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PARTON SHOWERS AND NONLEADING CORRECTIONS TO THE HARD SCATTER: A FACTORIZATION APPROACH

work in progress - collaboration with J. Collins

- How can we incorporate NLO hard scattering in parton shower Monti Carlo's?
- Are subtractive procedures useful? (Friborg-Sjöstrand)

Contents of this talk:
- How soft and collinear factorization properties may be used in this context
- Illustration in a specific example from DIS

Recent related papers:
- Friborg-Sjöstrand, hep-ph/9906343
- Collins, hep-ph/0004039
- Pumplin, hep-ph/9901346
- Cahn-Smyth, hep-ph/9905341
Cross section in a parton shower MC event generator:

\[ \sigma[\mathcal{W}] = \sum_{\text{final states } X} \mathcal{W}(X) \, \text{PS} \otimes H \]

- In standard MC, H is a LO matrix element and PS denotes showering from the partons in H.

- Construct NLO-improved MC:

\[ \text{PS} \otimes \left[ \mathcal{H}^{(\text{LO})} + \alpha_s \left( \mathcal{H}^{(\text{NLO})} - \text{PS}_i(1) \otimes \mathcal{H}^{(\text{LO})} - \text{PS}_f(1) \otimes \mathcal{H}^{(\text{LO})} \right) \right] \]

\[ \uparrow \text{LO events} \quad \uparrow \text{NLO correction events} \]

**Question:** Collinear regions accurately taken into account by subtraction terms. SOFT REGION?

- In usual MC's, soft singularities handled by IR cut-off: effective kernels \( P \cdot \Theta = P_{\text{cut-off}} \) in Sudakov form factors.

**Object of this work:** Systematic treatment of soft region.

\( \Rightarrow \) subtracted NLO matrix element purely UV.
Key point is to construct a decomposition of the type

\[ H^{(NLO)} = \sum_{\text{regions } R} A_{H}(R) + \text{nonleading power} \quad (*) \]

uniformly over the whole phase space

To do this, use gauge-invariant operator techniques

do possible extension to all orders?

**Note:**
- it avoids phase-space splitting
- instead, each term in (*) is equipped with counterterms

Next: show how the result (*) can be fit into the MC framework.

We find that the following changes in the algorithm are necessary (and sufficient):

- fully subtracted matrix element \( H_{(\text{subtr})}^{(NLO)} \)
- modified shower algorithm:
  \[ P_{\text{cut-off}} \rightarrow P - \text{counterterm} \]
Example: $g^* \rightarrow g g$ in DIS

lightcone momentum fractions: $\alpha = \frac{K^+}{x p^+}$, $\beta = \frac{K^-}{(Q^2/2x p^+)}$

generic observable: $\int \sum [p] = \int \frac{d\omega}{2\pi} \frac{d\beta}{2\pi} \int \frac{d\beta'}{2\pi} \int \frac{d\beta''}{2\pi} \mathcal{J}(x, \alpha, \beta) q(x, \alpha, \beta, \gamma) M(\alpha, \beta)$

matrix element contains weight function + showering

$M(\alpha, \beta) = (1-\beta)^2 \frac{1+(1+\alpha-\beta)^2}{\alpha \beta (1+\alpha-\beta)} + 2 + 6(1-\beta)^2$

→ To decompose $\Sigma$, apply the construction of Collins-Hautmann


eikonal lines along non-lightlike directions: $\mathbf{v}_\lambda = \exp[ig \int_{-\infty}^{\sigma} d\gamma \mathbf{u} \cdot \mathbf{A}(\gamma u)]$

$V_{\lambda}(u) = \exp[ig \int_{-\infty}^{\sigma} d\gamma \mathbf{u} \cdot \mathbf{A}(\gamma u)]$, $V_{\lambda}(u') = \exp[ig \int_{-\infty}^{\sigma} d\gamma \mathbf{u}' \cdot \mathbf{A}(\gamma u')]$

⇒ Soft term: $M_s(\alpha, \beta) = \frac{2}{\alpha \beta} - \frac{2}{(\alpha+\eta \beta) \beta} - \frac{2}{\alpha (\beta+\eta \alpha)}$

pure soft approximation to $M$

Collinear subtractions
Go on to the "larger" collinear regions:

\[
M_\text{\text{I}}(\alpha, \beta) = \frac{1}{\beta} \left( 1 + \left( \frac{1}{\alpha} \right)^2 \right) \frac{2}{\alpha(1+\beta)} - \frac{2}{\alpha \beta} + \frac{2}{\alpha \beta (1+\alpha \beta)} \\
M_\text{\text{F}}(\alpha, \beta) = \frac{1}{\alpha} \left( 1 + \left( \frac{1}{\beta} \right)^2 \right) \frac{2}{(1-\beta)(1-\beta)} - \frac{2}{\alpha \beta} + \frac{2}{\alpha \beta (1+\alpha \beta)}
\]

Fully subtracted matrix element:

\[
\rightarrow \quad M_{(\text{Subtr.})}(\alpha, \beta) = M - M_\text{S} - M_\text{I} - M_\text{F}
\]

\[
= \beta + \frac{\alpha}{(1+\alpha)(1+\alpha - \beta)} + \frac{6(1-\beta)^2}{(1+\alpha - \beta)}
\]

THIS STRUCTURE IS GENERAL. CAN WE REORGANIZE IT IN A WAY THAT IS SUITED FOR A PARTON SHOWER ALGORITHM?

\[\Rightarrow \text{CHOOSE } \eta, \eta' \text{ SO THAT } M_{S} = 0,\]

\[
\begin{align*}
M^\text{(MC)}_\text{\text{I}}(\alpha, \beta) &= \frac{1}{\beta} \left( 1 + \left( \frac{1}{\alpha} \right)^2 \right) \frac{2}{\alpha(1+\beta)} - \frac{1}{\alpha \alpha + \beta} \\
M^\text{(MC)}_\text{\text{F}}(\alpha, \beta) &= \frac{1}{\alpha} \left( 1 + \left( \frac{1}{\beta} \right)^2 \right) \frac{2}{(1-\beta)(1-\beta)} - \frac{2}{\alpha \beta} \frac{2}{\alpha \beta (1+\alpha \beta)}
\end{align*}
\]

First piece \[\rightarrow \text{Standard real-emission DGLAP kernel}\]

Second piece \[\rightarrow \text{Counterterm}\]

NOTE:

Effective cut-offs in initial-state and final-state showers are not independent!
CONCLUSIONS

- STUDIES TO APPLY SUBTRACTIVE METHODS TO NLO PARTON SHOWER MC'S ARE STARTING

- EFFORT TO RECAST FACTORIZATION IN A FORM THAT IS USEFUL FOR MC'S

- NO PRACTICAL IMPLEMENTATION AT PRESENT

- OPEN QUESTIONS:

  - A FINITE NUMBER OF NEGATIVE WEIGHTED EVENTS MAY BE GENERATED - TRICKS TO CONTROL THIS NUMBER?

  - APPARENT OR GENUINE NON-UNIVERSALITY OF SUDAKOV?

  - IMPROVED DEFINITIONS FOR PARTON KINEMATICS? (SEE COLLINS)

  - INCLUDE EXPLICIT PARTON TRANSVERSE MOMENTUM? (SEE MRAZEN)