2009/9/15 Hyp-X

Hypernuclear properties derived from the new interaction model ESC08

Repulsive U_{Σ} and Attractive U_{Ξ}

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with
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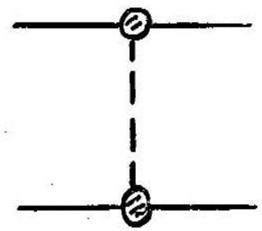
Proposed by Th.A. Rijken

Extended Soft-Core Model (ESC)

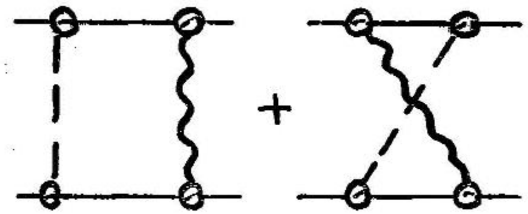
- Two-meson exchange processes are treated explicitly
- Meson-Baryon coupling constants are taken consistently with Quark-Pair Creation model

One-Boson-Exchanges:



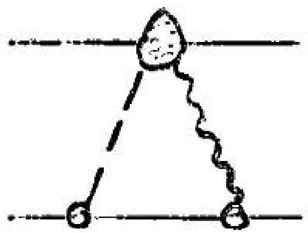
PS, S, V, AV nonets

Two-Meson-Exchanges:



PS-PS exchange

Meson-Pair-Exchanges:



(ππ),(πρ),(πω),(πη),(σσ),(πK)

Parameter fitting consistent with hypernuclear data (G-matrix)

Details are given by Rijken tomorrow

From ESC04 to ESC08 (Th.A. Rijken, M.M. Nagels and Y.Y.)

developed with 7 novel ingredients

Important:
Parameter search was performed imposing constraints from the requirement of attractive ΛΛ and ΞN forces

Features of QCM are included phenomenologically

Two versions : ESC08a & ESC08b

G-matrix result : U_Λ

Table 1: Values of U_Λ at normal density and partial wave contributions in $^{2S+1}L_J$ states for ESC08a/b from the G-matrix calculations with the QTQ prescriptions (Gap choice).

	$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	D	U_Λ
ESC08a	−12.7	−22.2	3.0	0.1	1.4	−3.6	−1.6	−35.6
ESC08b	−12.3	−19.7	2.7	−0.2	1.5	−4.2	−1.7	−34.0
ESC04a	−13.7	−20.5	0.6	0.2	0.5	−4.5	−1.0	−38.5
NSC97f	−14.3	−22.4	2.4	0.5	4.0	−0.7	−1.2	−31.8

ΛN G-matrices for ESC08a/b are similar to those for ESC04a

$$U_0(S) = \frac{1}{4}\{U(^3S_1) + U(^1S_0)\}$$

$$U_{\sigma\sigma}(S) = \frac{1}{12}\{U(^3S_1) - 3U(^1S_0)\}$$

	$U_0(S)$	$U_{\sigma\sigma}(S)$	$U_0(P)$	$U_{\sigma\sigma}(P)$	$U_{LS}(P)$	$U_{Ten}(P)$
ESC08a	−8.73	1.32	0.08	−0.82	−0.43	0.14
ESC08b	−8.02	1.44	−0.02	−0.75	−0.45	0.19
ESC04a	−8.55	1.73	−0.18	−0.25	−0.45	0.08
NSC97e	−9.55	1.05	0.72	−0.44	−0.46	0.17
NSC97f	−9.19	1.70	0.92	−0.50	−0.47	0.22

ESC08a/b

$U_{\sigma\sigma}(S)$ are between those of NSC97e and f

$U_0(P)$ are almost vanishing

$$U_B^{ls}(r) = K_B \frac{1}{r}\frac{d\rho}{dr}\vec{l}\vec{s} \qquad \text{with } B = N\,,\Lambda$$

where $K_N = -\frac{1}{2}\pi S_{LS}$ and $K_\Lambda = -\frac{1}{3}\pi(S_{LS} + S_{ALS})$

$$S_{LS,ALS} = \frac{3}{\bar{q}}\int_0^\infty r^3 j_1(\bar{q}r)\, G^{3O}_{LS,ALS}(r)\, dr$$

with $\bar{q} \sim 0.7\ \mathrm{fm}^{-1}$

Model	S_{SLS}	S_{ALS}	K_Λ
ESC08a	−23.3	15.5	8.1
ESC08b	−24.3	15.5	9.2
ESC04a	−24.9	12.1	13.4
NSC97f	−26.9	9.5	18.1

S_{ALS} of ESC08a/b is larger than those of ESC04 and NSC97 models

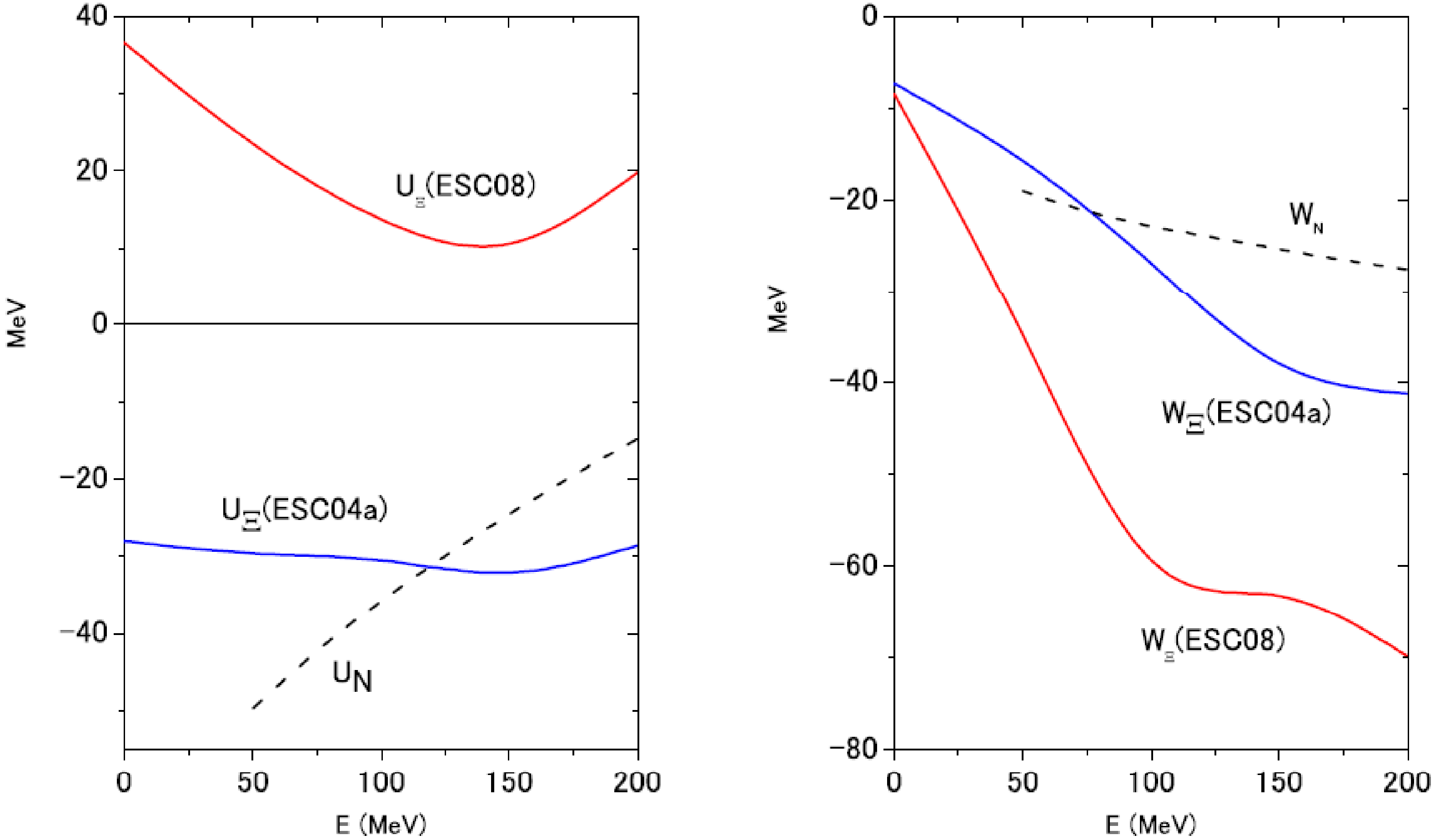
G-matrix result : U_Σ

model	T	$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	D	U_Σ
ESC08a	1/2	11.3	−23.9	2.3	1.7	−6.2	−1.4	−0.7	
	3/2	−11.7	44.8	−7.2	−1.7	6.5	0.2	−0.2	13.4
ESC08b	1/2	10.3	−26.2	2.5	2.2	−7.9	−1.7	−0.8	
	3/2	−10.6	52.7	−6.2	−2.0	7.4	0.8	−0.1	20.3
ESC04a	1/2	11.6	−26.9	2.4	2.7	−6.4	−2.0	−0.8	
	3/2	−11.3	2.6	−6.8	−2.3	5.9	−5.1	−0.2	−36.5
NSC97f	1/2	14.9	−8.3	2.1	2.5	−4.6	0.5	−0.5	
	3/2	−12.4	−4.1	−4.1	−2.1	6.0	−2.8	−0.1	−12.9

Pauli-forbidden state in QCM ➔ strong repulsion in T=3/2 $^3S_1$ state taken into account by adapting Pomeron exchange in ESC approach

Σ-optical potential in matter : $U_\Sigma(E>0)$

$k_F = 1.35\ \mathrm{fm}^{-1}$



as a function of incident energy E_Σ

Σ-nucleus scattering → Furumoto's talk

G-matrix result : U_Ξ

model	T	$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	U_Ξ	Γ_Ξ
ESC08a	0	6.0	–1.0	–0.3	–2.6	1.3	–0.9		
	1	8.5	–28.0	0.6	0.4	–3.7	–0.6	–20.2	5.8
ESC08a'	0	5.6	–1.1	–0.3	–2.6	1.3	–0.9		
adjusted	1	8.4	–21.5	0.6	0.4	–3.7	–0.6	–14.5	7.0
ESC08b	0	2.4	1.9	–0.6	–1.2	–0.1	–0.7		
	1	9.1	–37.8	0.6	–0.5	–3.6	–1.3	–31.8	0.9
ESC04d	0	6.4	–19.6	1.1	1.2	–1.3	–2.0		
	1	6.4	–5.0	–1.0	–0.6	–1.4	–2.8	–18.7	11.3

ESC08a' is consistent with $U_\Xi \approx -14$ MeV (experimental)
used for cluster model calculations

Attractive U_{Ξ} in ESC08

dominant contribution :
"deuteron-like" T=1 $^3S_1$ ($^{33}S_1$) state

Strong ΞN-$\Lambda\Sigma$-$\Sigma\Sigma$ coupling
tensor-type

Importance of tensor coupling in "deuteron-like" channels

Switching off coupling interactions

U_Λ ($T=1/2$ $^3S_1$) -21.2 ⟶ $+18.9$: ΛN-ΣN tensor

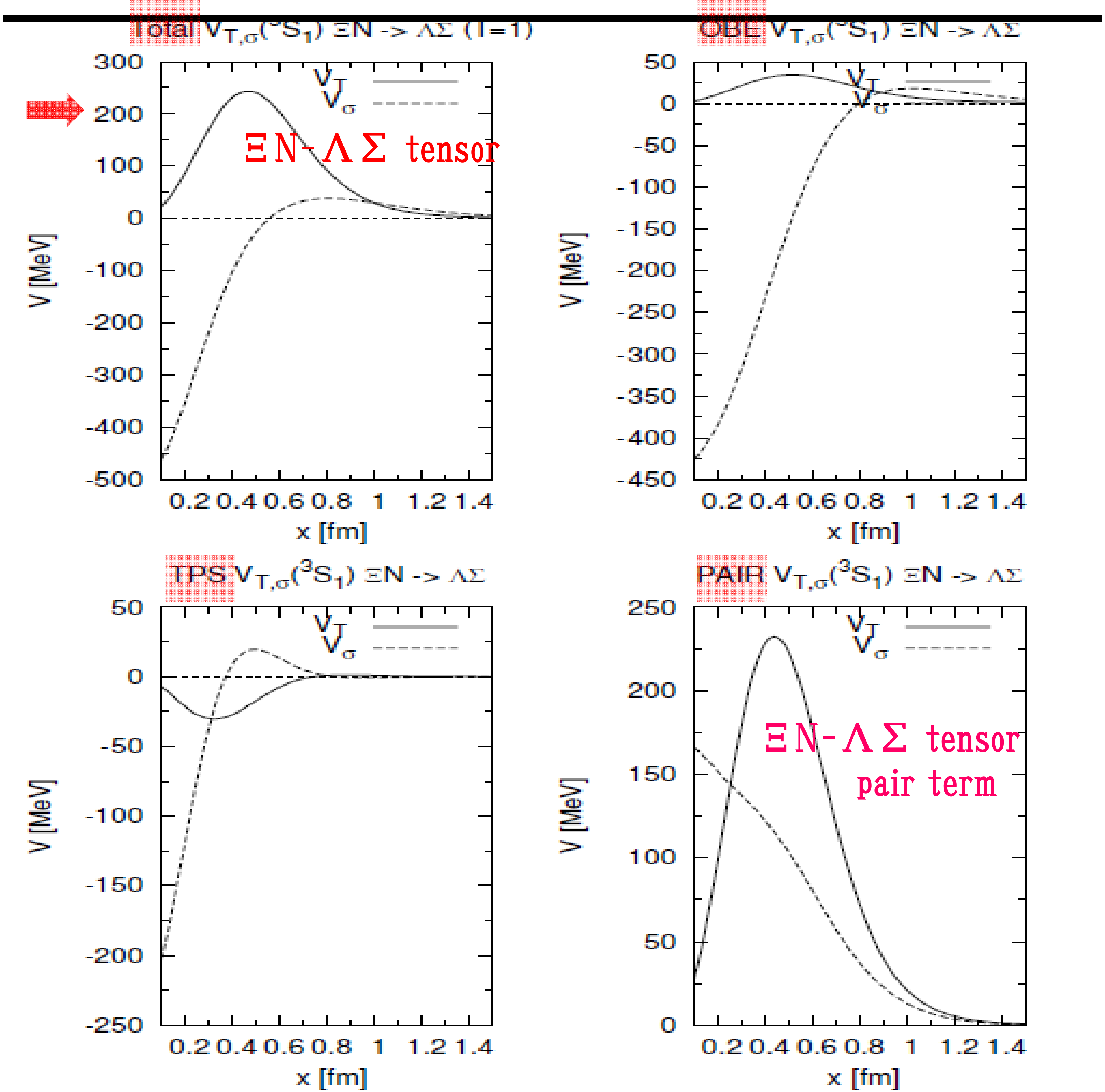
similar !

U_Ξ ($T=1$ $^3S_1$) -18.7 ⟶ $+14.7$: ΞN-$\Lambda\Sigma$-$\Sigma\Sigma$ tensor

in MeV

Strong $T=1$ $^3S_1$ ΞN attraction is not so peculiar !

Origin of ΞN-$\Lambda\Sigma$-$\Sigma\Sigma$ tensor coupling interaction ?



Total V_T,σ(3S1) ΞN -> ΛΣ (I=1)
ΞN-ΛΣ tensor
OBE V_T,σ(3S1) ΞN -> ΛΣ
TPS V_T,σ(3S1) ΞN -> ΛΣ
PAIR V_T,σ(3S1) ΞN -> ΛΣ
ΞN-ΛΣ tensor
pair term
V_T
V_σ
V [MeV]
x [fm]

An application of ΞN G-matrix interaction to Ξ-hypernuclei

PHYSICAL REVIEW C **78**, 054316 (2008)

Light Ξ hypernuclei in four-body cluster models

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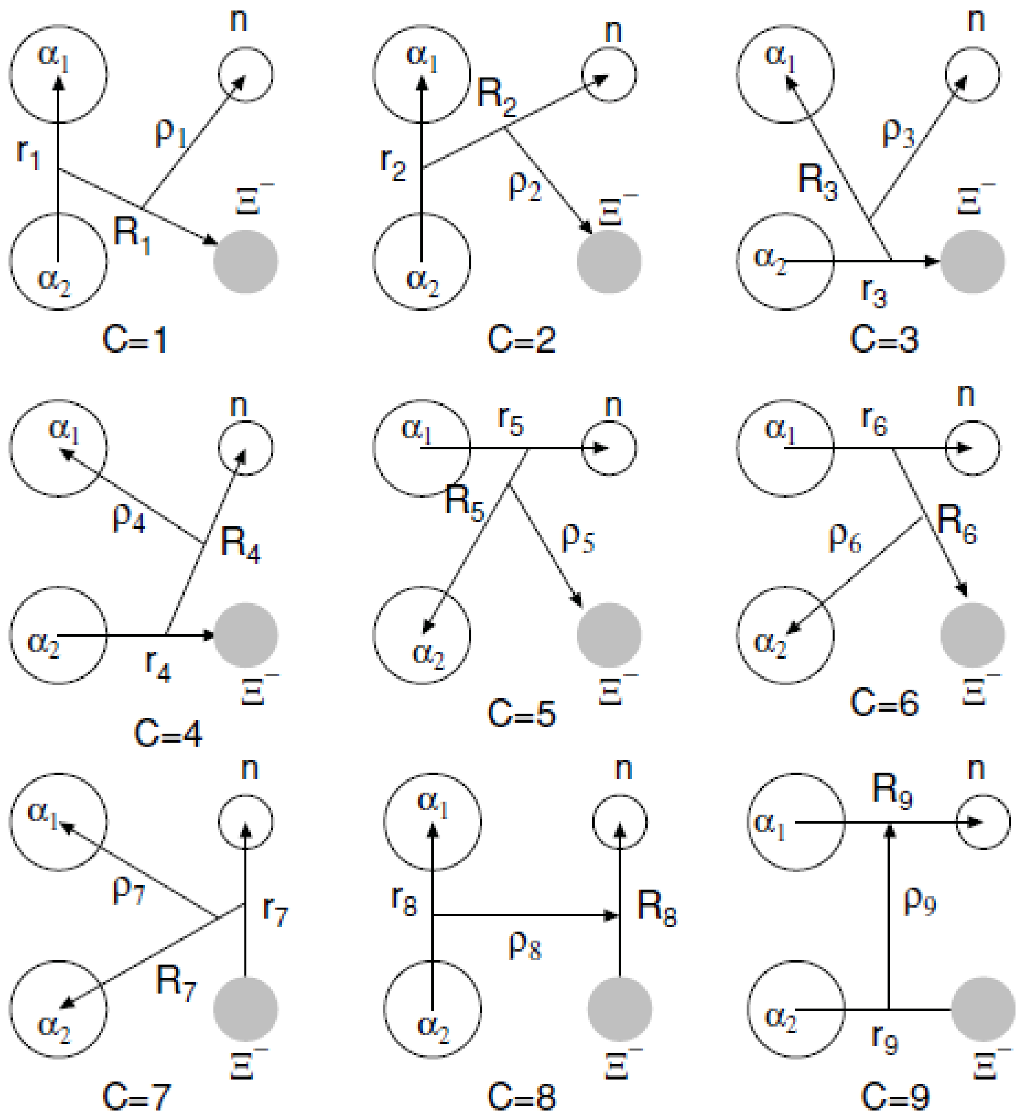
(Received 9 September 2008; published 24 November 2008)

$^{10}_{\Xi}\mathrm{Li}(\alpha\alpha n\Xi^-)$



$^{7}_{\Xi}\mathrm{H}\,(\alpha nn\Xi^-)$

αα ➡ nn　　n ➡ α

In (αnnΞ) system

Interactions (αn, αnn, αΞ, nΞ) are taken so as to reproduce binding energies of corresponding sub-systems

For Ξ α folding potential

Complex ΞN G-matrix interaction

$$G_{TS}^{(\pm)}(r, k_F) = \sum_{i=1}^{3} \left(a_i + b_i k_F + c_i k_F^2\right) \exp\left(-r^2/\beta_i^2\right),$$

where k_F is the Fermi momentum of nuclear matter

For nΞ^- interaction

T=1 $^3S_1$ ΞN-$\Lambda\Sigma$-$\Sigma\Sigma$ coupling effect is simulated by a single-channel interaction approximately

Exact coupled channel treatment is our future problem

Light Ξ^- hypernuclei produced by
$p(K^-, K^+)\Xi^-$ reactions on available nuclear targets

$^{12}C \Rightarrow {}^{12}_{\Xi^-}Be\ (\alpha\alpha t \Xi^-)$	bound (assumed)	
$^{11}B \Rightarrow {}^{11}_{\Xi^-}Li\ (\alpha\alpha nn \Xi^-)$	?	
$^{10}B \Rightarrow {}^{10}_{\Xi^-}Li\ (\alpha\alpha n \Xi^-)$	bound ($\alpha\alpha$ bound)	
$^{9}Be \Rightarrow {}^{9}_{\Xi^-}He\ (\alpha t n \Xi^-)$	?	
$^{7}Li \Rightarrow {}^{7}_{\Xi^-}H\ (\alpha nn \Xi^-)$	bound (αnn bound)	
$^{6}Li \Rightarrow {}^{6}_{\Xi^-}H\ (\alpha n \Xi^-)$	unbound	$\alpha p \Xi^-$ bound
$^{4}He \Rightarrow (pnn\Xi^-)$	unbound	
$^{3}He \Rightarrow (pn\Xi^-)$	bound (ESC04d)	
$^{3}H \Rightarrow (nn\Xi^-)$	unbound	
$^{2}H \Rightarrow (n\Xi^-)$	unbound	

$\Delta T_z=1$ transfer in a (K^-,K^+) reaction is not favorable to strong T=0 $^3S_1$ attraction in ESC04d

in the cases of ESC04d and NHC-D

Let us perform the same cluster-model calculations

using ESC08a'

ΞN interactions (ESC08a') in average are adjusted so as to be consistent with $U_\Xi \approx -14$ MeV or $B_\Xi(^{12}C_\Xi) \approx 2.2$ MeV

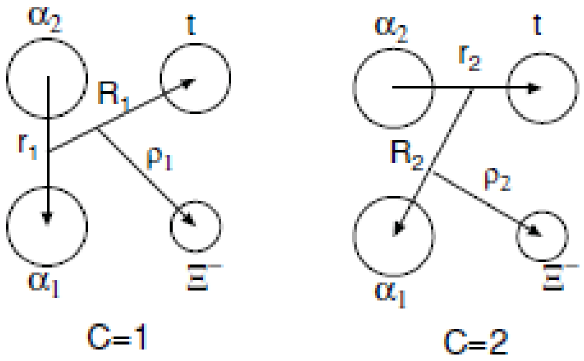
as well as ESC04d case

Note !

Spin- & isospin-averaged interactions of ESC04d and ESC08a' are adjusted so as to be similar to each other

$^{12}C\,(K^-,K^+)$

$^{12}_{\Xi^-}\mathbf{Be}(\alpha\alpha t\,\Xi^-)$



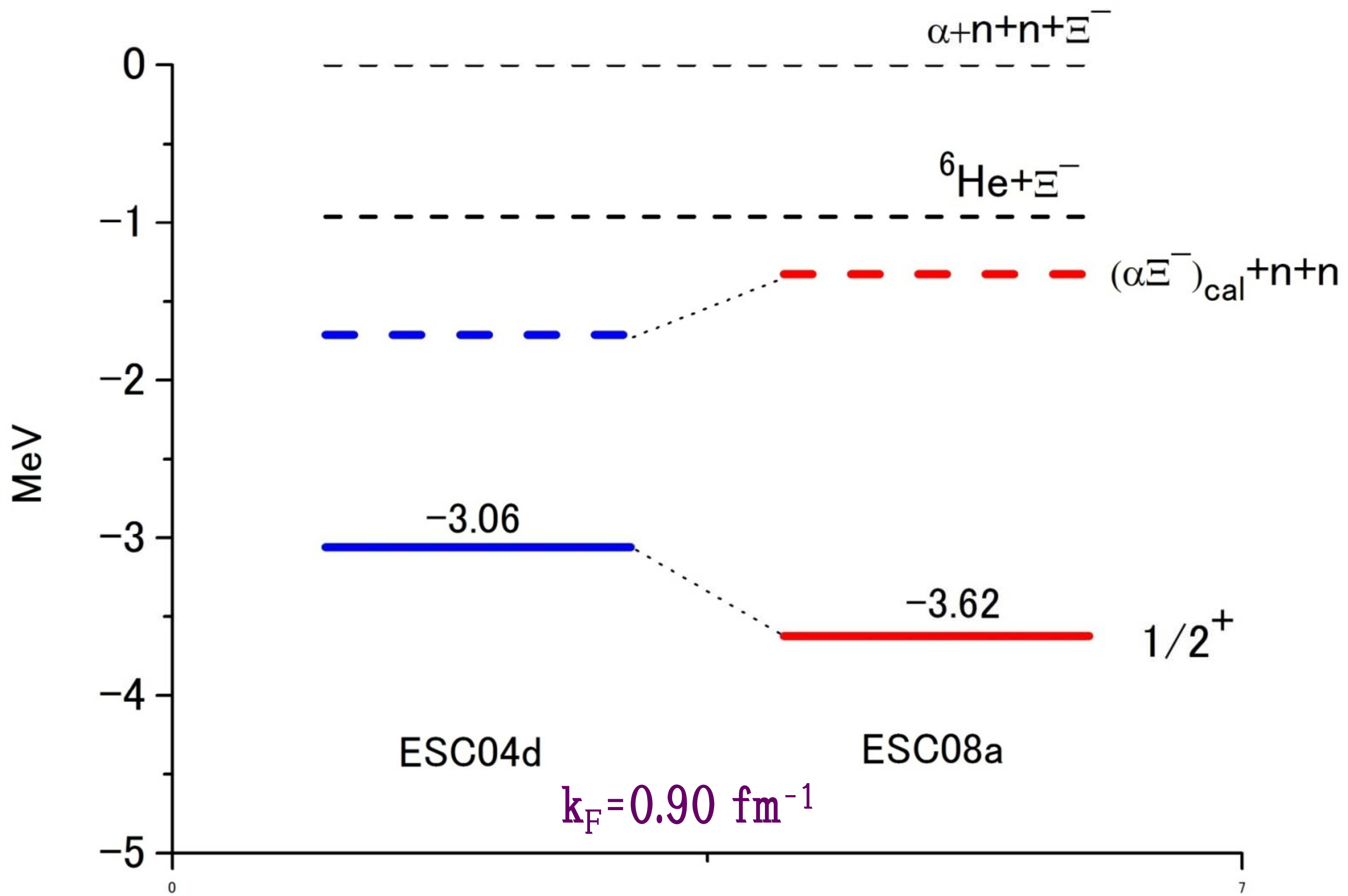
		ESC04d	ESC08a
	k_F (fm^{-1})	1.055	1.145
1^-	B_{Ξ^-} (MeV)	5.0	3.9
	(w/o Coulomb)	(2.2)	(2.2)
	Γ_{Ξ^-} (MeV)	4.6	2.3
2^-	B_{Ξ^-} (MeV)	6.1	4.6
	Γ_{Ξ^-} (MeV)	4.8	2.5

adjusted

calculated by E. Hiyama

^{7}Li(K$^-$,K$^+$) $^{7}_{\Xi}$H ($\alpha nn\Xi^-$)

calculated by E. Hiyama



ESC08a : $\alpha\Xi^-$ is less bound, but $\alpha nn\Xi^-$ is more bound owing to **more attractive ($n\Xi^-$) interaction**

Light Ξ^- hypernuclei produced by
$p(K^-, K^+)\Xi^-$ reactions on available nuclear targets

$^{12}C \Rightarrow {}^{12}_{\Xi^-}Be$	$(\alpha\alpha t\Xi^-)$	bound (assumed)
$^{11}B \Rightarrow {}^{11}_{\Xi^-}Li$	$(\alpha\alpha nn\Xi^-)$	bound (maybe)
$^{10}B \Rightarrow {}^{10}_{\Xi^-}Li$	$(\alpha\alpha n\Xi^-)$	bound ($\alpha\alpha$ bound)
$^{9}Be \Rightarrow {}^{9}_{\Xi^-}He$	$(\alpha t n\Xi^-)$	bound (maybe)
$^{7}Li \Rightarrow {}^{7}_{\Xi^-}H$	$(\alpha nn\Xi^-)$	bound (αnn bound)
$^{6}Li \Rightarrow {}^{6}_{\Xi^-}H$	$(\alpha n\Xi^-)$	bound (maybe)
$^{4}He \Rightarrow$	$(pnn\Xi^-)$	bound (maybe)
$^{3}He \Rightarrow$	$(pn\Xi^-)$	bound (maybe)
$^{3}H \Rightarrow$	$(nn\Xi^-)$	bound (maybe)
$^{2}H \Rightarrow$	$(n\Xi^-)$	$\sim$bound

(K⁻,K⁺) reactions lead to neutron-rich systems from available targets

in the cases of ESC08a'
owing to strong $n\Xi^-$ attractions

Various Ξ^- nuclear bound states are produced by (K^-,K^+) reactions !

Conclusion

S=0 and S=-1 sectors in ESC08 are of nice features especially $U_{\Sigma}>0$

ΞN parts in ESC08 are attractive enough to make various Ξ-hypernuclei

The attraction is caused mainly by the ΞN-$\Lambda\Sigma$-$\Sigma\Sigma$ tensor coupling interaction in $^{33}S_1$ state contribution

The strong attraction in $^{33}S_1$ $(n\Xi^-)$ state is favorable to Ξ-hypernuclei produced by (K^-,K^+) reactions on available nuclear targets