Elastic scattering measurements of the system $^7$Be + $^{28}$Si at near barrier energies

O. Sgouros$^1$, A. Pakou$^1$, D. Pierroutsakou$^2$, M. Mazzocco$^{1,4}$, L. Acosta$^5$, X. Aslanoglou$^1$, C. Betsou$^1$, A. Boiano$^2$, C. Boiano$^6$, D. Carbone$^5$, M. Cavallaro$^7$, J. Grebosz$^8$, N. Keeley$^9$, M. La Commarai$^{10}$, C. Manea$^4$, G. Marquinez-Duran$^3$, I. Martel$^3$, C. Parascandolo$^2$, K. Rusek$^{11}$, A. M. Sanchez-Benitez$^{12}$, C. Signorini$^{13}$, F. Soramel$^{3,4}$, V. Soukeras$^1$, C. Stefanini$^1$, E. Stiliaris$^{14}$, E. Strano$^{3,4}$, I. Strojek$^9$, D. Torresi$^{3,4}$

$^1$ Department of Physics and HINP, University of Ioannina, 45110 Ioannina, Greece.
$^2$ INFN, Sezione di Napoli, I-80125 Napoli, Italy.
$^3$ Dipartimento di Fisica e Astronomia, Università di Padova, I-35131 Padova, Italy.
$^4$ INFN, Sezione di Padova, I-35131 Padova, Italy.
$^5$ Departamento de Física Aplicada, Universidad de Huelva, E-21071 Huelva, Spain.
$^6$ INFN, Sezione di Milano, I-20133 Milano, Italy.
$^7$ INFN, Laboratori Nazionali del Sud, I-95125 Catania, Italy.
$^8$ IFJ-PAN, Krakow, Poland.
$^9$ National Centre for Nuclear Research, 05-400 Otwock, Poland.
$^{10}$ Dipartimento di Scienze Fisiche, Universita di Napoli “Federico II”, I-80125 Napoli, Italy.
$^{11}$ Heavy Ion Laboratory, University of Warsaw, Pasteura 5a, 02-093 Warsaw, Poland.
$^{12}$ Centro de Física Nuclear da Universidade de Lisboa, 1649-003 Lisboa, Portugal.
$^{13}$ INFN, Laboratori Nazionali di Legnaro, I-35020 Legnaro, Italy.
$^{14}$ Institute of Accelerating Systems and Applications and Department of Physics, University of Athens, Athens, Greece.

INTRODUCTION

Elastic scattering, has been well established in the past as the traditional tool for probing the optical potential. In the last decade, the energy dependence of the optical potential for weakly bound systems, at near and sub-barrier energies has attracted a strong interest. Standard theories deduced from tightly bound projectiles, referring to the potential threshold anomaly (TA) and the validity of the dispersion relation, have been studied and debated. In this respect, while for well bound systems the imaginary part connected with it with dispersion relations develops a localized peak, for weakly bound projectiles either an increasing trend is observed for the imaginary part or a decreasing one but which occurs well below barrier. Specifically, it has been shown that for $^4$Li and $^7$Li on low mass targets ($^{27}$Al, $^{28}$Si) the conventional TA is not any more applicable [1-5] and moreover the energy dependence of the potential for the two projectiles is not similar. While for $^4$Li the imaginary part of the optical potential presents a slight increasing trend as the energy decreases at the barrier and below it, for $^7$Li the energy dependence resembles more the one seen for well bound projectiles but where the flat imaginary potential persist till very low sub-barrier energies. For both projectiles the sudden drop of the imaginary part appears at very low sub-barrier energies. As the study of the energy dependence of the potential is strongly related with breakup and transfer processes, coupled to the elastic scattering and fusion, such studies are appealing for weakly bound radioactive nuclei, where such reaction mechanisms are reinforced. Into this context, we have proposed the present study involving a radioactive projectile as $^7$Be on the same $^{28}$Si target. This nucleus is a proton rich weakly bound radioactive nucleus, mirror to the weakly bound but stable $^7$Li nucleus. The breakup threshold for beryllium is 1.6 MeV, which is lower than the corresponding 2.45 MeV for $^7$Li, but similar to 1.48 MeV for $^4$Li. Is then the optical potential behavior of $^7$Be similar to the $^7$Li or that of $^4$Li? One of the goals of this study is to answer this question.

EXPERIMENTAL DETAILS AND DATA ANALYSIS

The $^7$Be secondary beam was produced at the EXOTIC facility [6] at the Laboratori Nazionali di Legnaro (LNL), Italy by means of the In Flight (IF) technique and the $^1$H($^7$Li,$^7$Be)n reaction. The $^7$Li$^{13}$ primary beam was delivered by the LNL-XTU Tandem Van de Graaf accelerator with an intensity of $\sim$150 pA and energies of 27 to 35 MeV. The primary beam was directed onto a 5 cm long gas cell with 2.2 µm thick Havar foil windows filled with H$_2$ gas at a pressure of $\sim$1000 mbar and a temperature of 93 K, corresponding to an effective thickness of 2 mg/cm$^2$. Two parallel plate avalanche counters (PPAC) were placed downstream 88 cm before the secondary target and used to monitor the beam as well as for the reconstruction of its trajectory. The $^7$Be beam was produced at 4 energies namely, 13, 17, 20 and 22 MeV, two of them with retuning the primary beam and two with degrader. The beam impinged on a $^{28}$Si target 0.4 mg/cm$^2$ thick and the elastically scattered ejectiles were recorded in the detector array of the EXOTIC facility. In more detail, the experimental setup included six telescopes from the detector array described in [7]. Each telescope comprises $\Delta$E and E double sided silicon strip detectors, with thicknesses of $\sim$ 55 µm and 300 µm, respectively. Both modules have active areas of 64x64 mm$^2$ with 32 strips per side, orthogonally oriented to define 2x2 mm$^2$ pixels. Details of the handling of the detector signals can be found in Ref.[7]. The electronics of the $\Delta$E stage are arranged such as to collect events every two strips giving to the system an angular resolution of 2 degrees. The trigger of the electronics was given by a signal created by the OR of
the ΔE stage of the telescopes in coincidence with the PPAC signal set. Preliminary results for the angular distribution at one of the projectile energies at 17 MeV are given in Figure 1.

The differential cross sections were obtained using the following relation:

$$\sigma(\theta) = \frac{N\sigma_{Pb}(\theta)T_{Pb} \Phi_{Pb}}{T\Phi_{Pb}N_{Pb}}$$  \hspace{1cm} (1)

where \(\sigma(\theta)\) is the differential cross section for the \(^7\)Be + \(^{28}\)Si quasi-elastic scattering at 17 MeV, \(N\) is the quasi-elastic scattering counting rate for \(^7\)Be on \(^{28}\)Si, \(\sigma_{Pb}(\theta)\) is the Rutherford scattering differential cross section for \(^7\)Be on a \(^{208}\)Pb target at the appropriate energy, \(\Phi_{Pb}\) is the beam flux during the run with the \(^{208}\)Pb target, \(N_{Pb}\) is the counting rate for the \(^{208}\)Pb run at the same angle as for the \(^{28}\)Si one, \(\Phi\) is the beam flux during the run with the \(^{28}\)Si target, and \(T_{Pb}, T\) are the \(^{208}\)Pb and \(^{28}\)Si target thicknesses, respectively. The absolute differential cross section obtained using Eqn. [1] was divided by the Rutherford scattering cross section and the quantity \(\Phi_{Pb} T_{Pb}/\Phi T\) was adjusted such that at the most forward angles the ratio to the Rutherford cross section was equal to 1. In this way the assigned error on the data is dominated by the statistical error.

Fig. 1. Quasi-elastic scattering data of \(^7\)Be+\(^{28}\)Si at \(\approx\)17 MeV are compared with CDCC and OMP calculations.

THE CALCULATIONS

Continuum-Discretized-Coupled-Channel(CDCC) calculations were performed with the code FRESCO [8] version FRXP.14 adopting cluster-folding descriptions, with the \(^7\)Be considered as a \(^4\)He+\(^3\)He cluster. The \(^4\)He+\(^3\)He binding potential was that used by Buck and Merchant [9], while the input potentials for \(^4\)He+\(^{28}\)Si and \(^3\)He+\(^{28}\)Si were taken from [10-11]. Further details of the calculation can be found in [12]. The CDCC results are compared with the data in Figure 1, presenting a good agreement with them. Moreover, Optical Model Potential(OMP) calculations were performed taking into account a BDM3Y1 interaction for both the real and imaginary part and fitting to the data the normalization factors \(N_{\text{real}}\) and \(N_{\text{mag}}\). These normalization factors are presented with the star in Figure 2, where previous data [1-2] describing the energy dependence of \(^6\)Li and \(^7\)Li on a silicon target are also presented. Although in the present study we have only one datum, it is obvious that the trend of the optical potential for \(^7\)Be+\(^{28}\)Si follows the one for \(^6\)Li and not for \(^7\)Li. However, more data at other energies are necessary to confirm this conclusion. The analysis of such data is under progress.

In summary, we have measured angular distributions of elastic scattering for \(^7\)Be+\(^{28}\)Si at various near barrier energies. We present here preliminary results for one of the energies at 17 MeV. We also present CDCC calculations and OMP calculations. In the last theoretical context comparisons are made between the energy dependence of weakly bound, but stable, projectiles with the present radioactive one on the same target.

Fig. 2. Previous data [1-2] on the optical potential energy dependence for \(^6\)Li and \(^7\)Li on silicon are compared with the present datum for \(^7\)Be+\(^{28}\)Si.