STUDY OF THE NEAR-BARRIER SCATTERING OF ^{8}He ON ^{208}Pb*

G. Marquínez-Durán[a], A.M. Sánchez-Benítez[a], I. Martel[a]
L. Acosta[b], K. Rusek[c], M.A.G. Álvarez[d], R. Berjillos[a]
M.J.G. Borge[e], A. Chbihi[f], C. Cruz[e], M. Cubero[g], J.A. Dueñas[h]
J.P. Fernández-García[i], B. Fernández-Martínez[j], J.L. Flores[h]
J. Gómez-Camacho[j,k], N. Keeley[l], J.A. Labrador[j], M. Marqués[m]
A.M. Moro[k], M. Mazzocco[n], A. Pakou[o], V.V. Parkar[p], N. Patronis[o]
V. Pesudo[q], D. Pierroutsakou[r], R. Raabe[s], R. Silvestri[r], N. Soic[t]
Ł. Standyło[l], I. Strojek[l], O. Tengblad[e], R. Wolski[u], A.H. Ziad[j]

[a]Departamento de Física Aplicada, Universidad de Huelva, 21071 Huelva, Spain
[b]Instituto de Física, Universidad Nacional Autónoma de México, Mexico
[c]Heavy Ion Laboratory, University of Warsaw, Pasteura 5A, 02-093 Warszawa, Poland
[d]Instituto de Física, Universidade de São Paulo, 05508-090, São Paulo, Brazil
[e]Instituto de Estructura de la Materia, CSIC, 28006 Madrid, Spain
[f]GANIL, CEA and IN2P3-CNRS, B.P. 5027, 14076 Caen cedex, France
[g]CICANUM, Universidad de Costa Rica, 11502-Apdo. 2060, San José, Costa Rica
[h]Departamento de Ingeniería Eléctrica, Universidad de Huelva, 21071 Huelva, Spain
[i]Laboratori Nazionali del Sud, INFN, Via Santa Sofia 62, 95123, Catania, Italy
[j]Centro Nacional de Aceleradores, 41092, Sevilla, Spain
[k]Departamento de Física Atómica, Molecular y Nuclear, Universidad de Sevilla 41080 Sevilla, Spain
[l]National Centre for Nuclear Research, A. Sołtana 7, 05-400 Otwock, Poland
[m]Laboratoire de Physique Corpusculaire, 14050 Caen cedex, France
[n]Dipartimento di Fisica and INFN, Universita di Padova, 35131 Padova, Italy
[o]Department of Physics, University of Ioannina, 45110 Ioannina, Greece
[p]Bhabha Atomic Research Centre, Mumbai, India
[q]Nuclear Physics Department, iThemba Laboratory for Accelerator Based Science Old Faure Road, Faure 7131, South Africa
[r]INFN — Sezione di Napoli, via Cintia, 80126 Napoli, Italy
[s]Instituut voor Kern- en Stralingsfysica, K.U. Leuven, Belgium
[t]Ruđer Bošković Institute, Bijenicka 54, 10000 Zagreb, Croatia
[u]Flerov Laboratory of Nuclear Reactions, JINR, Dubna 141980, Russian Federation

(Received November 17, 2015)

The structure and dynamics of ^{8}He have been studied through the collision process with a ^{208}Pb target at energies of 22 and 16 MeV, above and below the Coulomb barrier, respectively. The energy and angular distributions of the elastically scattered ^{8}He and the ^{6,4}He fragments were measured. In this paper, we discuss the method used to determine the effective position of the beam spot on the reaction target and the scattering and solid angles of each pixel of the detector array.

DOI:10.5506/APhysPolB.47.841

* Presented at the XXXIV Mazurian Lakes Conference on Physics, Piaski, Poland, September 6–13, 2015.

1. Motivation

Surprisingly, the scattering of ^{8}He from heavy targets at energies around the Coulomb barrier has not been deeply studied and only a few data sets are available [1, 2]. The peculiar structure of ^{8}He should affect the collision process in the presence of a strong Coulomb field, as is the case of the scattering from a heavy target at energies around the Coulomb barrier. Also, the role of the neutron skin on the dynamics of the scattering process is not clear. Since S_n and S_{2n} are similar, it is important to investigate the competition between the single and double neutron transfer channels and the direct breakup. Therefore, experiment E587S was performed at GANIL (Caen, France) in 2010 with the aim of studying the scattering of ^{8}He from ^{208}Pb at 16 and 22 MeV.

2. Experimental setup

The relatively low available intensities for radioactive beams necessitate the design of particle detection systems with large solid angle, high granularity and that cover a large angular range. With this purpose, the GLORIA detection system, described in [3], was developed at the University of Huelva and commissioned during the E587S experiment. This system is intended for the detection of charged reaction fragments produced in direct reactions with heavy targets at low energies (< 5 MeV/u). GLORIA consists of 12 DSSSD detectors, arranged in six particle telescopes with a first stage of 40 μm and a second stage of 1 mm thickness. The target is tilted at an angle of 30° to avoid shadows in the particle detector array arising from the target. The whole setup covers a continuous angular range from 15° to 165°, and a solid angle of 26.1% of 4π. In particular, two symmetric (A and B) telescopes cover the forward angles, while another two (C and D) cover the backward angles, with a further two located above and below the target (E and F).

3. General considerations for data analysis

The arrangement of the detectors in telescopes, *i.e.* ΔE–E_T pairs, allows for the distinction between different reaction channels in two-dimensional spectra, called mass spectra, where the identification of reaction fragments is possible thanks to the separation of mass and charge. For every spectrum, the number of events related to each reaction channel is integrated using the so-called integration regions. The definition of these regions can become difficult, for example, in the case of the elastic channel for large values of the scattering angle where the statistics are low. For this reason, integration regions were determined in summed spectra, obtained from the addition of single spectra from pixels with a similar scattering angle, which requires accurate energy calibration.

As a step towards the integration of the different events registered in the ΔE–E_T spectra, it is important to remove the largest possible number of non-physical events, for example, from noise–noise coincidences. Also, we should discard events that, despite having a physical meaning, are invalid, for example, particles that hit the detectors in the region between two strips distributing their energy between them, the so-called cross-talk effect. Non-valid events were removed during the process of analysis by imposing several conditions while generating the spectra.

Once the spectra are properly generated and the integration of the number of events is possible, it is crucial to properly evaluate the scattering and solid angles in order to calculate the cross sections.

4. Determination of the relative position of the beam spot on target and of the detectors

For an accurate evaluation of the scattering and solid angles, the effective position of the beam spot on target and of the detector array should be considered, especially in closed geometry systems like GLORIA. The search for this position is based on the hypothesis that at very forward angles, the ratio $d\sigma_{\mathrm{elastic}}/d\sigma_{\mathrm{Rutherford}}$ remains around one.

The methodology for searching for the effective relative position is explained in what follows. Firstly, a starting position for the detection system at each energy must be found, taking into consideration the number of elastic events detected by the forward telescopes. Based on this position and following a specific methodology explained below, several positions of the beam on target and the setup are tested in order to find the most appropriate. For the evaluation of each of the possible positions, a simulation of Rutherford scattering is carried out using the Geant4 code [4] in the NPTool [5] environment. In each simulation, the geometry of the detection system, according to the position being tested, must be implemented. In this way, the number $\mathrm{N}_{\mathrm{Rutherford}}$ of detected events is obtained for each pixel and the ratio $d\sigma_{\mathrm{elastic}}/d\sigma_{\mathrm{Rutherford}}$ can be calculated as the number of experimental elastic events divided by $\mathrm{N}_{\mathrm{Rutherford}}$.

In order to find a starting point position for the setup, a comparison between the experimental elastic events registered by the two forward telescopes as well as between their upper and lower halves must be carried out. As an example of the results obtained, the 22 MeV case is described. The pixels have been numbered in such a way that 1 and 14 denote the detector edges, while 7 and 8 correspond to their centres. In the upper panel of figure 1, it can be observed how for both forward telescopes A and B their lower halves systematically detect more events than their upper halves. In fact, the values of these differences increase from about 4% in the centres of the detectors to nearly 40% at the edges. In the lower panel, it is shown how the telescope B also registers more events than the supposedly symmetric telescope A.

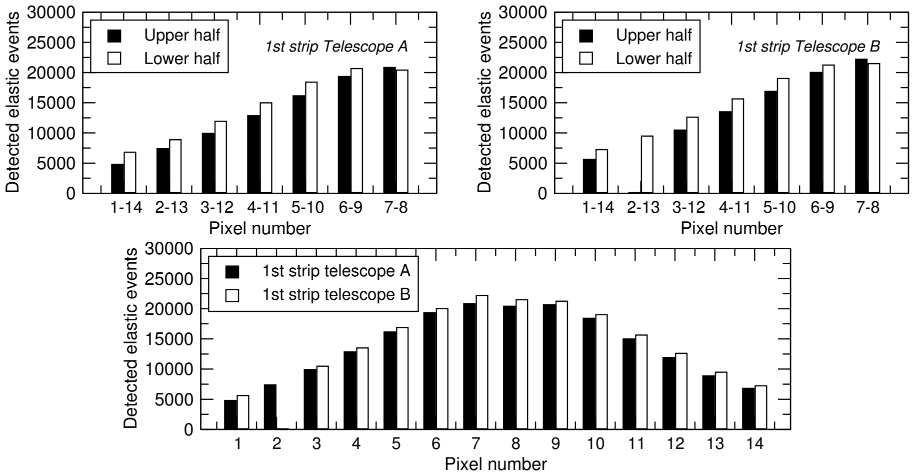

Fig. 1. (Upper panel) Comparison between the elastic events detected by the pixels in the upper and lower halves of the first strip of the forward telescopes A and B. (Lower panel) Comparison between the elastic events detected by the pixels in the first strip of telescopes A and B.

These comparisons allow us to understand the most probable displacements necessary to obtain the effective position of the detection system during the experiment. In particular, a horizontal displacement or rotation about the vertical axis is required in order to remove the differences between A and B seen in the lower panel of figure 1, while a vertical displacement could explain the differences between the upper and lower halves of these telescopes. An additional study was carried out with the aim of understanding if the latter differences were due to the rotation of the target. However, the main conclusion extracted from this study was that in the range between 15° and 45°, the differences between the number of counts registered in the upper and lower halves of the detectors due to the rotation of the target remain under 3%, insufficient to explain those observed experimentally.

Once a starting position for the beam-spot on target and the detection system has been defined, the methodology for obtaining the best position is as follows. Firstly, a set of pixels (those with $\theta_{\rm cm} < 27°$) for both telescopes A and B is chosen where Rutherford-like behaviour is expected. Then, for a given position of the telescopes, a simulation is performed giving as a result the ratios $d\sigma_{\rm elastic}/d\sigma_{\rm Rutherford}$ for each of these pixels. Finally, when all the ratios are known, they are fitted with a line whose slope should be as close as possible to zero, while the differences between the ratios and the line (following the χ^2 method) should be minimised. As an example of the results obtained, in figure 2, the χ^2 values for various positions of the detection system are shown.

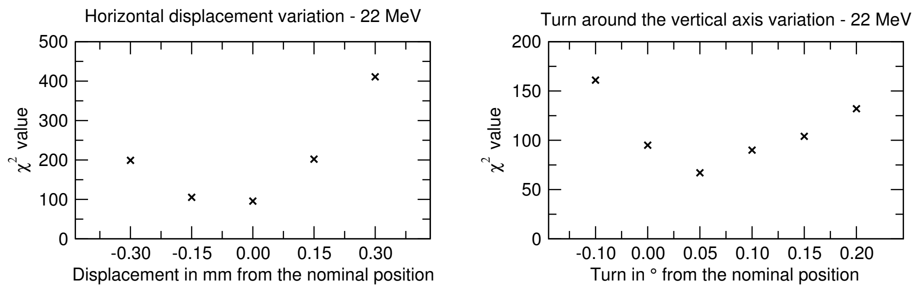

Fig. 2. (Left) χ^2 values obtained for horizontal movements of the setup with respect to its nominal position (*i.e.* no horizontal displacement) and (right) χ^2 values obtained for rotations around the vertical axis with respect to the nominal position (0° turn).

The final position for 22 MeV is determined as a vertical displacement of +1.20 mm and a rotation around the vertical axis of 0.05°, while for 16 MeV a −0.30° rotation around this axis is sufficient.

5. Elastic cross section angular distributions

Once the effective relative positions of the beam on target and the detector array were found at 16 and 22 MeV, simulations for the whole setup were carried out for these specific positions in order to obtain the scattering and solid angles, and calculate the elastic cross section for each pixel of every telescope. After an averaging process of the ratio for all pixels with the same scattering angle, the angular distribution of the elastic scattering cross section for the ^{8}He+^{208}Pb system at 22 MeV is presented in figure 3.

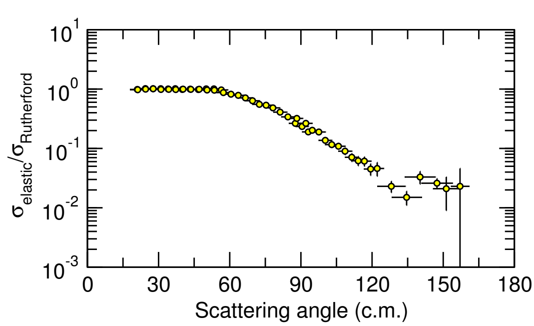

Fig. 3. Angular distribution of the elastic scattering cross section of the ^{8}He+^{208}Pb system at 22 MeV.

6. Conclusions

In this work, we have investigated the effect of the position of the beam spot on the counting rates and the normalisation of the cross sections in the data analysis of the experiment E587S. The angular distribution of the elastic scattering cross section for the ^{8}He+^{208}Pb system at 22 MeV was presented.

This work was supported in part by grants FPA2010-22131-C021-01 and FPA2014-59954-C3-1-P from the Spanish Ministry of Economy and Competitiveness, grant N202 033637 from the Ministry of Science and Higher Education of Poland and Contract EUI2009-04163 (EUROGENESIS) from the European Science Foundation.

REFERENCES

[1] A. Lemasson *et al.*, *Phys. Rev. C* **82**, 044617 (2010).

[2] A. Lemasson *et al.*, *Phys. Lett. B* **697**, 454 (2011).

[3] G. Marquínez-Durán *et al.*, *Nucl. Instrum. Methods A* **755**, 69 (2014).

[4] Geant4: A toolkit for the simulation of the passage of particles, `http://geant4.cern.ch`

[5] NPTool Package, `https://qithub.com/adrien_matta/nptool`