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Determination of the Nucleon Axial Vector Form-Factor from $\pi\Delta$ Electroproduction near Threshold

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Abstract

From measurements of the reaction $ep \to e\pi^-\Delta^{++}$ near threshold the nucleon axial-vector form factor is determined, using the PCAC calculations by Adler and Weisberger. The results are consistent with form factor determinations from single pion electroproduction. A dipole fit yields $m_A = (1.18 \pm 0.07)$ GeV. There is some disagreement between the results from electroproduction and those from neutrino reactions.

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The Q^2 dependence of the nucleon axial vector form factor $g_A(Q^2)$ has been determined in two essentially different ways. Direct determination is made from quasielastic νN scattering. Assuming the dipole form

$$g_A(Q^2) = g_A(0)\ (1 + Q^2/m_A^2)^{-2}$$

for the axial form factor the combined neutrino measurements give $m_A = (0.89 \pm 0.08)$ GeV.[1]* An alternative, more indirect determination is made from π^+ electroproduction

$$ep \rightarrow e'\pi^+n \qquad (1)$$

near threshold, assuming the validity of current algebra and of the PCAC hypothesis. Measurements of this reaction at various laboratories[2-5] have recently lead to rather consistent results, giving $m_A = (1.13 \pm 0.04)$ GeV in terms of the dipole formula. There may thus be a discrepancy with the ν results.

A difficulty occurs in using reaction (1) to determine $g_A(Q^2)$ due to the strong background from the resonant π^+n P-wave, which tends to mask the $g_A(Q^2)$ dependent term even close to threshold. This problem is absent in the reaction

$$ep \rightarrow e'\pi^-\Delta^{++}(1236) \qquad (2)$$

Here, the $g_A(Q^2)$ dependent equal time commutator term given by current algebra is the dominant term in a range of at least several 100 MeV above threshold. Adler and Weisberger have derived and thoroughly discussed the low-energy theorem[6] to be used in the determination of $g_A(Q^2)$ from measurements of reaction (2).

We have measured the dependence of reaction (2) on $Q^2 = -(k_e - k_e')^2$ using the DESY streamer chamber in conjunction with counter hodoscopes and proportional chambers to detect and identify all four particles in the final state, including the π^+ and p from Δ^{++} decay. The event sample used in the present analysis is twice as large as that used in a previous publication[7]. The cross section for reaction (2) was determined by maximum likelihood fits to the Dalitz plot of the hadronic $\pi^+\pi^-p$ final state, taking into account distributions appropriate for $\pi^-\Delta^{++}$, $\pi^+\Delta^o$, $\rho^o p$, and phase space. Corrections of typically 4 % and 18 % have been made for measurement inefficiencies and radiative effects, respectively (see Ref. 8 for details).

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* The determination in Ref.1 assumes CVC, smallness of the induced pseudoscalar term, and absence of second class currents. Relaxing the CVC requirement and so attempting to measure both m_A and m_V from the ANL neutrino experiment gives $m_A = 0.75\ ^{+0.21}_{-0.10}$ and $m_V = 0.92\ ^{+0.05}_{-0.11}$ GeV.

The cross section for reaction (2), as a function of the total final state hadron mass W, rises approximately linearly from threshold up to $W \approx 1.5$ GeV.[7,8] This is consistent with the expected strong dominance of the equal time commutator term or, in Born term terminology, of the contact (plus some pion exchange) term.[6]* The dominance of the commutator term is further supported by our observed Δ^{++} production and decay angular distributions. The Q^2 dependence of the cross section in this region, $1.3 < W < 1.5$ GeV, is shown in fig.1a (after dividing out the Q^2 dependent flux Γ_t of transverse virtual photons, defined in the conventional way[10]). The point at $Q^2 = 0$ comes from photoproduction[11].

We now compare this Q^2 dependence with the calculations by Adler and Weisberger[6], assuming PCAC. We have evaluated their expressions, valid in the exact soft pion limit ($q_\pi = 0$), for the $\pi^-\Delta^{++}$ final state. The cross section is very closely proportional to $g_A^2(Q^2)$, due to the strong dominance of the equal time commutator term. We refer to the calculated cross section, with $g_A(Q^2)$ set equal to 1, as $\sigma_{AW}(Q^2)$.

In order to compare it with our measured Q^2 dependence, the latter has to be extrapolated into the unphysical region at $q_\pi = 0$. The analysis which we have presented earlier[7] suggests a simple procedure to do this. In ref.7 it was shown that the matrix element of the reaction

$$\gamma_V p \rightarrow \pi^- \Delta^{++} \tag{3}$$

is to good approximation given by the Born contact (seagull) amplitude multiplied with a phenomenological form factor $G(Q^2)$,

$$<\Delta^{++}\pi^- \; |J_\mu|p>\varepsilon^\mu = G(Q^2)\; \bar{u}_\mu(\Delta)u(p)\varepsilon^\mu . \tag{4}$$

In the physical region for $W < 1.5$ GeV this matrix element describes very well the q_π, Q^2 and polarization dependences of the data. Thus our experimental data can be represented by

$$\frac{\sigma(Q^2)}{\sigma(0)} = G^2(Q^2)\; \frac{\sigma_{BORN}(Q^2, q_\pi \text{ physical})}{\sigma_{BORN}(0,\; q_\pi \text{ physical})} . \tag{5}$$

Assuming this relation to hold also between q_π at threshold and $q_\pi = 0$,

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* Pole term models of $\pi\Delta$ electroproduction have been discussed by Berends and Gastmans, by Bartl et al., and more recently in the framework of saturated fixed-t dispersion relations by Levi and Schmidt.[9]

we have

$$\frac{\sigma(Q^2,q_\pi \to 0)}{\sigma(0,\ q_\pi \to 0)} = G^2(Q^2)\ \frac{\sigma_{BORN}(Q^2,q_\pi \to 0)}{\sigma_{BORN}(0,\ q_\pi \to 0)} \tag{6}$$

where $\sigma(Q^2,q_\pi \to 0)$ is the extrapolated cross section which can be directly compared with $\sigma_{AW}(Q^2)$:

$$\frac{\sigma(Q^2,q_\pi \to 0)}{\sigma(0,\ q_\pi \to 0)} = \frac{g_A{}^2(Q^2)}{g_A{}^2(0)}\ \frac{\sigma_{AW}(Q^2)}{\sigma_{AW}(0)} \tag{7}$$

From this we determine $g_A{}^2(Q^2)/g_A{}^2(0)$.

The results are shown in fig. 1b. For comparison we also show the values that have been obtained in single pion electroproduction experiments (reaction (1)). They are consistent with our values, which however extend to larger Q^2. A fit by a dipole formula to our data* gives

$$m_A = (1.18 \pm 0.07)\ \text{GeV}.$$

Including all the electroproduction data shown in Fig. 1b, we obtain

$$m_A = (1.16 \pm 0.03)\ \text{GeV}$$

(with $\chi^2/n_{DF} = 0.52$). The data indicate a disagreement with the value $m_A = (0.89 \pm 0.08)$ GeV obtained from neutrino scattering (broken curve).[1]

We thus have confirmed (and extended) the determination of $g_A(Q^2)$ from threshold electroproduction, using a different reaction. The possible discrepancy between the electroproduction results on $g_A(Q^2)$ and those from ν reactions deserves further study.

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* The systematic error on our cross section normalization is included in the fit result.

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Figure Captions

1a Cross section $\sigma_T + \varepsilon\sigma_L$ of the reaction $\gamma_V p \to \pi^- \Delta^{++}$ for $1.3 < W < 1.5$ GeV, as function of Q^2. The point at $Q^2 = 0$ is taken from Ref. 11. The $Q^2 > 0$ points have, in addition to the statistical errors shown, an overall uncertainty of 10 %.

1b Nucleon axial vector form factor as determined from the single pion electroproduction reaction (1) (Refs. 2-4) and $\pi\Delta$ electroproduction (reaction (2), this experiment). The solid curve shows a fit of the form $(1 + Q^2/m_A^2)^{-2}$ to the electroproduction points. The broken curve shows the dipole form factor obtained from quasielastic neutrino scattering (Ref. 1).

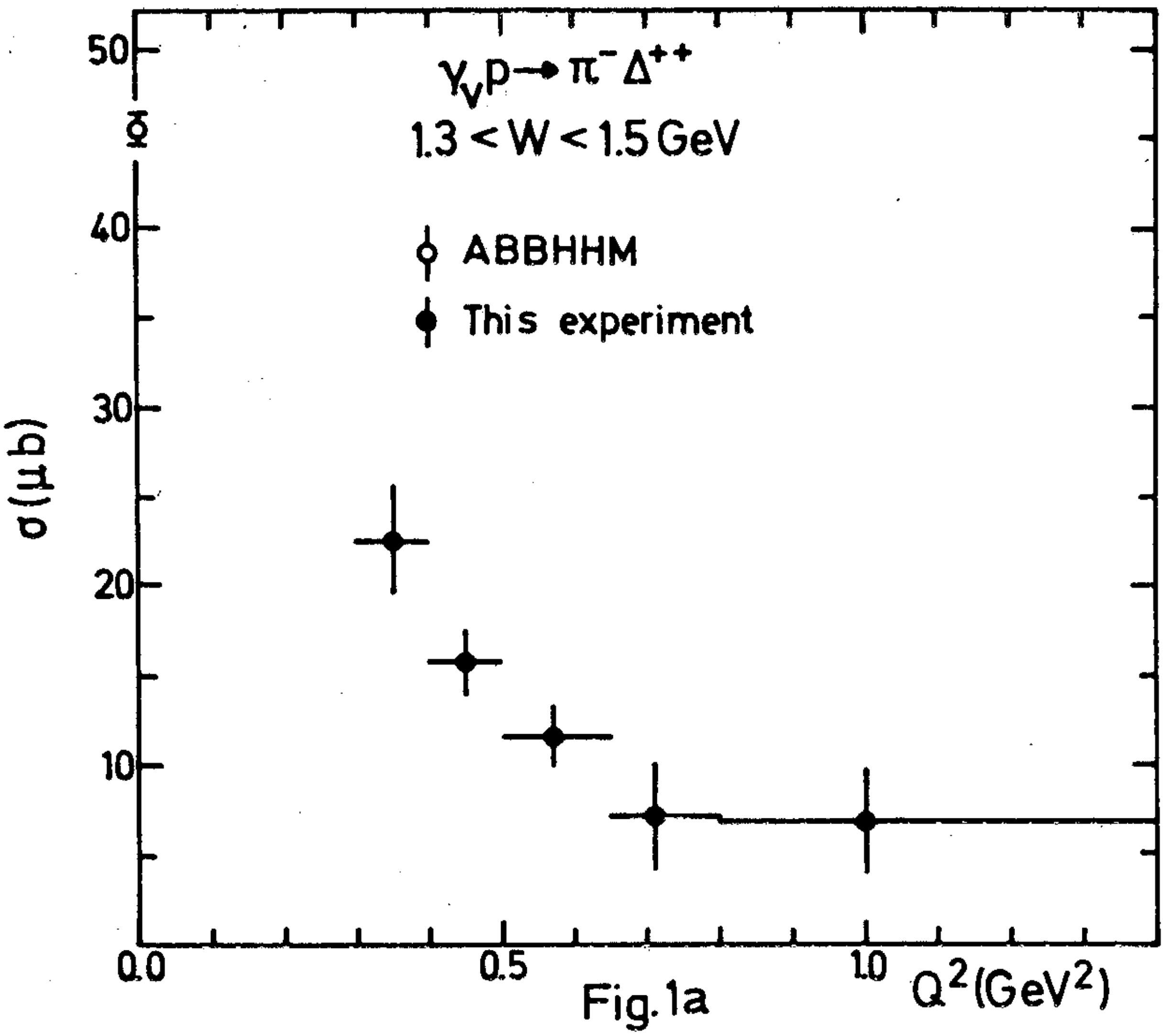
$\gamma_V p \to \pi^- \Delta^{++}$
$1.3 < W < 1.5$ GeV
ABBHHM
This experiment
$\sigma(\mu b)$
50
40
30
20
10
0.0
0.5
1.0
$Q^2(GeV^2)$

Fig. 1a

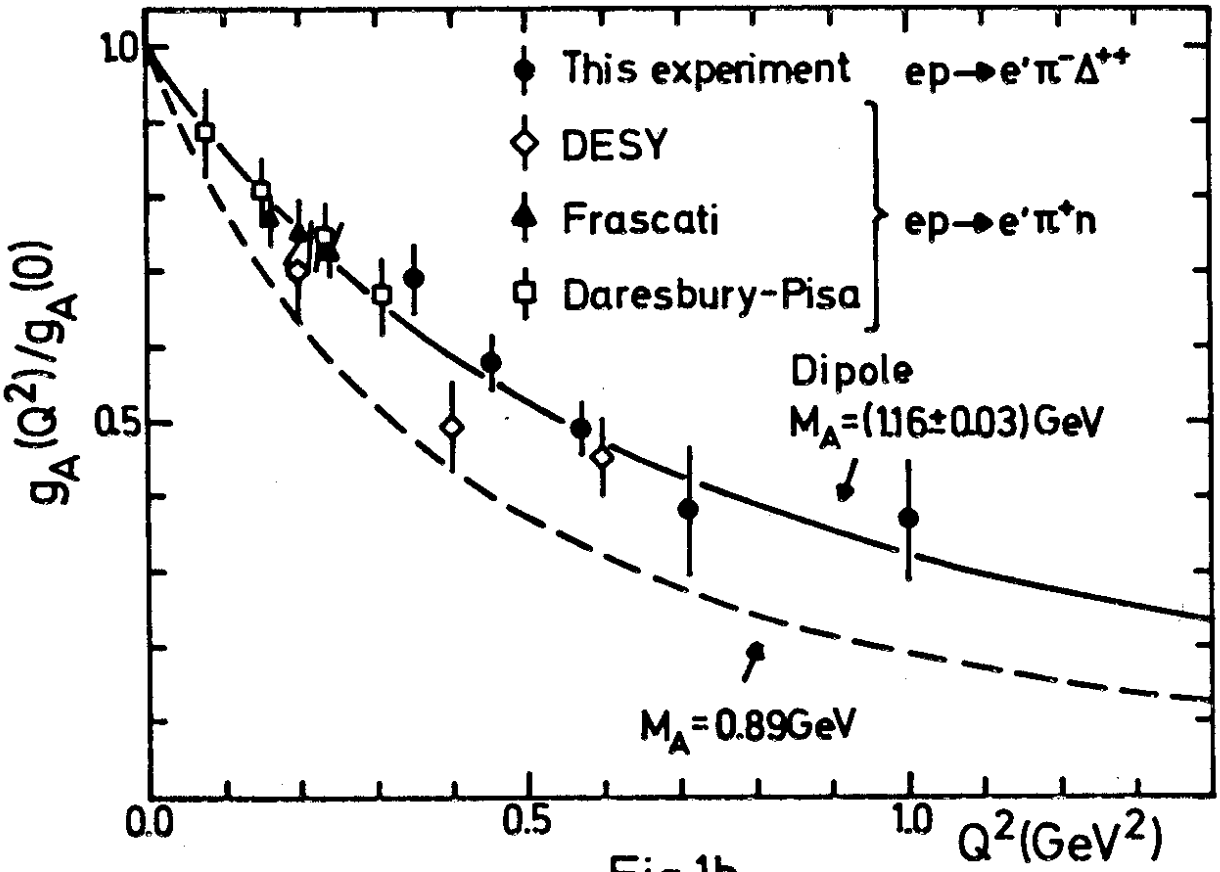
This experiment
$ep \to e'\pi^-\Delta^{++}$
DESY
Frascati
Daresbury-Pisa
$ep \to e'\pi^+n$
Dipole
$M_A = (1.16 \pm 0.03)$ GeV
$M_A = 0.89$ GeV
$g_A(Q^2)/g_A(0)$
1.0
0.5
0.0
0.5
1.0
$Q^2(GeV^2)$

Fig. 1b