Parton Showers, Local Recoils, and Coherence

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[SP & S.Gieseke, in preparation]

Motivation

We want and need matching/merging ...

Most easily done with showers

$\longrightarrow$ being hardness ordered

$\longrightarrow$ using local (i.e. per-splitting) recoils.

Motivation

Progress is being made to systematically correct showers order by order to the exact prediction.

In principle we could get rid of all (ambiguous) approximations, having confidence in being correct to some specific order in α_s.

So we take the most convenient shower.

Should we care about anything downstream?

Motivation

We do need confidence in the shower.

Is there a shower which performs properly while having all 'nice' features?

Rethink dipole-type showers.

Motivation

Anomalous dimensions?

Effects of finite recoils?

$p_\perp$ from initial state radiation?

Outline

Recoil strategy, and soft correctness.

A form factor analysis: Soft double counting and angular ordering.

Another way to remove soft double counting.

Scale choices and ordering.

Implementation.

Conclusions.

Not talking about:
Calculational frameworks and matching approaches.

Recoil strategy.

Introduce local recoils: Dipole-type picture as minimal case.

Recap derivation of (unregularized) DGLAP kernels.

$z = \frac{n \cdot q_i}{n \cdot p_{ij}}$, axial gauge $n \cdot A = 0$

$\longrightarrow$ Remaining gauge dof is rescaling the collinear direction n

Physical gauge(s): Choose any possible spectator momentum $n = p_k$.

$\longrightarrow$ Interferences supressed.

$\longrightarrow$ Singular behaviour from cut self-energies only.

The singular behaviour is invariant under rescaling the spectator momentum.

Recoil strategy: final state radiation

Extend the underlying Sudakov kinematics to exact momentum conservation.

Spectator takes longitudinal recoil of the splitting.

Collinear limit is the kinematics used in Herwig++ [Gieseke,Stephens,Webber]

Otherwise inverse of final state Catani-Seymour tilde kinematics.

$\longrightarrow$ Compatible with framework of physical gauge(s).

$\longrightarrow$ Producing the correct soft behaviour in the splitting function.

Interested in soft gluons, so $g \to q\bar{q}$ neglected from now on.

Soft correctness: The DGLAP case.

Using the physical gauge and recoil outlined above observe:

$$\left.\frac{P_{i\to i,g}(z)}{2q_i\cdot q_g}\right|_{n=p_k} = (\text{eikonal}) + (\text{collinear singular})$$

Indeed, using the usual colour algebra (and proper symmetry factor for $g \to gg$):

At leading order in α_s collinear factorization in physical gauge(s) is soft correct. $P_{i\to ig}|_{n=p_k}$ generates the complete soft behaviour for the i, k dipole.

If the correct soft behaviour would guarantee coherence, then any such DGLAP shower would be fine.

Soft correctness: The DGLAP case.

Recall the (dipole) form factor and anomalous dimensions from coherent branching: [Bassetto,Ciafaloni,Marchesini,Dokshitzer,Turnock,Webber,...]

$$-\ln \Delta_{ik}(Q^2,\mu^2) = \int_{\mu^2}^{Q^2} \frac{\mathrm{d}p_\perp^2}{p_\perp^2} \frac{\alpha_s(p_\perp^2)}{2\pi} \left(\Gamma_i(p_\perp^2,Q^2) + \Gamma_k(p_\perp^2,Q^2)\right)$$

$$\begin{aligned}
\Gamma_q(p_\perp^2,Q^2) &= C_F\left(\ln\frac{Q^2}{p_\perp^2} - \frac{3}{2}\right) \\
\Gamma_g(p_\perp^2,Q^2) &= C_A\left(\ln\frac{Q^2}{p_\perp^2} - \frac{11}{6}\right)
\end{aligned}$$

Soft correctness $\not\Rightarrow$ coherence.

Check the anomalous dimensions including recoil effects:

$$\frac{\mathrm{d}p_\perp^2}{p_\perp^2}\mathrm{d}z \to \frac{\mathrm{d}p_\perp^2}{p_\perp^2}\mathrm{d}z\left(1-\lambda\frac{p_\perp^2}{z(1-z)s_{ik}}\right)$$

Choose kinematical limits from restricting the emitter's virtuality (as would be the choice for virtuality or $p_\perp$ ordering):

$$\begin{aligned}\Gamma_q^V(p_\perp^2,Q^2) &= C_F\left(2\ln\frac{Q^2}{p_\perp^2}-\frac{3}{2}-2\lambda\frac{Q^2}{s_{ik}}\right)\\ \Gamma_g^V(p_\perp^2,Q^2) &= C_A\left(2\ln\frac{Q^2}{p_\perp^2}-\frac{11}{6}-2\lambda\frac{Q^2}{s_{ik}}\right)\end{aligned}$$

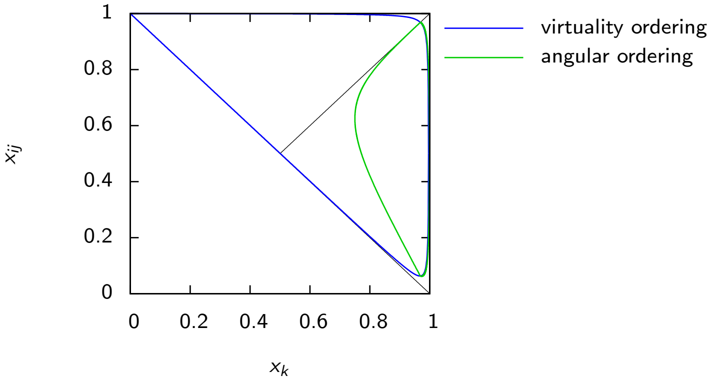
$\longrightarrow$ Leading logs screwed up.

$\longrightarrow$ Recoils enter at NLL level.

Soft double counting.

Choosing a phasespace restriction as for an angular ordered shower, get the correct ones.

- $\longrightarrow$ Double counting of soft emissions for virtuality cutoff.
- $\longrightarrow$ Not present for the angular ordered phasespace.



Another way to remove soft double counting.

→ Partial fraction the eikonal in the usual way.

$$\frac{p_i \cdot p_j}{p_i \cdot q \; p_j \cdot q} \rightarrow \frac{p_i \cdot p_j}{p_i \cdot q \; (p_i + p_j) \cdot q}$$

→ Need to have overlapping phasespace regions.

→ Minimal prescription to remove soft double counting.

→ Construction prescription for Catani-Seymour kernels.

No need for more complicated versions. If singular limits are correct, differences can only appear in finite terms.

Initial state radiation.

Taking CS literally for initial state radiation has shortcomings.

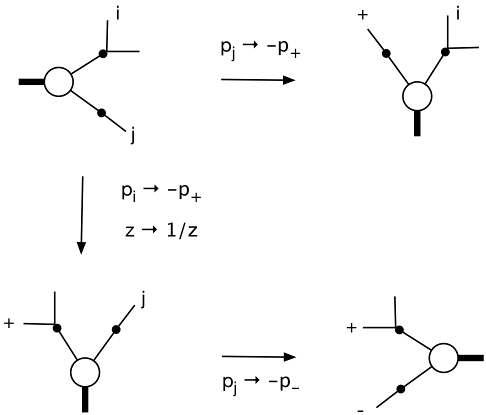
Most prominent:

- $\longrightarrow$ Final state colour singlets get $p_\perp$ from the very first initial state emission only.
- $\longrightarrow$ An initial-initial dipole has the spectator completely unchanged.

We seek a way to completely treat initial and final state radition on equal footing ($\sim$ crossing).

If the final state radiation behaves properly, we conjecture that the initial state radiation does as well.

Initial state radiation.



Exact phasespace factorization still possible.

Initial state radiation.

Allow each emission to generate intial state $p_\perp$.

Uppon termination of the cascade apply a boost for each incoming parton to realign it to the beam axis, while leaving the other one invariant.

As the kinematics are exact in each evolution step, this preserves the interesting features of the final state system while properly generating transverse momentum.

We do not boost a subset of the collision system. These are global Lorentz transformations.

Structure of splitting kernels.

Get universal structure of splitting kernels.

DGLAP	$0 \leftarrow p_\perp$	Split eikonal + recoil
$J(p_\perp^2, z)\frac{\alpha_s}{2\pi}\frac{\mathrm{d}p_\perp^2}{p_\perp^2}\mathrm{d}z$		$K(p_\perp^2, z)\left(1 - \frac{p_\perp^2}{s_{ik}}d(z)\right)\frac{\alpha_s}{2\pi}\frac{\mathrm{d}p_\perp^2}{p_\perp^2}$
$\frac{C}{z}$		$\frac{z\ C}{z^2+(p_\perp^2/s_{ik})c(z)}$
$P_0(z)$		$P_0(z)(1+\frac{p_\perp^2}{s_{ik}}s_0(z, p_\perp^2))$

Structure of splitting kernels.

Finite recoils supress hard emission either through phasespace or spectator PDF change.

We think this is an important feature, as a similar mechanism is present in angular ordered showers through the phasespace restriction.

Taking CS literally, this would not happen for an initial-initial dipole.

Form factor analysis repeated.

Phasespace overlap in soft region required (as opposed to DGLAP).

Find the correct anomalous dimensions with $Q^2 \to s_{ik}$:

$$\Gamma_q(p_\perp^2, \cdot) = C_F \left(\ln \frac{s_{ik}}{p_\perp^2} - \frac{3}{2} \right)$$

$$\Gamma_g(p_\perp^2, \cdot) = C_A \left(\ln \frac{s_{ik}}{p_\perp^2} - \frac{11}{6} \right)$$

Consequence of the screening of soft singularities at fixed $p_\perp$.

Some conclusions.

It is the phasespace restriction when evolving between two scales which determines the form factor.

$\longrightarrow$ Needs to be chosen appropriate. Choice can be related to the absence of soft double counting with given kernels.

Whatever appears as the hard scale in the anomalous dimensions is to be chosen as the hard scale for the evolution.

$\longrightarrow$ Invariant mass or $-t$ for split-eikonal kernels.

No conclusions can be drawn what ordering to chose.

$\longrightarrow$ Did look at zero or one emission so far.

Multiple emissions and ordering.

I do believe that exponentiation of leading logs is an important requirement.

It should be this property, which fixes the proper ordering.

Form factor analysis suggests a $p_\perp$ ordering, while allowing for kinematically possible unordered emissions.

Analytical exponentiation studies not completed yet. Working on all-orders treatment.

Numerical results do not show a significant difference between allowing unordered emissions or imposing a strict $p_\perp$ ordering.

Implementation and matching.

Implementation of the shower outlined above in place.

→ Add-on to Herwig++

→ Fairly general. Could also switch to taking CS literally.

Automatized POWHEG-type matching to NLO QCD.

→ MC@NLO variant also possible

Working horse: exsample

→ Adaptive sampling with on-the-fly unweighting.

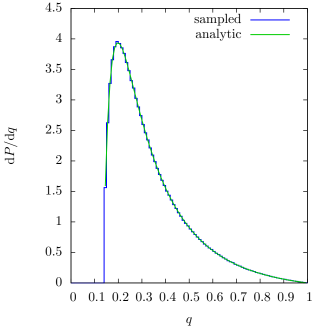
→ Crucial feature: Can deal with Sudakov-type distributions

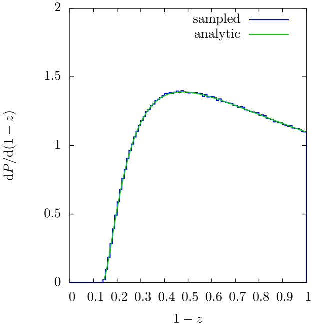
Sudakov-type distributions.

Adaptive version of the veto algorithm to sample densities of the type

$$F_f(x|y,\vec{z}) = \theta(y-x)f(x,\vec{z})\exp\left(\int_x^y \mathrm{d}t \int_V \mathrm{d}V(\vec{\xi})f(t,\vec{\xi})\right)$$

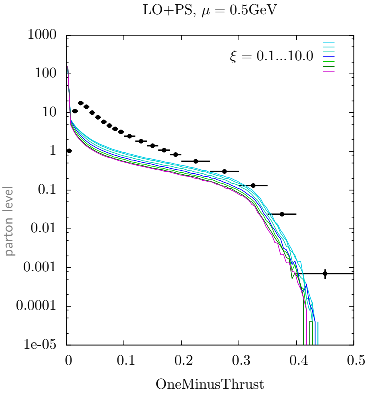
knowing f only numerically.

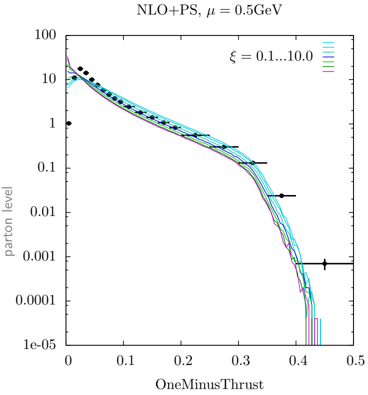




Example parton level results

Preliminary. Hadronization, detailed studies, hadron-hadron and more processes on the way.





Conclusions.

We do need to care about parton showers in a detailed manner. The techniques and possible pitfalls are known for more than 30 years.

Working under the premise of 'anything improvable up to some order' is a fixed-order statement. Parton showers are not fixed-order objects.

With some improvements CS-type showers indeed seem to work properly, while having all the nice features to do matching.

We have completely implemented a modified version along with automatized NLO matching.