Polarized WZ at LHC: a bird's-eye view of the differences between NLO QCD and merged multi-jet calculations

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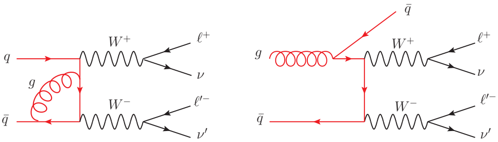
NLO QCD (1)

Fixed-order perturbative calculation: UV and IR divergences to be treated properly.

- UV singularities in virtual (V) corrections: cancelled after regularization and introducing renormalization counterterms (*e.g.* $\overline{\text{MS}}$-scheme) $\rightarrow$ running of α_s.
- IR singularities more tricky: only the sum of virtual (V) and real (R) corrections is free of them [Kinoshita-Lee-Nauenberg theorem].



- subtraction counterterms needed, *e.g.* dipoles D in Catani-Seymour formalism [Catani, Seymour 9605323] used by MoCaNLO:

$$d\sigma_{\text{nlo}}/d\xi = \int d\phi_n \left(B + V + \int d\phi_{\text{rad}}\, D \right)_{d=4} \delta_\xi^{(n)} + \int d\phi_{n+1} \left(R\, \delta_\xi^{(n+1)} - D\, \delta_\xi^{(n)} \right)_{d=4} \quad (1)$$

where δ_ξ are measurement functions.

NLO QCD (2)

$$d\sigma_{\text{nlo}}/d\xi = \int d\phi_n \left(B + V + \int d\phi_{\text{rad}}\, D \right)_{d=4} \delta_\xi^{(n)} + \int d\phi_{n+1} \left(R\, \delta_\xi^{(n+1)} - D\, \delta_\xi^{(n)} \right)_{d=4}$$

- The counterterms D's feature a factorized structure that mimics phase-space singularities (soft and collinear) of R.
- The (regularized) integration of counterterms D gives the same explicit singularities of V, with opposite-sign: $[V + \int d\phi_{\text{rad}}\, D]$ is IR-finite.
- For hadronic collisions: initial-state collinear counterterms must be added to cancel collinear singularities associated with incoming partons.

REMARKS:

(1) Fixed-order calculations treat soft and collinear configurations via a subtraction procedure, that is accurate at the order of the calculation.

(2) NLO accuracy **only for observables that are inclusive on the additional QCD radiation**, otherwise LO accuracy (*e.g.* p_{T} of the WZ system).

(3) No description of event structures with higher parton multiplicities.

Merging approach (1)

Parton shower (PS):

given a hard process, approximates real emissions at higher orders, relying on soft and collinear factorization of hard matrix-elements (ME) (as for subtraction dipoles at NLO)

approximate virtual corrections are obtained from unitarity of the branching process

→ probability for a branching at scale t (evolution starts at t_0):

$$\frac{d}{dt}\prod_{[ij],k}\exp\left[-\frac{1}{16\pi^2}\sum_i\int_t^{t_0}dt'\int dz\int d\phi\,\frac{D_{n+1}^{[ij],k}(t',z,\phi,\{k\})}{B_n(\{k\})}\right] \tag{2}$$

How to improve the PS?
Substitute the shower result at a given α_s order with exact perturbative-QCD ME.

How to do it? One possibility is LO merging:

- separate tree-level ME simulation of higher parton multiplicities.
- soft and collinear configurations of hard ME are regulated by resolution cuts.

Merging approach (2)

PS is combined with these multi-jet calculations: double-counting must be avoided!

How to do it? For $t > Q_{\rm cut}$ (cut-off scale) use hard ME, for $t < Q_{\rm cut}$ use PS.

Introduce a Sudakov suppression for a smooth transition between the two regimes $\rightarrow$ merging algorithm (MLM, CKKM).

A nice review on this topic: [Höche 1411.4085]. On the MLM algorithm : [Alwall et al. 0706.2569]. On the CKKM algorithm(s): [Catani et al. 0109231, Lönnblad 0112284]

REMARKS:

(1) LO merging approach with $+0j$ and $+1j$ samples, approximates the NLO result but **without a virtual corrections**.

(2) Samples are LO-accurate (plus leading-logs): **accuracy is closer to LO** than NLO.

(3) **Jet separation cuts** introduced in the $+1j$ sample, *e.g.* $p_{\rm T,j} > p_{\rm T}^{\rm min}$ in WZ.

(4) Merging introduces systematics to be tuned properly.

(5) Possible shape distortions (w.r.t. fixed NLO) in particular in the $p_{\rm T}$-distribution tails for EW final state particles produced in association with QCD jet(s).