

# Collaborative Studies of Baryon Spectroscopy at J-PARC

## between Theory and Experiment

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### Abstract

In this Reimei research, we have studied baryon spectroscopy and dense matter physics in collaboration between theory and experiment. We have progress in detector developments for baryon spectroscopy experiment J-PARC E45, and made a new experimental proposal to search for L(1670) as J-PARC E72. We have made a new collaboration and R&D works for the future heavy-ion program at J-PARC. A Reimei workshop was held in December 2017. The goal of the workshop was to bring together researchers from around the world to discuss the new aspects of hadron spectroscopy and relativistic heavy-ion physics, with an emphasis on what could be learned from experiments at J-PARC. Experts in the field reviewed new results in both experimental and theoretical areas of research, resulting in good discussion and new collaborative research directions.

### 1. Research Objectives

The research objectives are to develop new experimental and theoretical collaborations on the topics of this conference. Hadron spectroscopy is used to compare the masses of particles (such as baryons) that have absorbed energy from some source, producing a resonant quantum state at a specific mass (energy). These quantum states can then be compared with theoretical predictions from models and calculations based on Quantum Chromodynamics (QCD). Similarly, when heavy ions collide, the quarks and gluons can produce a new state of matter, similar to a plasma, where the particles interact strongly but are not confined within particles. Comparisons between experimental observables and theoretical predictions help us to learn more about this new state of matter and the ways that the theory of QCD are manifest in nature.

### 2. Research Contents

1. Experimental and theoretical studies of baryon systems at J-PARC.
2. Preparation for the experiment to study baryon excited states at J-PARC.
3. Investigation of physics of dense hadronic matter with heavy-ion beam at J-PARC.

In order to achieve these goals, we held the 41th Reimei workshop : Mini Workshop “Light baryon and hyperon spectroscopy at J-PARC” in June 21, 2017 at ASRC, and the 42th Reimei Workshop on Hadronic Resonances and Dense Matter on December 11-13, 2017 at Ibaraki

Quantum Beam Research Center in Tokai, followed by a J-PARC Heavy-Ion Collaboration Meeting on December 14.

The mini workshop was a kickoff meeting to discuss plans of the Reimei research. Actually, this discussion leads to a new experimental proposal of  $\Lambda(1670)$ , which will be describe below.

The research contents of the workshop on December 2017 are described on the website at URL: <https://asrc.jaea.go.jp/soshiki/gr/hadron/workshop/reimei2017/>

The keynote speaker was Prof. Anthony Thomas, Director of the Center for Subatomic Structure of Matter in Australia. Prof. Thomas gave an inspiring talk titled “From Quarks to Finite Nuclei and Neutron Stars”. His talk was followed by several speakers from the USA, Japan and elsewhere, on the topic of hadron spectroscopy, with emphasis on the overlapping interest between experiments at J-PARC and at other laboratories around the world. The second day focused on the spectroscopy of heavy quarks, as seen in data from Belle, LHCb and other facilities that have sufficient energy to produce charmed meson resonances. The workshop concluded on the third day with a series of talks from international speakers on the topic of a quark-gluon plasma and how experiments can recognize the type of phase transition from quarks confined to hadrons into a region of quarks and gluons in a nearly-free state. The possibility to do experiments with heavy-ion collisions sometime in the near future at J-PARC was discussed and good international collaboration seems possible. The subject was further discussed in the J-PARC Heavy-Ion collaboration meeting.

### 3. Research results

In experimental research, we made progress in the two experiments J-PARC E45 for baryon spectroscopy with  $(\pi, 2\pi)$  reactions proposed by K. Hicks and H. Sako, and a new experimental proposal (J-PARC E72) for  $\Lambda(1670)$  search by K. Tanida and K. Hicks.

The goal of E45 is to establish  $N^*$  and  $\Delta^*$  resonances experimentally up to 2 GeV/c<sup>2</sup> using  $(\pi N \rightarrow \pi\pi N)$  reactions using a large acceptance Time Projection Chamber with 2-order higher statistics than the previous experimental data. The goal of E72 is to search for a  $\Lambda(1670)$  resonance in  $K^+p \rightarrow \Lambda\eta$  reaction. A hint for this resonance was previously observed at Belle and Crystal Ball experiments. This resonance does not exist in quark models and therefore could be an exotic hadron.

We developed the spectrometer common to the two experiment (Hyperon Spectrometer). In this Reimei research, we achieved stable operation at 1.2 T for the superconducting Helmholtz magnet at KEK. We developed a prototype TPC hodoscope for the two-charged particle trigger, and achieved a good timing resolution of 180 ps. We completed the design of the liquid-hydrogen target system and tests are underway.

We took reviews of the two experiments in January 2018 by J-PARC Program Advisory Committee. E72 received a Stage 1 approval (approval for physics) successfully. E45 was reviewed for experimental feasibility (Stage-2 review). Most of experimental technical issues were solved, while more detailed validation of required beam time was requested by the committee, and E45 will be reviewed again in July 2018.

We studied also dense matter physics which is planned with heavy-ion beams at J-PARC in the future. We made a collaboration framework with QCD theorists, hadron experimentalists at J-

PARC, heavy-ion experimentalist at RHIC and LHC. Also, we also have a new international collaboration with Vinca Institute of University of Belgrade, and University of Grenoble. We have worked for R&D for high resolution time-of-flight counter with University of Tsukuba, and a fast data acquisition system with Nagasaki Institute of Advanced Science, and Center of Nuclear Study, University of Tokyo.

The research results of the Reimei Workshop on December 2017 are presented in the collection of slides from the 2017 Reimei Workshop. These slides are collected on the website [1]. A new paper by the keynote speaker has recently been published on one of the topics of this workshop [2]. In addition, this workshop shows that there is increased international interest for experiments to be done at J-PARC in the near future [3]. A white paper is being written in the USA to gather together people with common interests in hadron spectroscopy, which will be taken to the funding agencies in the USA. In addition, the heavy-ion community has a keen interest to find the critical point of the phase transition for the quark-gluon plasma, and such experiments could be carried out at J-PARC if the extension to the Hadron Hall is completed [4]. The increased international interest is demonstrated by the variety of talks given at the workshop [1].

#### 4. Conclusion

In summary, we have great progress in experimental and theoretical research on baryon spectroscopy and dense matter physics at J-PARC. We made good progress for  $N^*$  and  $\Delta^*$  spectroscopy and  $\Lambda(1670)$  search experiments and developed a plan for heavy-ion future experiment. The Reimei workshops were a definite success, to bring together researchers from around the world and focus their attention on the possibilities of doing experiments at J-PARC that have overlap with their own research plans. One of the goals of the Reimei grants is to create a new dawn in the research collaboration between Japan and the international community. This workshop succeeded in this goal and will lead to new ideas for both experimental and theoretical collaborations.

#### 5. References

- [1] <https://asrc.jaea.go.jp/soshiki/gr/hadron/workshop/reimei2017/>
- [2] “Implications of Neutron Star Properties for the Existence of Light Dark Matter”, T.F. Motta, P.A.M. Guichon and A.W. Thomas, J. Phys. G45, 05LT01 (2018).
- [3] “Strange and Charm Hadron Physics at J-PARC in Future”, H. Noumi, JPS Conf. Proc. 17, 111003 (2017).
- [4] “Extension of the J-PARC Hadron Facility in the Future”, H. Fujioka, arXiv: 1706.07916.