Revisit of unbound ^{12}O nucleus via the (*p*, *t*) reaction

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Workshop MUST2

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Outline

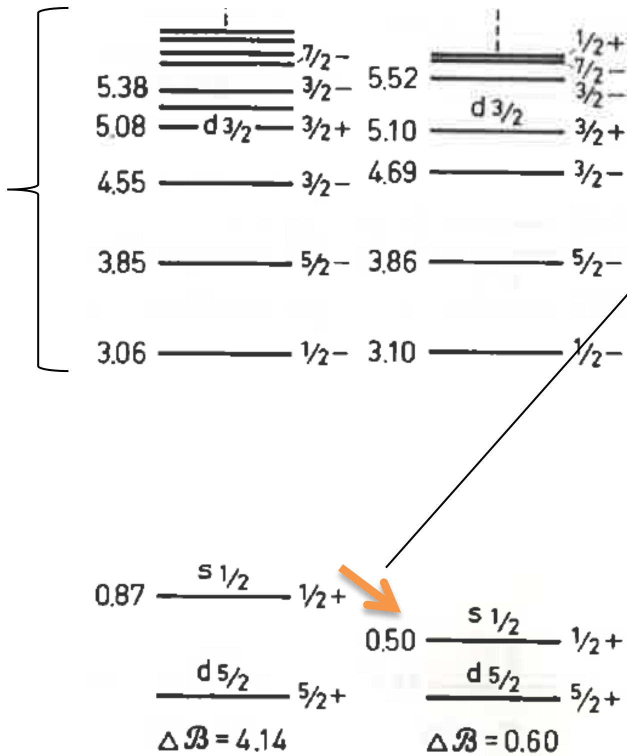
- Mirror symmetry near proton drip line
- Review $^{14}O(p,t)^{12}O$ experiment at SISSI/SPEG
  - ❑ SISSI's breakdown (April '07).
  - ❑ Only 24 hours of data.
- Revisit ^{12}O with LISE
  - ❑ 7 days (Oct. 2 – 10, '08)
  - ❑ Total beam counts (1.41 10^{10})
    10 times higher than SISSI/SPEG run (1.6 10^{9}).

Mirror symmetry: Classical example

Charge independence
NN force: $v^{(pp)} \sim v^{(nn)}$

- $v^{(pn)}$ 2% stronger than $v^{(pp)} \sim v^{(nn)}$
- Coulomb potential.

Symmetry



$^{17}_{8}O_9$ $^{17}_{9}F_8$

Slightly breaking

Mirror Energy Difference (MED)

- Finite system
  Coulomb energy reduces when valence orbits extend.
- Sensitivity to $s_{1/2}$ states (or halo).

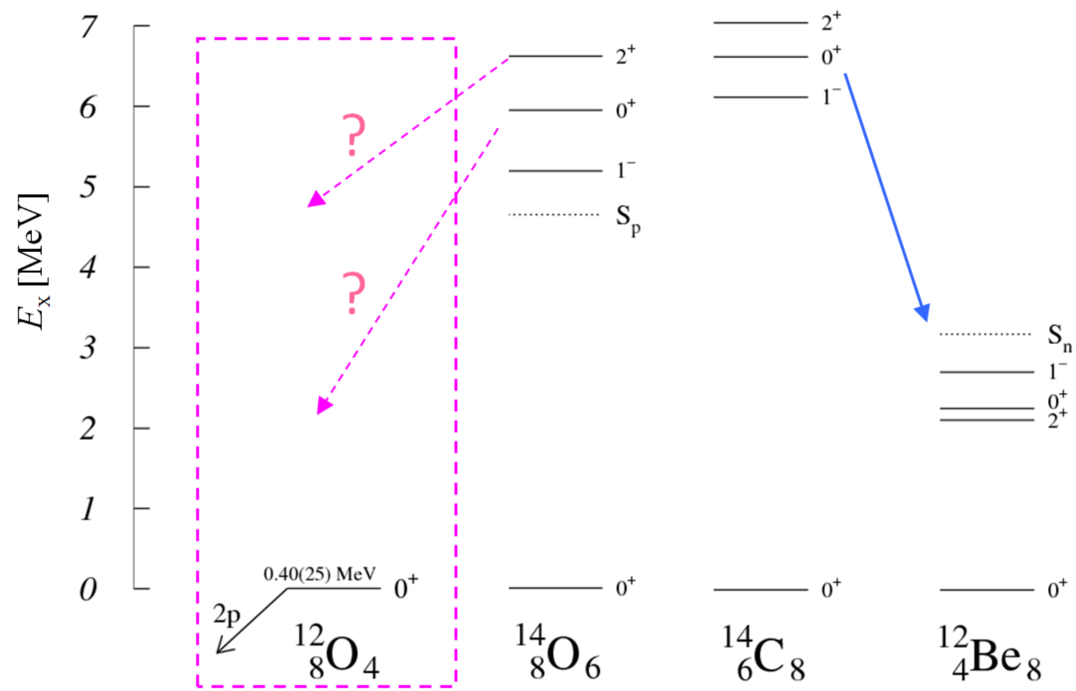
Bohr, Mottelson (World Scientific, ’69)

Region near ^{12}Be and ^{12}O

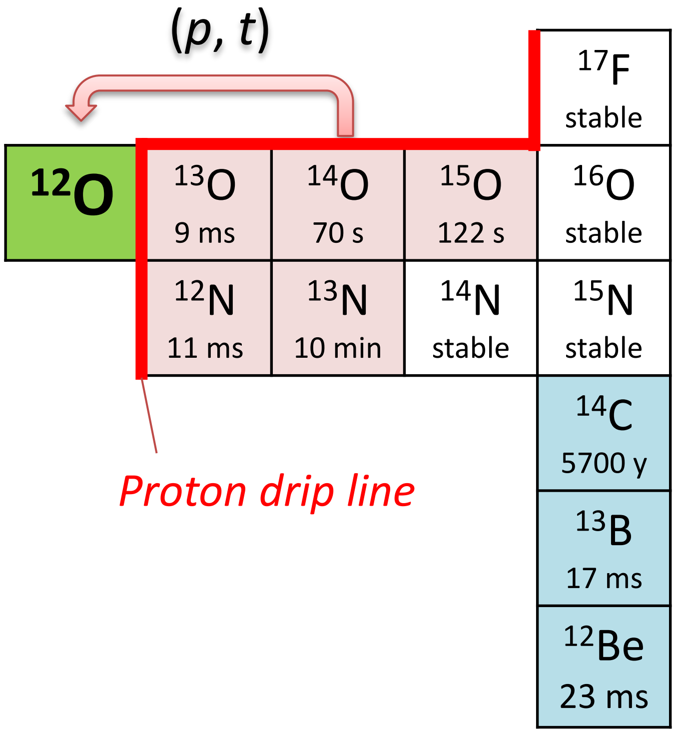
	^{11}O	^{12}O	^{13}O	^{14}O	^{15}O	^{16}O	^{17}O
	^{10}N	^{11}N	^{12}N	^{13}N	^{14}N	^{15}N	^{16}N
^{8}C	^{9}C	^{10}C	^{11}C	^{12}C	^{13}C	^{14}C	^{15}C
^{7}B	^{8}B	^{9}B	^{10}B	^{11}B	^{12}B	^{13}B	^{14}B
^{6}Be	^{7}Be	^{8}Be	^{9}Be	^{10}Be	^{11}Be	^{12}Be	^{13}Be
^{5}Li	^{6}Li	^{7}Li	^{8}Li	^{9}Li	^{10}Li	^{11}Li	^{12}Li
^{4}He	^{5}He	^{6}He	^{7}He	^{8}He	^{9}He	^{10}He	

- Shell breaking at $N = 8$
- $2s_{1/2}$ near Fermi surface
- Weak binding

- Shell breaking at $Z = 8$?
- $2s_{1/2}$ halo states from MED ?
  - ❑ 0_2^+, 1^- states



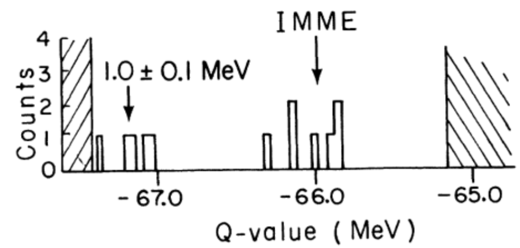
Travel beyond proton-drip line



$^{4}He(^{16}O, ^{12}O)\,^{8}He$ 117.4 MeV $\theta_L = 8°$

4*n* transfer

G.J. KeKelis et al.,
Physical Review C 17, 1929 ('78)

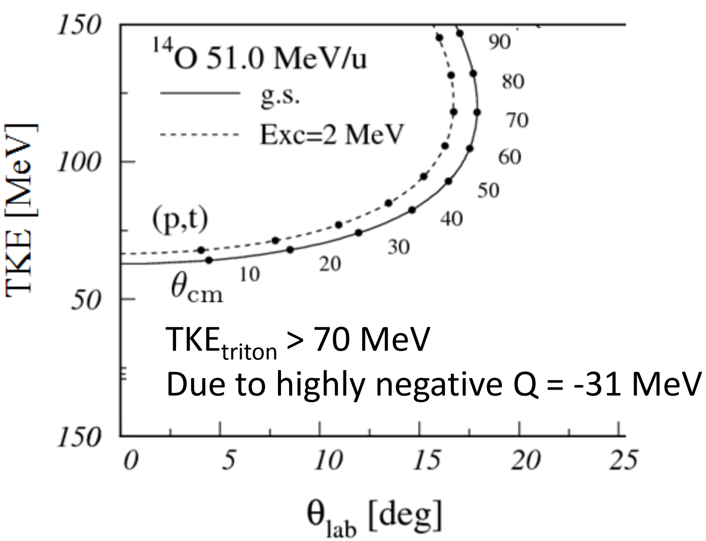


Statistics ↓ ↑ Resolution

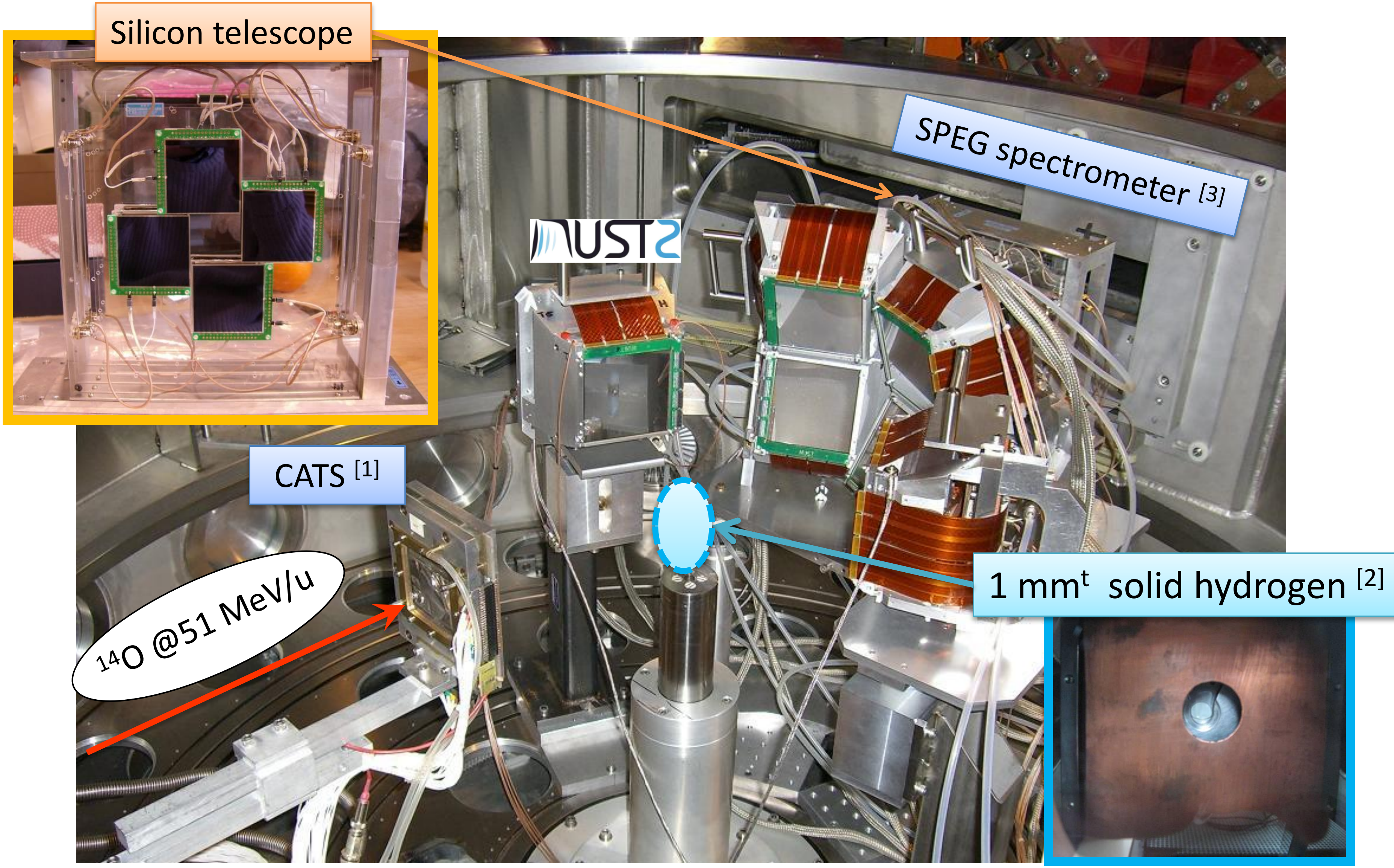
2*n* transfer (*p*, *t*) with ^{14}O RI beam

	$^{4}He(^{16}O,^{12}O)$	$^{14}O(p,t)$	
Beam	$5\ 10^{11}$ pps	10^{5} pps	$\times 10^{-7}$
Cross section	2 nb/sr	0.1 mb/sr	$\times 10^{5}$
Acceptance	1 msr	1 sr	$\times 10^{3}$
Target	1.9 mg/cm^2 (^{16}O) $6\ 10^{19}$/cm^2	7 mg/cm^2(H) $4\ 10^{20}$/cm^2	$\times 10^{1}$

Net gain ~10^2

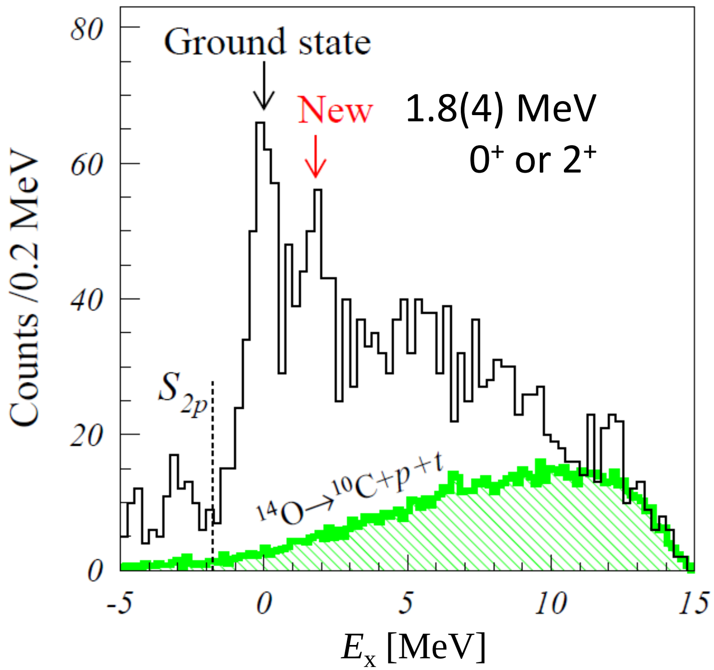


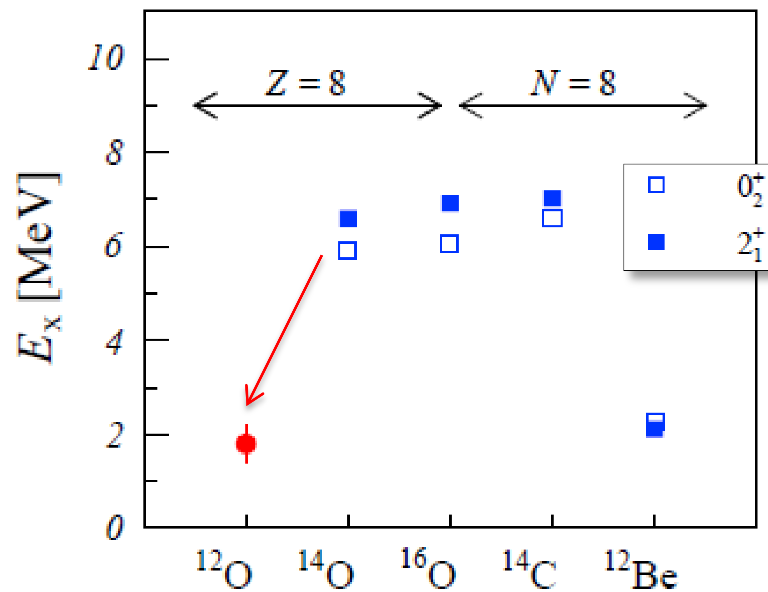
SPEG experiment ('07)



[1] S. Ottini-Hustache et al., NIM A 431, 476 (1999).
[2] P. Dolegieviez et al., NIM A 564, 32 (2006).
[3] L. Bianchi et al., NIM A 276, 509 (1989).

Results from SPEG data

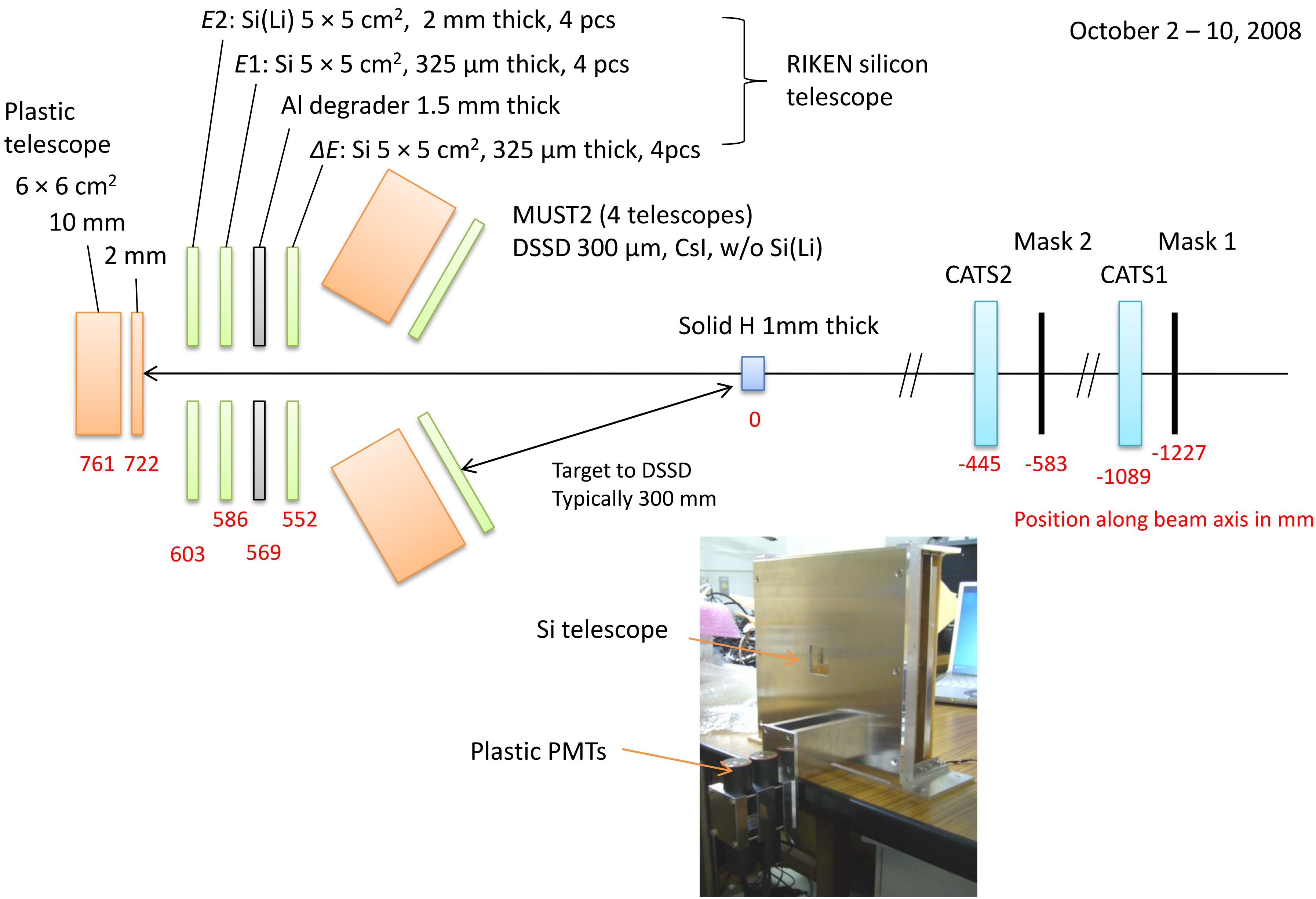




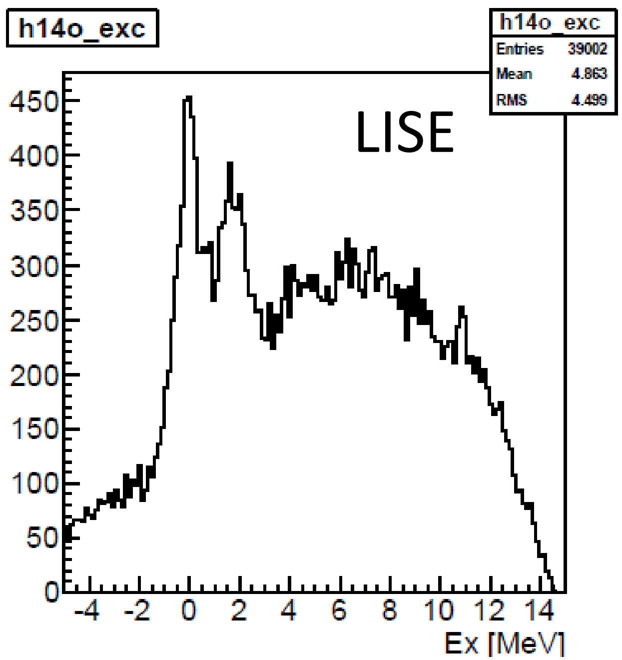
D. Suzuki *et al.*, Physical Review Letters 103, 152503 ('09).
D. Suzuki, European Physical Journal A 48, 130 ('12).

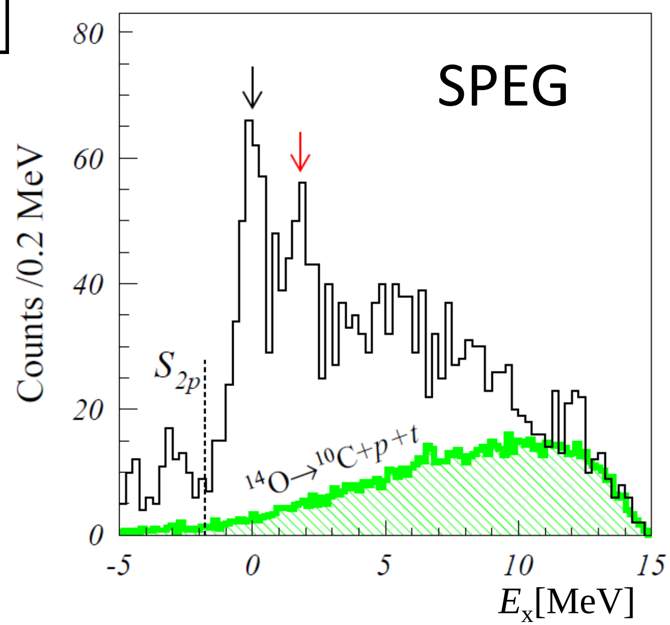
- Evidence for shell breaking at $Z = 8$.
- For precise MED, 0_2^+ and 2_1^+ states to be differentiated.

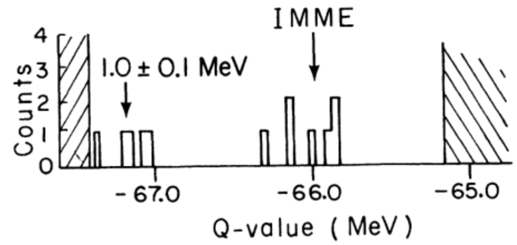
LISE experiment ('08)



New results from LISE data



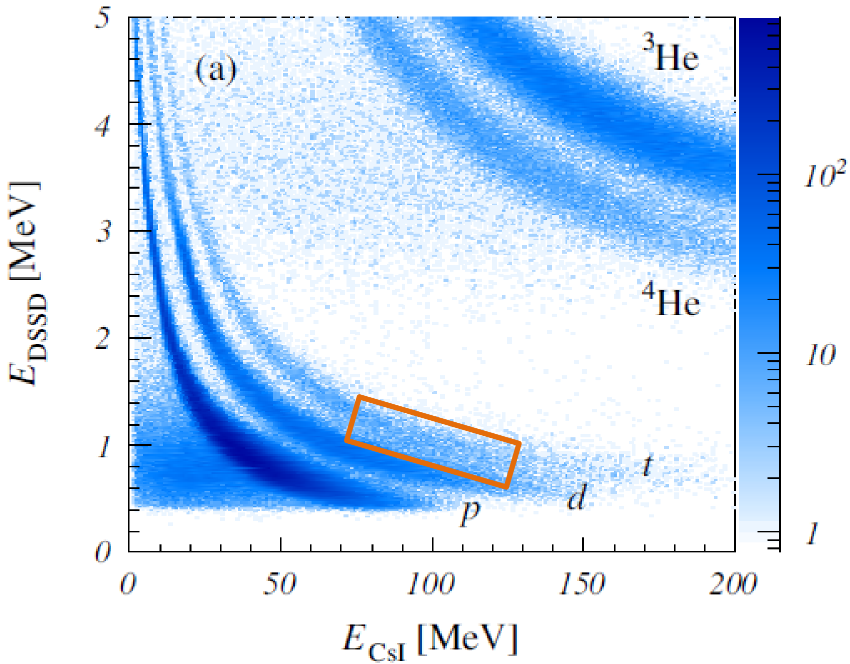




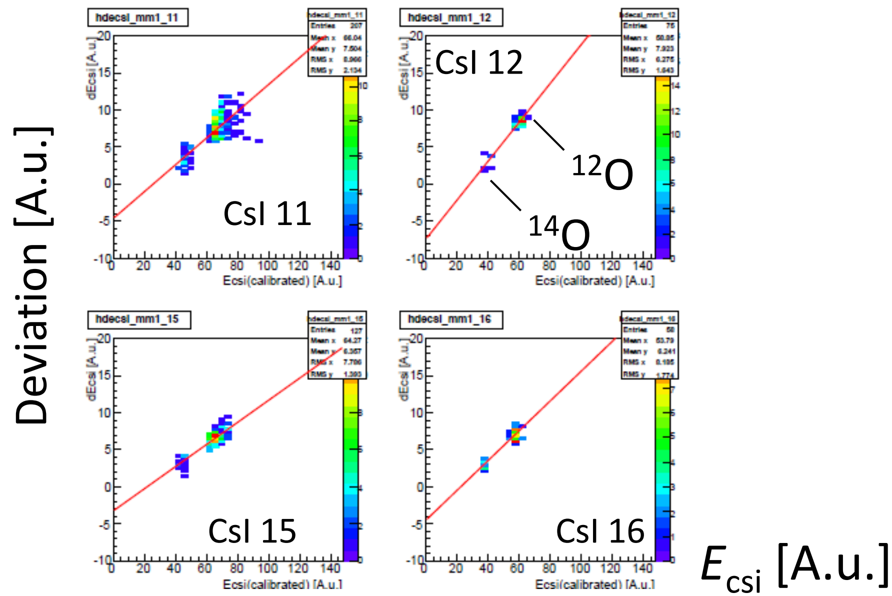
Accurate CsI energy calibration

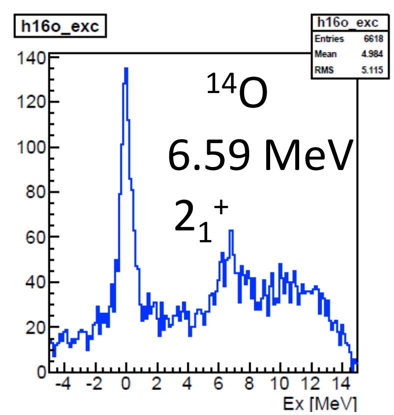
δE_x ±0.3 MeV (SPEG) → ±0.15 MeV (LISE)

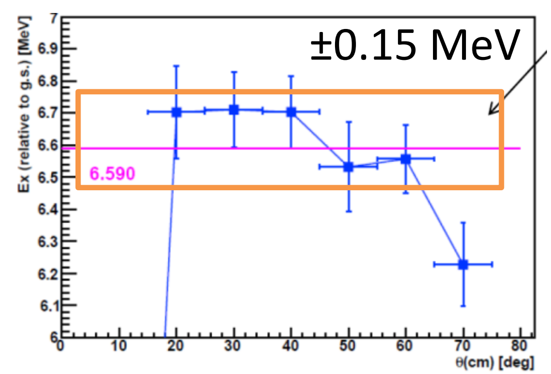
Calibration using E_{dssd}



Crystal-by-crystal fine tuning using $^{12}O_{g.s.}$ and $^{14}O_{g.s.}$ (calibration run)



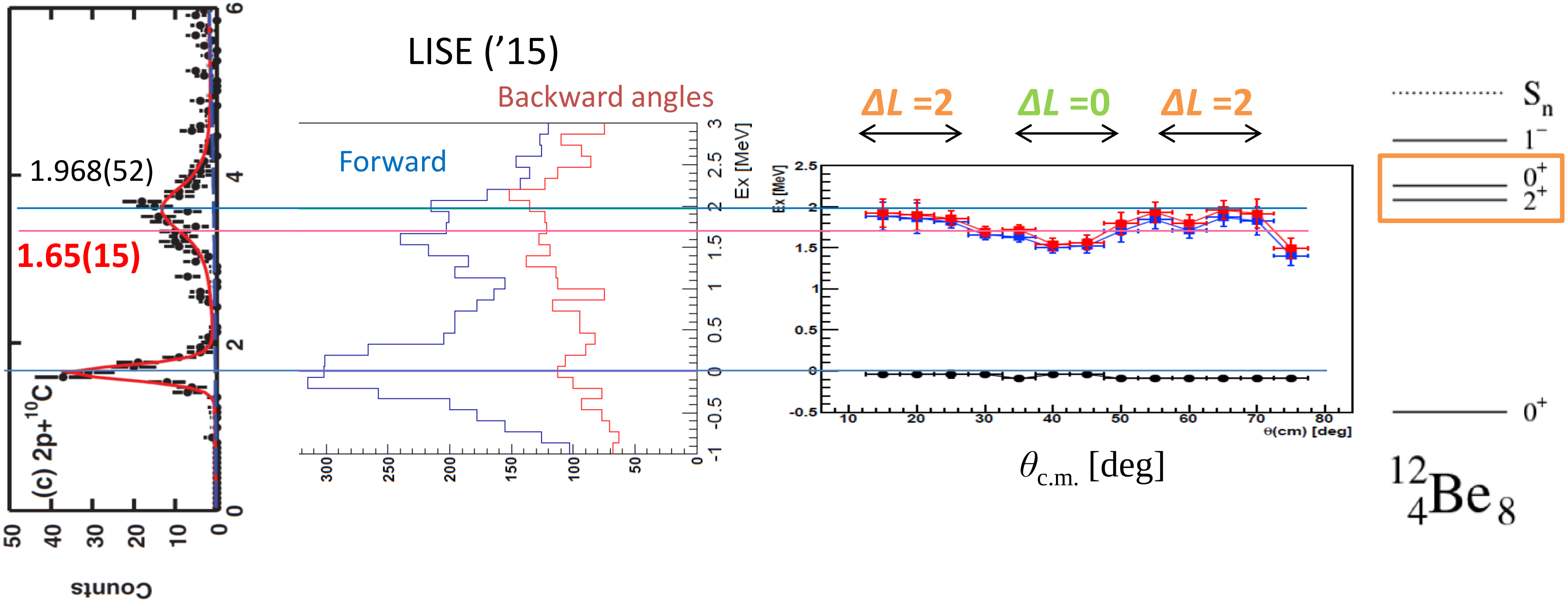




Comparison with Texas A&M data ('12)

Texas A&M ('12)

1n knockout of ^{13}O at 30 MeV/A on ^{9}Be



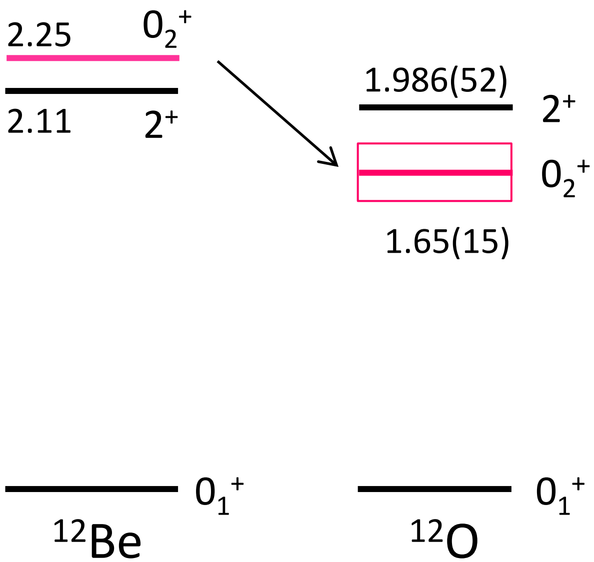
M.F. Jager *et al.,* Phys. Rev. C 86, 011304(R) ('12)

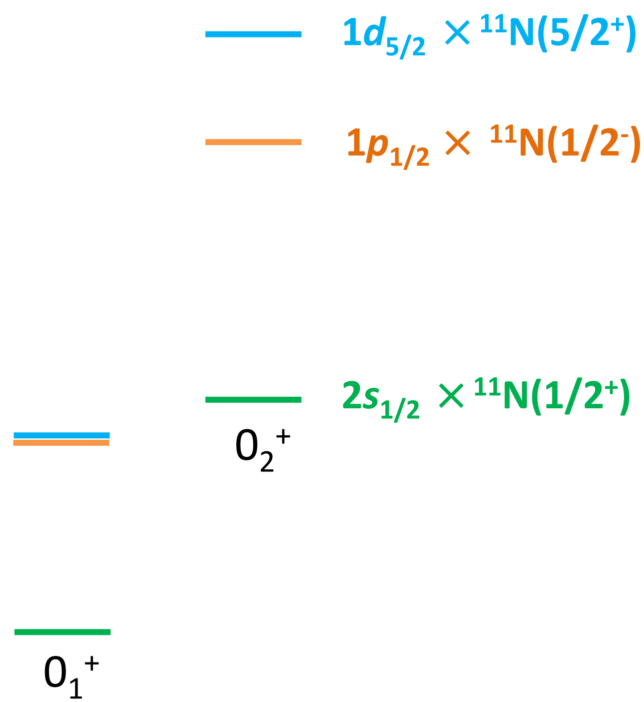
- Sizably lower than Texas A&M's state.
- Level mixing of 0_2^+ and 2_1^+ states is likely.
- Roughly speaking, 0_2^+ for LISE, and 2_1^+ for Texas A&M.

MED and its indication

- ^{11}N + p model with Woods-Saxon
- Potential depth tuned with $^{12,\,11}$Be

R. Sherr, H.T. Fortune, Phys. Rev. C 60, 064323 ('99)





- Ground state 0_1^+: $2s_{1/2}$ ~ 50%
- The second 0_2^+: $2s_{1/2}$ ~ $1d_{1/2}$
  - ❑ 40% of $2\hbar\omega$ from B(GT) to ^{12}B($1_{g.s.}^+$)
  - ❑ $2s_{1/2}$ only acounts for 20%. Halo structure unlikely to be a major component.

R. Meharchand, *et al.*,
Phys. Rev. Lett. 108, 122501 ('12)

Collaborators

H. Iwasaki[1,2], D. Beaumel[1], M. Assié[1], H. Baba[3], Y. Blumenfeld[1], F. de Oliveira Santos[4], N. De Séréville[1], A. Drouart[5], S. Franchoo[1], J. Gibelin[6], A. Gillibert[5], S. Grévy[4], S. Giron[1], J. Guillot[1], M. Hackstein[2], F. Hammache[1], N. Keeley[7], V. Lapoux[5], F. Maréchal[1], A. Matta[1], S. Mitimasa[8], L. Nalpas[5], F. Naqvi[2], H. Okamura[9], H. Otsu[3], J. Pancin[4], D.Y. Pang[4], L. Perrot[1], C. Petrache[1], E. Pollacco[5], R. Raabe[4], A. Ramus[1], W. Rother[2], P. Roussel-Chomaz[5], H. Sakurai[3], J-A. Scarpaci[1], O. Sorlin[4], P.C. Srivastava[4], I. Stefan[1], C. Stodel[4], S. Terashima[3]

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