Many-neutron systems: search for superheavy ^{7}H and its tetraneutron decay

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Many-neutron systems represent a fundamental question in Nuclear Physics. Since there is no firm theoretical claim about their existence as a bound or resonant state, their observation would require a deep reconsideration of our understanding of nuclei in general, and the strong force in particular. Two of these systems have attracted most of the attention over the last decades, ^{4}n and ^{7}H (that decays into t+$4n$). However, all the past experiments had in common several issues: they did not measure the four neutrons; the statistics and/or resolution were very low; and some results were in contradiction with each other.

The goal of the NP1512-SAMURAI34 experiment,[1)] carried out in July 2017, was to provide the definitive proof of existence of both ^{7}H and ^{4}n, and, in case of a positive answer, their detailed spectroscopy. Concerning the issues noted above, we proposed to obtain very high statistics (several 10^4 complete events) and resolution (about 100 keV) and, by detecting the four neutrons for the first time, have access to the decay properties and correlations within the system. In particular, the fact of measuring the neutrons in the decay $t+4n$ provides a unique opportunity to observe even very broad $4n$ resonances (undetectable using missing mass techniques), since any resonance would be unambiguously identified through the angular anti-correlation between the triton and the neutrons.

We measured the reaction ^{8}He$(p, 2p)^3$H+$4n$ in complete kinematics (see Fig. 1) at the SAMURAI[2)] facility of RIBF. The setup was similar to the one of the NP1312-SAMURAI21 experiment.[3)] The secondary beam of ^{8}He at 150 MeV/nucleon and 10^5 pps was produced by the fragmentation of an ^{18}O primary beam at 220 MeV/nucleon on a beryllium target, then selected by BigRIPS, and finally sent onto the 15 cm MINOS liquid-hydrogen target.[4)] The beam was detected by two plastic scintillators (SBTs) and tracked with two drift chambers (BDC1 and BDC2). The reaction was tagged through the detection of both the target and knocked-out protons with the MINOS TPC (trajectories) and 36 crystals of DALI2 arranged in a cylindrical configuration around the target (energies).

The outgoing triton was tracked by the two drift chambers (FDC0 and FDC2) at the two sides of the SAMURAI dipole magnet, with a 2.4 T field, and detected by the 40 scintillator bars of the extended hodoscope (HODOF+HODOP). The four neutrons were detected with the combination of NEBULA[5)] and four double-planes of NeuLAND,[6)] with an estimated efficiency $\varepsilon_{4n} \sim 1\%$. Moreover, since the complete 7-body kinematics are overdetermined, they can be reconstructed from the momenta of only 3 of the neutrons. This method can be crucial if the ground states of ^{7}H and/or ^{4}n were very close to threshold, since at such low energies the $3n$ efficiency can be about 20 times higher than the $4n$ one.

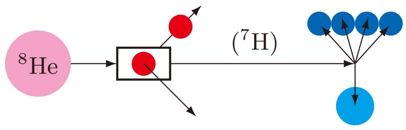

Fig. 1. Schematic view of the ^{8}He$(p, 2p)^3$H+$4n$ reaction on the MINOS target.

In order to validate the use of DALI2, originally developed as a γ-ray array, for the detection of high-energy protons, a test with an 80 MeV proton beam was done at CYRIC, and before the experiment cosmic runs were undertaken with the crystals placed along their three main directions, with the corresponding energy peaks covering a range of 30–90 MeV. In addition, the elastic scattering of protons was measured during the first hours with a 150 MeV proton beam, leading to clear kinematic lines.

The ^{8}He beam intensity and quality were stable during the 6-day run. The online analysis showed the proper operation of the different multidetectors, as well as of their correlations. The MINOS TPC trajectories and the high-energy hits in DALI2 showed the characteristic p-p back-to-back azimuthal pattern. Tritons were clearly identified in the hodoscope at the predicted location. The neutron multiplicities exhibited the expected distributions for different reaction channels, and a very preliminary analysis of those multiplicities in the ^{8}He$(p, 2p)^3$H channel, including causality conditions, lead to an estimate of several 10^4 complete $2p$+t+$4n$ events during the whole run, consistent with our proposal goal. The data analysis is in progress.

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References

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