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CALCULATIONS OF SINGLE-INCLUSIVE CROSS SECTIONS AND SPIN ASYMMETRIES IN PP SCATTERING

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We present calculations of cross sections and spin asymmetries in single-inclusive reactions in pp scattering. We discuss next-to-leading order predictions as well as all-order soft-gluon "threshold" resummations.

1. Introduction

Single-inclusive reactions in pp scattering, such as \( pp \to \gamma X \), \( pp \to \pi X \), \( pp \to \text{jet} X \), play an important role in QCD. At sufficiently large produced transverse momentum, \( p_T \), QCD perturbation theory (pQCD) can be used to derive predictions for these reactions. Since high \( p_T \) implies large momentum transfer, the cross section may be factorized at leading power in \( p_T \) into convolutions of long-distance pieces representing the structure of the initial hadrons, and parts that are short-distance and describe the hard interactions of the partons. The long-distance contributions are universal, that is, they are the same in any inelastic reaction, whereas the short-distance pieces depend on only large scales and, therefore, can be evaluated using QCD perturbation theory. Because of this, single-inclusive cross sections offer unique possibilities to probe the structure of the initial hadrons in ways that are complementary to deeply-inelastic scattering. At the same time, they test the perturbative framework, for example, the relevance of higher orders in the perturbative expansion and of power-suppressed contributions to the cross section.

Of special interest is the case when the initial protons are polarized. At RHIC, one measures spin asymmetries for single-inclusive reactions, in order to investigate the spin structure of the nucleon \(^1\). A particular focus here is on the gluon polarization in the nucleon, \( \Delta g \equiv g^\uparrow - g^\downarrow \).
Figure 1. NLO spin asymmetry for \( \pi^0 \) production, using several GRSV polarized parton densities with different gluon polarizations.

measurements of \( A_{LL} \) at RHIC should give direct and clear information. The "error bars" in the figure are uncertainties expected for measurements with an integrated luminosity of 3/\( \text{pb} \) and beam polarization \( P=0.4 \). We note that PHENIX has already presented preliminary data \( ^8 \) for \( A_{LL} \). We also mention that the figure shows that at lower \( p_T \) the asymmetry is not sensitive to the sign of \( \Delta g \). This is related to the dominance of the \( gg \) scattering channel which is approximately quadratic in \( \Delta g \). In fact it can be shown that \( A_{LL} \) in leading-power QCD can hardly be negative at \( p_T \) of a few GeV \( ^9 \). One may obtain better sensitivity to the sign of \( \Delta g \) by expanding kinematics to the forward rapidity region.

Figure 2 shows predictions for the spin asymmetry \( A_{LL} \) for high-\( p_T \) jet production. The gross features are rather similar to the pion asymmetry, except that everything is shifted by roughly a factor two in \( p_T \). This is due to the fact that a pion takes only a certain fraction of \( \sim \mathcal{O}(50\%) \) of the outgoing parton's momentum, so that the hard scattering took place at roughly twice the pion transverse momentum. A jet, however, will carry the full transverse momentum of a produced parton.

We emphasize that PHENIX and STAR have presented measurements \( ^{10} \) of the unpolarized cross section for \( pp \rightarrow \pi^0 X \). These are well described by the corresponding NLO QCD calculations \( ^3,^8 \), providing confidence that the NLO pQCD hard-scattering framework is indeed adequate in the RHIC domain. This is in contrast to what was found in comparisons \( ^{11} \) between NLO theory and data for inclusive-hadron production taken in the fixed-target regime. We will turn to this issue next.
fall rapidly with increasing $x_{a,b}$, threshold effects become more and more relevant as the hadronic scaling variable $x_T \equiv 2p_T/\sqrt{S}$ goes to one. This means that the fixed-target regime with $3 \text{ GeV} \lesssim p_T \lesssim 10 \text{ GeV}$ and $\sqrt{S}$ of 20–30 GeV is the place where threshold resummations are expected to be particularly relevant and useful.

The resummation is performed in Mellin-$N$ moment space, where the logarithms $\alpha_s^k \ln^{2k} (1 - \xi^2)$ turn into $\alpha_s^k \ln^{2k}(N)$, which then exponentiate. For inclusive-hadron production, because of the color-structure of the underlying Born $2 \to 2$ QCD processes, one actually obtains a sum of exponentials in the resummed expression. Details may be found in 4. Here, we only give a brief indication of the qualitative effects resulting from resummation. For a given partonic channel $ab \to cd$, the leading logarithms exponentiate in $N$ space as

$$\hat{\sigma}_{ab \to cd}^{(\text{res})}(N) \propto \exp \left[ \frac{\alpha_s}{\pi} \left( C_g^A + C_g^B + C_g^C - \frac{1}{2} C_g^d \right) \ln^2(N) \right], \quad (4)$$

where

$$C_g^A = C_A = N_c = 3, \quad C_g^B = C_B = (N_c^2 - 1)/2N_c = 4/3. \quad (5)$$

This exponent is clearly positive for each of the partonic channels, which means that the soft-gluon effects will lead to an enhancement of the cross section. Indeed, as may be seen from Fig. 3, resummation dramatically increases the cross section in the fixed-target regime. The example we give is a comparison of NLO and NLL resummed predictions at $\sqrt{S} = 31.5$ GeV with the data of E706 14 at that energy. We have used the "KKP" set of pion fragmentation functions 15, and the parton distributions of 16.

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