Annual Report

2012

J-PARC Branch

KEK Theory Center

Institute of Particle and Nuclear Studies

High Energy Accelerator Research Organization

Contents

1 Preface

The High Energy Accelerator Research Organization (KEK) initiated theory activities in Tokai from 2011 for supporting theoretical studies on J-PARC projects and for facilitating communications between theorists and J-PARC experimentalists. First, four KEK theory staff members:

Akinobu Dote, Kazunori Itakura, Shunzo Kumano, and Osamu Morimatsu

joined the Particle and Nuclear Physics Division of the J-PARC Center on March 1, 2011 by considering to start the activities on April 1, 2011. However, the great east Japan earthquake on March 11, 2011 delayed the project. The KEK theory center decided to start the J-PARC theory project from December 1, 2011 at the staff meeting of October 11, 2011 by assigning the name "J-PARC Branch, KEK Theory Center, Institute of Particle and Nuclear Studies, KEK". Five visiting staff members:

Toru Harada, Emiko Hiyama, Daisuke Jido, Makoto Oka, and Toru Sato

joined the J-PARC branch on December 1, 2011 for activating the branch. From April 1, 2012,

Toshiki Maruyama

joined the group as a research fellow.

We develop theory projects in close collaboration with J-PARC experimentalists. As a center for theoretical activities on the J-PARC projects, the visiting staff members together with KEK theory staff members organized workshops, collaboration meetings, and seminars. They are listed at the J-PARC branch home page, http://j-parc-th.kek.jp/html/English/e-index.html. The activities until March 31, 2013 are summarized in this report.

We hope that theorists as well as experimentalists actively use our branch for the success of the J-PARC project.

Shunzo Kumano
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2 Members

Name	Institution	Research field
KEK staff members		
Akinobu Dote	KEK	Strangeness nuclear physics
Kazunori Itakura	KEK	Hadron physics
Shunzo Kumano	KEK	High-energy hadron physics
Osamu Morimatsu	KEK	Hadron physics
Visiting staff members		
Toru Harada	Osaka Electro-Communication Univ/KEK	Hypernuclear reactions
Emiko Hiyama	RIKEN / KEK	Strange & charm nuclear physics
Daisuke Jido	Kyoto University /KEK	Exotic hadrons
Makoto Oka	Tokyo Institute of Technology / KEK	Charmed hadrons
Toru Sato	Osaka University /KEK	Neutrino-nucleus interactions
Research fellow		
Toshiki Maruyama	Japan Atomic Energy Agency / KEK	Strangeness / Neutron stars
Secretary		
Kieko Iioka	KEK	

3 Activity summary of visiting-staff members

3.1 Excitation spectra of strangeness nuclei and baryon-mixing states Toru Harada (Osaka Electro-Communication University/KEK)

One of the important subjects in strangeness nuclear physics is on the interactions of strange particles with nuclear systems [1]. The strange particles include both K mesons and hyperons (Λ, Σ, Ξ). A strangeness nucleus is a many-hadron system containing many nucleons and one or more strange particles. The production and spectroscopy of strangeness nuclei with $S = -1$ and -2 activate the strangeness degree of freedom in nuclear and hadron physics, which is regarded as "doorways" to the exploration of multi-strange hadronic matter, toward high-dense QCD matter and neutron star in astrophysics. The quark content of the strange particles is $K^- = u\bar{s}$, $\Lambda = s[ud]_0$, $\Sigma = s[ud]_1$, etc, where "s" indicates a strange quark. Thus, the spectroscopy of a strange particle embedded in a nucleus is often referred to as that of a "tagged strange quark." The study of the response of a many-body system to a hyperon "impurity" sheds light on the role of strange quarks in strong interactions, the $SU(3)$ structure of baryon-baryon interactions, which will be understood from lattice QCD in the near future.

Strangeness can be directly embedded in a nucleus as bound states of hyperons and K mesons via several nuclear reactions. At present, such experimental investigations are conducted in various accelerator facilities around the world [2]: (e, $e'K^+$) reactions at JLab, anti-hypernuclear production at RHIC, ($K^-_{\rm stop}$, π^-) reactions at DAΦNE ϕ factory, hyperfragments from heavy-ion beams at GSI, (e, $e'K^+$) reaction at Mainz, and high intensity pion/kaon beams at J-PARC. New experiments at J-PARC will bring us more advanced studies using ($\pi^\pm$, K^+), (K^-, $\pi^\mp$), (K^-, N) and (K^-, K^+) reactions.

Strangeness nuclear physics offers access to an exotic many-body spectroscopy, where we can find dynamical symmetries which are forbidden for ordinary nuclei by the Pauli principle and $SU(3)$ symmetry. The Λ hyperon can use a "impurity" to probe various aspects of nuclear structure. For example, the Λ makes a shrinkage of nuclear size due to its "glue"-like role, and the Λ coupled to a rotational band induces a change in the moment of inertia, leading to a change in these electromagnetic properties. The changes depend on the nature of the ΛN interaction, e.g., spin-isospin, tensor, spin-orbit, and ΛNN three-body forces.

It is very interesting that behavior of a hyperon in neutron-excess environment is strongly connected with the nature of neutron stars and compact stars. The presence of hyperons in high-density nuclear medium significantly affects the maximal mass of neutron stars because it makes the Equation of State (EoS) soften. Moreover, a baryon fraction in neutron stars is found to depend on properties of Λ, Σ^-, Ξ^- hypernuclear potentials. Therefore, the study of neutron-rich Λ hypernuclei is one of the most promising subjects to examine the hypernuclear potentials in the neutron-excess environment.

We have theoretically investigated the excitation spectra of Λ, Σ and Ξ-$\Lambda\Lambda$ hypernuclei in terms of double-charge exchange (DCX) reactions such as (K^-, K^+), (π^-, K^+), etc., in order to understand production, structure and decay of strangeness nuclei. This suggests that a one-step mechanism, as we mention later, in which a doorway state is populated by these reactions owing to the hyperon mixing, is very important for production using the DCX reactions [3, 4]. These excitation spectra provide valuable information on properties of the ΛN-ΣN and ΞN-$\Lambda\Lambda$ coupling interaction [5]. More detailed studies should be needed with the development of theoretical treatments in a comparison with forthcoming experimental data at J-PARC. Recently, several theorists had a new collaboration at the J-PARC branch of the KEK Theory Center to proceed these subjects, and discussed them together with experimentalists. In this contribution, I report the current status of the collaboration, together with motivation and background on several topics, and discuss a future perspective.

Neutron-rich Λ hypernuclei

Neutron-rich nuclei give us new information on properties of the nuclear structure and nucleon-nucleon interaction because unusual behaviors of the excess neutrons appear in a neutron-excess environment, e.g., neutron skin and neutron halo. We expect that a neutron-rich Λ hypernucleus is an exotic candidate because the Λ hyperon acts as a nuclear "glue" in the neutron-excess environment and can often make a system bound even if a core-nucleus is unbound. Several experimental attempts to produce neutron-rich Λ hypernuclei were carried out by DCX reactions such as ($K^-_{\rm stop}$, π^+) and (π^-, K^+) on nuclear targets. The (π^-, K^+) reaction on a ^{10}B target succeeded in the first measurement of a neutron-rich Λ hypernucleus $^{10}_{\Lambda}$Li owing to a very low experimental background from the incident pion beam.

A neutron-rich hypernucleus $^6_\Lambda$H is expected to be a good candidate due to the coherent ΛN-ΣN coupling, as predicted by Akaishi *et al.* Recently, evidence for the $^6_\Lambda$H hypernucleus was presented from the FINUDA experiment at DAΦFN, studying $\pi^+\pi^-$ pairs in coincidence from $K^-_{\rm stop} + ^6{\rm Li} \to \pi^+ + ^6_\Lambda{\rm H}$ followed by the $^6_\Lambda{\rm H} \to {}^6{\rm He} + \pi^-$ decay. The derived binding energy of $^6_\Lambda$H disagreed with the strength of the coherent ΛN-ΣN mixing effect predicted in neutron-rich strange matter. Very recently, the J-PARC E10 experiment of the ^{6}Li(π^-, K^+) reaction to confirm the $^6_\Lambda$H hypernucleus was carried out, and these analysis will be reported.

The nuclear (π^-, K^+) reaction would be governed by a one-step mechanism, $\pi^- p \to K^+\Sigma^-$ via Σ^- doorways due to the ΣN-ΛN coupling, rather than a two-step mechanism, $\pi^- p \to \pi^0 n$ followed by $\pi^0 p \to K^+\Lambda$, or $\pi^- p \to K^0 n$ followed by $K^0 p \to K^+\Lambda$. In fact, we have shown that the Λ-Σ coupling plays an important role of a Σ admixture in Λ hypernuclei via the DCX (π^-, K^+) reaction on nuclear targets, together with the feasibility of extracting a Σ^- admixture probability in the neutron-rich Λ hypernuclei [3]. In this viewpoint, the investigation of the DCX (π^-, K^+) reaction is in progress to understand the structure of $^6_\Lambda$H and its reaction mechanism.

Σ hypernuclei

The (π^-, K^+) reaction also provides the population of a Σ^- hypernucleus via the $\pi^- p \to K^+\Sigma^-$ reaction on a nuclear target. It is suggested that the Σ-nucleus potential would be strongly repulsive in medium to heavy nuclear systems based on the KEK-PS E438 experiment using the (π^-, K^+) spectra at 1.2 GeV/c. Up to now, there has been no measurement claiming a bound state of the Σ hyperon in a nucleus, except $^4_\Sigma$He, which was confirmed experimentally as a Σ quasibound state. However, we believe that a Σ hyperon in nuclei plays an important role in determining the structure of a Λ hypernucleus, where the Σ admixture caused by ΛN-ΣN coupling is connected to a three-body ΛNN force [5]. We recognize that the ($\pi^\pm$, K^+) reaction is a powerful tool to investigate Σ nuclear interactions and nuclear Σ states embedded in excitation spectra from Λ to Σ regions [6].

Ξ, $\Lambda\Lambda$ hypernuclei

It is important to understand properties of Ξ hypernuclei to access multi-strangeness systems as well as a two-body ΞN-$\Lambda\Lambda$ system. Because a Ξ hyperon in nuclei has to undergo a strong $\Xi N \to \Lambda\Lambda$ decay, widths of Ξ hypernuclear states give us a clue to a mechanism of Ξ absorption processes in nuclei. Several studies suggested that Ξ-nucleus (optical) potentials has $V_\Xi =(-14)$–(0) MeV in the Woods-Saxon potential. However, our knowledge of these Ξ-nucleus systems is very limited due to the lack of the experimental data. The J-PARC E05 experiment proposes to observe a bound-state peak in a ^{12}C(K^-, K^+)$^{12}_{\Xi}$Be reaction. After the existence of these $^{12}_{\Xi}$Be states is established, it is necessary to observe several light Ξ hypernuclei to investigate the spin and isospin dependence of the Ξ-nucleus potential.

The (K^-, K^+) reaction is one of the most promising ways of studying doubly strange systems such as Ξ^- hypernuclei. This reaction can also populate a $\Lambda\Lambda$ hypernucleus through a DCX two-step mechanism as $K^-p \to \pi^0\Lambda$ followed by $\pi^0 p \to K^+\Lambda$. Early theoretical predictions for two-step ^{16}O(K^-, K^+) reactions at $p_{K^-} = 1.1$ GeV/c (0°) have indicated small cross sections, ∼1 nb/sr for nuclear $\Lambda\Lambda$ states in $^{16}_{\Lambda\Lambda}$C. On the other hand, a one-step mechanism, $K^-p \to K^+\Xi^-$ via Ξ^- doorways caused by a $\Xi^-p \to \Lambda\Lambda$ transition can be also in an exotic production of $\Lambda\Lambda$ hypernuclei in the (K^-, K^+) reactions. The ΞN-$\Lambda\Lambda$ coupling induces the Ξ^- admixture in a $\Lambda\Lambda$ hypernucleus. This mechanism could give us a larger production cross section of ∼ 10 nb/sr depending on the ΞN-$\Lambda\Lambda$ coupling strength [4]. In the viewpoint of the nuclear ΞN-$\Lambda\Lambda$ dynamics, the investigation of the DCX (K^-, K^+) reaction is in progress.

In summary, we have proposed that one of the promising ways is to investigate production and spectroscopy of Λ, Σ (Ξ, $\Lambda\Lambda$) hypernuclei in terms of the hyperon mixing caused by the ΛN-ΣN (ΞN-$\Lambda\Lambda$) coupling interactions. The strategy of the collaboration is to apply it to some appropriate nuclear systems and to obtain quantitative and realistic results with theoretical developments for the forthcoming experiments at J-PARC.

3.2 Heavy Quark at J-PARC
Emiko Hiyama (RIKEN/KEK)

Workshop on heavy quark at J-PARC

December 2 - 5 in 2012, room number 227 at the first building at Tokai campus

Program

2nd December (Sun.)

13:00 - M. Oka (TokyoTech), Introduction

Chair M. Oka (TokyoTech)

13:10 - T. Takahashi (Gunma), Hadron interaction including heavy quark with Lattice QCD

14:00 - 15:00 Y. Yamaguchi (RCNP), Analysis of exotic hadron composed of heavy mesons and nucleons

15:00 - Discussion

3rd December (Mon.)

Chair: E. Hiyama (RIKEN)

10:00 - 11:00 A. Hosaka (RCNP), Di-quark correlation in heavy baryon

11:00 - 12:00 M. Oka (TokyoTech), Short-range repulsion between heavy baryon

12:00 - 14:00 Lunch

Chair A. Hosaka (RCNP)

14:00 - 15:00 K. Ozawa (KEK), Experiment on heavy quark at J-PARC and other facilities

15:00 - 16:00 H. Noumi (RCNP), Charm baryon spectroscopy at J-PARC

16:00 - 17:00 E. Hiyama (RIKEN), Structure of exotic hadron within the framework of constituent quark model

17:00 - Discussion

4th December (Tues.)

Chair. Yasui (KEK)

10:00 - 11:00 T. Hyodo (TokyoTech), DN interaction and excited state of charm baryon

11:00 - 12:00 A. Dote (KEK), Narrow quasi-bound states of DNN system

12:00 - 14:00 Lunch

14:00 - 15:00 A. Yokota (TokyoTech)), Nuclear bound state in charmonium

15:00 - Discussion

5th December (Wed.)

Chair. Hyodo (TokyoTech)

9:00 - 10:00 Okoda (RCNP), Production and decay of Zb and BBbar atomic state

11:00 - Discussion

It is important to study excited state of molecular resonant states and exotic hadronic state. In this situation, also it becomes of interest to study structure of exotic hadrons including heavy quarks such as charm and bottom. Indeed, at KEKB, RHIC and LHC, they are planning to produce such hadrons. Furthermore, we are now discussing the possibility to produce heavy hadrons using high momentum beam line at J-PARC.

In this workshop, we discussed DNN three-body state, J/ΨNN state, exotic quark state, Zb, etc. Using the Gaussian Expansion Method, we predicted the bound state in J/ΨNN state. However, still we need to discuss how to produce this state at J-PARC facility.

3.3 New direction in the study of hadron-nucleus bound systems Daisuke Jido (Yukawa Institute for Theoretical Physics, Kyoto University/KEK)

Workshop on new direction in the study of hadron-nucleus bound systems
August 8 - 10, 2012, KEK Tokai campus

Purpose of workshop: The purpose of this workshop was to discuss new trends of hadron-nucleus systems. Bound systems of a nucleus and a hadron can be experimental tools to investigate in-medium properties of hadrons. In addition, the systematic study of in-medium properties of hadrons will reveal the nature of more fundamental quantities, such as the in-medium value of the quark condensate. Especially, the precise spectroscopy of deeply bound pionic atoms has clarified the in-medium properties of pion and the value of the quark condensate at the density of $0.6\rho_0$, where ρ_0 is the nuclear saturation density. In this workshop we have discussed the new direction of the nucleus-hadron bound systems, such as the phenomenological methods to measure the values of the quark condensate at different densities and the ways to extract the fundamental feature of in-medium kaon using kaonic atoms.

Organizers: Daisuke Jido (KEK, YITP), Akinobu Dote (KEK), Shinji Okada (RIKEN)

Participants: Satoru Hirenzaki (Nara WU), Natsumi Ikeno (Nara WU), Soichiro Goda (Kyoto), Hiroyuki Fujioka (Kyoto), Takayasu Sekihara (KEK), Junko Yamagata-Sekihara (KEK), Kenta Itahashi (RIKEN), Takahiro Nishi (Tokyo), Kota Okochi (Tokyo)

Participants of mini-workshop: Emiko Hiyama (KEK, RIKEN), Yoichi Ikeda (Tokyo Tech) Takahisa Koike (RIKEN)

Program:

6 (Mon)	14:00	D. Jido “Opening : purpose of workshop and subjects to be discussed”
7 (Tue)	14:00	T. Sekihara “One and two nucleon absorptions of kaon”
8 (Wed)	**Mini-workshop on “Physics of precise measurement of kaonic atoms”**	
9 (Thu)	14:00	N. Ikeno “Formation of deeply bound pionic atoms in Sn isotopes”
	15:00	S. Goda “In-medium quark condensate evaluated by chiral perturbation theory”

Program of mini-workshop:

Aug. 8 (Web)

14:00 - 14:45	S. Okada	"Introduction"
14:45 - 15:30	S. Hirenzaki	"Kaonic atoms"
15:30 - 16:15	J. Yamagata-Sekihara	"Kaonic helium and lithium atoms"
16:15 - 16:30	Break	
16:30 - 17:15	Y. Ikeda	"Kbar-N interaction"
17:15 - 18:00	T. Koike	"Kaon mass"
18:00 - 19:00	Discussion	

3.4 Spectroscopy of heavy baryons and dibaryon bound states Makoto Oka (Tokyo Institute of Technology/KEK)

Dynamics of quarks in QCD depends on the quark mass, as the QCD is scale dependent and the color gauge coupling runs with the energy scale. The interaction is significantly weaker in the heavy quark systems than the light hadron systems. The effect is further enhanced in the case of the spin dependent interactions, where the magnetic coupling of the gluon to quarks is suppressed by the extra factor $1/m_Q$, inverse of the quark mass. Indeed, the heavy quark symmetry, in particular the heavy-quark spin symmetry, has a strong predictive power on the spectrum and decay amplitudes of heavy quark mesons and baryons.

In view of the new experimental opportunity for producing charmed mesons and baryons at the high-momentum beam lines in the J-PARC hadron physics facility[7], we have started discussions on physics opportunity related to the charm quark hadrons. Quite a few exciting physics subjects are on the discussion.

1. Heavy Baryon Spectroscopy (with A. Hosaka, T. Yoshida) [8]
   The spectrum of the charmed baryons has very limited data available. Most of the ground state baryons have been observed and their masses are well predicted (or fitted) by the lattice QCD calculation as well as various quark model approaches. In fact, the quark model is known to be successful quantitatively in the low-lying quarkonia, $Q\bar{Q}$. It is interesting to see that a similar success is seen in the baryon spectrum. While the ground states are well described in terms of a heavy quark plus two light quarks, the excited states are not fully explored. Some interesting issues are whether a strong di-quark type correlation is realized. If the scalar-isoscalar di-quark and the axial-vector-isovector di-quark are the dominant components of the Λ_Q and Σ_Q, respectively, the excited baryons may also be composed of the same building blocks, and then the excited states may be classified into the di-quark type and the independent-quark type.

2. Molecular Bound States of Two Heavy Hadrons (with Y.R. Liu, E. Hiyama, A. Yokota, W. Meguro, S. Maeda) [9, 10, 11]
   The heaviness of the heavy quark hadrons brings a new possibility to have shallow hadronic bound states of two heavy hadrons. The reason is that the kinetic energy (repulsion) is suppressed, while the color-singlet meson exchange interaction, which is dominated by the light mesons, is similarly strong as for the light hadrons. Furthermore, the small splittings of spin partners in the heavy hadron system may enhance the spin-dependent channel couplings via the tensor interaction, thus give extra attraction at large distances.

Indeed, recent model studies of $D^{(*)}\bar{D}^{(*)}$, $B^{(*)}\bar{B}^{(*)}$ mesons as well as the meson-baryon systems show variety of bound and resonance states. Such resonances have been experimentally observed as quarkonium-like exotic mesons at the Belle and the other heavy quark production processes.

Along these lines, we have studied the two baryon systems with heavy quarks [9, 10]. The effective Hamiltonian is constructed for the couplings of heavy baryons to mesons and the meson exchange potentials between the charmed baryon and nucleon and also between charmed baryons. With these interactions, we have predicted $\Lambda_c N$ and $\Lambda_c\Lambda_c$ di-baryon resonances, *i.e.* charmed deuterons. It is found that the couplings to the S and D-wave $\Sigma_c^{(*)}N$ or $\Sigma_c^{(*)}\Sigma_c^{(*)}$ channels are crucial for the bound states, where the tensor force from the one-pion exchange plays a dominant role.

We further study possible bound state of J/ψ and η_c (the charmonium mesons) to nuclei [11]. The $J/\psi - N$ interaction is weakly attractive. The interaction is dominated by the long-range attraction due to the color polarizations of the hadrons, called the van der Waals type force. As a guideline for the attraction, we have used the scattering lengths of $J/\psi N$ and $\eta_c N$ derived from lattice QCD calculation. We conclude that the both the J/ψ and η_c will make a bound state in ^{4}He, while there is no two-body bound state.

3. Heavy Quark Exotics and Its Production Cross Section (with S. Yasui, T. Hyodo, Y.R. Liu, K. Sudoh) [12]
   One of the very interesting object is the heavy quark meson that contains two heavy quarks (not quark and anti-quark), $T_{QQ} = (QQ\bar{u}\bar{d})$ $(I = 0)$ bound states. A bound state was predicted in the $J^\pi = 1^+$ channel. Using the di-quark picture of the T_{QQ} mesons, we expect that two 1^+ states exist, one of which has an exotic color configuration, color **6** representation for QQ, and mixes weekly with the standard one with color $\bar{\mathbf{3}}$. In order to promote searches of such states in the e^+e^- collisions, we have calculated the production cross sections of T_{cc} at the B-factory. The NRQCD (non-relativistic QCD) method is applied, assuming the factorization of the hard charm production and the soft hadronization processes. It is found that that standard $T_{cc}(\bar{\mathbf{3}})$ and color **6** $T_{cc}(\mathbf{6})$ show different dependences on the production momentum. This may be useful in distinguishing the two states in the production.

4. Computation of the Meson-Baryon Coupling Form Factors on the Lattice (with T. Takahashi, U. Can, G. Erkol) [13]
   In order to determine the meson-baryon couplings for the heavy hadrons, we developed the formulation to compute the meson-baryon coupling form factors on the lattice. The computation has been done for the vector and axial-vector couplings of D and D^* mesons, where we have used the PACS-CS gauge configuration with $2 + 1$ light quark flavors. The form factors are fitted to the PCAC and the vector-meson dominance form factors and the coupling constants are extracted.

These physics subjects have been the topics in various workshops and conferences. At the J-PARC branch, we organized two international workshops during the fiscal year, 2012, both of which had several foreign participants (from Korea and China). We invited several experts on the subject from the fields of lattice QCD and perturbative QCD and had a fruitful discussion. Some of the collaborative works have started in these workshops. It is also noted that many graduate students participated to these workshops and joined the discussion. We are grateful to the supports from the Theory Center of KEK and the High-Performance Computing Infrastructure (HPCI) and also from the MEXT Grant-in-Aid in the area of "New Hadron" for these workshops.

3.5 Toward construction of the unified lepton-nucleus interaction model from MeV to GeV region
Toru Sato (Osaka University/KEK)

A collaboration was formed to study the neutrino-nucleus reactions from MeV to GeV as the J-PARC theory project, J-PARC Branch, KEK Theory Center. From Dec. 2011 to March 2013, five meetings were held at J-PARC. About 10 theorist and experimentalist including graduate students participated the meetings.

The project is motivated by the recent development of neutrino physics. The breakthrough measurements of relatively large value of θ_{13} opened a possibility of CP violation in the lepton sector. To make progress in this direction by analyzing the next generation long baseline and atmospheric neutrino data, a quantitative understanding of neutrino-nucleus and neutrino-nucleon interaction needs to be understood at the level of 5% or better accuracy for the wide neutrino energy region from sub GeV to a few GeV. The relevant wide energy region as shown in Fig. 1(left) covers various mechanisms of neutrino-nucleus reaction. The quasi-elastic (QE) single nucleon knockout and the single pion production due to the Δ resonance excitation (RES) are the main mechanism for a long baseline accelerator neutrino experiment like T2K. Meanwhile, an atmospheric neutrino experiment expects to find effects of CP-violation/mass hierarchy in the higher resonance and deeply inelastic scattering (DIS) regions, as indicated in the figure. Contribution from each reaction mechanism to the neutrino-nucleus cross section is displayed in Fig. 1 (right). Obviously, it is very important to combine different expertise to perform a nontrivial task to construct a unified model for the wide kinematical region.

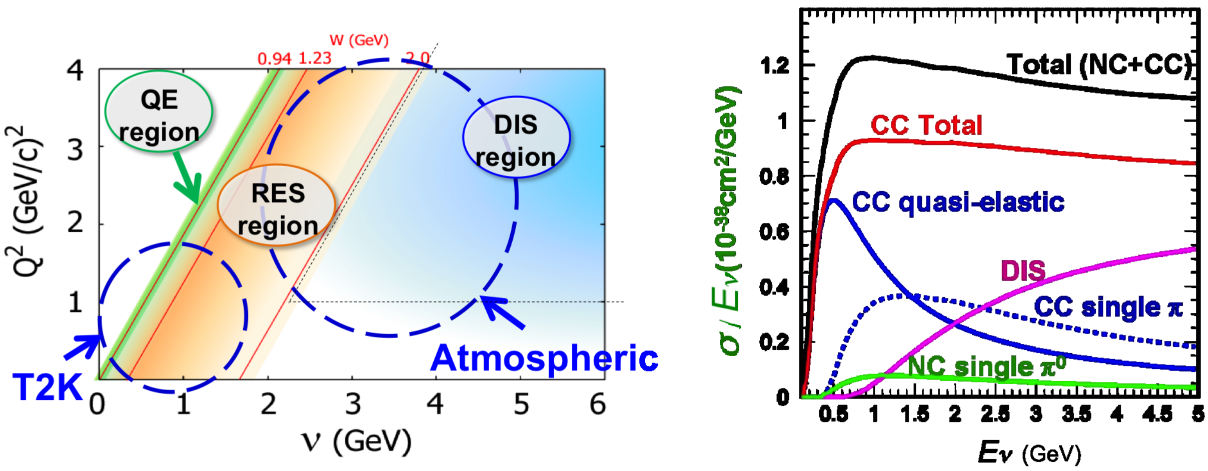

Figure 1: (Left) Kinematical region of neutrino-nucleus interaction relevant to the next-generation neutrino oscillation experiments. The neutrino energy and squared four-momentum transfer are denoted by ν and Q^2, respectively. (Right) Contribution of each reaction mechanism to the neutrino-nucleus interaction. The symbol σ denotes the cross section.

During this one year project, we have set up a baseline model for the neutrino-nucleus reaction: the spectral function approach of QE, coupled channel analysis of the meson production reaction in RES and nuclear correlation factors for the structure function from a global analysis of the DIS and Drell-Yan process. The outline of our approach is reported in Neutrino2012 [14] and Nuint2012 [15].

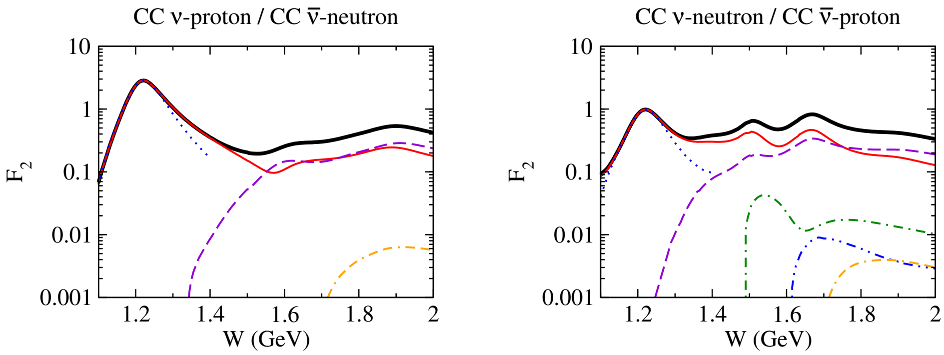

Figure 2: The structure function $F_2(Q^2 = 0)$ for the neutrino-induced meson productions from the DCC model. The solid (red), dashed (purple), dash-dotted (green), two-dotted dash (blue), and two-dash dotted (orange) curves are for the πN, $\pi\pi N$, ηN, $K\Lambda$ and $K\Sigma$ reactions, respectively. The sum of them is given by the thick solid (black) curve.

The first result of our efforts is the forward neutrino reaction in the resonance region. By using the coupled channel model of $\pi N \to X$ [16], the neutrino reactions were studied for the forward($Q^2 \sim 0$) region assuming Partially Conserved Axial Current (PCAC) hypothesis. Fig. 2 shows the structure function $F_2(Q^2 = 0)$ as a function of the total energy W of the hadronic final state. This is the first results on neutrino induced eta, kaon and two-pion production cross sections, which are based on a reaction model tested by the pion and photon induced meson production data.

Though the initial motivation for the study of neutrino-nucleus reaction was for the analysis of neutrino oscillation data, our efforts will also contribute to the nuclear astrophysics in the lower energy region and the physics of hadron-quark interplay in the transition region between resonance and DIS. The collaboration just started is expected to continue as a J-PARC theory project to complete our task and also will contribute as a nuclear physics part of ‘unification and development of the neutrino science frontier’ of Grant-in-Aid for Scientific Research on Innovative Areas.

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4 Workshops and meetings

4.1 Workshops

- Future prospects of hadron-nuclear physics at J-PARC
  June 10th-11th, 2011. Kobayashi Hall (KEK, Tsukuba campus)
  Sponsors: Institute for Particle and Nuclear Study, KEK, J-PARC Center, Joint Institute for Computational Fundamental Science, HPCI Strategic Program Field 5, Nishina Accelerator Research Center, RIKEN
  The number of participants: 80
  Organizers: M. Oka (KEK, Tokyo Inst. of Tech.), S. Kumano (KEK), A. Dote (KEK), S. Hashimoto (KEK), T. Hatsuda (RIKEN), E. Hiyama (KEK, RIKEN)
  Speakers: M. Nagamiya (J-PARC), S. Kumano (KEK), S. Sawada (KEK), D. Jido (KEK, YITP Kyoto Univ.), A. Dote (KEK), T. Sato (KEK, Osaka Univ.), T. Yamazaki (KMI), K. Takeda (KEK), E. Hiyama (KEK, RIKEN), T. Harada (KEK, Osaka Electro-Communication Univ.), A. Hosaka (RCNP), A. Ohnishi (YITP Kyoto Univ.), S. Aoki (Tsukuba Univ.), S. Hashimoto (KEK), T. Nakano (RCNP), H. Tamura (Tohoku Univ.), T. Hatsuda (RIKEN), S. Yasui (KEK)

- Meeting on Hadron Nuclear Theory at J-PARC
  December 16th-17th, 2011. Room 115 and 227, Tokai 1st building (KEK, Tokai campus)
  The number of the participants: 20
  Organizers: S. Kumano (KEK), A. Dote (KEK)
  Speakers: A. Dote (KEK), S. Kumano (KEK), D. Jido (KEK, YITP Kyoto Univ.), E. Hiyama (KEK, RIKEN), T. Harada (KEK, Osaka Electro-Communication Univ.), T. Sato (KEK, Osaka Univ.), K. Ozawa (KEK)

- Future Prospects of Hadron Physics at J-PARC and Large Scale Computational Physics in 2012
  February 9th-11th, 2012. Ibaraki Quantum Beam Research Center 2F (B201,B202)
  Sponsors: Institute for Particle and Nuclear Study, KEK, J-PARC Center, Joint Institute for Computational Fundamental Science, HPCI Strategic Program Field 5, Nishina Accelerator Research Center, RIKEN
  The number of participants: 80
  Organizers: A. Dote (KEK), O. Hashimoto (Tohoku), S. Hashimoto (KEK), T. Hatsuda (Tokyo/Riken), E. Hiyama (KEK, RIKEN), K. Imai (JAEA), S. Kumano (KEK), T. Maruyama (JAEA), M. Oka (KEK, Tokyo Inst. of Tech.), T. Takahashi (KEK)
  Invited speakers: S. Aoki (Tsukuba Univ.), G. Baym (Univ. Illinois), A. Gal (Hebrew Univ.), S. H. Lee (Yonsei Univ.), S. Nagamiya (J-PARC), H. Ohnishi (RIKEN), A. Parreno (Barcelona Univ.), M. Strikman (Penn State Univ.), H. Tamura (Tohoku Univ.), W. Weise (TU Munchen)

- Heavy Quark Hadrons at J-PARC 2012
  (Tokyo part)
  June 18th-22nd, 2012. Tokyo Institute of Technology, Ookayama Campus
  Speakers: K.Sudoh (Nishougakusha Univ.), S. Takeuchi (Japan Coll. Of Social Work), T. Takahashi (Gunma National College of Technology), S. L. Olsen (Seoul National Univ.), T. Hyodo (Tokyo Inst. of Tech.), Y. Yamaguchi (RCNP), R. Molina (RCNP), S. Ohkoda (RCNP), M. Harada (Nagoya Univ.), T. Takizawa (Showa Pharmaceutical Univ.), S. H. Lee (Yonsei Univ.), K. Kim (Yonsei Univ.), K. Suzuki (Tokyo Inst. of Tech.), K. Ozawa

(KEK), Y. Namekawa (Univ. of Tsukuba), S. Sasaki (Tohoku Univ.), Y. Koma (Numazu National College of Technology), Y. Kiyo (Juntendo Univ.), H. Fujii (Univ. of Tokyo)

(Tokai part)
June 25th-29th, 2012. Room 115, Tokai 1st building (KEK, Tokai campus)
Participants: C. Sungtae (Yonsei Univ.), A. Dote (KEK), A. Hosaka (RCNP), T. Hyodo (Tokyo Inst. of Tech.), D. Jido (KEK, YITP Kyoto Univ.), K. Kyuingil (Yonsei Univ.), S. Ohkoda (RNCP), M. Oka (KEK, Tokyo Inst. of Techn.), T. Sekihara (KEK), K. Suzuki (Tokyo Inst. of Tech.), T. Takahashi (KEK), M. Takizawa (Showa Pharmaceutical Univ.), K. Terasaki (YITP Kyoto Univ.), Y. Yamaguchi (RCNP), S. Yasui (KEK)
Organizers: M. Oka (KEK, Tokyo Inst. of Tech.), K. Ozawa (KEK), D. Jido (KEK, YITP Kyoto Univ.), M. Takizawa (Showa Pharmaceutical Univ.), A. Dote (KEK), S. Hashimoto (KEK), T. Hyodo (Tokyo Inst. of Tech.), A. Hosaka (RCNP), S. Yasui (KEK)

- Future Prospects of Hadron Physics at J-PARC and Large Scale Computational Physics in 2013
  February 11th-13th, 2013. Ibaraki Quantum Beam Research Center 2F (B201,B202)
  The number of participants: 62
  Organizers: A. Dote (KEK), S. Hashimoto (KEK), T. Hatsuda (RIKEN), E. Hiyama (KEK, RIKEN), K. Imai (JAEA), S. Kumano (KEK), T. Maruyama (JAEA), M. Oka (KEK, Tokyo Inst. of Tech.), T. Takahashi (KEK), H. Tamura (Tohoku)
  Invited Speakers: M. Alford (Washington Univ.), D. Blaschke (Univ. of Wroclaw), H. -W. Lin (Univ. of Washington), W. Melnitchouk (JLab), J. Millener (BNL), K. Ozawa (KEK), T. Rijekn (Univ. of Nijmegen), K. Sasaki (Tsukuba Univ.), T. Sato (KEK, Osaka Univ.)

- Hadron-structure physics at J-PARC and related topics
  March 18th, 2013. Room 227, Tokai 1st building (KEK, Tokai campus)
  Convener: Shuzno Kumano (KEK)
  Participants: W. -C. Chang (Academia Sinica), N. Doshita (Yamagata Univ.) Y. Goto (Riken), T. Iwata (Yamagata Univ.) H. Kawamura (KEK), S. Kumano (KEK), H. Matsuda (Yamagata Univ.), Y. Miyachi (Yamagata Univ.), K. Nakano (Tokyo Tech.), S. Sawada (KEK) T. Sekihara (KEK), T. Shibata (Tokyo Inst. of Tech.), K. Tanaka (Juntendo Univ.)

4.2 Collaboration meetings

- 1st collaboration Meeting on Neutrino-nucleus reactions from MeV to GeV
  December 17th-18th, 2011. Room 227, Tokai 1st building (KEK, Tokai campus)
  Conveners: T. Sato (KEK, Osaka Univ.), S. Kumano (KEK)
  Participants: Y. Hayato (Tokyo Univ. ICRR), M. Hirai (Tokyo Science Univ.) H. Kamano (Osaka Univ. RCNP), S. Kumano (KEK) Y. Nara (Akita International Univ.), K. Saito (Tokyo Science Univ.) M. Sakuda (Okayama Univ.), T. Sato (KEK, Osaka Univ.)

- 1st Meeting on Excitation spectra and baryon mixture of strangeness nuclei
  February 27th-March 3rd, 2012. Room 227, Tokai 1st building (KEK, Tokai campus)
  Conveners: T. Harada (KEK, Osaka Electro Communication Univ.), A. Dote (KEK)
  Participants: M. Isaka (Hokkaido Univ.), M. Kimura (Hokkaido Univ.), M. Shinmura(Gifu Univ.), A. Dote (KEK), H. Nemura(Tsukuba Univ.) Y. Hirabayashi (Information Initiative Center Hokkaido Univ.)

- 2nd Meeting on Neutrino-nucleus reactions from MeV to GeV
  March 19th-21st, 2012. Room 227, Tokai 1st building (KEK, Tokai campus)
  Conveners: T. Sato (KEK, Osaka Univ.), S. Kumano (KEK)
  Participants: S. Hashimoto (KEK), Y. Hayato (Tokyo Univ. ICRR), M. Hirai (Tokyo Science Univ.), H. Kamano (Osaka Univ. RCNP), S. Kumano (KEK), L. K.-P. Maggie (Tokyo Univ. ICRR), Y. Nara (Akita International Univ.), K. Saito (Tokyo Science Univ.), M. Sakuda (Okayama Univ.), T. Sato (KEK, Osaka Univ.), T. Yano (Okayama Univ.)

- 2nd Meeting on Excitation spectra and baryon mixture of strangeness nuclei
  August 1st-4th, 2012. Room 227, Tokai 1st building (KEK, Tokai campus)
  Conveners: T. Harada (KEK, Osaka Electro Communication Univ.), A. Dote (KEK)
  Participants: M. Isaka (Hokkaido Univ.), M. Kimura (Hokkaido Univ.), A. Dote (KEK), T. Harada (KEK, Osaka Electro Communication Univ.)

- Meeting on new direction in the study of hadron-nucleus bound systems
  August 6th-10th, 2012. Room 227, Tokai 1st building (KEK, Tokai campus)
  Conveners: D. Jido (KEK, YITP Kyoto Univ.), A. Dote (KEK), S. Okada (RIKEN)
  Participants: S. Hirenzaki (Nara women's Univ.), A. Dote (KEK) N. Ikeno (Nara women's Univ.), S. Gouda (Kyoto Univ.), H. Fujioka (Kyoto Univ.), T. Nishi (The Univ. of Tokyo), K. Okouchi (The Univ. of Tokyo), E. Hiyama (KEK, RIKEN), Y. Ikeda (Tokyo Inst. of Tech.), T. Koike (RIKEN) D. Jido (KEK, YITP Kyoto Univ.) T. Sekihara (KEK), J. Yamagata-Sekihara (KEK)

- 4th Meeting on Neutrino-nucleus reactions from MeV to GeV
  December 2nd-4th, 2012. Room 413, Tokai 1st building (KEK, Tokai campus)
  Conveners: T. Sato (KEK, Osaka Univ.), S. Kumano (KEK)
  Participants: T. Sato (KEK, Osaka Univ.), S. Kumano (KEK), S. Nakamura (Kyoto Univ.), M. Hirai (Tokyo Univ. of Science), M. Sakuda(Okayama Univ.), K.iro Saito (Tokyo Univ. of Science), H. Kamano (Osaka Univ.), W. Horiuchi (Hokkaido Univ.)

- Meeting on Heavy quark physics at J-PARC
  December 2nd-5th, 2012. Room 227, Tokai 1st building (KEK, Tokai campus)
  Conveners: M. Oka (KEK,Tokyo Inst. of Tech.), E. Hiyama (KEK, RIKEN), A. Dote (KEK)
  Participants: K. Imai (JAEA), S. Okoda (RCNP), K. Ozawa (KEK), N. Saito (KEK), T. Takahashi (Gunma National College of Technology), H. Noumi (RCNP), M. Oka (KEK, Tokyo Inst. of Tech.), E. Hiyama (KEK, Riken), A. Dote (KEK), T. Hyodo (Tokyo Inst. of Tech.), A. Yokota (Tokyo Inst. of Tech.), S. Maeda (Tokyo Inst. of Tech.),T. Yoshida (Tokyo Inst. of Tech.), A. Hosaka (RCNP), Y. Yamaguchi (RCNP)

- 5th Meeting on Neutrino-nucleus reactions from MeV to GeV
  March 8th-9th, 2013. Room 227, Tokai 1st building (KEK, Tokai campus)
  Conveners: T. Sato (KEK, Osaka Univ.), S. Kumano (KEK)
  Participants: M. Hirai (Tokyo Science Univ.), T. Kajino (NAOJ) S. Kumano (KEK), T. Maruyama (KEK), T. Murata (Osaka Univ.), S. Nakamura (Kyoto Univ.), S. Nasu (Osaka Univ.), R. Ohta (KEK), K. Saito (Tokyo Science Univ.), T. Sato (KEK, Osaka Univ.), K. Sumiyoshi (Numazu C.T.), T. Suzuki (Nihon Univ.)

5 List of research reports

- J-PARC-TH-0001
  "Test of CDF dijet anomaly within the standard model"
  H. Kawamura, S. Kumano, and Y. Kurihara
  arXiv:1110.6243 [hep-ph], Phys. Rev. D **84** (2011) 114003.

- J-PARC-TH-0002
  "Selected topics on parton distribution fuctions"
  M. Hirai, H. Kawamura, S. Kumano, and K. Saito
  arXiv:1110.0353 [hep-ph], AIP Conf. Proc. **1418** (2011) 154.

- J-PARC-TH-0003
  "Valence quark and meson cloud contributions for the $\gamma^*\Lambda \to \Lambda^*$ and $\gamma^*\Sigma^0 \to \Lambda^*$ reactions"
  G. Ramalho, D. Jido, and K. Tsushima
  arXiv:1202.2299 [hep-ph], Phys. Rev. D **85** (2012) 093014.

- J-PARC-TH-0004
  "Branching ratios of mesonic and nonmesonic antikaon absorptions in nuclear medium"
  T. Sekihara, J. Yamagata-Sekihara, D. Jido, and Y. Kanada-En'yo
  arXiv:1204.3978 [nucl-th], Phys. Rev. C **86** (2012) 065205.

- J-PARC-TH-0005
  "Compositeness of dynamically generated states in a chiral unitary approach"
  T. Hyodo, D. Jido, and A. Hosaka
  arXiv:1108.5524 [nucl-th], Phys. Rev. C **85** (2012) 015201.

- J-PARC-TH-0006
  "Discrimination of Σ-nucleus potentials in the angular distribution of elastic scattering of Σ^- hyperons from nuclei"
  T. Harada, and Y. Hirabayashi
  arXiv:1201.2214 [nucl-th], Phys. Rev. C **86** (2012) 014606.

- J-PARC-TH-0007
  "Strategy to find the two $\Lambda(1405)$ states from lattice QCD simulations"
  A. M. Torres, M. Bayar, D. Jido, and E. Oset
  arXiv:1202.4297 [hep-lat], Phys. Rev. C **86** (2012) 055201.

- J-PARC-TH-0008
  "Meson-induced pentaquark productions"
  T. Hyodo, A. Hosaka, and M. Oka
  arXiv:1203.0598 [nucl-th], Prog. Theor. Phys. **128** (2012) 523.

- J-PARC-TH-0009
  "Feasibility Study of Observing η' Mesic Nuclei with (p,d) Reaction"
  K. Itahashi, H. Fujioka, H. Geissel, R. S. Hayano, S. Hirenzaki, S. Itoh, D. Jido, V. Metag, H. Nagahiro, M. Nanova, T. Nishi, K. Okochi, H. Outa, K. Suzuki, T. Suzuki, Y. K. Tanaka, and H. Weick
  arXiv:1203.6720 [nucl-ex], Prog. Theor. Phys. **128** (2012) 601.

- J-PARC-TH-0010
  "Thermal Modification of Bottomonium Spectra from QCD Sum Rules with Maximum Entropy Method"
  K. Suzuki, P. Gubler, K. Morita, and M. Oka
  arXiv:1204.1173 [hep-ph], Nucl. Phys. A **897** (2013) 28.

- J-PARC-TH-0011
  "A narrow DNN quasi-bound state"
  M. Bayar, C. -W. Xiao, T. Hyodo, A. Dote, M. Oka, and E. Oset
  arXiv:1205.2275 [hep-ph], Phys. Rev. C **86** (2012) 044004.

- J-PARC-TH-0012
  "The $K^- d \to \pi\Sigma n$ reaction revisited"
  D. Jido, E. Oset, and T. Sekihara
  arXiv:1207.5350 [nucl-th], Eur. J. Phys. A **49** (2013) 95.

- J-PARC-TH-0013
  "Comprehensive application of a coupled-channel complex scaling method to the $\bar{K}N$-πY system"
  A. Dote, T. Inoue, and T. Myo
  arXiv:1207.5279 [nucl-th], Nucl. Phys. A **912** (2013) 66.

- J-PARC-TH-0014
  "Neutrino-induced forward meson-production reactions in nucleon resonance region"
  H. Kamano, S. X. Nakamura, T. -S. H. Lee, and T. Sato
  arXiv:1207.5724v1 [nucl-th], Phys. Rev. D **86** (2012) 097503.

- J-PARC-TH-0015
  "Modification of hadronic spectral functions under extreme conditions: An approach based on QCD sum rules and the maximum entropy method"
  K. Suzuki, P. Gubler, and M. Oka
  arXiv:1212.1594 [hep-ph], Nucl. Phys. A **914** (2013) 512.

- J-PARC-TH-0016
  "Extraction of Meson Resonances from Three-pions Photo-production Reactions"
  S. X. Nakamura, H. Kamano, T. -S. H. Lee, and T. Sato
  arXiv:1209.3402 [hep-ph], Phys. Rev. D **86** (2012) 114012.

- J-PARC-TH-0018
  "Production of doubly charmed tetraquarks with exotic color configurations in electron-positron collisions"
  T. Hyodo, Y-R. Liu, M. Oka, K. Sudoh, and S. Yasui
  arXiv:1209.6207 [hep-ph], Phys. Lett. B **721** (2013) 56.

- J-PARC-TH-0019
  "Formation of $\eta'(958)$-mesic nuclei by (p, d) reaction"
  H. Nagahiro, D. Jido, H. Fujioka, K. Itahashi, and S. Hirenzaki
  arXiv:1211.2506 [nucl-th], Phys. Rev. C **87** (2013) 045201.

- J-PARC-TH-0020
  "Production of hyperon resonances induced by kaon on a deuteron target"
  J. Yamagata-Sekihara, T. Sekihara, and D. Jido
  arXiv:1210.6108 [nucl-th], PTEP **2013** (2013) 043D02.

- J-PARC-TH-0022
  "Modification of hadronic spectral functions under extreme conditions: An approach based on QCD sum rules and the maximum entropy method"
  P. Gubler, K. Suzuki, K. Morita, and M. Oka
  arXiv:1212.1594 [hep-ph], Nucl. Phys. A **914** (2013) 512.

- J-PARC-TH-0023
  "Toward Construction of the Unified Lepton-Nucleus Interaction Model from a Few Hundred MeV to GeV Region"
  S. X. Nakamura , Y. Hayato, M. Hirai , H. Kamano, S. Kumano, M. Sakuda, K. Saito, and T. Sato arXiv:1303.6032 [hep-ph], Proceedings of the 8th International Workshop on Neutrino Nucleus Interactions in Few-GeV Region (NUINT 12), 22-27 Oct 2012. Rio de Janeiro, Brazil, in press.

- J-PARC-TH-0024
  "Neutrino-induced meson productions off nucleon at forward limit in nucleon resonance region"
  S. X. Nakamura , H. Kamano , T. -S. H. Lee, and T. Sato arXiv:1303.4152 [hep-ph], Proceedings of the 8th International Workshop on Neutrino Nucleus Interactions in Few-GeV Region (NUINT 12), 22-27 Oct 2012. Rio de Janeiro, Brazil, in press.