Shell evolution towards the neutron drip line in ^{10}Be, ^{12}Be and ^{20}O using solid and active targets

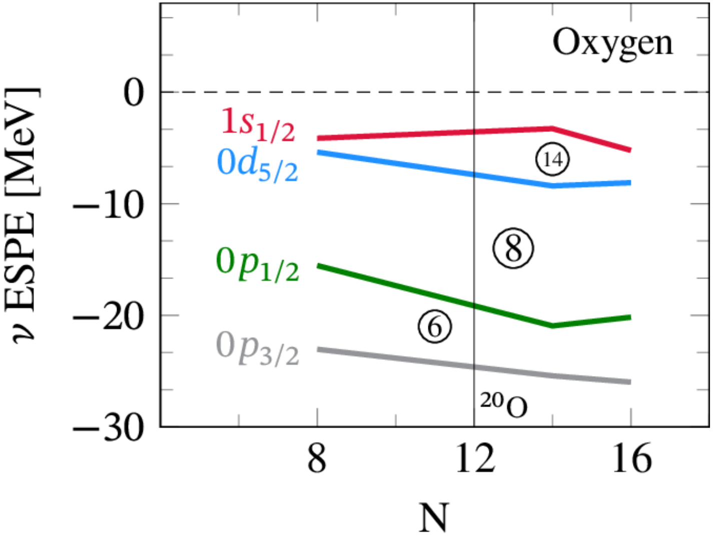
M. Lozano-González, B. Fernández-Domínguez, A. Matta, F. Delaunay,
J. Lois-Fuentes, I. Blanco-Calviño
On behalf of the E748 and E796 collaborations

GANIL Colloque 2026

Residual NN forces

Monopole NN forces cause evolution of single-particle levels towards the drip line

^{16}O	^{17}O	^{18}O	^{19}O	^{20}O	^{21}O	^{22}O	^{23}O	^{24}O



In this work

ν ESPEs in **^{20}O** measured through $^{20}O(d,t)^{19}O$ transfer using ACTAR TPC

⇓

Comparison with SM calculations suggests reduced **N = 8 gap** (~ 8 MeV) needed

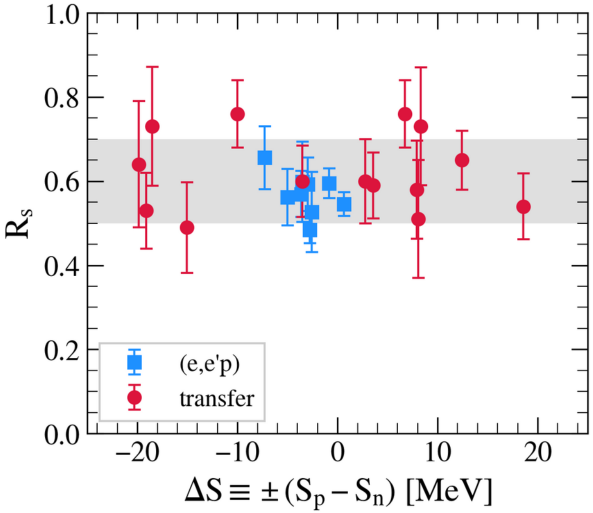
More details in B. Fernández-Domínguez talk on Thursday

NN correlations and other effects

Both long- and short-range correlations limit observed occupancy (C^2S) ⇒ Reduction factor R_s

$$R_s = \frac{C^2S_{\mathrm{exp}}}{C^2S_{\mathrm{SM}}} \simeq 60(10)\ \%$$

- Established through (e,e’p)
- Later verified in diverse transfer



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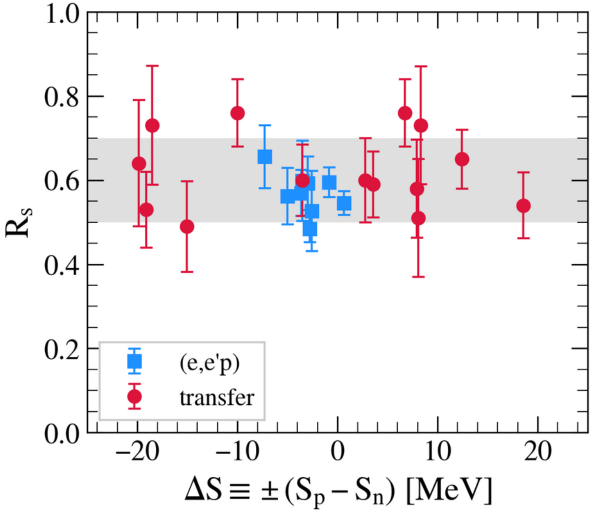

Exotic systems may present other phenomena further contributing to R_s

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Unbound or halo nuclei (⇒ ^{11}Li)

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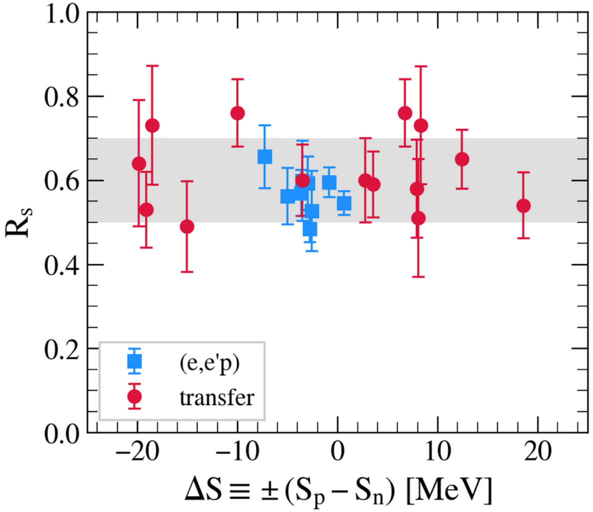

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^{11}Li(d,^{3}He)^{10}He

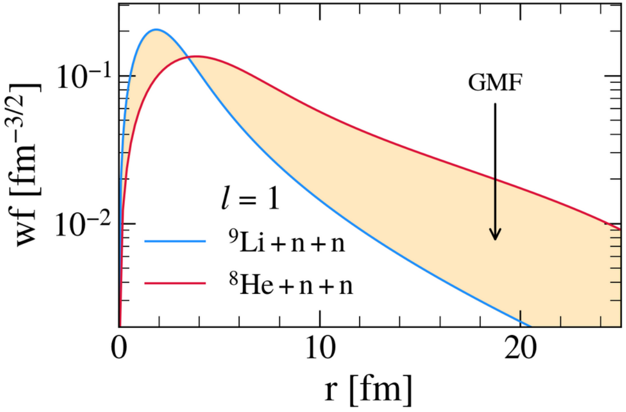
^{8}He + 2n, with $S_{2n}/2$= −0.73 MeV

^{9}Li + 2n, with $S_{2n}/2$ = 0.19 MeV

~ 1 MeV difference

Important reduction of ν radial overlap

Geometrical mismatch factor (GMF)



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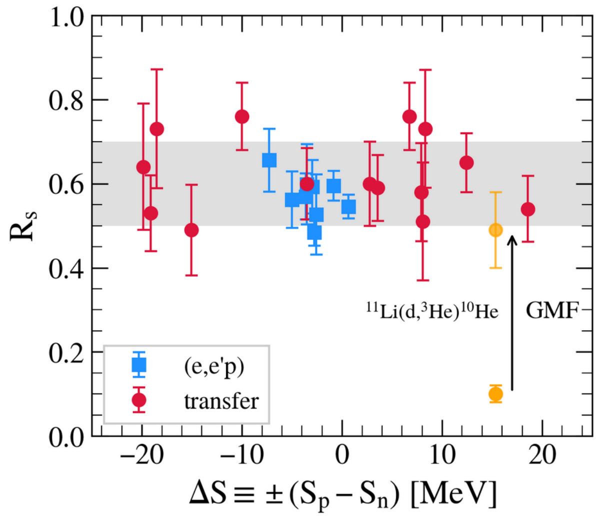

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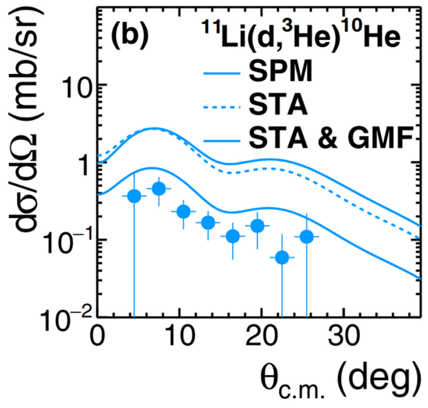
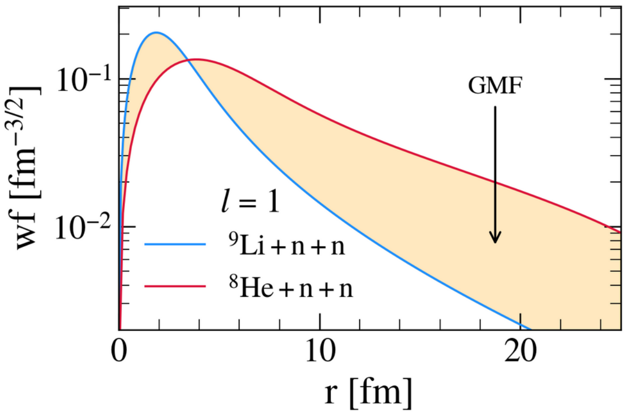


A. Matta et al. PRC 92 (2015)



$$R_s = 0.10(2) \xrightarrow{\text{Correcting for GMF} \simeq 0.20} R_s = 0.49(9)!$$

Objectives: a new study of the GMF

^{10}He is an unbound system

$\Downarrow$

Need to reduce uncertainties by measuring GMF in bound systems

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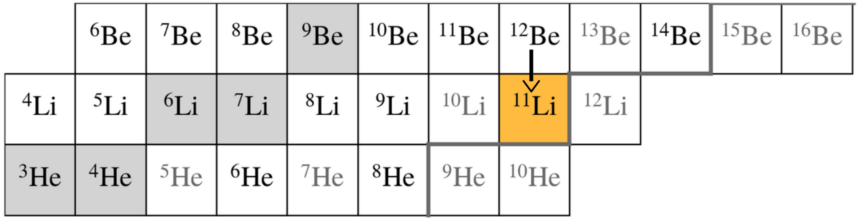


	^{6}Be	^{7}Be	^{8}Be	^{9}Be	^{10}Be	^{11}Be	^{12}Be	^{13}Be	^{14}Be	^{15}Be	^{16}Be
^{4}Li	^{5}Li	^{6}Li	^{7}Li	^{8}Li	^{9}Li	^{10}Li	^{11}Li	^{12}Li			
^{3}He	^{4}He	^{5}He	^{6}He	^{7}He	^{8}He	^{9}He	^{10}He				

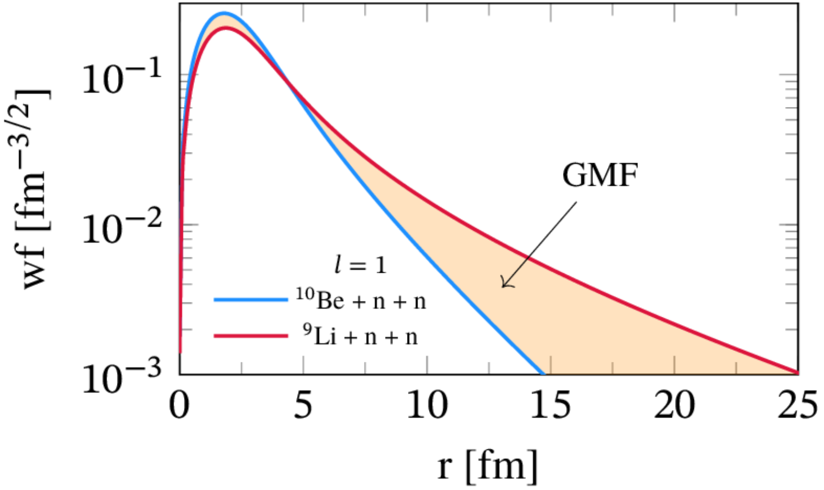
^{12}Be(d,^{3}He)^{11}Li

^{9}Li + 2n, with $S_{2n}/2$ = 0.18 MeV

^{10}Be + 2n, with $S_{2n}/2$ = 1.8 MeV

~ 1.5 MeV difference

Theoretical estimations suggest important mismatch, with GMF ≃ 0.8



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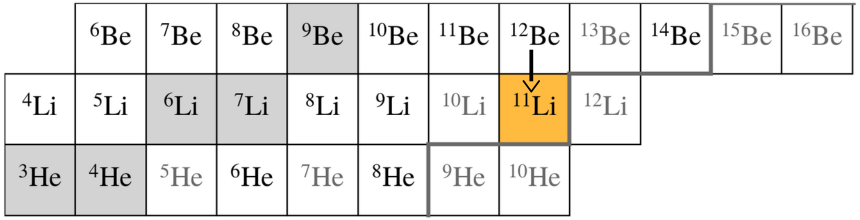

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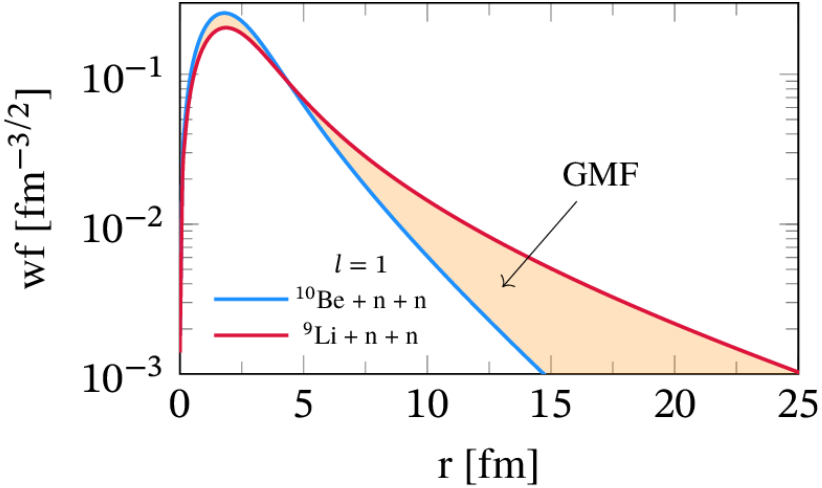


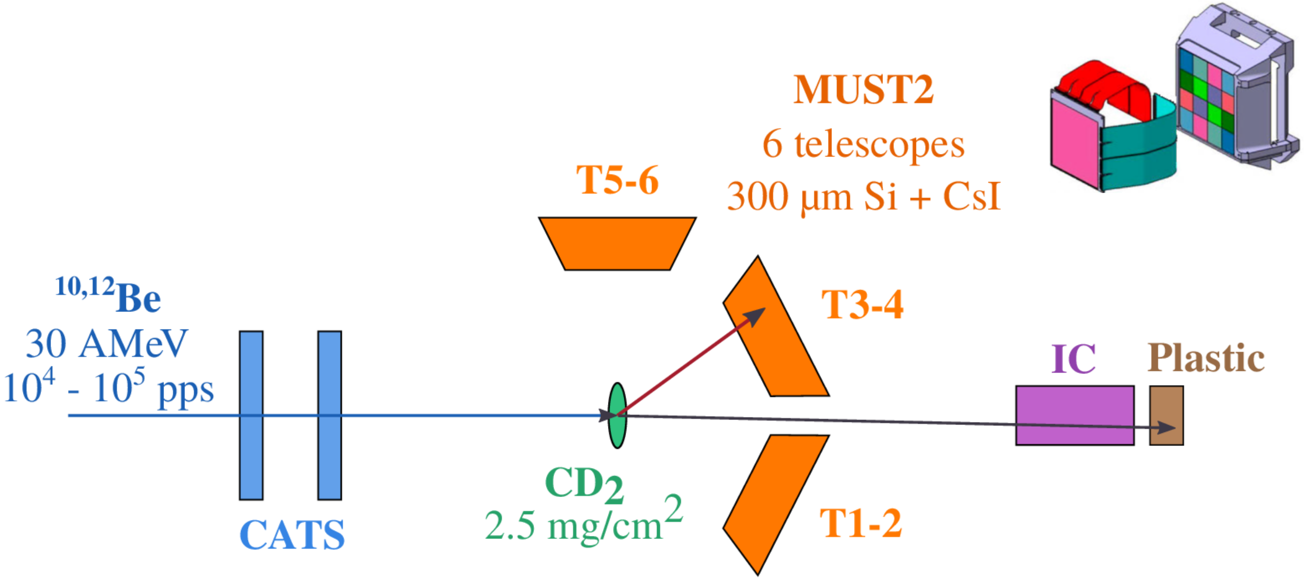
In this work

^{12}Be(d,^{3}He)^{11}Li
- Measure R_s
- Test GMF models

^{10}Be(d,t)^{9}Be
^{10}Be(d,^{3}He)^{9}Li
- Validate analysis

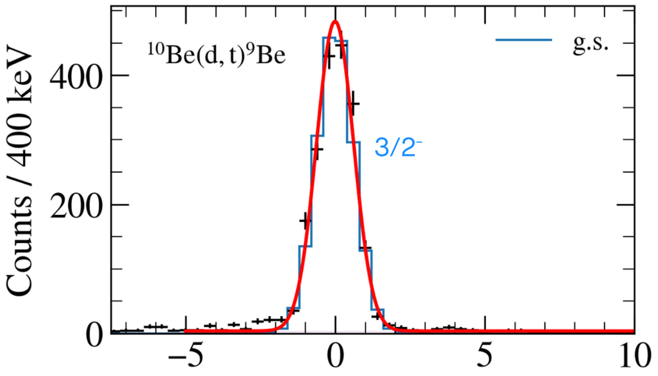
Methodology

Traditional solid target experiment @ LISE



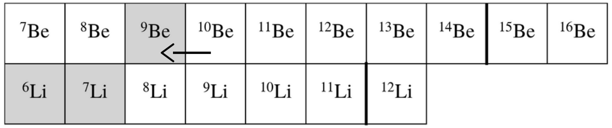
Missing-mass technique: E_{beam} + $(E,\theta)_{light}$ → E_x

Results: E_x spectra



^{10}Be(d,t)^{9}Be

Only g.s. is populated



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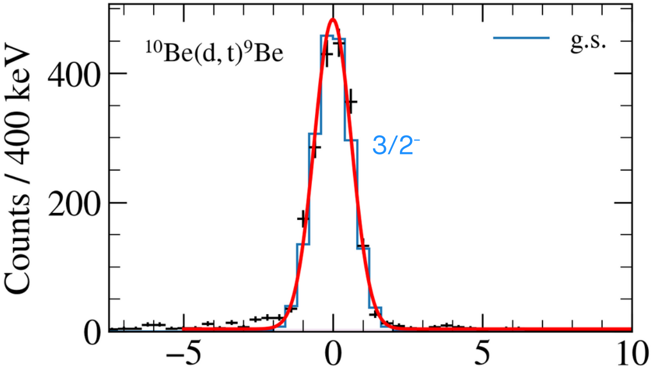

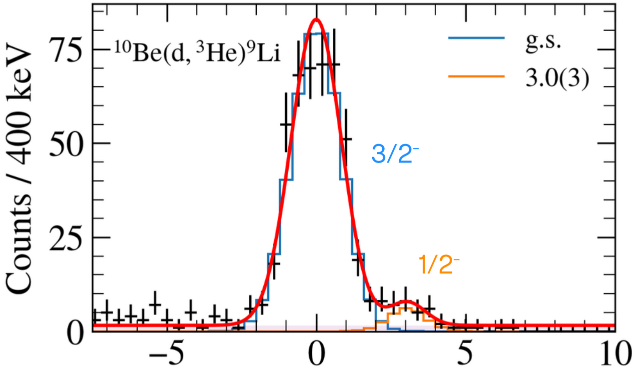

^{10}Be(d,t)^{9}Be

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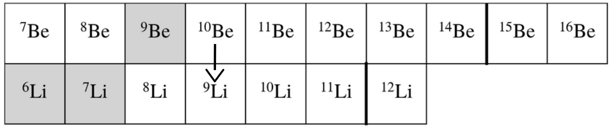
^{10}Be(d,^{3}He)^{9}Li

1st state compatible with previously observed 1/2$^-$ @ 3.0(3) MeV



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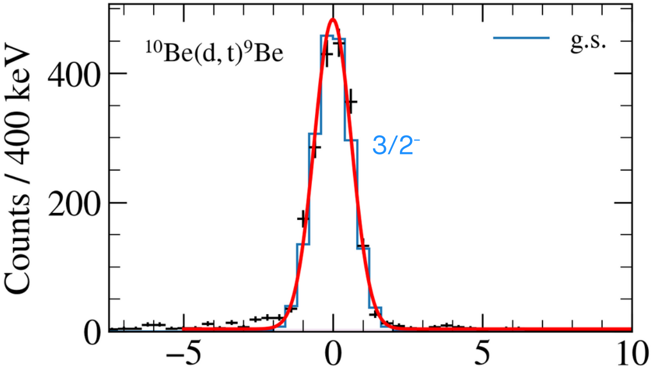

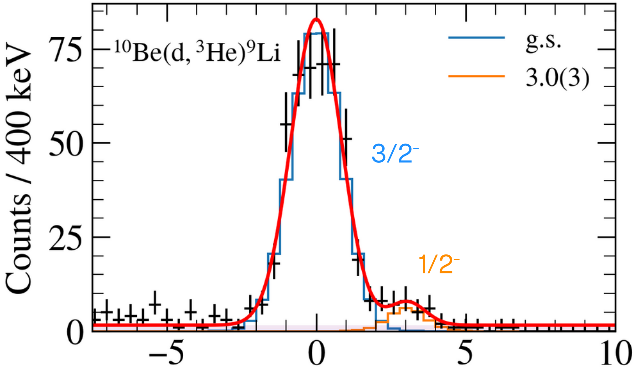

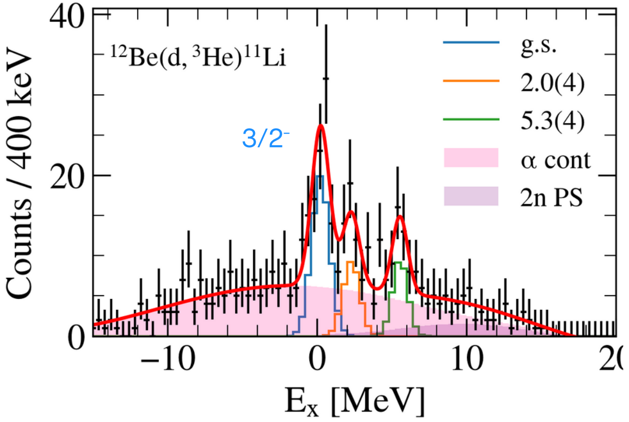

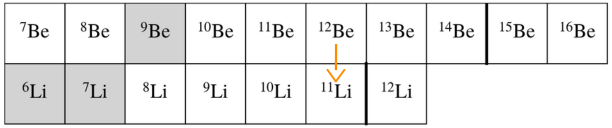

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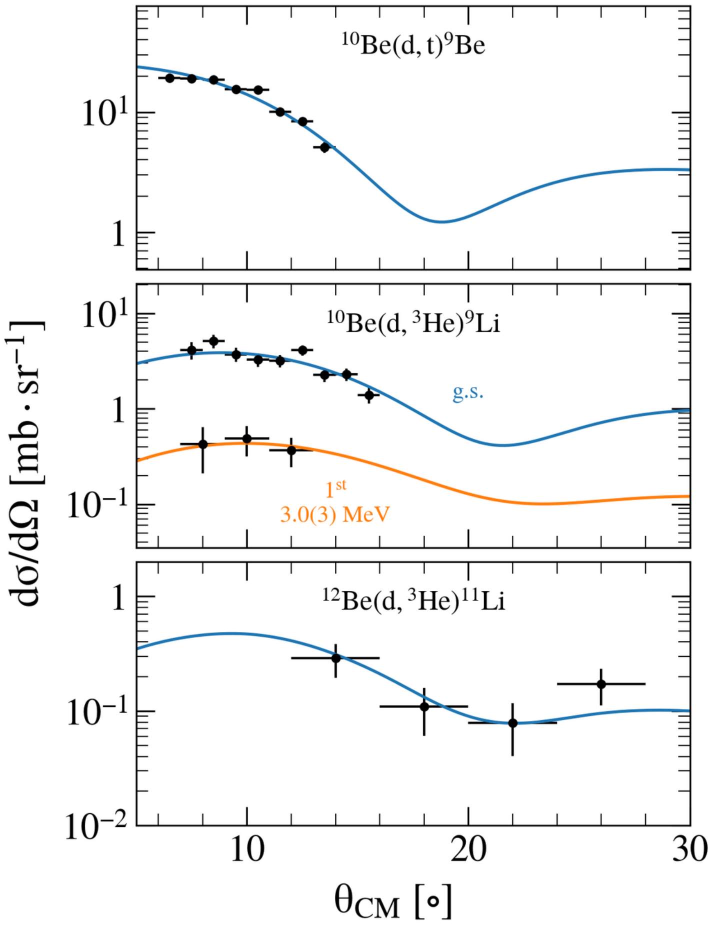
^{12}Be(d,^{3}He)^{11}Li

- Large α background from PID ⇒ explicitly included
- Two excited states observed but not further analysed due to low stats

Results: angular distributions



Finite-range **DWBA** calculations with **Fresco**

OMPs

- ^{10,12}Be + d: Daeh or Haixia
- ^{9,11}Be/Li + t/^{3}He: HT1p *D.Y. Pang et al. PRC 91 (2015)*

Light overlap | $\langle d|t\rangle$ $\langle d|^3He\rangle$

ab initio GFMC results

I. Brida et al. PRC 84 (2011)

Heavy overlap | $\langle ^{10}Be|^{9}Be\rangle, \ldots$

Standard Woods-Saxon (*stdWS*)
Well established method in literature
- r_0 = 1.25 fm
- a_0 = 0.65 fm

l = 1 shapes well reproduced!

$$\left.\frac{d\sigma}{d\Omega}\right|_{exp} = C^2S \cdot \left.\frac{d\sigma}{d\Omega}\right|_{theo}$$

Results: R_s factor

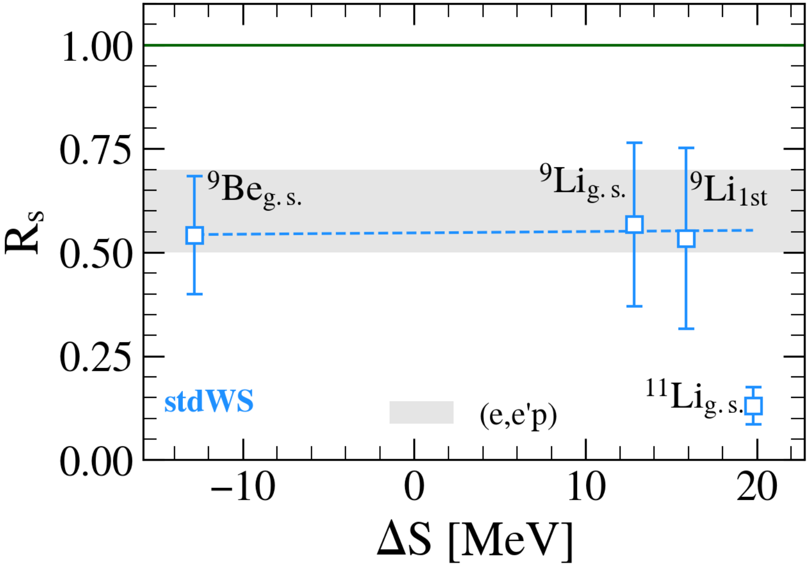
Experimental C^2S are reduced with respect to SM

	^{9}Be	^{9}Li$_{g.s.}$	^{9}Li$_{1st}$	^{11}Li
C^2S_{exp}	1.4(4)	1.0(3)	0.15(6)	0.21(7)
$C^2S_{SFO\text{-}tls}$	2.5	1.7	0.28	1.6

Shell-model calculations with **SFO-tls** interaction

T. Suzuki and T. Otsuka PRC 78 (2008)

Successfully predicts shell evolution in n-rich and low-mass nuclei



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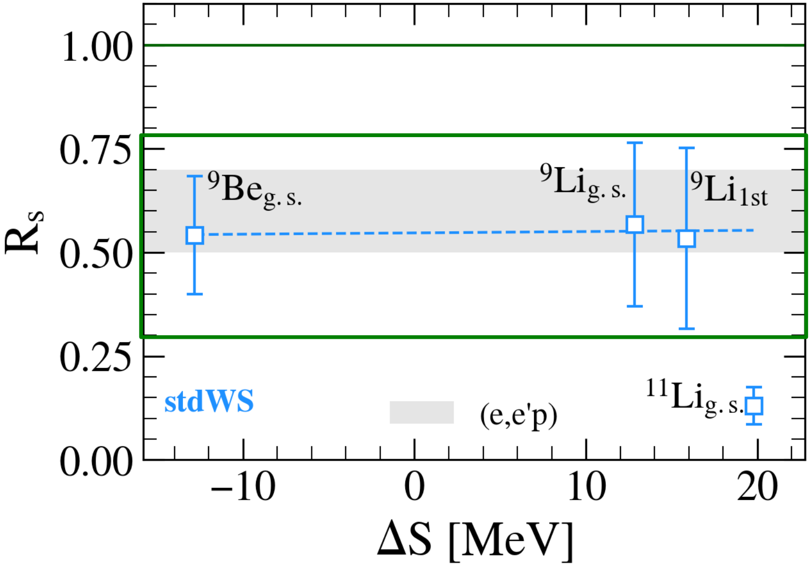

^{9}Be and ^{9}Li are compatible with (e,e'p) measurements

No trend with asymmetry energy (ΔS) is observed as in other transfer experiments

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

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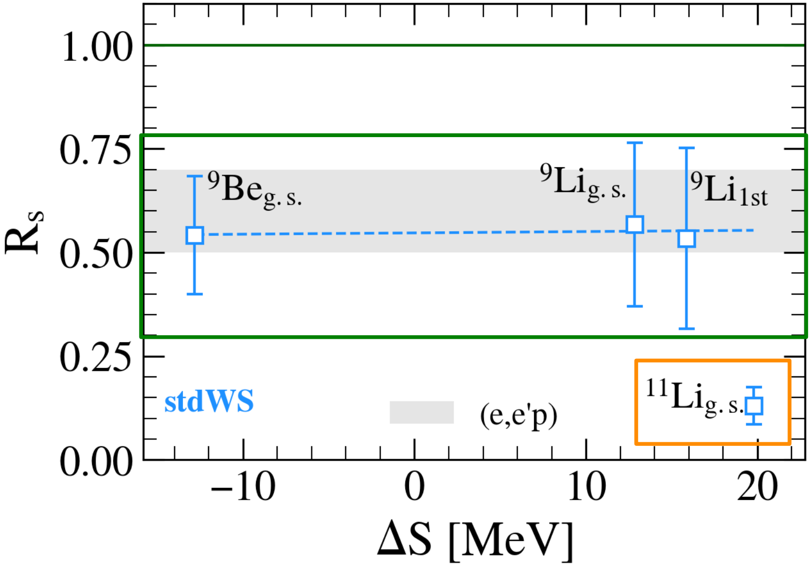

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^{11}Li presents a 13(4)% reduction ⇒ signature of **GMF**

Results: estimating the GMF

The C^2S can be factorised into proton (π) and neutron (ν) parts:

$$\mathrm{C}^2\mathrm{S} = \left|\langle\pi\left({}^{12}\mathrm{Be}\right)|\pi\left({}^{11}\mathrm{Li}\right)\otimes\pi 0p_{3/2}\rangle\cdot\langle\nu\left({}^{12}\mathrm{Be}\right)|\nu\left({}^{11}\mathrm{Li}\right)\rangle\right|^2$$

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Assuming cores of ^{10}Be and ^{9}Li plus two valence neutrons

$$|\nu({}^{12}\mathrm{Be})\rangle = \alpha\underline{|\nu_{s^2}({}^{10}\mathrm{Be})\rangle} + \beta\underline{|\nu_{p^2}({}^{10}\mathrm{Be})\rangle} + \gamma\underline{|\nu_{d^2}({}^{10}\mathrm{Be})\rangle}$$

$$|\nu({}^{11}\mathrm{Li})\rangle = \alpha'|\nu_{s^2}({}^{9}\mathrm{Li})\rangle + \beta'|\nu_{p^2}({}^{9}\mathrm{Li})\rangle + \gamma'|\nu_{d^2}({}^{9}\mathrm{Li})\rangle$$

Amplitudes from SM, with SFO-tls

Single-neutron wave functions in stdWS and $S_{2n}/2$

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$$\Downarrow$$

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In SM, these integrals = 1
assuming equal shapes

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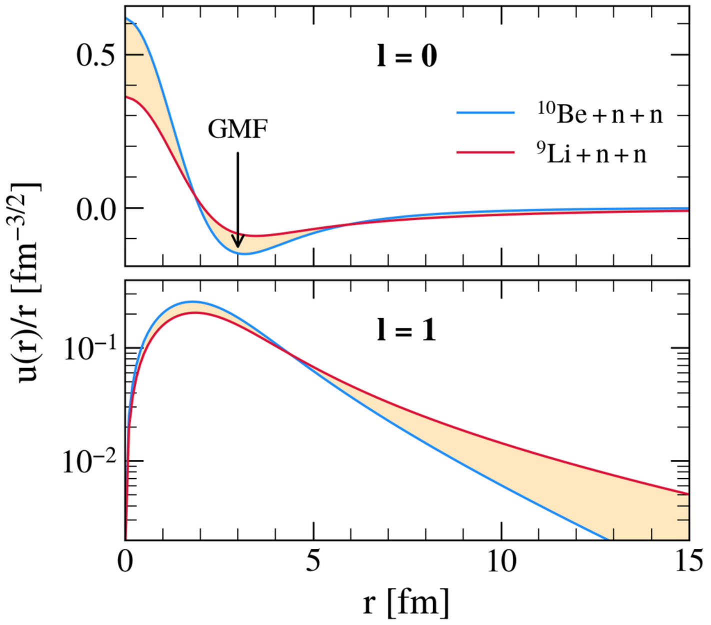
For large differences in $S_{2n}/2$, they no longer = 1:

l	s	p	d
Integral	0.85	0.95	0.99



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Single-neutron wave functions in stdWS and $S_{2n}/2$

$\Downarrow$

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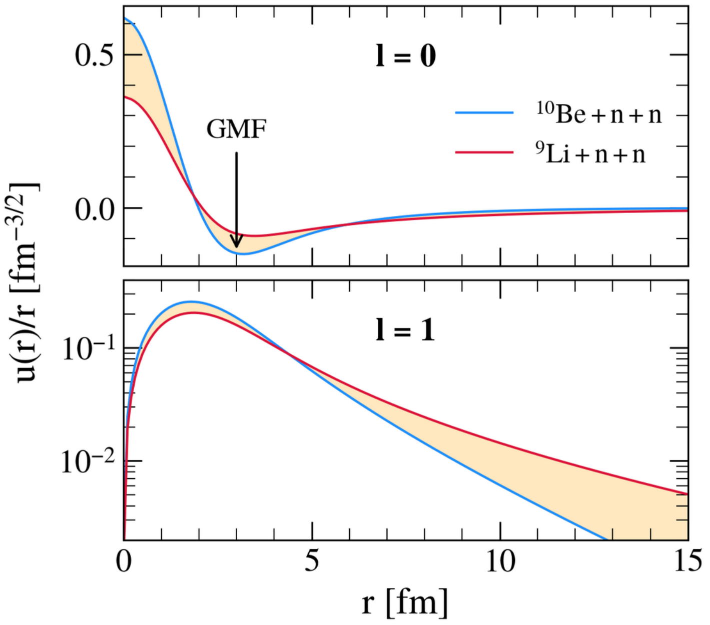


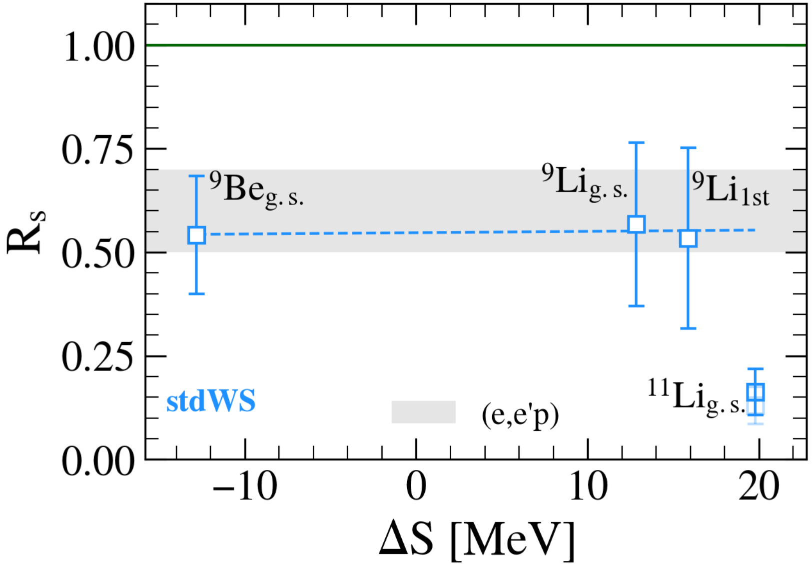
The GMF is a corrective factor for the neutron part

$$\mathrm{GMF} \equiv \left|\frac{\langle \nu({}^{12}\mathrm{Be})|\nu({}^{11}\mathrm{Li})\rangle_{\mathrm{realistic}}}{\langle \nu({}^{12}\mathrm{Be})|\nu({}^{11}\mathrm{Li})\rangle_{\mathrm{SM}}}\right|^2 = 0.8$$

Results: estimating the GMF

After correction: 16(6)% reduction

⇒ Insufficient to agree with (e,e'p) systematics!

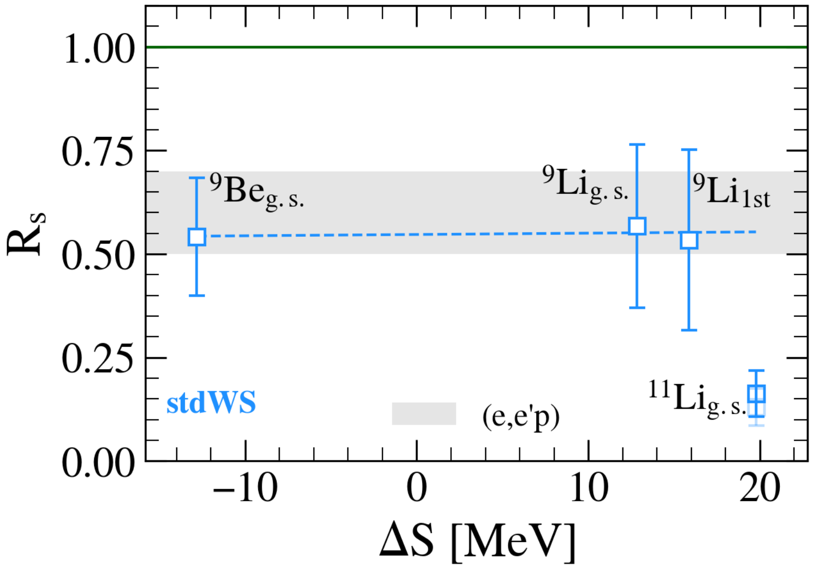


GMF = 0.22(7) is required!

Results: estimating the GMF

After correction: 16(6)% reduction

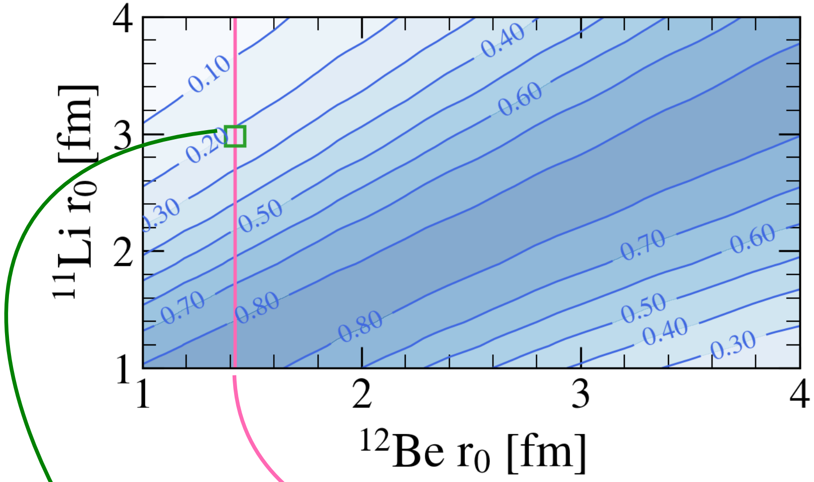
⇒ <u>Insufficient</u> to agree with (e,e’p) systematics!



GMF = 0.22(7) is required!

Geometry of the s.p. wave functions

⇒ Explore GMF by varying the WS **r_0** parameter



I. Tanihata et al. Prog. Part. Nucl. Phys. 68 (2013)

Experimental matter rms ^{12}Be = 2.59(6) fm

⇒ Equivalent r_0 = 1.42 fm

Required r_0 = 2.98 fm ⇒ matter rms = 4.10 fm

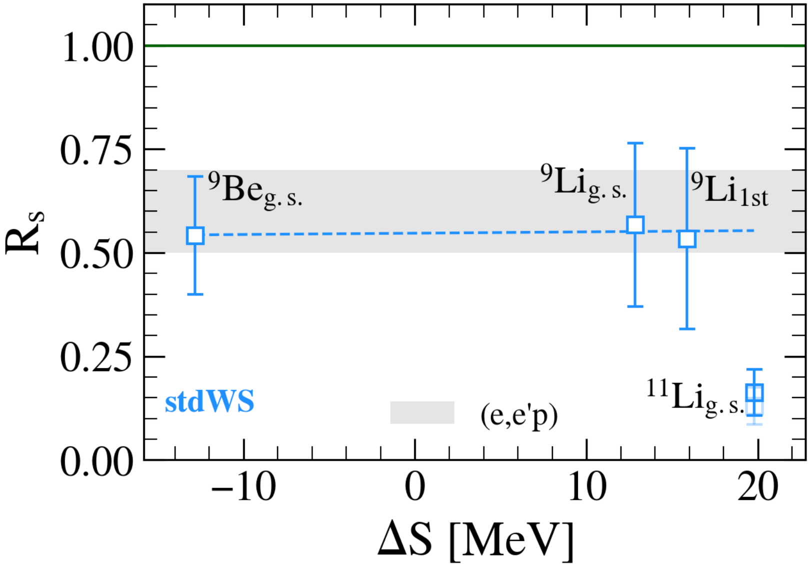
Experimental = 3.50(9) fm

I. Tanihata et al. Prog. Part. Nucl. Phys. 68 (2013)

Only 20% overestimation

Results: estimating the GMF

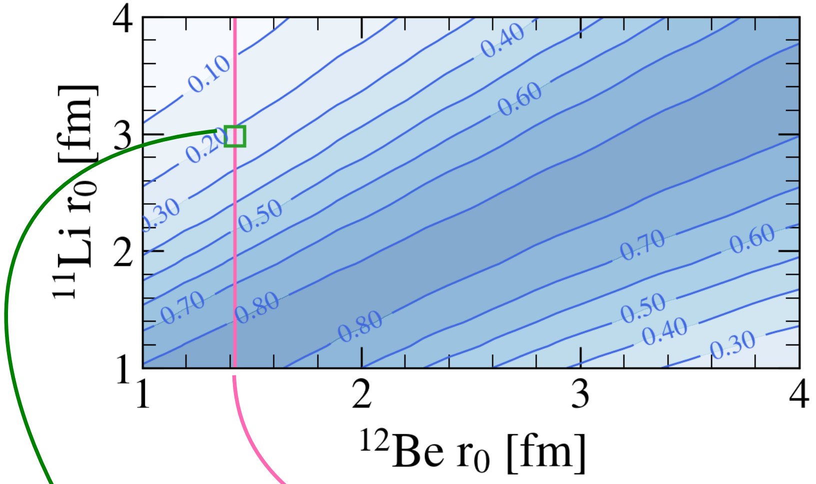
After correction: 16(6)% reduction
⇒ Insufficient to agree with (e,e’p) systematics!



GMF = 0.22(7) is required!

Geometry of the s.p. wave functions

⇒ Explore GMF by varying the WS **r_0** parameter



I. Tanihata et al. Prog. Part. Nucl. Phys. 68 (2013)

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Required r_0 = 2.98 fm ⇒ matter rms = 4.10 fm
Experimental = 3.50(9) fm

I. Tanihata et al. Prog. Part. Nucl. Phys. 68 (2013)

Only 20% overestimation

GMF is a clear footprint of halo nuclei

Next steps:
1n halos in C?
^{15,19}C

Conclusions

^{10}Be(d,t)^{9}Be and ^{10,12}Be(d,^{3}He)^{9,11}Li reactions were measured and R_s studied for ΔS in [−12, 20] MeV range

Accepted R_s ~ 0.6 found except for <^{12}Be|^{11}Li>, suggesting new observation of geometrical mismatch factor (GMF)

Estimated GMF (0.8) is insufficient to reconcile with accepted systematics. GMF ~ 0.20 required!

Varying geometry of valence-neutron wave functions, systematics recovered as well as experimental matter radii of both ^{12}Be and ^{11}Li

Thank you for your attention!

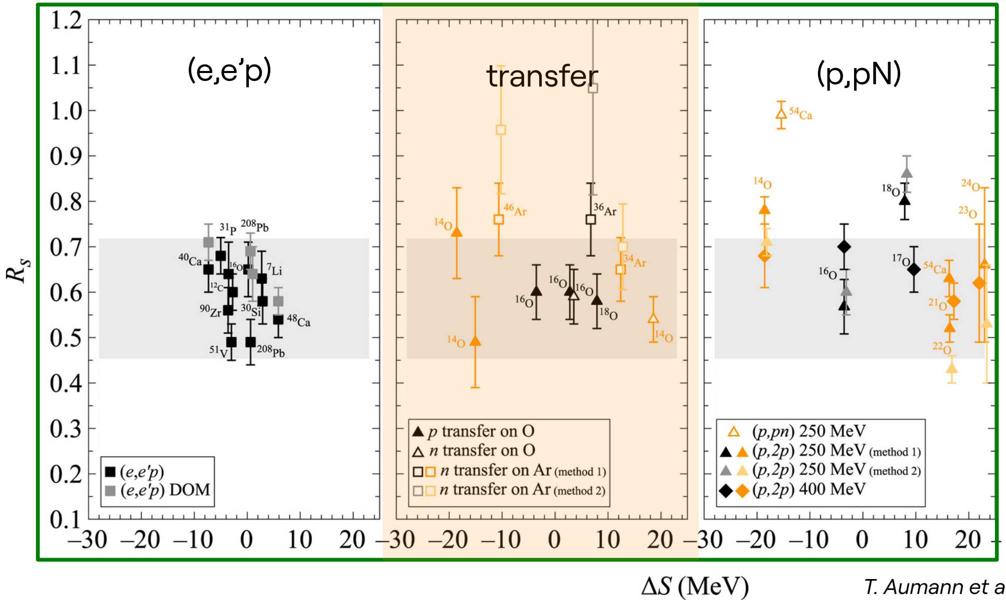
M. Lozano-González[1], B. Fernández-Domínguez[1], A. Matta[2], J. Lois-Fuentes[2], I. Blanco-Calviño[1],
F. Delaunay[2], T. Roger[3]
and the **MUST2** and **ACTAR TPC** collaborations

[1] *IGFAE and Dpt. of Particle Physics, Universidade de Santiago de Compostela, Spain*
[2] *LPC-Caen, ENSICAEN, CNRS/IN2P3, Caen, France*
[3] *GANIL, Caen, France*

Discrepancies in R_s

The reduction factor behaves differently with asymmetry energy (ΔS) depending on the probe

$\Delta S \equiv$
$S_n - S_p$ for n
$S_p - S_n$ for p



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

Limited dependence with the asymmetry energy:
$R_s \sim$ cte

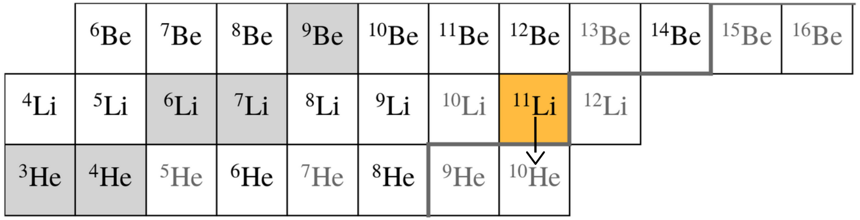
Strong trend with ΔS:
$R_s = 0.31 - 0.016\Delta S$

Our contribution:
new data for transfer at large $|\Delta S|$

Beyond NN correlations

If halo or unbound nuclei are present ⇒ lower expected occupancy (C^2S_{theo}) due to reduced wave-function overlap

Geometrical mismatch factor (GMF)



^{11}Li is an ideal candidate: two-neutron halo

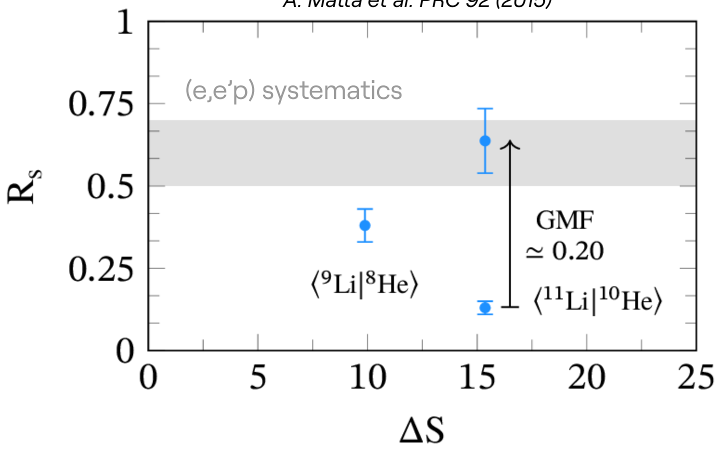
^{11}Li(d,^{3}He)^{10}He

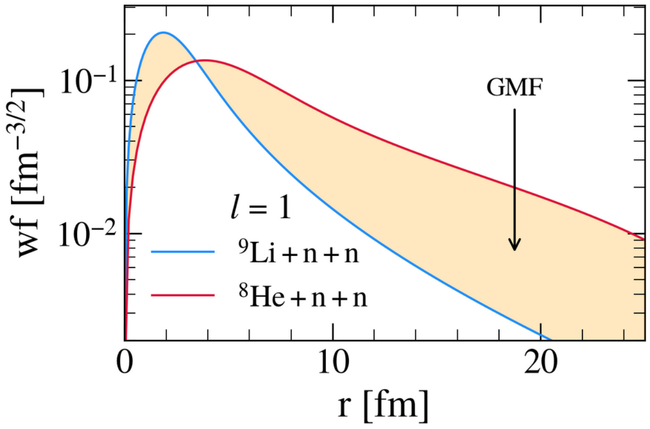
^{8}He + 2n, with $S_{2n}/2$= -0.73 MeV

^{9}Li + 2n, with $S_{2n}/2$ = 0.19 MeV

~ 1 MeV difference

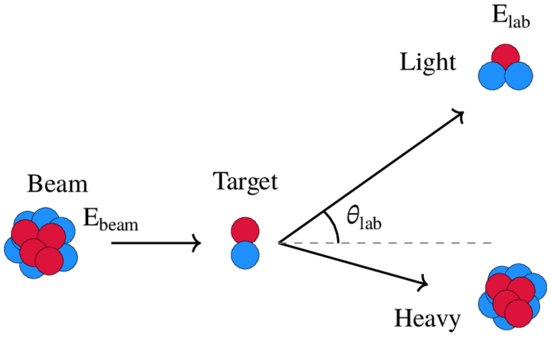
A. Matta et al. PRC 92 (2015)





Methodology: observables

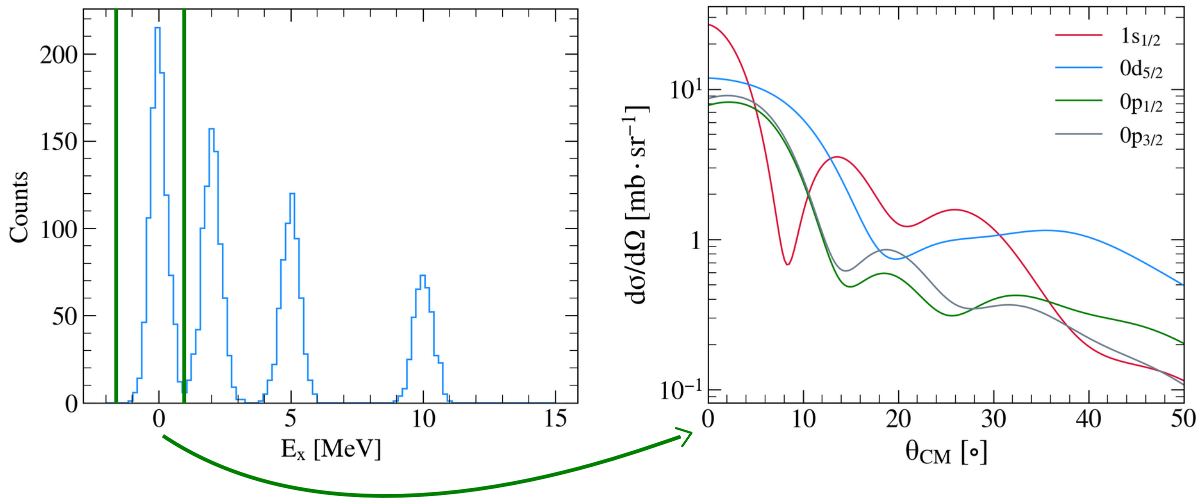
Transfer reactions in inverse kinematics



Missing-mass technique

E_{beam}, E_{lab}, θ_{lab}

E_x θ_{CM}



Counts per θ_{CM} slice

(d,t) | Occupancies
(d,³He) |

For each excited state: $$\left.\frac{d\sigma}{d\Omega}\right|_{exp} = \underset{\uparrow}{C^2S} \cdot \left.\frac{d\sigma}{d\Omega}\right|_{theo}$$

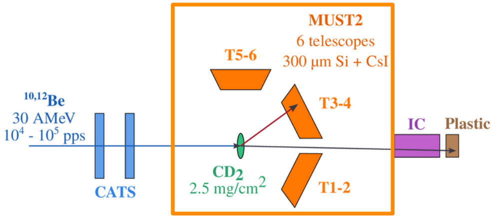
+ *l* assignment

DWBA to compute theoretical differential cross sections

Fresco

I. Thompson Comp. Phys. 7 (1988)

A glance at the analysis



1 Light PID

2 Heavy PID

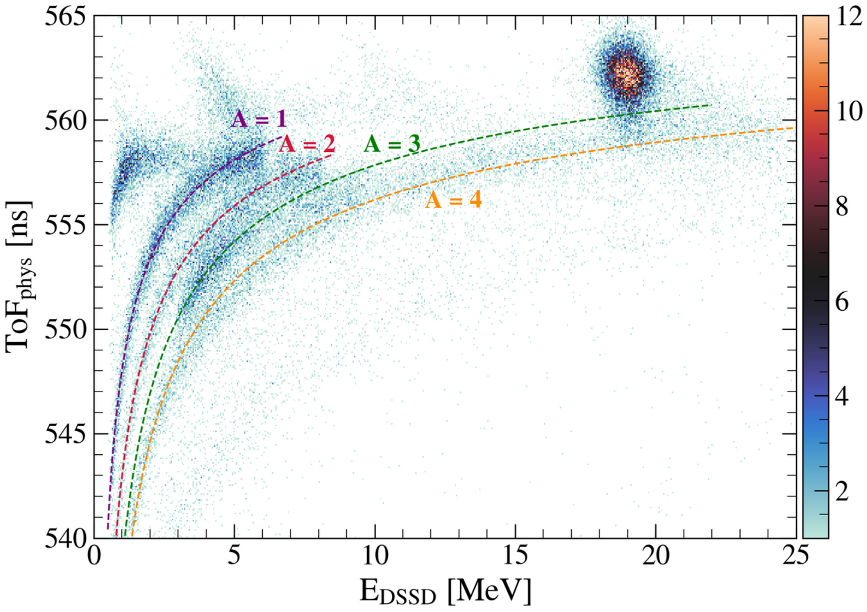
3 Missing-mass technique

Events of interest
stopped in DSSD

⇒ PID achieved with ToF-E technique

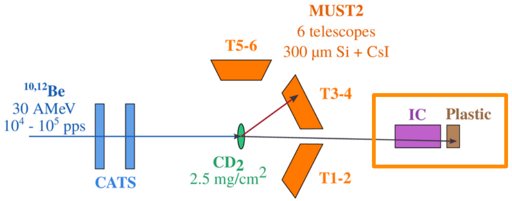
$$E = \frac{1}{2} m \left(\frac{d}{t} \right)^2$$

⚠ Only separation in mass
⇒ difficult t and ^{3}He distinction



Identification of heavy recoil
essential for disentangling t and ^{3}He

A glance at the analysis



1 Light PID

2 Heavy PID

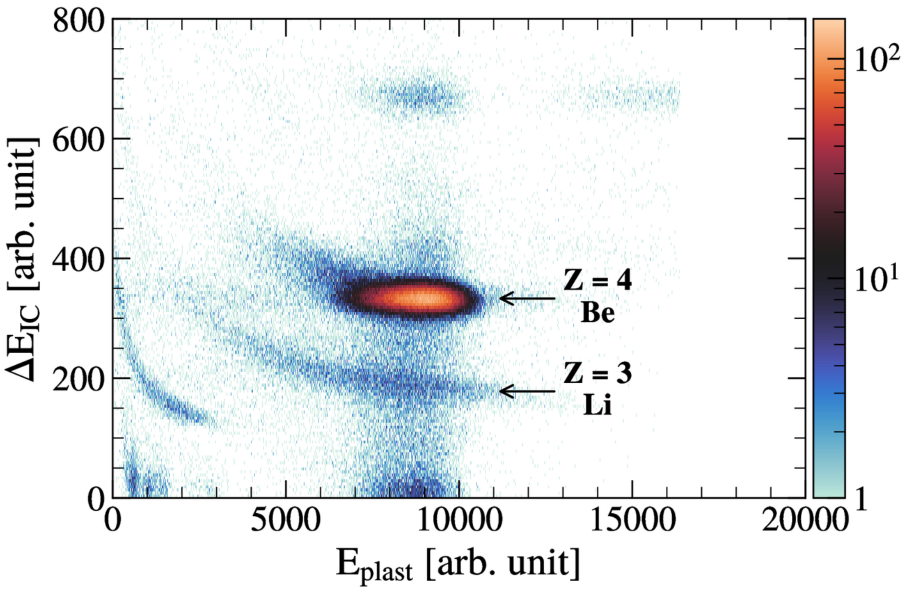
3 <u>Missing-mass</u> technique

PID with ΔE – E technique

$$-\frac{\mathrm{d}E}{\mathrm{d}x} \propto \frac{Z^2 A}{E}$$

⇒ Clear separation in Z
Not enough resolution for A

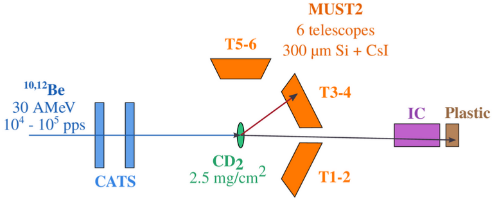
Equivalence
(d,t) ⇔ Be
(d,^{3}He) ⇔ Li



<u>Poor performance</u> throughout the experiment
⇒ Reduced intrinsic efficiency

→ Determined using elastic cross sections
Around 60 %

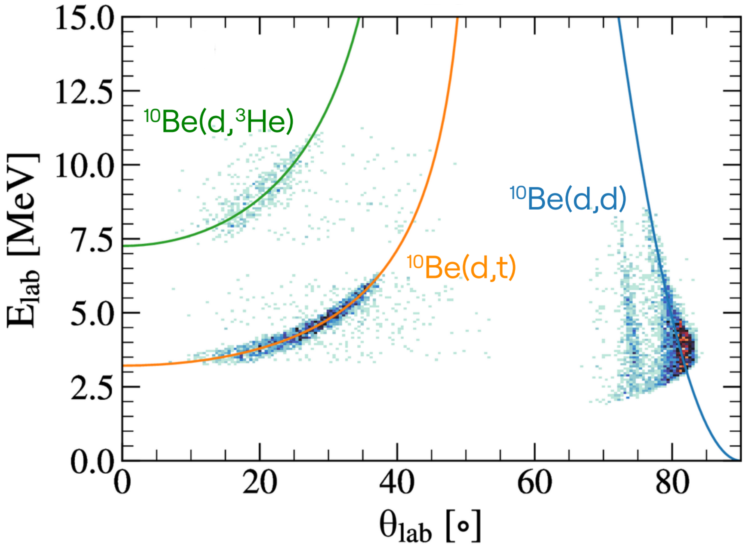
A glance at the analysis



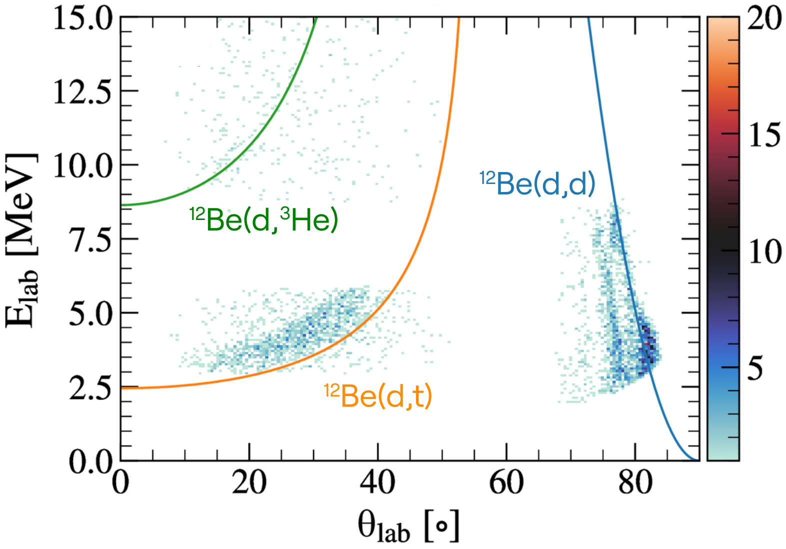
1 Light PID

2 Heavy PID

3 Missing-mass technique

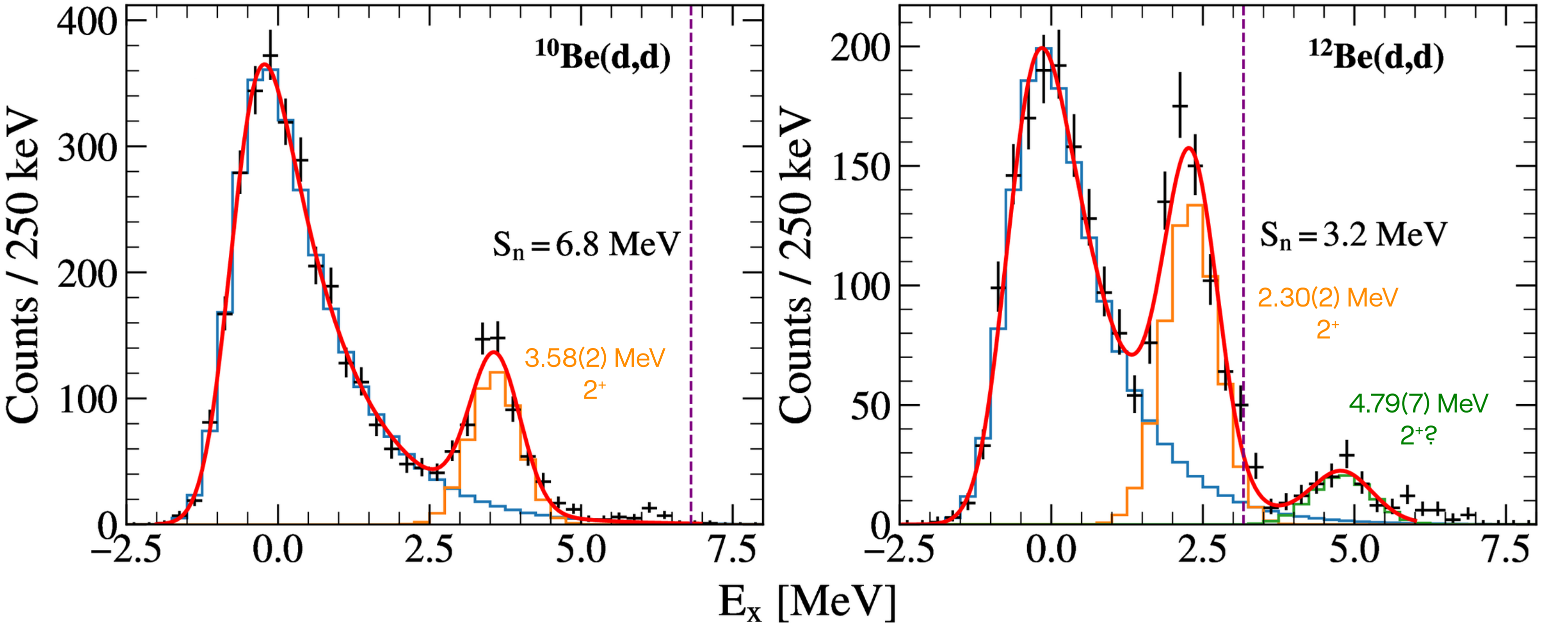


g.s. highly populated for reference reactions



⚠ Reduced stats for ^{12}Be(d,^{3}He)$^{\mathbf{11}}$**Li**

Elastic E_x spectra

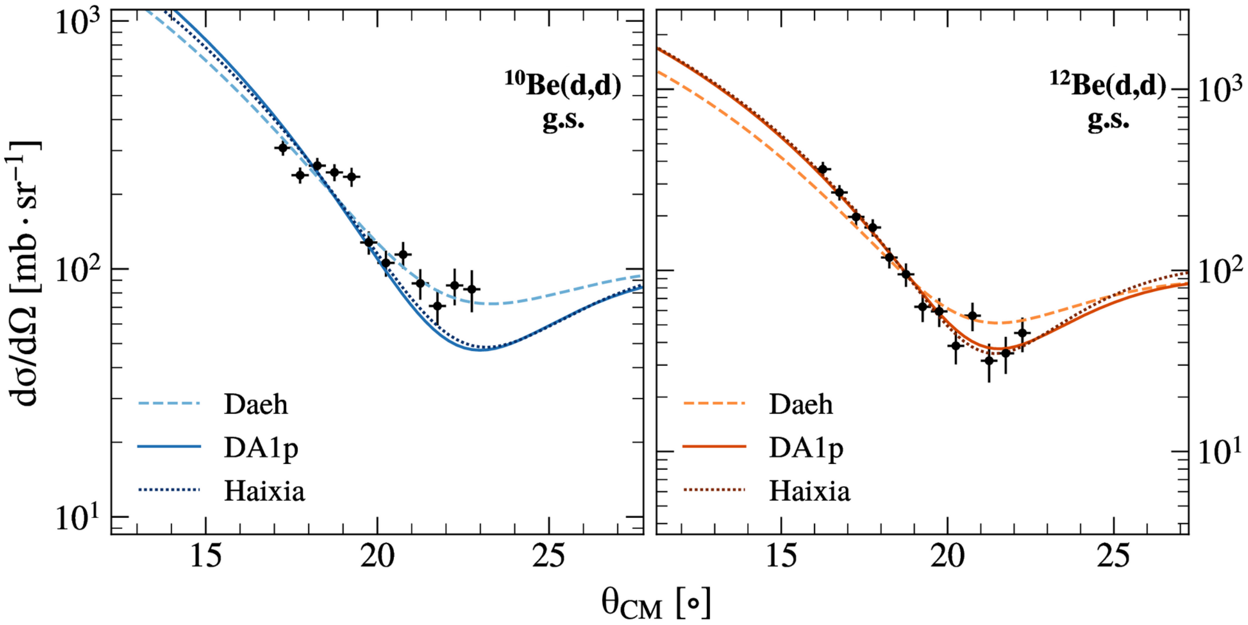


Ground state affected by large straggling in target

⇒ Fitted with convolution of Gaussian and exponential functions

✓ Focused only on g.s. to verify **normalisation** of cross sections

Elastic angular distributions



Theoretical normalised (α) to data through minimisation:

$$\left.\frac{d\sigma}{d\Omega}\right|_{\text{exp}} = \alpha \cdot \left.\frac{d\sigma}{d\Omega}\right|_{\text{theo}}$$

Subsequent dσ/dΩ are renormalised using α!

$\alpha(^{10}\mathrm{Be}) = 0.74(2)$
$\alpha(^{12}\mathrm{Be}) = 0.56(2)$

⚠ $\alpha \neq 1 \Rightarrow$ Issue with normalisation. Two sources: OMP systematic uncertainties + reduced ε of ZDD

OMP calculations with Fresco

^{10}Be → - Daeh *Daehnick et al. PRC 21 (1980)*
- DA1p *Zhang et al. PRC 94 (2016)*
^{12}Be → - Haixia *H. An and C. Cai PRC 73 (2006)*

STA R_s

Experimental C^2S from normalisation of cross sections

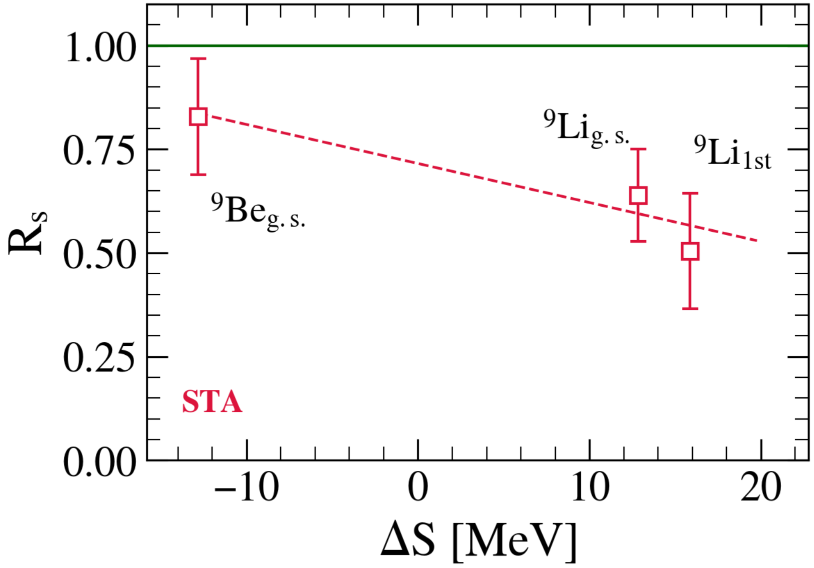
	^{9}Be	^{9}Li$_{g.s.}$	^{9}Li$_{1st}$	^{11}Li
C^2S_{exp}	1.3(2)	0.52(9)	0.07(2)	-
C^2S_{STA}	1.5	0.82	0.14	-

Missing in this model

Theoretical **STA** using large-scale SM calculations

N. Timofeyuk PRC 88 (2013)

$R_s \simeq 1$ is expected if inputs of **STA** correctly account for NN correlations



Improvement for ^{9}Be, but insufficient for ^{9}Li

$R_s \sim 1$ not reached

⇒ More accurate inputs required

Outlook: solid-target

Experimental setup

- Improve zero-degree detector: Z and A separation
- Add γ detectors to disentangle E_x states

Physics goals

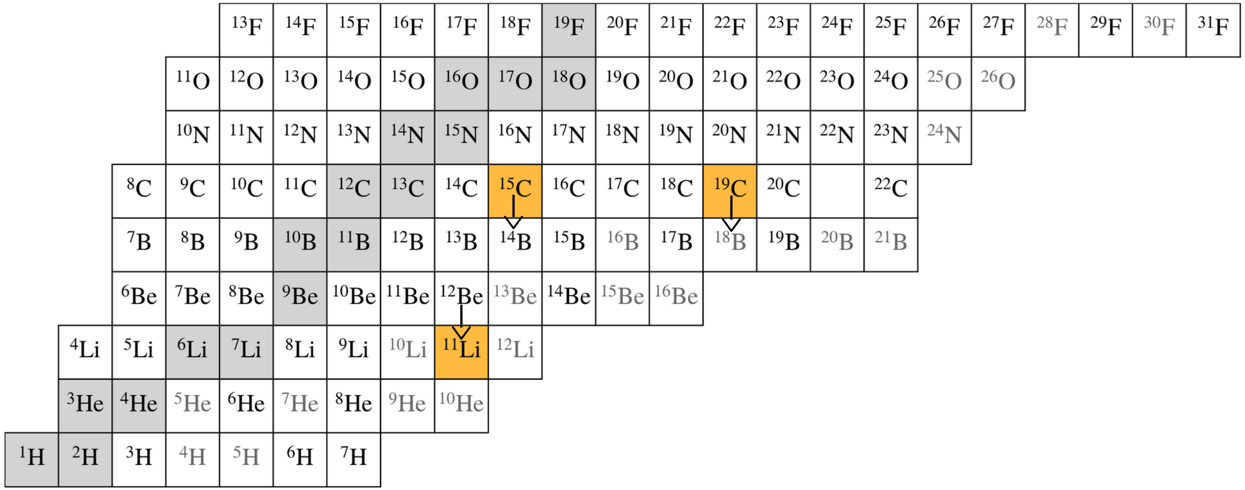
Study **GMF** in less exotic systems

$\Downarrow$

One-neutron carbon halos

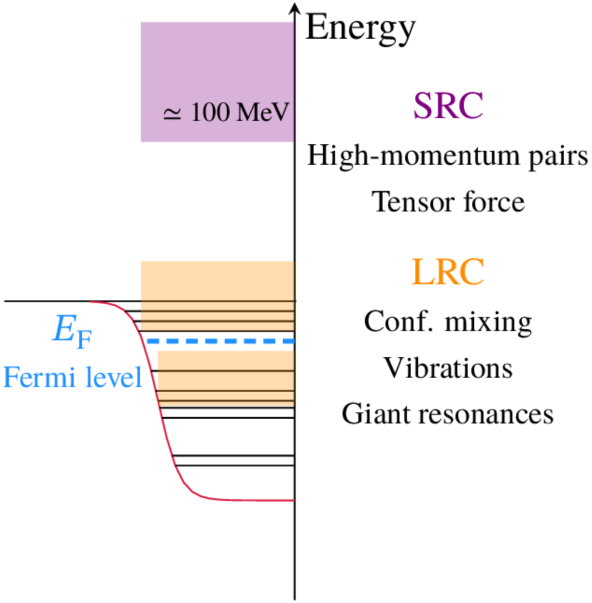
$^{15,19}C$

- $^{15}C(d,^{3}He)^{14}B \Rightarrow \Delta S_n = 0.3$ MeV
- $^{19}C(d,^{3}He)^{18}B \Rightarrow \Delta S_n = \underline{0.6 \text{ MeV}}$



Types of NN correlations

NN correlations fragment and displace single-particle occupancies



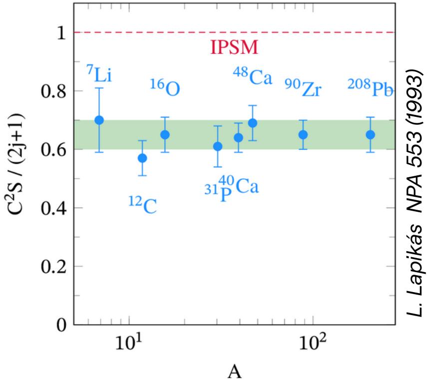
Short-range correlations

- Repulsive core
- Tensor favours deuteron states (S=1, T=0)
- Theoretical: 10-15% *W.H. Dickhoff et al. Prog. Part. Nucl. Phys. 52 (2004)*
- Experimental: 20% *R. Subedi et al. Science 320 (2008)*
- Enhancement for *minority* nucleons (p in n-rich)

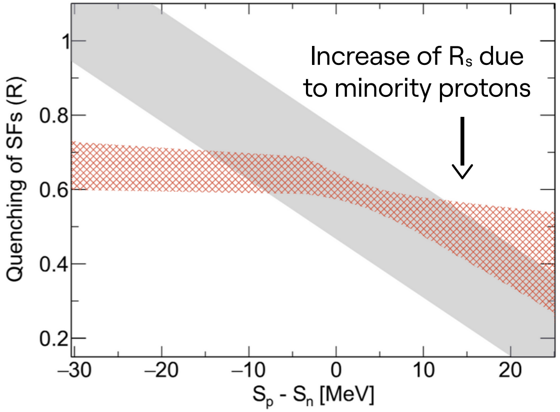
S. Paschalis et al. PLB 800 (2020)

Long-range correlations

- Sensitive to pairing gap
- Theoretical: 20% *W.H. Dickhoff et al. Prog. Part. Nucl. Phys. 52 (2004)*
- SM partially includes them depending on degree of p-h excitations



L. Lapikás NPA 553 (1993)

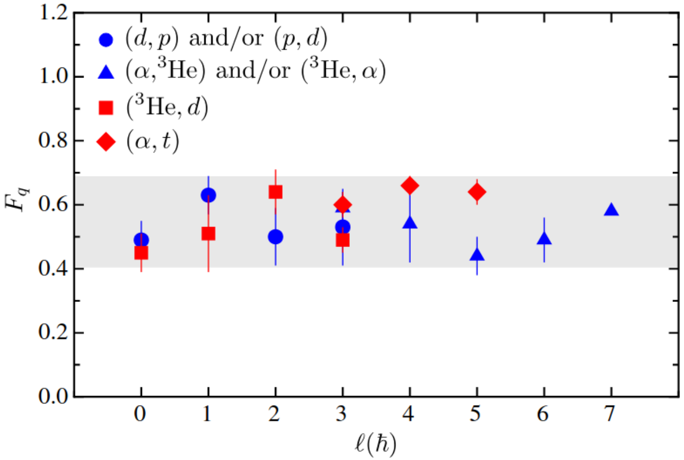


S. Paschalis et al. PLB 800 (2020)

Return to index

R_s with *l* and E_x

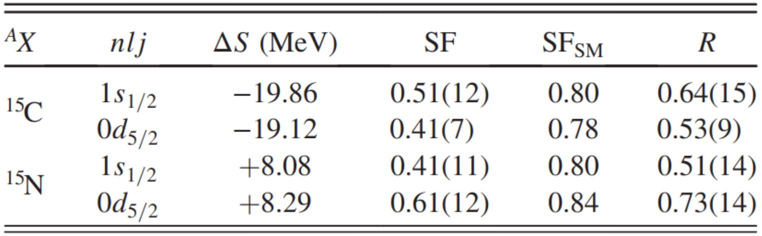
R_s has been shown to be independent of *l*



B. Kay et al. PRL 111 (2013)

And also investigated for excited states

^{15}C/^{15}N(d,p) reactions



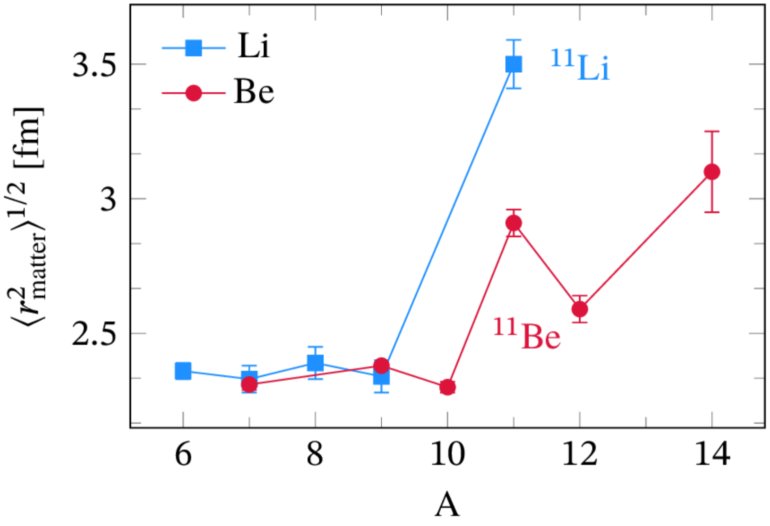
${}^AX$	nlj	ΔS (MeV)	SF	$\mathrm{SF_{SM}}$	R
^{15}C	$1s_{1/2}$	−19.86	0.51(12)	0.80	0.64(15)
	$0d_{5/2}$	−19.12	0.41(7)	0.78	0.53(9)
^{15}N	$1s_{1/2}$	+8.08	0.41(11)	0.80	0.51(14)
	$0d_{5/2}$	+8.29	0.61(12)	0.84	0.73(14)

B. Kay et al. PRL 129 (2022)

R_s = 0.5 wrt to IPSM [(2j+1)]
R_s = 0.6 wrt to SM

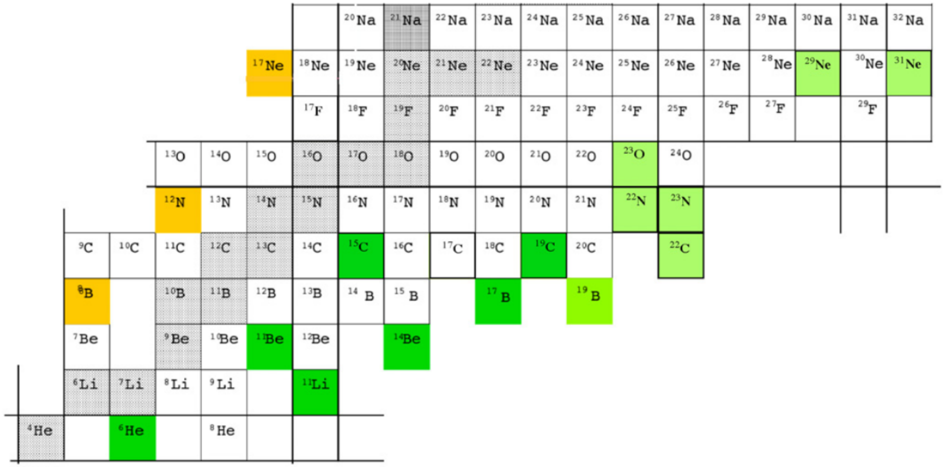
Return to index

Halo nuclei



Conditions for halos:

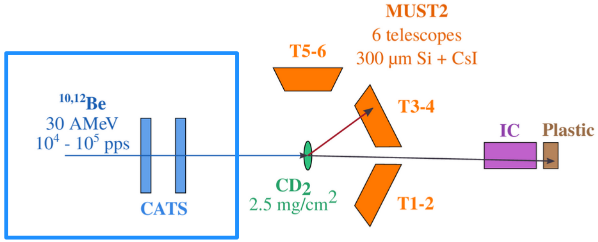
- Low valence-particles binding energies
- Low centrifugal barrier ⇔ low *l*
- Proton halos less frequent due to Coulomb barrier



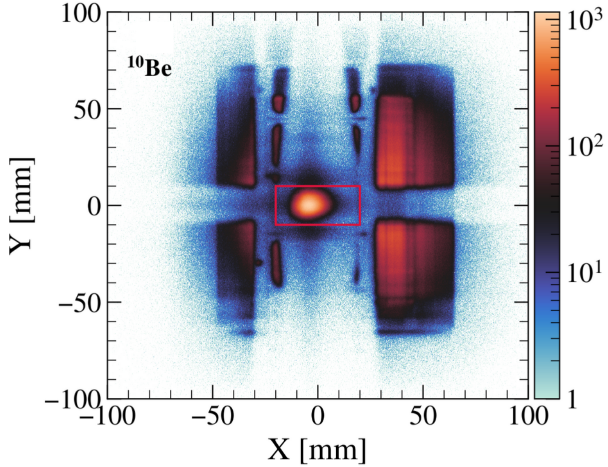
I. Tanihata et al. Prog. Part. Nucl. Phys. 68 (2013)

Return to index

Solid target: CATS and beam calibration



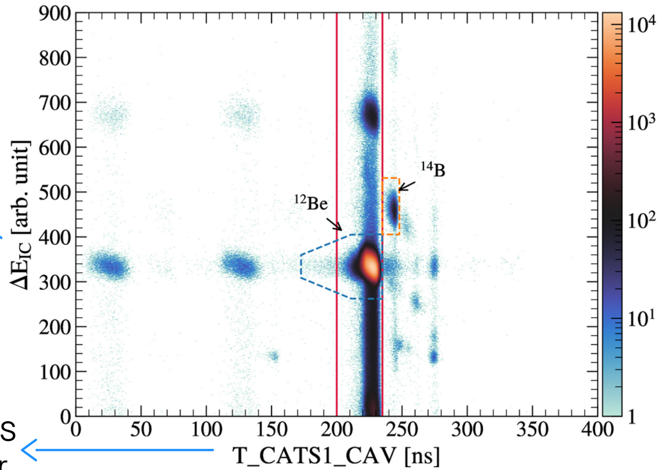
Position on target plane reconstructed with σ = 0.75 mm precision



⇒ Gate on target holder

E_{beam} calibration using ^{12}Be and ^{14}B contaminant

ΔE_{IC} for non-reacting events



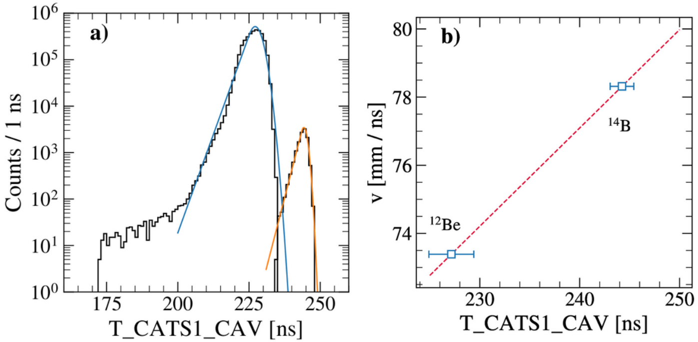
ToF between 1st CATS and in-line detector

ToF centroid determined for each species using a crystal ball function

⇓

Velocity conversion using Bρ = 2.36 Tm

E_{beam}
^{10}Be ⇒ 298 MeV
^{12}Be ⇒ 350 MeV

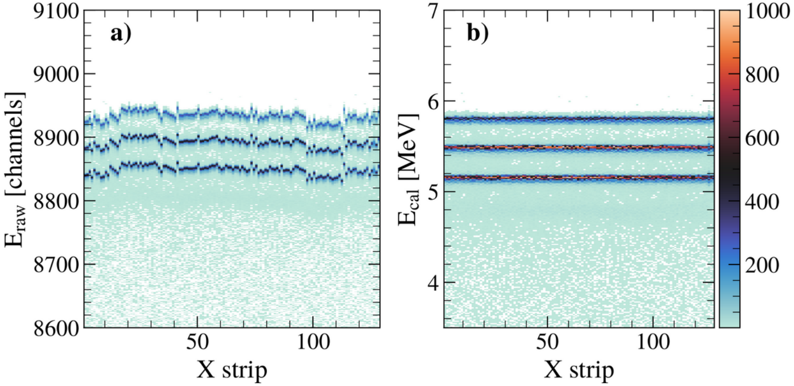


CB = Gaussian + power-law tail

Return to index

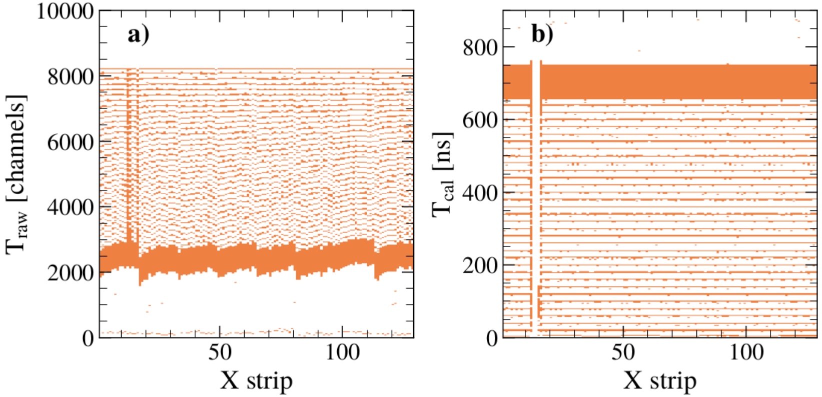
Solid target: MUST2 calibration

Energy calibration using 3α source



Average resolution:
FWHM ≃ 40 keV

Time calibration using pulser

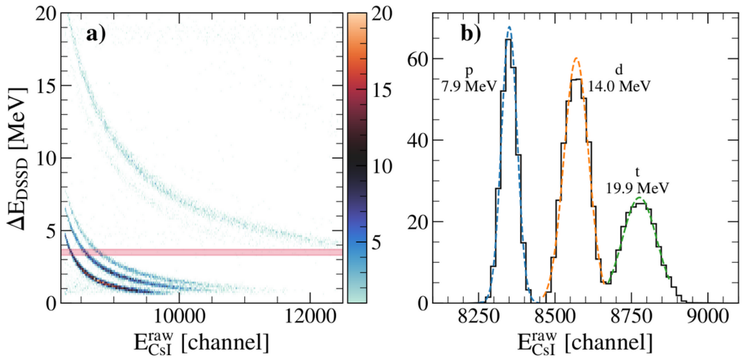


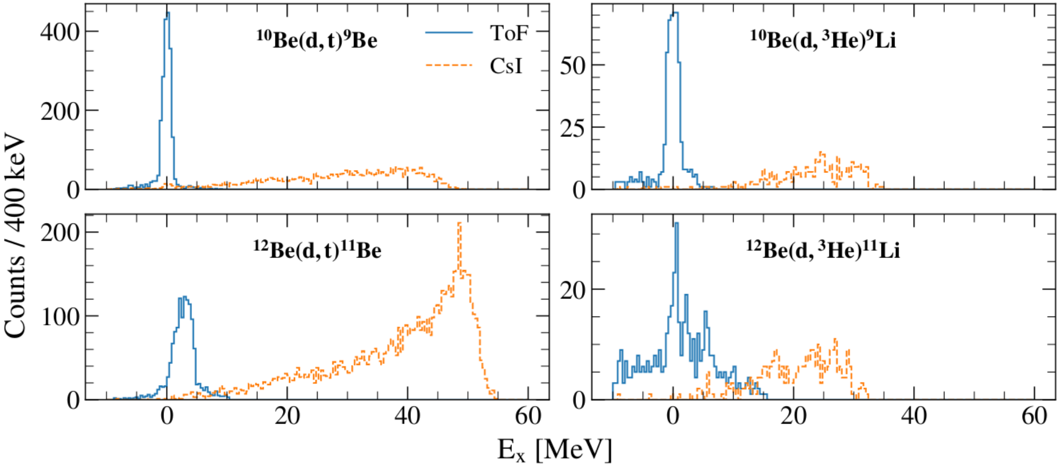
+
Time **alignment** on strip-by-strip basis
using CsI punch-through events
FWHM ~ 1 ns

Return to index

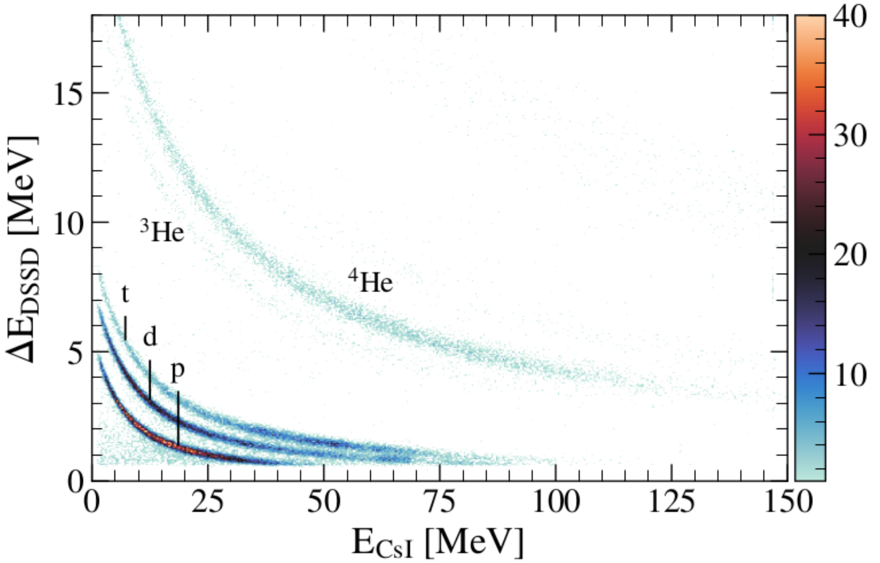
Solid target: CsI calibration

E_{CsI} from ΔE_{DSSD} method





Resulting **PID** matrix



CsI **contribution** not important for low E_x

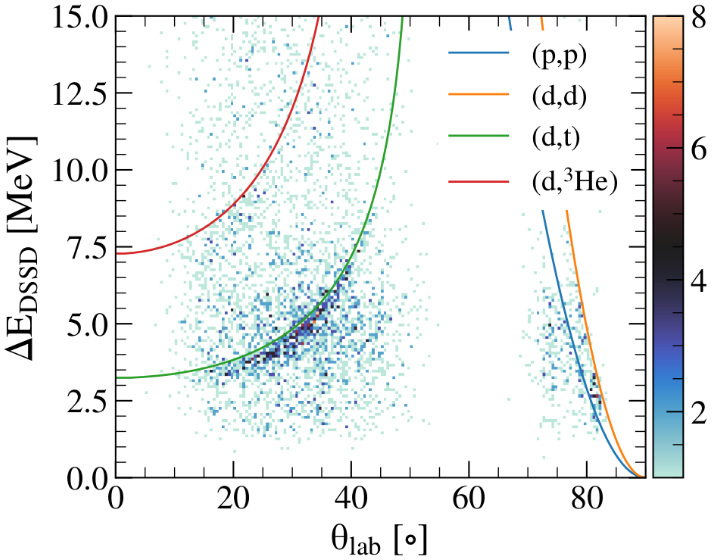
Return to index

Solid target: MUST2 analysis

Several steps:

1. Calibration and disabling missing strips
2. **Strip matching**: $|E_X - E_Y| < \varepsilon = 300\ \mathrm{keV}$
3. CsI matching: overlap shadow, equivalent to 34 strips
4. **Multiplicity = 1** i.e. only one light particle

Improved current algorithm to incorporate **interstrip** events

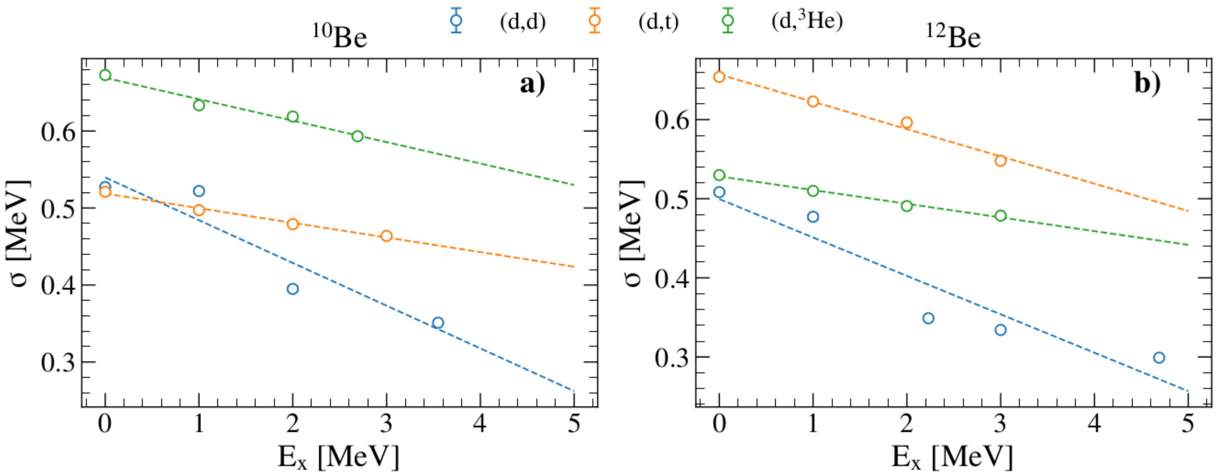


⇒ **8% gain** in statistics with MUST2

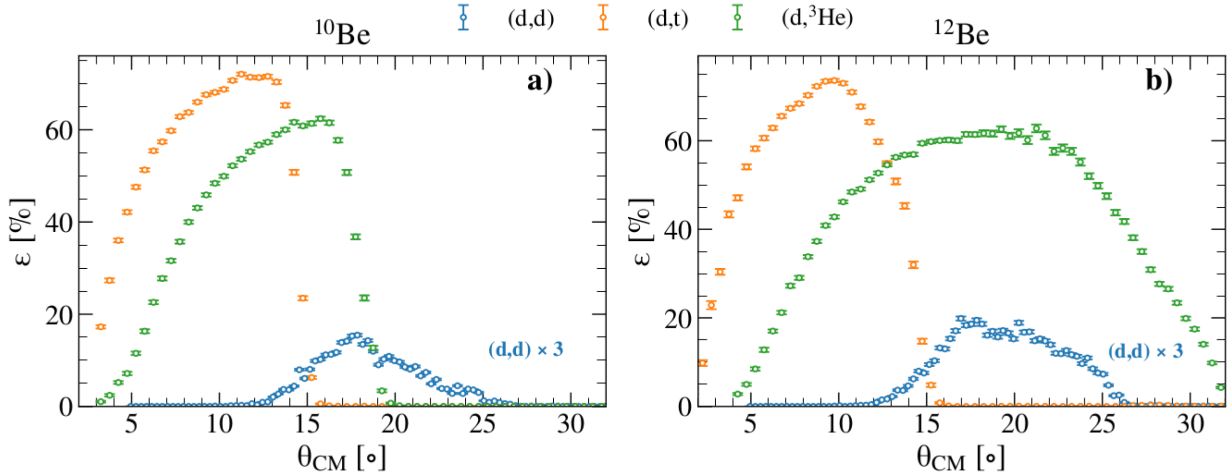
Return to index

Solid target: simulation

Resolution dependence on E_x

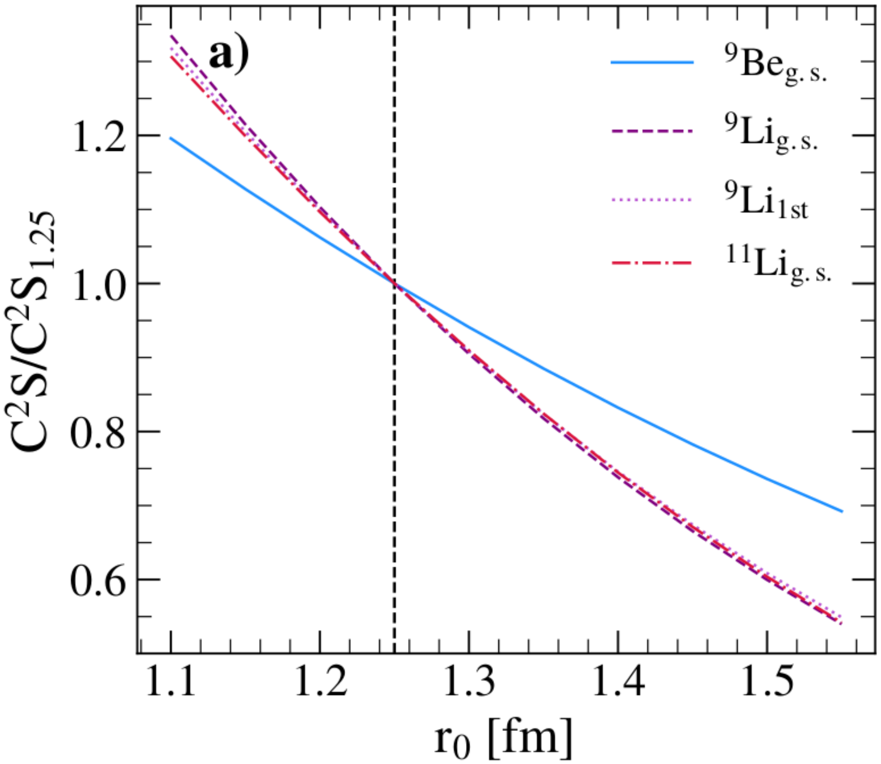


Efficiency in the CoM frame



Return to index

Solid target: stdWS r_0



Systematic effect of r_0 [1.1, 1.4] fm in spectroscopic factors

- 20% for ^{9}Be
- 30% for ^{9,11}Li

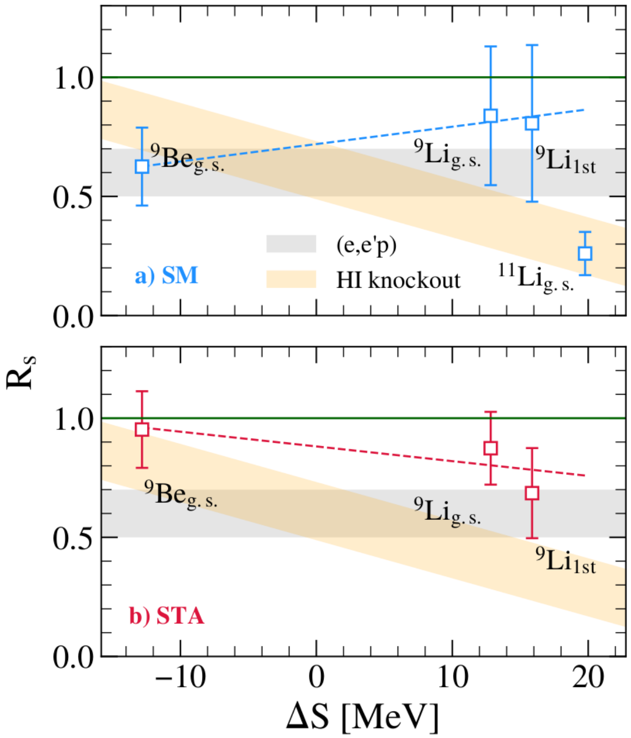
Taken r_0 reference range from large-scale calculations of

W.L. Hai et al. PRC 110 (2024)

Return to index

Solid target: Pang OMP

Results were also analysed with **Pang** OMP.



Results with HT1p OMP remain valid, although:

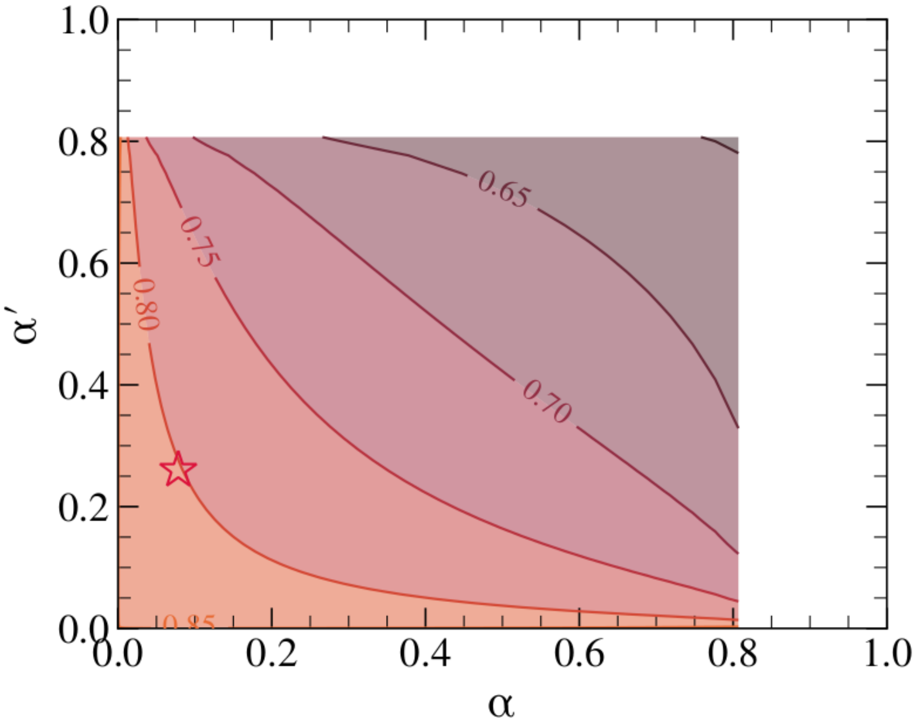
- Steeper dependence on ΔS for **stdWS**
- Better agreement with R_s ~ 1 for **STA**

Required ^{11}Li GMF to reach systematics:
GMF = 0.43(15)

Return to index

Solid target: α, β and γ impact on GMF

Explored also effect of linear expansion coefficients on GMF. Only for *s* and *p* waves



GMF = 0.22 (HT1p OMP) nor 0.43 (Pang OMP)
are reached
⇓
Something else is reducing occupancy

Return to index

Solid target: STA overlaps

The heavy-particule overlap is given by

$$S_{ij} = \int r^2 I_{ij}^2(r) dr = \int r^2 |\langle\Psi_i|\Psi_j\rangle|^2 dr$$

If Ψ from SM ⇒ *direct* evaluation:

- Might not exhibit correct radial behaviour
- Calculated in truncated spaces

⇓

Experimentally:
Woods-Saxon with fixed geometry

It can be calculated from *inhomogeneous* equation

$$(T + V_{\text{Coulomb}} + \varepsilon) I_{ij} = -U_{ij}(r)$$

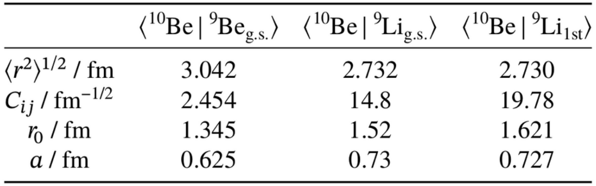
Exp binding energy

Source term

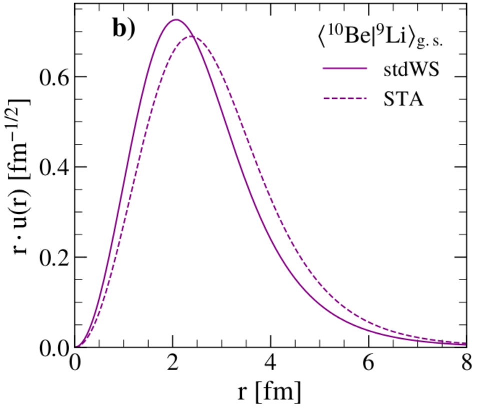
⇒ Resulting overlap has correct radial tail and incorporates missing spaces

⇓

In practice: WS with custom (r_0, a) to
reproduce ANC and rms of I_{ij}



	$\langle {}^{10}\text{Be} \,|\, {}^{9}\text{Be}_{\text{g.s.}}\rangle$	$\langle {}^{10}\text{Be} \,|\, {}^{9}\text{Li}_{\text{g.s.}}\rangle$	$\langle {}^{10}\text{Be} \,|\, {}^{9}\text{Li}_{1\text{st}}\rangle$
$\langle r^2\rangle^{1/2}$ / fm	3.042	2.732	2.730
C_{ij} / fm$^{-1/2}$	2.454	14.8	19.78
r_0 / fm	1.345	1.52	1.621
a / fm	0.625	0.73	0.727



Return to index

Solid target: STA overlaps x2

Heavy-particle overlap obtained from inhomogeneous equation

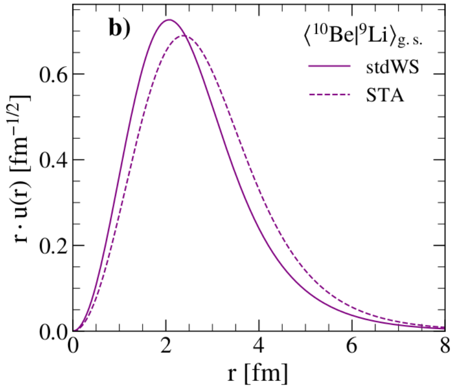
⇒ Incorporates NN correlations if exp. binding energy and proper interaction are included

$$\langle\Psi_B|T_A - T_B - \underbrace{(\varepsilon_A - \varepsilon_B)}_{\equiv \varepsilon_{AB}}|\Psi_A\rangle = \langle\Psi_B|V_B - V_A|\Psi_A\rangle,$$

This yields different WS potentials to reproduce rms radii and ANCs

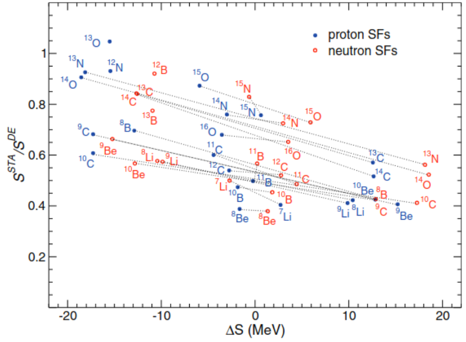
	$\langle^{10}\mathrm{Be}\,|\,^{9}\mathrm{Be}_{\mathrm{g.s.}}\rangle$	$\langle^{10}\mathrm{Be}\,|\,^{9}\mathrm{Li}_{\mathrm{g.s.}}\rangle$	$\langle^{10}\mathrm{Be}\,|\,^{9}\mathrm{Li}_{1\mathrm{st}}\rangle$
$\langle r^2\rangle^{1/2}$ / fm	3.042	2.732	2.730
C_{ij} / fm$^{-1/2}$	2.454	14.8	19.78
r_0 / fm	1.345	1.52	1.621
a / fm	0.625	0.73	0.727

Differences between **stdWS** and **STA**

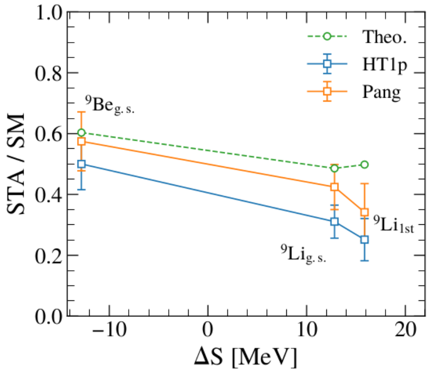


C²S of well-bound nucleon removals should be more quenched w.r.t. SM

N. Timofeyuk PRC 88 (2013)

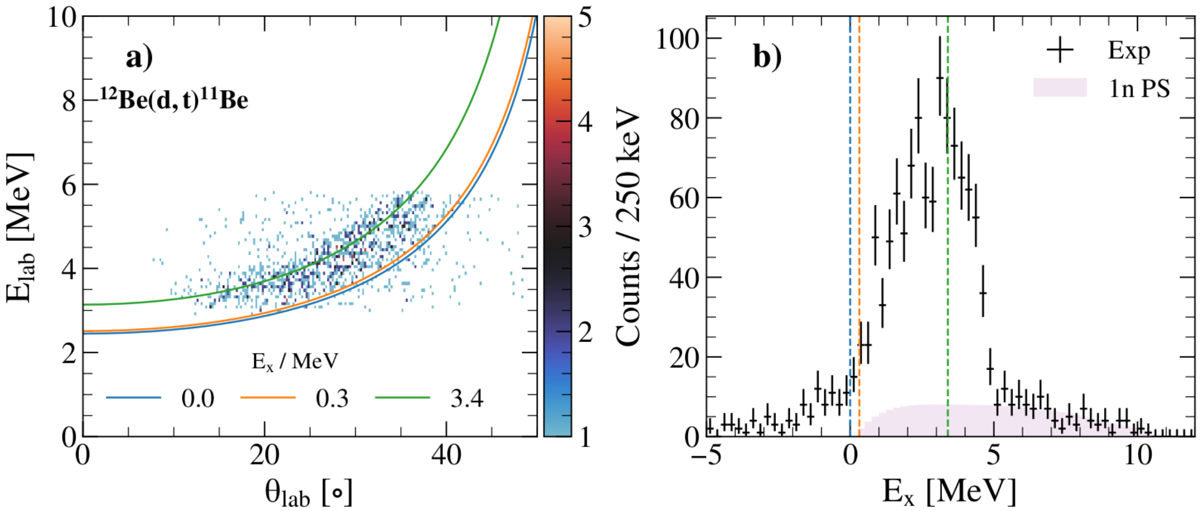


This was validated with our exp, dividing STA / SM spectroscopic factors

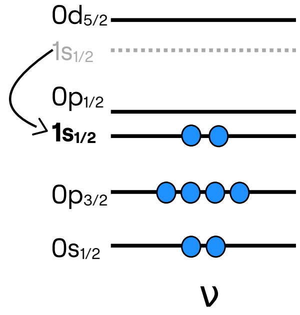


Return to index

Solid target: ^{12}Be(d,t)^{11}Be



^{11}Be presents *parity* inversion



Residual NN force produces breakdown of N = 8 for ^{11}Be

$$|(\vec{p}_{\text{in}} - \vec{p}_{\text{out}}) \times \vec{R}| \simeq l\hbar$$

Adapted for *l* = 1 according to E_{beam}

- 1/2$^-$ g.s. hindered ⇒ poor *l* matching of reaction?
- Region between 2-5 MeV cannot be resolved due to σ = 0.8 MeV
- One-neutron phase space does not account for that region

Solid target: more on GMF calculation

$$|^{12}\mathrm{Be}\rangle = \alpha|^{10}\mathrm{Be}\otimes \mathrm{s}^2\rangle + \beta|^{10}\mathrm{Be}\otimes \mathrm{p}^2\rangle + \gamma|^{10}\mathrm{Be}\otimes \mathrm{d}^2\rangle$$

$$|^{11}\mathrm{Li}\rangle = \alpha'|^{9}\mathrm{Li}\otimes \mathrm{s}^2\rangle + \beta'|^{9}\mathrm{Li}\otimes \mathrm{p}^2\rangle + \gamma'|^{9}\mathrm{Li}\otimes \mathrm{d}^2\rangle$$

Two-neutron amplitudes for s,p and d waves

⇒ Larger for p, as expected

	SFO-tls		Integral
l	$\|^{10}\mathrm{Be}\otimes l^2\rangle$	$\|^{9}\mathrm{Li}\otimes l^2\rangle$	I_l
s	0.28	0.51	0.850
p	0.87	0.74	0.953
d	0.41	0.43	0.993

Return to index