Finite formation time of hadrons: the QGP signatures

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In order to investigate the possible emergence of guark–gluon plasma, it is necessary to understand the properties of multiparticle productions mechanisms in more simple case than in the relativistic collision of heavy ions. The purpose of this article is to discuss some problems of the role of zone formation effect which are under active investigation nowadays. The formation length of hadron from particle-nuclei collision is derived and compared with those from relativistic ion collisions.

1. INTRODUCTION

The hot and dense matter created in relativistic heavy ion collisions provides the possibility to study the new state of matter the so-called quark-gluon plasma (QGP). Unfortunately, the space-time evolution of QGP and its hadronization process are still open questions in the research of this area. Information about parton propagation in cold nuclear matter is needed as an input for the interpretation of data in AA collisions [1, 2]. In this case one wants to use hadron suppression as a tool to extract the properties of the hot QGP created in the collision. To this purpose we need to develop well calibrated computational tools to relate the magnitude of hadron suppression to properties of the QGP like its density and temperature.

In inelastic scattering experiments the reaction products hadronize long before they reach the detector. By using elementary nucleon targets one cannot obtain information on the space-time picture of hadronization. A simple estimate of the hadron formation proper time *via* the hadronic radius r_h yields hadron formation lengths of the order $\gamma \cdot r_h$ in the laboratory frame. At high energies the Lorentz factor γ leads to formation lengths that may easily exceed typical nuclear dimensions. By utilizing nuclear targets one, therefore, has the unique possibility to investigate the final-state interactions of the prehadronic system and

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to study the dynamics of the hadronization process.

The key quantity we need to investigate is the hadronization time scale. Since hadronization is a non perturbative process, one has to resort to phenomenological models to describe it. Lepton-nucleus scattering provides a nontrivial possibility to study space–time evolution of jets inside a nuclear matter. In contrast with hadroprodaction, intranuclear cascading can be studied without complicate effects of projectile rescattering or interactions of projectile constituent [3, 4]. The physics of such reactions is very interesting. In others words lepton–nucleus scattering provides a nontrivial possibility to study space–time evolution of jets in a nuclear matter. Clearly, a full Monte Carlo study with a realistic simulation should be done to verify these opportunity.

However, at the present time it is not possible to calculate accurately all peculiarities of such reactions according to 'the first principles' of QCD. Instead of this we apply a simple phenomenological concept of the formation zone [5, 6]). The last few years have witnessed a great revival of interest in inclusive DIS (HERMES, NOMAD [7, 8]). In addition, the concept of the formation zone is widely used from few-body nuclei up to relativistic heavy ions collisions [9, 10].

2. THE MODEL

We developed a cascade model of multiproduction of neutrino-nuclei interaction. The model describes a branching process of the evolution of parton's jet (up to hadronization) in the atomic nucleus. We assume that the interaction between incident an lepton and a target nucleus takes place in a lepton-nucleon interaction. The nucleus is excited by a series of collisions between secondaries (produced in the first lepton-nucleon interaction) and the intranuclear nucleons. This process continues until all secondaries escape target nucleus. A part of the energy is spread through the nucleus to produce a fully-equilibrated nucleus which then decays statistically. The process of generation of particles is simulated by the Monte Carlo method. (More detail description of the model and the list of the references about experimental data can be found in [4].) The characteristics of the interactions of the neutrino and of the produced particles with nucleons in nucleus are taken from experiments with free nucleons [4]. (The parton spectra is assumed to be the same as hadronic one. That approach is based on the concept of *"Local Parton Hadron Duality"*.)

The space-time characteristics of lepton-nucleon interactions inside the target nucleus were taken into consideration. The cross section for the next collision of a secondary particle with a nucleon inside the nucleus is given by

$$\sigma_{hN} = \sigma_{hN}^{\exp}(1 - e^{-\tau/\tau_0}), \tag{1}$$

where τ is the time from the moment of production of this particle in the previous collision and $\sigma_{hN}^{\exp}$ is the experimentally determined total interaction cross section of a hadron with a free nucleon at the corresponding energy of the secondary particle produced. Thus, only after a relatively long time τ does the cross section of intranuclear interaction reach the value $\sigma_{hN}^{\exp}$. In our equation, the parameter τ_0 is a certain characteristic corresponding to the formation time of the secondary generated hadron. The equation for $\sigma_{_{hN}}$ can be rewritten in the form with the formation length parameter L_f. In the present model, at a finite value of L_f, secondary particles (pions) are formed not instantly but after a certain time.

3. CONCLUSION

Below, we present the theoretical results for neutrino–emulsion interaction and compare with experimental data [4]. Fig. 1 shows multiplicity distribution of particles from charged-current ν_μ-emulsion interactions. The dotted curves correspond to the calculation according to our model with formation parameter $L_f = 0$. The solid lines show the predictions with $L_f = 0.5$ fm. In our approach, the evolution of quark-gluon jets in nuclei is accompanied by a nucleon emission at backward angles and momentum ≥ 300 MeV/c. In our model the underlying mechanism responsible for energetic particles production was quasideuteron intranuclear absorption process. The average multiplicities of particles (pions and protons), produced in charged-current ν_μ-emulsion interaction, compared with the corresponding quantities calculated in our model at different values of L_f are presented in Table 1. In summary, our calculations of the formation time (≈ 0.5 fm/c) of particles from neutrino–nuclei scattering are in agreement with the results obtained from the analysis of the data for *another* reactions [10, 11]). This outcome gives an extra stimulus to include the formation time in studies of relativistic heavy ions reactions. As for the cumulative protons from neutrino–nuclei interaction, existing data can be interpreted without some "exotics", *e.g.*, multiquarks bags.

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Table 1. The average multiplicities of charged pions and protons produced in charged-current ν_μ-emulsion interactions obtained in the experiment [4] compared with the values calculated according to our model at different formation length parameter L_f.

Experiment	Theory			
	$L_f \to 0$	$L_f = 0.2$ fm	$L_f = 0.5$ fm	$L_f = 1$ fm
N_π 5.28 ± 0.26	6.40 ± 0.05	5.62 ± 0.03	5.22 ± 0.02	4.03 ± 0.02
N_p 1.33 ± 0.15	2.06 ± 0.02	1.73 ± 0.02	1.34 ± 0.02	0.83 ± 0.01

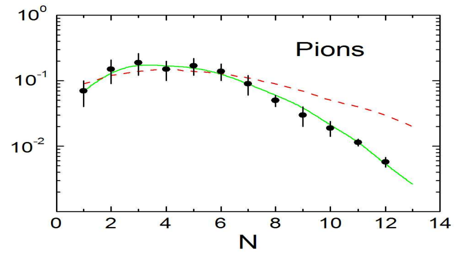

Figure 1. The multiplicity distribution of pions from charged-current ν_μ-emulsion interactions. The solid curve corresponds to the calculation according to our model with the formation length parameter $L_f = 0.5$ fm. The dashed curve represents the calculation with parameter $L_f = 0.0$.

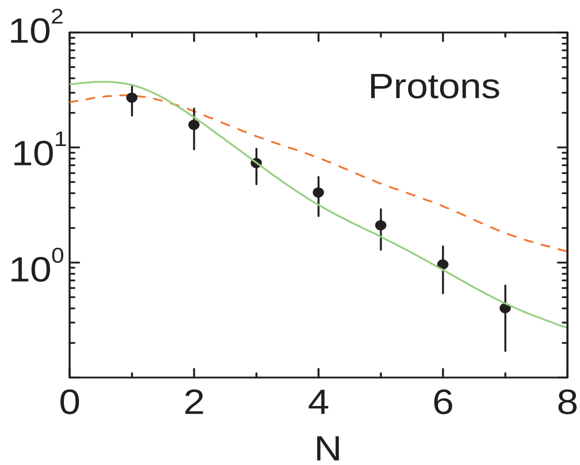

Figure 2. The multiplicity distribution of protons from charged-current ν_μ-emulsion interactions. The solid curve corresponds to the calculation according to our model with the formation length parameter $L_f = 0.5$ fm. The dashed curve represents the calculation with parameter $L_f = 0.0$.

FIGURE CAPTIONS

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TABLE CAPTION

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