Charge symmetry breaking effects in the A=4 iso-doublet hypernuclei

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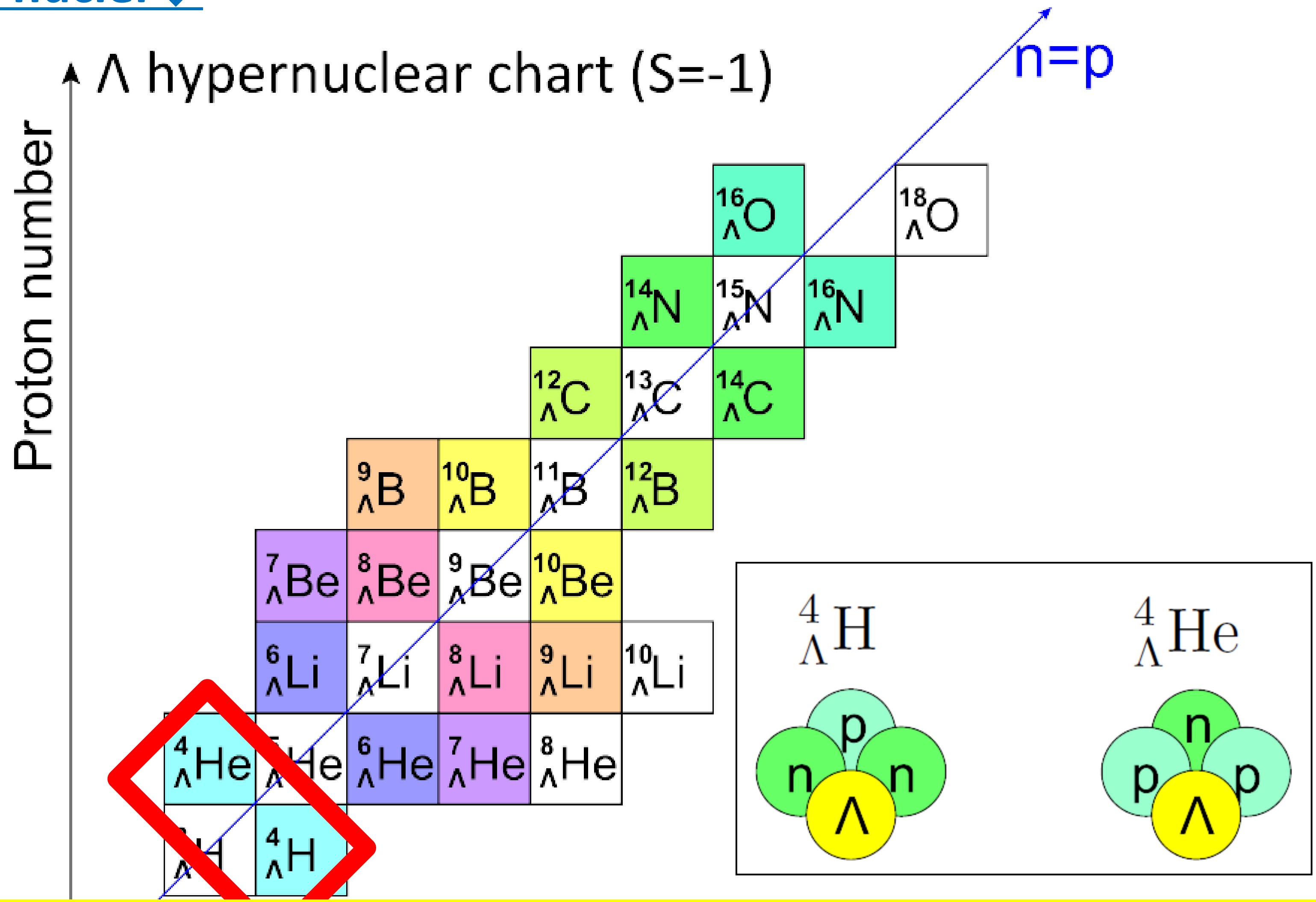
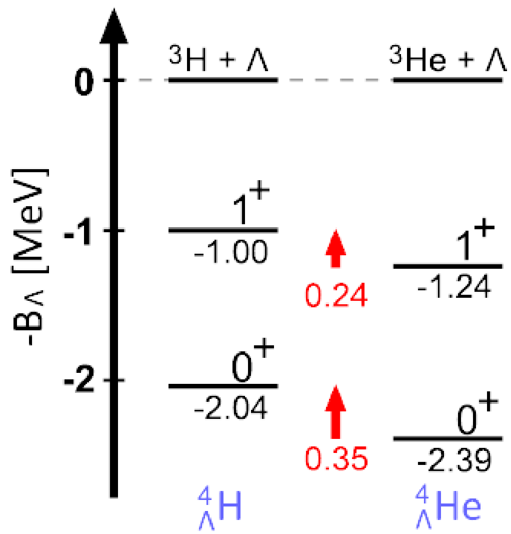
Introduction

◆Mirror nuclei◆

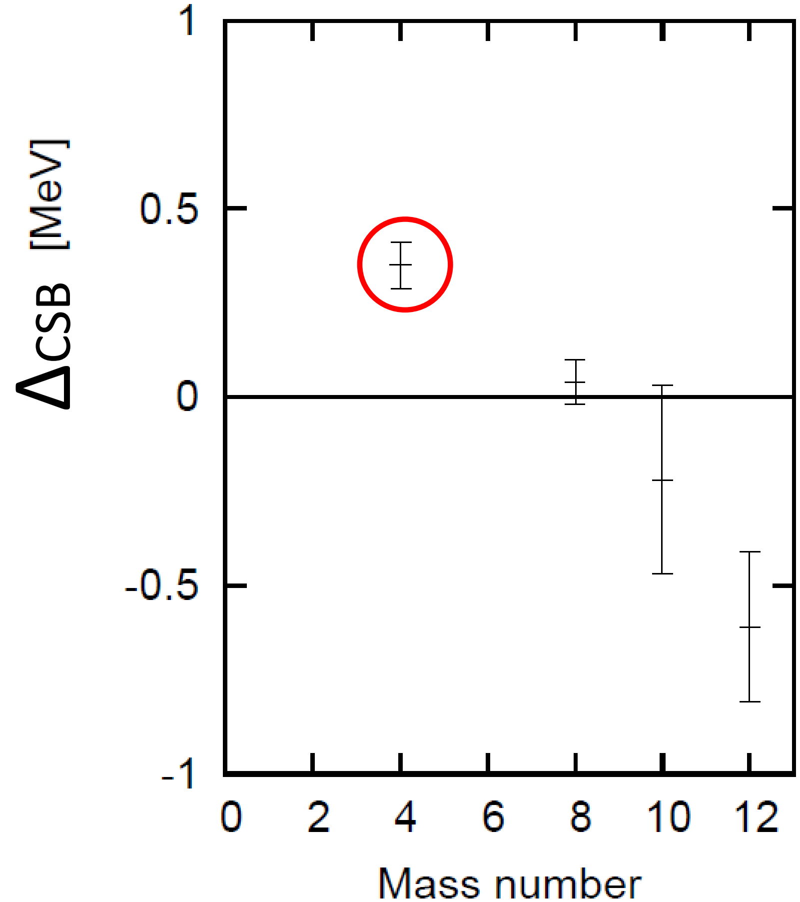


Charge symmetry breaking (CSB):
The differences between the properties of the mirror nuclei.

◆Λ Separation energies for mirror pairs◆



A		S.E [MeV]	Δ_{CSB} [MeV]
4	$^4_\Lambda$He	2.39 ±0.03	0.35 ±0.06
	$^4_\Lambda$H	2.04 ±0.04	
6	$^6_\Lambda$Li		
	$^6_\Lambda$He	4.18 ±0.10	
8	$^8_\Lambda$Be	6.84 ±0.05	0.04 ±0.06
	$^8_\Lambda$Li	6.80 ±0.03	
10	$^{10}_\Lambda$B	8.89 ±0.12	-0.22 ±0.25
	$^{10}_\Lambda$Be	9.11 ±0.22	
12	$^{12}_\Lambda$C	10.76±0.19	-0.61±0.20
	$^{12}_\Lambda$B	11.37±0.06	



◆Relate works◆

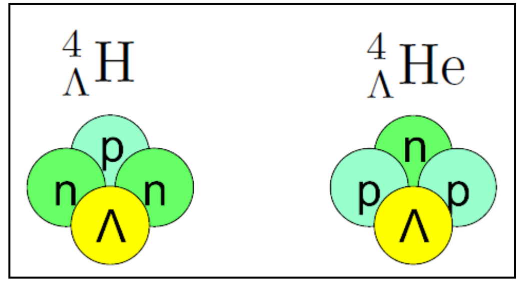
E.Hiyama, *et al.*, PRC65:011301 (2001)			
J^{π}	$B_{\Lambda}({}^{4}_{\Lambda}He)$	$B_{\Lambda}({}^{4}_{\Lambda}H)$	Δ_{CSB}
0^+	2.28	2.33	−0.05
1^+	0.54	0.59	−0.05

A.Nogga, *et al.*, PRL88:172501 (2002)			
J^{π}	$B_{\Lambda}({}^{4}_{\Lambda}He)$	$B_{\Lambda}({}^{4}_{\Lambda}H)$	Δ_{CSB}
0^+	1.54	1.47	0.07
1^+	0.72	0.73	−0.01

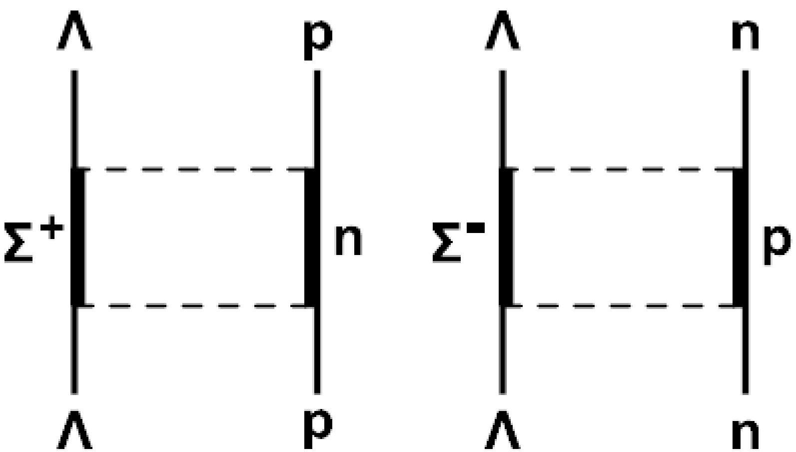
Expt.			
J^{π}	$B_{\Lambda}({}^{4}_{\Lambda}He)$	$B_{\Lambda}({}^{4}_{\Lambda}H)$	Δ_{CSB}
0^+	2.39±0.03	2.04±0.04	0.35±0.06
1^+	1.24±0.05	1.00±0.06	0.24±0.08

All energies are given in MeV

◆Contributions to CSB◆



Λ-Σ conversion



Σ^+,Σ^- states are not equally populated in two hypernuclei.

Contributions

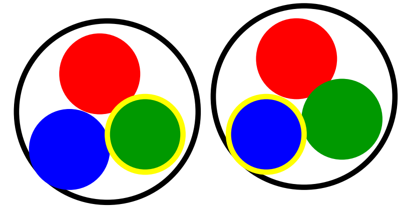
- ●Kinetic energy
- ●Strong YN interaction
- ●Coulomb interaction

<u>But, they could not described the experiment</u>

As the other contributions,
We consider the effects from u-d quark mass difference.

Interaction

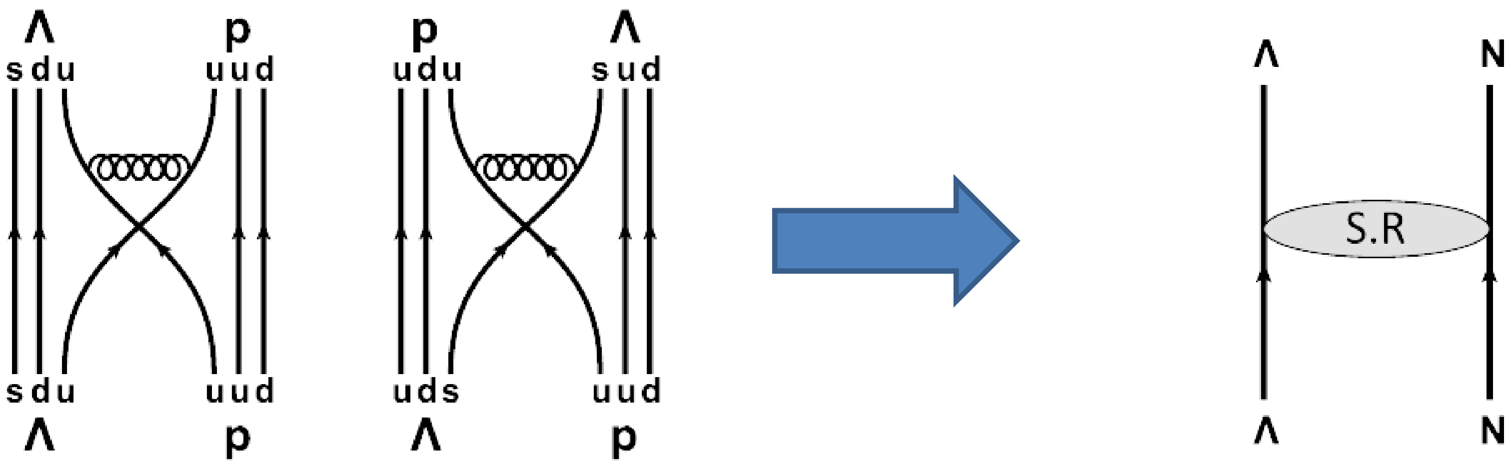
Quark –quark interaction:



$$\mathcal{H}^{(q_i q_j)} = -(\lambda_i \cdot \lambda_j)\frac{\pi \alpha_s}{6 m_i m_j}(\vec{\sigma}_i \cdot \vec{\sigma}_j)\delta^{(3)}(r_{ij})$$

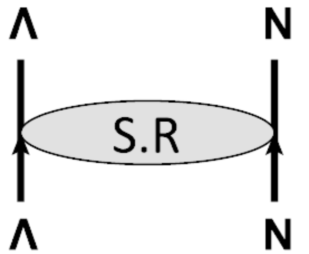
Mass dependence

Short range ΛN interaction



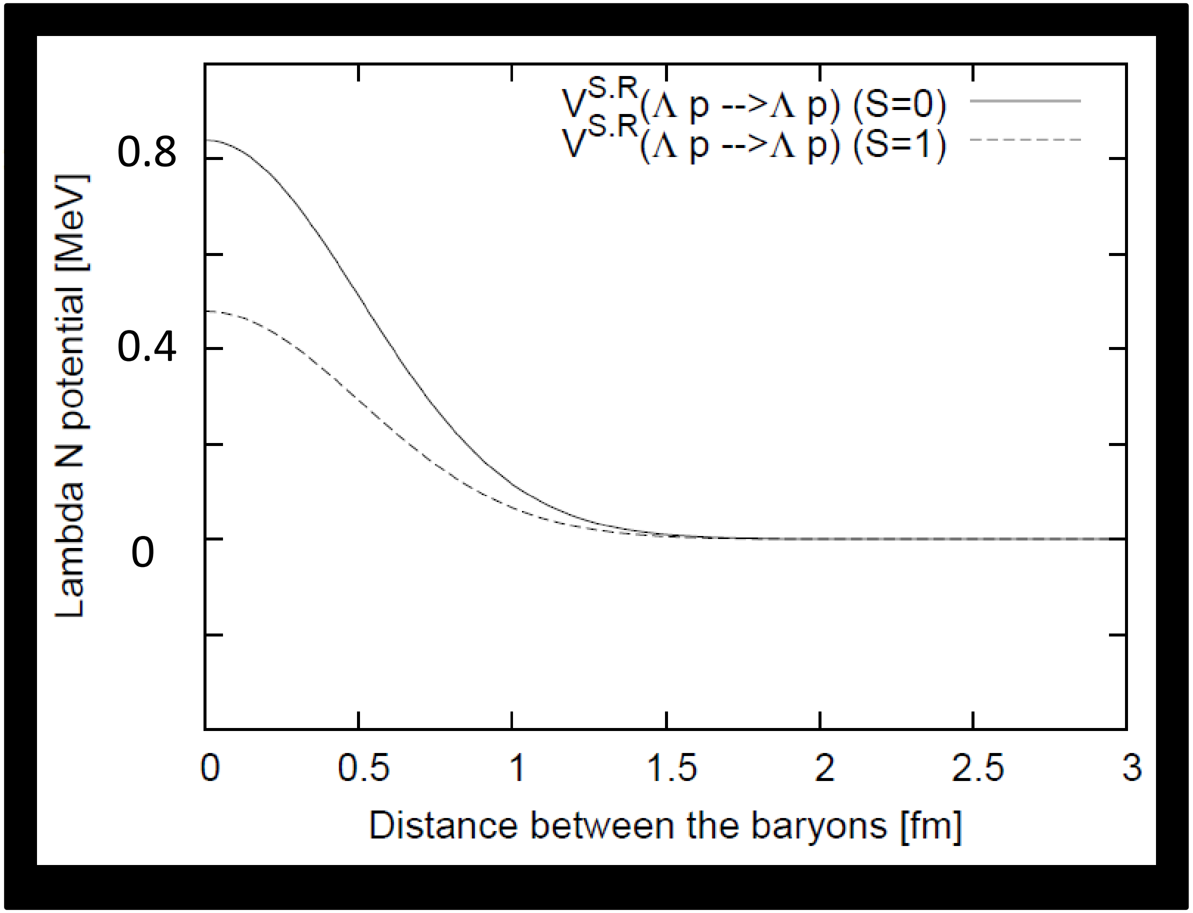
$$V_{\Lambda N} = \frac{1}{6}\sqrt{\frac{3}{\pi}}\frac{\beta^3 \alpha_s \delta m}{\hat{m}^3}\exp(-\frac{3}{4}\beta^2 r_{\Lambda N}^2)\tau_z(N)\left\{1 - \frac{\hat{m}}{4m_s} + \left(\frac{\hat{m}}{12 m_s} - \frac{5}{27}\right)\vec{\sigma}(\Lambda)\cdot\vec{\sigma}(N)\right\}$$

Short range ΛN interaction



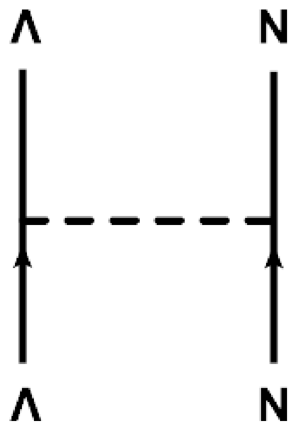
$$V_{\Lambda N} = \frac{1}{6}\sqrt{\frac{3}{\pi}}\frac{\beta^3\alpha_s\delta m}{\hat{m}^3}\exp(-\frac{3}{4}\beta^2 r_{\Lambda N}^2)\tau_z(N)\left\{1-\frac{\hat{m}}{4m_s}+\left(\frac{\hat{m}}{12m_s}-\frac{5}{27}\right)\vec{\sigma}(\Lambda)\cdot\vec{\sigma}(N)\right\}$$

$$\begin{aligned}\beta^{-1} &= 0.6\ [\mathrm{fm}]\\ \delta m &= 6\ [\mathrm{MeV}]\\ \hat{m} &= 330\ [\mathrm{MeV}]\\ m_s &= 550\ [\mathrm{MeV}]\end{aligned}$$



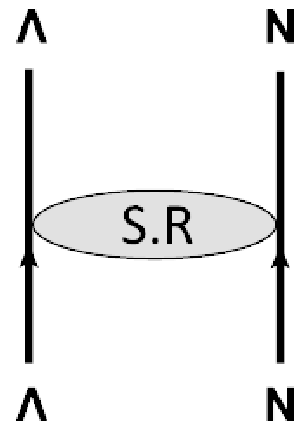
Calculation

◆ΛN interaction(1)◆



Nijmegen SC97f

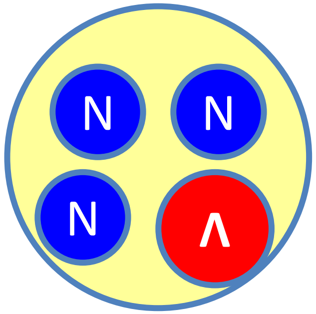
+



Short range ΛN interaction

- **The ΛN-ΣN coupling can be renormalized into the ΛN interaction.**
- **Strengths of V_s,V_{SLS},V_{ALS} are adjusted so as to reproduce of the observed data of $^4{}_\Lambda$H, $^7{}_\Lambda$Li, $^9{}_\Lambda$Be and $^{13}{}_\Lambda$C.**
- **The detail:**
  E. Hiyama *et al.*,
  Phys. Rev. C80,054321 (2009)

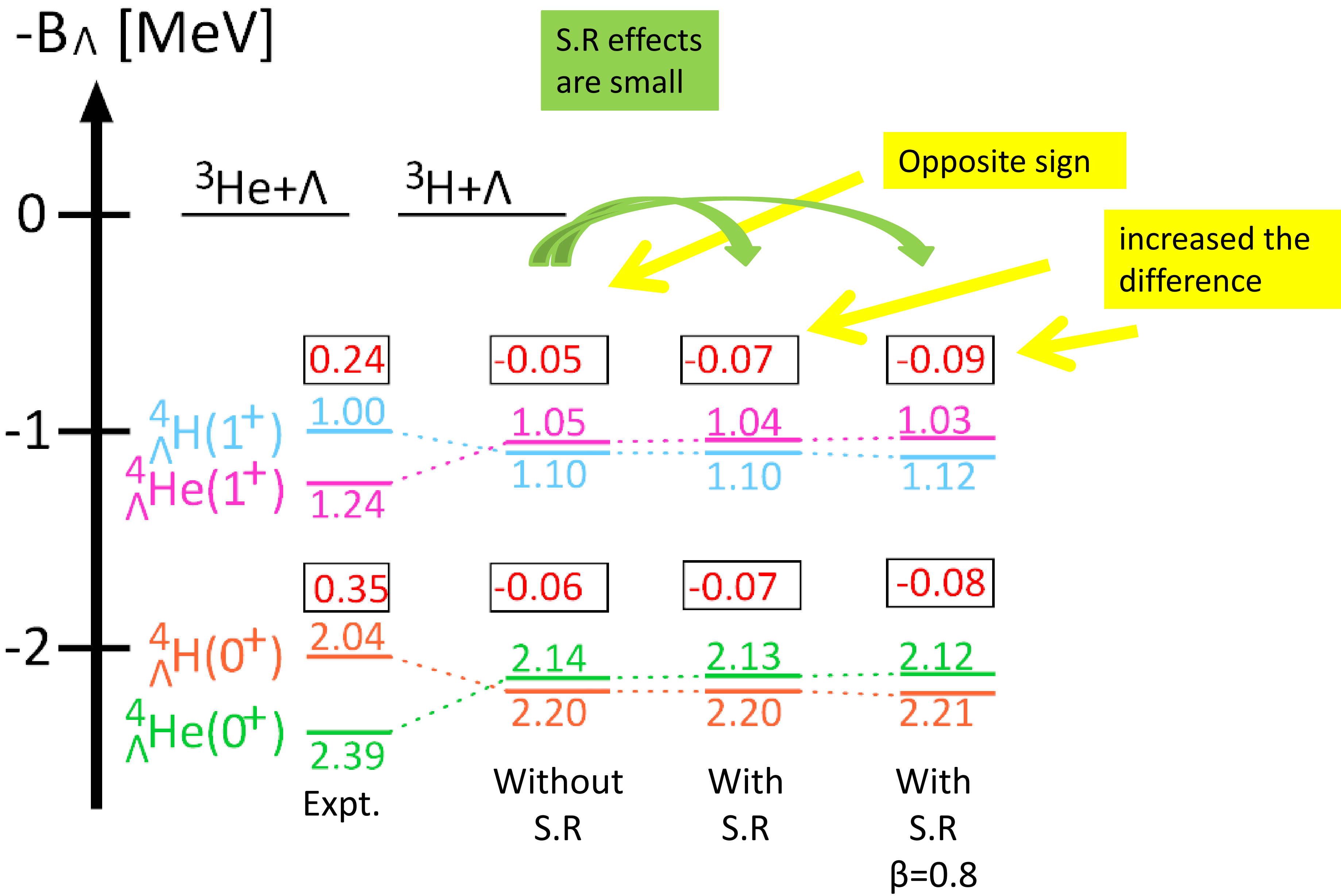
Calculation: using Gaussian Expansion Method
(E. Hiyama, Prog. Part. Nucl. Phys.51,223 (2003).



(3N+**Λ**)

→ Binding energies of $^{4}_{\Lambda}$He and $^{4}_{\Lambda}$H and their difference

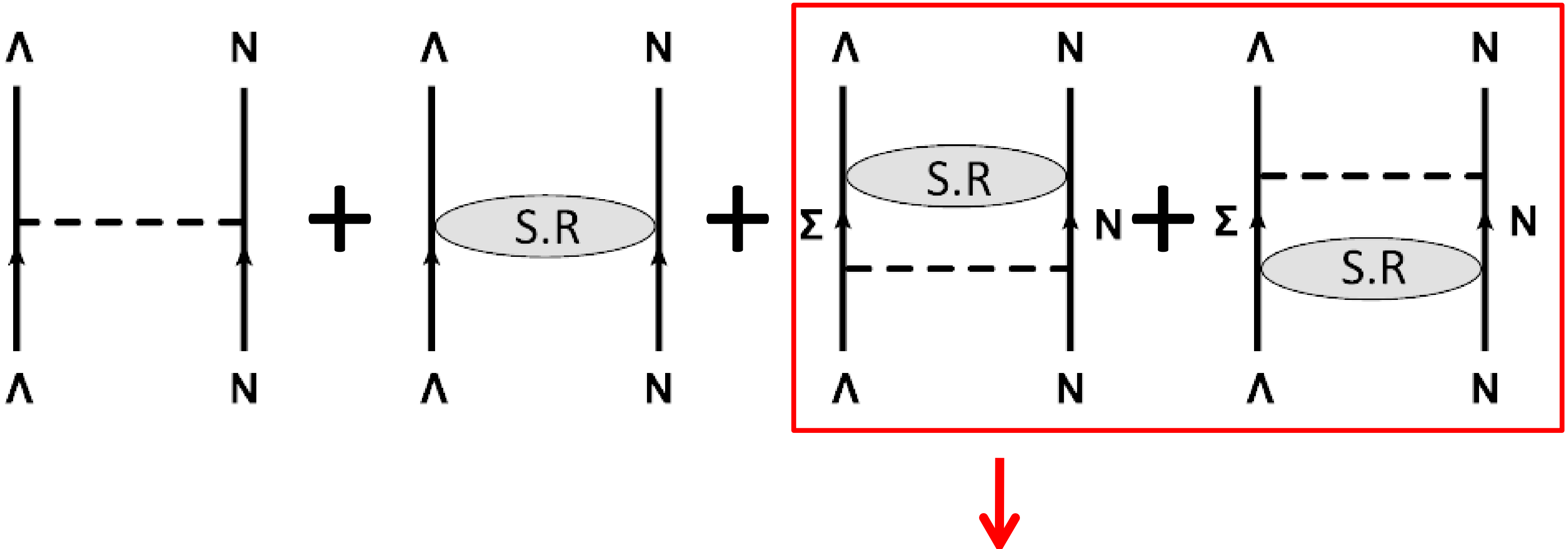
Result



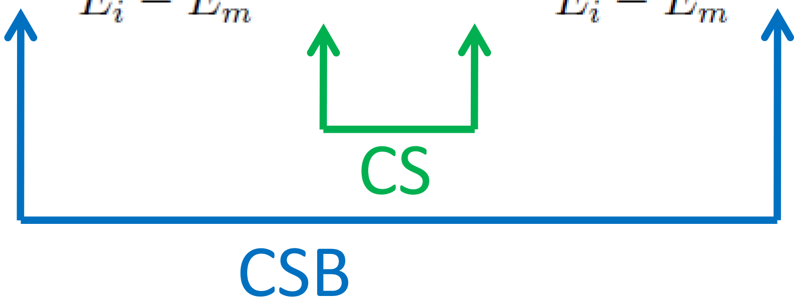
-BΛ [MeV]
0
-1
-2
S.R effects are small
Opposite sign
increased the difference
³He+Λ
³H+Λ
⁴ΛH(1⁺)
⁴ΛHe(1⁺)
⁴ΛH(0⁺)
⁴ΛHe(0⁺)
0.24
1.00
1.24
-0.05
1.05
1.10
-0.07
1.04
1.10
-0.09
1.03
1.12
0.35
2.04
2.39
-0.06
2.14
2.20
-0.07
2.13
2.20
-0.08
2.12
2.21
Expt.
Without S.R
With S.R
With S.R β=0.8

Other contributions

◆ΛN interaction(2)◆

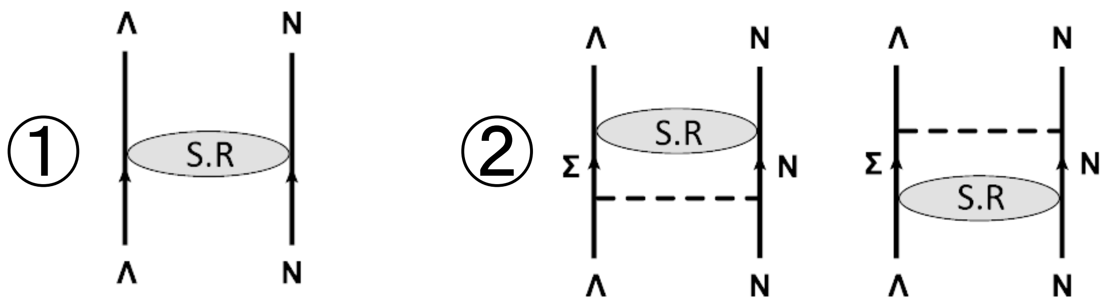


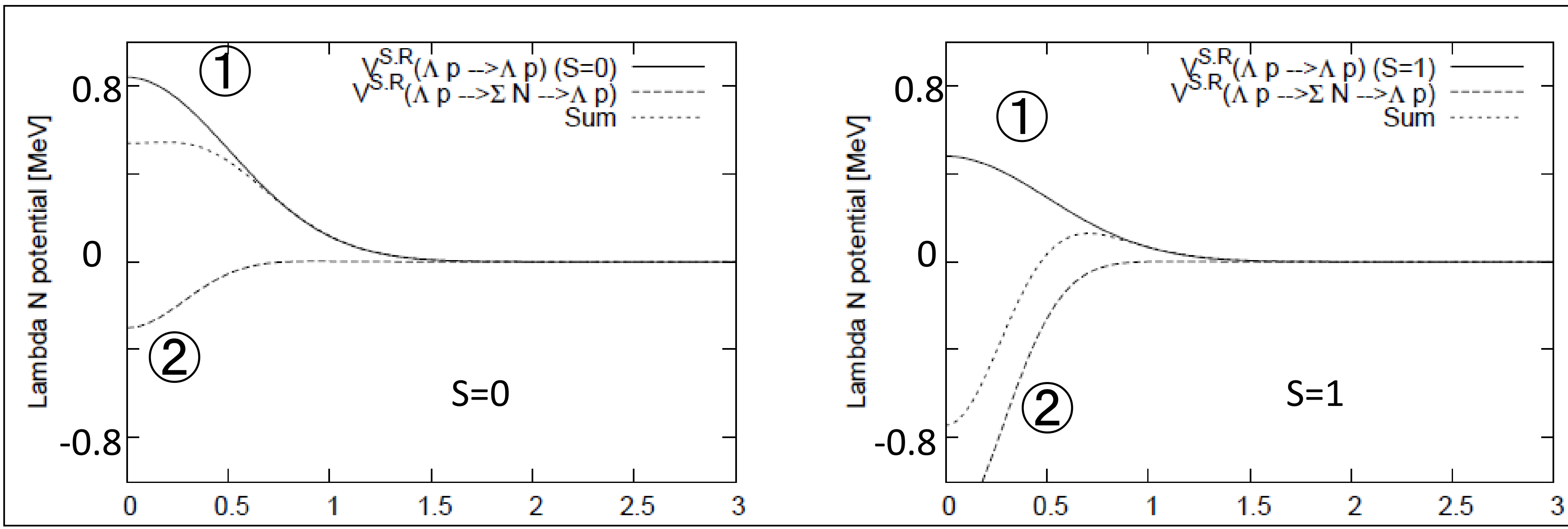
$$V_{\rm S.R}(\Lambda N \to \Sigma N \to \Lambda N) = {V_{\rm S.R}}^{\dagger} \frac{1}{E_i - E_m} V_{\rm SYM} + {V_{\rm SYM}}^{\dagger} \frac{1}{E_i - E_m} V_{\rm S.R}$$



◆The size of the effects◆

Compare the size of these contributions:





The effect of ② will be small.

Summary

- We studied the contributions of short range ΛN interaction to the separation energy difference Δ_{CSB}.
- We led the short range ΛN CSB interaction from quark model.
- Our results show that the short range effect is small, and have opposite sign to experimental data.
- Our results did not fit to the experimental data.