4th Symposium on "Clustering as a window on the hierarchical structure of quantum systems" 2020.05.28, on Zoom

A challenge to reveal new degrees of freedom to describe hadron

Status and Prospects of A02 projects

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A02

The world of hadrons



- Most of observed and identified hadrons are categorized as "normal" hadrons.
- Only small number of exotic hadron and hadron molecule candidates are known. No one knows the reason why.

A02

 Charmed baryon spectroscopy at J-PARC with high energy hadron beam



Detail investigation of Λ(1405) and Θ⁺
 at SPring-8/LEPS2 with photon beam











meson-baryon or penta-quark? (as an example)

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- Why $\Lambda(1405)$ is significantly lighter than non-strange negative parity baryons, e.g. N(1520)
- Exotic baryon $\Lambda(1405)$

$$I(J^{P}) = 0(\frac{1}{2})$$

Mass = 1405^{+1.3}_{-1.0} MeV
Width = 50.5 ± 2MeV

• $\Lambda(1405)$ stands only 27 MeV below $\overline{K}N$ threshold.

 $\Lambda(1405)$ will be bound state of \overline{KN} ?

Boson-Fermion molecule with $M_B{:}M_F{\,\sim\,}1{:}2$



Physics programs to access the property of $\Lambda(1405)$



Physics programs to access the property of $\Lambda(1405)$

• SPring-8/LEPS2 : photoproduction of $\Lambda(1405)$



Detail will be discussed in the next talk by Ryu-san Uniqueness of the measurement at the LEPS2 experiment "photon polarization"







Why existence of K-Nuclear **Bound states are important?**

- Interaction between $\overline{K}N$ is strongly attractive (in I=0 channel).
- Most simplest one is $\overline{K}NN$ bound state

ppn

1 fm

Existence of the $\bar{K}NN$ state is predicted via many theoretical approached with different potential models

T=0, J=1/2

ppnK

1 *fm*



Meson-Fermion-Fermion bound state K-pp bound state

J-PARC E15 experiment

• Search for K^-pp bound state via $K^- + {}^{3}He \to K^-pp + n$ reaction. $\downarrow \to \Lambda p \xrightarrow{\text{so}} 1$

 $M_{K^-pp} = 2324 \pm 3(stat.)^{+6}_{-3}(sys.)MeV/c^2$ $\Gamma_{K^-pp} = 115 \pm 7(stat.)^{+10}_{-20}(sys.)MeV/c^2$ B~50 MeV

- Clear peak structure seen below $\bar{K}NN$ threshold
- $\bar{K}NN$ bound state? or $\Lambda(1405)p$ bound state?
- What is needed as a next step?
 - measure the size of the state observed!

transition form factor has been measured \rightarrow result suggests formation of compact object!

• Can we measure $\Lambda(1405) - N$ scattering length? via final state interaction of $\Lambda(1405)$ and n in $K^-d \rightarrow \Lambda(1405)n$ at J-PARC E31?



K-pp ?

- What do we need ?
 - need to understand relation between deep bound state and shallow bound state
 - Property of the bound state? (quantum number, such as J^{PC})
- New projects to investigate K-pp are running,
 - K-pp production with $\gamma d \rightarrow K^+ \pi^- X$ reaction at LPES2/SPring-8



• J-PARC E15 upgrade





new Degrees of freedom (di-quark correlation)

• very important source of interaction between quarks inside baryon: Color Magnetic interaction



For example: di-quark in charmed baryon: Fermion-Fermion-Fermion with $M_F: M_F \sim 1:1:5$

The way to clarify effective DOFs inside hadron

- \cdot Two excitation modes are expected in baryon
- Those states will be degenerated in light hadron(qqq) existed states, but will be separated fo_{Charm baryon spectroscopy}





Physics programs with E50 spectrometer

- Charmed baryon (Λ_c^*) spectroscopy
- Ξ* spectroscopy (s=-2 baryon) : M. Naruki(Kyoto Univ.), K. Shirotori (RCNP)
- Λp scattering experiment via the $\pi^- p \to \Lambda K^*$: R. Hond
- Dibaryon search in $\pi^+ d \to \pi^- \pi^- (\Delta^{++} \Delta^{++}) / \pi^+ d \to \pi^+ \pi^+ (\Delta^- \Delta^-)$ reaction: T. Ishikawa (ELPH)
- Double Kaonic nuclear bound state formation with high momentum proton (K^-K^-pp) : T. Yamazaki
- Nucleon tomography (structure of nucleon, measurement of Drell-Yan process process : Wen-Chen Chang
- contribution to reducing the uncertainty of neutrino flux for T2K (EMPHATIC experiment)
- $\Lambda(1405)$ production with high momentum pion

high energy pion nucleus interaction

• EMPATHIC experiment

• The main purpose of the experiment is to measure hadron production cross-section for improving neutrino flux prediction for T2K, NOvA, ...



Fractional uncertainties of the $\nu\mu$ as a function of neutrino energy in NOvA near detector due to hadron production uncertainties

arXiv:1912.08841v1

EMPHATIC: A proposed experiment to measure hadron scattering and production cross sections for improved neutrino flux predictions

T. Akaishi,¹² L. Aliaga-Soplin,⁴ H. Asano,¹⁷ A. Aurisano,³ M. Barbi,¹⁴ L. Bellantoni,⁴ S. Bhadra,²⁴ W-C. Chang,²⁴ L. Fields,⁴ A. Fiorentini,¹⁸ M. Friend,⁵ T. Fukuda,¹⁰ D. Harris,⁴ M. Hartz,^{7,20} R. Honda,¹⁵ T. Ishikawa,¹⁶ B. Jamieson,²³ E. Kearns,¹ N. Kolev,¹⁴ M. Komatsu,¹⁰ Y. Komatsu,⁵ A. Konaka,²⁰ M. Kordosky,²² K. Lang,¹⁹ P. Lebrun,⁴ T. Lindner,^{23,20} Y. Ma,¹⁷ D. A. Martinez Caicedo,¹⁸ M. Muether,²¹ N. Naganawa,¹⁰ M. Naruki,⁹ E. Niner,⁴ H. Noumi,¹³ K. Ozawa,⁵ J. Paley,⁴,^{*} M. Pavin,²⁰ P. de Perio,²⁰ M. Proga,¹⁹ F. Sakuma,¹⁷ G. Santucci,²⁴ T. Sawada,¹¹ O. Sato,¹⁰ T. Sekiguchi,⁵,[†]
18 K. Shirotori,¹³ A. Suzuki,⁸ M. Tabata,² T. Takahashi,¹³ N. Tomida,¹³ R. Wendell,⁹ and T. Yamaga¹⁷ (The EMPHATIC Collaboration)

ENPHATIC experiment

• It was planned to perform 1st physics data taking in April/2020...



$\Lambda(1405)$ production via high energy pion

- Production cross-section of hadrons are strongly depended on the internal structure of the hadron (depending on a number of "constituent quarks")
- Detail theoretical investigation has been done by H. Kawamura, S. Kumano,and T. Sekihara (PHYS. REV. D 88, 034010 (2013)) in high energy $\pi^- p \rightarrow \Lambda(1405)K^0$ reaction.



• According to the paper, the effect can be seen at large $s^{1/2}$ region.

Indeed, the measurement can be performed as one of the E50 physics programs



Summary

• Reveal the relation between quark and hadron, hadron and nucleus hierarchy.

what is the effective DoFs to describe hadron

- Preparation of two experimental programs are in progress
 - J-PARC E50 experiment :

E50 spectrometer construction : in progress

- SPring-8/LEPS2-solenoid : (detail will be discussed in next talk) Commissioning run and 1st physics data taking in this FY
- Data analysis with existing data is on going
 - $\Lambda(1405)$: J-PARC E31 experiment
 - K-pp : J-PARC E15 experiment