Global Recoil Methods in Dipole Showers

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Parton Showers

- Bridge between hard matrix element and non-perturbative physics
- Facilitates resummation of leading logarithmic contributions
- Uses **emission kernels** to describe rate of emission for a propagating quark/gluon to emit an additional quark/gluon
- Contains **mapping** to factorise emissions within the phase space

$$d\sigma = d\sigma_{hard}(Q) \times PS(Q \to \mu) \times Had(\mu \to \Lambda) \times ...$$

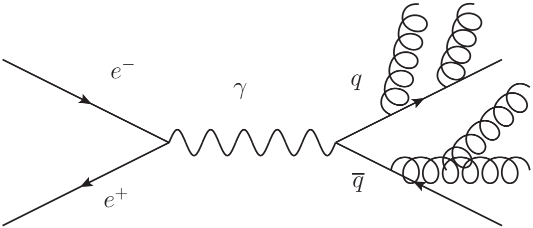

Diagram of an e^+e^- collision and possible parton shower

Recoil in parton showers

Existing methods :

- Dipole shower, recoil is absorbed locally, within dipole
- Angular shower, recoil treated globally after all emissions
- Issues at leading colour for two emissions[2]

New approaches:

- Improved shower algorithm, colour correlations beyond leading colour, CVolver[3]
- Global recoil in dipole shower framework
- Extend framework beyond one emission
- Improve simulation for non-global observables

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[2] Dasgupta et al. 2018; Bewick et al. 2019.

[3] Angelis, Forshaw, and Plätzer 2020; Forshaw, Holguin, and Plätzer 2020.

Building a parton shower

- Key components:
  - Kinematic mapping
  - Emission kernels/splitting functions
  - Choice of evolution variable and recoil scheme

Current implementation in Herwig (dipole shower):

$$\begin{aligned} \textit{Emitter} \rightarrow\ & q_i = zp_i + y(1-z)p_r + k_t\ , \\ \textit{Emission} \rightarrow\ & k_1 = (1-z)p_i + zyp_r - k_t\ , \\ \textit{Spectator} \rightarrow\ & q_r = (1-y)p_r\ , \end{aligned}$$

- Develop a new mapping in order to:
  - Distribute recoils globally
  - Easier extension to multiple emissions

Multi-emission mapping, one emission case

Mapping with soft and collinear parameters:

$$q_i = \frac{1}{\hat{\alpha}}\Lambda\left[(1-\alpha_{i1})p_i + (y_i - (1-\alpha_{i1})\beta_{i1})n_i - \sqrt{1-\alpha_{i1}}\sqrt{\alpha_{i1}\beta_{i1}}n^{(i)}_{\perp,1}\right] ,$$

$$k_{i1} = \frac{1}{\hat{\alpha}}\Lambda\left[\alpha_{i1}p_i + (1-\alpha_{i1})\beta_{i1}n_i + \sqrt{1-\alpha_{i1}}\sqrt{\alpha_{i1}\beta_{i1}}n^{(i)}_{\perp,1}\right] ,$$

$$q_r = \frac{1}{\hat{\alpha}}\Lambda p_r , \qquad (r = (1,..,n), \quad r \neq i)$$

- Above case is single emitter q_i with one emission k_{i1}, in this case $\alpha_{i1} \to (1-z)$ and $y_i = \beta_{i1}$
- Includes soft limit ($\alpha_1, y_i, \beta_{i1} \to 0$) and collinear limit ($y_i, \beta_{i1} \to 0$)
- $n_\perp$ represents the transverse component (k_t)
- Includes global treatment of recoil via Lorentz transformation, Λ

Action of Lorentz transformation

- Momentum conservation requires: $q_i + k_{i1} + q_r = p_i + p_r = Q$
- Use Lorentz transformation(LT) to distribute recoil
- n-vector gives backwards direction $n_i = Q - \frac{Q^2}{2p_i \cdot Q} p_i$

Can be expressed as:

$$\Lambda^{\mu}{}_{\nu} \left[Q^{\nu} + N^{\nu} \right] = \hat{\alpha} Q^{\mu} \,, \qquad N = \sum_{i \in \mathbf{S}} y_i n_i$$

- For single emitter $\hat{\alpha} = \sqrt{1 + y_i}$, in collinear limit $\hat{\alpha} \to 1$
- In collinear limit Λ acts as metric

Minimally modified mapping (Minmod)

Mapping with soft and collinear parameters:

$$
\begin{aligned}
q_i &= \kappa\Lambda z p_i, \\
k_{i1} &= \kappa\Lambda((1-z)\,p_i + (1-y)\,p_r - k_t), \\
q_r &= \kappa\Lambda\, y'\, p_r, \\
q_l &= \kappa\Lambda\, p_r \quad \forall l \in \mathrm{event}|l \neq i, r.
\end{aligned}
$$

- Includes soft limit ($z, y \to 1$) and collinear limit ($y \to 1$)
- Transverse momentum balanced via Lorentz transformation, Λ
- $y' = 1$ gives minimal version, $y' = y$ reproduces mapping from PanGlobal[4]
- Requires partitioning of splitting kernels and modification of phase space

[4] Dasgupta et al. 2020.

Minmod, Lorentz transformation

For $y' = 1$ case the total momentum before transforming is:

$$T = Q - k_t + (1 - y)p_r \ ,$$

where Q is total momentum.

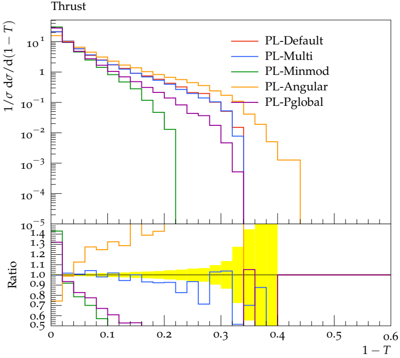
Momentum and energy conservation requires:

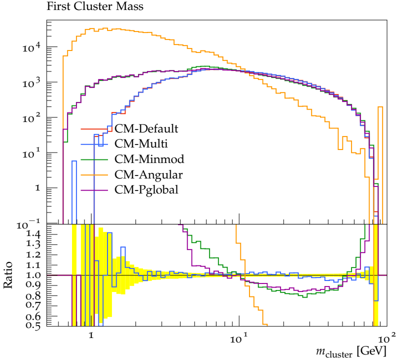
$$\kappa \Lambda^{\mu}{}_{\nu} T^{\nu} = Q^{\mu} \ , \quad \kappa = \sqrt{\frac{Q^2}{T^2}}$$

- In collinear limit Λ acts as metric and $\kappa \approx 1$
- Expression for y derived from on-shell conditions for momenta
- Transformation has the same form for $y' = y$ case, different expression for T
- Better describes anti-collinear limit for hard emission

Herwig Implementation

- Mappings inc. transform implemented in Dipole Shower
- Three mappings, Multi, Minmod ($y' = 1$ and $y' = y$)
- Parton level and cluster mass analyses
- Comparison to Herwig default dipole and angular showers





Plot of thrust and first cluster mass for 100,000 events (Preliminary plots)

Summary and WIP

Current progress:

- Global recoil treated by Lorentz transformation
- Multi mapping which is designed for multiple emissions
- Minmod recoil, balances k_t via transform, optional y'
- Phase space for mappings determined and partitioning expression

Work in progress:

- Implementation of splitting functions and phase space
- More analyses, specific non-global observables
- Steps towards two emission splitting functions and mapping in code

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