Multiplicities of charged pions and kaons from semi-inclusive deep-inelastic scattering on the proton and the deuteron

HERMES Collaboration

The development of the model of the basic building block of nuclear matter, the nucleon, in terms of partons, i.e., quarks and gluons, is one of the triumphs of twentieth century particle physics. But isolated quarks have never been observed in nature. Deep-inelastic scattering (DIS) of electrons or other high energy leptons by protons has been one of the most productive probes of the partonic structure of the proton. The DIS process can be pictured (see Fig. 1) as the absorption of a virtual photon generated in the scattering of the lepton, which is then absorbed by a charged quark or antiquark. When a quark or antiquark is ejected from a bound state of quarks and gluons by the absorption of such a high-energy virtual photon photon, as it separates from the ensemble, a shower or "jet" of hadrons is produced. There are a number of models of this showering process, but the final stage in all of these models is the generation of several "color-singlet" hadrons, that is, hadrons in which quarks have grouped in combinations in which the strong color fields of the quarks are neutralized. The pions and kaons generated in the final stages of the shower are such color-singlet particles. Modeling this hadronization process is essential to a complete picture of the interaction of quarks and gluons in Quantum ChromoDynamics (QCD).

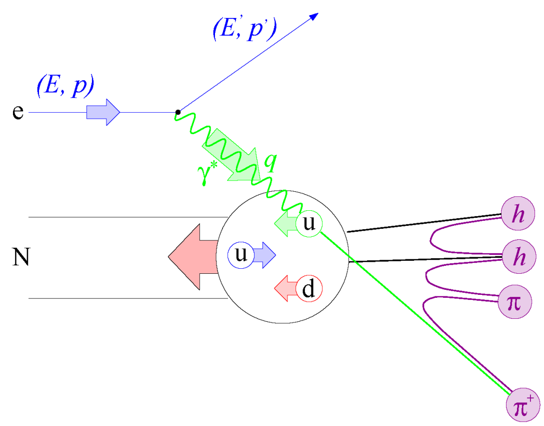

FIG. 1. Diagram of the deep-inelastic scattering process. The incoming lepton emits a virtual photon which is absorbed by one of the quarks in the nucleon. In the case depicted, the struck quark fragments into a pion in the final state. In semi–inclusive processes, the scattered lepton and part of the hadronic final state are detected in coincidence.

To model the absorption of the virtual photon one must have a parameterization of the structure of the proton in terms of the composite quarks of different flavors (up, down, and strange). Parton distribution functions, (PDFs) parameterize the flavor structure of the initial hadron state. The subsequent hadronization process which generates the final-state stable hadrons is described by a polarization-averaged fragmentation function (FF) D_f^h, which is the number density of hadron type h produced by the fragmentation of a struck quark/antiquark of flavor f. It is now generally accepted that the DIS process can be described in terms of the factorized combination of PDFs and FFs. While the knowledge of PDFs is highly developed, the data available to date for FFs have been much more limited, particularly for unfavored fragmentation in which a struck quark hadronizes into a final state hadron which does not contain a substantial strength of the flavor of the struck quark in its composition. The FFs provide the data base of the phenomenology of the hadronization process, and are therefore central to models of hadronization.

Measurement of normalized yields of specific hadrons in the final state in semi-inclusive DIS (SIDIS), i.e., particle multiplicities, provides a powerful means of extracting FFs. The HERMES experiment with its highly developed particle identification and pure gas targets is ideally suited for such measurements. The collaboration has been able to collect a high statistics data set produced by SIDIS for proton and deuteron targets. With these data it has been possible to study the multidimensional dependences of the multiplicities including kinematic dependence of the multiplicities on the component of hadron momentum transverse to the momentum transfer $P_{h\perp}$. Thus, these data reach beyond the usual standard collinear factorization, and access the transverse-momentum dependence of the fragmentation process. The extraction of multiplicities of pions and kaons separately for positive and negative charge provides sensitivity to the individual quark and antiquark flavors in the fragmentation process.

The data has been tabulated in several multidimensional decompositions, and for a number of kinematic projections of particular interest. They are plotted in Fig. 2 as a function of z, the fractional virtual-photon energy carried by the hadron produced, and compared to various predictions

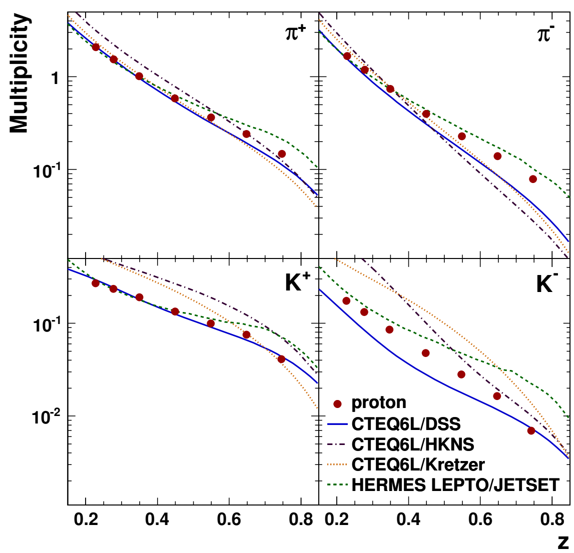

FIG. 2. Comparison of the vector-meson-corrected multiplicities measured on the proton for various hadrons with leading order calculations. Also shown are the values obtained from the HERMES Lund Monte Carlo. The statistical error bars on the experimental points are too small to be visible.

based on previous knowledge of fragmentation functions. While in fair agreement for pions, the impact of these data is apparent for kaons where large discrepancies with the predictions are observed. These data provide unique information on the fragmentation of quarks into final state hadrons and will contribute valuable input for the extraction of fragmentation functions using QCD fits. The multiplicities measured as a function of $P_{h\perp}$ will provide constraints on models of the motion of quarks in the nucleon in the transverse plane of momentum space, as well as on the models of the fragmentation process.