Multiplicity of Charged and Neutral Pions in Deep-Inelastic Scattering of 27.5 GeV Positrons on Hydrogen

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When an electron of sufficiently high energy (or its anti-particle, the positron) is incident on a hydrogen target, it interacts via the exchange of a virtual photon with the proton making up the nucleus of the hydrogen atom not as a whole, but with one of its constituents, the quarks. It is a unique feature of the interaction between quarks, the "strong force", that it is not possible for a quark to exist in isolation. A useful picture of why this is so is to imagine that as a quark is removed from the proton, a string is stretched between it and the remaining quarks. The further the quark is removed, the more energy accumulates in the string until there is sufficient energy to create a quark-antiquark ($q\bar{q}$) pair according to Einstein's well known equation for the equivalence of energy and matter (E= mc^2). The quark from the $q\bar{q}$ pair combines with the remaining quarks to form in the simplest case a proton or a neutron, while the antiquark combines with the outgoing quark to form a particle known as a meson (quark-antiquark pair). Reality is typically more complex; more exotic or a greater number of particles are often produced in the final state. The goal of this paper is to study certain aspects of the production of particles, in particular of pions, in high energy electron-proton collisions. Pions are examples of mesons. They are responsible for the long range part of the nuclear force as they are exchanged between protons and neutrons in the atomic nucleus.

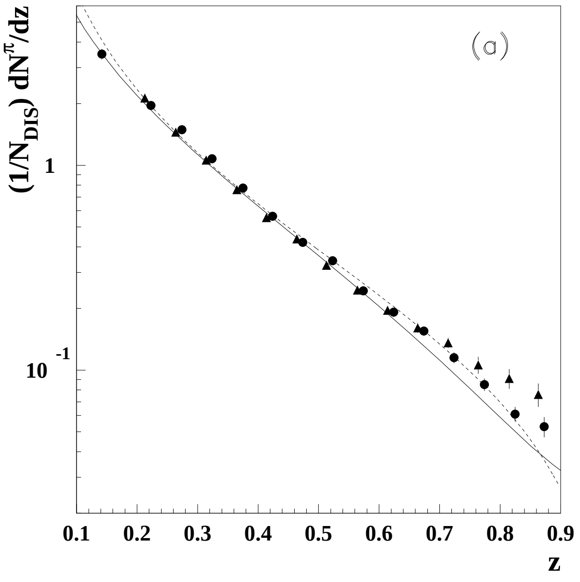

Figure 1: Neutral (circles) and average charged (triangles) pion multiplicities. The error bars are statistical. The systematic uncertainty for the charged (neutral) pions is 7% (9%). The solid and dashed lines are parameterizations using two theoretical models

The number of pions produced per electron scattered is called the multiplicity. Three aspects of multiplicities are studied in this paper: a comparison of charged and neutral pion production, the fraction of the total energy transferred that is carried by pions, and a test of how the multiplicities vary with the energy and momentum imparted to the struck quark.

It follows from theory that the number of neutral pions produced should be equal to the average number of charged pions. Fig. 1 shows the neutral and average charged pion multiplicities as a function of the variable z, the fraction of the total energy transferred in the scattering process, carried by the detected pion. The curves are parametrizations using two theoretical models. Notice that the vertical scale is logarithmic and that the multiplicity varies by a factor of about 30 to 60 over the measured range of z. This plot shows that the average charged pion multiplicity is indeed equal to the neutral pion multiplicity, at least for $z < 0.7$. Above this z value, the charged pion yield tends to be larger. This could be due to the presence of states (called resonances) formed in an intermediate step of the scattering process and which contribute differently to the three "isospin channels" (i.e. π^+, π^-, π^0). Further study is needed to elucidate this problem.

The distributions of Fig. 1 can be integrated (weighted by z) to determine the fraction carried off by all pions of the energy transferred in the reaction. Since the spectrometer does not cover all possible angles, this integral must be extended to the unmeasured region using a theoretical model, in this case the solid curve in Fig. 1. It has been determined that 26%±4.1% of the energy is carried off by neutral pions, while 51% ± 8.1% is carried by charged pions. This means that most of the energy is transferred to pions, with only 23% carried by protons, neutrons, or more exotic particles such as kaons which contain the unusual strange quark.

The multiplicities measured at HERMES have been compared to previous results from other experiments at SLAC (Stanford) and CERN (Geneva) to test how the multiplicities vary with Q^2, the mass of the virtual photon. The quantity Q^2 is a measure of the size of the structure probed by the scattering process; the larger the Q^2, the smaller the structure that can be resolved. Previous data from CERN are at significantly higher Q^2. Models of Quantum Chromodynamics (QCD), the theory of the strong interaction, predict how quantities such as fragmentation functions (closely related to multiplicities) and structure functions (the momentum distribution of quarks inside the proton) vary with Q^2. These models can be used to "evolve" the HERMES data to the same Q^2 or "size scale" as the CERN data. The average Q^2 differ by an order of magnitude: 2.5 GeV at HERMES, 25 GeV at CERN. Whether this procedure works down to the low Q^2 at HERMES is an interesting question. It was indeed found that, while the HERMES multiplicities are significantly larger than those measured at CERN, the agreement is very good after QCD corrections are made.

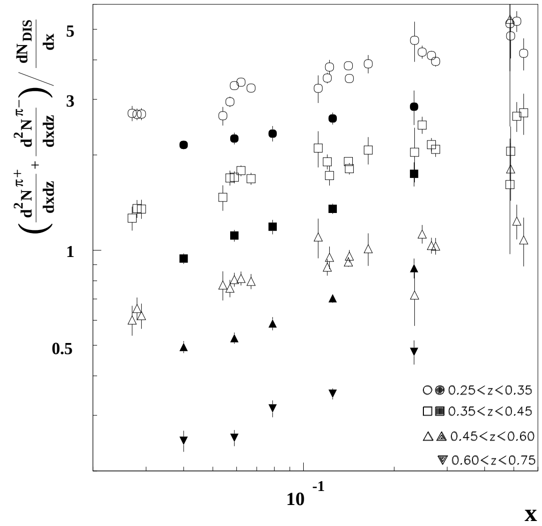

Figure 2: Charged pion multiplicities as a function of x in four different z bins, compared to charged hadron multiplicities from EMC (open symbols).

The data were also examined to determine whether they exhibit an unusual behaviour seen in previous experiments. The fragmentation process, where the outgoing quark produces mesons and other particles, should be independent of the mechanism that produced the outgoing quark. As a consequence, the multiplicities should depend only on z (and slowly on Q^2 when QCD effects as described above are included). They should not depend on the structure of the target proton, in particular on the variable x, which is a measure of the fraction of the momentum of the proton carried by the quark that was struck in the reaction. However, the multiplicities are seen to depend on x (see Fig. 2). The striking fact is that the variation (i.e. the slope of the data) seems to be the same at HERMES as it is at CERN, which is at much higher energy. The disagreement in the absolute values of the two data sets is simply explained by the fact that the CERN data are for all particle types while the HERMES data are for pions only. An intuitive explanation for x-dependent multiplicities is the emission of gluons (the carriers of the strong interaction) in the initial state which independently propagate into hadrons in the final state. This interesting effect is being studied further.