LA-UR- 97-3796

Conf-970731--

Title: SCATTERING LENGTH MEASUREMENTS FROM RADIATIVE PION CAPTURE AND NEUTRON-DEUTERON BREAKUP

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DEC 16 1997
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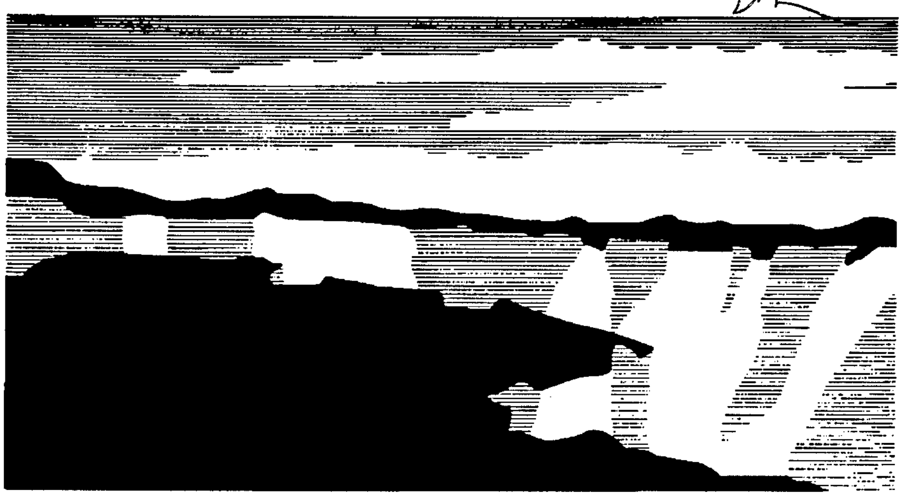
Submitted to: The Proceedings of the 15th Int'l Conf. on Few-Body Problems in Physics, Groningen, The Netherlands, 22-26 July 1997



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Scattering length measurements from radiative pion capture and neutron-deuteron breakup

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The neutron-neutron and neutron-proton $^1S_0$ scattering lengths a_{nn} and a_{np}, respectively, were determined simultaneously from the neutron-deuteron breakup reaction. Their comparison with the recommended values obtained from "two-body" reactions gives a measure of the importance of three-nucleon force effects in the three-nucleon continuum. In order to check on the result obtained for a_{nn} from the "two-body" π^--d capture reaction, a new measurement was performed at LANL. Preliminary results of the three experiments are given.

*Supported by the U.S. Department of Energy, Office of High Energy and Nuclear Physics, under Grant No. DEFG02-97-ER41033

1. INTRODUCTION

The motivation for the present NN scattering length measurements is to find out whether low-energy three-nucleon (3N) observables are influenced in a measurable way by 3N forces (3NFs). A reliable procedure is the determination of well-known nucleon-nucleon (NN) parameters from the analysis of accurate 3N data. If the results for NN parameters obtained from 3N data do not agree with the values known from free NN scattering, then there is strong evidence that 3NF effects are important in 3N systems.

The neutron-proton (np) scattering length a_{np} is very accurately known from free n-p scattering. Its recommended value is a_{np} = -23.748 ± 0.009 fm [1]. Due to the lack of free neutron targets, the neutron-neutron (nn) scattering length a_{nn} is much more difficult to determine experimentally. The recommended value of a_{nn} = -18.6 ± 0.4 fm [1] is based on two π^--d capture experiments. In Ref. [2] a -2 fm correction was applied to the uncorrected value of a_{nn} in order to account for the scattering probability of the neutrons generated in the liquid deuterium target before they reach an array of neutron detectors. Furthermore, the uncertainty associated with the relative detection efficiency of the neutron detectors used in Ref. [2] appears to be rather small considering more recent neutron detector efficiency studies. Therefore, it was felt worthwhile to perform a new determination of a_{nn} using the reaction ^{2}H(π^-, $nn\gamma$) (with two strongly interacting particles in the exit channel) to verify the accuracy of the recommended "two-body" result for a_{nn}, before a comparison is made with a_{nn} values obtained from the reaction ^{2}H(n, nnp) (with three strongly interacting particles in the exit channel).

2. NEUTRON-NEUTRON SCATTERING LENGTH FROM π^--d CAPTURE

The measurement was conducted in the low-energy pion cave at the Los Alamos Meson Physics Facility (LAMPF). Neutrons from the reaction ^{2}H(π^-, $nn\gamma$) were detected by an array of 24 liquid scintillators, and one arm of the LAMPF neutral meson spectrometer was used to detect the associated γ rays. The experimental setup is shown in Figure 1. System calibration parameters were determined from ^{1}H(π^-, $n\gamma$) measurements using a liquid hydrogen target, and sample uncorrelated backgrounds were measured using an empty target cell. Data were accumulated for two event types: those involving the detection of only one of the neutrons in coincidence with the associated γ ray, referred to as n-γ events, and those for which both neutrons were detected with the γ ray, called n-n-γ events. A total of 1.9×10^6 n-γ and 3×10^3 n-n-γ events were accumulated above background. The analysis of the n-γ events has been completed. Values for a_{nn} have been obtained by fitting our neutron time-of-flight spectra for n-γ coincidence data with theoretical predictions based on the method of Ref. [3]. Monte-Carlo techniques were used to fold the point-geometry calculations with the finite geometry and energy resolution of our experimental setup and detector system. Our preliminary result of a_{nn} = -18.2 ± 0.5 fm is in agreement with the recommended value [1]. The quoted uncertainty includes a conservative estimate of systematic effects. Because the statistical uncertainty is below ±0.1 fm, it is expected that a careful analysis of all possible systematic effects will result in an overall uncertainty of less than the presently quoted value of ±0.5 fm.

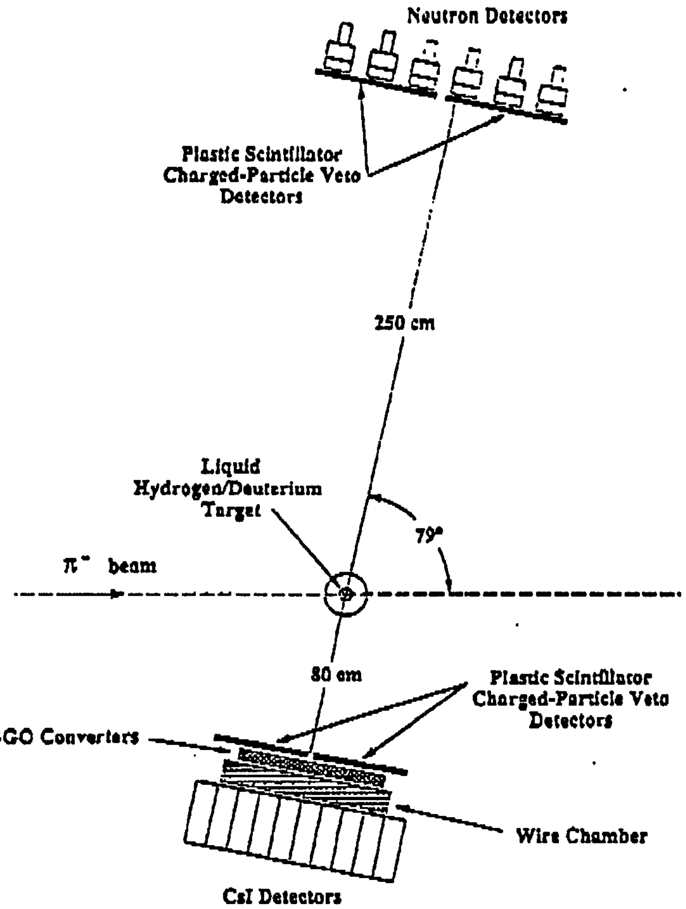

Figure 1. Experimental setup for neutron-neutron $^1S_0$ scattering length determination using the ^{2}H(π, $nn\gamma$) reaction.

3. NEUTRON-NEUTRON SCATTERING LENGTH FROM n-d BREAKUP

According to Ref. [1], the average value extracted for a_{nn} from kinematically complete ^{2}H(n, nnp) breakup experiments is a_{nn} = -16.7 ± 0.5 fm, in clear disagreement with the recommended value based on the reaction ^{2}H(π^-, $nn\gamma$). This discrepancy is presumably due to deficiencies in the analysis of the n-d breakup data performed in the seventies and/or 3NF effects acting in the exit channel of this reaction. Unfortunately, the existing ^{2}H(n, $nn\gamma$) data cannot be reanalyzed using modern NN potentials and rigorous 3N calculations, because some of the crucial experimental details are not available anymore. Therefore, a kinematically complete ^{2}H(n, nnp) experiment at an incident neutron energy of 13.0 MeV was performed at TUNL to either resolve or understand the discrepancy between the values of a_{nn} determined from the two reactions of interest. Because 3NF effects are expected to cause an angular dependence of the final-state-interaction (FSI) absolute cross sections used to extract a_{nn}, neutron detectors are placed at four production

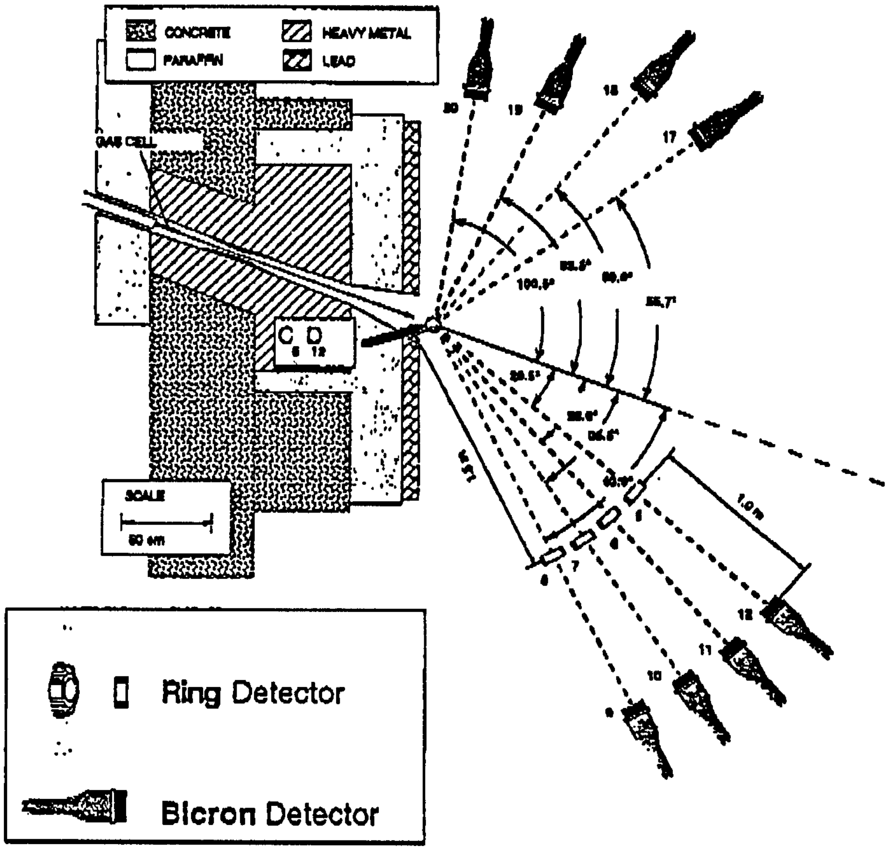

Figure 2. Experimental setup for simultaneous determination of the neutron-neutron and neutron-proton ${}^1S_0$ scattering lengths at four production angles of the n-n and n-p pairs using the ^{2}H(n, nnp) reaction.

angles of the n-n pair. The detector pairs labeled "Ring" and "Bicron" shown in Figure 2 on the right side of the incident neutron beam are used to detect the two neutrons in coincidence. Their energies are measured by time-of-flight with the start signal provided by the "breakup" proton produced in the liquid scintillator C_6D_{12} active target.

The data analysis is based on rigorous calculations of the n-d breakup cross section using a modified version of the Bonn B [4] NN potential. Cross-section libraries that span the finite geometry of each n-n FSI configuration studied were prepared for different values of a_{nn}. Monte-Carlo simulations used these libraries to calculate the n-n FSI cross sections. The simulations include the energy resolution, energy spread and finite-geometry effects of the experimental setup. We extracted values for a_{nn} for each n-n FSI configuration by direct comparison between simulated cross sections obtained for different values of a_{nn} and experimental cross sections. Our preliminary results for a_{nn} are -18.9 ± 0.6 fm, -18.8 ± 0.6 fm, -17.7 ± 0.7 fm, and -18.8 ± 0.8 fm for the nn production angles $\theta_{nn} = 20.5°, 28°, 35.5°$, and $43°$, respectively, where the systematic and statistical errors were added in quadrature. The Tucson-Melbourne [5] 3NF with a cutoff parameter of $\Lambda = 5.8\ m_\pi$ predicts a maximum difference of 7.5% in the values for a_{nn} in the angular range studied in our experiment. Within the quoted uncertainty, we do not see any sizeable 3NF effects in our data. Our preliminary, angle averaged result of $a_{nn} = -18.7 \pm 0.5$ fm is in excellent agreement with the recommended value of $a_{nn} = -18.6 \pm 0.4$ fm extracted from the reaction ^{2}H(π^-, $nn\gamma$), thus eliminating the long-standing discrepancy between these two approaches. It appears that a combination of theoretical and experimental problems was responsible for the previously observed discrepancy.

4. NEUTRON-PROTON SCATTERING LENGTH FROM *n-d* BREAKUP

Because the neutron-proton scattering length a_{np} is known to ± 0.009 fm, its determination from the reaction ^{2}H(n, npn) is by far the best case for searching for 3NF effects at low energies. Therefore, we measured the absolute *n-p* FSI cross section at *n-p* pair production angles of $20.5°, 28°, 35.5°$, and $43°$. We detected the neutron that travels together with the proton (which stops in the deuterated scintillator C_6D_{12}) in either the "Ring" or "Bicron" detector on the right side of the incident neutron beam direction, while the associated second neutron is detected in a "Bicron" detector on the left side (see Figure 2). Therefore, we obtained two determinations of a_{np} at four production angles. The a_{np} and a_{nn} FSI cross sections were measured at the same time, sharing 8 of the 12 detectors shown in Figure 2. The data analysis and theoretical treatment of the absolute cross-section data was similar to the procedure described in Section 3. Rigorous 3N calculations using Bonn B with different values for a_{np} were used in the Monte Carlo simulations of the experimental setup. As seen already for a_{nn}, the Tucson-Melbourne 3NF predicts a sizeable angular dependence in the FSI cross section, and therefore in a_{np} (8% effect in our angular range). Identically to a_{nn}, there are no 3NF influences predicted at $43°$. Our preliminary results for a_{np} obtained at $20.5°, 28°, 35.5°$, and $43°$ using the "Ring" detectors are -23.8 fm, -24.2 fm, -23.2 fm, and -24.2 fm, each with an overall uncertainty of ± 0.6 fm which is governed by systematic effects. Again, we do not see the predicted sizeable 3NF effects within our experimental uncertainty. Our average value of $a_{np} = -23.8 \pm 0.5$ fm is in excellent agreement with the value obtained from free *n-p* scattering.

5. CONCLUSION

Our accurate *n-d* breakup data do not provide evidence for sizeable 3NF effects in the 3N continuum at low energies.

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M98001539

Report Number (14) LA-UR--97-3796

CONF-970731--

Publ. Date (11) 199707

Sponsor Code (18) DOE/ER, XF

UC Category (19) UC-413, DOE/ER

19980619 061

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