# Emerging collectivity in neutron-hole transitions near double magic $^{208}$Pb


M. S. M. Gerathy,[1] A. J. Mitchell,[1] G. J. Lane,[1] A. E. Stuchbery[1] A. Akber,[1] H. A. Alshammari,[1] L. J. Bignell,[1] B.J.Coombes,[1] J. T. H. Dowie,[1] T. J. Gray,[1] T. Kibédi,[1] B. P. McCormick,[1] L. J. McKie,[1] M. S. Rahman,[1,2] M. Reece,[1] N. J. Spinks,[1] B. P. E. Tee,[1] Y. Y. Zhong,[1] and K. Zhu[1]

[1] Department of Nuclear Physics, Research School of Physics, The Australian National University, Canberra, ACT, 2601, Australia

[2] School of Science, The University of New South Wales, Canberra, ACT 2610, Australia


Australian National University

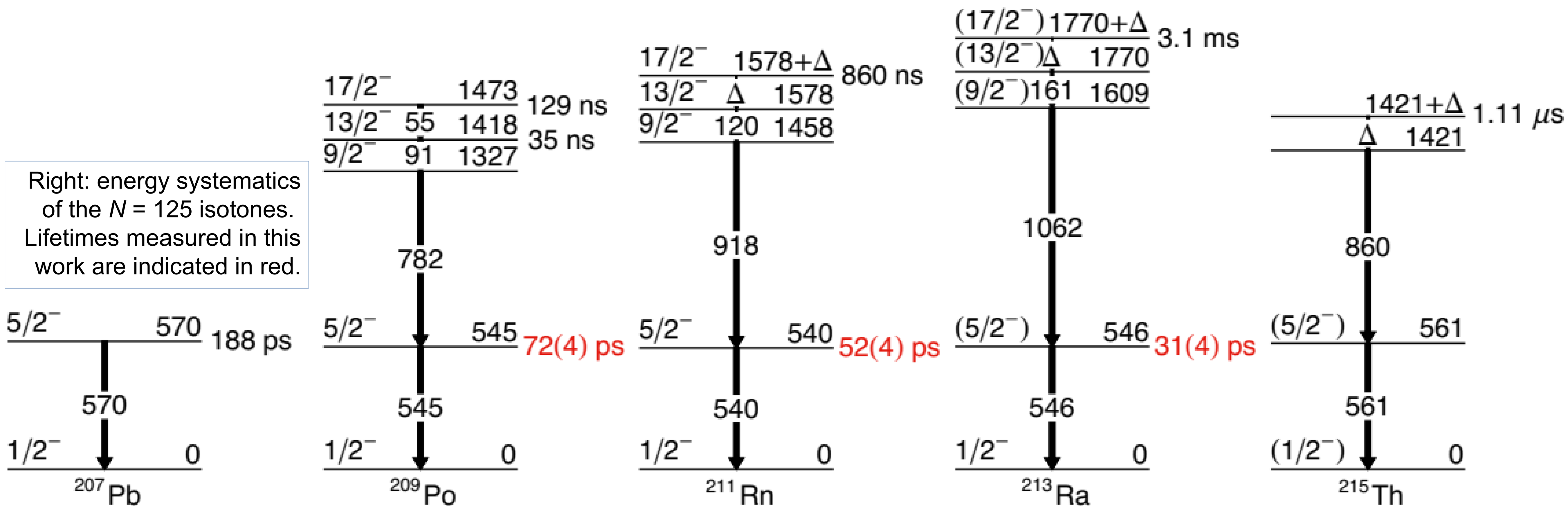
## 1. Motivation

While the high-spin states in nuclei near $^{208}$Pb have been studied extensively, data on electromagnetic transition rates between the low-spin states are scarce. Members of the $N$ = 125 isotone chain all exhibit a ground state with spin-parity of $J^\pi = 1/2^-$ , and a $5/2^-$ first excited state (shown below). The near constant excitation energy of the $5/2^-$ state suggests that it can be explained as a simple $p_{1/2} \rightarrow f_{5/2}$ neutron-hole excitation coupled to the $0^+$ ground-state of the $N$ = 126 semi-magic core. However, the potential downfalls of interpreting nuclear structure based on energy systematics alone are well known. Transition strengths, which can be deduced from measured state lifetimes, are required to probe the underlying nuclear structure.

## 2. Experiment

Lifetimes were measured for the first $5/2^-$ states in $^{209}$Po, $^{211}$Rn, and $^{213}$Ra.

Experiments were performed using a pulsed beam provided by the ANU 14UD accelerator. Emitted γ-rays were measured using the CAESAR array with six Compton-suppressed $LaBr_3$ detectors. Lifetimes were extracted from the out-of-beam, coincidence data using the GCD method.



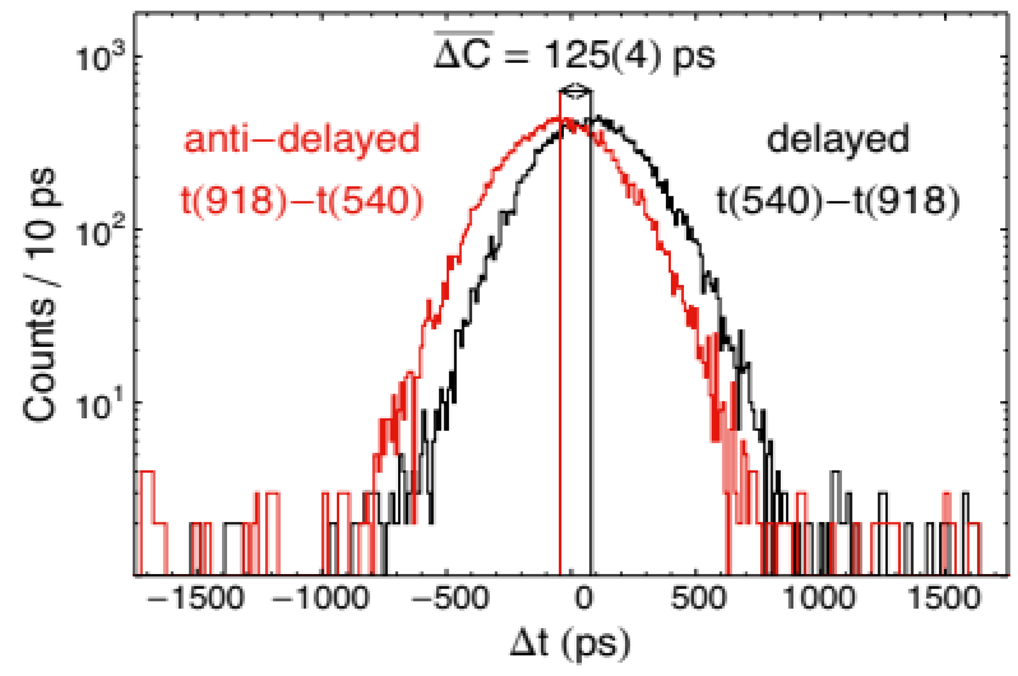

Right: energy systematics of the $N$ = 125 isotones. Lifetimes measured in this work are indicated in red.

## 3. Generalised Centroid Difference (GCD)

The GCD method [1,2] was used to extract state lifetimes. By gating on transitions above and below the state of interest and projecting the time distributions, the mean life of the intermediate state can be extracted using:

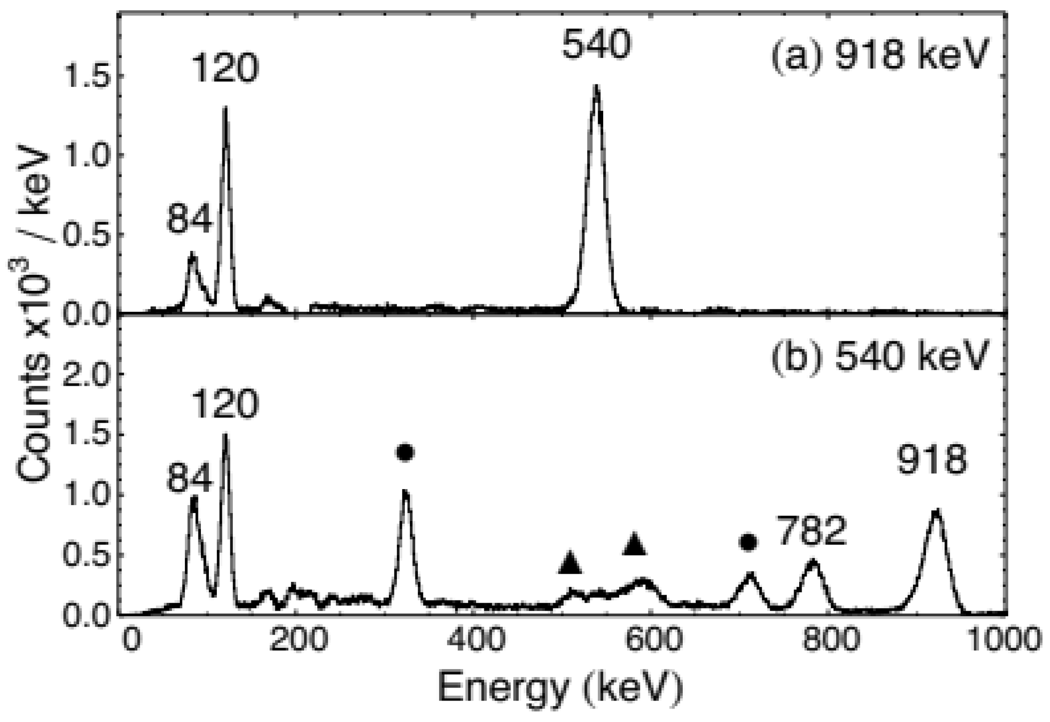
$$2\,\tau = \Delta C(E_{pop.},E_{depop.}) - \Delta PRD(E_{pop.},E_{depop.})$$

where $\Delta C(E_{pop.},E_{depop.})$ is the centroid difference between the delayed and anti-delayed time-difference spectra (produced by reversing the order of the 'start' and 'stop' gamma rays) and $\Delta PRD(E_{pop.},E_{depop.})$ is the difference in the prompt-response difference (PRD) between the populating and depopulating transitions.




Top: GCD measurement for the 918-540-keV transition in $^{211}$Rn.

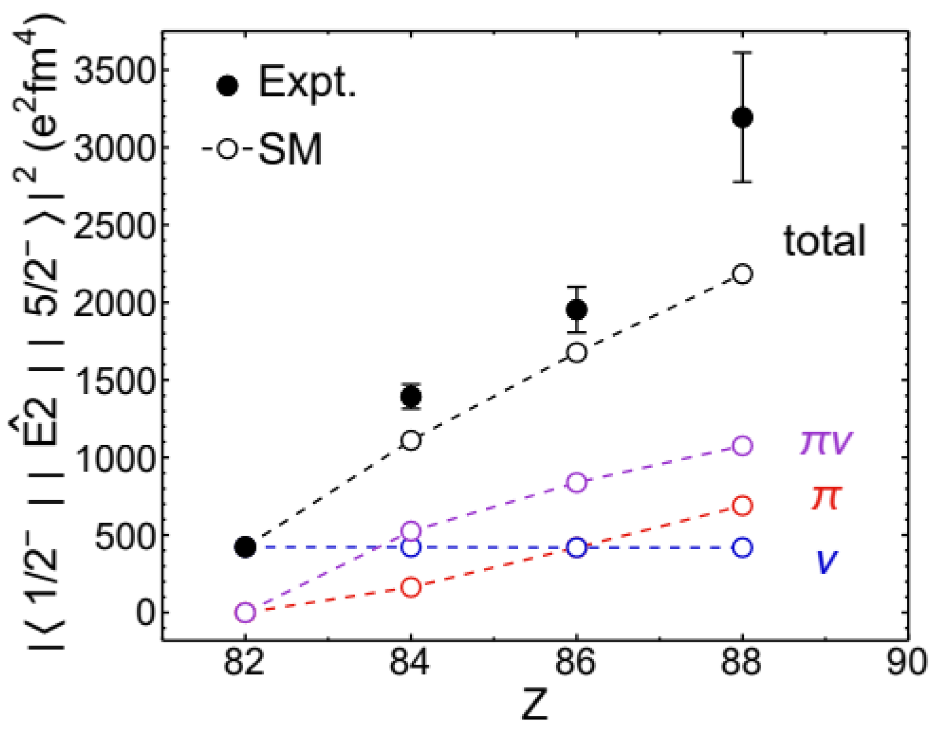
Bottom: background-subtracted, out-of-beam coincidence spectra gates by the (a) 918- and (b) 540-keV transitions from $^{211}$Rn.




## 4. Results

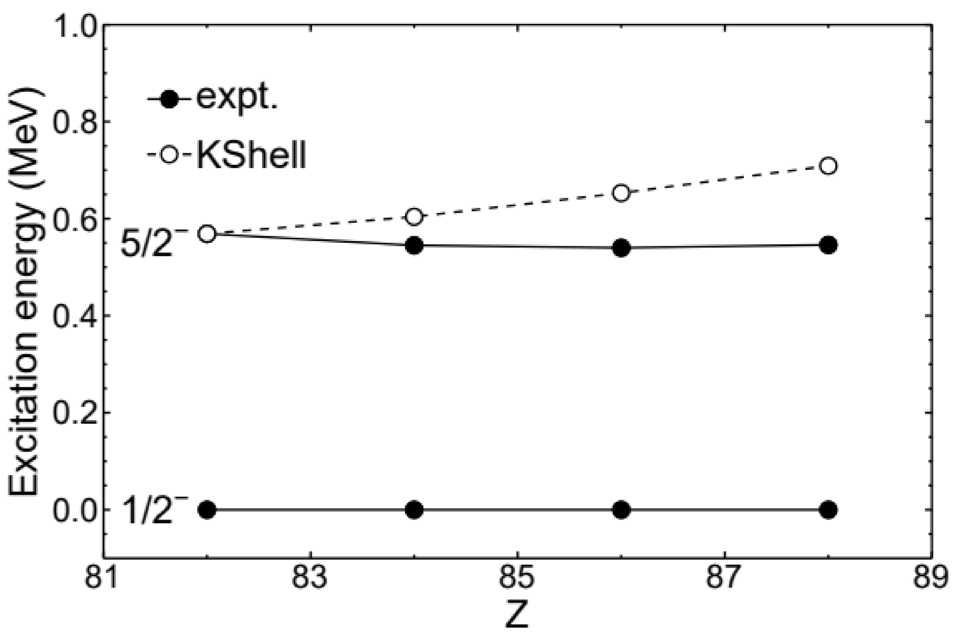
Lifetimes measured in the current work are shown in the table below. While the near constant excitation energy suggests that the excitation is a $f_{5/2} \rightarrow p_{1/2}$ neutron-hole transition coupled to the $N$ = 126 core, the systematic increase in *B(E2)* values indicates additional strength beyond the single-hole interpretation. Protons must contribute to the transition.

| Nucleus | $E_{pop.}$ (keV) | $E_{depop.}$ (keV) | ΔC (ps) | ΔPRD (ps) | τ (ps) | *B(E2)* (W.u.) |
|---|---|---|---|---|---|---|
| $^{209}$Po | 782 | 545 | 154(4) | 11(7) | 71(4) | 3.15(17) |
| $^{211}$Rn | 918 | 540 | 125(4) | 20(7) | 53(4) | 4.4(3) |
| $^{213}$Ra | 1063 | 546 | 92(3) | 30(7) | 31(4) | 7.0(9) |




Top: comparison of experimental and theoretical strengths for the $5/2^- \rightarrow 1/2^-$ transition.

Bottom: comparison of experimental and theoretical excitation energies for the $5/2^-$ state.




## 5. Discussion

Shell-model calculations were performed for the $N$ = 125 isotone chain using the KShell program [3] and the jj66 basis space and jj66pn interaction [4]. These show a systematic increase in *B(E2)* strength as protons are added, in qualitative agreement with experiment, but consistently underestimate the experimental values. Collectivity beyond the correlations included in the shell model calculations is evidently present and is increasing as proton pairs are added.

As additional evidence of emerging collectivity, the theory predicts a systematically increasing excitation energy, in contrast to the observed near-constant excitation energy with increasing mass. It appears that the near-constant energy is related to the evolving interplay between nucleon-nucleon interactions and emerging collectivity and is not evidence for the persistent single-particle nature of this transition.

## 6. Conclusion

Direct lifetimes measurements were performed for the $5/2^-$ states in the $N$ = 125 isotone chain. The resulting B(E2) strengths to the ground state were found to increase systematically along the isotone chain, indicating an increasing contribution from the valence protons. Shell-model calculations confirmed the observed B(E2) trend but fell short of explaining the full transition strength indicating the presence of emerging collectivity. To further constrain theory and illuminate the early stages of emerging quadrupole collectivity near $^{208}$Pb, it will be important to measure the $2^+ \rightarrow 0^+$ transition strengths of the $N$ = 126 isotones, which can be realised by Coulomb excitation of radioactive beams.

## 7. Acknowledgements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## 8. References


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