Resummation of Event-shapes at Hadron-hadron Colliders

G. Zanderighi

CERN, TH Division, CH-1211, Geneva 23, Switzerland
Fermilab, P.O. Box 500, 60510 Batavia, IL, US

We point out that a study of event shapes at hadron colliders allows one to explore novel aspects of QCD. These studies are today made easier by the development of a program which automates the resummation.

1. INTRODUCTION

In the last decades e^+e^- and subsequently DIS event shapes have proved to be a very powerful tool to study the all order properties of QCD (for a review see e. g. [1]). They allowed measurements of α_s and its renormalization group running, cross checks of the colour factors, tuning of Monte Carlos and studies of analytical hadronization models (e. g. the renormalon inspired power correction approach [2]). A key ingredient, which made those studies possible, was the fact that the coherence of QCD radiation allows one to reorganise the perturbative (PT) expansion so as to resum the leading and next-to-leading contributions. This is needed in the description of the more exclusive phase space region where the event-shape's value is very small. Here the real-virtual cancellation works only partially, leaving behind large logarithms of the value of the event shape, which need to be resummed to all orders. This machinery is today well-understood.

Despite their great success in e^-e^+ and in DIS, event shapes have been largely neglected at hadron-hadron colliders (hhc), the only measurements, to our knowledge, being a measurement of the broadening by CDF in 1991 [3] and a measurement of the thrust by D0 in 2002 [4]. One might consider the study of event-shapes at hadron colliders of limited interest, being almost a repetition of what has already been studied in great detail in e^+e^- and in DIS. The main point of this talk is to state that this is by no means the case.

First, it is important to mention that till date, comparison of next-to-leading logarithmic (NLL) resummed predictions with data have been carried out *only* for observables which vanish in the 2-jet limit: 2-jet e^+e^- event shape variables, [1+1] event-shapes in DIS and Drell-Yan vector boson production. At hhc, where two jets are already present in the initial state, any study of the final state goes beyond the known and well-tested domain. Dijet production in hhc represents a field where both, resummation and power corrections are completely untested.

It is however clear that the experimental environment in hhc is much more difficult. Due to the presence of the beam it is less clean then in e^+e^- and does not have the benefit of DIS experiments where one can considerably vary the hard scale (Q) of the process, thereby allowing a single experiment to explore a whole range of widely different scales. The study of a single or just few event shapes is then not enough to balance the experimentally more challenging environment. In order to extract some information from hhc experiments one needs to study a whole range of event shapes.

Following an old-fashioned, analytic approach, this would be barely possible: the complexity of analytical resummations increases drastically in multi-jet event shapes, e. g. the 3-jet thrust-minor calculation in the "simple" e^+e^- environment requires already the evaluation of five Mellin integrals [5]. In the study of hhc dijet event-shapes one has four QCD emitters and, additionally, one has to face new complications arising from the fact that the colour structure is not diagonal [6]. Even if possible, one must admit that facing similar, tedious calculations for a whole range of hhc dijet event shapes does not sound like the most appealing programme. However, recently an automated way of resuming event-shapes in e^+e^-, DIS and hhc was developed and implemented in the computer program CAE-SAR [7]. This made it possible to resum a whole range of observables in hhc and opened up the possibility to new phenomenological studies at the Tevatron, some of which are currently under way.

2. HADRON-HADRON COLLIDER EVENT SHAPES

An essential point when performing an automated resummation is that current understanding allows us to resum only observables which enjoy certain properties. A goal of an automated resummation tool is that it can be used without a detailed understanding of the analytical properties of the observable under consideration. It is therefore an essential property of CAESAR that it can test whether an observable is in its scope and only in this case it performs the resummation.

The detailed list of properties the observable has to fulfill has been given in [7]. Most of these properties were satisfied by all observables resummed analytically in the previous years and are insofar not very limiting. The experimentally more limiting requirement is that of *continuous globalness*. An observable is defined to be *global* [8] if it is sensitive to emissions everywhere in phase space (and is deemed to be *non-global* otherwise). Typical examples of non-global event-shapes are single-hemisphere observables in e^+e^- and many current hemisphere DIS event shapes. An important lesson which was learned from DIS is that *not measuring everywhere* does not necessarily mean *non-global*. There are event-shapes in DIS which measure particles only in the current hemisphere but are nonetheless sensitive to emissions in the remnant hemisphere, typically through the recoil of a hard parton. Often the sharp distinction between global and non-global event shapes is too coarse and it is useful to distinguish between various degrees of (non-)globalness. A more restricted class of global observables is that of *continuous global* ones, those for which the dependence on the transverse momentum is independent of the emission's direction (i. e. the observable should scale according to the same power of k_t everywhere) [8]. CAESAR is limited to those observables.

Having established the important criterion of continuous globalness, the first question is if there are hhc observables which do satisfy it. Detectors can cover always only a limited rapidity range (at the Tevatron $\eta_{\max} \sim 3.5$, at the LHC $\eta_{\max} \sim 5$). This makes observables non-global, since there might be emissions at $\eta > \eta_{\max}$ which emit radiation in the observed region. NLL resummations do not account for such effects. The theoretical requirement of globalness seems therefore to conflict with the experimental possibility of current experiments, thus making the resummation of global hhc event shapes a nice theoretical exercise, but without much practical use. Luckily, this is not the case. We present here three classes of observables which are specifically designed to solve the tension between experimental and theoretical needs [9]

1. <u>Directly global event shapes:</u> take $\eta_{\max}$ as large as experimentally possible and extend usual e^+e^- event-shapes by simply formulating them in the transverse plane. Use then the fact that emissions contribute significantly only if $v \simeq e^{-(a+b_\ell)\eta_{\max}}$.[1] This implies that standard NLL resummations are still valid, but in a limited region where v is not too small ($v \le e^{-(a+b_\ell)\eta_{\max}}$). These observables typically have $b_\ell = 0$ for incoming legs.

2. <u>Indirectly global event shapes with recoil term:</u> Define a central region $\mathcal{C}$ well away from the forward detector edges and define the observable in terms of only these emissions. Add then a recoil term which is constructed only with emissions in $\mathcal{C}$, but which is non zero if there are emissions in $\bar{\mathcal{C}}$ (e. g. the vectorial sum of all transverse momenta in $\bar{\mathcal{C}}$, or any power of it, to ensure continuous-globalness). Due to the presence of the recoil term exponentiation to NLL holds only in impact-parameter space, this is due to the fact the smallness of the observable is not necessarily to be attributed to a Sudakov effect, but could be due to a vectorial cancellation between harder emissions. This again limits the range of applicability of resummed calculations.

3. <u>Directly global event shapes with exponentially suppressed forward terms:</u> Define a central region $\mathcal{C}$ and define the observable in terms of only these emissions. Add then a term which is constructed with emissions in $\bar{\mathcal{C}}$ but which is not sensitive to details of the emission pattern, i. e. the term is exponentially suppressed in the rapidity of the emissions. The presence of the exponentially suppressed term reduces the sensitivity to the region $\bar{\mathcal{C}}$, but guarantees that the observable is global. These observables typically have $b_\ell = a$ for incoming legs.

---

[1]One of the assumptions of CAESAR is that the event shape has the following functional behaviour $V(\tilde{p}, k) = d_\ell \left(\frac{k_t}{Q}\right)^a e^{-b_\ell \eta} g_\ell(\phi)$ when a single, soft emission is emitted collinear to the hard leg ℓ. Here k_t, η and ϕ are measured wrt the leg ℓ.

By construction these observables reconcile the experimental and theoretical needs, making them a solid basis for phenomenological studies. Additionally they have complementary properties e. g. with respect to the sensitivity to the beam, making them a rich source of information. It is then possible to not only consider extensions of typical e^+e^- and DIS event-shapes (thrust, broadening, jet-masses, ...) but also to design new observables which arbitrarily enhance or suppress the importance of the beam radiation. [2]

To conclude, there are several aspects of QCD which can be studied by analyzing hhc dijet event-shapes:

- resummation for dijet event-shapes accounts for multiple soft, large angle radiation emitted from a four-parton system. Here quantum evolution of colour [6] enters the game. These novel perturbative QCD colour evolution structures have never been investigated before; [3]

- studies of hadronization corrections and power-corrections in multi-jet events;

- studies of underlying event, these are made easier by the fact that the forward sensitivity (to beam-fragmentation) can be arbitrary tuned.

3. CONCLUSIONS

Automated resummation makes it possible to study a large number of event shapes at hadron-hadron colliders. These observables can be designed so as to have complementary properties, e.g. the sensitivity to beam-fragmentation can be arbitrarily tuned. Studies of event-shapes at the Tevatron are currently under way. We very much hope that these measurements will turn out to be as successful as those in e^+e^- and DIS collider experiments.

Acknowledgments

References

[1] M. Dasgupta and G. P. Salam, J. Phys. G **30** (2004) R143.

[2] Y. L. Dokshitzer, G. Marchesini and B. R. Webber, Nucl. Phys. B **469**, 93 (1996).

[3] F. Abe *et al.* [CDF Collaboration], Phys. Rev. D **44** (1991) 601.

[4] I. A. Bertram [D0 Collaboration], Acta Phys. Polon. B **33**, 3141 (2002).

[5] A. Banfi, G. Marchesini, Y. L. Dokshitzer and G. Zanderighi, JHEP **0007**, 002 (2000).

[6] J. Botts and G. Sterman, Nucl. Phys. B **325**, 62 (1989); N. Kidonakis and G. Sterman, Phys. Lett. B **387** (1996) 867; Nucl. Phys. B **505** (1997) 321; N. Kidonakis, G. Oderda and G. Sterman, Nucl. Phys. B **531**, 365 (1998); G. Oderda, Phys. Rev. D **61** (2000) 014004; N. Kidonakis and J. F. Owens, Phys. Rev. D **63**, 054019 (2001).

[7] A. Banfi, G. P. Salam and G. Zanderighi, Phys. Lett. B **584**, 298 (2004); JHEP **0503**, 073 (2005).

[8] M. Dasgupta and G. P. Salam, Phys. Lett. B **512**, 323 (2001); JHEP **0208**, 032 (2002).

[9] A. Banfi, G. P. Salam and G. Zanderighi, JHEP **0408**, 062 (2004); Analyses and resummed results for a large number of observables are also available from `http://qcd-caesar.org/` .

[10] A. Banfi, Y. L. Dokshitzer, G. Marchesini and G. Zanderighi, JHEP **0103**, 007 (2001); JHEP **0105**, 040 (2001); A. Banfi, G. Marchesini, G. Smye and G. Zanderighi, JHEP **0111**, 066 (2001).

---

[2]Despite this, in hhc studies of event-shapes one always has to deal with an omnipresent underlying event. It is therefore important that these studies be supplemented by similar studies of multi-jet event shapes both in e^+e^- (3-jet) and in DIS [1+2], for which NLL predictions and power corrections exist [10].

[3]Notice that such effects enter also top threshold corrections.