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Recent Soft-core Baryon-Baryon Interactions*

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Abstract

We present recent results obtained with the Extended-Soft-Core (ESC) interactions. This ESC-model, henceforth called ESC03, describes nucleon-nucleon (NN), hyperon-nucleon (YN), and hyperon-hyperon (YY), in a unified manner using (broken) $SU_f(3)$-symmetry. Novel ingredients are the inclusion of (i) the axial-vector meson potentials, (ii) a zero in the scalar-meson form-factors. With these innovations, it proved possible for the first time to keep the parameters of the model closely to the predictions of the $^3P_0$ quark-pair-creation model (QPC). This is the case for the meson-baryon coupling constants and $F/(F+D)$-ratio's as well. Also, the YN and YY results for this model are rather excellent.

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I. INTRODUCTION

The Nijmegen soft-core baryon-baryon models are based on the study of the NN-, YN-, and YY-interactions in particle physics, i.e. effective QCD theories like e.g. the quark-model(QM), involving notably mesonic degrees of freedom. The feedback with (hyper) nuclear structure studies, based on applications of the resulting potentials, plays a crucial role in testing these interactions. In this contribution the most recent results are given and the changes w.r.t. the previous presentation [1] are reported. The emphasis is on the underlying quark-physics, rather than on the best possible fit to the scattering data in terms of the χ^2. For that purpose we restricted the freedom of the parameters considerably.

In synopsis, an exposition of a modern theoretical basis for the soft-core approach for the baryon-baryon interactions has been given in [2, 3]. In [2, 4] we reported on the ESC-model for baryon-baryon scattering pointing out that many dynamical aspects of low energy QCD and chiral-symmetry are accounted for. In ESC, the soft-core OBE-models [5–8] are extended to include uncorrelated two-meson-exchange (TPS) and, for the first time in baryon-baryon models, meson-pair exchanges (MPE).

In [1] we discussed the results of the first versions of the Extended-Soft-Core (ESC) models for baryon-baryon. In this contribution we present the most recent version, where novel ingredients are introduced, which leads to a description of the nuclear and hyper-nuclear forces that is to large extend compatible with the predictions of the $^3P_0$ quark-pair-creation (QPC) Model [9, 10].

In [1] the differences between the soft-core OBE-models, notably NSC97 [7, 8], and the ESC-model are discussed. It was found that NSC97 corrected the spin-dependence of the s-wave ΛN-interactions of the first YN soft-core OBE-model [6]. Akaishi and co-workers [11] showed that an s-wave interaction between that of NSC97e and NSC97f is compatible with their solution of the $^5_\Lambda He$ over-binding problem [12]. See also the presentation of that method by Nemura at this meeting [13]. Furthermore, Akaishi et al [14] showed that the NSC97e/f solutions are rather close in fitting the experimental Λ-separation energies for the Λ-hypernuclei $^3_\Lambda H$, $^A_\Lambda He$ $(A = 4, 5, \ldots, 11)$. However, it appeared that both satisfactory s- and p-wave interactions were not achieved in NSC97. For example, the p-waves of NSC97f have unfavorable consequences both for p-shell hypernuclei and neutron-star matter. Also the ΛN-spin-orbit interaction seems to be too strong [15].

The ΣN-sector is not fixed very well by the scattering data, since different Nijmegen models give rather different interactions in e.g. the $^3S_1(I = 3/2)$-wave. Dabrowski [16] analyzed the Lane part of the s.p. potential of the Σ in nuclear matter, using the YNG effective interactions [17]. It is argued that the NSC97 solutions are incompatible with the $(K^-, \pi^\pm)$ experiments at BNL on the ^9Be-target [18].

The first attempts with the ESC-model seemed to have solved these problems [1] in the $S = -1$-sector. Unfortunately, the $\Lambda\Lambda$-interaction was far too strong. In contrast to the believe for many years, the NAGARA-event [19] for $^6_{\Lambda\Lambda}He$ showed that the strength of the $\Lambda\Lambda(^1S_0)$-interaction is rather weak, and more in line of the predictions of the soft-core OBE-models [20].

In this report we present for the first time the results of an ESC-model, where a rather strict control over the model parameters is imposed. These new constraints come about by taking the QPC-model [9, 10] as a guidance. Since the latter has scored considerable successes [21] in predicting e.g. meson and resonance decay couplings, it is reasonable to expect that if such constraints are possible then the predictions for YN and YY will be better, at least qualitatively. The feasibility of the QPC-model and the ESC-model presumably is due to the two innovations, alluded to above, we introduced in ESC03. These are (i) the inclusion of the axial-vector mesons, and (ii) the introduction of a zero in the scalar meson form factors. (In an intermediate version, called ESC02, these two new elements were first introduced, but without the QPC-constraints. That version has good properties in the $S=0$ and $S=-1$ sectors, but rather strong potentials in various $S=-2$ channels. This version is not further discussed in this paper.) In ESC03 both the NN-couplings, as well as the $F/(F+D)$-ratios are constraint by the QPC-model. For the first time e.g. the near equalities $g_\omega \approx g_\epsilon$ and $g_\rho \approx g_{a_0}$ are explained and realized in a good fit to the scattering data for NN and YN.

In the soft-core OBE models the important scalar-meson nonet were found to have ideal meson-mixing conform the $Q\bar{Q}$-picture of the scalar-mesons. It was noted that the upshot of ideal scalar-mixing is a rather weak attraction in the $\Lambda\Lambda$-channel. The reason is that in this case the $F/(F+D)$-ratio $\alpha_S \approx 1$. The QPC-model also leads to such values, and this we adopt in ESC03 also for the scalar MPE-couplings. In contrast to former ESC-models, we have included only one scalar nonet in ESC03.

Another important element is that we have utilized $SU_f(3)$-breaking of the coupling constants, like in NSC97. The scheme of this breaking is worked out according to the QPC-model, but a little different as in NSC97. The need for this breaking can be viewed a necessity in order to have some freedom to fit YN, making the imposition of the quark-model relations possible.

Furthermore, an improvement is made in the joint fitting procedure of NN and YN. Now, we make a truly simultaneous fit with a single set of parameters. This procedure presumably is the reason for producing better p-waves in YN.

The contents of this paper is as follows. In section 2 we further describe briefly the physics ingredients of the ESC03-model in particular, indicate briefly how the ESC-model is extended to all baryon-baryon channels, and report on the most recent results for nucleon-nucleon. In section 3 we discuss the results for nucleon-nucleon, in particular the NNM-couplings and compare them with the QPC-model predictions. In section 4 we give the first results for hyperon-nucleon, and in section 5 we discuss the results of the ESC-model for the $\Lambda\Lambda$-interactions.

II. EXTENDED SOFT-CORE MODEL FOR BARYON-BARYON

The potentials of the ESC-models have been reviewed e.g. in [1]. Here, we discuss them briefly, and in particularly the new features for ESC03:

(i) The OBE-potentials described in [5–7]. In addition to pseudo-scalar-, vector-, scalar-, and diffractive-potentials, we include for the first time the potentials from the axial-meson nonet $J^{PC}=1^{++}$: $f_1(1285),\ a_1(1270),\ f_1(1420),\ K_1(1270)$.

(ii) In contrast to ESC00 [1] we included only the lowest-lying scalar nonet $J^{PC}=0^{++}$: $\varepsilon(760),\ a_0(962),\ f_0(993),\ \kappa(900)$. Special for ESC03 is the introduction of a zero in the scalar-meson form factors at $k^2=m_Z^2$, where $m_Z = 750$ MeV/c. This zero is natural in the QPC-model because of the p-wave overlap integrals, and has two important effects. First, it eliminates the strong inner attraction of the scalar mesons and helps to avoid deep bound states in e.g. $\Lambda N(^1S_0)$, which are present in the NSC97 solutions. Second, it reduces the $g_{\epsilon NN}$-coupling, bringing it in line with the QPC-model predictions.

(iii) Like in ESC00, the TPSE-potentials as given in Ref. [24, 25] are included. These are two-pseudo-scalar-exchange (PS-PS) potentials based on a combination of pseudo-vector (pv) and pseudo-scalar (ps) coupling to the baryon octet, described by a parameter a_{PV}. We note that we did not include uncorrelated two-meson-exchange potentials with vector- and scalar-mesons. Including these brings in a lot of exchanges with a mass > 1 GeV. Moreover, due to strong cancelations between the different diagrams for $I = 0$ mesons, one expects that these potentials can be described largely by OBE and MPE.

(iv) As in ESC00, we included a (complete) set of phenomenological baryon-baryon-meson-meson vertices, henceforth refered to as 'meson-pair-exchange' (MPE). The vertices and resulting potentials are given in [2, 25] for NN. The motivation for the MPE is mainly dynamical. Additional motivation for including these MPE-potentials is that similar interactions are required in chiral Lagrangian's [26]. They can be viewed upon as the result of the out integration of the heavy-meson and resonance degrees of freedom. Also, in view of the fact that the Gaussian form-factors do not contain explicit two-meson cuts, e.g. the $\pi\pi$-cut in case of the ρ-meson etc., the latter can be accounted for by the MPE.

In ESC03 we take only contributions from the MPE-interactions to first order in the pair couplings. Diagrams with two pair-couplings are very similar to taking into account the widths of the mesons in the OBE-potentials. Such effects are included for ϵ and ρ, where they are important. For heavier mesons, like a_1(1270 such effects are less important.

The extension of MPE to YN and YY is done by an $SU(3)$-classification of these pair-states, and the use of the proper $F/(F+D)$-ratio parameters for the baryon-baryon vertices, in analogy with those utilized for meson-baryon-baryon vertices. The included pairs are: $\{PP\}_{S_1}$, $\{PP\}_{S_8}$, $\{VP\}_{B_8}$, $\{PP\}_{V_8}$, $\{VP\}_{A_8}$, and $\{PS\}_{A_8}$. Here, P=pseudo-scalar, S=scalar, V=vector, and A,B=axial-vector, and S_1 stands for the symmetric unitary singlet combination etc. Typical example for each type S_1, S_8, B_8, V_8, A_8, and A_8 are respectively $(\pi\pi)_{I=0}$, $(\pi\eta)$, $(\pi\omega)$, $(\pi\pi)_{I=1}$, $(\pi\rho)_{I=1}$, $(\pi\sigma)$. In each case, the full $SU(3)$ structure is taken into account. To give an illustration, consider the MPE-interaction Hamiltonians for the cases $\{PP\}_{S_1}$ and $\{VP\}_{A_8}$:

$$
\begin{aligned}
\mathcal{H}_{S_1PP} &= \frac{g_{S_1PP}}{\sqrt{3}} \left\{ \boldsymbol{\pi}\cdot\boldsymbol{\pi} + 2K^\dagger K + \eta_8\eta_8 \right\} \cdot \widetilde{\sigma} \\
\mathcal{H}_{V_8PP} &= g_{A_8PP} \left\{ \frac{1}{2}\widetilde{\boldsymbol{\rho}}_\mu \cdot \boldsymbol{\pi}\times \overleftrightarrow{\partial^\mu}\boldsymbol{\pi} + \frac{i}{2}\widetilde{\boldsymbol{\rho}}_\mu \cdot (K^\dagger \boldsymbol{\tau}\overleftrightarrow{\partial^\mu} K) \right. \\
&\quad + \frac{i}{2}\left(\widetilde{K}^{*\dagger}_\mu \boldsymbol{\tau}(K\overleftrightarrow{\partial^\mu}\boldsymbol{\pi}) - h.c.\right) + i\frac{\sqrt{3}}{2}\left(\widetilde{K}^{*\dagger}_\mu \cdot\right. \\
&\quad \left.\left.(K\cdot \overleftrightarrow{\partial^\mu}\eta_8) - h.c.\right) + \frac{i}{2}\sqrt{3}\widetilde{\phi}_\mu (K^\dagger \overleftrightarrow{\partial^\mu} K) \right\}
\end{aligned}
$$

Here, $\widetilde{\sigma} = \bar{\psi}\psi$, $\widetilde{\boldsymbol{\rho}} = \bar{\psi}\gamma_\mu\boldsymbol{\tau}\psi$ etc., i.e. the baryon densities with the proper space-time properties.

III. NUCLEON-NUCLEON

As mentioned in e.g. [1], fitting this model to only the NN-data, using the 1993 Nijmegen single energy $pp + np$ phase shift analysis [27], leads to excellent results. Without the QPC-model constraints, fitting only the NN data, one reaches for the energies in the range $0 \leq T_{lab} \leq 350$ MeV, which contains 4233 data, typically a $\chi^2_{p.d.p.} = 1.11 - 1.15$. In a simultaneous fit of NN and YN we usually obtain an extra $\Delta\chi^2_{p.d.p.} \approx 0.10$. In ESC03 where we impose in addition the QPC-constraints rather strictly, we reached $\chi^2_{p.d.p.} = 1.35$. In Table I we show the fitted ESC03-parameters. The (rationalized) coupling constants and

TABLE I: ESC03: Meson- and meson-pair-couplings, and form factor masses.

pseudo-scalar		vector		scalar		pairs	
f_π	0.263	g_ρ	0.777	g_{a_0}	0.777	$g_{(\pi\pi)_0}$	-0.002
f_η	0.186	f_ρ	3.319	g_ϵ	3.214	$g_{(\pi\pi)_1}$	0.052
$f_{\eta'}$	0.160	g_ω	2.909	g_{A_2}	0.416	$f_{(\pi\pi)_1}$	0.034
		f_ω	-0.227	g_P	2.360	$g_{(\pi\eta)}$	-0.347
Λ_{P8}	853.2	Λ_{V8}	944.9	Λ_{S8}	775.2	$g_{(\pi\rho)_1}$	0.720
Λ_{P1}	1362.4	Λ_{V1}	803.8	Λ_{S1}	1191.1	$g_{(\pi\omega)}$	-0.110
a_{PV}	1.122			m_P	309.1	$g_{(\pi\sigma)}$	0.141

form factor masses are given in Table I. Here, the f_η was not fitted but derived from f_π using $\alpha_{pv} = 0.400$. The fitted α-parameters are: $\alpha_V^m = 0.448$, $\alpha_S = 0.852$. All other α parameters were fixed: $\alpha_{PV} = 0.40$, $\alpha_V^e = 1.0$, $\alpha_A = 0.368$, and $\alpha_D = 1.0$. The meson mixing used are the standard ones for the pseudo-scalar- and vector-mesons, see e.g. [6]. For the scalar mesons and the diffractive exchanges we used ideal mixing, and for the axial-mesons we took $\theta_A = 47.3^o$ [28].

In QPC-model [10] the NN-couplings can be written in the following form

$$f_{BBM}(\mp) = \gamma_M \left(\frac{4\pi}{9}\right)^{1/4} X_M\left(I_M, L_M, S_M, J_M\right)\; F_M^{(\mp)}$$

where (i) γ_M is the (running) pair-creation constant, (ii) X_M are the recoupling coefficients, which depend on the meson quantum numbers, and (iii) $F_M^{\mp}$ are the quark-wave function overlap integrals for the $Q\bar{Q}(L = 0, 1)$-mesons in terms of the nucleon and meson radii, respectively R_B and R_M. For $\rho \to e^+e^-$ the current-field-identity and the Van Royen-Weisskopf relation [22] give for the $\rho\pi\pi$ coupling

$$f_\rho = \frac{m_\rho^{3/2}}{\sqrt{2}|\psi_\rho(0)|} \Leftrightarrow \gamma\left(\frac{2}{3\pi}\right)^{1/2} \frac{m_\rho^{3/2}}{|\psi_\rho(0)|} \ ,$$

where the last expression on the r.h.s. is the QPC-model form of this coupling [10]. Identification leads to the prediction: $\gamma_M = \frac{1}{2}\sqrt{3\pi} = 1.535$. Taking $R_B = 0.8fm$ and $R_M = 0.56fm$, we obtain the predictions shown in Table II. From Table II one notices a couple of relations

TABLE II: ESC03 Couplings and $^3P_0$-Model Relations.

Meson	$r_M[fm]$	X_M	γ_M	$^3P_0$	ESC03
$\rho(770)$	0.56	$1/2$	1.53	$g = 0.78$	0.78
$\omega(783)$	0.56	$3/2$	1.53	$g = 2.40$	2.91
$a_0(962)$	0.56	$\sqrt{3}/2$	1.53	$g = 0.79$	0.78
$\epsilon(760)$	0.56	$3\sqrt{3}/2$	1.53	$g = 2.11$	3.21
$a_1(1270)$	0.56	$3\sqrt{3}/2$	1.53	$g = 2.73$	2.86

in the $^3P_0$-model: $g_\omega \approx 3g_\rho$, $g_\epsilon \approx 3g_{a_0}$, $g_{a_0} \approx g_\rho$, and $g_\epsilon \approx\ g_\omega$. The axial coupling satisfies $f_{NNa_1} \approx (m_{a_1}/m_\pi)f_{NN\pi}$, which is the Schwinger relation [23]. In the last column of Table II we show the fitted NN-couplings for the vector-, scalar-, and axial-couplings. One sees that all couplings in ESC03 are pretty much in line with the QPC-predictions. However, one must realize that the QPC-predictions are naive in the sense that in principle these couplings have to be renormalized by taking into account mesonic vertex dressing. Also, one expects that the mesons have different $Q\bar{Q}$-radii. Nevertheless, it is remarkable that the ESC03 couplings can be choosen close to QPC-predictions. Relaxing a bit on e.g. the ρ and a_0 couplings etc. one can easily reach $\chi^2_{p.d.p} \approx 1.25$. Also, the $\alpha = F/(F+D)$-ratios are predicted by the QPC-model, and these are $\alpha_{PV} = \alpha_A = 0.4$, $\alpha_V^e = \alpha_S = 1.0$. The α-parameters used in the fit are close to these values, see Table III below.

IV. HYPERON-NUCLEON

The form factor scheme employed in the ESC-models is the same as in the NSC97-model [7], see also [1]. We assign Λ_8 and Λ_1 for each meson-nonet, for respectively the $\{8\}$- and $\{1\}$-members. In the application to YN and YY we allow for $SU_f(3)$-breaking, by using different cut-off's for the $K = 853.2$ MeV. As mentioned above, similarly to NSC97 the coupling constants are $SU(3)$-broken. This breaking is introduced in the framework of the QPC-model by a single parameter. Namely, we distinguish between the pair creation constants for the non-strange and the strange quarks, i.e. $\gamma_u = \gamma_d \neq \gamma_s$. In ESC03 we have fitted $\gamma_s/\gamma_{u,d} = 0.792$, and used this breaking for all OBE-couplings. The pair-couplings are taken $SU(3)$-symmetric.

TABLE III: ES03: Meson coupling parameters.

mesons		{1}	{8}	F/(F+D)	angles
pseudo-scalar	f	0.220	0.262	$\alpha_{PV} = 0.400^{\star)}$	$\theta_P = -23.00^0$
vector	g	2.537	0.778	$\alpha_V^e = 1.0$	$\theta_V = 37.50^0$
	f	-0.972	3.319	$\alpha_V^m = 0.45^{\star)}$	
scalar	g	2.996	0.777	$\alpha_S = 0.85$	$\theta_S = 37.5^{0\ \star)}$
axial	g	1.593	2.858	$\alpha_A = 0.37$	$\theta_S = 47.30^{0\ \star)}$
diffractive	g	2.235	0.416	$\alpha_D = 1.0$	$\psi_D = 23.21^{0\ \star)}$

In addition to the parameters given in Table III, we fixed the $\alpha = F/(F+D)$ ratio's for MPE's. These are $\alpha^e_{pr,V} = 1.0, \alpha^m_{pr,V} = 0.275, \alpha_{pr,S} = 1.0, \alpha_{pr,A} = 0.40$. The fitting for the Nijmegen set of 35 YN-scattering data resulted in $\chi^2 = 43.3$. In this fit, the 12 Λp X-sections have $\chi^2(\Lambda p) = 6.7$, the 18 $\Sigma^- p$ X-sections $\chi^2(\Sigma^- p \to \Sigma^- p, \Sigma^0 n, \Lambda n) = 32.2$, and the 4 X-sections for $\Sigma^+ p$ have $\chi^2(\Sigma^+ p) = 0.5$. The capture ratio at rest was fitted to be $r_R = 0.45$, which close to its experimental value 0.468 ± 0.01 [33].

For $\Sigma^+ p$ the ESC03 low energy parameters are $a_s = -3.18$ fm $\ r_s = 3.95$ fm, and $a_t = -3.18$ fm $\ r_t = 1.30$ fm. Notice that the ESC03 ΣN-interactions are such that for free scattering the ${}^3S_1(I = 3/2)$-interaction is quite attractive. This is not in accordance with Dabrowski's finding [16]. One way out of this problem is the possibility of three-body forces (TBF), giving a substantial effective two-body repulsion in this channel.

For Λp the fit results in the low energy parameters $a_s = -2.119$ fm $\ r_s = 3.177$ fm, and $a_t = -1.824$ fm $\ r_t = 2.846$ fm.

In the Tables IV-VI we display the matter properties of the ESC03-interactions. These results were obtained from the YN G-matrix calculations in nuclear matter [17] using the ESC03-model of this paper. The Λ well depth $U_\Lambda \sim -30$ MeV, obtained from analyses of the (π^+, K^+) and (K^-, π^-) cross sections on nuclear targets [29] is well fit by ESC03 and NSC97f. From Table V one notices that K_Λ for ESC03 is the lowest value we ever obtained. Yet, the spin-orbit splitting seems still too large phenomenologically.

Also remarkable is that for ESC03 Γ_Σ is much smaller than is the case for the NSC97 models. This agrees nicely with the recently confirmed ${}^4_\Sigma He$ hypernucleus [30], which has a conversion width $\Gamma \approx 7$ MeV. This rather small Σ-conversion width has been explained by

TABLE IV: Partial wave contributions to $U_\Lambda(\rho_0)$

	$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	D	sum
ESC03	–11.1	–15.1	1.1	0.0	0.4	–4.3	–0.9	–29.8
NSC97e	–12.7	–25.5	2.1	0.5	3.2	–1.2	–1.1	–34.7
NSC97f	–14.3	–22.4	2.4	0.5	4.0	–0.7	–1.2	–31.7

TABLE V: Strenths of Λ spin-orbit splittings for various Nijmegen models. See [7] for the definitions of K_Λ and $S_{LS,ALS}$.

	S_{LS}	S_{ALS}	K_Λ
ESC03	–21.5	12.2	9.7
NSC97e	–25.8	9.8	17.
NSC97f	–26.7	9.5	18.

Harada et al. [31], using the SAP interactions derived using the Nijmegen hard-core model D.

V. HYPERON-HYPERON

In contrast to the believe for many years, the NAGARA-event [19] gives $\Delta B_{\Lambda\Lambda}(^{6}_{\Lambda\Lambda}He) = 1.01 \pm 0.20^{+0.18}_{-0.11}$, showing that the strength of the $\Lambda\Lambda(^1S_0)$-interaction is rather weak, and more in line of the predictions of the soft-core OBE-models [20]. This means a revolution in the $S = -2$-sector as compared to the situation at the time of HYP2000 [1]. As in NSC97 in ESC03 we have again $Q\bar{Q}$-ideal-mixing for the scalar mesons, which in view of the NAGARA-event seems to be favored by nature. The calculated values of $\Delta B_{\Lambda\Lambda}(^{6}_{\Lambda\Lambda}He)$ with the G-matrix interactions, including the $\Lambda\Lambda - \Xi N$-couplings, are in MeV $1.0, 0.6, 1.2$

TABLE VI: Partial wave contributions to $U_\Sigma(\rho_0)$

model		$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	D	U_Σ	Γ_Σ
ESC03-1	$T = 1/2$	6.1	–17.2	1.4	1.2	–4.8	–1.4	–0.6		
	$T = 3/2$	–8.9	8.7	–4.3	–1.8	5.0	–4.7	–0.3	–21.5	7.5
ESC02	$T = 1/2$	3.1	–18.9	0.7	2.1	–3.2	1.2	–0.5		
	$T = 3/2$	–10.7	86.3	0.7	–1.8	4.4	–6.5	0.3	57.1	25.3
NSC97e	$T = 1/2$	14.8	–9.3	2.0	2.3	–4.0	0.3	–0.4		
	$T = 3/2$	–12.1	–4.8	–3.9	–1.8	5.4	–2.8	–0.2	–14.6	16.3
NSC97f	$T = 1/2$	14.9	–9.6	1.9	2.3	–4.0	0.4	–0.4		
	$T = 3/2$	–12.2	–4.2	–3.8	–1.8	5.5	–2.7	–0.2	–13.9	16.0

respectively for NSC89 [6], NSC97f [7], and ESC03. A really striking positive result for the ESC-model.
As mentioned before [7], the soft-core OBE-models had difficulty to produce a strong attraction in $\Lambda\Lambda$, and this also holds for ESC if the scalar meson-mixing is close to ideal. We have in ESC03, $|V_{\Lambda\Lambda}(0^+)| \approx |V_{\Lambda N}(0^+)| < |V_{NN}(0^+)|$. The $\Lambda\Lambda$ low-energy parameters are $a_{\Lambda\Lambda}(^1S_0) = -2.94$ fm and $r_{\Lambda\Lambda}(^1S_0) = 2.53$ fm. Here, we have taken into account that the energy dependence due to the difference between the $\Lambda\Lambda$- and the $\Sigma\Sigma$-threshold leads to e.g. extra contributions to the non-local ϕ-function, giving some suppression of the $\Lambda\Lambda \to \Sigma\Sigma$- and $\Sigma\Sigma \to \Sigma\Sigma$-potentials.

In the ESC02-version $U_\Xi = -2.5$ MeV and $\Gamma_\Xi = 7.5$ MeV. However, in ESC03 $U_\Xi > 0$, indicating repulsion. This seems in conflict with experiment which reported $U_\Xi \approx -14$ MeV [32]. May be, also in this case the TBF-contribution could provide the missing attraction.

[1] Th.A. Rijken, In 'HYP2000', Proceedings of the Seventh Int. Conf. on Hypernuclear and Strange Particle Physics', Torino 2000, Nucl. Phys. **A 691** (2001) 322c-328c.

[2] Th.A. Rijken, Few-Body Problems in Physics '93, Suppl. 7, 1-12, Springer-Verlag 1994.

[3] Th.A. Rijken, H. Polinder, and J. Nagata, Phys. Rev. C **66**, 044008 (2002).

[4] Th.A. Rijken, 'The Soft-Core Nijmegen Hyperon-Nucleon and Hyperon-Hyperon Interactions', in *Few-Body Problems in Physics '99*, Proceedings of the 1st Asian Pacific Conference, Tokyo, Japan, August 23-28, 1999, p.317, Editors S. Oryu, M. Kamimura, and S.Ishikawa, Springer-Verlag (2000).

[5] M.M. Nagels, Th.A. Rijken, and J.J. de Swart, Phys. Rev. D**17**, 768 (1978).

[6] P.M.M. Maessen, Th.A. Rijken, and J.J. de Swart, C**40** (1989) 2226.

[7] Th.A. Rijken, Y. Yamamoto, V.G.J. Stoks, Phys. Rev. C**59** (1999) 21.

[8] V.G.J. Stoks and Th.A. Rijken, Phys. Rev. C**59** (1999) 3009.

[9] L. Micu, Nucl. Phys. **B 10**, 521 (1969); R. Carlitz and M. Kislinger, Phys. Rev. **D 2**, 336 (1970).

[10] A. Le Yaouanc, L. Oliver, O. Péne, and J.-C. Raynal, Phys. Rev. D 8, 2223 (1973); ibid **D 11**, 1272 (1975).

[11] Y. Akaishi, T. Harada, and S. Shinmura, Proceedings APCTP Workshop *Strangeness Nuclear Physics*, February 1999, Soul, p.28, Editors I-T Cheon, S-W Hong, and T. Motoba, World Scientific Publishing Co (2000).

[12] R.H. Dalitz, R.C. Herndon, and Y.C. Tang, Nucl. Phys. **B47** (1972) 109.

[13] H. Nemura, Y. Akaishi, and Y. Suzuki, Phys. Rev. Lett. **89**, 142504 (2002).

[14] K.S. Myint, T. Harada, S. Shinmura, Y. Akaishi, 'Neutron Rich Lambda Hypernuclei' in *Few-Body Problems in Physics '99*, Proceedings of the 1st Asian Pacific Conference, Tokyo, Japan, August 23-28, 1999, p.383, Editors S. Oryu, M. Kamimura, and S.Ishikawa, Springer-Verlag (2000).

[15] M. Bedjidian et al, Phys. Lett. 62B (1976) 467; Phys. Lett. 83B (1979) 252; M. May et al,Phys. Rev. Lett. **51** (1983) 2085; R.H. Dalitz, D.H. Davis, T. Motoba, and D.N. Tovee, Nucl. Phys. **A625**, 71 (1997); H. Tamura, Proceedings of the Seventh Int. Conf. on Hypernuclear and Strange Particle Physics', Torino 2000, Nucl. Phys. **A 691** (2001) 86c-92c.

[16] J. Dabrowski, Proceedings APCTP Workshop *Strangeness Nuclear Physics*, February 1999, Soul, p.136, Editors I-T Cheon, S-W Hong, and T. Motoba, World Scientific Publishing Co (2000); Nucl. Phys. **A 691** (2001) 58c-63c.

[17] Y. Yamamoto and H. Bandō, Progr. Theor. Phys. **83** (1990) 254.

[18] R. Sawafta, Nucl. Phys. **A 585**, 103c (1995); **A 639**, 103c (1998).

[19] H. Takahashi et al, Phys. Rev. Lett. **87** 212502 (2001).

[20] I.N. Filikhin and A. Gal, Proceedings 8th Conference 'Mesons and Nuclei', Edited by J. Adam, P. Bydzovsky, and J. Mares, AIP Conference Proceedings, Vol. 603 (2001) 405-416; I.N. Filikhin, A. Gal, and V.M. Suslov, Phys. Rev. C **68**, 024002 (2003).

[21] M. Chaichan and R. Kögerler, Ann. Phys. **124**, 61 (1980).

[22] R. van Royen and V.F. Weisskopf, Nuovo Cimento A **50**, 617 (1967).

[23] J. Schwinger, Phys. Rev. **167**, 1432 (1968); Phys. Rev. Lett. **18**, 923 (1967).

[24] Th.A. Rijken and V.G.J. Stoks, Phys. Rev. C**54** (1996) 2851.

[25] Th.A. Rijken and V.G.J. Stoks, Phys. Rev. C**54** (1996) 2869.

[26] S. Weinberg, Phys. Rev. **166**, (1968) 1568; Phys. Rev. **177**, (1969) 2604.
[27] V.G.J. Stoks, R.A.M. Klomp, M.C.M. Rentmeester, and J.J. de Swart, Phys. Rev. C**48**, 792 (1993).
[28] S.A. Coon, B.H.J. McKellar, and V.G.J. Stoks, nucl-th/9606054.
[29] D.J. Millener et al., Phys. Rev. C **38**, 2700 (1988).
[30] T. Nagae, Proc. of the 23rd INS Int. Symp., Tokyo, Japan, March 1995, Eds. S. Sugimoto and O. Hashimoto, p. 175.
[31] T. Harada, Y. Akaishi, S. Shinmura, and H. Tanaka, Nucl. Phys. **A 507**, (1990) 715.
[32] P. Khaustov et al., Phys. Rev. **C 61** (2000) 054603-1.
[33] In the mean time we have better fits quantitatively, but for these the YNG-results are not yet available.