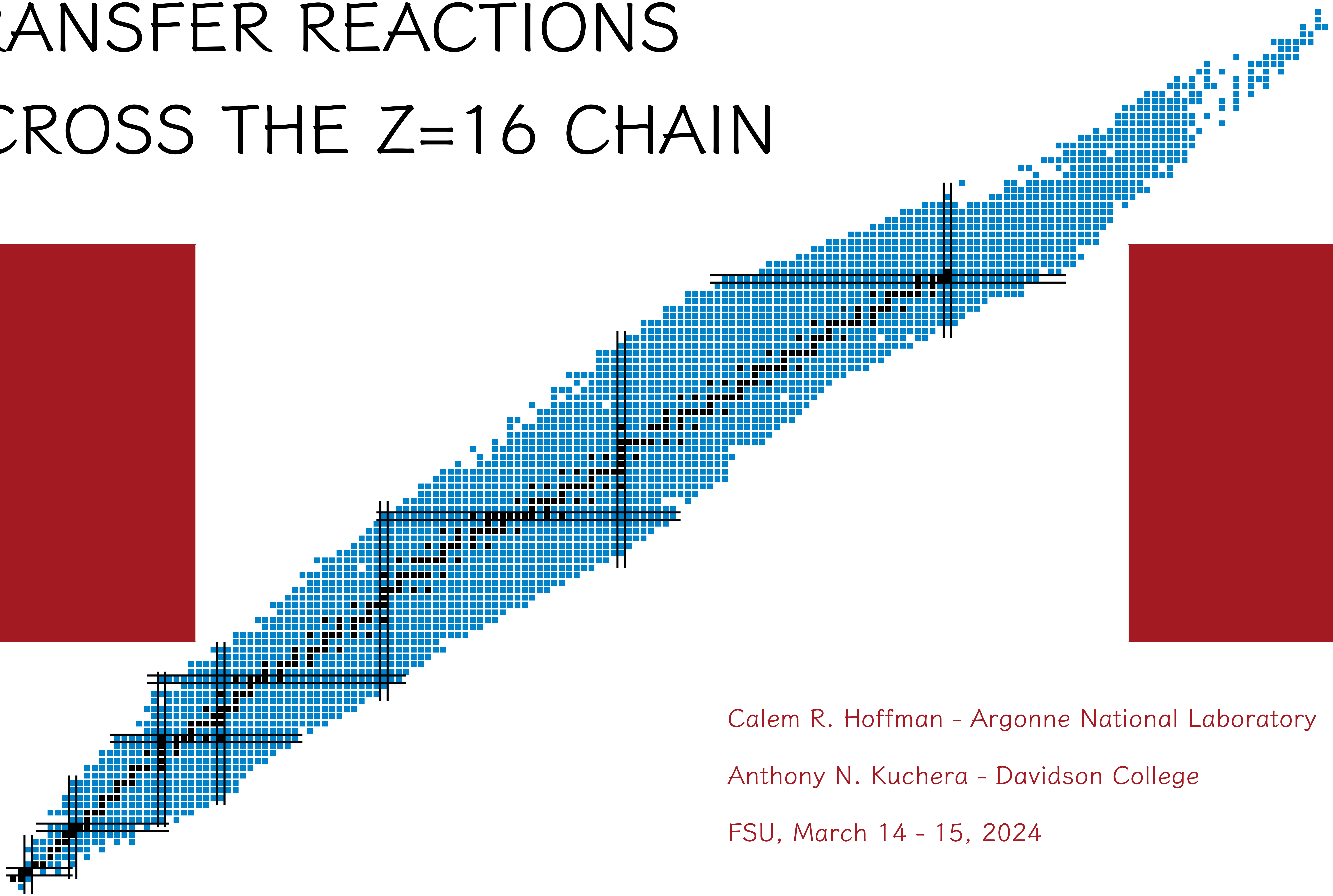
TRANSFER REACTIONS ACROSS THE Z=16 CHAIN



Calem R. Hoffman - Argonne National Laboratory

Anthony N. Kuchera - Davidson College

FSU, March 14 - 15, 2024

BRIEF OUTLINE

+ Proposed measurements

+ Motivation

+ On-going / complementary program

CORRELATIONS THROUGHOUT THE N=18-20-22 ISOTONES

Supplement available data with new & deeper pair transfer information

$^{34,36}S(t,p)^{36,38}S$ at ~6 MeV/u

Motivation

- Only 0^+_1 -> 0^+_1 data available for ^{34}S->^{36}S
- Systematics of 0^+_1 / 0^+_i cross sections [0^+_1 / 2^+_l]
- Disentangle $(fp)^2$ components
- Complements an inverse kinematics reaction planned at HELIOS
- Lack of definitive info in ^{38}S levels

SE-SPS [+ CeBrA]

- Dedicated run for angular distributions
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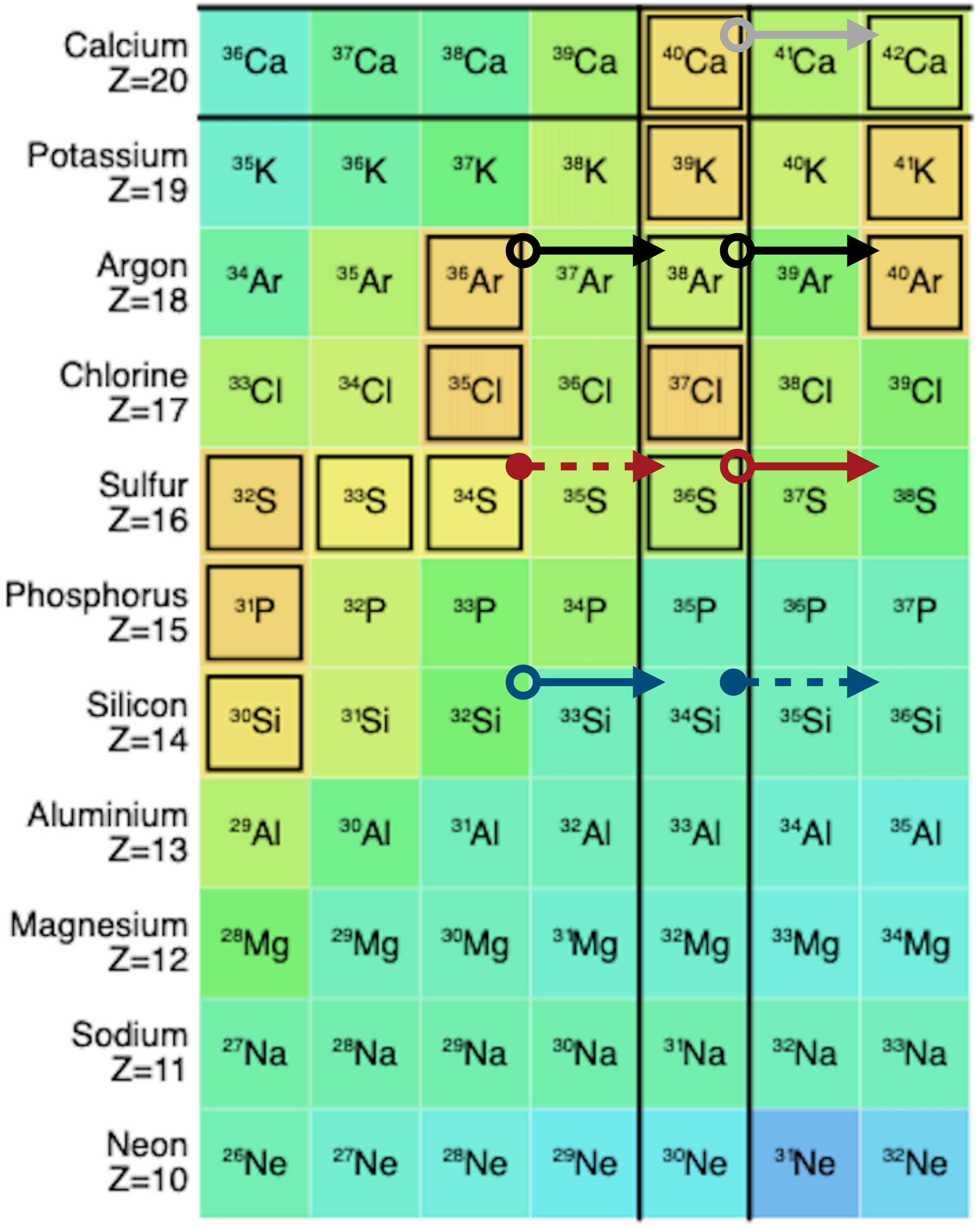
- New ^{36}S from CATS [AgS - 88% enriched] 10's ug/cm2



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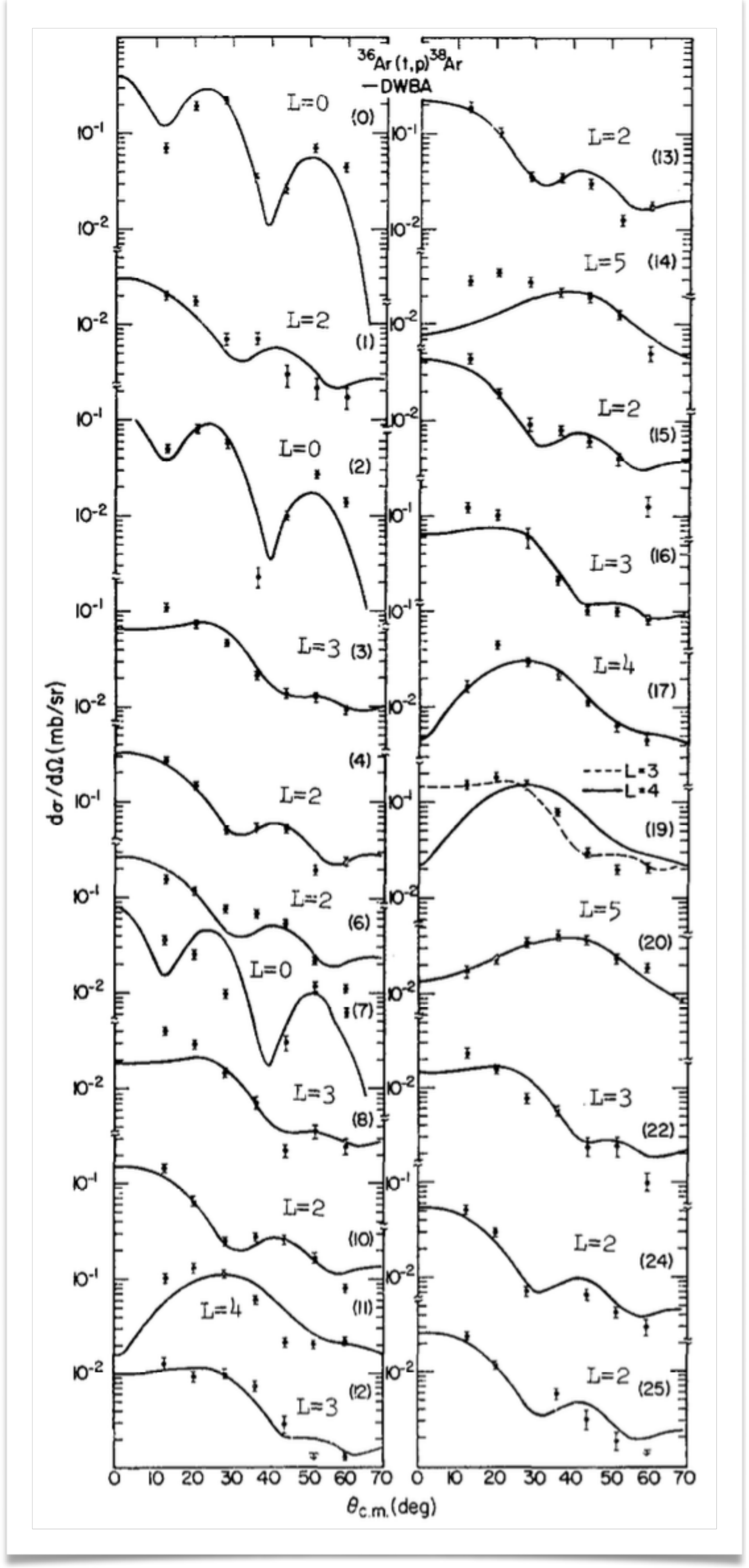

Volume 43B, number 6 PHYSICS LETTERS 19 March 1973

0+ STATES NEAR THE N=20 NEUTRON SHELL FROM Ar(t, p) REACTIONS☆

R.F. CASTEN*, E.R. FLYNN, J.D. GARRETT*, S. ORBESEN
Los Alamos Scientific Laboratory, University of California, Los Alamos, New Mexico 87544, USA
and
O. HANSEN
The Niels Bohr Institute, University of Copenhagen, Denmark

2.F
Nuclear Physics **A246** (1975) 117—140; © *North-Holland Publishing Co., Amsterdam*

THE (t, p) REACTION ON $^{36,38,40}Ar$

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Volume 87B, number 1,2 PHYSICS LETTERS 22 October 1979

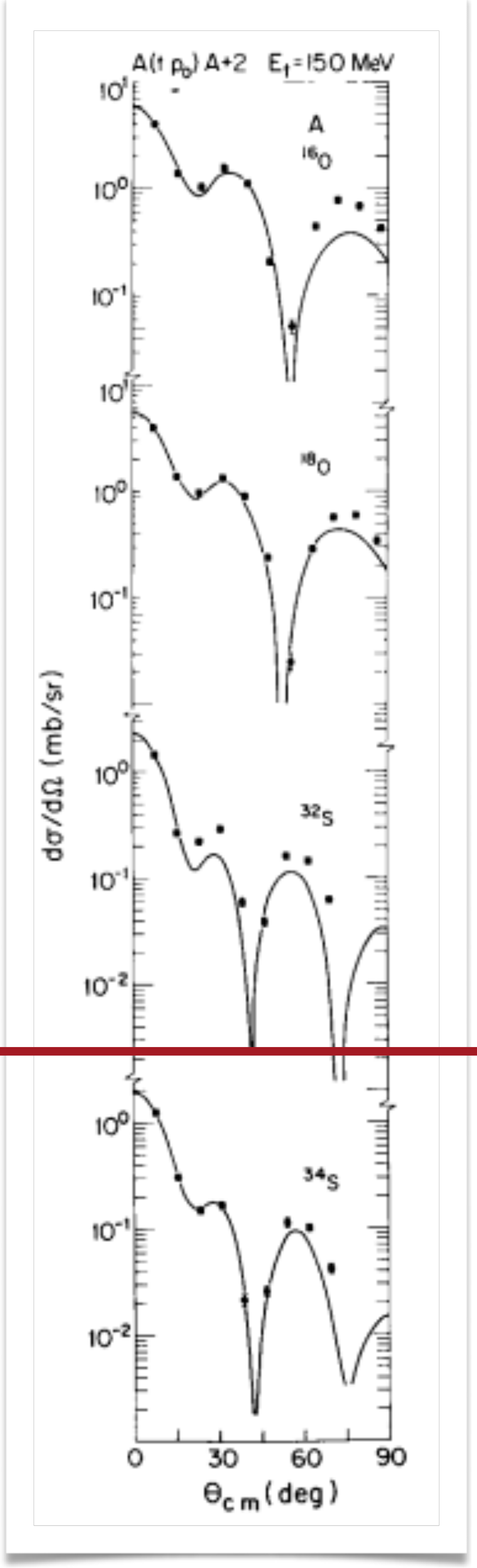
SYSTEMATICS OF GROUND-STATE (t,p) CROSS SECTIONS IN THE 2s–1d SHELL

Fortune et al., PLB (1979)

^{36}S

E(level)†	J^{π}‡	$T_{1/2}$#
0	0^+	stable
3290.9 *3*	2^+	83 fs *7*
3346 *4*	0^+	8.8 ns *2*
4192.7 *5*	3^-	0.62 ps *7*
4523.0 *6*	1^+	0.017 ps *8*
4575.2 *7*	2^+	55 fs *10*
5021.5 *3*	4^-	
5206.1 *3*	5^-	
5251.2 *10*	3^-	70 fs *30*

~55 keV separation



Argonne NATIONAL LABORATORY

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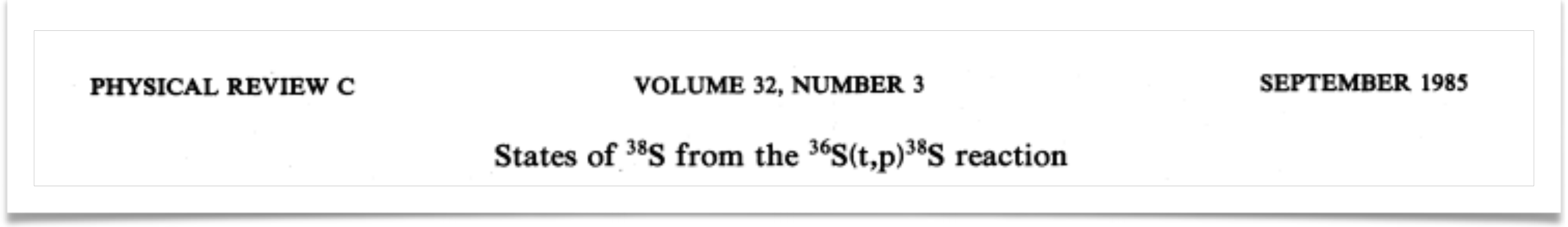
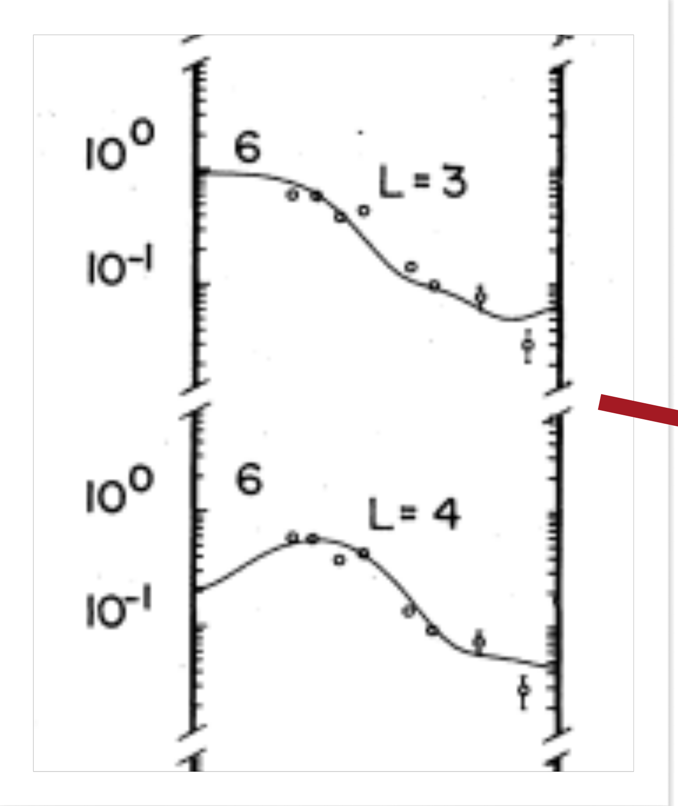
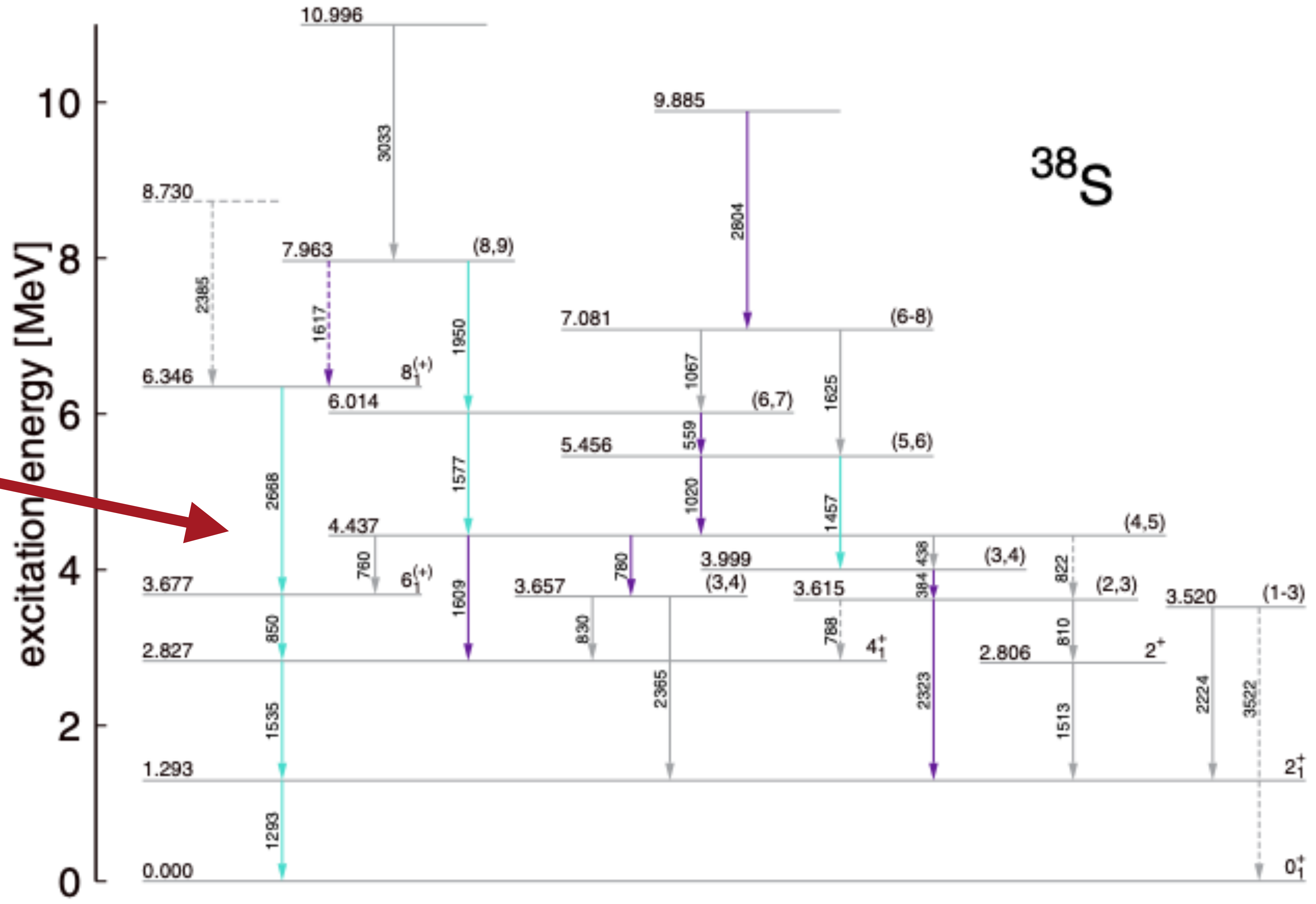

PHYSICAL REVIEW C VOLUME 32, NUMBER 3 SEPTEMBER 1985

States of ^{38}S from the ^{36}S(t,p)^{38}S reaction



Davis et al., PRC (1985)



Hoffman et al., PRC (2023)

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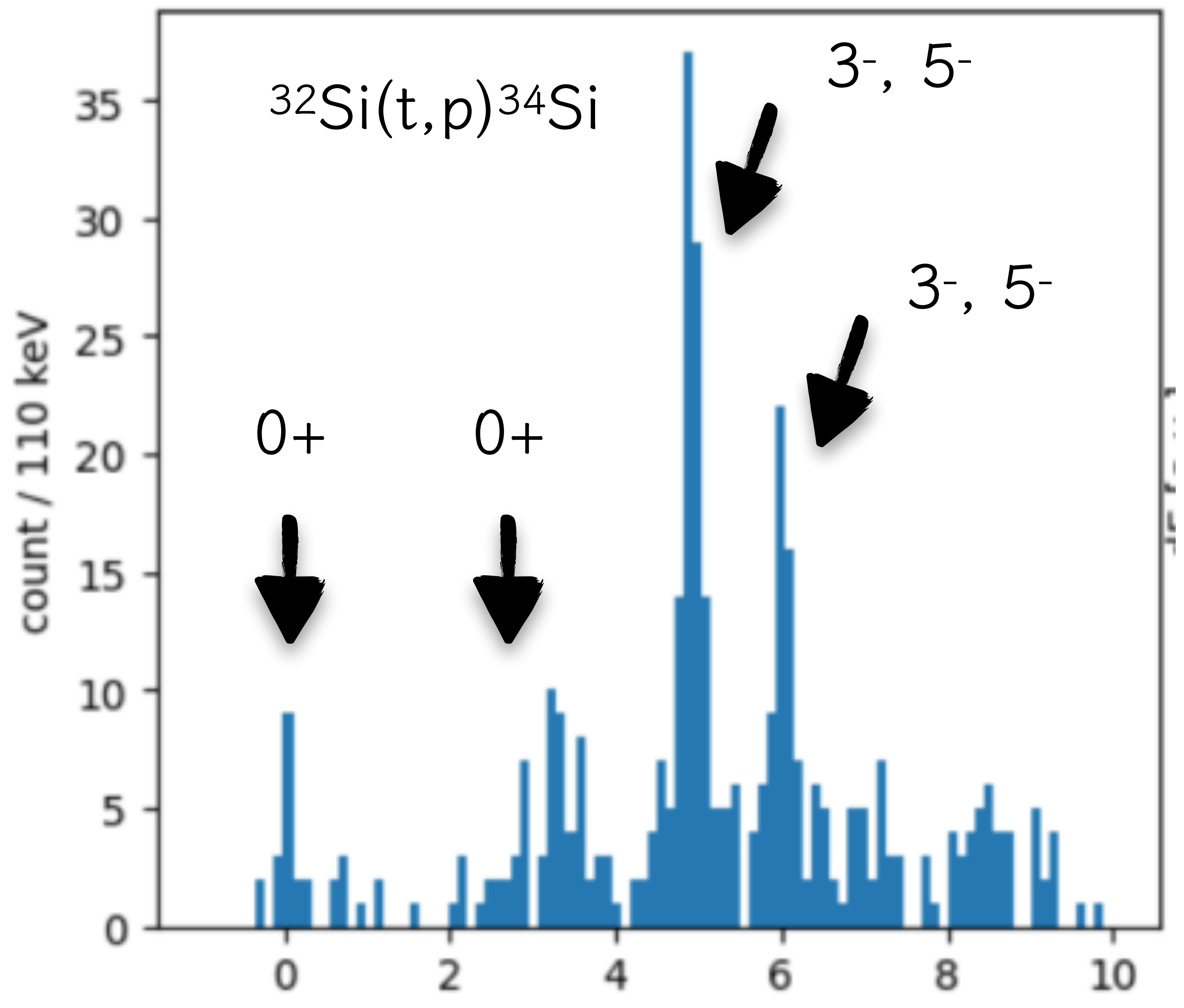

Watwood et al.,

CORRELATIONS ACROSS N=18-20-22 ISOTONES

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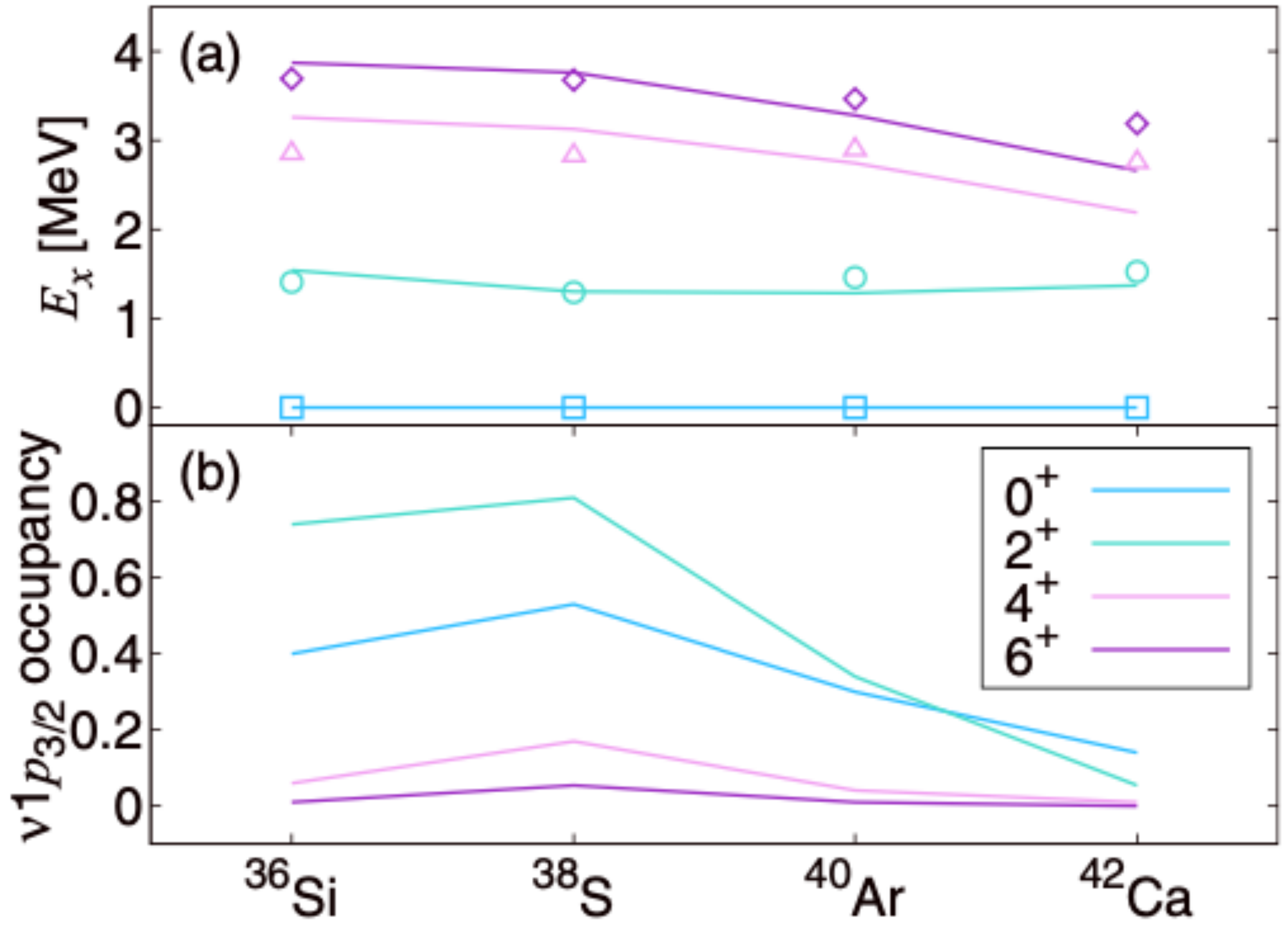
FSU Interaction



Hoffman et al., PRC (2023)

Argonne NATIONAL LABORATORY

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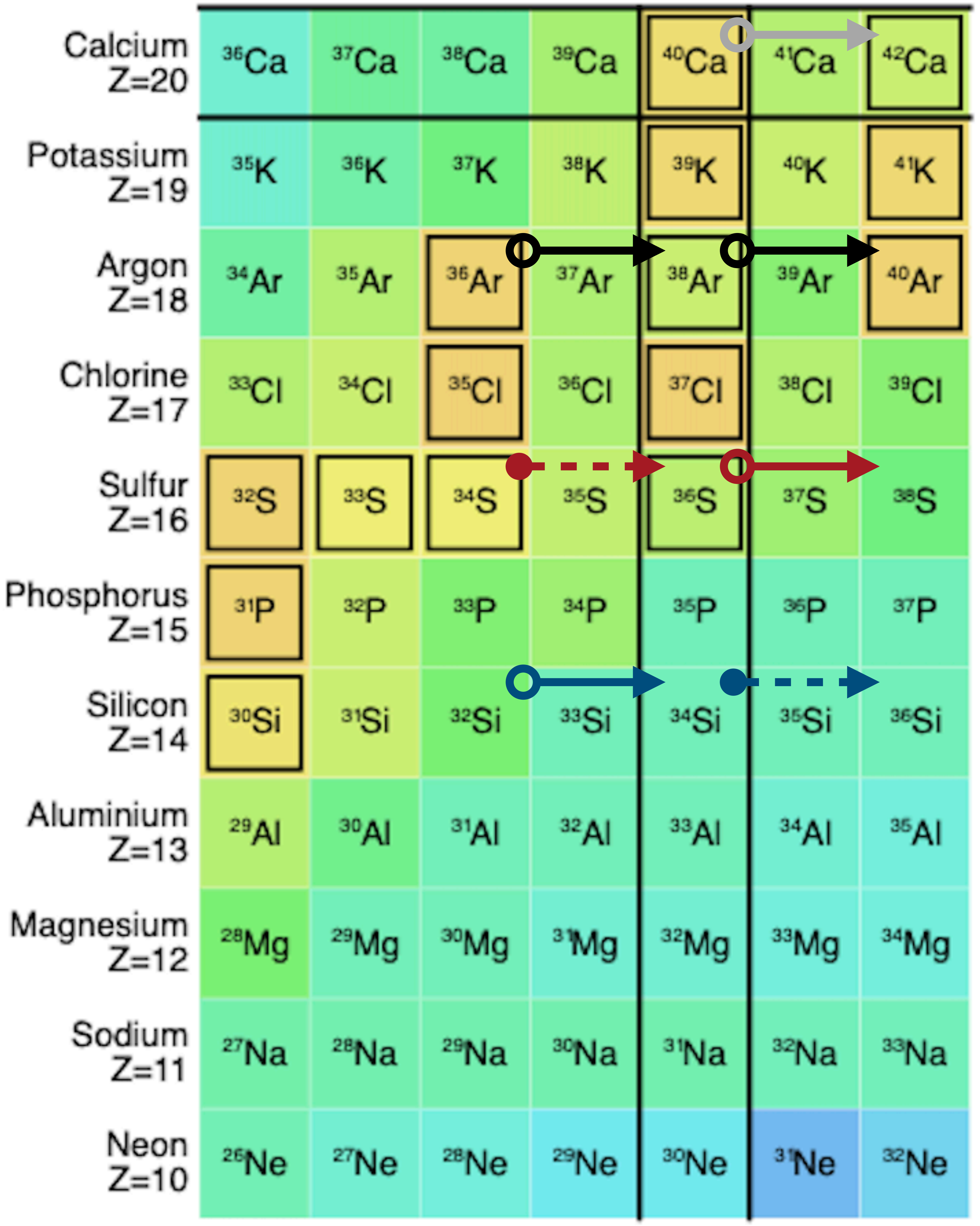
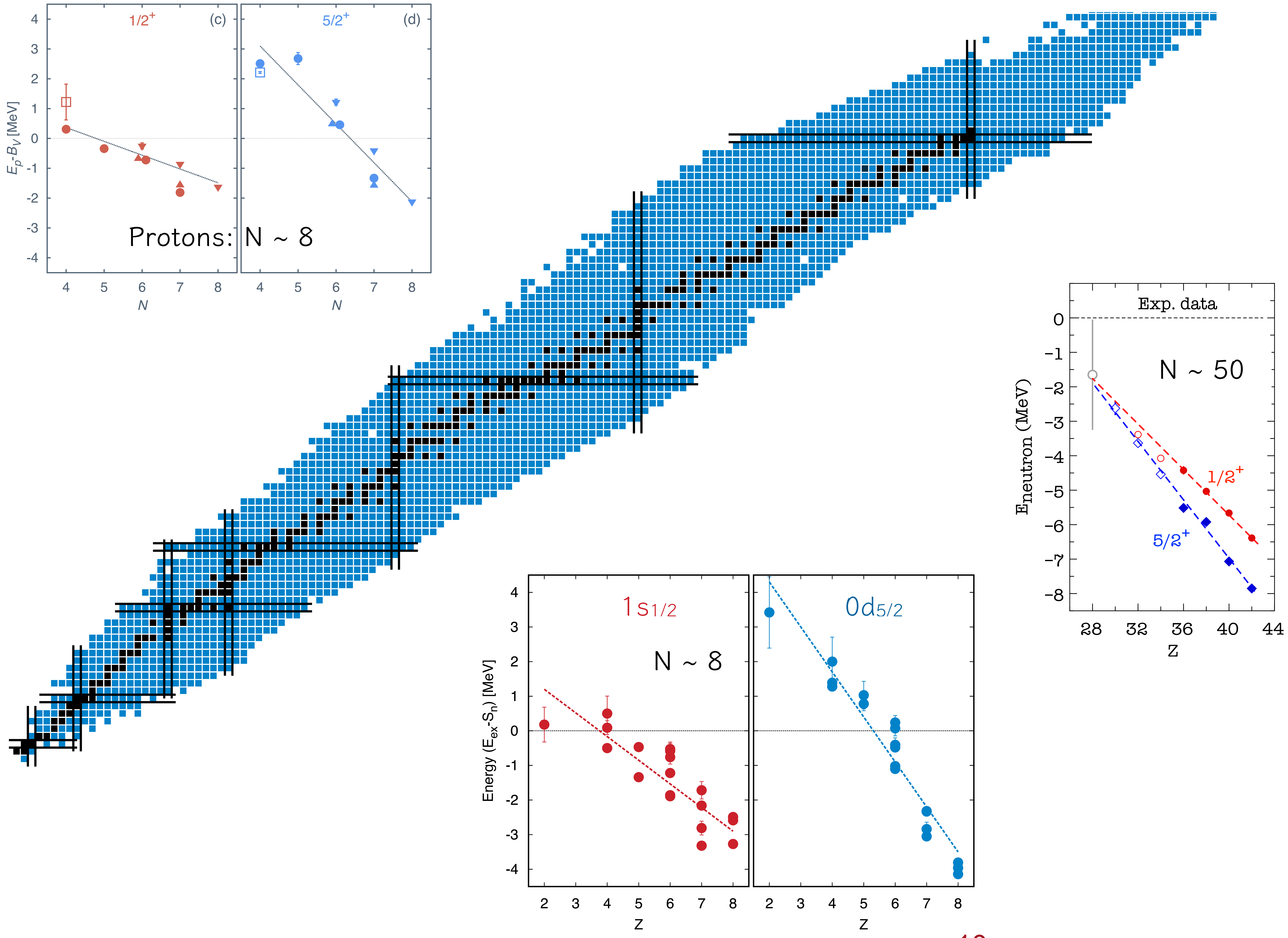
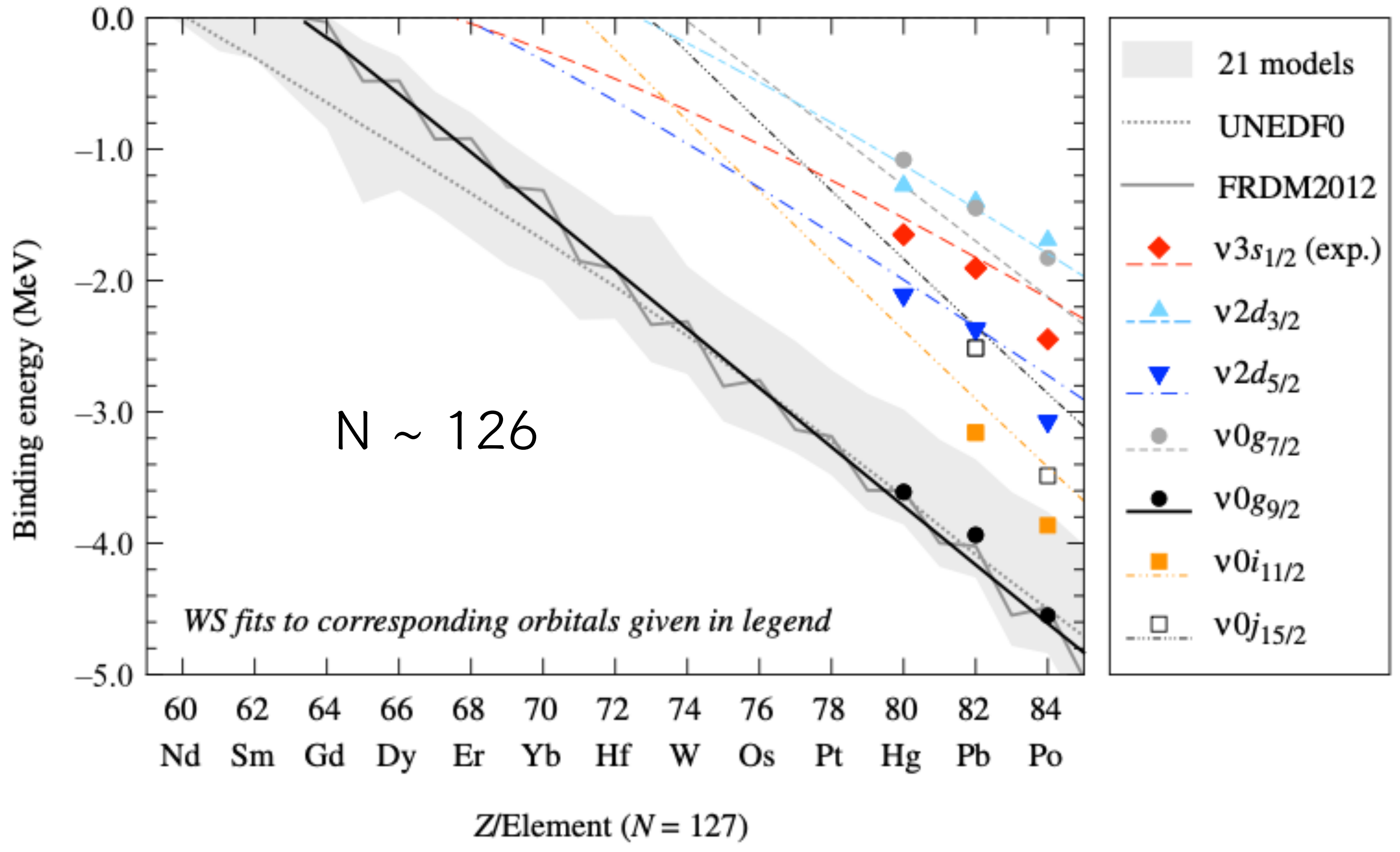
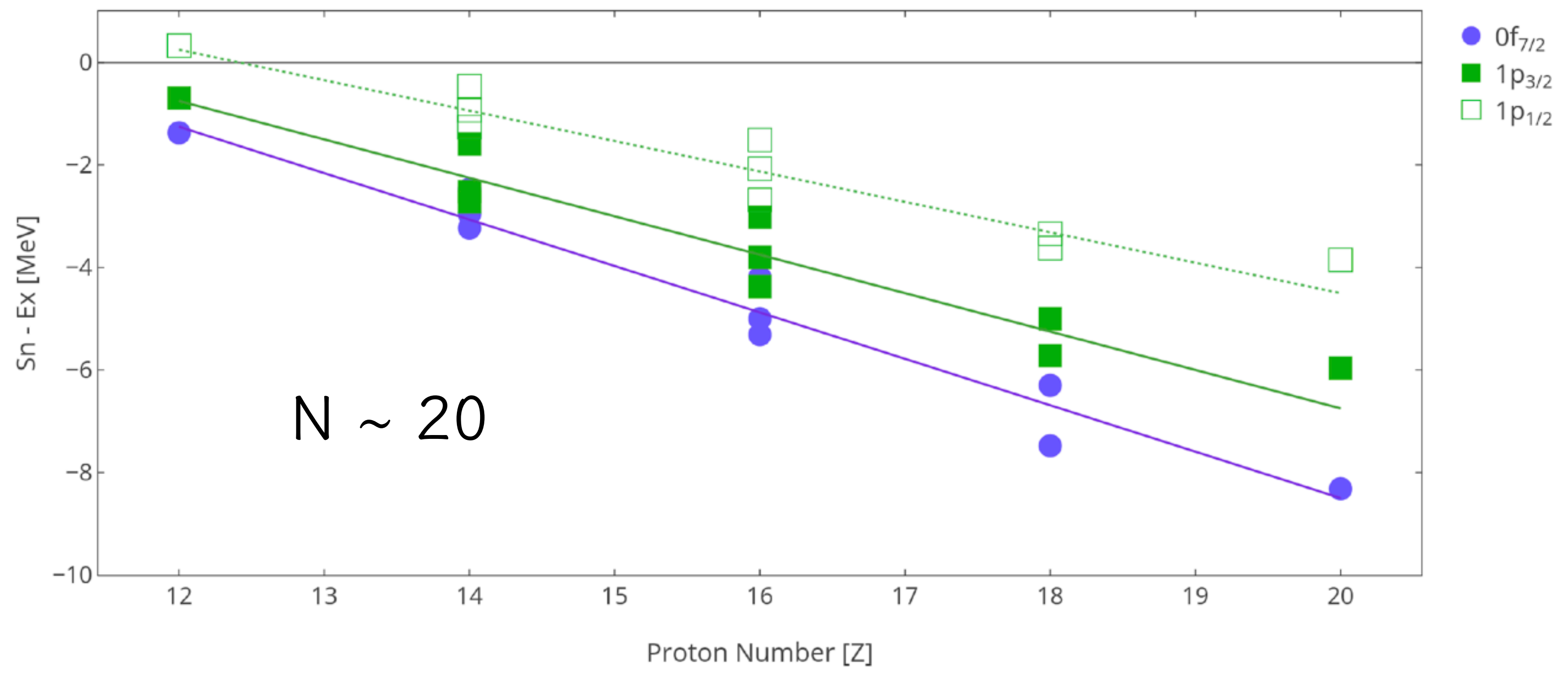


DESCRIPTION OF EVOLVING SINGLE-PARTICLE ENERGIES

Influx of data: radioactive beam era + enhanced equipment + techniques







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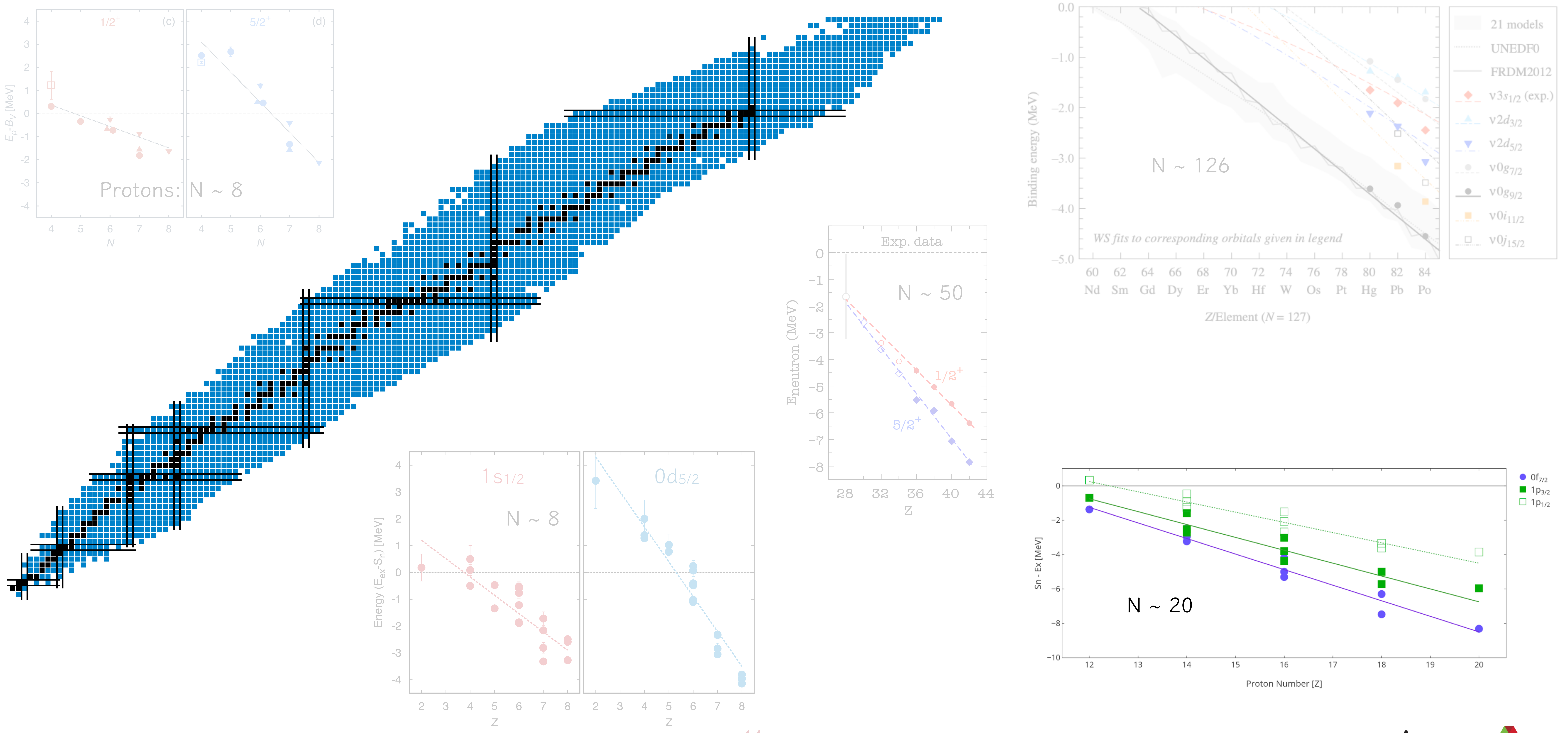
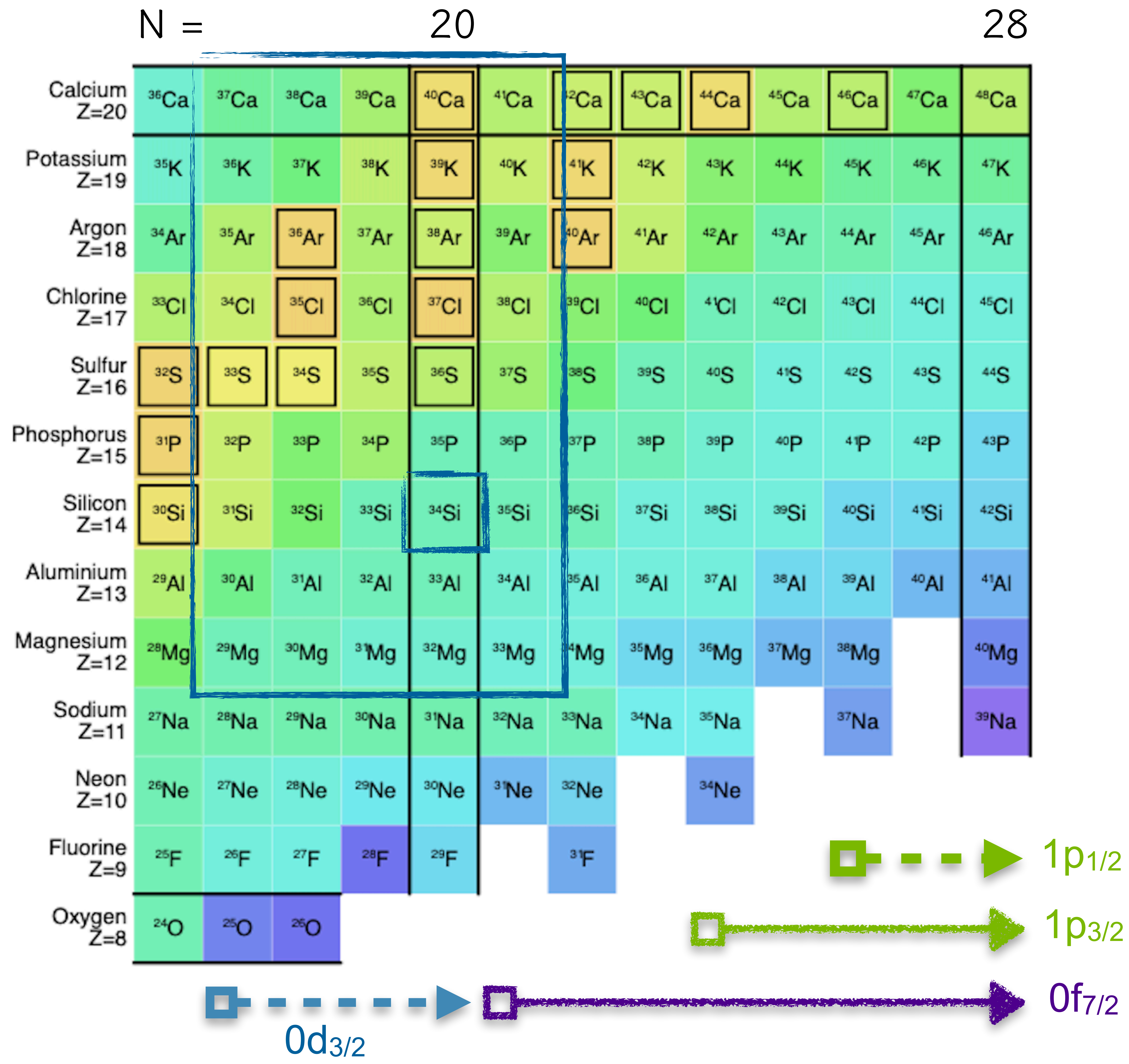
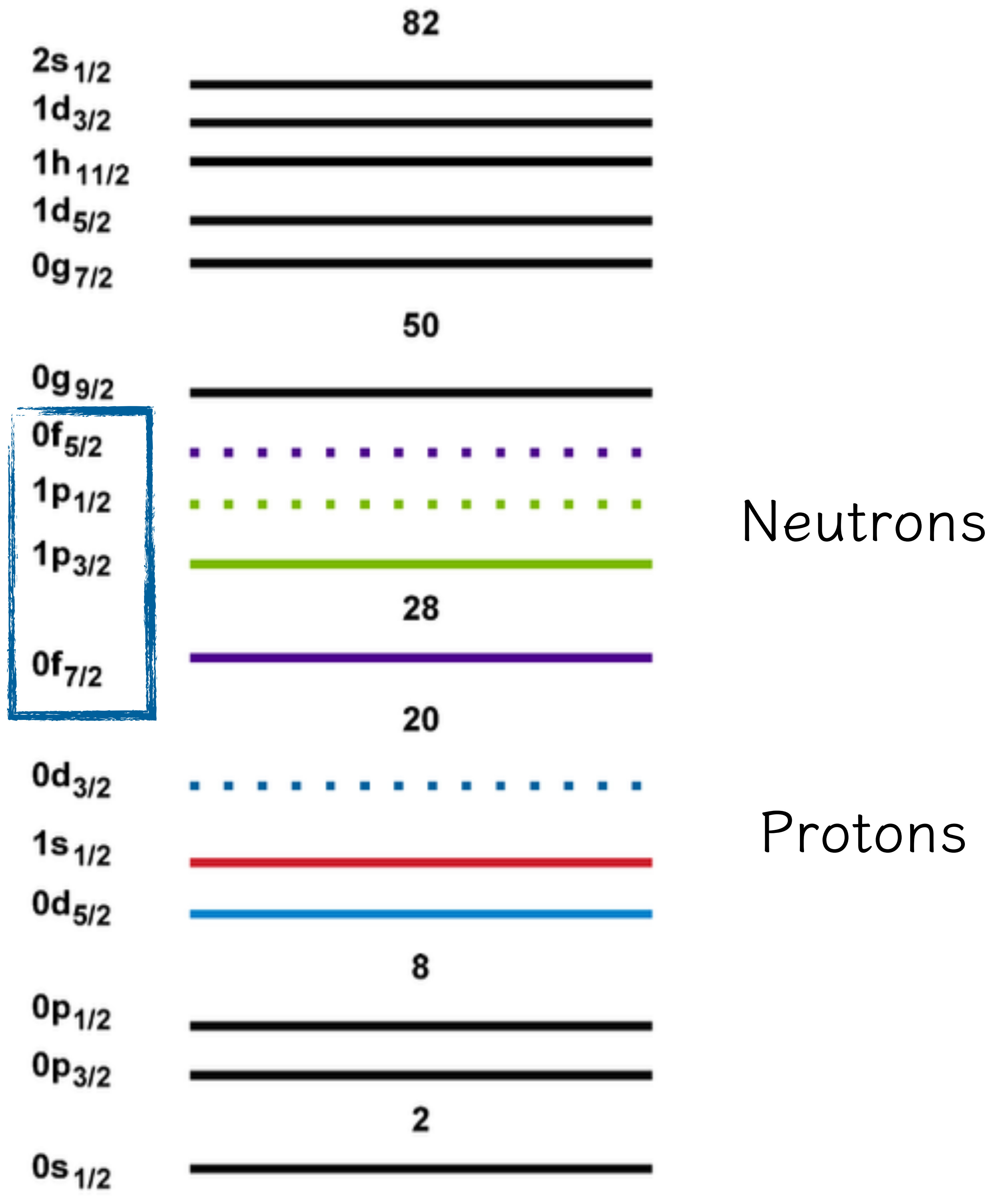


DESCRIPTION OF EVOLVING SINGLE-PARTICLE ENERGIES

The 0f-1p neutron-shell crossroads





Normal ordering of shells for fixed W-S parameter set

DESCRIPTION OF EVOLVING SINGLE-PARTICLE ENERGIES

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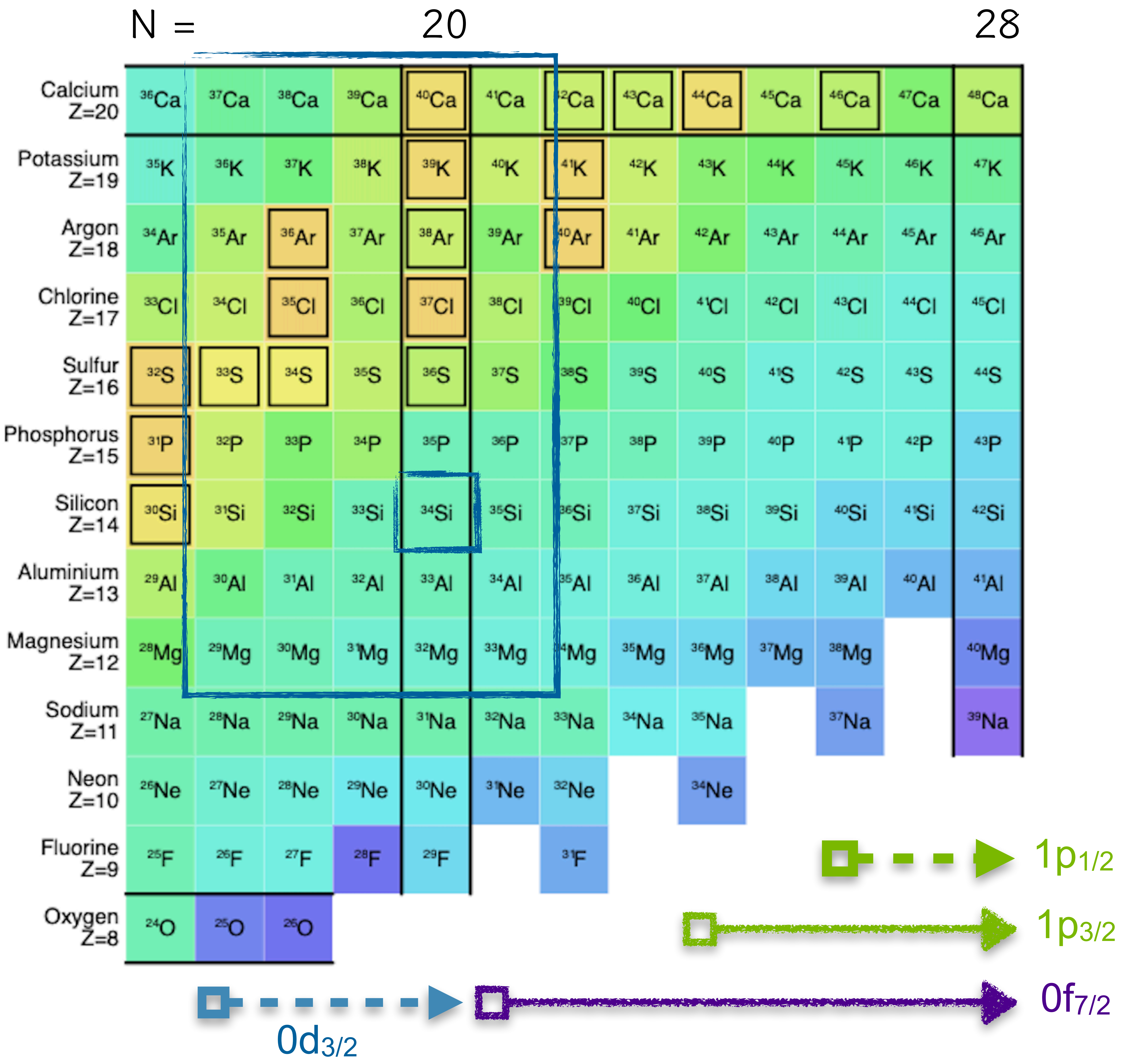
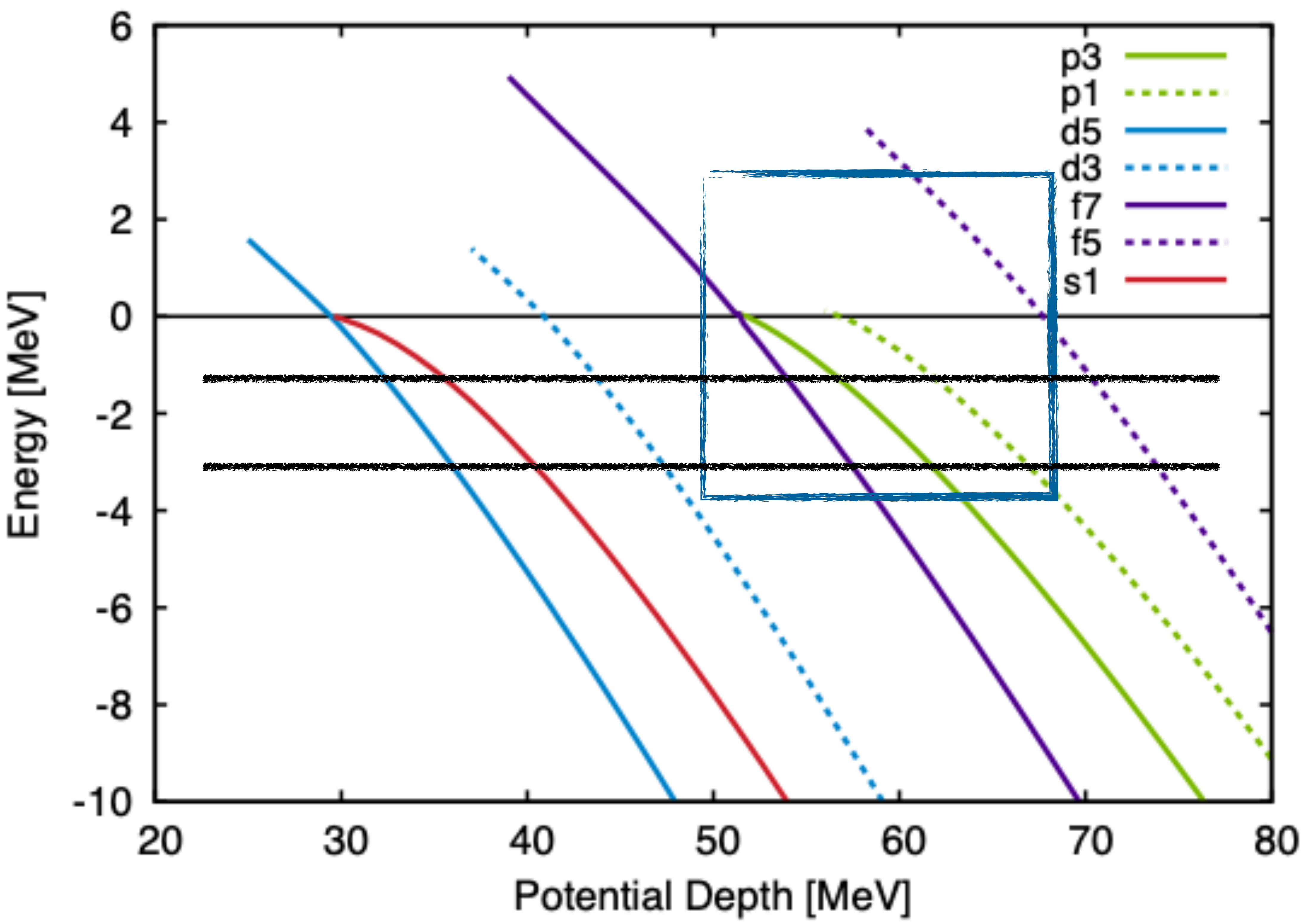


Evidence for threshold effects between 1p spin-orbit partners



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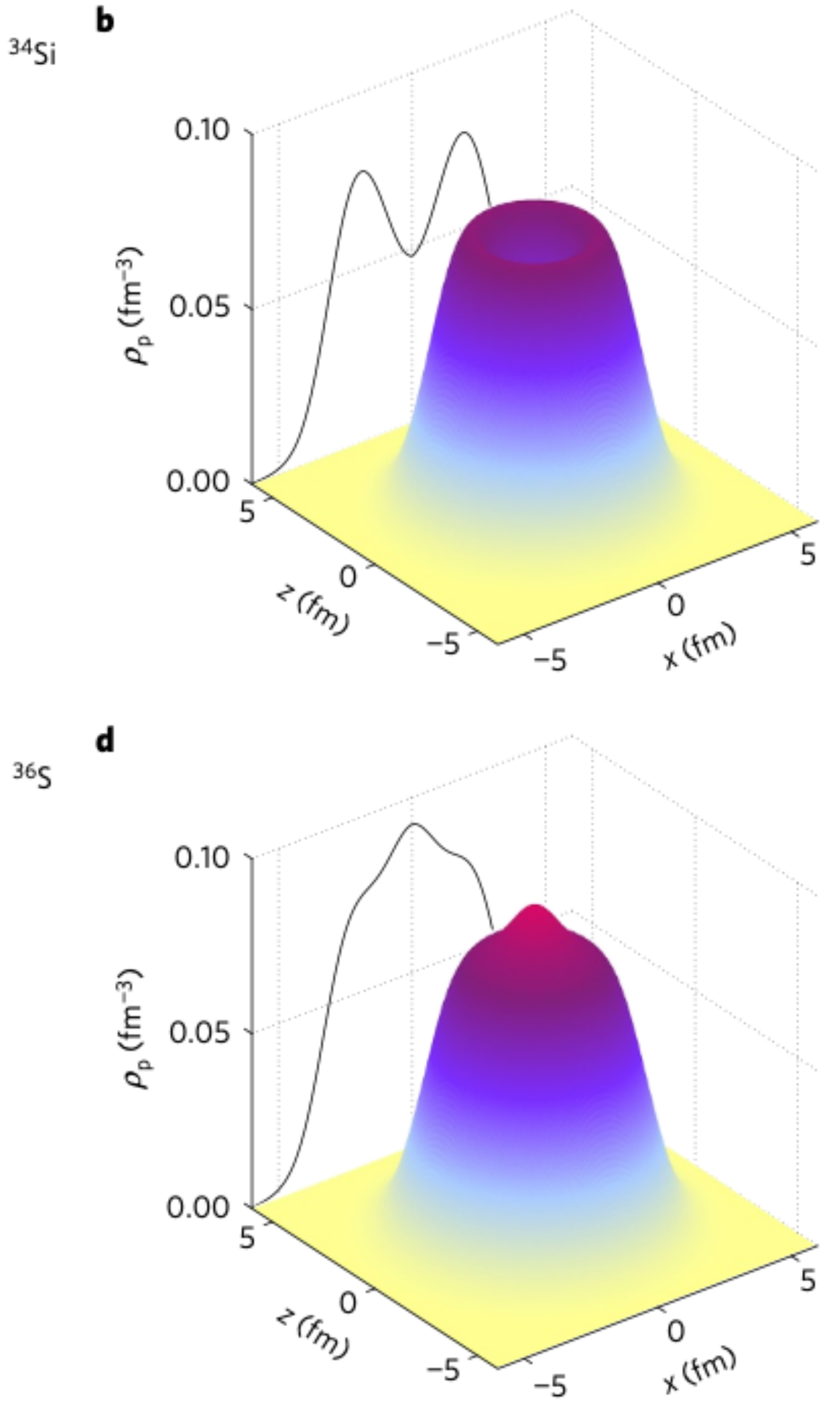
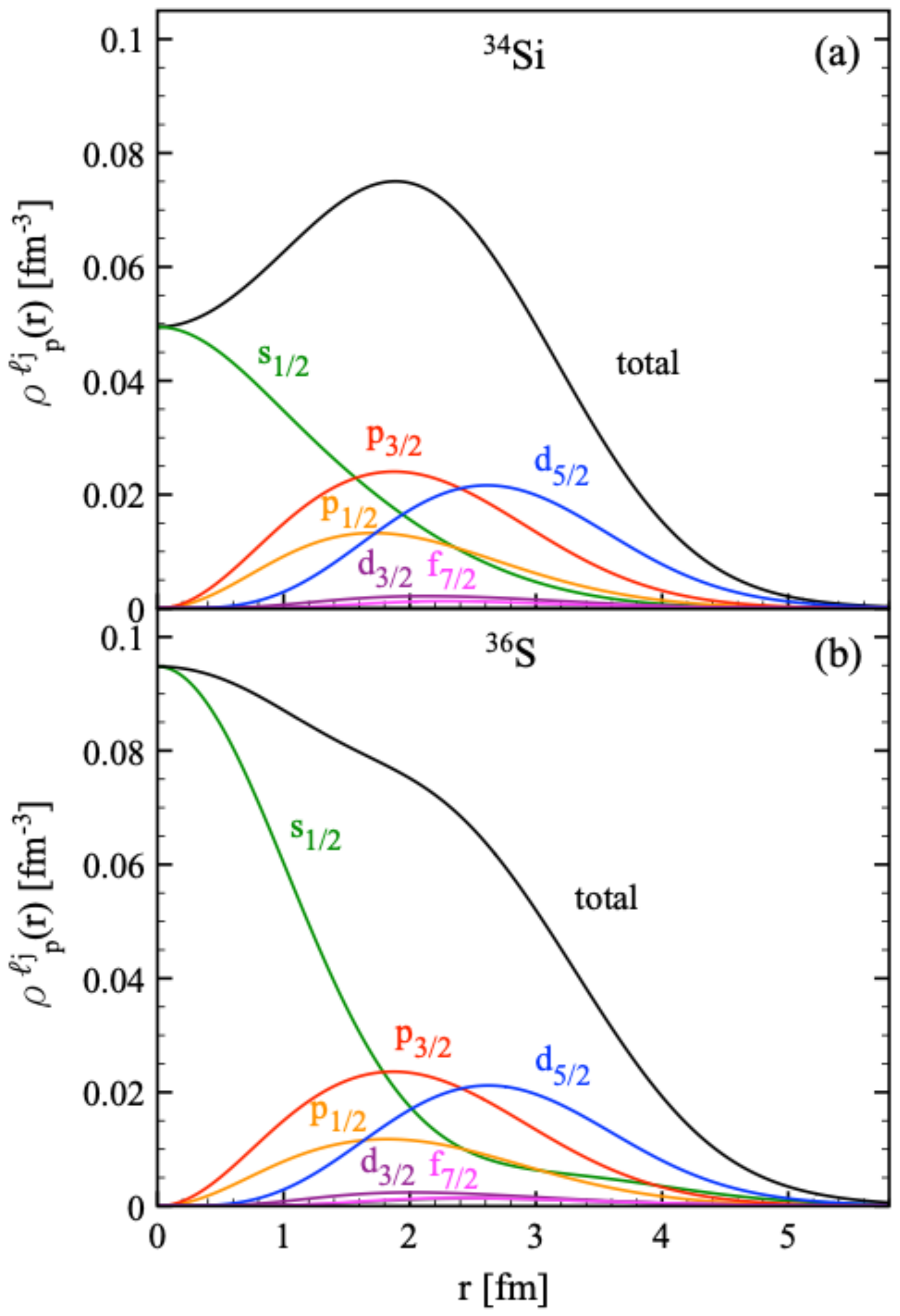
DESCRIPTION OF EVOLVING SINGLE-PARTICLE ENERGIES

Speculation of a proton 'bubble' in the Z=14, N=20 ^{34}Si nucleus

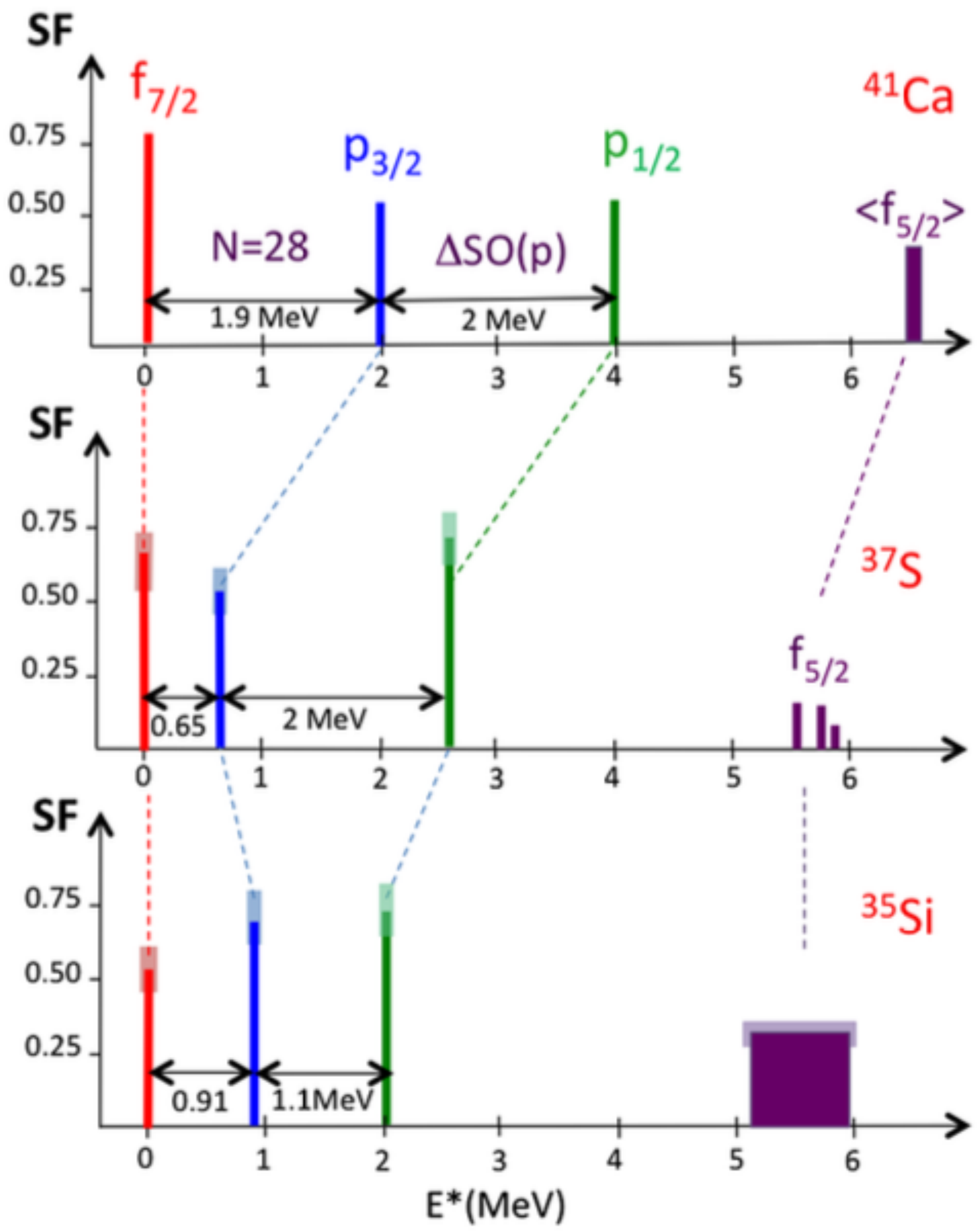
1. Fully vacant proton 1s1/2 orbital
2. Reduction / no particle-particle correlations

If bubble exists, does it impact the energy difference between spin-orbit pairs??





Mutschler Nature (2017)



Burgunder PRL (2014)

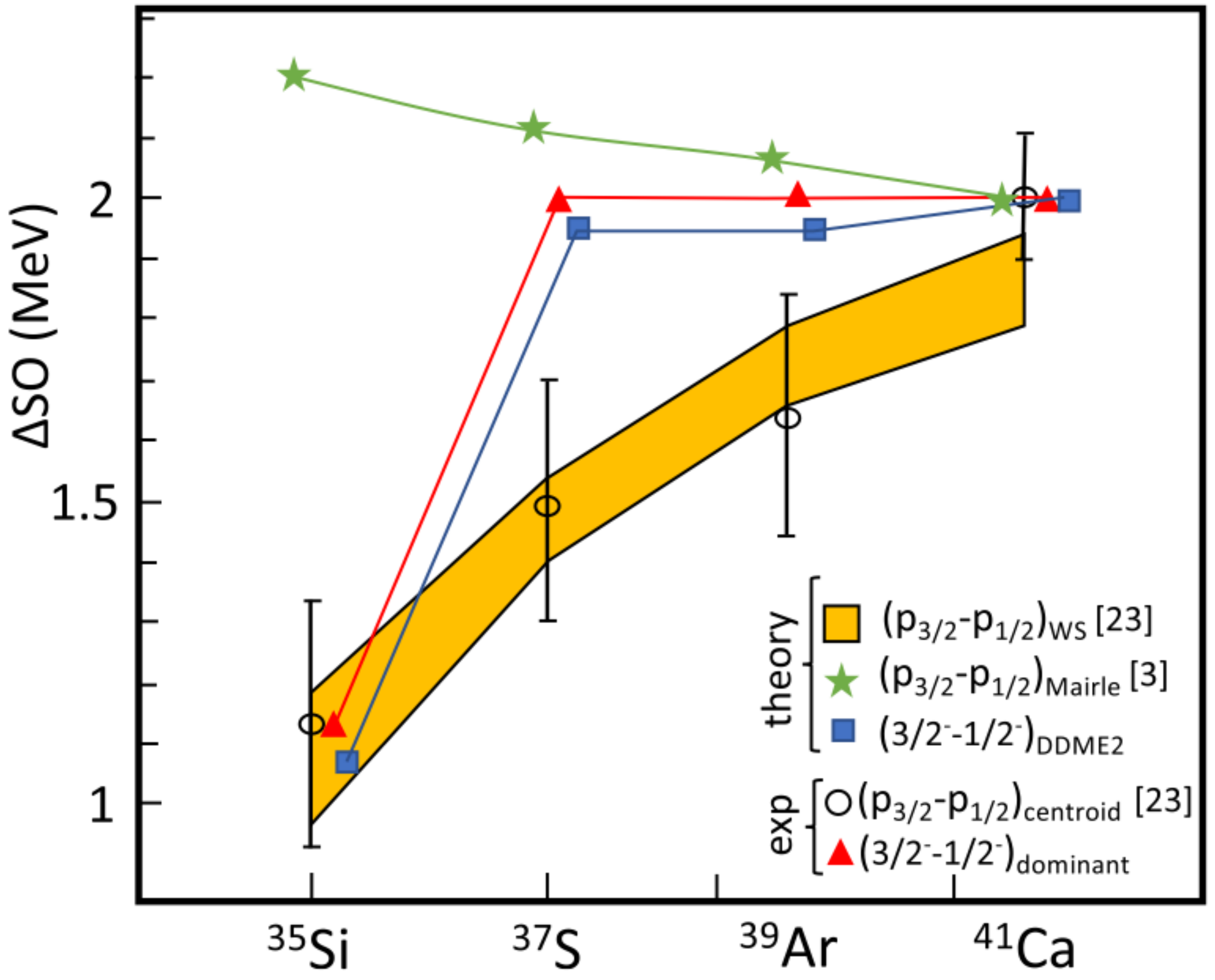
DESCRIPTION OF EVOLVING SINGLE-PARTICLE ENERGIES

Smooth behavior of $0f_{7/2}$, $1p_{3/2}$ and $1p_{1/2}$ neutron single-particle energies

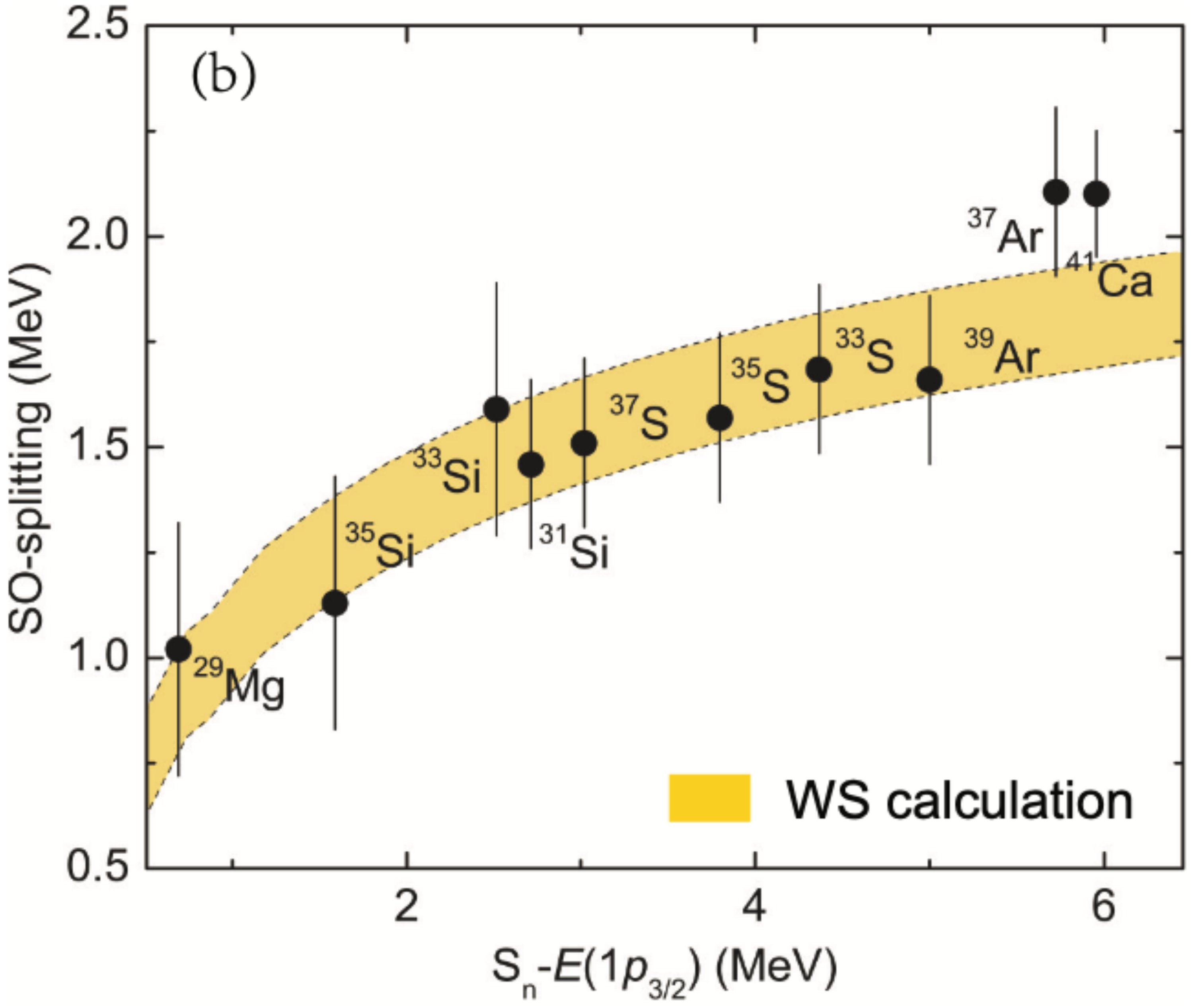
Proper energy centroid determination: No evidence for 'sudden' change in relative spin-orbit energies

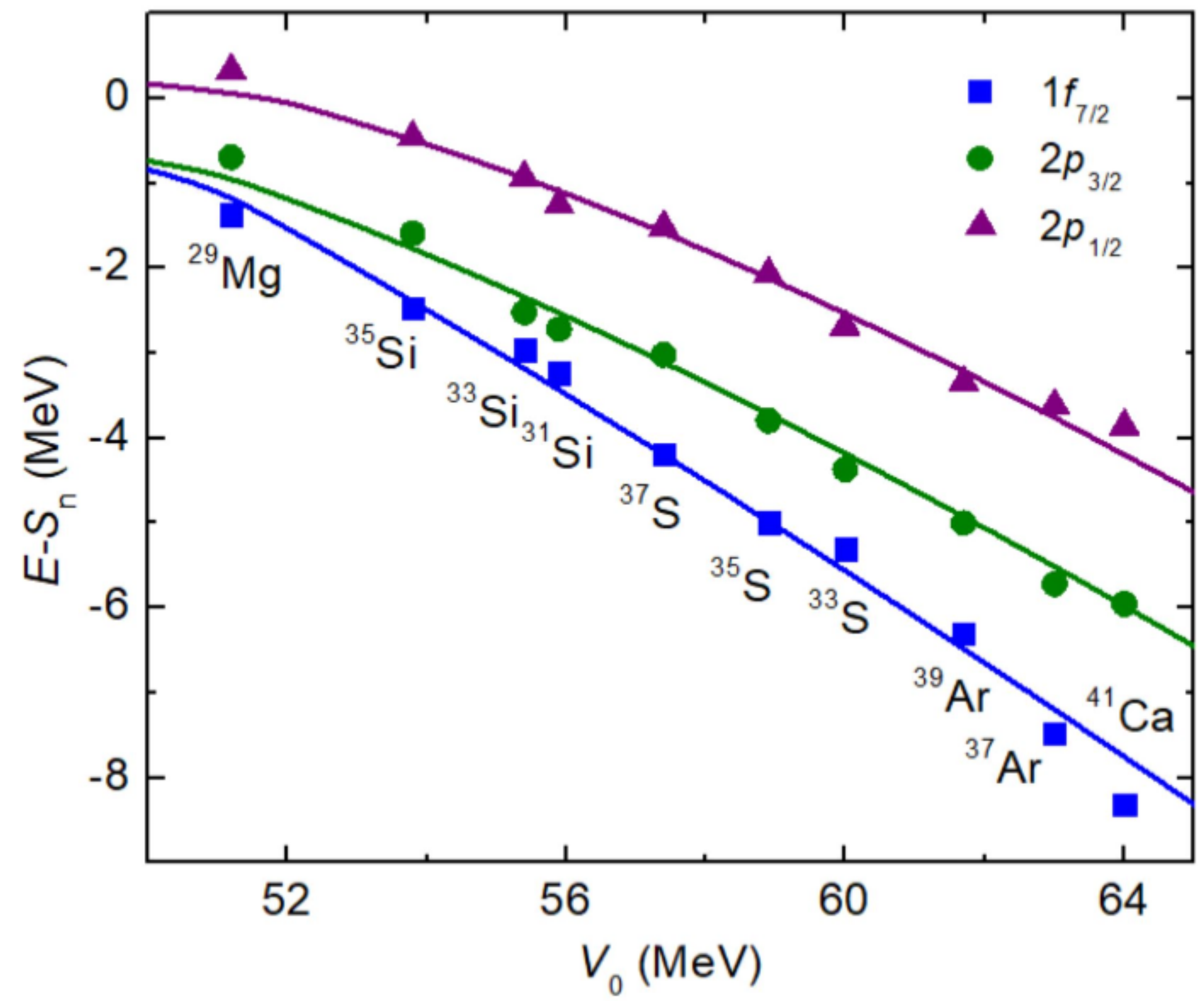
1. No atypical outlier in data
2. Full reproduction by W-S calculations

Solid lines: Wood-Saxon potential calculations for fixed A parameter set [varying potential depth]



Kay PRL (2017)



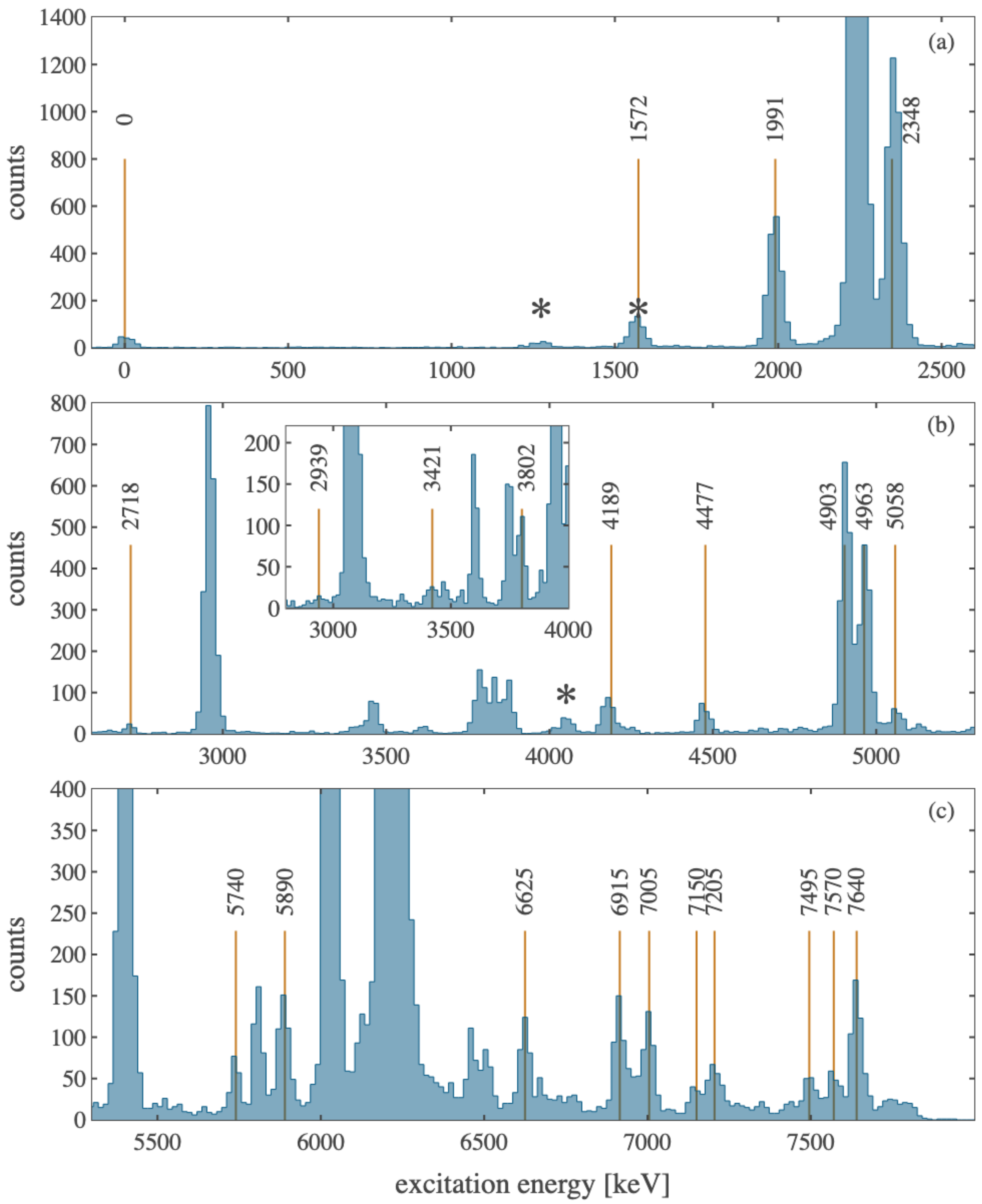


Chen et al., (2024)

^{34}S(D,P) MEASUREMENT @ FSU

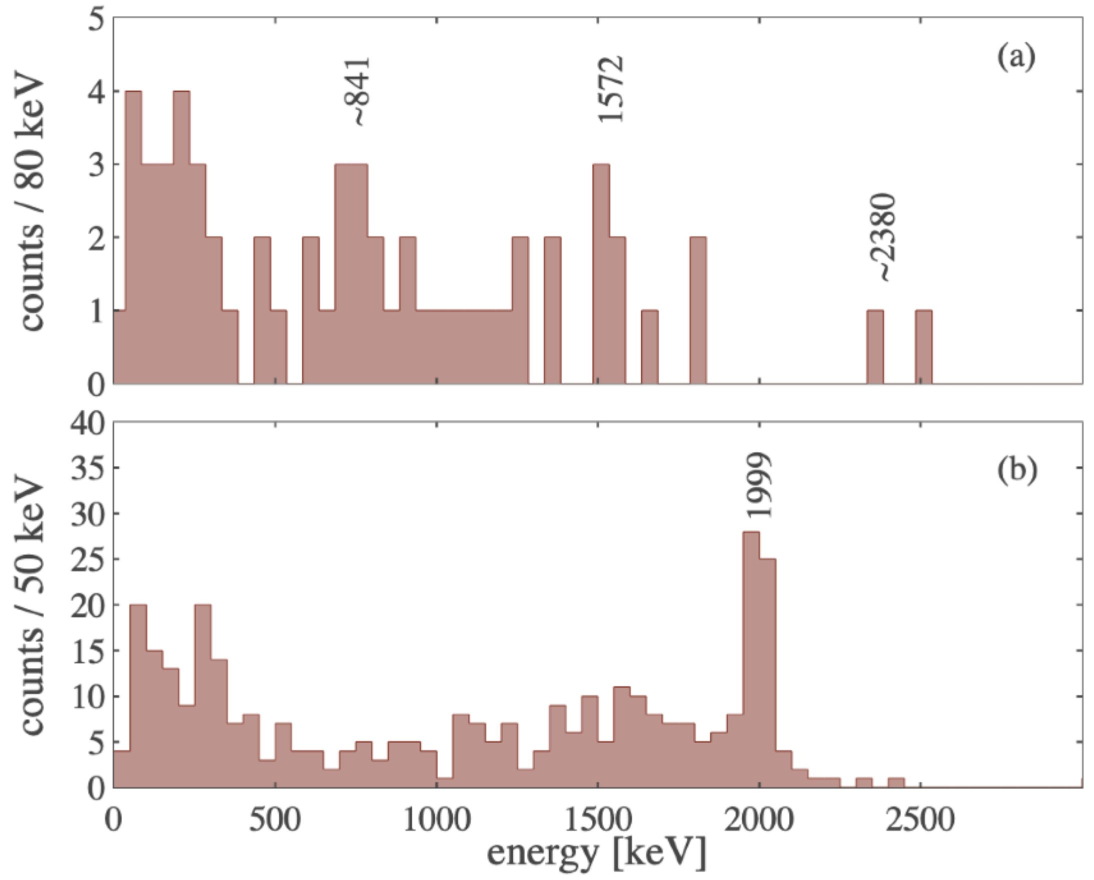
Extract $0f_{7/2,(5/2)}$ & $0p_{3/2,1/2}$ neutron strength distributions

States up through 7.5 MeV in ^{35}S

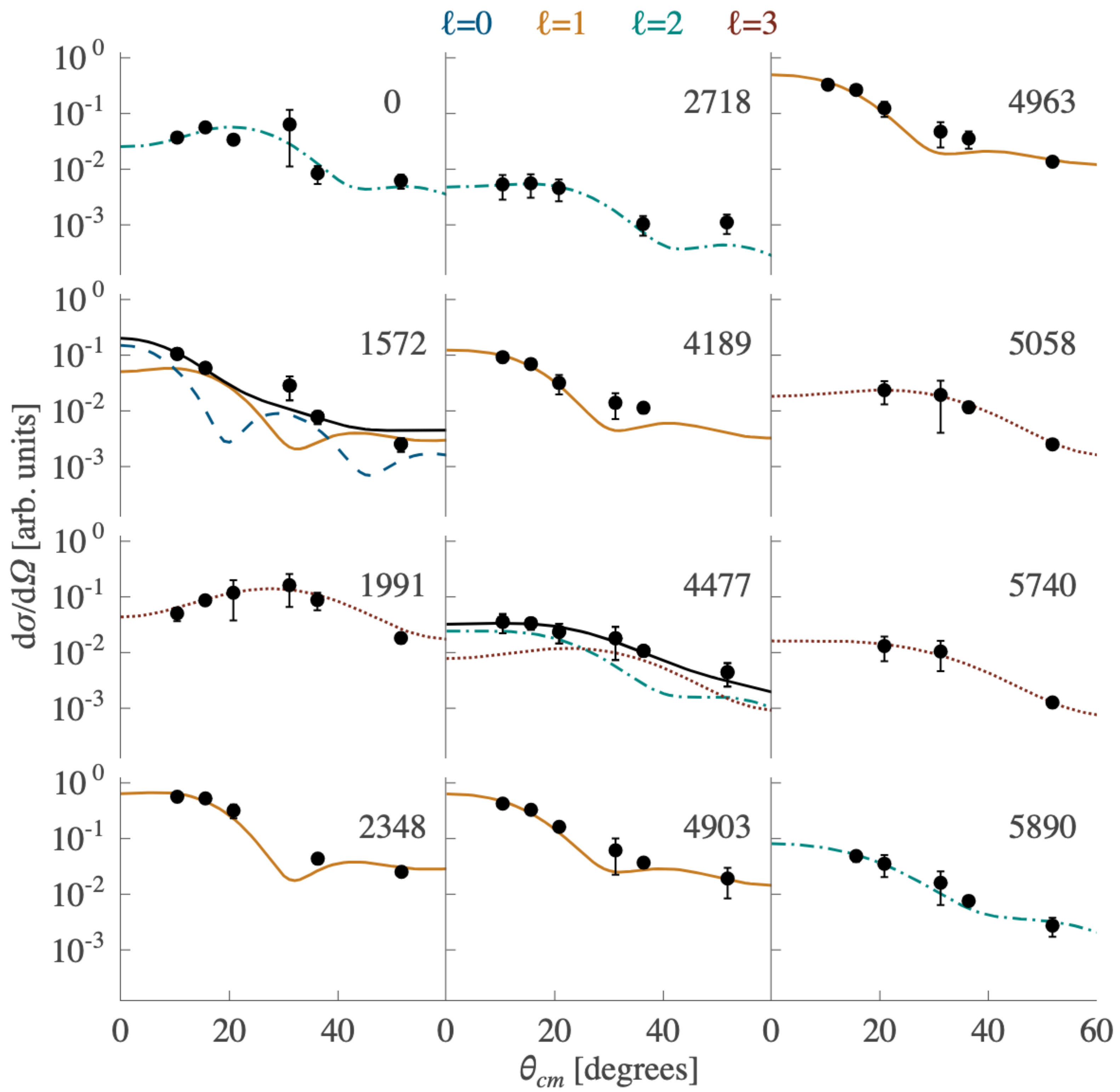


Kuchera et al., (2024)

Complement with CeBrA data
[Jπ, contaminant ID, etc.]



Consistent orbital angular momentum assignments



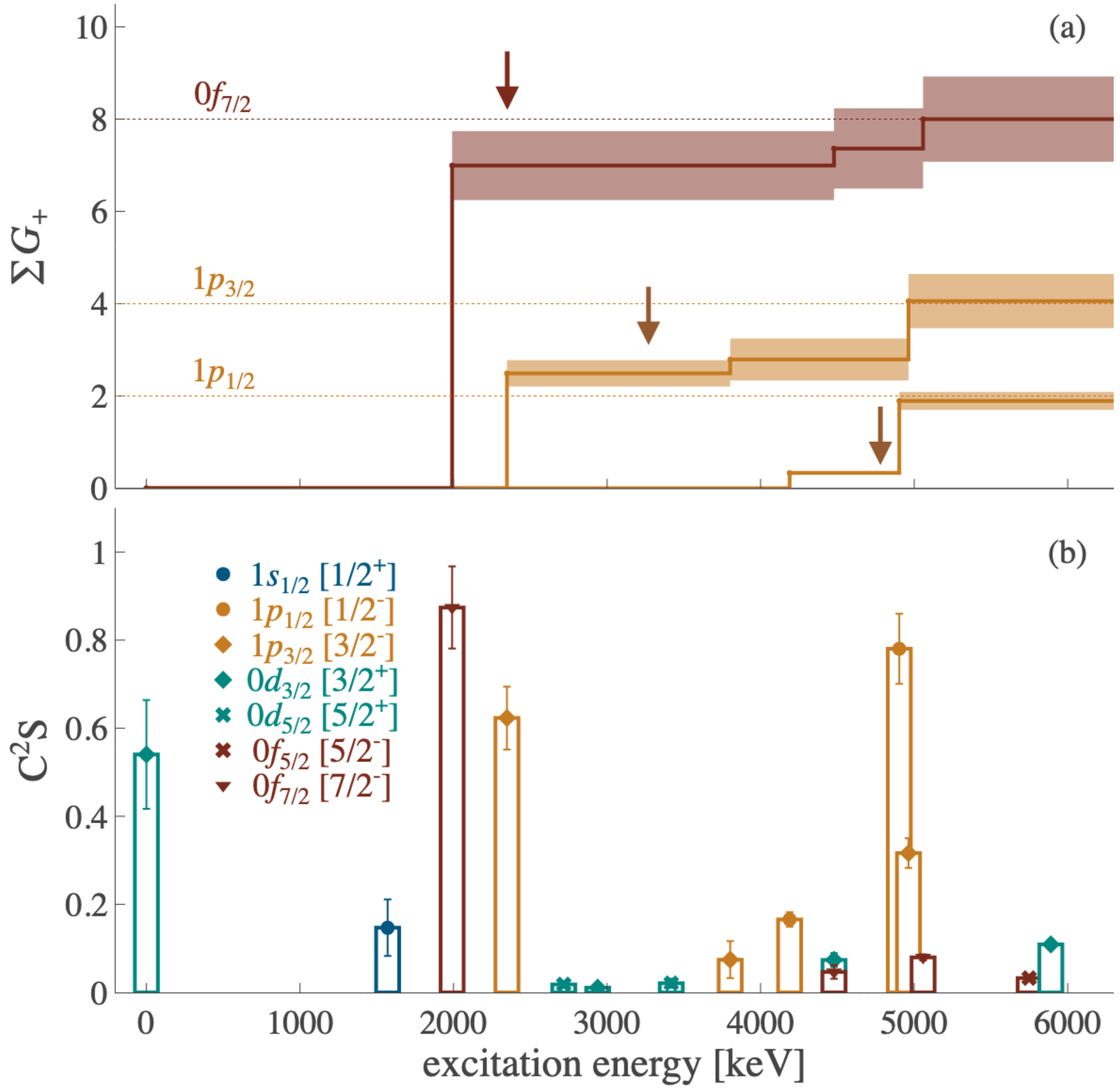
Argonne NATIONAL LABORATORY

^{34}S(D,P) MEASUREMENT @ FSU

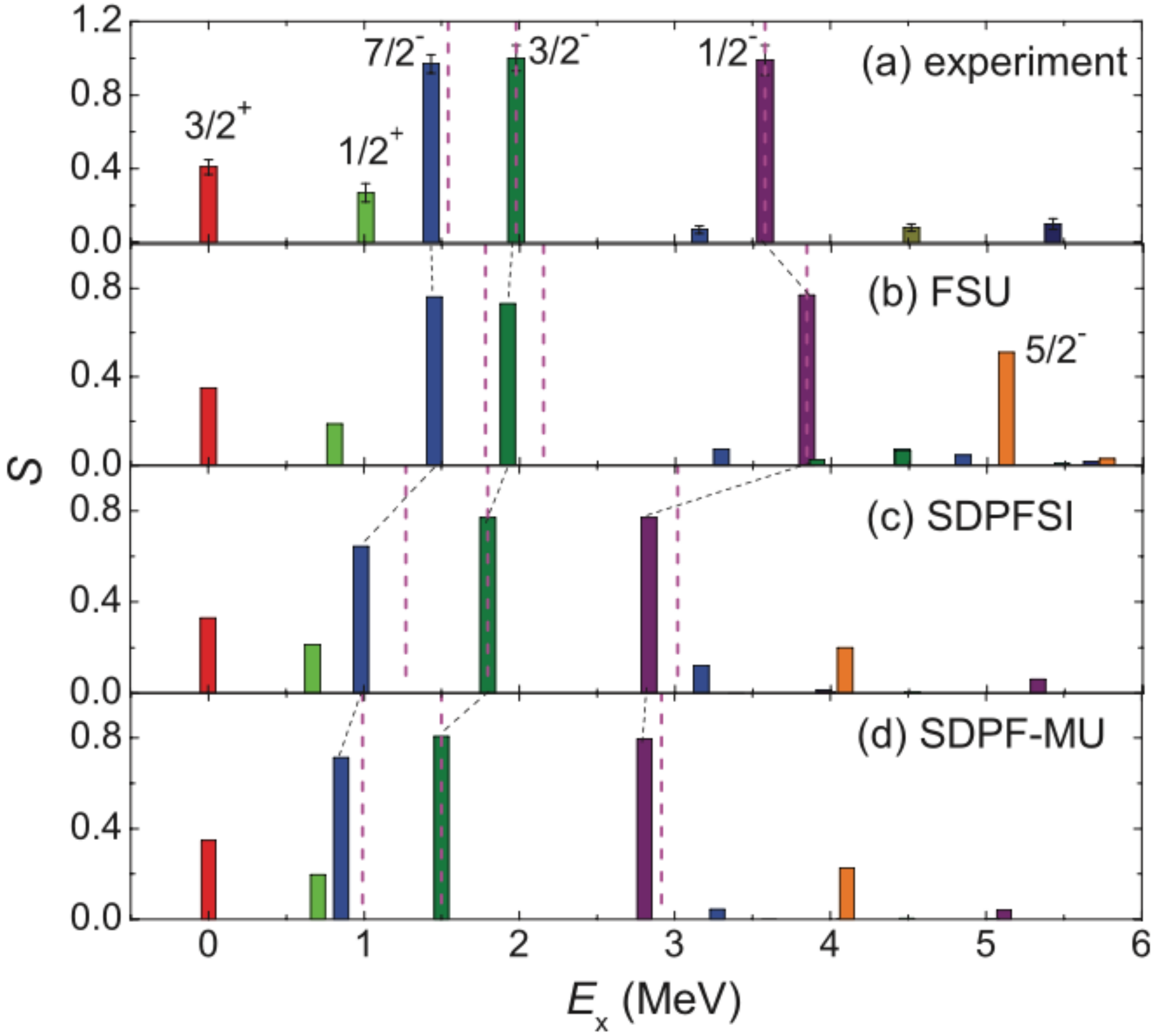
Extract $0f_{7/2,(5/2)}$ & $0p_{3/2,1/2}$ neutron strength distributions

Strength distribution - resolves conflicting information

Energy centroids - N = 28, 32, 34, & S-O spacings



Compare w/ reduced fragmentation in ^{33}Si

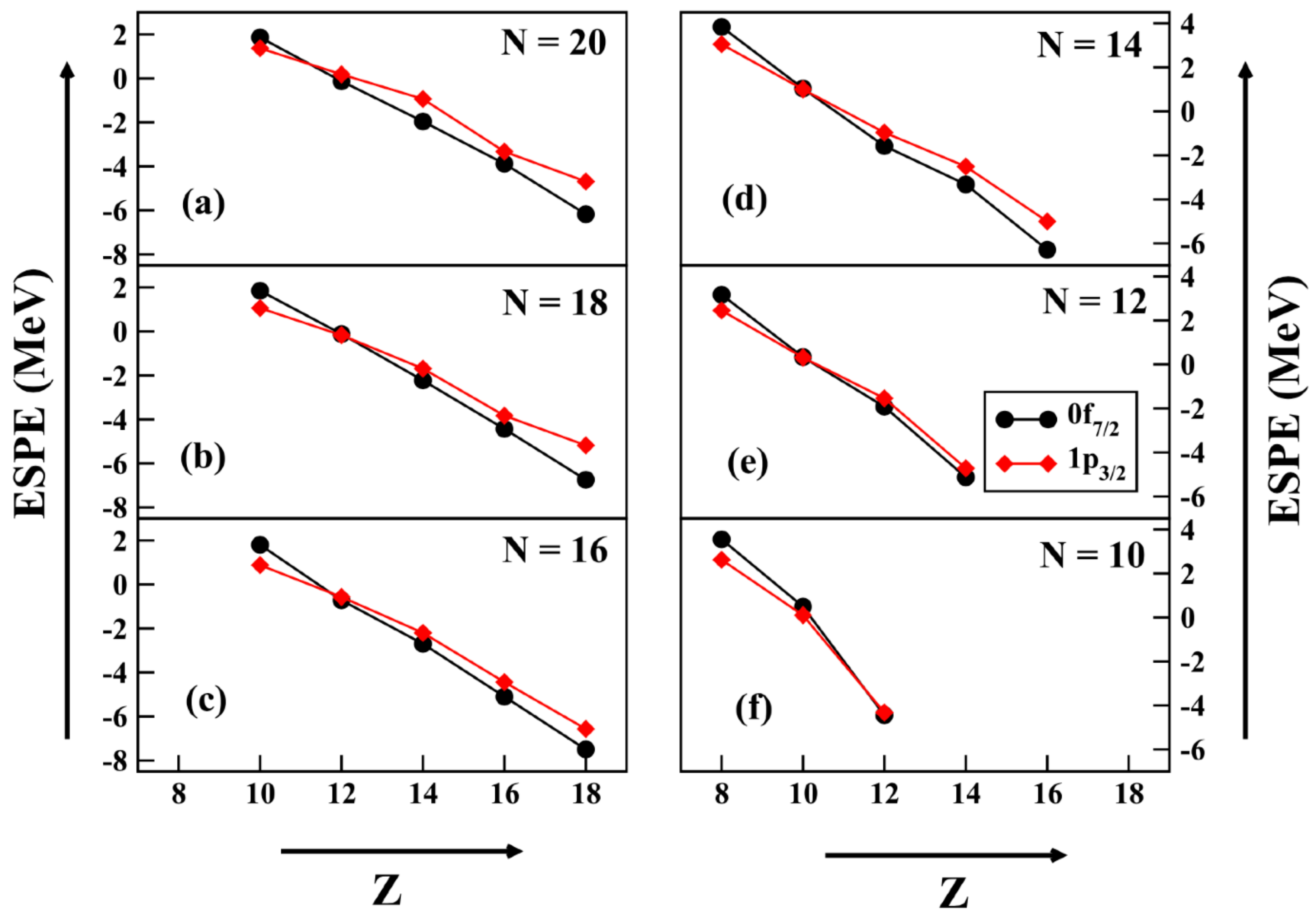


Chen et al., (2024)

DESCRIPTION OF EVOLVING SINGLE-PARTICLE ENERGIES

Summary of what we established

- Single-particle energy centroids demonstrate a smooth evolution in energy - reproduced well by Wood-Saxon potential calculations
- Bubble may persist but no clear evidence of impact on S-O size
- How much of the reduction in the N = 20 shell gap is accounted for by weak binding?
- What about (ground state) correlations - still missing information



Lubna et al., PRR (2020)

- FSU interaction has done well reproducing spectroscopy within the 0f-1p neutron shells
  - Derived from data closer to thresholds
  - calculated SPE's demonstrate the same trends as the W-S calculations

ADDITIONAL SINGLE-PARTICLE TRANSFER MEASUREMENTS

^{36}S: Neutron removal data not collected, still a missing $1/2^{+}$ state in ^{35}P

$^{36}S(t, \alpha)^{35}P$ / $^{36}S(d,p)(d,t)^{37,35}S$

Neutron Removal

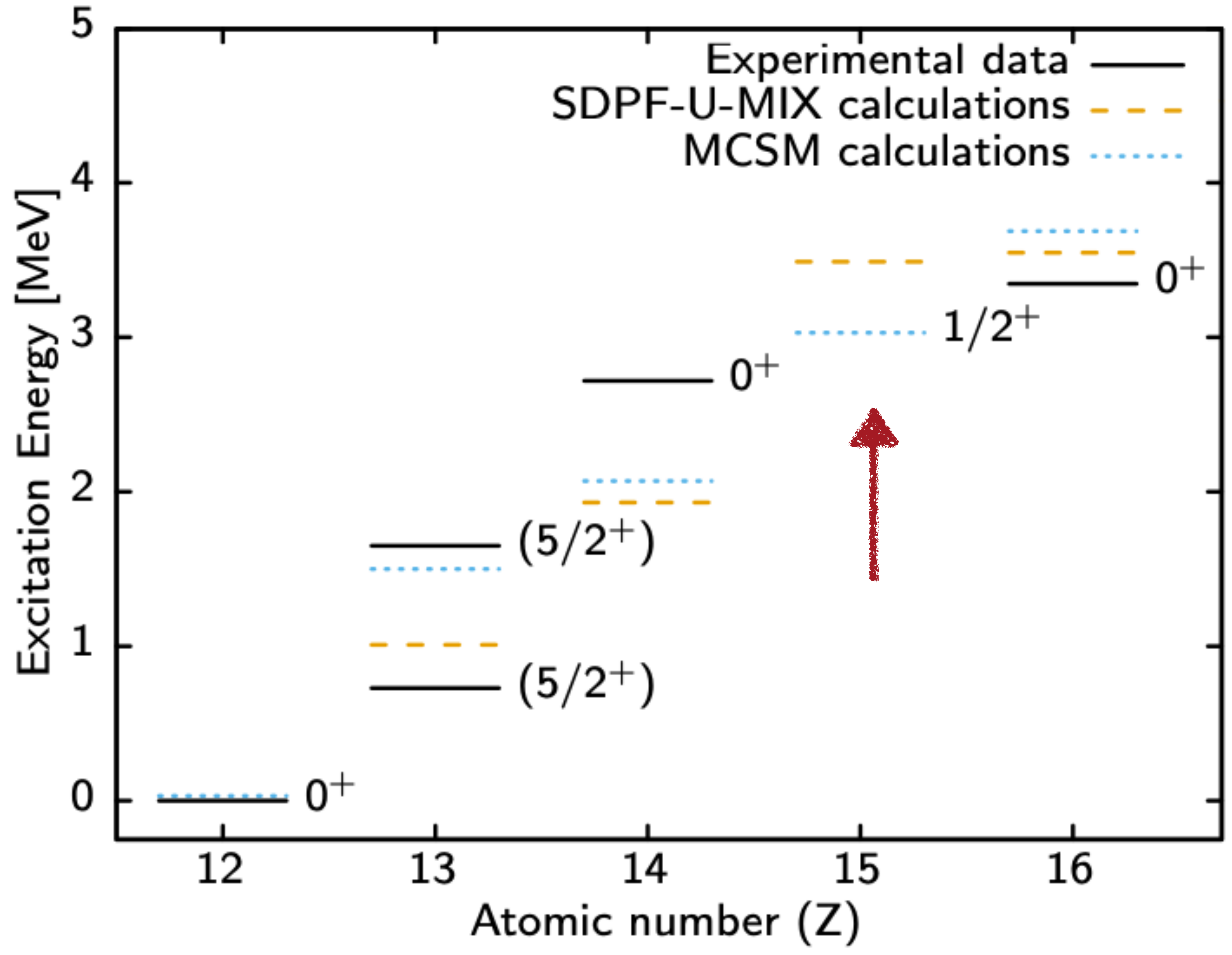
- Checking feasibility of (d,t) / (p,d) at >8 MeV/u
- Searching for ell=1 or 3 strength with states in ^{35}S
- Complement with adding reaction at higher Ex, $0f_{5/2}$ neutron orbital energy

Proton Removal

- Where is the 2p-2h (2hw) 1/2+ neutron state in ^{35}P?
- 0^{+}_{2} is the first excited state in ^{34}Si
- Detailed measurement over select excitation energy regions

Search for $1/2^{+}$ excited state in ^{35}P

In inverse kinematics



Salathe PRC (2020)

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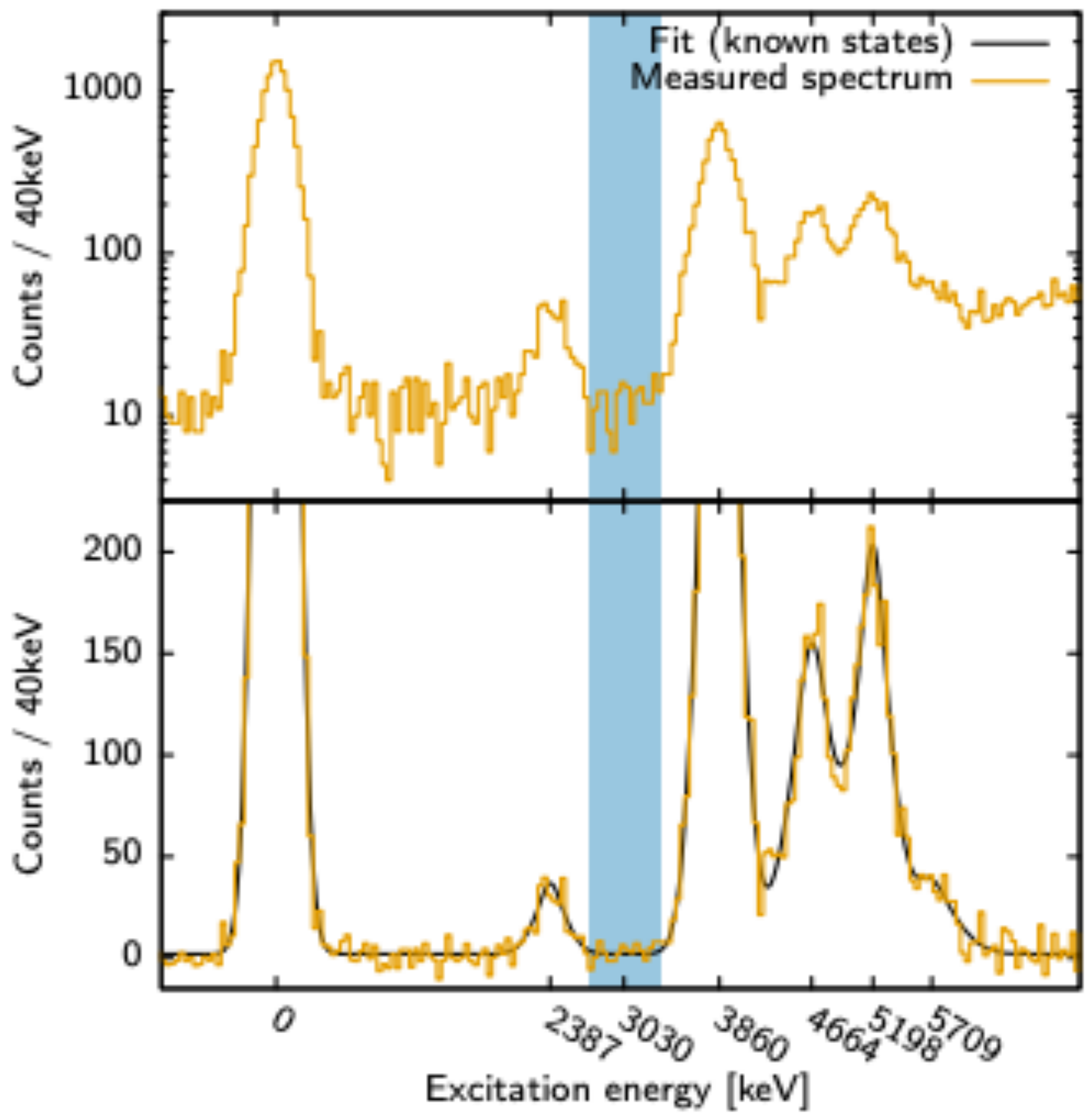

FIG. 5. The excitation energy measured in the ^{36}S(d, ^{3}He)^{35}P

Salathe PRC (2020)

SUMMARY

- Propose $^{34,36}S(t,p)$ reactions to investigate 2n pairing correlations
  - Integral part of a systematic study of single-particle vs. correlation energies in Z ~ 12 - 20 nuclei

- Exploring additional reactions on ^{36}S using both (t, α) and (p,d)/(d,t)
  - Complements recent (d,p) results, connecting stability to the Island of Inversion around N ~ 20

ACKNOWLEDGMENTS

- A. N. Kuchera, G. Ryan, B. D'Amato, O. M. Guarinello, P. S. Kielb - Davidson College
- L. T. Baby, A. L. Conley, B. Kelly, G. W. McCann, M. Spieker et al., - Florida State University
- B. P. Kay - Argonne Nat. Lab.
- Jie Chen - SUSTech, China

Calem R Hoffman - crhoffman@anl.gov

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