Reaction Dynamics Induced By The Radioactive Ion Beam ^{7}Be on Medium-Mass and Heavy Targets

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Abstract. We studied the reaction dynamics induced at Coulomb barrier energies by the weakly-bound Radioactive Ion Beam ^{7}Be (S_α = 1.586 MeV) on medium-mass (^{58}Ni) and heavy (^{208}Pb) targets. The experiments were performed at INFN-LNL (Italy), where a 2-3×10^5 pps ^{7}Be secondary beam was produced with the RIB in-flight facility EXOTIC. Charged reaction products were detected by means of high-granularity silicon detectors in rather wide angular ranges. The contribution presents an up-to-date status of the data analysis and theoretical interpretation for both systems.

INTRODUCTION

The study of the near-barrier reaction dynamics has attracted the interest of the Nuclear Physics community since the early stages of heavy-ion collision experiments. In the Eighties a large enhancement of the sub-barrier fusion cross section was observed [1] and detailed studies established that both static (such as, for instance, the nuclear deformation) and dynamics properties (such as, the presence of transfer channels with positive Q values) can increase the fusion probability. This scenario has recently acquired a renewed interest with the advent of Radioactive Ion

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Beams (RIBs), which might exhibit very exotic features, e.g. halo or nuclear skin structures and rather weak binding energies. Several review articles have been written on this topic [2, 3, 4, 5, 6, 7].

Within this framework, we undertook the study of ^{7}Be-induced reactions on medium mass and heavy targets. This RIBs is bound only by 1.586 MeV and its ground state has a very pronounced ^{3}He-^{4}He cluster configuration. Moreover, ^{7}Be constitutes the core of the even more exotic nucleus ^{8}B. Thus, any piece of information gained in the study of ^{7}Be-induced reactions could represent a doorway to better understand the dynamics triggered by the proton halo and very weakly-bound nucleus ^{8}B (S_p = 0.1375 MeV).

The contribution is organized as follows: Sect. 2 and 3 will present the experimental results for the system ^{7}Be + ^{58}Ni and ^{7}Be + ^{208}Pb, respectively. Some concluding remarks will finally be given in Sect. 4.

THE SYSTEM ^{7}Be + ^{58}Ni

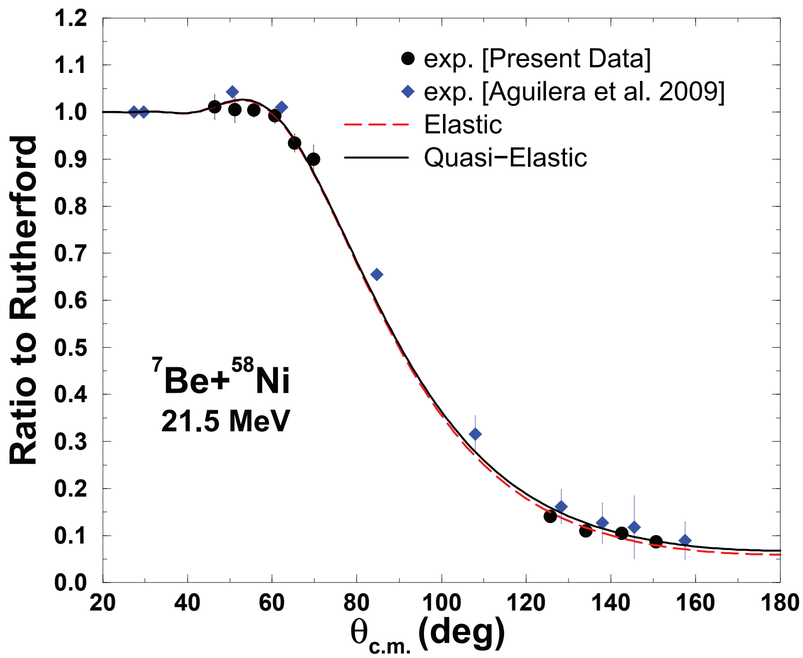

FIGURE 1. Quasi-elastic scattering angular distribution for the system ^{7}Be+^{58}Ni at 21.5 MeV beam energy. The results of the present evaluation are displayed with circles, while diamonds originate from an earlier measurement E.F. Aguilera and collaborators [8]. The dashed and continuous lines are the results of optical model calculations without any free parameters for the elastic and quasi-elastic process, respectively.

The system ^{7}Be+^{58}Ni was studied at the Laboratori Nazionali di Legnaro (LNL) of the Istituto Nazionale di Fisica Nucleare (INFN). The ^{7}Be RIB was produced at 22 MeV beam energy and with an intensity about 3×10^{5} pps by means of the facility EXOTIC [9]. Charged reaction products were detected with 3 ΔE-E_{res} telescopes of the detector array DINEX [10]. Each telescope consisted of 2 50 mm × 50 mm Double Sided Silicon Strip Detectors (DSSSDs), whose thickness was 40-42 and 1000 *mu*m for the inner and outer layer, respectively.

The secondary beam energy resolution and the target thickness (1 mg/cm^{2}) prevented the unambiguous detection of pure elastic scattering events and inelastic excitations leading to projectile (E_x = 0.429 MeV) and target (E_x = 1.414 MeV) first excited states. Thus we obtained the quasi-elastic angular distribution depicted with circles in Fig. 1. We can see that our evaluation compared remarkably well with the earlier measurement by E.F. Aguilera and collaborators [8]. Fig. 1 also shows the results of optical model calculations performed without any free parameters for the elastic (dashed line) and quasi-elastic (continuous line) channels. To account for the projectile energy loss into the target thickness (about 1 MeV), the theoretical calculations were computed at 21.5 MeV beam energy. Additional details on this topic can be found in a recently published article [11].

We also measured the angular distributions of the two ^{7}Be constituent clusters, ^{3}He and ^{4}He. The production yield of the heavier helium isotope resulted to be about 5 times larger than that for its lighter counterpart. This outcome immediately ruled out the possibility that the ^{7}Be reaction dynamics at Coulomb barrier energies were dominated by the exclusive breakup process ^{7}Be $\rightarrow$ ^{3}He + ^{4}He. In such a case, in fact, we would have expected similar yields for the two helium isotopes.

We investigated in detail the possibility that ^{4}He ions could be produced by the fusion-evaporation, the 1n-pickup (leading to ^{8}Be, eventually breaking into two ^{4}He), the 1n-stripping (producing ^{6}Be, then breaking into ^{4}He and two protons) and the exclusive breakup processes. The last three processes have in common the feature that they all foresee the presence of (at least) two charged fragments in the reaction exit channel. However, experimentally we did not observe any coincidence events. According to our Continuum-Discretized-Coupled-Channel (CDCC) and Distorted-Wave-Born-Approximation (DWBA) calculations for these three processes (described in detail in Ref. [11]), the lack of observation of coincidence events is compatible (within a 95% confidence level) with the statistics collected during the experiment and the geometrical efficiency of the detector set-up (estimated with a Monte-Carlo simulation).

The calculations performed with the statistical model code PACE2 [12] helped establishing that about 80% of the ^{4}He observed yield came from evaporation after compound nucleus formation. In addition, according to the CDCC and DWBA calculations, the remaining yield of ^{4}He should originate with rather similar probabilities from 1n-pickup, 1n-stripping, exclusive breakup and ^{3}He-stripping processes. On the other side, about 2/3 of the ^{3}He production should be triggered by the ^{4}He-stripping process and $\sim$ 1/3 by the exclusive breakup process.

PRELIMINARY RESULTS FOR THE SYSTEM ^{7}Be + ^{208}Pb

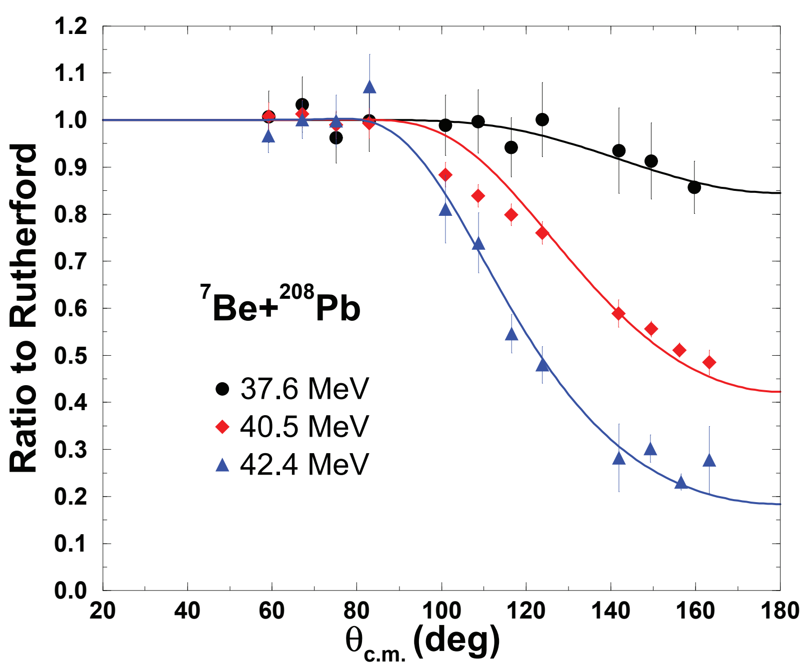

FIGURE 2. Quasi-elastic differential cross section at 3 near-barrier energies for the system ^{7}Be+^{208}Pb. Continuous lines are the results of an optical model best-fit analysis of the experimental data.

The study of the nuclear collisions at Coulomb barrier energy for the system ^{7}Be+^{208}Pb was also performed at INFN-LNL. The ^{7}Be RIB was delivered at three energies (37.6, 40.5 and 42.4 MeV) by means of the upgraded RIB in-flight facility EXOTIC [13]. The RIB intensity was about 3×10^{5}. Charged particles produced after the interaction with a 1 mg/cm^{2} ^{208}target were detected in the angular range θ_{lab} = [50°,170°] with 6 ΔE-E$_{res}$ telescopes of the newly developed detector array EXPADES [14]. Each telescope consisted of 2 64 mm $\times$ 64 mm DSSSDs. The thickness of the first and second telescope layer was 43-57 and 300 *mu*m, respectively.

Fig. 2 shows a preliminary evaluation of the quasi-elastic differential cross sections for the system ^{7}Be+^{208}Pb. We can clearly how the angular distribution at backward angles drops as the beam energy increases, according to the larger relevance of the nuclear absorption. A very preliminary optical model best-fit analysis, performed with the code FRESCO [15], of the collected data is also depicted in Fig. 2 with continuous lines.

The near-future steps of the data analysis will be the pixel-by-pixel analysis of the quasi-elastic events (so far only the strip-by-strip analysis was performed), then we will evaluate the angular and energy distributions for ^{1}H, ^{3}He and ^{4}He ions and, finally, we will search for coincidences between charged reaction products.

CONCLUDING REMARKS

The facility EXOTIC at INFN-LNL is now fully operational for the production of light weakly-bound RIBs by means of the in-flight technique. Several reaction dynamics studies at Coulomb barrier energies have been already performed. The investigation of the system ^{7}Be+^{58}Ni has been recently published. The quasi-elastic differential cross section showed a remarkable agreement with an earlier measurement. The study of the ^{3,4}He production suffered of low statistical accuracy, a rather common feature of all experiments involving RIBs. A detailed theoretical and kinematic study helped disentangling the possible origin(s) of the two helium isotopes. First-hand results for the system ^{7}Be+^{208}Pb were also presented. In this case a deeper understanding of the reaction dynamics should be achieved, since a larger statistics was collected with respect to the other reaction.

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