Reevaluation of the parton distribution of strange quarks in the nucleon

(The HERMES Collaboration)

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.

The existence of quarks was established in a series of pioneering deep-inelastic experiments, 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.

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 convenient experimental probes sensitive to strangeness, very limited information on the features of the PFDs for strange quarks were available until recently despite decades of scattering experiments.

In 2008 the HERMES experiment made a direct measurement of the strange quark PDFs, using the technique of flavor-tagging in deep-inelastic scattering. 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. 1. To probe the flavor of strangeness, one detects, in coincidence with the scattered electron, charged K mesons, which contain strange and anti-strange quarks.

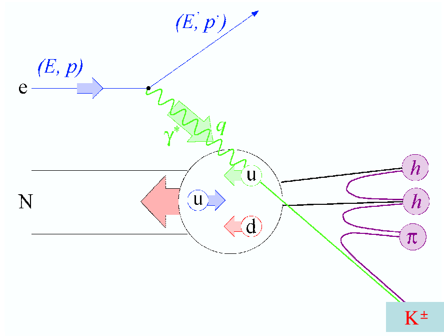

FIG. 1: A diagram of semi-inclusive deep-inelastic scattering of a electron by a nucleon. As depicted here, the up quark struck by the virtual photon has fragmented into a charged kaon which is observed in coincidence with the scattered electron. In the reaction which gives the sensitivity to strange quarks, it is one of the strange sea quarks, not shown, which is struck by the virtual photon and converted to a kaon.

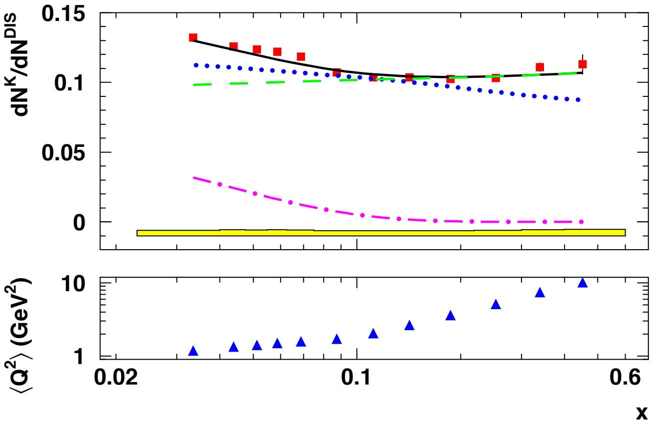

FIG. 2: The multiplicity corrected to 4π of charged kaons in semi-inclusive DIS from a deuterium target, as a function of Bjorken x. The continuous curve is the result of the HERMES analysis described here. The dashed(dash-dotted) curve is the nonstrange(strange) quark contribution to the multiplicity 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.

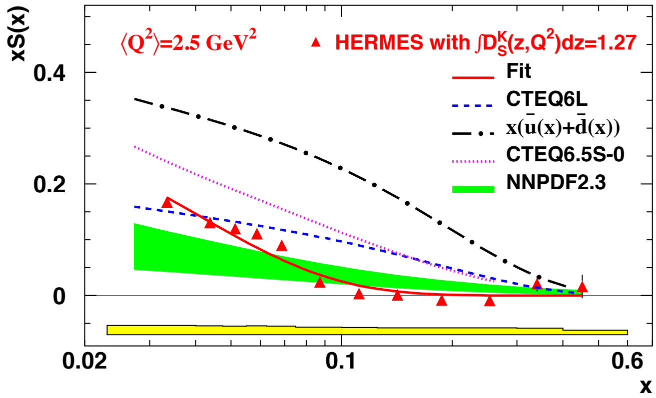

FIG. 3: The strange-parton distribution $xS(x)$ from the measured HERMES multiplicity data for charged kaons. The red line is a fit to the data, and the dashed, dot-dash, dotted curves are the strange-quark distributions from the global fits of CTEQ6L (strange and average of the light sea) and the special strangeness fit of CTEQ6.5S0, respectively. The green band represents the results from a global neural-network PDF analysis including its uncertainty.

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 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, e.g., dotted curve of Fig. 2 for the case of the new analysis) did 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 (cf. curve in Fig. 2) to the multiplicity was 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 was 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.

HERMES has recently finalized the extraction of multiplicities for each charged state of π and K. In the extraction, all the correction for acceptance, kinematic smearing, losses due to decay in flight and secondary strong interactions, and radiative effects had been carefully revisited which resulted in significant changes in the final multiplicities. These final multiplicity data were used in an update of the extraction of the strange-quark distribution. As in the earlier extraction from the HERMES experiment the new measurement confirms that the distribution of strange quarks in the nucleon differs in shape substantially from the one of the non-strange sea quarks (see Fig. 3) though the rise at low x is less pronounced than previously reported.