HEJ+Pythia

Merging High Energy and Soft-Collinear Resummation

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Matching to Exclusive Predictions

- Well-proven procedures exist for matching parton showers to *inclusive* predictions (e.g. CKKW-L for FO) - creates exclusive states from inclusive.
- We propose a general procedure to merge *exclusive* predictions with parton shower resummation while *preserving the accuracy of both*.
- For this study we merge the high energy resummation of *High Energy Jets* 2 (HEJ2) with PYTHIA8.
- HEJ2 is exclusive in most of phase space: applies the LL BFKL corrections to LL and NLL processes from LO . Non-HEJ-resummable states matched to LO.
- HEJ describes well effects from hard, wide-anlge emissions; parton showers describe well soft-collinear effects and the dynamics where we observe $p_\perp$-hierarchies.

Complications with Exclusive-Exclusive Merging

- Both HEJ and PYTHIA are exclusive across most of phase space. We want to include both towers of logarithms (cover phase space twice) without double counting.
- Solution: feed HEJ events into PYTHIA, express HEJ resummation in shower language, veto PYTHIA emissions according to the probability HEJ has already perfomed them.
- HEJ splitting function (factor of 1/2 accounts for colour-averaging in HEJ):

$$dk_\perp^2\, dz \int d\phi \frac{1}{16\pi^2} \frac{\left|\mathcal{M}^{n+1}\right|^2}{|\mathcal{M}^{n}|^2} \sim \frac{dk_\perp^2}{k_\perp^2} dz \frac{\alpha_s}{2\pi} P(z), \quad P^{\mathrm{HEJ}} = \frac{1}{2}\frac{1}{16\pi^2} \frac{\overline{\left|\mathcal{M}^{n+1}_{\mathrm{HEJ}}\right|^2}}{\overline{\left|\mathcal{M}^{n}_{\mathrm{HEJ}}\right|^2}}$$

HEJ and PYTHIA Splitting Probabilities

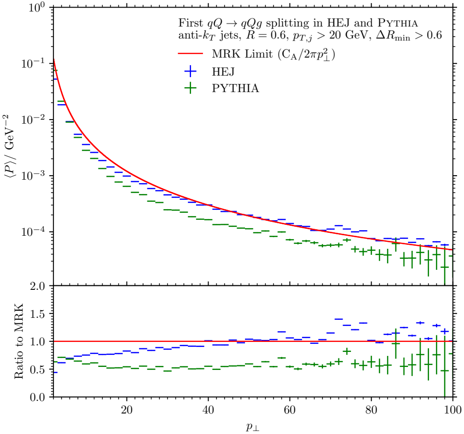

Figure: Average splitting functions for the first emission in $qQ \to qQg$ from HEJ and PYTHIA. For wide-angle emissions, HEJ dominates the hard spectrum, while subtraction is needed in the soft region. All probabilities are stripped of α_s and PDF factors.

Proposed Merging Procedure

- The non-HEJ-resummable input at LO, we merge via CKKW-L in PYTHIA.
- For resummable HEJ states input we construct shower histories - clustering back to the $2 \to 2$ hard process - and perform a (subtracted) trial shower in PYTHIA.
- For each (trial) emission from PYTHIA, we veto the emission with probability

$$\mathscr{P}^{\text{veto}} = \frac{P^{\text{HEJ}}}{P^{\text{PYTHIA}}}. \tag{1}$$

- If we keep the emission from PYTHIA we append it to the HEJ event record and continue with the (subtracted) trial shower, appending each emission we keep.
- The result is a HEJ event whose history has been dressed with shower emissions; this can be further showered+hadronised in PYTHIA.

Considerations for New Merging Procedure

- Appending trial emissions to later stages of the history requires a recoil strategy.
- Currently: distribute momentum from splitting across final state particles such that the rapidity and on-shellness of each are conserved.
- Colour connections: we locate the dipole that split in the trial emission in all the subsequent states in the history and connect the trial splitting appropriately.
- Many prescriptions for these: result should be insensitive to *sensible* choice of recoil strategy and colour assignment.
- Inclusion of CKKW-L contribution: need to make sure one route exists to each exclusive phase space configuration.

Comparisons to Data (arXiv:1407.5756)

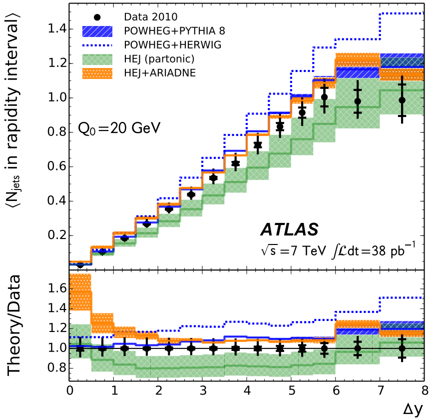

Figure: Average N_j in the rapidity interval formed between the two hardest jets against Δy. Corrections from HEJ (green) are crucial to describe the jet distribution. ($\sqrt{s} = 7$ TeV, anti-$k_\perp$ jets, R=0.6, $p_{\perp,1} > 60$ GeV, $p_{\perp,2} > 50$ GeV, $p_{\perp,j} > 20$ GeV, $|y_j| < 4.4$)

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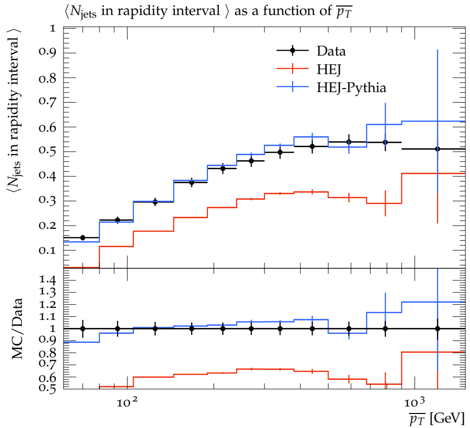

Figure: Average N_j in the rapidity interval formed between the two hardest jets against $\overline{P_T}$ (right), for jets with $\Delta y > 1$. These predictions include matching only to the 'first' emission.
($\sqrt{s} = 7$ TeV, anti-$k_\perp$ jets, R=0.6, $p_{\perp,1} > 60$ GeV, $p_{\perp,2} > 50$ GeV, $p_{\perp,j} > 30$ GeV, $|y_j| < 4.4$)

Conclusions and Next Steps

Conclusions:

- Merging high energy-resummed predictions with a parton shower improves description of observables requiring shower input (e.g. where we observe a $p_\perp$-hierarchy).
- Interplay between the higher order HE effects and later CKKW-L corrections not always straightforward

Next steps:

- Complete implementation of procedure to dress the full HEJ event history with shower emissions.
- Examine the interplay between the subleading corrections in HEJ and the later splittings in PYTHIA.
- Generalise for all HEJ-compatible processes (W,Z/γ,H+jets).

Backup

Differences with Prev. Implementation (arXiv:1712.00178)

Procedural Differences

- Matching was available up to the 'first' emission from PYTHIA, now we (aim to) dress the full history with shower emissions.
- Merge non-HEJ-resummable LO states via CKKW-L.
- Inclusion of LL resummation on NLL processes in HEJ.
- Phase space distribution fully-encoded in subtraction - no need for a merging scale to partition phase space.

Implementational Differences

- Code should be available as a plugin requiring a working HEJ and PYTHIA installation - no source modification required[1].

[1] This functionality may need to be removed later to allow for subtraction in the shower post-merging.

High Energy Limit

- High Energy (HE) or Multi-Regge-Kinematic (MRK) limit for $2 \to n$ (momenta $p_A, p_B \to p_1, \ldots, p_n$) process defined by:

$$\begin{aligned} & y_i \ll y_{i+1} \quad \text{and} \quad \left| p_{i\perp} \right| \sim p_\perp \quad \forall\, i \in \{1, \ldots, n\} \\ \Leftrightarrow \quad & \hat{s} \gg \hat{s}_{ij} \gg p_\perp \quad \forall\, i, j \in \{1, \ldots, n\} \,. \end{aligned} \tag{2}$$

- Define rapidity y and Mandelstam variable s via:

$$y_i = \frac{1}{2} \frac{E + p_{i,z}}{E - p_{i,z}} \,, \qquad s_{i,j} = (p_i + p_j)^2 \,. \tag{3}$$

- In the MRK (and quasi-MRK) limits, large logarithms $\log\left(\frac{s}{-t}\right) \to \Delta y$ arise.
- t-channel domination for partonic processes (t-channel gluon exchanges).

High Energy Jets

High Energy Jets - applies LL corrections in BFKL to the LL states and NLL states produced at LO:

- Constructs $\mathscr{M}$ in the MRK limit and matches to LO.
- t-channel exchanges are *Reggeised* gluons. Extra emissions mediated by effective vertices (Lipatov vertices).
- All-order virtual corrections given by *Lipatov ansatz.*
- Amplitudes regularised (cancellation of IR and UV divergences organised).