# Research Group for Hadron Nuclear Physics

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The research goals of the Hadron Nuclear Physics Group are to experimentally study 1) exotic hadrons and nuclei with strange and charm quarks, and 2) hot and dense partonic/hadronic matter at J-PARC (Japan), BNL-RHIC (USA), and Belle (II) (Japan). Through these studies, we explore many-body problems of quarks and hadrons in relation to Quantum Chromo Dynamics (QCD).

**Hadron experimental studies at J-PARC**

On the X-ray spectroscopy of $\Xi^-$ atoms, we developed a novel experimental method with emulsion and germanium detectors [1]. We searched for signals of $\Xi^-$-Br and $\Xi^-$-Ag atoms in the X-ray energy spectrum. Although we found no signal, we reduced the background level by a factor of 170 [2]. We also proposed an experiment to search for a $\Xi^-$-C atom, which was approved with Stage-1 status (for its physical significance).

We have analyzed the data for the first experiment to search for H-dibaryon with the Hyperon Spectrometer. Using the track reconstruction algorithm developed with the Time Projection Chamber (TPC), we obtained clear peaks for $\Lambda$ and $K_s$, in the $p\pi^-$ and $\pi^-\pi^-$ invariant mass spectra, respectively. We demonstrated clear identification of $\pi$ and p with the energy deposit in the TPC. We also proposed a new experiment to study $\Sigma$N cusp, which has been approved as Stage-1 status.

We have been making final detector preparations to study $\Xi^-$-nucleus for the beam time planned in June 2023.

We studied $\Sigma^+$p elastic scattering using the data of an experiment to study of $\Sigma^\pm$p scattering [3]. Analyzing 2400 scattering events, 80 times the number of events in previous experiments, we obtained precise differential cross sections and phase shifts, where the latter are related to the strength of the interaction. As shown in Fig. 1, the phase shift of $\Sigma^+$-p scattering is found to be twice as large as that of p-p scattering, that indicates strong repulsive force between $\Sigma^+$ and p. A press release was published for the result.

In the experiment to study $\Lambda(1405)$ via ($K^-$, n) reaction on the deuteron target, we obtained a precise pole position of $\Lambda(1405)$ in d($K^-$, n)$\pi\Sigma$ reactions [4]. We published a press release for this result.

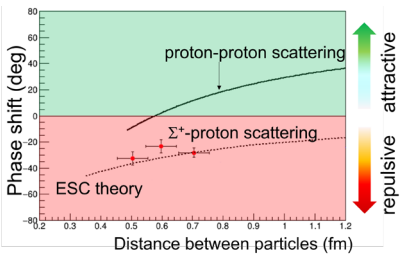


Fig.1: Phase shifts of proton-proton and $\Sigma^+$-proton scatterings.

We study modification of the $\phi$ meson mass with $\phi$ decay into $e^+e^-$ inside the nucleus at J-PARC. We evaluated the electron identification performance of Hadron Blind Detectors and Lead Glass Calorimeters with the data of the commissioning run in 2021 [5]. A new experimental proposal of $\phi\rightarrow K^+K^-$ measurement has been approved with Stage-1 status. We have developed and tested Multi-gap Resistive Plate Chambers with high-rate capability and achieved a timing resolution of 74 ps and a detection efficiency of 95%.

**Other research activities**

A future heavy-ion beam program at J-PARC (J-PARC-HI) is proposed to create dense baryonic matter and search for phase structures in the high-density region of the QCD phase diagram. In this fiscal year, we submitted "A request to investigate heavy-ion acceleration" to J-PARC, which started the official investigation of heavy-ion acceleration at J-PARC. We also submitted "Future academic promotion plans" for J-PARC-HI from Univ. of Tsukuba as a representative of the community.

We studied exotic hadrons at Belle and Belle II experiments. In heavy-ion collisions, we performed the STAR experiment to study high-density matter, and made final preparations for Intermediate Silicon Tracker (INTT) for the sPHENIX experiment to study the quark-gluon plasma at RHIC.

***Reimei* research programs**

We continued the *Reimei* program "Collaborative research to evaluate QCD vacuum properties at high density from $\phi$ meson decay inside the nucleus" starting from JFY2021, led by S. H. Lee (Yonsei Univ.) to study $\phi$ properties inside the nucleus. We studied the relation between decay kinematics of $\phi\rightarrow e^+e^-$ and $\phi\rightarrow K^+K^-$ decays. We found that $\phi$ polarization can be distinguished in both decays with the decay angle of the daughter particles [6]. In particular with $\phi\rightarrow K^+K^-$, both longitudinally and transversely polarized $\phi$ can be clearly distinguished. We held a *Reimei* Workshop "Polarization phenomena and Lorentz symmetry violation in dense matter" at Yonsei University and online with 41 participants in Oct. 2022.

**References**

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