Report on comparison between analyses for semi- and dileptonic channel HH production at HL-LHC

Izaak Neutelings (University of Zurich)

November 18, 2015

In this reports, I tempt to reproduce selection level significances from the analysis note on the HH $\to$ bbWW $\to$ bblνlν channel by C. Delaere *et al.* [1].

1 Samples

The Monte Carlo samples of the analysis note were generated by MadGraph_aMC@NLO, and the parton shower and hadronization was done in Pythia6. Our samples were fully produced in Pythia6 including all final states. All samples were finally reconstructed with Delphes for the CMS Phase II technical proposal.

For our analysis we select the events with the final state (bbWW $\to$ bblνlν or bbWW $\to$ bbqqlν) in question at generator level, where taus from one of the W (or Z) are excluded. The HH-samples also include H $\to$ ZZ to allow for WW and ZZ interference.

2 Event selections & clean-up

To reproduce the results by C. Delaere *et al.* the event selections and clean-up as described in their analysis note are applied to our samples. (The code can be found here: [7] [8].) These cuts and the ones we use for the semileptonic final state are compared in Table 1.

For the semileptonic sample, the ΔR_{ll} cut at generator level is replaced with ΔR_{ql}, where q is the closest quark to the lepton. Please note that there are no equivalent cuts to ΔR_{ll}, m_{ll} or $\Delta\phi_{\mathrm{bb,ll}}$ used in the clean-up, leading to bigger differences between the two cases.

3 Cross section

For our analysis, we have been using the cross sections at $\sqrt{s} = 14$ TeV given in Table 2. The analysis note lists next leading order σ_{LO} with k-factor k_{NNLO} of the samples (Table 3). We calculate back to the full cross section of HH or $\mathrm{t\bar{t}}$ production using

$$\sigma_1 = \frac{k_{\mathrm{NNLO}}\sigma_{\mathrm{LO}}}{e\mathcal{B}} \tag{1}$$

with the appropriate branching ratio $\mathcal{B}$. The $\mathrm{t\bar{t}}$ cross section is divided by the filter efficiency of $e = 0.37$ to account for the 63% loss of events after cuts on our $\mathrm{t\bar{t}}$ sample at generator level. For the HH sample, we assume $e = 1$, as the analysis not describes no cuts at generator level in this case.

4 Significance & yield

Using the yield

$$N = \sigma L \tag{2}$$

with integrated luminosity $L = 3000\ \mathrm{fb}^{-1}$, the Punzi significance is calculated as:

$$P = \frac{N(\mathrm{HH})}{\sqrt{1 + N(\mathrm{t\bar{t}})}}. \tag{3}$$

Table 1: Event selectiona and clean-up: comparison between the dileptonic and semileptonic final state.

dileptonic final state	semileptonic final state
Gen level cuts on background	
b-quarks: $p_T > 15$ GeV	b-quarks: $p_T > 15$ GeV
leptons: $p_T > 15$ GeV, $\|\eta\| < 2.5$	lepton: $p_T > 15$ GeV, $\|\eta\| < 2.5$
$\Delta R_{\mathrm{ll}} < 2.5$	$\Delta R_{\mathrm{ql}} < 2.5$
Selection	
two b-jets: $p_T > 30$ GeV, $\|\eta\| < 2.5$	two b-jets: $p_T > 30$ GeV, $\|\eta\| < 2.5$
	two non b-jets: $p_T > 20$ GeV, $\|\eta\| < 2.5$
two oppositely charged leptons with:	one lepton with:
muons: $p_T > 20$ GeV, $\|\eta\| < 2.5$	muon: $p_T > 20$ GeV, $\|\eta\| < 2.5$
electrons: $p_T > 25$ GeV, $\|\eta\| < 2.5$	electron: $p_T > 25$ GeV, $\|\eta\| < 2.5$
MET > 20 GeV	MET > 20 GeV
Clean-up	
60 GeV $< m_{\mathrm{bb}} <$ 160 GeV	60 GeV $< m_{\mathrm{bb}} <$ 160 GeV
$\Delta R_{\mathrm{bb}} < 3.1$ GeV	$\Delta R_{\mathrm{bb}} < 3.1$ GeV
$m_{ll} < 85$ GeV	
$\Delta R_{\mathrm{ll}} < 2$	
$\Delta\phi_{\mathrm{bb,ll}} < 1.7$	

Table 2: Cross sections at NNLO and $\sqrt{s} = 14$ TeV [2][3], branching ratios (excluding W $\to \tau\bar{\tau}$) [5][6] and number of Monte Carlo events per process in our analysis sample.

process	$\sigma\mathcal{B}$ [fb]	branching ratio $\mathcal{B}$	number of MC events
HH	**40**		**979 907**
HH $\to$ bbWW $\to$ bbqqlν	2.86	0.0715	166 483
HH $\to$ bbWW $\to$ bblνlν	0.452	0.0113	22 812
t$\bar{\text{t}}$	**984 500**		**499 600**
t$\bar{\text{t}}$$\to$ bbWW $\to$ bbqqlν	282 846	0.2873	164 661
t$\bar{\text{t}}$$\to$ bbWW $\to$ bblνlν	44 598	0.0453	22 546

Table 3: Cross sections for their Monte Carlo samples listed in the analysis note by C. Deleare *et al.* [1] and σ_1 from Eq. (1) with a filter efficiency $e = 1$ for HH and $e = 0.37$ for t$\bar{\text{t}}$ to account for cuts at generator level.

process	σ_{LO} [fb]	k_{NNLO}	σ_1[fb]	number of MC events
HH $\to$ bbWW $\to$ bblνlν	0.163	2.3	33.2	1.1M
t$\bar{\text{t}}$ full leptonic	9030	1.85	994 493	4.8M

Table 4: Number of MC events in our sample at each level of selection.

	dileptonic final state		semileptonic final state	
selection level	signal	background	signal	background
Sample without any cuts	22812	22546	166483	164661
Gen level cuts on background	22812	8339	166483	68011
Selection	2748	1755	28203	19401
Clean-up	2149	296	22189	8748

Table 5: Comparison of the significance and yields between the semileptonic and dileptonic final state for our results using the cross sections at NNLO from Table 2 and the results by C. Deleare *et al.* at $\sqrt{s} = 14$ TeV and with integrated luminosity $L = 3000$ fb^{-1}.

	dileptonic final state			semileptonic final state			
	P	$N(\mathrm{HH})$	$N(\mathrm{t\bar{t}})$	P	$k_{\mathcal{B}}P$	$N(\mathrm{HH})$	$N(\mathrm{t\bar{t}})$
Initial significance, before any cuts							
Assuming NNLO	0.117	1356	133 793 550	0.295	0.117	8580	848 540 550
Gen level cuts on background							
Assuming NNLO	0.193	1356	49 485 692	0.458	0.182	8580	350 478 202
Selection							
Assuming NNLO	0.051	163	10 414 605	0.145	0.058	1454	99 978 350
C. Delaere *et al.*	0.043	113	6 759 579				
Clean-up							
Assuming NNLO	0.096	127	1 756 537	0.170	0.068	1144	45 080 698
C. Delaere *et al.*	0.075	90	1 437 144				
Neural network							
C. Delaere *et al.*	0.60	37	3875				

To obtain the significance at after each round of cuts, we multiply each yield with the ratio of the number of Monte Carlo events that made the cut and the total number of Monte Carlo events run on. The total number of Monte Carlo events per event in our analysis are listed in Table 2.

5 Results

Results are summarized in Table 5. To compare the dileptonic to the semileptonic case, the significance of the latter is also scaled by $k_{\mathcal{B}} = \sqrt{\mathcal{B}(\mathrm{WW} \to \mathrm{l\nu l\nu})/\mathcal{B}(\mathrm{WW} \to \mathrm{qql\nu})} \approx 0.397$.

References

[1] C. Delaere *et al.*, *Study of HH production with $H \to bb$, $H \to WW \to l\nu l\nu$ for an upgraded CMS detector at the HL-LHC*, CMS draft analysis note 2014/141.

[2] D. de Florian & J. Mazzitelli, *Higgs Boson Pair Production at Next-to-Next-to-Leading Order in QCD*. Phys. Rev. Lett. **111** (Nov, 2013) 201801, `doi:10.1103/PhysRevLett.111.201801`, `arXiv:1309.6594`.

[3] *NNLO+NNLL top-quark-pair cross sections - ATLAS-CMS recommended predictions for top-quark-pair cross sections using the Top++v2.0 program (M. Czakon, A. Mitov, 2013)*, `https://twiki.cern.ch/twiki/bin/view/LHCPhysics/TtbarNNLO#Top_quark_pair_cross_sections_at`.

[4] R. Frederix *et al.*, *Higgs pair production at the LHC with NLO and parton-shower effects*, Phys. Rev. Lett. **B723** (May, 2014) 142, `doi:10.1016/j.physletb.2014.03.026`, `arXiv:1401.7340`.

[5] *Higgs cross sections for European Strategy studies in 2012*, `https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HiggsEuropeanStrategy2012#SM_Higgs_decay_branching_ratio_M`.

[6] J. Beringer *et al.* (Particle Data Group), PR **D86**, 010001 (2012) and 2013 partial update for the 2014 edition (`http://pdg.lbl.gov/2013/listings/rpp2013-list-w-boson.pdf`).

[7] I. Neutelings (Oct, 2015), `https://github.com/IzaakWN/Delphes/blob/IzaakFall2015/python/HHEventSelection_dilep.py`

[8] I. Neutelings (Oct, 2015), `https://github.com/IzaakWN/Delphes/blob/IzaakFall2015/python/ttEventSelection_dilep.py`