VBF working group activity report

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The 18th Workshop of the LHC Higgs Working Group - 01.12.2021-03.12.2021

Introduction

- e-group: lhc-higgs-vbf: please subscribe!
- A twiki page is available to document group activity:
  https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWGVBF
- Please welcome Stephane and Mathieu as the new VBF conveners
- Roadmap for the VBF group
  - Theory inputs needed by the LHC Higgs analyses
  - Focus on major studies to be released in short/middle-long timescale (up to 1 year)
  - We tried to gather a list of topics of interest
  - Additional suggestions are welcome !!!

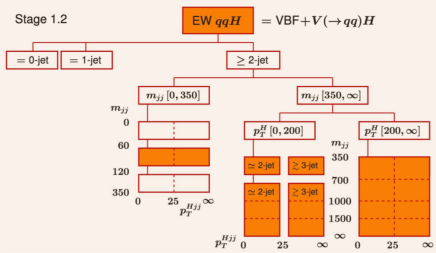
Completed topics

- Stage 1.2 Simplified Template Cross-Sections uncertainties:
  - VBF + V(qq)H uncertainties implemented in a standalone tool here
  - Acceptance and uncertainties estimated with full EW H+2j calculation
  - HAWK NLO EW correction available across the stage 1.2 bins (additional studies required)
  - See also slides for more information

Stage 1.2 Simplified Template Cross-Sections uncertainties

- Acceptances updated using HJets + Herwig7
- What to use for the uncertainty sources ?
  - In HJets and POWHEG, the 3rd jet is generated at LO and from PS, hence the HJets/POWHEG QCD scale uncertainties in the bins are not reliable
    $\rightarrow$ Should be estimated from FO or PS scale variations
- Hybrid sources solution:
  - S-channel contribute only in the low Mjj region so HJets can be used for Δ60-120 and Δ1-2
  - FO can then be used for Δ25, Δ200 and Δ350-1500

obs	source	FO (NNLO)	POWHEG (NLO)	HJets (NLO)	Hybrid
-	Δ_{tot}	14.972	15.131	21.539	21.539
p_T^H	Δ_{200}	0.622	1.081	2.989	0.622
M_{jj}	Δ_{60}	8.057	9.511	8.003	8.003
	Δ_{120}	6.840	8.286	13.446	13.446
	Δ_{350}	7.389	5.025	5.385	7.389
	Δ_{700}	4.201	5.973	8.158	4.201
	Δ_{1000}	3.115	3.545	7.045	3.115
	Δ_{1500}	1.764	2.614	6.404	1.764
p_T^{Hjj}	Δ_{25}	27.387	2.674	35.460	27.387
$p_T^{j1,2}$	$\Delta_{1/2}$	17.355	18.617	33.412	33.412

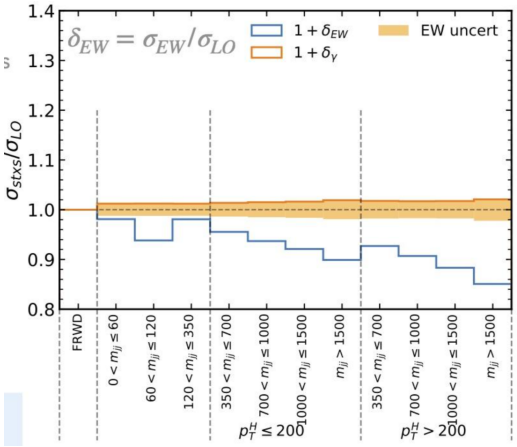


- 10 nuisances accounted
- 1 yields uncertainty on the inclusive cross-section, + 9 migration uncertainties:
  - for the 2 jets requirement
  - for cut
  - cut on for 2 to 3 jets requirement
  - +6 NPs to describe spectrum

EWK corrections : EWK H+2 jets at Stage 1.2

- The state of the art calculation from HAWK 2.0 arxiv.org/abs/1412.5390
  - Provides complete NLO QCD and EWK corrections and includes *s*-channel and interferences
  - Provides predictions for partonic channels with incoming photons as part of NLO EW corrections (*NNPDF 3.1 luxqed*)
- EW corrections order of 5-10 % in VBF production
- Enhanced electroweak corrections at high energies: driven by Sudakov $\log\alpha \to \alpha\log(Q/M_W)$ at high Higgs p_T tail
- Uncertainty estimated following the same prescription as in the Yellow Report 4

$$\Delta_{EW} = max(0.5\%, \delta^2_{EW}, \sigma_\gamma/\sigma_{VBF})$$



- Proposal for uncertainty scheme:
  - Since EW correction is driven by Sudakov log, consider δ^2_{EW} as pure Sudakov effect : Δ_{sud}
  - σ_γ be considered as a separate nuisance for non-Sudakov effect : Δ_γ

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- Jet multiplicities merging and parton shower accuracy:
  - Default recoil scheme nonphysical for VBF/VBS processes. Local recoil can currently only be used with POWHEG.
  - The uncertainties are typically below 10%, and are dominated by differences in normalisation rather than shapes for most observables
  - Studies published in Eur.Phys.J.C 80 (2020) 8, 756

Jet multiplicities merging and parton shower accuracy

- Parton-shower effects in Higgs production via Vector-Boson Fusion arXiv:2003.12435
- Comparison NLO QCD+PS (with Herwig7 and Pythia8) and NNLO QCD (proVBFH)

generator	matching	SMC	shower recoil	used in Sec. 4.2
VBFNLO+Herwig7/Matchbox	$\oplus$	HERWIG 7.1.5	global ($\tilde{q}$) / local (dipole)	✓ ($\tilde{q}$)
HJets+Herwig7/Matchbox	$\oplus$	HERWIG 7.1.5	global ($\tilde{q}$) / local (dipole)	
MadGraph5_aMC@NLO 2.6.1	$\oplus$	HERWIG 7.1.2	global	✓
MadGraph5_aMC@NLO 2.6.1	$\oplus$	PYTHIA 8.230	global	
POWHEG BOX V2	$\otimes$	PYTHIA 8.240	local (dipole)	✓
POWHEG BOX V2	$\otimes$	PYTHIA 8.240	global	
POWHEG BOX V2	$\otimes$	HERWIG 7.1.4	global ($\tilde{q}$)	

Table 1. The various generators used in the comparisons throughout this paper and their respective settings. The column 'matching' refers to either MC@NLO ($\oplus$) or POWHEG ($\otimes$) style matching. For a more detailed discussion of the setup of the various generators please see sections 4.1.1–4.1.3. The last column indicates which setup is being used in the final comparison of Sec. 4.2.

Jet multiplicities merging and parton shower accuracy

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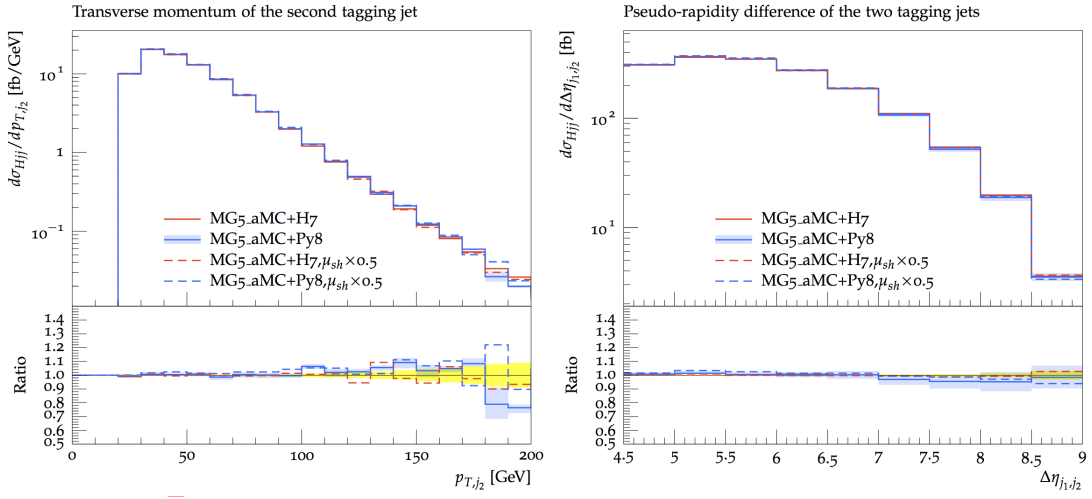

- For observables defined at LO, rather good agreement between different predictions

Jet multiplicities merging and parton shower accuracy

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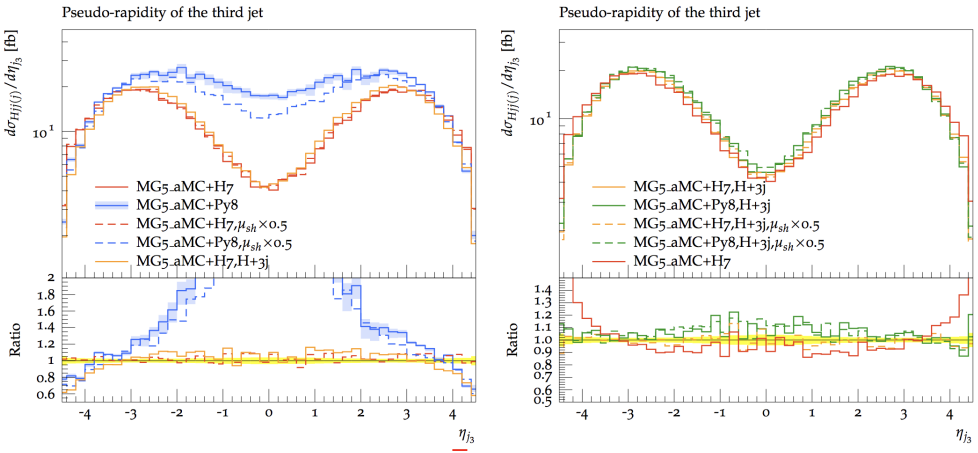
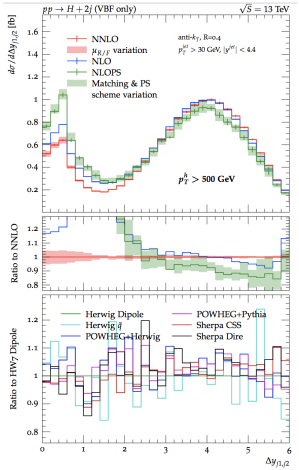


- Poor agreement for observables defined beyond LO (with higher corrections or with PS)
- Comparing with H+3j computation (truth): Pythia predictions off
- Default (global) recoil scheme of Pythia not appropriate (unphysical)

Jet multiplicities merging and parton shower accuracy

- Parton-shower effects in High p_T Higgs production via Vector-Boson Fusion arXiv:2105.11399
- Multi-jet merging of Higgs production via Vector-Boson Fusion arXiv:2109.03730; also studied in arXiv:2106.10987 at leading-order using Vincia and Pythia

arXiv:2105.11399



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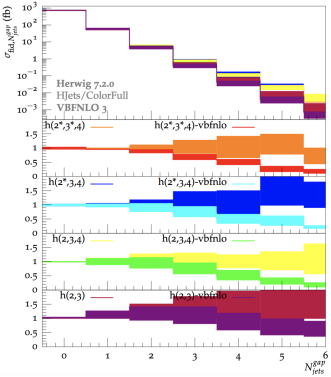

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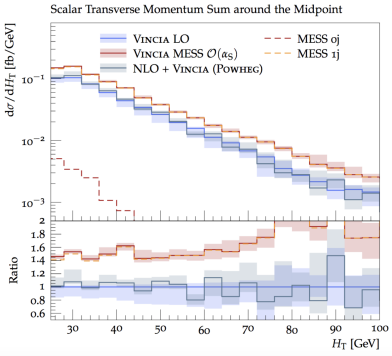
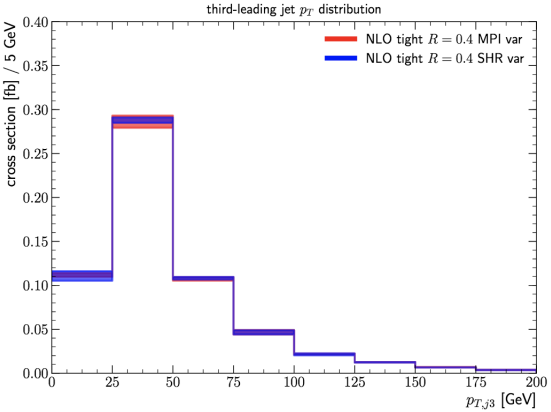
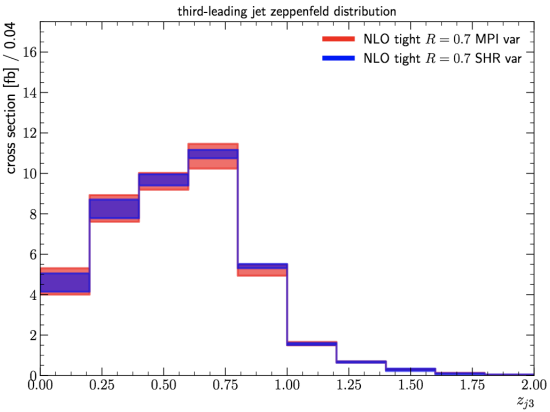


- Generators mostly consistent, but significant deviations from NNLO for high Higgs p_T
- Significant impact of VBF approximation and NLO corrections to higher multiplicities

Jet multiplicities merging and parton shower accuracy

- Effects of Multi-Parton Interactions (MPI) in VBF Z production arXiv:2110.01623



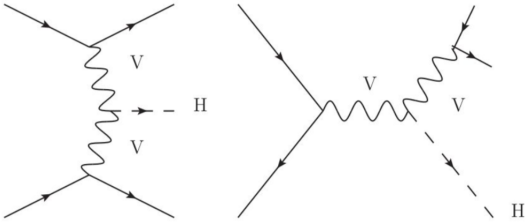


- MPI variations become comparable to shower variations in NLO matched prediction

Jet multiplicities merging and parton shower accuracy

- Several studies about Parton-shower effects in Higgs production via Vector-Boson Fusion

- Conclusions/Recommendations:
  - Theoretical uncertainties estimated by renormalisation and factorisation scale variations: small in *standard* VBF regions, but more studies needed in high Higgs p_T/ high jet multiplicity
  - Use dipole recoil scheme with compatible matching (Powheg) or use Herwig
  - Be careful about VBF approximation – might impact shower initial conditions even in presence of matching / merging
  - Multi-parton interactions, colour reconnection and hadronisation are also important



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- High Higgs p_T
  - First measurements of the high-p_T Higgs spectrum (above 0.5 TeV) are being published
  - Dedicated calculations to account for finite quark mass effects at higher orders in QCD and with additional jets are needed to be compared to data
  - Published in the HL-HLC yellow report and in ArXiv:2005.07762

Possible future directions

- Gluon-gluon Fusion (ggF) background:
  - Modelling
    - Best ggH background estimated using NNLOPS (2nd jet LO)
    - Recent work from HEJ suggests the cross-section is overestimated under VBF cuts
  - Uncertainties:
    - Large contamination of theory uncertainties from ggHjj in VBF phase-space
    - Large higher order QCD corrections to Higgs boson production in association with jets in ggF
    - Higher multiplicities (>2 jets) need to be considered in order to reach a reasonable theoretical accuracy (see sllides)
  - Closer collaboration with GGF and VH WG1 is required

- Higher-order corrections:
  - While NNLO QCD and NLO EWK exist at fixed order, no prescriptions are available on how to apply them to events generated after parton shower and underlying event simulation.

- Higgs Spin/CP in VBF:
  - The Higgs spin can be constrained by looking at VBF tagging jets
  - Preliminary studies available from LH2019 (ArXiv:2003.01700)

Possible future directions

- Anomalous couplings:
  - Prescription on how to re-weight existing simulations to NNLO QCD and NLO EWK without affecting the simulation precision
- Different signatures
  - VBF H + γ (probe of W/Z exchange, EW corrections)
  - Exploring new signatures
  - VBF vs. VBS (off/on-shell, EW corrections, Higgs width)
- Higher-order corrections and uncertainties:
  - NLO QCD+EW for VBH + 1j
  - NLO QCD+EW matched to PS
  - Impact of soft QCD
- Your Ideas !!!

Any questions? Comments?

If you have ideas or suggestions,
please speak out or contact us directly!

NB: VBF meeting planned for January/February Presentation of new results + discussions of projects