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Atomic mass dependence of hadron production in deep inelastic scattering on nuclei

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Abstract

Hadron production in lepton–nucleus deep inelastic scattering is studied in an absorption model. In the proposed model, the early stage of hadronization in the nuclear medium is dominated by prehadron formation and absorption, controlled by flavor-dependent formation lengths and absorption cross sections. Computations for hadron multiplicity ratios are presented and compared with the HERMES experimental data for pions, kaons, protons and antiprotons. The mass-number dependence of hadron attenuation is shown to be sensitive to the underlying hadronization dynamics. Contrary to common expectations for absorption models, a leading term proportional to $A^{2/3}$ is found. Deviations from the leading behavior arise at large mass-numbers and large hadron fractional momenta.

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1. Introduction

Recent HERMES results give precise data on hadron production in deep inelastic scattering (DIS) of 27.6 GeV positrons on D, He, N, Ne, and Kr nuclei [1–3]. The main observable is the multiplicity ratio, R_M, defined as the ratio between the hadron multiplicity on nucleus and on deuterium. R_M has been studied as a function of the hadron fractional momentum z, of the virtual photon energy ν, of its virtuality Q^2, for different hadrons and for different nuclei. The use of nuclear targets allows to study the hadronization process near the interaction point of the photon and probe hadron formation only some fermi away.

There are many proposed models to describe how hadronization in presence of a nucleus evolves in space and time. The model computations range from a color string breaking mechanism [4–9] with final state interaction [10,11], to gluon bremsstrahlung for leading hadrons [12,13] and pure energy loss models [14–16]. Two classes of models of hadron formation compete with each other. The first one is based on nuclear absorption, where the color of the struck quark is neutralized after a short time by the formation of a prehadron, the predecessor of the final hadron, which interacts with surrounding nucleons and is absorbed on its way out of the nucleus. The second model assumes energy loss from medium-induced radiation of the struck quark as dominant process. The first interpretation emphasizes the hadronic aspects of particle production, the second one focuses on partonic degrees of freedom and postpones hadronization outside the nucleus. Neglecting the production of secondary particles, both mechanisms reduce the number of hadrons emerging from the nucleus. The current belief is that the dependence of hadron attenuation from the mass-number A of the target nucleus can differentiate the two processes: in the absorption model, hadron attenuation is commonly believed to be proportional to the path length of the (pre)hadron in the nucleus ($\propto A^{1/3}$), whereas in the energy loss model the attenuation is supposed to depend on the square of the distance the quark traverses in the nucleus ($\propto A^{2/3}$). A careful measurement of the A-dependence of the nuclear attenuation would therefore allow to discriminate between the two different processes.

In a previous paper [17], we have calculated the nuclear modifications of hadron production in DIS in an absorption model. The hadron formation length has been computed analytically in the framework of the Lund string model [5,18] as a two-step process. In the first step a quark–antiquark pair from the break-up of the color string forms a prehadron. In the second step the final state hadron is created. Both the prehadron and the hadron, if they form inside the nucleus, interact with target nucleons and may be absorbed. Setting the prehadron nucleon cross section equal to the hadron nucleon cross section in Ref. [17] we had to increase the formation length by using an effective string tension $\kappa = 0.4$ GeV/fm, much smaller than the expected $\kappa \approx 1$ GeV/fm (see Ref. [19], for example).

In this paper we correct the model by combining a realistic formation length based on the expected string constant with smaller prehadronic cross sections. We pay special attention to the flavor dependence of the formation length, which is naturally induced by the Lund model, and calculate the multiplicity ratio R_M^h for different hadron species h as functions of kinematic variables z and ν. Finally, we study the A-dependence of the nuclear attenuation $1 - R_M^h$, and challenge common expectations by showing, analytically and numerically, a $A^{2/3}$ dependence for the absorption model.