Monte Carlo developments and data comparison

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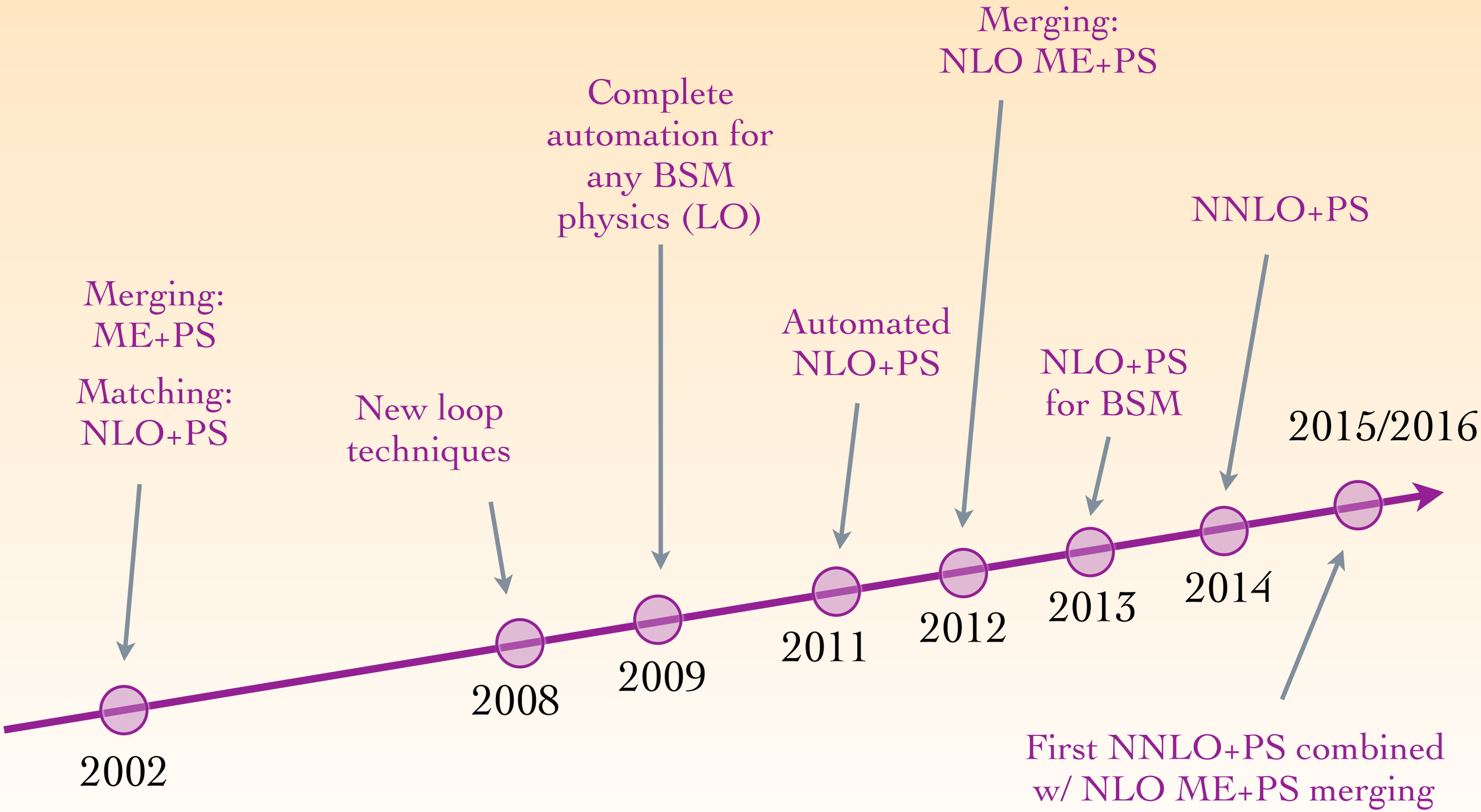
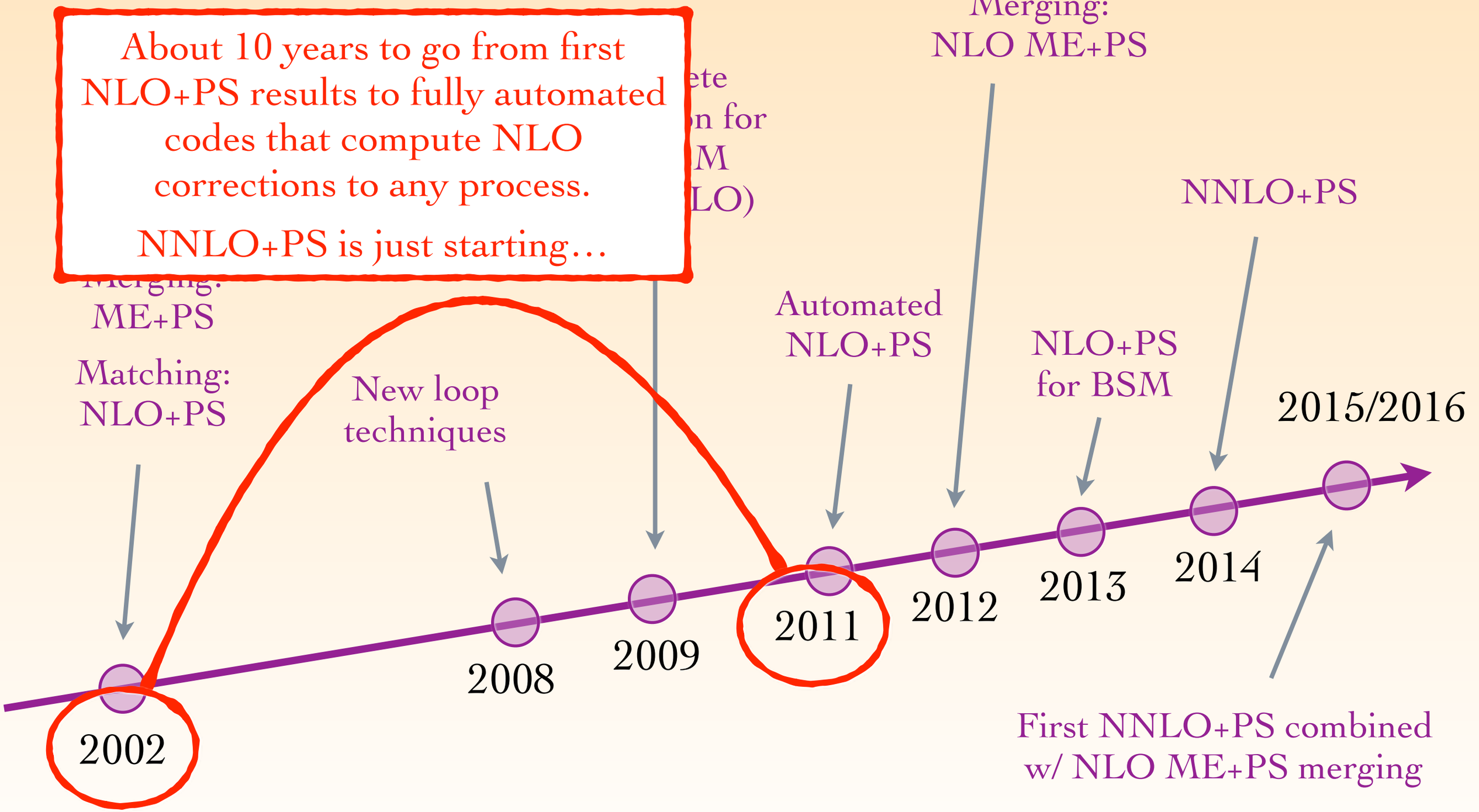
Recent progress in accuracy of Predictions



Recent progress in accuracy of Predictions

About 10 years to go from first NLO+PS results to fully automated codes that compute NLO corrections to any process.

NNLO+PS is just starting…



Contents

- In this talk, I'll discuss the following two topics
  - Vector boson plus multi-jet production at NLO+PS accuracy, using FxFx merging
    [RF, Frixione, Papaefstathiou, Prestel, Torrielli, JHEP 1602 (2016) 131]
  - Combining NNLO+PS with higher multiplicities at NLO (without a merging scale)
    [RF, Hamilton, JHEP 1605 (2016) 042]
- The topic of this talk is rather large: "Monte Carlo Development and Data Comparison". There have been numerous results presented in the literature.
  In this talk, I'll focus on my own work exclusively

V+jets with FxFx

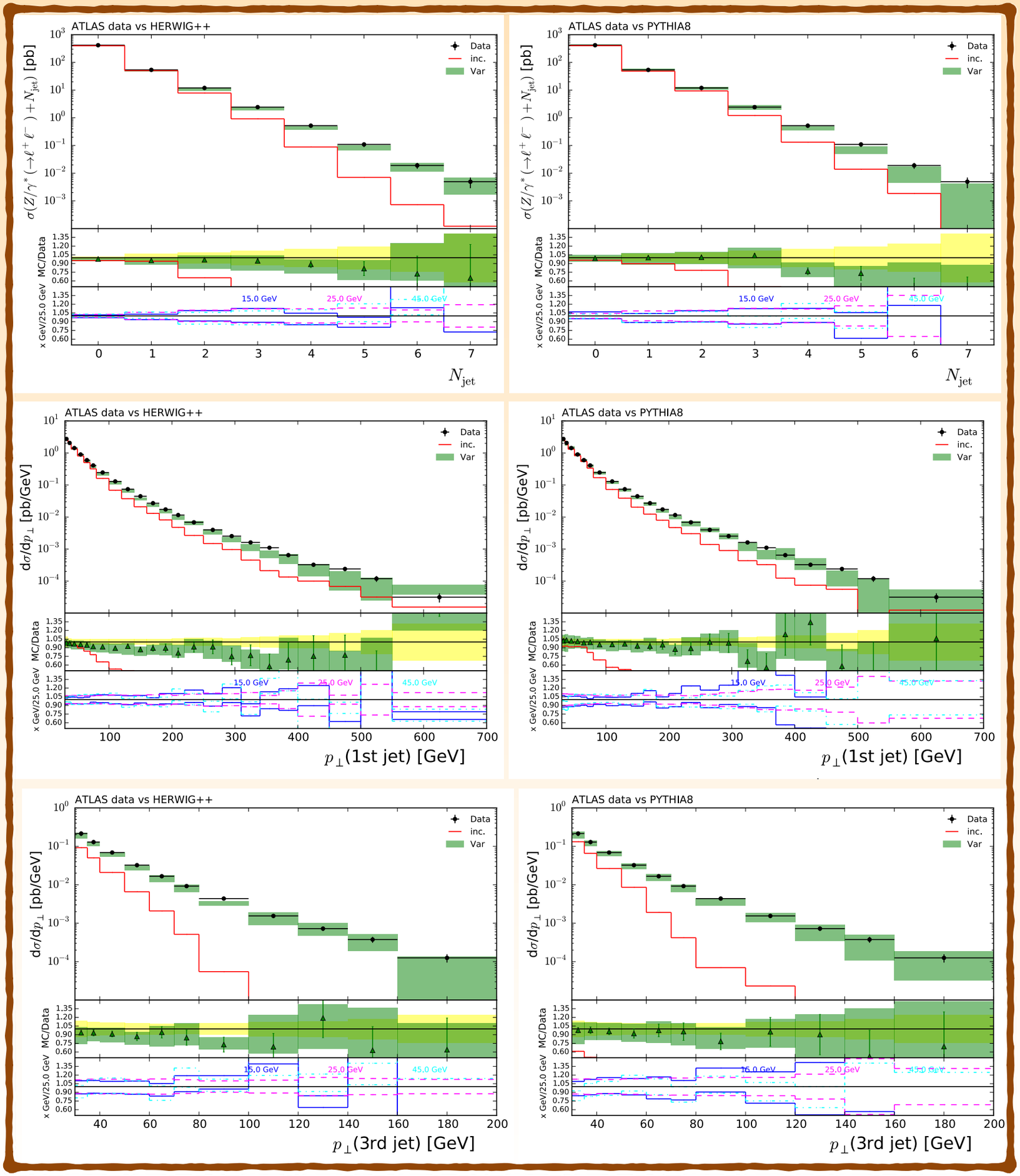
Multi-jet production in association with an EW boson

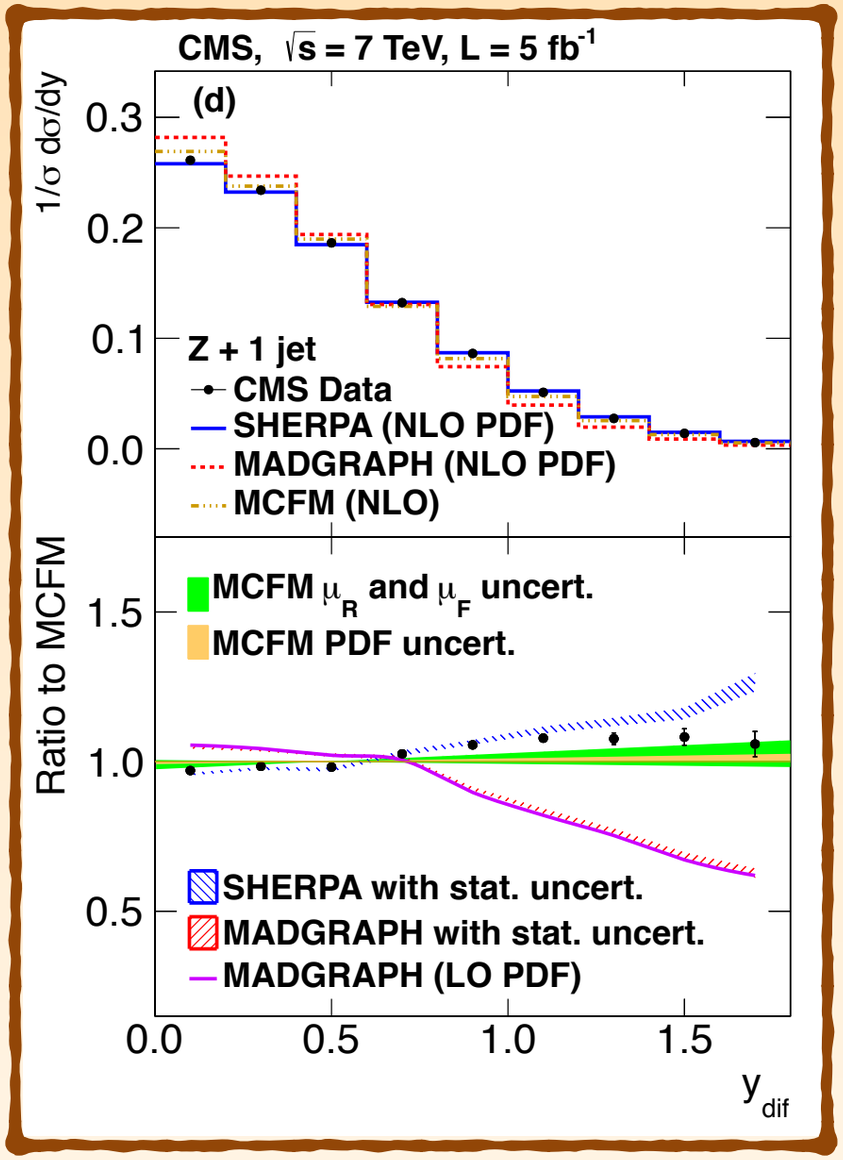
- Combine various multiplicity final states at NLO accuracy using the FxFx merging method
- To remove double counting between matrix elements and the shower:
  - Matrix elements are augmented with Sudakov form factors, à la MiNLO [Hamilton, Nason, Zanderighi]
  - On top of that there is an MLM-type rejection at the shower stage
  - Similar methods on the market: MEPS@NLO [Hoeche et al], UNLOPS [Lonnblad, Prestel]
- Use and validate the FxFx merging method with matching to Herwig++ and Pythia8
- Merging for W and Z plus up to 2 jets at NLO for LHC 7 TeV

	$\mu_Q = 15$ GeV	$\mu_Q = 25$ GeV	$\mu_Q = 45$ GeV	inclusive	
Z+jets	2.055(−0.9%)	2.074	2.085(+0.5%)	2.012(−3.0%)	HW++
	2.168(+0.8%)	2.150	2.117(−1.5%)	2.011(−6.5%)	PY8
W+jets	20.60(−0.9%)	20.78	20.87(+0.4%)	19.96(−3.9%)	HW++
	21.71(+1.0%)	21.50	21.18(−1.5%)	19.97(−7.1%)	PY8

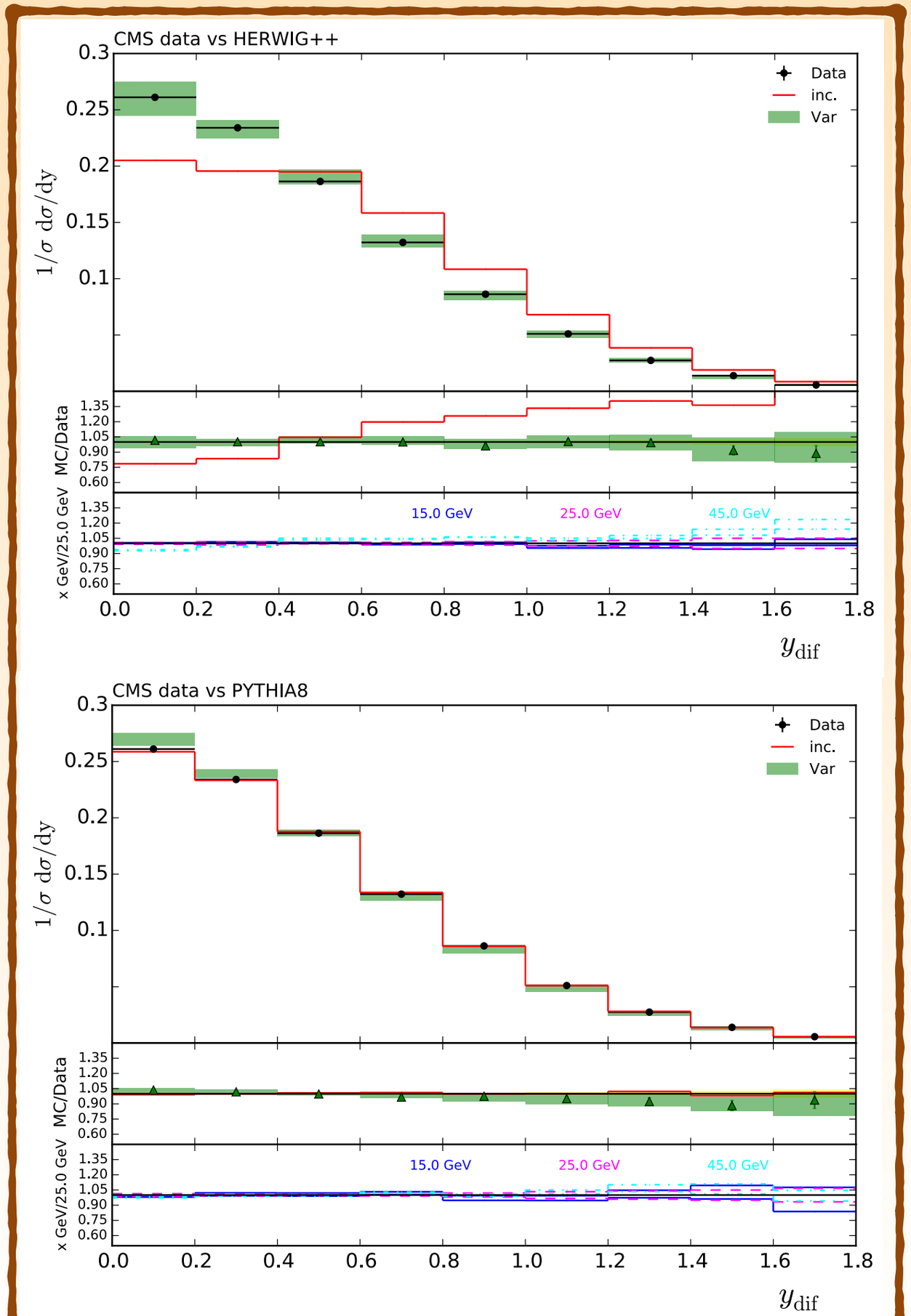
- ✦ FxFx Merged results close to the NLO inclusive cross sections
- ✦ Order 1% dependence on the merging scale for total rates
  - o slightly smaller for HW++ than for PY8
- ✦ Slightly larger cross section for PY8 than for HW++
- ✦ For comparisons to data (next slides) no normalisation factors applied: the normalisation of the predictions is as they come out of the code

- Z+jets
- Exclusive jet multiplicity and hardest and 3rd hardest jet pT spectra
- Uncertainty band contains ren. & fac. scale, PDF & merging scale dependence
- Rather good agreement between data and theory





- Rapidity difference between Z-boson and hardest jet.
- Sensitive to higher multiplicity matrix elements
- LO predictions off (in particular MadGraph)
- No discrepancies at NLO



- W+jets
- Agreement between FxFx merged results, matched to Herwig++ and Pythia8, and Atlas and CMS data is rather good
- Where data and theory differ, also differences between the results matched to HW++ and PY8 differ

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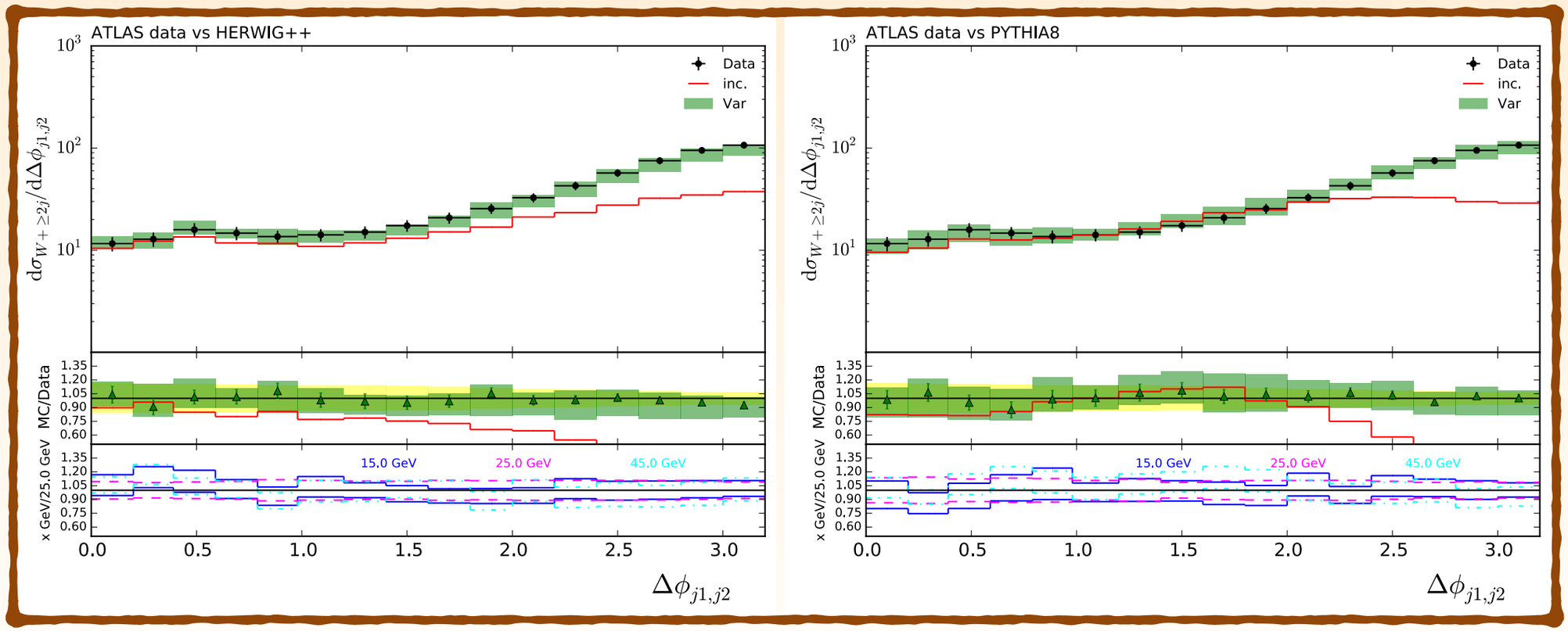

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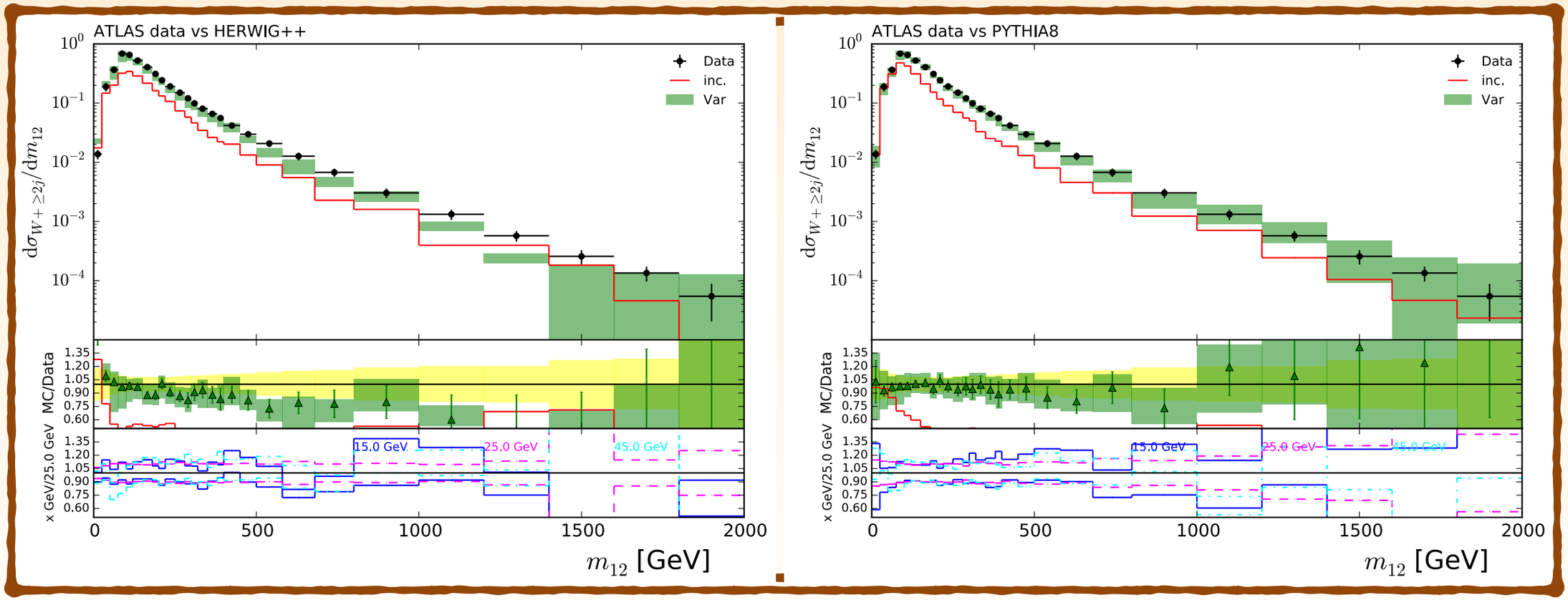


Extending Minlo'

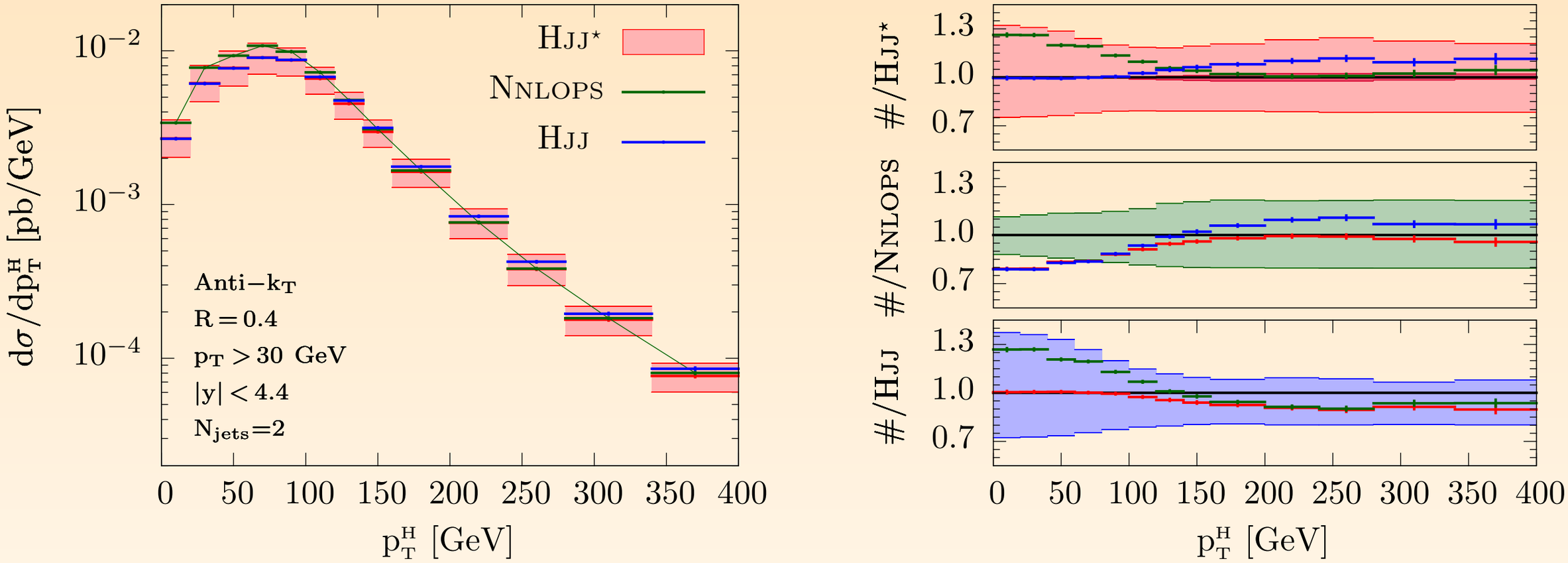
MINLO'

- Minlo for a B+m-jet process leads to spurious terms in B+(m-1)-jet distributions hampering NLO accuracy of the latter
  [Hamilton, Nason, Zanderighi (2012)]
  - Original Minlo' idea is to remove these terms by explicit calculation
    [Hamilton, Nason, Oleari, Zanderighi (2013)]
    - New idea: numerically derive these terms by enforcement of unitarity in the complete B+(m-1)-jet phase-space
      [RF, Hamilton (2015)]
- Independent from the process and multiplicity
- Can combine various multiplicities (just like FxFx, MEPS@NLO and UNLOPS) without the introduction of an artificial merging scale
- Can include NNLO corrections to lowest multiplicity

Proof-of-concept

- Apply the method to **Higgs production by gluon fusion** in the infinite top quark limit (which is not a good approximation at high scales, but not a problem for a proof of concept)
- Start from H+J Minlo', corrected to include NNLO for H. Already available in the POWHEG BOX [Hamilton, Nason, Re, Zanderighi (2013)]
- Apply the extended Minlo' method to HJJ at NLO to get
  - NLO+PS predictions for inclusive HJJ observables
  - NLO+PS predictions for inclusive HJ observables
  - NNLO+PS predictions for inclusive H observables
- Study renormalisation/factorisation scale dependence and dependence on freezing parameter ρ (which we vary $\rho=\{1, 3, 9, 18, 27\}$)

Higgs boson p_T in events with exactly 2 jets



- At small p_T, all scales are of the same order. The Minlo method does not do much: HJJ⋆ agrees with HJJ
- At large p_T, HJJ⋆ agrees with NNLOPS dominated by events with one hard jet ($p_T(j_1) \sim p_T(H)$) and one soft jet: a 30 GeV jet comes basically for free
  - The pT(H) spectrum with N_{jets}=2 becomes essentially $N_{jets}\geq 1$ pT(H) distribution

Conclusions

- Great improvements in accuracy in Event Generation
  - Matched & merged NLO+PS readily available
  - "Era of NLO"
  - Agreement with data for W/Z+jets production rather good
  - First results including NNLO corrections are becoming available as well