Boosted Higgs in gluon fusion

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LHC Higgs XSWG2 meeting

CERN, July 18, 2014

based on:

1309.5273 *by A.Azatov and A.Paul*

1312.3317 *by C.Grojean, ES, M.Schlaffer and A.Weiler*

see also: 1308.4771 *by A.Banfi, A.Martin and V.Sanz*

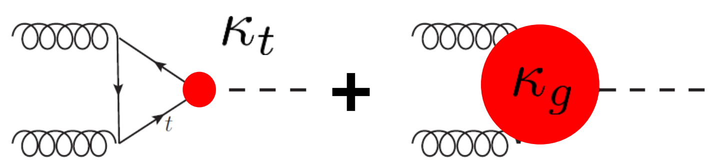
Higgs production in gluon fusion

- Consider parameterization

$$\mathcal{L}_{\text{couplings}} = -\kappa_t \frac{m_t}{v} h t \bar{t} + \kappa_g \frac{\alpha_s}{12\pi} \frac{h}{v} G_{\mu\nu} G^{\mu\nu}$$

- For **inclusive production**,

$$\mathcal{M}(gg \to h) \ = $$



(in terms of dimension-6 operators:

$$\mathcal{L}_6 \ = \ c_y \frac{y_t}{v^2} H^\dagger H \overline{q}_L \widetilde{H} t_R + \text{h.c.} + \ c_g \frac{\alpha_s}{12\pi v^2} H^\dagger H G^A_{\mu\nu} G^{\mu\nu\, A}$$

$$\Rightarrow \quad \kappa_t = 1 - \text{Re}\, c_y \,, \qquad \kappa_g = c_g$$

)

Higgs production in gluon fusion

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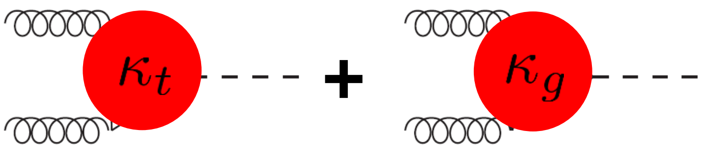


also effectively seen as point-like interaction!

$$(\hat{s} = m_h^2)$$

$$\mu_{\text{incl}} \simeq (\kappa_t + \kappa_g)^2$$

degeneracy between ‘long-distance’ and ‘short-distance’ contributions

In the SM:

$m_H\,(\text{GeV})$	$\frac{\sigma_{NLO}(m_t)}{\sigma_{NLO}(m_t \to \infty)}$
125	1.061
150	1.093
200	1.185

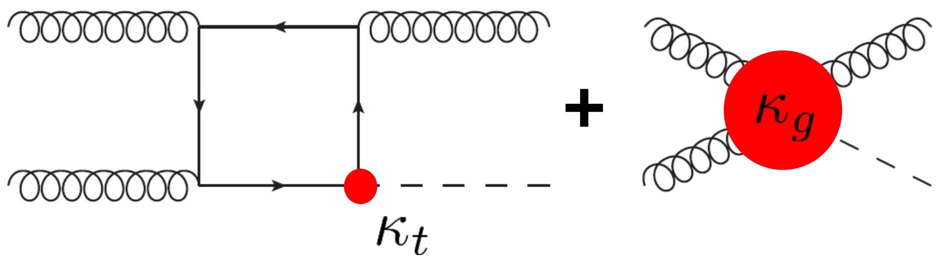
$$\mathcal{M}_{m_t} \simeq \mathcal{M}_\infty \left(1 + \frac{7}{30} \frac{m_h^2}{4m_t^2}\right)$$

Boosted regime

1312.3317

Higgs recoiling against a large - p_T jet

$$\mathcal{M}(gg \to gh) \sim$$



for $p_T \gg m_t$, resolve the top loop

same degeneracy as in inclusive rate

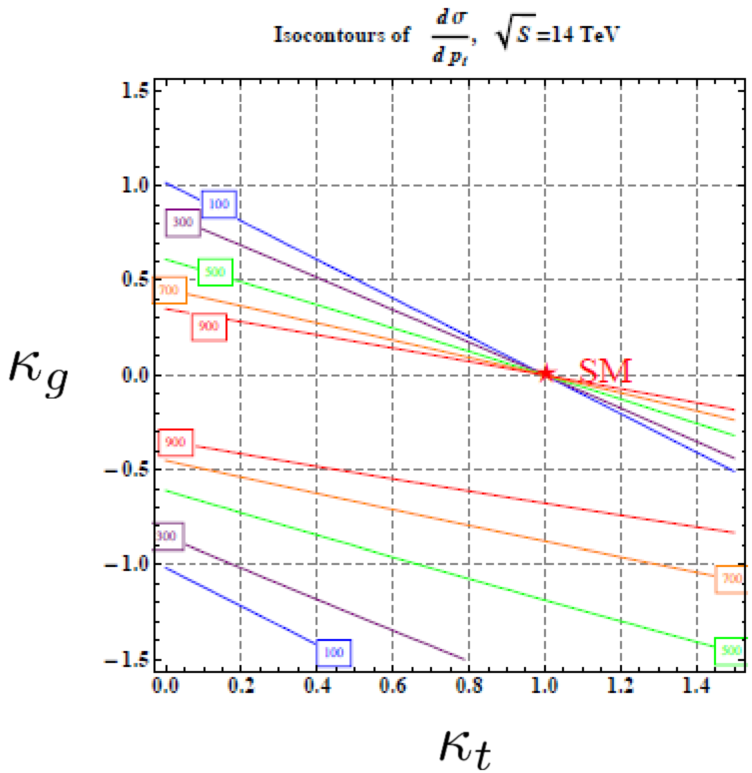
$$\frac{\sigma_{p_T^{\min}}(\kappa_t,\kappa_g)}{\sigma^{\rm SM}_{p_T^{\min}}} = (\kappa_t + \kappa_g)^2 + \delta\, \kappa_t \kappa_g + \epsilon\, \kappa_g^2$$

resolve short-distance *vs* long-distance

$p_T^{\min}$ [GeV]	$\sigma^{\rm SM}_{p_T^{\min}}$ [fb]	δ	ϵ
100	2180	0.0031	0.031
150	837	0.070	0.13
200	351	0.20	0.30
250	157	0.39	0.56
300	74.9	0.61	0.89
350	37.7	0.85	1.3
400	19.9	1.1	1.7
450	10.9	1.4	2.3
500	6.24	1.7	2.9
550	3.68	2.0	3.6
600	2.22	2.3	4.4
650	1.38	2.6	5.2
700	0.871	3.0	6.2

Boosted regime/2

1309.5273



- Measurement at each p_T constrains couplings to a line.
- Combining different p_T's gives a finite region of the plane.

Ultimately, want to **measure the whole p_T distribution**

Estimate of measurement: $h \to \tau\tau$

To break the degeneracy in (κ_t, κ_g) plane, **combine** measurements of inclusive and boosted rates

For boosted measurement, to reduce theory uncertainty use ratio

$$\mathcal{R} = \frac{\sigma(p_T > 650\,\mathrm{GeV})}{\sigma(p_T > 150\,\mathrm{GeV})}$$

NB: QCD-NLO corrections to Higgs p_T spectrum are not known yet for finite m_t

Assume decay $h \to \tau\tau$, take efficiencies from 'ditau-jet tagging' (theory) analysis of Katz et al. (1011.4523),

$$\epsilon_{\mathrm{tot}} = \mathrm{BR}(h \to \tau\tau) \left(\sum_{i \in \tau_\ell\tau_\ell, \tau_\ell\tau_h, \tau_h\tau_h} \mathrm{BR}(\tau\tau \to i)\, \epsilon_i \right) \simeq 2 \times 10^{-2}$$

Only a first estimate. More realistic collider study in **Schlaffer et al., 1405.4295**

Breaking the degeneracy

1312.3317

Combine measurements using simple procedure (no background):

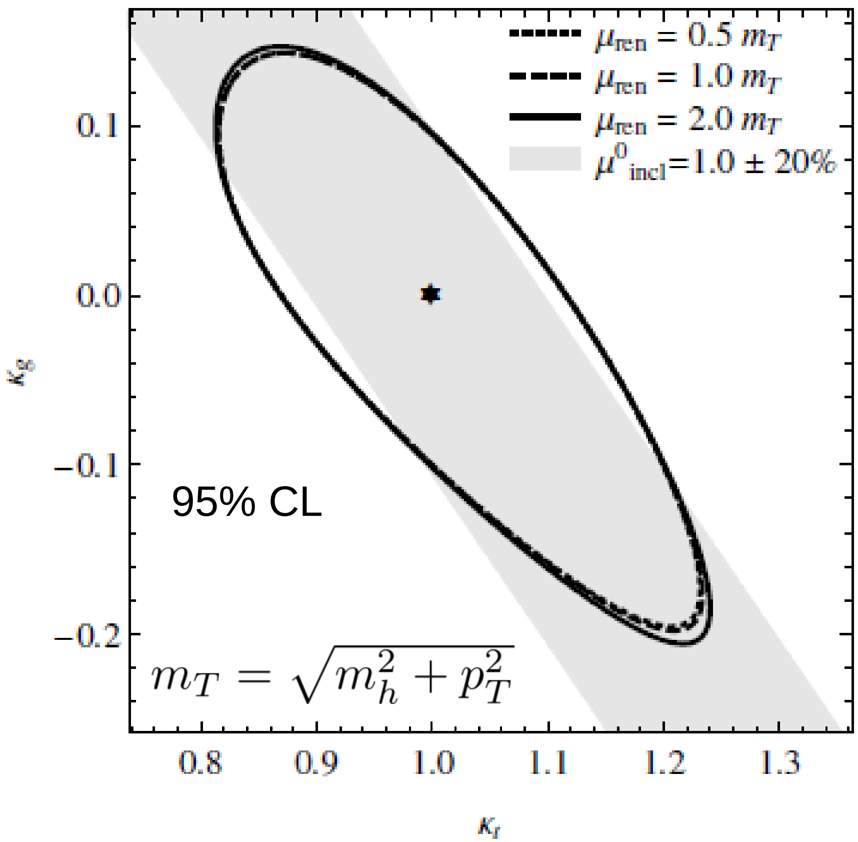
$$\chi^2(\kappa_t, \kappa_g) = \left(\frac{\mathcal{R}(\kappa_t,\kappa_g) - \mathcal{R}^*}{\delta\mathcal{R}}\right)^2 + \left(\frac{\mu_{\rm incl}(\kappa_t,\kappa_g) - \mu^*_{\rm incl}}{\delta\mu_{\rm incl}}\right)^2$$

assuming 10% syst uncertainty

on all measurements **+** stat uncertainty

on $N_{\rm events}^{p_T>650\,{\rm GeV}}$, $N_{\rm events}^{p_T>150\,{\rm GeV}}$

$$\sqrt{s} = 14\,{\rm TeV}, \quad 3000\,{\rm fb}^{-1}$$



$$\mathcal{R} = \frac{\sigma(p_T > 650\,{\rm GeV})}{\sigma(p_T > 150\,{\rm GeV})}$$

$$\mu_{\rm incl} \simeq (\kappa_t + \kappa_g)^2$$

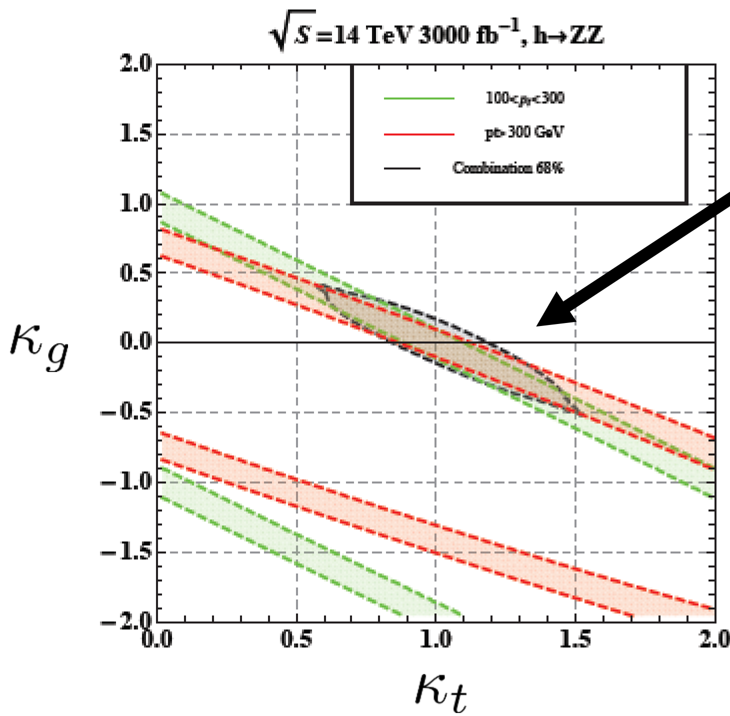
Estimate of measurement: *h → ZZ* → 4l*

Combine measurements of low- p_T and high- p_T cross sections:

1309.5273

$$\sigma^- = \int_{100\,\mathrm{GeV}}^{300\,\mathrm{GeV}} \frac{d\sigma}{dp_T} dp_T\,, \qquad \sigma^+ = \int_{300\,\mathrm{GeV}}^{1000\,\mathrm{GeV}} \frac{d\sigma}{dp_T} dp_T$$

Assume decay $h \to ZZ^* \to 4l$ and compute background at parton level



degeneracy broken

To reduce theory uncertainties, define ratio

$$r_\pm \equiv \frac{\sigma^+}{\sigma^+_{\mathrm{SM}}} \Big/ \frac{\sigma^-}{\sigma^-_{\mathrm{SM}}}$$

experimentally,

$$r_\pm = \frac{N^+/N^-}{\sigma^+_{\mathrm{SM}}/\sigma^-_{\mathrm{SM}}}$$

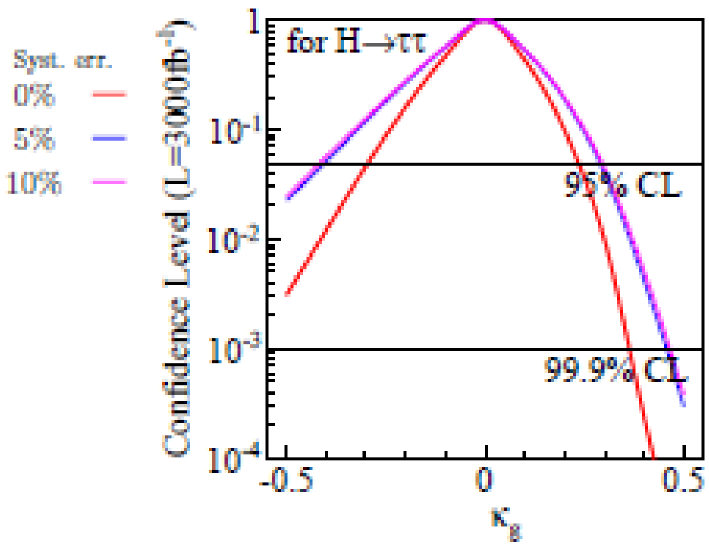
with $N^\pm$ numbers of events in each bin

Backup

Boosted Higgs shapes

1405.4295

- Collider analysis focusing on $h \to 2\ell + \mathrm{MET}$ via $h \to \tau\tau, WW^*$ and taking into account backgrounds
- Large boost improves the collinear approximation for Higgs mass reconstruction in $h \to \tau\tau$ mode, which does better compared to $h \to WW^*$
- Estimate of capability to distinguish non-SM couplings in presence of backgrounds: assume $\kappa_t + \kappa_g = 1$



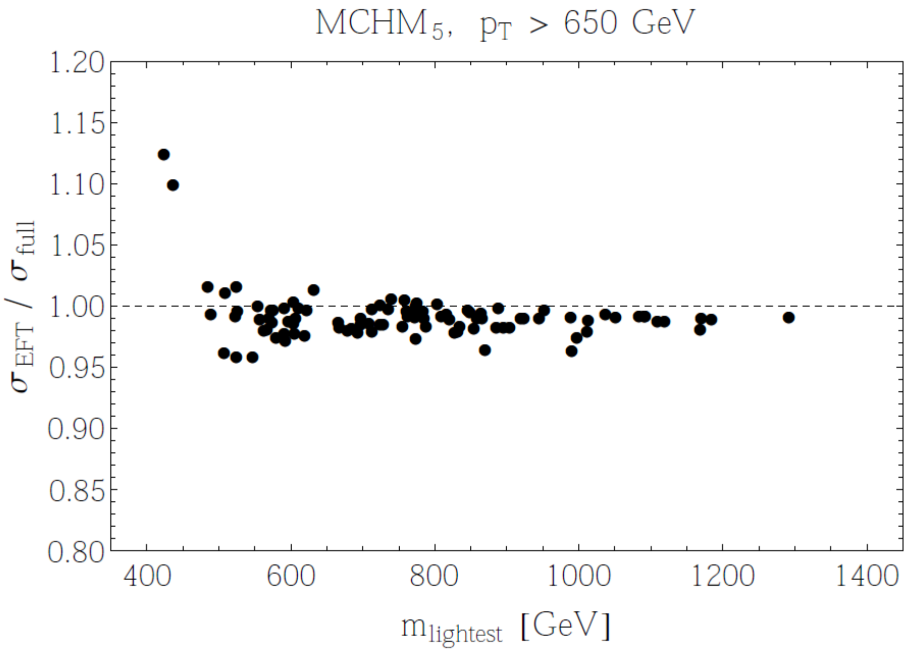
- assuming 0% syst. uncertainty, at 95% CL

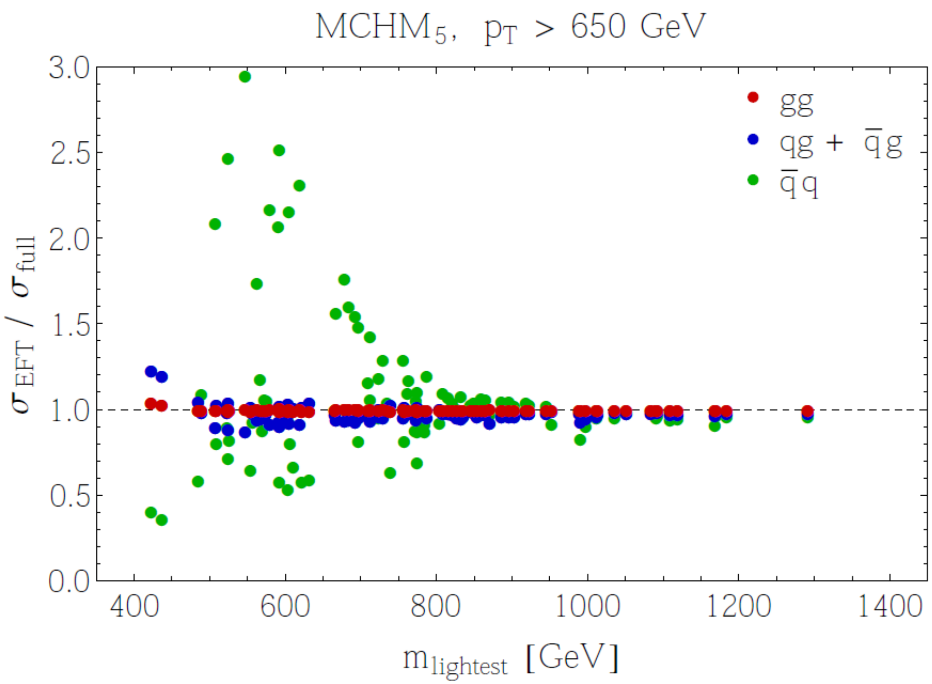
$$-0.29 < \kappa_g < 0.24$$

- assuming 10% systematics,

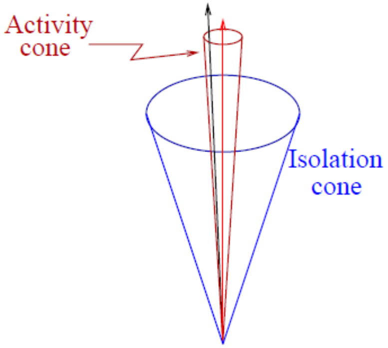
$$-0.4 < \kappa_g < 0.3$$

Validity of EFT





‘Ditau-jet’ tagging

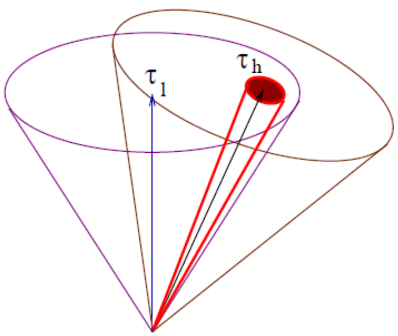


For $p_T = 650\,\mathrm{GeV}$, the taus have typical angular separation

$\Delta R \sim 2m_h/p_T \sim 0.4$ ➡ single tau-tag fails

Introduce ‘mutual isolation’.

For example, for **semi-leptonic** ditaus:



- find a lepton which fails isolation within $\Delta R = 0.4$ cone
- find hardest hadronic track inside cone
- draw small (0.07) tau-candidate cone around this track
- check if lepton passes isolation when removing

  the tau candidate (use only tracker + EM calo)
- if lepton passes, apply standard hadronic tau-tag, ignoring lepton for requirement of tau isolation.

Similarly for two hadronic taus.

See **Katz, Son and Tweedie, Phys.Rev. D83, 2011 (1011.4523)**