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

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USC-IGFAE, LPC-Caen and FRIB

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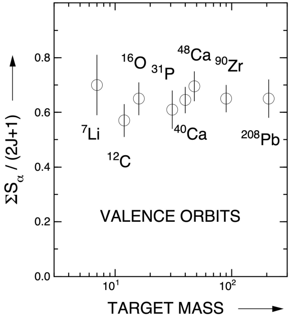
A recap on spectroscopic factors

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

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

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

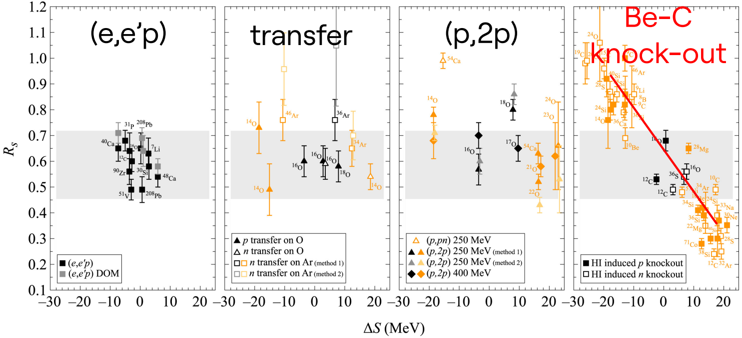
- **Short-range** correlations: tensor forces,...
- **Long-range**: vibrations, giant resonances,...



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**!

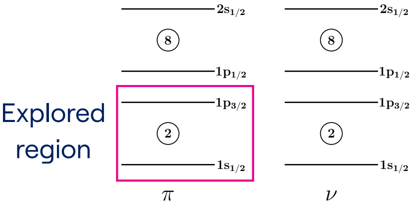


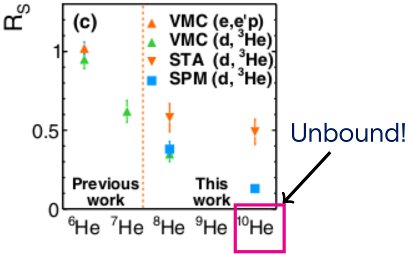
T. Aumann et al. Prog. Part. Nucl. Phys. 118 (2021)

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

Status with light isotopes

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





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

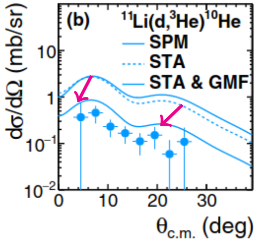
Several challenges in this region:

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

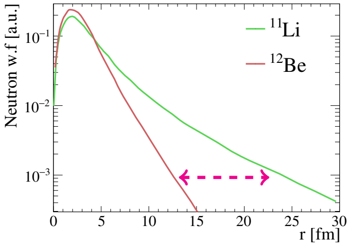
2 Many-body dynamics and/or core excitations

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)

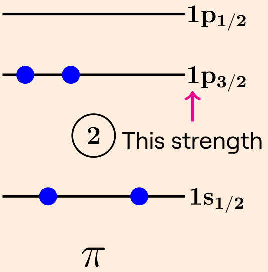
$\Rightarrow$ Need to establish more systematics for this parameter

Physics case of E748

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

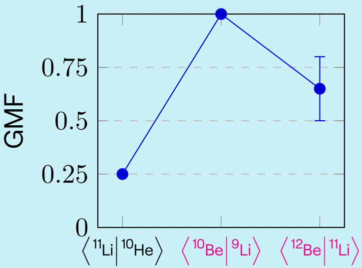
Overlaps:

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



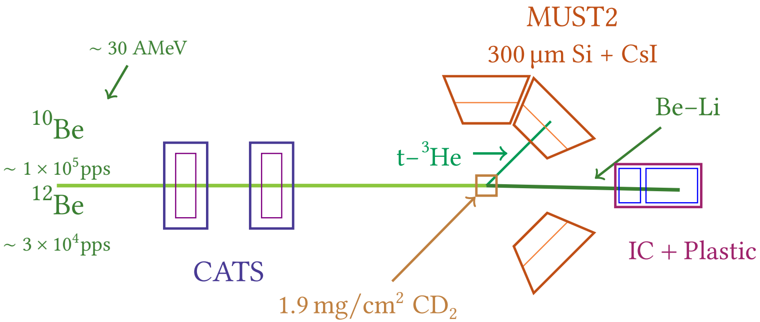
Explore effects of GMF:

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



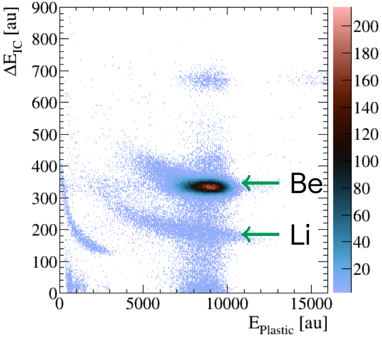
Experimental setup

Tradional solid target experiment @ LISE

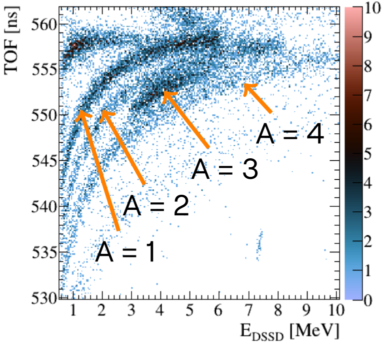


A glance at the analysis

1 **Heavy** ID at 0°



2 **Light** PID in DSSD

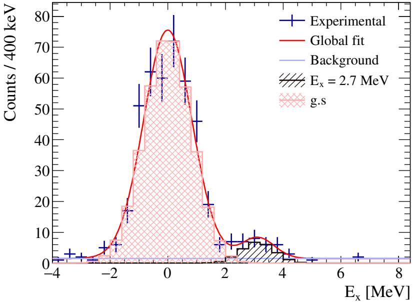


3 E_x from **missing mass technique**

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

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

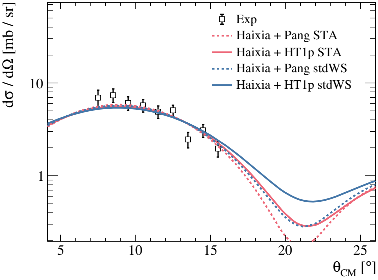
Excitation energy spectrum with all data:



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:

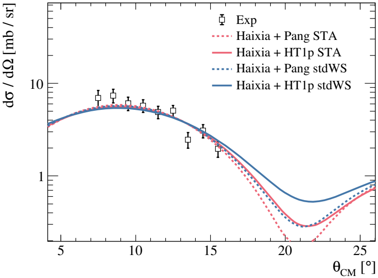
- In: Haixia *H. An et al. PRC 73 (2006)*
- Out: Pang and HT1p *D. Y. Pang et al., PRC 79, 91 (2009, 2015)*

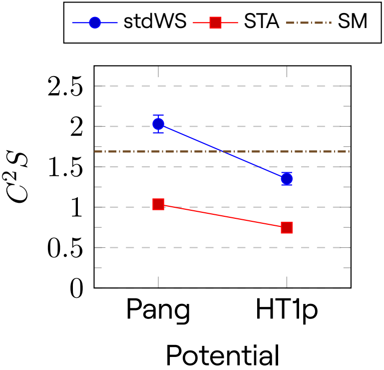
1 $\langle {}^{10}\mathrm{Be} | {}^{9}\mathrm{Li} \rangle$

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

2 $\langle \mathrm{d} | {}^{3}\mathrm{He} \rangle$: Accurate GFMC
I. Brida et al., PRC 84 (2011)

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





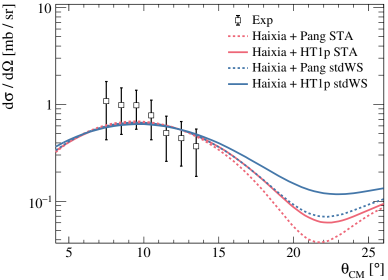
- stdWS yields twice the STA SF
- Sensitivity to r_0 to be further investigated

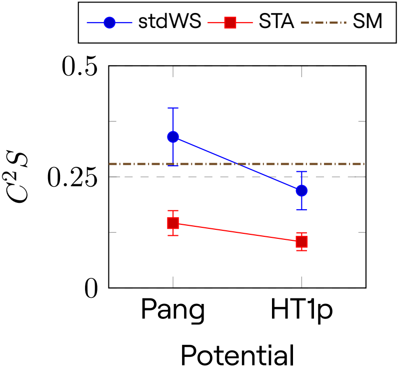
F. Flavigny et al., PRC 97 (2018)

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.



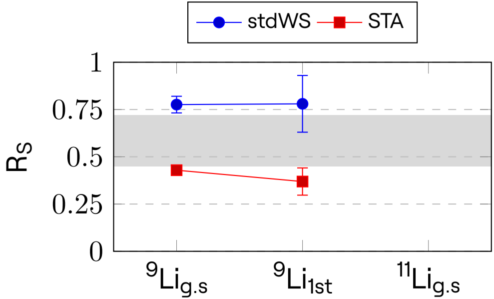


- **First** direct measurement!
- Same trends as for g.s.

Shell model:
$C^2S = 0.279$

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

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

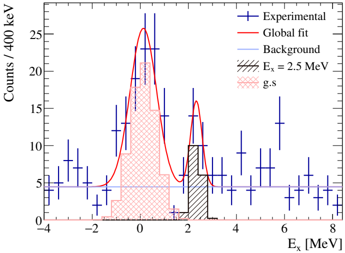


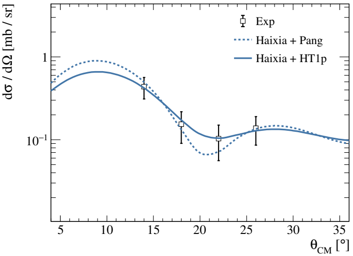
Compatible with accepted values for R_S in transfer

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.



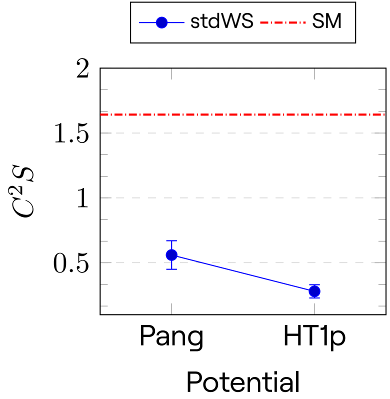


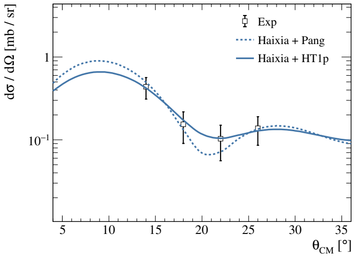
Much lower cross section!

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.



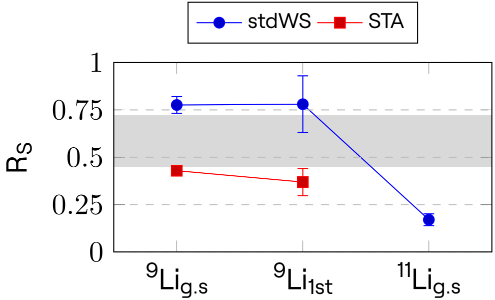


STA **not available** yet!

Shell model:
$C^2S = 1.642$

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

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



- $17(3)$ % **reduction**!
- Largest GMF only recovers up to ~ 35 %

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

Conclusions

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

Found strong sensitivity to nuclear overlap: stdWS or newer STA

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

R_S for $\langle {}^{12}\mathrm{Be} | {}^{11}\mathrm{Li} \rangle$ displays a ~ 17 % reduction likely related to GMF

Acknowledgments

The E748 collaboration:

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  C. Stodel
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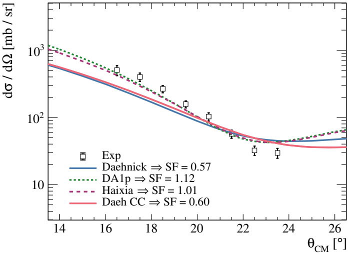
  D. Suzuki
- Surrey:
  N. Timofeyuk

Backup

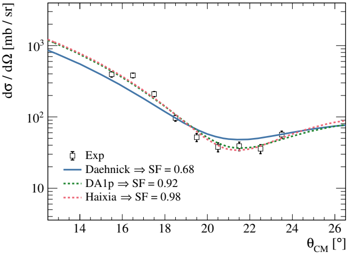
Elastic cross sections

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

^{10}Be(d,d)

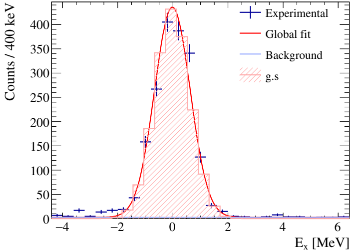


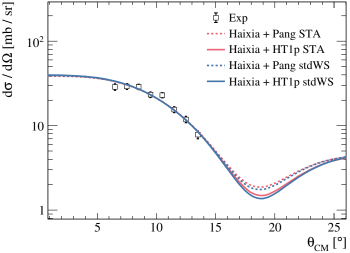
^{12}Be(d,d)



Best OMP: new ones DA1p and Haixia!

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

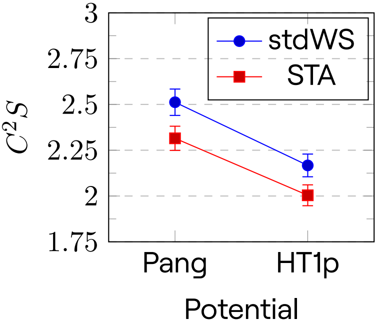


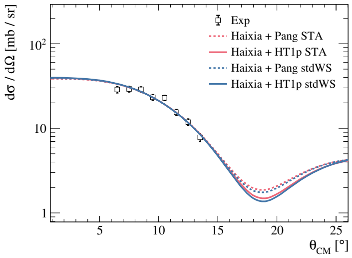


Same behaviour as for the other channels

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

Kinematical lines