Dynamics of highly unstable exotic light nuclei and few-body systems

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I. SCIENTIFIC ISSUE

The aim of this workshop is to review the recent experimental programs as well as the progress in theoretical ab-initio methods allowing us to study the unstable light neutron (or proton) rich structures. The ultimate goal is to obtain predictions, expected to serve as a guide in designing and interpreting ongoing and future experiments. It will also help us to improve our understanding of the interaction between the neutrons as well as the dynamics of highly unstable nuclei.

Exploring and understanding the structure of the most neutron-rich nuclei is a primary goal of present day nuclear physics. The advent of the very intense neutron/proton-rich secondary beams at RIKEN's RIBF, as well as the future GSI's FAIR and MSU's FRIB projects, is opening a unique window into the understanding of many-neutron systems. Moreover, a better insight into the neutron-neutron interaction can be obtained through the exploration of mirror proton-rich structures, since the proton-proton interaction is better established than its neutron-neutron counterpart.

Within the context of the present workshop, we wish to confront the state-of-the-art theoretical predictions for the very light neutron-rich systems with the most recent experiments. We also hope to use the predictions as a guide in designing and interpreting future experiments. In parallel, some related atomic, molecular as well as hadronic systems will be discussed from the unifying point of view of few-body theory. For example, the existence of a pentaquark, unstable hypernuclei, Efimov states... Indeed, these systems share many common features driven by the similar dynamical properties of weakly bound quantum systems.

From the experimental point of view, this workshop is scheduled in the very middle of a sustained research program at RIKEN and J-PARC aimed to clarify the situation in the multineutron systems, at least in the simplest ones. The Kisamori *et al.* experiment [1] has been repeated few months ago and is being reanalyzed by S. Shimoura and collaborators. Two other different experimental approaches to the problem have already been accepted, involving some of the participants to this workshop (M. Marqués, N. Orr, D. Beaumel). It is then an appropriate time to discuss about these subjects.

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Other light neutron-rich systems will be in the periscope of this workshop. In particular Hydrogen-5, for which there exist some contradictory experimental results. Also resonant Hydrogen-7 structures, which are objects of intensive experimental studies [2] involving several colleagues from LPC-Caen, IPN-Orsay and SPhN-Saclay. Both systems are within the reach of cluster models or models based on simplistic nucleon-nucleon interaction.

From the theoretical side we have to develop methods for obtaining accurate solutions of the Schrödinger equation for bound and – especially – resonant states. In this respect, the interplay between different scientific communities and alternative methods is of great interest. We have been pioneers in exploring the possible existence of 4n resonances [3, 4] using ad-hoc theoretical methods and interactions. It has been recently found that the 4n system is unlikely to exhibit near-threshold resonances with visible impact on experimental data, and alternative explanations have to be explored to account for the observed signals [1, 5].

First we would like to try to construct some simplistic models for $^4He(^8He,^8Be)4n$ reaction, used in RIKEN experiment to identify resonant 4n events [1]. Next we will concentrate on the (4He,4n) reaction, which will be explored in RIKEN and JPARC [6]. This is one of the unique reactions one is able to explore rigorously using the complete reaction mechanism. Aside from the tetraneutron stability, the possible existence of heavier multineutrons (like 6n or 8n) is one of our goals. We also hope to establish tighter links between theory and experiment. In view of obvious difficulties in creating and identifying exotic nuclei as well as limited reach of ab-initio reaction theory, there is clear necessity to identify the most pertinent measurements.

II. GOALS OF THE PROJECT

The workshop will bring together a few leading experimentalists and theoreticians (mostly from France and Japan) exploring the light exotic nuclear systems. The following key issues will be object of discussion :

- Relation and efficiency of different ab-initio techniques : Faddeev-Yakubovsky equations, Hyperspherical Harmonics, Gaussian expansion method.
- Description of the weakly bound and unstable few-particle quantum systems (^{4}n, ^{5}H, ^{7}H, pentaquark,..).
- Dynamics of the unstable nuclei – key observables, correlations. Reaction mechanisms and models, impact of broad resonances on the experimental observables : description of $^4He(^8He,^8Be)4n$ reaction using approximate reaction mechanism, ab-initio description of $\pi^-(^4He, 4n)\pi^+$ reaction, envisaged in RIKEN and JPARC experiment aiming to put into evidence 4n resonances.
- Relation between neutron-rich and proton-rich sector (^{4}H and ^{4}Li, ^{5}H and ^{5}Be...). Signatures of charge symmetry breaking.

We expect that through the discussions we will arrive to refine our numerical techniques to solve few-particle Schrödinger equation, in particular related with the description of experimentally employed reactions to identify a ^{4}n system. We hope that the feedback between theory and experiment should allow us to identify future projects with the highest possible physics output.

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[1] K. Kisamori *et al.*, Phys. Rev. Lett. 116, 052501 (2016).
[2] F. M. Marqués *et al.*, "Search for superheavy hydrogen 7H and its tetraneutron decay", NP1512-SAMURAI34 RIKEN (2015).
[3] R. Lazauskas, J. Carbonell, Phys. Rev. C 72, 034003 (2005).
[4] E. Hiyama, R. Lazauskas, J. Carbonell, N. Kamimura, Phys. Rev. C 93, 044004 (2016).
[5] F. M. Marques *et al.*, Phys. Rev. C **65**, 044006 (2002).
[6] H. Fujioka *et al.*, arXiv :1609.00079.

III. LIST OF POTENTIAL SPEAKERS

— E. Hiyama, RIKEN (hiyama@riken.jp) : Structure of light neutron-rich nucleus, ^{5}H
— R. Lazauskas, IPHC Strasbourg (Rimantas.Lazauskas@iphc.cnrs.fr) : Description of neutron-rich light nuclei using FY equation formalism
— J. M. Richard, IPN Lyon (j-m.richard@ipnl.in2p3.fr) : Level-rearrangement in three-body systems
— T. Myo, Osaka Institute of Technology (myo@rcnp.osaka-u.ac.jp) : Tensor-optimized antisymmetrized molecular dynamics for light nuclei with bare interaction

— M. Marques, LPC Caen (marques@lpccaen.in2p3.fr) : Experimental constraints on the formation and detection of neutron clusters
— D. Beaumel, IPN Orsay (beaumel@ipno.in2p3.fr) : Heavy hydrogens studied by transfer
— Yoichi Ikeda, Osaka Univ. (yikeda@riken.jp) : Exotic hadrons from lattice QCD
— S. Shimoura, Tokyo Univ. (shimoura@cns.s.u-tokyo.ac.jp) : Tetra-neutron system populated by reaction of exotic beam
— P. Naidon, RIKEN (pascal@riken.jp) : Interacting Bose polarons : from the Yukawa to the Efimov attraction
— M. Valdés, IPHC Strasbourg (mateo.valdes-dupuy@iphc.cnrs.fr) : Resonant antiproton-positronium collisions and antihydrogen production
— H. Fujioka, Kyoto Univ. (fujioka@scphys.kyoto-u.ac.jp) : pion DCX reaction revisited, as an alternative method to populate the 4n state
— R. Kezerashvili, City Univ New York (rkezerashvili@citytech.cuny.edu) : Mechanisms of pion double charge reaction and search of trineutron and tetraneutron
— L. Pricoupenko, LTMC Jussieu, Paris (pricoupenko@lptmc.jussieu.fr) Few atoms in atomic wave-guides
— M. Ploszajczak, CEA/GANIL (ploszajczak@ganil.fr) : Ab-initio No-Core Gamow Shell Model calculations with realistic interactions
— T. Nakamura, TIT (nakamura@phys.titech.ac.jp) : Structure of nuclei along and beyond the neutron drip line
— S. Paschalis, (spaschalis@ikp.tu-darmstadt.de and stefanos.paschalis@york.ac.uk) : Does (^{8}He)-alpha=(^{4}n) or just 4n ? An experimental approach
— M. Gattobigio, Nice Un. (mario.gattobigio@inln.cnrs.fr) : Exploring the unitary limit using potential models
— H. Sakai RIKEN, (hsakai@ribf.riken.jp) : Revisiting 3n system and possible new peasurements
— Y. Sun SPhN Saclay (yelei.sun@cea.fr) : Coulomb and nuclear breakup of halo nuclei
— Y. Kubota RIKEN, (kubota@ribf.riken.jp) : Two-neutron correlation in Borromean nuclei via the quasi-free (p,pn) reaction
— T. Uesaka, RIKEN, (uesaka@riken.jp)
— N. Orr, LPC Caen (orr@lpccaen.in2p3.fr)
— J. Carbonell

IV. FINAL PROGRAM

For all the talks, we will allocate 1 hour to each speaker, which can be distributed into 45 min. for the talk and 15 m. for questions and discussions.

N.B : Physicists willing to participate to this workshop are welcome. They have to be registered, by sending an e-mail to the contact organizer (J. Carbonell).

N.B : A short presentation of the ESNT framework and projects will be given on the first day by the SPhN copilot of the steering committee.

Monday 30	Tuesday 31	Wednesday 1	Thursday 2	Friday 3
ARRIVAL	10h D. Beaumel	10h J.M. Richard	10h T. Nakamura	10h P. Naidon
AND	11h E. Hiyama	11h T. Myo	11h Y. Ikeda	11h L. Pricoupenko
DISCUSSIONS	12h H. Sakai	12h M. Valdes	12h M. Marques	12h Y. Kubota
12h30 **Lunch**	13h00 **Lunch**	13h **Lunch**	13h **Lunch**	13h **Lunch**
14h00 ESNT				
14h30 S. Shimoura	DISCUSSIONS	DISCUSSIONS	14h30 S. Paschalis	DISCUSSIONS
15h30 R. Lazauskas			15h30 M. Ploszajczak	
16h30 **Coffee Break**			**Coffee Break**	
17h00 H. Fujioka			17h00 Y. Sun	
18h00 R. Kezerashvili				