1 Electron-Nucleus collisions within GiBUU

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1.1 Introduction

The study of the interaction of hadrons, produced by elementary probes in a nucleus, with the surrounding nuclear medium can help to answer important questions. We investigate this by means of the semiclassical GiBUU transport code [1], which not only allows for absorption of newly formed hadrons, but also for elastic and inelastic scattering as well as for side feeding through coupled channel effects. A study of parton interactions in cold, ordinary nuclear matter of known properties is important to disentangle effects of the interaction of partons from those of the medium in which they move.

Our model relies on a factorization of hadron production into the primary interaction process of the lepton with a nucleon, essentially taken to be the free one, followed by an interaction of the produced hadrons with nucleons. We have modeled the prehadronic interactions such that the description is applicable at all energy regimes and describes the transition from high to low energies correctly.

For the first step we use the PYTHIA model, that has been proven to very successfully describe hadron production, also at the low values of Q^2 and ν treated in our studies. This model contains not only string fragmentation but also direct interaction processes such as diffraction and vector-meson dominance. In this first step we take nuclear effects such as Fermi motion, Pauli blocking and nuclear shadowing into account [2]. The relevant production and formation times are obtained directly from PYTHIA [3]; for a definition of these times we refer to [4]. In the second step we introduce prehadronic interactions between the production and the formation time and the full hadronic interactions after the hadron has been formed.

The actual time dependence of the prehadronic interactions presents an interesting problem in QCD. Dokshitzer et al. [5] have pointed out that QCD and quantum mechanics lead to a time-dependence somewhere between linear and quadratic. We also note that a linear behavior has been used by Farrar et al. [6] in their study of quasi-exclusive processes. In our calculations we work with different time-dependence scenarios, among them a constant, lowered prehadronic cross section, a linearly rising one, and a quadratically rising one. In addition, we study a variant of the latter two, where the cross section for leading hadrons, i.e., hadrons that contain quarks of the original target nucleon, starts from a pedestal value $\sim 1/Q^2$, thus taking into account possible effects of color transparency (for details see [4]).

Fig. 1 shows a comparison of these various model assumptions. It is clearly seen that the assumption of prehadronic cross section reduced to a constant value (=0.5) in the leftmost figure leads to a significantly too large attenuation for the EMC experiment, while the HERMES data can be described reasonably well (this should be no surprise since the constant has essentially been fitted to the HERMES data). On the contrary, the quadratic time-dependence gives a good description of the EMC data but underestimates the attenuation significantly for the HERMES data.

This nearly perfect agreement is also seen in comparisons with data taken by the HERMES collaboration for pions, kaons, and protons, which give the attenuation R as a function

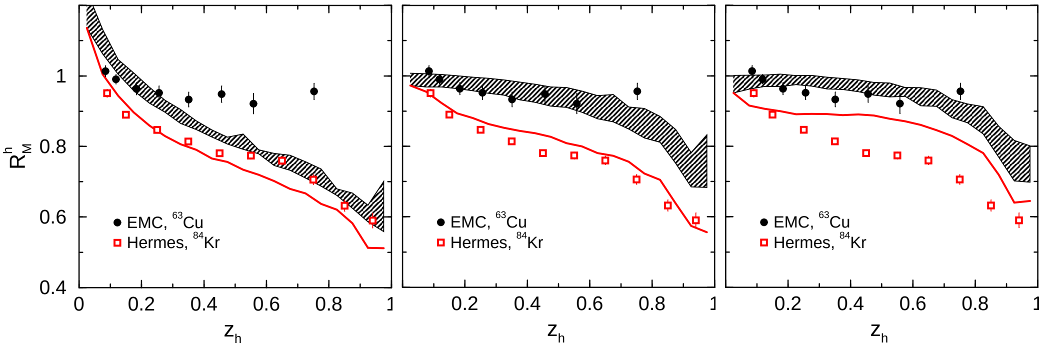

Figure 1: Nuclear modification factor for charged hadrons. Experimental data are shown for HERMES at 27 GeV and for EMC at 100/280 GeV . The cross section scenarios are (from left to right): constant, linear and quadratic increase with time after production.

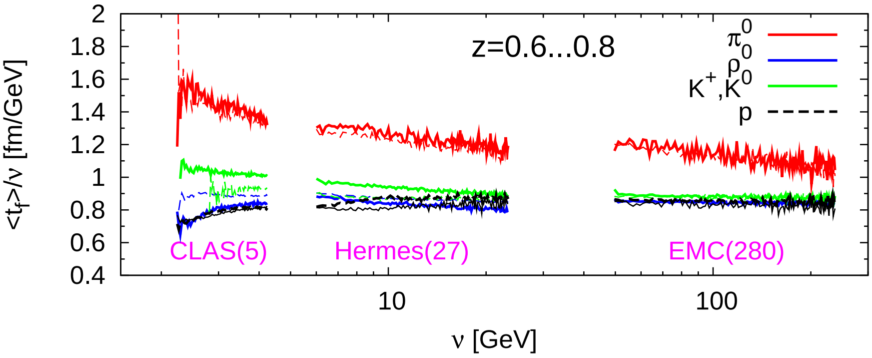

Figure 2: The average formation time of different particles divided by ν as a function of ν for several experimental setups.

of energy transfer ν, relative energy $z_h = E_h/\nu$, momentum transfer Q^2 and the squared transverse momentum p_T^2 [7]. The dependence of R on all these dynamical variables is described very well [4]. The rise of R with ν is mainly an acceptance effect, as we have shown in [2], whereas the weaker rise of R with Q^2 reflects the pedestal value $\sim 1/Q^2$ of the prehadronic cross sections.

In Fig. 2 we show the average formation time for different particle species as a function of the boson energy ν. One realizes a smooth transition from CLAS at 5 GeV up to EMC at 280 GeV for all particle species. We thus may conclude, that within our model the formation time of a hadron in its rest frame is proportional to its mass, $\tau_f \simeq m_H$, contrary to common assumptions of a constant formation time for all hadron species.

1.2 Hadron Attenuation at EIC: Strong Q^2 Dependence

One may now look at hadron attenuation at EIC conditions. Fig. 3 shows the expected attenuation for different hadron species within several Q^2 bins as function of ν and z for a collider setup $(3 + 30)$ GeV, which is close to former EMC conditions. One observes a large Q^2 dependence: while for low Q^2 values, the attenuation of all hadron species decreases to

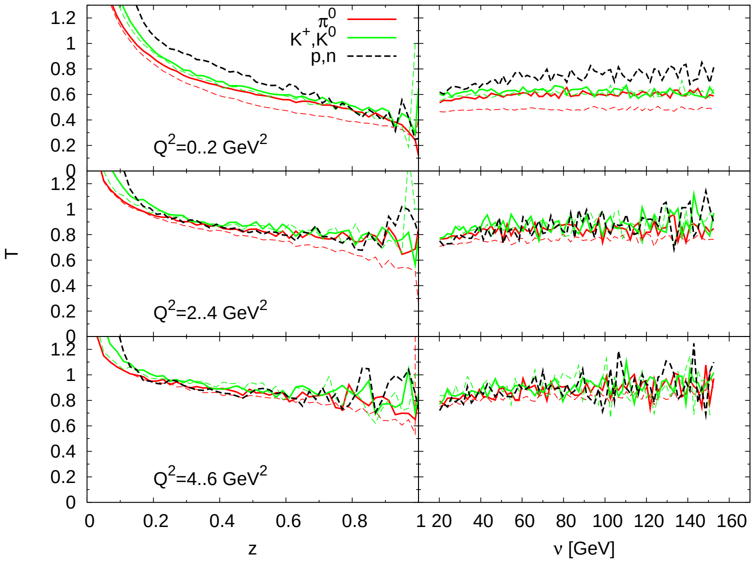

Figure 3: The hadron attenuation for different hadron species within several Q^2 bins as function of z (left panel) and ν (for $z > 0.2$, right panel) for a collider setup $(3 + 30)\,$GeV.

approx. 0.5 at $z \to 1$, the attenuation is only approx. 0.8 for $Q^2 > 4\,\mathrm{GeV}^2$. This is also shown in Fig. 4, where the same attenuation is shown, but now as a function of Q^2 and integrated over all ν and $z > 0.2$ values. It is worthwhile to mention, that there is nearly no ν dependence for all Q^2 bins visible in our calculations.

1.3 Hadron Attenuation at EIC: π^0 vs. η

As already seen in Fig. 3, some differences in the resulting attenuation ratio show up for different hadron species. It has been suggested, that a comparison of η and π^0 attenuation ratios will distinguish between energy-loss models and absorption models. In Fig. 5 we show our results for the attenuation of these two particle species. Both attenuation signals are close to each other, but showing a somehow stronger absorption for π^0 than for η mesons. This is contrary to what has been expected above, there this ordering has been considered to be a signal for energy-loss models. In Fig. 5 we also show the hadronic interaction cross section of pions and eta mesons with nucleons. For laboratory momenta larger than 2 GeV, these are nearly identical. Thus differences in the attenuation are due to formation time effects.

1.4 Slow Neutrons and Final-State-Interaction Length

Within collider kinematics, it is very elucidating to look at nucleons, which are to be considered 'slow' with respect to the (fast) target nucleon, as, e.g., indicated in [8]. There the considered kinetic energies of slow neutrons is below 10 MeV. Performing some exploratory calculations within the GiBUU framework, we are confronted with a lot of complications. In Fig. 6 we show some distributions of slow neutrons as a function of energy for different production points in the longitudinal axis, normalized to the corresponding number of scattered electrons. This result is to be considered as preliminary, since we learned, that we need a more accurate treatment of Pauli-blocking and binding effects in the few MeV region.

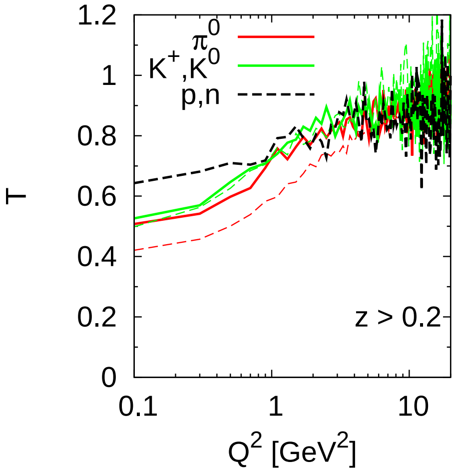

Figure 4: The hadron attenuation for different hadron species as function of Q^2 integrated over all ν and $z > 0.2$ for a collider setup $(3+30)$ GeV.

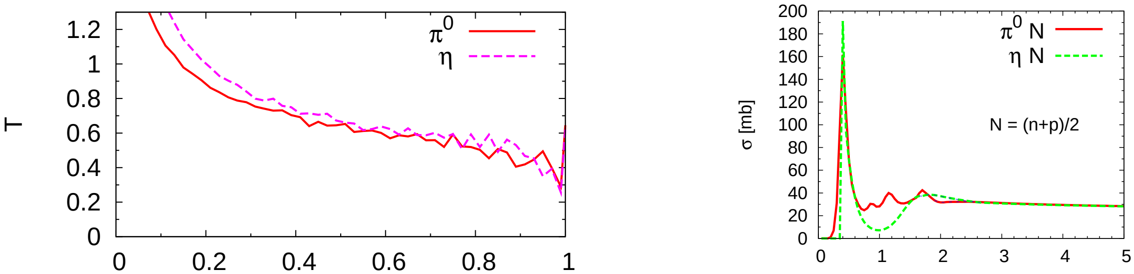

Figure 5: Left panel: The hadron attenuation for π^0 and η mesons for a collider setup $(3+30)$ GeV. Right panel: The hadronic interaction cross section of π^0 and η mesons with (resting) nucleons as a function of the meson momentum.

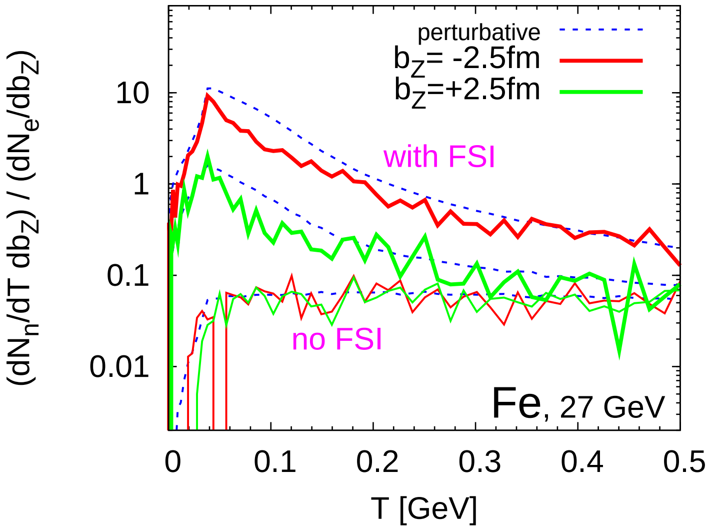

Figure 6: Production cross section of neutrons with low momenta for different longitudinal production points, normalized to the corresponding number of events. (Calculations have to be considered as preliminary; work in progress.)

In addition, we need to take into account the production of slow nucleons via evaporation and fragmentation. This work is currently in progress by inclusion of a multi-fragmentation framework (SMM) [9] and correcting for effects of the large energy gap between initial interaction and fragmenting nucleons.

It has been proposed by Ciofi degli Atti and coworkers in many works, that the interaction cross section of the jet particles within a SIDIS event with the debris of the target nucleus shows interesting length dependencies.

We see a large potential power of our GiBUU model to study all these questions.

References

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