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

LISE Workshop 2024

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on behalf on the E748 collaboration

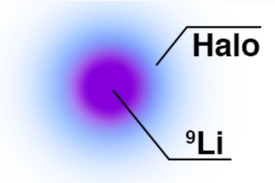
IGFAE–USC and LPC–Caen

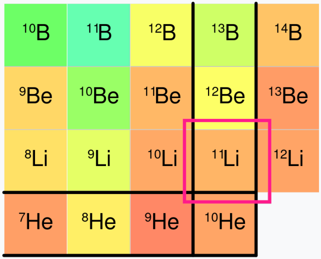
Overview of the exotic Be-Li region

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.





Overview of the exotic Be-Li region

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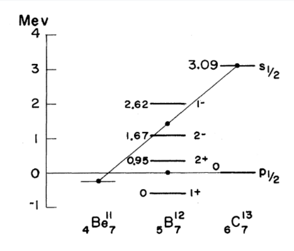
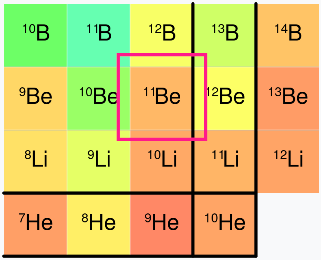
Two prime examples can be showcased:

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

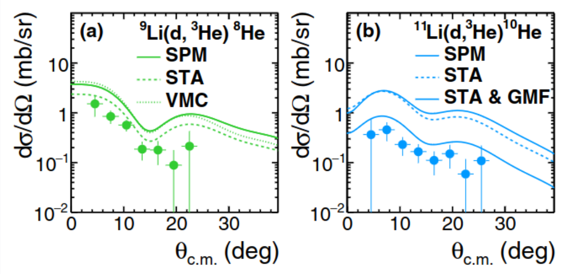


I. Talmi and I. Unna, PRL 4 (1960).



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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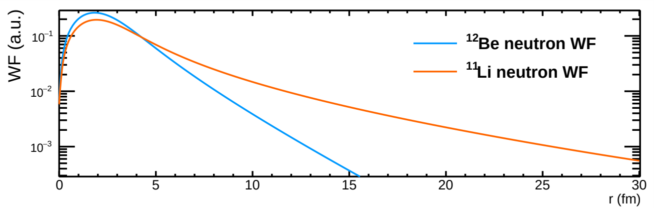


GMF of neutron w.f for $^{12}\mathrm{Be}(d, {}^3\mathrm{He})^{11}\mathrm{Li}$

Possible **explanations**:

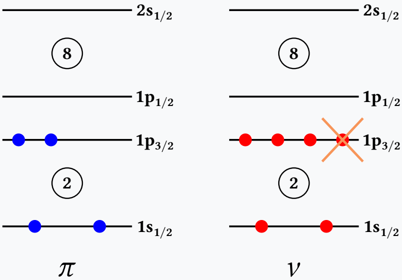
- Role of the many-body interactions.
- Overestimation of the nuclear overlap $\langle {}^{9,11}\mathrm{Li} | {}^{8,10}\mathrm{He} \rangle$.

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

Reactions to be studied

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

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



*^{10}**Be** shell model.*

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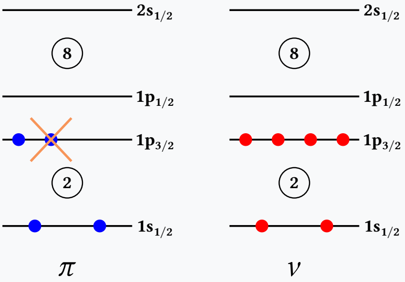

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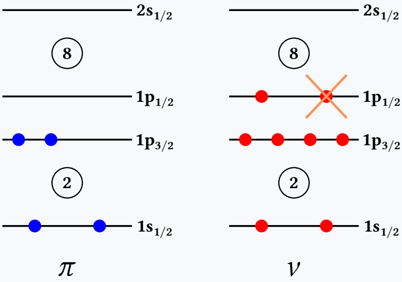

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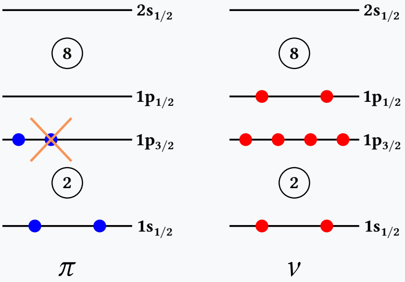
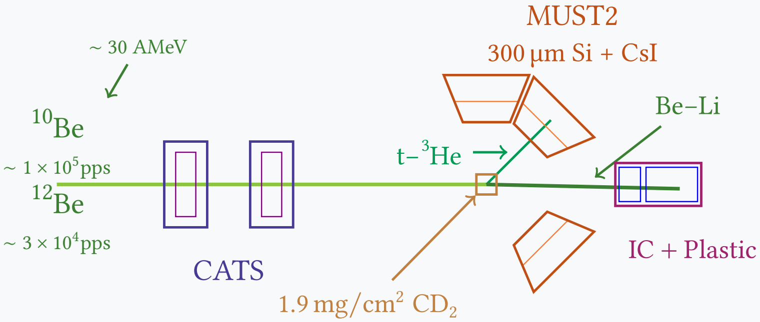
- **^{12}Be(d, ^{3}He)^{11}Li**: same p-orbital as before.



^{12}***Be*** *shell model.*

Experimental setup for E748

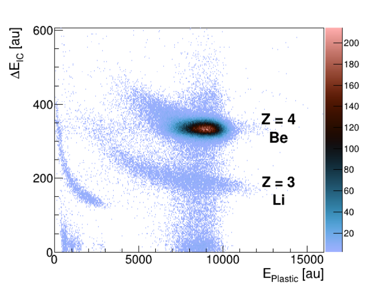
Traditional **solid target** experiment @ D6. Below a sketch of the setup:



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.

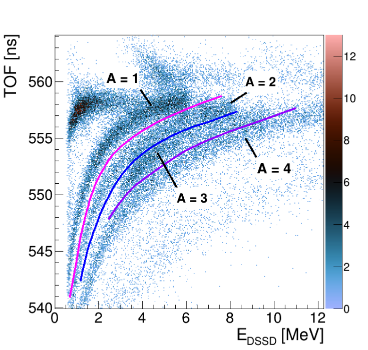


Analysis at a glance

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

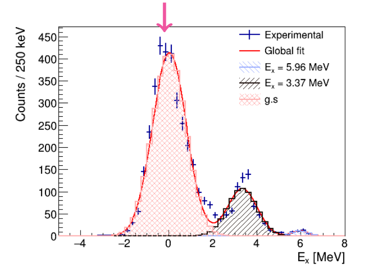
2. **Light ID**: Using only stopped particles in Si layer, but low TOF resolution. Separation of **$t - {}^3He$** attained with kinematics!

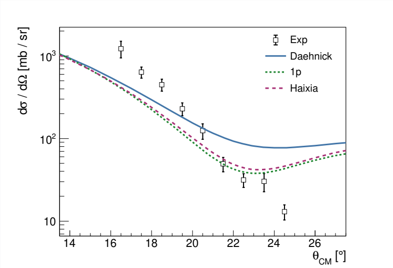
Missing mass technique:
$E_{\mathrm{beam}} + (E, \theta)_{\mathrm{Lab}} \to \mathbf{E_x}$



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 to the data.
- Failure at low and high angles.
- Overall agreement in magnitude.

Likely to be a miscalculation in **efficiency**

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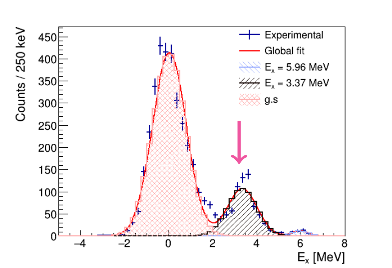
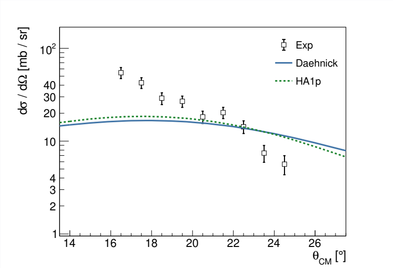
Cross-section for the 1st excited state is also achievable.



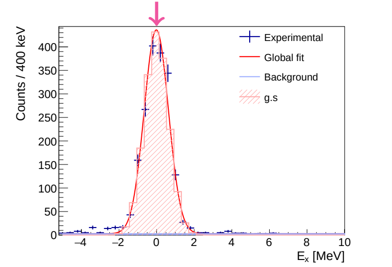


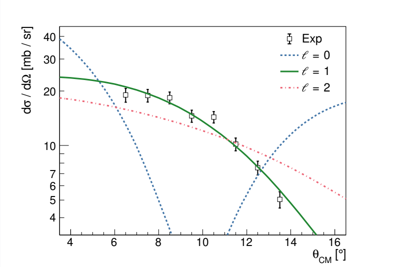
- Potential deformed in both Coulomb and nuclear parts
- Using $B(E2)$ for other experiments.

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

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

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





Theoretical calculations with **DWBA**:

- Daehnick + Pang OMPs.
- Only single-particle overlaps.
- Finite range calculation.

Best fit is $\ell = 1$
with $j = 3/2$.
$\Rightarrow C^2S = 1.522(44)$

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

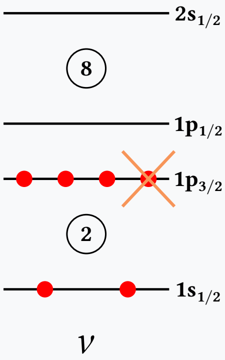
Needs reformulation!! In light of those results, two conclusions may be drawn:

- ^{9}Be **g.s** tagged as $3/2^{-}$ state.
- $C^2S = 2.21(9) < 4$ could be due to:

  $\Rightarrow$ Strength shared with other excited states.

- Excellent agreement with D. L. Auton et al. Nucl. Phys. A 1 (1970):

$$C^2S = 2.19(48)$$

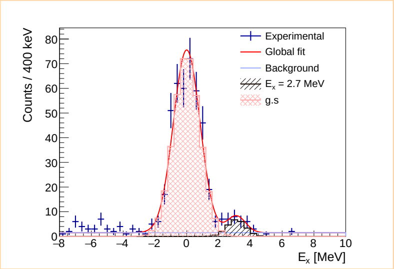


Neutron shells of ^{10}Be.

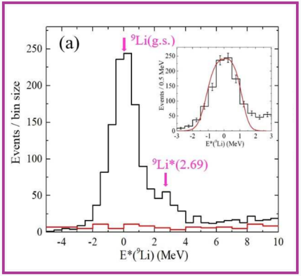
Proton removal: $^{10}\mathrm{Be}(d, {}^{3}\mathrm{He})^{9}\mathrm{Li}$

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)

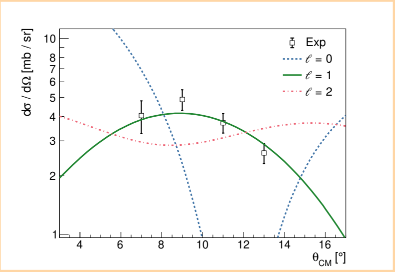
A **second** excited state is observed!

No longer true (CsI disabled)

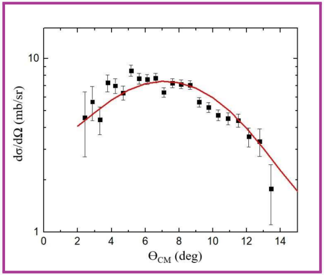
Proton removal: $^{10}\mathrm{Be}(\mathrm{d}, {}^{3}\mathrm{He})^{9}\mathrm{Li}$

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 $\ell = 1 \implies 3/2^-$.
$C^2S = 1.456(93)$

Original publication:
$C^2S = 1.74$

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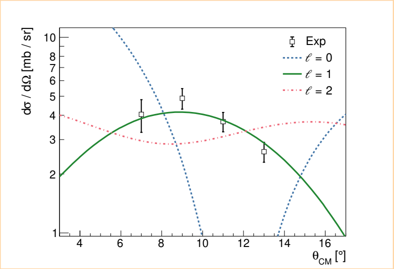
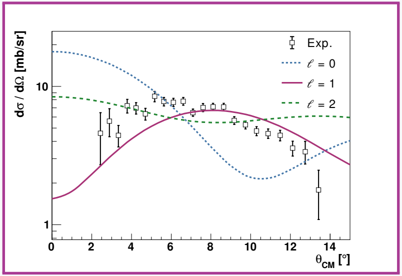


Reanalyis of Acculinna's data

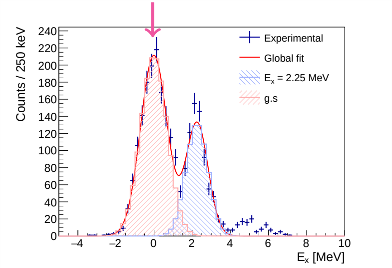


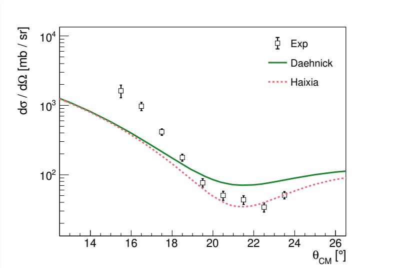
Again $\ell = 1 \implies 3/2^-$.
$C^2S = 1.456(93)$

$\ell = 1 \implies C^2S = 3.13(6)$
Different **input parameters** in the models!

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

Yet another validation method of the normalization.





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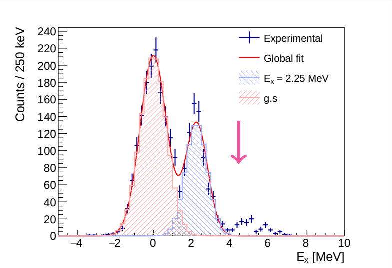

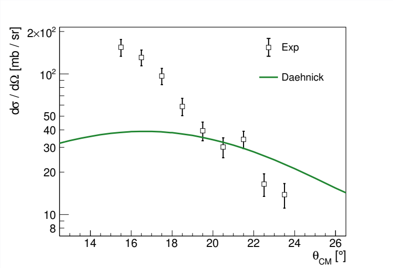

- Potential deformed in both Coulomb and nuclear parts
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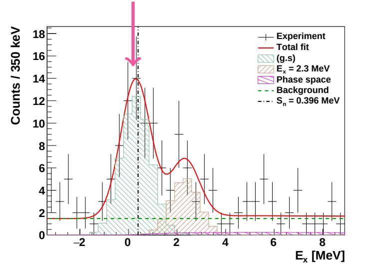
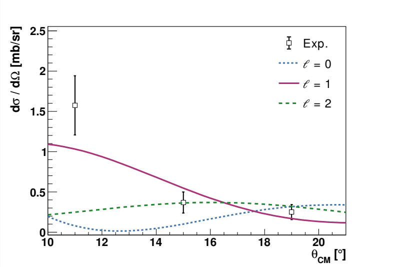
To be further investigated.
$\Rightarrow C^2S = 0.519(30)$ with Daehnick

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

Two states are populated despite low stats. Angular distribution for **g.s** in $\theta_{CM} \in [10, 20]\,°$





- **Further** developments are needed, but a tentative $\ell = 1$ shape is recognized for the **g.s** $\implies 3/2^-$.
- J^π not known for state at 2.3 MeV $\implies$ feasible in the future?

Conclusions and outlook

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

- $^{10}\mathrm{Be}(\mathrm{d},\mathrm{t})^{9}\mathrm{Be}$ shows a clear $p_{3/2}$ orbital with $C^2S = 2.21(9)$.
- In $^{10}\mathrm{Be}(\mathrm{d},{}^{3}\mathrm{He})^{9}\mathrm{Li}$ three states are present and g.s. tagged as $p_{3/2}$.
- In $^{12}\mathrm{Be}(\mathrm{d},{}^{3}\mathrm{He})^{11}\mathrm{Li}$ a *tentative* $p_{3/2}$ could be assigned to the g.s.

Future prospects

Extract $\frac{d\sigma}{d\Omega}$ for **excited** states.

In-detail study of $^{12}\mathrm{Be}(\mathrm{d},\mathrm{t})^{11}\mathrm{Be}$.

Comprehensive analysis of the employed **reaction model**.

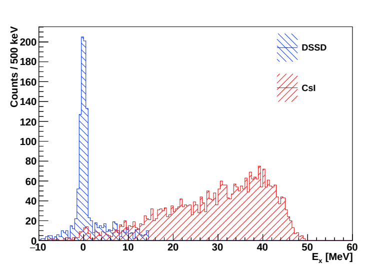
Thanks for your attention!

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

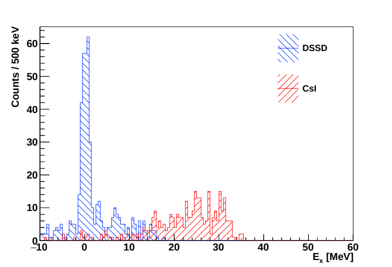
Not part of the talk!

CsI on or off?

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



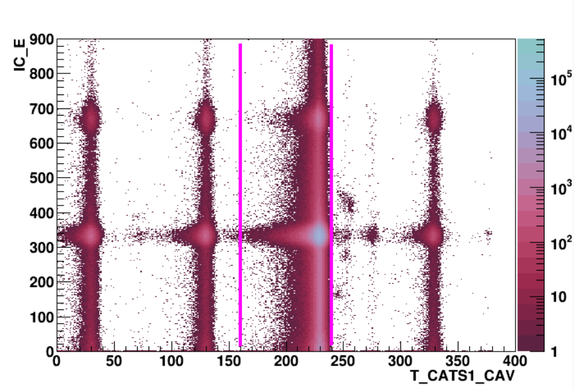
For $^{10}Be(d,t)^{9}Be$



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

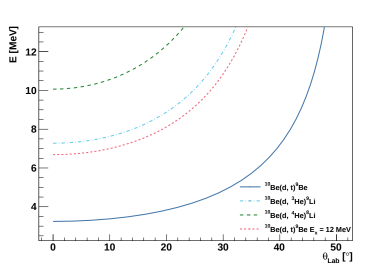
Beam ID

Using Caviar to CATS1 TOF and energy loss in IC

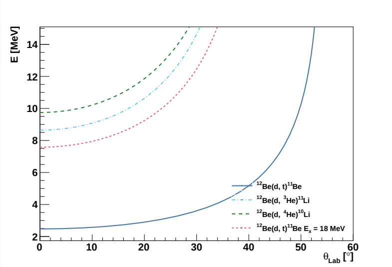


For ^{10}Be

Kinematic lines



For ^{10}Be beam



For ^{12}Be beam