Nuclear p_t-Broadening at HERMES

Yves Van Haarlem(1), Anton Jgoun(2), Pasquale Di Nezza(3)
on behalf of the HERMES Collaboration

1- Department of Subatomic and Radiation Physics, University of Gent, 9000 Gent, Belgium

2- Petersburg Nuclear Physics Institute, St. Petersburg, Gatchina, 188350 Russia

3- Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Frascati, 00044 Frascati, Italy

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. In the HERMES kinematics it is very likely that hadronization takes place inside the nucleus. In this regime the nucleus acts as a nano lab providing multiple scattering centers in the form of nucleons. Effects like 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. Besides the measurement of a ratio of average hadron transverse momentum (p_t-ratio): $\langle p_t^2\rangle_A^h/\langle p_t^2\rangle_D^h$ a new observable has been used: $\Delta\langle p_t^2\rangle^h$, also called p_t-broadening:

$$\Delta\langle p_t^2\rangle^h = \langle p_t^2\rangle_A^h - \langle p_t^2\rangle_D^h, \tag{1}$$

where $\langle p_t^2\rangle_A^h$ is the average transverse momentum squared obtained by a hadron of type h produced on a nuclear target with atomic mass number A, and $\langle p_t^2\rangle_D^h$ 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 of the target. This makes the interaction easier to interprete and might help to understand the more complex heavy-ion collisions.

p_t-broadening might be the most sensitive probe for the *production time* as it provides a direct measurement of the production time t_p ($\Delta\langle p_t^2\rangle \propto t_p$) in specific models, e.g. [3]. This is because the hadronizing quark only contributes at time intervals $t < t_p$ to the p_t-broadening. As soon as the pre-hadron is formed, no further broadening occurs, because inelastic interactions are suppressed for the pre-hadron (at $z > 0.5$), thus only broadening via elastic rescattering is still possible. Here, z is the energy fraction of the virtual photon carried by the produced hadron. However, the elastic cross section is so small that even for pions the mean free path in nuclear matter is about 20 fm. It is even longer for a small-size pre-hadron due to color transparency. A disappearance of the broadening effect is expected at large $z \to 1$ because of energy conservation.

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 [4]. 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 ν is the virtual photon energy. Pions and Kaons are identified in the momentum range $2< P <15$ 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, ν, and z for different hadron types produced on ^{3}He, ^{4}He, N, Ne, Kr, and Xe targets.

The pion sample was corrected for exclusive ρ^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-ratio becomes consistent with one and the p_t-broadening with zero (in the highest z-bin).

The p_t-broadening was corrected for detector smearing, acceptance effects and QED radiative effects using a Pythia Monte Carlo generator together with a Geant3 simulation of the Hermes spectrometer. For p_t-broadening an unfolding method was used. For the p_t-ratio a Monte Carlo study showed that most acceptance effects cancel out except the Cahn effect which was included into the systematic uncertainty. Identified hadron samples were corrected for misidentified hadrons using an unfolding method.

The systematic uncertainty includes contributions from the correction for ρ^0 decay pions, detector smearing and acceptance, radiative effects, and hadron misidentification (if applicable). The dominant part in the systematic uncertainty of the p_t-broadening is coming from the model dependence of the acceptance correction (~ 5 %), which is estimated using the Pythia and the Lepto generator, and from the Cahn effect for the p_t-ratio (4 %).

3 Results

In figure 1 (upper panel) a clear dependence of p_t-broadening on the atomic number A can be seen. It also shows that the p_t-broadening becomes consistent with zero as $z \rightarrow 1$. The latter is expected by energy conservation as the fact that a hadron with a high z value is detected means that no energy could have been lost in any kind of interaction or reaction process. In this case the final-state hadron had to be formed immediately and $t_p \rightarrow 0$. p_t-broadening increases as a function of Q^2, figure 1 (lower panel).

Figure 2 shows the $\langle p_t^2 \rangle$ ratio as a function of the atomic mass number for different momentum ranges. For $^{3,4}He$ targets the ratio is close to one for small momenta. This indicates that the size of the helium nucleus is smaller than the hadron production time. For heavier targets the ratio increases in the momentum range 2-7 GeV with a maximum around 7 GeV and then decreases. The behavior of the p_t-ratio for heavy targets at relative small momenta (below 7 GeV) can be caused by a production time that is smaller than the size of the nucleus. This could explain the increase of the p_t-ratio for increasing hadron momentum. The p_t-ratio decreases for high momentum, i.e. that the production time decreases with increasing final hadron momentum. At very large hadron momentum there are values smaller than one. In this regime z has to be close to 1 because these hadrons have the maximum possible momentum. Such behavior could point out that the intrinsic momentum of the quark in a nucleon inside the nucleus is smaller than for a quark in the free nucleon.

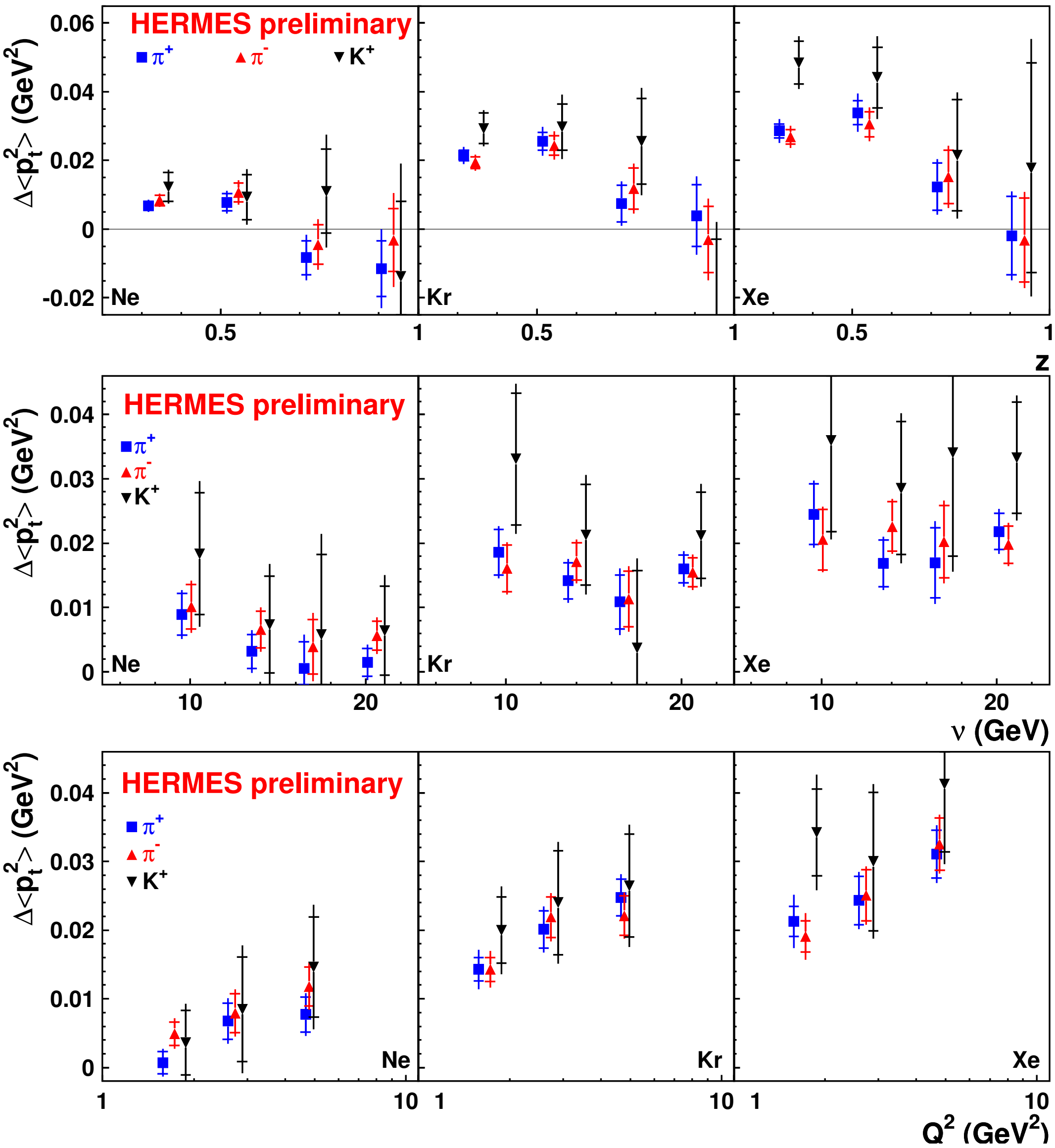

Figure 1: p_t-broadening for different hadron types produced from Ne, Kr, and Xe targets as a function of z (upper panel), ν (middle panel), and Q^2 (lower panel). The inner error bars represent the statistical error and the outer ones the quadratic sum of the statistical and systematic uncertainties.

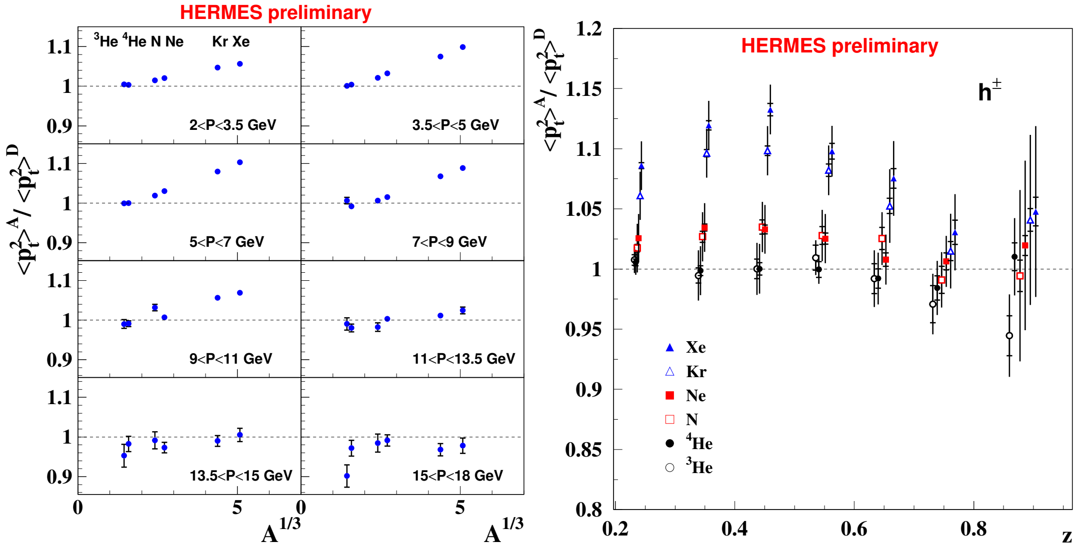

Figure 2: (Left) p_t^2-ratio versus $A^{1/3}$ for different hadron momentum regions for all charged hadrons. (Right) Charged hadron p_t-ratio versus z for several nuclear targets for all charged hadrons. The inner error bars represent the statistical error and the outer ones the quadratic sum of the statistical and systematic uncertainties.

4 Conclusions

The first measurement of p_t-broadening effects on ^{3,4}He, N, Ne, Kr, and Xe targets have been presented [7]. 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 were a profound interest has been expressed by theoreticians.

References

[1] Slides:
`http://indico.cern.ch/contributionDisplay.py?contribId=291&sessionId=6&confId=9499`

[2] Hermes Collaboration, A. Airapetian et al., Eur. Phys. J. **C20** (2001) 479; A. Airapetian et al., Phys. Lett. **B577** (2003) 37; A. Airapetian et al., Phys. Rev. Lett. **96** (2006) 16230; A. Airapetian et al., submitted to Nucl. Phys. **B**, arXiv:0704.3270v1 [hep-ex].

[3] B.Z. Kopeliovich, Nucl. Phys. **A740** (2004) 211.

[4] Hermes Collaboration, K. Ackerstaff et al., Nucl. Instr. Meth. **A417** (1998) 230.

[5] T. Sjöstrand et al., Comp. Phys. Comm. **135** (2001) 238.

[6] Hermes Collaboration, A. Airapetian et al., Eur. Phys. J. **C17** (2000) 3898.

[7] Hermes public plots: www-hermes.desy.de/notes/pub/trans-public-subject.html