NLO QCD Corrections to $Wb\bar{b}$ Production with Many Jets at the LHC

A Study of $H(\rightarrow b\bar{b})W$ Backgrounds

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Based on arXiv:1712.05721, with F.R. Anger, H. Ita and V. Sotnikov
$HW \rightarrow b\bar{b}W$ production at the LHC

$\sim 58\% \ Hbb \ BR$ makes it a key signature. Constrain Higgs sector/BSM. **Associated production** necessary to tame backgrounds!

Early $H(\rightarrow b\bar{b})V$ evidence from Tevatron and ATLAS+CMS Run I combined data. Run II data should finally deliver **discovery**

Very **complex multi-scale multi-channel signature**. Example $m_T^W$ distribution. Here we focus on the $Wb\bar{b}+$jets backgrounds
Precisions studies of $Wb\bar{b} + n$-jet production

<table>
<thead>
<tr>
<th>NLO QCD</th>
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<tbody>
<tr>
<td>$n = 0, \ m_b = 0$</td>
<td>Ellis, Veseli</td>
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<td>(1999)</td>
<td>(Bern, Dixon, Kosower)</td>
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<td>NLO QCD</td>
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<td>$n = 0$ on-shell</td>
<td>FFC, Reina, Wackeroth</td>
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<td>(2006)</td>
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<td>NLO QCD</td>
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<td>$n = 0$ (2011)</td>
<td>Badger, Campbell, Ellis;</td>
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<td>Oleari, Reina</td>
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<tr>
<td>NLO QCD</td>
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<td>$n = 1$ w. PS</td>
<td>Luisoni, Oleari, Tramontano</td>
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<td>(2015)</td>
<td>(Reina, Schutzmeier)</td>
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<td>NLO QCD</td>
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<td>$n \leq 3$ w. excl. sums (2018)</td>
<td>Anger, FFC, Ita, Sotnikov</td>
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Mass effects exploited in more inclusive sample studies!

$p_t > 25$ GeV $|\eta| < 2.5$

$W^+ b\bar{b}$

- NLO Inc
- NLO Exc
- LO

$W^- b\bar{b}$

- Total
- qq
- qg

arXiv:0906.1923
Massive high-multiplicity NLO QCD with BlackHat/Sherpa

- **New version** of the BlackHat library which can handle massive fermions
- Using **numerical unitarity** and its extension to massive quarks (Ellis, Giele, Kunszt, Melnikov), exploiting a map to 4-D algebra (Anger, Sotnikov)
- We observe similar properties for **numerical stability** as in previous massless studies
- Inclusion of massive close loops have **percent-level** effects in total cross sections and similar impact over distributions (see related work by Campbell and Ellis)
- We use the **automated massive-dipole subtraction** (Catani, Dittmaier, Seymour, Trocsanyi) in Sherpa for computing full NLO QCD corrections

NLO QCD corrections and theoretical uncertainties

- Importance of quantum corrections across multiplicities
- Release of kinematical constrains; opening of initial-state channels
- Scale sensitivity reduction at NLO
- Cross sections dominated by virtual contributions
- NLO scale plateau relatively low
- Differences with $V+\text{light-jet}$ behavior due to difference in leading subprocesses
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As a means to reduce quantum corrections when large tree-like real-radiation contributions are found, exclusive studies have been proposed, but the sensitivity to $p_T^{\text{veto}}$ can spoil perturbative convergence! Here we propose the usage of exclusive sums.
Exclusive sums from fixed-order multi-jet predictions

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Consider NLO QCD \textit{inclusive} and \textit{exclusive} cross secs with $n$ light jets:

$$\sigma_n^{\text{inc}}, \quad \sigma_n^{\text{exc}}$$

Then, considering $Wb\bar{b}$ production, we define two exclusive sums by:

$$\sigma^{\text{NLO+}} = \sigma_0^{\text{exc}} + \sigma_1^{\text{inc}},$$

$$\sigma^{\text{NLO++}} = \sigma_0^{\text{exc}} + \sigma_1^{\text{exc}} + \sigma_2^{\text{inc}}$$
Key observables for $H(\rightarrow b\bar{b})W$

- A key irreducible background to $H(\rightarrow b\bar{b})W$ measurement are QCD production of $Wb\bar{b}+$jets
- This signature gives access to $y_b$
- NLO+ a exclusive sum: adds NLO corrections to hard contributions
- From NLO++ and $\sim 10\%$ $p_T^{\text{veto}}$ sensitivity deduce need for NNLO QCD

Similar results studied for the observables $p_T^W$ and $M_{b\bar{b}}$
Conclusions

▶ We have presented a precision study of $Wb\bar{b} + n$-jet production at the LHC and showed that NLO QCD correction are needed for numerically reliable results
▶ We studied the impact of our results for $H(\rightarrow b\bar{b})W$ phenomenology, in particular for measurements of the bottom Yukawa coupling
▶ As a means to avoid jet $p_T^{\text{veto}}$ dependencies and to improve predictions from high-multiplicities fixed-order results we used exclusive sums
▶ $Wb\bar{b}$ production might well be one of the most pressing cases for NNLO QCD corrections for $2 \rightarrow 3$ processes at the LHC
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Thanks!
Extra slide
We employ a dynamical scale $\mu = \mu_r = \mu_f = \hat{H}_T^f/2$ and the CT14-NF4 PDF sets, together with the pseudo-PDF error set PDF4LHC15_nlo_nf4_30. We set $m_b = 4.75$ GeV, $m_t = 172$ GeV, $M_W = 80.385$ GeV, $\Gamma_W = 2.085$ GeV. Impose the kin. cuts:

- $p_T^l > 25$ GeV
- $|\eta^l| < 2.5$
- $p_T^\nu > 20$ GeV
- $M_W^T > 20$ GeV
- Anti-$k_T$ jets with IR-safe flavor tag
- $R = 0.4$
- $p_T^{jet} > 25$ GeV
- $|\eta^{jet}| < 2.4$

We have collected results for $W^\pm b\bar{b} + n$-jet production ($n = 0, 1, 2, 3$) at the LHC $\sqrt{s} = 13$ TeV as $n$-tuple files that can be used for computing generic IR safe observables.