Nuclear $p_t$-broadening of semi-inclusive produced mesons

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The first direct measurement of $p_t$-broadening effects in cold nuclear matter has been studied as a function of several kinematic variables for different hadron types. The data have been accumulated by the HERMES experiment at DESY, in which the HERA 27.6 GeV lepton beam scattered off several nuclear gas targets.

1 Introduction

At HERMES nuclear semi-inclusive deep-inelastic scattering (SIDIS) is used to study hadronization. The nucleus acts as a nano lab providing multiple scattering centers in the form of nucleons and nuclear effects on hadronization can be investigated. The EMC effect and nuclear attenuation [2] are already measured. An effect that is measured for the first time at HERMES is the modification of the transverse momentum in nuclear matter or $p_t$-broadening which is presented in this work. Here, $p_t$ is the transverse momentum of the produced hadron with respect to the direction of the virtual photon. A new observable has been used: $\Delta \langle p_t^2 \rangle_h$, also called $p_t$-broadening:

$$\Delta \langle p_t^2 \rangle_h = \langle p_t^2 \rangle_A - \langle p_t^2 \rangle_D, \quad (1)$$

where $\langle p_t^2 \rangle_A$ is the average transverse momentum squared obtained by a hadron of type $h$ produced on a nuclear target with atomic mass number $A$, and $\langle p_t^2 \rangle_D$ is the same but for a Deuterium target. These measurements increase our knowledge about the space-time evolution of hadronization.

Nuclear SIDIS has the advantage that there are no initial state interactions due to the fact that leptons are point-like particles that do not contain quarks which can interact before scattering off the target. This makes the interaction easier to interprete and might help to understand the more complex heavy-ion collisions.

It has been suggested that hadron production proceeds through three qualitatively distinct stages that involve the propagation and interaction of:

(i) the initial struck quark (the “partonic” stage),

(ii) the subsequently formed colorless state (the “color-neutralization” stage, often also termed “pre-hadronic” stage), and

(iii) the final produced hadrons (the “hadronic” stage).

This proceeding reports the first detailed measurement of another observable, which may help to better constrain models, especially with regard to the role of the “partonic” stage: the broadening of the transverse momentum distribution of various hadrons.

In terms of the quark-parton model and QCD, there are several contributions to the transverse momentum distribution of hadrons produced in semi-inclusive DIS:

(a) primordial transverse momentum,

(b) gluon radiation of the struck quark,

a “quark” is used in this proceeding for both quarks and antiquarks

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(c) the formation and soft multiple interactions of the “pre-hadron”, and
(d) the interaction of the formed hadrons with the surrounding hadronic medium.

In semi-inclusive DIS off nuclear targets, the struck quark propagates through a “cold” nuclear medium. In the nuclear medium the primordial transverse momentum of quarks may be modified by various effects like Fermi motion of nucleons inside the nucleus, modification of the nucleon size, formation of non-nucleonic degrees of freedom like multiquark states or exchange mesons mediating the nuclear force. Also, the probabilities of the processes (b-d) may be enhanced resulting in a larger transverse momentum magnitude of the observed hadrons relative to the process in the vacuum or in a free nucleon. In particular, process (b) may cause an increased transverse momentum magnitude and energy loss of the quark and therefore it has recently been suggested [3] that the broadening of hadron distributions in semi-inclusive DIS may be the most direct way to probe the “partonic” stage.

2 Analysis

The data have been accumulated by the HERMES experiment at DESY, in which the HERA 27.6 GeV positron beam scattered off several nuclear gas targets [5]. Events were selected by requiring $Q^2 > 1$ GeV$^2$, $W^2 > 10$ GeV$^2$, and $\nu < 23$ GeV where $W$ is the invariant mass of the photon-nucleon system and $\nu$ is the virtual photon energy. Pions and Kaons are identified in the momentum range $2$ GeV $< P < 15$ GeV using the information from a ring imaging Čerenkov detector.

The $p_T$-broadening effects have been studied as a function of the atomic number $A$, $Q^2$, $\nu$, and $z$ for $\pi^+$, $\pi^-$, $K^+$ produced on Ne, Kr, and Xe targets.

The pion sample was corrected for exclusive $\rho^0$ decay pions using a Monte Carlo simulation. This correction was only significant in the highest $z$ bin where these decay pions contribute more than 50%. After the correction the $p_T$-broadening becomes consistent with zero (in the highest $z$-bin).

The $p_T$-broadening was corrected for detector smearing, acceptance effects and QED radiative effects with an unfolding method using a PYTHIA Monte Carlo generator together with a GEANT3 simulation of the HERMES spectrometer. Identified hadron samples were corrected for misidentification also with an unfolding method.

The systematic uncertainty includes contributions from the correction for $\rho^0$ decay pions, detector smearing and acceptance, radiative effects, and hadron misidentification (if applicable). The dominant part in the systematic uncertainty is coming from the model dependence of the acceptance correction ($\sim 5\%$), which is estimated using the PYTHIA and the LEPTO generator. A more detailed description of the analysis can be found in [4].

3 Results

Figure 1 (upper panel) shows that the $p_T$-broadening becomes consistent with zero as $z \rightarrow 1$. At high $z$ the partonic broadening has to be very small as the quark could not have lost energy.

The $p_T$-broadening increases as a function of $Q^2$, as seen in Figure 1 (lower panel). At HERMES $Q^2$ and $x$ are highly correlated due to the forward acceptance of the HERMES spectrometer, so the $Q^2$ might have an underlying $x$ dependence. This result is difficult to interpret but might help to distinguish between different models.

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Figure 1: $p_t$-broadening for different hadron types produced from Ne, Kr, and Xe targets as a function of $z$ (upper panel), $\nu$ (middle panel), and $Q^2$ (lower panel). The inner error bars represent the statistical error and the outer ones the quadratic sum of the statistical and systematic uncertainties.
In Figure 2 shows the A-dependence of the $p_t$-broadening. An increasing effect with increasing A without any sign of saturation is observed. This suggest that $p_t$-broadening originates from the partonic stage and that the hadron formation happens near the surface of the nucleus or outside. This view is consistent with the constant $p_t$-broadening observed as a function of $\nu$ in Figure 1. If the prehadron was formed inside the nucleus one would expect an increase of the effect as a function of $\nu$ due to time dilation. More recent results of this analysis can be found in [8].

4 Conclusions

The first measurement of $p_t$-broadening effects on Ne, Kr, and Xe targets have been presented [9]. Results were investigated for different hadron types and as a function of several kinematic variables. A clear signal of broadening is observed and it provides very important information to this physics field where a profound interest has been expressed by theoreticians.

References

[1] Slides:
http://indico.cern.ch/contributionDisplay.py?contribId=257&sessionId=3&confId=53294


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