Polarized SIDIS: comment on purity method for extraction of polarized quark distributions

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Abstract

The role of hadronization mechanism in polarization phenomena in semi inclusive deep inelastic scattering (SIDIS) and a purity method for extraction of polarized distribution functions are discussed. According to the Monte Carlo (MC) event generator, on which this method is based, hadrons can be produced via quark (diquark) fragmentation or light cluster decays. In contrast, the purity method assumes that only quark fragmentation gives contribution to hadron production in the current fragmentation region. The ignorance of contributions from diquark fragmentation and cluster decays to asymmetry can be source of incorrect values of polarized quark distributions extracted by the purity method.

The investigation of deep inelastic scattering (DIS) of leptons is an excellent source to study the internal structure of nucleon. We know with good precision the unpolarized parton distribution functions. Many efforts has been done to investigate also the polarized parton content of nucleon. In this case, for example, to separate the individual polarized parton distributions in the LO we still need more data ($g_1$ measurement at very high $Q^2$, or asymmetry measurements in neutrino DIS on polarized target) or some additional input like information from hyperon $\beta$-decay. Experimental progress in recent years allows to investigate SIDIS. There is hope that, for example, the measurement of different hadron production asymmetries on proton and neutron targets will allow a further flavor separation of polarized quark distributions.

Recently the new preliminary data from HERMES on quark flavor separation has been presented [2]. The LO analysis of semi inclusive DIS has been done by using the purity method and suggests that “the strange sea appears to be positively polarized” in contrast to generally accepted negatively polarized strange sea scenario at LO (see discussion in [3]). An “explanation” of HERMES result of a positively polarized strange sea is

*The main idea of this note has been presented in [1].
The idea is in transverse momentum dependence of polarized photon-gluon fusion process $\gamma^* g \rightarrow q\bar{q}$. In my opinion this explanation can not be accepted by two reasons. First, the quantity $g_1^{\gamma^* g \rightarrow q\bar{q}}$ for $q = s$ can not be interpreted as a strange see contribution to nucleon spin. Second, HERMES made a LO analysis of the measured asymmetries.

It is evident that theoretical description of SIDIS is much more complicated than DIS due to our poor knowledge of nonperturbative hadronization mechanism. Traditionally one distinguishes two regions for hadron production: the current fragmentation region, $x_F > 0$ and the target fragmentation region, $x_F < 0$. The common assumption is that when selecting hadrons in the current fragmentation region and imposing a cut $z > 0.2$ we are dealing with the quark fragmentation.

To make flavor decomposition into polarized quark distributions the purity method has been used in the HERMES analysis [2]. In the LO approximation the virtual photon asymmetry for hadron $h$ production is given by

$$A_1^h \simeq \sum_q e_q^2 \Delta q(x) \int_{z_{\text{min}}}^1 dz D_q^h(z) \sum_q e_q^2 q(x) \int_{z_{\text{min}}}^1 dz D_q^h(z). \quad (1)$$

This equation can be rewritten in the form

$$A_1^h \simeq \sum_q P_h^q(x) \frac{\Delta q(x)}{q(x)}, \quad (2)$$

where the purity, $P_h^q(x)$, is defined as

$$P_h^q(x) = \frac{e_q^2 q(x) \int_{z_{\text{min}}}^1 dz D_q^h(z)}{\sum_{q'} e_{q'}^2 q'(x) \int_{z_{\text{min}}}^1 dz D_q^h(z)}. \quad (3)$$

and calculated using an unpolarized MC event generator LEPTO [5]. Then, using measured asymmetries for different hadrons one can find $\Delta q(x)$ by solving Eq. (3). The main assumption of this method is that all hadrons in the current fragmentation region with $z > 0.2$ are produced from the quark fragmentation and there is no additional terms in both the numerator and the denominator of Eqs. (1) and (2).

However, this assumption fails for moderate energies of current fixed target experiments. In LEPTO generator hadronization is performed by JETSET [6] program which is based on Lund fragmentation model. In this program there is a pointer which shows the origin of produced hadrons. They can be originating from the quark or target remnant diquark fragmentation or from small mass cluster isotropic decay.

Let us consider a sample of generated with LEPTO events for HERMES energy and select hadrons in the current fragmentation region. The fraction of events with hadrons produced via quark fragmentation,

$$F_q = \frac{N_{\text{hadron}}(\text{from quark fragmentation})}{N_{\text{hadron}}(\text{tot})},$$

is presented in Fig. 1 for different hadrons as a function of $z$. As one can see this fraction has a weak dependence on $z$ and is less than one even at large values of $z$. With additional cut on the final hadron system mass, $W > 6\text{GeV}$ this fraction becomes higher, but it is still about 20% less than one. From this consideration I conclude that even if data
Figure 1: Fraction of hadrons originating from quark fragmentation. Full line – hadrons are selected with cuts $x_F > 0$ and $z > 0.2$, dashed line – additional cut $W > 6\text{GeV}$ is also imposed.

on asymmetries show little dependence on $z$ this doesn’t mean that we deal with the independent quark fragmentation.

Thus, the assumption that hadrons in the current fragmentation region are produced only via quark fragmentation is not valid in the Lund model and purities obtained with LEPTO generator include contributions from the target remnant and cluster fragmentation. Taking into account these contributions the SIDIS cross section in general can be expressed as

$$d\sigma^h_p \propto \sum_q [q(x)D^h_q(z) + M^{h/p}_q(x,z)].$$

(4)

The last term has to be considered as contribution from fracture functions introduced in [7]. The same holds also for polarized case. Then, Eq. 4 for virtual photon asymmetry is modified:

$$A^h_{1p} = \frac{\sum_q [\Delta q(x)D^h_q(z) + \Delta M^{h/p}_q(x,z)]}{\sum_q [q(x)D^h_q(z) + M^{h/p}_q(x,z)]}.$$  

(5)

The additional contributions from diquark fragmentation and other sources arise in numerator and denominator.

To investigate the stability of purity method the following MC exercise has been done. Using PEPSI polarized MC event generator [8] the sample of $10^8$ SIDIS events has been generated at HERMES energy for each relative polarization state of beam and target. The GRSV2000 LO (standard scenario) [9] polarized and corresponding GRV98 LO [10] unpolarized distribution functions have been used. The events with $\pi^+, \pi^-, K^+, K^-, h^+$ and $h^-$ (here $h$ stands for hadrons without type identification) in the current fragmentation region with $x_F > 0$ and $z > 0.2$ have been selected. It is known that unpolarized data are well described by MC event generator (denominator in Eq. 5). In contrast, nothing is known about polarized fracture functions $\Delta M^{h/p}_q(x,z)$ (numerator in Eq. 5). As an
example, the asymmetry

\[ A^{\text{obs}}_h = \frac{N^\uparrow\downarrow_h - N^\uparrow\uparrow_h}{N^\uparrow\downarrow_h + N^\uparrow\uparrow_h} \]

is calculated under two different assumptions for numerator:

- **Model 1**: all selected generated events gives contribution into numerator. In this case \( \Delta M_{q/h/p}^{h/p}(x, z) \propto \Delta q(x) \).

- **Model 2**: only hadrons from the quark fragmentation gives contribution into numerator \((\Delta M_{q/h/p}^{h/p}(x, z) = 0)\).

Then, the purities are calculated using unpolarized MC sample and Eq. 2 is solved. Reconstructed polarized distributions are presented in Fig. 2. As one can see the two models give very different results. Of course, the second model has to be considered as an extreme example which only was chosen to demonstrate instability of purity method. In particular, with negative input for polarized strange sea distribution the Model 2 leads to positive \( \Delta s \).

![Figure 2: Reconstructed by purity method polarized quark distributions as a function of \( x_{Bj} \): empty triangles – Model 1, full triangles – Model 2, solid line – the input distribution.](image)

Recently the importance of target remnant effects in SIDIS has been pointed out in many articles [11]-[14]. In [12] the model for \( \Lambda \) hyperons longitudinal polarization in SIDIS has been developed. This model takes into account that at moderate energies of fixed target experiments according to **LEPTO** event generator \( \Lambda \) hyperons are mainly originating from target remnant diquark fragmentation even in the current fragmentation region.
Our model is able to describe all existing data on Λ hyperons longitudinal polarization in SIDIS. Within this model the NOMAD data [15] on Λ hyperons longitudinal polarization imply that the strange quarks inside the nucleon has opposite polarization to that of struck valence quark.

In conclusion, I have demonstrated that due to additional sources of hadrons in the current fragmentation region the purity method can not be accepted as a precise tool for extraction of polarized quark distribution. Within this method the ignorance of contributions from diquark fragmentation and cluster decays to asymmetry can bring to incorrect conclusions about light sea polarization. At least, the uncertainties due to these effects have to be included into theoretical systematic errors in extracted by purity method polarized quark distributions.

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