Quenching of spectroscopic factors in ^{10,12}Be(d, ^{3}He) reactions

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USC-IGFAE and LPC-Caen

ASTRANUCAP and CPAN Days 2024

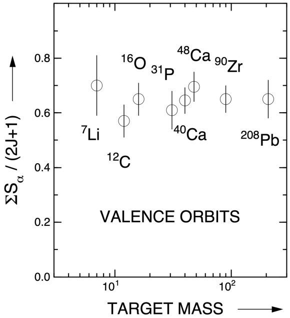
A recap on spectroscopic factors

Spectroscopic factors shed light on the occupancy of single-particle states:

$$\left.\frac{d\sigma}{d\Omega}\right|_{exp} = C^2 S \cdot \left.\frac{d\sigma}{d\Omega}\right|_{s.p}, \quad \sum C^2 S = (2j+1) \text{ in IPSM}$$

Experimentally:
Reduction of $\sim 65\,\%$!

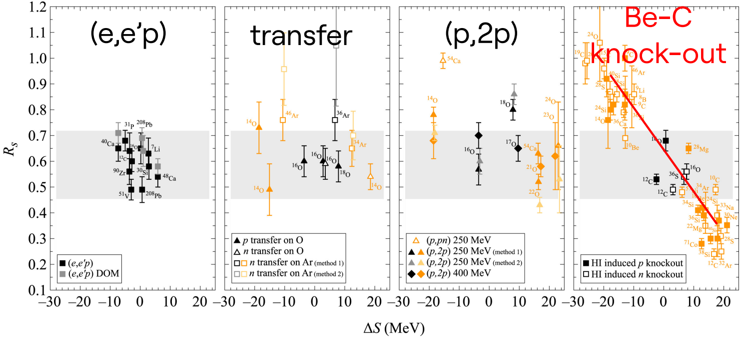
- **Short-range** correlations: tensor forces,...
- **Long-range**: vibrations, giant resonances,...



L. Lapikás, Nuclear Phys. A 553 (1993)

A long-standing puzzle

A trend with asymmetry energy $\Delta S \equiv S_n - S_p$ is found depending on the experimental **probe**!

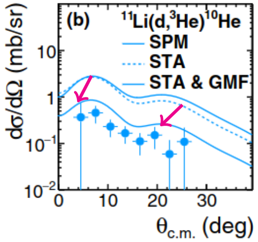


T. Aumann et al. Prog. Part. Nucl. Phys. 118 (2021)

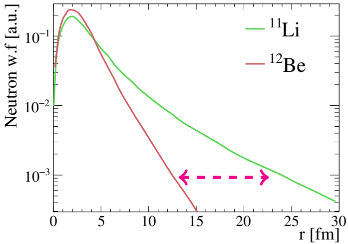
⇒ measure towards more exotic nuclei: $|\Delta S| \uparrow$

Importance of GMF

Towards exotic nuclei (loosely bound or halo), a ***geometrical mismatch factor*** emerges from the very different w.f. in the overlap:



A.Matta et al., Phys. Rev. C 92 (2015)



N. K. Timofeyuk, private communication (in E748 proposal)

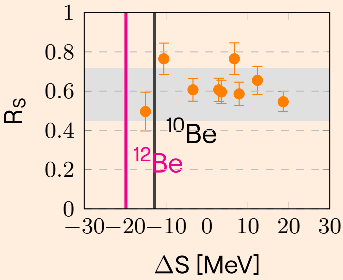
$\Rightarrow$ Need to correct C^2S by its value!

Physics case of E748

E748 @ GANIL back in 2017. Using ^{10,12}Be(d,^{3}He) reactions to:

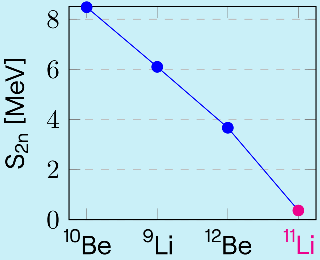
R_S and ΔS dependence:

- $\left\langle {}^{10}\text{Be} \middle| {}^{9}\text{Li} \right\rangle, \Delta S = -12.8\,\text{MeV}$
- $\left\langle {}^{12}\text{Be} \middle| {}^{11}\text{Li} \right\rangle, \Delta S = -19.8\,\text{MeV}$



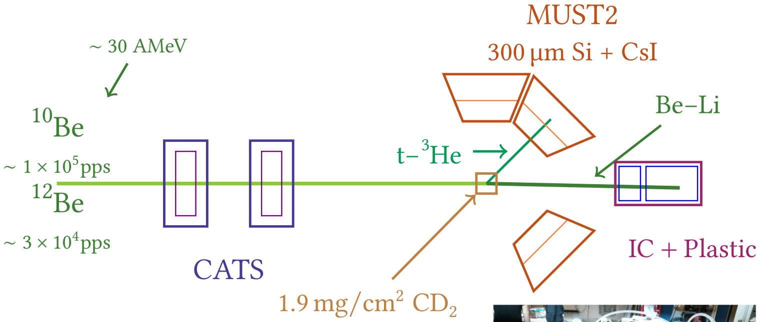
Explore effects of GMF:

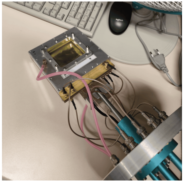
- $\left\langle {}^{10}\text{Be} \middle| {}^{9}\text{Li} \right\rangle$, GMF ~ 1
- $\left\langle {}^{12}\text{Be} \middle| {}^{11}\text{Li} \right\rangle$, GMF $\sim 0.5?$

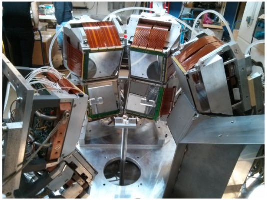


Experimental technique

Tradional solid target experiment @ LISE

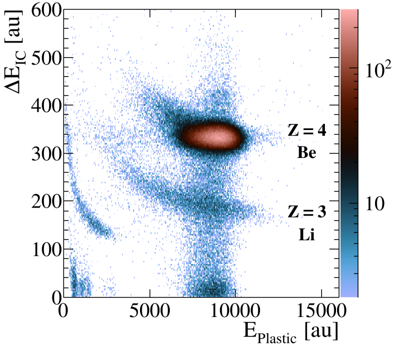




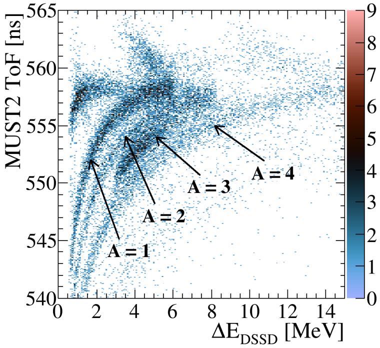


A glance at the analysis

1 **Heavy** ID at 0°



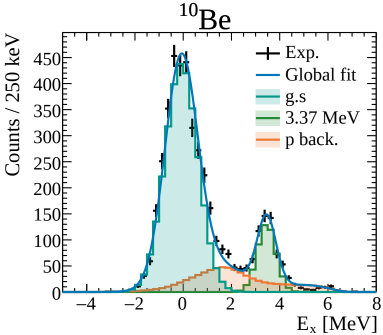
2 **Light** PID in DSSD

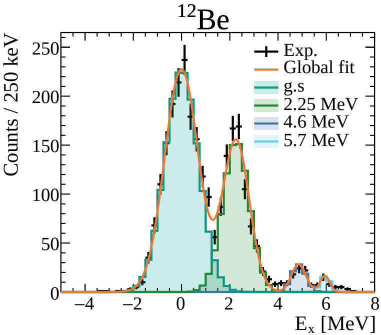


3 E_x from **missing mass technique**

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

Results: Elastic $^{10,12}Be(d,d)^{10,12}Be$





Results: Elastic ^{10,12}Be(d,d)^{10,12}Be

Experimental cross-section formula:

$$\frac{d\sigma}{d\Omega} = \frac{N}{N_{\text{beam}} N_{\text{targets}} \epsilon \Delta\Omega} = \frac{N}{N_{\text{beam}} \alpha \epsilon_{\text{np}} \Delta\Omega}$$

1 **Target thickness** not measured during experiment:

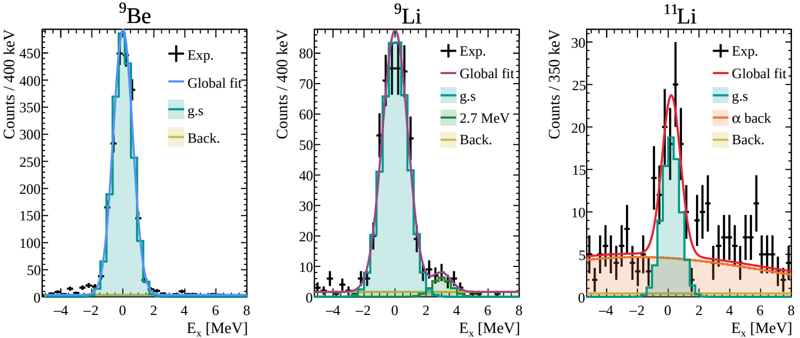
- Set it from normalization of elastic
- **Ongoing**: fix it from simulation

2 ZDD had a poor performance. Averaged ϵ:

- IC: $30\,\%$
- Plastic: $50\,\%$

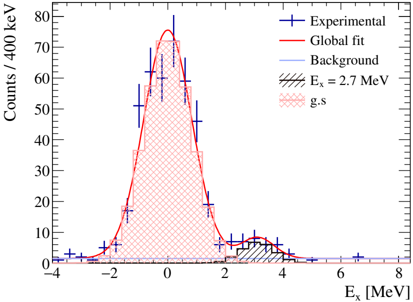
From **npsimu**: $\epsilon_{\text{np}} = \epsilon_{\text{geo, MUST2}} \cdot \epsilon_{\text{reconstruction}} \cdot \epsilon_{\text{geo, ZDD}}$
Agglutinate missing factors: $\alpha = N_{\text{targets}} \cdot \epsilon_{\text{instrinsic, ZDD}} \cdot \epsilon_{\text{other?}}$

Results: transfer channels



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

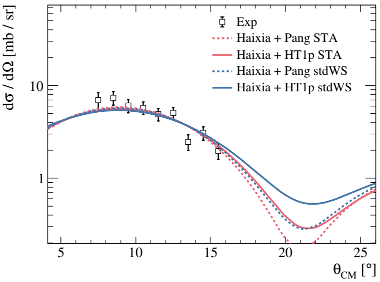
Excitation energy spectrum with all data:



Counts per θ_{CM} bin $\Rightarrow$ **Angular distribution**
Theo. model: finite-range **DWBA** in *FRESCO* code

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

Ground state: known $3/2^{-}$ $(\ell = 1)$



OMP:

- In: Haixia *H. An et al. PRC 73 (2006)*
- Out: Pang and HT1p *D. Y. Pang et al., PRC 79, 91 (2009, 2015)*

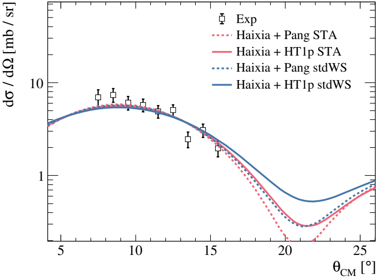
1 $\left\langle {}^{10}\text{Be} \middle| {}^{9}\text{Li} \right\rangle$

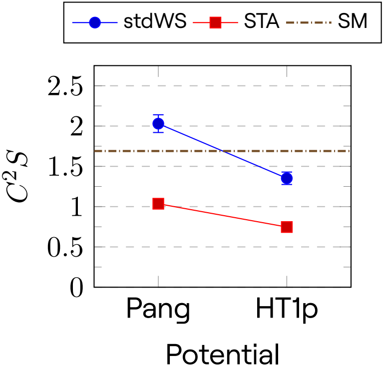
- A standard Wood-Saxon
- The novel source-term approach (STA) *N. Timofeyuk PRC 81 (2010)*

2 $\left\langle \text{d} \middle| {}^{3}\text{He} \right\rangle$: Accurate GFMC

I. Brida et al., PRC 84 (2011)

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





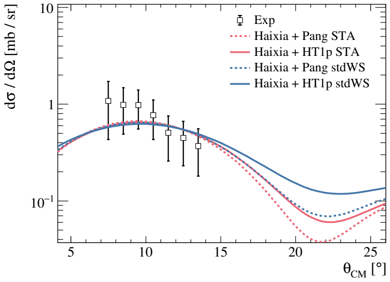
- stdWS yields twice the STA SF
- Sensitivity to r_0 to be further investigated

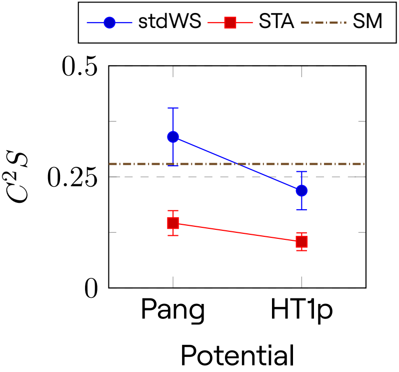
  F. Flavigny et al., PRC 97 (2018)

Shell model calculation with SFO-tls interaction: $C^2S = 1.69$

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

The **first** excited state $1/2^-$ ($\ell = 1$) is also accessible.



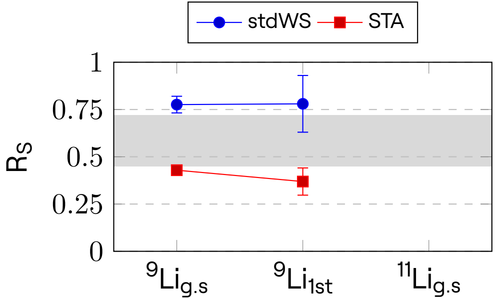


- **First** direct measurement!
- Same trends as for g.s.

Shell model with SFO-tls:
$C^2S = 0.279$

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

The reduction factor $R_S = C^2 S_{exp}/C^2 S_{SM}$ is computed:

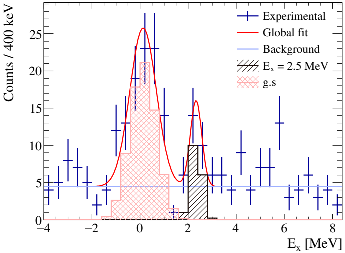


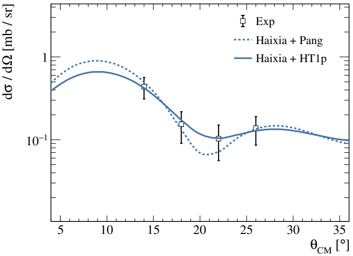
Compatible with accepted values for R_S in transfer

Systematic $50\,\%$ difference STA−stdWS

Results: $^{12}Be(d,{}^{3}He)^{11}Li$

So far only the **ground state** $3/2^-$ $(\ell = 1)$ is analyzed.



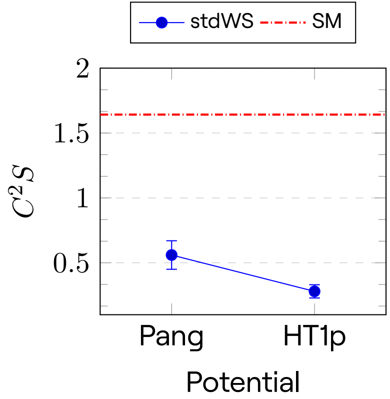


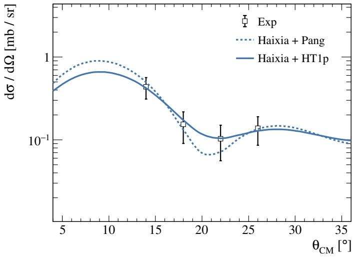
Much lower cross section!

Expected sizeable contribution of GMF

Results: ^{12}Be(d,^{3}He)^{11}Li

So far only the **ground state** $3/2^-$ ($\ell = 1$) is analyzed.



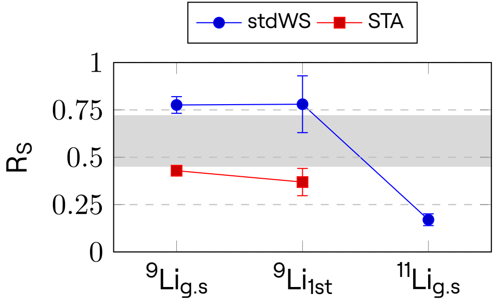


STA **not available** yet!

Shell model with SFO-tls:
$C^2S = 1.642$

Results: $^{12}Be(d,^{3}He)^{11}Li$

The reduction factor $R_S = C^2 S_{exp}/C^2 S_{SM}$ is computed:



- $17(3)$ % **reduction**!
- Need to correct for **GMF** (ongoing)

- **STA** still in development
- **stdWS** requires physical constraints to r_0

Conclusions

Angular distributions for ^{10,12}Be(d,^{3}He) have been extracted and compared with DWBA

Found strong sensitivity to nuclear overlap: stdWS or newer STA

R_S for $\left\langle {}^{10}\mathrm{Be} \middle| {}^{9}\mathrm{Li} \right\rangle$ in agreement with systematics

R_S for $\left\langle {}^{12}\mathrm{Be} \middle| {}^{11}\mathrm{Li} \right\rangle$ displays a strong reduction linked to GMF

Acknowledgments

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- LPC-Caen:
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  N. Orr
- IJCLab:
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  M. Assié
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  A. Meyer
  I. Stefan
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  M. Rejmund
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  O. Sorlin
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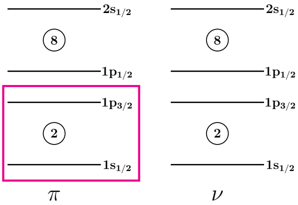
  B. Bastin
  F. de Oliveira
  C. Stodel
- RIKEN:
  S. Koyama
  D. Suzuki
- Surrey:
  N. Timofeyuk

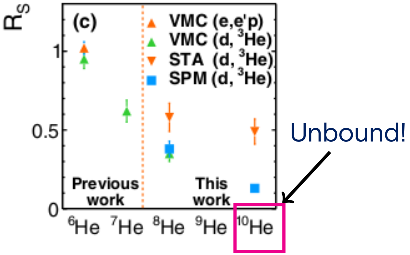
Backup

Status with light isotopes

Several experiments allowed for the extraction of C^2S with Li-induced (d, ^{3}He) reactions:

Explored region





A. Matta et al., Phys. Rev. C 92 (2015)

Several challenges in this region:

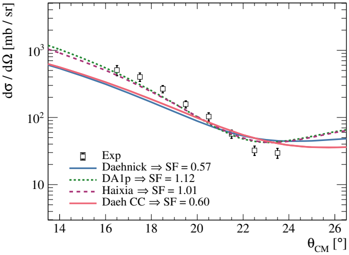
1 Dealing with **unbound** nuclei (^{10}He)

2 Many-body dynamics and/or core excitations

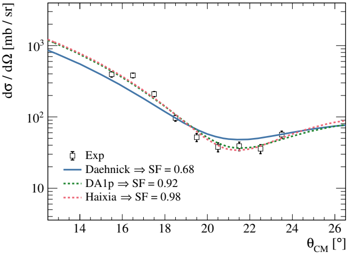
Elastic cross sections

Normalization of all cross-sections was obtained from fits to the elastic data using the Haixa potential.

^{10}Be(d,d)

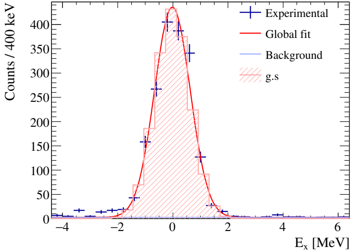


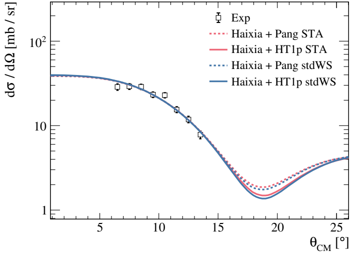
^{12}Be(d,d)



Best OMP: new ones DA1p and Haixia!

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

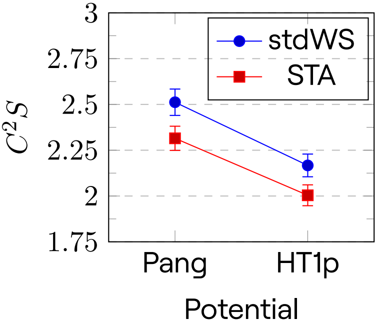


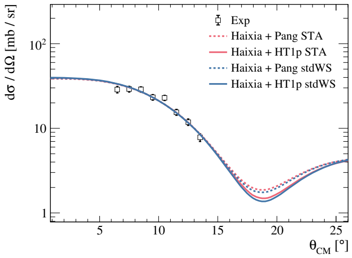


Same behaviour as for the other channels

Match with $\sim 65\,\%$ reduction if $C^2 S_{\mathrm{SM}} = 3.1$
Not likely!

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



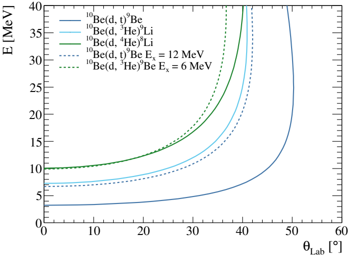


Same behaviour as for the other channels

Match with ~ 65 % reduction if $C^2 S_{\mathrm{SM}} = 3.1$
Not likely!

Kinematical lines

^{10}Be



^{12}Be