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

LISE Workshop 2024

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on behalf on the E748 collaboration

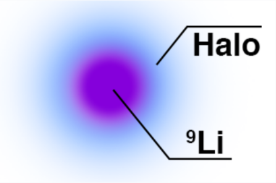
IGFAE–USC and LPC–Caen

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.



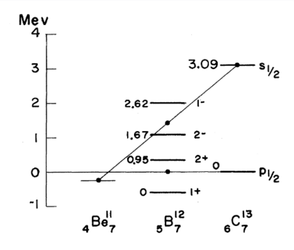
^{10}B	^{11}B	^{12}B	^{13}B	^{14}B
^{9}Be	^{10}Be	^{11}Be	^{12}Be	^{13}Be
^{8}Li	^{9}Li	^{10}Li	^{11}Li	^{12}Li
^{7}He	^{8}He	^{9}He	^{10}He	

Overview of the exotic Be-Li region

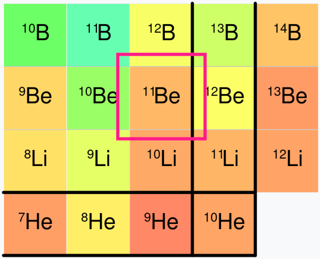
Be and Li isotopes close to the neutron drip line have been extensively studied due to their exotic properties.

Two prime examples can be showcased:

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

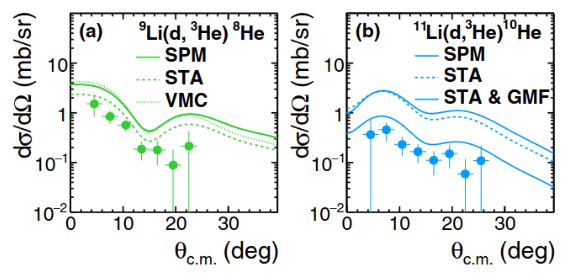


I. Talmi and I. Unna, PRL 4 (1960).



Recently gathered information

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



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

Possible **explanations**:

- Role of the many-body interactions.

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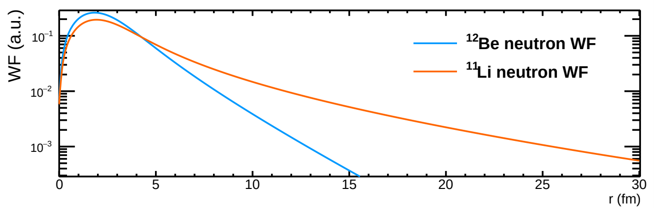


GMF of neutron w.f for ^{12}Be(d, ^{3}He)^{11}Li

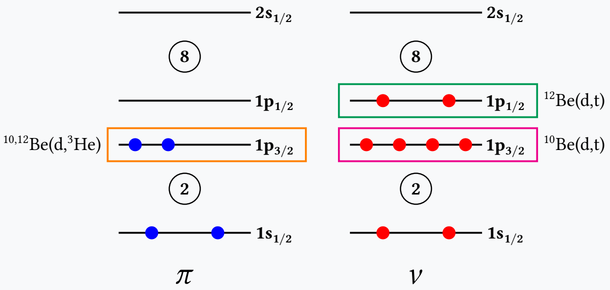
Possible **explanations**:

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

Collect more $\mathrm{d}\sigma/\mathrm{d}\Omega$ data!

Reactions to be studied

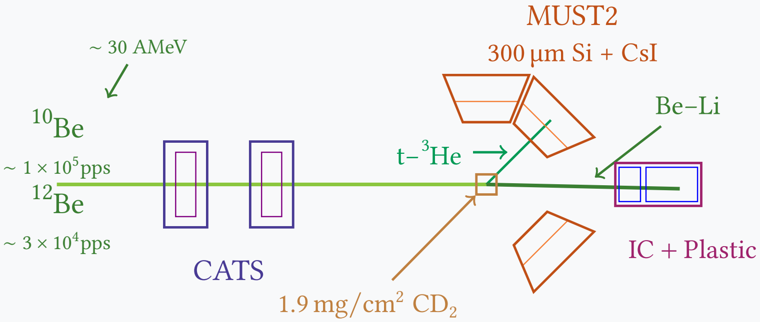
E748 at GANIL during the MUST2@LISE campaign. Neutron and proton removal reactions from ^{10,12}Be beams have been performed to probe key orbitals:



Shell model for ^{10,12}Be

Experimental setup for E748

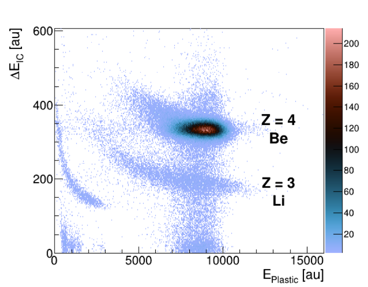
Traditional **solid target** experiment @ D6. Below a sketch of the setup:



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.

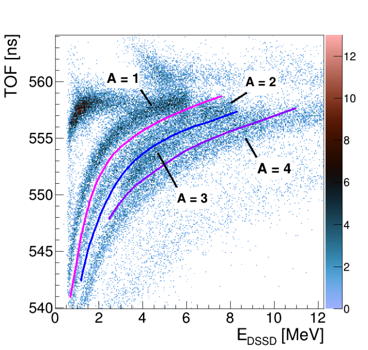


Analysis at a glance

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

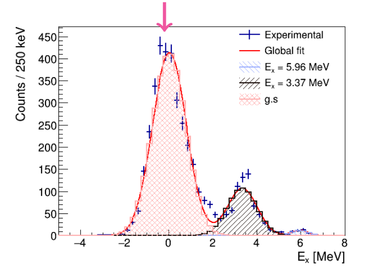
2. **Light ID**: Using only stopped particles in Si layer, but low TOF resolution. Separation of **$t-{}^3He$** attained with kinematics!

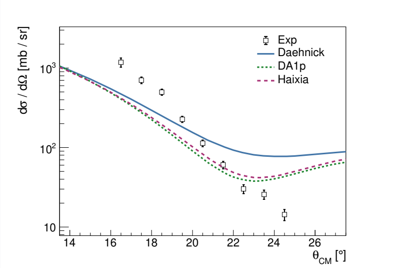
Missing mass technique:
$E_{\text{beam}} + (E,\theta)_{\text{Lab}} \rightarrow \mathbf{E_x}$



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

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





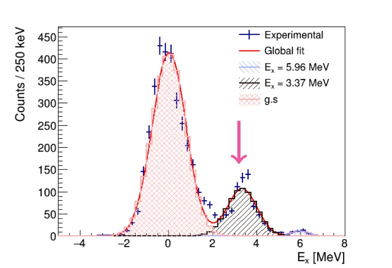
- Modern models (Haixia and DA1p) adjust better the minimum.
- Overall agreement in magnitude.

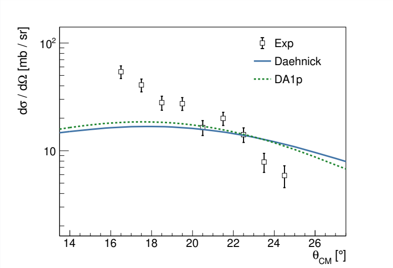
Error in **efficiency**

Proton **contamination** at low E

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

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



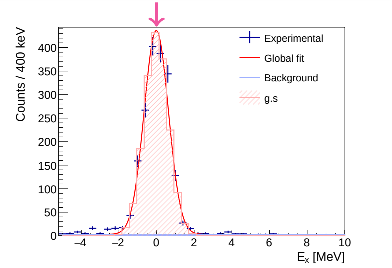


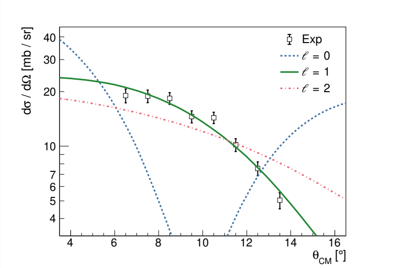
- DWBA: potential deformed in both Coulomb and nuclear parts
- Using $B(E2)$ from other experiments
- **Same** error as before?

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

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

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



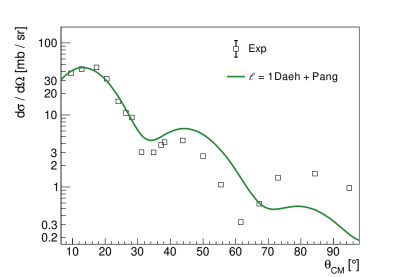


- **DWBA** with Daehnick (d) and Pang (t) OMPs
- **Best fit** is $\ell = 1$ with $j = 3/2$

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

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

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



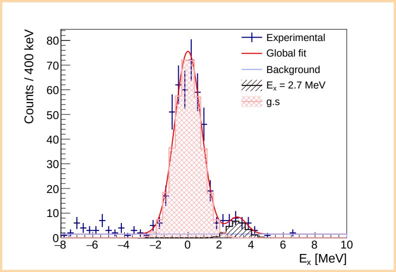
- No errors could be extracted from paper
- Poor quality at large θ_{CM}
- $C^2S = 1.951(54)$

Agreement with our results

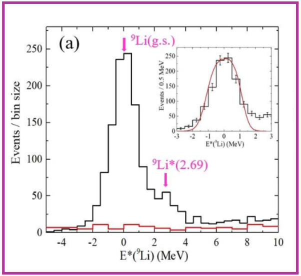
Proton removal: $^{10}\mathrm{Be}(\mathrm{d}, {}^{3}\mathrm{He})^{9}\mathrm{Li}$

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

Our experiment @ 30 AMeV



E. Y. Nikolskii et al. @ 42 AMeV

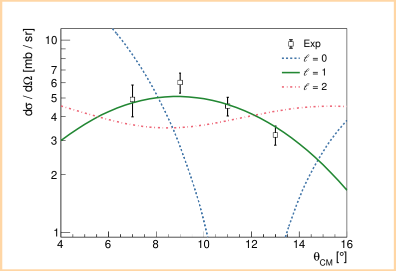


Recently published: NIMPR B 541 (2023)

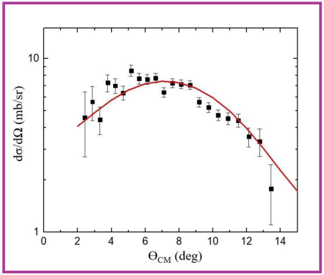
Proton removal: $^{10}\mathrm{Be}(\mathrm{d}, {}^{3}\mathrm{He})^{9}\mathrm{Li}$

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

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



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



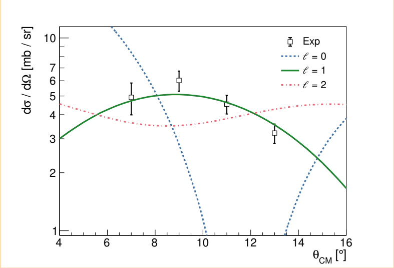
Again $\ell = 1 \implies 3/2^{-}$.
$C^2S = 1.80(11)$

Original publication:
$C^2S = 1.74$

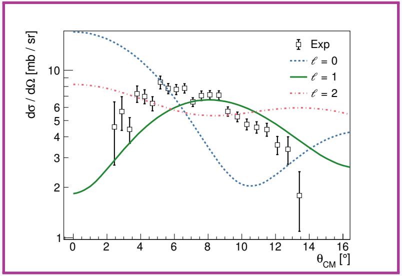
Proton removal: ^{10}Be(d, ^{3}He)^{9}Li

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

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



Reanalyis of Acculinna's data

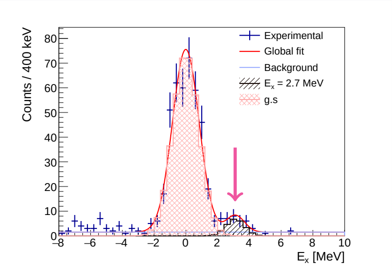


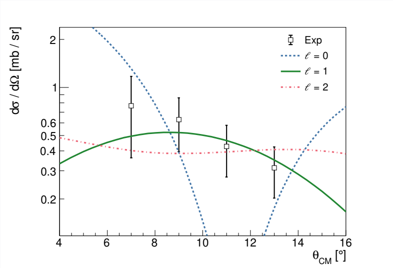
Again $\ell = 1 \implies 3/2^-$.
$C^2S = 1.80(11)$

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

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

A first excited state is also accesible.



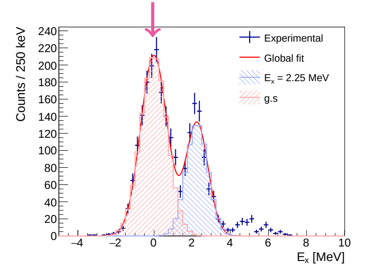


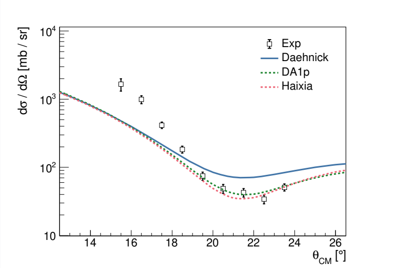
- **Best fit** is $\ell = 1$
- Assuming $j = 1/2$
- Spectroscopic factor: $0.185(36)$

New C^2S value!

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

Yet another validation method of the normalization.



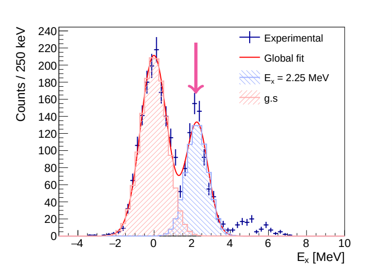


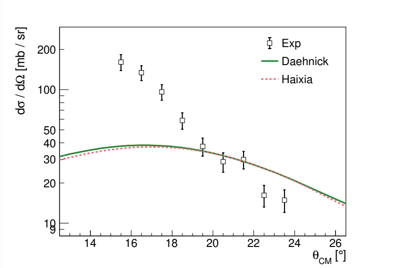
- Same behaviour as for ^{10}Be
- **Normalization** is also **fine**

Clearly the same *systematic* error

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

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

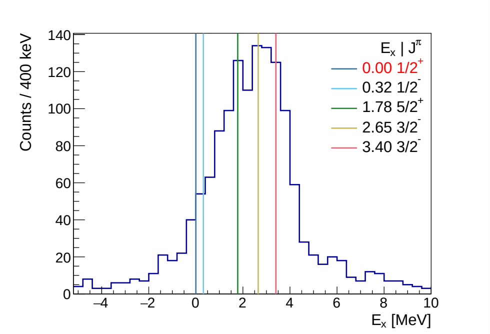




- Same procedure as before

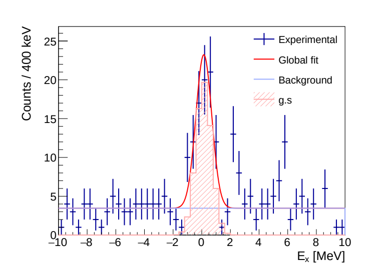
To be further investigated.
$\Rightarrow C^2S = 0.519(30)$
with Daehnick

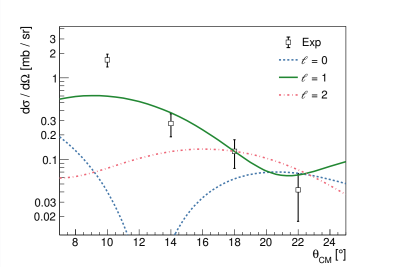
Challenging channels: $^{12}\mathrm{Be}(d,t)^{11}\mathrm{Be}$



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

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





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

Best fit $\ell = 1$
$\Rightarrow C^2S = 0.510(85)$ with Daehnick + Pang

Conclusions and outlook

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

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

Conclusions and outlook

Future prospects

Solve discrepancies in **elastic** channels

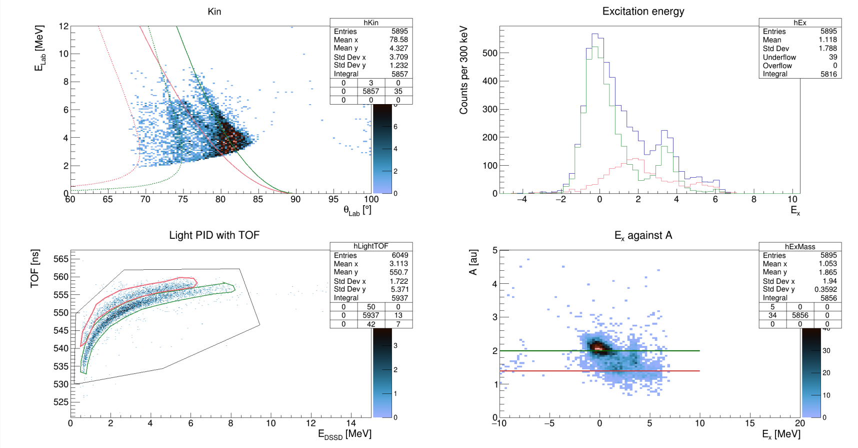
Reduce contamination in ^{3}He PID

Compare with **shell model** calculations

Thanks for your attention!
And special thanks to the ***E748*** collaboration.

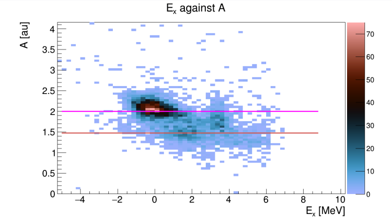
Not part of the talk!

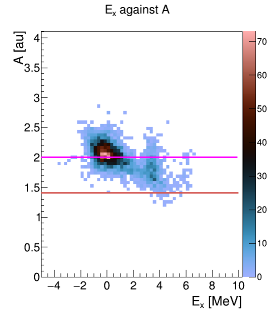
Proton contamination



Proton contamination

And regarding the masses:

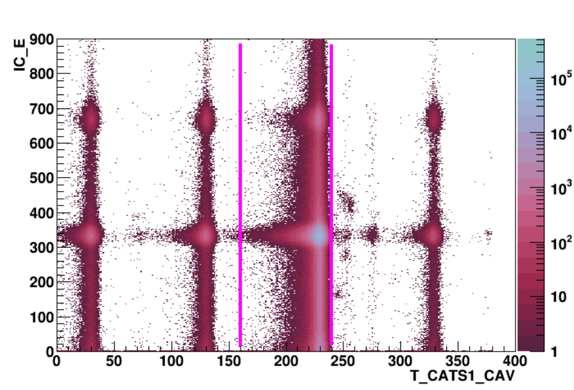




Left: All data in ToF spectrum. Right: Gate on d

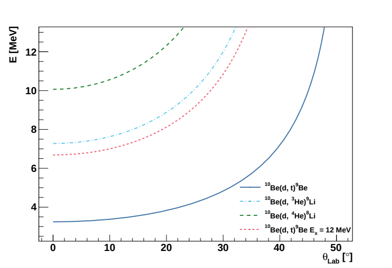
Beam ID

Using Caviar to CATS1 TOF and energy loss in IC

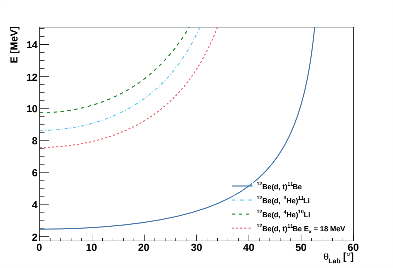


For ^{10}Be

Kinematic lines



For ^{10}Be beam



For ^{12}Be beam