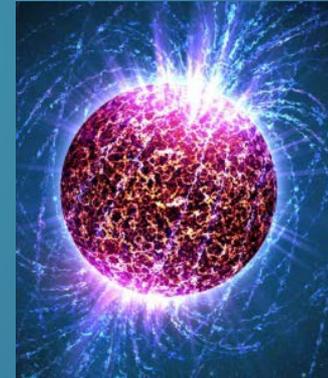
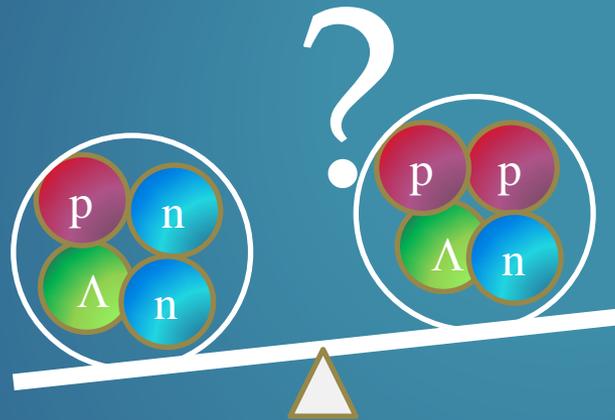


Spectroscopy of Lambda Hypernuclei



Satoshi N. Nakamura

Tohoku University

12 March 2017

SNP 2017 @ Osaka E-C Univ.

Congratu on your re Fukuda

I defended my thesis in 1995. O



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What we were discussing in 1995.

M. Rozon, R. Sawafuta, H. Schmitt, R. A. Schumacher, R. L. Stearns, R. Stotzer,
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A. I. Smirnov, V. M. Suvorov, and A. V. Zhelamkov

(π^+, K^+)

Stopped K^-

Σ hyper

Polarized hypernucl. and
weak decay

Lifetime of Λ hyper

H dibaryon

$S=-2$

Σ^+p scat.

$K\bar{N}$ int

What we are discussing in 2017.

CSB, 3BRF for hyperon puzzle

| | | | | | | | |
|--------------|------------------|---|---------------|-----------------|-------------------------|---|--|
| Registration | | | | | | | |
| Fukuda | Osaka E-C. Univ. | Opening address | $(e, e' K^+)$ | T. Sekihara | JAEA | On the structure observed in the in-flight $^3\text{He} (K^-, \text{Lambda } p) n$ reaction at J-PARC | |
| Fukuda | | | | Renli Xu | Nanjing Univ. | Dynamics of kaonic nuclei in an improved quark mass density-dependent model | |
| N. Nakamura | Tohoku Univ. | Spectroscopy of Lambda Hypernuclei | | K. Inoue | RCNP | Analysis status of the $d(K^-, n)\pi^+$ $\Sigma^+ \rightarrow \pi^+$ and $d(K^-, p) \pi^0$ at J-PARC K1.8BR beam line | |
| I. Isaka | RCNP | Hypernuclear structure with antisymmetrized molecular dynamics | | Lunch | | | |
| Funaki | Beihang Univ. | Clusters in ^{12}C and ^{13}C | | Q. Zhao | IHEP | Phi meson in nucleus at J-PARC | |
| Umeya | NIT | P-shell hypernuclear structure and its production rates based on the $\pi^- p$ reaction | | H. Ohnishi | RIKEN | Quark mass dependence of H-dibaryon in Lambda-Lambda scattering | |
| | | | | Y. Yamaguchi | RIKEN | KN scattering and hyperon resonance | |
| | | | | X-H. Zhong | Hunan Univ. | | |
| | | | | Break | | | |
| Ren | Nanjing Univ. | | | T. Nagae | Kyoto Univ. | Baryon Spectroscopy with Heavy Flavors at J-PARC | |
| Nemura | Tsukuba Univ. | Lambda-N and Sigma-N interactions from 2+1 lattice QCD | | H. Noumi | RCNP | Charm hadron interactions from lattice QCD | |
| Harada | Osaka E-C. Univ. | Production of hypernuclei | | Y. Ikeda | RCNP | Kondo effect for charm hadrons in nuclear matter | |
| Honda | Osaka Univ. | Recent progress of search for H Σ -Lambda via the $^6\text{Li}(\pi^-, K^+)$ reaction | | S. Yasui | TIT | Lambda $_c$ N interaction from lattice QCD and Lambda $_c$ nuclei | |
| Fujioka | Kyoto Univ. | A plan to search for a tetra-neutron state in the $^4\text{He}(\pi^-, \pi^+)$ reaction | | T. Miyamoto | YITP | Universal physics of two neutrons with one flavored meson | |
| Tokiyasu | Tohoku Univ. | Hypernuclear spectroscopy via the real photo-induced reaction | | T. Hyodo | YITP | | |
| | | | | Workshop dinner | | | |
| | | | | Break | | | |
| | | | | Ekimae campus | | | |
| Noumi | RCNP/KEK | | | H. Tamura | Tohoku Univ. | Recent developments in strangeness nuclear physics and the hyperon puzzle | |
| Nagae | Kyoto Univ. | Spectroscopy of S=-2 systems with (K^-, K^+) reaction | | A. Ohnishi | YITP | Strangeness in Compact Stars | |
| Motoba | Osaka E-C. Univ. | Production and structure of Ξ^- -hypernuclei | | R. Xu | Peking Univ. | Hyperon stars at zero temperature with the variational method | |
| Sasaki | YITP | QCD simulations on the S = -2 baryon-baryon interaction | | H. Togashi | RIKEN | | |
| S. Geng | Beihang Univ. | A relativistic formulation of baryon-baryon interactions in chiral perturbation theory | | Break | | | |
| Ekawa | Kyoto Univ. | Experimental study of double hypernuclei with a hybrid emulsion | | Y. Ma | CAS | The strangeness quark mean field theory | |
| | | | | J. Hu | Nankai Univ. | Quark matter in compact stars: implication from recent observations | |
| | | | | C-J. Xia | CAS | B-B interaction and neutron star EOS | |
| | | | | Y. Yamamoto | RIKEN | | |
| | | | | Lunch | | | |
| Hiyama | RIKEN | | | X-R. Zhou | East China Normal Univ. | Strangeness production in RHIC beam energy scan | |
| Zhao | IHEP | Understanding the shortened lifetime of Hypertriton | | Y. Ma | IAS | Strangeness production in heavy ion collisions at RHIC beam energy scan | |
| Nagao | Tohoku Univ. | Design of an experiment for hypernuclear lifetime measurement | | P. K. Saha | IAS | Search for a new Lambda $^+$ resonance with ^3He beam | |
| | | | | K. Tanida | JAEA | Search for a new Lambda $^+$ resonance with ^3He beam | |
| | | | | E. Hiyama | RIKEN | Lambda $_c$ decay and $K^- p \rightarrow \Lambda^0 \pi^0$ | |
| | | | | Closing | | | |
| Harada | Osaka E-C. Univ. | | | | | | |
| Sakuma | RIKEN | Experimental studies on the $K^+ n$ interaction | | | | | |

Lattice QCD

Meson in nucleus

n-rich HY with DCX

Charmonic hadrons

S=-2

Hyperon puzzle

Lifetime of $^3_\Lambda\text{H}$

Strangeness with HI beam

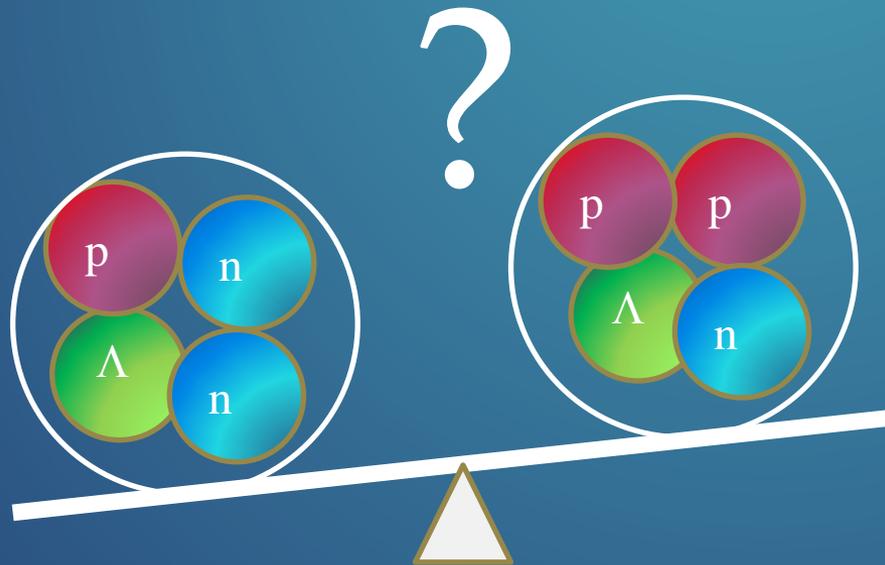
$K^+ n$ int

Recent

Mysteries in Hypernuclear Physics

Large CSB for $A=4$ hypernuclei

Hyperon Puzzle



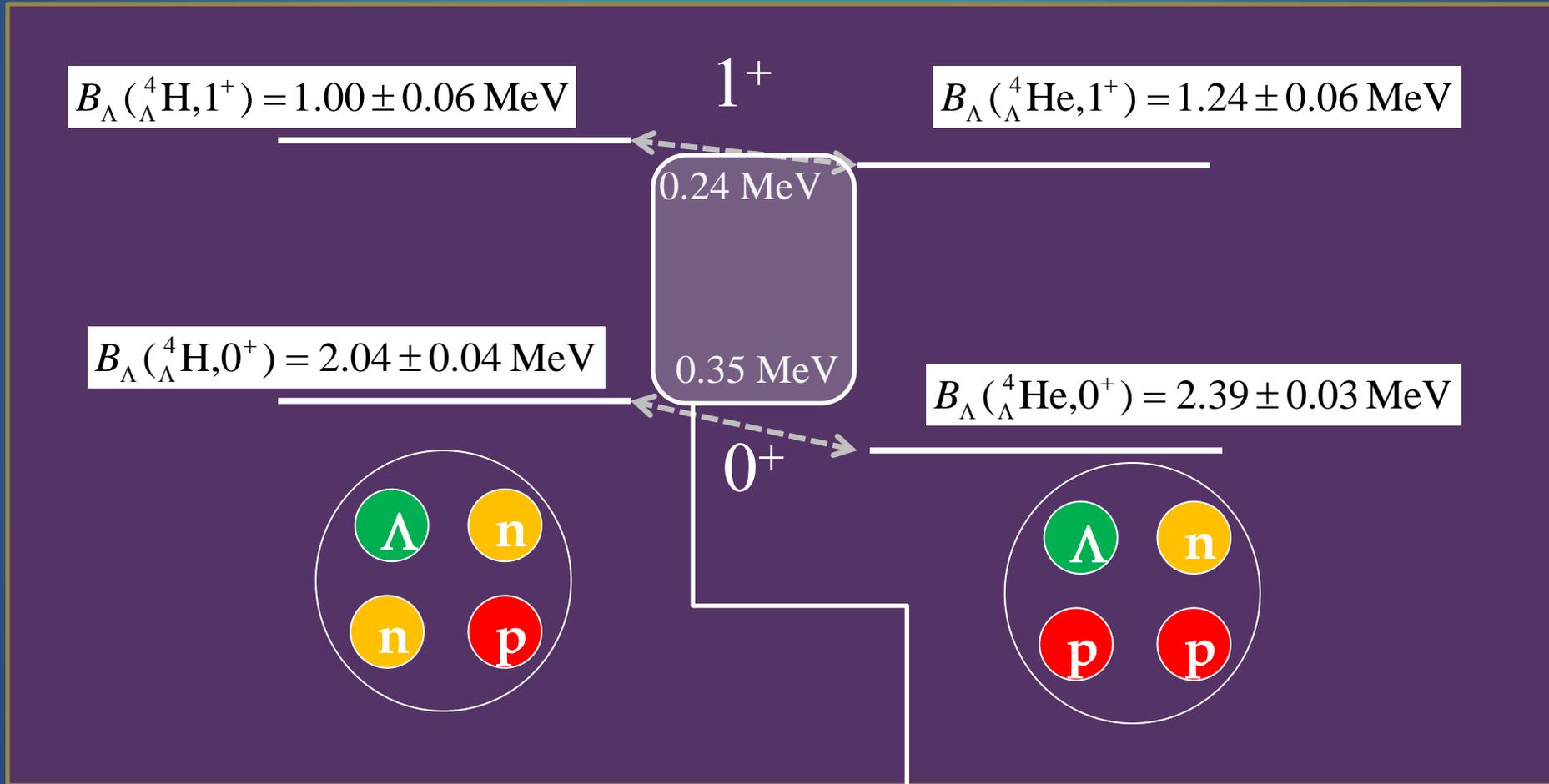
Two solar mass neutron stars

Charge Symmetry Breaking of the ΛN interaction

A=4 system CSB ΛN potential

Data from
Emulsion
NaI γ -ray

Before 2015



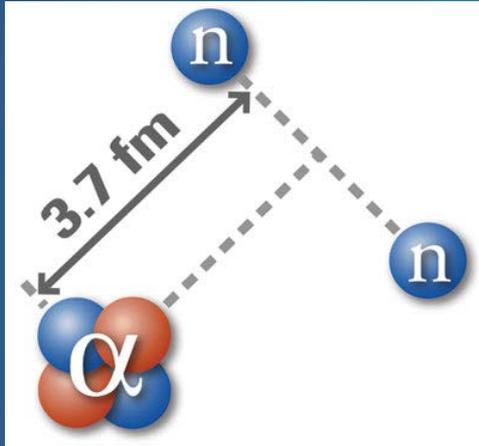
Coulomb effect is very small.

$$-\Delta B_c = 0.050 \pm 0.02 \text{ MeV},$$

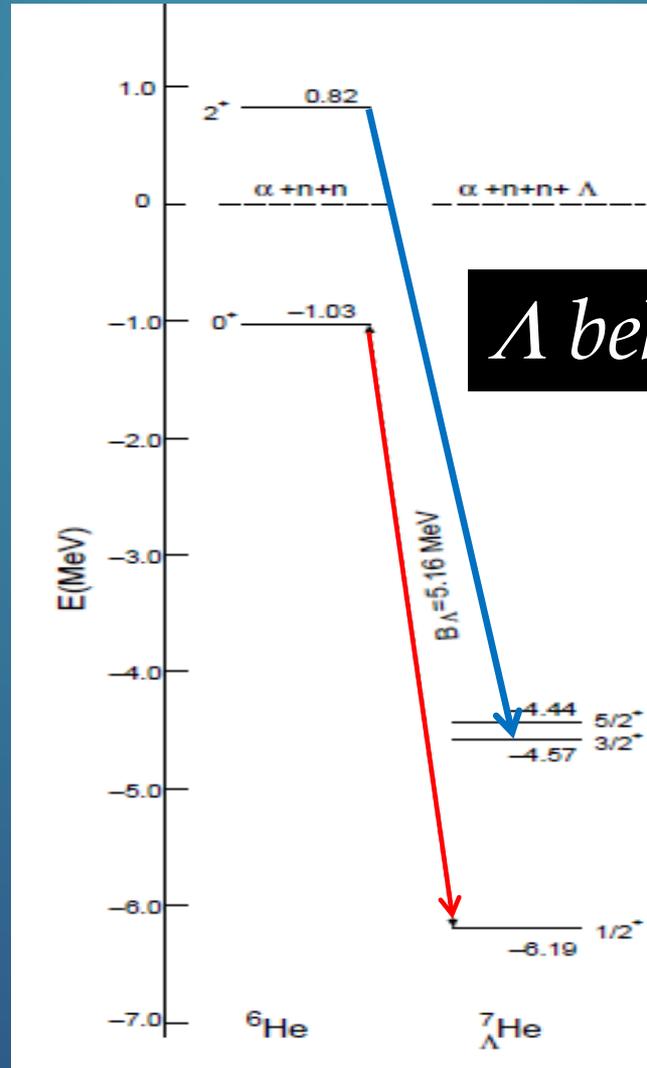
$$-\Delta B_c^* = 0.025 \pm 0.015 \text{ MeV}$$

Charge Symmetry Breaking

cf) $B({}^3\text{H}) - B({}^3\text{He}) - \Delta B_c \sim 70 \text{ keV}$



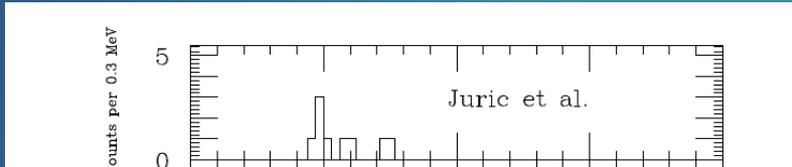
${}^6\text{He}$: 2n halo



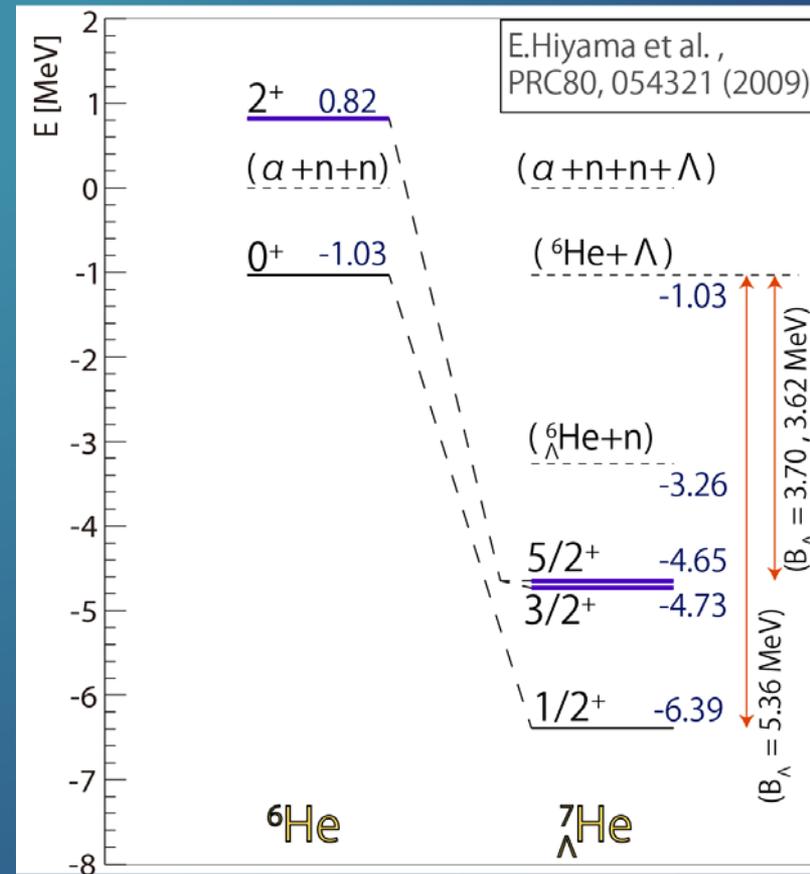
Λ behaves like glue

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

Juric et al., Nucl. Phys. A484 (1988) 520



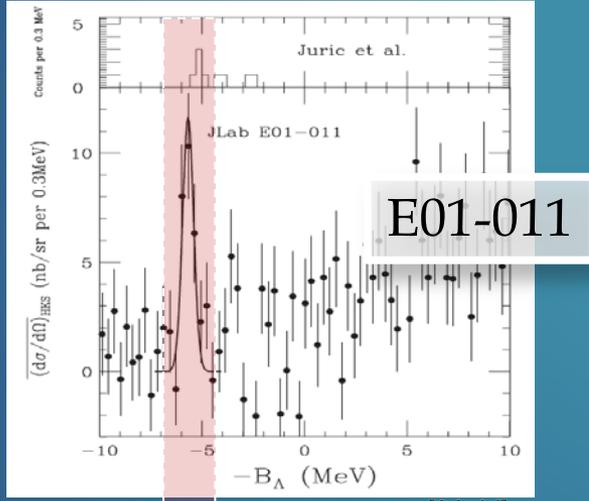
No B_{Λ} was obtained.



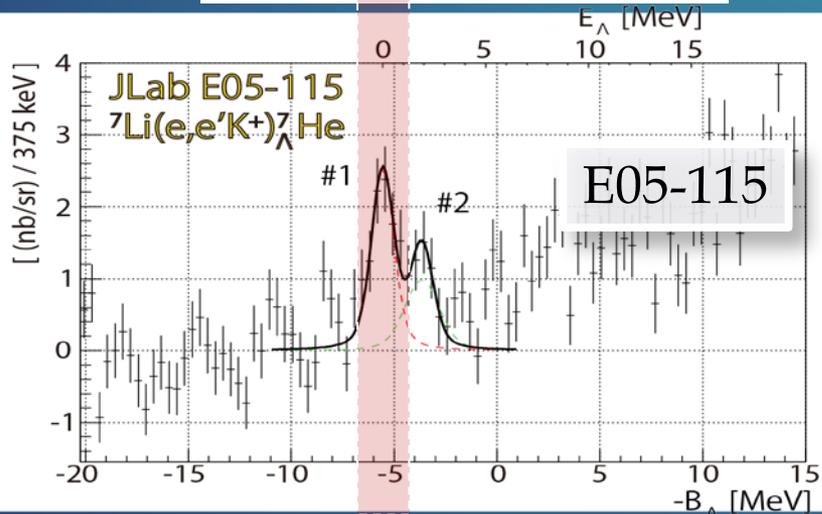
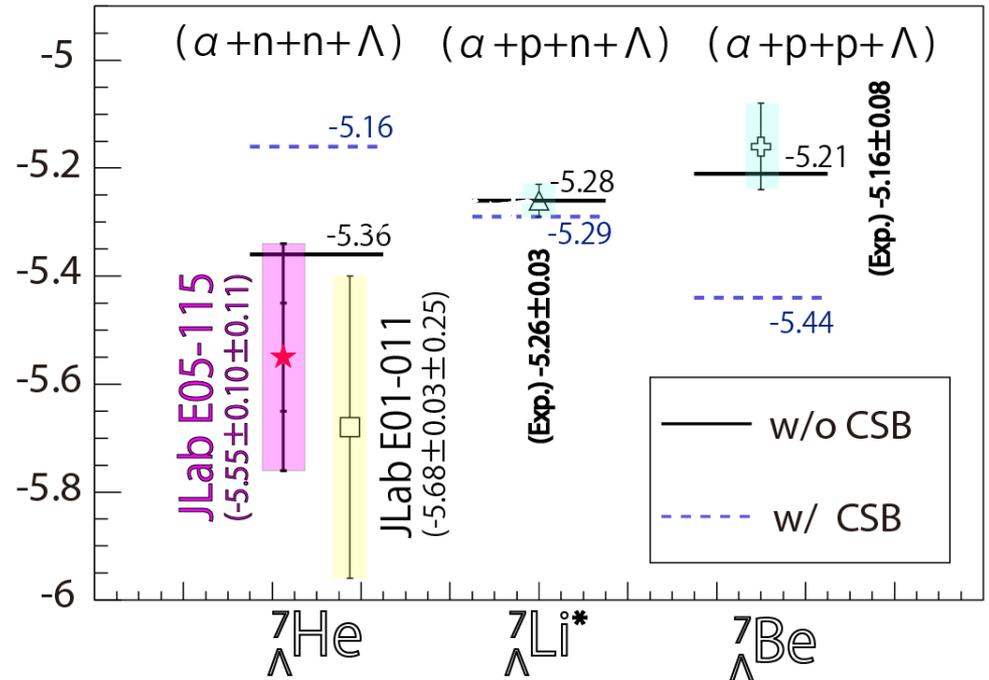
CSB interaction test for A=7

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

SNN et al., PRL 110, 012502 (2013)



Prediction by E.Hiyama et al.
PRC80, 054321 (2009)



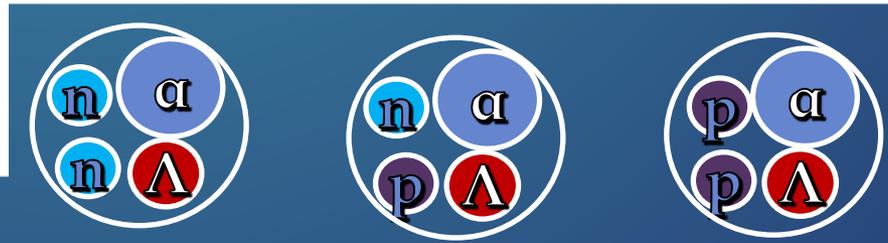
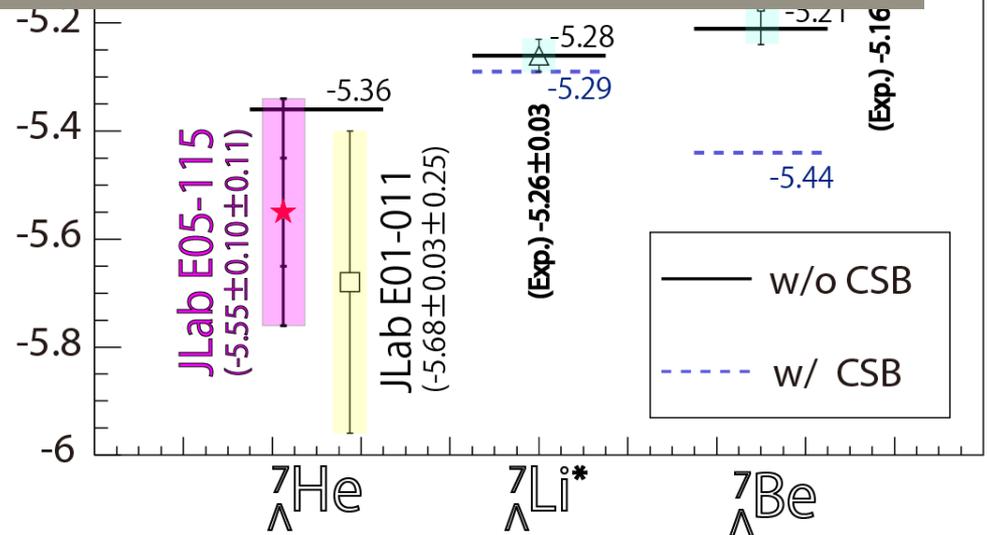
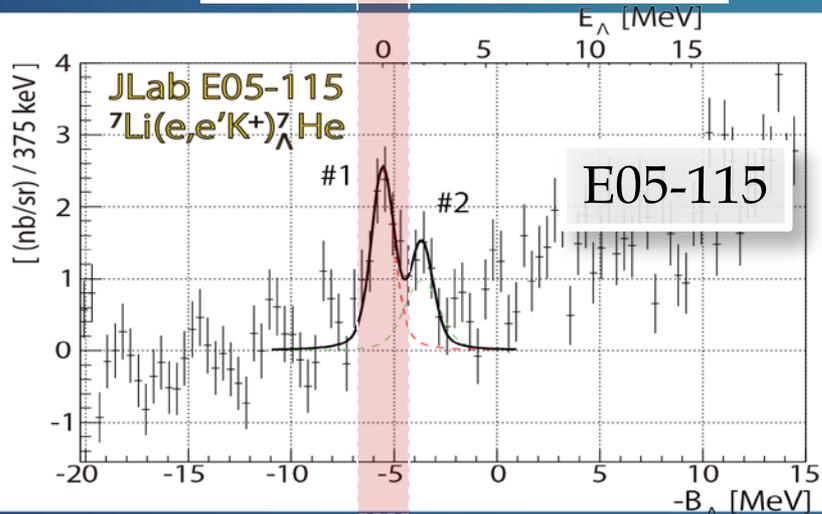
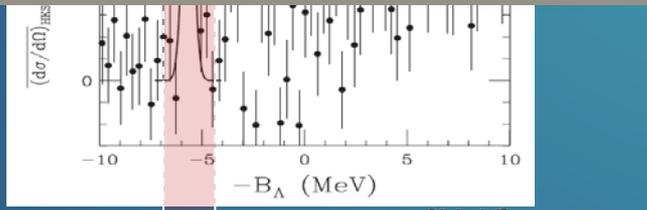
T.Gogami et al., PRC 94 (2016) 021302(R)



CSB interaction test in $A=7$

CSB potential is not necessary for $A=7$
 Assumed CSB potential is too naïve or
 problem for $A=4$ data

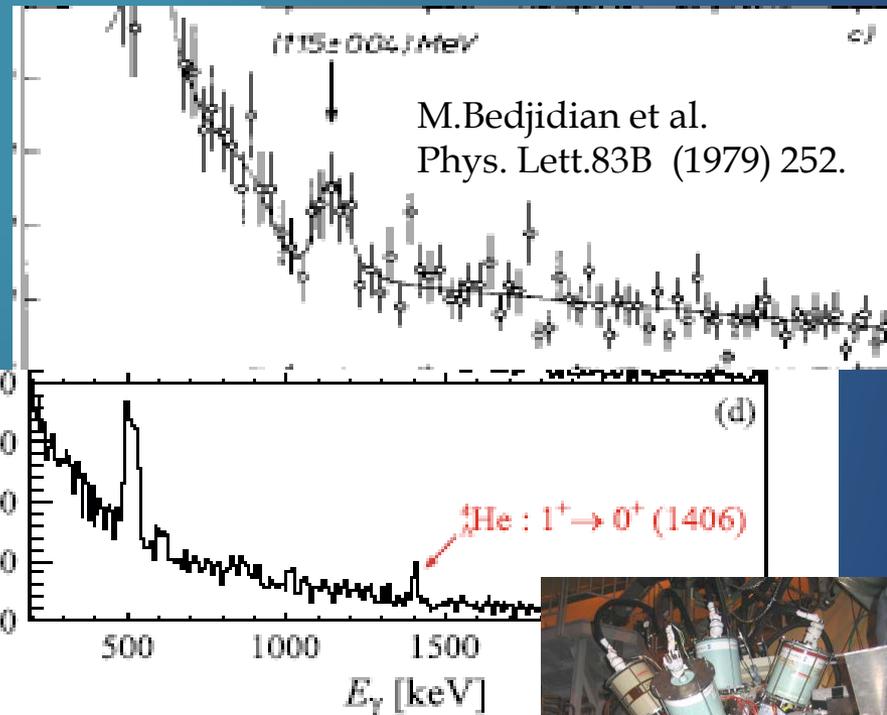
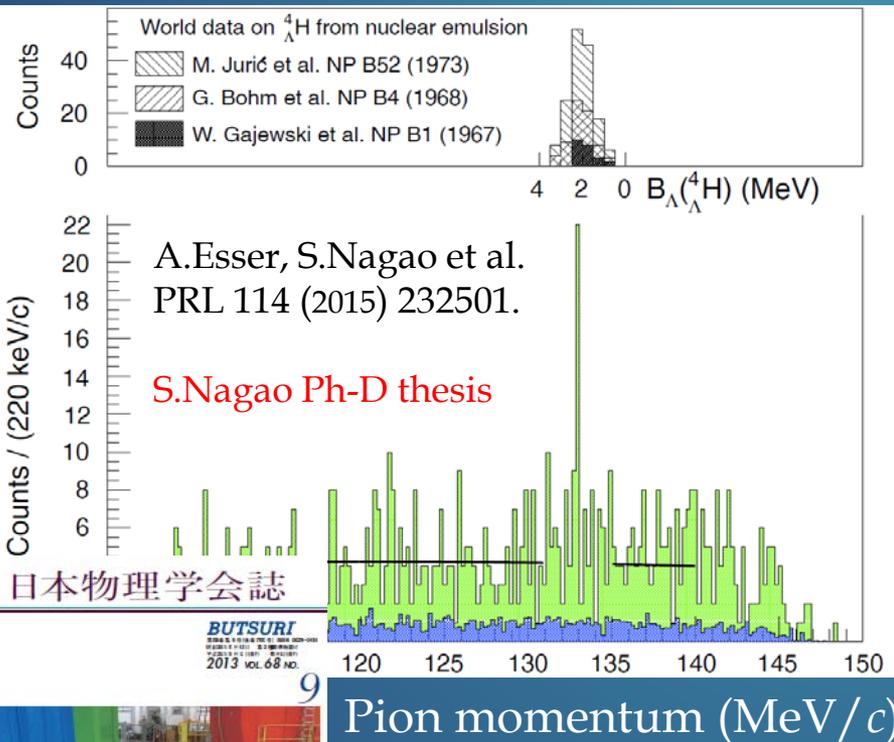
→ *New exps. at MAMI and J-PARC*



New Experiments at Mainz and J-PARC

${}^4_{\Lambda}\text{H}$

${}^4_{\Lambda}\text{He}$



T.O. Yamamoto et al. PRL 115 (2015) 222501.

T.O. Yamamoto Ph-D thesis



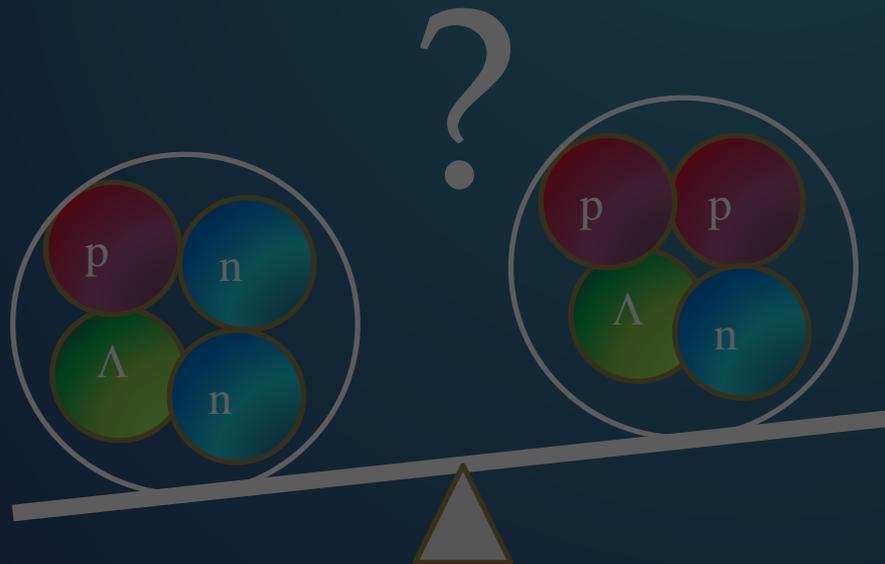
New Decay π spectroscopy @ MAMI

Hyperball Experiment @ J-PARC

Recent

Mysteries in Hypernuclear Physics

Large CSB for $A=4$ hypernuclei



Hyperon Puzzle

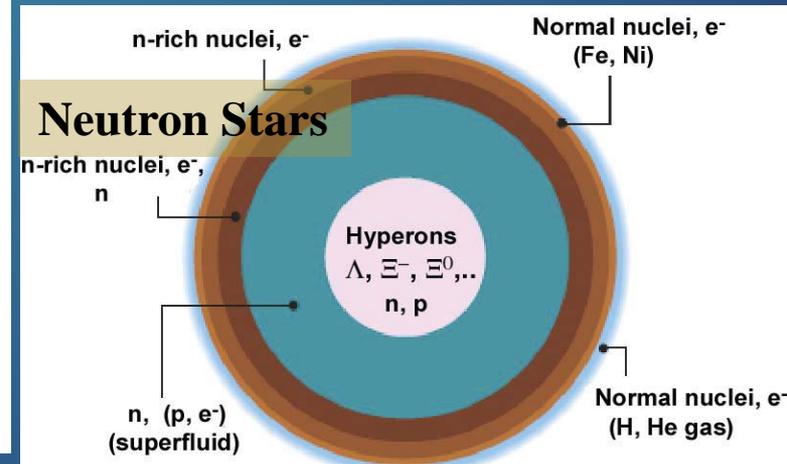
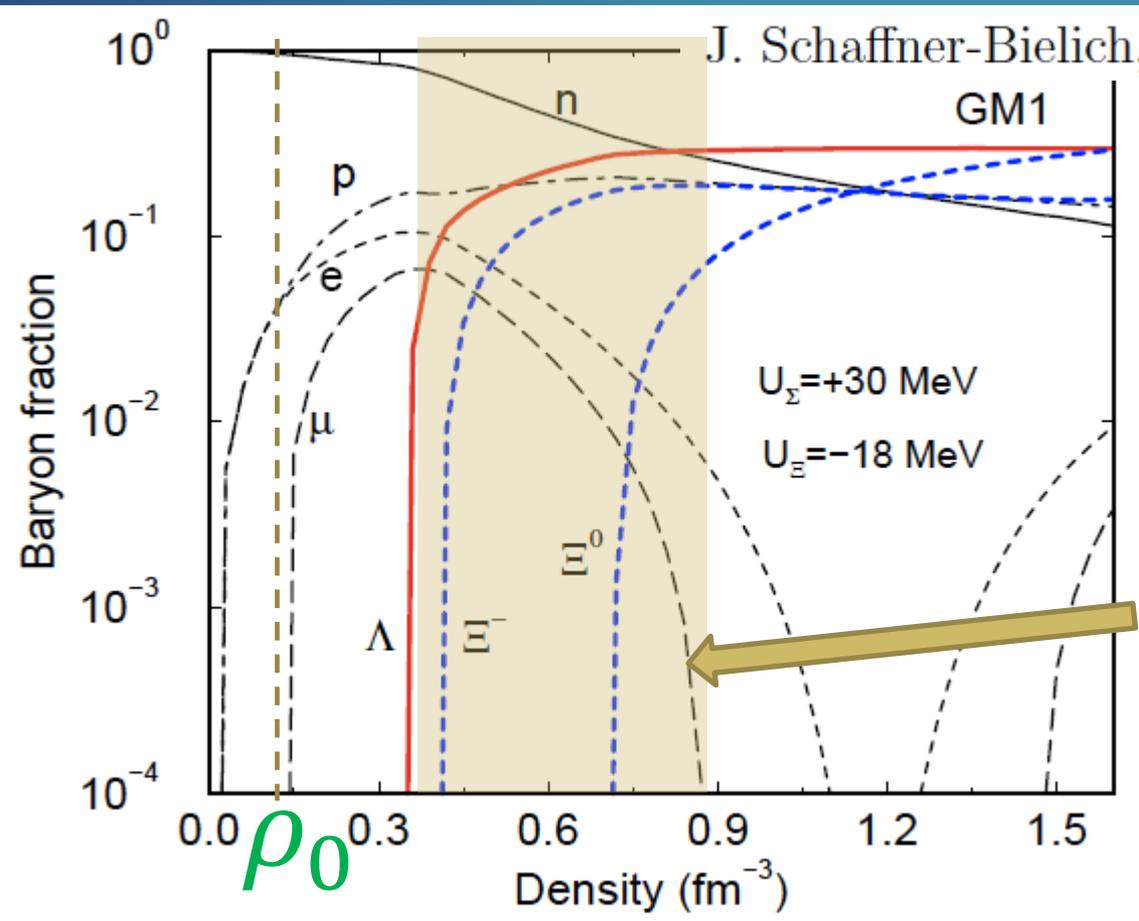


Two solar mass neutron stars

Neutron star and Strange hadronic matter

Sym. Nucl. Matter : Limit for size (due to Coulomb force)

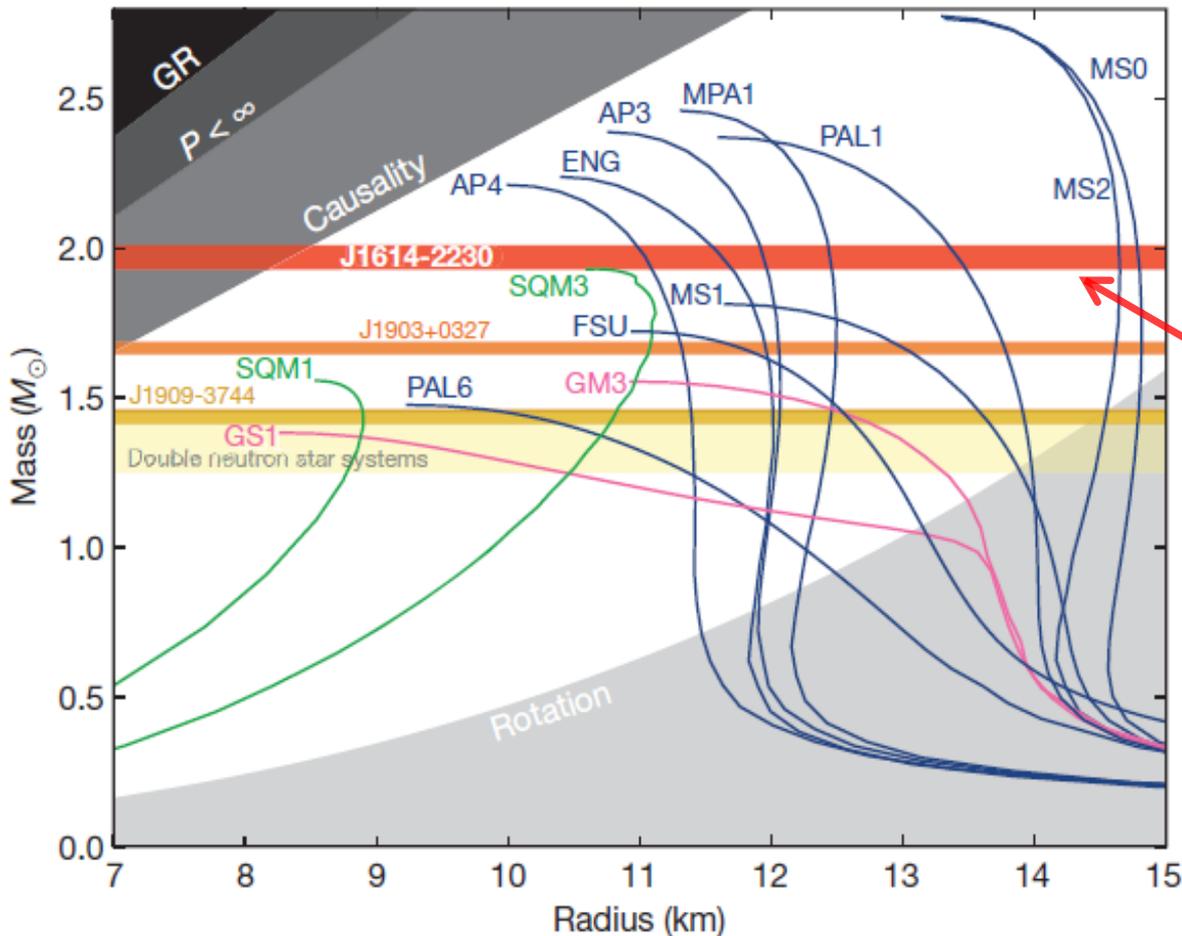
Asym. Nucl. Matter : Neutron Stars, Strange Hadronic Matter



Hyperon Puzzle

Based on our knowledge on Baryonic Force:

Hyperon should appear at high density ($\rho=2\sim 3\rho_0$)



Too Soft EOS

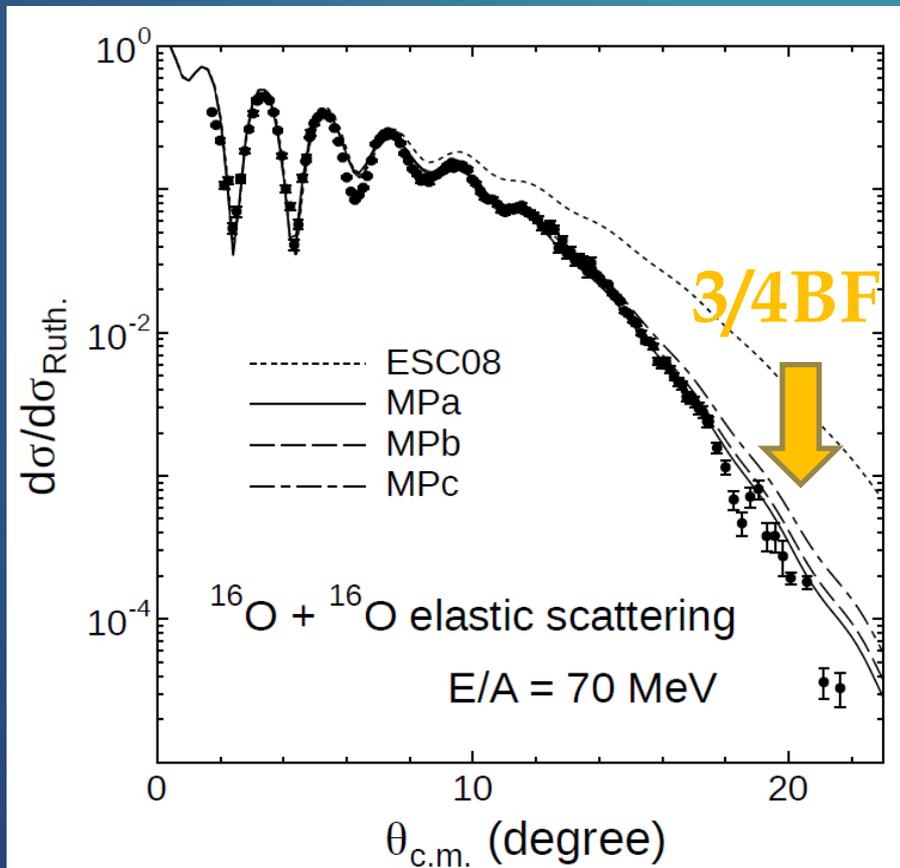
Contradict
to
observation

2 M_{solar} Neutron Stars

Hyperon Puzzle :
One of most
important issues
to be solved
in nuclear physics

EOS of nuclear matter

Microscopic nuclear force model @ $\rho_0 \rightarrow 2\rho_0$

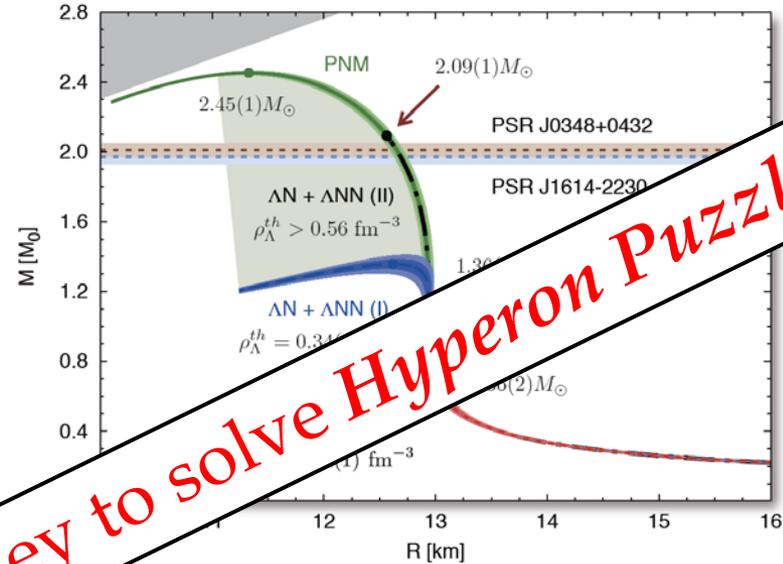
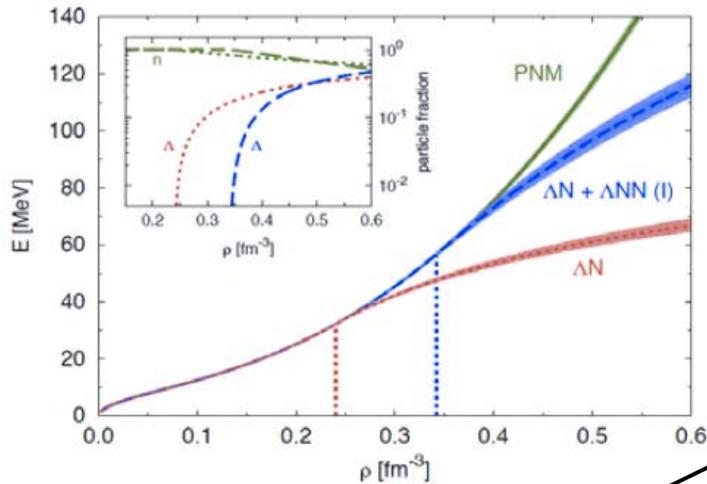


Higher density

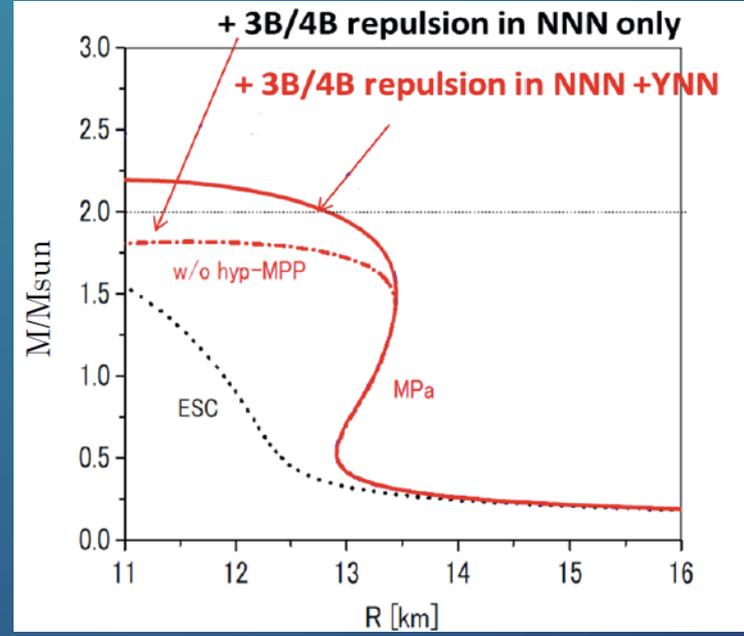
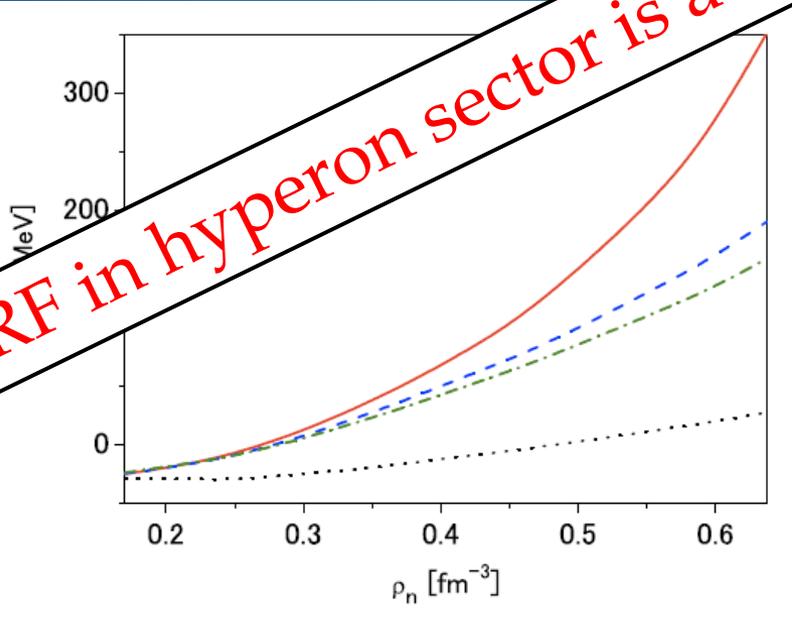


3B/4BF play key roles

Promising scenario to solve Hyp. Puzzle
Repulsive 3B/4B force in YN sector



3BRF in hyperon sector is a key to solve Hyperon Puzzle!



Mid-heavy data from (π, K) exp.

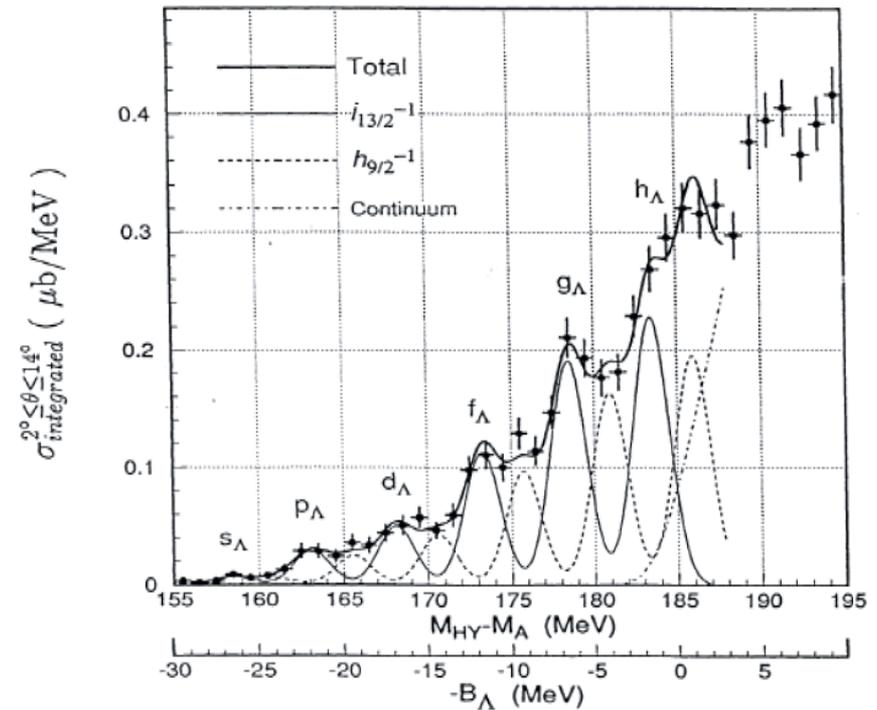
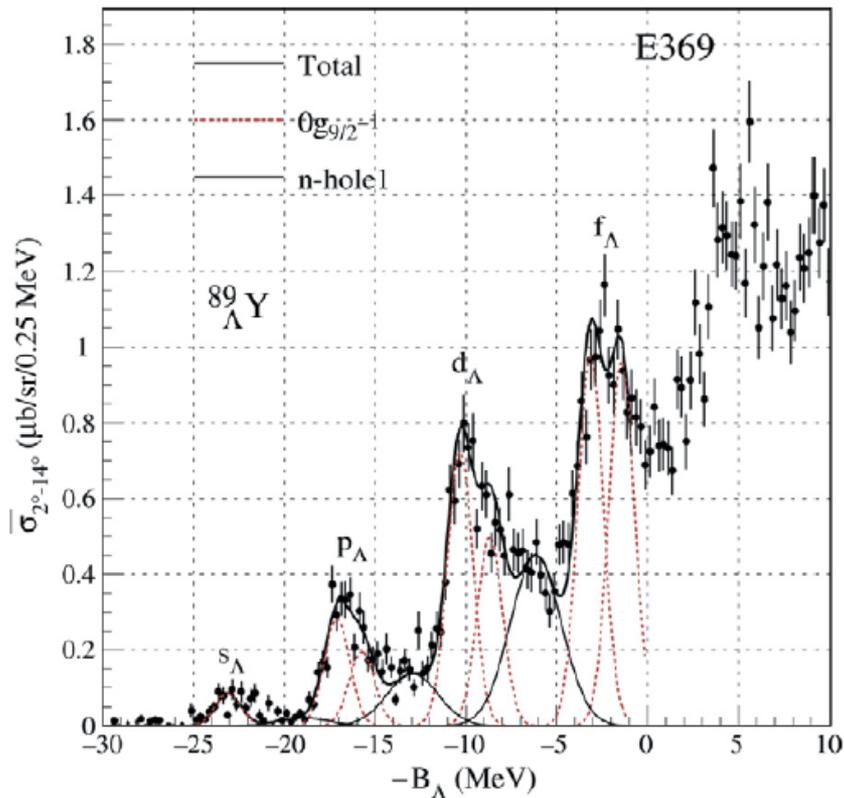
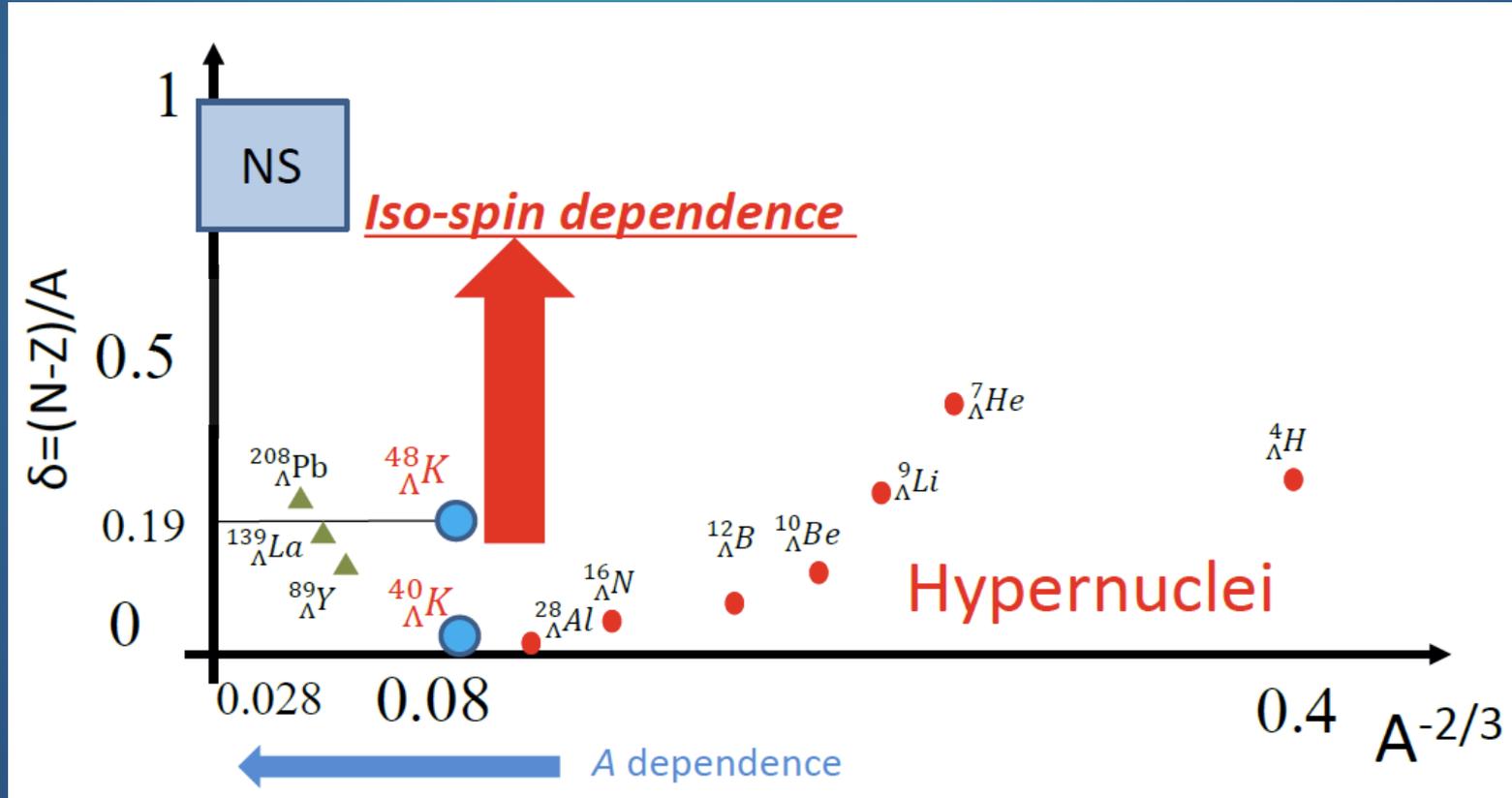


Figure B-5: Experimental $^{208}\text{Pb}(\pi^+, K^+)^{208}\text{Pb}$ excitation energy plot [HAS96].

From hypernuclei to neutron star



${}^{48}\text{Ca}$ and ${}^{40}\text{Ca}$ targets

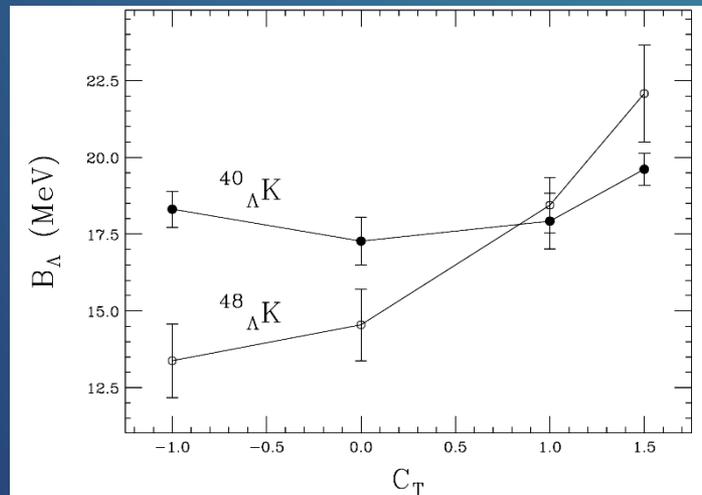
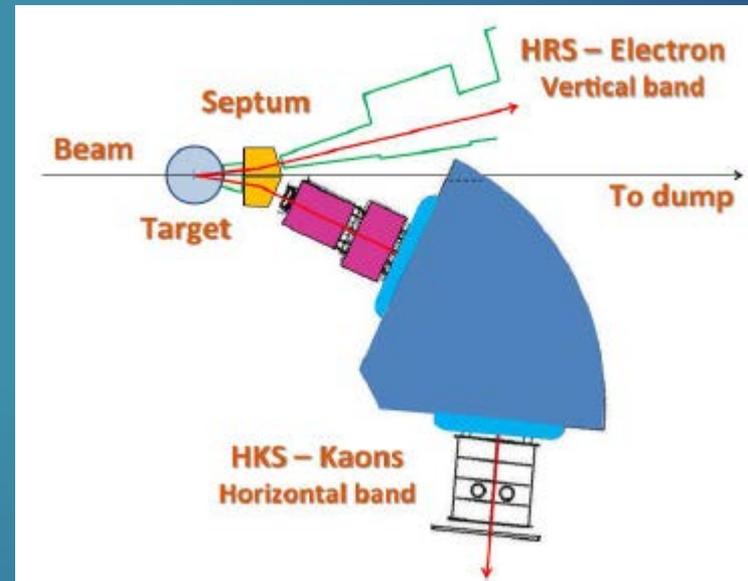
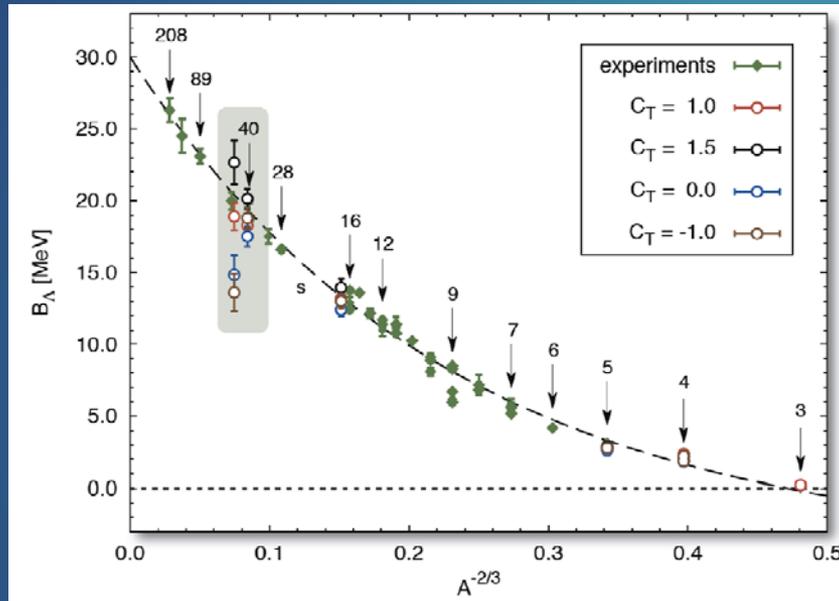


Key issues : A Dependence of 3BRF
Iso-spin Dependence

So far, NO experimental inputs for iso-spin dependence in mid-heavy HY

Phenomenological 3BRF+AFDMC

JLab Hall-A



$^{40}\text{Ca}(e, e'K^+)^{40}_\Lambda K$ and $^{48}\text{Ca}(e, e'K^+)^{48}_\Lambda K$

New experiment was approved as E12-15-008.

New Septa magnet + HKS + HRS

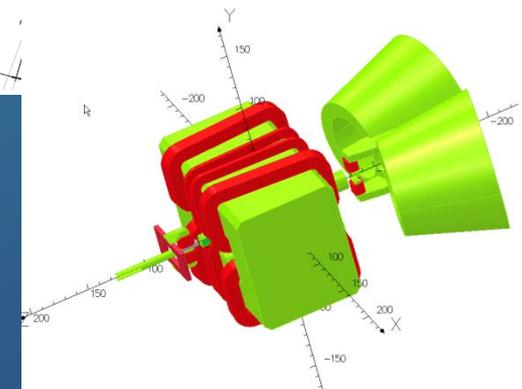
JLab Hypernuclear Collaboration Meeting 23, 24 March, 2017

- 10:00 Opening : Nue Nakamura
- 10:15 Hall Status : Steve Wood
- 10:30 Status of Septum magnet design : Nakamura, Aida
- 11:00 HKS platform design and Hall-A floor plan : Robin Wines, Alan Gavalya
Discussion about Mechanical items
Sieve Slit, Collimator, Interface between Septa and HKS/HRS
- 11:45 Magnets PS requirements, Hall-A Power, Water : Jack Segal, Nakamura

12:15-14:00 Lunch Break

- 14:00 Target (Ca40, 48) : Nakamura based on report by D.
- 14:30 Hall-A DAQ : Alexandre Camsonne
- 15:00 HKS Detectors
 - HDC : Tang
 - HTF : Gogami
 - AC : Reinhold
 - WC : Gogami
 - HRS Detectors : TBA

17:00 Discussion (necessary resources) & Summary of 1st day

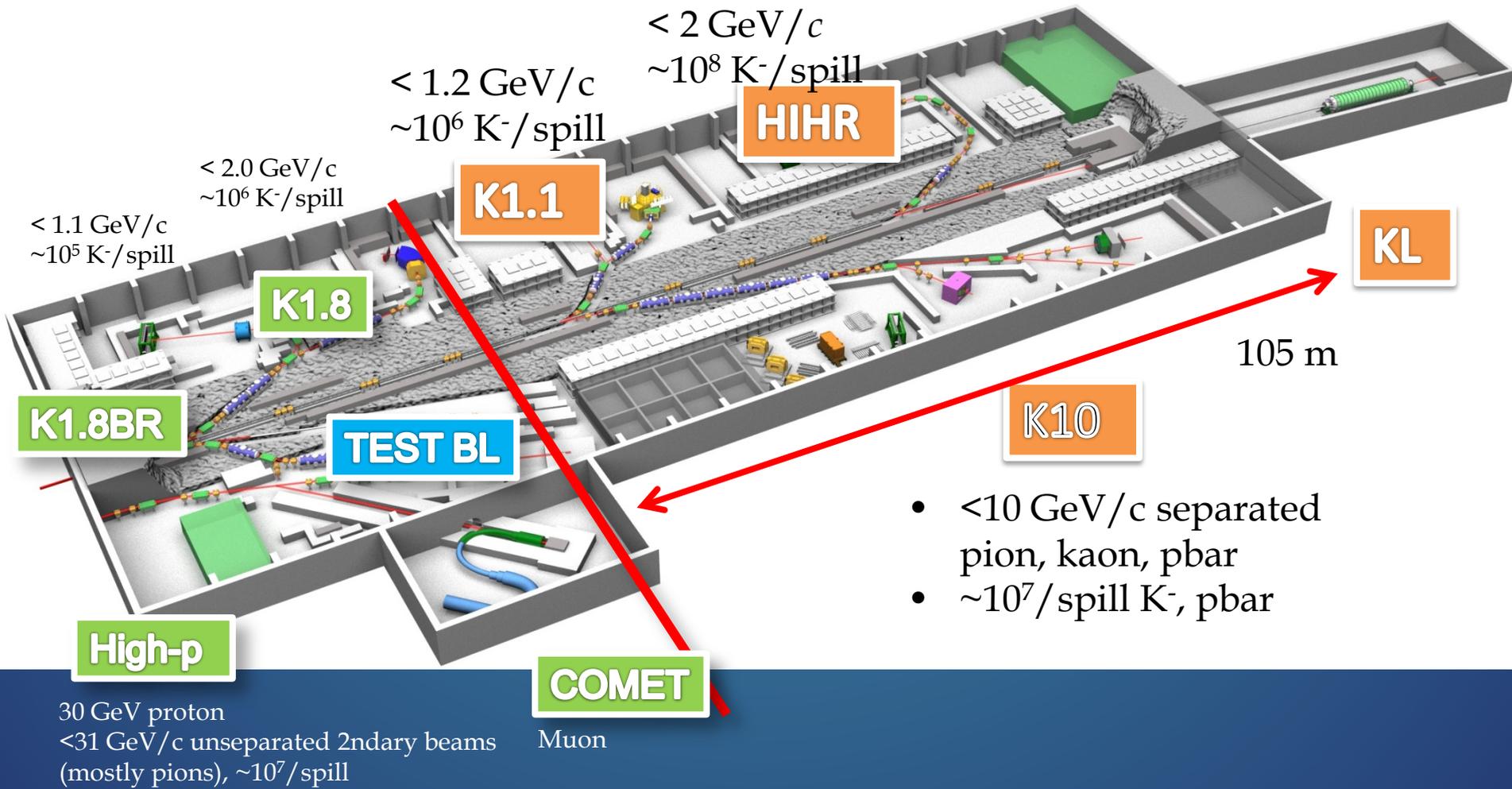


New Project@J-PARC

Hadron Experimental hall Extension

Selected as one of 4 high-priority projects
at KEK Program Implementation Plan Committee
(May 2016)

WP DL and supporter sign-up from:
<https://kds.kek.jp/indico/event/23853/>



$< 1.1 \text{ GeV}/c$
 $\sim 10^5 \text{ K}^-/\text{spill}$

$< 2.0 \text{ GeV}/c$
 $\sim 10^6 \text{ K}^-/\text{spill}$

$< 1.2 \text{ GeV}/c$
 $\sim 10^6 \text{ K}^-/\text{spill}$

$< 2 \text{ GeV}/c$
 $\sim 10^8 \text{ K}^-/\text{spill}$

105 m

K1.8BR

K1.8

TEST BL

K1.1

HIHR

K10

KL

High-p

COMET

30 GeV proton
 $< 31 \text{ GeV}/c$ unseparated 2ndary beams
(mostly pions), $\sim 10^7/\text{spill}$

Muon

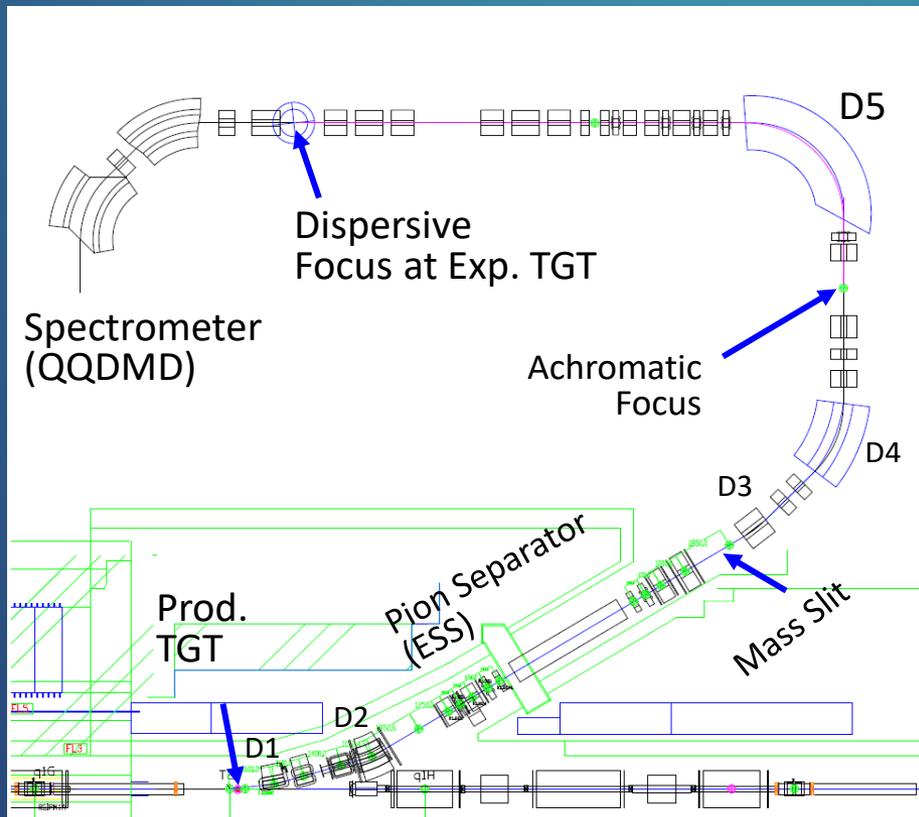
- $< 10 \text{ GeV}/c$ separated pion, kaon, pbar
- $\sim 10^7/\text{spill} \text{ K}^-$, pbar

Future Plan at J-PARC : HIHR

Present beam lines:

$\sim 10^6$ pions/pulse, $\Delta p/p \sim 1/1000$

- High-Intensity High-Resolution Beam line for High Precision (π , K^+) Spectroscopy with $\Delta E=0.1$ MeV
 - Dispersion matching + no beam tracking



Intensity: $\sim 1.8 \times 10^8$ pion/pulse
(1.2 GeV/c, 58 m, 1.4msr*%,
100kW, 6s spill, Pt 60mm)
 $\Delta p/p \sim 1/10000$



Complementary Program
to the JLab program

Summary

CSB of Λ hypernuclei

Determination of $B_{\Lambda}(^7_{\Lambda}\text{He}_{gs})$ triggered intensive study for $A=4$ iso-doublet hypernuclei ($^4_{\Lambda}\text{H}$ and $^4_{\Lambda}\text{He}$)

⇒ Mainz : Decay π spectroscopy
J-PARC E13 : γ -ray spectroscopy

Indicates that 0^+ large CSB, 1^+ small CSB

ΛNN 3BRF to solve the hyperon puzzle

New experiment for ($^{40}_{\Lambda}\text{K}$ and $^{48}_{\Lambda}\text{K}$) is under preparation to clarify the isospin dependence of 3BRF which is necessary to solve the hyperon puzzle.

⇒ Future HIHR at J-PARC Extended Hadron Hall