Some of my Interests

Sebastian Sapeta

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1. Corrections beyond NLO for processes with large K-factors

2. NLO + Parton Shower matching

3. Forward jets, High Energy Factorization, Transverse Momentum Dependent Factorization
1. Corrections beyond NLO for processes with large K-factors
Higher order QCD corrections

Fixed order perturbative expansion in $\alpha_s$:

$$\sigma = \sigma_0 + \alpha_s \sigma_1 + \alpha_s^2 \sigma_2 + \cdots$$

Naively, if $\sigma_i \simeq 1$ and $\alpha_s \ll 1$, the series converges and $\mu_F, \mu_R$ variation should give an estimate of the size of neglected higher orders.

However, quite often we get...

Huge K-factor! $K = \sigma_{\text{NLO}} / \sigma_{\text{LO}} \simeq 5$

$\Rightarrow$ new incoming channels and new topologies
(though formally NLO diagrams for Z+jet, these are in fact leading contributions)
Determine dominant part of corrections coming from new topologies and new channels that open up at higher orders.

→ Works for broad class of processes and provides bulk of missing higher order corr.

\[ \sigma_{\text{nNLO}} - \sigma_{\text{NNLO}} = \mathcal{O} \left( \frac{\alpha_s^2}{K_{\text{NNLO}}} \right) \]

\[ K_{\text{NNLO}} \gtrsim K_{\text{NLO}} \gg 1 \]
Explore and get insight

LoopSim has been tested/used for a number of processes:
Drell-Yan, dijets, Z+jets (Tevatron, LHC), W+jets (LHC), WZ, WW

But there is still more to look at!

► WH at $\bar{\pi}$NLO: very similar to Drell-Yan process, where LoopSim gets nearly 100% of NNLO, will it be the same here?
► ZZ, Z$\gamma$ at $\bar{\pi}$NLO: improved sensitivity to anomalous couplings searches?
► W/Z+jets at $\bar{\pi}\bar{\pi}$NLO

Understanding the large K-factors:

► For a set of most common processes ($e^+e^- \rightarrow$ jets, DY, DIS, $gg \rightarrow H$), at the level of the total cross section, is it possible to understand the pattern of the NLO corrections?
► What are the key elements that are responsible for the large K-factors? Phase space integration, choice of factorization scheme? Could one organize the perturbative expansion in a better way?
2. NLO+Parton Shower matching
NLO+PS matching

- Apart from computing corrections at fixed $\alpha_s$, another common thing to do is to combine NLO results with the parton shower. The latter resums multiple emissions in collinear approximation.

- Two well established approaches: MC@NLO and POWHEG.

Let’s take Drell-Yan in $q\bar{q}$ channel

$$q\bar{q} \rightarrow Z \rightarrow \ell^+\ell^-$$

The NLO part of the cross section in the collinear factorization in $\overline{\text{MS}}$ scheme

$$\sigma^{\mathcal{O}(\alpha_s)}_{\text{DY}} = \sigma^{B}_{\text{DY}} \otimes f^{\overline{\text{MS}}}(x_1, \mu^2) \otimes \frac{\alpha_s}{2\pi} C_{q}^{\overline{\text{MS}}}(z) \otimes f^{\overline{\text{MS}}}(x_2, \mu^2),$$

where

$$C_{q}^{\overline{\text{MS}}}(z) = C_F \left[ 4 \left(1 + z^2\right) \left(\frac{\ln(1-z)}{1-z}\right) + 2 \frac{1+z^2}{1-z} \ln z + \delta(1-z) \left(\frac{2}{3} \pi^2 - 8\right) \right].$$

We want to reproduce this with Monte Carlo, in a fully exclusive way.

With $\overline{\text{MS}}$ PDFs, we need to generate these purely collinear terms. But Monte Carlo lives in 4 dimensions and not in the phase space restricted by $\delta(k_T^2)$. 
Matching in MC scheme: KrkNLO method

[Jadach, Kusina, Płaczek, Skrzypek, Sławińska '13]

1. Change the factorization scheme from $\overline{\text{MS}}$ to MC scheme

$$q_{\text{MC}}(x, Q^2) = q_{\text{MS}}(x, Q^2) + \int_x^1 \frac{dz}{z} q_{\text{MS}}\left(\frac{x}{z}, Q^2\right) \Delta C_{2q}(z)$$

$$\Delta C_{2q}(z) = \frac{\alpha_s}{2\pi} C_F \left[\frac{1 + z^2}{1 - z} \ln \left(\frac{(1 - z)^2}{z} + 1 - z\right) + 1 - z\right]_+$$

2. Reweight the shower with virtual+soft

$$W_{\bar{q}q}^{V+S} = \frac{\alpha_s}{2\pi} C_F \left[\frac{4}{3} \pi^2 - \frac{5}{2}\right],$$

and real weight

$$W_R^{q\bar{q}}(\alpha, \beta) = 1 - \frac{2\alpha\beta}{1 + (1 - \alpha - \beta)^2},$$

where $\alpha = 2k \cdot p_B/\sqrt{s}$ and $\beta = 2k \cdot p_F/\sqrt{s}$. 
Matched results

[Jadach, Płaczek, Sapeta, Siódmok, Skrzypek; in preparation]

Next:

- Implementation with Herwig
- Phenomenology
- PDFs fitted directly in MC scheme?
3. Forward jets, High Energy Factorization, Transverse Momentum Dependent Factorization
\[ x_1 = \frac{1}{\sqrt{s}} \left( p_{1t} e^{y_1} + p_{2t} e^{y_2} \right) \]

\[ x_2 = \frac{1}{\sqrt{s}} \left( p_{1t} e^{-y_1} + p_{2t} e^{-y_2} \right) \]

In the forward limit

\[ y_1, y_2 \gg 1 \quad \Rightarrow \quad x_1 \sim 1, \quad x_2 \ll 1 \]

\[ \leftrightarrow \text{Sensitivity to low-}x\text{ region of gluon density.} \]

\[ k_t^2 = |\vec{p}_{1t} + \vec{p}_{2t}|^2 = p_{1t}^2 + p_{2t}^2 + 2p_{1t}p_{2t} \cos \Delta \phi \]

In the back-to-back limit

\[ \Delta \phi \sim \pi \quad \Rightarrow \quad k_t \sim 0 \]

\[ \leftrightarrow \text{Sensitivity to small } k_t \text{ region of gluon density.} \]
High Energy Factorization

In the small-$x$ limit and for nearly back-to-back configurations, \( Q_s \ll k_t \ll |\vec{p}_{1t}|, |\vec{p}_{2t}| \)

one can use the High Energy Factorization

\[
\frac{d\sigma^{pA \rightarrow \text{dijets}+X}}{dy_1 dy_2 d^2 p_{1t} d^2 p_{2t}} = \sum_{a,c,d} \frac{1}{16\pi^3(x_1 x_2 s)^2} |\mathcal{M}_{ag \rightarrow cd}|^2 x_1 f_{a/p}(x_1, \mu^2) F_A(x_2, k_t) \frac{1}{1 + \delta_{cd}}
\]

And it gives you good description of data!

[van Hameren, Kotko, Kutak, Sapeta '14]
Effective Transverse Momentum Factorization

But for $Q_s \sim k_t \ll |\vec{p}_{1t}|, |\vec{p}_{2t}|$, only effective factorization can be established

[Dominguez, Marquet, Xiao, Yuan ’11]

$$
\frac{d\sigma^{pA \rightarrow \text{dijets} + X}}{dy_1 dy_2 d^2 p_{1t} d^2 p_{2t}} = \frac{\alpha_s^2}{(x_1 x_2 s)^2} \left[ \sum_q x_1 f_q/p(x_1, \mu^2) \sum_i H^{(i)}_{qg} F^{(i)}_{qg}(x_2, k_t) + \frac{1}{2} x_1 f_g/p(x_1, \mu^2) \sum_i H^{(i)}_{gg} F^{(i)}_{gg}(x_2, k_t) \right]
$$

Questions:

- Where exactly is the HEF formalism justified and where does it break?
- Could we introduce $k_t$ dependence to the “matrix elements”, $H^{(i)}$, of the effective TMD formula?
- What happens to the effective TMD factorization beyond large-$N_c$ limit?