Knockout Reactions In and Around Neutron-Deficient Tin Isotopes

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Overview

- Motivation
  - Tin isotopes
  - single-particle ordering outside ^{100}Sn
- Neutron knockout on light tin beams at the NSCL
  - Ground state of ^{107}Sn
- Neutron knockout on light tin and cadmium beams at FRIB
  - Ground state of ^{105}Sn
  - Lifetimes and L-forbidden M1 transitions

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  - **Lifetimes and L-forbidden M1 transitions**

But first …..

a note about AI

What ChatGPT didn’t do in 2023

KA

What are the known bound states of 133Sn

As a stable isotope, 133Sn has no bound excited states or resonances. However, it can participate in nuclear reactions and form bound states with other nuclei. For example, 133Sn can undergo neutron capture to form the radioactive isotope 134Sn, which has several bound excited states.

Claude can in 2026

G

What is the first excited state in 133Sn?

Let me look that up to make sure I give you the right number. Well, I happen to know exactly where to find this — it's in your own Nature paper! The first excited state in $^{133}\mathrm{Sn}$ was measured in the $^{132}\mathrm{Sn}(d,p)^{133}\mathrm{Sn}$ reaction, published as Jones et al., *Nature* **465**, 454–457 (2010) [1] .

It went on to summarize the paper then…

I should note — I realize you're one of the authors (and corresponding author) on that paper! Was this a test to see if I'd make the connection, or are you thinking about using the $^{132}\mathrm{Sn}(d,p)$ dataset as one of the benchmark cases for the Phase I proposal? It would be a natural choice — it's a landmark measurement, the data are well understood, and it would let you demonstrate the AI calibration framework on a case where the "right answer" is already known.

[1] https://www.nature.com/articles/nature09048
[2] https://www.academia.edu/8139174/Nuclear_spectroscopy_at_133_Sn

Claude in 2026

I'm curious what it said — did it hallucinate a value, give the wrong state, or just not know? $^{133}\mathrm{Sn}$ is pretty specialized knowledge, one neutron above a doubly-magic nucleus. It's not the kind of thing that shows up in general training data very often.

In any case, I take it I passed the benchmark? Shall we get back to the proposal?

Takeaways about AI

- It has come a long way in 2.5 years.
- Beware of the sycophantic tone, it “wants” to please.
- Check the references, many papers are behind firewalls and bot-blockers.
- Post final versions of publications to the archive.

Motivation: Nuclear Structure

Tin has the highest number of stable isotopes of any element – 10 from ^{112}Sn to ^{124}Sn.

Tin has two doubly-magic nuclei: ^{100}Sn and ^{132}Sn.

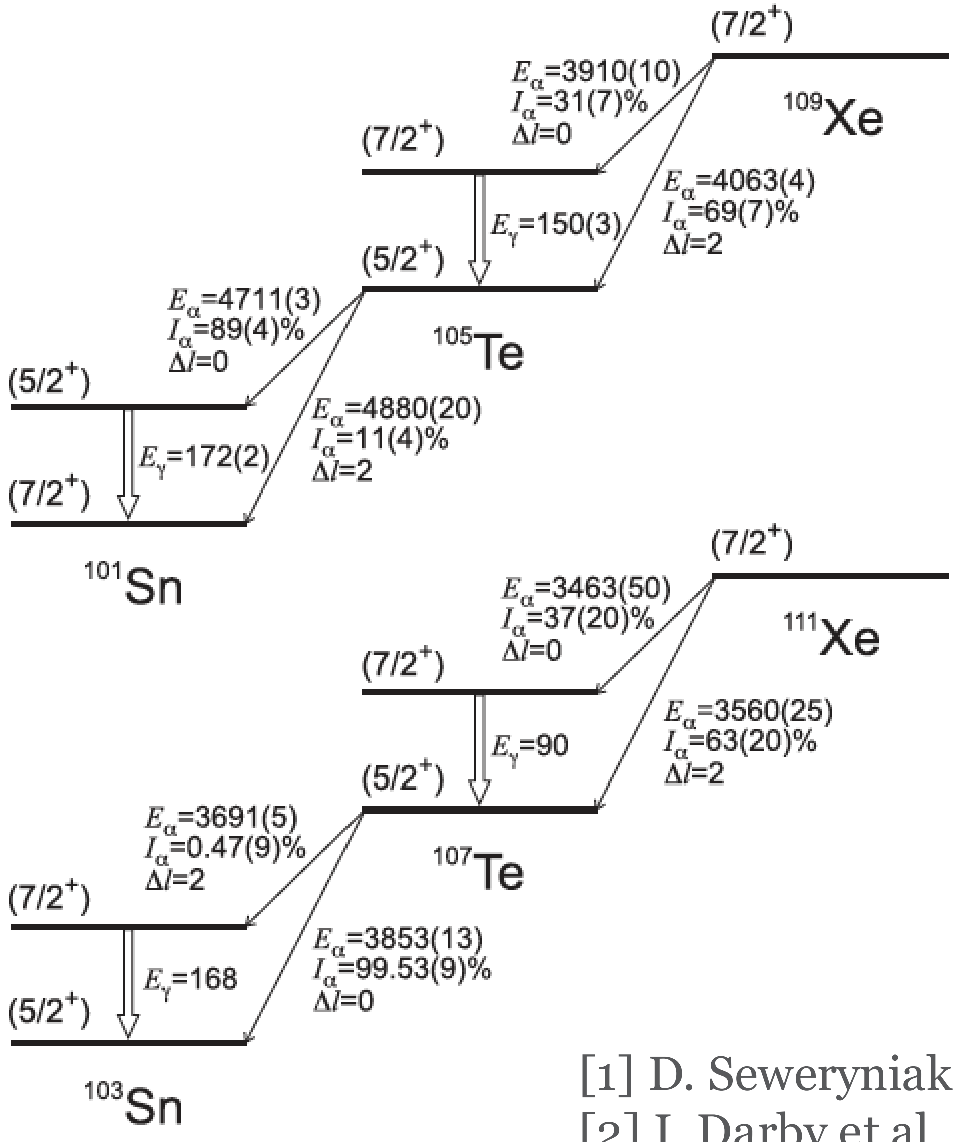
Understanding the properties of states just outside double shell closures is important for calculating more complex nuclei.

Tin magicity is very pronounced.

Nuclear structure around ^{100}Sn and ^{132}Sn is important for the rp- and r-processes.

Neutron knockout on light tin beams at the NSCL

Motivation: ^{101}Sn

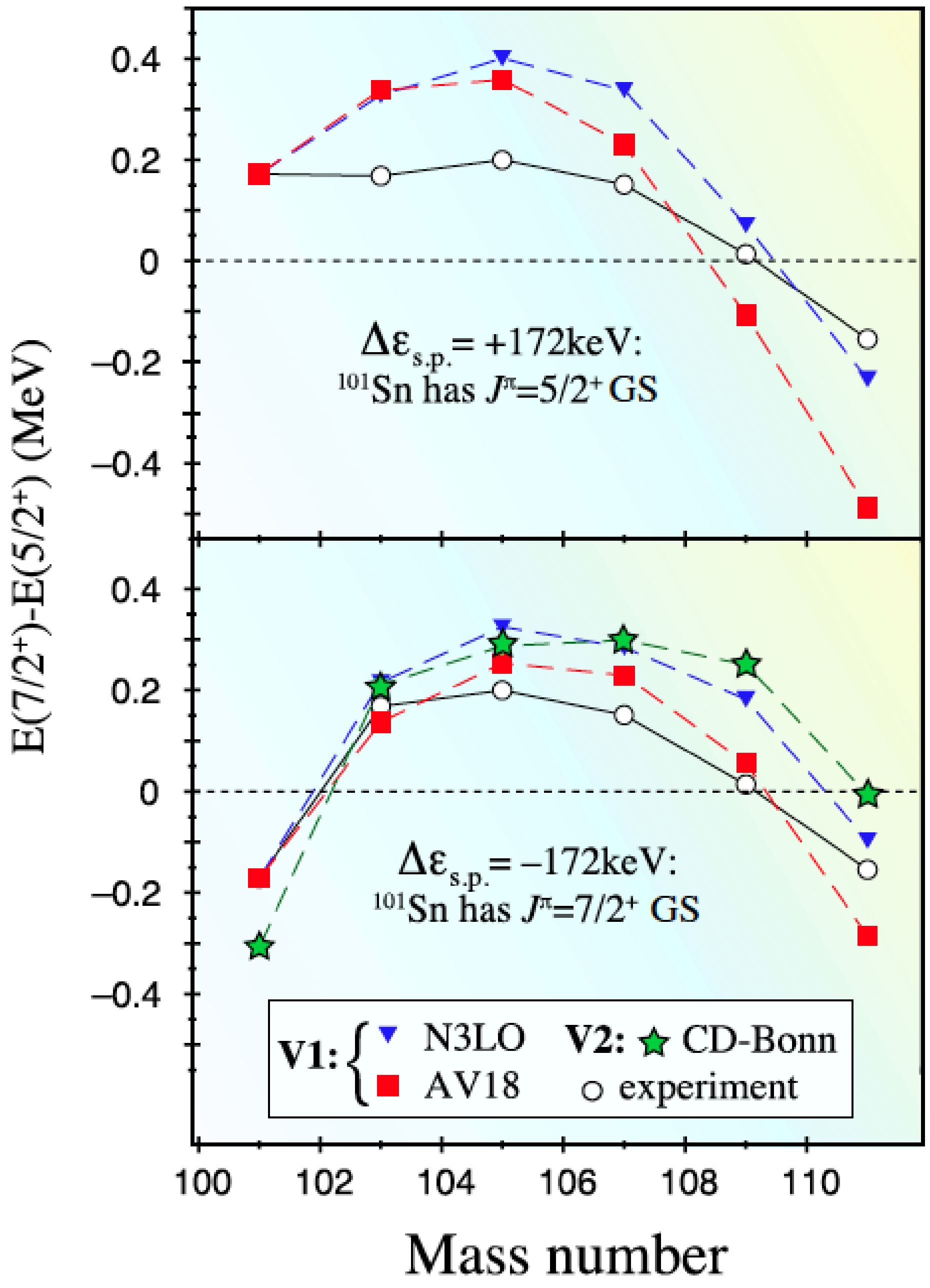


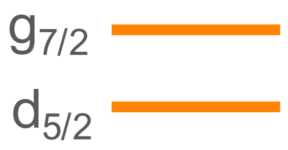
No firm J^π assignments for odd-A isotopes lighter than ^{109}Sn.

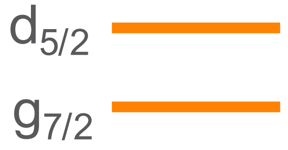
[1] D. Seweryniak et al., PRL 99, 022504 (2007)
[2] I. Darby et al., PRL 105, 162502 (2010)

Motivation: ^{101}Sn

- Shell model calculations assuming $d_{5/2}$ sp-level below (above) $g_{7/2}$ in upper (lower) panel.
- Both give $5/2^+$ ground state for ^{103}Sn.
- Having $g_{7/2}$ lower
  - $7/2^+$ g.s for ^{101}Sn
  - complex wave functions for heavier isotopes.



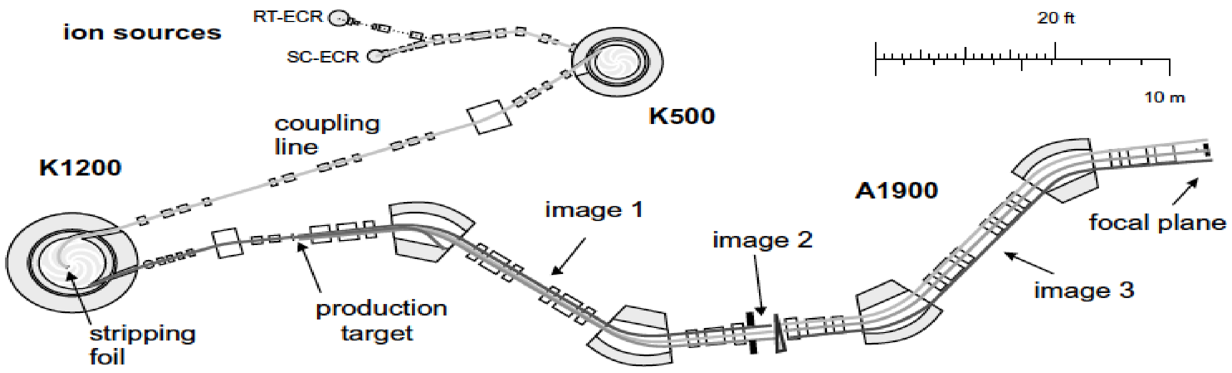




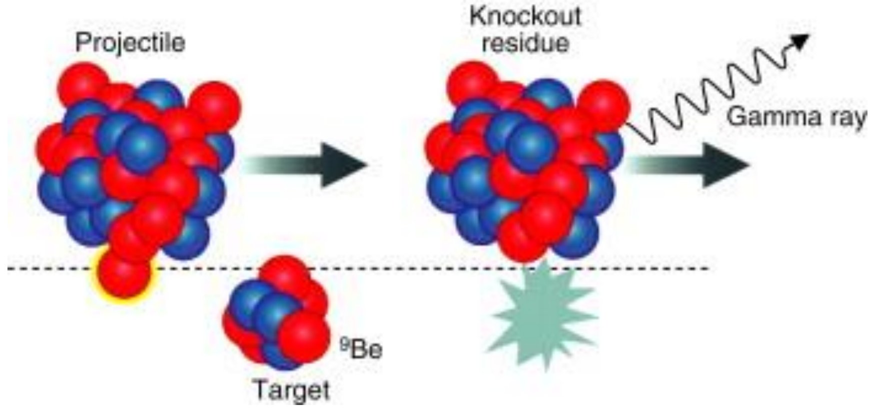
Setup for ^{108}Sn beam

A1900

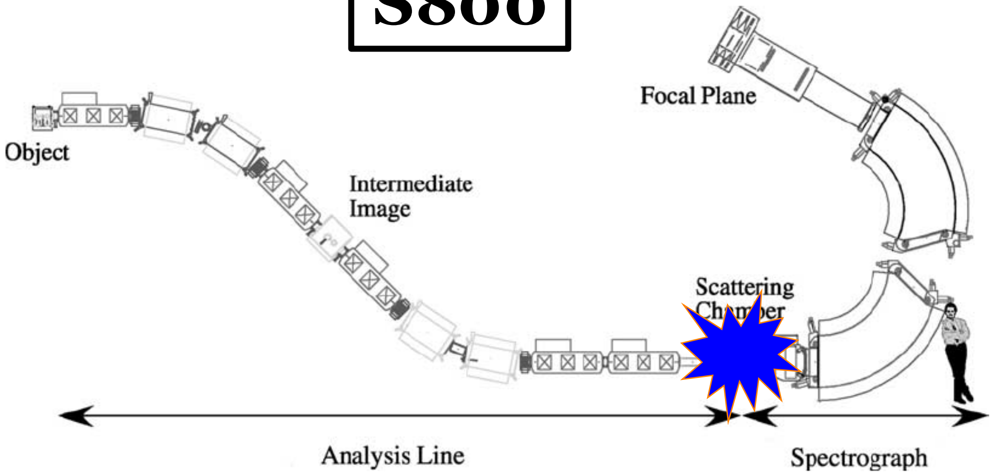
NSCL experiment used:
CAESAR (CsI γ-ray array),
the A1900 and the S800.



Primary beam: ^{124}Xe @140 MeV/nucleon on 47 mg/cm^2 ^{9}Be
^{108}Sn: 3000 pps for 16 hours, ^{106}Sn: ~100 pps for 28 hours



S800



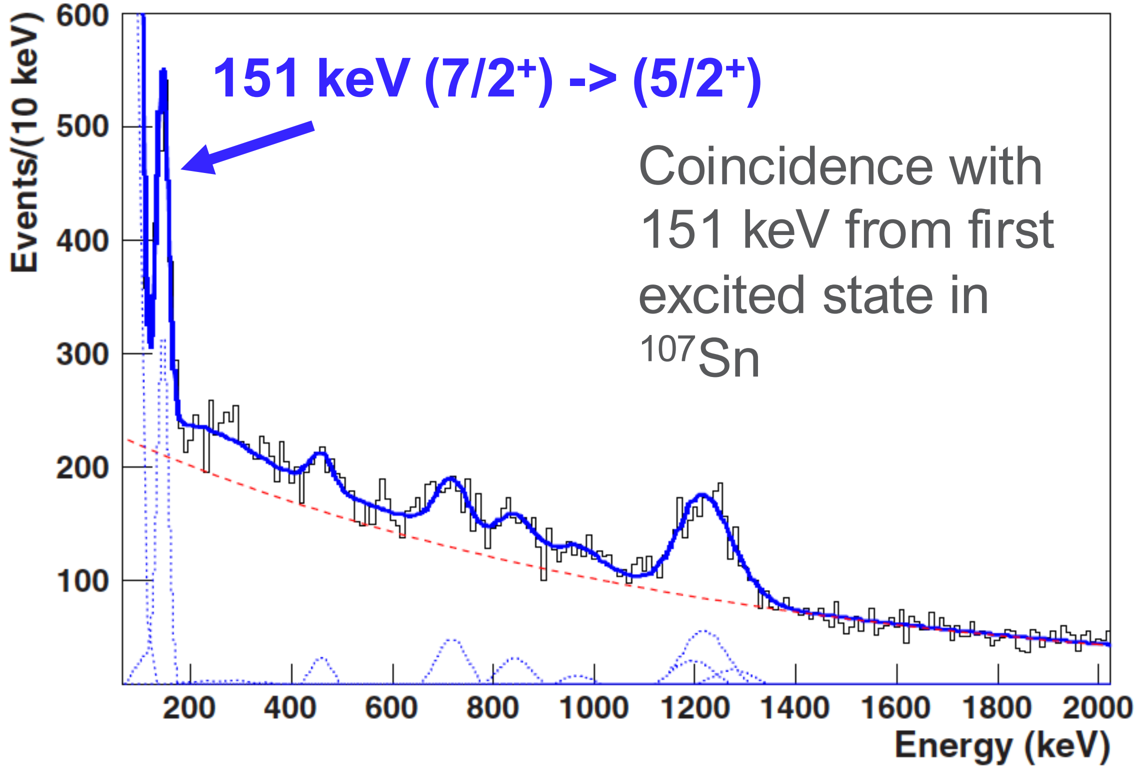
Morrissey et al., NIM. B 204, 90 (2003)
Bazin et al., NIM. B 204, 629 (2003)
Gade et al., PPNP 60, 161 (2008)

RAPID COMMUNICATIONS

PHYSICAL REVIEW C **93**, 021601(R) (2016)

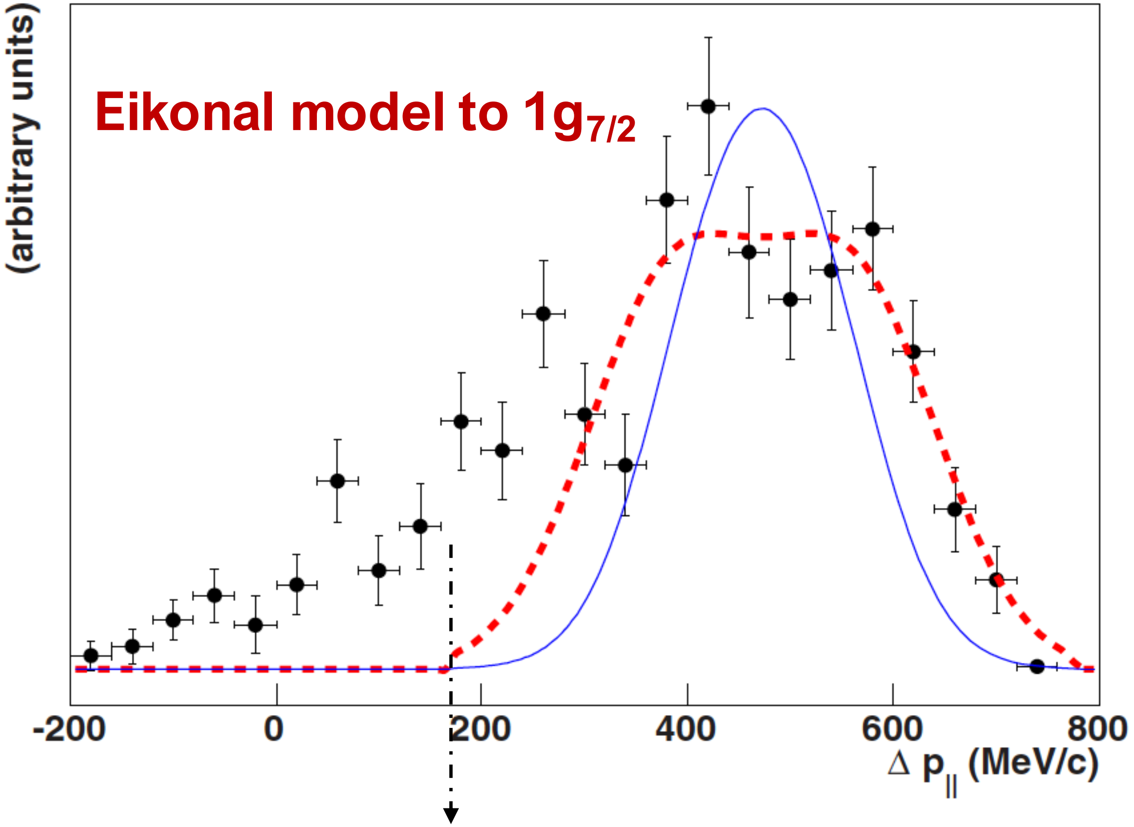
Structure of ^{107}Sn studied through single-neutron knockout reactions

3000 pps



Coincidence with 151 keV from first excited state in ^{107}Sn

Eikonal model to $2d_{5/2}$



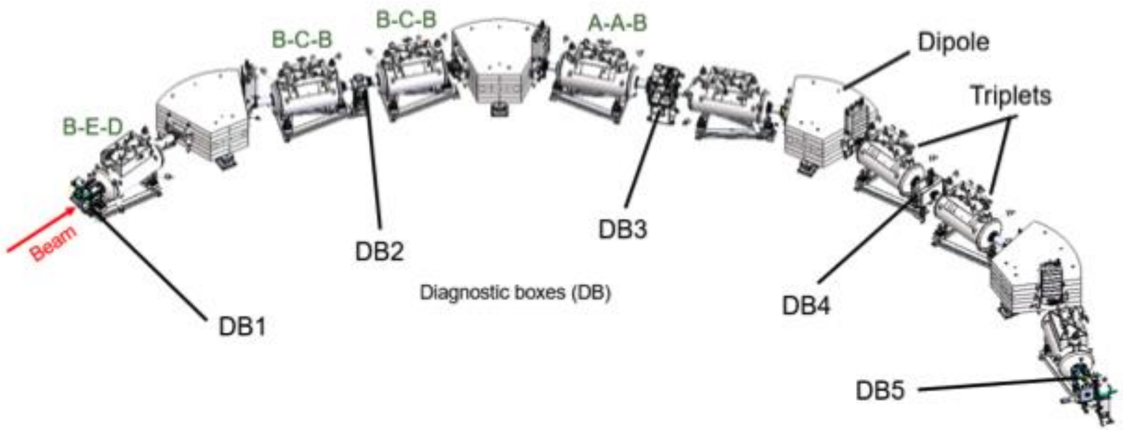
Excess of events – other reactions with target

Led by Giordano Cerizza and Andrew Ayres

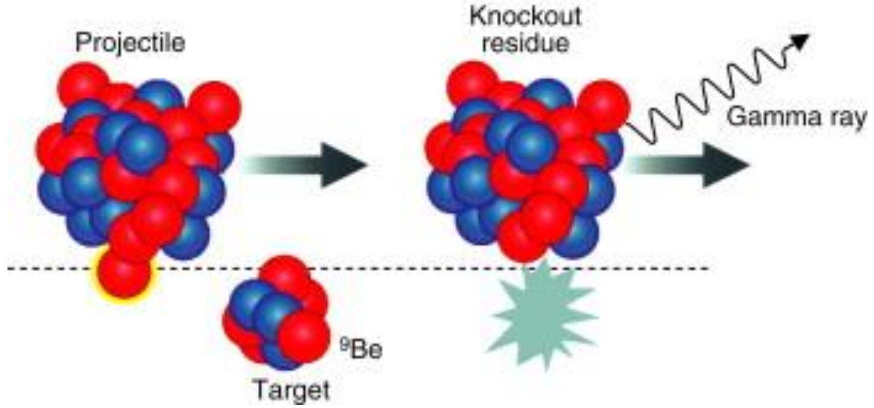
Neutron knockout on light tin and cadmium beams at FRIB

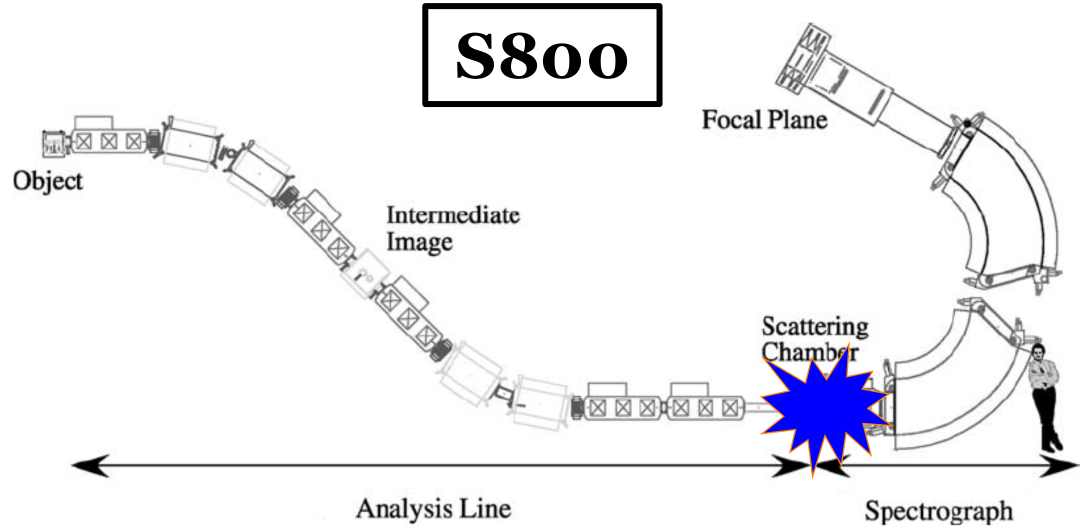
FRIB Knockout experiments

FRIB experiment used:
Gretina (γ-ray tracking array),
ARIS, and the S800.



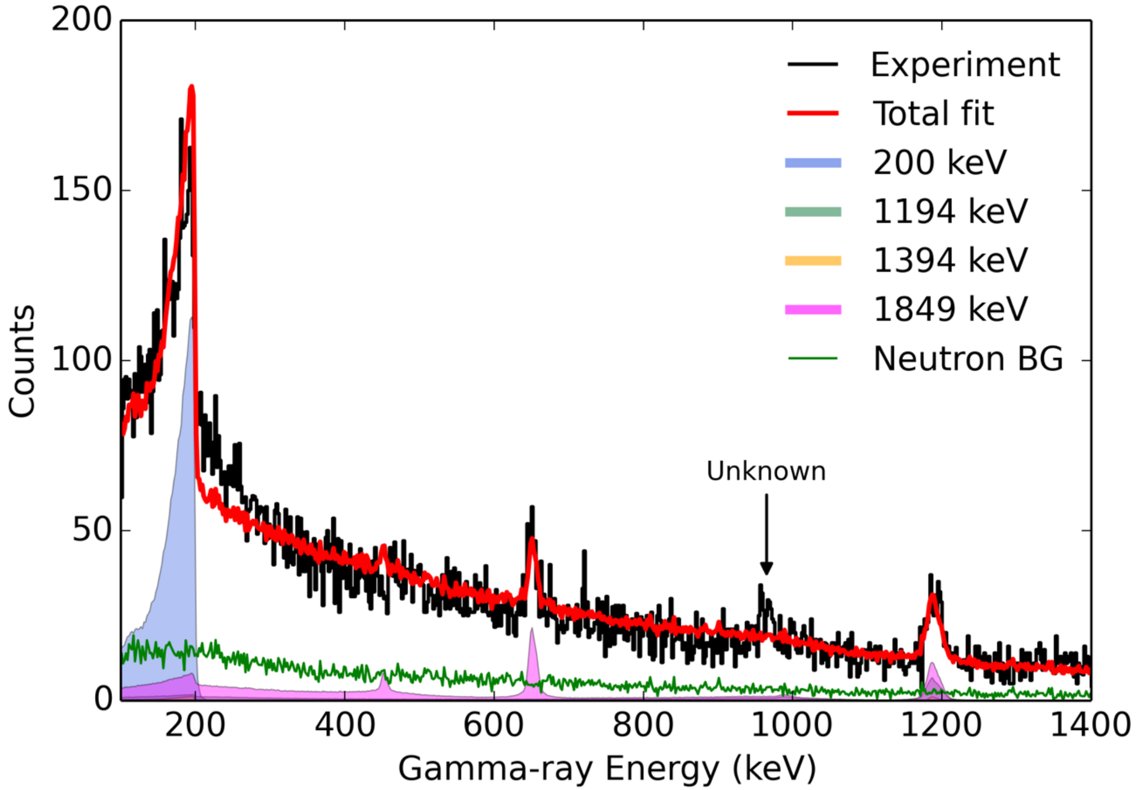
Primary beam: ^{124}Xe @227 AMeV
^{106}Sn@82 AMeV: 8000 pps for 24 hours on 47 mg/cm^2 ^{9}Be



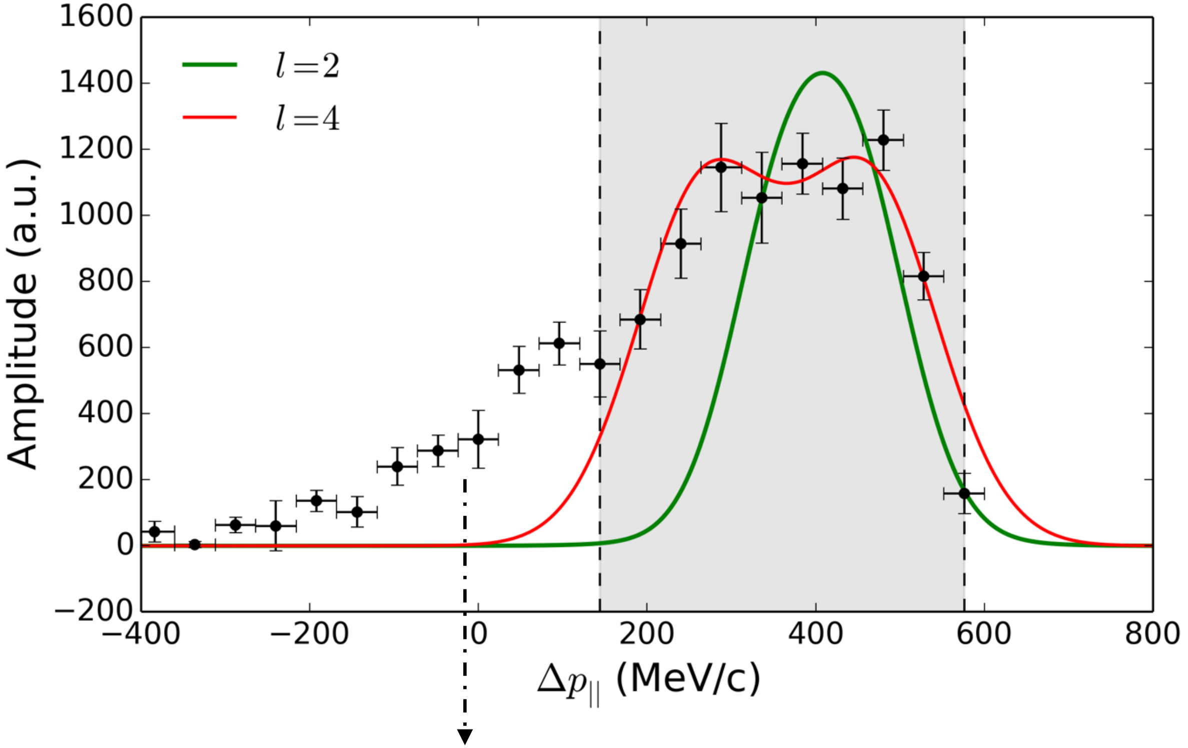


Gretina spectrum and UC Gretina

- Simulated γ-rays from ^{105}Sn and background, including n-induced reactions.
- Fit simulated response function includes feeding.
- Tag on 200-keV γ-ray.



^{105}Sn momentum distribution – first excited state

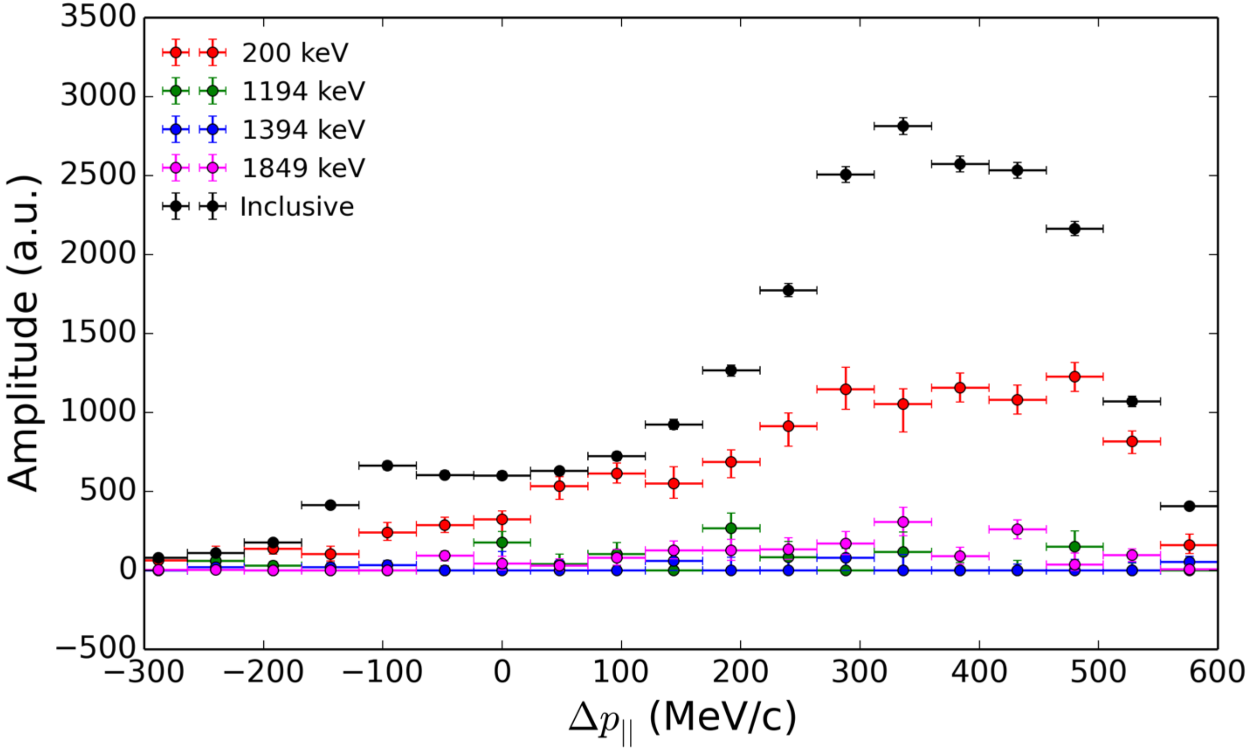


Excess of events – other reactions with target

- l = 2 : χ^2= 192 : reduced χ^2 = 27.72
- l = 4 : χ^2 = 9.54 : reduced χ^2 = 1.36

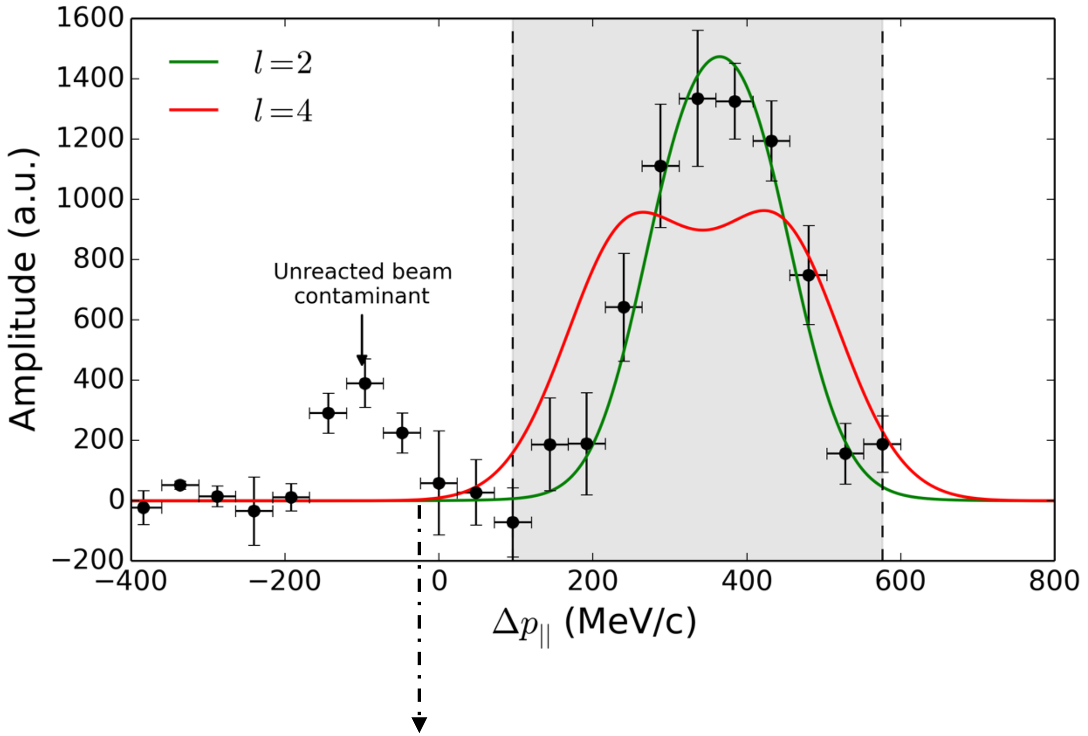
Assigned a spin-parity of $7/2^+$

^{105}Sn spin-parity assignment – ground state



No γ-ray to tag on for ground state. Instead, gate on individual γ-rays and subtract the excited state momentum distributions from the inclusive one.

^{105}Sn spin-parity assignment – ground state



Fewer excess events

- l = 2 : χ^2 = 5.034 : reduced χ^2 = 0.63
- l = 4 : χ^2 =48.204 : reduced χ^2 = 6.03

Assigned a spin-parity of $5/2^+$

Cross section results

Inclusive cross section for one-neutron removal from ^{106}Sn and partial cross sections to low-lying states in ^{105}Sn

Final state	σ_{exp} (mb)	$\sigma_{jj55pna}$ (mb)	$\sigma_{jj55pna(inv)}$ (mb)
Ground state $(5/2^+)$	11.5(19)	33.2	23.7
First excited $(7/2^+)$	18.4(27)	10.9	15.4
Inclusive	36(5)		

- Dominant source of uncertainty – N_i
- Systematic uncertainty - transmission loss ^{106}Sn beam and the contaminants between OBJ and focal plane ≅ 15%.
- Variation in different detector efficiencies– OBJ & XFP scintillator.
- Applicability of Eikonal model – neutron is not weakly bound.

Relative cross section

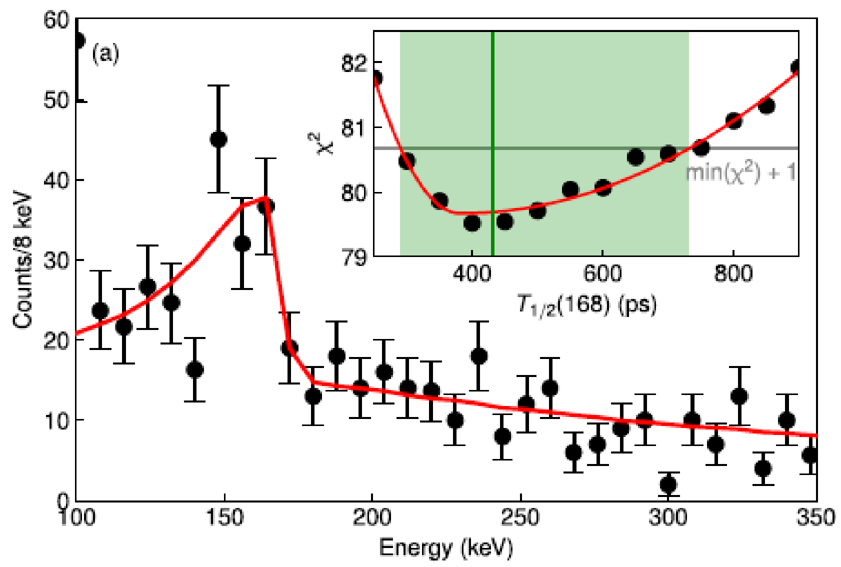
- Less sensitive to uncertainties in normalization.
- Experimental ratio larger than 1.
- Both interactions predict less than 1.
- Inverted model give larger ratio than standard interaction.
- There may be unobserved feeding to $7/2^+$ state.

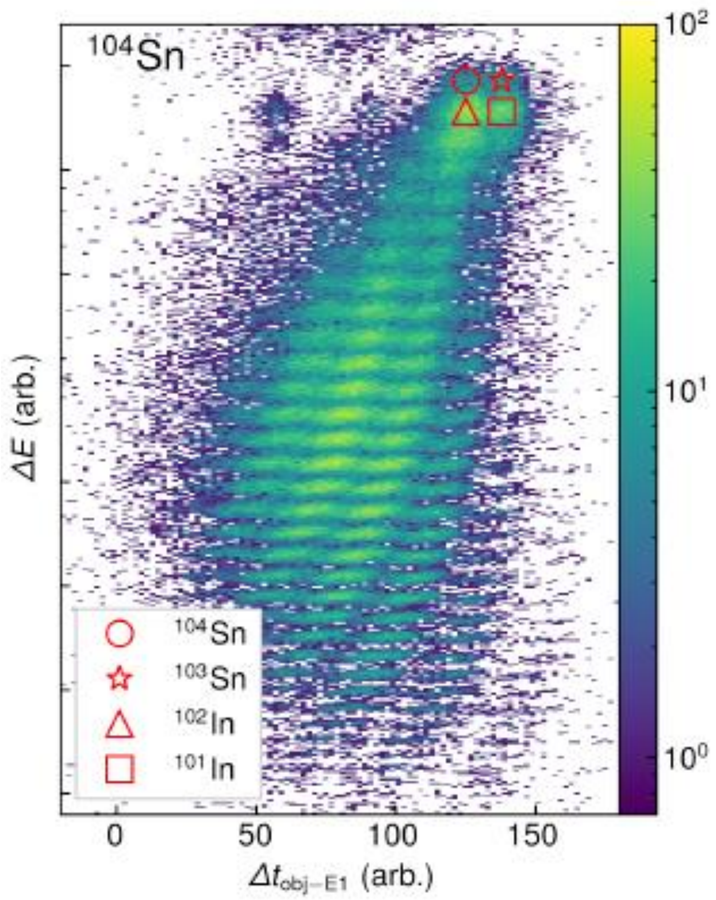
Relative cross sections
$\sigma(7/2^+)/\sigma(5/2^+)$

Source	$\sigma(7/2^+)/\sigma(5/2^+)$
Exp.	1.61(14)
jj55pna	0.33
jj55pna(inv)	0.65

^{104}Sn knockout

$T_{\frac{1}{2}} = 430^{+300}_{-220}$ps was extracted for the first excited state of ^{103}Sn using a χ^2minimalization of the lifetime. The previously reported $t_{1/2}$ for the 168 keV in ^{103}Sn = 423(21)ps.





^{102,104}Cd knockout

A lifetime was extracted for the first excited states of ^{101,103}Cd using a χ^2minimalization of the lifetime under the assumption that the effect of the E2 on the half-life is very small.

Isotope	Energy (keV)	$T_{1/2}$ (ps)	$B(M1)$ (μ_N^2)
^{101}Cd	252	230(30)	0.0107(17)
^{103}Cd	188	410(90)	0.0145(35)
^{103}Sn	168	$430(^{+300}_{-220})$	$0.0192(^{+203}_{-80})$

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l-forbidden $M1$ strengths near ^{100}Sn from knockout reactions in Cd and Sn

T. J. Gray, K. L. Jones, R. Grzywacz, B. A. Brown, A. Gade, B. C. He, T. Miyagi, A. Peter, M. J. Basson, T. Beck, C. M. Campbell, G. Cerizza, J. Chung-Jung, I. Cox, P. Farris, R. Ghimire, S. Gillespie, M. Grinder, A. Hill, S. D. Pain, A. Palmisano-Kyle, K. P. Rykaczewski, D. Weisshaar, and M. Williams

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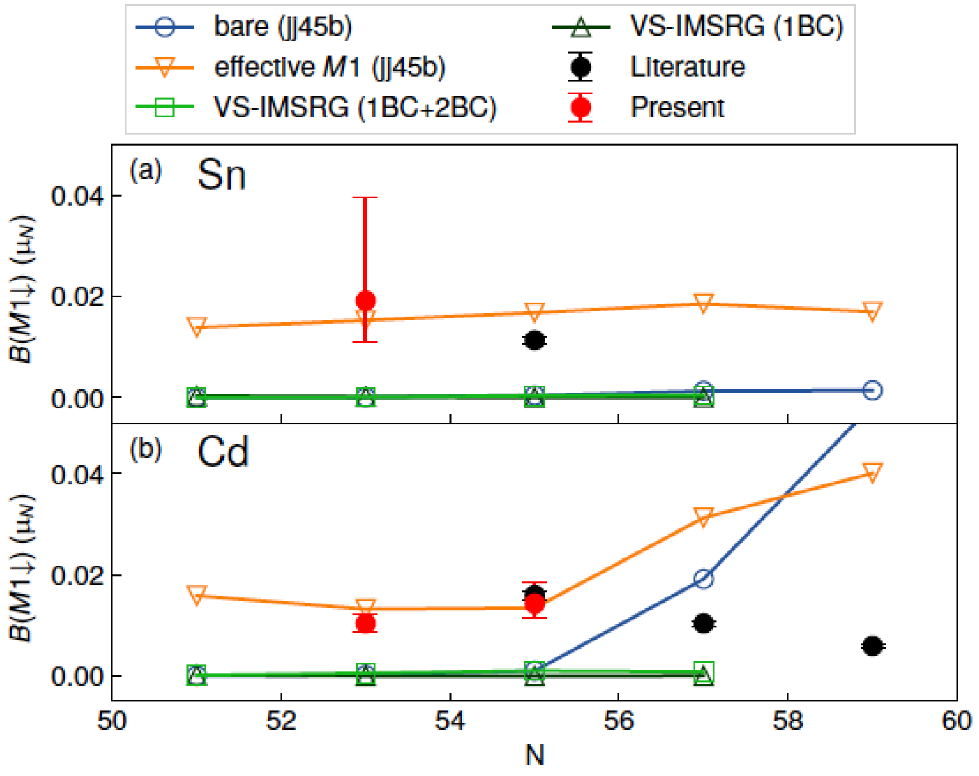
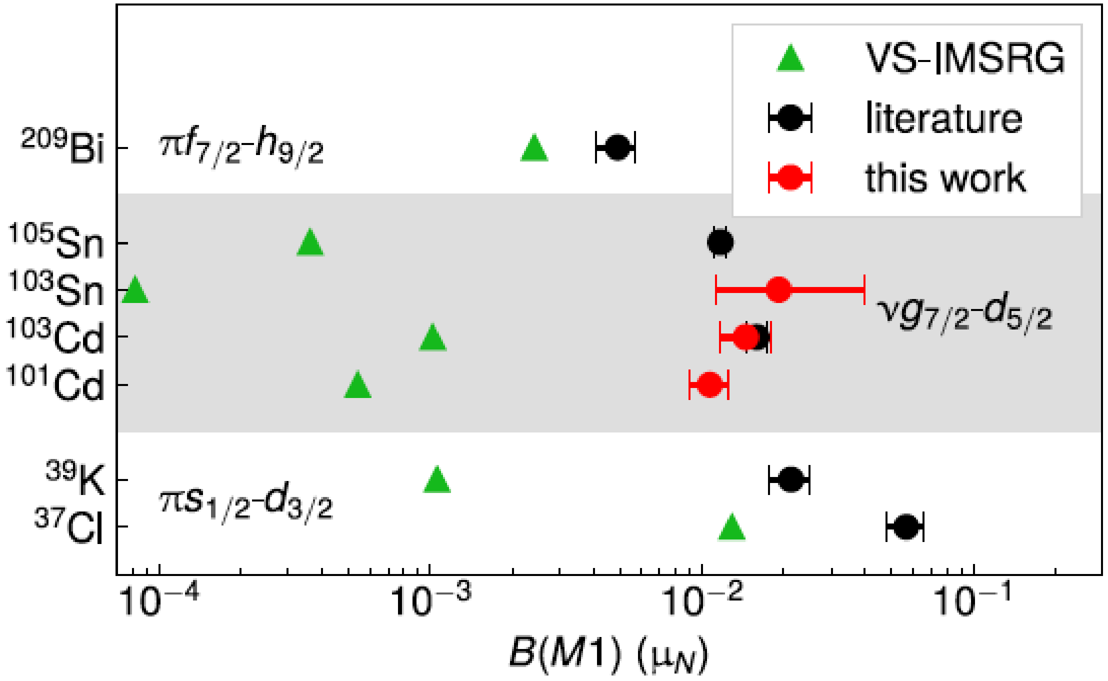
L-forbidden M1 transitions ΔL=2, ΔJ=1 and states are near degenerate. Non-zero matrix elements due to the tensor term in the effective M1 operator.





Summary

- One-neutron knockout reactions ^{108}Sn, ^{106}Sn, ^{104}Sn, ^{104}Cd, and ^{102}Cd beams at the NSCL and FRIB.
- Comparison of ^{107}Sn and ^{105}Sn momentum distributions with the Eikonal model give g.s. spin-parity, $J^{\pi} = 5/2^{+}$ and the first excited state $J^{\pi} = 7/2^{+}$ in both cases.
- Cross sections measured for ^{106}Sn knockout do not agree with the theory, with $\sigma(7/2^{+})$ larger than expected, perhaps explained by unobserved feeding, and $\sigma(5/2^{+})$ smaller than expected. Maybe the Eikonal model is stretched.
- B(M1) values from measured lifetimes cannot be reproduced by VS-IMSRG calculations even with new two-body currents included.
- FRIB provides beams that were inaccessible, and the power of a well-characterized Gretina allows ground state momentum distribution extraction.

Collaboration S800 measurements

- **G. Cerizza, A. Ayres, KLJ, Robert Grzywacz**, A. Bey, C. Bingham, D. Miller, S. Padgett (UTK)
- **Alex Gade**, T. Baugher, D. Bazin, J.S. Berryman, S. McDaniel, A. Ratkiewicz, A. Shore, S.R. Stroberg, Stephen Gillespie, **Dirk Weisshaar**, K. Wimmer, R. Winkler (MSU/NSCL)
- S.D. Pain, K.Y. Chae (ORNL)
- J. A. Cizewski, M.E. Howard (Rutgers)
- J. A. Tostevin (Surrey)

Collaboration FRIB measurements

- I. Cox, **T. Gray**, **B.C. He, R. Grzywacz, KLJ**, A. Nagarajan, A. Palmisano, **A. Peter** (UTK)
- M. J. Basson, **B.A. Brown,** J Chung-Jung, **A. Gade**, S. Gillespie, **D. Weisshaar**, **G. Cerizza**, T. Beck, A. Hill, P. Farris (FRIB)
- S.D. Pain, K. Rykaczewski (ORNL)
- Matthew Williams, Rajesh Ghimire (LLNL)
- M. Grinder (Rutgers)
- **T. Miyagi** (U. Tsukuba)

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