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EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-Of-Flight Experiments Committee

Measurement of the ^{8}Li(α,n) ^{11}B Reaction

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Abstract

We propose to study the ^{4}He(^{8}Li,n)^{11}B reaction in the energy range of 1 MeV < E_{cm} < 7 MeV using ^{8}Li beams at REX-ISOLDE. These data should clarify the poorly known cross section for this reaction, which is important for the inhomogeneous big bang model (IBBM). We request (12 + 3) shifts of ^{8}Li from REX-ISOLDE with energies from 0.3 to 2.2 MeV/u, depending on the beam characteristics and quality at the time of the experiment.

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I. Introduction

The predicted abundances for light nuclei up to ^4He in the Inhomogeneous Big Bang Model (IBBM) [1,2] are similar to those predicted by the Standard (homogeneous) Big Bang Model (SBBM) [3]. However, the IBBM model predicts a considerably larger production of ^7Li, ^9Be, ^{11}B and heavier nuclei, with ^{11}B and the $^8Li(\alpha,n)^{11}B$ reaction serving as the dominant gateway, and thus making the cross section measurement for the $^8Li(\alpha,n)^{11}B$ reaction critical for a test of the IBBM.

II. Previous Measurements

Several measurements [4-7] of the $^8Li(\alpha,n)^{11}B$ reaction were reported in the literature. They are summarized in Mizoi *et al*. and reproduced in Fig. 1. The following can be observed from the data: a) there are disagreements between some measurements, b) errors are large and c) there is scarcity in the low energy data below 0.5 MeV. The data also present inconsistencies with the theoretical calculations of Descouvemont *et al*. [8]. This strongly suggests a need for new and more accurate measurements as we propose here.

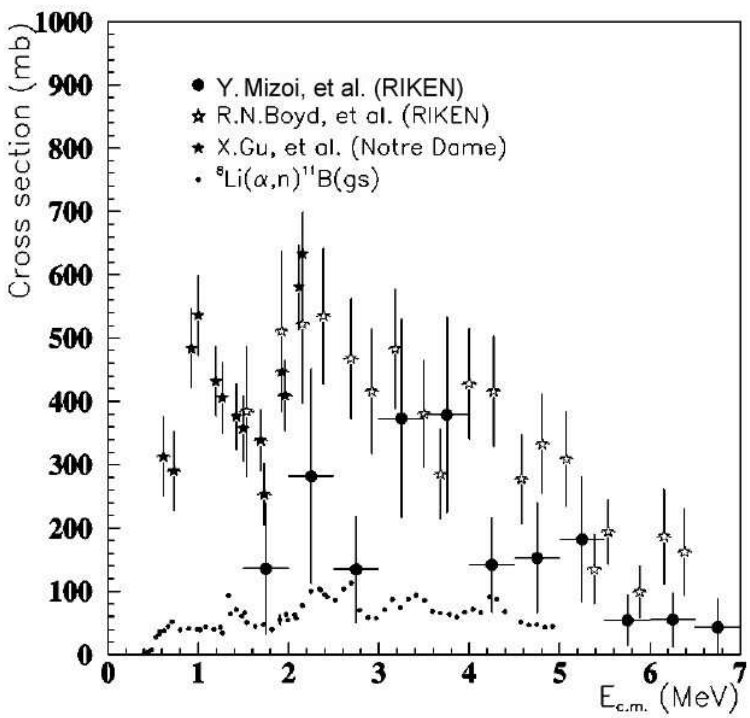

Figure 1. Experimental data available in the literature from Refs. [4-7].

The experiment carried out by Paradellis *et al*. involved the inverse reaction, where neutrons impinged on ^{11}B in its ground state and the reaction events were measured by detecting ^8Li nuclei through alpha activity. It was carried out in the range of E_{cm} = 0.4 to 4.9 MeV with an uncertainty in energy of ±0.2 MeV, as no energy degradation was involved. It may be noted from the data (labeled with 'gs') in Fig. 1 that this experiment measured the cross section involving only the ^{11}B ground state. Following this, three measurements of the direct reaction were performed by Boyd *et al.*, Gu *et al.* and Mizoi *et al.* spanning from E_{cm} = 0.6 to 7.0 MeV with beam intensities of approximately 10^3/s. All allowed excited states of ^{11}B contributed to the cross section in these measurements, resulting in the total reaction cross sections, unlike the Paradellis *et al.* data. The data of Boyd *et al.* and Gu *et al.* involve a large uncertainty in the energy definition of the ^{8}Li beam (up to 1.5 MeV) due to the energy degradation from 45 to 2 MeV/u. Cross sections were obtained by detecting only the ^{11}B in Boyd *et al.* and Gu *et al.* data, whereas Mizoi *et al.* also detected the neutrons with approximately 20% efficiency.

We propose to minimize the experimental errors in a direct reaction measurement with: a) higher beam intensities (10^6/s), b) good energy definition of ^{8}Li by avoiding energy degradation of beams and c) neutron detection with large efficiency. In the current proposal we concentrate on the energy range available at REX-ISOLDE and studied by the previous groups.

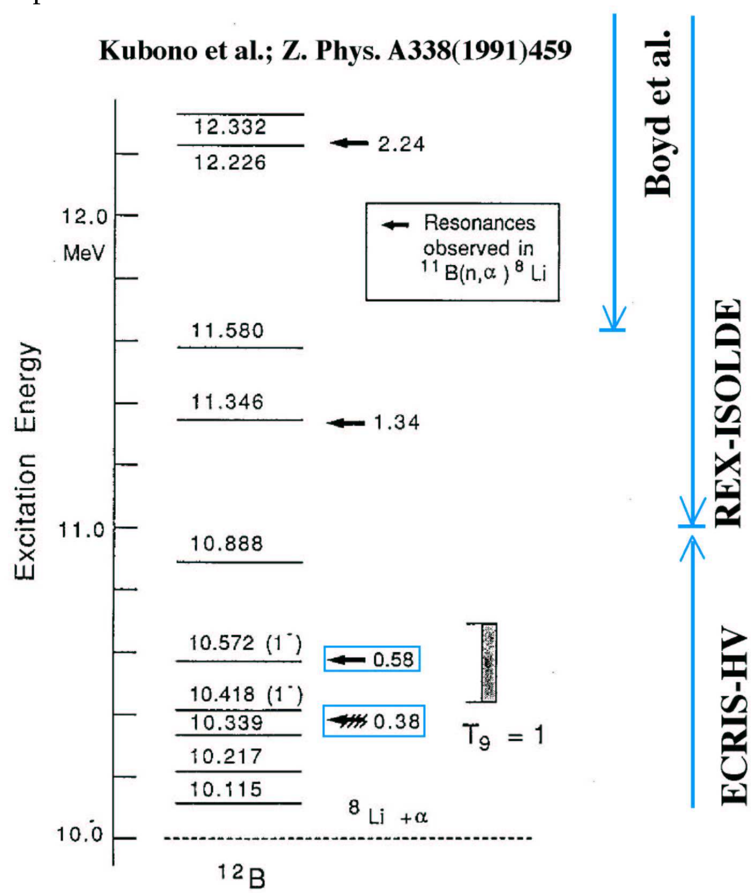

Figure 2. States in ^{12}B of relevance for the study of the $^{8}Li(\alpha,n)^{11}B$ reaction.

In Fig. 2 we show the spectroscopy of ^{12}B and the states that are in the region of interest for cosmological (and stellar) environment(s) at temperatures of approximately 1 GK [9]. It is clear that the data thus far available as well as the data that we propose to collect using REX-ISOLDE are just at the upper end of the region of interest for nuclear astrophysics. A complete study of this reaction requires experiments at even lower energies at approximately 50-150 keV/u. Upon completion of the REX-ISOLDE phase we propose in the future to extend this measurement to yet lower energies by using a new setup with the ECRIS ion source coupled to a high voltage platform (ECRIS-HV setup) as already discussed in our previous letter of intent to INTC [10] and expanded at the end of this proposal.

III. The Proposed Experiment

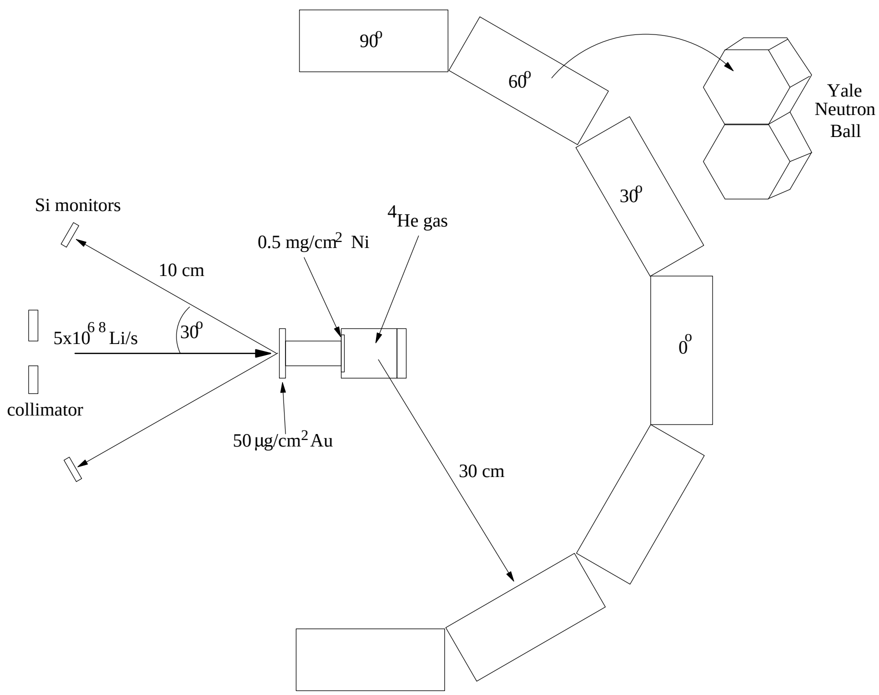

Figure 3. The proposed experimental setup.

The proposed experimental procedure is shown in Fig. 3. The beam flux will be measured by scattering the beam off a thin (50 μg/cm^2) gold foil. Scattered ^{8}Li projectiles will be observed by two silicon surface barrier detectors situated at 150 degrees and 10 cm from the scattering target. The beam will enter a 3 cm long helium gas cell through a 0.5 mg/cm^2 Ni foil, and stop in the cell's thick exit foil. The pressure inside the gas cell will be maintained at 100 torr, creating a target of 10^{19} He/cm^2. Neutrons from the ^{8}Li(α,n)^{11}B reaction will be detected in 14 neutron detectors, 30 cm away from the gas cell.

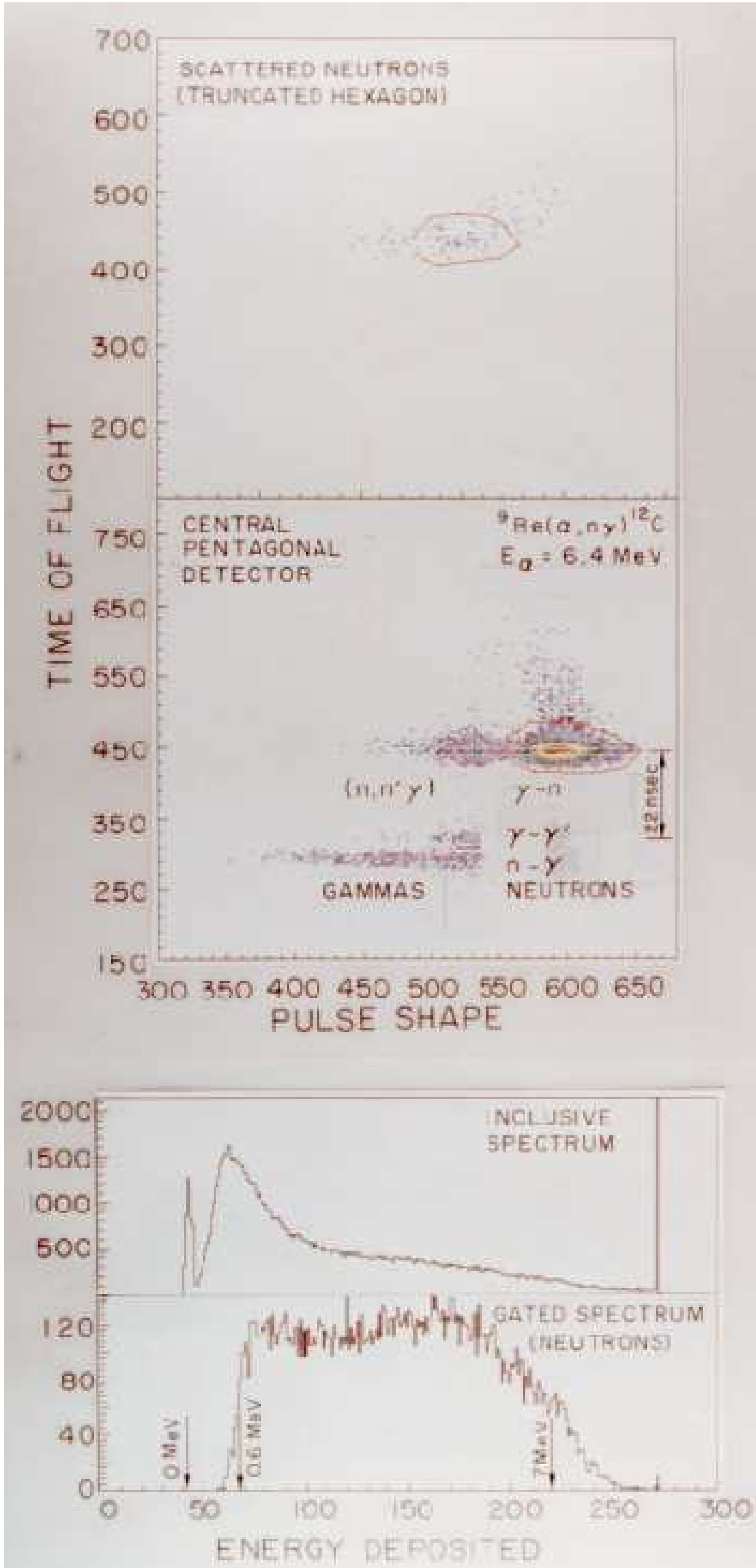

Figure 4. Neutron detector performance.

The large available beam current ($5x10^6$ $^8Li/s$) assures, for the proposed experiment, a luminosity of $5x10^{25}$ $s^{-1}cm^{-2}$. A cross section of 100-500 mb yields a neutron production rate of 5-25 Hz. The seven pairs of neutron detectors cover 20% of 4π solid angle, and have an intrinsic efficiency of approximately 25%. The resulting count rate is 500 counts/hour per 100 mb. Requiring 2-4 hours for data taking with a few percent (1-3%) statistical uncertainty and 3 hours to change the beam energy, each data point will require 5-7 hours, which means approximately 42 hours for 7 energies.

Neutron detection will be performed using the existing Yale Neutron Ball array of liquid scintillators. We will employ Pulse Shape Discrimination (PSD) and Time-Of-Flight (TOF) for removing gamma background. Sample spectra from the neutron detectors that will be used may be seen in Fig. 4, which shows their excellent TOF and PSD characteristics. With these cuts, we expect the background in the proposed work to be very low.

IV. Beam Time Request

In view of the above, and taking into account the possibility of a lower ^8Li rate than the stated $5x10^6$ $^8Li/s$ due to potential limitation of the trap and other factors, we request 12 shifts for this run, including setup time. In order to calibrate accurately the entire experimental setup, it will be desirable to measure reactions with a known cross section using stable beams. Two such examples are the $^9Be(\alpha,n)^{12}C$ and the $^{22}Ne(\alpha,n)^{25}Mg$ reactions. To do so will require the laser ion source for ^9Be, but ^{22}Ne will most likely be copiously produced in any source. We request 3 more shifts for this purpose.

TOTAL REQUESTED SHIFTS = (12+3) SHIFTS.

Upon submission of this proposal we learned that a similar proposal has been discussed by the TRIUMF-PAC at its meeting in December, 2002. No technical details are available at this time.

V. Future Experiments

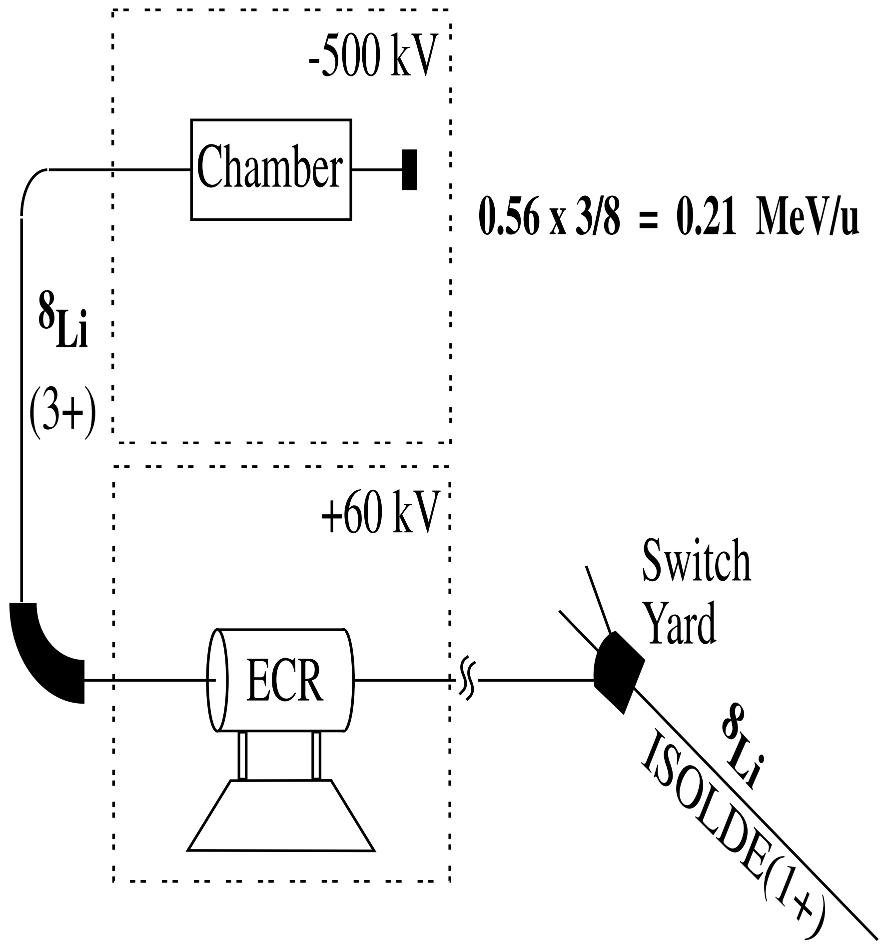

Figure 5. The proposed ECRIS-HV platform setup [10].

As we discuss above, a complete study of the $^{8}Li(\alpha,n)^{11}B$ reaction cross section must extend to lower energies so as to probe the energy region of interest for nuclear astrophysics with accelerated ^{8}Li beams in the energy range of 50-150 keV/u. While there is a need for measurements at such low energies, no adequate facility exists so far anywhere in the world to address such problems. In addition to $^{8}Li(\alpha,n)^{11}B$ proposed here, such a setup will facilitate the study of other reactions of interest in nuclear astrophysics. As suggested in our 2001 letter of intent to the INTC [10], there is a strong need to measure the $^{7}Be(p,\gamma)^{8}B$ reaction at very low energies. The motivation for this experiment has recently become even stronger with new data that has been reported by the WI [11] and by the GSI2 group [12], where the standard extrapolation to low energies of the astrophysical cross section factor, $S_{17}(0)$, is revisited.

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