POWHEG NLO matching in Herwig++

Jon Tully, IPPP Durham

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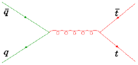
work in collaboration with Peter Richardson and Keith Hamilton

- **Monte Carlo event generators** are crucial tools for planning and analysis of experiments



Generally a leading order QCD, EW (or BSM) calculation.

  - leading order *n* body configuration generated
  - external legs undergo Sudakov evolution down to hadronization scale
  - hadronization and decay models applied
- corresponds to summing collinear and soft leading logarithm terms to all orders
- underestimates hard radiation - match to exact higher order terms - ME Corrections [1], CKKW[2] etc

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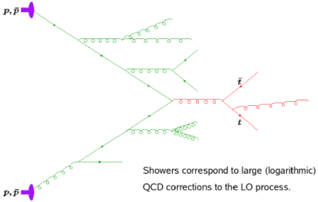

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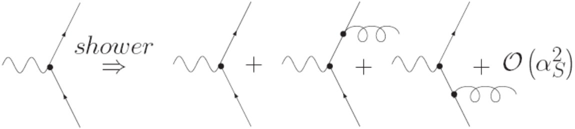
- **NLO matching** combines features of parton shower and NLO
  - inclusive observables in agreement with NLO
  - LL accuracy of shower retained
- naive MC+NLO:
  - NLO generator (eg MCFM) generates n and $n+1$ body events
  - attach events to parton shower
- this approach would result in **double counting**



- MC@NLO [3] scheme available for many processes
  - subtracts shower emission weights from NLO
  - not positive definite

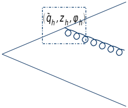
- POWHEG [4] method of Nason is an alternate scheme
  - produces only positive weight events
  - requires modification of the shower (truncated and vetoed showers)
- POWHEG has been implemented for a few processes but with no or approximated truncated shower
- KH, PR, JT implented within Herwig++ with full truncated shower for processes
  - $e + e-$ annihilation to hadrons.
  - Drell-Yan vector boson production.
- POWHEG method contains two steps:
  1. reorganisation of the angular ordered shower

$$\text{shower} = \text{hardest} + \text{truncated} + \text{vetoed}$$

  2. generation of hardest emission with modified Sudakov Form Factor

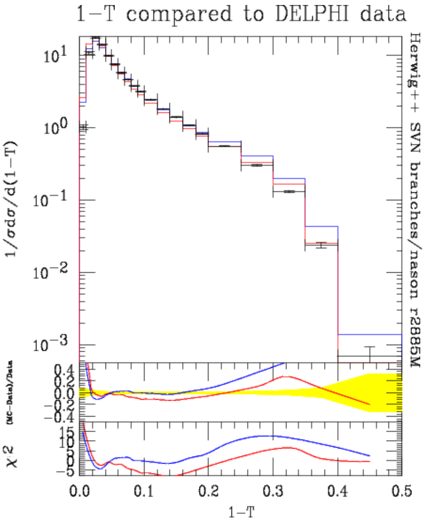
- Produce full POWHEG shower as a single Herwig++ shower with conditions applied

  1. hardest emission generated
  2. $n+1$ body configuration $\longrightarrow$ n body configuration with shower emission $(\tilde{q}_h, z_h, \phi_h)$

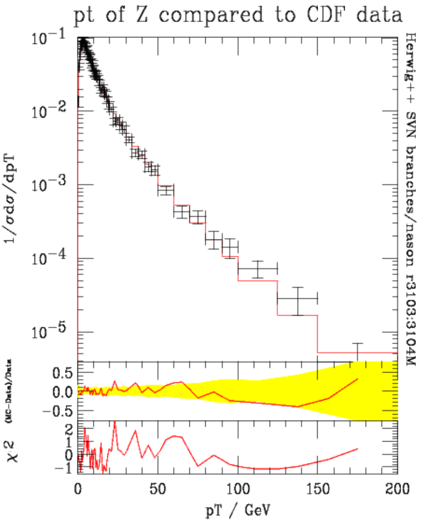


  3. truncated shower evolves down to hardest emission scale $\tilde{q}_h$
     - $p_T < p_{T_h}$
     - $\tilde{q}z > \tilde{q}_h$
     - non flavour changing emission
  4. hardest emission is forced with emission variables $(\tilde{q}_h, z_h, \phi_h)$
  5. shower evolves down to hadronization scale with veto at p_{T_h}

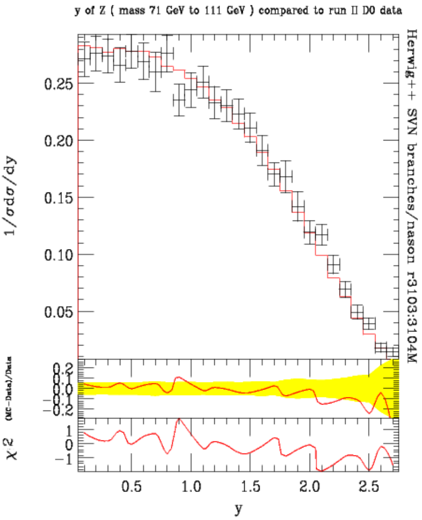
$e+e-$ plots with DELPHI LEP [5] data: Thrust



Drell Yan plots with CDF run I data [6] : Z p_T



Drell Yan plots with D0 run II data [7] : Z rapidity



Summary and outlook

- POWHEG is a positive weight NLO matching scheme
- method fully implemented in Herwig++ for
  - $e+e-$ annihilation to hadrons
  - Drell Yan vector boson production
- reasonable agreement found with data, similar to ME corrections. Paper soon.
- infra-structure in place to allow for straight forward implementation of other processes
  - $gg \to H$

- General QCD NLO cross section may be written

$$\mathrm{d}\sigma = \bar{B}(v)\mathrm{d}v[\Delta_R^{(NLO)}(0) + \Delta_R^{(NLO)}(p_T)\frac{R(v,r)}{B(v)}\mathrm{d}r] \quad (1)$$

- with modified Sudakov Form Factor

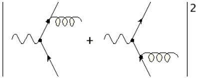
$$\Delta_R^{(NLO)}(p_T) = \exp - \int \mathrm{d}v\mathrm{d}r\frac{R(v,r)}{B(v)}\Theta(k_T(v,r) - p_T) \quad (2)$$

$$\bar{B}(v) = B(v) + V(v) + \int (R(v,r) - C(v,r))\,\mathrm{d}r \quad (3)$$

- monte carlo interpretation
  1. generate n body configurations (v) according to $\bar{B}$
  2. generate radiative $n+1$ configurations according to

$$\Delta_R^{(NLO)}(p_T)\frac{R(v,r)}{B(v)}$$

- positive weights only

- Ingredients for $e+e-$ hardest emission generation:
  - radiative corrections 
- p_T chosen as one of the radiative variables leading to a simple implementation of $\Theta(k_T - pT)$
- modified splitting function given by:

$$\frac{R(v,r)}{B(v)}\mathrm{d}r = \frac{C_F\alpha_S}{\pi}\frac{x_1^2(p_T,y)+x_2^2(p_T,y)}{(1-x_1(p_T,y))(1-x_2(p_T,y))}\frac{p_T}{s}\mathrm{d}p_T\mathrm{d}y \tag{4}$$

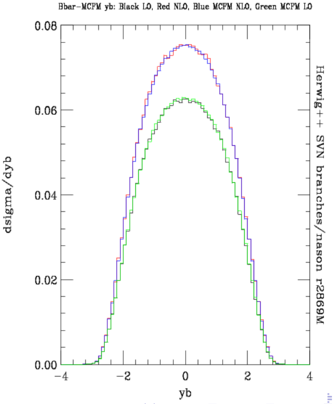
- $\bar{B}$ in this case is just integrated cross section

$$\bar{B} = \sigma_{LO}\left(1+\frac{\alpha_S}{\pi}\right) \tag{5}$$

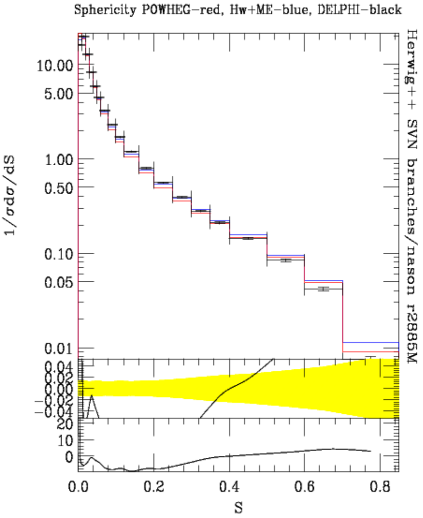
Drell Yan hard generator

- three partonic processes in real corrections
  - $q\bar{q} \rightarrow gV$, $qg \rightarrow qV$, $g\bar{q} \rightarrow \bar{q}V$
- $\bar{B}$ requires full NLO calculation differential in y_B

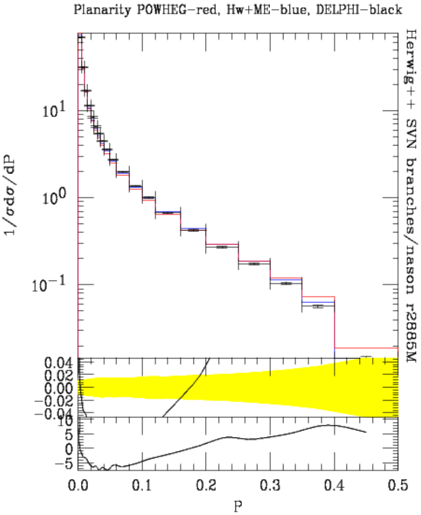
- calculation performed in CALKUL [10] gauge
  - born factorised result
  - implemented as reweighting of LO ME
- $\bar{B}$ and MCFM agree to 0.5%



$e+e-$ plots with DELPHI LEP [5] data: Sphericity



$e+e-$ plots with DELPHI LEP [5] data: Planarity



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