Computation of three- and four-neutron resonance positions in the complex energy plane

Jaume Carbonell *(Carbonell@ipno.in2p3.fr)*
Institut de Physique Nucléaire, Université Paris-Sud, 91406 Orsay Cedex, France

Rimantas Lazauskas *(rlazausk@iphc.cnrs.fr)*
CNRS/IPHC, Strasbourg

Emiko Hiyama (*hiyama@riken.jp)*
Strangeness Nuclear Physics Laboratory, RIKEN,
2-1 Hirosawa, Wako-shi Saitama, 351-0198 JAPAN

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I. SCIENTIFIC ISSUE

The existence of small neutron clusters has been investigated since the first days of nuclear physics both from the experimental and the theoretical points of view [1, 2].
The neutron-neutron interaction is indeed quite attractive, almost as much as the neutron-proton one. The dineutron is supposed to be unbound but the large size of the scattering length indicates that it is very close to binding: few hundreds of additional keV would be enough. The 3n system has a "symmetric bound state" of about 1 MeV and the symmetric 4n system is bound by about 5 MeV [3, 4]. Nature however discards these "symmetric fermionic states" which are damned to live (forever?) in the computer of some theoreticians. The antisymmetric 3n and 4n states – the only ones allowed by the Pauli principle – are well above in the corresponding spectra and far, very far, from being bound [3, 4, 7–9, 11].
It is interesting [10] to draw some parallels with a similar, and more accessible, fermionic system: the ^{3}He atomic clusters. Despite the fact that ^{3}He atomic dimers (N=2) are unbound, as well as trimers (N=3) and tetramers (N=4), it has been found that small ^{3}He droplets with N ~ 30 can definitely form a bound state [17].
Should we expect a similar situation with neutrons? Assuming, as all theoretical calculations predict, that infinite neutron matter is indeed unbound, is it reasonable to expect some stability islands in the way going from N=2 to N=1 neutrons. If yes, where? If not, why?
About fifteen years ago, an experiment performed at GANIL [5] reported some indications compatible with the observation of bound few-neutron systems, the most promising structure being the tetraneutron (bound state of 4 neutrons). Further investigations [6], using independent techniques, could not confirm this result but pointed out that the analysis of ^{8}He(d,^{6}Li)4n reaction cannot be explained by phase space analysis involving both four free neutrons and two non-correlated dineutron pairs in the final state. However the experimental spectra are compatible with abroad 2-3 MeV width structure in the continuum. The search for

multineutron resonances - essentially 4n and 6n -has been pursued and a very recent experiment at RIKEN [12, 13] indicated a possibility for the low energy resonance state of tetra-neutron $E_{4n} = 0.83 \pm 0.25$ MeV.

If the several theoretical studies indicate that there is no any reasonable chance for 3n and 4n to be bound, the existence of resonant states near the threshold is indeed a priori not excluded. An estimation of such a possibility was even performed in [7] by extrapolating the results of a 4n system confined on a trap and concludes about a possible few MeV resonant state.

A proper computation of a resonant position for $N > 2$ is however a very delicate task since it requires the solution of the Schrödinger equation in the complex energy plane. This was achieved by R. Lazauskas and J. Carbonell in [4, 11] using the Fadeev-Yakubovsky equations combined with complex scaling and analytic continuation techniques. The positions of 3- and 4-neutron resonant states in the complex energy plane were determined for the first time. The results obtained in this work indicate that all the 4n resonances are quite far from the threshold, have widths ~ 15 – 20 MeV and may not have distinguishable contribution in the physical observable. This conclusion creates an obvious tension with the experimental results and deserves some further studies.

The direct calculations of the 3n and 4N resonances of Refs. [4, 11] still remain the only ones. It seems thus necessary to check stability of these results with respect to the existent uncertainties in nuclear Hamiltonian, as well using different numerical techniques.

Prof. E. Hiyama, from RIKEN, will bring her expertise in the ab-initio Few-Body calculations and in the technique of correlated Gaussian basis [14, 15] to solve the 4-body problem in the continuum.

From the common work done by the three organizers of this project, it is expected that some conclusion may be drawn about the eventual observation of the 4n resonances, at least from the perspective of the theoretical nuclear physics.

Useful references

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II. GOALS OF THE WORKSHOP

In summary, the goals of the project are
1. Compute using two independent methods (Faddeev-Yakubovsky and Variational Gaussian basis) the position of 3n and 4n resonances in the complex energy plane;
2. Study the eventual experimental signature of these states.

III. SHORT-TERM VISITORS

Prof. Emiko Hiyama from RIKEN (Japan) and R. Lazauskas from IPHC Strasbourg will stay at the ESNT for several days during the project period.

A seminar will be given at SPhN by E. Hiyama about:
Recent progress of hypernuclear physics

See: *http://esnt.cea.fr/Phocea/Page/index.php?id=55*