Electroproduction of pions at the threshold: determination of the pion radius and analysis of axial-vector form factor of the nucleon

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We analyze the pion form factor and the nucleon axial-vector form factor, determined from the cross section for electroproduction of pions on protons at threshold with separation of the transverse and longitudinal component. A fit yields a pion radius $\langle r_\pi^2\rangle^{1/2} = 0.48 \pm 0.18$ F and an axial mass $M_A = 0.97 \pm 0.06$ GeV (dipole fit).

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Investigation of the electroproduction of pions on protons at threshold, together with separation of the transverse and longitudinal components of the cross section, makes it possible to determine not only the axial-vector form factor F_A of the nucleon (with a model-dependent uncertainty lower than in other experiments), but also the pion form factor F_π.[1] We have performed such measurements with the Khar'kov linear electron accelerator at 4-momentum transfers $k^2 = 0.136$, 0.195 and 0.311 GeV^2.[2,3] With the aid of the model of[1] we have obtained F_A and F_π from the transverse E_{0^+} and longitudinal S_{0^+} multipoles of the s wave at threshold.[2,3]

We present here an approximation of the dependences of the form factors F_A and F_π on k^2. The fit was aimed at determining the rms radius $\langle r^2\rangle^{1/2}$ of the pion from $F_\pi(k^2)$ and the axial mass M_A from $F_A(k^2)$. The results are compared with the direct measurements of M_A in experiments on neutrino scattering and of $\langle r^2\rangle^{1/2}$ from experiments on pion scattering by electrons, and also with data of experiments of other types on pion electroproduction.

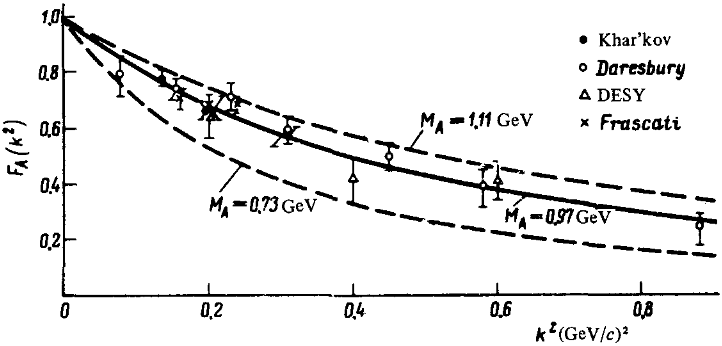

FIG. 1. Axial-vector form factor of the nucleon $F_A(k^2)$ obtained from experiments on electroproduction of pions at the threshold.

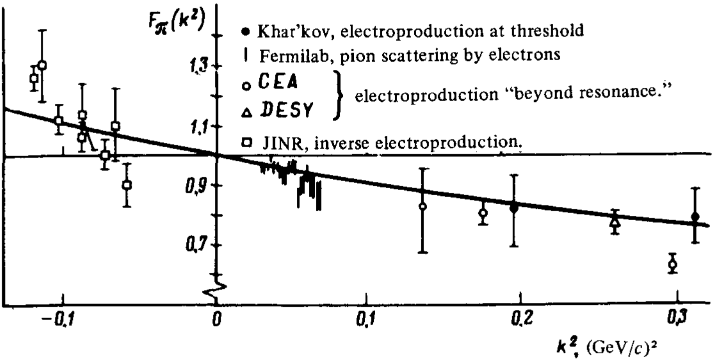

FIG. 2. Pion form factor $F_\pi(k^2)$ in the time-like and space-like regions of the 4-momentum transfer.

The function $F_A(k^2)$ was approximated by the dipole relation $F_A = (1 + k^2/M_A^2)^{-2}$. That the dipole fit is preferable to the monopole fit has been demonstrated in[4], where the measurements were made up to values $k^2 = 0.88$ GeV². The optimal value of M_A for our data is 0.97 ± 0.06 GeV and agrees within the limits of errors with the results of an analysis of the coincidence experiments[4-7], namely $M_A = 0.96 \pm 0.03$ GeV. In the direct experiment on neutrino scattering, an appreciable increase of accuracy was attained and the resultant values were $M_A = 0.84 \pm 0.11$ GeV (from the differential cross section) and $M_A = 0.98 \pm 0.13$ GeV (from the total cross section).[8] The agreement between the different types of experiment is very good, thus offering weighty grounds for using the methods of current algebra and the PCAC hypothesis for the description of electro-production at the threshold.

The results of the determination of F_A, obtained by us[2,3] and in a number of other laboratories,[4-7] are shown in Fig. 1. The solid curve corresponds to the best fit to the Khar'kov data. The dashed curves show the corridor of the values of F_A from a neutrino experiment.[8] Figure 1 illustrates clearly the favorable situation in the experimental determination of the axial-vector form factor of the nucleon.

TABLE I.

Form of parametrization	$G_{en} = 0$		$G_{en} = \frac{-\tau}{1 + 5.6\tau} G_{mn} > 0$	
	M_x, GeV	$\langle r_\pi^2 \rangle^{1/2}$, F	M_x, GeV	$\langle r_\pi^2 \rangle^{1/2}$, F
Dipole	1.49 ± 0.30	0.46 ± 0.09	1.76 ± 0.44	0.39 ± 0.09
Monopole	1.01 ± 0.21	0.48 0.10	1.21 ± 0.32	0.40 ± 0.10
Linear	–	0.42 ± 0.07	–	–

Note: $\tau = k^2/4M^2$, where M is the nucleon mass. A metric in which $k^2 > 0$ is used.

TABLE II.

Measurement method	$\langle r_\pi^2\rangle^{1/2}$, F	Remarks
Electroproduction of pions at threshold	0.48 ± 0.10	Present work
Direct method ($\pi^- e^- \to \pi^- e^-$)	0.57 ± 0.06	Fermilab[10]
	0.78 ± 0.10	Serpukhov[14]
Electroproduction in first resonance	0.86 ± 0.14	CEA[15]
Electroproduction at energy above resonance	0.704 ± 0.007	CEA[11]
Inverse electroproduction	0.75 ± 0.09	JINR[9]
ρ-dominance prediction	0.632	—

Figure 2 shows the value of F_π in the time-like[9] and space-like[3,10–12] regions of the 4-momentum transfer k^2, and indicates the type of experiment. When determining the pion radius from our data it was necessary to take into account the fact that k^2 is relatively large and the behavior of the pion form factor differs from the linear relation $F_\pi = 1 - 1/6k^2 \langle r_\pi^2\rangle$. We have therefore carried out, besides the linear fit, also a monopole fit $F_\pi = (1 + k^2/M_x^2)^{-1}$ and dipole fit $F_\pi = (1 + k^2/M_x^2)^{-2}$ with a variable parameter M_x. The results of the approximation and the ensuing values of the pion radius are listed in Table I.

The form factors $F_\pi(k^2)$ were obtained in [3] under the assumption that $G_{en} = 0$. To assess the degree of sensitivity of the determined $\langle r^2\rangle^{1/2}$ to the charge form factor of the neutron, we determined $F(k^2)$ at $G_{en} = [-\tau/(1 + 5.6\tau)]G_{mn} > 0$. This behavior of $G_{en}(k^2)$ follows from experiments on *ed* scattering.[13] It is seen from Table I that these values of the charge form factor of the neutron lead to somewhat smaller pion radii. Unfortunately, the analysis of[13] is strongly dependent on the choice of the neutron wave function and does not lead to unambiguous conclusions for G_{en}. This uncertainty introduces an additional error in the pion radius, amounting to ~ 0.08 F.

The dipole and monopole parametrizations yield practically the same values of $\langle r^2\rangle^{1/2}$, and the deviation from the linear dependence does not exceed the experimental error (see Table I). The main result of the determination of the pion is assumed by us to be the variant in which the monopole formula is used (as in the case of ρ dominance) and $G_{en} = 0$. It corresponds to the solid curve in Fig. 2.

The results of various methods of determining the pion radius are compared in Table II.

Our result agrees within the limits of errors with the data of the latest experiment[10] on a direct determination of the pion radius from the scattering of 100-GeV π^- mesons by electrons.

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