Observation of the coherent production of an a_1^- meson in antineutrino interactions of a charged current in neon

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A process of the coherent production of single a_1^- mesons has been distinguished in antineutrino interactions in neon nuclei. The experimental data obtained are compared with a theoretical prediction.

This letter reports a study of the coherent production of a_1^- mesons at neon nuclei in antineutrino interactions of a charged current found in the Fermilab 15-foot bubble chamber. The coherent neutrino production of individual pions at various nuclei had been studied previously[1–6] with the goal of testing the hypothesis of the partial conservation of axial-vector current. The neutrino production of individual a_1 mesons is insensitive to the predictions of this hypothesis, since the region of small Q^2 [$Q^2 = -(k_\nu - k_\mu)^2$, where k_ν and k_μ are the 4-momenta of the antineutrino and the muon], which is determined by the Adler relation, makes a negligible contribution to the total cross section. Interest in this process stems from the possibility of studying the interaction of an a_1^- meson with nucleons.[7] The reaction $\tilde{\nu}_\mu \mathrm{Ne} \to \mu^+ \mathrm{Ne} a_1^-$ is determined entirely by the contribution of the axial-vector current, and the cross section for this reaction can be expressed in terms of the cross section for the elastic scattering of a_1 mesons by a nucleon. In the diffractive production of a_1 mesons in the interaction of pions with nuclei, corresponding information could not be obtained because large inelastic contributions have to be taken into consideration on the basis of a model.[8] In a neutrino interaction, in contrast, the contribution of inelastic corrections is negligible. This circumstance makes the coherent interactions of neutrinos with nuclei a unique source of experimental information on the $a_1 N$ interaction.

It follows from Ref. 9 that coherent events of the type $\tilde{\nu}_\mu \mathrm{Ne} \to \mu^+ \mathrm{Ne} a_1^-$, like $\tilde{\nu}_\mu \mathrm{Ne} \to \mu^+ \mathrm{Ne} \pi^-$ events, should dominate at the small values $p_L^2 < 0.06$ GeV^2 and $p_T^2 < 0.1$ GeV^2, where p_L is the projection of the 3-momentum acquired by the neon nucleus after the interaction onto the direction of the 3-momentum transferred from the lepton vertex, $\mathbf{q} = \mathbf{k}_\nu - \mathbf{k}_\mu$ ($\mathbf{k}_\nu$, and $\mathbf{k}_\mu$ are the 3-momenta of the antineutrino and the muon), and p_T is the projection of the nuclear momentum onto the plane perpendicular to the vector $\mathbf{q}$. The distribution in p_T^2 for events involving the coherent and incoherent neutrino production of a_1 mesons is a decaying exponential function with significantly different slope parameters. In the present experiment, the number of interactions involving the coherent production of a_1 mesons was thus determined from the p_T^2 distribution.

The 15-foot Fermilab bubble chamber was filled with a heavy neon-hydrogen mixture (64% neon atoms) and exposed to a "broad" beam of muon antineutrinos. For the selection of coherent interactions of the type $\tilde{\nu}_\mu \mathrm{Ne} \to \mu^+ \mathrm{Ne} a_1^-$, an analysis was made of 8000 antineutrino events of a charged current in the antineutrino energy range 10–200 GeV and at muon momenta > 4 GeV^2. The experiment is described in more detail in Ref. 9. A search for coherent a_1^- mesons was carried out on the basis of the decays $a_1^- \to \rho^0 \pi^-$ and $\rho^0 \to \pi^+ \pi^-$. For the subsequent analysis we accordingly selected 80 events having only $\mu^+ \pi^+ \pi^- \pi^-$ in the final state. Interactions in which the momentum of the pion was measured within a relative error greater than 30% were excluded from the analysis; their loss was dealt with by the method described in Ref. 10. For the selected events, the average correction factor, which also incorporates the detection efficiency, was 1.43.

Figure 1 shows a two dimensional distribution in (p_L^2, p_T^2) for four-prong events from the interval $1.0 < M(\pi^+ \pi^- \pi^- < 1.2$ GeV of effective masses of the three pions. This interval lies in the vicinity of the mass of the a_1 meson. The values of p_L^2 and p_T^2 were calculated by means of 0–C fit with the experimental values of the muon and pion momenta under the assumption that the mass of the target particle was equal to the mass of a neon nucleus. The error bars correspond to the errors in the measurement of p_L^2 and p_T^2. It can be seen from this figure that five events are observed in the region of

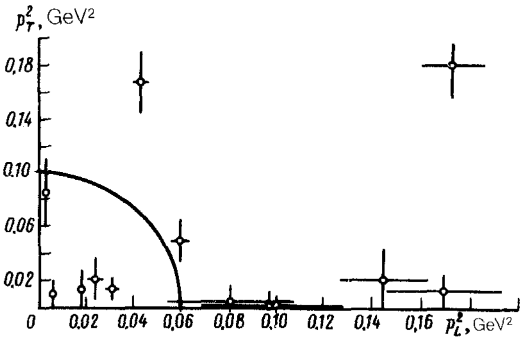

FIG. 1. Distribution in the (p_L^2, p_T^2) plane of four-prong events from the interval $1.0 < M(\pi^+\pi^-\pi^-) < 1.2$ GeV of the effective masses of the three pions.

p_L^2 and p_T^2 values bounded by the solid line. In each of these events there is at least one pair of $\pi^+\pi^-$ mesons with an effective mass in the region of the mass of the ρ^0 mesons $[0.7 < M(\pi^+\pi^-) < 0.9$ GeV$]$. The probability for an incorrect assignment of the pion mass to a positively charged hadron track turned out to be negligible in these events. This point was checked through a redetermination of the mass of this track in accordance with the mass of a proton and through a calculation of the initial momentum of the nucleon by means of a 0-C fit. The momenta found as a result were many times the maximum possible momentum of a nucleon in a nucleus.

Shown for comparison in Fig. 2 is a two-dimensional distribution in (p_L^2, p_T^2) for four-prong events from the mass region $1.2 < M(\pi^+\pi^-\pi^-) < 1.6$ GeV, which lies away from the mass of the a_1 meson. The width of this region is twice the interval of $M(\pi^+\pi^-\pi^-)$ values for the events which are part of the distribution in Fig. 1. It can be seen from this figure that there is only a single event in the region bounded by the solid line.

Figure 3 shows the p_T^2 distribution for four-prong events which fall in the interval $p_L^2 < 0.06$ GeV^2 in Fig. 1. At values $p_T^2 < 0.1$ GeV^2 we see a coherent peak, in agreement with the prediction of Ref. 7. Since the slope in the p_T^2 distribution for the incoherent neutrino production of a_1 mesons is much smaller than the slope of the corresponding distribution of coherent events, we assumed that the background from

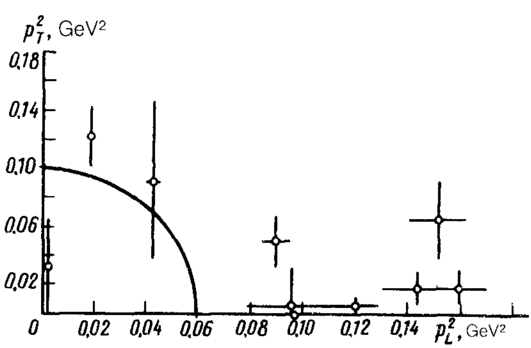

FIG. 2. Distribution in the (p_L^2, p_T^2) plane of four-prong events from the interval $1.2 < M(\pi^+\pi^-\pi^-) < 1.6$ GeV of the effective masses of the three pions.

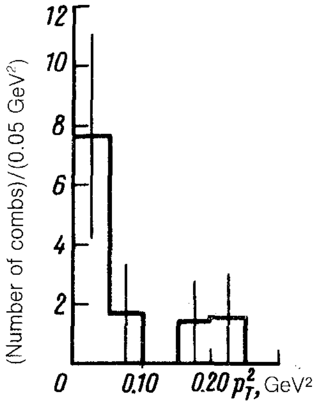

FIG. 3. Distribution in p_T^2 of four-prong events from the interval $1.0 < M(\pi^+\pi^-\pi^-) < 1.2$ GeV of the effective masses of the three pions for $p_L^2 < 0.06$ GeV^2.

the production of a a_1^- meson at a nucleon was distributed uniformly over the interval $0.0 < p_T^2 < 0.3$ GeV^2. Furthermore, for the events of this experiment we verified that the background from interactions which do not lead to the production of an a_1^- meson (including the reaction $\tilde{\nu}_\mu N \to \mu^+ \rho^0 \Delta^-$ at values $p_L^2 < 0.06$ GeV^2 is also distributed uniformly over this p_T^2 interval. Accordingly, the total background for the coherent production of a_1^- mesons can be estimated from those events in Fig. 3 which fall in the interval $0.1 < p_T^2 < 0.3$ GeV^2: $1^{+1.3}_{-0.3}$ event. If we assume that the entire observed signal is caused by the background, we find the probability for this case to be no greater than 1.7%. Subtracting the value found from the background from the number of events in the region $p_T^2 < 0.1$ GeV^2 in the distribution in Fig. 3, we find a corrected number of coherent events: $N_{a_1} = 8^{+6}_{-4}$. The errors listed here were found under the assumption that the background fell in the 66% confidence interval.

The cross section for the coherent production of a_1^- mesons in this experiment was found with the help of the cross section for, and the number of, interactions of antineutrinos with a nucleon in a charged current over the antineutrino energy interval 10–200 GeV. At an average antineutrino energy of 23 GeV the value is $(0.30^{+0.21}_{-0.15}) \times 10^{-38}$ cm^2, in agreement with the prediction of Ref. 7.

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