



INSTITUTO GALEGO  
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DE ALTAS ENERXÍAS

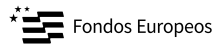
25 → \* 1999  
2024

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

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USC-IGFAE and LPC-Caen

ASTRANUCAP and CPAN Days 2024



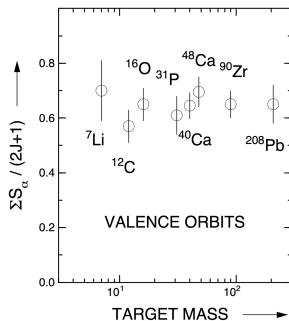
# A recap on spectroscopic factors

**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!**

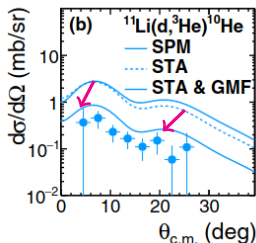


*T. Aumann et al. Prog. Part. Nucl. Phys. 118 (2021)*

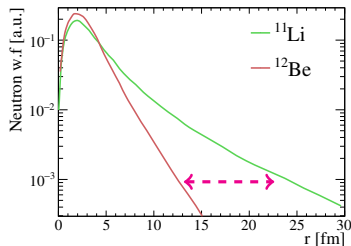
⇒ measure towards more exotic nuclei:  $|\Delta S| \uparrow$

# 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)

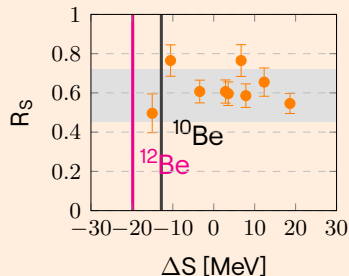
⇒ Need to correct  $C^2S$  by its value!

# Physics case of E748

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

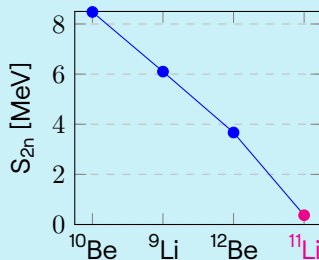
$R_S$  and  $\Delta S$  dependence:

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



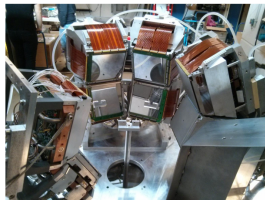
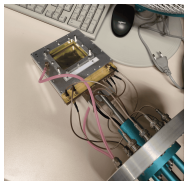
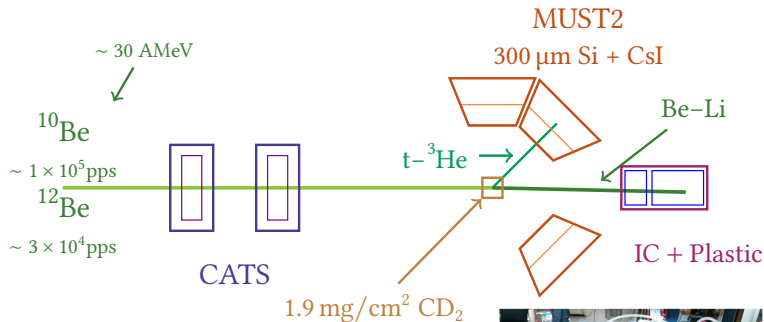
Explore effects of GMF:

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



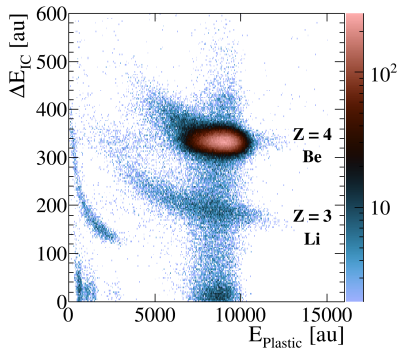
# Experimental technique

## Traditional solid target experiment @ LISE

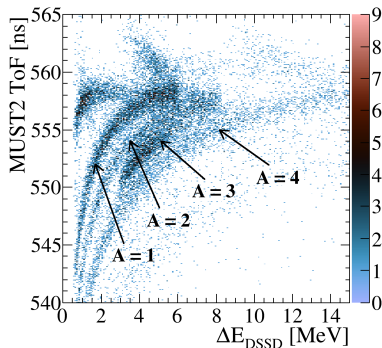


# A glance at the analysis

## 1 Heavy ID at 0°



## 2 Light PID in DSSD

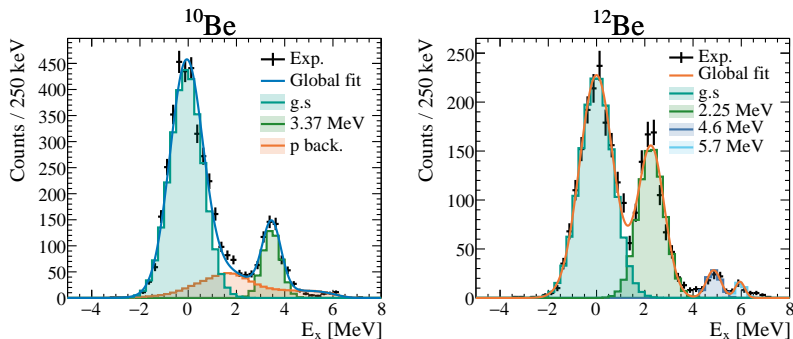


## 3 $E_x$ from missing mass technique

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

# Results: (In)elastic $^{10,12}\text{Be}(d,d)^{10,12}\text{Be}$

The **ground state** provides a means to test our normalization



First  $2^+$  is seen in both cases but not yet exploited!



# Results: (In)elastic $^{10,12}\text{Be}(\text{d},\text{d})^{10,12}\text{Be}$

Experimental cross-section formula:

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

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

- Set it from normalization of elastic

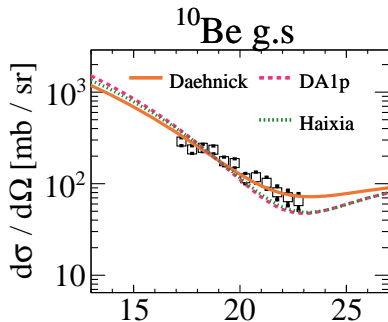
**2 ZDD** had a poor performance.

- $\epsilon \sim 20\text{--}30\%$

Agglutination of unknown factors:  $\alpha = N_{\text{targets}} \cdot \epsilon_{\text{intrinsic, ZDD}}$

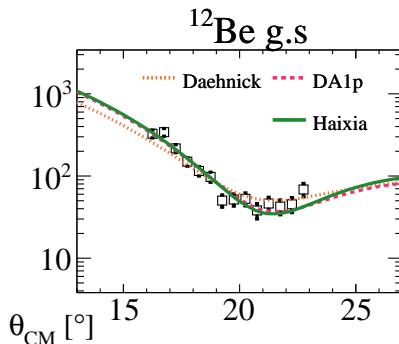
# Results: (In)elastic $^{10,12}\text{Be}(d,d)^{10,12}\text{Be}$

The best OMP potentials can also be deduced from the fit quality.



$^{10}\text{Be} + d$ : **Daehnick**

*W. Daehnick et al. PRC 21 (1980)*

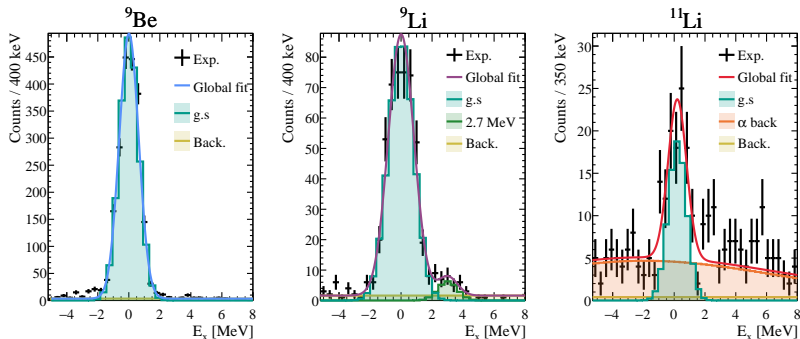


$^{12}\text{Be} + d$ : **Haixia**

*H. Ann, C. Cai. PRC 73 (2006)*

# Results: transfer

The **ground states** of the heavy recoils are populated.



**First state at 2.7 MeV of  ${}^9\text{Li}$  is seen too!**

# Results: transfer

**Fresco** is employed to perform the **DWBA** calculations.

## 1 OMP:

- In: set from elastic

- Out: Pang or HT1p

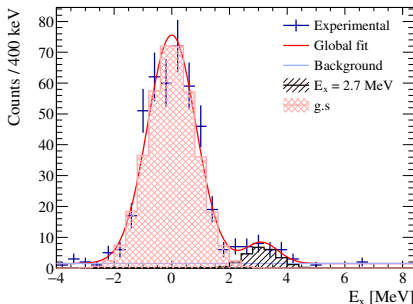
*D. Y. Pang et al., PRC 79, 91 (2009, 2015)*

## 1 Light overlap $\langle d|t, {}^3\text{He} \rangle$ : Accurate GFMC

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

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

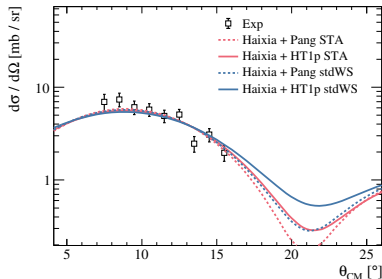
Excitation energy spectrum with all data:



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

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

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



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

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

OMP:

■ In: Haixia *H. An et al. PRC 73 (2006)*

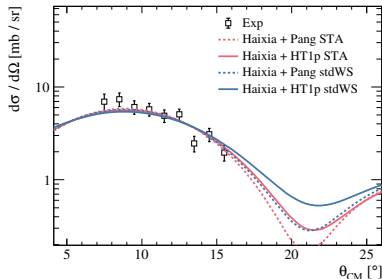
■ Out: Pang and HT1p  
*D. Y. Pang et al., PRC 79, 91 (2009, 2015)*

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

■ A standard Wood-Saxon

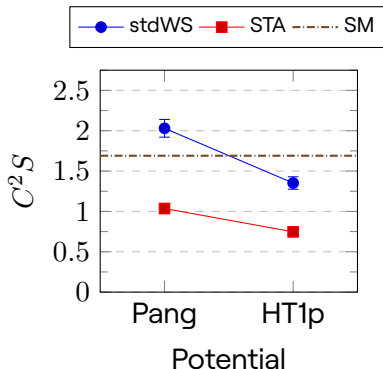
■ The novel source-term approach (STA) *N. Timofeyuk PRC 81 (2010)*

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



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

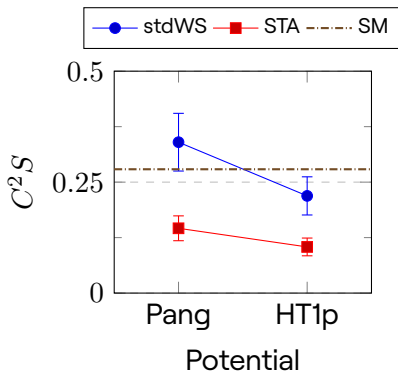
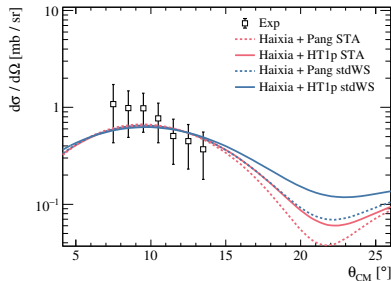
*F. Flavigny et al., PRC 97 (2018)*



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

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

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



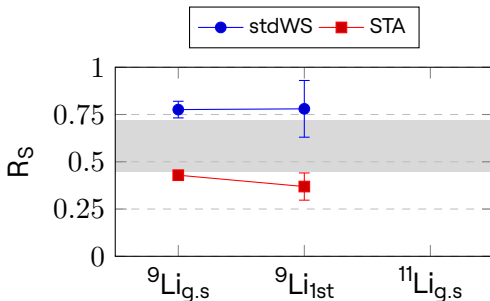
- **First** direct measurement!
- Same trends as for g.s.

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



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

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

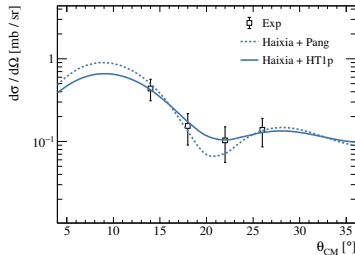
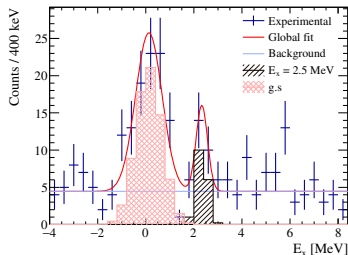


Compatible with  
accepted values for  $R_S$  in  
transfer

Systematic 50 %  
difference STA–stdWS

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

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

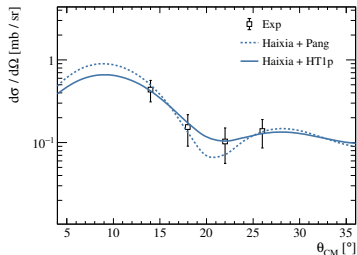
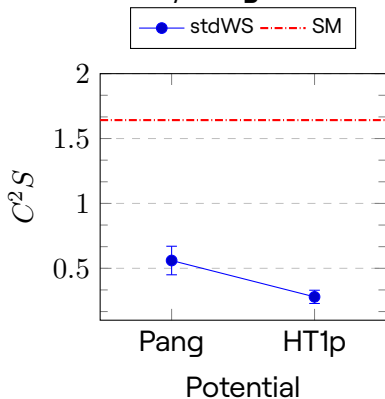


Much lower cross section!

Expected sizeable  
contribution of GMF

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

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

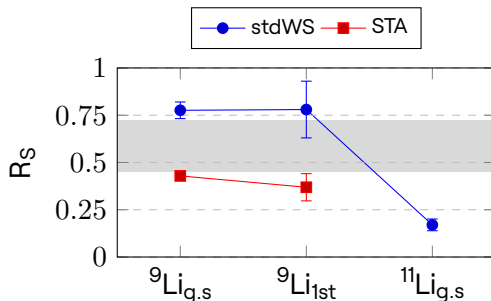


STA **not available** yet!

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

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

The reduction factor  $R_S = C^2 S_{\text{exp}} / C^2 S_{\text{SM}}$  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  $^{10,12}\text{Be}(d, ^3\text{He})$  have been extracted and compared with DWBA

Found strong sensitivity to nuclear overlap: stdWS or newer STA

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

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

# Acknowledgments

## The E748 collaboration:

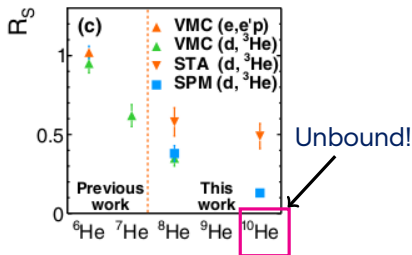
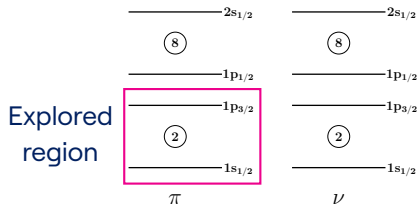
- Santiago:  
B. Fernández
- LPC-Caen:  
A. Matta  
F. Delaunay  
N. L. Achouri  
F. Flavigny  
J. Gibelin  
M. Marques  
N. Orr
- IJCLab:  
D. Beaumel  
M. Assié  
Y. Blumenfeld  
S. Franchoo  
A. Georgiadou  
V. Girard-Alcindor  
F. Hammache  
N. de Séreville  
A. Meyer  
I. Stefan
- GANIL:  
B. Jacquot  
O. Kamalou  
A. Lemasson  
M. Rejmund  
T. Roger  
O. Sorlin  
J.C. Thomas  
M. Vandebrouck  
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,  $^3\text{He}$ ) reactions:



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

Several challenges in this region:

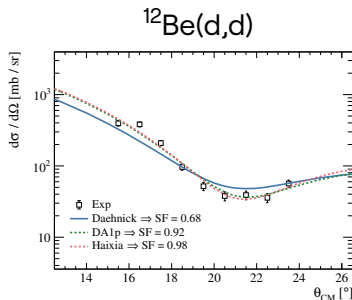
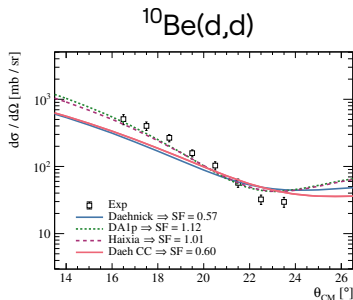
1 Dealing with **unbound** nuclei ( $^{10}\text{He}$ )

2 Many-body dynamics and/or core excitations



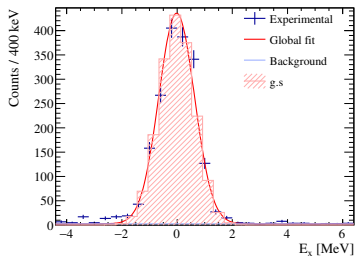
# Elastic cross sections

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

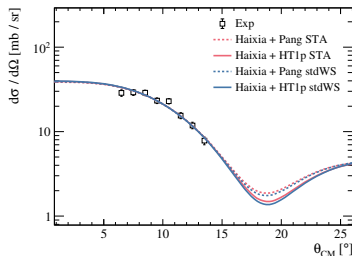


Best OMP: new ones DA1p and Haixia!

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

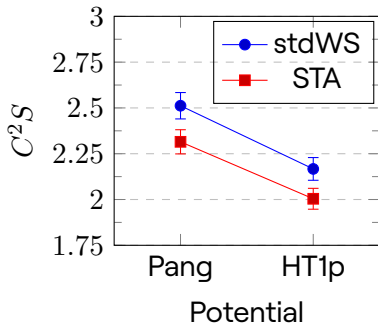


Same behaviour as for the  
other channels

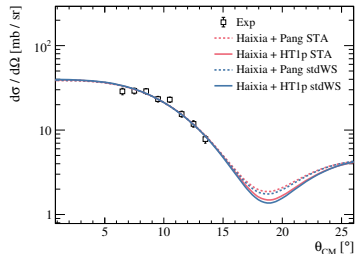


Match with  $\sim 65\%$  reduction  
if  $C^2 S_{\text{SM}} = 3.1$   
Not likely!

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



Same behaviour as for the other channels



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

# Kinematical lines

