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Gluon-fusion background to VBF Higgs production

based on arXiv:2509.10368

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22nd Workshop of the LHC Higgs Working Group

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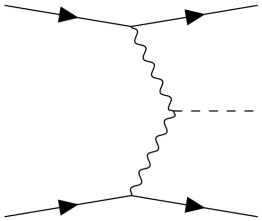
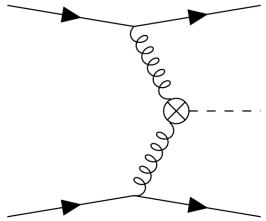


VBF Higgs production ideal to probe boosted Higgs and couplings to weak bosons (→ talk by S. Ferrario-Ravasio) but requires precise knowledge of gluon-fusion H+2j production as irreducible background.



Previous study (LH '19):
Consistent simulation of VBF Higgs production up to NNLO and NLO+PS.

Results:

⇒ central predictions and uncertainties agree at the level expected by perturbative QCD

New study (LH '23):
Consistent simulation of ggF background at NLO and NLOPS.

Goals:

→ match ATLAS and CMS setups

→ reliable uncertainty estimates

→ disentangle uncertainty sources

[2105.11399]

A comparative study of Higgs boson production from vector-boson fusion

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[2509.10368]

Theory uncertainties of the irreducible background to VBF Higgs production

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We considered the following theory predictions:

NNLOJET
→ H+1j @ NNLO

MiNNLOPS + Pythia / Herwig
→ NNLO for 0j, NLO for 1j, LO for 2j
→ proxy for ATLAS/CMS setups

Powheg Box + Pythia / Herwig
→ H+2j @ NLO
→ Herwig only at parton level

Sherpa
→ H+2j MC@NLO
→ MEPS@NLO with NLO up to 2 jets and LO up to 5 jets

4 parton-shower algorithms:
- Sherpa CS shower
- Pythia default ("simple") shower
- Pythia dipole-recoil shower
- Herwig angular-ordered shower

perturbative accuracy

	Setup	H	H+1j	H+2j
fixed-order	NNLOJET	-	NNLO	NLO
inclusive setups	MiNNLOPS + Pythia / Herwig	NNLO+PS	NLO+PS	LO+PS
	Sherpa MEPS@NLO	NLO+PS	NLO+PS	NLO+PS
exclusive NLO+PS setups	Sherpa MC@NLO	-	-	NLO+PS
	Powheg Box + Pythia / Herwig	-	-	NLO+PS

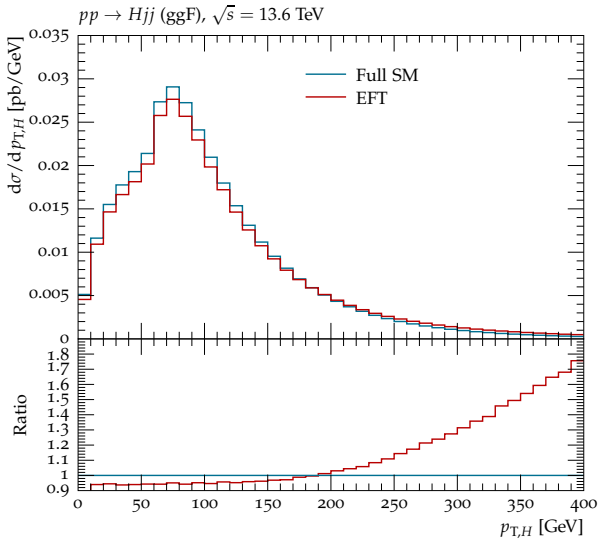
Consistency established at fixed order (up to NLO if available).

Setup

on-shell Higgs production in gluon-fusion channel in the heavy-top limit at $\sqrt{s} = 13.6$ TeV with scale choice

$$\mu_{\mathrm{R}} = \mu_{\mathrm{F}} = \frac{1}{2}\left[\sqrt{m_H^2 + p_{\mathrm{T},H}^2} + \sum_{i \in \text{partons}} p_{\mathrm{T,i}}\right]$$

and PDF4LHC21_40 NNLO PDFs.



Kinematics

motivated by STXS setup: anti-kT jets with $R = 0.4$ (alternatively $0.3, 0.6, 0.8$) and

$$p_{\mathrm{T}}^{\mathrm{jet}} > 30 \text{ GeV}, \quad |y^{\mathrm{jet}}| < 4.4$$

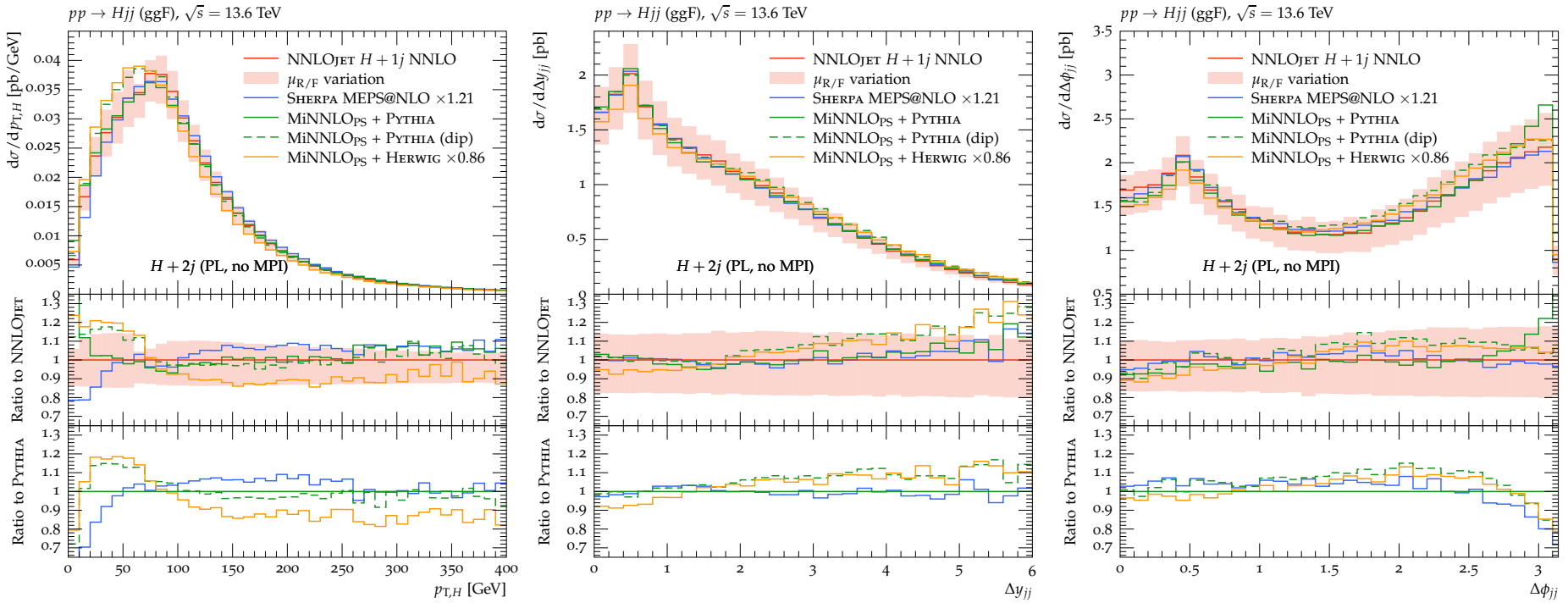
and Higgs in central rapidity region $|y_H| < 2.4$.

Observables

- transverse momentum of the Higgs, $p_{\mathrm{T},H}$
- invariant mass of the two leading jets, m_{jj}
- rapidity separation of the two leading jets, Δy_{jj}
- azimuthal separation of the two leading jets, $\Delta \phi_{jj}$

Generator setups, RIVET analysis, and further figures at https://zenodo.org/records/17015614

First compare **inclusive setups** MEPS@NLO and MiNNLO$_{PS}$ (parton level, no MPI, no hadronisation)



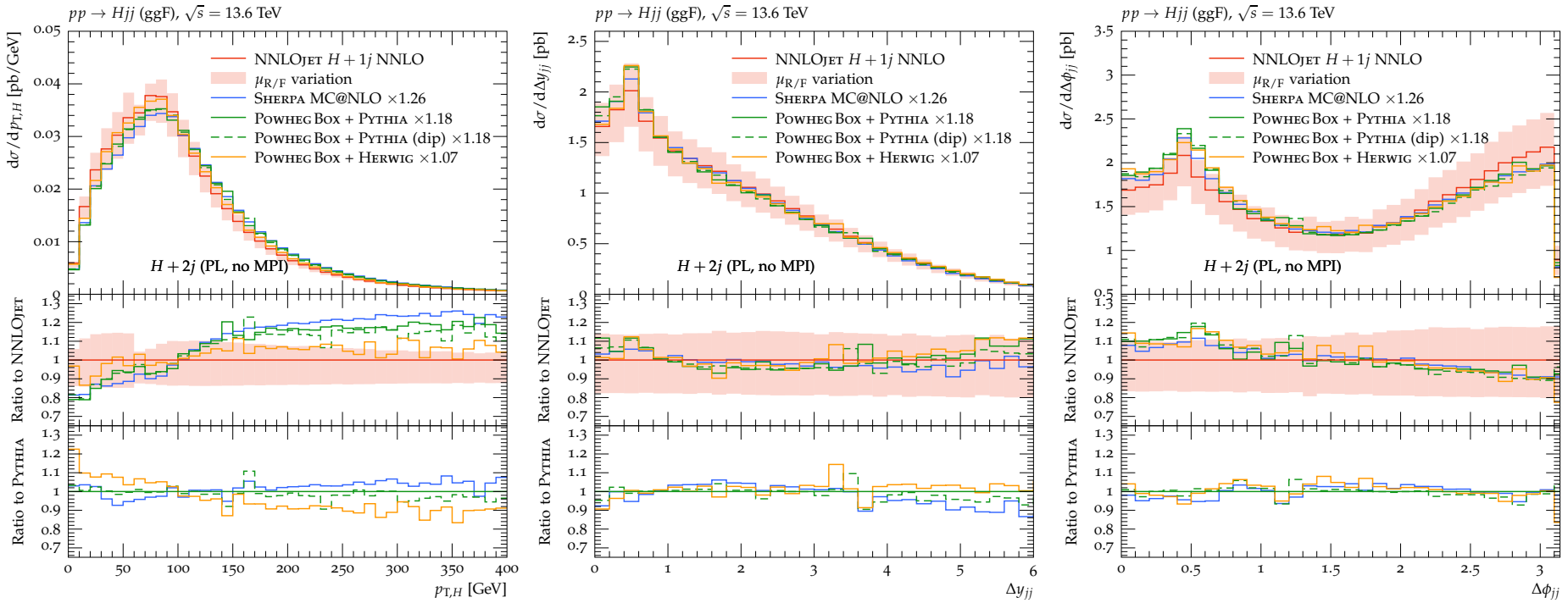
Rescaling factors based on agreement in NLO Higgs rapidity distribution.

→ inclusive setups within NLO scale uncertainty except at large observable values

→ mostly 10-20% agreement between MEPS@NLO and MiNNLO$_{PS}$ results

→ significant differences at low $p_{T,H}$ and large $\Delta\phi_{jj}$

Compare **NLO+PS setups** SHERPA MC@NLO, POWHEG BOX + PYTHIA / HERWIG (parton level, no MPI, no hadronisation)



Rescaling factors based on agreement in NLO Higgs rapidity distribution.

→ except for $p_{\mathrm{T},H}$ NLO+PS within NLO scale uncertainty

→ very good 5-10% agreement between different NLO+PS results

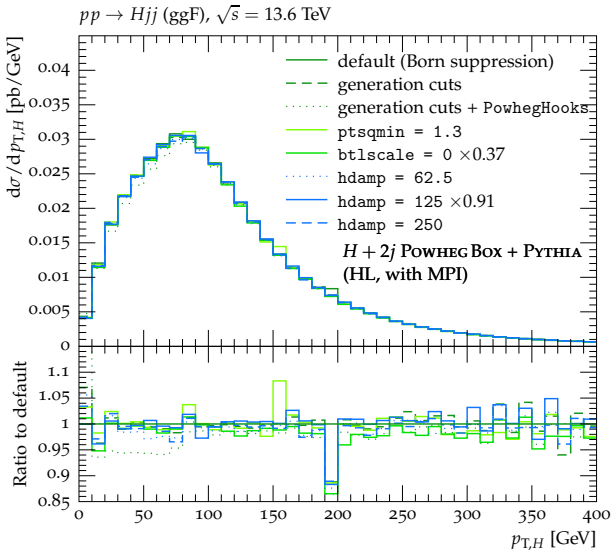
→ shape difference in $p_{\mathrm{T},H}$ and $\Delta\phi_{jj}$ spectrum between NLO+PS and NLO

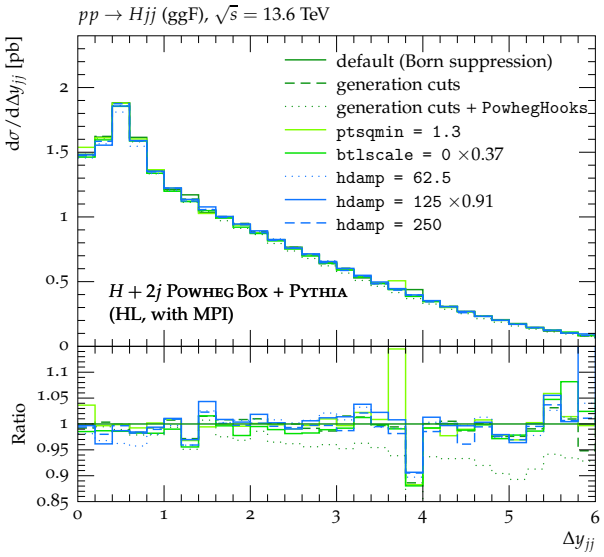
Matching-scheme variations

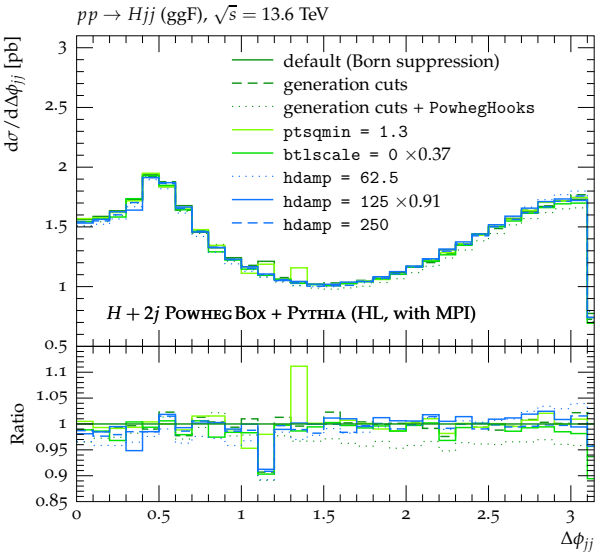
Estimate **matching-scheme uncertainties** in POWHEG BOX + PYTHIA

- Born suppression vs generation cuts (POWHEG BOX)
- `hdamp` factor (POWHEG BOX)
- emission cutoff `ptsqmin` (POWHEG BOX)
- scale setting `btlscale` (PYTHIA)
- `PowhegHooks` and `pThard` (PYTHIA)

(hadron level, with MPI, with string fragmentation)





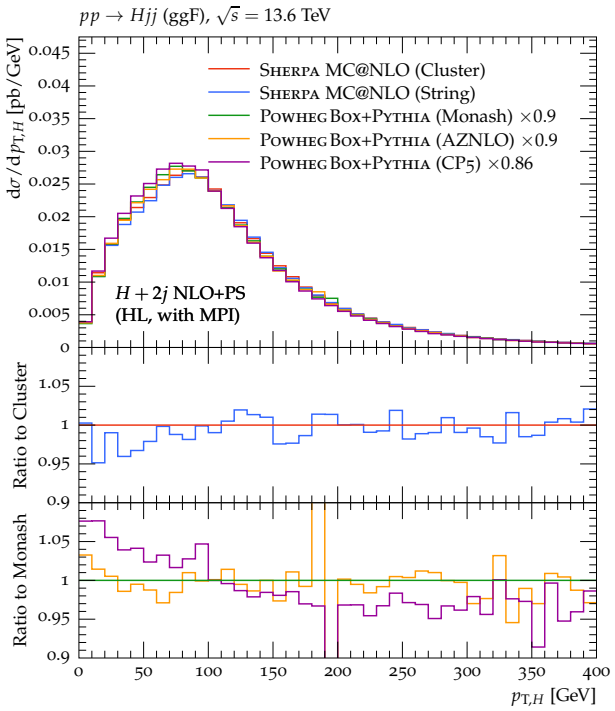


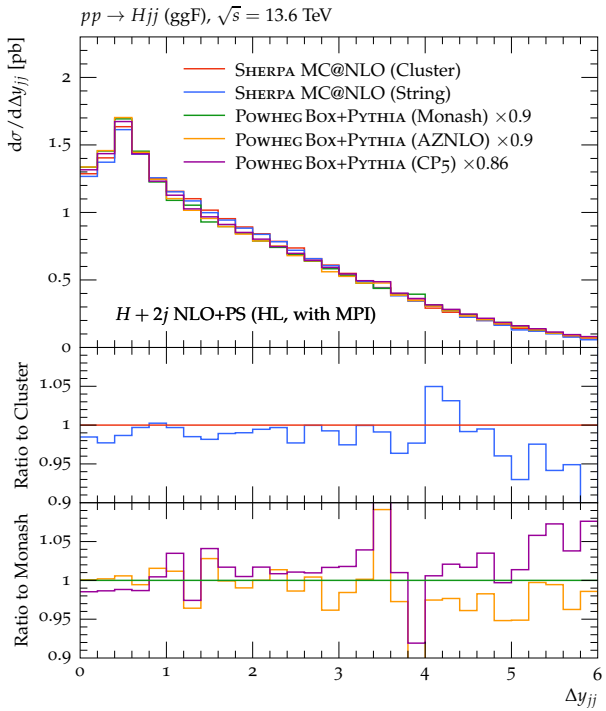
Rescaling factors based on agreement in NLO Higgs rapidity distribution.

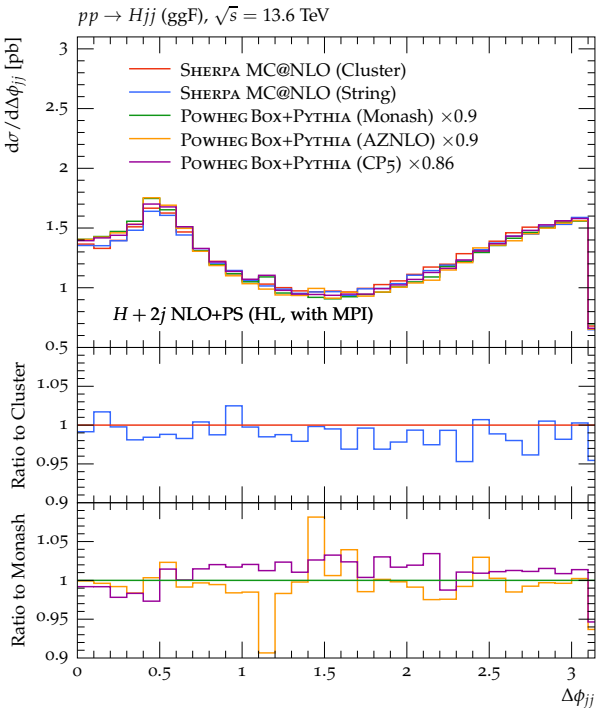
→ **excellent agreement** (< 5% differences) in all cases

Tune and non-perturbative variations

Estimate uncertainties from non-perturbative models and tunes
(hadron level, with MPI, string/cluster fragmentation)







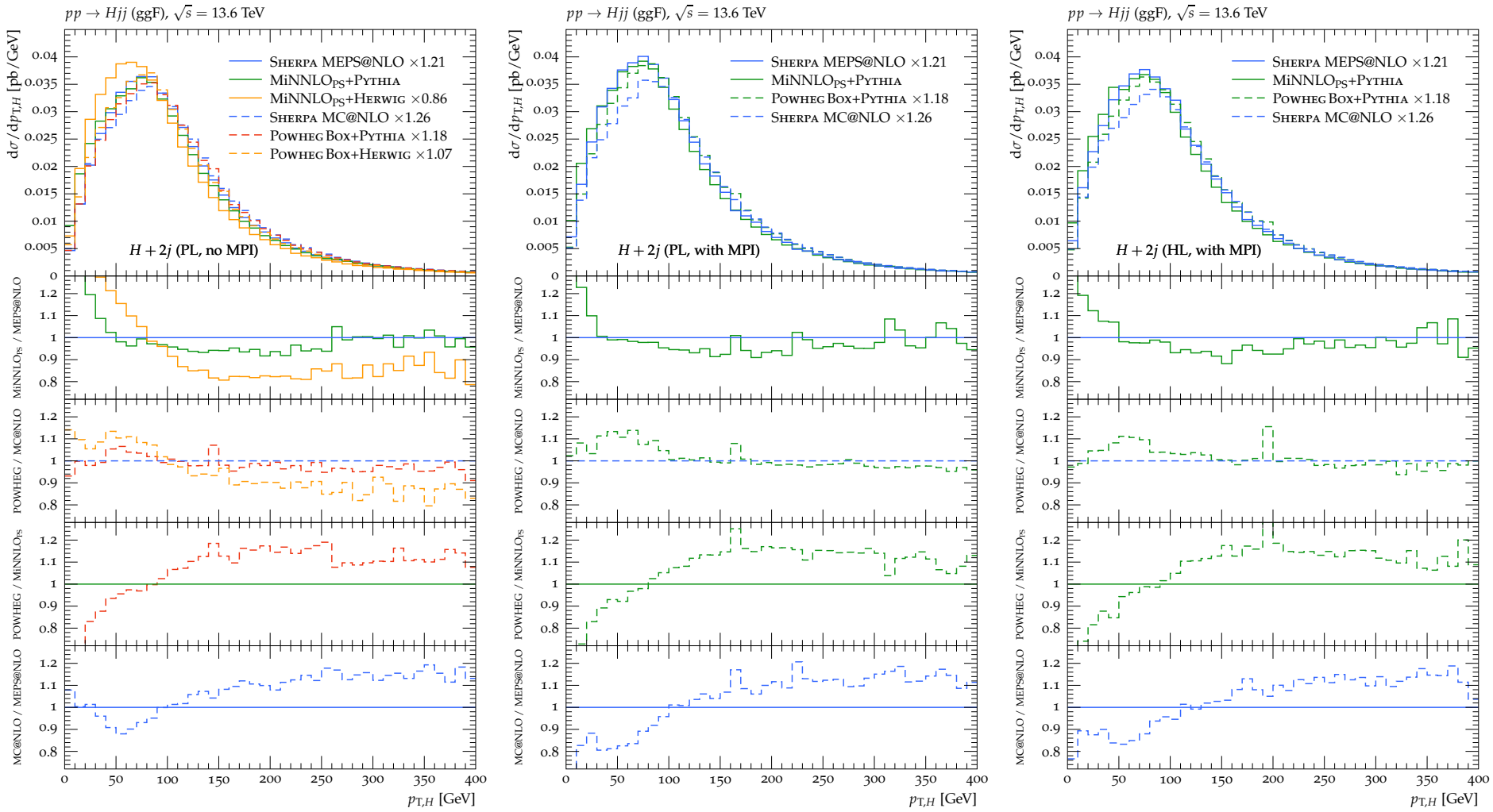
Rescaling factors based on agreement in NLO Higgs rapidity distribution.

→ excellent < 5% agreement between cluster and string fragmentation in SHERPA

→ 5-10% agreement between Monash, AZNLO, and CP5 tunes in PYTHIA

→ slightly larger differences with CMS CP5 tune

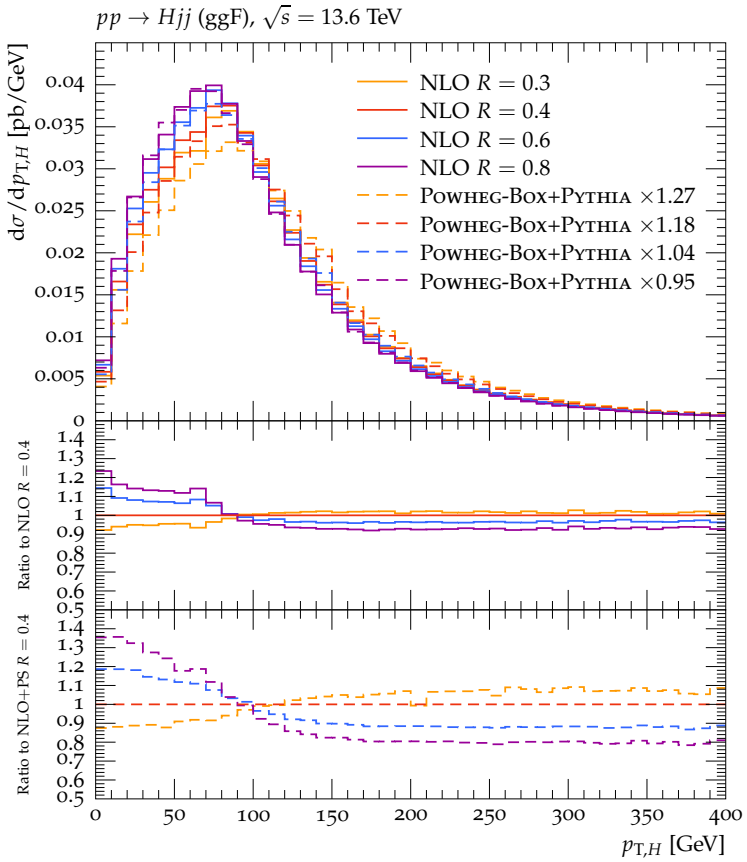
Probe transition from parton level to parton level + MPI and hadron level + MPI.

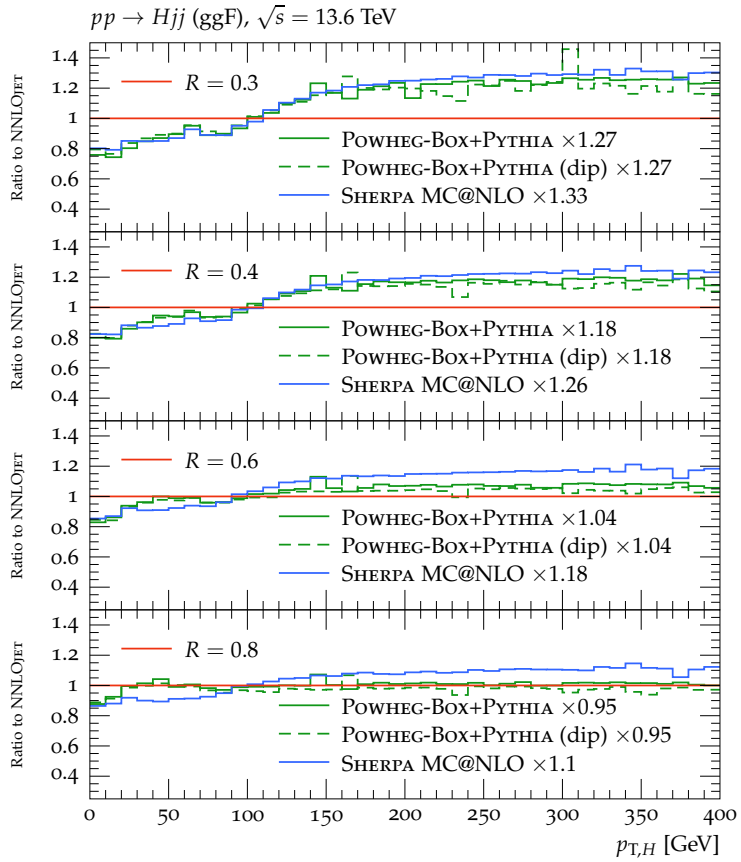


→ Herwig **outlier** at parton level, fixed MPI scale **prevents full simulations**

Cone-size dependence

Validate influence of different jet radii.





→ Higgs transverse momentum $p_{\mathrm{T},H}$ shows largest variations with R

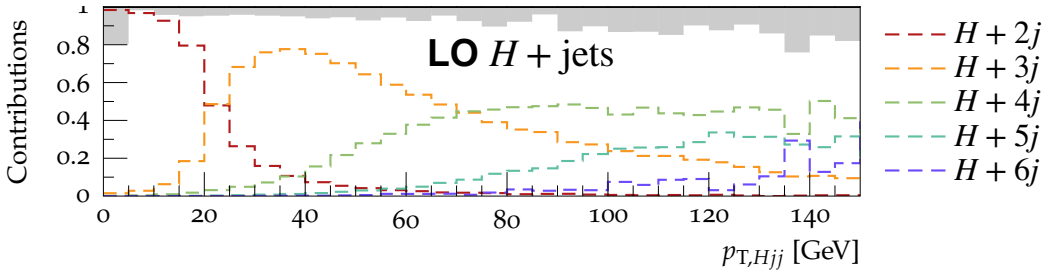
→ fixed-order NLO predictions less affected by jet-radius variations

→ generally better agreement between NLO+PS and NLO for larger jet radii

Transverse momentum of the Hjj system

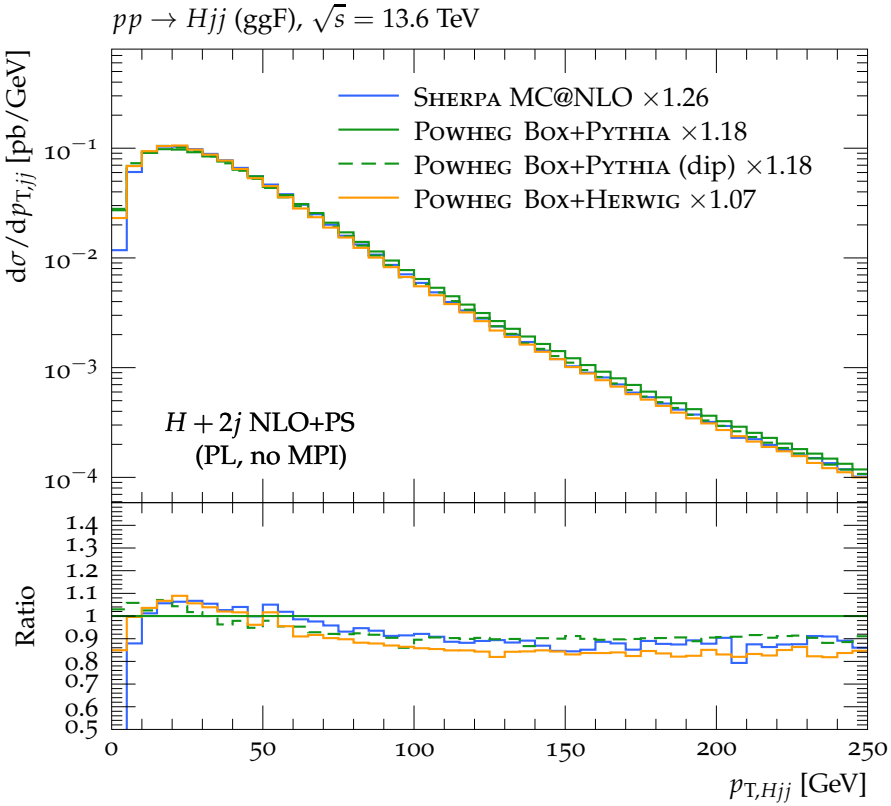
Accurate modelling of $p_{\mathrm{T},Hjj}$ requires **inclusion of higher multiplicities**.

[Höche et al. 2106.10987]



Nevertheless, **consistent predictions** at NLO+PS between SHERPA MC@NLO, POWHEG BOX + HERWIG, and POWHEG BOX + PYTHIA dipole.

POWHEG BOX + PYTHIA default **overestimates radiation** with respect to the other NLO+PS predictions.



Conclusions

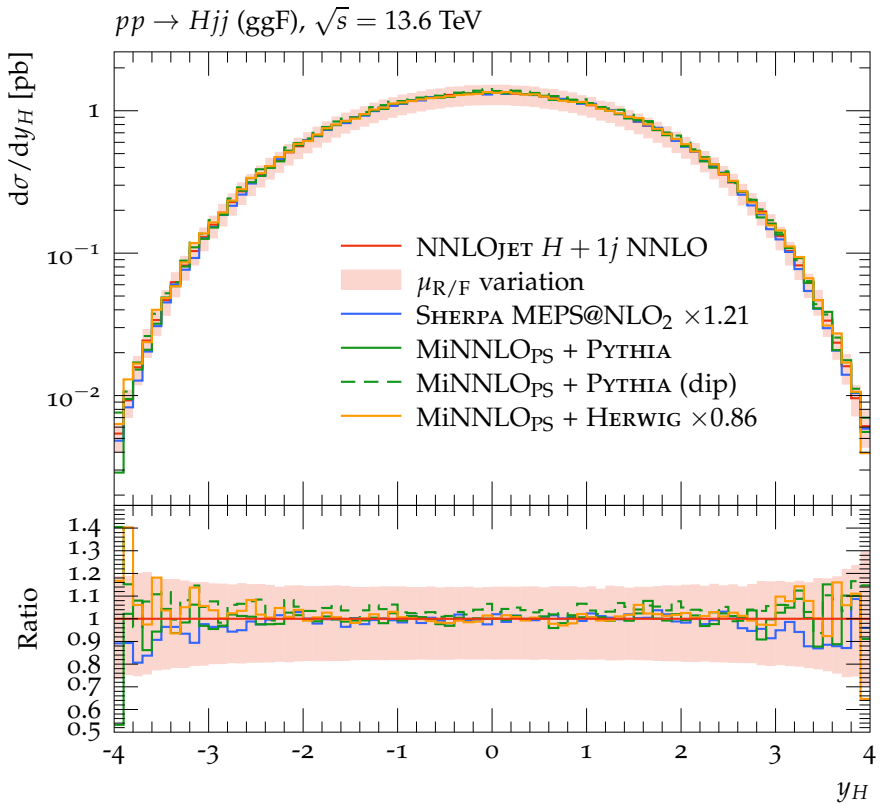
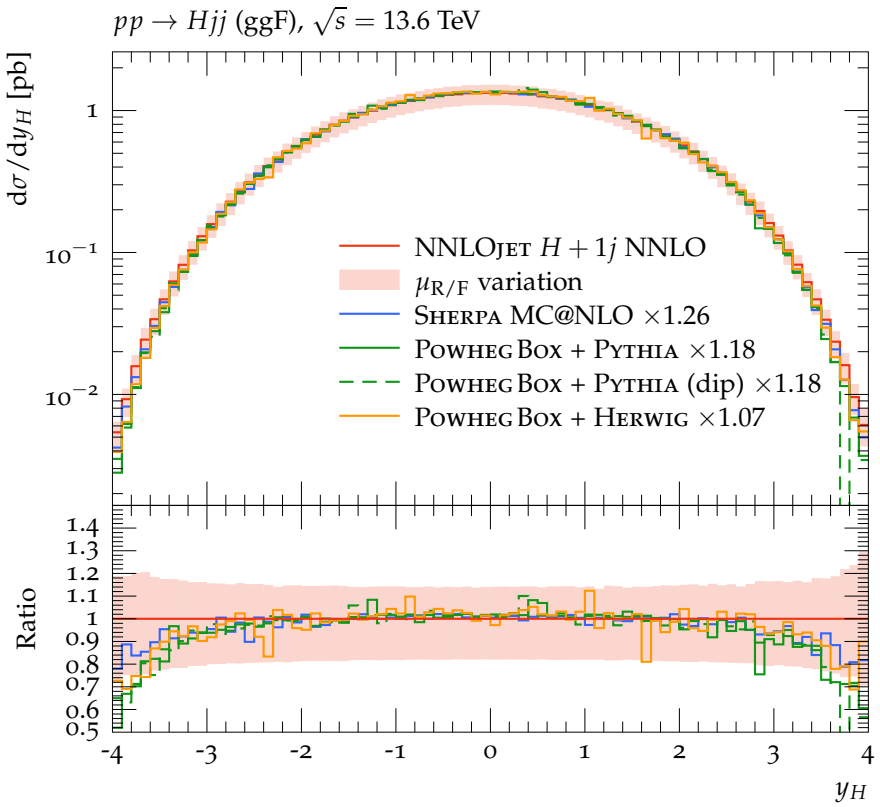
Conclusions

Uncertainties quoted for ggF background by ATLAS and CMS may be overstated, because they effectively rely on **LO predictions below the NLO state of the art**.

Different NLO+PS setups with PYTHIA, HERWIG, and SHERPA are in **very good agreement** (< 10%) with well understood matching and non-perturbative systematics.

Differences between NLO+PS and inclusive setups remain below 10% **if the H+2j configuration is included at NLO** (e.g. MEPS@NLO).

HERWIG's fixed MPI starting scale leads to unphysical results when used with the Born suppression approach in the POWHEG BOX H+2j process.

Backup

Normalisation to Higgs rapidity distribution in the fiducial H+2j phase space.