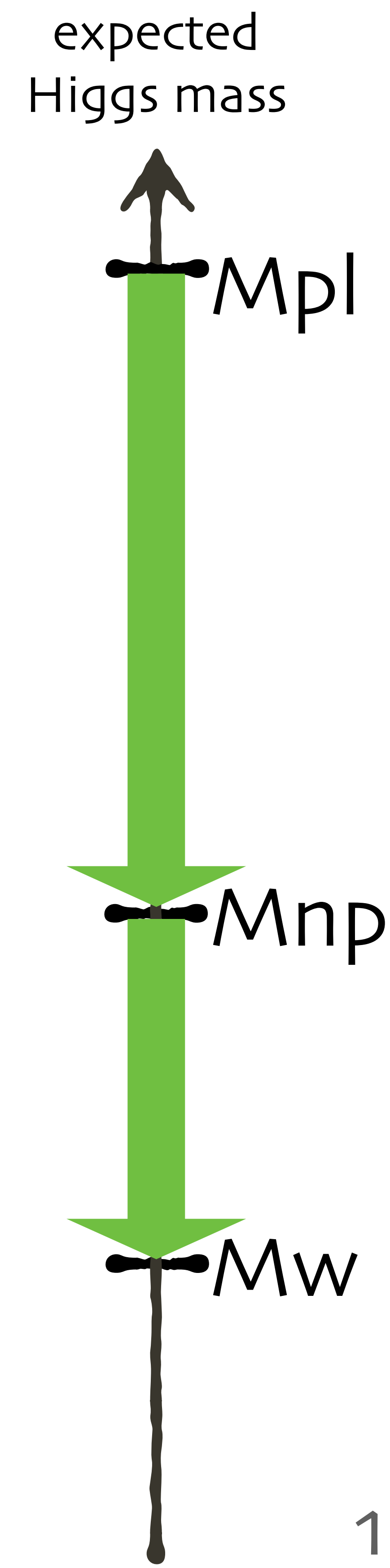
- UV can be screened by TeV scale New Physics

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

- Higgs realized as a Goldstone boson can be naturally light

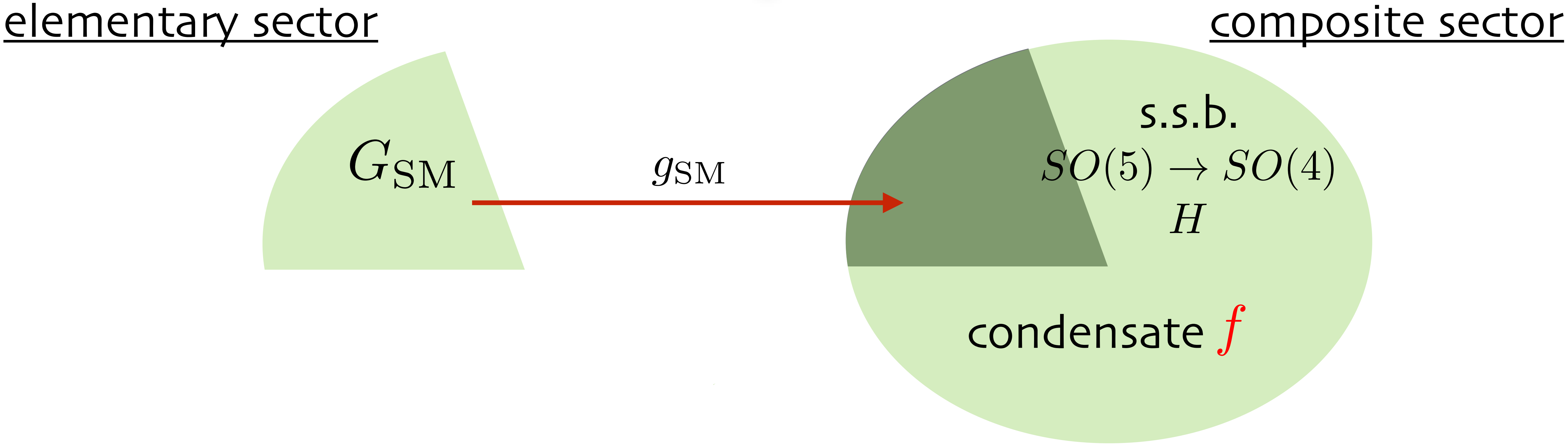


$$\delta m_h^2 \simeq \frac{g_{\not G}^2}{16\pi^2}\,m_\rho^2$$



[Georgi,Kaplan;Contino,Nomura,Pomarol]

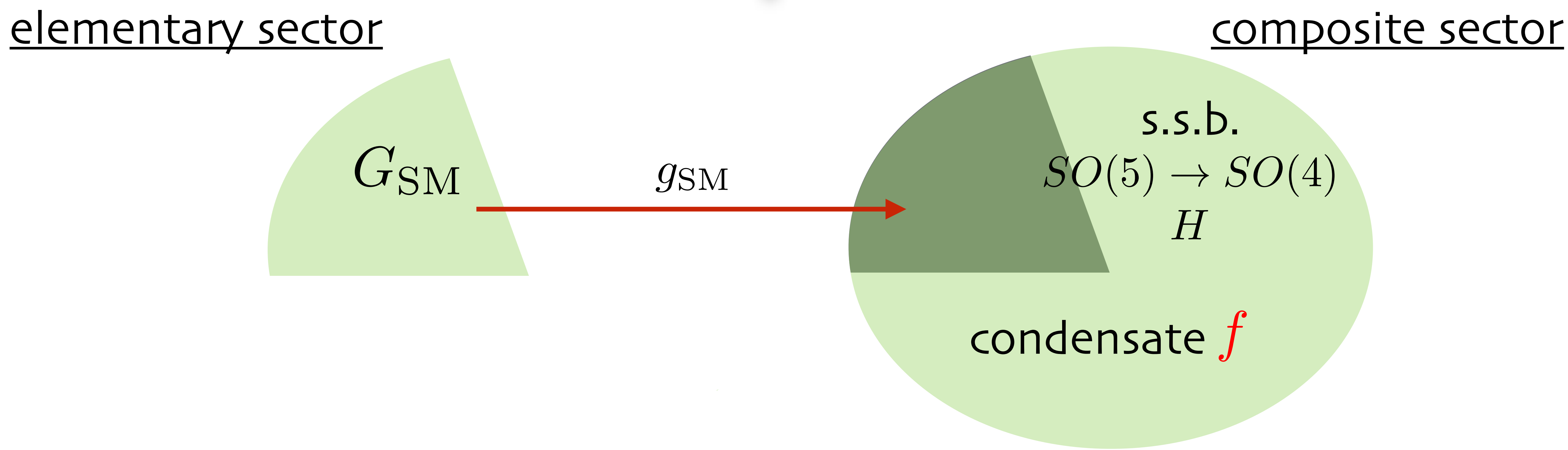
Mass Spectrum



$$SO(5) \to SO(4)$$

- 4 NGB - doublet under $SU(2) \subset SO(4)$
- $SO(4) \sim SU(2)_L \times SU(2)_R$ custodial symmetry

Mass Spectrum



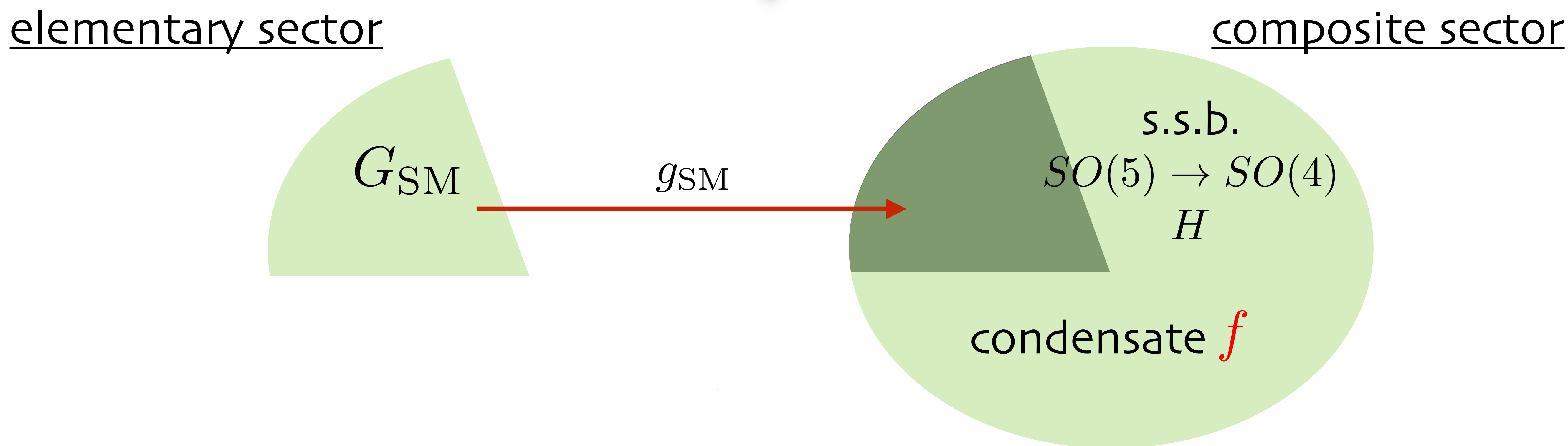
- f sets all the mass scales of the theory
- masses are proportional to f and the strength of coupling to it:

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

SM: $m_{\rm SM} \sim g_{\rm SM} f$

$$v_{SM} \sim f$$

Mass Spectrum



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

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

$v_{\mathrm{SM}} \ll f$

extra scale separation from tuning

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

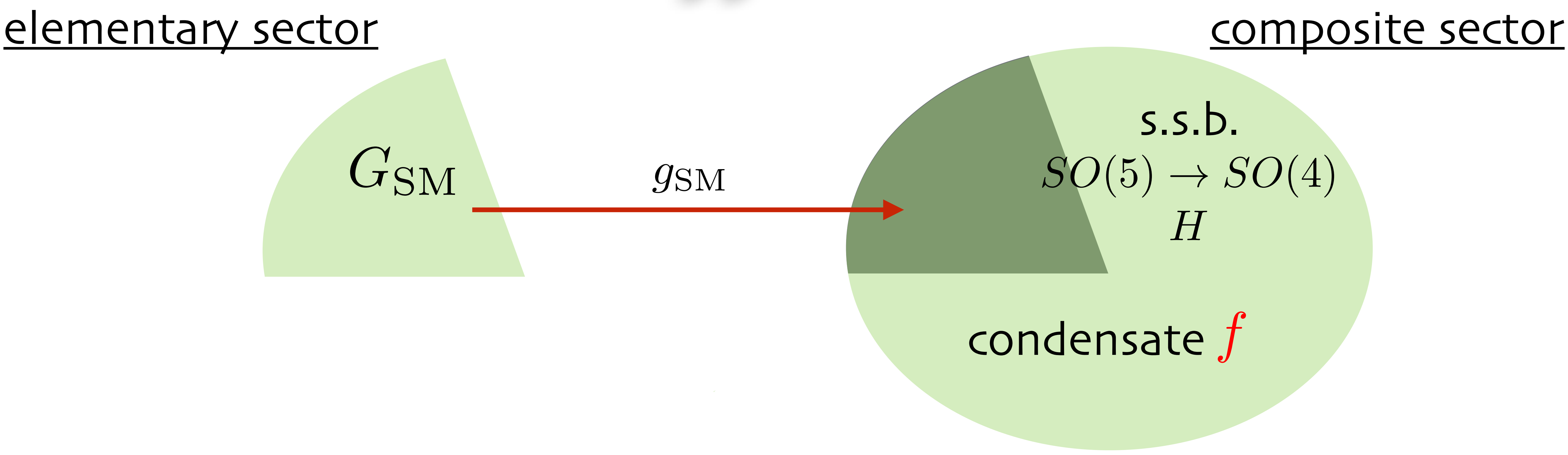
possible since Gsm can be embedded into SO(4)

currently

$\xi \lesssim 0.2$

$f \gtrsim 600\, GeV$

Higgs Mass



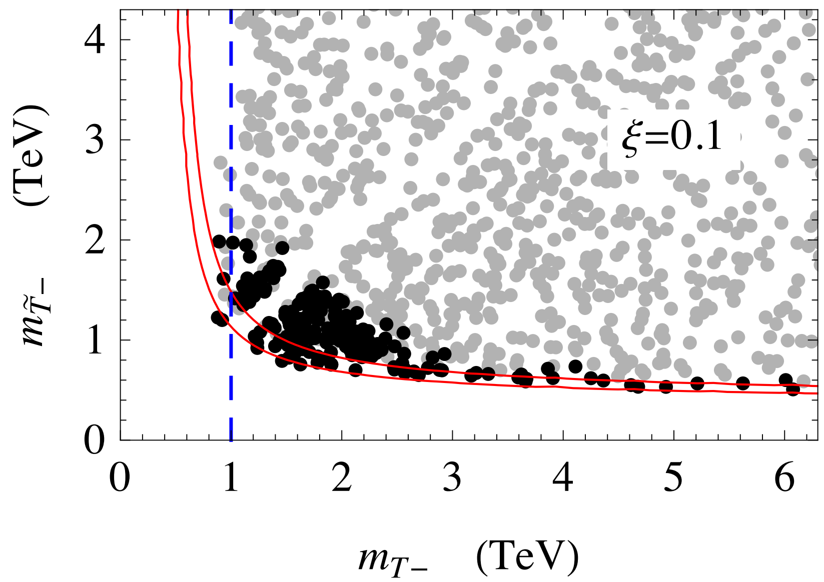
- Higgs mass has to be ~ Goldstone symmetry breaking parameters
- SM symmetry gauges just a subgroup of the strong sector global symmetry, hence the largest SM coupling is the most important

Higgs Mass

- potential from the 1-loop of colored fermions (top + top partners):

$$m_h^2 \simeq N_c \frac{y_t^2}{2\pi^2} \boxed{\xi m_\star^2} \qquad \begin{array}{c}\xi \simeq 0.1 \\ m_\star \simeq 0.7\, TeV\end{array} \qquad \frac{m_\star}{f} \sim 1$$

- in concrete models the constraint is slightly weaker



arXiv:1204.6333

$$\frac{m_\star}{f} \lesssim 2.5$$

- additional tuning (on ξ or other params) can allow for heavier NP scale arXiv:1210.7114

- less minimal models (e.g. Twin-Higgs) may allow for heavier colored NP without tuning. Generically:

$$\frac{m_\star}{f} \lesssim 4\pi$$

Higgs Couplings Deformation

- Higgs as NGb generically induces non-renormalizable interactions

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

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

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

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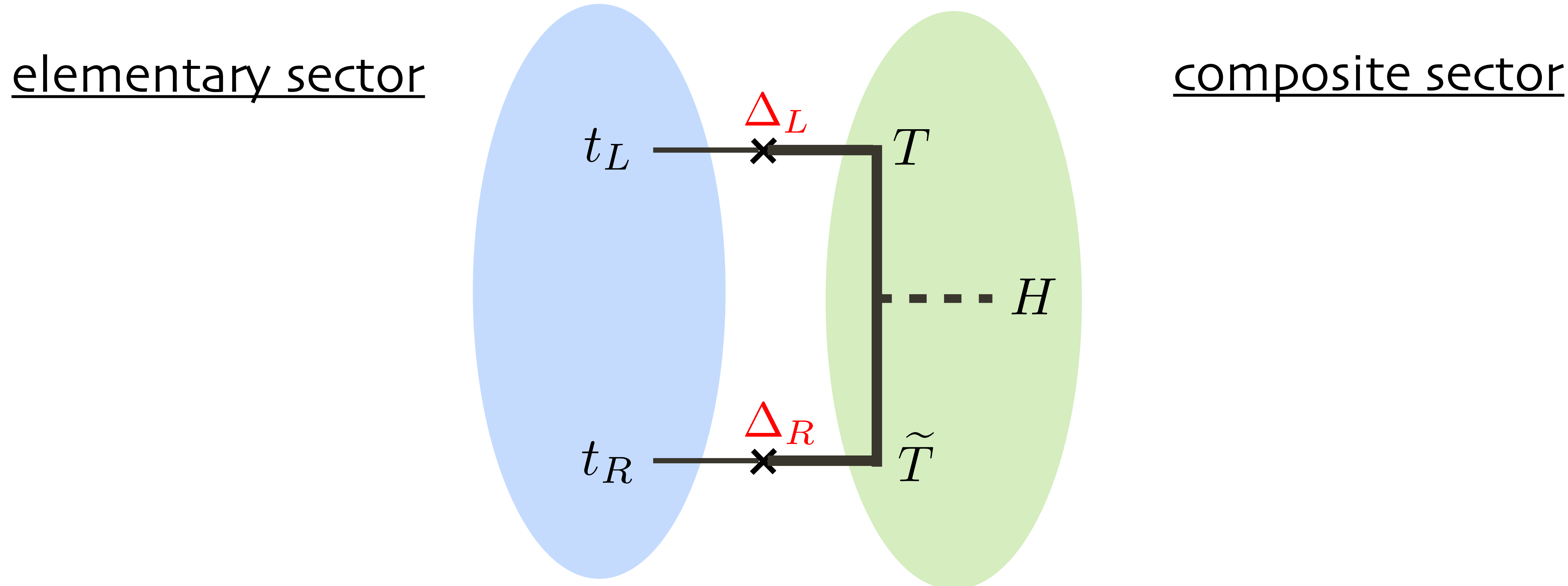
- one expects NP in higher order operators $\frac{g_\rho^2\, v^2}{m_\rho^2} \ \sim \xi$

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

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

Distortions due to Partial Compositeness



SM fermions become "partially composite" $t_L^{`} = \cos\phi_L \, t_L + \sin\phi_L \, T_L$

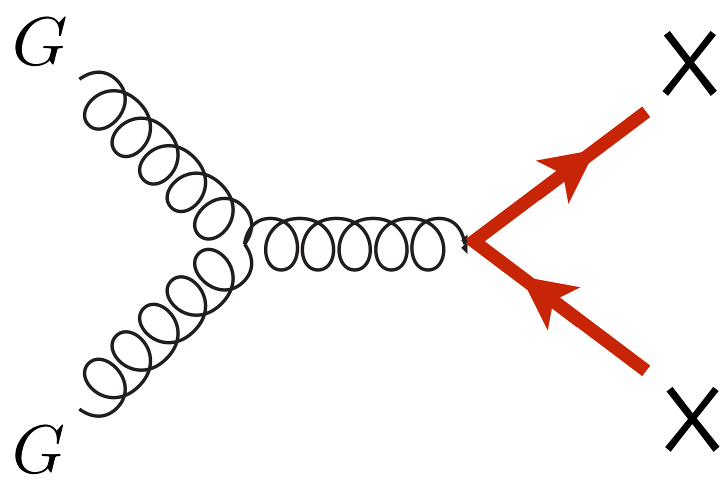
with a degree of compositeness $\sin\phi_L \simeq \dfrac{\Delta_L}{M_T}$

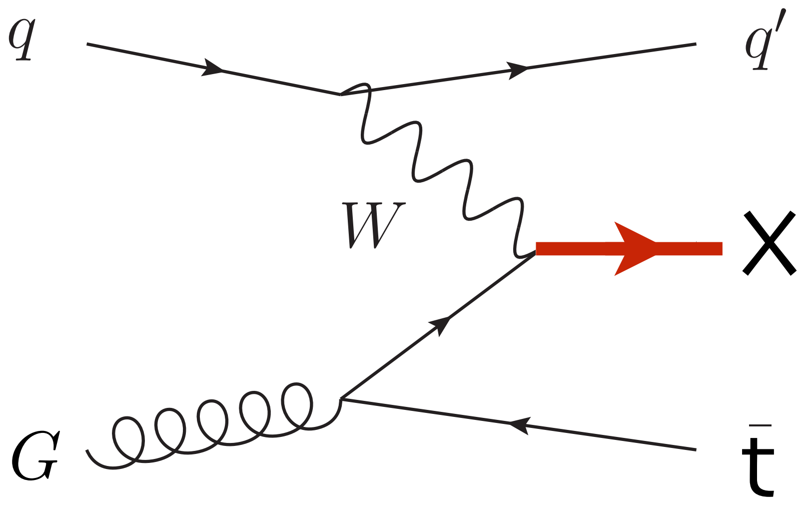
top mixings are the most sizable $m_q \sim \dfrac{\Delta_L \Delta_R}{\min(M_T, M_{\tilde{T}})} \dfrac{\langle h \rangle}{f}$ $\Delta^2 \sim M_T m_q$

2. Direct Detection of Composite Resonances

Direct Detection

- top partners at the hadronic machines





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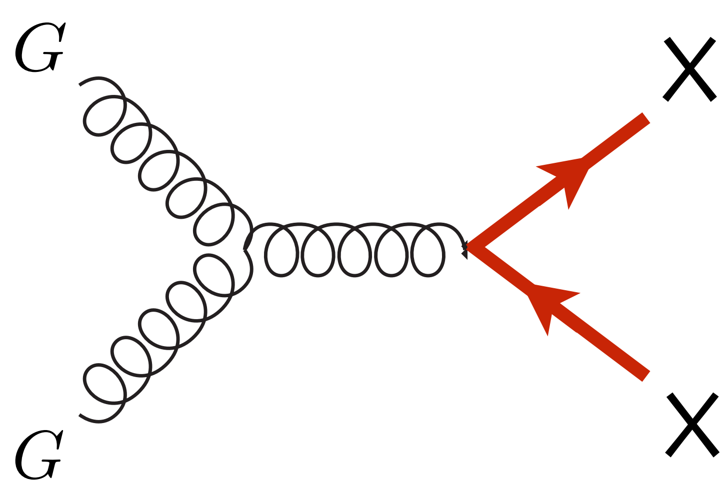
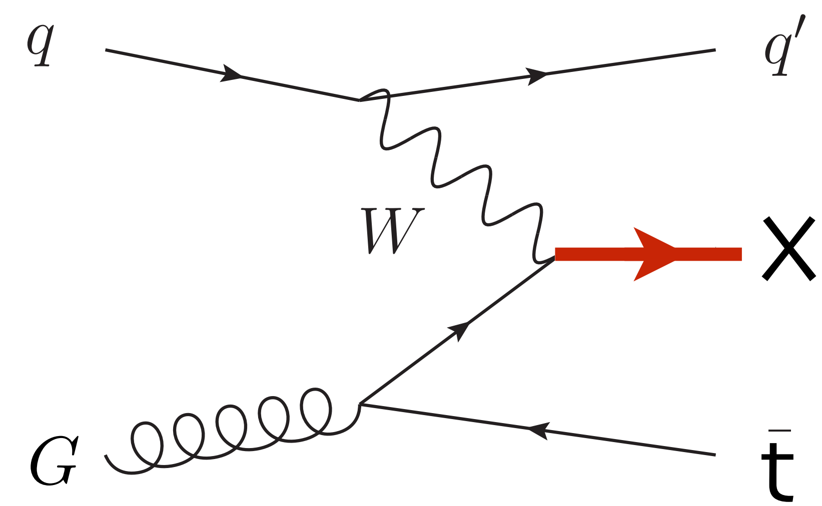
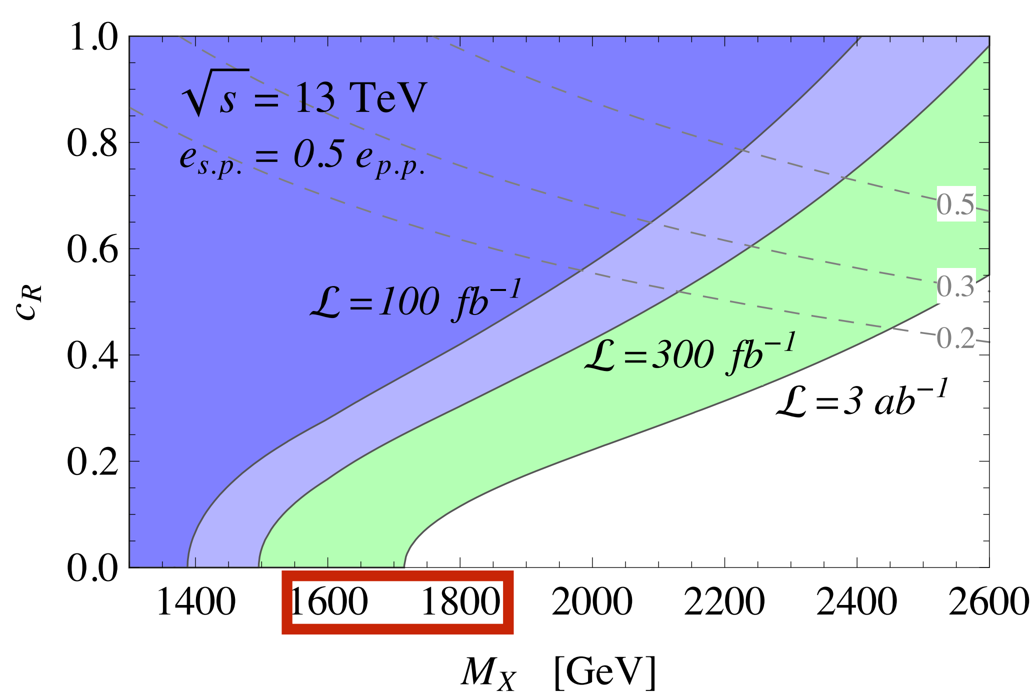
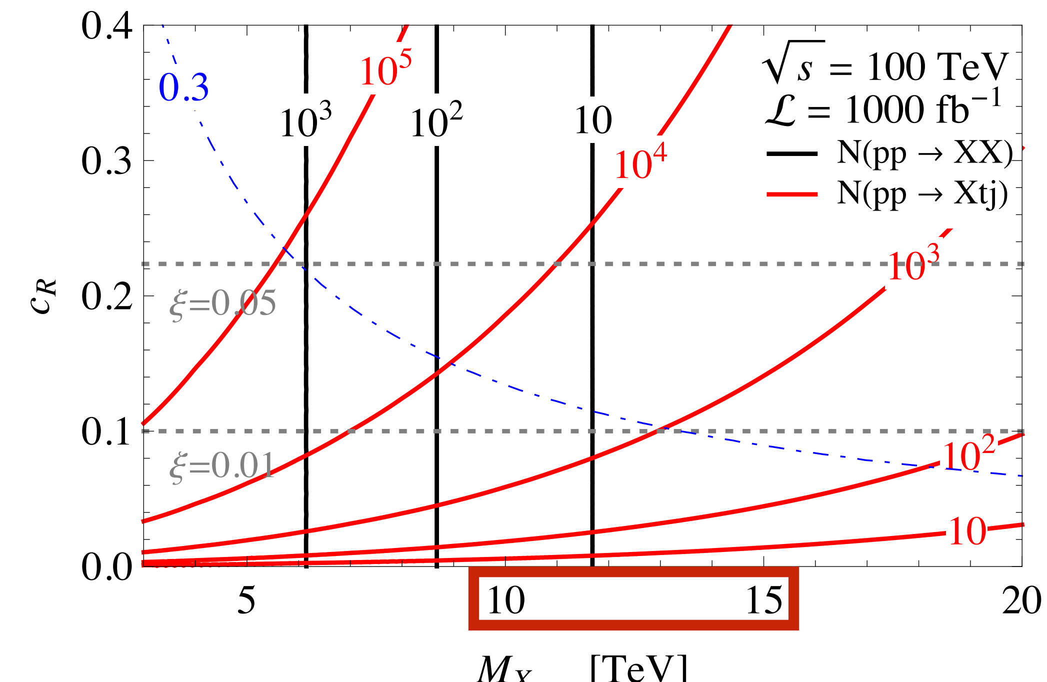




- LHC 13 projection



- 100TeV collider estimate



[1409.0100]

Direct Detection

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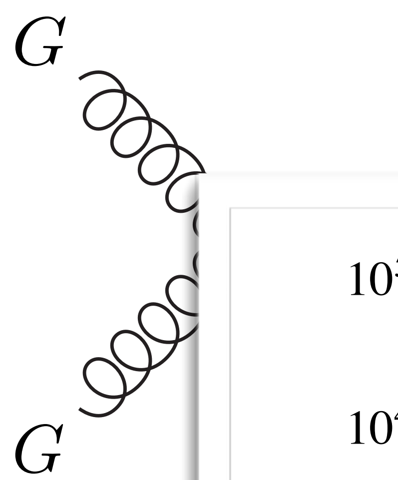
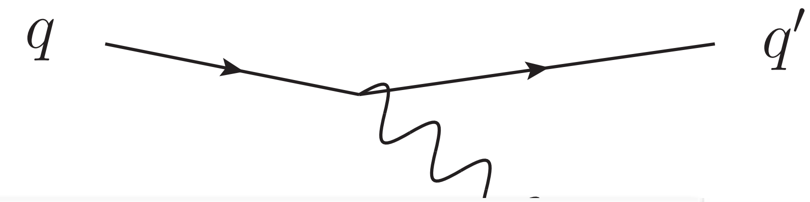
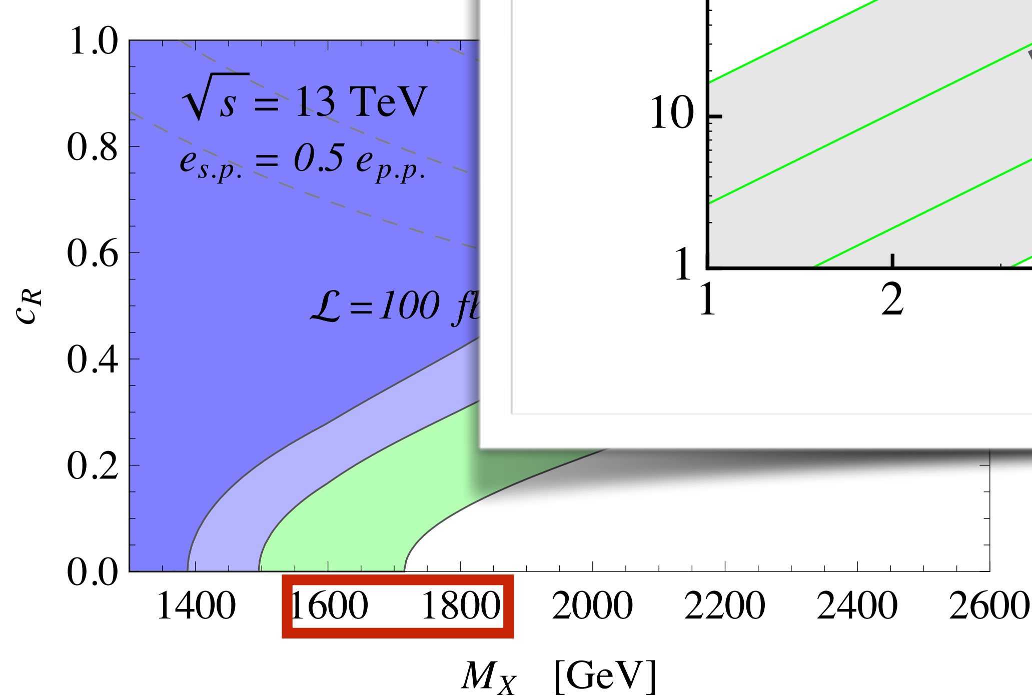
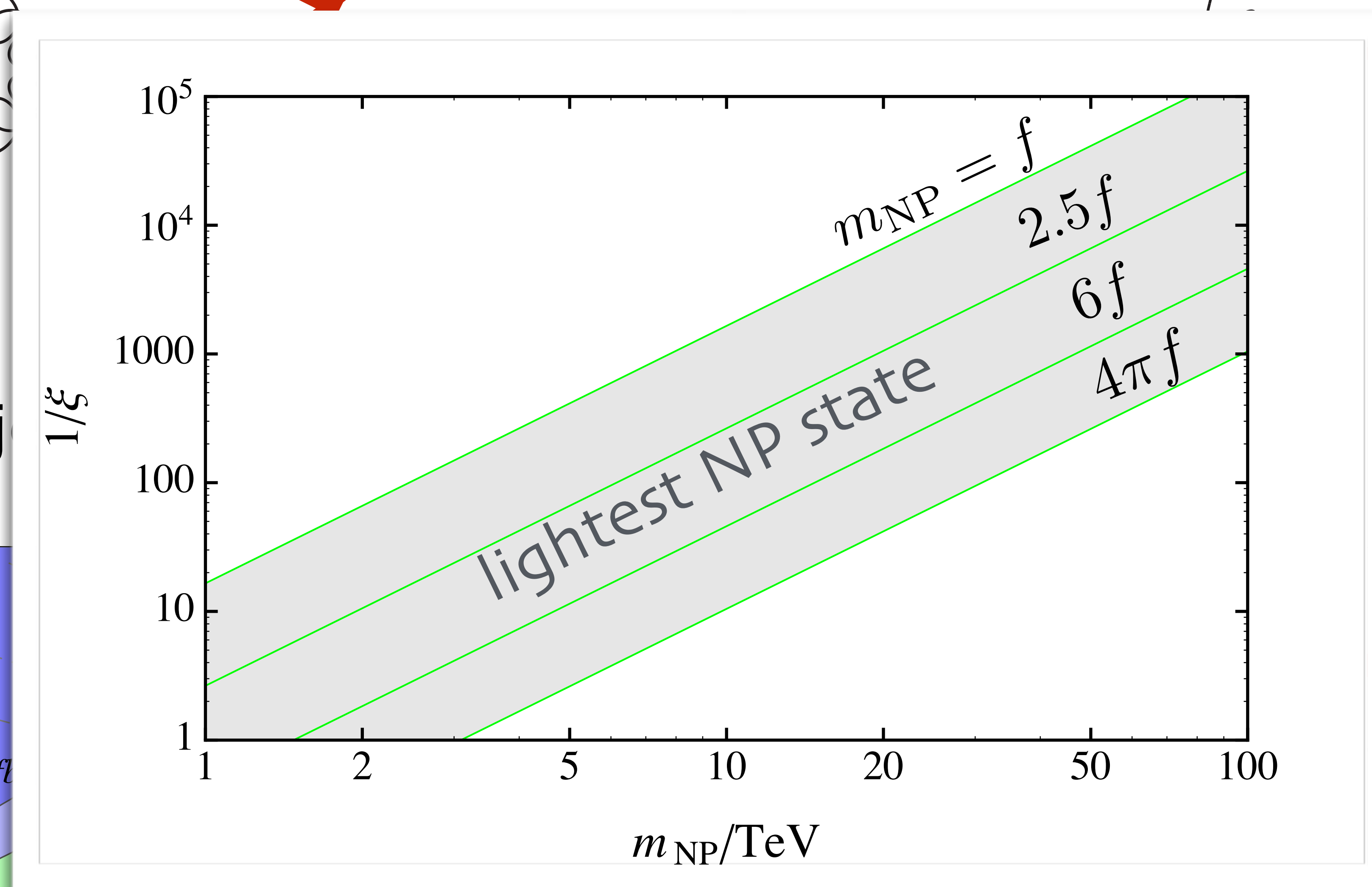
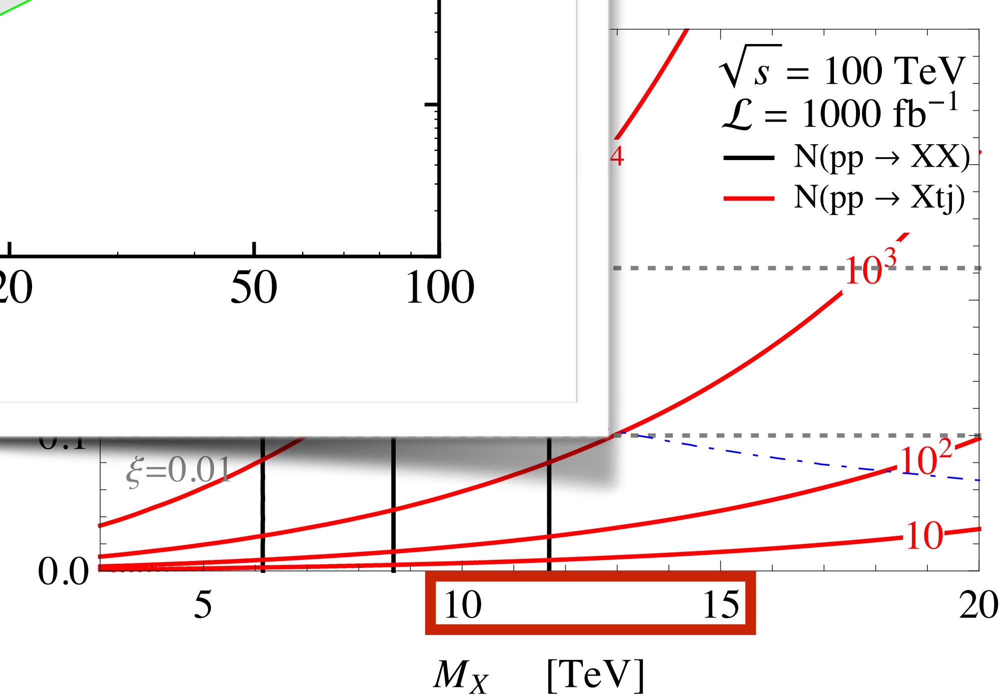




- LHC 13 proj ... er estimate







[1409.0100]

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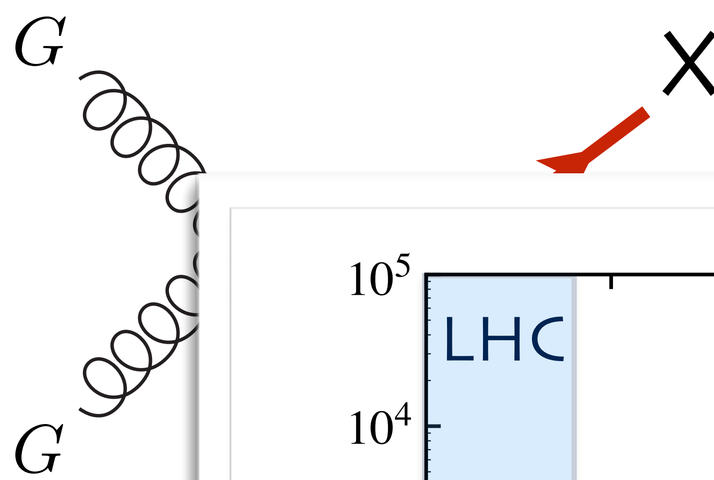

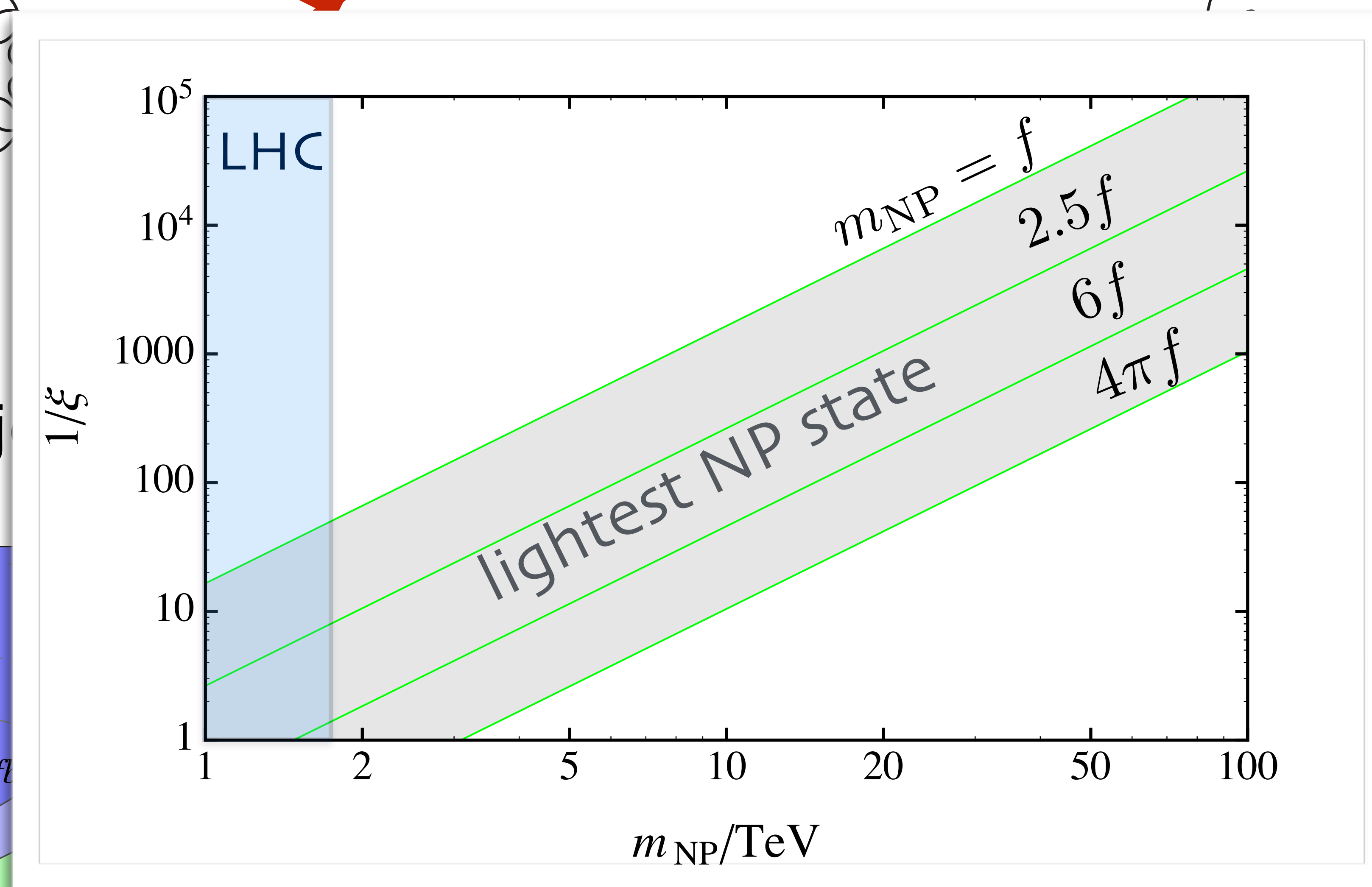

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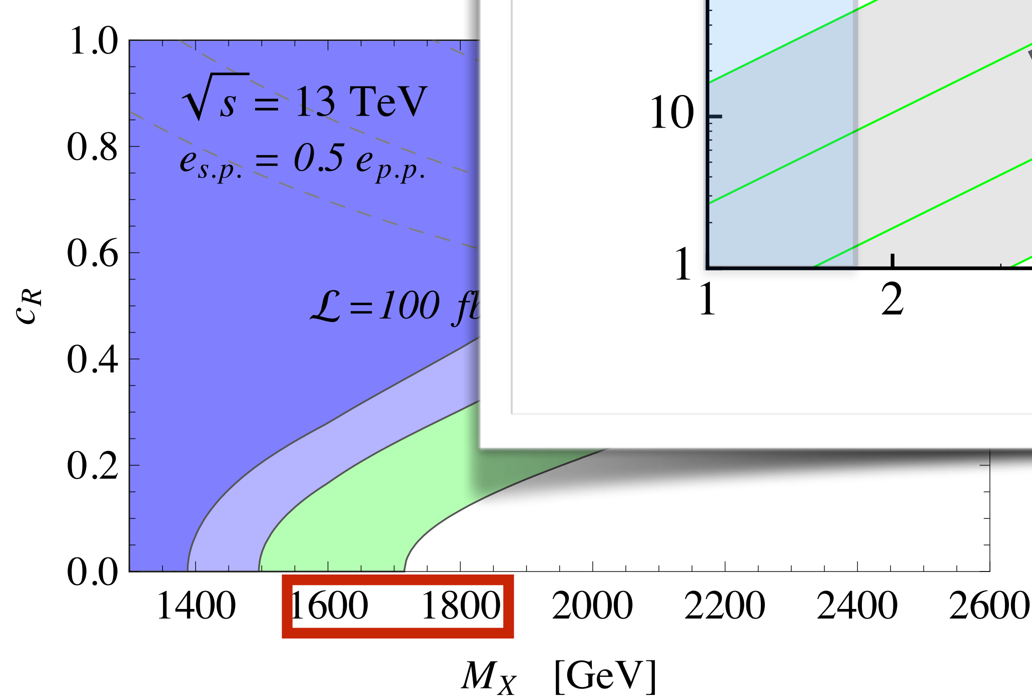

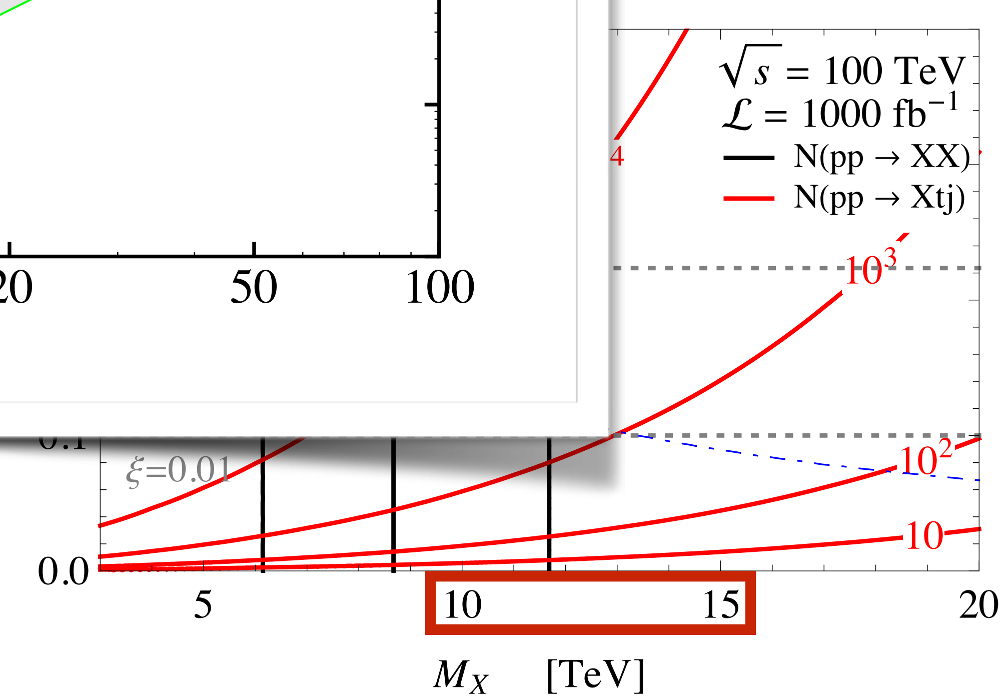

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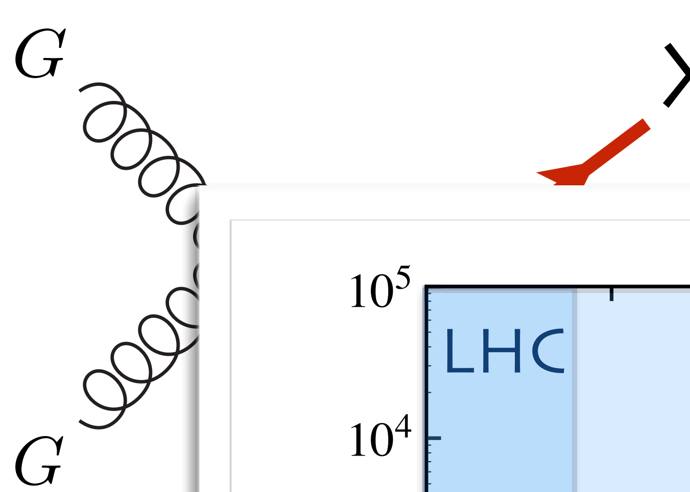

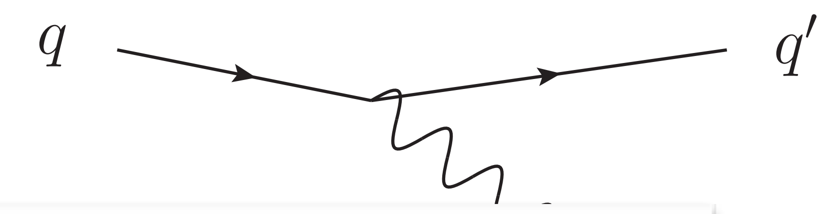

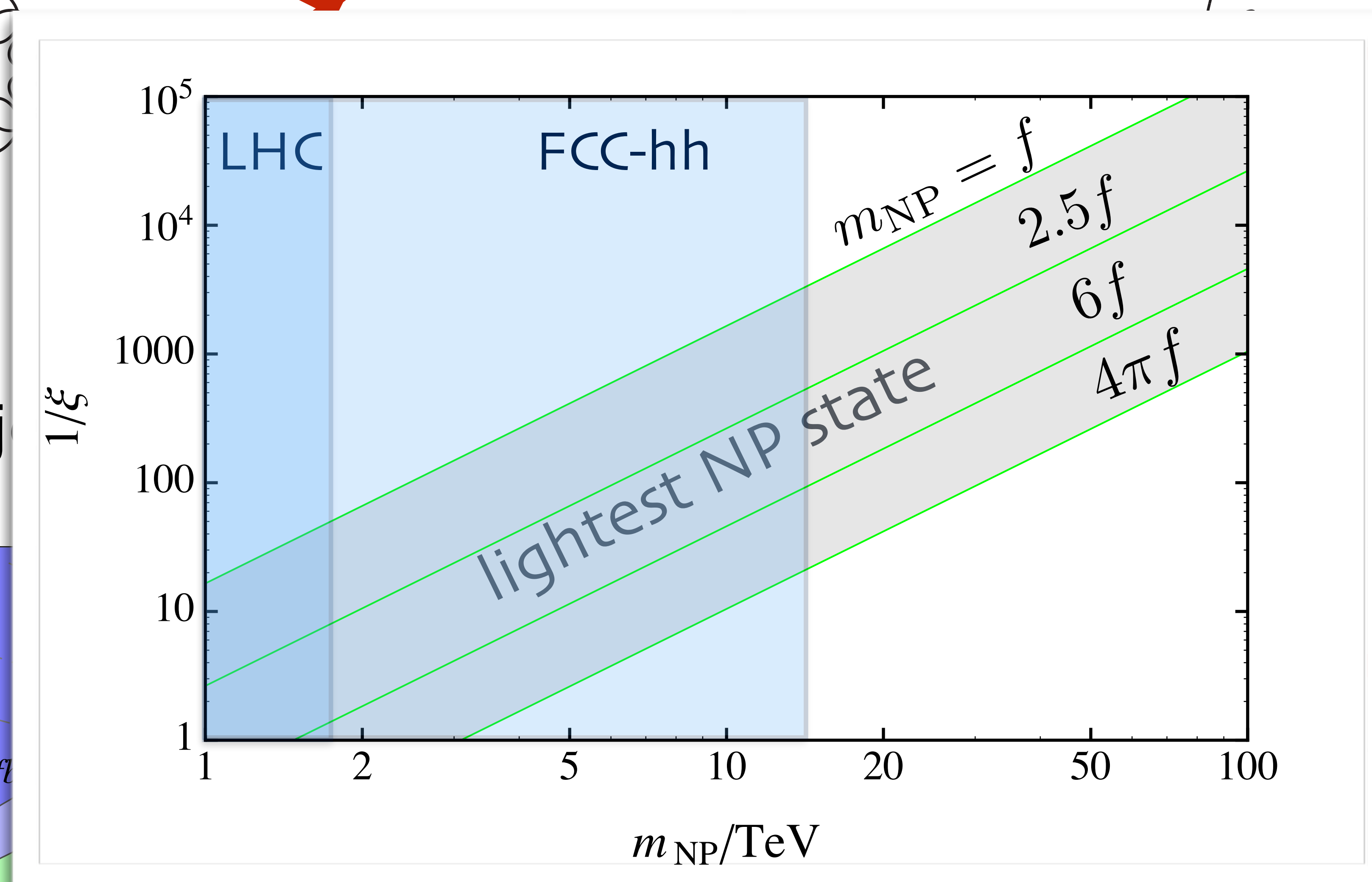

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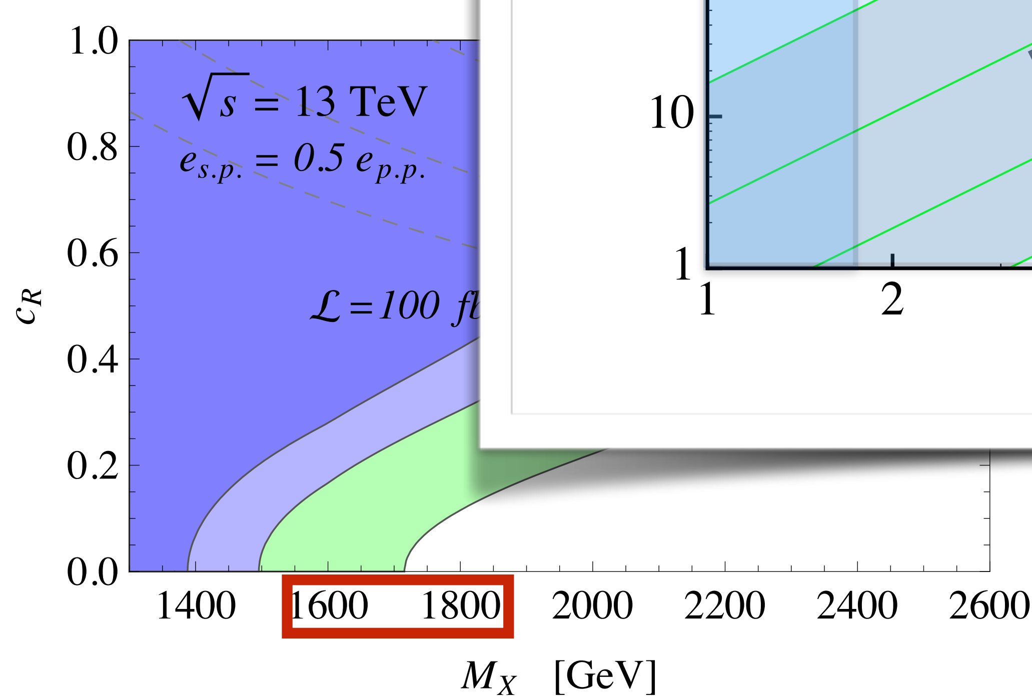
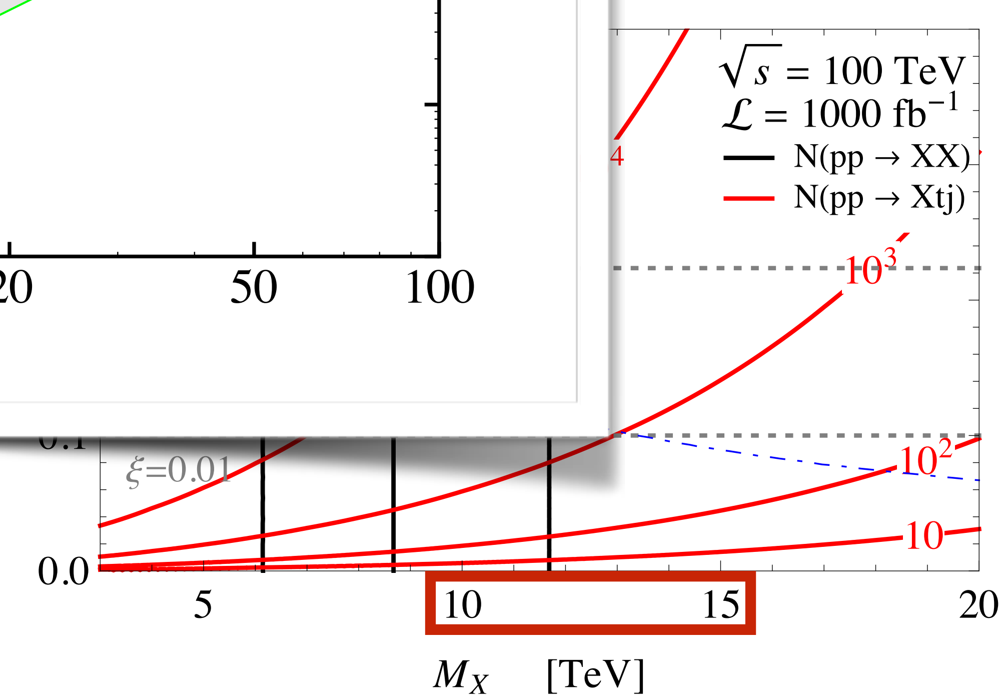




[1409.0100]

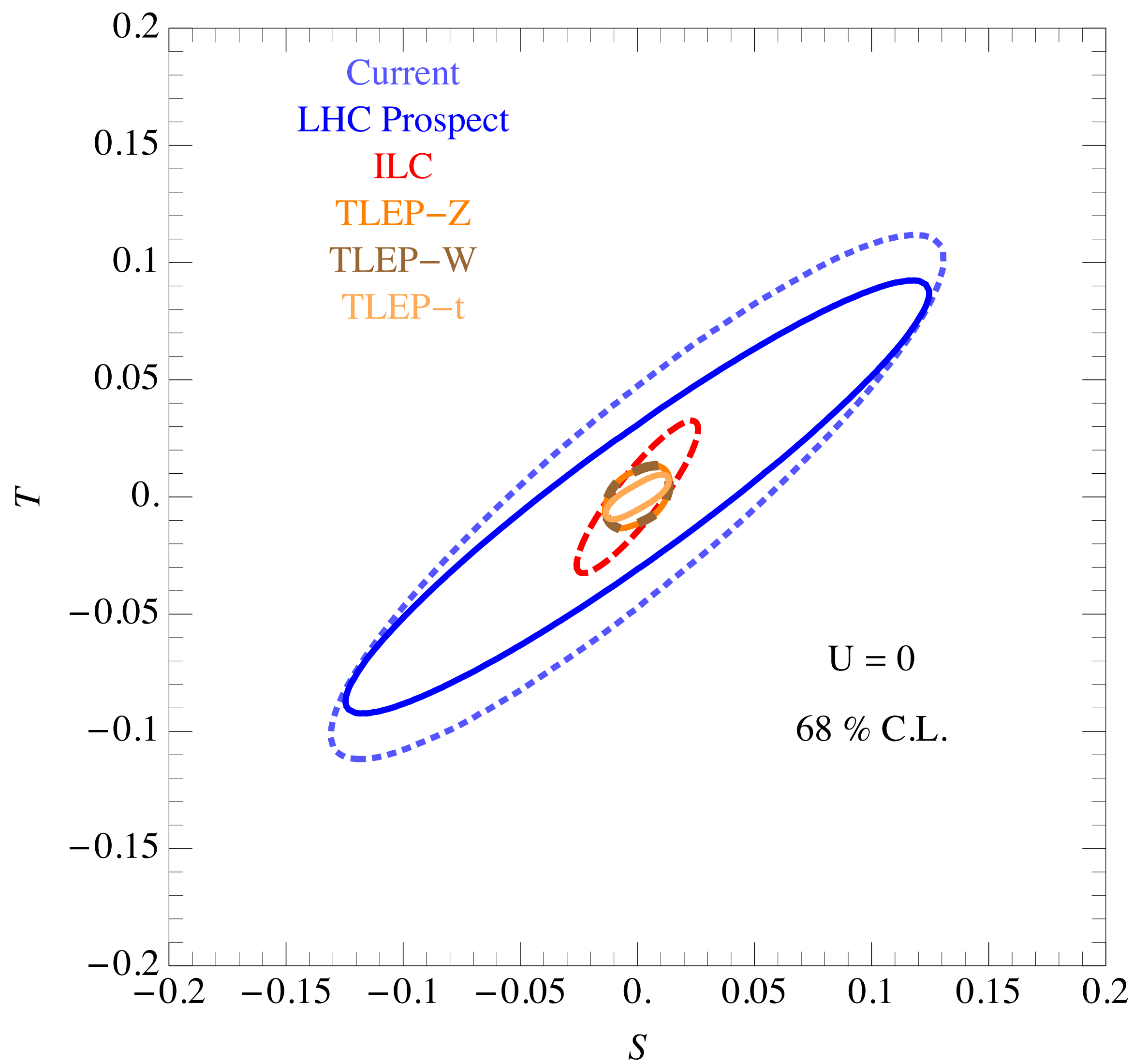
3. Precision Physics Constraints

1. whether TLEP will be able to see composite NP signals after the LHC 13 without signs of NP

2. improvements in the bounds on CH naturalness in case of negative signal

Indirect Signals

- EWPT: test new physics in self-energies of SM gauge bosons



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

$$T \sim \Pi_{W^\pm}(0) - \Pi_{W_3}(0)$$

~ x10 improvement at TLEP

[Fan,Reece,Wang,1411.1054]

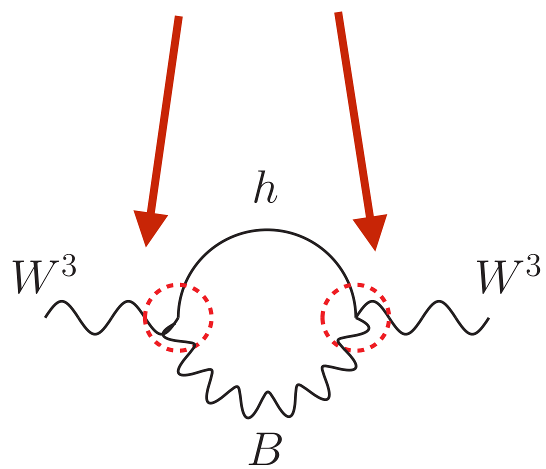
Indirect Signals

- **EWPT:** test new physics in self-energies of SM gauge bosons

S and T receive contributions from different sectors:

1) universal modifications of HVV couplings:

$$g_{hVV} \to \sqrt{1-\xi}\, g_{hVV}$$



$$\Delta\hat{T}^h = -\frac{3g'^2}{64\pi^2}\xi \log\left(\frac{m_\rho^2}{m_h^2}\right)$$

2) positive UV contribution to S

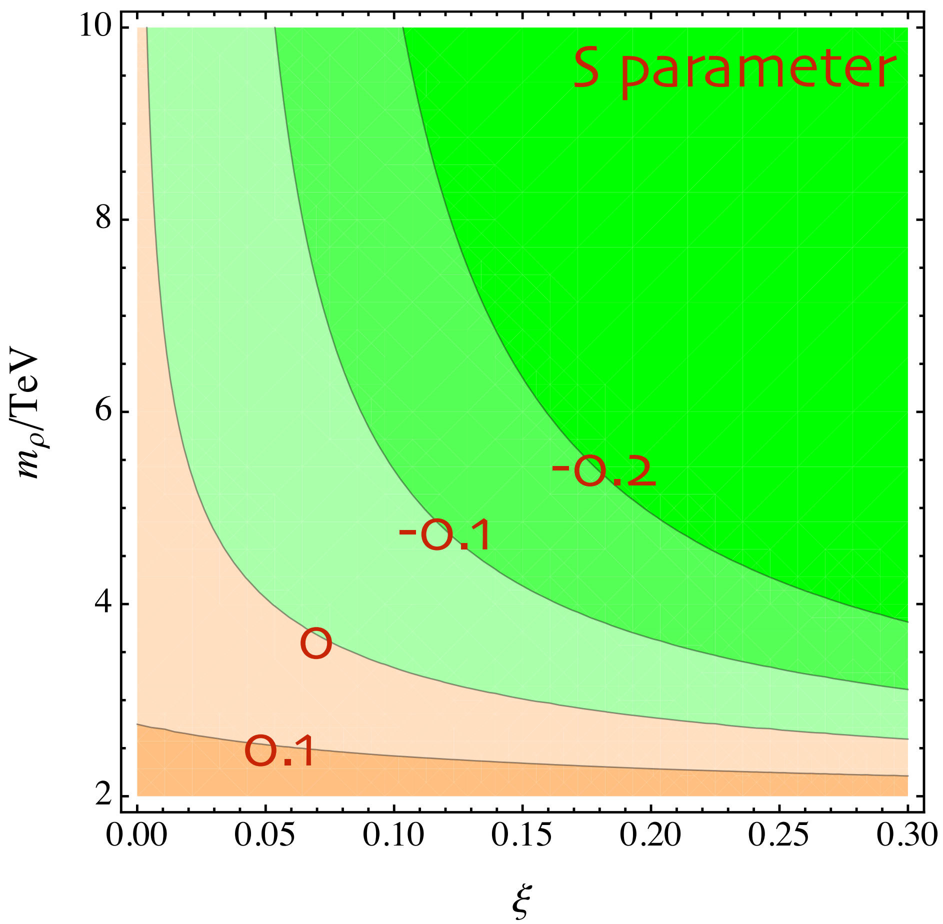
$$\Delta\hat{S} \simeq \frac{m_W^2}{m_\rho^2}$$

Indirect Signals

- EWPT: test new physics in self-energies of SM gauge bosons

S and T receive contributions from different sectors:

3) model-dependent fermionic contributions



c=1

Indirect Signals

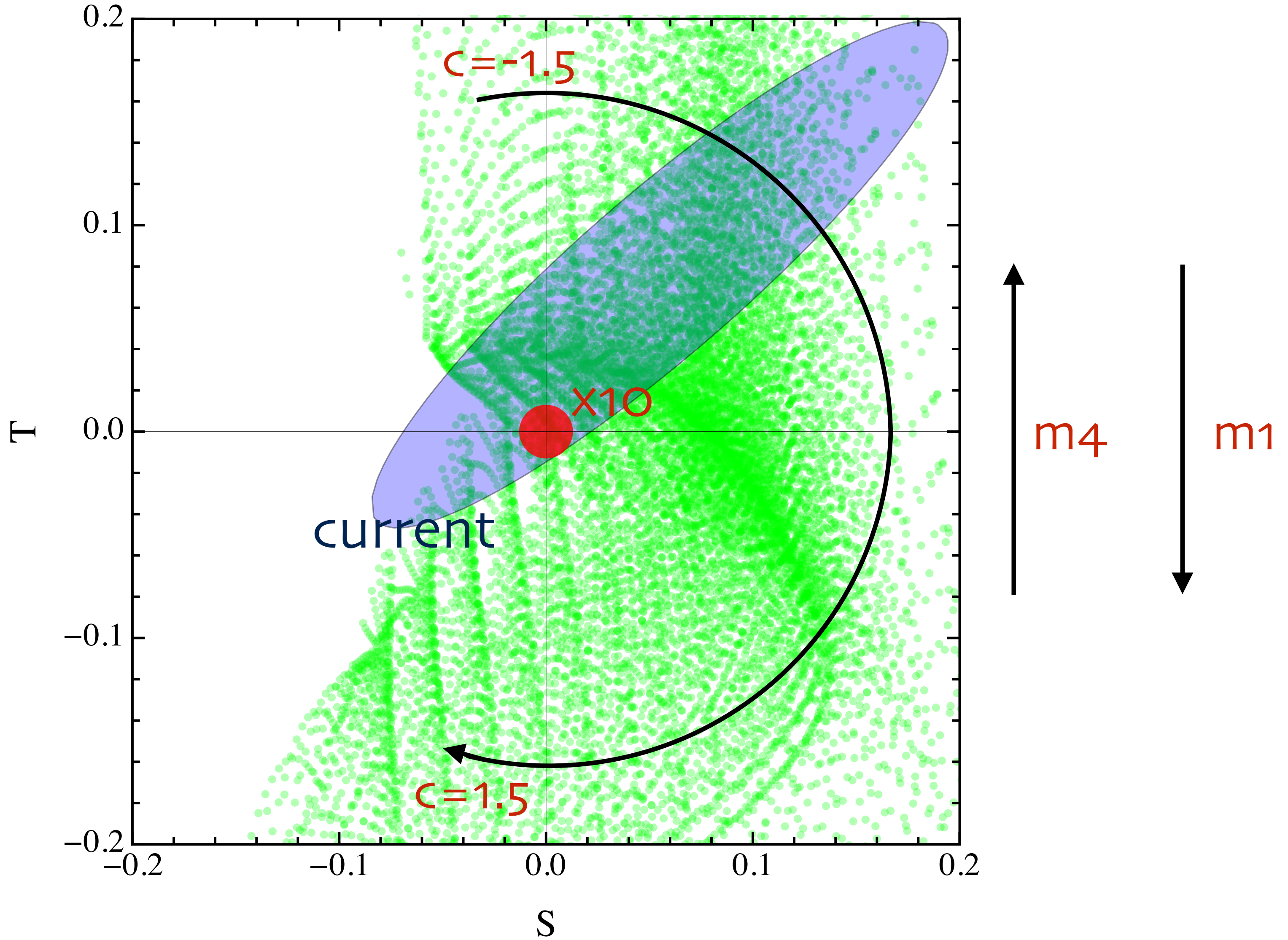
- **EWPT:** test new physics in self-energies of SM gauge bosons

S and T receive contributions from different sectors:

3) model-dependent fermionic contributions

4+1 partners in DCHM5
m partners > 1.7 TeV

$$\xi = 0.05$$
$$m_\rho = 6\,TeV$$
m_h fixed

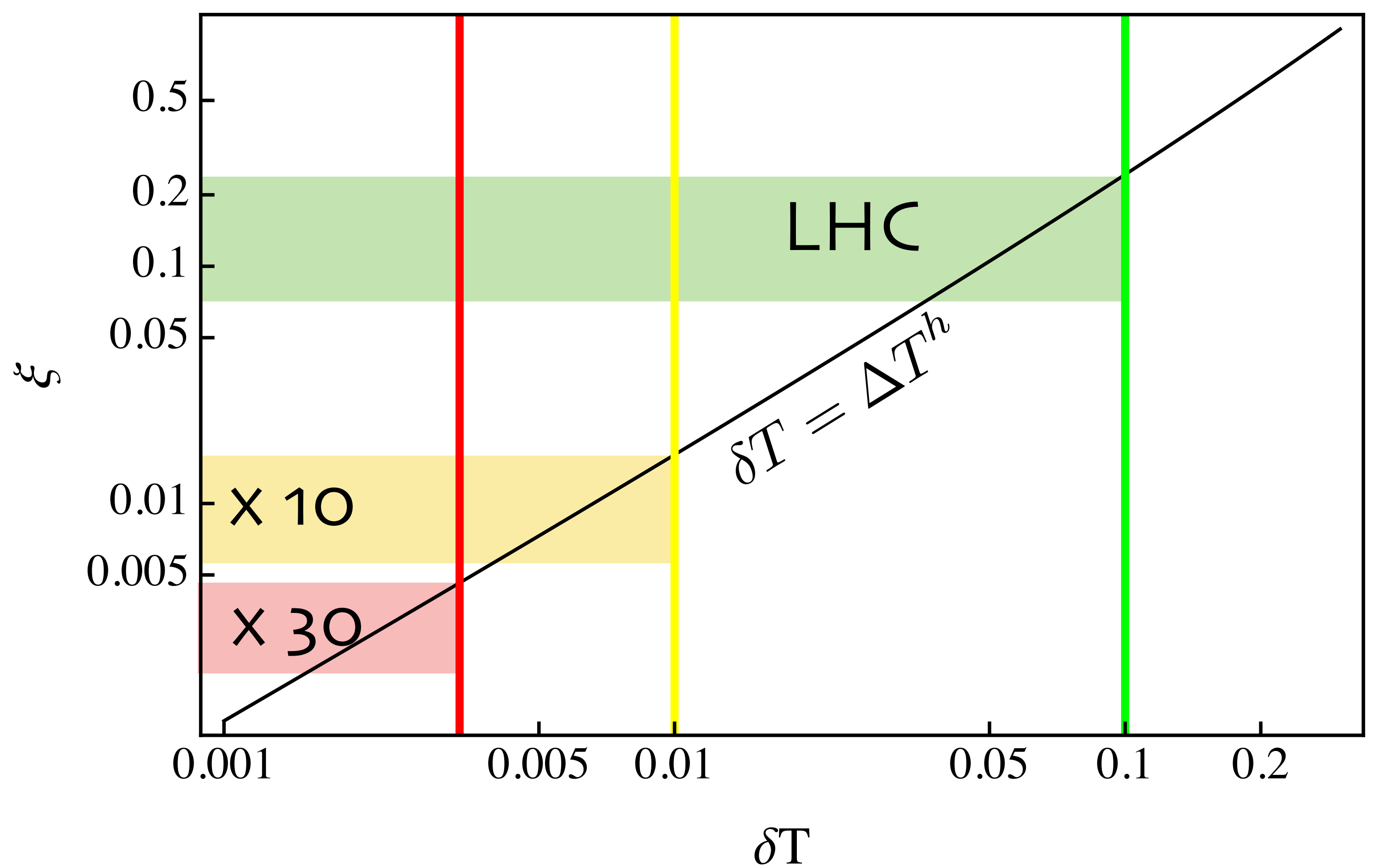


Indirect Signals

- **EWPT:** test new physics in self-energies of SM gauge bosons

estimate of tuning needed to pass EWPT for no signal case
using the largest model-independent contribution

$$\Delta \hat{T}^h = -\frac{3g'^2}{64\pi^2}\xi \log\left(\frac{m_\rho^2}{m_h^2}\right)$$



Indirect Signals

- Higgs couplings

deviations are rather insensitive to model parameters
but can discriminate the symmetry properties

		FCCee [JHEP01(2014)164]	sensitive to ξ 3σ
• tree-level			
HVV	$k_{\rm V} = 1 - 1/2\,\xi$	0.05%	0.003 (universal)
HFF	$k_{\rm F} = 1 - 3/2\,\xi$	0.19%	0.004
• loop-level			
HGG	$k_{\rm G} = 1 - 1/2\,\xi$	0.79%	0.02 (non-universal)

Indirect Signals

Fermions-vectors

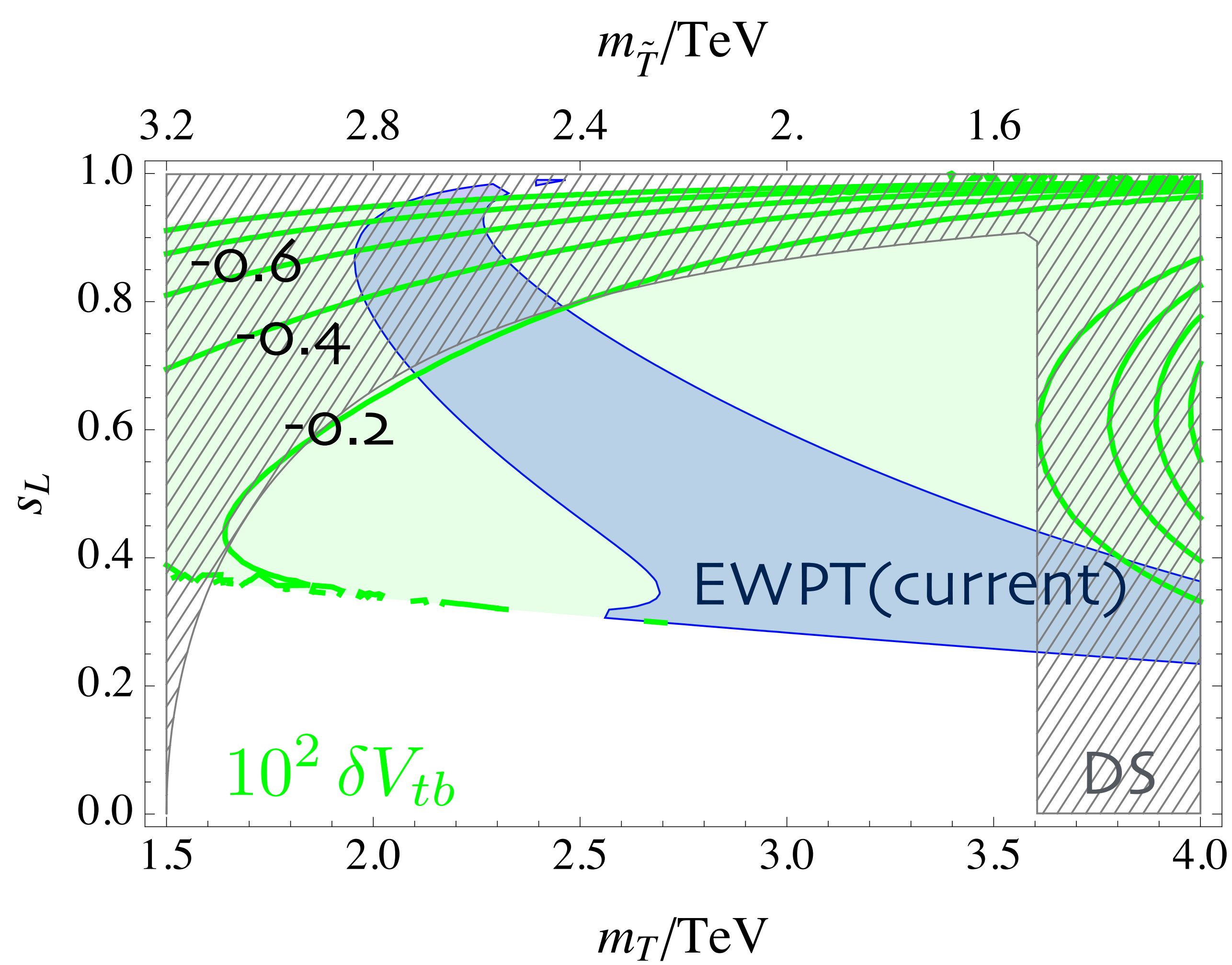
- as any distortion with respect to SM are controlled by ξ
- particularly sensitive to the symmetry structure of the model: e.g. Zbb can change by an order of magnitude depending on the bottom quantum numbers
- sensitive to the mixings and strong sector parameters

		FCCee	
Vtb	from Γ_t	0.37%	good test of top partial compositeness
Ztt	from σ_{tt}	???%	
Zbb	Z-decays	0.02%	

Indirect Signals

- Fermions-vectors

$\delta V_{tb} = \delta g_{t_L}$ as a consequence of ZbLbL suppression



$c = -1/\sqrt{2}$

$\xi = 0.05$

Indirect Signals

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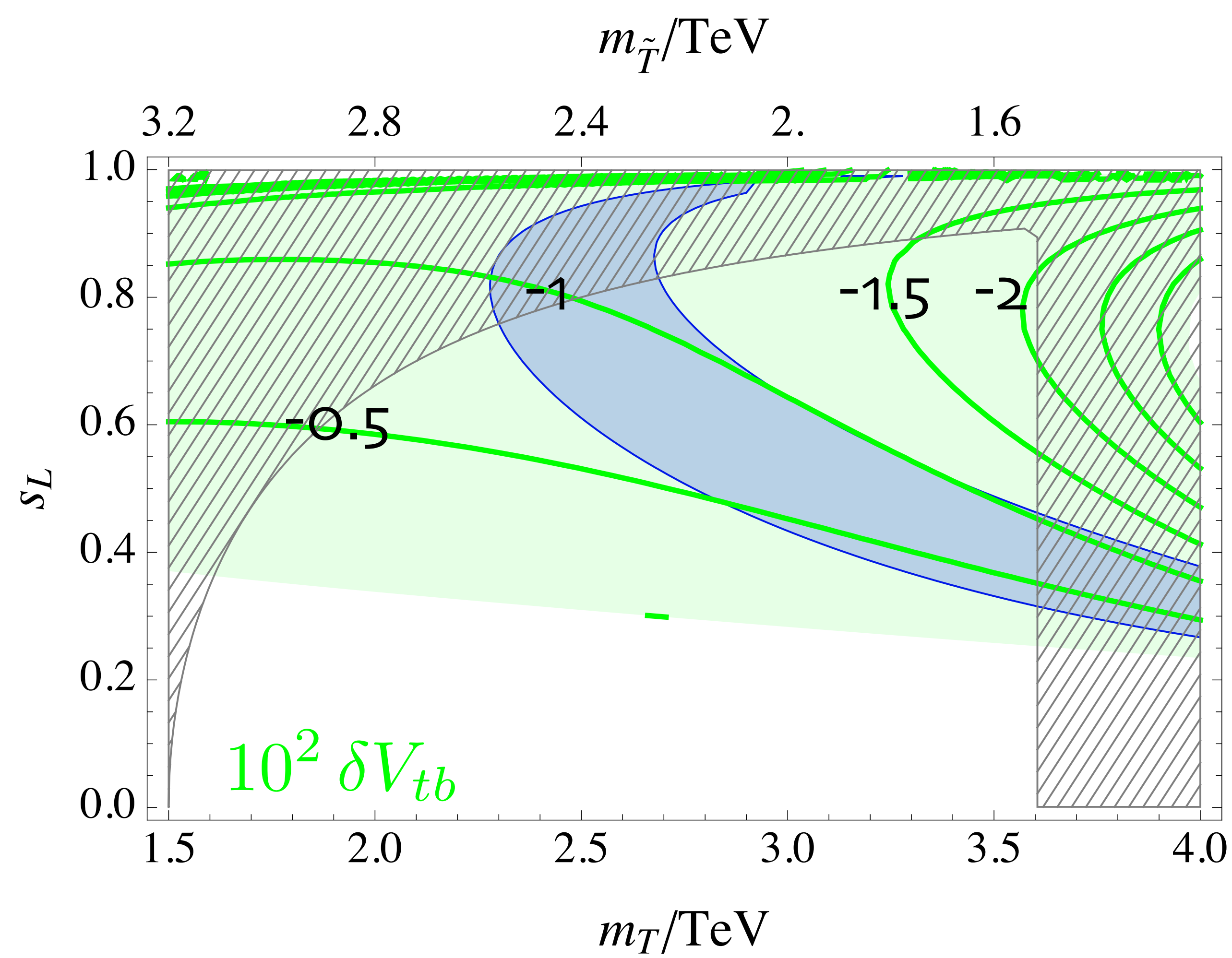

$c = 0$

$\xi = 0.05$

Indirect Signals

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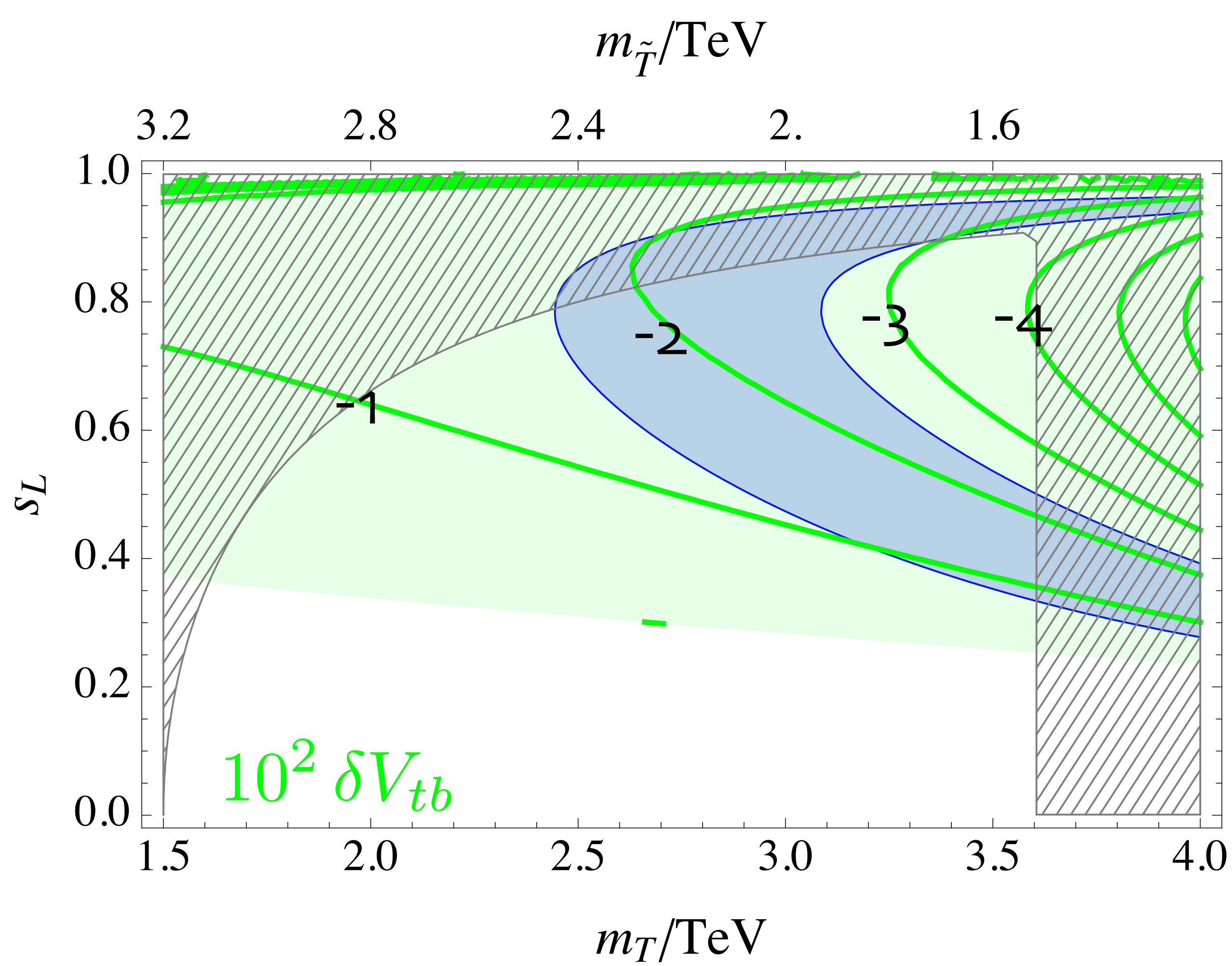
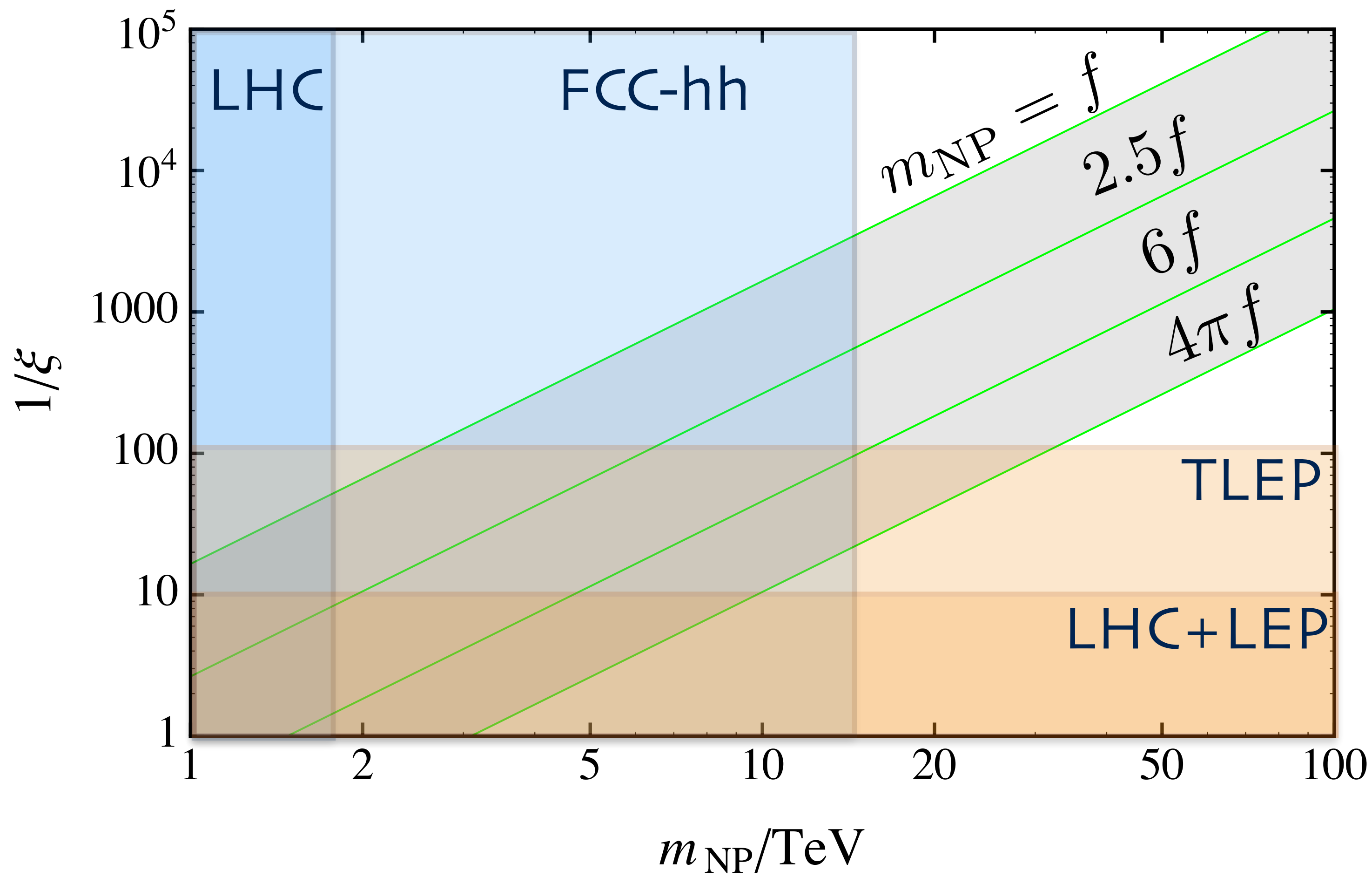


$$c = 1/\sqrt{2}$$

$$\xi = 0.05$$

Summary: Direct vs Indirect



Conclusions

- TLEP can be a major step forward in testing the Natural Composite Higgs, allowing to test the very concept of it and not just some particular models.

- In case of positive signal a lot of useful information can be extracted about the general symmetry structure of the theory, as well as particular values of its parameters.