Investigation of Baryon Interactions with Strangeness (Group-B01)

2020/1/23

T.Takahashi (KEK-IPNS)

Contents

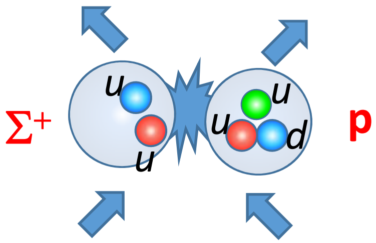
- Overview of Group-B01 researches
- Subjects and status of experiments at J-PARC
  - E40: Σp scattering
  - E42: Search for *H*-dibaryon
  - E03: X-ray spectroscopy of Ξ-atom
- Summary

Cluseters of strange hadrons for investigating hierarchical structure of matter (Group-B01)

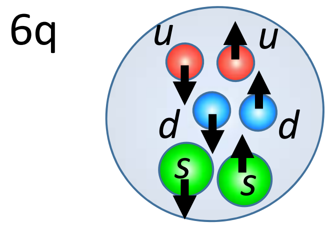
PI: H.Tamura (Tohoku U.), CI: T.Nagae (Kyoto U.), T.Takahashi (KEK), K.Miwa(Tohoku U.)

1. Origin of nuclear force

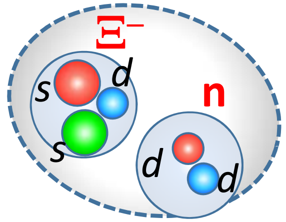
NN → YN and YY



Σp, Λp scattering exp.



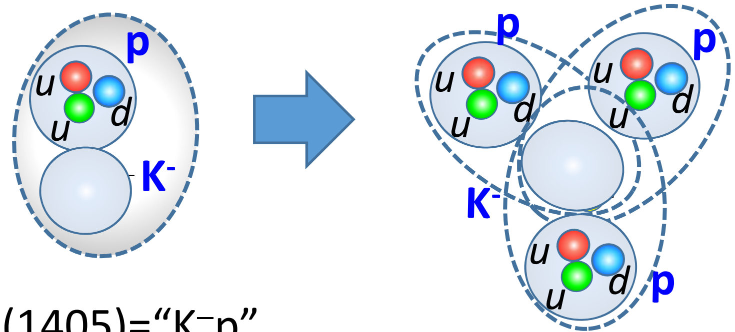
Search for *H*-dibaryon



Search for Ξ^-n bound nuclei

ΞN int. & Ξ-nuclei

2. Meson-Baryon molecule

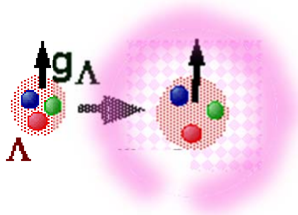


$\Lambda(1405)$="K^-p"

Strucure of "K^-ppp" nucleus

K^-pK^-p nucleus

3. In-medium baryon properties

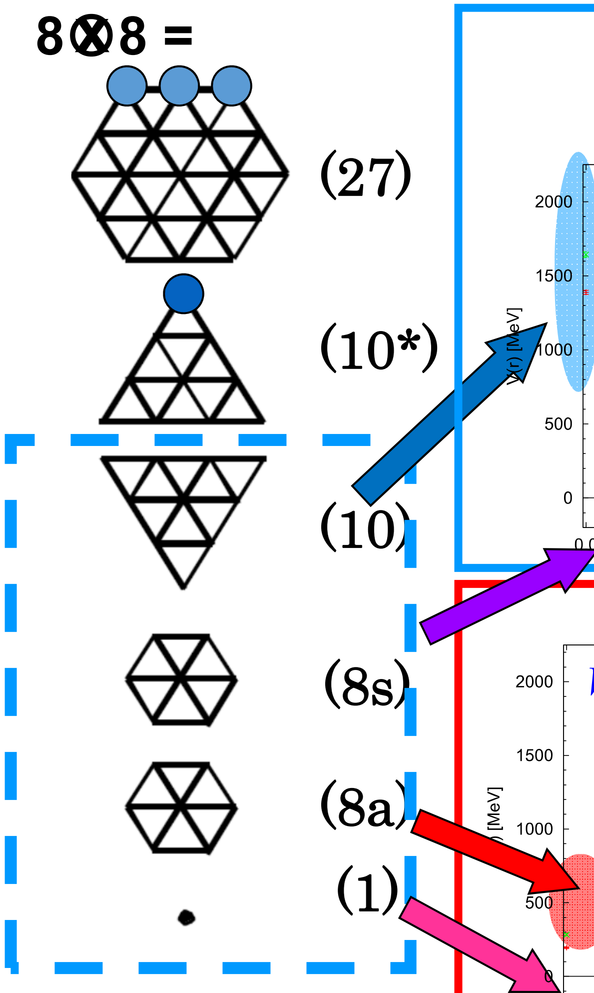


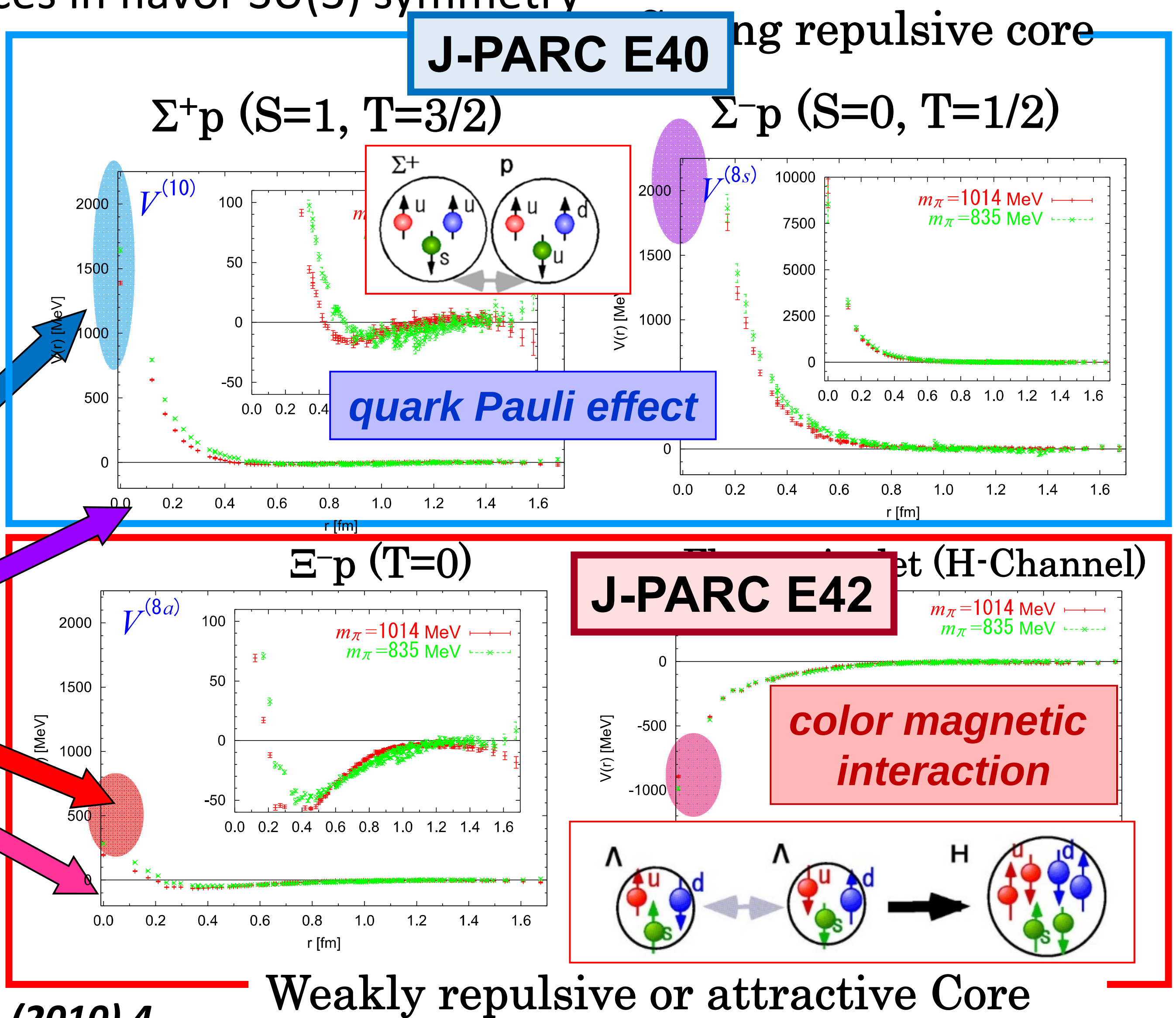
Modification of g_Λ in medium

Slide by Koji Miwa

Baryon Baryon interaction by Lattice QCD

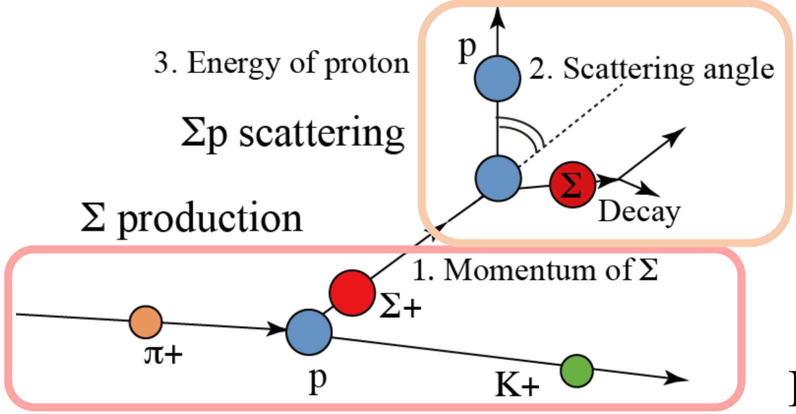
6 independent forces in flavor SU(3) symmetry



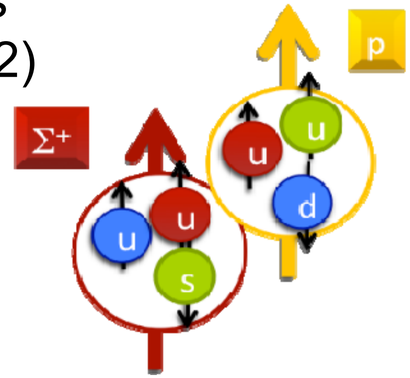


Lattice QCD calc.
T. Inoue et al.
Prog. Theor. Phys. 124 (2010) 4

J-PARC E40: $\Sigma^{\pm}p$ Scattering Experiment （Miwa et al.)



Very large repulsive core is predicted in ΣN (T=3/2,S=3/2) due to quark Pauli effect

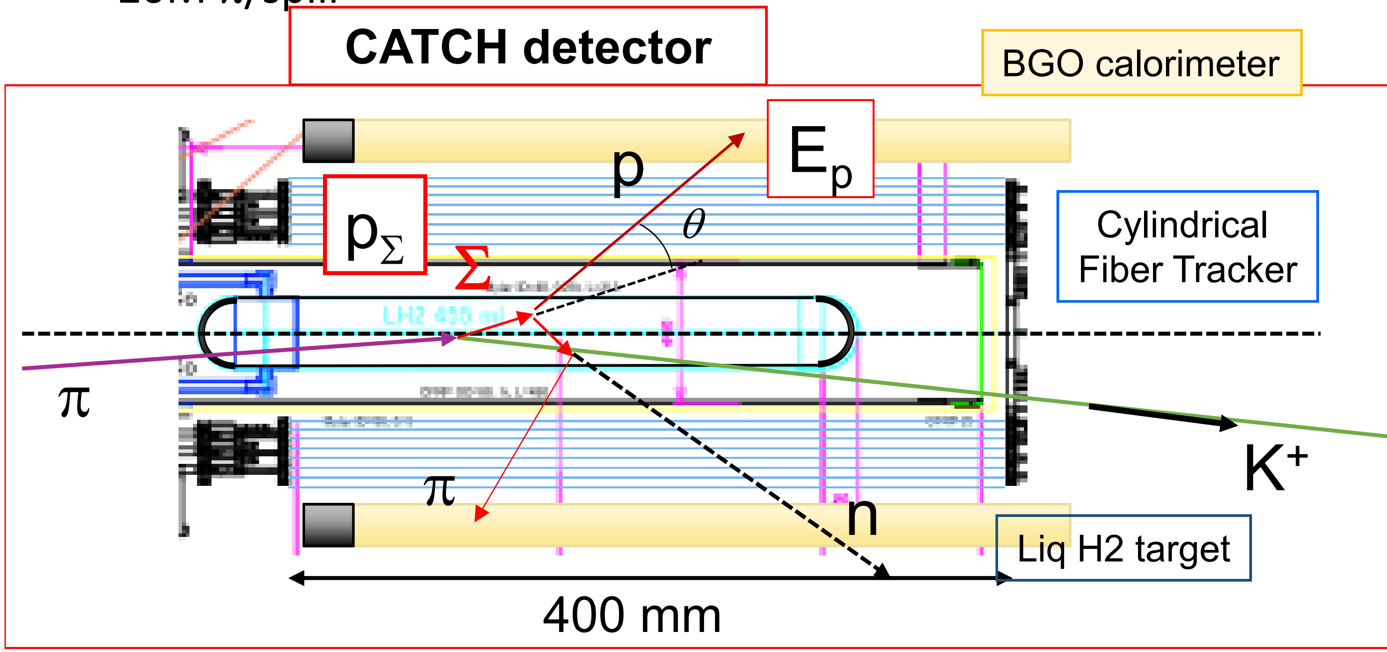


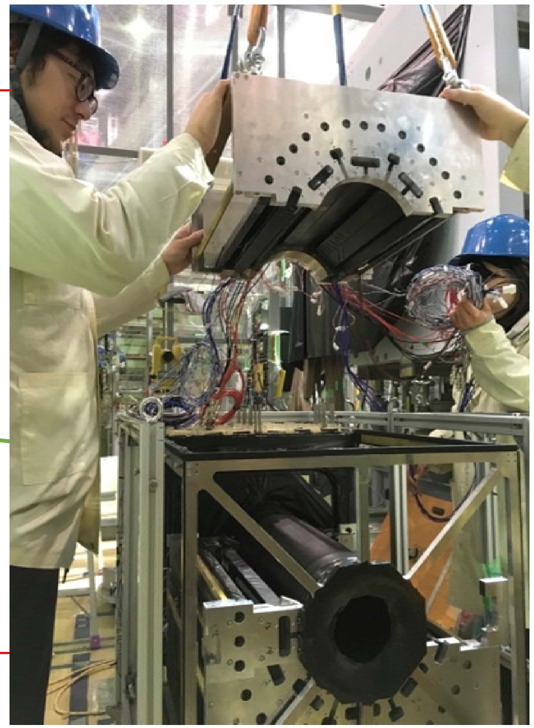
Σ production via $\pi^{\pm}p \rightarrow K^{+}\Sigma^{\pm}$

p_{Σ} = 0.4 ~ 0.8 GeV/c

Measure $d\sigma/d\Omega$ for $\Sigma^{+}p$, $\Sigma^{-}p$, $\Sigma^{-}p \rightarrow \Lambda n$

~20M π/spill





Slide by K. Miwa

History of E40: Σ-proton scattering exp.

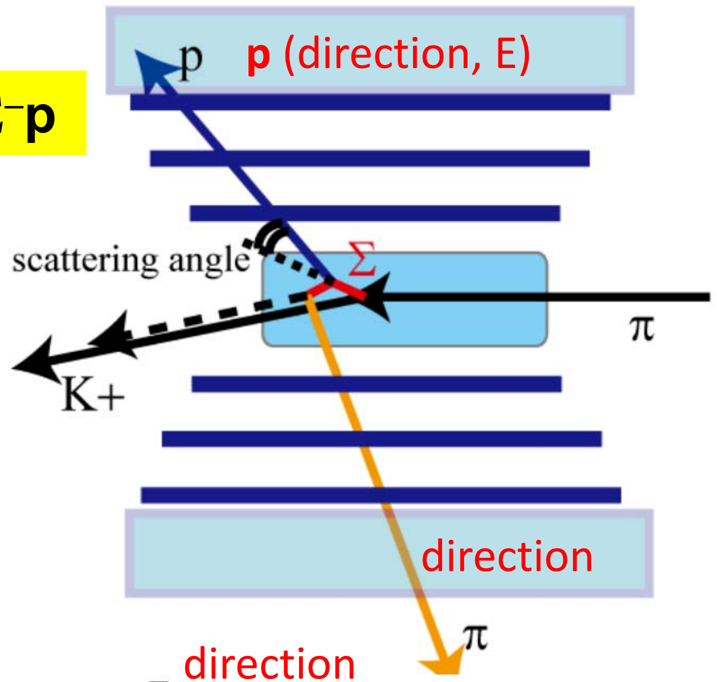
- Feb. 2018
  - Detector Commissioning
- June 2018
  - $\Sigma^{-}p$ 1st production run (~2 days)
- Feb. — Apr. 2019
  - $\Sigma^{-}p$ 2nd production run (~20 days) done
  - $\Sigma^{+}p$ 1st production run (~13 days)

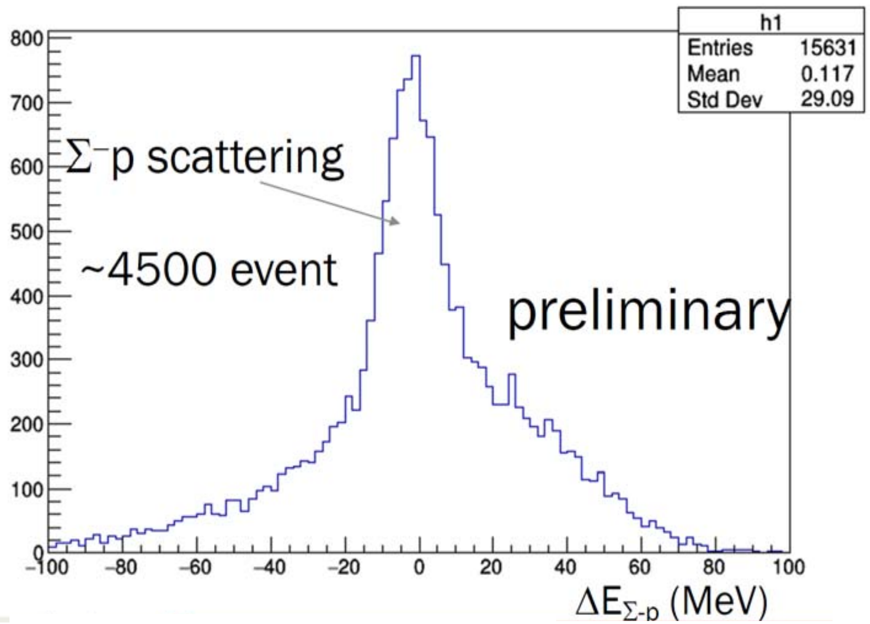
    terminated due to Acc. trouble
- Feb. 2020 —
  - $\Sigma^{+}p$ 2nd production run (~14 days) to be completed

Slide by K. Miwa

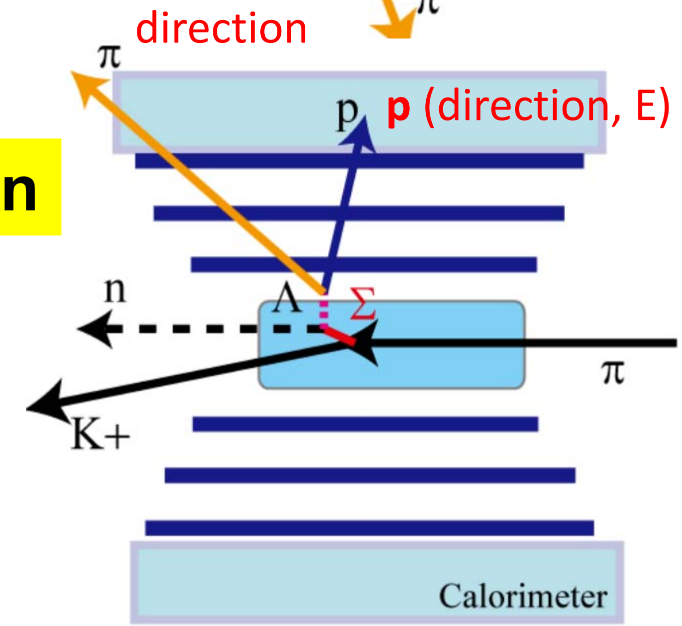
Kinematical matching

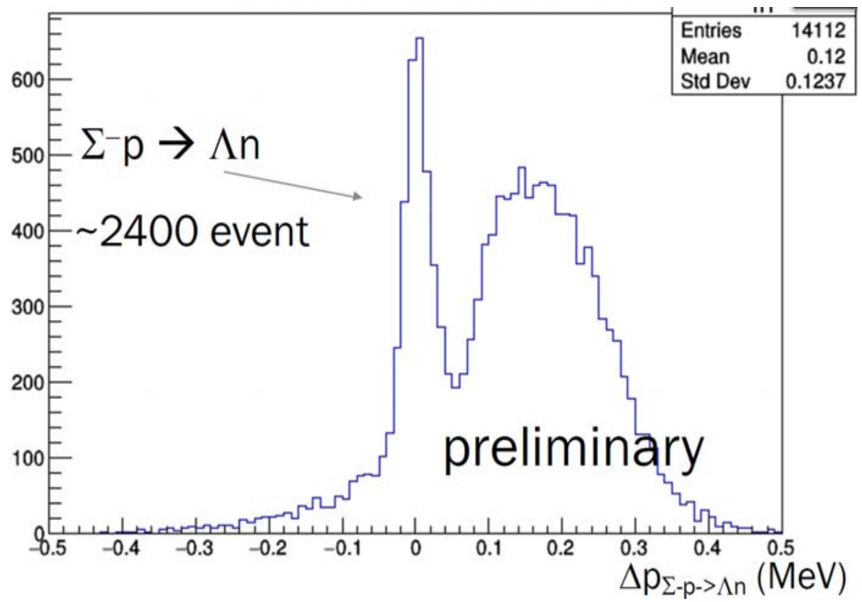
Σ⁻p → Σ⁻p





Σ⁻p → Λn

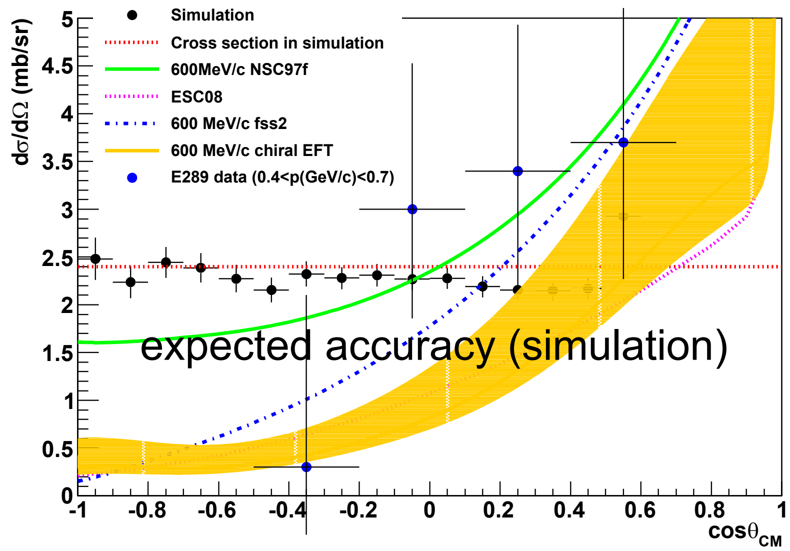




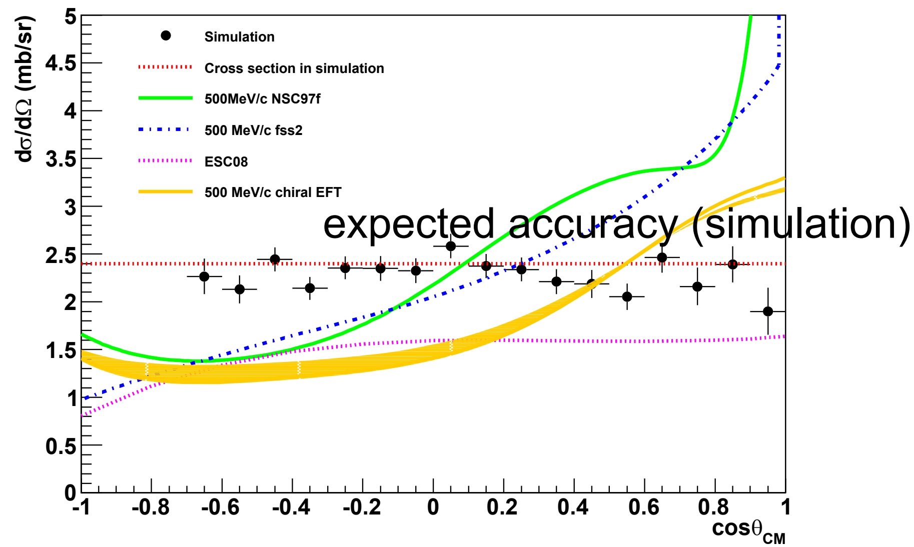
Slide by K. Miwa

Data (angular distribution)

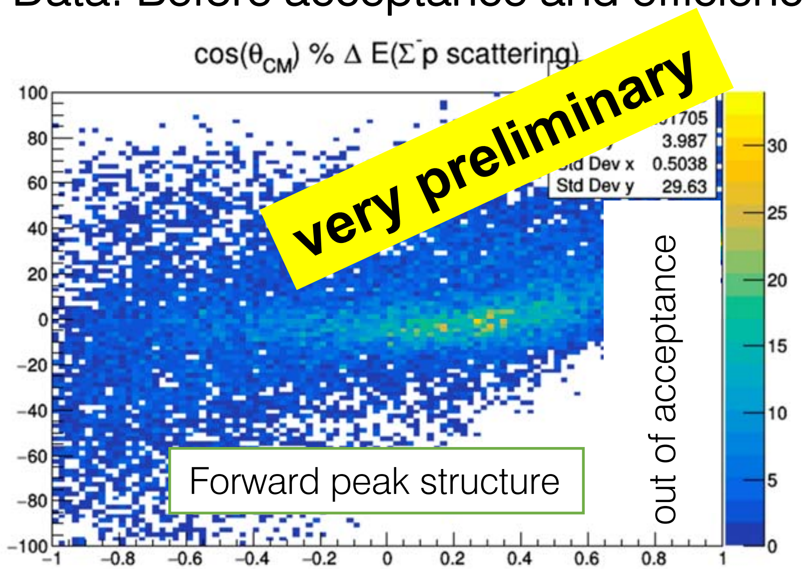
$\Sigma^{-}p \rightarrow \Sigma^{-}p$ (0.55 < p (GeV/c) < 0.65)

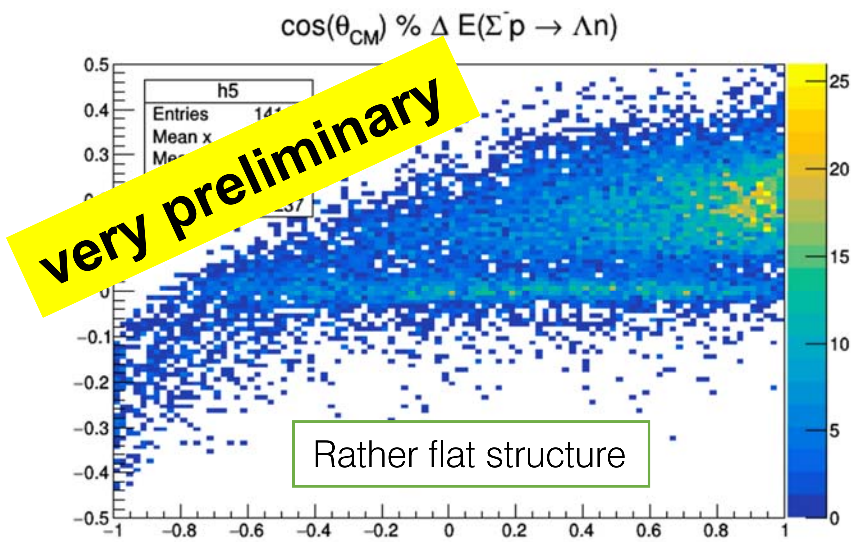


$\Sigma^{-}p \rightarrow \Lambda n$ (0.55 < p (GeV/c) < 0.65)

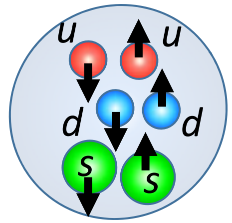


Data: Before acceptance and efficiency correction





H-dibaryon



- 6 quarks (uuddss) system with I=0, $J^{\pi}=0^{+}$

$$BB^{(1)} = H = -\sqrt{\frac{1}{8}}\Lambda\Lambda + \sqrt{\frac{3}{8}}\Sigma\Sigma + \sqrt{\frac{4}{8}}\Xi N$$

- Deeply bound state was predicted by R.L.Jaffe in 1977

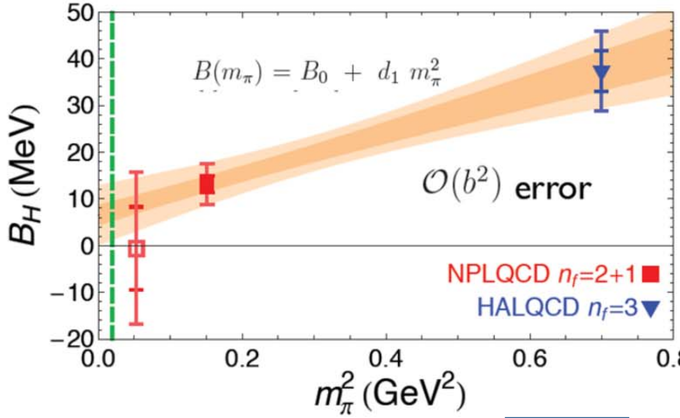
→ Deeply bound state was rejected by NAGARA event (${}^{6}_{\Lambda\Lambda}$He)

$$M_H \geqq 2M_\Lambda - 7.25 \text{ MeV}$$

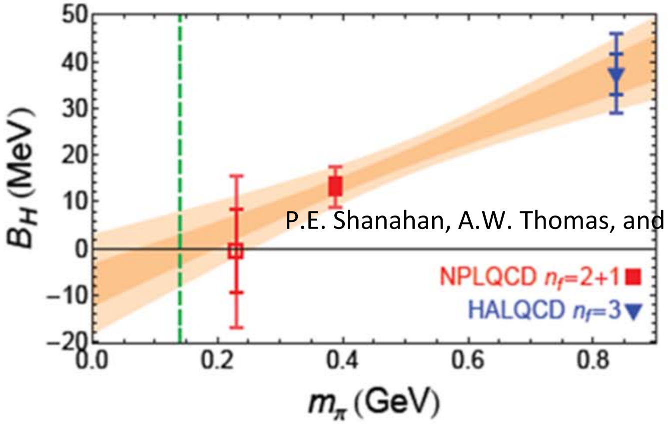
- lattice QCD simulation at almost physical point
  - exist around near ΞN threshold !?
- No experimental evidence

Lattice QCD calculation for H dibaryon

Physical π mass



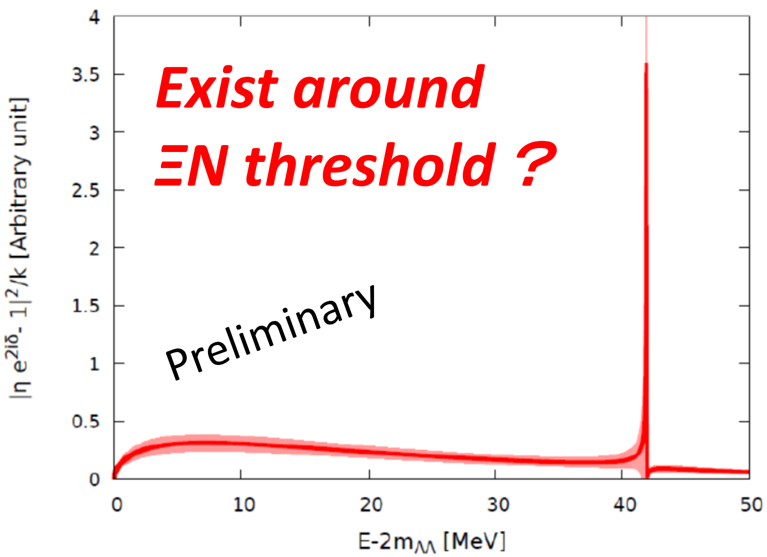
Physical π mass



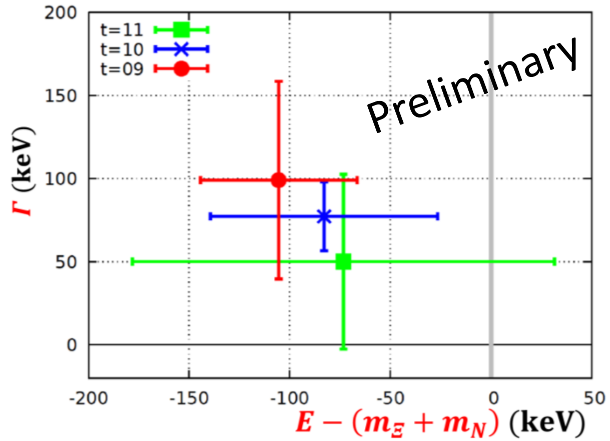
P.E. Shanahan, A.W. Thomas, and R.D. Young, PRL 107 (2011).

Calculation at almost physics point

	Mass [MeV]
π	146
K	525
m_π/m_K	0.28
N	956±12
Λ	1121±4
Σ	1201±3
Ξ	1328±3



K. Sasaki for the HAL Collab., Reimei 2016, Inha (2016).



HAL QCD

arXiv:1912.08630v1 18-Dec-2019

$^{11}S_0$ interaction

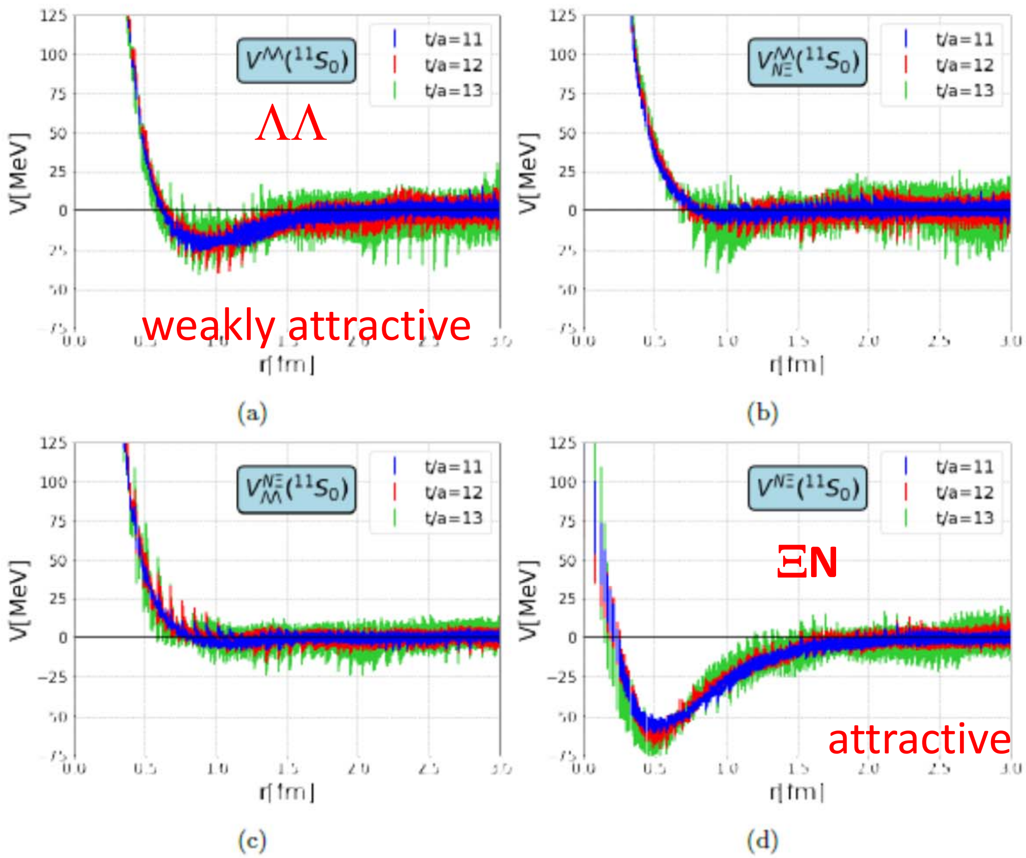


Figure 1: The S-wave coupled-channel $\Lambda\Lambda$-$N\Xi$ potential in $^{11}S_0$. The $V^{\Lambda\Lambda}$, $V^{\Lambda\Lambda}_{N\Xi}$, $V^{N\Xi}_{\Lambda\Lambda}$ and $V^{N\Xi}$ potentials are shown in (a), (b), (c) and (d), respectively.

Baryon	mass $[m_B/a]$	mass [GeV]	fit range $[t/a]$
N	0.40949(78)(52)	0.9553(18)(12)(74)	13 – 17
Λ	0.48856(49)(9)	1.1398(11)(2)(88)	15 – 20
Σ	0.52365(37)(64)	1.2217(9)(15)(94)	15 – 20
Ξ	0.58087(51)(3)	1.3552(12)(1)(105)	20 – 25

Weak ΞN→ΛΛ conversion

ΞN (quasi) bound states?

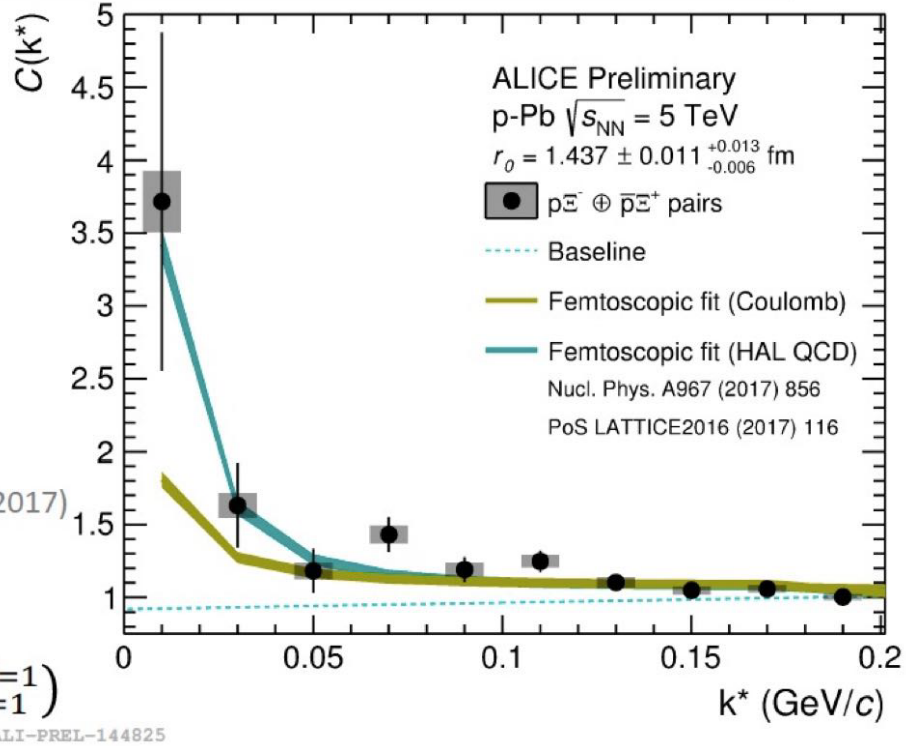
Lattice QCD vs ALICE data

p-Ξ⁻ Correlation Function in p-Pb 5.02 TeV

- **First observation of strong attractive interaction in p-Ξ⁻**
  - p-Value with and without strong potential (Coulomb only): 0.055 vs. 0.004
- modeled with preliminary QCD strong potential by the HAL QCD collaboration

  (Hatsuda et al., NPA967 (2017) 856, PoS Lattice2016 (2017) 116)

$$C(k^*) = \frac{1}{8}\left(C_{I=0}^{S=0} + C_{I=1}^{S=0}\right) + \frac{3}{8}\left(C_{I=0}^{S=1} + C_{I=1}^{S=1}\right)$$



Talk by Valentina Mantovani Sarti (TUM) at MESON2018 (June 8, 2018)

Past experiment for H-dibaryon

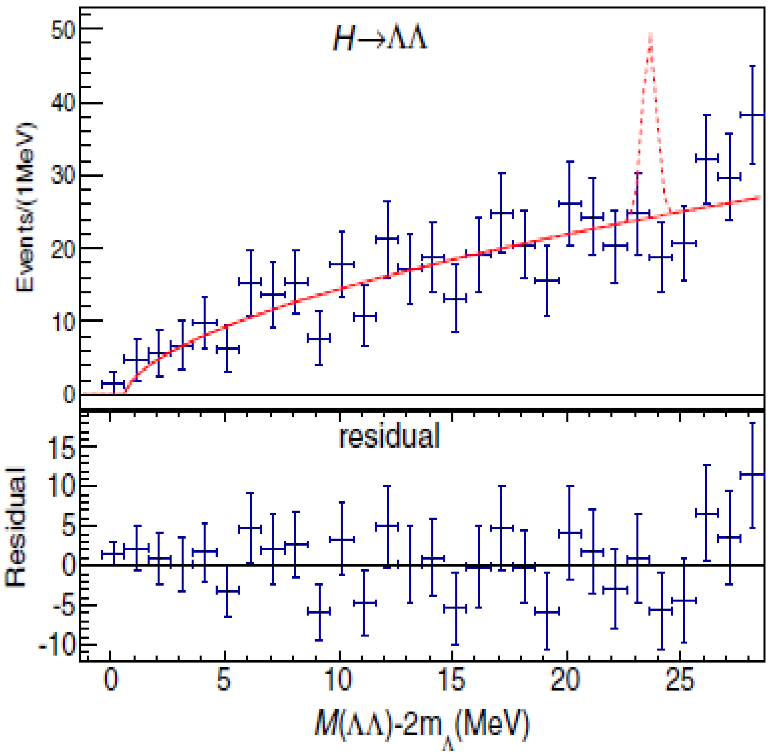
Hint of H dibaryon?

Belle data:

ΛΛ invariant mass
from Υ(1s) and Υ(2s) decay

No peak was observed

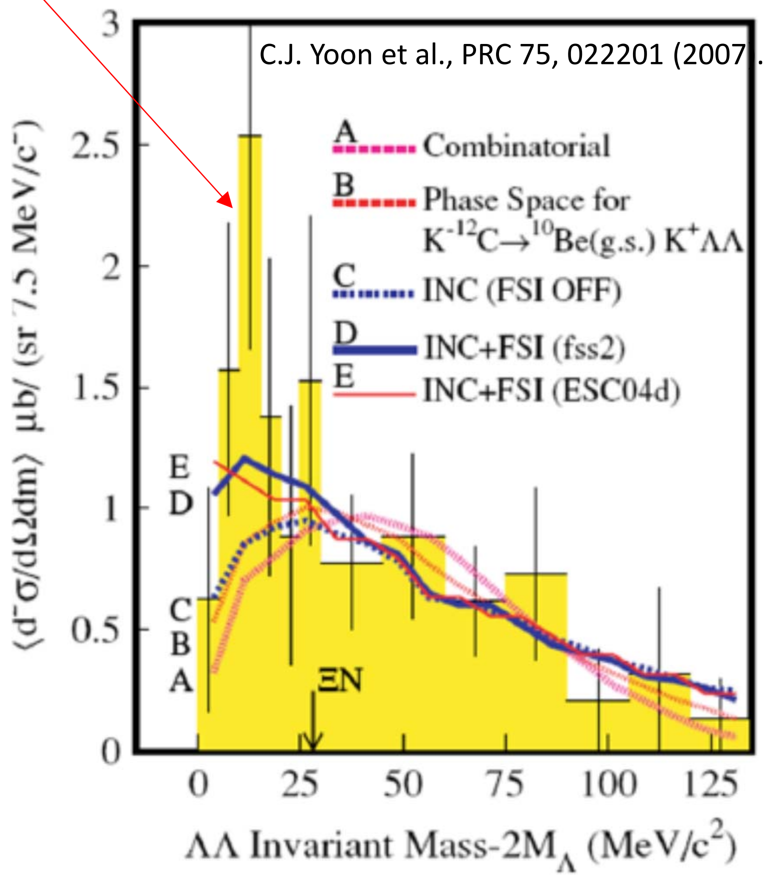
B.H. Kim et al., PRL 110, 222002(2013).



KEK E522:

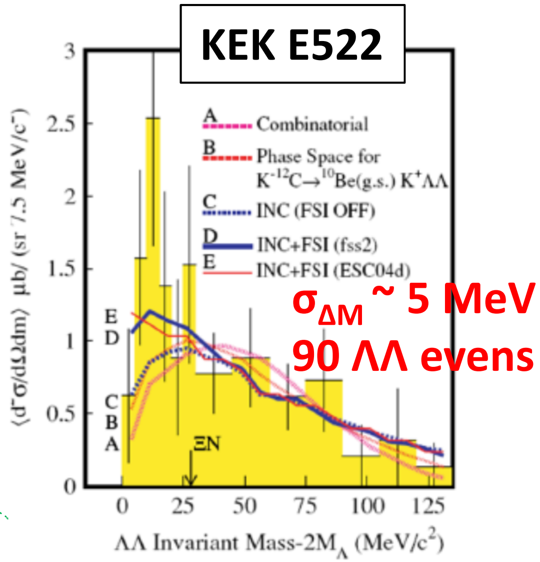
"pp"(K^-, K^+)ΛΛ reaction
with SciFi active target (CH_2)

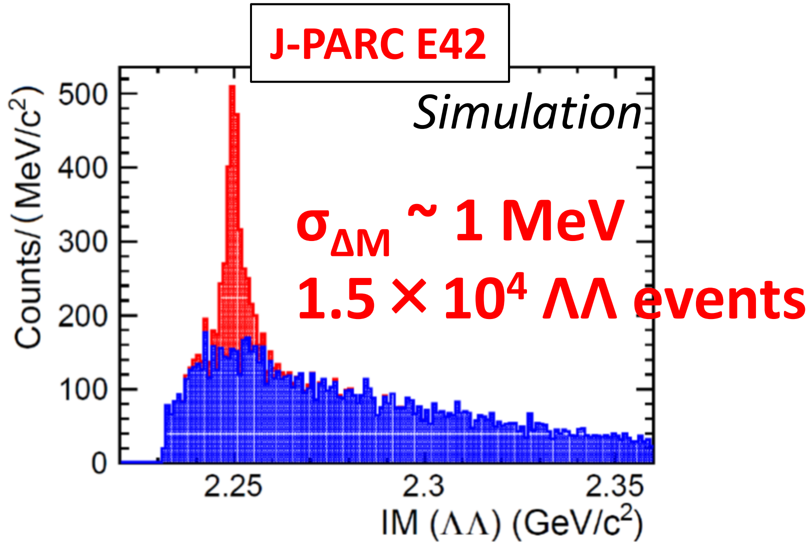
C.J. Yoon et al., PRC 75, 022201 (2007).

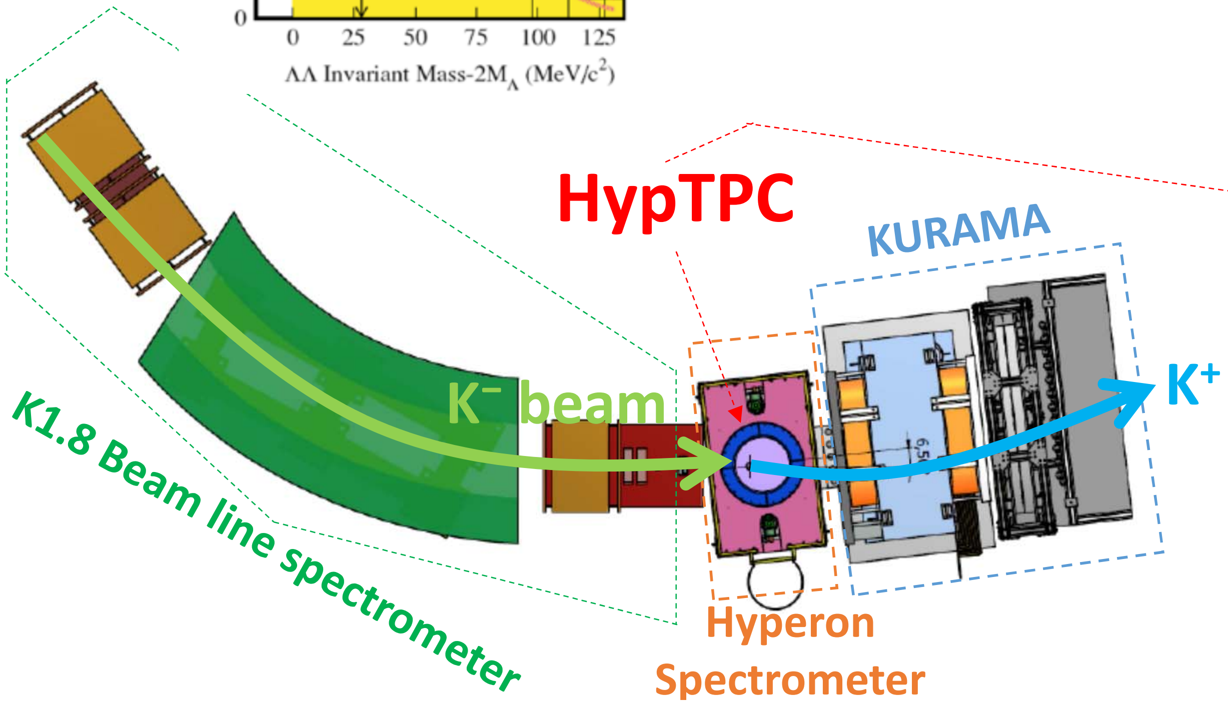


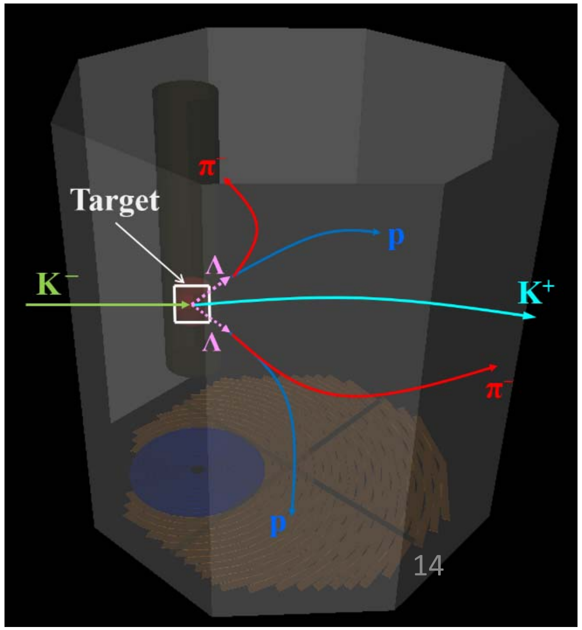
J-PARC E42 experiment

H-dibaryon search by using "pp"(K^-, K^+)*H* reaction with diamond target



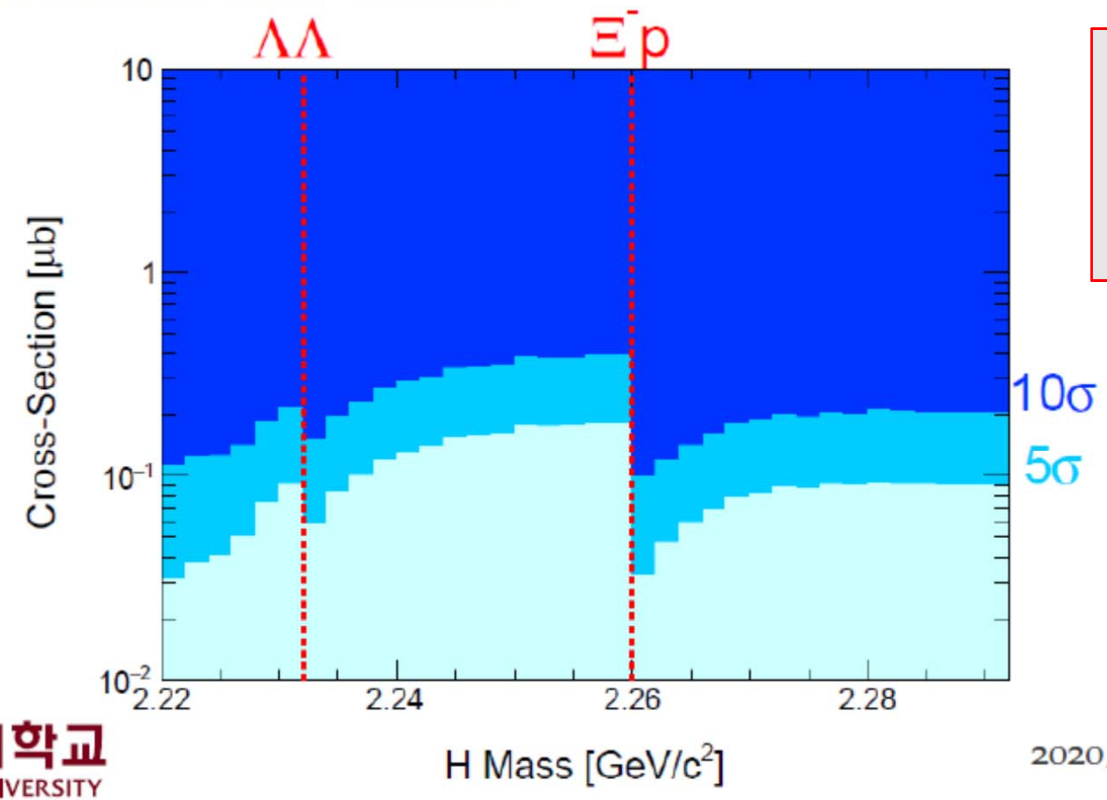






Sensitivity

- E42 has a good sensitivity over a broad range of the H mass from the bound to unbound regions above the $\Xi^- p$ mass threshold.
- Statistical significance $S/\sqrt{S+B}$ with H-production cross section as a function of the H mass.



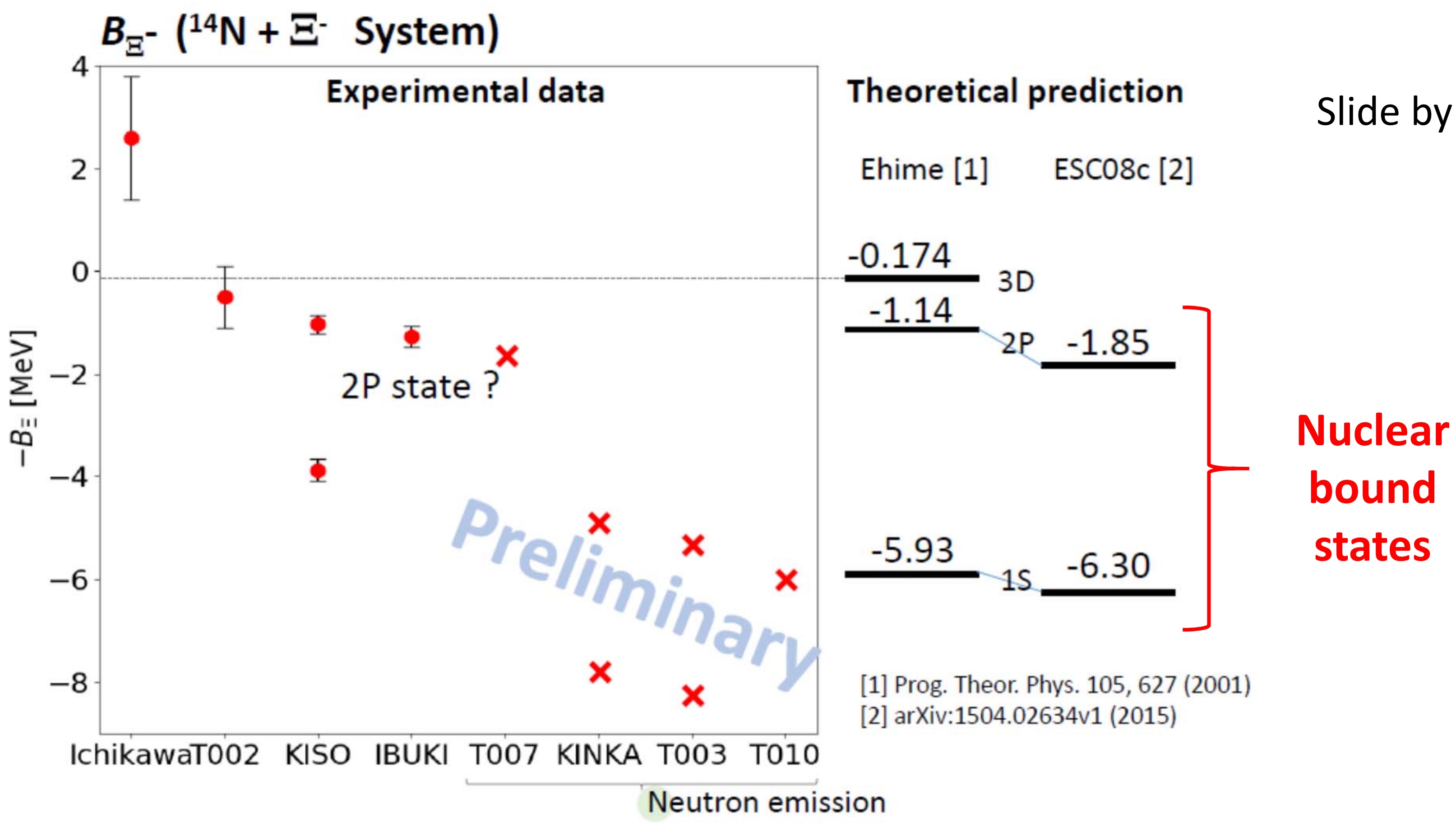
$H \to \Lambda\, p\, \pi^-$
$H \to \Lambda\, \Lambda$
$H \to \Xi^-\, p$

From 29th J-PARC PAC by J.K.Ahn

E42: Schedule at K1.8 of J-PARC HEF

- Feb. - Mar. 2020 E40 physics run
  - Parasite test of TPC detector
- Apr. - Oct. 2020   Setup KURAMA spectromter
  - Excitation test of H.S. magnet with KURAMA magnet
- Nov. 2020 E03 physics run
  - KURAMA detector (Water Cherenkov) & trigger study
- Dec.2020 - Feb.2021   H.S. installation
- Mar. - Apr. 2021   E42 comm. + physics run

ΞN interaction & Ξ-Nuclei
Several event-samples on Ξ^- - ^{14}N system



Slide by J.Yoshida

- **Multiple candidates of Ξ hypernucleus has been detected.**
- The errors for neutron emission case are under validation.
- These events suggest multiple bound states of Ξ^- in the Ξ^- + ^{14}N system.

Outline of the E03 experiment

- **World first measurement of X-ray from Ξ^- atom**

  → **Direct information on the Ξ-nucleus(A) optical potential**

- **First step of systematic measurements to obtain 10% statistics of the original proposal.**

  → **Establishing experimental method in this experiment**

Method:

- Produce Ξ^- by the Fe(K^-,K^+) reaction

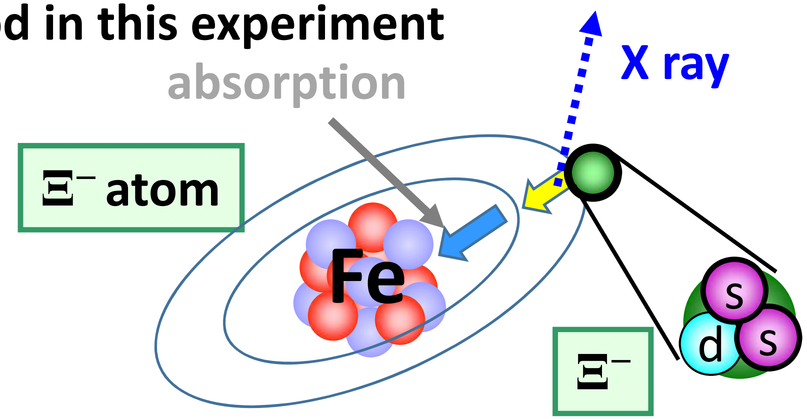
Magnetic spectrometers for $K^{\pm}$

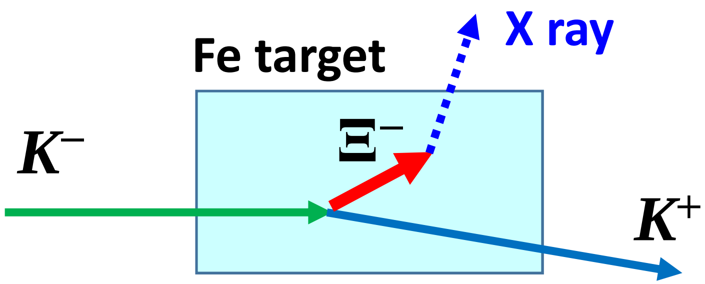
- Stop Ξ^- in the target → Ξ^- atom

Dense Fe target

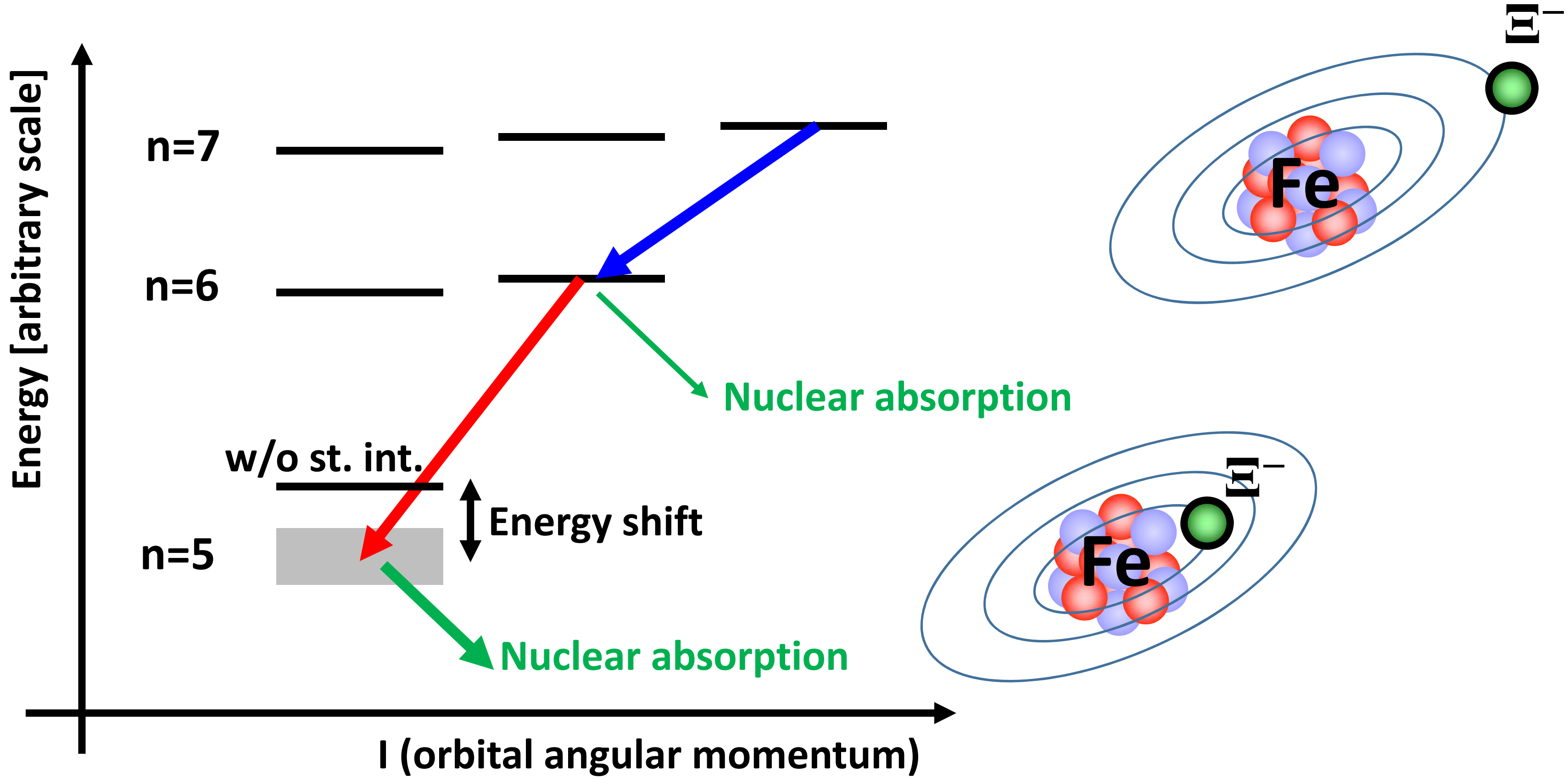
- Measure X rays

Ge detectors





Level scheme of Fe Ξ^- atom



n=7→6 : X-ray energy = 172 keV ← small shift/width

n=6→5 : X-ray energy = ~286 keV ← finite shift/width due to ΞN interaction

expected shift ~ 4keV, width(Γ) ~ 4keV

(theoretical case study with W.S. pot. of -24-3i MeV)

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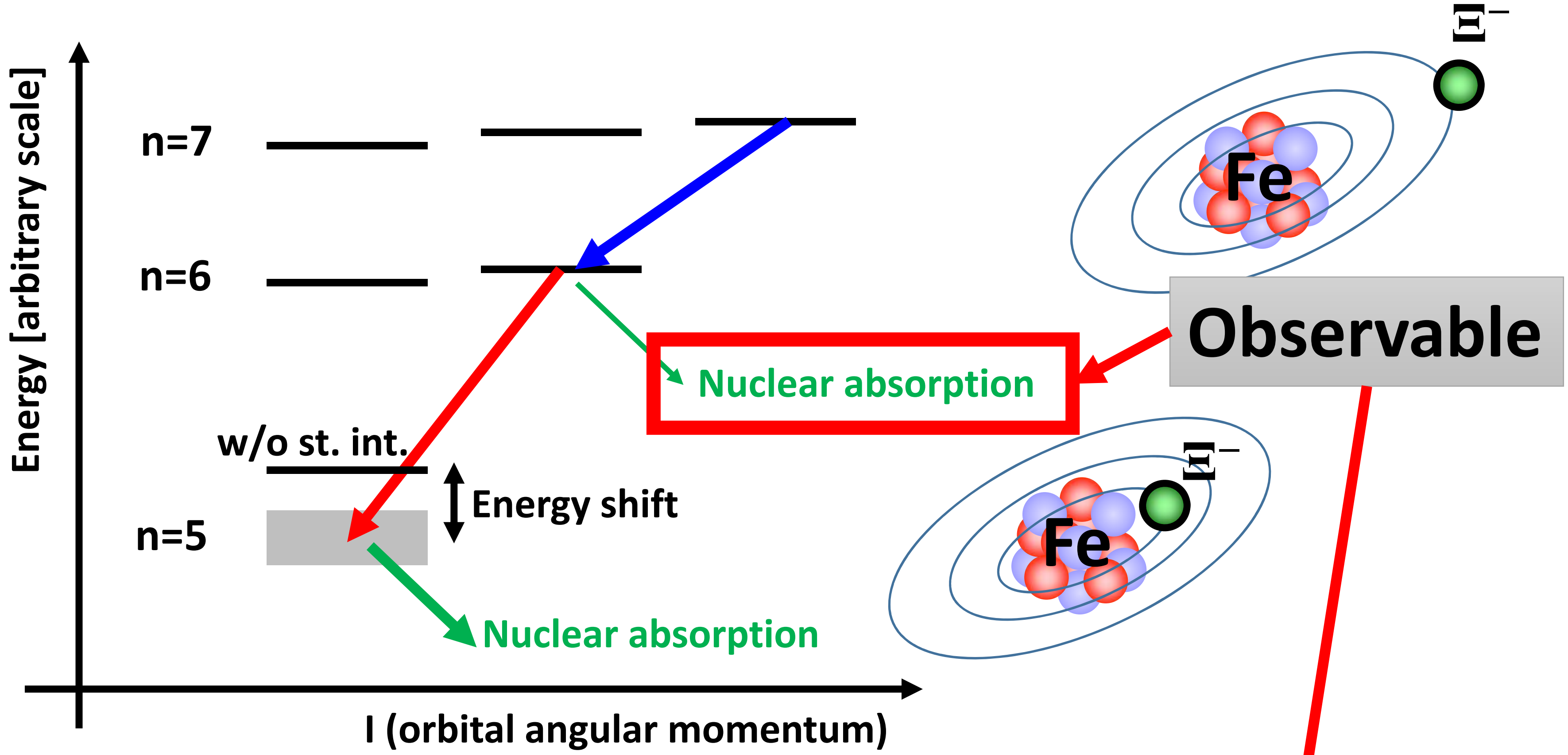

Ge detector

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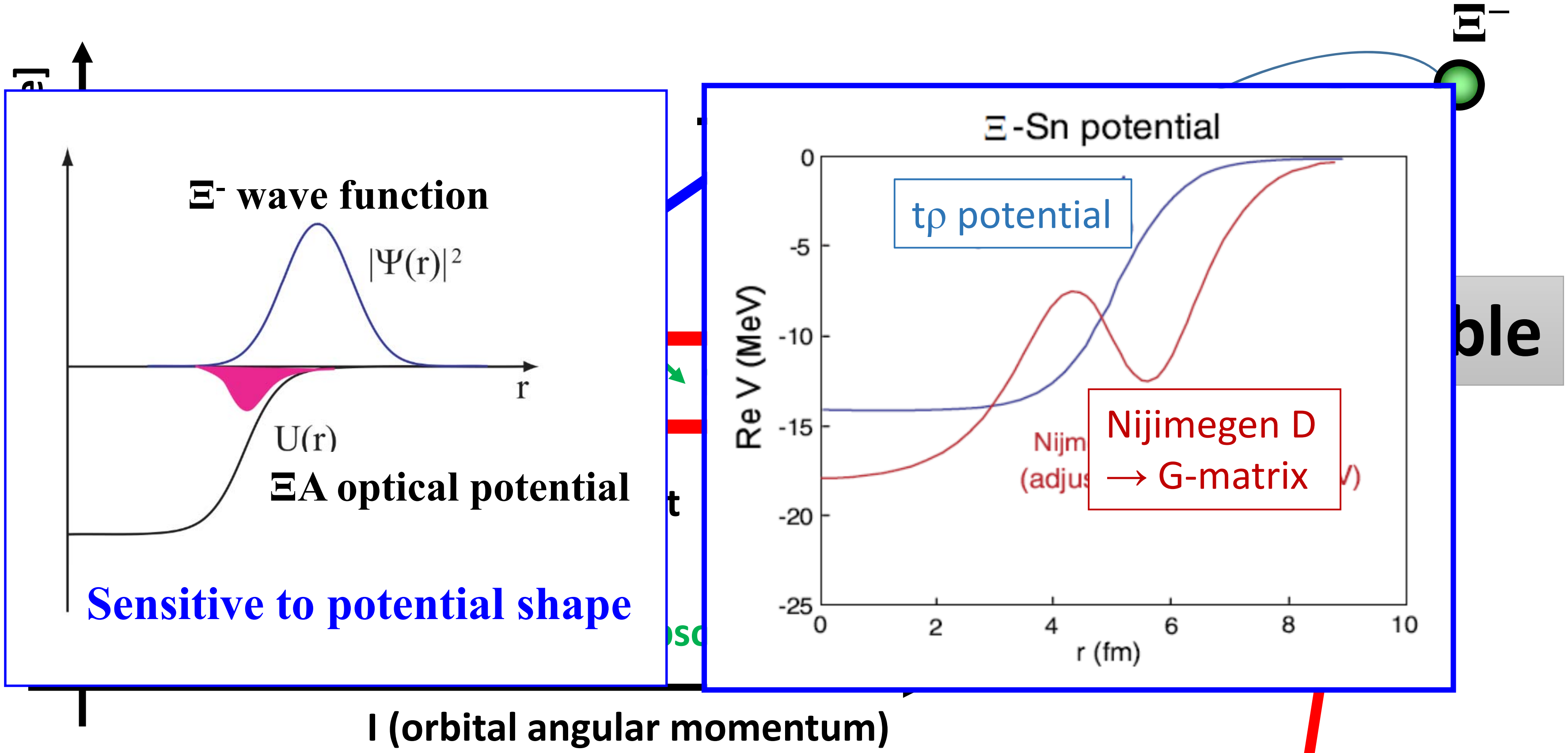

Phase-1 Physics run in Nov. 2020

Summary

- Group-B01 researches aim to investigate the origin of nuclear force, meson-baryon molecule, and hadron properties in medium, by adding strangeness (s-quark) .
- Three experiments to investigate baryon-baryon interactions; YN scattering, *H*-dibaryon, and Ξ-atom, are in progress or carried out soon at J-PARC.