Jet Production with Polarized Beams at Next-to-Leading Order

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Jet production cross-sections in polarized proton-proton and electron-proton collisions are studied to next-to-leading order accuracy. Phenomenological results are presented for RHIC and HERA kinematics.

The last decade has seen an important advance in our understanding of polarized nucleon structure functions as a result of the analysis of deep inelastic scattering (DIS) data. Unfortunately, the use of DIS data alone does not allow an accurate determination of the polarized parton densities. This is true in particular for the gluon, since this quantity contributes to DIS in leading order (LO) only via the Q^2-dependence of the spin asymmetry (A_1^N).

At variance with DIS, collider physics offers a relatively large number of processes whose dependence upon the gluon density is dominant already at LO. The study of these processes is therefore crucial in order to measure this density in a direct way. Among them, jet production is an obvious candidate, because of the large rates.

In order to make reliable quantitative predictions for high-energy processes, it is crucial to determine the NLO QCD corrections to the Born approximation. The key issue here is to check the perturbative stability of the process considered. Only if the corrections are under control a process that shows good sensitivity to, say, Δg at the lowest order can be regarded as a genuine probe of the polarized gluon distribution and be reliably used to extract it from future data. NLO QCD corrections are expected to be particularly important for the case of jet-production, since it is only at NLO that the QCD structure of the jet starts to play a rôle in the theoretical description, providing for the first time the possibility to realistically match the experimental conditions imposed to define a jet.

The main purpose of this talk is, therefore, to study the perturbative stability and the phenomenological consequences of jet production cross-sections to NLO accuracy. We have implemented the NLO QCD corrections to jet production in polarized proton-proton and electron-proton (in the photoproduction regime) collisions by extending the unpolarized MonteCarlo code constructed in ref. [1] to the case of polarized beams. As a result, we present a customized code, with which it is possible to calculate any infrared-safe quantity corresponding to either single- or di-jet production to NLO accuracy. For the theoretical details about the implementation, we refer the reader to refs. [1–4].

The best way to analyze the effect of NLO corrections on the perturbative stability of an observable is to study the dependence of the full NLO result on the renormalization and factorization scales. Throughout we will set the two scales equal, i.e. $\mu_R = \mu_F \equiv \mu$, and vary μ as a way to quantify the theoretical uncertainty on the cross section. In fig. 1a we show the next-to-leading and leading order p_T-distributions for polarized pp collisions for the three different scales: $\mu_0, 2\mu_0$ and $\frac{1}{2}\mu_0$. Figure 1b is the corresponding plot for the unpolarized case. Clearly, the dependence on the scale is substantially reduced when going to next-to-leading order. The situation in the polarized case is indeed very similar to the unpolarized one. We have observed the same reduction in the scale dependence for other single and double-differential observables. It is therefore sensible to

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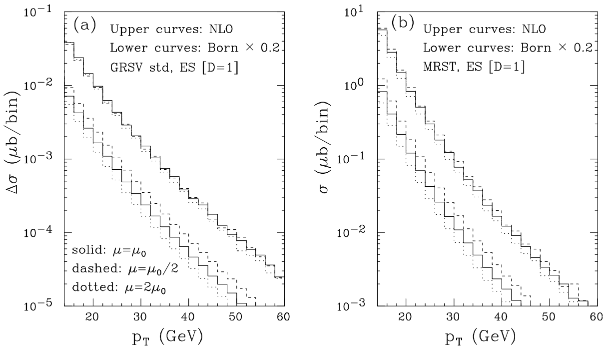

Figure 1. Scale dependence of the next-to-leading order and Born p_T-distributions in pp collisions.

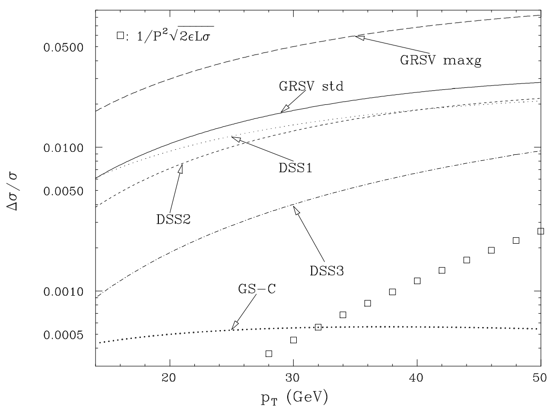

Figure 2. Single-inclusive jet asymmetry in pp collisions for various polarized parton densities.

use our code to investigate a few phenomenological issues relevant to hadronic physics at RHIC. In fig. 2, the one-jet asymmetry is shown as a function of p_T. The results have been obtained by choosing six different parametrizations of the polarized parton densities [5]. Figure 2 clearly shows that the choice of the polarized parton densities induces an uncertainty on the theoretical results of more than two orders of magnitude. This enormous spread is basically due to the fact that at this energy the jet cross section is dominated by gg- and qg-initiated parton processes. Therefore, and since the minimum value of the asymmetry observable at RHIC is quite small, the measurement of the polarized jet cross section at RHIC will be useful in order to rule out some of the polarized sets that are at present consistent with the data. The Born results differ from those presented in fig. 2 for a factor up to 20% and the shape is also different. Therefore, NLO corrections give non-trivial information on the structure of the asymmetries

Moving to the case of electron-proton collisions, it is clear that in order to obtain large statistics one should go to the photoproduction regime. In this case the cross-sections can be approximated as a convolution of the photon-proton cross sections with the Weizsäcker-Williams flux. The photon-proton cross section is given by a sum of two terms, denoted as the point-like and hadronic components. In order to compute the hadronic component one needs, besides the polarized parton distributions in the proton, also the polarized densities in the photon , which are completely unmeasured so far. To obtain a realistic estimate for the theoretical uncertainties due to these densities, we use the two very different scenarios considered in ref. [6].

We have studied the scale dependence of several observables at NLO and found that the variation of the scale induces a variation of the cross section of the order of 10% over most of the η range considered. The scale dependence is also strongly reduced when going from Born to NLO results.

We now turn to the problem of studying the dependence of our results upon the available proton and photon polarized parton densities. In fig. 3 we present the results for the asymmetry in terms of the pseudorapidity of the single-inclusive jet at polarized HERA, obtained using GRSV STD as the polarized proton set and both polarized photon sets. The Born and NLO results are both shown. We can see that in the large η region the difference induced by the choice of the two photon sets is extremely large. On the other hand, towards negative η values this difference tends to vanish. This is because in that region the point-like component, which does not depend upon photon densities, is the dominant one. We can also observe that in the positive η region there is a very small difference between the NLO and LO results, while for negative η's the radiative corrections are

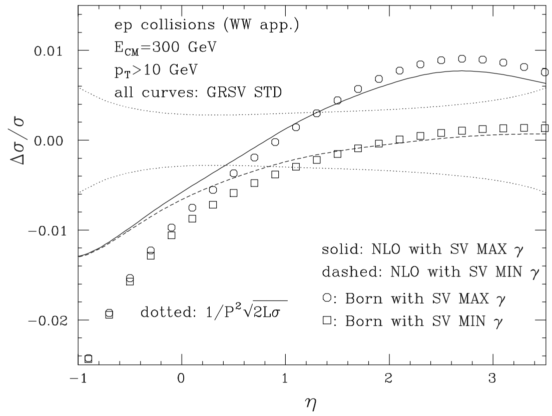

Figure 3. Asymmetries in single-inclusive jet production in electron–proton collisions.

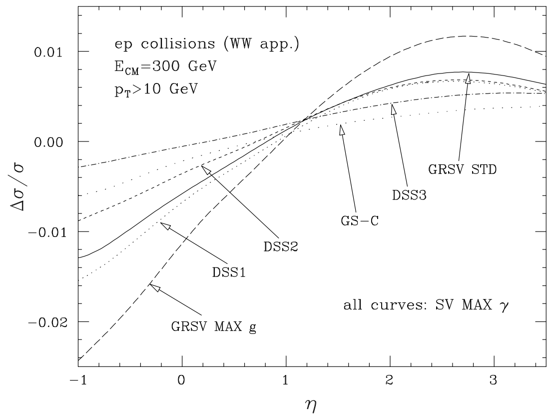

Figure 4. Same as fig.3 for different polarized proton distributions

positive and reduce the asymmetry considerably. In fig. 4, we show the curves obtained by fixing the polarized photon set to SV MAX γ, and by considering the various polarized proton sets. As expected, the largest differences can be seen at negative η values, where theoretical predictions can vary for about one order of magnitude. It follows that, if high luminosity will be collected, it will be possible to get information on the polarized parton densities in the proton. As far as the polarized photon densities are concerned, if the "real" densities are similar to those of the set SV MIN γ, it will be extremely hard to even get the experimental evidence of a hadronic contribution to the polarized cross section. On the other hand, a set like SV MAX γ appears to give measurable cross sections.

In conclusion, we reported the calculation of jet cross-sections in polarized hadron-hadron and electron–hadron (in the photoproduction regime) collisions, which is accurate to NLO in perturbative QCD. For all the observables considered, it has been found that the scale dependence is smaller than that of the LO result. The inclusion of the NLO terms changes the size of the asymmetries by 20% in the case of proton-proton collisions at RHIC and, considerably reduces it, in the case of electron-proton collisions at HERA in the pseudorapidity region where the contamination from the hadronic photon contribution is minimal. From our analysis, it is clear that the inclusion of the NLO corrections is indispensable in order to have reliable quantitative calculations.

Measurements of jet cross-sections with polarized beams at RHIC and HERA will be fundamental tools in order to extract the polarized gluon distribution in the proton. It is, therefore, worth emphasizing that the theoretical tools for the future NLO analysis of the forthcoming data are already available.

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