From Underlying Event Sensitive To Insensitive

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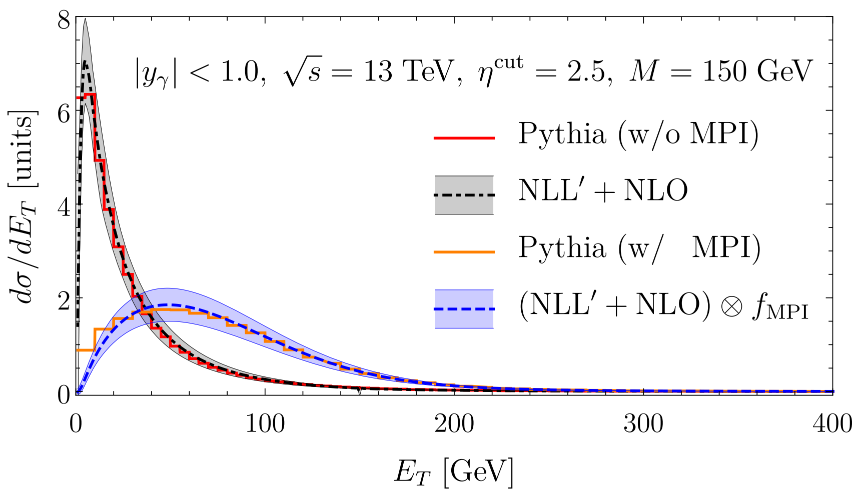
Many observables are sensitive to UE/PU

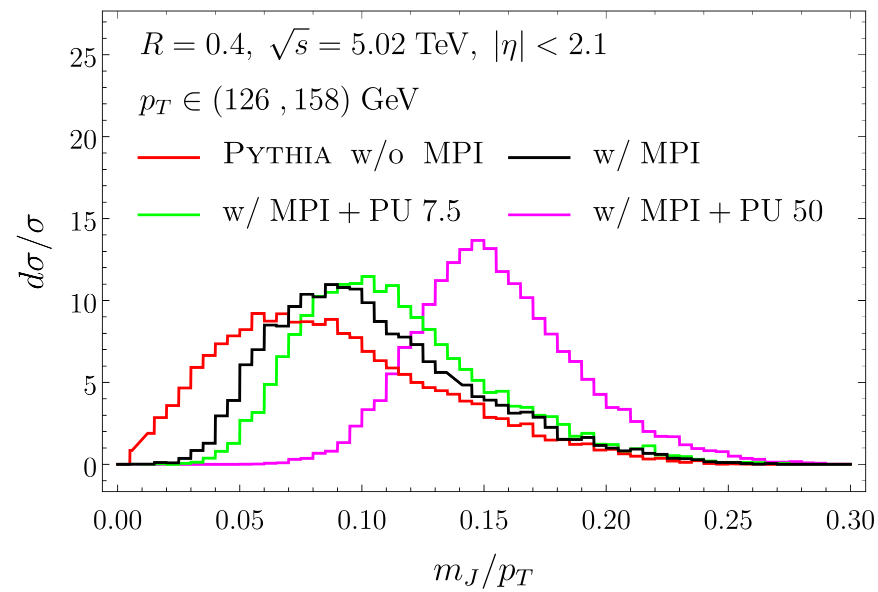
- Drell-Yan: transverse energy (cf pT), beam thrust
- jet substructures: jet mass, angularity, n-subjettiness, $\cdots$

Drell-Yan E_T distribtion



$$E_T(\eta_{\rm cut}) = \sum_i p_T^{(i)} \Theta(\eta_{\rm cut} - |\eta^{(i)}|)$$

jet mass distribution



Many observables are sensitive to UE/PU

- No first principle approach is available for UE.
- Large source of uncertainties in theory predictions.
- Several options to handle:
  - tuned models MPI/soft QCD in Monte Carlo Simulation
  - useful robust observables: pT (over ET), small jet radius
  - removing soft particles from jet using grooming algorithms
  - *new statistical approach: subtracted cumulants*

A lesson with a simple model in Drell-Yan

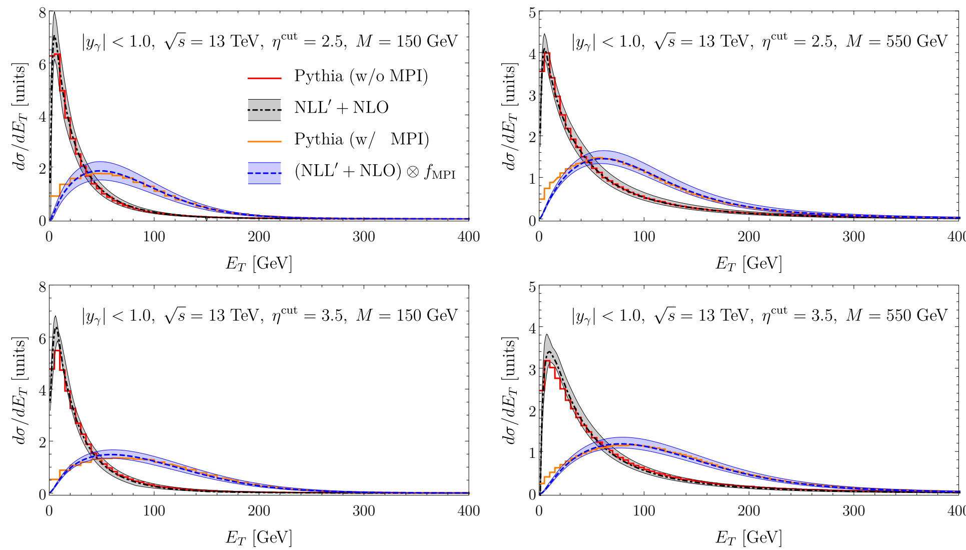
- An excellent agreement between a simple model and Pythia MPI.

$$f_{\mathrm{MPI}}(E_T, \eta_{\mathrm{cut}}) = \mathcal{N} \exp\left[- \left(\frac{E_T}{\alpha(\eta_{\mathrm{cut}})\sqrt{\pi}} \right)^2 \right]$$

- A single parameter is constant in wide range of hard scales and rapidities.

$$\alpha(\eta_{\mathrm{cut}}) = A\, \eta_{\mathrm{cut}}$$

$$A = 22.7\ \mathrm{GeV}$$



- Similar observations in jet mass: inclusive jet, H/Z + jet process, top-quark jet

1405.6722 Stewart, Tackmann, Waalewjin, 1708.02586 Hoang, Mantry, Pathak, Stewart, 1803.03645 Z. Kang, Lee, Liu

Subtraction of moments

- The model is un-correlated to hard scale Q, while the perturbative contribution is correlated.

$$f_{\rm MPI}(E_T,\eta_{\rm cut}) = \mathcal{N} \exp\Big[-\Big(\frac{E_T}{\alpha(\eta_{\rm cut})\sqrt{\pi}}\Big)^2\Big]$$

- The model UE contribution is additive in the moments

$$\langle E_T(Q)\rangle = \langle E_T(Q)\rangle_{\rm pert} + \langle E_T\rangle_{\rm MPI}$$

- Uncorrelated model contributions are cancelled in the subtraction between moments at Q and Q_0

$$\begin{aligned}\Delta E_T(Q,Q_0) &\equiv \langle E_T(Q)\rangle - \langle E_T(Q_0)\rangle \\ &= \Delta E_{T,\rm pert}(Q,Q_0)\end{aligned}$$

Subtracted Cumulants

- The cumulant is excellent quantity to generalize this idea
  - defined by a generating function
  - one-to-one with the moments for an observable e:

$$\kappa_1(e) = \langle e \rangle \qquad \kappa_2(e) = \langle e^2 \rangle - \langle e \rangle^2 \qquad \kappa_3(e) = \langle e^3 \rangle - 3\langle e^2 \rangle \langle e \rangle + 2\langle e \rangle^3$$

  - Additivity if e_B and e_S are independent

$$\kappa_n(e_S + e_B) = \kappa_n(e_S) + \kappa_n(e_B)$$

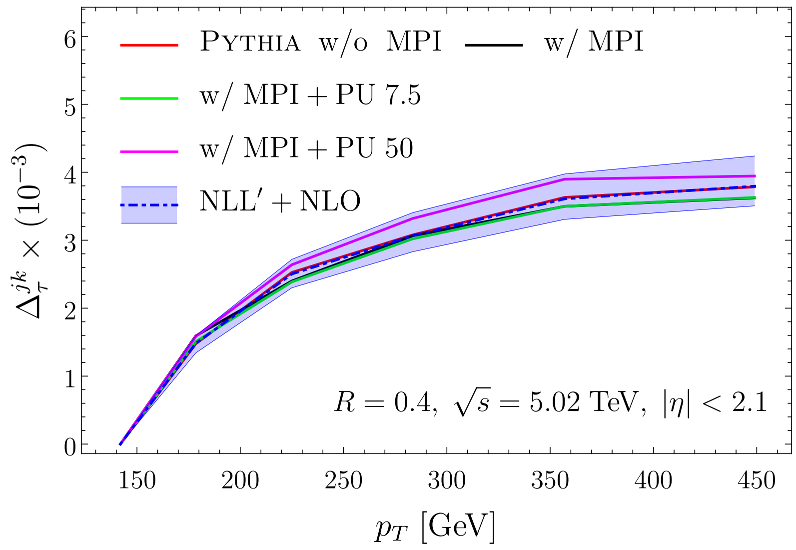
- At any n-th order the subtracted cumulants is insensitive to the uncorrelated contributions (e_B=UE, PU)
- What observables work?
  Individual particle contributions are added in total.
  transverse energy, beam thrust, jet angularity, ≈jet mass, $\cdots$

Example with first cumulant of jet mass

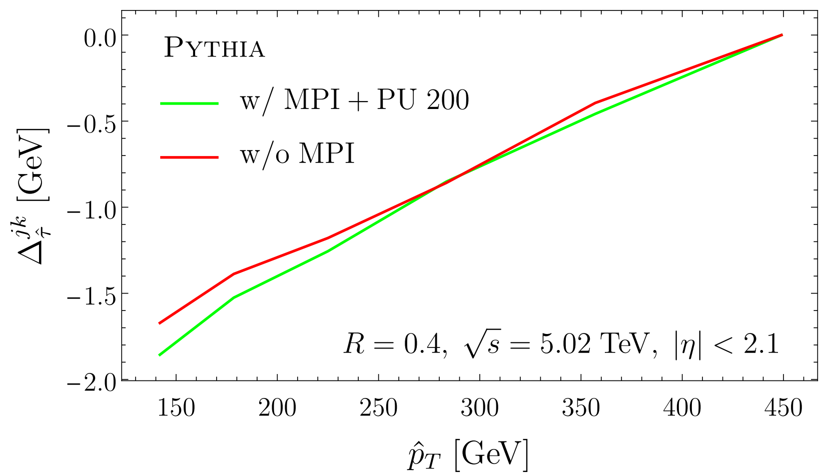
- definitions: $$\hat{\tau} = 2\cosh(\eta)\sum_{i\in\mathrm{jet}} p_i^+ = \frac{m_J^2}{p_T}\left[1+\mathcal{O}\left(\frac{m_J^2}{p_T^2}\right)\right]$$

$$\Delta_\tau^{jk} = \langle\tau\rangle^{[j]} - \langle\tau\rangle^{[k]}\,\frac{\langle p_T^{-1}\rangle^{[j]}}{\langle p_T^{-1}\rangle^{[k]}}$$

- Robust under Pythia UE and PU



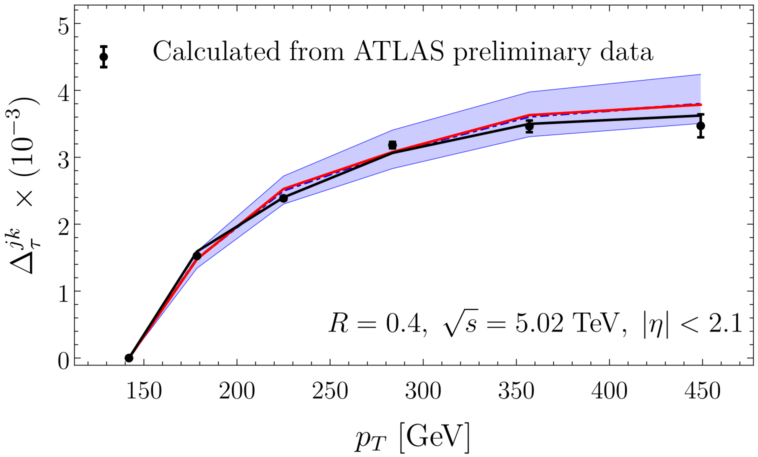
high luminosity (200 PU)



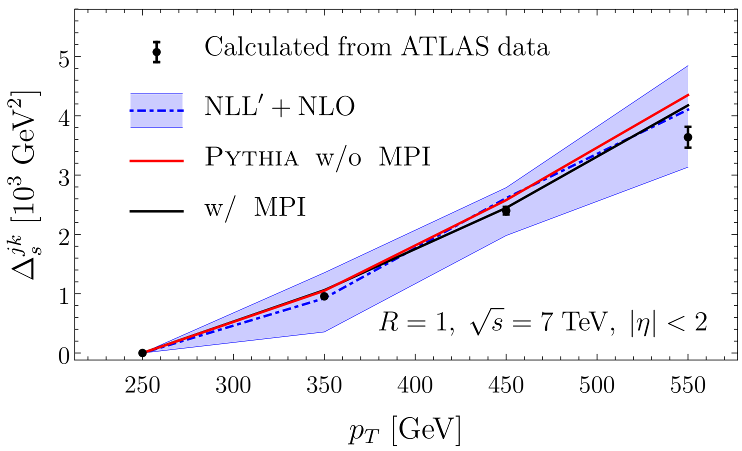
Comparison to ATLAS measurement

- We use ATLAS data for mass distributions at 5 TeV and at 7 TeV and compute subtracted cumulants.

5 TeV



7 TeV



- two curves are different: $\tau = m_J^2/p_T^2$ (left) $s = m_J^2$ (right)
- *Error bars only include statistical uncertainties.*

Summary and outlook

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- excellent performance of a simple UE model observed.
- subtracted cumulants for DY and for jet substructure:
  mitigating large background such as UE, PU
  a simple way to compare theory calculations to measurement
- example: jet mass shows a good agreement with ATLAS data

- higher-order cumulants, more jet substructure observables
- precision predictions beyond NLL'+NLO are available for several jet substructure and can be tested using our method.
- application to heavy-ion collisions with hard scattering

Backup

Sensitivity to quark/gluon jet fraction

- Medium effect in heavy-ion collisions changes q/g jet fraction.

$$\langle \tau \rangle^{[j]} = f_g^{[j]} \langle \tau \rangle_g^{[j]} + (1 - f_g^{[j]}) \langle \tau \rangle_q^{[j]}$$

- visible change in subtracted cumulant