

Transfer reactions with Be-Li isotopes near the drip-line

LISE Workshop 2024

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on behalf on the E748 collaboration

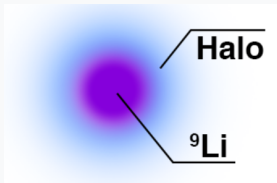
IGFAE-USC and LPC-Caen

Overview of the exotic Be-Li region

Be and Li isotopes close to the neutron drip line have been extensively studied due to their exotic properties.

Two prime examples can be showcased:

^{11}Li is a neutron-rich nuclei displaying a 2n **halo** structure.



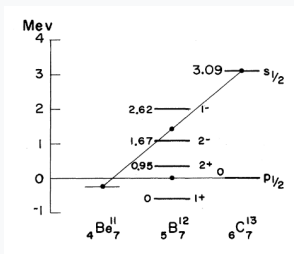
^{10}B	^{11}B	^{12}B	^{13}B	^{14}B
^9Be	^{10}Be	^{11}Be	^{12}Be	^{13}Be
^8Li	^9Li	^{10}Li	^{11}Li	^{12}Li
^7He	^8He	^9He	^{10}He	

Overview of the exotic Be-Li region

Be and Li isotopes close to the neutron drip line have been extensively studied due to their exotic properties.

Two prime examples can be showcased:

¹¹Be presents parity inversion: g.s. has **positive** parity when negative expected.

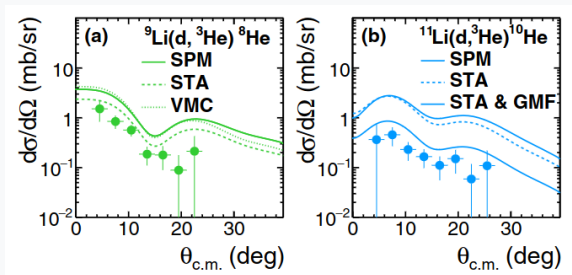


I. Talmi and I. Unna, PRL 4 (1960).

¹⁰ B	¹¹ B	¹² B	¹³ B	¹⁴ B
⁹ Be	¹⁰ Be	¹¹ Be	¹² Be	¹³ Be
⁸ Li	⁹ Li	¹⁰ Li	¹¹ Li	¹² Li
⁷ He	⁸ He	⁹ He	¹⁰ He	

Recently gathered information

During the MUST2 @ RIKEN campaign, an unexpected **reduction** of the cross-section was observed in $^9,^{11}\text{Li}(d, ^3\text{He})^{8,10}\text{He}$ reactions.



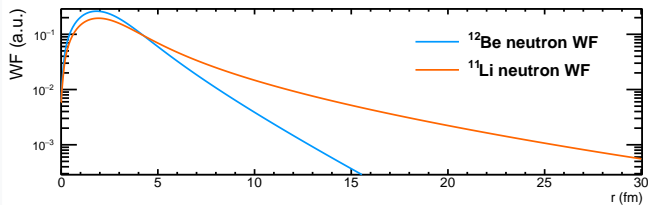
A. Matta et al., PRC 92 (2015).

Possible **explanations**:

- Role of the many-body interactions.

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GMF of neutron w.f for ${}^{12}\text{Be}(d, {}^3\text{He}){}^{11}\text{Li}$

Possible **explanations**:

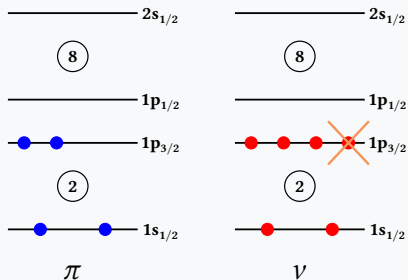
- Role of the many-body interactions.
- Overestimation of the nuclear overlap $\langle {}^9,{}^{11}\text{Li} | {}^8,{}^{10}\text{He} \rangle$.

Collect more
 $d\sigma/d\Omega$ data!

Reactions to be studied

E748 at GANIL during the MUST2@LISE campaign. Neutron and proton removal reactions from $^{10,12}\text{Be}$ beams have been performed to probe key nuclei:

- $^{10}\text{Be}(\text{d}, \text{t})^9\text{Be}$: Benchmark reaction. n-**occupancy** in $p_{3/2}$.

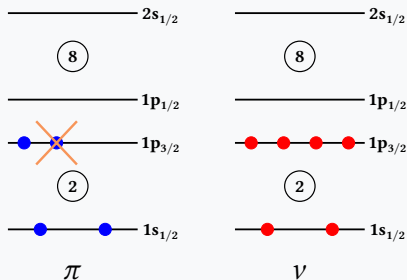


^{10}Be shell model.

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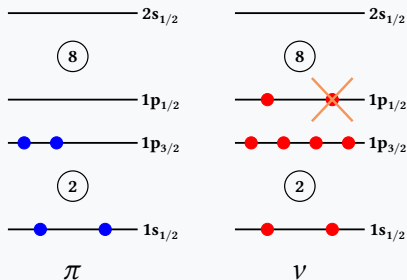


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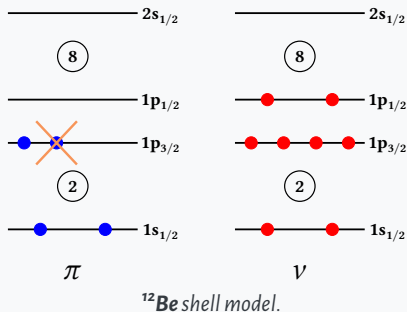


^{12}Be shell model.

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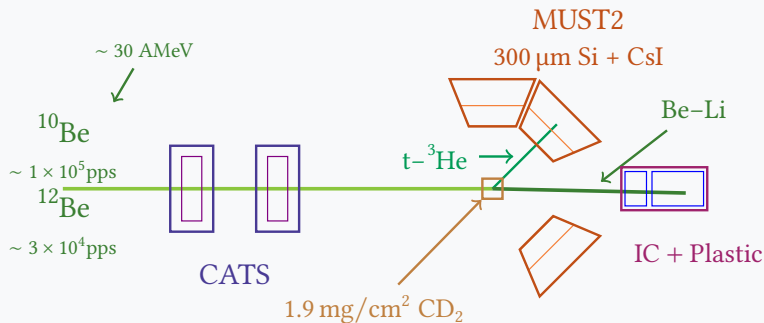
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- $^{12}\text{Be}(d, t)^{11}\text{Be}$: higher orbital $p_{1/2}$.
- $^{12}\text{Be}(d, ^3\text{He})^{11}\text{Li}$: same p-orbital as before.



Experimental setup for E748

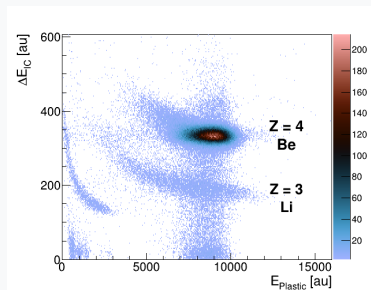
Traditional **solid target** experiment @ D6. Below a sketch of the setup:



Analysis at a glance

A **common** procedure is employed in all the reactions. Different gates are applied in a sequential manner, as follows:

1. **Heavy ID:** Only distinction in Z : separation of Be from Li residuals, but not along isotopic chain.



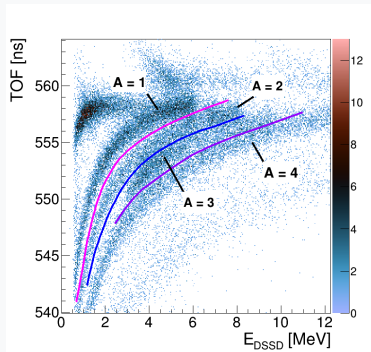
Analysis at a glance

A **common** procedure is employed in all the reactions. Different gates are applied in a sequential manner, as follows:

2. **Light ID:** Using only stopped particles in Si layer, but low TOF resolution. Separation of **t-³He** attained with kinematics!

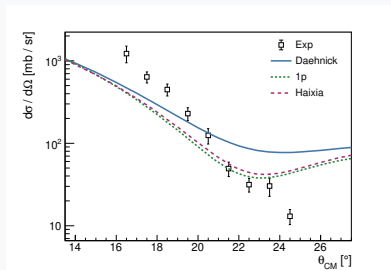
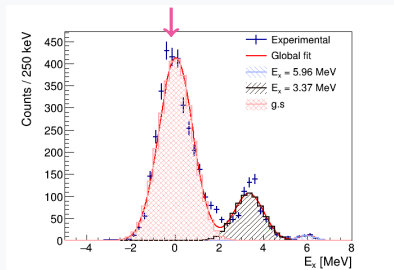
Missing mass technique:

$$E_{\text{beam}} + (E, \theta)_{\text{Lab}} \rightarrow \mathbf{E}_{\mathbf{x}}$$



Elastic: $^{10}\text{Be}(d, d)^{10}\text{Be}$

Serves as a test of the analysis, allowing us to ascertain the **normalization** factors N_t and N_b .



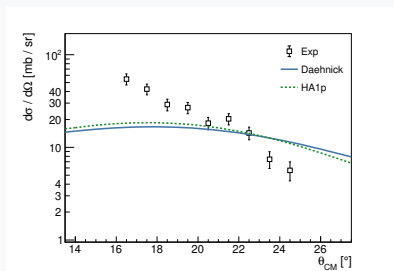
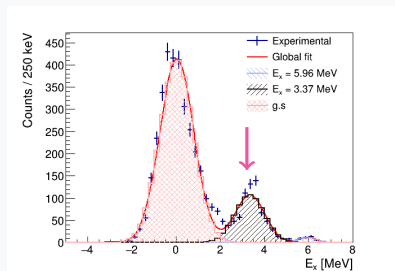
- Modern models (Haixia and DA1p) adjust better the minimum.
- Overall agreement in magnitude.

Error in **efficiency**

Proton **contamination** at
low E

Elastic: $^{10}\text{Be}(d, d)^{10}\text{Be}$

Cross-section for the 1st excited state is also achievable.

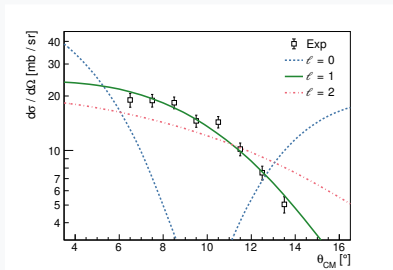
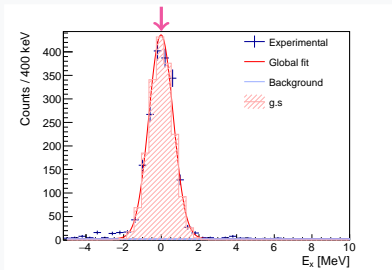


- DWBA: potential deformed in both Coulomb and nuclear parts
- Using $B(E2)$ from other experiments
- **Same** error as before?

To be further investigated.
 $\Rightarrow C^2S = 0.270(22)$
with Daehnick

Neutron removal: $^{10}\text{Be}(d, t)^9\text{Be}$

Only the **ground state** is accessible. Angular distributions are determined in the interval $\theta_{\text{CM}} \in [5, 20]^\circ$.

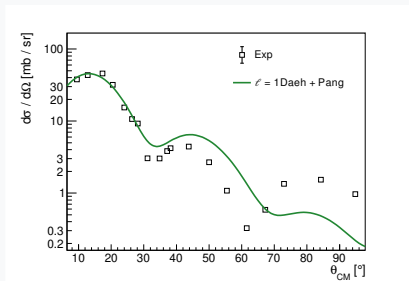


- **DWBA** with DAEHNICK (d) and PANG (t) OMPs
- **Best fit** is $\ell = 1$ with $j = 3/2$

$$\Rightarrow C^2S = 1.522(44)$$

Neutron removal: $^{10}\text{Be}(d, t)^9\text{Be}$

Another measurement is available in D.L Auton Nucl. Phys. A (1970). A reanalysis with **our model** is executed:



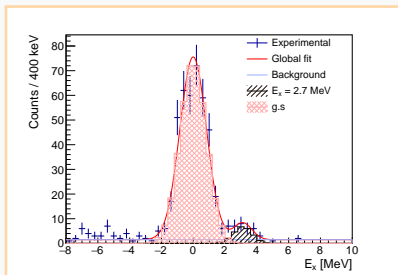
- No errors could be extracted from paper
- Poor quality at large θ_{CM}
- $C^2S = 1.951(54)$

Agreement with our results

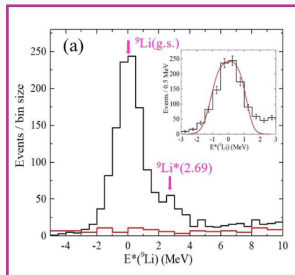
Proton removal: $^{10}\text{Be}(d, ^3\text{He})^9\text{Li}$

E748 can be compared with a recent experiment carried out at the Acculinn facility. For the E_x :

Our experiment @ 30 A MeV



E. Y. Nikolskii et al. @ 42 A MeV

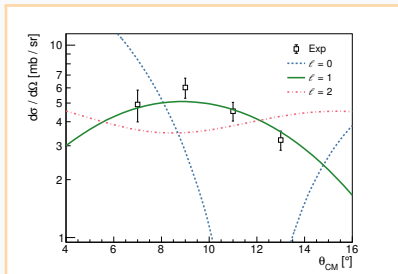


Recently published: NIMPR B 541 (2023)

Proton removal: $^{10}\text{Be}(d, ^3\text{He})^9\text{Li}$

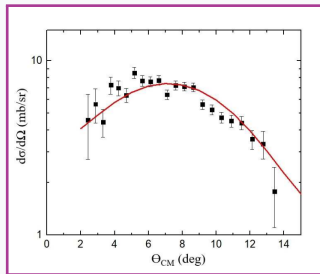
Angular distributions for the **ground state** are extracted:

Our experiment, $\theta_{\text{CM}} \in [6, 14]^\circ$



Again $\ell = 1 \implies 3/2^-$.
 $C^2S = 1.80(11)$

Acculinna one, $\theta_{\text{CM}} \in [3, 13]^\circ$

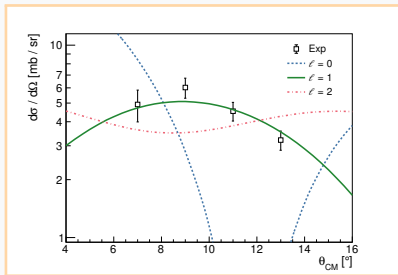


Original publication:
 $C^2S = 1.74$

Proton removal: $^{10}\text{Be}(d, ^3\text{He})^9\text{Li}$

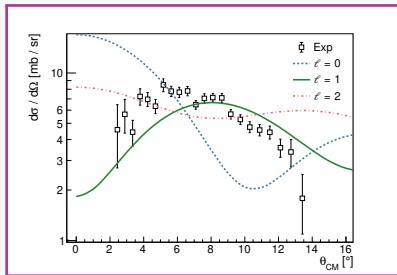
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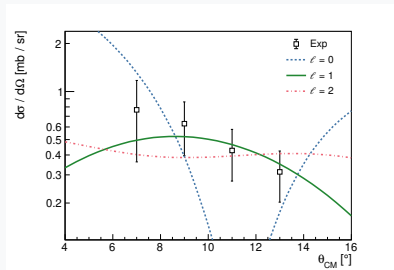
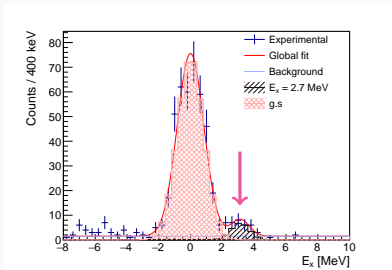
Reanalysis of Acculinnna's data



$\ell = 1 \implies C^2S = 2.679(45)$
Investigate **input parameters**
in the models!

Proton removal: $^{10}\text{Be}(d, ^3\text{He})^9\text{Li}$

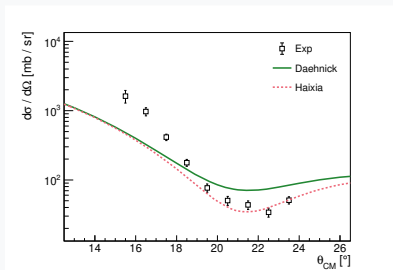
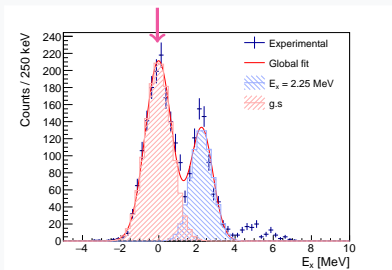
A first excited state is also accesible.



- **Best fit** is $\ell = 1$
- Assuming $j = 1/2$
- Spectroscopic factor: 0.185(36)

Elastic: $^{12}\text{Be}(d, d)^{12}\text{Be}$

Yet another validation method of the normalization.

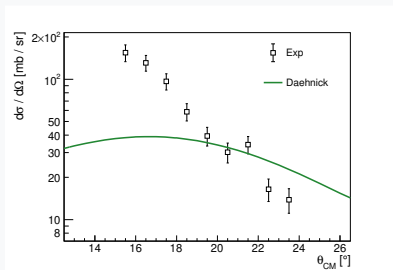
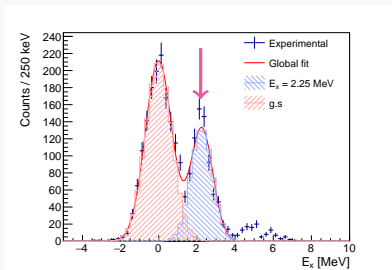


- Same behaviour as for ^{10}Be
- Normalization fine for this beam also

Clearly the same
systematic error

Elastic: $^{12}\text{Be}(d, d)^{12}\text{Be}$

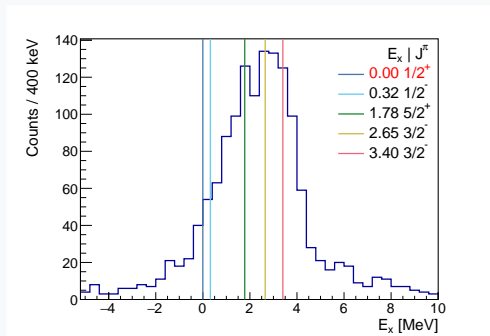
Cross-section for the 1st excited state is also achievable.



- Same procedure as before

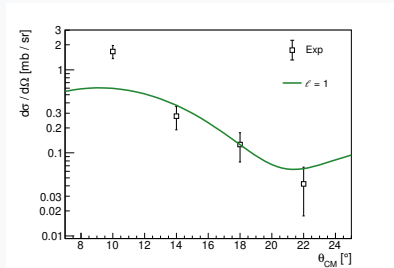
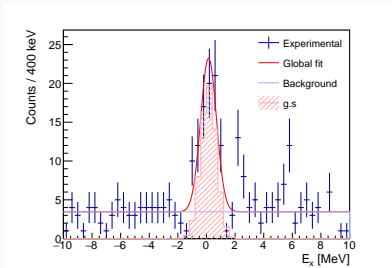
To be further investigated.
 $\Rightarrow C^2S = 0.519(30)$ with Daehnick

Challenging channels: $^{12}\text{Be}(d, t)^{11}\text{Be}$



- Strong **inhibition** of the ground state
- Why? Related to parity inversion in ^{11}Be ?

Challenging channels: $^{12}\text{Be}(d, ^3\text{He})^{11}\text{Li}$



- Low cross-section
- Subject to **contamination**: hard to disentangle $A = 3$

$\Rightarrow C^2S = 0.510(85)$ with Daehnick

Conclusions and outlook

We investigated several proton and neutron pick-up reactions on $^{10,12}\text{Be}$:

	Channel	Status	Pending
^{10}Be	(d,d)	Normalization OK	Requires study
	(d,t)	Completed	C^2S matches other measures.
	(d, ^3He)	Completed	Two new C^2S
^{12}Be	(d,d)	Normalization OK	Same as ^{10}Be
	(d,t)	Puzzled	?
	(d, ^3He)	Needs clean	New C^2S

Conclusions and outlook

Future prospects

Solve discrepancies in **elastic** channels

Reduce contamination in ^3He PID

Compare with **shell model** calculations

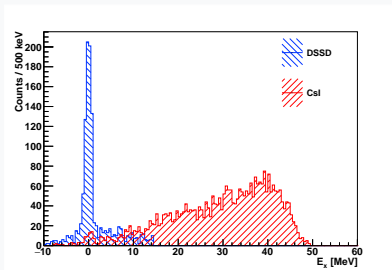
Thanks for your attention!

And special thanks to the **E748** collaboration.

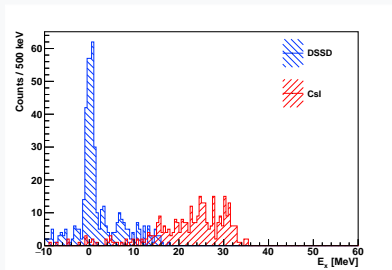
Not part of the talk!

Csl on or off?

So far, studied excited states are *compressed* in the DSSD layer:



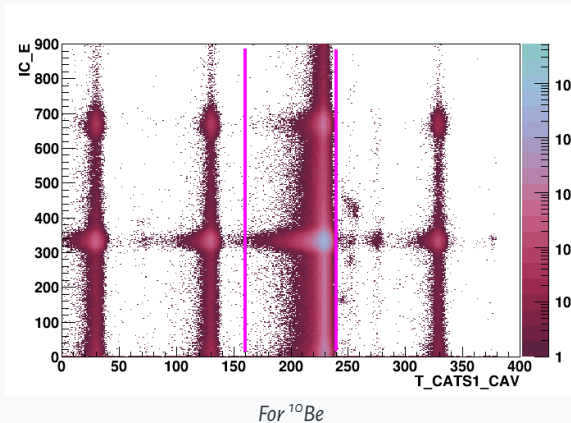
For $^{10}\text{Be}(d, t)^9\text{Be}$



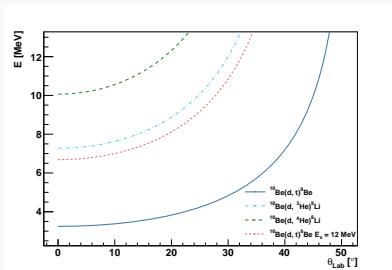
For $^{10}\text{Be}(d, ^3\text{He})^9\text{Li}$

Beam ID

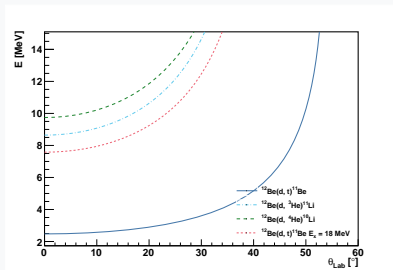
Using Caviar to CATS1 TOF and energy loss in IC



Kinematic lines



For ^{10}Be beam



For ^{12}Be beam