Measurement of the z- and x-dependence of the Mean Transverse Momentum of Charged Hadrons, Charged Pions and K_s^0 at HERMES

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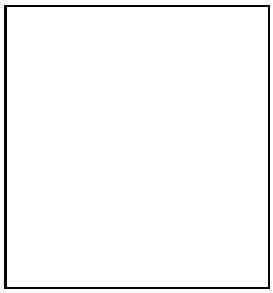

The mean transverse momenta of hadrons, $< P_\perp >$, produced in e^+N deep inelastic scattering was studied as a function of the hadron energy fraction z and the Bjorken variable x. The statistical accuracy of the HERMES data permitted to observe at high z differences in $< P_\perp >$ between hadrons with positive and negative charges, h^+, h^- and K_s^0 for the first time. These differences can presumably be explained by the flavour dependence of the intrinsic transverse momentum distributions of quarks in the initial nucleon.

1 Introduction

The mean transverse momentum $< P_\perp >$ of hadrons h produced in semi-inclusive deep inelastic scattering (SIDIS) $e + N \to e' + h + X$, studied in dependence on kinematic variables, can give information about the quark transverse momentum distribution in the initial nucleon and the hadronization process. High-z data are more sensitive to the transverse momentum distribution of quarks in the initial nucleon whereas low-z data are preferentially influenced by the quark fragmentation process. The flavour dependence of the primordial momentum distribution of initial quarks can be investigated by studying $< P_\perp >$ for different hadrons produced in SIDIS. The flavour dependence of the internal quark momentum distribution can manifest itself as a target isospin dependence of $< P_\perp >$ and can be studied in SIDIS on targets with different isospin.

2 Results

The cross section of hadron production in SIDIS is determined by five independent variables Q^2, x, z, $P_\perp$, ϕ^γ. Here $-Q^2$ is the virtual photon four-momentum squared, x is the Bjorken scaling variable, z is the ratio of the hadron energy to the photon energy in the laboratory system,

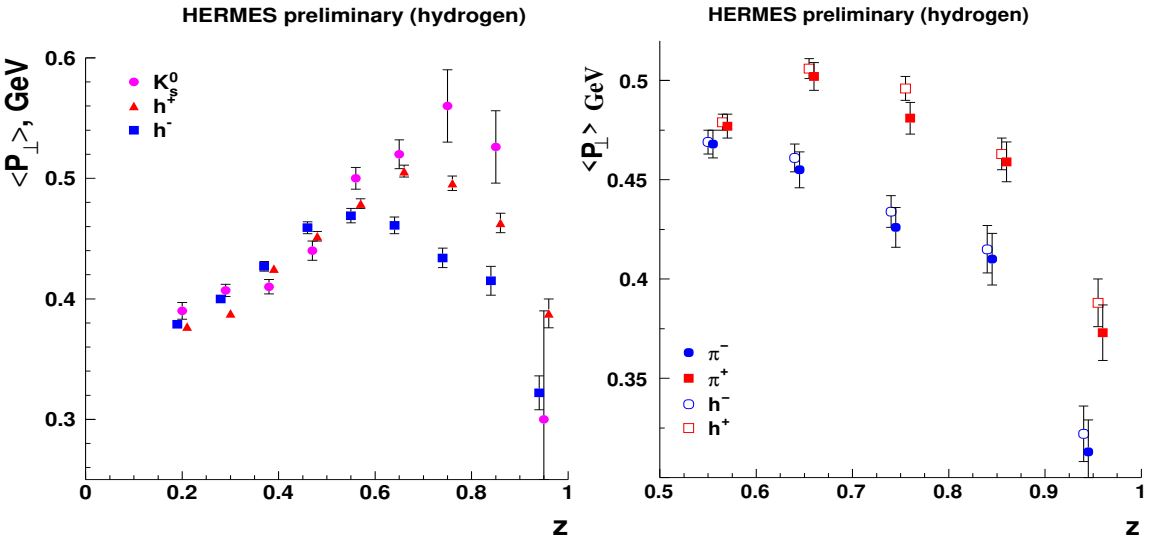

Figure 1: *Behaviour of* $< P_\perp >$ *for* K_s^0 *and* $h^\pm$ *over the full measured z-range (left). Comparison of* $h^\pm$ *and* $\pi^\pm$ *data in the high-z range (right).*

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and $P_\perp = |\vec{P}_\perp|$ is the transverse momentum of the hadron h with respect to the direction of the photon. The azimuthal angle ϕ^γ is the angle between the positron scattering plane and the hadron production plane, both having the direction of the virtual photon in common.

The analysis of the experimental data was based on a multi-dimensional unfolding procedure. The radiative corrections to $P_\perp$ and to the number of events observed in every bin have been calculated with the programs GMC and POLRAD2 [1]. The main systematic uncertainties are those related to the unfolding procedure and they were estimated to be less than 1.5% for $h^\pm-$ production. The systematic uncertainty due to the ϕ^γ-dependence of the cross section and the detector efficiency is less than 1%. Other uncertainties (particle misidentification, cut dependence of the results etc.) are smaller compared to these numbers. For K_s^0 production the total systematic uncertainty is less than 3%.

All systematic uncertainties have been added in quadrature to the statistical errors, the combined values are shown in the figures.

2.1 Dependence of $< P_\perp >$ *on z*

From the left panel of Fig. 1 the z-dependences of $< P_\perp >$ for h^+, h^- and K_s^0 can be seen to be similar for $0.2 < z < 0.6$. In this region $< P_\perp >$ increases approximately linearly with z. The main part of the statistics is located in this region of z so that the slopes of the cross sections versus $P_\perp^2$ are approximately equal to each other for all particles considered above.

For $z > 0.6$ HERMES data show a significant difference in the dependence of $< P_\perp >$ on z for h^+, h^- and K_s^0: the average transverse momenta of h^+ and K_s^0 are higher than that for h^-. It appears worth noting that some indication of this effect exists in the SLAC [2] and EMC [3] data already, albeit the large statistical uncertainties precluded a clear statement.

The pion fraction in the hadronic events is about 80-90% for $z > 0.6$. From Fig. 1 (right) can be seen that within statistical uncertainties $< P_\perp >$ for pion and hadron agrees with one another, for both charges. In principle, the difference between π^+ and π^- can be, at least partially, caused by exclusive processes. However, Fig. 2 (left) shows that the application of different cuts in the missing mass up to 2 GeV does not change the observed difference of $< P_\perp >$ between π^+ and π^-.

The difference of $< P_\perp >$ between π^+ and π^- could possibly be related to the fragmentation process. Indeed, usually the contribution of u-quarks dominates in deep inelastic lepton-nucleon scattering and u-quarks can create π^+-mesons in a one-step process picking up $\bar{d}$-quarks from

the vacuum. In contrast, a u-quark producing a π^- needs at least a three-step process: the u-quark radiates first a gluon that subsequently converts into a $d\bar{d}$-pair from which the d-quark then picks up a $\bar{u}$-quark from the vacuum. The transverse momentum acquired in such a three-stage process is on average greater than that in the one-step process, while Q^2, y and z remain unaffected. Hence the transverse momenta of π^- should be higher than that of π^+ at large z, where few-step processes are more important than at low z where multi-step processes dominate. While Monte Carlo simulations confirm these qualitative considerations, the experimental data are in the strong contradiction with this picture; $< P_\perp >$ for π^+ is measured to be greater than that for π^-. This presumably means that the difference of $< P_\perp >$ between h^+ and h^- is not a result of some difference in their fragmentation.

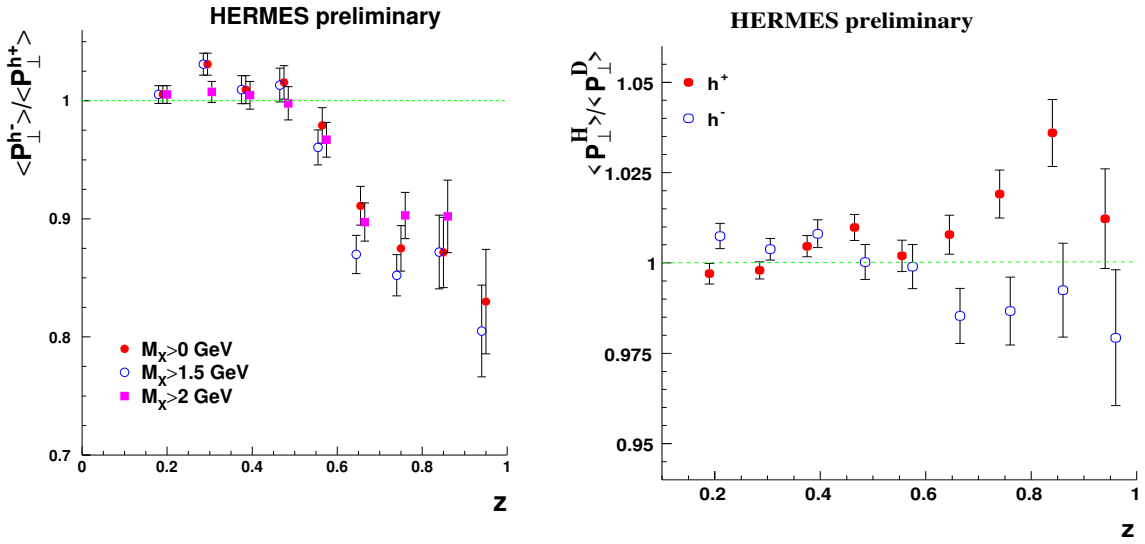

Figure 2: *Ratios of $< P_\perp >$ for h^- and h^+ vs. z for different cuts on M_X (left) and ratios of $< P_\perp >$ for hydrogen and deuterium targets vs. z for h^+ and h^- (right).*

The assumption that the transverse momentum distribution of quarks in the nucleon is strongly flavour-dependent would manifest itself in a difference of $< P_\perp >$ for differently charged leading mesons in SIDIS at high z. If then the difference in $< P_\perp >$ between π^+ and π^- is related to the difference of the internal transverse momenta of u- and d-quarks, a dependence of $< P_\perp >$ on the target isospin may be anticipated. Indeed, the HERMES data indicate that such a tendency might exist, as can be seen from Fig. 2 (right). The following MC parameters were tuned to arrive at a decent description of the data: the average intrinsic momenta for u- and d-quarks, average fragmentation transverse momentum and minimal mass of the string system. Neither z- nor $x-$dependences of $< P_\perp >$ could be described satisfactorily in the full kinematic region and the obtained parameters for u- and d-quarks ($< q_\perp^u >= 0.54$ GeV and $< q_\perp^d >= 0.16$ GeV) are so much different from one another that they appear unrealistic.

2.2 Dependence of $< P_\perp >$ on x

Figure 3 shows the x-dependence of $< P_\perp >$ for h^+, h^- and K_S^0 produced on hydrogen for different z-cuts. As can be seen from Fig. 3 (left), the x-dependences of $< P_\perp >$ for h^+ and h^- coincide within the statistical uncertainty. Applying instead the cut $z > 0.6$, the relative contribution of the primordial transverse momentum of the initial quarks to $< P_\perp >$ is increased. A clear difference of $< P_\perp >$ between h^-, h^+ and K_s^0 appears at large z, see Fig. 3 (right). No significant x-dependence of $< P_\perp >$ can be observed in the region $z > 0.6$, this agrees well with the factorization property of the transverse and longitudinal momentum distributions of quarks in the nucleon.

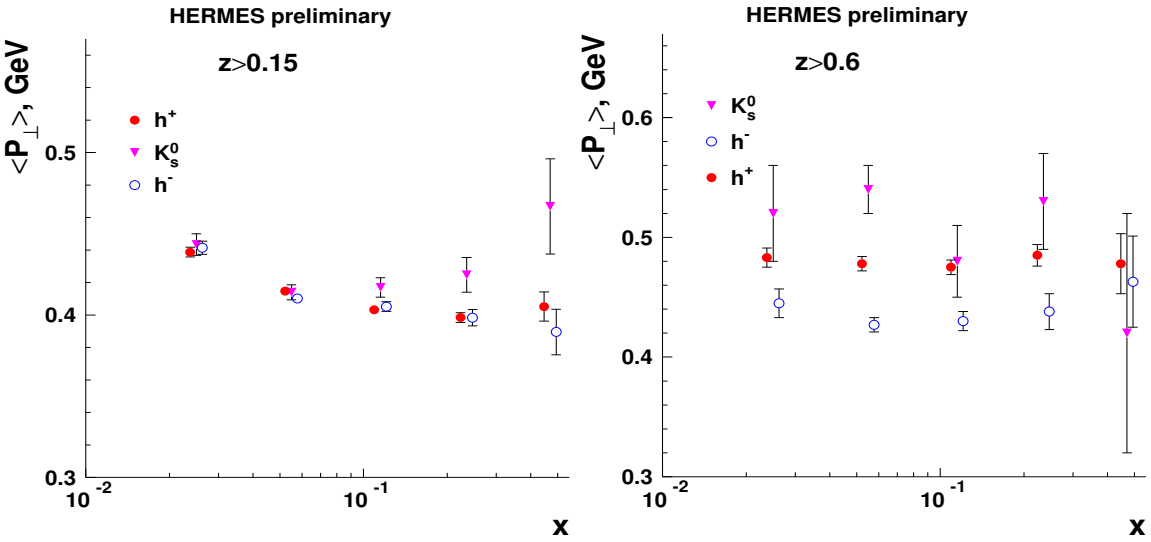

Figure 3: $< P_\perp >$ *for* K_s^0 *and* $h^\pm$ *vs. x for a hydrogen target, shown for* $z > 0.15$ *(left) and* $z > 0.6$ *(right).*

3 Conclusions

The main features of the behaviour of average transverse momenta as seen in the HERMES data are the following:

- Similar behaviour of average transverse momenta of K_s^0, h^+, and h^- at $z < 0.5$.
- A clear difference of $< P_\perp >$ between positive and negative hadrons for $z > 0.6$.
- The LUND model of fragmentation predicts a higher transverse momentum for h^- than for h^+ at $z > 0.6$, while HERMES data show the opposite.
- The difference in $< P_\perp >$ for h^+, h^- and K_s^0 can be explained by the hypothesis that the internal transverse momentum distributions of quarks in the nucleon are flavour dependent. The difference of $< P_\perp >$ between h^+ and h^- observed in DIS on hydrogen and deuterium targets does not contradict this hypothesis.

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