Available online at www.sciencedirect.com
SCIENCE DIRECT®

PHYSICS LETTERS B

Physics Letters B 564 (2003) 199–204

www.elsevier.com/locate/npe

The neutron charge form factor and target analyzing powers from $^3\overrightarrow{\mathrm{He}}(\vec{\mathrm{e}}, \mathrm{e}'\mathrm{n})$ scattering

J. Bermuth [g], P. Merle [f], C. Carasco [a], D. Baumann [f], R. Böhm [f], D. Bosnar [k], M. Ding [f], M.O. Distler [f], J. Friedrich [f], J.M. Friedrich [f], J. Golak [d], W. Glöckle [b], M. Hauger [a], W. Heil [g], P. Jennewein [f], J. Jourdan [a,*], H. Kamada [i], A. Klein [h], M. Kohl [c], B. Krusche [a], K.W. Krygier [f], H. Merkel [f], U. Müller [f], R. Neuhausen [f], A. Nogga [j], Ch. Normand [a], E. Otten [g], Th. Pospischil [f], M. Potokar [e], D. Rohe [a], H. Schmieden [f], J. Schmiedeskamp [g], M. Seimetz [f], I. Sick [a], S. Širca [e], R. Skibiński [d], G. Testa [a], Th. Walcher [f], G. Warren [a], M. Weis [f], H. Witała [d], H. Wöhrle [a], M. Zeier [a]

[a] *Departement für Physik und Astronomie, Universität Basel, Switzerland*
[b] *Institut für Theoretische Physik II, Ruhr-Universität Bochum, Germany*
[c] *Institut für Kernphysik, Technische Universität Darmstadt, Germany*
[d] *Institute of Physics, Jagiellonian University, Kraków, Poland*
[e] *Institute Jožef Stefan, University of Ljubljana, Ljubljana, Slovenia*
[f] *Institut für Kernphysik, Johannes Gutenberg-Universität, Mainz, Germany*
[g] *Institut für Physik, Johannes Gutenberg-Universität, Mainz, Germany*
[h] *Department of Physics, Old Dominian University, Norfolk, VA, USA*
[i] *Department of Physics, Kyushu Institute of Technology, Tobata, Kitakyushu, Japan*
[j] *Department of Physics, University of Arizona, Tucson, AZ, USA*
[k] *Department of Physics, University of Zagreb, Zagreb, Croatia*

Received 7 April 2003; received in revised form 12 May 2003; accepted 12 May 2003

Editor: J.P. Schiffer

Abstract

The charge form factor of the neutron has been determined from asymmetries measured in quasi-elastic $^3\overrightarrow{\mathrm{He}}(\vec{\mathrm{e}}, \mathrm{e}'\mathrm{n})$ at a momentum transfer of 0.67 $(\mathrm{GeV}/c)^2$. In addition, the target analyzing power, A_y^0, has been measured to study effects of final state interactions and meson exchange currents.

PACS: 21.45.+v; 25.10.+s; 24.70.+s; 25.40.Lw

Keywords: Neutron charge form factor; Final-state interaction

* Corresponding author.
E-mail address: juerg.jourdan@unibas.ch (J. Jourdan).

0370-2693/03/$ – see front matter © 2003 Published by Elsevier B.V.
doi:10.1016/S0370-2693(03)00725-1

1. Introduction

The form factors of the nucleon are fundamental observables. Precise data allow for sensitive tests of the theory of the strong interaction—quantum chromodynamics (QCD)—in the non-perturbative regime. A complete study of the theoretical concepts requires measurements not only for the proton but also for the neutron. Accurate data at low momentum transfer are also required for the calculation of nuclear form factors.

Due to the lack of a free neutron target only neutrons bound in light nuclei can be studied. In this case, determinations of the charge, G_{en}, and magnetic, G_{mn}, form factor from elastic or quasi-elastic cross section data via the Rosenbluth technique do not lead to data with the desired precision. The subtraction of the proton contribution, theoretical corrections due to the unfolding of the nuclear structure and corrections to final state interaction (FSI) and meson-exchange currents (MEC) limit the accuracy to $\sim 30\%$.

Measurements of precise data of the neutron form factors became possible by means of alternative techniques exploiting polarized electron beams and polarized targets or recoil polarimeters. The technique to determine G_{en} with a precision of $<10\%$ relies on asymmetry measurements in quasi-free $(\mathrm{e}, \mathrm{e}'\mathrm{n})$ coincidence experiments in which the asymmetry is given by the interference term and is proportional to $G_{\mathrm{en}} \cdot G_{\mathrm{mn}}$ in the plane wave impulse approximation (PWIA). The small contribution of G_{en} is amplified by the large value of G_{mn} and a measurement of the asymmetry allows for significant improvements in the precision [1–3]. The continuous wave (cw) electron beams available today allowed for the determination of G_{mn} with accuracies of $\sim 2\%$ [4].

Because of its low binding energy, the deuteron is usually employed for studies of neutron properties. However, for polarization studies ^{3}He is particularly suitable due to the fact that for the major part of the ground state wave function the spins of the two protons are coupled antiparallel, so that spin-dependent observables are dominated by the neutron [5]. In addition, at least at low Q^2, corrections due to nuclear structure effects, FSI, and MEC can be calculated using modern three-body calculations. These calculations allow for a quantitative description of the three-nucleon system with similar precision as for the deuteron [6,7].

The asymmetry in double polarization experiments is determined with

$$A(\theta^*, \phi^*) = \frac{1}{P_e P_t} \frac{N^+ - N^-}{N^+ + N^-}, \tag{1}$$

where θ^*, ϕ^* are the polar and the azimuthal angle of the target spin direction with respect to the three momentum transfer $\vec{q}$. The polarizations of beam and target are given by P_e and P_t and the normalized $^3\overrightarrow{\mathrm{He}}(\vec{\mathrm{e}}, \mathrm{e}'\mathrm{n})$ events for positive (negative) electron helicity are N^+ (N^-). With the target spin orientation parallel and perpendicular to $\vec{q}$ two independent asymmetries $A_\parallel = A(0°, 0°)$ and $A_\perp = A(90°, 0°)$ can be measured. In PWIA G_{en} can then be determined via

$$G_{\mathrm{en}}^{\mathrm{PWIA}} = \frac{b}{a} \cdot G_{\mathrm{mn}} \frac{(P_e P_t V)_\parallel}{(P_e P_t V)_\perp} \frac{A_\perp}{A_\parallel}, \tag{2}$$

with the kinematical factors a and b [8]. The factor V accounts for a possible dilution due to contributions with vanishing asymmetry. As P_e, P_t, and V do not depend on the target spin orientation they cancel in principle in the determination of $G_{\mathrm{en}}^{\mathrm{PWIA}}$. In practice, $A_\parallel$ and $A_\perp$ are measured in sequence, as such P_e and/or P_t may change during the two asymmetry measurements. It will be discussed below that such changes are measured and accounted for.

In order to study the FSI-corrections necessary for the determination of G_{en} the target analyzing power A_y^{o} provides an experimental quantity that is sensitive to these effects. For an unpolarized beam and the target spin aligned perpendicular to the scattering plane the target analyzing power can be measured with

$$A_y^{\mathrm{o}} = \frac{1}{P_t} \frac{N^\uparrow - N^\downarrow}{N^\uparrow + N^\downarrow} \tag{3}$$

where $N^\uparrow$ $(N^\downarrow)$ are the normalized $^3\overrightarrow{\mathrm{He}}(\vec{\mathrm{e}}, \mathrm{e}'\mathrm{N})$ events for target spin aligned parallel (antiparallel) to the normal of the scattering plane. For coplanar scattering A_y^{o} is identical to zero in PWIA due to the combination of time reversal invariance and hermiticity of the transition matrix [9]. Thus, a non-zero value of A_y^{o} signals FSI and MEC effects and its measurement provides a check of the calculation of these effects.

The present Letter reports about a new determination of G_{en} from measurements of $A_\perp$ and $A_\parallel$ of $^3\overrightarrow{\mathrm{He}}(\vec{\mathrm{e}}, \mathrm{e}'\mathrm{n})$ scattering at a four-momentum transfer of

$Q^2 = 0.67\ (\mathrm{GeV}/c)^2$. The same kinematics is chosen as for the measurements by Rohe et al. [10]. In addition, the same technique and almost the same apparatus is employed which allows to combine the data reducing the statistical error bar of G_{en} by almost a factor of two.

Consequently, the improved precision requires a careful determination of FSI and MEC effects. Target analyzing powers A_y^{o} have been measured at the same Q^2 and at $Q^2 = 0.37\ (\mathrm{GeV}/c)^2$ in order to properly determine FSI and MEC corrections of the combined result.

2. Experimental setup

At the Mainz Microtron (MAMI) [11] longitudinally polarized electrons with a polarization of ~ 0.8 were produced with a strained layer GaAsP crystal at a typical current of 10 μA [12]. The polarized cw electron beam was accelerated to an energy of 854.5 MeV and guided to the three-spectrometer hall [13]. The $^3\overrightarrow{\mathrm{He}}$ target consisted of a spherical glass container with two cylindrical extentions sealed with oxygen-free 25 μm Cu windows. Coating the glass container with Cs led to relaxation times of about 80 h. The Cu windows were positioned outside of the acceptance of the spectrometer (~ 5 cm) and shielded with Pb blocks to minimize background from beam–window interactions. The ^{3}He target was polarized via metastable optical pumping to a typical polarization of 0.5 and compressed to an operating pressure of 4 bar [14].

Spectrometer A with a solid angle of 28 msr and a momentum acceptance of 20% was used to detect the quasi-elastically scattered electrons at a scattering angle of 78.6°. The recoiling nucleons were detected in coincidence with an array of plastic scintillator bars placed at 32.2°, the direction of $\vec{q}$ for the maximum of the quasi-elastic peak.

The hadron detector consisted of an array of four layers of five plastic scintillator bars with dimensions $50 \times 10 \times 10\ \mathrm{cm}^3$ preceded by two 1 cm thick ΔE detectors for particle identification. The detector was placed at a distance of 160 cm from the target, resulting in a solid angle of 100 msr. The neutron efficiency during the present experiment was determined to 18.3%. The entire detector was shielded with 10 cm Pb except for an opening towards the target were the Pb shield was reduced to 2 cm.

The entire $^3\overrightarrow{\mathrm{He}}$ target was enclosed in a rectangular box of 2 mm thick μ-metal and iron. The box served as an effective shield for the stray field of the magnetic spectrometers and provided a homogeneous magnetic guiding field of $\approx 4 \times 10^{-4}$ T produced by three independent pairs of coils. With additional correction coils a relative field gradient of less than $5 \times 10^{-4}\ \mathrm{cm}^{-1}$ was achieved. The setup also allowed for an independent rotation of the target spin in any desired direction with an accuracy of 0.1° by remote control.

The product of target and beam polarization was monitored during the data taking via determination of the asymmetry for elastic $^3\overrightarrow{\mathrm{He}}(\vec{\mathrm{e}}, \mathrm{e})$ scattering for which the form factors, hence the asymmetries, are accurately known [15]. The analysis of these data resulted in a polarization product of 0.279 ± 0.010 for runs with $A = |A_\parallel|$ and 0.282 ± 0.003 for $A = |A_\perp|$. The different error bar results from the sensitivity of elastic scattering to the target spin direction.

In addition, the time-dependence of the polarization of the target cell was continuously measured during the experiment by Nuclear Magnetic Resonance, while the absolute polarization was measured by the method of Adiabatic Fast Passage [16]. The mean target polarization from these measurements was 0.356 ± 0.015. From the elastic scattering data and the target polarization measurements a beam polarization of $P_e = 0.788 \pm 0.036$ was extracted which agreed well with the determination with a Møller polarimeter (0.827 ± 0.017).

3. Determination of G_{en}

To determine G_{en} the asymmetries $A_\perp$ and $A_\parallel$ of $^3\overrightarrow{\mathrm{He}}(\vec{\mathrm{e}}, \mathrm{e}'\mathrm{n})$ have been measured. The same kinematics was chosen as in [10] with the motivation to combine the two measurements hereby decreasing the statistical error bar of G_{en}.

In the analysis of the data the neutron is identified with a cut on the coincidence time and the absence of a hit in the ΔE amplitude spectrum for two consecutive ΔE detectors. Neutrons from (p, n) charge exchange in the Pb-shielding contribute in first order to the dilution factor V, but the effect cancels in the determination of G_{en} through Eq. (2).

In order to minimize the dependence on the target polarization, data were accumulated alternatively for $A_{\perp}$ and $A_{\parallel}$ at regular intervals by corresponding rotations of the target spin. The polarization ratio that enters in the determination of G_{en} (see Eq. (2)) was unity within 2.6%.

Experimental corrections have been determined via Monte Carlo simulation of the experiment based on PWIA with the momentum distribution compiled by Jans et al. [17]. Accounting for energy loss via bremsstrahlung and for asymmetric angle and momentum acceptances of the spectrometer and the hadron detector can be reliably done [10]. The dominant correction is due to the asymmetric acceptance of the electron spectrometer which leads to an angle shift of $\vec{q}$. The resultant effect is an enhancement of the measured $A_{\perp}$ value due to the contribution proportional to G_{mn}^2. Bremsstrahlung and missing energy lead to a similar effect. The total correction from these effects amounts to $-7.4 \pm 3.0\%$.

Finally, the value for the magnetic form factor required for the determination of G_{en} is taken from the parameterization by Kubon et al. [4] with $G_{\mathrm{mn}} = (1.037 \pm 0.012)\mu_{\mathrm{n}} G_{\mathrm{D}}$ where μ_{n} is the magnetic moment of the neutron in units of nuclear magnetons and G_{D} the dipole form factor. The resulting experimental value is $G_{\mathrm{en}}^{\mathrm{PWIA}} = 0.0416 \pm 0.0102_{\mathrm{stat}} \pm 0.0024_{\mathrm{syst}}$.

This value is in good agreement with the value by Rohe et al. [10]. A weighted average of the two values leads to $G_{\mathrm{en}}^{\mathrm{PWIA}} = 0.0468 \pm 0.0064_{\mathrm{stat}} \pm 0.0027_{\mathrm{syst}}$ which corresponds to a reduction of the statistical error bar by almost a factor of two.

4. Target analyzing power

The target analyzing power A_y^{o} has been measured for $^3\overrightarrow{\mathrm{He}}(\mathrm{e}, \mathrm{e}'\mathrm{n})$ and $^3\overrightarrow{\mathrm{He}}(\mathrm{e}, \mathrm{e}'\mathrm{p})$ at $Q^2 = 0.67\ (\mathrm{GeV}/c)^2$ (the kinematics of the G_{en} measurement) and at $0.37\ (\mathrm{GeV}/c)^2$. The measurement at $0.37\ (\mathrm{GeV}/c)^2$ was performed by lowering the beam energy to 600 MeV as the geometrical constraints of the target shielding box and the hadron detector did not permit a change of the scattering or recoil angle. An unpolarized beam was used and the target spin was aligned perpendicular to the scattering plane and reversed every 2 minutes.

The analysis of the A_y^{o} data is very similar to the one described above. Electrons are accepted for energy transfers $\omega = 225$–290 MeV (314–408 MeV) for the low (high) Q^2-point. The hadron is identified with a cut on the coincidence time and the ΔE amplitude spectrum.

Contrary to the determination of $G_{\mathrm{en}}^{\mathrm{PWIA}}$, dilution effects do not cancel for A_y^{o} and have to be determined. The 2 cm Pb absorber of the hadron detector leads to misidentified proton/neutron events due to charge exchange scattering in the Pb absorber. The 3 times larger e–p cross section and the 5 times larger efficiency of the hadron detector for protons leads to a dilution effect that is negligible for $A_{y(\mathrm{e},\mathrm{e}'\mathrm{p})}^{\mathrm{o}}$ but must be taken into account for $A_{y(\mathrm{e},\mathrm{e}'\mathrm{n})}^{\mathrm{o}}$.

The correction was measured by replacing the ^{3}He gas in the target with hydrogen and tagging the recoil protons with the elastically scattered electrons. The fraction of protons, misidentified as neutrons amounts to 0.18 ± 0.01 (0.13 ± 0.01) for the low (high) Q^2-point. An additional contribution results from the uncorrelated background in the coincidence time spectrum determined to 0.056 (0.025) for the $(\mathrm{e}, \mathrm{e}'\mathrm{n})$ events.

The $A_{y(\mathrm{e},\mathrm{e}'\mathrm{n})}^{\mathrm{o}}$ values have been corrected according to

$$A_{y(\mathrm{e},\mathrm{e}'\mathrm{n})}^{\mathrm{o}} = \frac{A_{y\,\mathrm{total}}^{\mathrm{o}} - x A_{y\,\mathrm{back}}^{\mathrm{o}}}{1 - x} \tag{4}$$

with x the total fraction of background events, $A_{y\,\mathrm{back}}^{\mathrm{o}}$ its analyzing power and $A_{y\,\mathrm{total}}^{\mathrm{o}}$ the analyzing power of the total $(\mathrm{e}, \mathrm{e}'\mathrm{n})$ yields.

The corrected experimental results for A_y^{o} are shown in Table 1. Total error bars are given. The errors are dominated by statistics with a small contribution of systematic errors due to false asymmetries and polarization measurements.

For both $(\mathrm{e}, \mathrm{e}'\mathrm{n})$ and $(\mathrm{e}, \mathrm{e}'\mathrm{p})$ the agreement of the experimental values at $Q^2 = 0.37\ (\mathrm{GeV}/c)^2$ with the result of a complete calculation by Golak et al. [18] is quite satisfactory. Neglecting the contribution of MEC in the calculation has little effect on A_y^{o} for $(\mathrm{e}, \mathrm{e}'\mathrm{n})$. On the other hand, a calculation for $(\mathrm{e}, \mathrm{e}'\mathrm{n})$ was also performed setting the proton form factors G_{ep} and G_{mp} to zero. As can be seen from Table 1 the effect

Table 1
Results of $A_y^{\rm o}$ for the $^3\overrightarrow{\rm He}({\rm e,e'n})$ and $^3\overrightarrow{\rm He}({\rm e,e'p})$ reactions. The experimental data at $Q^2 = 0.37$ (GeV/c)^2 are compared to results of a complete Faddeev calculation. For (e, e′n) the effects of dropping different contributions in the calculation are also shown

Q^2 (GeV/c)^2	0.37	0.67
$^3\overrightarrow{\rm He}({\rm e,e'n})$:		
Experiment	0.144 ± 0.034	0.028 ± 0.010
Theory	0.178	
Theory without MEC	0.186	
Theory with $G_{\rm ep} = G_{\rm mp} = 0$	0.004	
$^3\overrightarrow{\rm He}({\rm e,e'p})$:		
Experiment	-0.025 ± 0.005	-0.016 ± 0.005
Theory	-0.017	

is quite dramatic suggesting that 98% of the FSI effect measured with $A^{\rm o}_{y({\rm e,e'n})}$ results from a coupling of the virtual photon to the proton followed by a (p, n) charge exchange reaction in the three-body system.

A similar theoretical study is not possible at $Q^2 = 0.67$ (GeV/c)^2 due to the non-relativistic nature of present day calculations and the fact that the transferred energy is well above the pion production threshold.

5. FSI corrections of $G_{\rm en}$

For the same reason the FSI effects in $A_\perp/A_\parallel$ which are needed as corrections to determine $G_{\rm en}$ cannot be calculated at this Q^2 using today's non-relativistic Faddeev codes. However, we will discuss in the following that with the measurements of $A_y^{\rm o}$ and the measurements by Carasco et al. [19] a reliable estimate of the effects can be made. In this approach, we first determine $G_{\rm en}^{\rm PWIA}$ which accounts for relativistic kinematics—the only significant relativistic effect to consider at this Q^2 [19]—and then apply the FSI corrections based on the acquired experimental information.

Two effects contribute to the FSI correction and have to be considered at first order. First, the photon couples to one of the protons followed by a charge exchange process in the three-body system simulating an (e, e′n) event. At $Q^2 = 0.37$ (GeV/c)^2 the complete Faddeev calculation by Golak et al. [18] which successfully predicted $A_y^{\rm o}$ predicts a total FSI effect for the ratio $A_\perp/A_\parallel$ of 25%. The calculations also show that the charge exchange process which is responsible for 98% of $A_y^{\rm o}$ amounts to 60% of the total FSI effect in $A_\perp/A_\parallel$.

The ratio of the elementary cross sections $\sigma_{\rm ep}/\sigma_{\rm en}$, which is a measure for the probability of the photon coupling to a proton or a neutron is similar at Q^2 of 0.37 (GeV/c)^2 and 0.67 (GeV/c)^2. We therefore assume that the charge exchange process also contributes with 60% to the FSI effect in $A_\perp/A_\parallel$ at 0.67 (GeV/c)^2.

With the experimental knowledge of $A_y^{\rm o}$ at both Q^2 values the contribution of the charge exchange processes in $A_\perp/A_\parallel$ can be determined with the ratio of the experimental $A_y^{\rm o}$ values scaling the effect to 0.67 (GeV/c)^2. This results in a FSI correction of 3% in $G_{\rm en}$.

Second, the photon couples to the neutron followed by a rescattering process in the three-body continuum which may also lead to FSI effects. The effect for this type of FSI in $A_\parallel$ and $A_\perp$ of (e, e′p) has been discussed in detail by Carasco et al. [19]. The results of a calculation which treats only the FSI between the two (slow) spectator nucleons agree well with the experimental data. The same calculation has been used to compute $A_\parallel$ and $A_\perp$ of (e, e′n). Contrary to the significant FSI effect for $A_\perp$ and $A_\parallel$ of (e, e′p) observed in [19] the corresponding contribution is small for the asymmetries of (e, e′n). The resulting FSI

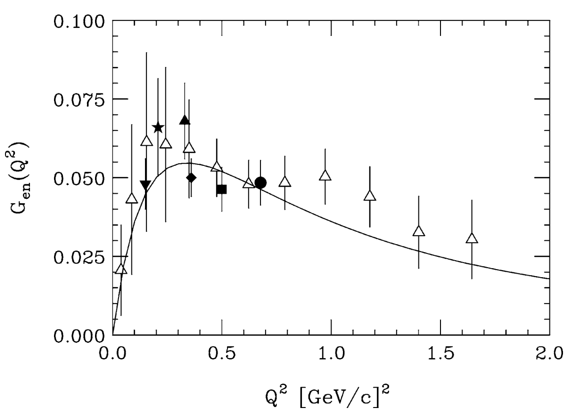

Fig. 1. Experimental results of $G_{\rm en}$. Shown are the results from double-polarization experiments, the present result (●), [20] (■), [21] (◆), [22] (▼), [23] (▲), and [24] (★), and the results from the elastic quadrupole form factor [25], (△). The solid line is the parameterization by Galster [26].

effect of this process averaged over the accepted phase space is 0.4% in G_{en}.

Thus, we conclude that the total FSI correction to G_{en} at 0.67 $(\mathrm{GeV}/c)^2$ is small (of the order of 3.4%) and dominated by charge-exchange processes. The correction is accounted for in the final result with a relative uncertainty of 50% added in quadrature to the quadratic sum of the experimental uncertainties of the combined G_{en} result. The final value of $G_{\mathrm{en}} = 0.0484 \pm 0.0071$ is shown in Fig. 1. This result is in excellent agreement with the G_{en} values deduced from the quadrupole form factor of elastic e–d scattering [25].

6. Conclusions

In the present experiment, G_{en} has been measured via the double polarization reaction ${}^3\overrightarrow{\mathrm{He}}(\vec{\mathrm{e}}, \mathrm{e}'\mathrm{n})$. It has greatly improved the accuracy of our knowledge of G_{en} from such measurements at $Q^2 = 0.67\ (\mathrm{GeV}/c)^2$. The applied contribution from FSI is estimated as $(3.4 \pm 1.7)\%$ at this high Q^2 which is considerably smaller than the statistical uncertainty. The good agreement of the final value of $G_{\mathrm{en}} = 0.0484 \pm 0.0071$ with data from other double polarization experiments corrected for FSI is very satisfactory. The value for G_{en} also agrees well with G_{en} values extracted from the quadrupole form factor determined in elastic e–d scattering.

Acknowledgements

This work was supported by the Schweizerische Nationalfonds, Deutsche Forschungsgemeinschaft (SFB 443), the Polish Committee for Scientific Research, the Foundation for Polish Science and the NSF. The numerical calculations have been performed on the Cray SV1 of the NIC, Jülich, Germany.

References

[1] R.G. Arnold, C.E. Carlson, F. Gross, Phys. Rev. C 23 (1981) 363.
[2] B. Blankleider, R.M. Woloshyn, Phys. Rev. C 29 (1984) 538.
[3] H. Arenhoevel, Z. Phys. A 331 (1988) 123.
[4] G. Kubon, et al., Phys. Lett. B 524 (2001) 26.
[5] J. Golak, G. Ziemer, H. Kamada, H. Witała, W. Glöckle, Phys. Rev. C 63 (2001) 034006.
[6] A. Kievsky, M. Viviani, S. Rosati, D. Hüber, W. Glöckle, H. Kamada, H. Witała, J. Golak, Phys. Rev. C 58 (1998) 3085.
[7] W. Glöckle, et al., Electronuclear Physics with Internal Targets and the BLAST Detector, World Scientific, Singapore, 1999, p. 185.
[8] A.S. Raskin, T.W. Donnelly, Ann. Phys. 191 (1989) 78.
[9] H.E. Conzett, Nucl. Phys. A 628 (1998) 81.
[10] D. Rohe, et al., Phys. Rev. Lett. 83 (1999) 4257.
[11] H. Herminghaus, H. Euteneuer, K.H. Kaiser, in: Proc. LINAC'90, Albuquerque, NM, 1990, p. 362.
[12] K. Aulenbacher, et al., Nucl. Instrum. Methods A 391 (1997) 498.
[13] K.I. Blomqvist, et al., Nucl. Instrum. Methods A 403 (1998) 263.
[14] R. Surkau, et al., Nucl. Instrum. Methods A 384 (1997) 444.
[15] A. Amroun, et al., Nucl. Phys. A 579 (1994) 596.
[16] E. Wilms, et al., Nucl. Instrum. Methods A 401 (1997) 491.
[17] E. Jans, et al., Nucl. Phys. A 475 (1987) 687.
[18] W. Glöckle, J. Golak, H. Kamada, H. Witała, R. Skibiński, A. Nogga, Phys. Rev. C 65 (2002) 044002.
[19] C. Carasco, et al., Phys. Lett. B in press, 2003, nucl-ex/0301016.
[20] H. Zhu, et al., Phys. Rev. Lett. 87 (2001) 081801.
[21] J. Becker, et al., Eur. Phys. J. A 6 (1999) 329;
J. Golak, et al., Phys. Rev. C 63 (2001) 034006.
[22] C. Herberg, et al., Eur. Phys. J. A 5 (1999) 131.
[23] M. Ostrick, et al., Phys. Rev. Lett. 83 (1999) 276.
[24] I. Passchier, et al., Phys. Rev. Lett. 82 (1999) 4988.
[25] R. Schiavilla, I. Sick, Phys. Rev. C 64 (2001) 041002.
[26] S. Galster, H. Klein, J. Moritz, K.H. Schmidt, D. Wegener, J. Bleckwenn, Nucl. Phys. B 32 (1971) 221.