A Comparative Study of VBF Production at the HL-LHC and HE-LHC

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Azzi, P. et al. "Standard Model Physics at the HL-LHC and HE-LHC." arXiv:1902.04070.

October 11, 2019

Overview

Motivation

- To extend the discovery potential of LHC, the LHC will undergo an upgrade, the High-Luminosity Large Hadron Collider (HL-LHC). The HL-LHC project will increase luminosity by a factor of 5 greater than LHC and will accumulate 10 times more data.
- The HL-LHC will be operational from 2026. With increasing of luminosity, physicists can explore mechanisms of Higgs boson in great details. The HL-LHC will produce at least 15 million Higgs boson per year, compare to about three million Higgs boson in 2017.

HL-LHC

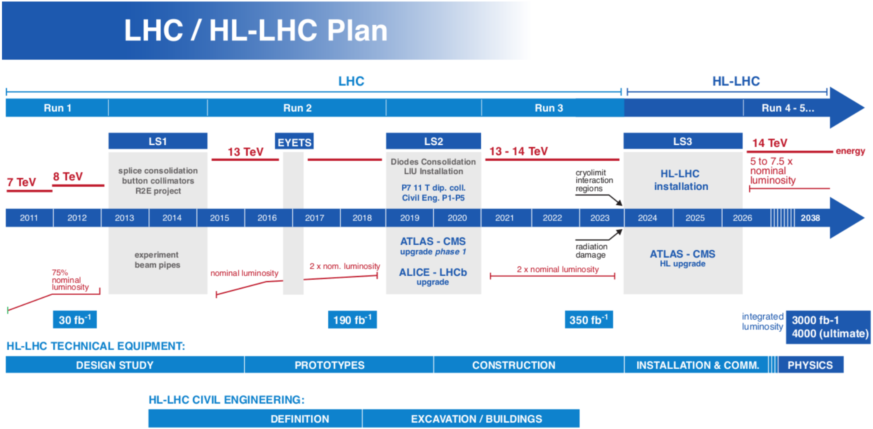


Figure: The HL-LHC plan. Credit: project-hl-lhc-industry.web.cern.ch

HE-LHC

- Further upgrade of the HL-LHC is the High-Energy LHC (HE-LHC), a 27 TeV pp collider.
- The HE-LHC will improve the precision of the HL-LHC measurements.
- Extend the potential of HL-LHC in searching new particles, approximately double the centre-of-mass energy.
- Establish the structure of the symmetry-breaking Higgs potential.
- Explore the possible future LHC discovery in great details and confirm preliminary discovery of LHC.

Vector Boson Fusion and Higgs-strahlung

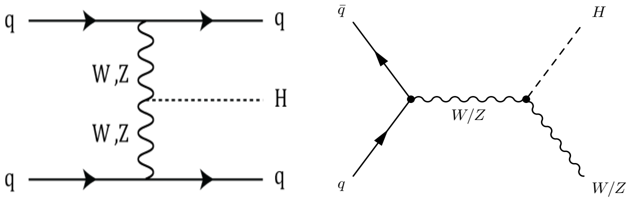


Figure: *Contribution to Higgs boson production from associated vector boson fusion (LHS) $qq \to qqV^*V^* \to qqH$ and $q\bar{q} \to V^* \to VH$ production (RHS) at lowest order. Credit: Spira, Michael. "Higgs boson production and decay at hadron colliders." Progress in Particle and Nuclear Physics 95 (2017): 98-159.*

Objectives and Techniques

Herwig 7

`Herwig 7` is a multi-purpose particle physics event generator [1]–[4]. It provides all the different simulation steps such as hard process generation, parton shower, hadronization and multiple parton interactions. Detail information and tutorials can be obtained from the website `https://herwig.hepforge.org/`.

HJets++

`HJets++ 1.1` is a plugin for Matchbox providing amplitudes for the calculation of electroweak Higgs boson plus jets production at NLO(next-to-leading order) QCD [5]–[7]. All relevant topologies of either VBF or Higgs-Strahlung type are taken into account along with all interferences. It is built in the *LHC-Matchbox.in* file.

VBFNLO

VBFNLO is a fully flexible parton level Monte Carlo program for the simulation of vector boson fusion, double and triple vector boson production in hadronic collisions at NLO QCD [8]–[11]. VBFNLO version 3.0 beta 5 is used for VBF approximation matrix elements.

Rivet

Rivet (Robust Independent Validation of Experiment and Theory) is a toolkit that allows for the comparison of Monte Carlo simulations and experimental data. It is also a widely used analysis code from the LHC and other high energy particle experiments [12], [13].

XSEDE and Open Science Grid

XSEDE (Extreme Science and Engineering Development Environment) is a virtual cyberinfrastructure that scientist use to share computing resources and data. It has many allocated resources can be used include Stampede2, Open Science Grid (OSG) [14], [15], etc.

Setup

The gauge boson masses and widths are set to

$$m_W = 80.385 \text{ GeV}, \qquad \Gamma_W = 2.085\text{GeV}. \tag{1}$$

$$m_Z = 91.1876 \text{ GeV}, \qquad \Gamma_Z = 2.4952 \text{ GeV}. \tag{2}$$

and the Fermi constant is

$$G_F = 1.16637 \cdot 10^{-5} \text{ GeV}^{-2}. \tag{3}$$

Assume the Higgs to be in the narrow width approximation and use the Higgs mass

$$m_H = 125 \text{ GeV}. \tag{4}$$

Setup Cont.

The choice for parton distribution function is `PDF4LHC15_nlo_100_pdfas` and set the central renormalization and factorization scale to $\mu_0 = m_W$.
Inclusive cuts

$$p_{\mathrm{T}}^{j} > 30 \text{ GeV}, \qquad |y_j| < 5. \tag{5}$$

The tight VBF cuts for $\sqrt{s} = 14$ TeV is defined as

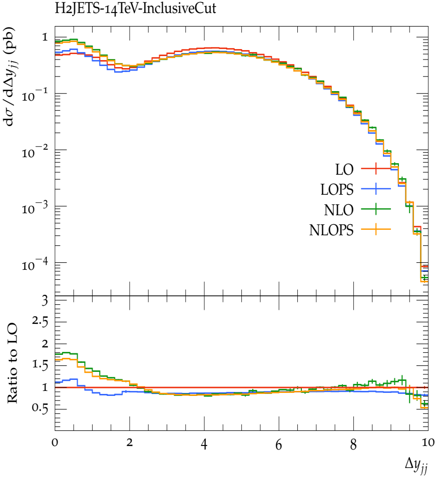
$$p_{\mathrm{T}}^{j} > 30 \text{ GeV}, \qquad |y_j| < 5.0. \tag{6}$$

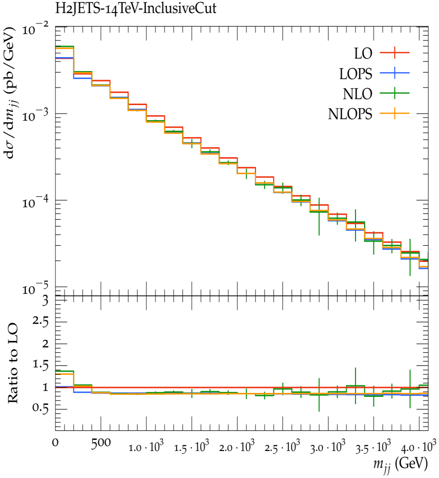
$$|y_{j_1} - y_{j_2}| > 3.0, \qquad m_{jj} > 130 \text{ GeV}. \tag{7}$$

The tight VBF cuts for $\sqrt{s} = 27$ TeV is defined as

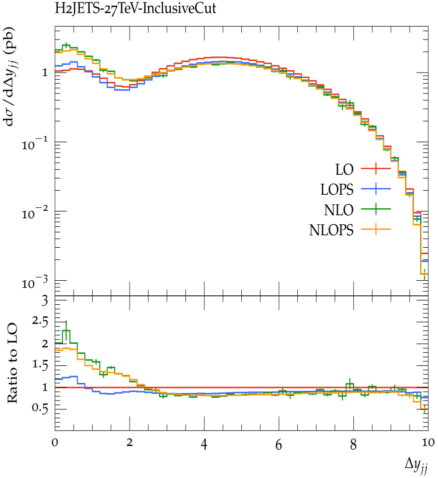
$$|y_{j_1} - y_{j_2}| > 4.5, \qquad m_{jj} > 600 \text{ GeV}. \tag{8}$$

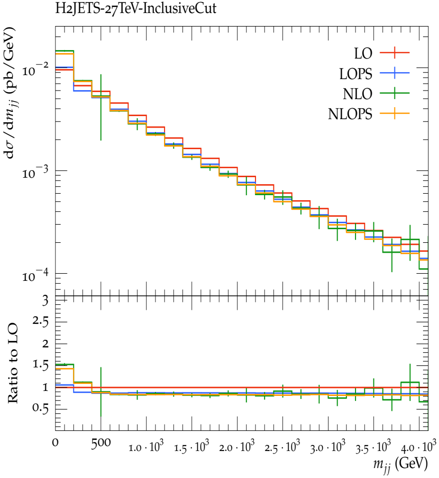
Inclusive Cuts Comparison at 14 TeV



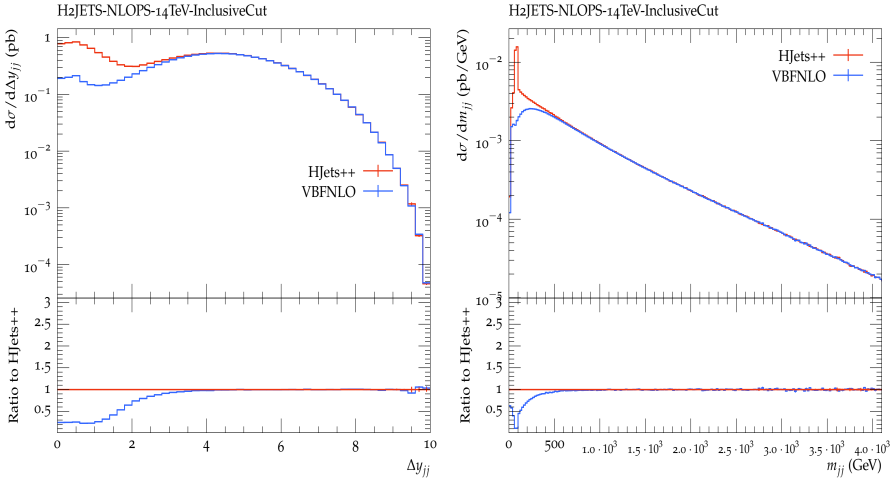


Inclusive Cuts Comparison at 27 TeV

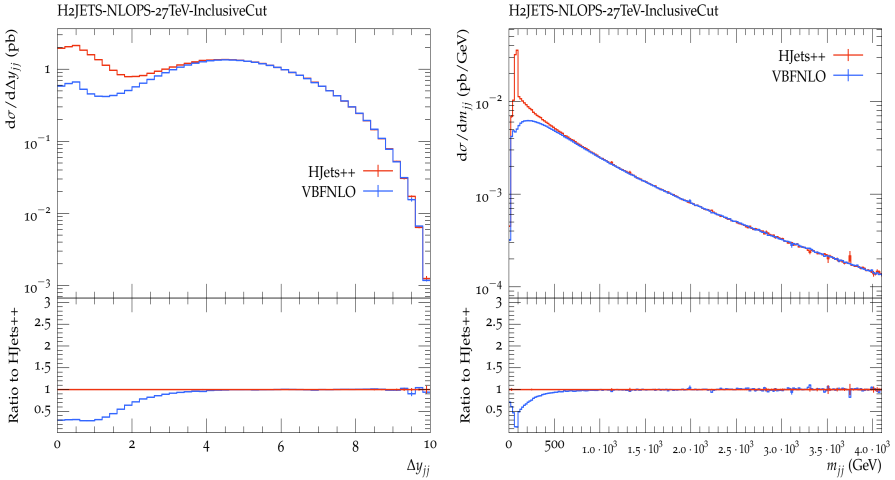




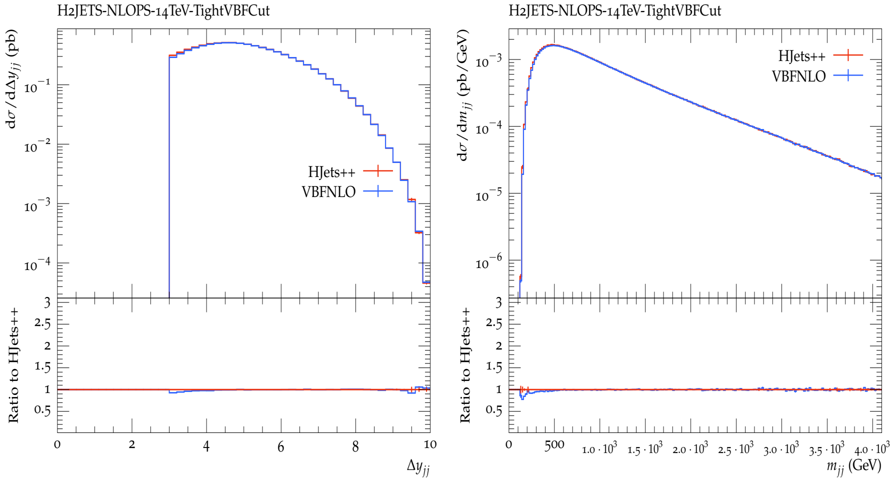
HJets and VBFNLO Comparison at 14 TeV



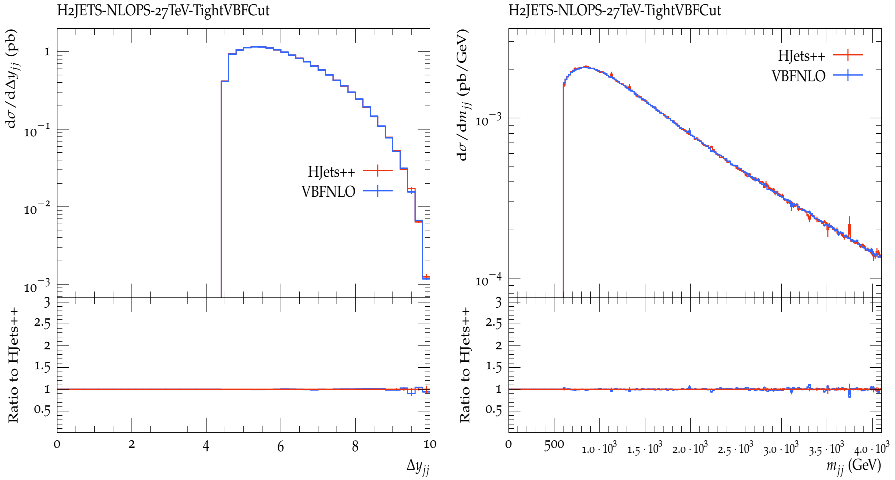
HJets and VBFNLO Comparison at 27 TeV



Tight VBF Cuts at 14 TeV



Tight VBF Cuts at 27 TeV



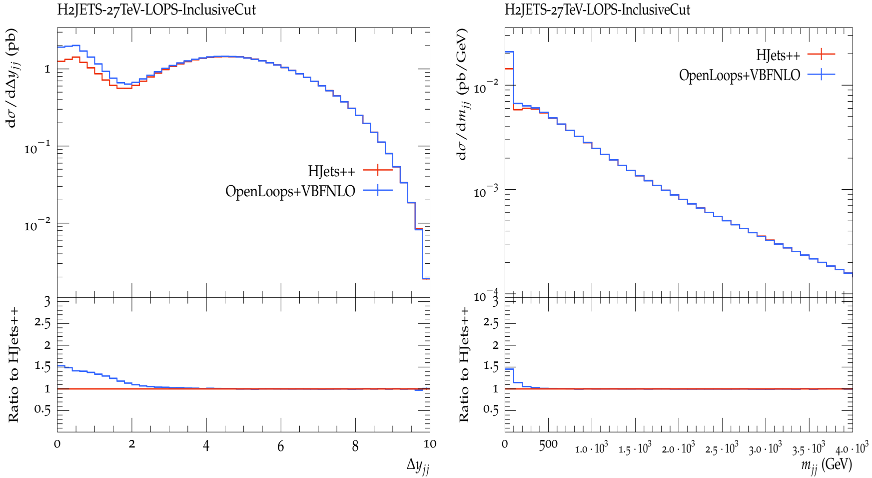


Figure: Preliminary comparison results between full calculation and approximate calculation. OpenLoops [16]–[19] provides the matrix elements of $pp \to hW^+$, $pp \to hW^-$, $pp \to hZ$.

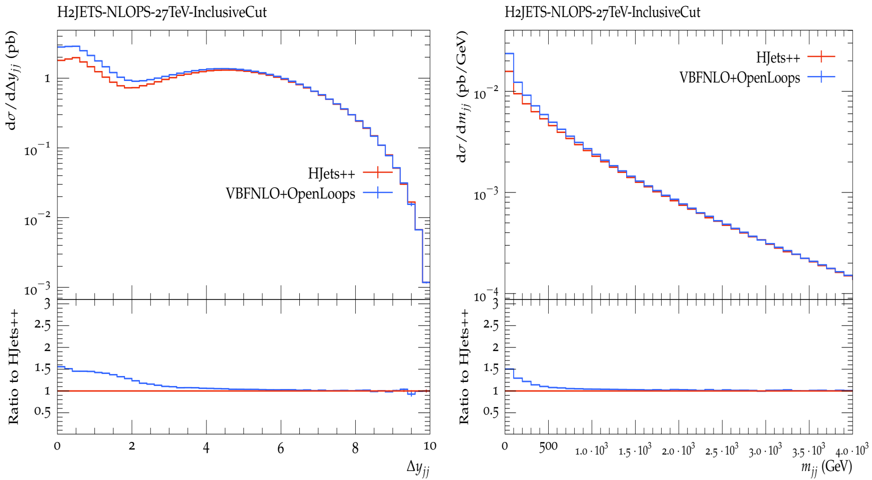


Figure: *Preliminary comparison results between full calculation and approximate calculation. OpenLoops provides the matrix elements of $pp \to hW^+$, $pp \to hW^-$, $pp \to hZ$.*

Summary

Both HJets++ and VBFNLO matrix elements have agreements in select kinematic variables for the selected tight VBF cuts.

The distribution of kinematic variables have been presented in the leading order and next-to leading order plus parton shower at $\sqrt{s} = 14$ TeV and $\sqrt{s} = 27$ TeV.

Thank You

Back up slides

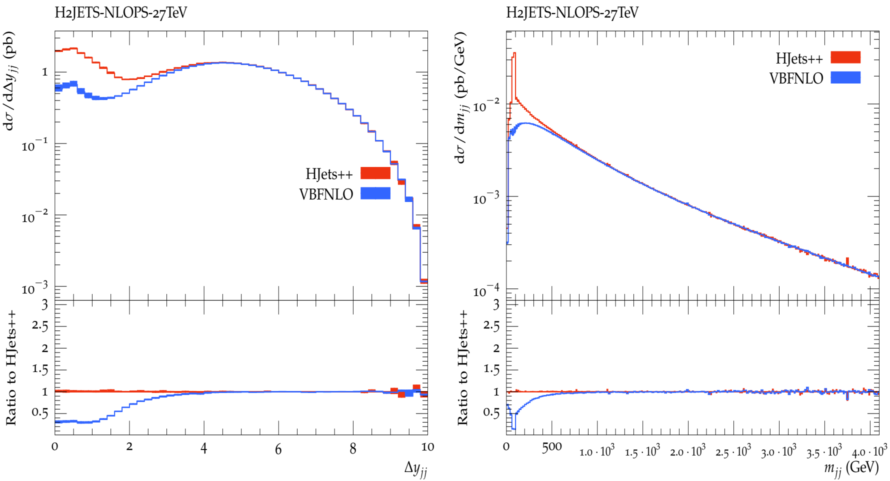


Figure: Preliminary results for comparison of HJets and VBFNLO for the scale variation plots.The band represents the normalization and factorization scale vary by factor of 2.

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