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N.M. Agababyan [1], V.V. Ammosov, N. Grigoryan [2],
H. Gulkanyan [2], A.A. Ivanilov *, Zh. Karamyan [2],
V.A. Korotkov

A STUDY OF THE DOUBLE HADRON NEUTRINOPRODUCTION ON NUCLEI

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[1] Joint Institute for Nuclear Research, Dubna, Russia
[2] Yerevan Physics Institute, Armenia
* E-mail: ivanilov@mx.ihep.su

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Abstract

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The nuclear medium influence on the dihadron neutrino charged current production is investigated using the data obtained with SKAT bubble chamber. An indication is obtained that the nuclear attenuation of the dihadron production is more expressed for kinematically closest hadron pairs. The experimental data are compared with predictions of the string model.

Аннотация

Агабабян Н.М., Григорян Н., Иванилов А.А. и др. Изучение парного рождения адронов во взаимодействиях нейтрино с ядрами: Препринт ИФВЭ 2010–8. – Протвино, 2010. – 10 с., 5 рис., библиогр.: 14.

Изучено влияние ядерной среды на парное рождение адронов во взаимодействиях нейтрино через заряженный ток на основе данных, полученных на пузырьковой камере СКАТ. Получено указание на то, что ядерное ослабление образования пары адронов более выражено для кинематически близких пар. Экспериментальные данные сравниваются с предсказаниями струнной модели.

1. INTRODUCTION

The space-time structure of the quark string fragmentation in leptoproduction reactions imposes certain correlations between two-hadron formation processes. A unique information on the latter can be inferred from experiments on nuclear targets ([1–4] and references therein). The first measurements of the dihadron leptoproduction performed recently [5] using a 27.6 GeV positron beam with nuclear targets showed that the available theoretical models do not satisfactorily describe the experimental data, especially on heavier targets.

The aim of the present work is to obtain the first experimental data on the dihadron neutrinoproduction at comparatively lower energies where the nuclear attenuation effects are expected to be more prominent. To this end, the data from the SKAT bubble chamber [6] were used. In Section 2 the experimental procedure is described. Section 3 presents the data on the dihadron attenuation versus its relative and collective kinematic variables. In Section 4 the data on the dihadron to single hadron ratio are compared with theoretical predictions. The results are summarized in Section 5.

2. EXPERIMENTAL PROCEDURE

The experiment was performed with SKAT bubble chamber exposed to a wideband neutrino beam obtained with a 70 GeV primary protons from the Serpukhov accelerator. The chamber was filled with a propane-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/c were selected. Other negatively charged particles were considered to be π^- mesons. Protons with momentum below 0.6 GeV/c and a fraction of protons with momentum 0.6–0.85 GeV/c were identified by their stopping in the chamber. To non-identified positively charged particles the pion mass was assigned. All negatively and positively charged particles (except identified protons) are labelled, respectively, as h^- and h^+. Events with errors in measuring the momenta of all charged secondaries and photons less than 27% and 100%, respectively, were selected. Each event was given a weight to correct for the fraction of events excluded due to improperly reconstruction. More details concerning the experimental procedure, in particular the reconstruction of the neutrino energy E_ν, can be found in our previous publications [7,8].

The events with $3 < E_\nu < 30$ GeV were accepted provided that the reconstructed mass W of the hadronic system exceeds 2 GeV and $y = \nu/E_\nu < 0.95$, ν being the energy transferred to the hadronic system. No restriction was imposed on the transfer momentum squared Q^2. The number of accepted events was 3469 (4852 weighted events). The contamination from the neutral current (NC) interactions to the selected event sample was estimated to be (2.6±0.2)%. The mean values of the kinematic variables were $\langle E_\nu \rangle$ = 10.0 GeV, $\langle W \rangle$ = 2.9 GeV, $\langle W^2 \rangle$ = 9.1 GeV^2, $\langle Q^2 \rangle$ = 2.7 (GeV/c)^2 and $\langle \nu \rangle$ = 5.8 GeV.

The nuclear attenuation effects studied below are inferred with the help of a comparison of the dihadron characteristics in two event subsamples: the nuclear subsample (B_A) and quasinucleon subsample (B_N) composed using a number of topological and kinematic criteria [8, 9]. The B_N subsample includes events with no indication of the nuclear disintegration or a secondary intranuclear interaction: the total charge of secondary hadrons is required to be $q = +1$ (for the subsample B_n of interactions with a neutron) or $q = +2$ (for the subsample B_p of interactions with a proton), while the number of recorded baryons (these included identified protons and Λ -hyperons, along with neutrons that suffered a secondary interaction in the chamber) was forbidden to exceed unity, baryons flying in the backward hemisphere being required to be absent among them. Moreover, a constraint was imposed on the effective target mass $M_t < 1.2$ GeV/c^2, the M_t being defined as $M_t = \Sigma(E_i - p_i^L)$ where the summation is performed over the energies E_i and the longitudinal momenta p_i^L (along the neutrino direction) of all recorded secondary particles. Events that did not satisfy aforementioned criteria were included in the subsample B_S of cascade events. As a result, the weighted numbers of the B_p, B_n and B_S proved to be 1119, 1124 and 2609, the NC contamination being 4.3%, 3.2% and 1.7%, respectively.

The validity of the selection of the B_p and B_n subsamples was verified [8, 9, 10] by comparison of a large number of the multiplicity and spectral characteristics of hadrons in these subsamples with the available data obtained on hydrogen and deuterium targets, resulting in a satisfactory agreement and giving a sufficient ground to conclude that the B_p and B_n subsamples may contain only a minor contamination from events where the secondary intranuclear interactions deteriorate the characteristics of the primary hadrons. We checked the sensitivity of the dihadron characteristics (presented in the next sections) relative to the choice of the boundary value of M_t, varying the latter from 1.1 to 1.4 GeV/c^2, e.g. changing the event numbers in the B_p, B_n and B_S subsamples and continuously increasing the contamination from secondary interactions in the subsamples B_p and B_n (see Fig. 1 in [9]). We found that the variation of the dihadron characteristics have been on an average fivefold smaller as compared to the statistical errors.

As it follows from the composition of the propane-freon mixture about 36% of subsample B_p is contributed by interactions with free hydrogen (at the ratio of νn and νp CC cross sections being equal to 2). Weighting the quasiproton events with a factor of 0.64, one can compose a pure nuclear subsample $B_A = B_S + B_n + 0.64B_p$ and a quasinucleon subsample $B_N = B_n + 0.64B_p$. As it follows from the percentage of C, F and Br nuclei in the propane-freom mixture the mean atomic weight of the composite target $\overline{A} = 27.6$ for neutrinonuclear interactions. However, since the nuclear attenuation effects are under consideration, it seems more relevant to introduce an effective nucleus $A_{\rm eff}$ in which the probability of the hadron absorption is the same, as that obtained from averaging over the target nuclei. The calculations (see [11] for details) result in $19 \leq A_{\rm eff} \leq 23$, depending on the momentum of the neutrinoproduced hadron. Therefore $A_{\rm eff} \approx 21$ provides a proper comparison with other data.

3. THE NUCLEAR ATTENUATION VERSUS DIHADRON RELATIVE AND COLLECTIVE KINEMATIC VARIABLES

Below we will consider hadrons produced in the forward hemisphere in the hadronic c.m.s. (i.e. in the region of $x_{\rm F} > 0$, $x_{\rm F}$ being the Feynman variable), because in this region the nuclear attenuation effects for hadrons dominate over multiplication effects which lead to an enhancement of their yield, observable in the region of $x_{\rm F} < 0$ (see e.g. [8,10]).

In this section we present the data which demonstrate the nuclear medium influence on the inclusive dihadron yield in dependence on relative and collective kinematic variables describing the double-hadron system. For a given relative or collective variable v the nuclear influence is characterized by the ratio $R_2(v) = n_2^A(v)/n_2^N(v)$, where $n_2^A(v)$ and $n_2^N(v)$ are the dihadron differential mean multiplicities (yields) in the nuclear and quasinucleon subsamples, respectively.

Fig. 1 demonstrates the dependence of R_2 on the relative kinematic variables of two hadrons: $\Delta x_{\rm F} = |x_{\rm F1} - x_{\rm F2}|$ and $\Delta z = |z_1 - z_2|$, z_1 and z_2 being the fractions of the quark energy ν carried by hadrons. In this and next figures below only statistical errors are plotted. The systematic uncertainties related to the contamination of the B_N subsample caused by secondary interactions play a unsignificant role (see Section 2). It should be also noted, that smearing effects caused by experimental resolutions of variables $x_{\rm F}$ and z (as well as other kinematic variables discussed below) are largely cancelled in the ratio R_2 being negligible as compared to the statistical errors.

The data are presented separately for the like-sign (h^+h^+), unlike-sign (h^+h^-) and charged (hh) hadron pairs. The most interesting feature of the data of Fig. 1 is that the attenuation of the unlike-sign pair produced in the quark fragmentation region (at $x_{\rm F} > 0.15$) tends to strengthen with decreasing relative kinematic variables (the middle panels of Fig. 1). This tend, as it can be seen from the middle panels of Fig. 1, kepts also after exclusion of h^+h^- pairs with effective masses 0.7–0.85 GeV/c^2 which could originate from the ρ^0 meson decay. The said feature is less expressed for the like-sign pairs (the top

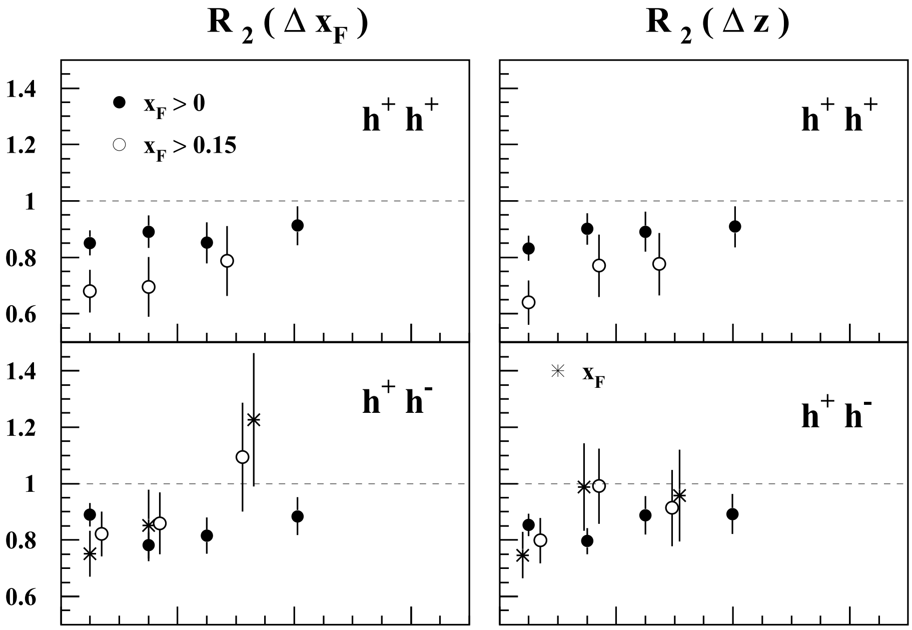

Figure 1. The dependence of the dihadron attenuation factor R_2 on $\Delta x_{\rm F}$ (left panel) and Δz (right panel). The curve is the model prediction (see text).

panels of Fig. 1). Note also, that no definite dependence of R_2 on the relative kinematic variables is observed at a less strict cut $x_{\rm F} > 0$.

Fig. 2 shows the ratio R_2 versus the collective kinematic variables of the dihadron $x_{\rm F}^{\rm pair}$ and $z^{\rm pair}$. For the case of $x_{\rm F} > 0.15$ no significant dependence on collective variables is observed except a possible rise of R_2 with increasing $z^{\rm pair}$ (the right panel of Fig. 2). For the case of the cut $x_{\rm F} > 0$ the value R_2 is consistent with 1 at the smallest value of $x_{\rm F}^{\rm pair}$ and $z^{\rm pair}$.

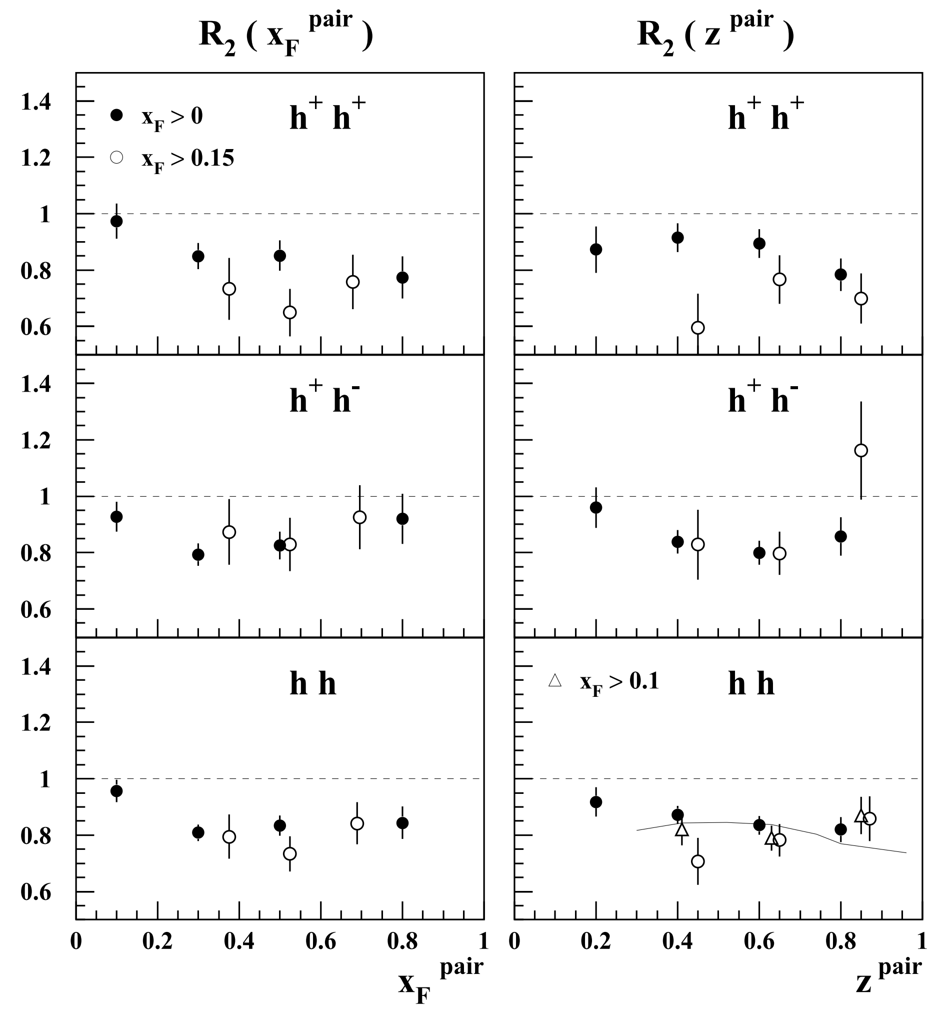

Figure 2. The dependence of the dihadron attenuation factor R_2 on $x_F^{\rm pair}$ (left panel) and $z^{\rm pair}$ (right panel). The curve is the model prediction (see text).

4. THE RESULTS ON THE DOUBLE RATIO

For a given variable v the nuclear influence is also characterized by the ratio $R_2(v_1, v_2) = n_2^A(v_1, v_2)/n_2^N(v_1, v_2)$ of the dihadron differential yields $n_2^A(v_1, v_2)$ and $n_2^N(v_1, v_2)$

in the nuclear and quasinucleon subsamples. Theoretical predictions ([3, 4]) and experimental data ([5]) exist for the double ratio

$$r_{21}(z_1, z_2) = \frac{R_2(z_1, z_2)}{R_1(z_1)} \tag{1}$$

where the ratio $R_1(z) = n_1^A(z)/n_1^N(z)$ is the inclusive single-hadron attenuation factor.

Before presenting the data on the double ratio it will be useful to consider separately the single-hadron and dihadron attenuation factors $R_1(z_1)$ and $R_2(z_1, z_2)$. The latter are plotted in Fig. 3 for charged hadrons with $x_F > 0.1$. The values of $R_1(z_1)$ are quoted numerically and indicated by dashed lines which represent one standard deviation boundary. As it is seen, in general $R_2(z_1, z_2) < R_1(z_1)$ due to the additional attenuation of the yield of the accompanying hadron with $z = z_2$.

As it was already mentioned in the previous section, the attenuation is more expressed for kinematically close pairs, in particular at $0.12 < z_1(z_2) < 0.24$ and $0.24 < z_1(z_2) < 0.34$ (Fig. 3, top panel). Similar observations can be done from Fig. 4 where the double ratio $r_{21}(z_1, z_2)$ is plotted as a function of z_1 and z_2 for charged hadrons with $x_F > 0.1$.

The double ratio $r_{21}(z_1, z_2)$ was measured in electronuclear interactions [5] at $z_1 > 0.5$ for the leading trigger particle and $z_2 = z_{sub}$ for the subleading particle, being the fastest one among particles accompanying the leading particle. Fig. 5 presents the data of [5] on the nitrogen target ($A = 14$) for charged hadron combinations (the top panel) and, in the bottom panel, for all pion combinations (including π^0 mesons), except h^+h^-, in order to exclude the contribution from the ρ^0 decay. In the same figure we also plot our data for charged hadron combinations (the top panel), for combinations including also π^0 mesons (the middle panel), and the same but without combinations from the ρ mass region. As it is seen, our data are mainly compatible with electroproduction data, exhibiting however an enhancement at the region of low z_2, probably due to the more pronounced intranuclear cascading effects in a slightly heavier composite target ($A_{eff} \approx 21$) used in our experiment.

We undertook an attempt to describe our data on $R_1(z)$, $R_2(z_1, z_2)$ and the double ratio $r_{21}(z_1, z_2)$ in the framework of the Two-Scale Model (TSM) [12] (see also [4]) which incorporates the space-time pattern of the quark string fragmentation followed from the Lund model [1, 13]. The TSM contains four free parameters: the quark string tension κ and the following string-nucleon interaction cross sections, namely, σ_q for the initial string stretched between the struck quark and the target nucleon remnant, σ_s for the intermediate string stretched between the struck quark and a created antiquark (which becomes a valence one for the hadron being looked at) and σ_h for the formed colorless system with quantum numbers and valence content of the final hadron. The TSM predictions presented below concern pions and pion pairs.

First of all we checked the compatibility of our data on the single hadron attenuation factor with the TSM. A reasonable description of the data on $R_1(z)$ for hadrons with $x_F > 0.1$ (Fig. 3) can be reached at the following set of the model parameters: $\kappa =$ 0.8 GeV/fm, $\sigma_q = 0$, $\sigma_s = 10$ mb and $\sigma_h = 20$ mb (note, that this set somewhat differs from those estimated in [12] and [4]). The TSM predictions for $R_2(z_1, z_2)$ and $r_{21}(z_1, z_2)$,

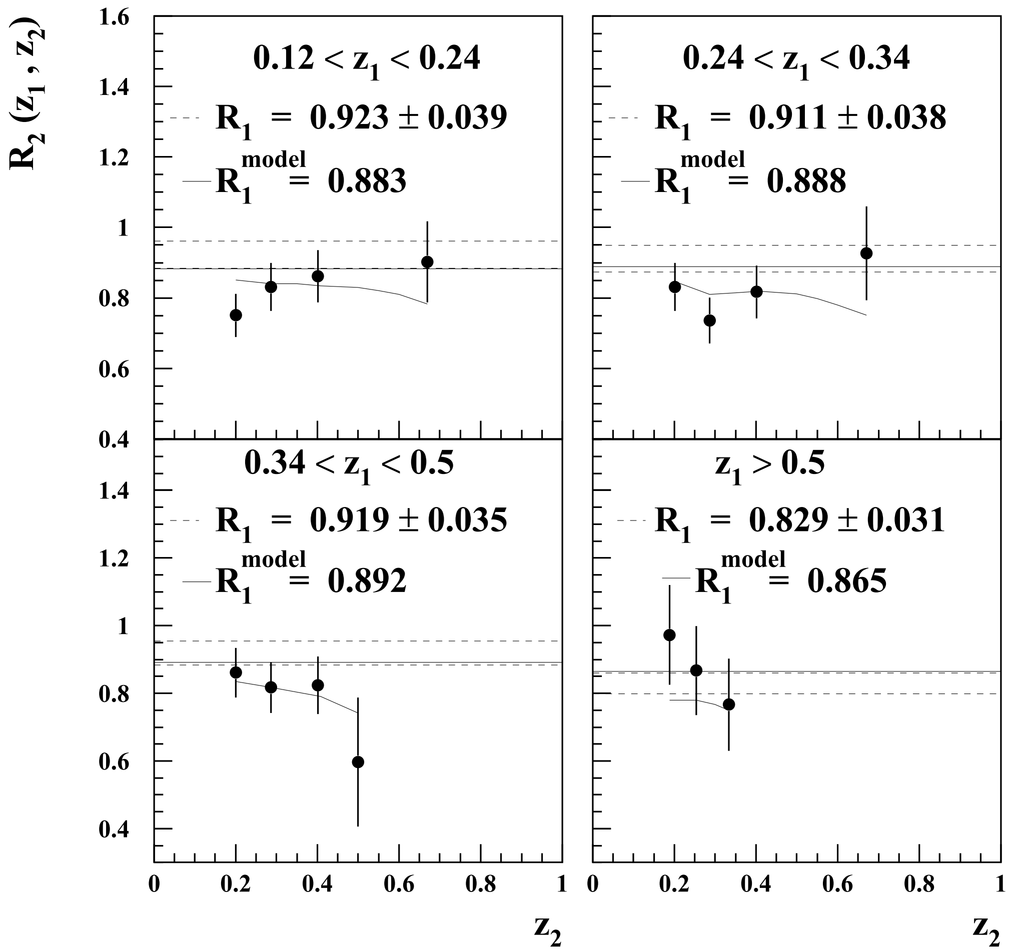

Figure 3. The dependence of the dihadron attenuation factor $R_2(z_1, z_2)$ as a function of z_1 (for trigger particle) and z_2 (for accompanying particle). Dashed and solid lines in figures concerns, respectively, experimental boundaries and the model prediction for single-particle attenuation factor $R_1(z)$. The cut $x_{\mathrm{F}} > 0.1$ was applied.

obtained with these parameters, are plotted in Figs. 3, 4 and 5. As it is seen, the model predictions are, in general, compatible with experimental data. The model, however, does not describe the reduced yield of the pair of low z hadrons with $0.12 < z_1(z_2) < 0.24$ (Figs. 3 and 4, the left top panel). A similar inconsistency is also seen for $R_2(\Delta z)$ at low values of variable $\Delta z = |z_1 - z_2|$ for charged hadrons with $x_{\mathrm{F}} > 0.15$ (Fig. 1, the right

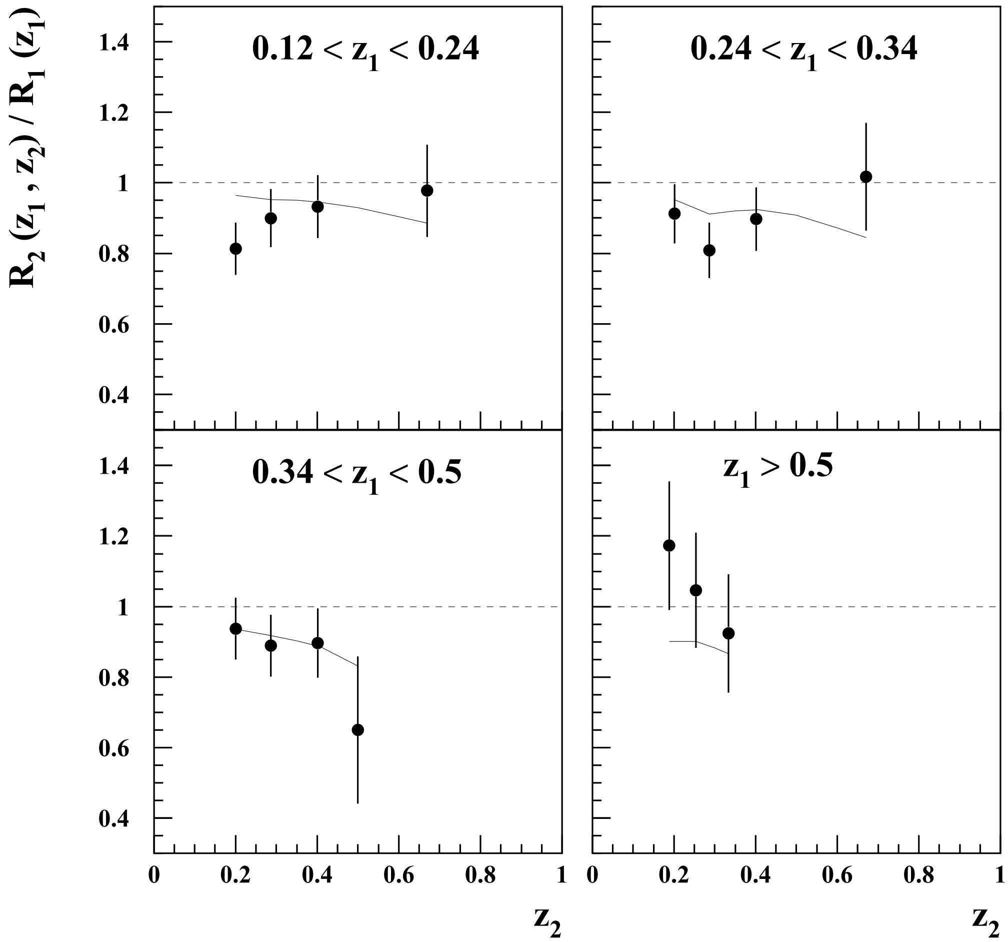

Figure 4. The double ratio $r_{21}(z_1, z_2) = R_2(z_1, z_2)/R_1(z_1)$ as a function of z_1 and z_2. The cut $x_{\mathrm{F}} > 0.1$ was applied.

bottom panel). On the other hand, the model underestimates the value of R_2 (z^{pair}) at largest values on the collective variable $z^{\mathrm{pair}} = z_1 + z_2$ for charged hadrons with $x_{\mathrm{F}} > 0.1$ (Fig. 2, the right bottom panel). Note also, that the data on the double ratio $r_{21}(z_1 > 0.5, z_2)$ at $z_2 < 0.24$ (Fig. 5, the bottom panel) significantly exceed the model predictions, probably due to the fact that the latter do not incorporate the intranuclear cascading processes which could enhance the yield of low z hadrons, as well as due to a possible contamination of the data by non-identified protons. This contamination, however, takes

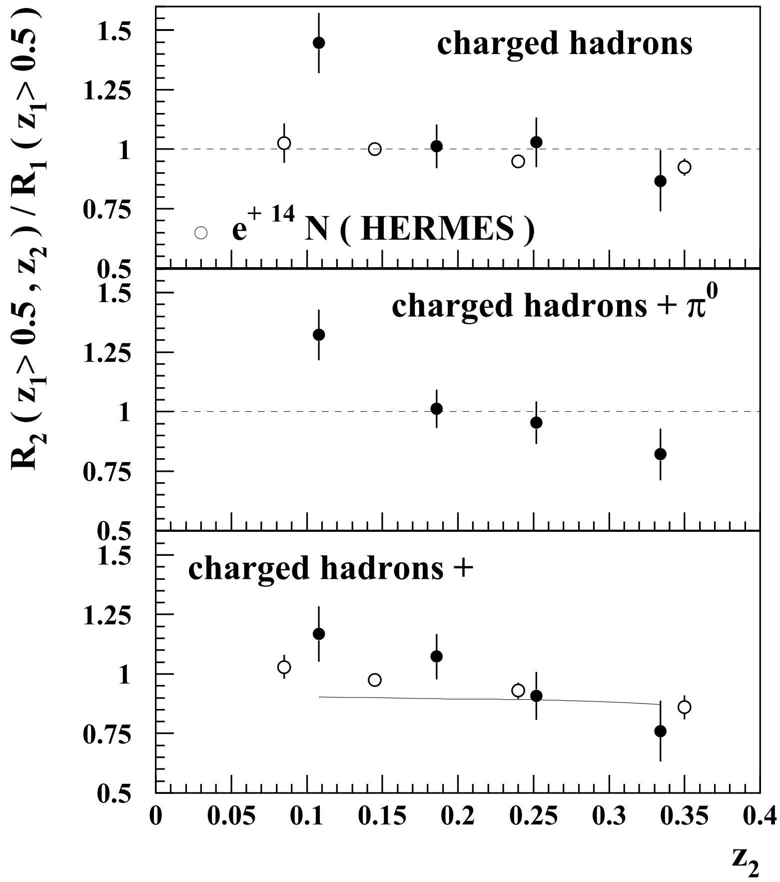

Figure 5. The double ratio $r_{21}(z_1 > 0.5, z_2)$ as a function of z_2 at $z_1 > 0.5$. The cut $x_{\rm F} > 0$ was applied. The curve is a prediction of the two-scale string fragmentation model.

place both in the B_N and B_A subsamples and expected to partly cancel in the R_1 and R_2. To check this expectation, we compared the value of $R_1^{h^+}(x_F > 0) = 0.922 \pm 0.024$ for h^+- particles with $x_F > 0$, measured in our experiment, with that for π^- mesons (under the assumption of charge symmetry) evaluated from the data on antineutrino-neon and antineutrino-nucleon interactions, $R_1^{\pi^-}(x_F > 0) = 0.90 \pm 0.04$ [14]. As it is seen, the attenuation ratio R_1 for positively charged hadrons is practically the same as for an almost pure sample of pions.

5. SUMMARY

For the first time for neutrino-nucleus interactions, the nuclear medium influence on the dihadron production is investigated at an effective atomic weight $A_{\rm eff} \approx 21$ of a composite target.

The dihadron attenuation factor R_2 is measured versus various kinematic variables of the dihadron. An indication is obtained that the nuclear attenuation strengthens with decreasing relative variables of two hadrons reaching about $R_2 \approx 0.7$ for kinematically closest pairs.

It is shown that the experimental data on the attenuation factor $R_2(z_1, z_2)$ and the double ratio $r_{21}(z_1, z_2) = R_2(z_1, z_2)/R_1(z_1)$ are compatible with predictions of the two-scale string fragmentation model, except for the case of pairs of low z hadrons with $0.12 < z_1(z_2) < 0.24$ and pairs of subleading ($z < 0.24$) and leading ($z > 0.5$) hadrons.

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