Improving the Herwig Dipole Shower

Work in Collaboration with Simon Plätzer and Jack Holguin

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Introduction

What's Eating Dipole Showers?

Event generators (e.g. Herwig, Pythia, Sherpa) aim to simulate events down to the full final state.

Perturbative QCD governs two components:

- Hard scattering process
- Parton shower
    - Improving & extending $1 \to 2$ and $2 \to 3$ branching frameworks (Dire [1506.05057], Vincia [0707.3652], Deductor [1401.6364])
    - More/Better embedding of quantum numbers (e.g. spin, colour)
    - Higher-order splitting functions (e.g. [1705.00742], [1705.00982], [1611.00013])
    - Most recently: Amplitude-level evolution (e.g. [1802.08531], [1905.08686], [2003.06400])

Parton Showers

"Logarithmic accuracy of parton showers" [1805.09327] asked:

> What is the accuracy of a parton shower and do they do what they claim (i.e. leading-log (LL) resummation)?

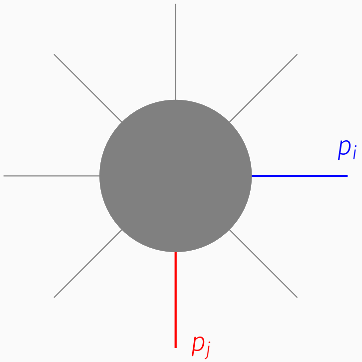
Their conclusions about transverse-momentum ordered showers:

> *The pattern of multiple emission that they generate has flaws in singular regions that are arguably serious.*

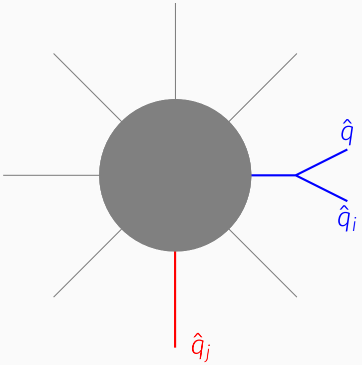
So what can we do? "Building a Consistent Parton Shower" [2003.06400] derived a dipole shower without these issues from the amplitude-level Parton Branching Algorithm [1802.08531] [1905.08686]

Outline of Philosophy

[Adapted from “Building a Consistent Parton Shower”]



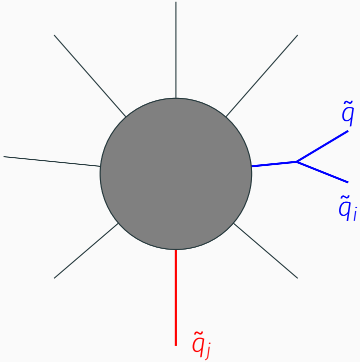
(a) Pre-branching



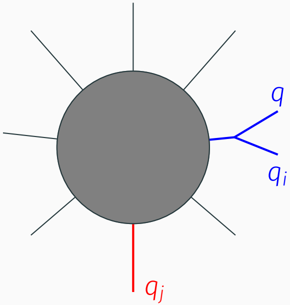
(b) Post-branching

Momentum imbalance: $R = \hat{q} + \hat{q}_i + \hat{q}_j - p_i - p_j$

Outline to Philosophy



(c) Lorentz Boost



(d) Rescale to lab

Boost to return to centre-of-momentum frame, and rescale 4-momentum to ensure we return to lab frame

Our Improvements

Technical notes

In this work, consider only **massless** partons

In this talk, will only present **final-final** dipole kinematics, but we have set up the framework for **all dipole types** (FI, IF, and II), i.e. it works for hadron colliders (including multiple-parton interactions)

Hadronization not currently integrated. Decays turned off.

Minimal Lightcone Exchange Map (I)

We propose the kinematics map:

$$
\begin{aligned}
\hat{q} &= \quad z\, p_i + \quad b \quad p_j + k_\perp \\
\hat{q}_i &= (1-z)p_i + \quad \beta \quad p_j - \gamma f k_\perp \\
\hat{q}_j &= \quad \alpha\, p_i + (1-cb)p_j - \gamma(1-f)k_\perp
\end{aligned}
$$

where

$\gamma \in (0,1) \rightarrow k_\perp$ imbalance in branching

$f \in (0,1) \rightarrow k_\perp$ sharing between recoiler and spectator

$c \in (0,1) \rightarrow$ longitudinal recoil of spectator

$$b = \frac{-k_\perp^2}{2z(p_i \cdot p_j)}$$

α, β are determined by $\hat{q}_j$ and $\hat{q}_i$ on-shell conditions.

Minimal Lightcone Exchange Map (II)

We propose the kinematics map:

$$
\begin{aligned}
\hat{q} &= \quad z\, p_i + \quad b \quad p_j + k_\perp \\
\hat{q}_i &= (1-z) p_i + \quad \beta \quad p_j - \gamma f k_\perp \\
\hat{q}_j &= \quad \alpha\, p_i + (1-cb) p_j - \gamma (1-f) k_\perp
\end{aligned}
$$

Momentum imbalance is then given by:

$$R = \alpha p_i + \big(\beta + 1 + (1-c)b\big) p_j + (1-\gamma) k_\perp$$

Forshaw-Holguin-Plätzer	PanGlobal*
$c = 0, \gamma = 0$	$c = 1, \gamma = 0$
$\hat{q} = z p_i + b p_j + k_\perp$	$\hat{q} = a p_i + b p_j + k_\perp$
$\hat{q}_i = (1-z) p_i$	$\hat{q}_i = (1-a) p_i$
$\hat{q}_j = p_j$	$\hat{q}_j = (1-b) p_j$
$R = b p_j + k_\perp$	$R = k_\perp$

Post-branching Adjustments

Conservation of energy and momentum (see Appendix A.2 of 2112.14454) choice of the form:

$$\delta^{(D)}\Big(\frac{\Lambda}{\hat{\alpha}}\big(\sum_{l\neq i,j} p_l + \hat{q} + \hat{q}_i + \hat{q}_j\big) + \Lambda \sum_i k_i - Q\Big) = \delta^{(D)}\Big(\frac{\Lambda}{\hat{\alpha}}\big(P + K - Q\big)\Big)$$

where P is the (massless) parton momenta pre-branching, and K the (massive) colourless momenta pre-branching.

This defines the Lorentz boost and rescaling:

$$\frac{\Lambda}{\hat{\alpha}}\Big(\hat{\alpha}K + Q + R - K\Big) = Q$$

i.e. quadratic equation in $\hat{\alpha}$. The boost is of the form:

$$\Lambda^{\mu}_{\nu}(p_1 \to p_2) = g^{\mu}_{\nu} + \frac{2p_2^{\mu}p_{1\nu}}{p_1^2} - \frac{2(p_1+p_2)^{\mu}(p_1+p_2)_{\nu}}{(p_1+p_2)^2}$$

Extension to FI, IF, II dipoles

Extending the kinematics map to the other dipole types straightforward, but we make the choice that any initial-state partons do not recoil.

Thus, defining rescaling equation becomes:

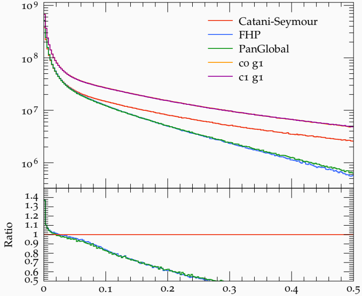
$$\frac{\Lambda}{\hat{\alpha}}\left(\hat{\alpha}K + Q' + R - K\right) = Q'$$

where

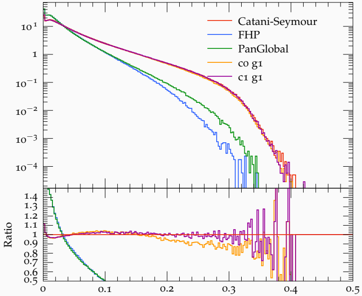
Dipole Type	Q'
FF	$p_a + p_b$
FI	$\hat{q}_j + p_b$
IF	$\hat{q}_i + p_b$
II	$\hat{q}_i + \hat{q}_j$

Some Plots*

Some Plots*



(e) C Parameter



(f) Heavy Jet Mass

Pinch of salt: we have not yet included the dipole partitioning from [2011.15087]

Conclusion and Outlook

Questions Yet Unanswered

We've outlined and implemented a flexible recoil scheme for hadron collisions.

Things left to do:

- Fix the partitioning of dipoles
- PanGlobal mapping **always** rescales incoming partons (i.e. **for all** dipole types). Is there a (qual/quant)itative difference to ours?
- Does our prescription work for e.g. deep-inelastic scattering?

Parton showers are undergoing a transformative time, and it will be interesting