Fragmentation function studied with e^+-e^- data and its impact on the nucleon spin structure analysis

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Fragmentation and parton distribution functions Fragmentation and parton distribution functions are essential objects for analyzing hard scattering processes. The functions are interpreted at leading order as probability for fragmenting to a hadron with an energy fraction z from a parton, and finding a parton with a momentum fraction x in a parent hadron. Especially single-inclusive e^+ e^- annihilation into a hadron h (SIA), $e^+ + e^- \rightarrow h + X$, and deep inelastic scattering (DIS), $l + h \rightarrow l' + X$, are typical processes where these functions play main roles.

Fragmentation function parametrization Fragmentation functions for various hadrons have been parametrized with QCD analysis using available SIA data. It is commonly taken for its functional form $D_q^h(z) = N \cdot z^\alpha \cdot (1-z)^\beta / B[\alpha+2, \beta+1]$, where B is the Euler beta function and N represents 2nd-moment of the function $N = \int_0^1 zD(z)\mathrm{d}z$. Although most of the available data were obtained at the Z^0 mass scale, some lover scale data, e.g., TASSO at DESY-PETRA, exist. They help to determine fragmentation function from gluon. Fragmentation function for pion was rather well determined with SIA data. On the other hand, kaon fragmentation function was poorly determined because of the limited experimental information. Recent fragmentation function analysis included experimental data on hadron production in deep inelastic scattering and proton-proton collision. The additional data helps to remove several constraints which were needed in the previous analysis, such as $D_{\mathrm{s}}^{\pi^+} = D_{\bar{\mathrm{s}}}^{\pi^+} = D_{\mathrm{d}}^{\pi^+} = D_{\bar{\mathrm{u}}}^{\pi^+}$. Especially, kaon multiplicity at HERMES and kaon cross section data from RHIC improved the fragmentation function from strange quark to kaon, D_s^K.

Proton spin problem Proton spin 1/2 can be decomposed as

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta\mathrm{G} + L, \tag{1}$$

where $\Delta\Sigma = \sum_{\mathrm{u,d,s,...}} (\Delta\mathrm{q} + \Delta\bar{\mathrm{q}})$ is a net contribution from quark spin to the proton spin, and ΔG is a net contribution of gluon. There is also orbital angular moment contribution from quark and gluon L. The spin contribution is a first moment of corresponding "helicity" distribution, $\Delta\mathrm{q} = \int_0^1 \Delta\mathrm{q}(x)\mathrm{d}x$ ($\mathrm{q} = \mathrm{u}, \mathrm{d}, \mathrm{s}, ..., \mathrm{g}$). The helicity distribution is a difference of parton distribution of helicity + and −, $\Delta\mathrm{q}(x) = \mathrm{q}^+(x) - \mathrm{q}^-(x)$, while the usual parton distribution function is the sum of those.

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By analyzing data form polarized deep inelastic scattering, $\vec{l} + \vec{N} \rightarrow l' + X$, one can determine the helicity distribution functions. The results indicated rather small quark spin contribution, $\Delta\Sigma = 0.2 \sim 0.3$ and large positive gluon contribution ΔG ~ 1. The small quark contribution with SU(3) flavor non-singlet axial charges determined by β and hyperon decay under SU(3) flavor symmetry also indicated negative polarized strange quark inside the proton,

Semi-inclusive measurement of polarized deep inelastic scattering (SIDIS), provides flavor information of the struck quark. Leading order extraction of Δq(x) for u, d, ū, d̄, and s based on fragmentation function obtained with the string model Monte-Carlo were carried by the HERMES collaboration. This analysis is free from assumption for the functional form and flavor SU(3) symmetry. HERMES measured the double spin asymmetry of pion, and kaon production cross section with the proton and deuteron target. The extracted Δu(x) and Δd(x) were consistent with the QCD analysis with the inclusive DIS data, while sea quark helicity distributions were consistent to zero within their uncertainties. Especially the strange quark distribution Δs(x) was observed slightly positive in the measured x range.

Recently, the pion and kaon double spin asymmetries and data from polarized proton-proton collision were also included in the helicity distribution determination as for the fragmentation function analysis. In the analysis the updated pion and kaon fragmentation functions were also used. The updated experimental information and new fragmentation functions allowed more freedom in the parametrization form, and also to loose the constraint on the quark flavor symmetry. The extracted strange quark helicity distribution appears positive in the x region covered by the SIDIS data, and changes the sign in the small x, which makes the fist moment of Δs(x) negative.

Fragmentation function at Belle More data from polarized proton-proton collision at RHIC become available in the near future. They are expected as a key for the gluon polarization determination. As in the strange quark case, the fragmentation function from gluon becomes more important. In order to improve the gluon fragmentation function, data from lower scale experiment like Belle is essential. It may be noted that most of SIDIS and RHIC for the proton spin analysis stay at quite lower scale where almost no data exist from the SIA experiment.