# Measurement of Parton Distributions of Strange Quarks in the Nucleon

(The HERMES Collaboration)

New HERMES results illuminate directly one of the basic features of the internal structure of the nucleon, the presence and contribution of strange quarks to its properties. The momentum and spin distributions for strange quarks are substantially different than those previous assumed. Beyond their intrinsic interest, the HERMES data are also important because of their impact on high priority experiments currently in progess or planned at high energy hadron colliders such as the LHC at CERN.

The nucleon is the basic building block of all the visible matter in our universe. The positively charged proton is the nucleus of the hydrogen atom. Protons and uncharged neutrons bound together by their mutual interaction comprise the nuclei of all the elements in our universe. But we know that the nucleon is itself a composite particle composed of nearly massless pointlike quarks and gluons. The quarks are bound by the strongest force in nature through the exchange of gluons. Most of the features of the strong force are successfully described by the laws of Quantum Chromo Dynamics (QCD), the theory of the interaction of quarks and gluons. A central goal of particle physics is to understand the structure and properties of the nucleon in terms of the quarks and gluons of QCD. Basic issues include the composition of the nucleon in terms of the different types of component quarks and their contributions to its mass. Just as a spinning top has angular momentum, elementary particles possess inherent quantized angular momentum or "spin". A second issue is the manner in which the spin of the quarks and gluons combine to generate the spin of the parent nucleon.

The existence of quarks was established in a series of pioneering deep-inelastic experiments such as that pictured in Fig. 1 involving the scattering of high energy electrons by protons. We now know that three different "flavors", up, down, and strange, distinguish the quark types present in the nucleon. It is the composition of up and down quarks which give the proton and neutron their separate identities. The manner in which these "partons" contribute to the properties of the parent nucleon are described by parton distribution functions (PDFs). They summarize basic features of the partonic structure of the nucleon. Spin-averaged PDFs for the various flavors describe their contributions to the mass of the nucleon, while differences in the PDFs for quark spins parallel and antiparallel to the spin of the parent nucleon describe the flavor dependent contributions of the quark spins to the spin of the nucleon.

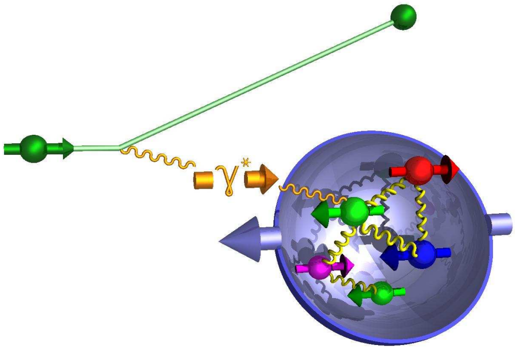

FIG. 1: A diagram of deep-inelastic scattering of a polarized electron by a polarized nucleon. The spins of the particles are indicated by the arrows. Here the nucleon spin is aligned in the opposite direction of that of the incoming virtual photon which has been emmitted by the scattered electron. The nucleon here is composed of three "valence" quarks and a quark antiquark pair interacting by the exchange of gluons.

Current models of the proton assume it to be composed of three valence quarks, two up quarks and one down quark, and a sea of quark-antiquark pairs. We have very detailed knowledge of the parton distributions for up and down quarks in the proton, which typically comes from deep-inelastic scattering experiments. As the proton has no strangeness, there are no strange valence quarks. So, strange quarks are objects which reflect directly properties of the nucleon sea, and consequently, they are of special interest. However, because of the lack of an experimental probe sensitive to strangeness, until now we have had very limited information on the features of the PFDs for strange quarks. Now for the first time, using the technique of flavor-tagging in deep-inelastic scattering, the HERMES experiment has made a direct measurement of the strange quark PDFs.

Flavor tagging is the technique of observing particles produced in coincidence with the scattered electron in deep-inelastic scattering. By measuring the yields of particles with specific quark flavor compositions it is possible to isolate contributions of specific quark flavors to the properties of interest in the target nucleon. The reaction which has been studied at HERMES is shown diagrammatically in Fig. 2. To probe the flavor of strangeness, one detects, in coincidence with the scattered electron, charged K mesons which contain strange and antistrange quarks.

The spin averaged PDFs for the strange quarks were determined from the shape and magnitude of the measured yield of charged kaons per deep-inelastic scattering event, i.e. the charged kaon multiplicity, in a given interval of the parameter $x_{Bj}$. This parameter measures the fraction of momentum of the parent proton carried by the struck quark. In the absence of experimental data

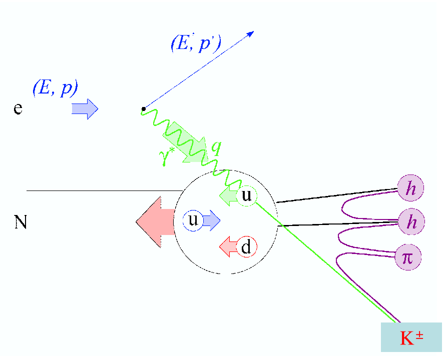

FIG. 2: A diagram of semi-inclusive deep-inelastic scattering of a electron by a nucleon. As depicted here, the up quark struck by the virtual photon has fragmented into a charged kaon which is observed in coincidence with the scattered electron. In the reaction which gives the sensitivity to strange quarks, it is one of the strange sea quarks, not shown, which is struck by the virtual photon and converted to a kaon.

for strange quarks it had been customary to assume the shape of the strange quark PDF is the average of that of the up and down quarks. Attempts to fit the HERMES data using this assumption (see dotted curve of Fig. 3 do not provide a reasonable fit to the observed multiplicity curve. However, by taking the strange quark PDF as an unknown, using known values for the up and down quark PDFs together with known values for the fragmentation functions which describe the conversion of the struck quark into the final kaon, it was possible to obtain a good fit to the data. The improved fit (continuous curve in Fig. 3) to the multiplicity is an indication that the actual distribution is substantially different from the average of those of the nonstrange antiquarks. This deviation in shape from that of light sea quarks is a clear manifestation of the violation of SU(3) symmetry. This symmetry between up, down and strange quarks is usually assumed to be valid for strong forces. It is clearly violated in the strange quark sector.

The HERMES measurements were taken for two spin configurations, beam and target spins parallel and antiparallel. The multiplicity measurements described above result from summing the data for the two configurations. The strange quark helicity distribution, i.e. the difference in the parallel and antiparallel quark spin densities can be obtained by measuring the difference in the cross sections for the two spin configurations. By analyzing the cross section differences for inclusive scattering in which only the scattered electron is detected and the differences for the semi-inclusive process in which a charged kaon was observed as well as the scattered electron, HERMES was able to determine the strange quark helicity distribution for various values of $x_{Bj}$. The results indicate that, within experimental uncertainty, the strange quarks are unpolarized and make no contribution to the spin of the proton. Furthermore, in large measure the strange sea is generated by gluon conversion into quark-antiquark pairs. Consequently, the HERMES result suggests that the gluons in the proton are themselves are not strongly polarized.

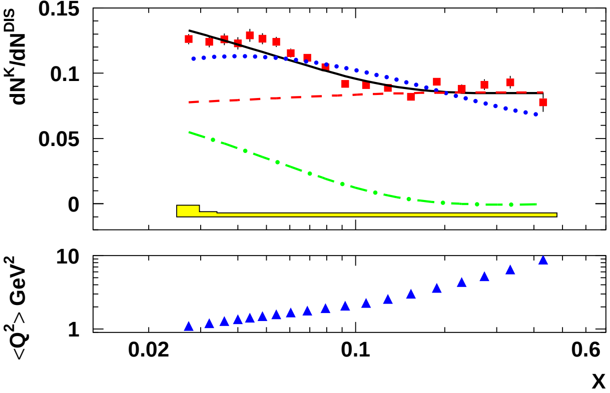

FIG. 3: The multiplicity corrected to $4\pi$ of charged kaons in semi-inclusive DIS from a deuterium target, as a function of Bjorken $x$. The continuous curve is the result of the HERMES analysis described here. The dashed(dash-dotted) curve is the nonstrange(strange) quark contribution to the multiplicity for this fit. The dotted curve is the best fit obtained using previously assumed strange quark PDFs. The error bars are statistical. The band represents the systematic uncertainties. The values of $\langle Q^2 \rangle$ for each $x$ bin are shown in the lower panel.