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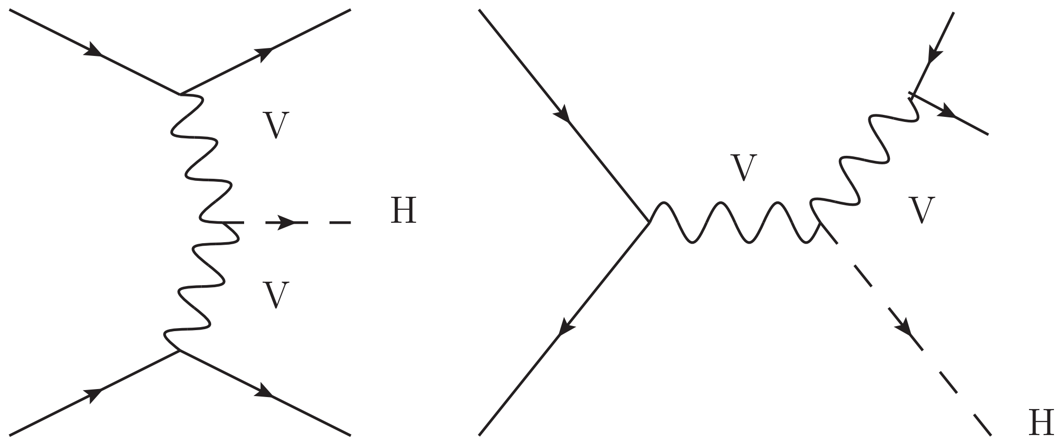

Parton-Shower Effects in Higgs Production via Vector-Boson Fusion

Work done in collaboration with Barbara Jäger, Alexander Karlberg, Simon Plätzer and Marco Zaro (Eur. Phys. J. C 80 (2020) 8, 756)

26.05.2021, Johannes Scheller

Outline

- Introduction
- Setup of the calculation
- The VBF Approximation
- Discussion of generator-specific uncertainties
  - Intrinsic uncertainties in `MadGraph5_aMC@NLO`
  - Intrinsic uncertainties in `POWHEG`
  - Intrinsic uncertainties in `Herwig7/Matchbox`
- Comparison of the different generators

Introduction

- Discussions about parton shower (PS) uncertainties going on for some years in the community
- Theory uncertainties dominating in VBF channel
- Special interest in behavior of some third jet observables: known to be very sensitive to influence of PS
- Study aimed to address these concerns, quantize influence of PS on observables
- Ideally: give recommendations on optimal setup(s) for the different generators to experimentalists
- General idea: Compare different NLO+PS implementations of the VBF-H process

Setup

Possible variations:

- Generator
- Matching scheme (MC@NLO ($\oplus$) or POWHEG ($\otimes$) style)
- Shower (SMC program, angular vs. dipole)
- Recoil (global vs. local)
- Intrinsic generator variables, scales...

generator	matching	SMC	shower recoil	used in comparison
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 ($\tilde{q}$)	

Setup

- Consider pp scattering at the LHC with $\sqrt{s} = 13\,\text{TeV}$
- PDF set: `PDF4LHC15_nnlo_100_pdfas` (`LHAPDF ID=91200`)
- Relatively tight VBF cut set:

$$|y_j| < 4.5, \quad p_{T,j} > 25\,\text{GeV}$$
$$m_{jj} > 600\,\text{GeV}, \quad |\Delta y_{j_1 j_2}| > 4.5, \quad y_{j_1} \cdot y_{j_2} < 0$$

- Jets defined with anti-k_t algorithm ($R = 0.4$) (if not stated otherwise)
- no hadronisation or underlying event effects considered!

The VBF Approximation

- VBF approximation: neglect s-channel contributions, as well as interference between t- and u-channel
- No color exchange between quark lines
- Valid up to the percent level within appropriate cuts (!)
- Distinct experimental signature (low jet activity between tagging jets)
- Used in all our setups, except for `HERWIG7` when interfaced with `HJets`

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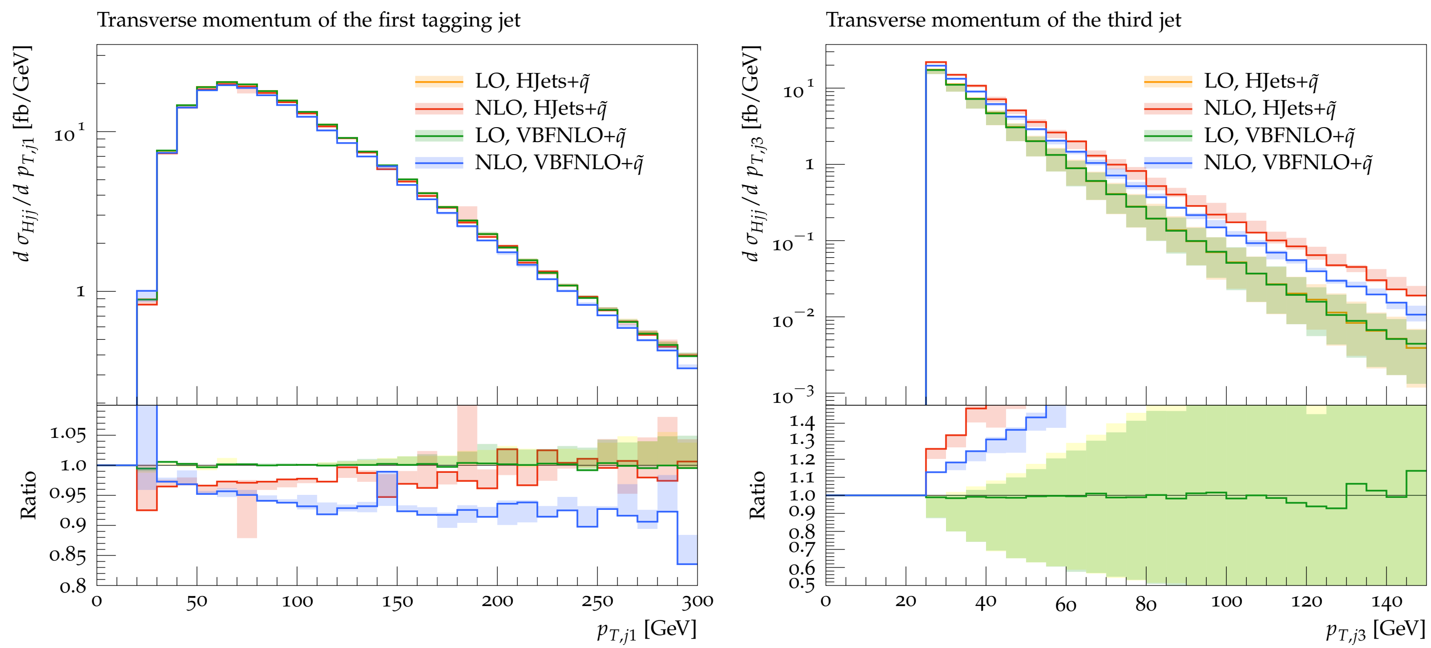
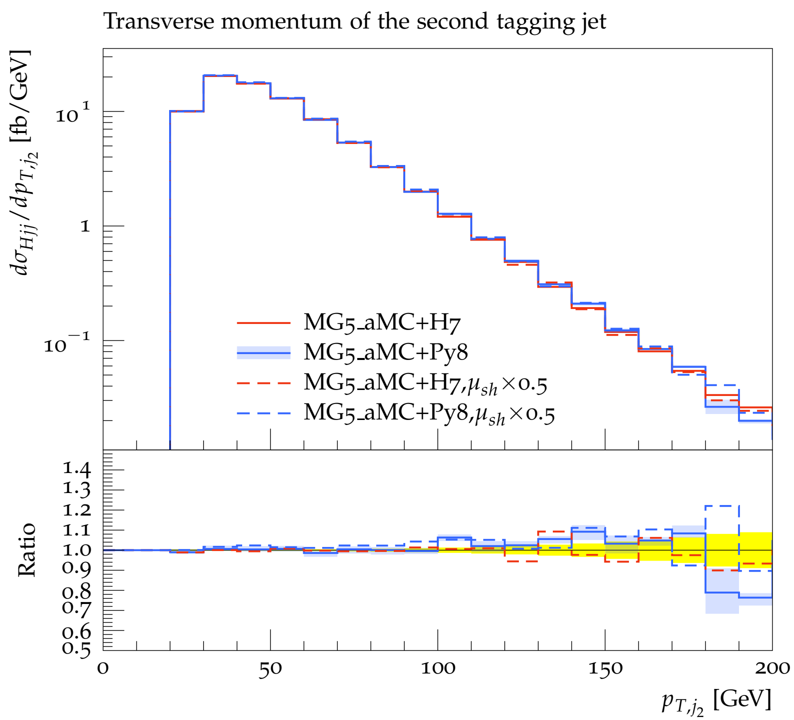
The validity of the VBF Approximation

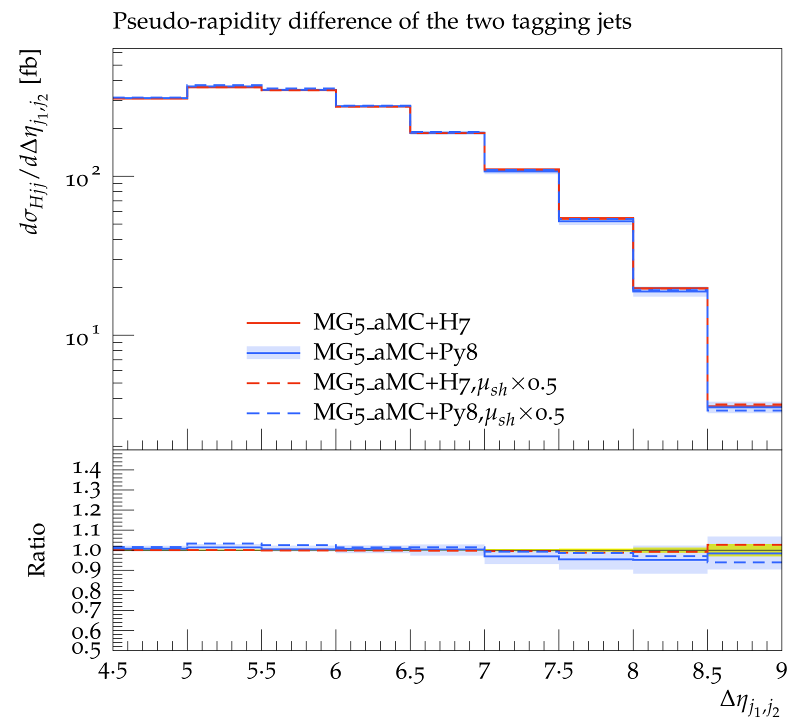


- `Herwig7/Matchbox` interfaced with `HJets` (full EW production mode) or `VBFNLO` (VBF approximation)
- Very good agreement within typical VBF cuts
- Loose cuts lead to significant differences at NLO

  here: $|\Delta\eta_{j_1j_2}| > 1, \quad m_{j_1j_2} > 200$ GeV

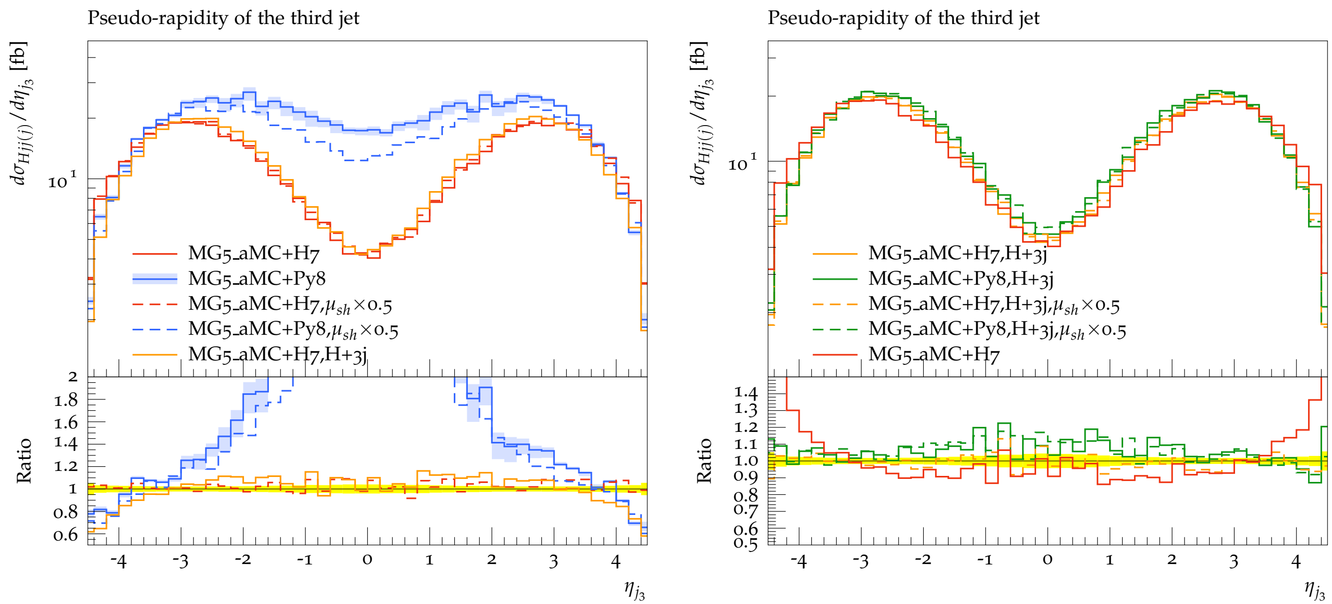
MG5_aMC





- `MadGraph5_aMC@NLO` matched to `HERWIG7` and `PYTHIA8`
- Examined uncertainties by variation of SMC and shower starting scale μ_{sh}
- Very good agreement for hard observables (within scale variation)

MG5_aMC

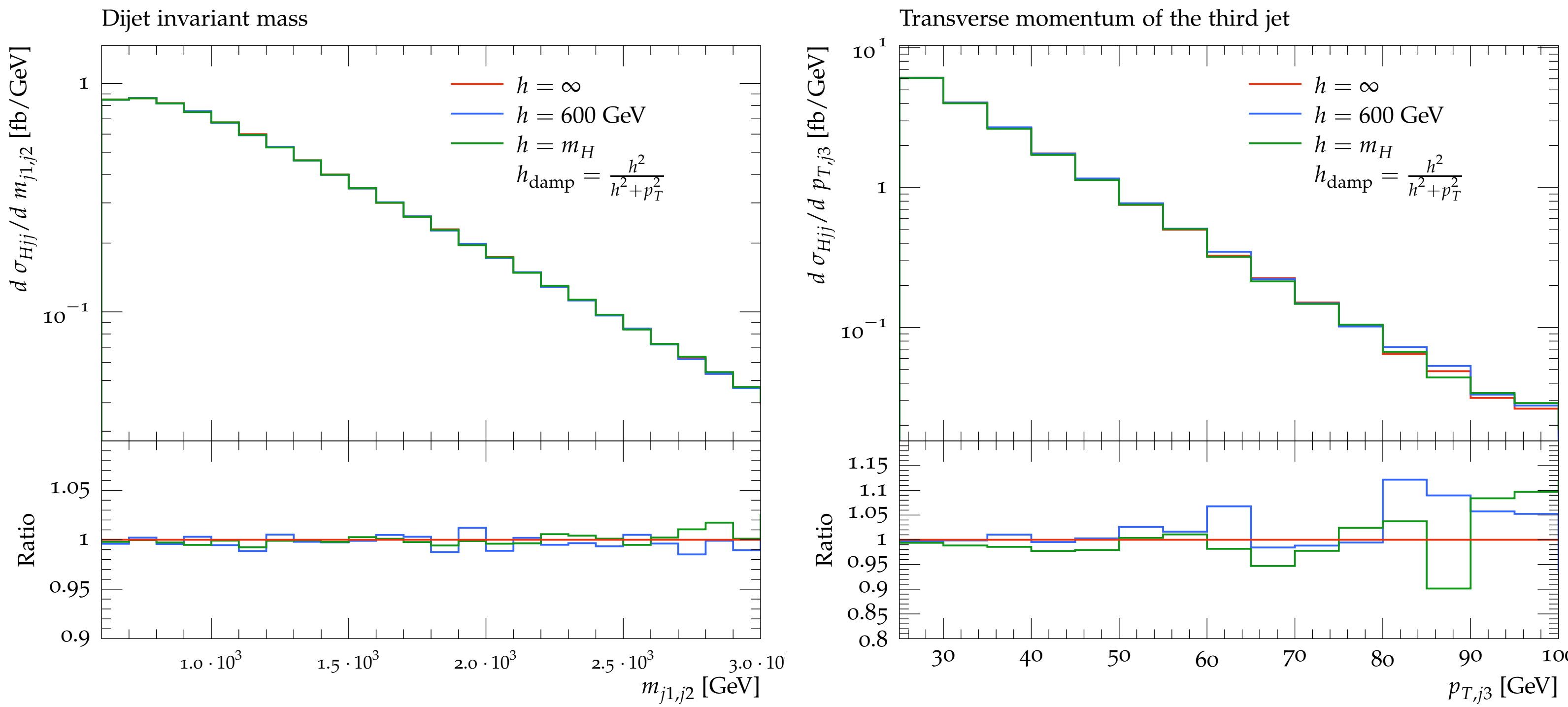


- Very different picture for third jet observables:
- Huge discrepancies outside of scale variation, especially in central rapidity region
- Very good agreement with `HERWIG7` results when moving to VBF-$H+3J$
  $\rightarrow$ `PYTHIA8` matching clearly gives unphysical results!

The Recoil Schemes in Pythia8

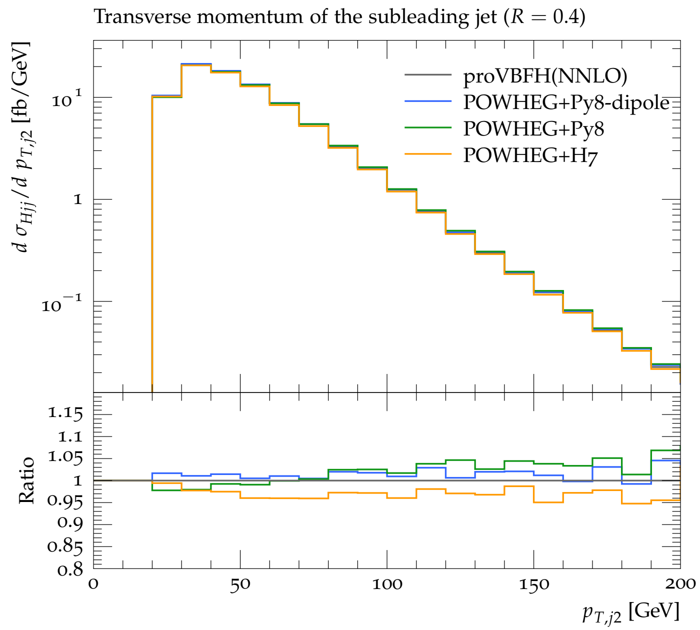
- PYTHIA8 offers two different recoil schemes
- (Default) global recoil scheme: valid, if no color flow between IS and FS (e.g. Drell-Yan)
- New dipole approach with local recoil: for processes with initial-final color flow, e.g. DIS
- VBF: no color connection between incoming partons $\Rightarrow$ global distribution of recoil clearly unphysical
- POWHEG-BOX V2 can be interfaced to both recoil schemes, MadGraph5_aMC@NLO only to default scheme

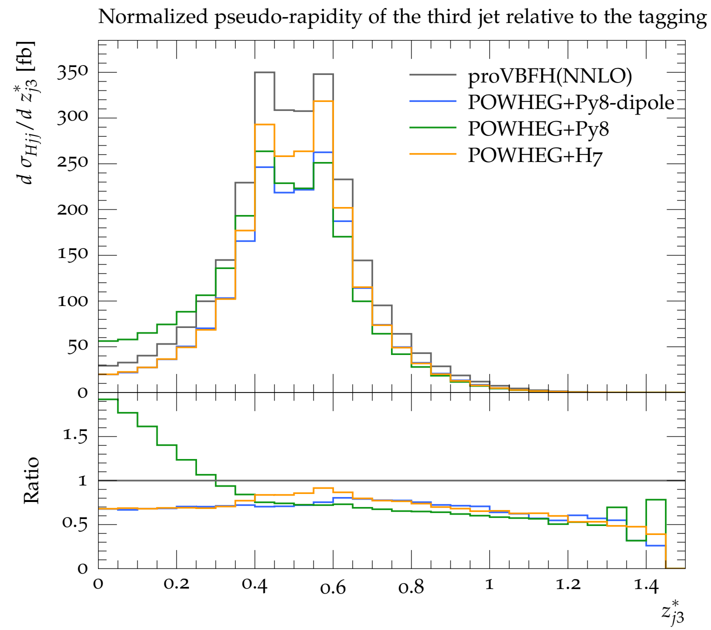
POWHEG-BOX



- Intrinsic uncertainties assessed by variation of SMC and `hdamp` parameter with $\texttt{hdamp} = \frac{h^2}{h^2+p_T^2}$
- Nearly no influence of `hdamp` variation

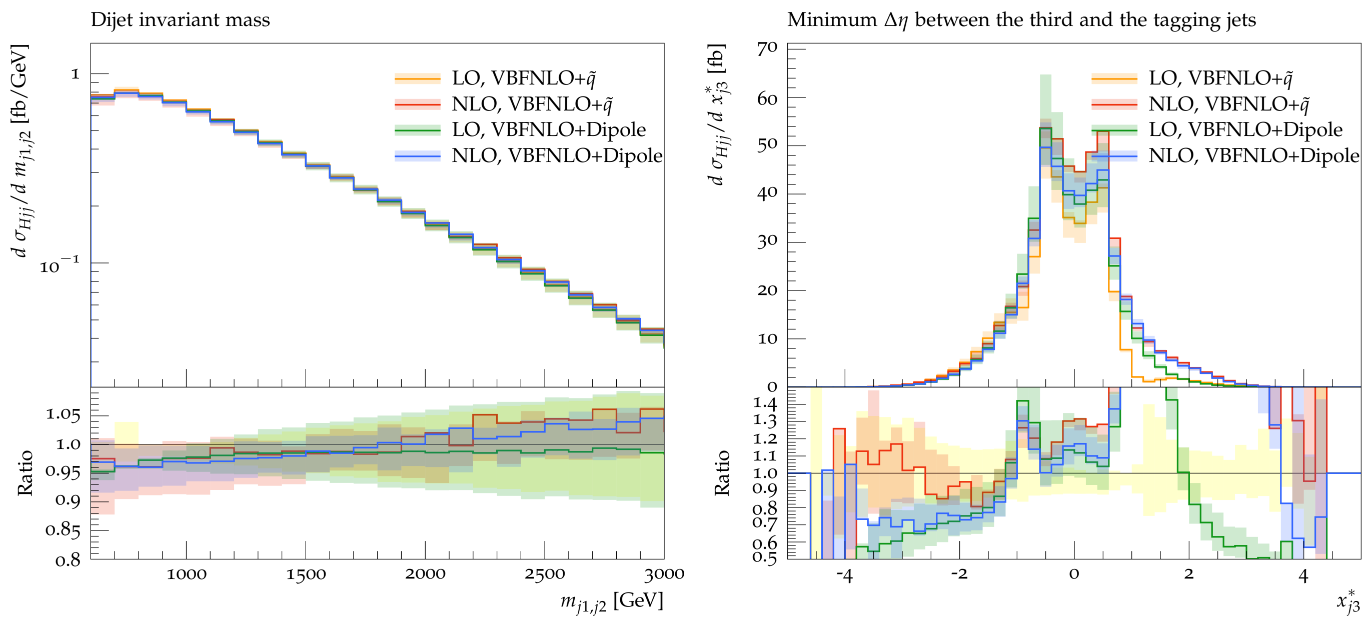
POWHEG-BOX





- Matching to HERWIG and PYTHIA8, the latter one with default global recoil and local (dipole) recoil
- Only small differences for hard observables
- Larger differences in third jet observables, confirms unphysical behavior of default recoil of PYTHIA8 for VBF

Matchbox



- `Herwig7/Matchbox` gives access to both an angular ordered as well as a dipole shower, here matched to `VBFNLO`
- Variation of scales (hard scale of shower eveolution, μ_R, μ_F) cover differences for hard observables
- Larger differences observed for observables sensitive to additional radiation

Best Predictions

generator	matching	SMC	shower recoil	used in comparison
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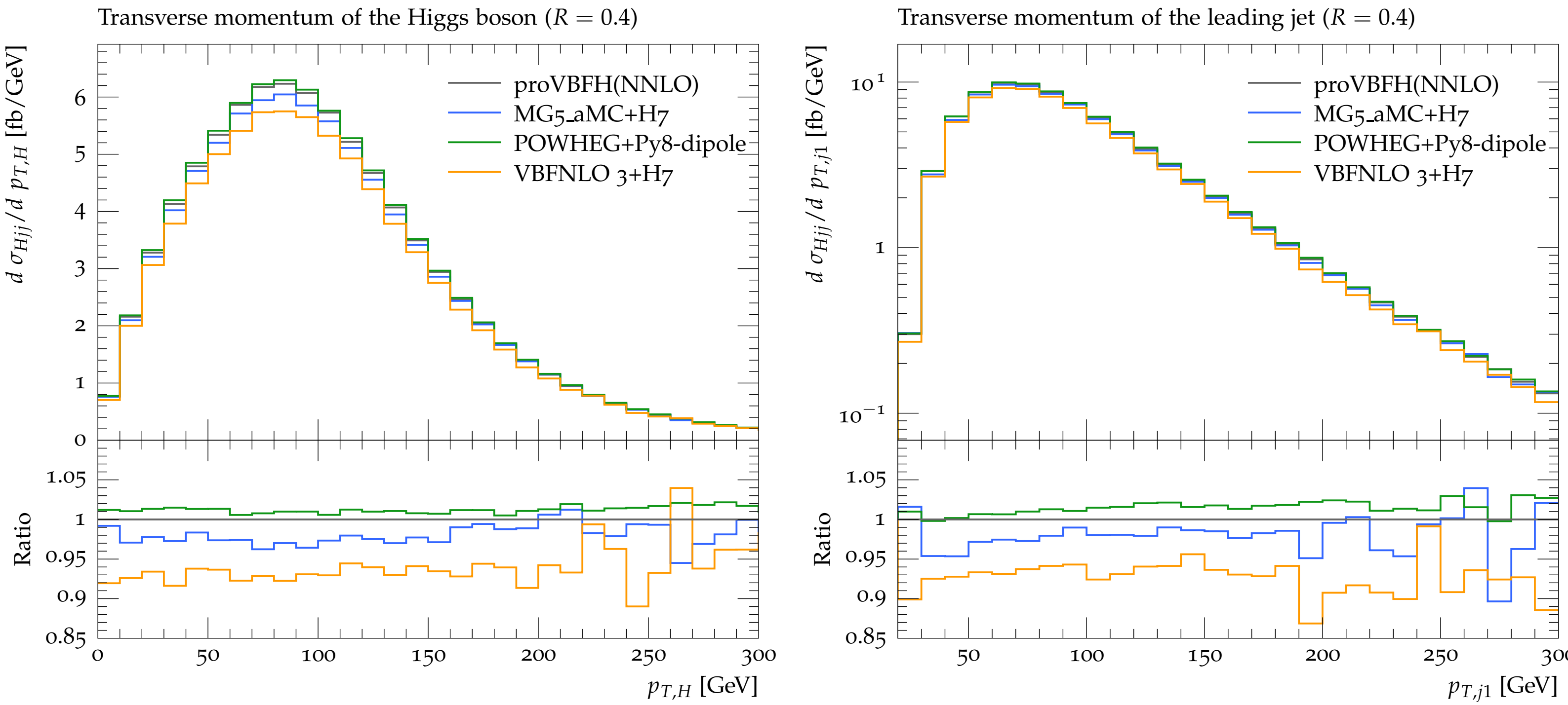
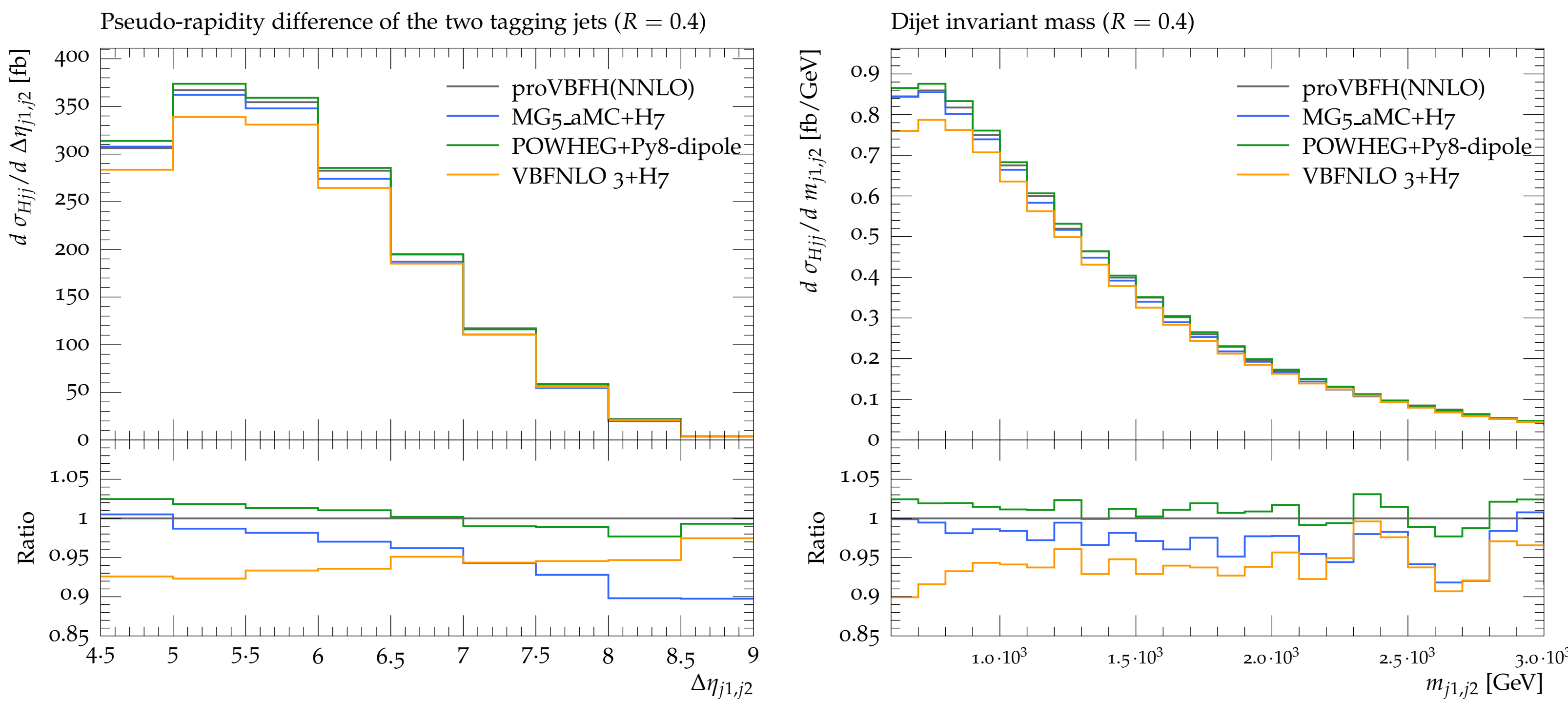
Now: compare 'best' setups, selected based on the results shown before.
We compare to a fixed-order NNLO calculation by proVBFH

Comparing All Generators



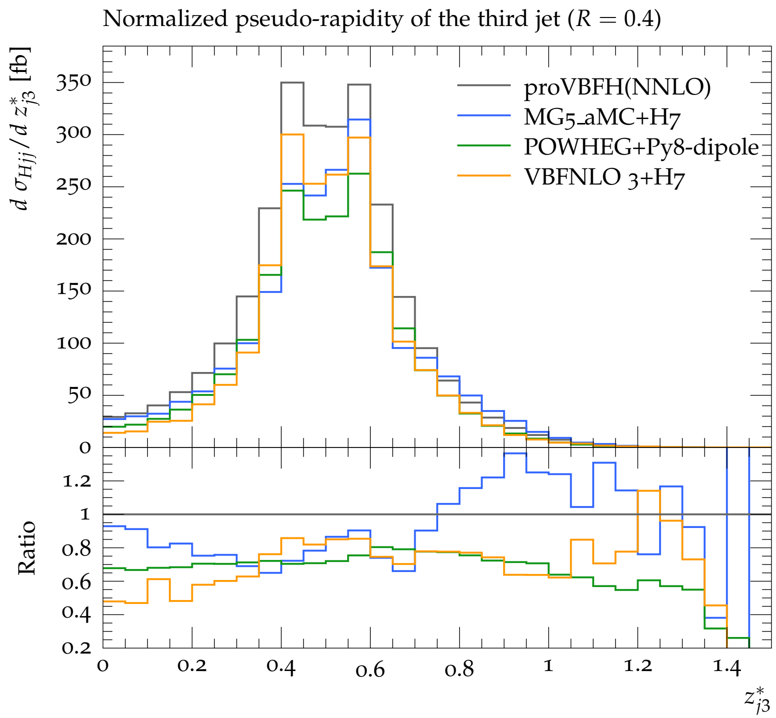
- For very inclusive quantities: nearly only differences in normalization
- Very similar shapes

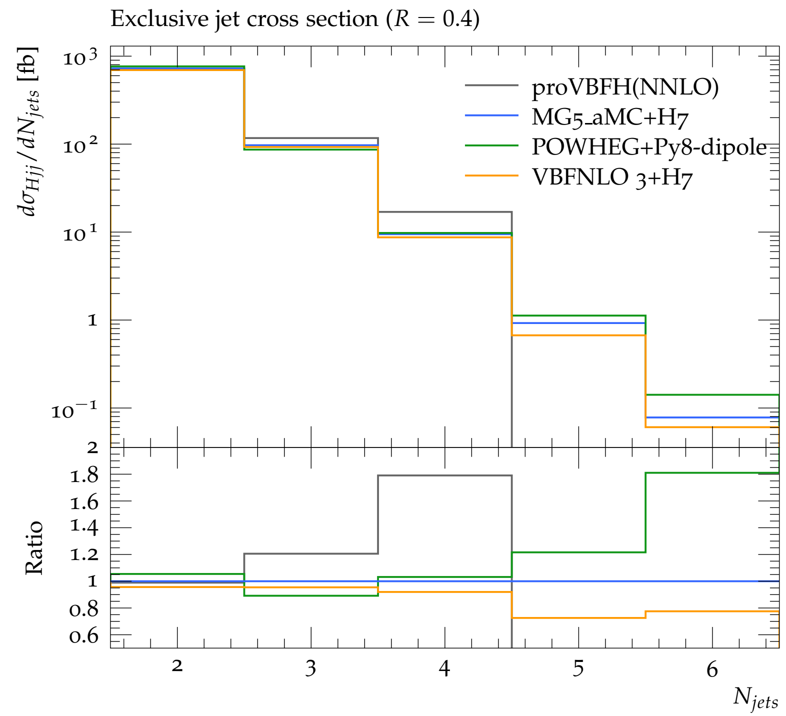
Comparing All Generators



- For typical VBF observables: some shape differences at $\mathcal{O}(10\%)$
- Still dominated by differences in normalization

Best Predictions: Third Jet Observables





- Much larger discrepancies for higher jet multiplicities
- NLO accuracy only for the two hardest jets
- Monte Carlos predict significantly lower cross section in three and four jet bins $\rightarrow$ soft radiation outside of jet cone

Conclusions and Recommendations

- Comprehensive study of parton shower effects in VBF
- Only small dependence on matching prescription
- More significant differences between different SMCs, mainly in normalization
- Prefer local dipole shower over (default) global recoil within `PYTHIA8`
- Uncertainties of third jet observables at $\sim 20\%$
- Possible future studies: include MPI/UE, study radius dependence, comprehensive study of $H + 3J$

Thank you!

Questions?

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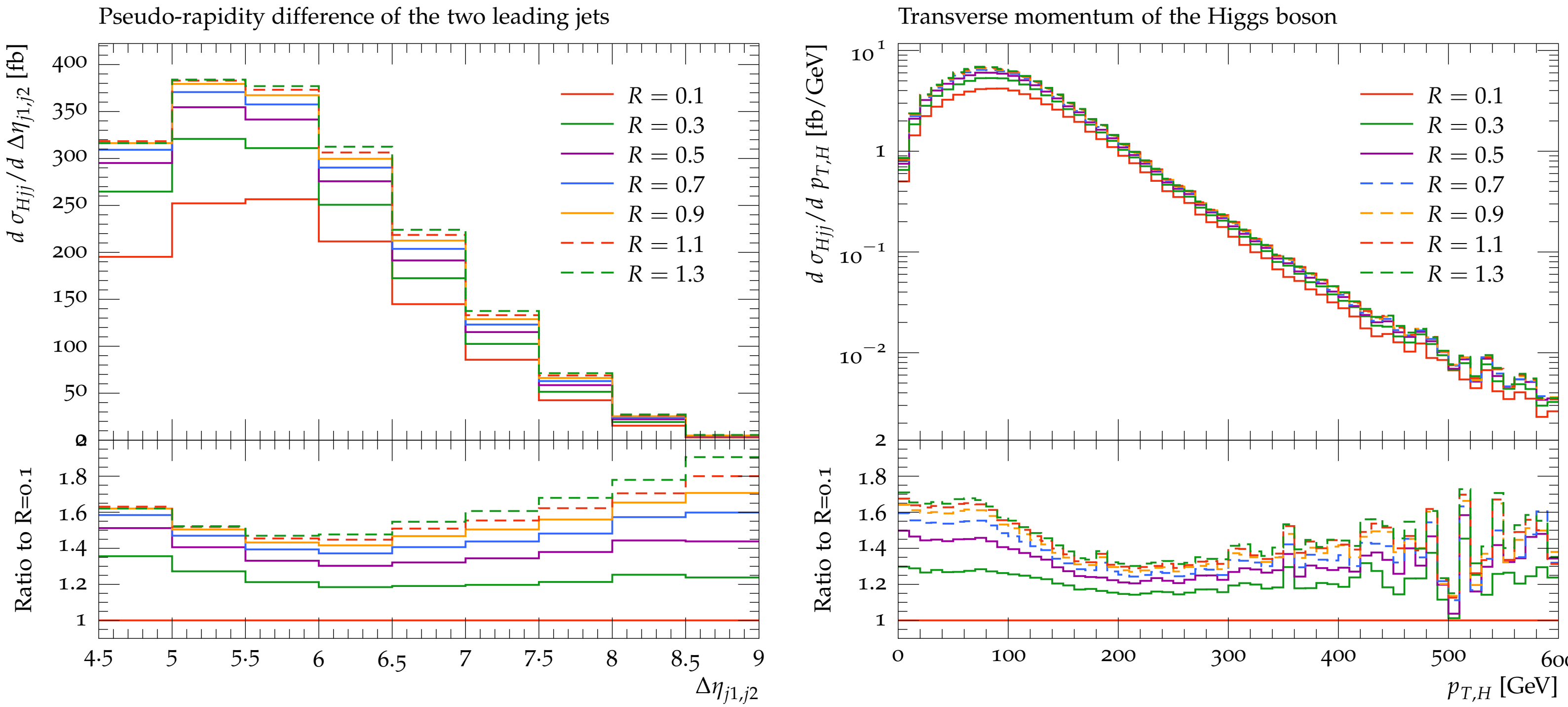
Backup: Jet Radius Dependence



- Large part of higher order corrections in VBF related to radiation outside of jet cones
- Around $R = 0.4$: Differences in shape and normalization of $\mathcal{O}(10\%)$
- Consider larger jet radii to minimize sensitivity to PS effects