Quark transverse asymmetry of the octet baryons

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Introduction

Burkardt interpreted a transversity based decomposition of the quark angular momentum that shows a correlation between the transverse spin and the angular momentum carried by quarks [1]. Since chiral-odd generalized parton distributions (GPDs) are sensitive to the transverse spin of quarks [2], they offer a framework to quantify this correlation in unpolarized hadrons. Specifically, the transverse distortion in parton distributions is characterized by the linear combination of chiral-odd GPDs that provides the baseline for the spin-orbit correlations.

This work presents Burkardt's relation, which interprets the transversity asymmetry of the quark total angular momentum $\langle \delta^x J^x_q \rangle_B$. The diquark spectator model is used to study the transversity asymmetry inside the low-lying octet baryons B. Firstly, we present the results for the proton p and their comparison with available data to validate the model. The calculation is then extended to the hyperon Ξ^0, to emphasize the variation arising in the contribution of the u quark flavor to the transversity asymmetry of the quark total angular momentum.

Diquark Spectator Model

In the spectator diquark model, a baryon is considered as a two-body system, comprised of an active quark q that participates actively in the interaction process, and the remaining two quarks are treated as a single entity, termed as a spectator diquark. Spectator diquarks can be scalar or axial-vector diquarks depending on the spin. Further, these axial-vector diquarks are categorized as isoscalar and isovector spectator diquarks to achieve a realistic flavor analysis. In general, the light-cone wave function for a scalar $\mathfrak{s}$ and axial-vector $\mathfrak{a}$ diquark can be defined as

$$\psi^{\lambda_B}_{\lambda_q}(x, \mathbf{k}_\perp) = \sqrt{\frac{k^+}{(p-k)^+}} \frac{\bar{u}\mathcal{Y}_{\mathfrak{s}} U}{k^2 - m_q^2}, \quad (1)$$

$$\psi^{\lambda_B}_{\lambda_q \lambda_{\mathfrak{a}}}(x, \mathbf{k}_\perp) = \sqrt{\frac{k^+}{(p-k)^+}} \frac{\bar{u}\epsilon^*_\mu \mathcal{Y}^\mu_{\mathfrak{a}} U}{k^2 - m_q^2}, \quad (2)$$

respectively. u (U) is the spinor of quark (baryon) with k (p) and λ_q (λ_B) as its four-vector momentum and helicity. ϵ_μ is the polarization vector of an axial-vector diquark with helicity $\lambda_{\mathfrak{a}}$ and m_q is the quark mass.

Transversity Asymmetry

The projection operator $P_{\pm\hat{x}}$ on the eigenstate of transverse spin commutes with $\gamma^{0,y,z}$, as a result of which the components of energy momentum tensor neither $T^{0y}_{q,+x}$ nor $T^{0y}_{q,-x}$ merge between transversity in the x direction with respect to transversity and they can be decomposed as

$$T^{0y}_{q,\pm x} = \frac{i}{2}\bar{\psi}[\gamma^0 D^y + \gamma^y D^0] P_{\pm\hat{x}} \psi = \frac{1}{2}(T^{0y}_q \pm \delta^x T^{0y}_q), \quad (3)$$

where $\bar{\psi}$ and ψ are quark field operators. On the similar lines, the dependence of J^x on the quark tranversity is defined by

$$J^x_{q,\pm x} = \frac{1}{2}(J^x_q \pm \delta^x J^x_q), \quad (4)$$

where

$$\delta^x J^x_q = \int d^3x (\delta^x T^{0z} y - \delta^x T^{0y} z)) = \frac{1}{2}\int d^3x \bar{\psi}[-(\sigma^{x0}\overleftrightarrow{D}^z + \sigma^{xy}\overleftrightarrow{D}^0)y + (\sigma^{x0}\overleftrightarrow{D}^y + \sigma^{xy}\overleftrightarrow{D}^0)z]\psi. \quad (5)$$

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The operator written in this equation resembles with nonforward matrix elements of light-like correlation functions of the tensor current, which can be parameterized in terms of the gravitational form factors (GFFs) A_{T20}, $\bar{A}_{T20}$, B_{T20} and $\bar{B}_{T21}$ with the transversity density as

$$\begin{aligned}\langle p'|\bar{\psi}\sigma^{\lambda\mu}\gamma_5 i\overleftrightarrow{D}^{\nu}\psi|p\rangle &= \bar{u}\sigma^{\lambda\mu}\gamma_5 u\bar{p}^{\nu}A_{T20}(t)\\ &+\frac{\epsilon^{\lambda\mu\alpha\beta}\Delta_{\alpha}\bar{p}_{\beta}\bar{p}^{\nu}}{M^2}\bar{u}u\bar{A}_{T20}(t)\\ &+\frac{\epsilon^{\lambda\mu\alpha\beta}\Delta_{\alpha}\bar{p}^{\nu}}{M^2}\bar{u}\gamma_{\beta}uB_{T20}(t)\\ &+\frac{\epsilon^{\lambda\mu\alpha\beta}\bar{p}_{\alpha}\Delta^{\nu}}{M^2}\bar{u}\gamma_{\beta}u\bar{B}_{T21}(t),\end{aligned} \quad (6)$$

with $\lambda = x$, $\mu = 0$, $\nu = z$ and $\lambda = x$, $\mu = 0$, $\nu = y$, respectively [1]. Therefore, in an unpolarized baryon target, the expectation value of the trannsversity asymmetry in terms of GFFs is given by

$$\langle \delta^x J_q^x \rangle_B = \frac{A_{T20}(0) + 2\bar{A}_{T20}(0) + B_{T20}(0)}{2}. \quad (7)$$

The explicitly expressions of GFFs in the overlap form of light-cone wave functions can be found in Refs. [3, 4].

Results and Discussion

The numerical parameters used to calculate the contribution of the light quark flavor $q(=u,d)$ of proton p (uud) and a hyperon Ξ^0 (ssu) to the expectation value of transversity asymmetry have been taken from Ref. [4]. Firstly, the quantity $\langle \delta^x J_q^x \rangle_p$ for the proton has been calculated and we found that $\langle \delta^x J_u^x \rangle_p = 0.77$ and $\langle \delta^x J_d^x \rangle_p = 0.22$. These values are compared with the harmonic oscillator (HO) model [5], chiral quark soliton model (CQSM) [6], basis light-front quantization (BLFQ) [3], light-front constituent quark model (LFCQM) [7], and light-front chiral quark-soliton model (LFχQSM) [7]. We found that the quantity $\langle \delta^x J_q^x \rangle_p$ shows model-dependent results, with a broader spread in observed values for the u quark flavor than the d quark flavor of the proton among different model predictions. Further. in our model calculations, the contribution of the u quark flavor to $\langle \delta^x J_u^x \rangle_{\Xi^0}$ comes out to be 0.30, representing 61% reduction compared to its corresponding value in the proton.

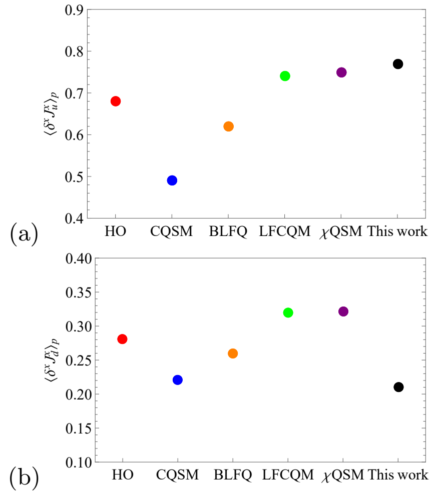

FIG. 1: Comparison of the value of transversity asymmetry $\langle \delta^x J_q^x \rangle_p$ of (a) u and (b) d quark flavors of proton with available model predictions [3, 5–7].

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