

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

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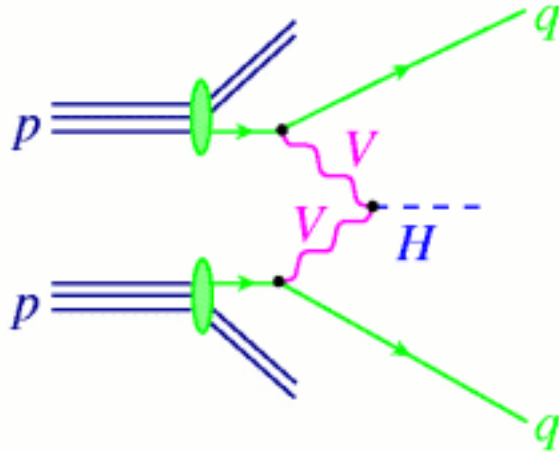
Higgs plus dijets at the  
LHC

Jan 10, 2018



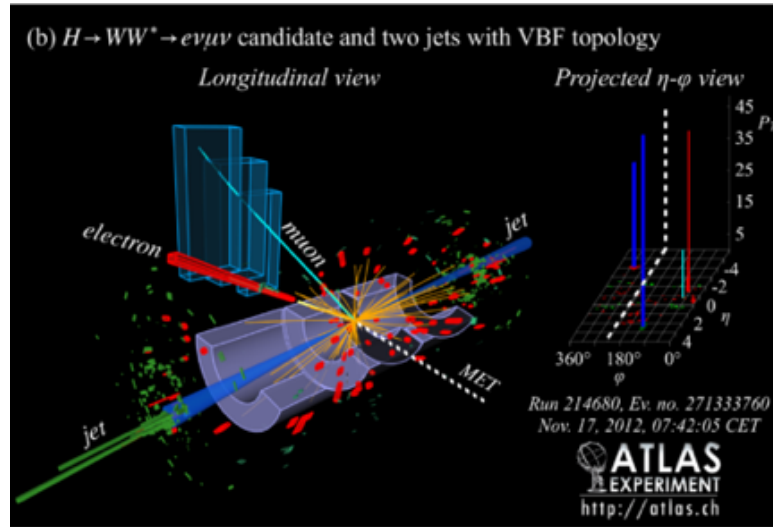
WICHITA STATE  
UNIVERSITY

# Vector Boson Fusion



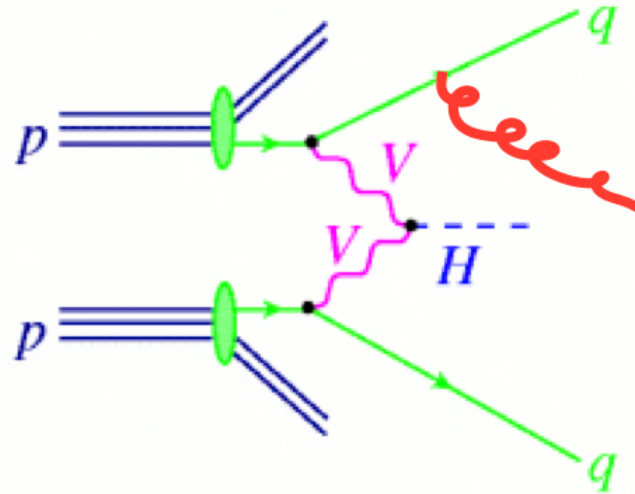
- Energetic jets in the forward/backward directions.
- Higgs decays products in central rapidity region.
- Suppressed QCD radiation in central rapidity region.

# Vector Boson Fusion

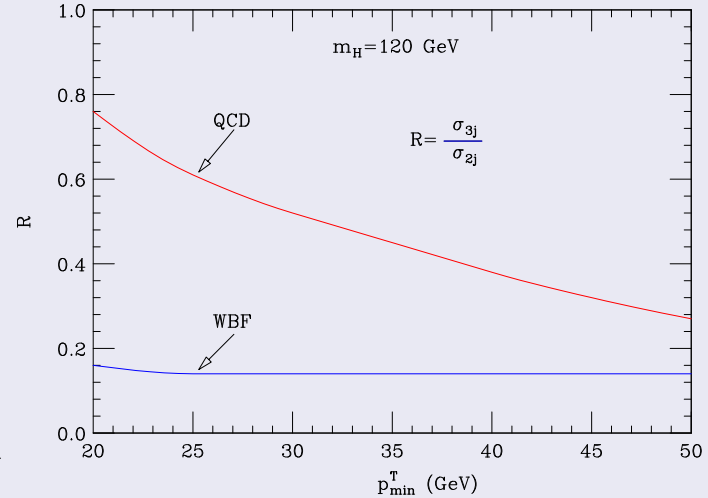
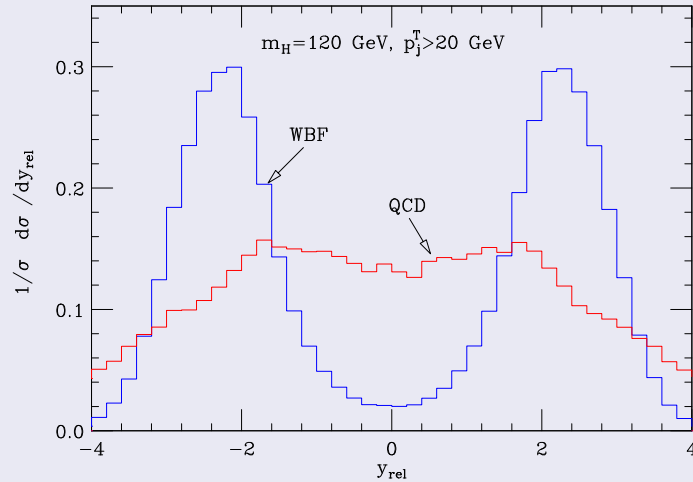


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# Vector Boson Fusion + Jet



# Vector Boson Fusion + Jet

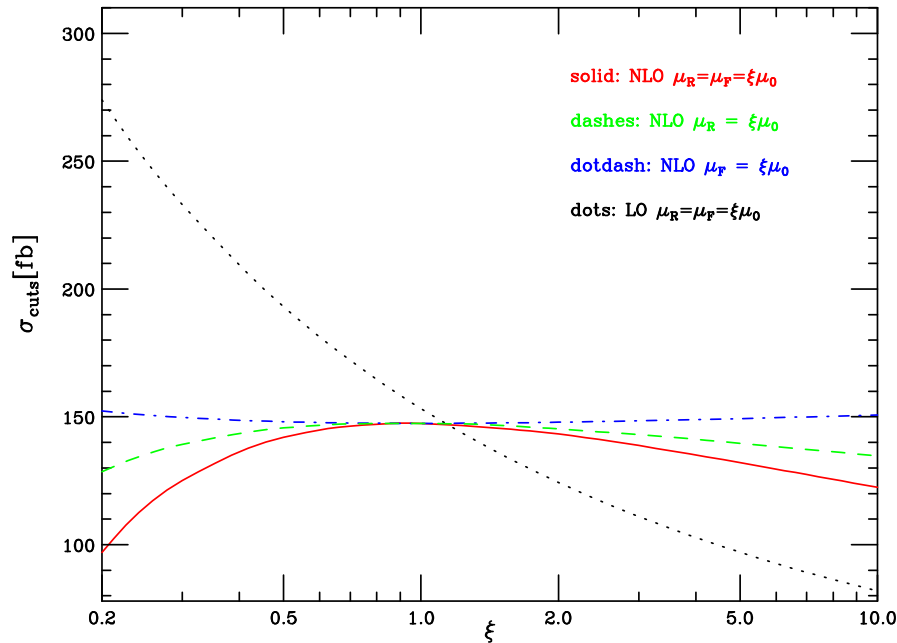


JHEP 05 (2004) 064

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

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

## Total Cross Section

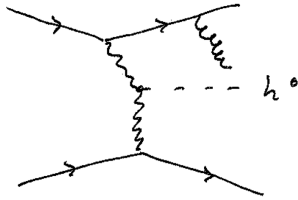


### Scale Variations:

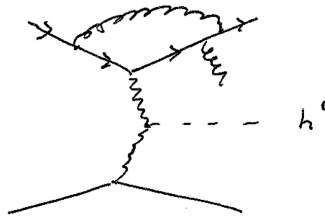
- LO: +26% to -19%
- NLO: less than 5%

JHEP 0802 (2008) 076 [arXiv:0710.5621]

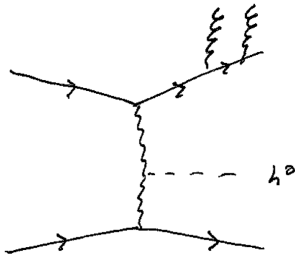
# H+3 Jets via VBF (only t-channels)



LO



NLO virt.

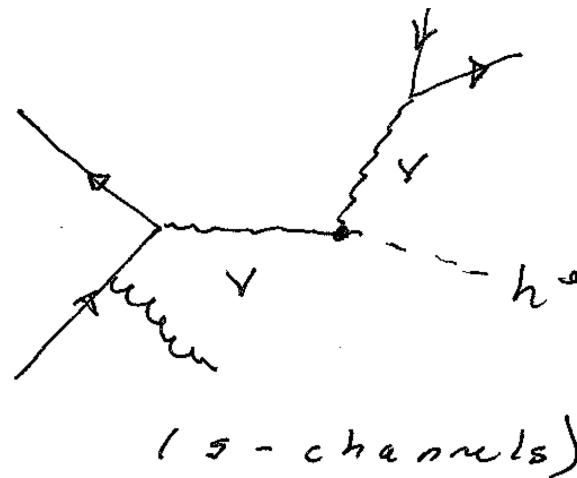
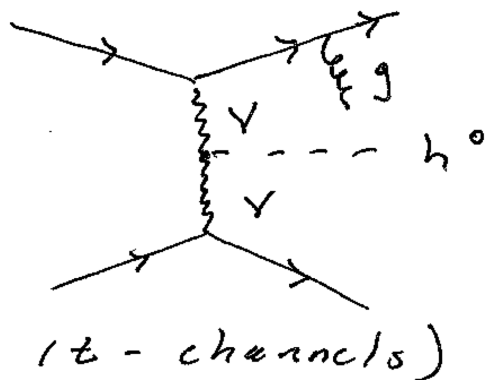


NLO Real

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

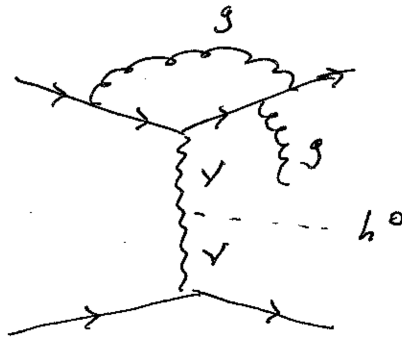
JHEP 0802 (2008) 076 [arXiv:0710.5621]

# Going for all of it: EW H+3 Jets

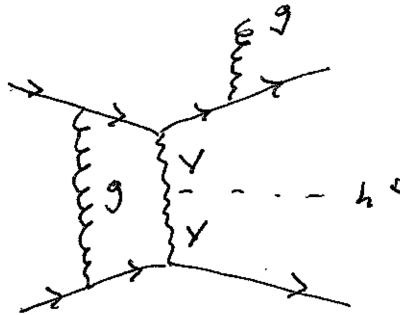




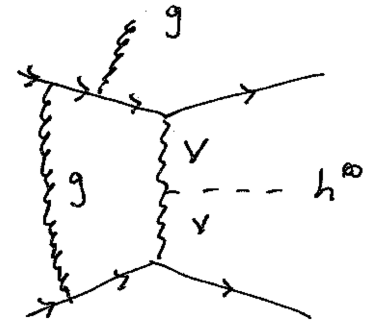
# Going for all of it: EW H+3 Jets



box lines



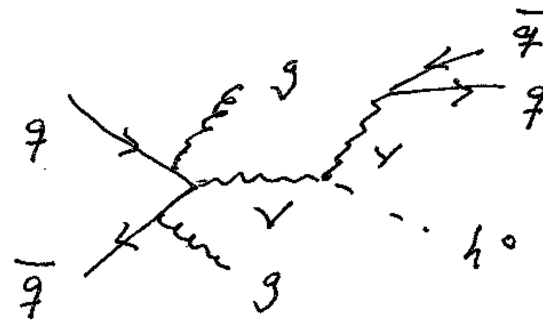
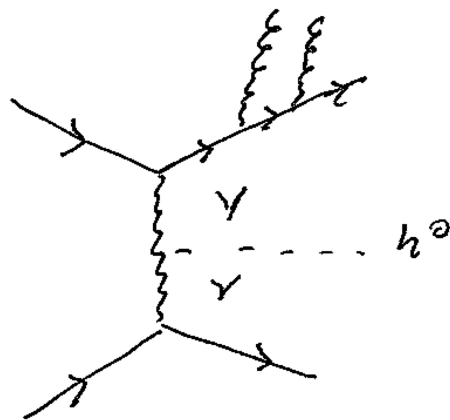
pentagons



hexagons

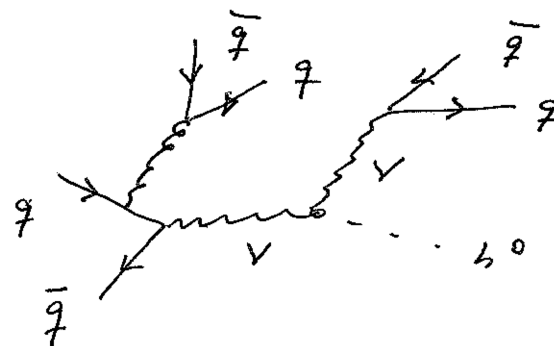
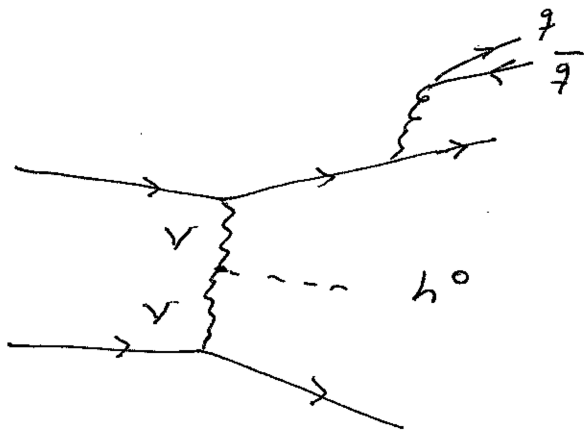
Virtual Corrections

# Going for all of it: EW H+3 Jets



Real Corrections

# Going for all of it: EW H+3 Jets



# EW H+3 Jets: Implementation Details

F. Campanario, 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. Campanario, 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 ( $M_W$ ) and sum of transverse momentum of reconstructed jets (HT)

# Notation:

$y_i$ : rapidity

$\phi_i$ : azimuthal angle

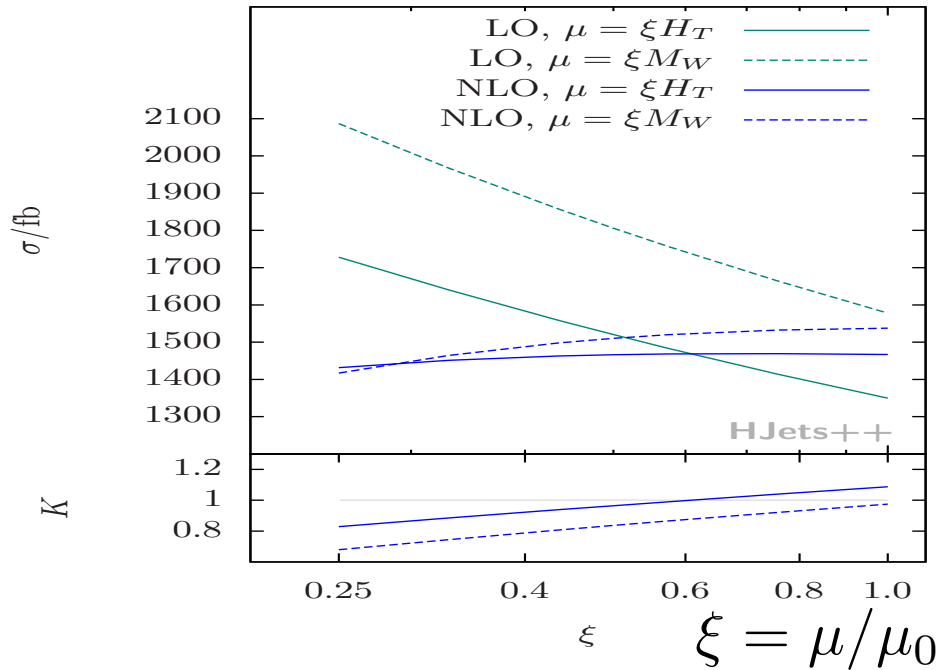
$p_i$ : four momentum vector of  $i$

$\Delta y_{ij} = |y_i - y_j|$ : 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



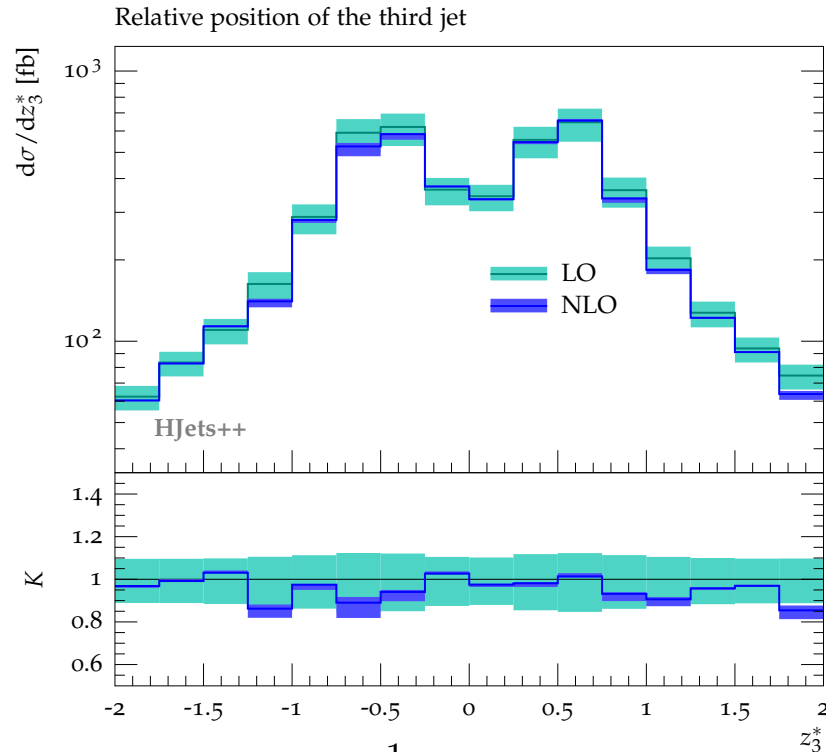
$$K = \sigma_{NLO}/\sigma_{LO}$$

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

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



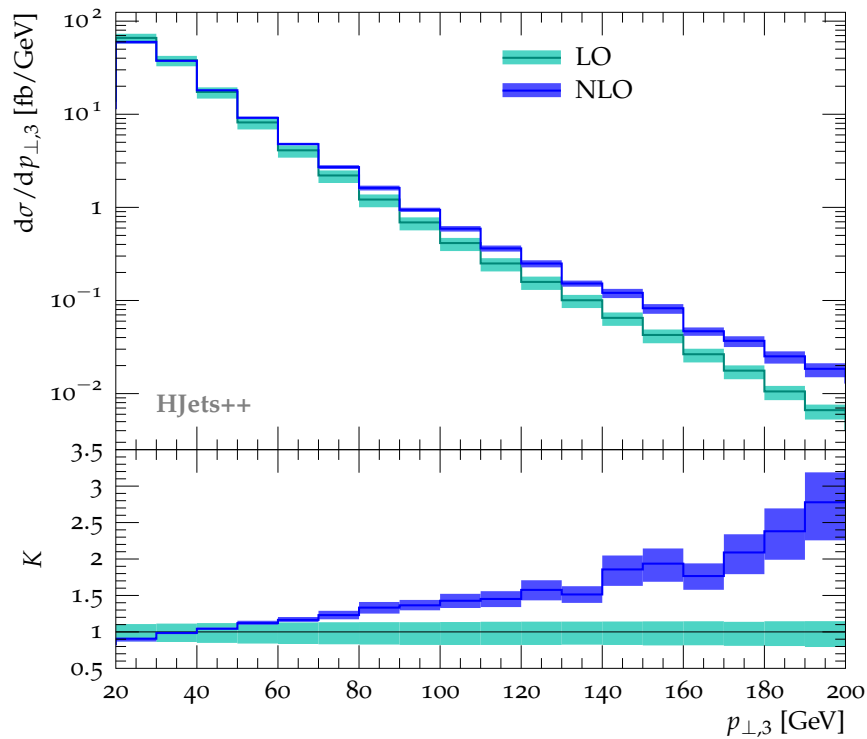
# EW H+3 Jets: The Third Jet



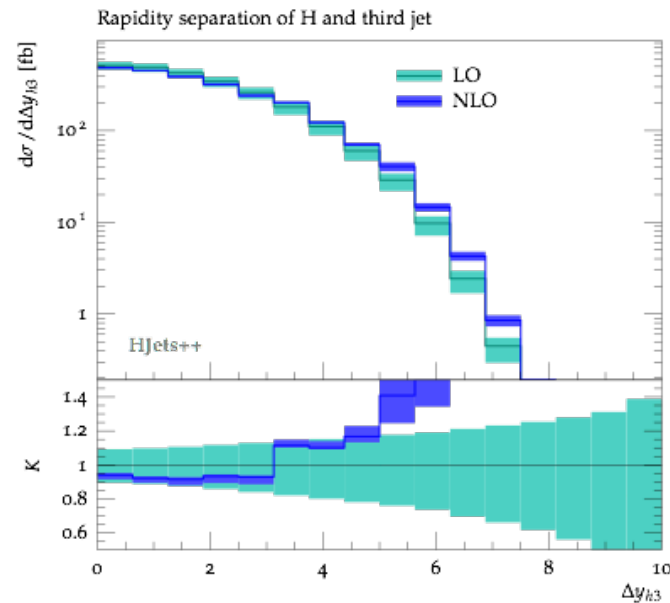
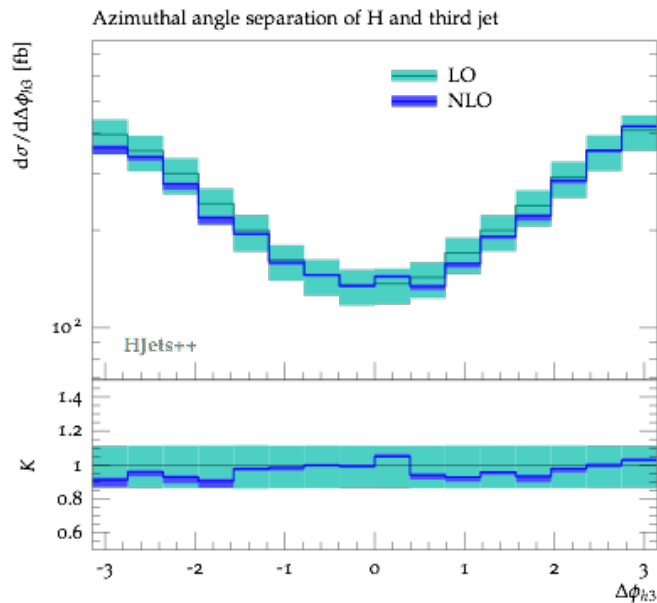
$$z_3^* = (y_3 - \frac{1}{2}(y_1 + y_2))/(y_1 - y_2)$$

# EW H+3 Jets: The Third Jet

Transverse momentum of third jet.



# EW H+3 Jets: Higgs Boson



# Comparison to VBFNLO

In collaboration with Simon Platzer, Peter Schichtel, Michael Rauch, Malin Sjordahl, and Francisco Campanario

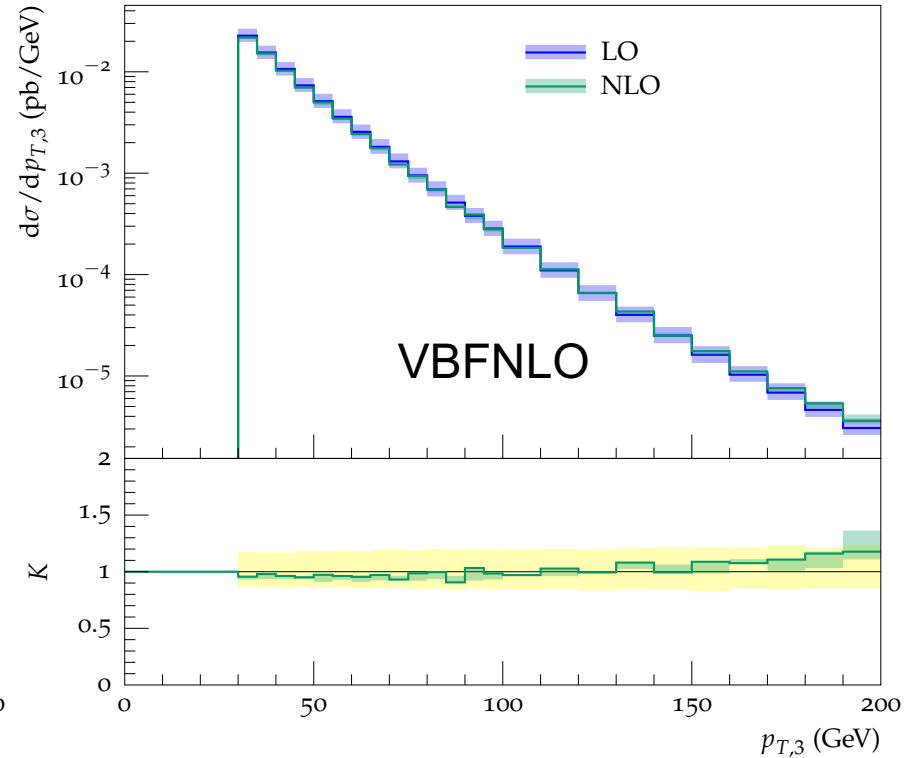
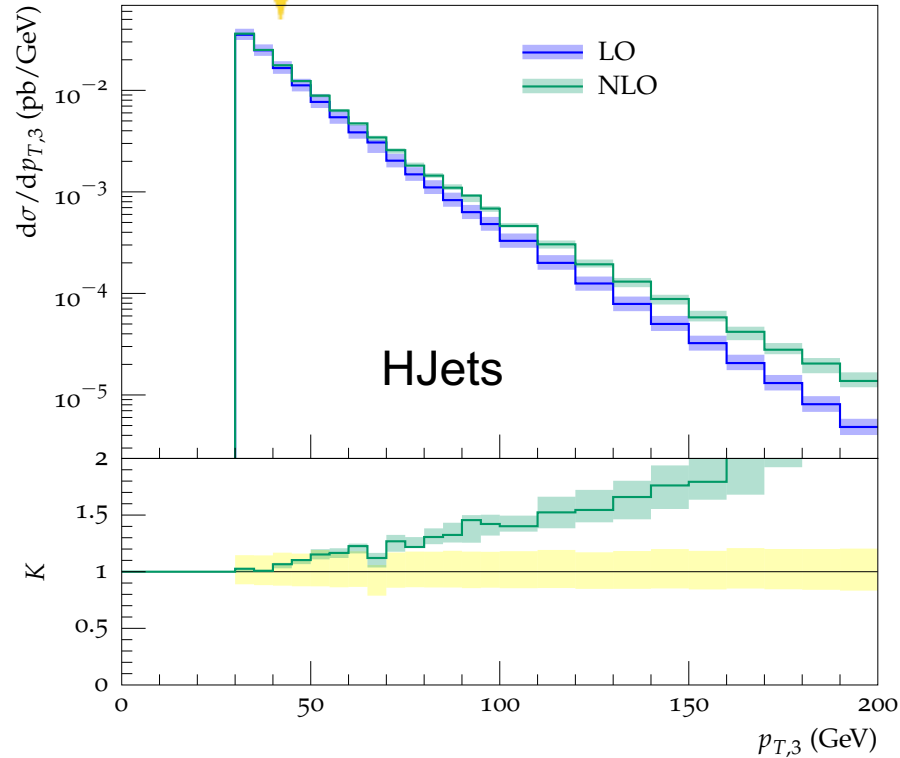
- Collider Energy and Cuts used: Anti-kt jet clustering with  $R=0.4$

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

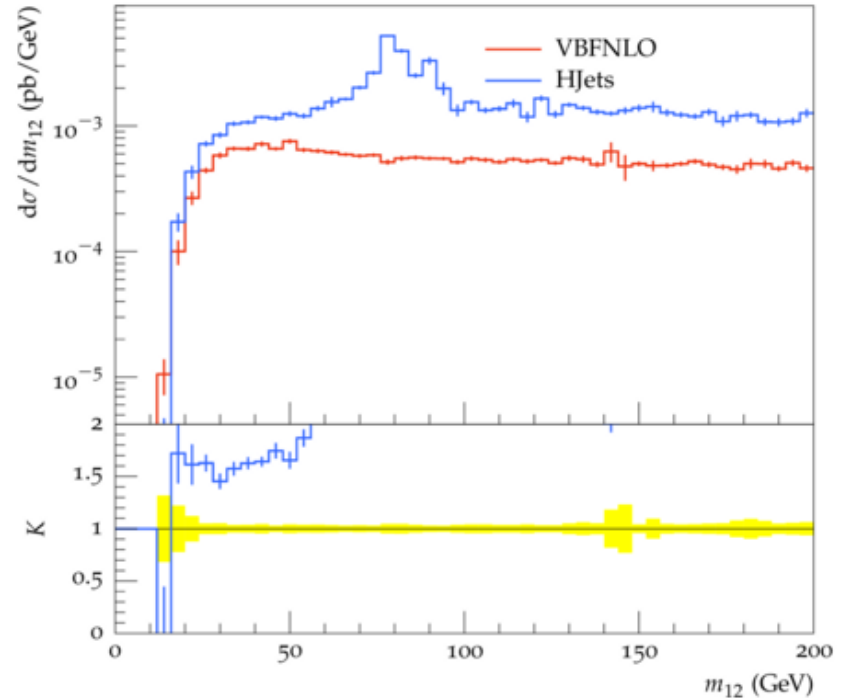
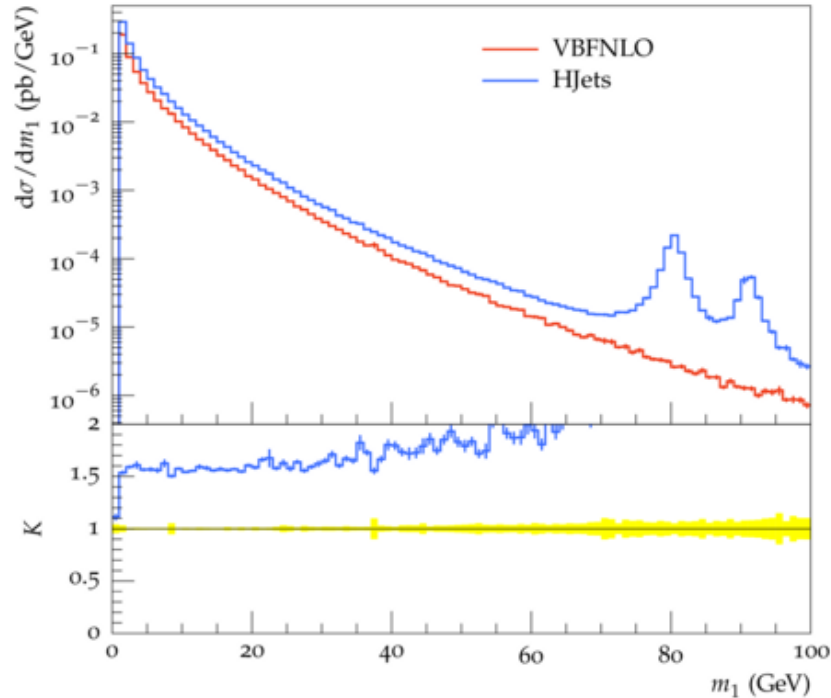
$$p_{Tj} > 30 \text{ GeV} \quad |y_j| < 4.4$$

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

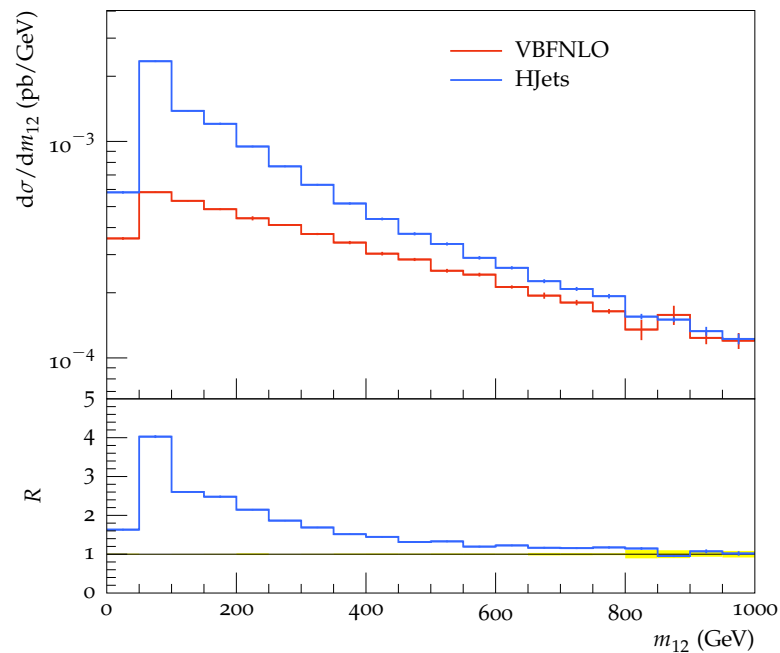
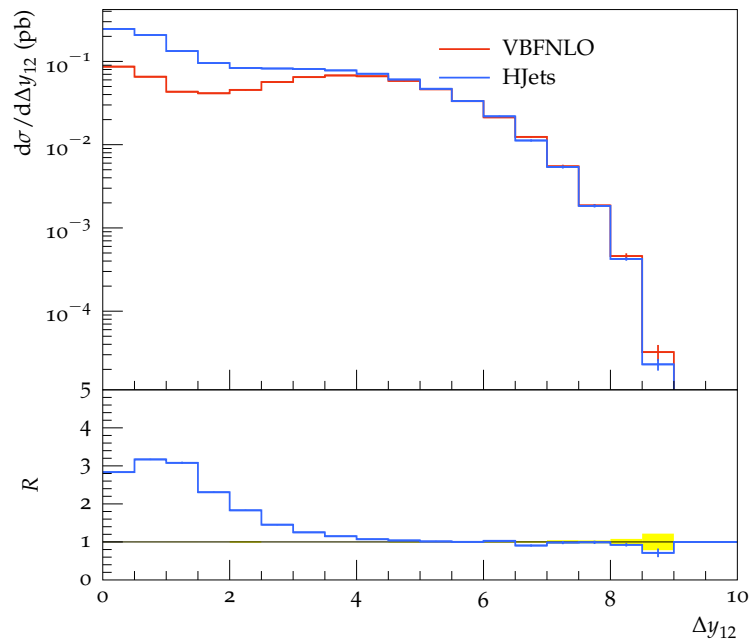
# Comparison to VBFNLO: Inclusive Cuts



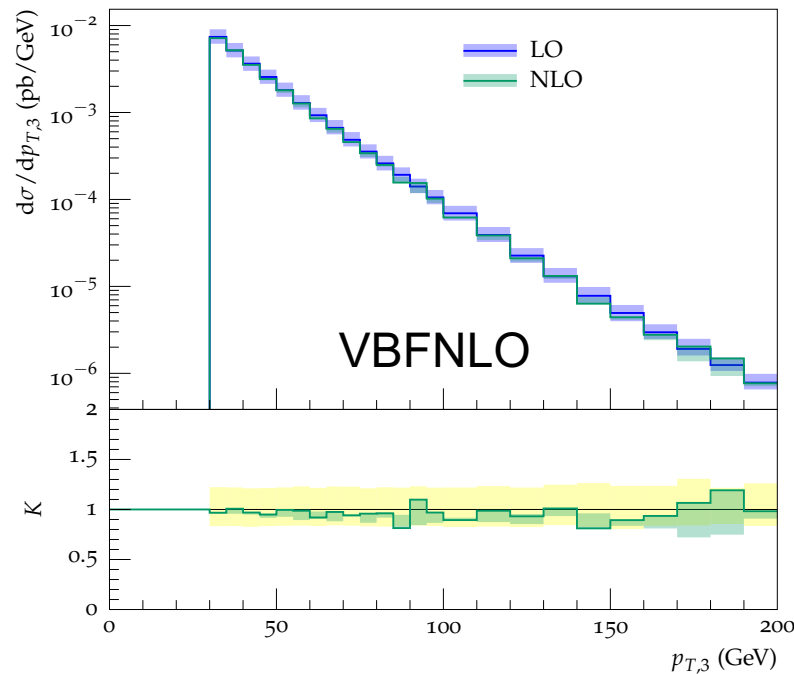
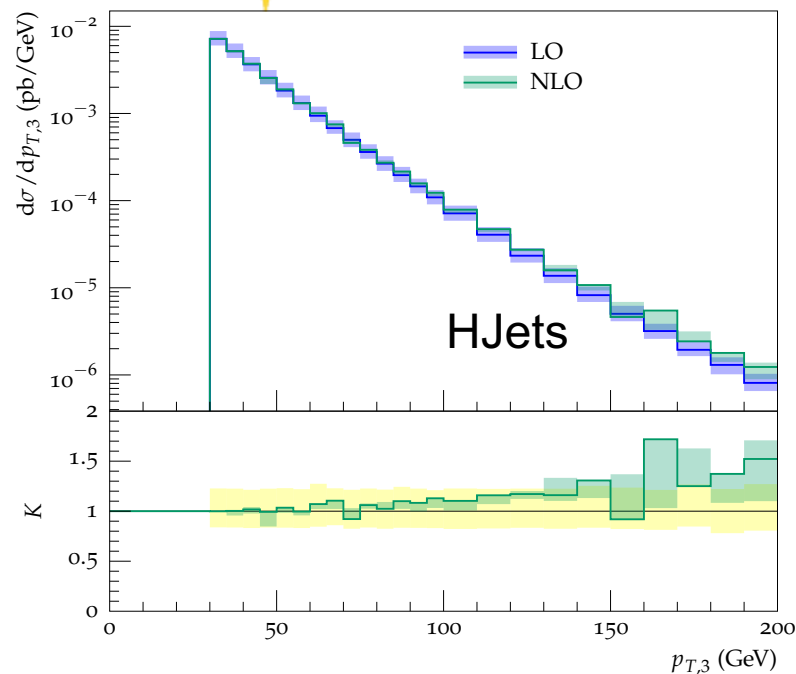
# Comparison to VBFNLO: Inclusive Cuts



# Comparison to VBFNLO: VBF cuts



# Comparison to VBFNLO: VBF cuts

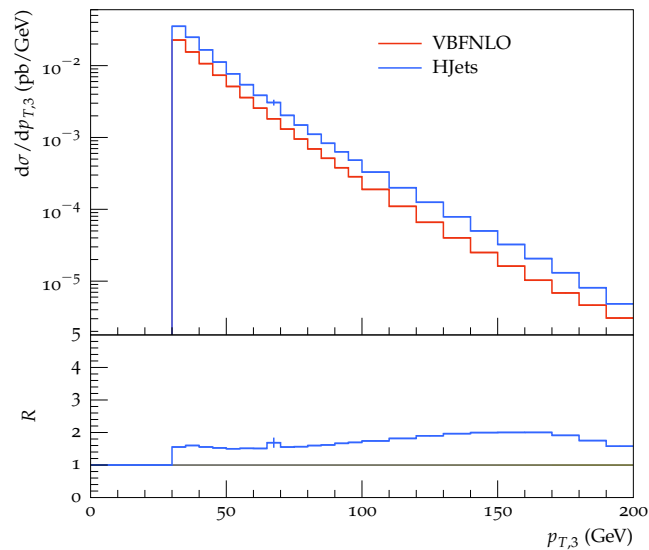


VBF Cuts:  $m_{12} > 600 \text{ GeV}$   $\Delta y_{12} = |y_1 - y_2| > 3$

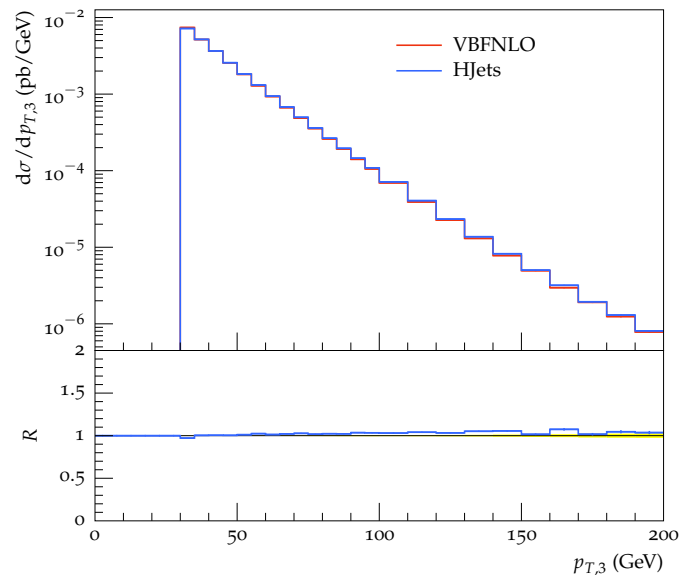


# LO Comparison to VBFNLO

## Inclusive Cuts

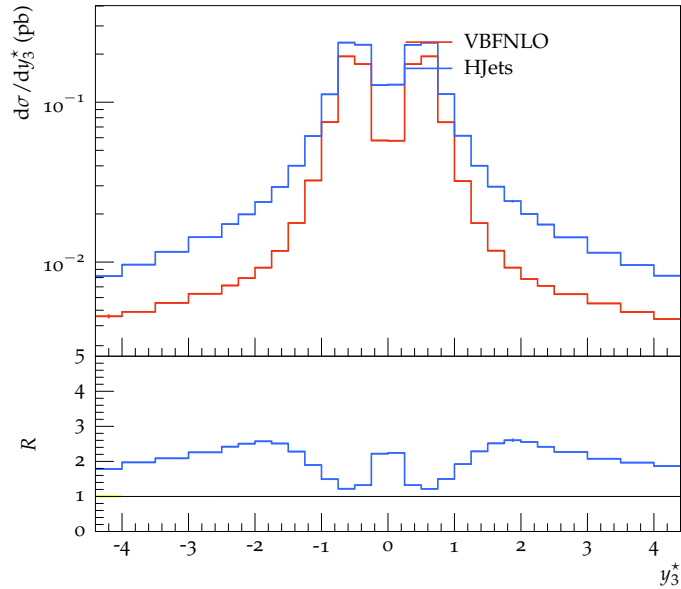


## VBF cuts

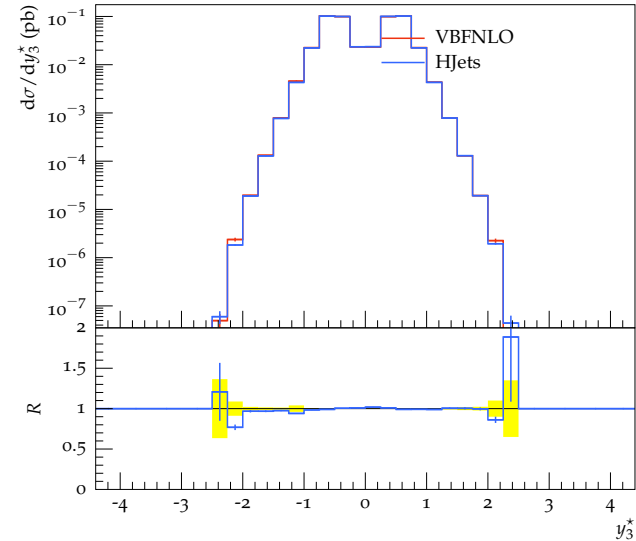


# LO Comparison to VBFNLO

## Inclusive Cuts

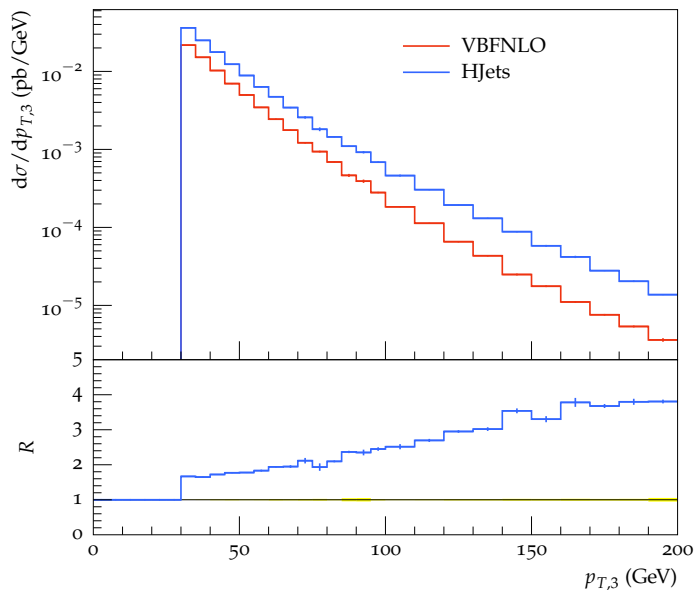


## VBF cuts

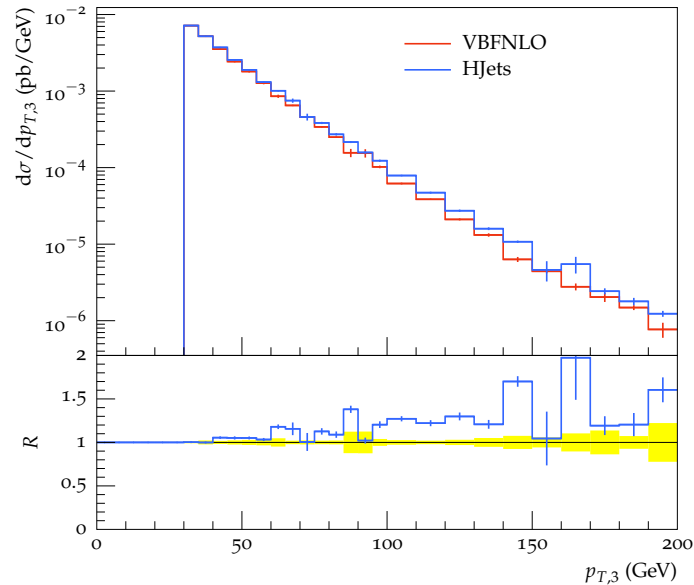


# NLO Comparison to VBFNLO

## Inclusive Cuts

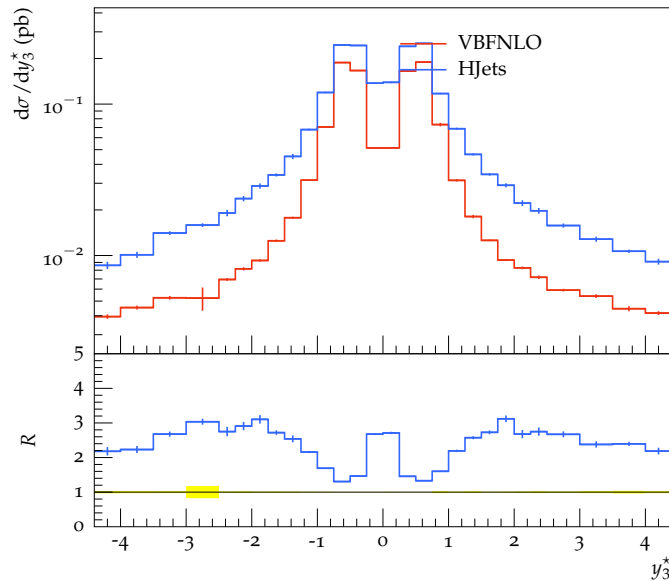


## VBF Cuts

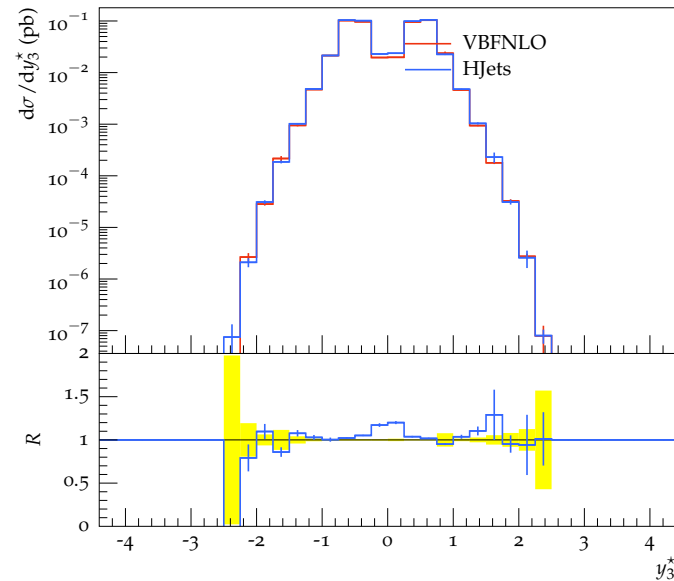


# NLO Comparison to VBFNLO

## 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).

# NLO+Parton Shower Results

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

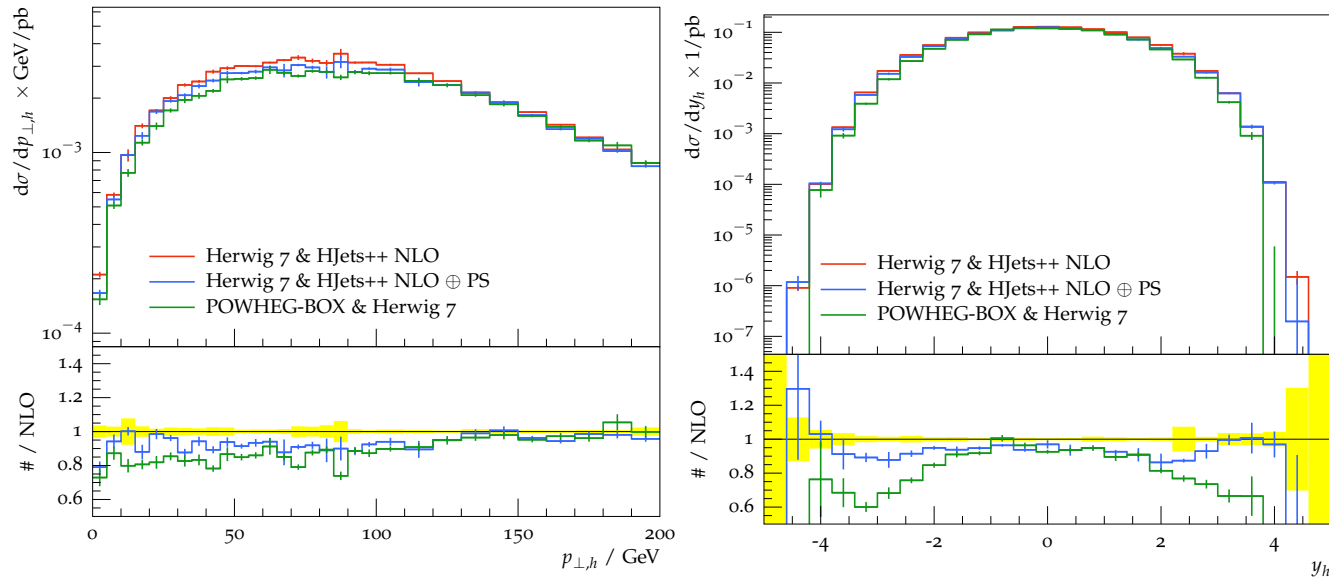
$$\sqrt{S} = 13 \text{ TeV}$$

$$|y_j| < 5.0 \qquad p_{Tj} > 20 \text{ GeV}$$

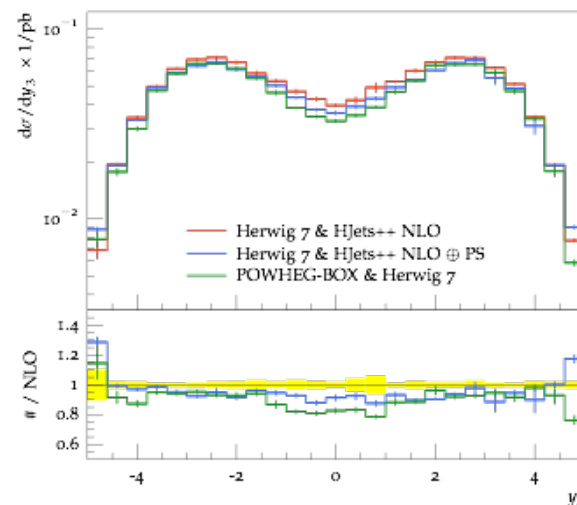
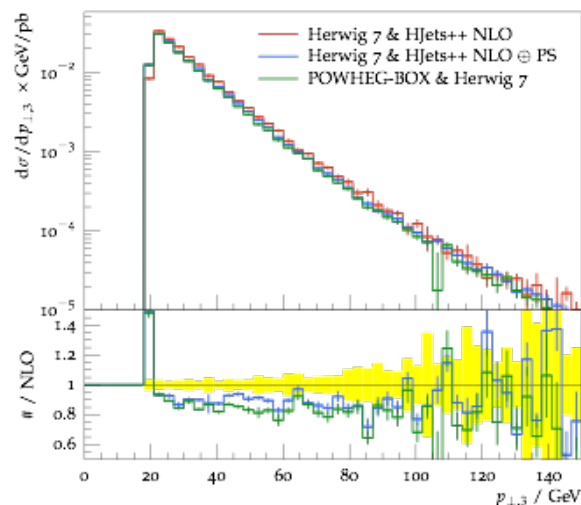
$$m_{jj} > 130 \text{ GeV} \qquad \Delta y_{jj} > 3.0$$

- 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



# NLO+Parton Shower Results





# 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?

# Auxiliary Slides

