ELECTROWEAK HIGGS BOSON PRODUCTION IN ASSOCIATION WITH THREE JETS (A.K.A. VBF + 1 JET) AT NLO QCD

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OUTLINE

- Introduction
- Details of calculation
- Results
- Outlook

Total SM Higgs cross sections at the LHC



Total SM Higgs cross sections at the LHC



Vector Boson Fusion



Event Characteristics

- Energetic jets in the forward and backward directions $(p_T > 20 \text{ GeV})$
- Higgs decay products between tagging jets
- Little gluon radiation in the central-rapidity region, due to colorless W/Z exchange (central jet veto: no extra jets with $p_T > 20$ GeV and $|\eta| < 2.5$)

Vector Boson Fusion Central Jet Veto

Example: Gluon fusion vs vector boson fusion



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

Hiji via VBF at NLO (only t-channels) Total Cross section



HJETS++

- Our aim was to compute the missing pieces (s, t, and u-channel one-loop amplitudes) in H+3 Jets production where the Higgs boson is produced via the HVV coupling (a.k.a VBF+Jet).
- Virtuals: Hexagons, Pentagons, Boxes, and Triangles
- Reals: H+6 parton amplitudes (6 quark + H, 4 quark + 2 gluons +H)



$$\begin{split} & \mathcal{C}_{ab}^{NLO}(p,\bar{p}) = \sigma_{ab}^{NLO\{4\}}(p,\bar{p} + \sigma_{ab}^{NLO\{3\}}(p,\bar{p}) \\ & + \int_{ab}^{+} dx [\hat{\sigma}_{ab}^{NLO}]^{3}(x,xp,\bar{p}) + \hat{\sigma}_{ab}^{NLO\{3\}}(x,p,x\bar{p})] \\ & \sigma_{ab}^{NLO\{3\}}(p,\bar{p}) = \int_{3} [d\sigma] f_{b}^{b}(p,\bar{p}) + d\sigma_{ab}^{B}(p,\bar{p}) \otimes \mathbf{I}]_{\epsilon=0} \\ & \int_{0}^{1} dx \hat{\sigma}_{ab}^{NLO[3]}(x,xp,\bar{p}) = \sum_{a',0} \int_{0}^{1} dx \int_{3} [d\sigma_{ab}^{F}(xp,\bar{p})] \\ & \otimes [\mathbf{P}(x) + \mathbf{K}(x)]^{a'}]_{\epsilon=0} \end{split}$$

For the H+2,3, and 4 jet amplitudes we use the in-house spinor library of Matchbox.

HJETS++

- 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://home.thep.lu.se/~malin/ ColorMath.htm#ColorMath, ColorFull will soon be public.]
- Tensorial Reduction [F. Capanario, arXiv:1105.0920]
- Scalar Loop Integrals: OneLOop [A. van Hameren arXiv:1007.4716]

THE RESULTS

- Input parameters and selection cuts.
- Scale variations for total cross section.
- Kinematic distributions.

INPUT PARAMETERS

- Ecm=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)

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*

Scale Variations on Integrated Cross-sections



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

 $\sigma_{LO} = 1520(8)^{+208}_{-171}$ fb

 $\sigma_{NLO} = 1466(17)^{+1}_{-35}$ fb

JET DISTRIBUTIONS





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

Rapidity separation





 Δy_{23}

Higgs Boson Distributions





Transverse momentum

Rapidity

Higgs Boson Distributions



Jet Masses







H+3 JETS AND H+2 JETS



Distributions with VBF cuts





Mass of first and third jet

- $m_{j_1 j_2} > 600 \text{ GeV}$ $\Delta y_{j_1 j_2} > 4.0$

Distributions with VBF cuts





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Distributions with VBF cuts





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- $m_{j_1 j_2} > 600 \text{ GeV}$ $\Delta y_{j_1 j_2} > 4.0$



Mass of the third jet







OUTLOOK

- NLO + Parton Shower matching
- Perform comprehensive phenomenology for Run 2
- Matching H+2 jets and H+3 jets to parton shower

Parton-shower effects on Higgs boson plus 3 jets (arXiv:1405.6950) [Jager, Schissler, Zeppenfeld]



Comparison to VBFNLO

