OUT-OF-PLANE QCD RADIATION IN DIS EVENTS WITH HIGH P_T JETS*

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(Received July 1, 2002)

We present the QCD analysis of the out-of-event-plane momentum distribution in DIS events with high p_t jets. The achieved accuracy allows the measurement of the running coupling and the study of non-perturbative effects, in particular the test of universality of power corrections in a new experimental regime.

PACS numbers: 13.87.Ce, 13.87.Fh, 12.38.Lg

1. Introduction

Event shape variables describe the energy and momentum flow in high energy collisions. Being collinear and infrared safe they can be computed with high accuracy, so that they generally allow a good measurement of α_s. Furthermore they are sensitive to extra soft non perturbative emissions, so that they prove to be a powerful tool to study the up to now fairly unknown low energy domain.

2. Two- and multi-jet event shape variables

Event shapes were originally defined for e^+e^- collisions [1–3], only quite recently their QCD calculation have been extended to Deep Inelastic Scattering (DIS) collisions [4,5]. Calculations for DIS processes are in principle a simple extension of the e^+e^- case. Of course, just from a pure kinematical point of view one expects some differences: e^+e^- collisions are characterized by only one hard scale, the center-of-mass energy $\sqrt{s}$, while DIS processes depend on one additional hard scale, the virtuality Q of the incoming gauge boson. A further difference is the presence of a hadron in the initial state in DIS collisions. This implies that observables are finite only *after* introducing

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

a factorization scale to extract collinear divergences due to initial state radiation. Finally, since no measurements can be performed close to the beam region, in DIS analyses one needs to introduce a kinematical rapidity cut $\eta < \eta_0$ ($\sim \mathcal{O}(1)$) along the direction of the incoming parton.

Till recently, both in e^+e^- and in DIS physics, attention was focused on so called 2-jet observables, *i.e.* on those observables whose first non-zero contribution is at order α_s. Such observables are sensitive to any kinematical final state, therefore prove to have a rich phenomenology [6-13]. On the other hand, 3-jet observables, *i.e.* observables whose first non-vanishing contribution is at order α_s^2 are sensitive to the non-abelian structure of QCD already at leading order and are therefore more interesting from a theoretical point of view. In particular in DIS processes 3-jet observables are sensitive to the gluon density at leading order. Therefore these studies should provide a powerful method to study QCD dynamics and to constrain the parton distribution functions.

3. Out-of-plane radiation

The computation of 3-jet observables at the same standard accuracy available for 2-jet observables (*i.e.* single logarithmic resummation, second order exact results, matching and leading power corrections) proves to be much more cumbersome. This project started some years ago with the study of some 3-jet observables in e^+e^- [14, 15], results were then extended to Drell–Yan processes [16] and finally to DIS observables [17,18]. The first 3-jet observable studied in DIS measures the cumulative out-of-plane momentum distribution $K_{\rm out}$ [17], where the event-plane is fixed kinematically by the Breit- and thrust major axis. Pure three jet events are selected by imposing a lower bound for the 2-jet resolution variable y_2.

At first order in α_s, *i.e.* when only 2 final state partons are present, momentum conservation ensures that the event is planar so that the observable vanishes. The first non trivial contribution is therefore at $\mathcal{O}\alpha_s^2$.

The $K_{\rm out}$ observable, as other event shapes, is characterized by the following theoretical features:

- On a perturbative (PT) level, in the kinematical region where $K_{\rm out} \ll Q$ vetoing real emissions gives rise to a large mismatch between real and virtual contributions, so that large logarithms $L \equiv \ln(K_{\rm out}/Q)$ need to be resummed at double- (DL) and single logarithmic (SL) level.

- From a non perturbative (NP) point of view also ultra-soft emissions contribute to the observable, so that (at least) leading $1/Q$ power corrections need to be taken into account.

3.1. Perturbative result

At DL level the perturbative answer is quite straightforward: vetoing radiation from any of the 3 emitting partons gives rise to a Sudakov exponent which is simply the sum of the 3 single-parton Sudakovs, each one forbidding radiation from one hard parton regardless of the presence of the other 2.The Sudakov factor needs to be weighted with the hard squared matrix element $|M|^2$ and convoluted with the incoming parton density $\mathcal{P}(\mu)$

$$\Sigma(K_{\mathrm{out}}) \sim \mathcal{P}(\mu) \otimes |M|^2 \, \mathrm{e}^{-\frac{\alpha_{\mathrm{s}}}{\pi}(2C_F+C_A)\ln^2 \frac{Q}{K_{\mathrm{out}}}} \, . \tag{1}$$

A naive DL result is known to be insufficient to make quantitative predictions. A more rich and informative answer is found at SL level where the answer is sensitive to coherence and interference effects. In particular to hard parton recoil effects, to soft large angle radiation, to collinear (initial) state radiation and to the running of α_{s} (at 3 different scales).

The total answer at SL level [17] turns out to be quite involved, but can be interpreted easily in terms of the above SL effects.

3.2. Non-perturbative effects

As is now well established, for event shapes PT results at whatever order need to be supplemented by an NP contribution whose actual size and form depends strictly on what has been already included in the PT calculations. The kinematical origin of such a sensitivity to hadronization effects is evident: event shapes measure momentum flow, they are therefore sensitive to the momentum degradation which occurs during the colour blanching. Also from a more formal point of view the need for NP corrections is clear: regardless of details of the behaviour of the coupling in the infrared PT expansions are divergent and therefore intrinsically ambiguous, such an ambiguity in the final answer needs to be canceled by an additional NP term.

To deal with NP effects we adopted the now standard procedure of extending the notion of α_{s} in the NP regime [19]. The total answer depends then on α_{s} and on one NP parameter α_0 which is related to the average of the dispersive coupling in the NP domain (the choice of μ_I is conventional)

$$\alpha_0 = \frac{1}{\mu_I} \int_0^{\mu_I} dk_t \, \alpha_{\mathrm{s}}(k_t) \, , \qquad \mu_I \sim 2\,\mathrm{GeV} \, . \tag{2}$$

α_0 is the same parameter which appears in the calculation of other event shapes. The fact that many observables depend on only one additional NP parameter is a consequence of the universal (linear) behaviour of such observables on the transverse momentum of the secondary partons. The

rapidity (and azimuthal) dependence determines the observable-dependent, PT-calculable coefficient of the NP corrections. In the present case, since $K_{\rm out}$, as the Broadenings, is by definition rapidity-independent, the rapidity integral of the NP gluons would diverge if extended naively to infinity as is usually done. One then needs to introduce an effective rapidity cutoff, which is provided by the PT recoil of the hard partons. Due to this interplay between PT & NP physics the NP-shift depends on the PT value of the observable. In particular, according to the kinematical region under consideration the shift is log-enhanced ($\propto \ln(K_{\rm out}/Q)$) or proportional to $1/\sqrt{\alpha_{\rm s}}$ (with a rich and informative colour structure).

3.3. Universality of power corrections

Universality implies that a simultaneous fit of $\alpha_{\rm s}$ and α_0 from different observables gives the same answer. Fig. 1 shows a 1-σ contour plot for some DIS event shapes [20].

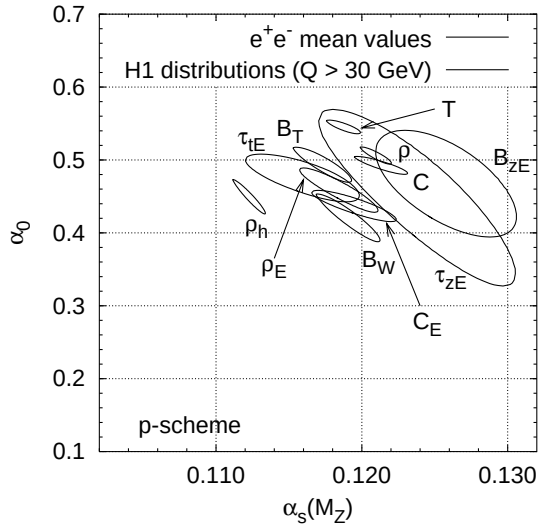


Fig. 1. 1-σ contour plot for the $\alpha_{\rm s} - \alpha_0$ fit for some DIS event shape variables.

Universality is found with an accuracy of about 10–15%, which is in agreement with the size of higher order neglected terms. Up to now this universality hypothesis has been tested only in 2-jet observables, so that there is a quite large correlation between different fits which is usually not taken into account. Indeed fits are done using the same experimental data and fitting observables which are fairly similar (think of the thrust T and C-parameter for which at leading order $C = 6\,(1 - T)$).

The computation of the out-of-plane momentum distribution provides a possibility of checking this universality hypothesis in a more uncorrelated environment. This check is particularly relevant since universality of α_0 relies on the assumption of NP gluons being distributed uniformally in rapidity, which is quite non trivial in the 3-jet case.

This work has been done in collaboration with Andrea Banfi, Yuri Dokshitzer, Pino Marchesini and Graham Smye. Thanks also to Gavin Salam for many precious hints.

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