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Proton halo effects in the ^{8}B+^{64}Zn collision around the Coulomb barrier

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Abstract. The ^{8}B+^{64}Zn reaction at 38.5 MeV has been studied at HIE-ISOLDE CERN to investigate proton halo effect on the reaction dynamics. For the first time it was used the only existing post-accelerated ^{8}B beam. The measured elastic scattering angular distribution showed a small suppression of the Coulomb-nuclear interference peak, opposite to what observed for the one-neutron halo nucleus ^{11}Be on the same target where a large suppression was observed instead. Inclusive angular and energy distributions of breakup fragments were also measured showing that, both, elastic and non-elastic breakup contribute. The presence of the additional Coulomb interactions halo-core and halo-target in ^{8}B makes the reaction dynamics in this proton-halo nucleus different than the neutron-halo case.

1. Introduction

^{8}B has a very low breakup threshold of 0.138 MeV and thus is a good candidate for having a proton-halo structure. Huge efforts have been made in the past years to understand the reaction dynamics around the Coulomb barrier with neutron-halo nuclei; on the other hand the dynamics at the barrier with proton-halo is expected to be different, but very few experimental data exist

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(for a review see [1]). Many of the investigations performed with ^{8}B beams concern Coulomb dissociation at energies well above the Coulomb barrier in order to get indirect information on the radioactive capture reaction ^{7}Be(p,α), but not many studies exist to investigate the reaction dynamics of proton-halo nuclei. All experiments have been done using in-flight ^{8}B beam, therefore with some limitations associated with the caracteristics of such beams (purity, energy spread and beam emittance) compared to the post-accelerated ones. In the Coulomb dissociation process, proton-halo nuclei behave differently from neutron-halo, since the loosely bound proton participates in the reaction process. Namely, for a dynamic polarization effect the valence proton is displaced behind the nuclear core and shielded from the target; this effect causes a reduction of break-up probability compared to first-order perturbation theory predictions and higher-order corrections are required [e.g. [2, 3]]. As experimentally observed [4], nuclear processes are expected to have a primary role in the dissociation of ^{8}B [5]. Conversely for the neutron-halo nucleus ^{11}Be on the same target at a similar energy the Coulomb contribution far exceeds the nuclear one [6]. Unlike neutron-halo, in reactions with proton-halo nuclei there is an additional Coulomb interaction between the p and the core and the p and the target whose effect is to create an effective barrier which makes the proton of the halo effectively more bound [6].
In the case of reactions induced by neutron-halo nuclei, coupling to the continuum result in a suppression in the Coulomb-nuclear interference region in the elastic scattering angular distribution relative to the Rutherford [e.g. [7, 8, 9, 10, 11], and a large total reaction cross-section is, as a consequence, observed. Moreover, a large fraction of total reaction cross-section is due to direct processes such as break-up or transfer [8, 12, 13].

Unlike the ^{8}B+^{208}Pb result at 170 MeV, the total reaction cross-section, for the low energy experiments around the Coulomb barrier [14, 15], was found to be large as in the case of neutron-halo reactions.

In this last case of ^{8}B+^{58}Ni the inclusive break-up was measured [14] by detecting the ^{7}Be fragments. These data showed that in order to reproduce the experimental spectra, high order effects had to be considered in the breakup process. Summarising the experimental evidence shows that the reaction dynamics for neutron-halo and proton-halo nuclei seems to be different. The availability at ISOLDE of a post accelerated ^{8}B beam gives the possibility to investigate the above topic with a better precision that the one so far available.

2. Experiment

The experiment was performed at HIE-ISOLDE facility at CERN whith the first post-accelerated ^{8}B beam [16]. The the ^{8}B beam was produced from the protons coming from the CERN PSBooster with energy of 1.4 GeV through the reaction on a a multiwalled carbon nanotube target (CNT). A molecular ^{8}BF$_2$ beam was extracted from the target; ^{8}B was charge bred in REX-EBIS to 3^+ and accelerated to an energy of 4.9 A MeV. The final ^{8}B average intensity on target was ∼400pps. The reaction target was a 1.021 mg/cm^2 isotopically enriched ^{64}Zn target. This was placed at an angle of 30° with respect to the beam direction, in order to allow measurements at 90°. The experimental setup consisted of six silicon telescopes made of two stages of detectors, 40 μm and 1000 μm thick respectively. Each detector was a 50x50 mm^2 Doube Sided Silicon Strip detector (DSSSD) segmented into 16+16 strips [17]. The large segmentation allowed for high angular resolution for the angular distribution measurement which was, in fact, limited by the statistics.

3. Results

The ^{8}B+^{64}Zn elastic scattering angular distribution is shown in fig. 1 as a ratio to the Rutherford cross-section. Unlike the neutron-halo nucleus ^{11}Be at similar $E_{\mathrm{c.m.}}/\mathrm{V_C}$ [10, 11], a clear Coulomb-nuclear interference peak is visible at around 35°.

The measured angular distribution is compared with continuum-discretized coupled-channels (CDCC) calculations in which the ^{8}B is described as a two-cluster system, a ^{7}Be and a proton. Details of the calculations are reported in [16]. Fig. 1 shows the result of these calculations.

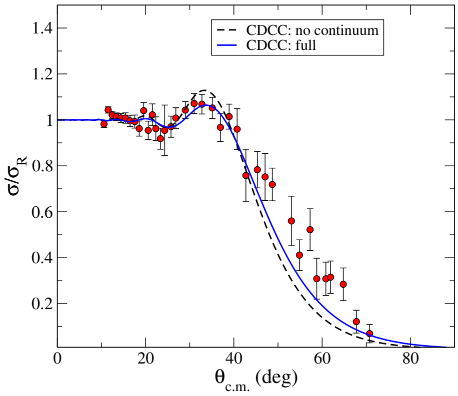

Figure 1. Experimental elastic scattering angular distribution for ^{8}B+^{64}Zn (symbols). CDCC calculations with (full line) and without (dashed line) coupling to the continuum.

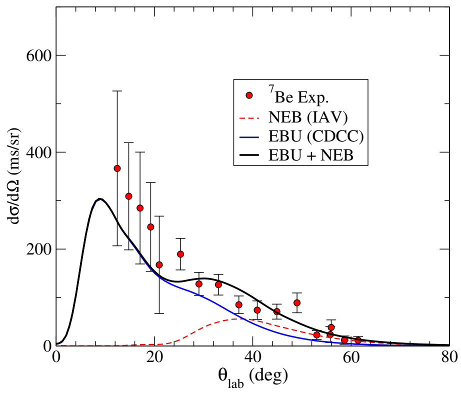

Figure 2. Experimental ^{7}Be angular distribution (symbols). Continuous blue line: EBU from CDCC calculations. Dashed red line: NEB. Continuous black line: sum of EBU+NEB contributions.

The cross-section obtained from the CDCC calculations is shown in fig. 1 as a solid line. To show the effect of the ^{8}B elastic breakup on the elastic data, the calculation omitting the coupling to the continuum channels (dashed line) is also shown for comparison. From the figure it is possible to see that the elastic breakup produces a small suppression of the elastic cross-section, but does not suppress completely the Coulomb-nuclear interference effect. Figure 2 shows the angular distribution for ^{7}Be events.The present breakup data is inclusive, implying that several processes can in principle contribute to the ^{7}Be yield: on one side, the elastic breakup (EBU) process, in which the ^{8}B is dissociated into ^{7}Be+p, leaving the target in its ground state; on the other side, the nonelastic breakup (NEB) processes in which the dissociated proton interacts non-elastically with the target, including non-capture breakup accompanied by target excitation, proton absorption by the target (incomplete fusion) and proton transfer.

The agreement between the experiment and the sum of EBU and NEB cross-section is fairly good, with only some underestimation of the data for $\theta_{\rm lab} <20^{\circ}$. From this comparison it can be observed that the dominant reaction mechanism for the ^{7}Be production at forward angles is the EBU.

4. Summary

The ^{8}B+^{64}Zn elastic scattering angular distribution unlike the neutron-halo case, shows the presence of the Coulomb-nuclear interference peak. The comparison with CDCC calculations disclosed the evidence that reaction dynamics for the proton-halo ^{8}B shows only modest effects of coupling to the continuum and its total reaction cross-section is similar to that of ordinary weakly bound nuclei on the same target.

The inclusive angular and energy ^{7}Be distributions distinctively shows a dominance of elastic breakup at small angles, whereas non-elastic breakup becomes non negligible only at larger angles.

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