QCD matrix elements and truncated showers

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Combining ME & PS

Why do we combine ME and PS ... ?

Because accelerated QCD charges radiate !

Well-defined schemes to account for the bulk of radiation effects in certain regions of phase space exist (DGLAP, BFKL, ...)
Shower generators implement these schemes to simulate QCD events

But this is not the end of the story !

All resummation calculations are, in the end, approximate
If we are interested in a particular QCD final state, however,

We should correct this approximation with a matrix element without spoiling the inclusive picture of the event

Designing the method

The starting point: QCD evolution

$$\frac{\partial}{\partial \log(t/\mu^2)} \frac{g_a(z,t)}{\Delta_a(\mu^2,t)} = \frac{1}{\Delta_a(\mu^2,t)} \int_z^{\zeta_{\max}} \frac{\mathrm{d}\zeta}{\zeta} \sum_{b=q,g} \mathcal{K}_{ba}(\zeta,t)\, g_b(z/\zeta,t)$$

Defines backward no-branching probability for showers

$$\mathcal{P}^{(B)}_{\mathrm{no},\,a}(z,t,t') = \frac{\Delta_a(\mu^2,t')\, g_a(z,t)}{\Delta_a(\mu^2,t)\, g_a(z,t')} = \exp\left\{ -\int_t^{t'} \frac{\mathrm{d}\bar{t}}{\bar{t}} \int_z^{\zeta_{\max}} \frac{\mathrm{d}\zeta}{\zeta} \sum_{b=q,g} \mathcal{K}_{ba}(\zeta,\bar{t})\, \frac{g_b(z/\zeta,\bar{t})}{g_a(z,\bar{t})} \right\}$$

Requirements for ME-PS merging

- Above equation for shower evolution is preserved
- Hardest emissions are described by matrix elements through

$$\mathcal{K}_{ab}(z,t) \rightarrow \frac{1}{\sigma_a^{(N)}(\Phi_N)} \frac{\mathrm{d}^2\sigma_b^{(N+1)}(z,t;\Phi_N)}{\mathrm{d}\log(t/\mu^2)\,\mathrm{d}z}$$

How does it work ?

Slicing the phase space

$$\mathcal{K}^{\rm ME}_{ab}(\xi,\bar{t}) = \mathcal{K}_{ab}(\xi,\bar{t})\;\Theta[Q_{ab}(\xi,\bar{t}) - Q_{\rm cut}] \qquad \mathcal{K}^{\rm PS}_{ab}(\xi,\bar{t}) = \mathcal{K}_{ab}(\xi,\bar{t})\;\Theta[Q_{\rm cut} - Q_{ab}(\xi,\bar{t})]$$

Patching it up

Let us veto the shower

$$\tilde{\mathcal{P}}^{(B)\,\rm PS}_{\rm no,\;\mathit{a}}(z,t,t') = \frac{\Delta^{\rm PS}_a(\mu^2,t')\,\tilde{g}_a(z,t)}{\Delta^{\rm PS}_a(\mu^2,t)\,\tilde{g}_a(z,t')} = \exp\left\{-\int_t^{t'}\frac{{\rm d}\bar{t}}{\bar{t}}\int_z^{\zeta_{\max}}\frac{{\rm d}\zeta}{\zeta}\sum_{b=q,g}\mathcal{K}^{\rm PS}_{ba}(\zeta,\bar{t})\,\frac{\tilde{g}_b(z/\zeta,\bar{t})}{\tilde{g}_a(z,\bar{t})}\right\}$$

At first glance we obtain a different evolution …

… but this is easily corrected by adding the missing part

$$\mathcal{P}^{(B)}_{\rm no,\;\mathit{a}}(z,t,t') = \frac{\Delta^{\rm ME}(\mu^2,t')}{\Delta^{\rm ME}(\mu^2,t)}\,\mathcal{P}^{(B)\,\rm PS}_{\rm no,\;\mathit{a}}(z,t,t') \quad \text{where} \quad \mathcal{P}^{(B)\,\rm PS}_{\rm no,\;\mathit{a}}(z,t,t') = \frac{\Delta^{\rm PS}_a(\mu^2,t')\,g_a(z,t)}{\Delta^{\rm PS}_a(\mu^2,t)\,g_a(z,t')}$$

Note

- Method is independent of the definition of Q
- Phase space is by definition completely filled

Defining the phase space separation

Now we need a definition of Q

$$Q_{ij}^2 \;=\; 2\,p_i p_j\;\min_{k\neq i,j}\;\frac{1}{C_{i,j}^k+C_{j,i}^k}\;\;;\quad C_{i,j}^k\;=\;\left\{\begin{array}{cc}\dfrac{p_i p_k}{(p_i+p_k)p_j}-\dfrac{m_i^2}{2\,p_i p_j} & \text{if } j=g\\ 1 & \text{else}\end{array}\right.$$

Make sure this is sensible

- Soft limit

$$\frac{1}{Q_{ij}^2}\to\frac{1}{\lambda^2}\,\frac{1}{2\,p_i\,q}\,\max_{k\neq i,j}\left[\frac{p_i p_k}{(p_i+p_k)\,q}-\frac{m_i^2}{2\,p_i q}\right]$$

- (Quasi-)Collinear limit

$$\frac{1}{Q_{ij}^2}\to\frac{1}{2\,\lambda^2}\,\frac{1}{p_{ij}^2-m_i^2-m_j^2}\left(\tilde C_{i,j}+\tilde C_{j,i}\right)\;;\quad \tilde C_{i,j}=\left\{\begin{array}{cc}\dfrac{2\,z}{1-z}-\dfrac{m_i^2}{p_i p_j} & \text{if } j=g\\ 2 & \text{else}\end{array}\right.$$

Truncated showers

Why is a standard shower not enough ?

Assume we have a ME, predefining a branching at t with hard scale t'.
Filling the remaining phase space means computing

$$\mathcal{P}^{(B)\,\mathrm{PS}}_{\mathrm{no},\,a}(z,t,t') = \frac{\Delta^{\mathrm{PS}}_a(\mu^2,t')\,g_a(z,t)}{\Delta^{\mathrm{PS}}_a(\mu^2,t)\,g_a(z,t')}$$

$\Rightarrow$ We need a shower evolving between t' and t, i.e. a "truncated" one.

What is the catch of it ?

The ME branching at t sets the evolution-, splitting and angular variable of a predefined node to be inserted later.
After any emission above t, this node must be reconstructed.

Stuffing it all into Sherpa

The current ingredients (preliminary)

- Catani-Seymour subtraction based shower (CSS) JHEP03(2008)038
- The matrix element generator Comix JHEP12(2008)039

Why those ?

CSS provides

- very good approximation of NLO real emission ME
- invariant definitions of variables
- excellent recoil strategy

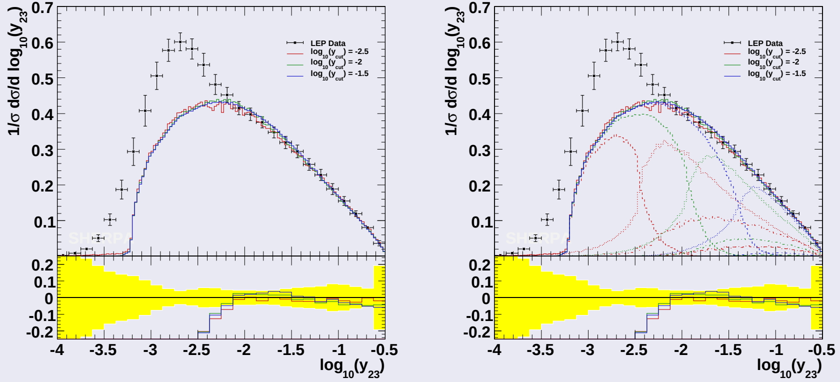
Comix provides

- explicit colour assignment
- trivial projection onto large N_C

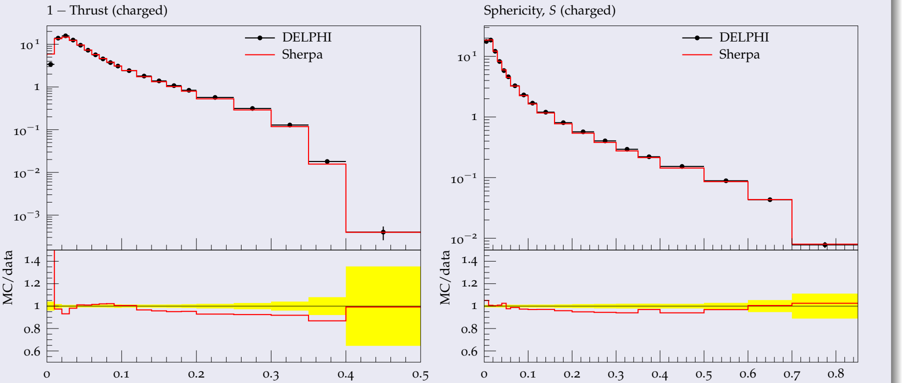
All in all: Way better analytic control

Results: $e^+e^- \longrightarrow$ hadrons @ LEP I

Durham 2 → 3 jet rate (parton level)

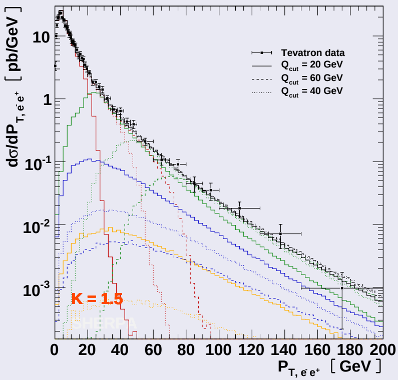


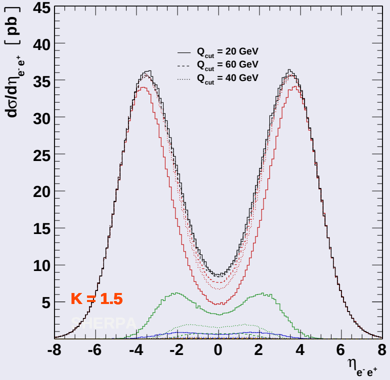
Shape observables (hadron level, untuned)



Results: Drell-Yan @ Tevatron Run I

Lepton observables





Jet observables (parton level)