PB parton showers applied to Drell Yan + jets production

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Why TMDs?

R. A. Martinez et al. [APP B46 (2015) 12, 2501–2534]

TMD: Transverse momentum dependent parton distribution

- Small transverse momentum phenomena
- Small-x phenomena
- DY, and semi-inclusive DIS
- Transverse momentum effects from intrinsic kt and evolution

Parton Branching (PB) method

FH et al. [PLB 772 (2017) 446–451]
FH et al. [JHEP 2018, 70 (2018)]
ABM et al. [PRD 99, 074008 (2019)]

- Evolution of TMDs (and collinear PDFs)
- Resummation of soft gluons at LL and NLL
- Solution valid at LO, NLO and NNLO
- Determination of TMDs from the fully exclusive solution
- **Backward evolution fully determines the TMD shower**

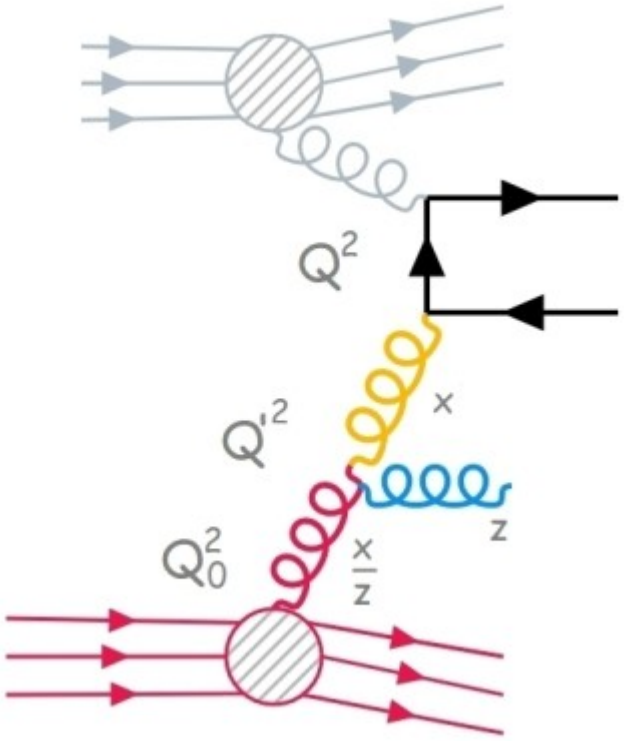
→ consistently treats perturbative and non-perturbative transverse momentum effects

PB method

PB iterative solution:

$$A_a^{(1)}(x,\mathbf{k_t};Q^2) = \Delta_a(Q^2,Q_0^2)A_a(x,\mathbf{k_t};Q_0^2)+$$

$$+\sum_b \int_{Q_0^2}^{Q^2} \frac{d^2\mathbf{Q}'}{\pi Q'^2} \frac{\Delta_a(Q^2,Q_0^2)}{\Delta_a(Q'^2,Q_0^2)} \int_x^{z_M} dz P_{ab}^{(R)}\left(z,\alpha_s(Q'^2)\right)\Delta_b(Q'^2,Q_0^2)A_b\left(\frac{x}{z},\mathbf{k_t}+(1-z)\mathbf{Q}';Q_0^2\right)$$



- kinematics of the splittings is known
- physics ➡ mapping of evolution variables to splitting kinematics
- TMD from cumulative kt of the branchings in forward PB evolution
- **Initial-state shower fully determined by TMD and its backward PB evolution**
- **Parton shower exactly matches the evolution of the TMD**

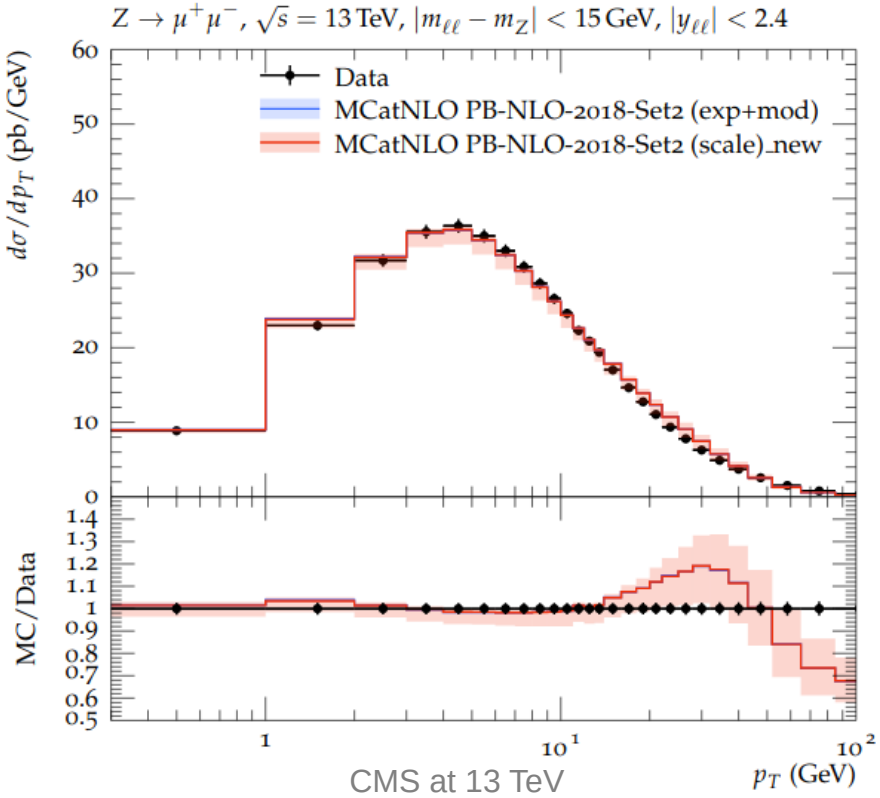
Application to a wide range of DY mass

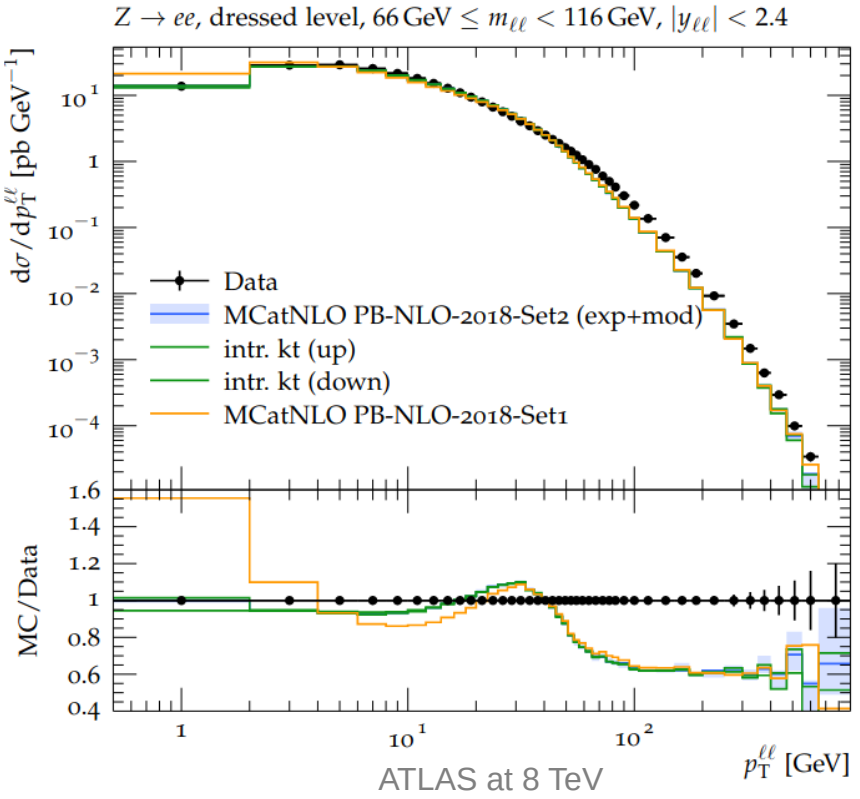
Application to high mass DY production

DY pt spectrum

- Combined with MC@NLO
- **Excellent description of DY pT spectrum**
- **Non-perturbative TMD effects not significant at high pT**
- **Multi-jet contributions needed at high pT**

ABM et al. [PRD 100, 074027 (2019)]
ABM et al. [EPJC 80, 598 (2020)]



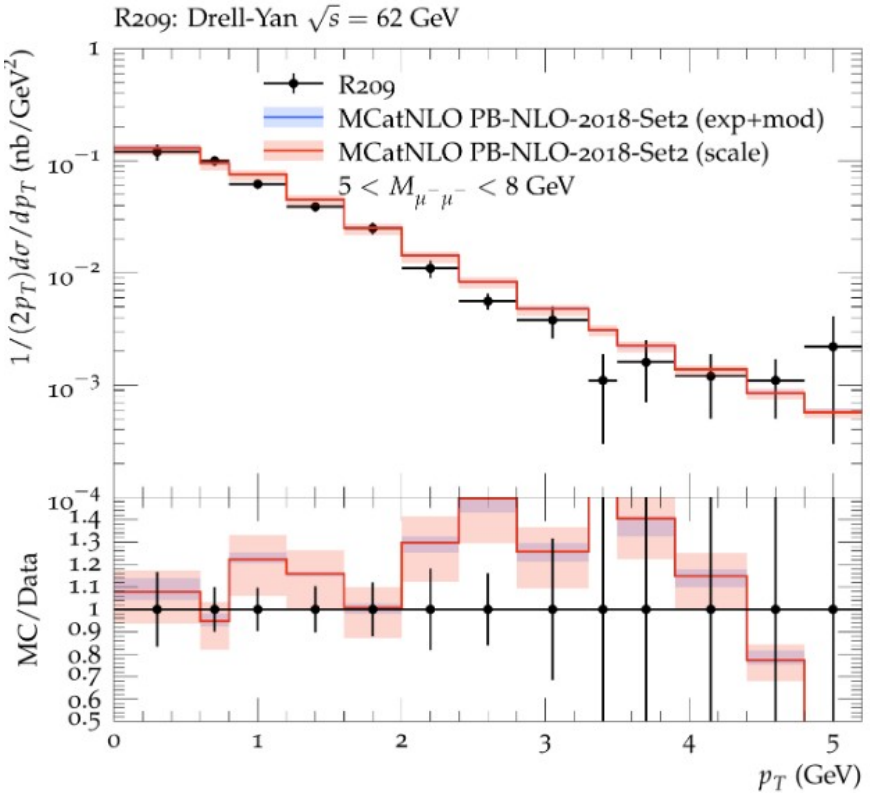


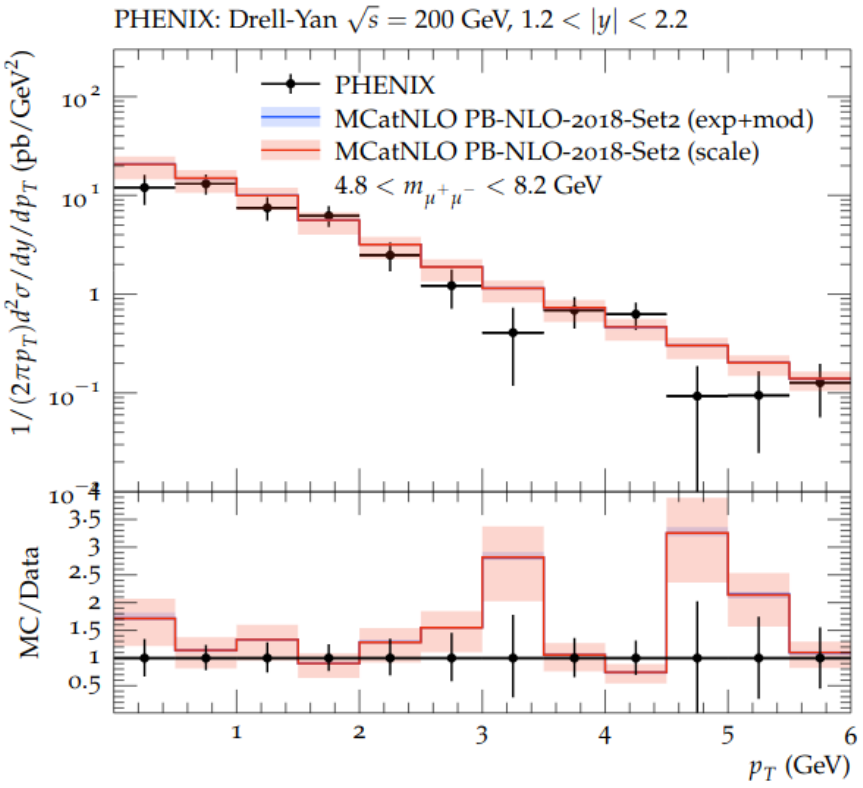
Application to low mass DY production

DY pt spectrum

- Combined with MC@NLO
- Excellent description of DY pT spectrum
- **First simultaneous description of both low and high-mass DY pT spectrum**
- **No more low pT crisis** Bacchetta et al. [PRD 100 (2019) 014018]; ABM et al. [EPJC 80, 598 (2020)]

ABM et al. [PRD 100, 074027 (2019)]
ABM et al. [EPJC 80, 598 (2020)]



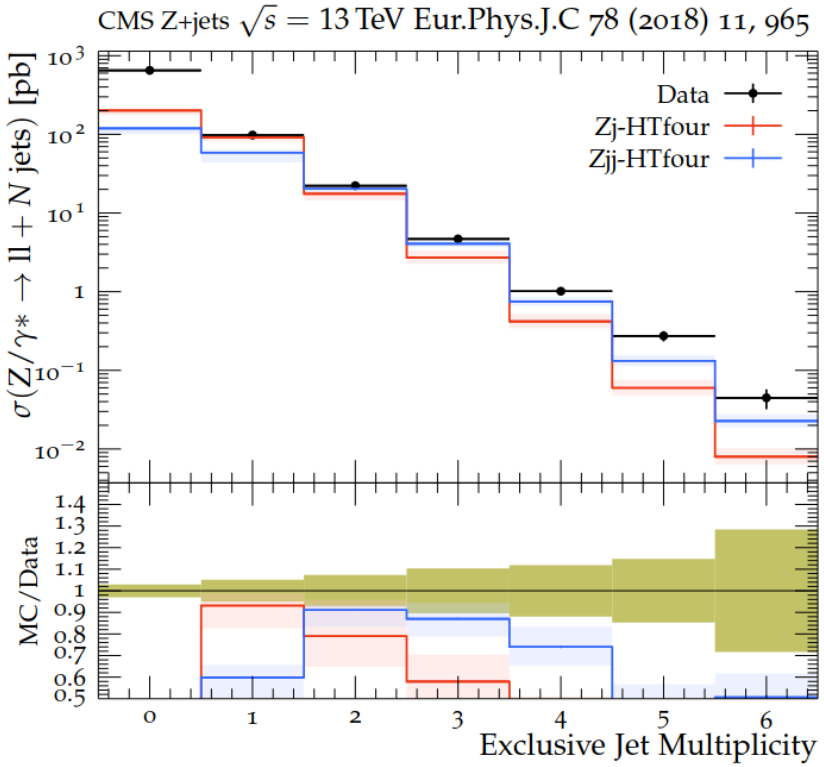


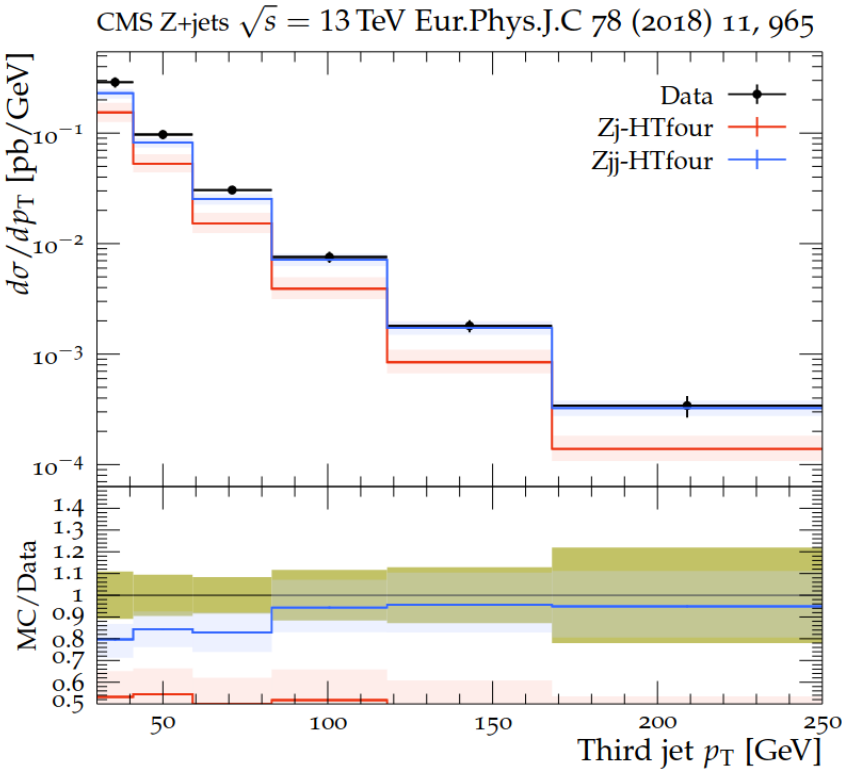
Application to Z + jets production

Application to Z + jets production

Jet multiplicity and third jet pT spectrum

- PB shower combined with Z + jj and Z + jjj MC@NLO
- Suffers at higher multiplicities
- **Good description of third jet pT spectrum given by higher orders**

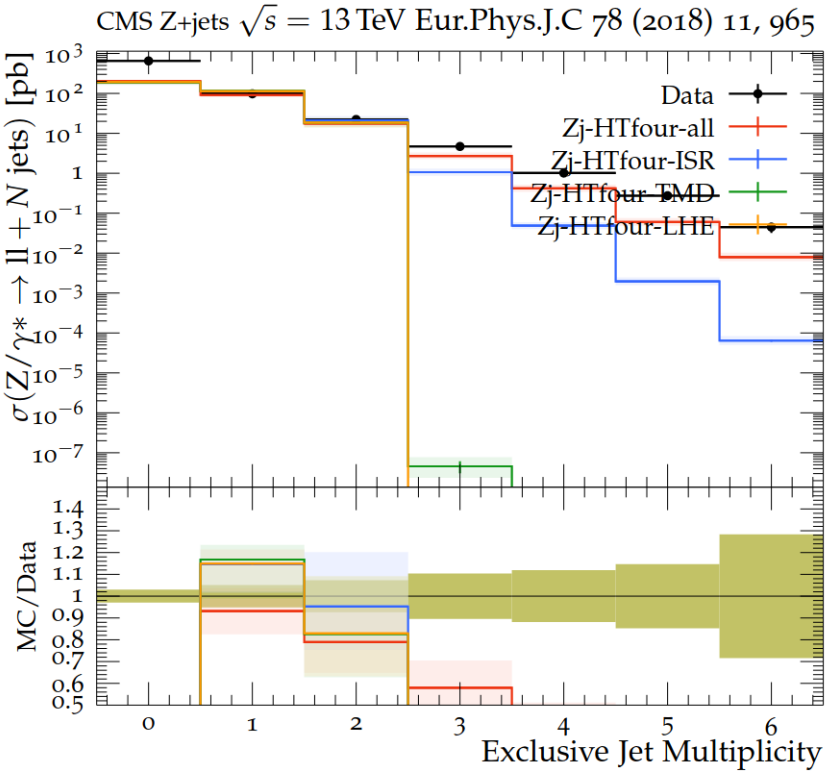


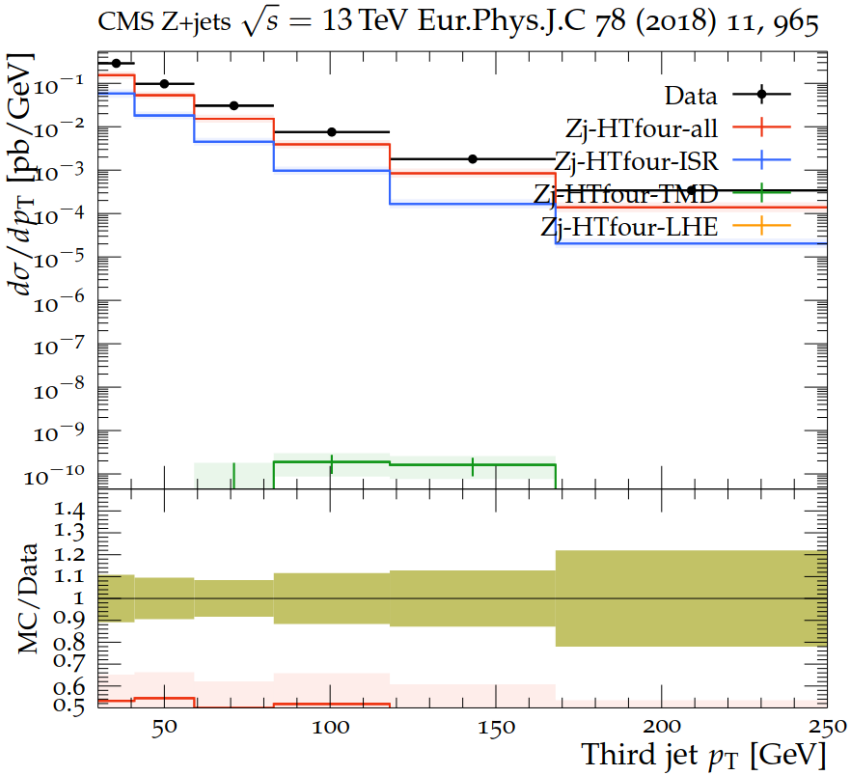


Application to Z + jets production

Jet multiplicity and third jet pT spectrum

- **Significant contribution from perturbative part of TMD**
- Final state emissions important at higher multiplicities





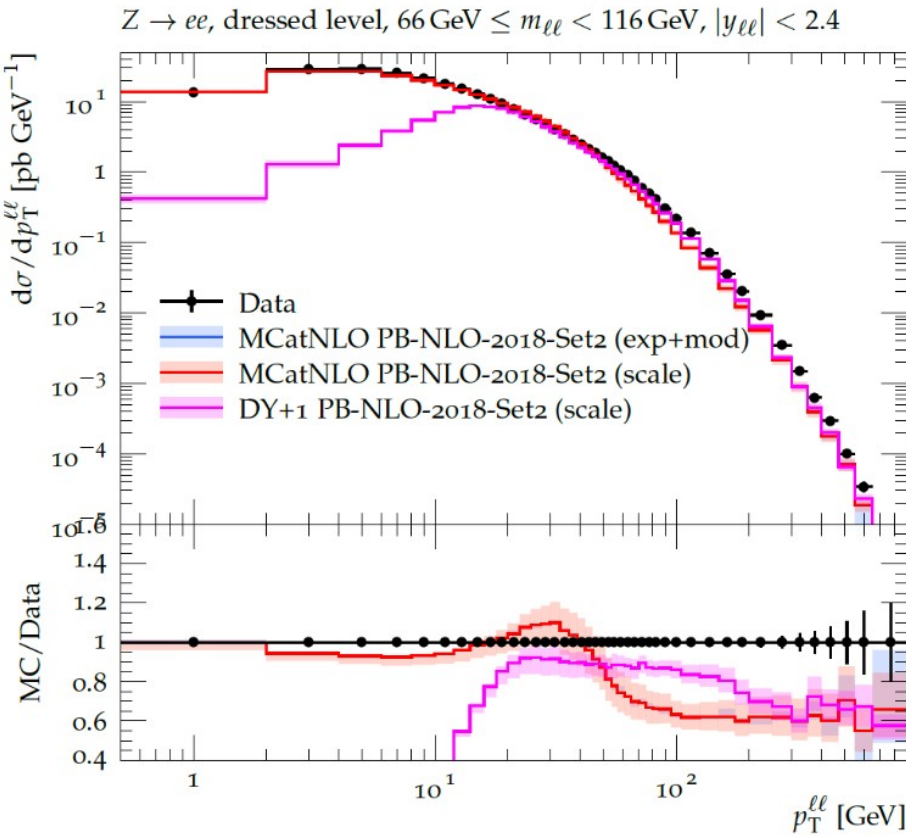
Combining TMD shower with higher orders

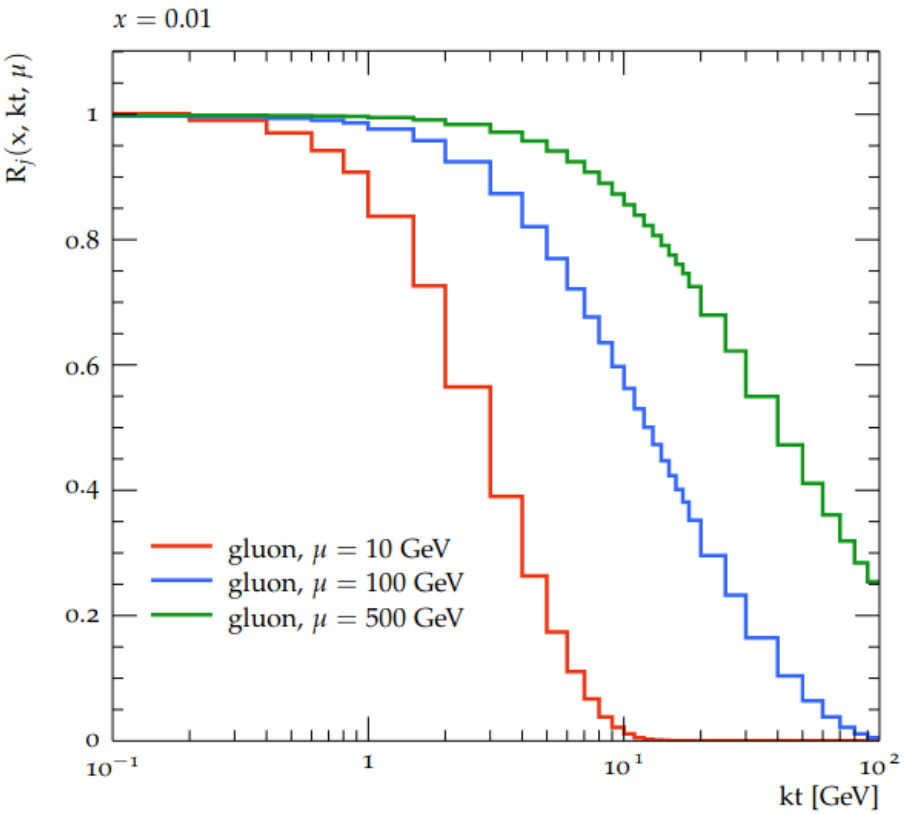
Combining TMD shower with higher orders

DY pt spectrum

- Important deficit at high pT with Z at NLO
- Potentially large corrections by higher orders
- **Try combining high pT TMD effects with multiple higher orders**

ABM et al. [PRD 100, 074027 (2019)]
ABM et al. [arXiv:2107.01224]



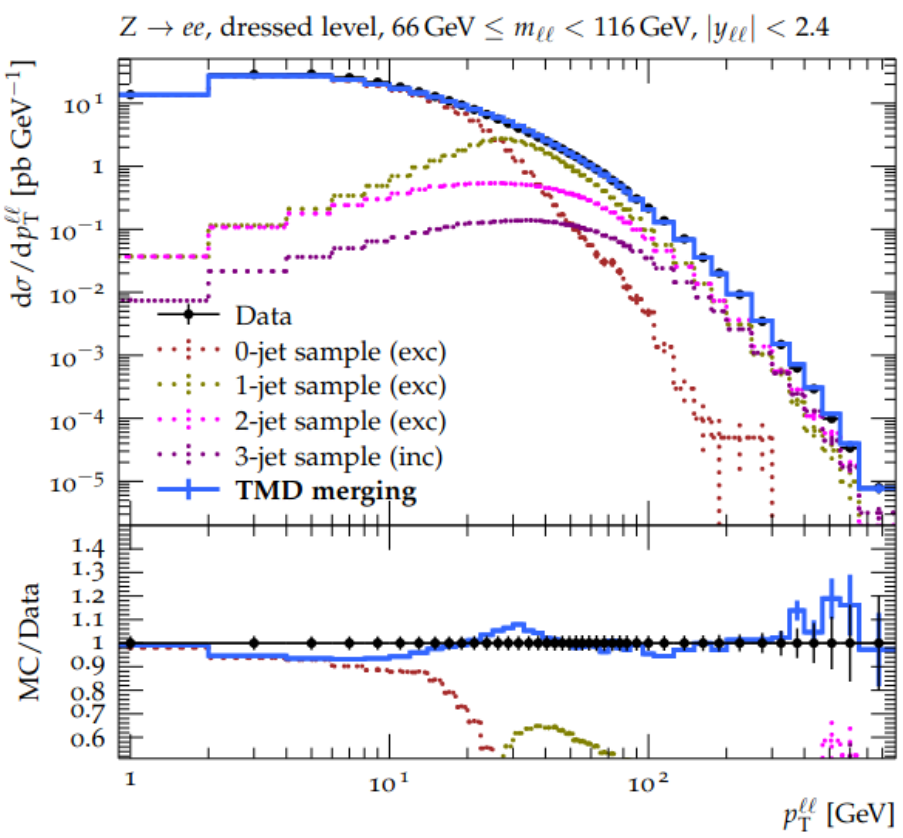


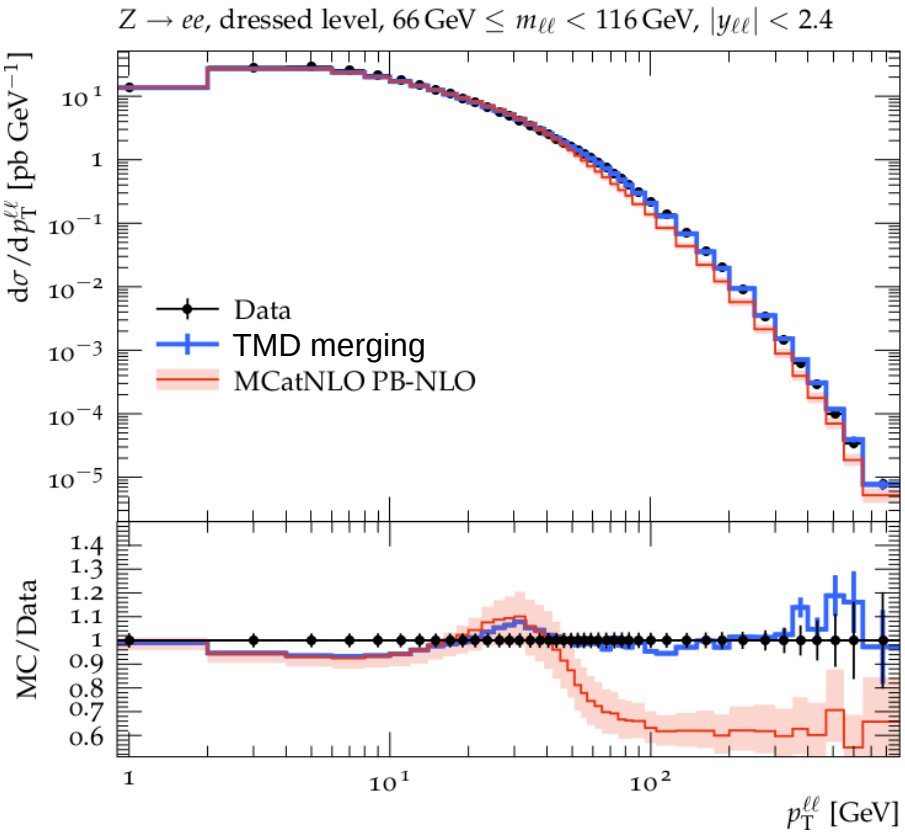
Combining TMD shower with higher orders

DY pt spectrum

- TMD evolution with multi-jet merging achieved at LO
- **Low as well as high-pt now nicely described**
- **Consistent with MCatNLO PB-NLO at low pT**

New! ABM et al. [arXiv:2107.01224]



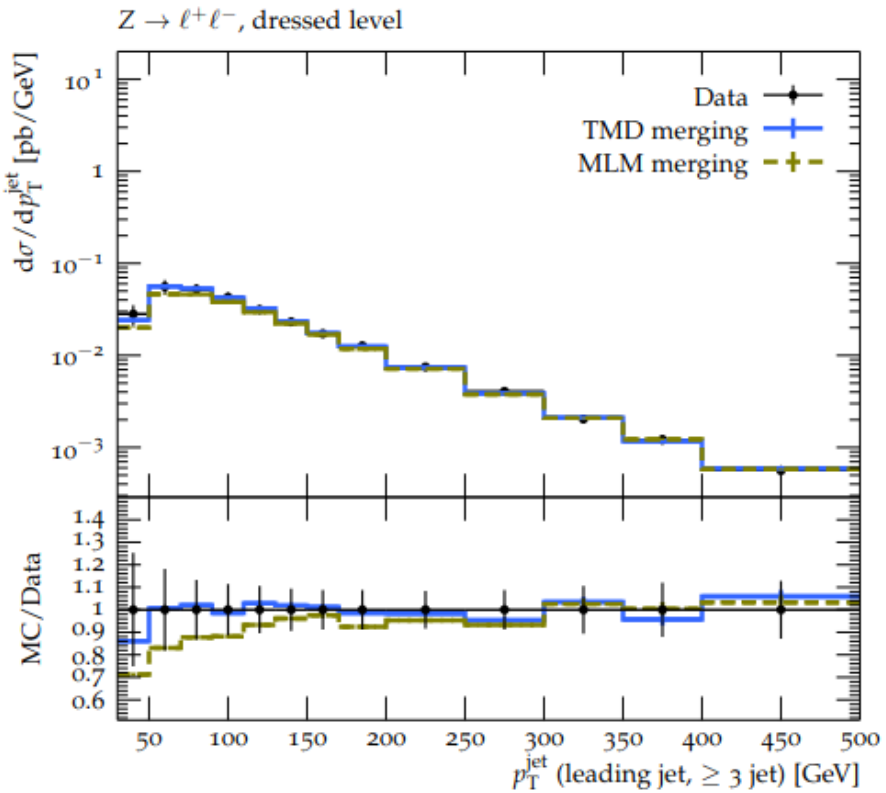


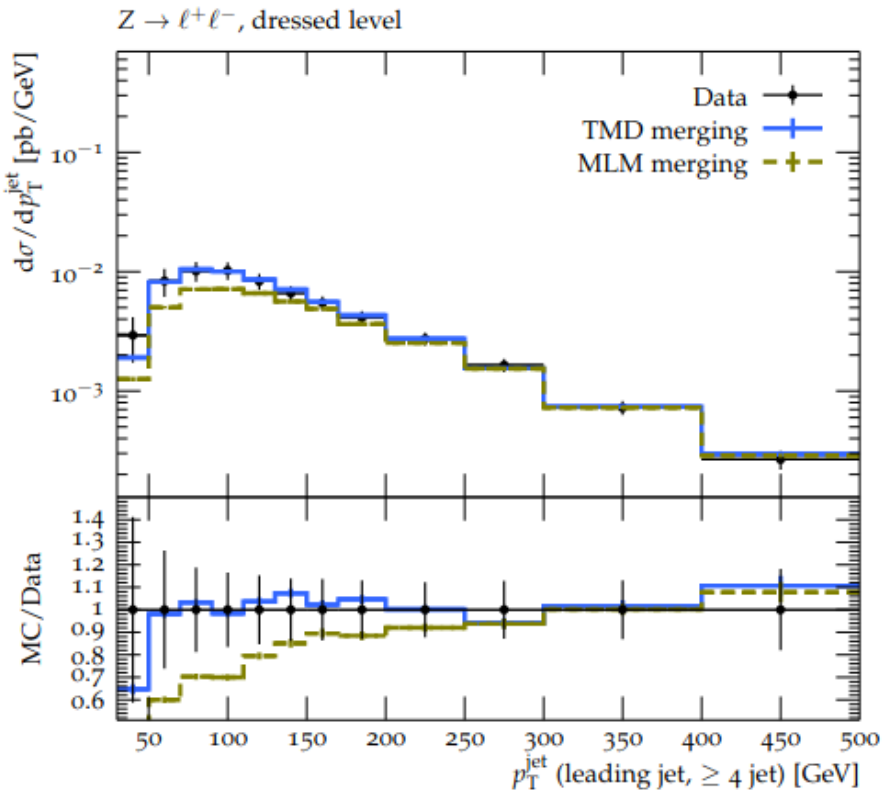
Combining TMD shower with higher orders

Jets pt spectrum

New! ABM et al. [arXiv:2107.01224]

- Not only overall recoil but also jet pT
- **The description of jet pT improves at high multiplicities**





Conclusions

- PB TMD evolution provides excellent description of DY pt spectrum in a wide range of DY mass
- Parton shower from PB TMD evolution have significant contribution to jet multiplicity and jet pt spectra
- Higher fix-order contributions to PB TMD evolution potentially significant
- First combination of TMD evolution effects with multi-jet merging for Z pt and jet spectra

Thank you