Search for ^{6}He+^{4}He Clustering in ^{10}Be

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1 Abstract

Two ^{7}Li induced reactions, namely 2–proton pick–up using a ^{12}C target and triton transfer with a ^{7}Li target, will be used to populate unbound states in ^{10}Be. A search will be made for states that possess a large overlap with a ^{6}He+^{4}He cluster configuration by observing their decays to this final state. By measuring the complete kinematics of the reactions the excitation energies and spins of the ^{10}Be states with this cluster configuration can be determined, as well as any excitations in the daughter nuclei.

These measurements form part of the CHARISSA collaboration's program to study neutron and proton rich light ions ($^{10\rightarrow 14}$Be, ^{8,9}B, ^{10}C, and ^{17}Ne), and compliment work with radioactive beams being carried out by the collaboration at GANIL.

The data from this experiment will form part of a Ph.D. thesis at York.

2 Introduction

There has been much recent experimental and theoretical interest in the neutron rich beryllium isotopes [1–9]. In three previous measurements we have studied the neutron decay of the halo nucleus ^{11}Be [3] at the Australian National University (ANU), and the symmetric fission of ^{12}Be [4] and the ground state breakup of ^{14}Be [7] at GANIL. These experiments successfully used the resonant particle spectroscopy (RPS) technique [10], developed in our studies of exotic clustering in light alpha–conjugate nuclei [11]. Using this technique the cluster states of interest are investigated by the coincident detection of the cluster fragments after breakup. The current CHARISSA experimental set–up at the VIVITRON was specifically designed for such measurements.

Although the extremes of neutron richness are impossible to reach using stable beam and target combinations, it is possible to access the first three nuclei in the isotopic sequence, namely ^{9}Be, ^{10}Be and ^{11}Be. This present proposal concentrates on the ^{10}Be nucleus. This nucleus and other light nuclei with a ^{8}Be core can be studied within the framework of the two–centre shell model [12] because the underlying $\alpha+\alpha$

cluster structure of the ^{8}Be nucleus has an important impact on the addition of nucleons to the core. A series of four states near 6MeV in ^{10}Be (see figure 1) have been described in terms of configurations of nucleons in two–centre orbits [9]. Possible decay modes of these states are ^{6}He+^{4}He, ^{9}Be+n and ^{8}Be+2n.

Recent measurement of the ^{7}Li(^{7}Li,^{4}He)^{10}Be* reaction by Soić *et al.* [8] indicate that ^{10}Be states at 9.6 and 10.2MeV decay by ^{6}He emission. The state at 10.2MeV is close to the energy predicted for the 4^{+} member of a rotational band, with the band head at 6.18MeV (0^{+}) and the 2^{+} state at 7.54MeV (figure 1). The small energy separation between states implies a large moment of inertia, *ie.* a very extended nuclear system. However, the spins of the 9.6 and 10.2MeV states observed by Soić are unknown and information on the widths of the states was limited by the detector resolution.

Using large area, multi–strip silicon detectors backed by CsI scintillators the efficiency and angular coverage for measuring the ^{6}He+^{4}He and ^{9}Be+n breakup channels for the proposed experiment will be two orders of magnitude larger than in the experiment of Soić, permitting the measurement of spins using angular correlation techniques [13]. The strip detectors also possess a much better position resolution than that quoted by Soić and have excellent energy resolution down to a few MeV – and thus will give a much improved excitation energy resolution.

3 Experimental Method

Two reactions will be employed to study the cluster breakup of ^{10}Be. The ^{12}C(^{7}Li,^{9}B)^{6}He+^{4}He reaction (Q=–17.52MeV) has not previously been studied, whereas an incomplete study of the ^{7}Li(^{7}Li,^{4}He)^{6}He+^{4}He reaction (Q=+7.37MeV) has been made by Soić *et al* [8] but with poor resolution and detection efficiency. Both reactions will use a beam energy of 70MeV.

3.1 The ^{12}C(^{7}Li,^{9}B)^{6}He+^{4}He Reaction

A schematic of the experimental set–up for this reaction is shown in figure 2a. The ^{9}B ejectile is particle unstable and fragments sequentially to ^{8}Be+p and finally $\alpha+\alpha$+p. Complete measurement of the reaction kinematics can be achieved by recording four of the five final state particles. The missing momentum can be used to reconstruct the properties of the fifth unobserved particle. All three ^{9}B fragments will be recorded in two 16–strip position–sensitive silicon detectors (PSSDs). The PSSDs are backed by CsI scintillators to record and identify protons passing through the silicon. Although there will be no specific particle identification for particles stopping in the silicon, decays from the ground state of ^{8}Be can be identified as a sharp peak at 93keV in a plot of the relative energy of two–fold hits in the PSSDs (an example relative energy spectrum is shown in figure 3).

On the other side of the beam an arrangement of two PSSDs will record the ^{4}He or ^{6}He from breakup of the ^{10}Be nucleus. There is no identification for these particles since they are too low in energy, however, by assuming in turn that the recorded particle is ^{6}He then ^{4}He the Q–value and relative energy between the ^{6}He and ^{4}He can be determined. Only when the particle is correctly identified will the Q–value equal –17.52MeV and the relative energy reveal the states in ^{10}Be from which the decay occurred. In addition to the ^{6}He+^{4}He decay the ^{9}Be+n decay channel is also accessible with the same detection arrangement.

The experiment will be performed using the CHARISSA beam–line, scattering chamber and data acquisition system. The target will be self–supporting ^{12}C.

Calibration of the detection elements using ^{7}Li ions elastically scattered from ^{12}C and ^{197}Au targets will require two different beam energies. A 40MeV ^{7}Li beam will be used to calibrate the four PSSDs in the energy regime of the reaction products. A higher ^{7}Li beam energy of 70MeV is required so that ^{7}Li particles are produced with sufficient energy to pass through to the two CsI detectors. A total of 14 shifts of calibration and reaction beam–time is requested. A further 1 shift for beam focusing, and 1 shift for re–calibration after the experiment is also required. The request is summarised in table 1. Prior to the measurements we will require at least two days access to the experimental area for preparations.

3.2 The ^{7}Li(^{7}Li,^{4}He)^{6}He+^{4}He Reaction

The experimental set–up for the second reaction study is somewhat simpler due to a fewer number of final state particles. This reaction cannot be identified easily on the basis of the kinematics alone, as in the previous reaction, therefore, in this case particle identification will be made explicitly on both sides of the beam. The detector arrangement is shown schematically in figure 2b.

The ^{4}He ejectile will emerge with enough energy to pass through the PSSD and into the CsI stopping detector behind to give a full angle, energy, charge and mass measurement. Again, one or other of the ^{10}Be breakup fragments will be detected on the other side of the beam. Particle identification in this case will be achieved by the use of a gas filled passing detector placed in front of the PSSD. Again the ^{9}Be+n decay channel can be recorded simultaneously and easily separated from the ^{6}He+^{4}He channel.

Competition from the reaction ^{7}Li(^{7}Li,^{8}Be$\rightarrow \alpha + \alpha$)^{6}He, which gives rise to the same final state particles as the reaction of interest, can be eliminated by plotting the relative energies between the three different combinations of final particles. A two–dimensional plot of two of these relative energies will reveal loci corresponding to the excited states of interest in ^{10}Be or states in the contaminant ^{8}Be which can then be gated out, for a more in–depth review of this technique see, for example, references [8, 14].

The coincidence requirement of one hit on either side of the beam that will be made in the data acquisition system is not susceptible to the coincident detection of elastically scattered ^{7}Li particles since the angular placement of the detectors precludes measurement of both ^{7}Li elastics ejectile and recoil simultaneously.

This experiment will use the same equipment and beam as the previous experiment. A LiF target will be used. Only calibration of the gas detector is required, this can be achieved using a 70MeV ^{7}Li beam scattered of targets of ^{12}C and ^{197}Au. A total of 10 shifts of beam–time is requested for the breakup measurement, with an additional 2 shifts at the end of the experiment for re–calibration. A summary of the beam–time request is made in table 1.

4 Beam–time Request Summary

A summary of the time required to carry out the proposed measurements is given in table 1. Ideally the measurements should run back to back with only a twelve hour break to allow the rearrangement of the detector layout.

Measurement	Beam	Energy (MeV)	Target	Shifts
Ion source + focusing	^{7}Li	$\sim$30$\rightarrow$40 + 70	none	1
Calibrations	"	"	^{12}C, ^{197}Au	3
^{10}Be breakup ^{12}C(^{7}Li,^{9}B)^{6}He+^{4}He	"	70	^{12}C	10
Re–calibration	"	"	^{12}C, ^{197}Au	1
^{10}Be breakup ^{7}Li(^{7}Li,^{4}He)^{6}He+^{4}He	"	"	LiF	10
Re–calibration	"	$\sim$30$\rightarrow$40 + 70	^{12}C, ^{197}Au	2
TOTAL				27

Table 1: Summary of requested beam–time.

References

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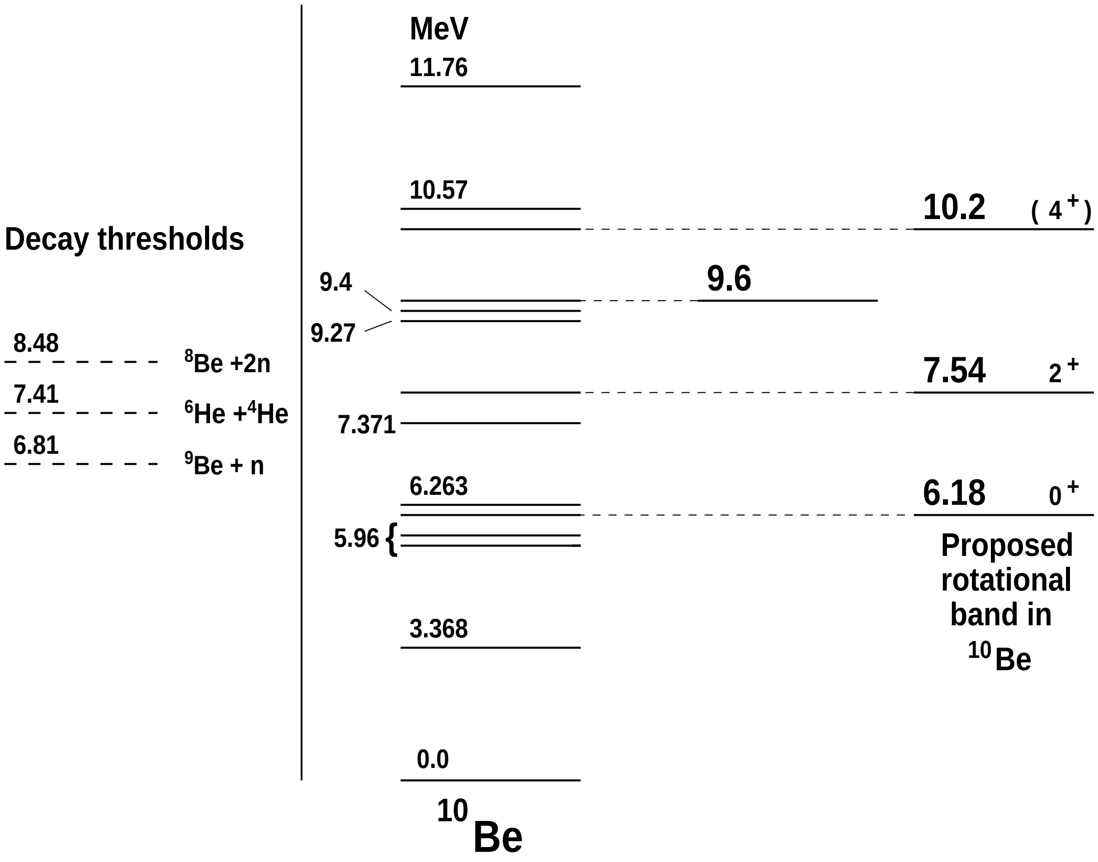

Figure 1: Energy level scheme for ^{10}Be (taken from reference [15]), showing the threshold energies for the various decay channels on the left, and on the right the rotational band with a ^{6}He–^{4}He structure proposed by Soić *et al.* [8]. The states at 9.6 and 10.2MeV are from [8].

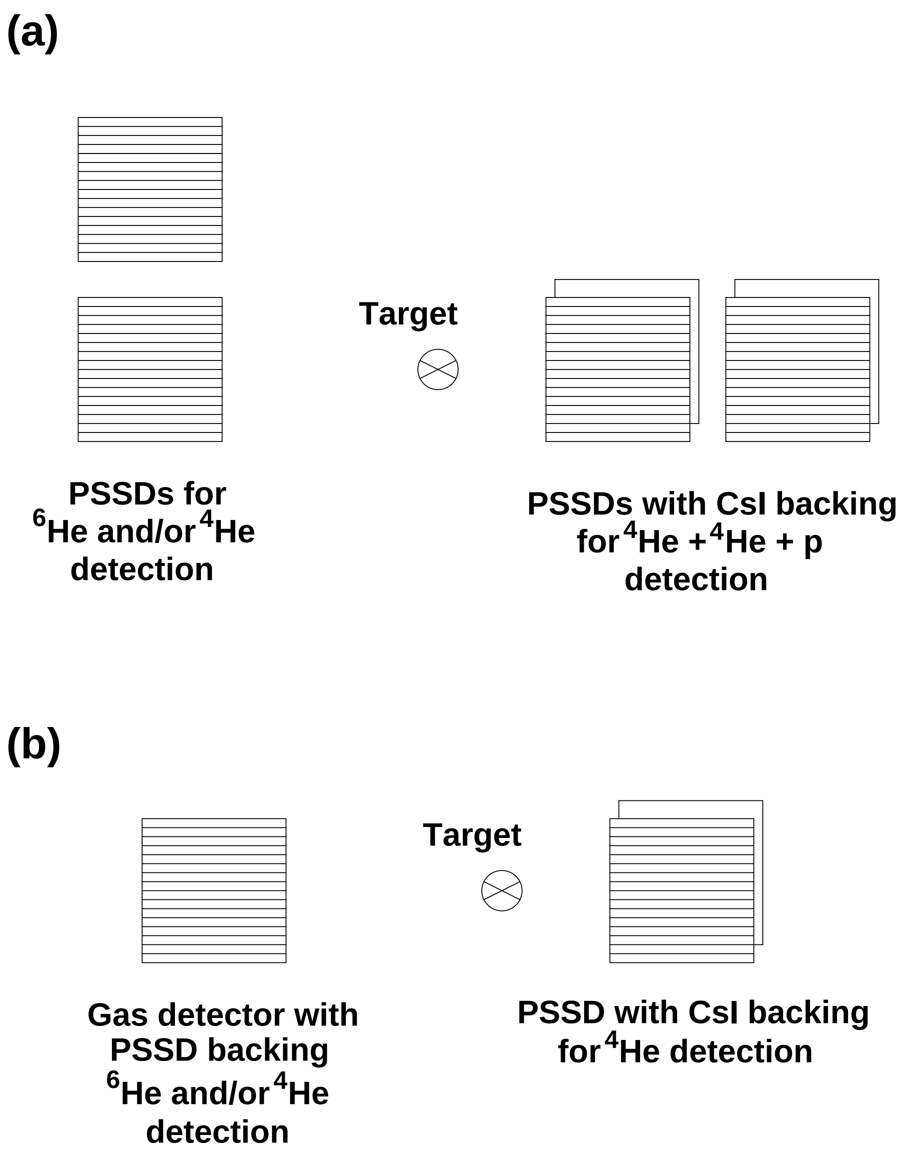

Figure 2: Schematics of the set–ups for the ^{12}C(^{7}Li,^{9}B)^{6}He+^{4}He experiment (a) and the ^{7}Li(^{7}Li,^{4}He)^{6}He+^{4}He experiment (b).

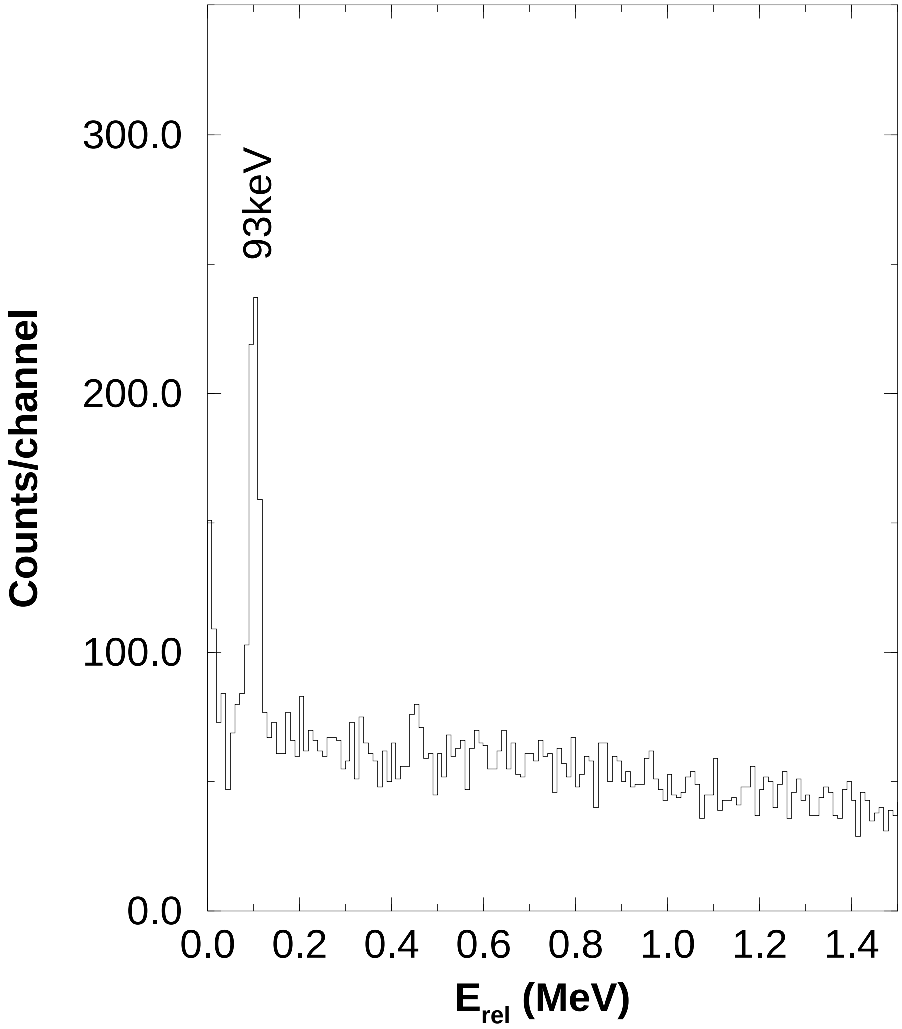

Figure 3: Example plot of the relative energy between two–fold hits in a PSSD. The peak at 93keV corresponds to decays from the ground state of ^{8}Be to $\alpha + \alpha$.