Recent MC developments for V+jets production

Top 2013, Durbach

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Recent developments in three areas:

1. NLO QCD at the parton level

- State of the art predictions for V+jets from BLACKHAT+SHERPA:
  - W+$\leq$ 5 jets
  - Z/γ^*+$\leq$ 4 jets

2. Matching NLO and parton showers

- Z/γ^*+2 jets using POWHEG
- W+3 jets using SHERPA

3. Combining NLO+PS simulations for different jet multiplicities

- W+0,1 jets using aMC@NLO
- W+0,1 jets using PYTHIA8 (UNLOPS)
- Z+0,1 jets using POWHEG and MINLO
- W+0,1,2 jets using SHERPA (MEPS@NLO)

NLO QCD at parton level

NLO calculations

$$\sigma_{\text{NLO}} = \int \mathrm{d}\phi_B (\mathcal{B} + \mathcal{V} + \mathcal{I}) + \int \mathrm{d}\phi_R (\mathcal{R} - \mathcal{S})$$

Building blocks:

- Tree-level matrix elements $\mathcal{B}$, $\mathcal{R}$
- Infrared subtraction $\mathcal{S}, \mathcal{I}$ (e.g. Catani-Seymour or FKS)
- 1-loop matrix elements $\mathcal{V}$ ($\rightarrow$ often interfaced)
- Phase space integration

Features in SHERPA

- Provides $\mathcal{B}$, $\mathcal{R}$, $\mathcal{S}$, $\mathcal{I}$, multi-channel integration
- Interfaces to 1-loop ME generators (e.g. BLACKHAT, GOSAM, NJET, OPENLOOPS)
- Efficient ROOT ntuple event output
- cheap variations of scale/PDF/jet definition
- Highly efficient CPU parallelisation through MPI

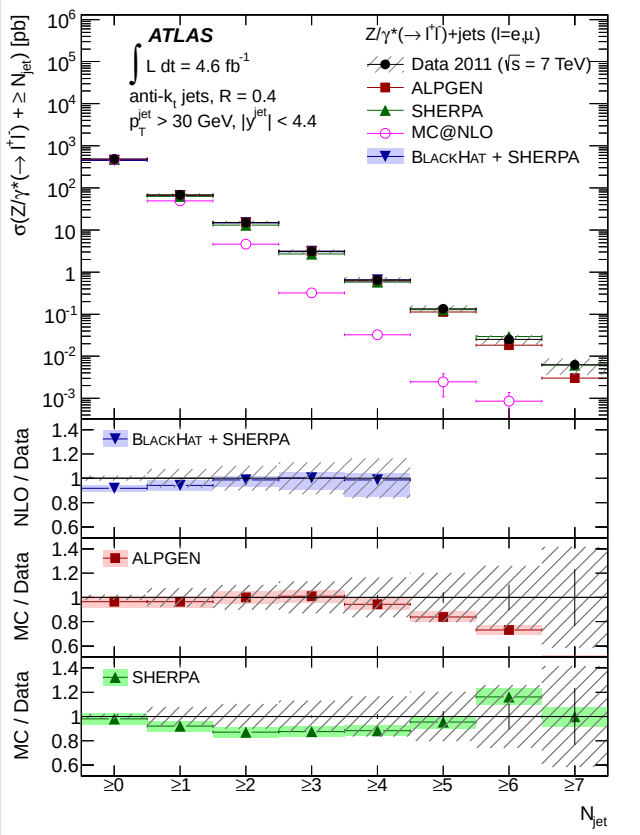
W + 5 jets with BlackHat + Sherpa

[Bern, Dixon, Febres Cordero, Höche, Ita, Kosower, Maitre, Ozeren] Phys.Rev. D88 (2013) 014025

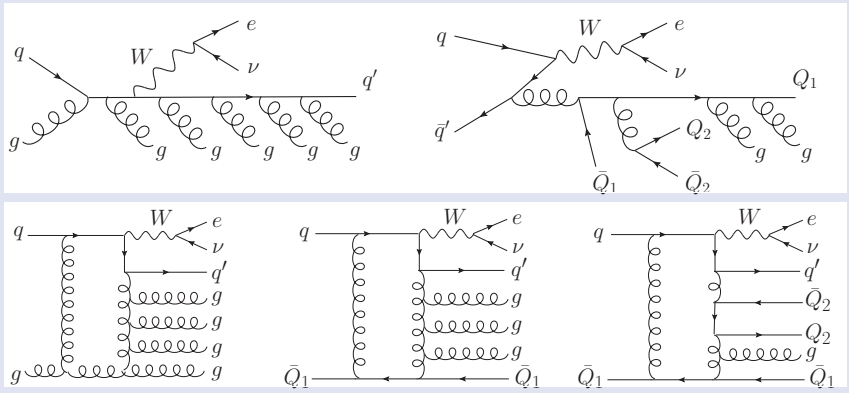
V+jets at the LHC

- Very high jet multiplicities, e.g. ATLAS $Z/\gamma^* + 7$ jets
  JHEP 1307 (2013) 032

$\Rightarrow$ quest for precise predictions



$W + 5$ jets with BlackHat+Sherpa



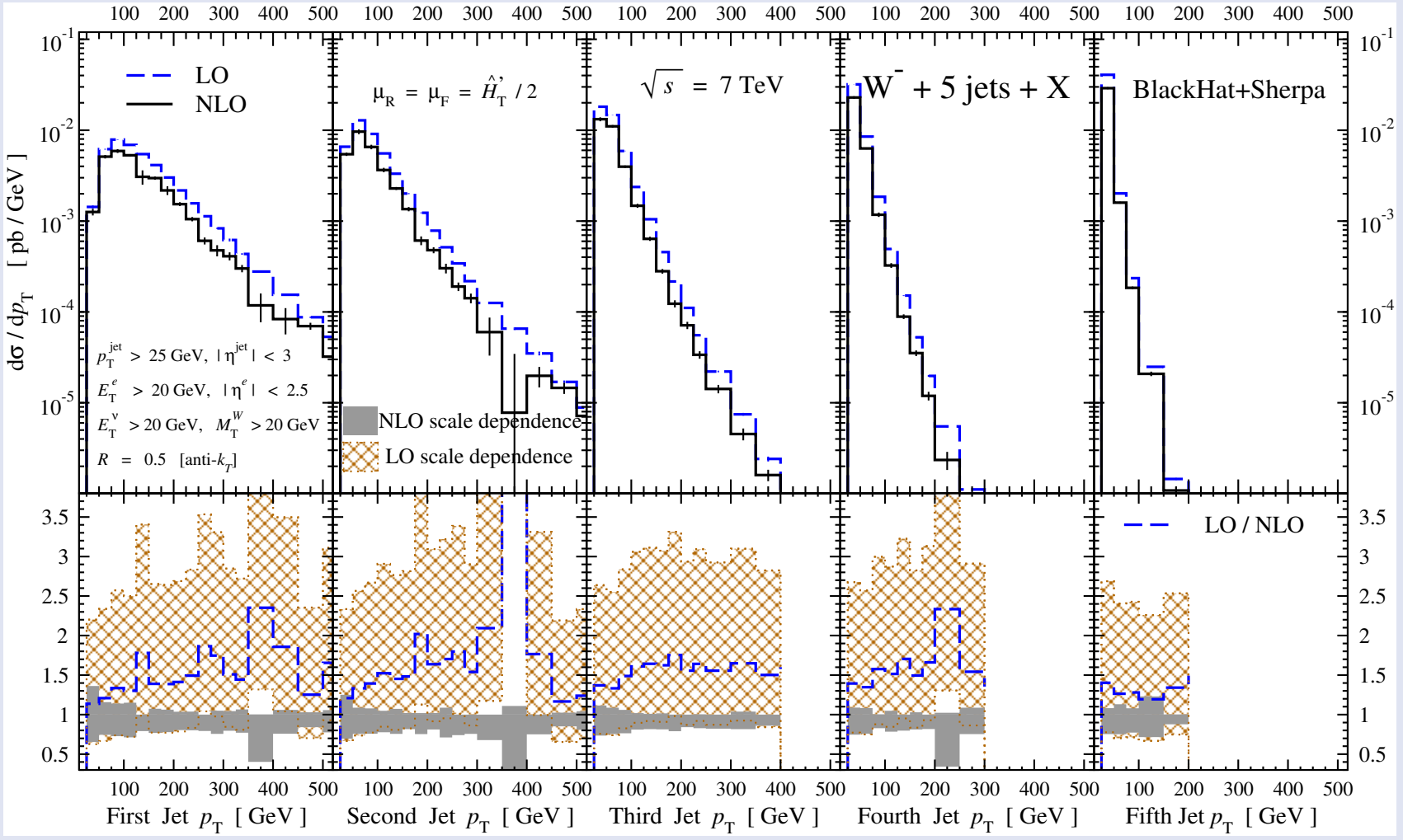
Approximations in this calculation:

- leading-colour for virtual diagrams
  estimated uncertainty $< 3\%$
- real corrections only ≤ 3 quark pairs
  estimated uncertainty $< 1\%$
- no diagrams involving top-quark loops
- parton-level only
  no non-perturbative corrections applied

W + 5 jets: $p_\perp$ spectra

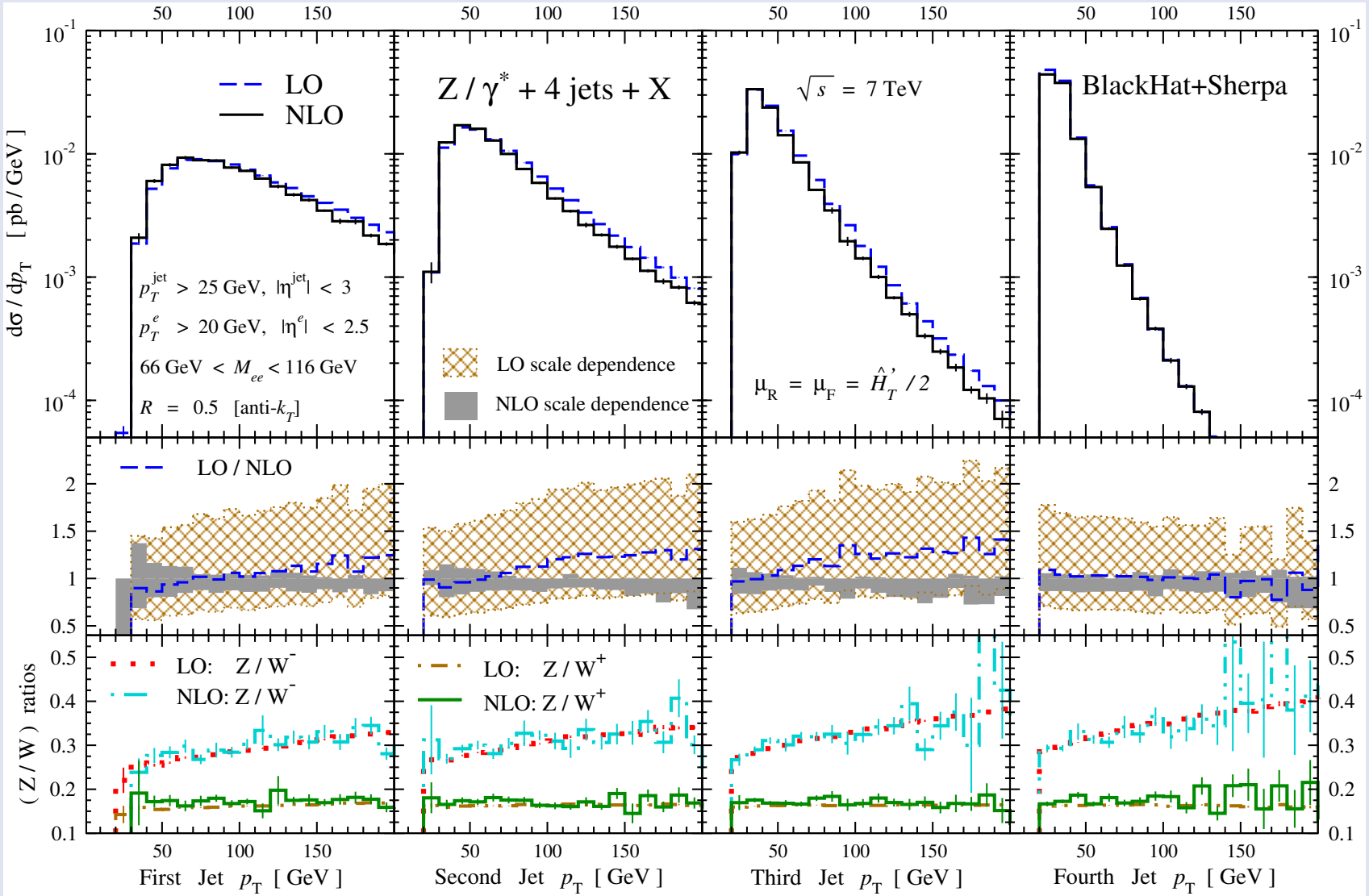
[Bern, Dixon, Febres Cordero, Höche, Ita, Kosower, Maitre, Ozeren] Phys.Rev. D88 (2013) 014025

Leading five jet $p_\perp$ in W^- + 5 jets events



Z/γ^* + 4 jets: $p_\perp$ spectra [Ita, Bern, Dixon, Febres Cordero, Kosower, Maitre] Phys.Rev. D85 (2012) 031501

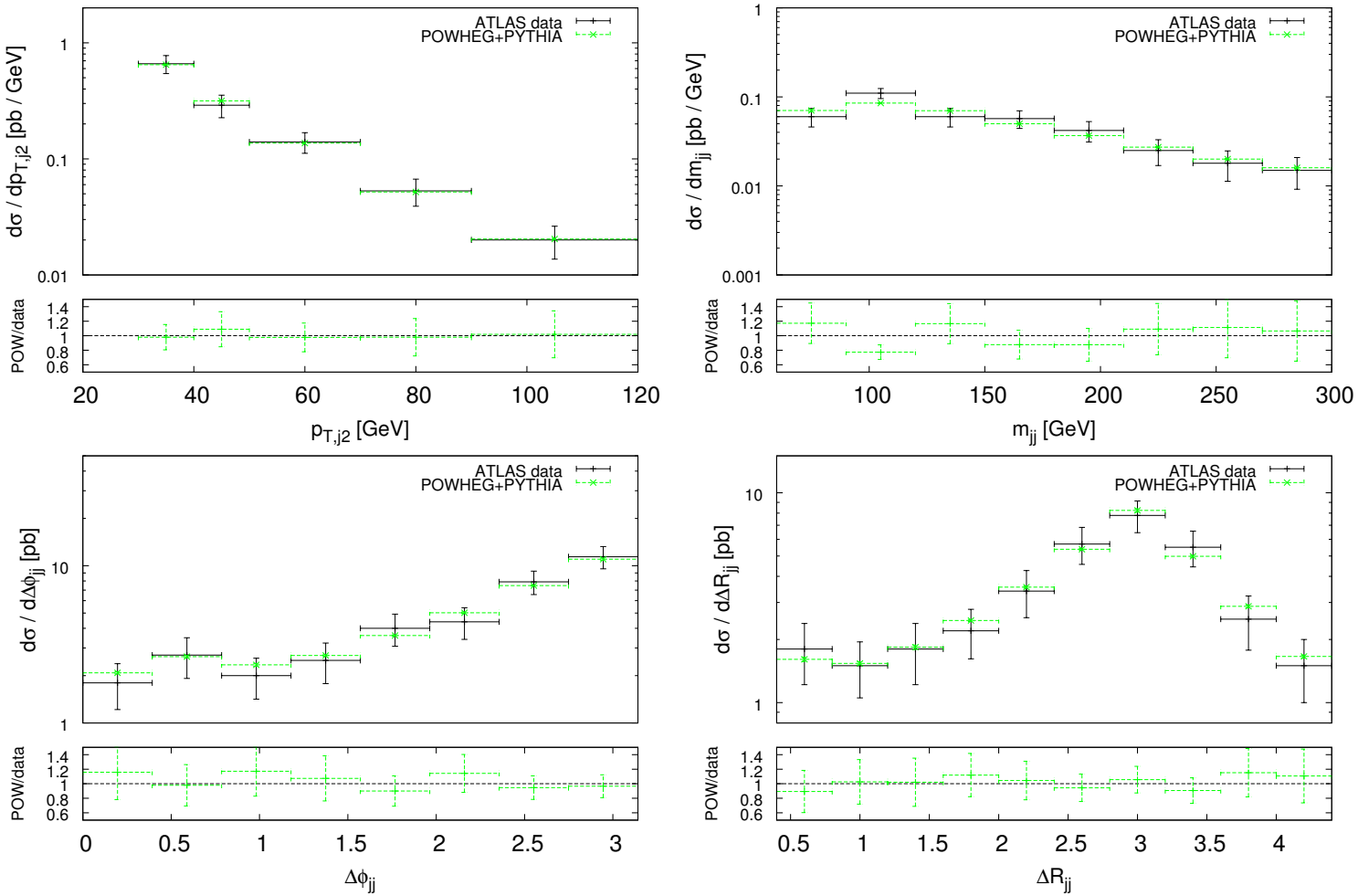
Leading four jet $p_\perp$ in Z/γ^* + 4 jets events



Z/γ^*+2 jets using POWHEG [Re] JHEP 1210 (2012) 031

Implementation

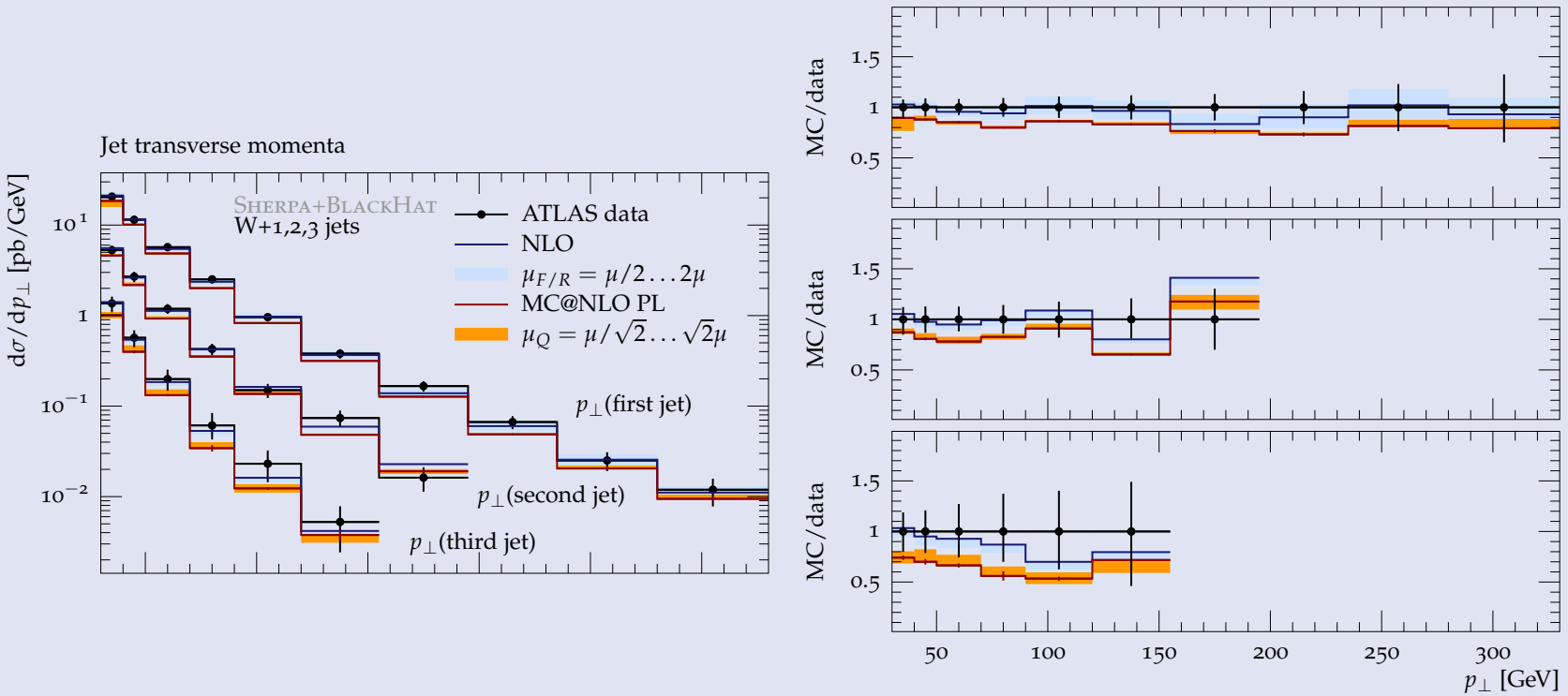
- Uses POWHEGBOX for Powheg matching ingredients
- Real correction MEs from MADGRAPH, virtual corrections from BLACKHAT



W + 3 jets using SHERPA

[Höche, Krauss, Schönherr, FS] Phys.Rev.Lett. 110 (2013) 052001

Comparison to ATLAS data



Physical assessment of resummation uncertainty: Variation of resummation scale μ_Q

ATLAS measurement

Phys.Rev. D85 (2012) 092002

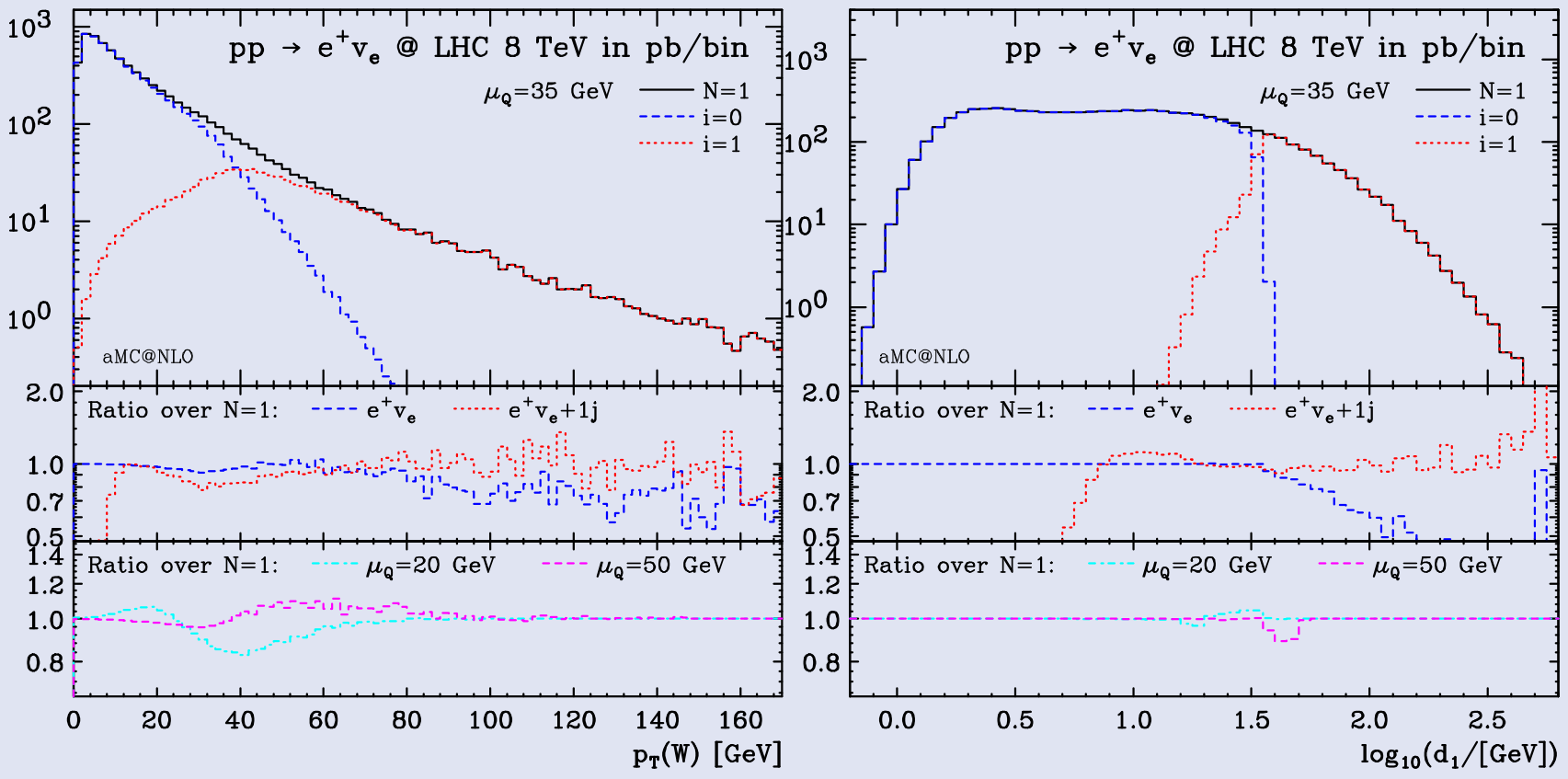
SHERPA+BLACKHAT NLO+PS predictions (at parton shower level)

W+0,1 jets using aMC@NLO [Frederix, Frixione] JHEP 1212 (2012) 061

Details of merging algorithm

⇝ Talk by R. Frederix

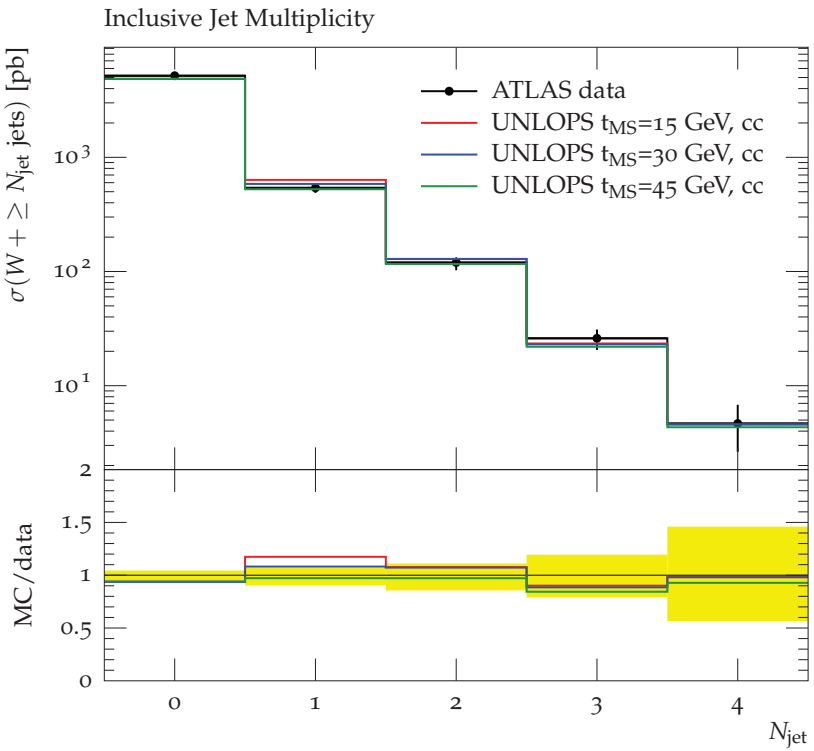
Example results for W^++jets production

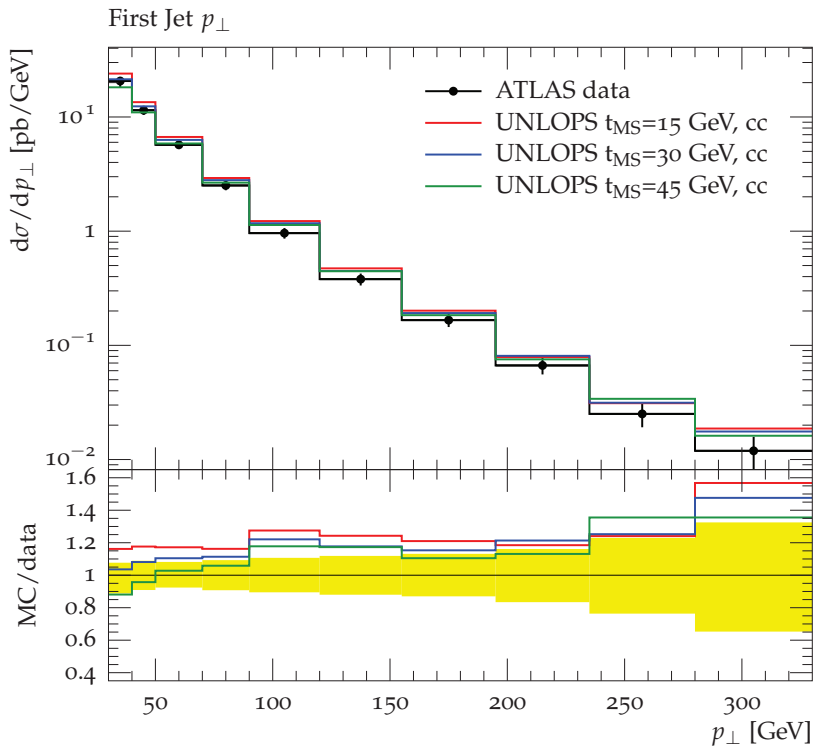


W+0,1 jets using PYTHIA8 (UNLOPS) [Lönnblad, Prestel] JHEP 1303 (2013) 166

Features of UNLOPS

- Based on UMEPS: Unitarisation of ME+PS multi-jet merging by subtracting from lower multiplicities exactly what is added in higher multis
- Preserves NLO inclusive cross section
- Improved logarithmic behaviour in low-multi jet observables





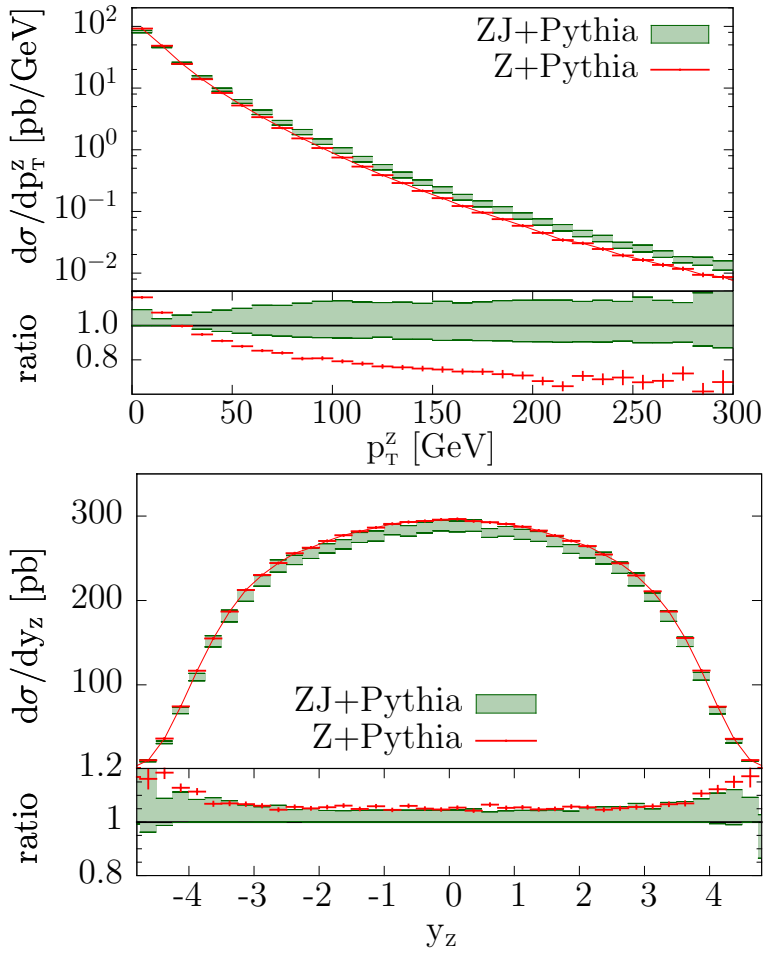
Z+0,1 jets using POWHEG and MINLO

[Hamilton, Nason, Oleari, Zanderighi] JHEP 1305 (2013) 082

Simplified summary

- Use Z+j POWHEG simulation
- Apply MINLO prescription:
  [Hamilton, Nason, Zanderighi] JHEP 1210 (2012) 155
  - CKKW scales
  - NLO-subtracted Sudakov factors
- Send $p_T^j \to 0$ (logs cancelled) for inclusive simulation
- Reweight with local NNLO K-factor
- Same available for W+j

$\Rightarrow$ Effectively predictions for V+0,1j without merging separate samples



ME+PS@NLO merging in SHERPA [Höche, Krauss, Schönherr, FS] JHEP 1304 (2013) 027

Main idea from tree-level ME+PS merging

Phase space slicing for QCD radiation in shower evolution

- Hard emissions $Q_{ij}(z,t) > Q_{\text{cut}}$
  - Events rejected
  - Compensated by events starting from higher-order ME regularised by Q_{cut}

  $\Rightarrow$ Splitting kernels replaced by exact real-emission matrix elements

  (But Sudakov form factors $\Delta^{(\text{PS})}$ remain unchanged)
- Soft/collinear emissions $Q_{ij,k}(z,t) < Q_{\text{cut}}$
  $\Rightarrow$ Retained from parton shower

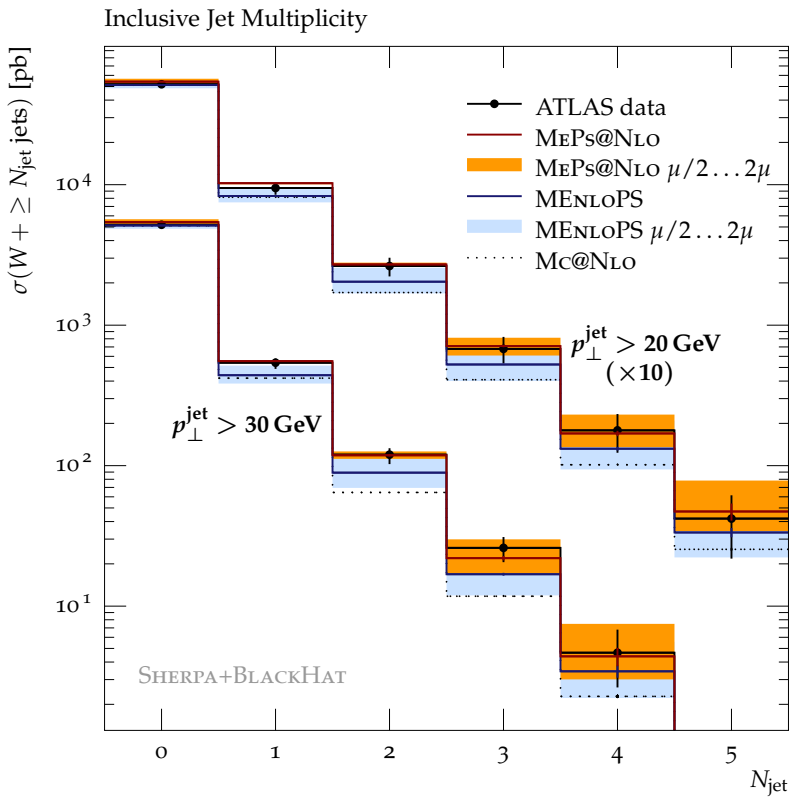
Features:

- Full hadron-level predictions
- Hard jet production with exact MEs
- Intra-jet evolution preserved

ME+PS@NLO merging

- Basics continued from tree-level ME+PS merging but with NLO+PS input
- Double counting in $\mathbb{S}$-events avoided by truncated "NLO-vetoed" shower:
  First hard emission is only ignored, no event veto

W+0,1,2 jets using SHERPA (MEPS@NLO)

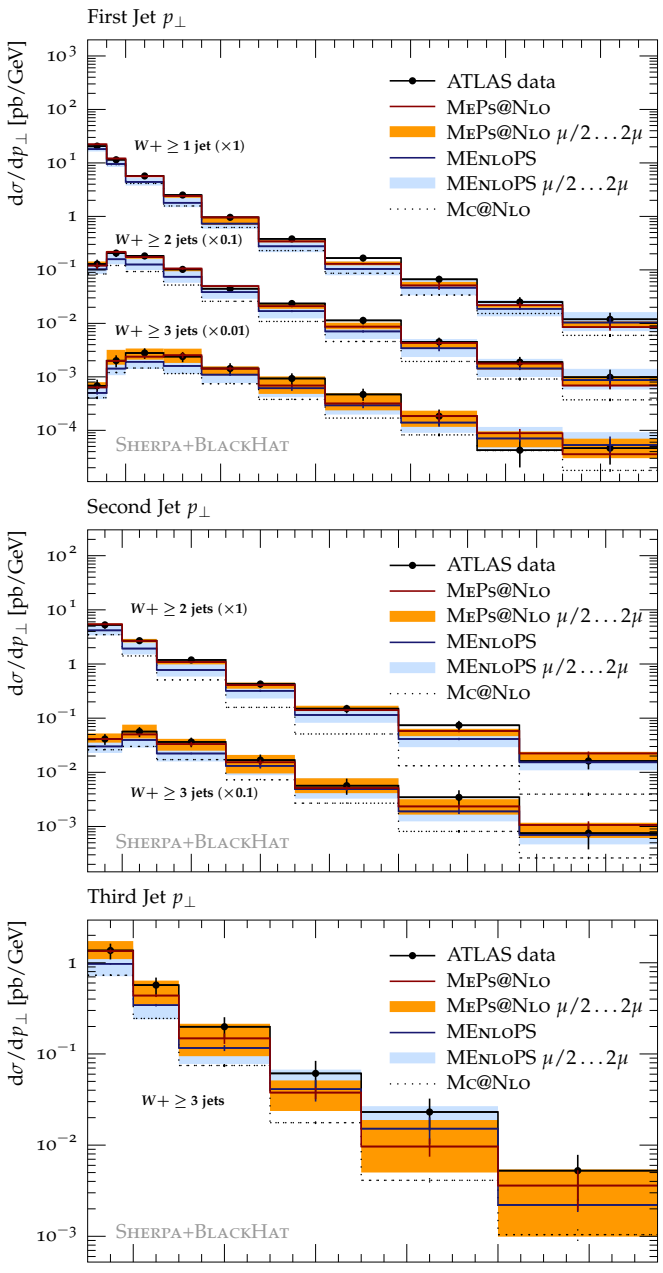


- Comparison to ATLAS measurement

  Phys.Rev. D85 (2012), 092002

- Significant reduction of ME+PS@NLO scale uncertainties in "NLO" multiplicities ($pp \to W + 0, 1, 2$ jets)
- Improved agreement with data

[Höche, Krauss, Schönherr, FS] JHEP 1304 (2013) 027



Conclusions

Summary

Many recent developments for V+jets predictions:

- NLO calculations for high jet-multiplicities with BLACKHAT+SHERPA
- Matching to parton shower for complicated processes becomes feasible
- Multi-jet final states simulated at NLO accuracy in inclusive samples with different approaches

Outlook

- New approaches with largely similar formal accuracy

$\Rightarrow$ Need effort to assess inherent systematic uncertainties for:

- fixed-order properties,
- but also resummation!