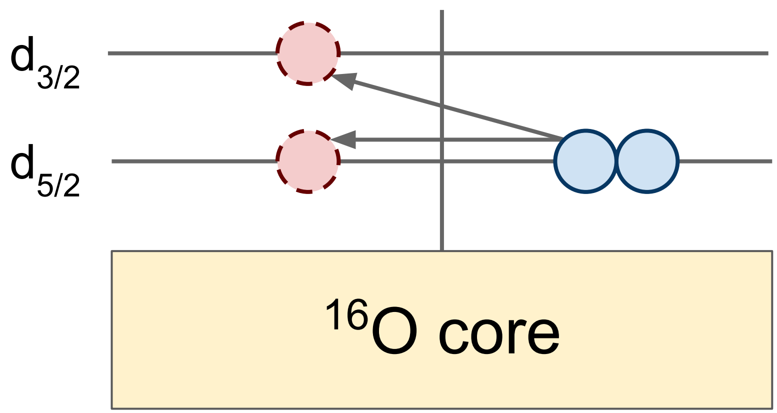
Low-Energy Super GT state observed in the high resolution $^{18}O(^{3}He,t)$ measurement at 0-degree

Hirohiko Fujita (RCNP, Osaka)



2015/11/16-19, “High-resolution Spectroscopy and Tensor interactions”, HST15

Experiment

$^{18}O(^{3}He,t)$ measurement at 0-degree

Spectrometer angle : 0-degree
Incident energy : 140 MeV/nucleon
Target : Gas target system†, with Aramid foil
FP Detector : Two VDCs (X+U) and two plastics
Beam transport : Lateral and angular dispersion matching
Vertical scatt. angl. : Over-focus mode††

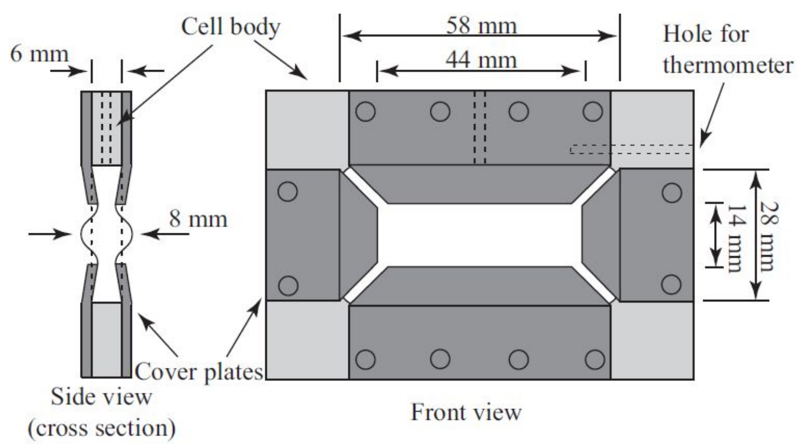
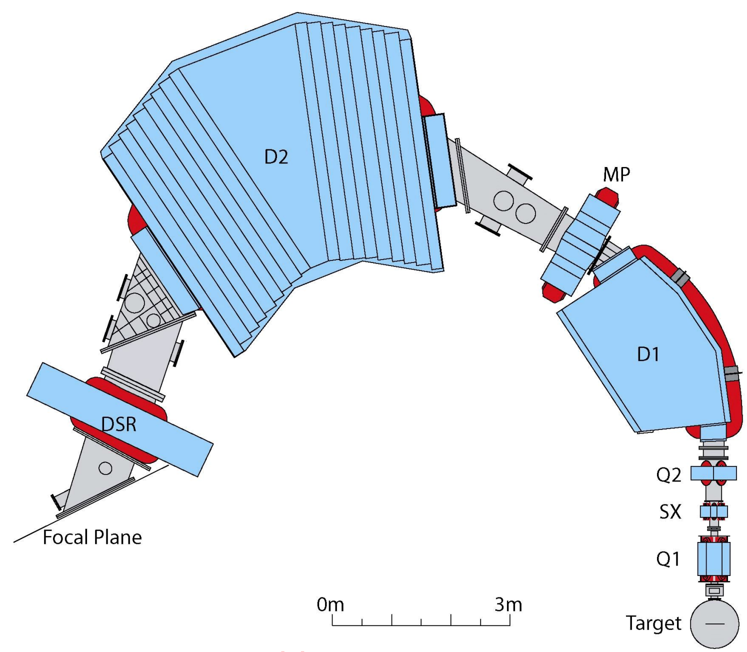
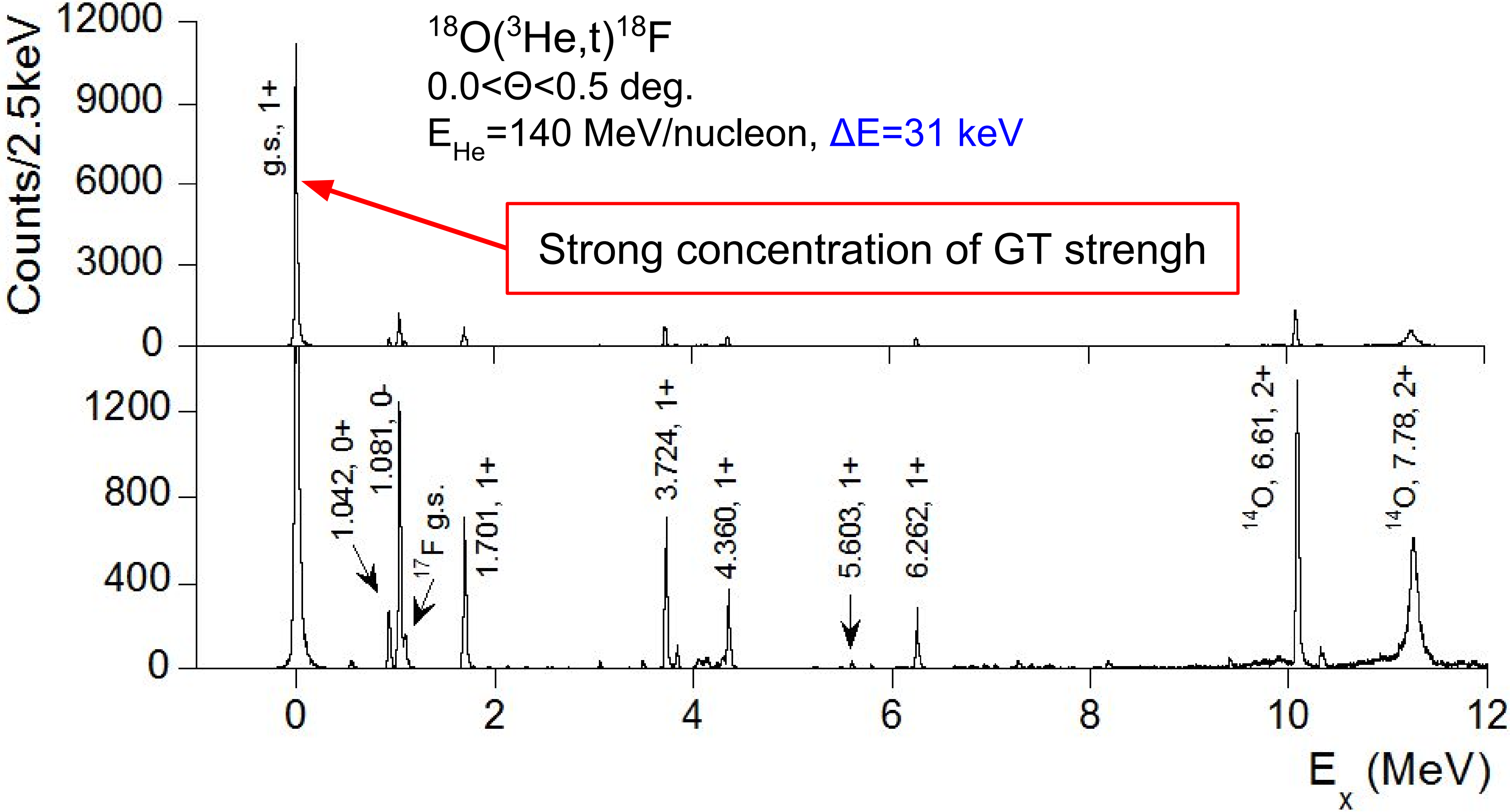


Fig. 5. Schematic figure of a target cell. The cell body is made of copper. The cover plates are made of aluminum. Aramid films with a thickness of 6 µm are used as the window foils.



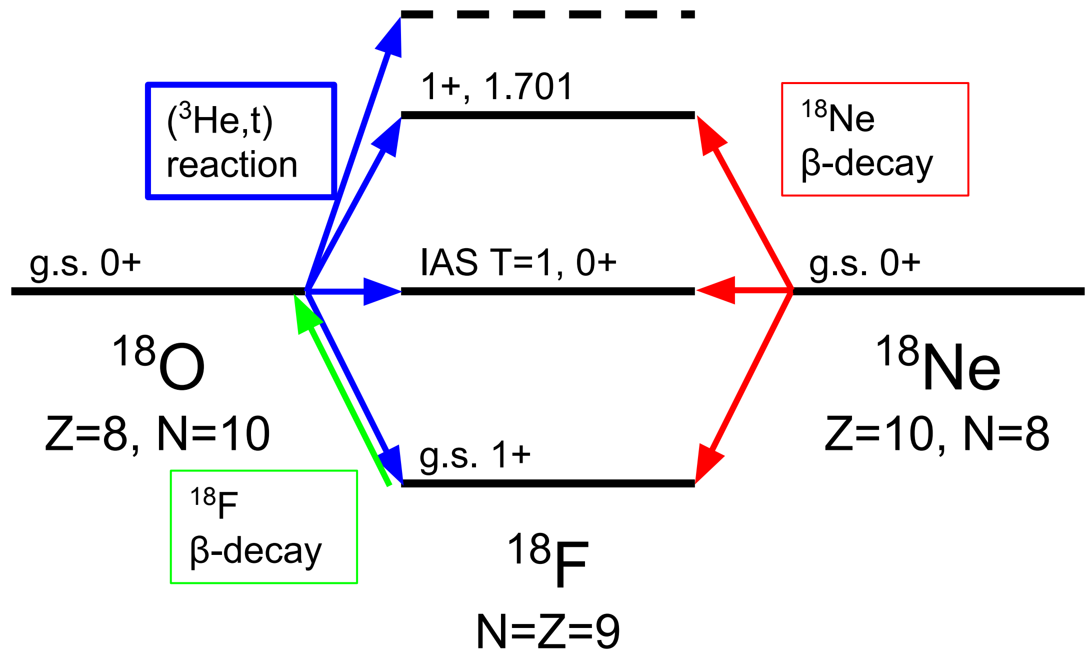
† H. Matsubara et. al., NIM A678, 122 (12), ††H. Fujita et, al., NIM A469, 55 (01)

Spectrum



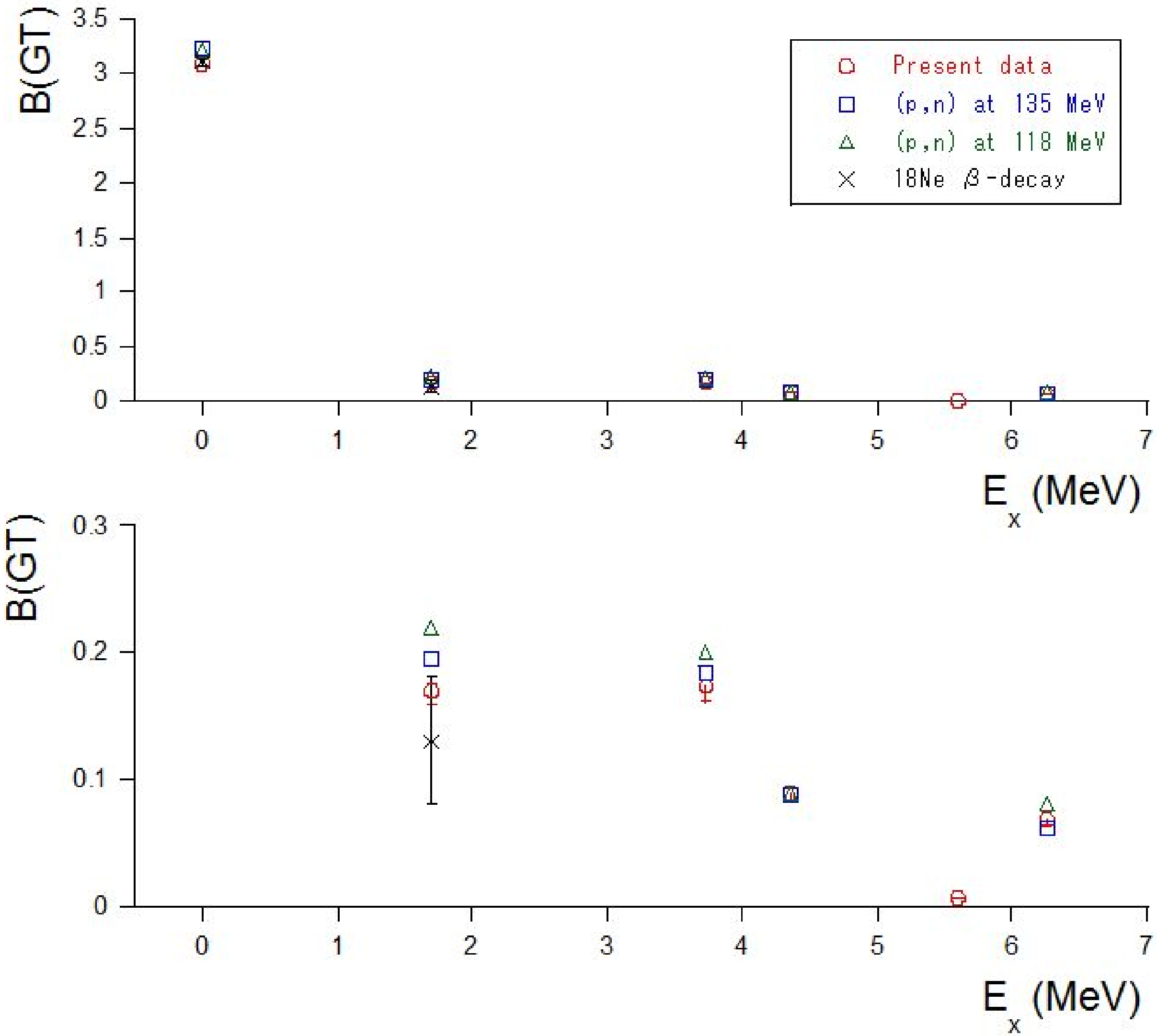
$^{18}O(^{3}He,t)^{18}F$
0.0<Θ<0.5 deg.
E_{He}=140 MeV/nucleon, ΔE=31 keV
Strong concentration of GT strengh
Counts/2.5keV
12000
9000
6000
3000
0
1200
800
400
0
g.s., 1+
1.042, 0+
1.081, 0-
^{17}F g.s.
1.701, 1+
3.724, 1+
4.360, 1+
5.603, 1+
6.262, 1+
^{14}O, 6.61, 2+
^{14}O, 7.78, 2+
0
2
4
6
8
10
12
E_x (MeV)

Absolute B(GT) values from β-decay



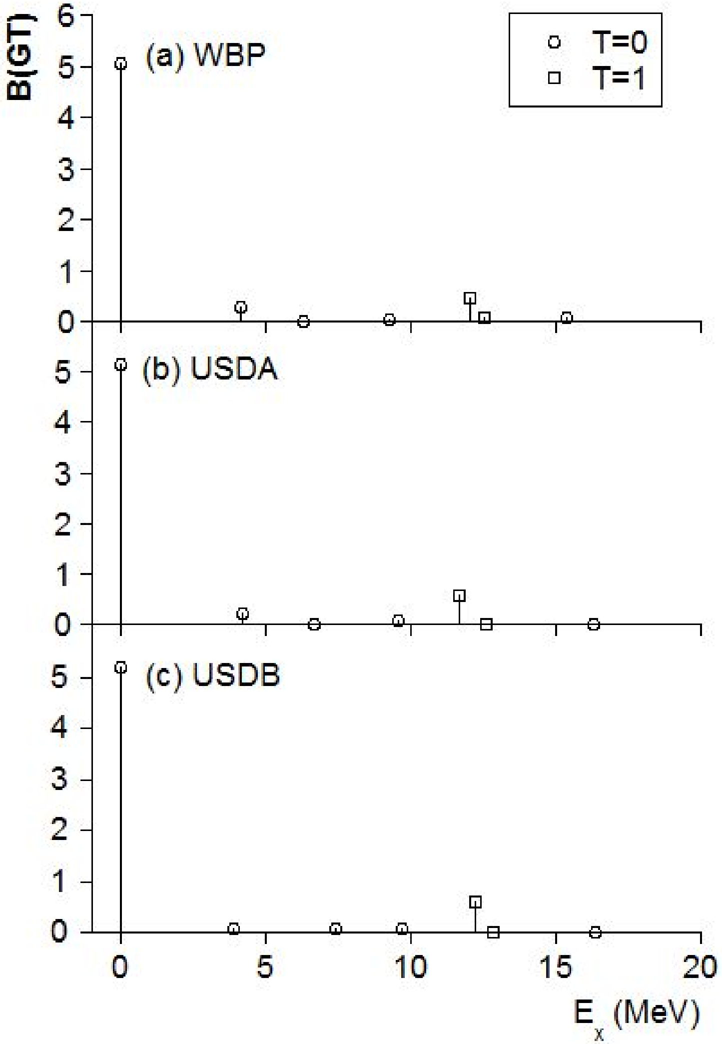
	^{18}F β-decay (J coupling factor considered)	^{18}Ne β-decay
g.s., 1+	3.092(16)	3.11(3)
IAS, 0+		2.1(2)
1+, 1.701		0.130(5)

B(GT) distributions



B.D. Anderson et al., PRC 27, 1387 (83), I.J. van Heerden et al., PRC 59, 1488 (1999)

Shell-model calculation

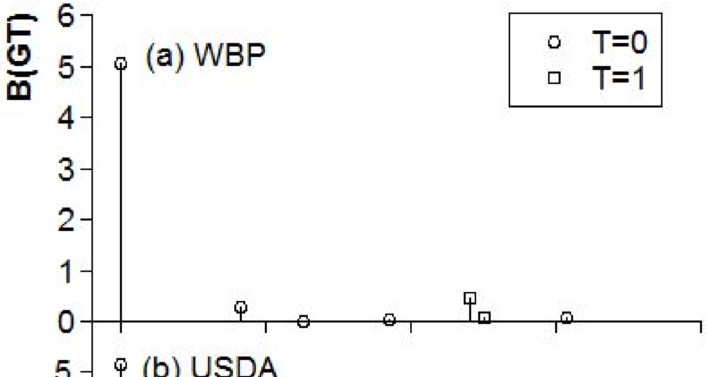


Code : Nushell

Interaction : WBP (SPSDPF), USDA, USDB (SD)

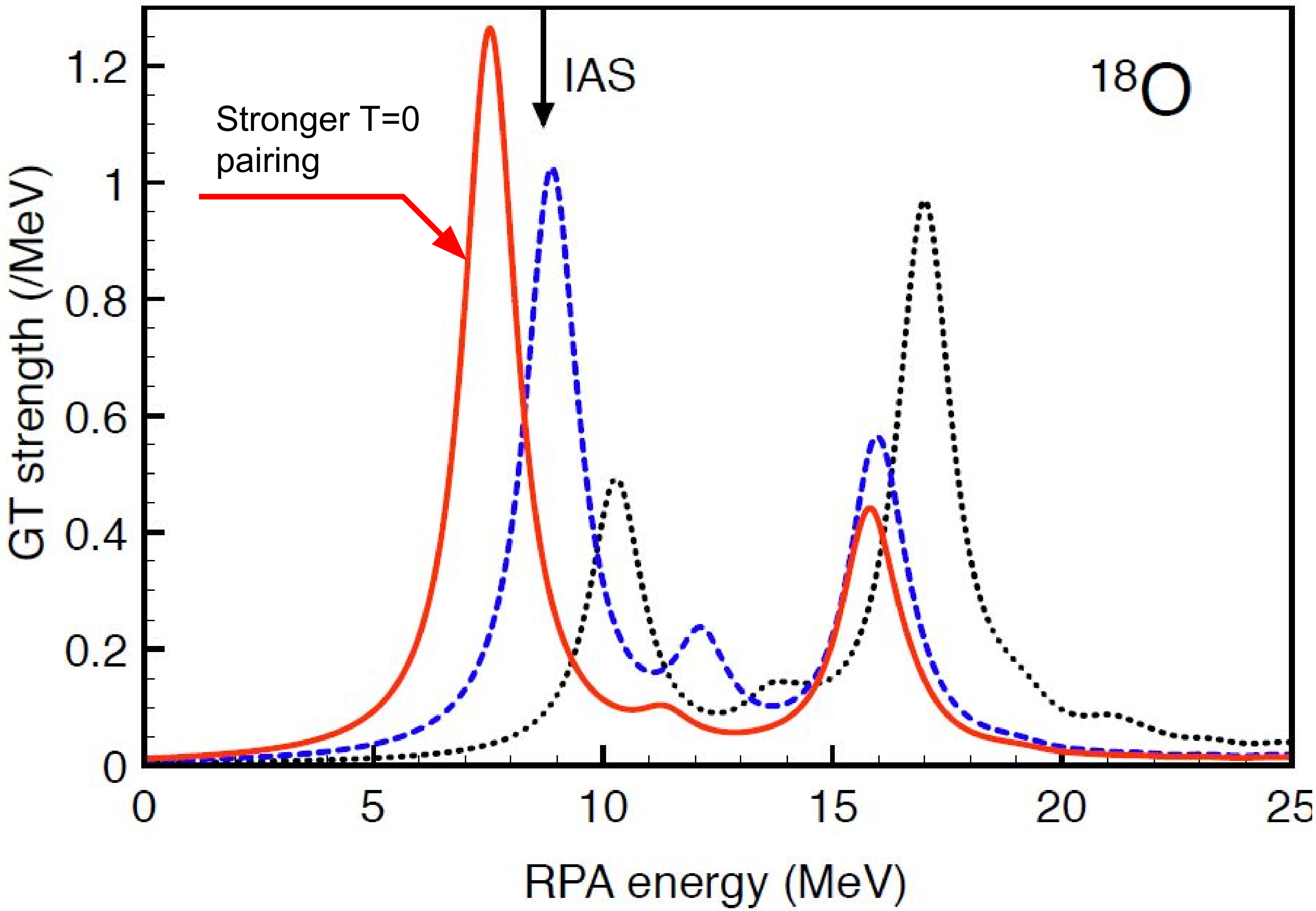
Similar results were obtained in all calculations, in which strong concentration to the 1st 1+ state was found.

Shell-model calculation



WBP	$d_{5/2} \rightarrow d_{5/2}$	$d_{3/2} \rightarrow d_{5/2}$	$d_{5/2} \rightarrow d_{3/2}$	$d_{3/2} \rightarrow d_{3/2}$	$2s_{1/2} \rightarrow 2s_{1/2}$	Sum	B(GT)
$1+_1$, Strong	-0.7948	-0.2330	-0.6905	0.0001	-0.5318	-2.250	5.062
$1+_2$	-1.082	0.0220	0.0652	-0.017	0.4818	-0.5309	0.2818
$1+_3$	-0.2391	0.2417	0.7164	-0.0192	-0.6166	0.0831	0.0069

RPA calculation



K. Yoshida, Niigata Univ., private communication

Low-Energy Super GT state in the $^{42}Ca(^3He,t)$ data†

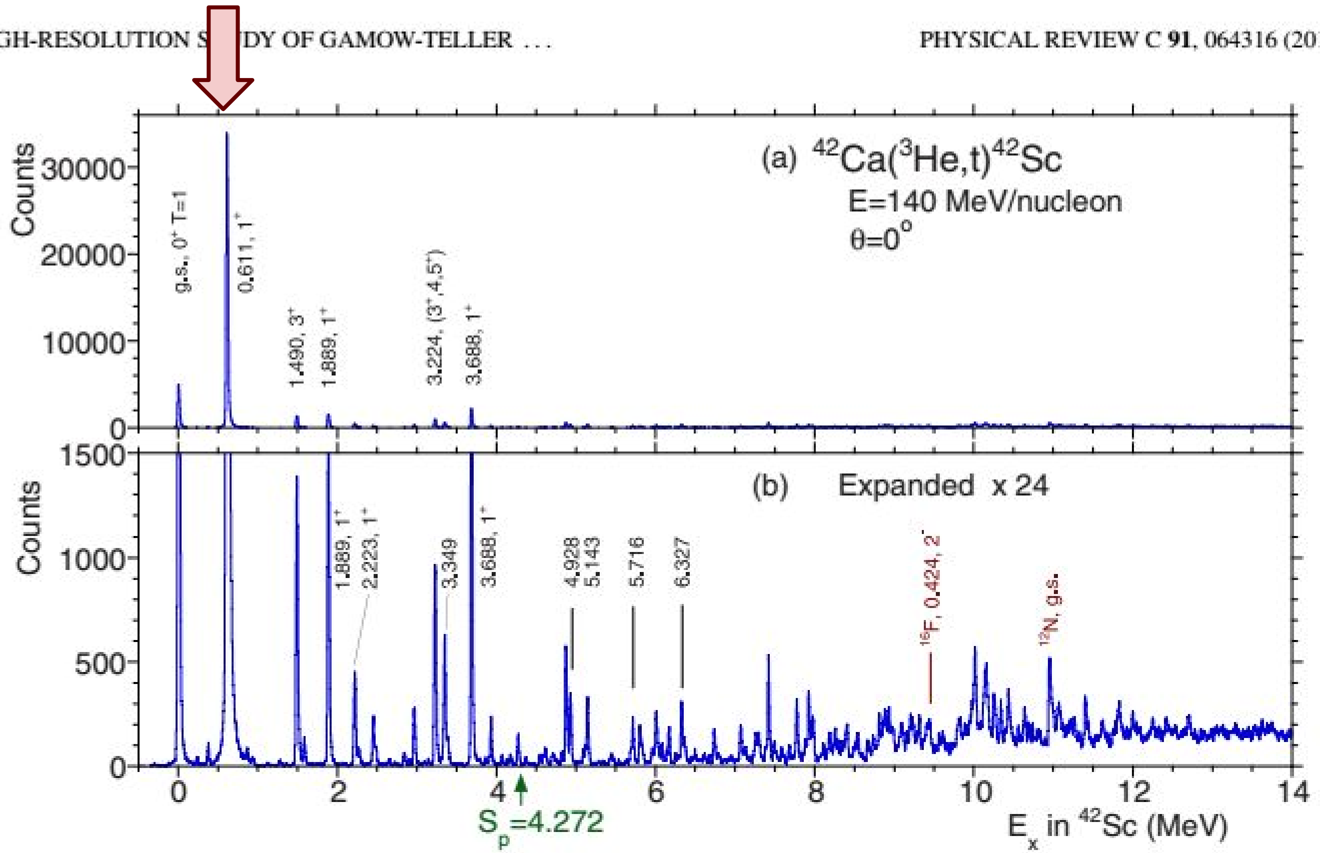


FIG. 1. (Color online) The 0°, $^{42}Ca(^3He,t)^{42}Sc$ spectrum on two scales. The events within the range of scattering angles $\Theta \leqslant 0.5°$ are included. (a) The full count range spectrum. Two prominent peaks are observed in the low-energy region and less prominent ones up to 4 MeV. (b) The vertical scale is magnified by a factor of 24. A fine structure of many states is observed up to $E_x = 12.7$ MeV. Major states populated in $\Delta L = 0$ transitions ($\Delta L = 0$ states) below 7 MeV are indicated by their excitation energies in MeV. The $\Delta L = 0$ states in the region above 7 MeV are indicated in Fig. 5(a) in Sec. IV.

† Y. Fujita et al., PRC 91, 064316 (15)

Low-Energy Super GT state

Specific character of p-p type (closed core + two valences) structure?

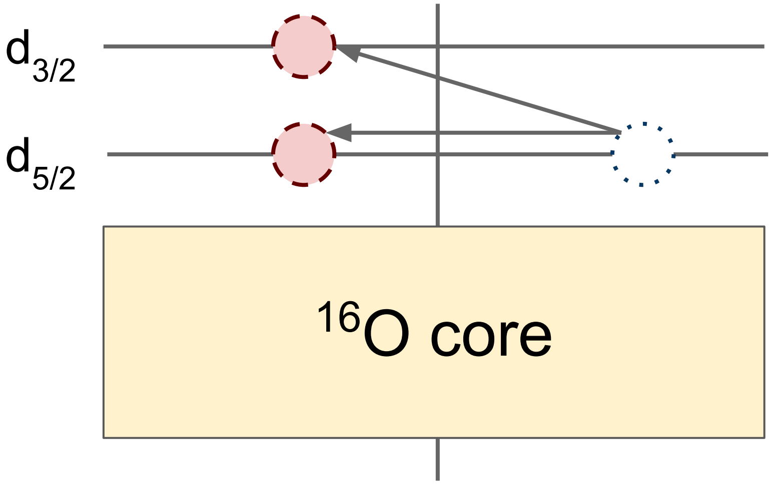
Shell-model calculation suggests all possible configurations work constructively.

HIGH-RESOLUTION STUDY OF GAMOW-TELLER . . . PHYSICAL REVIEW C **91**, 064316 (2015)

TABLE VI. Results of the pf-shell SM calculation using the GXPF1J interaction. The matrix elements M(GT) of GT transitions exciting individual $J^\pi = 1^+$ GT states in ^{42}Sc from the g.s. of ^{42}Ca are shown for each configuration. The results are shown for all excited GT states predicted in the region up to 9.82 MeV. The notation $f7 \rightarrow f7$, for example, stands for the transition with the $\nu f_{7/2} \rightarrow \pi f_{7/2}$ type and $p3 \rightarrow p3$ the $\nu p_{3/2} \rightarrow \pi p_{3/2}$. The summed value of the matrix elements is denoted by ΣM(GT) and its squared value is the B(GT), where the B(GT) values do not include the quenching factor of the SM calculation.

States in ^{42}Sc		Configurations						Transition strengths	
E_x (MeV)	T	$f7 \rightarrow f7$	$f7 \rightarrow f5$	$f5 \rightarrow f7$	$p3 \rightarrow p3$	$p3 \rightarrow p1$	$p1 \rightarrow p3$	ΣM(GT)	B(GT)
0.33	0	1.383	0.548	0.063	0.031	0.024	0.016	2.07	4.28
4.41	0	0.719	−0.742	−0.085	−0.079	−0.073	−0.048	−0.31	0.09
7.41	0	0.193	−0.788	−0.090	0.142	0.060	0.040	−0.44	0.19
8.62	0	−0.151	0.385	0.044	0.109	−0.071	−0.047	0.30	0.09
9.82	1	0.0	1.196	−0.137	0.0	−0.053	0.035	1.04	1.08

B(GT) values from the $^{17}O(p,n)$ data†



Jp and Ex	B(GT)
5/2+, g.s.	1.062 (F subtracted)
3/2+, 5.00	0.57

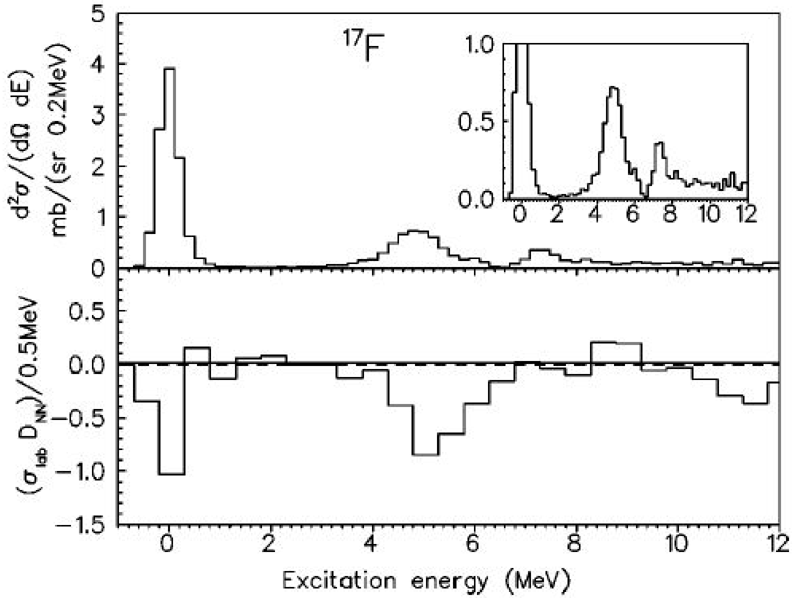


FIG. 5. Double-differential cross sections as a function of excitation energy for the $^{17}O(\vec{p},\vec{n})$ reaction at $\theta = 0°$ (top panel) and product of double-differential cross sections and D_{NN} coefficients binned in 0.5 MeV steps (bottom panel).

† I.J. van Heerden et al., PRC 59, 1488 (1999)

B(GT) in A=18 and A=17

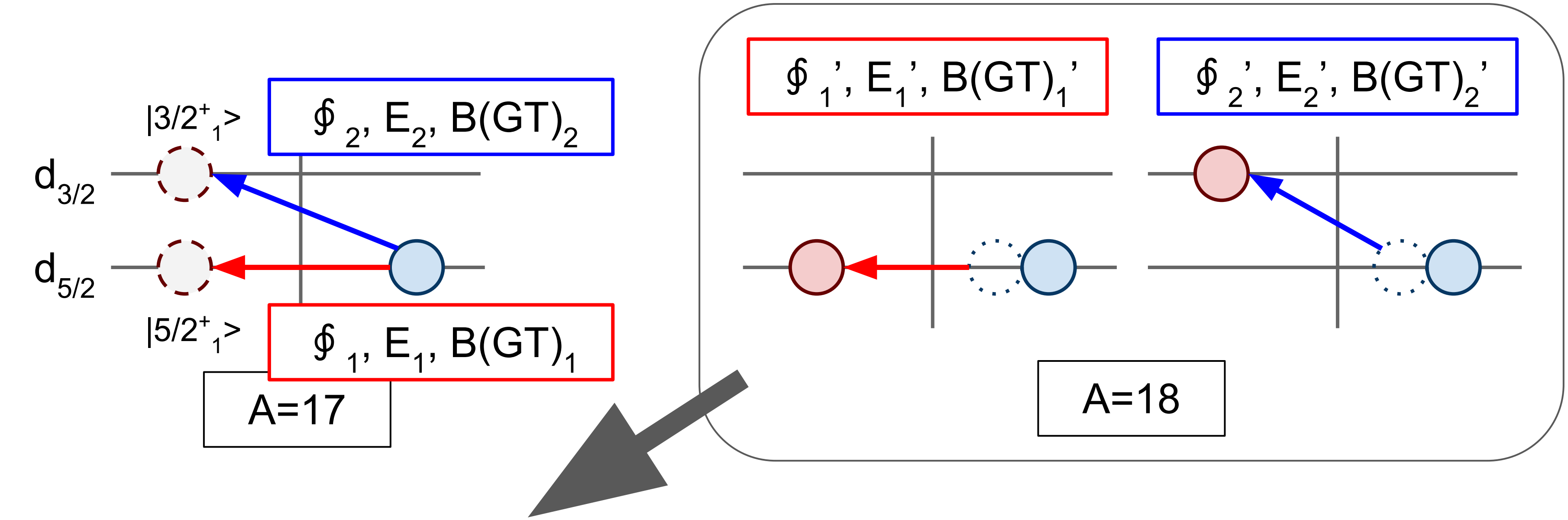
$^{17}O(p,n)^{17}F$	$^{18}O(^{3}He,t)^{18}F$ (present data)
5/2+, B(GT) = 1.062	1st 1+, B(GT) = 3.09
3/2+, B(GT) = 0.57	2nd 1+, B(GT) = 0.17
	3rd 1+, B(GT) = 0.17
Total B(GT) = 1.63	1st + 2nd = 3.26

promising?

Sum of B(GT) values of the 1st and 2nd 1+ states in $^{18}O \rightarrow ^{18}F$ is exactly twice of $^{17}O \rightarrow ^{17}F$ 1st and 2nd B(GT).

By combining these two states in ^{17}F, can the 1st and 2nd 1+ states in ^{18}F be reconstructed?
(Low-lying 1+ states in ^{18}F <=> Low-lying states in ^{17}F?)

A=18 and A=17 systems



$$\begin{pmatrix} E_1' & g_{11} & g_{12} & g_{12} \\ g_{11} & E_1' & g_{12} & g_{12} \\ g_{12} & g_{12} & E_2' & g_{22} \\ g_{12} & g_{12} & g_{22} & E_2' \end{pmatrix} \begin{pmatrix} \phi_1' \\ \phi_1' \\ \phi_2' \\ \phi_2' \end{pmatrix} \xrightarrow{\text{Diagonalization}} \begin{pmatrix} e_a & 0 & 0 & 0 \\ 0 & e_b & 0 & 0 \\ 0 & 0 & e_c & 0 \\ 0 & 0 & 0 & e_d \end{pmatrix} \begin{pmatrix} \phi_a \\ \phi_b \\ \phi_c \\ \phi_d \end{pmatrix}$$

Free parameters

A=18 and A=17 systems

$$\begin{pmatrix} E'_1 & g_{11} & g_{12} & g_{12} \\ g_{11} & E'_1 & g_{12} & g_{12} \\ g_{12} & g_{12} & E'_2 & g_{22} \\ g_{12} & g_{12} & g_{22} & E'_2 \end{pmatrix} \begin{pmatrix} \phi'_1 \\ \phi'_1 \\ \phi'_2 \\ \phi'_2 \end{pmatrix} \Rightarrow \begin{pmatrix} e_a & 0 & 0 & 0 \\ 0 & e_b & 0 & 0 \\ 0 & 0 & e_c & 0 \\ 0 & 0 & 0 & e_d \end{pmatrix} \begin{pmatrix} \phi_a \\ \phi_b \\ \phi_c \\ \phi_d \end{pmatrix}$$

$$|\phi_a\rangle = \alpha\,|\phi'_1\rangle + \beta\,|\phi'_2\rangle + \alpha\,|\phi'_1\rangle + \beta\,|\phi'_2\rangle$$

Constructive state
^{18}F g.s. LESGT?

$$|\phi_b\rangle = -\beta\,|\phi'_1\rangle + \alpha\,|\phi'_2\rangle - \beta\,|\phi'_1\rangle + \alpha\,|\phi'_2\rangle$$

Destructive “partner”
^{18}F 2nd 1^+?

$$|\phi_c\rangle = \frac{1}{\sqrt{2}}\,|\phi'_1\rangle - \frac{1}{\sqrt{2}}\,|\phi'_1\rangle$$

$$|\phi_d\rangle = \frac{1}{\sqrt{2}}\,|\phi'_2\rangle - \frac{1}{\sqrt{2}}\,|\phi'_2\rangle$$

Strong cancellation
of GT strength

Destructive partner state?

A=18

WBP	**$d_{5/2} \rightarrow d_{5/2}$**	$d_{3/2} \rightarrow d_{5/2}$	**$d_{5/2} \rightarrow d_{3/2}$**	$d_{3/2} \rightarrow d_{3/2}$	$2s_{1/2} \rightarrow 2s_{1/2}$	Sum	B(GT)
$1+_1$, Strong	-0.7948	-0.2330	-0.6905	0.0001	-0.5318	-2.250	5.062
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HIGH-RESOLUTION STUDY OF GAMOW-TELLER … PHYSICAL REVIEW C **91**, 064316 (2015)

A=42

TABLE VI. Results of the pf-shell SM calculation using the GXPF1J interaction. The matrix elements M(GT) of GT transitions exciting … GT states in ^{42}Sc from the g.s. of ^{42}Ca are shown for each configuration. The results are shown for all excited GT states …n up to 9.82 MeV. The notation $f7 \rightarrow f7$, for example, stands for the transition with the $\nu f_{7/2} \rightarrow \pi f_{7/2}$ type and $p3 \rightarrow p3$ … $\nu p_{3/2} \rightarrow \pi p_{3/2}$. The summed value of the matrix elements is denoted by ΣM(GT) and its squared value is the B(GT), where the B(GT) values do not include the quenching factor of the SM calculation.

States in ^{42}Sc		Configurations						Transition strengths	
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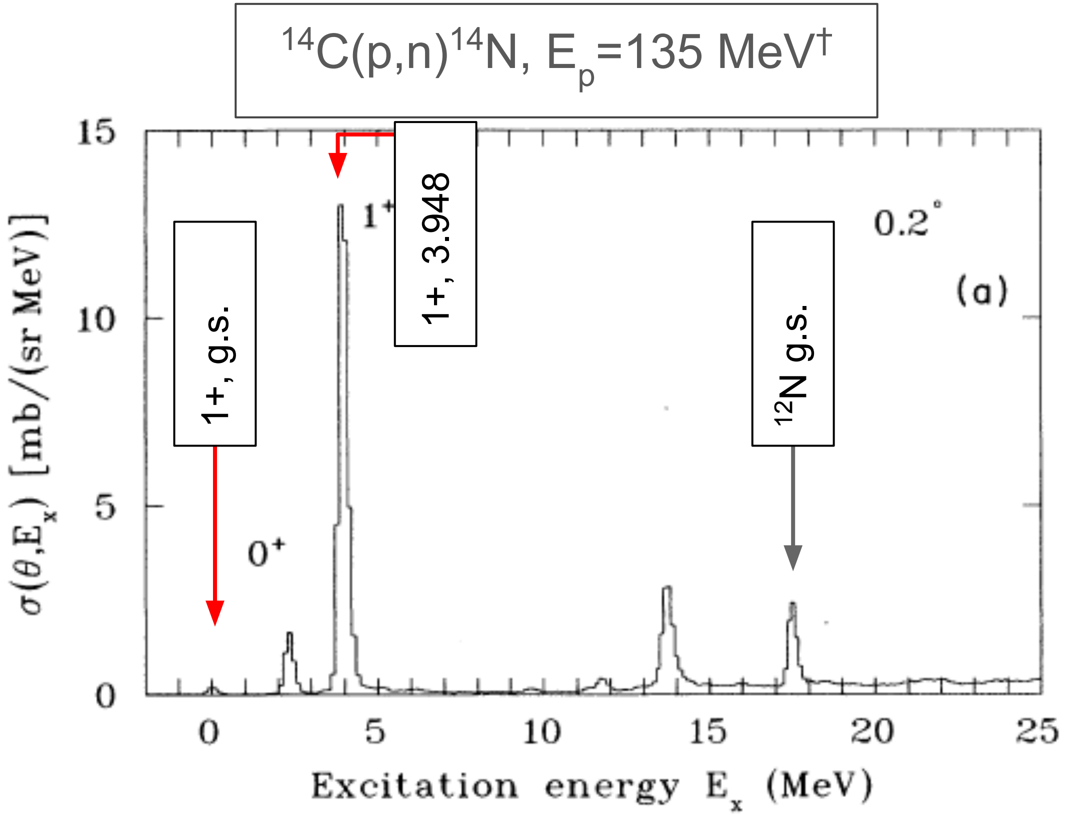
4.41	0	0.719	−0.742	−0.085	−0.079	−0.073	−0.048	−0.31	0.09
7.41	0	0.193	−0.788	−0.090	0.142	0.060	0.040	−0.44	0.19
8.62	0	−0.151	0.385	0.044	0.109	−0.071	−0.047	0.30	0.09
9.82	1	0.0	1.196	−0.137	0.0	−0.053	0.035	1.04	1.08

Further application : ^{16}O + two holes

Abnormally weak GT transition, $^{14}C \rightarrow ^{14}N$

^{14}C g.s. (0+) → ^{14}N g.s. (1+), known as "abnormally weak" GT transition

($T_{1/2}$ ~ 5700(30) years, B(GT)~0)

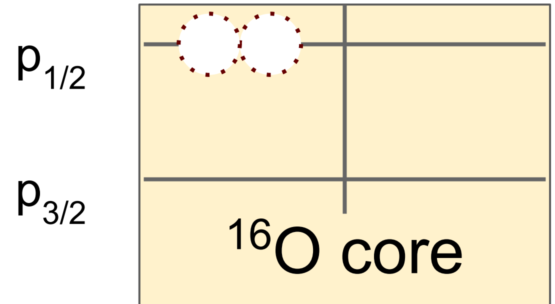


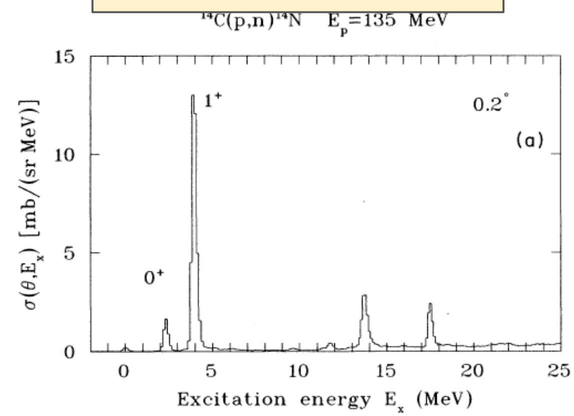
† B.D. Anderson et al., PRC 43, 1630 (1991)

B(GT) values in A=14 and A=15 systems

$^{14}C \rightarrow ^{14}N$

^{16}O+2 holes



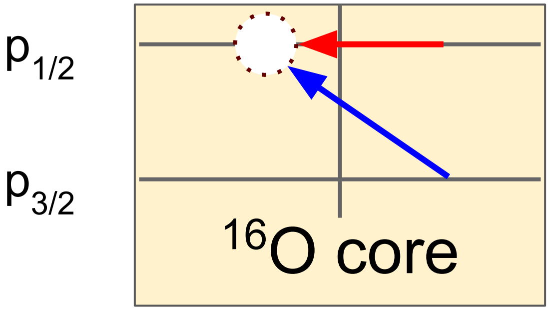


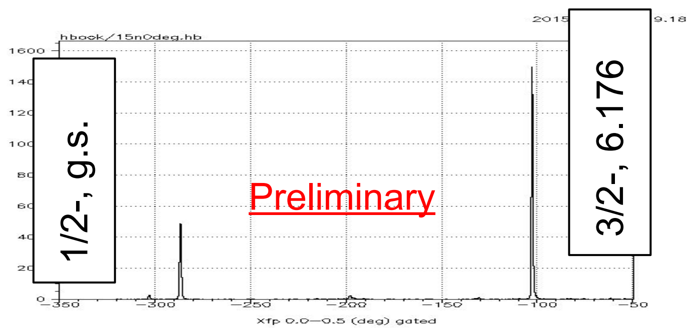
Jp and Ex	B(GT)
$1+_1$, g.s.	~0
$1+_2$, 3.948	2.8

B(GT) values in A=14 and A=15 systems

$^{15}N \rightarrow {}^{15}O$

^{16}O+1 hole

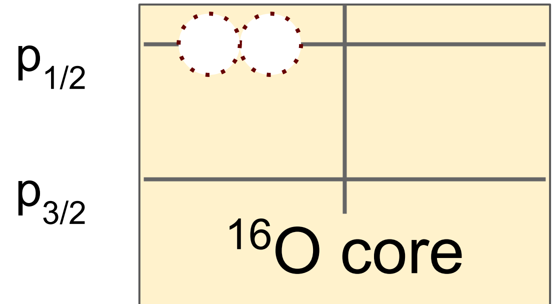


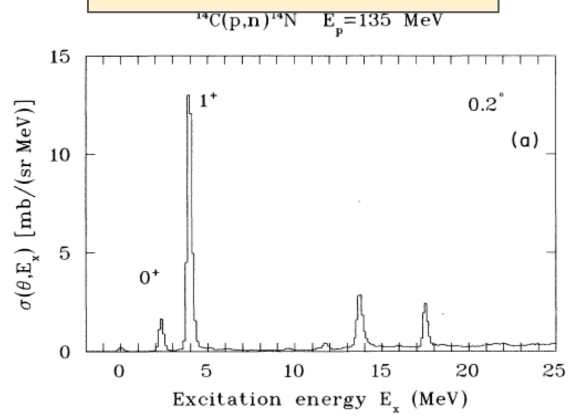


Jp and Ex	Preliminary B(GT)
1/2-, g.s.	0.26 from ^{15}O β-decay
3/2-, 6.176	1.09 (R^2=5.46 assumed)
Total	1.35

$^{14}C \rightarrow {}^{14}N$

^{16}O+2 holes





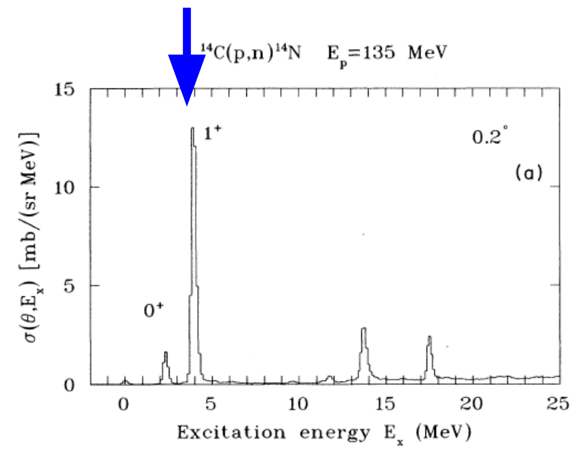
Jp and Ex	B(GT)
$1+_1$, g.s.	~0
$1+_2$, 3.948	2.8

B(GT) values in A=14 and A=15 systems

$^{15}N \rightarrow {}^{15}O$

$^{14}C \rightarrow {}^{14}N$

Similar to A=18 case?
2nd 1^+ in ^{14}N can be another LESGT state?



Excitation energy E_x (MeV)

Jp and Ex	Preliminary B(GT)
1/2-, g.s.	0.26 from ^{15}O β-decay
3/2-, 6.176	1.09 (R^2=5.46 assumed)
Total	1.35

Jp and Ex	B(GT)
$1+_1$, g.s.	~0
$1+_2$, 3.948	2.8

Summary

High resolution $^{18}O(^{3}He,t)$ measurement at 0-degree

- ▷ Gas target system was used
- ▷ Resolution of 31 keV was realized

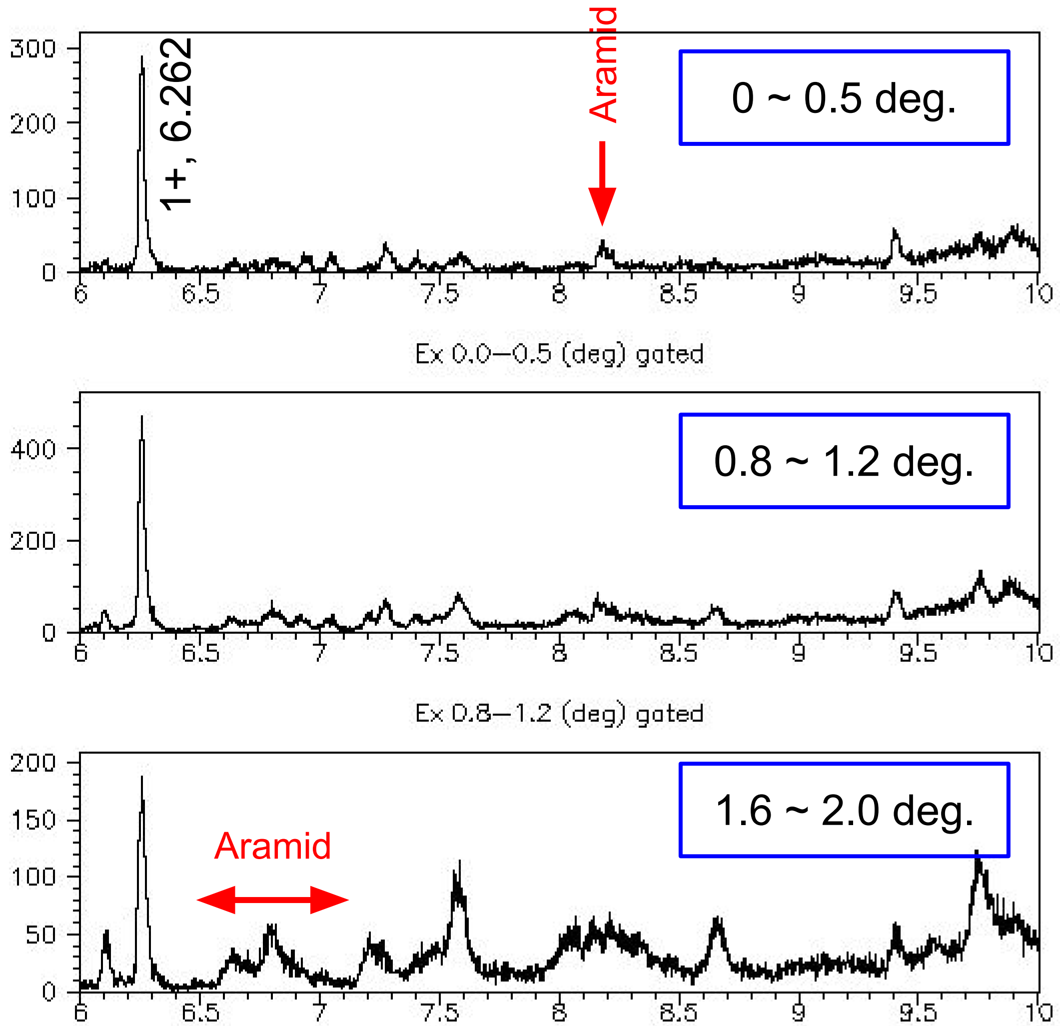
Strong concentration of GT strength to the g.s. was found

- ▷ Low-Energy Super Gamow-Teller (LESGT) state
  - ▷ Quite similar to the A=42 (^{40}Ca + 2n) case
    - ▷ Strong T=0 pairing interaction?

Reconstruction of the LESGT state

- ▷ LESGT state has a “destructive partner” state?
- ▷ Similar application to the A=14 system (and A=38, 42, ...)?

ΔL>0 resonance? (Optional)



ΔL>0 Isovector Giant Resonance?

B(GT) reconstruction (Optional)

$$B(\mathrm{GT})_1 = \left|\langle\phi_1|\sigma\tau|i\rangle\right|^2 \qquad B(\mathrm{GT})_2 = \left|\langle\phi_2|\sigma\tau|i\rangle\right|^2$$

$$B(\mathrm{GT})_a + B(\mathrm{GT})_b = \left|\langle\phi_a|\sigma\tau|i'\rangle\right|^2 + \left|\langle\phi_b|\sigma\tau|i'\rangle\right|^2$$

$$= \left|2\alpha\,\langle\phi'_1|\sigma\tau|i'\rangle + 2\beta\,\langle\phi'_2|\sigma\tau|i'\rangle\right|^2 + \left|2\beta\,\langle\phi'_1|\sigma\tau|i'\rangle - 2\alpha\,\langle\phi'_2|\sigma\tau|i'\rangle\right|^2$$

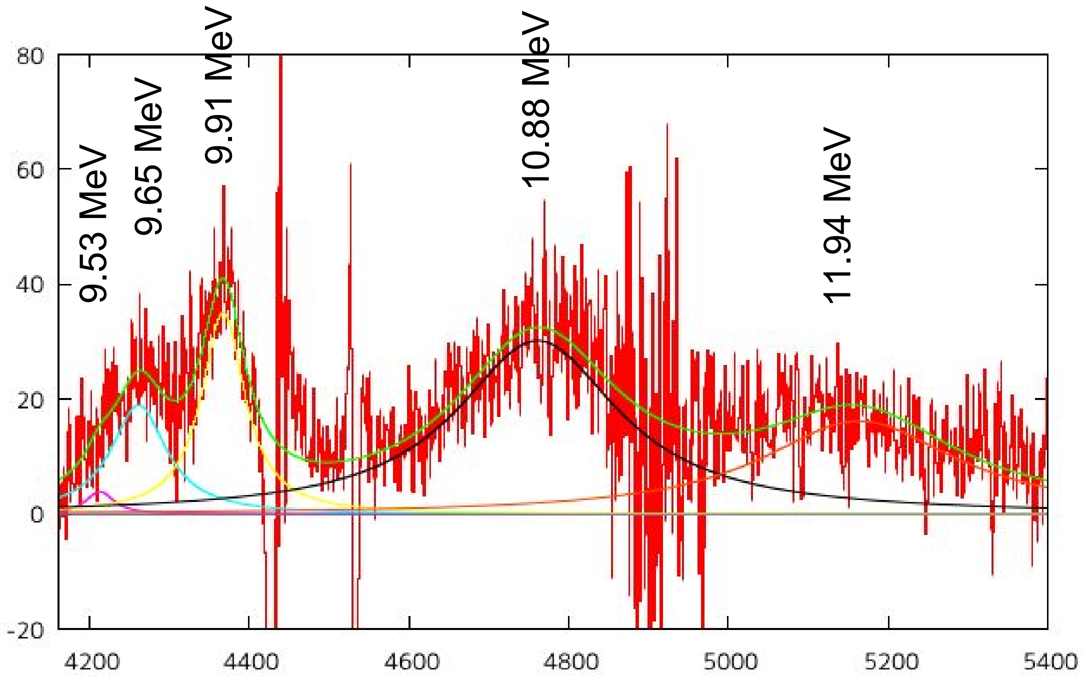
$$= (4\alpha^2 + 4\beta^2)\left|\langle\phi'_1|\sigma\tau|i'\rangle\right|^2 + (4\alpha^2 + 4\beta^2)\left|\langle\phi'_2|\sigma\tau|i'\rangle\right|^2$$

$$= 2\left|\langle\phi'_1|\sigma\tau|i'\rangle\right|^2 + 2\left|\langle\phi'_2|\sigma\tau|i'\rangle\right|^2 \qquad \left(2\alpha^2 + 2\beta^2 = 1\right)$$

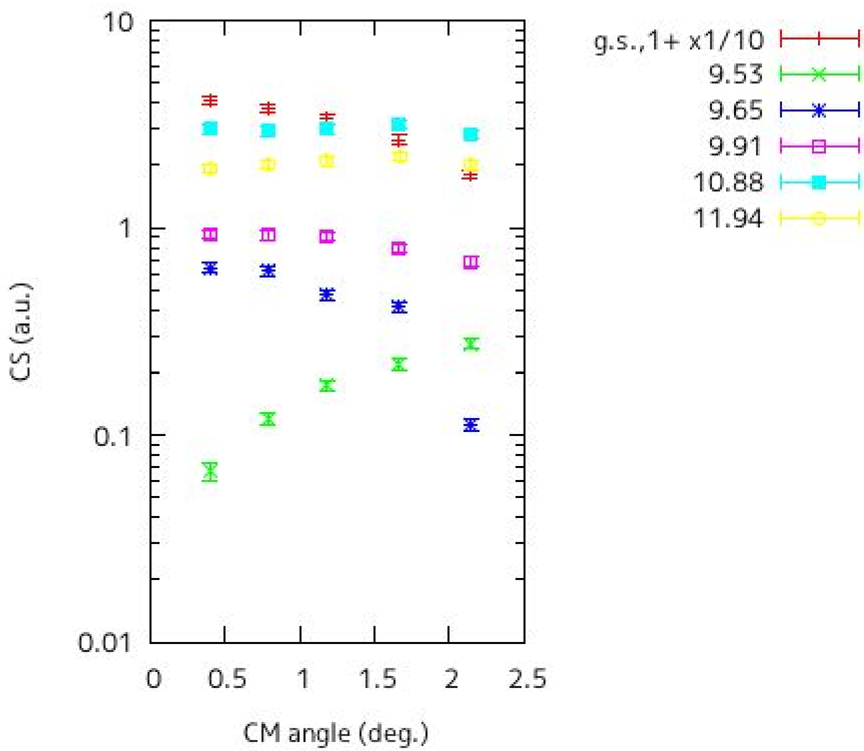
$$\text{if } \left|\langle\phi'_1|\sigma\tau|i'\rangle\right|^2 = \left|\langle\phi_1|\sigma\tau|i\rangle\right|^2 \text{ and } \left|\langle\phi'_2|\sigma\tau|i'\rangle\right|^2 = \left|\langle\phi_2|\sigma\tau|i\rangle\right|^2,$$

$$= 2\left(B(\mathrm{GT})_1 + B(\mathrm{GT})_2\right)$$

T=1 states? (Optional)



T=1 states? (Optional)



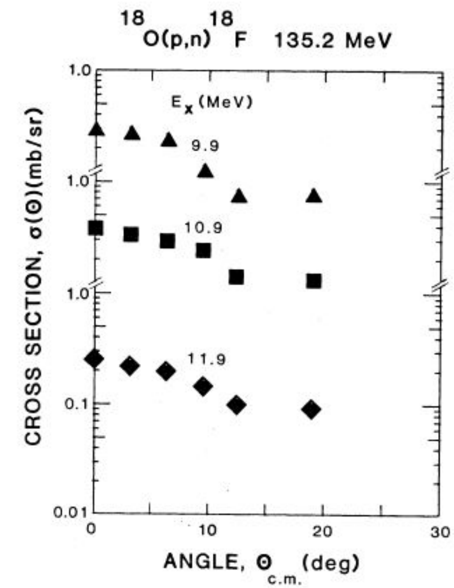


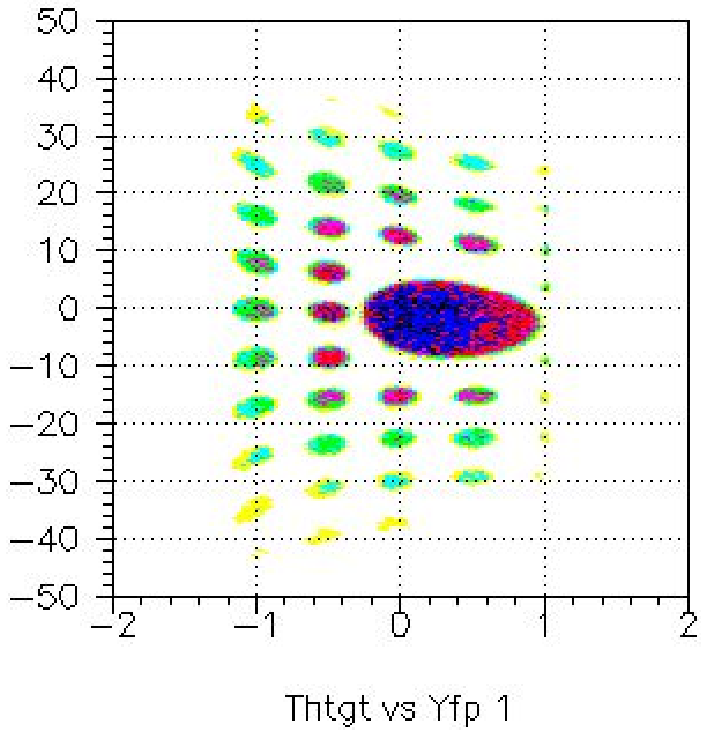
FIG. 3. Meaured angular distributions for the three bumps observed in the $^{18}O(p,n)^{18}F$ reaction at excitation energies between 9.5 and 12 MeV.

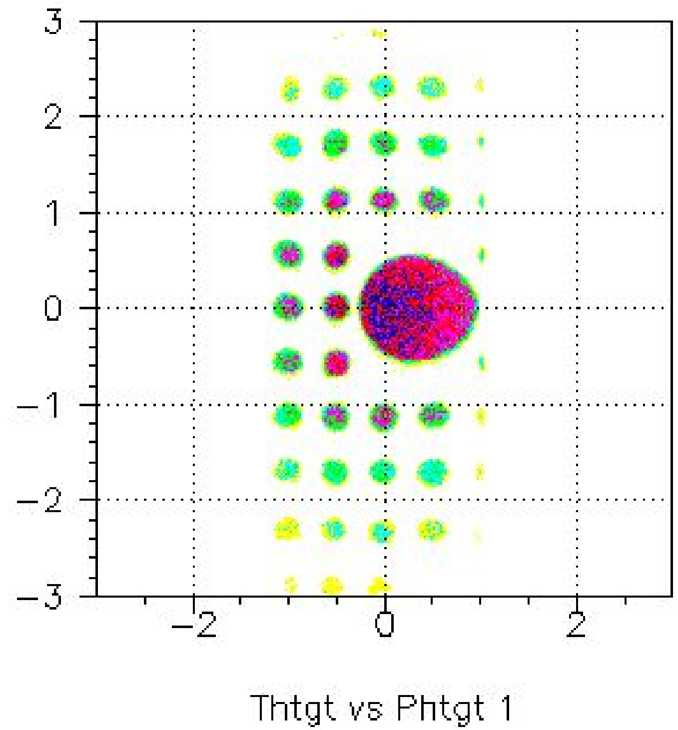
B.D. Anderson et al., PRC 27, 1387 (83)

T=1 states? (Optional)

Present data		(p,n) at 135 MeV		(p,n) at 118 MeV	
Ex	B(GT)	Ex	B(GT)	Ex	B(GT)
9.65	0.053(4)				
9.91	0.077(5)	9.9	0.059	9.9	0.15(2)
10.88	0.25(2)	10.9	0.088	11.1	0.19(3)
11.94	0.17(1)	11.9	0.064	12.0	0.12(2)

Scattering angle calibration (Optional)

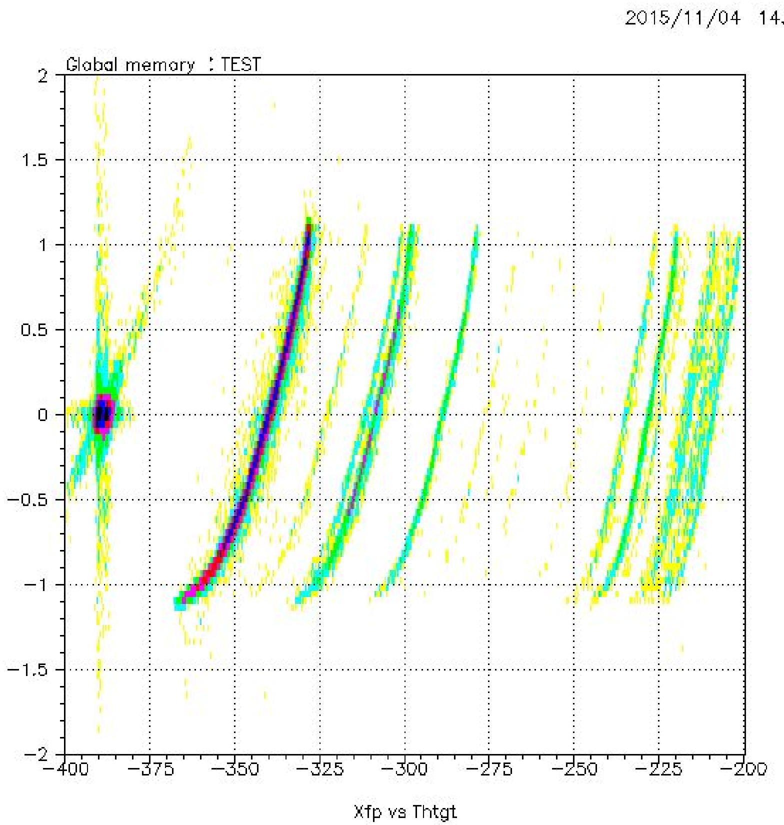


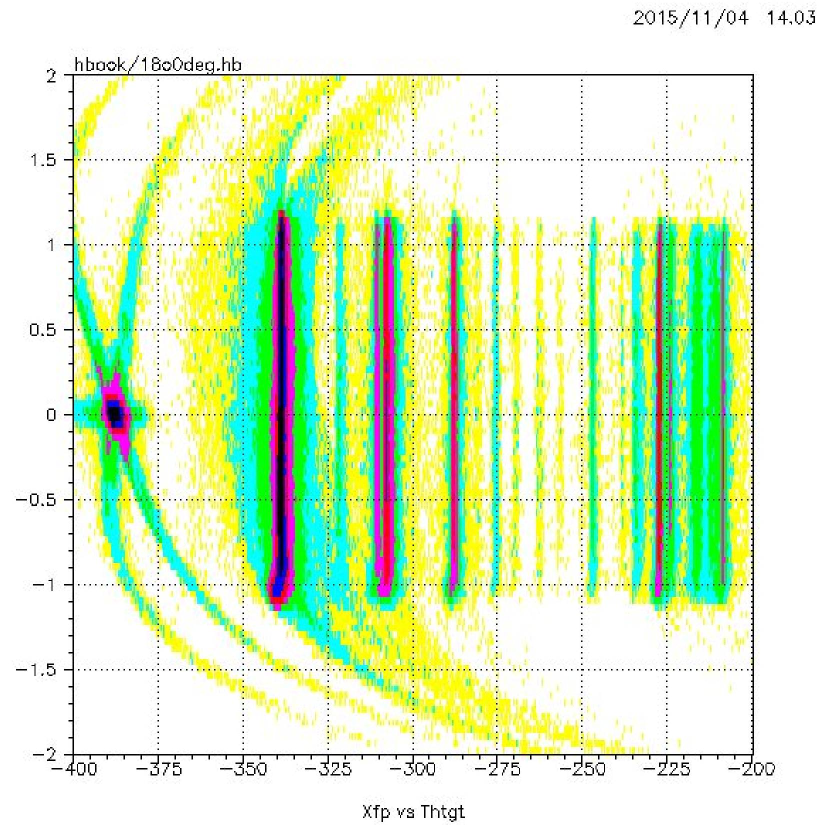


Left : Theta at the target - Y in the focal plane

Right : Theta at the target - Phi at the target

Focal plane correction (Optional)

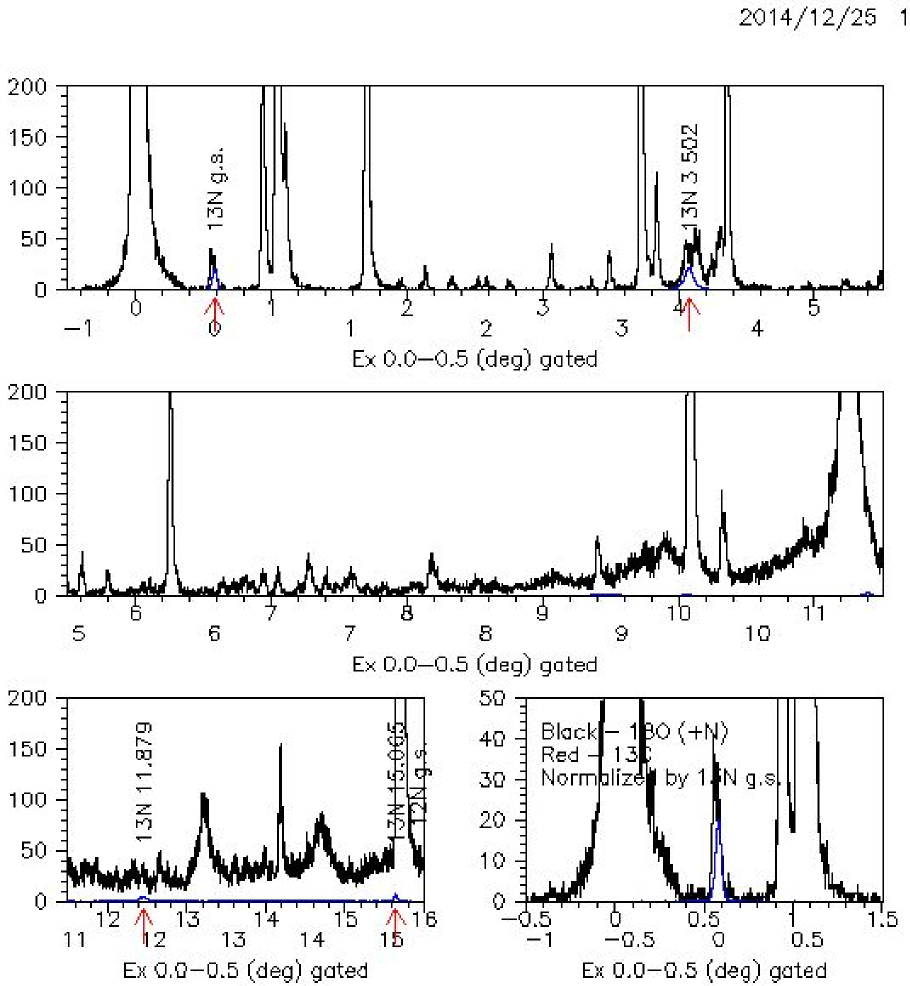




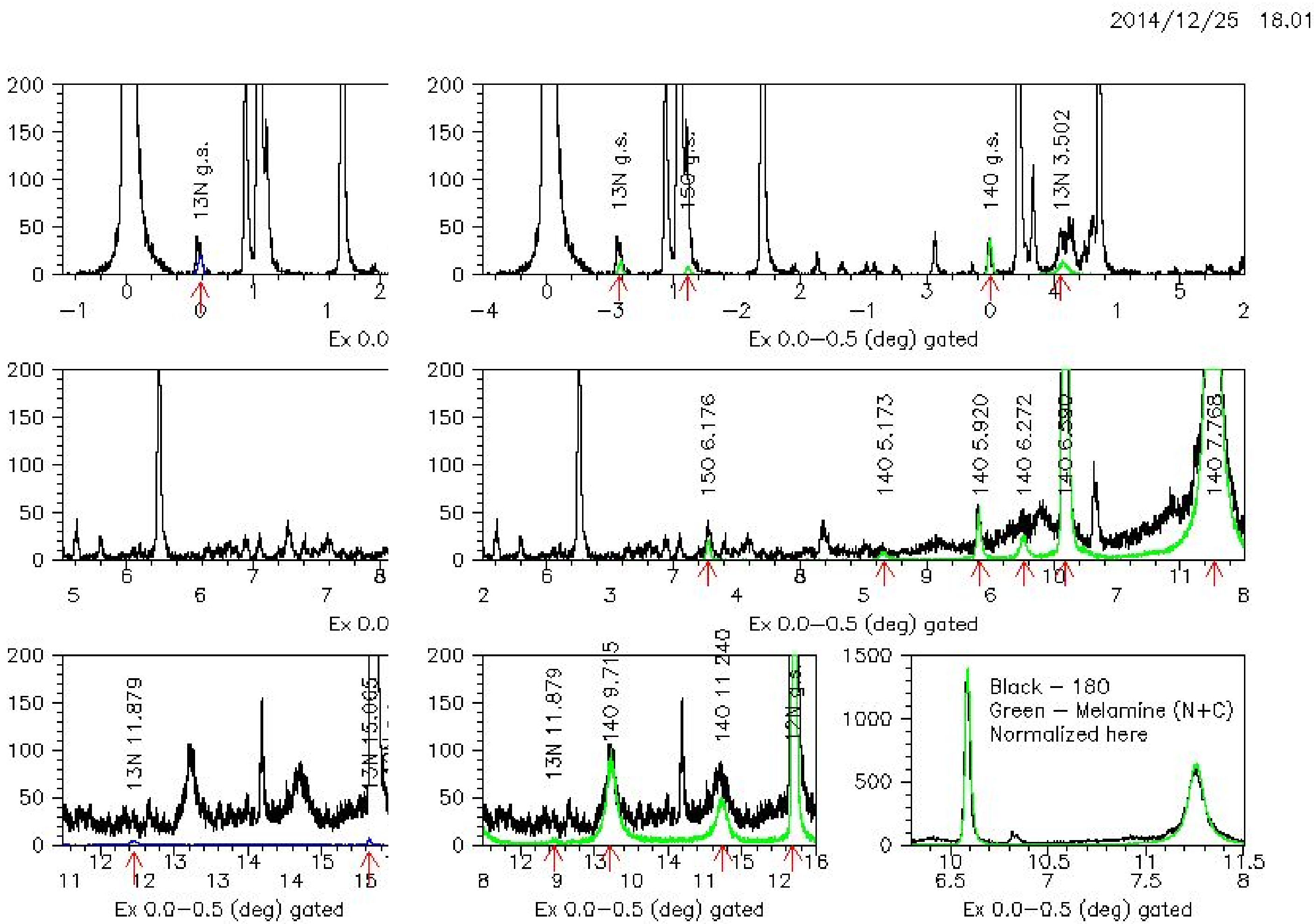
Left : X - Theta 2-D plot before correction

Right : After correction

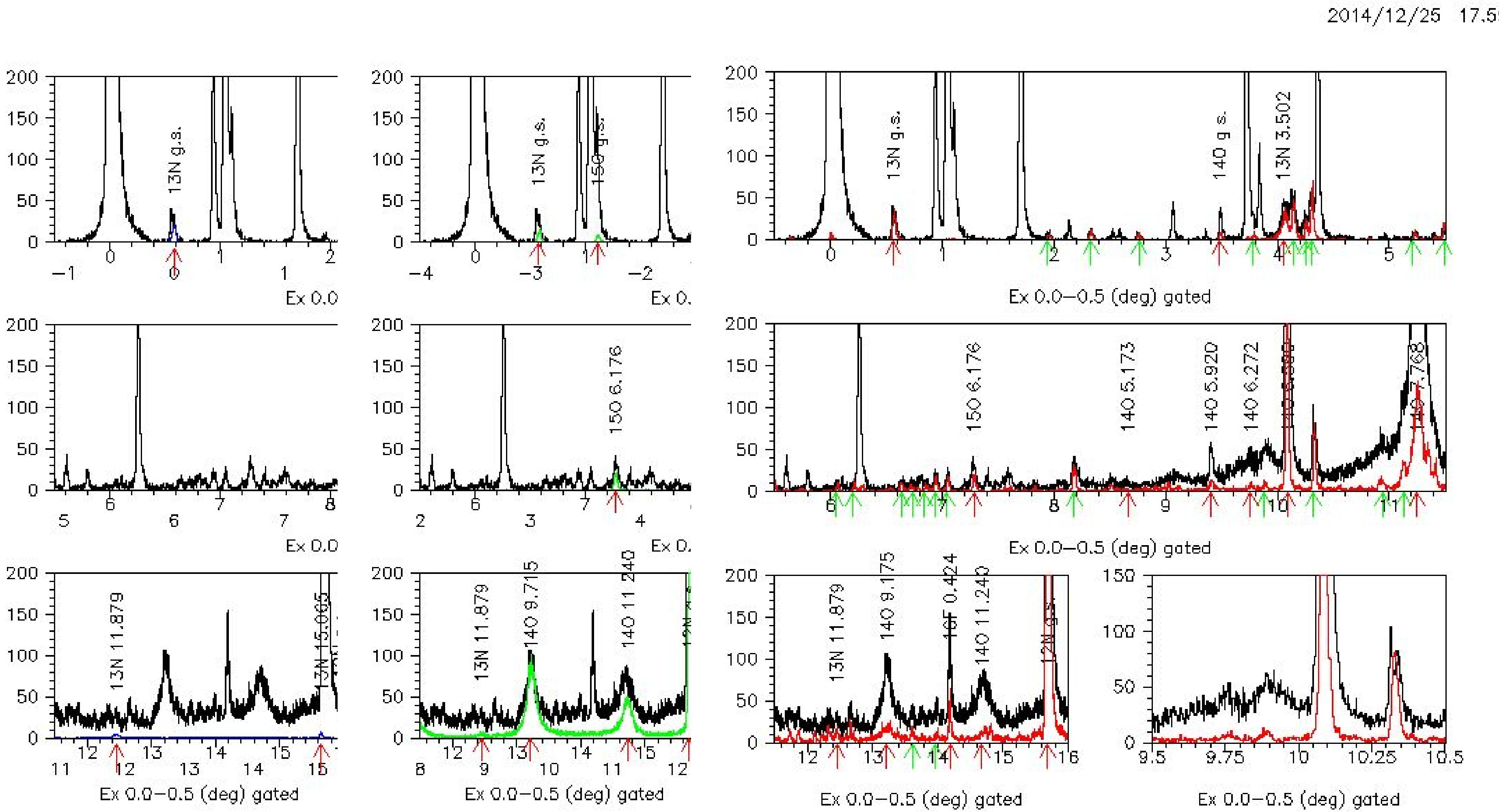
BG subtraction (Optional)



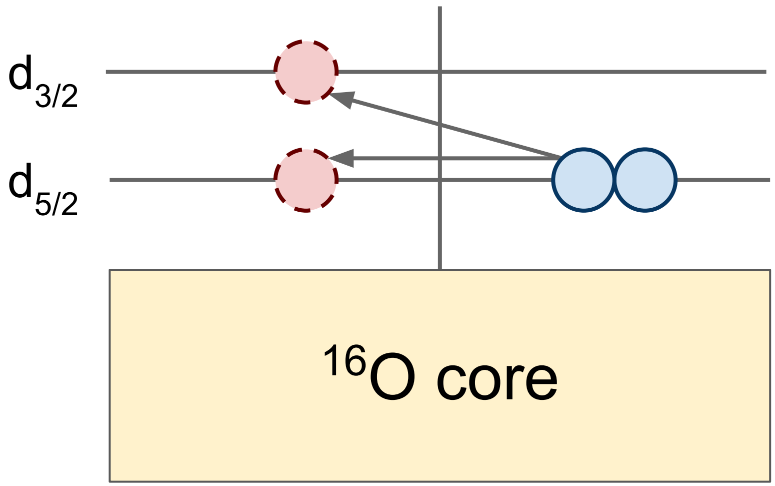
BG subtraction (Optional)



BG subtraction (Optional)



Gamow-Teller transition from ^{18}O



Simple structure : $^{16}O + 2n$,

Gamow-Teller transition : $d_{5/2} \to d_{5/2}$ and $d_{5/2} \to d_{3/2}$