# Subleading-twist effects in single-spin asymmetries in semi-inclusive deep-inelastic scattering on a longitudinally polarized hydrogen target

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It has been known for some time now that the nucleon is made of constituents: quarks and gluons. Hence it is a composite particle and not an elementary particle. What is not or not so well known is the distribution of these quarks and gluons inside the nucleon and how their interplay causes all the various properties of the nucleon. In particular one aspect of the nucleon – its spin – has caused "headaches" for many, theorists and experimentalists alike. It could be viewed as its *intrinsic rotation* much like a spinning ball. The quest for the answer to the question of how the various constituents conspire to yield the spin of the proton, $1/2\hbar$, gave inspiration for many experiments around the world. The Hermes experiment at Desy has been build to shed light on exactly that question. It uses the (polarized) electron beam of Hera, a storage ring for electrons and protons. Hermes also has polarized targets which are bombarded by the electrons of the beam. The energy of the beam electrons is large enough to break up a target nucleon. The fragments of the nucleon will then form new particles, mostly pions, which consequently can be detected with the Hermes spectrometer. In this way one is able to obtain information about the constituents of the nucleon and, e.g. with electrons and nucleons both polarized, also about the spin of these constituents. This has been done at Hermes but it is not the story of this measurement. Here we rather look where all the produced particles go when only the target is polarized but not the electron beam. It should be noted that it is not the electron itself that hits one of the constituents and knocks it out. When the electrically charged electron approaches the nucleon it "feels" the electro-magnetic fields of the *charged* constituents of the nucleon. It will hence be deflected. But no action without reaction: the constituent as well will be deflected. It absorbs the energy and momentum that is necessary to balance the change in energy and momentum of the electron. In a quantum-field-theoretical approach this energy and momentum is transferred via a virtual photon, the mediator of the electromagnetic force in the theory of Quantum Electrodynamics. As only charged particles are involved we will from now on forget about the gluons and only concentrate on quarks inside the nucleon.

A few years ago the Hermes experiment discovered that hadrons produced in semi-inclusive deep-inelastic scattering events are not distributed uniformly in the azimuthal angle around the exchanged virtual photon direction. They rather prefer certain directions depending on the spin of the nucleon. Let's have a look at a semi-inclusive scattering event as described above. In Fig. 1 one can see, schematically, the incoming and outgoing lepton (**l** and **l**), and the virtual photon $\gamma^*$ (**q**) that probes the nucleon. The direction $\mathbf{P}_h$ of one of the produced hadrons is also shown. All these vectors don't have to lie in one plane. In fact, one can define a plane that includes the lepton and the virtual photon momenta, but also a plane spanned by the momenta of the virtual photon and the outgoing hadron. The distribution of produced hadrons is then measured as a function of $\phi$, the azimuthal angle between the lepton scattering plane and the hadron production plane. What Hermes had found is that the hadrons prefer to go to one side of the lepton scattering plane ($0 < \phi < \pi$) rather than to the other side.

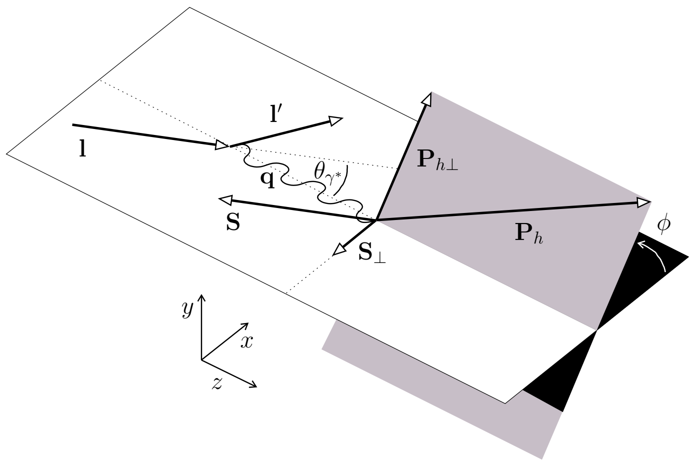


FIG. 1: The definitions of the azimuthal angle $\phi$ of the hadron production plane, relative to the plane containing the momentum $\boldsymbol{l}$ ($\boldsymbol{l'}$) of the incident (scattered) lepton, the polar angle $\theta_{\gamma^*}$ between the virtual photon and the incoming lepton directions, and of the transverse component $\boldsymbol{S}_\perp$ of the target spin $\boldsymbol{S}$ with respect to the photon direction $\boldsymbol{q} \equiv \boldsymbol{l} - \boldsymbol{l'}$.

In the theory of semi-inclusive deep-inelastic scattering there is space for such a behavior. The azimuthal distribution can even depend on the polarization of the target with respect to the exchanged virtual photon. As the direction of the virtual photon is in general different for different events, experimentally one can not polarize the nucleons along that direction. The next best solution is to polarize nucleons along the incoming lepton beam axis. That this is not such a bad approach can be seen in the fact that the cosine of the angle $\theta_{\gamma^*}$ between the incoming lepton and the virtual photon is almost unity: the lepton and the photon are basically collinear. However, there is a small component of the nucleon polarization that is transverse to the photon direction when the nucleon is longitudinally polarized (see Fig. 1). This component is proportional to $\sin\theta_{\gamma^*}$ and at Hermes can be up to 15%. It has been speculated for some time already that a transverse polarized nucleon can be the cause for preferred hadron directions and the Hermes result created a lot of excitement because most of the interpretations connected the observation to the transverse component of the nucleon spin. This would have opened the door to quark distributions in the nucleon that are presently unknown: the distribution of transversely polarized quarks and the distribution of unpolarized quarks in a transversely polarized nucleon.

But can't the longitudinal component of the nucleon spin, which as seen before is the dominating component, be also responsible for such an asymmetric distribution of hadrons? It can be. However, such a mechanism is usually suppressed compared to the mechanisms mentioned for transversely polarized nucleons. It is a *subleading-twist* effect compared to the *leading-twist* effect caused by transversely polarized nucleons. However, in this case the question arises which of the two suppressions is stronger: the subleading-twist suppression of the longitudinal spin asymmetry, or the $\sin\theta_{\gamma^*}$ suppression of the transverse component of the spin.

One way to find that out is to measure the azimuthal distribution of hadrons on nucleons that are transversely polarized with respect to the lepton direction. Now the transverse component of the spin is not any longer suppressed. Such a measurement can be used to subtract the contribution of the transverse component in case the target is polarized longitudinally with respect to the lepton direction since the suppression factor ($\sin\theta_{\gamma^*}$) can be calculated for each event.

This is exactly what HERMES has done. In 2002 and 2003 it collected enough data on a transversely polarized hydrogen target in order to extract the contribution from the transverse spin component for a longitudinally polarized hydrogen target. The result can be seen in Fig. 2 where the measured azimuthal asymmetry in the hadron distribution on longitudinally polarized hydrogen is shown (open triangles) as well as the two contributions stemming from either the longitudinal spin component (red) or the transverse spin component (open squares).

As one can see the subleading-twist contribution coming from the longitudinal spin component dominates, at least for positive pions, the measured asymmetries on longitudinally polarized hydrogen. Moreover the contribution from the transverse spin component is only a small "correction" of the measured longitudinal asymmetry. This shows that subleading-twist effects can a priori not be neglected since, although formally suppressed, they may be sizeable. The observed asymmetric distribution of produced hadrons on a longitudinally polarized hydrogen target can therefore not be explained by the distribution of unpolarized or transversely polarized quarks inside transversely polarized nucleons.

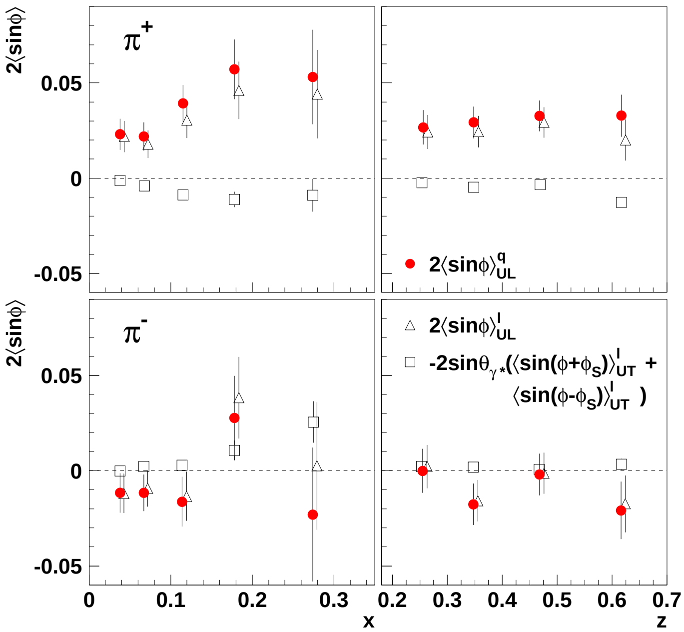


FIG. 2: The various asymmetries appearing in the measurement of single-spin asymmetries on a longitudinally polarized hydrogen target for charged pions as functions of $x$ and $z$. The open symbols are the measured asymmetries. The asymmetries from a transversely polarized target are scaled by $-\sin\theta_{\gamma^*}$ according to their contribution to the measured longitudinal asymmetries. The closed symbol is the subleading-twist contribution to the measured asymmetries on a longitudinally polarized hydrogen target. The triangles are slightly shifted horizontally for distinction.