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Status Report to the ISOLDE-Neutron Time of flight Committee

Experiment IS444: EXPLORING HALO EFFECTS IN THE SCATTERING OF ^{11}Be ON A HEAVY TARGET AT REX-ISOLDE

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Abstract

We report on the results of the test-run of experiment IS444, performed last November 2006. We measured the scattering of ^{11}Be on ^{120}Sn at 2.91 MeV/u. The experimental results show a clear separation between quasi-elastic (^{11}Be) and break-up (^{10}Be) events, allowing the determination of quasi-elastic and break-up angular distributions at forward angles. The distinction between elastic and inelastic events in ^{11}Be was not possible.

We propose to extend the beam time in order to prove the break-up mechanism in ^{11}Be at energies close to the Coulomb barrier. We will concentrate in the angular region $15^o \leq \theta_{lab} \leq 70^o$, where cross sections are sizable and reaction effects are important. The use of a thinner target of 1.2 mg/cm^2 will improve the energy resolution of the measured channels. The accurate determination of the energy distribution of break-up events will provide unambiguous information on the break-up mechanism.

We request a total of 22 shifts of beam from a Ta-foil target with RILIS plus 3 shifts of rest gas.

1 Experimental Setup and Results

We studied the scattering of ^{11}Be on ^{120}Sn at 2.91 MeV/u. The experimental setup is shown in Fig. 1. We used an array of DSSD telescopes, with typical thicknesses of about (40 + 1500) μm, which allowed the measurement of the angular distribution of the different nuclei. During the experiment, the performance of the detection system was outstanding. More than 190 of the 198 available energy channels worked fine, setting the almost ideal conditions needed to perform a successful experiment.

Due to the low beam intensity, we used a relatively thick (3.5 mg/cm^2) ^{120}Sn target, measuring angular distributions of elastic and break-up cross sections in the angular range $15^o \leq \theta_{lab} \leq 38^o$. Under these conditions, we were not able to resolve the first excited state in ^{11}Be (320 keV). In addition, the low cross section and limited measuring time hindered the measurement at angles $\theta_{lab} > 40^o$.

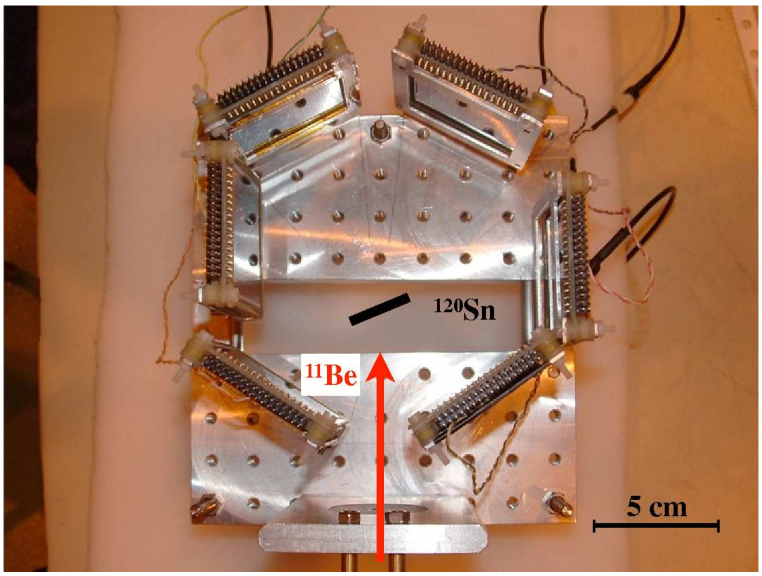

Figure 1: Photo of the experimental setup used for the test-run of experiment IS444. Six DSSDs surrounded the ^{120}Sn target, measuring the angular distribution of break-up and scattering events. The direction of the ^{11}Be beam and the position of the target during the experiment are also shown.

A typical ΔE-E particle identification plot can be seen in Fig. 2. The spectrum is the result of 22.6 h of beam time of ^{11}Be on ^{120}Sn (3.5 mg/cm^2). Despite the thick target used, the separation between scattered ^{11}Be nuclei and ^{10}Be break-up events is clearly observed and permits the evaluation of the break-up probability in the measured angular range. However, the low elastic scattering and break-up cross sections limited the

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angular distribution measurements to forward angles. The results from this analysis in the measured angular range are shown in Fig. 3, and compared to theoretical predictions.

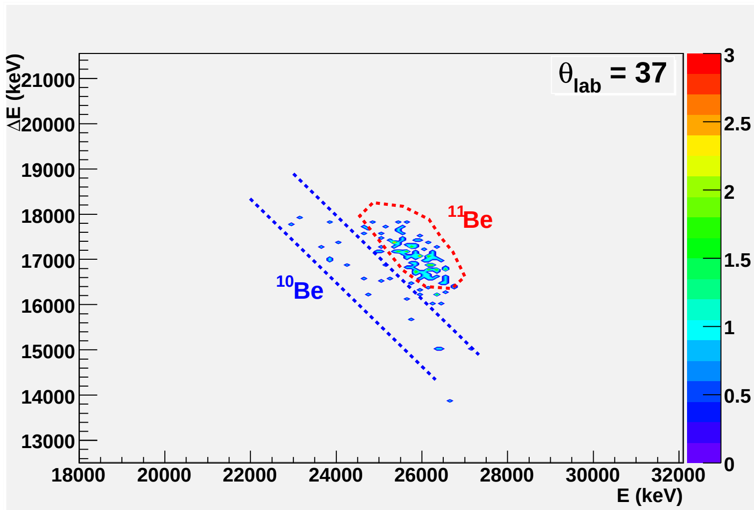

Figure 2: ΔE vs. E plot measured at $\theta_{lab} = 37^o$ (one strip). As it can be seen, it is possible to distinguish between scattered (^{11}Be) and break-up (^{10}Be) events.

During the experiment, we also measured the scattering of ^{11}Be on ^{197}Au at the same incident energy. The measured Rutherford cross sections provided useful information on the production yield. This information is used afterwards in the request of beam time (Section 5).

From the analysis of the experimental data, we can conclude the following:

- The measurement at $\theta_{lab} < 20^o$ is useful to estimate Rutherford cross sections. Break-up events are a small fraction (below 1%) in that angular range.
- ^{10}Be fragments, coming from break-up events, were measured for $\theta_{lab} > 20^o$. We find that break-up probability increases with scattering angle, in the angular range $40 > \theta_{lab} > 20^o$ (see Fig. 3).
- The target thickness of 3.5 mg/cm^2 blurs the separation between elastic and break-up events. A thinner target is desirable.
- The energy distribution of the break-up fragment could be measured. Direct break-up events, characterized by an energy distribution around 10/11 of the elastic peak, could be clearly identified. However, the disentanglement of transfer to the continuum components, in which the break-up fragments have a similar energy to the elastic peak, was difficult due to energy resolution

2 Theoretical interpretation

In this section we present the calculations to illustrate the physics that can be learnt from performing an improved scattering experiment of ^{11}Be + ^{120}Sn around the Coulomb barrier.

In order to allow a comparison with the experimental results, the calculations of elastic scattering presented here include explicitly the effect of inelastic excitation of ^{11}Be, to its $1/2^+$ excited state. In addition, the coupling to break-up states of ^{11}Be into ^{10}Be + n is considered.

In Fig. 4 we represent the effects of break-up states in the quasi-elastic scattering of ^{11}Be + ^{120}Sn at 2.91 MeV/u. It should be noticed that in the theoretical calculation, elastic and inelastic scattering are calculated, and added to generate the quasi-elastic cross sections, which then can be compared to experiment. Calculations show a strong reduction, due to the effect of coupling to the continuum, which is about 5% at 30 degrees and 20% at 60 degrees (centre of mass). Below 20 degrees, the cross section is given by the Rutherford expression, and this fact can be used for normalization.

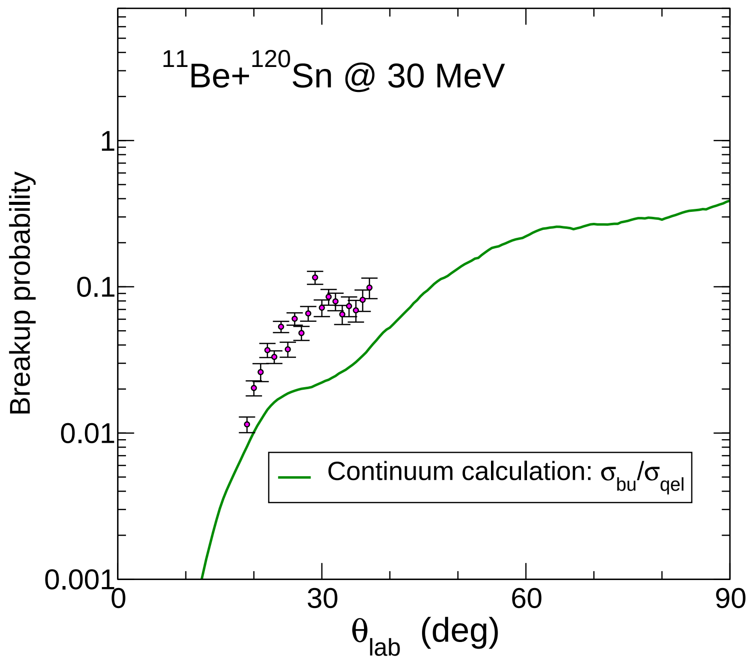

Figure 3: Break-up probability of ^{11}Be on ^{120}Sn at 2.91 MeV/u. The solid line is the result of a CDCC calculation, which includes explicitly the coupling to the continuum states in ^{11}Be. This calculation has been performed assuming an incident energy of 30 MeV, which is close to the estimated energy of the beam in the interaction point of the target. The data indicate a higher break-up probability than expected.

In Fig. 3 we present the probability of break-up, defined as the ratio of the ^{10}Be fragments to the ^{11}Be scattered nuclei, as a function of the scattering angle. Here we compare the calculations with the experimental data taken during the test-run. It should be noticed that there can be some uncertainties in the break-up probability, associated to the separation of the break-up from the quasi-elastic events. This separation should be improved in an experiment with a smaller target thickness. The data in Fig. 3 indicates that the break-up is higher than expected. This indicates that the dynamic effects of break-up may be even larger than what we have included in the calculation, and this is a further motivation to perform an improved experiment. Also, it should be taken into account that the calculations consider only "elastic" break-up, in which the ^{120}Sn target is not excited, while data may include target excitation components.

In Fig. 5 we present the energy distribution of the ^{10}Be break-up fragments, referred to the average energy of the elastic peak in each angular range [6, 7]. We expect that, within this angular range, the dominant mechanism for break-up will be the direct break-up mechanism that we have explicitly considered in the calculations. In the figure we indicate with arrows the estimated energies of the ^{10}Be fragments, using two different

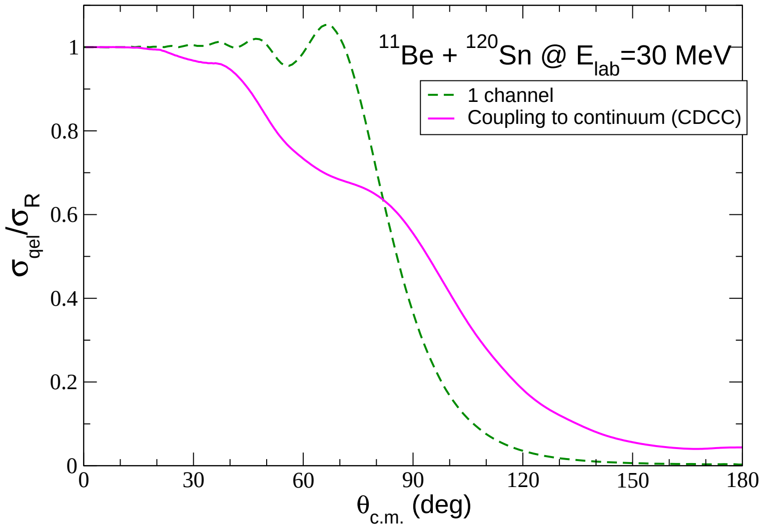

Figure 4: Quasi-elastic cross section of ^{11}Be on ^{120}Sn at 2.91 MeV/u. The effect of coupling to the bound $1/2^-$ state and to the break-up continuum are considered in the full line. The dashed line excludes the effects of coupling to continuum states.

models for the break-up process, namely, the transfer to the continuum (TC) and direct break-up (DBU) models. In the TC model, a neutron is transferred to a state just above the threshold of ^{121}Sn. The DBU model corresponds to leave ^{11}Be in an excited state just above the ^{10}Be(gs)+n threshold. Also, we show the energy of the ^{10}Be fragment (DBU*), if this is left in the 2^+ excited state. We see that a reliable measurement of the energy distribution of the ^{10}Be fragments should test our understanding of the break-up process, and it will indicate if there are evidences of core excitation.

3 Proposed experiment

We propose to complete the experiment to determine the scattering of the halo nucleus ^{11}Be on ^{120}Sn at energies around the Coulomb barrier. We will use a thinner target of 1.2 mg/cm^2, aiming to reduce the energy straggling and improve the separation of the ^{11}Be quasi-elastic events and the ^{10}Be fragments. We will optimize the angular coverage, to measure the region between 15 and 70 degrees, where Coulomb break-up and neutron transfer will dominate the reaction (see Figs. 3,4).

From the evaluation of the elastic cross sections, and the deviation from Rutherford values, we expect to see the effect of Coulomb dipole polarizability. The ratio of the ^{10}Be fragments to the ^{11}Be scattered nuclei will be measured more accurately, and this will prove our understanding of the neutron removal reaction mechanism. Finally, the energy structure of the ^{10}Be cross sections (see Fig. 5) will indicate the relative importance of the direct break-up vs. transfer to the continuum reaction mechanism, and the presence of ^{10}Be 2^+ core excitation in the ground state of ^{11}Be.

Given the intensities and the resolution that we obtained in the previous test-run, we will focus our priorities for the experiment.

The main objective is to measure elastic and break-up cross sections of ^{11}Be on ^{120}Sn. We will focus on the energy of 2.91 MeV/u, for which we have obtained feasible intensity in the test experiment.

The angular coverage will be from 15 to 70 degrees. At larger scattering angles, we

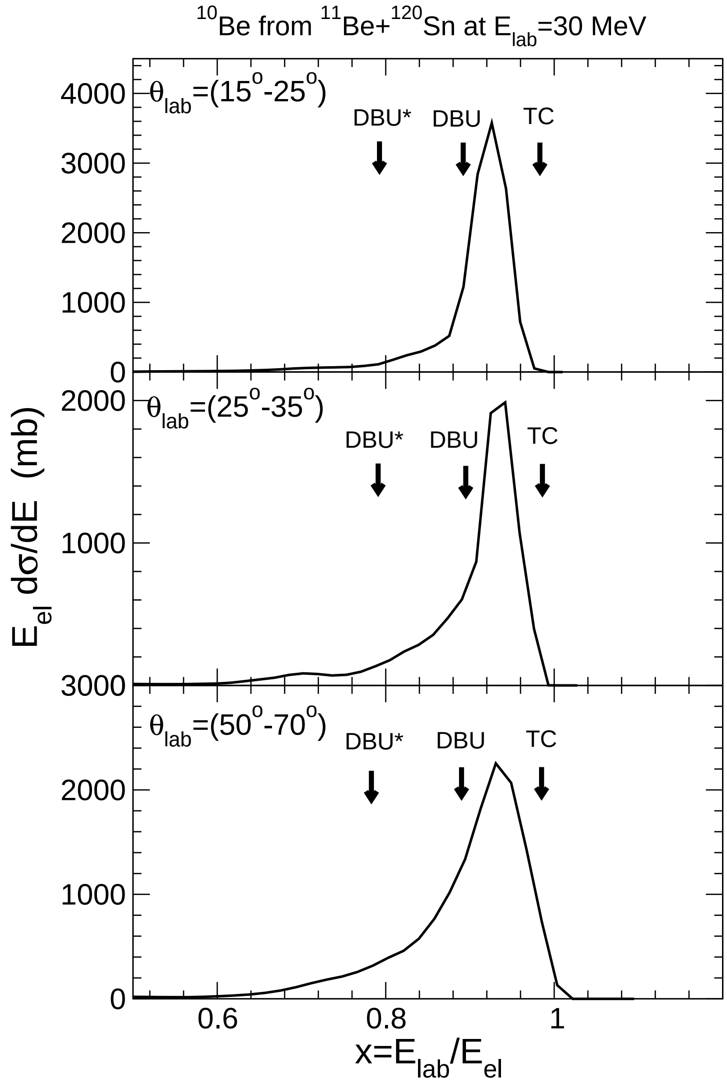

Figure 5: Energy distribution of ^{10}Be fragments coming from the scattering of ^{11}Be on ^{120}Sn at 30 MeV. See the text for details.

expect that the cross sections will be very small, and so accurate measurements of elastic or break-up cross sections will not be achieved.

For a good separation of the channels, we find that the detector thickness was at the limit due to the change of effective thickness due to the scattering angle. Thus, for the middle angular region we foresee the use of 20μm detectors, developed recently by Micron-Electronics.

Regarding the statistics (see Table 1 for an estimate of the count rates), we aim to increase substantially the number of counts obtained during the test-run. Taking into account that the target thickness has to be reduced, we will require to have about 150 hours of beam time.

In order to obtain information of the solid angles, and have a reference of the Rutherford cross sections throughout the experiment, we will use a gold target, for which we do not expect to have sizable dipole polarizability or break-up contributions. So, the number of counts on a gold target will be proportional to the Rutherford cross sections corresponding to each strip.

$N(\theta)$/h	$N(16^o$-$26^o)$/h	$N(27^o$-$37^o)$/h	$N(50^o$-$70^o)$/h
Elastic events	691	130	15
Break-up events	10.5	9.6	4.3

Table 1: Total number of counts expected per hour in the detector array per range of scattering angles θ, assuming a target thickness of 1.2 mg/cm^2 and the same intensity as in the test-run. The rates in the angular range 50^o-70^o have been extrapolated from the data using theoretical predictions.

4 Goals of the Experiment

Considering the previously described experimental situation, we aim to:

a) Observe the reduction in the elastic scattering cross sections in ^{11}Be. Due to its large dipole polarizability, cross sections should deviate from the Rutherford formula, in an angular range which, for normal nuclei, will be dominated by Coulomb forces. In particular, we will investigate the reduction in the cross sections produced around 30^o (see Fig. 4), where we expect to see reductions about 5%, which would be due to dipole polarizability. At larger angles, around 60 degrees, there will be a larger reduction associated to Coulomb and nuclear break-up [1, 2, 3, 4, 5].

b) Investigate the angular distribution of break-up cross sections, which lead to the production of ^{10}Be. These cross sections will test our understanding on the wavefunction of the halo neutron in ^{11}Be and on the interaction between this halo neutron and the superfluid ^{120}Sn target [6, 7, 8].

c) Investigate the energy distribution of the ^{10}Be fragments produced in the collision. This distribution will give information on the reaction mechanism that is relevant. Direct break-up processes will produce ^{10}Be fragments with similar velocity to the elastically scattered projectiles, which will then have a smaller kinetic energy. However, transfer to bound or weakly unbound neutron states will produce projectiles with a similar energy to the elastic peak. Also, the measurement of the fragment energy will separate the contributions of the excitation of the ^{10}Be core, which are present in the ^{11}Be g.s wavefunction.

5 Summary and Beam-time request

We propose to study the effect of the halo neutron in the quasi-elastic scattering and break-up processes by measuring the scattering of ^{11}Be on ^{120}Sn at 2.91 MeV/u using the REX ISOLDE Facility. Based on the measured ^{11}Be intensities during the previous test-run, the number of shifts requested has been calculated to obtain a sufficient number of break-up events which allow the study of the energy distribution of ^{10}Be fragments. We also need to have a reference of the stable ^{9}Be isotope, where halo effects should be much less important. 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 foreseen as buffer of the ISOL trap to avoid ^{22}Ne contamination. We also request the use of the ISOLDE Data Acquisition System.

Therefore we request:

- A suitable stable beam, such as ^{12}C, during **3** shifts.
- A 2.91 MeV/u beam of ^{9}Be (stable beam) during **3** shifts.
- A 2.91 MeV/u beam of ^{11}Be for **19** shifts.

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