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THE A-DEPENDENCE OF ρ^0 NEUTRINOPRODUCTION ON NUCLEI

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Abstract

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The A -dependence of ρ^0 meson production in neutrino-induced reactions is investigated for the first time, using the data obtained with SKAT bubble chamber. The nuclear medium influence on the ρ^0 total yield and inclusive distributions on $z = E_\rho/\nu$ and Feynman x_F variable is found to be approximately the same as for pions. It is shown, that these distributions, with increasing A , tend to shift toward smaller values of z and x_F , thus indicating on an increasing role of secondary intranuclear interactions. The predictions of a simplified model incorporating the latter are found to be in qualitative agreement with experimental data.

Аннотация

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Впервые изучена A -зависимость нейтринообразования ρ^0 -мезонов в нейтринных реакциях на основе данных, полученных на пузырьковой камере СКАТ. Найдено, что влияние ядерной среды на полный выход ρ^0 и инклюзивные распределения по $z = E_\rho/\nu$ и фейнмановской переменной x_F примерно такое же, как для пионов. Показано, что эти распределения при увеличении A имеют тенденцию к смещению в область малых значений z и x_F , демонстрируя тем самым возрастание роли вторичных внутриядерных взаимодействий. Предсказания простой модели, учитывающей внутриядерные процессы, находятся в качественном согласии с экспериментальными данными.

1. Introduction

The total yields and inclusive spectra of different species of hadrons in leptonuclear interactions reflect the complicated space-time structure of the quark string fragmentation, the hadron formation and the secondary intranuclear interactions. The experimental investigations on this topic concern mainly stable hadrons (pions, kaons, (anti)protons). Meanwhile, the data concerning hadronic resonances (being, predominantly, direct products of the quark string fragmentation) can provide a valuable additional information about the nuclear medium influence on the leptonproduction processes. Hitherto, no data are available for the A-dependence of the total yields and inclusive spectra of hadronic resonances in lepton-induced reactions.

This work is devoted to the study, for the first time, of the A-dependence of ρ^0 meson neutrino production on nuclei. To this end, the data from the SKAT bubble chamber are used. In Section 2, the experimental procedure is described. The experimental data on the A-dependence of the total yield and inclusive spectra of ρ^0 are presented in Section 3 and discussed in Section 4. The results are 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 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. Non-identified positively charged particles were considered to be π^+ mesons. Events in which errors in measuring the momenta of all charged secondaries and photons were less than 60% and 100%, respectively, were selected. Each event is given a weight which corrects 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 [2,3].

The events with $3 < E_\nu < 30$ GeV were accepted, provided that the reconstructed mass W of the hadronic system exceeds 2 GeV. No restriction was imposed on the transfer momentum squared Q^2 . The number of accepted events was 4353 (5508 weighted events). The mean values of the kinematical variables were $\langle E_\nu \rangle = 10.7$ GeV, $\langle W \rangle = 3.0$ GeV, $\langle W^2 \rangle = 9.6$ GeV², $\langle Q^2 \rangle = 2.8$ (GeV/c)².

Further, the whole event sample was subdivided, using several topological and kinematical criteria [3,4], into three subsamples: the 'cascade' subsample B_S with a sign of intranuclear secondary interaction, the 'quasiproton' (B_p) and 'quasineutron' (B_n) subsamples. 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 subsample $B_A = B_S + B_n + 0.6B_p$ and a 'quasinucleon' subsample $B_N = B_n + 0.6B_p$. It has been verified [4,5], that the multiplicity and spectral characteristics of secondary particles in the $B_p(B_N)$ subsample are in satisfactory agreement with those measured with a pure proton (deuteron) target. The effective atomic weight corresponding to the subsample B_A is estimated [6] to be approximately equal to $A_{eff} = 21 \pm 2$, when taking into account the probability of secondary intranuclear interactions in the composite target.

In order to extract the A-dependence of the ρ^0 neutrino-production, we use in the next section the data obtained for subsamples B_N and B_A , as well as the published data [7] on neutrino-freon interactions (with $A_{eff} = 45 \pm 2$).

3. The A-dependence of the ρ^0 mean multiplicity and inclusive spectra

The $(\pi^+\pi^-)$ effective mass distribution for subsamples B_N and B_A is plotted in Fig. 1. Clear signals near the ρ^0 mass, as well as faint signals near the $f_0(980)$ mass are seen. The distributions are fitted by expression

$$dN/dM_{\pi^+\pi^-} = BG \cdot (1 + \alpha_\rho \cdot BW_\rho + \alpha_f \cdot BW_f), \quad (1)$$

where the mass dependence of the background distribution is parametrized as

$$BG = \alpha_1 \cdot \exp(\alpha_2 \cdot M + \alpha_3 \cdot M^2), \quad (2)$$

while for BW_ρ and BW_f the corresponding relativistic Breit-Wigner functions [8] for ρ^0 and $f_0(980)$ were used, taking into account the experimental mass resolution $\sigma(M) = 35$ MeV. The mass and width of resonances are fixed as: $M_\rho = 775$ MeV and $\Gamma_\rho = 150$ MeV from the PDG data [9] and $M_f = 963$ MeV and $\Gamma_f = 35$ MeV from the recent NOMAD measurements [10].

The resulting total yields of ρ^0 and $f_0(980)$ are presented in Table 1, where the SKAT data for ρ^0 in neutrino-freon interactions [7] are also given. The data on $f_0(980)$ are corrected for the undetectable mode ($\pi^0\pi^0$). For comparison, the data on the π^- yields are shown too.

The A-dependences of the ρ^0 and π^- yields, plotted in Fig. 2, are rather similar. An exponential parametrization ($\sim A^\beta$) of the yields leads to compatible values of $\beta_{\rho^0} = 0.07 \pm 0.13$ and $\beta_{\pi^-} = 0.052 \pm 0.007$. As a result, no A-dependence of the $\langle \rho^0/\pi^- \rangle$ ratio is observed (the last column of Table 1).

Note, that a comparison with higher-energy neutrino-induced data shows that this ratio tends to increase with increasing W , reaching up to 0.128 ± 0.030 at $\langle W \rangle = 4.8$ GeV [11] and 0.156 ± 0.028 at $\langle W \rangle = 6.1$ GeV [12].

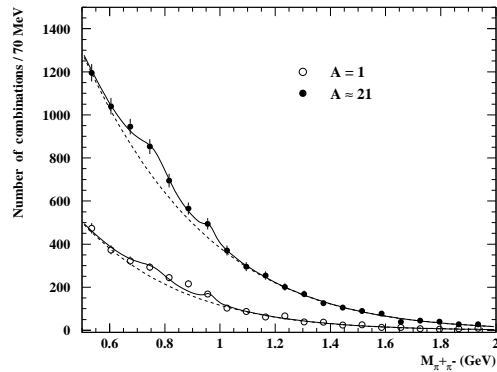


Figure 1. The effective mass distribution for the system $(\pi^+\pi^-)$. The curves are the result of the fit (see the text).

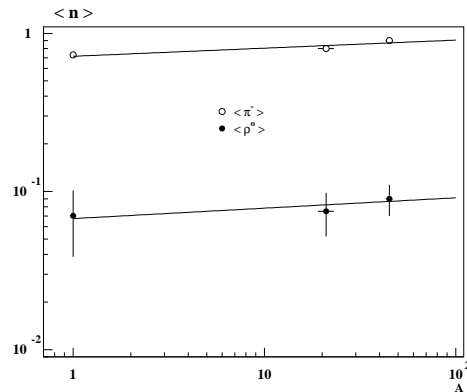


Figure 2. The A -dependence of the total yields of ρ^0 and π^- . The lines are the results of the exponential fit.

Our estimations of the $f_0(980)$ total yield are rather rough. They do not contradict, within the experimental uncertainties, the only published data [10], $\langle n_{f_0(980)} \rangle = 0.018 \pm 0.004$, obtained at higher neutrino energies ($\langle E_\nu \rangle = 45$ GeV).

Table 1. The mean multiplicities of ρ^0 , $f_0(980)$ and π^- and the ratio $\langle n_{\rho^0} \rangle / \langle n_{\pi^-} \rangle$.

A	$\langle n_{\rho^0} \rangle$	$\langle n_{f_0(980)} \rangle$	$\langle n_{\pi^-} \rangle$	$\langle n_{\rho^0} \rangle / \langle n_{\pi^-} \rangle$
1	0.070 ± 0.031	0.030 ± 0.015	0.73 ± 0.02	0.096 ± 0.043
21	0.075 ± 0.023	0.019 ± 0.011	0.80 ± 0.01	0.094 ± 0.029
45	0.09 ± 0.02	—	0.90 ± 0.01	0.10 ± 0.02

Table 2 presents the yields of ρ^0 and π^- and their ratio in the forward ($x_F > 0$, x_F being the Feynman variable) and backward ($x_F < 0$) hemispheres in the hadronic c.m.s. The data on π^- indicate, in accordance with our previous studies (see details in [3,5,6]) a clear depletion in the forward hemisphere (due to the nuclear attenuation) and a significant enhancement in the backward hemisphere (due to the secondary inelastic intranuclear interactions). A faint indication on similar effects are also seen for ρ^0 .

Table 2. The yields of ρ^0 and π^- and their ratio in the forward ($x_F > 0$) and backward ($x_F < 0$) hemispheres.

A_{eff}	$\langle n_{\rho^0} \rangle$	$\langle n_{\pi^-} \rangle$	$\langle n_{\rho^0} \rangle / \langle n_{\pi^-} \rangle$
	$x_F > 0$		
1	0.066 ± 0.026	0.435 ± 0.014	0.15 ± 0.06
21	0.050 ± 0.016	0.399 ± 0.009	0.12 ± 0.04
	$x_F < 0$		
1	0.005 ± 0.017	0.239 ± 0.012	0.02 ± 0.06
21	0.025 ± 0.016	0.402 ± 0.009	0.06 ± 0.04

As it is seen from Table 2 and Fig. 3 where the distributions on x_F for ρ^0 and π^- are plotted, the overwhelming part of ρ^0 in νN interactions and the most part of that in nuclear interactions are produced in the forward hemisphere, as a result of the current quark (u or \bar{d}) fragmentation into a favorable hadron ρ^0 (which can contain the current quark), while the production of the (unfavorable) π^- meson occurs mainly in the central region. As a result, the ratio $\langle \rho^0/\pi^- \rangle$ for the fastest hadrons (with $x_F > 0.5$) significantly exceeds that in other ranges of the variable x_F , as it can be seen from Fig. 4. Note, that a comparison of our data with those obtained at higher energies does not reveal any W -dependence of the $\langle \rho^0/\pi^- \rangle$ ratio in the forward hemisphere. Indeed, the values of $\langle \rho^0/\pi^- \rangle_N = 2.42 \pm 1.08$ at $x_F > 0.5$ for νN -interactions and $\langle \rho^0/\pi^- \rangle_A = 0.12 \pm 0.04$ at $x_F > 0$ for νA -interactions obtained in this work are compatible, respectively, with $\langle \rho^0/\pi^- \rangle_p = 1.99 \pm 0.44$ measured in νp -interactions at $\langle W \rangle = 6.1$ GeV [12] and $\langle \rho^0/\pi^- \rangle_{Ne} = 0.13 \pm 0.03$ measured in νNe -interactions at $\langle W \rangle = 4.8$ GeV [11].

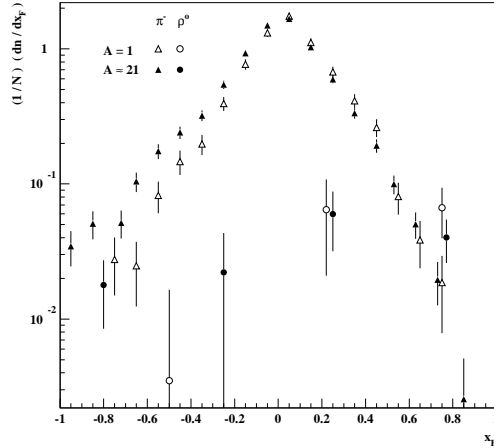


Figure 3. The distribution on x_F for ρ^0 and π^- .

It is interesting to compare the relative yield of strange and non-strange favorable mesons, $K^+(890)$ and ρ^0 , with that of unfavorable ones, K^0 and π^- . The former can be extracted using our recent data on $K^+(890)$ neutrino-production [13]. The ratio of the $K^+(890)$ and ρ^0 total yields is estimated to be 0.19 ± 0.14 (for $A = 1$) and 0.20 ± 0.11 (for $A \approx 21$) which seems to exceed that for K^0 and π^- measured in [6]: 0.055 ± 0.013 (for $A = 1$) and 0.070 ± 0.011 (for $A \approx 21$). These data, therefore, indicate, that the strangeness content in favorable mesons in neutrino-induced reactions is higher than that for unfavorable ones.

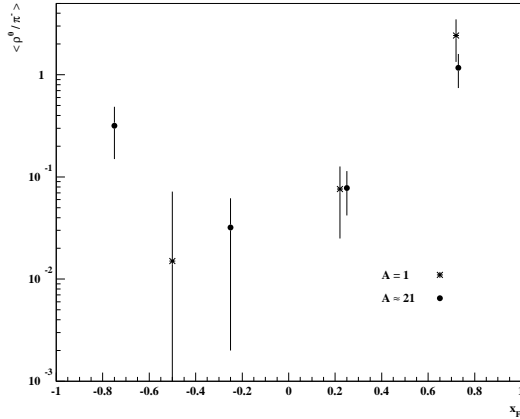


Figure 4. The x_F -dependence of the ratio ρ^0/π^- .

The inclusive spectra of ρ^0 for 'quasinucleon' and nuclear interactions were compared with those measured in neutrino-freon interactions [7].

Fig. 5 shows the invariant distribution on x_F . It is seen, that the data do not exhibit a significant A -dependence in the forward hemisphere, while at $x_F < 0$ the ρ^0 yield in νA -interactions is enhanced as compared to νN -interactions.

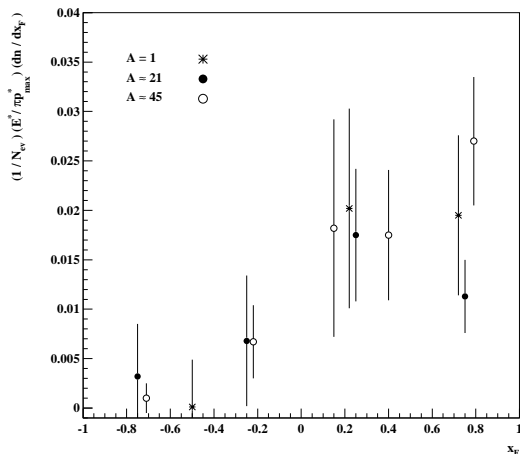


Figure 5. The invariant distribution on x_F .

The distributions on the variable $z = E_{\rho^0}/\nu$ are presented in Fig. 6. It is seen, that they tend to shift towards lower values of z with increasing A , as expected due to the effects of secondary intranuclear interactions. Fig. 7 shows the z -dependence of the ratio $\rho^0/(\pi^+ + \pi^-)/2$. The data exhibit no significant dependence on A , thus indicating that the nuclear effects are approximately the same for ρ^0 and pions (averaged over π^+ and π^-).

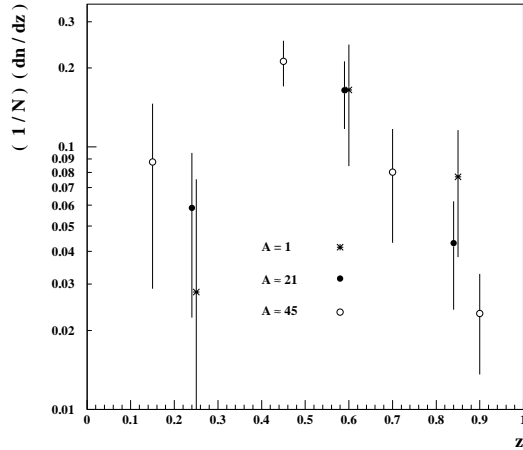


Figure 6. The distribution on z

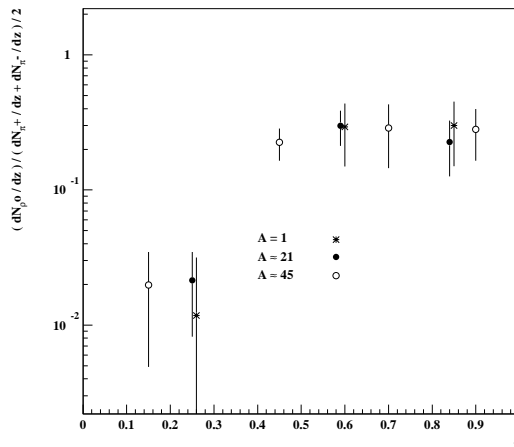


Figure 7. The z -dependence of the ratio $\rho^0/(\pi^+ + \pi^-)/2$.

4. Discussion

The data presented in the previous section indicate on a small but not negligible role of nuclear effects in the ρ^0 neutrino production. It is interesting to clarify whether these effects are compatible with expectations based on the accounting for intranuclear interactions of secondary pions, $\pi N \rightarrow \rho^0 X$, resulting in a ρ^0 multiplicity gain $\delta_{\rho^0}^{sec}$ (mainly at $x_F < 0$), as well as the absorption processes, $\rho^0 N \rightarrow (\text{no } \rho^0)$, resulting in a yield reduction, $\delta_{\rho^0}^{abs}$ (mainly at $x_F > 0$). The details of a simple model incorporating these processes can be found in [6] and references therein.

The gain $\delta_{\rho^0}^{sec}(p_\pi)$ induced by pions with momenta $p_\pi \pm \Delta p_\pi$ is determined by the differential multiplicity of pions, $\Delta n(p_\pi)$, the mean probability of their secondary inelastic interactions $\langle w_A(p_\pi) \rangle$ averaged over the nuclei of the composite target, and by the mean multiplicity $\bar{n}_{\rho^0}(p_\pi)$ of ρ^0 in inelastic πN interactions. The values of $\bar{n}_{\rho^0}(p_\pi)$ extracted (with an uncertainty

of about $\pm 15\%$) from the available experimental data [14] vary from 0.002 at $p_\pi = 0.9 - 1 \text{ GeV}/c$ up to 0.22 at $p_\pi = 10 - 15 \text{ GeV}/c$ (the end of the pion spectrum in this experiment).

The product $\delta_{\rho^0}^{sec}(p_\pi) = \Delta n(p_\pi) \cdot \langle w_A(p_\pi) \rangle \cdot \bar{n}_{\rho^0}(p_\pi)$ was integrated over the momentum spectra of charged pions measured in 'quasinucleon' interactions. The contribution from secondary interactions of π^0 mesons is assumed to be the average of those for π^+ and π^- mesons. The resulting values of $\delta_{\rho^0}^{sec}$ are found to be 0.031 ± 0.005 for $A_{eff} \approx 45$ and 0.023 ± 0.003 for $A_{eff} \approx 21$. The latter value can be compared with the experimental value of $\delta_{\rho^0}^{exp}(x_F < 0) = 0.020 \pm 0.012$, inferred from the last two lines of Table 2 (note, that in the evolution of the error in $\delta_{\rho^0}^{exp} = \langle n_{\rho^0} \rangle_A - \langle n_{\rho^0} \rangle_N$ the correlation between the values of $\langle n_{\rho^0} \rangle_A$ and $\langle n_{\rho^0} \rangle_N$ was taken into account here and below).

In order to estimate the ρ^0 yield decreasing, $\delta_{\rho^0}^{abs}$, one needs to know the ρ^0 absorption cross section $\sigma_{\rho^0}^{abs}$ via the channel $\rho^0 N \rightarrow (\text{no } \rho^0)$. As $\sigma_{\rho^0}^{abs}$ is not known, we use tentative values in between $5 < \sigma_{\rho^0}^{abs} < 10 \text{ mb}$. At these values, the probability $w_{\rho^0}^{abs}$ of the ρ^0 absorption is estimated to be $23 \pm 6\%$ for $A_{eff} \approx 45$ and $18 \pm 5\%$ for $A_{eff} \approx 21$ (see [3] for details of the absorption probability calculations). With these probabilities, the value of $\delta_{\rho^0}^{abs} = -w_{\rho^0}^{abs} \cdot \langle n_{\rho^0}(x_F > 0) \rangle_N$ is equal to -0.016 ± 0.008 and -0.012 ± 0.006 , respectively. The latter value can be compared with $\delta_{\rho^0}^{exp}(x_F > 0) = -0.016 \pm 0.020$ inferred from the first two lines of Table 2.

The total multiplicity gain, $\delta_{\rho^0} = \delta_{\rho^0}^{sec}(x_F < 0) + \delta_{\rho^0}^{abs}(x_F > 0)$, is predicted to be $\delta_{\rho^0} = 0.011 \pm 0.007$ for $A_{eff} \approx 21$ and 0.015 ± 0.009 for $A_{eff} \approx 45$. These values are compatible with a rather weak variation of $\langle n_{\rho^0} \rangle$ with A (cf. Table 1), resulting in a total multiplicity gain $\delta_{\rho^0}^{exp} = 0.005 \pm 0.020$ for $A_{eff} \approx 21$ and 0.020 ± 0.037 for $A_{eff} \approx 45$. The large errors in $\delta_{\rho^0}^{exp}$ do not allow to check quantitatively the predictions of the model incorporating secondary intranuclear interactions.

5. Summary

New experimental data on ρ^0 production in νN and νA ($A \approx 21$) interactions are obtained at intermediate energies ($\langle E_\nu \rangle = 10.7 \text{ GeV}$, $\langle W \rangle = 3.0 \text{ GeV}$). For the first time, nuclear effects in ρ^0 neutrino productions are observed. These effects for the total yield $\langle n_{\rho^0} \rangle$ of ρ^0 are found to be rather small and compatible with those for pions. Using also the SKAT data for $A_{eff} \approx 45$, the slope parameter β in the exponential parametrization of the total yields ($\langle n \rangle \sim A^\beta$) is found $\beta_{\rho^0} = 0.07 \pm 0.13$ which agrees with that for π^- mesons, $\beta_{\pi^-} = 0.052 \pm 0.007$. The ratio of $\langle n_{\rho^0} \rangle / \langle n_{\pi^-} \rangle$ is found to be independent of A being equal about 0.1. A comparison with the data at higher energies reveals a slight increase of this ratio with increasing energy, while no energy dependence is observed for that in the forward hemisphere ($x_F > 0$).

A comparison of the ρ^0 inclusive spectra in νN and νA - interactions indicates, that the major influence of the nuclear medium consists in their shifting towards smaller values of x_F and z , thus indicating on a non-negligible role of the secondary intranuclear interactions. The predictions of a simplified model incorporating the latter are found to be in qualitative agreement with experimental data.

A comparison of the relative yield of the favorable strange and non-strange mesons ($K^+(890)$ and ρ^0) with that for unfavorable ones (K^0 and π^-) indicates, that the strangeness content in the former is higher than in the latter.

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