Study of ^{14}B using the (d,p) reaction in Inverse Kinematics*

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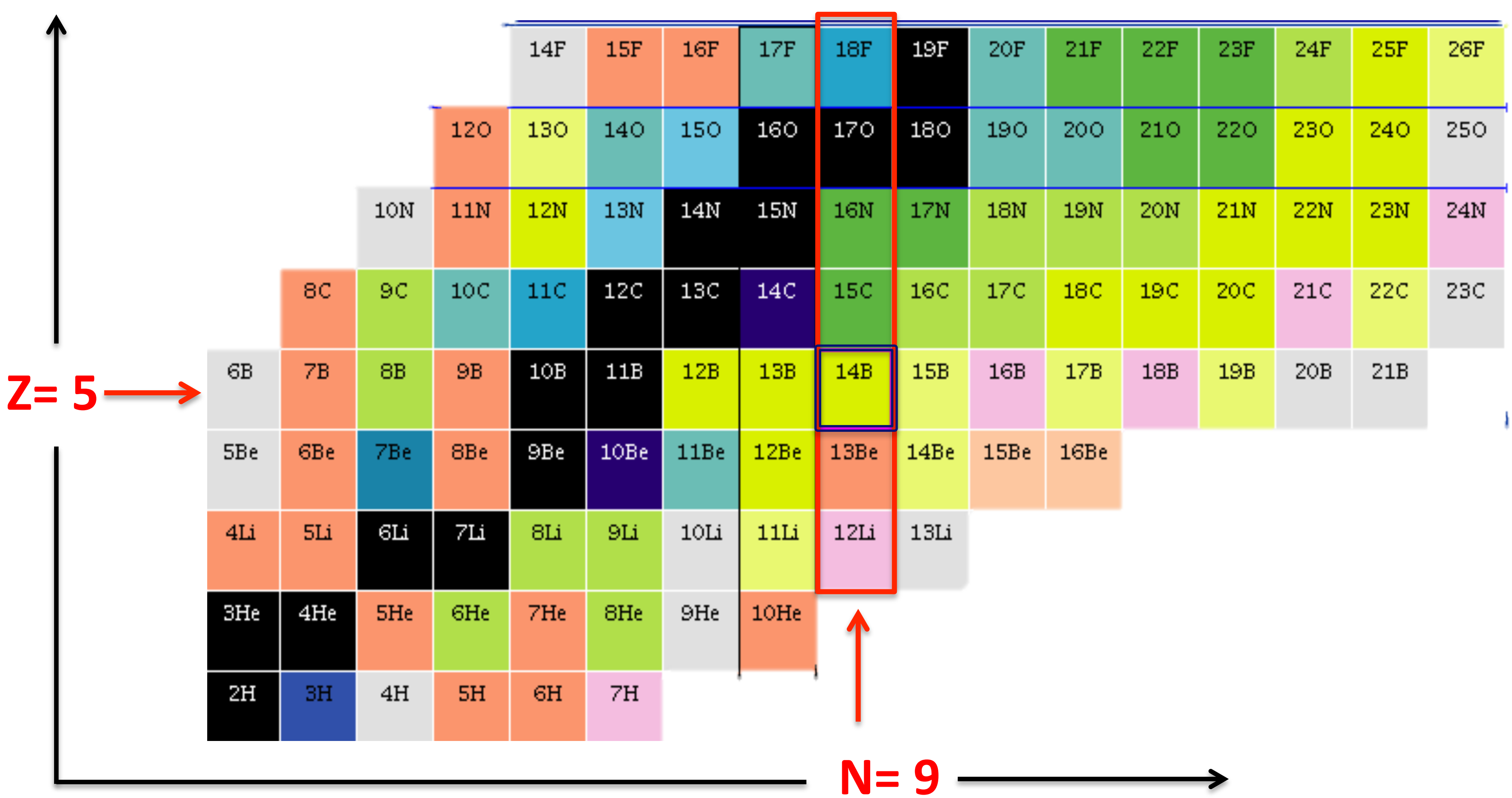
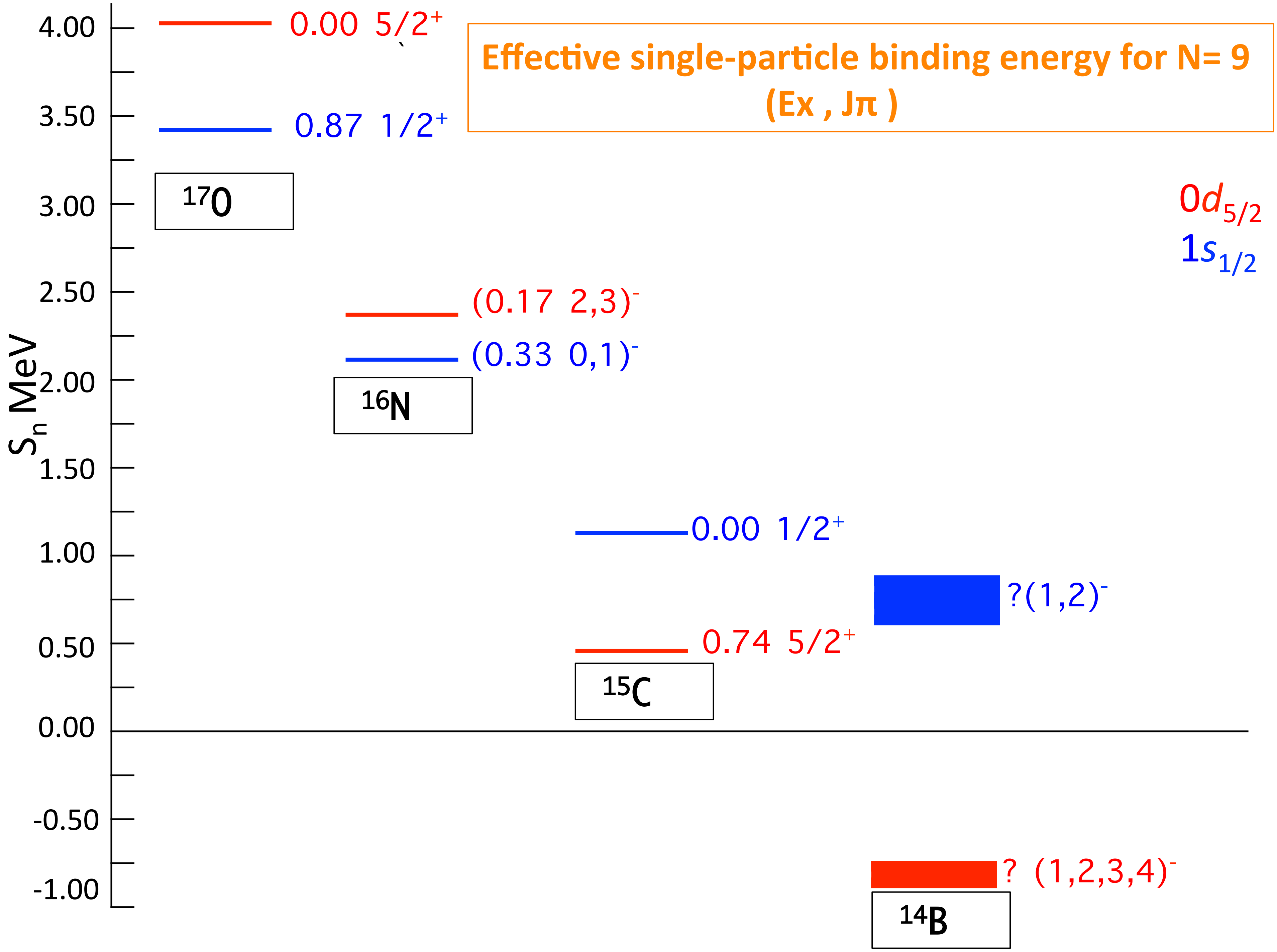
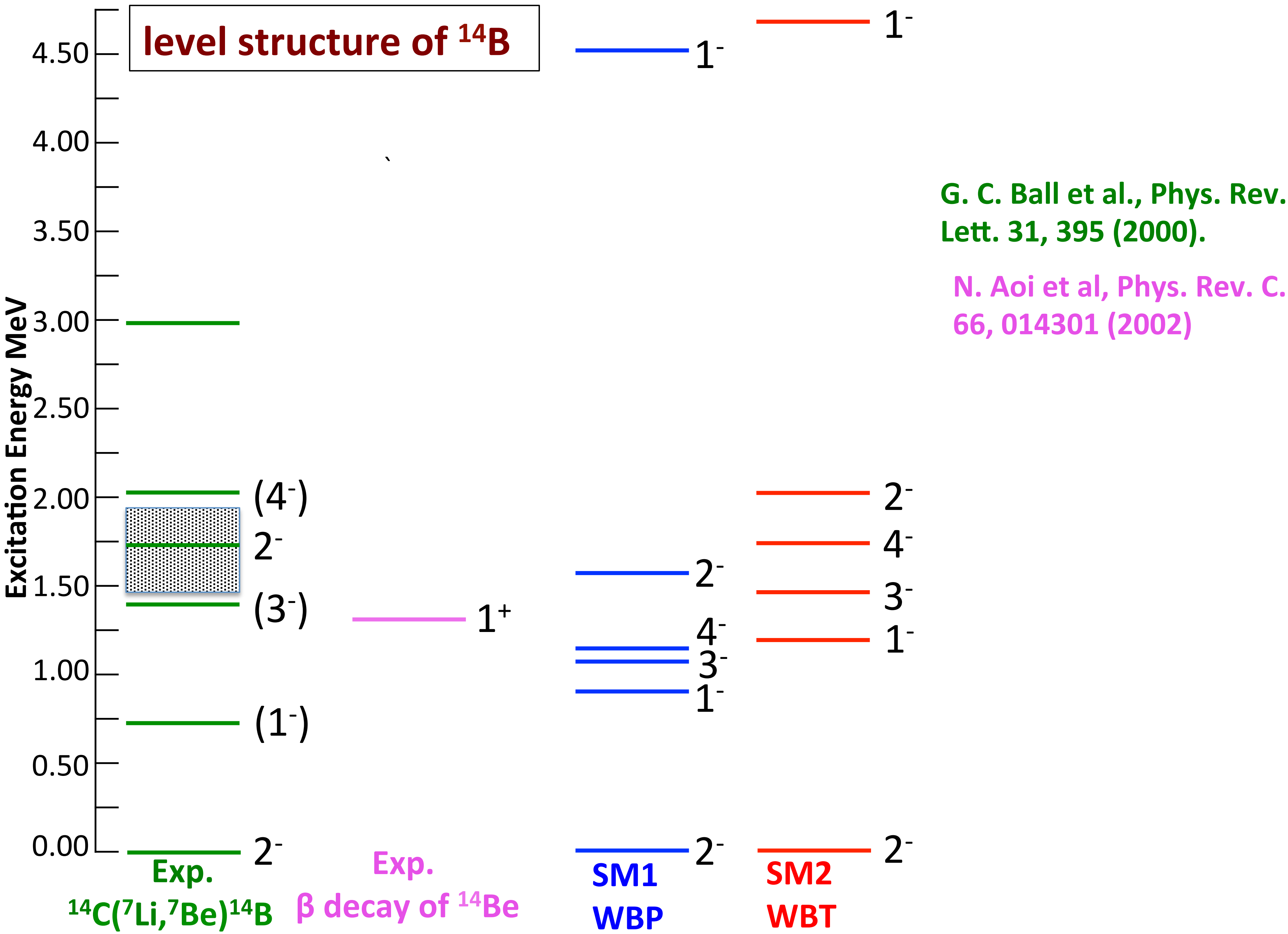
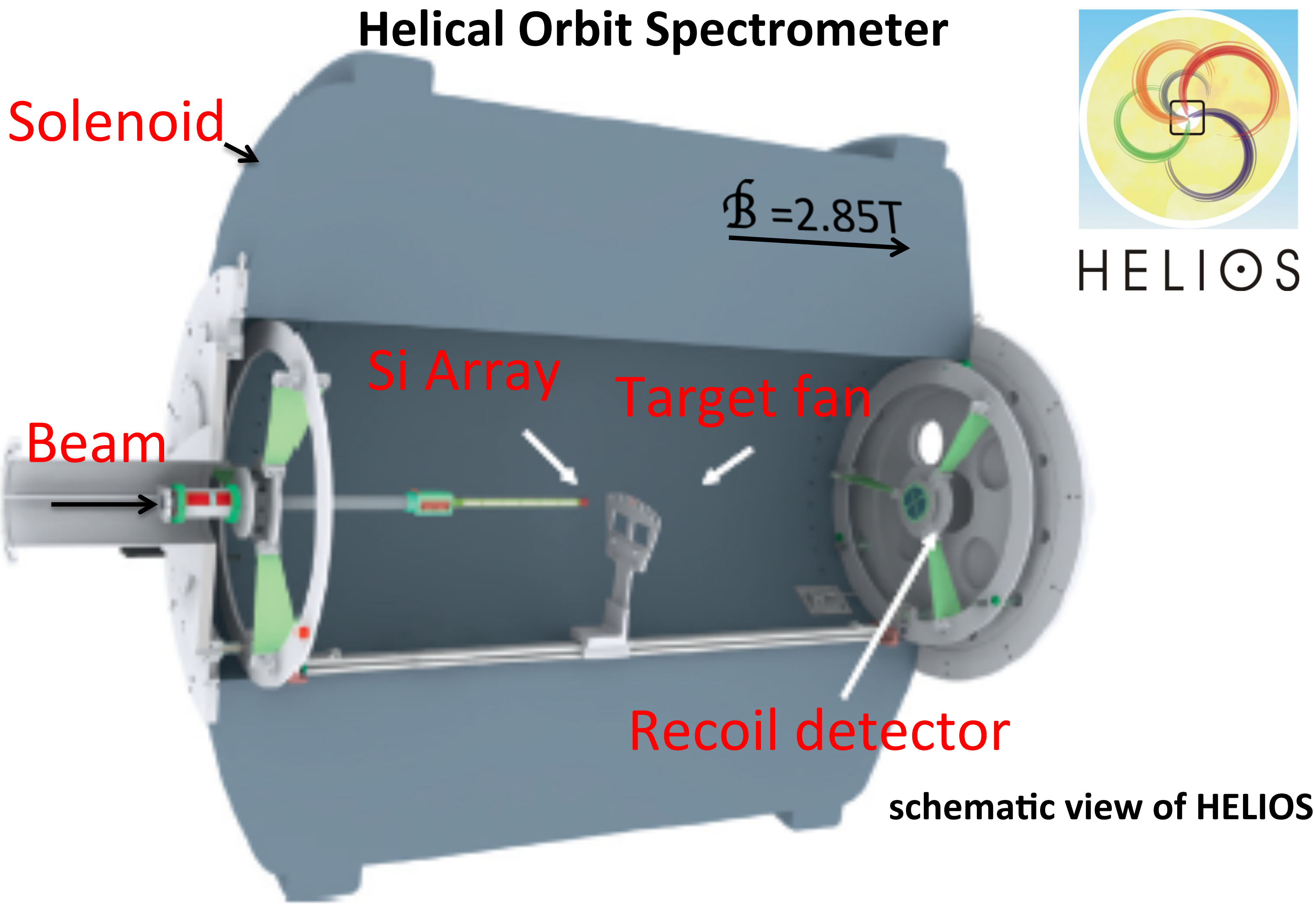
The Nucleus ^{14}B is the lightest N = 9 isotone that is particle-bound in its ground state.




Effective single-particle binding energy for N= 9
(Ex , Jπ)
$0d_{5/2}$
$1s_{1/2}$
S_n MeV
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0.00 5/2+
0.87 1/2+
17O
(0.17 2,3)-
(0.33 0,1)-
16N
0.00 1/2+
0.74 5/2+
15C
?(1,2)-
? (1,2,3,4)-
14B

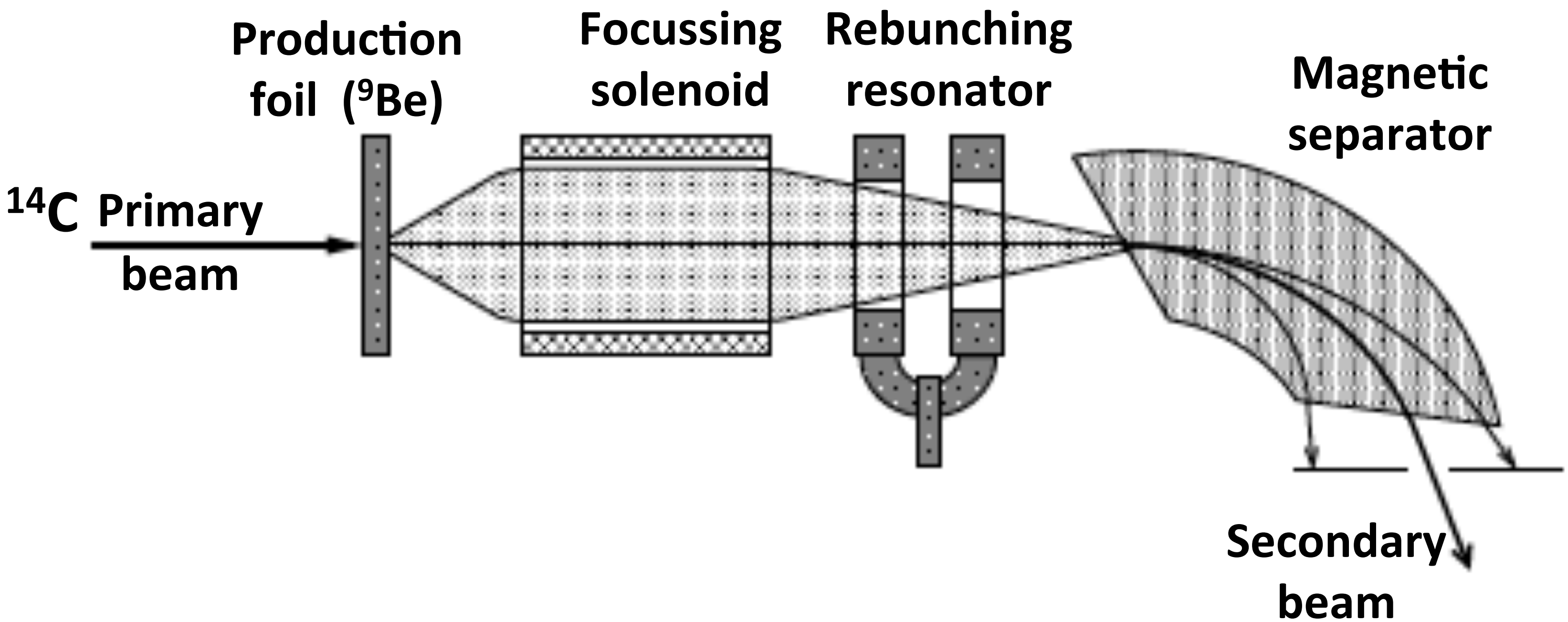


level structure of ^{14}B
Excitation Energy MeV
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
(4⁻)
2⁻
(3⁻)
(1⁻)
2⁻
1⁺
1⁻
2⁻
4⁻
3⁻
1⁻
2⁻
1⁻
2⁻
4⁻
3⁻
1⁻
2⁻
Exp.
$^{14}C(^{7}Li,^{7}Be)^{14}B$
Exp.
β decay of ^{14}Be
SM1
WBP
SM2
WBT
G. C. Ball et al., Phys. Rev. Lett. 31, 395 (2000).
N. Aoi et al, Phys. Rev. C. 66, 014301 (2002)



schematic view of HELIOS

- J.P. Schiffer, in: C. Baktash, I.Y. Lee, K.E. Rehm (Eds.), in:Proceedings of the Workshop on Experimental Equipment for and Advanced ISOL Facility, LBNL Report LBNL-43460, 1999, p. 669.
- A.H. Wuosmaa et al, Nuclear Instruments and Methods in Physics Research A 580 (2007) 1290–1300
- J.C. Lighthall et al, Nuclear Instruments and Methods in Physics Research A622 (2010) 97–106



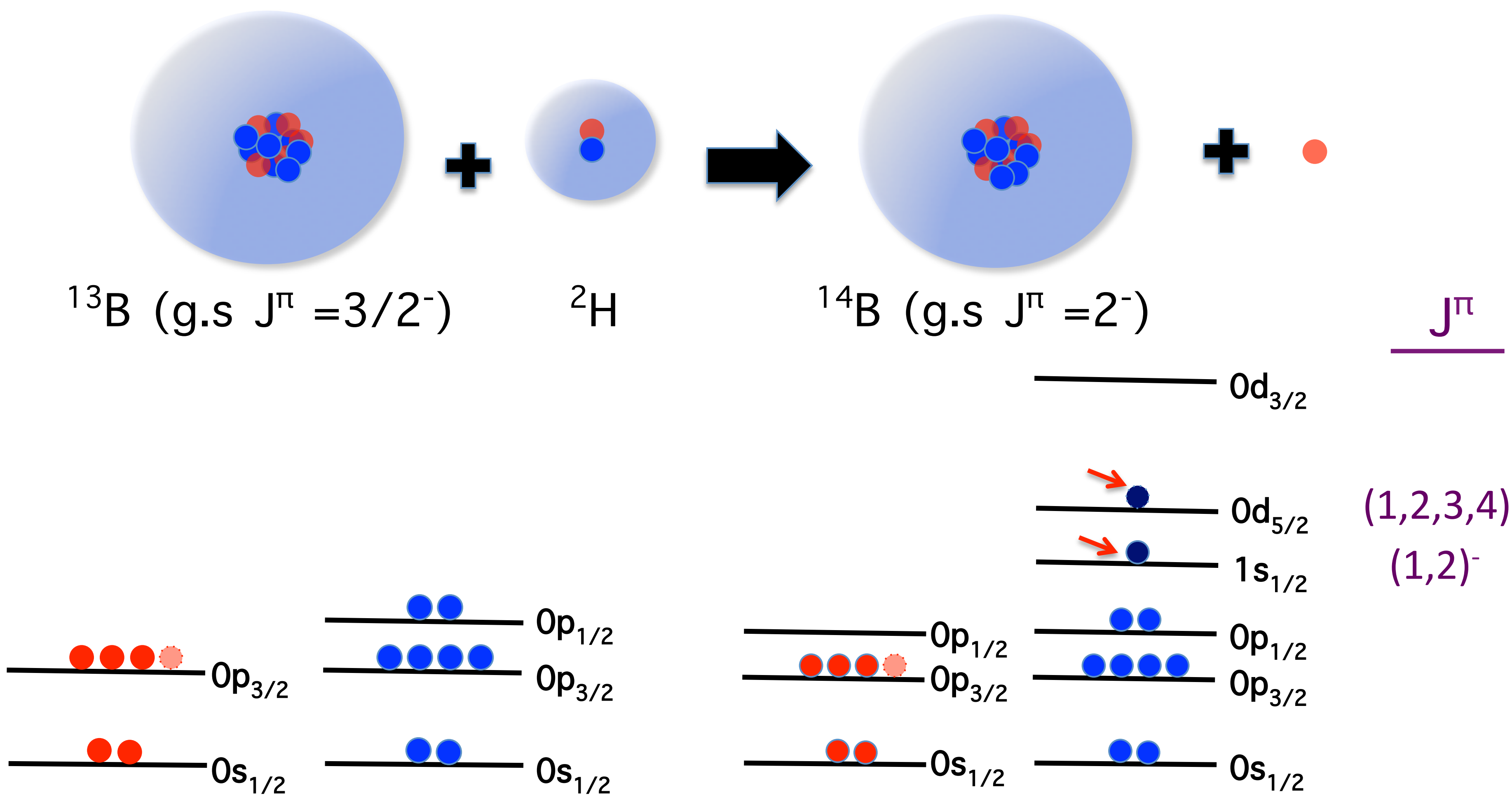
Primary Beam energy ~ 17.5 MeV/A

$^{9}Be(^{14}C,^{10}B)^{13}B$, Q-value = -14.246 MeV

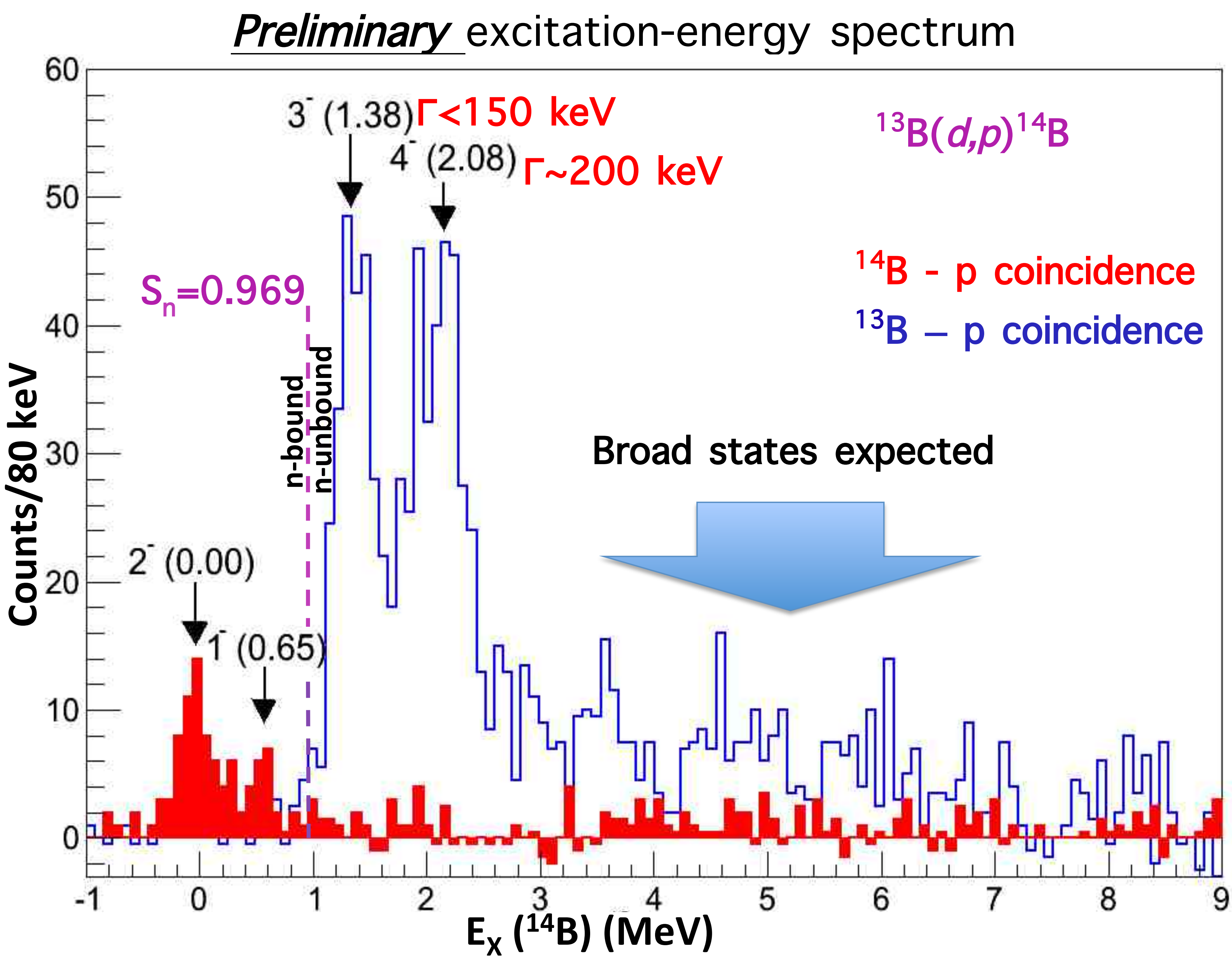
Secondary Beam energy ~ 15.7 MeV/A with intensity between 2-4 x 10^4 pps

Harss et al, REVIEW OF SCIENTIFIC INSTRUMENTS VOLUME 71, NUMBER 2, 2000

$d(^{13}B,p)^{14}B$

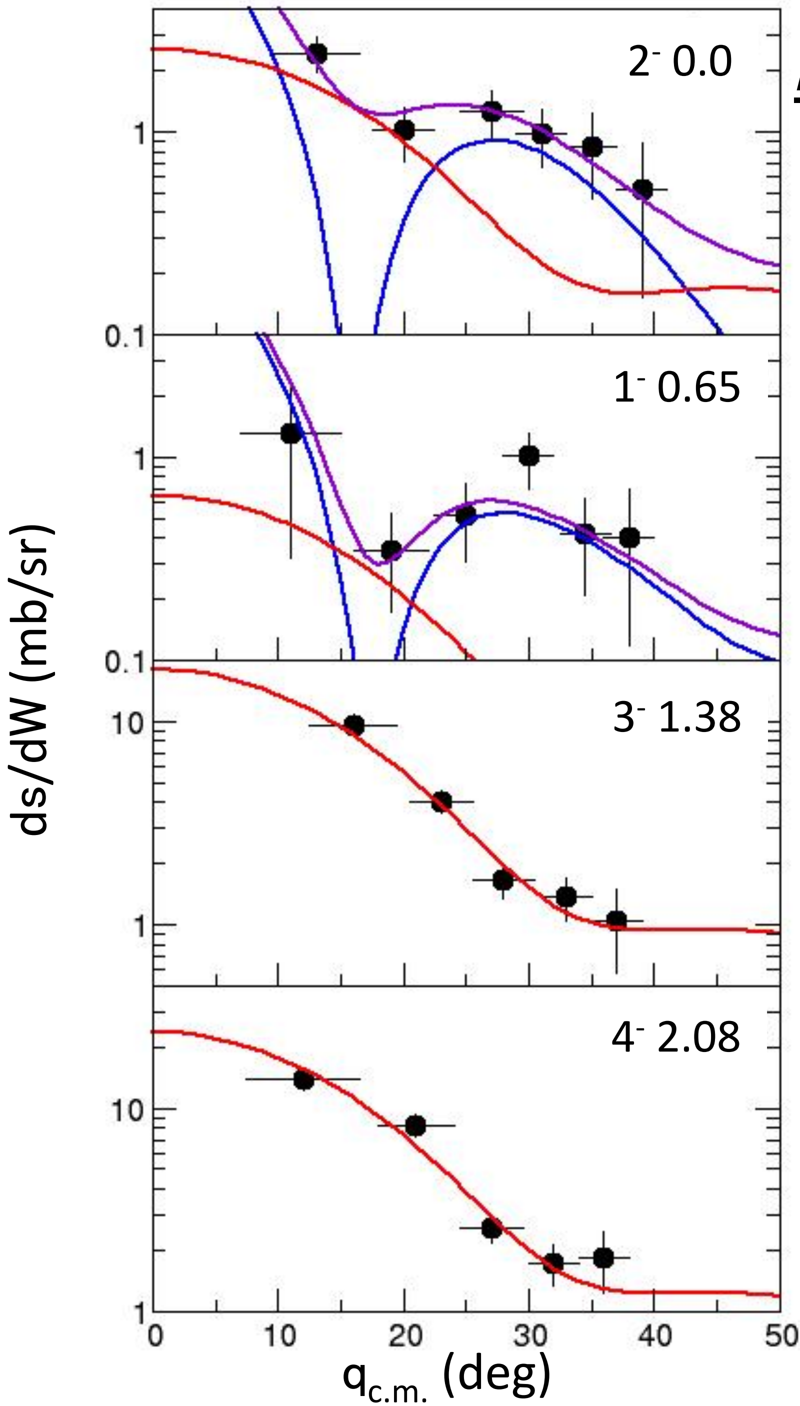


*Assuming no contribution from $0d_{3/2}$



Preliminary excitation-energy spectrum
3- (1.38) Γ<150 keV
4- (2.08) Γ~200 keV
$^{13}B(d,p)^{14}B$
^{14}B - p coincidence
^{13}B – p coincidence
S_n=0.969
n-bound
n-unbound
Broad states expected
2- (0.00)
1- (0.65)
Counts/80 keV
E_X (^{14}B) (MeV)

Preliminary $^{13}B(d,p)^{14}B$ angular distributions



Blue: L=0

Red: L=2

Violet: L=0 + L=2

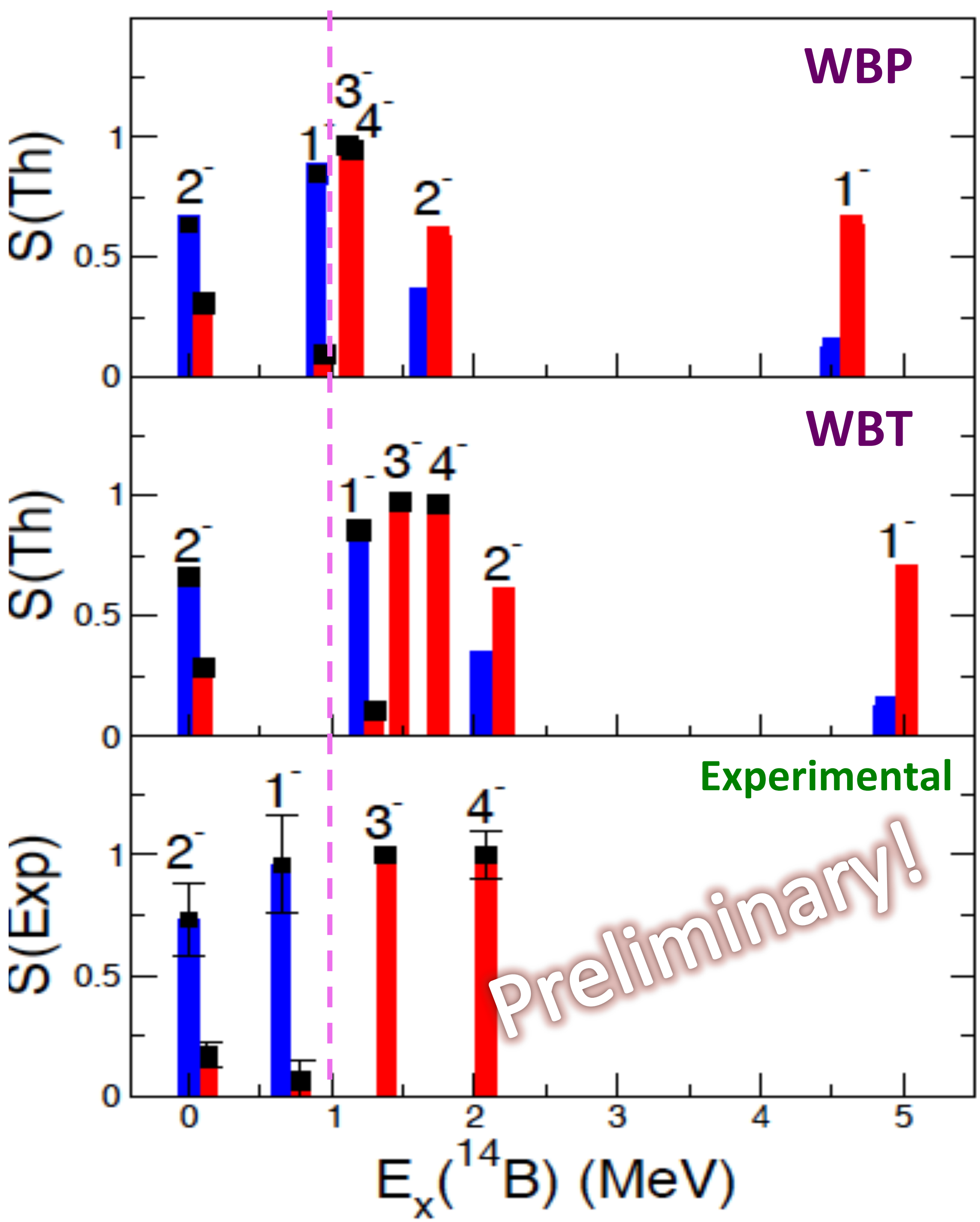
$2^-(0.00)$: $S_0=.71$ $S_2=.17$

$1^-(0.65)$: $S_0=0.96$ $S_2=.06$

$3^-(1.38)$: $S_2=1.00$ (fixed)

$4^-(2.08)$: $S_2=1.00$

OMPs fit 30 MeV $d+^{12}C$, $p+^{12,13}C$ elastic scattering



$^{13}B(d,p)^{14}B$ Excitation energies and relative spectroscopic factors from the shell model (upper two windows; WBP and WBT), and from the experimental data (lower window)

Blue: L=0, $1s_{1/2}$

Red: L=2, $0d_{5/2}$

Assume no contribution from $0d_{3/2}$

2^- mixed L=0+2

1^- ~ pure L=0

Sum Rules and ^{13}B(d,p)^{14}B

$$J_i^\pi = 3/2^- \ , 1s_{1/2} : J_f^\pi = (1,2)^- \ , for \ \ 0d_{5/2} : J_f^\pi = (1,2,3,4)^-$$

$$\#holes \ = \sum_n S_n \frac{(2J_f + 1)_n}{(2J_i + 1)_n}$$

$$\#holes \ for \ s_{1/2} \ = 2 \ and \ for \ d_{5/2} \ = 6$$

$experimentally$:

$$1s_{1/2} : \#holes = 1.6$$

$$0d_{5/2} : \#holes = 4.3$$

Assume no contribution from $0d_{3/2}$

M. H. MACFARLANE and J. B. FRENCH, Rev. Mod. Phys. 32 (1960)

Low-lying 1^- and 2^- states in ^{14}B

Assume no contribution from $0d_{3/2}$

$$\psi(2_1^-) = \alpha_2 \upsilon(1s_{1/2}) + \beta_2 \upsilon(0d_{5/2})$$

$$\psi(2_2^-) = -\beta_2 \upsilon(1s_{1/2}) + \alpha_2 \upsilon(0d_{5/2})$$

Observed

$$\psi(1_1^-) = \alpha_1 \upsilon(1s_{1/2}) + \beta_1 \upsilon(0d_{5/2})$$

$$\psi(1_2^-) = -\beta_1 \upsilon(1s_{1/2}) + \alpha_1 \upsilon(0d_{5/2})$$

Observed

α_J and β_J given by S.F; S_0 and S_2

Then:

Experimentally;

$$1s_{1/2} : \#holes = \; 1.9$$

$$0d_{5/2} : \#hole = 5.9$$

Compared to the sum-rule values of 6.0 and 2.0 for $0d_{5/2}$ and $1s_{1/2}$ respectively.

Can we estimate the $1s_{1/2}$ and $0d_{5/2}$ single-particle energies in ^{14}B?

No narrow states left.

We assume $^{14}B(2^-_2)$ is the broad state at 1.86 MeV,

and we assume $^{14}B(1^-_2)$ is a broad state at 3.6 MeV

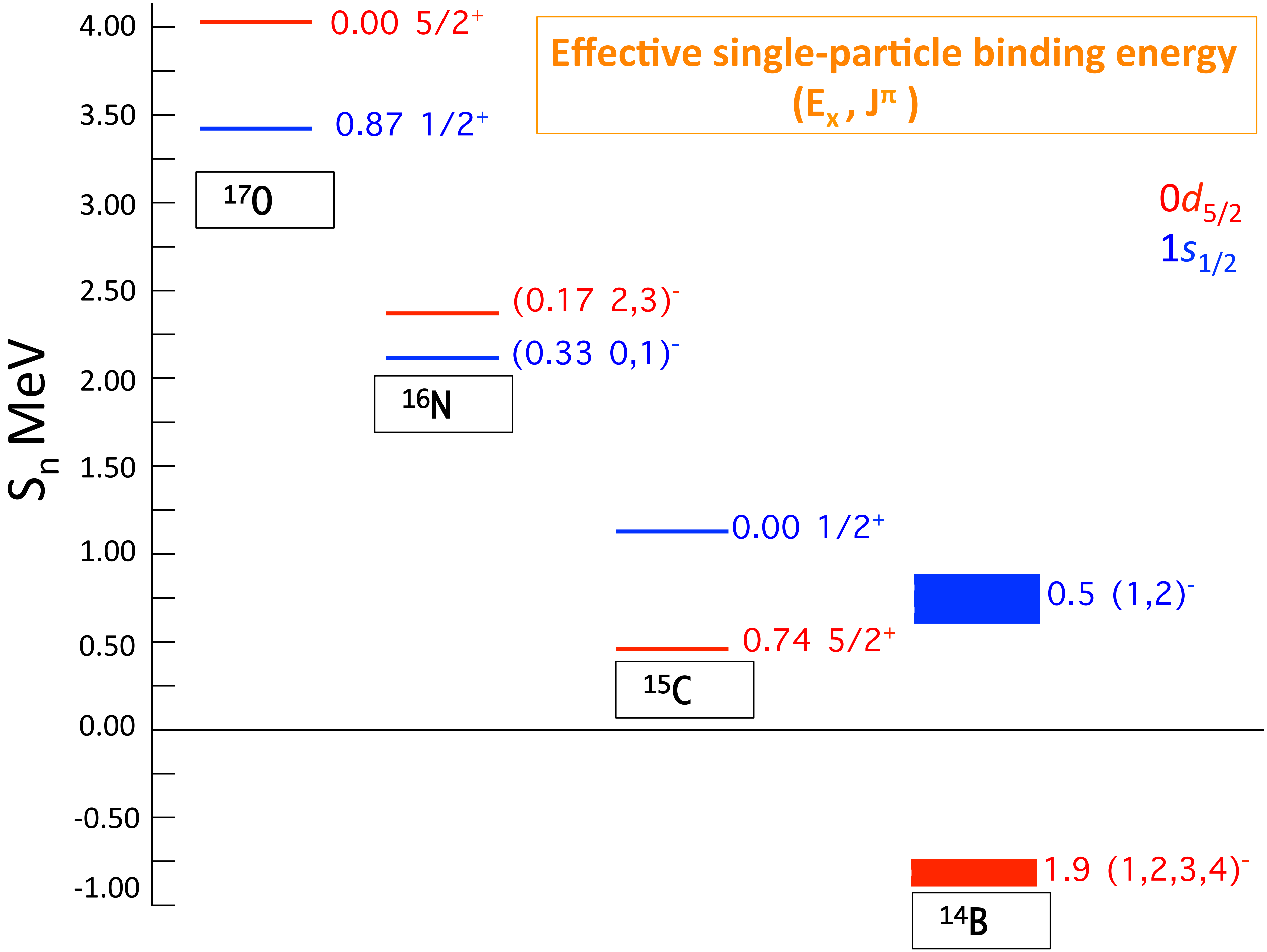
$$\langle E_0 \rangle_J = \frac{\sum_n (2j_n+1)\, S_n \;\; E_n}{\sum_n (2j_n+1)\, S_n}$$

Then:

$<E_0>_{(1s1/2)}=0.5$ MeV

$<E_0>_{(0d5/2)}=1.9$ MeV

$<E_0>_{(0d5/2)}-<E_0>_{(1s1/2)}=1.4$ MeV


Effective single-particle binding energy
(E_x , J^π)
S_n MeV
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0.00 5/2+
0.87 1/2+
17O
(0.17 2,3)-
(0.33 0,1)-
16N
0.00 1/2+
0.74 5/2+
15C
0.5 (1,2)-
1.9 (1,2,3,4)-
14B
0d5/2
1s1/2

Conclusions

4 negative parity states had been observed; namely $(2,1,3,4)^-$ at energies: 0.00, 0.65, 1.38, and 2.08 MeV respectively.

The ground state has a mix of L= 0 and L= 2 , dominated by the s-wave configuration with a loosely bound valance neutron: one neutron halo nucleus.

The first excited state (1^-) has a nearly pure s-wave configuration. Is better halo than the g.s.

The s-d splitting is increased compared to ^{15}C.

The 4^- state shows a natural width $\Gamma \sim 200$ keV consistent with S.F. $(4^-) = 1.0$ ($\Gamma_{s.p} \approx 200$ keV).

Thank you all

^{13}Be s.p. energies from n-knockout

286 *H. Simon et al. / Nuclear Physics A 791 (2007) 267–302*

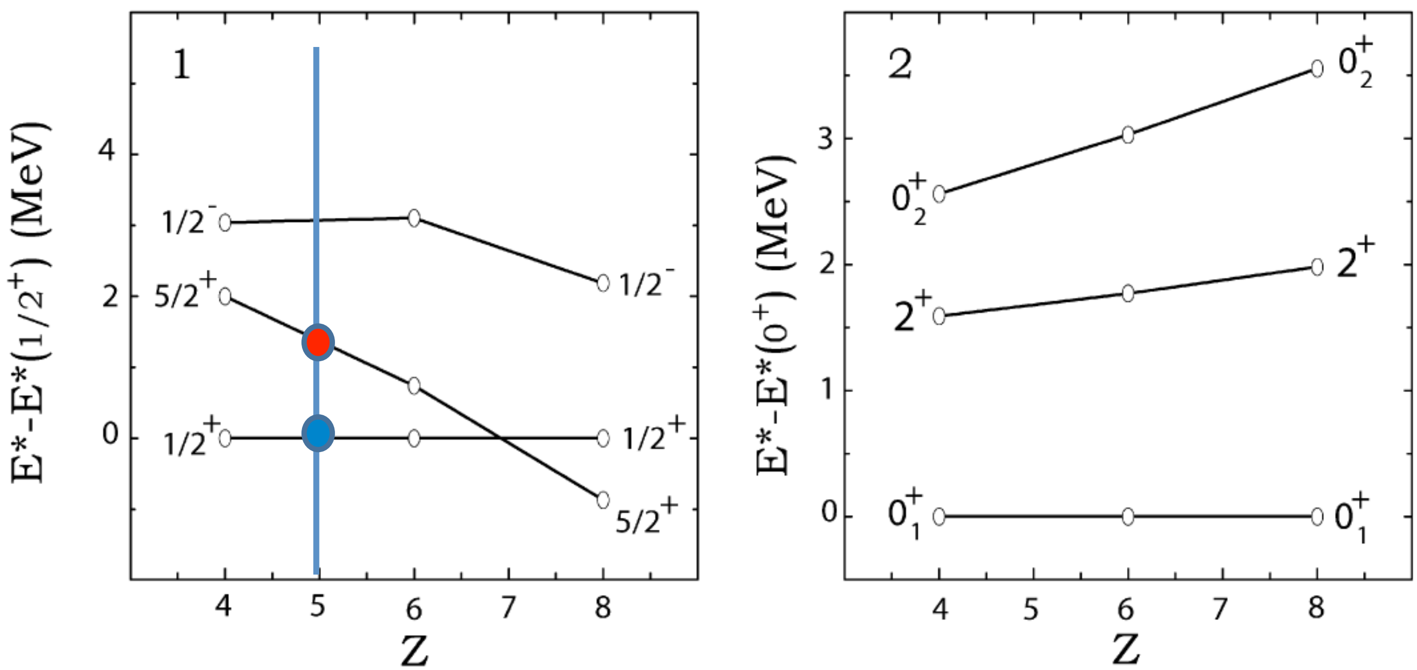
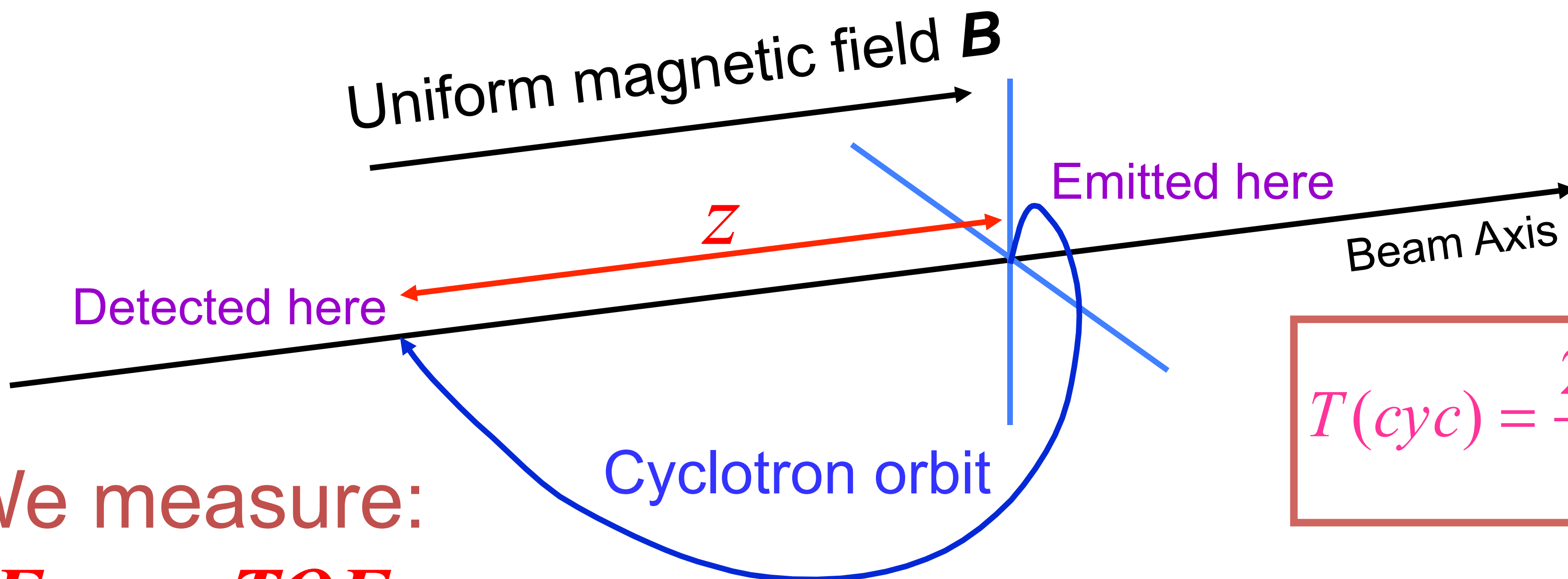


Fig. 8. Level schemes for $N = 9$ and $N = 10$ isotones. Panel 1 shows the energies of $1/2^+$, $1/2^-$ and $5/2^+$ states in ^{13}Be , ^{15}C and ^{17}O, relative to the energy of $1/2^+$ state. Panel 2 shows the energies of the 0_2^+ and 2^+ states for ^{14}Be, ^{16}C and ^{18}O, relative to the energy of the first 0_1^+ state.

The HELIOS approach to inverse kinematics



$$T(cyc) = \frac{2\pi m}{qB}$$

We measure:

E_{lab}, z, TOF

We deduce:

E_{CM}, q_{CM}

$$\mathrm{Cos}(\theta_{c.m.}) \propto Z$$

$$E_{c.m.} = E_{lab} + A - BZ$$

For a given state

$$\Delta E_{c.m.} = \Delta E_{lab}$$

For two states at fixed z

HELIOS

PHYSICAL REVIEW C **81**, 021301(R) (2010)

Ab initio nuclear structure simulations: The speculative ^{14}F nucleus

P. Maris,[1] A. M. Shirokov,[1,2,*] and J. P. Vary[1]

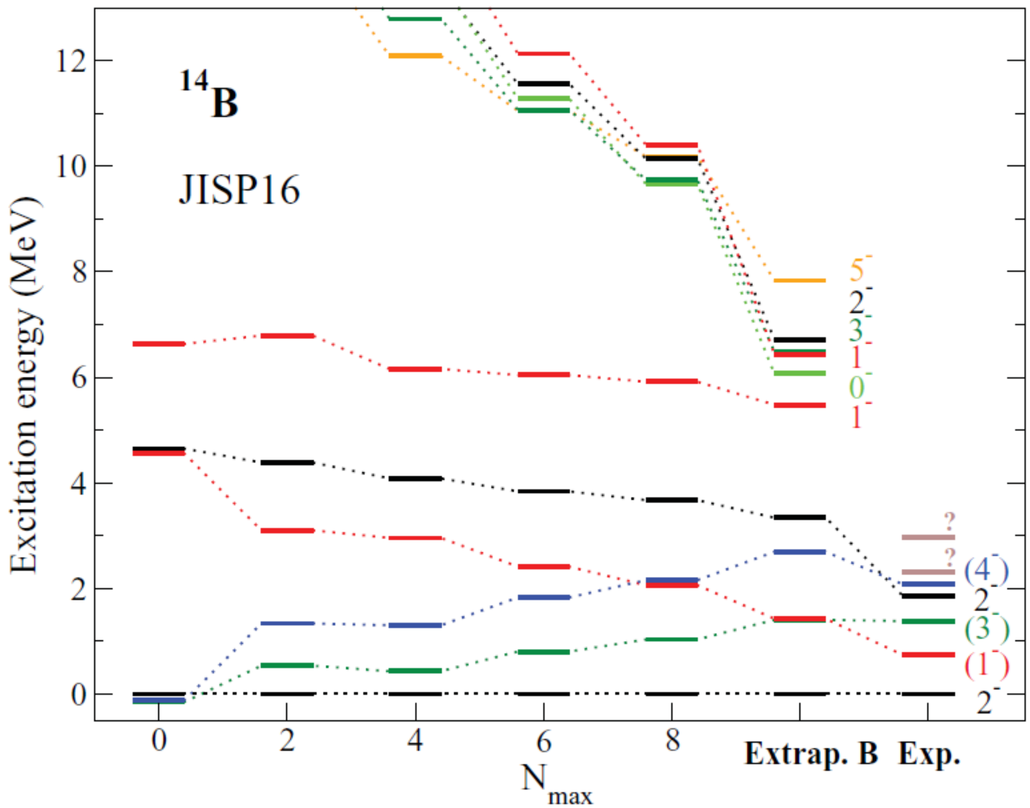
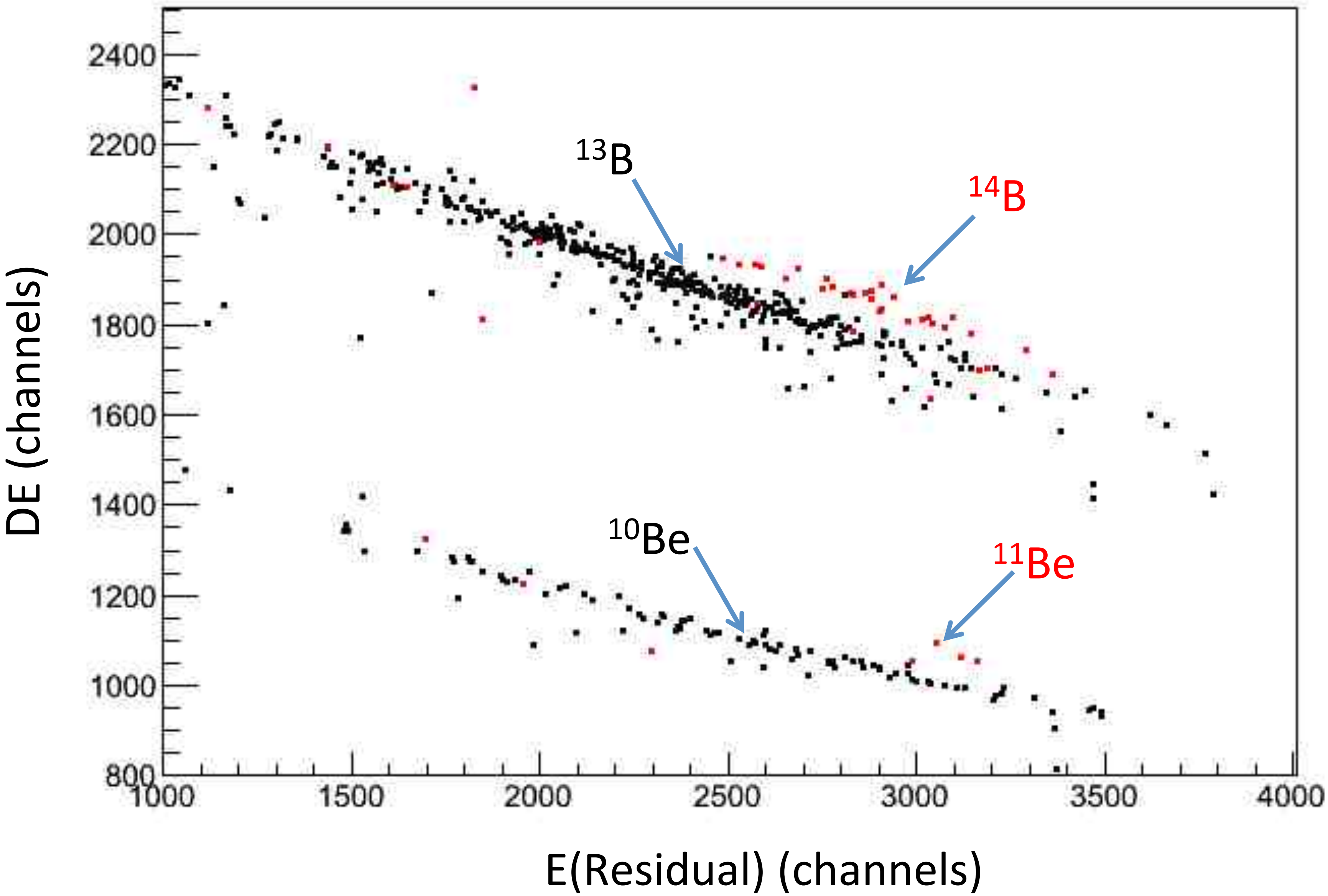
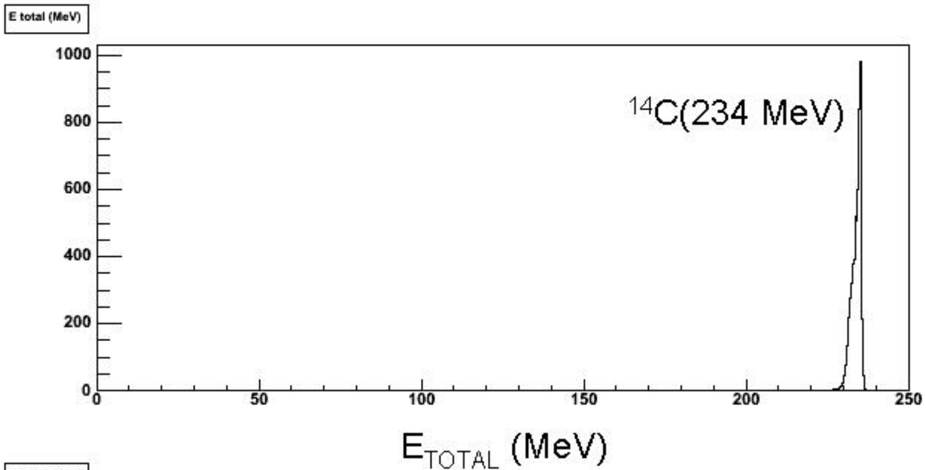


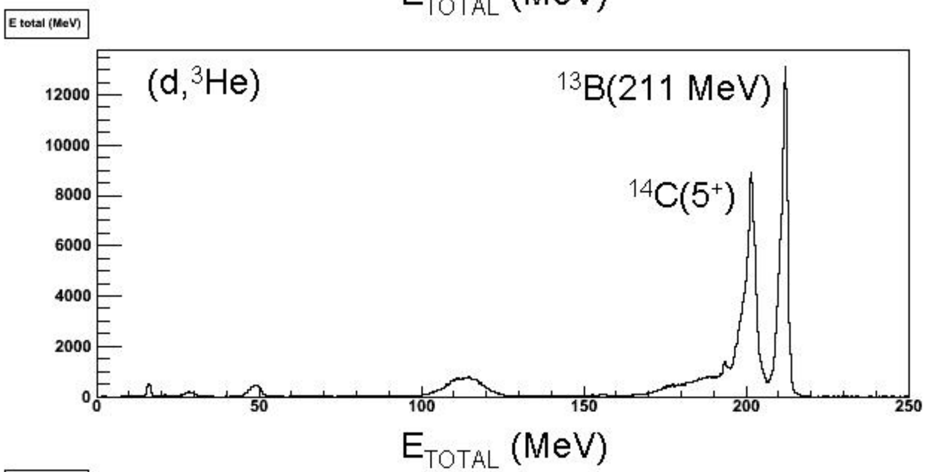
FIG. 3. (Color online) Negative-parity ^{14}B spectrum obtained with JISP16 at fixed $\hbar\Omega = 25$ MeV in successive basis spaces and extrapolated to infinite basis space using extrapolation B. Experimental (exp.) data are taken from Ref. [13].

Recoil particle identification

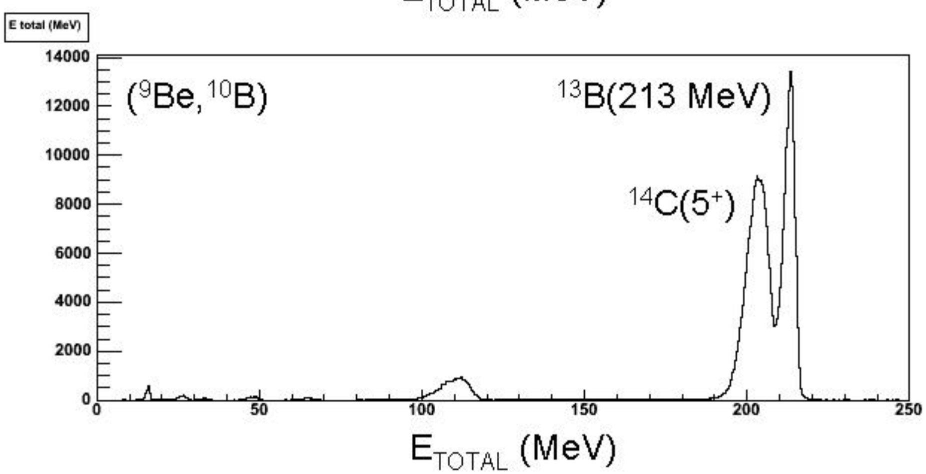


^{13}B beam quality



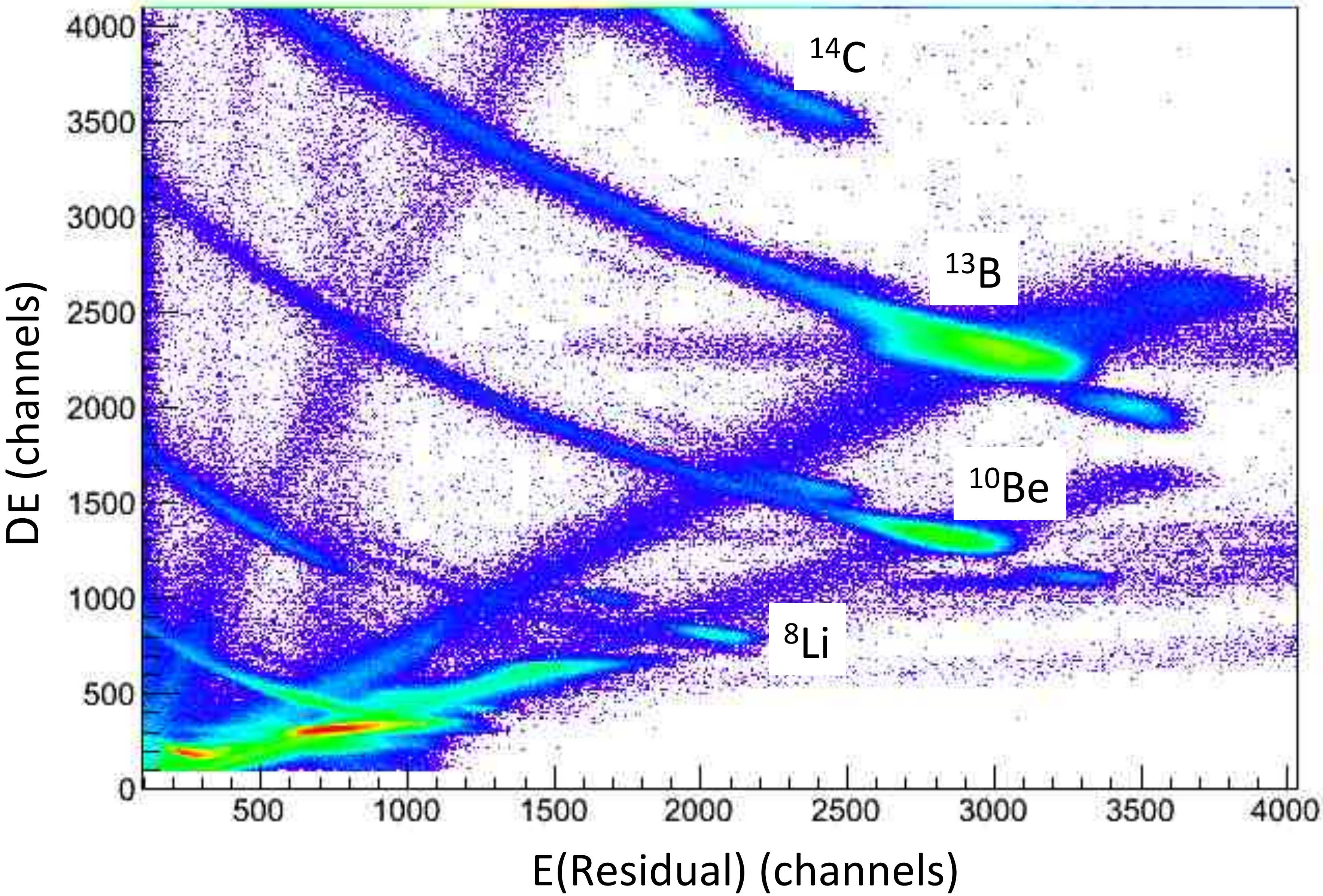


From $d(^{14}C,^{13}B)^{3}He$
$2X10^{4}$ pps

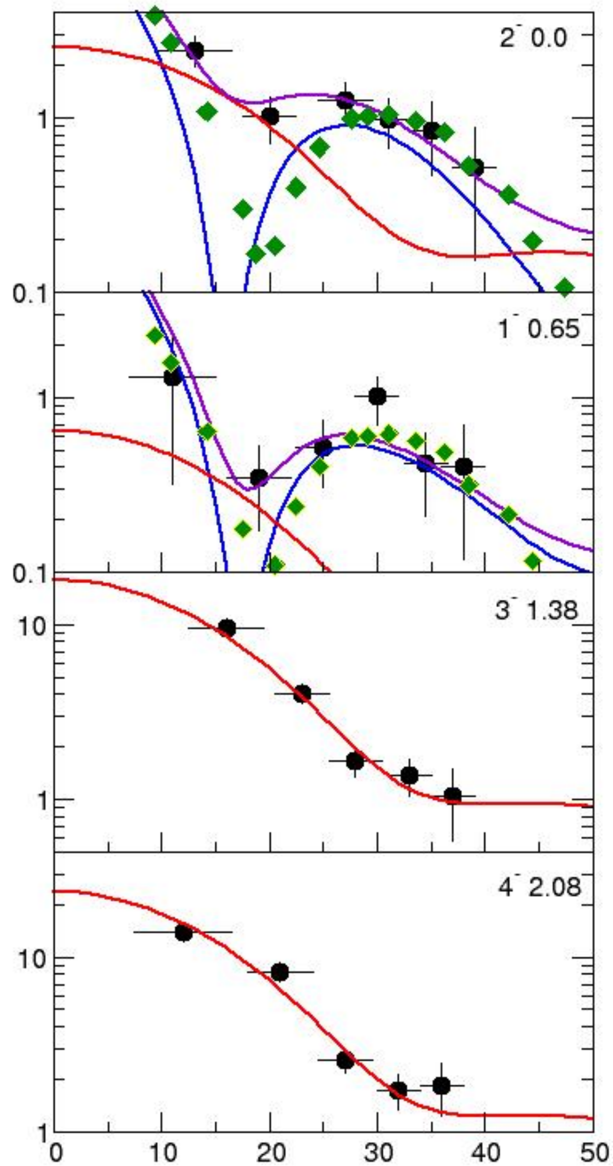


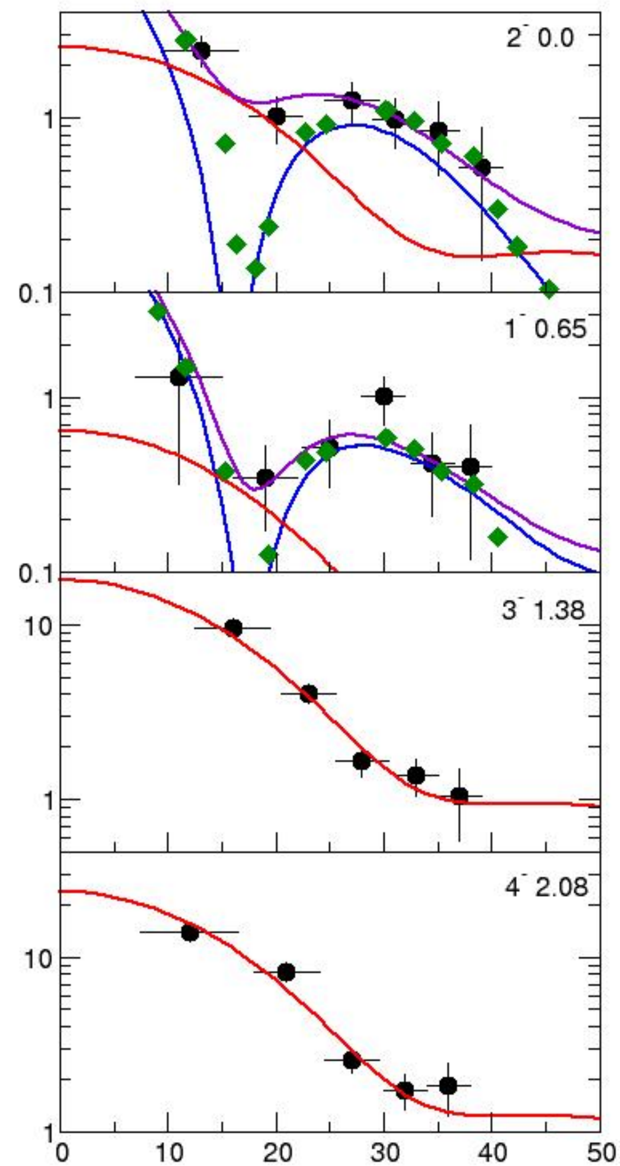
From $^{9}Be(^{14}C,^{13}B)^{10}B$
$4X10^{4}$ pps

^{13}B and friends… from $^{14}C+^{9}Be$

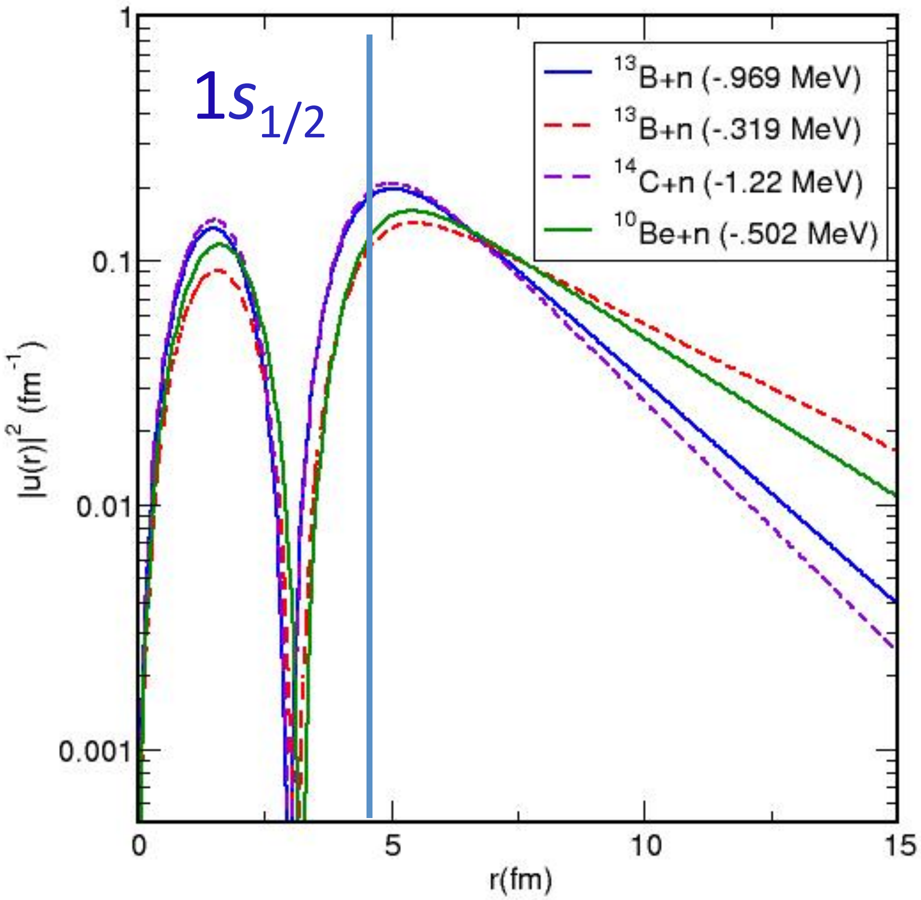


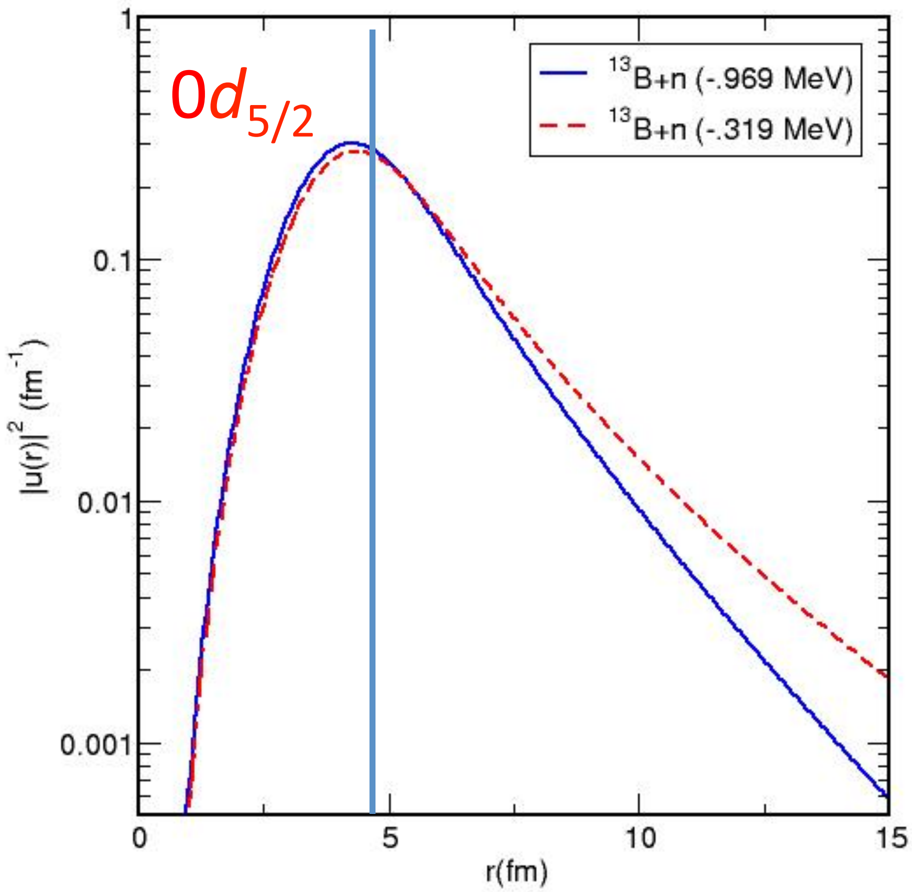
With $^{16}O(d,p)^{17}O(1/2+)$





$1s_{1/2}$ and $0d_{5/2}$ neutron form factors





Woods-Saxon potential, r_0=1.35, a=.6, V_0 adjusted for BE

Table 1
Levels in ^{14}F.

E_R (MeV)[a]	E_x[b]	J^π	Γ (keV)	Γ/Γ_{sp}
1.56 ± 0.04	0.00	2^-	910 ± 100	0.85
2.1 ± 0.17	0.54	1^-	~ 1000	0.6
3.05 ± 0.060	1.49	3^-	210 ± 40	0.55
4.35 ± 0.10	2.79	4^-	550 ± 100	0.5

[a] Energy above ^{13}O + p decay threshold.
[b] Excitation energy in ^{14}F.

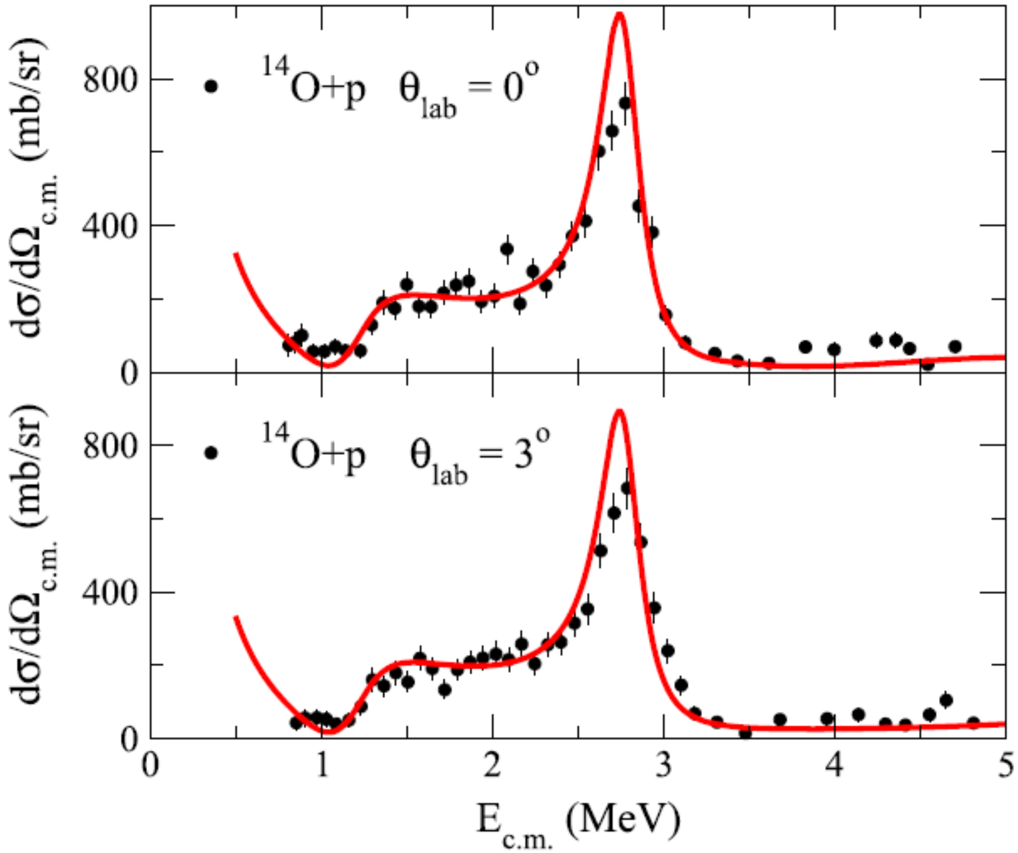
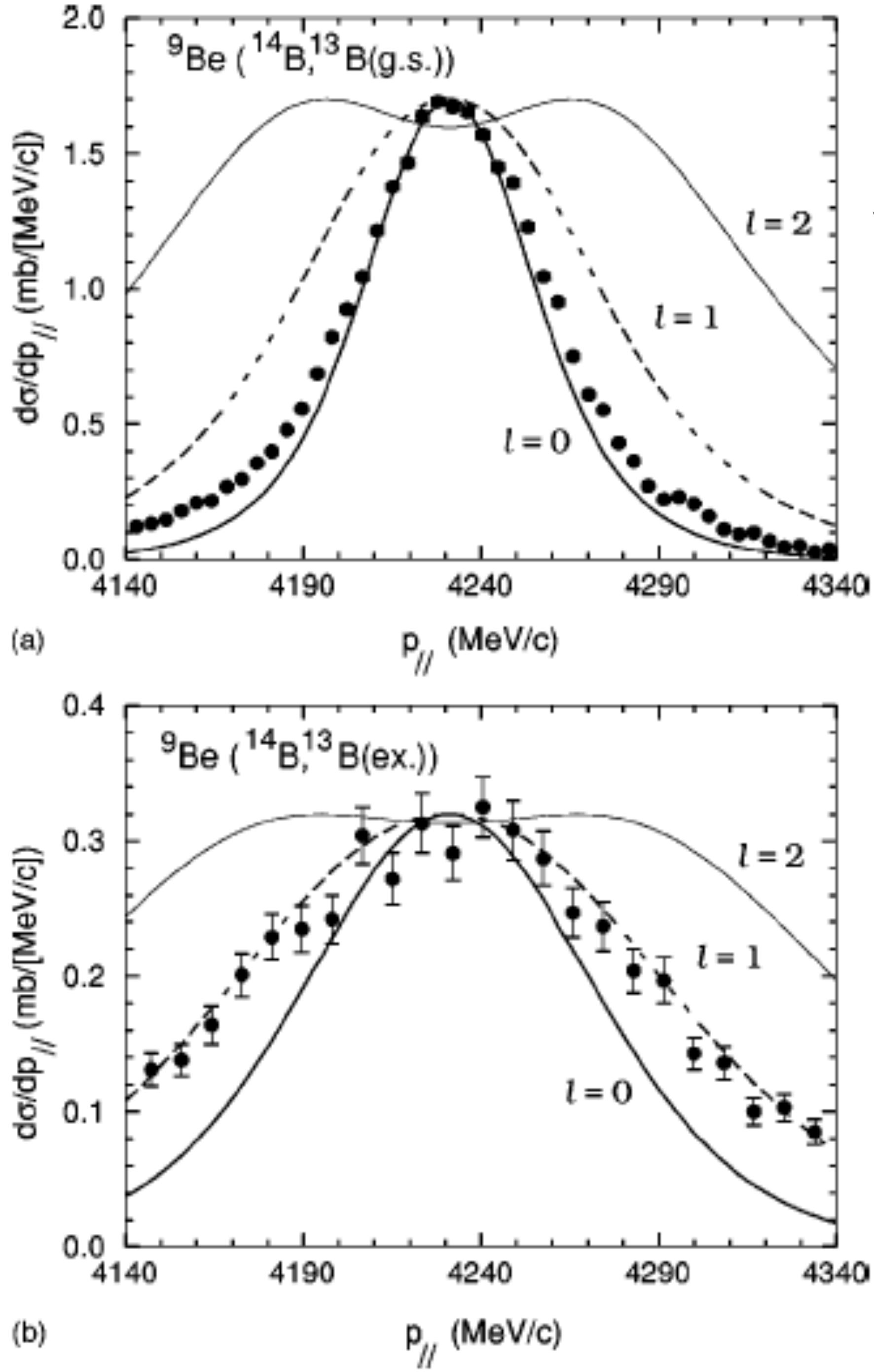


Fig. 4. (Color online.) Results of ^{14}O + p calibration measurements from this work compared with potential model calculations from [8].

^{14}F from p+^{13}O (TAMU)



Spectroscopy of ^{13,14}B via the one-neutron knockout reaction

V. Guimaraes et al, PHYSICAL REVIEW C, VOLUME 61, 064609