Eur Phys J A (2005) **24**, s1, 123–125
DOI: 10.1140/epjad/s2005-05-022-x

EPJ A direct
electronic only

Parity violation in few-nucleon systems

J. Carlson[1] and M. Paris[2]

[1] Theoretical Division, Los Alamos National Laboratory
[2] Theory Division, Jefferson Lab

Received: 20 October 2004 / Published Online: 8 February 2005

Abstract. We summarize recent results on parity-violation in few-nucleon systems, including *pp* elastic scattering and *np* radiative capture. These results are relevant to recent or present experimental measurements at TRIUMF and LANSCE, respectively. We also present results for other potential or planned experiments, summarizing the contributions they will make to understanding the weak parity-violating NN interaction. Dependencies upon the NN strong interaction are also addressed.

PACS. 21.30.+v Few-body systems – 24.80.+y Nuclear tests of fundamental interactions and symmetries

1 Introduction

New experiments to explore parity-violation in the NN interaction have recently been completed or are presently underway or in planning stages at various institutions around the world. These include measurements of parity-violating (PV) interactions in *pp* elastic scattering [1] at TRIUMF, *np* radiative capture [2] and deuteron electro-disintegration [3] at JLAB. These measurements are designed to probe various aspects of the weak PV NN interaction, including the weak PV πNN coupling, typically denoted f_π. We review a recent analyses of these and other potential experiments within a consistent framework, using two- and few-nucleon systems as a tool for forming a reliable understanding of the weak PV NN interaction.

2 Framework

Here we adopt the nucleon-nucleon PV potential developed by Desplanques *et al.* [4] in terms of meson exchanges. This model parameterizes the PV NN interaction in terms of π-, ρ-, and ω-meson exchanges, where the strengths of the interaction are obtained from the product of a weak PV coupling on one vertex and a strong coupling at the other. It is now clear that meson couplings other than the pion in the DDH model should not be taken too literally, but rather as a simple representation of the PV mixings in low-energy NN scattering.

The aim of these calculations is to develop a systematic framework for studying PV observables in the few-nucleon systems, where accurate microscopic calculations are feasible, and to use available and forthcoming experimental data on these observables to constrain the strengths of the short- and long-range parts of the two-nucleon weak interaction. We have performed calculations with various

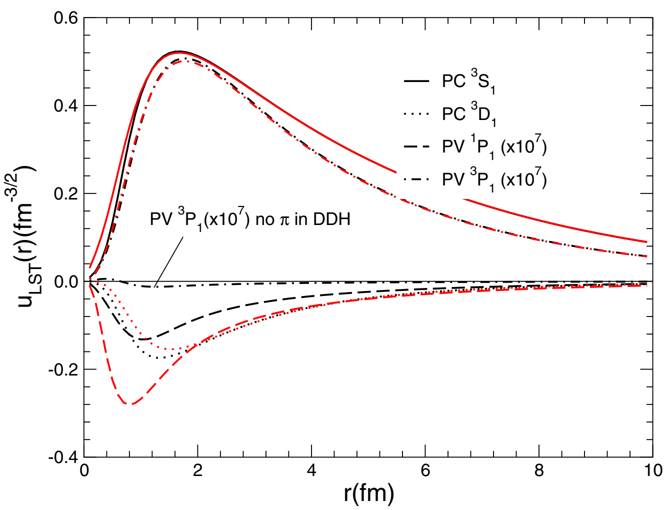

Fig. 1. PV components of the deuteron, with and w/o pion coupling in DDH

models of the strong-interaction parity-conserving (PC) NN interaction, including the Argonne v_{18} (AV18) [5], Nijmegen I (NIJM-I) [6], and CD-Bonn (BONN) [7] models. These all provide high-quality fits to the available NN scattering data, though there are some differences in their structures. One does not expect the weak PV couplings extracted from experimental results to be precisely the same for different strong-interaction models. The various experiments, though, when analyzed with any consistent strong- and weak-interaction model, should consistently be reproduced by the same NN mixing angles.

The PV mixing angles are obtained [8] from the asymptotic behavior of the 2 solutions for J=0, and the 4 solutions for J>0. The PV couplings introduce, for example, p-wave components in the deuteron, as illustrated in Fig. 1.

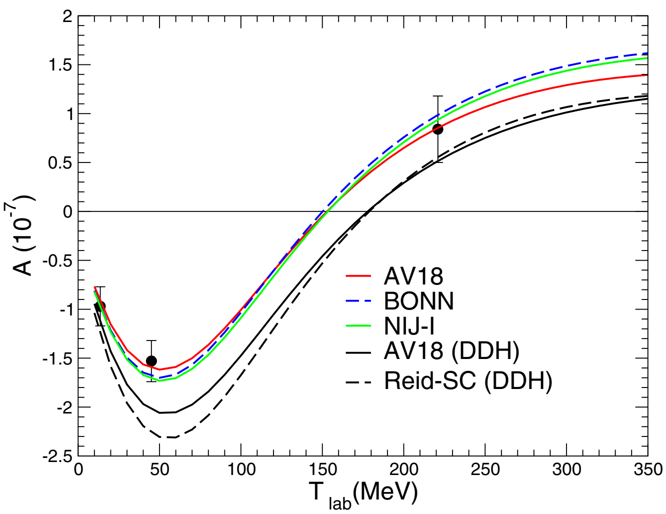

Fig. 2. Comparison of original and adjusted DDH models with **p***p* TRIUMF measurements

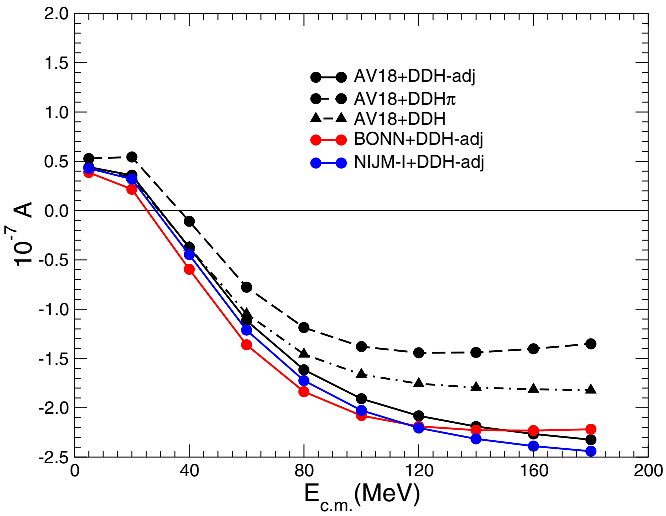

Fig. 3. Longitudinal asymmetry in **n***p* polarized scattering for various weak interaction models (see text)

Note that, for the same coupling constants, the ^{3}P wave is nearly independent of the strong-interaction potential, while the ^{1}P wave does show some dependence.

3 Results

An analysis of the **p***p* longitudinal asymmetry places some constraints on the short-range part of the T=1 PV interaction.[9] Somewhat surprisingly, the original DDH model of the PV interaction, obtained from fairly simple estimates of the hadronic physics, did a reasonable job of predicting the longitudinal asymmetries measured at around 40 and 220 MeV. Small adjustments in the couplings, as illustrated in Fig. 2, can be used to reproduce the experimental results.

In principle a similar longitudinal asymmetry experiment could be performed for **n***p* scattering. We have also computed this result for various PV interactions. Figure 3 shows the expected asymmetry for various strong interaction models (AV18, BONN, and NIJM-I). The strong-interaction model dependence is quite weak. The figure also presents results for the DDH model adjusted to reproduce the **p***p* longitudinal asymmetry (DDH-adj), and for a model with only a non-zero pion weak coupling (DDH-π).

The **n***p* longitudinal asymmetry depends upon a mixture of short-range and long-range (pion) components of the PV NN interaction, while the **p***p* longitudinal asymmetry does not depend upon the pion coupling f_π at all. In the DDH model, the short-range parts of the interaction are parameterized as heavy meson (ρ and ω) exchange. The longest-range part of the interaction should be directly accessible to experiment, and in principle could be calculated from QCD. The experimental situation regarding this part of the interaction is still under debate, however.

Analysis of circular polarization of the photons in ^{18}F decay indicates a small value of the weak πNN coupling. While calculations of the strong-interaction eigenstates in these nuclei are more difficult than in few-nucleon systems, in this particular measurement a known β-decay can be used to infer the strength of the relevant two-body matrix element. Analyses of other recent experiments, in particular ^{133}Cs, yield a potentially different answer, however. This measurement would seem to indicate a larger value of the pion coupling. A recent analysis of the situation is given in the paper of Haxton, Liu, and Ramsey-Musolf. [10]

The **n***p* $\rightarrow d\gamma$ experiment underway at the LANSCE facility is designed to study the weak πNN coupling f_π. The correlation between the photon asymmetry and the initial neutron spin is a parity-violating observable, and depends almost solely on the pion coupling. In table 1, we report results for the photon asymmetry using various strong interaction models, with both the full DDH model and the pion coupling alone.

The two-nucleon currents required for current conservation play a significant role in the total thermal cross section (see Table 1), and can also affect the PV asymmetry. However, the Siegert theorem can be used to essentially elminate the model dependence in these currents, as shown by the excellent agreement between various strong interaction models.

It is, of course, also possible to use explicit exchange current models to perform these calculations. The low-energy photon asymmetry, though, involves delicate cal-

Table 1. Total cross-section σ^γ and parity-violating asymmetry a^γ in the **n***p* radiative capture at thermal neutron energies (see text)

	σ^γ(mb)		$a^\gamma \times 10^8$	
Interaction	Impulse Current	Full Current	DDHπ	DDH-adj
AV18	304.6	334.2	-4.98	-4.92
NIJM-I	305.4	332.5	-5.11	-5.02
BONN	306.5	331.6	-4.97	-4.89

Table 2. Neutron spin-rotation angle in Hydrogen per unit length (units of 10^{-9} rad cm^{-1}), in the limit of vanishing incident neutron energy

	DDH − adj	DDHπ	DDH
AV18	5.09	5.21	7.19
NIJM-I	4.94	5.35	7.64
BONN	4.63	5.18	7.35
Plane waves	-5.67	-6.87	-5.85

culations between contributions to the asymmetry. Exchange-current terms which are typically quite small, such as those associated with interaction terms involving two powers of the nucleon's momenta, must be included precisely to reproduce the Siegert results. These same currents can then be used to analyze any possible contributions from the PV NN interaction to quasi-elastic parity-violating electron scattering, such as measured at SAMPLE. These contributions have been found to be quite weak at SAMPLE kinematics.

We have also evaluated the spin rotation of a polarized neutron transmitted through hydrogen, see Table 2. Note that the pion coupling plays a significant role, and also that the sign of the spin rotation is opposite what one would calculate from plane-wave only, ignoring strong interaction effects. This sign change arises because of the bound state in the deuteron channel.

We have also begun calculations of the spin rotation in Helium-4 using Quantum Monte Carlo techniques. The $(1/2)^-$ s and p-wave scattering states can be calculated in Green's function Monte Carlo, and the relevant PV NN matrix elements determined. Experiments have also been performed in such systems, though to date the experimental errors are larger than the signal. When combined with the p-alpha measurements, such an experiment could provide another check on the value of f_π.

4 Conclusion

Of course it is natural to ask if the few parameters available in the DDH model are sufficient to describe the present-day experiments. After all, the strong interaction models require of order 50 parameters to provide very high-quality fits to the experimental data. However, the strong-interaction data is very precise and extends to high energies, while most of the experiments here are at quite low energies. The one possible exception is the TRIUMF measurement of the pp longitudinal asymmetry at ≈ 220 MeV. In addition the PV NN interaction effects are always perturbative, in contrast to strong-interaction effects in few-nucleon systems. Hence, it should be possible to use a simplified model such as the one considered here to analyze the experimental data.

We have carried out a systematic study of parity-violating observables in the np and pp systems, including longitudinal asymmetries, the photon asymmetry in np capture to the deuteron, in $d(\gamma, n)p$ photo-disintegration, and spin rotation in elastic neutron scattering. When combined with upcoming experiments and calculations for few-nucleon observables, a consistent picture of the parity-violating NN interaction should be possible.

References

1. A.R. Berdoz et al.: Phys. Rev. Lett. **87**, 272301 (2001)
2. W.M. Snow et al.: Nucl. Instrum. and Methods Phys. Res. A **440**, 729 (2000)
3. B. Wojtsekhowski, W.T.H. van Oers (spokespersons): JLAB letter-of-intent 00-002
4. B. Desplanques, J.F. Donoghue, B.R. Holstein: Ann. Phys. (N.Y.) **124**, 449 (1980)
5. R.B. Wiringa, V.G.J. Stoks, R. Schiavilla: Phys. Rev. C **51**, 38 (1995)
6. V.G.J. Stoks, R.A.M. Klomp, C.P.F. Terheggen, J.J. de Swart: Phys. Rev. C **49**, 2950 (1994)
7. R. Machleidt: Phys. Rev. C **63**, 024001 (2001)
8. R. Schiavilla, J. Carlson, M. Paris: Phys. Rev. C, to be published (nucl-th/0404082)
9. J. Carlson, R. Schiavilla, V.R. Brown, B.F. Gibson: Phys. Rev. C **65**, 035502 (2002)
10. W.C. Haxton, C.-P. Liu, M.J. Ramsey-Musolf: Phys. Rev. Lett. **86**, 5247 (2001)