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THREE-PARTICLE SYSTEMS AT LOW AND INTERMEDIATE ENERGIES

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ABSTRACT

Recent experimental investigations of systems consisting of three nucleons or of a pion and two nucleons are commented on. Sensitivities with regard to the nucleon-nucleon and pion-nucleon interactions are discussed. Discrepancies between experimental observables and theoretical predictions do not require the inclusion of explicit three-body forces at the present level of precision.

I. THE THREE-NUCLEON SYSTEM

1. The N-d system in the low energy region

The three-nucleon system is the more important laboratory to test the adequacy of nucleon-nucleon potentials in describing within the framework of the Faddeev equations the three-nucleon pair wise interactions. However, before any discrepancies between experiment and theory can be ascribed with certainty to genuine three-body interactions or to more exotic phenomena, like signatures of the quark structure of the nucleons, one must ascertain how well a particular nucleon-nucleon potential reproduces the N-N observables, one must check its off-shell behavior, and establish the importance of relativistic effects. The nucleon-nucleon potential parameters are obtained by fitting existing N-N data. It is to be noted that even the modern potentials, e.g. the Paris¹ and Bonn² potentials differ substantially in the predictions for certain observables like for instance the spin correlation parameter A_{nn} in n-p elastic scattering. Figure 1 shows predictions for the observable A_{nn} at two energies 210 MeV and 325 MeV together with calculations based upon various phase shift analyses.

Fig. 1. Various predictions for the spin correlation parameter A_{nn} for n-p elastic scattering (a) at 210 MeV, (b) at 325 MeV.

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Fig. 2. Predictions for the $3D_2$ phase shift based upon the Paris and Bonn potentials compared to the results of phase shift analyses.

CM-P00067448

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Fig. 3. Proton-proton bremsstrahlung analyzing powers for various angle pairs $(\theta_3 - \theta_4)$ compared with predictions based upon the soft-photon approximation and the Paris and Bonn potentials. The angle θ_4 is the combined result for two angular settings.

predictions based upon the Paris and Bonn potentials.⁵ It is clear that the potential model calculations given the better description of that data. Unfortunately, the data as presented here do not allow a distinction between the two potential models. It is to be noted that the TRIUMF experiment,⁴ from which the data shown in Fig. 3 form a small subset, presents the first direct observation of off-energy-shell effects in the N-N interaction with $|\vec{p}_{\text{off}} - \vec{p}_{\text{on}}| < 200\text{--}400 \text{ MeV}/c$. For reasons given by Loiseau et al.⁶ no consideration is given here to other nucleon-nucleon potentials (their off-energy-shell behavior is questionable).

A recurring problem when making comparisons between the p-d observables and theoretical predictions is with the treatment of the Coulomb interaction, especially at the lower energies (incident proton energies less than 10 MeV). High precision n-d elastic scattering and breakup data are now becoming available removing the extra degree of uncertainty related to the treatment of the Coulomb interaction. An example of high precision n-d elastic scattering analyzing power data⁷ is shown in Fig. 4.

These analyzing power data, measured at Karlsruhe with a white neutron beam, are presented in the form of angular distributions for 10 energy bins (from 18 to 50 MeV).

The data are compared with a series of Faddeev calculations made in collaboration with Y. Koike using the Graz II (shown in the Figure) and PEST4 separable N-N interactions. The agreement obtained although not perfect is rather satisfactory for the whole energy range under consideration. Also obtained were n-d

Fig. 4. Analyzing powers for $^2\text{H}(n,n')^2\text{H}$ elastic scattering for 10 energy bins from 18 to 50 MeV.

breakup analyzing power data for the n-p final state interaction (FSI) region.

One of the older experimental problems in low energy p-d scattering is the determination of the doublet scattering length. Due to the existence of a pole at a negative energy (analogous to the n-d system) the effective range expansion is anomalous and can be written

$$2K = \frac{1/2a + 1/2 \cdot 2r_0k^2}{1 + k^2/k_0^2}$$

The behavior of $2K$ can only be established through a phase shift analysis of low-energy p-d scattering data. Even the introduction of differential cross section angular distributions at seven energies between 0.4 and 1.0 MeV for scattering angles from 44.5° to 149.2° c.m. having relative errors about 0.5% and absolute errors less than 1% and analyzing power angular distributions at 0.8, 0.9, and 1.0 MeV with statistical errors of about 5×10^{-4} did not allow establishing a nonlinear behavior of $2K$ for decreasing energy⁸ (see Fig. 5). Due to the magnitude of the Coulomb interaction precision differential cross section measurements for incident proton energies less than 0.5 MeV will constitute a formidable task. The question whether the experimental p-d doublet scattering length lies on the Phillips line remains open.

Initial measurements of the tensor analyzing powers A_{xx} and A_{yy} for d-p breakup initiated by polarized deuterons incident on protons have been made for 79 MeV incident deuterons.⁹ In this experiment a symmetric constant relative energy geometry was adopted. In this geometry the three cm nucleon momenta in the final state form an equilateral triangle, with the two proton momenta symmetric with respect to the incident beam direction. The analyzing powers are plotted with respect to the variable α , which is the supplement of the angle which the neutron makes with respect to the incident beam direction in the cm system. If the comparison with predictions based upon the (local)

Fig. 5. Comparison of the $2S$ effective range function for p-d scattering as determined in the phase shift analysis of Kuttel et al.⁸ (shaded area) with various theoretical predictions labelled p-d. The triangles represent the results of the p-d phase shift analysis of Arvieux. The results of the n-d phase shift analysis (now outdated) by van Oers and Seagrave is represented by the short-dashed curve. For details see Ref. 8.

Fig. 6. Tensor analyzing powers A_{xx} and A_{yy} for the $H(d,pp)n$ reaction at an incident deuteron energy of 79 MeV. The data are compared with Faddeev calculations based upon the (local) Reid soft-core interaction (labelled Tjon) and upon separable interactions.

Reid soft-core interaction and upon separable interactions is considered to be of statistical significance than such measurements may be sensitive to the N-N potential used (see Fig. 6). A higher precision measurement (to ± 0.04 in the analyzing powers) is planned for the near future at IUCF using 95 MeV incident deuterons.

As pointed out by Kotke, Plassas, and Zankel¹⁰ a valid criticism of most Faddeev calculations of three-nucleon observables is the use of inadequate N-N interactions. In momentum-space Faddeev calculations one has used up to now (non-local) separable N-N potentials which fell short in reproducing a reasonable off-energy-shell behavior or proper mixing of coupled partial waves. In configuration-space Faddeev calculations one did not succeed in using other than phenomenological N-N potentials. For a more meaningful comparison between experimental observables and theoretical predictions, the latter should be based upon N-N potentials that present a realistic meson-exchange model, e.g., the Paris and Bonn potentials. But as stated above further improvements are required for these potential model descriptions of the N-N interaction.

2. p-d interactions at intermediate energies

2.1 p-d elastic scattering

Due to the complexity of the computational problem and due to the limitations of potential models to represent the N-N interaction, p-d scattering at intermediate or high energies cannot in practice be described by Faddeev three-body calculations. One has to resort to multiple scattering descriptions which contain severe approximations.

For N-d elastic scattering the scattering matrix is a 6×6 matrix of complex amplitudes. Assuming rotational invariance, parity conservation, and time-reversal invariance there remain 12 independent amplitudes. After removing a common phase one needs to measure at least 23 observables at each energy or wave number and scattering angle to completely determine the scattering matrix. The general polarization observable $C_{ij,k}$ is related to the amplitudes by

$$C_{ij,k} = \text{Tr}[(\sigma_k \otimes \hat{p}_k) M(\sigma_i \otimes \hat{p}_j) M^\dagger] / \text{Tr}(M M^\dagger)$$

where σ_i and $\hat{p}_j$ and $(\sigma_k$ and $\hat{p}_k)$ are the spin operators of the ingoing (outgoing) protons and deuterons, respectively. It is clear that 23 observables arbitrarily chosen do not constitute an independent set and thus care must be taken in defining the observables which are going to be measured. As pointed out by Spertsen¹¹ at an incident proton laboratory energy of 10 MeV a set of 19 p-d elastic scattering observables has been measured: the unpolarized differential cross section, the 5 analyzing powers, and further 3 proton-to-proton and 10 proton-to-deuteron polarization transfer coefficients. These observables were found to constitute an independent although not complete set. At 800 MeV measurements have been restricted to a limited range of momentum transfers due to the rapid decrease in the magnitude of the differential cross section. For $0.03 < -t < 0.17$ (GeV/c)² a complete set of 24 observables now exists consisting of the unpolarized differential cross section, 4 analyzing powers, 4 proton-to-proton transfer coefficients and (obtained with both incident proton beam and deuteron target polarized) 15 second and third order spin dependent observables. Further measurements are being made to allow a complete determination of the 12 scattering amplitudes up to momentum transfers of $-t < 0.8$ (GeV/c)². An example of existing data is shown in Fig. 7.

Clearly determining the 12 p-d elastic scattering amplitudes is a very large enterprise. Parallel with such efforts one may try to identify which observables are particularly sensitive to preselected

Fig. 7. Double and triple scattering observables measured for $p + d \rightarrow p + d$ elastic scattering at 800 MeV.

aspects of the N-N interaction or the deuteron wave function. Such theoretical investigations have been made by Bleszynski and collaborators.¹² In particular they have tried to identify sensitivity to the double-spin-flip part of the N-N scattering amplitude and to the importance of relativistic descriptions.

2.2 $^2\text{H}(p,2p)n$

A new extensive set of differential cross section measurements has been made of the $^2\text{H}(p,2p)n$ reaction at 507 MeV.¹³ These measurements also include a coplanar symmetric angular distribution for recoil momenta between 12 and 650 MeV/c. At present the only amenable theoretical approach at these energies is an impulse approximation description. One expects that the momentum of the recoil neutron should mirror closely the internal momentum distribution of the struck proton, at least up to moderate values of the momenta. For low neutron recoil momenta (<100 MeV/c) precision five fold differential cross sections were obtained. These data have an absolute uncertainty of 1.9 to 2.7%. Comparison has been made with theoretical predictions based upon the impulse approximation which include rescattering and final-state interaction terms. The data underestimate the theoretical predictions by 5.1 to 6.7% in agreement with previous observations of missing strength in the experimental momentum distribution. At the larger recoil momenta (>200 MeV/c) the measured five fold differential cross sections are larger than predicted by the impulse approximation calculation which includes rescattering and FSI terms. Improvements are obtained when one further considers diagrams representing virtual excitation of the $\Delta(1232)$ (see Fig. 8). This figure shows the

Fig. 8. Coplanar symmetric angular distribution for the $^2\text{H}(p,2p)n$ reaction at 507 MeV. Only the data for recoil momenta above 150 MeV/c are shown. The dashed curve represents a PWIA calculation for a deuteron wave function obtained from the Paris potential. The solid curve represents the contribution due to diagrams involving virtual excitation of the $\Delta(1232)$.

importance of including the latter to the impulse approximation description of the $^2\text{H}(p,2p)n$ reaction. So far no considerations have been given to off-energy-shell effects. Impulse approximation calculations of the analyzing power indicate sensitivity to the off-energy-shell behavior of the N-N interaction.

II. THE πNN SYSTEM

A systematic experimental investigation of the πNN system is of considerable importance. The πNN system is another three-body system where one can obtain reliable theoretical predictions using pair wise interactions within the framework given by the Faddeev equations. In the πNN system one should make a simultaneous comparison of the theoretical observables for all reaction channel with theoretical predictions. The various coupled reaction channels can be schematically denoted as:

There exists a wealth of data for the N-N elastic scattering channel up to energies well above 1 GeV. Nevertheless, even up to 800 MeV there are still considerable uncertainties in the n-p elastic scattering channel exemplified by the n-p phase shift analyses. A considerable amount of data exist also for the $pp + \pi^+d$ production/absorption channel. With regard to the πd elastic scattering channel there now exists data on the differential cross sections, vector analyzing powers, and tensor polarizations. In the last few years attention has furthermore been given to the inelastic channels $\text{NN} + \pi\text{NN}$, essentially $pp + \pi^+np$ and to $\pi d + \pi np$.

So far no calculations of all five channels have been made simultaneously; at most two or three channels have been considered at the same time. Most difficulties are encountered in reproducing the $pp + \pi^+d$ and $\text{NN} + \pi\text{NN}$ pion production channels. In the following, comments will be made in particular regarding πd elastic and inelastic scattering, and the $\text{NN} + \pi\text{NN}$ reaction.

1. πd elastic scattering

Recently, πd elastic scattering measurements have been made by a number of groups at SIN,¹⁴ at LAMPF,¹⁵ and at TRIUMF.^{16,17} These measurements include the vector analyzing powers $iT_{11}(\theta)$, the tensor polarizations $t_{20}(\theta)$, and the tensor analyzing powers $T_{20}(\theta)$, the latter using a polarized deuteron target of the frozen spin type. The ETH group has made a single energy phase shift analysis of differential cross sections, vector analyzing powers, and their measured tensor polarizations at five energies 117, 125, 134, 142, and 151 MeV.¹⁸ To fit in particular these tensor polarizations the ETH group introduced Breit-Wigner resonances to represent dibaryons. The tensor polarizations $t_{20}(\theta)$ or the analyzing powers $T_{20}(\theta)$ have now been measured at three laboratories by four experimental groups. The

data obtained at LAMF and at TRIUMF are essentially in agreement, while the results of the ETH group disagree considerably with the other three data sets.

The results of the LAMF and TRIUMF experiments show that t_{20} and T_{20} are negative and smoothly varying for all energies and angles investigated. The measured tensor analyzing powers T_{20} can be converted to tensor polarizations t_{20} by admixing calculated values of T_{21} and T_{22} (which are small). The data obtained by the ETH group on the other hand show rapid variation with angle and energy as shown in Fig. 9. An explanation of this discrepancy has not yet been given. As shown in Fig. 9 the relativistic three-body model used by

Fig. 9. Tensor polarizations t_{20} as function of energy and angle for π^+ -d elastic scattering. The data are from SIN (open circles), LAMF (open triangles and squares), and TRIUMF (filled circles). The curves are theoretical predictions by Garcilazo (Ref. 19).

Fig. 10. Tensor analyzing powers $T_{20}(\theta)$ for π^+ -d elastic scattering compared with theoretical predictions by Blankleider and Afnan (Ref. 20) (solid curves, full calculation, dash-dot curves no P_{11} rescattering and no absorption) and by Garcilazo (dashed curves).

channels. The discrepancies between the various model calculations is due to differences in the treatment of the pion-nucleon P_{11} interaction. The important conclusion to be drawn is that the measured tensor polarizations can be explained with a relativistic Faddeev calculation without introducing exotic phenomena such as dibaryon resonances. An open problem is the detailed treatment of the P_{11} pion-nucleon interaction.

2. π -d breakup

π -d breakup has been studied at SIN at various incident pion energies. Extensive data on the five-fold differential cross sections $d^5\sigma/(d\Omega_1 d\Omega_2 d\Omega_3 d\Omega_4 d\Omega_5)$ were obtained at 228 and 294 MeV incident pion energy.²¹ Similarly, data in a large region of phase space were obtained for the vector analyzing power V_{11} at 180, 228, and 294 MeV as function of θ_π , θ_p , ($\phi_\pi = \phi_p = 180^\circ$), and P_π , the momentum of the observed proton.²² The data have been compared with a relativistic Faddeev calculation, the same calculation that reproduced so well the π -d elastic scattering results. There is a spectacular agreement with the shape and absolute magnitude of the momentum distributions for the vast majority of the differential cross section data. When comparing the analyzing power data with the theoretical predictions one finds that the general trend of the data is quite well reproduced (see Fig. 11). The analyzing power which can be described in terms of the interference of various terms of the scattering amplitude is much more sensitive to the details of the calculations. In particular in the low momentum region, where the differential cross section is down by almost three orders in magnitude, the theoretical calculations are sensitive to the π -p final state interaction. It is clear that with such good agreement between theory and experiment there is little room for more exotic phenomena.

3. $NN + \pi NN$

With the good agreement between experiment and conventional relativistic three-body calculations for π -d elastic and inelastic scattering it will be most challenging to find next an adequate theoretical description of the $pp + \pi^+np$ reaction. Improvements in the comparison of experimental $pp + \pi^+np$ data at 800 MeV and the three-body model of Dubach, Kloeit, and Silber occurs when $^1S_0$ and $^3S_1$ final state interactions are introduced explicitly²³ (see Fig. 12). This points to the requirement of introducing in such three-body models both pion-nucleon and nucleon-nucleon interactions as input. With a reasonable amount of data available for $pp + \pi^+np$ including analyzing powers and spin correlation parameters in the energy range 400 MeV to 1.5 GeV, new experimental efforts are directed to measure $np + \pi^+p$ differential cross sections and analyzing powers (Saturne and TRIUMF). These experiments will measure the reaction amplitude with $I=0$ in the initial channel and consequently determine the importance of the non-resonant contributions to the np pion production reactions.

Fig. 11. Vector analyzing powers iT_{11} for $\pi^+\bar{d}$ breakup as function of the proton momentum for various pion-proton angle pairs at an incident pion energy of 228 MeV. The solid curves are the results of Faddeev calculations by Garciázo.

Fig. 12. Differential cross sections for the reaction $pp + \pi^+n$ at 800 MeV as function of the proton momentum for $\theta_p=15^\circ$ and $\theta_\pi=21^\circ$ lab. The solid curve is a calculation which includes FSI using the Watson-Migdal expression after multiplying it with a factor 0.57. The dashed-dotted curve is from the same calculation before FSI.

III. π^+ AND π^- INTERACTIONS WITH TRITIUM AND HELIUM-3

1. π^+ and π^- elastic scattering on tritium and helium-3

Charge symmetry refers to the invariance under a reflection in isospin space about the 1-2 plane. The charge symmetry operator transforms T_3 , the third component of the isospin, into $-T_3$, thus replacing any particle by its mirror counter part, e.g., $p \rightarrow n$, $\pi^+ \rightarrow \pi^-$, or $u \rightarrow d$. Charge symmetry is broken by the electromagnetic interaction and thus one expects effects of the order of the fine structure constant $\alpha = 1/137$. Nefkens et al.²⁴ have made measurements of 180 MeV π^+ and π^- elastic scattering on ^3H and ^3He between 44° and 96° c.m. Charge symmetry implies that the super ratio $R \equiv [d\sigma(\pi^+{}^3He)/d\sigma(\pi^-{}^3H)]/[d\sigma(\pi^+{}^3H)/d\sigma(\pi^-{}^3He)] \equiv 1$. The initial measurements found this ratio R to vary with angle reaching an uncomfortably small minimum value of 0.76 ± 0.05 . Direct Coulomb effects cannot account for such a large deviation from one. It is to be noted that the super ratio is independent to first order of many systematic errors except for those in the ^3He to ^3H gas pressure ratio. But even in the case of an error in the determination of the relative gas pressures the super ratio R should be constant with angle. More recent measurements have brought the super ratio closer to one.²⁵ It will be a difficult task to separate the direct Coulomb effects from the intrinsically more interesting ones, like $\rho^0\omega$ and $\pi^0\eta$ meson mixing and short and medium range effects due to the u and d quark mass differences.

2. Pion absorption on helium-3

Pion absorption on ^3He is dominated by the two-nucleon contribution. Unlike deuterium where pion absorption is on a $T=0$, $S=1$ nucleon pair ($nd \rightarrow 2N$), absorption of pions in ^3He involves both $T=0$, $S=1$ and $T=1$, $S=0$ nucleon pairs. Experimental investigations of $^3He(\pi^+, pp)n$ and $^3He(\pi^-, pn)n$ were executed at SIN, LAMPF, and TRIUMF. Since π^- absorption must involve an initial pp pair (with $T=1$) in the target to yield a final pn pair, whereas π^+ absorption involves an initial pn pair (with $T=0$ or 1) the ratio of the two differential cross sections yields information on the isospin dependence of the pion absorption process. Theoretical models have considerable difficulty in reproducing the experimental ratio of the differential cross sections.²⁶ A non-negligible fraction of the pion absorption cross section though is through a three-nucleon absorption process. The observed energy distributions show a pure phase space behavior. Within the errors of the measured differential cross sections there are no differences between π^+ and π^- absorption.²⁷

REFERENCES

1. M. Lacombe, B. Loiseau, J.M. Richard, R. Vinh Mau, J. Coté, P. Pirès, and R. de Tourreil, Phys. Rev. C21, 861 (1980).
2. R. Machleidt, in Quarks and Nuclear Structure, ed. K. Bleuler, Proceedings of the 3rd Klaus Erkelenz Symposium, Bad Honnef,

- 1983, Lecture Notes in Physics, Vol. 197 (Springer Verlag, Berlin, 1984).
3. R. Machleidt, private communication.
4. P.J. Kitching, private communication.
5. R.L. Workman and H.W. Fearing, TRIUMF preprint TRI-PP-85-68; private communication.
6. B. Loiseau, L. Mathelitsch, W. Plessas, and K. Schwarz, Phys. Rev. C32, 2165 (1985).
7. F.P. Brady, P. Doll, G. Fink, W. Heeringa, K. Hofman, H.O. Klages, W. Nitz, J. Wlaczynski, in Proceedings Sixth Int. Symp. Polar. Phenom. in Nucl. Phys., Osaka, 1985, J. Phys. Soc. Japan 55, 864 (1986) Suppl.
8. E. Huttel, W. Arnold, H. Baumgart, H. Berg, and G. Clausnitzer, Nucl. Phys. A406, 443 (1983).
9. R.E. Brown, R.A. Hardkopf, N. Jarmie, F.D. Correll, J.M. Lambert, P.A. Treado, I. Slaus, P. Schwandt, W.W. Jacobs, H.O. Meyer, E.J. Stephenson, J.Q. Yang, W.T.H. van Oers, P. Dolleschall, and J.A. Tjon, Nucl. Instrum. Meth. B10/11, 356 (1985).
10. Y. Koike, W. Plessas, and H. Zankel, Phys. Rev. C32, 1796 (1985).
11. F. Sperisen, in Proceedings Sixth Int. Symp. Polar. Phenom. in Nucl. Phys., Osaka, 1985, J. Phys. Soc. Japan, 55, 852 (1986) Suppl.
12. M. Bleszynski, Phys. Lett. 92B, 91 (1980);
D.L. Adams and M. Bleszynski, Phys. Lett. 150B, 405 (1985).
C.F. Perdisat, V. Punjabi, M.B. Epstein, D.J. Margaziotis, A. Bracco, H.P. Gubler, W.P. Lee, P.R. Poffenberger, W.T.H. van Oers, Y.P. Zhang, H. Postma, H.J. Sebel, and A.W. Stetz, Phys. Lett. 156B, 38 (1985).
14. V. König, A. Chisholm, W. Grüebler, J. Ulbricht, P.A. Schmeltz, M. Merdzan, and K. Elsener, J. Phys. G Nucl. Phys. 9, 1211 (1983).
15. E. Unglrich, W.S. Freeman, D.F. Geesaman, R.J. Holt, J.R. Specht, B. Zeitman, E.J. Stephenson, J.D. Moses, M. Farkhondeh, S. Gliad, and R.P. Redwine, Phys. Rev. C31, 934 (1985).
16. Y.M. Shin, K. Itoh, N.R. Stevenson, D.R. Gill, D.F. Ottewell, G.D. Wait, T.E. Drake, D.F. Frekers, R.B. Schubank, and G.J. Lolos, Phys. Rev. Lett. 55, 2672 (1985).
17. G.R. Smith, A. Altman, P.P.J. Delheij, D.R. Gill, D.C. Healey, R.R. Johnson, G. Jones, D. Ottewell, F.M. Rozon, M.E. Sevior, F. Tervisides, R.P. Treille, G.D. Wait, P. Walden, G.J. Lolos, E.L. Mathie, S.I.H. Nayvi, E.T. Boschitz, C.R. Ottermann, G.S. Kyle, and P. Amaudruz, TRIUMF preprint TRI-PP-86-13; private communication.
18. M. Merdzan, W. Grüebler, V. König, J. Ulbricht, and P.A. Schmeltz, Proceedings Sixth Int. Symp. Polar. Phenom. in Nucl. Phys., Osaka, 1985, J. Phys. Soc. Japan 55, 842 (1986) Suppl.
19. H. Garcilazo, Phys. Rev. Lett. 53, 652 (1984).
20. B. Blankleider and I.R. Afnan, Phys. Rev. C24, 1572 (1981).
21. W. Gyles, E.T. Boschitz, H. Garcilazo, W. List, E.L. Mathie, C.R. Ottermann, G.R. Smith, R. Tacik, and R.R. Johnson, Phys. Rev. C33, 583 (1986).
22. W. Gyles, E.T. Boschitz, H. Garcilazo, E.L. Mathie, C.R. Ottermann, G.R. Smith, S. Mango, J.A. Konter, and R.R. Johnson, Phys. Rev. C33, 595 (1986).
23. J. Dubach, W.M. Kloet, and R.R. Silbar, Phys. Rev. C33, 373 (1986).
24. B.M.K. Nefkens, W.J. Briscoe, A.D. Elchon, D.H. Fitzgerald, J.A. Holt, A.A. Mokhtari, J.A. Wightman, M.E. Sadler, R.L. Boudrie, and C.L. Morris, Phys. Rev. Lett. 52, 735 (1984).
25. B.M.K. Nefkens, private communication.
26. O.V. Maxwell and C.Y. Cheung, TRIUMF preprint TRI-PP-85-69, unpublished.
27. K.A. Antol, A. Altman, R.R. Johnson, H.W. Roser, R. Tacik, U. Wienands, D. Ashery, J. Alster, M.A. Moinester, E. Piasetzky, R. Sackler, B. Sackler, D.R. Gill, and J. Vincent, TRIUMF preprint TRI-PP-85-99, unpublished;
G. Backenstos, M. Izzycki, P. Salvisberg, M. Steinacher, P. Weber, H.J. Weyer, S. Gierjacks, S. Ljungfelt, H. Ulbricht, M. Furtić, and T. Petković, Phys. Rev. Lett. 55, 2782 (1985).