

# Dynamic studies of $^{11}\text{Li}$ and its core $^9\text{Li}$ on $^{208}\text{Pb}$ near the Coulomb barrier

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**Abstract.** We measured the scattering of the halo nucleus  $^{11}\text{Li}$  and its core  $^9\text{Li}$  on the lead target at TRIUMF at energies below and around to the Coulomb barrier. We report here on our preliminary analysis of the inclusive breakup reaction.

**Keywords:** Halo nuclei,  $^{11}\text{Li}$ ,  $^9\text{Li}$ , Elastic scattering, Breakup channel.

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## INTRODUCTION

In the past 20 years there has been an interest in the nuclear physics community to study the halo structure.  $^{11}\text{Li}$  is the archetype halo nucleus composed of a  $^9\text{Li}$  core and two neutrons with very low binding energy ( $S_{2n}=369.15$  (65) keV [1]). Recent theoretical calculations predicted a deviation from the standard elastic cross-section for stable nuclei, due to the distortion of the wave function of this loosely bound system when passing near a strong Coulomb field.

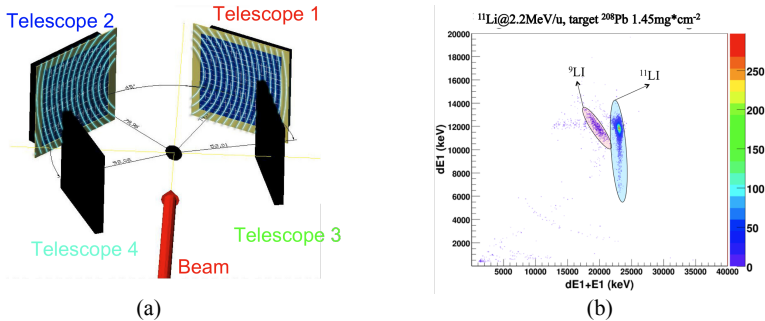
To study this effect an experiment to measure the elastic and breakup cross-sections of  $^{11}\text{Li}$  on  $^{208}\text{Pb}$  at energies below and around the Coulomb barrier was performed in ISAC II (Isotope Separator and Accelerator) at TRIUMF laboratory in Vancouver, Canada.

Both  $^{11}\text{Li}$  and  $^9\text{Li}$  were measured with the same center of mass energies using the same setup. This will help us disentangle the contribution of the  $^{11}\text{Li}$  halo to the process and to precisely determine the optical model parameters describing the scattering process.

## EXPERIMENTAL SET-UP AND DATA ANALYSIS

We used a set of four telescopes with angular coverage from  $10^\circ$  to  $140^\circ$ . The forward telescopes consisted of  $40\ \mu\text{m}$  DSSSD (Double Side Silicon Strip Detector) backed by a  $500\ \mu\text{m}$  Silicon PAD. The backward telescopes have a very thin  $20\ \mu\text{m}$  SSSD (Single Side Silicon Strip Detector) backed by a  $60\ \mu\text{m}$  DSSSD to separate the contribution for the elastic  $^{11}\text{Li}$  and breakup,  $^9\text{Li}$  nuclei. See figure 1.

We selected the doubly magic nucleus,  $^{208}\text{Pb}$ , as a target to avoid any extra effect contributing to the breakup process. The target thickness chosen was  $1.45\ \text{mg}\cdot\text{cm}^{-2}$  as a compromise between sufficient statistics and extra broadening due to the straggling. The target was at  $15^\circ$  with respect to the beam in order to avoid shadowing from the target frame on the detector.



**FIGURE 1.** Experimental set-up and pixel-by-pixel analysis. (a) Artistic view of the setup. The polar angle distribution is shown on the DSSSD. (b) The picture displays the bi-dimensional plot  $\Delta E$  versus  $\Delta E+E$  of the scattering events of the  $^{11}\text{Li}$  beam on  $^{208}\text{Pb}$  at  $2.2\ \text{MeV}\cdot\text{u}^{-1}$  for the angular range  $20^\circ$  to  $35^\circ$ .

We measured  $^9\text{Li}$  beam at  $2.67$  and  $3.27\ \text{MeV}\cdot\text{u}^{-1}$  energies for a total of 19h with the  $1.45\ \text{mg}\cdot\text{cm}^{-2}$  target of  $^{208}\text{Pb}$ . In order to select the optimal thickness of the target and to characterize the optical potential we studied  $^9\text{Li}$  at  $3.27$  and  $3.67\ \text{MeV}\cdot\text{u}^{-1}$  with a target of  $1.9\ \text{mg}\cdot\text{cm}^{-2}$  during 41.5h. Afterwards we studied  $^{11}\text{Li}$  at  $2.2$  and  $2.7\ \text{MeV}\cdot\text{u}^{-1}$  during about 100h with the target of  $1.45\ \text{mg}\cdot\text{cm}^{-2}$ . During the experiment the detectors were calibrated with the standard  $\alpha$ -sources  $^{148}\text{Gd}$ ,  $^{239}\text{Pu}$ ,  $^{241}\text{Am}$  and  $^{244}\text{Cm}$ .

In the data analysis several conditions were used. (i) Energy thresholds were determined from the  $\alpha$ -sources. (ii) The difference between the energy in front and back strips is less than  $70\ \text{keV}$  so that multi-scattering from light particles like betas as well as charge sharing between strips was avoided.

Figure 1 (b) shows the elastic and breakup events of  $^{11}\text{Li}$  at energies well below the Coulomb barrier. The considerable amount of breakup events observed at these close to forward angles indicates that the effect on the scattering process of the loosely bound structure of  $^{11}\text{Li}$  is higher than expected.

## REFERENCES

1. M. Smith et al., *Phys. Rev. Lett.* **101**, 202501 (2008).
2. A. Moro et al., *Phys. Rev. C* **75**, 064607 (2007).