The POWHEG Method

MC+NLO schemes combine best features of SMC and NLO calculations.

POWHEG scheme of Nason [hep-ph/0409146].

- No negative weights produced
- Hardest Emission generation MC independent
- Requires some changes to shower

Method implemented for e+e→hadrons and Drell-Yan vector boson production processes.
POWHEG Scheme

Hardest emission separated in shower.

\[ S(t_L) = \Delta(t_L, t_0) \langle | \rangle + \sum_{l, k=0}^{\infty} \int \frac{t_L}{z_l t_l'} \ldots \frac{z_k t_k'}{z_l t_l'} \ldots \frac{z_{\infty}}{z_l t_l'} t_0 \]

Hardest emission generated from exact Matrix Elements.

- Hardest emission NLO configuration generated.
- Shower with a $p_T$ veto down to hard scale (truncated shower).
- Shower from with a $p_T$ veto.
Hardest Emission

NLO cross section can be written as,

\[ d\sigma = \bar{B}(v) d\Phi_v \left[ \Delta_R^{(NLO)}(0) + \Delta_R^{(NLO)}(p_T) \frac{R(v,r)}{B(v)} d\Phi_r \right] \]

\[ \Delta_R = \exp \left( - \int d\Phi_r \frac{R(v,r)}{B(v)} \Theta(k_T(v,r) - p_T) \right) \]

\[ \bar{B}(v) = B(v) + V(v) + \int (R(v,r) - C(v,r)) d\Phi_r \]

NLO agreement with cross section retaining LL accuracy of shower

Born variables generated according to \( \bar{B}(v) d\Phi_v \)

Radiative variables generated according to \( \Delta_R^{(NLO)}(p_T) \frac{R(v,r)}{B(v)} d\Phi_r \)
e+e- Hardest Emission

To generate the radiative variables, need NLO radiative cross-section.

\[\sigma_r = \frac{\sigma_b C_F \alpha_s}{2\pi} \int dx_1 dx_2 \frac{x_1^2 + x_2^2}{(1-x_1)(1-x_2)}\]

Choose radiative variables \((p_T, y)\) – simplifies integration region.

\[y = \frac{1}{2} \log \frac{1-x_2}{1-x_1} \quad p_T^2 = s(1-x_1)(1-x_2)\]

Exponent of Sudakov Form Factor is:

\[\int d\Phi_r \frac{R(v,r)}{B(v)} \Theta(k_T(v,r) - p_T) = \int^{p_T} dp_T' dy' \frac{C_F \alpha_s p_T}{\pi s} \frac{x_1^2 + x_2^2}{(1-x_1)(1-x_2)},\]

\((p_T, y)\) generated using the veto algorithm.

Born generation trivial in this case.

\[\bar{B} = \sigma_{LO} \left(1 + \frac{\alpha_s}{\pi}\right)\]
Drell-Yan Hardest Emission

Three partonic processes contribute to radiative cross section:

\[ q\bar{q} \rightarrow Vg \]
\[ qg \rightarrow Vq \]
\[ \bar{q}g \rightarrow V\bar{q} \]

\( p_T \) chosen as a radiative variable to simplify integration region.

\[ p_J = (p_T \cosh y_J, p_T \sin \phi, p_T \cos \phi, p_T \sinh y_J), \]
\[ p_B = (m_T \cosh y_B, p_T \sin \phi, p_T \cos \phi, m_T \sinh y_B). \]

The \( q\bar{q} \) contribution gives:

\[
\int d\Phi_r \frac{R(v,r)}{B(v)} = C_F \frac{\alpha_s}{\pi} \int \frac{f_q(x_1) f_{\bar{q}}(x_2)}{f_{\bar{q}}(x'_1) f_q(x'_2)} \left[ (\hat{t} - M^2)^2 + (\hat{u} - M^2)^2 \right] \frac{1}{\hat{s} \hat{t} \hat{u}} p_T d\rho_T dy_J.
\]

\( B(v) d\Phi_v \) is now a non-trivial function of \( y_B \).
**Bbar in Drell-Yan**

Requires NLO cross section as non-singular function of born variable.

Use born factorised result.

\[ \bar{B}(y_B) = B(y_B) \int W(y_B, \tilde{x}, v) d\tilde{x} dv \]

Reweighting of born ME.

Points generated using acdc.

\((\tilde{x}, v)\) thrown away.

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Inverse Momentum Reconstruction

Hardest emission generator for each process
- generates radiative variables
- constructs n+1 momenta

N+1 particles momenta and branching history.

Inverse momentum reconstruction.

Set of 1->2 shower emissions.

Nason shower proceeds as a single shower with simple modifications.
POWHEG Shower Procedure

- Leading order configuration generated from reweighted ME.
- Hardest emission generator produces \( (\hat{q}_h, z_h, \phi_h) \).
- Truncated shower evolves down to hardest emission scale. 
  no flavour changing 
  \( pT \) veto
  \[ z\hat{q} > \hat{q}_h \]
- Splitting forced at \( (\hat{q}_h, z_h, \phi_h) \).
- Vetoed shower evolves down to hadronization scale. 
  \( pT \) veto
e+e- Plots

1–T compared to DELPHI data

Thrust Major compared to DELPHI data

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Drell-Yan Plots

- pT of Z (mass 60 GeV to 116 GeV) compared to TVT data
- y of Z (mass 71 GeV to 111 GeV) compared to TVT data

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