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LETTER TO THE EDITOR

THE AXIAL FORM FACTOR OF THE NUCLEON FROM ELECTRO-PION PRODUCTION AT LOW $q^{2,1}$

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Results of the measurement of the transverse and longitudinal cross-section for coincident electro-production of positively charged pions on protons measured in parallel kinematics at the invariant mass of $W = 1125$ MeV and at three four-momentum transfers $q^2 = -0.117$, -0.195 and -0.273 GeV^2 are presented. An axial-mass parameter of high accuracy was extracted from a preliminary analysis of the transverse cross-section within the Mainz effective Lagrangian model of the nucleon. The value supports the prediction of the chiral perturbation theory that pion-loop corrections effectively increase the value of the axial mass extracted from pion electro-production data relative to that from neutrino scattering.

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Quantum chromodynamics (QCD) is believed to be a successful fundamental theory underlying the strong interaction. Yet it is far from being well understood in its low energy domain, the quark confinement being the most characteristic problem. Instead of the first-principles calculations, several QCD-guided semi-phenomenological models as well as effective low energy field theories like the chiral perturbation theory (ChPT) have been proposed to study quark behaviour in this region indirectly. As the nucleon is widely adopted as an important laboratory for this purpose, various accurately measured observables of the nucleon are most welcome to test these theoretical approaches.

With the arrival of the new generation of electron accelerators, new possibilities became available to measure or re-measure various observables within previously inaccessible kinematic ranges and/or with improved statistical accuracy. In particular, at MAMI in Mainz, where the first such accelerator has been operating for several years, one of the early projects of the A1 Collaboration was to re-measure

[1] Complete results of this measurement will be published elsewhere by A. Liesenfeld et al.

the transverse and longitudinal cross-section for the reaction p(e,e′π^+)n as a function of small four-momentum transfers. Due to the pseudo-scalar nature of the pion, its coupling to the nucleon has to draw in the transition axial-vector nucleon current. So it turns out that near the threshold, the reaction amplitude is highly sensitive to the axial form factor of the nucleon.

In the past, the interplay of experimental and theoretical investigations of the axial form factor as a function of q^2, $g_{\mathrm{A}}(q^2)$, led to a general belief that this observable may well be approximated by a dipole form

$$\frac{g_{\mathrm{A}}(q^2)}{g_{\mathrm{A}}(0)} \simeq \frac{1}{(1 - q^2/M_{\mathrm{A}}^2)^2} ,$$

where $g_{\mathrm{A}}(0) = 1.2670 \pm 0.0035$ is the well-known axial coupling constant, and the parameter M_{A} is the so-called axial-vector (dipole) mass.

The literature shows there are two principal ways to determine the value of the axial-mass parameter (Fig. 1). The first one is through the reaction of electro-pion production near the threshold. Large errors in particular values which are due to low statistical precision and high systematic errors, including uncertainties in the theoretical approaches used in the analysis, are a common characteristic of the results. Only because of the numerous measurements is the error of the average value $M_{\mathrm{A}} = (1.068 \pm 0.017)$ GeV rather small. The second source of information on the parameter M_{A} is that from analyses of (anti)neutrino scattering. Here the values obtained are also burdened with large errors, mainly of similar origin to those above. The error bar on the average value is again rather small, $M_{\mathrm{A}} = (1.017 \pm 0.023)$ GeV.

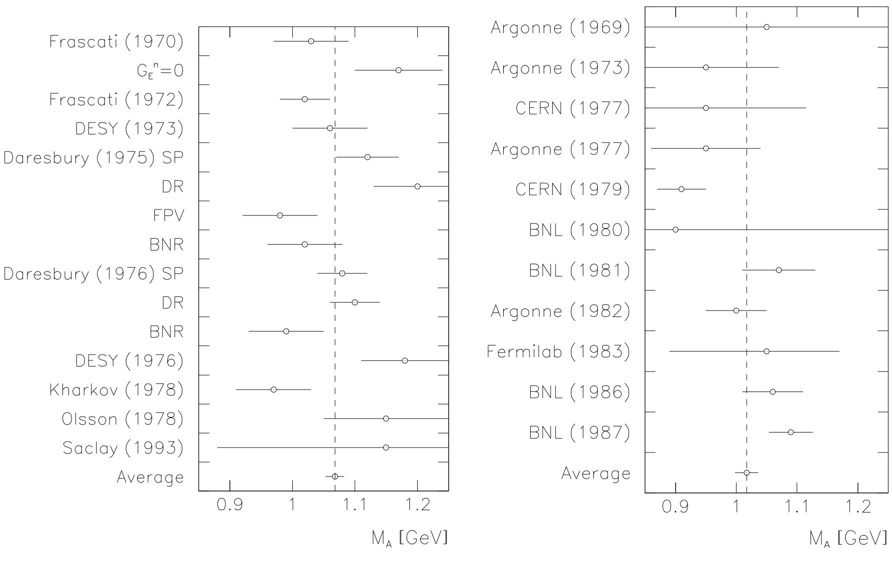

Fig. 1. The axial mass M_{A} as extracted from charged pion electro-production experiments (left figure) or (anti)neutrino scattering (right figure).

The difference between the two average values may be non-trivial and therefore interesting. It may indicate the possibility that the observed discrepancy is in favour of a prediction of the ChPT.

Our measurement of the p(e,e′π^+)n reaction was performed with MAMI's continuous current of a few tens of μA using a liquid hydrogen target and two of the three high-resolution, large-acceptance magnetic spectrometers of the A1 Collaboration [1]. The experiments were done at an invariant energy of $W = 1125$ MeV, i.e. about 46 MeV above the threshold, in parallel kinematics at three four-momentum transfers $q^2 = -0.117$, -0.195 and -0.273 GeV^2, for each particular q^2 at three different photon polarisations ε (or $\varepsilon_\mathrm{L} = -q^2\varepsilon/\omega^2$).

For unpolarised electrons and target protons, the cross-section can be expressed in terms of four partial cross-sections reflecting the nucleon electro-magnetic current components, the transverse and/or the longitudinal ones, relative to the direction of the virtual photon:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}E'_\mathrm{e}\,\mathrm{d}\Omega'_\mathrm{e}\,\mathrm{d}\Omega^\star_\pi} = \Gamma_\mathrm{v}\left[\frac{\mathrm{d}\sigma_\mathrm{T}}{\mathrm{d}\Omega^\star_\pi} + \varepsilon^\star_\mathrm{L}\frac{\mathrm{d}\sigma_\mathrm{L}}{\mathrm{d}\Omega^\star_\pi} + \sqrt{2\,\varepsilon^\star_\mathrm{L}(1+\varepsilon)}\,\frac{\mathrm{d}\sigma_\mathrm{LT}}{\mathrm{d}\Omega^\star_\pi}\,\cos\phi_\pi + \varepsilon\frac{\mathrm{d}\sigma_\mathrm{TT}}{\mathrm{d}\Omega^\star_\pi}\right],$$

where Γ_v is the virtual photon flux and the asterisk * denotes quantities in the centre-of-mass frame. In parallel kinematics ($\theta^\star_\pi = 0$) the interference terms $\mathrm{d}\sigma_\mathrm{LT}/\mathrm{d}\Omega^\star_\pi$ and $\mathrm{d}\sigma_\mathrm{TT}/\mathrm{d}\Omega^\star_\pi$ vanish, and by plotting the cross-section as a function of the virtual-photon polarisation (Fig. 2), it is possible, for each q^2, to separate the transverse part (the intercept on the cross-section axis) and the longitudinal part of the cross-section (the slope).

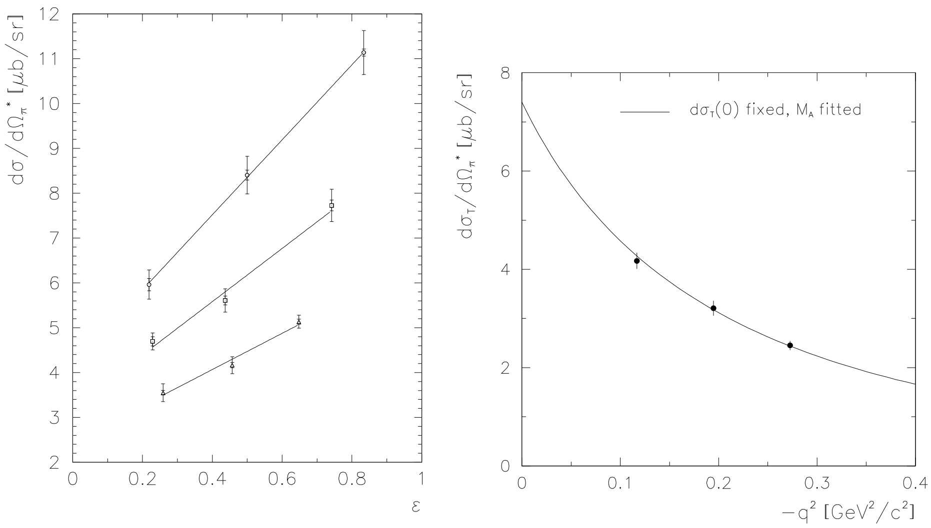

Fig. 2. Left: least-squares straight-line fits to the measured cross-sections at constant values of q^2 as functions of the virtual photon polarisation ε. Right: q^2-dependence of the transverse cross-section fitted by the model of Drechsel and Tiator [3].

In a previous work within the A1 Collaboration [2] we showed that in the effective Lagrangian model of Drechsel and Tiator [3] the transverse cross-section in our q^2-region is dominated by the E_{0+} amplitude and therefore quite sensitive to the axial form factor, and consequently, to the axial dipole mass parameter M_{A}. As the other form factors entering the model are well known, the axial one could be treated as an open parameter and, by fitting to the experimental transverse cross-section determined in a practically model-independent way. Utilising this approach our transverse cross-section values obtained as functions of q^2 were fitted to the calculations based on this model, satisfying the gauge invariance even more stringently [3,4].

Fixing $\mathrm{d}\sigma_{\mathrm{T}}/\mathrm{d}\Omega^{\star}_{\pi}(q^2 = 0)$ to (7.3 ± 0.4) μb/sr as indicated by the photoproduction dispersion analysis of Ref. 5, we found for the axial-mass parameter the value $M_{\mathrm{A}} = (1.073 \pm 0.030)$ GeV, a result of the accuracy which is half of an order of magnitude better than the previous ones.

Our value for M_{A} lies within the average value of all the previously measured values by electro-pion production, so it highly increases the reliability of the prediction of the ChPT that the axial mass parameter determined by (anti)neutrino scattering should be about 5% smaller than the value from the electro-pion production. As already mentioned, this reduction is due to the calculable correction terms (stemming from the processes involving pion loops) to the reaction amplitude, in fact to the mean-square axial radius, in the chiral limit.

It is clear, however, that for a reliable confirmation of the axial mass discrepancy predicted by the ChPT, new accurate results from neutrino scattering with errors as low as the one of the average value are also needed.

To conclude, let us mention that the energy and momentum transfers in our p(e,e$'\pi^+$)n experiments are still too high to test ChPT more thoroughly by comparing the calculated cross-section to the experimental one. The potential power of the results, however, remains and could be used as soon as the abilities of the theory develop correspondingly. On the other hand, the QCD-motivated semi-phenomenological models are challenged.

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AKSIJALNI FAKTOR OBLIKA NUKLEONA IZ TVORBE ELEKTRON-PION ZA MALE q^2

Opisuju se ishodi mjerenja poprečnog i uzdužnog udarnog presjeka za višestruku elektrotvorbu pozitivnih piona u paralelnoj kinematici.