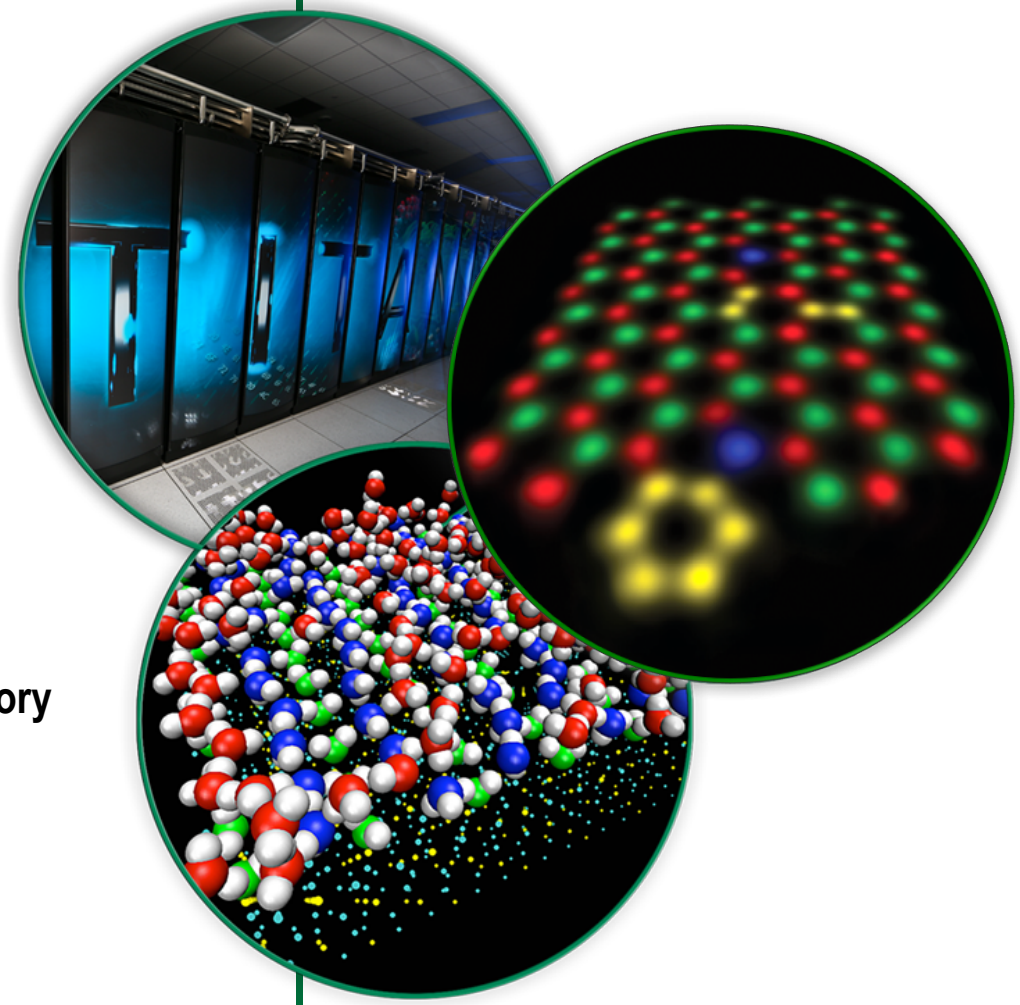
Day 1 FRIB: Nuclear Structure

Shapes, Coexistence, and Shell Closures
Towards the Limits: Exploring the Nature of Nucleon Interactions



James Mitchell Allmond
Physics Division – Oak Ridge National Laboratory

August 2, 2017

*The following slides represent a partial view of nuclear structure.

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

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  - **Need versatile Decay Station on Day 1 and HRS + GRETA + FRIB expedited.**

- Many of the interesting $E(2^+)$ values will have been measured by Day 1; there will be competition (e.g., RIKEN).
  - **In these cases, focus on where detailed spectroscopy can be done for first time but keep a lookout for unique circumstances/opportunities.**

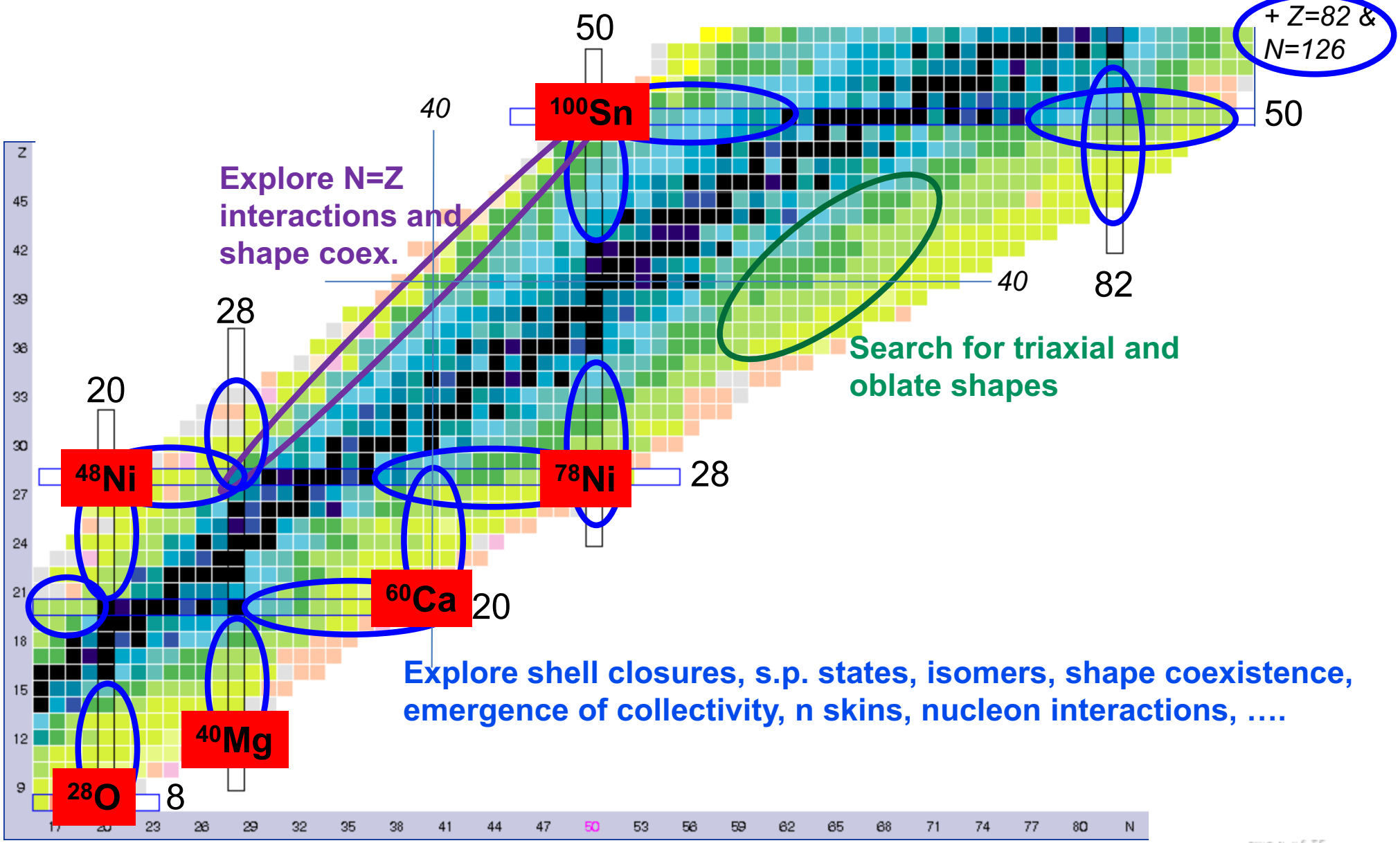
- Stopped and ReA beams offer an opportunity for the most detailed spectroscopy but the beams will be less exotic and many of the traditional decay and reaction methods require relatively pure beams.
  - **Need firm grasp on beam contamination; new techniques and detectors may need development if purity is nominally < 50%.**

- There is only one GRET(IN)A, which must be shared between Fast and ReA beams.
  - **A second array may be needed for ReA at times (e.g., CLARION2 will be ready for campaigns).**

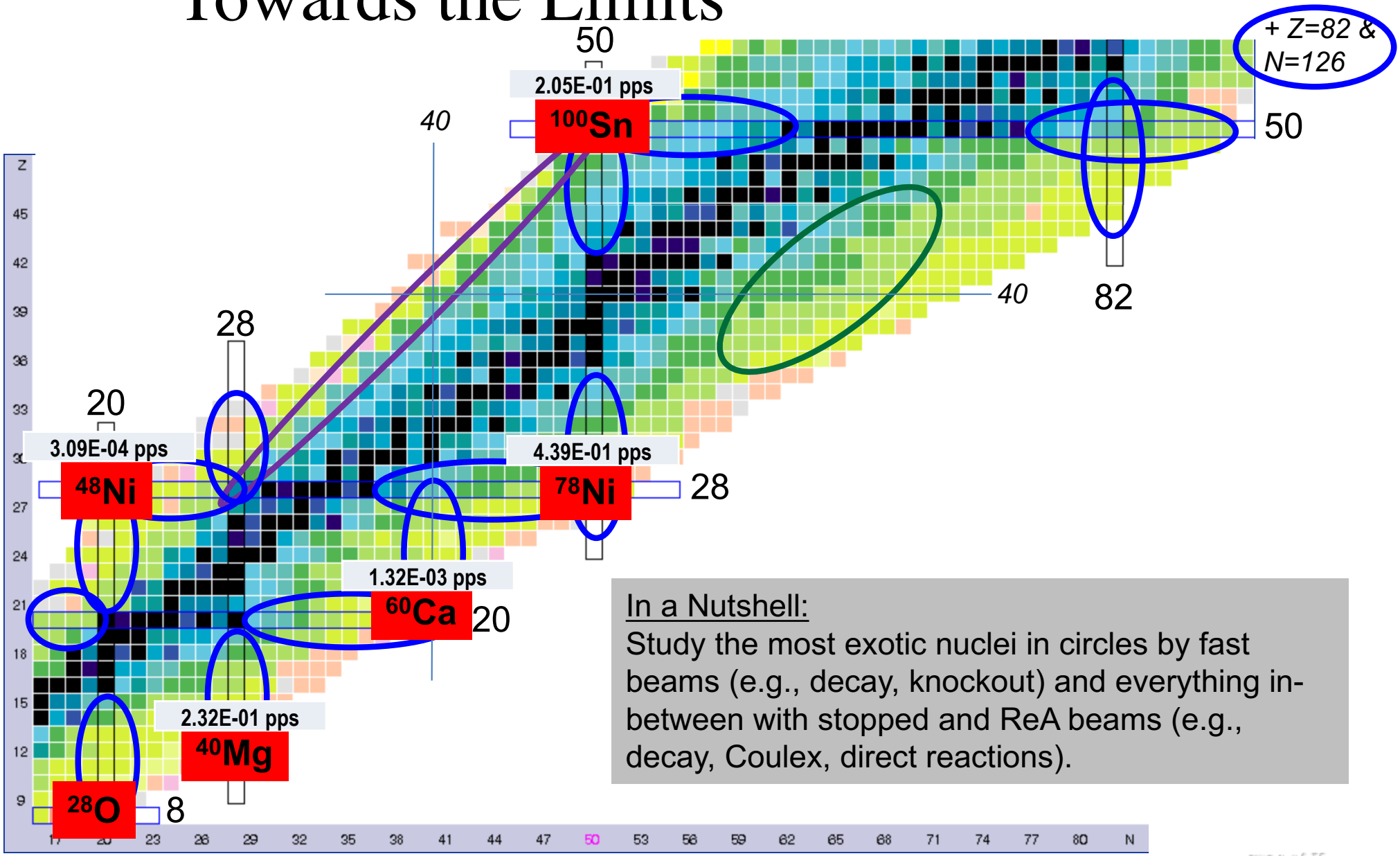
- Many γ-ray transitions of interest (e.g., seniority isomers) and x-rays will be low energy.
  - **Need some HPGe with high efficiency at 20-200 keV (e.g., BEGe), particularly when expanding to heavier nuclei.**

Regions of Interest (partial)

Many opportunities for both exploration and detailed spectroscopy towards the driplines

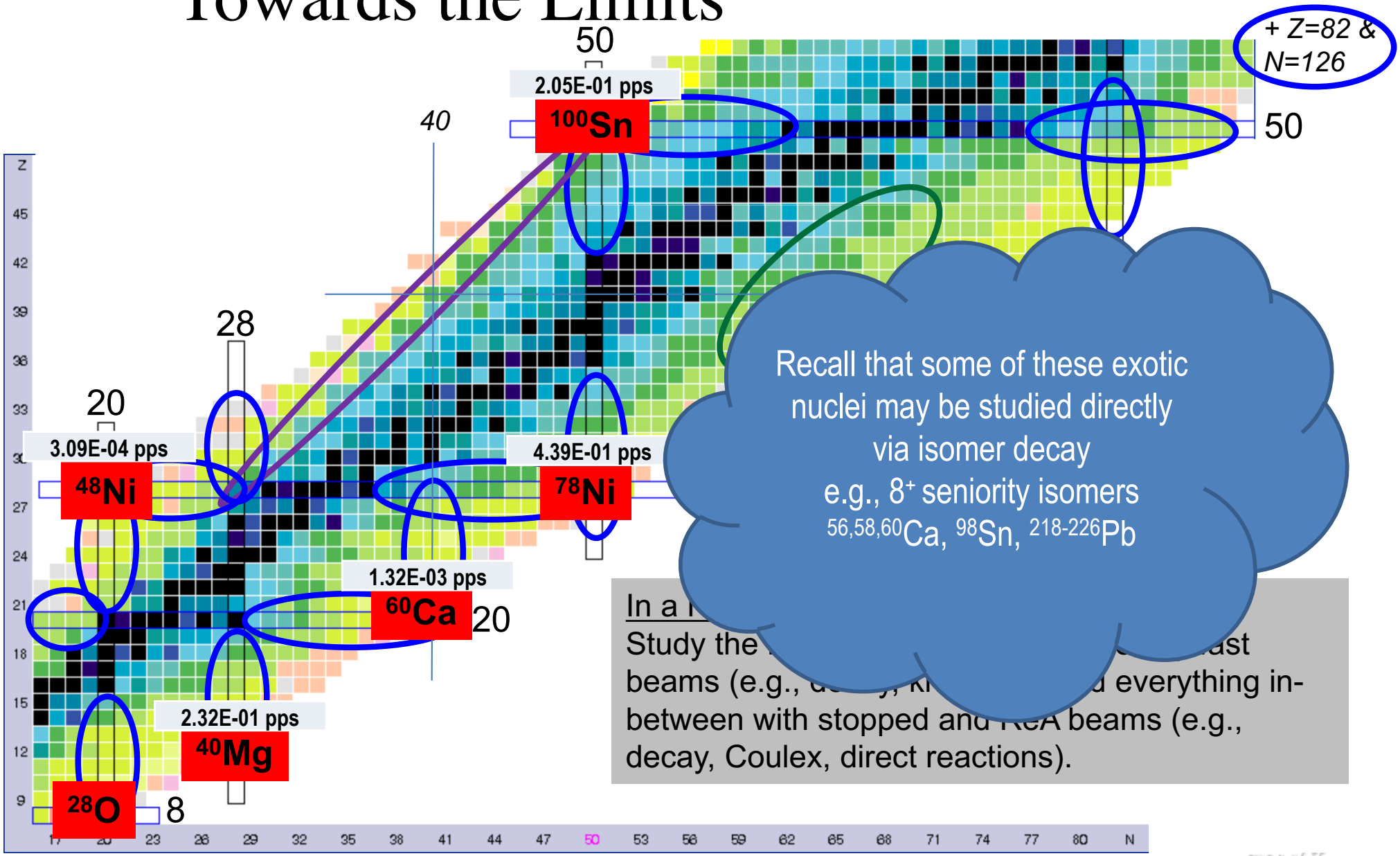


Shapes, Coexistence, and Shell Closures Towards the Limits



In a Nutshell:
Study the most exotic nuclei in circles by fast beams (e.g., decay, knockout) and everything in-between with stopped and ReA beams (e.g., decay, Coulex, direct reactions).

Shapes, Coexistence, and Shell Closures Towards the Limits



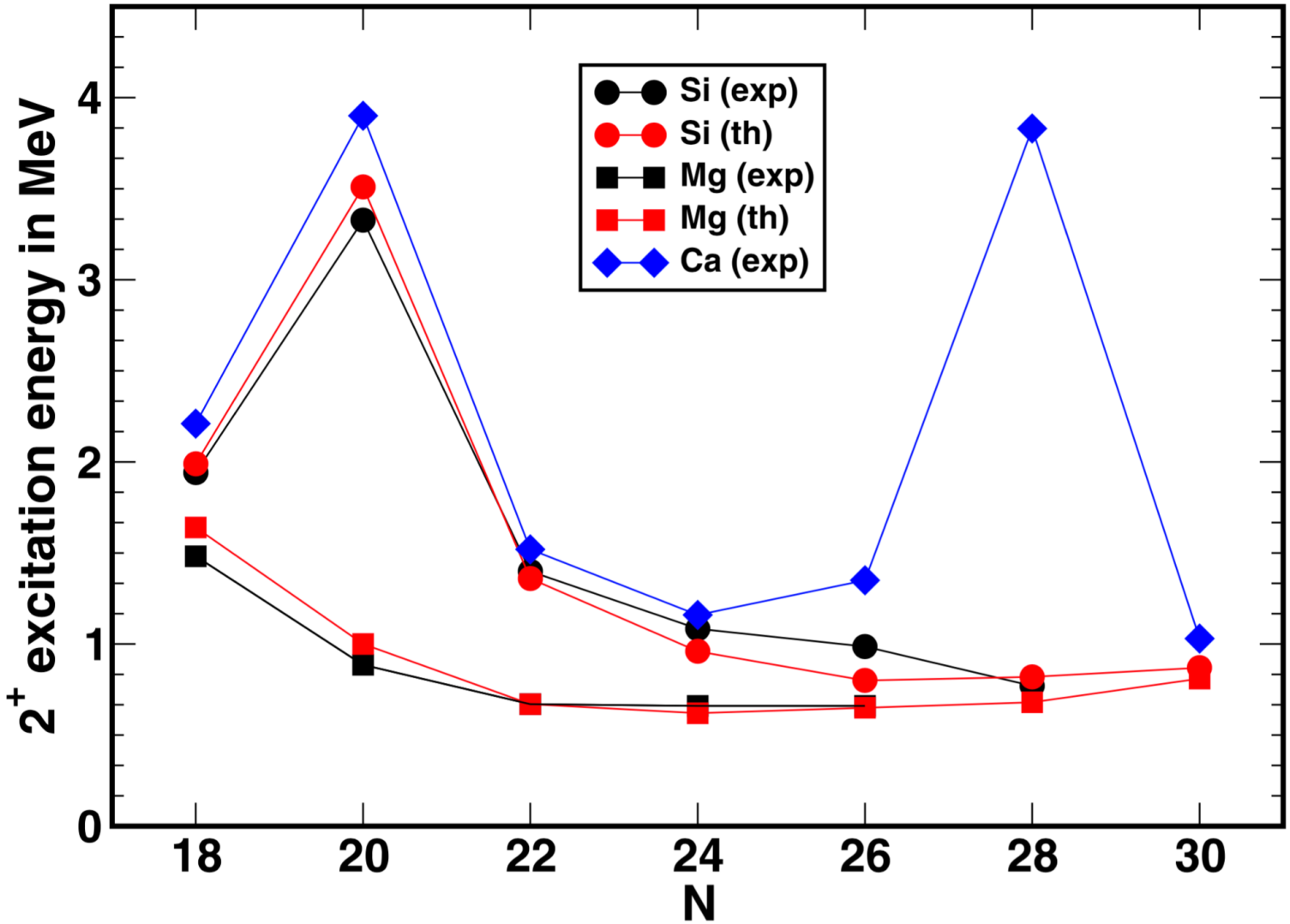
Recall that some of these exotic nuclei may be studied directly via isomer decay e.g., 8^+ seniority isomers $^{56,58,60}Ca$, ^{98}Sn, $^{218-226}Pb$

In a r
Study the ast
beams (e.g., d , ki d everything in-
between with stopped and ReA beams (e.g., decay, Coulex, direct reactions).

Example Storylines and Experiments For Day 1 FRIB

(FAST pps)
(ReA pps)
(Stopped pps)

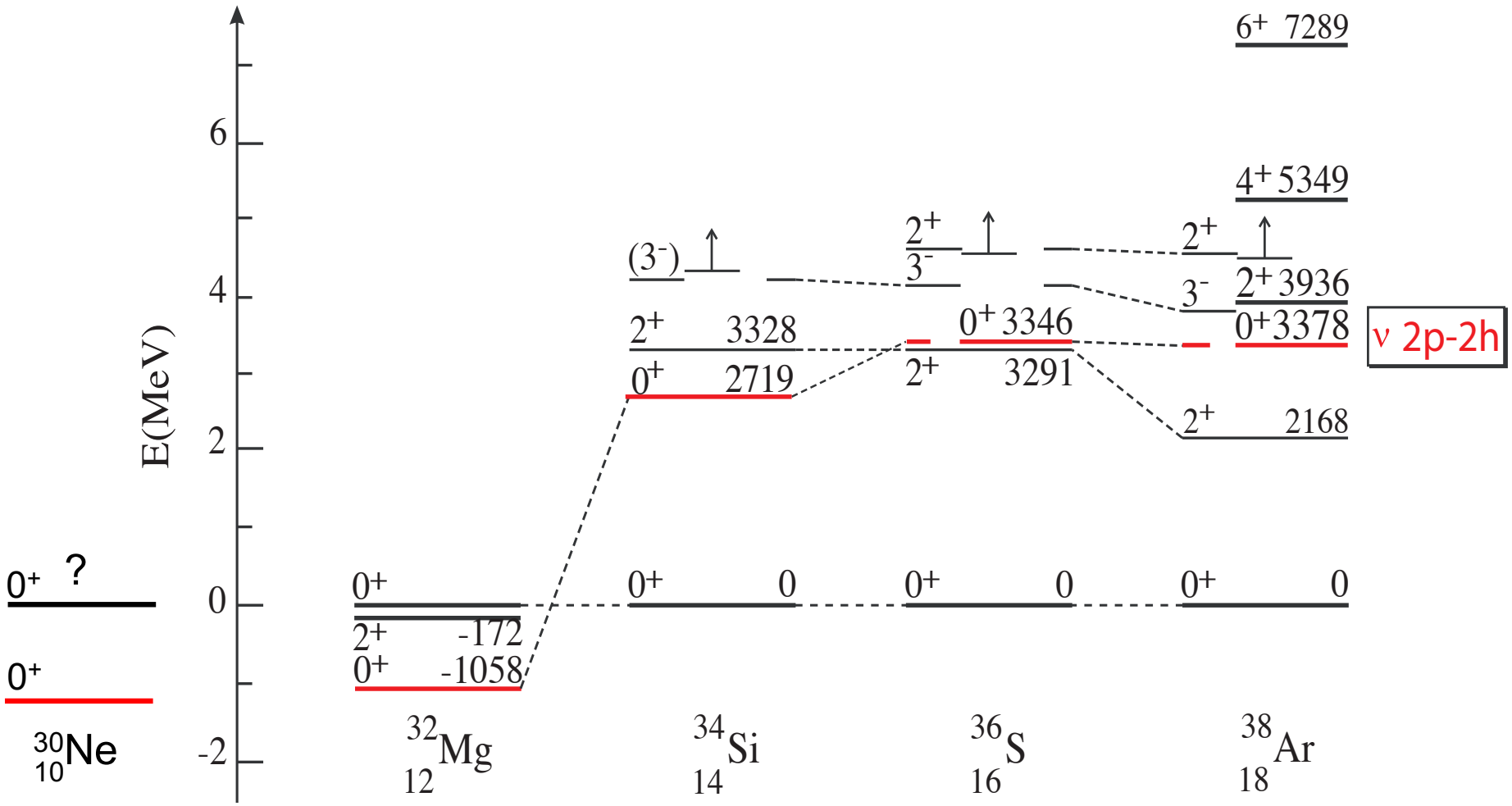
N=20 and 28 Shell Closures



*calculated values with the SDPF-U-MIX interaction.

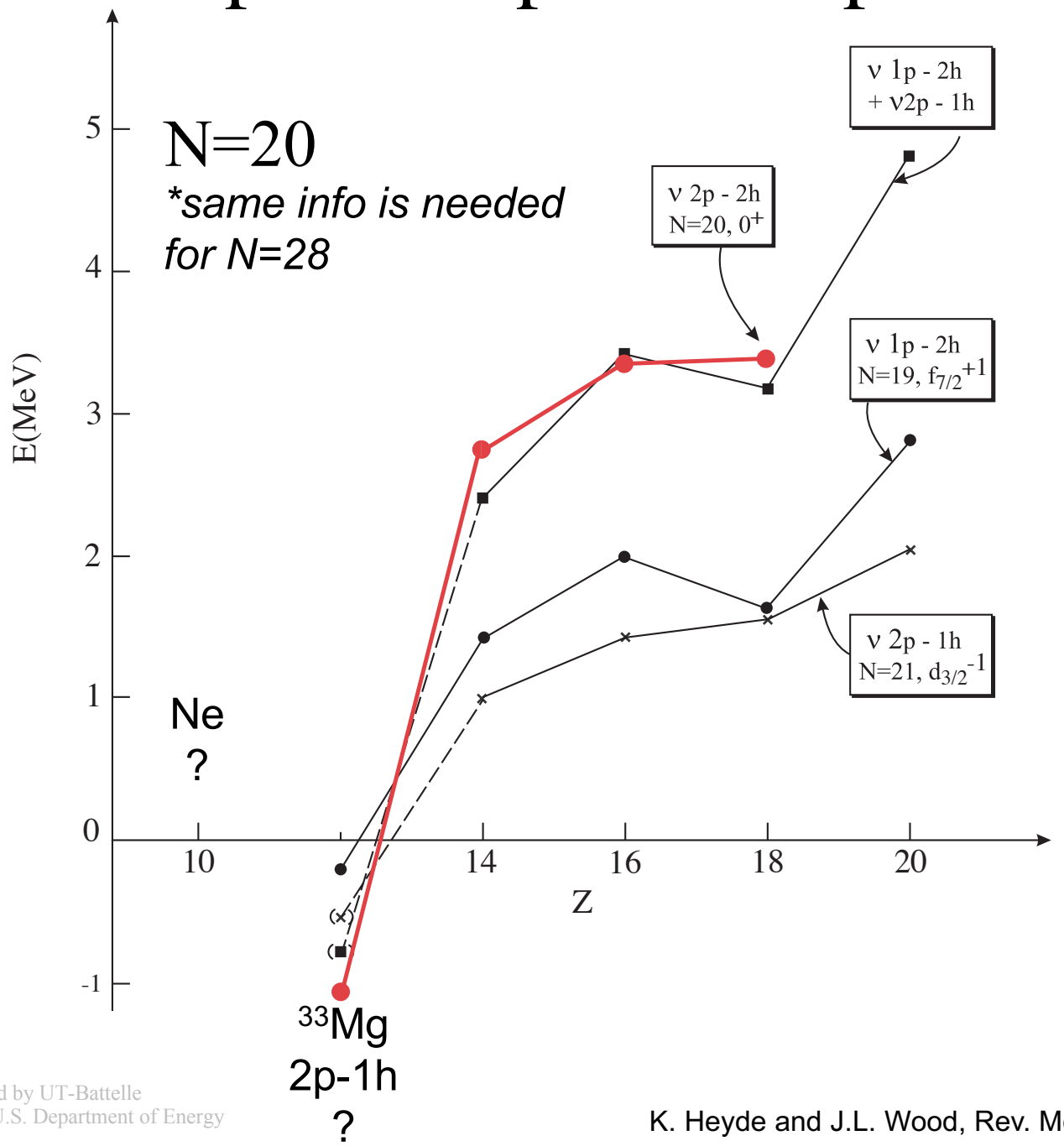
A. Poves, J. Phys. G: Nucl. Part. Phys. **44**, 084002 (2017).

N=20 2p-2h Systematics



K. Heyde and J.L. Wood, Rev. Mod. Phys. **83**, 1467 (2011).

1p-2h + 2p-1h → 2p-2h Correlation



^{33}Mg 2p-1h:
1n ko with ^{34}Mg (4E4)
Safe Coulex (2E4)
(t,p) with ^{31}Mg (8E5)
Decay with ^{33}Na (1E3)
Decay-n with ^{34}Na (1E2)

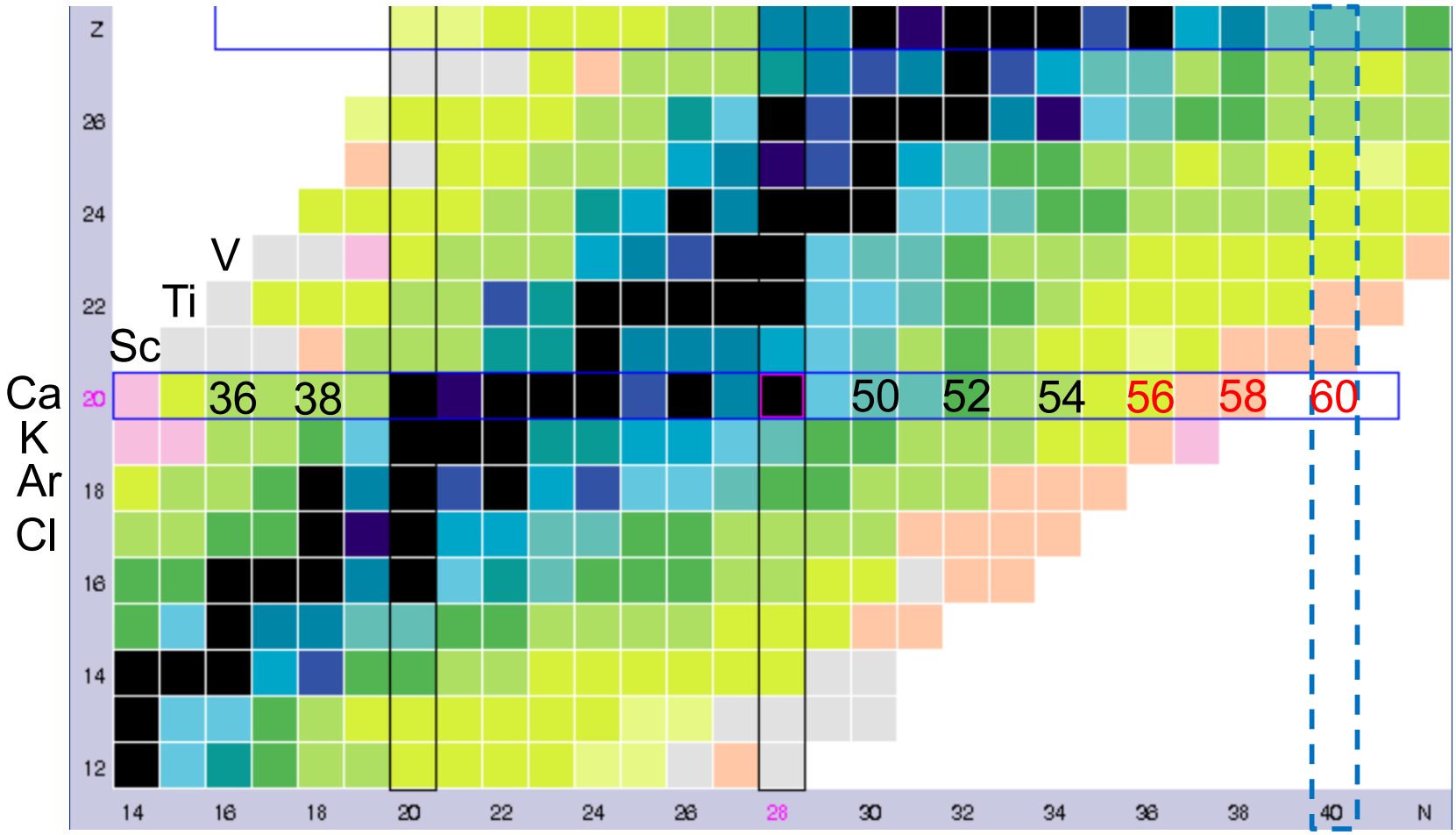
^{30}Ne 0p-0h:
2n ko with ^{32}Ne (3E1)

^{29}Ne 1p-2h:
2n ko with ^{31}Ne (3E2)
Fast Coulex (2E4)
Decay with ^{29}F (5E1)

^{31}Ne 2p-1h:
1n ko with ^{32}Ne (3E1)
Fast Coulex (3E2)

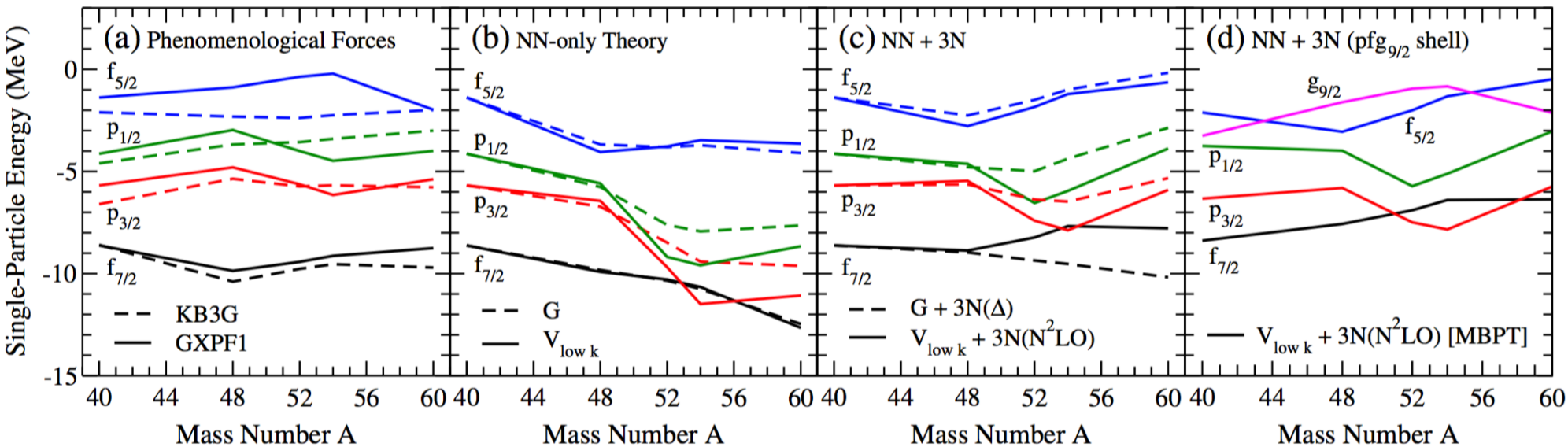
K. Heyde and J.L. Wood, Rev. Mod. Phys. **83**, 1467 (2011).

Ca (Z=20) Isotopes



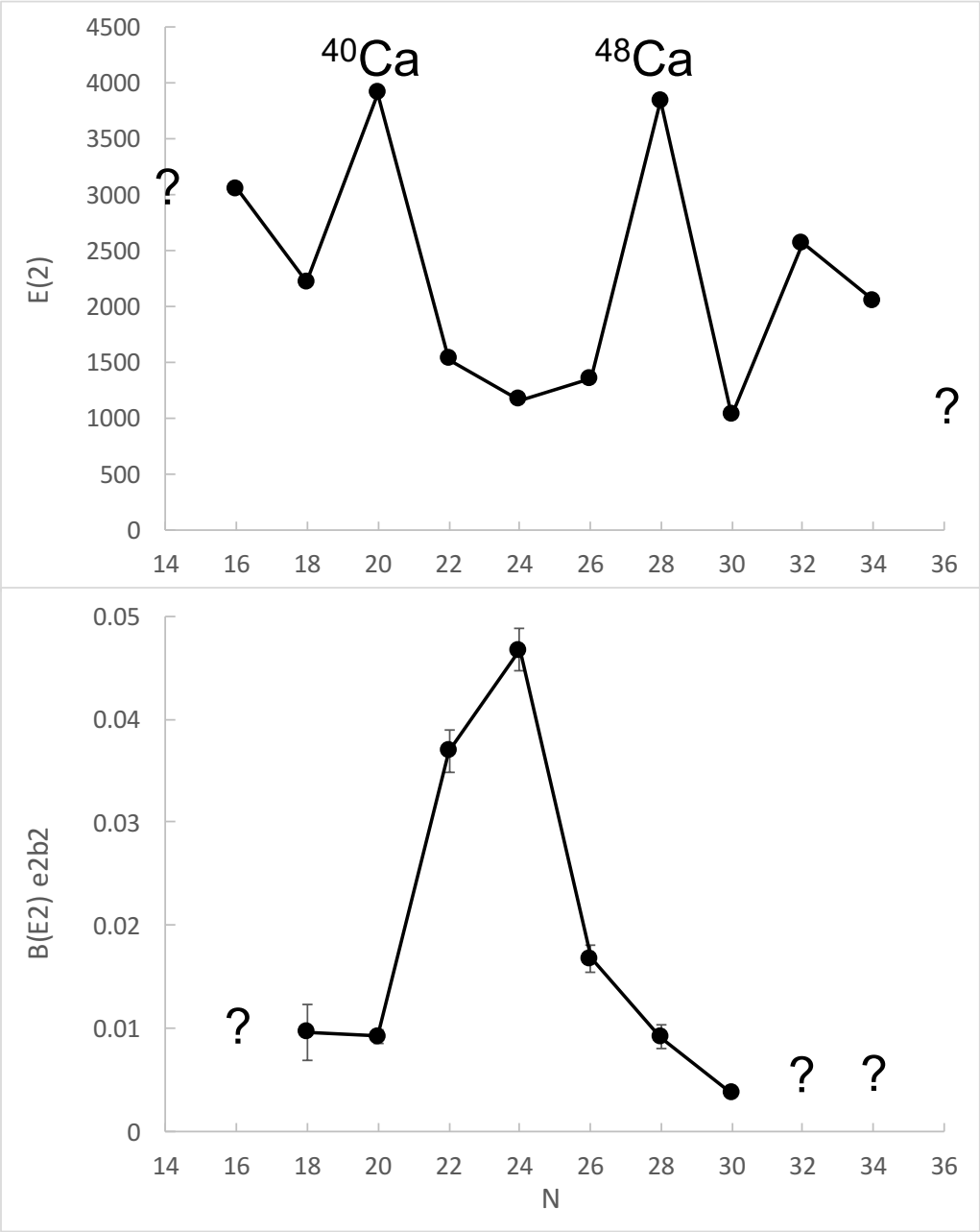
Ca (Z=20) Isotopes: Test of 3N Forces

*3N calculations to be updated



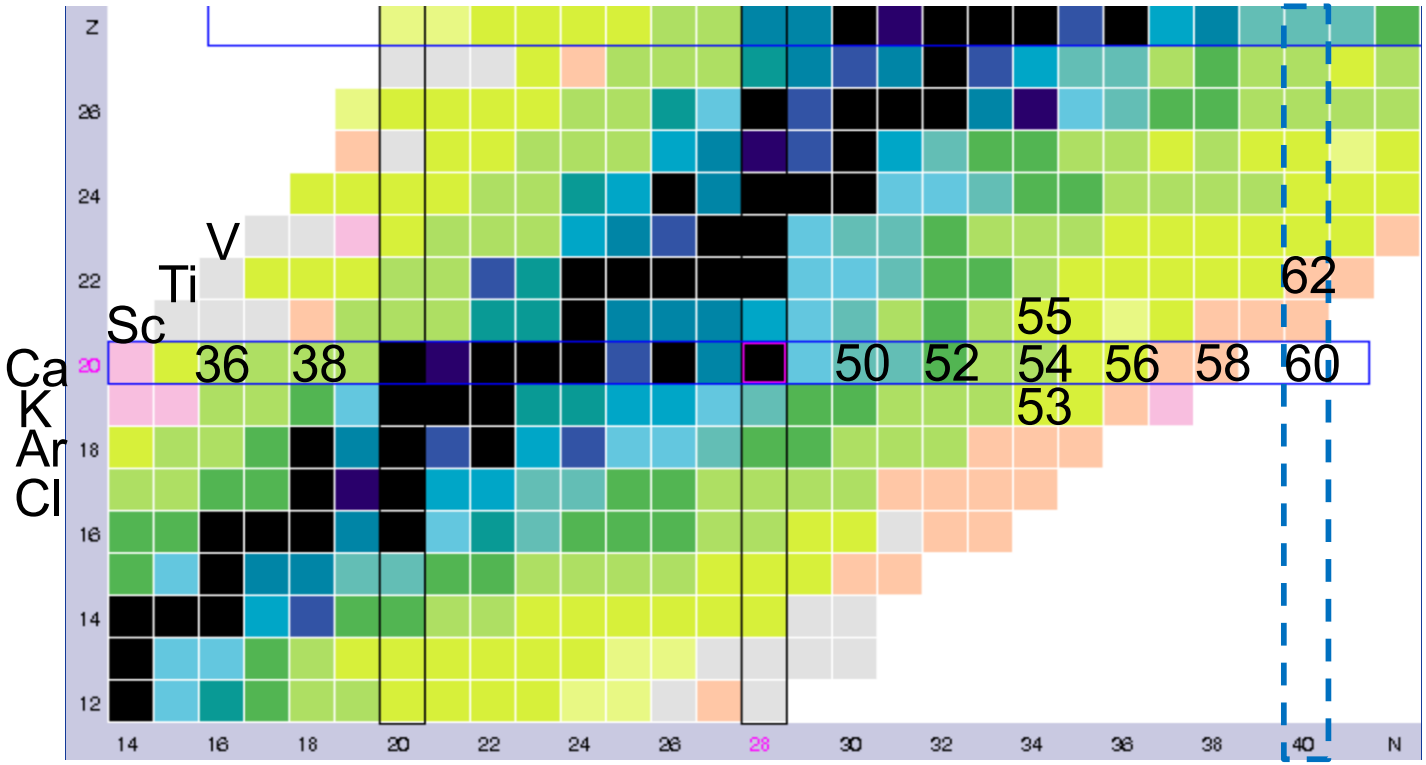
J.D. Holt *et al.*, J. Phys. G: Nucl. Part. Phys. **39**, 085111 (2012).
*J.D. Holt, Private Communication (2017).

Ca (Z=20) Isotopes



*E(2^+) not sufficient indicator of subshell closure if J=1/2 is near Fermi Surface. G.S. may be depressed from strong mixing.

Ca Region: Ideal Day 1



B(E2):

^{54}Ca	^{54}Ca	2.64E+2	Fast Coulex
	^{55}Sc	5.87E+3	1p knockout
	^{56}Ti	9.68E+4	2p knockout
^{52}Ca	^{52}Ca	1.24E+4	Fast Coulex
	^{53}Sc	5.87E+3	1p knockout
	^{54}Ti	2.15E+6	2p knockout
^{36}Ca	^{36}Ca	9.60E+3	Fast Coulex

Q(2) and precise B(E2):

^{50}Ca	4.69E+4	Coulex
^{38}Ca	9.19E+4	Coulex

E&M g.s. Moments:

^{53}Ca	5.13E+02	Laser / βNMR

GT Strength Distributions:

^{60}Ca	1.32E-3	Decay
^{54}Ca	6.83E+1	Decay
^{52}Ca	4.92E+3	Decay

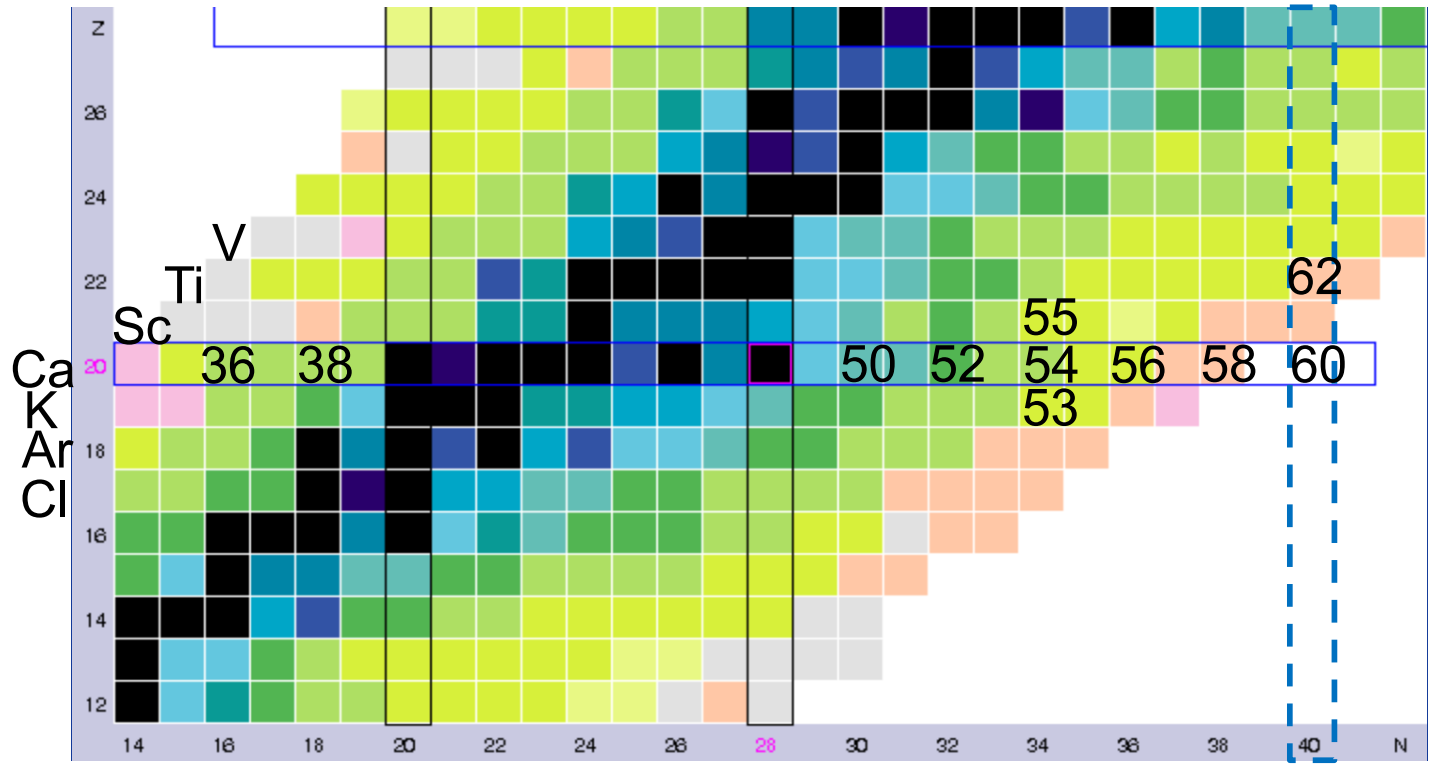
E(2) and B(E2) at N=40:

^{62}Ti	^{63}V	4.25E+1	1p Knockout

g9/2 Seniority Isomers?

^{60}Ca	1.32E-3	Decay
^{58}Ca	6.52E-2	Decay
^{56}Ca	4.33E+0	Decay

Ca Region: Ideal Day 1



E(0_2)?

^{54}Ca	^{54}K	1.04E+0	Decay
	^{55}K	1.18E-1	Decay-n
	^{56}Ti	9.68E+4	2p knockout

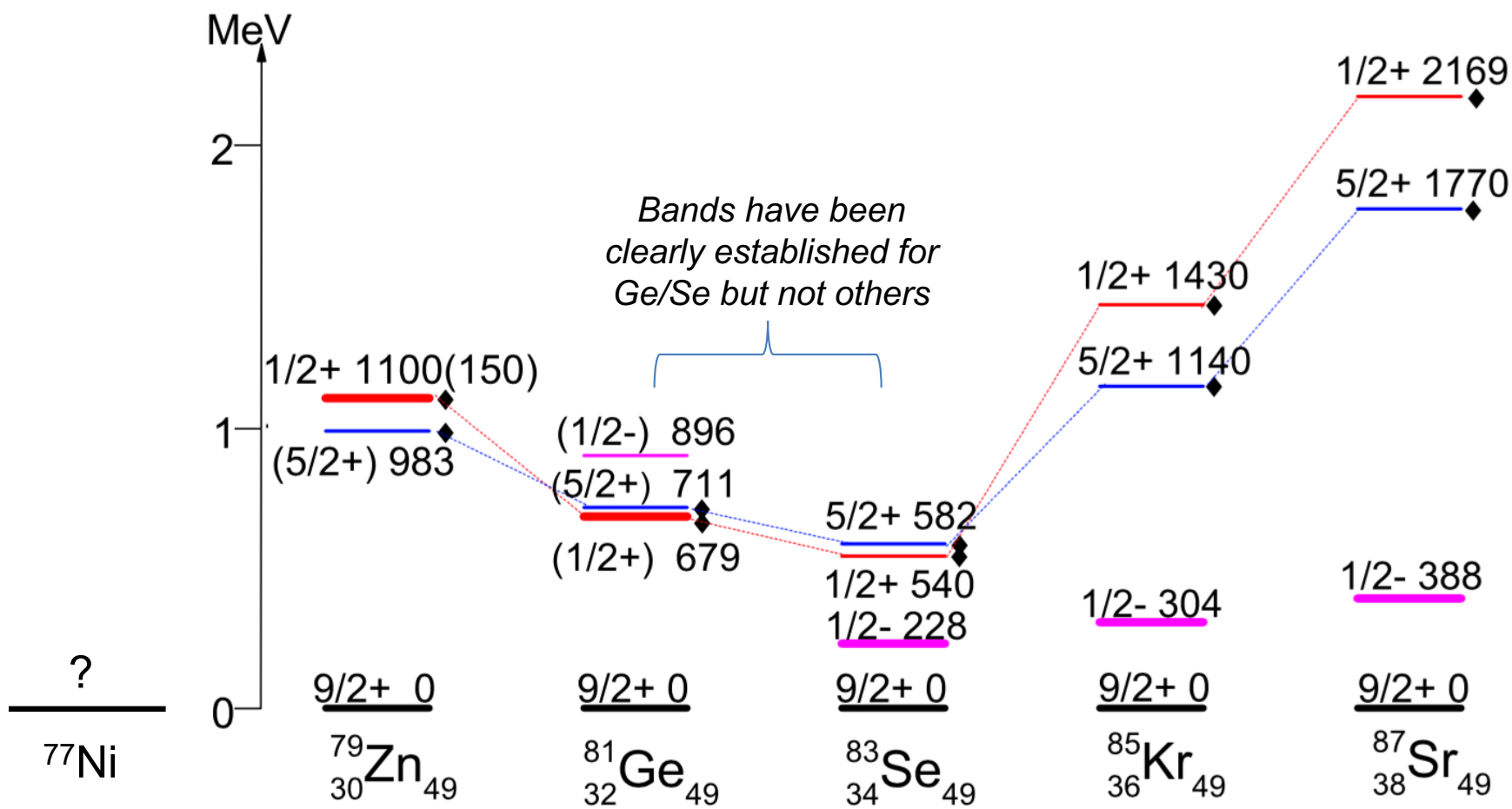
2p-1h and1p-2h:

^{55}Sc	^{56}Sc	9.04E+2		1p knockout
	^{55}Ca	3.46E+1	5.93E-1	Decay
	^{56}Ca	4.33E+0	4.80E-1	Decay-n
^{53}K	^{55}Sc	5.87E+3		2p knockout
	^{53}Ar	2.64E-2		Decay
	^{54}Ar	3.07E-3		Decay-n

s.p. states:

^{51}Ca	^{50}Ca	4.69E+4		(d,p), (α, ^{3}He)
	^{52}Ca	1.24E+4		1n knockout
	^{51}K	5.87E+2	2.14E+2	Decay
	^{52}K	7.50E+1	2.16E+1	Decay-n
^{53}Ca	^{54}Ca	2.64E+2		1n knockout
	^{53}K	8.99E+0	1.13E+0	Decay
	^{54}K	1.04E+0	1.30E-2	Decay-n
^{55}Ca	^{56}Ca	4.33E+0		1n knockout
	^{55}K	1.18E-1		Decay
	^{56}K	1.40E-2		Decay-n

N=49 1p-2h Systematics Near ^{78}Ni

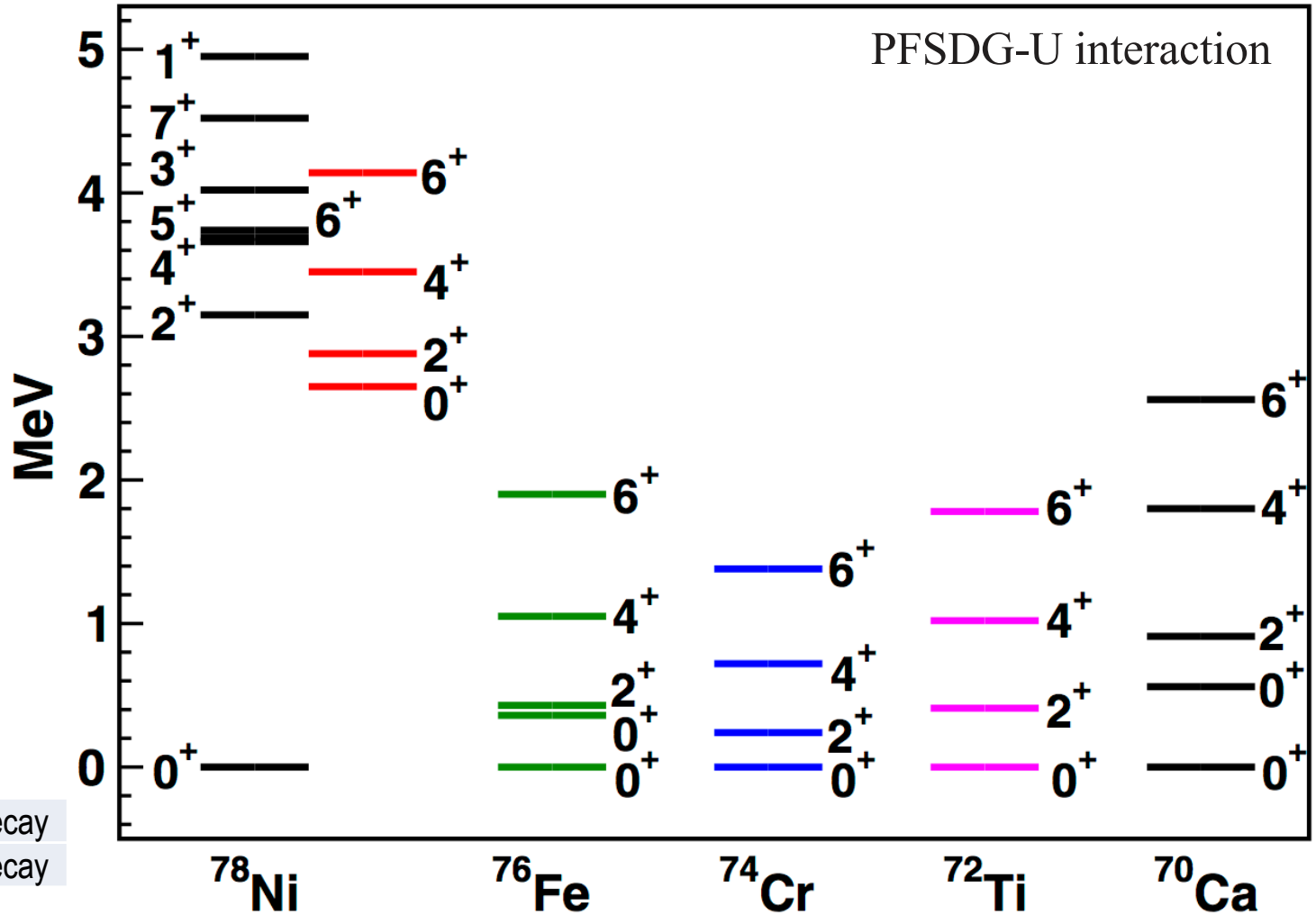


^{77}Ni	^{77}Co	1.34E-2	Decay
	^{78}Co	5.56E-4	Decay-n
	^{78}Cu	1.57E+2	1p knockout
	^{79}Zn	3.56E+3	2p knockout

*$E(0_2) < E(2_1)$ found recently in ^{80}Ge

X. F. Yang et al., PRL **116**, 182502 (2016)

Portal to the Fifth Island of Inversion



GT Strength:

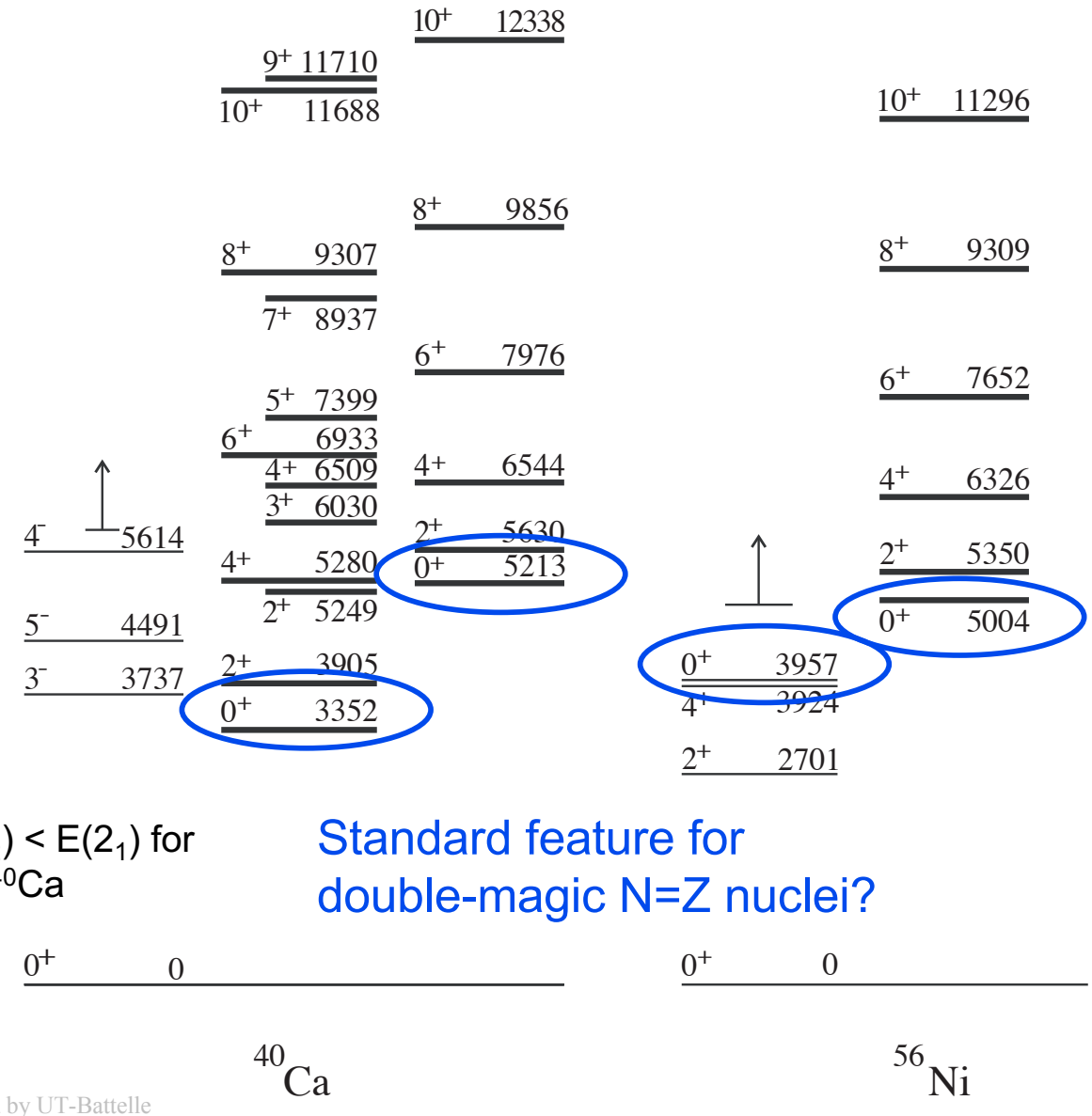
^{78}Ni	4.39E-01	1.5E-01	Decay
^{76}Fe	3.81E-04		Decay

$E(0_2)$, $E(2_1)$?

^{78}Ni	^{79}Co	1.71E-4	Decay-n
	^{78}Co	5.56E-4	Decay

F. Nowacki et al., PRL **117**, 272501 (2016)

Double-Magic N=Z



*$E(0_2) < E(2_1)$ for ^{16}O, ^{40}Ca

Standard feature for double-magic N=Z nuclei?

0_2^+ near or below 2_1^+?

^{100}Sn	^{100}Sn	2.05E-1	Decay
	^{101}Sn	8.60E+0	1n knockout
	^{102}Sn	3.80E+2	2n knockout

0^+

^{100}Sn

K. Heyde and J.L. Wood, Rev. Mod. Phys. **83**, 1467 (2011).

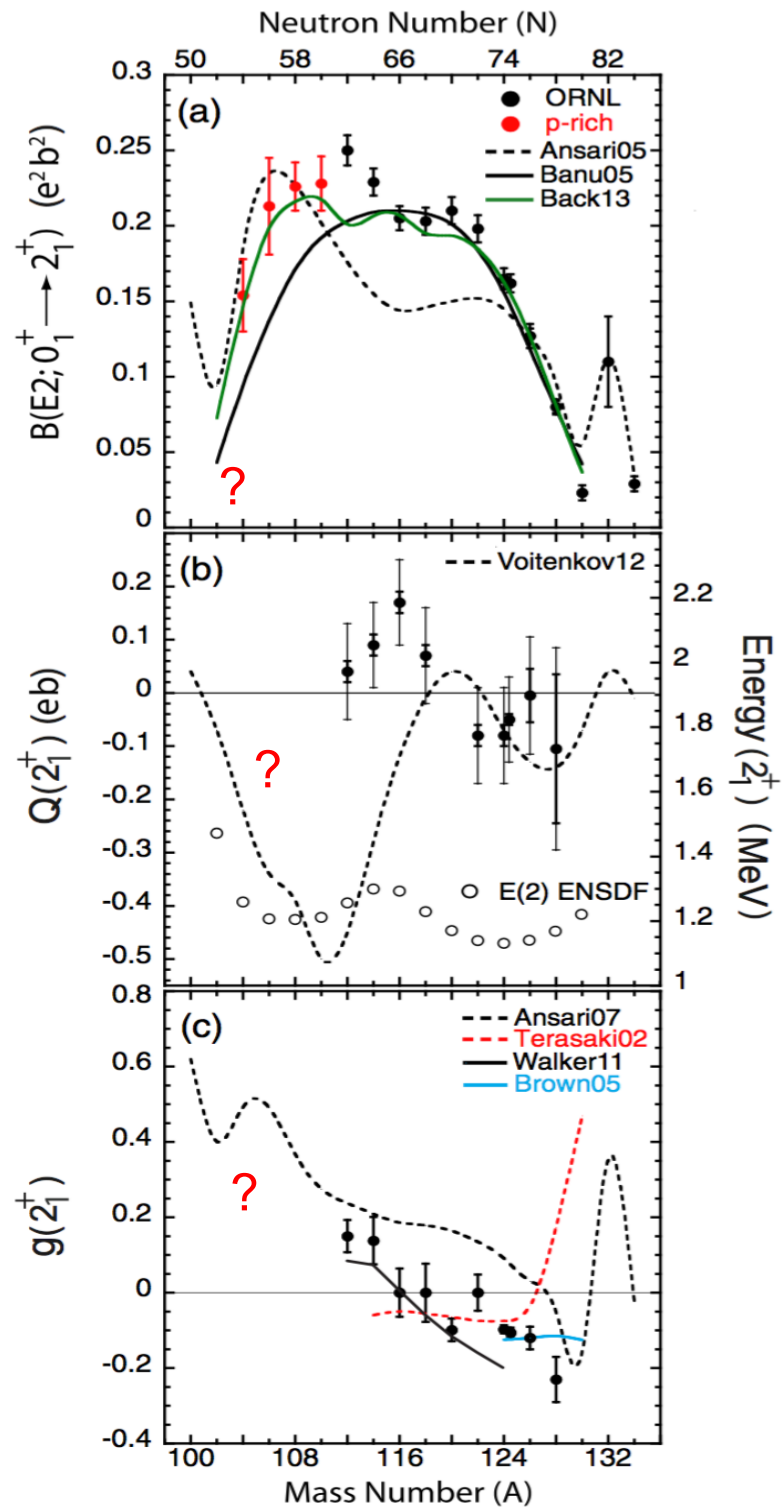
Soft ^{100}Sn Core? E&M Moments and S.P. States

E&M Moments:

^{102}Sn	3.80E+2	Fast Coulex
^{104}Sn	1.68E+4	Coulex
^{106}Sn	5.78E+5	Coulex
^{108}Sn	1.88E+6	Coulex
^{110}Sn	1.66E+6	Coulex

S.P. States:

^{101}Sn	^{102}Sn	3.80E+2	1n knockout
^{103}Sn	^{104}Sn	1.68E+4	(d,t), (^{3}He, α)
^{105}Sn	^{104}Sn	1.68E+4	(d,p), (α, ^{3}He)
	^{106}Sn	5.78E+5	(d,t), (^{3}He, α)
^{107}Sn	^{106}Sn	5.78E+5	(d,p), (α, ^{3}He)
	^{108}Sn	1.88E+6	(d,t), (^{3}He, α)
^{109}Sn	^{108}Sn	1.88E+6	(d,p), (α, ^{3}He)
	^{110}Sn	1.66E+6	(d,t), (^{3}He, α)
^{111}Sn	^{110}Sn	1.66E+6	(d,p), (α, ^{3}He)



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Thank You