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

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

<table>
<thead>
<tr>
<th>System</th>
<th>Experiments</th>
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| $S=-1$ | - $\Lambda$ hypernuclear $\gamma$-ray spectroscopy  
- Neutron rich $\Lambda$ hypernuclei search  
- $\Sigma p$ scattering experiment  
- $\Sigma$ hypernuclear spectroscopy  
- Kaonic nuclei search |
| $S=-2$ | - Hybrid emulsion experiment  
- $\Xi$ hypernuclear spectroscopy  
- $\Xi$ atom X-ray spectroscopy |

#### K1.8BR
- **1 stage electrostatic separator**
- Up to 1 GeV/c beam

<table>
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<th>System</th>
<th>Experiments</th>
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| $S=-1$ | - Kaonic nuclei search  
- Kaonic atom X-ray spectroscopy  
- Hypertriton lifetime measurement |
Study of Charge symmetry breaking in $\Lambda N$ interaction via the gamma-ray spectroscopy of $\Lambda$ hypernuclei
Study of Charge symmetry breaking in $\Lambda N$ interaction via the gamma-ray spectroscopy of $\Lambda$ hypernuclei

Charge symmetry breaking between $\Lambda p$ and $\Lambda n$ interaction and its spin dependence is confirmed.
Study of origin of the nuclear repulsive core via the $\Sigma^+p$ scattering experiment

$\Sigma^+ + p \to \Sigma^+ + p'$

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

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

Beam $\pi^+$
$p_{\pi^+} = 1.4$ GeV/c

H$_2$ target

$Scatt. K^+$
$p_K \sim 0.8$ GeV/c

KURAMA (Dipole magnet)

CFT + BGO

Scintillation fiber tracker

Calorimeter

CATCH

$\Sigma\pi$ scattering

$\Sigma$ production

1. Momentum of $\Sigma$
2. Scattering angle
3. Energy of proton

$\Sigma^p$ scattering ID
CATCH
CFT + BGO
Study of origin of the nuclear repulsive core via the $\Sigma^+p$ scattering experiment

Why $\Sigma^+p$ scattering?

$\Sigma^+p$ data analysis is now under going.

Large repulsive core is expected in Lattice QCD

Large $d\sigma/d\Omega$ is predicted

First result of J-PARC E40 ($\Sigma^-p$ result) published in Oct. 28th 2021
K. Miwa et al, PRC 104,045204(2021)
Study of $S=-2$ $\Xi N$ interaction via the hybrid emulsion experiment

$Scatt.\ K^+\ \ \ \ p_K\sim 1.2\ \ GeV/c$

$Beam\ K^-\ \ \ \ p_K=1.8\ \ GeV/c$

"$p"(K^-,\ K^+)\ "\Xi-"

Reaction in the C target

Recoiled $\Xi^-$ travel from C target to nuclear emulsion

Stopped $\Xi^-$ capture in the atomic orbit of nucleus of nuclear emulsion

After de-exitation in atomic orbit, $X^-$ is absorbed by nuclei

$(\Xi N \rightarrow \Lambda \Lambda : Q \text{ value } = 23\ \text{MeV})$

$p$ in Carbon target

As quasi free production

Nuclear emulsion

Carbon target
Study of $S=-2 \ \Xi N$ interaction via the hybrid emulsion experiment

**Irrawaddy event: Twin $\Lambda$ hypernuclear event**

$\Xi^-$ captured and absorbed on $^{14}\text{N}$

$^{14}\text{N} + \Xi^- \rightarrow ^{15}\Xi^-\text{C}$

$\rightarrow ^5\Lambda\text{He} + ^5\Lambda\text{He} + ^4\text{He} + n$

$\Xi^- \text{ binding energy of } ^{14}\text{N} + \Xi^- \text{ system found in emulsion}$

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

First observation of a nuclear 1s state of the $\Xi$-hypernucleus

- Weakly attractive $\Xi N$ interaction
- Very weak $\Xi N \rightarrow \Lambda\Lambda$ conversion width
Future prospect of Strangeness Nuclear Physics

Existing hall

- K1.8
- HIHR
- K1.1
- KOTO2
- High-p/π20
- COMET

Extension plan

- K10
- HIHR

Existing hall:
- HIHR
- High resolution spectroscopy of hypernuclei
- ΛNN three body interaction (P84)

Extension plan:
- K1.1 (existing or extended hall)
- Λπ 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
- Λπ scattering experiment (LOI)