Measurement of Sivers Asymmetry for Di-jets at STAR in Polarized p+p Collisions at 200GeV

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STAR Collaboration is reporting measurement of transverse single spin asymmetry (TSSA) for di-jet produced in collisions of transversely polarized protons at RHIC at $\sqrt{s} = 200$ GeV. The measurement probes (Sivers) correlations between the transverse spin orientation of a proton and the transverse momentum directions of its partons. Measured TSSA are consistent with zero. It agrees with recent calculations basedon on non-zero HERMES results from DIS folded with contrabalancing ISI and FSI required to restore time reversal invariance, violated by postulated Sivers mechanism in p+p. With both beams polarized, the wide pseudorapidity ($-1 \leq \eta \leq +2$) coverage for jets permits separation of Sivers functions for the quark and gluon dominated kinematic regime.

1 Introduction

The decomposition of the proton's intrinsic spin among helicity preferences and orbital angular momentum of its quark and gluon constituents is a topic of intense interest [2] and ongoing experiments [3, 4, 5]. Parton orbital contributions are particularly difficult to measure, with one possible manifestation being the so-called Sivers effect [6]: a correlation of parton transverse momentum ($\vec{k}_T$) with the proton's spin ($\vec{s}_{\rm p}$) and momentum ($\vec{p}_{\rm p}$) directions, yielding $\langle \vec{s}_{\rm p} \cdot (\vec{p}_{\rm p} \times \vec{k}_T) \rangle \neq 0$. Such a three-vector correlation is allowed, without violating time reversal invariance, if orbital components of the proton's light-cone wave function combine with initial (ISI) and/or final-state interaction (FSI) contributions to the process of interest [7, 8].

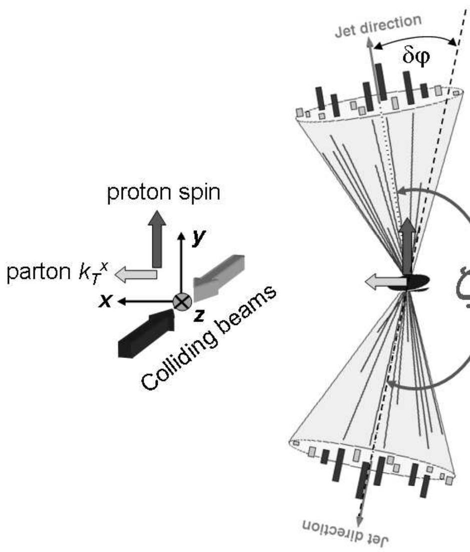

Figure 1: Sivers effect gives a spin dependent sideways kinematic boost to jet momenta. The spin dependent opening angle ζ is defined as $\pi + \delta\phi$ or $\pi - \delta\phi$ for spin direction up or down, respectively.

For colliding proton beams moving along the $\pm\hat{z}$-axis and vertically polarized along $\pm\hat{y}$, the Sivers effect gives a preferential sideways (along $\pm\hat{x}$) kinematic boost to jet momenta (see Fig.1), causing [9] a spin-dependent average deviation ($\delta\phi$) from 180° azimuthal jet opening angle. For colliding partons with different x_B values, there is

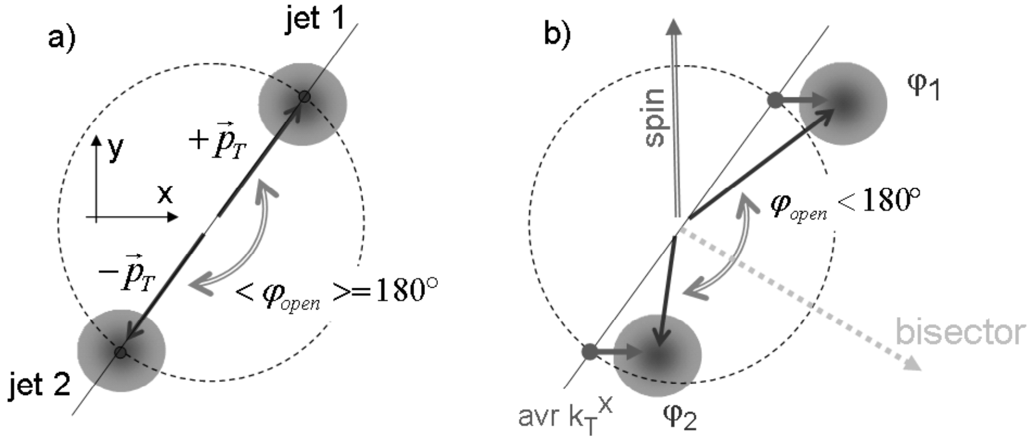

Figure 2: Simple M-C model of Sivers TSSA results with correlation of direction of di-jet bisector vector with the direction of proton spin. a) Random initial state $\vec{k}_T$ of scattered partons yields back-to-back configuration. b)A non-zero average transverse k_T^x of parton correlated with transverse polarization of initial proton leads to experimentaly measurable side boost of both jets.

an additional longitudinal boost of the jets that we exploit to separate high-x_B parton from low-x_B gluon Sivers functions.

2 Experimental results

We report measurements made in 2006 at RHIC with an integrated pp luminosity of 1.1 pb^{-1} sampled by the STAR detector [10]. The detector subsystems most critical to the present measurements are the barrel (BEMC) and endcap (EEMC) electromagnetic calorimeters [10], which provide full azimuthal (ϕ) coverage spanning pseudorapidities $|\eta| \leq 0.98$ and $1.08 \leq \eta \leq 2.0$, respectively. The EMC's are subdivided into towers that subtend small regions in $\Delta\eta$ and $\Delta\phi$. Digitized signals from the towers are summed in STAR trigger hardware over $\Delta\eta \times \Delta\phi \approx 1.0 \times 1.0$ "jet patches". The hardware (level 0) trigger used for the present measurements required a transverse energy (E_T) sum exceeding 4.0 GeV for at least one BEMC or EEMC jet patch, plus a summed (over the full EMC) $E_T^{tot} > 14$ GeV. The trigger further required coincident signals indicating a valid collision from forward ($3.3 \leq |\eta| \leq 5.0$) beam-beam counters (BBC) located at each end of the STAR detector [11]. These conditions were supplemented by a software (level 2) trigger that passed events that had at least two localized (to $\Delta\eta \times \Delta\phi = 0.6 \times 0.6$) EMC energy depositions, one with E_T exceeding 3.6 GeV and the other 3.3 GeV, with an azimuthal separation $\geq 60^\circ$.

In order to validate the off-line event analysis algorithm a simple M-C model generating events with non-zero Sivers TSSA has been constructed, as illustrated in Fig. 2. Two-parton scattering events were generated randomly with a uniform distribution in $\hat{\phi}_1$ (and initially with $|\hat{\phi}_2 - \hat{\phi}_1| = 180^\circ$) and a p_T distribution reproducing the p_T spectrum of experimentaly reconstructed di-jets. Each colliding parton was given a random initial-state transverse momentum drawn from a model $\vec{k}_T$ distribution centered at zero for the y-component, but with non-zero $\pm\langle k_T^x \rangle$ for the x-component (Fig. 2b), with the sign correlated with $\vec{s}_{\rm p} \times \vec{p}_{\rm p}$ to simulate the Sivers effect. The resulting vector sum $\vec{k}_T^{+z} + \vec{k}_T^{-z}$ was added to the initially thrown outgoing parton momenta $\vec{p}_{T,1}$ and $\vec{p}_{T,2}$ to deduce boosted azimuthal angles $\phi_{1,2}$. The magnitude of $\vec{K}_T$ smearing was adjusted to reproduce experimental width of di-jet opening angle ζ. These could then be further smeared with a resolution Gaussian of width $\sigma(\phi) = 6.3°$, deduced by comparing EMC-only jet reconstruction to the parent parton directions in a simulation utilizing the PYTHIA 6.205 event generator [12] and GEANT [13] modeling of the STAR detector response.

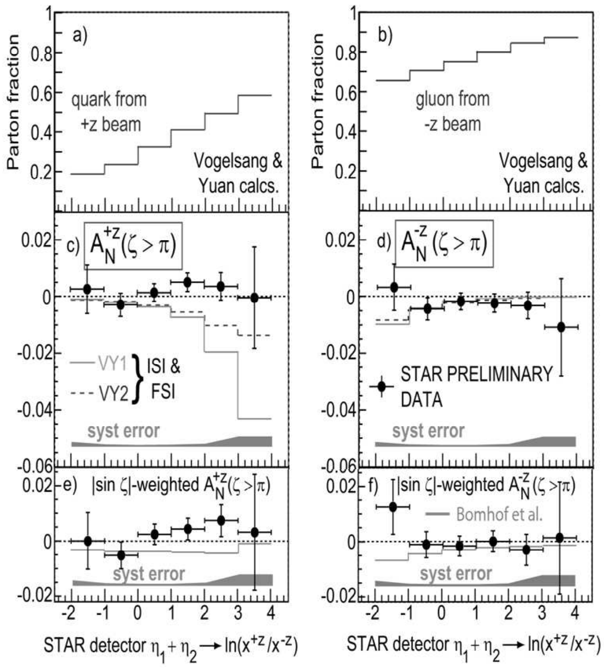

Figure 3: Measured and calculated asymmetries vs. di-jet pseudorapidity sum for $+\hat{z}$ (left) and $-\hat{z}$ (right) beams. (a,b): Fraction of the calculated di-jet cross section with a quark (gluon) from the $+\hat{z}$ ($-\hat{z}$) beam. (c,d): Unweighted asymmetries compared with pQCD calculations [14] (histograms). (e,f): Asymmetries for $|\sin\zeta|$-weighted yields, compared with calculations [14, 16] based on twist-3 quark-gluon correlations. We have reversed the sign of the calculated A_N to apply the Madison convention. Vertical (horizontal) bars on the data indicate statistical uncertainties (bin widths). The systematic error bands combine in quadrature the f uncertainty and the effect of multi-jet contributions to the ζ distribution. The systematic error bands exclude a $\pm 20\%$ beam polarization normalization uncertainty.

The measure of Sivers TSSA, A_N, is defined as:

$$A_N \overline{P} f = \frac{N_L - N_R}{N_L + N_R}$$

where N_L (N_R) is the di-jet yield for the bisector vector (see Fig. 2b) pointing to the left (right) with respect to direction of polarization of the proton. $\overline{P}$ is projection of beam polarization magnitude on the axis perpendicular to bisector axis. The factor $f = 0.85 \pm 0.07$ corrects for dilution of a parton-level asymmetry by the trigger-level ϕ resolution smearing. It was defined from simple M-C simulation described above.

In this paper we axtracted A_N using the cross ratio method to exploit azimuthal symmetry of the STAR detector and alternating polarization pattern of both colliding beams at RHIC.

The measured asymmetries, shown in Fig. 3c-e as a function of $\eta_1 + \eta_2$, are compared to calculations [14] for two models of quark Sivers functions fitted to SIDIS results [15]. Figure 3(e-f) compares measured and calculated [14] A_N with yields weighted by $|\sin\zeta|$ [16], as needed to connect to a more robustly interpretable gauge link structure [17], given the apparent breakdown of factorization for back-to-back dijets [18].

3 Conclusions

We report first measurement of Sivers TSSA for di-jets produced in proton-proton collisions. Integrated over the STAR EMC η acceptance and $|\zeta - 180°| \leq 68°$, the full analyzed sample yields 2.6×10^6 di-jets with average $A_N^{\pm z}$ values consistent with zero for both beams, within statistical uncertainties $\approx \pm 0.002$. From simple M-C model, these results probe Sivers $\langle k_T^x \rangle$ preferences as small as $\sim \pm 3$ MeV/c, or $\pm 0.2\%$ of the inferred rms width of the $k_T^{x,y}$ distributions. Appearent discrepancy with non-zero Sivers TSSA observed in DIS by HERMES has been attributed [14] to cancelation between ISI vs. FSI and u- and d-quark Sivers functions required in calculation of di-jet production in p+p.

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