Constraining Transversity and Nucleon Transverse-polarization Structure Through Polarized-proton Collisions at STAR

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Studies of jet and di-hadron production from polarized-proton collisions can expand current knowledge of nucleon transverse-polarization structure. In data collected in 2006 at $\sqrt{s} =$ 200 GeV, STAR observes for the first time in $p^{\uparrow}+p$ nonzero asymmetries from transversity coupled to Collins and di-hadron fragmentation functions. Measurements at 500 GeV allow sensitivity to different mixes of partonic subprocesses; and comparisons of all measurements at 200 and 500 GeV may enlighten theoretical questions concerning evolution, universality, and factorization-breaking in non-collinear formulations of pQCD. Results from analyses of STAR data collected in 2011 at $\sqrt{s} = 500$ GeV are presented, including first-ever measurements offering constraints on models involving gluon linear polarization.

1 Introduction

Azimuthal transverse single-spin asymmetries, A_{UT}, from polarized-proton collisions present a challenge and an opportunity. To account for nonzero A_{UT} from high-p_T hadroproduction (e.g. Ref. [1]) one is challenged to understand pQCD beyond the collinear formulation at leading twist [2]. By so doing, one gains the opportunity for insight into the transverse polarization structure of the nucleon.

Two approaches that can generate nonzero A_{UT} in pQCD are to formulate collinear pQCD to account for higher twist multi-parton correlators (twist-3 formalism) [3, 4] or to formulate pQCD to account for intrinsic transverse momentum dependence (TMD formalism) [5, 6]. In the twist-3 formalism one can obtain asymmetries, in principle, from both the parton distribution functions or the fragmentation functions (e.g. Refs. [7, 8]). Similarly, in the TMD formalism one can obtain asymmetries, in principle, from both the parton distribution functions (the so-called "Sivers effect") [5, 6] and the fragmentation functions, e.g. the so-called "Collins effect" [9]. Furthermore, it has been shown that the intrinsic transverse momentum integrals of the TMD functions are closely related to the twist-3 functions (e.g. Ref. [10]).

One avenue to enrich understanding of nucleon spin structure is through jet production from high-energy polarized-proton collisions [11]. By measuring the spin-dependent, azimuthal asymmetry in the jet production ($A_{UT}^{\sin\phi_S}$), one can access the twist-3 parton distribution function, sensitive to the Sivers function. Additionally, by measuring different spin-dependent, azimuthal modulations in the distribution of hadrons within a jet ($A_{UT}^{\sin(\phi_S-\phi_H)}$ or $A_{UT}^{\sin(\phi_S-2\phi_H)}$), one can gain sensitivity to transversity or gluon linear polarization coupling to spin-dependent Collins or "Collins-like" [12] fragmentation functions, respectively. Similarly to the Collins effect, one can also access transversity coupled to polarized "interference fragmentation functions" (IFF) through spin-dependent, azimuthal asymmetries in the relative orientation of two hadrons from the same parton (e.g. Ref. [13]). While IFFs survive in the leading-twist, collinear formulation of pQCD with factorization expected to hold, the Collins effect depends upon TMD-factorization that is broken, in general, for high-p_T hadroproduction [14]. Thus, by studying both Collins and IFF asymmetries for overlapping kinematics, one opens the possibility to enlighten deep theoretical questions, such as TMD factorization-breaking and universality.

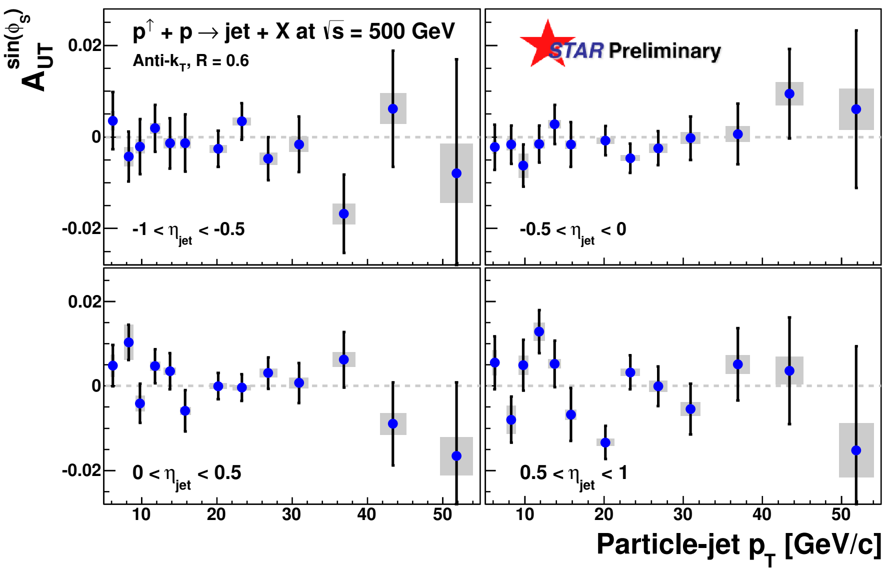

Figure 1: Inclusive jet azimuthal transverse single-spin asymmetries as a function of particle-jet transverse momentum for four bins of jet pseudorapidity relative to the polarized beam. Statistical uncertainties are shown by error bars and systematic uncertainties by error boxes. Measurements show no sign of large asymmetries and may suggest further constraints on the gluon Sivers function through the sensitivity of the twist-3 parton distribution function.

The STAR detector [15] at RHIC has seen the first signatures of transversity in polarized-proton collisions from charged-pion Collins [16] and IFF [17] asymmetries at $|\eta| < 1$ from 2.4 pb^{-1} at $\sqrt{s} = 200$ GeV collected in 2006. In 2011 STAR integrated 25 pb^{-1} of luminosity from $p^{\uparrow} + p$ at $\sqrt{s} = 500$ GeV with 53% polarization. This dataset allows the first measure of these asymmetries at $\sqrt{s} = 500$ GeV, including the first-ever measurement of the "Collins-like" asymmetry, with sensitivity to gluonic subprocesses enhanced relative to $\sqrt{s} = 200$ GeV. Comparison of all asymmetry modulations across $\sqrt{s} = 200$ and 500 GeV is expected to extend the current knowledge of these effects to broader kinematics as well as inform questions about the evolution of transversity and the TMD functions.

2 Analysis

The present data were collected with a minimum-bias trigger (VPDMB), requiring a coincidence in STAR's vertex position detector (VPD) [18], as well as with "jet-patch" triggers, requiring patches of energy in STAR's barrel (BEMC) and endcap (EEMC) electromagnetic calorimeters [15]. Jets are reconstructed using the "anti-k_T" algorithm [19] with a radius of 0.6 and utilize energy deposition in the BEMC and EEMC as well as charged-particle tracks from STAR's time projection chamber (TPC) [15].

Descriptions of the analysis techniques and simulation studies are given in Ref. [20]. The dominant systematic uncertainties arise from jets reconstructed at the detector level that fail to match to one at the parton-jet level. Additional systematic uncertainties come from the contamination of kaons, protons, and electrons to the charged-pion signal; trigger bias; the "leak-through" of competing effects coupling to non-uniform detector acceptance; uncertainties from calorimeter gains, efficiencies, and response to charged hadrons; tracking efficiency; and Monte Carlo simulation statistics. Measured asymmetries are corrected for smearing due to finite azimuthal-angle resolution.

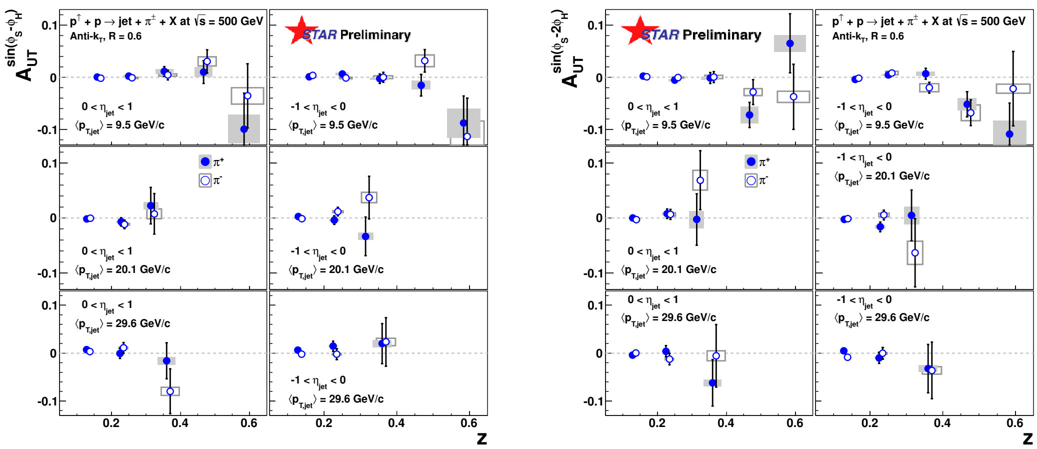

Figure 2: (left) Collins and (right) "Collins-like" asymmetries as a function of pion z for three bins of jet p_T and two bins of jet pseudorapidity relative to the polarized beam. Collins asymmetries are consistent with zero at low jet p_T, where gluonic subprocesses dominate, and are statistics limited at high jet p_T, where the best sensitivity to quark subprocesses is expected. The present "Collins-like" asymmetries should provide the first experimental constraints on model predictions utilizing linearly polarized gluons.

3 Results

In Fig. 1 the measured azimuthal asymmetries in the inclusive jet production are presented as a function of particle-jet p_T for four bins of jet pseudorapidity relative to the polarized beam. No large asymmetries are observed, consistent with expectation from measurements at $\sqrt{s}$ = 200 GeV [21, 22, 23] as well as model predictions [7]. The present data may suggest further constraints on the gluon Sivers function through the sensitivity of the twist-3 parton distribution function.

The left-hand panel of Fig. 2 shows Collins asymmetries as a function of $z = p_\pi/p_{jet}$ for three bins of jet p_T and two bins of jet psuedorapidity relative to the polarized beam. At low p_T, Collins asymmetries are expected to be quite small due to the prevalence of gluonic subprocesses [24], and this is consistent with the present measurement. For the higher two bins of jet p_T, quark-gluon scattering is expected to begin to dominate the underlying partonic cross section [24]. Thus, one may expect sensitivity to a nonzero Collins effect at higher p_T, however, the present data are statistics limited in this kinematic region. Analysis of STAR's high-statistics dataset at $\sqrt{s} = 200$ GeV, collected in 2012, will provide good sensitivity to effects from quark subprocesses in a region where nonzero signals are already observed [16, 25].

The right-hand panel of Fig. 2 shows the "Collins-like" asymmetries as a function of z for three bins of jet p_T and two bins of jet psuedorapidity relative to the polarized beam. Existing model predictions are unconstrained by measurement and suggest a maximum possible upper-limit of $\approx 2\%$ [11]. The present data fall well below this maximum with the best precision at lower values of z, where models suggest the largest effects may occur. Thus, the present data should allow for the first experimental constraints beyond the positivity bounds.

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