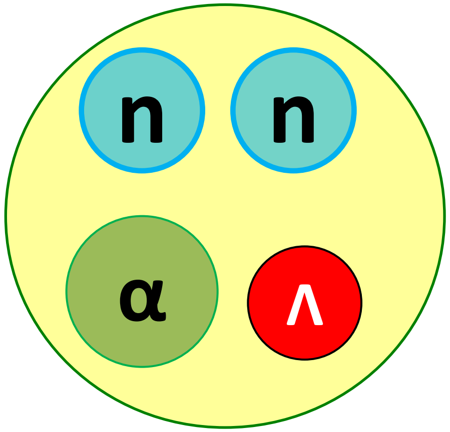
Structure of neutron-rich Λ hypernuclei

E. Hiyama (RIKEN)

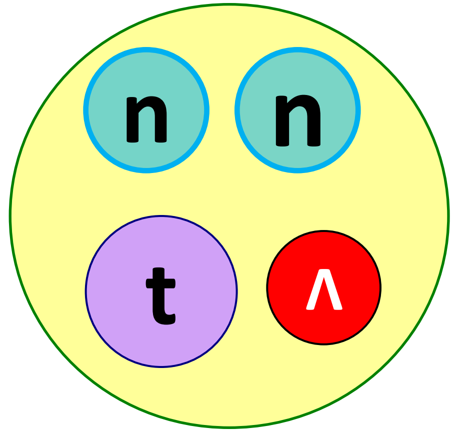
In 2012 and 2013, we had three epoch-making data from the view point of few-body problems.

${}^{7}_{\Lambda}\mathrm{He}$

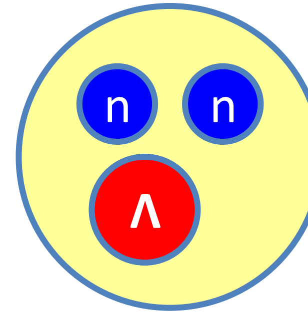


JLAB experiment-E011, Phys. Rev. Lett. **110**, 12502 (2013).

${}^{6}_{\Lambda}\mathrm{H}$



FINUDA collaboration & A. Gal, Phys. Rev. Lett. **108**, 042051 (2012).



${}^{3}_{\Lambda}\mathrm{n}$

C. Rappold et al., HypHI collaboration Phys. Rev. C 88, 041001 (R) (2013)

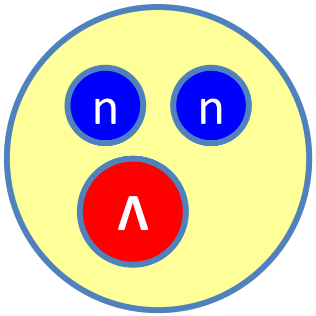
Observation of Neutron-rich **Λ-**hypernuclei

These observations are interesting from the view points of few-body physics as well as physics of unstable nuclei.

Outline

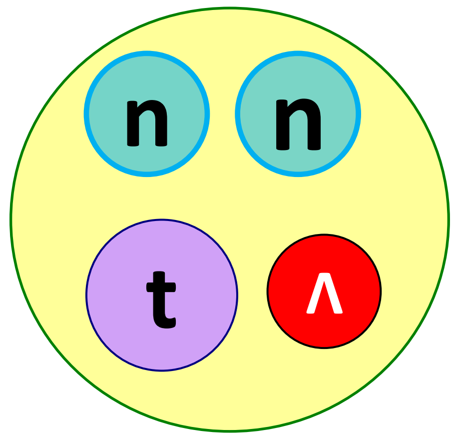
(1) Introduction

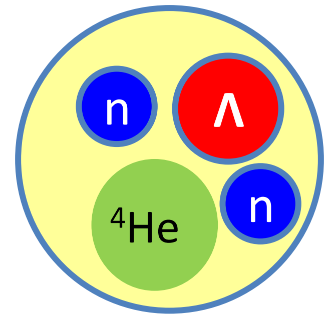
(2)



${}^{3}_{\Lambda}n$

${}^{6}_{\Lambda}H$

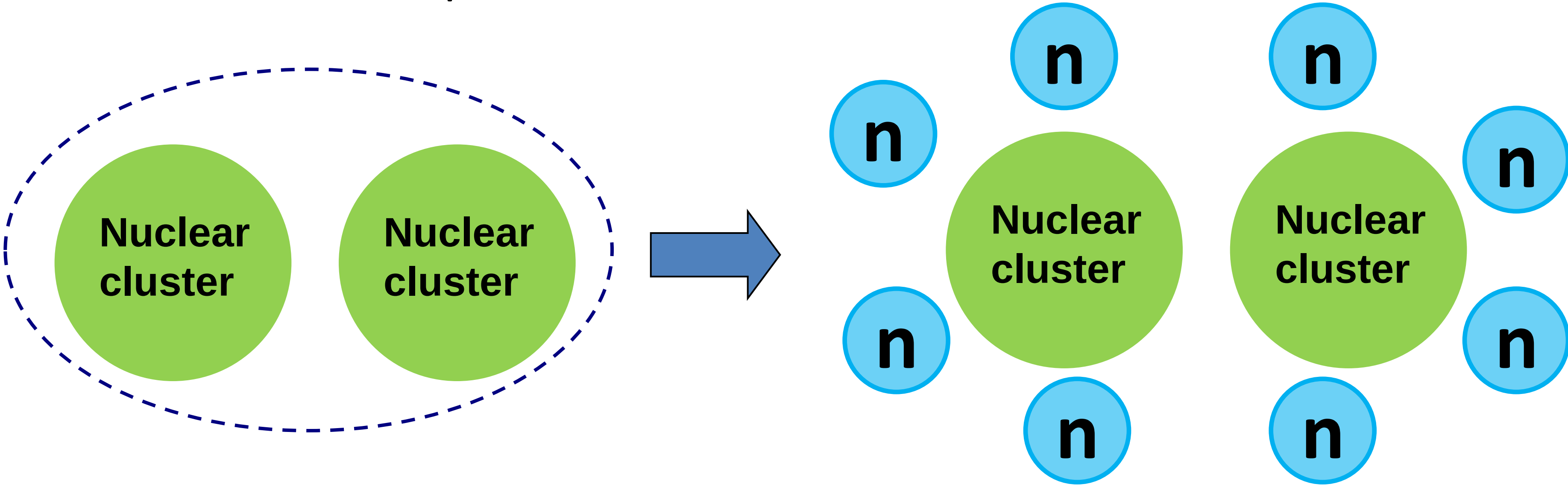




${}^{7}_{\Lambda}He$

Sec.1 Introduction

In neutron-rich and proton-rich nuclei,

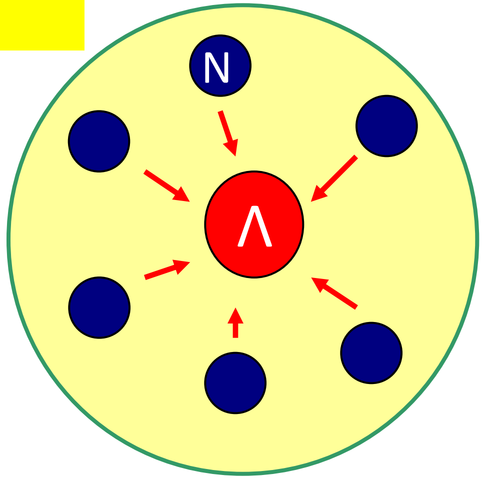


When some neutrons or protons are added to clustering nuclei, additional neutrons are located outside the clustering nuclei due to the Pauli blocking effect.

As a result, we have neutron/proton halo structure in these nuclei. There are many interesting phenomena in this field as you know.

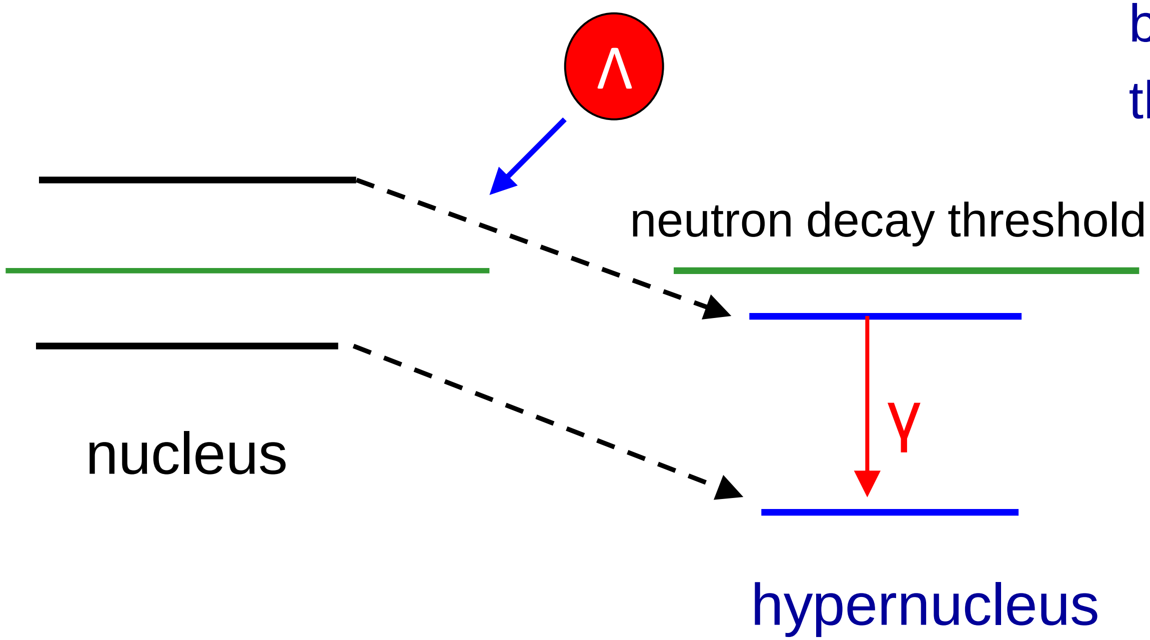
No Pauli principle
Between N and Λ

Λ particle can reach deep inside, and attract the surrounding nucleons towards the interior of the nucleus.



Hypernucleus

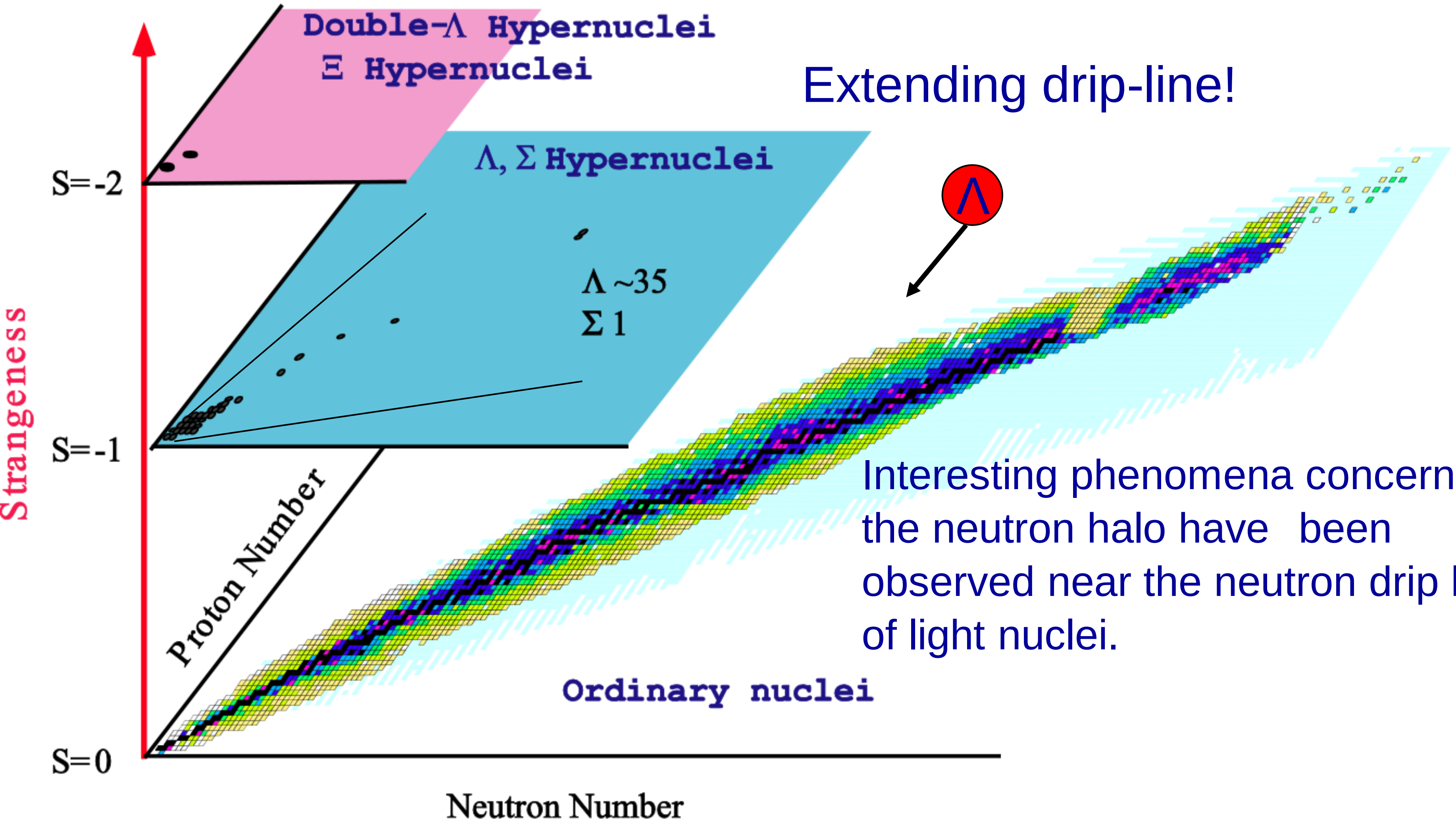
Due to the attraction of Λ N interaction, the resultant hypernucleus will become more stable against the neutron decay.



Nuclear chart with strangeness

Multi-strangeness system
such as Neutron star

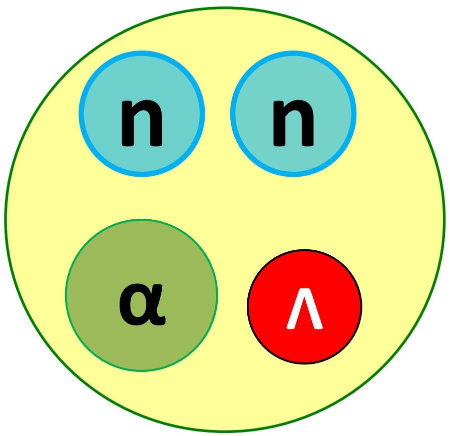
Extending drip-line!



Interesting phenomena concerning the neutron halo have been observed near the neutron drip line of light nuclei.

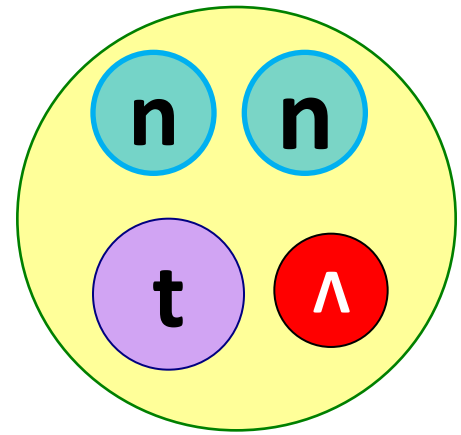
Question : How is structure change when a Λ particle is injected into neutron-rich nuclei?

${}^{7}_{\Lambda}$He

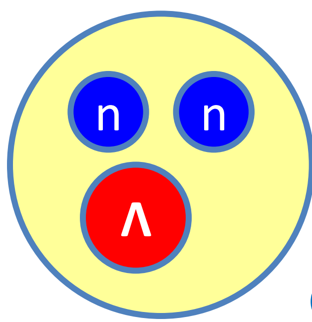


Observed at JLAB, Phys. Rev. Lett. **110**, 12502 (2013).

${}^{6}_{\Lambda}$H



Observed by FINUDA group, Phys. Rev. Lett. **108**, 042051 (2012).



${}^{3}_{\Lambda}$n

C. Rappold et al., HypHI collaboration
Phys. Rev. C 88, 041001 (R) (2013)

In order to solve few-body problem accurately,

Gaussian Expansion Method (GEM) , since 1987,

▪A variational method using Gaussian basis functions

▪Take all the sets of Jacobi coordinates

Developed by Kyushu Univ. Group, Kamimura and his collaborators.

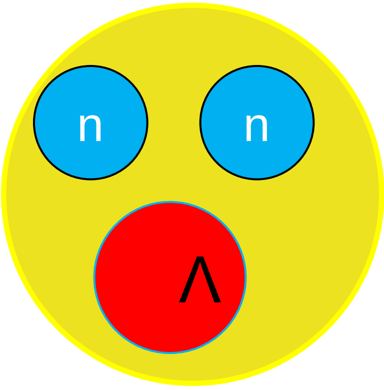
Review article :
E. Hiyama, M. Kamimura and Y. Kino, Prog. Part. Nucl. Phys. 51 (2003), 223.

High-precision calculations of various 3- and 4-body systems:

Exotic atoms / molecules ,
3- and 4-nucleon systems,
multi-cluster structure of light nuclei,
Light hypernuclei,
3-quark systems,
^{4}He-atom tetramer

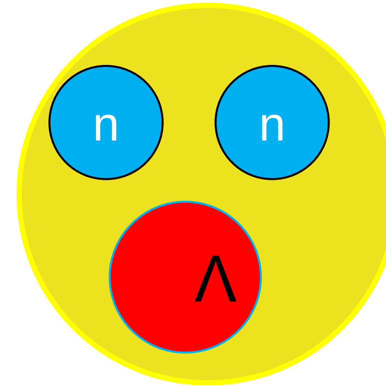
Section 2

three-body calculation of ${}^{3}_{\Lambda}n$



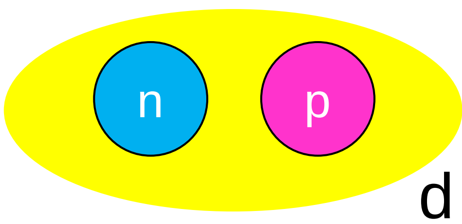
E. Hiyama, S. Ohnishi,
B.F. Gibson, and T. A. Rijken,
PRC89, 061302(R) (2014).

What is interesting to study nnΛ system?



S=0

The lightest nucleus to have a bound state is deuteron.



n+p threshold

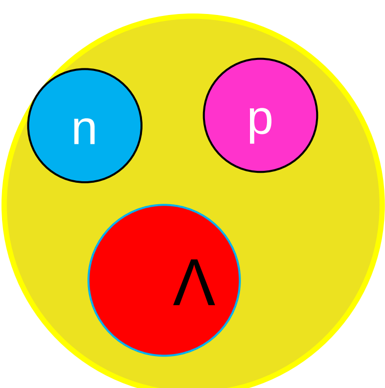
J=1^+

-2.22 MeV

Exp.

S=-1 (Λ hypernucear sector)

n+p+Λ



Lightest hypernucleus to have a bound state

d+Λ

${}^{3}_{\Lambda}$H (hyper-triton)

0.13 MeV

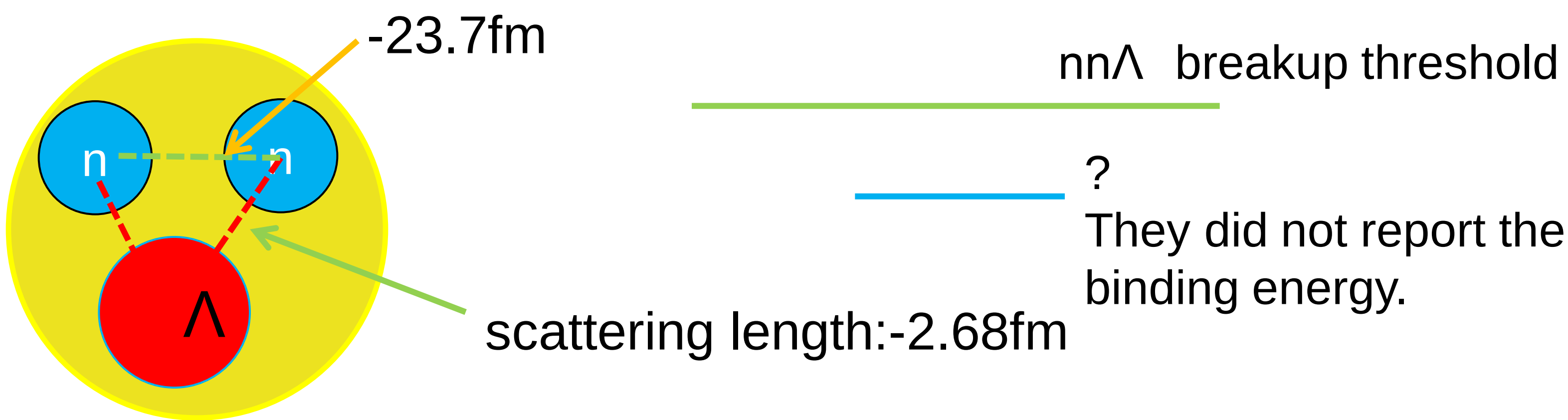
J=$1/2^+$

Exp.

PHYSICAL REVIEW C 88, 041001(R) (2013)

Search for evidence of ${}^{3}_{\Lambda}n$ by observing $d+\pi^-$ and $t+\pi^-$ final states in the reaction of ${}^{6}\mathrm{Li}+{}^{12}\mathrm{C}$ at 2A GeV

C. Rappold,[1,2,*] E. Kim,[1,3] T. R. Saito,[1,4,5,†] O. Bertini,[1,4] S. Bianchin,[1] V. Bozkurt,[1,6] M. Kavatsyuk,[7] Y. Ma,[1,4] F. Maas,[1,4,5] S. Minami,[1] D. Nakajima,[1,8] B. Özel-Tashenov,[1] K. Yoshida,[1,5,9] P. Achenbach,[4] S. Ajimura,[10] T. Aumann,[1,11] C. Ayerbe Gayoso,[4] H. C. Bhang,[3] C. Caesar,[1,11] S. Erturk,[6] T. Fukuda,[12] B. Göküzüm,[1,6] E. Guliev,[7] J. Hoffmann,[1] G. Ickert,[1] Z. S. Ketenci,[6] D. Khaneft,[1,4] M. Kim,[3] S. Kim,[3] K. Koch,[1] N. Kurz,[1] A. Le Fèvre,[1,13] Y. Mizoi,[12] L. Nungesser,[4] W. Ott,[1] J. Pochodzalla,[4] A. Sakaguchi,[9] C. J. Schmidt,[1] M. Sekimoto,[14] H. Simon,[1] T. Takahashi,[14] G. J. Tambave,[7] H. Tamura,[15] W. Trautmann,[1] S. Voltz,[1] and C. J. Yoon[3]
(HypHI Collaboration)



Observation of nnΛ system (2013)

Lightest hypernucleus to have a bound state

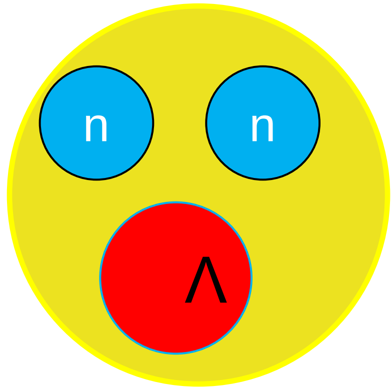
Any two-body systems are unbound.=>nnΛ system is bound.

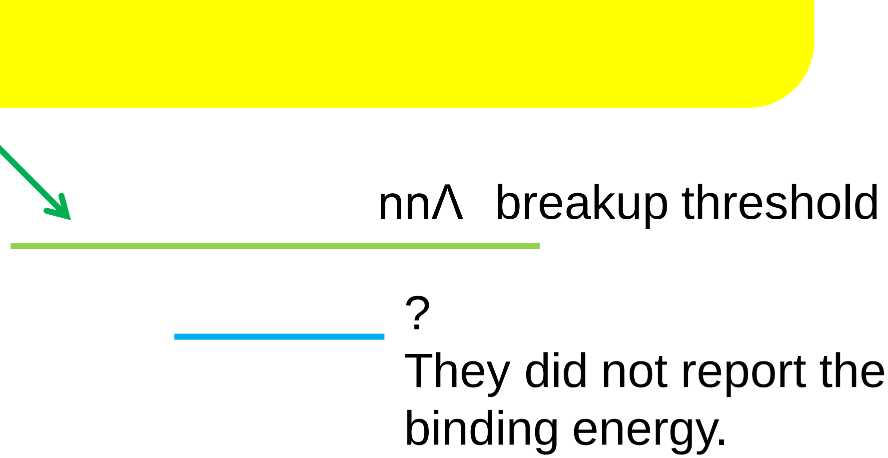
Lightest Borromean system.

Theoretical important issue:

Do we have bound state for nnΛ system?

If we have a bound state for this system, how much is binding energy?





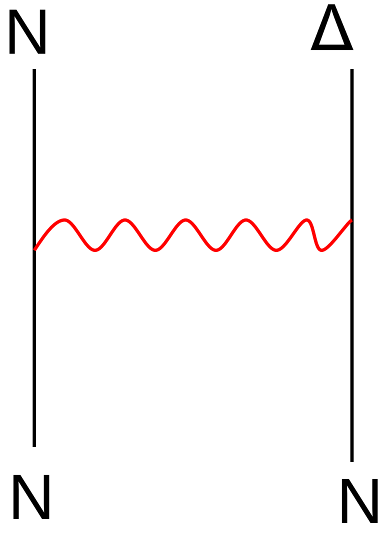
NN interaction : to reproduce the observed binding energies of ^{3}H and ^{3}He

NN: AV8 potential

We do not include 3-body force for nuclear sector.

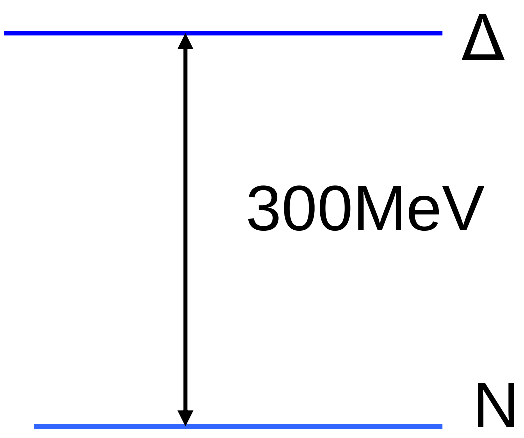
How about YN interaction?

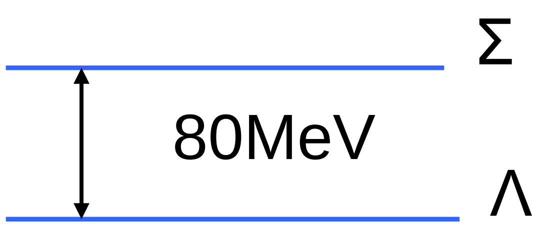
Non-strangeness nuclei

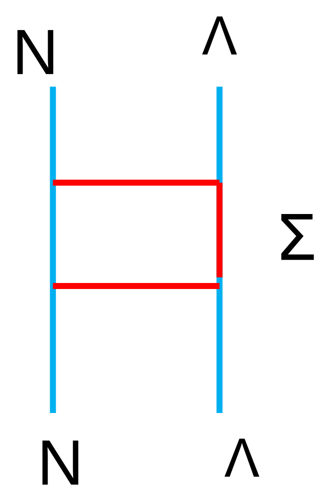


Nucleon can be converted into Δ.
However, since mass difference between nucleon and Δ is large, then probability of Δ in nucleus is not large.

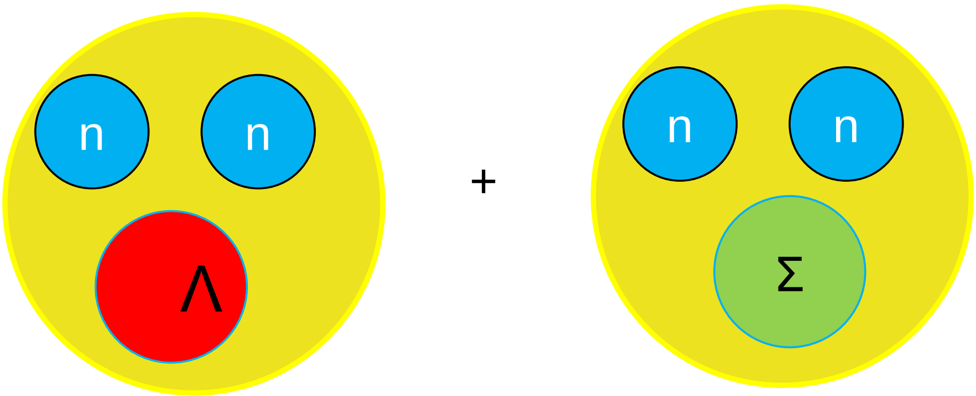
On the other hand, the mass difference between Λ and Σ is much smaller, then Λ can be converted into Σ particle easily.





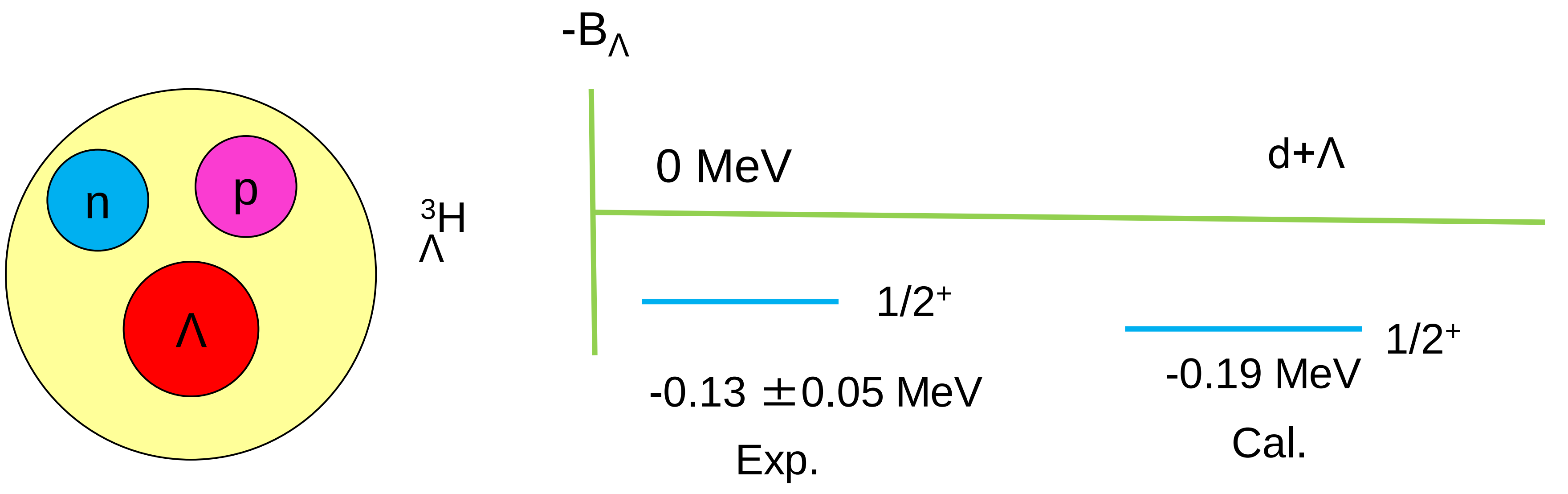


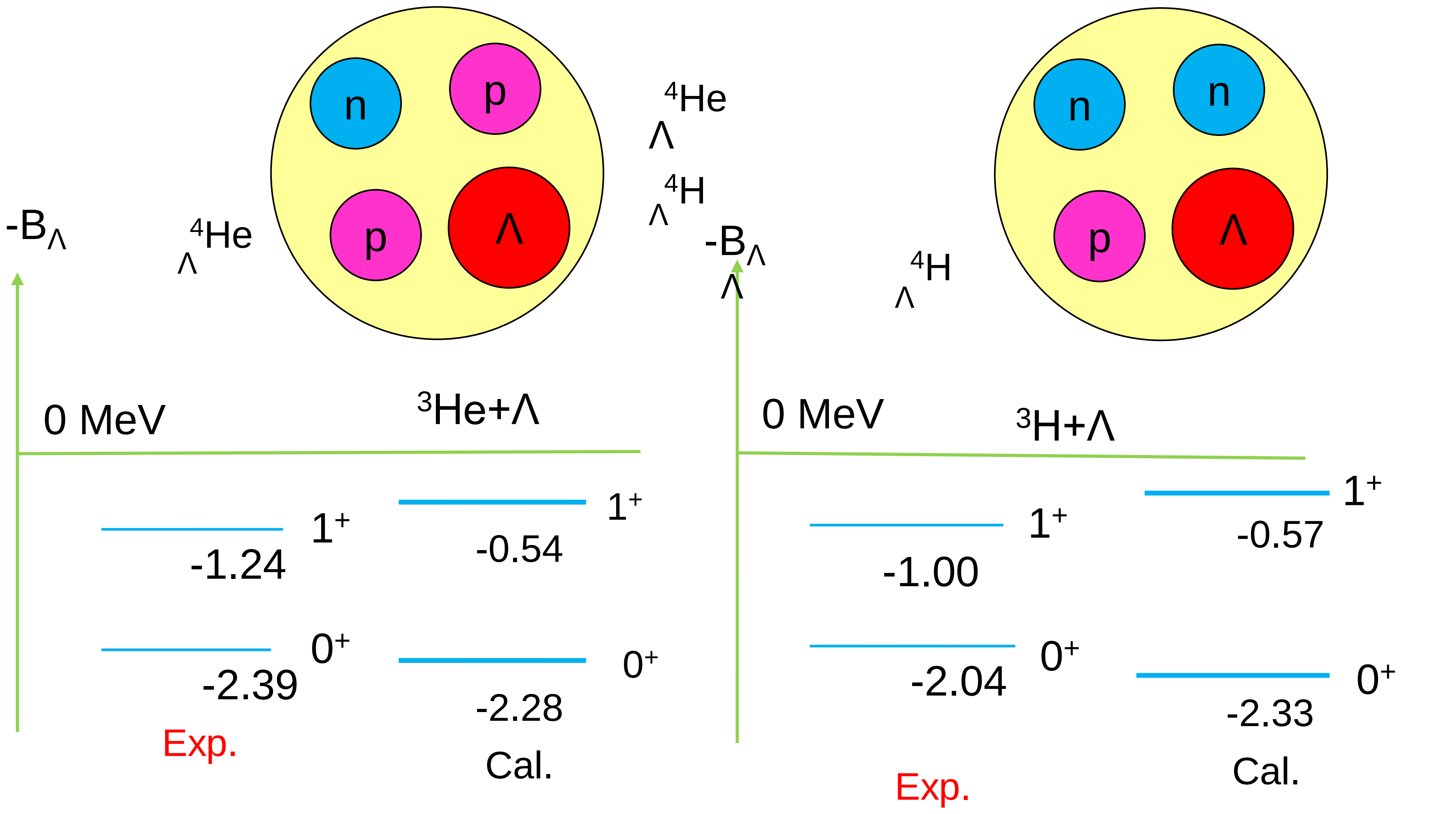
To take into account of Λ particle to be converted into Σ particle, we should perform below calculation using realistic hyperon(Y)-nucleon(N) interaction.



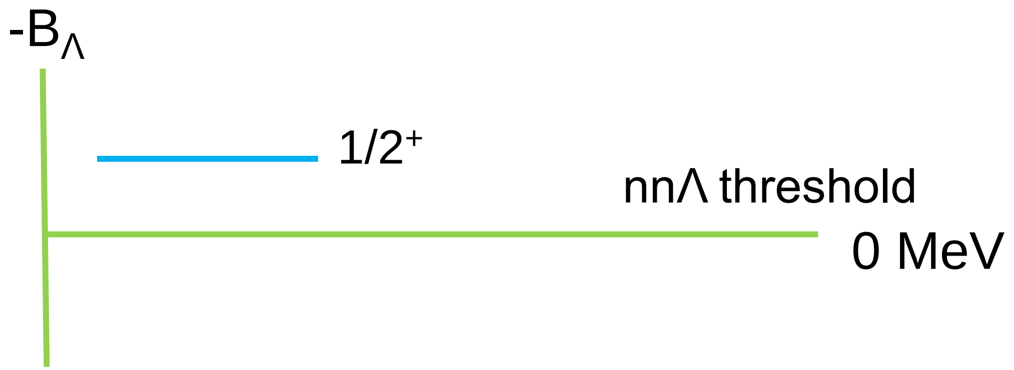
YN interaction: Nijmegen soft core '97f potential (NSC97f) proposed by Nijmegen group

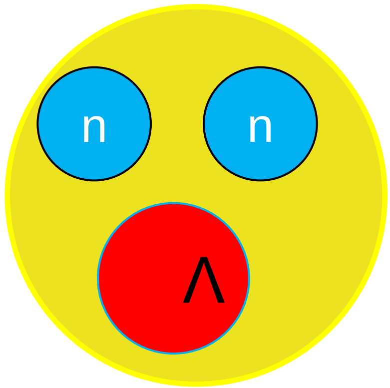
reproduce the observed binding energies of ${}^{3}_{\Lambda}H$, ${}^{4}_{\Lambda}H$ and ${}^{4}_{\Lambda}He$


n
p
Λ
$^{3}_{\Lambda}H$
$-B_{\Lambda}$
0 MeV
d+Λ
1/2+
-0.13 ±0.05 MeV
Exp.
1/2+
-0.19 MeV
Cal.



What is binding energy of nnΛ?





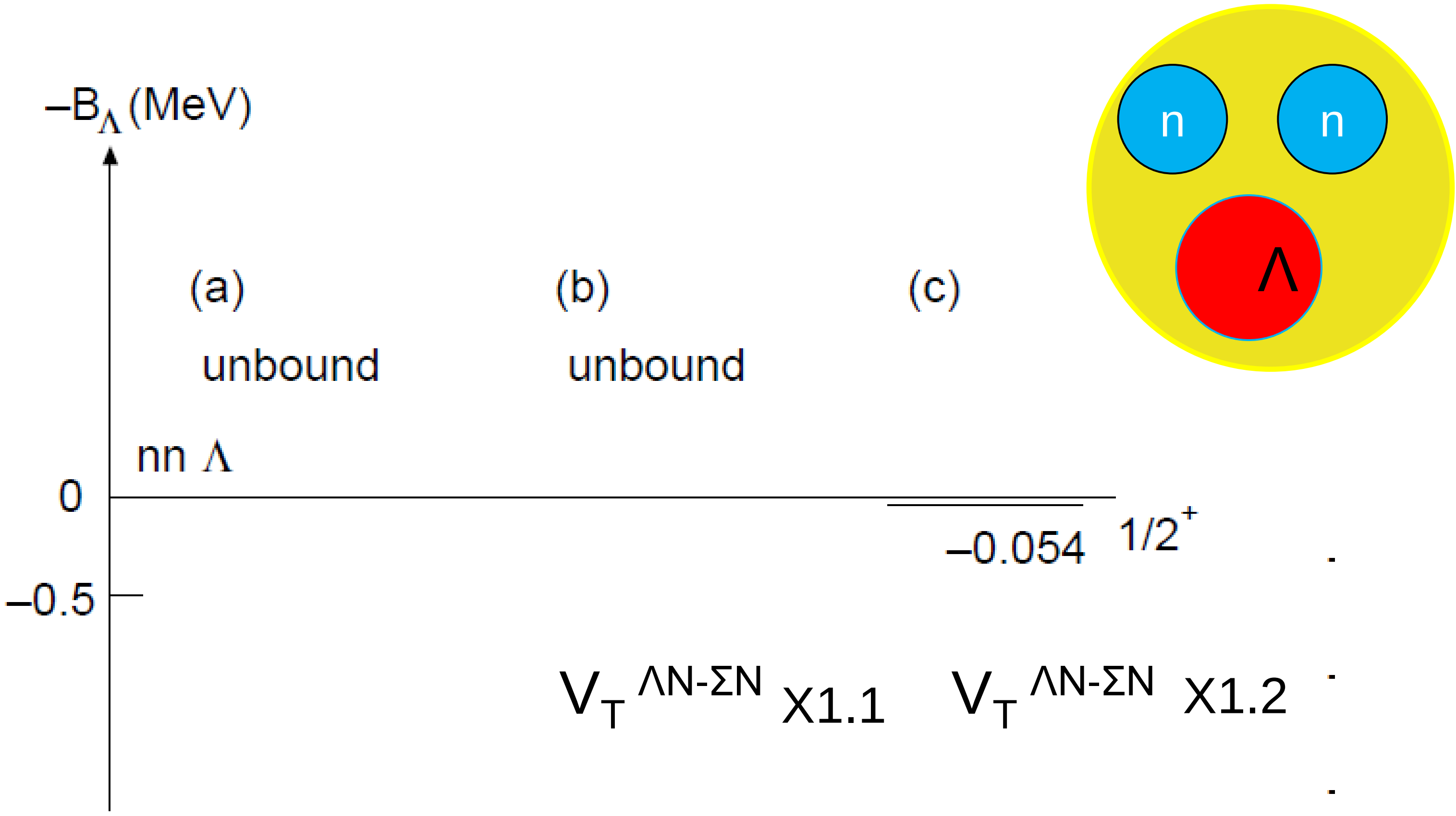
We have no bound state in nnΛ system.
This is inconsistent with the data.

Now, we have a question.

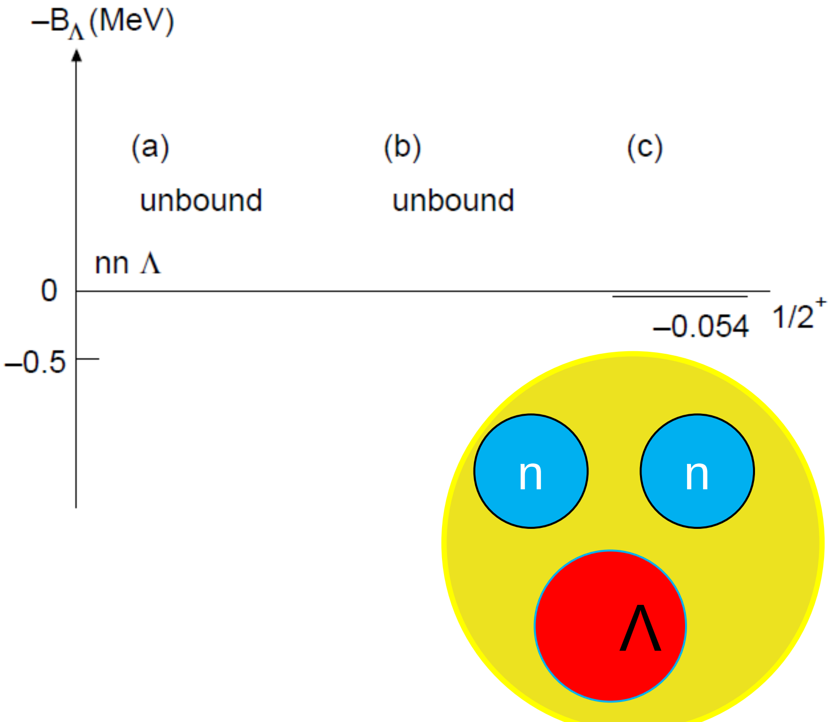
Do we have a possibility to have a bound state in nnΛ system tuning strength of YN potential ?

It should be noted to maintain consistency with the binding energies of ${}^{3}_{\Lambda}$H and ${}^{4}_{\Lambda}$H and ${}^{4}_{\Lambda}$He.

$V_T^{\Lambda N\text{-}\Sigma N}$ X1.1, 1.2



When we have a bound state in nnΛ system, what are binding energies of ${}^{3}_{\Lambda}H$ and A=4 hypernuclei?



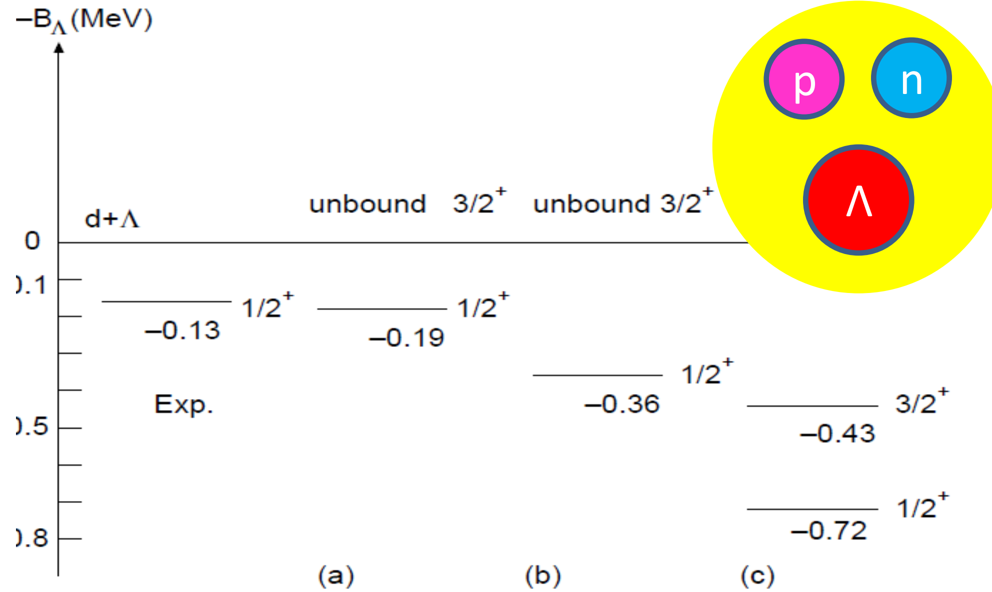
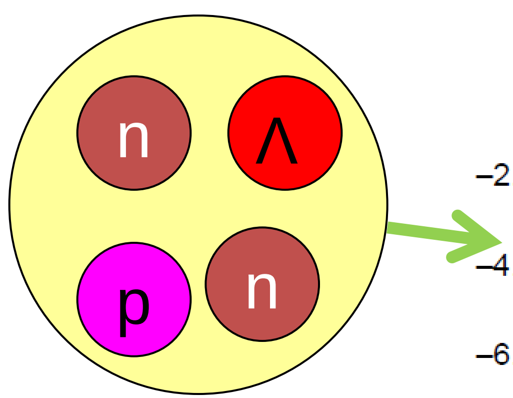
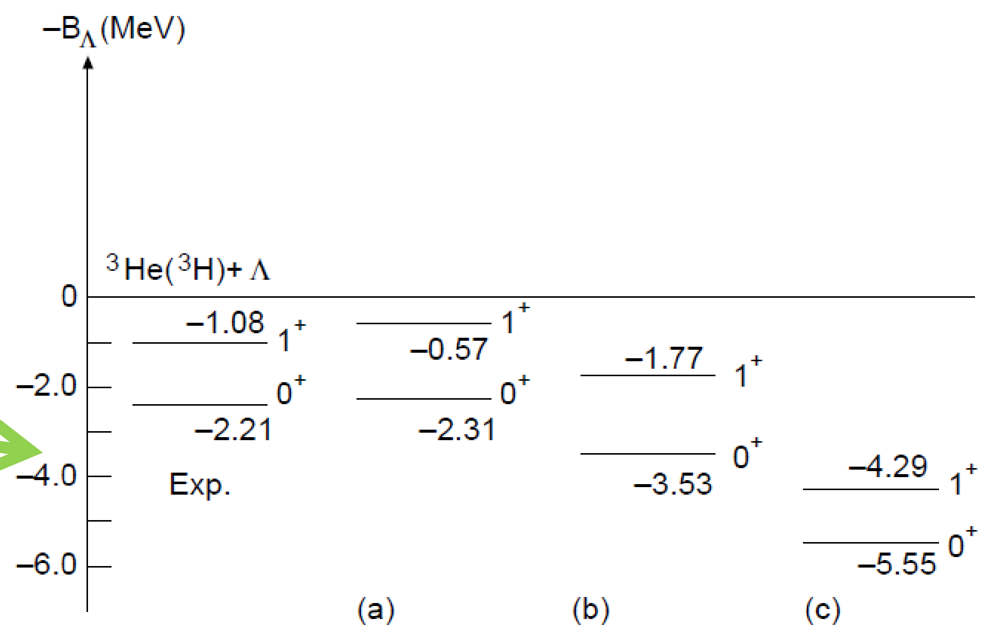


FIG. 3: Calculated Λ-separation energy for $^3_\Lambda$H with (a) $^3V^T_{N\Lambda-N\Sigma}$ × 1.00, (b) $^3V^T_{N\Lambda-N\Sigma}$ × 1.10, and (c) $^3V^T_{N\Lambda-N\Sigma}$ ×

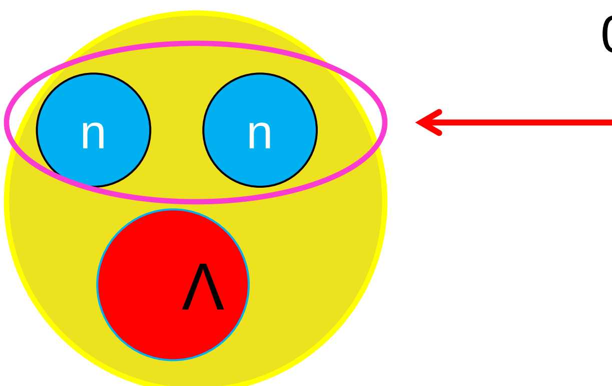
We have no possibility to have a bound state in nnΛ system.





Question: If we tune $^1S_0$ state of nn interaction,
Do we have a possibility to have a bound state in nnΛ?
In this case, the binding energies of ^{3}H and ^{3}He reproduce the observed data?

Some authors pointed out to have dineutron bound state in nn system. Ex. H. Witala and W. Gloeckle, Phys. Rev. C85, 064003 (2012).



T=1, $^1S_0$ state
I multiply component of $^1S_0$ state by 1.13 and 1.35. What is the binding energies of nnΛ ?

PHYSICAL REVIEW C **85**, 064003 (2012)

Di-neutron and the three-nucleon continuum observables

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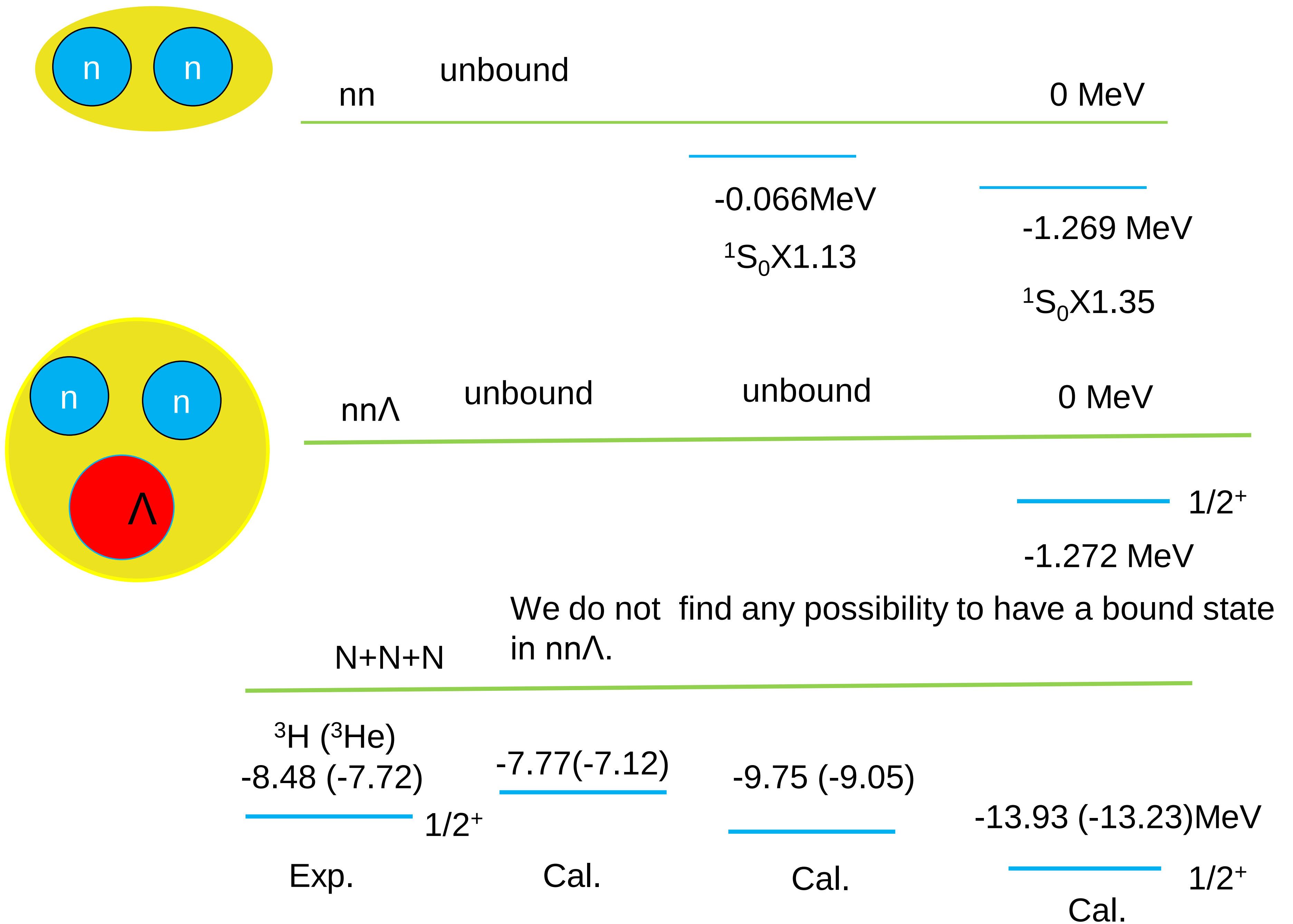
(Received 24 April 2012; published 25 June 2012)

We investigate how strongly a hypothetical $^1S_0$ bound state of two neutrons would affect observables in neutron-deuteron reactions. To that aim we extend our momentum-space scheme of solving the three-nucleon Faddeev equations and incorporate in addition to the deuteron also a $^1S_0$ di-neutron bound state. We discuss effects induced by a di-neutron on the angular distributions of the neutron-deuteron elastic scattering and deuteron breakup cross sections. A comparison to the available data for the neutron-deuteron total cross section and elastic scattering angular distributions cannot decisively exclude the possibility that two neutrons can form a $^1S_0$ bound state. However, strong modifications of the final-state-interaction peaks in the neutron-deuteron breakup reaction seem to disallow the existence of a di-neutron.

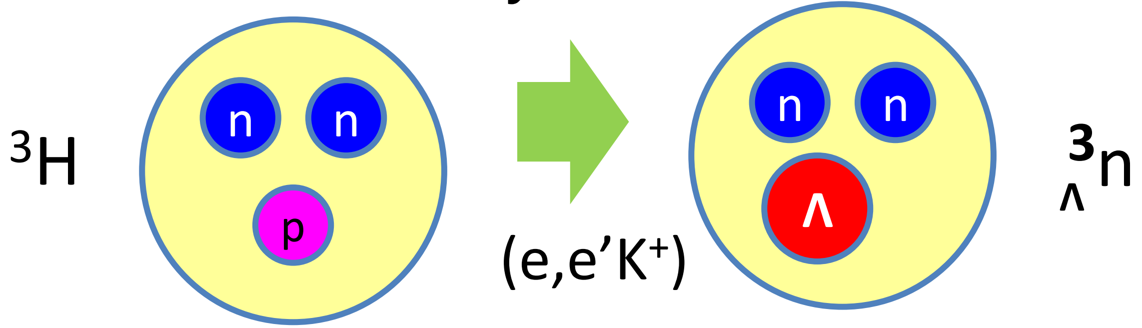


n
n
nn
unbound
0 MeV
-0.066MeV
$^1S_0$X1.13
-1.269 MeV
$^1S_0$X1.35
n
n
Λ
nnΛ
unbound
unbound
0 MeV
$1/2^+$
-1.272 MeV
We do not find any possibility to have a bound state in nnΛ.
N+N+N
^{3}H (^{3}He)
-8.48 (-7.72)
$1/2^+$
-7.77(-7.12)
-9.75 (-9.05)
-13.93 (-13.23)MeV
$1/2^+$
Exp.
Cal.
Cal.
Cal.

Summary of nnΛ system:

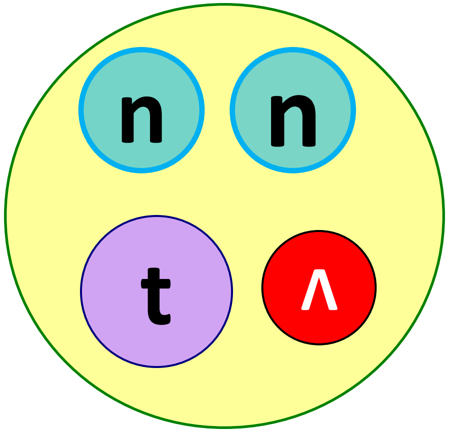
Motivated by the reported observation of data suggesting a bound state nnΛ, we have calculated the binding energy of this hyperucleus taking into account ΛN-ΣN explicitly.
We did not find any possibility to have a bound state in this system. However, the experimentally they reported evidence for a bound state. As long as we believe the data, we should consider additional
missing elements in the present calculation. But, I have no idea.
Unfortunately, they did not report binding energy.

It might be good idea to
perform search experiment of nnΛ system at Jlab to conclude whether or not the system exists as bound state experimentally.



Section 3

Four-body calculation of ${}^{6}_{\Lambda}H$



E. H, S. Ohnishi, M. Kamimura, Y. Yamamoto, NPA **908** (2013) 29.

PRL **108,** 042501 (2012) PHYSICAL REVIEW LETTERS week ending 27 JANUARY 2012

Evidence for Heavy Hyperhydrogen $^{6}_{\Lambda}$H

M. Agnello,[1,2] L. Benussi,[3] M. Bertani,[3] H. C. Bhang,[4] G. Bonomi,[5,6] E. Botta,[7,2,*] M. Bregant,[8] T. Bressani,[7,2] S. Bufalino,[2] L. Busso,[9,2] D. Calvo,[2] P. Camerini,[10,11] B. Dalena,[12] F. De Mori,[7,2] G. D'Erasmo,[13,14] F. L. Fabbri,[3] A. Feliciello,[2] A. Filippi,[2] E. M. Fiore,[13,14] A. Fontana,[6] H. Fujioka,[15] P. Genova,[6] P. Gianotti,[3] N. Grion,[10] V. Lucherini,[3] S. Marcello,[7,2] N. Mirfakhrai,[16] F. Moia,[5,6] O. Morra,[17,2] T. Nagae,[15] H. Outa,[18] A. Pantaleo,[14,†] V. Paticchio,[14] S. Piano,[10] R. Rui,[10,11] G. Simonetti,[13,14] R. Wheadon,[2] and A. Zenoni[5,6]

(FINUDA Collaboration)

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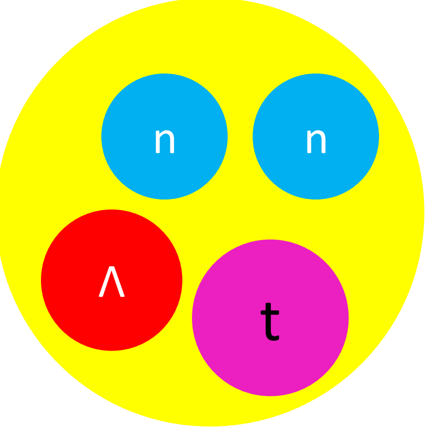
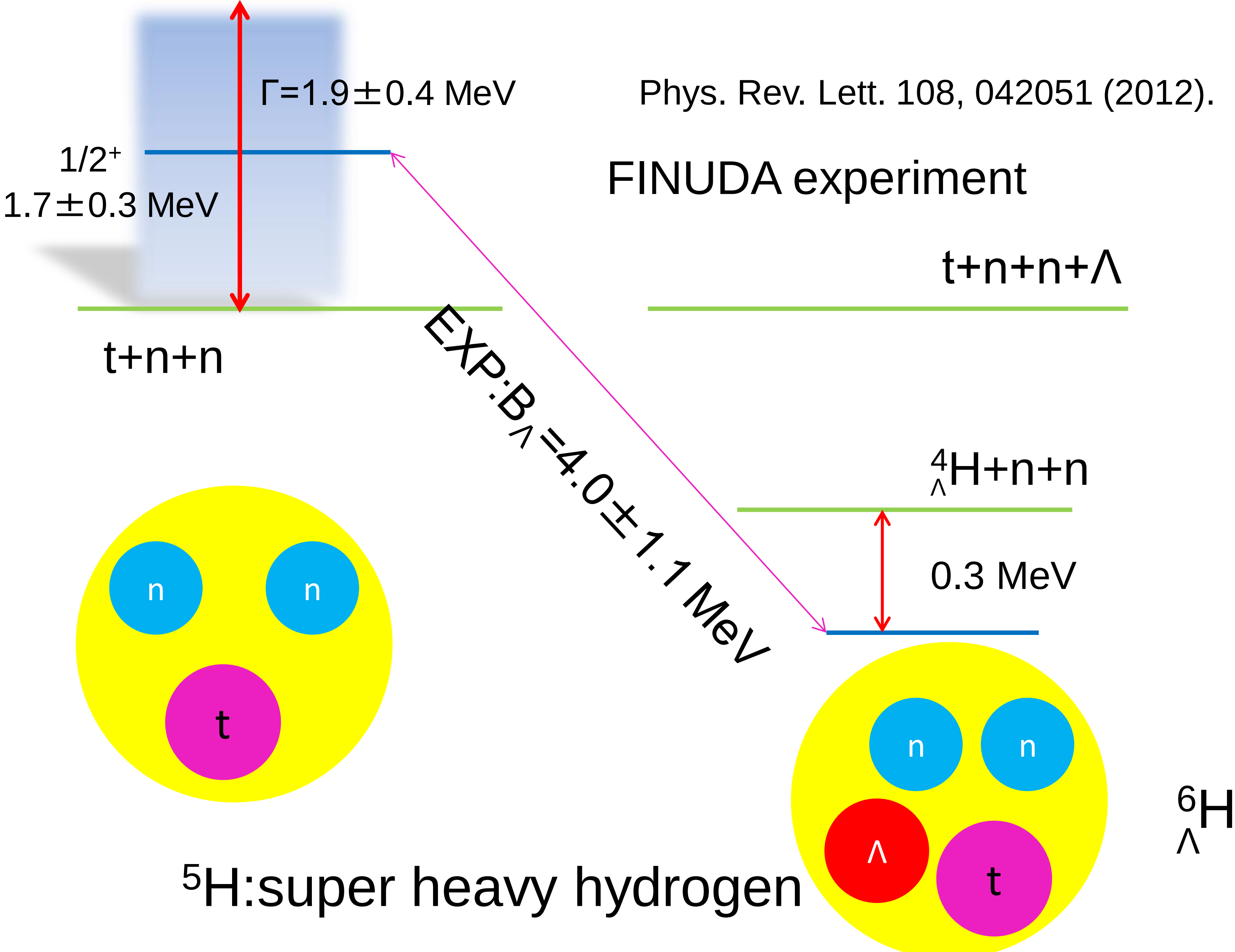
(Received 2 November 2011; published 24 January 2012)



$^{6}_{\Lambda}$H



Phys. Rev. Lett. 108, 042051 (2012).
FINUDA experiment
Γ=1.9±0.4 MeV
1/2+
1.7±0.3 MeV
t+n+n
t+n+n+Λ
EXP:B_Λ=4.0±1.1 MeV
⁴_ΛH+n+n
0.3 MeV
n
n
t
n
n
Λ
t
⁶_ΛH
⁵H:super heavy hydrogen

Before experiment, the following authors calculated the binding energies by shell model picture and G-matrix theory.

(1) R. H. Dalitz and R. Kevi-Setti, Nuovo Cimento 30, 489 (1963).

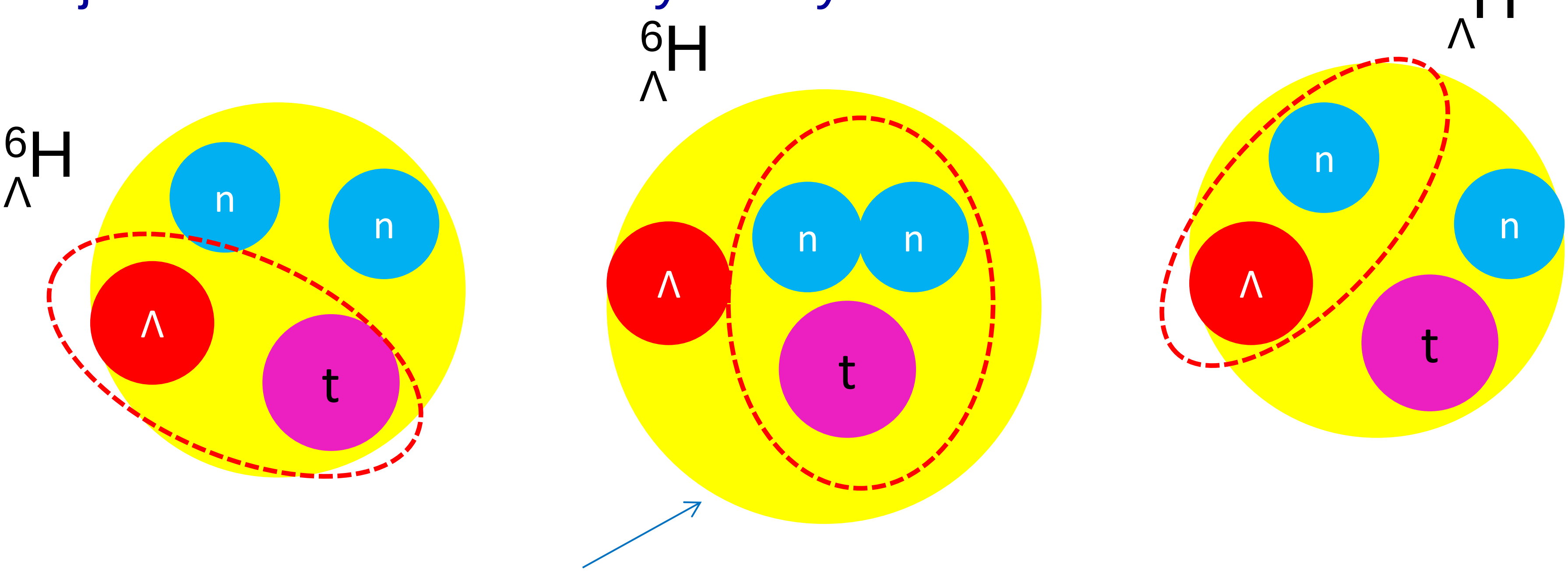
(2) L. Majling, Nucl. Phys. A585, 211c (1995).

(3) Y. Akaishi and T. Yamazaki, Frascati Physics Series Vol. 16 (1999).

Motivating the experimental data, I calculated the binding energy of ${}^{6}_{\Lambda}H$ and I shall show you my result.

Before doing full 4-body calculation,
it is important and necessary to reproduce the observed binding energies of all the sets of subsystems in $^{6}_{\Lambda}H$.

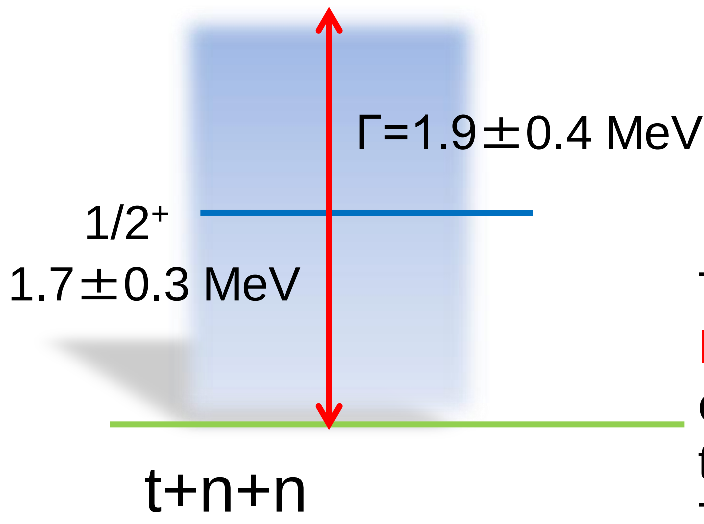
Namely, All the potential parameters are needed to adjust in the 2- and 3-body subsystems.



Among the subsystems, it is extremely important to adjust the energy of ^{5}H core nucleus.

Framework:

To calculate the binding energy of $_{\Lambda}{}^{6}H$, it is very important to reproduce the binding energy of the core nucleus ^{5}H.



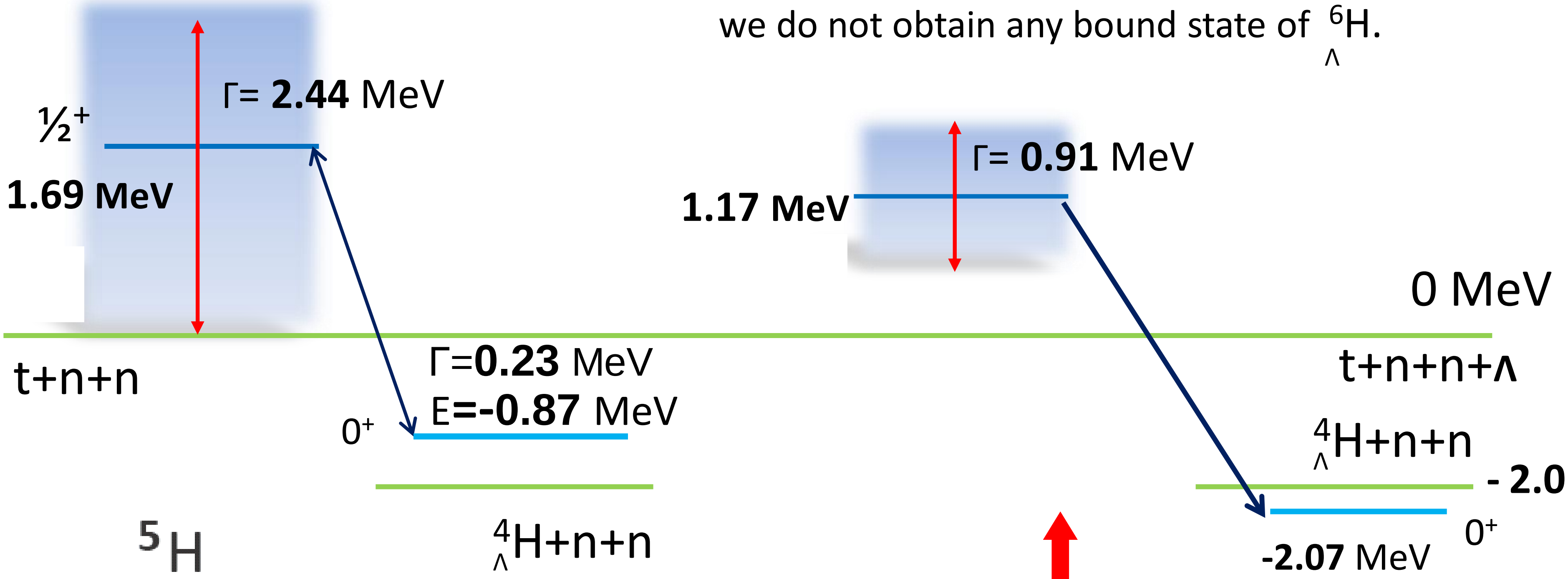
transfer reaction p(^{6}He, ^{2}He)^{5}H

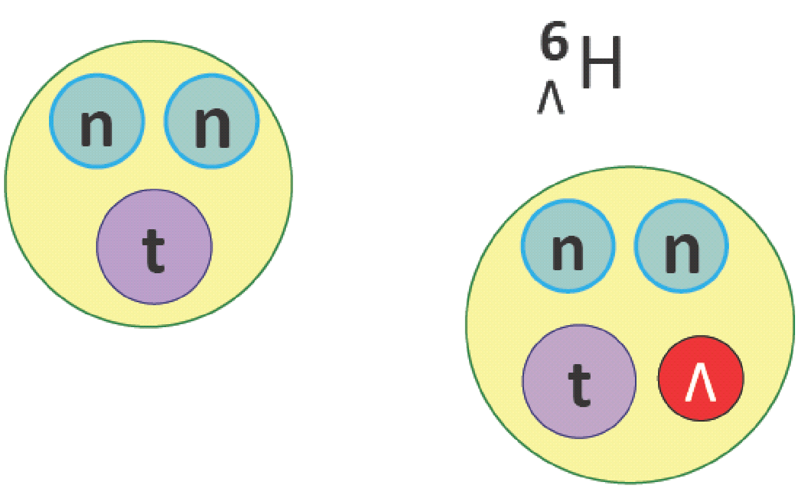
A. A. Korcheninnikov, et al. Phys. Rev. Lett. 87 (2001) 092501.

To reproduce the data, for example,
R. De Diego et al, Nucl. Phys. A786 (2007), 71.
calculated the energy and width of ^{5}H with t+n+n three-body model using complex scaling method. The calculated binding energy for the ground state of ^{5}H is 1.6 MeV with respect to t+n+n threshold and width has 1.5 MeV.

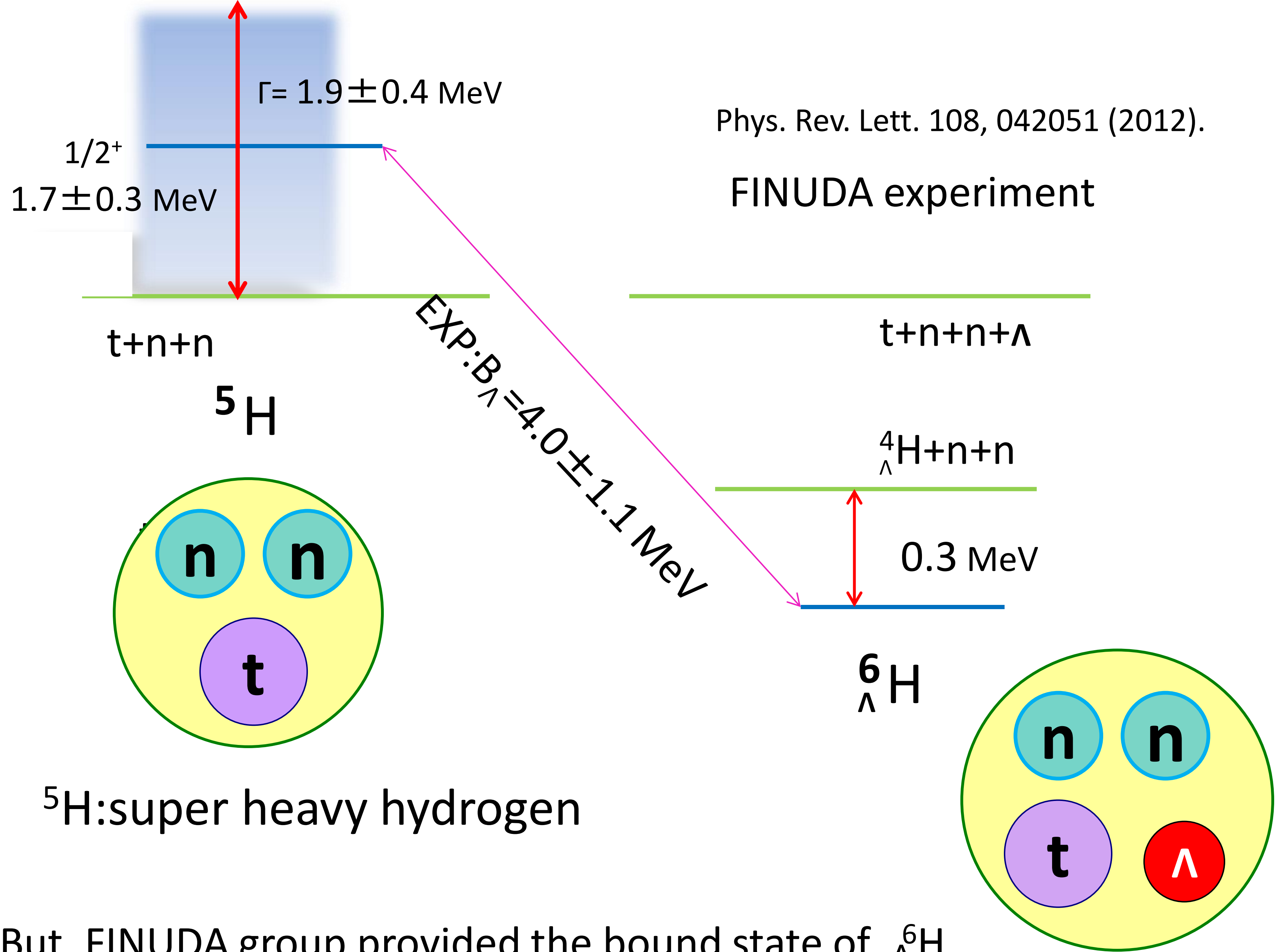
Exp: 1.7 ±0.3 MeV
Γ=1.9 ±0.4 MeV

Even if the potential parameters were tuned so as to reproduce the lowest value of the Exp. , E=1.4 MeV, Γ=1.5 MeV, we do not obtain any bound state of ${}^{6}_{\Lambda}$H.





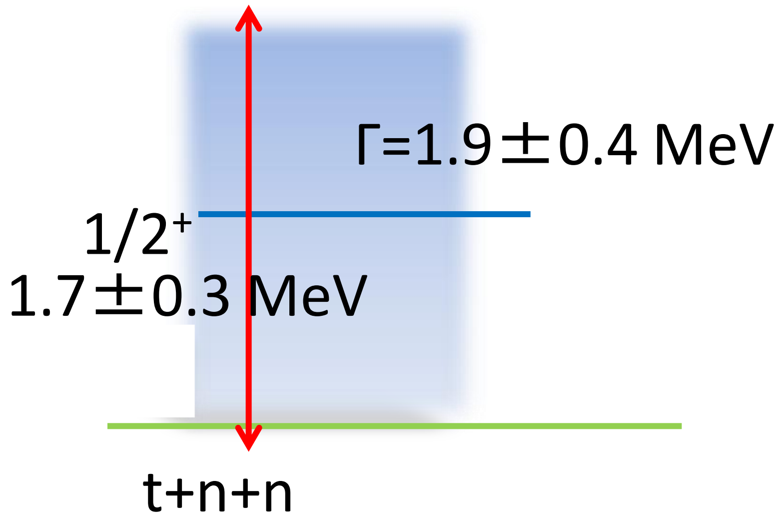
On the contrary, if we tune the potentials to have a bound state in ${}^{6}_{\Lambda}$H, then what is the energy and width of ^{5}H?



But, FINUDA group provided the bound state of ${}^{6}_{\Lambda}H$.

How should I understand the inconsistency between our results and the observed data?

We need more precise data of ^{5}H.



A. Korcheninnikov, et al. Phys. Rev. Lett. 87 (2001) 092501.

To get bound state of $^{6}_{\Lambda}$H, the energy should be lower than the present data.

It is planned to measure the energy and width of ^{5}H more precisely at RCNP in December in 2014 . We should wait for new data at RCNP.

(E_R, Γ_R) (MeV)	
J^π	$1/2^+$
^{5}H (full)	(1.57, 1.53)
^{5}H ($d = 0$)	(1.55, 1.35)
Theor. [16]	(2.26, 2.93)
Theor. [12]	(2.5–3.0, 3–4)
Theor. [13]	(3.0–3.2, 1–4)
Theor. [15]	(1.59, 2.48)
Exp. [3]	$(1.7 \pm 0.3, 1.9 \pm 0.4)$ ←
Exp. [8]	$(1.8 \pm 0.1, < 0.5)$
Exp. [4]	(1.8, 1.3)
Exp. [5]	(2, 2.5)
Exp. [6]	(3, 6)
Exp. [9]	$(5.5 \pm 0.2, 5.4 \pm 0.6)$

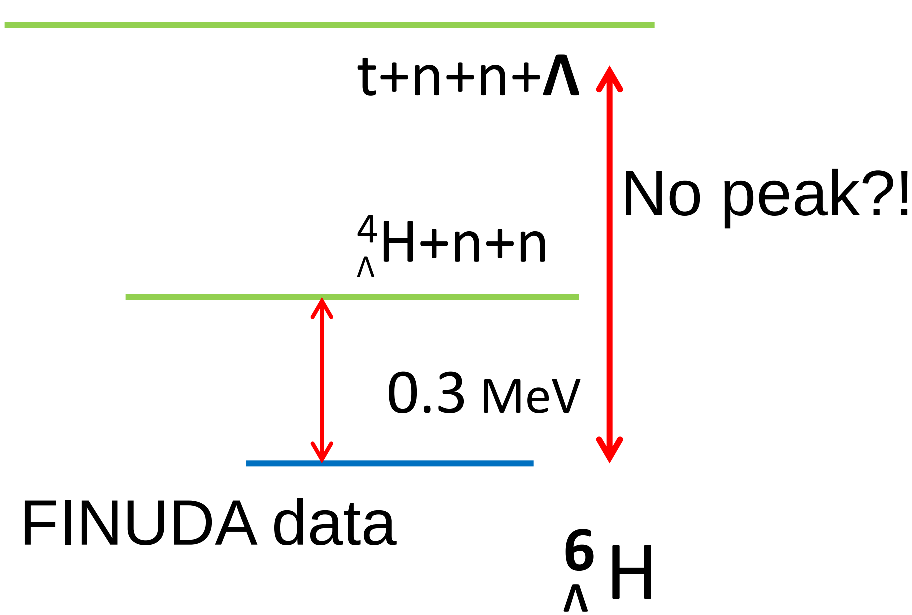
We cited this experiment.
However, you have many
different decay widths.
width is strongly related to
the size of wavefunction.
Then, I hope that
The decay width will be
determined at RCNP this year

[3] A.A. Korosheninnikov et al., PRL87 (2001) 092501
[8] S.I. Sidorchuk et al., NPA719 (2003) 13
[4] M.S. Golovkov et al. PRC 72 (2005) 064612
[5] G. M. Ter-Akopian et al., Eur. Phys. J A25 (2005) 315.

Search for ${}^{6}_{\Lambda}$H hypernucleus by the ^{6}Li(π^-, K^+) reaction at p_{π^-} = 1.2 GeV/c

H. Sugimura[a,b,*], M. Agnello[c,d], J.K. Ahn[e], S. Ajimura[f], Y. Akazawa[g], N. Amano[a], K. Aoki[h], H.C. Bhang[i], N. Chiga[g], M. Endo[j], P. Evtoukhovitch[k], A. Feliciello[d], H. Fujioka[a], T. Fukuda[l], S. Hasegawa[b], S. Hayakawa[j], R. Honda[g], K. Hosomi[g], S.H. Hwang[b], Y. Ichikawa[a,b], Y. Igarashi[h], K. Imai[b], N. Ishibashi[j], R. Iwasaki[h], C.W. Joo[i], R. Kiuchi[i,b], J.K. Lee[e], J.Y. Lee[i], K. Matsuda[j], Y. Matsumoto[g], K. Matsuoka[j], K. Miwa[g], Y. Mizoi[l], M. Moritsu[f], T. Nagae[a], S. Nagamiya[b], M. Nakagawa[j], M. Naruki[a], H. Noumi[f], R. Ota[j], B.J. Roy[m], P.K. Saha[b], A. Sakaguchi[j], H. Sako[b], C. Samanta[n], V. Samoilov[k], Y. Sasaki[g], S. Sato[b], M. Sekimoto[h], Y. Shimizu[l], T. Shiozaki[g], K. Shirotori[f], T. Soyama[j], T. Takahashi[h], T.N. Takahashi[o], H. Tamura[g], K. Tanabe[g], T. Tanaka[j], K. Tanida[i], A.O. Tokiyasu[f], Z. Tsamalaidze[k], M. Ukai[g], T.O. Yamamoto[g], Y. Yamamoto[g], S.B. Yang[i], K. Yoshida[j],
(J-PARC E10 Collaboration)

arXiv:1310.6104v1 [nucl-ex] 23 Oct 2013



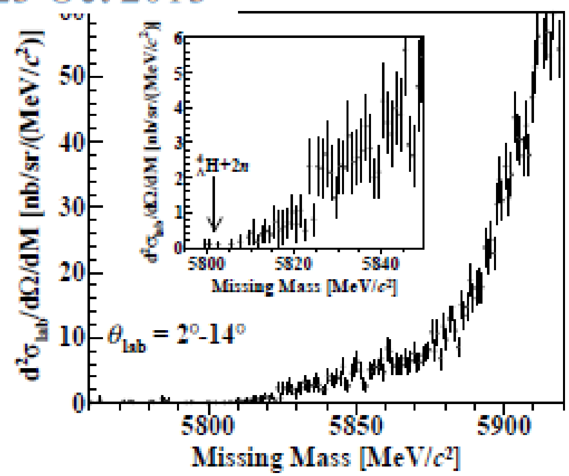
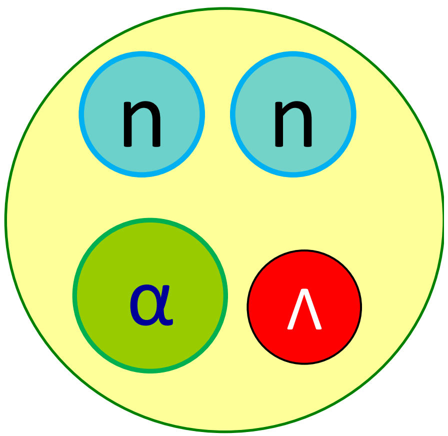


Figure 5: Missing-mass spectrum of the ^{6}Li(π^-, K^+) reaction at 1.2 GeV/c. A magnified view around the Λ bound region is shown in the inset. The arrow labeled as ${}^{4}_{\Lambda}$H+2n shows the particle decay threshold (5801.7 MeV/c^2).

Theoretically, we might understand by the following reason.
If the state is resonant state, the reaction cross section would be much smaller than that we expect. => I should calculate reaction cross section ^{6}Li (π,K) ${}^{6}_{\Lambda}$H.

$^{7}_{\Lambda}$He

To be submitted in PRC



$^{7}_{\Lambda}$He

Resonant states of neutron-rich Λ hypernucleus, $^{7}_{\Lambda}$He

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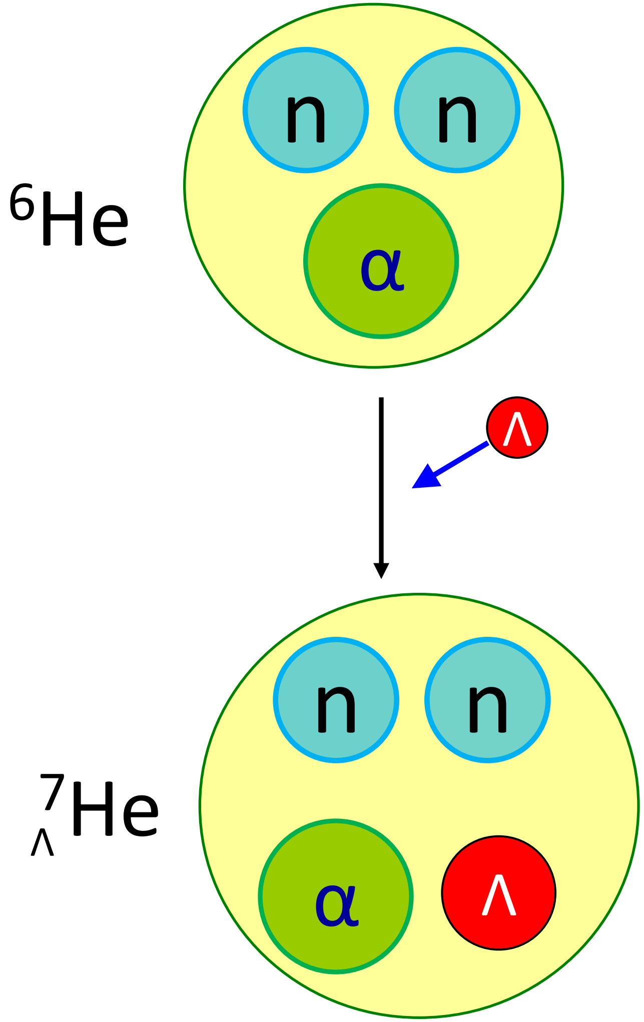
Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8317, Japan

The structure of neutron-rich Λ hypernucleus, $^{7}_{\Lambda}$He is studied within the framework of $\alpha+\Lambda+n+n$ four-body cluster model. We predict second $3/2^+$ and $5/2^+$ states as narrow resonant states to be 0.03 MeV and 0.07 MeV with width $\Gamma \sim 1$ MeV with respect to $\alpha+\Lambda+n+n$ threshold which correspond to the second 2^+ state of ^{6}He coupled to $0s$ Λ. By estimation of differential cross section of ^{7}Li$(\gamma,K^+)^{7}_{\Lambda}$He, there is a possibility to observe these state at JLab in the future. We also calculate second 2^+ state of ^{6}He as resonant state within the framework of $\alpha+n+n$ three-body cluster model. Our result is 2.81 MeV with $\Gamma = 4.63 MeV$ with respect to $\alpha+n+n$ threshold, which is inconsistent with the recent SPIRAL data. It is suggested that search experiment at JLab of the second $3/2^+$ and $5/2^+$ states of $^{7}_{\Lambda}$He would provide an opportunity to confirm the second 2^+ state of the core nucleus ^{6}He.



^{6}He : One of the lightest n-rich nuclei

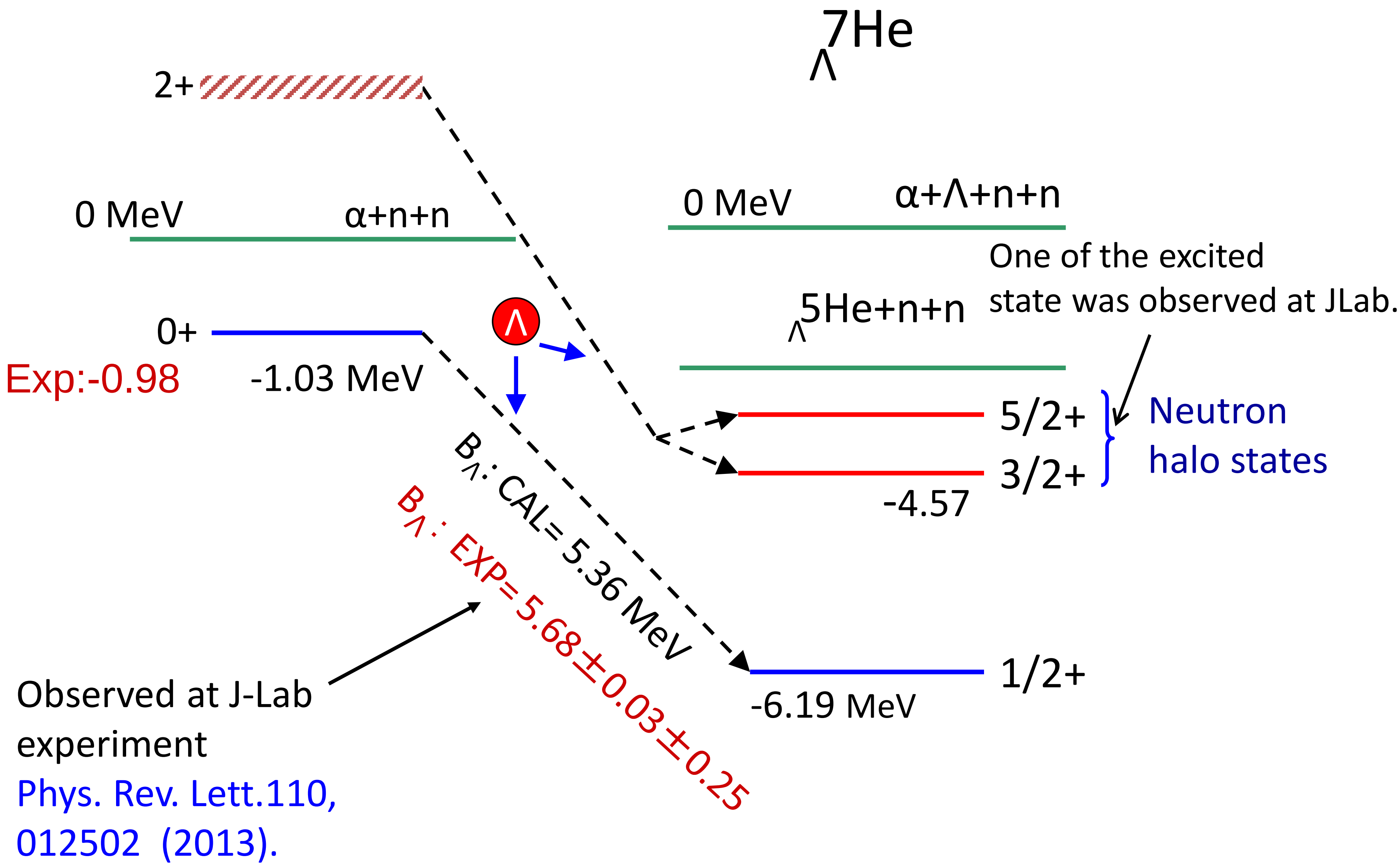
$^{7}_{\Lambda}$He: One of the lightest n-rich hypernuclei

Observed at JLAB,
Phys. Rev. Lett. 110, 12502 (2013).

CAL: E. Hiyama et al., PRC 53, 2075 (1996), PRC 80, 054321 (2009)

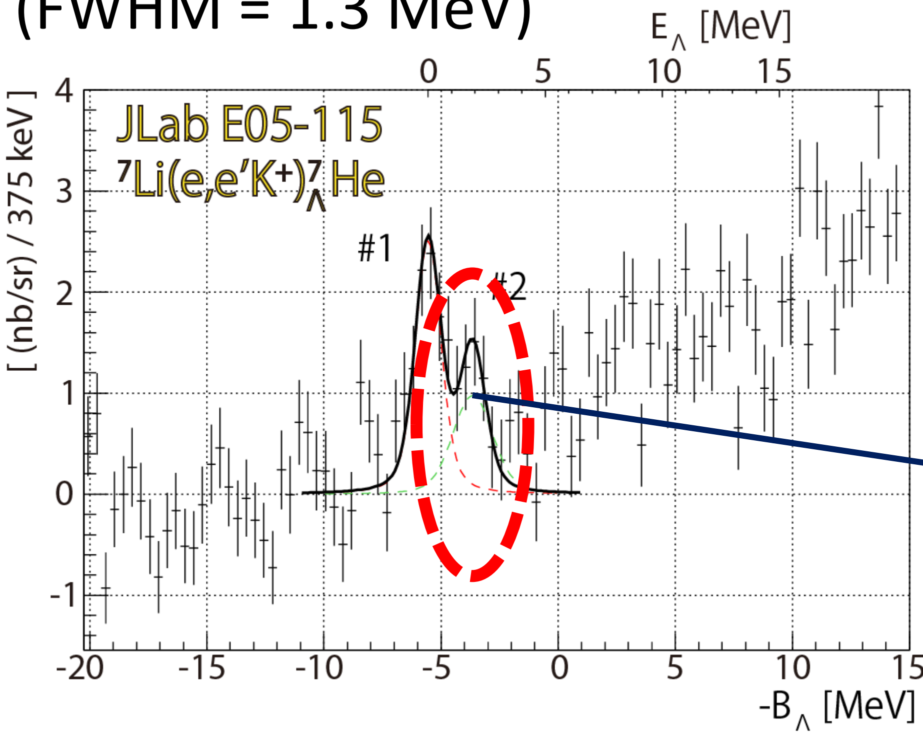
6He

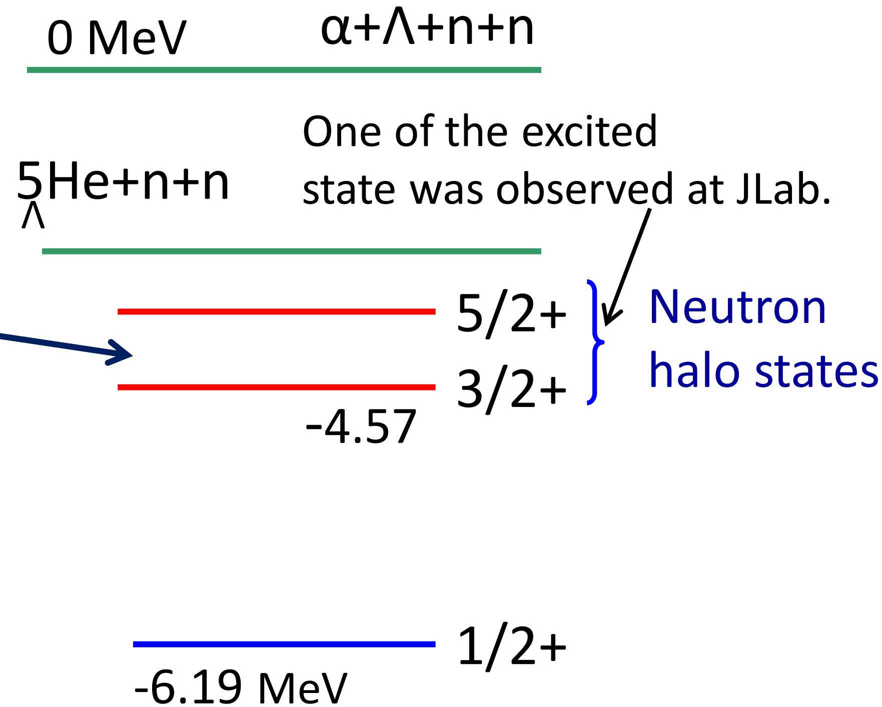
Another interesting issue is to study the excited states of $^{7}_{\Lambda}$He.



$^{7}Li(e,e'K^{+})^{7}_{\Lambda}He$

(FWHM = 1.3 MeV)

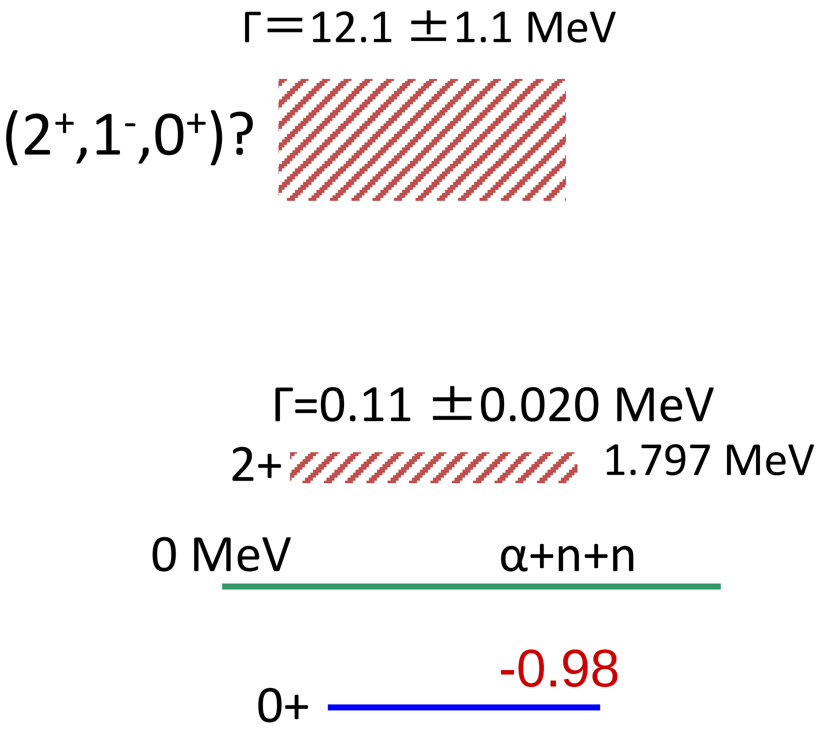




The calculated energy of the excited state is in good agreement with the data.

Question: In ${}^{7}_{\Lambda}$He, do we have any other new states?
If so, what is spin and parity?

First, let us discuss about energy spectra of ^{6}He core nucleus.

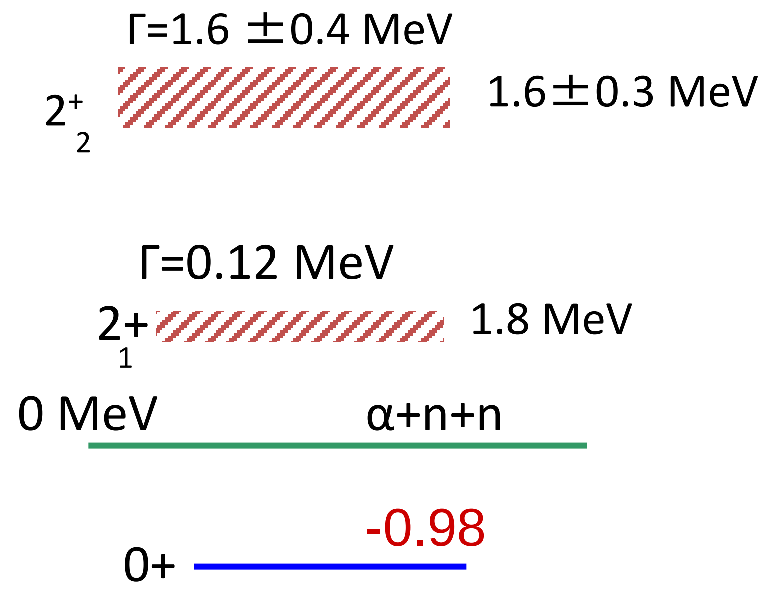


^{6}He

Exp.

Data in 2002

Core nucleus



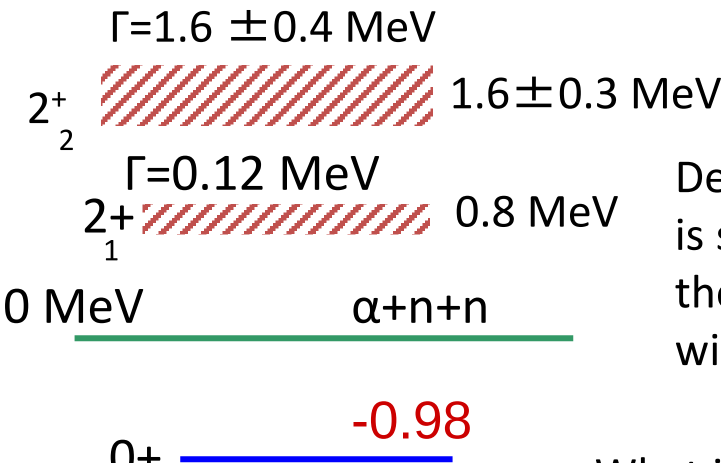
^{6}He

Exp.

Data in 2012

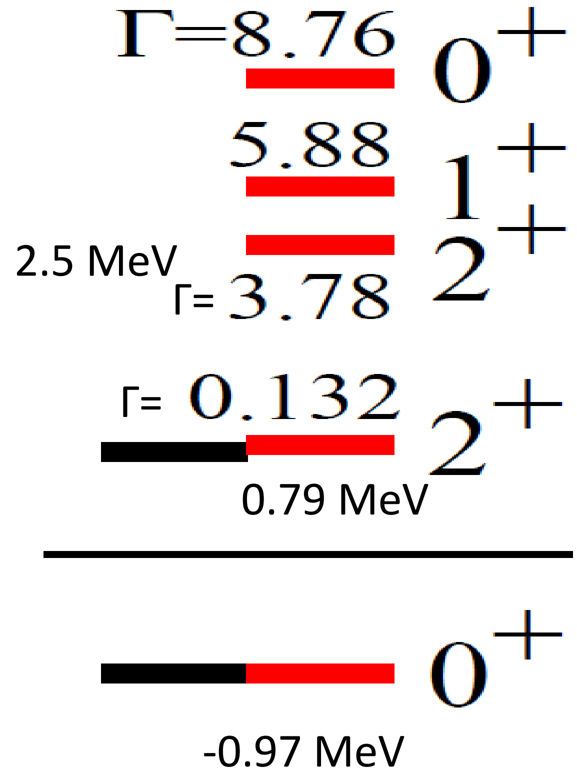
X. Mougeot et al., Phys. Lett. B 718 (2012) 441. p(^{8}He, t)^{6}He

How about theoretical result?



Decay with is smaller than the calculated width.

What is my result?



^{6}He

theory

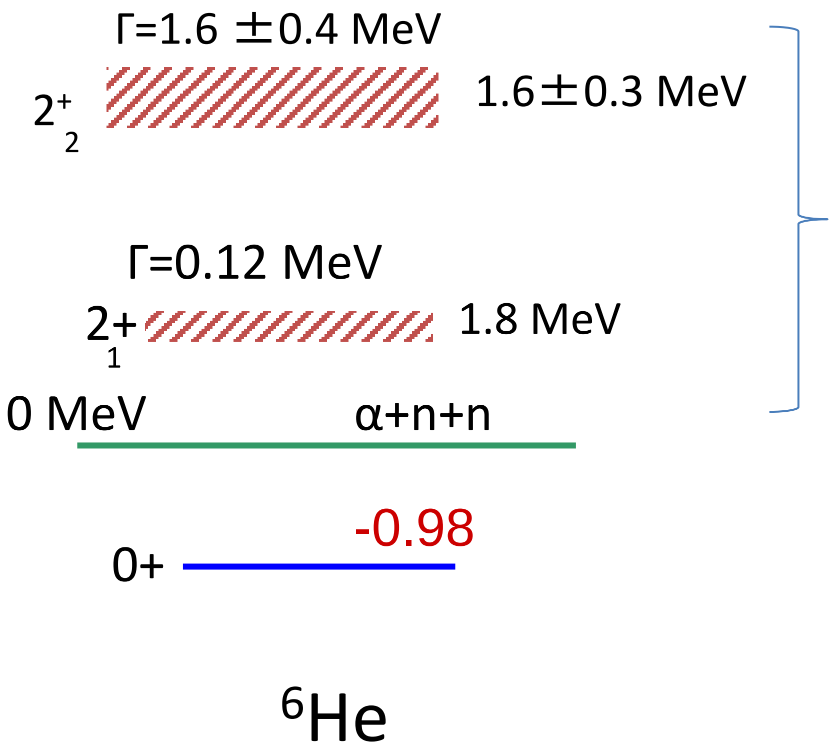
Exp.

Myo et al., PRC 84, 064306 (2011).

Data in 2012
X. Mougeot et al., Phys. Lett. B 718 (2012) 441. p(^{8}He, t)^{6}He

^{6}He

Question: What are theoretical results?



These are resonant states.

I should obtain energy position and decay width.

To do so, I use complex scaling method which is one of powerful method to get resonant states.
I will not explain about this method.

Exp.

Data in 2012
X. Mougeot et al., Phys. Lett. B 718 (2012) 441. p(^{8}He, t)^{6}He

The Hamiltonian for ^{6}He is written as

$$H = T + V_{NN} + + \sum_{i=1}^{2} [V_{\alpha N_i} + V_{\alpha N_i}^{\text{Pauli}}] \quad ,$$

and for $^7_\Lambda$He is written as

$$H = T + V_{NN} + V_{\Lambda\alpha} + \sum_{i=1}^{2} [V_{\Lambda N_i} + V_{\alpha N_i} + V_{\alpha N_i}^{\text{Pauli}}] \quad .$$

Complex scaling is defined by the following transformation.

$$U(\theta)f(\boldsymbol{x}) = \exp\left(i\frac{3}{2}\theta\right)f(\exp(i\theta)\boldsymbol{x})$$

$$H(\theta) = U(\theta)HU(\theta)^{-1} ,$$

$$|\Psi_\theta\rangle = U(\theta)|\Psi\rangle .$$

As a result, I should solve this Schroediner equation.

$$H(\theta)|\Psi_\theta\rangle = E(\theta)|\Psi_\theta\rangle$$

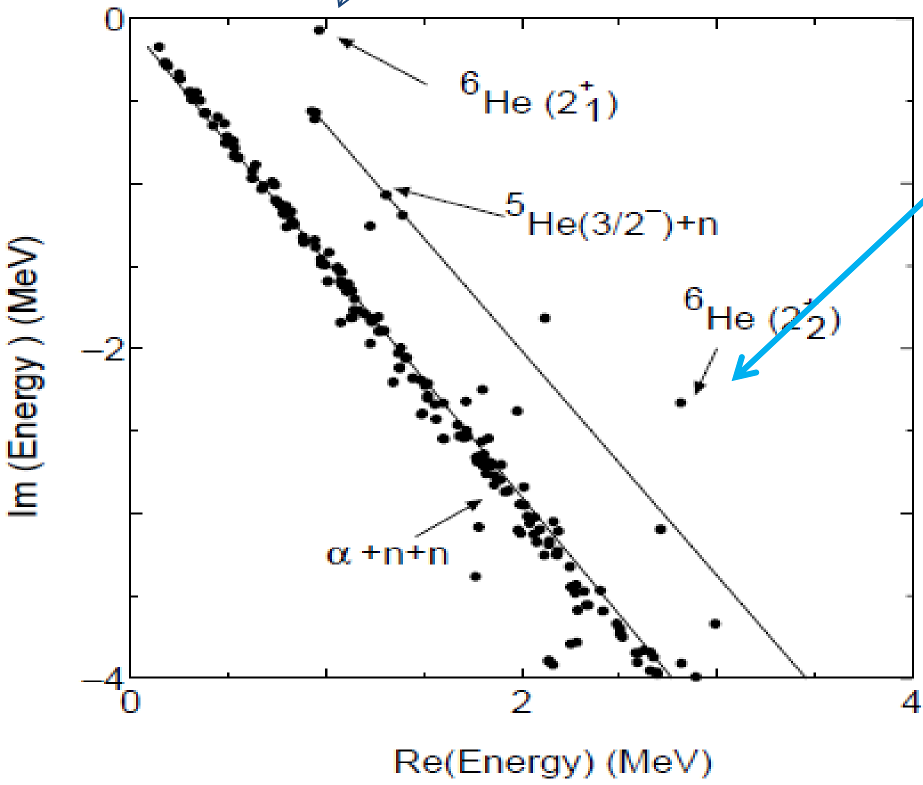
$E = E_r + i\Gamma/2$

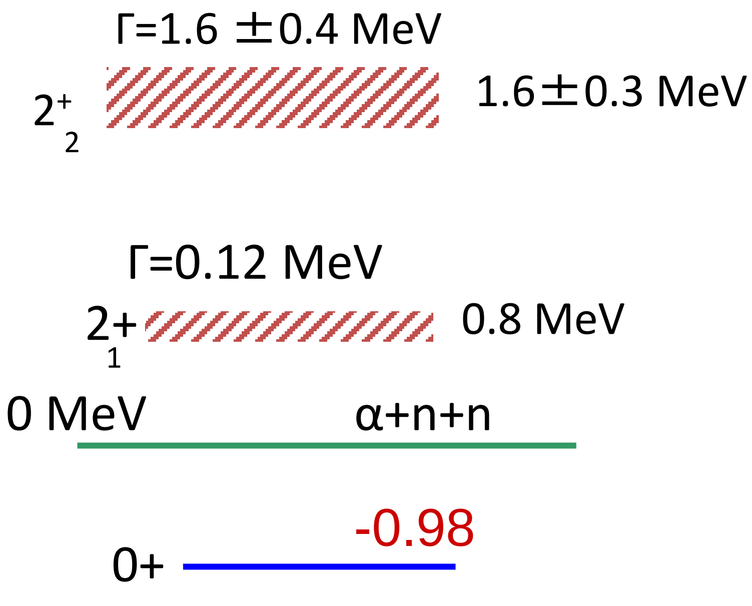
My result

E=0.96 + 0.14 MeV

θ=28°　～33°
The pole is stable.

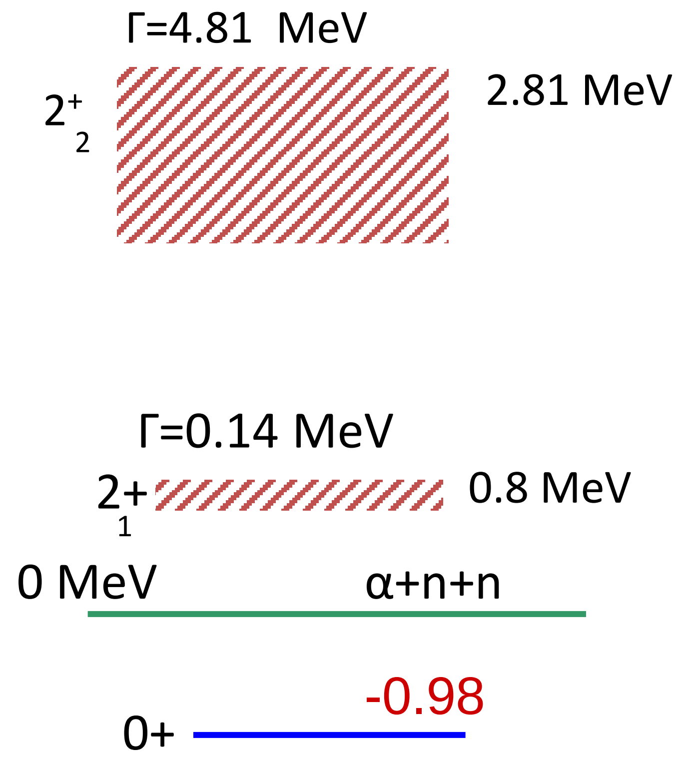
E=2.81 +4.81 MeV





^{6}He

Exp.



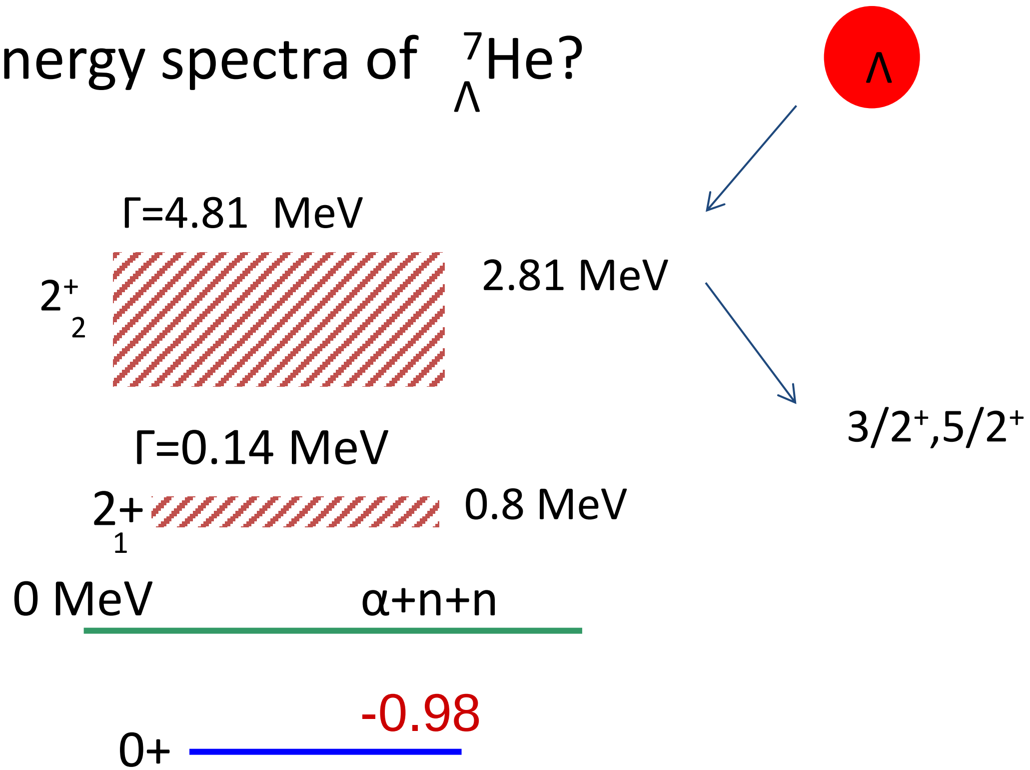
^{6}He

Cal.

Data in 2012

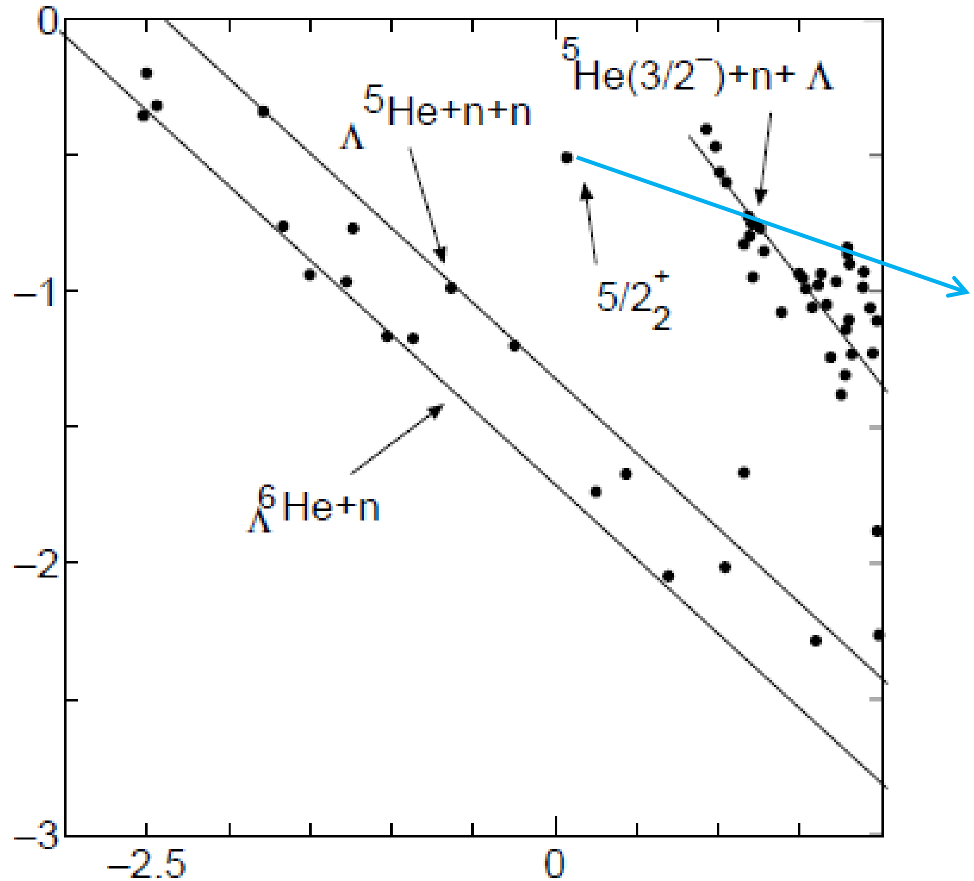
X. Mougeot et al., Phys. Lett. B 718 (2012) 441. p(^{8}He, t)^{6}He

How about energy spectra of $^{7}_{\Lambda}He$?

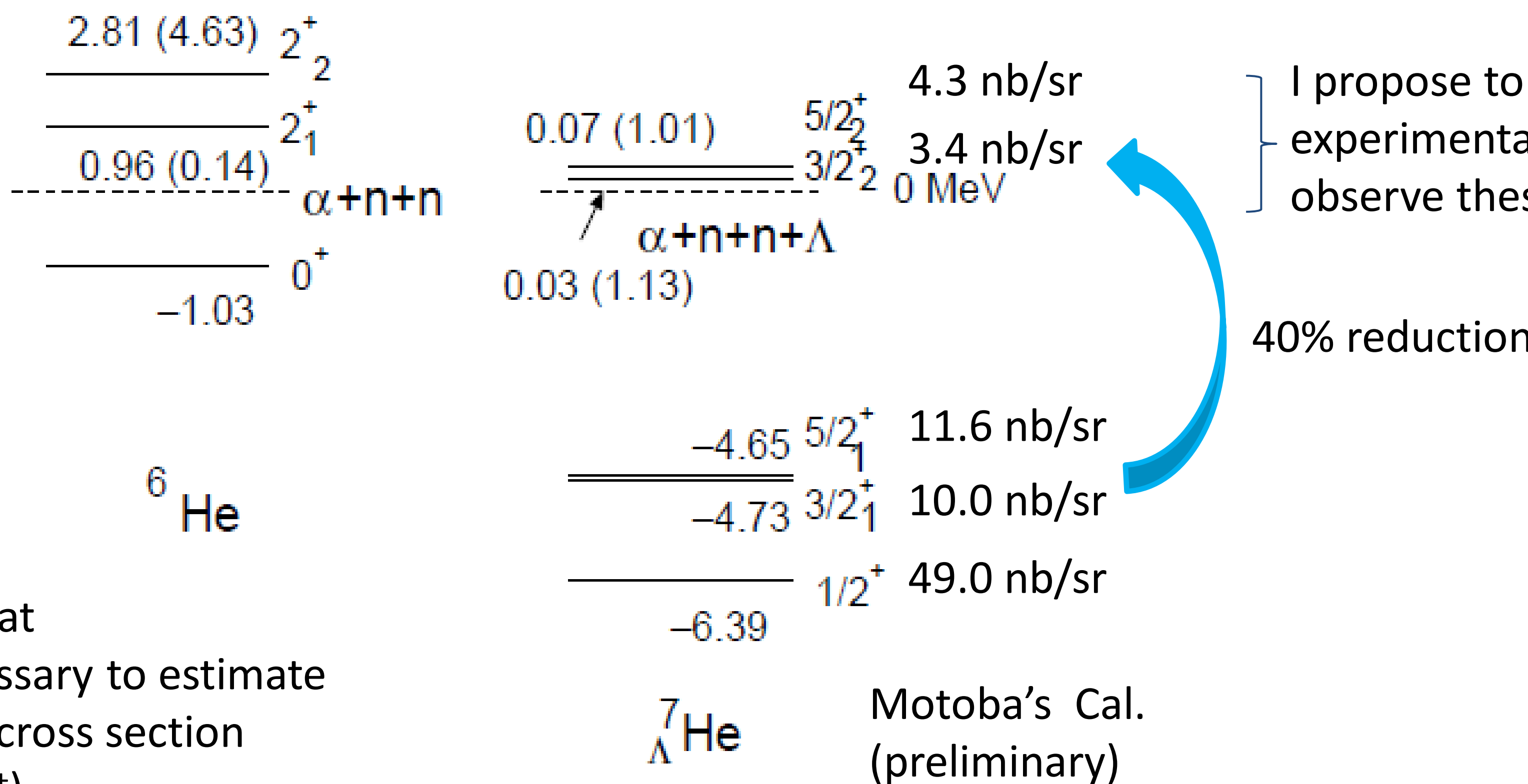


^{6}He

Cal.



E=0.07 MeV+1.13 MeV
The energy is measured with respect to α+Λ+n+n threshold.



I propose to experimentalists to observe these states.

I think that
It is necessary to estimate reaction cross section ^{7}Li (e,e'K$^+$).

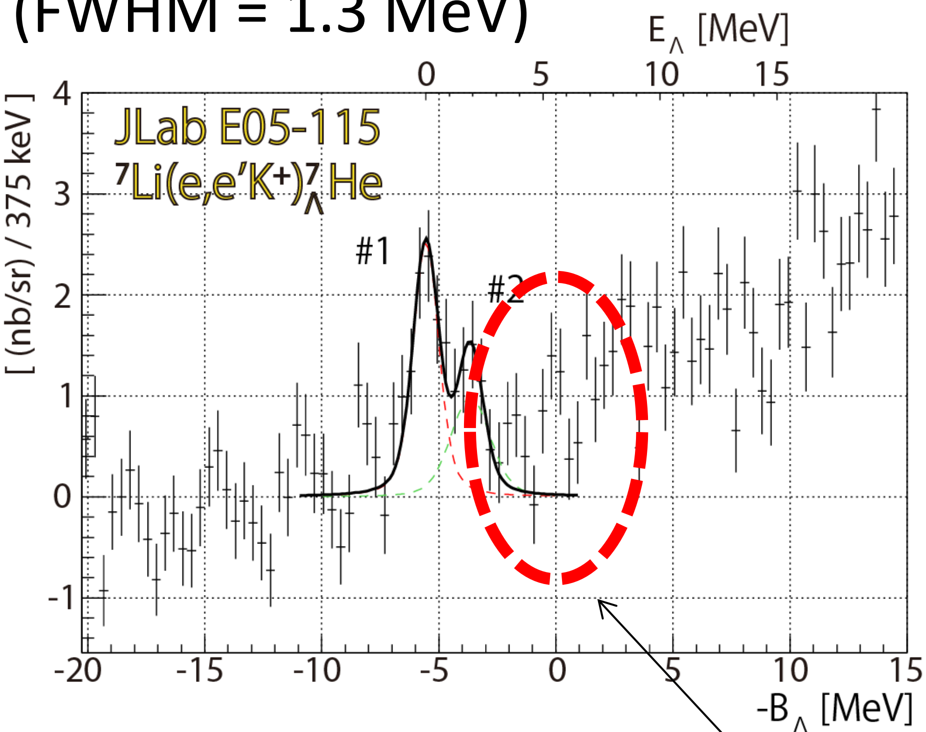
Motoba san recently estimated differential cross sections for each state.

At E^{lab}=1.5 GeV and θ=7 deg (E05-115 experimental kimenatics)

^{7}Li(e,e'K^{+})$^{7}_{\Lambda}$He

At present, due to poor statics,
It is difficult to have the third peak.
But, I hope that next experiment
at Jlab will observe the third peak.

(FWHM = 1.3 MeV)



Fitting results

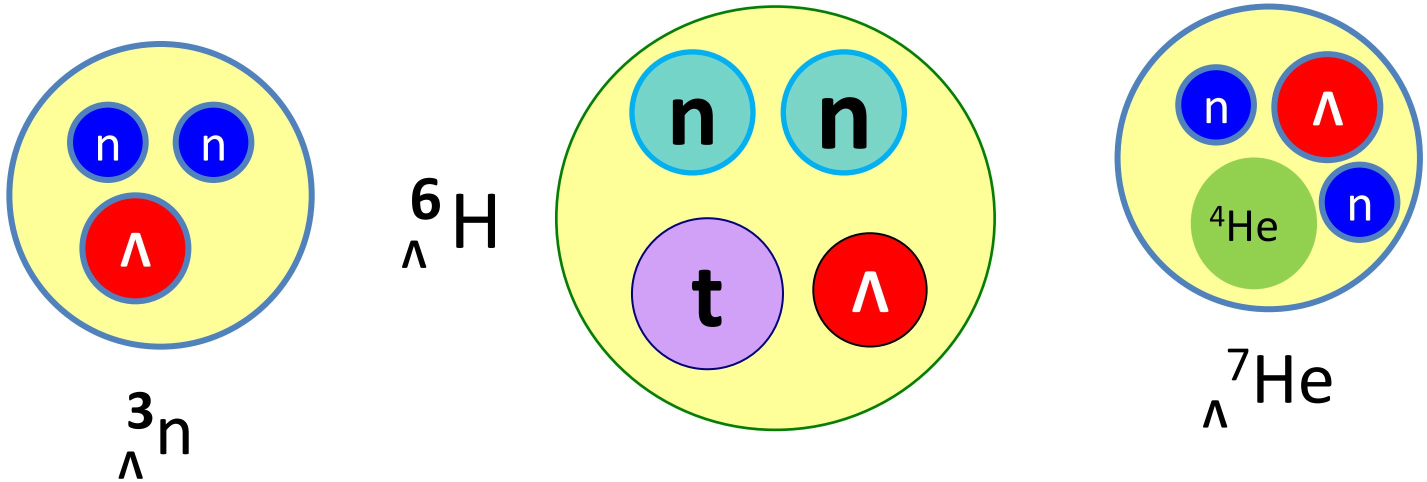
Peak number	State $^{6}\mathrm{He}[J_C] \otimes j^{\Lambda}$	Number of events	$-B_{\Lambda}$ [MeV] (E_{Λ})	$\left(\frac{d\sigma}{d\Omega_K}\right)\Big\vert_{1^\circ-13^\circ}$ [nb/sr]
1	$1/2^{+}$ $[0^{+}; \mathrm{g.s.}] \otimes s^{\Lambda}_{1/2}$	413±20	-5.55±0.10±0.11 (0.0)	10.7±0.5±1.7
2	$3/2^{+}, 5/2^{+}$ $[2^{+}; 1.80] \otimes s^{\Lambda}_{1/2}$	239±15	-3.65±0.20±0.11 (1.90±0.22±0.05)	6.2±0.4±1.0

Good agreement with my prediction

Third peak???

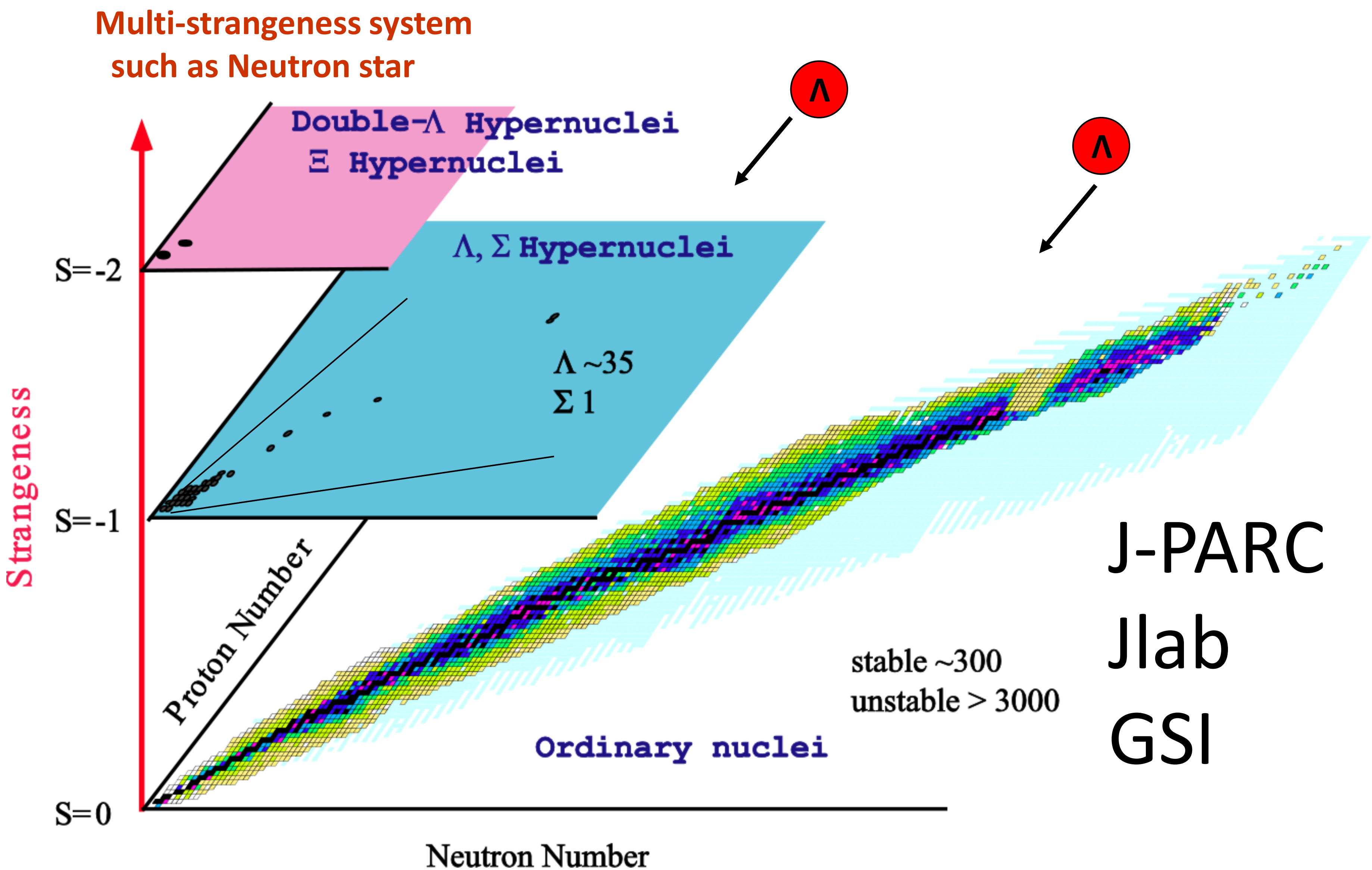
They plan to submit their proposal for $^{7}_{\Lambda}$He to JLab next June.

Summary



Neutron-rich Λ hypernuclei

Nuclear chart with strangeness



J-PARC
Jlab
GSI

Thank you!