Investigation of the low-lying excitation region in ^{9}B

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Abstract. A measurement of the ^{9}Be(^{3}He,t)^{9}B* reaction at 50 MeV was performed. A high-efficiency silicon detector array was used to detect the brake-up particles from excited states in ^{9}B$*$ in coincidence with the tritons in the high-resolution K600 spectrometer focal plane. The low-lying excitation region in ^{9}B was populated and the different decay channels identified and characterised; these populated excited states were the ground-state $\frac{3}{2}^-$, the 2.36 $\frac{5}{2}^-$, and the 2.75 $\frac{1}{2}^+$. Preliminary analysis are presented regarding the complex observation and characterisation of the first $\frac{1}{2}^+$ in ^{9}B.

1. Introduction

The mirror symmetry in the ^{9}Be/^{9}B isospin doublet has been used to address important phenomena in astrophysics and nuclear structure. For example, the properties of low-lying unbound states in ^{9}Be are important for determining the ^{4}He(αn,γ)^{9}Be stellar reaction rate, which is a crucial reaction that occurs after core-collapse supernovae and results in the creation of seed nuclei around A$\sim$80 for the r-process [1]. A revised ^{4}He(αn,γ)^{9}Be reaction rate was obtained at TRIUMF [2] by studying states in ^{9}B produced via the decay of ^{9}C and using isospin symmetry to deduce the properties of states in ^{9}Be, where experimental data was lacking. From a nuclear structure perspective, this mirror nuclei have been described either as a cluster-like Borromean system, where the nuclei are described in a similar configuration as a H_2^+ molecule in which two unbound α-particles are held together by a covalent σ-type neutron or proton [3] or as a ^{8}Be core plus a neutron or proton occupying the *sd* shell. By determining the Coulomb displacement energies between the analog states in these nuclei will be possible to shed light in the nuclear structure front. Despite the first observation of the unbound ^{9}B nucleus 70 years ago, information on the low-lying excitation region still remains inconclusive [4]. While the astrophysically relevant first $\frac{1}{2}^+$ in ^{9}Be has been well established over several years, at E_x = 1.684 MeV with Γ = 0.217 MeV, there have been discrepancies in both theoretical and experimental attempts to identify its isobaric analog $\frac{1}{2}^{+}$ in ^{9}B. Calculations with a simple single-particle Woods-Saxon potential model yield a regular Thomas-Ehrman shift, with E_x ($\frac{1}{2}^{+}$;^{9}B)$\approx$ 1.0 MeV [5–8]. This result is further validated by microscopic cluster model calculations [9, 10]. An R-matrix calculation on the other hand, yields an inverted Thomas-Ehrman shift with $E_x > 1.7$ MeV [11], due to the analog state in ^{9}Be being above the ^{8}Be(g.s) + $s_{\frac{1}{2}}$ neutron threshold. Finally, a revised calculation by Barker [12] using a modified potential yielded the excited E_x ($\frac{1}{2}^{+}$;^{9}B) to be either 1.36 or 1.74 MeV. On the experimental side, the results have been far from conclusive as well. A ^{6}Li + ^{6}Li reaction [13] speculates the excitation energy lie between 0.8 - 1.2 MeV, in agreement with a Thomas-Ehrman shift that is expected from solely an *s*-wave proton. Several other experiments have been performed, reporting a highly discrepant excitation energies ranging from $E_x = 0.7$ to 1.9 MeV [14–20] favoring either a cluster-like configuration or a shell-model configuration. The most recent measurements were performed at Munich [18] and RCNP [20] respectively, employing a transfer reaction with the ^{9}Be(^{3}He,t)^{9}B*. In the former experiment, a DSSSDs array was placed on the right side of the beam axis and was used to tag α-events from the breakup of ^{8}Be nuclei, while in the latter a triton singles spectrum was obtained using the Grand-Raiden spectrometer at 0°, which was deconvoluted using an elaborate procedure. Both these experiments indicated a resonance around 1.85 MeV which agrees with Barker's R-matrix predictions. However, there is no conclusive information in these experiments that obtain the J^{π} of the observed 1.85 MeV state.

2. Experimental Details

The experiment was performed at the iThemba LABS cyclotron with a ^{3}He beam at an energy of 50 MeV incident on a 600 $\frac{\mu g}{cm^2}$ self supporting ^{9}Be target (fabricated at the iThemba LABS). The ^{9}Be(^{3}He,t)^{9}B* (Q = –1.0866 ± 1 MeV) reaction of interest populated states in the low-lying excitation region in ^{9}B < 6 MeV, above the ^{8}Be + proton threshold. The triton ejectiles were detected and momentum-analysed at the K600 spectrometer (on a 0°configuration) by a multi-wire chamber positioned at the middle-dispersion focal plane and a plastic scintillator detector, the latter was also used for triggering CAKE (Coincidence Array for K600 Experiments) as well as for particle identification purposes. The high-efficiency silicon detector array CAKE was placed inside the scattering chamber at backward angles and is composed by five MMM-silicon detectors, each segmented into 16 independent concentric strips on the front and 8 sectors on the back, with a solid angle coverage of 26% and was used to detect the products from the decay of excited states in ^{9}B.

3. Preliminary Analysis

One of the first steps in the reconstruction of the excited region of interest in any K600 experiment is the identification of that particle of interest in the focal plane as shown in Fig. 1. For the present work, the identification of tritons is vital, as mentioned above, as they were utilised as a trigger for CAKE, and subsequently for the generation of the ^{9}B spectra.

Once the tritons have been identified and momentum-analysed a triton spectrum was generated, in which the triton energies correspond to a specific excitation energy of excited states in ^{9}B as it is shown in Fig. 2.

After the excitation region of interest was identified, a two-dimensional plot was generated in order to find the different decay channels of excited states in ^{9}B. For this, the focal plane X position is plotted versus those events detected by CAKE as shown in Fig. 3. A time-gate was placed in order to reduce the background and discard random coincidence. Fig. 4 shows the 3 different decay-channels in the reaction, ^{8}Be$_{g.s.}$ + proton, the ^{8}Be$_{1st}$ + proton and the ^{5}Li + α channel.

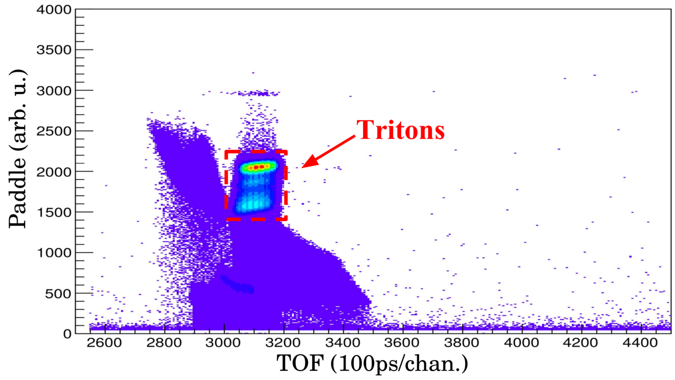

Figure 1. Red dashed-box corresponds to those identified tritons through time-of-flight and energy-loss in the focal plane.

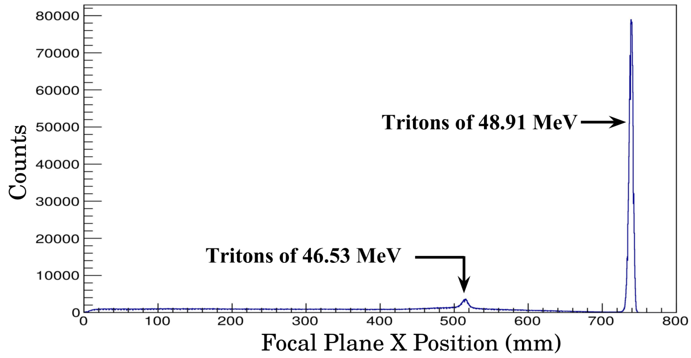

Figure 2. Spectrum of the selected tritons in Fig. 1 corresponding to excited states in ^{9}B.

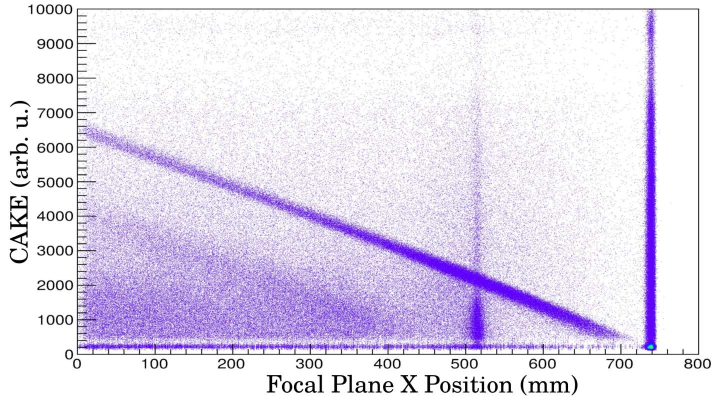

Figure 3. Two-dimensional plot showing triton events at the focal plane versus those detected at the silicon array CAKE.

A calibration of the focal plane was required in order to obtain the precise excitation energy of the populated resonances in ^{9}B (the ground-state, the 2.3 MeV and the 2.7 MeV) as shown in Fig. 5. From this two-dimensional plot, it was possible to generate a gate around the ^{8}Be$_{g.s.}$ + p locus, so the contribution of the sharp 2.3 MeV state was reduced. In Fig. 6 are shown both, the projection of the two-dimensional plot on the x-axis corresponding to the total low-lying

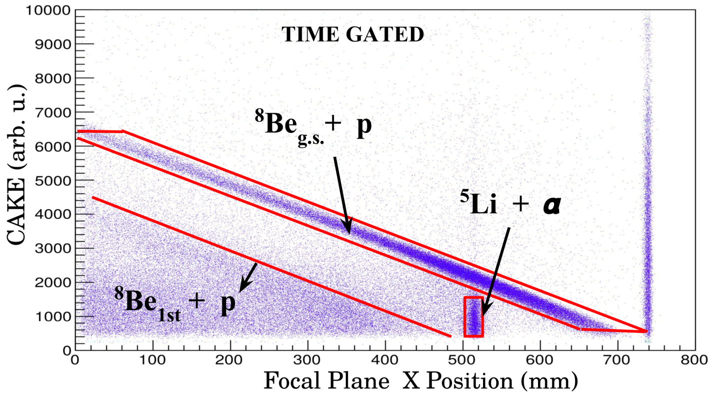

Figure 4. Two-dimensional time-gated plot. From top to bottom, the first diagonal line corresponds to the $^8Be_{g.s.}$ + p decay channel, the second to the $^8Be_{1st}$ decay channel and the vertical line to the ^{5}Li + α decay channel.

spectra in ^{9}B and the projection of the gated region around the locus of interest. The latter clearly shows the broad resonances under the sharp 2.3 MeV excited state.

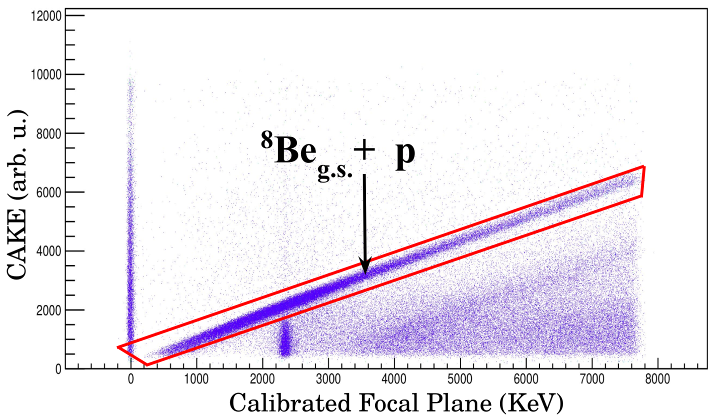

Figure 5. Boron-9 excitation energy versus decay particles detected by CAKE. The $^8Be_{g.s.}$ + p decay channel shown inside the red box.

As shown in Fig. 6, the broad resonance of 2.7 MeV is clearly identified when gating in the $^8Be_{g.s.}$ + p, showing the robustness of the coincidence two-dimensional plot, but also it is clear that the identification of a $\frac{1}{2}^+$ state in that range of energy is complicated. As it was mentioned in reference [18], the expected energy of such state should be at or below 1.9 MeV decaying exclusively via the $^8Be_{g.s.}$ + p channel. Further analysis will follow including an angular proton distribution for states of interest, specifically for the first $\frac{1}{2}^+$.

4. Conclusions

An experiment was performed using the ^{9}Be(^{3}He,t)^{9}B transfer reaction at a beam energy of 50 MeV where the low-lying excitation energy region in ^{9}B was populated and identified. The robustness of the detection technique used in the presented work which includes the combination of the K600 and the silicon detector array CAKE for the identification of different decay channels was discussed, being highly efficient in reducing the background and random coincidences. A

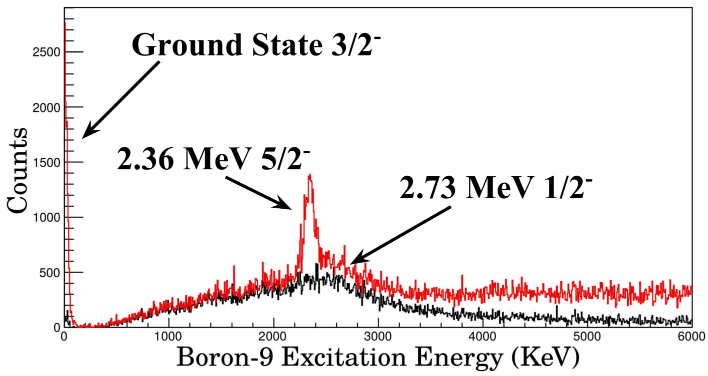

Figure 6. Black color line represents the projection onto the x-axis of Fig. 5 and red line the projection of the gate around the locus of interest showing the broad resonances under the sharp 2.3 MeV peak.

broad energy region below the 2.3 MeV excited state in ^{9}B was identified, which mainly decays through the ^{8}Be$_{g.s.}$ + p channel.

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