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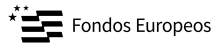
25 → \* 1999  
2024

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

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USC-IGFAE and LPC-Caen

Status by October 2024



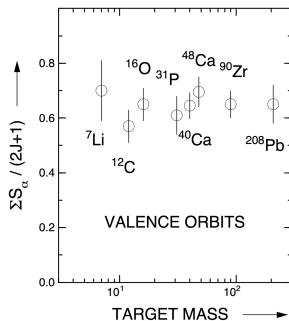
# A recap on spectroscopic factors

**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!**

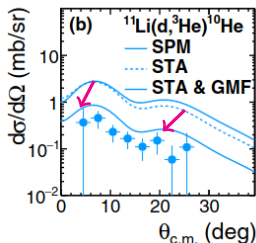


*T. Aumann et al. Prog. Part. Nucl. Phys. 118 (2021)*

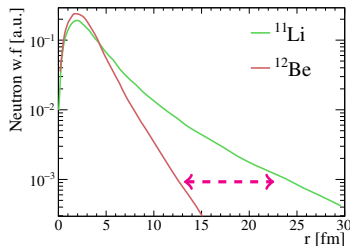
⇒ measure towards more exotic nuclei:  $|\Delta S| \uparrow$

# 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)

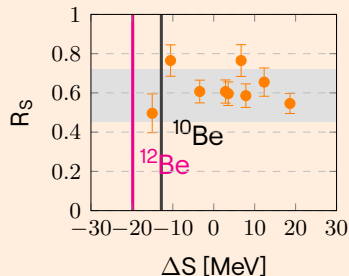
⇒ Need to correct  $C^2S$  by its value!

# Physics case of E748

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

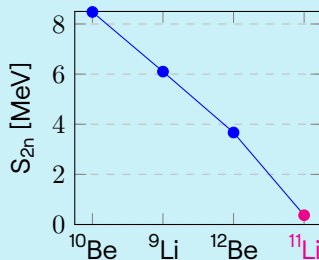
$R_S$  and  $\Delta S$  dependence:

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



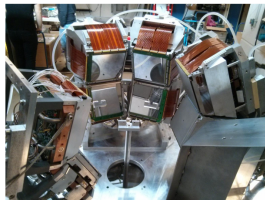
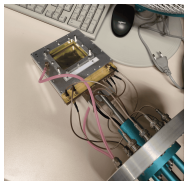
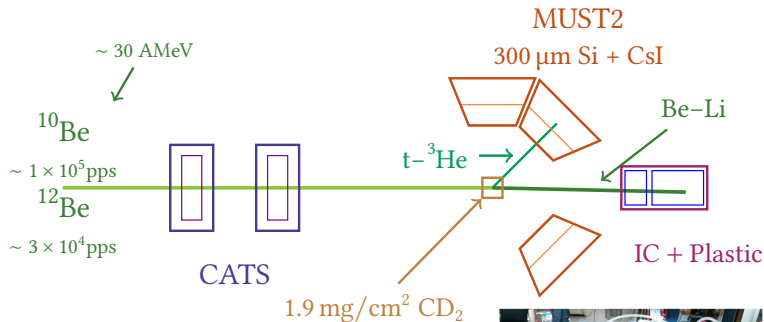
Explore effects of GMF:

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



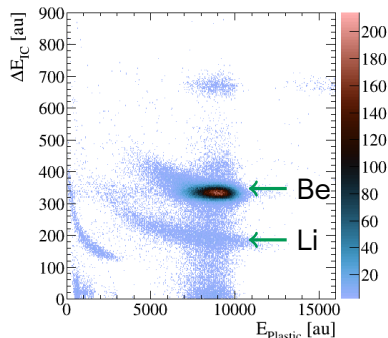
# Experimental technique

## Traditional solid target experiment @ LISE

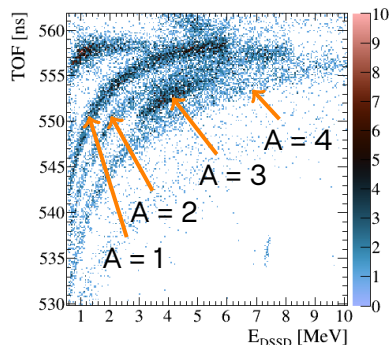


# A glance at the analysis

## 1 Heavy ID at 0°



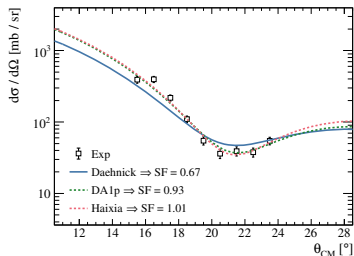
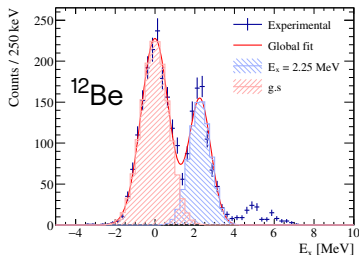
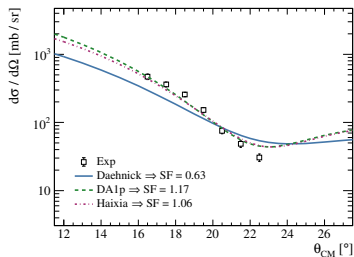
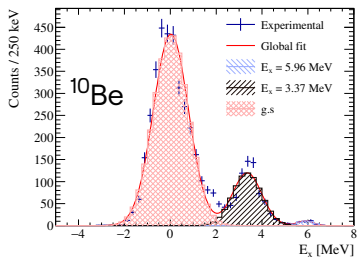
## 2 Light PID in DSSD



## 3 $E_x$ from missing mass technique

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

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





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

Experimental cross-section formula:

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

**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  $\epsilon$ :

- 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:  $\alpha = N_{\text{targets}} \cdot \epsilon_{\text{intrinsic, ZDD}} \cdot \epsilon_{\text{other?}}$

# About DWBA calculations

## 1 OMPs for elastic

- $^{10,12}\text{Be} + d$ : Haixia
- $^{9,11}\text{Be}, \text{Li} + t, ^3\text{He}$ : Pang and HT1p

2 **Light** overlap. Usually determines the xs strength.

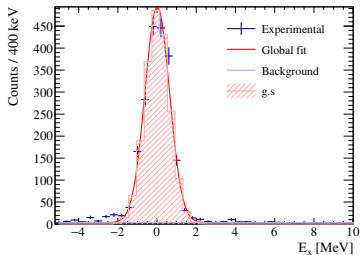
- $\langle t | d + n \rangle$
- $\langle ^3\text{He} | d + p \rangle$

From GFMC calculations (*ab initio*)

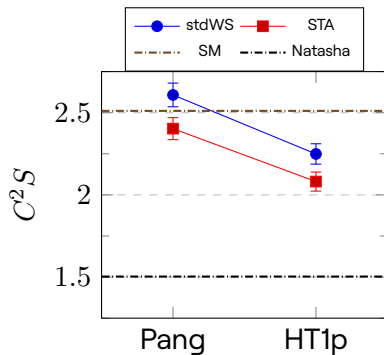
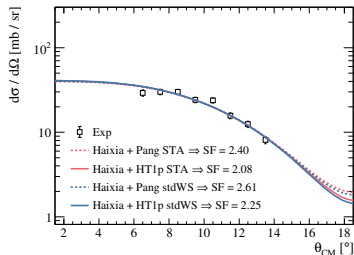
3 Heavy overlap  $\langle ^{10,12}\text{Be} | ^{9,11}\text{Be}, \text{Li} \otimes n, p \rangle$ . Two WS prescriptions:

- Standard  $r_0 = 1.25 \text{ fm}$
- *N. Timofeyuk PRC 81 (2010)* Source Term Approach (STA): includes in a phenomenological way some correlations among nucleons.  $r_0$  for each channel.

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

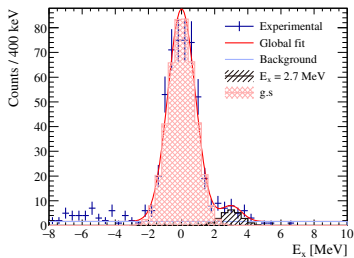


$g_0 = 3/2^+ g.s.$

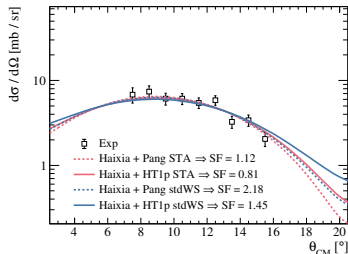


# Results: $^{10}\text{Be}(d, ^3\text{He})^9\text{Li}$

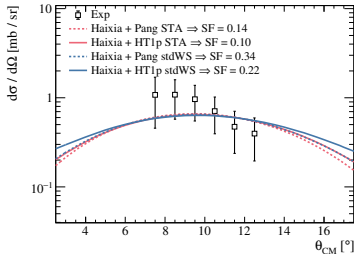
$3/2^-$  ground state and  $1/2^-$  1st excited state.



## Ground state

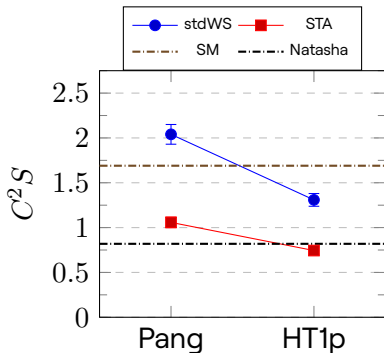


## 1st excited



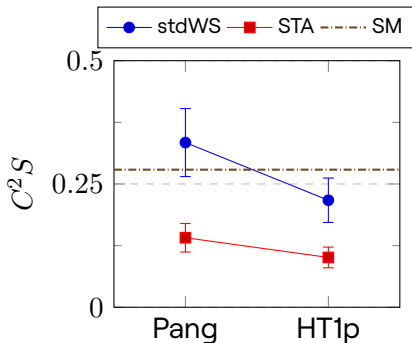
# Results: $^{10}\text{Be}(d, ^3\text{He})^9\text{Li}$

Ground state



**STA** fit agrees with N. Timofeyuk prediction!

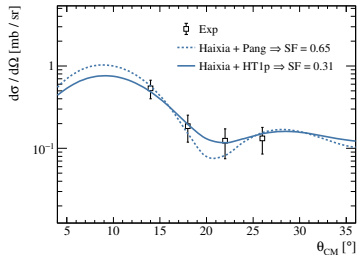
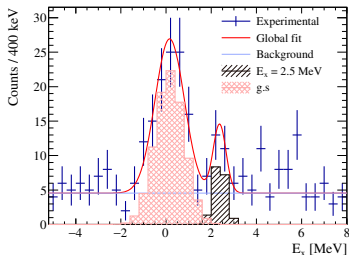
1st excited



**First** direct measurement!

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

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

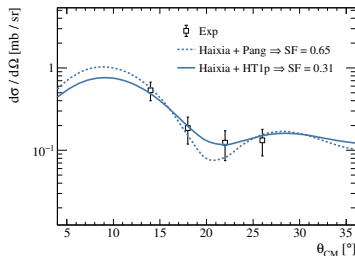
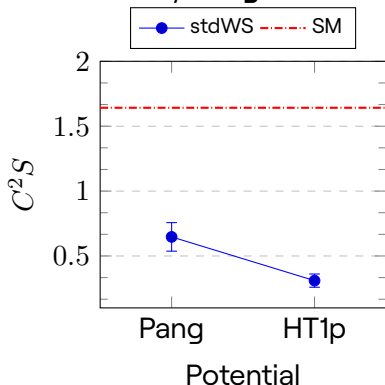


Much lower cross section!

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.

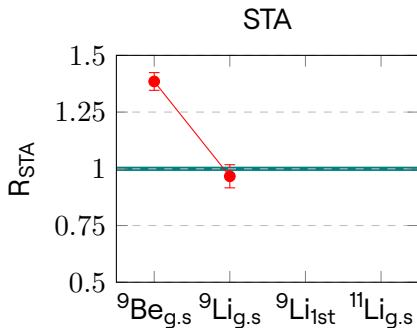
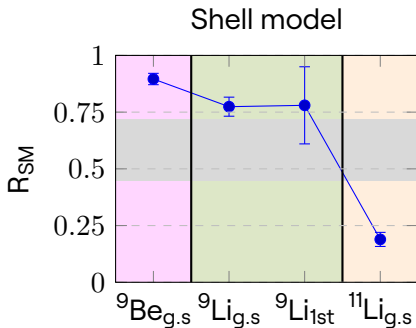


STA **not available** yet!

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

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

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



What happens with  $^9\text{Be}$ ?

$R_S$  compatible with literature

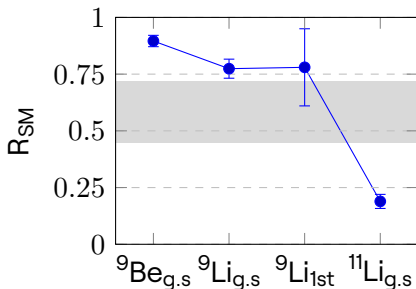
~ 20 % reduction  
**GMF** playing a role



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

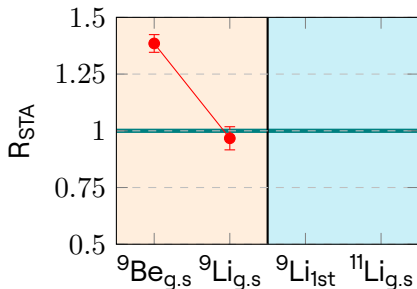
The reduction factor  $R_S = C^2 S_{\text{exp}} / C^2 S_{\text{theo}}$  is computed:

Shell model



Great prediction for  $^9\text{Li}$   
but underestimates SF for  
 $^9\text{Be}$ !

STA



**Missing** predictions for  
 $^9\text{Li}_{1\text{st}}$  and  $^{11}\text{Li}$

# Conclusions

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

$R_S$  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

Need more theoretical insights to check validity of STA

# Current issues

**1** Found a quite low efficiency for the ZDD. This lowers the general efficiency since it is mandatory to gate on the heavy particle to identify on the ToF plot.

## 3- Combined efficiency of IC (= CHIO) and PL

Algorithm to count efficiency on physics data:

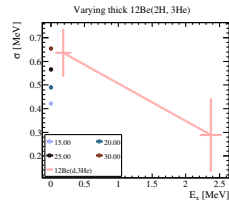
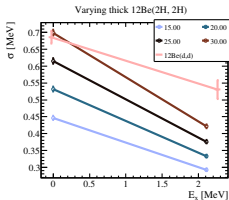
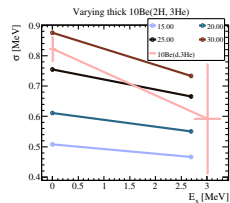
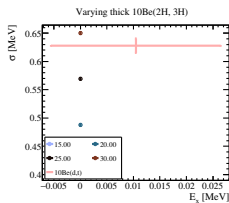
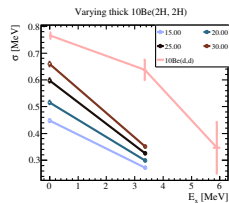
1. Select all the physical runs for 10Be or 12Be with PID already applied (this implies good CATS reconstruction as there is a cut in target position)
2. Count events with Must2Multiplicity  $\geq 1$
3. Relatively to that, count events with  $0 \leq \text{IC\_E} \leq 3000$  (there is a constant overflow at 60000)
4. Relatively to those good IC events, count QPlast  $> 0$  (contrary to IC, here there is a constant underflow at -1000)

Here are the results for both beams

Beam	IC / Must2	PL / IC	Combined [%]
10Be	0.265027	0.532634	14.116
12Be	0.198695	0.587892	11.681

# Current issues

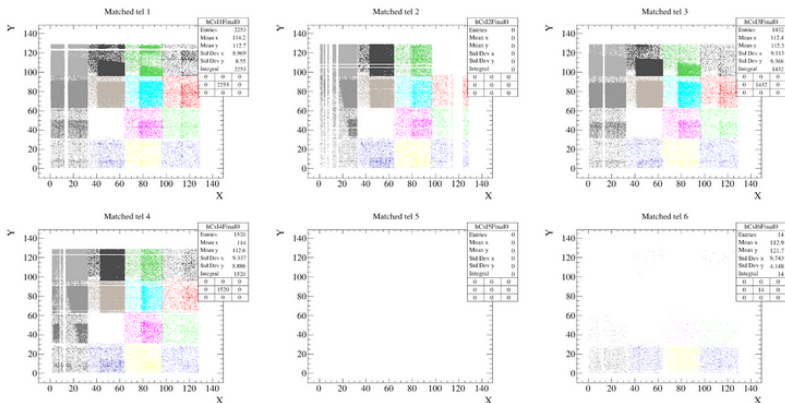
2 Experimental and simulated  $\sigma$  do not match  $\rightarrow$  Work in progress to infer target thickness from this feature.



Clearly all (but 10Be(d,d)...) agree when thickness  $\sim 28 \mu\text{m}$

# Current issues

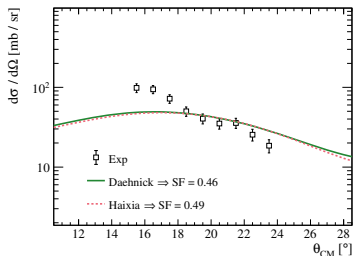
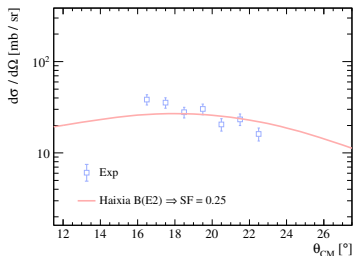
## 3 There is an issue with the Csl matching.



Check this link for further info

# Current issues

- 4 What happens with the B(E2) deformations of  $^{10-12}\text{Be}$ ?



**Coulomb** deformation:

$$p_2 = \sqrt{B(E2)}$$

**Nuclear** deformation:

$$p_2 = \beta_2 \cdot R_0 \text{ with } R_0 = 1.3 \text{ fm} \cdot A^{1/3}$$

# Acknowledgments

## The E748 collaboration:

- Santiago:  
B. Fernández
- LPC-Caen:  
A. Matta  
F. Delaunay  
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J. Gibelin  
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N. Orr
- IJCLab:  
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Y. Blumenfeld  
S. Franchoo  
A. Georgiadou  
V. Girard-Alcindor  
F. Hammache  
N. de Séreville  
A. Meyer  
I. Stefan
- GANIL:  
B. Jacquot  
O. Kamalou  
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T. Roger  
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J.C. Thomas  
M. Vandebrouck  
B. Bastin  
F. de Oliveira  
C. Stodel
- RIKEN:  
S. Koyama  
D. Suzuki
- Surrey:  
N. Timofeyuk

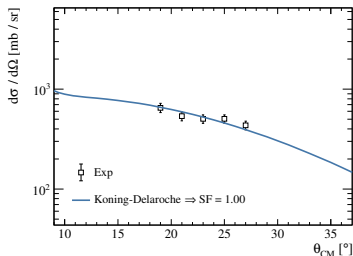
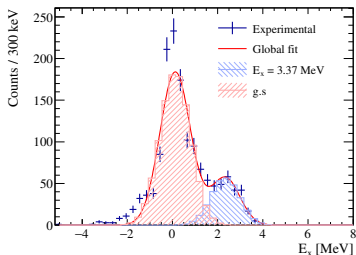


Backup



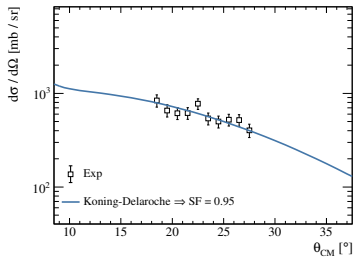
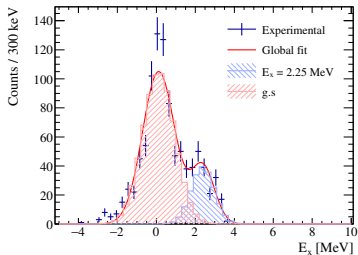
## Additional: $^{10}\text{Be}(p,p)$

This ground state is employed to obtain the number of protons in the target



## Additional: $^{12}\text{Be}(p,p)$

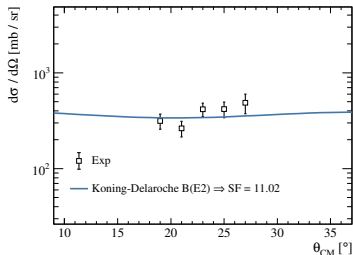
Same as before but for  $^{12}\text{Be}$



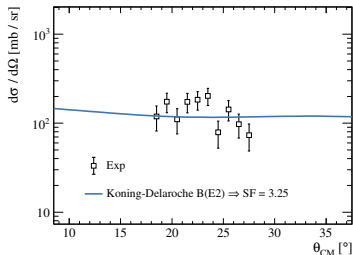
## Additional: inelastic B(E2) with protons

The deformations included in the potential are exactly the same as for (d,d) channel.

$^{10}\text{Be}(p,p)$



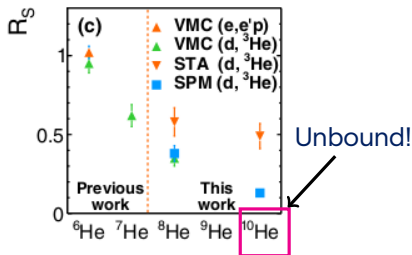
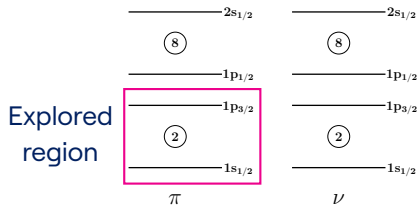
$^{12}\text{Be}(p, p)$



For  $^{10}\text{Be}(p,p)$  efficiency is critical: events impinge onto the boundary of the telescope

# 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

# Kinematical lines

