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Nuclear attenuation – 2 dimensional dependences at HERMES

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Hadron multiplicity ratios in semi-inclusive deep-inelastic scattering have been measured on neon, krypton and xenon targets relative to deuterium at an electron-beam energy of 27.6 GeV by the HERMES experiment. They were determined as function of the virtual-photon energy ν, its virtuality Q^2, the fractional hadron energy z and the transverse hadron momentum with respect to the direction of the virtual photon p_t. Dependences are presented for positively and negatively charged pions and kaons as well as protons and antiprotons in a two-dimensional representation, *i.e.* in the form of detailed binning over one variable and three slices over the other variable. These results will help to constrain mechanisms and models of hadronization much more decisively than by the use of integrated results.

A few features are highlighted in this contribution showing, in particular, that the kinematic dependences of positively charged kaons and, in particular, protons deviate significantly from those of pions.

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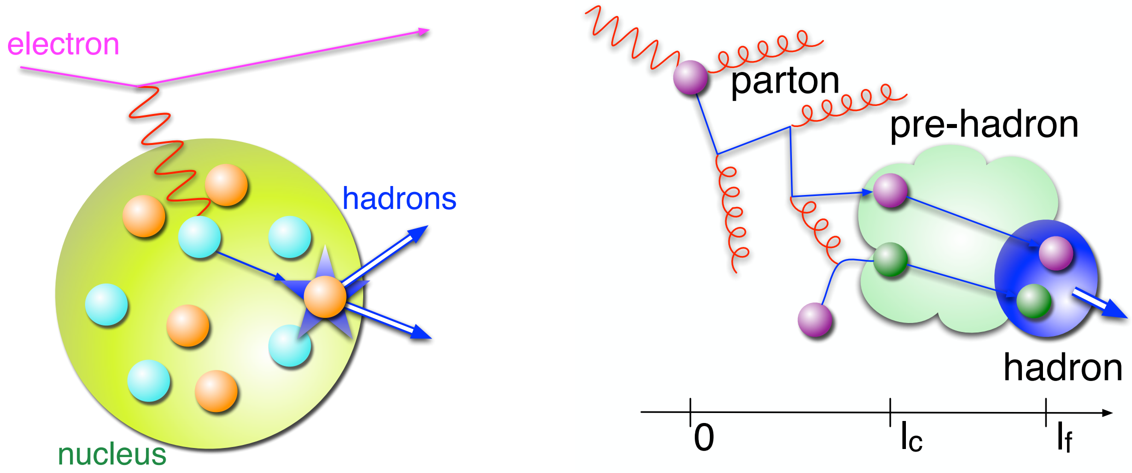

Figure 1: Schematic view of nuclear deep inelastic scattering and the hadronization process in the nucleus. In a first stage, at length scales below l_c, the parton is believed to propagate radiating gluons and undergoing partonic re-scattering. In this picture, the subsequently formed pre-hadron is thought to posses the quantum numbers of the hadron, 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 its size. Thus, using nuclei of different sizes, the properties of this process can be studied.

Semi-inclusive production of hadrons in deep-inelastic lepton nucleus scattering (SIDIS) provides a way to study quark fragmentation or hadronization. Naïve drawings depicting the principal concepts are sketched in Fig. 1. Lepto-production of hadrons has the virtue that the energy and momentum transfered to the hit parton are well determined, as it is "tagged" by the scattered lepton. In these studies the nucleus is basically used as a scale probe of the underlying hadronization mechanism: by using nuclei of increasing size one can investigate the the space(time) development of hadronization. The most convenient experimentally measurable observable for this process is the multiplicity ratio:

$$R_A^h(\nu, Q^2, z, p_t^2) = \frac{\left(\frac{N^h(\nu,Q^2,z,p_t^2)}{N^e(\nu,Q^2)}\right)_A}{\left(\frac{N^h(\nu,Q^2,z,p_t^2)}{N^e(\nu,Q^2)}\right)_D} \quad , \tag{1}$$

which is the ratio of the number of hadrons N^h produced and the number of deep-inelastic scattering events N^e on a given nucleus A compared to the same ratio on the deuteron D. This ratio depends on four independent kinematic variables, which were taken to be the photon energy ν and its virtuality Q^2, the fraction of the virtual-photon energy carried by the hadron z, and the square of the hadron momentum component transverse to the direction of the virtual photon p_t^2.

The available experimental data [1–6] are presented in most cases as a function of one variable, integrating over the other variables within the experimental acceptance (one-dimensional dependences), in order to keep the statistical uncertainties at a reasonable level. Only in one case was a two-dimensional dependence extracted, for a combined sample of charged pions [6]. In this analysis the same data as that of Ref. [6] have been used to study R_A^h for all charged hadron final states separately for neon (Ne), krypton (Kr), and xenon (Xe) targets, using a detailed binning in

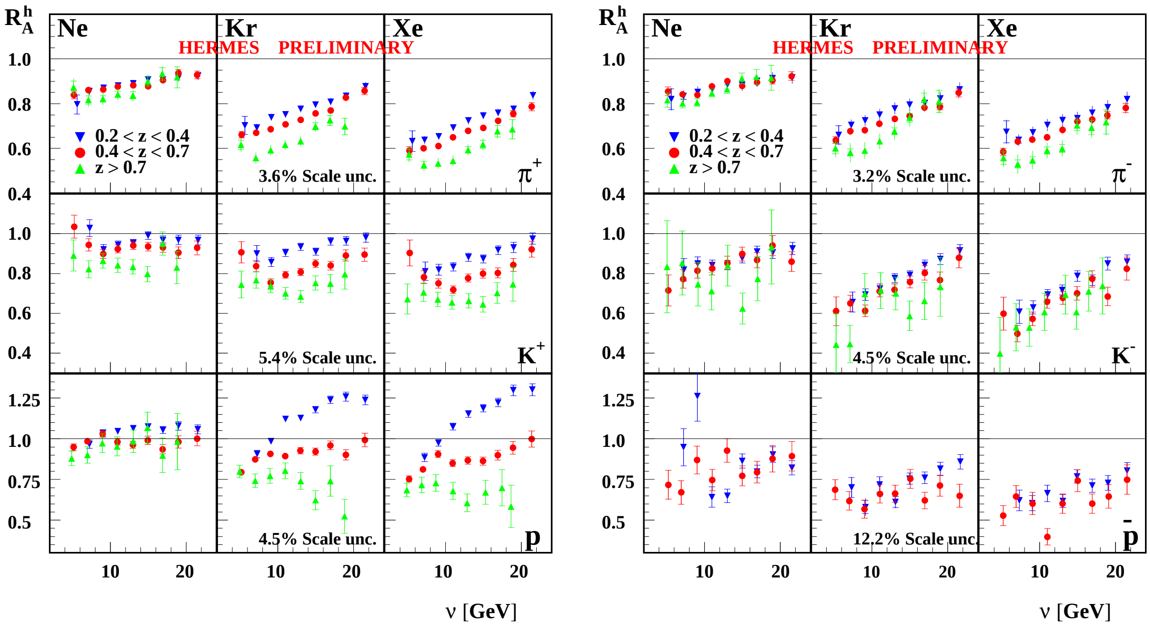

Figure 2: Dependence of R_A^h on ν for positively and negatively charged hadrons for three slices in z as indicated in the legend. The inner and outer error bars indicate the statistical and total uncertainties, respectively. For the latter the statistical and systematic bin-to-bin uncertainties were added in quadrature. The scale uncertainties depend only on the hadron type and are, hence, stated separately.

one variable and three slices in another one. This allows us to study the dependences in more detail, while keeping the statistical errors, at least for pions, K^+ and protons, at moderate levels.

From the theoretical side there is significant interest in hadron-multiplicity ratios, as exemplified by the diversity of model calculations in Refs. [7–12] and references therein. It is beyond the scope of this report to compare the results of the various models with the data. Instead some of the most prominent features of the data are presented and discussed. It is expected that the present results provide the input needed to further constrain the models of hadronization.

The measurements were performed with the HERMES spectrometer [13] using 27.6 GeV positron and electron beams stored in HERA at DESY. SIDIS data were collected in the years 1999, 2000, 2004 and 2005 with gaseous targets of D, Ne, Kr, and Xe. The identification of charged hadrons was accomplished using information from the dual-radiator ring-imaging Čerenkov detector (RICH) [14], which provides separation of pions, kaons and (anti)protons in the momentum range between 2 and 15 GeV/c. The analysis was performed analogously to the analysis described in Ref. [6], using the same constraints with the sole exception of the hadron identification algorithm. Here we used an approach, which is based on direct ray tracing [15].

The multiplicity ratio R_A^h, as defined in Eq. 1, for Ne, Kr, and Xe targets was determined for combinations of the kinematic variables ν, Q^2, z, and p_t^2 for the six hadron types: π^+, K^+, p, π^-, K^-, $\bar{p}$, using fine binning in one of the variables, while using three course slices in another variable, and integrating over the other variables within the acceptance of the experiment. Here we only show a few examples that highlight the observed effects. A publication containing the full information is currently in preparation.

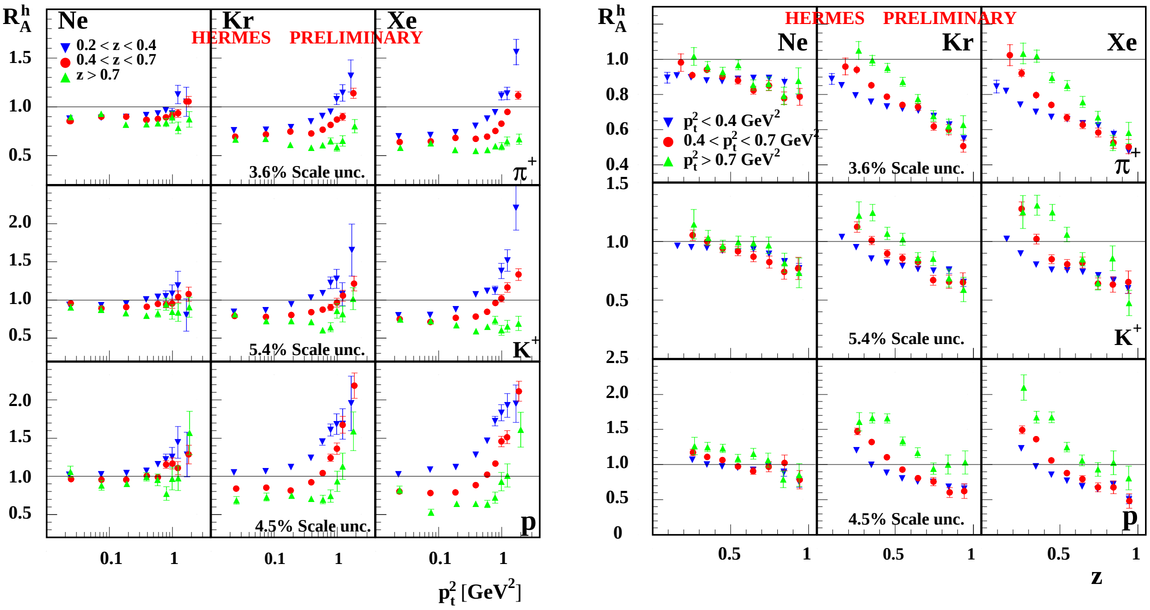

Figure 3: Dependences of R_A^h for positively charged hadrons on p_t^2 for three slices over z (left), and on z for three slices over p_t^2 (right). Slices are taken as indicated in the respective legends. Statistical and total errors are shown as in the previous figure.

The dependence of R_A^h on ν for three slices in z is shown in Fig. 2. The global trend that R_A^h steadily increases with ν seems to be broken at low values of ν for the higher z-ranges for π^+, π^- and, in particular, for K^+ and protons.

The results for protons are very different from those for the other hadrons. For the heavier nuclei, R_A^h behaves very differently for the three z-slices, becoming even larger than unity at higher ν for the lower z slice. In contrast, for $z > 0.7$, R_A^h is smaller than unity, and remains constant or drops with ν. At the lowest values of ν the differences between the z ranges seem to disappear. A possible explanation may be due to differing kinematic dependences of hadronization and knock-out processes. In contrast to other hadrons, for protons the production may be dominated by the latter, at least in certain kinematic regimes. An enhanced yield, by factors of 3 to 10, of protons compared to antiprotons confirms this conjecture.

The left panel of Fig. 3 shows the dependence of R_A^h on p_t^2 for three slices in z for positively charged hadrons. For π^- a compatible behaviour within statistical errors compared to π^+ was found. The rise at high p_t^2 is attributed to a broadening of the p_t^2 distribution. Such p_t^2-behaviour was predicted for values of $z \geq 0.5$ in Ref. [8]. However, the enhancement of R_A^h at large values of p_t^2 predicted in Ref. [8] considerably overshoots our data, in particular for pions and kaons. Protons show a much stronger rise in the p_t^2 dependence which, in contrast to the case of pions and kaons, does hardly diminish when going to higher ranges in z. This is consistent with assuming a large contribution from knock out processes.

Another representation of the z-dependence of the broadening is given by plotting R_A^h on z for three slices in p_t^2 in the right panel of Fig. 3. This dependence of R_A^h on z turns out to be stronger at higher values of p_t^2, an effect which is emphasised with increasing target mass. At high z the dependence on p_t^2 disappears, at least for π^+, π^-, and K^+. The effect for protons is similar, but much stronger (note the vertical scale).

In summary, we have extracted first two-dimensional multiplicity ratios for protons, antiprotons and positively and negatively charged pions and kaons separately. By giving this ratio for neon, krypton and xenon targets normalised to deuterium we observe significant structures which will help to constrain future models on hadronization. The ν dependence of positive kaons shows distinct features while K^- behave similar to both positive and negative pions; this is somehow reversed in the z and p_t^2 dependences where positive kaons behave similarly to pions. A very striking observation is that the dependence of protons on ν changes its slope from a strong rise to a constant, if not a decrease, when looking at different slices of z. A possible interpretation of the latter effect may be that a large fraction of the observed protons could be produced in knock-out processes rather than hadronization.

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