Study of the scattering of 15C at energies around the Coulomb barrier

Downloaded from: https://research.chalmers.se, 2026-10-07 21:57 UTC

Citation for the original published paper (version of record):
Ovejas, J., Knyazev, A., Martel, I. et al (2020). Study of the scattering of 15C at energies around the Coulomb barrier. Journal of Physics: Conference Series, 1643(1).
http://dx.doi.org/10.1088/1742-6596/1643/1/012095

N.B. When citing this work, cite the original published paper.

research.chalmers.se offers the possibility of retrieving research publications produced at Chalmers University of Technology. It covers all kind of research output: articles, dissertations, conference papers, reports etc. since 2004. research.chalmers.se is administrated and maintained by Chalmers Library

(article starts on next page)

Journal of Physics: Conference Series **1643** (2020) 012095 doi:10.1088/1742-6596/1643/1/012095

Study of the scattering of ^{15}C at energies around the Coulomb barrier

J D Ovejas[1], A Knyazev[2], I Martel[3,4], O Tengblad[1], M J G Borge[1], J Cederkall[2], N Keeley[5], K Rusek[6], C García-Ramos[4], T Pérez[4], L A Acosta[7], A A Arokiaraj[8], M Babo[8], T Cap[5], N Ceylan[4], G De Angelis[9], A Di Pietro[10], J P Fernández[10], P Figuera[10], L Fraile[11], H Fynbo[12], D Galaviz[13], J H Jensen[12], B Jonson[14], R Kotak[15], T Kurtukian[16], M Madurga[17], G Marquínez-Durán[4], M Munch[12], A K Orduz[18], R Honório[13], A Pakou[19], L Peralta[13], A Perea[1], R Raabe[8], M Renaud[8], K Riisager[12], A M Sánchez-Benítez[4], J Sánchez-Segovia[4], O Sgouros[19], V Soukeras[19], P Teubig[13], S Viñals[1], M Wolinska-Cichocka[6], R Wolski[20] and J Yang[8].

[1]Instituto de Estructura de la Materia, Spain
[2]Lund University, Sweden
[3]University of Liverpool, United Kingdom
[4]University of Huelva, Spain
[5]National Centre for Nuclear Research, Poland
[6]Heavy Ion Laboratory, Poland
[7]Instituto de Física-UNAM, Mexico
[8]KU Leuven, Belgium
[9]INFN Laboratori Nazionali di Legnaro, Italy
[10]INFN Laboratori Nazionali del Sud, Italy
[11]Universidad Complutense de Madrid, Spain
[12]Aarhus University, Denmark
[13]LIP Lisbon, Portugal
[14]Chalmers University of Technology, Sweden
[15]Queen's University Belfast, United Kingdom
[16]Centre Etudes Nucléaires de Bordeaux Gradignan, France,
[17]Texas A&M University, USA
[18]Ganil, France
[19]Department of Physics and HINP, Greece
[20]Henryk Niewodniczanski Institute of Nuclear Physics PAS, Poland

E-mail: [3]imartel@uhu.es

Abstract. The neutron rich carbon isotope ^{15}C is the only known case of an almost "pure" $2s_{1/2}$ single-neutron halo ground state configuration. At collision energies around the Coulomb barrier the reaction dynamics is expected to be dominated by single neutron transfer and breakup. To investigate these effects, we have measured the scattering of ^{15}C with a ^{208}Pb target at 65 MeV at the HIE-ISOLDE facility in CERN (Geneva, Switzerland). The preliminary data demonstrates the presence of a strong long-range absorption pattern in the angular distribution of the elastic cross section. The results are discussed in the framework of Optical Model calculations.

1. Introduction

Nuclear systems such as ^{6}He, ^{11}Li or ^{11}Be are known to have an extended neutron distribution, the so-called neutron halo [1]. Halos are formed in weakly bound nuclei close to the neutron drip line, where the valence neutrons can tunnel out the barrier with larger probability. This effect enhances the

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

diffuseness of the nuclear surface, leading to an extended density distribution known as the nuclear halo. The presence of a halo can be probed at high collision energies by the observation of narrow momentum distribution in the breakup fragments and large interaction cross sections [2]. At Coulomb barrier energies (~ 5 MeV/u), the halo structure manifests itself with a strong absorption pattern in the angular distribution of the elastic cross sections, where the nuclear rainbow completely disappears [3].

The nucleus ^{15}C has the last neutron in a $2s_{1/2}$ wave [4]. This favours the possible presence of this halo structure in spite of the relatively large binding energy for this last neutron of S_n=1218.1(8) keV [5]. The total interaction cross-section is about 30% larger than its neighbor isotope ^{14}C, and the transverse-momentum distribution exhibits a very narrow width of only 67(3) MeV/c [6]. Despite its interest [7], there are no data on the scattering of ^{15}C at Coulomb barrier energies. Coupled-channels calculations [3] show that the dynamics should be determined by the competition between single-neutron transfer and breakup. We investigate the scattering of ^{15}C with a ^{208}Pb target at 65 MeV at the HIE-ISOLDE facility at CERN (Geneva, Switzerland) (experiment IS619) to elucidate its behaviour.

2. Experimental setup

The experiment was carried out at the XT03 beamline of the HIE-ISOLDE facility at CERN (Switzerland). The radioactive beam was produced via nuclear reactions on a CaO primary target placed in a hot-cathode plasma source irradiated with the 1.4 GeV proton beam from the CERN Proton Synchrotron Booster (PSB). After extraction, purification and mass-separation, the ^{15}C ions were post-accelerated up to 4.37 MeV/u by the HIE-ISOLDE superconducting linac.

The experiment was carried with GLORIA detector system (Figure 1), which consists of six 16x16 two-stage DSSSD silicon-telescopes, with 40 μm (ΔE) and 1 mm (E) thicknesses, respectively [8]. Two high-purity ^{208}Pb targets (>98%) of 1.5 mg/cm^2 and 2.1 mg/cm^2 thickness were used for the measurements. The ^{15}C beam had an average intensity of $3\cdot10^3$ pps at the Scattering Experiments Chamber (SEC). A typical ΔE -E particle identification spectrum of the forward telescope A is shown in Figure 2 (Left). Despite the large spread arising from the lead straggling, the detector telescope can separate the regions corresponding to $^{15}C^{5+}$ and other contaminants like $^{15}N^{5+}$.

As the Coulomb barrier in the ^{15}N+^{208}Pb scattering system is around 79 MeV, much higher than the nominal collision energy of 65 MeV, the angular distribution follows a pure Rutherford angular distribution shown in Figure 2 (Right). The ^{15}N data was therefore used for normalization and solid angle calculations. The experiment-averaged fraction of carbon to nitrogen was $\simeq$ 0.03.

3. Data analysis and experimental results

A preliminary data analysis has been carried out for the two forward telescopes A and B, which cover the first 15°-65° Lab of the elastic angular distribution. The data from the other four telescopes, covering laboratory angles up to 165° is still under analysis.

The ^{15}C and ^{15}N elastic scattering yields have been integrated for each of the 16x16 pixels of the telescopes. The scattering angle subtended by each pixel has been obtained by a χ^2 fit of the angular distribution of the ^{15}N yield assuming a pure Rutherford scattering. The elastic cross section of ^{15}C scattering normalized to Rutherford was obtained from the ratios of ^{15}C to ^{15}N yields, which removes the solid angle dependence. Finally, the data collected in the different pixels with similar angles were statistically averaged and normalised to unity as at 20º we expect Rutherford scattering behaviour. The resulting angular distribution is shown in Figure 3.

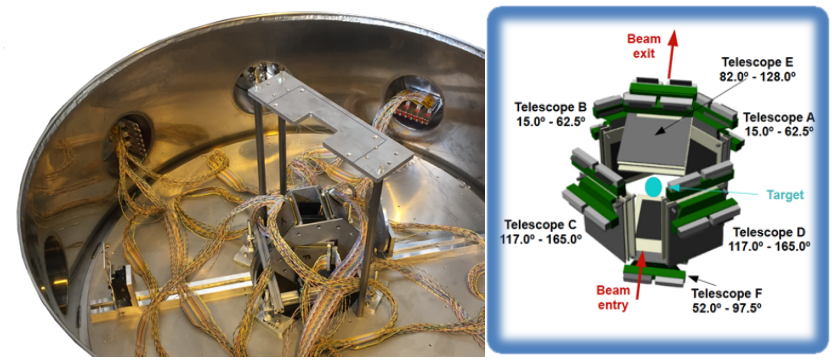

Figure 1. Left: Setup of GLORIA in SEC. Right: 3D representation of the silicon detector arrangement (note the 90° rotation as to the left figure).

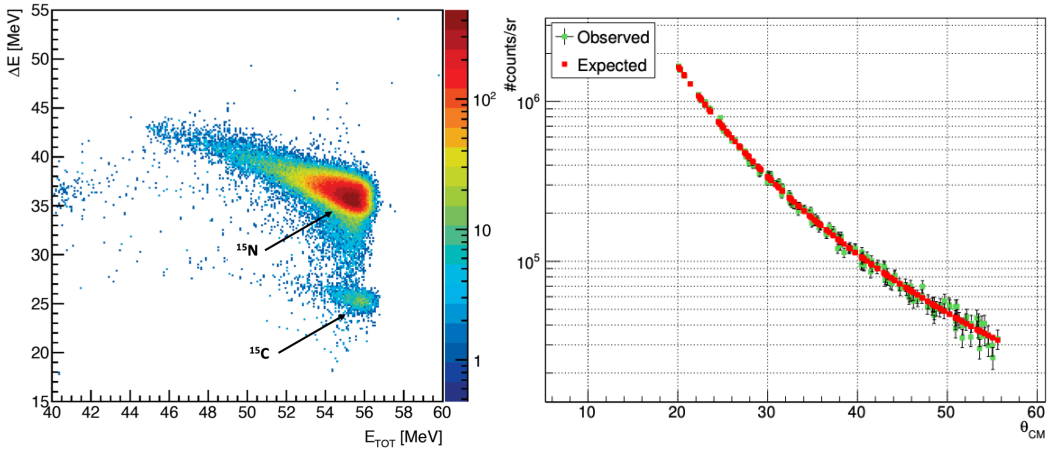

Figure 2. Left: ΔE-E 2D plot of the forward telescope A covering 17°-21° Laboratory angles. Contributions of ^{15}C and ^{15}N scattering are clearly identified are identified. Right: Fit of the elastic scattered ^{15}N ions angular distribution (green dots) in telescope A using a Rutherford scattering angular distribution (red dots).

The angular distribution of elastic scattering provides useful information on the interactions governing the relative motion, as well as the relevance of non-elastic channels through the deviation with respect to Rutherford scattering. In Figure 3, the effect of the halo in the Coulomb barrier scattering of ^{15}C is illustrated by comparison to the well-known system ^{12}C+^{208}Pb at the same collision energy [9]. We observe the expected effects found in previous halo systems, like the disappearance of the rainbow and the strong absorption pattern. A significant deviation from Rutherford scattering occurs already at CM angles around 40°, which corresponds to a distance of closest approach of $\simeq$ 21 fm in a classical Coulomb trajectory. Might the final data analysis confirm this result, the long-range absorption would be similar to that found in the Coulomb barrier scattering of the two-neutron halo ^{6}He [9]. This extraordinary absorption might be due to the unique s-wave nature of the halo wave function in ^{15}C.

To further investigate this effect we have carried out a preliminary Optical Model analysis of the angular distributions. The optical potentials were parametrized in terms of the usual Woods-Saxon forms, with real and imaginary volume parts. As the data analysis is in a very preliminary stage, the calculations didn't aim to fit the data but just to reproduce the overall angular trend. The results are summarised in Table 1 together with the case of ^{12}C from Ref. [10]. In order to reproduce the ^{15}C scattering data a large imaginary diffuseness of a_{i0} = 1.560 fm has to be introduced, giving a reaction cross section of σ_R = 3035 mb, about seven times larger than the value of σ_R = 429 mb found for ^{12}C scattering [10]. This extraordinary large imaginary diffuseness suggests an extremely extended neutron

distribution comparable to that of the ^{6}He isotope. This is the first dynamical study carried out so far for the halo nucleus ^{15}C at Coulomb barrier energies.

Table 1. Optical Model analysis of the present data on $^{15}C+^{208}Pb$ scattering at 65 MeV lab, and for $^{12}C+^{208}Pb$ [10] at the same collision energy.

	V_0(MeV)	r_{r0}(fm)	a_{r0}(fm)	W_0(MeV)	r_{i0}(fm)	a_{i0}(fm)
$^{15}C+^{208}Pb$	32.90	1.256	0.560	22.10	1.256	1.560
$^{12}C+^{208}Pb$	65.50	1.282	0.463	163.71	1.265	0.365

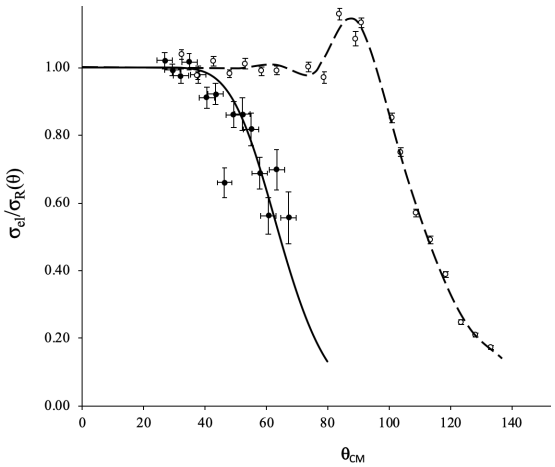

Figure 3. Angular distribution of the elastic cross section normalized to Rutherford for the system $^{15}C+^{208}Pb$ (full circles, present work) and $^{12}C+^{208}Pb$ (empty circles, Ref. [10]) at 65 MeV. The solid and dashed lines are OM calculations, which parameter values are given in Table 1. See text for details.

Acknowledgements

I. Martel and O. Tengblad (Spokespersons) are grateful to the IS619 collaboration and to the HIE-ISOLDE team for delivering the ^{15}C beam. J. D. Ovejas is grateful to CSIC (Spain) for the PhD fellowship BES2016-077059. Work partially supported by the Spanish research grants PGC2018-095640-B-I00, FPA2015-64969-P and FPA2017-87568-P; the Portuguese FCT grants CERN/FIS-PAR/0005/2017; the Mexican project PAPIIT-DGAPA IA103218 and the grant ENSAR2 from the H2020 program of the European Union.

References

[1] P.G. Hansen and B. Jonson, Europhys. Lett. **4** 409 (1987).
[2] T. Aumann, Eur. Phys. J. A **26** 441 (2005).
[3] N. Keeley, K.W. Kemper and K. Rusek, Eur. Phys. J. A **50** 145 (2014).
[4] J.R. Terry, et al., Phys. Rev. C **69**, 054306 (2004).
[5] G. Audi and A. H. Wapstra, Nucl. Phys A **565** 66 (1993).
[6] A. Ozawa, Nucl. Phys. A **738** 3844 (2004).
[7] N. Keeley and N. Alamanos, Phys. Rev. C **75**, 054610 (2007).
[8] G. Marquínez-Durán et al., Nucl. Inst. Meth. A **755**, 69 (2014).
[9] J.J. Kolata et al., Eur. Phys. J. A **52** 123 (2016).
[10] S. Santra, et al., Phys. Rev. C **64** 024602 (2001).