2009/2/27 熱海

Japan–Nijmegen collaboration

YN･YY 相互作用はどこまでわかったか？

そしてこれから（近未来）
（Hiyama strategyへのコメント）

Yamamoto

YN・YY相互作用とハイパー核

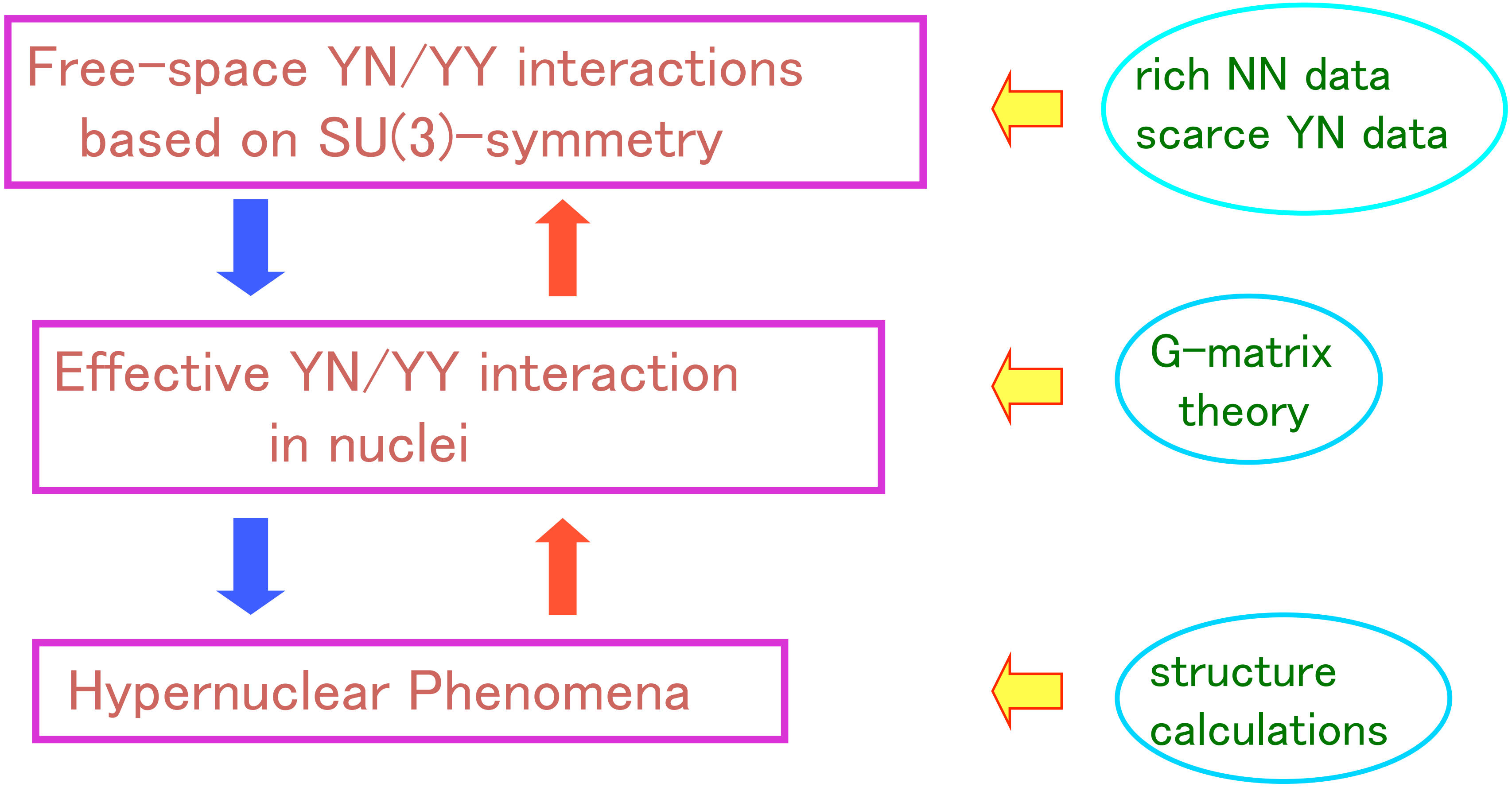
YN・YY相互作用模型は2体散乱データの貧困さのために非常に不定性が大きい

ハイパー核データによる模型の制限や選択が重要な役割を果たす

ハイパー核データがNN核力における2体散乱データの役割を果たすわけでない

YN散乱データはベースである
それなしにNijmegen modelは作れなかった

Japan–Nijmegen approach



Free–space YN/YY interactions
based on SU(3)–symmetry

rich NN data
scarce YN data

Effective YN/YY interaction
in nuclei

G–matrix
theory

Hypernuclear Phenomena

structure
calculations

Feedback from hypernuclei to interaction models

complementing the lack of YN scattering data

’50年代
emulsion
experiments

C,N,O,Ag,Br

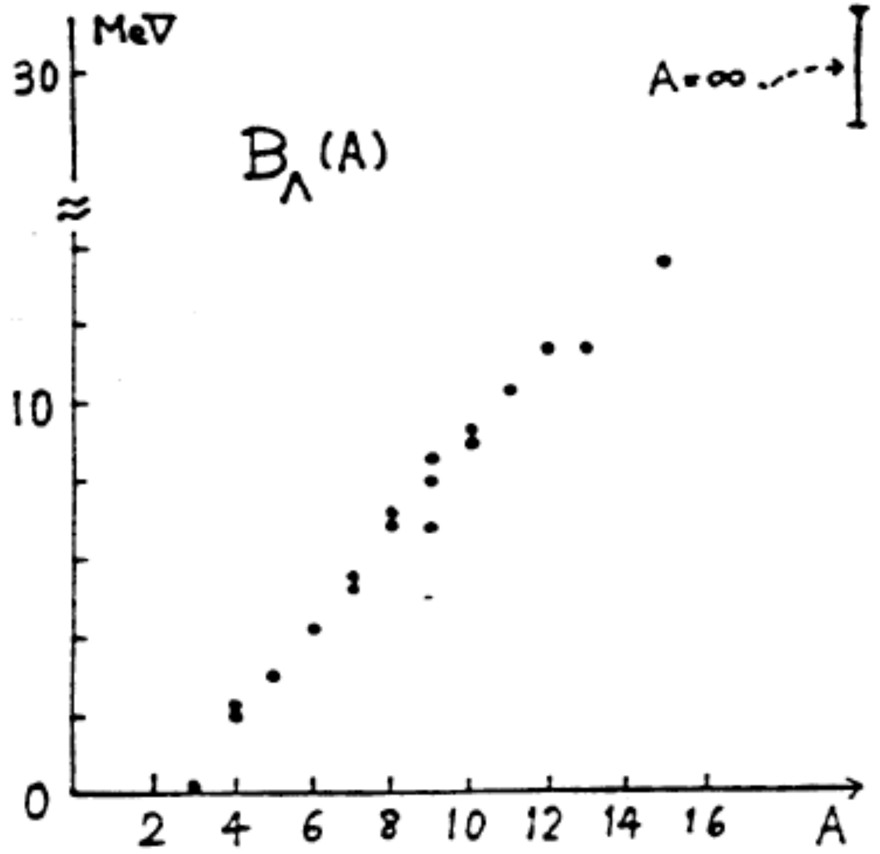


Fig.7. Mass number (A) dependence of the observed binding energy $B_\Lambda(A)$.

$$\boxed{B_\Lambda(A=\infty) = 30 \pm 5\ \mathrm{MeV}}$$

Overbinding problems

U_Λ in nuclear matter
s−shell hypernuclei

Hard core
Majorana exchange
Tensor force
ΛN−ΣN coupling
ΛNN TBF

坂東さんのハイパー核
事始め (1980)
NN tensor の役割

⇨ ND/NFの登場！

Nijmegen Hard−Core models

Including all of important effects such as **repulsive core, Majorana exchange, tensor force,** ΛN−ΣN coupling

Model D (**ND**) 1977
Model F (**NF**) 1979

ΛN G−matrix calculations in nuclear matter

Rozynek & Dabrowski 1979 単発的
Bando & Nagata 1982 系統的研究へ

Basic features of **Λ**-binding in nuclear matter

Why ND was used in 1980s ?

Features of **NF**

- Too repulsive U_Σ
- Too weak $V_{\Lambda\Lambda}$
- Repulsive U_Ξ

Inadequate !!!

Very different from present situation

← **Σ**-hypernucleus ${}_{\Sigma}\mathrm{Be}^{9}$

← Old data of Double-**Λ** hypernuclei

← **Ξ**-hypernuclei (compiled by Dover-Gal)

ND was a “standard” model for us in this period

as a qualitative representation for **ΛN**, **ΣN**, **ΛΛ**, **ΞN** interactions

as a practical model with adjustable parameters (especially h.c. radius)

1980年代「only one model」としてのND

ΛN相互作用としての定量性：
ORGを用いた構造計算における補足的意味程度
○○○でも理解できる

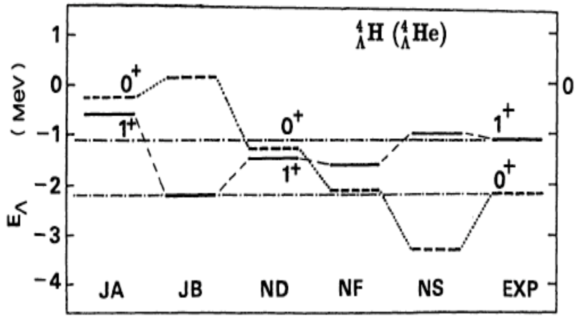
現代の肥山計算におけるNSC/ESCの果たす役割
とは根本的に異なる

ハイパー核情報から相互作用模型へ

典型例としてのΛN spin-spin interaction

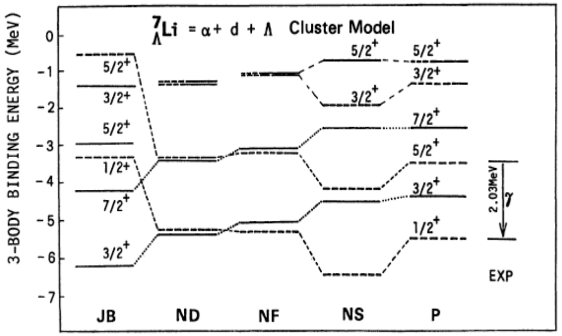
Λハイパー核におけるspin-doublet statesでのテスト

ND　×
NF　△
JA/JB　×



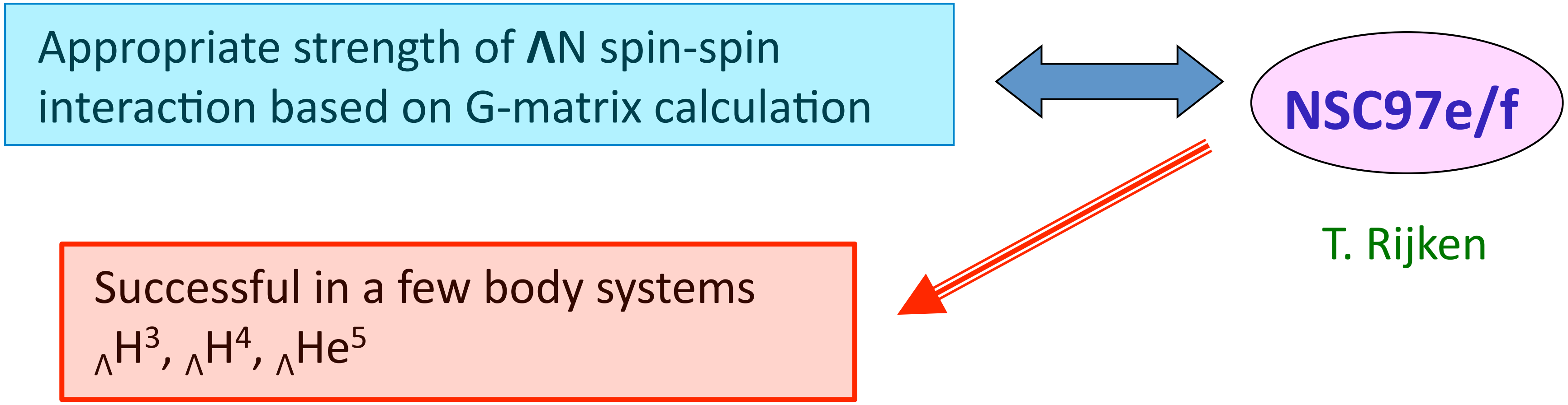
模型構築における必要条件として考慮

NSC97e/f
ESC04
FSS/fss2



spin-doublet states

Proposal of NSC97 models



Appropriate strength of ΛN spin-spin interaction based on G-matrix calculation

NSC97e/f

T. Rijken

Successful in a few body systems

${}_{\Lambda}H^3$, ${}_{\Lambda}H^4$, ${}_{\Lambda}He^5$

Remained Problems of NSC97 models

- ΛN odd-state interaction is strongly repulsive
- U_Σ is attractive

少数体計算で否定されるモデルの例

NSC89 strongly repulsive spin-spin

too strong ΛN-∑N coupling故$_{\Lambda}He^5$

がbound しない

Jeulich A/B, NSC97abcd

attractive or weakly repulsive spin-spin

$_{\Lambda}H^3$ がboundしない

SLS/ALS problem

SLS/ALS は手にp-statesで効くshort-range interaction
多体効果の影響を受けにくい
Λ s.o. splitting in nucleiと素直にリンクする

γ線分光実験によるΛ s.o. splittingの精密測定は
90年代における代表的成果のひとつである

相互作用模型への反映

“Strong cancellation of SLS & ALS” はQMの専売特許ではなさそう
also possible in ESC modeling

ESC model 開発のモチベーション

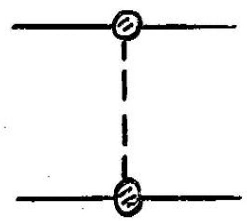
理論の内的要因：effective meson (boson)からreal mesonsへ

OBE models (NSC89/97)で残された問題の解決へ
（small s.o., repulsive UΣ、attractive UΞ， etc）

Extended Soft-Core Model ESC04

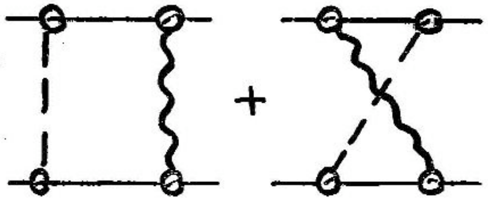
- Two-meson exchange processes are treated explicitly
- Meson-Baryon coupling constants are taken consistently with Quark-Pair Creation model

One-Boson-Exchanges:



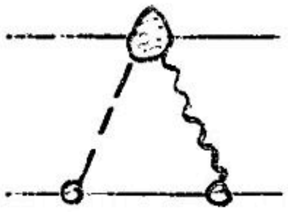
PS, S, V, AV nonets

Two-Meson-Exchanges:



PS-PS exchange

Meson-Pair-Exchanges:



(ππ),(πρ),(πω),(πη),(σσ)

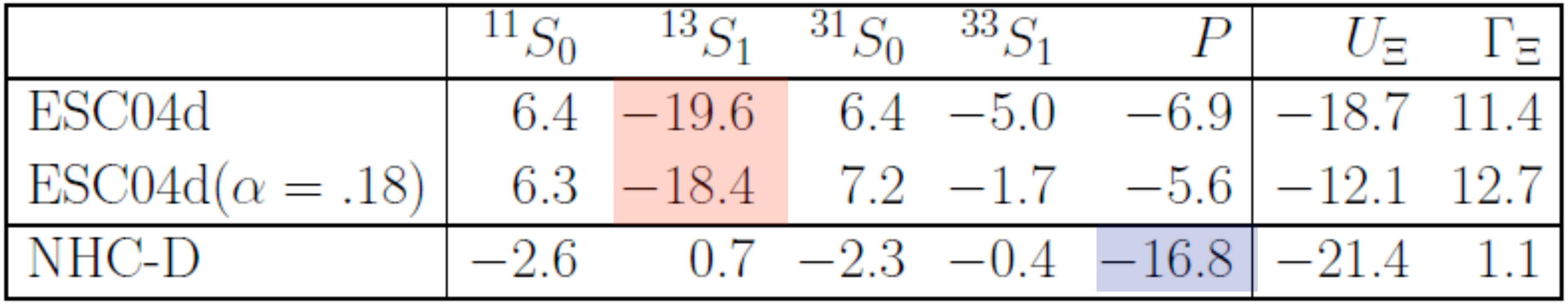
+(πK),(πK*)・・・ strangeness exchange

ESC07 small s.o. splitting

attractive U_{Ξ} (~ −14 MeV) を与える

相互作用模型は可能か?

Partial-wave contributions to U_Ξ (G-matrix calculation)



	$^{11}S_0$	$^{13}S_1$	$^{31}S_0$	$^{33}S_1$	P	U_Ξ	Γ_Ξ
ESC04d	6.4	−19.6	6.4	−5.0	−6.9	−18.7	11.4
ESC04d($\alpha = .18$)	6.3	−18.4	7.2	−1.7	−5.6	−12.1	12.7
NHC-D	−2.6	0.7	−2.3	−0.4	−16.8	−21.4	1.1

α is an parameter for three-body repulsive effect

adjusting the attraction suitably

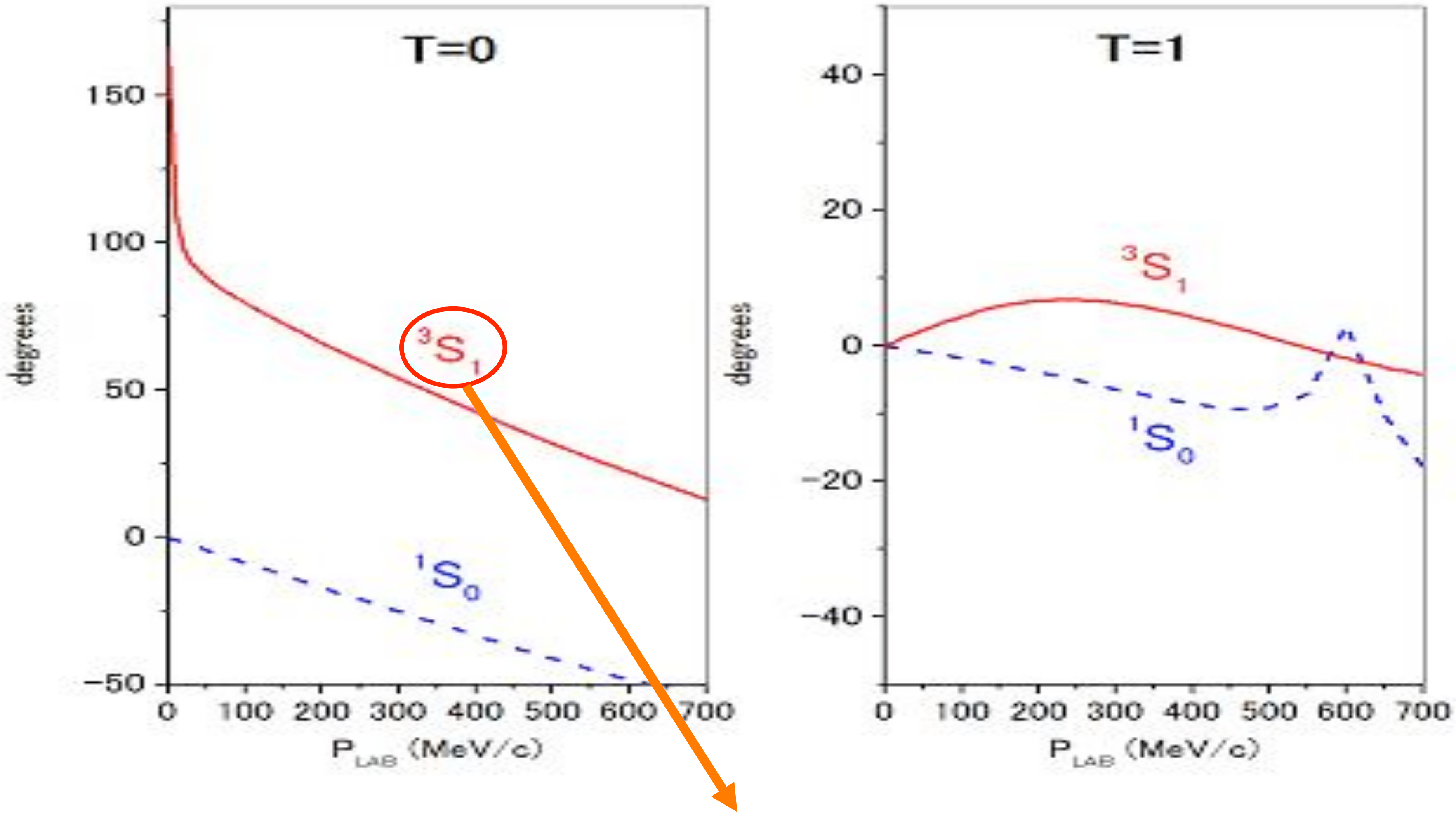
Main contributions to attractive values of U_Ξ

ESC04d : $^{13}S_1$-state attraction

NHC-D : P-state attraction

Large conversion width Γ_Ξ in ESC04d

ΞN phase shifts for ESC04d



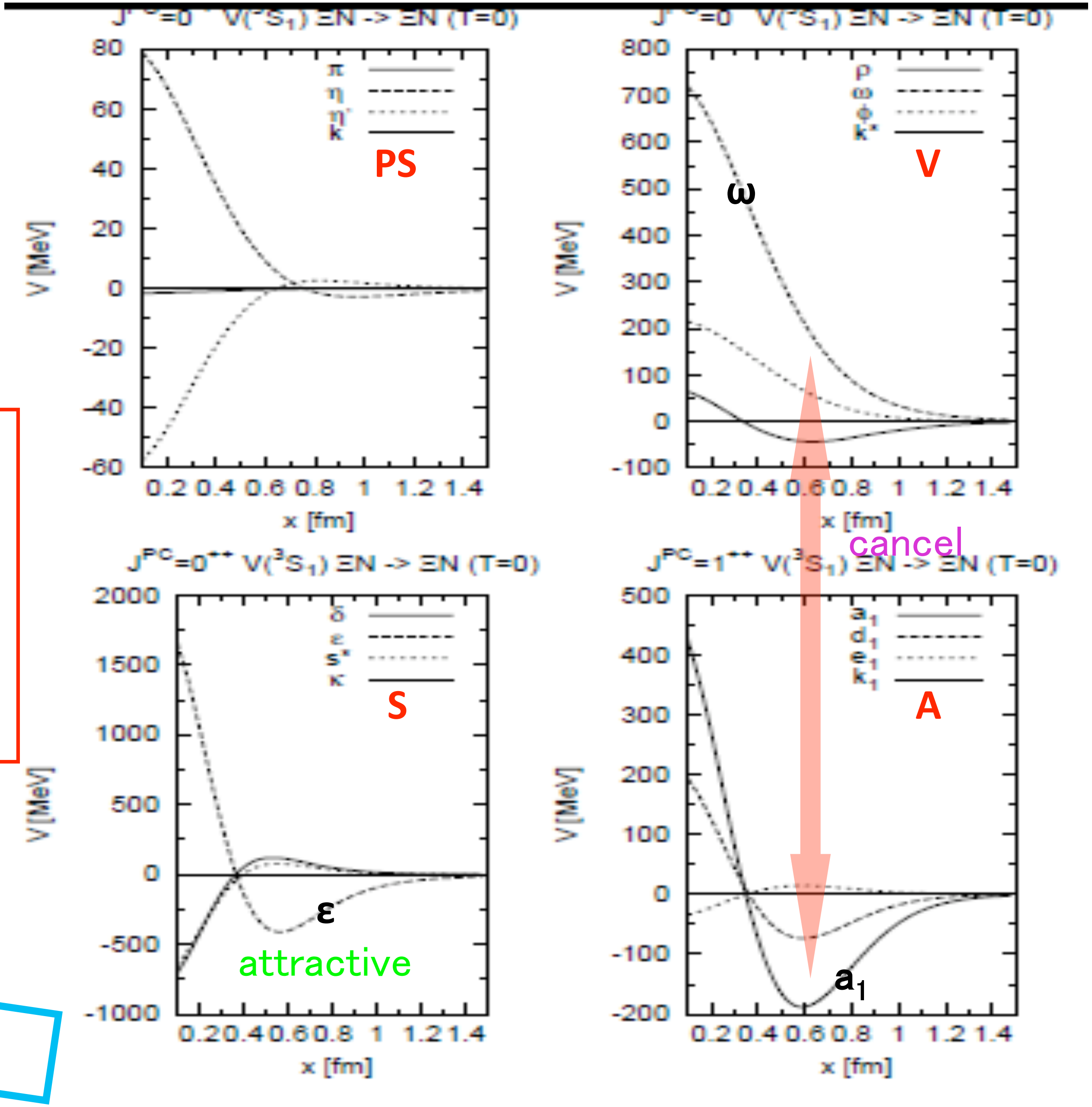
Specific bound states in 2−,3−,4−body systems

ΞN $^{13}S_1$– state attraction

Canceling of
V and A

↓

Attraction
of S appears



accidental ?

Contributions from PS–, S–, V–, AV–mesons

Attractive U_{Ξ} に対する
another modeling は可能か？

この問題以外についてはESC07はほぼ”完璧”である
but ・・・

Σ-Nucleus potentials U_Σ

Intermediate states in (π,K) reactions

Σ-nucleus scattering

.....

Interesting problems

repulsive ?

isospin-dependence

spin-orbit interaction

imaginary parts (scattering & conversion)

Nijmegen soft–core models

(NSC89/97, ESC04/07)

Origin of cores

pomeron

ω meson

Repulsive cores are similar to each other in all channels

Quark Pauli–forbidden states ?

Are repulsive ∑-potentials obtained from Nijmegen models?

NHC-F ok
but…

NO (maybe) ← standard NSC/ESC modeling

in spite of elaborate works by Rijken

Import the feature of quark model !

Recent Nijmegen approach

ESC core = pomeron + ω

Assuming
“equal parts” of ESC and QM are similar to each other

Almost Pauli–forbidden states in [51] are taken into account by changing the pomeron strengths for the corresponding channels

$$g_P \Longrightarrow \mathrm{sqrt}(2.5)\ g_P$$

ESC07 models

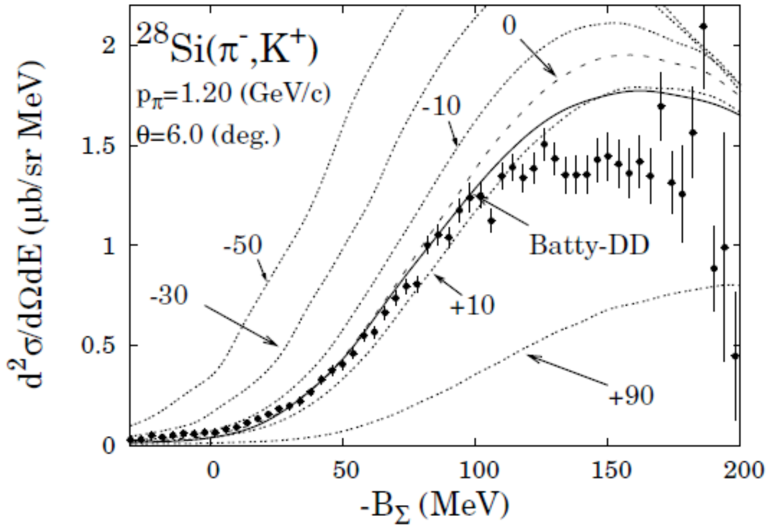
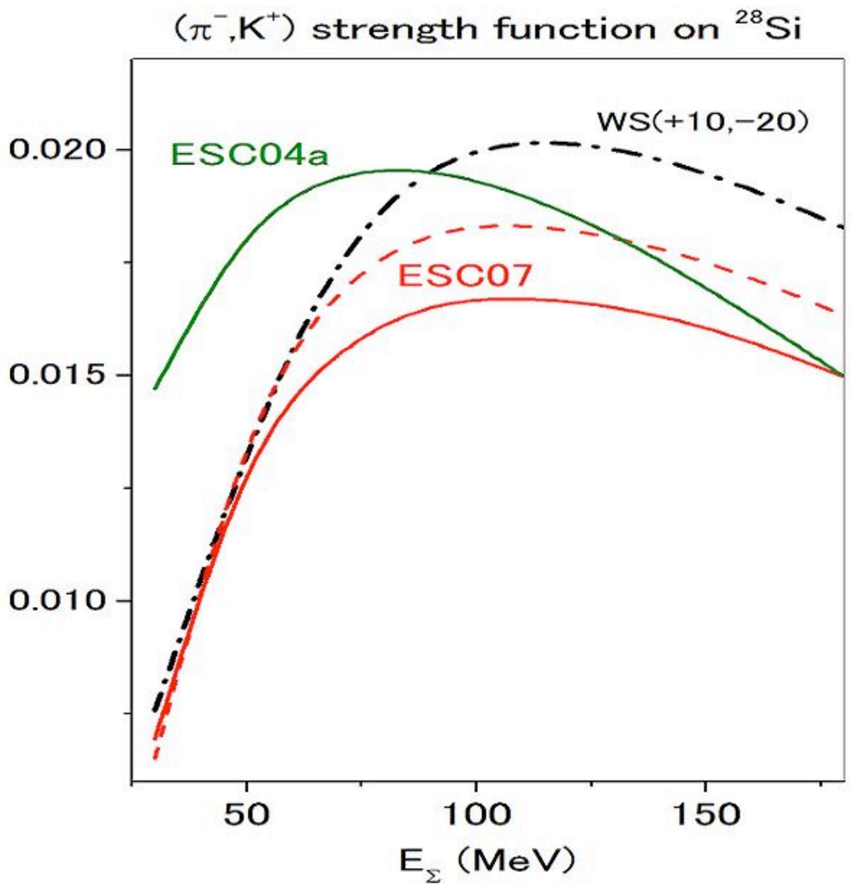


Fig. 2. Differential cross section of (π^-, K^+) reaction on ^{28}Si target at the incident momentum of p_π=1.2 GeV/c. The solid line shows result of Batty's DD potential with LOFAt + DWIA, Other line are calculated results with LOFAt + DWIA with potential depth of V_0=-50, -30, -10, 0, +10, +90 MeV(up to down), respectively. Imaginary part is fixed to be -20 MeV.



相互作用模型の選別は可能か???

肥山計算における

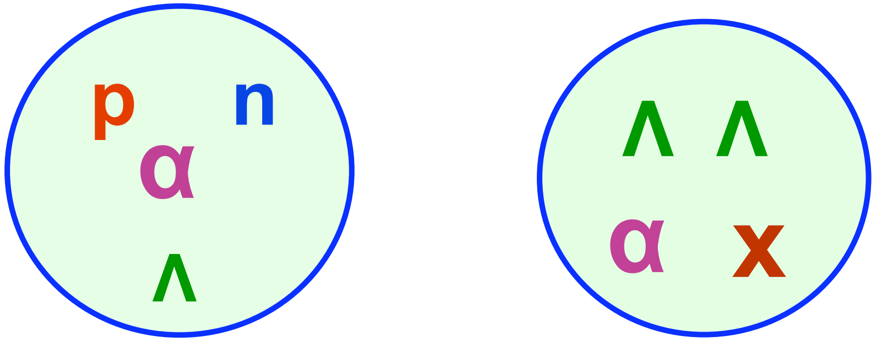
realistic effective interactions

Developed cluster models including rearrangement channels

by Hiyama-Kamimura

Most important point in Hiyama's 3-4 cluster models based on the Threshold Rule

⇒ excellent reliability and predictive power



Λα : G-matrix interaction folding
ΛN : free-space interaction (effective !!!)

Threshold rule に基づいて調節される
ΛN−ΣN coupling は現象論的に繰り込まれる

ΞN−ΛΣ−ΣΣ coupling

$_{\Lambda}\mathrm{H}^{4}$($_{\Lambda}\mathrm{He}^{4}$)
fitted

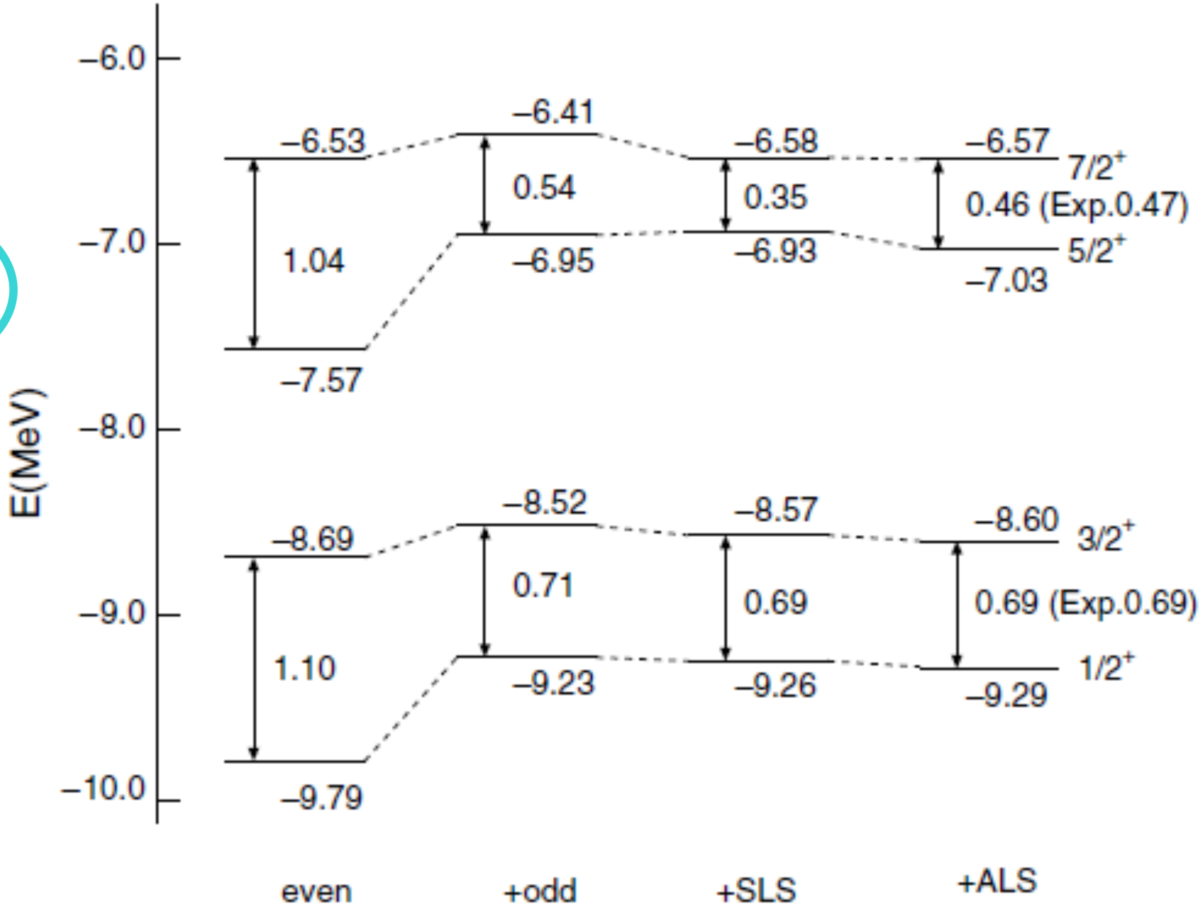
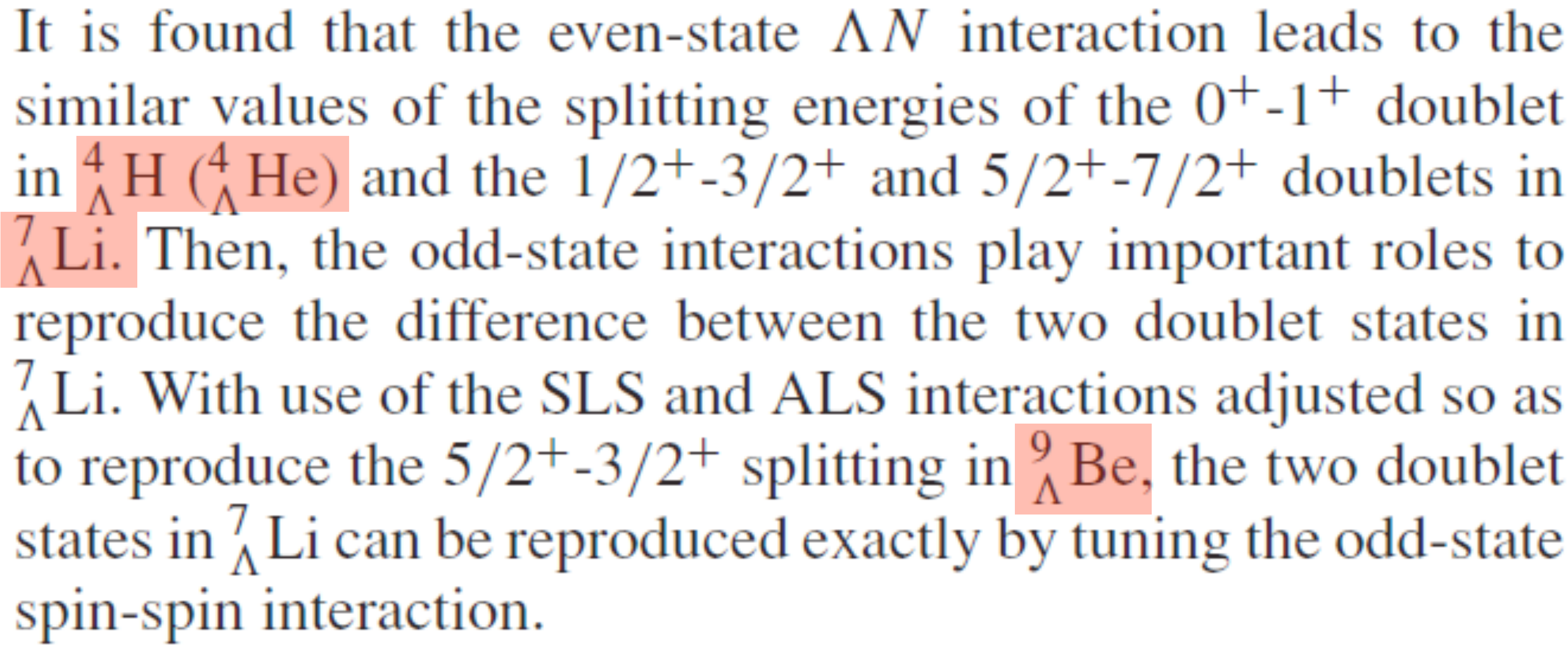
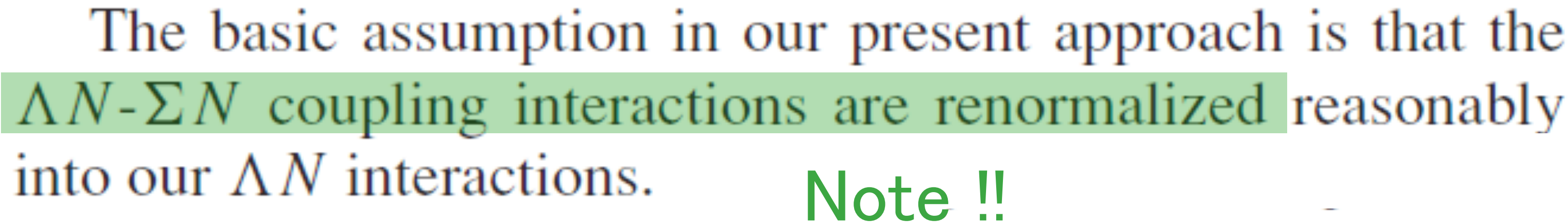


FIG. 2. Calculated energy levels of $^{7}_{\Lambda}\mathrm{Li}$ on the basis of $\alpha + \Lambda + n + p$ model. The energies are measured from the $\alpha + \Lambda + n + p$ threshold. The observed energy splittings of $3/2^{+}$-$1/2^{+}$ and $7/2^{+}$-$5/2^{+}$ are 0.69 and 0.47 MeV, respectively.

Conclusion of the paper



It is found that the even-state ΛN interaction leads to the similar values of the splitting energies of the 0^+-1^+ doublet in ${}^{4}_{\Lambda}$H (${}^{4}_{\Lambda}$He) and the $1/2^+$-$3/2^+$ and $5/2^+$-$7/2^+$ doublets in ${}^{7}_{\Lambda}$Li. Then, the odd-state interactions play important roles to reproduce the difference between the two doublet states in ${}^{7}_{\Lambda}$Li. With use of the SLS and ALS interactions adjusted so as to reproduce the $5/2^+$-$3/2^+$ splitting in ${}^{9}_{\Lambda}$Be, the two doublet states in ${}^{7}_{\Lambda}$Li can be reproduced exactly by tuning the odd-state spin-spin interaction.



The basic assumption in our present approach is that the ΛN-ΣN coupling interactions are renormalized reasonably into our ΛN interactions.

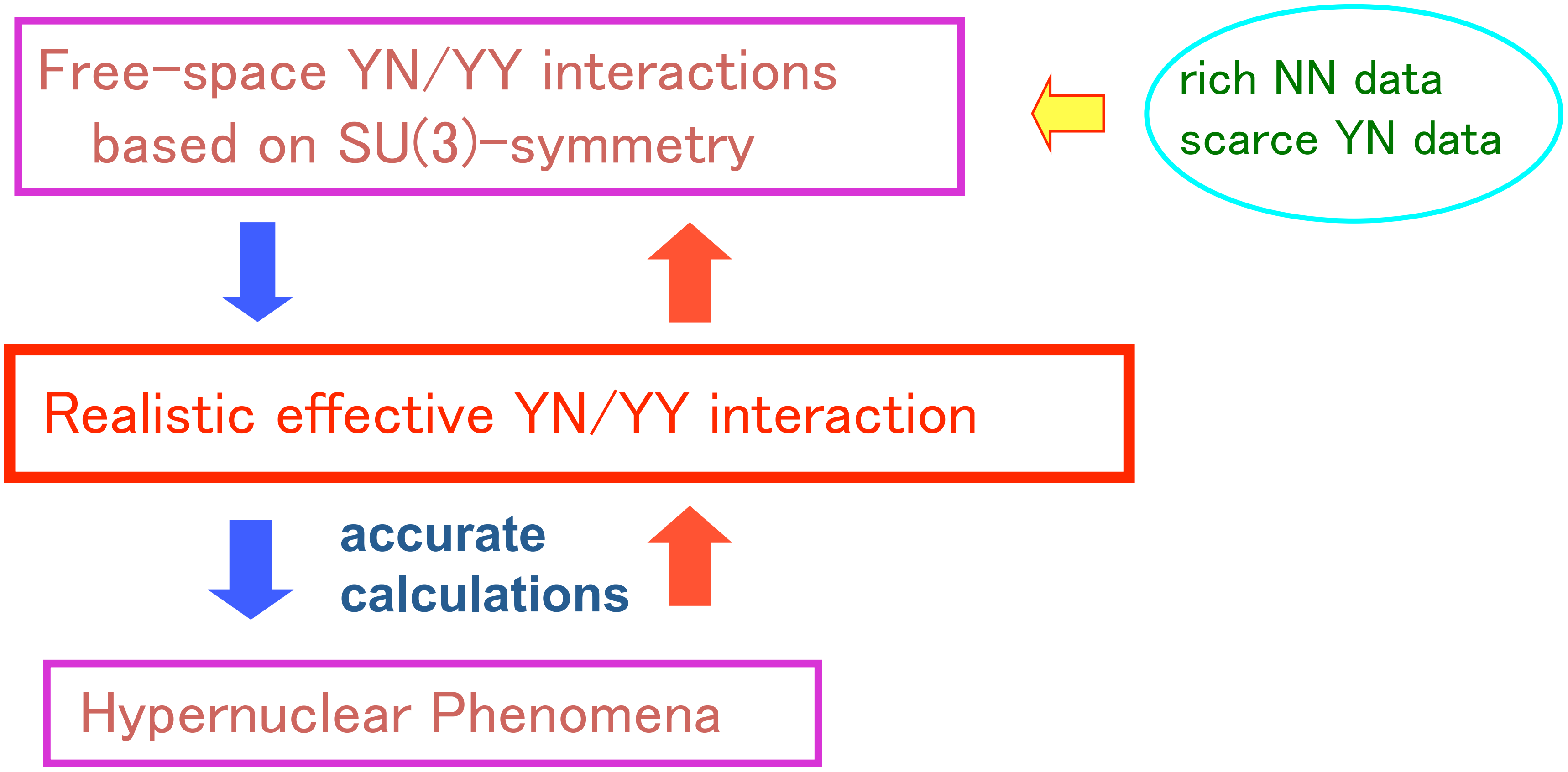
Note !!

Hiyama cluster-model approach　においては
相互作用の種としてbare interactions (NSC/ESC)の
特徴を取り込んだ上で、厳密計算+精密実験データ
に基づきinteraction parametersを正確に決める

いわゆるab initio 計算ではない！
step by step に相互作用の特徴を解明する
spin-spin, spin-orbit, ➔

ΛNの次のstepはCSB
final goal はΛN-∑N coupling

Our approach to hypernuclear physics



Free-space YN/YY interactions
based on SU(3)-symmetry

rich NN data
scarce YN data

Realistic effective YN/YY interaction

accurate calculations

Hypernuclear Phenomena

Feedback from hypernuclei to interaction models

complementing the lack of YN scattering data

G−matrix interaction
double−counting problem

肥山計算

3−, 4−, 5−body cluster model space で使える
realistic effective interaction simulating ESC

$$V=V_0+V_{ss}+V_{so}+V_{ten}+V_{cpl}$$

<k|G|k>がESCと一致するように
free-space Gaussian interactionを作る（G-matrix equivalent）

Model spaceでexplicitに扱うcoupling part (ΛN-ΣN etc）は残し
取り扱わない部分は繰りこむ（ΞN-ΛΣ-ΣΣ etc）

この路線で系統的にやれないか

How to treat CSB interaction in Hiyama calculations for A=4 and 7 systems ?

Shinmura's report 1983

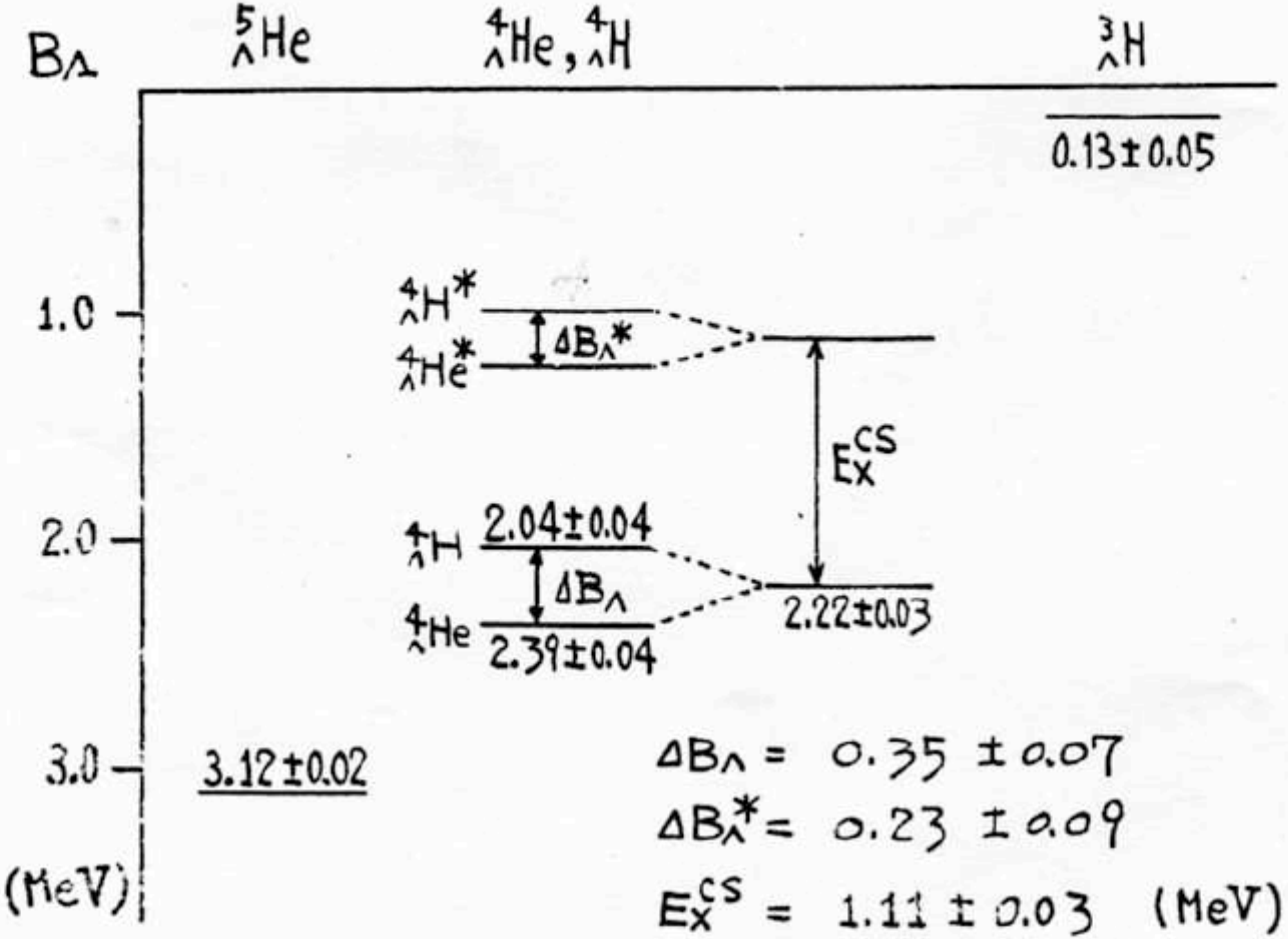
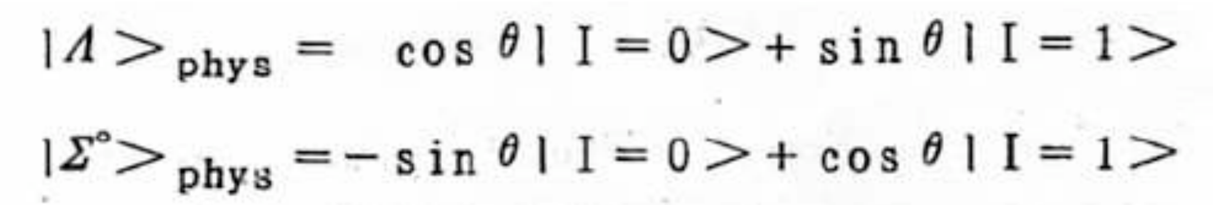


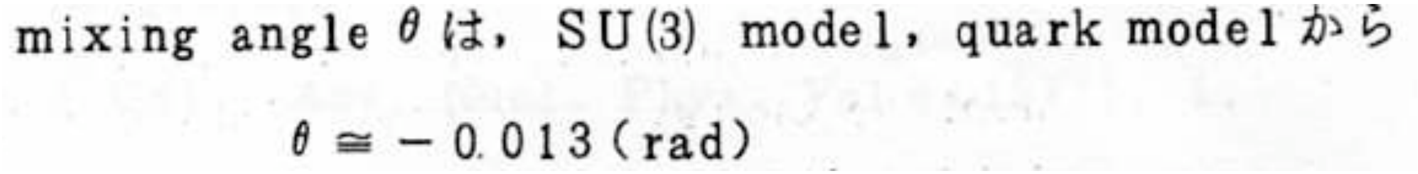
Fig. 1. Experimental values used here

Dalitz and Von Hippel



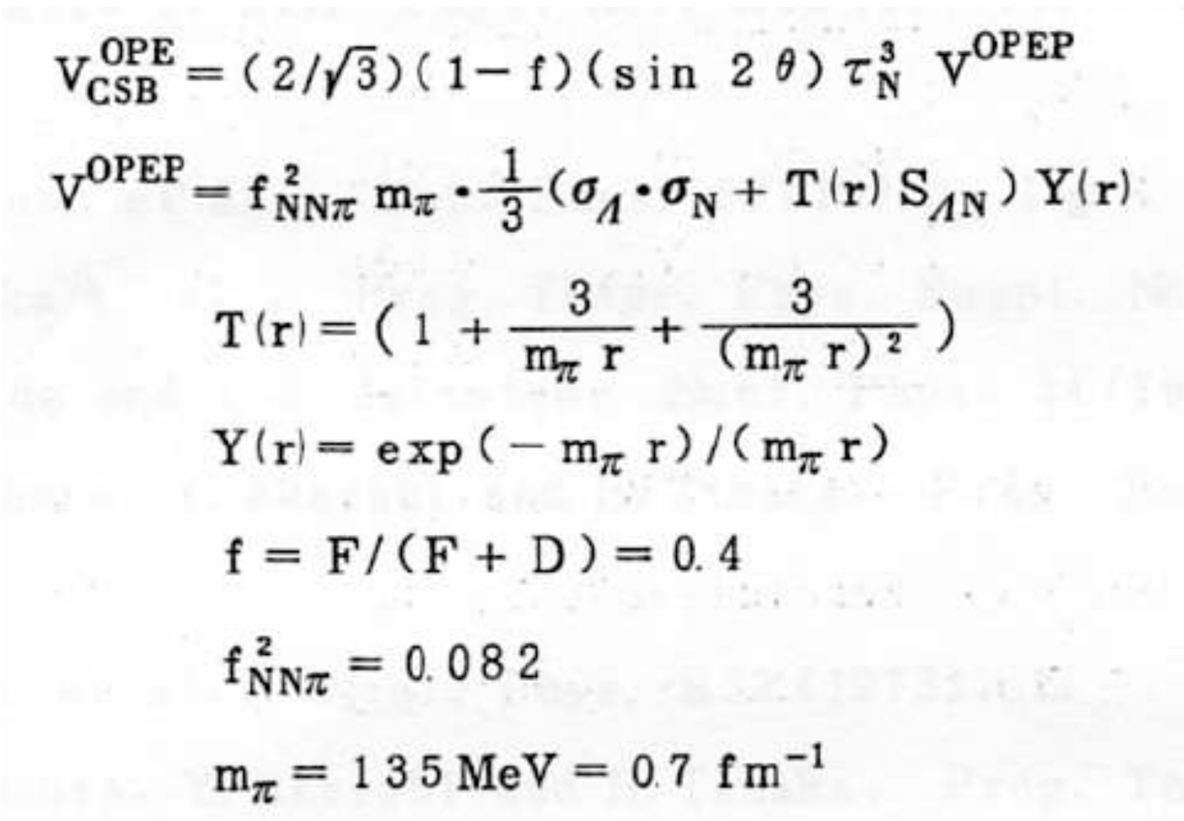
$$|\Lambda\rangle_{\mathrm{phys}} = \cos\theta\,|I=0\rangle + \sin\theta\,|I=1\rangle$$

$$|\Sigma^{\circ}\rangle_{\mathrm{phys}} = -\sin\theta\,|I=0\rangle + \cos\theta\,|I=1\rangle$$



mixing angle θ は，SU(3) model，quark model から

$$\theta \cong -0.013\,(\mathrm{rad})$$



$$V_{\mathrm{CSB}}^{\mathrm{OPE}} = (2/\sqrt{3})(1-f)(\sin 2\theta)\,\tau_{N}^{3}\;V^{\mathrm{OPEP}}$$

$$V^{\mathrm{OPEP}} = f_{NN\pi}^{2}\,m_{\pi}\cdot\frac{1}{3}(\sigma_{\Lambda}\cdot\sigma_{N} + T(r)\,S_{\Lambda N})\,Y(r)$$

$$T(r) = \left(1 + \frac{3}{m_{\pi}r} + \frac{3}{(m_{\pi}r)^{2}}\right)$$

$$Y(r) = \exp(-m_{\pi}r)/(m_{\pi}r)$$

$$f = F/(F+D) = 0.4$$

$$f_{NN\pi}^{2} = 0.082$$

$$m_{\pi} = 135\,\mathrm{MeV} = 0.7\,\mathrm{fm}^{-1}$$

Coulomb-force effect

$$\Delta B_\Lambda = B_\Lambda({}^4_\Lambda\mathrm{He}) - B_\Lambda({}^4_\Lambda\mathrm{H})$$
$$\Delta B_\Lambda^{CSB} = \Delta B_\Lambda^{exp} - \Delta B_c^{CS}$$

ΔB_Λ^{exp}=0.35 MeV
ΔB_c^{CS} calculated with charge sysmmetric ΛN interaction and Coulomb interaction

Values of $-\Delta B_c^{CS}$
Friar-Gibson: ~0.02 MeV
Dalitz-Hippel: ~0.08 MeV
Bodmer=Usmani: ~0.05 MeV ⇒ ΔB_Λ^{CSB}=0.40 MeV

In oeder to fit the data phenomenologically, some spin-independent interaction is needed (OPEP-type is insufficient)

Four-body study for

${}^{4}_{\Lambda}\mathrm{H}\,(pnn\Lambda)$ ${}^{4}_{\Lambda}\mathrm{He}\,(ppn\Lambda)$

${}^{7}_{\Lambda}\mathrm{He}\,(\alpha nn\Lambda)$ ${}^{7}_{\Lambda}\mathrm{Li}^{T=1}\,(\alpha pn\Lambda)$ ${}^{7}_{\Lambda}\mathrm{Be}\,(\alpha pp\Lambda)$

Realistic effective interactions
(renormalized ΛN-ΣN coupling)

$$V = V_0 + V_{ss} + V_{tensor} + V^{CSB}$$

$$V^{CSB} = V_{DH}^{CSB} + V_0^{phenom}$$

作ったけれど４体計算は大変（時間）、人手が足りない

ΛN−ΣN coupling

Λ-binding における重要性は自明である
基本的にはeffective ΛN interactionへの
くりこみで理解できる

問題は
多体系における特徴的な現れ
模型依存性の大きいstrengthの決定

Hiyama’s strategy： step by step

今後に向けての結語

3-,4-,5-cluster model studies

bare interactionを使ったら良いわけでない
現象にそくしてmodel space を設定せよ
そしてmodel space に相応しいeffective interactionを
realisticにつくりましょう
これが永田流「核力から核構造」の秘伝である

肥山さんの下で修業する若手がいれば
realistic effective interactions をジャカジャカ作れる
テーマがいっぱいありすぎて肥山さんだけでは
到底足りません

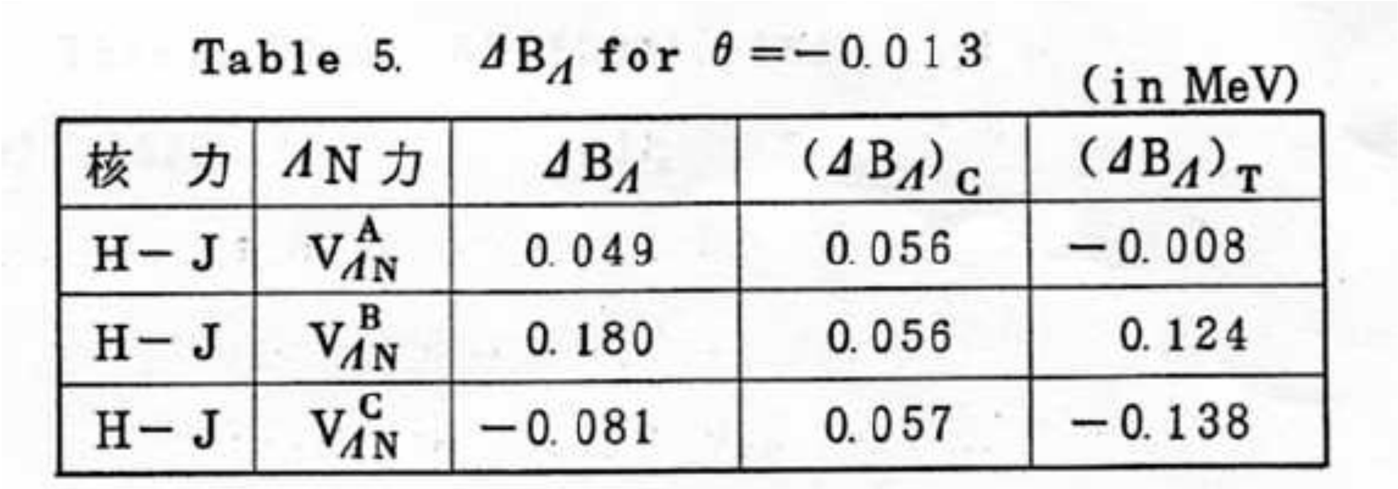
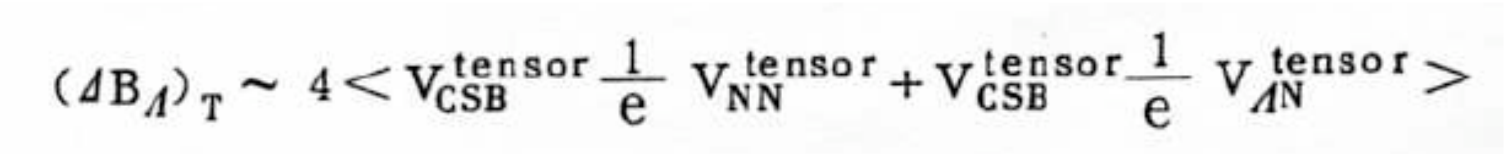


Table 5. ΔB_Λ for $\theta=-0.013$ (in MeV)

核　力	ΛN 力	ΔB_Λ	$(\Delta B_\Lambda)_C$	$(\Delta B_\Lambda)_T$
H−J	$V^A_{\Lambda N}$	0.049	0.056	−0.008
H−J	$V^B_{\Lambda N}$	0.180	0.056	0.124
H−J	$V^C_{\Lambda N}$	−0.081	0.057	−0.138

Exp=0.35 (but…)



$$(\Delta B_\Lambda)_T \sim 4 < V^{tensor}_{CSB} \frac{1}{e} V^{tensor}_{NN} + V^{tensor}_{CSB} \frac{1}{e} V^{tensor}_{\Lambda N} >$$

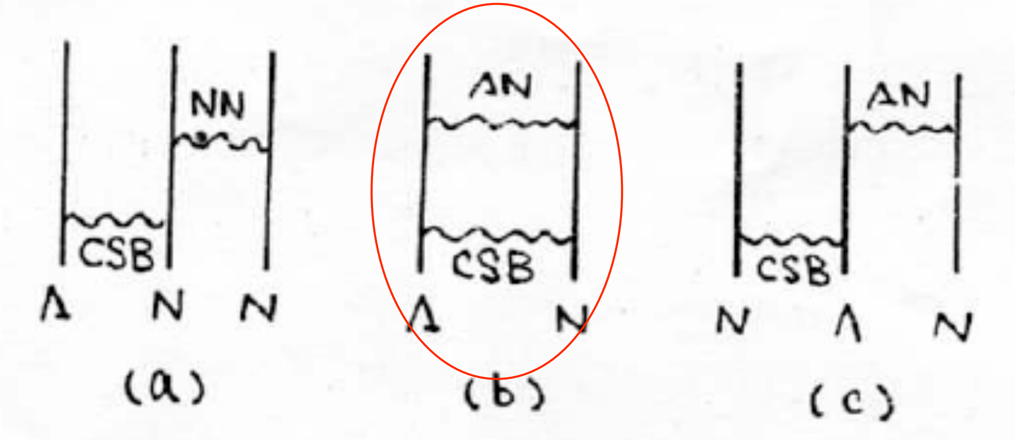


Fig. 4. The diagrams which represent the lowest order contributions from the tensor part of the CSB component to energy. the wavy lines denote tensor interactions.