Unitarity Bounds on New Physics From Higgs Couplings

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Why Measure Higgs Couplings?

All SM parameters are determined to high accuracy

$$m_h = 125.18 \pm 0.16 \text{ GeV} \longrightarrow g_{hhh}$$

$$m_Z = 91.187 \pm 0.0021 \text{ GeV} \longrightarrow g_{hZZ}$$

$$m_t = 172.76 \pm 0.3 \text{ GeV} \longrightarrow g_{htt}$$

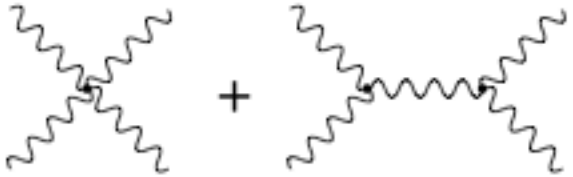
⇒ measurements of Higgs couplings are searches for BSM physics

- New light states? ⟶ direct searches
- New physics at high energies? ⟶ precision measurements

Any deviation from SM prediction ⇒ unitarity violation at high energies
⇒ model-independent bound on scale of new physics

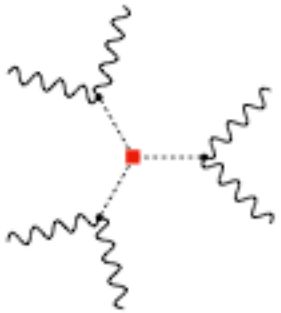
The Scale of New Physics

SM without the Higgs:

$W_L W_L \to W_L W_L$:  $\sim \frac{E^2}{v^2}$ $\Rightarrow E_{\rm NP} \lesssim {\rm TeV}$

"New" physics = Higgs

SM with h^3 deviation: $\delta_{h3} = \frac{g_{hhh} - g_{hhh}^{(\rm SM)}}{g_{hhh}^{(\rm SM)}}$

 $+ \cdots \sim \delta_{h3} \frac{E^2}{v^2}$ $\Rightarrow E_{\rm NP} \lesssim 4\ {\rm TeV} \left(\frac{\delta_{h3}}{10}\right)^{-1/2}$

SM: cancellations $\Rightarrow \sim \frac{1}{E^2}$

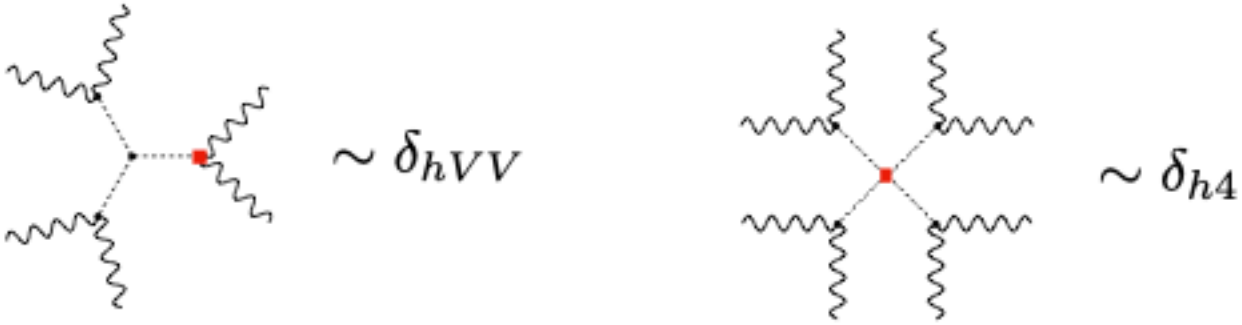
New physics = 

Bottom-up Approach

Allow arbitrary couplings consistent with experiment:

$$\mathcal{L} = \mathcal{L}_{\rm SM} - \delta_{h3}\frac{m_h^2}{2v}h^3 - \delta_{h4}\frac{m_h^2}{8v^2}h^4 + \cdots$$

E.g. contribution from g_{hVV} deviation is negligible



Processes with additional legs depend on unknown couplings

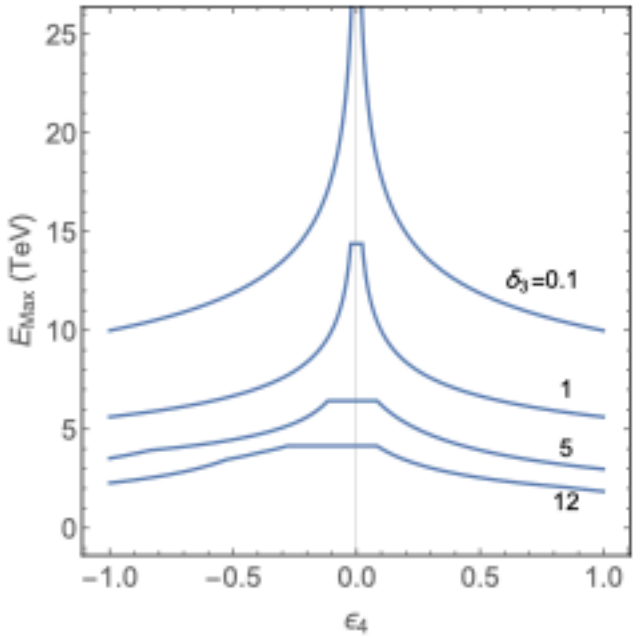
SMEFT without SMEFT

For $E_{\rm NP} \gg {\rm TeV}$ we expect that δ_{h3} can be parameterized by dimension-6 SMEFT operator

$$\mathcal{L}_{\rm SMEFT} = -\frac{1}{M^2}(H^\dagger H)^3 \qquad \Rightarrow \delta_{h4} = 6\delta_{h3}$$

How accurate is this?

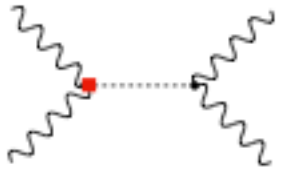
$$\epsilon_4 = \frac{\delta_{h4} - \delta_{h4}^{(\rm SMEFT)}}{\delta_{h4}^{(\rm SMEFT)}}$$

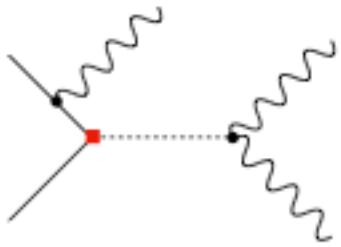


Higgs Couplings to W, Z, t

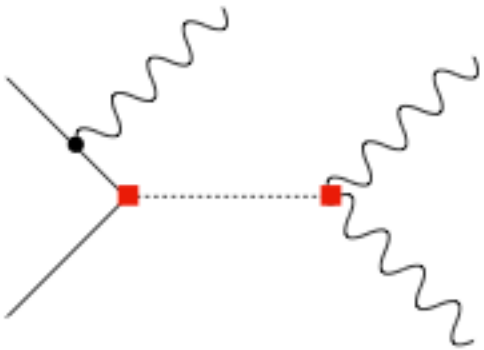
Assume custodial symmetry:

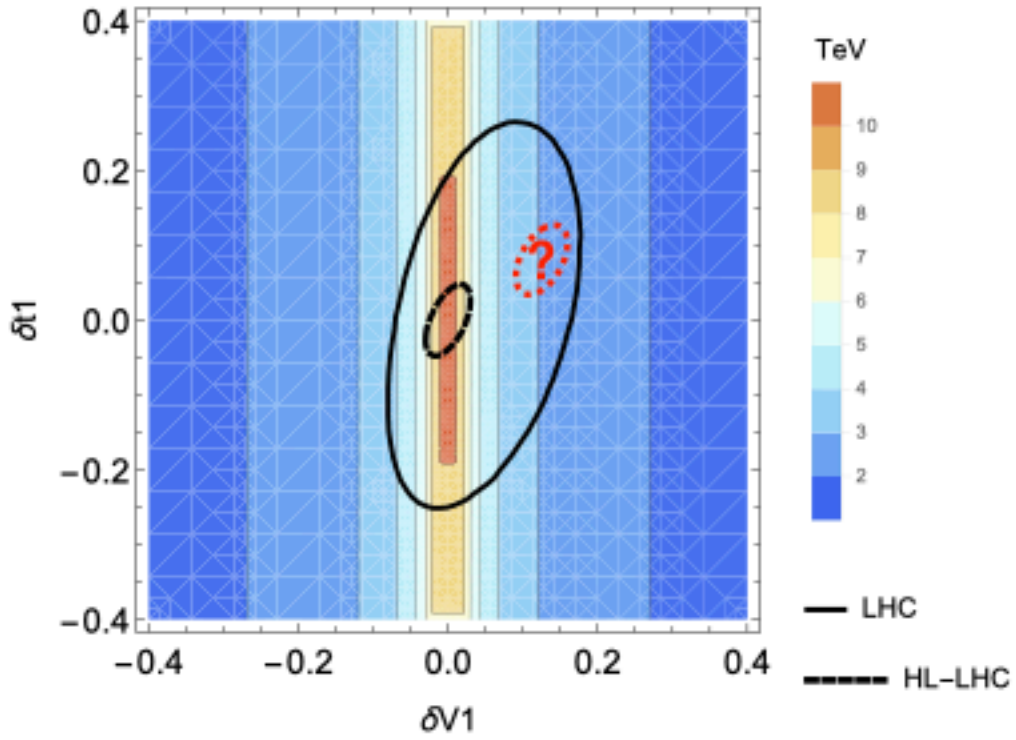
$$\mathcal{L} = \mathcal{L}_{\rm SM} + \delta_{V1}\left[\frac{m_Z^2}{v} h Z^\mu Z_\mu + \frac{2m_W^2}{v} h W^{\mu+} W^+_\mu\right] + \delta_{t1} h \bar{t} t + \cdots$$

$W_L W_L \to W_L W_L$:  $+\cdots \quad \Rightarrow E_{\rm NP} \lesssim 2\ {\rm TeV} \left(\frac{\delta_{V1}}{0.2}\right)^{-1/2}$

$t\bar{b} \to W_L W_L W_L$:  $+\cdots \quad \Rightarrow E_{\rm NP} \lesssim 10\ {\rm TeV} \left(\frac{\delta_{t1}}{0.2}\right)^{-1/2}$

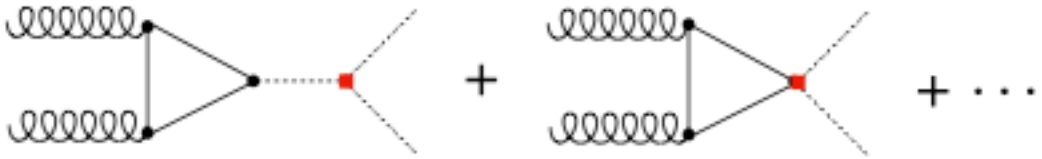
Projections



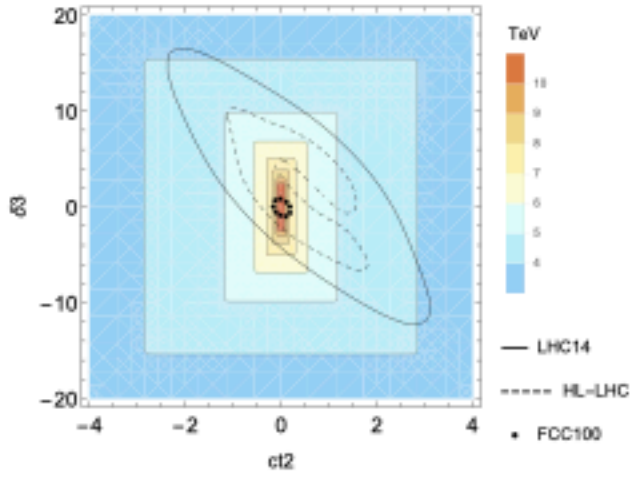


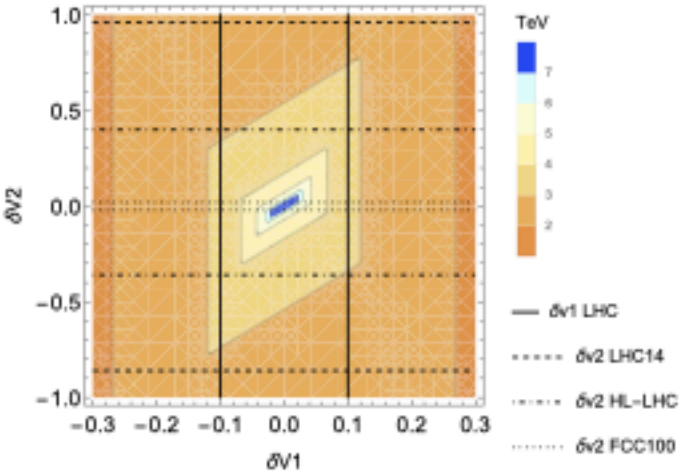
BSM Higgs Couplings

$$\mathcal{L} = \mathcal{L}_{\rm SM} - \delta_{h3}\frac{m_h^2}{2v}h^3 - c_{t2}\frac{1}{v}h^2\bar{t}t + \cdots$$



$$+ \delta_{V2}\left[\frac{m_Z^2}{2v^2}h^2 Z^\mu Z_\mu + \frac{m_W^2}{v^2}h^2 W^{\mu+}W_\mu^+\right] + \cdots$$





For Discussion

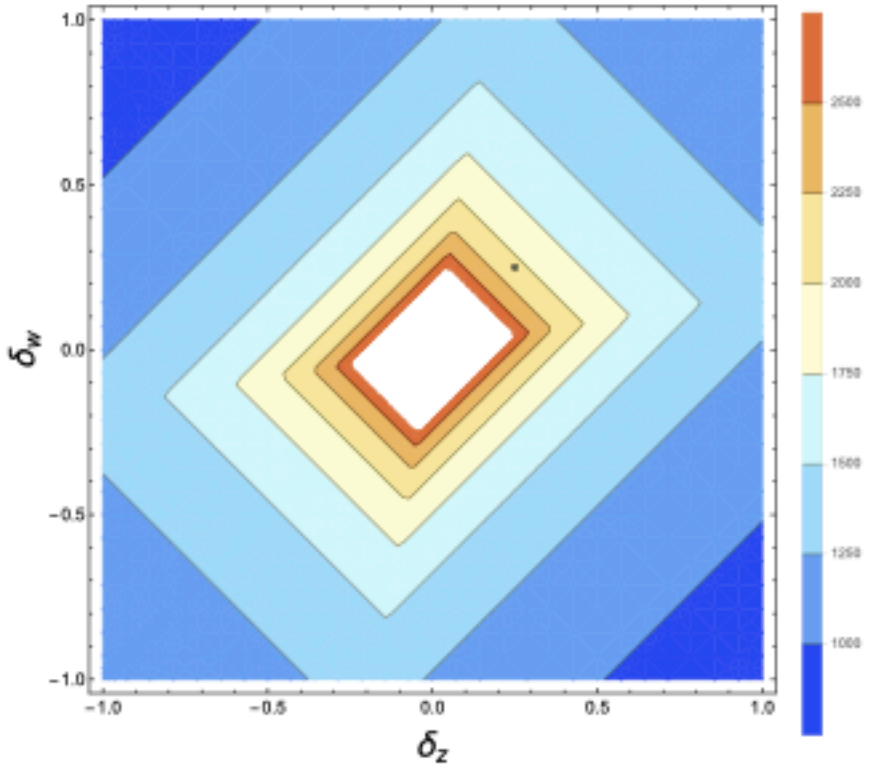
- Any observed deviation from SM predictions for couplings points to a scale of new physics that can be explored in future experiments

  Use this to help make the case for HL-LHC/future colliders?

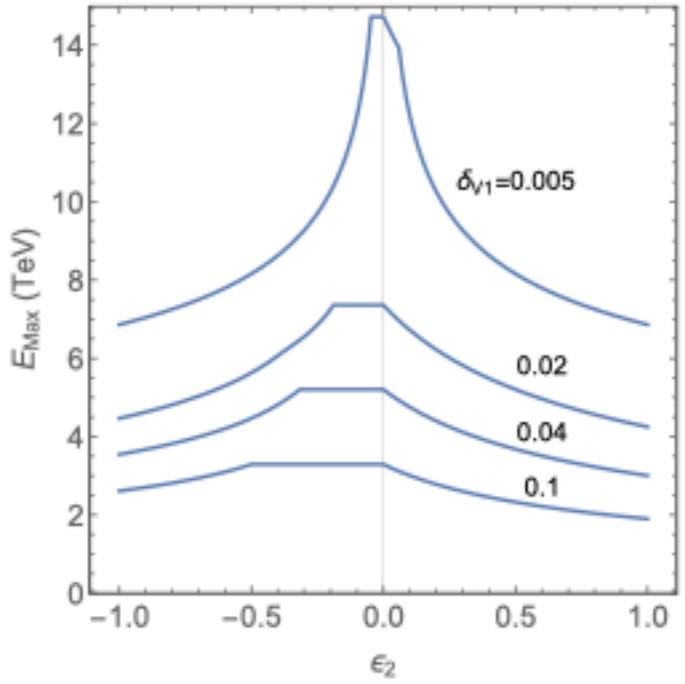
- Projections of scale of new physics from upcoming data?

- Explore bounds on “unitarity partners” in specific models?

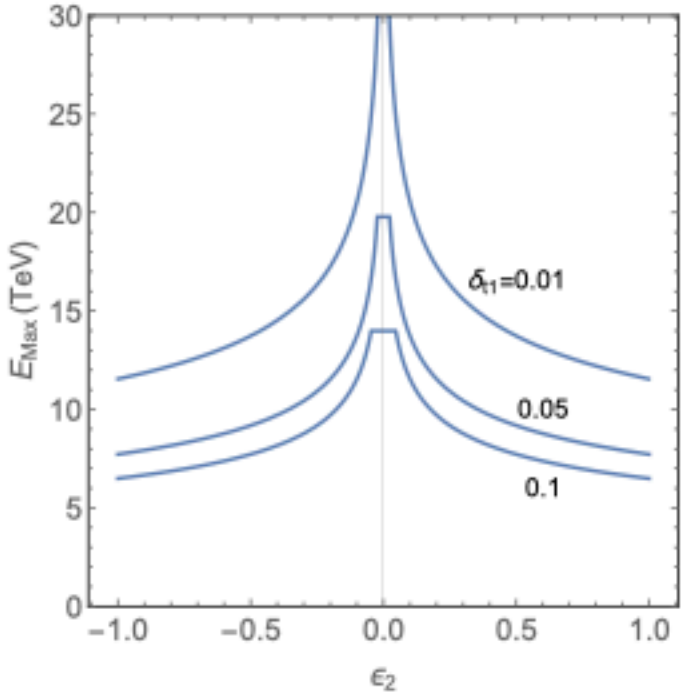
hWW *vs.* hZZ


1.0
0.5
0.0
−0.5
−1.0
δ_W
−1.0
−0.5
0.0
0.5
1.0
δ_Z
2500
2250
2000
1750
1500
1250
1000

More SMEFT without SMEFT



$$\epsilon_2 = \frac{\delta_{V1} - \delta_{V2}^{(\mathrm{SMEFT})}}{\delta_{V2}^{(\mathrm{SMEFT})}}$$



$$\epsilon_2 = \frac{\delta_{t1} - \delta_{t2}^{(\mathrm{SMEFT})}}{\delta_{t2}^{(\mathrm{SMEFT})}}$$