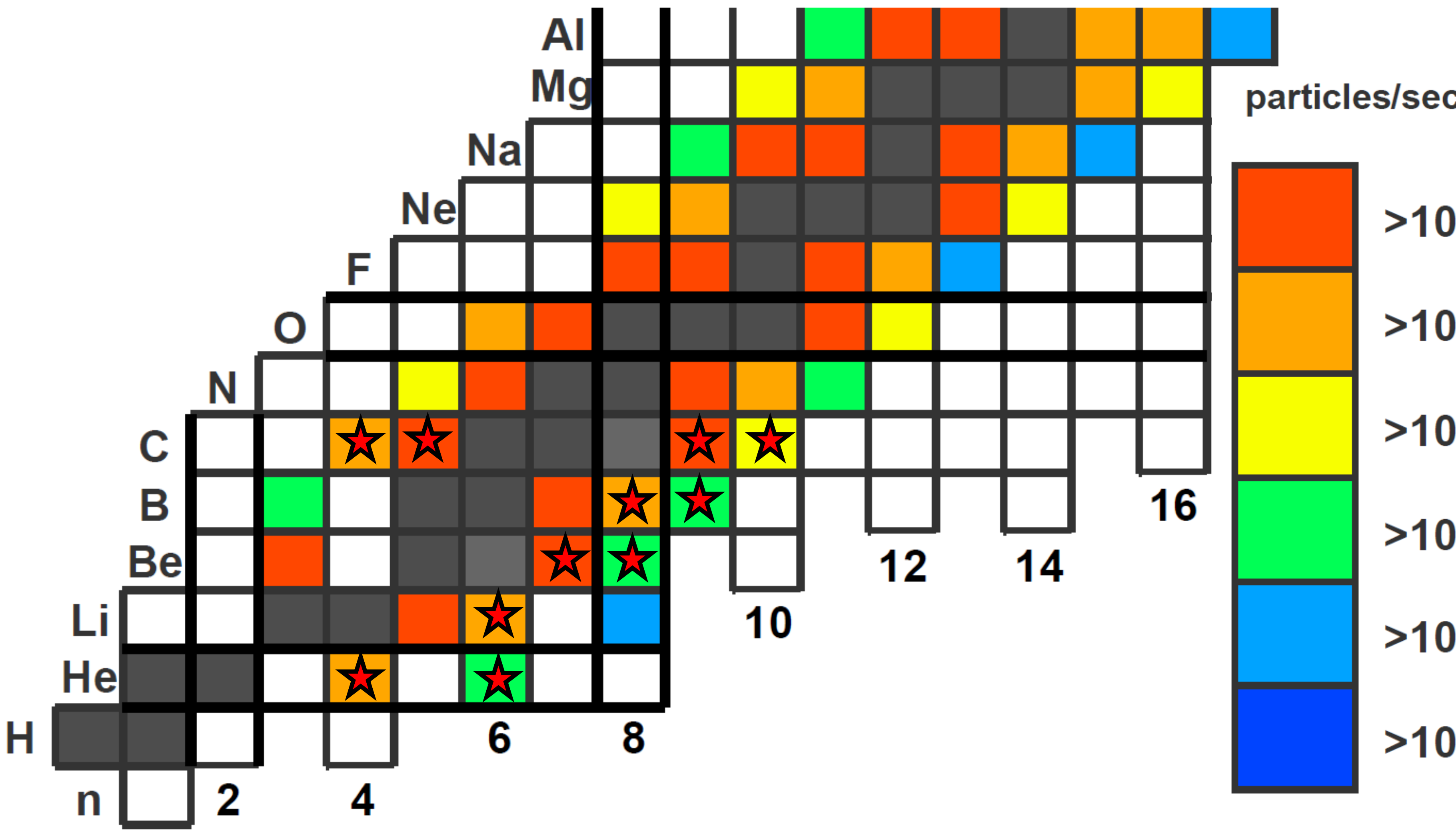
Physics opportunities with HELIOS (+AIRIS)

HELIOS excels at direct transfer reactions

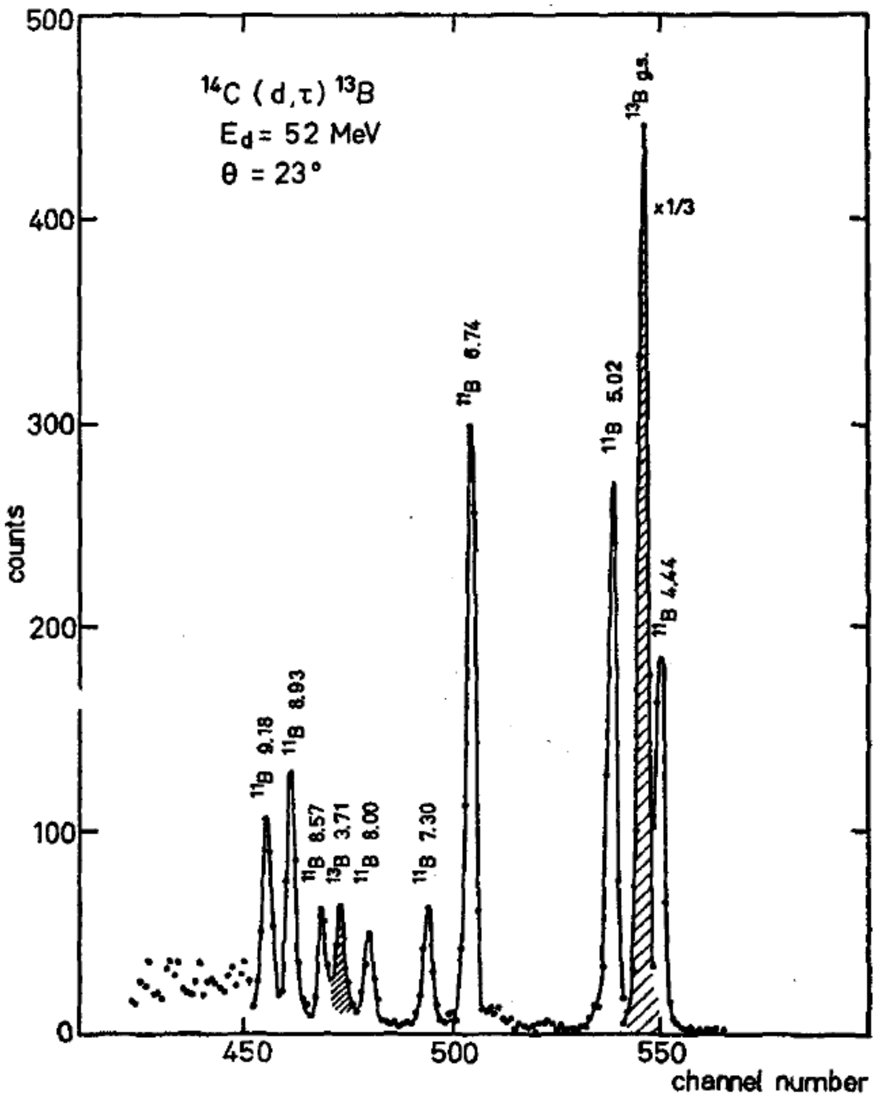
- Neutron stripping – (*d*,*p*) – σ ~ 1-50 mb/sr
- Proton stripping – (^{3}He,*d*) – σ ~ .1-10 mb/sr
- Proton pickup – (*d*,^{3}He) – σ ~ few mb/sr
- Neutron pickup – (*d*,*t*) – σ ~ few mb/sr
- Two-neutron stripping – (*t*,*p*) σ ~ .1- few mb/sr
- Proton-neutron pickup – (*d*,α) σ ~ .1- few mb/sr
- Proton-neutron stripping – (α,*d*) σ ~ .1- few mb/sr

Most reactions are within reach with beam intensities down to approximately 10^4 pps

Interesting light beams from AIRIS



HELIOS – it's not just for (*d*,*p*) anymore…



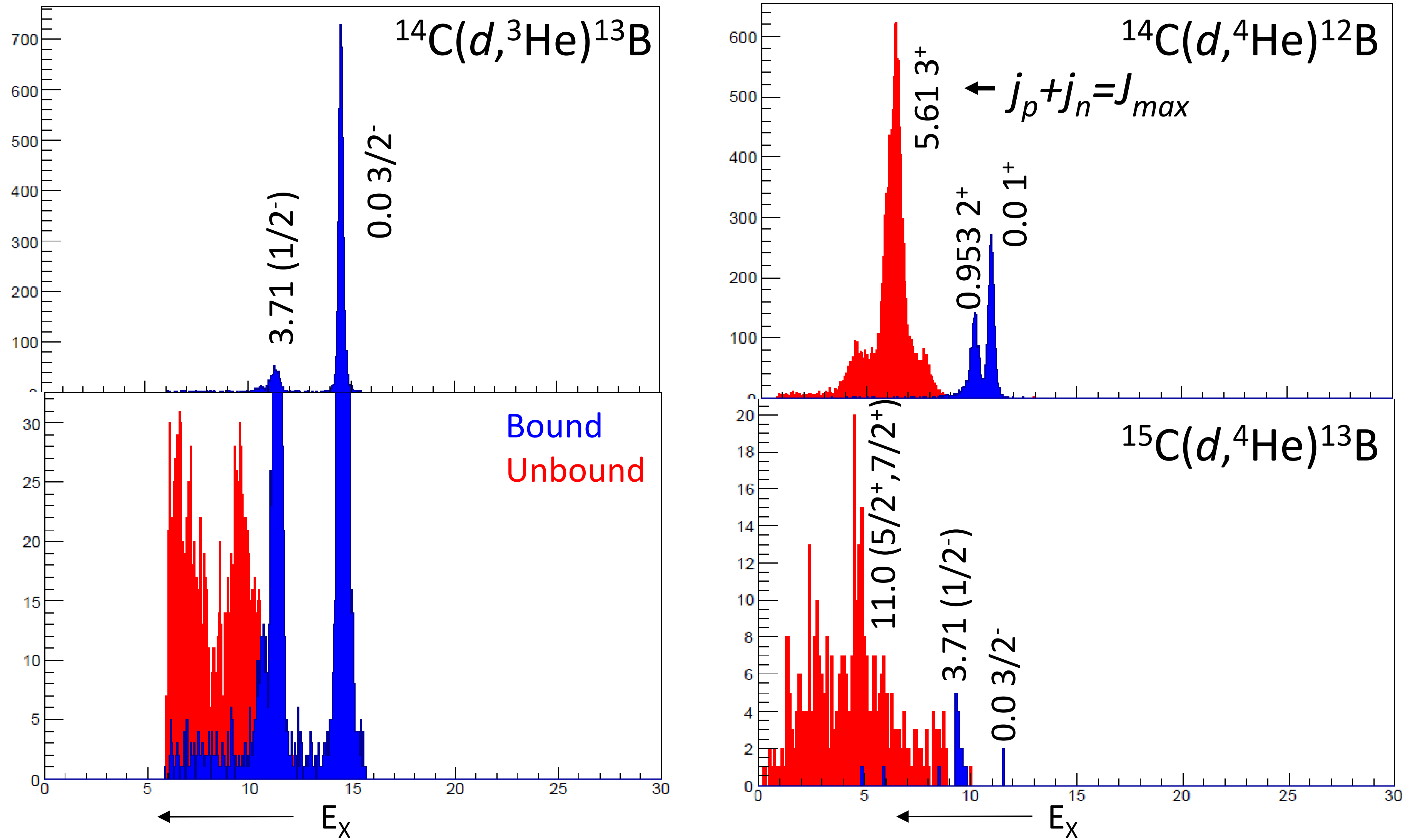
Part of study of proton correlations in the ground states of $^{12,13,14}C$.

$^{14}C(d,^{3}He)^{13}B$ - target was 40% ^{14}C, 60% ^{12}C

Result – spectroscopic factors in agreement with CK shell model, show reduction in $0p_{1/2}$ proton occupancy with increasing *N*, but absolute values have large uncertainties

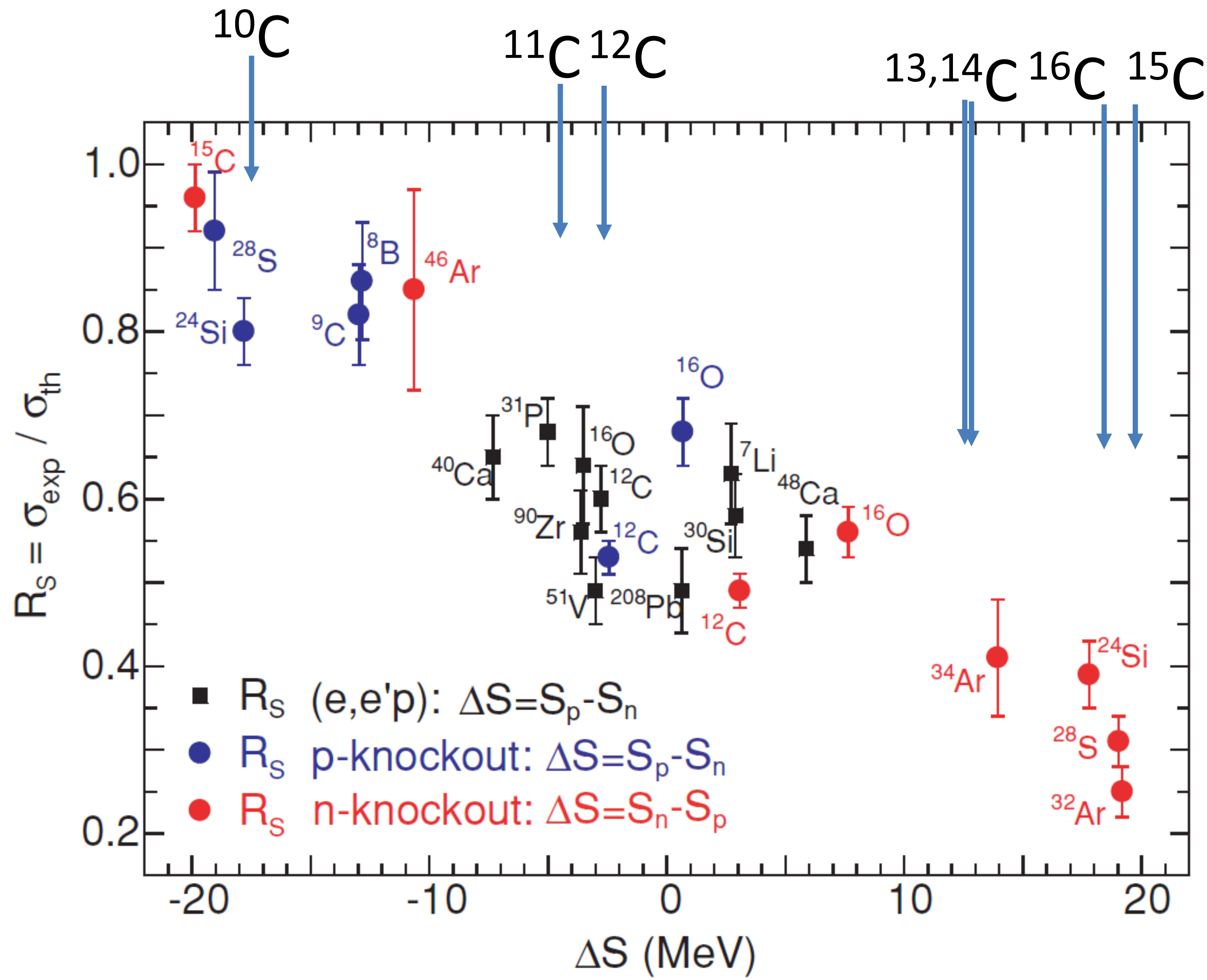
Mairle and Wagner, NPA **253**, 253 (1975)

HELIOS – it's not just for (*d*,*p*) anymore…



(S. Bedoor, preliminary)

Gade systematics and proton removal from ^{A}C

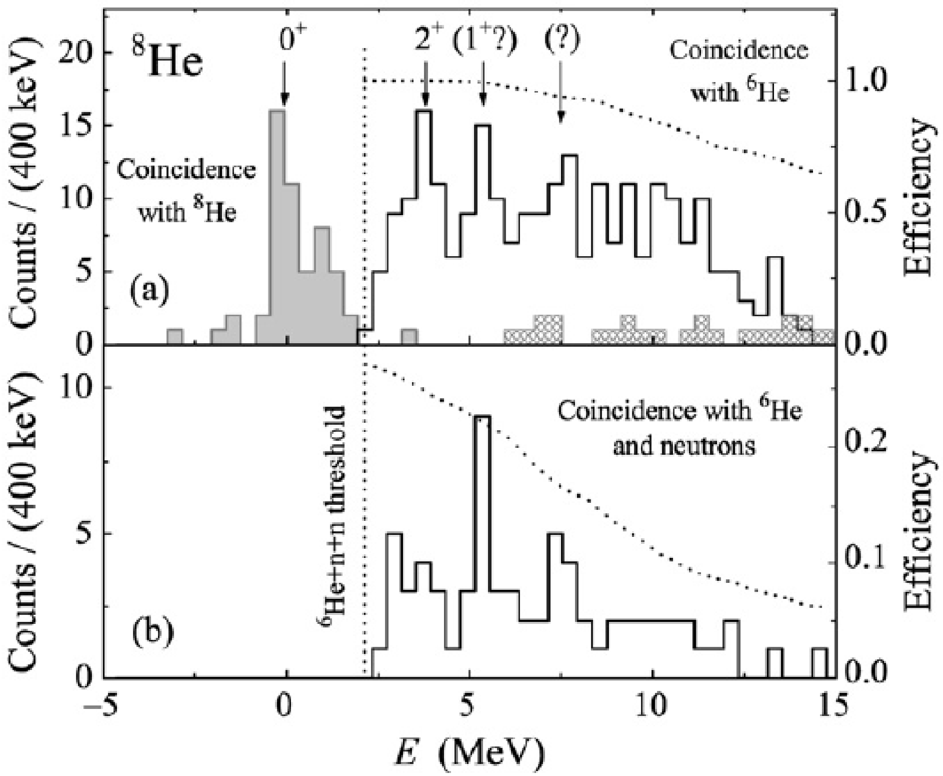


A. Gade et al, PRC 77, 044306 (2008)

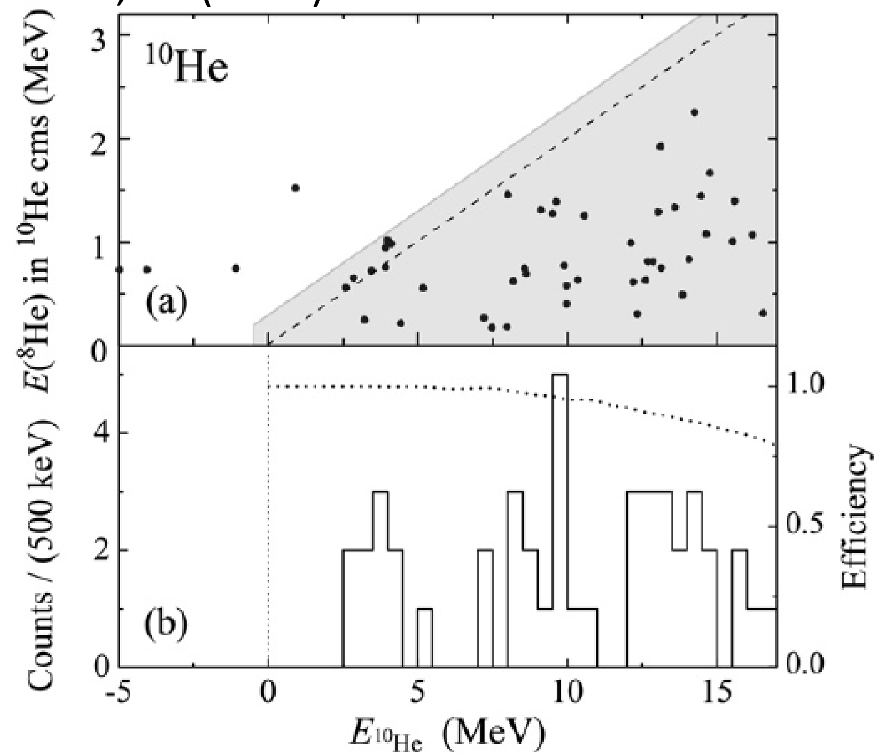
Access with $^{A}C(d,^{3}He)^{A-1}B$

Pair transfer with (*t*,*p*)

Golovkov *et al.*, PLB **672**, 22 (2009)



^{6}He(*t*,*p*)^{8}He



^{8}He(*t*,*p*)^{10}He

^{4,6,8}He(*t*,*p*)^{6,8,10}He with HELIOS: Improve statistics and resolution. Detailed properties of wave functions

Pair transfer with (*t*,*p*)

N=8 magicity broken in $^{11,12,(13)}$Be
But restored in ^{14}Be?

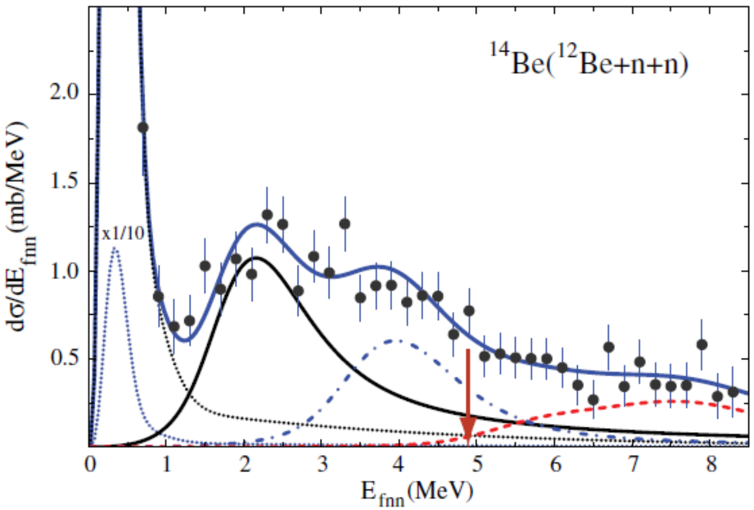


FIG. 1 (color online). Relative-energy spectrum ($d\sigma/dE_{fnn}$) of the ^{12}Be + n + n system after inelastic scattering of 304 MeV/u ^{14}Be in a liquid hydrogen target. The curves show the decomposition of the spectrum into Breit-Wigner shaped resonances, with the experimental resolution taken into account. The arrow indicates the position of the four-neutron decay threshold.

Aksyutina et al., PRL 111, 242501 (2013).

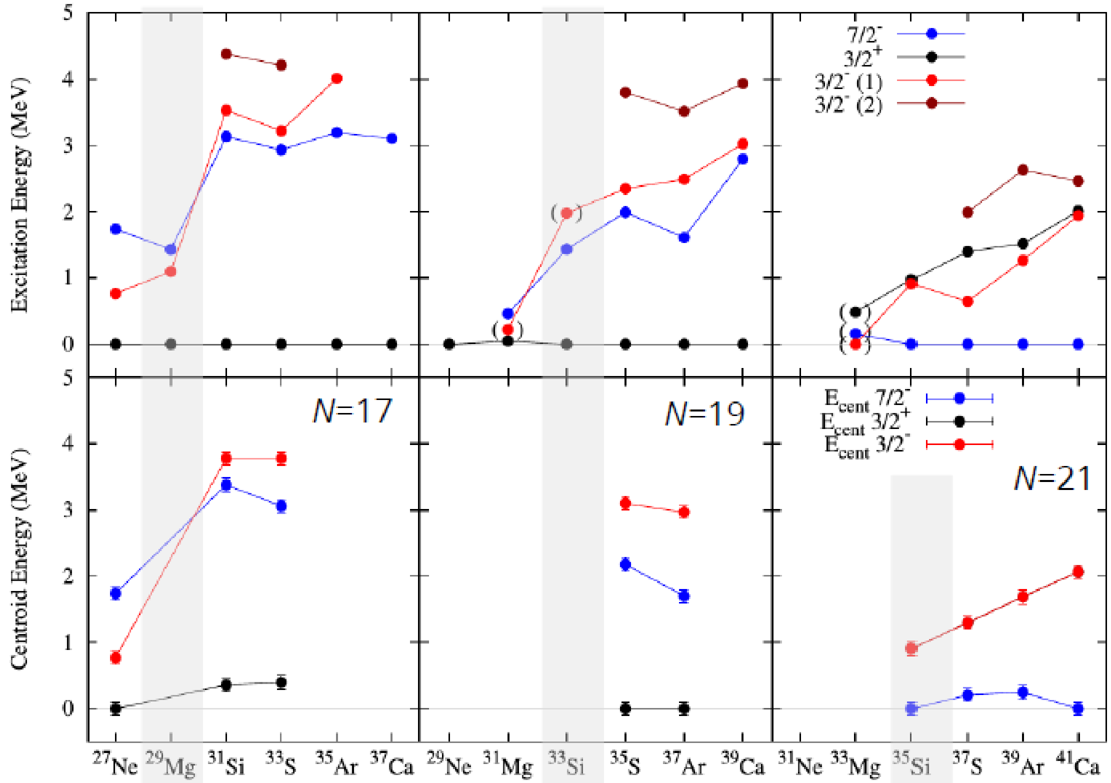
Excitation energies of 2_1^+ and deformation lengths of ^{12,14}Be from inelastic scattering on a ^{12}C target are compared between the experiment and shell model calculations. A three-body model calculation for ^{14}Be(2_1^+)[16] is also shown

	e_p/e	e_n/e	E_x (MeV)	M_p ($e$fm^2)	M_n ($e$fm^2)	δ (fm)
^{12}Be Exp.[2]			2.10			1.93(11)
PSDMK	1.3	0.5	4.04	6.37	2.93	1.18
SFO	1.3	0.5	2.53	7.99	10.76	2.28
SFO	1.11	0.27	2.53	5.73	8.64	1.83
^{14}Be Present Exp.			1.54(13)			1.18(13)
PSDMK	1.3	0.5	2.16	8.98	13.11	2.29
SFO	1.3	0.5	1.93	9.18	13.41	2.34
SFO	1.05	0.20	1.93	5.63	10.11	1.63
3-body[16]			1.10			

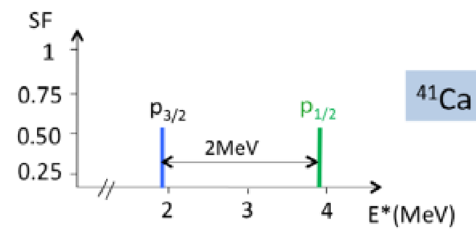
Sugimoto et al., PLB 654, 160 (2007)

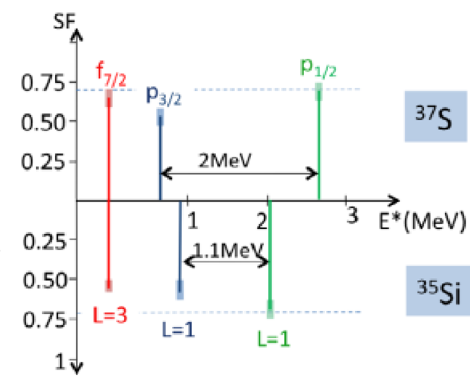
^{12}Be(*t*,*p*)^{14}Be offers a complementary probe of wave functions in ^{14}Be

Single-particle centroids in proximity of the "Island of Inversion"



Secondary Beam	Expected Rate	Reaction(s)
^{28}Mg	$>10^5$	(d,p)
^{32}Si	$>10^5$	(d,p), (d,^{3}He)
^{33}Si	$>10^4$	(d,^{3}He)
^{34}Si	$>10^4$	(d,p), (d,^{3}He)



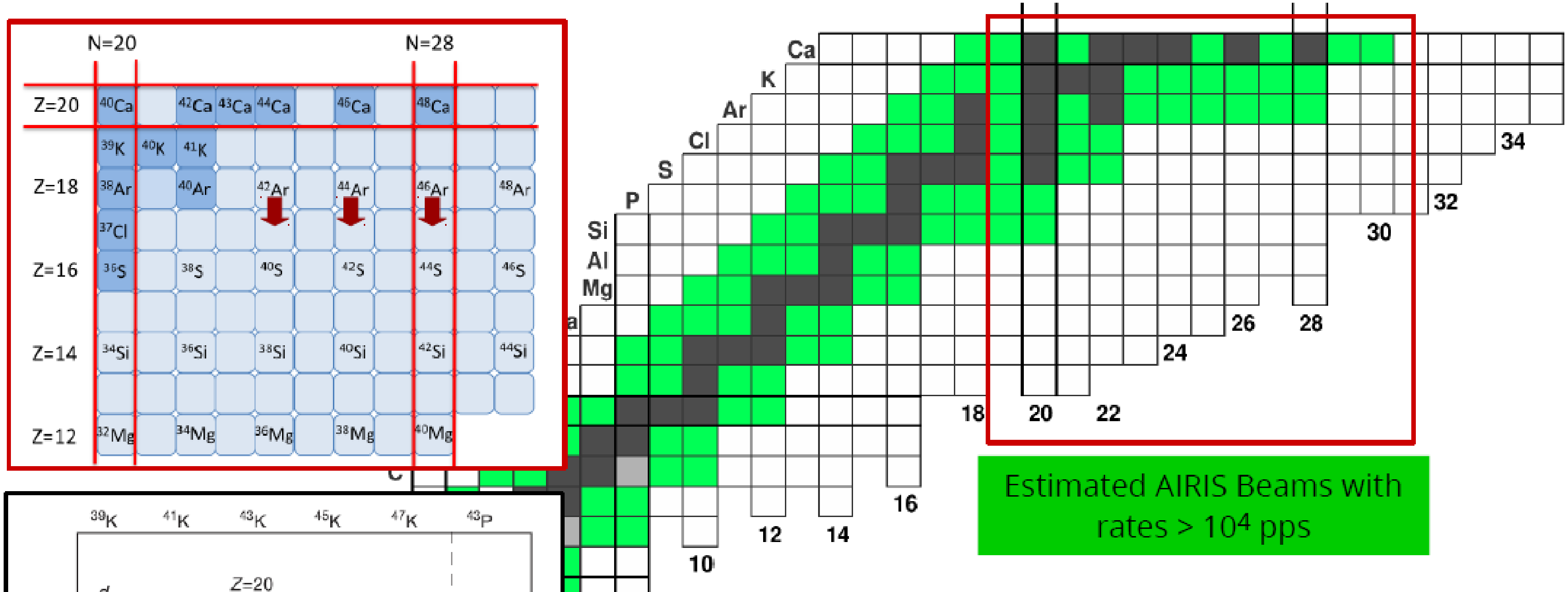


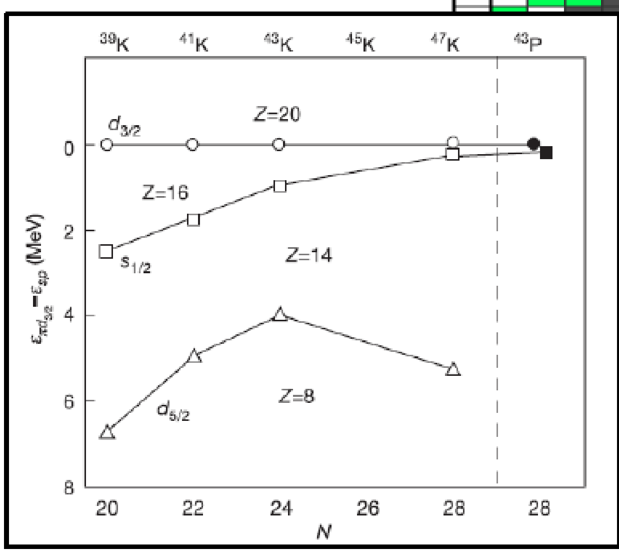
Sorlin and Porquet, Phys. Scr. T152 (2013)

- Single-neutron adding into *N*=17, 19, & 21 nuclei
- Complete and extend centroid systematics
- Testing of the spin-orbit splitting strength
- Single-proton removal into the Island of Inversion ($^{31-33}$Al)

C. R. Hoffman

Single-particle structure near the neutron-rich *N*=28 region of shape coexistence



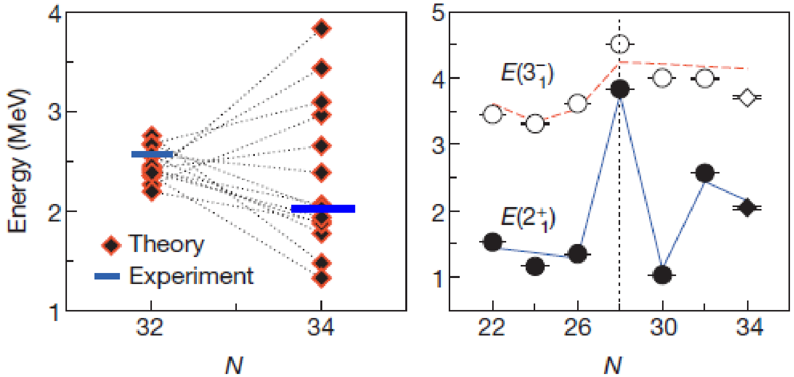


- Single-proton states in Cl probed through the (d,^{3}He) reaction on ^{42,44,46}Ar (N=24, 26, & 28)
  → Analogous to *Z*=19, track emergence of the Z=14 sub-shell
- Complimentary comparisons with knock-out data
- Challenging level separations in ^{41,43,45}Cl
  → Excellent opportunity for improved resolving power of **HELIOS**

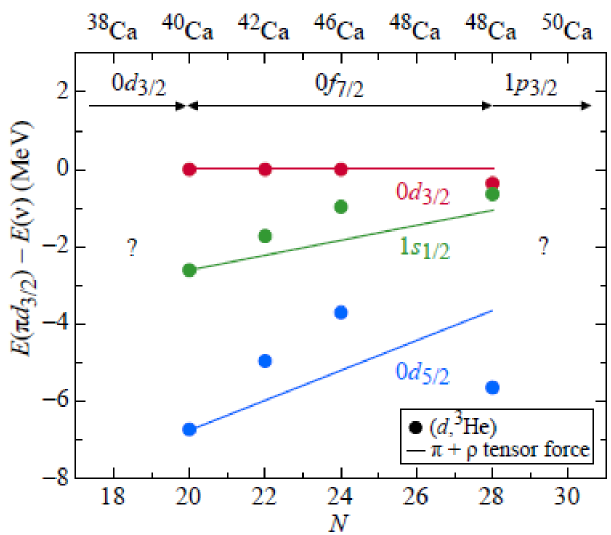
C. R. Hoffman

Sorlin and Porquet, Phys. Scr. T152 (2013), Fridmann et al., Nature 435 (2005)

The Ca chain with AIRIS beams and HELIOS



D. Steppenbeck et al., Nature ***502****, 207 (2013)*



T. Otsuka et al., PRL ***95****, 232502 (2005)*

To date

- No quantitative measures of admixtures
- Non-yrast states populated weakly
- Ingredients for SM calculations missing - may reduce some uncertainties in calculations of $N = 32,34$ shell gaps

Measure transfer reactions - spectroscopic factors

- Quantitative constraints for SM calculations
- Determine centroids of ***neutron*** $p_{3/2,1/2}$ and $f_{5/2}$ with (d,p)
- Determine centroids of ***proton*** $d_{3/2}$, $s_{1/2}$, $d_{5/2}$ with $(d,^3He)$ (caveat, the $d_{5/2}$ may be too deeply bound)
- Determine $T = 1$ $(p_{3/2})^2$ matrix elements from $^{49}Ca(d,p)$
- Proton hole states below $N = 20$ and above $N = 28$

Beam	Intensity (AIRIS)	Reactions to study
^{38}Ca	2.1×10^5	$(d,^3He)$
^{49}Ca	3.3×10^6	(d,p), $(d,^3He)$
^{50}Ca	1.3×10^5	(d,p), [(t,p)], $(d,^3He)$

Contribution: S. J. Freeman, University of Manchester

Summary

- *Many* new opportunities would be made available with HELIOS+AIRIS beams
  - Higher intensity RIBS
  - RIBS further from stability
  - A variety of reactions to choose from
- Many cases for different mass regions
- I have not mentioned CARIBU – but there are many opportunities there as well