Recent results of Texas Active Target (TexAT) detector: structure of ^{13}Be, clustering in ^{18}Ne, and neutron up-scattering on Carbon

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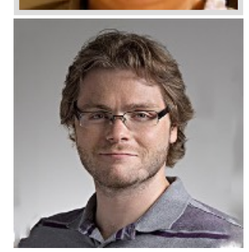
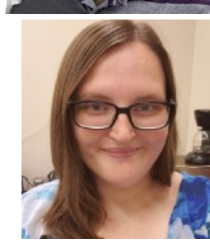
Outline

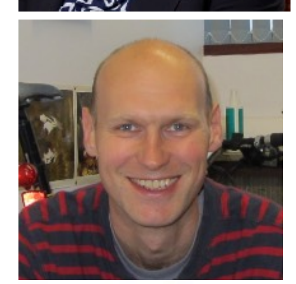
- The role of neutrons in carbon nucleosynthesis
- Clustering in mirror pairs, the case study for A=18
- Structure of ^{13}Be.

Acknowledgement

Texas A&M U: *E. Aboud (now at* ***LLNL****), S. (Tony) Ahn (now at* ***RAON****), M. Barbui, J. Bishop, J. Hooker (ind.), C. Hunt (now at* ***FRIB****), H. Jayatissa (now at* ***Argonne NL****), R. O'Dwyer, C. Parker, E. Koshchiy, B. Roeder, M. Roosa, D. Scriven, A. Saastamoinen, S. Upadhyayula (now at* ***TRIUMF****), E. Uberseder;* ***IRFU, CEA, Saclay, France:*** *E.C. Pollacco;* ***Washington U.:*** *L. Sobotka, C. Pruitt, R.J. Charity;* ***Louisiana State University:*** S. O'Marley, R. Malecek; ***U Sao Paulo:*** V. Guimaraes, M. Assuncao, J.C. Zamora; ***UFF, Rio de Janeiro:*** R. Linares; ***U of Birmingham:*** T. Kokalova-Weldon, C. Weldon, ***EWHA Womans U:*** Insik (Kevin) Hahn, Se Young Han; ***Ohio U:*** *C. Brune*, Z. Meisel, T.N. Massey, N. Singh, D. Soltesz, et al.





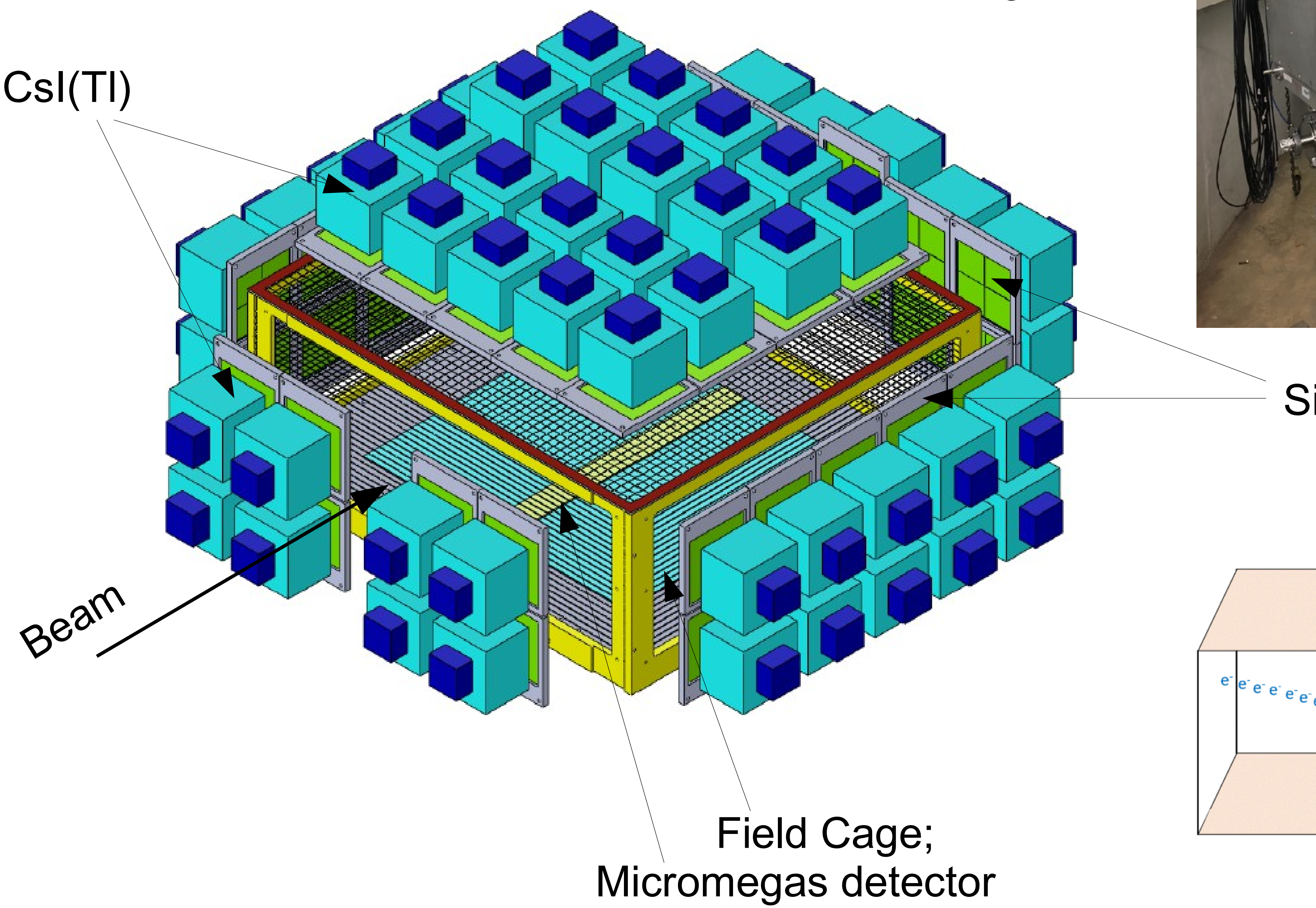


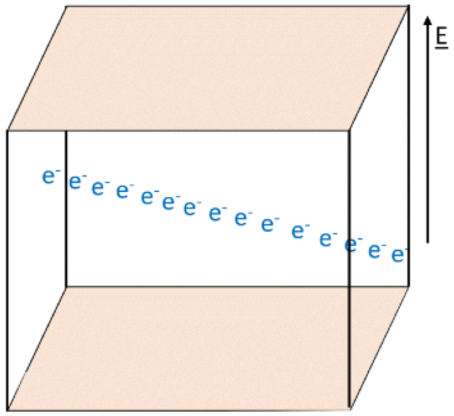


Texas Active Target

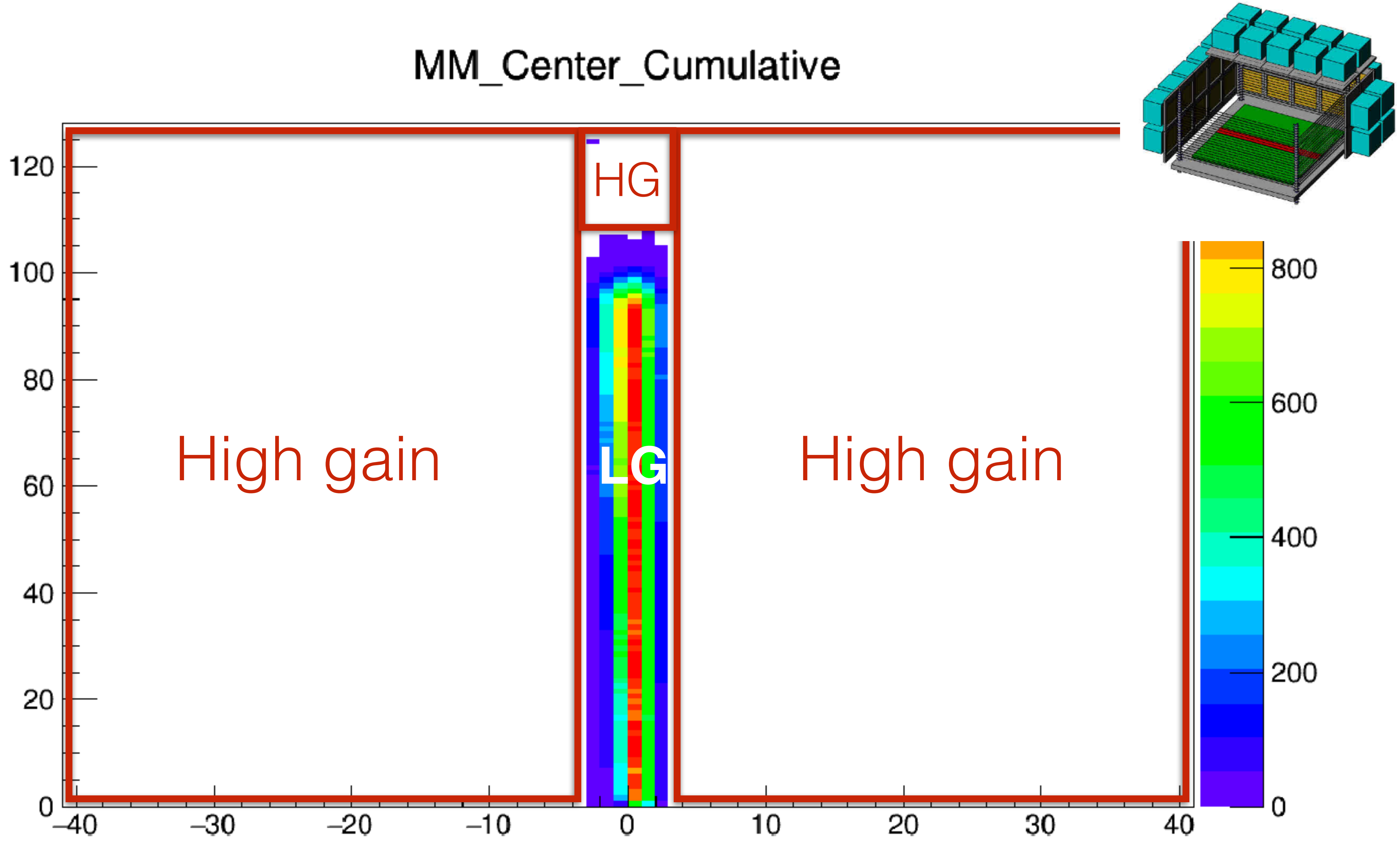
E. Koshchiy, GR, E. Pollacco, et al., NIM, A 957 (2020) 163398

Detectors: Si
CsI(TI)
Micromegas: 1024





High/Low gain regions



Past TexAT experiments

☑ Resonance scattering

- Resonances in ^{9}C - $^{8}B(p,p)$
- Clustering in ^{14}O - $^{10}C(\alpha,\alpha)$ resonance elastic scattering
- **Clustering in ^{18}Ne - $^{14}O(\alpha,\alpha)$ resonance elastic scattering**
- **Structure of ^{13}Be - T=5/2 IAS in ^{13}B through $^{12}Be(p,p)$**
- Structure of ^{10}Li - T=2 IAS in ^{10}Be through $^{9}Li(p,p)$ and $^{9}Li(p,n)$

☑ Transfer reactions

- Structure of ^{12}B(g.s.) - $^{12}B(d,^{3}He)^{11}Be$
- Search for excited state in tritium - $^{1}H(^{6}He,^{4}He)$

☑ Fusion reactions

- $^{8}B+^{40}Ar$ fusion

☑ β-delayed charged particle emission

- (12N,β3α) - Hoyle state
- Search for Efimov effect in ^{12}C below the Hoyle state.

☑ Neutron-induced reactions

- **$^{12}C(n,n')^{12}C$(Hoyle)**
- $^{16}O(n,\alpha)^{12}C$

The role of neutrons in carbon nucleosynthesis

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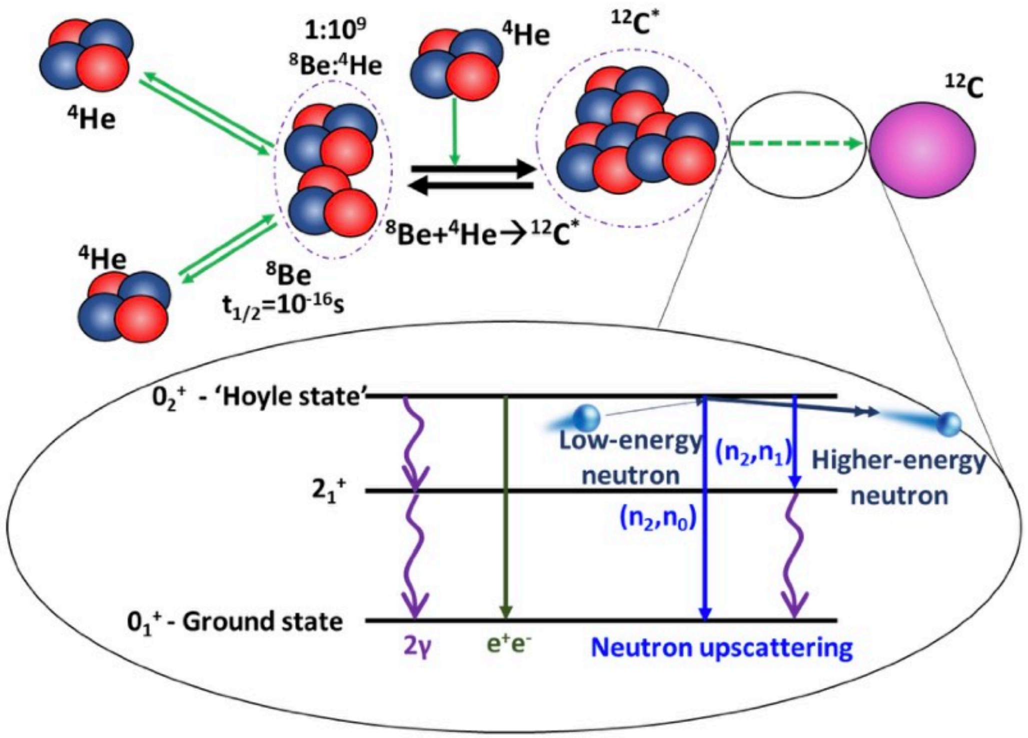
Triple-alpha reaction and neutron upscattering

- Three alphas produce Hoyle state in ^{12}C (through ^{8}Be(g.s.))
- Hoyle state can be de-excited by:
  - gamma cascade
  - electron-positron pair
  - neutrons + Hoyle scattering
  - protons + Hoyle scattering
  - α+Hoyle scattering OR **decay back to 3α**



PRL 119, 112701 (2017) PHYSICAL REVIEW LETTERS week ending 15 SEPTEMBER 2017

Enhancement of the Triple Alpha Rate in a Hot Dense Medium

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[2]*Joint Institute for Nuclear Astrophysics, National Superconducting Cyclotron Laboratory, Michigan State University, 640 South Shaw Lane, East Lansing, Michigan 48824-1321, USA*
(Received 10 March 2017; revised manuscript received 3 July 2017; published 15 September 2017)

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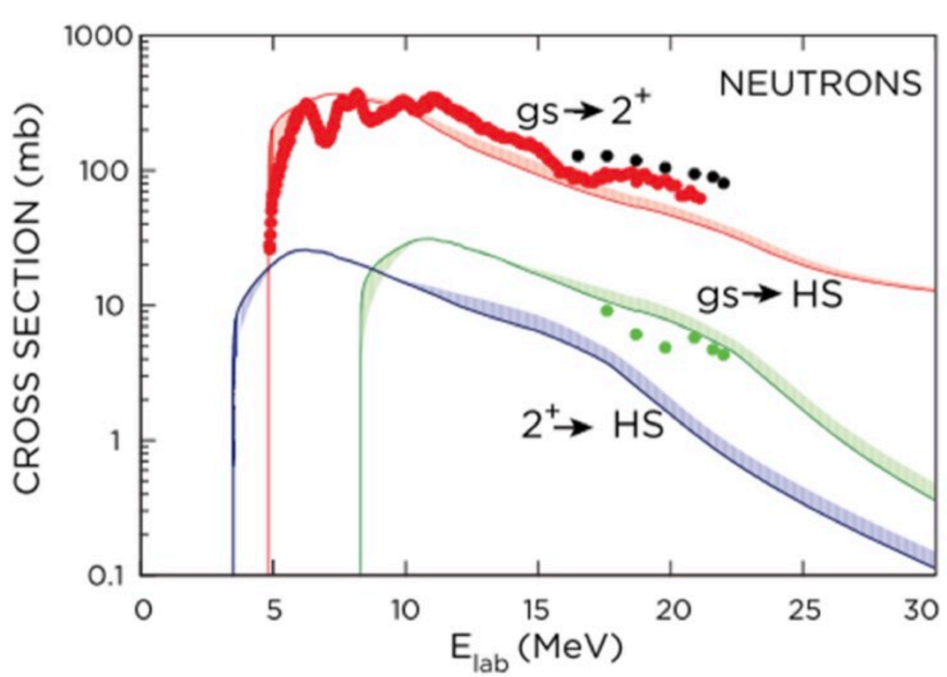
Article | Published: 02 December 2020

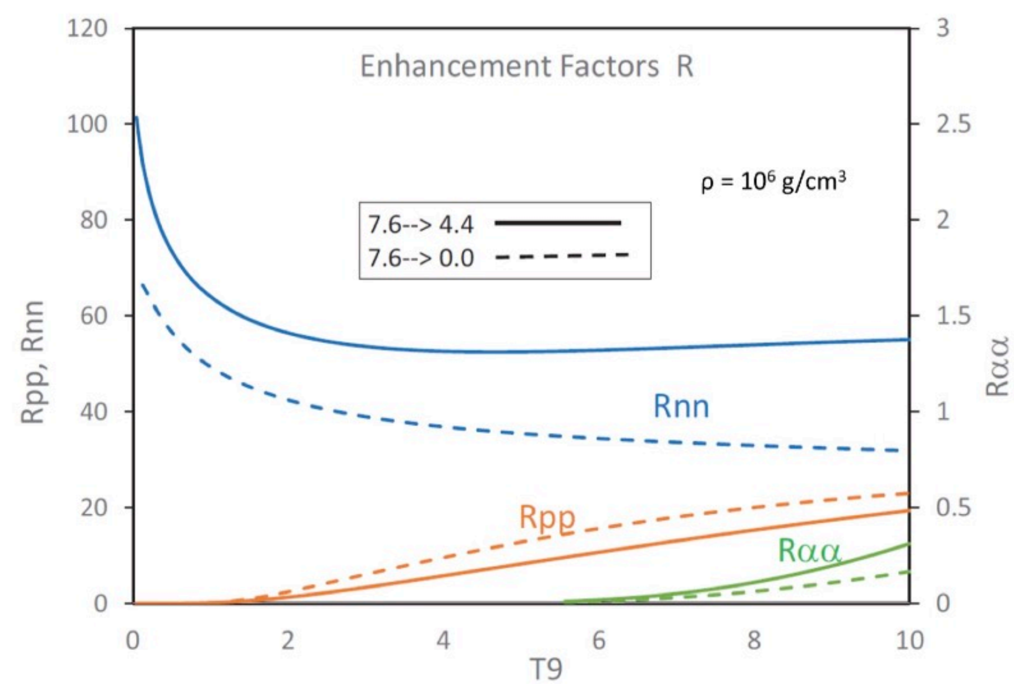
Enhanced triple-α reaction reduces proton-rich nucleosynthesis in supernovae

Shilun Jin, Luke F. Roberts, Sam M. Austin & Hendrik Schatz

Nature **588**, 57–60 (2020) | Cite this article

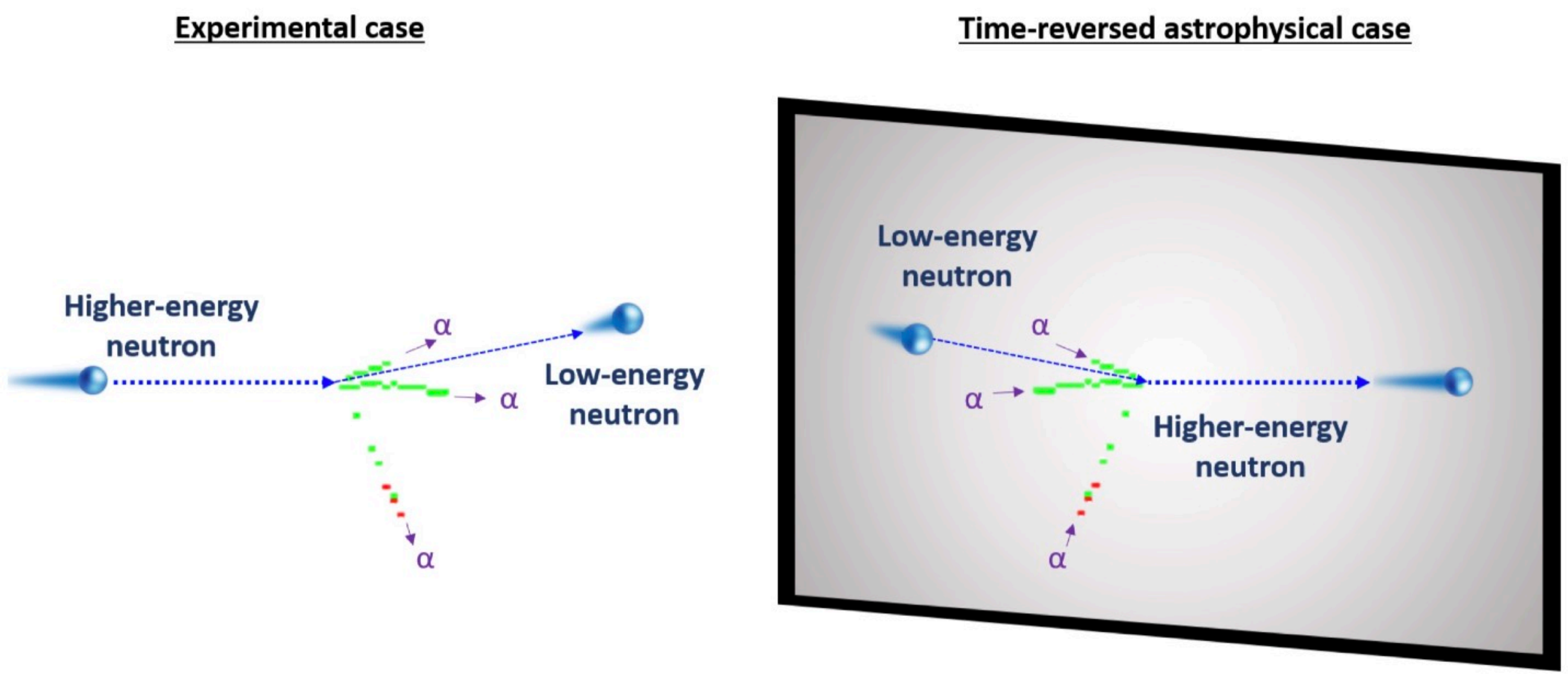
[M. Beard et al. Phys. Rev. Lett. 119, 112701]





Using Hauser Feshbach XS predictions. High-density environment, large neutron enhancements at low temperature (≈ 0.2 GK (T9))

Measuring time-reversed reaction



Time-reversal symmetry

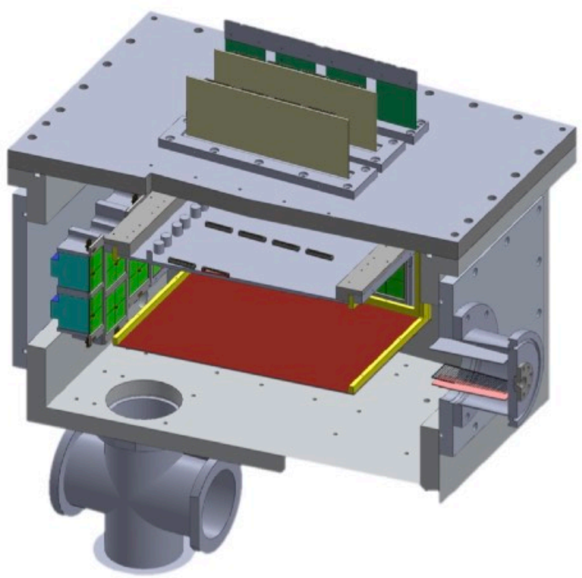
Quantum mechanically we can relate a reaction and the time reverse of that reaction using "detailed balance"

TPCs and neutron beams

TPCs can be well-suited to many different types of neutron-induced measurements

Active-target (gas IS the target and readout medium) TPC filled with CO_2 looking to measure:

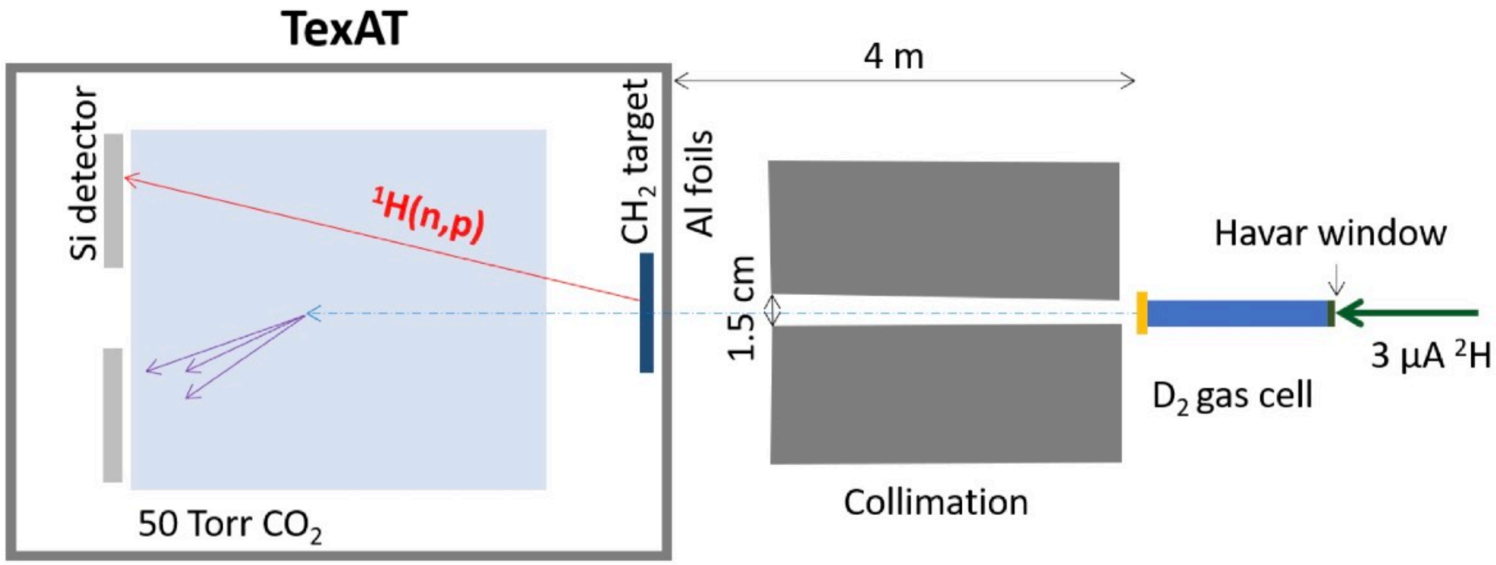
- $^{12}\mathrm{C}(n, n_2)3\alpha$ - inelastic neutron scattering to the Hoyle state
- $^{12/16}\mathrm{C}/\mathrm{O}(n, \alpha)$ - hugely important reactions for nuclear data measured parasitically

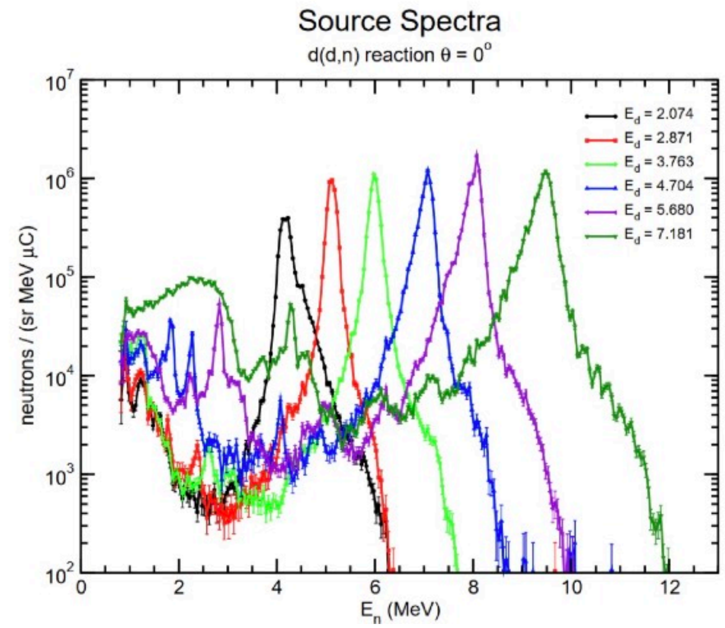


Can be measured with the TexAT with 50 Torr CO_2 gas.
Represents a great opportunity for future measurements with low-energy recoil products - can be well resolved using low pressure TPC.

TPCs and neutron beams

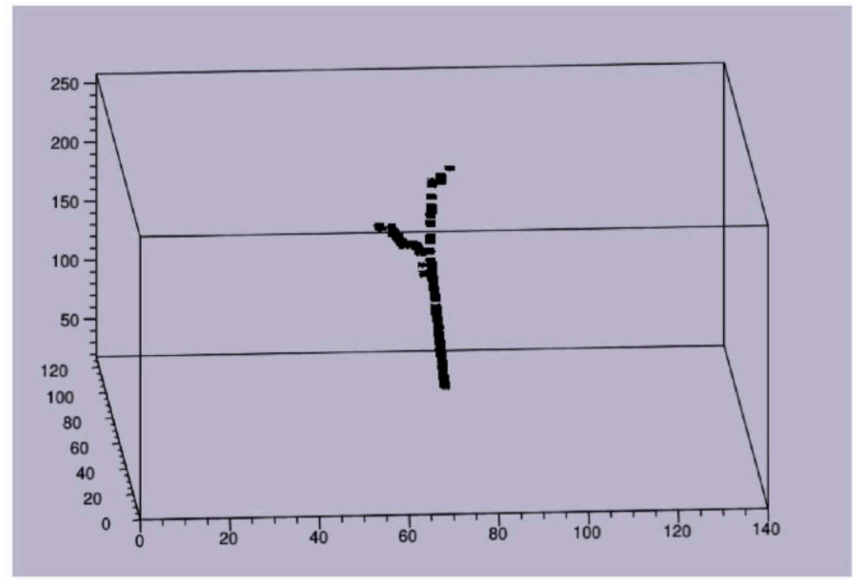
- Edwards Accelerator Lab - Ohio University
- Deuteron beam from accelerator: $\approx 10^{13}$ pps
- Neutron beam from $d(d,n)$ reaction - scanning from 7.2-10.0 MeV
- 5×10^3 neutrons/s: $\sigma(E_n) \approx 200$ keV
- Normalization is a big issue! Use ${}^1\mathrm{H}(n,p)$

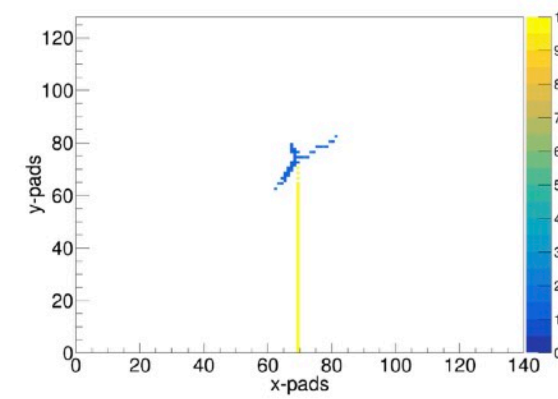




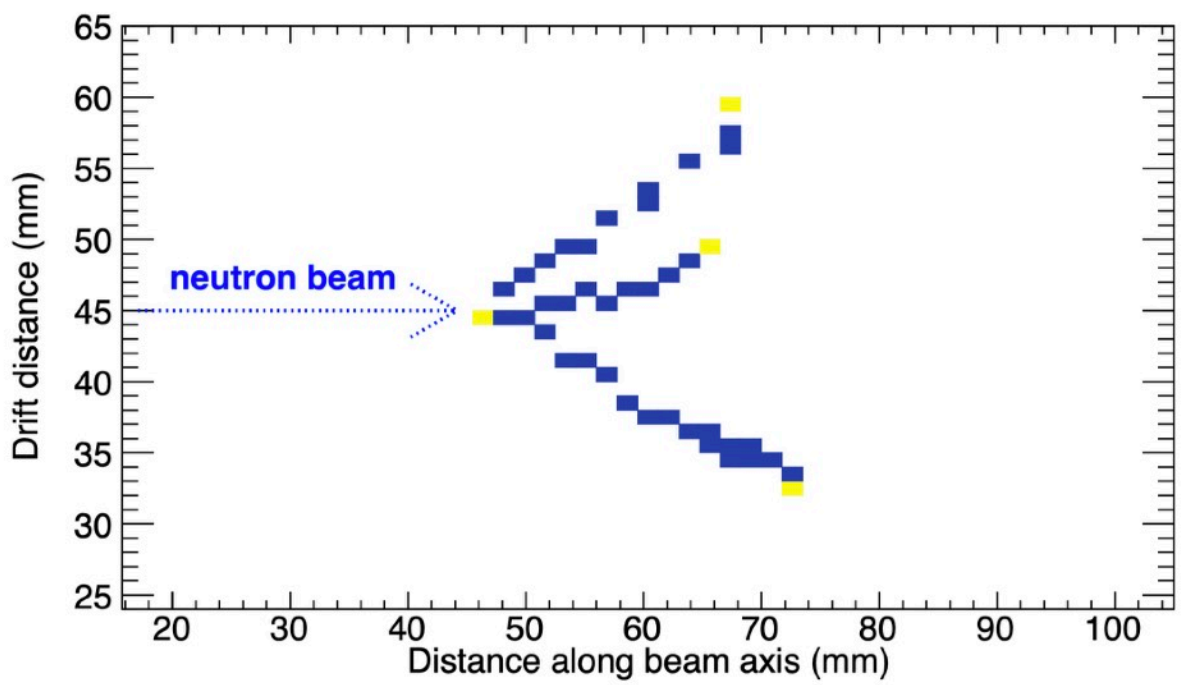
Identifying Hoyles with TexAT

Observing ^{12}N decay with TexAT





Typical $^{12}C(n,n_2)$Hoyle event



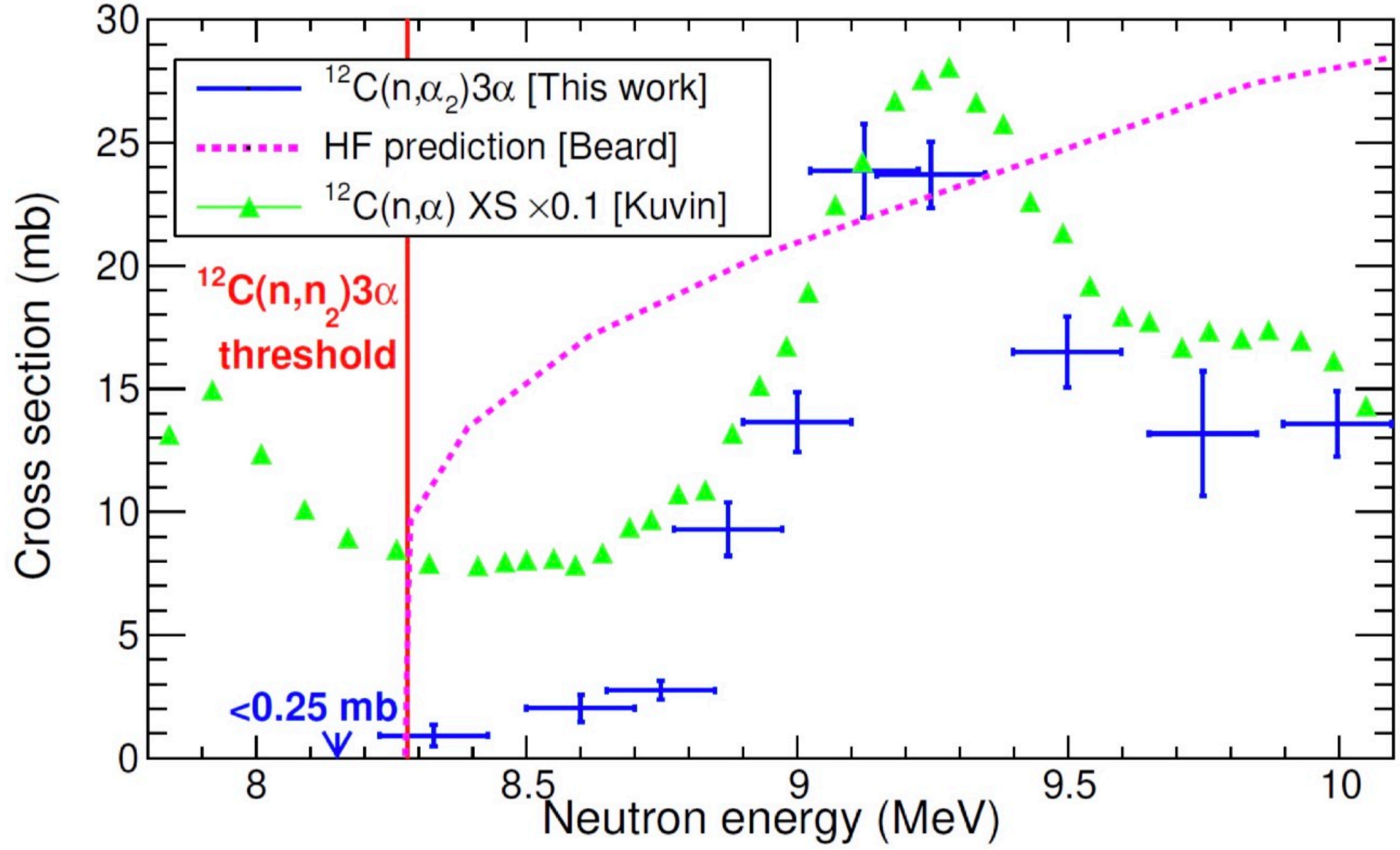
J. Bishop, et al., NIM A964 (2020) 163773.

J. Bishop, et al., PRC 102 (2020) 041303.

J. Bishop, et al., PRC Letter 103 (2021)

$^{12}C(n,n_2)$Hoyle reaction XS

Reconstruct three α-particles to make Hoyle state, count the events and neutrons!
$^{12}\mathrm{C}(n, \alpha_{1,2})^9\mathrm{Be}^\star$ contribution is removed



Remarkable similarity between the $^{12}\mathrm{C}(n, n_2)3\alpha$ and $^{12}\mathrm{C}(n, \alpha)$ demonstrates the dominance of the compound nucleus reaction (i.e. make $^{13}\mathrm{C}$ and then it decays again)

Understanding the resonances in $^{13}\mathrm{C}$ we can perform a multi-channel R-Matrix fit using channel data:

- $^{12}\mathrm{C}(n, n_0)$
- $^{12}\mathrm{C}(n, n_1)$
- $^{12}\mathrm{C}(n, n_2)3\alpha$
- $^{12}\mathrm{C}(n, \alpha_0)^9\mathrm{Be}$
- $^{9}\mathrm{Be}(\alpha, n_2)3\alpha$

Aim to get the $^{12}\mathrm{C}(n_0, n_2)$ and $^{12}\mathrm{C}(n_1, n_2)$ cross sections (impossible to measure experimentally - must only be inferred) and their inverses through detailed balance

R-Matrix

R-Matrix relates the resonances to the observed cross sections for compound nucleus reactions

Enhancement of the upscattering enhancement is evaluated by the following:

$$R = k_n \rho_n T_9^{-1.5}(2J_i + 1) \times \int_0^\infty \sigma_{nn'}(E)(E - Q)\exp(-11.605E/T_9)dE, \quad (1)$$

$k_n = 6.557\times10^{-6}\ \mathrm{K}^{\frac{3}{2}}\mathrm{cm}^3\mathrm{g}^{-1}$, J_i is the spin factor (0 for g.s. to Hoyle, 2 for 2^+ to Hoyle), E is COM energy, Q is the reaction Q-value, T_9 is temperature in GK and σ is our measured XS.

- Higher COM E more important at higher T
- Hoyle $\rightarrow 2_1^+$ more important by a factor of 5!

J. Bishop

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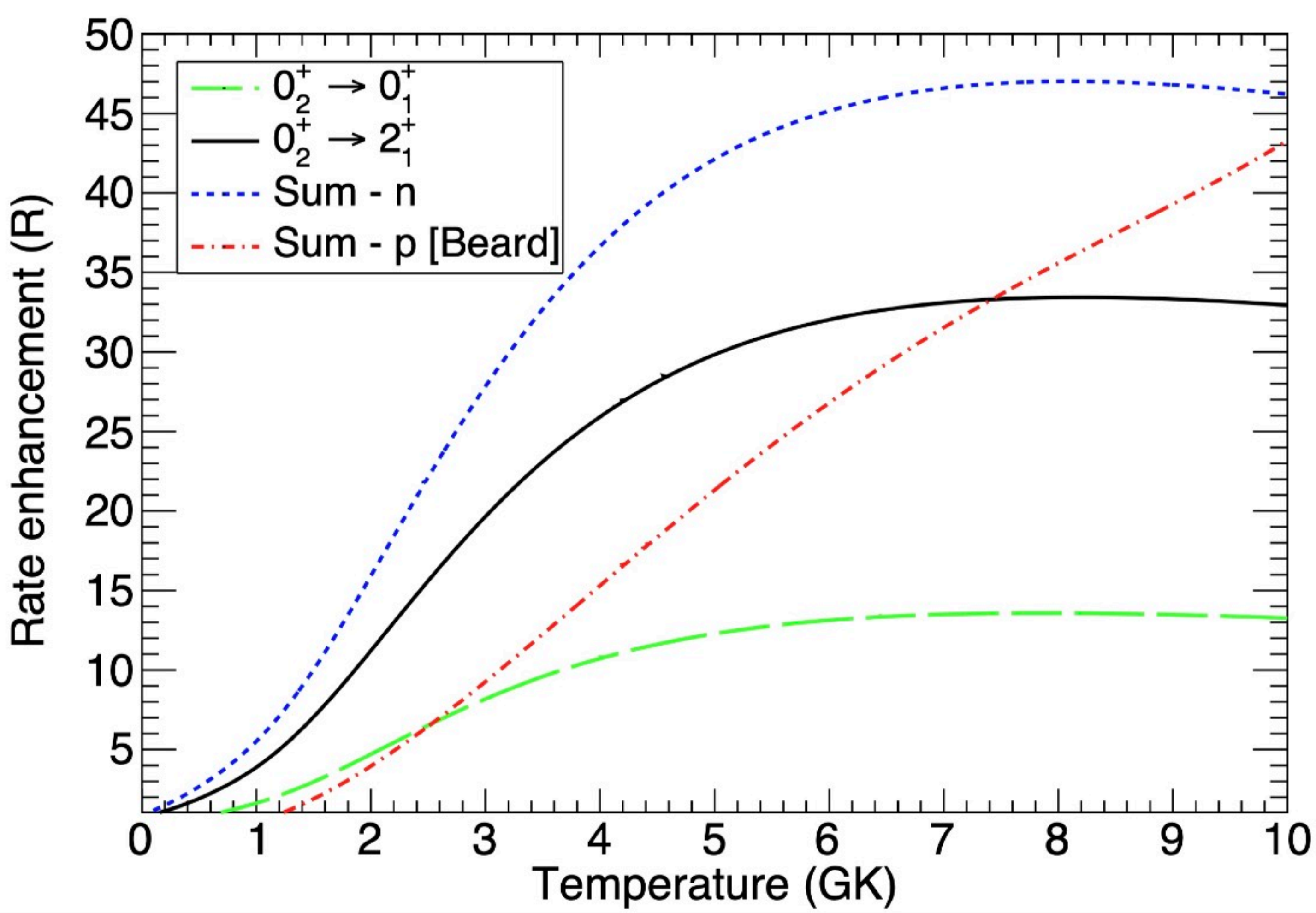
Neutron-upscattering enhancement of the triple-alpha process

J. Bishop, C. E. Parker, G. V. Rogachev, S. Ahn, E. Koshchiy, K. Brandenburg, C. R. Brune, R. J. Charity, J. Derkin, N. Dronchi, G. Hamad, Y. Jones-Alberty, Tz. Kokalova, T. N. Massey, Z. Meisel, E. V. Ohstrom, S. N. Paneru, E. C. Pollacco, M. Saxena, N. Singh, R. Smith, L. G. Sobotka, D. Soltesz, S. K. Subedi, A. V. Voinov, J. Warren & C. Wheldon — Show fewer authors

Nature Communications **13**, Article number: 2151 (2022) | Cite this article



Enhancement is not as important as previously thought to be! Different astrophysical sites have different temperatures

21/22

Clustering in ^{18}O-^{18}Ne mirrors

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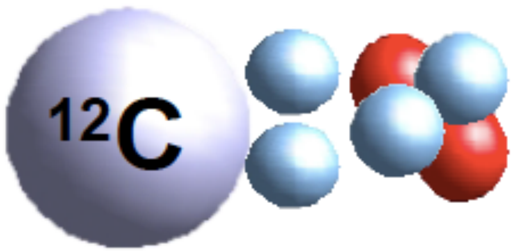
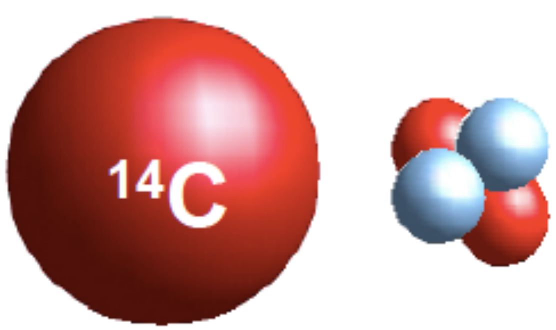
Clustering in ^{18}O



Molecular-type configuration

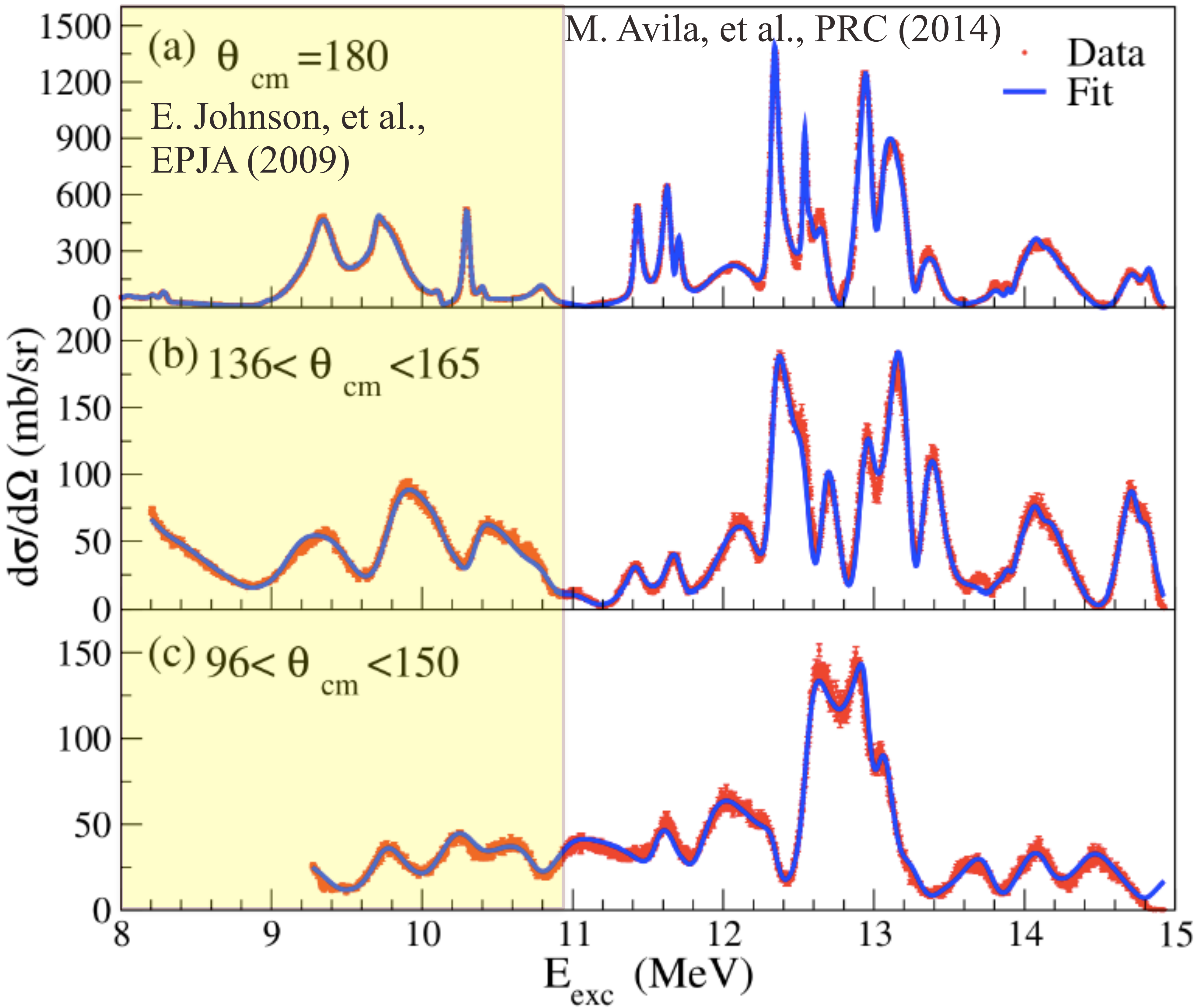
"Shell model" configuration



α-cluster configuration

Cartoon is borrowed from W. von Oertzen, et al., EPJA 43, 17 (2010)

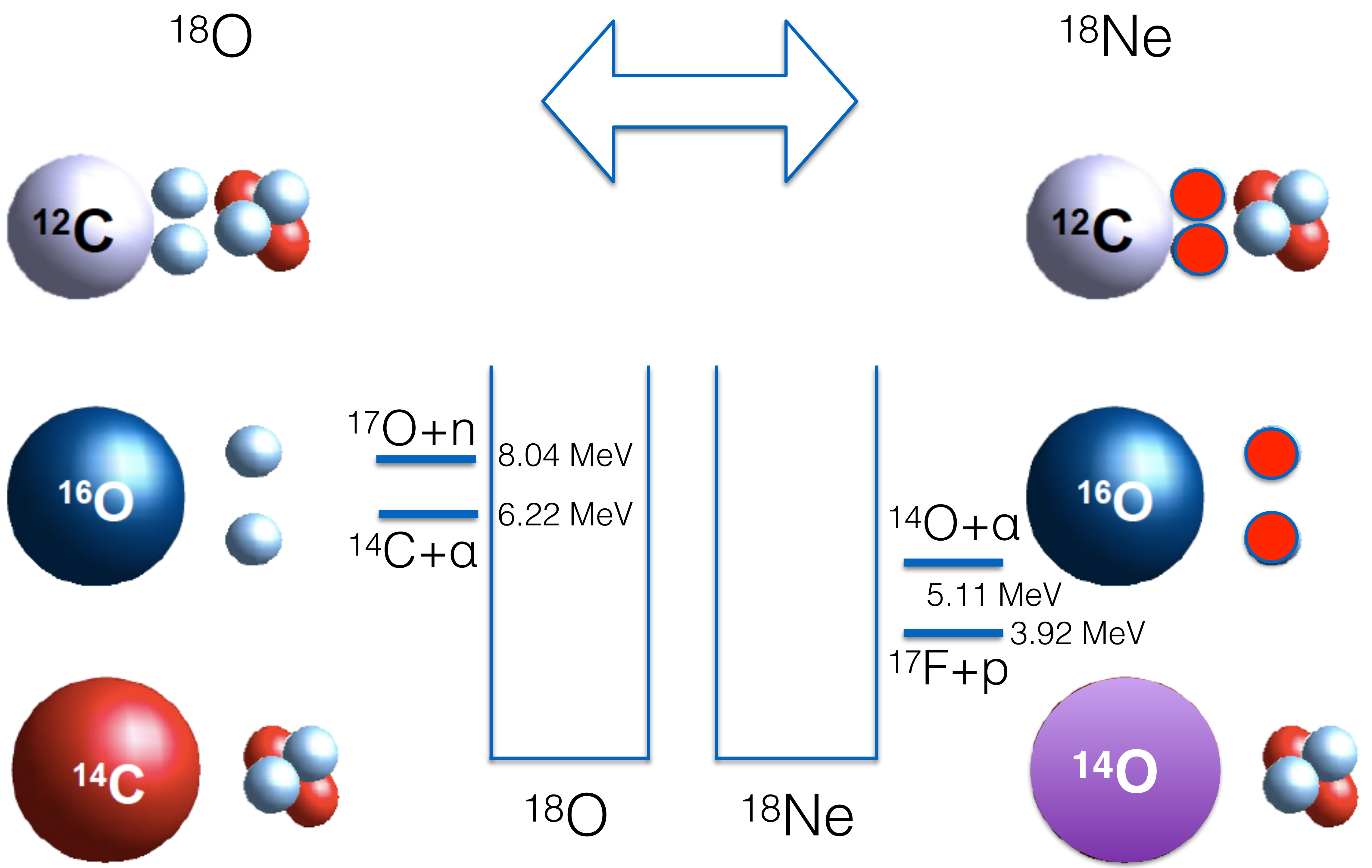
Excitation functions for $^{14}C+\alpha$



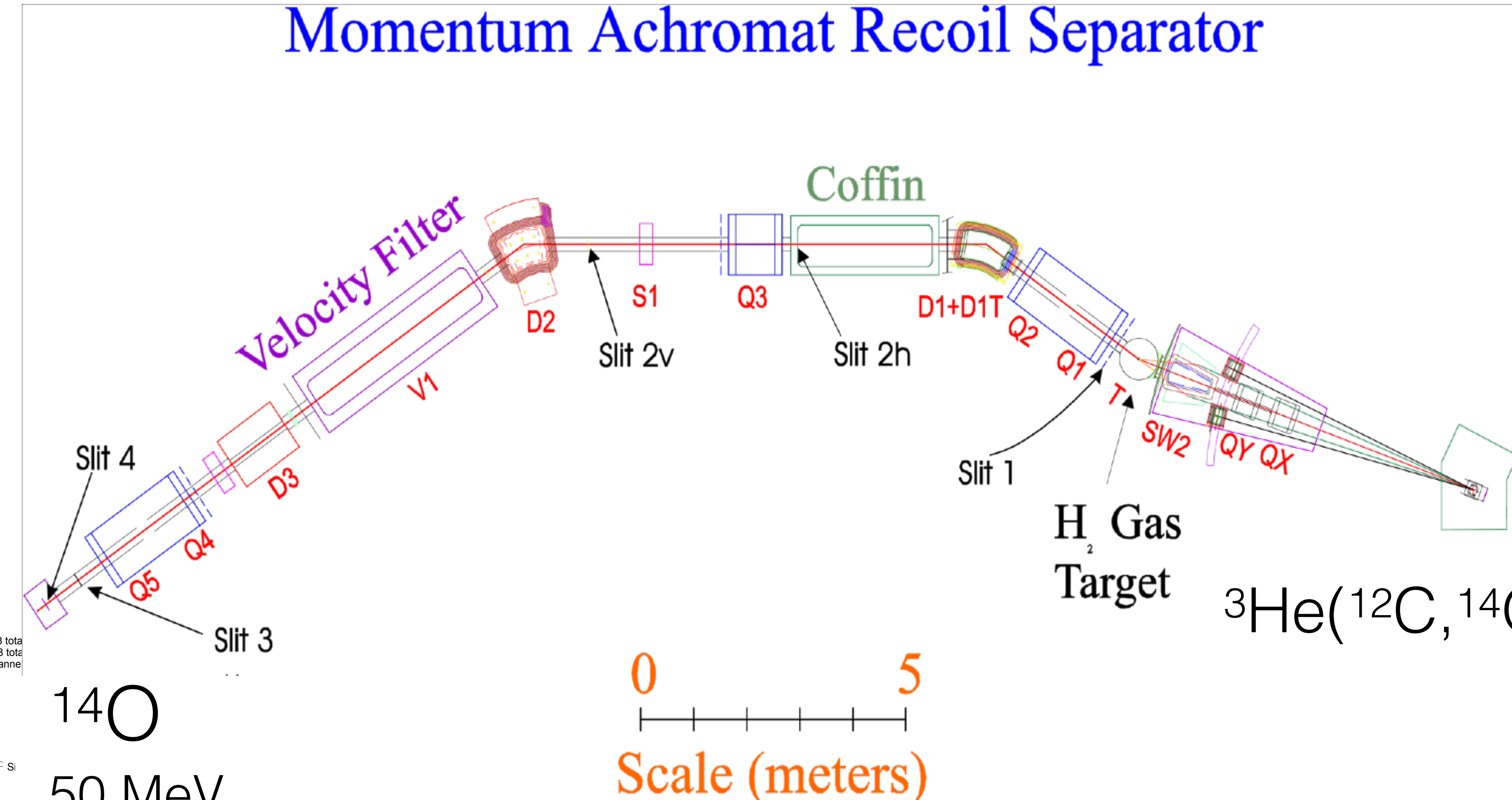
Levels in ^{18}O

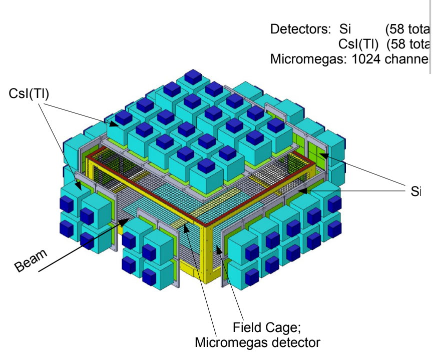
E^*(MeV)	J^π	Γ_{tot}(keV)	Γ_α(keV)	θ_α^2
8.04	1^-	2	2	0.02
8.21	2^+	1.9	1.7	0.03
8.28	3^-	8.5	2.9	0.18
8.82	2^+	58	0.3	<0.01
8.96	2^+	69	5	0.02
9.19	1^-	218	199	0.20
9.35	3^-	176	112	0.48
9.70	3^-	137	15	0.04
9.76	1^-	679	626	0.46
9.79	2^+	173	90	0.10
9.86	0^+	3209	3209	1.85
10.11	3^-	16	7	0.01
10.29	4^+	29	19	0.09
10.40	3^-	66	18	0.03
10.42	2^+	182	44	0.03
10.80	1^-	688	629	0.29
10.98	2^+	284	21	0.01
11.31	2^+	248	86	0.02
11.43	4^+	41	32	0.05
11.62	3^-	144	28	0.01
11.63	5^-	40	31	0.13
11.67	1^-	201	117	0.02
11.70	6^+	23	12	0.23
11.95	3^-	561	297	0.17
12.12	1^-	414	49	0.02
12.21	2^+	1073	960	0.37
12.34	5^-	39	26	0.06
12.46	1^-	910	271	0.08

E^*(MeV)	J^π	Γ_{tot}(keV)	Γ_α(keV)	θ_α^2
12.54	4^+	6	5	<0.01
12.57	6^+	71	49	0.38
12.64	3^-	103	5	<0.01
12.71	3^-	285	118	0.05
12.90	2^+	310	285	0.09
12.94	5^-	38	14	0.02
12.96	2^-	4788	4788	1.56
12.98	3^-	1039	768	0.32
13.08	5^-	176	122	0.18
13.17	2^+	147	129	0.04
13.33	1^-	306	33	<0.01
13.38	2^+	252	215	0.07
13.45	4^+	838	23	0.01
13.48	4^+	465	196	0.11
13.69	2^+	531	40	0.01
13.82	5^-	25	2	<0.01
13.89	4^+	60	28	0.01
13.96	3^-	144	74	0.03
14.01	3^-	2615	2098	0.70
14.07	5^-	560	260	0.23
14.12	2^+	155	96	0.03
14.30	1^-	955	403	0.10
14.47	1^-	449	228	0.05
14.52	4^+	2212	81	0.03
14.70	5^-	280	230	0.16
14.77	4^+	943	446	0.18
14.82	5^-	142	102	0.07


^{18}O
^{18}Ne
^{12}C
^{12}C
^{17}O+n
8.04 MeV
6.22 MeV
^{14}C+α
^{16}O
^{14}O+α
^{16}O
5.11 MeV
3.92 MeV
^{17}F+p
^{14}C
^{14}O
^{18}O
^{18}Ne

Clustering in ^{18}Ne





^{3}He(^{12}C,^{14}O)n

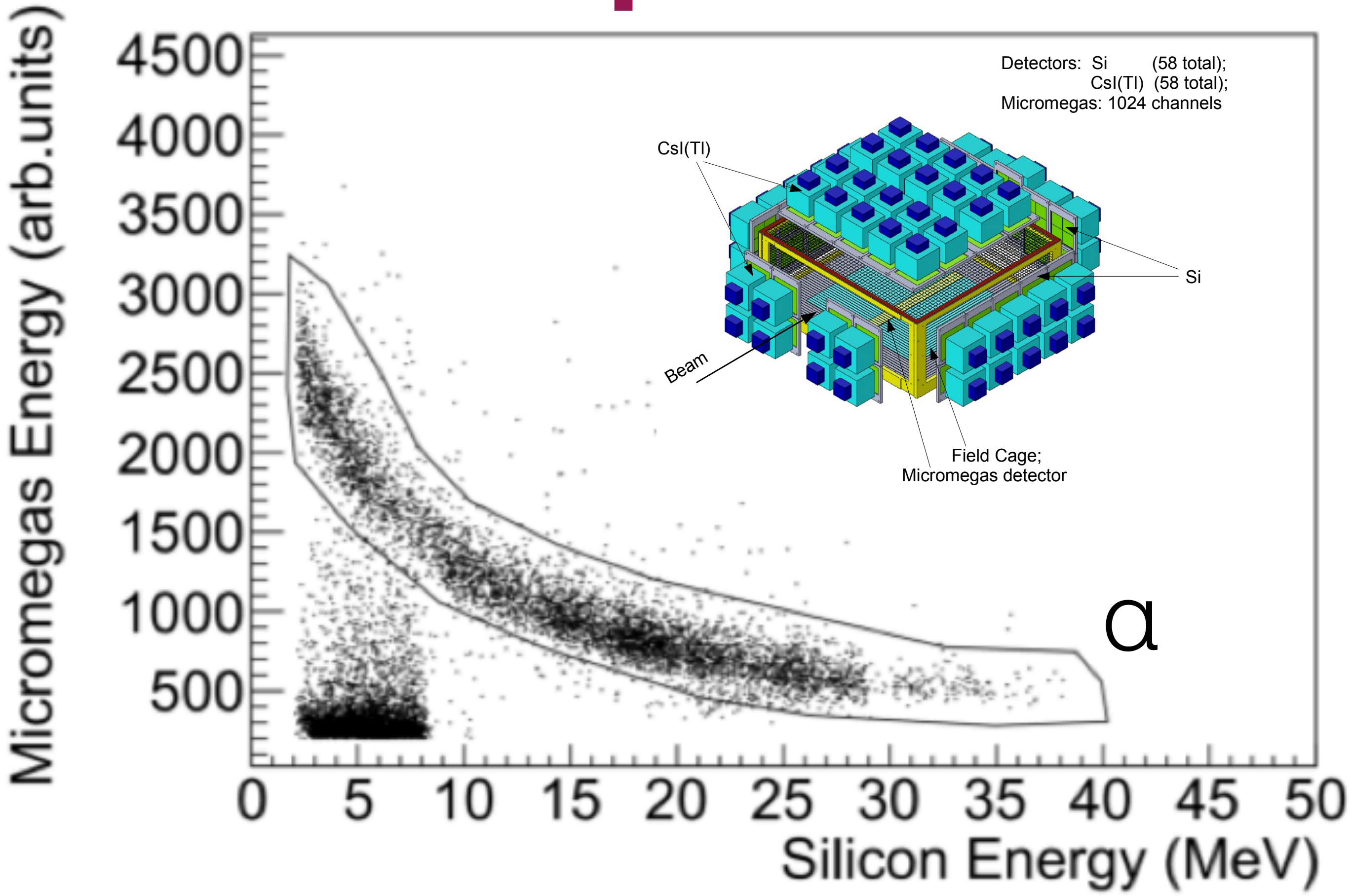
^{14}O

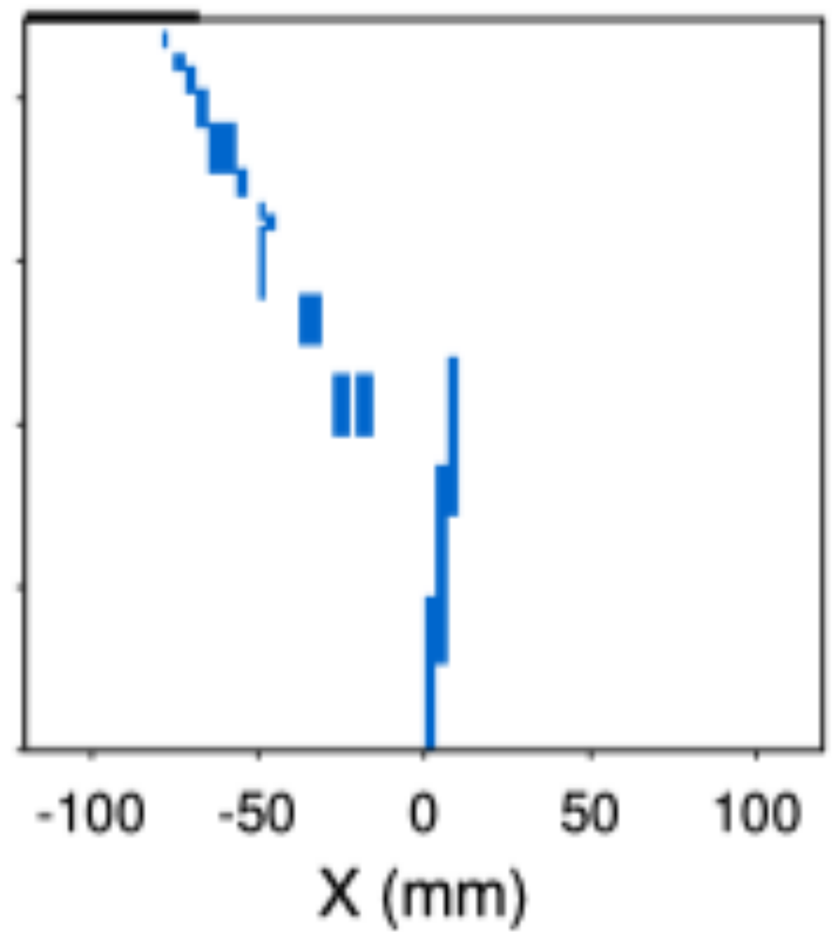
50 MeV,

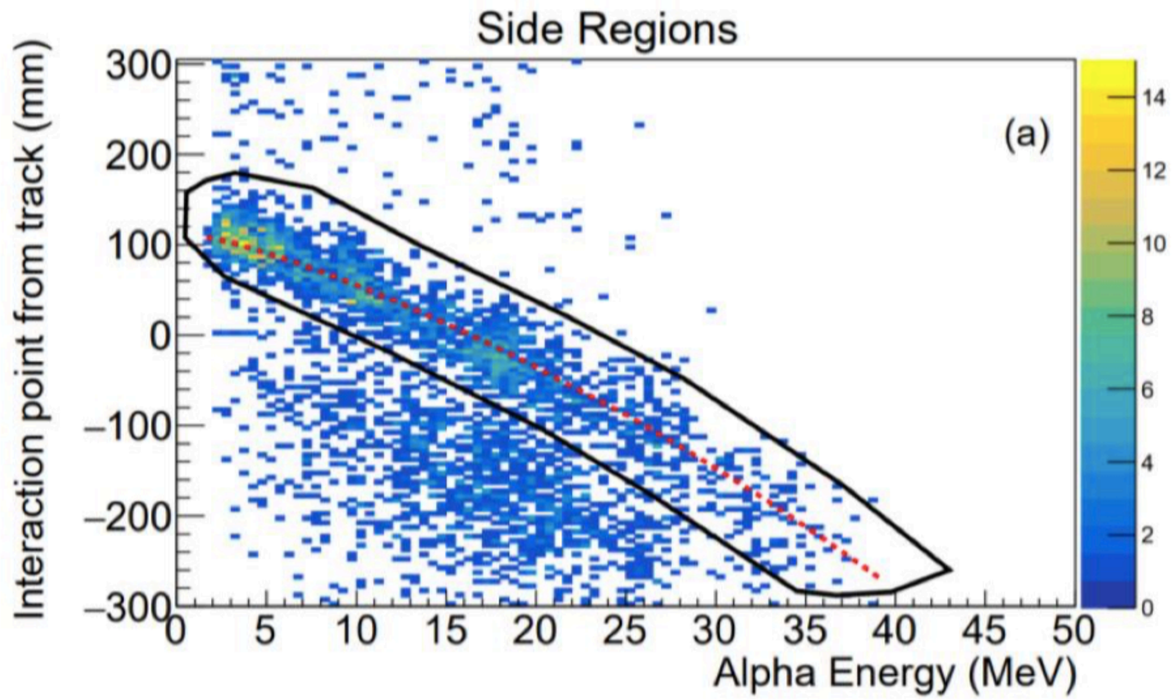
10^4 pps,

95 %

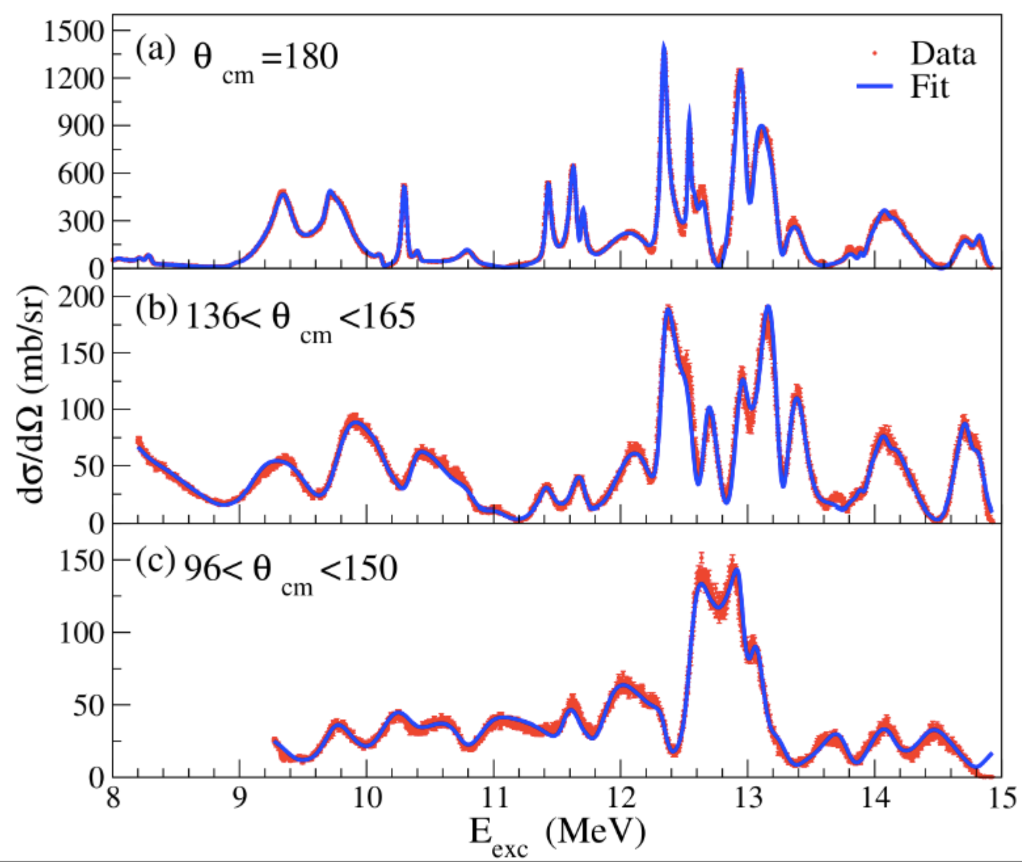
^{14}O+α experiment: event selection



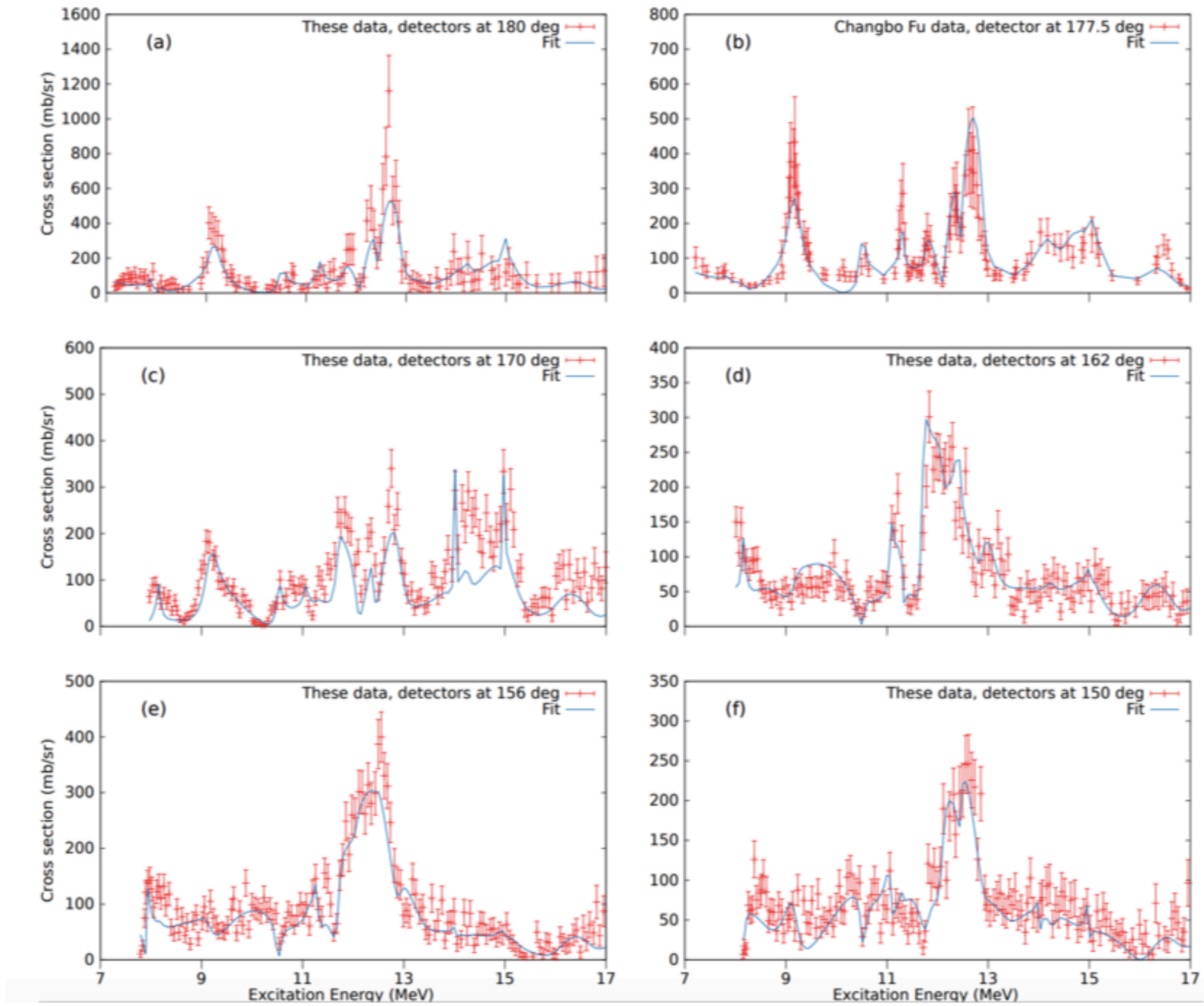




$^{14}C+\alpha$ excitation function

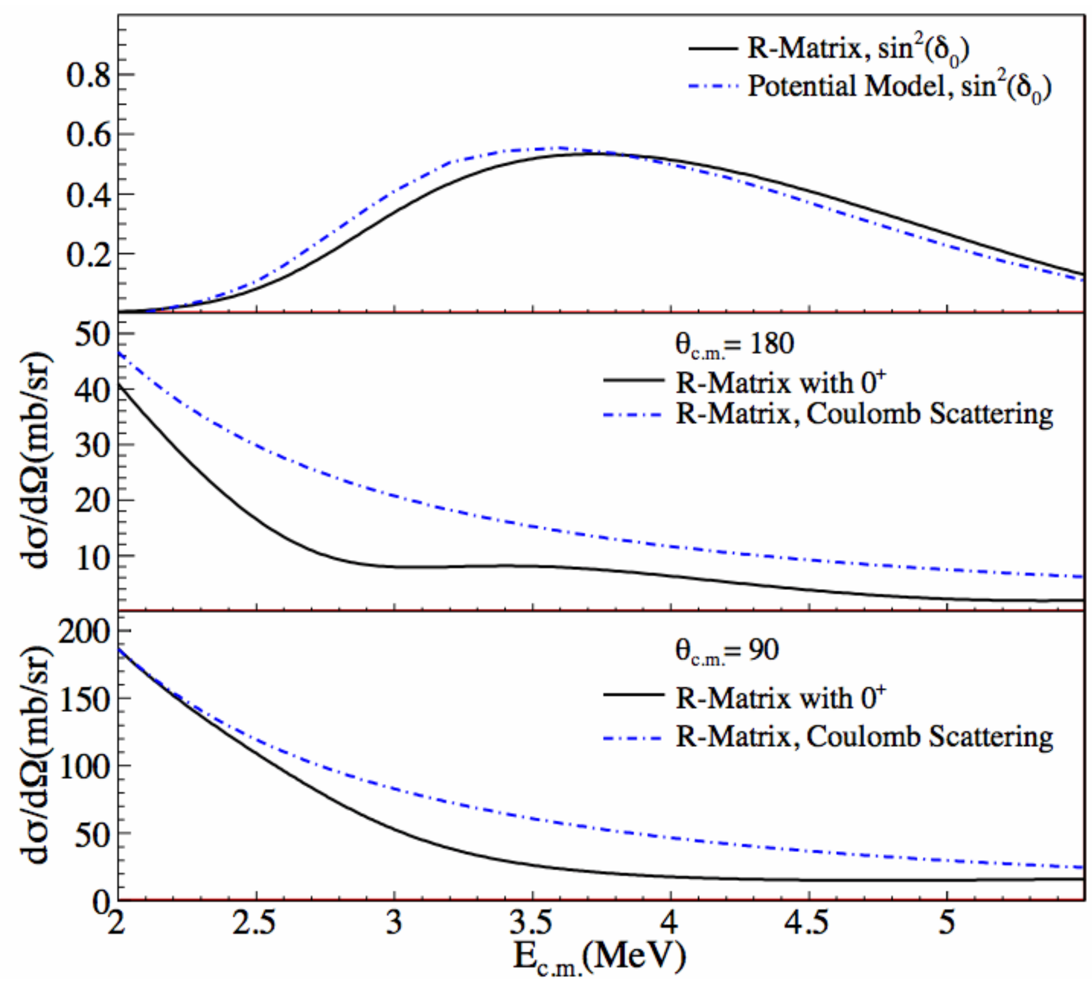


$^{14}O+\alpha$ excitation function

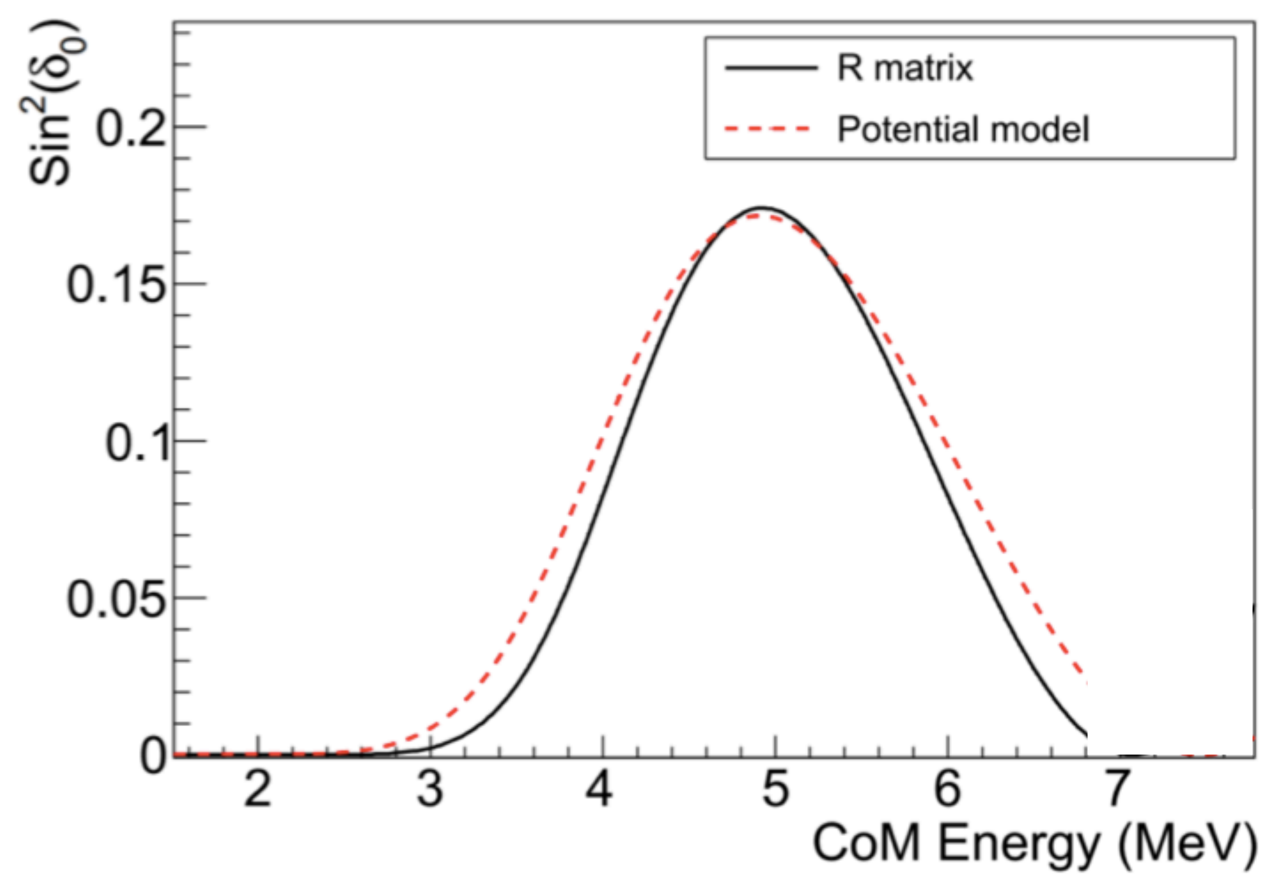


Scattering feature in 0^+ wave in A=18

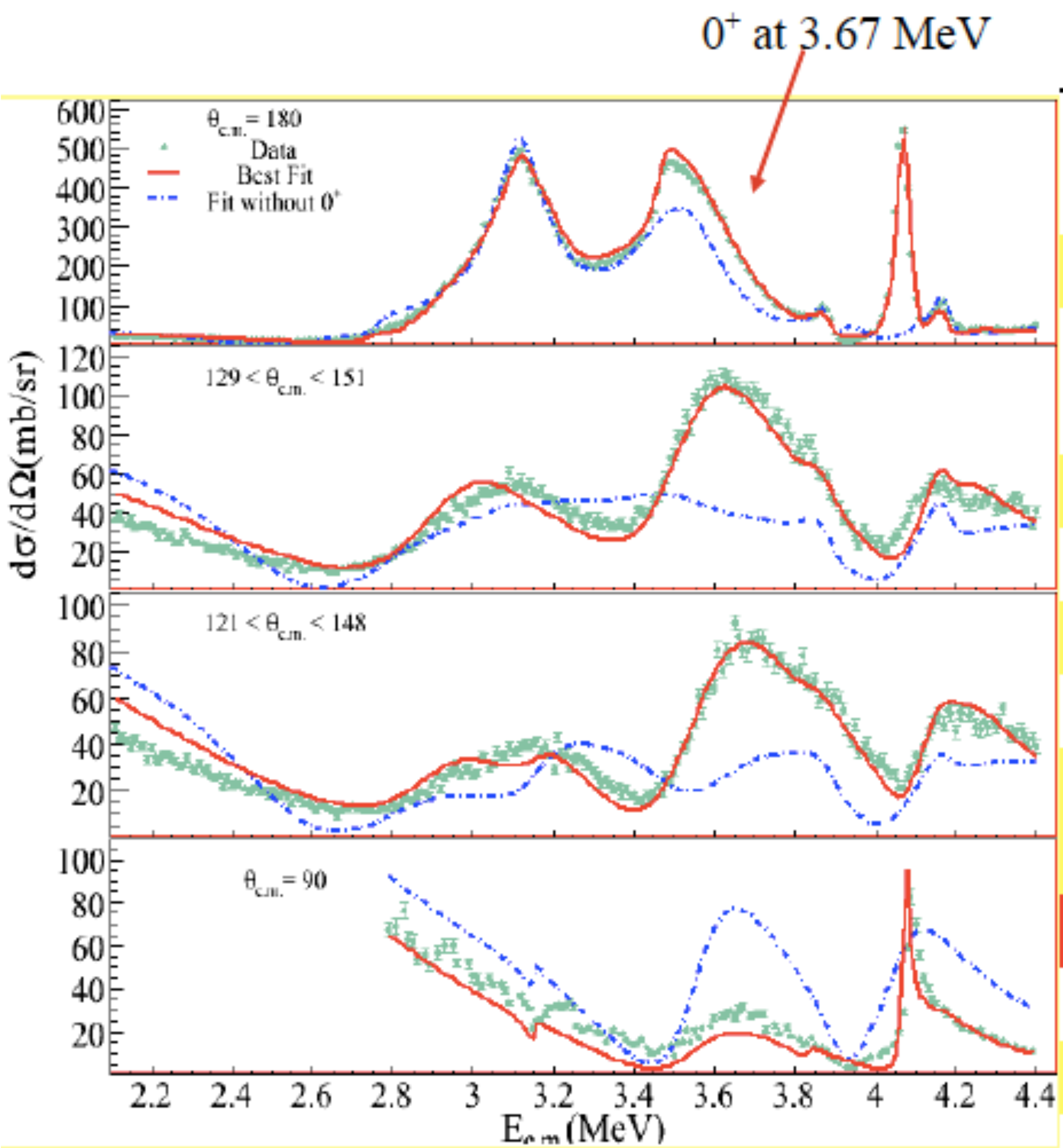
^{18}O
0+ scattering feature
at 9.9 MeV



^{18}Ne
0+ scattering feature
at 9.8 MeV



E.D. Johnson, et al., EPJA, 42 135 (2009)



16 States were used to fit the data

E*(MeV)	J^π	Γ_{tot}(keV)	Γ_α(keV)	θ_α^2
8.04	1^-	2	2	0.02
8.21	2^+	1	1	<0.01
8.29	3^-	8	2	0.09
8.78	2^+	70	1	<0.01
8.98	2^+	60	4	0.01
9.17	1^-	240	205	0.24
9.36	2^+	24	1	<0.01
9.39	3^-	155	103	0.47
9.69	3^-	56	0.1	<0.01
9.79	2^+	263	167	0.20
9.76	1^-	740	658	0.48
9.90	0^+	2100	2100	1.20
10.10	3^-	17	12	0.02
10.30	4^+	23	16	0.08
10.34	2^+	111	20	0.02

Comparing the 6^+ states in A=18

^{18}O

12.57(1) 6^+ — $\theta^2 = \mathbf{0.38(8)}$

11.69(5) 6^+ — $\theta^2 = \mathbf{0.23(1)}$

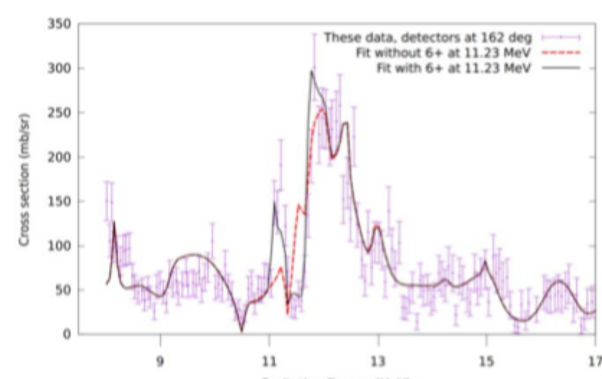
$$\theta_\alpha^2 = \frac{\Gamma_\alpha}{\Gamma_{sp}}$$

^{18}Ne

12.4(2) 6^+ — $\theta^2 = \mathbf{0.56(26)}$

11.8(2) 6^+ — $\theta^2 = \mathbf{0.30(7)}$

[11.23(8) 6^+] — $\theta^2 = 0.04(3)$



13.0 6^+ — $\theta^2 = 0.28$

11.1 6^+ — $\theta^2 = 0.20$

Cluster Nucleon Configuration Interaction Model (CNCIM)

Splitting is due to strong configuration mixing $(0p)^2(1s0d)^2$ and $(1s0d)^4$

Comparing cluster 1^- states in A=18

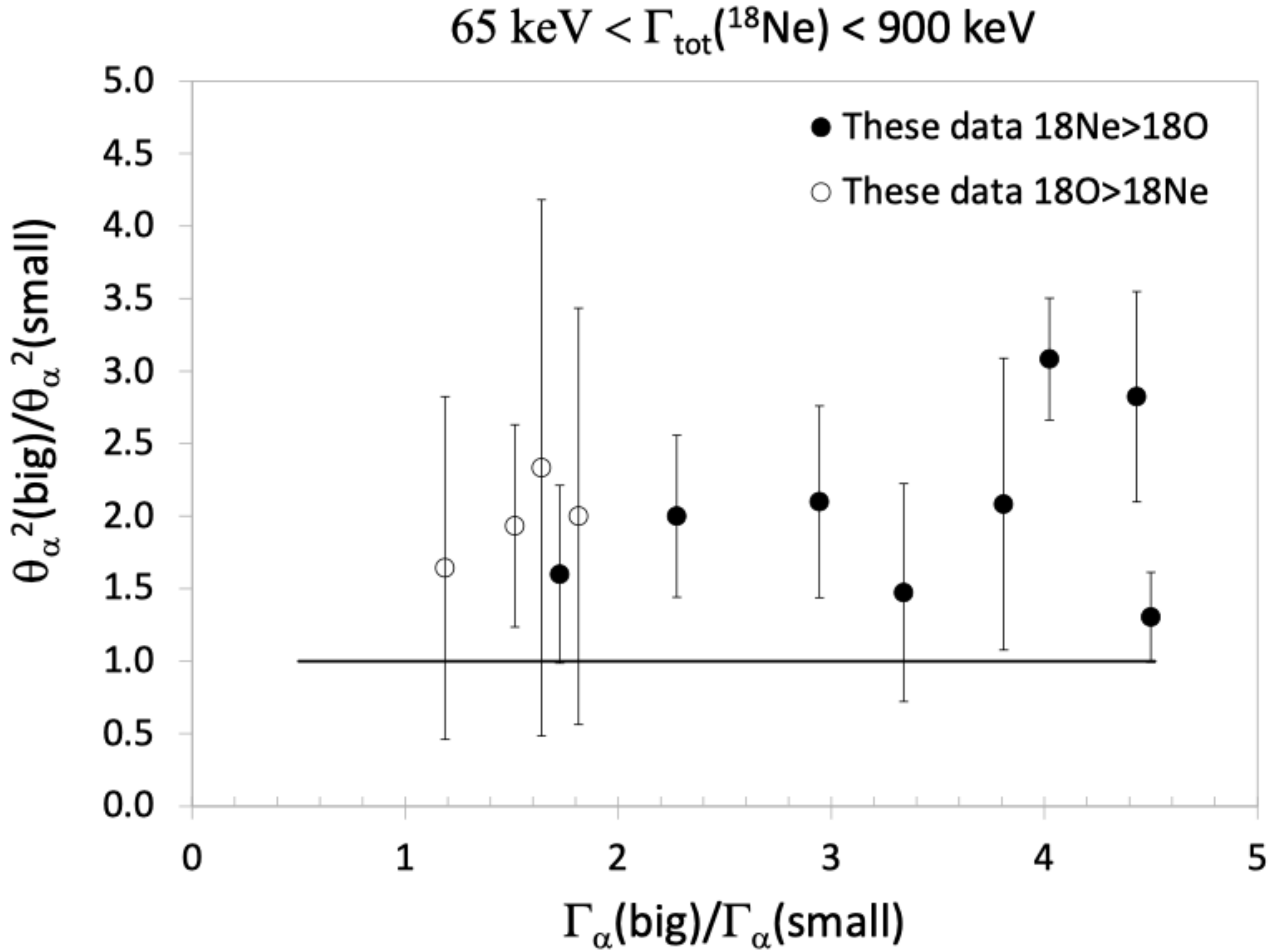
^{18}O			^{18}Ne		
10.8(3)	1^-	$\theta^2 = 0.29(4)$	10.58(3)	1^-	$\theta^2 = 0.15(5)$
9.76(2)	1^-	$\theta^2 = 0.46(4)$	9.57(2)	1^-	$\theta^2 = 0.51(5)$
9.19(2)	1^-	$\theta^2 = 0.20(1)$	9.08(2)	1^-	$\theta^2 = 0.21(1)$

M. Barbui

alpha-cluster structure of 18Ne

M. Barbui, A. Volya, E. Aboud, S. Ahn, J. Bishop, V.Z. Goldberg, J. Hooker, C.H. Hunt, H. Jayatissa, Tz. Kokalova, E. Koshchiy, S. Pirrie, E. Pollacco, B.T. Roeder, A. Saastamoinen, S. Upadhyayula, C. Wheldon, G.V. Rogachev

https://doi.org/10.48550/arXiv.2206.10659



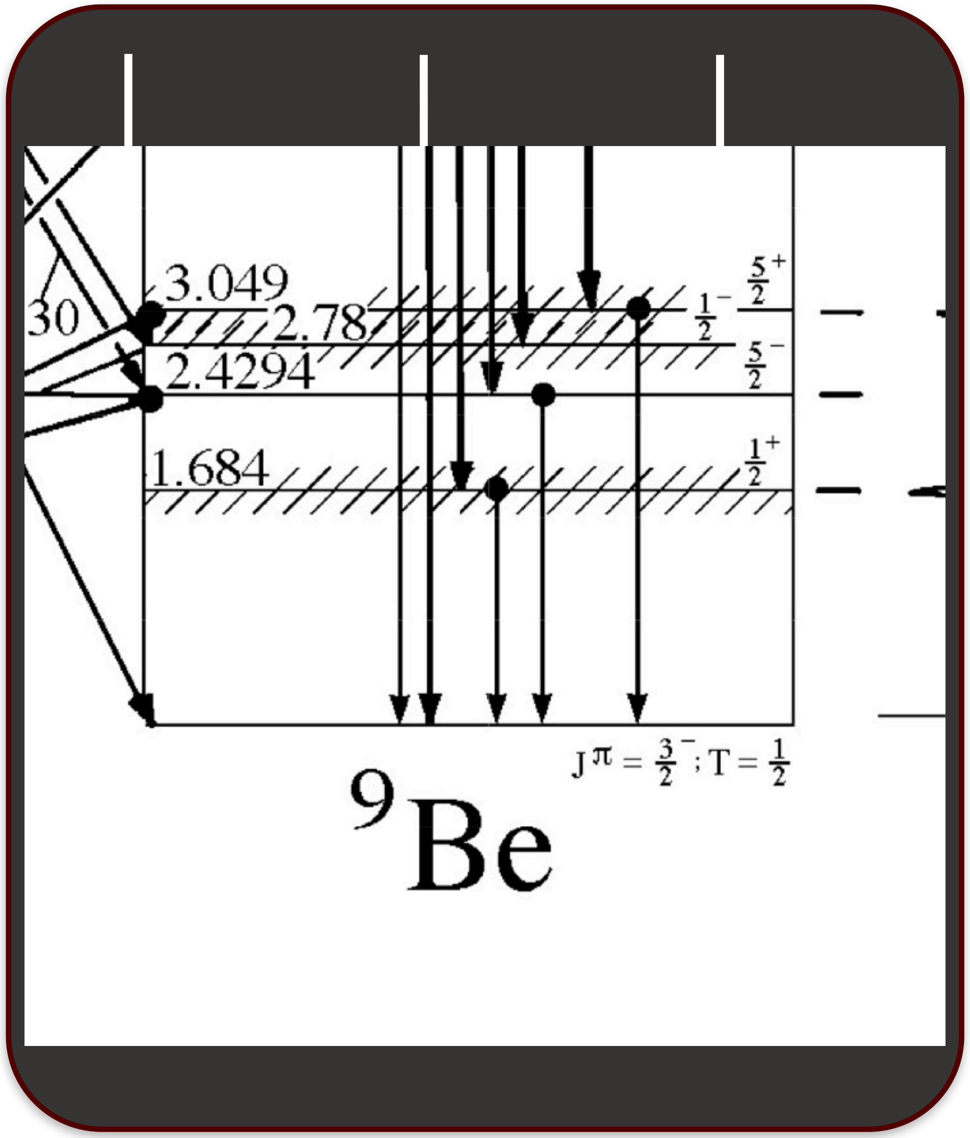
65 keV < Γtot(18Ne) < 900 keV
θα²(big)/θα²(small)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
Γα(big)/Γα(small)
These data 18Ne>18O
These data 18O>18Ne

Highlights

- The first detailed, large-scale comparison of cluster states in mirror pairs was performed.
- A direct link between cluster structures in A=18 mirrors was established.
- Evidence for a systematic difference between the mirror systems - the states with larger total widths also get large alpha-core(g.s.) SF factor.

Structure of ^{13}Be

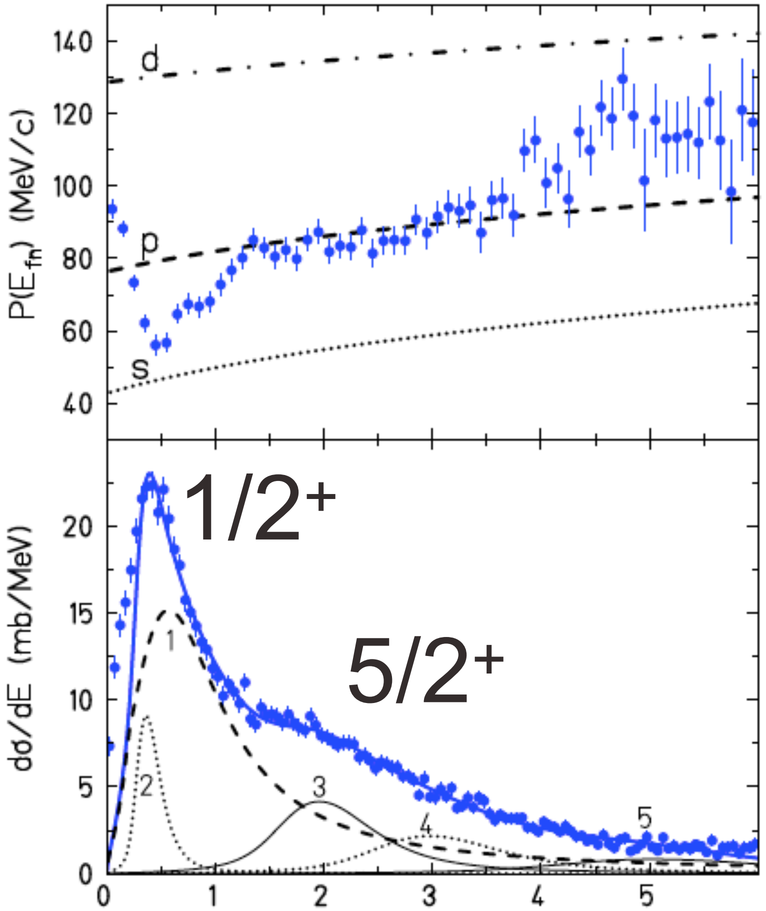
Is the N=8 magicity breaking in ^{13}Be?



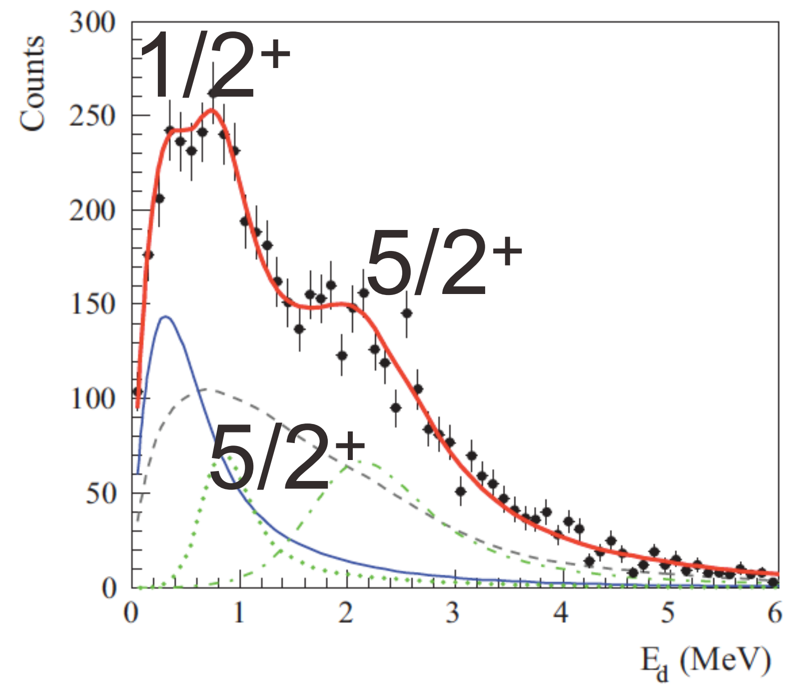
- Naively the g.s. and first excited state in ^{13}Be should be $5/2^+$ and $1/2^+$
- ^{15}C and ^{17}O are “good” examples of N=9 nuclei

However:

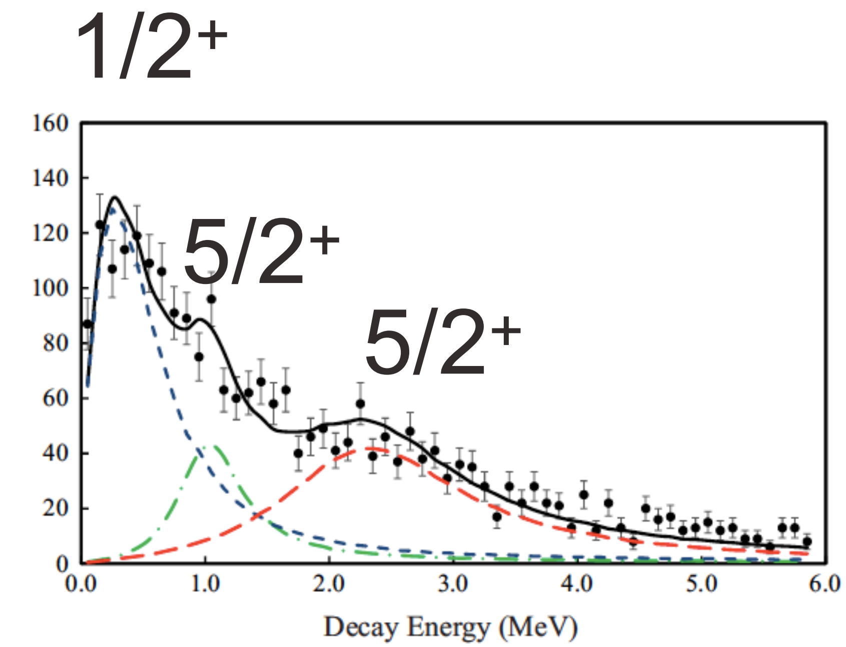
- ^{11}Be (N=7) has $1/2^+$ g.s., followed by $1/2^-$, so should the g.s. of ^{13}Be be $1/2^-$ with $1/2^+$ filled?
- Should there be more low-lying states in ^{13}Be?



Yu. Aksyutina et al.
Phys. Lett. B 718
(2013) 1309

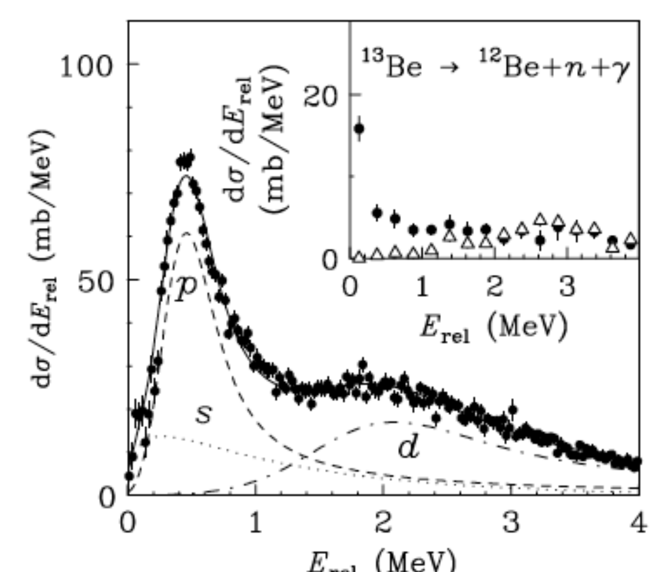


G. Randisi, et al.
Phys. Rev. C 89,
034320 (2014)



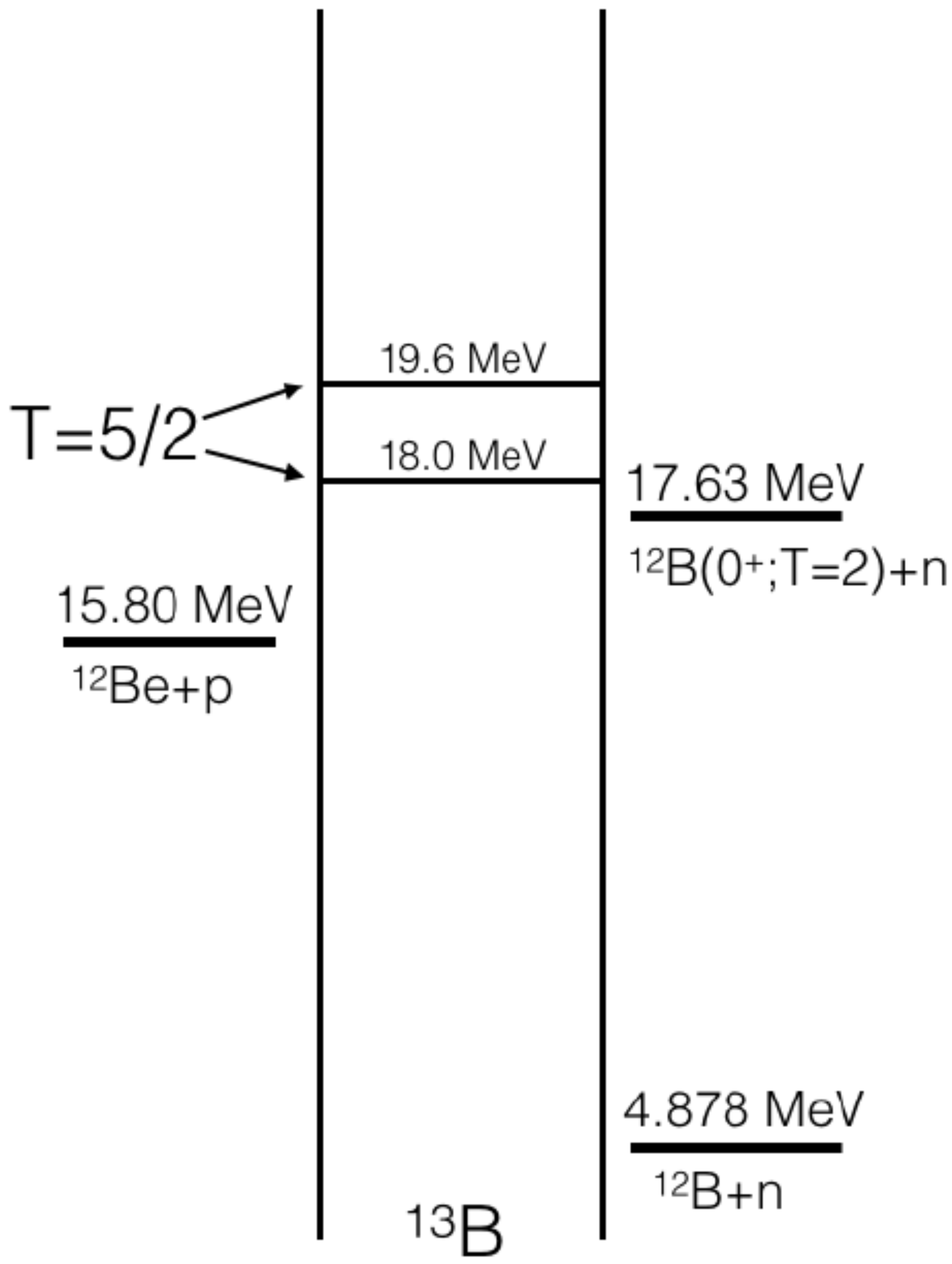
B.R. Marks, et al.,
Phys. Rev. C 92,
054320 (2015)

- ☑ All results are from break up at high energies
- ☑ Interpretation is challenging
- ☑ No conclusive spin-parity assignments



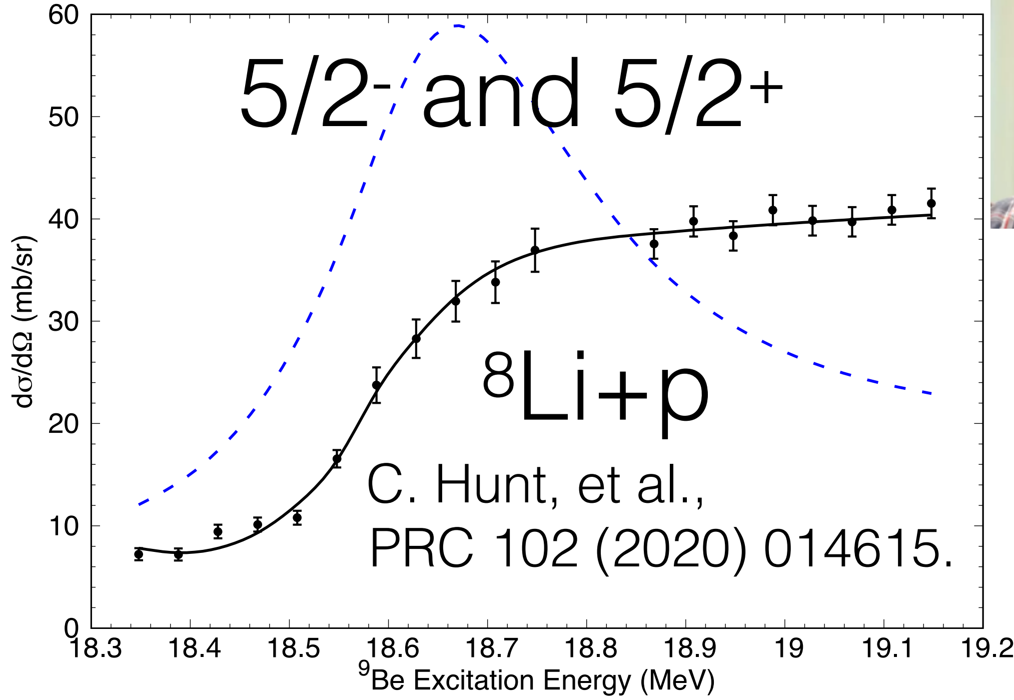
Y. Kondo et al.
Physics Letters B 690 (2010) 245

Structure of ^{13}Be through T=5/2 states in ^{13}B



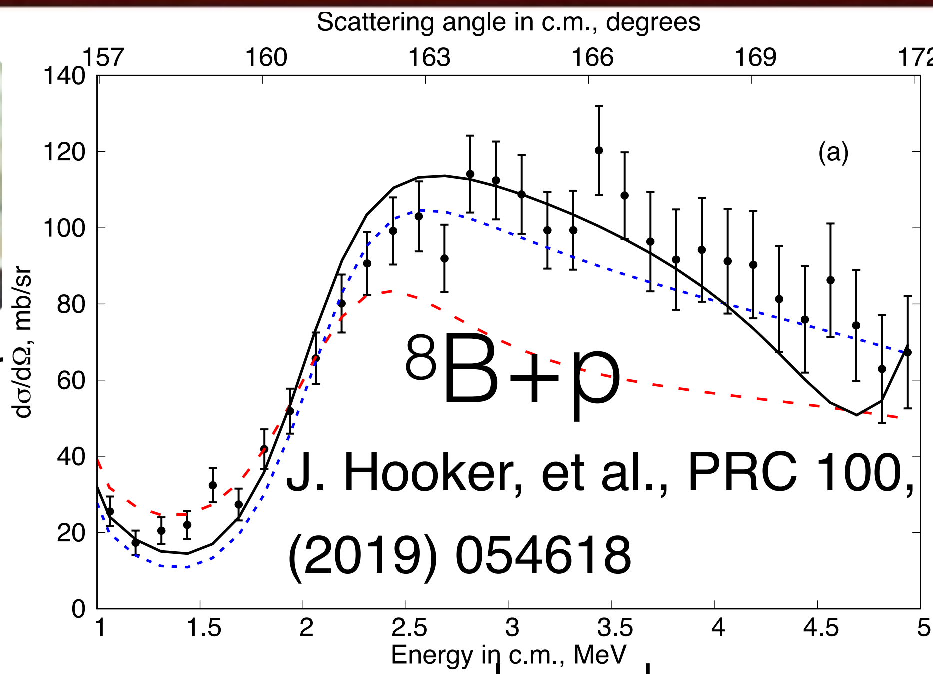
- ☑ We studied ^{13}Be through the T=5/2 IAS in ^{13}B, populated in resonance elastic scattering ^{12}Be+p
- ☑ ^{12}Be+p excitation function measured
- ☑ The T=5/2 states dominate the ^{12}Be+p excitation function

How well does this work?

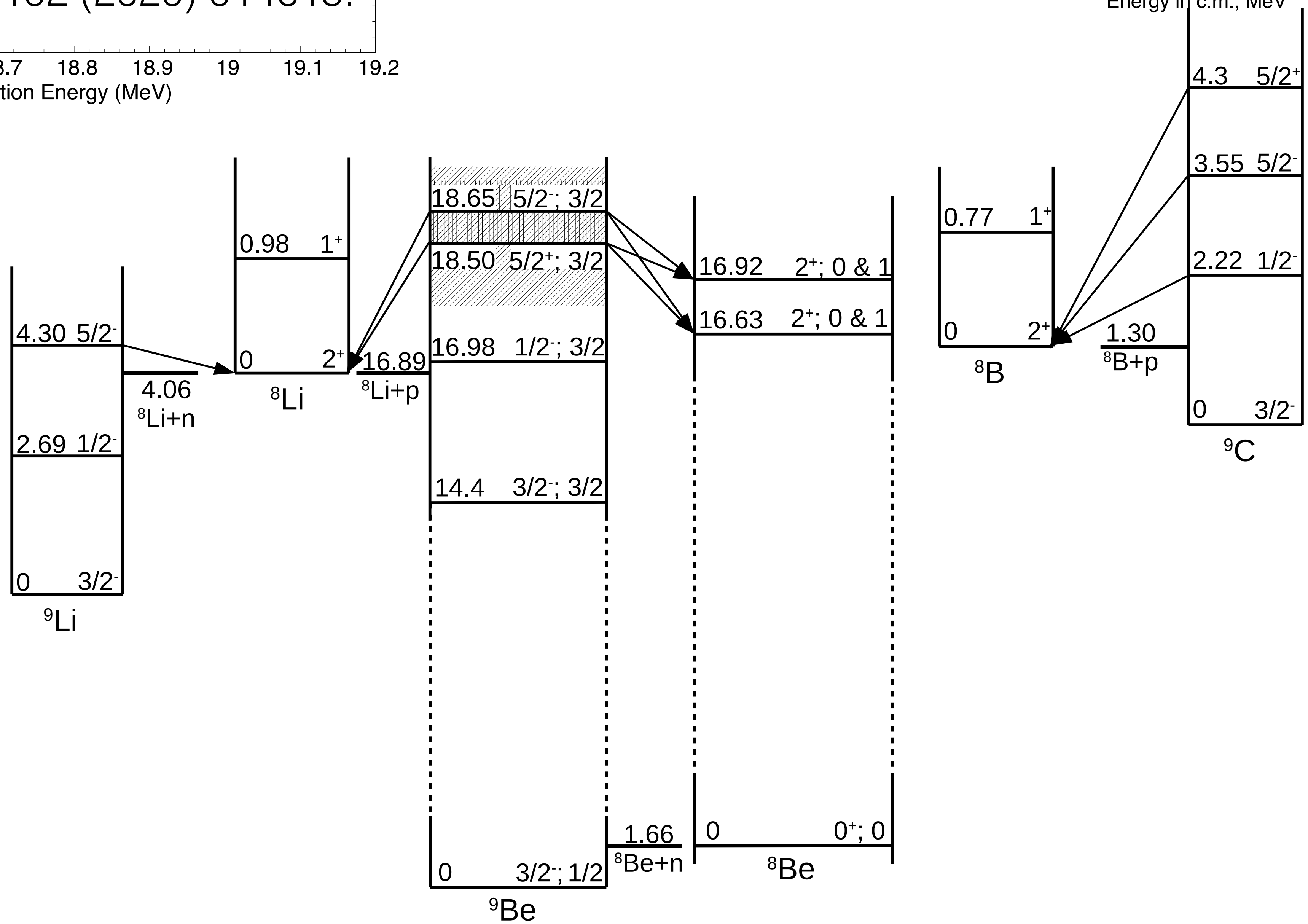


C. Hunt

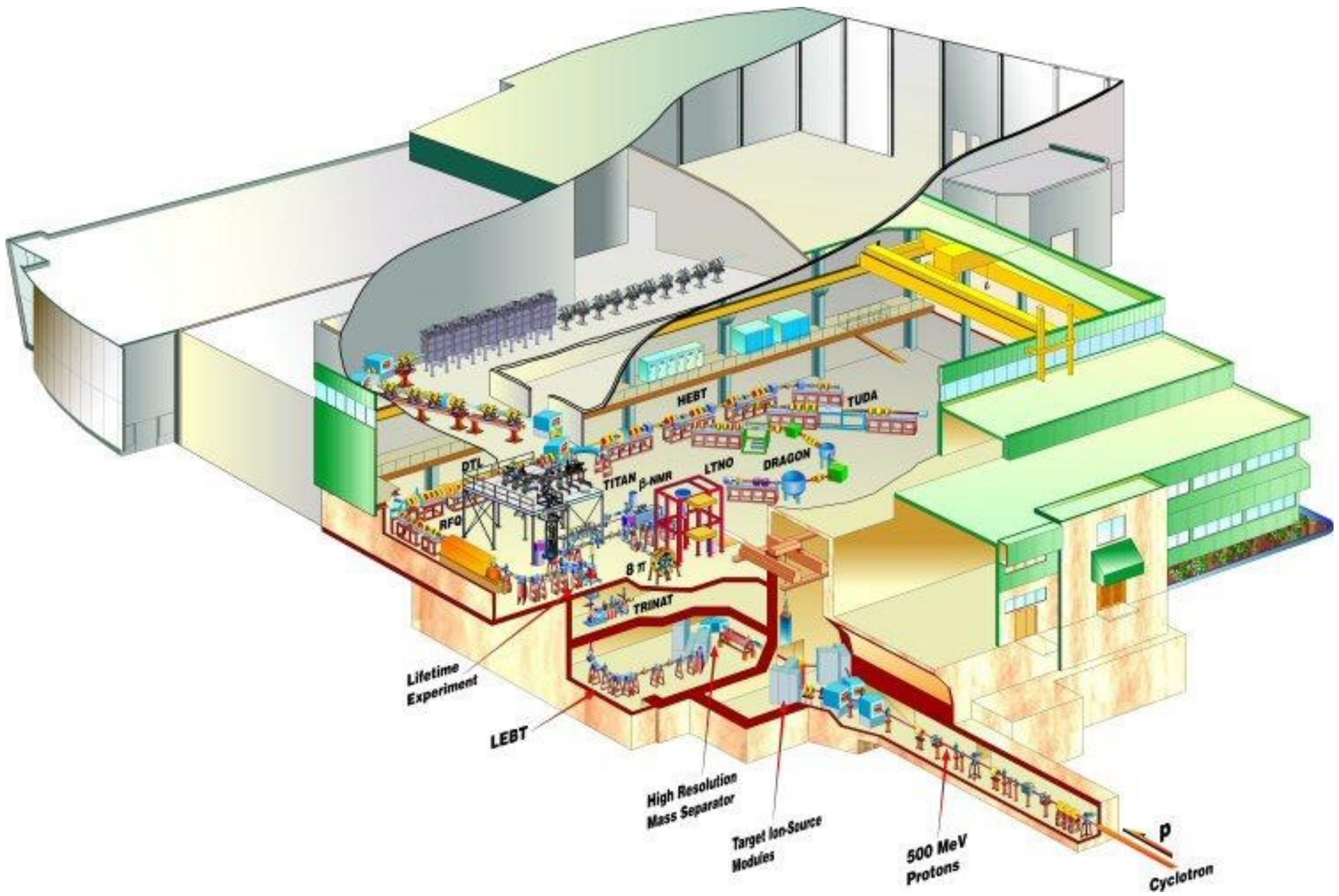
J. Hooker



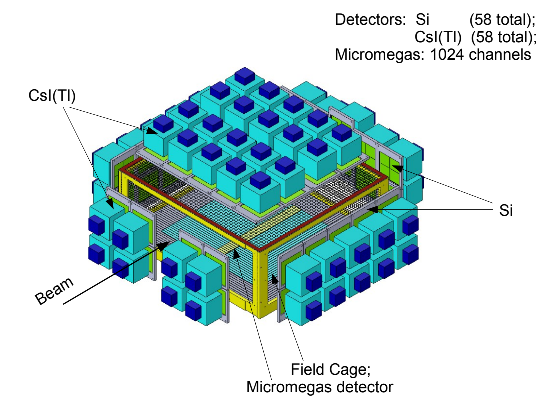
All R-matrix parameters are fixed by the prior, except for 5/2+ E_{ex}!



^{12}Be+p experiment



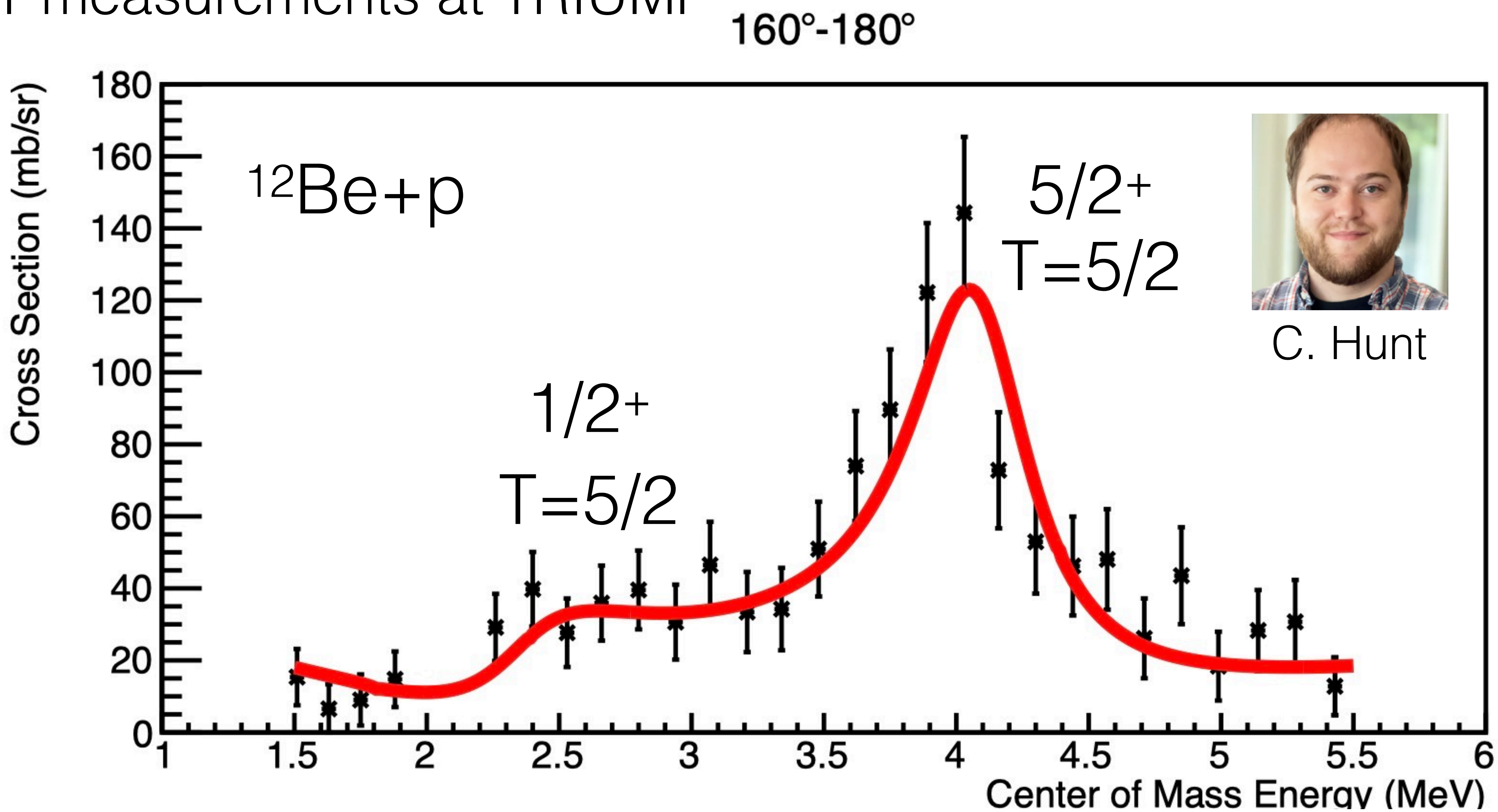
TRIUMF



TexAT

500 pps of ^{12}Be beam at 60 MeV

TexAT measurements at TRIUMF

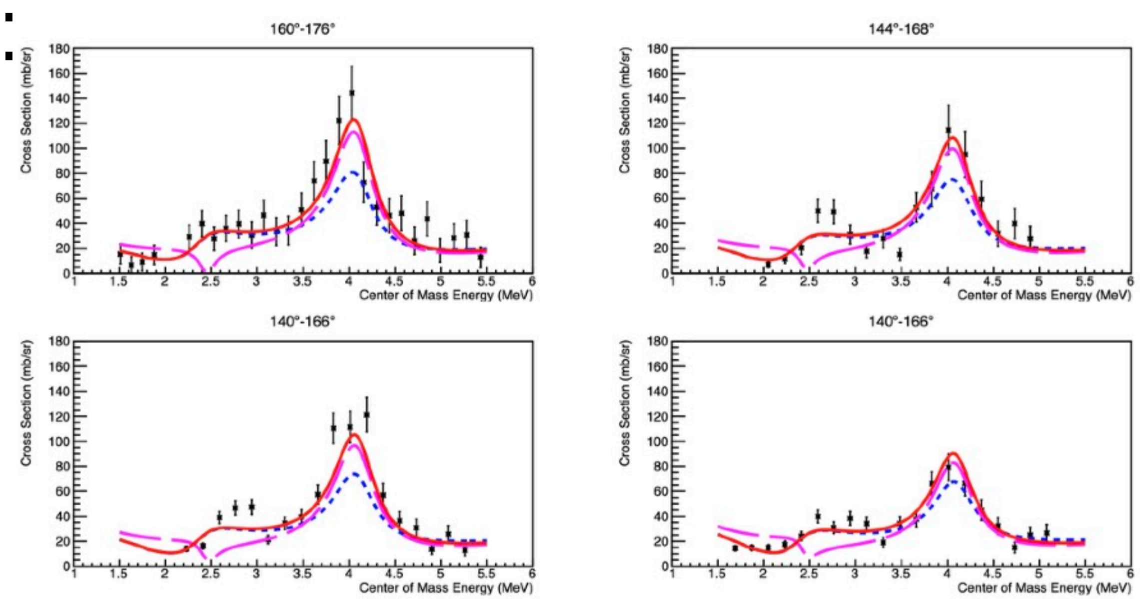


C. Hunt

Converting to ^{13}Be energies:

1/2^{+}	0.6 MeV	SF=0.2
5/2^{+}	2.3 MeV	SF=0.4

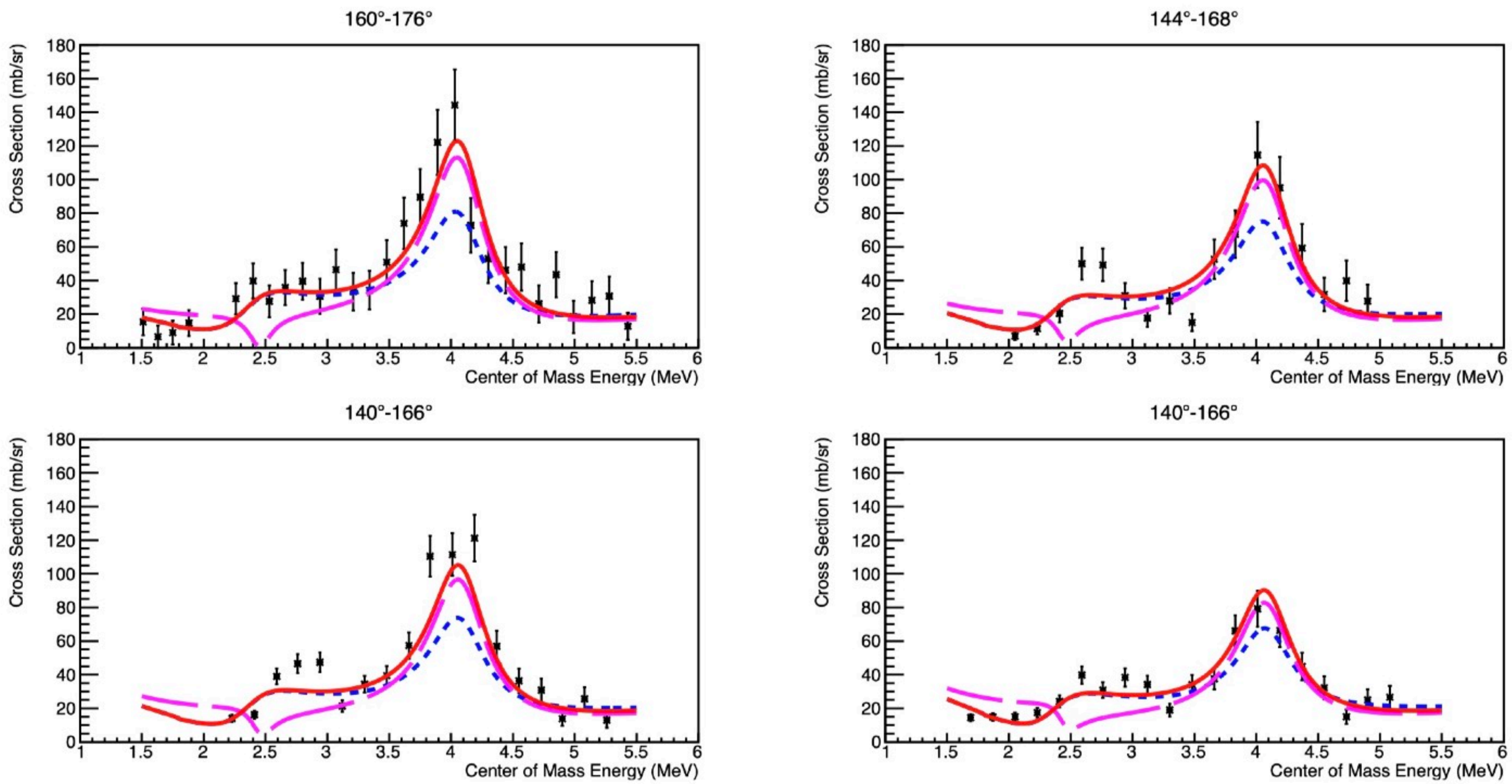
energies are with respect to the ^{12}Be+n threshold



Shell Model with FSU Hamiltonian | Experiment

Shell Model with FSU Hamiltonian			Experiment		
1/2-(1) T=5/2 0	0.436083	l=1			
1/2+(1) T=5/2 0.1788	0.283016	l=0	1/2+(1) T=5/2 0.0	0.2(1)	l=0
3/2-(1) T=5/2 1.7761	0.0914305	l=1			
5/2+(1) T=5/2 1.7819	0.480836	l=2	5/2+(1) T=5/2 1.7	0.4(1)	l=2
5/2+(2) T=5/2 2.0454	0.211212	l=2			
5/2-(1) T=5/2 2.3707	0.000506811	l=3			

0hω and 2hω configurations are mixed in these SM calculations



Highlights

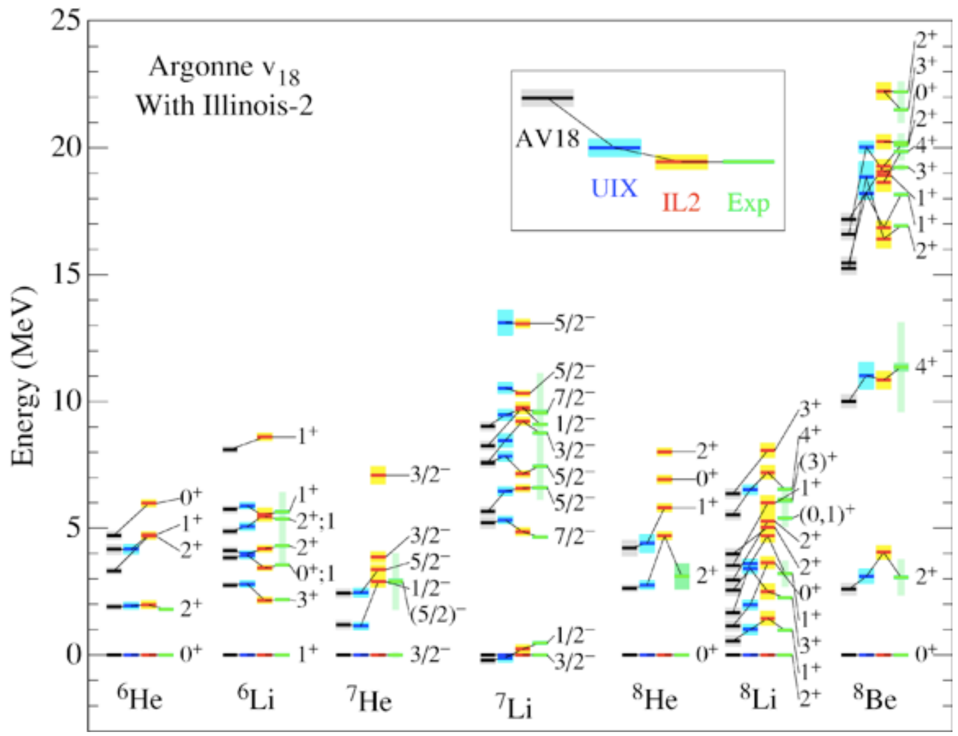
- Excitation function for $^{12}Be+p$ resonance elastic scattering is described by T=5/2 resonances ONLY.
- Ground state appears to be $1/2^+$, but low SF indicates that N=8 is not a shell closure.
- The role of configuration mixing is significant.
- More states of negative parity may be present and consistent with the data (but not required).

Summary

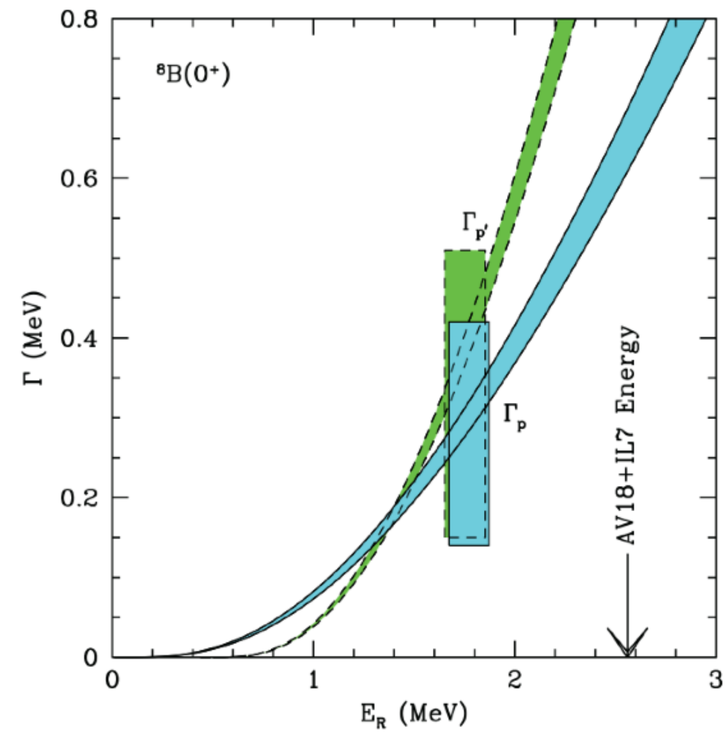
- A wide range of experiments with exotic beams can be performed using active targets.
- First measurements with neutron beam in active target indicate that neutron upscattering is not as important in carbon nucleosynthesis as was believed previously.
- A study of clustering in A=18 mirror system ^{18}O - ^{18}Ne reveals similarities, but also curious differences
- The first observation of the T=5/2 states in ^{13}B shed light on the ^{13}Be structure.

Structure of light exotic nuclei

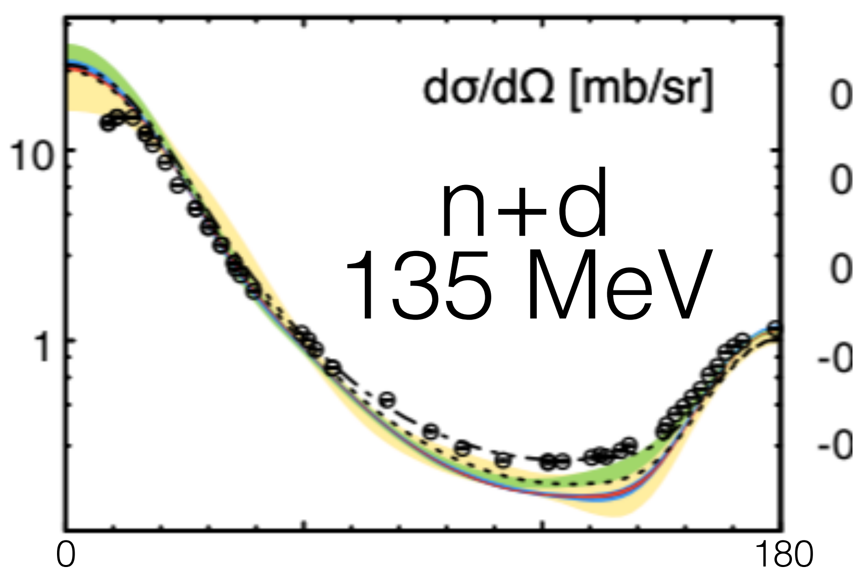
Theoretical advances



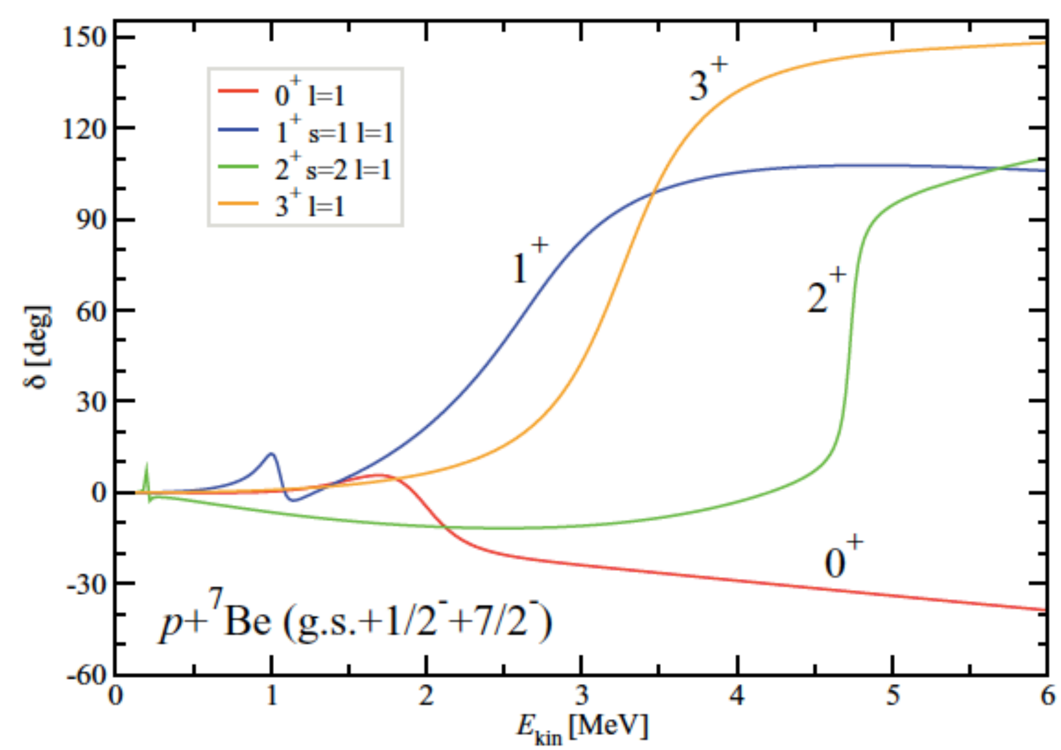
S. Pieper, et al., PRC 70 054325 (2004)



K.M. Nollet, PRC 86 (2012) 044330



S. Binder, et al., PRC 98 014002 (2018)
LENPIC collaboration



P. Navratil, et al. PRC 82, 034609 (2010)

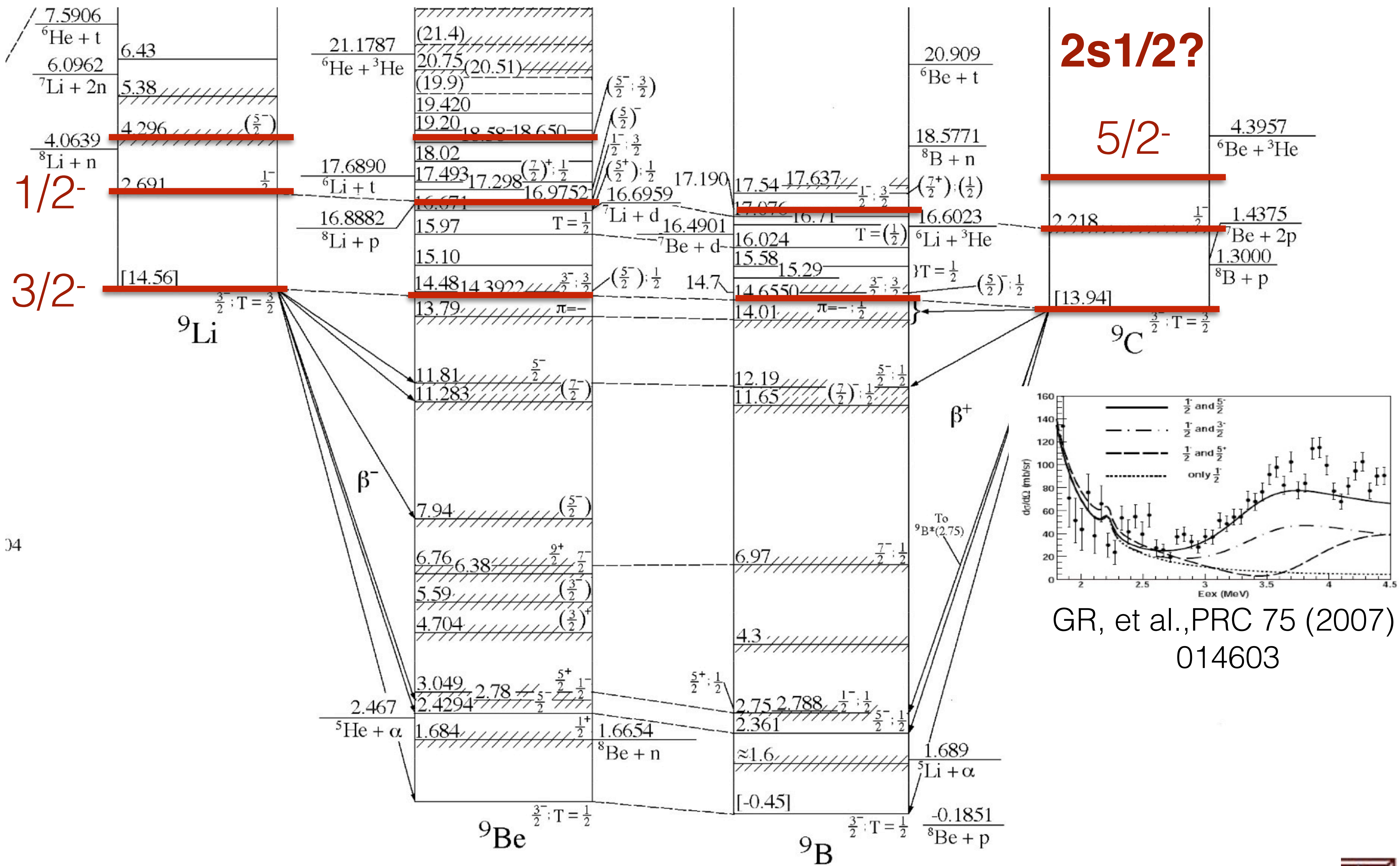
A=9 T=3/2 iso-multiplet
Where is the 2s1/2 shell?

TEXAS A&M UNIVERSITY

We used Active Target detector TexAT to populate resonance in ^9C in ^8B+p scattering

Now is a short technical detour…

A=9 T=3/2



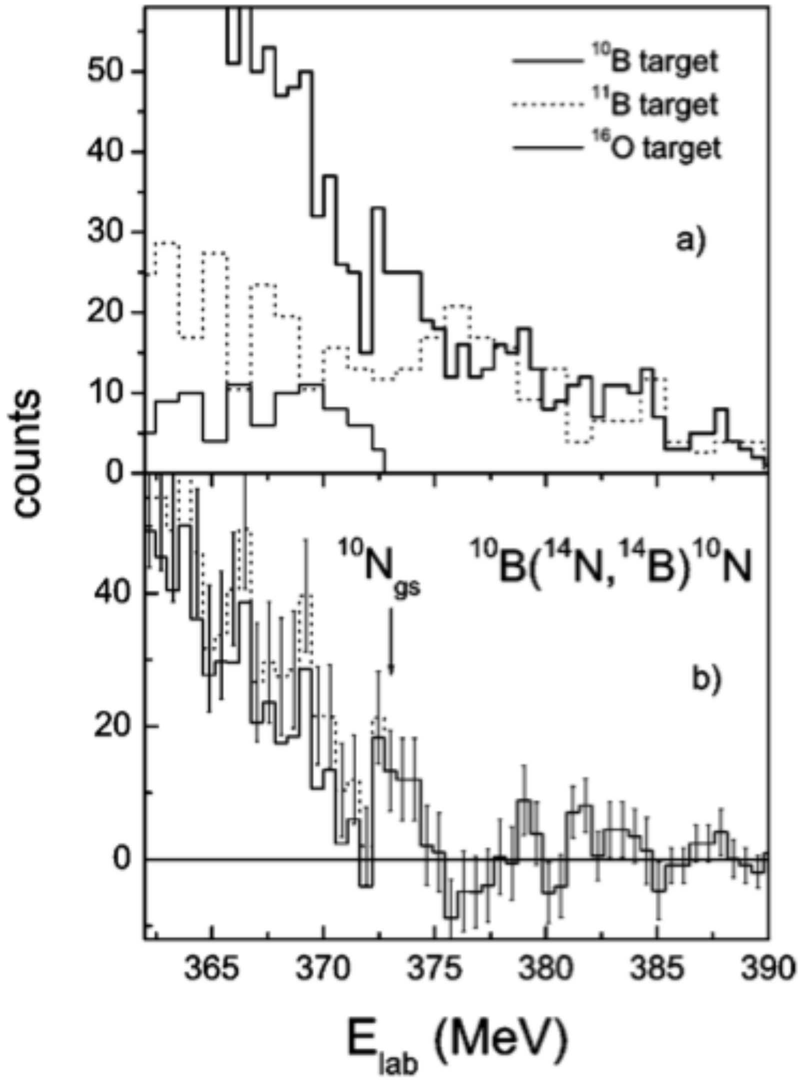
GR, et al.,PRC 75 (2007) 014603

A=10 T=2 iso-multiplet - what is the ground state?

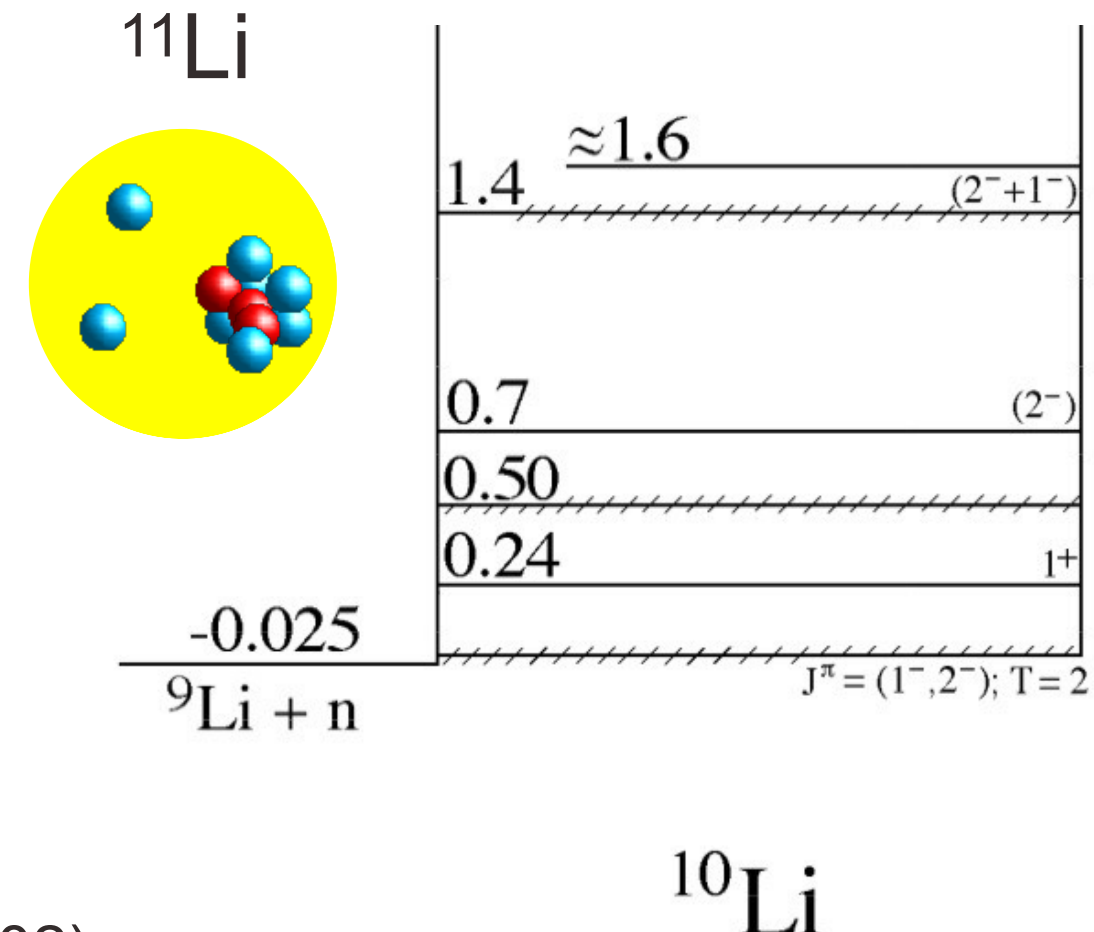
Structure of ^{10}N

- Very little was known about ^{10}N
- Possibly a state observed at 2.6 MeV above p-decay threshold. [A. Lepine-Szily, et al., PRC 65 (2002)]
- Odd-odd psd-shell challenge to both experiment and theory.

$$3/2^- \otimes 1/2^- = 2^+;\ 1^+$$
$$3/2^- \otimes 1/2^+ = 1^-;\ 2^-$$

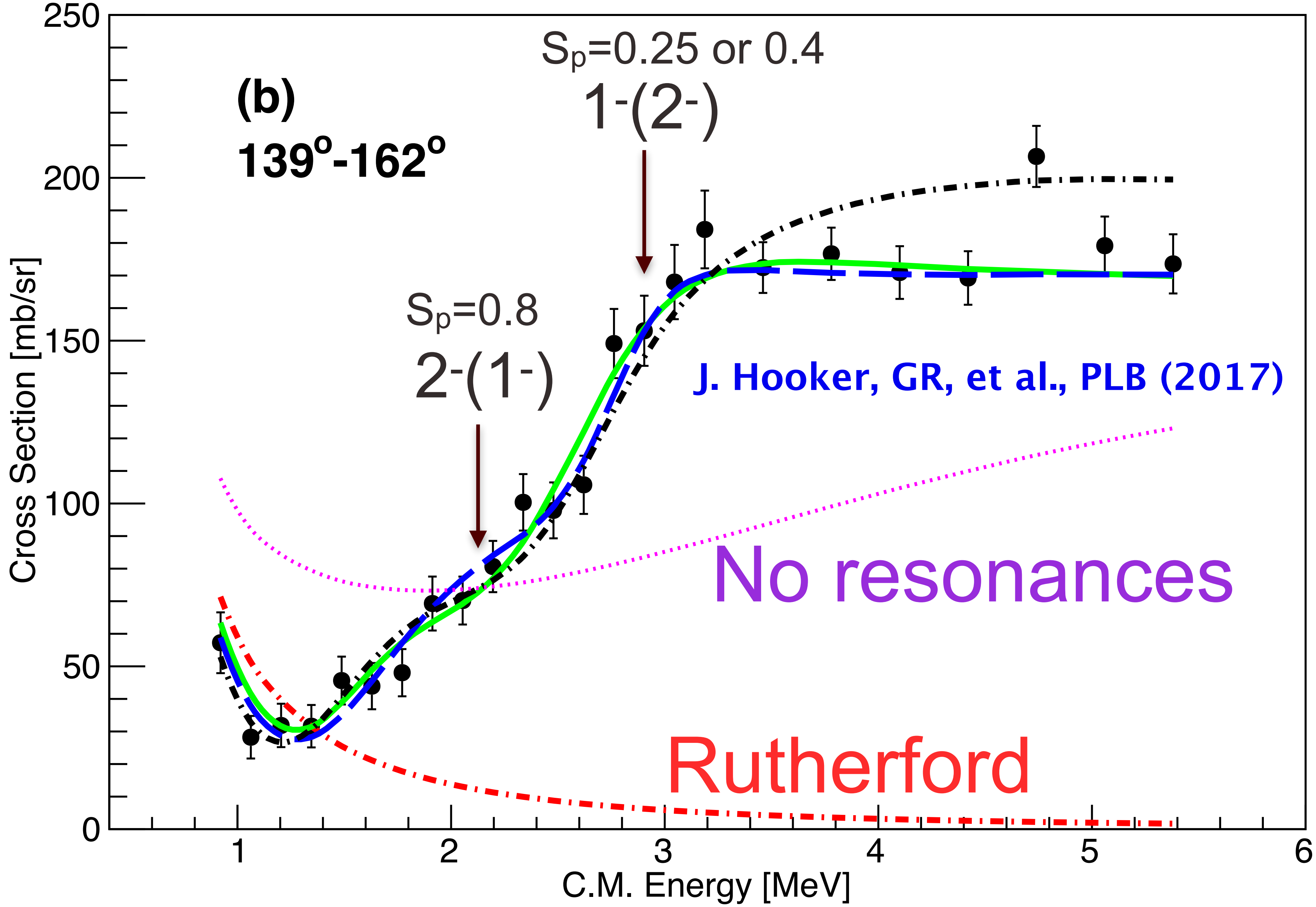


A. Lepine-Szily, et al., PRC 65 (2002)



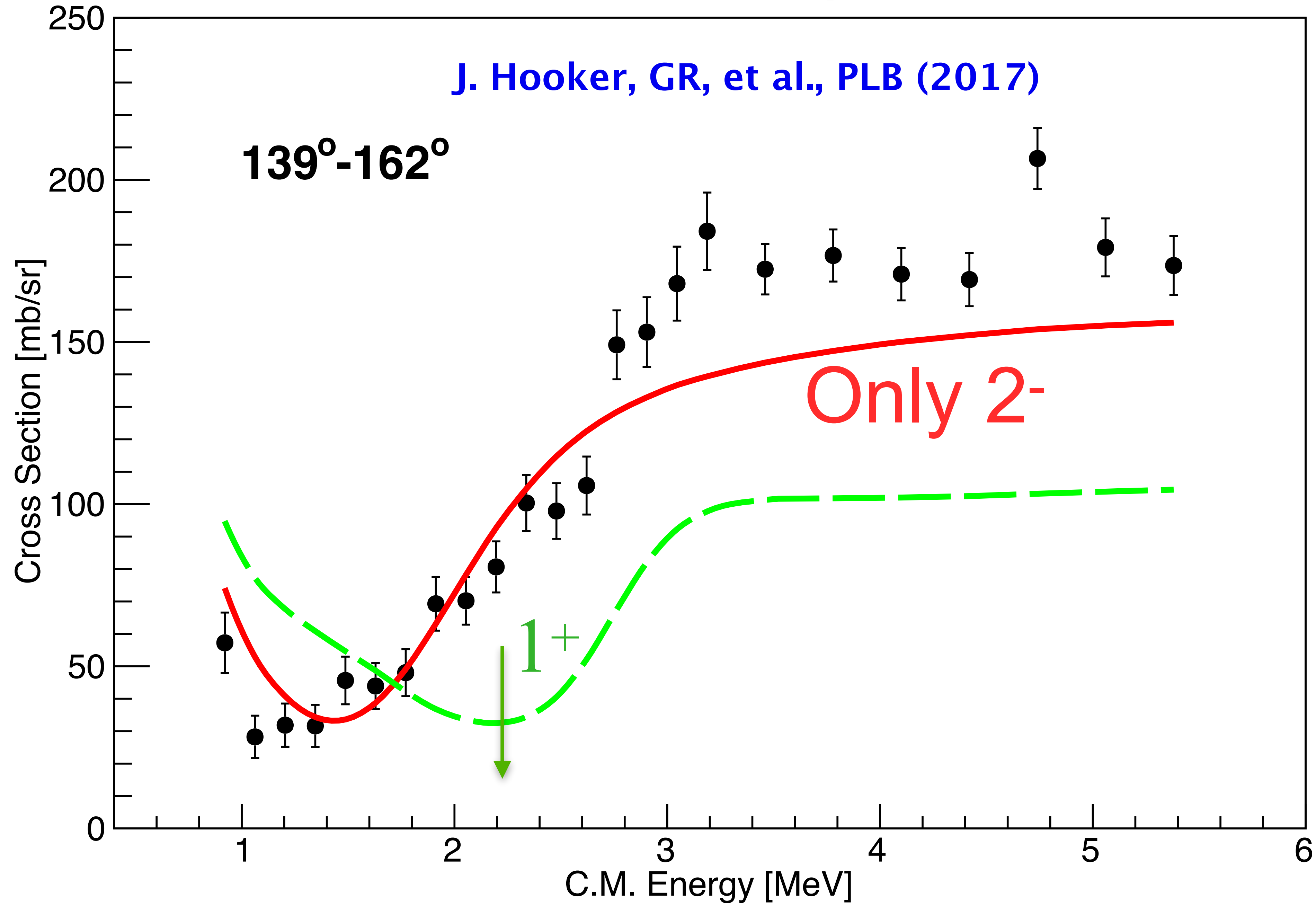
Structure of ^{10}N

Excitation function for ^{9}C+p elastic scattering



Structure of ^{10}N

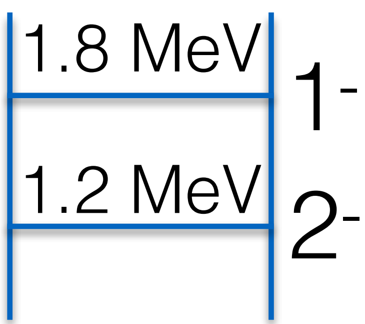
Excitation function for ^{9}C+p elastic scattering



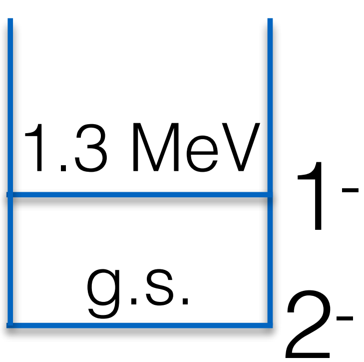
Nordheim rule?

1. If $(\ell_1 + \ell_2 + j_1 + j_2)$ is even, then $I = |j_1 - j_2|$.

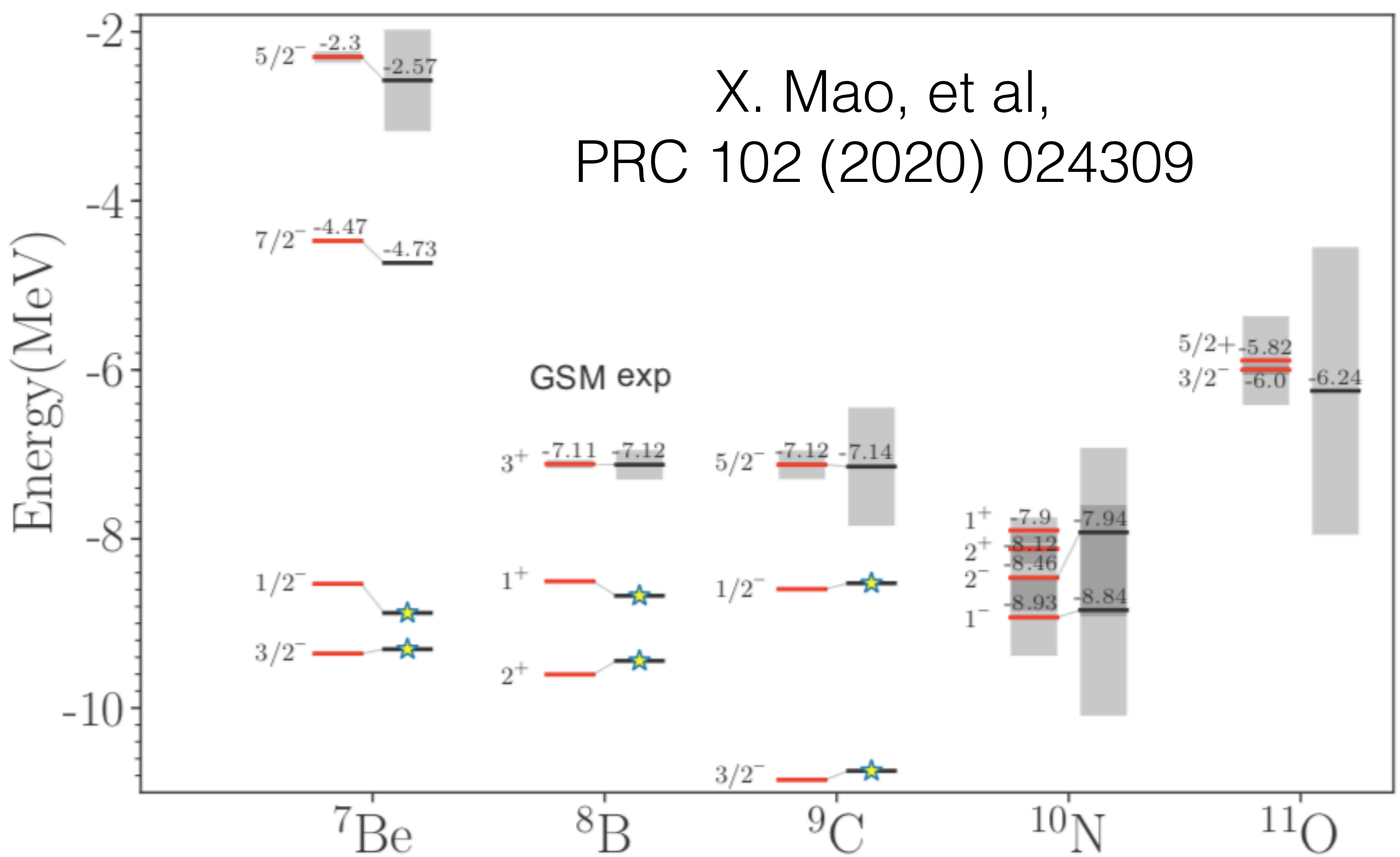
2. If $(\ell_1 + \ell_2 + j_1 + j_2)$ is odd, then I will be large so we use $I = (j_1 + j_2)$.



^{12}N



^{10}N



^{10}Li

1-

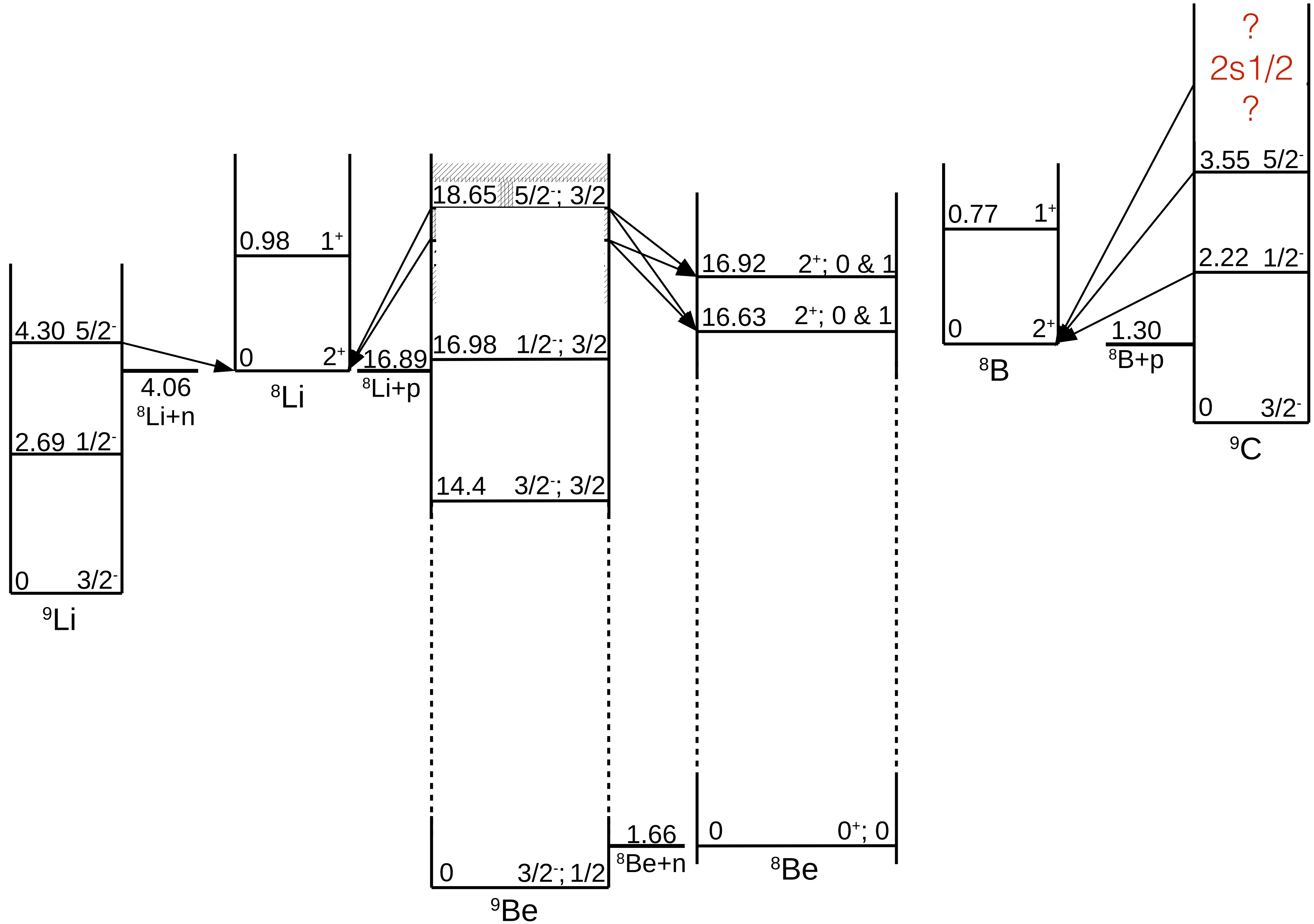
2-

Evidence for 1p1/2 - 2s1/2 shell degeneracy in ^{13}Be

TexAT "Hoyle" Publications

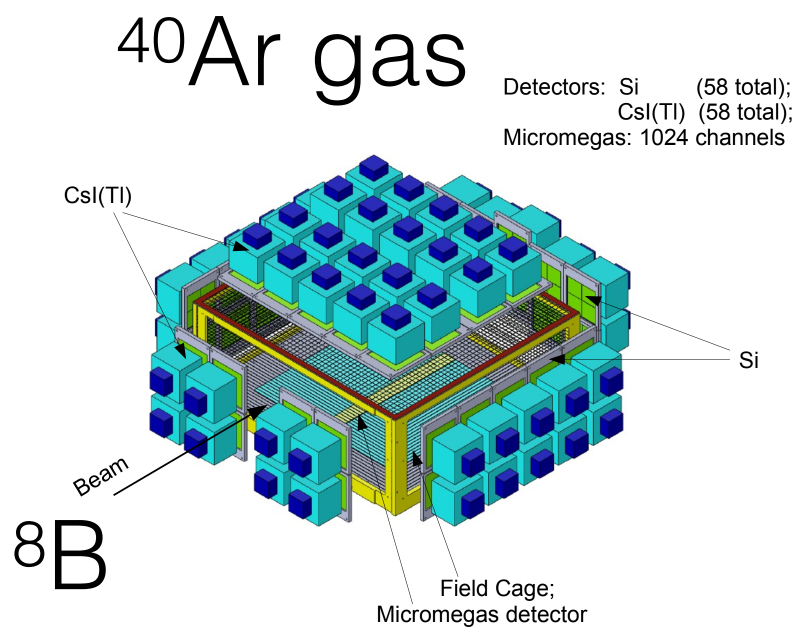
- J. Bishop, et al., NIM A964 (2020) 163773.
- J. Bishop, et al., PRC 102 (2020) 041303.
- J. Bishop, et al., PRC Letter 103 (2021) L051303.
- J. Bishop, et al., Nature Communication 13 (2022) 2151

Structure of ^{9}C



Direct measurement of fusion with TPC

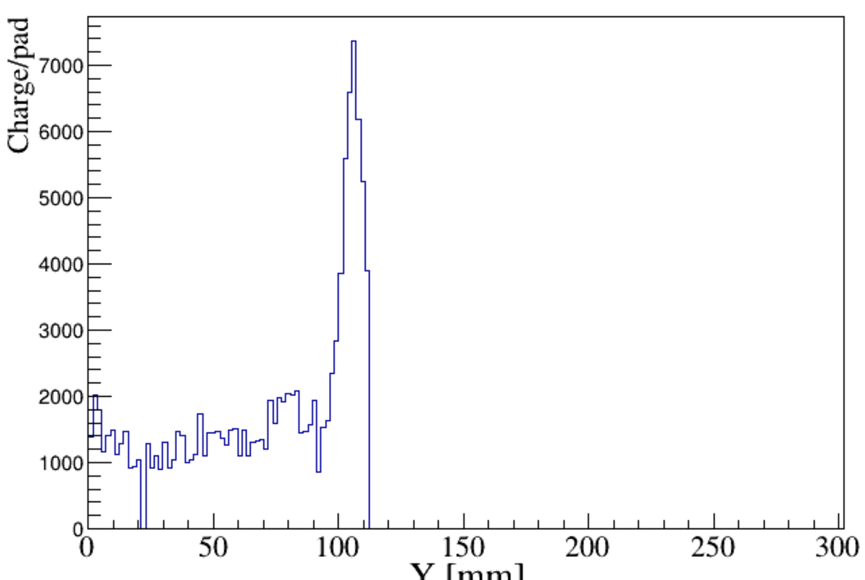
Valdir Guimarães

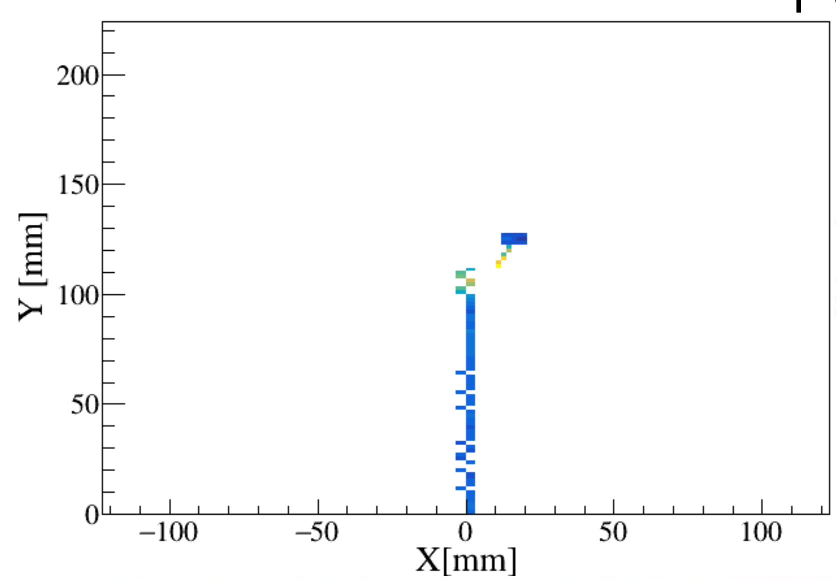


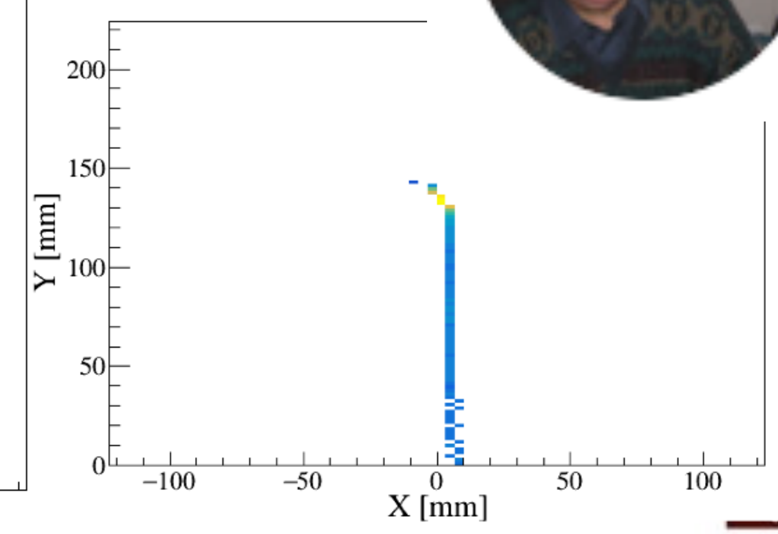
Juan Zamora

Direct ^{8}B+^{40}Ar fusion measurement

Yurii Penionzhkevich

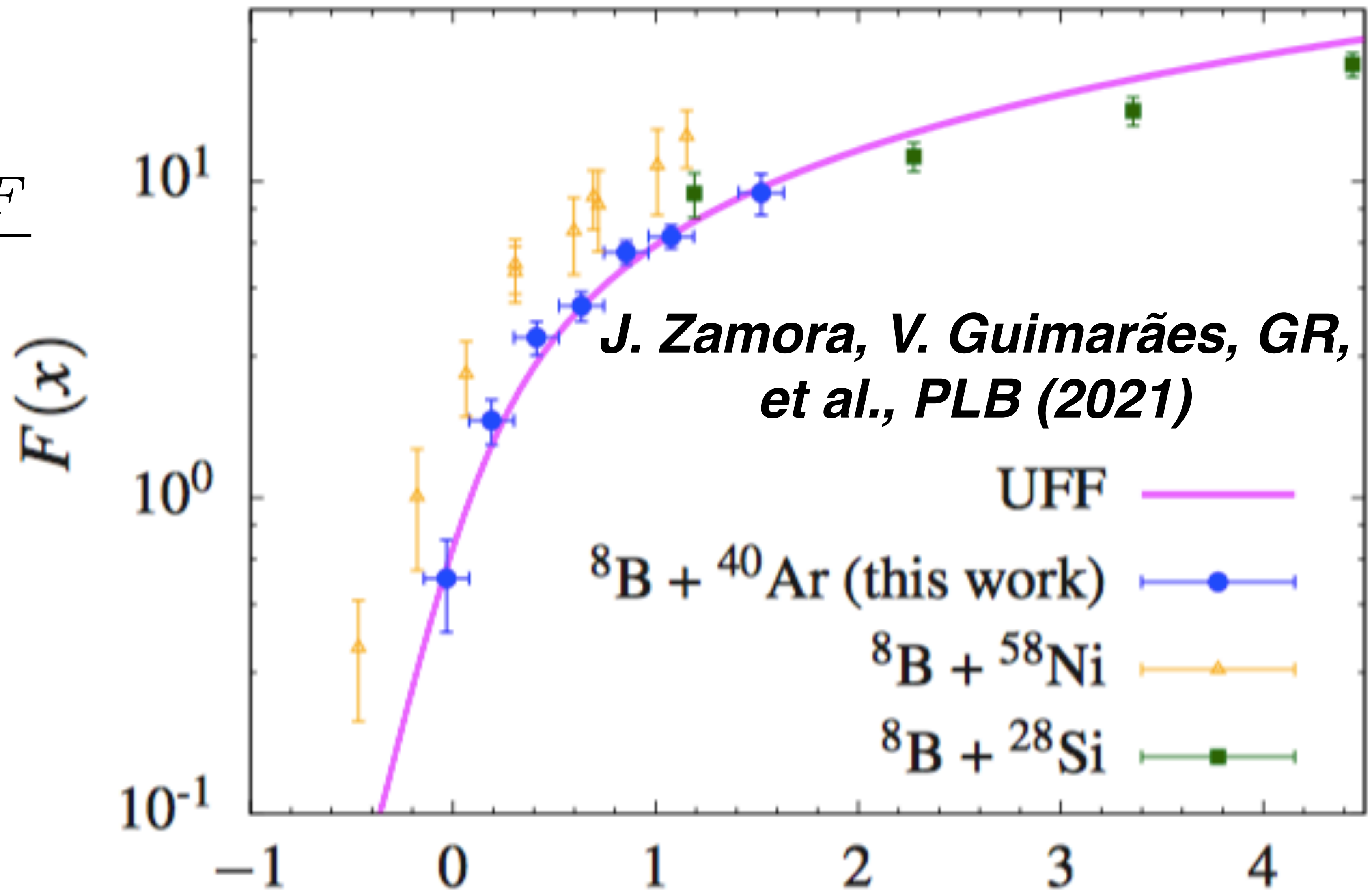






Direct measurement of fusion with TPC

$$F(x) = \frac{2E_{c.m.}\sigma_F}{\hbar\omega R_B^2}$$



UFF - Universal Fusion Function

x

$$x = \frac{E_{c.m.} - V_B}{\hbar\omega}$$

Table 1: Barrier parameters employed for the reduction of the TF cross section. These values were extracted from the bare SPP using a numerical interpolation.

Target	R_B [MeV]	V_B [MeV]	$\hbar\omega$ [MeV]	Ref.
^{28}Si	8.15	11.28	3.59	[27]
^{40}Ar	8.57	13.87	3.76	This work
^{58}Ni	8.90	20.83	4.14	[51]

Direct measurement of fusion with TPC

PRL 107, 092701 (2011) PHYSICAL REVIEW LETTERS week ending 26 AUGUST 2011

Near-Barrier Fusion of the $^{8}B + ^{58}Ni$ Proton-Halo System

E. F. Aguilera,* P. Amador-Valenzuela, E. Martinez-Quiroz, D. Lizcano, P. Rosales, H. García-Martínez, and A. Gómez-Camacho
Instituto Nacional de Investigaciones Nucleares, Apartado Postal 18-1027, DF-11801, México

J. J. Kolata, A. Roberts, L. O. Lamm,† and G. Rogachev‡
Physics Department, University of Notre Dame, Notre Dame, Indiana, 46556-5670, USA

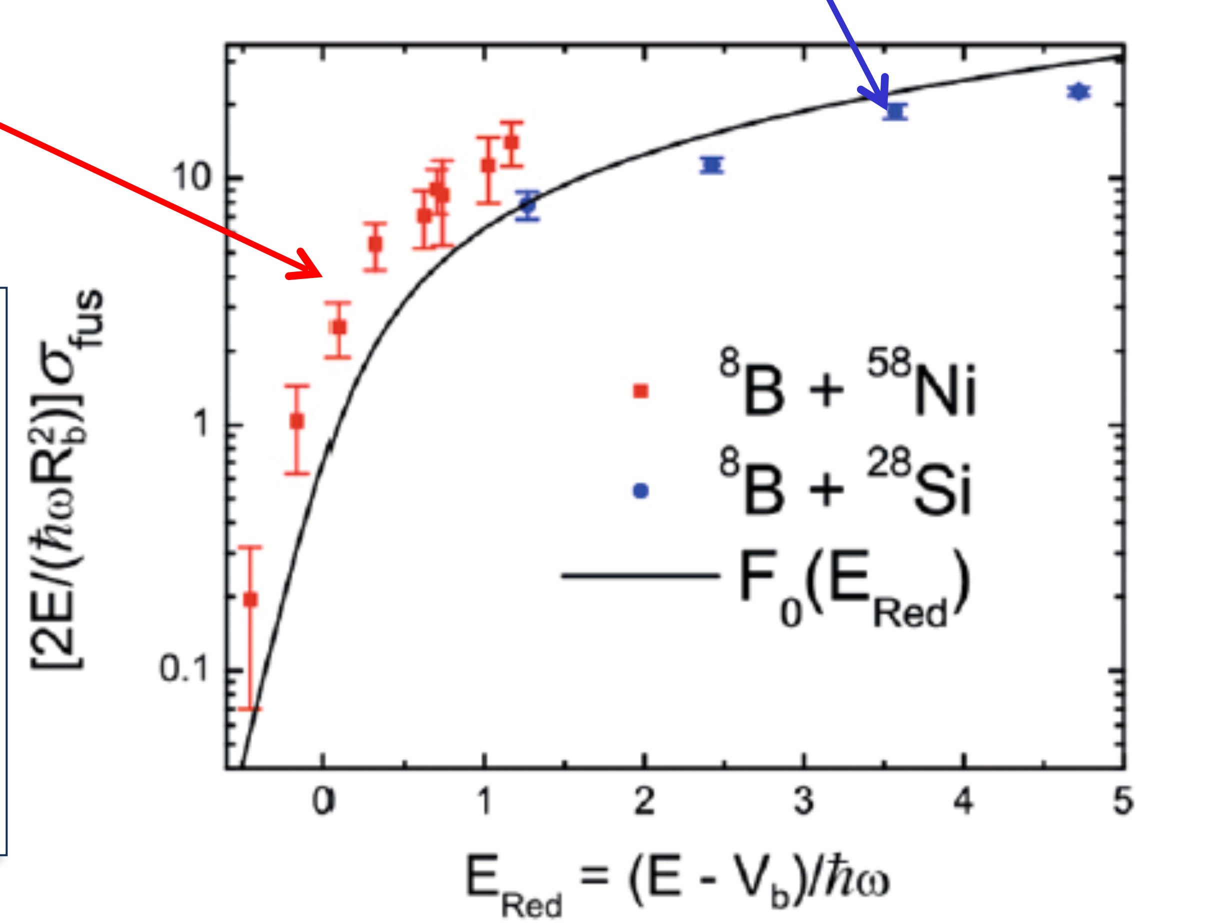
V. Guimarães

Fusion $^{8}B+^{28}Si$ – INFN-Italy
(alpha multiplicity - model dependent

Fusion suppression above barrier ?

Fusion $^{8}B+^{58}Ni$ – ND - USA
(proton multiplicity – model dependent)

Fusion enhancement below barrier ?



PHYSICAL REVIEW C 93, 034613 (2016)

Above-barrier fusion enhancement of proton-halo systems

E. F. Aguilera,* P. Amador-Valenzuela, E. Martinez-Quiroz, and J. Fernández-Arnáiz
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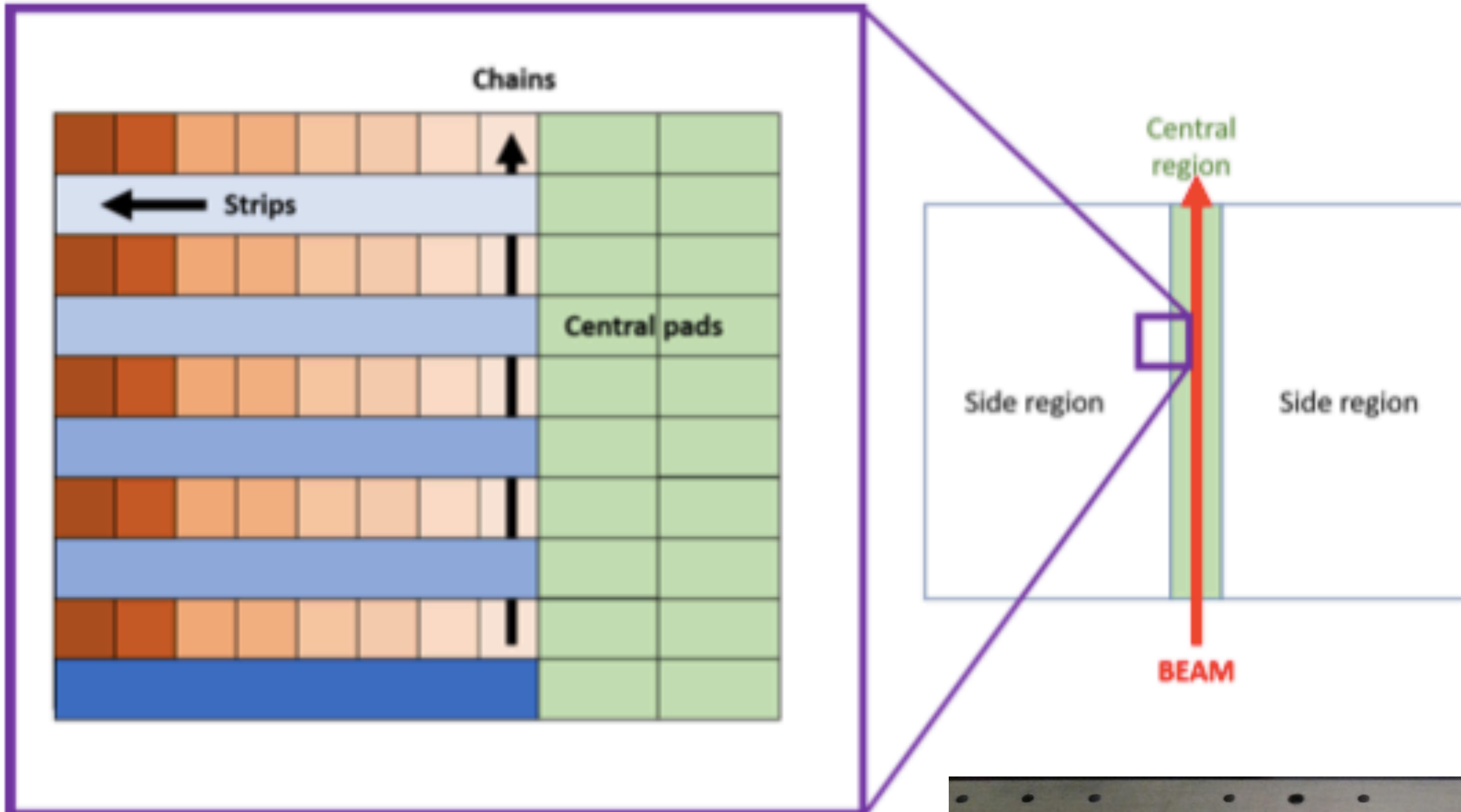
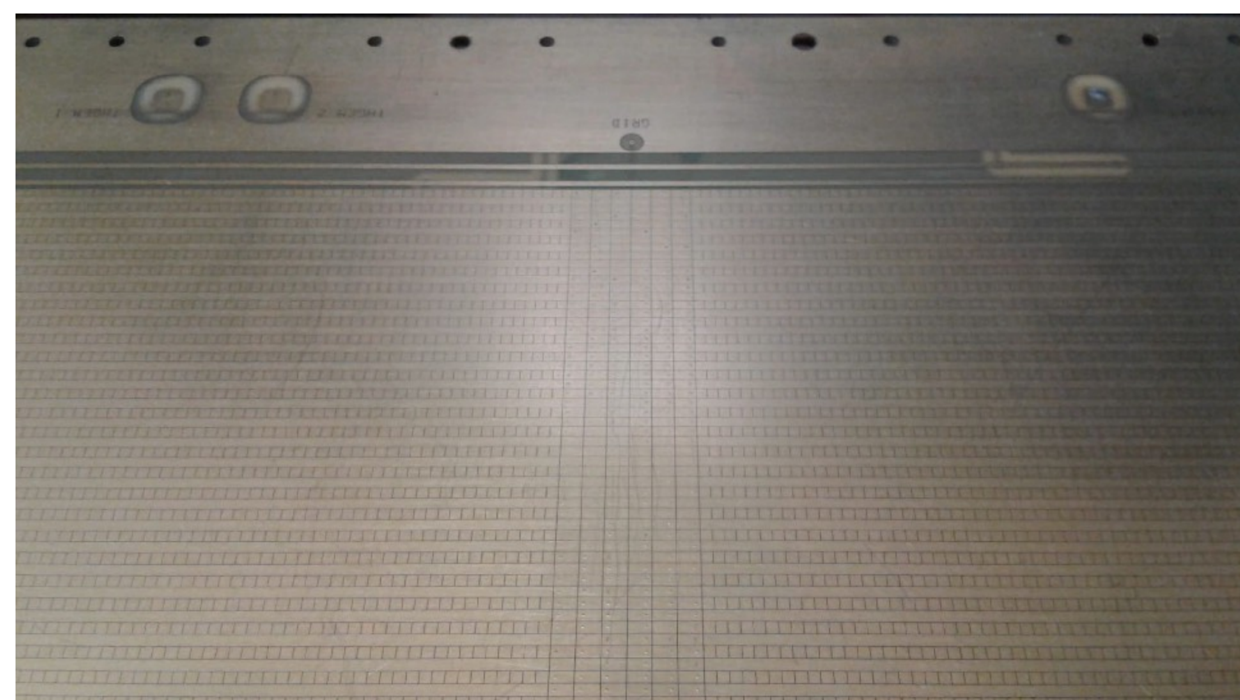
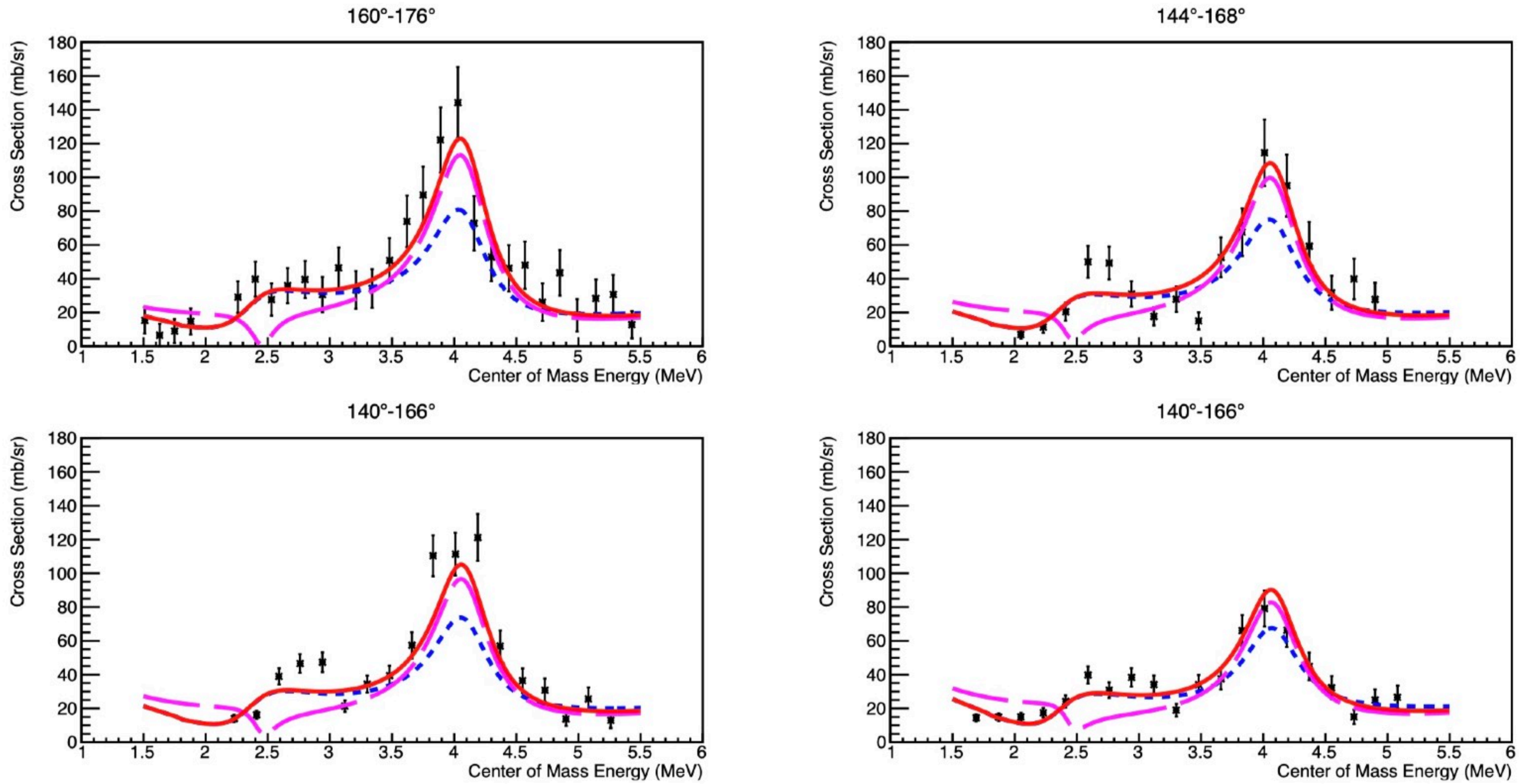
Instituto de Fisica, Universidade de São Paulo, P.O. Box 66318, 05389-970 São Paulo, São Paulo, Brazil
(Received 22 October 2015; revised manuscript received 19 February 2016; published 16 March 2016)

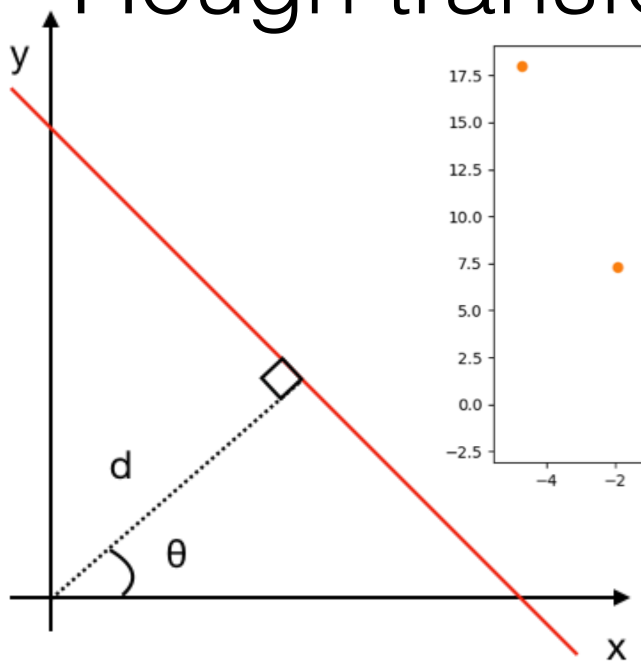

Chains
Strips
Central pads
Central region
Side region
Side region
BEAM

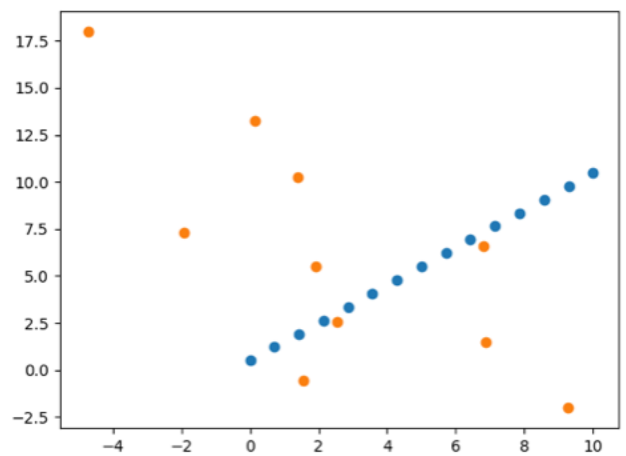


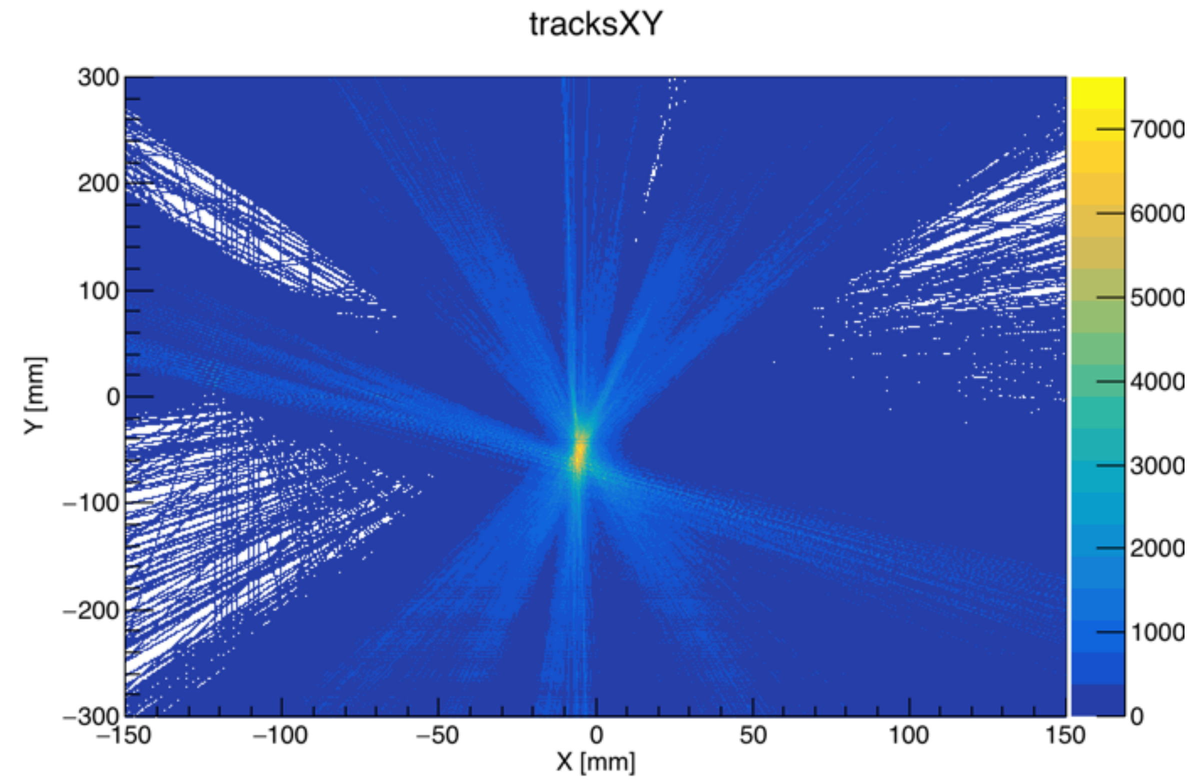

160°-176°
144°-168°
140°-166°
140°-166°
Cross Section (mb/sr)
Center of Mass Energy (MeV)

Tracking in TexAT

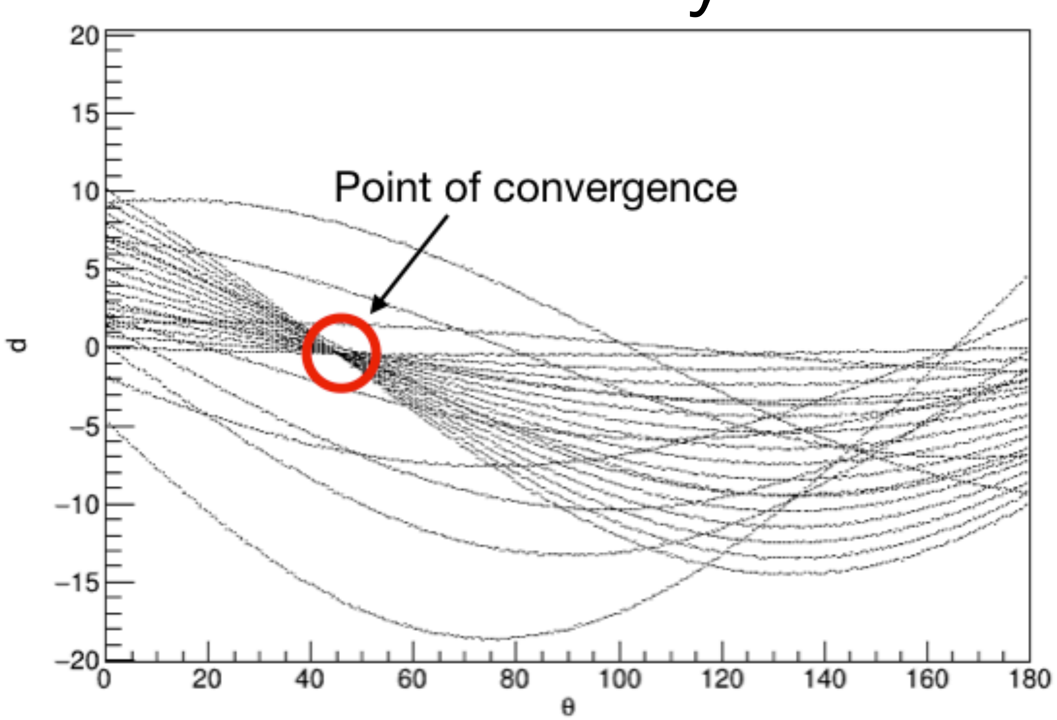
Hough transform

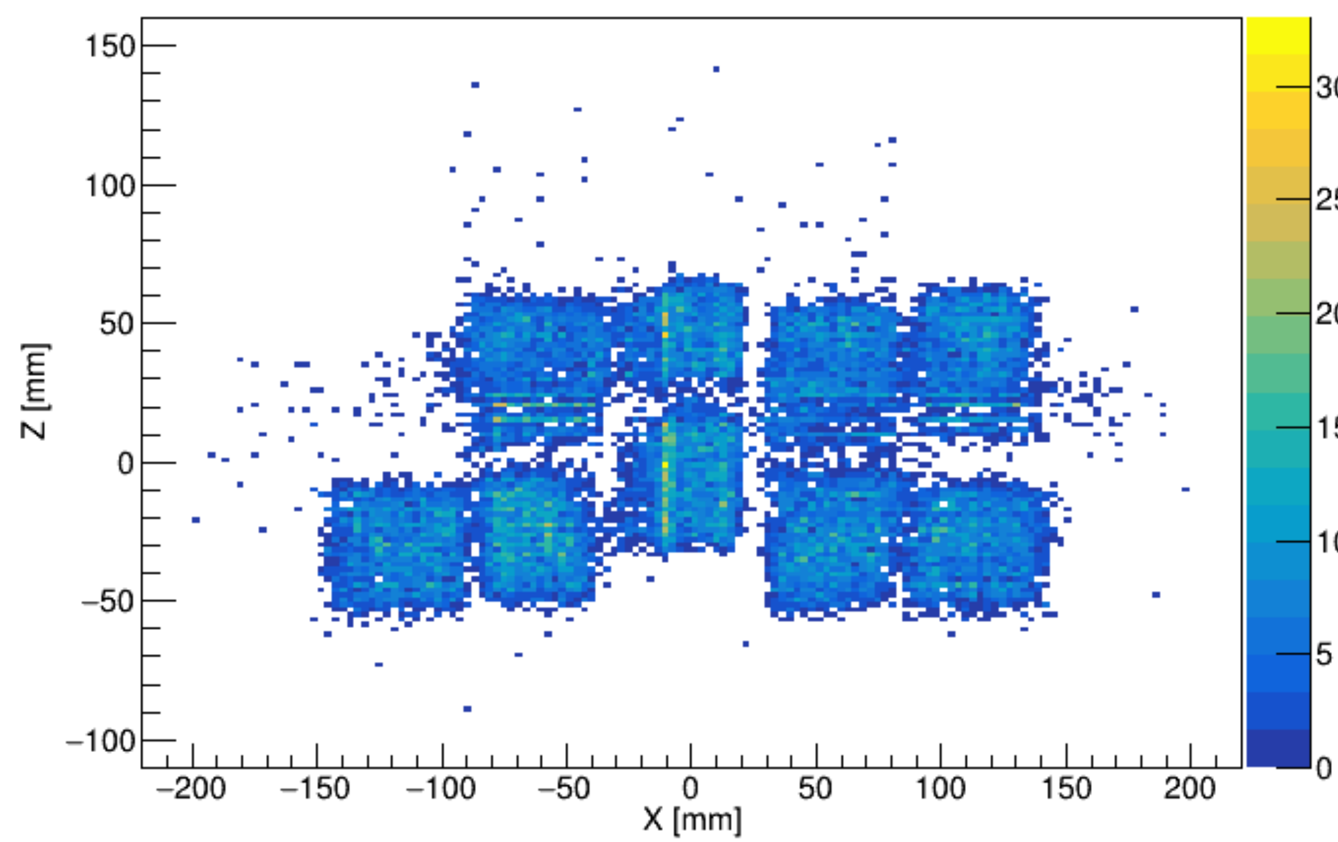


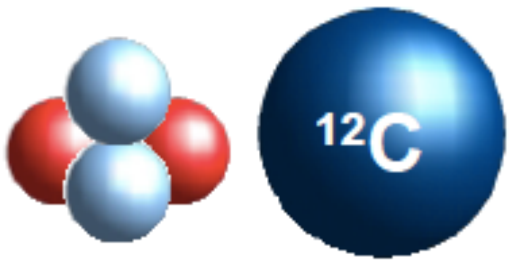


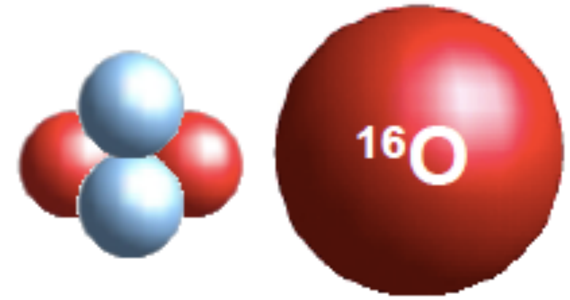


$$d = x \cos\theta + y \sin\theta$$

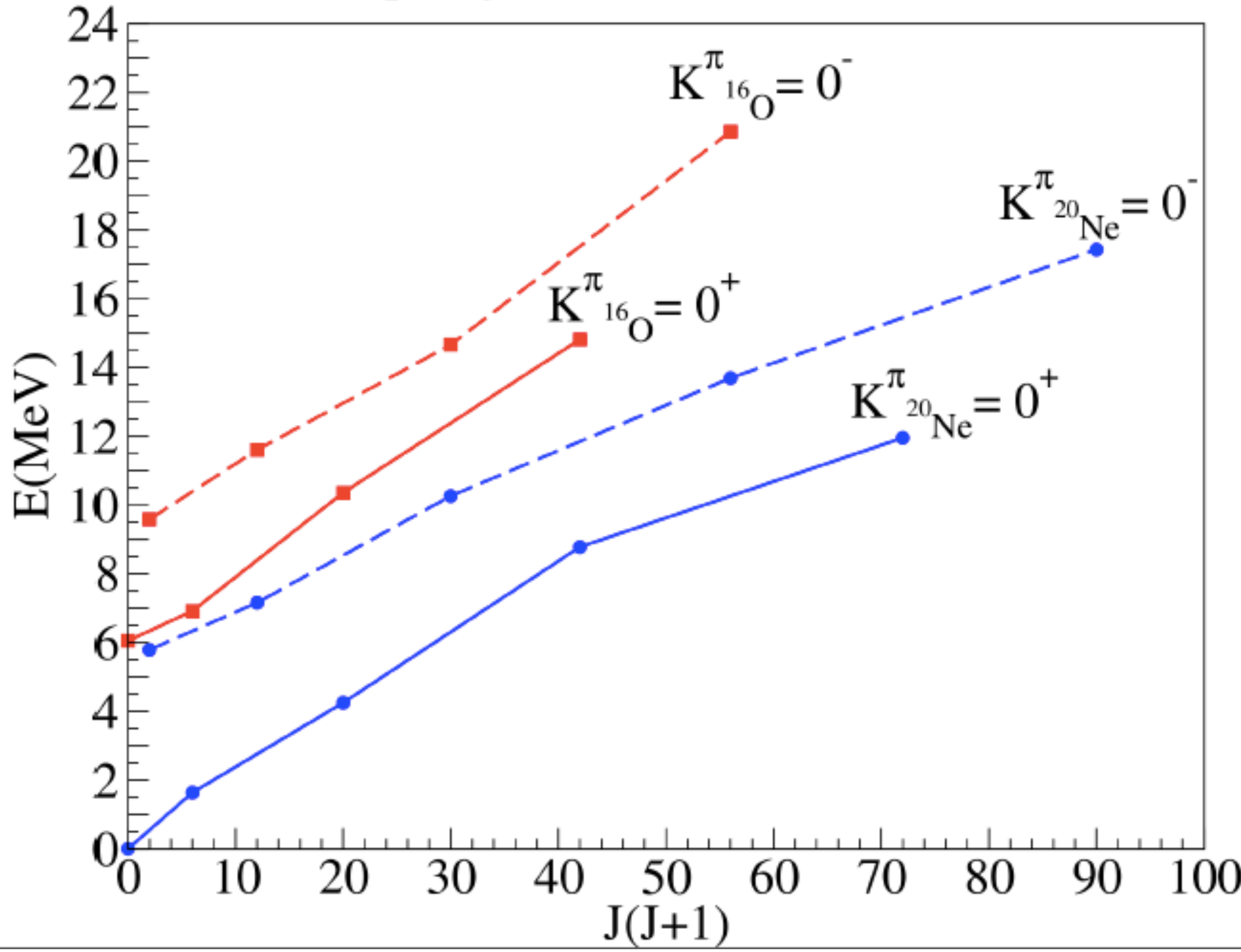








α-cluster parity doublets in ^{16}O and ^{20}Ne

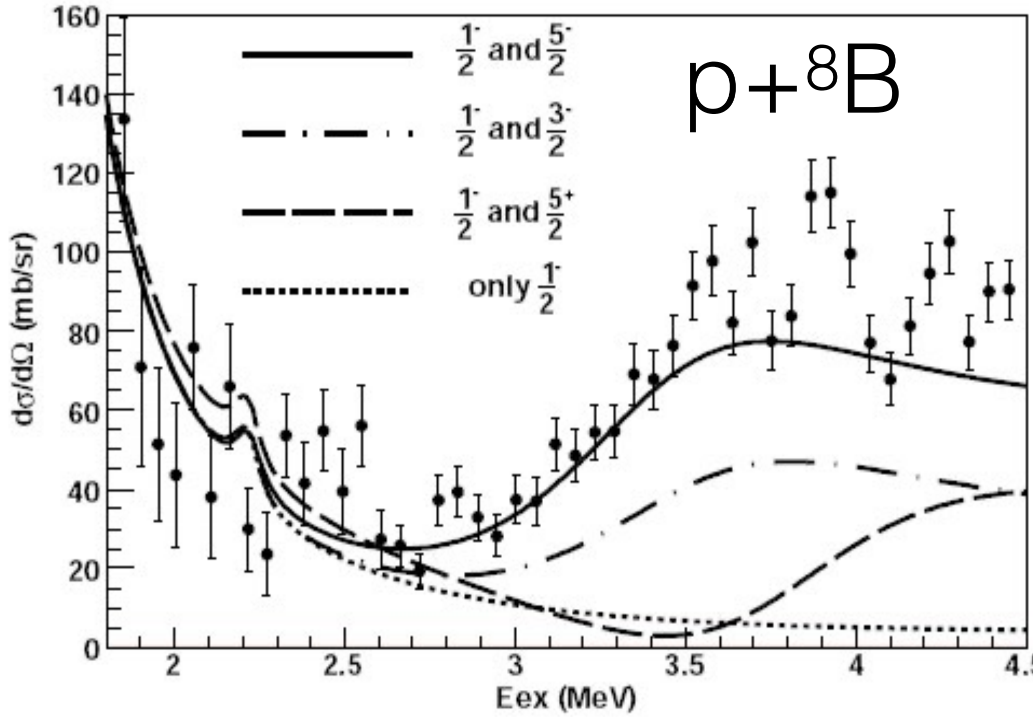


… and now back to:
A=9 T=3/2 iso-multiplet
Where is the 2s1/2 shell?

TEXAS A&M UNIVERSITY

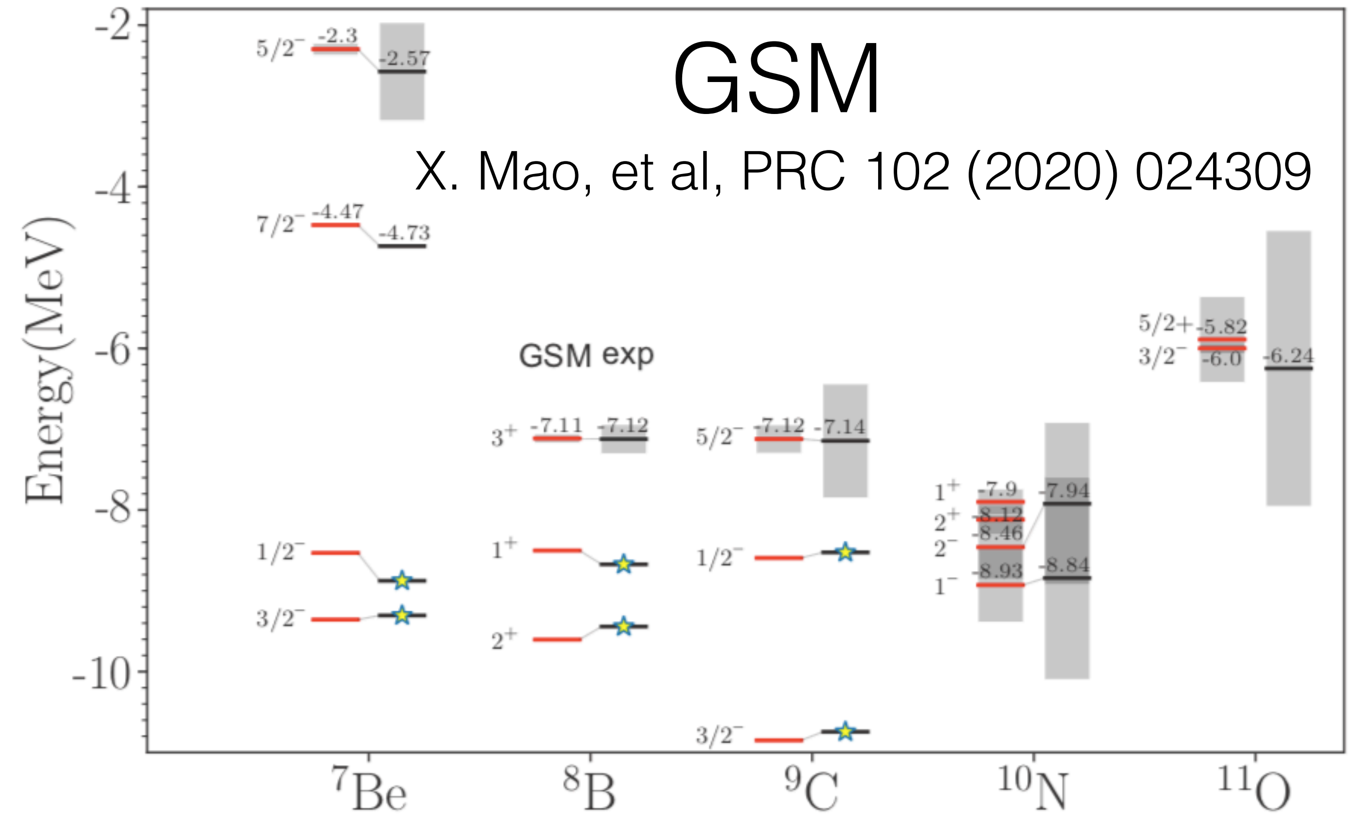
Structure of ^{9}C

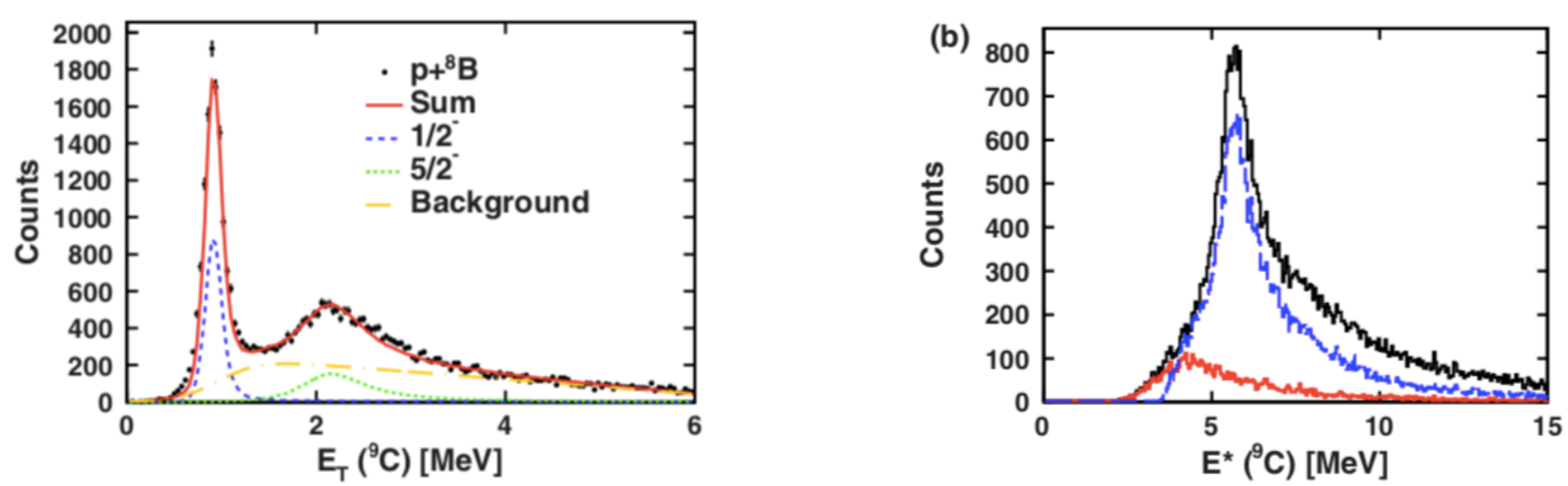
GR, et al.,PRC 75 (2007) 014603



GSM

X. Mao, et al, PRC 102 (2020) 024309

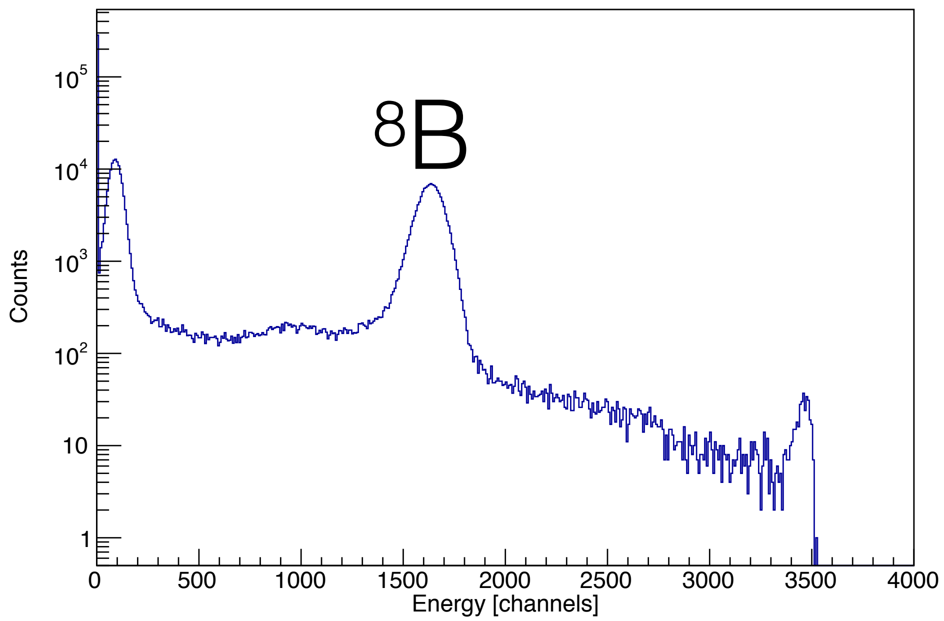




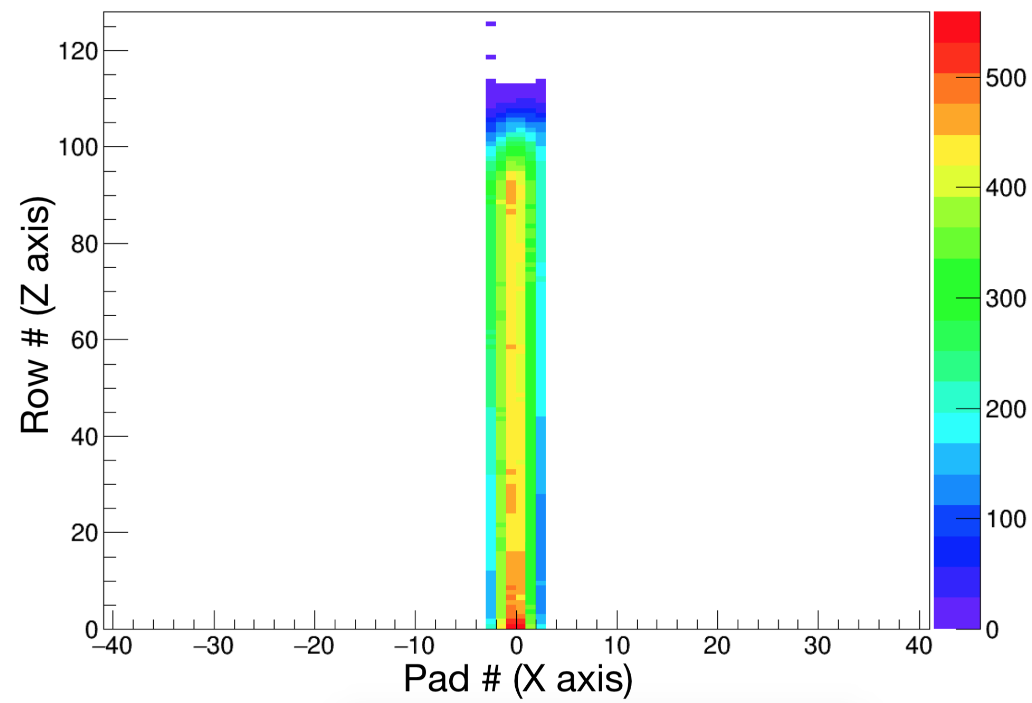
K.W. Brown, et al., PRC 95 (2017) 044326

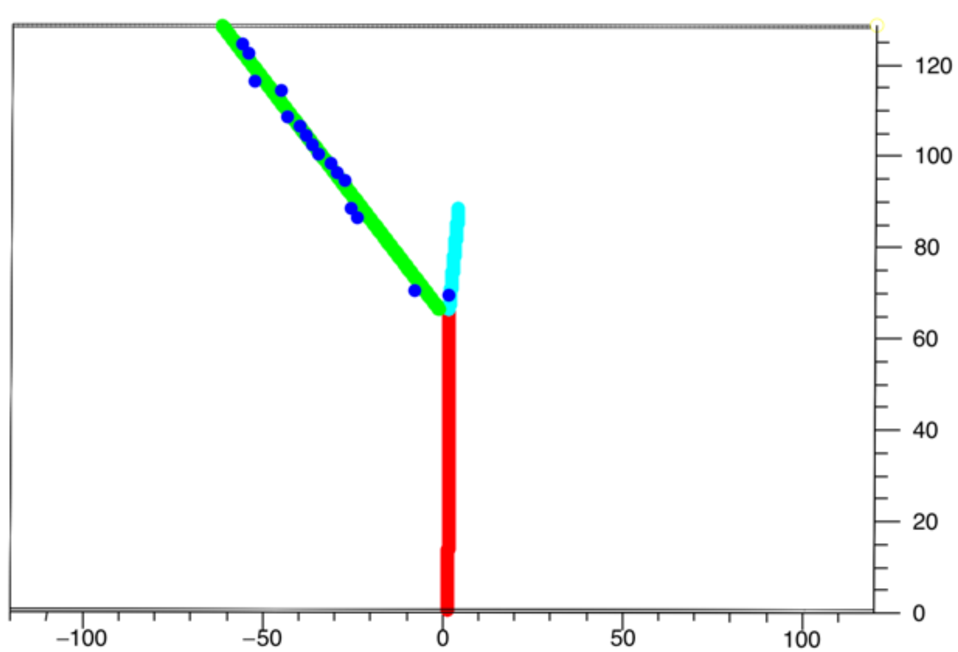
Structure of ^{9}C

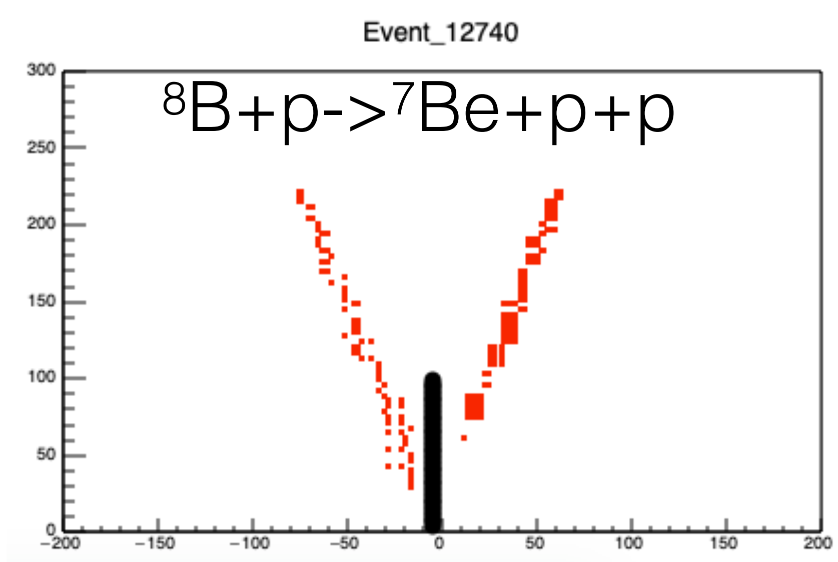
Josh Hooker
2019 graduate



^{8}B - cumulative tracks



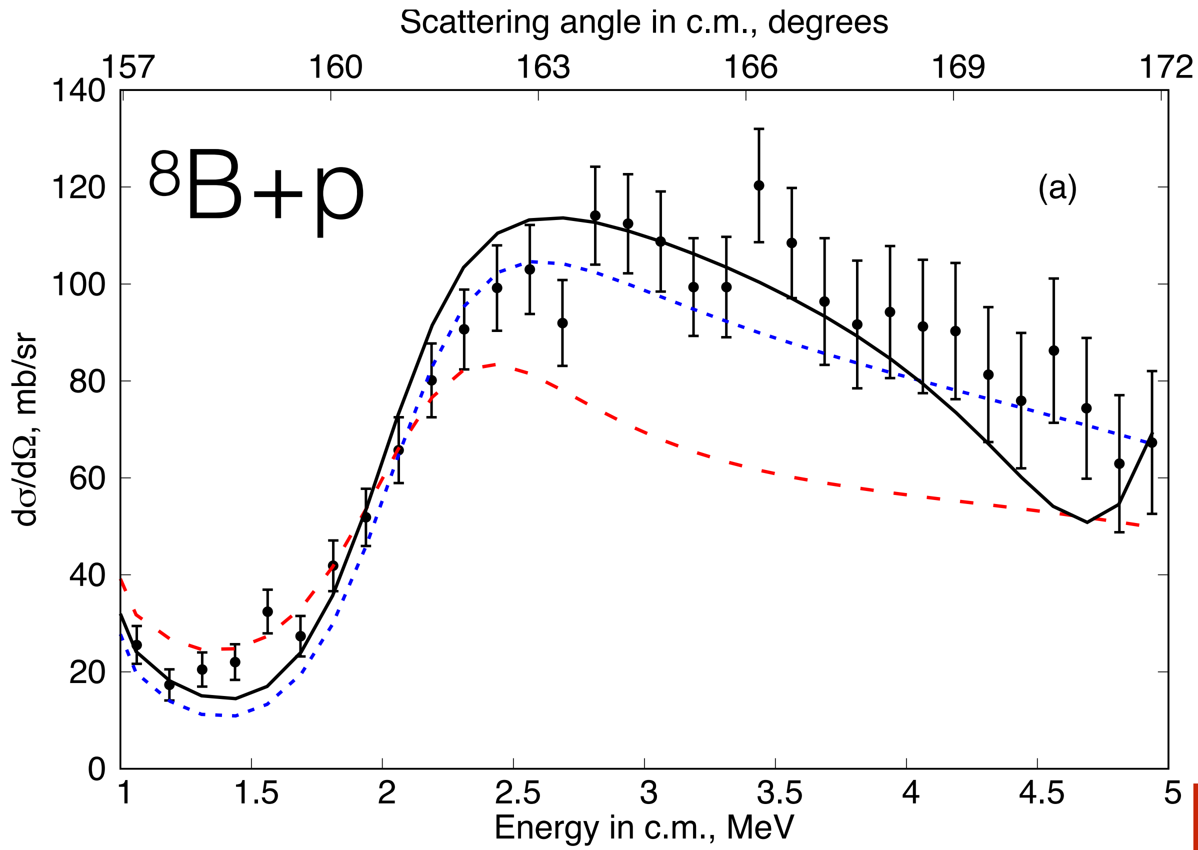


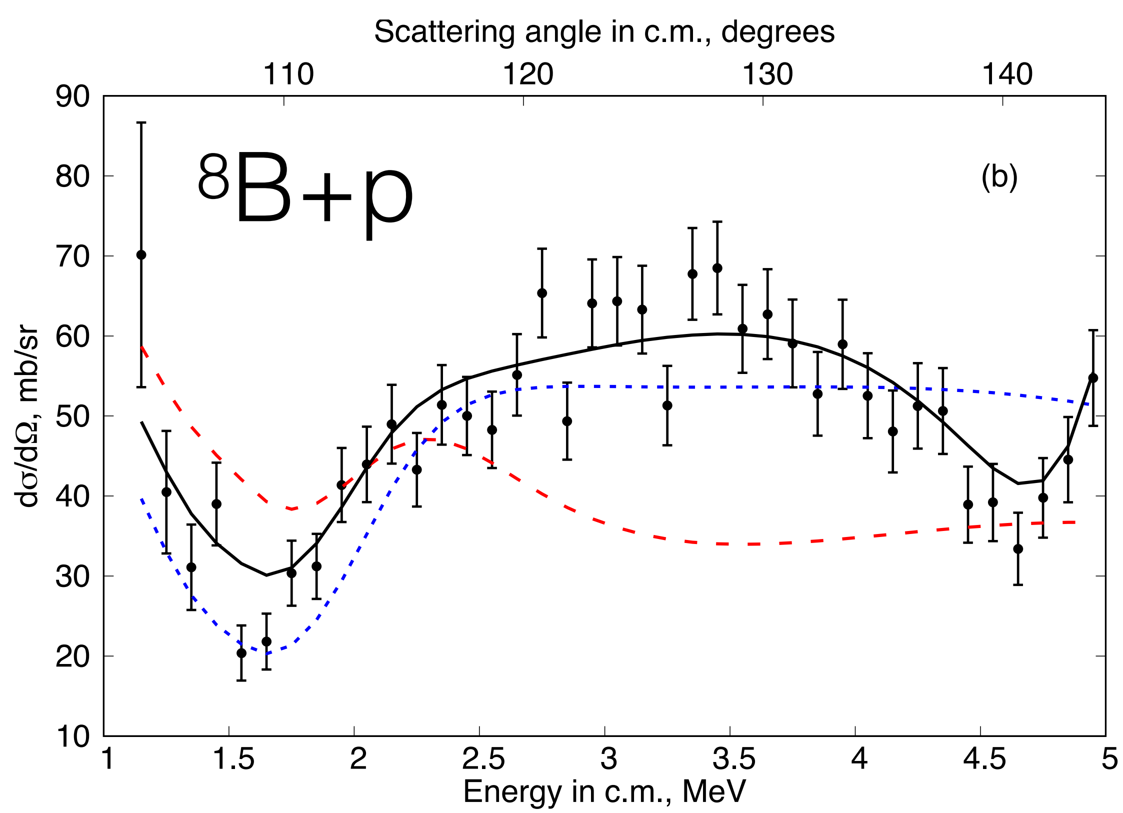


Structure of ^{9}C

Josh Hooker

J. Hooker, GR, E. Koshchiy, et al., Phys. Rev. C 100, (2019) 054618





Curves are R-matrix fits

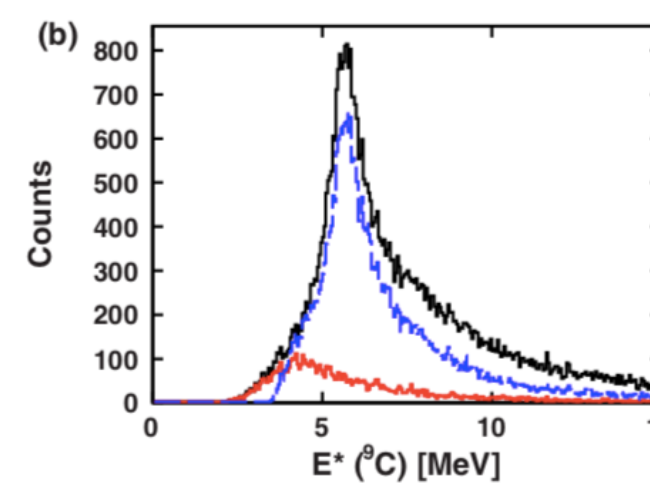
- - - - - - $1/2^-$ (0.9) + $5/2^-$ (2.3)

- - - - - - $1/2^-$ (0.9) + $5/2^-$ (2.3) + **$5/2^+$ (3)**

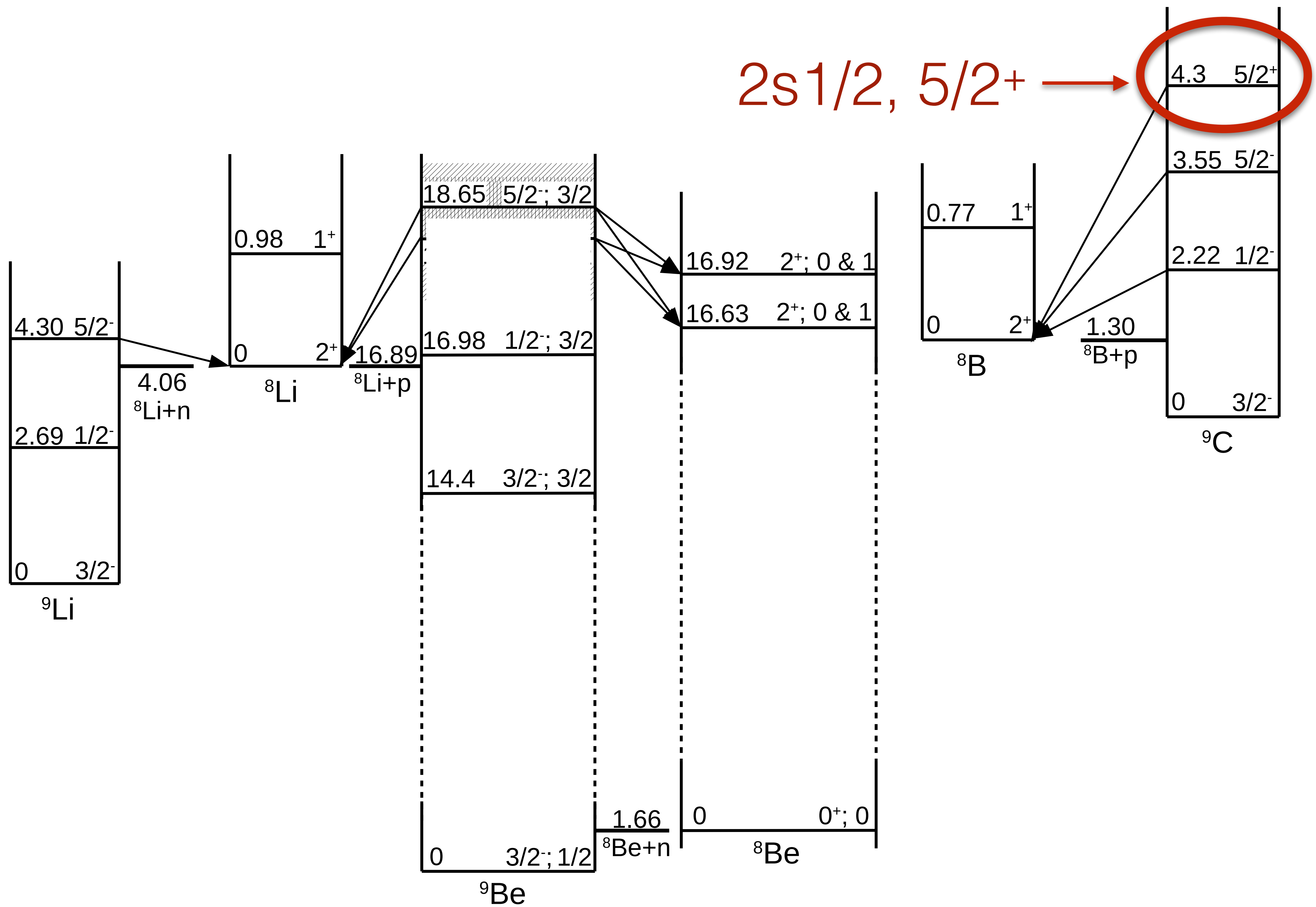
——— $1/2^-$ (0.9) + $5/2^-$ (2.3) + **$5/2^+$ (3)** + $7/2^-$ (5)

$5/2^+$ is located at 4.3(3) MeV excitation energy in ^{9}C
$\Gamma = 4^{+2}_{-1.4}$ MeV

K. Brown, et al., PRC (2017) 4.40(4); Γ=2.75(11)



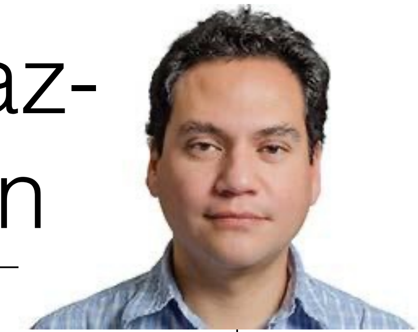
Structure of ^9C

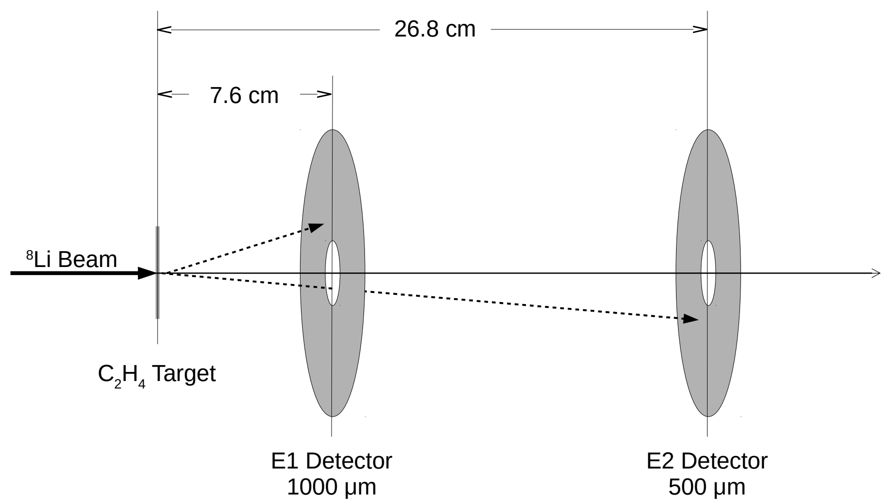


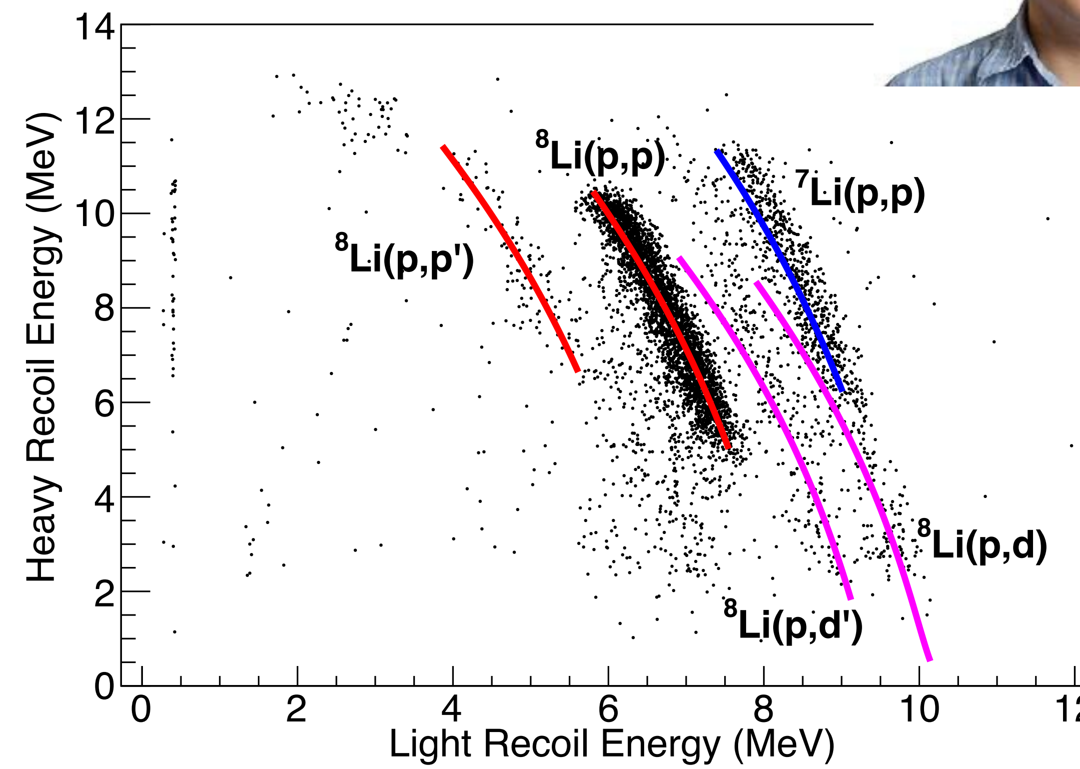
C. Hunt

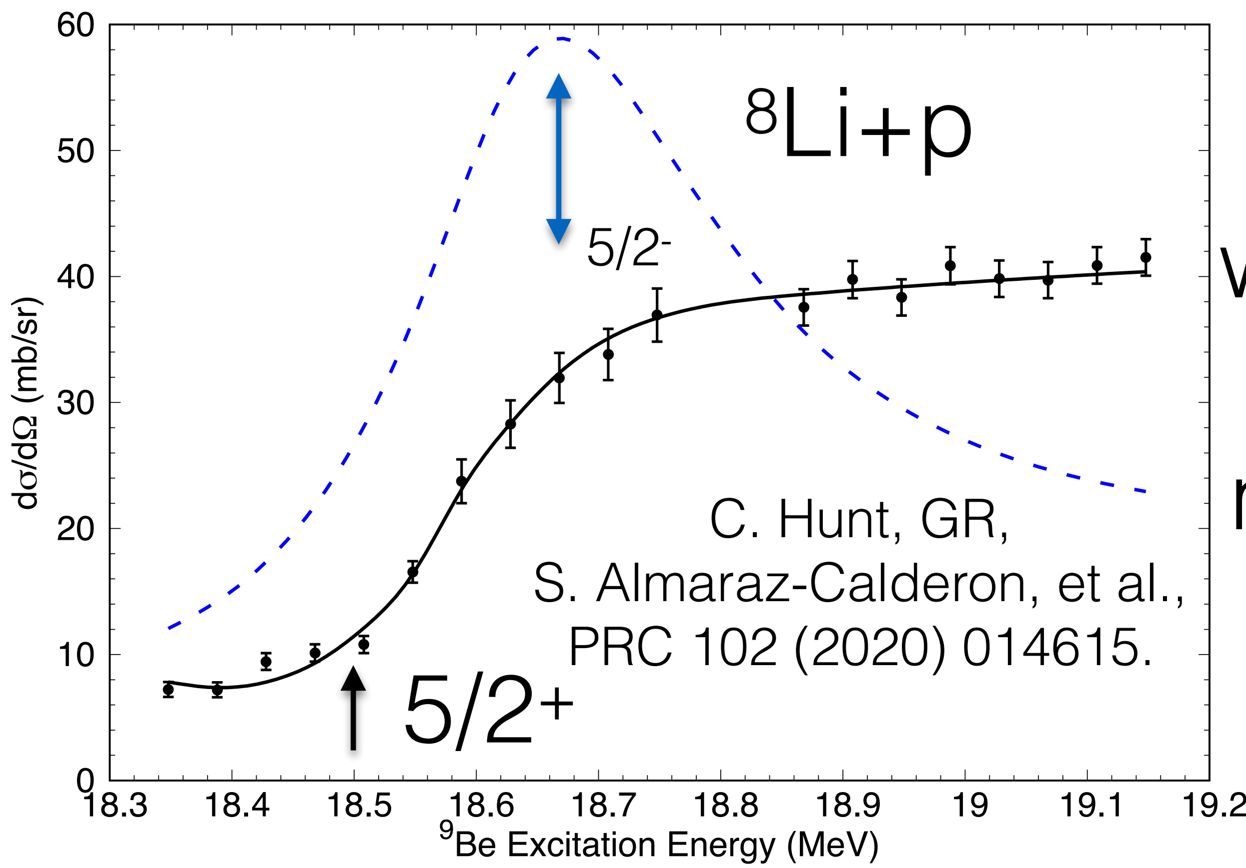
IAS in ^{9}Be

S. Almaraz-Calderon







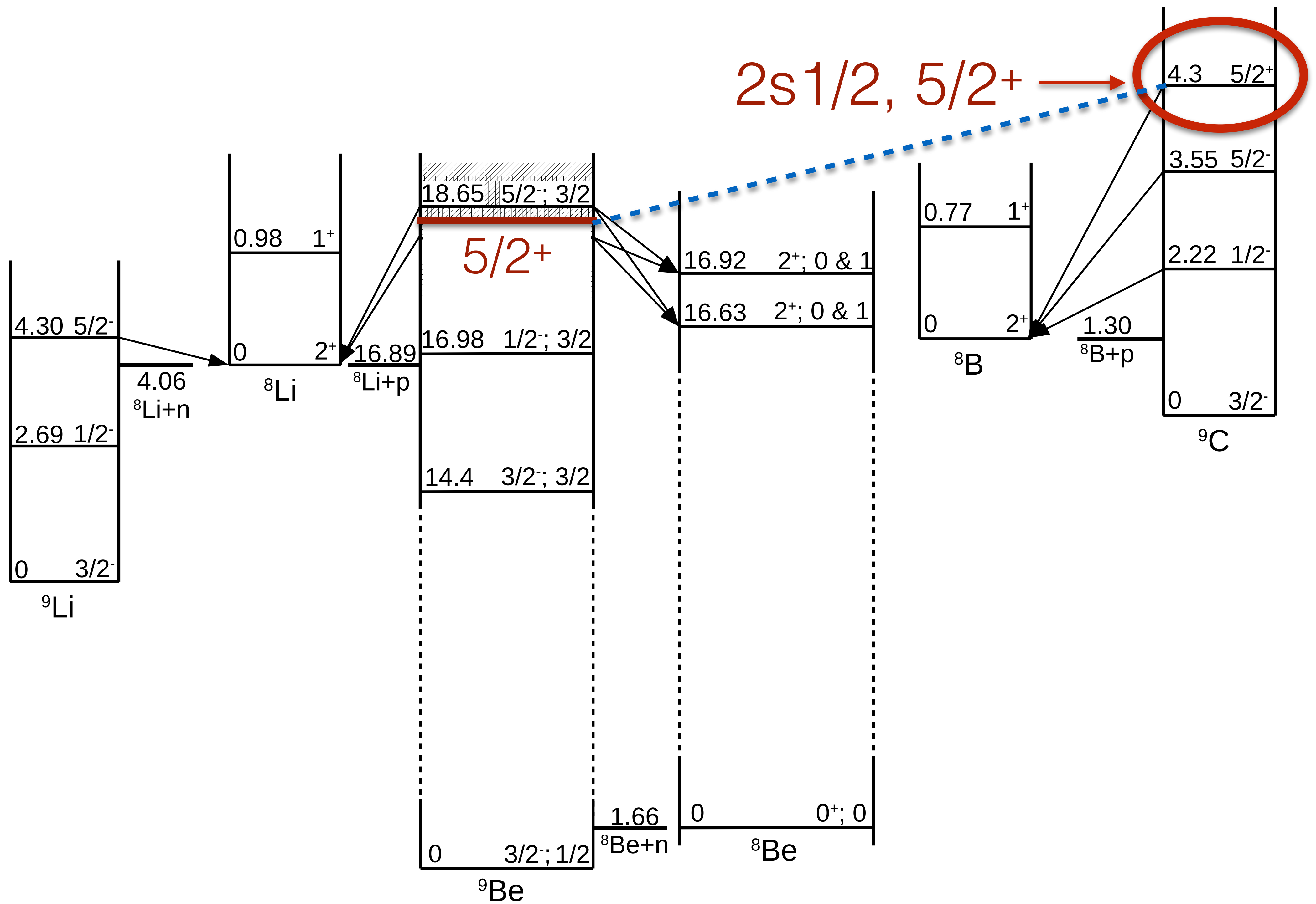


with 2s1/2

no 2s1/2

All R-matrix parameters are CALCULATED here, except for one: 5/2+ E_{ex}

IAS in ^{9}Be



2s1/2, 5/2+
4.3 5/2+
3.55 5/2-
2.22 1/2-
0 3/2-
9C
0.77 1+
0 2+
8B
1.30
8B+p
18.65 5/2-; 3/2
5/2+
16.98 1/2-; 3/2
14.4 3/2-; 3/2
0 3/2-; 1/2
9Be
1.66
8Be+n
16.92 2+; 0 & 1
16.63 2+; 0 & 1
0 0+; 0
8Be
0.98 1+
0 2+
8Li
16.89
8Li+p
4.30 5/2-
2.69 1/2-
0 3/2-
9Li
4.06
8Li+n

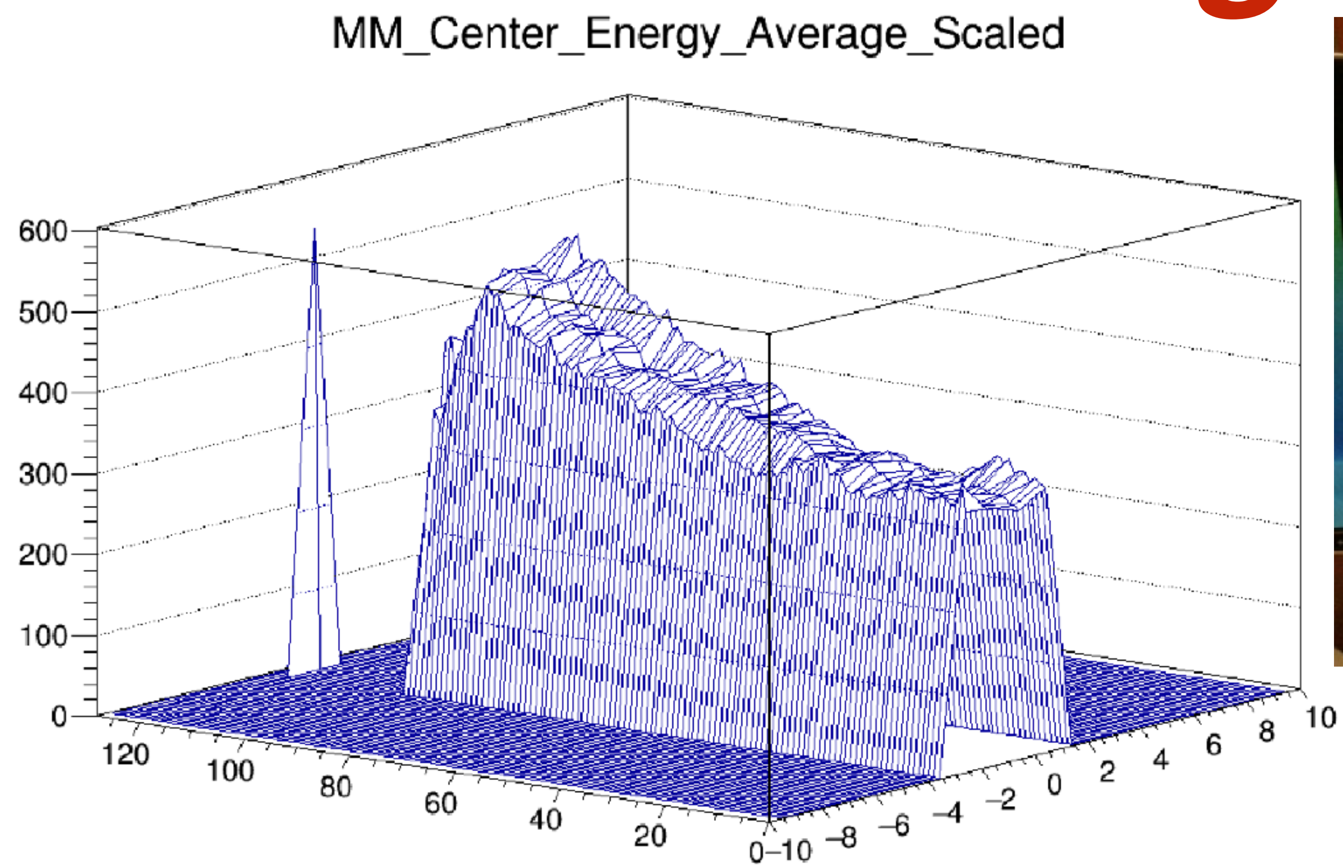
References

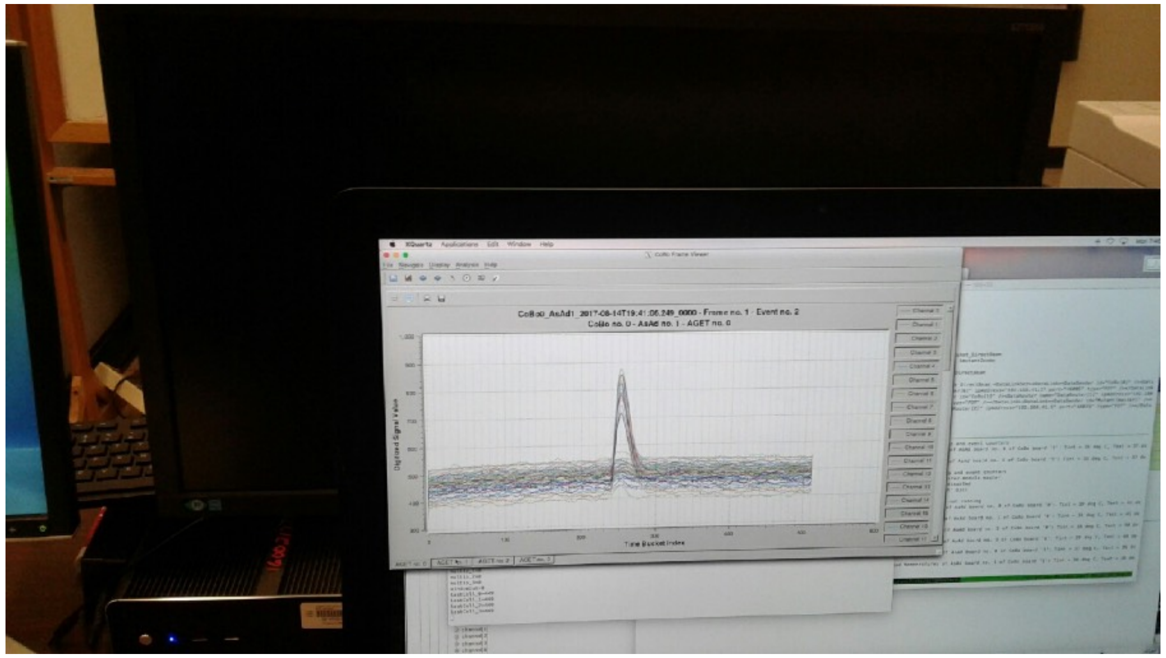
- E. Koshchiy, GR, E. Pollacco, et al., NIM A 957 (2020) 163398 - **TexAT**
- J. Hooker, GR, E. Koshchiy, et al., PRC 100, (2019) 054618 - **Structure of ^{9}C**
- J. Hooker, GR, E. Koshchiy, et al., PLB 769 (2017) 62 - **Structure of ^{10}N**
- C. Hunt, GR, S. Almaraz, et al., PRC 102 (2020) 014615 - **T=3/2 states in ^{9}Be**
- E. Uberseder, GR, V.Z. Goldberg, et al., PLB 754 (2016) - **Structure of ^{9}He**
- S. Upadhyayula, GR, et al., PRC 101 (2020) 034604 - **Clustering in ^{10}Be**
- J. Bishop, GR, S. Ahn, et al., NIM A 964 (2020) 163773 - **Hoyle decay**
- J. Bishop, GR, S. Ahn, et al. PRC 102 (2020) 041303 (R) - **Hoyle decay**
- H. Jayatissa, GR, et al., PLB 802 (2020) 135267 - **^{22}Ne(α,γ) reaction rate**
- S. Ota, G. Christian, et al., PLB 802 (2020) - **n/γ br. ratios for ^{22}Ne(α,γ)**
- R. Linares, V. Guimaraes, GR, et al., PRC (2021) submitted - **^{10}C+^{208}Pb el.sc.**
- J. Zamora, V. Guimaraes, GR, et al., PLB (2021) submitted - **^{8}B+^{40}Ar fusion**
- J. Bishop, GR, et al., PRL (2021) submitted - **search for Efimov states in ^{12}C**

TexAT Utilizes GET Electronics

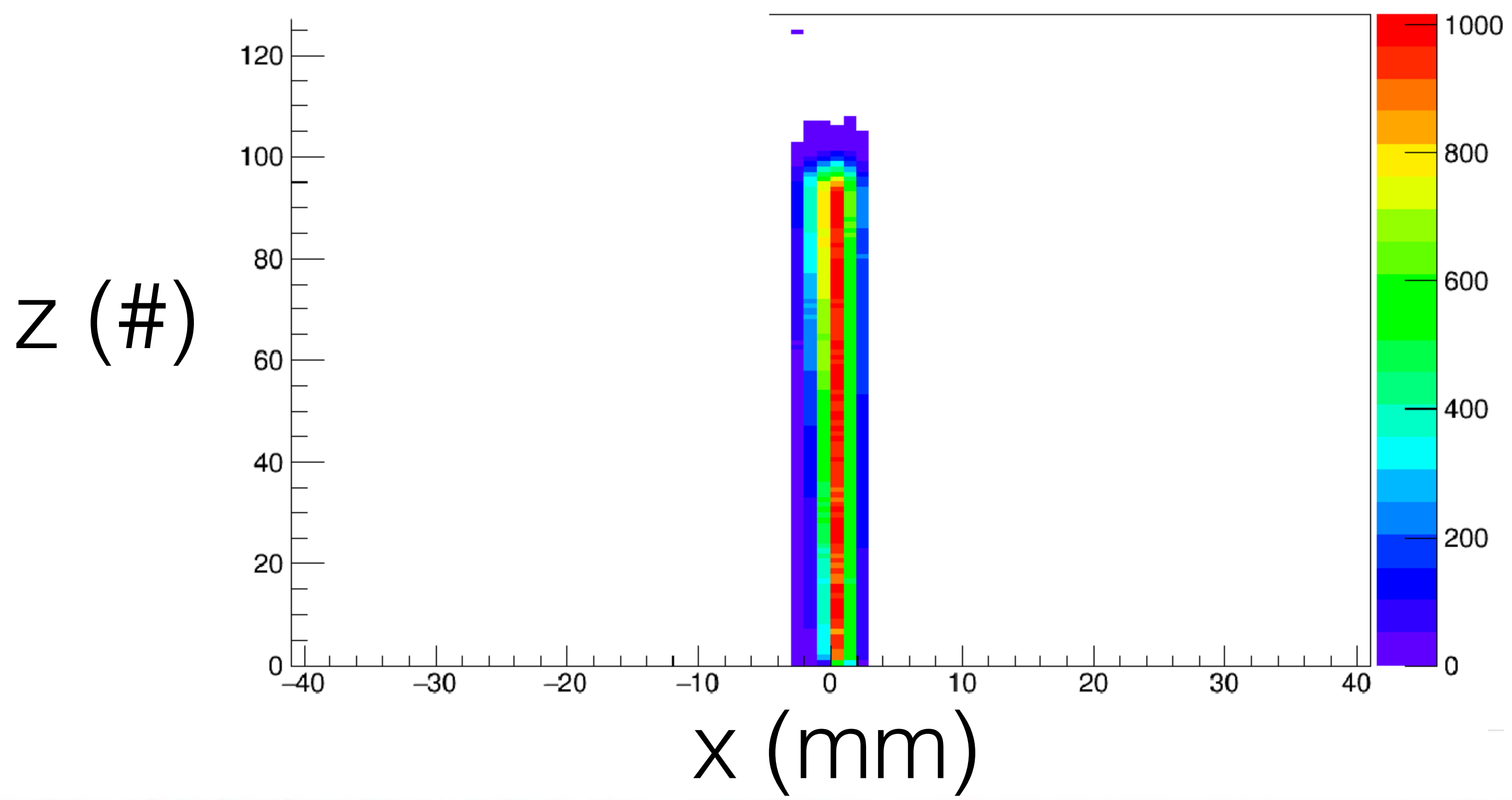
8 AsAd boards - 2048 channels
2 CoBos, 1 MUTANT
GET is used to read out ALL channels -
microMegas (1024); Si - (256); CsI(Tl) - (64)

First light! ^{12}C beam - 50 MeV





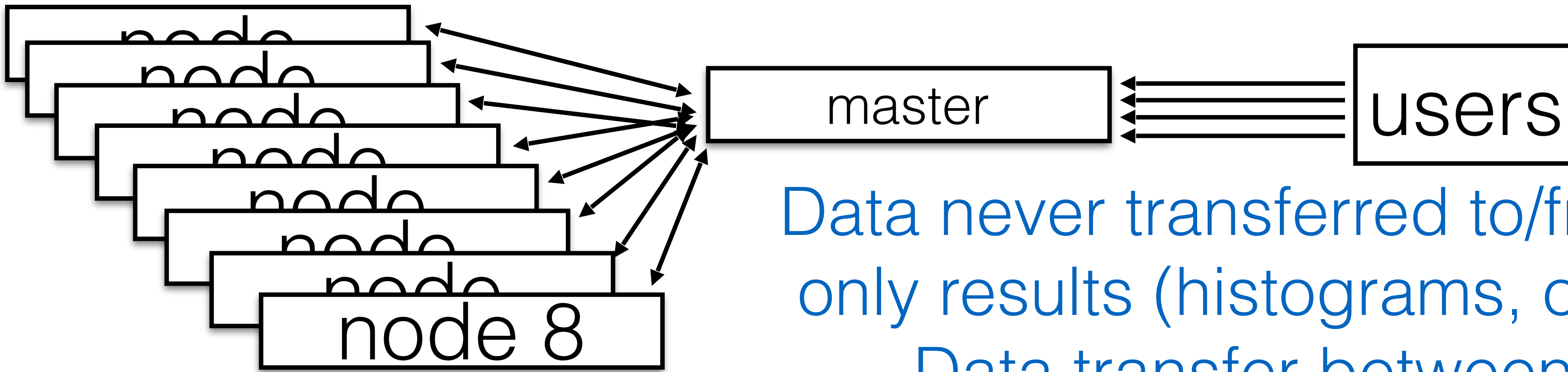
FIRST EVER BEAM EVENT IN TexAT
August 14, 2017 19:54:03



Analysis Computing Infrastructure

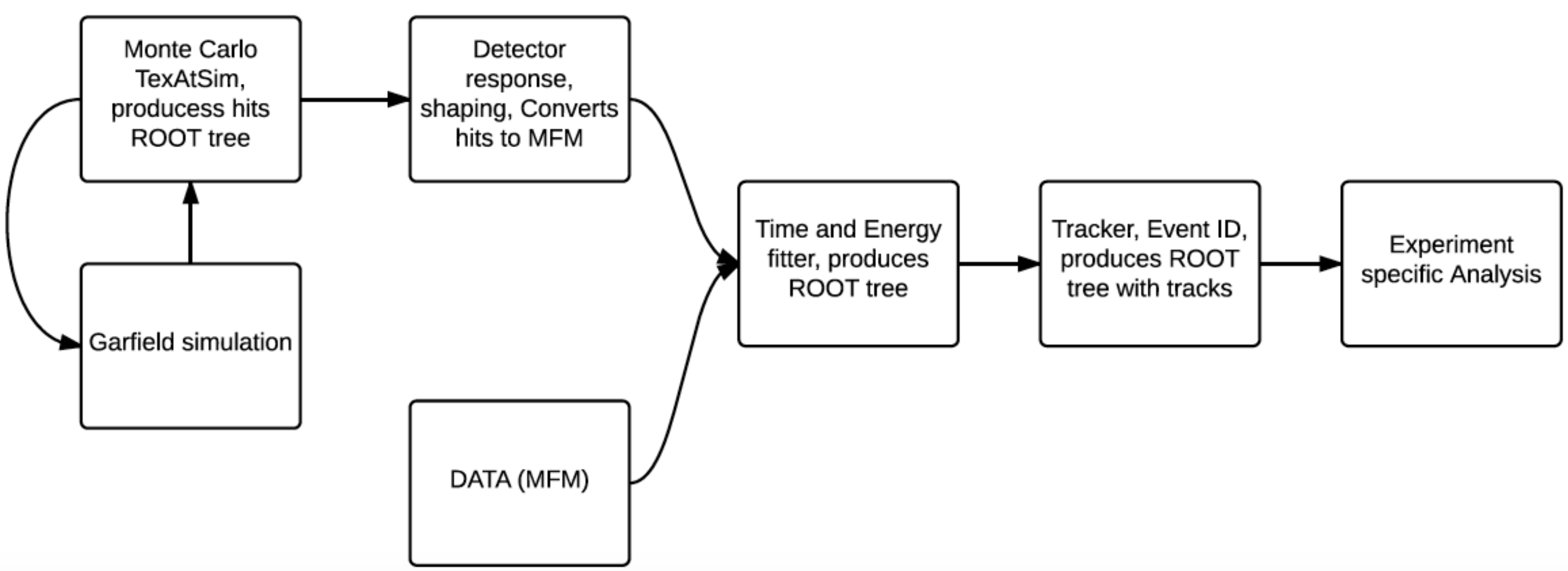
- Using "Big Data" tools actively supported and developed by a very large community (but still open source!)
- HDFS (Hadoop Distributed File System) for all data storage
  - Redundant, fault-tolerant, high-availability *distributed* file system
- Spark cluster engine handles parallel tasks
  - Spark + PyROOT gives parallel, **data local**, parallel processing of ROOT trees with TSelectors, similar to PROOF but more general with larger development base
  - Simple Python wrapper (less lines than a Condor script) allows easy batch processing (i.e. Geant4 applications)
- Entire compute/data node environment is contained in a Docker image and runs in a container
  - Setup of entire node after operating system install takes < 5 minutes

TexAT designated Cluster architecture



Data never transferred to/from master,
only results (histograms, of example)
Data transfer between nodes
minimized automatically by Spark software

TexAT software suite flowchart



Analysis Computing Infrastructure

Parallel Analysis Example:

~30 GByte data
230,000,000 events
1 Gbit network

Case 1		Case 2
• 1 node, 1 core • All files looped with TChain • No data locality		• 4 nodes, 24 cores • Each file processed as separate task • Data locality preferred
870 seconds 0.27 Gbit/s	⟵ *90%* ⟶	40 seconds 6.0 Gbit/s

With existing 8 node / 120 cores cluster **260 TB** of data can be **ALL** analyzed in few **days**