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Study of the structure of borromean nucleus ^{17}Ne*

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Abstract The ^{17}Ne nucleus is a possible candidate with a two-proton borromean halo structure. Since the theoretical model is difficult to handle the three-body system, it is difficult to determine the two-proton halo structure in ^{17}Ne. In the present research, we try to study the breakup reaction of ^{17}Ne. For the Borromean nuclei, one-proton knockout results in an unstable nucleus which is decaying further by proton emission. This process will result in an angular correlation between the direction of the aligned recoiling unstable nucleus and its decay products. The angular correlations can give us information about the configuration of the valence proton in the ^{17}Ne. Furthermore, theoretical calculations indicate that the momentum distributions of ^{16}F c.m are sensitive to the structure of the halo in ^{17}Ne. Thus the measurement of momentum distributions of ^{16}F c.m may also give us conclusive information on the structure of ^{17}Ne. The present experiment has been done at IMP in Lanzhou using the radioactive beam ^{17}Ne at 30.8 MeV/u on a 43mg/cm^2 ^{12}C target. The data analysis is under procedure and the primary results are provided.

Key words two-proton halo, ^{17}Ne, breakup reaction

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1 Introduction

Since ^{17}Ne nucleus is the lightest proton-rich borromean nucleus (^{15}O+p+p) with a small two-proton separation energy S_{2p}=0.94 MeV, it is an possible candidate with a two-proton halo structure and attracts a lot of theoretical and experimental studies. But so far a consistent conclusion has not obtained. For example, Zhukov et al.[1] treated ^{17}Ne as a three-body system within the hyperspherical-coordinate method and in the coordinate-space Faddeev method. Their results showed that there is 73% probability of a valence proton being outside the rms core radius. Thus they suggested that the ^{17}Ne may has two-proton halo structure. At the same time, Timofeyuk et al.[2] studied ^{17}Ne and its mirror nucleus ^{17}N within a three-cluster generator-coordinate model, which combines the advantages of both the cluster model and the shell model, concluded that although the last two protons in ^{17}Ne and the last two neutrons in ^{17}N mainly occupy $2s_{1/2}$ orbit, but their radii as well as proton and neutron density distribution does not support the existence of a proton halo in ^{17}Ne. In Refs. [2—4], people also studied on the asymmetry in the $\beta \pm$ decays of ^{17}Ne and ^{17}N to the first excited states in the daughter nuclei. Borge et al.[3] suggested a proton halo structure in ^{17}Ne, while Timofeyuk et al.[2] argued that large asymmetries are irrelevant for the halo effect. Furthmore, Millener[4] concluded that the $(d_{5/2})^2$ configuration in ^{17}Ne is dominate and supported a non proton-halo structure. Nakamura et al.,[5] and Fortune et al.[6] studied the Coulomb displacement energy derivation. In Ref. [5], the dominating configuration was predicted to be $(s_{1/2})^2$, but in Ref. [6], the $(d_{5/2})^2$ is preferred.

Warner et al.[7] measured the total reaction cross in Si target of ^{17}Ne at intermediate energies, sections

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and suggested that the proton halo does not exist in ^{17}Ne. In Ref. [8], Kanungo et al. measured the longitudinal momentum distribution of ^{15}O core and two-proton removal cross section for the ^{17}Ne + ^{9}Be system at 66 *A*MeV. The few-body Glauber-model analysis of these data as well as interaction cross sections in ^{17}Ne + ^{12}C system at 680 *A*MeV[9], indicates that about 90% *s*-wave occupancy of the valence protons, which suggests a two-proton halo structure in ^{17}Ne. Based on the three-body model, a recent reanalysis[10] of the above momentum distribution[9] concluded that *d*-wave occupancy probability is larger than 75%. In addition, the theoretical calculations[10] found that no matter how much the s/d ratio in ^{17}Ne, the calculated 2p removal cross section is much smaller than the experimental data[9]. Thus for the experimental results based on the inclusive measurements in breakup reaction of ^{17}Ne[9], the mechanism of *p*-wave proton removal from the ^{15}O core can not be neglected.

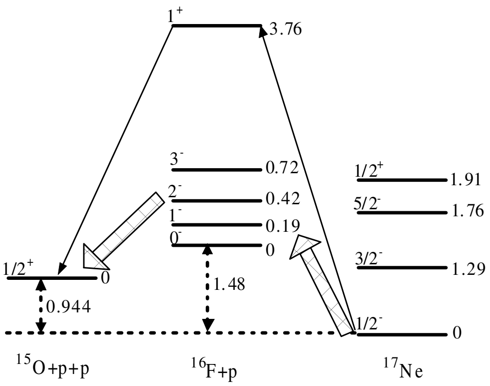

Fig. 1. Level scheme of the low-lying states in ^{17}Ne, ^{16}F, and ^{15}O.

2 Breakup reaction of ^{17}Ne

In the present research, we try to study the breakup reaction of ^{17}Ne on ^{12}C target. For the Borromean nucleus, Aleksandrov et al. found that the dominant reaction mechanism is a two-step process[11]: knock out of one valence nucleon which results in a unstable nucleus, it will be followed by the other valence nucleon emission. In the ^{17}Ne case, if a *s*-wave proton is knocked out from ^{17}Ne, the remaining ^{16}F will locate at 0^- or 1^- states, while if a *d*-wave proton is knocked out, ^{16}F will locate at 2^- or 3^- states. But a *p*-wave proton removal from ^{15}O ($1/2^-$) core will involve 1^+ states of ^{16}F(as shown in Fig.1). Thus, in the present research, we hope that with the invariant mass measurement of ^{15}O and proton, it will help us to distinguish the processes of proton knock out from the halo and proton knock out from the core and exclude the core contributions in the experiment. The exclusive experimental data of the longitudinal momentum distribution of ^{15}O core and two-proton removal cross section for the ^{17}Ne, which is obtained from simple breakup reaction mechanism, can provide better comparison with the theoretical results.

Based on the sudden approximation, Chulkov et al.[12] have found that in the breakup reaction of Borromean nucleus, the two-step process will result in an angular correlation between the direction of the aligned recoiling unstable nucleus and its decay products. The angular correlations can give us the information about the configuration of the valence nucleon in the Borromean nucleus. This characteristic has been used to determine the exact s/p configuration mixing in Borromean neutron halo nuclei ^{6}He[13] and ^{11}Li[14]. In the present study, with the coincident measurements of ^{15}O and protons, their angular correlations may help us to determine s/d mixing ratio in the ^{17}Ne. Furthermore, theoretical calculations [10] indicate that the ratios and shapes of the momentum distributions of ^{16}F c.m are very sensitive to the structure of the halo in ^{17}Ne. Thus, comparison of such distributions between the experimental data and theoretical calculations could also give us conclusive information on the structure of ^{17}Ne.

3 Experimental setup and primary results

The present experiment was performed at the Institute of Modern Physics in Lanzhou, China. The primary beam for the experiment was 76.8 MeV per nucleon ^{20}Ne ions produced by HIRFL, which impinged on a ^{9}Be target with a thickness of 387 mg/cm^2. The ^{17}Ne fragments were collected, separated, and purified using the Radioactive Ion Beam Line in Lanzhou (RIBLL). The energy of the ^{17}Ne beam is 30.8 MeV per nucleon. The purity of the ^{17}Ne beam before the secondary ^{12}C target (43 mg/cm^2) was only 5% with ^{15}O as the dominant contamination. As shown in Fig. 2, the ^{17}Ne particles can be selected by time of flight measurements with respect to two plastic scintillators upstream.

Figure 3 shows the experimental setup at center angular. Two parallel plate avalanche counters (PPAC's) were placed in front of ^{12}C target to track the incoming beam. The reaction products ^{15}O and protons were detected by a multiple stack particle telescope. The first quartered silicon detector (QSD, 300-μ m-thick) and the first double sided silicon strip detector (DSSD, 1-mm-thick) were used to identify, track and stop the ^{15}O fragments. Since the outgoing proton has more penetrate power, the second quartered silicon detector (QSD, 1-mm -thick), the second double sided silicon strip detector (DSSD, 500-μm-thick) and 3×3 CsI(Tl) detector array were used for the energy and position measurement of the outgoing protons. To get the outgoing direction of the proton, the signal of the first DSSD was transferred to the preamplifier with two different gain settings(low gain for ^{15}O, high gain for proton). To detect the outgoing proton at large angle, we also put three telescopes around the center multiple stack telescope. Each telescope consists of a position sensitive silicon detector (PSD), a large surface silicon detector (SSD) and a 2×2 CsI(Tl) detector array.

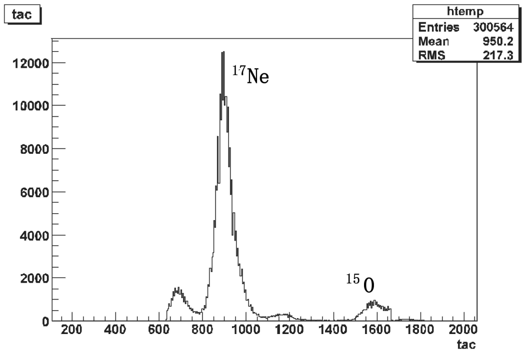

Fig. 2. Time-of-flight spectra of the beam after excluding the most contaminant of ^{15}O.

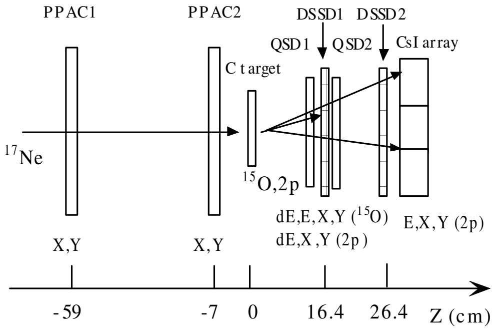

Fig. 3. Sketch of the central part of the exprerimental setup designed for the kinematically complete detection of all reaction products.

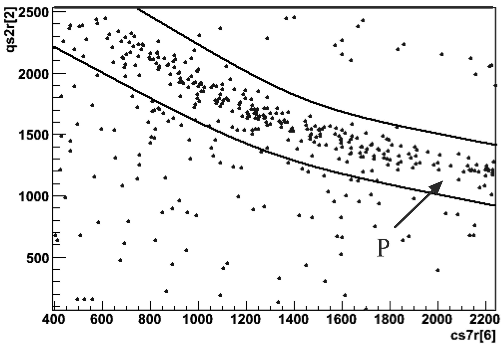

Fig. 4. Plotted the energy loss in one quarter of the second QSD versus the energy deposited in one piece of CsI crystal.

Before the formal experimental running, we test the energy resolution of all the silicon and CsI(Tl) detectors with ^{241}Am α source. The performances of these detectors are very good. Simulations were also made to determine the optimal experimental setup. At present, the data analysis of the ^{17}Ne experiment is under procedure and the primary results are presented. Fig. 4 shows the energy loss in one quarter of the second QSD versus the energy deposited in one piece of CsI crystal. It demonstrates the identification of one proton hits. Fig. 5 shows the identification of coincident ^{15}O with the above protons.

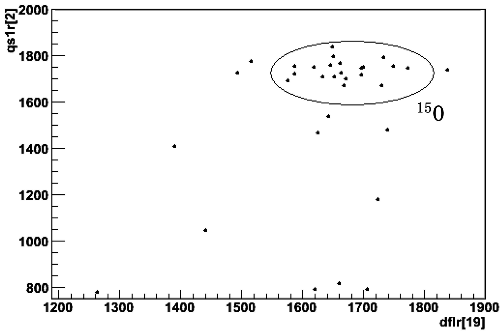

Fig. 5. The coincident ^{15}O with the protons in Fig. 4. The energy loss in one quarter of the first QSD is plotted versus the deposited energy in the first DSSD.

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