EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN–INTC/2006-010
INTC-P206
20 January 2006

Proposal to the ISOLDE-Neutron Time of flight Committee

EXPLORING HALO EFFECTS IN THE SCATTERING OF ^{11}Be ON A HEAVY TARGET AT REX-ISOLDE

M.V. Andrés(1), M.J.G. Borge(2), L.M. Fraile(3), H. Fynbo(4), J. Gómez-Camacho(1),
J.M. Espino(1), M.A.G. Alvarez(1), B. Jonson(5), I. Martel(6), I. Mukha(1) A. Moro(1)
T. Nilsson(5) G. Nyman(5), K. Riisager(3), H.B. Jeppesen(3), O. Tengblad(2) M. Turrión(2)
and the REX-ISOLDE Collaboration(4)

Århus[4]-CERN[3]-Göteborg[5]-Huelva[6]-Madrid[2]- -Sevilla[1]-Collaboration

Spokesperson: M.J.G Borge and J. Gómez-Camacho
Contactperson: H.B. Jeppesen

ABSTRACT

We propose to measure the scattering of ^{11}Be on heavy targets at energies around the Coulomb barrier with the aim to study the effect of the neutron halo on the reaction mechanisms. We expect to see deviations of the elastic cross sections with respect to Rutherford, even at energies below the barrier, due to the effect of dipole polarizability. We also expect to observe the inelastic excitation from the $1/2^{+}$ ground state to the $1/2^{-}$ excited state. One neutron transfer, as well as break-up cross sections will be obtained from the analysis of the ^{10}Be fragments produced in the collision. We expect to obtain information on the $B(E1)$ distribution in the low energy continuum of ^{11}Be.

In a previous experiment, ^{11}Be was produced and accelerated at REX-ISOLDE with an intensity of 10^{5} pps. This beam intensity would allow us to measure the scattered fragments, at forward and backward angles, with a detector array based on silicon strip detectors. We ask for a total of 27 shifts of beam from a Ta-foil target with RILIS plus 3 shifts of rest gas.

---

(1) Facultad de Física, Apartado 1065, Universidad de Sevilla, E-41080 Sevilla, Spain
(2) Instituto de Estructura de la Materia, CSIC, E-28006 Madrid, Spain
(3) ISOLDE, PH Department, CERN, CH-1211 Geneva 23, Switzerland
(4) Institut for Fysik og Astronomi, Århus Univ., DK-8000 Århus, Denmark
(5) Department of Physics, Chalmers University of Technology, S-41296 Göteborg, Sweden
(6) Departamento de Física Aplicada, Universidad de Huelva, E-21071 Huelva, Spain

1 Introduction

Halo nuclei are composed of a core nucleus and one or two almost unbound neutrons. Due to the loosely bound structure, they should be easily polarizable. Thus, in the presence of a strong electric field, the nucleus will be distorted, so that, with respect to the centre of mass of the nucleus, the halo neutrons will move opposite to the electric field, while the positively charged core will move in the direction of the field.

The B(E1) distribution is a measurement of the importance of polarizability. Large B(E1) values at low excitation energies (close to the break-up threshold) indicate that the nucleus is easily polarizable. In terms of the ground state wavefunction, large B(E1) values at energies close to the break-up threshold indicate a large probability that the halo neutrons are in the extreme asymptotic tail [1, 2].

The phenomenon of dipole polarizability should strongly affect the elastic scattering of halo nuclei on heavy targets, even at energies below the Coulomb barrier, where the nuclear force should not be of importance [3, 4]. Two effects are relevant: First, Coulomb break-up will reduce the elastic cross section. Second, the distortion of the wavefunction generated by the displacement of the charged core with respect to the centre of mass of the nucleus will reduce the Coulomb repulsion, and with it the elastic cross sections.

A simple way of describing the effect of polarizability is by means of a dipole dynamic polarization potential (DDPP). It has an attractive real part, that describes the reduction of the Coulomb repulsion, and an absorptive imaginary part, which describes the reduction of the elastic cross section due to Coulomb break-up. The DDPP can be obtained using a semiclassical derivation [5], and it is such that, given the B(E1) distribution, the projectile and target and the scattering energy, it is completely determined by an analytic expression.

The DDPP has been used to describe experimental data on scattering of d+^{208}Pb [10], ^{7}Li+^{208}Pb [11], and ^{6}He+^{208}Pb [9] at energies around the Coulomb barrier. It was found that the inclusion of the DDP-potential in the calculations done using standard Coulomb and nuclear potentials accounts for the reduction observed in the experimental cross sections at a range of scattering angles, for which the nuclear potentials plays a minor role.

We have performed an experiment to measure elastic scattering and break-up of ^{6}He on ^{208}Pb [7, 8], where we were able to determine accurate values for the elastic and inclusive break-up cross sections over a wide range of angles. From the analysis of the data, we found evidence of the importance of dipole polarizability in the scattering of ^{6}He. We also found evidence for the presence of a long range absorption, which is related to break-up processes, produced both by the nuclear and the Coulomb force. We found indications that the optical potentials required to fit the data showed an energy dependence at energies around the Coulomb barrier which is consistent with dispersion relations.

We want to investigate the effects of dipole polarizability in the scattering of other weakly bound systems. ^{11}Li would be the best choice, given its break-up threshold. However, the production of ^{11}Li at REX-ISOLDE that we observed in a previous run was very small. This is due to the short half life of this nucleus. As an alternative, we consider the case of ^{11}Be. It is also weakly bound, but it has a larger life time than ^{11}Li. Besides, previous experiments at REX-ISOLDE have found intensities on the order of 10^{5} pps. This intensity is sufficient to obtain accurate measurements of a similar accuracy to our ^{6}He measurements. The choice of target ^{120}Sn is conditioned by the need of having the scattering of ^{11}Be around the Coulomb barrier of the target.

A special characteristic of ^{11}Be is the presence of a low energy $1/2^{-}$ excited state, which is strongly coupled to the ground state through E1 excitation. It will be important to resolve the ground state $1/2^+$ from the excited state $1/2^-$, and to obtain information about the probability of inelastic excitation.

We have performed preliminary calculations describing the values of the elastic, inelastic and break-up cross sections for ^{11}Be on ^{120}Sn around the Coulomb barrier. In figure 1 we present the enegy dependence of the elastic cross sections with the scattering angles, for several energies around the Coulomb barrier. This is a simple calculation where only the effect of dipole coulomb coupling to the $1/2^-$ state is included. One can see the important reduction of the elastic cross sections at forward angles. This cross section goes to the inelastic channel.

In figure 2 we present, for the energy of 30 MeV, the effect of coupling to the $1/2^-$, and to the continuum of break-up states. We present here the quasielastic cross sections, which are the sum of elastic and inelastic cross section to the $1/2^-$ state. The dashed line is the calculation using a “Cluster folding” potential, that takes into account the halo effect in the potential. The full black line is the result of the coupled channels calculation including only the $1/2^-$ state.The magenta line indicates includes also the coupling to the continuum. One can see that the effect of coupling to the continuum, which is closely associated to the dipole polarizability, predicts a sharp reduction of the cross sections in the rainbow region, which is around 60 degrees.

In figure 3 we present the excitation probability of the $1/2^-$ state, and the break-up probability of the ^{11}Be nucleus. This break-up probability, at the range of angles below 60 degrees (for which nuclear effects are not very important), is associated the B(E1) distribution to the continuum.

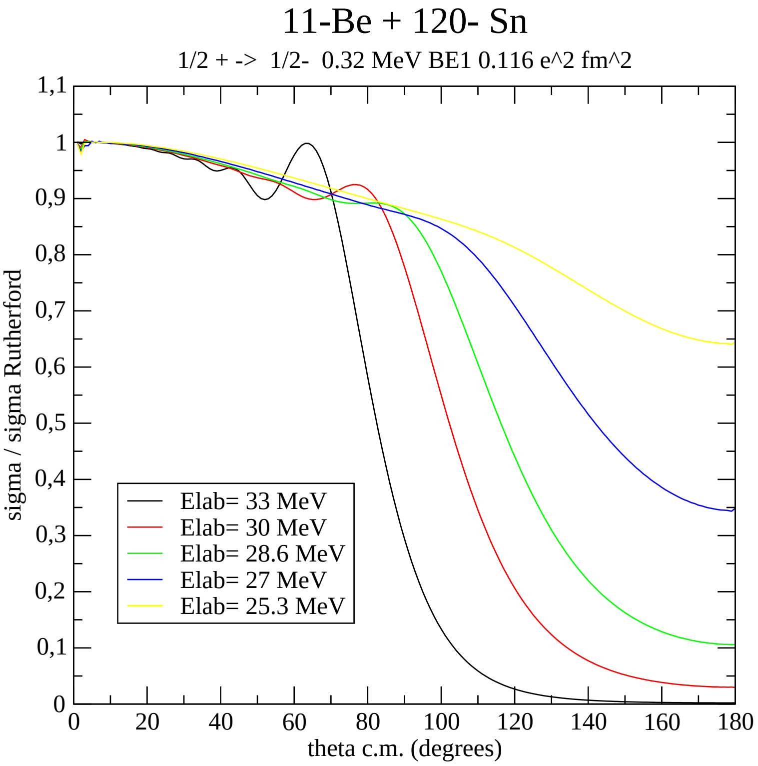

Figure 1: Quasi-elastic cross section of ^{11}Be on ^{120}Sn for several values of the energy, around the Coulomb barrier.

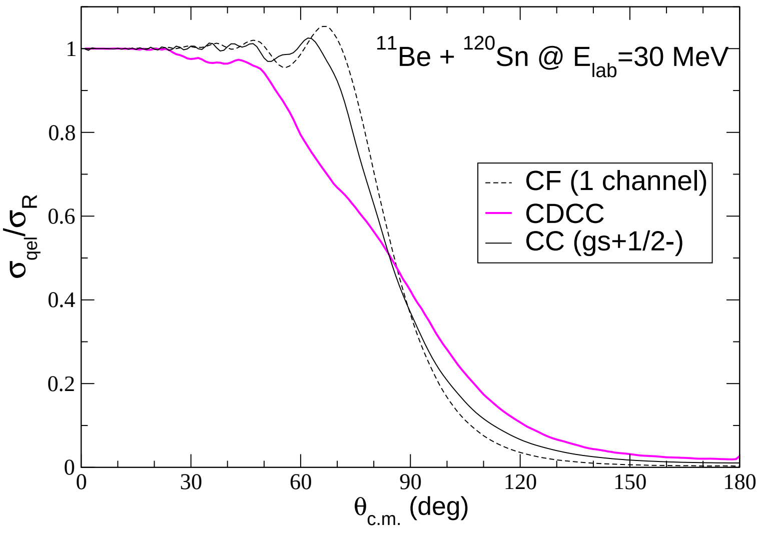

Figure 2: Quasi-elastic cross section of ^{11}Be on ^{120}Sn at 30 MeV. The effect of coupling to the bound $1/2^-$ state and to the break-up continuum is considered.

1.1 Energy dependence of ^{11}Be scattering

The range of energy between 2.2 MeV/u and 3.0 MeV/u in ^{11}Be covers a range of energies around the coulomb barrier of ^{11}Be+^{120}Sn, which can be estimated as 28 MeV. Thus, the investigation of the scattering cross sections in this range of energy allows to disentangle nuclear effects from coulomb effects. Purely coulomb effects, such as dipole polarizability, should dominate at low energies. Transfer and nuclear break-up will be more relevant at higher energies. In particular, the dipole excitation to the 1/2 state will appear as a combination of the coulomb dipole force, dominant at low energies, and the nuclear force, dominant at higher energies.

Moreover, a careful analysis of the elastic scattering might give some indication on the presence, or absence, of a sharp energy dependence of the optical potential around the coulomb barrier. This effect, which is called the threshold anomaly, is present in the scattering of most stable nuclei, and it is an open question whether it should also appear in the scattering of halo nuclei. Our analysis of the ^{6}He data [7] indicate that there is some indication of the presence of a threshold anomaly in a long range component of the potential.

1.2 Systematics of Be isotopes

It should be stressed that the strong effect of dipole polarizability in ^{11}Be scattering is a consequence of the low break-up threshold. Other Be isotopes, such as ^{9}Be, ^{10}Be, should present only minor diferences to the Rutherford cross section at energies below the barrier. A systematic study of the cross sections of Be isotopes could be illuminating. At energies well below the barrier (24 MeV), the scattering cross sections for ^{10}Be and ^{9}Be should be accurately described by the Rutherford formula, while that of ^{11}Be should display an important reduction in the cross sections at backward angles.

Besides, at higher energies, the measurement of the scattering cross sections of ^{9}Be and ^{10}Be will allow to determine the optical potentials for these nuclei, which is required for a proper understanding of the reaction mechanisms of ^{11}Be.

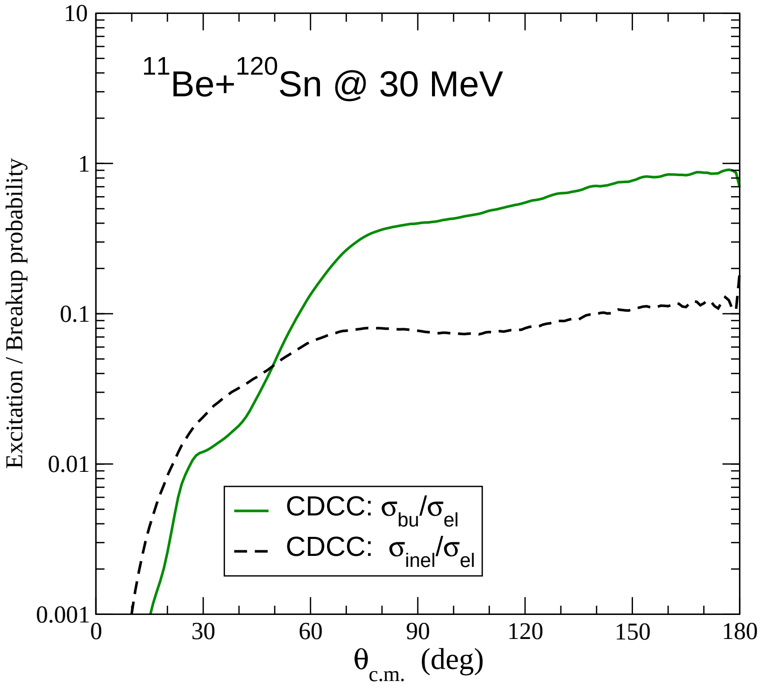

Figure 3: Excitation and break-up probability of ^{11}Be on ^{120}Sn at 30 MeV.

1.3 Inclusive break-up cross sections of ^{11}Be

The reduction in the elastic cross sections of ^{11}Be at backward angles is due to the combined effect of the real, attractive part of the polarization potential, which is caused by the reduction of the Coulomb repulsion, and the imaginary, absorptive potential, which is due to the effect of the Coulomb break-up. This latter effect can be investigated by looking at the fragments of ^{11}Be, in particular to the ^{10}Be fragments. This fragment can be differentiated from the ^{11}Be nuclei just by taking into account that they will have approximately 10/11 of the energy of ^{11}Be. Thus, the ratio of ^{10}Be to ^{11}Be events will be a complementary measurement of the effect of dipole polarizability, which depends on the imaginary part of the polarization potential, while the reduction in the elastic cross sections of ^{11}Be depends both on the real and imaginary parts of the polarization potentials.

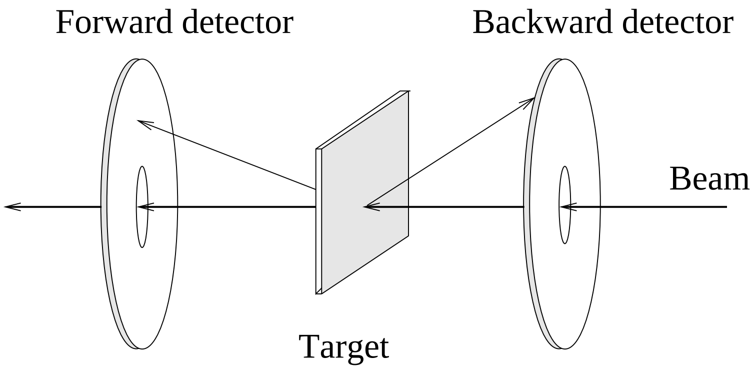

Figure 4: Schematic view of the detector setup.

	N(F)/h	N(B)/h	N(B)/strip/h
Counts (2.2 MeV/u)	$1.354 \cdot 10^6$	444	3.45
Counts (2.6 MeV/u)	$0.969 \cdot 10^6$	318	2.48
Counts (3.0 MeV/u)	$0.728 \cdot 10^6$	239	1.87

Table 1: Total number of counts expected per hour in the different detectors arrays, and per backward strip of our experimental setup, for the different energies, assuming a beam intensity of 10^5 pps.

2 Proposed experiment

The proposed experiment consists in measuring the elastic differential cross section of ^{11}Be on ^{120}Sn at energies between 2.2 and 3.0 MeV/u laboratory energy at the REX-ISOLDE facility. This will be complemented with the detection of the ^{10}Be fragments coming from break-up, and from a systematic study of the scattering of the other isotopes ^{9,10}Be at the same beam energy. We expect to detect and quantify the reduction of the differential cross sections at backward angles for ^{11}Be, compared to the Rutherford cross sections expected for the other Berillium isotopes.

The main limiting factor for this experiment is the intensity of the ^{11}Be beam. We will make the assumption that we can achieve an intensity of 10^5 ^{11}Be per second impinging on the ^{120}Sn target. This estimate is consistent with the observed production in a previous experiment. We propose to use a detector setup as shown in figure 4. It contains two CD telescopes, covering all the azimuthal angles and a range of scattering angles from θ=15^o to 65^o for the forward detector (F), and from θ=115^o to 165^o for the backward detector (B). These detectors are formed each one by 4 quadrants, which are divided into 16 strips each, which allow to get information on the scattering angle.

Uncertainties in the solid angles of the detectors could be avoided determining in the same way the ratio of forward to backward counts for an stable isotope such as ^{9}Be.

Assuming that the incident beam is pure ^{11}Be, after the collision with the target one will get elastically scattered ^{11}Be, as well as break-up fragments. Of these, the most important fragment will be ^{10}Be coming from the removal of the halo neutron. We plan to use 1.2 mg/cm^2 target of ^{120}Sn in our set-up. The expected count rate for the different detectors, at different energies, is shown in table 1. It should be noticed that this count rate includes all Be-like events: Elastic, inelastic, break-up and neutron transfer channels. We expect that, at energies below the Coulomb barrier (2.2 MeV per nucleon), most of the events will be elastic. However, at energies above the barrier (3.0 MeV per nucleon), most of the events at backward angles will be break-up events, and so the detected particles will be mainly ^{10}Be. The inelastic events leading to the $1/2^-$ state would be between 5% and 20% of the elastic events (except at very small angles). We expect to be able to separate elastic from inelastic events, which correspond to 300 keV excitation.

The number of break-up events gives complementary information to the elastic cross sections, in order to determine the break-up mechanism. The data presented in table 1 corresponds to the total number of events that would be detected in the range of angles covered by the detector arrays. However, it should be considered that the detector arrays are segmented, so that for backward angles there will be 64 strips (16 for each sector). Also, a relevant fraction of the area (about 50%) will not be covered by the active area of the strips. To take this into account, we evaluate the average number of counts per strip dividing the total number of backward angles by 128. The results are shown in table 1.

This means that, at the higher energy (3.0 MeV), we expect to have a rate of counts per hour of about 1.87 in each strip. In 9 shifts (72 hours) we would have about 130 counts, which allows to obtain an accuracy in the cross sections on the order of 10%. Also, it should be taken into account that at the higher energy, the probability of break-up is higher, and so the number of elastic events is lower. For this reason, we request more beam time at the 3.0 MeV.

It is useful to define ratios which are independent from the efficiencies and solid angles of the strips, and which only depend on the reaction mechanism. If we scatter ^{9}Be from ^{120}Sn below the barrier, we expect to find pure Rutherford scattering. Let us consider a certain strip R, which is taken as a reference. This strip is at forward angles, so the cross sections, for all the cases, are given by pure Rutherford scattering. For the other Be isotopes, we can define the following ratios, where

$$R(S,A) = \frac{N(S,A)N(R,9)}{N(R,A)N(S,9)}$$

Where $N(S,A)$ is the number of counts in an strip S, for a Be isotope with mass A and $N(R,A)$ is the number of counts at the reference strip R, for a Be isotope with mass A.

Note that in this ratio, any uncertainty associated to the solid angle, the efficiency of the detector or the intensity of the beams disappears. For the isotopes ^{10}Be, the value of this ratio should be 1, showing that the effect of dipole polarizability is small, at all scattering angles. However, for ^{11}Be, the ratio should be significantly smaller than one, and thus one will see a systematic change in the behavior of ^{11}Be with respect to the rest of the isotopes, which is yet another manifestation of the halo structure of this nucleus.

3 Goals of the Experiment

We will consider an experimental situation as previously described. We expect to achieve the following objectives:

a) To observe that, in contrast to what happens for normal nuclei, for which the elastic cross sections at energies below the barrier is accurately given by the Rutherford formula, ^{11}Be behaves differently, due to its large polarizability, and gives elastic cross sections which are considerably smaller. In particular, we will investigate the change in the elastic cross sections between ^{9}Be, ^{10}Be and ^{11}Be at the same bombarding energy (24 MeV), which is well below the barrier.

b) To investigate the dependence of the elastic, inelastic, break-up and transfer cross sections induced by ^{11}Be as the bombarding energy increases above the coulomb barrier. In this way, we will investigate the nature of the reaction mechanisms involving the collisions of halo nuclei, and learn about dipole polarizability, coulomb-nuclear interference effects, break-up effects in the elastic and inelastic scattering, and the possible presence of a threshold anomaly in the collisions induced by ^{11}Be.

4 Summary and Beam-time request

We propose to study the effect of the halo neutron in the elastic scattering, inelastic scattering, and break-up by measuring the scattering of ^{11}Be on ^{120}Sn at energies from 2.2 to 3.0 MeV/u using the REX ISOLDE Facility. Based on an expected beam intensity of 10^{5} ions/s of ^{11}Be interacting in our target, the number of shifts requested has been calculated to obtain a 10% accuracy in the cross sections at backward angles. We also need to study the other Be-isotopes, therefore we request:

- A 2.69 MeV/u beam of ^{9}Be during **3** shifts.
- A 2.42 MeV/u beam of ^{10}Be for **3** shifts.
- A 2.20 MeV/u beam of ^{11}Be^{3+} for **6** shifts.
- A 2.60 MeV/u beam of ^{11}Be for **6** shifts.
- A 3.00 MeV/u beam of ^{11}Be for **9** shifts.

We also request 3 shifts of stable beam to align and adjust our experimental setup at the end of REX-ISOLDE. The target to be used is a Ta-foil target with RILIS. Purified ^{20}Ne gas should be forseen as buffer of the ISOL trap to avoid ^{22}Ne contamination. We also request the use of the ISOLDE Data Acquisition System.

References

[1] C.A. Bertulani and A. Sustich, Phys. Rev **C46** (1992) 2340.
[2] A. Cobis, D.V. Fedorov and A.S. Jensen, Phys. Rev **C58** (1998) 2403.
[3] K. Yabana, Y. Ogawa and Y. Suzuki, Phys. Rev **C45** (1992) 2909.
[4] L.F. Canto et al., Phys. Rev **C52** (1995) R2848.
[5] M.V. Andrés, J. Gómez-Camacho and M.A.Nagarajan, Nucl. Phys. **A579** (1994) 273-284.
[6] M.V. Andrés et al., Nucl. Phys. **A612** (1997) 82-90.
[7] A. Sánchez-Benitez et al, Acta Physica Polonica **B34** (2003) 2391; J. Phys.G: Nucl. Phys **31** (2005) S1953-S1958
[8] J. Gómez-Camacho et al, AIP Conference Series **791**2005 146-153.
[9] O. Kakuee et al Nuclear Physics **A728** (2003) 339-349; Nucl. Phys **A765** (2006) 294-306.
[10] A.M. Moro and J. Gómez-Camacho, Nucl. Phys. **A648** (1999) 141-156.
[11] I. Martel et al., Nucl. Phys. **A641** (1998) 188-202.
[12] M. Zinser et al, Nucl. Phys. **A619** (1997) 151.
[13] M. V. Andrés and J. Gómez-Camacho, Phys. Rev. Lett. **82** (1999) 1387-1390.
[14] N. Keeley et al., Nucl. Phys. **A571** (1993) 326.
[15] I. Martel et al., Nucl. Phys. **A575** (1994) 412.