Studying Low-Lying States of ^{9}B with the Super-Enge Split-Pole Spectrograph

R. M. Malecek[1], S. T. Marley[1], E. Good[1], G. Morgan[1], G. Wilson[1], I. Wiedenhoever[2], L. Baby[2], G. McMann[2], Y. Koshchiy[3], T. Ahn[3], G. Rogachev[3], L. Sobotka[4]

[1]Louisiana State University, [2]Florida State University, [3]Texas A&M University, [4]Washington University

Motivation

We are using the single particle transfer reactions ^{10}B(^{3}He,*α*) and d(^{8}B,p) to investigate the structure of the light, neutron-deficient nucleus ^{9}B in order to test modern nuclear theories, including ab initio nuclear models and reaction theories. We are interested in ^{9}B specifically because significant previous efforts have yet to agree on definitive results for the energy, width, and spin-parity of its first-excited state (Table 1). This state is thought to be the mirror of the first-excited state of ^{9}Be (J^{π}= ½$^{+}$, E_x =1.684±20 MeV, Γ=214±5 keV) and by comparing the current energy levels of ^{9}B and ^{9}Be (Figure 1) we can see how much more information we have on the latter. By evaluating the low-lying structure of ^{9}B with both neutron-adding and neutron-removing reactions, we hope to gain further insight into its first excited state as well as modern nuclear theories.

Year	Author	E (MeV)	Γ (MeV)	Reaction
1968	J. J. Kroepfl[1]	~1.6	0.7	^{10}B(^{3}He, α)
1983	A. Djaloeis[2]	1.65 ± 0.03	1 ± 0.2	^{9}Be(^{3}He,t)
1987	K. Kadija[3]	1.16 ± 0.05	1.30 ± 0.05	^{9}Be(^{3}He,t)
1988	M. Burlein[4]	1.32 ± 0.08	0.86 ± 0.26	^{9}Be(^{6}Li,^{6}He)
1988	N. Arena[5]	1.8 ± 0.2	0.9 ± 0.3	^{10}B(^{3}He, α)
1995	T. D. Tiede[6]	0.73 ± 0.05	0.3 ± 0.05	^{6}Li(^{6}Li,t)
2012	M. A. Baldwin[7]	0.9 ± 0.1	~1.5	^{6}Li(^{6}Li,d)^{10}B*
2015	C. Wheldon[8]	1.85 ± 0.06	0.65 ± 0.125	^{9}B(^{3}He,t)^{9}B

Table 1: A non-comprehensive summary of measurements of the first-excited state of ^{9}B including the year of publication, first author, the reaction used and the resulting energy and width with uncertainties. The Kroepfl et al. and Arena et al. studies are highlighted in red because we are using the same reaction to study ^{9}B.

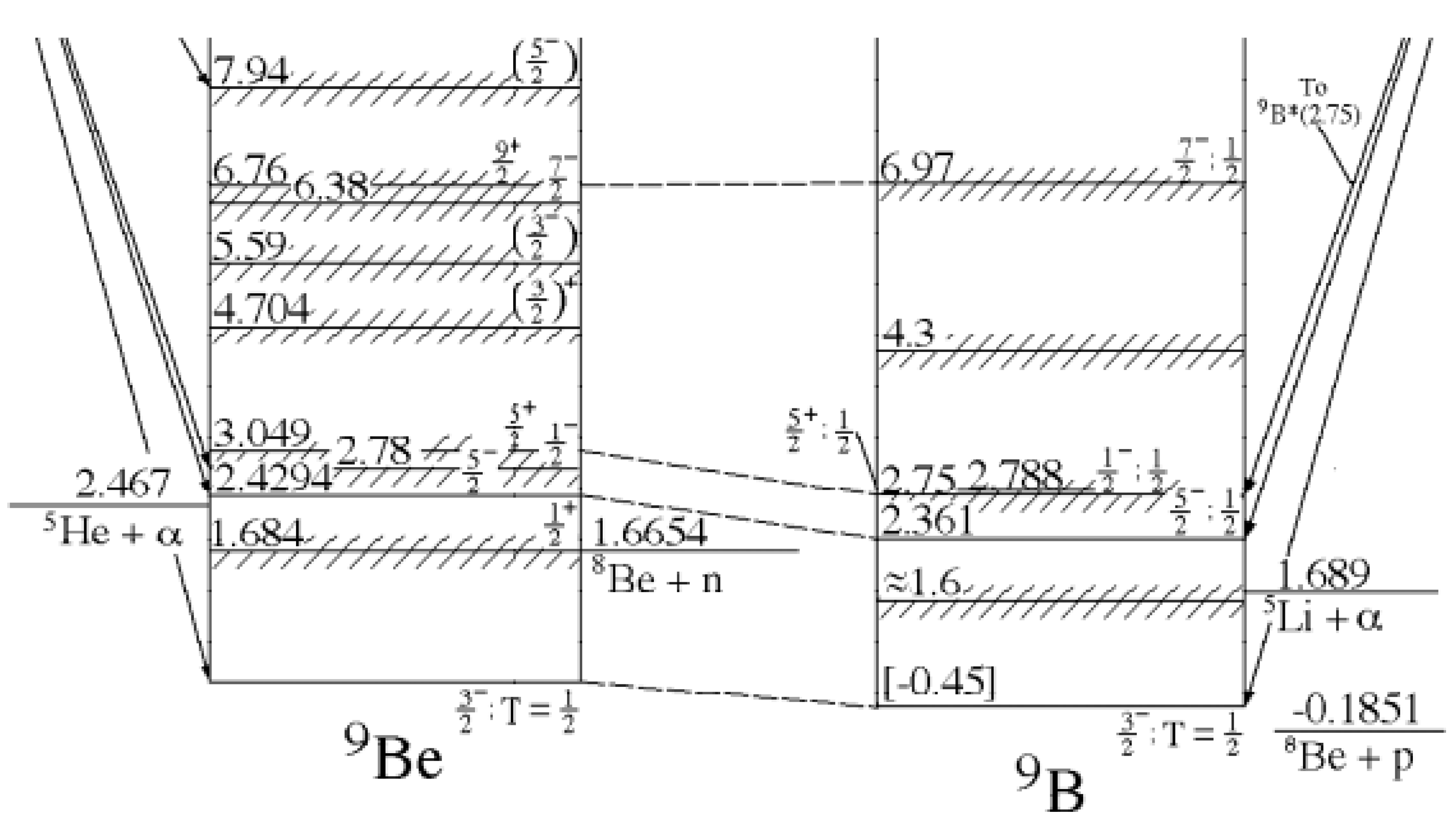

Figure 1: Comparing the energy levels diagrams of ^{9}B and its mirror nucleus ^{9}Be. Figure from the TUNL Database.

^{10}B(^{3}He,*α*)^{9}B Experiment at FSU

- Performed in January 2019 at the John D. Fox Accelerator Laboratory at Florida State University (FSU) with the new Super-Enge Split Pole Spectrograph (SE-SPS) (Figure 2).
- A 24-MeV ^{3}He beam was incident on an isotopically-enriched, self-supporting ^{10}B target that was provided by John Greene from Argonne National Laboratory.
- Alpha particles were momentum-analyzed by the SE-SPS then detected at the focal plane (Figure 3) while backscattered and decay particles were seen by a DSSD.
- The light byproducts' forward angle trajectories can be seen in the top-down schematic of the SE-SPS (Figure 4).
- Data was taken every 5 degrees between 5° and 35° in the laboratory frame with both the ^{10}B target and a LiF target for calibration.

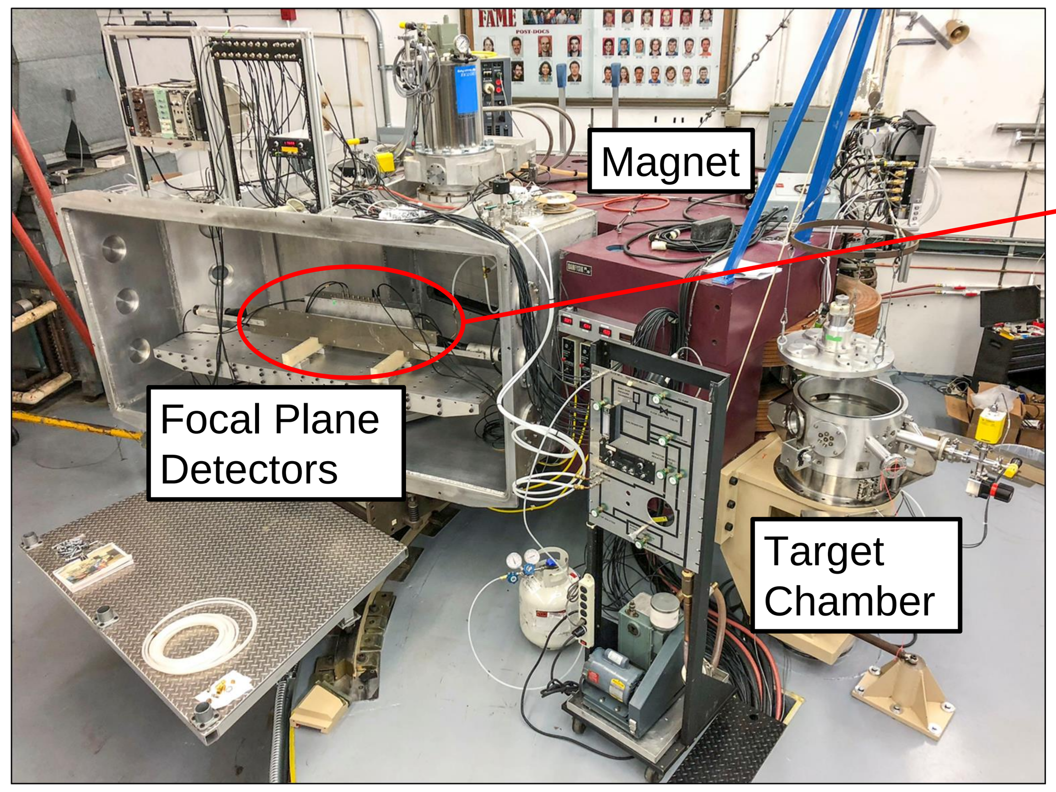

Figure 2: Photo of SE-SPS at FSU with key components labeled.

Figure 3: Photo of the interior of the focal plane detector.

Focal Plane Detector

- Gas filled proportional counter
- Position along focal plane gives magnetic rigidities Bρ
- Energy loss is used to identify particles

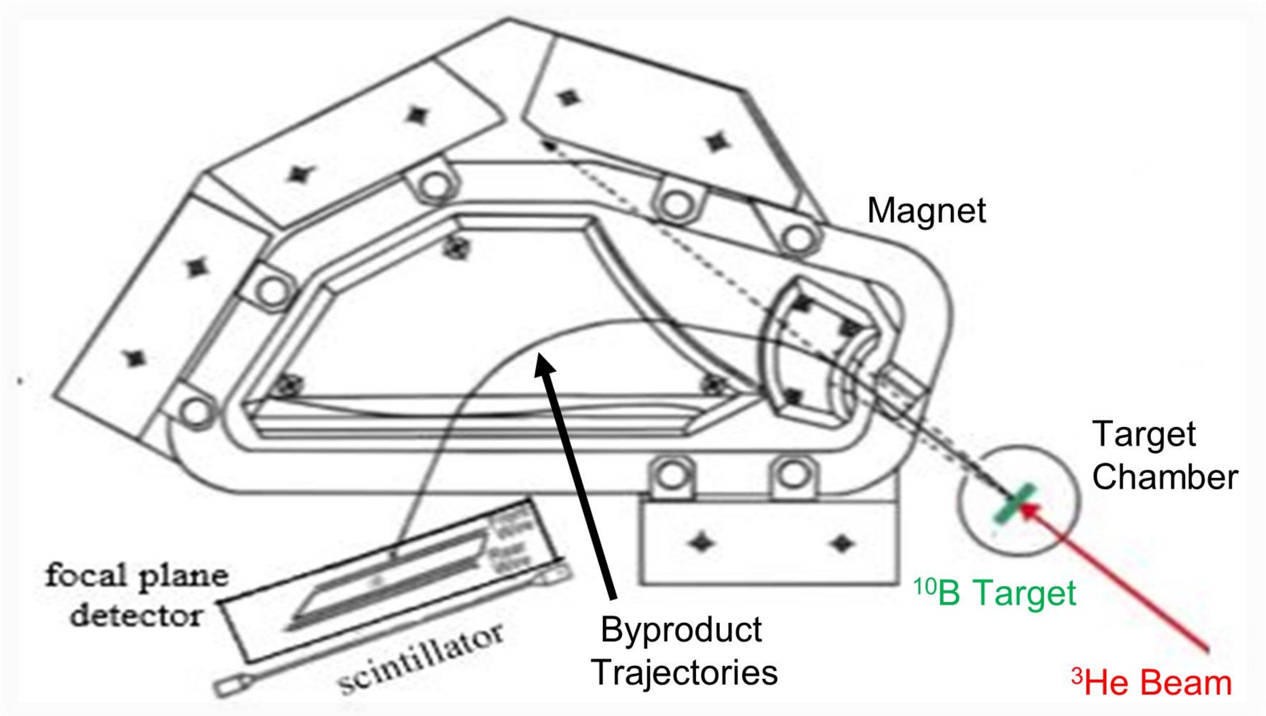

Figure 4: Top down schematic of SE-SPS at FSU showing the particle's trajectories which are governed by the equation **Bρ=mv/q**.

^{10}B(^{3}He,*α*)^{9}B Analysis

- A raw spectrum from this experiment has significant background that makes it difficult to identify important peaks (Figure 5a).
- Looking at the energy loss (anode signal) versus the focal plane position we can identify different particles and gate on the byproducts of interest, in our case alpha particles (Figure 5b).
- Now making a spectrum with the alpha particle gate applied greatly reduces the background and makes it easier to define important peaks (Figure 5c).

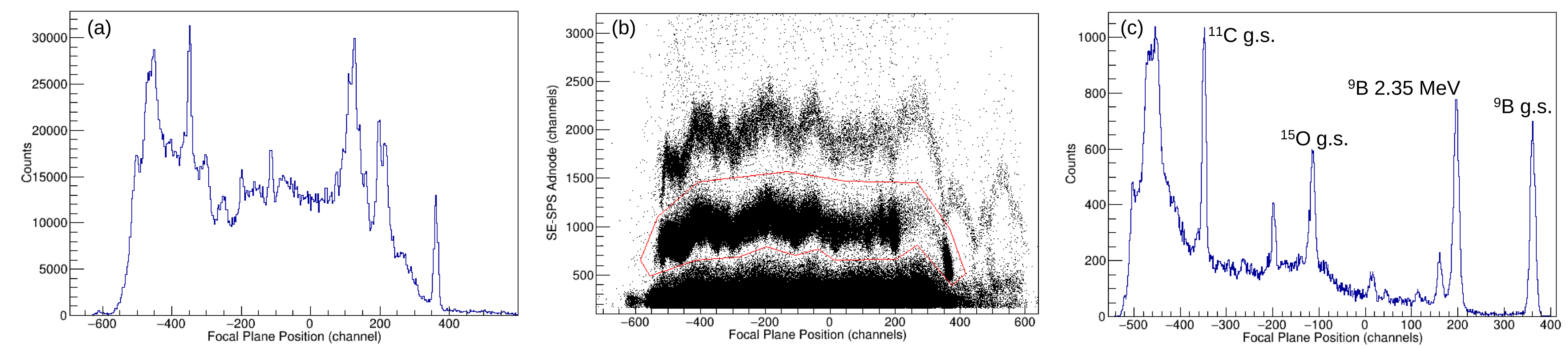

Figure 5: All spectra were generated from a 2 hour long run with a ^{10}B target and the SE-SPS set to 10 degrees. (a) Raw spectra showing all particle counts along the focal plane. (b) Anode channels versus focal plane position where the alpha particles are gated around with a red graphical cut. (c) The graphical cut from 5b is applied to the data shown in 5a and distinct peaks are labeled.

Future Work

Complete ^{10}B(^{3}He,*α*)^{9}B Analysis

- Reconstruct focal plane to improve precision of calibration and resolution. This is done by using Figure 6 and solving the following equations for a new (x,y) position.

$$(P_1 - P_2)y + Sx - P_2 S = 0$$

$$\frac{x}{(1+ctg^2\alpha)^{1/2}} + \frac{y}{(1+tg^2\alpha)^{1/2}} - H = 0$$

- Look at DSSD data in coincidence with focal plane data

^{2}H(^{8}B,p)^{9}B at Texas A&M University

- ^{8}B beam development with the Momentum Achromat Recoil Spectrometer (MARS) is scheduled for Sept. 2019 and we plan to perform the experiment in winter 2019.
- Deuterated-polyethylene (CD_2) targets will be made at LSU.
- TECSA chamber is being refurbished to house the detector set up.

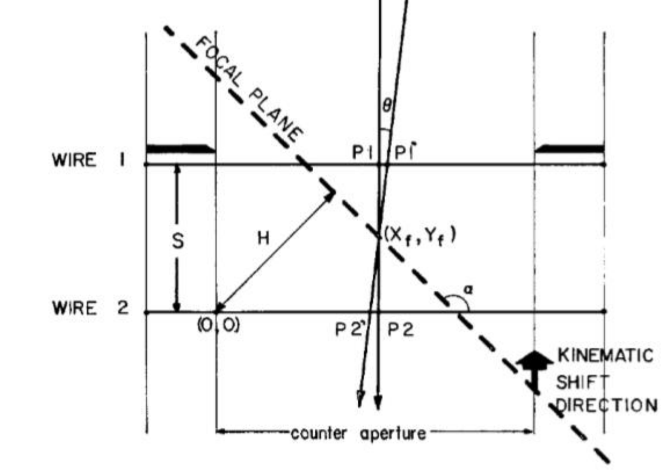

Figure 6: Schematic of the detector not on the focal plane[9].

References

[1] J. J. Kroepfl and C. P. Browne, Nucl. Phys. A **108**, 289 (1968).
[2] A. Djaloeis, J. Bojowald, and G. Paic, Proc. Int. Conf. on Nuclear Physics, Florence, Vol. **1**, p. 235 (1983).
[3] K. Kadija, G. Paic, B. Antolkovic, A. Djaloeis, and J. Bojowald, Phys. Rev. C **36**, 1269 (1987).
[4] M. Burlein, et al., Phys. Rev. C **38** (1988) 2078.
[5] N. Arena, Seb. Cavallaro, G. Fazio, G. Giardina, A. Italiano, and F. Mezzanares, Europhys. Lett. 5, 517 (1988).
[6] M. A. Tiede, et al., Phys. Rev. C **52** (1995) 1315.
[7] T. D. Baldwin, et al., Phys. Rev. C **86** (2012) 034330.
[8] C. Wheldon, T. Kokalova, and M. Freer, Phys. Rev. C **91**, (2015).
[9] D. Shapira, et al., Nuc. Instruments and Methods 129 (1975)

Acknowledgements

We thank the Center of Excellence in Nuclear Training and University-Based Research and the National Nuclear Security Administration for supporting this work at Louisiana State University. We also thank the LSU Department of Physics & Astronomy for additional support. We thank our collaborators at Florida State University and Texas A&M University for all their help and the use the use of their facilities. Lastly, we thank our collaborators at Washington University for providing detectors.