Dipole Showers, Coherence, and Higher Orders

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Coherence aspects: [SP & S.Gieseke, arXiv:0909.5593, submitted to JHEP]

More formalism & numerical results: [SP & S.Gieseke, in preparation]

Outline.

Dipole showers.

Matching MC and higher orders.

Implementational details & simulation results.

Conclusions & Outlook.

Why dipole showers?

Conventional showers restore energy-momentum conservation at the end of the evolution.

→ Behaviour (fixed-order expansion) hard to calculate exactly.
→ Hardest emission not neccesarily the first one.

Dipole-type showers implement local (i.e. per branching) recoils.

→ Hardest emission can be chosen to be the first one.
→ Fixed-order expansion well-defined.
→ Suited for matching to higher-order calculations.

Dipole showers.

Ariadne (Lund dipoles) [Lönnblad]

Catani-Seymour dipoles ($1+1 \to 2+1$) suggested for NLO matching [Nagy,Soper]

CS implementations [Krauss,Schumann], [Dinsdale,Ternick,Weinzierl]

Lund dipoles revisited [Winter,Krauss]

Vincia (antenna subtraction terms) [Giele,Kosower,Skands]

No NLO matching. Coherence not clear.

Dipole showers and coherence.

Investigate parton showers with local recoils. [SP & S.Gieseke, arXiv:0909.5593]

$\longrightarrow$ Coherence for soft gluon radiation?

$\longrightarrow$ Generation of $p_\perp$ from initial state radiation?

Dipole showers and coherence.

Investigate parton showers with local recoils. [SP & S.Gieseke, arXiv:0909.5593]

Coherence manifest in Sudakov anomalous dimension

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

[Bassetto,Ciafaloni,Marchesini],[Marchesini,Webber]

Dipole showers and coherence.

Investigate parton showers with local recoils. [SP & S.Gieseke, arXiv:0909.5593]

Coherence manifest in Sudakov anomalous dimension

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

Not correct for virtuality ordering.
Recoils ($\to \lambda$) enter at level of single logs.

Dipole showers and coherence.

Investigate parton showers with local recoils. [SP & S.Gieseke, arXiv:0909.5593]

Herwig++ with angular ordering and local recoils

$$\Gamma_q^{AO}(p_\perp^2, Q^2) = C_F \left(\ln \frac{Q^2}{p_\perp^2} - \frac{3}{2} \right) + C_F \frac{p_\perp}{Q} \left(1 - 2\lambda \frac{Q^2}{s_{ik}} \right) + \mathcal{O}\left(\frac{p_\perp^2}{Q^2} \right)$$

$$\Gamma_g^{AO}(p_\perp^2, Q^2) = C_A \left(\ln \frac{Q^2}{p_\perp^2} - \frac{11}{6} \right) + 2C_A \frac{p_\perp}{Q} \left(1 - \lambda \frac{Q^2}{s_{ik}} \right) + \mathcal{O}\left(\frac{p_\perp^2}{Q^2} \right)$$

Recoils ($\to \lambda$) enter as power corrections.

Dipole showers and coherence.

Investigate parton showers with local recoils. [SP & S.Gieseke, arXiv:0909.5593]

CS dipoles with $p_\perp$ ordering, physical kinematics & right choice of phasespace boundaries

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

Recoils ($\rightarrow \lambda$) enter as power corrections.
Hard scale given by available phasespace.
Ordering in $p_\perp$ $\longrightarrow$ eases NLO matching

Matching MC and higher orders.

Rigorously calculate fixed orders of the shower.

Consider generating functional of parton shower transition probabilities, including all details. [SP, S.Gieseke, in preparation]

$\longrightarrow$ evolution equation from Markov property & unitarity

$\longrightarrow$ solve order by order

$\longrightarrow$ convolute with fixed-order g.f. , subtract double-counted terms

Known NLO matching prescriptions reproduced.

Allows to calculate even higher orders in a convenient way.

$\longrightarrow$ NNLO matching condition recently calculated.

NLO matchings in a nutshell.

NLO in subtraction (symbolic for readability).

$$
\begin{aligned}
\sigma[u] \quad = \quad & \int_n u(p_n)\mathrm{d}\sigma^{(n,0)}(p_n) \\
& +\alpha_s \int_n u(p_n) \left[\mathrm{d}\sigma^{(n,1)}(p_n) + \int_1 \mathrm{d}\sigma_A^{(n+1,0)}(p_{n+1})\right]_{\epsilon=0} \\
& +\alpha_s \int_{n+1} \left[u(p_{n+1})\mathrm{d}\sigma^{(n+1,0)}(p_{n+1}) - u(p_n)\mathrm{d}\sigma_A^{(n+1,0)}(p_{n+1})\right]
\end{aligned}
$$

NLO matchings in a nutshell.

Fixed-order expansion of NLO+PS: double counting evident

$$\begin{aligned}
\sigma[u] \;=\; & \int_n u(p_n)\mathrm{d}\sigma^{(n,0)}(p_n) \\
& +\alpha_s \int_n u(p_n) \left[\mathrm{d}\sigma^{(n,1)}(p_n) + \int_1 \mathrm{d}\sigma_A^{(n+1,0)}(p_{n+1})\right]_{\epsilon=0} \\
& +\alpha_s \int_{n+1} \left[-u(p_n)\mathrm{d}P(p_n, p_{n+1}) - u(p_n)\mathrm{d}\sigma_A^{(n+1,0)}(p_{n+1})\right] \\
& +\alpha_s \int_{n+1} \left[u(p_{n+1})\mathrm{d}\sigma^{(n+1,0)}(p_{n+1}) + u(p_{n+1})\mathrm{d}P(p_n, p_{n+1})\right]
\end{aligned}$$

NLO matchings in a nutshell.

Matched calculation: subtract double counting

$$
\begin{aligned}
\sigma[u] \;=\; & \int_n u(p_n)\mathrm{d}\sigma^{(n,0)}(p_n) \\
& +\alpha_s \int_n u(p_n) \left[\mathrm{d}\sigma^{(n,1)}(p_n) + \int_1 \mathrm{d}\sigma_A^{(n+1,0)}(p_{n+1})\right]_{\epsilon=0} \\
& +\alpha_s \int_{n+1} \left[u(p_n)\mathrm{d}P(p_n, p_{n+1}) - u(p_n)\mathrm{d}\sigma_A^{(n+1,0)}(p_{n+1})\right] \\
& +\alpha_s \int_{n+1} \left[u(p_{n+1})\mathrm{d}\sigma^{(n+1,0)}(p_{n+1}) - u(p_{n+1})\mathrm{d}P(p_n, p_{n+1})\right]
\end{aligned}
$$

NLO matchings in a nutshell.

MC@NLO type: tedious (basically redo NLO calculation).

$$
\begin{aligned}
\sigma[u] \;=\; & \int_n u(p_n)\mathrm{d}\sigma^{(n,0)}(p_n) \\
& +\alpha_s \int_n u(p_n) \left[\mathrm{d}\sigma^{(n,1)}(p_n) + \int_1 \mathrm{d}\sigma_A^{(n+1,0)}(p_{n+1})\right]_{\epsilon=0} \\
& +\alpha_s \int_{n+1} \left[u(p_n)\mathrm{d}P(p_n, p_{n+1}) - u(p_n)\mathrm{d}\sigma_A^{(n+1,0)}(p_{n+1})\right] \\
& +\alpha_s \int_{n+1} \left[u(p_{n+1})\mathrm{d}\sigma^{(n+1,0)}(p_{n+1}) - u(p_{n+1})\mathrm{d}P(p_n, p_{n+1})\right]
\end{aligned}
$$

NLO matchings in a nutshell.

MC@NLO made easy: $\mathrm{d}P(p_n, p_{n+1}) = \mathrm{d}\sigma_A^{(n+1,0)}(p_{n+1})$

$$
\begin{aligned}
\sigma[u] \quad = \quad & \int_n u(p_n)\mathrm{d}\sigma^{(n,0)}(p_n) \\
& +\alpha_s \int_n u(p_n) \left[\mathrm{d}\sigma^{(n,1)}(p_n) + \int_1 \mathrm{d}\sigma_A^{(n+1,0)}(p_{n+1})\right]_{\epsilon=0} \\
& +\alpha_s \int_{n+1} \left[u(p_n)\mathrm{d}\sigma_A^{(n+1,0)}(p_{n+1}) - u(p_n)\mathrm{d}\sigma_A^{(n+1,0)}(p_{n+1})\right] \\
& +\alpha_s \int_{n+1} \left[u(p_{n+1})\mathrm{d}\sigma^{(n+1,0)}(p_{n+1}) - u(p_{n+1})\mathrm{d}\sigma_A^{(n+1,0)}(p_{n+1})\right]
\end{aligned}
$$

NLO matchings in a nutshell.

POWHEG type: $\mathrm{d}P(p_n, p_{n+1}) = \mathrm{d}\sigma^{(n+1,0)}(p_{n+1})$ ('ME correction')

$$
\begin{aligned}
\sigma[u] \;=\; & \int_n u(p_n)\mathrm{d}\sigma^{(n,0)}(p_n) \\
& +\alpha_s \int_n u(p_n) \left[\mathrm{d}\sigma^{(n,1)}(p_n) + \int_1 \mathrm{d}\sigma_A^{(n+1,0)}(p_{n+1})\right]_{\epsilon=0} \\
& +\alpha_s \int_{n+1} \left[u(p_n)\mathrm{d}\sigma^{(n+1,0)}(p_{n+1}) - u(p_n)\mathrm{d}\sigma_A^{(n+1,0)}(p_{n+1})\right] \\
& +\alpha_s \int_{n+1} \left[u(p_{n+1})\mathrm{d}\sigma^{(n+1,0)}(p_{n+1}) - u(p_{n+1})\mathrm{d}\sigma^{(n+1,0)}(p_{n+1})\right]
\end{aligned}
$$

Implementational details & simulation results.

Implementation of coherent dipole shower. [SP, S.Gieseke, in preparation]

$\longrightarrow$ add-on library to Herwig++.

POWHEG matching automated: NLO right from the start

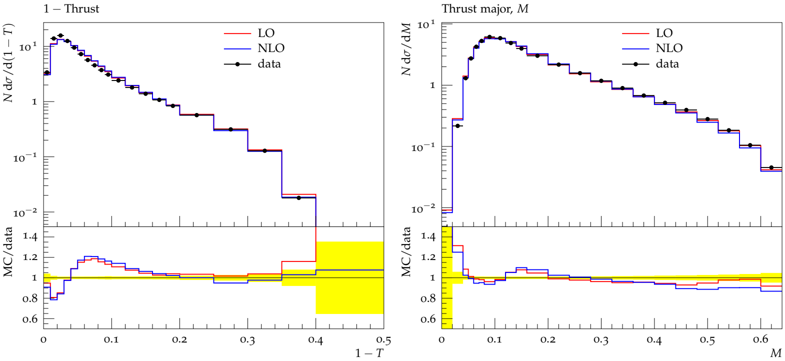
$\longrightarrow$ only need to interface building blocks of (CS subtracted) NLO
$\longrightarrow$ interface specification drafted [SP, to appear in Les Houches 2009 proceedings]

Working horse: exsample2 [SP, unpublished]

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

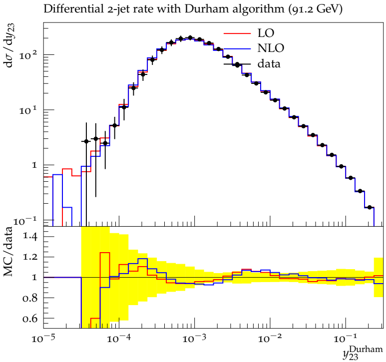
e^+e^- – proof of concept

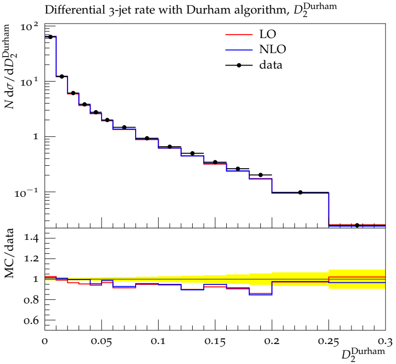
Preliminary tune to LEP data.



e^+e^- – proof of concept

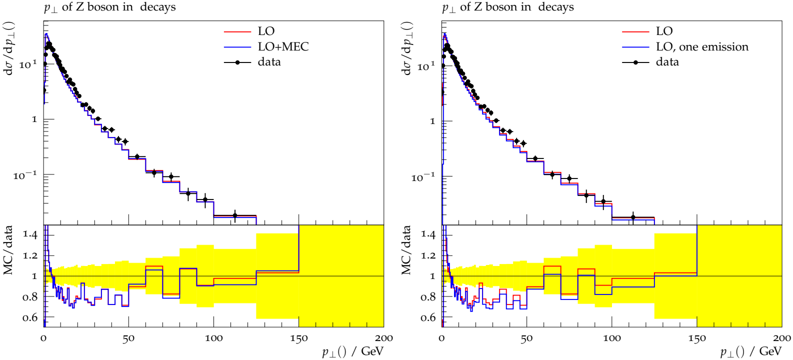
Preliminary tune to LEP data.





Drell-Yan.

Relevance of initial state $p_\perp$



Preliminary, no intrinsic $p_\perp$.

Conclusions & Outlook.

New coherent dipole shower, integrates well with Herwig++.

NLO matching machinery very generic.

Simple processes checked, more to come ...