proVBFHH: High Precision Vector Boson Fusion di-Higgs Production

Alexander Karlberg (Universität Zürich)

Higgs Couplings 2018

Based on 1811.07906 and 1811.07918 in collaboration with Frédéric Dreyer (Oxford)

This work

- First fully differential NNLO calculation of VBF di-Higgs production

$\rightarrow$ Extension of the single Higgs production calculation using the *projection-to-Born* method

- Corrections in general smaller than in single-Higgs VBF production and usually contained within scale variation bands
- Large shrinkage of residual scale uncertainty when NLO $\rightarrow$ NNLO
- Calculation available in a fully flexible Monte Carlo called `proVBFHH`
- The program is also capable of computing the inclusive cross section up to N3LO in the structure function approximation
- Given limited time I will only focus on the phenomenology...

Motivation

- No need to motivate the study of di-Higgs production to this audience (short talk...)
- Audience may wonder why we are calculating NNLO and N3LO corrections to a process which hasn't even been observed...

$\rightarrow$ Main reason: Because we can!

- Calculation could easily be extended to any number of Higgs bosons (tri-Higgs etc)
- Electroweak current written in such a way that BSM can easily be implemented
- At HL-LHC expect ~ 6000 events and at HE-LHC (27 TeV) expect ~ 120000 events

$\rightarrow$ Precision di-Higgs VBF production doable within my lifetime...

Phenomenology

We study 14 TeV LHC collisions with $M_H = 125$ GeV and PDF4LHC_nnlo. We use the following VBF cuts:

- Jets defined with anti-k_t, $R = 0.4$ and $p_t > 25$ GeV
- Two hardest jets within $|y| < 4.5$
- High dijet invariant mass, $M_{j_1 j_2} > 600$ GeV, and separation, $\Delta y_{j_1 j_2} > 4.5$
- Hardest jets in opposite hemispheres, $y_{j_1} y_{j_2} < 0$

We choose a central scale which approximates well $\sqrt{Q_1 Q_2}$ and symmetrically vary by a factor 2 up and down

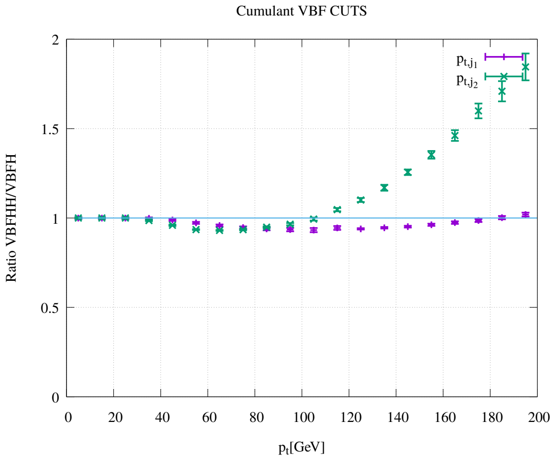
$$\mu_0^2(p_{t,HH}) = \frac{M_H}{2}\sqrt{\left(\frac{M_H}{2}\right)^2 + p_{t,HH}^2}$$

Fiducial cross sections

	$\sigma^{\text{(no cuts)}}$ [fb]	$\sigma^{\text{(VBF cuts)}}$ [fb]
LO	$2.016^{+0.164}_{-0.142}$	$0.799^{+0.082}_{-0.069}$
NLO	$2.049^{+0.007}_{-0.021}$	$0.726^{+0.005}_{-0.020}$
NNLO	$2.053^{+0.000}_{-0.003}$	$0.713^{+0.004}_{-0.001}$

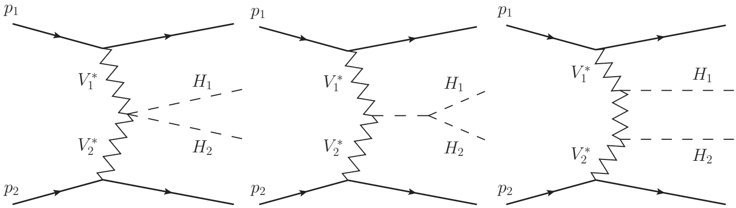
- NNLO corrections tiny $(\sim 2‰)$ without cuts and size-able with VBF cuts $(\sim 2\%)$
- NNLO results inside NLO band (as opposed to single-Higgs VBF)
- Negative corrections due to radiation outside jet cone. di-Higgs production has significantly harder jets than single-Higgs
- 35% of the events pass the VBF cuts compared to 22% in single-Higgs production

Jet spectra



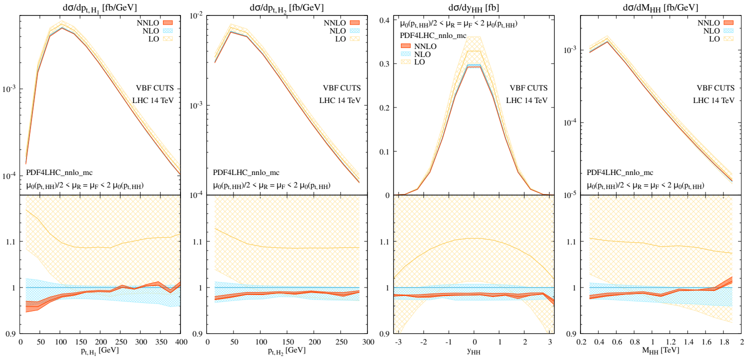
Second jet much harder in di-Higgs production compared to single-Higgs production → more events pass the VBF cuts.

Jet spectra



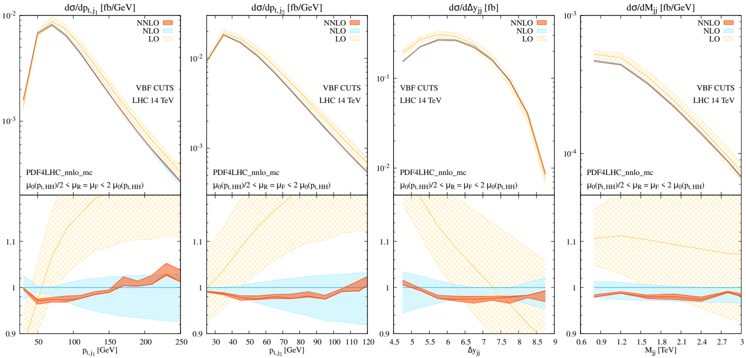
- Momentum transfer, Q_i, on virtual vector bosons much larger in di-Higgs production due to the final state being $2m_H$ rather than m_H in single-Higgs production
- $p_{\mathrm{T},j_1} \sim Q_{\mathrm{T},1}$ and $p_{\mathrm{T},j_2} \sim Q_{\mathrm{T},2}$
- Hence jets expected to be harder in di-Higgs production

HH distributions



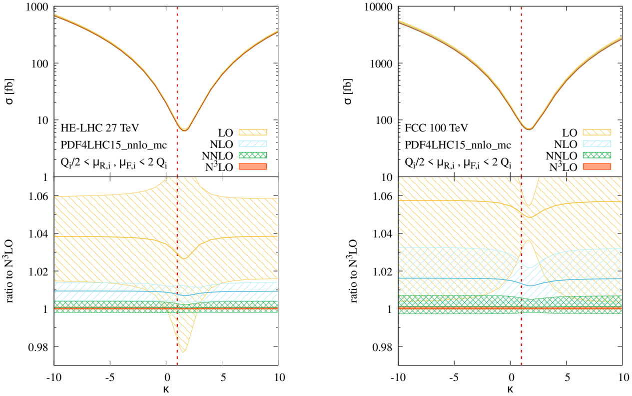
- Higgs bosons ordered in p_T such that $p_{\mathrm{T},H_1} > p_{\mathrm{T},H_2}$
- p_{T,H_1} gets the largest corrections of about 4% when very soft.
- Otherwise corrections very modest and inside uncertainty band
- Some kinematic dependence but most flat corrections
- This is expected as the Higgs observables are mainly affected through the cuts

Jet observables



- More pronounced corrections for jet observables
- The transverse momentum distributions receive corrections of $2-4\%$ with some kinematic dependence
- Corrections mostly within scale variation band of NLO
- Large reduction in scale uncertainty

Some inclusive observations...



- Calculation can easily be modified to include BSM. Here minimal scan in κ defined as $\lambda = \kappa\lambda_{SM}$.
- Cross section very sensitive to deviation from the SM, and QCD corrections mostly independent of the value of the tri-linear coupling.

Conclusions

- Presented first fully differential NNLO calculation of VBF di-Higgs production using the projection-to-Born method
- NNLO corrections are very modest and usually contained within the scale uncertainty band
- This is most likely due to harder jets in di-Higgs production generated by the larger virtuality needed to produce two on-shell Higgs bosons
- This in turn also means that the di-Higgs VBF cross section suffers less from the VBF cuts
- Cross section very sensitive to deviation in the tri-linear coupling
- Our calculation can easily be extended for BSM use

The calculation is available in the form of a Monte Carlo program from https://provbfh.hepforge.org/