PE10

Progress of Strangeness Nuclear Physics at J-PARC in 10 years

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abstract

To study the baryon system such as the neutron star as well as nucleus, understanding of baryon-baryon interaction, in particular, hyperon-nucleon and hyperon-hyperon interaction is essential.

High intensity and high purity Kaon beam is available at J-PARC Hadron Experimental Facility K1.8 and K1.8BR beam lines. Strangeness nuclear physics programs are vigorously performed in this ten years.

Three prominent progress of strangeness nuclear physics at J-PARC HEF are introduced in this paper.

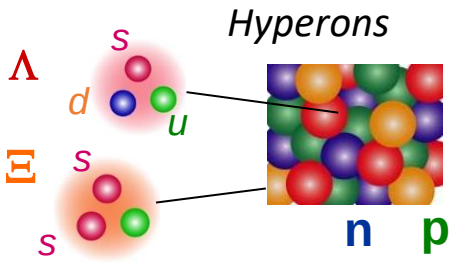
- Charge symmetry breaking in ΛN interaction via the gamma-ray spectroscopy of hypernuclei
- Origin of the nuclear repulsive core via the Σp scattering experiment
- ΞN interaction study via the hybrid emulsion experiment

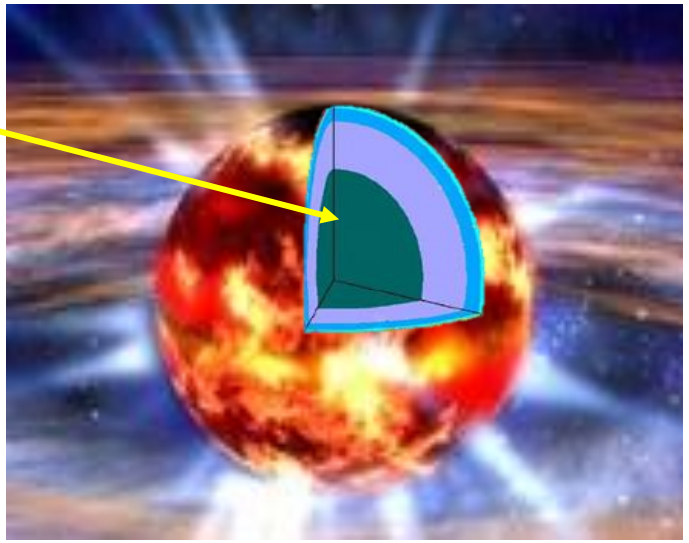
Motivation of Strangeness nuclear physics

Hyperon nucleon(YN) and hyperon-hyperon (YY) interaction study

Strange Hadronic Matter in neutron star ?

Hyperon's appearance is reasonable scenario

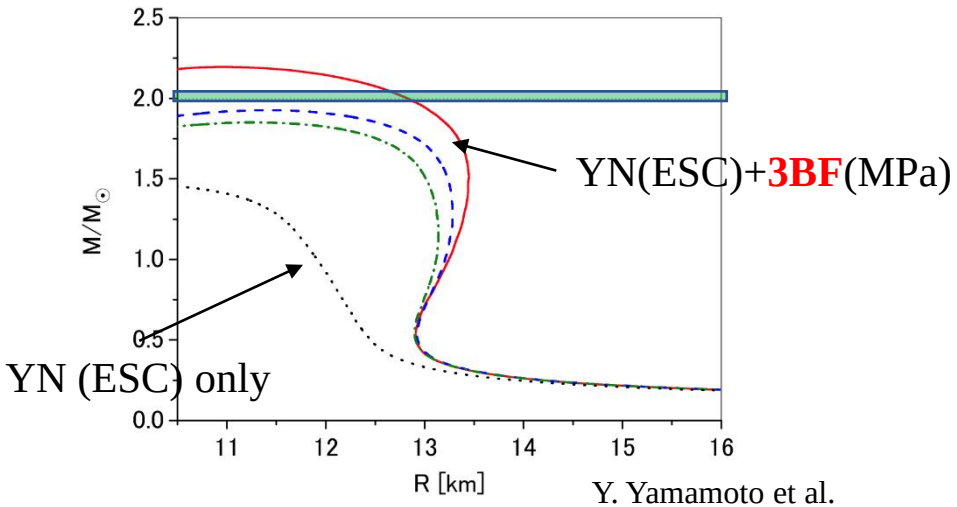




How can we reconcile ?

Softening of EOS w/ hyperon appearance

Two-solar-mass NS



Y. Yamamoto et al.
PRC90, 045805 (2014)

Accumulation of YN and YY interaction data is essential

Strangeness Nuclear Physics programs at J-PARC Hadron Experimental Facility

K1.8

2 stage electrostatic separator
Up to 2 GeV/c beam

S=–1 system

- Λ hypernuclear γ-ray spectroscopy
- Neutron rich Λ hypernuclei search
- Σp scattering experiment
- Σ hypernuclear spectroscopy
- Kaonic nuclei search

Pickup!

Pickup!

S=–2 system

- Hybrid emulsion experiment
- Ξ hypernuclear spectroscopy
- Ξ atom X ray spectroscopy

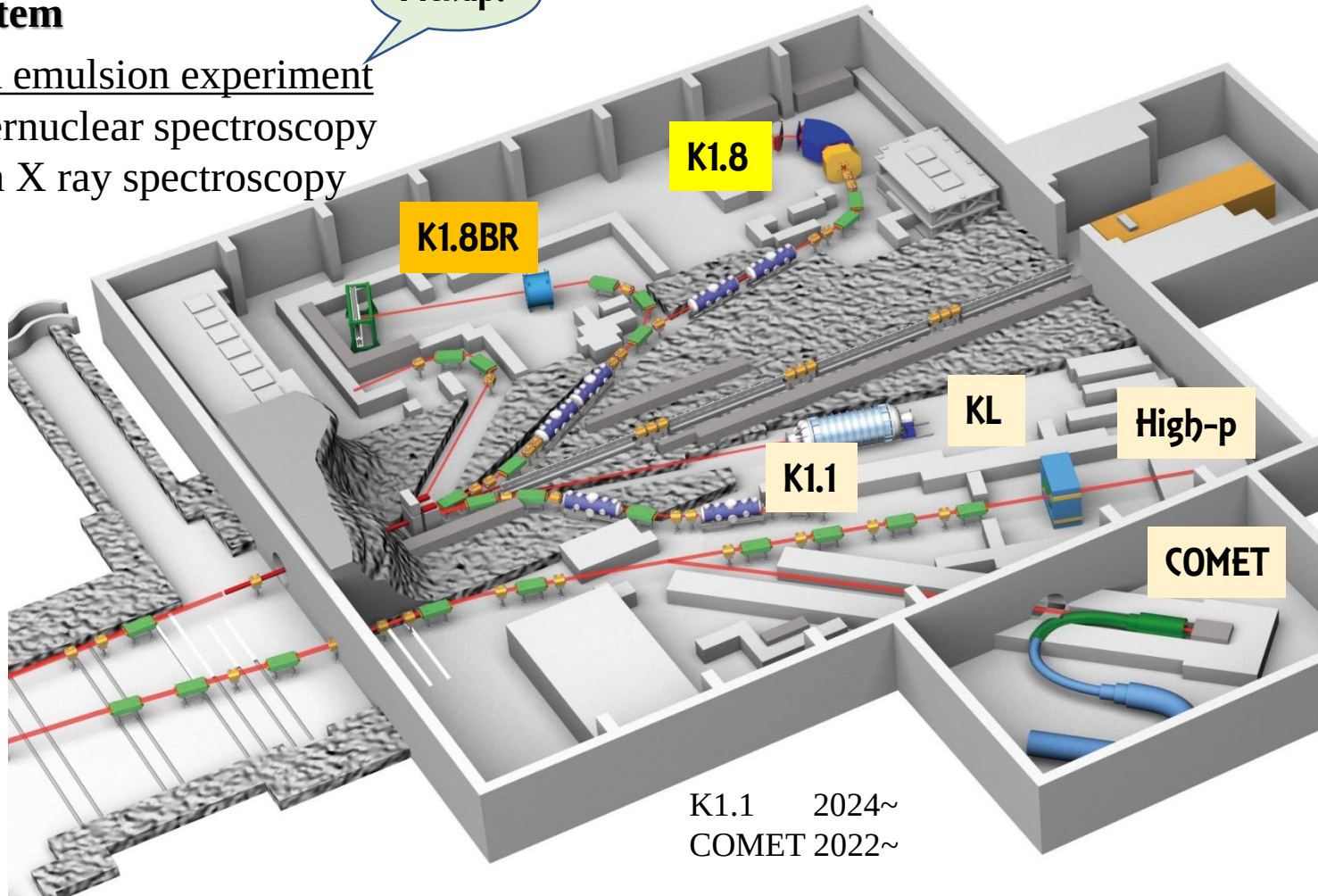
Pickup!

K1.8BR

1 stage electrostatic separator
Up to 1 GeV/c beam

S=–1 system

- Kaonic nuclei search
- Kaonic atom X-ray spectroscopy
- Hypertriton lifetime measurement



K1.1 2024~
COMET 2022~

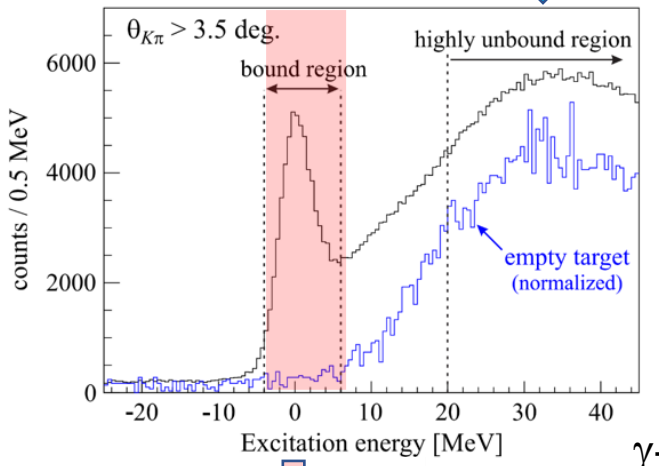
J-PARC E13

2013~2015

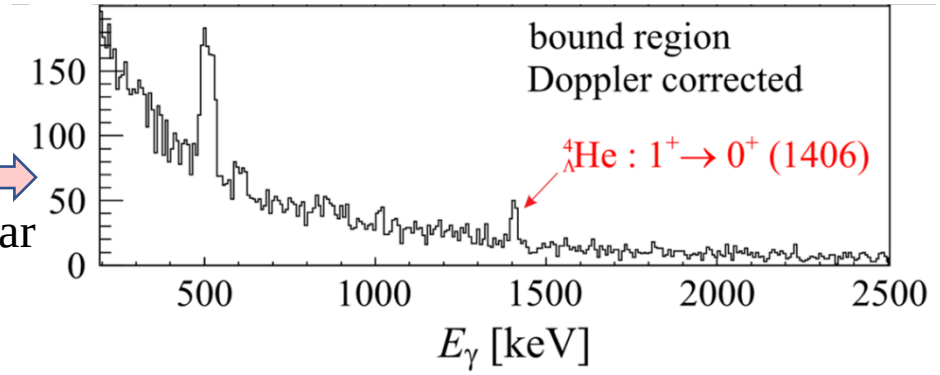
Study of Charge symmetry breaking in ΛN interaction via the gamma-ray spectroscopy of Λ hypernuclei

$$^{4}\mathrm{He}\,(K^{-},\pi^{-})\,{}^{4}_{\Lambda}\mathrm{He}^{*} \rightarrow {}^{4}_{\Lambda}\mathrm{He} + \gamma$$

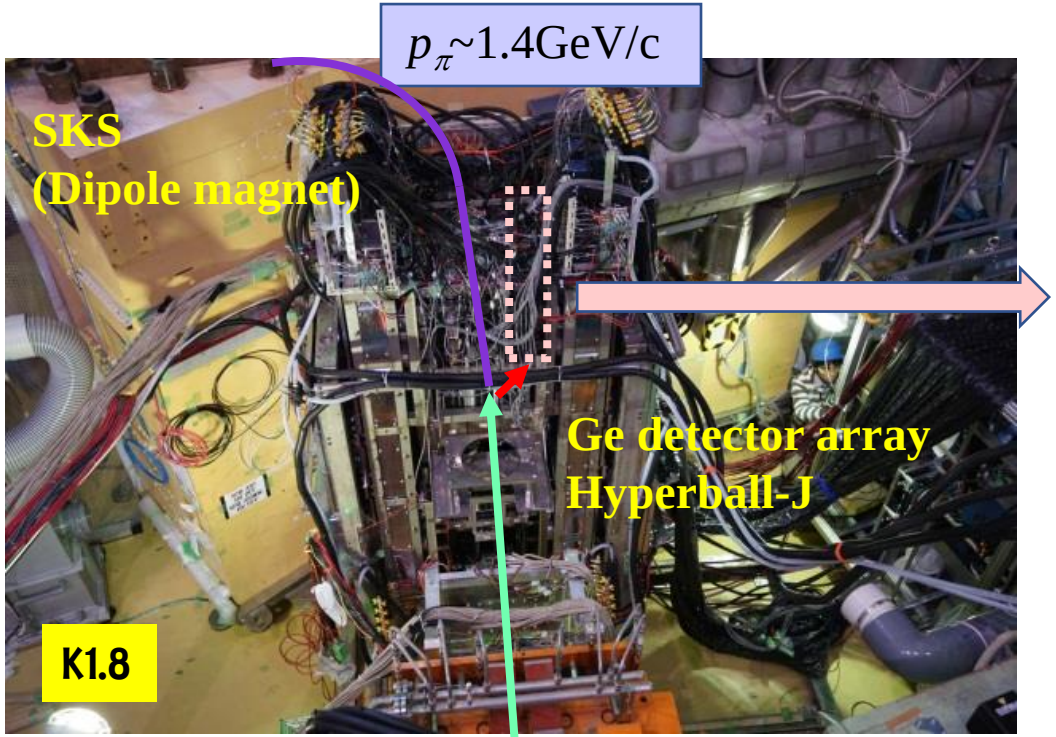
Missing mass spectrum



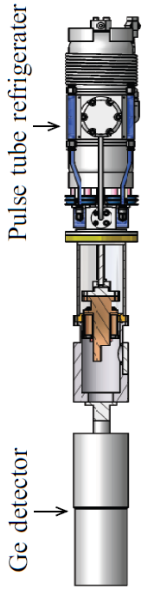
γ-ray energy spectrum



Select hypernuclear production event



K^{-} beam
p_{K}=1.5GeV/c



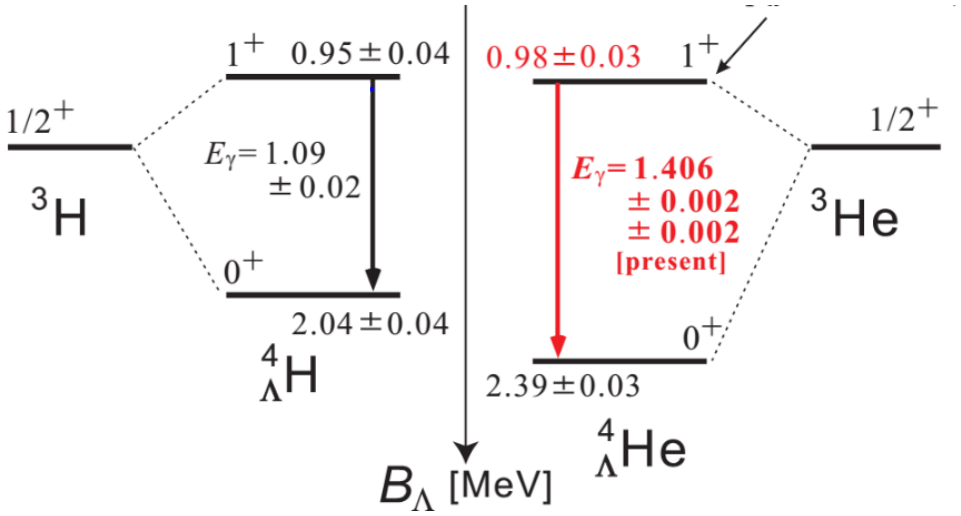
Germanium(Ge) detector

T.O.Yamamoto PRL
(Selected Editor's suggestion)

J-PARC E13

2013~2015

Study of Charge symmetry breaking in ΛN interaction via the gamma-ray spectroscopy of Λ hypernuclei

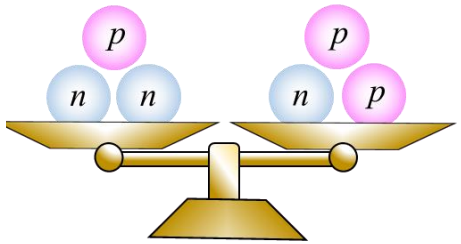


Level scheme of 4-body mirror hypernucleus

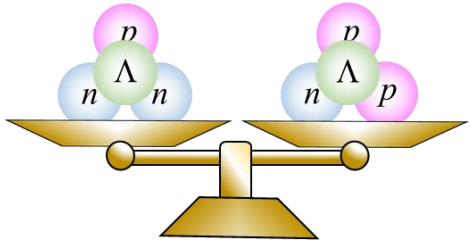
Charge symmetry of NN interaction

$M_{^3H} \sim M_{^3He}$

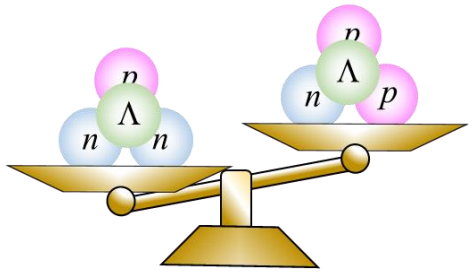
※EM effect corrected



$M_{^3H\uparrow\Lambda\uparrow} \sim M_{^3He\uparrow\Lambda\uparrow}$



$M_{^3H\uparrow\Lambda\downarrow} > M_{^3He\uparrow\Lambda\downarrow}$

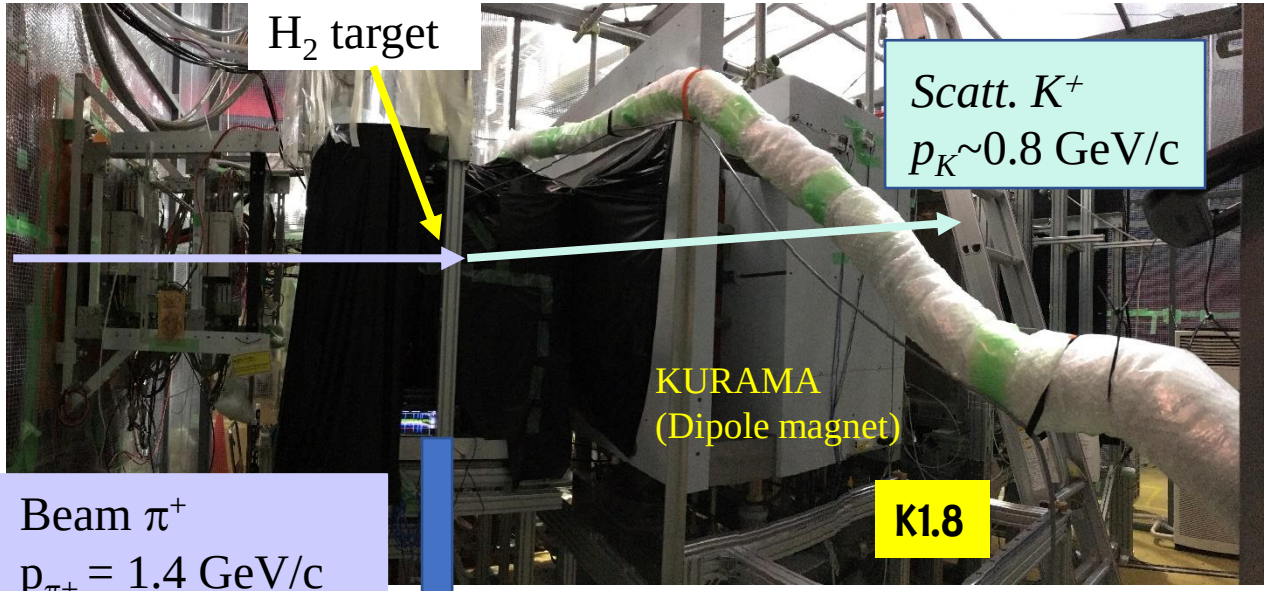


Charge symmetry breaking between Λp and Λn interaction and its spin dependence is confirmed.

J-PARC E40

2018~2020

Study of origin of the nuclear repulsive core via the Σ^+p scattering experiment



Beam π^+
$p_{\pi+}$ = 1.4 GeV/c

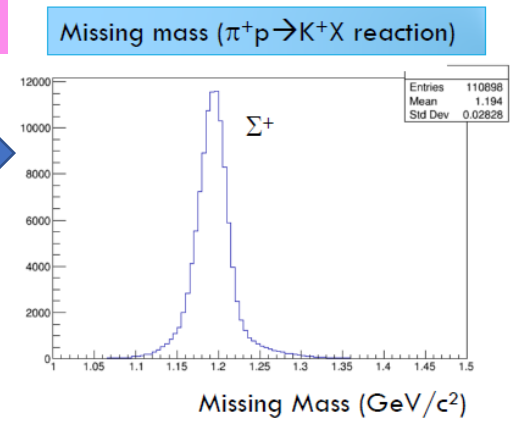
$$p(\pi^-, K^+)\,\Sigma^+$$

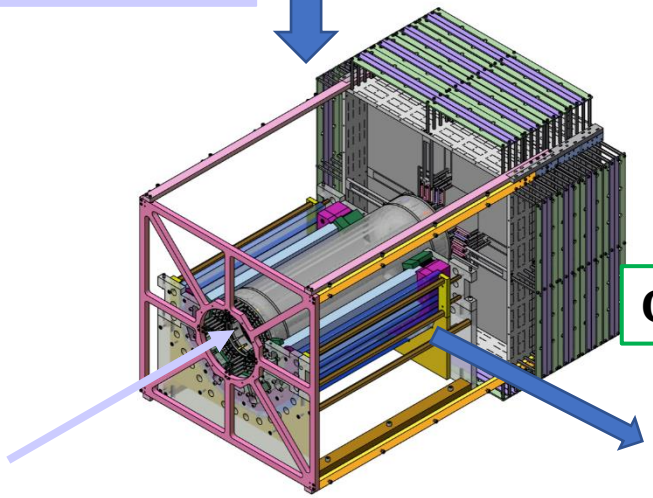
$$\Sigma^+ + p \rightarrow \Sigma^{+\prime} + p'$$

CATCH

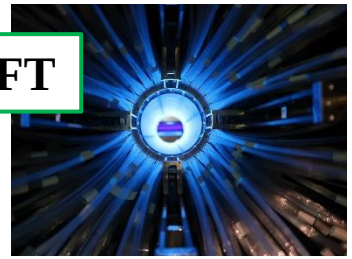
$$\Sigma^+ \rightarrow p + \pi^0$$

CATCH





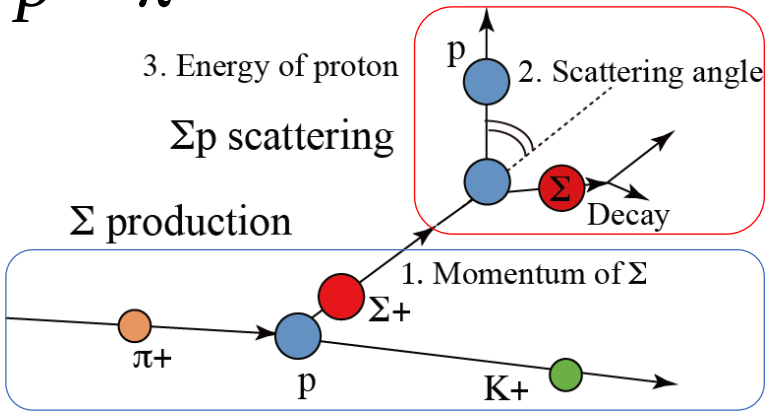
CATCH



CFT + BGO

Calorimeter

Scintillation fiber tracker



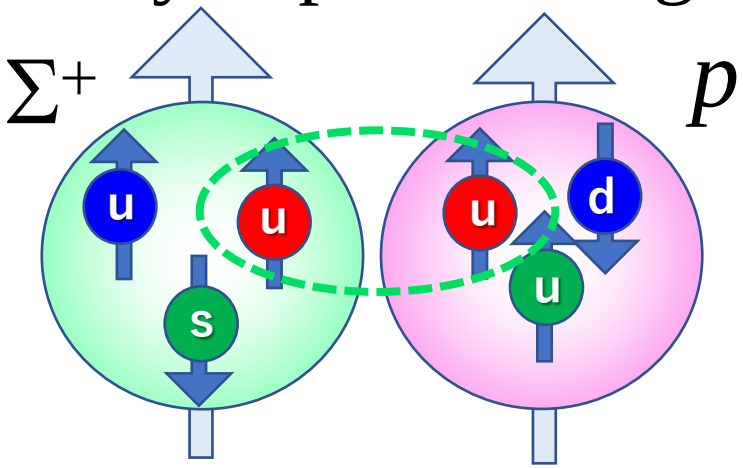
Σp scattering ID
CATCH
CFT + BGO

J-PARC E40

2018~2020

Study of origin of the nuclear repulsive core via the Σ^+p scattering experiment

Why Σ^+p scattering ?

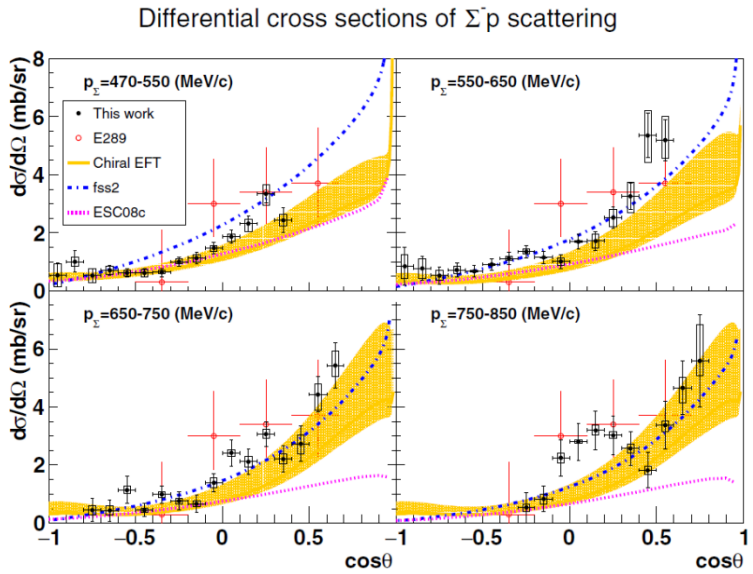


Pauli effect in quark level

Large repulsive core is expected in Lattice QCD

Large dσ/dΩ is predicted

Σ^+p data analysis is now under going.



First result of J-PARC E40 (Σ^- p result) published in Oct. 28th 2021
K. Miwa et al, PRC 104,045204(2021)

PHYSICAL REVIEW C **104**, 045204 (2021)

Measurement of the differential cross sections of the Σ^-p elastic scattering in momentum range 470 to 850 MeV/c

K. Miwa,[1] J. K. Ahn,[2] Y. Akazawa,[3] T. Aramaki,[1] S. Ashikaga,[4] S. Callier,[5] N. Chiga,[1] S. W. Choi,[2] H. Ekawa,[6] P. Evtoukhovitch,[7] N. Fujioka,[1] M. Fujita,[8] T. Gogami,[4] T. Harada,[4] S. Hasegawa,[8] S. H. Hayakawa,[1] R. Honda,[3] S. Hoshino,[9] K. Hosomi,[8] M. Ichikawa,[4,14] Y. Ichikawa,[8] M. Ieiri,[3] M. Ikeda,[1] K. Imai,[8] Y. Ishikawa,[1] S. Ishimoto,[3] W. S. Jung,[2] S. Kajikawa,[1] H. Kanauchi,[1] H. Kanda,[10] T. Kitaoka,[1] B. M. Kang,[2] H. Kawai,[11] S. H. Kim,[2] K. Kobayashi,[9] T. Koike,[1] K. Matsuda,[1] Y. Matsumoto,[1] S. Nagao,[1] R. Nagatomi,[9] Y. Nakada,[9] M. Nakagawa,[6] I. Nakamura,[3] T. Nanamura,[4,8] M. Naruki,[4] S. Ozawa,[1] L. Raux,[5] T. G. Rogers,[1] A. Sakaguchi,[9] T. Sakao,[1] H. Sako,[8] S. Sato,[8] T. Shiozaki,[1] K. Shirotori,[10] K. N. Suzuki,[4] S. Suzuki,[3] M. Tabata,[11] C. d. L. Taille,[5] H. Takahashi,[3] T. Takahashi,[3] T. N. Takahashi,[15] H. Tamura,[1,8] M. Tanaka,[3] K. Tanida,[8] Z. Tsamalaidze,[7,12] M. Ukai,[3,1] H. Umetsu,[1] S. Wada,[1] T. O. Yamamoto,[8] J. Yoshida,[1] and K. Yoshimura[13]

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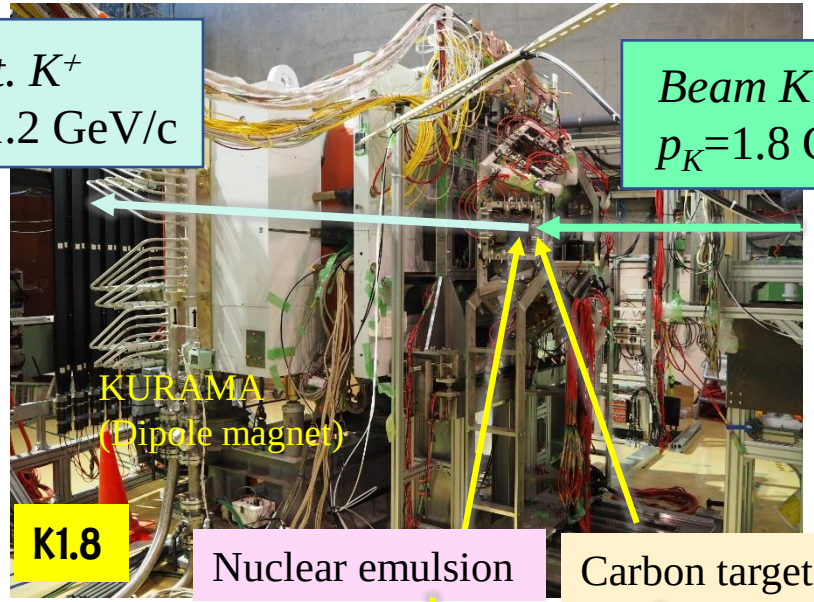
J-PARC E07

2016~2017

Study of S=-2 ΞN interaction via the hybrid emulsion experiment

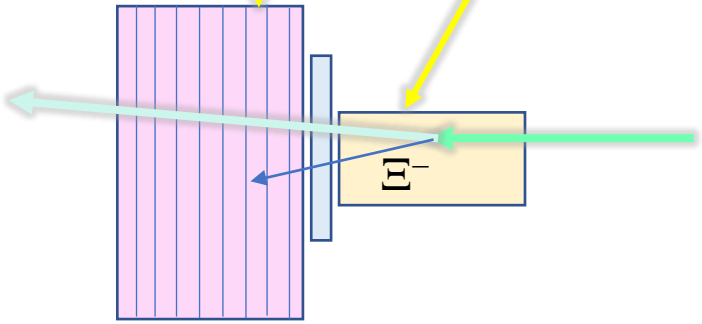


Scatt. K^+
p_K~1.2 GeV/c

Beam K^-
p_K=1.8 GeV/c

Nuclear emulsion

Carbon target



SSD

p in Carbon target

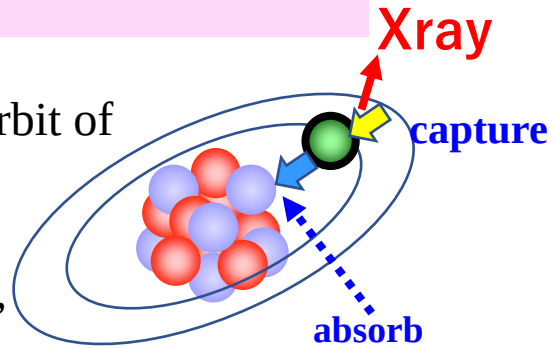
As quasi free production

"*p*"(K^-, K^+) "Ξ^-"

Reaction in the C target

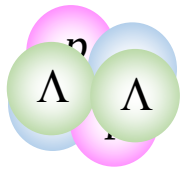
Recoiled Ξ^- travel from C target to nuclear emulsion

Stopped Ξ^- **capture** in the atomic orbit of nucleus of nuclear emulsion

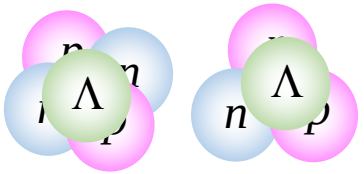


After de-exitation in atomic orbit, X- is absorbed by nuclei
($\Xi N \rightarrow \Lambda\Lambda$:Q value =23 MeV)

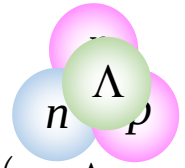
ΛΛ hypernuclei



Twin Λ hypernuclei



Single Λ hypernuclei



(one Λ escape)

other

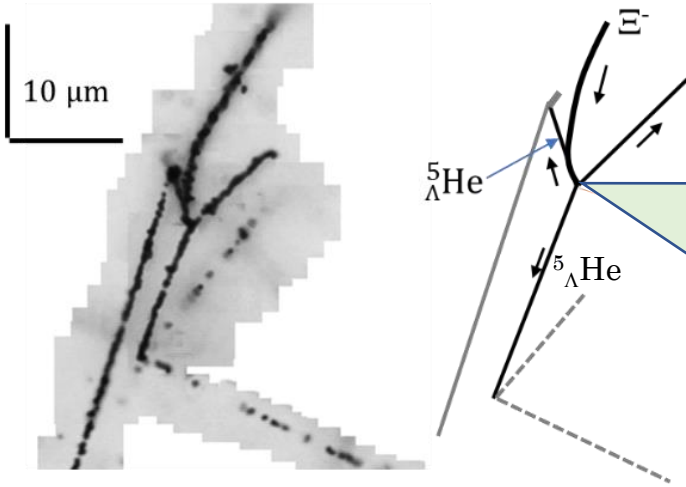
(two Λs escape)

J-PARC E07

2016~2017

Study of S=-2 ΞN interaction via the hybrid emulsion experiment

Irrawaddy event: Twin Λ hypernuclear event



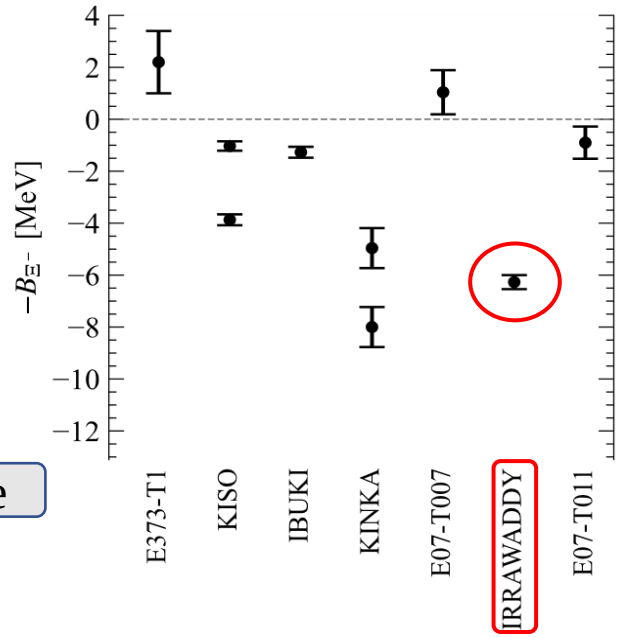
Ξ⁻ captured and absorbed on ^{14}N

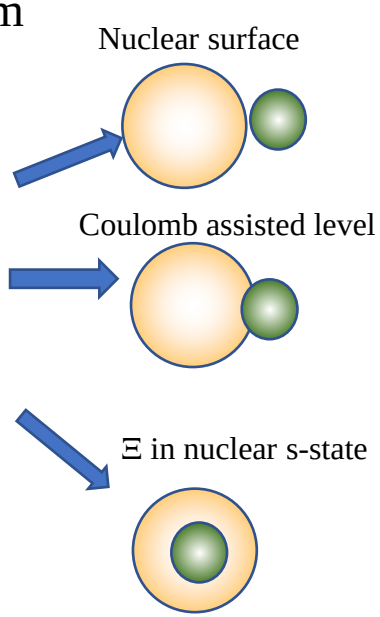
$^{14}N + \Xi^- \rightarrow {}^{15}_{\Xi}C \rightarrow {}^{5}_{\Lambda}He + {}^{5}_{\Lambda}He + {}^{4}He + n$

invisible

M. Yoshimoto et al., PTEP2021,073D02(2021)

Ξ⁻ binding energy of ^{14}N+ Ξ⁻ system found in emulsion





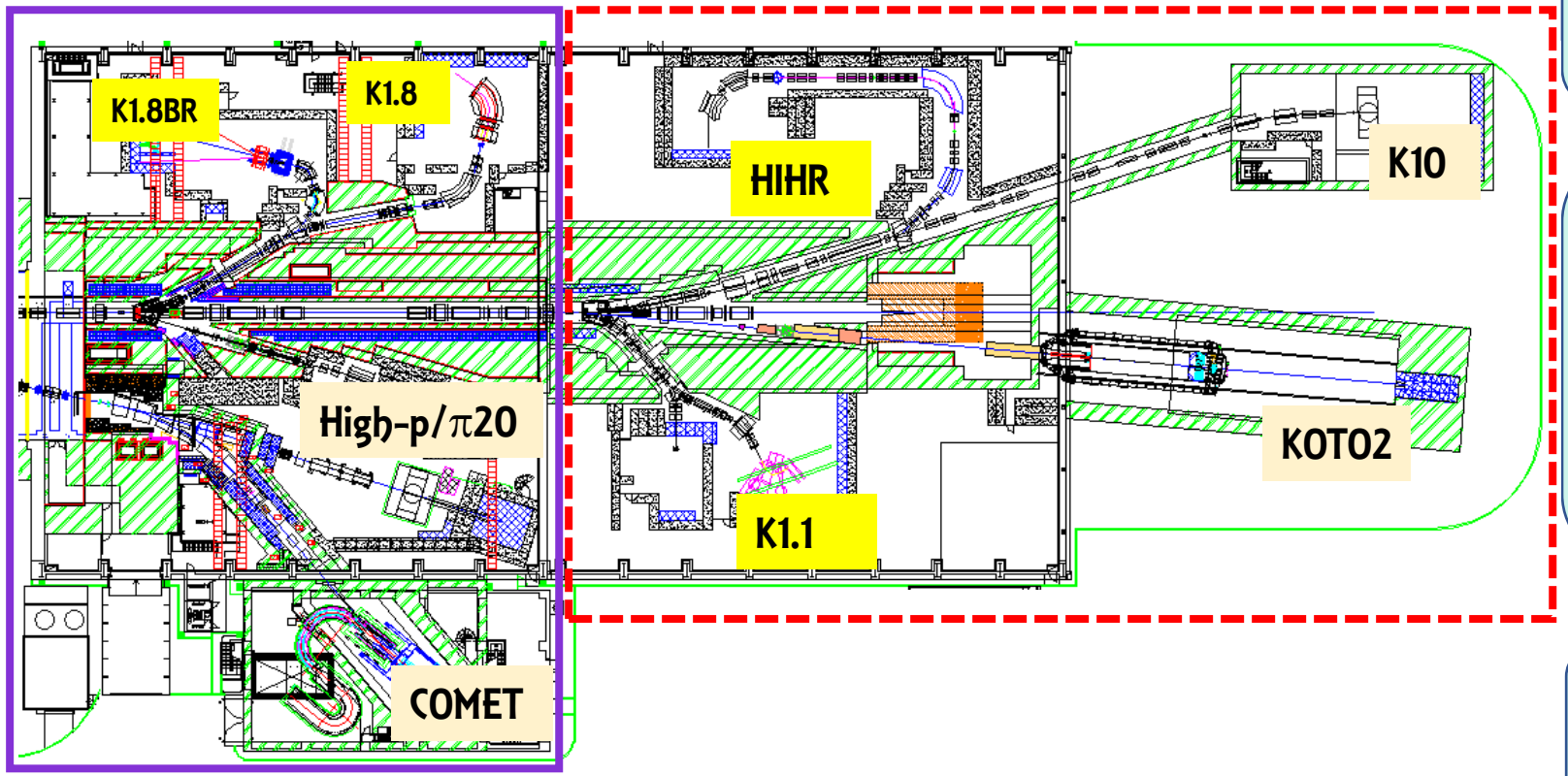
First observation of a nuclear 1s state of the Ξ-hypernucleus

- Weakly attractive ΞN interaction
- Very weak ΞN →ΛΛ conversion width

Future prospect of Strangeness Nuclear Physics

Existing hall

Extension plan



HIHR
High resolution spectroscopy of hypernuclei
ΛNN three body interaction (P84)

K1.1 (existing or extended hall)
ΛP scattering experiment (P86)
gamma-ray spectroscopy of hypernuclei
g-factor of Λ in hypernuclei (E63)
Charge symmetry breaking (E63)
Λ hypernuclear β decay (LOI)

π20
Λp scattering experiment (LOI)