Title: The Two Scales of New Physics in Higgs Couplings

Speakers: Gabriele Rigo

Series: Particle Physics

Date: October 27, 2023 - 1:00 PM

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Abstract: Higgs coupling deviations from Standard Model predictions contain information about two scales of Nature: that of new physics responsible for the deviation, and the scale where new bosons must appear. The two can coincide, but they do not have to. The scale of new bosons can be calculated by going beyond an effective field theory description of the coupling deviation. I will discuss model-independent upper bounds on the scale of new bosons for deviations in Higgs to WW and ZZ couplings, and explain how any measured deviation at present or future colliders requires the existence of new bosons within experimental reach. This has potentially interesting implications for naturalness.

Zoom link https://pitp.zoom.us/j/97203814123?pwd=U3F3N2xxTmJSQmxIQ0Rib3ZwN3Fldz09

The Two Scales of New Physics in Higgs Couplings

[arXiv:2305.19325 [hep-ph]]

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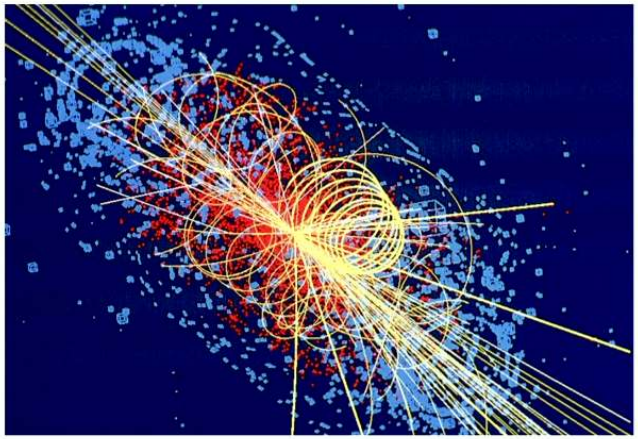
Particle Physics Seminar

27 October 2023

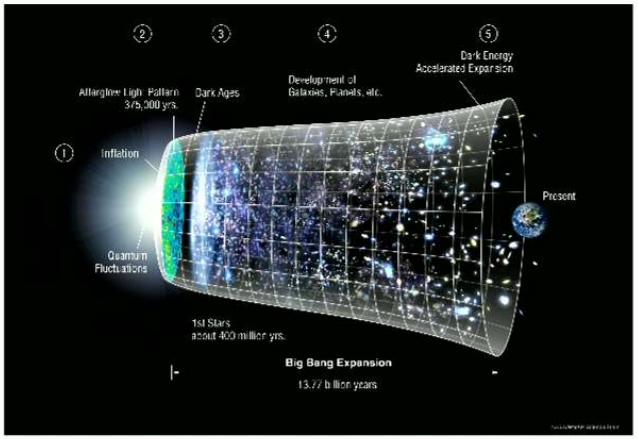
Basic Questions

Origin of mass?



Hierarchy problem

Composition of the Universe?



Dark matter

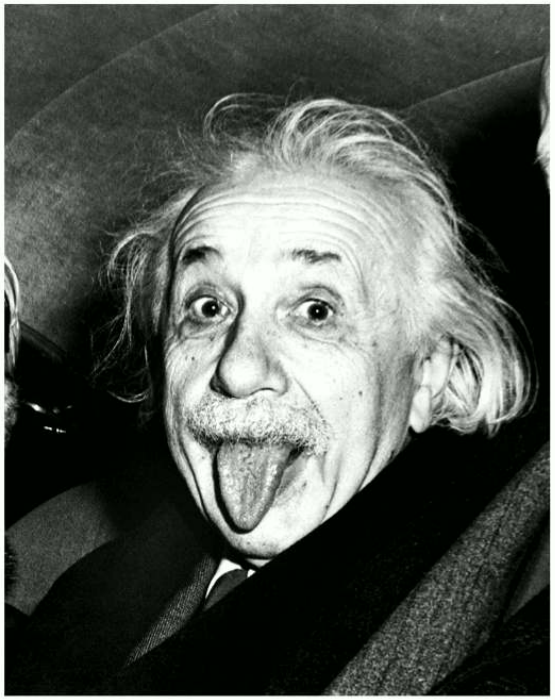
COMMON PREDICTION

New physics at the weak scale

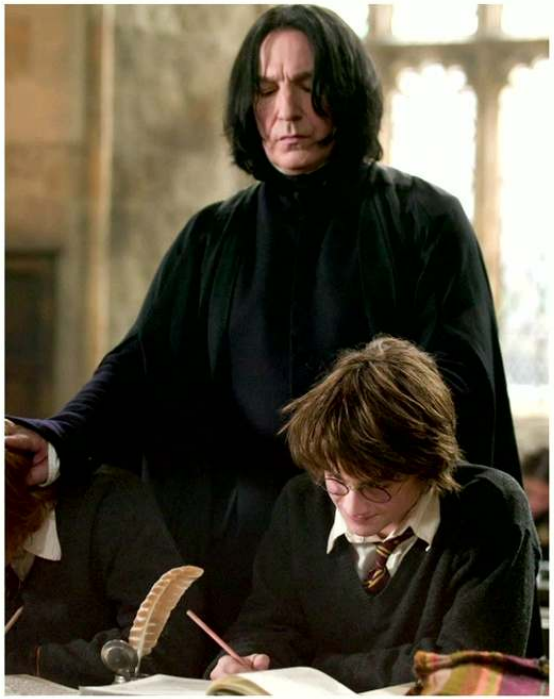
Expectations

Reality

Two Kinds of Physicists



Model-building

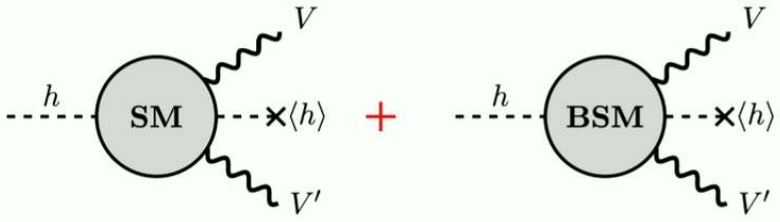


EFT

General Idea

Higgs mass:

Production and decay:



MODEL-INDEPENDENT STATEMENT?

Naturalness $\longleftrightarrow$ Higgs couplings

Outline

1. **The Ingredients**
2. **The Recipe**
3. **The Cake**

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The Question

Suppose there is a deviation in hWW or hZZ.

What can we say about new bosons?

Proof by Contradiction

How to bound new bosons?

- BSM fermions in generic representation
- Yukawas $\mathcal{L} \supset -yLHN^c - y^cL^cH^\dagger N$

[Arkani-Hamed, Blum, D'Agnolo, Fan 2012; Blum, D'Agnolo, Fan 2015]

Proof by Contradiction

How to bound new bosons?

- BSM fermions in generic representation
- Yukawas $\mathcal{L} \supset -yLHN^c - y^cL^cH^\dagger N$
  1. Deviations in hWW and hZZ
  2. Instability in RGEs
- Vary masses and representations
- Conservative upper bound on Λ_B

[Arkani-Hamed, Blum, D'Agnolo, Fan 2012; Blum, D'Agnolo, Fan 2015]

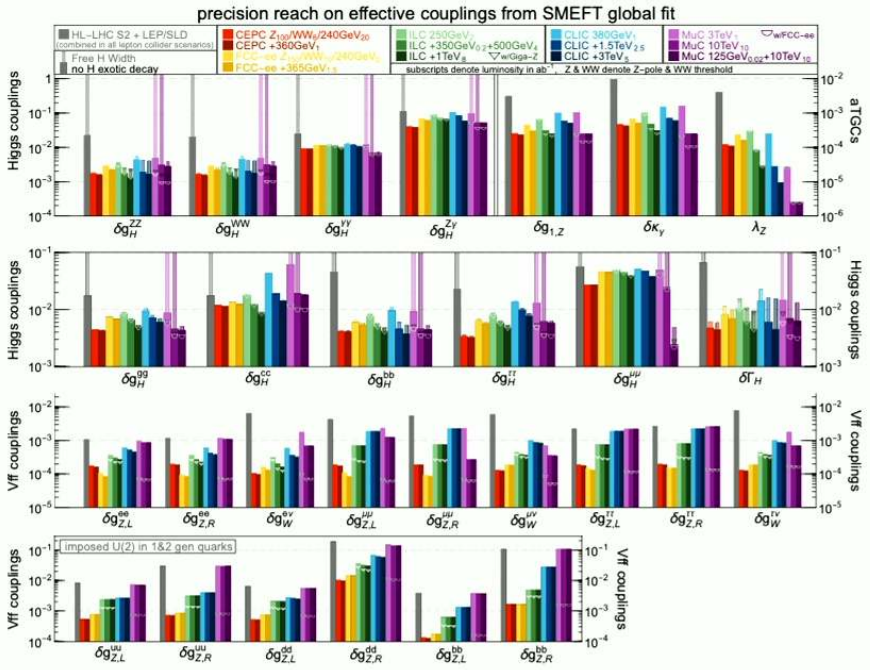
Focus on Fermions

Generic requirements:

1. Responsible for deviations
2. Consistent with experiment
3. No gauge anomalies

VECTOR-LIKE FERMIONS

Why These Couplings?



[de Blas et al. 2022]

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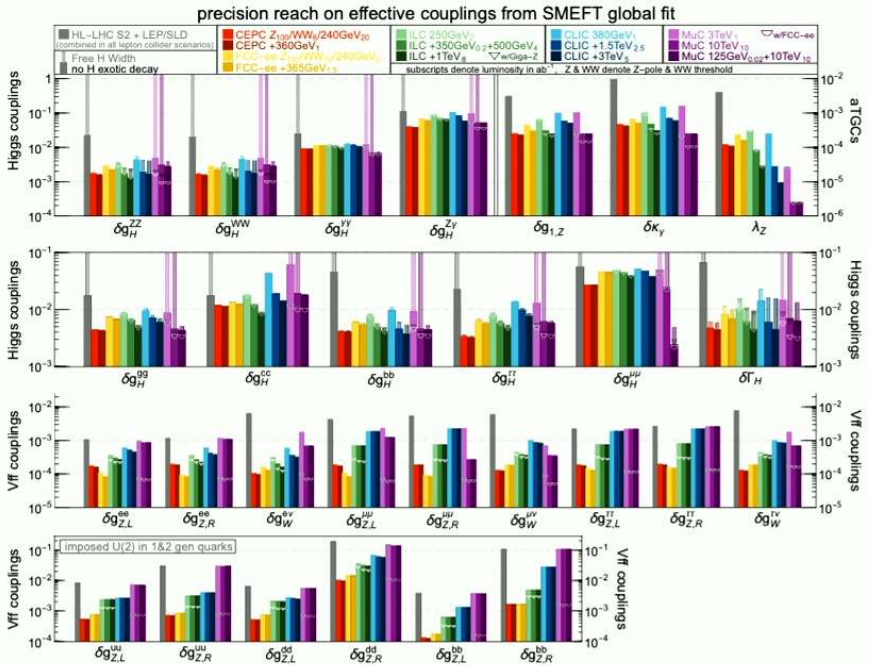

tree SM vs loop BSM

[de Blas et al. 2022]

Why Beyond EFT?

EFT intuition:

- Deviation $\delta g_h \simeq c(v^2/\Lambda^2)$
- New physics $\Lambda \simeq v\sqrt{c/\delta g_h}$
- Additionally, $\Lambda_B > \Lambda$

SPOILER

$\Lambda_B \simeq \Lambda$ for HL-LHC deviations

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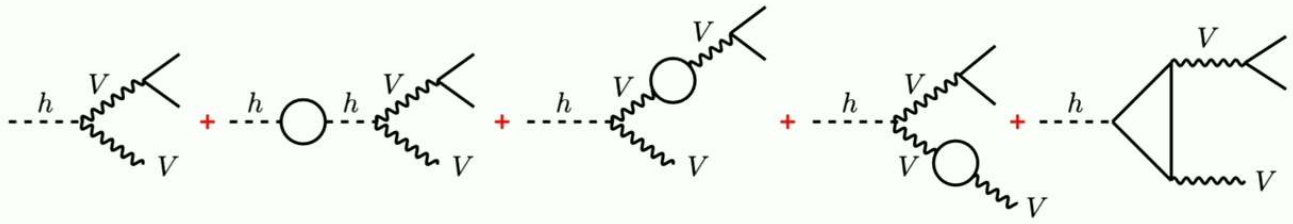
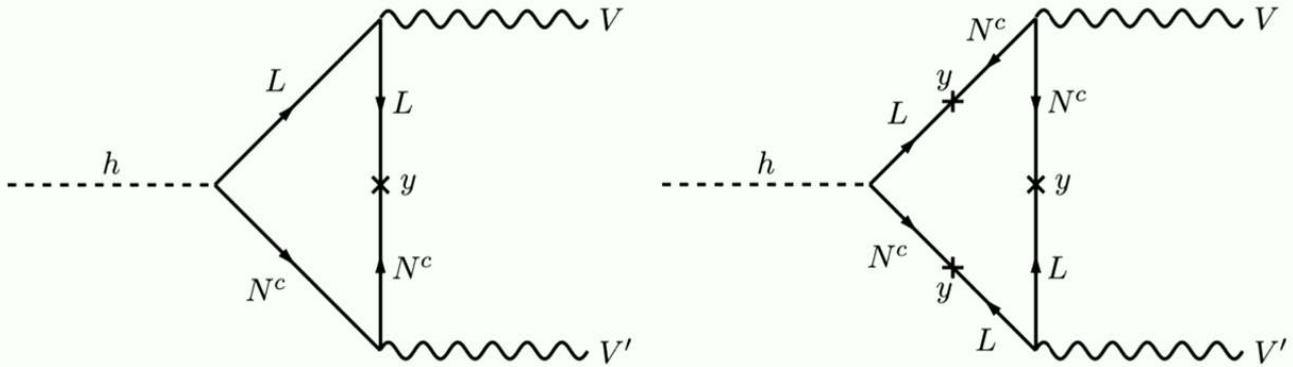
Step One



- Renormalize SM + VLFs $\longrightarrow \delta\mu_{hVV} \sim f(y, M)$
- Measured quantities α, M_Z, G_F

$$\delta\mu_{hWW} = \frac{y^2 v^2}{80\pi^2 M^2}\left[y^2\frac{(1+c_W^2)}{c_W^2 - s_W^2} - \frac{m_h^2}{v^2} - \frac{g^2}{4}\frac{s_W^2}{c_W^2 - s_W^2}\right] + \dots$$

Naive Dimensional Analysis



$$\delta g_{hWW} \sim \frac{g^2 y^4 v^3}{16\pi^2 M^2}$$

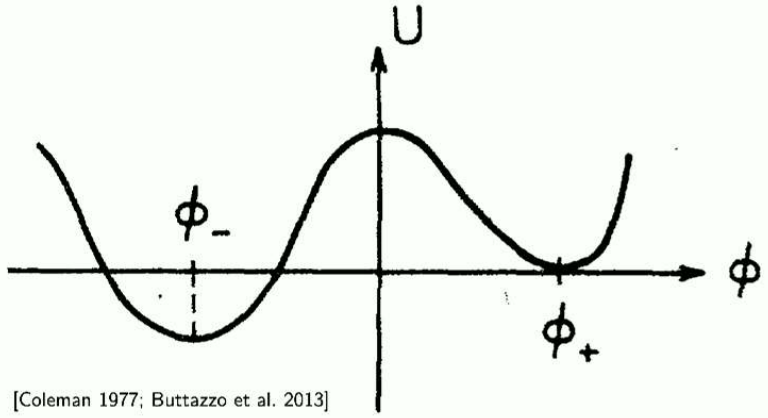
Step Two

Two instabilities:

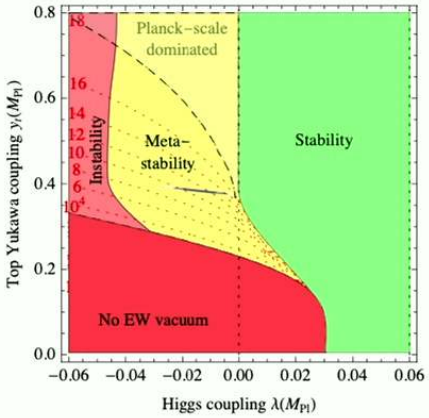
- Higgs quartic, $\mathrm{d}\lambda/\mathrm{d}\log\mu \sim -y^4/16\pi^2$
- Landau pole, $\mathrm{d}y/\mathrm{d}\log\mu \sim y^3/16\pi^2$

$\Big\}\ \Lambda_B$

- Crucially only rectified by bosons
- SM vacuum decay at $\lambda(\Lambda_B)^{-1} = -14.53 + 0.153\log(\mathrm{GeV}/\Lambda_B)$



[Coleman 1977; Buttazzo et al. 2013]



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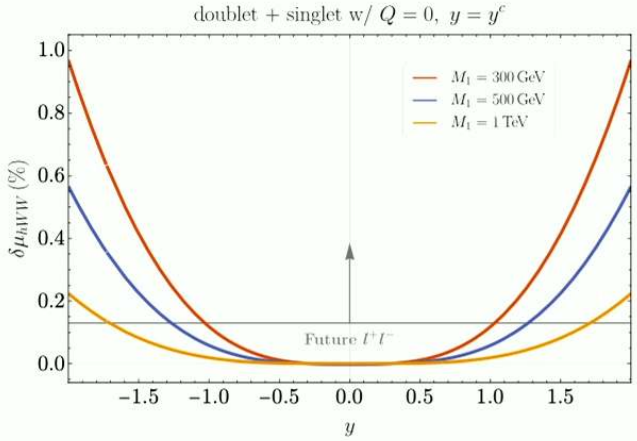
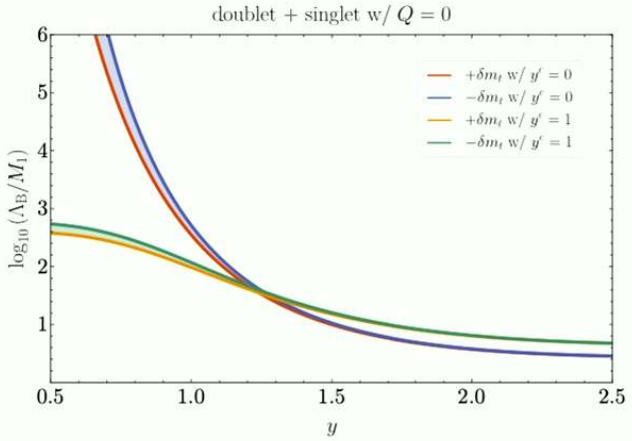




Scaling with Color

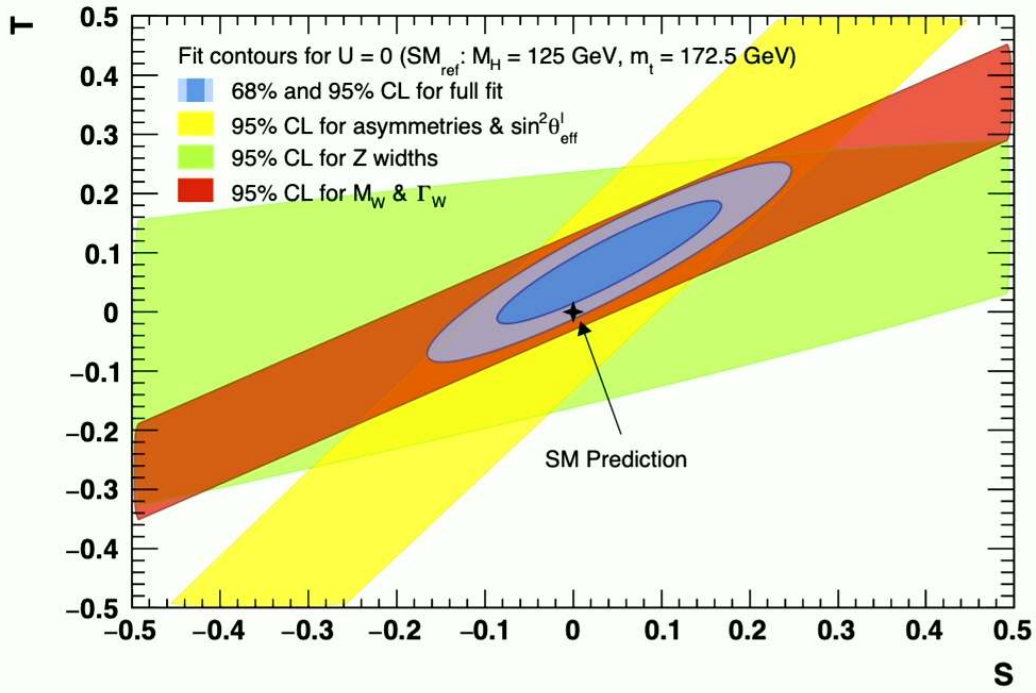
$$\delta g_{hVV} \sim r\frac{\alpha_V}{4\pi}\frac{y^4 v^2}{M^2} = \frac{\alpha_V}{4\pi}\frac{y_r^4 v^2}{rM^2} \lesssim \frac{\alpha_V}{4\pi}\frac{y_r^4 v^2}{rM_{\rm exp}^2}$$

$$\frac{\mathrm{d}y}{\mathrm{d}\log\mu} \sim r\frac{y^3}{16\pi^2} \longrightarrow y_r \equiv y\sqrt{r} \qquad \text{'t Hooft coupling}$$

VECTOR-LIKE LEPTONS

$$L = (1, n)_{Y-1/2}\,, \qquad N^c = (1, n-1)_{-Y}$$
$$L^c = (1, n)_{-Y+1/2}\,, \qquad N = (1, n-1)_{Y}$$

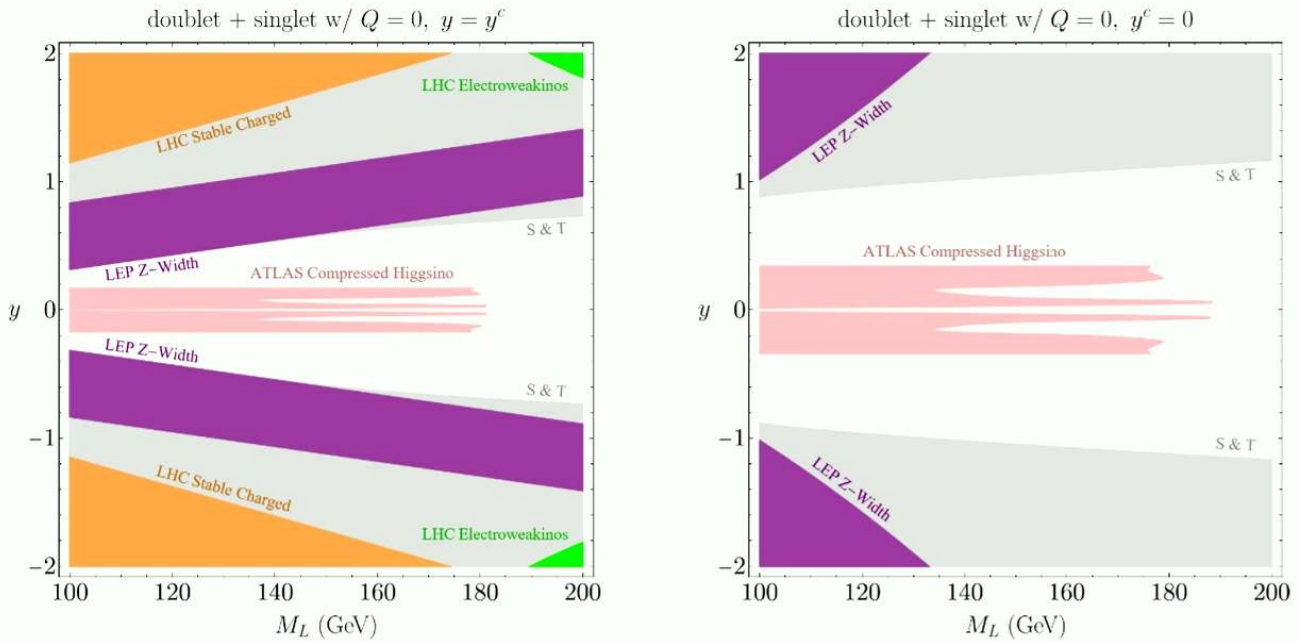
Step Three



Experimental constraints (EWPTs, collider)

[The Gfitter Group 2018]

Step Three



Experimental constraints (EWPTs, collider)

[The Gfitter Group 2018]

Aside on Strong Coupling

Strong coupling:

$$\text{correction } \mathcal{O}\left(v^2/f^2\right), \qquad m_* = 4\pi f$$

Compare with

$$\text{correction } \mathcal{O}\left(y^4 v^2/16\pi^2 M^2\right) \longrightarrow f_{\text{eff}} \simeq 4\pi M/y^2$$

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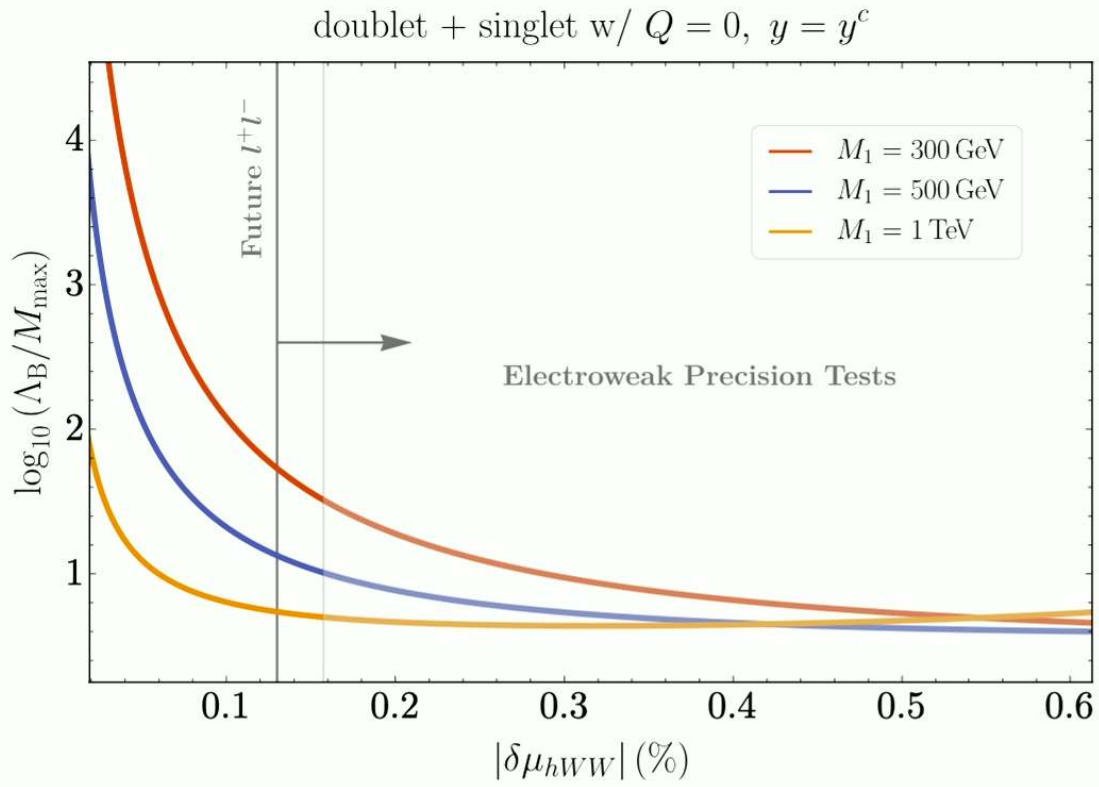
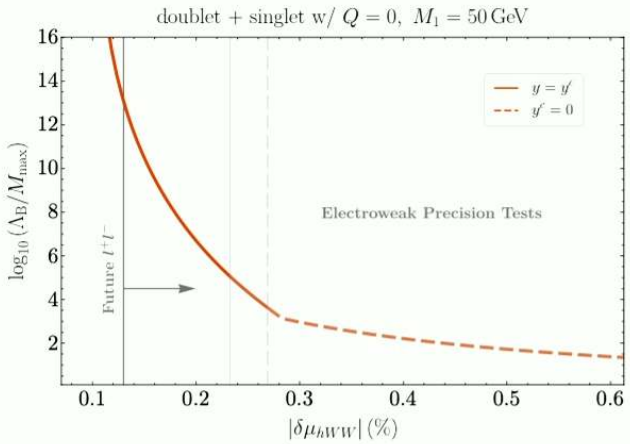
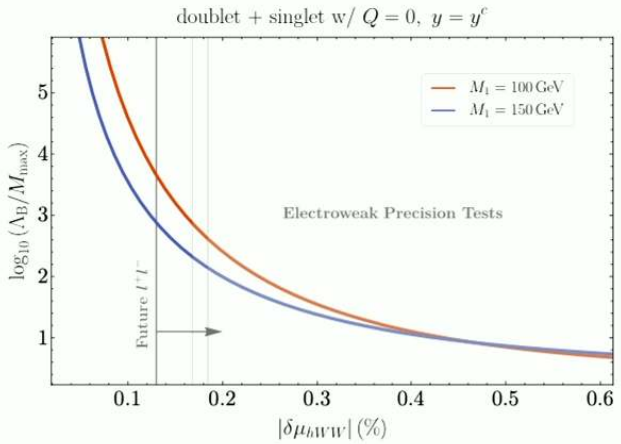
Money Plots: hWW

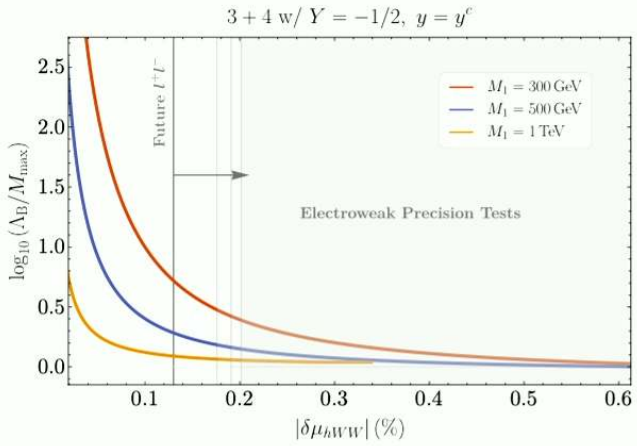


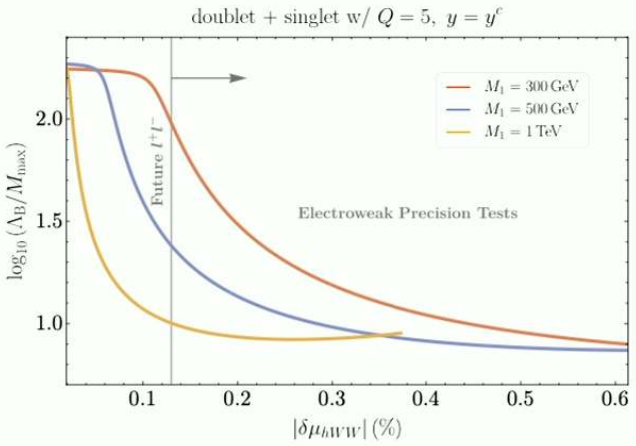
Money Plots: hWW



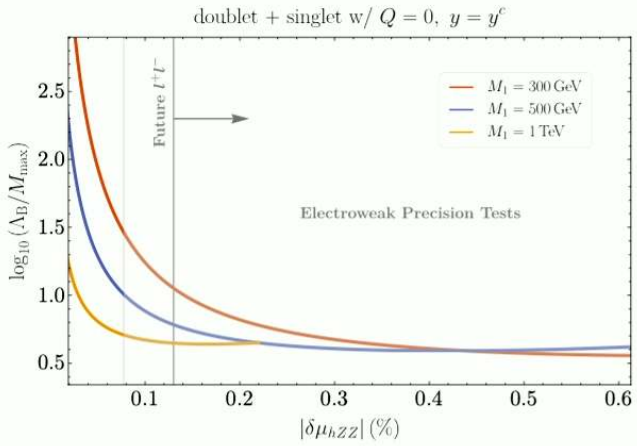


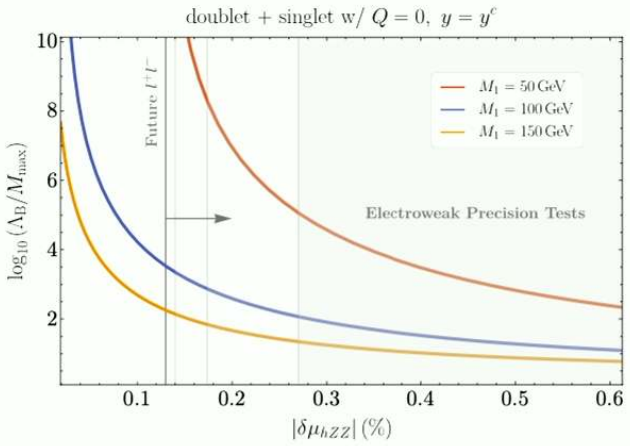
Money Plots: hWW





Money Plots: hZZ





Summary and Future

- Deviation at HL-LHC requires new bosons
- Deviation at future colliders:
  1. light new fermions
  2. new bosons under 100 TeV
- Systematically study $h\gamma\gamma$ and $hZ\gamma$

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- Deviation at HL-LHC requires new bosons
- Deviation at future colliders:
  1. light new fermions
  2. new bosons under 100 TeV
- Systematically study $h\gamma\gamma$ and $hZ\gamma$
- Powerful probes of new physics!

Thank you!