MENU 2007
11th International Conference
on Meson-Nucleon Physics and
the Structure of the Nucleon
September10-14, 2007
IKP, Forschungzentrum Jülich, Germany

EFFECTIVE FIELD THEORY FRAMEWORK FOR $\overline{K}d$ SCATTERING

B. Borasoy, U.-G. Meißner, R. Nißler, A. Rusetsky
Helmoltz-Institut für Strahlen- und Kernphysik,
Universität Bonn,
Nußallee 14-16, 53115 Bonn, Germany

U. Raha
Department of Physics and Astronomy,
University of Basel
Klingelbergstrasse 82, CH-4056 Basel, Switzerland

Abstract

An effective field theory framework is proposed to study $\overline{K}d$ scattering at threshold. At lowest order, the approach reproduces the well-known result obtained by the re-summation of the multiple-scattering series in the static limit. It has been demonstrated that the approach enables one to systematically evaluate corrections to the lowest-order result.

The SIDDHARTA experiment at LNF-INFN [1] is aimed at a high-precision measurement of the energy shift and the decay width of the ground-state of the kaonic hydrogen at a few percent accuracy in 2008. Moreover, the collaboration plans the first ever measurement of the ground state energy shift and width of the kaonic deuterium. Together, these two independent measurements in principle suffice to determine the values of two complex $\overline{K}N$ scattering lengths a_0 and a_1 in the isospin symmetry limit. In order to extract these from the experimental data, however, one needs in addition the theory that links the observables of the hadronic atoms to a_0 and a_1 in a model-independent manner and to the accuracy that matches the experimental precision.

The main stumbling point that should be addressed in the theory, is the relation of a_0 and a_1 to the $\overline{K}d$ scattering length $A_{\overline{K}d}$, which is directly extracted from the experimental data on kaonic deuterium. For a long time, the only framework to study this problem was provided by the potential scattering model, which enables one to calculate $A_{\overline{K}d}$ through solving Faddeev equations with input "realistic" $\overline{K}N$ and NN potentials. Explicit hyperonic channels ($Y = \Lambda, \Sigma$) are shown to contribute only up to a few percent in Faddeev calculations of $A_{\overline{K}d}$ and can therefore be safely neglected [2]. Moreover, assuming the nucleons to be static, it is possible to give an explicit expression of $A_{\overline{K}d}$ through a_0 and a_1 in a form of the re-summed multiple-scattering series [3]. In most cases, these series reproduce the result of the full Faddeev calculation with a reasonable accuracy (see, e.g. [4]).

The above approach, however, suffers from obvious deficiencies:

- It is very difficult to control the systematic error, arising from the model-dependent input and the approximations done.
- The Faddeev equations relate $A_{\overline{K}d}$ to a_0 and a_1 only indirectly. The result of numerical calculations can not be straightforwardly used for the extraction of a_0 and a_1 from the data.

In recent years, investigations of the problem within the framework of effective field theories have started to appear [5]. At lowest order (static nucleons, no derivative couplings) the approach readily reproduces the re-summed multiple scattering series of the potential model. One may expect that the lowest order is already reasonably accurate for the description of $A_{\overline{K}d}$ and perturbation theory must be applicable beyond the leading order. This conjecture, however, still has to be confirmed by actual calculations.

Below we give a schematic description of the proposed framework. In this framework, $\overline{K}$ and nucleons are described by a non-relativistic effective Lagrangian. Particle creation/annihilation is forbidden, as well as explicit coupling to the hyperonic channels. Both these effects are implicitly contained in the couplings of the effective Lagrangian.

Further, the $\overline{K}N$ interaction, as well as the three-body force in the $\overline{K}NN$ system is described by local Lagrangians containing any number of space derivatives acting on the fields (the terms with higher derivatives are suppressed by inverse powers of a heavy scale). Dimensional regularization is used to tame the ultraviolet divergences arising in the calculation of the Feynman diagrams. The couplings in the $\overline{K}N$ sector are related to the effective range parameters of $\overline{K}N$ scattering – the scattering lengths a_I, the effective ranges r_I, etc – through the matching procedure (here, $I = 0, 1$). For this reason, the perturbative expansion in the non-relativistic effective theory coincides with the multiple-scattering expansion.

Finally, the NN interaction is described by a non-local energy-independent potential, calculated in chiral effective theories (see, e.g. [6]). Within the present framework, the explicit form of the potential is assumed to be given.

The following conclusions can be drawn:

1. As already pointed out, assuming static nucleons and retaining only leading-order (non-derivative) $\overline{K}N$ vertices, one reproduces the re-summed multiple scattering series of the potential model. In addition, in the field-theoretical approach the physical meaning of the re-summation becomes crystal clear. Namely, it can be shown that the difference between the re-summed and conventional multiple scattering series has the same form as the terms emerging from the 3-body Lagrangian and can therefore be removed by renormalization of the 3-body couplings. In other words, the re-summation of the multiple scattering series can only be justified in the presence of the 3-body force.

2. The 3-body force is the main source of the systematic uncertainty in the present approach. One may estimate the imaginary part of the 3-body contribution from experimental data on the two-nucleon absorption of K^- on the deuteron. Owing to the fact that the total two-nucleon absorption rate is equal to $1.22 \pm 0.09\%$ [7], one may expect that the systematic uncertainty due to the three-body force in $A_{\overline{K}d}$ should not exceed a few percent.

3. Despite the large isospin-breaking in the $\overline{K}N$ amplitudes, the net isospin-breaking effect in $A_{\overline{K}d}$ is small (the same result has been obtained in Ref. [3] within the potential approach). The reason for this can be immediately seen from the explicit expression of $A_{\overline{K}d}$. Although the individual $\overline{K}N$ amplitudes in this expression possess the unitary cusp that leads to the large isospin-breaking effect, the final expression has no cusp.

4. Going beyond the leading-order approximation, the derivative couplings in the $\overline{K}N$ sector can be considered (finite-range corrections). Due to the presence of the sub-threshold $\Lambda(1405)$ one could *a priori* expect rapid variations of the $\overline{K}N$ amplitudes in the vicinity of threshold, resulting in an enhancement of the effective range term. Our calculations, however, show that this is not the case. The net effect amounts up to a few percent.

5. The most interesting (and difficult) application of the present framework are calculations beyond the static limit, together with the non-perturbative re-summation of the multiple scattering series. We construct the perturbation theory in the parameter $\xi = M_K/m_N$. The

expansion of a particular matrix element proceeds in powers of $\xi^{1/2}$ and can be performed by applying the threshold expansion technique [8] to the Feynman integral, which defines this matrix element. The cancellation of the retardation corrections, which have been widely discussed in the literature (see, e.g. [9]), in the new language is equivalent to the cancellation of the leading contributions in ξ and can be studied by using the powerful technique of Ref. [8].

Why does the static approximation in the Faddeev approach work so well, even if $\xi \simeq 0.5$ in real world? We plan to address this question in our subsequent investigations.

Acknowledgments

The authors would like to thank E. Epelbaum, E. Oset and C. Wilkin for the interesting discussions. Partial financial support from the EU Integrated Infrastructure Initiative Hadron Physics Project (contract number RII3-CT-2004-506078), DFG (SFB/TR 16, “Subnuclear Structure of Matter”) and the EU Contract No. MRTN-CT-2006-035482 “FLAVIAnet” is acknowledged.

References

[1] C. Curceanu *et al.*, *Eur. Phys. J.* **A31**, 537 (2007).

[2] L.H. Schick and B.F. Gibson, *Z. Phys.* **A288**, 307 (1978); G. Toker, A. Gal and J.M. Eisenberg, *Nucl. Phys.* **A362**, 405 (1981).

[3] R. Chand and R.H. Dalitz, *Ann. Phys.* **20**, 1 (1962).

[4] A. Gal, *Int. J. Mod. Phys.* **A22**, 226 (2007).

[5] S.S. Kamalov, E. Oset and A. Ramos, *Nucl. Phys.* **A690**, 494 (2001); U.-G. Meißner, U. Raha and A. Rusetsky, *Eur. Phys. J.* **C47**, 473 (2006).

[6] E. Epelbaum, *Prog. Part. Nucl. Phys.* **57**, 654 (2006).

[7] V.R. Veirs and R.A. Burnstein, *Phys. Rev.* **D1**, 1883(1970).

[8] M. Beneke and V.A. Smirnov, *Nucl. Phys.* **B522**, 321 (1998) [arXiv:hep-ph/9711391].

[9] G. Fäldt, *Phys. Scripta* **16**, 81 (1977); V. Baru, C. Hanhart, A. E. Kudryavtsev and U. G. Meißner, *Phys. Lett.* **B589**, 118 (2004).