Double spin azimuthal asymmetries $A_{LT}$ and $A_{LL}$ in semi-inclusive DIS

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Abstract. Within the LO QCD parton model of SIDIS, $\langle N! hX \rangle$, with unintegrated quark distribution and fragmentation functions, we study the transverse momentum and azimuthal dependencies of the double spin asymmetries $A_{LT}$ and $A_{LL}$. For later we include $O(k^2 = Q)$ kinematic corrections, which induce an azimuthal modulation of the asymmetry, analogous to the Cahn effect in unpolarized SIDIS. We show that a study of these asymmetries allows to extract the transverse momentum dependence of the unintegrated helicity distribution function $g_{1L}(x;k^2)$ and $g_{1T}(x;k^2)$.

This report is based on research published in [1, 2], where predictions are given for ongoing COMPASS, HERMES and JLab experiments.

Keywords: SIDIS, transverse momentum, double spin azimuthal asymmetries

PACS: 13.88.+e, 13.60.-r, 13.87.Fh, 13.85.Ni

Following Ref. [3], we consider the polarized SIDIS processes at twist-two in the parton model with transverse momentum dependent distribution and fragmentation functions (TMD DFs and FFs), taking into account $O(k^2 = Q)$ kinematical correction for $A_{LL}$ asymmetries (so called Cahn effect [4]).

The cross section for polarized SIDIS can be written as:

$$
\frac{d^5\sigma^{pol}}{dxdydzd^2P_{hT}} = \frac{2\alpha_s^2}{x y^2 s} \lambda (S_L H_{g1L} + S_T H_{g1T}) + \cdots : \quad (1)
$$

In the case of longitudinally polarized target, where longitudinal (according to the laboratory setup) refers to the initial lepton direction, one get a transverse – with respect to the $\gamma$ direction – spin component:

$$
S_T = S\sin\theta_T; \sin\theta_T = \frac{4M^2 x^2}{Q^2 + 4M^2 x^2} \frac{1}{1 - y} \frac{M^2 x y^2}{Q^2}, \frac{2 M x^2}{Q} \frac{1}{Q} \quad (2)
$$

This component gives contributions of order $M=Q$.

We assumes a simple factorized and gaussian behavior of the involved TMD PDFs and FFs

$$
f_1^q(x;k^2) = f_1^q(x) \frac{1}{\pi \mu_0^2} \exp \frac{k^2}{\mu_0^2}; D_q^h(x;p^2) = D_q^h(x) \frac{1}{\pi \mu_D^2} \exp \frac{p^2}{\mu_D^2} \quad (3)
$$

$$
g_{1L}^q(x;k^2) = g_{1L}^q(x) \frac{1}{\pi \mu_1^2} \exp \frac{k^2}{\mu_1^2}; g_{1T}^q(x;k^2) = g_{1T}^q(x) \frac{1}{\pi \mu_2^2} \exp \frac{k^2}{\mu_2^2} \quad (4)
$$
Following Ref. [5] we use $\mu_0^2 = 0.25 \text{ (GeV}/c)^2$, $\mu^2_D = 0.20 \text{ (GeV}/c)^2$ while we consider $\mu_1^2$ and $\mu_2^2$ as free parameters.

For the longitudinally polarized target we consider the $P_{hT}$ dependence of the double longitudinal spin asymmetry

$$A_{LL}(x,y;z;P_{hT}) = \frac{\int_{0}^{2\pi} d\phi_h [d\sigma \frac{1}{1} d\sigma \frac{1}{1}]}{\lambda S_L \int_{0}^{2\pi} d\phi_h [d\sigma \frac{1}{1} + d\sigma \frac{1}{1}]}; \quad (5)$$

and the $\cos \phi_h$ weighted asymmetry, defined as

$$A_{LL}^{\cos \phi_h}(x,y;z;P_{hT}) = \frac{2\int_{0}^{2\pi} d\phi_h [d\sigma \frac{1}{1} d\sigma \frac{1}{1}] \cos \phi_h}{\lambda S_L \int_{0}^{2\pi} d\phi_h [d\sigma \frac{1}{1} + d\sigma \frac{1}{1}]} \quad (6)$$

Similarly, we define the asymmetry for transversely polarized target

$$A_{LT}^{\cos \phi_h \phi_S}(x,y;z;P_{hT}) = \frac{\int_{0}^{2\pi} d\phi_h \phi_S [d\sigma \frac{1}{n} d\sigma \frac{1}{#}] \cos \phi_h \phi_S}{\lambda S_T \int_{0}^{2\pi} d\phi_h \phi_S [d\sigma \frac{1}{n} + d\sigma \frac{1}{#}]}; \quad (7)$$

and also asymmetry weighted with $S_T = (P_{hT} \cdot M) \cos (\phi_h \phi_S)$ [6]

$$A_{LT}^{P_{hT} \cdot M \cos \phi_h \phi_S}(x,y;z;P_{hT}) = \frac{\int_{0}^{2\pi} dP_{hT} \phi_S [d\sigma \frac{1}{n} d\sigma \frac{1}{#}] P_{hT} \cdot M \cos \phi_h \phi_S}{\lambda S_T \int_{0}^{2\pi} dP_{hT} \phi_S [d\sigma \frac{1}{n} + d\sigma \frac{1}{#}]}; \quad (8)$$

As examples of our results we present here some plots from [1,2]. According to the range covered by the setups of the experiments we use the following cuts which are aimed to enhance asymmetries:

- COMPASS: positive ($h^+$), all ($h$) and negative ($h^-$) hadron production, $Q^2 > 1 \text{ (GeV}/c)^2$, $W^2 > 25 \text{ GeV}^2$, $0.1 < x < 0.6$, $0.5 < y < 0.9$ and $0.4 < z < 0.9$
- HERMES: $\pi^+$, $\pi^0$ and $\pi$ production, $Q^2 > 1 \text{ (GeV}/c)^2$, $W^2 > 10 \text{ GeV}^2$, $0.1 < x < 0.6$, $0.45 < y < 0.85$ and $0.4 < z < 0.7$
- JLab at 6 GeV: $\pi^+$, $\pi^0$ and $\pi$ production, $Q^2 > 1 \text{ (GeV}/c)^2$, $W^2 > 4 \text{ GeV}^2$, $0.2 < x < 0.6$, $0.4 < y < 0.85$ and $0.4 < z < 0.7$.

Concerning the usual integrated distribution and fragmentation functions we use the LO GRV98 [7] unpolarized and the corresponding GRSV2000 [8] polarized (standard scenario) DFs, and Kretzer [9] FFs.

In the left panel of Fig. 1 the $P_{hT}$-dependence of $A_{LL}$ asymmetries are presented. Notice that they are leading-twist quantities, not suppressed by any inverse power of $Q$. Although our numerical estimates are based on the gaussian factorization ansatz, Eqs.
The right panel of Fig. 1 we present the
3, 4, we expect them to have a more general interpretation and information content. In
uous and deuteron – dashed line targets, for COMPASS.

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dashed lines. Right panel: predicted dependence of $A_{LL}$ on $h_T$, for COMPASS.

Using the Lorentz invariance relations [10] and Wandzura-Wilczek approximation [11]
the following relation [6] has been derived

$$ \frac{1}{2M^2} g_{1T}^{q}(x; k_T^2) = \frac{\mu_1^2}{2M^2} \frac{1}{2} \int \frac{d^2 k_T}{(2\pi)^2} \sqrt{2} \frac{k_T^2}{M^2} g_{1T}^{q}(x; k_T^2) $$

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which allows to express $g_{1T}^{q}(x; k_T^2)$ through the well known integrated helicity distributions.

In the left panel of Fig. 2 the predictions for $A_{LT}^{(P_{LT}; M)} \cos(\phi_h \cdot \phi_z)$ asymmetry dependence on $x, y$ and $z$ are shown for production of positive ($h^+$), all charged ($h$) and negative ($h^-$) hadrons at COMPASS. In the right panel of Fig. 2 we present the predicted dependence of $A_{LT}^{\cos(\phi_h \cdot \phi_z)}$ on $x, y$ and $z$ with $P_{LT, min} = 0.5$ GeV/c for proton – continuous and neutron – dashed line targets, for COMPASS.

The measurement of discussed asymmetries will allow

- to extract the $k_T$-dependence of TMD DFs,
• to verify the self-consistency of the leading order QCD picture of polarized SIDIS,
• to check the validity of Lorentz invariance relations,
• perform ‘global’ phenomenological analysis by simultaneous extraction of TMD DF’s parameters from experimental data taking into account the general positivity constraints [15] for TMD DFs.

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