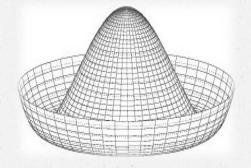


Snowmass, December 1, 2020 S. Dawson, BNL



## At the 10-20% level:

- Fermion couplings to b, t,  $\tau$
- Gauge boson couplings to W/Z/g/γ
- Higgs h<sup>2</sup> coupling: mass to .1%
- Little information on  $hZ\gamma$ ,  $2^{nd}$  generation fermions,  $h^3$ ,  $h^4$  couplings....
- Generically, Higgs coupling deviations in BSM:

$$\mathcal{O}\left(\frac{v^2}{M^2}\right) \sim 5\% \left(\frac{1 \ TeV}{M}\right)^2$$

Much work to do!

## Higgs self-couplings

$$V = -\mu^2 \Phi^{\dagger} \Phi + \lambda (\Phi^{\dagger} \Phi)^2$$
$$V \to -\frac{M_h^2}{2} h^2 + \lambda_3 h^3 + \lambda_4 h^4$$

hhh and hhhh couplings predictions of theory

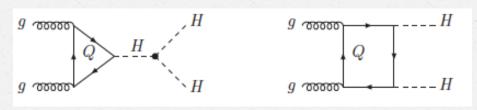
• Perturbative: 
$$\lambda_3=\frac{m_h^2}{2v}\sim .13v$$
  $\lambda_4=\frac{m_h^2}{8v^2}=.03$ 

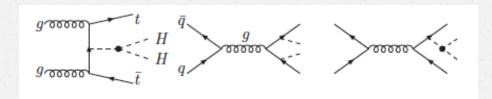
In Effective Field theory, new physics at scale M:

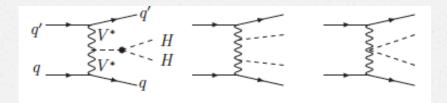
Corrections to relationship between  $\lambda_3$  and  $\lambda_4$  of O(1/M<sup>2</sup>)

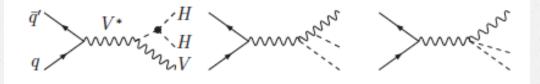
\* This is NOT true in models with new light particles or resonances

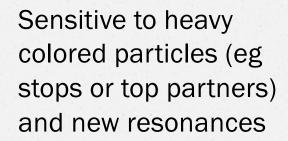










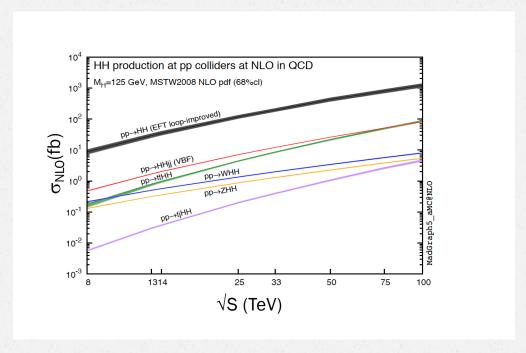


Sensitive to anomalous top-Higgs couplings

Sensitive to anomalous VVhh couplings

Note that these processes are related to corresponding single Higgs processes

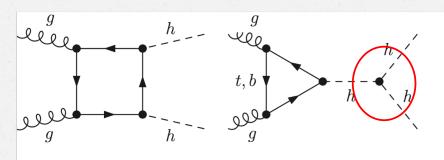




 $\sigma(pp \rightarrow hhh) = .01fb$  at 14 TeV LHC



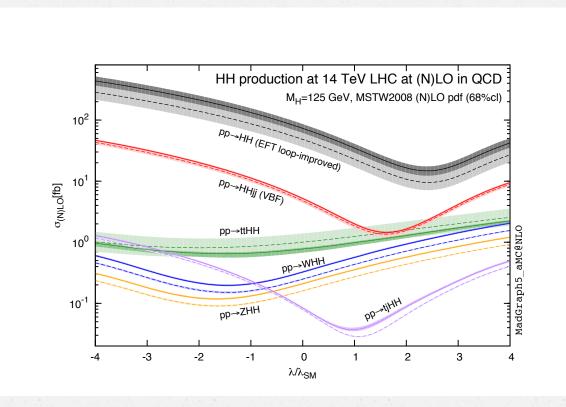
### Production of hh



- Dominant production from gluon fusion through top quark loops
- Sensitive to Higgs tri-linear coupling
- Large cancellation between box and triangle (vanishes at threshold)  $\longrightarrow$  reduces sensitivity to  $\lambda_3$

IN SM  $\lambda_3$  IS FIXED!!!

## Dependence on λ<sub>3</sub>



Everything SM except  $\lambda_3$ 



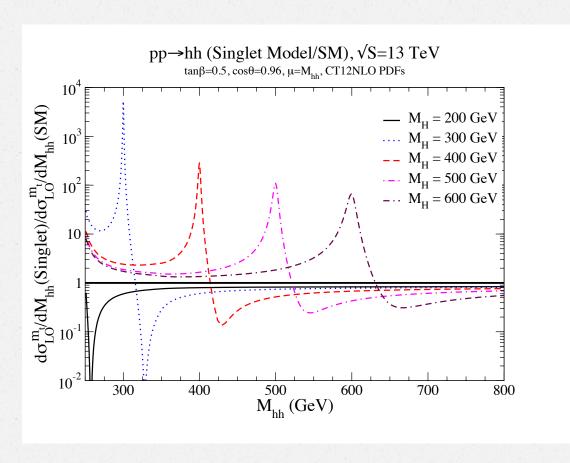
#### Non-resonant production

- Not just  $\lambda_3$ , but variation of all couplings away from SM values (eg, tth, tthh....)
- Variation of couplings affects single Higgs production, top physics, gauge boson interactions...

#### Resonant production

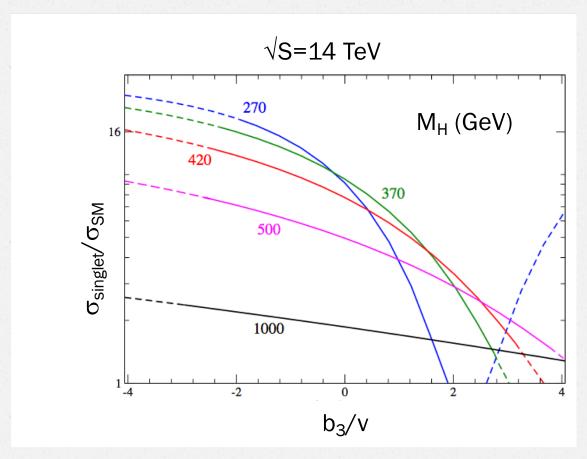
- Test specific models by looking for resonances
- Can produce 2 different mass Higgs bosons





Simple model with extra scalar

# Di-Higgs a "Smoking Gun"



 $b_3$  is  $S^3$  term





### Get Involved

 Come to EF01 meetings and subscribe to mailing list/Slack channel

https://snowmass21.org/energy/higgs

 Participate in informal hh discussions and subscribe to mailing list

hh-snowmass2021@cern.ch