On the factorizable and non-factorizable QCD corrections to Vector Boson Fusion

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Higgs Couplings 2019
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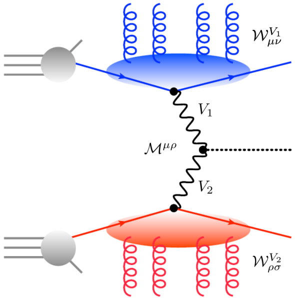
Work done in Collaboration with Frédéric Dreyer to appear soon

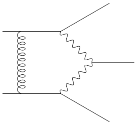
The factorized picture



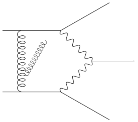
- Historically QCD corrections to VBF have been computed in a framework where the two incoming protons do not exchange coloured particles
- In this framework one can think of VBF as two protons undergoing deep inelastic scattering
- One can therefore obtain the VBF cross section directly from DIS ingredients [Han, Valencia, Willenbrock (1992)]

- This approach omits a large number of known contributions: s-channel, t/u-channel interference, ggF interference, single-quark line and heavy quark loop induced contributions
- Although some of these can be sizeable when no cuts are applied, they are all reduced to or below the permille level when VBF cuts are applied [Bolzoni et al. (2011)]

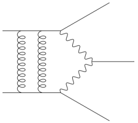
Non-factorizable corrections pre June 2019



→ Identically zero due to colour conservation



→ Contributes to the three jet cross section [Campanario et al. (2013)], but is known to be kinematically suppressed in the VBF phase space [Bolzoni et al. (2011)]



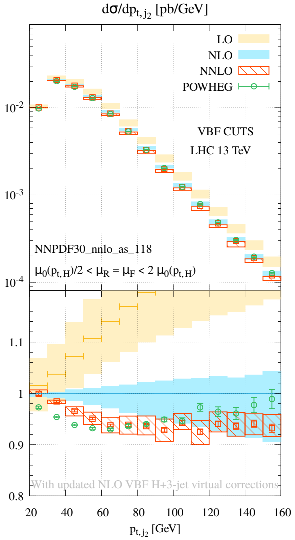
→ Impossible to compute but estimated to contribute at the permille level based on colour suppression $(1/N_c^2)$ and lower order Abelian calculation [Bolzoni et al. (2011)]

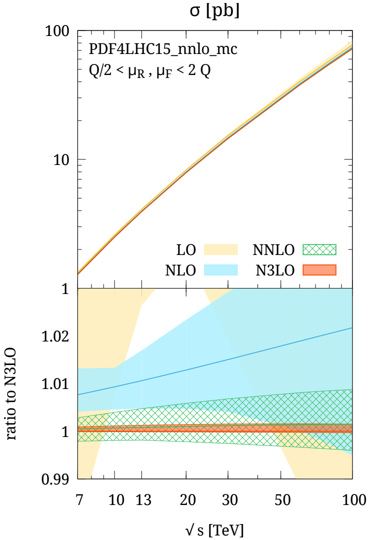
History of factorizable QCD corrections

- Due to these considerations a lot of effort has been put into computing radiative corrections in the factorized picture
- The full NLO corrections were computed a long time ago [Figy, Oleari, Zeppenfeld (2003)]. They are moderate in size and have small residual scale uncertainties.
- The inclusive NNLO corrections followed [Bolzoni et al. (2011)] with small corrections and residual scale uncertainties.
- However under VBF cuts the corrections were shown to be larger than the NLO scale uncertainties suggested [Cacciari et al. (2015)], [Cruz-Martinez et al. (2018)]
- Finally the inclusive N3LO corrections were computed with tiny corrections and residual scale uncertainties, showing excellent convergence of the perturbative series [Dreyer, AK (2016)]

$\rightarrow$ VBF understood at the 1%-level

History of factorizable QCD corrections





Non-factorizable QCD [1906.10899]

- Very recently the non-factorizable QCD corrections were estimated in the eikonal approximation [Liu, Melnikov, Penin (2019)]
- Result expressed as an expansion in $p_{t,j}/\sqrt{s}$, which is argued to be small due to large m_{jj} requirement in typical VBF analyses
- Only leading power available, but argued to have an uncertainty of a few percent in most regions of phase space
- Result proportional to Born cross section, as real emission diagrams show up at higher power

$$\mathrm{d}\sigma_{\mathrm{nf}}^{\mathrm{NNLO}} = \left(\frac{N_c^2-1}{4N_c^2}\right)\alpha_s^2\chi_{\mathrm{nf}}\left(q_{\perp,1},q_{\perp,2}\right)\mathrm{d}\sigma^{\mathrm{LO}}$$

! Colour suppressed but π^2-enhanced (Glauber phase)

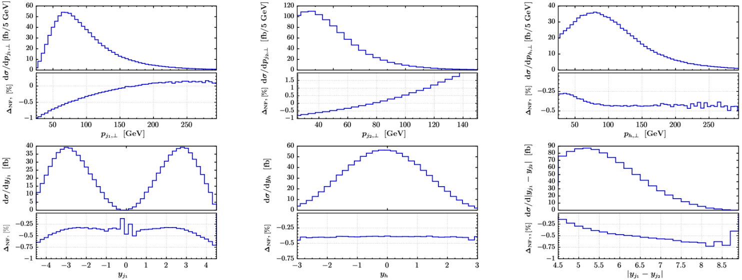
Non-factorizable QCD [1906.10899]

VBF cuts: $m_{jj} > 600$ GeV, $\Delta y_{jj} > 4.5$, $y_{j_1} y_{j_2} < 0$

$$\mathrm{d}\sigma^{\mathrm{LO}} = 957 \text{ fb}, \qquad \mathrm{d}\sigma_{\mathrm{nf}}^{\mathrm{NNLO}} = -3.73 \text{ fb}, \qquad \mathrm{d}\sigma_{\mathrm{f}}^{\mathrm{NNLO}} = -32 \text{ fb}$$

Although non-factorizable corrections are of the order of several permille, they are clearly suppressed compared to their factorizable counterparts.

Fiducially they can grow to the percent level:

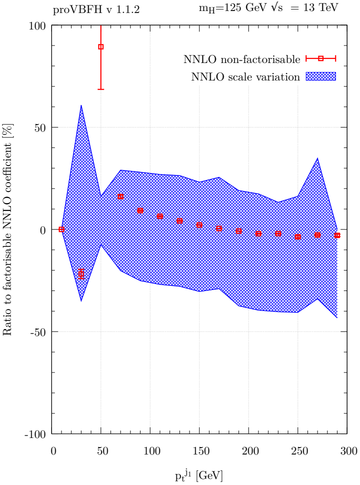


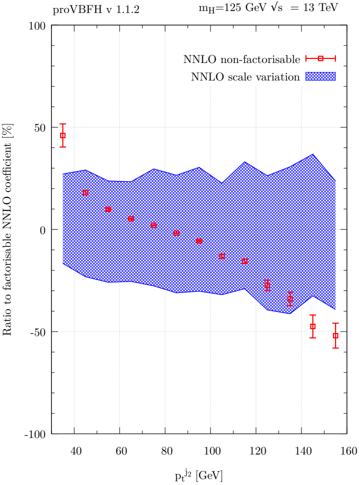
Factorizable vs non-factorisable

- Although this calculation "completes" the computation of NNLO QCD corrections to VBF, there are a few questions that need a more detailed study:
  - How do the NF corrections compare fiducially to the F corrections and the associated scale uncertainty?
  - How good is the eikonal approximation when VBF cuts are applied?
  - How good is the eikonal approximation when no cuts are applied?

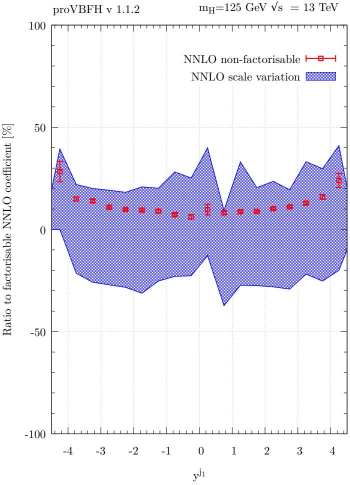
→ Address these questions quantitatively and qualitatively

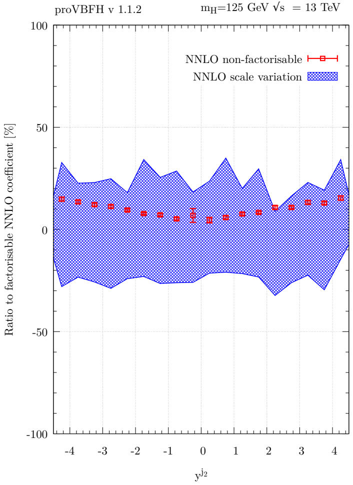
Factorizable vs non-factorisable



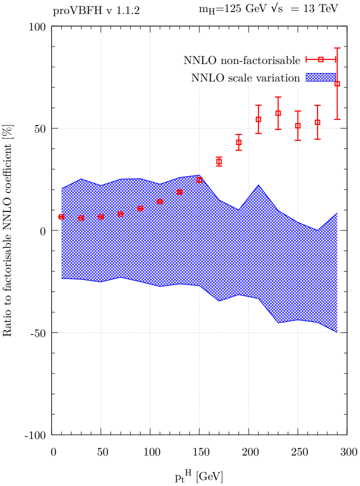


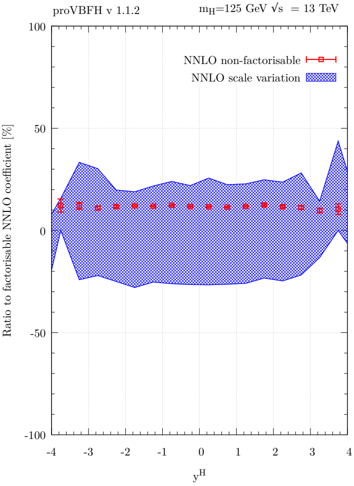
Factorizable vs non-factorisable



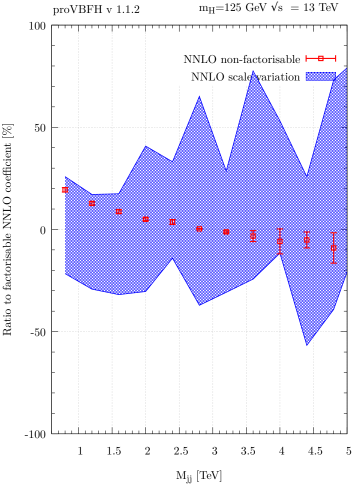


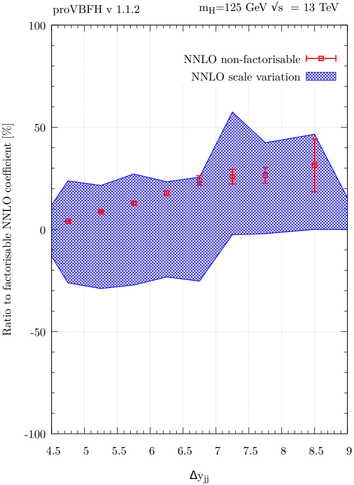
Factorizable vs non-factorisable



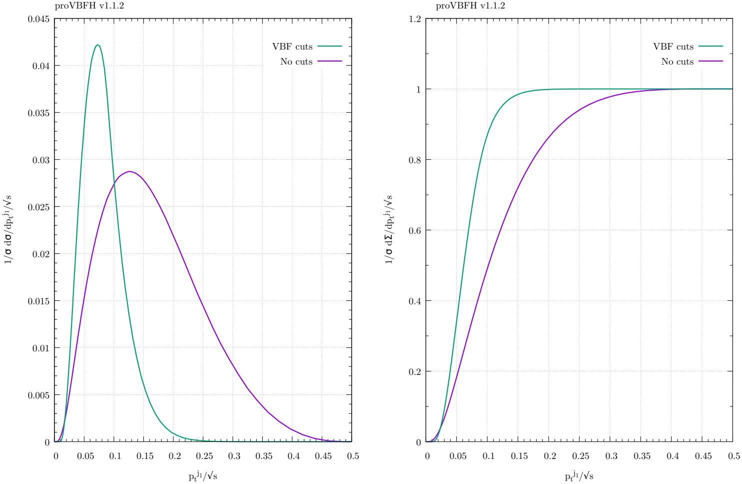


Factorizable vs non-factorisable



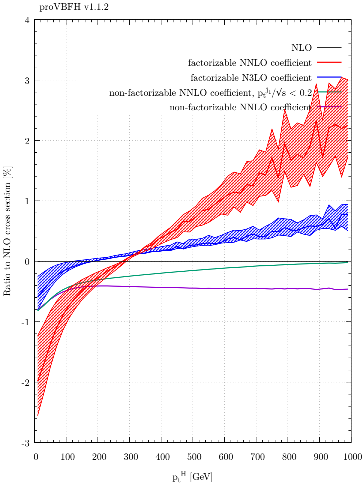


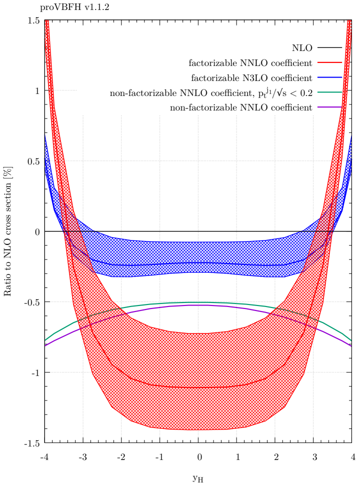
Validity of eikonal approximation



Large fraction of VBF cross section has $p_{t,j}/\sqrt{s} < 0.2$

Inclusive results



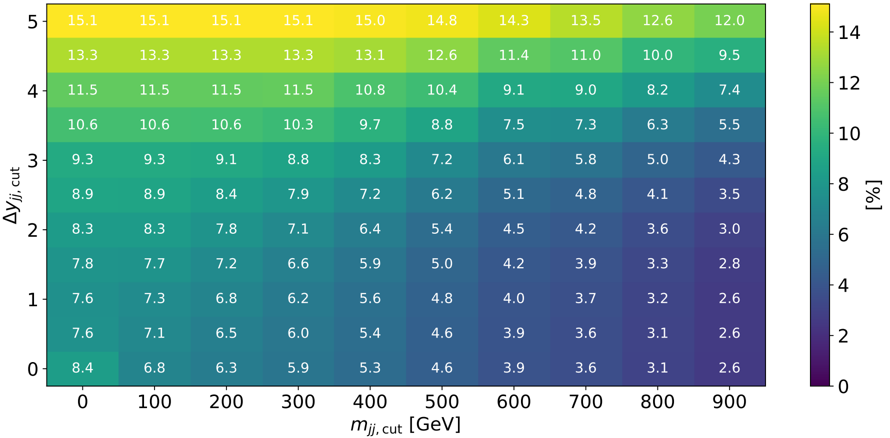


$p_{t,j}/\sqrt{s} < 0.2$ cut only changes the NF corrections at large $p_{t,H}$

Inclusive results

- When the eikonal approximation breaks down, we no longer expect the NF corrections to be enhanced by a Glauber phase
- Therefore the usual argument about them being subdominant applies
- The corrections computed in the eikonal approximation can therefore be used to *estimate* the size of the full NF corrections
- The results seem to suggest that the NF corrections are
    - of the same order of magnitude as the F corrections when considering the fully inclusive cross section
    - significantly larger than the F N3LO corrections
    - outside the scale uncertainty band of the F NNLO corrections

NF vs F



15.1 15.1 15.1 15.1 15.0 14.8 14.3 13.5 12.6 12.0
13.3 13.3 13.3 13.3 13.1 12.6 11.4 11.0 10.0 9.5
11.5 11.5 11.5 11.5 10.8 10.4 9.1 9.0 8.2 7.4
10.6 10.6 10.6 10.3 9.7 8.8 7.5 7.3 6.3 5.5
9.3 9.3 9.1 8.8 8.3 7.2 6.1 5.8 5.0 4.3
8.9 8.9 8.4 7.9 7.2 6.2 5.1 4.8 4.1 3.5
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7.6 7.1 6.5 6.0 5.4 4.6 3.9 3.6 3.1 2.6
8.4 6.8 6.3 5.9 5.3 4.6 3.9 3.6 3.1 2.6
$\Delta y_{jj,\,\mathrm{cut}}$
5
4
3
2
1
0
0 100 200 300 400 500 600 700 800 900
$m_{jj,\,\mathrm{cut}}$ [GeV]
[%]
14
12
10
8
6
4
2
0

Conclusions

- Recent calculation of NNLO NF corrections found that they are Glauber phase enhanced
- However NF corrections almost everywhere contained within F scale uncertainty band $\rightarrow$ same size as N3LO corrections
- When going fully inclusive the eikonal approximation breaks down
- However, it still captures the bulk of the NF corrections
- In this inclusive setup the NF corrections are found to be of the same order of magnitude as their F counterparts
- NF corrections have been implemented in `proVBFH` and will be released soon

Di-Higgs (low stats)