Stress-Testing the VBF Approximation with Higgs Boson plus Three Jet Production

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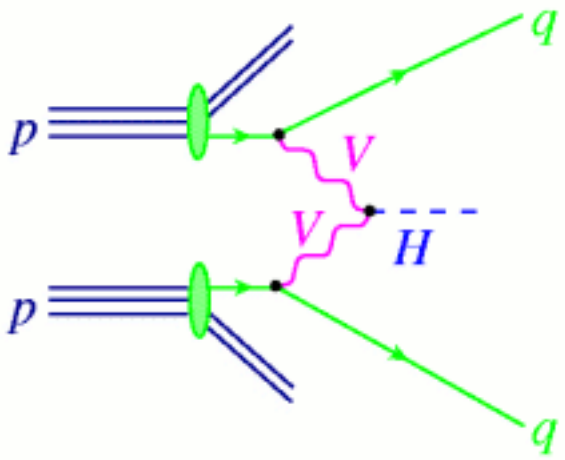
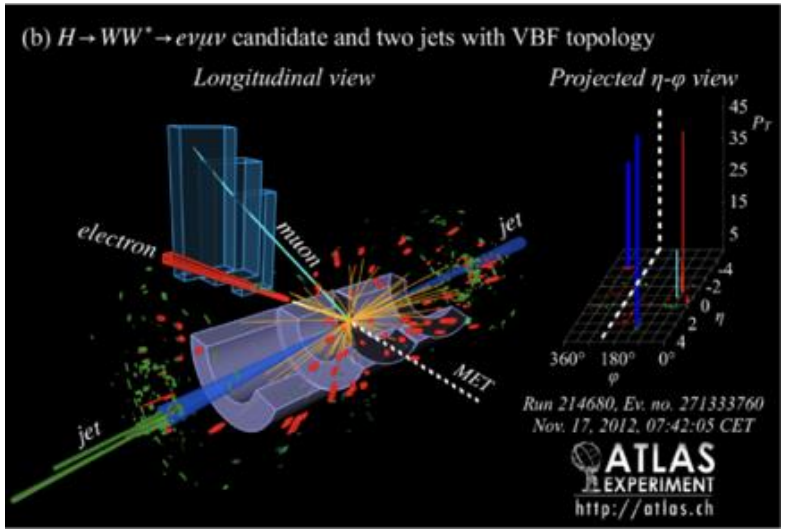
Particle Physics on the Plains

Vector Boson Fusion



- Energetic jets in the forward/backward directions.
- Higgs decays products in central rapidity region.
- Suppressed QCD radiation in central rapidity region.

Vector Boson Fusion



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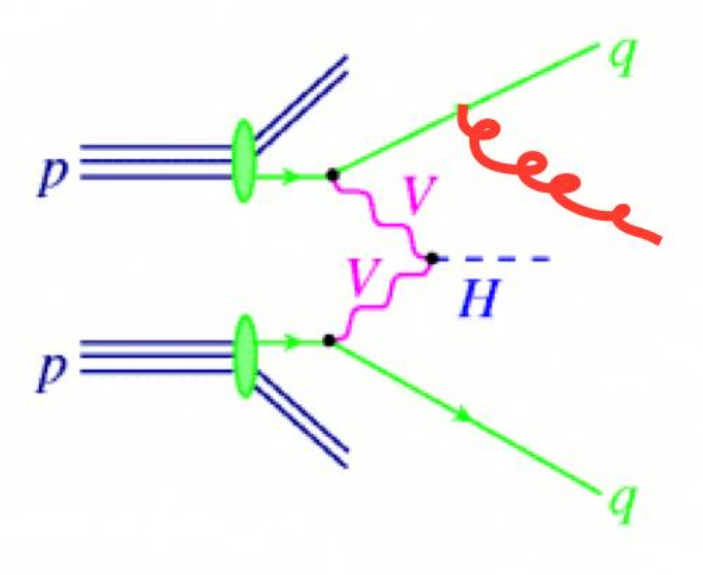
Vector Boson Fusion + Jet



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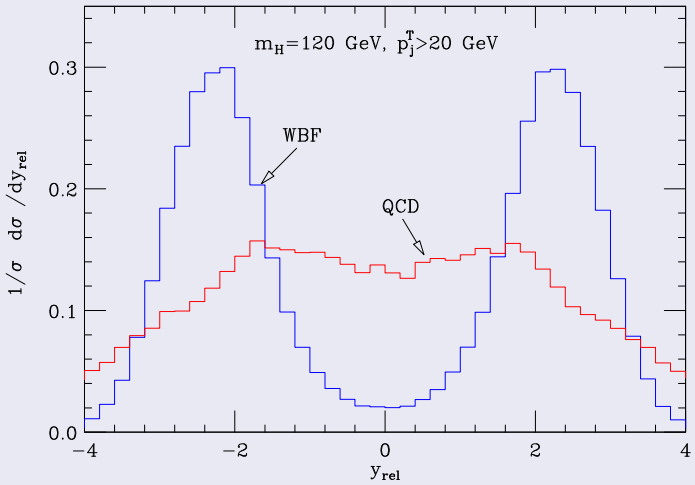
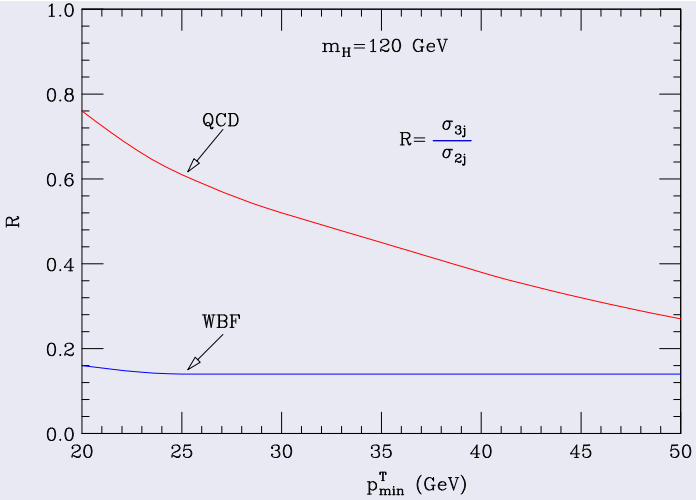
Vector Boson Fusion + Jet





JHEP 05 (2004) 064

$$y_{rel} = y_j^{veto} - (y_j^{tag\ 1} + y_j^{tag\ 2})/2$$

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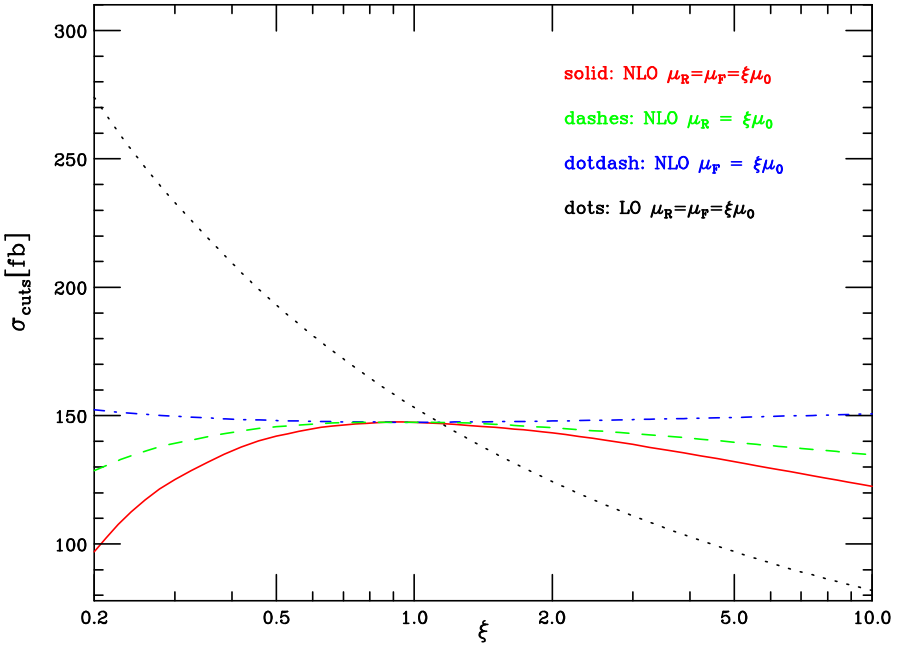
H+3 Jets via VBF (only t-channels)

Total Cross Section



Scale Variations:

- LO: +26% to -19%
- NLO: less than 5%

JHEP 0802 (2008) 076 [arXiv:0710.5621]

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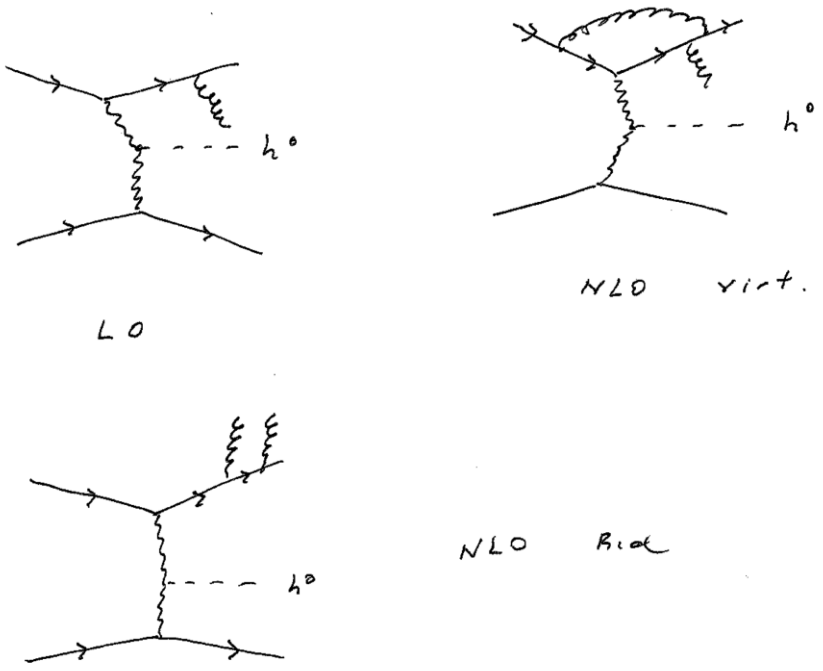
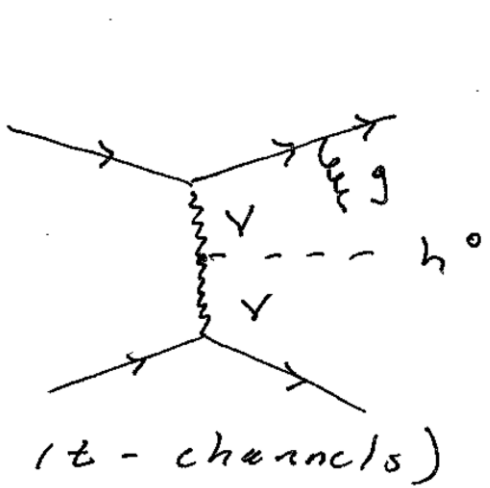
H+3 Jets via VBF (only t-channels)



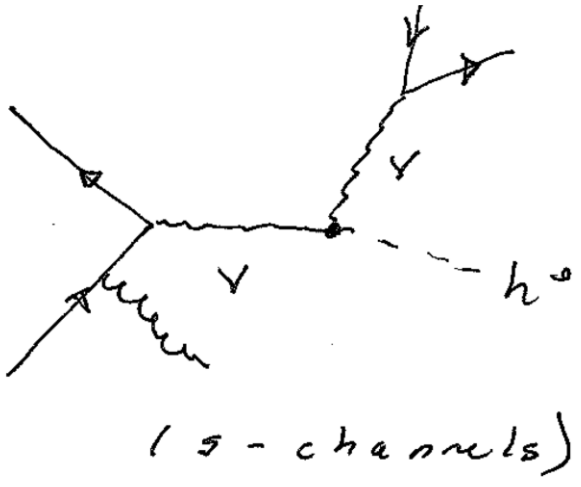
- No pentagon or hexagon diagrams included.
- Approximate as two deeply inelastic scattering processes that exchange a gauge boson.

JHEP 0802 (2008) 076 [arXiv:0710.5621]

Going for all of it: EW H+3 Jets



(t - channels)



(s - channels)

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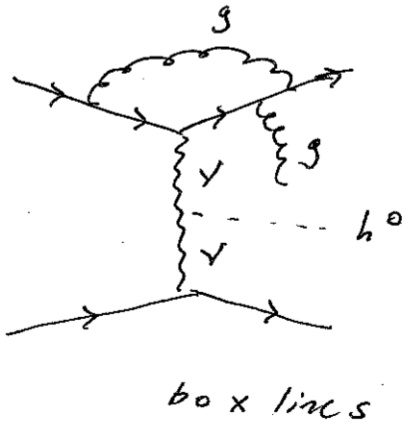
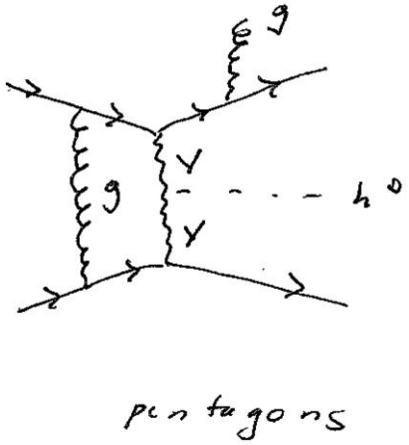
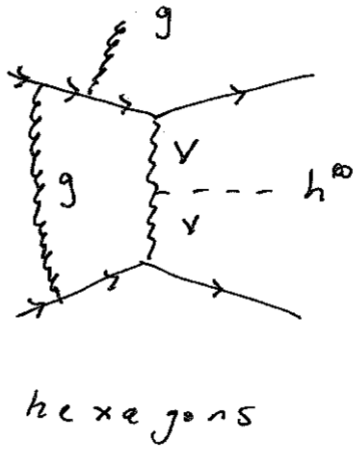
Going for all of it: EW H+3 Jets







Virtual Corrections

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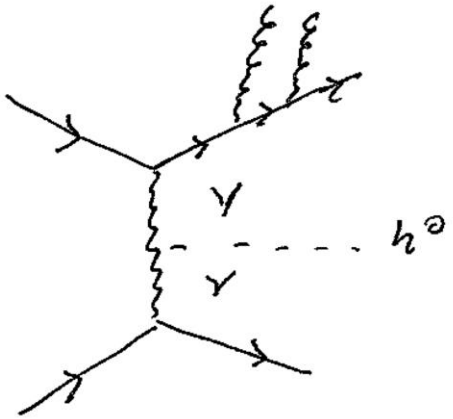
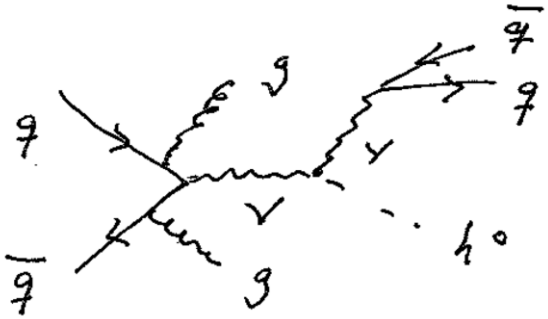
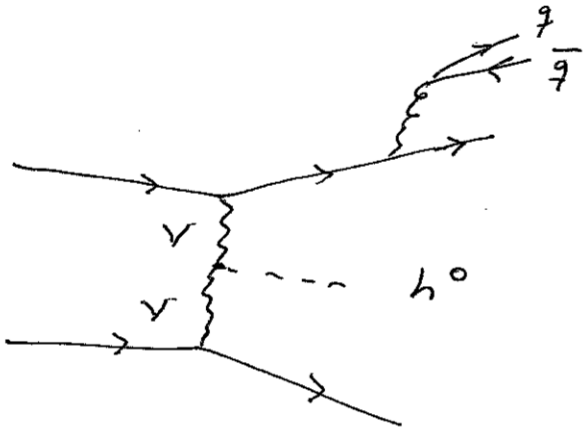
Going for all of it: EW H+3 Jets

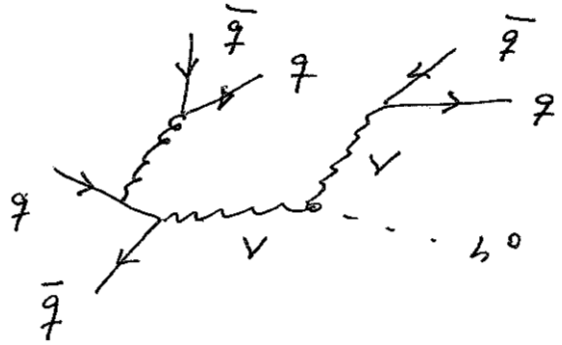




Real Corrections

Going for all of it: EW H+3 Jets





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EW H+3 Jets: Implementation Details

F. Campario, T. M. Figy, S. Platzer, and M. Sjodahl, PRL 111, 211802

- Matchbox [S. Platzer and S. Gieseke, arXiv:1109.6256]
  - Catani-Seymour Dipole subtraction [hep-ph/9605323]
  - Subtractive and POWHEG style matching to parton shower
  - ColorFull [M. Sjodahl, arXiv:1211.2099, http://colorfull.hepforge.org]
- Tensorial Reduction [F. Capanario, arXiv:1105.0920]
- Scalar Loop Integrals: OneLOop [A. van Hameren arXiv:1007.4716]

EW H+3 Jets: Publicly Available

- HJets++ (https://hjets.hepforge.org)

- Herwig 7 (https://herwig.hepforge.org)
  - Herwig 7/Herwig++ 3.0 Release Note

Input Parameters

- 14 TeV (proton - proton LHC)
- At least three anti-KT D=0.4 (E-scheme recombination) of 20 GeV and rapidity within -4.5 and 4.5 using FastJet [arXiv:0802.1189, arXiv:1111.6097]
- PDF choices: CT10 for NLO and CTEQ 6L1 for LO [arXiv:hep-ph/0201195, arXiv:1007.2241]
- Scales: W-boson mass (MW) and sum of transverse momentum of reconstructed jets (HT)

Notation:

y_i: rapidity

ϕ_i: azimuthal angle

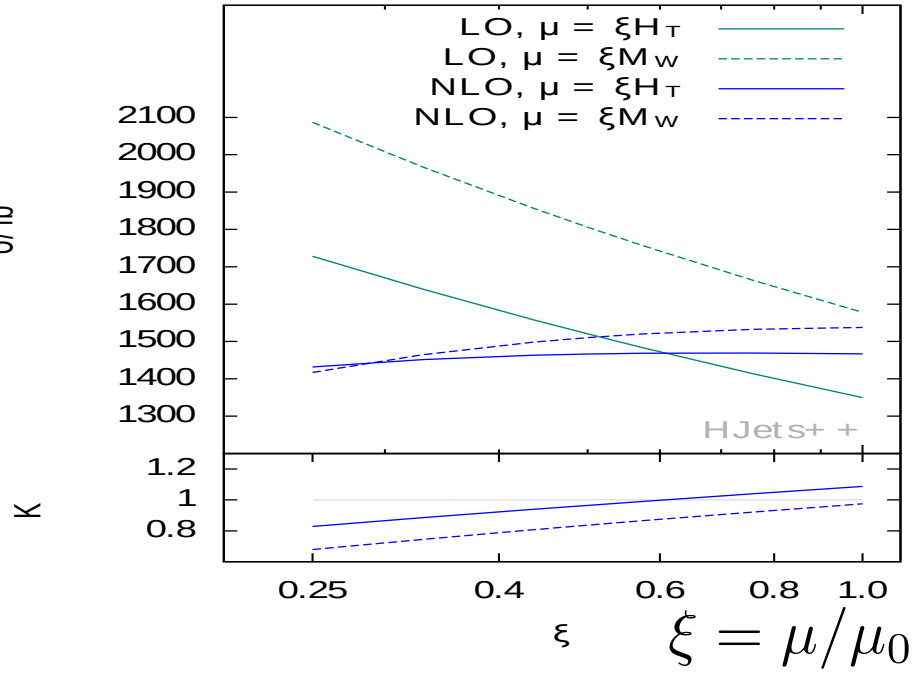
p_i: four momentum vector of i

$\Delta y_{ij} = |y_i - y_j|$: absolute rapidity difference between i and j

$\Delta\phi_{ij} = |\phi_i - \phi_j|$: absolute azimuthal angle difference between i and j

$m_{ij} = \sqrt{(p_i + p_j)^2}$: invariant mass of i and j

EW H+3 Jets: Scale Uncertainties



$$K = \sigma_{NLO}/\sigma_{LO}$$

$\mu_R = \mu_F = H_T/2$ $(M_W/2)$:
30% (24%) at LO and 2% (8%) at NLO

$$\mu_0 = H_T \ (M_W) \qquad H_T = \sum_j p_{T,j}$$

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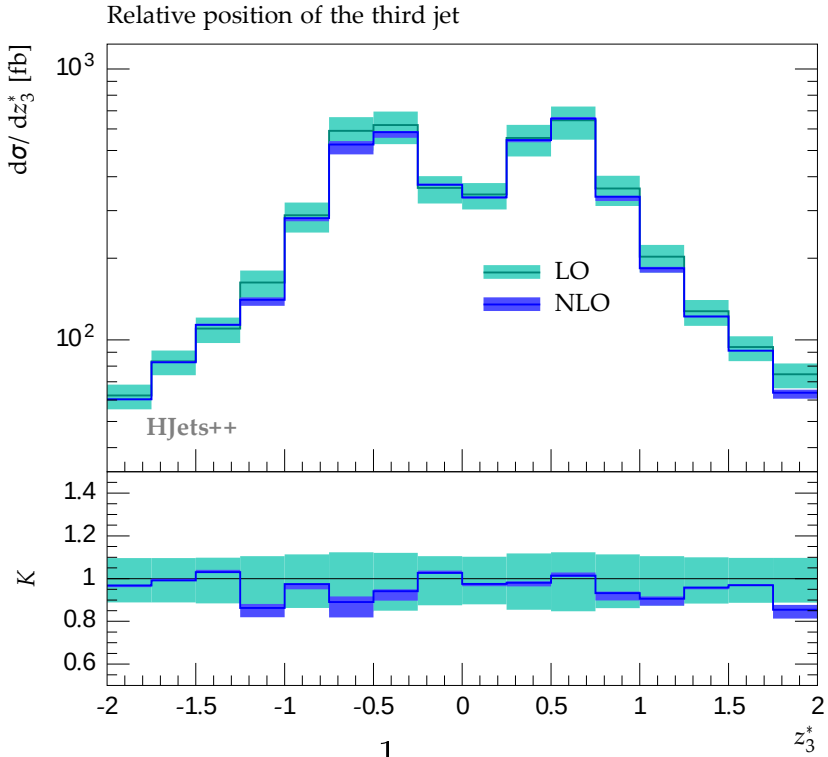
EW H+3 Jets: The Third Jet



$$z_3^\star = (y_3 - \frac{1}{2}(y_1 + y_2))/(y_1 - y_2)$$

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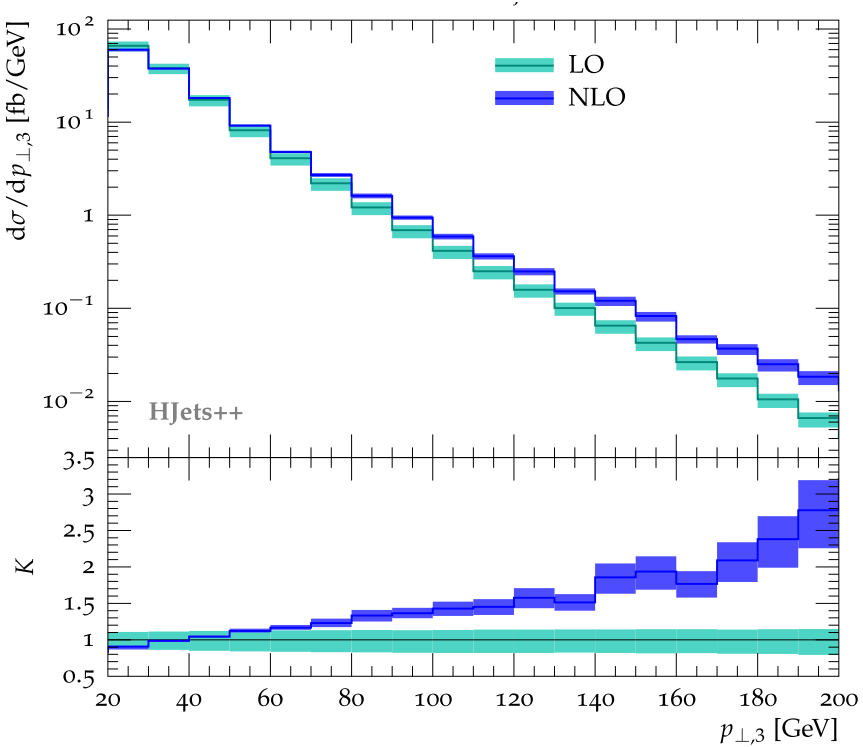
EW H+3 Jets: The Third Jet

Transverse momentum of third jet.



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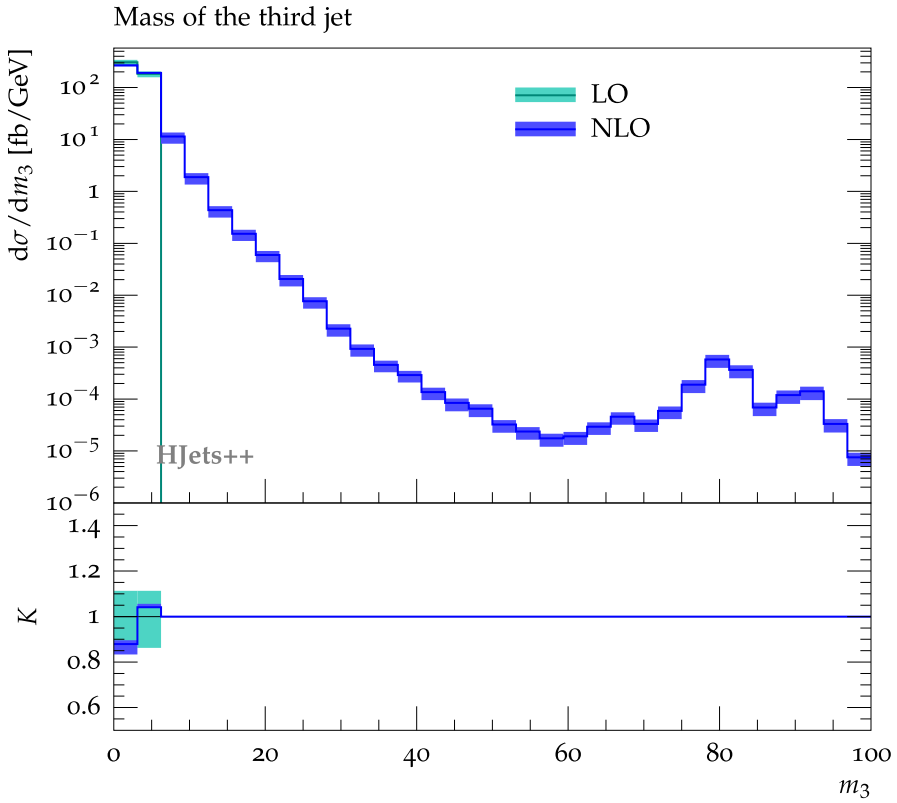
EW H+3 Jets: Jet Masses



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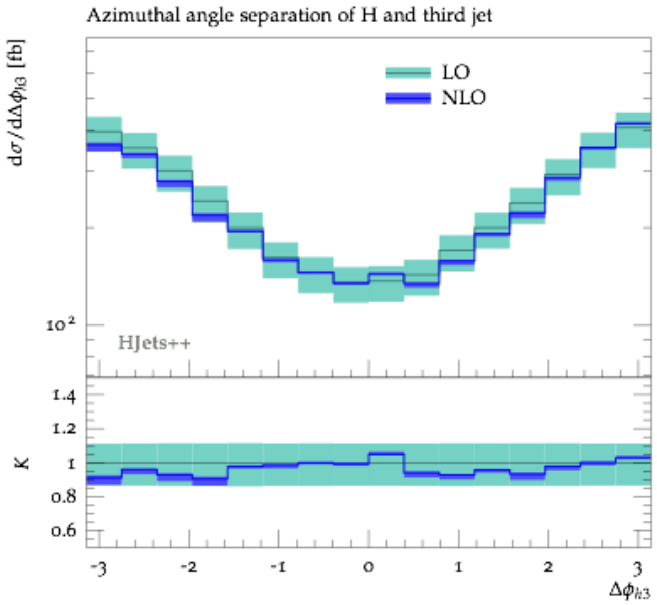
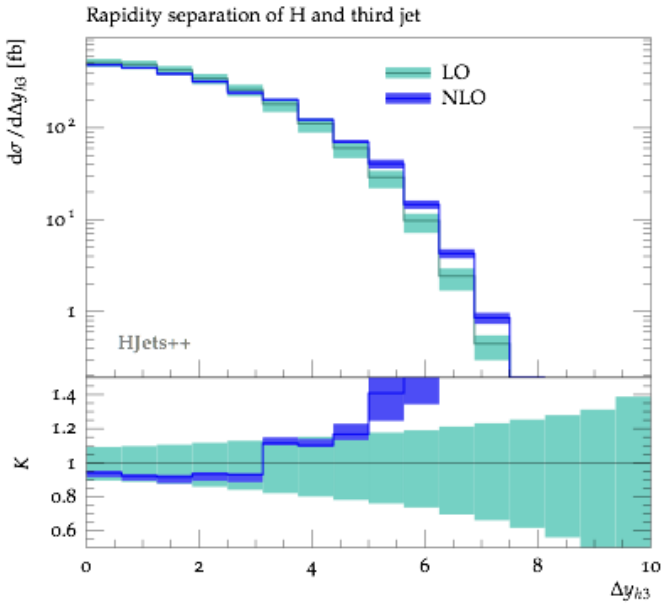
EW H+3 Jets: Higgs Boson





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Comparison to VBFNLO

In collaboration with Simon Platzer, Peter Schichtel, and Michael Rauch.

- Collider Energy and Cuts used: Anti-kt jet clustering with R=0.4

$$\sqrt{S} = 13 \text{ TeV}$$

$$p_{Tj} > 30 \text{ GeV} \qquad |y_j| < 4.4$$

- PDF set: MMHT2014
- Scales: HT(jets)

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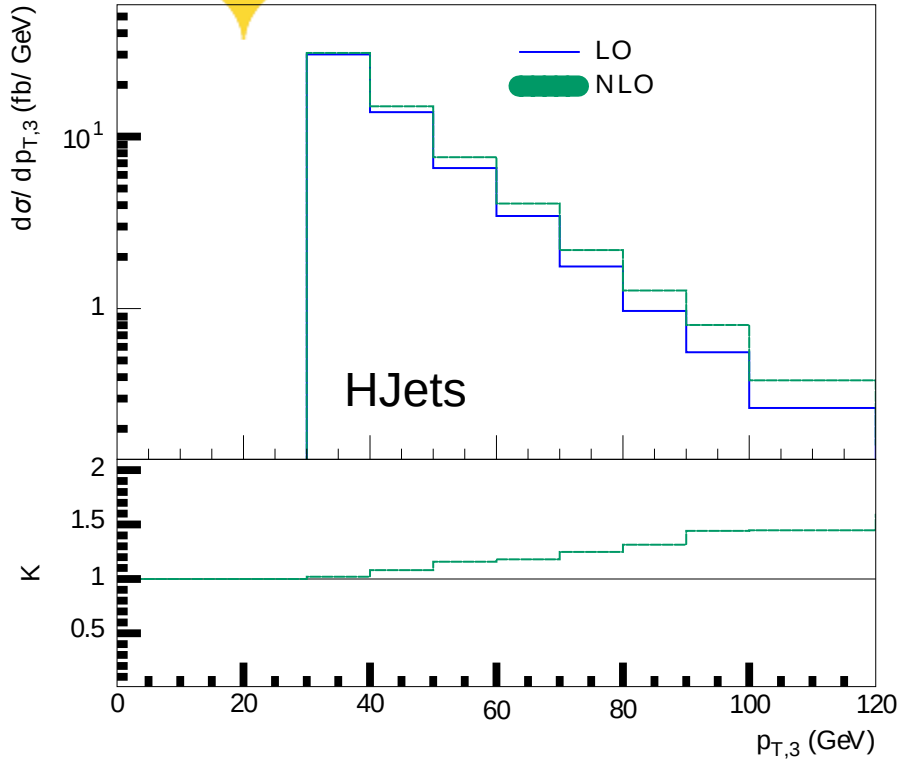
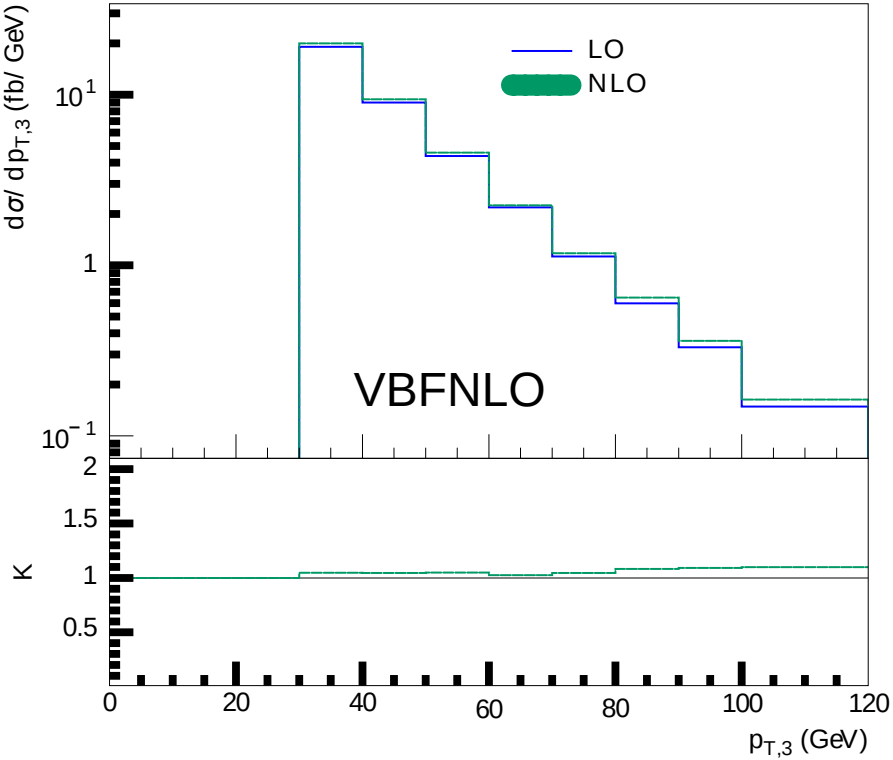
Comparison to VBFNLO: Inclusive Cuts





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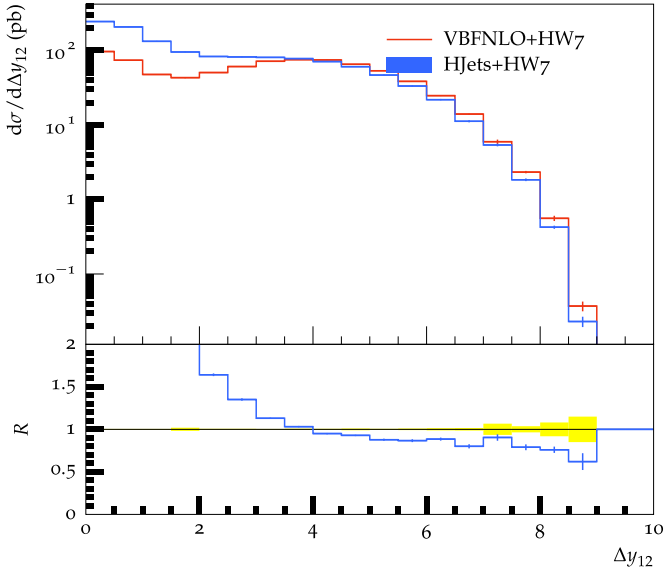
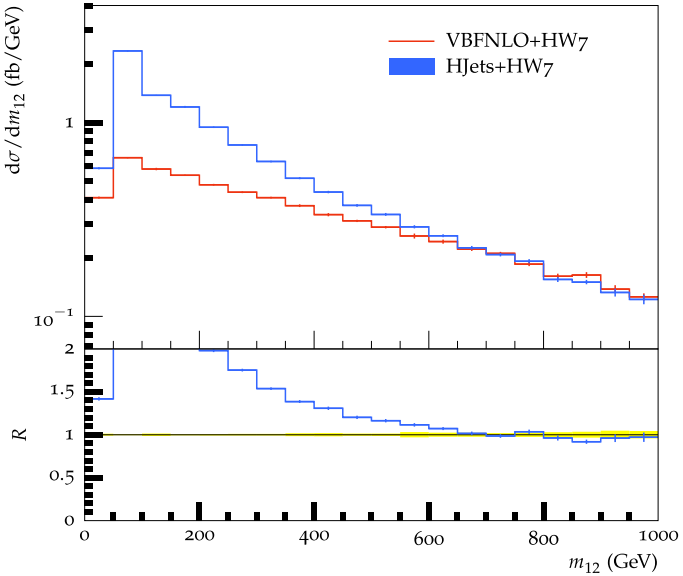
Comparison to VBFNLO: VBF cuts





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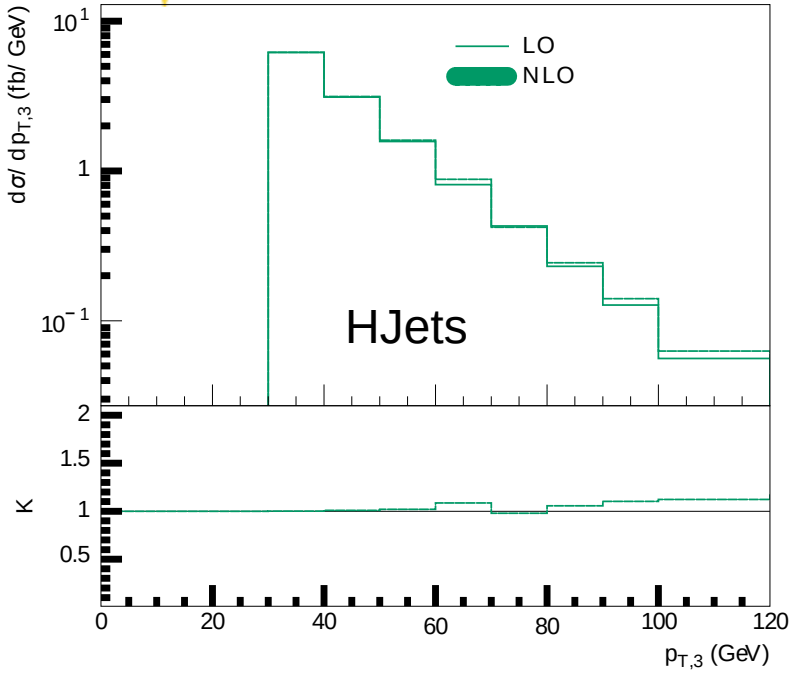
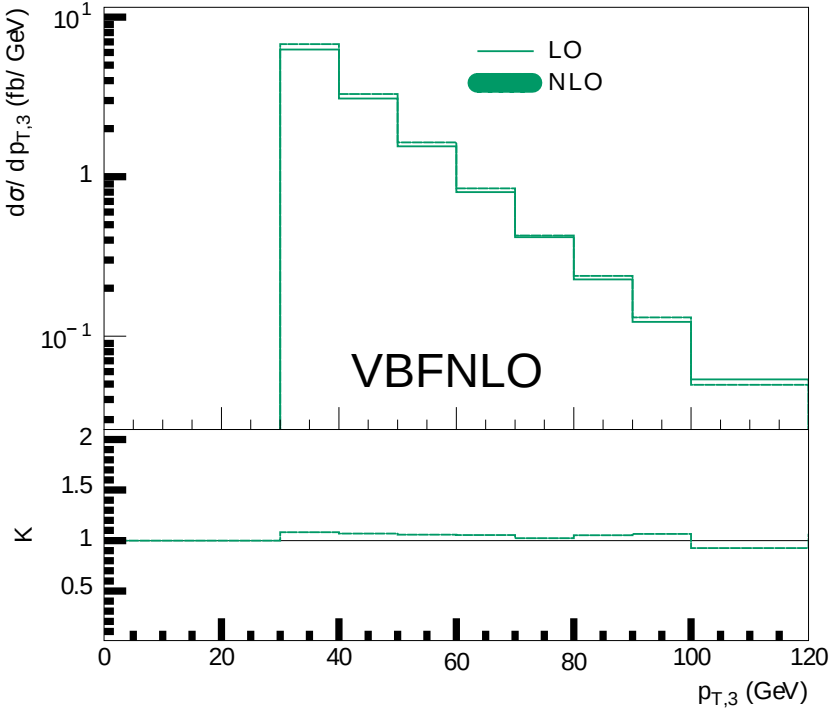
Comparison to VBFNLO: VBF cuts





$$m_{12} > 600 \text{ GeV } \Delta y_{12} = |y_1 - y_2| > 3$$

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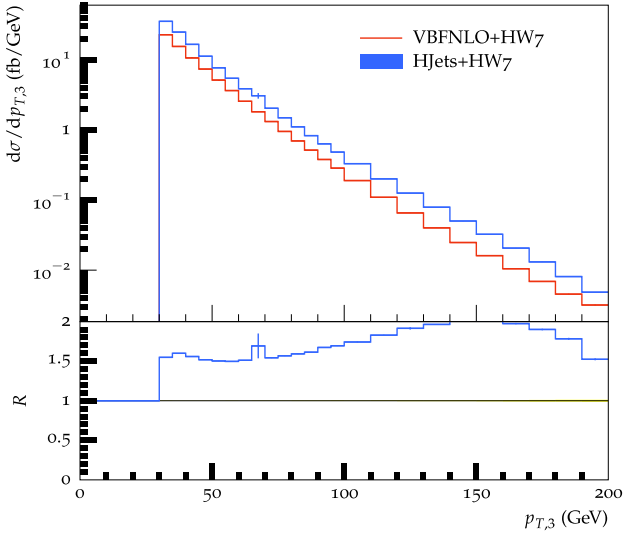
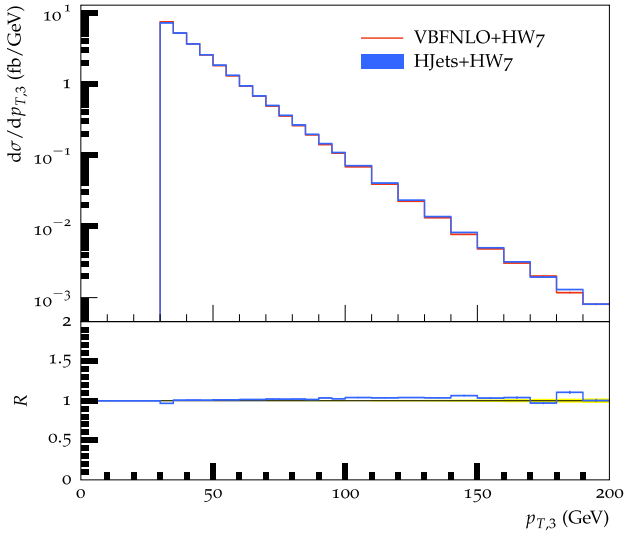
LO Comparison to VBFNLO

Inclusive Cuts



VBF cuts



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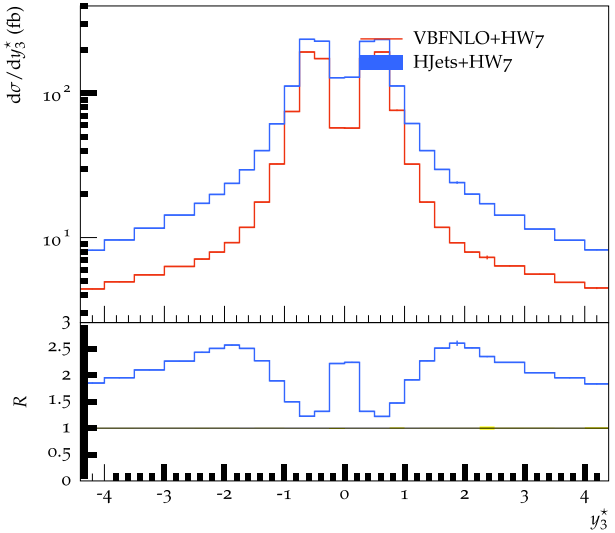
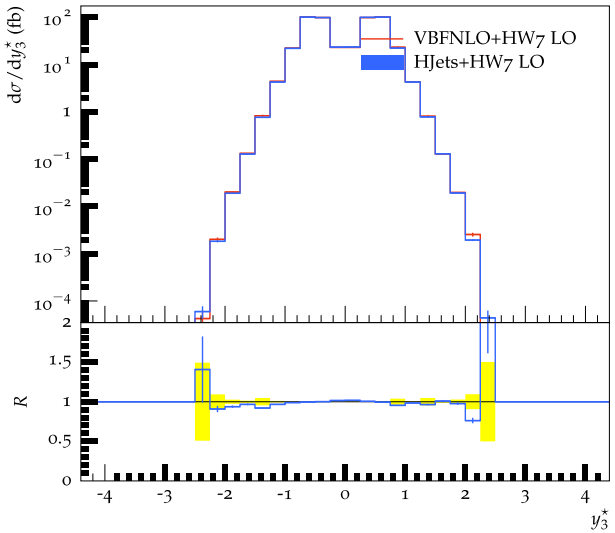
LO Comparison to VBFNLO

Inclusive Cuts



VBF cuts



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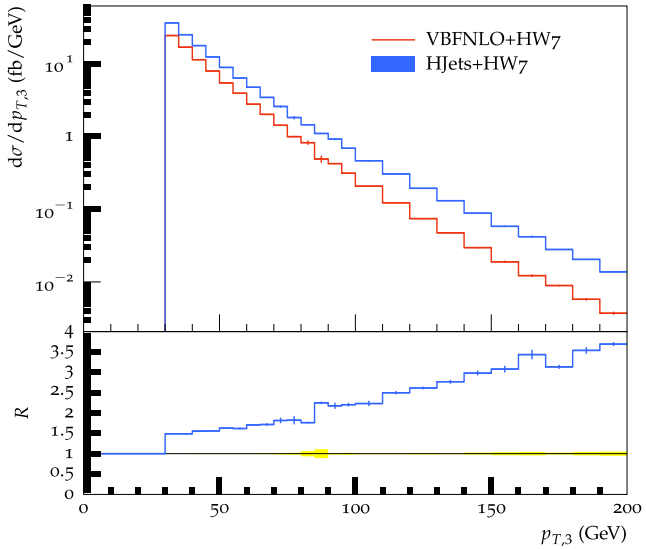
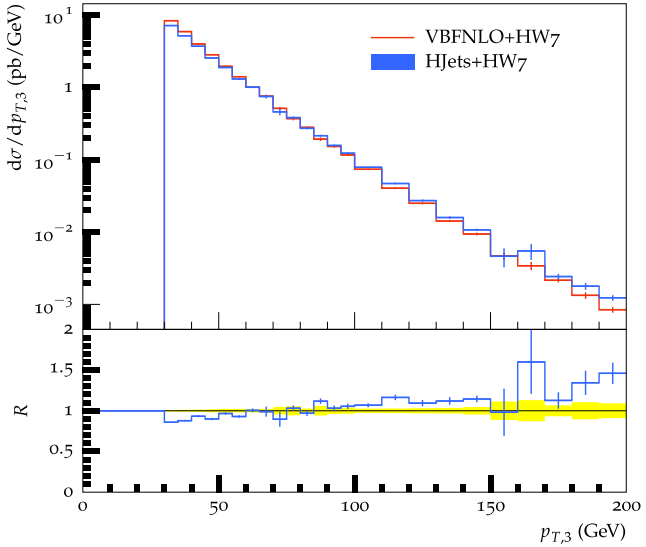
NLO Comparison to VBFNLO

Inclusive Cuts



VBF Cuts



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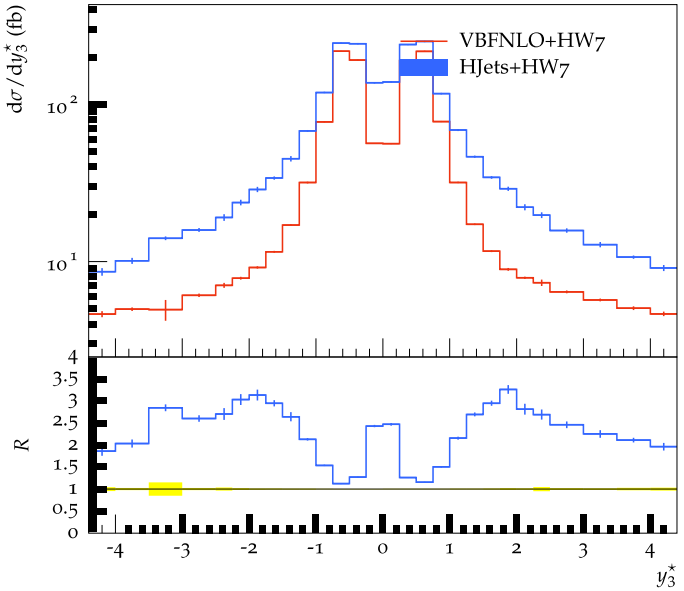
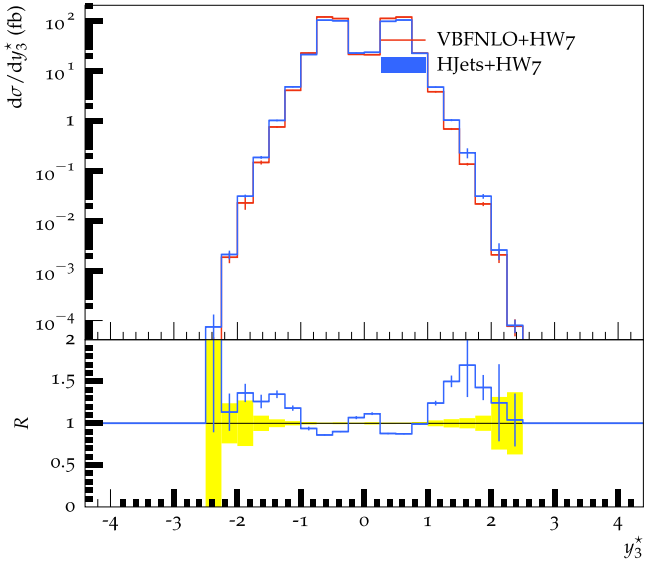
NLO Comparison to VBFNLO

Inclusive Cuts



VBF Cuts



NLO+Parton Shower Results

- Compared HJETS++ with POWHEG BOX at the level of NLO+PS.
- Deviations between the results of HJETS++ and POWHEG BOX due the various approximations implemented in POWHEG BOX. (The core matrix elements in POWHEG BOX are essentially taken from VBFNLO).

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NLO+Parton Shower Results

- Collider Energy and Cuts used: Anti-kt jet clustering with R=0.4

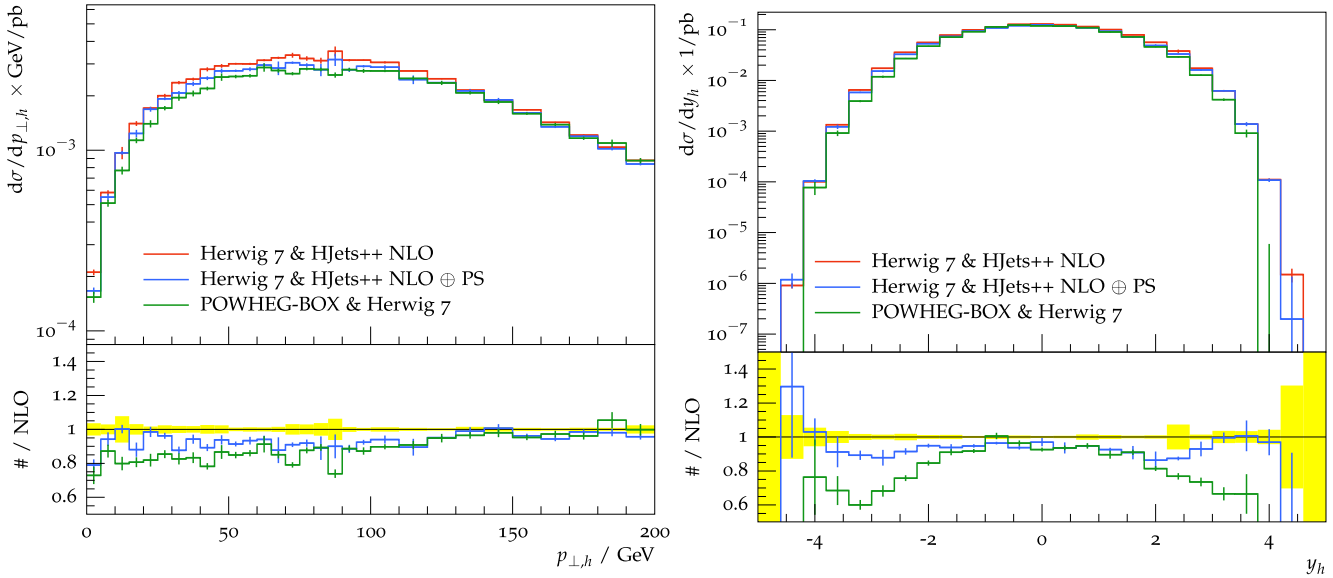
$$\sqrt{S} = 13 \text{ TeV}$$

$$|y_j| < 5.0 \qquad p_{\mathrm{T}j} > 20 \text{ GeV}$$

$$m_{jj} > 130 \text{ GeV} \qquad \Delta y_{jj} > 3.0$$

- PDF set: four flavor CT10
- Results included in the “Handbook of LHC Higgs Cross Section: 4”, LHC HXWG, arXiv:1610.07922.

NLO+Parton Shower Results



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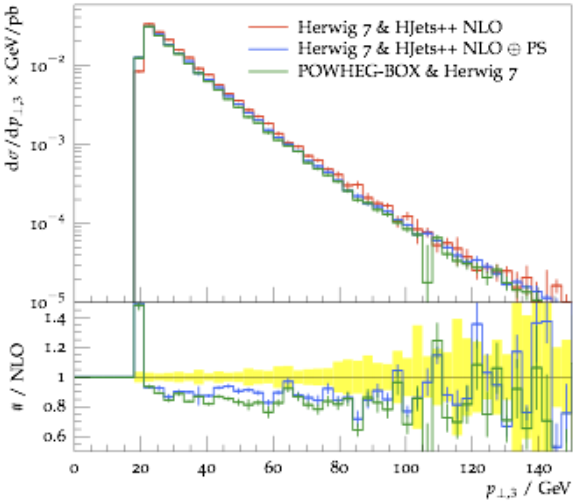
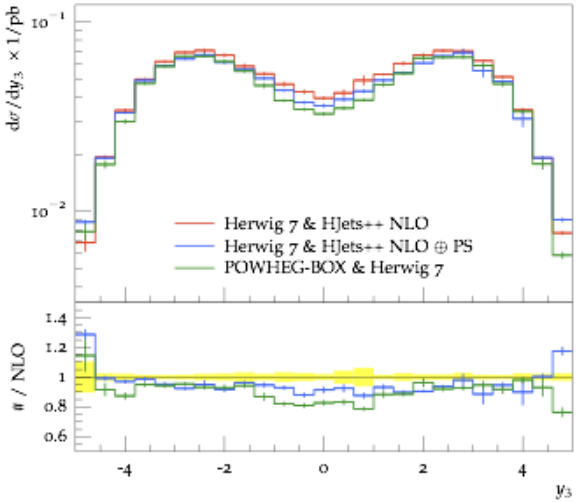
NLO+Parton Shower Results





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Conclusions

- I have discussed the implementation of the full NLO QCD corrections for electroweak Higgs boson production in association with three jets at the LHC within the Matchbox framework of Herwig 7.

- Kinematic distributions have been presented at fixed order at NLO and at NLO+PS.
- Questions?

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