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Lowest Order Effective Field Theory for the weak ΛN interaction*

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The $|\Delta S| = 1$ ΛN interaction, responsible for the decay of hypernuclei, is studied by means of an Effective Field Theory (EFT) where the long range physics is described by pion and kaon exchange mechanisms, and its short range counterpart is obtained from the most general non-derivative local four-fermion interaction. We show that, including the Lowest Order Parity Conserving (PC) contact terms, allows us to reproduce the total decay rates for ${}^{5}_{\Lambda}$He, ${}^{11}_{\Lambda}$B and ${}^{12}_{\Lambda}$C with a reasonable value of $\hat{\chi}^2$, while in order to get a prediction for the Parity Violating (PV) asymmetry compatible with experiments, we have to include the Lowest Order PV contact pieces.

In analogy to the familiar NN phenomenology, the weak ΛN interaction has traditionally been modeled using meson-exchange approaches. It is well known that the long-range part of the interaction is well explained by one-pion exchange (OPE), which can approximately reproduce the hypernuclear non mesonic decay rates—Γ—but not the ratio between the partial rates, $\Gamma_n/\Gamma_p = (\Lambda n \to nn)/(\Lambda p \to np)$. The large energy released in the process ($m_\Lambda - m_N \approx 177$ MeV) suggests that short range contributions could well be important. Along this line, the literature shows us that the inclusion of the kaon (OKE) is particularly convenient, due to the specific interference between OPE and OKE in the PC and PV channels[1,2,3], which substantially enlarges the Γ_n/Γ_p ratio, while reducing the total decay rate by a factor of 2. One way of accounting for short range contributions on top of OKE, is to parametrize the physics contained in that region in terms of local four-fermion interaction terms. This will be the approach followed here, and we will see that, despite the significant degree of SU(3) symmetry breaking, we can get an stable chiral expansion for the $\Lambda N \to NN$ process. Not considered here is the intermediate-range 2π-exchange (two orders higher in the chiral expansion than the corresponding single pion-exchange piece), nor the last member of the SU(3) Goldstone-boson octet, the η, since the strong ηNN coupling is an order of magnitude smaller than the corresponding πNN and $K\Lambda N$ couplings[4].

The explicit forms for our OPE and OKE transition potentials can be found elsewhere[1, 5]. Here, only the form of the 4-fermion contact potential, $V_{4P}(\vec{r})$, is presented. Assume

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the ΛN wave function to be in a $L=0$ relative state. Then, without any model-dependent assumptions, we can parametrize the two-body transition through the following Lowest Order (LO) amplitudes: [3].

$\Lambda N \to NN$ partial wave	operator
PC: ${}^1S_0 \to {}^1S_0$, ${}^3S_1 \to {}^3S_1$	$\hat{1} \cdot \delta^3(\vec{r}),\ \vec{\sigma}_1 \cdot \vec{\sigma}_2 \cdot \delta^3(\vec{r})$
PV: ${}^1S_0 \to {}^3P_0$, ${}^3S_1 \to {}^1P_1$	$(\vec{\sigma}_1 - \vec{\sigma}_2) \cdot \{\vec{p}_1 - \vec{p}_2\,,\,\delta^3(\vec{r})\},\ (\vec{\sigma}_1 - \vec{\sigma}_2) \cdot [\vec{p}_1 - \vec{p}_2\,,\,\delta^3(\vec{r})],$ $\mathrm{i}\,(\vec{\sigma}_1 \times \vec{\sigma}_2) \cdot \{\vec{p}_1 - \vec{p}_2\,,\,\delta^3(\vec{r})\},\ \mathrm{i}\,(\vec{\sigma}_1 \times \vec{\sigma}_2) \cdot [\vec{p}_1 - \vec{p}_2\,,\,\delta^3(\vec{r})]$
PV: ${}^3S_1 \to {}^3P_1$	$(\vec{\sigma}_1 + \vec{\sigma}_2) \cdot \{\vec{p}_1 - \vec{p}_2\,,\,\delta^3(\vec{r})\},\ (\vec{\sigma}_1 + \vec{\sigma}_2) \cdot [\vec{p}_1 - \vec{p}_2\,,\,\delta^3(\vec{r})]$

Here, p_i is the derivative operator acting on the "ith" particle, and $\delta^3(\vec{r})$ denotes the contact interaction, which we smear by using a normalized Gaussian form ($f_{ct}(r)$ below), with a typical vector meson range $\delta \approx 0.36$ fm. The resulting leading order $V_{4\mathrm{P}}(\vec{r})$ potential for both PV and PC terms can be written as:

$$V_{4P}(\vec{r}) = \left\{ {C_0}^0 + {C_0}^1\,\vec{\sigma}_1\vec{\sigma}_2 + \frac{2r}{\delta^2}\left[{C_1}^0\,\frac{\vec{\sigma}_1 \cdot \hat{r}}{2\overline{M}} + {C_1}^1\,\frac{\vec{\sigma}_2 \cdot \hat{r}}{2M} + {C_1}^2\,\frac{(\vec{\sigma}_1 \times \vec{\sigma}_2)\cdot \hat{r}}{2\tilde{M}} \right] \right\} \times f_{ct}(r) \times \left[C_{\mathrm{IS}}\,\hat{1} + C_{\mathrm{IV}}\,\vec{\tau}_1 \cdot \vec{\tau}_2 \right], \quad (1)$$

where $\overline{M} = (M_N + M_\Lambda)/2$, $\tilde{M} = (3M + M_\Lambda)/4$, ${C^j}_i$ is the jth LEC at ith order, and the last factor represents the isospin part of the 4-fermion interaction[4], containing isoscalar (C_{IS}) and isovector (C_{IV}) pieces.

Standard nuclear structure techniques[5] are used to decouple from our initial hypernuclei a ΛN pair, which will connect through the two-body potential to a NN final pair. In addition, the effects of the strong interaction are accounted for by using the realistic (one-boson-exchange) NSC97f baryon-baryon interaction model[6].

Our results are shown in Table 1. It is noticeable that including the LO PV terms, which are one order higher in the chiral expansion, does not substantially alter the previously fitted LO PC coefficients, thus supporting the validity of our expansion. Moreover, they barely modify the total and partial rates but significantly affect the asymmetry, $\mathcal{A}$, as one should expect for an observable defined by the interference between PV and PC amplitudes. Finally, we find coefficients of natural size with significant error bars, reflecting the level of experimental uncertainty.

The present study then supports the validity of the EFT framework for nonmesonic hypernuclear weak decay, and we hope to be able to much better constrain the parameters in such studies with the next generation of high-precision experimental data, currently under analysis.

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[3]The higher order ${}^3S_1 \to {}^3D_1$ transition is excluded in the present analysis.
[4]Note that we only allow for $\Delta I = 1/2$ transitions.

Table 1
Results obtained for the weak decay observables and LEC, when a fit to the Γ and n/p for ${}^{5}_{\Lambda}$He, ${}^{11}_{\Lambda}$B and ${}^{12}_{\Lambda}$C is performed. The values between parenthesis have been obtained including the helium asymmetry, $\mathcal{A}({}^{5}_{\Lambda}\mathrm{He})$, in the fit.

	π	$+K$	+ LO PC	+ LO PV	EXP:
$\Gamma({}^{5}_{\Lambda}\mathrm{He})$	0.42	0.23	0.43	0.44 (0.44)	0.41 ± 0.14[7]
					0.50 ± 0.07[8]
$\Gamma_n/\Gamma_p({}^{5}_{\Lambda}\mathrm{He})$	0.09	0.50	0.56	0.55 (0.55)	0.93 ± 0.55[7]
					0.50 ± 0.10[9]
$\mathcal{A}({}^{5}_{\Lambda}\mathrm{He})$	-0.25	-0.60	-0.80	0.15 (0.24)	0.24 ± 0.22[10]
$\Gamma({}^{11}_{\Lambda}\mathrm{B})$	0.62	0.36	0.87	0.88 (0.88)	0.95 ± 0.14[8]
$\Gamma_n/\Gamma_p({}^{11}_{\Lambda}\mathrm{B})$	0.10	0.43	0.84	0.92 (0.92)	$1.04^{+0.59}_{-0.48}$[7]
$\mathcal{A}({}^{11}_{\Lambda}\mathrm{B})$	-0.09	-0.22	-0.22	0.06 (0.09)	-0.20 ± 0.10[11]
$\Gamma({}^{12}_{\Lambda}\mathrm{C})$	0.74	0.41	0.95	0.93 (0.93)	1.14 ± 0.2[7]
					0.89 ± 0.15[8]
					0.83 ± 0.11[12]
$\Gamma_n/\Gamma_p({}^{12}_{\Lambda}\mathrm{C})$	0.08	0.35	0.67	0.77 (0.77)	0.87 ± 0.23[13]
$\mathcal{A}({}^{12}_{\Lambda}\mathrm{C})$	-0.03	-0.06	-0.05	0.02 (0.03)	-0.01 ± 0.10[11]
$\hat{\chi}^2$			0.98	1.50 (1.16)	
C_0^0			-1.51 ± 0.38	-1.09 ± 0.36 (-1.02 ± 0.35)	
C_0^1			-0.86 ± 0.24	-0.63 ± 0.35 (-0.57 ± 0.29)	
C_1^0			$---$	-0.45 ± 0.42 (-0.47 ± 0.17)	
C_1^1			$---$	0.17 ± 0.22 (0.20 ± 0.19)	
C_1^2			$---$	-0.48 ± 0.20 (-0.48 ± 0.22)	
C_{IS}			5.08 ± 1.27	5.69 ± 0.74 (5.83 ± 0.82)	
C_{IV}			1.47 ± 0.39	1.49 ± 0.23 (1.52 ± 0.24)	

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