New physics and signal-background interference in $gg \to HZ$ production at LHC

ALBERTO TONERO

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ICTP-SAIFR and IFT-UNESP, São Paulo (Brazil)

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Motivations

- The processes $pp \to ZZ$ and $pp \to HZ$ are excellent candidates to constrain new physics in the Higgs sector exploiting large momentum transfers *[Azatov et al. JETP120,354(20150), Englert et al. JHEP02,145(2015), Buschmann et al. JHEP02,038(2015), Englert et al. PRD89,242001(2014), Hespel et al JHEP06,065(2015)]*
- The process $gg \to HZ$ contributes as 10% of $pp \to HZ$ but becomes relevant for large momentum transfers (same for $gg \to ZZ$)
- The same type of physics can enhance both $gg \to HZ$ and $gg \to ZZ$
- We study the final state $pp \to b\bar{b}\ell^+\ell^-$ ($\ell = e, \mu$) as signal for $pp \to HZ \to b\bar{b}\ell^+\ell^-$ and investigate the effects of new physics in $gg \to HZ$, taking into account the irreducible electroweak background $pp \to ZZ \to b\bar{b}\ell^+\ell^-$

New physics effects in $gg \to HZ$

Parametrized by the following dim-6 operators

$$
\begin{aligned}
\mathcal{O}_{Ht} &= \frac{i\bar{c}_{Ht}}{v^2}(\bar{t}_R\gamma^\mu t_R)(\Phi^\dagger \overleftrightarrow{D}_\mu \Phi) \\
\mathcal{O}_t &= -\frac{\bar{c}_t}{v^2} y_t \Phi^\dagger\Phi\, \Phi^\dagger \cdot \bar{Q}_L\, t_R + \text{h.c.}
\end{aligned}
$$

$\Phi =$ Higgs doublet, $Q = (t\ b)$, $y_t =$ top Yukawa, $v = 246$ GeV

- modification of $\bar{t}_R t_R Z$ coupling

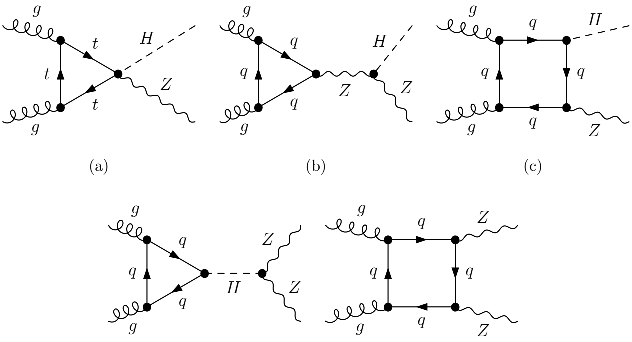
$$
\frac{2}{3} g \frac{s_W^2}{c_W} \to \frac{2}{3} g \frac{s_W^2}{c_W} + g \frac{\bar{c}_{Ht}}{2c_W}
$$

- modification of the top Yukawa coupling

$$
y_t \to y_t(1 + \bar{c}_t)
$$

Feynman diagrams

$gg \to (H, Z)Z \to b\bar{b}\ell^+\ell^-$ (decays not shown in the figure)



(a) (b) (c)

(d) (e)

New effective vertex $\bar{t}tHZ$ genertaed by $\bar{c}_{Ht}$ in (a)

Methods

- Implementation of the effective operators in FEYNRULES

- Generation of $gg \to (HZ + ZZ) \to b\bar{b}\ell^+\ell^-$ events at 13 TeV by:
  - computing the one-loop amplitudes with FEYNARTS + FORMCAL + LOOPTOOLS;
  - iterfacing with VBFNLO to implement the phase-space integration, $p_{T\ell^+\ell^-} > 100$ GeV, $\sigma(gg \to b\bar{b}\ell^+\ell^-) \sim 1$ fb

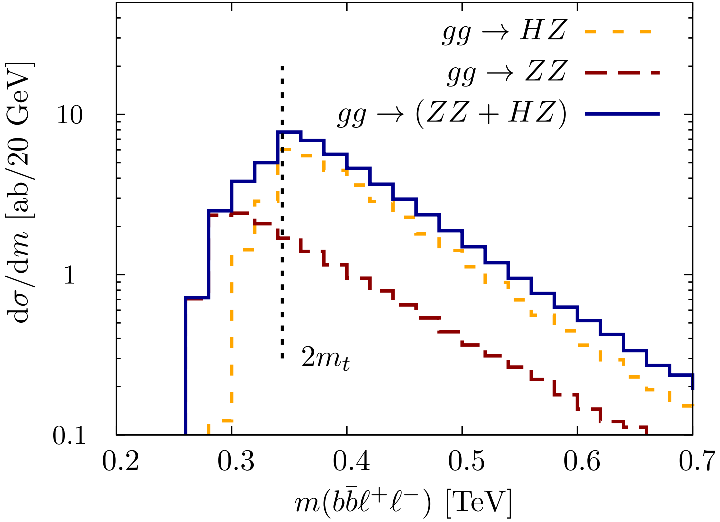
- Generation of $q\bar{q} \to (HZ + ZZ) \to b\bar{b}\ell^+\ell^-$ events at 13 TeV with:
  - MADGRAPH5, using identical imput parameters, $\sigma(q\bar{q} \to b\bar{b}\ell^+\ell^-) \sim 10$ fb

- Pass the events through HERWIG++ to obtain full hadronic final states.

- Normalize the samples to NLO QCD prediction, using a K-factor of 1.2 and 1.8 for $q\bar{q}$- and gg-initiated events

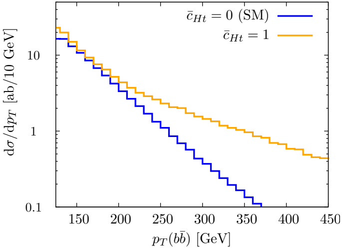
Parton level analysis I

Interference effects between $gg \to HZ$ and $gg \to ZZ$ in the SM



Parton level analysis II

Estimation of the sensitivity to the effective operators



- Selection cuts

$$p_T(\ell^+\ell^-) > 150\text{GeV} \qquad 110\text{GeV} < m(b\bar{b}) < 140\text{GeV}$$

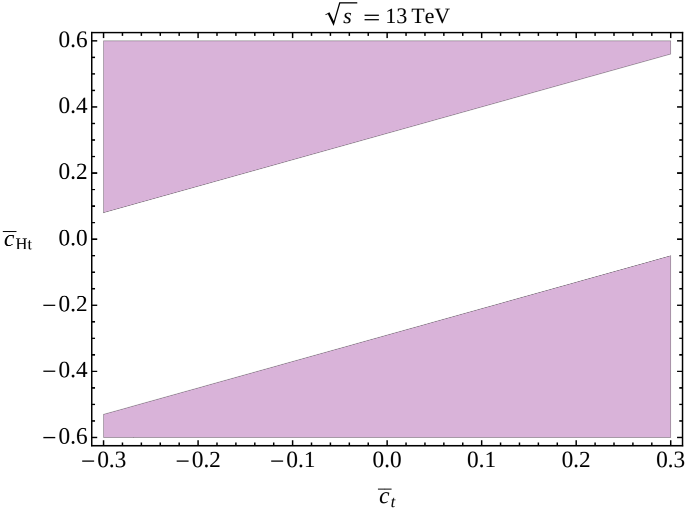
- Log-likelihood hypothesis test for shape comparison of $p_T(b\bar{b})$

$$\mathcal{Q} = -2\log\frac{L(\text{data}\,|\,\bar{c}_t, \bar{c}_{Ht})}{L(\text{data}\,|\,\bar{c}_t = 0, \bar{c}_{Ht} = 0)}$$

- Exclusion limits are computed using the CL$_s$ method

Parton level analysis III

Projected exclusion at 95% CL_s for the boosted analysis ($\mathcal{L} = 100$ fb^{-1})



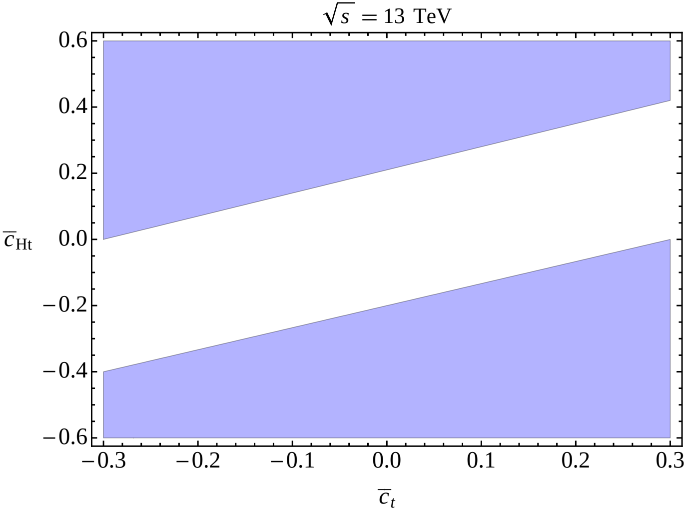
Showering and hadronization I

Typical HZ final state selection cuts:

- 2 oppositely charged same-flavor leptons: $|\eta_\ell| < 2.5$, $p_T(\ell) > 30$ GeV
- 80 GeV $< m(\ell^+\ell^-) < 100$ GeV
- $p_T(\ell^+\ell^-) > 200$ GeV
- perform a typical BDRS analysis: $p_{T,j} > 200$ GeV, at least one jet in $|\eta| < 2.5$, fat jet filtering, mass-dropping and double b-tagging with total efficiency of 36%
- Higgs candidates: 110 GeV $< m(b\bar{b}) < 140$ GeV evaluated on the b-tagged subjets
- $\sigma_{BDRS}(gg + q\bar{q} \to b\bar{b}\ell^+\ell^-) \sim 0.2$ fb

Showering and hadronization II

Projected exclusion at 95% CL_s for the boosted analysis ($\mathcal{L} = 3$ ab^{-1})



Conclusions

- New physics effects that impact $pp \to ZZ$ can also leave footprints in boosted analysis for $pp \to HZ$
- Robust limit setting in $pp \to HZ$ will require a large integrated luminosity $\mathcal{L} = 3$ ab^{-1}
- Projected limits for complementary Higgs searches $\mathcal{L} = 3$ ab^{-1}:

$$|\bar{c}_t| \leq 10^{-2}$$ [Englert et al. 1511.05170]

- Electroweak constraints $|\bar{c}_{Hu}| < 0.02$ [Contino et al. JHEP07,035(2013)]
- Projected limits for complementary $t\bar{t}Z$ searches $\mathcal{L} = 3$ ab^{-1}:

$$-0.13 < \bar{c}_{Ht} < 0.64$$ [Rontsch et al. JHEP09,132(2015)]

$\Rightarrow gg \to HZ$ provides additional discriminating power if trivial flavour structure assumption is relaxed

Thank you!