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

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USC-IGFAE and LPC-Caen

Status by October 2024

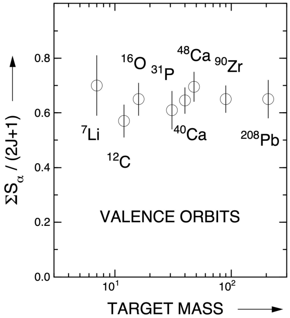
A recap on spectroscopic factors

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 $\sim 65\,\%$!

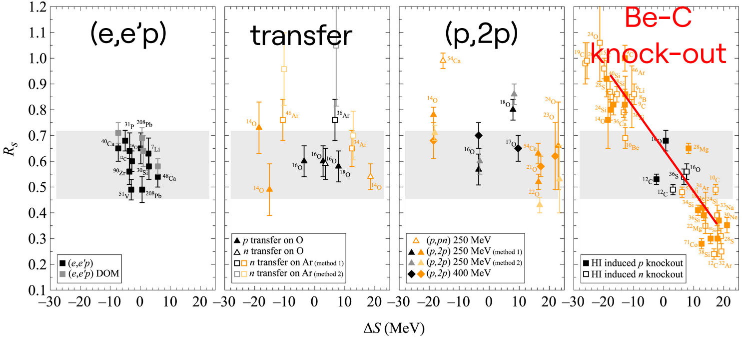
- **Short-range** correlations: tensor forces,...
- **Long-range**: vibrations, giant resonances,...



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**!

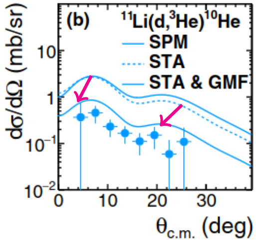


T. Aumann et al. Prog. Part. Nucl. Phys. 118 (2021)

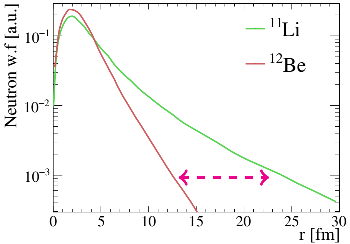
$\Rightarrow$ measure towards more exotic nuclei: $|\Delta S| \uparrow$

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)

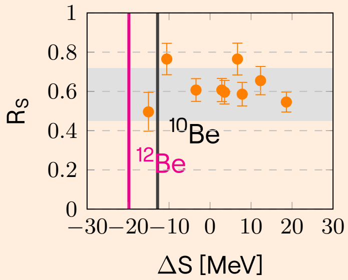
$\Rightarrow$ Need to correct C^2S by its value!

Physics case of E748

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

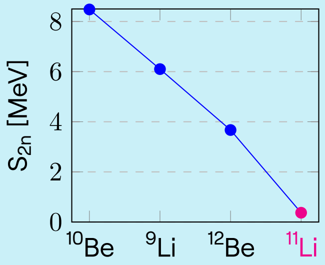
R_S and ΔS dependence:

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



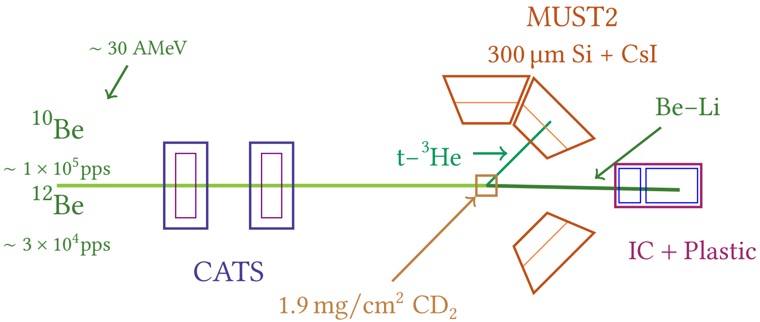
Explore effects of GMF:

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



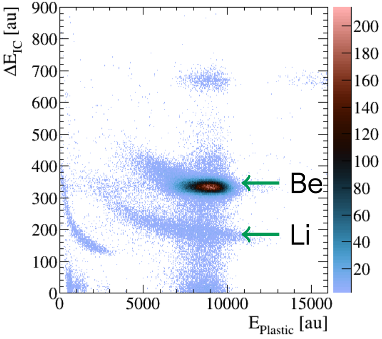
Experimental technique

Tradional solid target experiment @ LISE

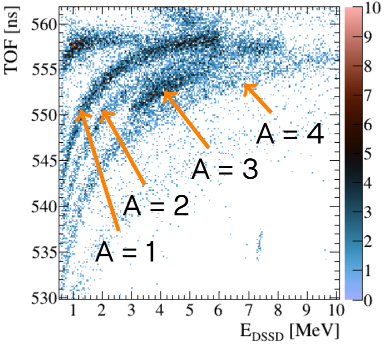


A glance at the analysis

1 **Heavy** ID at $0°$



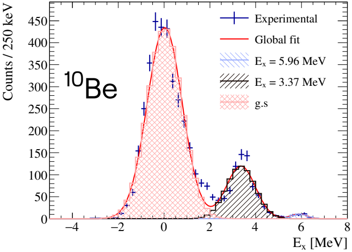
2 **Light** PID in DSSD

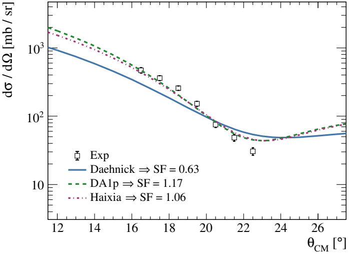


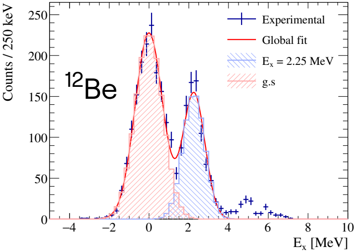
3 E_x from **missing mass technique**

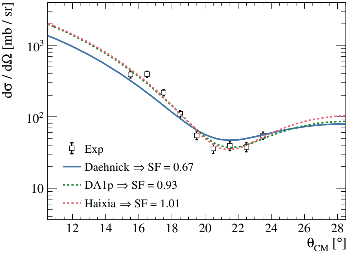
$$E_{\text{beam}} + (E, \theta)_{\text{Lab}} \rightarrow E_x$$

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









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

About DWBA calculations

1 OMPs for elastic

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

2 Light overlap. Usually determines the xs strength.

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

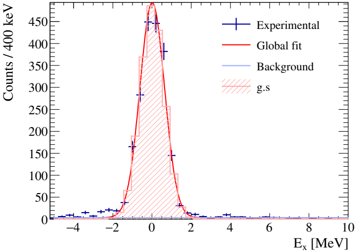
From GFMC calculations (*ab initio*)

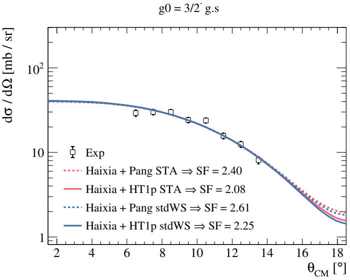
3 Heavy overlap $\langle {}^{10,12}\mathrm{Be} | {}^{9,11}\mathrm{Be}, \mathrm{Li} + \mathrm{n}, \mathrm{p} \rangle$. Two WS prescriptions:

- Standard $r_0 = 1.25$ 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: $^{10}Be(d,t)^{9}Be$

Relatively high statistics. Used for benchmarking analysis routines.



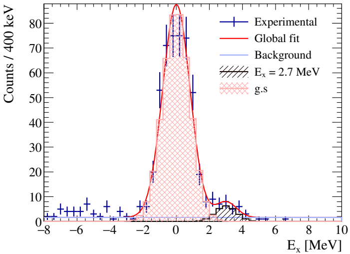


STA prediction:
$C^2S = 1.50$
Our result: $C^2S_{\text{exp}} = 2.08$

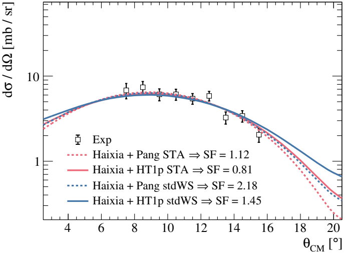
SFO-tls shell-model:
$C^2S = 2.51$

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

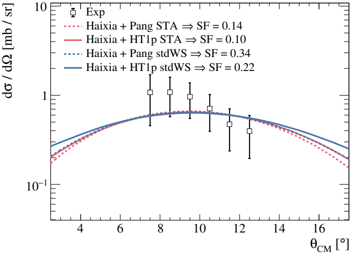
$3/2^-$ ground state and $1/2^-$ 1st excited state.



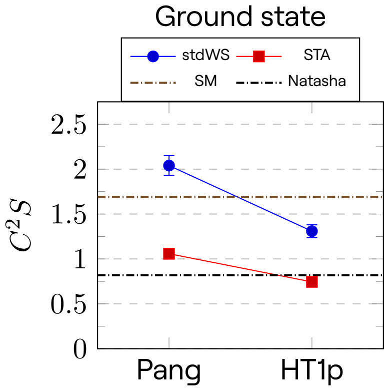
Ground state

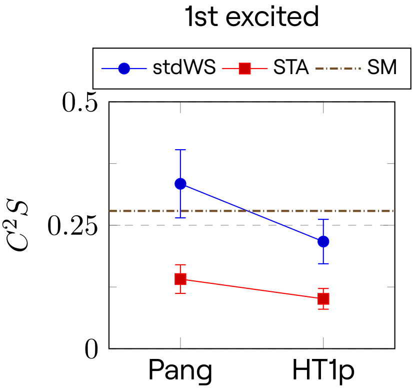


1st excited



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



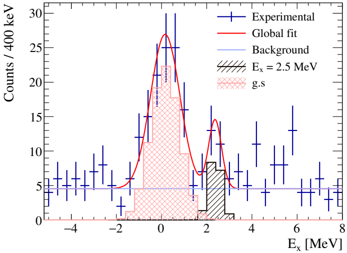


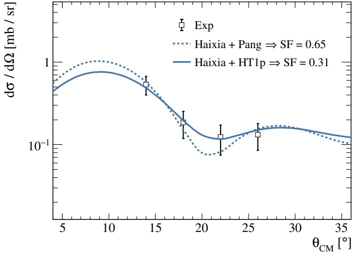
STA fit agrees with N. Timofeyuk prediction!

First direct measurement!

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

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



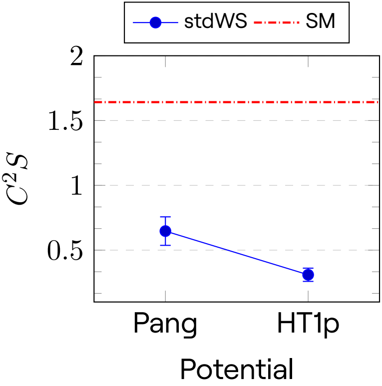


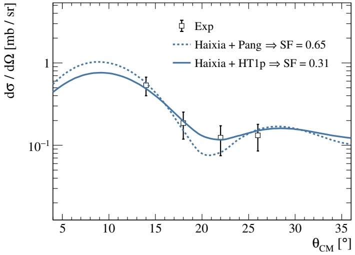
Much lower cross section!

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.



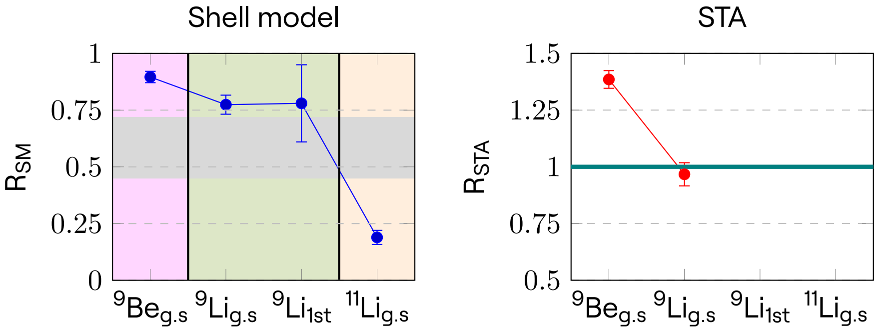


STA **not available** yet!

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

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

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



What happens with 9Be?

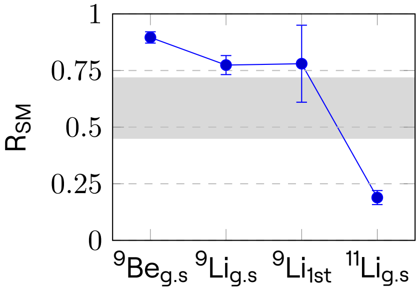
R_S compatible with litterature

$\sim 20\,\%$ reduction **GMF** playing a role

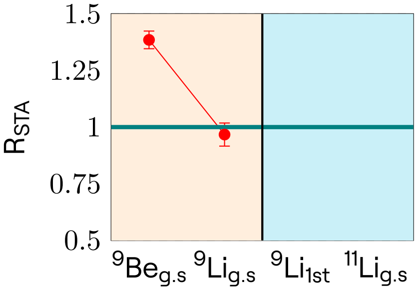
Results: ^{12}Be(d,^{3}He)^{11}Li

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

Shell model



STA



Great prediction for ^{9}Li but understimates SF for ^{9}Be!

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

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

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

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:

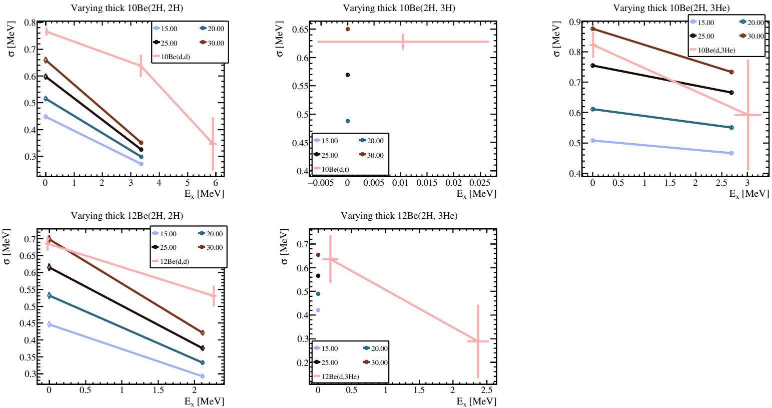
1. Select all the physical runs for 10Be or 12Be with PID already applied (this implies good CATS reconstruction as there is a cut in target position)
2. Count events with Must2Multiplicity >= 1
3. Relatively to that, count events with 0 <= IC_E <= 3000 (there is a constant overflow at 60000)
4. Relatively 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

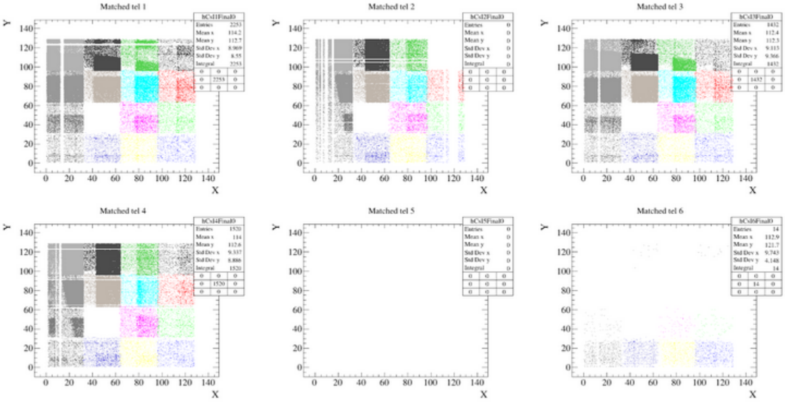
2 Experimental and simulated σ do not match $\rightarrow$ Work in progress to infer target thickness from this feature.



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

Current issues

3 There is an issue with the CsI matching.

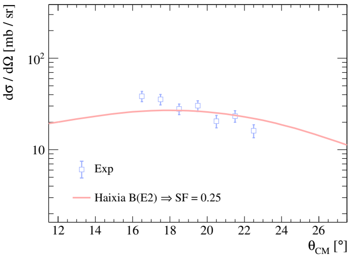


Check this link for further info

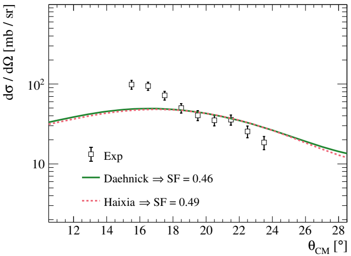
Current issues

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

^{10}Be(d,d)



^{12}Be(d,d)



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

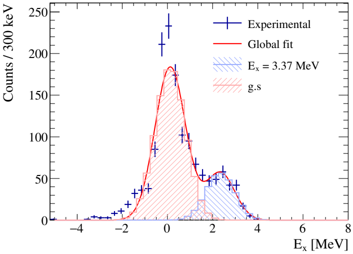
The E748 collaboration:

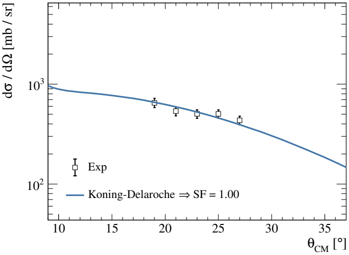
- Santiago:
  B. Fernández
- LPC-Caen:
  A. Matta
  F. Delaunay
  N. L. Achouri
  F. Flavigny
  J. Gibelin
  M. Marques
  N. Orr
- IJCLab:
  D. Beaumel
  M. Assié
  Y. Blumenfeld
  S. Franchoo
  A. Georgiadou
  V. Girard-Alcindor
  F. Hammache
  N. de Séreville
  A. Meyer
  I. Stefan
- GANIL:
  B. Jacquot
  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

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

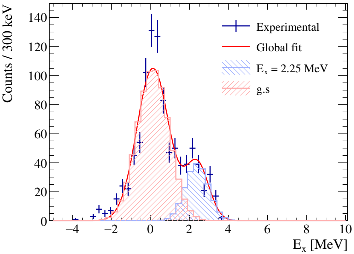
This ground state is employed to obtain the number of protons in the target

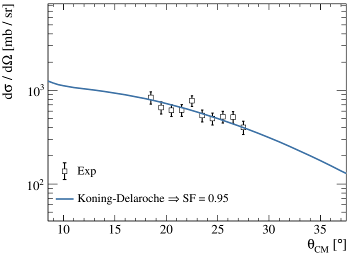




Additional: ^{12}Be(p,p)

Same as before but for ^{12}Be

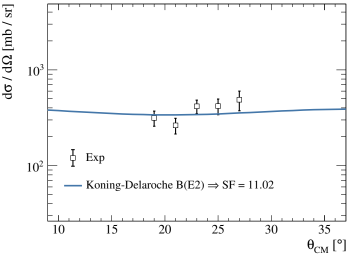




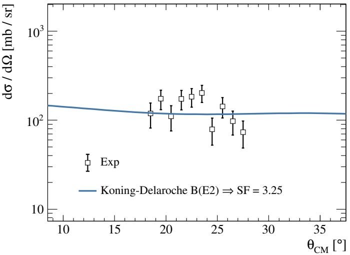
Additional: inelastic B(E2) with protons

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

^{10}Be(p,p)



^{12}Be(p, p)

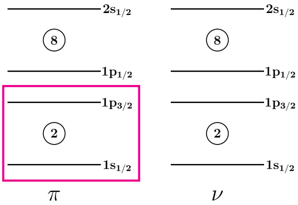


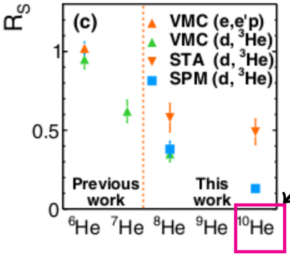
For ^{10}Be(p,p) efficiency is critical: events impinge onto the boundary of the telescope

Status with light isotopes

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

Explored region





Unbound!

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

Kinematical lines