EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Search for higher excited states of ^{8}Be* to study the cosmological ^{7}Li problem

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Abstract: We would like to study the unresolved ^{7}Li abundance anomaly by carrying out experiments that destroy the rare isotope ^{7}Be, the main source of ^{7}Li. Utilizing a 35 MeV ^{7}Be beam from HIE-ISOLDE, we would like to measure the (d,p) and (d,d) reactions with T-REX. The higher beam energy, for the first time, would allow us to measure higher excitation energies in ^{8}Be up to about 20 MeV. With a wider angular coverage, we can make improved average cross-section measurement without assuming isotropy done in earlier works.

Requested shifts: [18] shifts
Beamline: MINIBALL + T-REX

1 Introduction

The basic details of big bang nucleosynthesis (BBN) are well explained decades ago [1]. Nucleosynthesis predictions are in good agreement with the abundances of ^{2}H, ^{3}He and ^{4}He observed in metal-poor environments. However, the abundance of ^{7}Li has been a long-standing problem. Recent observations of metal-poor halo stars and the high precision measurement of the baryon-to-photon ratio of the Universe by WMAP demands a deeper thought on the ^{7}Li abundance anomaly. The predicted abundance is higher by a factor of 3 than that observed in metal-poor halo stars. In a related work, the ^{6}Li abundance also poses a 2-3 order of magnitude discrepancy between theory and experiment [1]. The lithium and beryllium isotopes indeed play crucial roles in BBN. There has been some efforts to explore a purely nuclear physics solution to the ^{7}Li problem [2, 3, 4].

To explain the discrepancy in ^{7}Li yield, one possible nuclear physics solution is that if ^{7}Be is destroyed more quickly in the early universe than was previously thought, less would be available to decay to ^{7}Li, reducing the predicted BBN abundance [5]. It has been proposed that a resonant enhancement of the ^{7}Be(d,p)2α or ^{7}Be(d,γ) reaction could resolve the cosmological lithium problem [3]. However, an experiment [2] carried out using the ^{7}Be(d,p)2α reaction found no enhancement of the rate compared to prior calculations and earlier work [6]. In that experiment, using a 5.8 MeV ^{7}Be beam, measurements of the ^{7}Be(d,p)2α cross section up to excitation energies in ^{8}Be of E_x = 13.8 MeV was carried out. In addition to the reactions through the ground and first excited state of ^{8}Be, reactions via the broad 4^{+} state at an excitation energy of 11.4 MeV in ^{8}Be was also observed. The results show that the higher energy states of ^{8}Be that were not observed in [6] contribute about 35% of the total astrophysical S-factor instead of the 300% estimated in [7]. It was pointed out in [2] that the ^{7}Be(d,p)^{8}Be reaction rate is smaller by a factor of about 2 at energies in the range 1.0-1.23 MeV and by about 10 at energies relevant to BBN, than previously estimated.

2 Proposed Experiment

It is apparent at present that solutions to the cosmological ^{7}Li problem is indeed a challenging issue. Measurements of the relevant nuclear reaction rates at the upcoming HIE-ISOLDE facility offering higher beam energies and intensity of the rare isotope beam ^{7}Be needs to be studied before physics beyond the standard BBN model is considered. In the earlier work [2], though at low beam energy of 5.55 MeV, high Q-value of the reaction ^{7}Be(d,p)^{8}Be of 16.49 MeV permitted the reaction to occur through several higher excited states of ^{8}Be. However, because of the Coulomb barrier in the final state, their contributions were expected to be negligible. At a lower energy of 1.71 MeV only about 50% of the contribution of the 4^{+} broad state was observed.

We would like to utilize ^{7}Be beam from HIE-ISOLDE at an energy of 5 MeV/A to study the higher excitation energies in ^{8}Be up to about E_x = 20 MeV. This would allow us to study the ^{7}Be(d,p)2α reaction rate in greater detail. Because of the Coulomb barrier, the contributions of the higher states were negligible in earlier experiments performed at lower energies. In those measurements, only a small angular range was covered (θ_{lab} = 7.6^o-17.4^o) and full isotropy was assumed in calculating the average cross section. The proposed experiment at a much higher energy of 35 MeV and covering an angular range of at least 5^o- 50^o for higher excitation energies would enable us to measure the ^{7}Be destruction cross-section with better accuracy. The study may also throw light on interesting breakup channels of ^{8}Be into ^{7}Li + p and ^{6}Li + d at E_x = 17.2 and 22.3 MeV respectively in the context of the ^{7}Li abundance anomaly. The proposed experiment would also search for a resonance at 16.7 MeV in ^{9}B through the ^{7}Be(d,d) reaction. The previous work [4] utilizing a 10 MeV ^{7}Be beam did not observe such a resonance.

3 Implementation

The proposed experiment would like to use the T-REX [8] to measures the (d,p) and (d,d) reactions with the rare isotope beam ^{7}Be. We would like to use a CD_2 target and a 35 MeV ^{7}Be beam of about 10^8 particles per second. We plan to observe the ^{7}Be + d reaction via kinematically allowed higher energy levels up to about E_x= 20 MeV in addition to the already observed 3.04 (2^+) and 11.4 (4^+) excited states in ^{8}Be, at lower beam energies [2, 6]. With a total estimated cross section of 500 mb, beam intensity of 10^8 pps, CD_2 target thickness of 1 mg/cm^2, we can expect a count rate of the order of 1000/sec.

For zero excitation energy in the (d,p) reaction the protons would have energies in the range of 20-40 MeV that would not stop in CD (ΔE= 500 μm, E = 1.5 mm) as well as forward barrel (ΔE= 140 μm, E = 1 mm) detectors of T-REX. For the decay of ^{8}Be through higher excited states of about E_x= 20 MeV, the protons would be emitted at 4-14 MeV in the angular range of 5^o - 50^o. The 4-10 MeV protons can be detected only in barrel while 10-14 MeV protons can be detected both in CD as well as in barrel. The corresponding α-particles would completely stop in ΔE detectors of T-REX. For zero excitation in ^{7}Be, the deuterons would be emitted at 5-25 MeV in the angular range of 5^o - 60^o that would allow determination of optical model parameters for DWBA calculations. A 5 MeV excitation in ^{7}Be would correspond to 5-15 MeV deuterons. The 5-10 MeV deuterons can be detected only in barrel while 10-15 MeV deuterons can be detected both in CD as well as in barrel. The 15-25 MeV deuterons can be detected only in CD. The kinematics plot is depicted in figure 1. The energy resolution of T-REX [8] would be sufficient for particle identification in this experiment. The energy loss in various detectors for different angles are shown in figure 2. Typical energy loss of the ^{7}Be beam in the CD_2 target would be about 1 MeV.

The excitation energies of the populated states of interest can be reconstructed from deposited energies in various detectors for stopping particles. For particles that punch through, a model dependent analysis can be carried out to reconstruct energies. The breakup of ^{8}Be into two alpha particles that stop in the ΔE detectors of T-REX, can be identified by using a multiplicity trigger.

At ISOLDE, ^{7}Be is produced with very high yields and even with a modest charge breeding efficiency 2-3% we should get plenty of beam at the end of the linac. Energy should be well above 5.5 MeV/A for this A/q. Concerning contaminations of the beam, both ^{14}N and ^{21}Ne can be suppressed completely by selecting $^{7}Be^{4+}$ after a stripping foil inserted at the end of the linac ($^{7}Be^{3+}$ being accelerated up to the stripper foil).

As the halflife is long we will not reach saturation for the radiation level during the run. There are no restriction from a radiation protection point of view. If (for example) we take 10^{8} pps for 3 x 8 h shifts we will end up with $\sim 9\text{x}10^{12}$ ions collected which lead to an activity of 0.2 MBq. Regarding the radiological hazards of radioactive nuclei produced at ISOLDE, the activity we need for our experiment is only a very small fraction of the authorization limit LA (very small internal exposure risk). The hazard related to external exposure, assessed via the h10 quantity which for ^{7}Be = 0.008 (mSv/h)/GBq at 1 m quantity which give the dose rate at 1 m per GBq of activity.

Summary of requested shifts: 15 shifts of beam on target, 3 shifts for beam preparation and calibrations. Installation: [MINIBALL + T-REX]

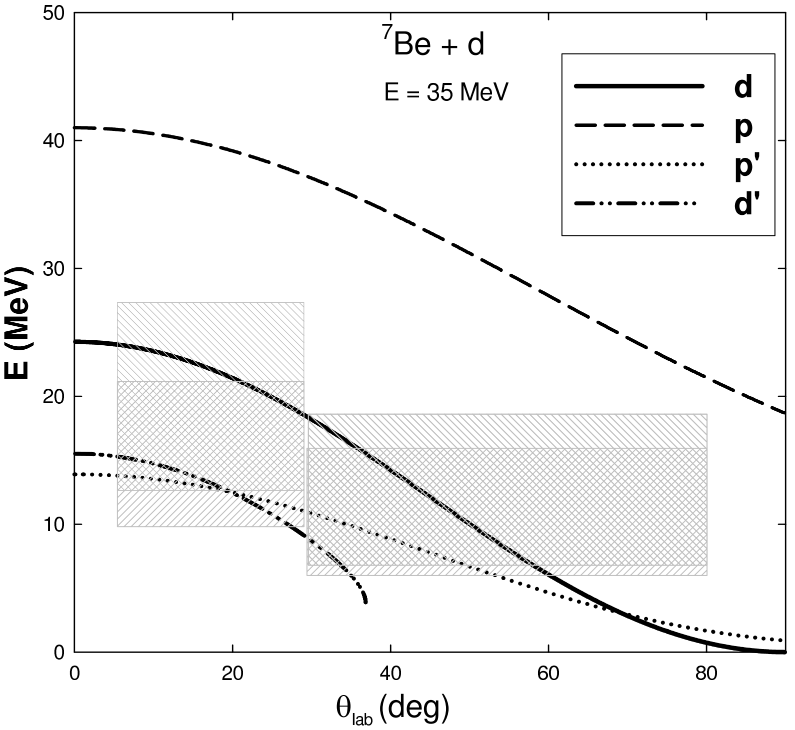

Figure 1: Kinematics of the ^{7}Be(d,d), ^{7}Be(d,p) reactions for ground state (d) (p), excitation of 20 MeV (p'), 5 MeV (d') respectively. The forward hashed (backward hashed) areas cover the detected p (d) energies and angles in CD and barrel detectors of T-REX.

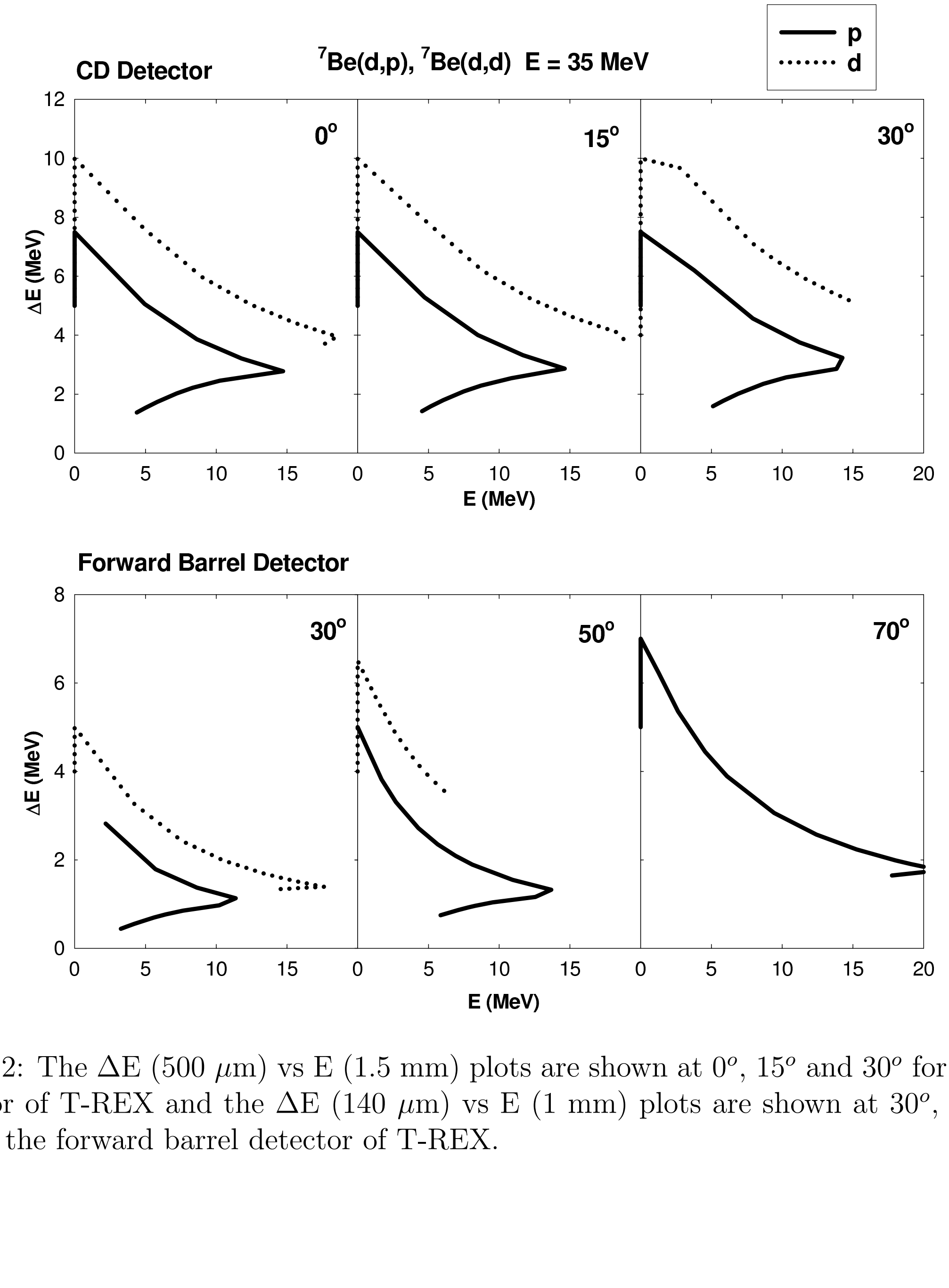

Figure 2: The ΔE (500 μm) vs E (1.5 mm) plots are shown at 0^o, 15^o and 30^o for the CD detector of T-REX and the ΔE (140 μm) vs E (1 mm) plots are shown at 30^o, 50^o and 70^o for the forward barrel detector of T-REX.

References

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Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT
The experimental setup comprises:

Part of the	Availability	Design and manufacturing
MINIBALL + T-REX	☒ Existing	☒ To be used without any modification

HAZARDS GENERATED BY THE EXPERIMENT
Hazards named in the document relevant for the fixed MINIBALL + T-REX installation.

Additional hazards: none