Multidimensional Study of Hadronization in Nuclei

The HERMES Collaboration

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A key stone for the understanding of nucleons and their interactions is to study how hadrons, *i.e.* protons, neutrons, pions, kaons, *etc.* are formed from quarks and gluons, the so-called "hadronization". One experimental approach is to compare yields of those hadrons when scattering electrons(positrons) on target nuclei with various sizes. As the path length of hadronization is comparable to the size of a nucleus one can study the length(time)-dependence of hadronization. This is because hadron yields depend on whether hadronization occurs inside or outside nuclear matter. See Fig. 1 for illustration.

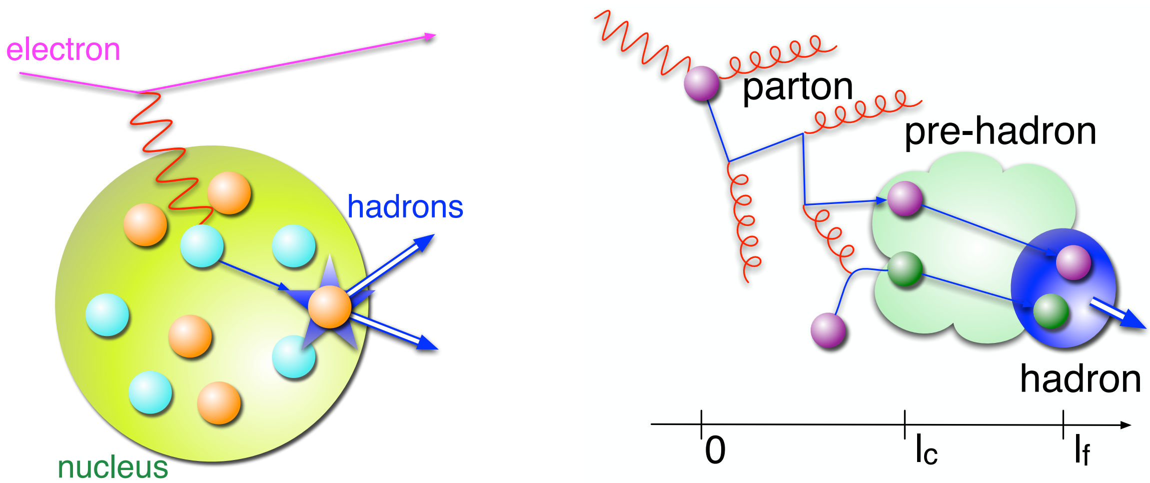

Figure 1: Schematic view of nuclear deep-inelastic scattering (left) and the hadronization process in the nucleus (right). In a first stage, at length scales below l_c, the parton is believed to propagate, radiating gluons and undergoing partonic re-scattering. In this picture, the subsequently formed pre-hadron is thought to possess the quantum numbers of the hadron and be colourless, but off its mass shell. The actual hadron is expected to be formed only after a propagation length l_f, which can be up to 10 fm and, hence, outside or inside the nucleus depending on the size of the latter. Thus, using nuclei of different sizes, the properties of the hadronization process can be studied.

The ratio of normalised yields Y_A^h on neon (Ne), krypton (Kr) and xenon (Xe) targets, denoted by A, compared to the same quantity on a deuterium D target: $R_A^h = Y_{\mathrm{A}}^h / Y_{\mathrm{D}}^h$ was measured, where h indicates positively and negatively charged pions ($\pi^{+/-}$) and kaons ($\mathrm{K}^{+/-}$), protons (p) and antiprotons ($\bar{\mathrm{p}}$). For the first time a two-dimensional representation is chosen for all hadrons separately. This allows to observe features that are hidden when integrating over large kinematic ranges, some of which are discussed in the following.

The measurements were performed at the HERMES experiment at the DESY research centre in Hamburg, Germany. It utilised electrons and positrons accelerated to 26.7 billion electron volts (GeV) impinging on the nuclei in a narrow gas-filled tube. The scattered electron(positron) and produced pion, kaon, proton or antiproton were detected and identified in an 8 m long array of dedicated detectors around a large magnet, which deflects charged particles.

The results show, for example (see Fig. 2), that π^+ and π^- behave similarly. However, their dependences with the virtual-photon energy ν change with the fraction carried by the hadron z. K^+ show different features compared to K^- which could be due to their different quark content. Particularly striking is the behaviour of protons, which show completely different trends in different ranges of z. Presmably, this is due to a sizable contribution of final-state interactions, such as knock-out processes, in addition to the fragmentation process.

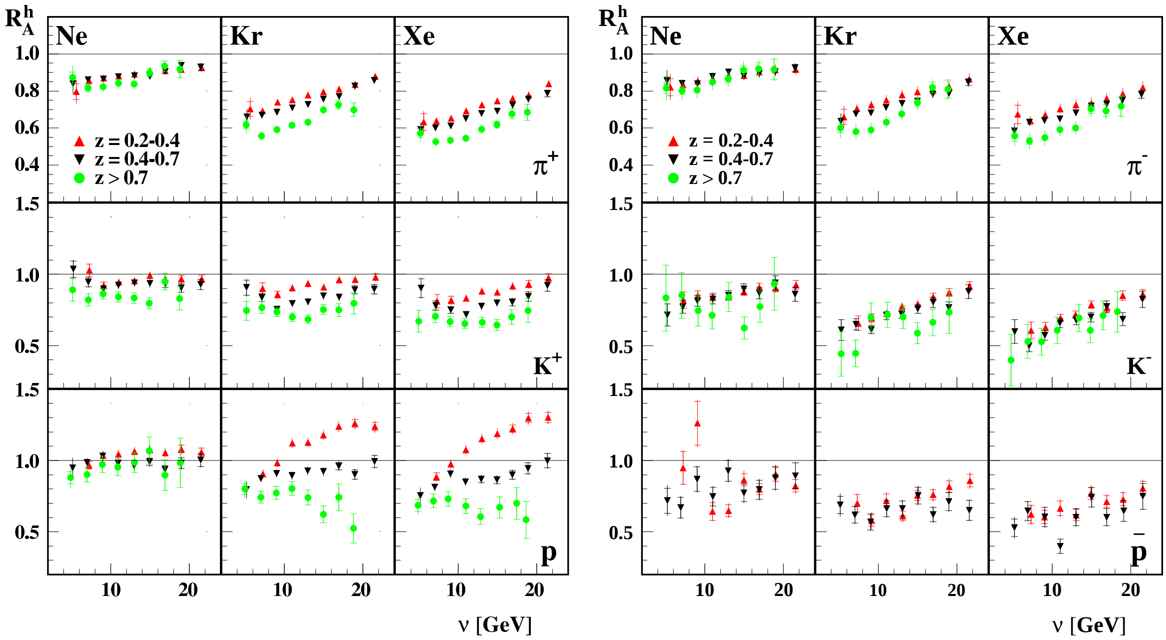

Figure 2: Dependence of R_A^h on the virtual-photon energy ν for positively and negatively charged hadrons for three slices in the fractional energy z, carried by the hadron, as indicated in the legend. The inner and outer error bars represent the statistical and total uncertainties, respectively. For the latter the statistical and systematic bin-to-bin uncertainties were added in quadrature. In addition, scale uncertainties of 3%, 5%, 4%, and 10% are to be considered for pions, kaons, protons and antiprotons, respectively.

In conclusion, the two-dimensional distributions of R_A^h for identified π^+, π^-, K^+, K^-, protons and antiprotons, shown in this publication provide detailed information which is generally not accessible in the one-dimensional distributions (in which all kinematic variables except one are integrated over, as has been traditionally done). These new detailed data are expected to be an essential ingredient for constraining models of hadronization and, hence, improving our understanding of hadron formation.