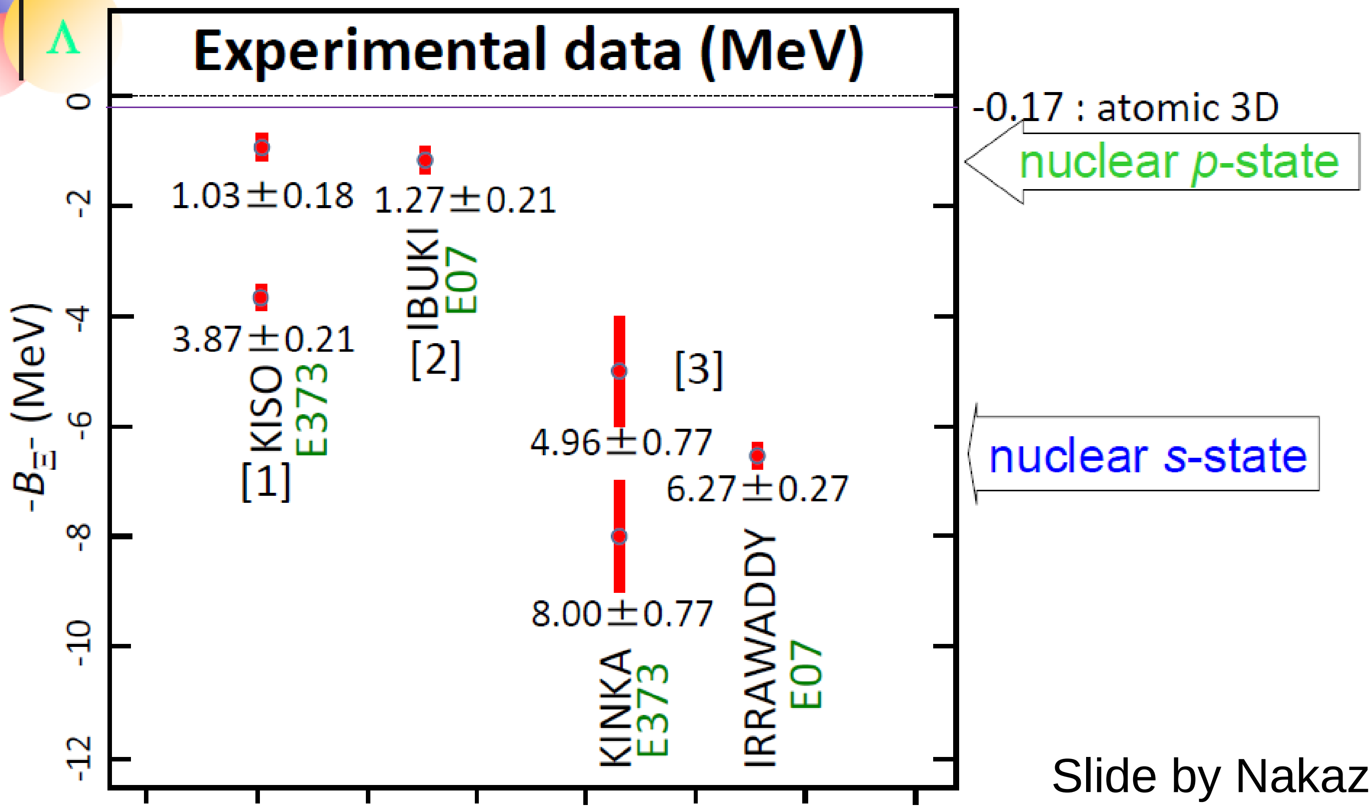
Structure of Ξ hypernuclei

E. Hiyama (Tohoku Univ./RIKEN)

Study of ΞN interaction is one of the important issue in hypernuclear physics.

$$V_{\Xi N} = V_0 + \boldsymbol{\sigma}\cdot\boldsymbol{\sigma}\, V_{\sigma\cdot\sigma} + \boldsymbol{\tau}\cdot\boldsymbol{\tau}\, V_{\tau\cdot\tau} + (\boldsymbol{\sigma}\cdot\boldsymbol{\sigma})(\boldsymbol{\tau}\cdot\boldsymbol{\tau})\, V_{\sigma\cdot\sigma\ \tau\cdot\tau}$$

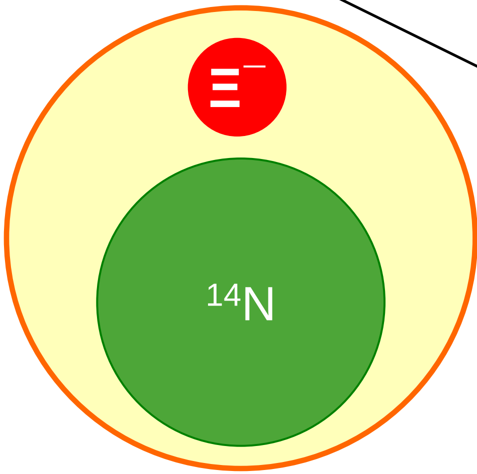
Level scheme of Ξ hypernucleus ($^{15}_{\Xi}C$ [Ξ^--^{14}N])



Slide by Nakazawa

[1] K. Nakazawa, et. al., Prog. Theor. Exp. Phys. **2015**, 033D02 (2015),
E. Hiyama and K. Nakazawa, Ann. Rev. Nucl. Part. Sci. **68**, 131 (2018).
[2] S. Hayakawa, et. al., Phy. Rev. Lett., **126**, 062501 (2021).
[3] M. Yoshimoto, et. al., Prog. Theor. Exp. Phys. **2021**, 073D02 (2021).

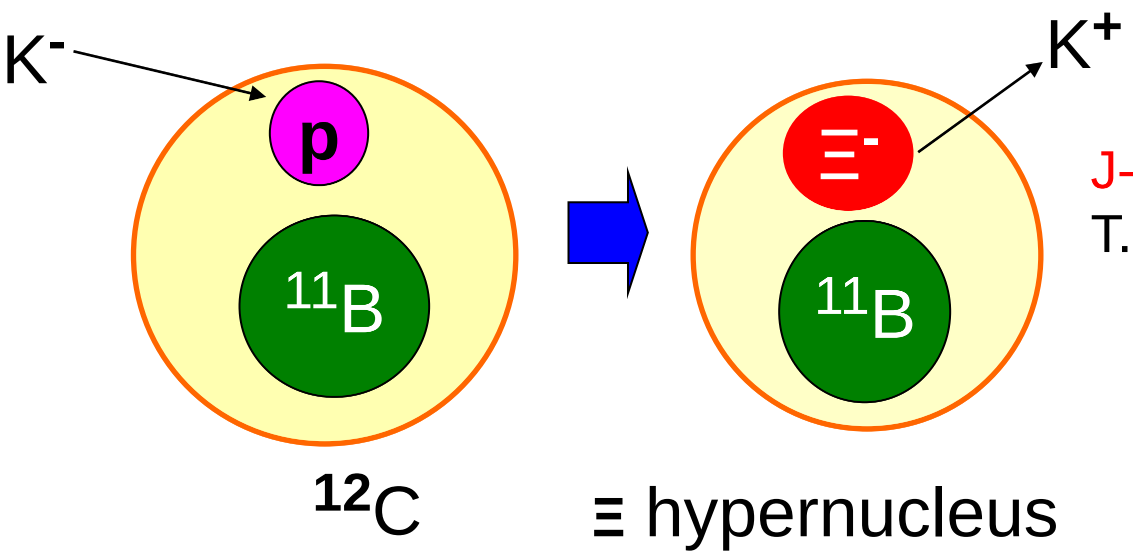
$$V_{\Xi N} = V_0 + \boldsymbol{\sigma}\cdot\boldsymbol{\sigma}\, V_{\sigma\cdot\sigma} + \boldsymbol{\tau}\cdot\boldsymbol{\tau}\, V_{\tau\cdot\tau} + (\boldsymbol{\sigma}\cdot\boldsymbol{\sigma})(\boldsymbol{\tau}\cdot\boldsymbol{\tau})\, V_{\sigma\cdot\sigma\ \tau\cdot\tau}$$



By observation of ^{14}N-Ξ, we understand

$V_{\Xi N}$ is attractive.

Based on this observation,
Now it is important to predict
the level structure of ^{11}B+Ξ system.

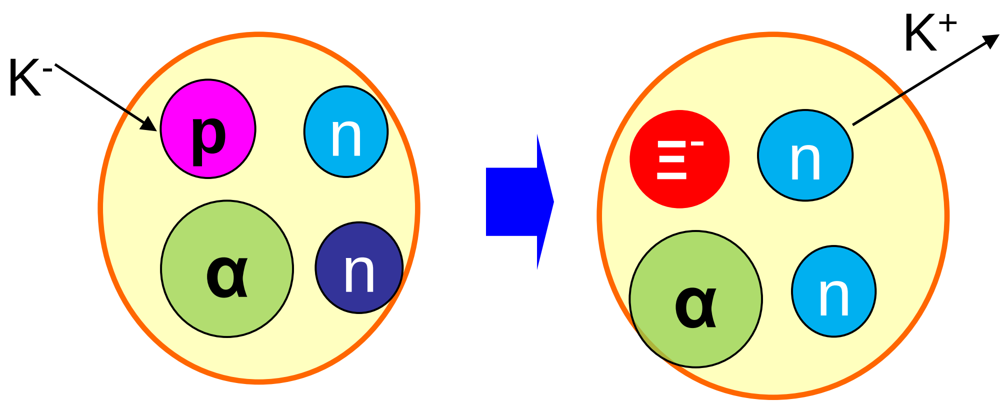


J-PARC: E70: spokesperson
T. Nagae

The theoretical calculation
will be introduced by
Y. Tanimura at the end of this
Session.

After observation of ^{11}B-Ξ(J-PARC-E70 exp.), we want to know V_0 term, first.

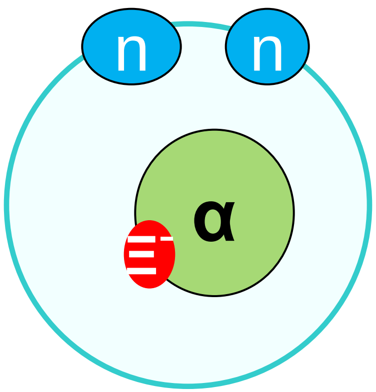
$$V_{\Xi N} = V_0 + \boldsymbol{\sigma}\cdot\boldsymbol{\sigma}\, V_{\sigma\cdot\sigma} + \boldsymbol{\tau}\cdot\boldsymbol{\tau}\, V_{\tau\cdot\tau} + (\boldsymbol{\sigma}\cdot\boldsymbol{\sigma})(\boldsymbol{\tau}\cdot\boldsymbol{\tau})\, V_{\sigma\cdot\sigma\ \tau\cdot\tau}$$



^{7}Li (T=1/2) ^{7}H (T=3/2)

E. H. PRC78,054316(2008).

(more realistic illustration)



$^{7}_{\Xi^-}\mathrm{H}$ (T=3/2)

Core nucleus ^{6}He is known to be halo nucleus. Then, valence neutrons are located far away from α particle.

Valence neutrons (n) are located in p-orbit, whereas Ξ particle (Ξ-) is located in 0s-orbit.

Then, distance between Ξ and **n** is much larger than the interaction range of Ξ and **n**.

Then, αΞ potential, in which only V_0 term works, plays a dominant role in the binding energies of this system.

ΞN interaction

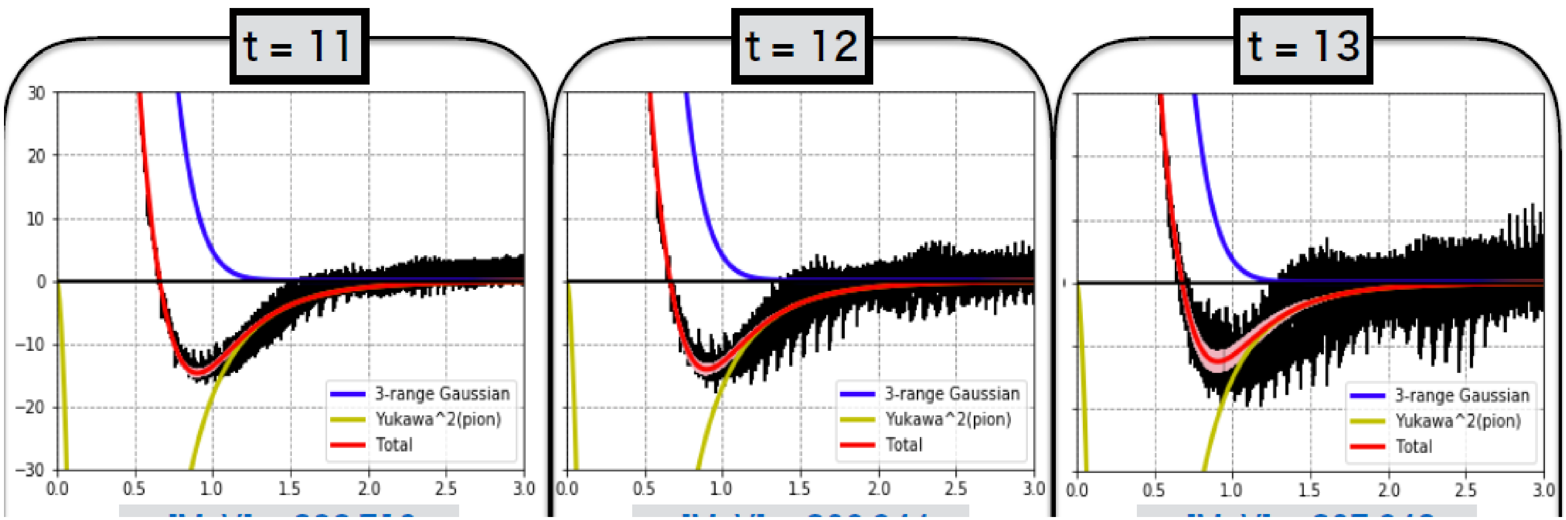
Nijmegen potential : Nijmegen model-D(ND), Extended soft core '04d

E. Hiyama et al., PRC**78** (2008) 054316

HAL potential(Base on Lattice QCD potential:HAL collaboration) by K. Sasaki, Miyamoto, T. Doi, T. Hatsuda et al.

$$V_{\Xi N}=V_0(r)+(\sigma_\Xi\cdot\sigma_N)V_s(r)+(\tau_\Xi\cdot\tau_N)V_t(r)+(\sigma_\Xi\cdot\sigma_N)(\tau_\Xi\cdot\tau_N)V_{ts}(r)$$

All terms are central parts only.



Property of the spin- and isospin-components of ESC04, ND,HAL

V(T,S)	ESC04	ND	HAL
T=0, S=1	strongly attractive (a bound state)	weakly attractive	Weakly attractive
T=0, S=0	weakly repulsive		Strongly attractive
T=1, S=1	weakly attractive		Weakly attractive
T=1, S=0	weakly repulsive		Weakly repulsive

Although the spin- and isospin-components of these potentials are very different (due to the different meson contributions),

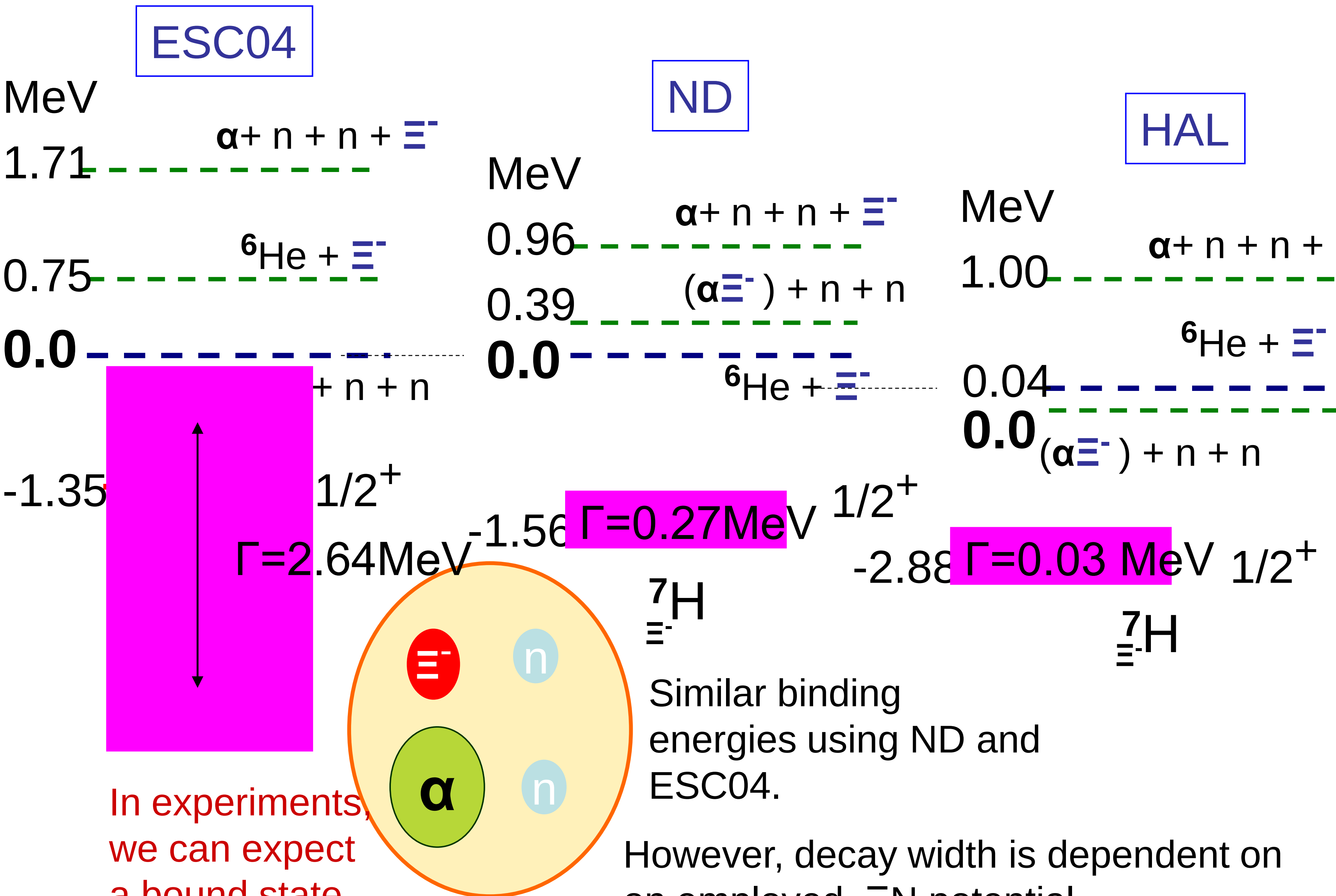
we find that the spin- and isospin-averaged property,

$$V_0 = [\ V(0,0) + 3V(0,1) + 3V(1,0) + 9V(1,1)\ ] / 16,$$

namely, strength of the V_0- term is similar to each other.

4-body calculation of $^{7}_{\Xi^-}H$

E. Hiyama et al., PRC**78** (2008) 054316



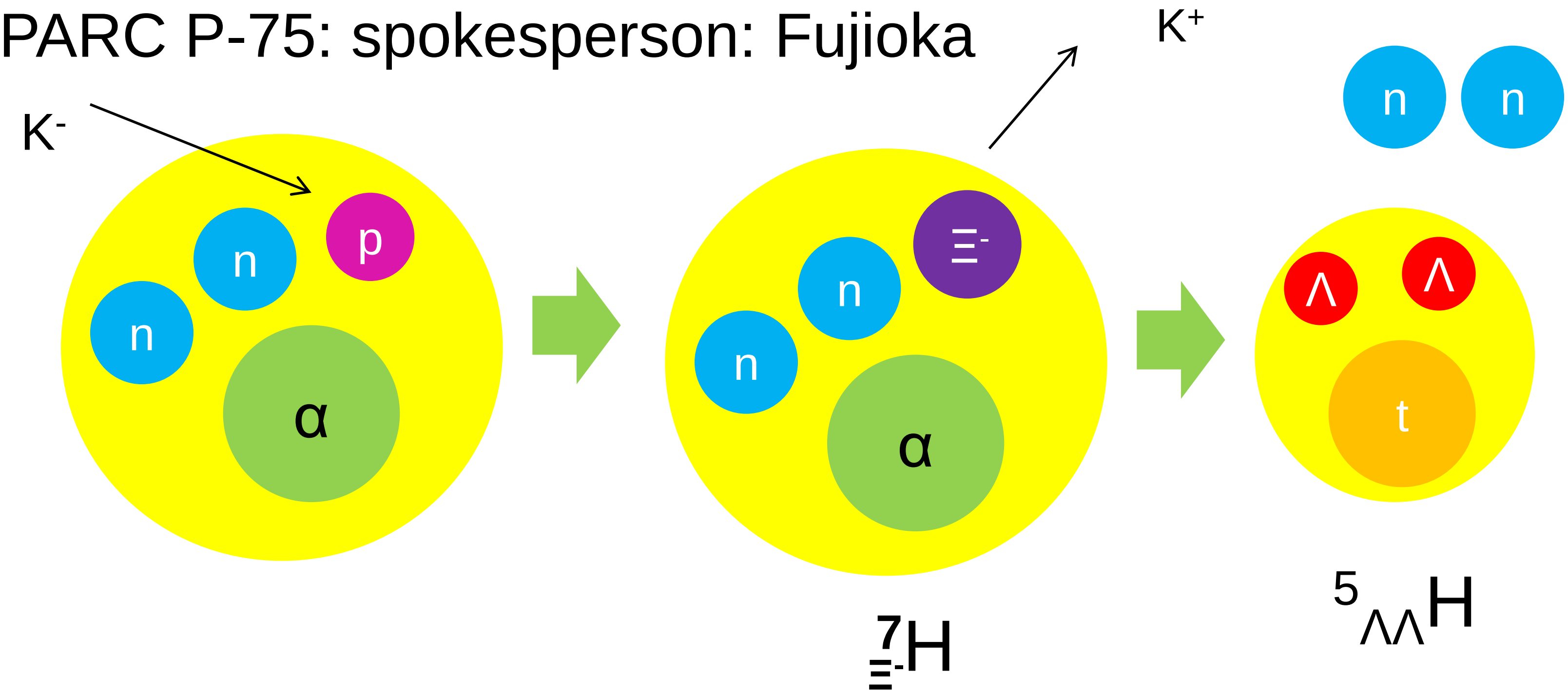
Similar binding energies using ND and ESC04.

In experiments, we can expect a bound state.

However, decay width is dependent on on employed ΞN potential

In this way, the binding energy of Ξ hypernucleus with A=7 is dominated by αΞ potential, namely, spin-, and iso-spin independent ΞN interaction (V_0).

J-PARC P-75: spokesperson: Fujioka



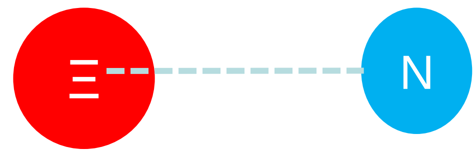
T S

$$V_0 = [\, V(0,0) + 3V(0,1) + 3V(1,0) + 9V(1,1) \,] / 16,$$

which partial contribution makes attractive for V_0 **?**

ΞN interaction:

T=0, S=0
T=0, S=1
T=1, S=0
T=1, S=1



t=1/2
S=1/2

t=1/2
S=1/2

we have a two-body bound state for ΞN system?
No idea

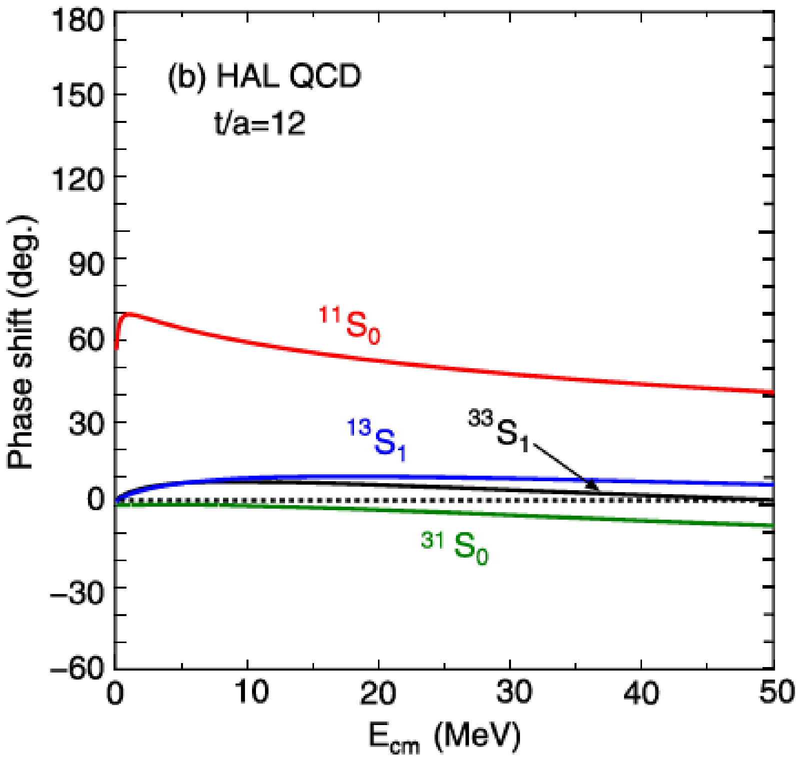
Cf. NN interaction

T=0, S=0
T=0, S=1
T=1, S=0
T=1,S=1

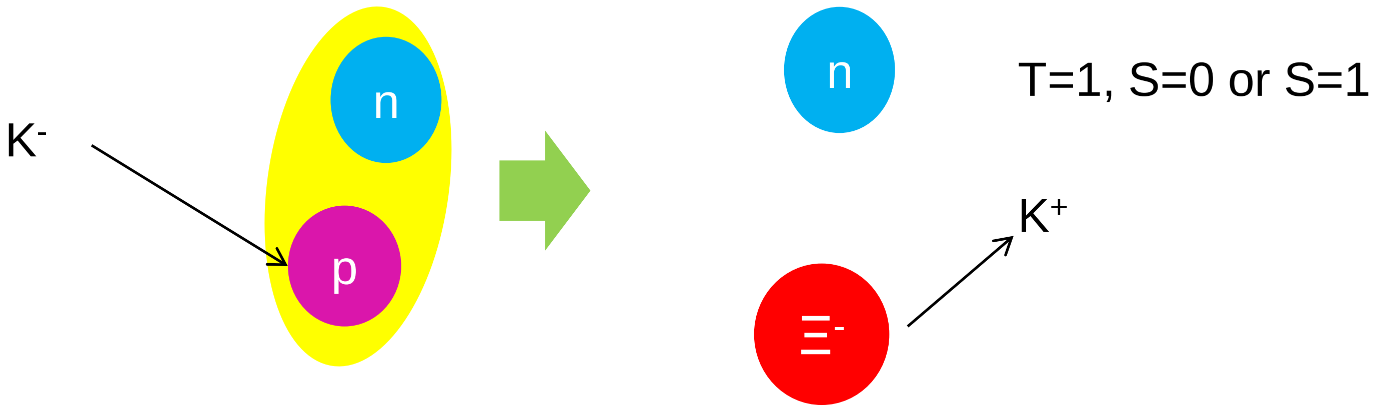
strong attraction to have a bound state as a deuteron

Property of the spin- and isospin-components of HAL

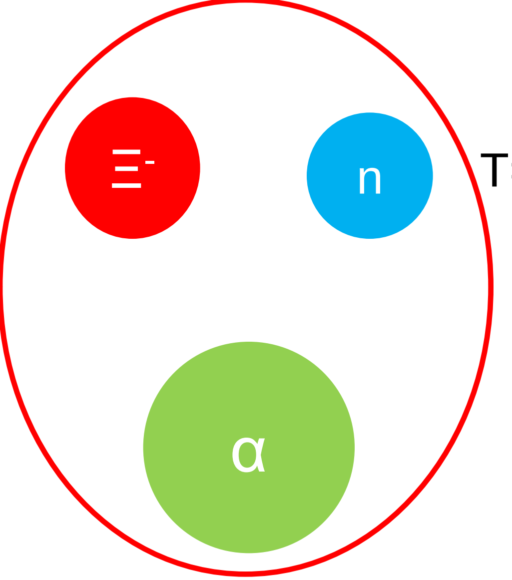
V(T,S)	HAL
T=0, S=1	Weakly attractive
T=0, S=0	Strongly attractive
T=1, S=1	Weakly attractive
T=1, S=0	Weakly repulsive



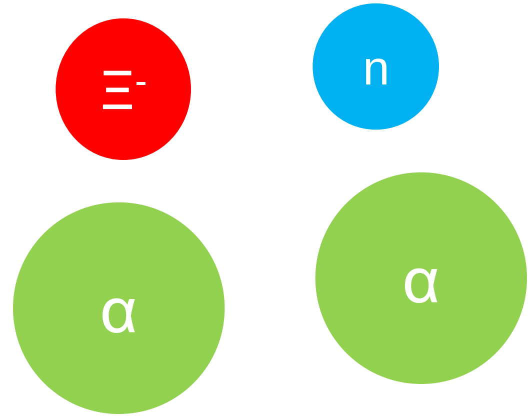
To investigate bound state of ΞN system, it might be possible to perform the following experiment:



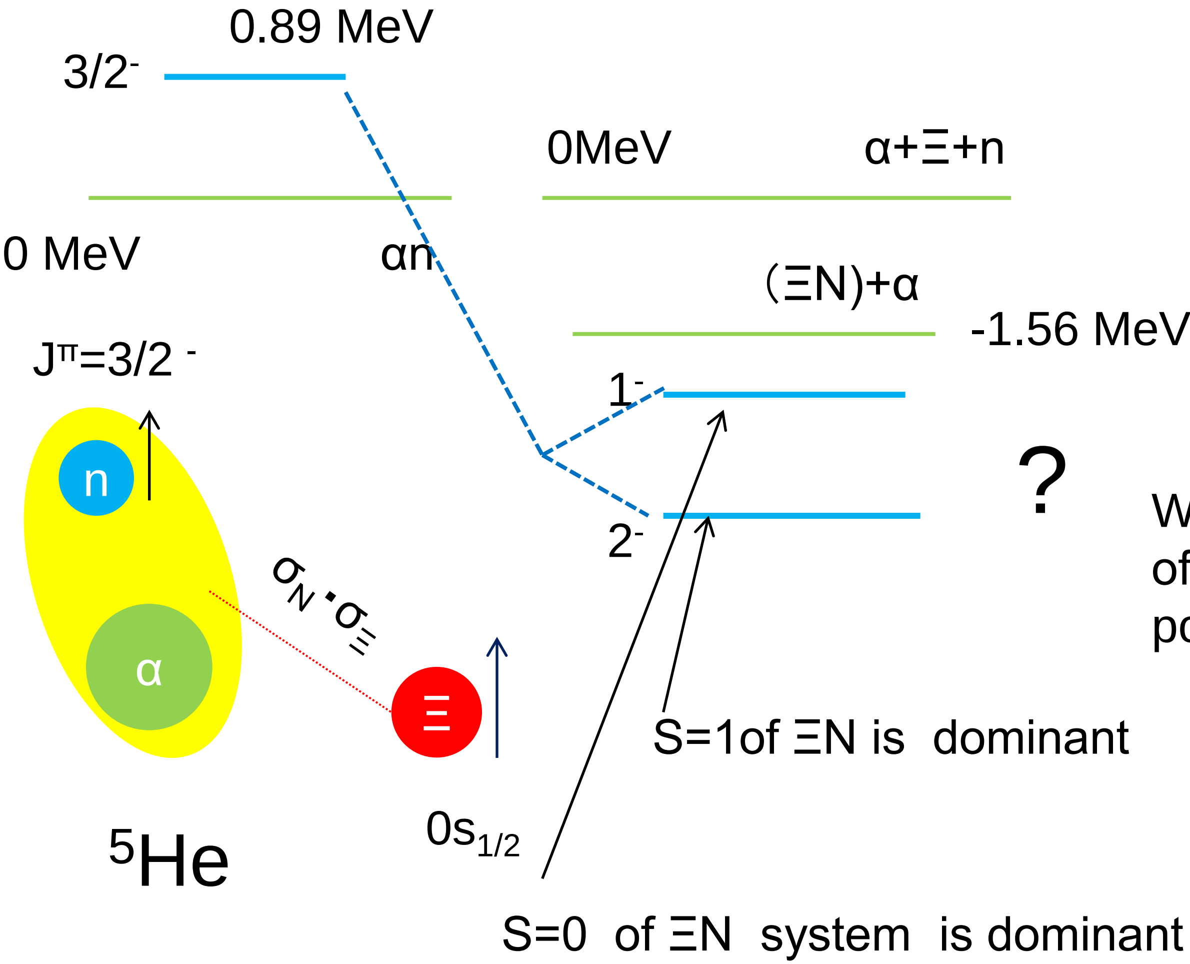
It would be difficult to obtain information on ΞN interaction (T=1,S=0 or 1). Because, there might be no bound state for this system.

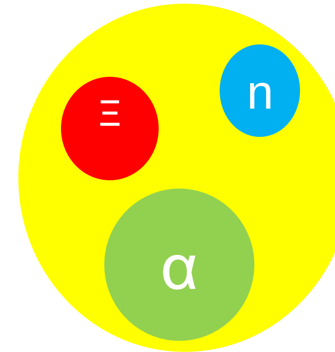


T=1, S=0 or S=1



We can add a α or two α_s.
Due to the attraction of αΞ and αN interactions,
ΞN system might have bound system.





What about level structure of αΞN system using HAL potential?

0MeV α+Ξ+n

No bound

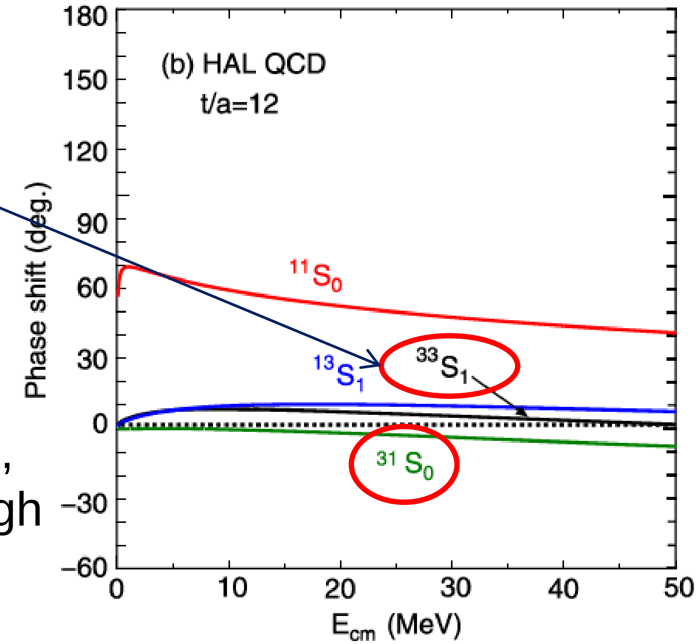
-1.22

(αΞ)+n

HAL

T=1

T=1,S=1



Attractions of T=1,S=1, T=1,S=0 are not enough to make bound states.

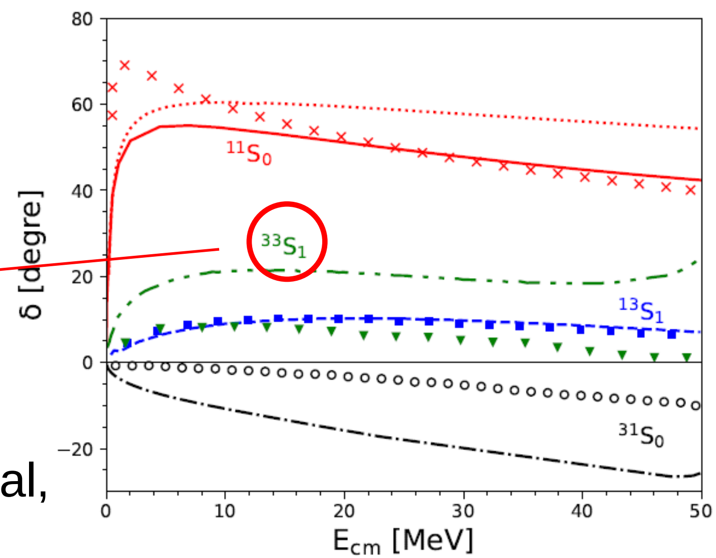
0MeV α+Ξ+n

(αΞ)+n

-1.22

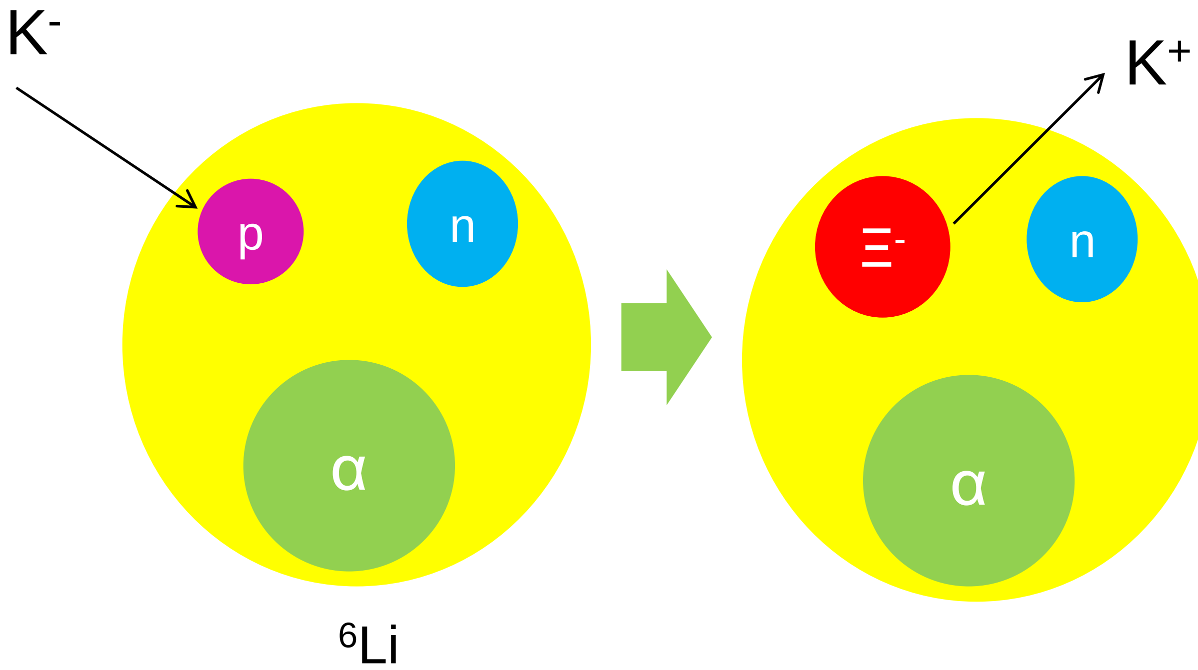
2^-

-1.47 MeV



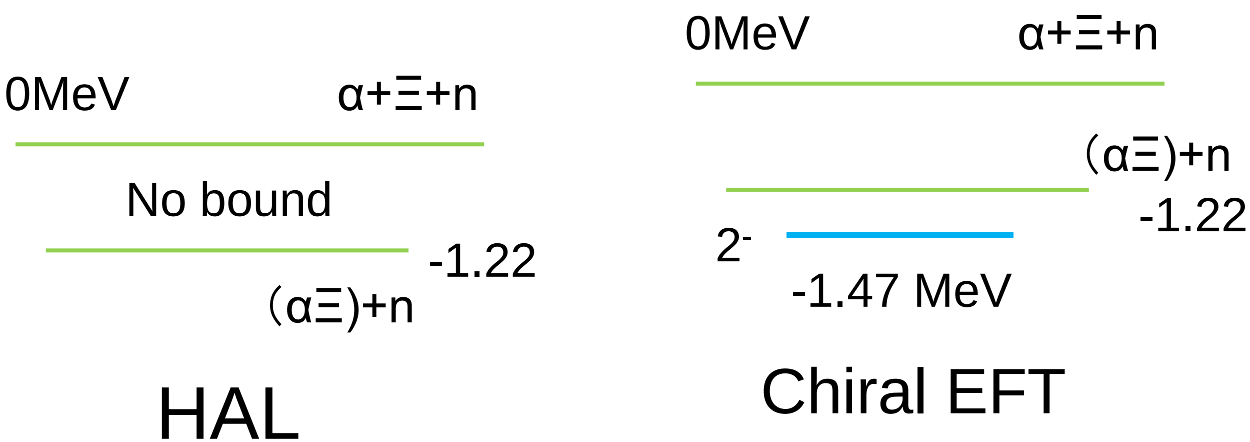
If we use $^{33}S_1$ information based on chiral EFT potential, We have a bound state in 2^-.

H. Le, et al., EPJA57,339(2021)
Chiral EFT ΞN interaction.

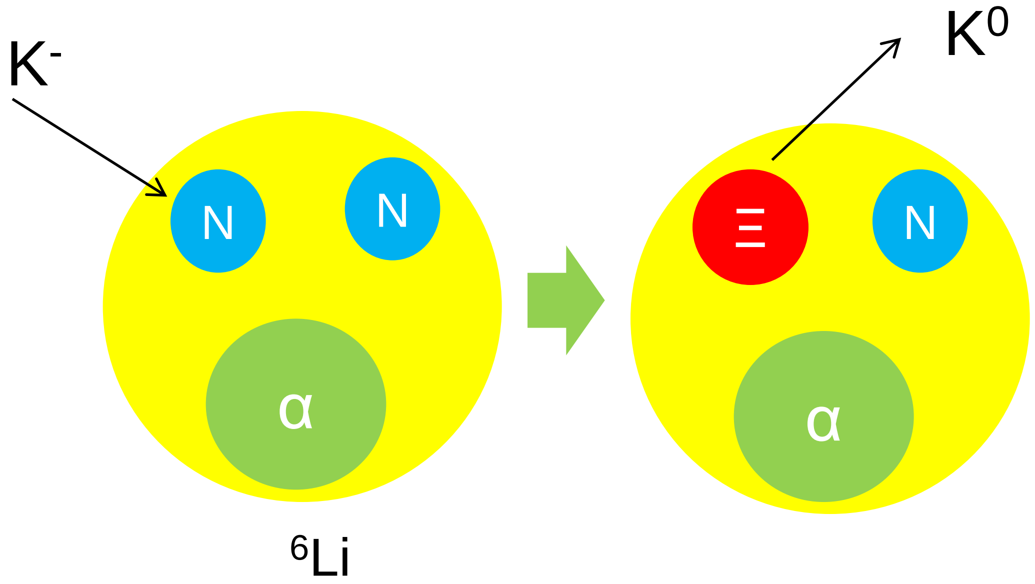


T=1,S=0 or S=1

Experimentally,
It is possible to
produce Ξ hypernucleus.

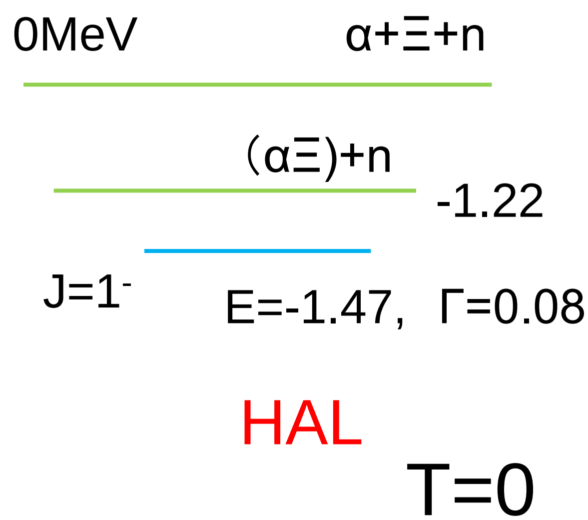


Bound state is dependent on ΞN potential employed. Then, it would be risky to use ^{6}Li target by (K^-,K^+) reaction.



T=0,S=0 or S=1

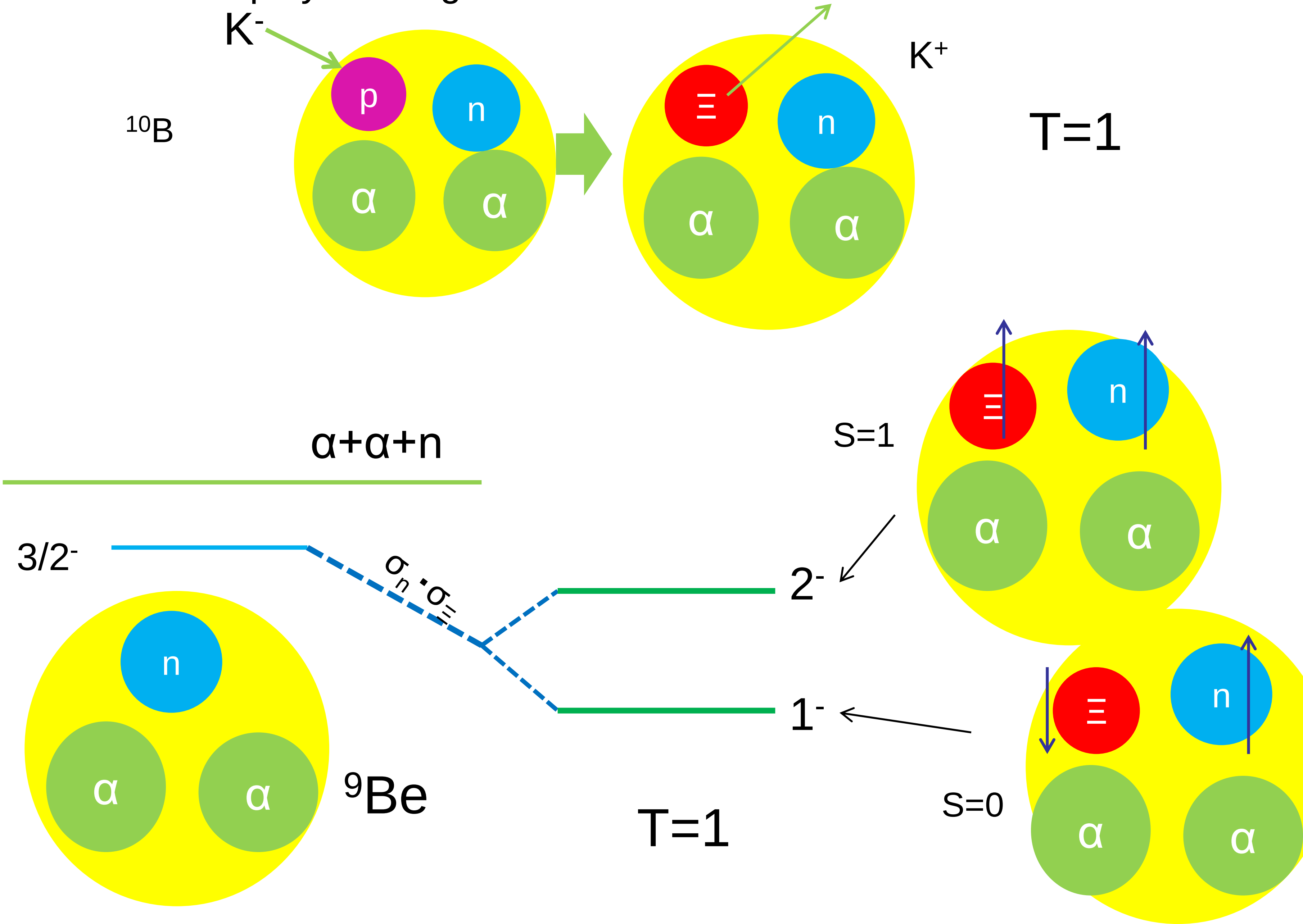
We can obtain information on T=0, S=0 and S=1 ΞN interaction.

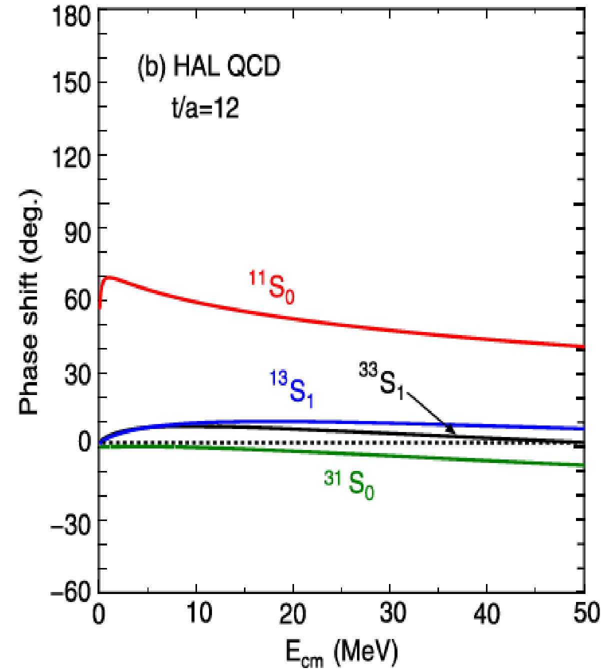


T=0,S=0 of ΞN interaction dominate

Currently, (K^-,K^0) reaction would be difficult experiment. Then, it might be risky to use ^{6}Li target.

To obtain information on two-body partial wave contribution, it is useful to employ ^{10}B target.





preliminary

If the level structure of
A=10 Ξ hypernuclei,
we obtain information
on partial wave of
ΞN interaction.
Level ordering is important.

Conlcusion

Since the observation of ^{14}N+Ξ hypernucleus, it is important to obtain information on ΞN interaction. In this talk, I introduce the study of A=6 and 10 Ξ hyperuclei, to obtain information on partial wave of ΞN interaction.

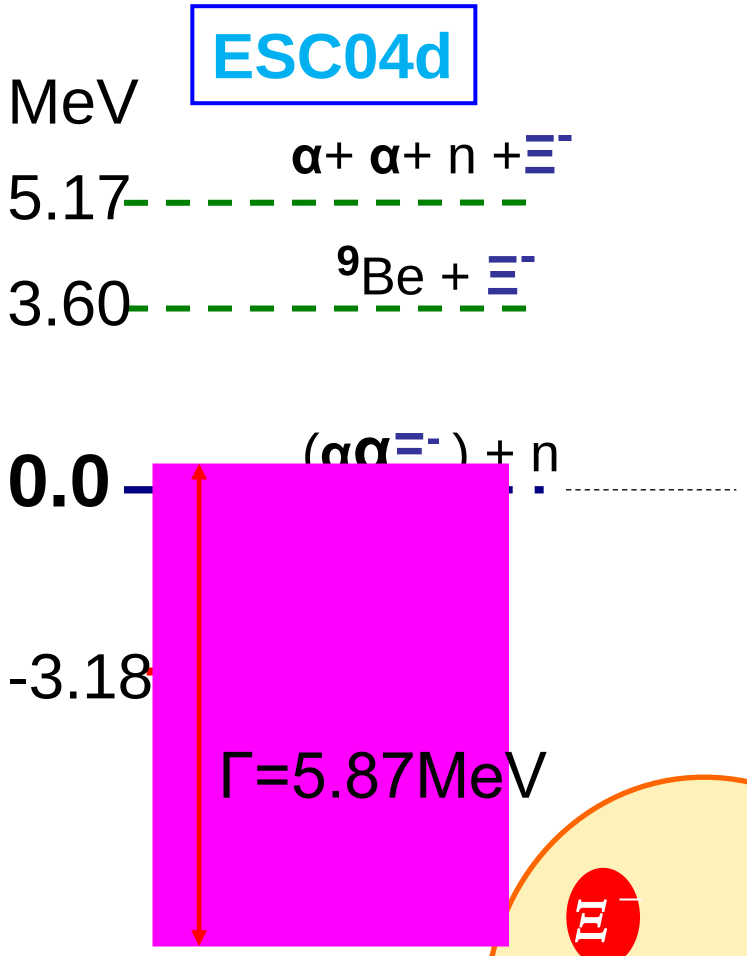
Currently, the production experiments of A=7 and 12 Ξ hypernuclei at J-PARC are planned.
Since the bound states of A=6 Ξ hypernuclei are dependent on ΞN potentials employed, then it would be risky to perform experiment using ^{6}Li target.

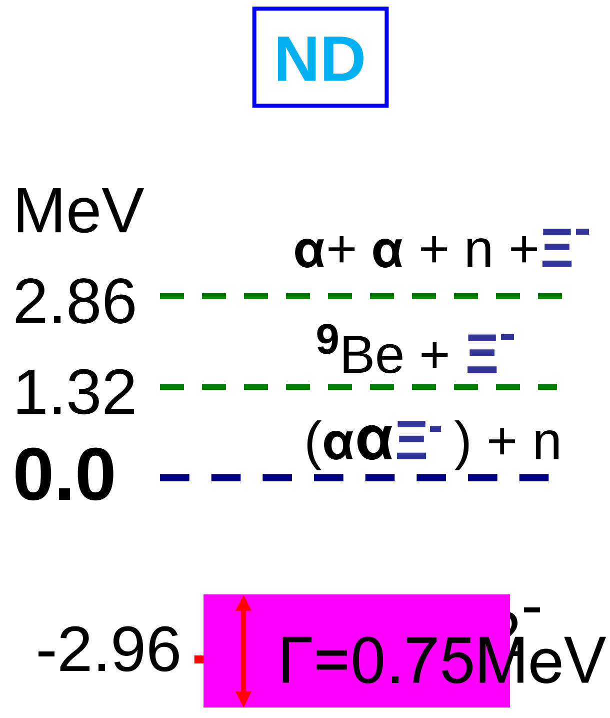
Then, I suggest to perform experiment using ^{10}B target at J-PARC.

Thank you!

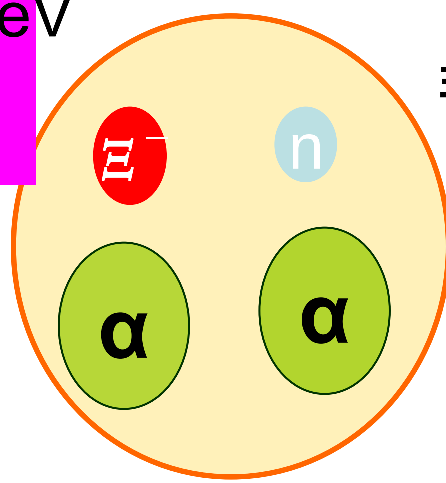
4-body calculation of $^{10}_{\Xi^-}Li$

E. Hiyama et al., PRC**78** (2008) 054316





$^{10}_{\Xi^-}Li$



Similar binding energies using ND and ESC04d.

Independent on employed ΞN potential

But, decay width is dependent on employed ΞN interaction.

In experiments, we can expect a bound state.