Matching NLO QCD computations to parton shower simulations

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Outline

- Introduction to parton shower generators.

- The MC@NLO method of improving p.s. generator predictions.

- Plots.

Monte Carlo p.s. generators

- P.s. generators are program codes which attempt to simulate signals and backgrounds to new physics at the LHC and ILC.

- The results are tested & tuned against existing SLC, LEP and Tevatron data before predictions are made for future experiments.

- A p.s. generator simulates enhanced QCD radiation from the partons to all orders and implements a hadronization model e.g. **Herwig++, Pythia.**

- P.s. generators produce hadrons in the final state but only work well in regions of high multiplicity and low relative transverse momenta.

Parton shower generators

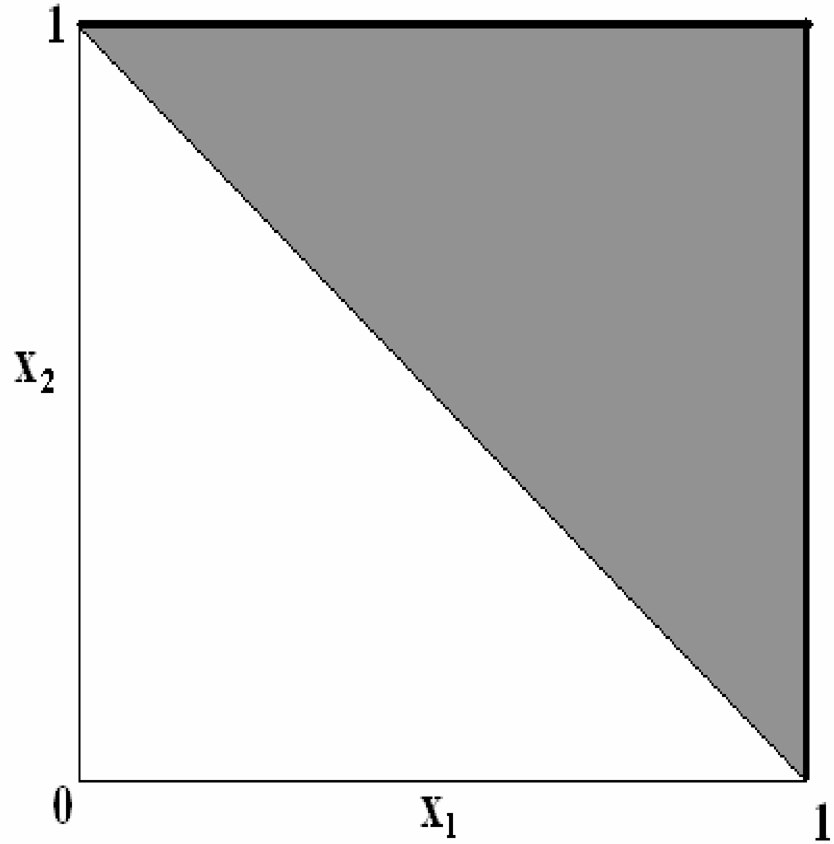
- Consider the process:

$$e^+e^- \rightarrow q\bar{q}g$$

- The differential cross-section for this process can be written in terms of energy fractions x_1 and x_2 as:

$$\frac{d^2\sigma}{dx_1dx_2} = \frac{\alpha_S}{2\pi} C_F \sigma_0 \frac{x_1{}^2 + x_2{}^2}{(1-x_1)(1-x_2)}$$

- This is singular as x_1 and/or $x_2 \rightarrow 1$.
- Physically, this means the differential cross-section is singular when the gluon is soft or collinear with either the quark or antiquark.
- The parton shower approximation treats these regions where the QCD radiation is enhanced and resums the leading logarithms to all orders.



How they work

- The sum of the leading logarithms to all orders is achieved by using the Sudakov form factor.
- This is probability of a parton evolving between scale Q and the cut-off q_c without emitting any resolvable *collinear* radiation.
- Armed with this, p.s. generators generate successive *angular-ordered* splittings up to the cut-off scale at which hadronization sets in. Angular ordering includes *soft* enhancements and interference effects.
- This achieves leading log accuracy for exclusive observables and leading order accuracy for inclusive quantities e.g. total cross-section.
- The MC@NLO method as we shall see achieves NLO accuracy for inclusive quantities while maintaining LL accuracy for exclusive observables.

MC@NLO

- Consider the process:

$$e^+e^- \rightarrow q\bar{q}g$$

- At NLO, the c.s. for this process can be written as:

$$d\sigma = d\sigma_B + d\sigma_V + d\sigma_R$$

- Both $d\sigma^R$ and $d\sigma^V$ have collinear and soft singularities which can be isolated after dimensional regularization as $1/\varepsilon$ and $1/\varepsilon^2$ poles and cancel out to give the finite cross-section.

MC@NLO
Naive Subtraction

- The cross-section for $e^+ e^-$ annihilation can be written explicitly as

$$\sigma = \sigma_0 \left[1 + \frac{\alpha_S}{2\pi} C_F \left(-\frac{2}{\varepsilon^2} - \frac{3}{\varepsilon} - 8 + \pi^2 \right) + \frac{\alpha_S}{2\pi} C_F \left(\frac{2}{\varepsilon^2} + \frac{3}{\varepsilon} + \frac{19}{2} - \pi^2 \right) \right]$$

which can be re-written in integral form over $x_{1,} x_2$ as

$$\sigma = \sigma_0 \int dx_1 dx_2 \left[2 - \frac{\alpha_S}{2\pi} C_F (M - 3) + \frac{\alpha_S}{2\pi} C_F M \right]$$

where M is the $e^+ e^- \rightarrow q\bar{q}g$ matrix element.

- Using this ,we can define a functional, F representing hadronic final states as

$$F = \sigma_0 \int dx_1 dx_2 \left[F_{q\bar{q}} \left\{ 2 - \frac{\alpha_S}{2\pi} C_F (M - 3) \right\} + F_{q\bar{q}g} \left\{ \frac{\alpha_S}{2\pi} C_F M \right\} \right]$$

where $F_{q\bar{q}}$ and $F_{q\bar{q}g}$ represent states arising from $q\bar{q}$ and $q\bar{q}g$ configurations.

- However, this is bound to fail because the weights diverge as $x_{1,} x_2 \rightarrow 1$ and furthermore we still have the problem of double-counting.

MC@NLO

Modified Subtraction

- To avoid double counting, we need to subtract the NLO shower terms, M_C from the co-efficient of $F_{q\bar{q}g}$ on the previous slide and add it back to the co-efficient of $F_{q\bar{q}}$ as shown below.

$$F = \sigma_0 \int dx_1 dx_2 \left[F_{q\bar{q}} \left\{ 2 - \frac{\alpha_S}{2\pi} C_F \left(M - M_C - 3 \right) \right\} + F_{q\bar{q}g} \left\{ \frac{\alpha_S}{2\pi} C_F \left(M - M_C \right) \right\} \right]$$

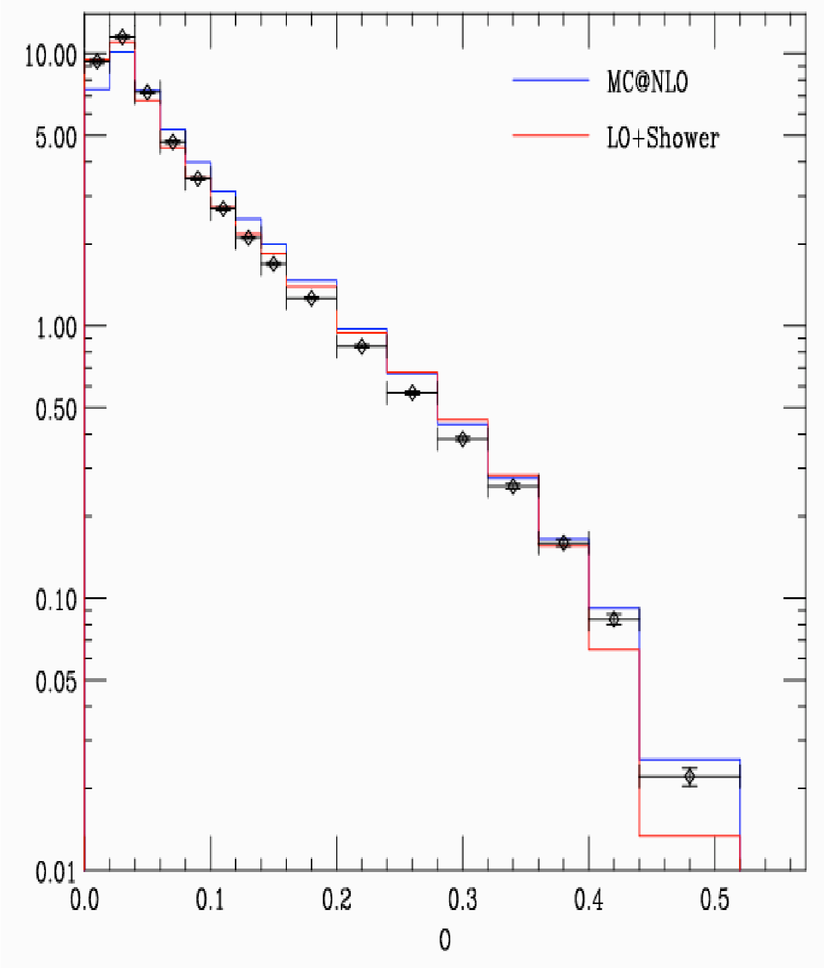
- In addition, since $M \rightarrow M_C$ as $x_1, x_2 \rightarrow 1$, the weights are now finite.
- Now this subtraction is only relevant in the parton shower regions, so F becomes

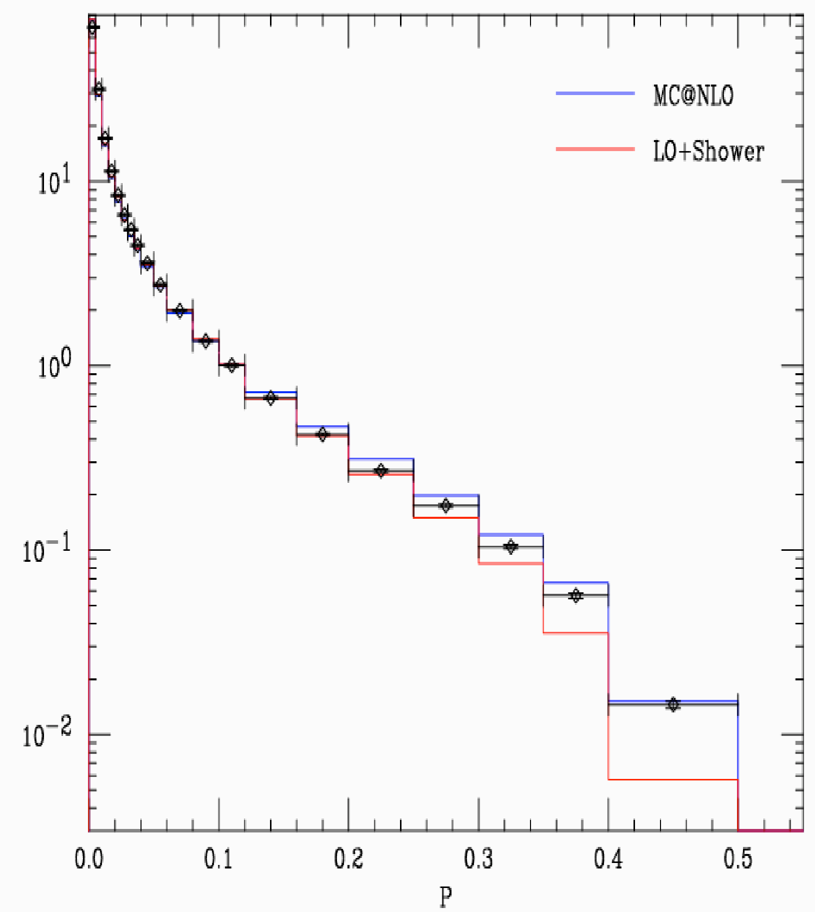
$$F = \sigma_0 \left[\begin{array}{l} \int_J dx_1 dx_2 \left[F_{q\bar{q}} \left\{ 2 - \frac{\alpha_S}{2\pi} C_F \left(M - M_C - 3 \right) \right\} + F_{q\bar{q}g} \left\{ \frac{\alpha_S}{2\pi} C_F \left(M - M_C \right) \right\} \right] \\ + \int_D dx_1 dx_2 \left[F_{q\bar{q}} \left\{ 2 - \frac{\alpha_S}{2\pi} C_F \left(M - 3 \right) \right\} + F_{q\bar{q}g} \left\{ \frac{\alpha_S}{2\pi} C_F M \right\} \right] \end{array} \right]$$

- Note that as expected we recover the total cross-section by replacing each F_x with 1.
- For e^+e^-, $M < M_C$ in the shower regions and hence we generate a small proportion of events with negative weight.

LEP Eventshapes

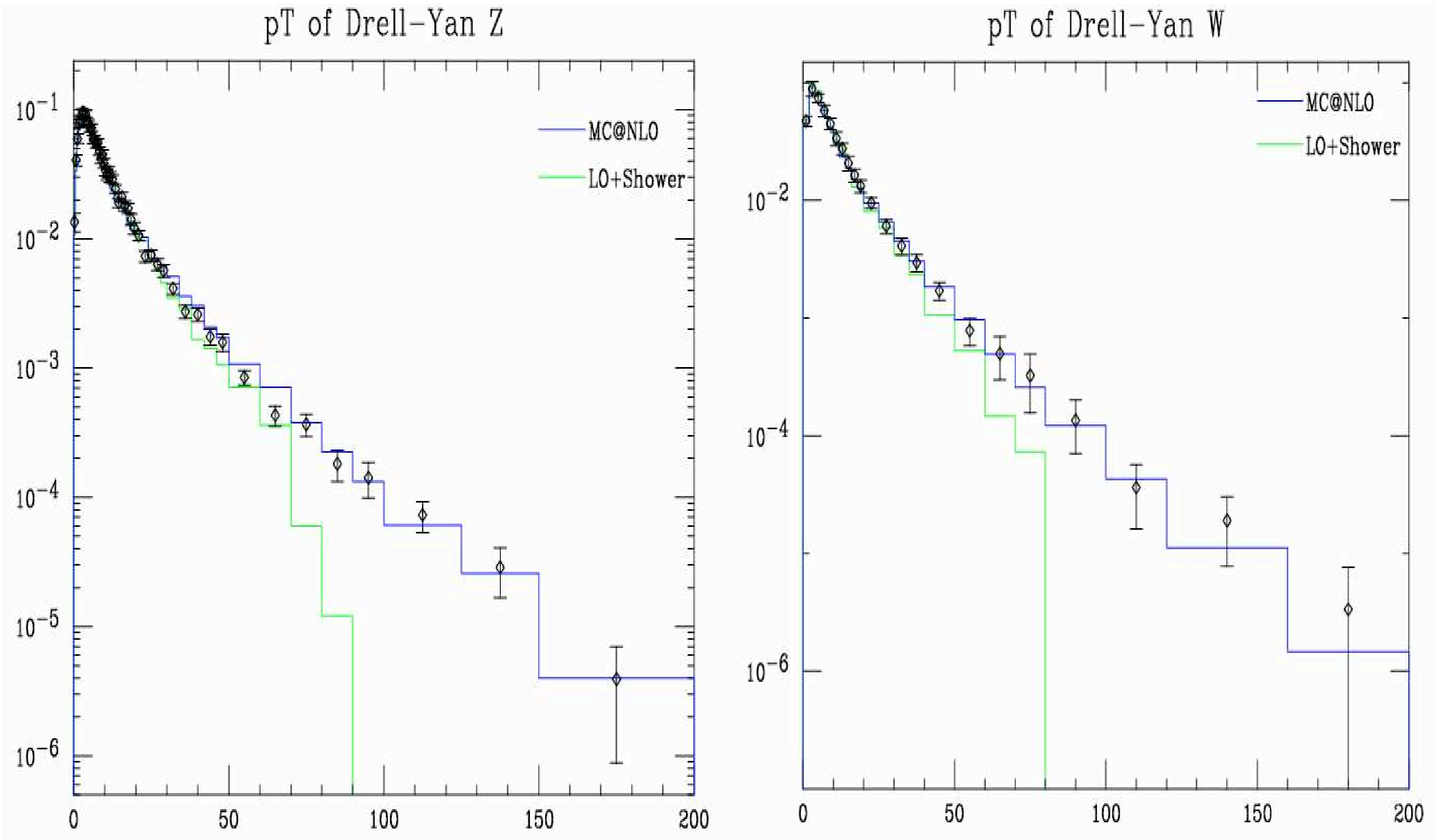
hep-ph/0612281





Tevatron Drell Yan

arXiv:0708.4390



Summary & Conclusions

- NLO improvements of parton showers are essential for near accurate predictions of eventshapes at future colliders.
- MC@NLO achieves this by matching the parton shower and NLO matrix element whilst avoiding double counting.
- The method although not very straightforward to apply has demonstrated success in comparison with existing collider data.
- Presently, work is ongoing to expand the list of processes simulated at NLO in time for the LHC as well as the ILC.