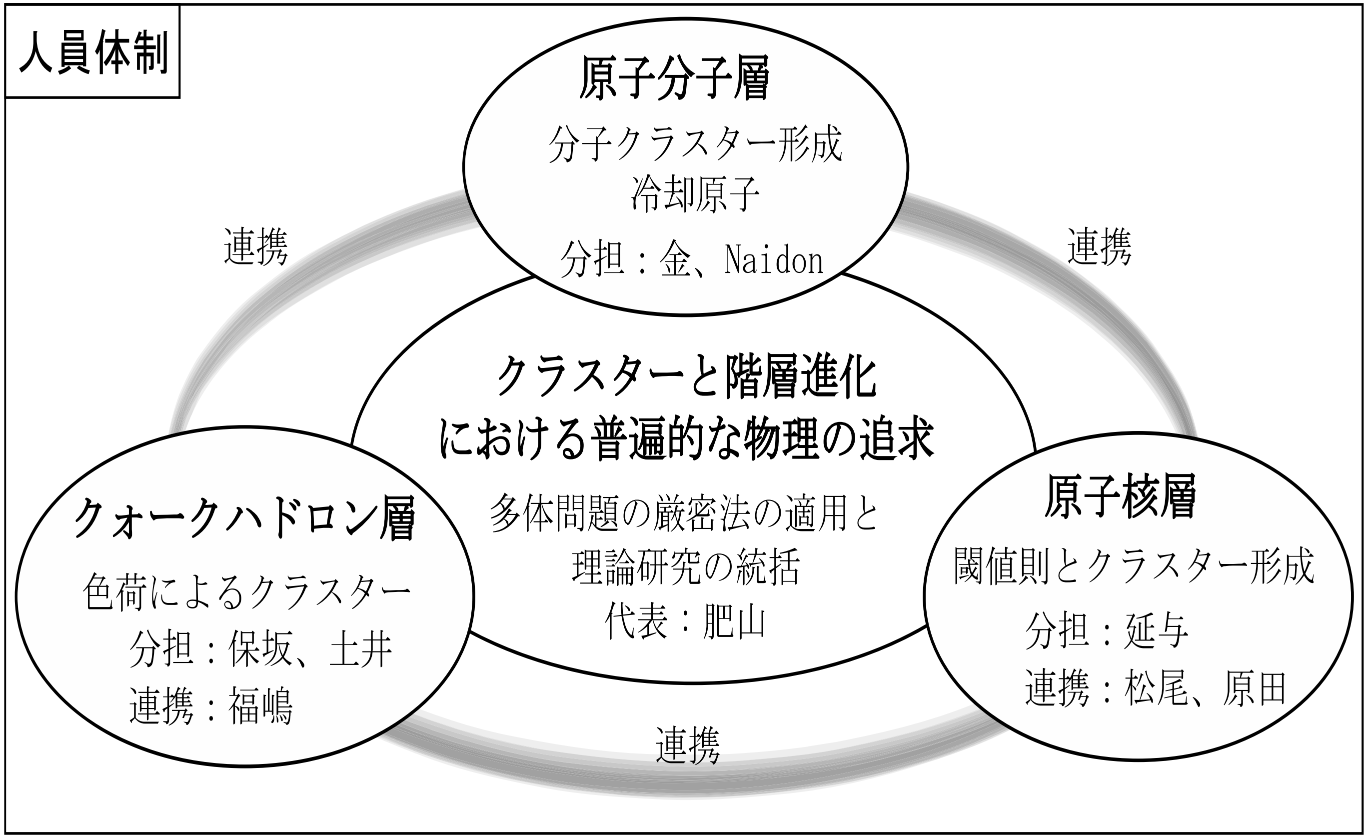
少数多体系問題から見た原子・原子核・ハドロン

肥山詠美子（九大/理研）

第一原理計算の観点から、階層構造の解明へ



格子QCDによるハドロン間相互作用の統一的理解：土井琢身（理研）

ハドロン物理の反応生成の研究：保坂淳（阪大RCNP） ⟷ 共同研究

原子核のクラスター形成メカニズムの研究：延与佳子（京大）

第一原理分子動力学法による原子・分子凝縮系
ダイナミクスの研究：金賢得（京大）

冷却原子によるエフィモフ状態の研究：Naidon Pascal（理研）

⟷ 共同研究

第一原理計算による原子・分子、原子核・ハドロン物理の包括的研究：
肥山詠美子（九大/理研）

新学術領域が始まった今、行っていること：格子QCDによる
ΞN相互用＋少数多体系計算

B01班との連携

Quark model estimate of hidden-charm pentaquark resonances

Emiko Hiyama*
Department of Physics, Kyushu University, Fukuoka, Japan, 819-0395
Nishina Center for Accelerator-Based Science, RIKEN, Wako, 351-0198, Japan
Advanced Science Research Center, Japan Atomic Energy Agency, Tokai, Ibaraki, 319-1195 Japan and
Research Center for Nuclear Physics, Osaka University, Ibaraki, Osaka 567-0047, Japan

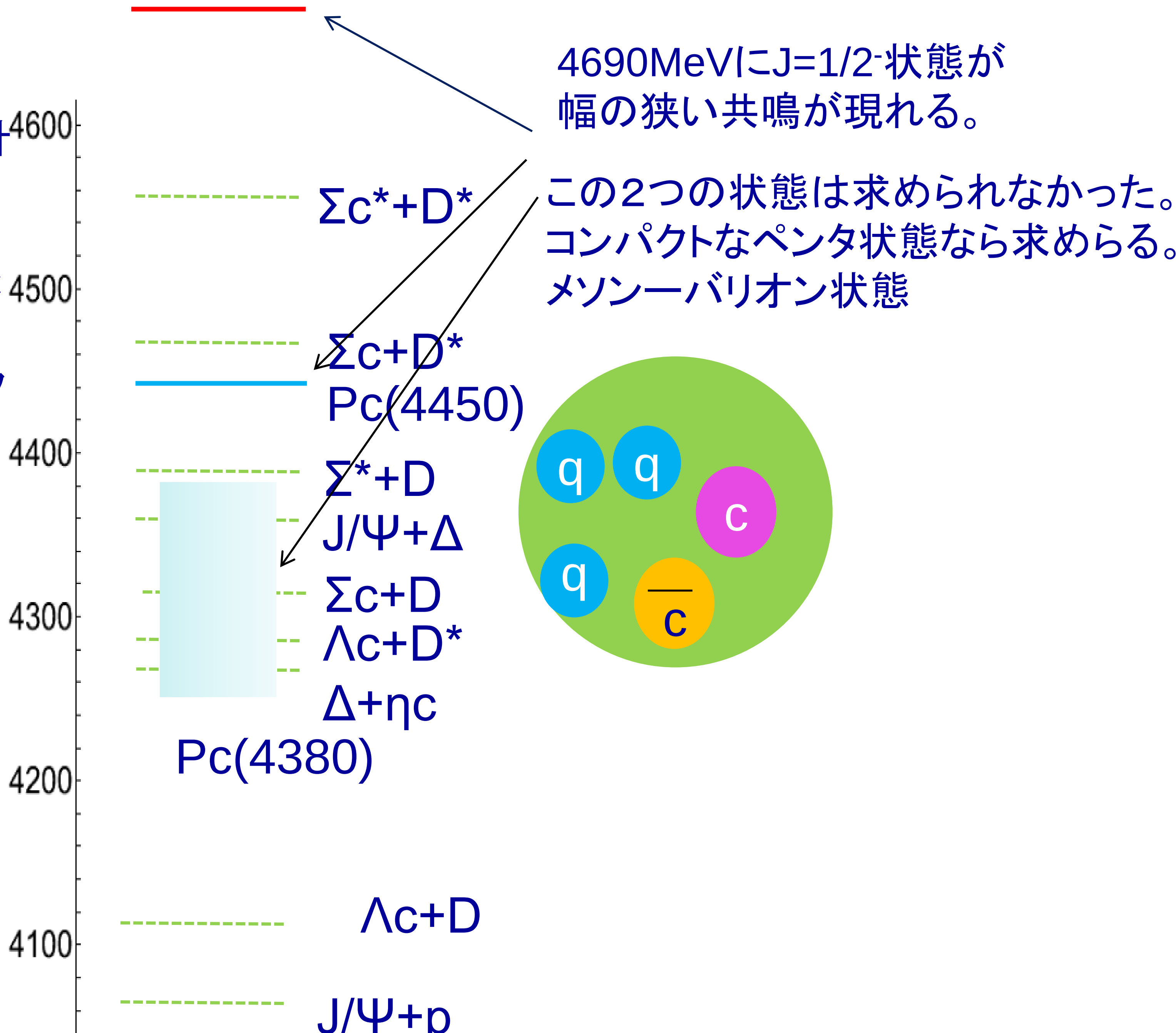
Atsushi Hosaka†
Research Center for Nuclear Physics, Osaka University, Ibaraki, Osaka 567-0047, Japan and
Advanced Science Research Center, Japan Atomic Energy Agency, Tokai, Ibaraki, 319-1195 Japan

Makoto Oka‡
Department of Physics, H-27, Tokyo Institute of Technology, Meguro, Tokyo 152-8551, Japan and
Advanced Science Research Center, Japan Atomic Energy Agency, Tokai, Ibaraki, 319-1195, Japan

Jean-Marc Richard§
Université de Lyon, Institut de Physique Nucléaire de Lyon, IN2P3-CNRS–UCBL,
4 rue Enrico Fermi, 69622 Villeurbanne, France
(Dated: March 23, 2018)

Published in PRC last month

ペンタクオーク
の共鳴状態を計算するコードが
完成。
今後のJ-PRACなどでの
テトラやペンタクオーク
のクラスター解析に
活用可能



格子QCDによるハドロン間相互作用の統一的理解：土井琢身（理研）

ハドロン物理の反応生成の研究：保坂淳（阪大RCNP) ⟷
共同研究

原子核のクラスター形成メカニズムの研究：延与佳子（京大）

第一原理分子動力学法による原子・分子凝縮系
ダイナミクスの研究：金賢得（京大）

冷却原子によるエフィモフ状態の研究：Naidon Pascal（理研）
⟷ Collaboration: talk

第一原理計算による原子・分子、原子核・ハドロン物理の包括的研究：
肥山詠美子（九大/理研）

新学術領域が始まった今、行っていること：格子QCDによる
ΞN相互用＋少数多体系計算

B01班との連携

Major goals of hypernuclear physics

To understand baryon-baryon interactions

Fundamental and important for the study of nuclear physics

Total number of
Nucleon (N) -Nucleon (N) data: 4,000

↕

- Total number of differential cross section
  Hyperon (Y) -Nucleon (N) data: **40**
- **NO** YY scattering data

⇒

YN and YY potential models so far proposed (ex. Nijmegen, Julich, Kyoto-Niigata) have large ambiguity.

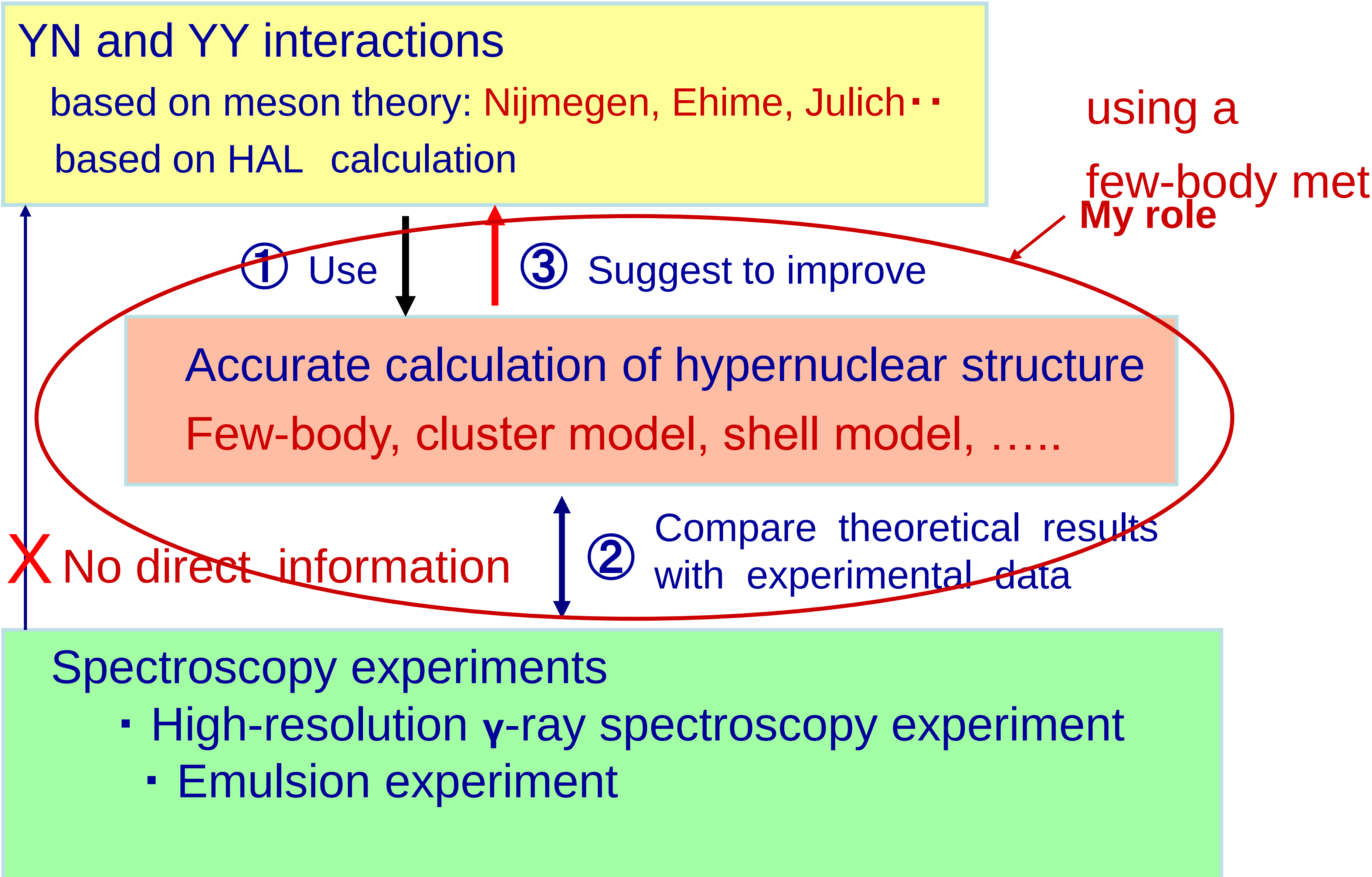
Therefore, as a substitute for the 2-body

limited YN and non-existent YY scattering data,

the systematic investigation of the

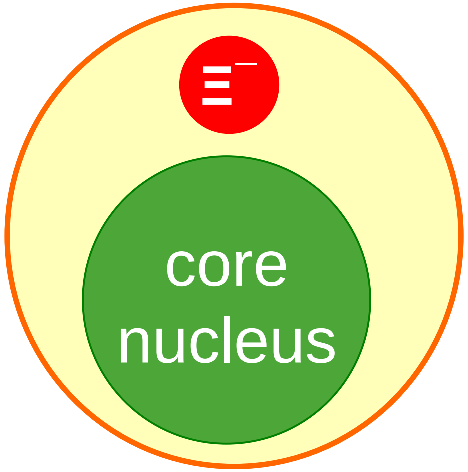
structure of light hypernuclei is essential.

Strategy to determine YN and YY interactions from the studies of light hypernuclear structure



For this purpose, we have been obtaining information on ΛN interaction.

Next step, it is important to extract information on ΞN interaction.



For the study of ΞN interaction, it is important to study the structure of Ξ hypernuclei.

PTEP

Prog. Theor. Exp. Phys. **2015**, 033D02 (11 pages)
DOI: 10.1093/ptep/ptv008

The first evidence of a deeply bound state of Xi$^-$–^{14}N system

K. Nakazawa[1,*], Y. Endo[1], S. Fukunaga[2], K. Hoshino[1], S. H. Hwang[3], K. Imai[3], H. Ito[1], K. Itonaga[1], T. Kanda[1], M. Kawasaki[1], J. H. Kim[4], S. Kinbara[1], H. Kobayashi[1], A. Mishina[1], S. Ogawa[2], H. Shibuya[2], T. Sugimura[1], M. K. Soe[1], H. Takahashi[5], T. Takahashi[5], K. T. Tint[1], K. Umehara[1], C. S. Yoon[4], and J. Yoshida[1]

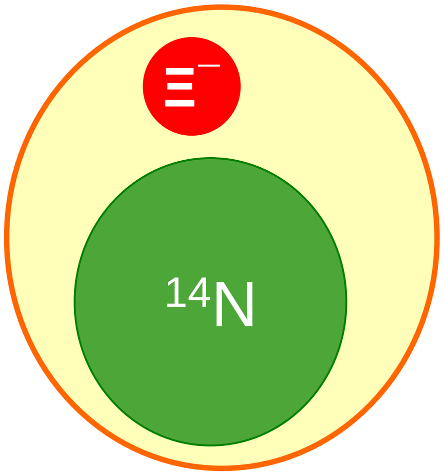
[1] *Physics Department, Gifu University, 1-1 Yanagido, Gifu 501-1193, Japan*
[2] *Department of Physics, Toho University, Funabashi 274-8510, Japan*
[3] *Advanced Science Research Center, JAEA, Tokai 319-1195, Japan*
[4] *Department of Physics, Gyeongsang National University, Jinju 660-701, Korea*
[5] *Institute of Particle and Nuclear Studies, KEK, Tsukuba 305-0801, Japan*
*E-mail: nakazawa@gifu-u.ac.jp

Received October 27, 2014; Revised December 25, 2014; Accepted January 9, 2015; Published March 5, 2015

^{14}N-Ξ-

0 MeV

-4.38 ± 0.25 ～
-1.10 ± 0.25 MeV



Kiso event

We observed bound Ξ hypernucleus, for the first time in the world. Now, we understood that ΞN interaction should be attractive. Also, it is important to interpret spin-parity by comparing theory and experimental data.

Physical Review C 94, 064319 (2016)

Mean field approaches for Ξ^- hypernuclei and current experimental data

T. T. Sun,[1,2] E. Hiyama,[1,*] H. Sagawa,[1,3] H.-J. Schulze,[4] and J. Meng[5,6]

[1]*RIKEN Nishina Center, Wako 351-0198, Japan*
[2]*School of Physics and Engineering, Zhengzhou University, Zhengzhou 450001, China*
[3]*Center for Mathematics and Physics, University of Aizu, Aizu-Wakamatsu, Fukushima 965-8560, Japan*
[4]*INFN Sezione di Catania, Via Santa Sofia 64, I-95123 Catania, Italy*
[5]*School of Physics and State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, China*
[6]*School of Physics and Nuclear Energy Engineering, Beihang University, Beijing 100191, China*

Motivated by the recent observed ${}^{15}_{\Xi}\mathrm{C}({}^{14}\mathrm{N}+\Xi^-)$ of Kiso event, we identify the state of this system theoretically within the framework of the relativistic-mean-field and Skyrme-Hartree-Fock theories. The ΞN interactions are constructed to reproduce two possible observed Ξ^- binding energies, 3.8 MeV and 1.1 MeV. The present result is preferable to be ${}^{14}\mathrm{N(g.s.)}+\Xi^-(1p)$ which is consistent with the experimental interpretation by Kiso event.

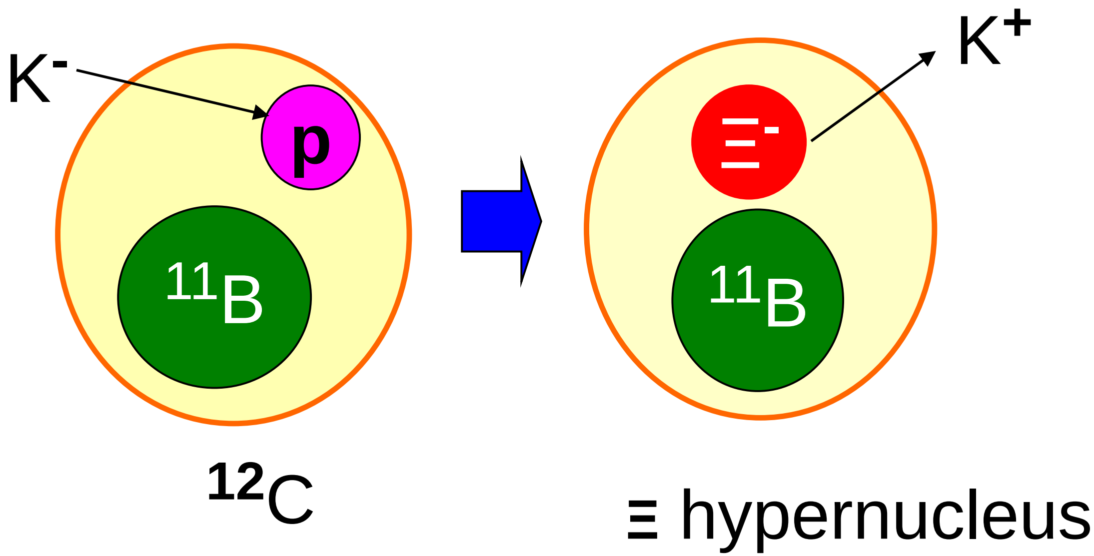
PACS numbers: 21.80.+a, 13.75.Ev, 21.60.Jz, 21.10.Dr

Using RMF theory, we interpret that Kiso event is observation of ^{14}N(g.s) +Ξ(0p) state.
Weak point: RMF theory focus on the only ground state of ^{14}N, not the excited state of ^{14}N. It is planning to take into account of the excited state of ^{14}N for further analysis of Kiso event using α+α+α+d+Ξ 5-body cluster model.

“Spectroscopic study of Ξ-Hypernucleus, $^{12}_{\Xi^-}$Be,

via the ^{12}C(K$^-$,K$^+$) Reaction”

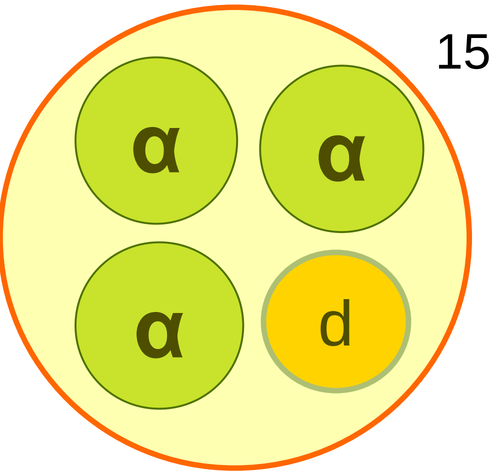
by Nagae and his collaborators



This experiment has been done.
Also it is planned to perform this experiment again to confirm bound states in this system.

Question: what kind of part in ΞN interaction can we extract in this Ξ hypernucleus, theoretically?

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

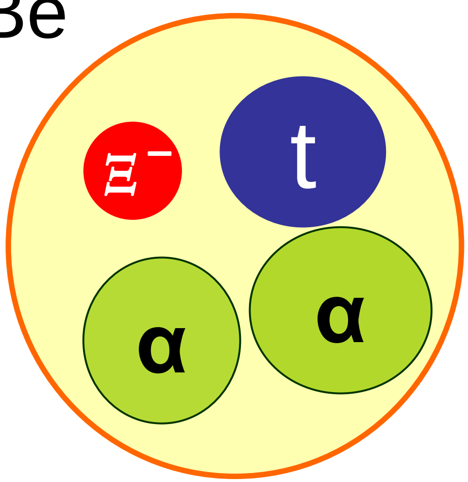


$^{15}_{\Xi}C$

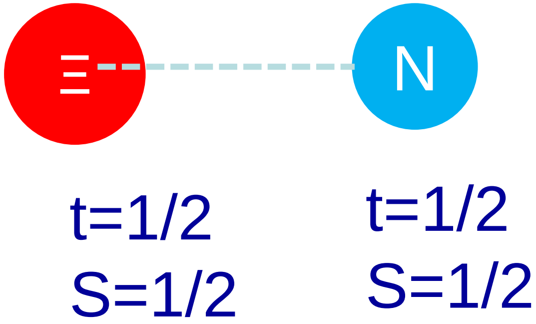
In this way, we are finding to have bound states in these systems and then we shall get information that $V_{\Xi N}$ itself is attractive.

All of the terms contribute to binding energy of $^{12}_{\Xi^-}Be$ and $^{15}_{\Xi}C$ (^{11}B and ^{14}N is not spin-, isospin- saturated).

$^{12}_{\Xi^-}Be$

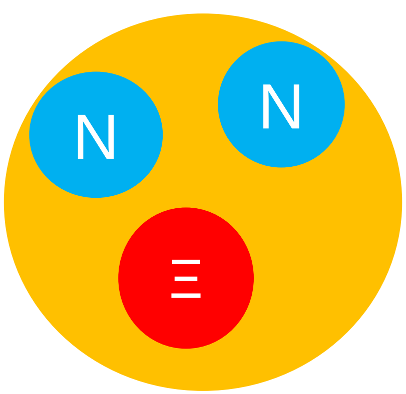


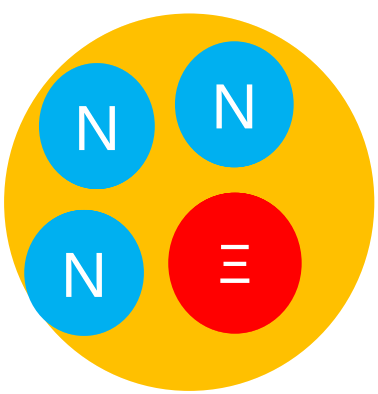
ΞN interaction: T=0, S=0
T=0, S=1
T=1, S=0
T=1, S=1

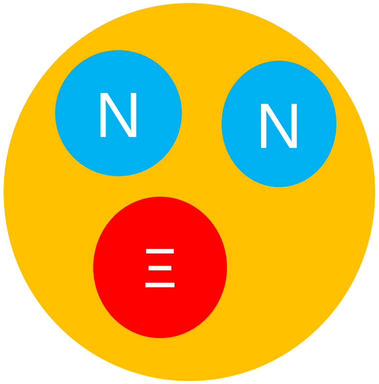


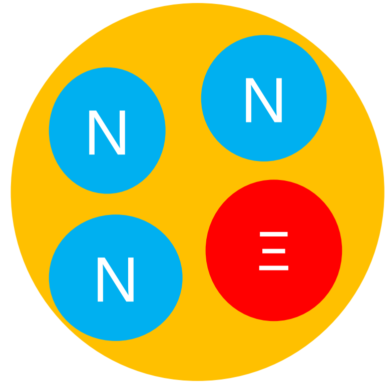
We want to know which partial wave is attractive or repulsive.

The suited systems to study are s-shell Ξ hypernuclei such as NNΞ and NNNΞ systems.









I show my new results of these light systems.

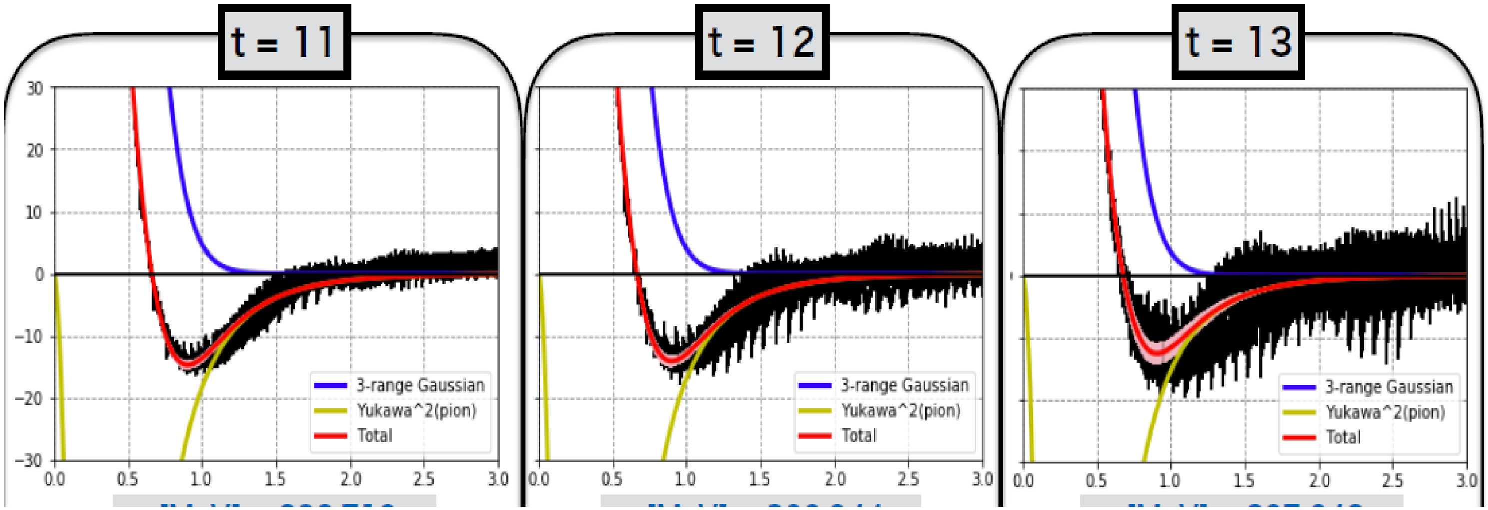
NN interaction: AV8 potential
ΞN interaction :
Nijimegen extended soft core potential (ESC08c)
Realistic potential (only ΞN channel)

ΞN interaction by HAL collaboration (Lattice QCD calculation)
The potential was made by K. Sasaki and Miyamoto.

HAL potential

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

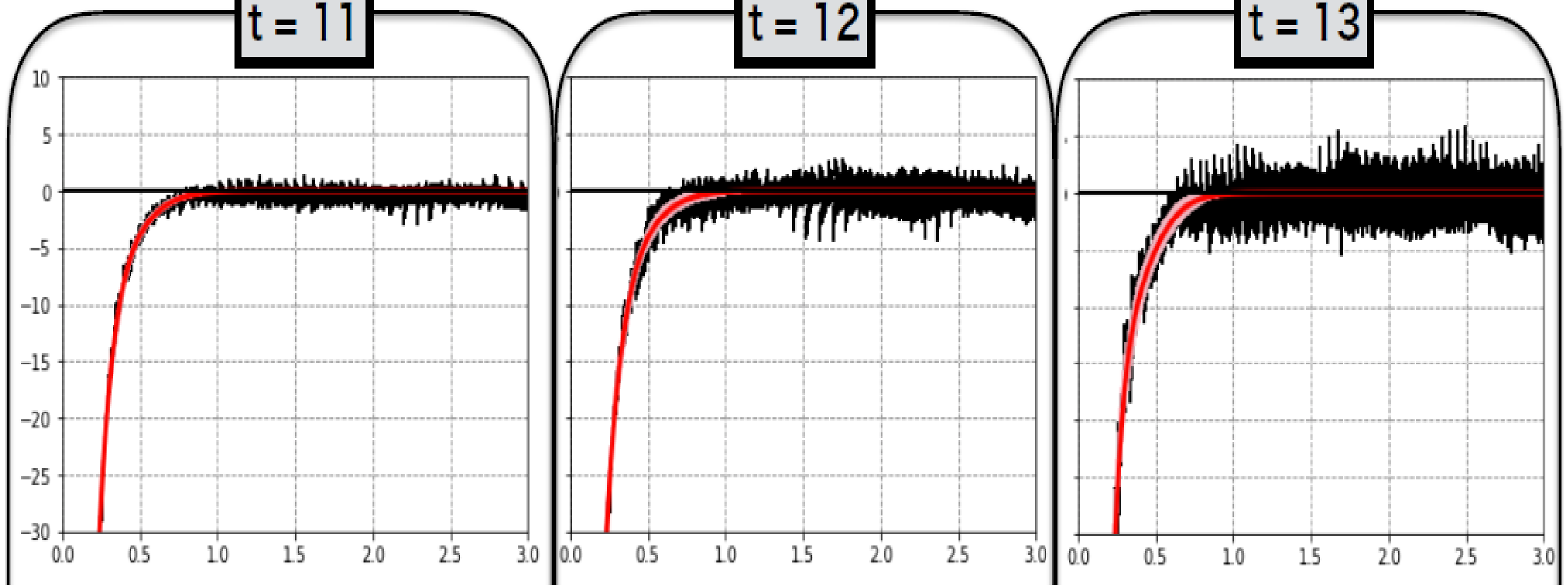
All terms are central parts only.



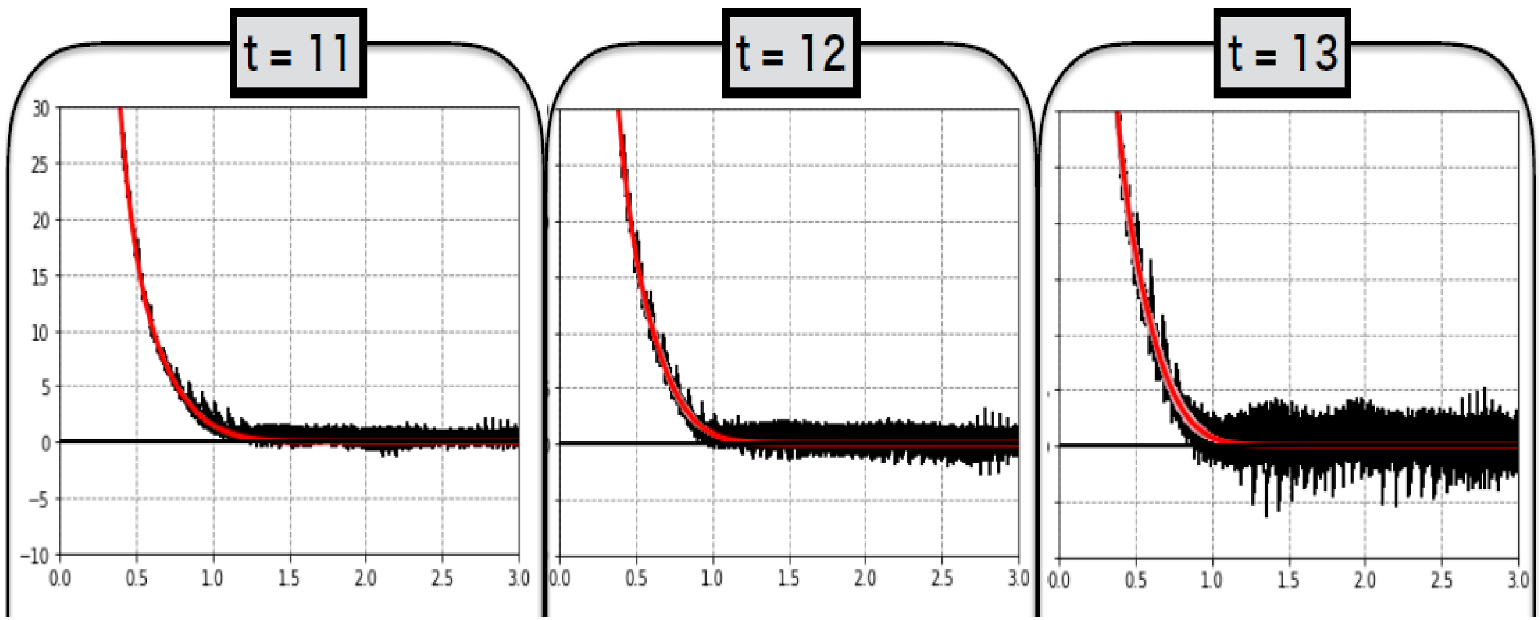
$V_0(r)$

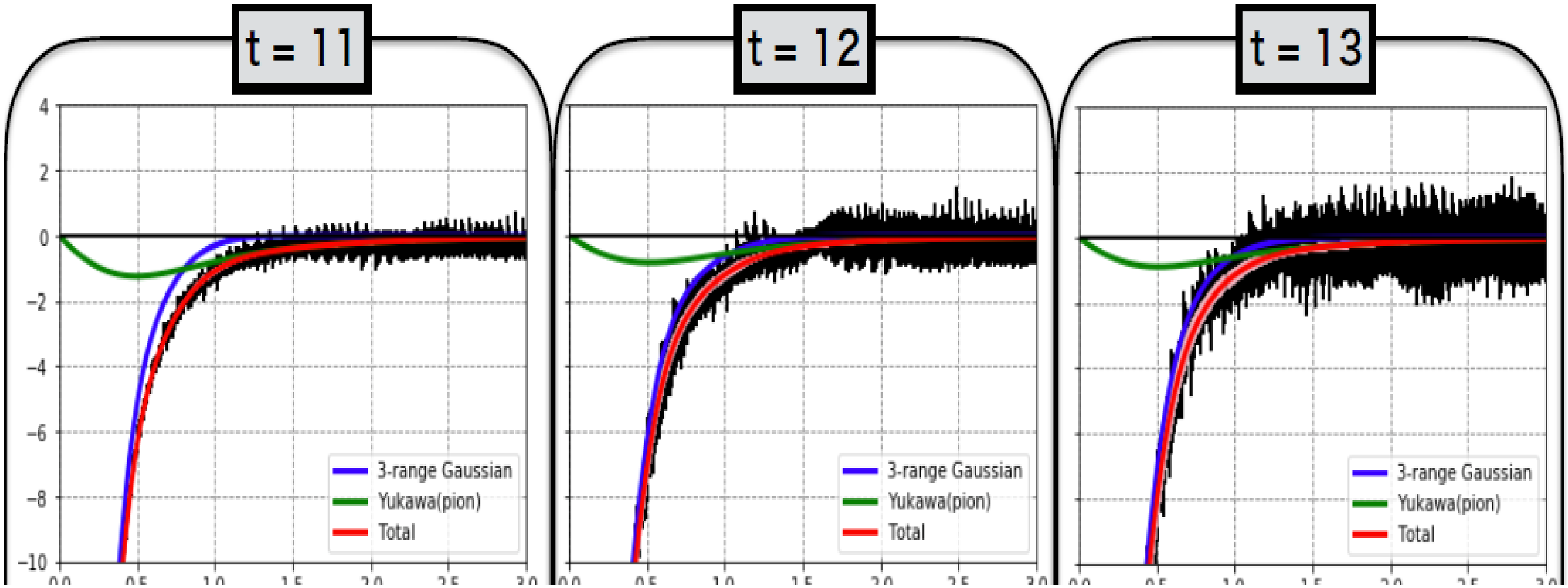
In HAL potential , the statistical errors are NOT included.

$(\sigma_\Xi \cdot \sigma_N) V_s(r)$



$(\tau_\Xi \cdot \tau_N) V_t(r)$





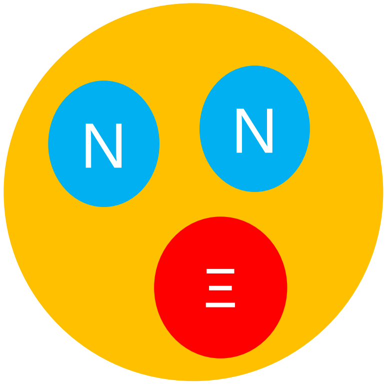
$$(\sigma_{\Xi} \cdot \sigma_N)(\tau_{\Xi} \cdot \tau_N) V_{ts}(r)$$

Property of the spin- and isospin-components of ESC08 and HAL

V(T,S)	ESC08c	HAL
T=0, S=1	strongly attractive	Weakly attractive
T=0, S=0	weakly repulsive	Strongly attractive
T=1, S=1	strong attractive	Weakly attractive
T=1, S=0	weakly repulsive	Weakly repulsive

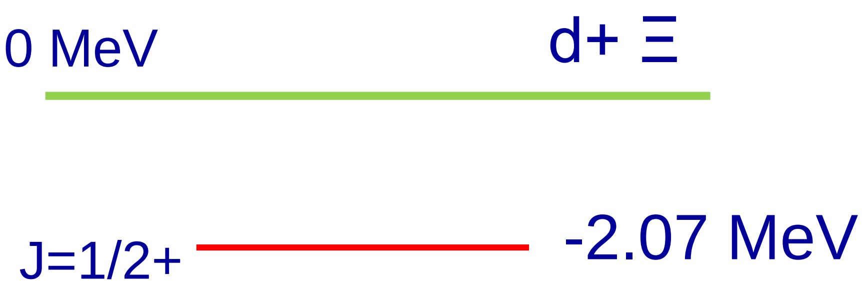
Although the spin- and isospin-components of these two models are very different between them.

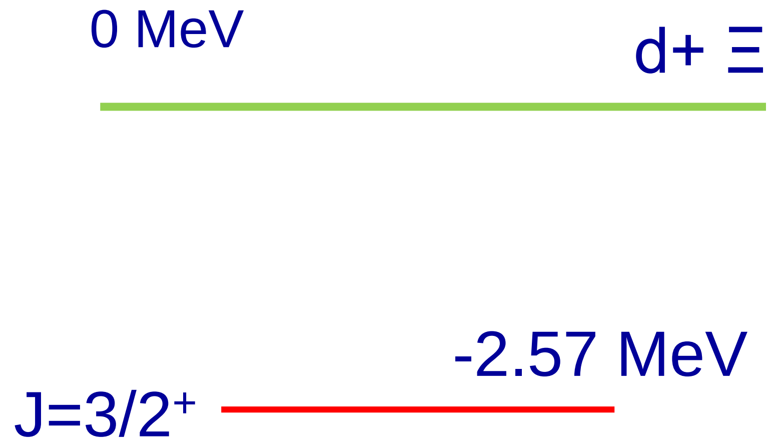
It is interesting to see the difference in the energy spectra in s-shell Ξ hypernuclei.



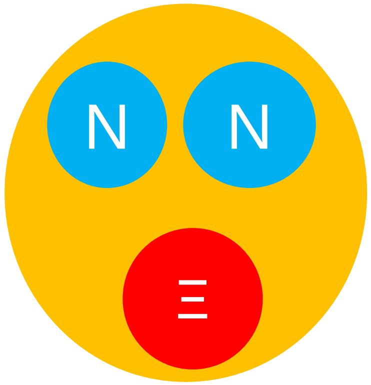
T=1/2, J=1/2$^+$ and J=3/2$^+$

ESC08c





I used the different version of ESC08c (realistic force).
However, I also have two bound states in three-body system.



T=1/2, J=1/2^{+} and J=3/2^{+}

HAL potential

0 MeV

d+ Ξ

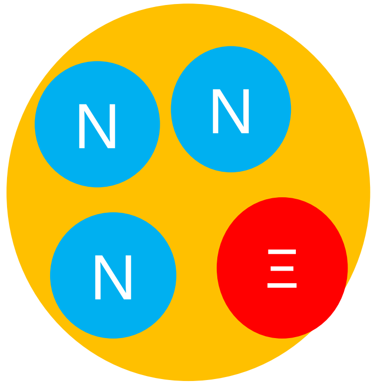
0 MeV

d+ Ξ

J=1/2+

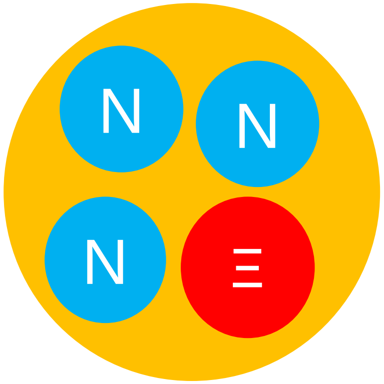
No bound state

J=3/2^{+}



T=1 state

ESC08c		HAL potential	
0 MeV	3N+Ξ	0 MeV	3N+Ξ
-1.81 MeV	0^+	No bound state	
-8.84MeV	1^+		



In HAL potential , the statistical errors are NOT included.

T=0 state

0 MeV

$3N+\Xi$

-7.76 MeV

$J=1^+$

ESC08c

0 MeV

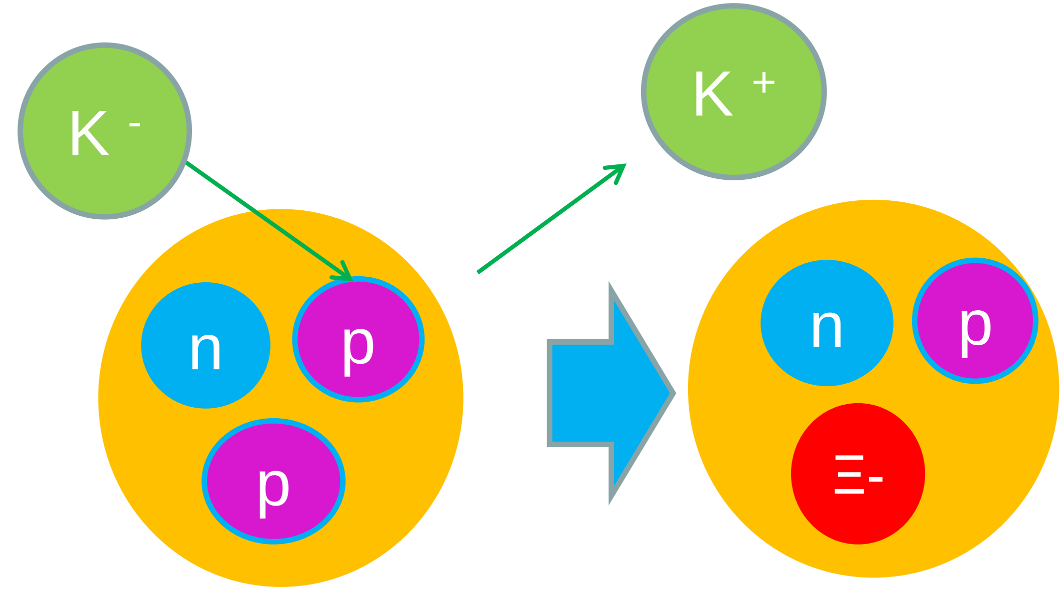
$3N+\Xi$

1^+

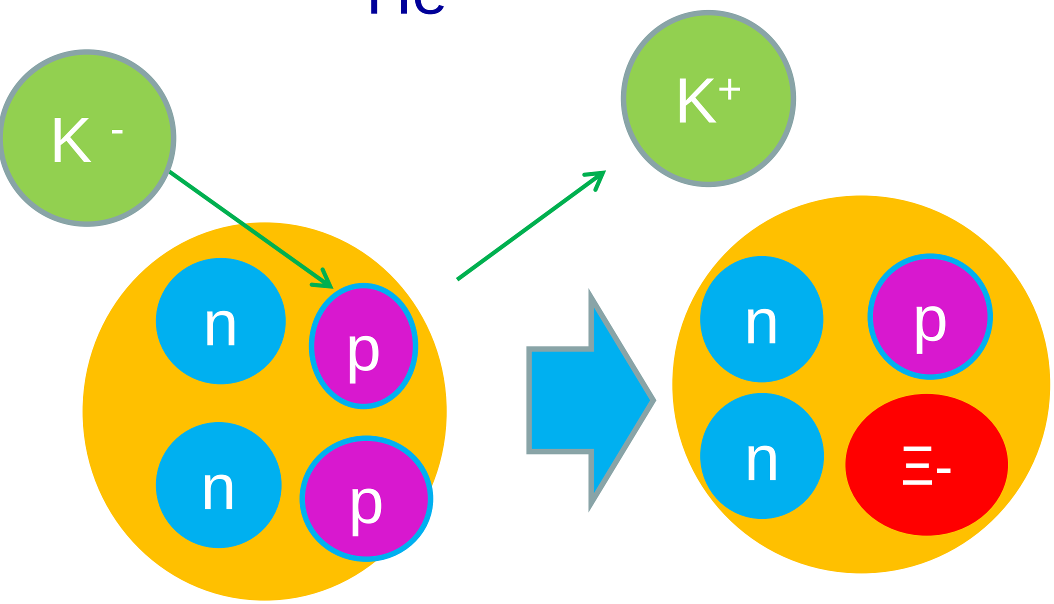
0.01 MeV～0.3 MeV

Preliminary result

HAL potential



^{3}He



^{4}He

T=1

It is possible to produce NNΞ three-body system using 3He target.

T=1/2

If we use Nijimegen potential, T=1 four-body system becomes bound state.
But, HAL potential does not produce bound state in T=1 system,
But produce a bound state for T=0 state.
How do we produce bound state with T=0?
One possibility is to use heavy ion collision Experiment.

格子QCDによるハドロン間相互作用の統一的理解：土井琢身（理研）

ハドロン物理の反応生成の研究：保坂淳（阪大RCNP)

原子核のクラスター形成メカニズムの研究：延与佳子（京大）

第一原理分子動力学法による原子・分子凝縮系
ダイナミクスの研究：金賢得（京大）

冷却原子によるエフィモフ状態の研究：Naidon Pascal（理研）

第一原理計算による原子・分子、原子核・ハドロン物理の包括的研究：
肥山詠美子（九大/理研）

新学術領域が始まった今、行っていること：格子QCDによる
ΞN相互用＋少数多体系計算

B01班との連携

理論班としての活動:

・物質階層を考える会
第1回: ΞN相互作用とその実験について(10月15日京大基研)
第2回: Σ―p散乱実験の現状およびΣN相互作用に関連した話題
(12月4日理研)
Specificな話題を議論したい人、いつでもwelcome

International lecture series
第1回
Lecturers:Jaume Carbonel(Orsay)
Title : The Few-Nucleon System : from Yukawa to LQC
日時・場所:11月28日13:30ー16:10・ウエスト1号館B211
11月29日13:30-17:30・ウエスト1号館B211
11月30日10:30ー16:10・ウエスト1号館A711

- The second lecture

8th Jan. 2018, RIKEN

- Pascal Naidon
- Efimov state

The third lecture

20th ～ 23th Feb., Kyoto Univ.

Organized by Kim san

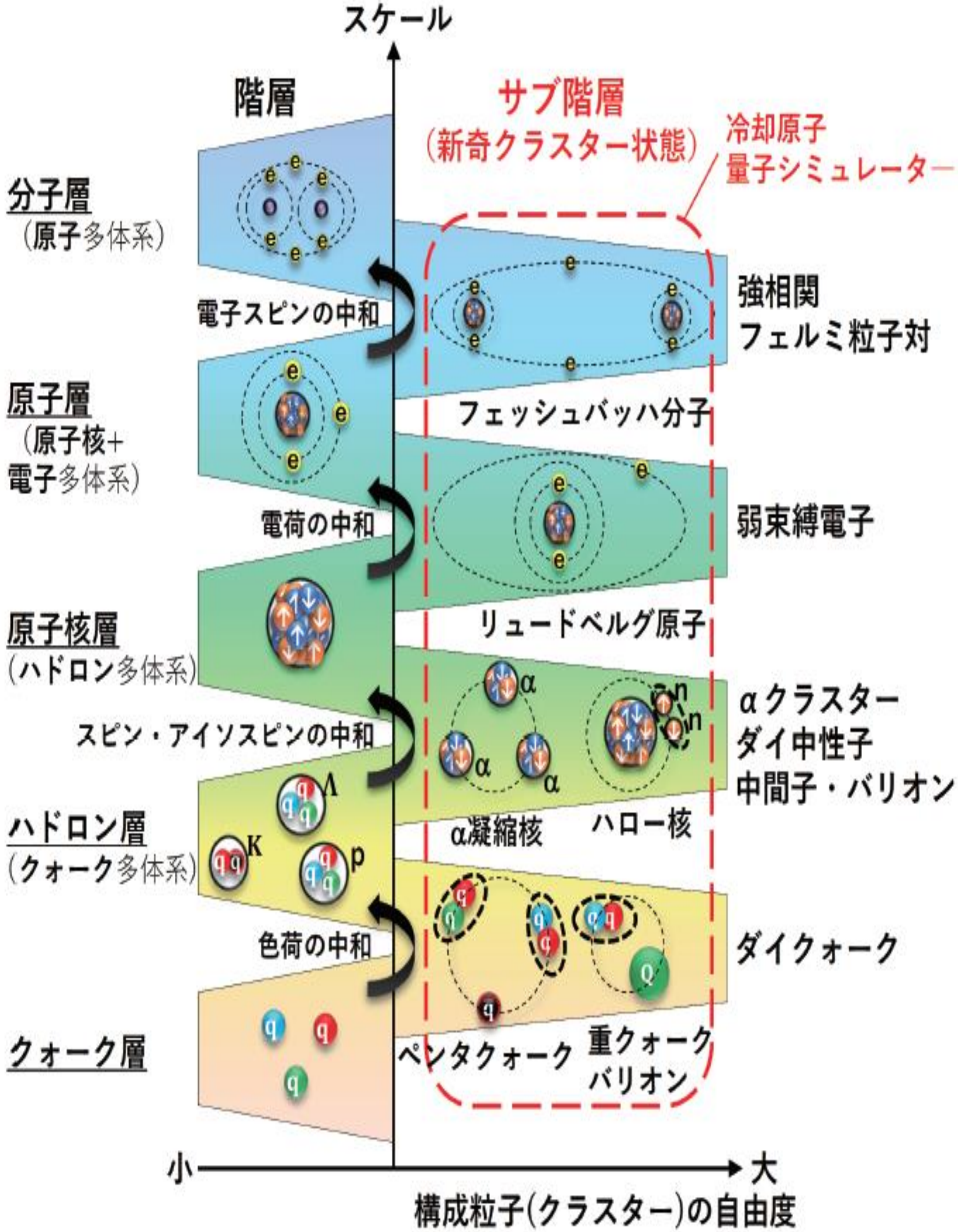
Atomic and molecular physics

The fourth lecture

Evgeny Epelbaum (Ruhr-Universität Bochum)

22th and 23 March, Kyoto Univ.

Organized by Enyo san



スケール
階層
サブ階層
(新奇クラスター状態)
冷却原子
量子シミュレーター
分子層
(原子多体系)
電子スピンの中和
強相関
フェルミ粒子対
フェッシュバッハ分子
原子層
(原子核+
電子多体系)
電荷の中和
弱束縛電子
リュードベルグ原子
原子核層
(ハドロン多体系)
スピン・アイソスピンの中和
αクラスター
ダイ中性子
中間子・バリオン
α凝縮核
ハロー核
ハドロン層
(クォーク多体系)
色荷の中和
ダイクォーク
ペンタクォーク
重クォーク
バリオン
クォーク層
小
大
構成粒子(クラスター)の自由度