High-Accuracy Measurement of the Spin-Dependent Neutron Scattering Length of the Deuteron

B. van den Brandt [a], P. Hautle [a], J. Kohlbrecher [a], J.A. Konter [a], H. Glättli [b], H.W. Grießhammer, and O. Zimmer
[a] Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland
[b] CEA Saclay / SPEC and LLB, F-91191 Gif-sur-Yvette, France

In the past few years, a new and very promising strategy has been developed to describe nuclear forces at low energy. Chiral perturbation theory (χPT) is an effective field theory, which describes interactions of pions and between pions and nucleons (N). It requires much less experimental input than traditional models based on phenomenological potentials. Moreover, since it leads to a systematic expansion of the scattering amplitude in powers of small momenta and the pion mass, for the first time the accuracy of a calculation in a model independent theory of nuclear interactions can be estimated. Many important low-energy quantities can be calculated reliably, like e.g. ground state properties of bound systems and cross sections relevant for big-bang and stellar nucleosynthesis. Steven Weinberg showed that chiral three-nucleon forces appear naturally [1]. The most relevant processes are: a two-pion exchange, a 2N contact interaction with pion exchange, and a 3N contact interaction. The contact interactions parameterize the short-range physics. As in Fermi's theory of weak interaction, they are characterized by effective couplings, called low energy constants (LEC's). These have to be fixed by measured data of two independent low energy 3N observables. Very recently a first complete analysis of nd scattering at next-to-next-to-leading order has been performed with impressive results [2].

An even simpler approach to the nuclear few-body problem is an effective field theory without pionic degrees of freedom [3,4]. This theory starts out from point-like interactions between nucleons, which only have to respect the symmetries of QCD. Like χPT, it describes phenomena in a systematic way, but is applicable only at energies well below a breakdown scale set by the mass of the pion. Only two experimental LEC's are required to predict observables on the 1% level of accuracy in processes involving three nucleons. However, this can only be achieved if the inputs are known with sufficient accuracy. Best suited LEC's are the binding energy of the triton and the doublet nd-scattering length a_2. A simple argument why a_2 is very sensitive to 3N forces goes as follows. In the quartet channel, both neutrons of the problem have their spins parallel, so that 3N-forces do not play any role at low momentum transfer due to the Pauli principle. In contradistinction, the doublet channel allows for a momentum-independent 3N interaction, and it turns out even necessary to achieve results which are not sensitive to physics at high energy scales, or respectively, at short distances beyond the range of applicability of the theory.

At present, the doublet nd-scattering length a_2 is known only with 6% accuracy, which is considerably worse than the theoretical uncertainty. Experimentally, it can be obtained from a linear combination of the spin-dependent, incoherent nd-scattering length $a_{i,d}$, and the spin-independent, coherent one, $a_{c,d}$. A high-accuracy measurement of the latter is under way at the NIST interferometer at Washington DC. $a_{i,d}$ dominates the uncertainty of a_2, and it is the scope of our French-Swiss-German collaboration to measure it with 10^{-3} accuracy. The experiment will employ pseudomagnetic neutron precession through a target of polarised deuterons and protons, using a Ramsey apparatus for a cold neutron beam. It will be performed at the fundamental physics beam at PSI starting next year.

References

[1] S. Weinberg, Nucl. Phys. **B363(3)** (1991)
[2] E. Epelbaum, A. Nogga, W. Glöckle *et al.*, nucl-th/0208023
[3] J.-W. Chen, G. Rupak, M.J. Savage, Nucl. Phys. **A653** (1999) 386
[4] P.F. Bedaque, H.-W. Hammer, G. Rupak, H. Grieshammer, nucl-th/0207034