Study of Hadronisation in Deep Inelastic Lepton-Nucleus Scattering at HERMES

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Abstract: Precise experimental data on hadron distribution from deep inelastic electron-nucleus (eA) scattering in the range of relatively low transfered energy $\nu \lesssim 25$ are needed to investigate the space-time structure of the hadronisation process and to test models concerning quark interaction in nuclear matter. An answer to theses question is of fundamental interest and would help to better understand the hadron production in more complex reactions e.g. heavy ion collisions. Here the idea and aims of such experiment at HERMES are discussed.

1 Introduction

The production of hadrons from excited quarks, which is observed in high energy collisions, is a process, which still cannot be calculated by any theory. Although QCD is well established as the theory to describe the interaction between quarks, the hadron formation process itself cannot be approached by existing techniques of pertubative QCD, since Q^2, the square of the four-momentum transfer is much smaller than the QCD-scale Λ_{QCD}. Various models have been developed to circumvent this problem. They reproduce many details of the hadron distributions measured in deep inelastic scattering (DIS) and e^+e^-annihilation. However, for a deeper understanding of this process it is necessary to answer fundamental questions such as of the space-time structure of the hadronisation and the nature of the quantum state just before the final state hadrons exist in the form, in which they are observed them in the detector.

Results from e^+e^-collision and lepton-proton deep inelastic scattering (DIS) experiments are well suited to study correlations amongst the final state hadrons and to test fine details of the models, but not to address the above quesitons. In DIS on nuclei, however, one can benefit from secondary interaction of the final state particles for the investigation. Hadrons produced instantaneously at the γ^*-parton interaction point would would undergo rescattering in the nuclear matter and the observed hadron spectra would become softer. If the hadrons are in parts produced outside the nucleus because of a finite hadron formation time τ_h, this softening becomes smaller and eventually vanishes.

The picture becomes more complicated, it one also considers a possible interaction of the constituent quarks of the hadron with the nuclear matter and a finite time τ_c, after which these constituent quarks appear (see Fig.1 for an illustration).

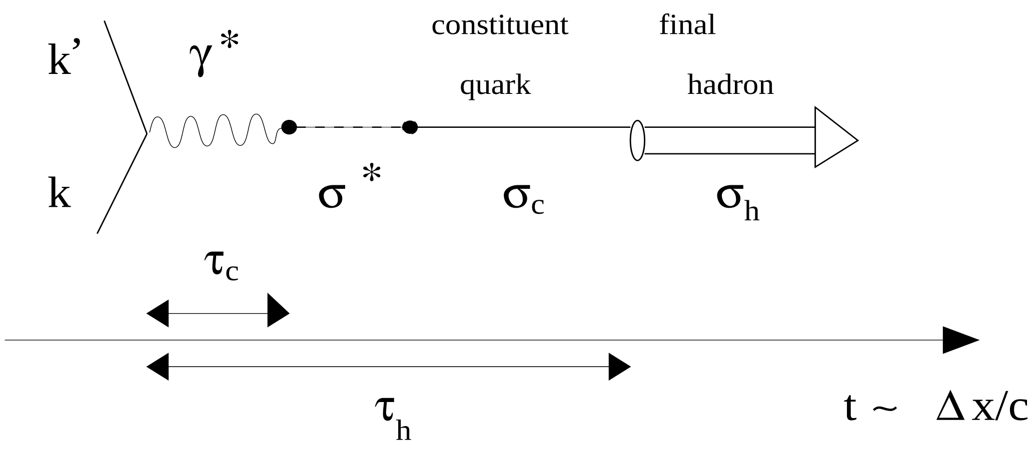

Figure 1: Illustration of the different time scales and interaction cross sections involved in space-time structure of the hadronisation. σ_h is assumed to be the π-nucleon cross section above the resonances ($\approx 20\,\mathrm{mb}$), σ_c and σ^* are the cross section of constituent quarks and for a possible interaction before the constituent quarks exist. k, k' are the four momenta of the incoming and scattered lepton.

variable	description
$Q^2 = -(k-k')^2 = -q^2$	square of four momentum transfer
$\nu = (Pq)/(Pk)$	energy of the boson exchanged (energy transfer in target rest frame)
$x = Q^2/(2Pq) = Q^2/(2M_{nucleuon}\ \nu)$	Bjorken scaling variable
$z_h = E_{had}/\nu$	fraction of the photon energy carried by a hadron, where E_{had} is the hadron energy in the target rest frame

Table 1: Kinematic variables in DIS used in this text; k, k' and P are the four momenta of the incoming (scattered) electron and the target nucleon respectively.

The target nucleus in DIS can be used is as a kind of passive 'detector' at the scale of some fermi to test the various models of the space-time structure and quark reinteraction. . In contrast to hadron scattering no deconvolution of the distributions of the projectile and target fragmentation particles has to be made, so that differences in the hadron distributions in DIS on different nuclei can most directly reflect nuclear effects in the hadronisation.

2 Experiments on Lepton-Nucleus Scattering in the Past

Hadron distributions in lepton-nucleus scattering have been investigated in several DIS experiments in the range of the energy transfer ν between ~ 5 and $\sim 400\,\mathrm{GeV}$ (for a review see [1, 2]). (The kinematic variables used in this paper are explained in Tab.1.) Fig.2 shows the ν dependence of the ratio of forward charged hadron mulitiplicities ($z_h > 0.2$) on copper and deuterium. For $\nu < 25\,\mathrm{GeV}$ a strong reduction of the hadron multiplicity in DIS on copper is observed which can be explained by inelastic intranuclear reaction of final state hadrons so that the z_h spectra of hadrons for lepton-nucleus scattering becomes softer as compared to DIS on free nucleons. This effect vanishes at $\nu \gtrsim 100\,\mathrm{GeV}$.

The data are compared with the several predictions for the space-time structure (see [3,

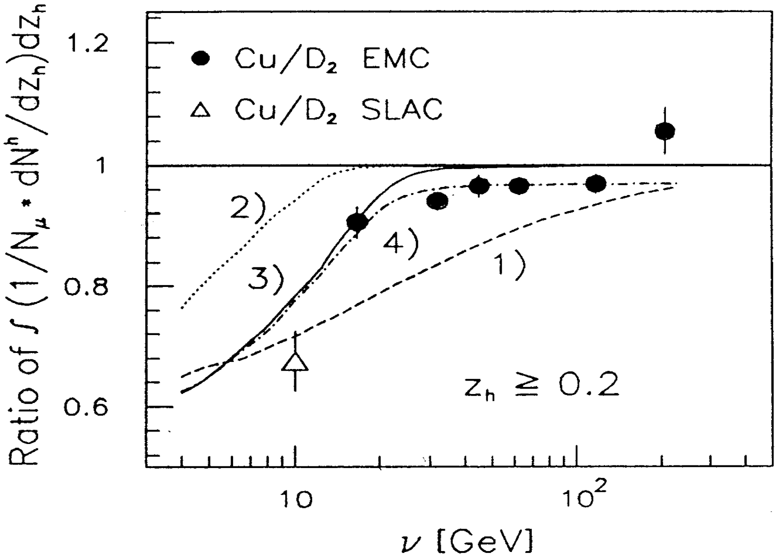

Figure 2: The ratio of the hadron multiplicity integrated over $z_h > 0.2$ for copper and deuterium as a function of ν. The data are compared with predictions of models for intranuclear reinteraction. (1): model with $\tau_h \propto E_{had}$, $\sigma_q = 0\,\mathrm{mb}$; (2-4) model with two scales τ_h, τ_c (string model [10]): (2) $\sigma_q = 0\,\mathrm{mb}$ (3) $\sigma_q = 20\,\mathrm{mb}$ in both cases $\sigma^* = 0\,\mathrm{mb}$ (4) (dashed-dotted line) $\sigma_q = 20\,\mathrm{mb}$ and $\sigma^* = 0.75\,\mathrm{mb}$.

1, 4] for details). The model with two time scales (τ_h, τ_c) as extracted from the Lund string fragmentation model [10] fits the ν dependence best. Date from ν-nucleus scattering [2] in the energy range from $8 < \nu < 64\,\mathrm{GeV}$ qualitatively confirm this result. In the mean time more elaborated models have been developed to calculate the energy loss of quarks by gluon radiation [5, 6, 7].

All experiments so far suffer from insufficient statistics, so that the distributions had to be integrated over large intervals of Q^2, x and/or z_h. In particular in the low energy range between ν $5 - 30\,\mathrm{GeV}$, where large nuclear effects have been observed, more precise data are requested to discriminate between the various theoretical concepts and ideas concerning the hadron formation time and a possible interaction during the preconfinement state.

3 HERMES as an Electron-Nucleus Scattering Experiment

It has been already pointed out earlier in time [1, 8, 9] that electron scattering experiments using a gas jet target in an intensive electron beam offers ideal conditions to measure hadron distributions in eA scattering with high statistical accuracy and minimal systematic errors. The gas jet target used in the HERMES experiment has a small longitudinal extension and the sort of gas (i.e. target nucleus) can be very easily and frequently changed so that systematic errors due to different detector acceptances for different targets are minimized. The effects of reinteraction of the final state hadrons inside the target and external Bremsstrahlung are small because of the density being much smaller in gas jet target than in any other kind of targets.

classes of models :		
models with 1 time scale : $\tau_h \propto \nu$ or $\propto z_h\nu$ free param.'s: σ_c	model with 2 time scales τ_h, τ_c from string model [10] free param.'s: σ_c,σ^*	gluon radiation from quark $\tau_h \propto \frac{\nu}{\kappa}(1-z_h)$ κ = energy loss of quark per unit of path length κ is Q^2-dependent
experimental test:		
$r_A(z_h)\,|_{\nu\ fixed}$ $z_h > 0.4$ $R_A(\nu)\,|_{Q^2\ fixed}$ $z_h > 0.5, 0.7$	$R_A(\nu)\,|_{Q^2\ fixed}$ $z_h > 0.5, 0.7$ determination of σ_c, σ^* (A-dependence)	$r_A(z_h)\,|_{\nu,Q^2\ fixed}$ $z_h > 0.4$ $R_A(Q^2)\,|_{\nu\ fixed}$ $z_h > 0.5, 0.7$

Table 2: Models for space-time structure of the hadronisation process and proposed measurements to investigate them. By $r_A(z_h)$ ($R_A(..)$) the ratio of z_h distributions ($1/N_{evt} * dN^h/dz_h$) and the ratio of integrated z_h distributions $\int_{z_h,min}^1 1/N_{evt} * dN^h/dz_h$ are denoted respectively.

At the HERMES experiment the achievable luminosities allow to measure hadron multiplicities with $< 1\%$ statisitical errors for $z_h > 0.5$ in bins of $\Delta\nu \sim 2\,\mathrm{GeV}$ and $\Delta Q^2 \sim 2-3\,\mathrm{GeV}^2$ up to $Q^2 = 30\,\mathrm{GeV}^2$ in about 500 h data collecting time , which correspond to several months running time (see [11] for details). This comfortably permits to perform all the measurements outlined in Table 2. In addition valuable information about the interaction mechanism can be extracted from the measurement of the nuclear broadening of hadron transverse momentum p_t distributions (i.e. measuring $< p_t^2 >$ in eA scattering). Static forces which retard an undressed quark should lead only lead to change of the energy, whereas rescattering of either hadrons or quarks inside the nucleus would increase the value of $< p_t^2 >$.

The list of concepts concerning the space-time structure of the hadronisation and necessary measurements to test them, which is given in Table 2, is not meant to be complete but indicates the way how the data from a eA scattering experiment at HERMES would contribute to study the problems and questions rised in the introduction.

4 Conclusions

Measurements of hadron distributions from eA scattering in the HERMES experiment will provide most valuable and precise information about nuclear effects in the hadron production. The data are very much needed and important to investigate the question on the space-time structure of the hadron formation process and possible quark interaction in nuclear matter, since existing data are not precise enough or cover a higher energy range where nuclear effects are small. A better understanding of these aspects of the hadronisation is important not only on its own but also for the interpretation of the results from heavy ion collisions at high energies.

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