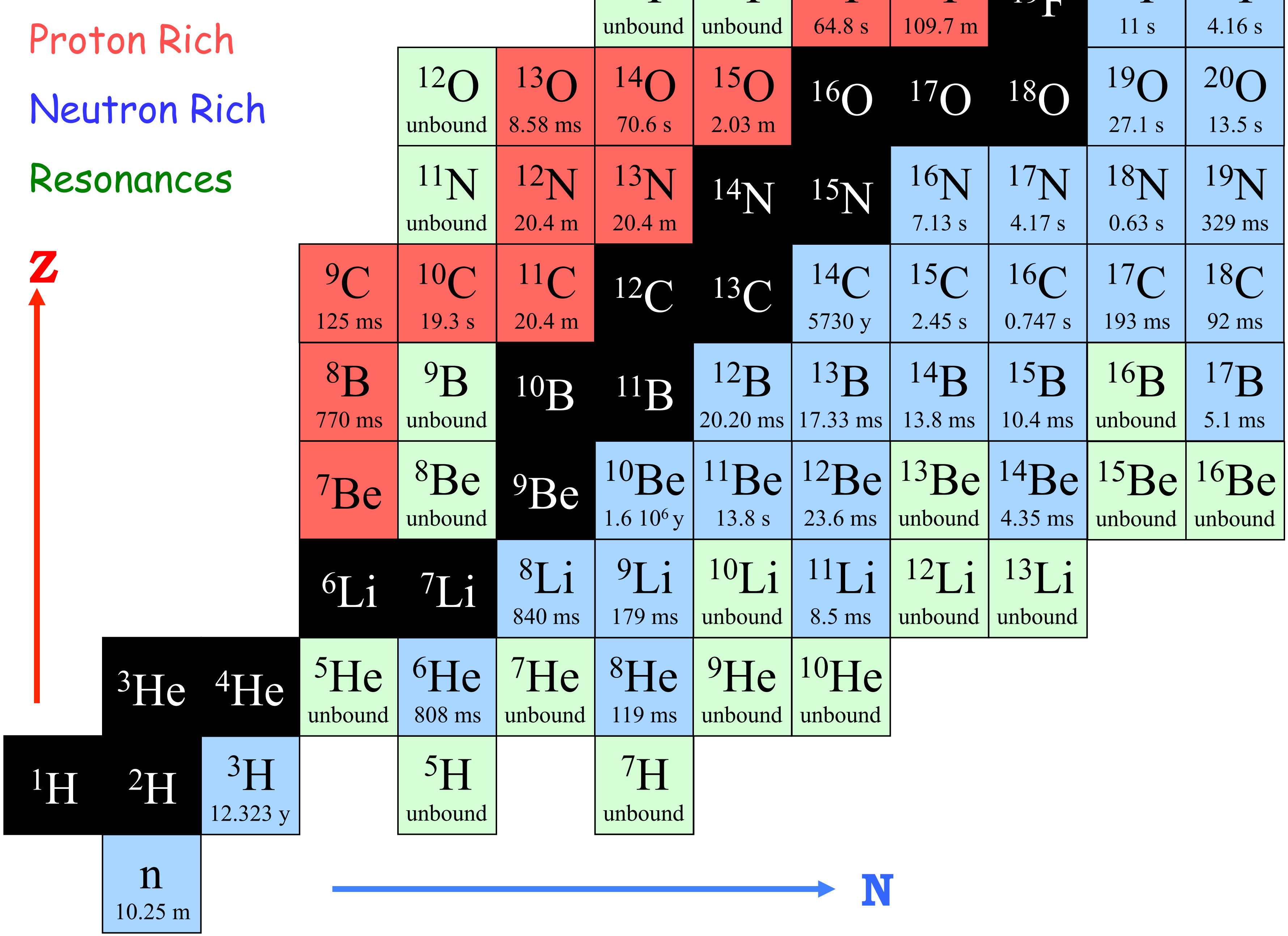
Studying nuclei at the dripline and unbound nuclei

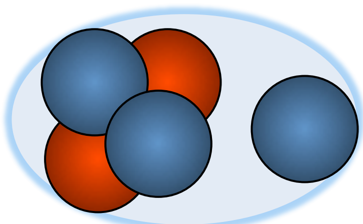
NUSTAR Week 2013
University of Helsinki (Kumpula Campus)
October 10, 2013

Björn Jonson

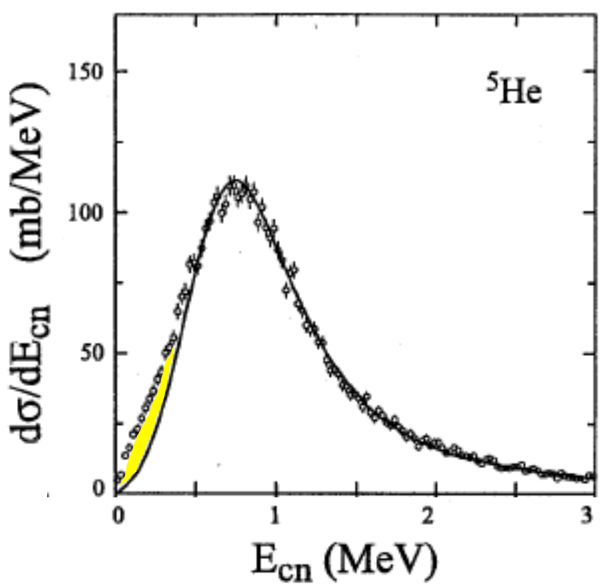
Light Nuclei in Nature



^{3}He	^{4}He	^{5}He	^{6}He	^{7}He	^{8}He	^{9}He	^{10}He
		unbound	808 ms	unbound	119 ms	unbound	unbound

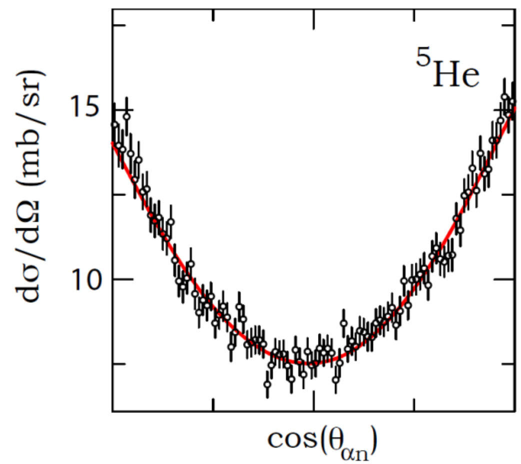


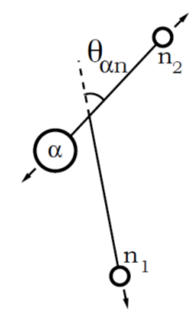
K. Markenroth *et al.*, NPA **679** (2001) 462



$$(p_n = -p_f)$$

$$^{6}\mathrm{He} : {}^{4}\mathrm{He} \otimes \left(\nu p_{3/2}\right)^2$$



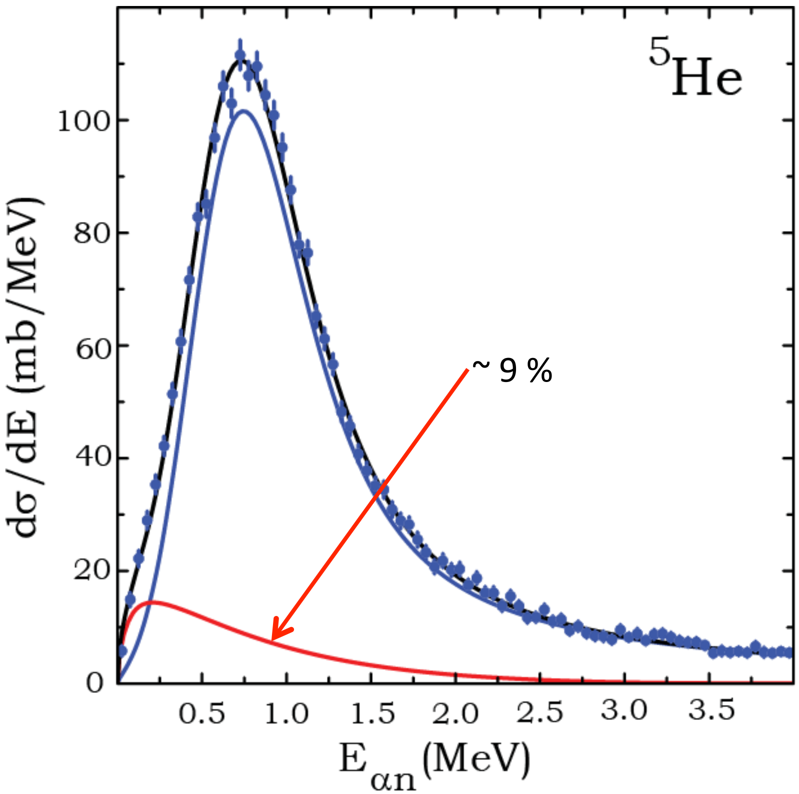


L.V. Chulkov *et al.,* PRL **79** (1997) 201

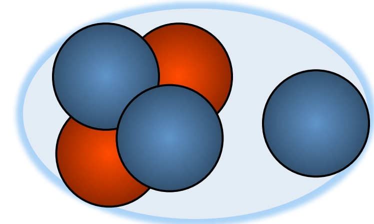
$$W(\theta_{\alpha n}) = 1 + 1.5\cos^2(\theta_{\alpha n})$$

$$(p_{1/2})^2 \sim 7\ \%$$

L.V. Chulkov, G. Schrieder, Z. Phys **A359** (97) 231



Yu. Aksyutina et al., PLB **679** (2009) 191



$$d\sigma / dE_{fn} \propto \frac{\Gamma_l(E_{fn})}{[E_r + \Delta_l(E_{fn}) - E_{fn}]^2 + \frac{1}{4}\Gamma_l^2(E_{fn})}$$

s-wave: Effective-range approximation

$$\frac{d\sigma}{dE_{fn}} \propto p_{fn}\left[\frac{1}{k^2 + p_{fn}^{\;2}}\right]^2 \left[\cos(\delta) + \frac{k}{p_{fn}}\sin(\delta)\right]^2$$

$$p_{fn}\cot(\delta) = -\frac{1}{a} + \frac{1}{2} r_0 p_{fn}^{\;2} + O(p_{fn}^{\;4})$$

Bertch *et al.*, PRC **57** (1998) 1366

$$k = \sqrt{2\mu\varepsilon}$$

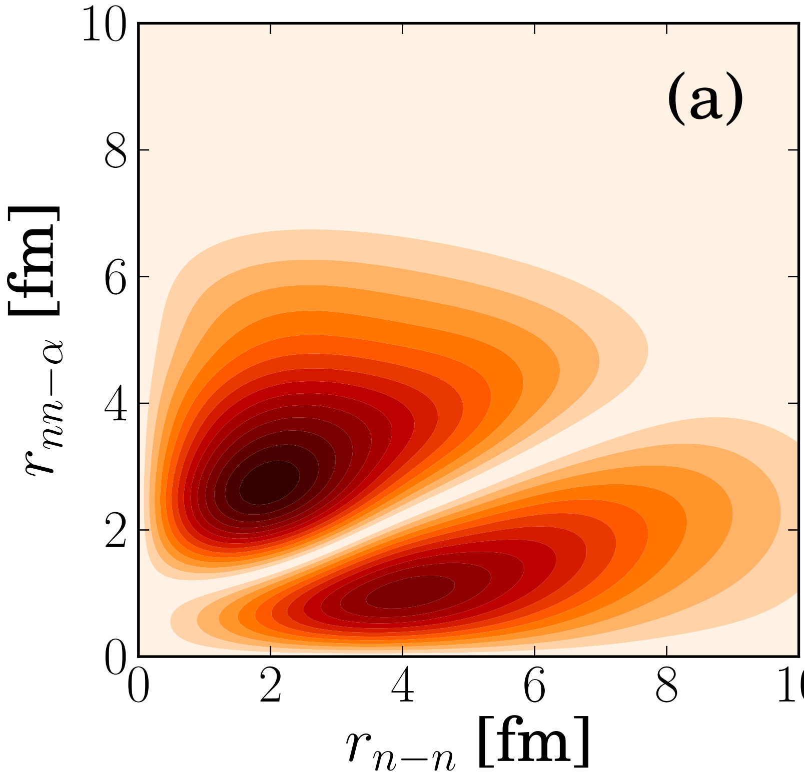
$$\varepsilon = 0.94(23)\,MeV$$

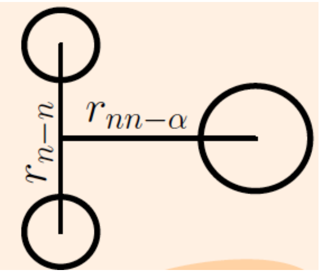
$$a = 3.37(38)\,fm$$

$(p_{3/2})^2$ ~ 86 %
$(p_{1/2})^2$ ~ 5 %
$(s_{1/2})^2$ ~ 7 %

B.V. Danilin et al., NPA **632** (98) 383

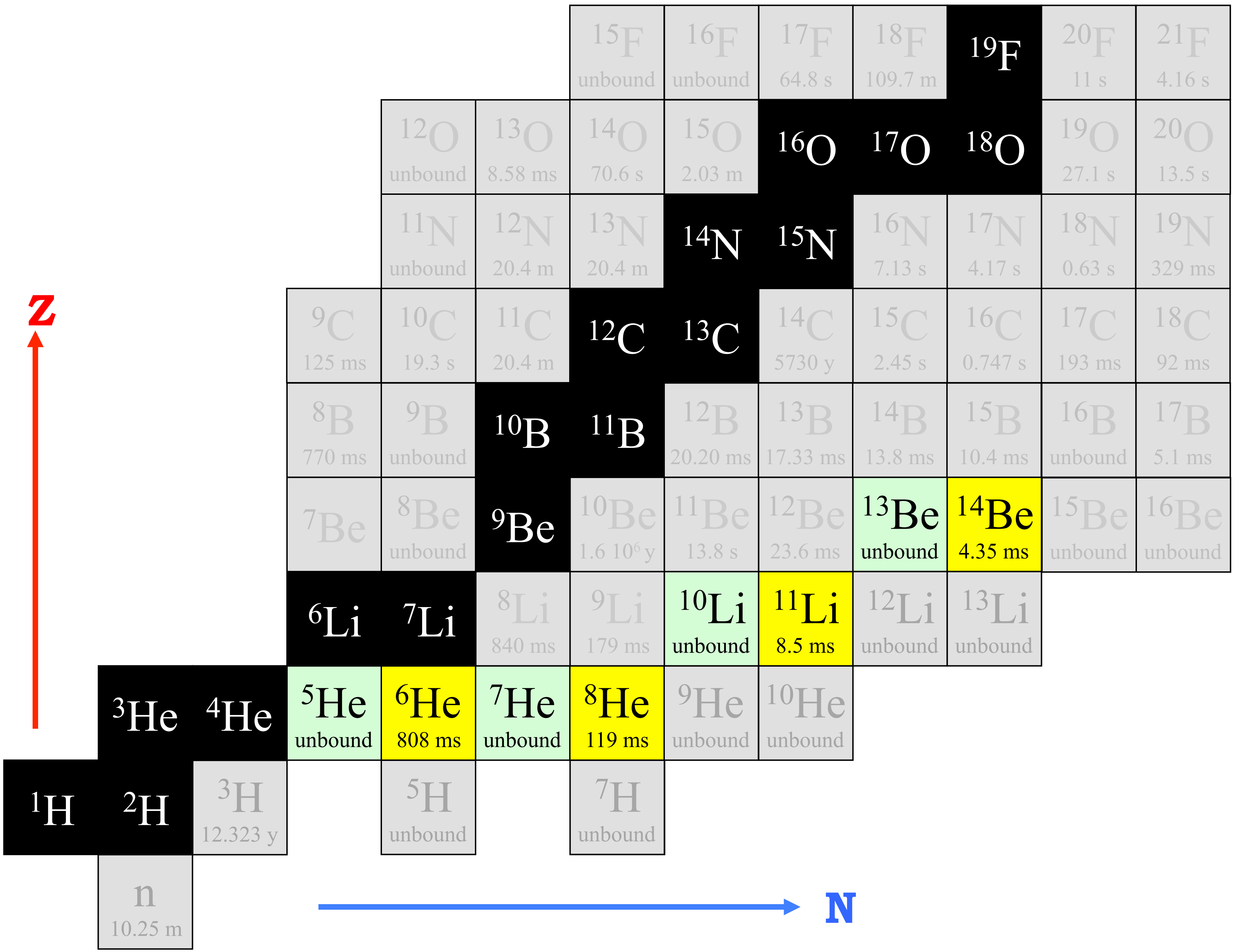
Ab initio no-core shell model



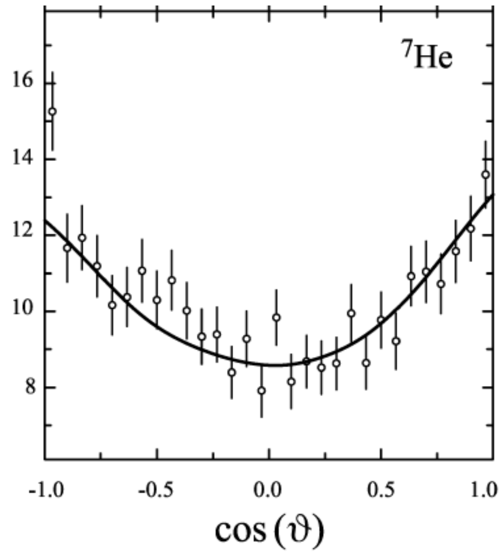


$$(1s_{1/2})^2 \approx 4\%$$

Sääf and Forssén, to be published

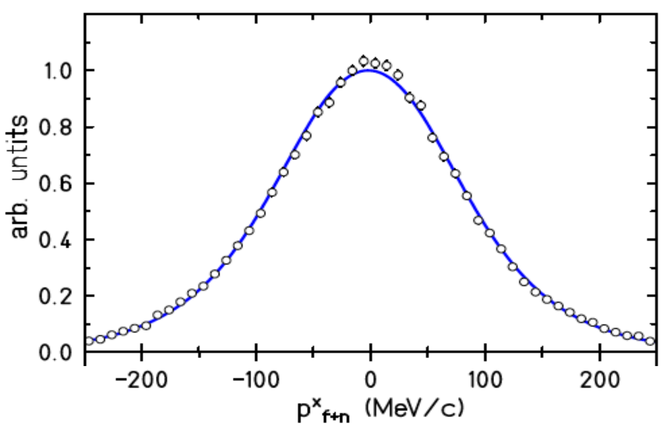


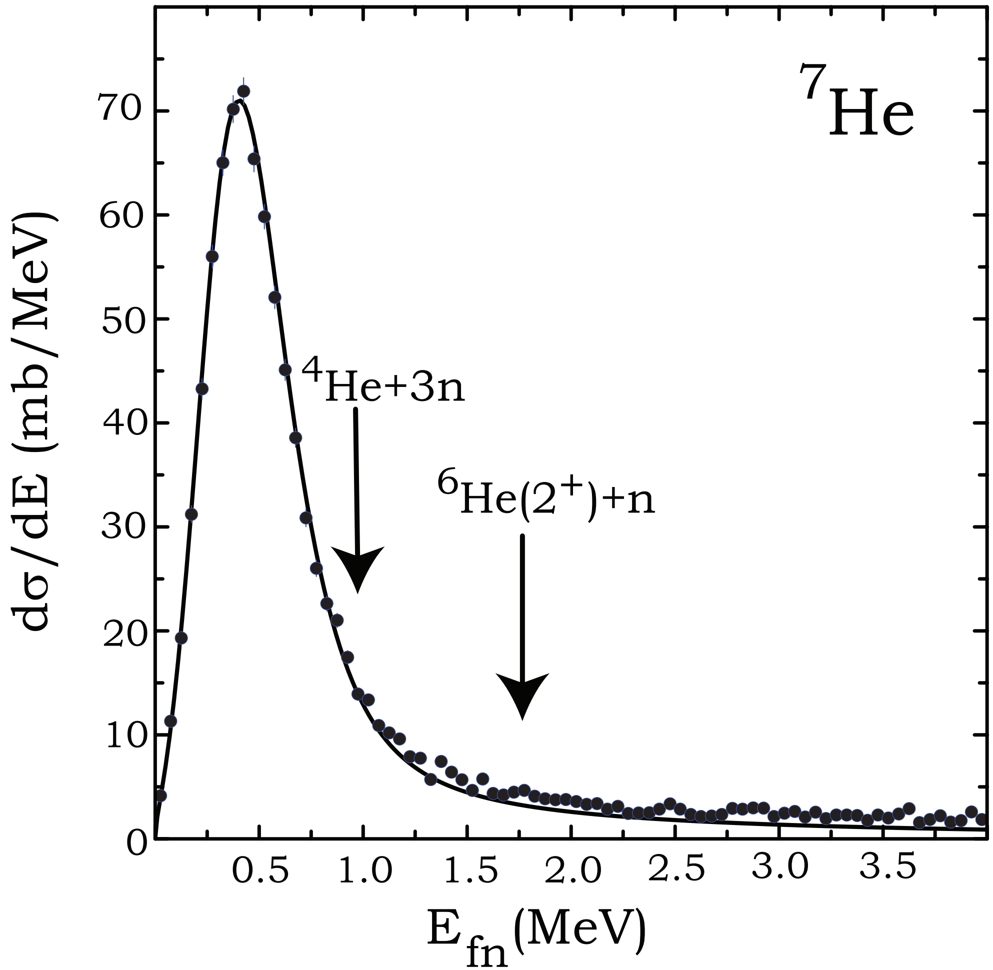
^{15}F unbound
^{16}F unbound
^{17}F 64.8 s
^{18}F 109.7 m
^{19}F
^{20}F 11 s
^{21}F 4.16 s
^{12}O unbound
^{13}O 8.58 ms
^{14}O 70.6 s
^{15}O 2.03 m
^{16}O
^{17}O
^{18}O
^{19}O 27.1 s
^{20}O 13.5 s
^{11}N unbound
^{12}N 20.4 m
^{13}N 20.4 m
^{14}N
^{15}N
^{16}N 7.13 s
^{17}N 4.17 s
^{18}N 0.63 s
^{19}N 329 ms
Z
^{9}C 125 ms
^{10}C 19.3 s
^{11}C 20.4 m
^{12}C
^{13}C
^{14}C 5730 y
^{15}C 2.45 s
^{16}C 0.747 s
^{17}C 193 ms
^{18}C 92 ms
^{8}B 770 ms
^{9}B unbound
^{10}B
^{11}B
^{12}B 20.20 ms
^{13}B 17.33 ms
^{14}B 13.8 ms
^{15}B 10.4 ms
^{16}B unbound
^{17}B 5.1 ms
^{7}Be
^{8}Be unbound
^{9}Be
^{10}Be 1.6 10^{6} y
^{11}Be 13.8 s
^{12}Be 23.6 ms
^{13}Be unbound
^{14}Be 4.35 ms
^{15}Be unbound
^{16}Be unbound
^{6}Li
^{7}Li
^{8}Li 840 ms
^{9}Li 179 ms
^{10}Li unbound
^{11}Li 8.5 ms
^{12}Li unbound
^{13}Li unbound
^{3}He
^{4}He
^{5}He unbound
^{6}He 808 ms
^{7}He unbound
^{8}He 119 ms
^{9}He unbound
^{10}He unbound
^{1}H
^{2}H
^{3}H 12.323 y
^{5}H unbound
^{7}H unbound
n 10.25 m
N



K. Markenroth *et al.*, NP **A679** (2001) 462

$$W(\vartheta_{^6\mathrm{He-n}}) \sim 1 + 0.7(1)\cos^2(\vartheta_{^6\mathrm{He-n}})$$





Yu. Aksyutina *et al.*,
PLB **679** (2009) 191

$$\frac{d\sigma}{dE_{\mathrm{fn}}} \propto \frac{\Gamma_l(E_{\mathrm{fn}})}{[E_r + \Delta_l(E_{\mathrm{fn}}) - E_{\mathrm{fn}}]^2 + \frac{1}{4}\Gamma_l^2(E_{\mathrm{fn}})}$$

$$\Gamma_l = 2P_l(E_{\mathrm{fn}})\gamma^2$$

$$\gamma_{\mathrm{sp}}^2 = \tfrac{2}{3}\hbar^2/\mu R^2$$

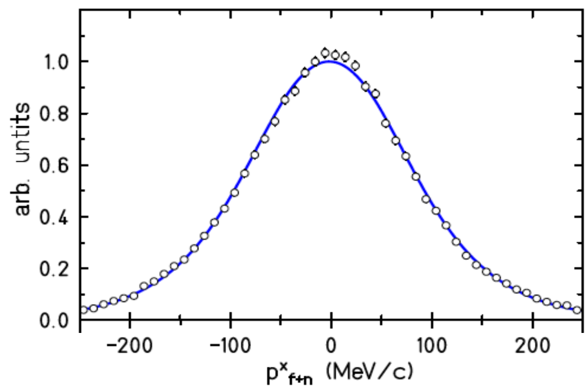
$$\mathcal{S}_{\mathrm{n}} = \gamma_{\mathrm{obs}}^2/\gamma_{\mathrm{sp}}^2$$

Yu. Aksyutina *et al.*, PLB **679** (2009) 191

^{5}He $\quad \gamma_{\mathrm{obs}}^2 = \gamma_{\mathrm{sp}}^2$

^{7}He: ^{6}He(0^+) + n $\quad \mathcal{S}_{\mathrm{n}} = 0.61(3)$

→ not a pure single-particle $p_{3/2}$-state



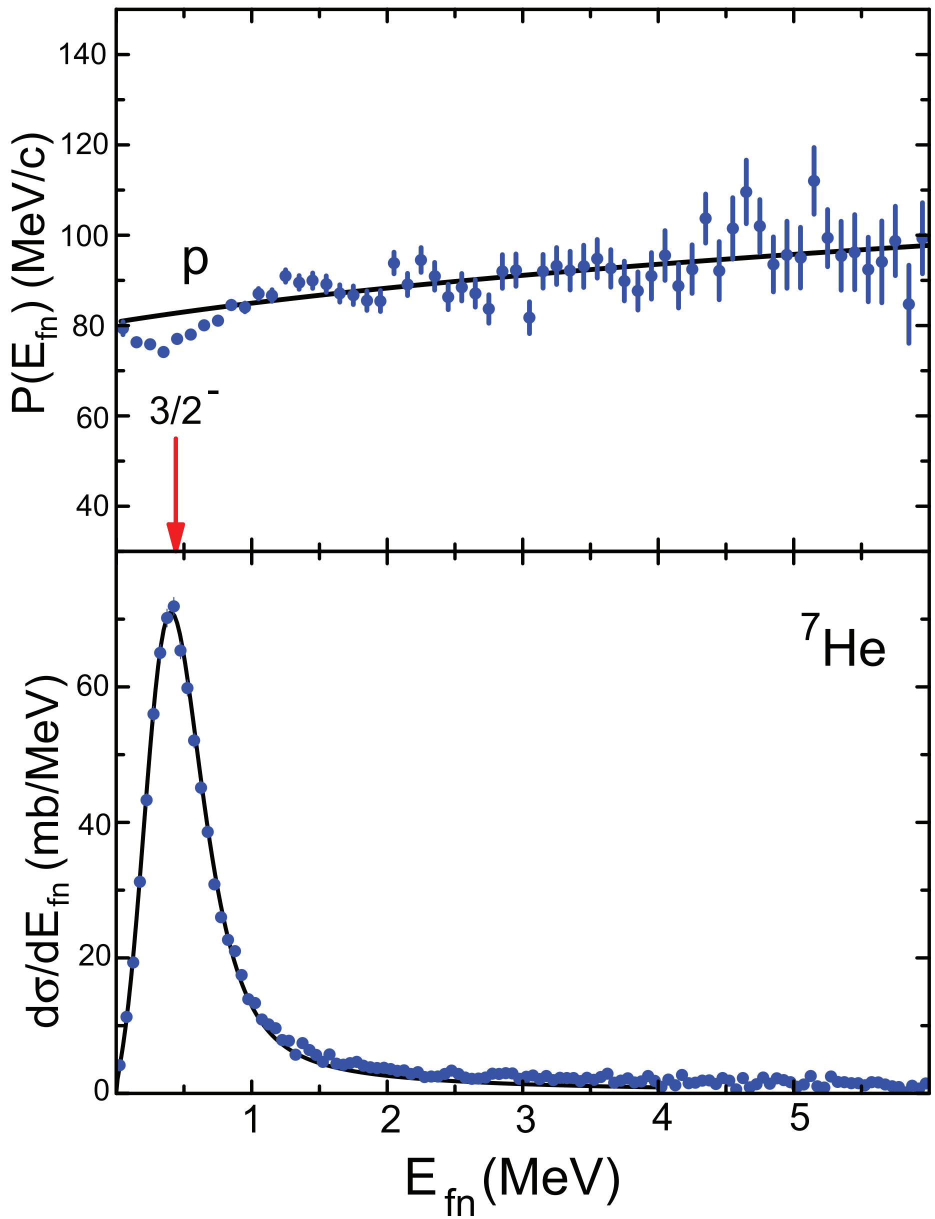
Momentum Profile Function

$$P(E_{fn}) = \sqrt{\left\langle (p_f^x + p_n^x)^2 \right\rangle - \left\langle (p_f^x + p_n^x) \right\rangle^2}$$

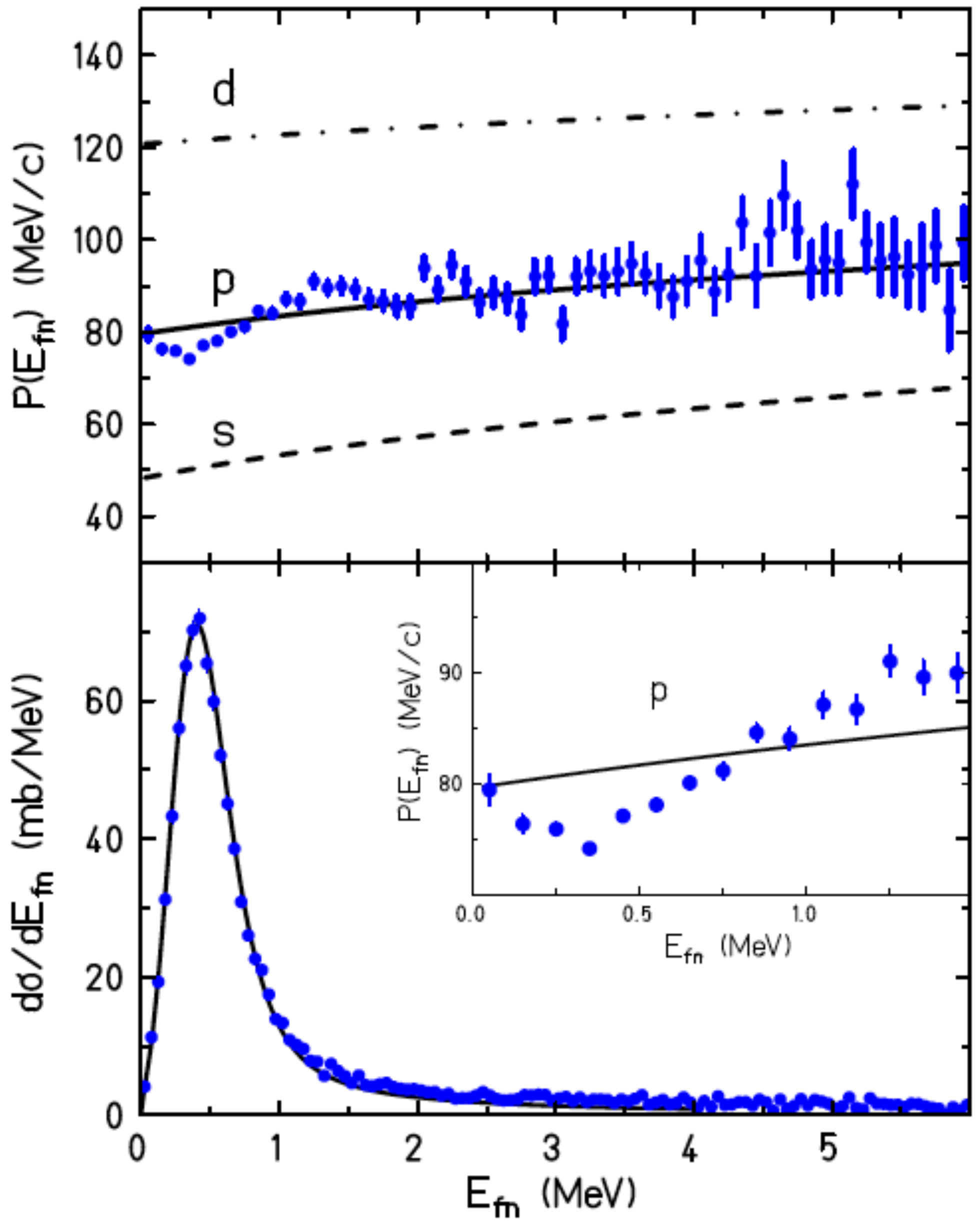
Transverse Momentum Distribution

$$\frac{dN}{dp}(l=0) \propto K_1^2(\xi) - K_0^2(\xi)$$

P.G. Hansen, PRL **77** (1996) 1016
D. Basin et al., Phys. Rev. **57** (1998) 2156



Yu. Aksyutina *et al.*,
PLB **718** (2013) 1309

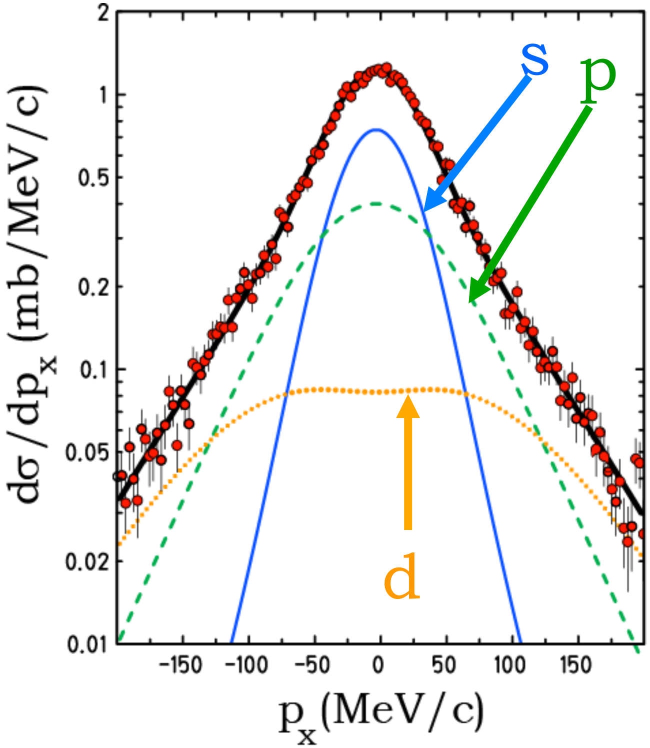


$$P_{r.e.}(E_{fn}) = \sqrt{\alpha_s \sigma_s^2 + (1-\alpha_s)\sigma_p^2}$$

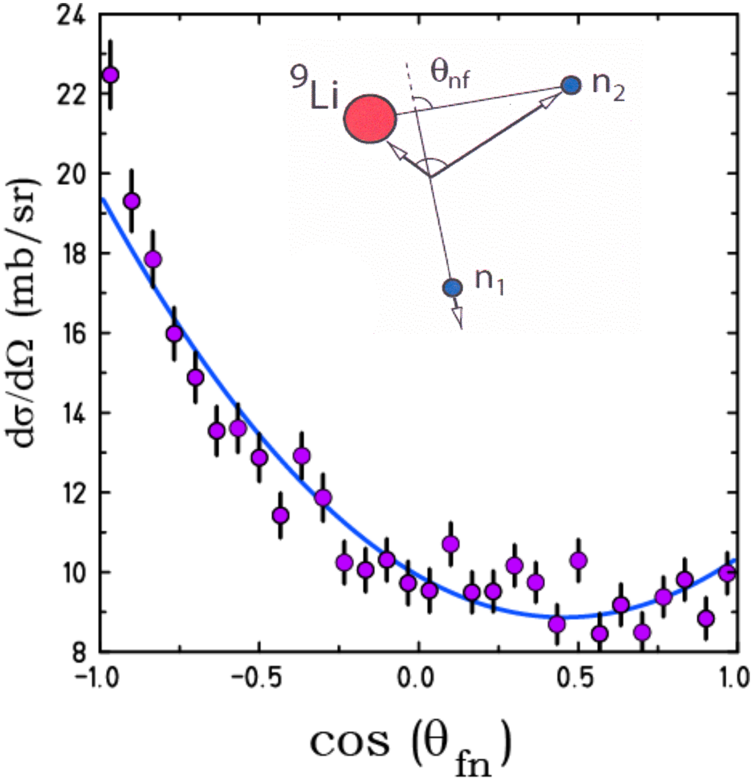
$l = 0$ $\quad$ $l = 1$

$12\% \ (1s_{1/2})^2$

GSI, 287 MeV/u ^{11}Li

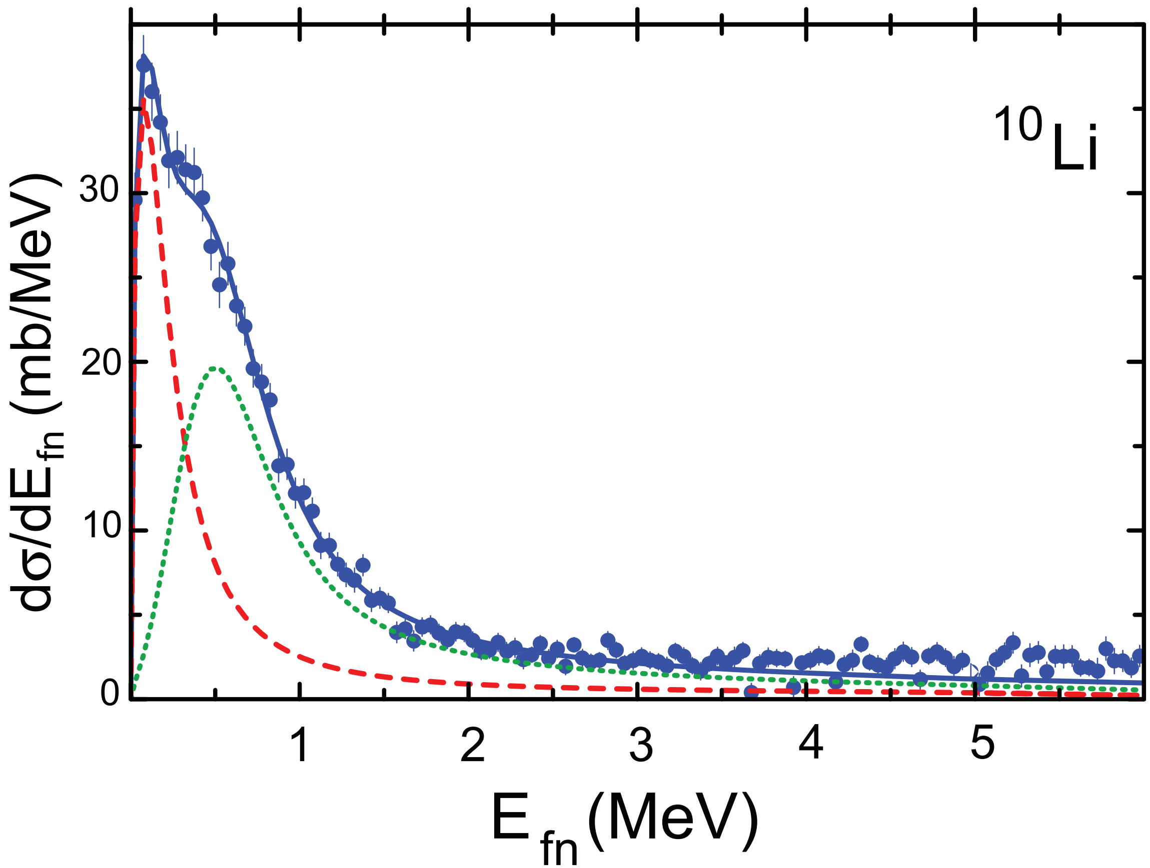


$$\mathbf{p}_{n1} = -(\mathbf{p}_{n2} + \mathbf{p}_{9Li})$$



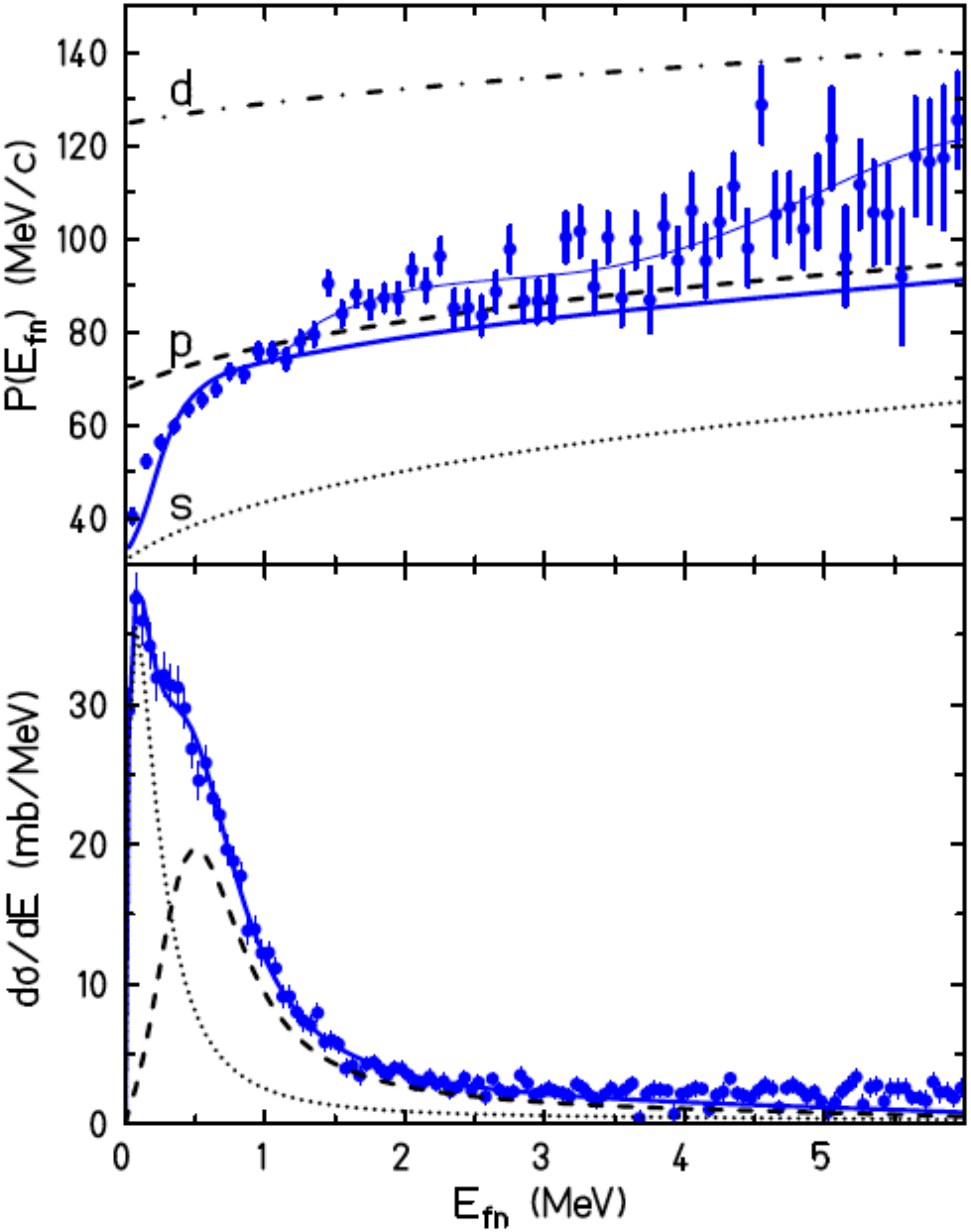
$$W(\theta_{nf}) = 1 - 1.03\cos(\theta_{nf}) + 1.41\cos^2(\theta_{nf})$$

Simon, *et al.*, Nucl. Phys. **A791** (2007) 267.



Momentum Profile Function

$$P(E_{fn}) = \sqrt{\left\langle (p_f^x + p_n^x)^2 \right\rangle - \left\langle (p_f^x + p_n^x) \right\rangle^2}$$



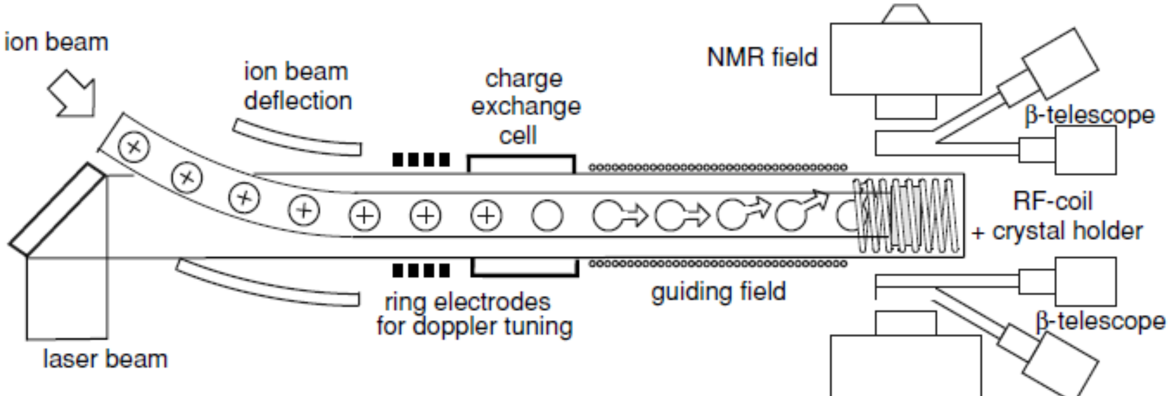
$$P_{r.e.}(E_{fn}) = \sqrt{\alpha_s \sigma_s^2 + (1-\alpha_s)\sigma_p^2}$$

$$\alpha_d = (P_{exp}^2 - P_{r.e.}^2)/(\sigma_d^2 - P_{r.e.}^2)$$

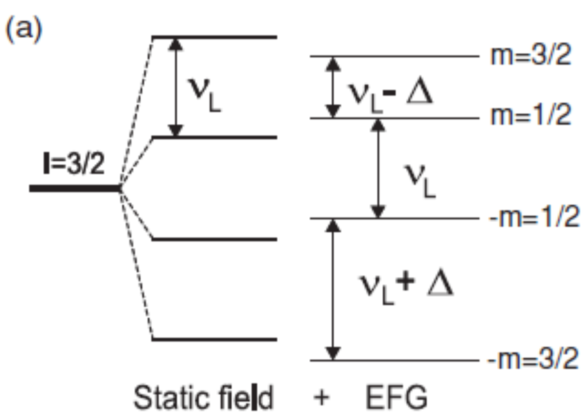
$(0d_{5/2})^2$
11(2) %

Aksyutina *et al.*
PLB **718** (2013) 1309

^{6}Li	^{7}Li	^{8}Li	^{9}Li	^{10}Li	^{11}Li	^{12}Li	^{13}Li
		840 ms	179 ms	unbound	8.5 ms	unbound	unbound
			$I^{\pi}=3/2^{-}$		$I^{\pi}=3/2^{-}$		



D. Borremans et al., PRC 72 (2005) 044309



Si [LiF] → $\mu(^{11}\text{Li}) = 3.6712(3)\ \mu_N$

Zn [LiNbO_3] → $|Q(^{11}\text{Li})| = 33.3(5)$ mb

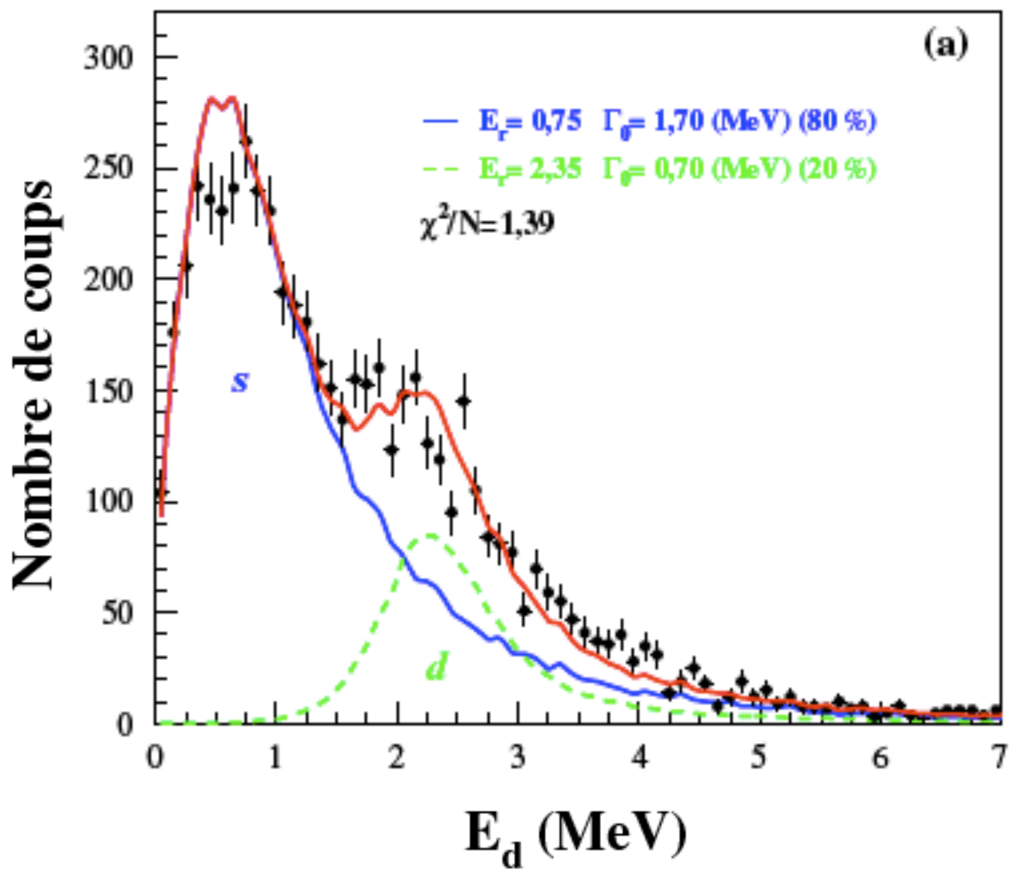
R. Neugart et al., PRL **101**(2008) 132502

$|Q(^{11}\text{Li})/Q(^{9}\text{Li})| = 1.088(15)$

^{7}Be	^{8}Be	^{9}Be	^{10}Be	^{11}Be	^{12}Be	^{13}Be	^{14}Be	^{15}Be	^{16}Be
	unbound		1.6 10^{6} y	13.8 s	23.6 ms	unbound	4.35 ms	unbound	unbound

GANIL

41 MeV/u ^{14}B, C target



J.L. Lecouey, Few Body Systems 34 (2004)21
G. Randisi, Thesis Uni. Caen (2011)

^{16}Be

Spyrou *et al.*,,
PRL 108(2012) 102501

^{15}Be

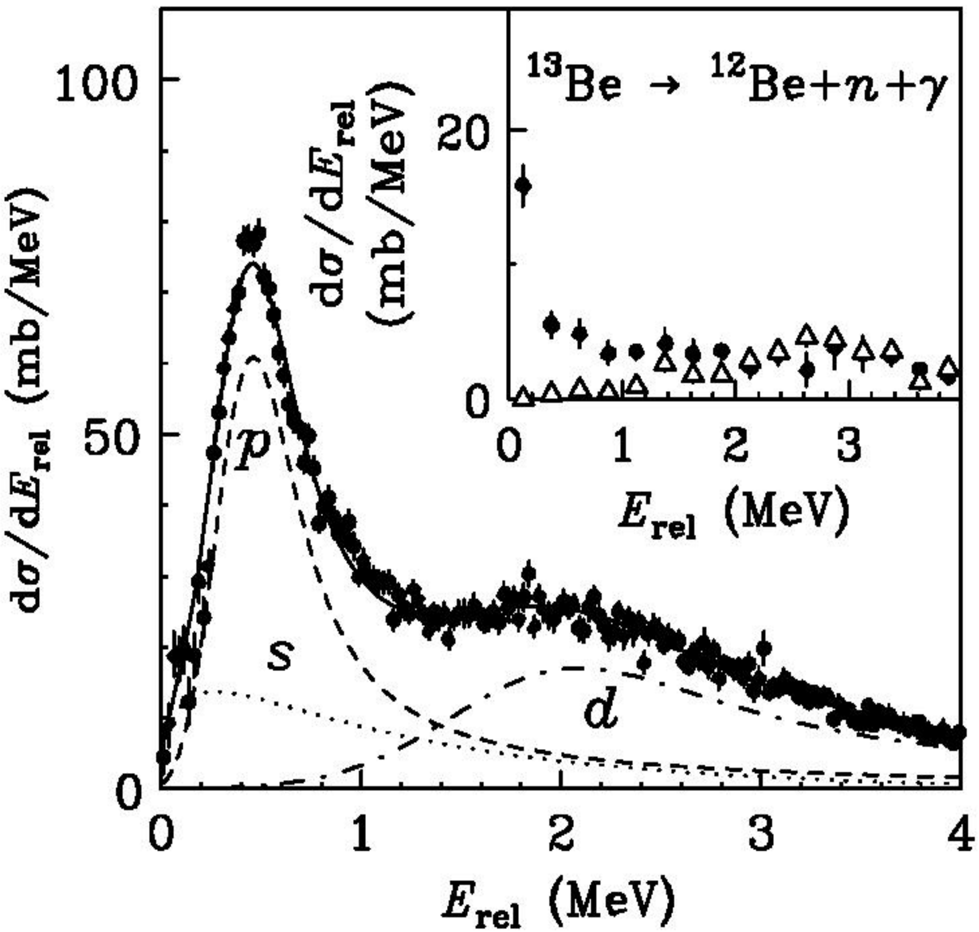
Snyder *et al.*,,
PRC 88(2013) 031303

^{14}B

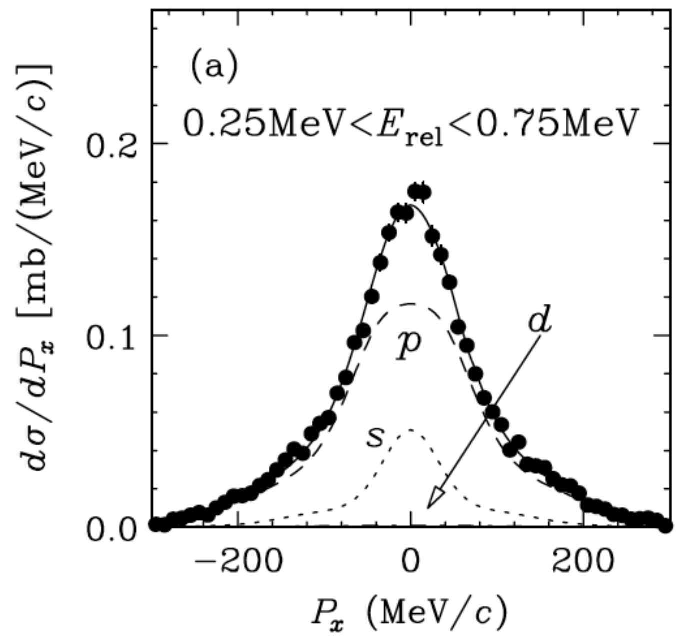
$$^{13}\mathrm{B}(3/2^{-}) \otimes (sd)$$

RIKEN

69 MeV/u ^{14}Be, Lq H target

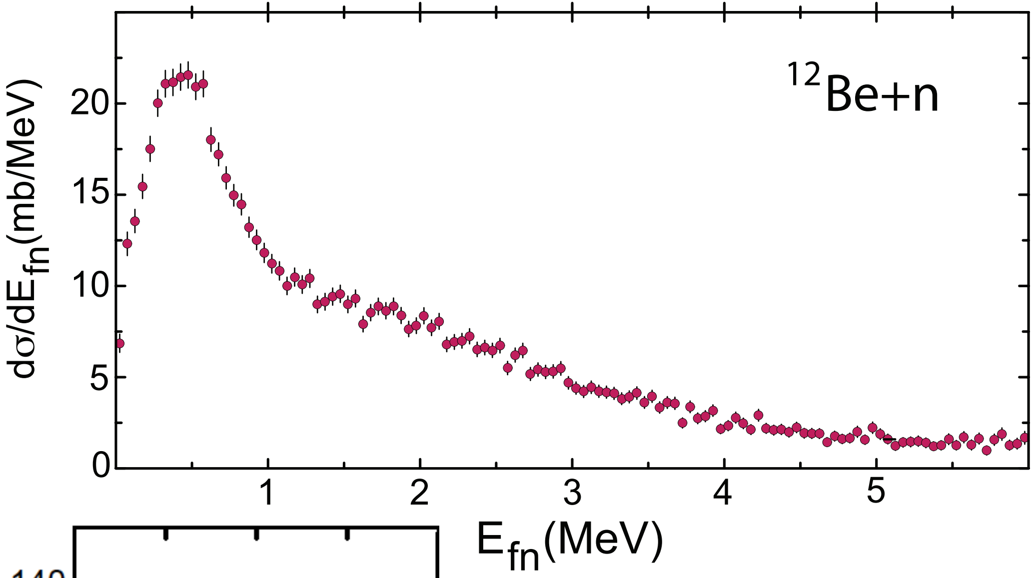


Y. Kondo *et al.,* PLB **690** (2010) 245

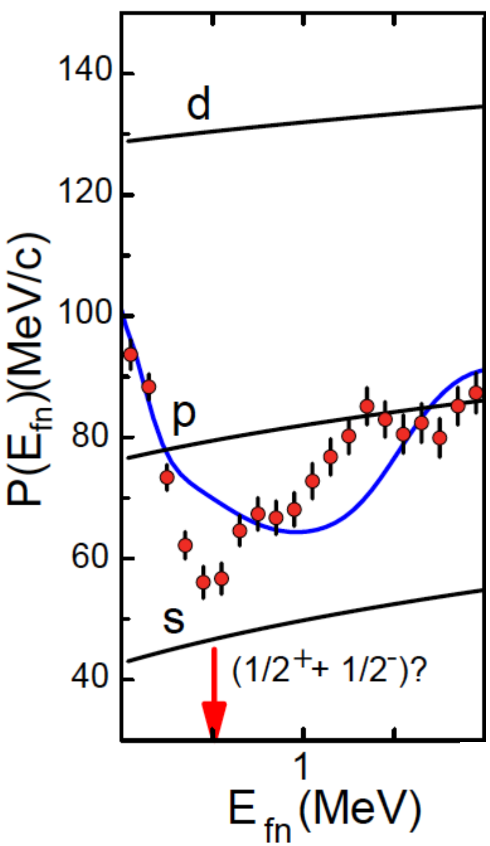


$n-\gamma$ *coincidences*

$2.11\ MeV$ *and* $2.71\ MeV$

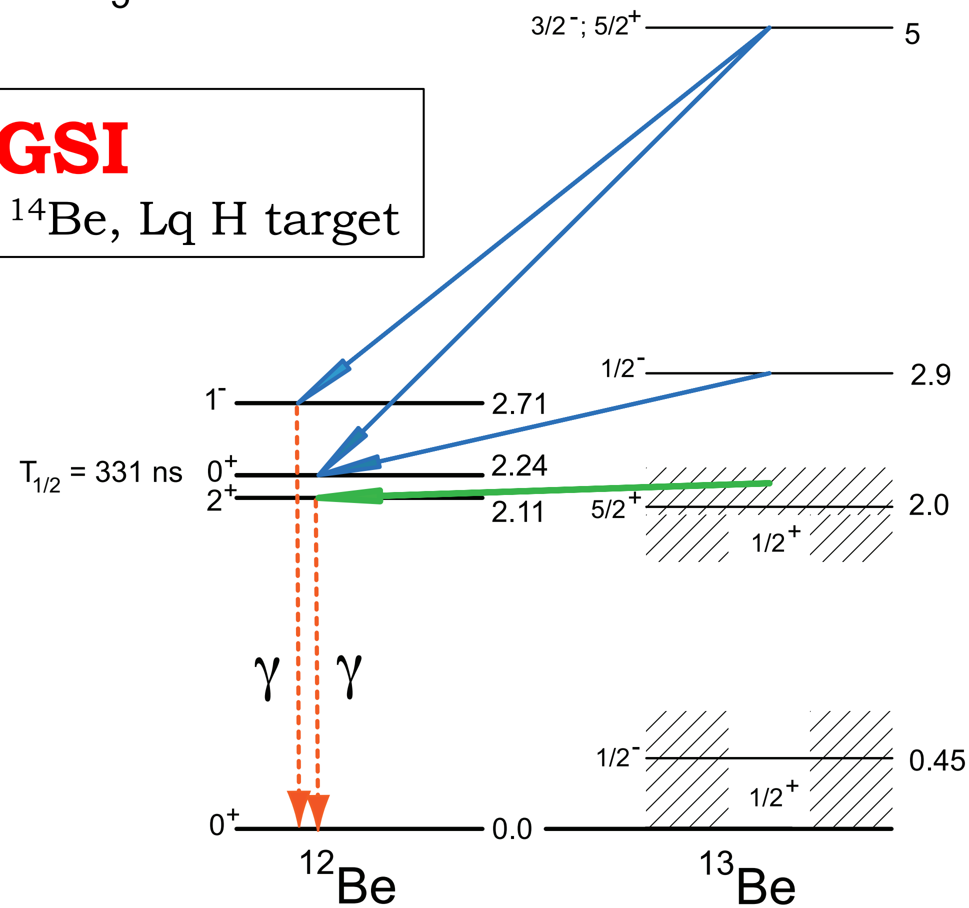


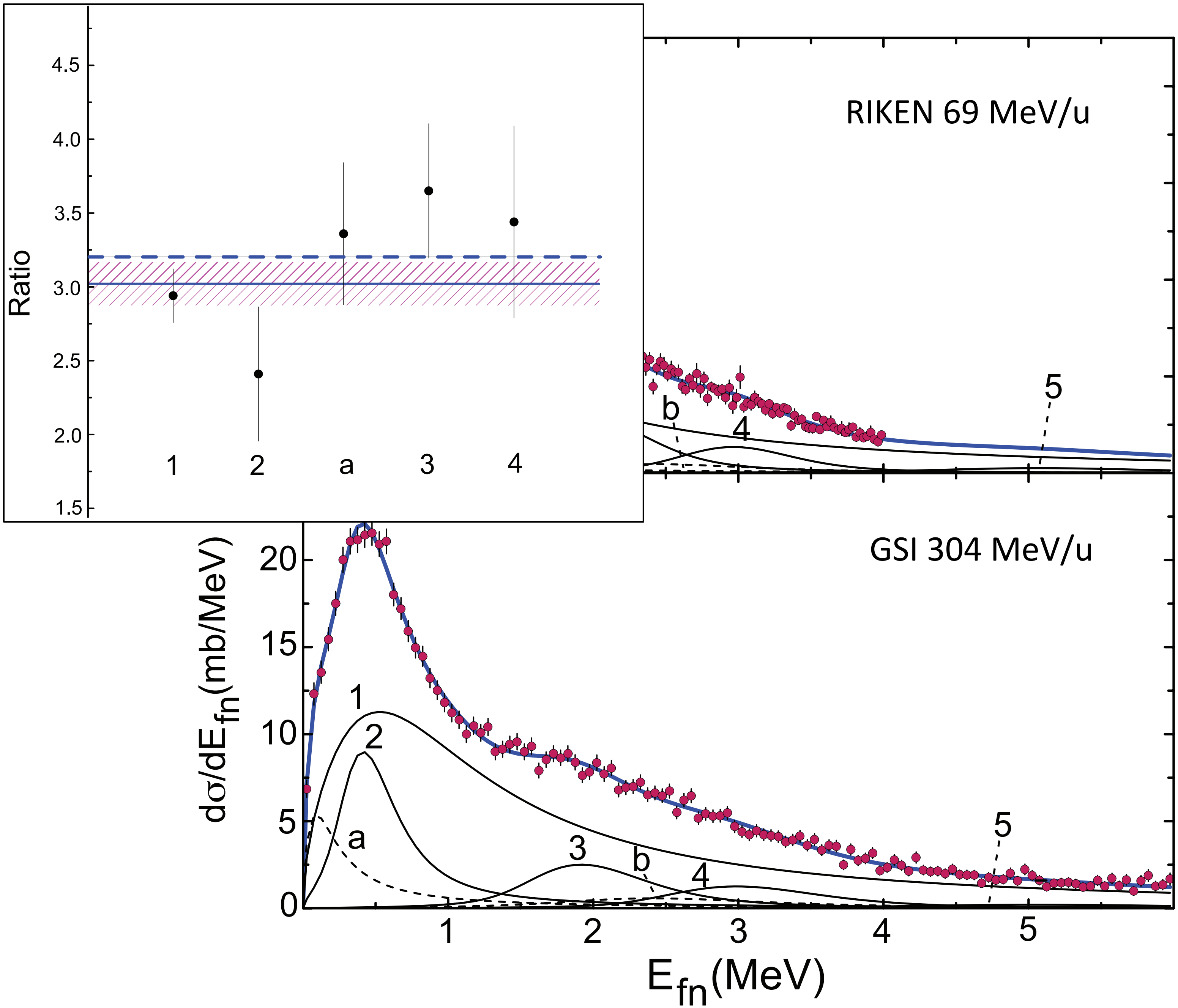
Yu. Aksyutina *et al.*,
Phys. Rev. C **87** (2013) 064316



GSI

304 MeV/u ^{14}Be, Lq H target




RIKEN 69 MeV/u
GSI 304 MeV/u
Ratio
1
2
a
3
4
b
5
dσ/dE$_{fn}$(mb/MeV)
E$_{fn}$(MeV)

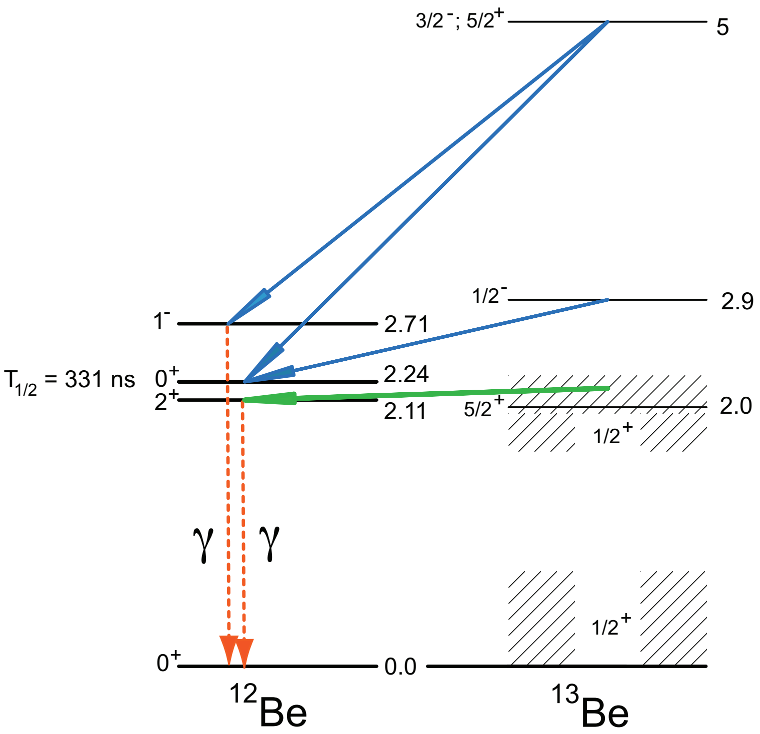
INTERFERENCE ?

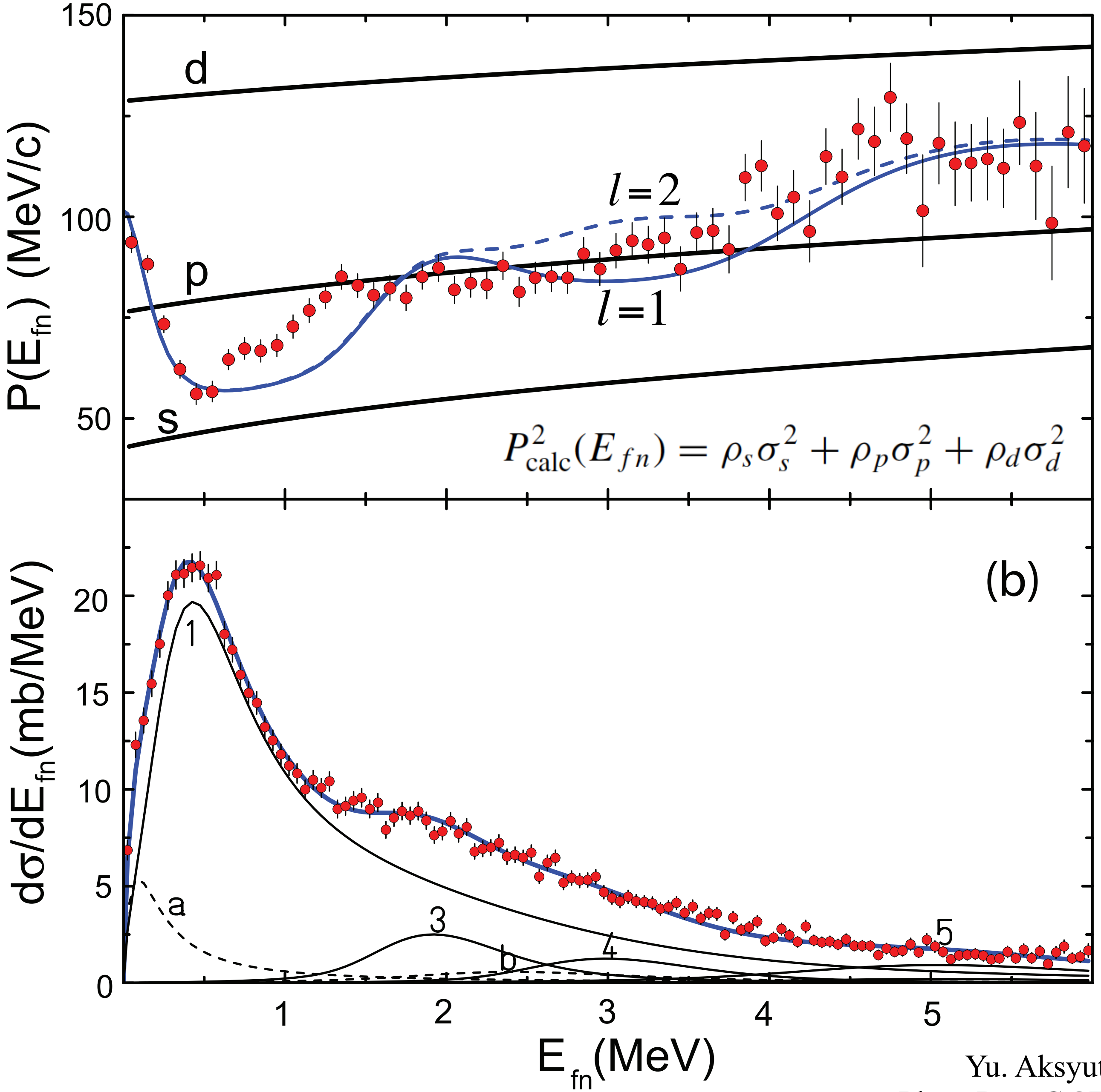
$$^{12}\text{Be}(0^+) = \alpha[^{10}\text{Be} \otimes (1s_{1/2})^2] + \beta[^{10}\text{Be} \otimes (0p_{1/2})^2] + \gamma[^{10}\text{Be} \otimes (0d_{5/2})^2],$$

$$\alpha^2 = 0.35, \beta^2 = 0.31, \gamma^2 = 0.34$$

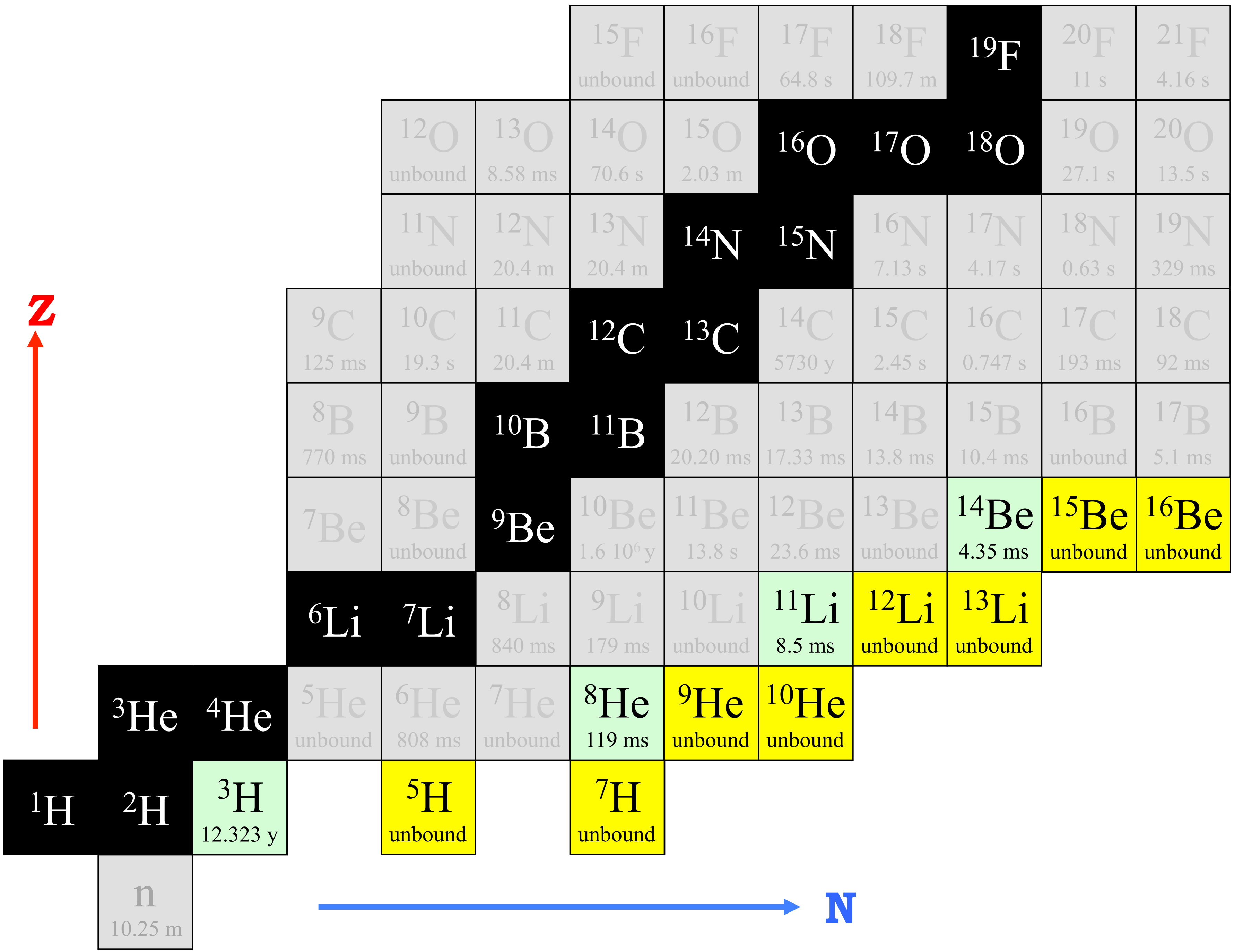
$$^{13}\text{Be}(1/2_2^+) = \mu[^{10}\text{Be} \otimes (0p_{1/2})^2 \otimes (1s_{1/2})] - \lambda[^{10}\text{Be} \otimes (0d_{5/2})^2 \otimes (1s_{1/2})]$$

$$^{13}\text{Be}(1/2_1^+) = \lambda[^{10}\text{Be} \otimes (0p_{1/2})^2 \otimes (1s_{1/2})] + \mu[^{10}\text{Be} \otimes (0d_{5/2})^2 \otimes (1s_{1/2})].$$





Yu. Aksyutina *et al.*,
Phys. Rev. C **87** (2013) 064316


^{15}F unbound
^{16}F unbound
^{17}F 64.8 s
^{18}F 109.7 m
^{19}F
^{20}F 11 s
^{21}F 4.16 s
^{12}O unbound
^{13}O 8.58 ms
^{14}O 70.6 s
^{15}O 2.03 m
^{16}O
^{17}O
^{18}O
^{19}O 27.1 s
^{20}O 13.5 s
^{11}N unbound
^{12}N 20.4 m
^{13}N 20.4 m
^{14}N
^{15}N
^{16}N 7.13 s
^{17}N 4.17 s
^{18}N 0.63 s
^{19}N 329 ms
Z
^{9}C 125 ms
^{10}C 19.3 s
^{11}C 20.4 m
^{12}C
^{13}C
^{14}C 5730 y
^{15}C 2.45 s
^{16}C 0.747 s
^{17}C 193 ms
^{18}C 92 ms
^{8}B 770 ms
^{9}B unbound
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^{11}B
^{12}B 20.20 ms
^{13}B 17.33 ms
^{14}B 13.8 ms
^{15}B 10.4 ms
^{16}B unbound
^{17}B 5.1 ms
^{7}Be
^{8}Be unbound
^{9}Be
^{10}Be $1.6\ 10^{6}$ y
^{11}Be 13.8 s
^{12}Be 23.6 ms
^{13}Be unbound
^{14}Be 4.35 ms
^{15}Be unbound
^{16}Be unbound
^{6}Li
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^{12}Li unbound
^{13}Li unbound
^{3}He
^{4}He
^{5}He unbound
^{6}He 808 ms
^{7}He unbound
^{8}He 119 ms
^{9}He unbound
^{10}He unbound
^{1}H
^{2}H
^{3}H 12.323 y
^{5}H unbound
^{7}H unbound
n 10.25 m
N

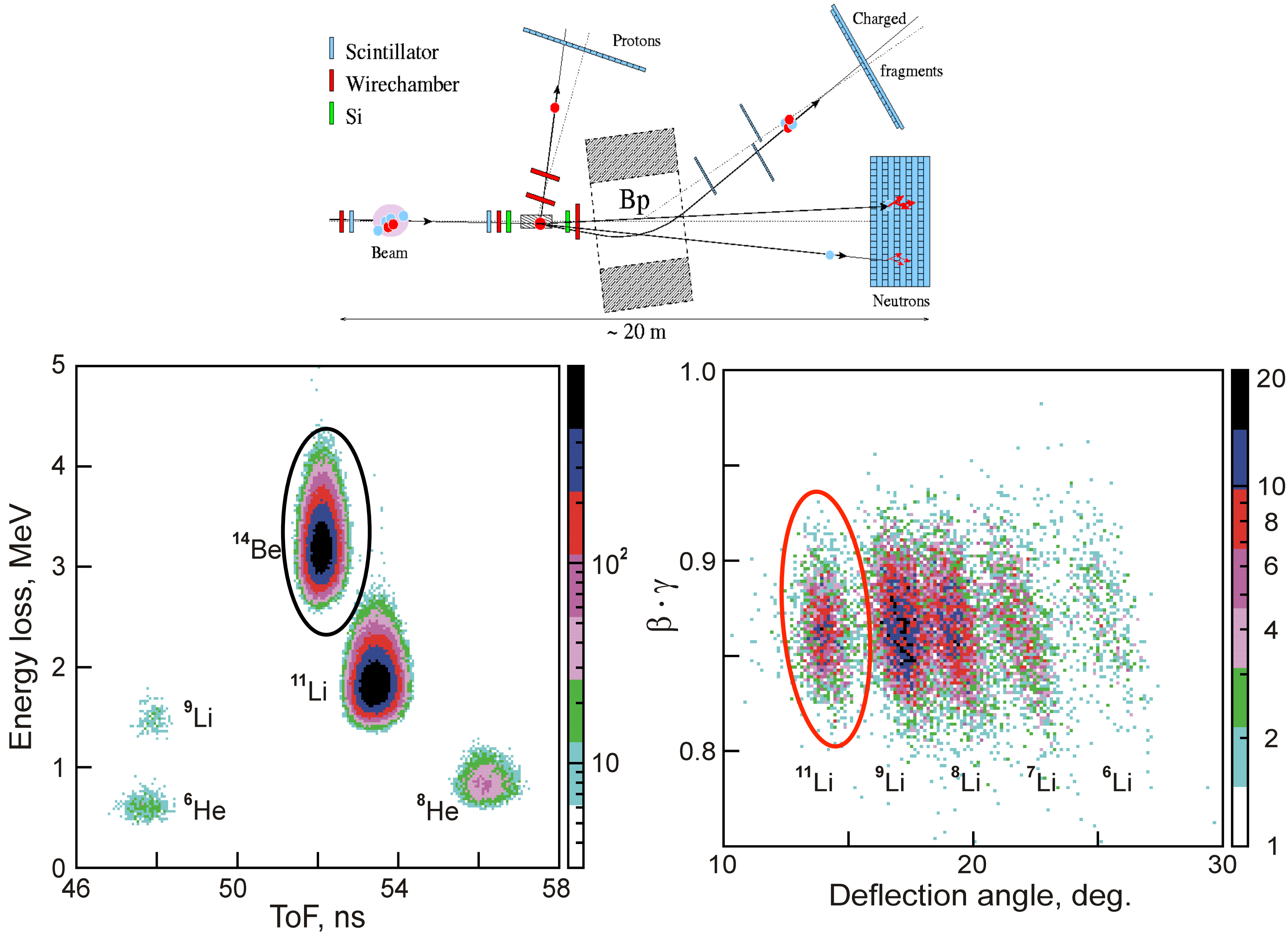
Dripline nuclei as stepping stones towards the unbound

	^{7}Be	^{8}Be unbound	^{9}Be	^{10}Be 1.6 10^{6} y	^{11}Be 13.8 s	^{12}Be 23.6 ms	^{13}Be unbound	^{14}Be 4.35 ms
	^{6}Li	^{7}Li	^{8}Li 840 ms	^{9}Li 179 ms	^{10}Li unbound	^{11}Li 8.5 ms	^{12}Li unbound	^{13}Li unbound
^{4}He	^{5}He unbound	^{6}He 808 ms	^{7}He unbound	^{8}He 119 ms	^{9}He unbound	^{10}He unbound		
				^{7}H unbound				

^{11}Li: Neutron knock-out reaction -> ^{10}Li
Proton knock-out reactions -> ^{9,10}He

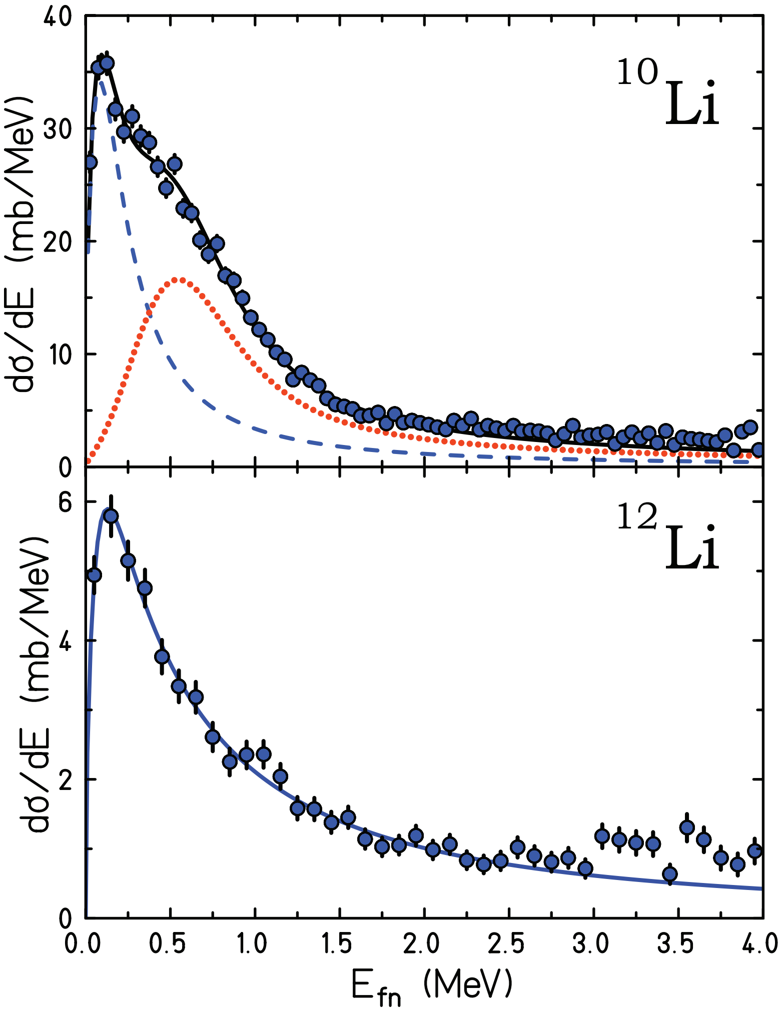
^{14}Be: Neutron knock-out reaction -> ^{13}Be
Proton knock-out reactions -> ^{12,13}Li

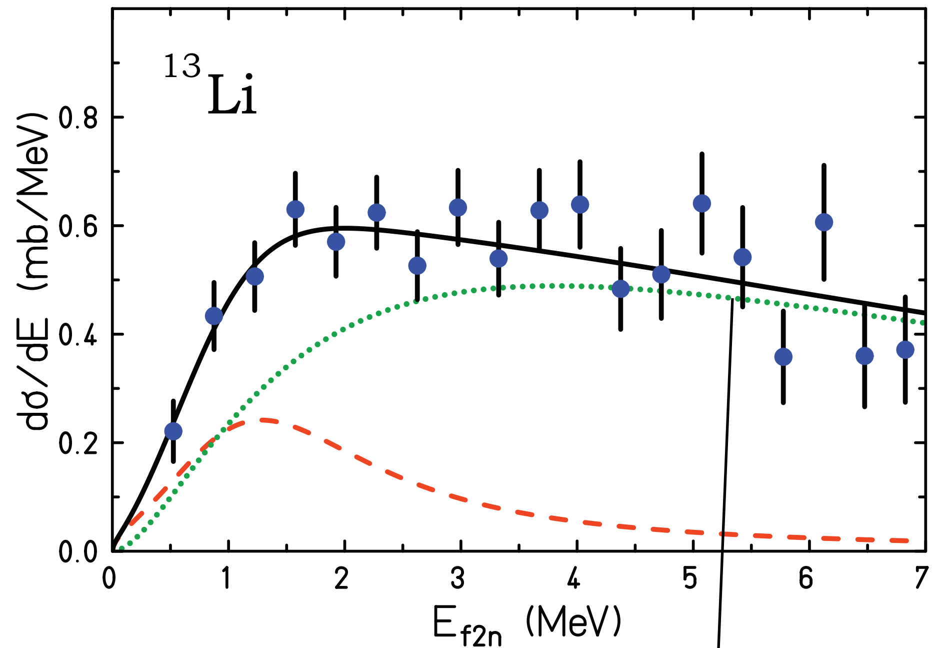
^{8}He: Neutron knock-out reaction -> ^{7}He
Proton knock-out reaction -> (^{7}H)



Scintillator
Wirechamber
Si
Protons
Charged
fragments
Bρ
Beam
Neutrons
~ 20 m
Energy loss, MeV
ToF, ns
14Be
11Li
9Li
6He
8He
10
10²
β·γ
Deflection angle, deg.
11Li
9Li
8Li
7Li
6Li

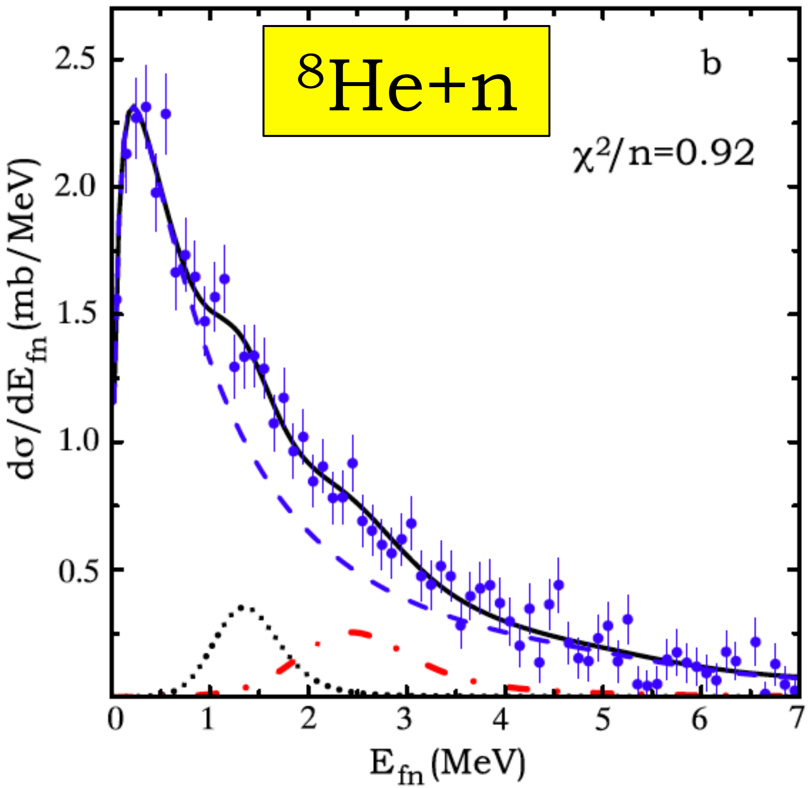
^{6}Li	^{7}Li	^{8}Li 840 ms	^{9}Li 179 ms	^{10}Li unbound	^{11}Li 8.5 ms	^{12}Li unbound	^{13}Li unbound



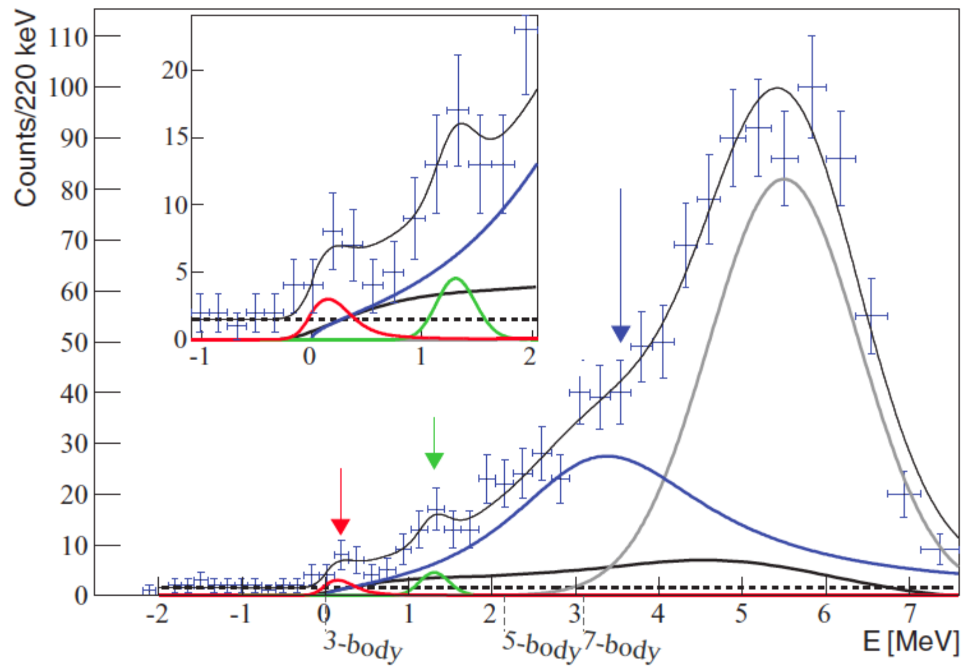


Forssén *et al*. Nucl. Phys. **A 673**(2000) 143

^{3}He ^{4}He	^{5}He	^{6}He	^{7}He	^{8}He	^{9}He	^{10}He
	unbound	808 ms	unbound	119 ms	unbound	unbound



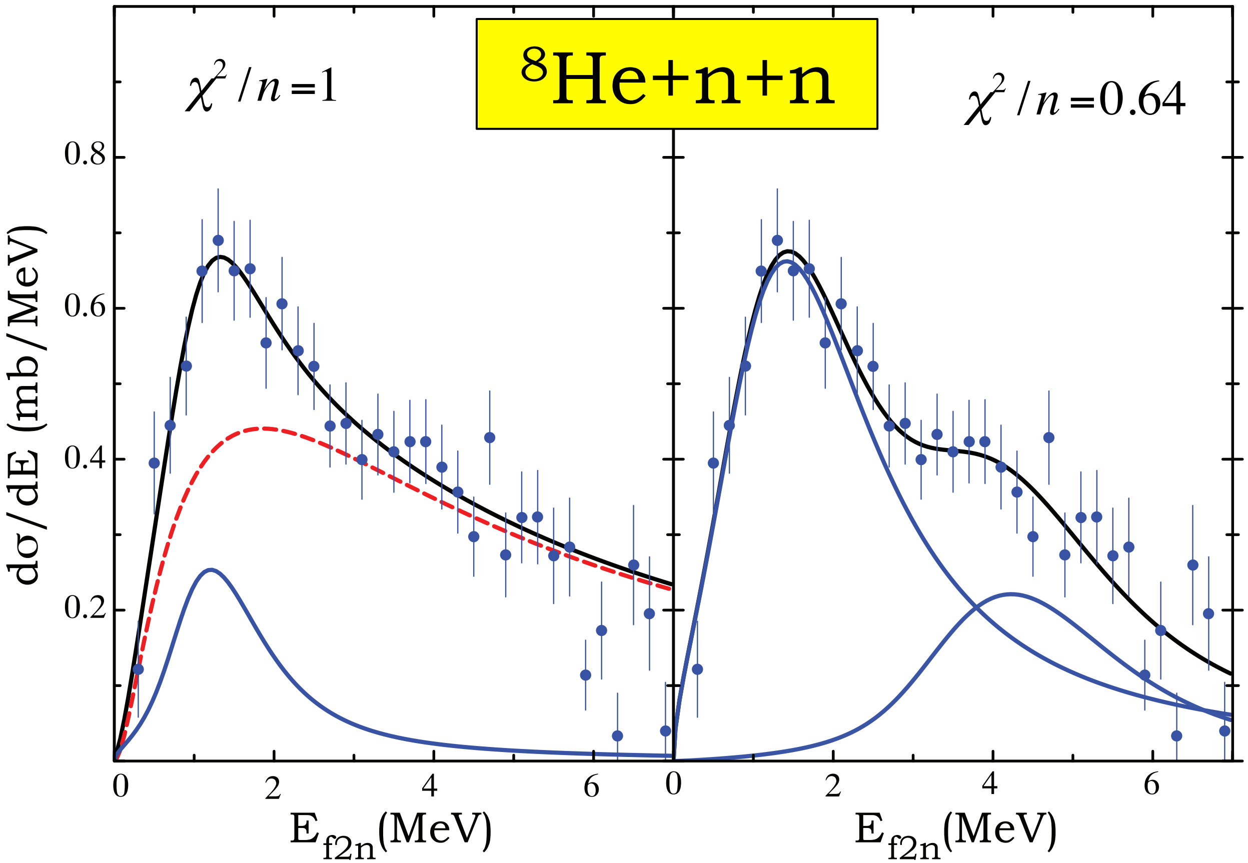
$^{8}He(d,p)^{9}He$



Johansson et al., Nucl. Phys. **A842** (2010) 15

Al Kalanee et al., PRC **88** (2013) 034301

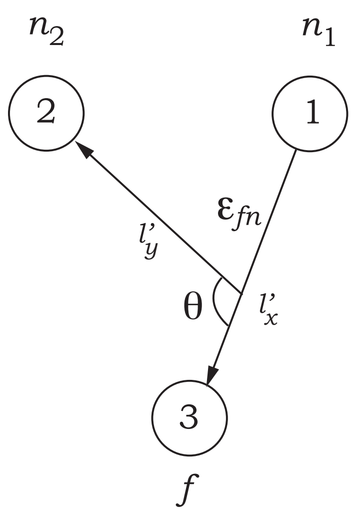
^3He	^4He	^5He unbound	^6He 808 ms	^7He unbound	^8He 119 ms	^9He unbound	^{10}He unbound



$$\sqrt{2\chi^2} - \sqrt{2n-1} = -1.56$$

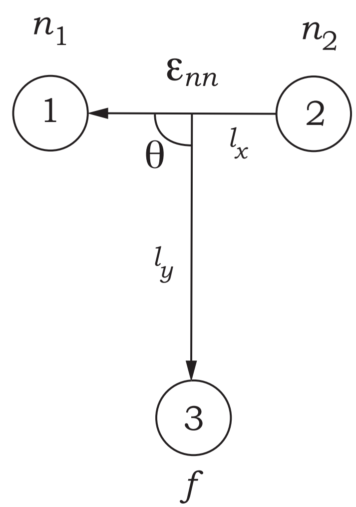
Neyman-Pearson test

$^{8}He+n+n$



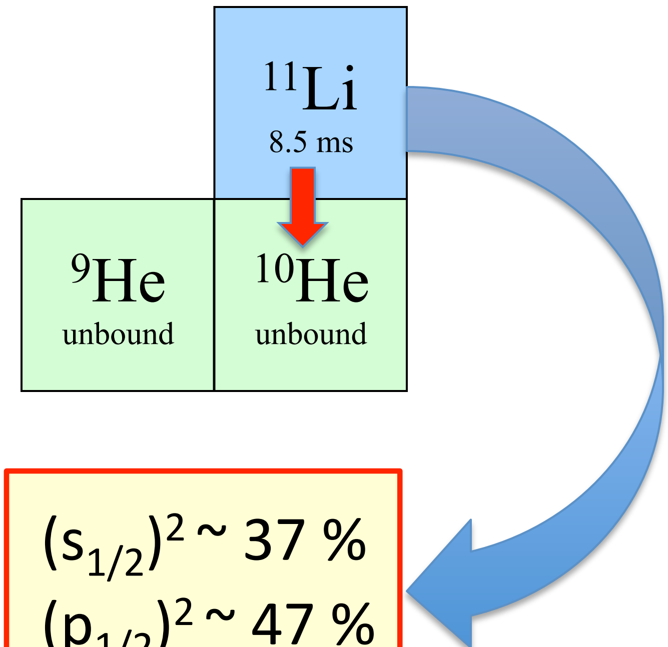
Y-system

$$\varepsilon_{fn} = E_{fn}/E$$



T-system

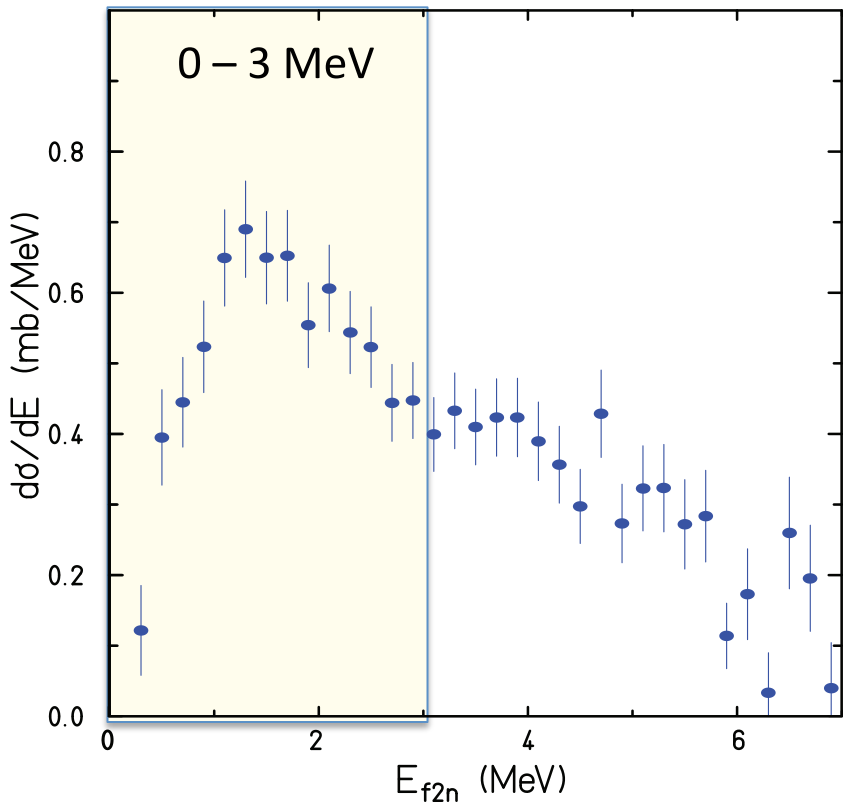
$$\varepsilon_{nn} = E_{nn}/E$$

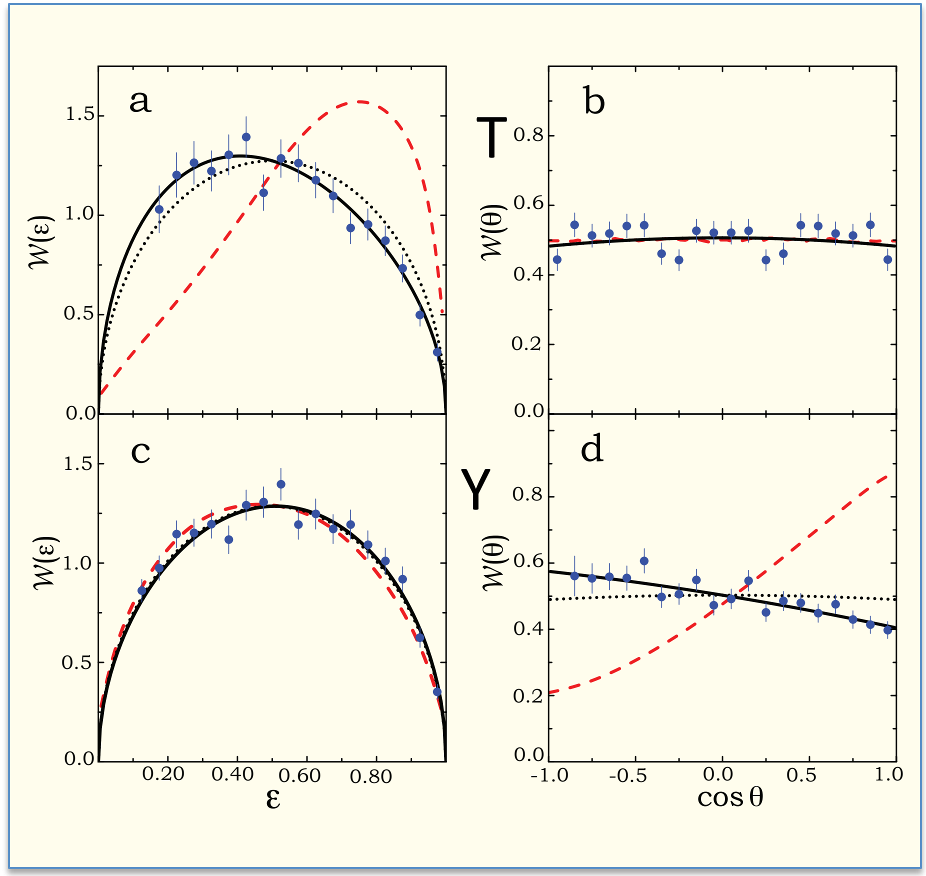


$(s_{1/2})^2 \sim 37$ %
$(p_{1/2})^2 \sim 47$ %
$(p_{3/2})^2 \sim 9$ %

N.B. Shulgina *et al*., Nucl. Phys. **A825** (2009) 175

Energy and angular correlations

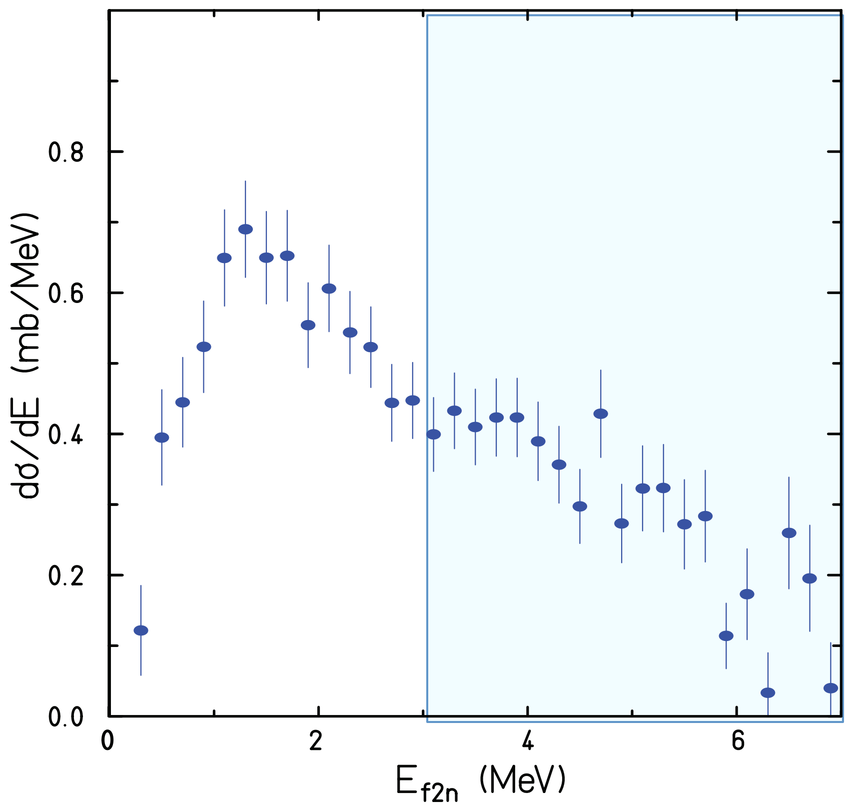


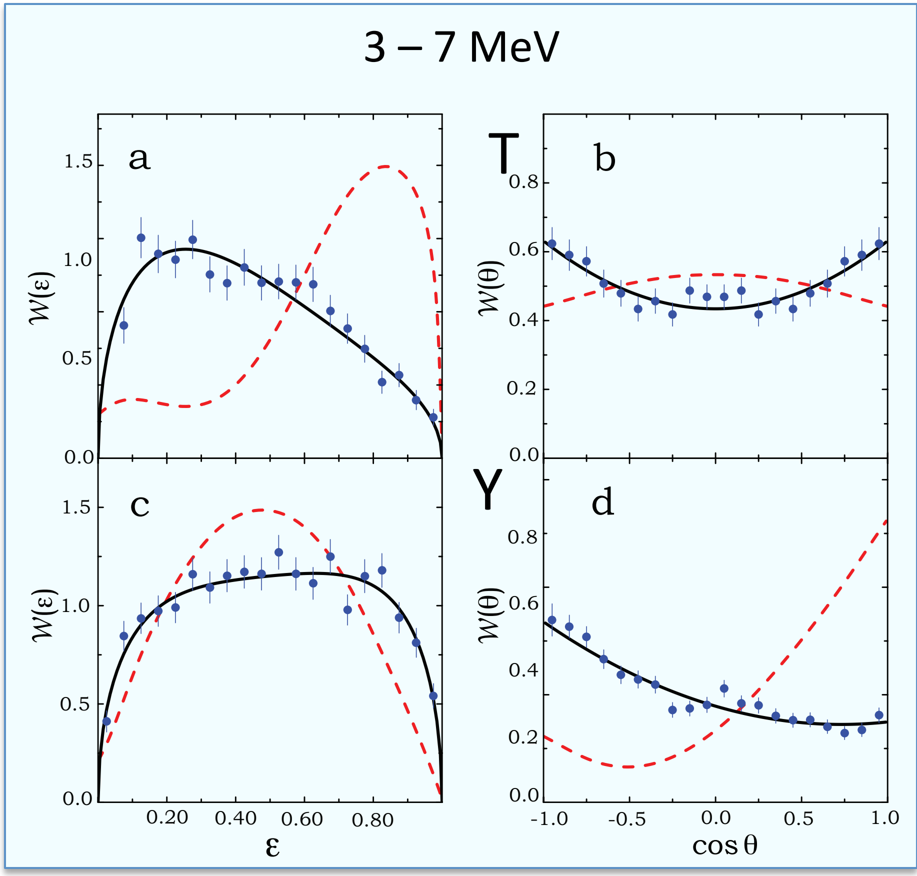


Restricted series of hyperspherical harmonics assuming $I^{\pi} = 0^{+}$ and $K \leq 2$

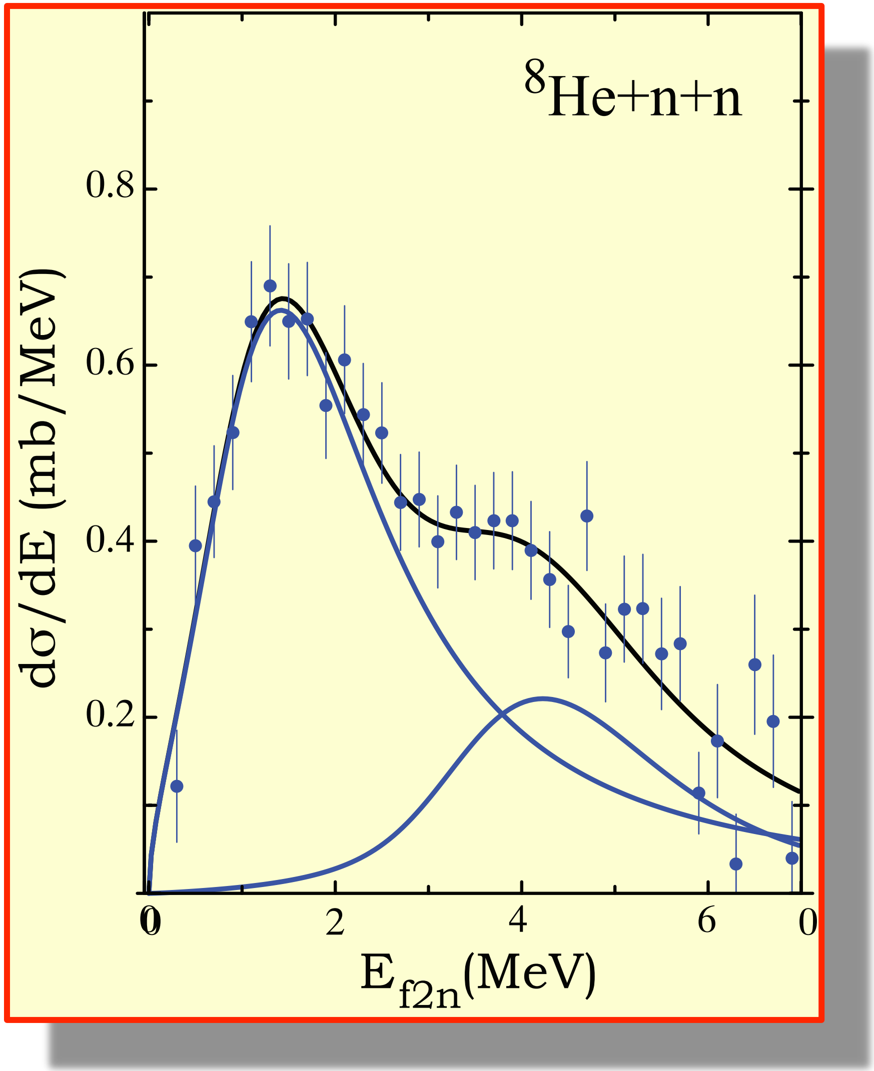
$$
\begin{aligned}
&\mathcal{W}_{0^+}(\varepsilon, \cos\theta) \\
&= \frac{4}{\pi}\sqrt{\varepsilon(1-\varepsilon)}\big(|A^{000}_{00}|^2 + 4|A^{000}_{00}|[(1-2\varepsilon)|A^{200}_{00}|\cos\varphi^{200}_{00} \\
&\quad - 2\sqrt{2}\varepsilon(1-\varepsilon)(1-3\cos^2\theta)|A^{400}_{22}|\cos\varphi^{400}_{22}] + 4[(1-2\varepsilon)|A^{200}_{00}|^2 \\
&\quad - 4\sqrt{2}\varepsilon(1-\varepsilon)(3-2\varepsilon)(1-3\cos^2\theta)|A^{200}_{00}||A^{400}_{22}|\cos(\varphi^{200}_{00}-\varphi^{400}_{22}) \\
&\quad + 2\varepsilon(1-\varepsilon)\big((1-\cos^2\theta)|A^{211}_{11}|^2 + 4\varepsilon(1-\varepsilon)(1-3\cos^2\theta)^2|A^{400}_{22}|^2\big)]\big)
\end{aligned}
$$

Energy and angular correlations





Restricted series of hyperspherical harmonics assuming $I^{\pi} = 2^{+}$ and $K \leq 4$



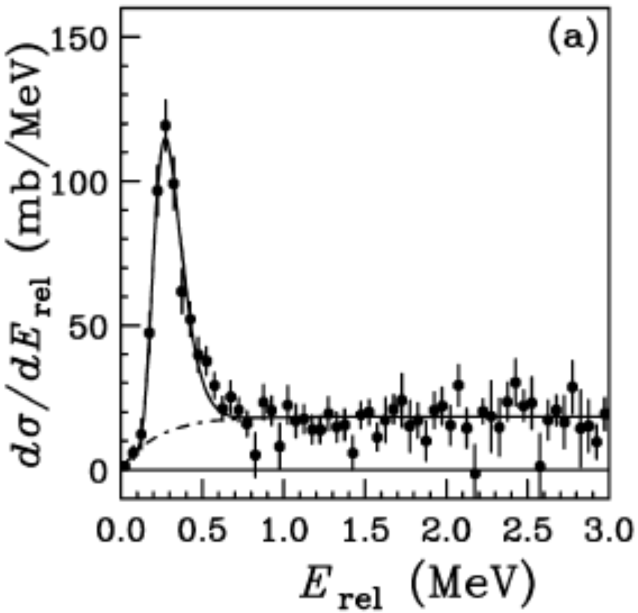
$^{8}He + n + n$

$Ground\ state\ I^{\pi} = 0^{+}$

$Excited\ state\ I^{\pi} = 2^{+}$

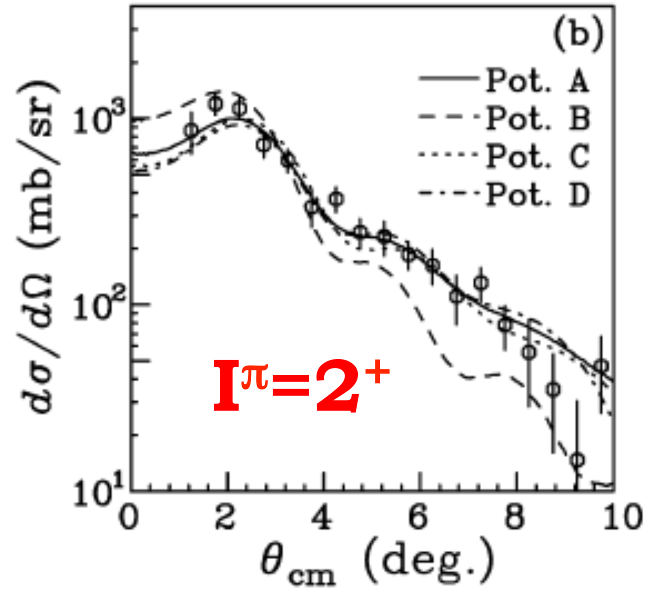
Johansson et al., Nucl. Phys. **A847** (2010) 66

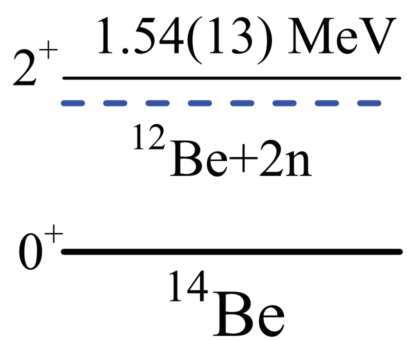
^{7}Be	^{8}Be unbound	^{9}Be	^{10}Be 1.6 10^{6} y	^{11}Be 13.8 s	^{12}Be 23.6 ms	^{13}Be unbound	^{14}Be 4.35 ms	^{15}Be unbound	^{16}Be unbound

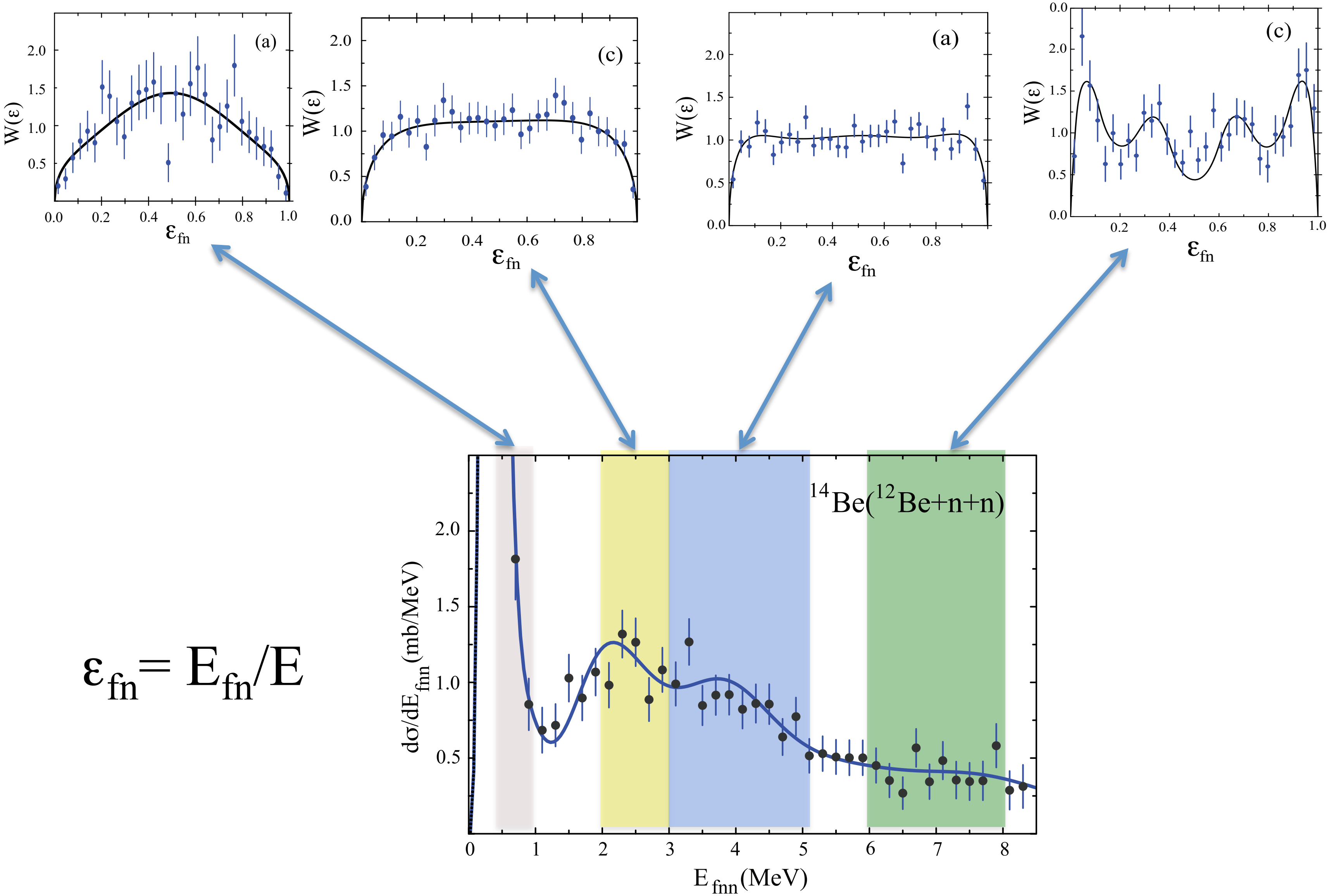


Sugimoto *et al.*,
Phys. Lett. **B654** (2007) 160

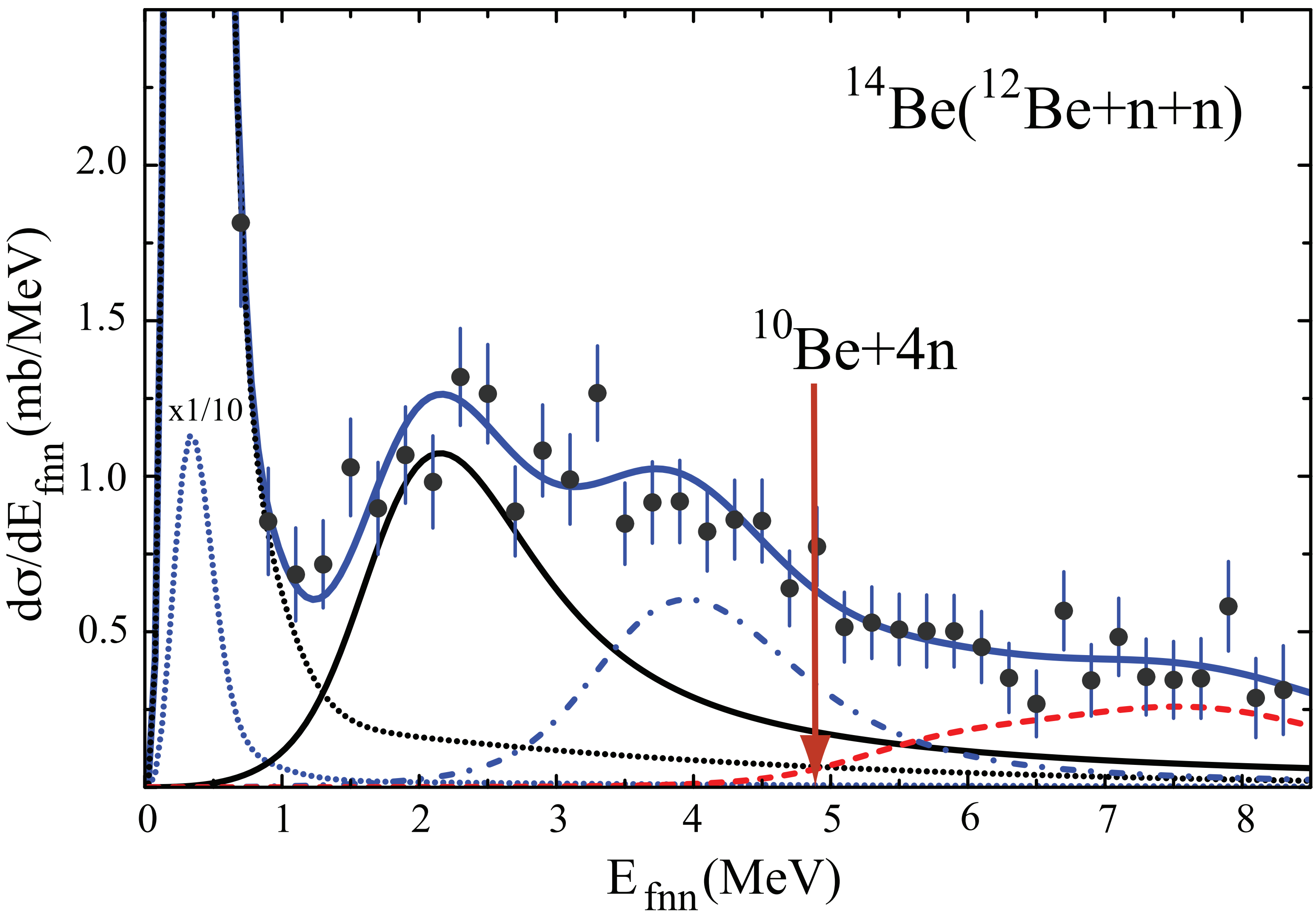
RIKEN
68 MeV/u ^{14}Be,
^{12}C target





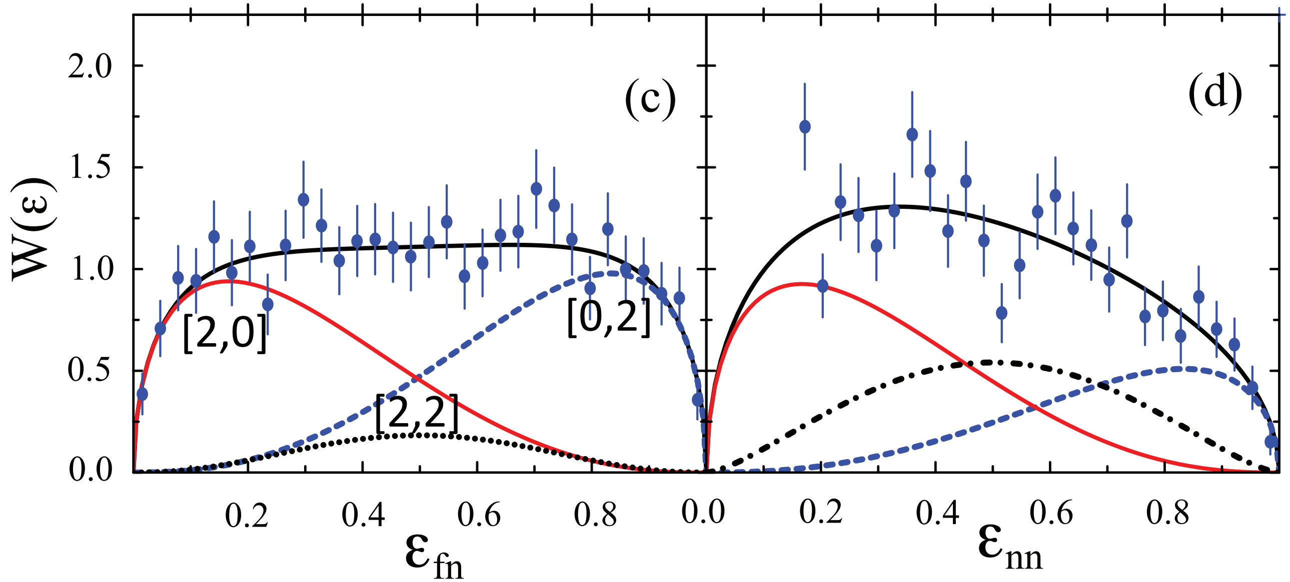


$$\varepsilon_{fn} = E_{fn}/E$$



^{14}Be(^{12}Be+n+n)
^{10}Be+4n
x1/10
dσ/dE$_{fnn}$(mb/MeV)
E$_{fnn}$(MeV)
0.5
1.0
1.5
2.0
0
1
2
3
4
5
6
7
8

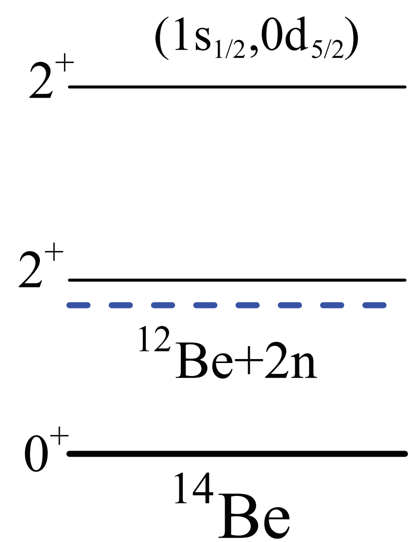
2 MeV < E_{fnn} < 3 MeV

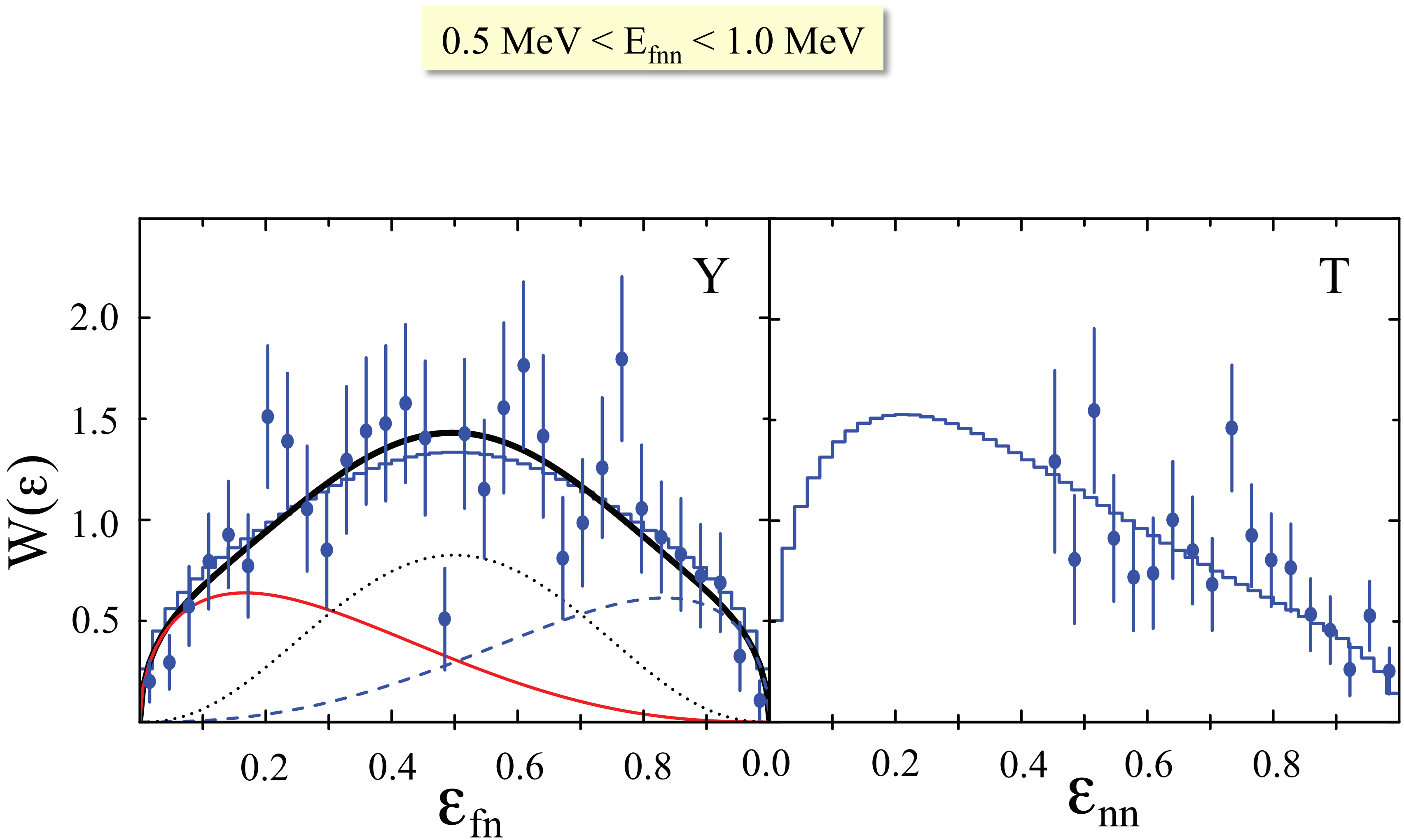


L.M. Delves, Nucl. Phys. **20** (1960) 275

$$W(\epsilon) \sim \sum_i A_i^2 \epsilon^{l_x^i + \frac{1}{2}} (1-\epsilon)^{l_y^i + \frac{1}{2}}$$

$E^* = 3.54(16)$ MeV, $\Gamma = 1.5$ MeV
$I^{\pi} = 2^+$
$(1s_{1/2}, 0d_{5/2}) \approx 90$ %




0.5 MeV < E_fnn < 1.0 MeV
Y
T
W(ε)
2.0
1.5
1.0
0.5
0.2
0.4
0.6
0.8
0.0
ε_fn
ε_nn

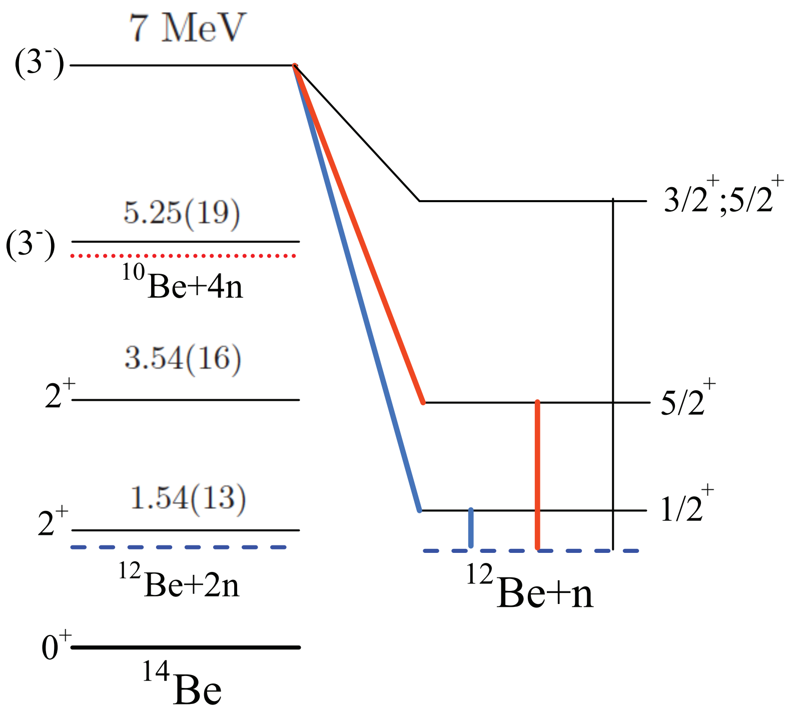
$$^{12}\mathrm{Be}(0^+) = ^{10}\mathrm{Be} \otimes \left[\alpha (1s_{1/2})^2_{I=0} + \beta (0p_{1/2})^2_{I=0} + \gamma (0d_{5/2})^2_{I=0} \right]$$

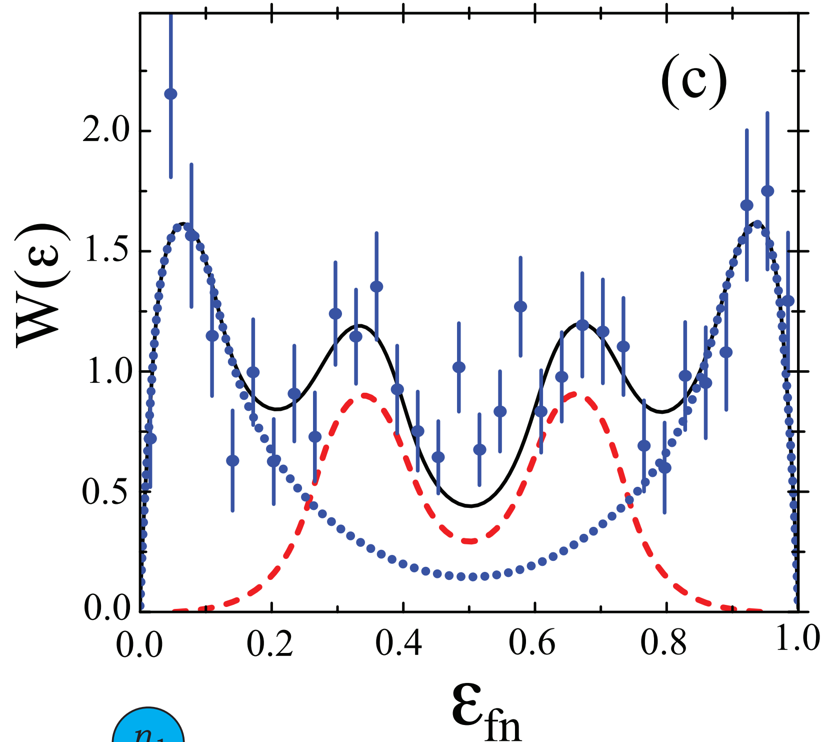
$$^{14}\mathrm{Be}(2^+) = ^{10}\mathrm{Be} \otimes \left[\left\{ \begin{array}{c} \alpha_1 (1s_{1/2})^2_{I=0} \\ \alpha_2 (0p_{1/2})^2_{I=0} \\ \alpha_3 (0d_{5/2})^2_{I=0} \end{array} \right\} (0d_{5/2})^2_{I=2} + \left\{ \begin{array}{c} \beta_1 (0p_{1/2})^2_{I=0} \\ \beta_2 (0d_{5/2})^2_{I=0} \end{array} \right\} (1s_{1/2}, 0d_{5/2})_{I=2} \right]$$

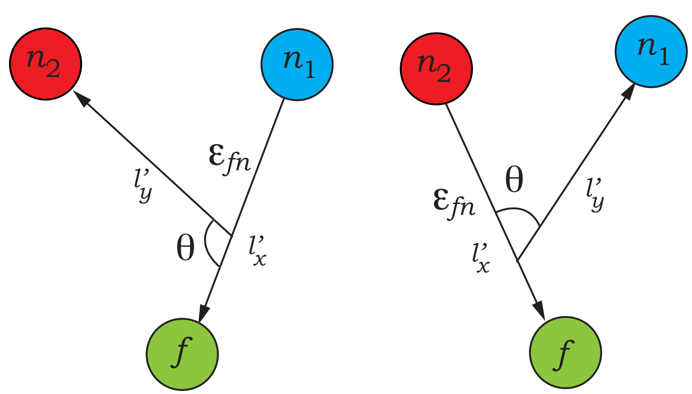
$$\alpha_1 \alpha + \alpha_2 \beta + \alpha_3 \gamma \quad l = 2$$

$$\beta_1 \beta + \beta_2 \gamma \qquad l = 0, 2$$

Sequential Decay

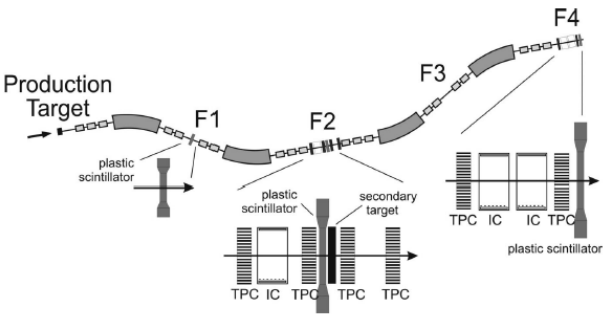


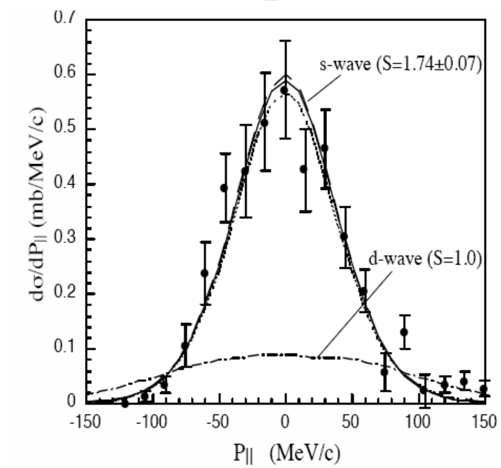




$^{20}\mathrm{F}$ 11 s	$^{21}\mathrm{F}$ 4.16 s	$^{22}\mathrm{F}$ 4.236 s	$^{23}\mathrm{F}$ 2.23 s	$^{24}\mathrm{F}$ 0.34 s	$^{25}\mathrm{F}$ 50 ms	$^{26}\mathrm{F}$ 10.2 ms	$^{27}\mathrm{F}$ 4.29 ms		$^{29}\mathrm{F}$ 2.6 ms		$^{31}\mathrm{F}$ >260 ns
$^{19}\mathrm{O}$ 27.1 s	$^{20}\mathrm{O}$ 13.5 s	$^{21}\mathrm{O}$ 3.4 s	$^{22}\mathrm{O}$ 2.25 s	$^{23}\mathrm{O}$ 82 ms	$^{24}\mathrm{O}$ 61 ms				$^{28}\mathrm{O}$ unbound		
$^{18}\mathrm{N}$ 0.63 s	$^{19}\mathrm{N}$ 329 ms	$^{20}\mathrm{N}$ 142 ms	$^{21}\mathrm{N}$ 95 ms	$^{22}\mathrm{N}$ 24 ms	$^{23}\mathrm{N}$ 14.5 ms						
$^{17}\mathrm{C}$ 193 ms	$^{18}\mathrm{C}$ 92 ms	$^{19}\mathrm{C}$ 49 ms	$^{20}\mathrm{C}$ 14 ms		$^{22}\mathrm{C}$ 6.2 ms						

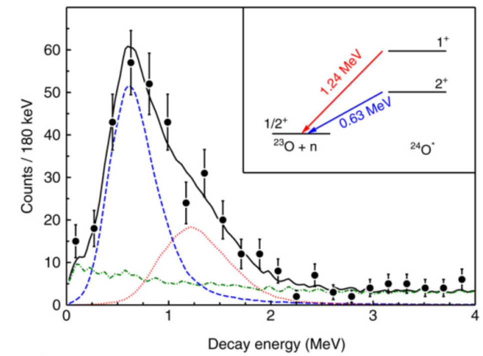
GSI

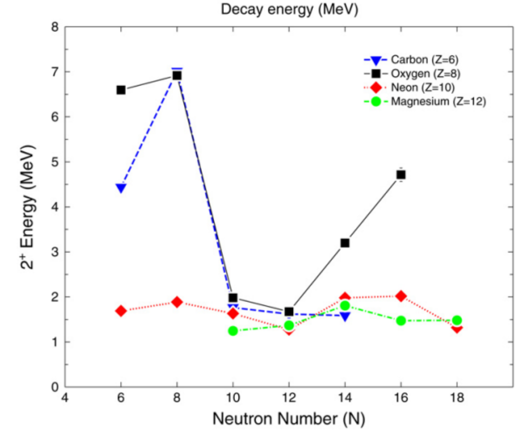




S=1.74(19)

MSU





2^+: 4.7 MeV

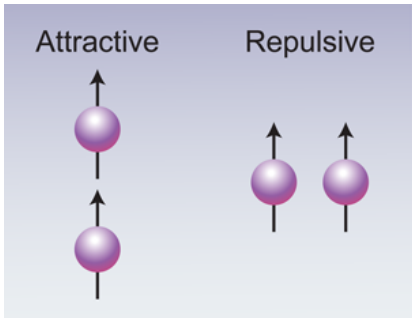
C.R. Hoffman et al., PLB **672** (2009) 17

R. Kanungo *et al.*, PRL **102** (2009) 152501

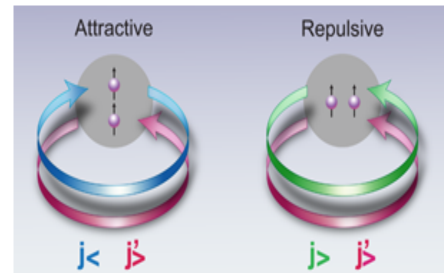
Shell evolution and nuclear forces

N.A. Smirnova *et al.*, PLB **686** (2010) 109

Novel Features of Nuclear Forces and Shell Evolution in Exotic Nuclei

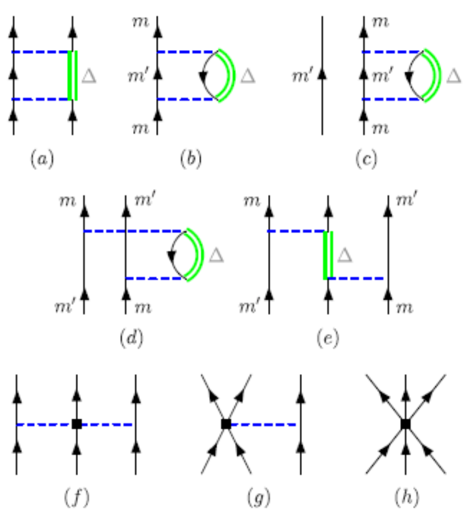


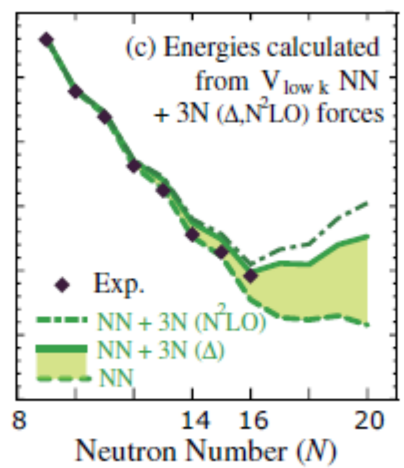
T. Otsuka *et al.*, PRL **104** (2010) 032501

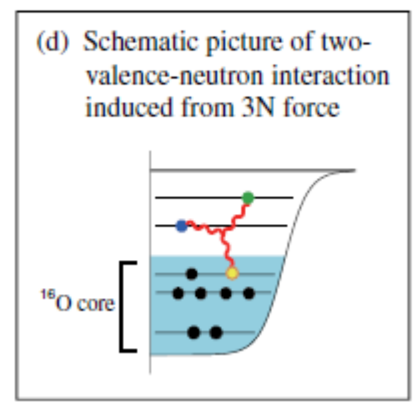


Three-Body Forces and the Limit of Oxygen Isotopes

T. Otsuka *et al.*, PRL **105** (2010) 032501





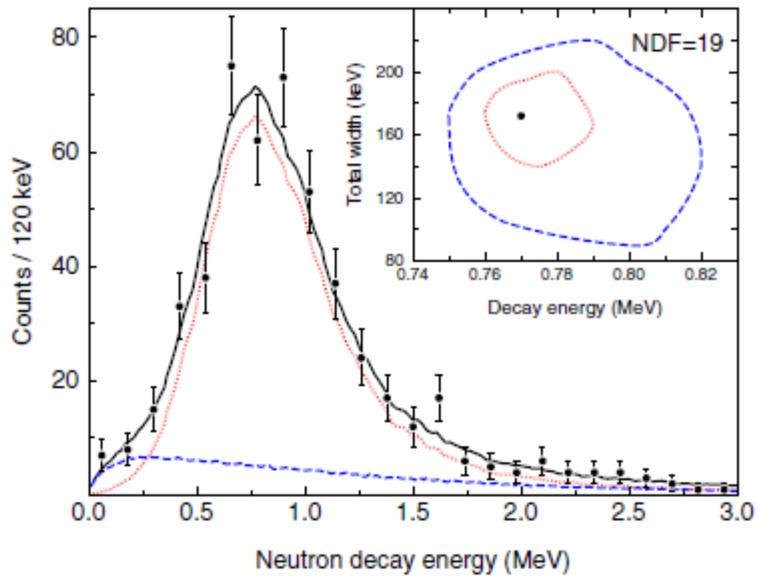


GSI : Data September 2010

^{24}F 0.34 s	^{25}F 50 ms	^{26}F 10.2 ms	^{27}F 4.9 ms	^{28}F unbound	^{29}F 2.6 ms	^{30}F unbound	^{31}F >260 ns
^{23}O 82 ms	^{24}O 61 ms	^{25}O unbound	^{26}O unbound		^{28}O unbound		

MoNA

C.R. Hoffman *et al*. PRL **100** (2008) 152502



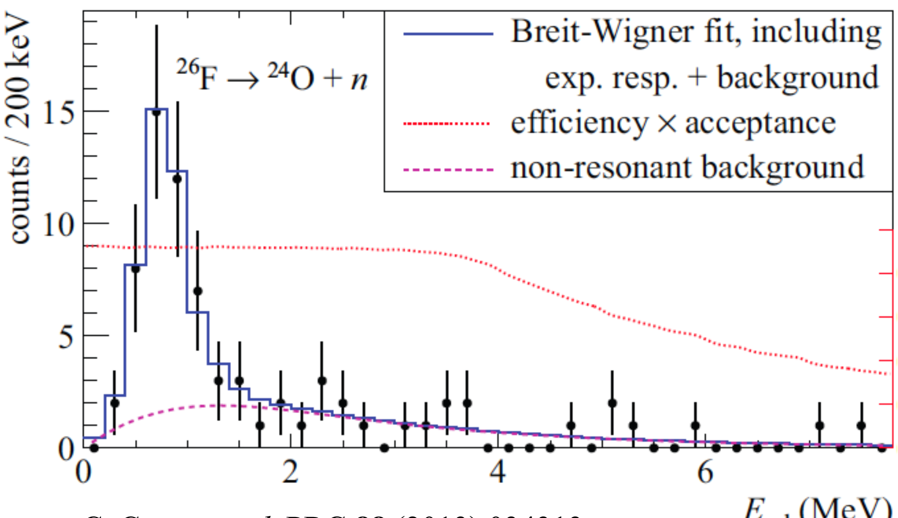
E_{decay}=770 keV, Γ= 172 keV, l=2

Shell gap $\nu 1s_{1/2} - \nu 0d_{3/2}$
4.86(13) MeV

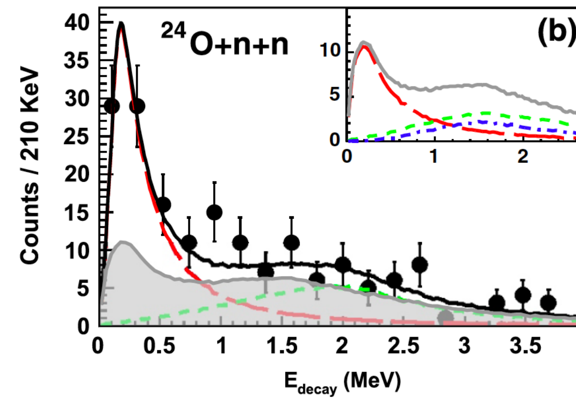
B. Jurado*et al*. PLB **649** (2007) 43

GSI : Data September 2010

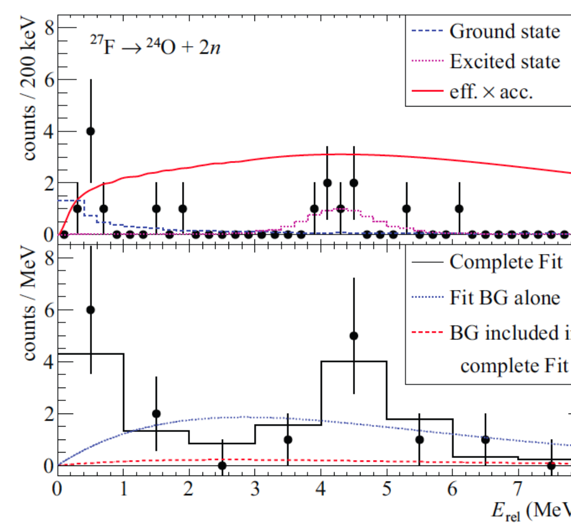
^{24}F 0.34 s	^{25}F 50 ms	^{26}F 10.2 ms	^{27}F 4.9 ms	^{28}F unbound	^{29}F 2.6 ms	^{30}F unbound	^{31}F >260 ns
^{23}O 82 ms	^{24}O 61 ms	^{25}O unbound	^{26}O unbound		^{28}O unbound		



C. Caesar *et al*. PRC **88** (2013) 034313



E. Lunderberg *et al*. PRL **108** (2012) 142503



Two-neutron radioactivity ?

L.V. Grigorenko *et al*. PRL **111** (2013) 042501

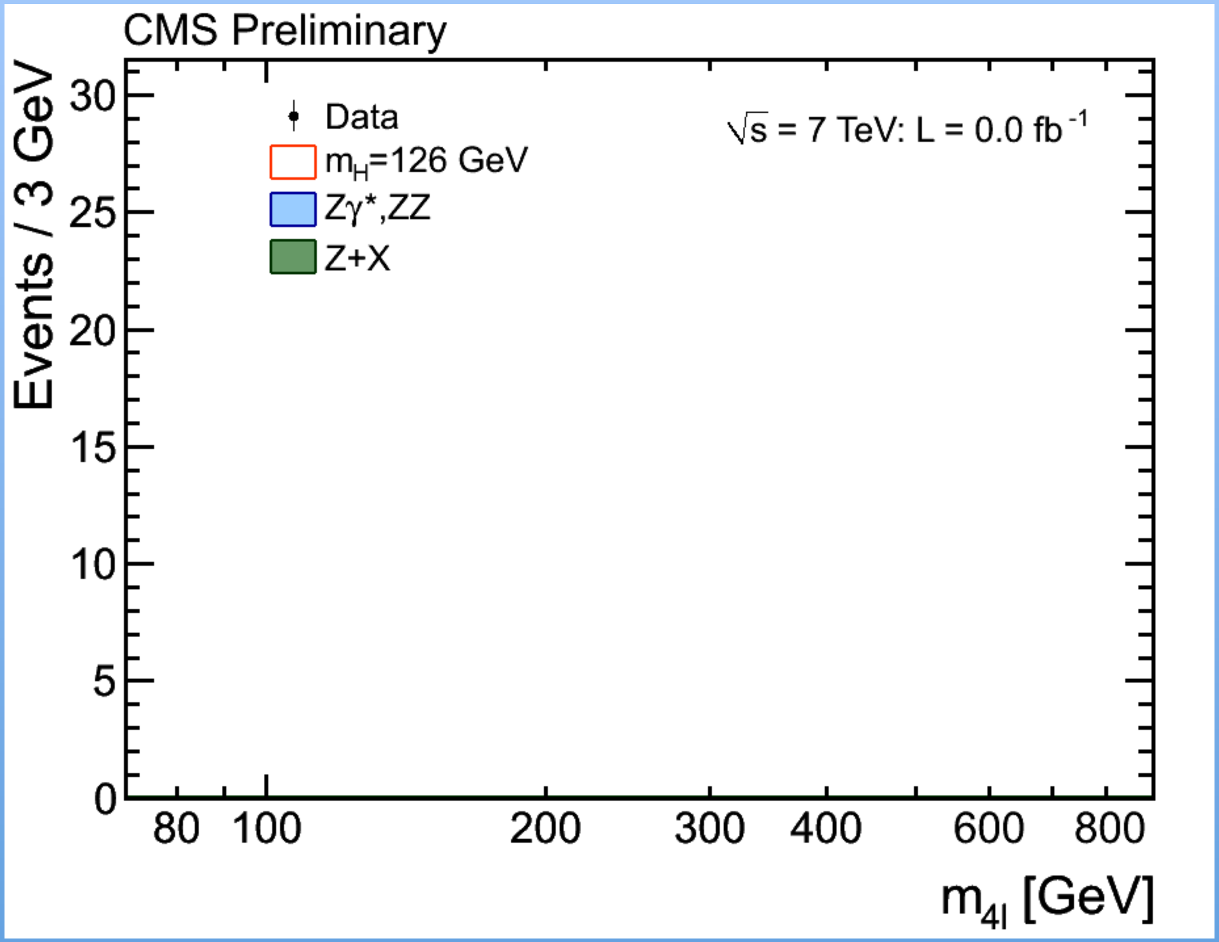
Z. Kohley *et al*. PRL **110** (2013) 152501 ← $4.5^{+1.1}_{-1.5} \pm 3\ ps$

Nobelpriset i fysik 2013

François Englert
Université libre de Bruxelles, Belgium

Peter W. Higgs
University of Edinburgh, UK

"For the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider."



CMS Preliminary
Data
m_H=126 GeV
Zγ*,ZZ
Z+X
$\sqrt{s}$ = 7 TeV: L = 0.0 fb^{-1}
Events / 3 GeV
0
5
10
15
20
25
30
80
100
200
300
400
600
800
m_{4l} [GeV]