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A STUDY OF THE NUCLEAR MEDIUM INFLUENCE ON TRANSVERSE MOMENTUM OF HADRONS PRODUCED IN DEEP INELASTIC NEUTRINO SCATTERING

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Abstract

Agababyan N.M. , Ammosov V.V., Atayan M. et al. A Study of the Nuclear Medium Influence on Transverse Momentum of Hadrons Produced in Deep Inelastic Neutrino Scattering: IHEP Preprint 2004–34. – Protvino, 2004. – p. 13, figs. 7, tables 4, refs.: 31.

The influence of nuclear effects on the transverse momentum (p_T) of neutrinoproduced hadrons is investigated using the data obtained with SKAT propane-freon bubble chamber irradiated in the neutrino beam (with E_ν = 3–30 GeV) at Serpukhov accelerator. It has been observed, that the nuclear effects cause an enhancement of $< p_T^2 >$ of hadrons produced in the target fragmentation region at low invariant mass of the hadronic system ($2 < W < 4$ GeV) and at low energies transferred to the hadrons ($2 < \nu < 9$ GeV). At higher W and ν, no influence of nuclear effects on $< p_T^2 >$ is observed. Measurement results are compared with predictions of a simple model, incorporating secondary intranuclear interactions of hadrons, which qualitatively reproduces the main features of the data.

Аннотация

Агабабян Н.М., Аммосов В.В., Атаян М. и др. Изучение влияния ядерной среды на поперечный импульс адронов в глубоконеупругом рассеянии нейтрино: Препринт ИФВЭ 2004–34. – Протвино, 2004. – 13 с., 7 рис., 4 табл., библиогр.: 31.

Изучено влияние ядерных эффектов на поперечный импульс (p_T) адронов, образованных нейтрино в эксперименте на пропан-фреоновой пузырьковой камере СКАТ, экспонированной в нейтринном пучке (E_ν = 3–30 ГэВ) Серпуховского ускорителя. Полученные данные свидетельствуют о том, что ядерные эффекты вызывают увеличение $< p_T^2 >$ адронов, образованных в области фрагментации мишени при малых величинах инвариантной массы адронной системы ($2 < W < 4$ GeV) и при малой энергии, переданной адронам ($2 < \nu < 9$ ГэВ). При больших W и ν влияния ядерных эффектов на $< p_T^2 >$ не наблюдается. Основные особенности полученных данных качественно воспроизводятся простой моделью, учитывающей вторичные внутриядерные взаимодействия адронов.

1. Introduction

The experimental study of the hadron production in deep inelastic scattering (DIS) of leptons on nuclei is an important source of information on the space-time evolution of the leptoproduced quark strings. Depending on the features of the latter, the nuclear medium influences differently the inclusive spectra of final hadrons, in particular, affecting their yields and the mean transverse momentum in various domains of the phase space. Hitherto no detailed data inferred in the same experiment are available for transverse momentum distributions in the lepton-nucleus DIS. This gap is partly filled by the present work, where the influence of the nuclear effects on the transverse momentum of neutrinoproduced hadrons is explored using the data collected in the neutrino experiment with bubble chamber SKAT.

In Section 2, the experimental procedure is briefly described. The experimental results are presented in Section 3, discussed in Section 4 and summarized in Section 5.

2. Experimental procedure

The experiment was performed with SKAT bubble chamber [1], exposed to a wideband neutrino beam obtained with a 70 GeV primary protons from the Serpukhov accelerator. The chamber was filled with a propan-freon mixture containing 87 vol% propane (C_3H_8) and 13 vol% freon (CF_3Br) with the percentage of nuclei H:C:F:Br = 67.9:26.8:4.0:1.3 %. A 20 kG uniform magnetic field was provided within the operating chamber volume.

Charged current interactions, containing a negative muon with momentum $p_\mu > 0.5$ GeV are selected. Other negatively charged particles are considered to be π^--mesons. Protons with momentum below 0.6–0.65 GeV/c and a fraction of protons with momentum up to 0.85 GeV/c were identified by their stopping in the chamber. More details concerning the experimental procedure, in particular, the event selection criteria and the reconstruction of the neutrino energy E_ν could be found in our previous publications [2,3,4,5]. Each event is given a weight (depending on the charged particle multiplicity) which corrects for the fraction of events excluded due to improperly reconstruction.

For further analysis the events with $3 < E_\nu < 30$ GeV were accepted, provided that the invariant mass of the hadronic system $W > 2$ GeV and the transfer momentum squared $Q^2 > 1$ (GeV/c)^2. The full sample consists of 2222 events (3167 weighted events). The mean values of

the kinematical variables are: $< E_\nu > = 10.8$ GeV, $< Q^2 > = 3.6$ (GeV/c)^2, $< W > = 3.0$ GeV, $< W^2 >= 9.5$ GeV^2, and, for the energy ν transferred to the hadronic system, $< \nu >= 6.5$ GeV.

The whole event sample is subdivided, using several topological and kinematical criteria [4,5], into three subsamples: the "cascade" subsample B_S with a sign of intranuclear secondary interactions, the "quasiproton" (B_p) and "quasineutron" (B_n) subsamples, the latters two composing the "quasinucleon" subsample ($B_N \equiv B_p + B_n$) for which no sign of secondary interactions is observed. The corresponding event numbers for B_S, B_p and B_n subsamples are 1190, 477 and 555 (weighted numbers $N_S = 1736$, $N_p = 680$ and $N_n = 751$), respectively.

About 40% of subsample B_p is contributed by interactions with free hydrogen. Weighting the "quasiproton" events with a factor of 0.6, one can compose a "pure" nuclear sample: $B_A = B_S + B_n + 0.6B_p$ (with an effective atomic weight $\bar{A} = 28$). It could be also shown [4,5], that a subsample composed as $B_D = B_n + 0.6B_p$ approximately corresponds to the neutrino-deuterium interactions.

3. Experimental results

In present analysis the identified protons are not included. All rest positively (labelled as h^+) and negatively (labelled as π^-) charged hadrons are given the pion mass m_π. The transverse momentum p_T of hadrons is defined with respect to the weak current direction given by the vector difference of the neutrino and muon momenta.

In Fig. 1a the p_T^2-distributions for h^+ and π^- are plotted for the whole sample of events. Both distributions are fitted to the form $exp[-b(p_T^2 + m_\pi^2)^{1/2}]$, with parameter $b(h^+) = 5.57 \pm 0.06$ and $b(\pi^-) = 7.48\pm$ 0.15 GeV^{-1}, respectively. The latters are close to those extracted from the neutrino interactions with a heavier composite target (CF_3Br) at the same incident energies [6]. The p_T^2- distributions for the B_S subsample are less steeper than for the B_N subsample (both shown in Figs. 1b and 1c), owing to an additional transverse momentum acquired by final hadrons in the intranuclear scattering processes. These distributions can be also fitted to the same form resulting in $b_S(h^+) = (5.30\pm\ 0.08)$ and $b_S(\pi^-) = (7.22 \pm 0.21)$ GeV^{-1} for the "cascade" subsample which are by about 10–15% smaller than those in the "quasinucleon" subsample, $b_N(h^+) = (6.06 \pm 0.10)$ and $b_N(\pi^-) = (7.99 \pm 0.25)$ GeV^{-1}.

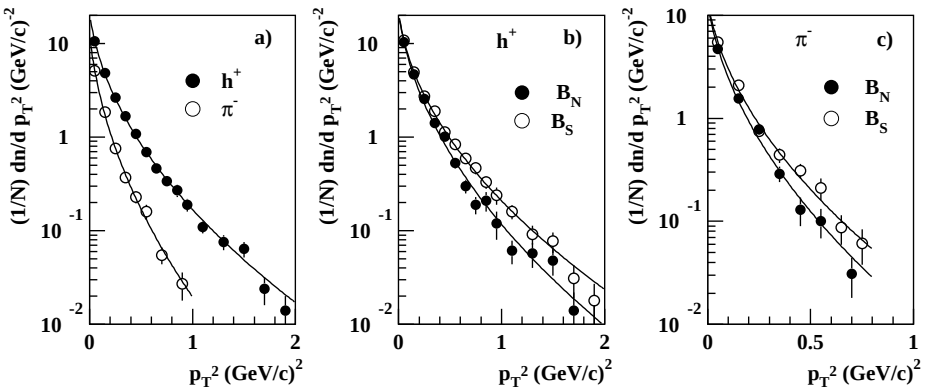

Figure 1. The p_T^2–distributions of h^+ and π^- for the whole event sample **(a)**, h^+ for B_N and B_S subsamples **(b)**, π^- for B_N and B_S subsamples **(c)**. Lines are results of the fit (see text).

Fig. 2 shows the p_T^2-distributions for charged hadrons ($h^{\pm}$) produced in the current quark and the target fragmentation regions (with Feynman variable $x_F > 0$ and $x_F < 0$, respectively). While at $x_F > 0$ the parameter b is almost the same for subsamples B_N and B_S, $b_N(x_F > 0) = (6.57 \pm 0.12)$ (GeV/c)$^{-1}$ and $b_S(x_F > 0) = (6.43 \pm 0.13)$ (GeV/c)$^{-1}$, at $x_F < 0$ $b_S(x_F < 0) = (5.29 \pm 0.10)$ (GeV/c)$^{-1}$ is by 16% smaller than $b_N(x_F < 0) = (6.13 \pm 0.15)$ (GeV/c)$^{-1}$. The values of $b_N(x_F > 0)$ and $b_N(x_F < 0)$ for the "quasinucleon" subsample B_N are consistent with those measured in νp [7] and νD [8] interactions at somewhat higher $< W^2 >$.

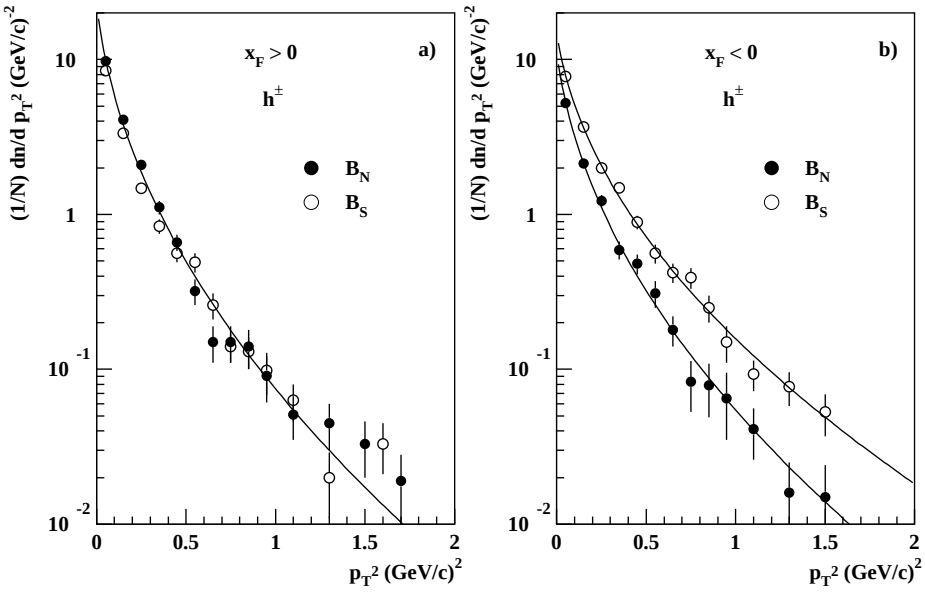

Figure 2. The p_T^2–distributions of charged hadrons for B_N and B_S subsamples at $x_F > 0$ **(a)** and $x_F < 0$ **(b)**. Lines are results of the fit (see text).

More informative (with respect to the nuclear effects) are the values of $< p_T^2 >$ collected in Table 1 for several subsamples and various regions of x_F and W^2. As it is seen, the nuclear effects influence faintly the $< p_t^2 >$ for π^- mesons, as well as for h^+ with $x_F > 0$ both in low ($4 < W^2 < 9$ GeV^2) and high ($9 < W^2 < 25$ GeV^2) regions of W^2. On the contrary, the $< p_T^2 >$ for h^+ with $x_F < 0$ increases by $\Delta(p_T^2) =< p_T^2 >_S - < p_T^2 >_N = (0.061 \pm 0.013)$ (GeV/c)^2 due to the secondary intranuclear interactions. One should emphasize, that this rise is more prominent at $W^2 < 9$ GeV^2, where $\Delta(p_T^2) = (0.077 \pm 0.016)$ (GeV/c)^2, than at $W^2 > 9$ GeV^2, where $\Delta(p_T^2) = (0.043 \pm 0.021)$ (GeV/c)^2. This is in accordance with the recent observations [4,5,9] that the effects of the secondary intranuclear interactions are weakening with increasing of W^2.

Another consequence of the intranuclear interactions is that the region of $x_F > 0$ turns out to be somewhat depleted, while the region of $x_F < 0$ enriched for the subsample B_S relative to the subsample B_N. This can be clearly seen from the data on the mean multiplicities presented in Table 2. The depletion and enrichment effects can be characterized by the ratios $\rho(x_F > 0) = < n(x_F > 0) >_S / < n(x_F > 0) >_N$ and $\rho(x_F < 0) =< n(x_F < 0) >_S / < n(x_F < 0) >_N$, respectively. For π^- mesons, the depletion effect is rather weak, $\rho^-(x_F > 0) = 0.92 \pm 0.05$, while the multiplicity gain at $x_F < 0$ reaches $\rho^-(x_F < 0) = 1.66 \pm 0.11$. Slightly larger effects are observed for positively charged hadrons: $\rho^+(x_F > 0) = 0.83 \pm 0.02$ and $\rho^+(x_F < 0) = 1.80 \pm 0.08$. Note, that latter value can be somewhat influenced by the contamination from

the non-identified recoil protons emitted during the secondary interaction processes. The lower limit of the mean multiplicity of these protons, evaluated from the identification efficiency for protons with $0.6 < p_p < 0.85$ GeV/c (almost all having $x_F < 0$), turns out to be about 5% of $< n_{h^+}(x_F < 0) >_S$. The data of Table 2 also indicate that the depletion and enrichment effects depend on W only slightly.

Table 1. The mean values of $< p_T^2 >$ in (GeV/c)^2 of h^+ and π^- for several subsamples and various regions of x_F and W^2.

	$< p_T^2 >_N$	$< p_T^2 >_S$	$< p_T^2 >_D$	$< p_T^2 >_A$
		$4 < W^2 < 25$ GeV^2		
$h^+(x_F > 0)$	0.180±0.006	0.190±0.007	0.182±0.007	0.187±0.005
$\pi^-(x_F > 0)$	0.129±0.009	0.128±0.008	0.131±0.009	0.129±0.006
$h^+(x_F < 0)$	0.207±0.009	0.268±0.009	0.205±0.009	0.252±0.007
$\pi^-(x_F < 0)$	0.126±0.009	0.141±0.008	0.127±0.009	0.137±0.006
		$4 < W^2 < 9$ GeV^2		
$h^+(x_F > 0)$	0.163±0.007	0.170±0.007	0.161±0.007	0.166±0.005
$\pi^-(x_F > 0)$	0.101±0.009	0.119±0.010	0.104±0.009	0.113±0.007
$h^+(x_F < 0)$	0.189±0.011	0.266±0.011	0.186±0.011	0.245±0.008
$\pi^-(x_F < 0)$	0.106±0.009	0.127±0.009	0.108±0.009	0.122±0.007
		$9 < W^2 < 25$ GeV^2		
$h^+(x_F > 0)$	0.205±0.012	0.217±0.013	0.214±0.013	0.216±0.009
$\pi^-(x_F > 0)$	0.154±0.015	0.134±0.013	0.156±0.016	0.144±0.010
$h^+(x_F < 0)$	0.228±0.015	0.271±0.014	0.229±0.016	0.259±0.011
$\pi^-(x_F < 0)$	0.149±0.018	0.157±0.019	0.151±0.018	0.155±0.011

To compare our data with the results of other experiments, as well as to extract quantitative characteristics of the secondary intranuclear interactions, the data on $< p_T^2 >$, corresponding to νD and νA interactions, $< p_T^2 >_D$ and $< p_T^2 >_A$, respectively, are presented in Table 1. The values of $< p_T^2 >_D$ and $< p_T^2 >_A$ are defined as

$$< p_T^2 >_D = \frac{0.6 N_p}{N_D} < p_T^2 >_p + \frac{N_n}{N_D} < p_T^2 >_n , \quad (1)$$

$$< p_T^2 >_A = \frac{N_D}{N_A} < p_T^2 >_D + \frac{N_S}{N_A} < p_T^2 >_S . \quad (2)$$

Here $N_D = N_n + 0.6 N_p$, $N_A = N_S + N_D$ and $< p_T^2 >_p$ and $< p_T^2 >_n$ are the values of $< p_T^2 >$ for subsamples B_p and B_n, respectively.

Table 2. The mean multiplicities of h^+ and π^- for several subsamples and various regions of x_F and W^2.

	$< n >_N$	$< n >_S$	$< n >_D$	$< n >_A$
		$4 < W^2 < 25$ GeV^2		
$h^+(x_F > 0)$	1.441±0.023	1.198±0.023	1.402±0.023	1.279±0.017
$\pi^-(x_F > 0)$	0.449±0.019	0.412±0.017	0.474±0.019	0.437±0.013
$h^+(x_F < 0)$	0.725±0.023	1.303±0.036	0.677±0.023	1.052±0.024
$\pi^-(x_F < 0)$	0.325±0.017	0.541±0.022	0.339±0.018	0.460±0.015
		$4 < W^2 < 9$ GeV^2		
$h^+(x_F > 0)$	1.349±0.026	1.106±0.027	1.319±0.026	1.193±0.019
$\pi^-(x_F > 0)$	0.325±0.019	0.309±0.018	0.360±0.021	0.329±0.014
$h^+(x_F < 0)$	0.632±0.027	1.172±0.040	0.589±0.027	0.935±0.027
$\pi^-(x_F < 0)$	0.277±0.019	0.480±0.024	0.295±0.020	0.405±0.016
		$9 < W^2 < 25$ GeV^2		
$h^+(x_F > 0)$	1.596±0.042	1.349±0.042	1.545±0.042	1.425±0.030
$\pi^-(x_F > 0)$	0.660±0.036	0.579±0.032	0.671±0.036	0.615±0.024
$h^+(x_F < 0)$	0.883±0.043	1.516±0.066	0.829±0.043	1.248±0.044
$\pi^-(x_F < 0)$	0.408±0.032	0.640±0.041	0.417±0.033	0.553±0.028

The average multiplicities $< n >_A$ and $< n >_D$ are defined similarly (see Table 2). The measured values of $< p_T^2 >_A - < p_T^2 >_D$ and $< n >_A - < n >_D$ will be compared with theoretical predictions in Section 4.

The dependence of the mean value of $< p_T^2 >$ of charged hadrons (combined h^+ and π^-) on the DIS kinematical variables W^2 and ν is presented in Figs. 3 and 4. It is seen from Fig. 3a, that $< p_T^2 >$ for particles with $x_F > 0$ increases with W^2, as it was observed in earlier investigations with neutrino and muon beams [8,10,11,12,13,14]. At the considered range of W^2, this rise is essentially caused by increase in the available phase space. With increasing of W^2, the QCD effects are predicted [15] to play more and more significant role in the rise of $< p_T^2 >$. The data show (Figs. 3a and 3c), that the nuclear effects practically do not influence $< p_T^2 >$ at $x_F > 0$. On the contrary, they cause a significant increase of $< p_T^2 >$ at $x_F < 0$ in the region of $W^2 < 15$ GeV^2, where the difference $< p_T^2 >_A - < p_T^2 >_D$ is about 0.04 (GeV/c)^2 and practically independent of W^2.

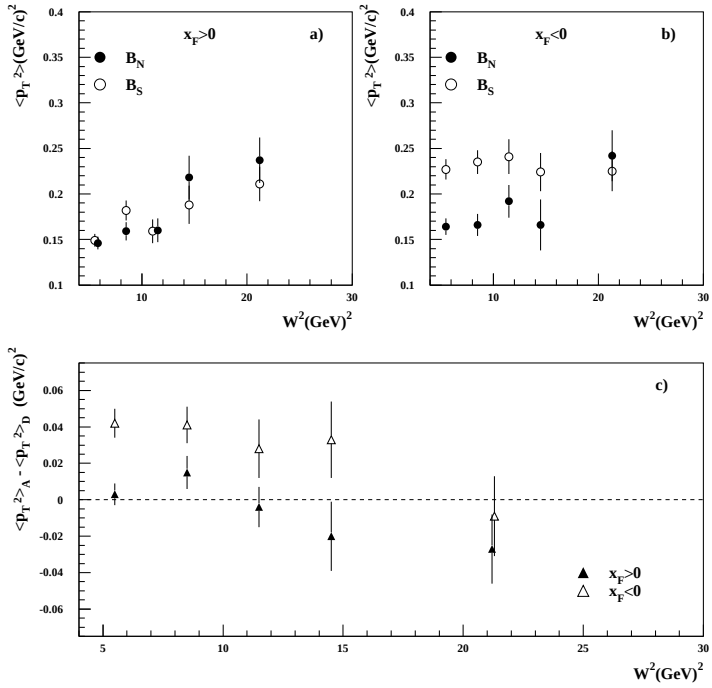

Figure 3. The W^2–dependence of $< p_T^2 >$ at $x_F > 0$ for B_N and B_S subsamples **(a)**, $< p_T^2 >$ at $x_F < 0$ for B_N and B_S subsamples **(b)**, the difference $< p_T^2 >_A - < p_T^2 >_D$ **(c)**.

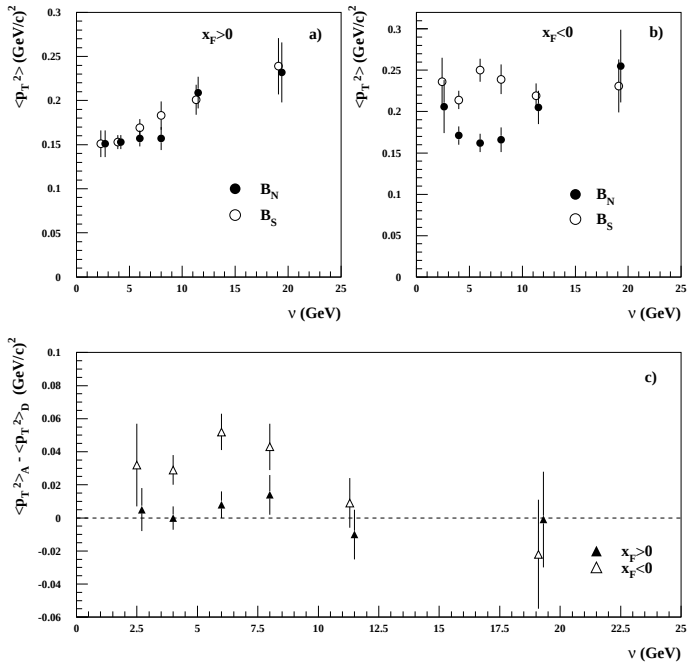

Figure 4. The ν–dependence of $< p_T^2 >$ at $x_F > 0$ for B_N and B_S subsamples **(a)**, $< p_T^2 >$ at $x_F < 0$ for B_N and B_S subsamples **(b)**, the difference $< p_T^2 >_A - < p_T^2 >_D$ **(c)**.

The dependence of $< p_T^2 >$ on ν (see Fig. 4) reveals analogous significant nuclear effects for particles with $x_F < 0$ in the region of $\nu < 9$ GeV, where the difference $< p_T^2 >_A - < p_T^2 >_D$ is around (0.03-0.05) (GeV/c)^2. At ν higher than 9 GeV, the nuclear effects on $< p_T^2 >$ are negligible. As for particles with x_F >0, the effects of secondary intranuclear interactions practically do not influence $< p_T^2 >$.

The dependence of $< p_T^2 >$ for charged hadrons on their kinematical variables is presented in Figs. 5 and 6.

The dependence of $< p_T^2 >$ on x_F (Fig. 5a) has a typical "seagull" form (cf., for example, [6,11]), both for B_N and B_S subsamples. For the latter, a small part (about 3%) of positively charged hadrons occupies the region of $x_F <$ -1, kinematically forbidden for reactions on a free nucleon (the so called "cumulative" region), where $< p_T^2 >_S$ reaches a rather high value of $< p_T^2 >_S \sim$ 0.6 (GeVc)^2. About third of these cumulative hadrons are estimated to be non-identified protons with $0.6 < p_p < 0.85$ GeV/c and $< p_T^2 > =$ (0.51±0.06) (GeV/c)^2. It is seen from Fig. 5b, that the influence of nuclear effects is significant only at $x_F <$ -0.6, where the difference $< p_T^2 >_A - < p_T^2 >_D$ is about (0.07±0.03) (GeV/c)^2.

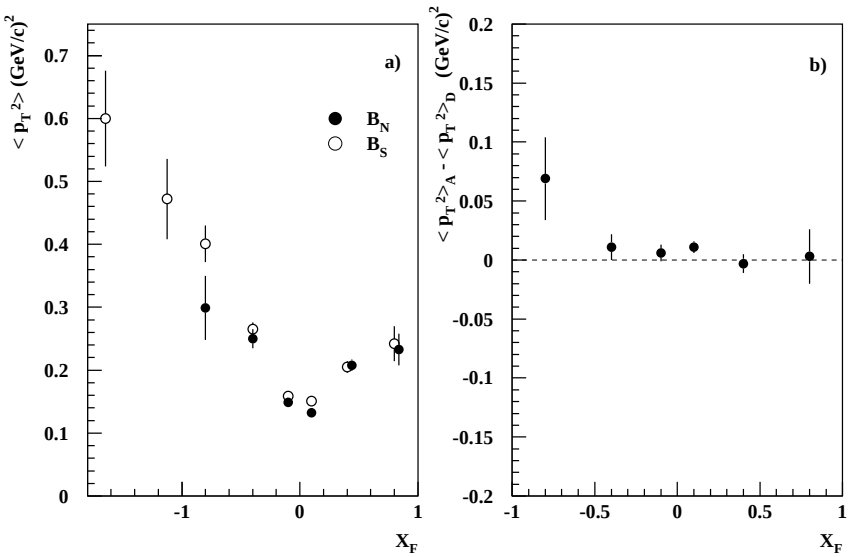

Figure 5. The x_F–dependence of $< p_T^2 >$ for B_N and B_S subsamples **(a)**, the difference $< p_T^2 >_A - < p_T^2 >_D$ **(b)**.

Fig. 6 shows the dependences of $< p_T^2 >_N$, $< p_T^2 >_S$ and $< p_T^2 >_A - < p_T^2 >_D$ on the variable $z = E_h/\nu$, the fraction of the current quark energy carried by the hadron. The rise of $< p_T^2 >_N$ with z for forward hadrons (Fig. 6c), observed earlier in [10,11,13], is mainly caused by the intrinsic transverse momentum of the current quark inside the nucleon [16] (see Section 4 for details). It is seen from Fig. 6b, that the secondary intranuclear interactions induce a significant difference of $< p_T^2 >_A - < p_T^2 >_D$ almost in the whole range of z. The rise of $< p_T^2 >_A - < p_T^2 >_D$ at $0 < z < 0.3$ is contributed by particles with $x_F < 0$ (cf. Fig. 6f), while its fall at $z > 0.3$ is caused by the increasing contribution of forward particles for which the difference $< p_T^2 >_A - < p_T^2 >_D$ is rather small (Fig. 6d), in accordance with recent observations in deep inelastic scattering of muons and positrons on light and intermediate mass nuclei [17,18].

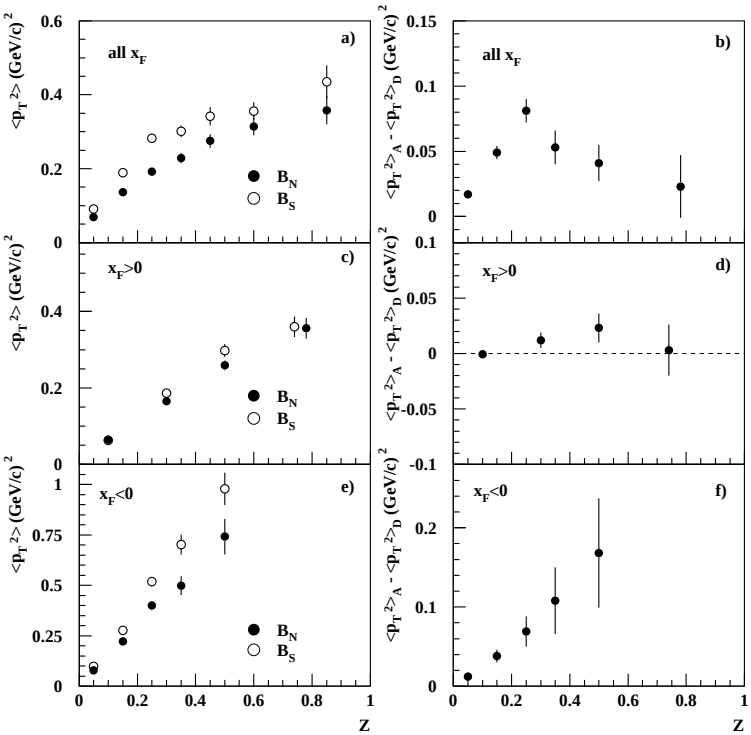

Figure 6. The z-dependence of $< p_T^2 >$ for B_N and B_S subsamples **(a, c, e)** and of the difference $< p_T^2 >_A - < p_T^2 >_D$ **(b, d, f)**.

4. Model calculation and discussion

The data on $< p_T^2 >_N$ of hadrons with x_F >0 in the subsample B_N were checked to be consistent with the conventional picture of the quark string fragmentation (see e.g. [16] for review). According to the latter, the z- dependence of $< p_T^2 >_N$ for leading hadrons (containing the current quark) can be parameterized as [19]:

$$< p_T^2 >_N = < p_T^2 >_{Frag} + z^2 < k_T^2 > + < p_T^2 >_{QCD} \ , \tag{3}$$

where $< p_T^2 >_{Frag}$ is the contribution from the fragmentation process, k_T is the primordial transverse momentum of the current quark inside the nucleon, while $< p_T^2 >_{QCD}$ is the contribution of QCD effects (involving hard gluon emission and $q\bar{q}$ production). At W^2 available in this experiment ($W^2 < 25$ GeV^2), the latter term can be approximately parameterized as [20]

$$< p_T^2 >_{QCD} = a(W^2 - W_0^2) \ , \tag{4}$$

with $a = 3.5 \cdot 10^{-3}$ (GeV/c)^2 and $W_0^2 = 2$ GeV^2.

Fig. 7 shows the z^2- dependence for $< p_T^2 >$ of positively charged hadrons in the current fragmentation region for two intervals of W^2, $W^2 < 9$ GeV^2 and $W^2 > 9$ GeV^2 (containing approximately equal statistics). The data for fast hadrons (with $z^2 > 0.16$), containing with

a high probability the current quark, are fitted to dependence (3). The QCD term in (3) was fixed according to (4). At $z^2 > 0.16$ the mean value of $< W^2 >$ in present experiment is practically independent of z^2: $< W^2 > \approx 6$ GeV^2 leading to $< p_T^2 >_{QCD} = 0.014$ (GeV/c)^2 for the region $W^2 < 9$ GeV^2, and $< W^2 > \approx 14$ GeV^2 leading to $< p_T^2 >_{QCD} = 0.042$ (GeV/c)^2 for the region $W^2 > 9$ GeV^2. The fit results are plotted in Figs. 7a and 7b. The fitted values of $< p_T^2 >_{Frag}$ and $< k_T^2 >$ turn out to be independent of W^2 within statistical uncertainties: $< p_T^2 >_{Frag} = (0.17 \pm 0.03)$ (GeV/c)^2, $< k_T^2 > = (0.23 \pm 0.10)$ (GeV/c)^2 at $W^2 < 9$ GeV^2, and $< p_T^2 >_{Frag} = (0.22 \pm 0.07)$ (GeV/c)^2, $< k_T^2 > = (0.30 \pm 0.19)$ (GeV/c)^2 at $W^2 > 9$ GeV^2. The quoted values of $< k_T^2 >$ are consistent with those extracted from the data on νp [21] and μp [22,23] deep inelastic scattering at higher W^2 ($16 < W^2 < 400$ GeV^2). The values of $< p_T^2 >_{Frag}$ are also consistent with that estimated in [21], however somewhat underestimate the value of $< p_T^2 >_{Frag} = 0.274 \pm 0.059$ extracted from e^+e^- annihilation at the LEP energies [24].

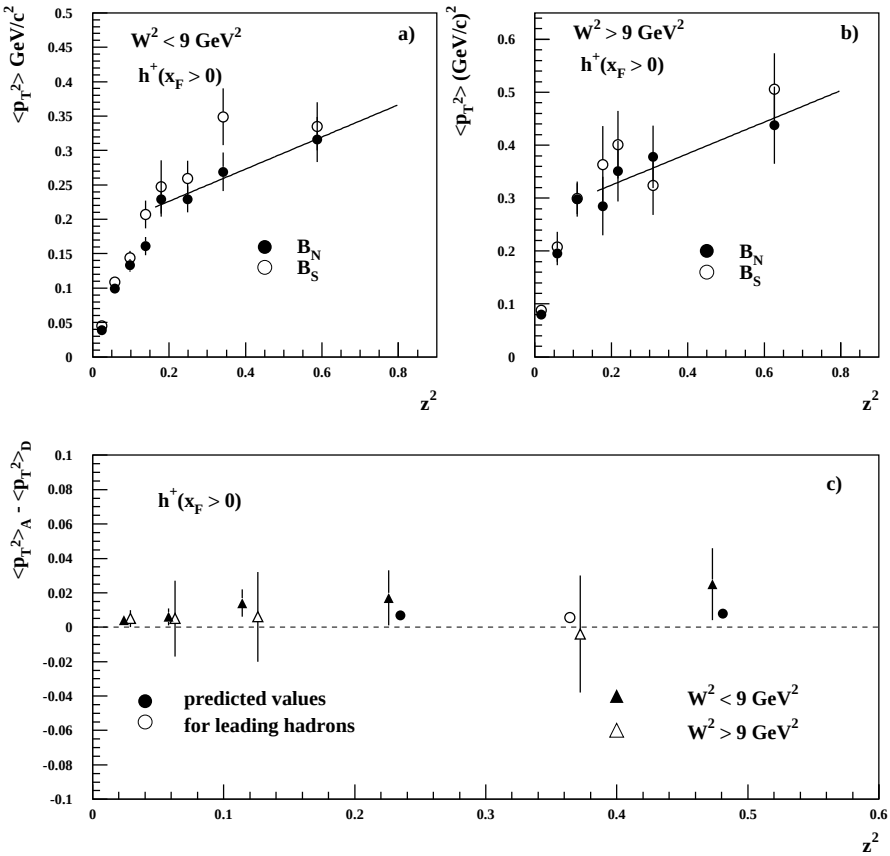

Figure 7. The z^2–dependence of $< p_T^2 >$ **(a,b)** and $< p_T^2 >_A - < p_T^2 >_D$ **(c)** of positively charged hadrons with $x_F > 0$. The lines in Figs. 7a ($W^2 < 9$ GeV^2) and 7b ($W^2 > 9$ GeV^2) are the fit results (see text). The two full circles in Fig. 7c are predictions for leading particles with $0.16 < z^2 < 0.3$ and $z^2 > 0.3$ at $W^2 < 9$ GeV^2. The empty circle is a prediction for particles with $z^2 > 0.2$ at $W^2 > 9$ GeV^2.

In Fig. 7c the difference $< p_T^2 >_A - < p_T^2 >_D$ versus z^2 is plotted. The data at low W^2, $W^2 < 9$ GeV^2, indicate, that the additional transverse momentum, acquired by forward hadrons (with $x_F > 0$) due to the intranuclear interactions, slightly increases with z, while at larger $W^2 > 9$ GeV^2 no significant nuclear effects are observed.

Below an attempt is undertaken to describe the obtained experimental data on differences $< n >_A - < n >_D$ and $< p_T^2 >_A - < p_T^2 >_D$, which characterize the strength of nuclear effects, with the help of a simple model incorporating the secondary intranuclear interactions of produced pions [25]. We assume that the formation lenght l_π of pions is determined [26] in the framework of the Lund fragmentation model [27]:

$$l_\pi = \nu\, z[\frac{ln(1/z^2) - 1 + z^2}{1 - z^2}]\,/k\,, \tag{5}$$

where $k \approx 1$ GeV/fm is the quark string tension. The expression (5) has a maximum at $z \approx 0.3$ and behaves as $l_\pi \approx 2\nu\, z \ln(0.61/z)/k$ at $z < 0.2$ and approximately (with an accuracy better than 20%) as $l_\pi \approx \nu\,(1-z)\,/k$ at $z > 0.5$. The latter behaviour (predicted also in [28]) was found to be consistent with recent experimental data [4,5,29]. We assume, that a pion can interact in the nucleus, starting from the distance l_π from the νN scattering point. The model considers both elastic and inelastic interactions of pions with $x_F > 0$ produced in the νN scattering and having relatively large momenta, while only the elastic scattering of pions with $x_F < 0$ (having small momenta) is considered. The contribution from non-identified recoil protons (the overwhelming part of which occupies the region of $x_F < 0$) is taken into account also.

A comparison with the experimental data is given in Tables 3 and 4. As it is seen from Table 3, a reasonable consistency with the data on $< n(x_F > 0) >_A \; - \; < n(x_F > 0) >_D$ is observed. Particularly, the model predicts a stronger depletion for the yield of h^+ than for π^- in the forward hemisphere in agreement with the data. The data description at $x_F < 0$ is worse. The model overestimates the enhancement of the π^- yield at $W^2 < 9$ GeV^2 by factor two, but is in agreement with the data at $W^2 > 9$ GeV^2 within experimental uncertainties. On the other hand, the predicted value of $< n_{h^+}(x_F < 0) >_A \; - \; < n_{h^+}(x_F < 0) >_D$ agrees with the measured one at $W^2 < 9$ GeV^2, but underestimates significantly that at $W^2 > 9$ GeV^2. Nevertheless, the model reproduces the nuclear depletion and enhancement effects for the yield of h^+ and π^- qualitatively and, in particular, predicts, in accordance with the experimental observation, these effects to be more significant for h^+ than for π^-. The model describes satisfactorily the data on the difference $< p_T^2 >_A - < p_T^2 >_D$ (Table 4). In particular, the model reproduces rather small values of this difference at $x_F > 0$, as well as the data for π^- mesons with with $x_F < 0$.

The predicted values of $< p_T^2 >_A - < p_T^2 >_D$ for leading particles (with $z^2 > 0.16$) shown in Fig. 7c are, in agreement with the data, rather small and do not contradict the trend of the latters with variation of z^2 and W^2.

Finally, one needs to note, that although the applied model reproduces the majority of the experimental data (presented in Tables 3 and 4 and Fig. 7c), it is rather crude and uses several simplified assumptions which should be summarized: i) the calculations concerning the secondary intranuclear interactions are performed for fixed average momenta of π^+– and π^-– mesons, $\bar{p}_{\pi^\pm}(x_F > 0)$ and $\bar{p}_{\pi^\pm}(x_F < 0)$, instead of more extensive calculations averaged over the momentum spectra; ii) the second-order effects of two or more intranuclear collisions of a pion are neglected; iii) the model does not incorporate the production of hadronic resonances, in particular, ρ mesons (composing about 10% of charged pions [30,31]), with a proper space-time structure of their formation, intranuclear interactions and decay.

Table 3. The measured and predicted differences $< n >_A - < n >_D$ at $x_F > 0$ and $x_F < 0$.

Range of W^2(GeV^2)	Particle type	$< n >_A - < n >_D$ measured	calculated
4< W^2 <9	$h^+(x_F > 0)$	-0.123±0.019	-0.136±0.045
	$\pi^-(x_F > 0)$	-0.037±0.015	-0.008±0.032
	$h^+(x_F < 0)$	0.375±0.025	0.407±0.084
	$\pi^-(x_F < 0)$	0.121±0.017	0.241±0.069
9< W^2 <25	$h^+(x_F > 0)$	-0.119±0.036	-0.059±0.041
	$\pi^-(x_F > 0)$	-0.056±0.029	-0.006±0.039
	$h^+(x_F < 0)$	0.418±0.048	0.284±0.051
	$\pi^-(x_F < 0)$	0.136±0.032	0.186±0.044

Table 4. The measured and predicted differences $< p_T^2 >_A - < p_T^2 >_D$ at $x_F > 0$ and $x_F < 0$.

Range of W^2(GeV^2)	Particle type	$< p_T^2 >_A - < p_T^2 >_D$(GeV/$c$)^2 measured	calculated
4< W^2 <9	$h^+(x_F > 0)$	0.005±0.006	0.003±0.008
	$\pi^-(x_F > 0)$	0.009±0.008	0.001±0.011
	$h^+(x_F < 0)$	0.059±0.009	0.032±0.019
	$\pi^-(x_F < 0)$	0.014±0.008	0.036±0.024
9< W^2 <25	$h^+(x_F > 0)$	0.002±0.011	0.000±0.012
	$\pi^-(x_F > 0)$	-0.012±0.013	-0.002±0.015
	$h^+(x_F < 0)$	0.030±0.013	0.010±0.016
	$\pi^-(x_F < 0)$	0.004±0.008	0.016±0.019

5. Summary

New experimental data concerning the influence of the nuclear medium on the transverse momentum of neutrinoproduced hadrons are presented.

The p_T^2-distribution of hadrons (both positively and negatively charged) is less steeper in "cascading" (and "nuclear") than in "quasinucleon" (and "quasideuteron") interactions. While in the quark fragmentation region (x_f >0) these subsamples have just the same p_T^2-distributions.

The influence of the nuclear medium on the dependence of $< p_T^2 >$ on kinematical variables of the DIS and of final hadrons is studied. The nuclear effects, leading to an enhancement of $< p_T^2 >$, are more prominent for the following ranges of variables:

– for $x_F < 0$ at $W^2 < 15$ GeV^2 or $\nu < 9$ GeV, while no significant enhancement of $< p_T^2 >$ is observed at higher W^2 or ν;
– for $x_F <$ -0.6, while at $x_F >$ -0.6 the manifestation of nuclear effects is faint;
– practically for the whole range of z.

The observed z^2–dependence of $< p_T^2 >_N$ for fast hadrons in the "quasinucleon" subsample follows the conventional picture of the quark string fragmentation. The extracted parameters governing the transverse momentum of produced hadrons, $< p_T^2 >_{Frag} = (0.19\pm0.03)$ (GeV)^2 and $< k_T^2 > = (0.24\pm0.09)$ (GeV)^2 (estimated for the whole range of $4 < W^2 < 25$ GeV^2), are compatible with values obtained at higher energies.

The experimental data on nuclear effects are compared with predictions of a simple model incorporating the secondary intranuclear interactions of produced hadrons with the formation length taken into account. The model predicts a depletion of the particle yield at $x_F > 0$ and an enhancement of that at $x_F < 0$ (more pronounced for positively charged hadrons for both regions of $x_F > 0$ and $x_F < 0$) in agreement with the data. The model describes satisfactory also the data on the difference $< p_T^2 >_A - < p_T^2 >_D$ both for h^+ and π^- with $x_F > 0$ and $x_F < 0$, as well as for the leading particles with $z > 0.4$.

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