Vol. 33 (2002) ACTA PHYSICA POLONICA B No 10

COMBINING MATRIX ELEMENTS AND PARTON SHOWERS*

Frank Krauss

Institut für Theoretische Physik, TU Dresden
D-01062 Dresden, Germany
e-mail: krauss@theory.phy.tu-dresden.de

(Received June 24, 2002)

A method is suggested to combine tree level QCD matrix for the production of multi jet final states and the parton shower in hadronic interactions.

PACS numbers: 12.38.Bx, 12.38.Cy

1. Introduction

In recent years, multijet events in high energetic scattering processes became increasingly important as search grounds for new physics and are in focal interest for precision studies concerning the gauge structure of QCD (for recent experimental studies see *e.g.* [1]). For their simulation in the framework of event generators, however, two approaches have traditionally been considered:

- One might use exact matrix elements (ME) at some given perturbative order in the coupling constant(s), say $\alpha_{\rm s}$. At tree level then the final state particles are identified with jets with appropriate cuts on their phase space.
- Alternatively one might use the parton shower (PS) taking correctly into account the soft and collinear limits of parton emission in a factorized form, such that multiple parton emission and thus multijet events can be generated.

Both methods have their shortcomings, related to the treatment of fragmentation when employing the MEs, or related to the neglect of interference effects and thus a loss of information concerning the topological structure of

* Presented at the X International Workshop on Deep Inelastic Scattering (DIS2002) Cracow, Poland, 30 April–4 May, 2002.

events in the case of the PS approach. Thus it seems to be mandatory to try to combine both approaches benefitting from their strengths and evading their respective weaknesses. For some recent approaches in this direction, some even at NLO level, see [2]. However, in this talk I'd like to summarize the approach of [3], capable to combine arbitrary tree level matrix elements for jet production in e^+e^- annihilations with the parton shower, and extend this method to arbitrary (hadronic) initial states, see also [4].

2. ME+PS in e^+e^- annihilations

Let me start with a summary of the method proposed in [3] for the case of $e^+e^- \to$ jets. The basic idea is to divide the phase space for parton emission into two regimes, namely:

1. The region of **jet production**, *i.e.* hard and wide angle parton emission, where interference effects are important. This region will be populated by corresponding multi jet MEs at the tree level.

2. The region of **jet evolution**, *i.e.* comparably soft and collinear parton emission. This region will be populated by the PS [1] resumming correctly leading (LL) and next-to leading (NLL) logarithms.

The separation above is achieved by means of the $k_\perp$ or *Durham*-algorithm [6]. There, two particles are resolved as different jets, if their "distance"

$$y_{ij} = \frac{2\mathrm{min}\{E_i^2, E_j^2\}(1-\cos\theta_{ij})}{s} > y_{\mathrm{jet}}\,, \tag{1}$$

where the parameter y_{jet} regulates the "hardness" of the jets and $s = E^2_{\mathrm{c.m.}}$ is the c.m. energy squared of the e^+e^- pair.

The next step is that the parton emissions in hard region are reweighted in such a fashion that they reproduce both the corresponding order in the coupling constant and the leading and next-to leading logarithms of the form $\log y_{\mathrm{jet}}$. In other words, the reweighting procedure is such that differential jet rates correct at the NLL level are reproduced. This is achieved in the following way:

1. Generate n parton ensembles according to the differential cross section, where $\alpha_{\mathrm{s}} = \alpha_{\mathrm{s}}(Q_{\mathrm{jet}})$ with $Q_{\mathrm{jet}} = \sqrt{y_{\mathrm{jet}}s}$.

2. Construct the correct "PS history":

[1] For details on the PS, see *e.g.* [5]

- Merge the two partons i and j with the smallest y_{ij}. The momentum of the new parton is the sum of the momenta of i and j.
- Repeat the step above until only a $q\bar{q}$ pair remains.

3. For each parton line of type p between $q_{\rm in}$ and $q_{\rm out}$ apply a weight

$$\frac{\Delta_p^{\rm NLL}(q_{\rm in}, Q_{\rm jet})}{\Delta_p^{\rm NLL}(q_{\rm out}, Q_{\rm jet})}\,, \tag{2}$$

where $q_{\rm out}$ might be $Q_{\rm jet}$ for outgoing partons and the Δ are Sudakov form factors at NLL.

4. For each QCD node apply a correction factor

$$\frac{\alpha_{\rm s}(q_{\rm node})}{\alpha_{\rm s}(Q_{\rm jet})}\,. \tag{3}$$

5. Accept or reject the kinematical configuration according to the combined weight.

The subsequent PS for each outgoing parton starts at the scale, where this parton was produced, independent of subsequent, softer emissions "within" the ME. However, a veto is applied on all PS emissions at scales above $Q_{\rm jet}$. That way it can be shown that the dependence on $y_{\rm jet}$ cancels at the NLL level [3].

3. ME+PS in hadronic processes

For hadronic initial states, the idea is the same as above, *i.e.* division of phase space, reweighting the ME and vetoing the PS. To reweight the ME, again a clustering of initial and final state particles has to be performed, until a $2 \to 2$ process remains setting the hardest scale. This clustering is achieved step by step in the c.m. system of the incoming partons according to the longitudinal invariant $k_\perp$ scheme [7]. In this the scheme initial and final state partons are included in the following fashion:

- If the two particles considered are both outgoing, their measure y_{ij} is given by

$$\begin{aligned} y_{ij} &= \frac{2\min\{E_i^2, E_j^2\}(1-\cos\theta_{ij})}{\hat{s}} \\ &\to \frac{\min\{p_{\perp,i}^2, p_{\perp,j}^2\}\left[(\eta_i-\eta_j)^2+(\phi_i-\phi_j)^2\right]}{\hat{s}}\,, \end{aligned}$$

see Eq. (1). Here, $\hat{s}$ is the invariant mass squared of the outgoing particles, $p_\perp$ are their transverse momenta w.r.t. the beam axis and η and ϕ are their pseudorapidities and azimuthal angles.

If two outgoing, *i.e.* final state, particles are clustered, the resulting particle again is a final state particle with $p = p_i + p_j$.

- If one of the two particles, say j is one of the two incoming **partons** then

$$y_{ij} = \frac{2E_i^2(1-\cos\theta_{ij})}{\hat{s}} \to \frac{p^2_{\perp,i}}{\hat{s}}\,. \tag{4}$$

If an incoming and an outgoing particle are clustered, the new particle is incoming, and its momentum is $p = p_j - p_i$. Note that in such a case a boost is in order to the c.m. frame of the new pair of two incoming particles.

Note that in case one considers DIS–like processes the measures are given by the energies and the cosines, whereas in case of purely hadronic initial states the measures are given in terms of transverse momenta [8]. Now the hardest $k_\perp^2$ in the "core" $2 \to 2$–subprocess has to be determined according to the change in the color flow of the QCD particles[2]. Examples are:

- $\hat{s} = M_{ll}^2$ in Drell–Yan type $q\bar{q} \to l\bar{l}$ subprocesses.
- $\frac{2\hat{s}\hat{t}\hat{u}}{\hat{s}^2+\hat{t}^2+\hat{u}^2}$ in QCD subprocesses.

The weight on the ME again is given by ratios of NLL-Sudakov form factors and by ratios of α_s at different scales, see Eqs. (2) and (3). For more details and some examples I'd like to refer the reader to [4].

4. Summary

In this talk I have summarized a method to combine MEs at the tree level for multi jet production in e^+e^- annihilations with the subsequent parton shower. This method correctly reproduces the tree level result weighted with all leading and next-to leading logarithmic contributions stemming from soft and collinear emissions. Suitable starting conditions for the PS and a corresponding veto ensure a cancellation of the dependence on the jet measure at NLL accuracy. The method has been implemented in the event generator `AMEGIC++/APACIC++` [9] and successfully confronted with experimental data.

[2] This scale coincides with the choice of scale one would use in the parton distribution functions for the evaluation of the according $2 \to 2$ cross section.

Furthermore, I have proposed an extension of this method to hadronic initial states. However, I'd like to stress that in contrast to the e^+e^- case this extension lacks both the proof of its correctness up to NLL accuracy and an implementation into a multi-purpose event generator. This is work in progress.

Parts of this talk are based on a paper together with Bryan Webber, Stefano Catani, and Ralf Kuhn. It is a pleasure for me to thank them and Stefano Frixione for intensive and pleasant discussions about this subject.

REFERENCES

[1] P. Abreu *et al.* [DELPHI Collaboration], *Phys. Lett.* **B449**, 383 (1999); G. Abbiendi *et al.* [OPAL Collaboration], *Eur. Phys. J.* **C20**, 601 (2001); C. Adloff *et al.* [H1 Collaboration], *Phys. Lett.* **B515**, 17 (2001).

[2] M.H. Seymour, *Comput. Phys. Commun.* **90**, 95 (1995); *Nucl. Phys.* **B436**, 443 (1995); J. Andre, T. Sjostrand, *Phys. Rev.* **D57**, 5767 (1998); G. Corcella, M.H. Seymour, *Nucl. Phys.* **B565**, 227 (2000); M. Dobbs, *Phys. Rev.* **D64**, 034016 (2001); L. Lonnblad, `hep-ph/0112284`; *Acta Phys. Pol.* **B33**, 3171 (2002); S. Frixione, B.R. Webber, `hep-ph/0204244`.

[3] S. Catani, F. Krauss, R. Kuhn, B.R. Webber, *J. High Energy Phys.* **0111**, 063 (2001).

[4] F. Krauss, `arXiv:hep-ph/0205283`.

[5] R.K. Ellis, W.J. Stirling, B.R. Webber, *QCD and Collider Physics*, Cambridge University Press, Cambridge, 1996 and references therein.

[6] S. Catani, Y.L. Dokshitzer, M. Olsson, G. Turnock, B.R. Webber, *Phys. Lett.* **B269**, 432 (1991).

[7] S. Catani, Y.L. Dokshitzer, B.R. Webber, *Phys. Lett.* **B285**, 291 (1992).

[8] S. Catani, Y.L. Dokshitzer, M.H. Seymour, B.R. Webber, *Nucl. Phys.* **B406**, 187 (1993).

[9] F. Krauss, R. Kuhn, G. Soff, *J. High Energy Phys.* **0202**, 044 (2002); R. Kuhn, F. Krauss, B. Ivanyi, G. Soff, *Comput. Phys. Commun.* **134**, 223 (2001).