New observables

for effective Higgs couplings.

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DESY

in collaboration with
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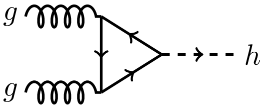
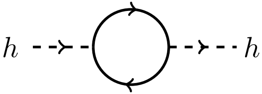
Higgs Hunting 2013

Motivation: Where is the new physics?

New physics can show up at several places in Higgs production:

- Long range: Modified Higgs-top coupling
- Short range: Non-SM particles in loop
- $\mathcal{L} = k_g \frac{\alpha_S}{12\pi} \frac{|H|^2}{v^2} G^{a\ 2}_{\mu\nu} - c_t y_t \bar{q}_L \tilde{H} t_R$





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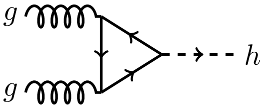
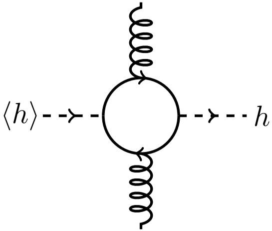


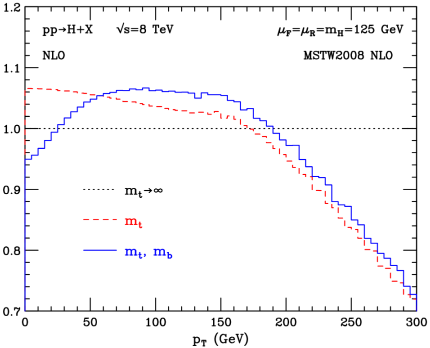


Motivation: Degeneracy

> $$\frac{\sigma_{NLO}(m_t, m_b)}{\sigma_{NLO}(m_t \to \infty)} = 0.988$$
[e.g. Grazzini, Sargsyan, arXiv: 1306.4581]

> Degeneracy in partonic xsec:
$$\frac{\sigma(gg \to h)}{\sigma_{SM}(gg \to h)} = |k_g + c_t|^2$$

> $t\bar{t}h$ channel is difficult

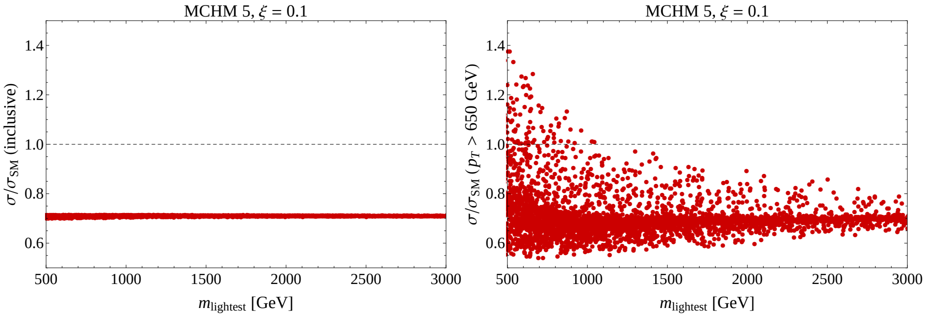


[Grazzini, Sargsyan, arXiv: 1306.4581]

$\boxed{\text{Break degeneracy by high } p_T \text{ Higgs}}$

Composite Higgs Model: Top partners

$$\frac{\sigma}{\sigma_{SM}}(\text{inclusive}) \qquad \frac{\sigma}{\sigma_{SM}}(p_T > 650\text{GeV})$$



High p_T tail is sensitive to new particles in the loop

Disentangle short and long physics

$$\mu_i = \frac{\sigma}{\sigma_{SM}}(pp \to h)$$

$$\mu_b = \frac{\sigma}{\sigma_{SM}}(pp \to h + jet)$$

inclusive:

$$\boxed{\frac{\sigma(gg\to h)}{\sigma_{SM}(gg\to h)} = |k_g + c_t|^2}$$

$\underline{\mu_i = 0.8}$

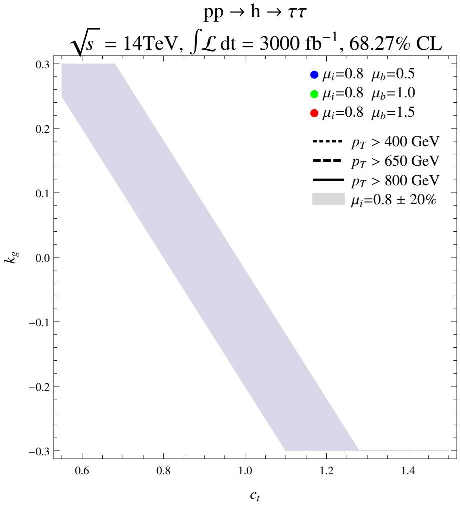
- μ_b=0.5
- μ_b=1.0
- μ_b=1.5

$p_T >$ 400 GeV

$p_T >$ 650 GeV

$p_T >$ 800 GeV

$\mu_i \pm 20\%$



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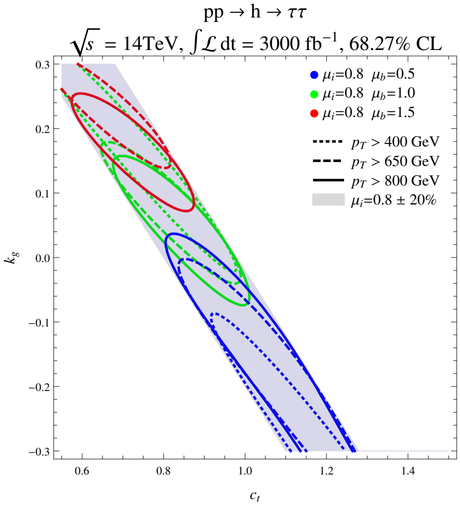

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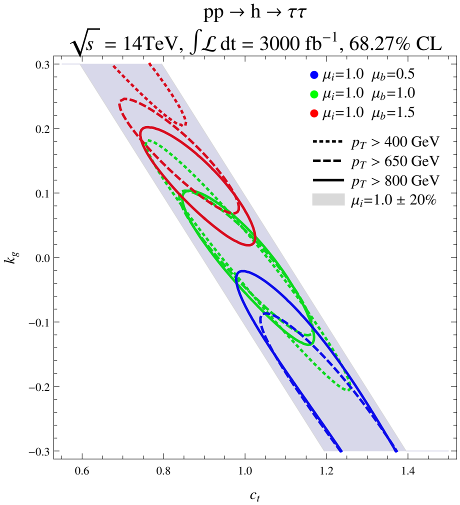
- $\mu_i \pm 20\%$



Disentangle short and long physics

$$\mu_i = \frac{\sigma}{\sigma_{SM}}(pp \to h)$$

$$\mu_b = \frac{\sigma}{\sigma_{SM}}(pp \to h + jet)$$

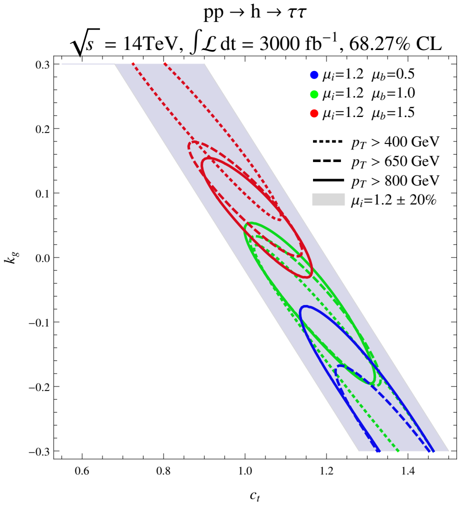
inclusive:

$$\boxed{\frac{\sigma(gg\to h)}{\sigma_{SM}(gg\to h)} = |k_g + c_t|^2}$$

$\mu_i = 1.2$

- μ_b=0.5
- μ_b=1.0
- μ_b=1.5

$p_T > 400$ GeV
$p_T > 650$ GeV
$p_T > 800$ GeV
$\mu_i \pm 20\%$



Questions & Conclusion

- Gain sensitivity to top partners,
- Disentangle c_t and k_g...
- ... @ LO
- What will $\mathrm{NLO}_{\mathrm{m_t}}$ QCD corrections do?
- Benefit from $\mathrm{N^3LO}_\infty$ for inclusive σ?
- Benefit from $\mathrm{NLO}_{\mathrm{m_t}}$ for Higgs + jet?
- Other channels:
  - $H + Z$?
  - $H + \gamma\gamma$?

Thank you for your attention

… questions?

LET: Derivation, part 1 [Low, Rattazzi & Vichi, arXiv: 0907.5413]

Aim: Low energy effective Lagrangian for ggh-interaction

[J. R. Ellis, M. K. Gaillard and D. V. Nanopoulos, Nucl. Phys. B 106 (1976) 292;

M. A. Shifman, A. I. Vainshtein, M. B. Voloshin and V. I. Zakharov, Sov. J. Nucl. Phys. 30 (1979) 711]

$$\mathcal{O}_{ggh} = f(h) G^a_{\mu\nu} G^{a\,\mu\nu}$$

$$\begin{aligned}
\mathcal{L}_{eff} &= -\frac{1}{4} \frac{1}{g^2_{eff}(\mu, h)} G^a_{\mu\nu} G^{a\,\mu\nu} \\
&= -\frac{1}{4} \left(\frac{1}{g_S^2(\mu)} - b \frac{t_r}{4\pi^2} \log \frac{m(h)}{\mu} \right) G^a_{\mu\nu} G^{a\,\mu\nu}
\end{aligned}$$

$t_r =$ Dynkin index of multiplet $= \frac{1}{2}$ for fund. rep.

$$b = \begin{cases} 2/3 & \text{Dirac fermion} \\ 1/6 & \text{complex scalar} \end{cases}$$

LET: Derivation, part 2 [Low, Rattazzi & Vichi, arXiv: 0907.5413]

$$\delta\mathcal{L} = \frac{g_S^2}{16\pi^2}\left(\frac{2}{3}\sum_{r_F} t_{r_F}\log m_{r_F}(h) + \frac{1}{6}\sum_{r_S} t_{r_S}\log m_{r_S}(h)\right) G^a_{\mu\nu}G^{a\,\mu\nu}$$

$$h \to h + v$$

$$\mathcal{L}_{ggh} = \frac{g_S^2}{48\pi^2}\frac{h}{v}\left(2\sum_{r_F} t_{r_F}\frac{\partial \log m_{r_F}(v)}{\partial \log v} + \frac{1}{2}\sum_{r_S} t_{r_S}\frac{\partial \log m_{r_S}(v)}{\partial \log v}\right) G^a_{\mu\nu}G^{a\,\mu\nu}$$

$$= \frac{\alpha_S}{12\pi v} k_g\, h\, G^a_{\mu\nu}G^{a\,\mu\nu}$$

$$\boxed{\Rightarrow \quad k_g = \sum_{r_F} t_{r_F}\frac{\partial \log \det \mathcal{M}^\dagger_{r_F}\mathcal{M}_{r_F}}{\partial \log v} + \frac{1}{4}\sum_{r_S} t_{r_S}\frac{\partial \log \det \mathcal{M}^\dagger_{r_S}\mathcal{M}_{r_S}}{\partial \log v}}$$

LET: k_g in different models [Carmi, Falkowski, Kuflik, Volansky, arXiv:1202.3144]

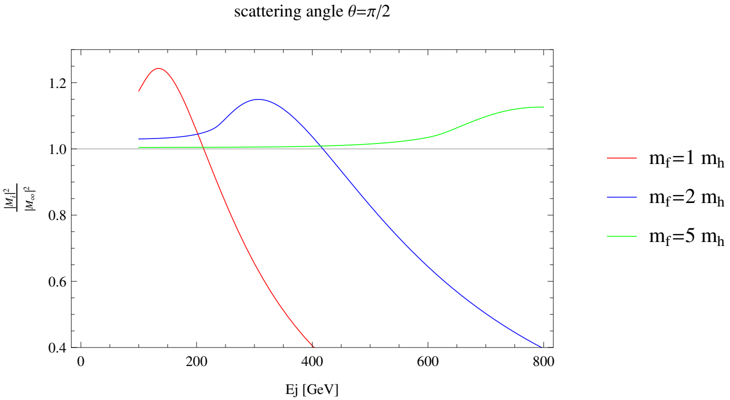
$$\mathcal{L} = \frac{\alpha_S}{12\pi v} k_g \, h \, G^a_{\mu\nu} G^{a\,\mu\nu}$$

Model		k_g
SM	$\mathcal{L}_{SM}$	1
Stop	$\mathcal{L}_{stop} = -\left(yHQt^c + h.c.\right) - \left\lvert\tilde{t}\right\rvert^2 \left(M^2 + \lambda \left\lvert H\right\rvert^2\right)$ $m^2_{\tilde{t}} = M^2 + \lambda \frac{v^2}{2}$	$1 + \lambda \frac{v^2}{m^2_{\tilde{t}}}$
Top-partner	$\mathcal{L}_{top} = -yHQt^c - MTT^c$	$1 - \frac{m_t^2}{M^2}$

Deviations from the SM are expected in natural models

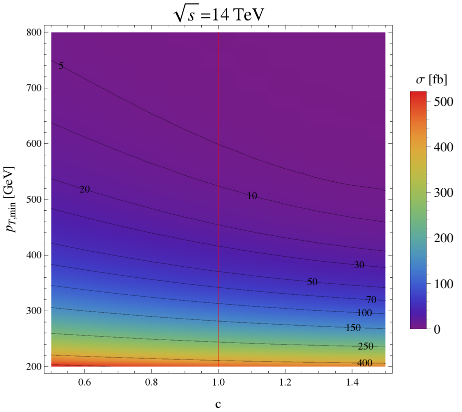
LET: Breakdown

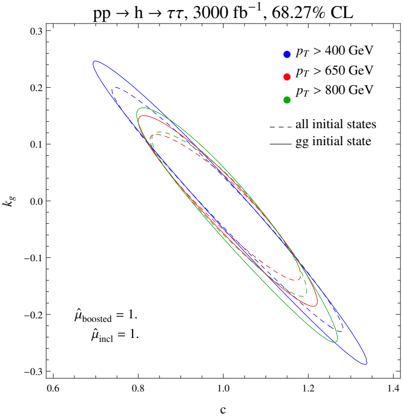
Normalized cross section for $g\,g \to h\,g$



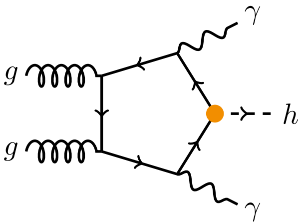
$\Rightarrow$ LET fails at high jet energies

Higgs + jet: Resolution



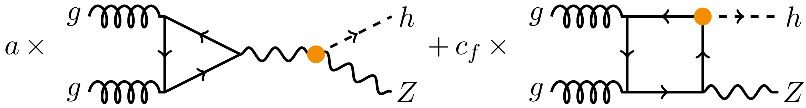


Higgs + 2γ



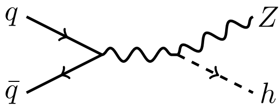
- $\mathcal{L} = \frac{1}{16\pi^2}\frac{1}{m_t^5}F_{\mu\nu}F^{\mu\nu}G^a_{\mu\nu}G^{a\,\mu\nu}h$
- $h \to b\bar{b}$
- Large background from $b\bar{b}$ production with ISR/FSR
- $\frac{\hat{\sigma}_{\text{signal}}}{\hat{\sigma}_{\text{background}}}[14\text{TeV}] \approx \frac{1}{80}$

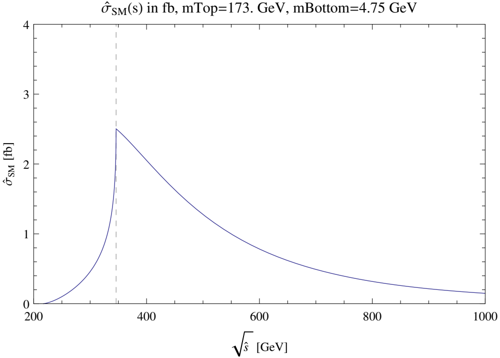
Higgs + Z: pros [Kniehl, Phys.Rev.D42, 3100]



- Cancellation to $\mathcal{O}(\frac{1}{m_f^4})$ between boxes and triangles if $a = c_f$
- Can we see effects if $c_f \neq a$?
- The smaller c_f the bigger the cross section
  $\Rightarrow$ if $c_t = -1$ we get $\hat{\mu} = 4.8$

Higgs + Z: cons





> Gluon fusion only 10% of associated production