Structure of the Goldstone Bosons

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Abstract. The feasibility of measuring the pion and kaon structure functions has been investigated. A high luminosity electron-proton collider would make these measurements feasible. Also, it appears feasible to measure these structure functions in a nuclear medium. Simulations using the RAPGAP Monte Carlo of a possible pion structure function measurement are presented.

Understanding hadron structure from the underlying quark and gluon degrees of freedom and understanding modifications of hadrons in nuclear matter are two of the most important goals of nuclear physics. The light mesons have a central role in nucleon and nuclear structure. The masses of the lightest hadrons, the mesons, are believed to arise from explicit chiral symmetry breaking. In particular, the light mesons are the Goldstone bosons of quantum chromodynamics [1]. The pion, being the lightest meson, is particularly interesting not only because of its importance in chiral perturbation theory, but also because of its importance in explaining the quark sea in the nucleon and the nuclear force in nuclei.

THE PION STRUCTURE FUNCTION

At present, the pion is believed to contain a valence quark and antiquark as well as a partonic sea. Several theoretical calculations are aimed at explaining the pion structure function in the valence region. These include Dyson-Schwinger [2] and Nambu Jona-Lasinio models [3,4]. Lower order moments of the structure function were determined in lattice gauge calculations [5]. Typical agreement with the pion structure function is shown in Fig. 1. Here, a curve from the Dyson-Schwinger model is compared with the data from a pionic Drell-Yan experiment [6] in the valence region. The general features of the valence structure of the pion are qualitatively understood. However, there is no good understanding of the pion sea.

Recently, measurements of the pion structure function [7] at very low x, in the region of the pion sea have been performed. The results of this work show two interesting findings: (1) the sea in the pion has the same shape in x as the sea in the proton, and (2) the pion sea has approximately one-third of the magnitude as

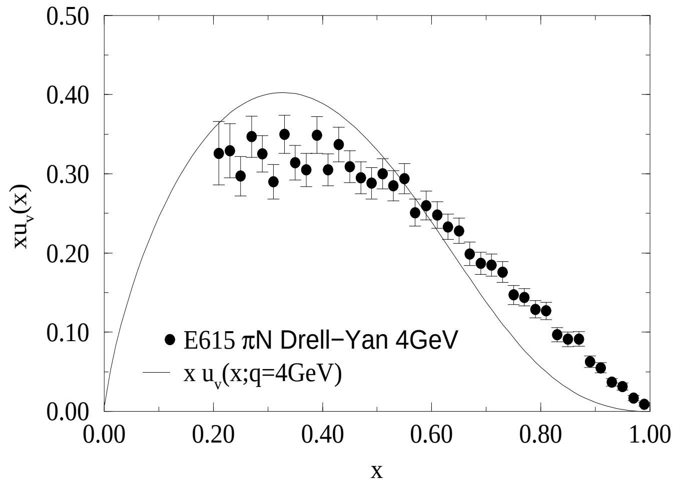

FIGURE 1. Existing data for the pion structure function from Drell-Yan scattering [6]. The solid curve represents a calculation of Hecht *et al.* [2].

the sea in the proton. This latter result is especially surprising since one expects that the pion sea to be two-thirds the value of the proton sea. These findings are even more surprising from the viewpoint of a chiral quark model [8]. This model predicts that the pion sea carries a larger momentum fraction than the proton sea. It appears that a comparison of the sea in the pion and the proton is a clue to understanding the nonperturbative structure of constituent quarks. Thus, it is essential to measure the pion structure function, especially the sea component, throughout the x region from 0.02, the highest value of the HERA data, up to 0.3, the lower value of the Drell-Yan data. This will map out the sea region where models should have a high degree of validity. Also, since there appears to be a discrepancy between the data and the theoretical calculation at very high x, another measurement using a different technique at high x would be important.

KAON STRUCTURE FUNCTION

The valence structure of the kaon is comprised of a light u or d quark/antiquark and a strange quark/antiquark. If our understanding of the meson structure is correct, then the large difference between the strange quark and u or d quark masses gives rise to a very interesting effect for the kaon structure function. In this case, the strange quark, because of its large mass, carries more of the kaon's momentum than the u quark, say. Then, the u_v quark distribution in the kaon should be shifted lower in x than that in the pion.

A Nambu Jona-Lasinio calculation [3,4] exhibits this behavior as shown in Fig. 2. Here, the ratio of the valence u quark in the kaon to that in the pion is shown as the curve in the figure. Drell-Yan measurements [9] of the ratio of K^- to π^- shows a consistency with unity over most of the x region, with a suggestion that the ratio

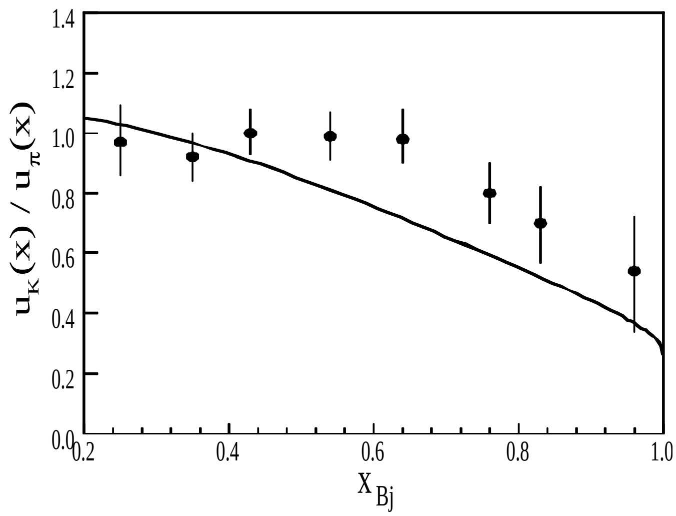

FIGURE 2. Existing data for K^-/π^- ratio from Drell-Yan scattering [9]. The solid curve represents a calculation of Suzuki [12,3].

is dropping at high x. However, the data are not of sufficient quality to verify our understanding of this process. Thus, it is essential to measure the structure function at high x as well as in the sea region.

MESON STRUCTURE IN THE NUCLEAR MEDIUM

The role of pions, and particularly, pion excess in the nuclear medium have been long-standing issues in nuclear physics. The pion excess has not been observed in either Drell-Yan experiments [10] at FNAL or in A(e,e'π) reactions [11] at Jefferson Lab. The main question is whether the pion or kaon structure function in a nuclear medium is modified from the free structure function. Calculations within the framework of a Nambu Jona-Lasinio model [12] indicate that the medium modification for the pion structure function should be small. However, if one invokes Brown-Rho scaling [13], then the effect is large. These calculations are shown in Fig. 3. Here the NJL calculation is the solid curve, while the dashed curve represents the Brown-Rho scaling.

MEASUREMENT OF THE MESON STRUCTURE FUNCTIONS

The scattering process illustrated in Fig. 4 was simulated using the RAPGAP Monte Carlo program [14]. RAPGAP models processes in which there is a large rapidity gap between a fast outgoing nucleon and the remainder of the inelastic scattering fragments. These processes include DIS from an exchanged pion [15–17]

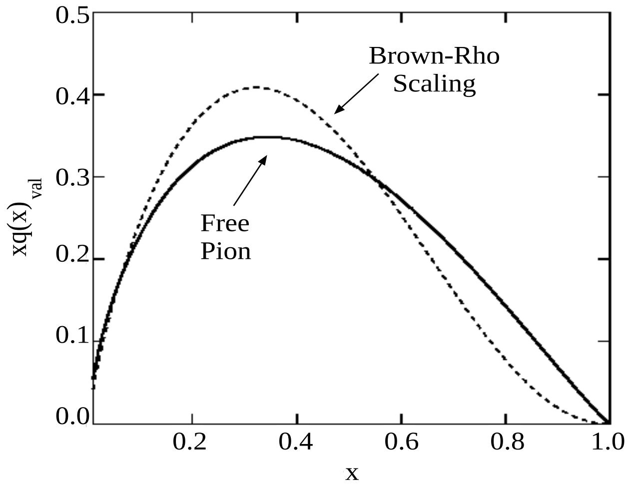

FIGURE 3. The solid curve represents the NJL calculation in a nuclear medium, while the dashed curve gives the effect of Brown-Rho scaling in nuclear matter [12].

or pomeron.. A comparison of results from RAPGAP with HERA data show reasonable agreement for fast outgoing neutrons [7].

For a 5 GeV electron beam on a 25 GeV proton beam, RAPGAP calculates 22 nb cross section for the $eq \to e'q'$ process. The expected accuracy of the experiments was calculated using events in which a "spectator" neutron was identified. In general, the neutron is scattered less than 50 mrad from the nominal proton beam axis. Events were cut on $-q^2 > 1$ GeV^2. The expected errors are shown in Fig. 5. A luminosity of 10^{32} cm^{-2}s^{-1} was assumed for a run lasting 10^6 s.

The K^+ structure function can be measured by considering deep inelastic scattering from the kaon cloud surrounding a proton. The basic Feynman diagram would be the same as in Fig. 4 with the pion replaced by a kaon and the neutron replaced by a Λ. The probability for scattering from the K^+ cloud surrounding the proton should be comparable to that for the π^+ since the K$N\Lambda$ coupling constant is comparable to that of the πNN vertex. In fact, one would only expect about a factor of two reduction in the vertex function for the kaon compared to the pion.

The difficulty with this process is in the detection of the Λ. The Λ decays predominantly (64%) to a proton and a π^-. Thus, a special forward proton spectrometer as well as a forward pion spectrometer would be necessary. This should

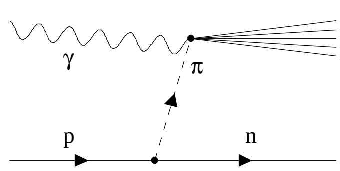

FIGURE 4. Deep inelastic scattering from the pion cloud surrounding a proton.

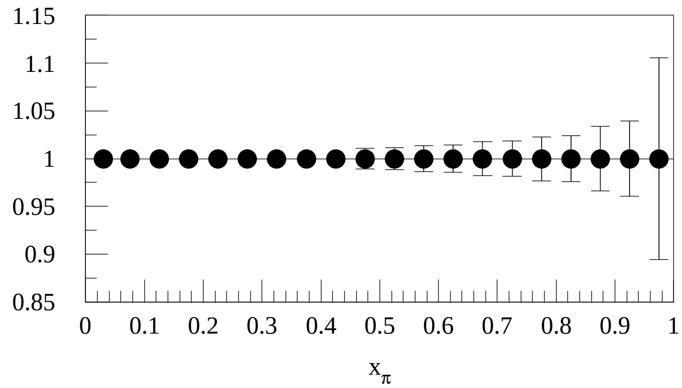

FIGURE 5. Simulated errors for DIS events using a 5 GeV electron beam on a 25 GeV proton beam with a luminosity of 10^{32}cm^{-2}s^{-1} and 10^6s of running.

be feasible since the ZEUS and H1 experiments at HERA have already successfully employed forward proton spectrometers. When designing the ring magnets, one should take into account the possibility of detecting both positively and negatively charged forward going hadrons. Simulations for this part of the experiment would be necessary to optimize the detection efficiency.

A collider should also render these studies feasible for nuclei up to ^{4}He. For the pion case, the idea would be to detect all of the forward going nucleons from the deep inelastic scattering from the pion. In the case of a deuterium target, for example, one would detect both forward going neutrons or forward going protons, depending on whether the DIS occurred from the π^+ or the π^-, respectively.

SUMMARY

In summary, a measurement of the pion and kaon structure functions over a large $x_{\pi/K}$ region was shown to be feasible with an electron proton collider, where the electron energy is 5 GeV, the proton energy is 25 GeV, and the luminosity is 10^{32} cm^{-2}s^{-1}. A collider will also open up other very interesting possibilities such as a measurement of the meson structure function in the nuclear medium.

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