Transversity in two-hadron fragmentation

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Summary

The interaction between quarks and gluons is successfully described by the theory of Quantum Chromodynamics (QCD). However, this by no means implies that we understand how these particles behave inside the proton. In fact, we don't even know how the confinement of quarks in hadrons can be calculated within the framework of QCD. Another property of the proton that we do not yet fully understand is its spin. The proton has spin $\frac{1}{2}$ and it should be possible to describe this total proton spin in terms of the dynamics of its constituents. In the 80s we have learned that not only the spin of the quarks is responsible for the proton spin. At present, it is well-known that the proton has a rich internal structure and that also the spin of the gluons and the orbital angular momentum of both the quarks and the gluons can contribute to the spin of the proton, which is reflected in the helicity sum rule, Eq. 1.2. In this equation, the first term ($\frac{1}{2}\Delta\Sigma$) represents the helicity of the quarks, which account for about 30% of the proton spin, i.e., $\frac{1}{2}\Delta\Sigma \sim 30\%$. However, the size of the other contributions to the total proton spin, given in Eq. 1.2, is still largely unknown. This is caused by the fact that it is difficult to isolate these contributions experimentally.

The type of experiments that are used to study the internal spin structure of the proton are polarized deep-inelastic scattering experiments. By polarizing the proton and varying the polarization direction (longitudinally or transversely with respect to the lepton beam), the proton can be prepared in different ways, both giving different insights into its internal spin structure. The contributions to the helicity of the proton, expressed in Eq. 1.2, can be studied when the proton is longitudinally polarized. When the proton is transversely polarized, the contributions of the constituents to the total spin are reflected in the transverse-spin sum rule, Eq. 1.4. This equation clearly shows an advantage of studying the spin structure of a transversely polarized proton, as in this case there are less contributions to consider, i.e., there is no contribution from transversely polarized gluons to the total proton spin. Therefore, it is easier to disentangle the contributions to the proton spin when the proton is transversely polarized. The only contributions come from the angular momenta of the quarks and gluons and the quark transversity distribution function h_1.

The transversity distribution function (transversity) describes the distribution of transversely polarized quarks inside a transversely polarized proton. At leading order in M/Q, i.e., at leading twist, transversity is the only missing distribution function needed to describe the quark structure

of the nucleon. Also, the first moment of the transversity distribution function can be related to the tensor charge of the nucleon, for which predictions are available from Lattice QCD.

In this thesis, the spin structure of transversely polarized protons is investigated using two-pion semi-inclusive deep-inelastic scattering. This process was proposed in Refs. [83, 84] as a probe of the transversity distribution function h_1. The dependence of the cross section for two-pion semi-inclusive DIS on the relative momentum of the two hadrons can be related to h_1 times an unknown dihadron fragmentation function $H_1^{\sphericalangle}$. In this thesis, the azimuthal amplitude $A_{UT}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta}$ of the transverse single-spin asymmetry A_{UT} is determined, which is directly proportional to the product of h_1 and $H_1^{\sphericalangle}$.

The main questions that have been addressed in this thesis are: is it feasible to measure two-pion semi-inclusive deep-inelastic scattering at an electron-proton scattering experiment like HERMES and, if so, is it possible to use this process to study transversity? It has been shown that indeed this process can be measured at HERMES. However, it was shown as well that these measurements are influenced by large detector acceptance effects. These effects can occur also for other processes measured at an experiment with a limited geometrical acceptance like HERMES, but can be particularly large in two-hadron semi-inclusive DIS, due to the combination of the relatively small cross section and the strong dependence of the cross section on the invariant mass of the pion pair. Also the second question has been answered positively. The present data indicate that the azimuthal amplitude $A_{UT}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta}$ deviates with 3–4 σ (stat.) from zero, which implies that both transversity and the fragmentation function $H_1^{\sphericalangle}$ are likely to be nonzero, and thus that two-pion semi-inclusive deep-inelastic scattering can be used as a probe of transversity (the systematic uncertainties are listed in Table 4.7).

The measurements were compared with model predictions. It was found that the present data are inconsistent, with a probability of $P > 0.999$, with the model of Jaffe, Jin and Tang [118, 119], which describes the dihadron fragmentation function $H_1^{\sphericalangle}$ in terms of $\pi - \pi$ phase shifts measured in pion-nucleon scattering experiments. The model predicts a sign change of the azimuthal amplitude $A_{UT}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta}$ at the invariant mass of the ρ^0. However, no such sign change is observed in the present data. The model of Bacchetta and Radici [122], describes the two-pion semi-inclusive deep-inelastic scattering process within the context of a spectator model. Their model prediction is consistent with the dependence of the data on the invariant mass, as well as with the dependence on x and z. However, this model does not predict the sign and overestimates the measured amplitude by about a factor of 4.

In this thesis, an effort was made to contribute to the understanding of the spin structure of the proton. The results can be used in combination with planned measurements by the BELLE collaboration of the dihadron fragmentation function $H_1^{\sphericalangle}$ to extract transversity. As the measured asymmetries are small and the corresponding uncertainties typically quite large, a high-precision determination of transversity will require a combined analysis of the results from various experiments.