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Beta Decay in Weakly Bound Nuclei

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Nuclear Science Division, Lawrence Berkeley National Laboratory

FRIB-TA Topical Program: Future Directions in Nuclear Beta Decay at FRIB
September 15, 2025

Overview

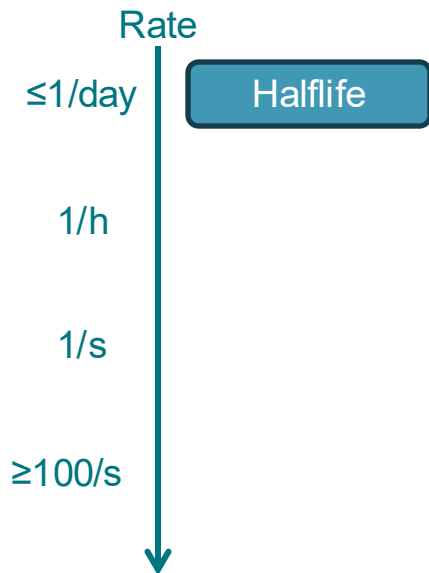
- Observables in decay spectroscopy in neutron-rich nuclei
- Decay near the N=28 Island of Inversion (E21062)
- Half-lives at extreme Q_β
- Decay in halo nuclei

Beta Decay Spectroscopy as a Tool

- Decay spectroscopy (beta and otherwise) is a critical experimental technique
- After isotope discovery, decay experiments are typically the first, or among the first to be feasible

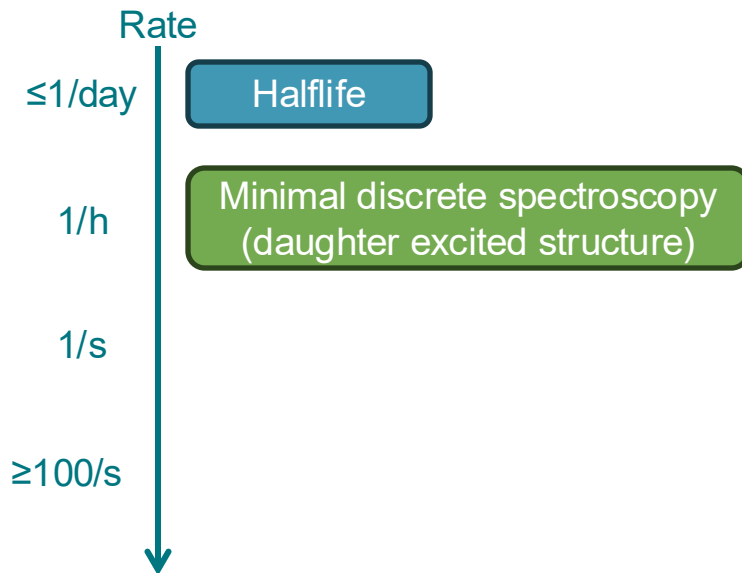
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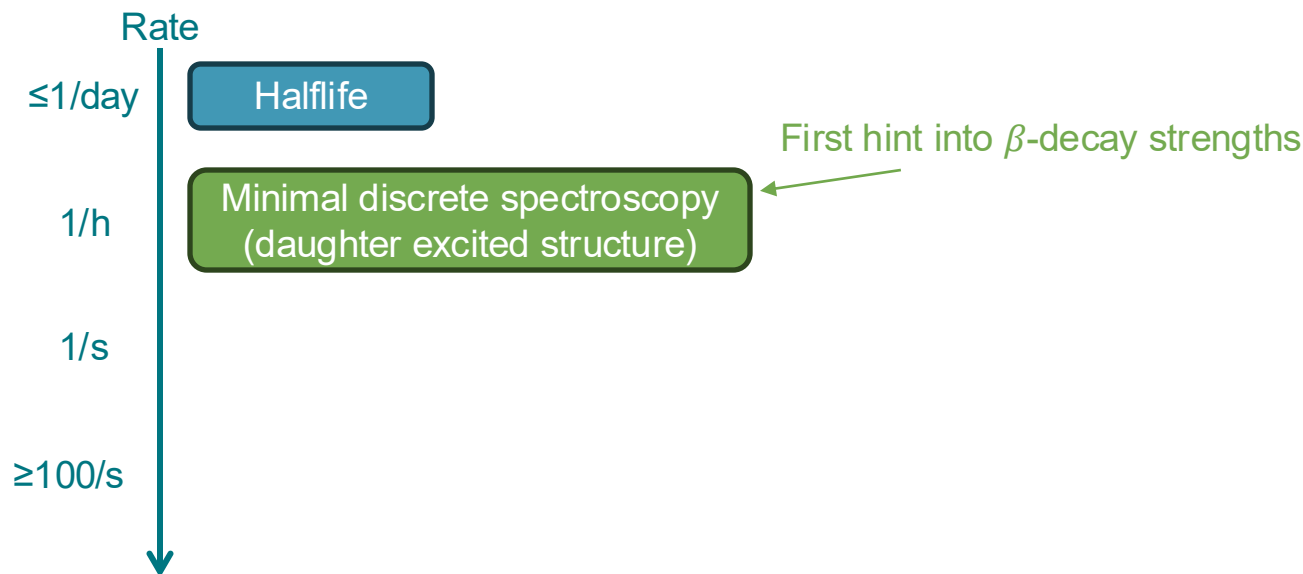
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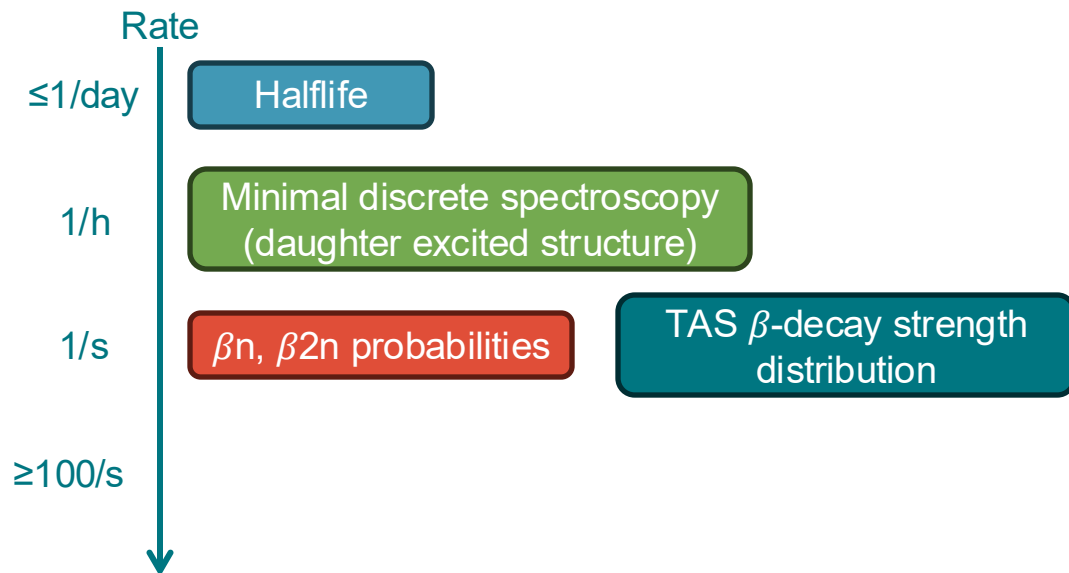
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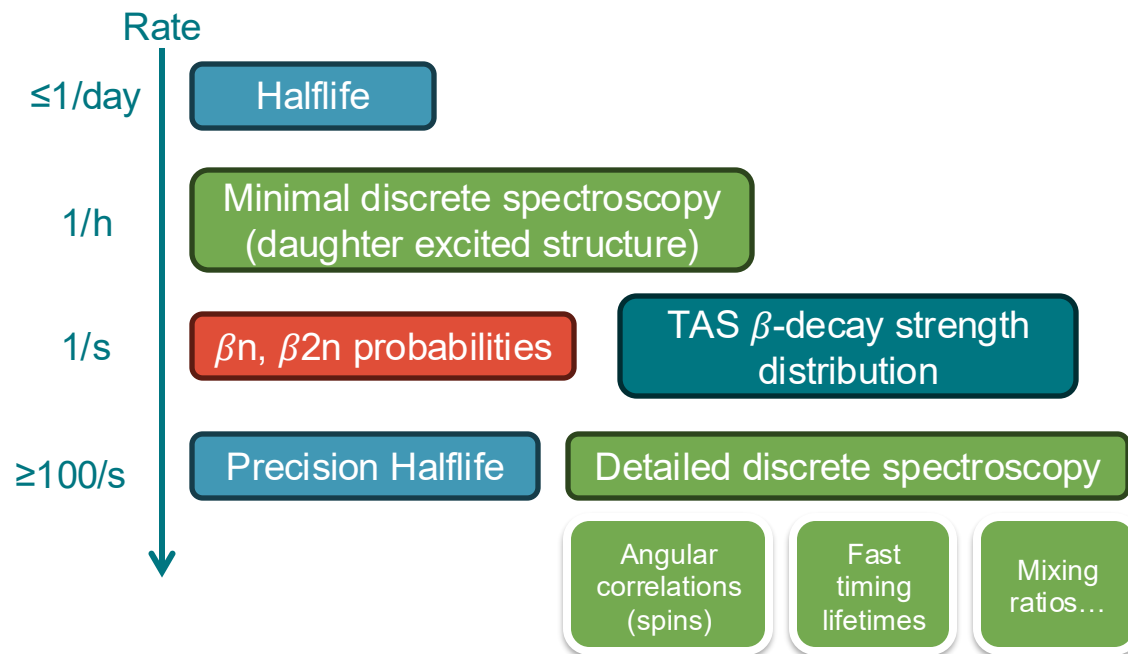
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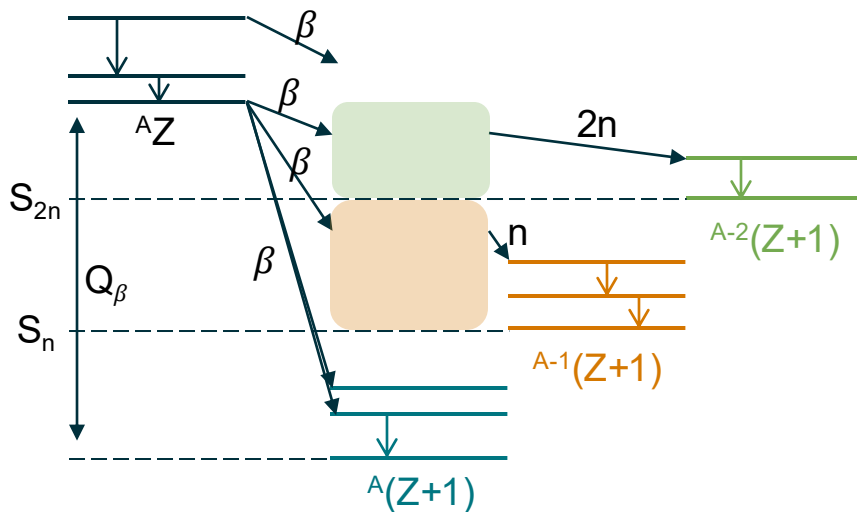
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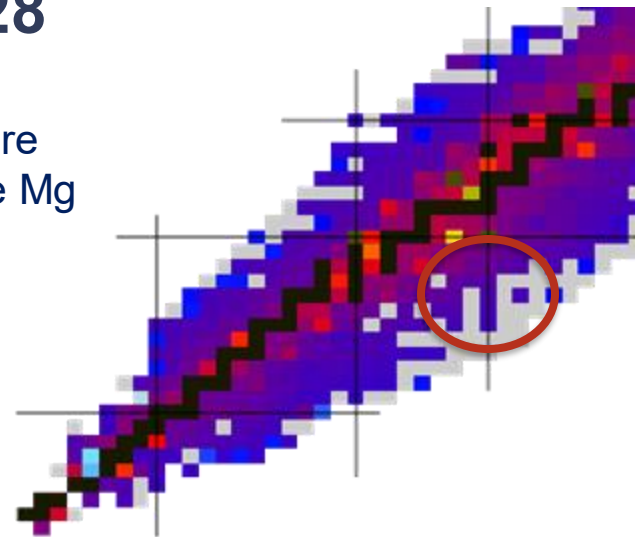
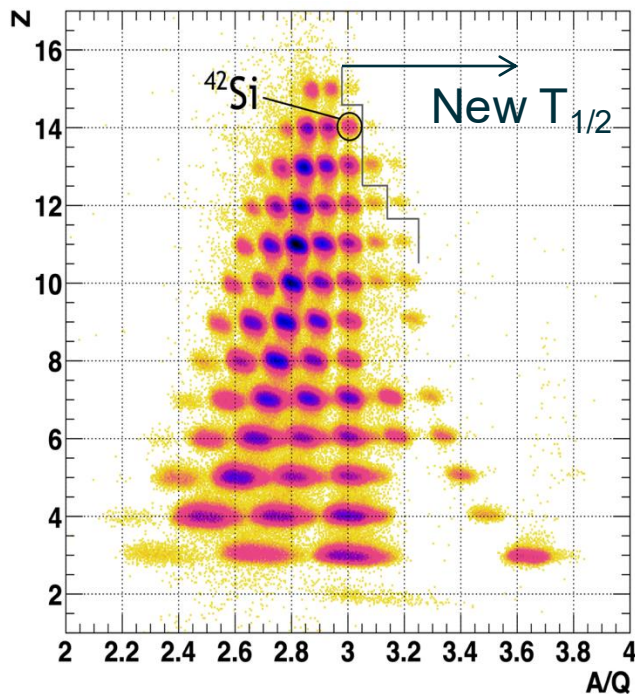
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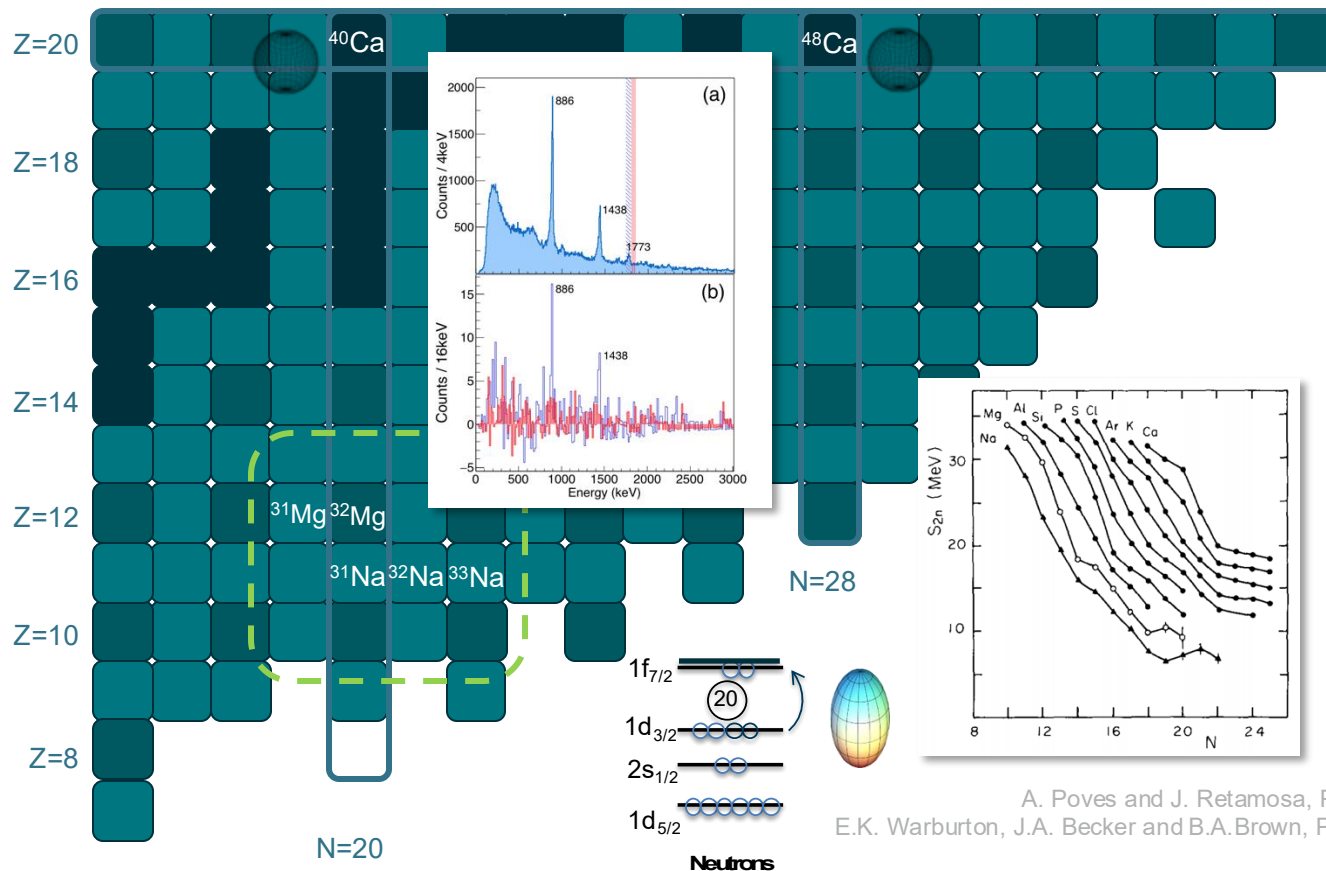


E21062: Decay Spectroscopy Near N=28

- β -decay provides a powerful tool to study nuclear structure all the way to the decay of ^{40}Mg and beyond N=28 above Mg

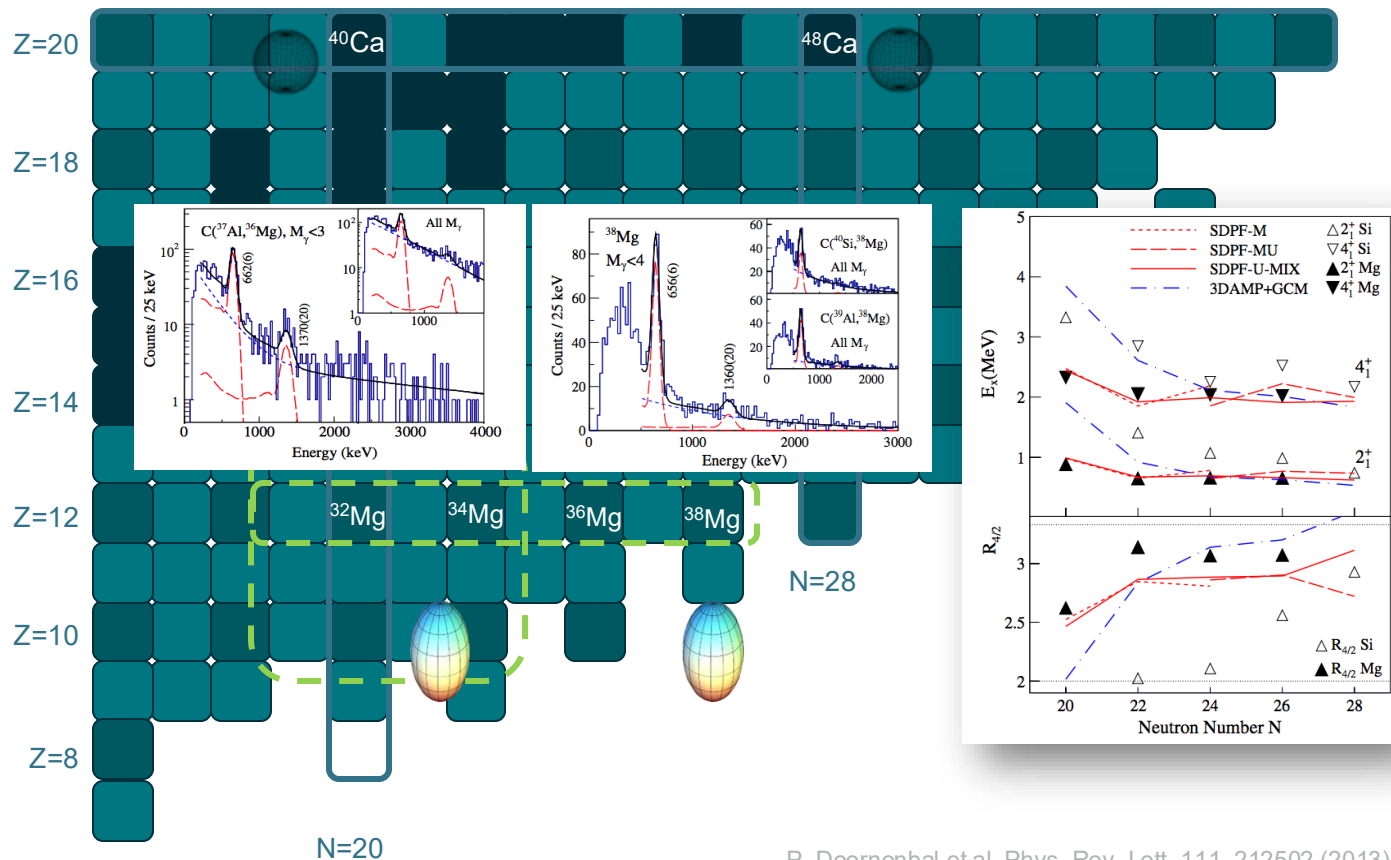


Why This Region? N=20 Island of Inversion

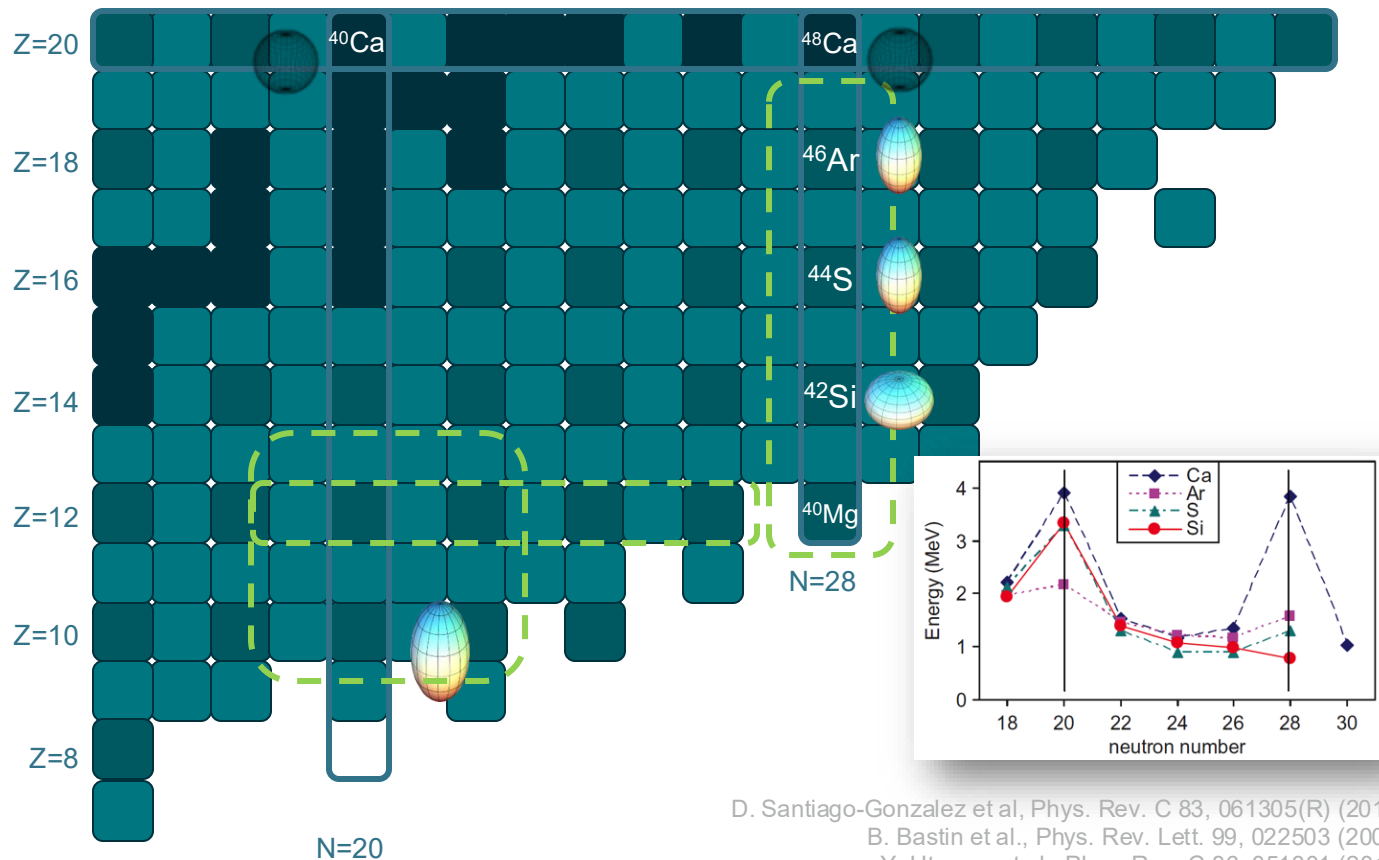


A. Poves and J. Retamosa, Phys. Lett. B 184, 311 (1987).
 E.K. Warburton, J.A. Becker and B.A. Brown, Phys. Rev. C 41, 1147 (1990).

Why This Region? Z=12 'Peninsula' of Inversion



Why This Region? $N=28$ Evolution of Nuclear Shapes

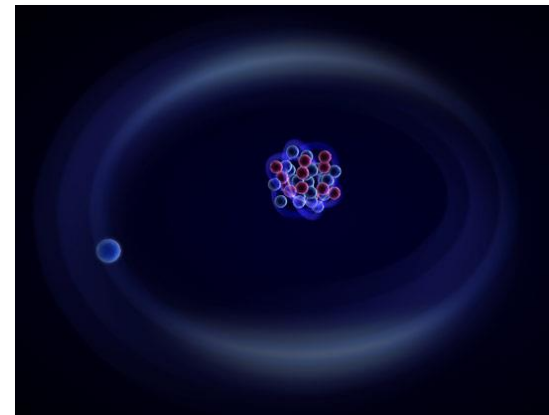
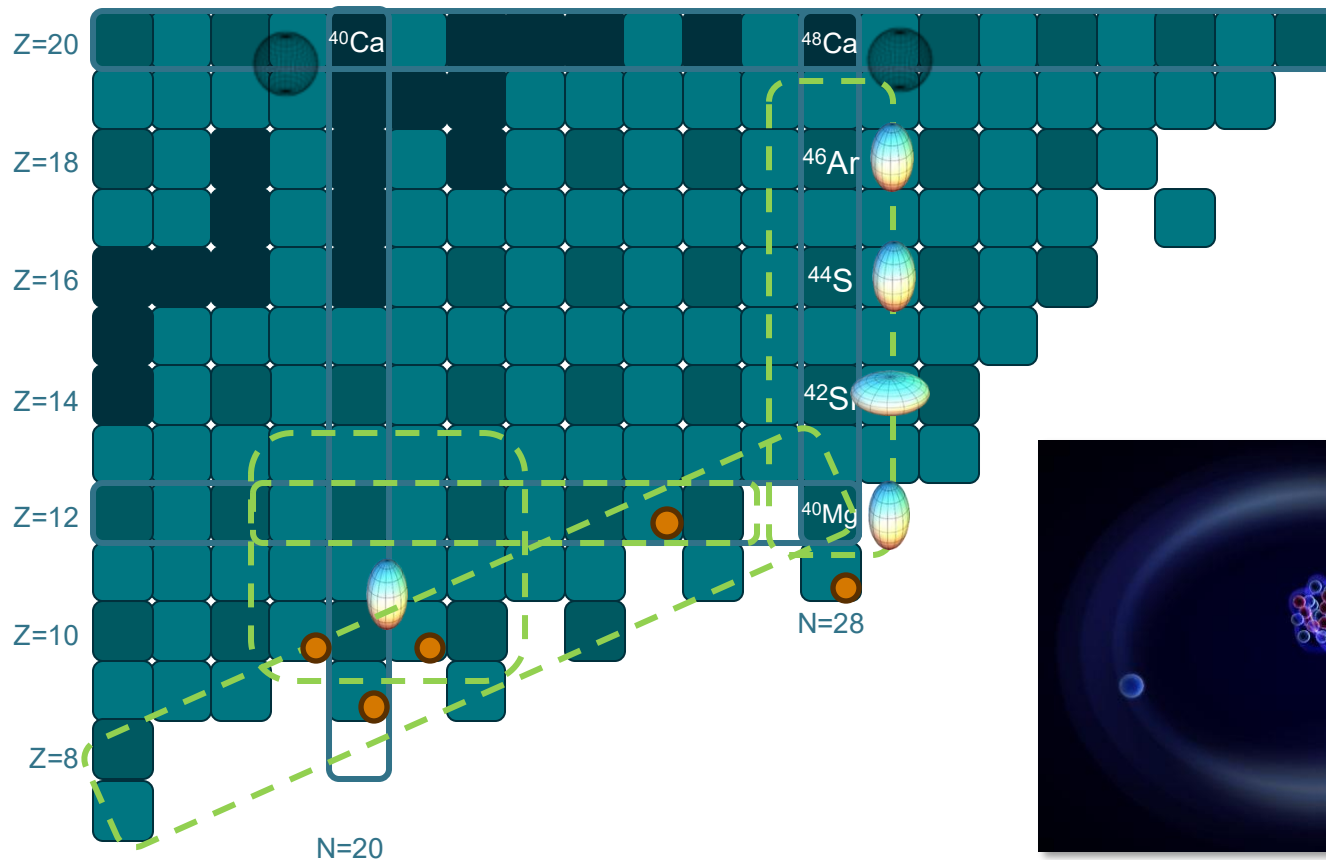


D. Santiago-Gonzalez et al, Phys. Rev. C 83, 061305(R) (2011).

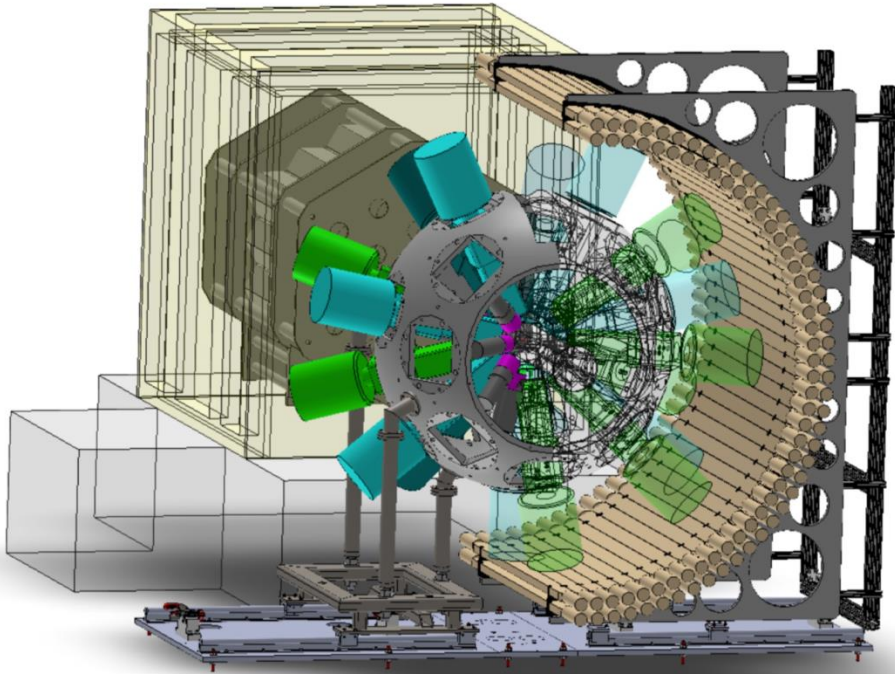
B. Bastin et al., Phys. Rev. Lett. 99, 022503 (2007).

Y. Utsuno et al., Phys. Rev. C 86, 051301 (2012).

Why This Region? Halo Structures



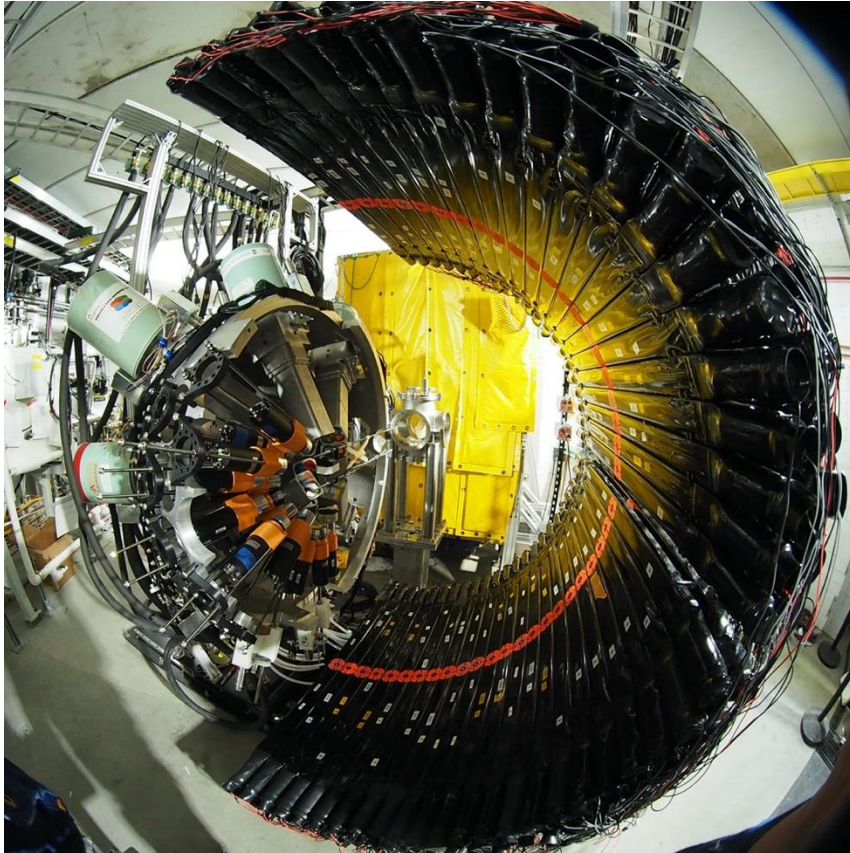
The FRIB Decay Station Initiator (FDSi)



Decay studies with the FRIB Decay Station Initiator (FDSi)

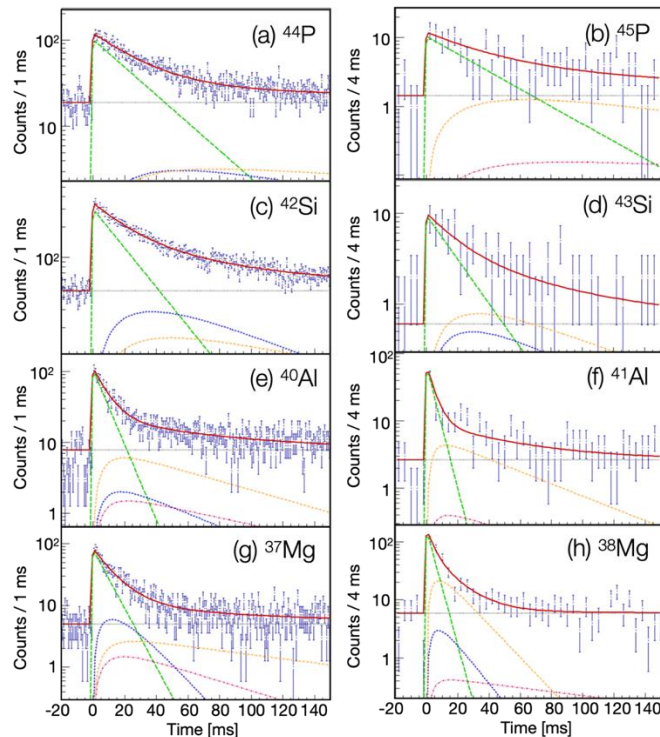
- FDSi enables total decay spectroscopy, with γ , particle and neutron spectroscopy
- Segmented YSO implantation detector with segmented SiPM readout
- HPGe clovers and LaBr₃ fast-timing detectors
- Neutron detection with detectors from VANDLE
- Combination with MTAS (or SuN) further extends the physics

FRIB Decay Station Initiator (FDSi)

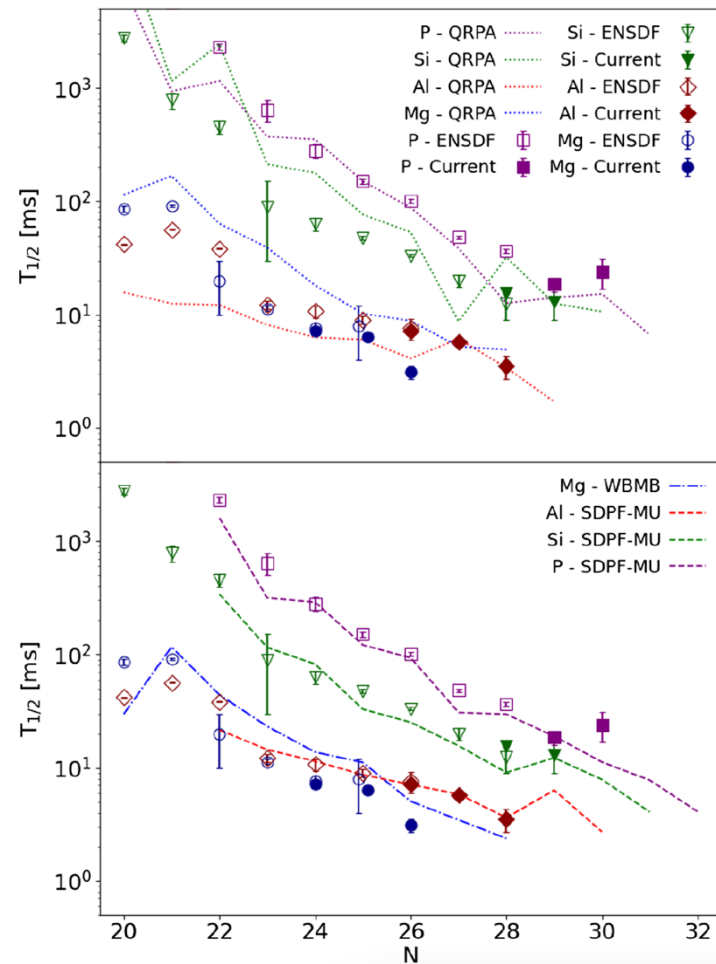


Decay Spectroscopy Near N=28

- 5 isotopes with no published half-life information were measured, with improved half-life values provided for numerous additional species



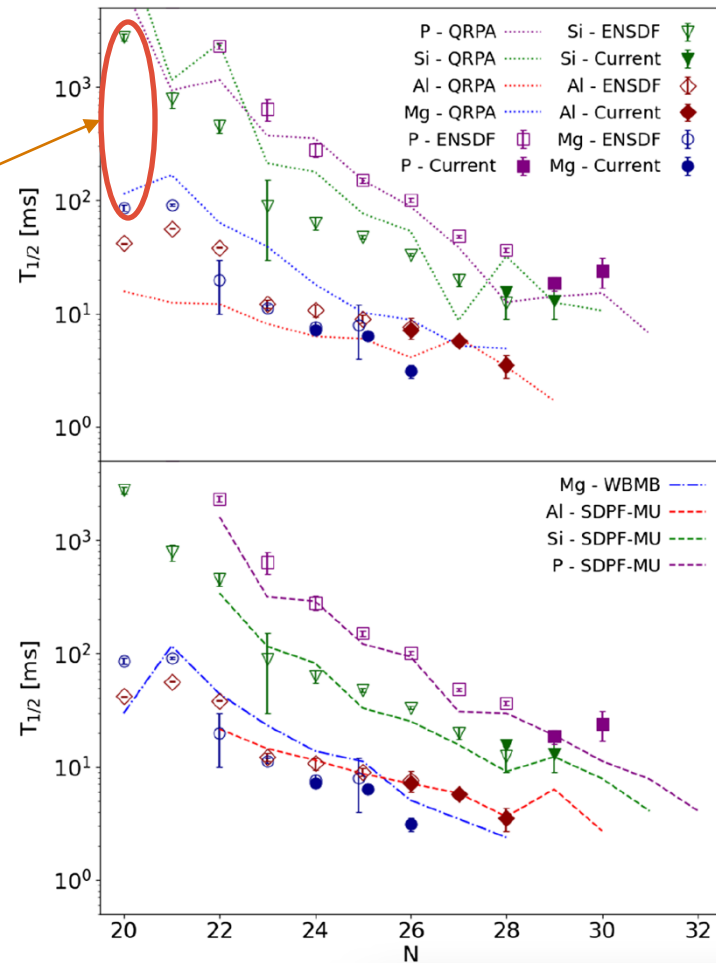
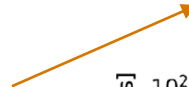
HLC et al., PRL 129, 212501 (2022).



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Z=14 subshell closure in ^{34}Si



HLC et al., PRL 129, 212501 (2022).

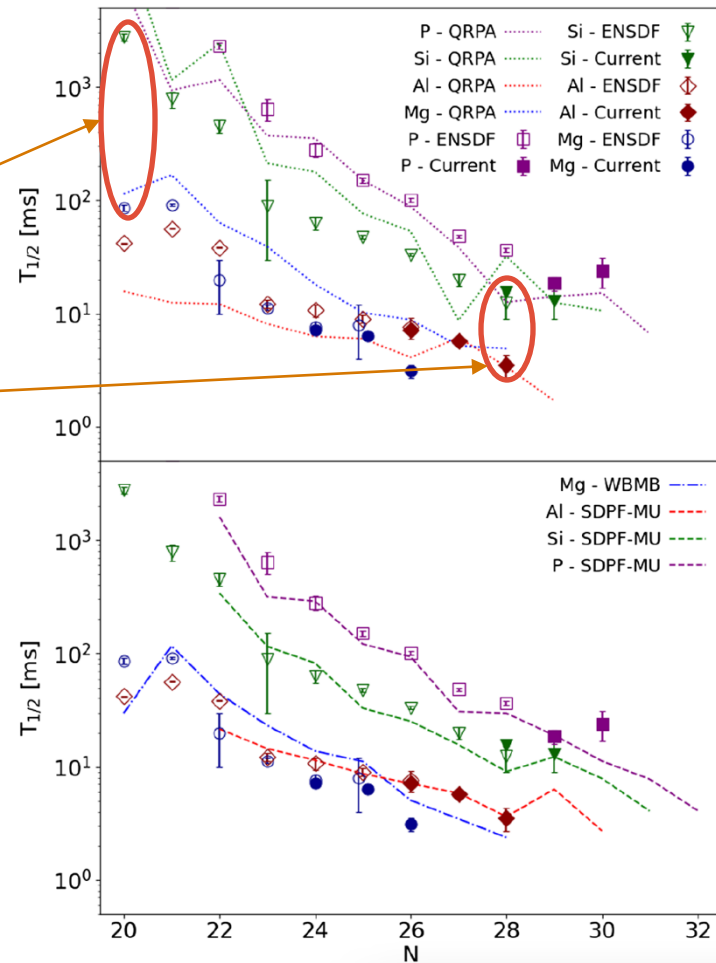
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Z=14 quenched at N=28



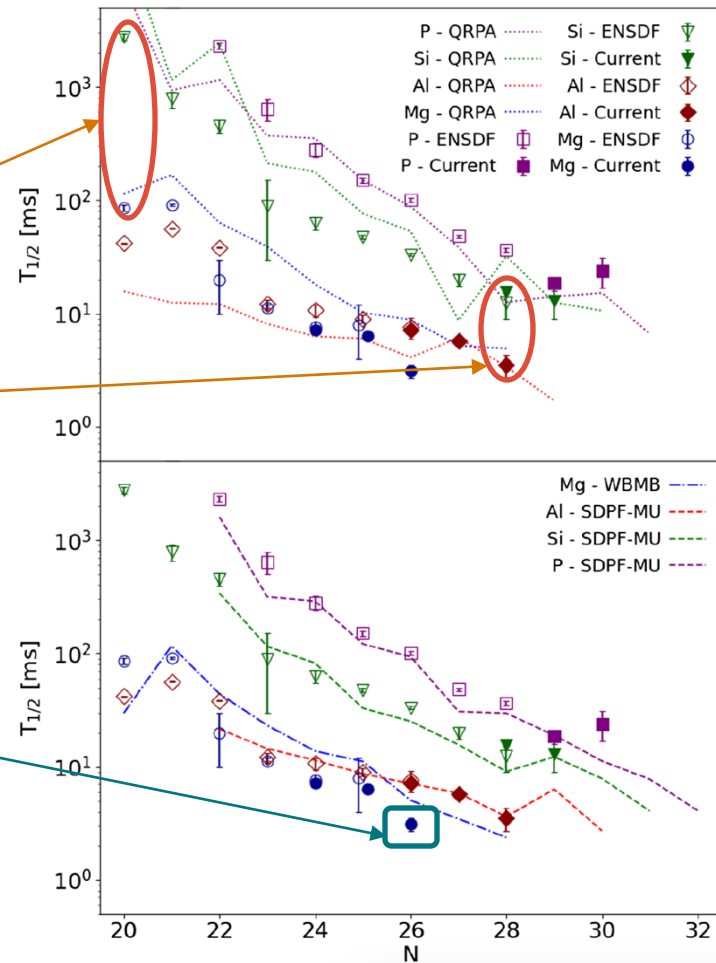
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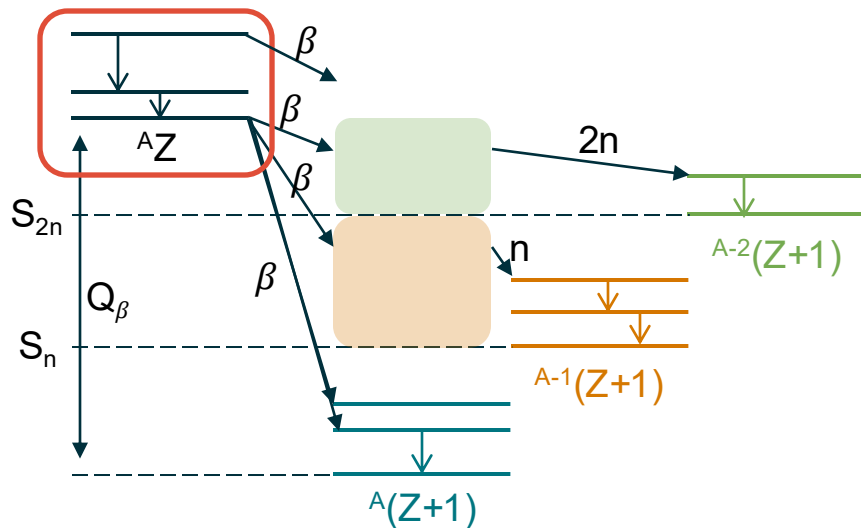
Z=14 quenched at N=28

^{38}Mg half-life drops by a factor of >2 relative to ^{37}Mg while Q_β increases slightly (by $\sim 4\%$)



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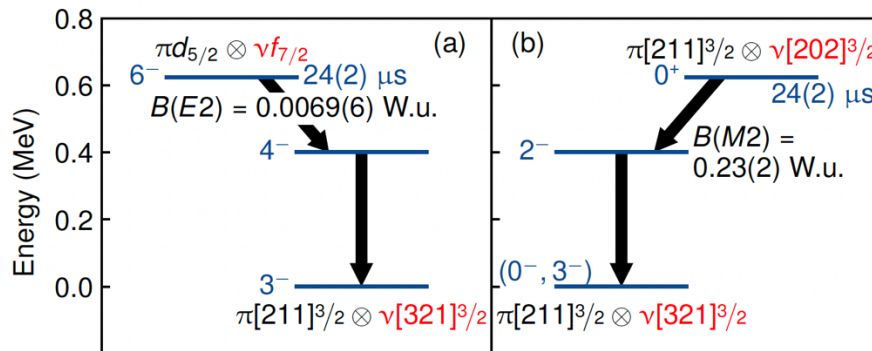
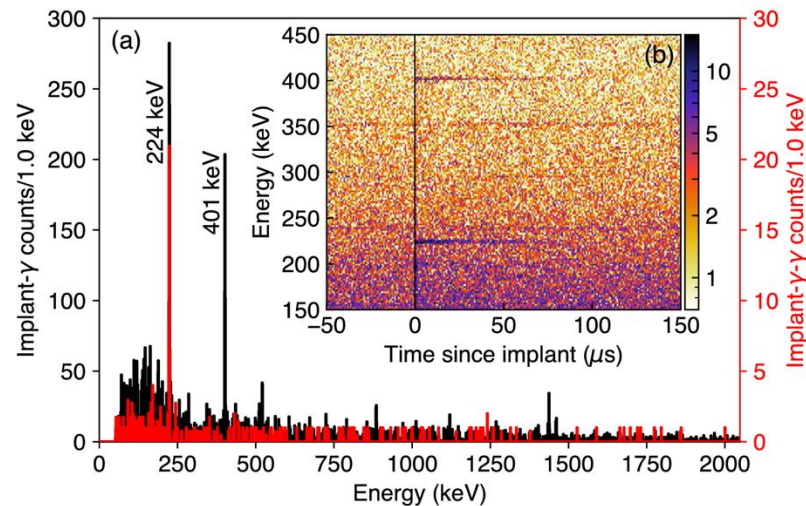
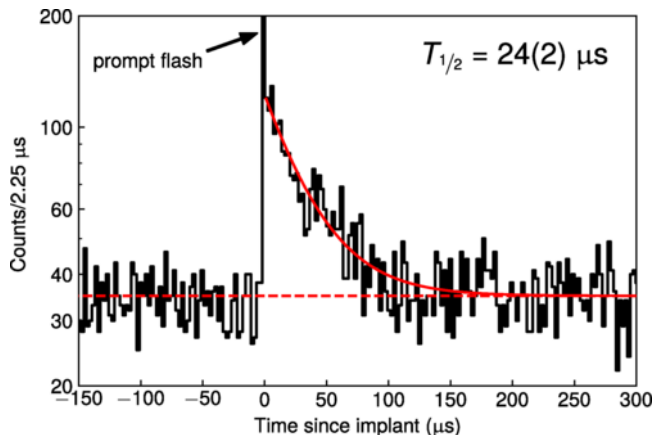
Beam Isomer Spectroscopy



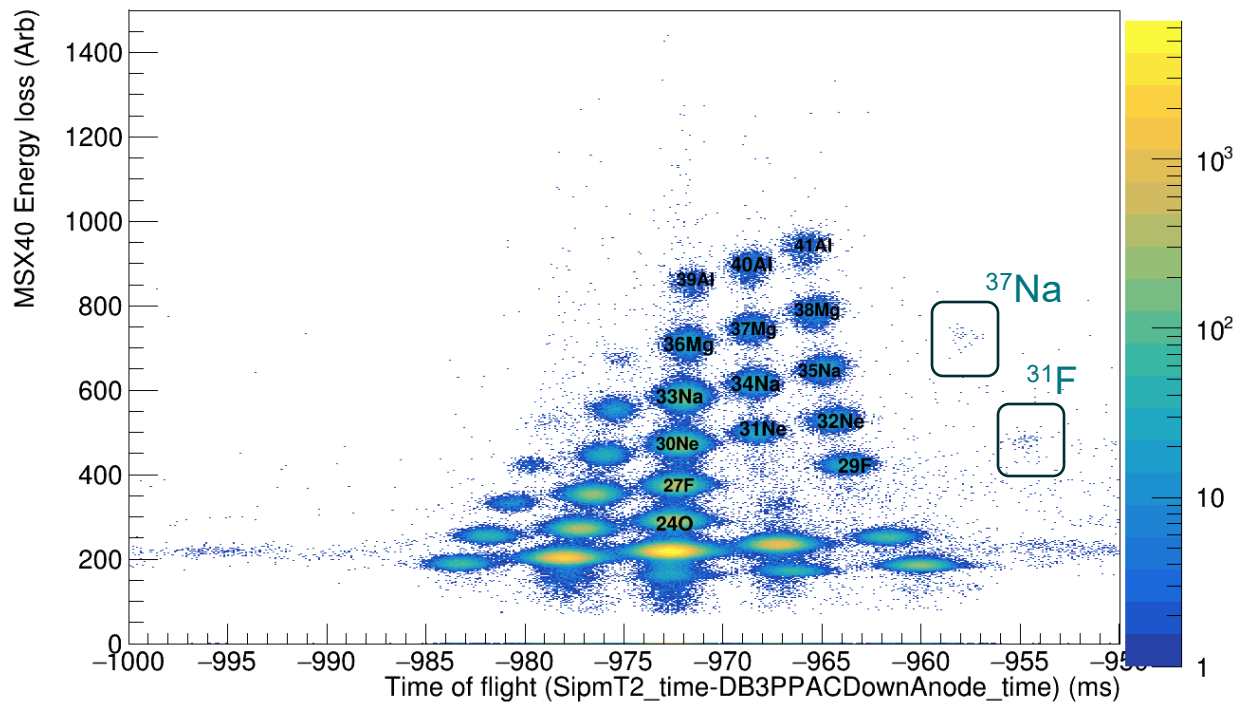
- Decay spectroscopy experimental setups are typically also sensitive to beam isomers which might be populated in fragmentation
- Sensitive to both gamma-emission but also to β -decaying isomers (usually through observation of a two-component half-life)

A Microsecond Isomer in ^{32}Na

- A newly identified microsecond isomer was observed in ^{32}Na
- Attributed to either a 6^- spherical shape isomer or a 0^+ deformed spin isomer decaying to the $(0^-, 3^-)$ g.s.



E21062B: Decay Spectroscopy Near N=28

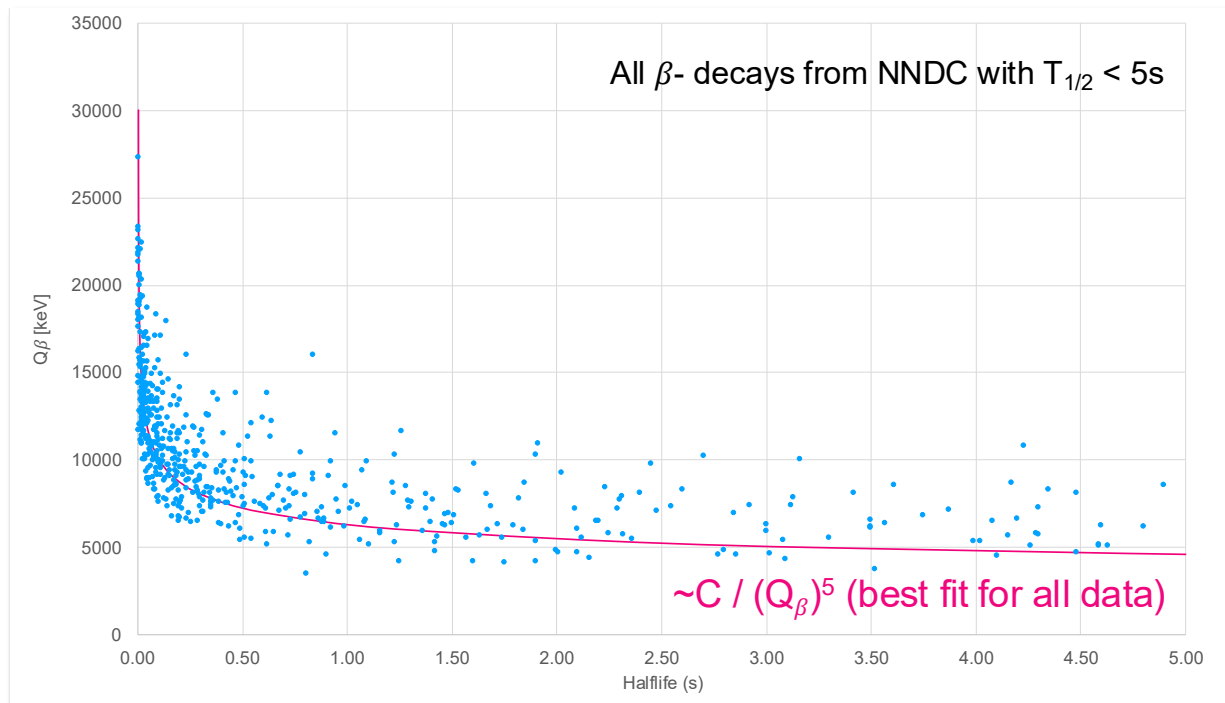


T. Mosaad *et al.*, under analysis.

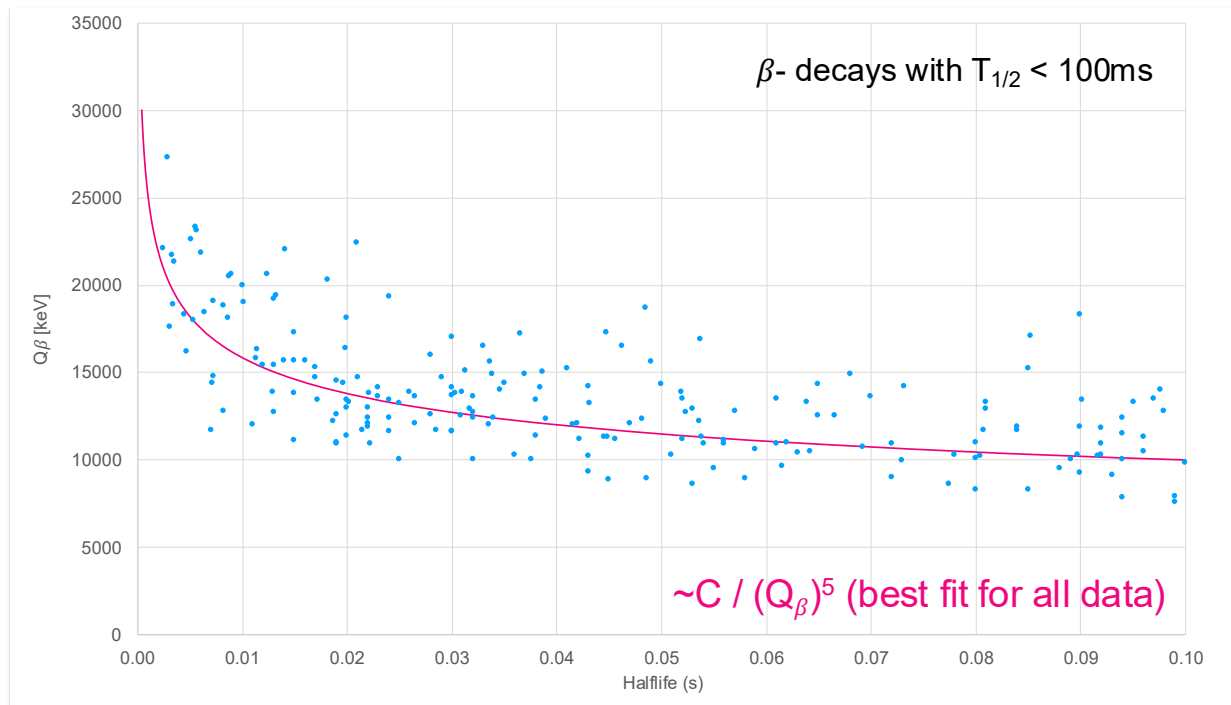
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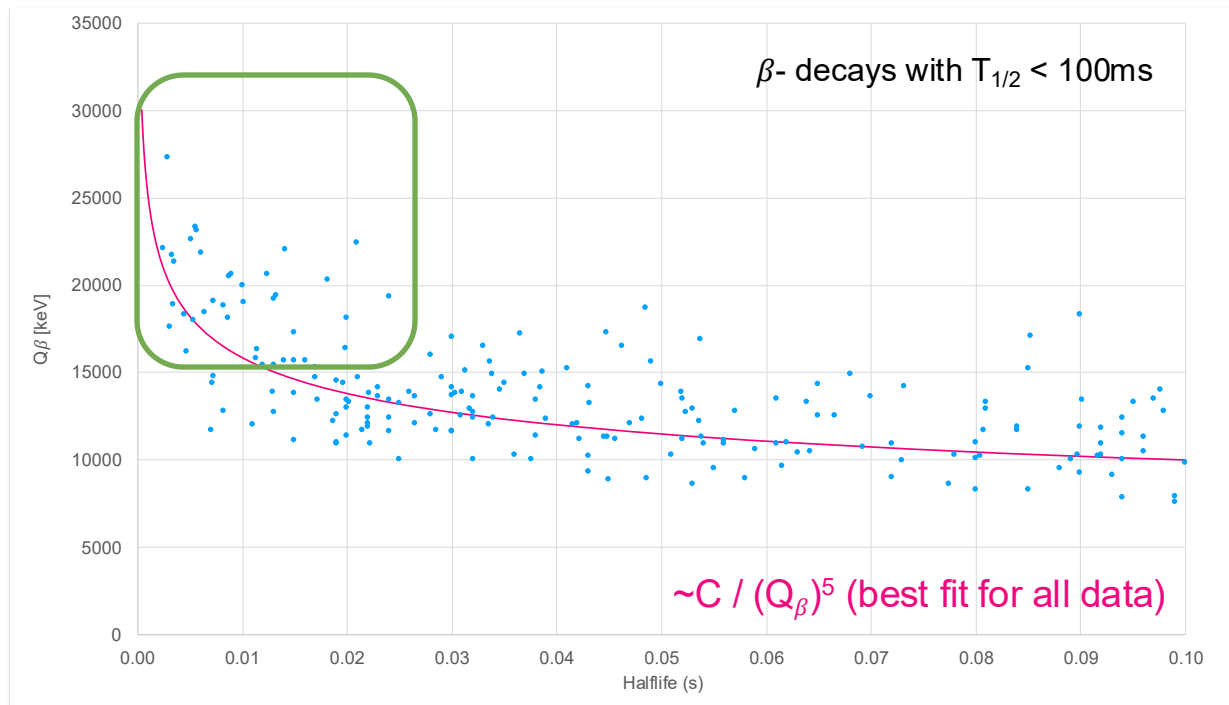
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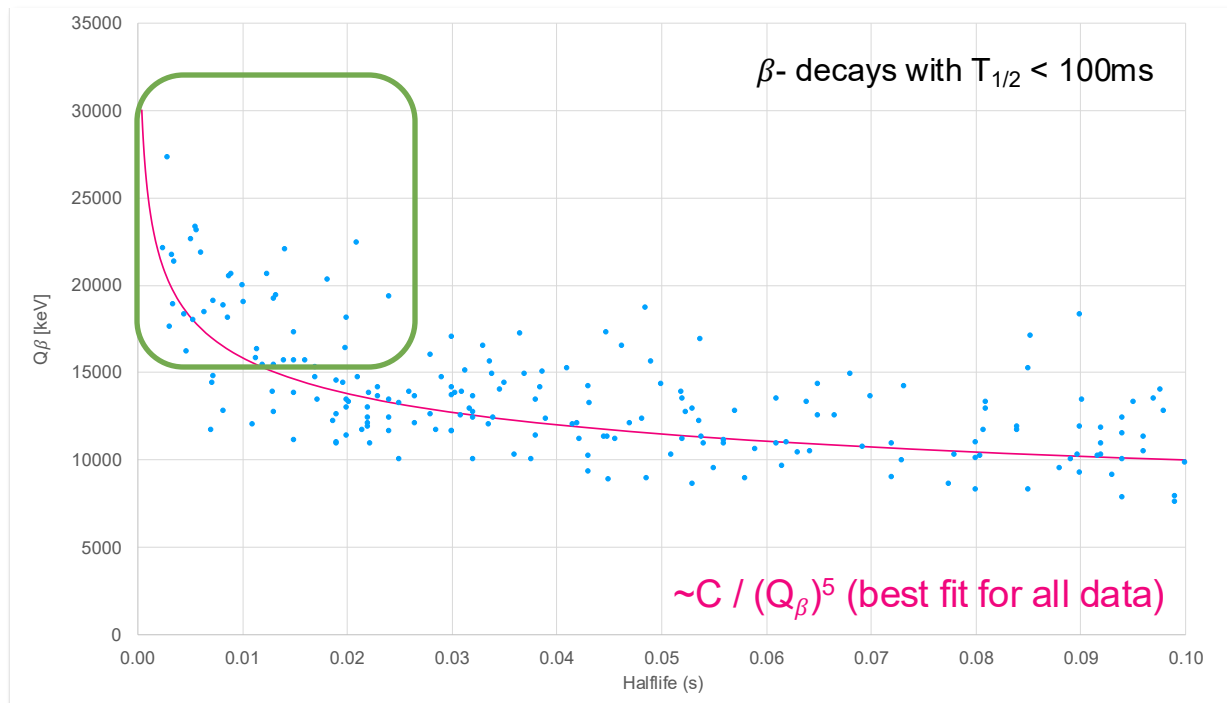


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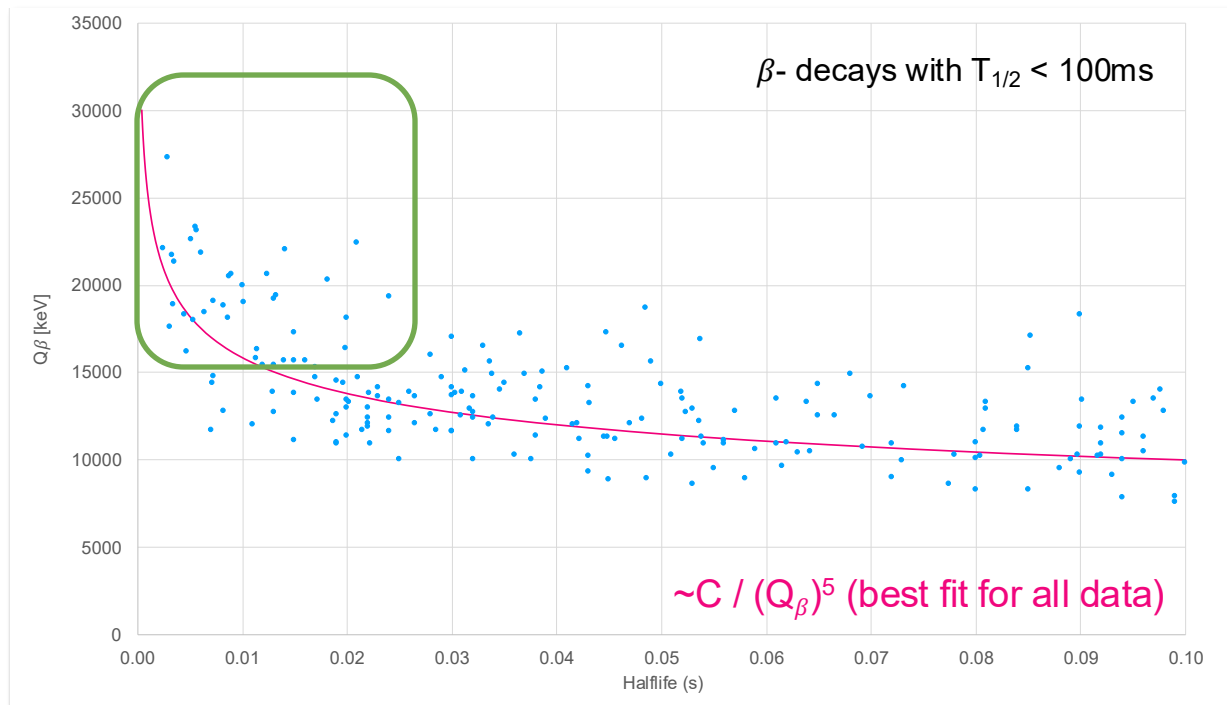
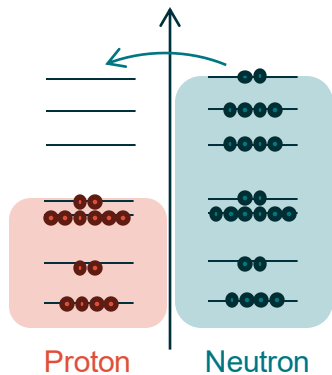
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Based on a fit across a broad range of data, for high Q_β observed half-lives seem longer than expected from energetics alone – or is it just scatter of small numbers?



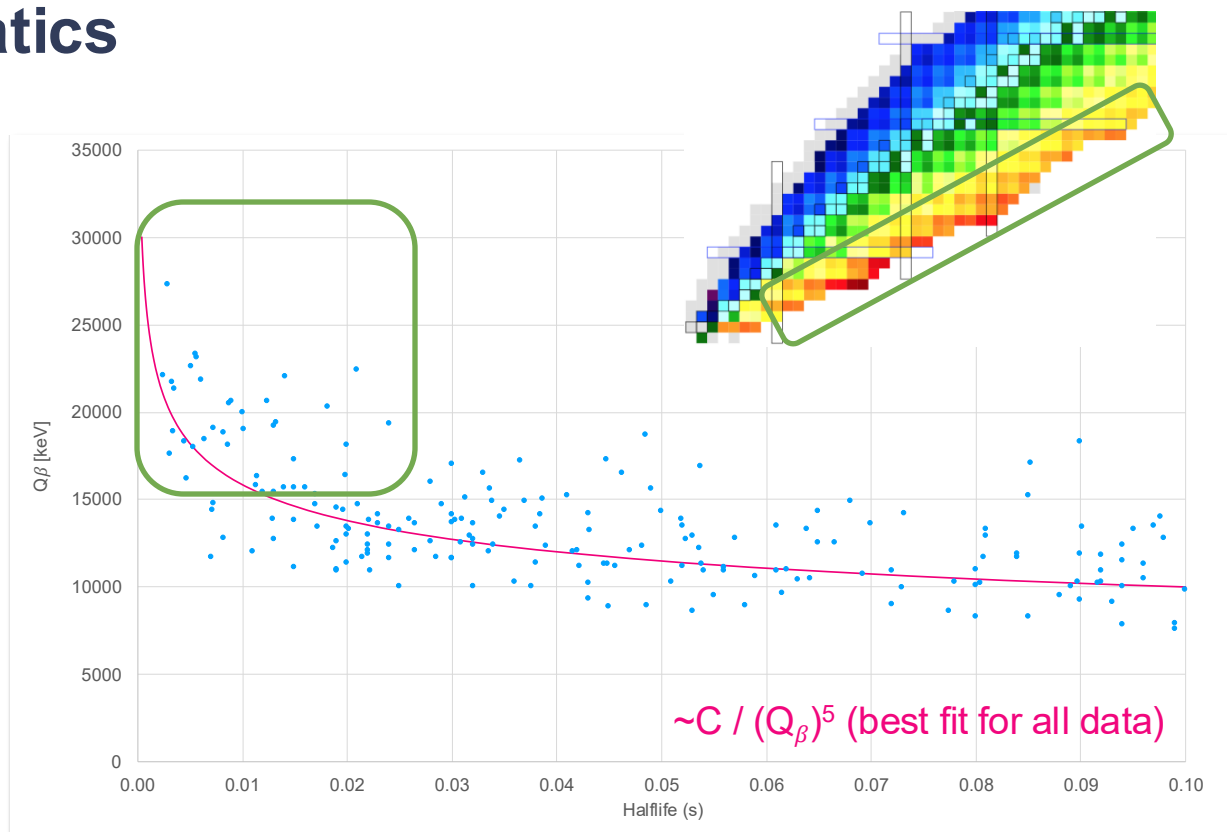
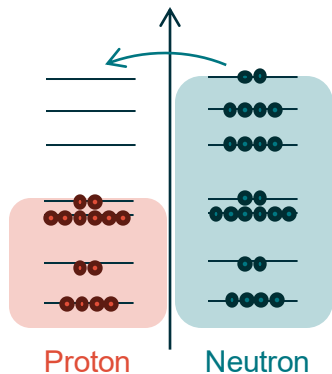
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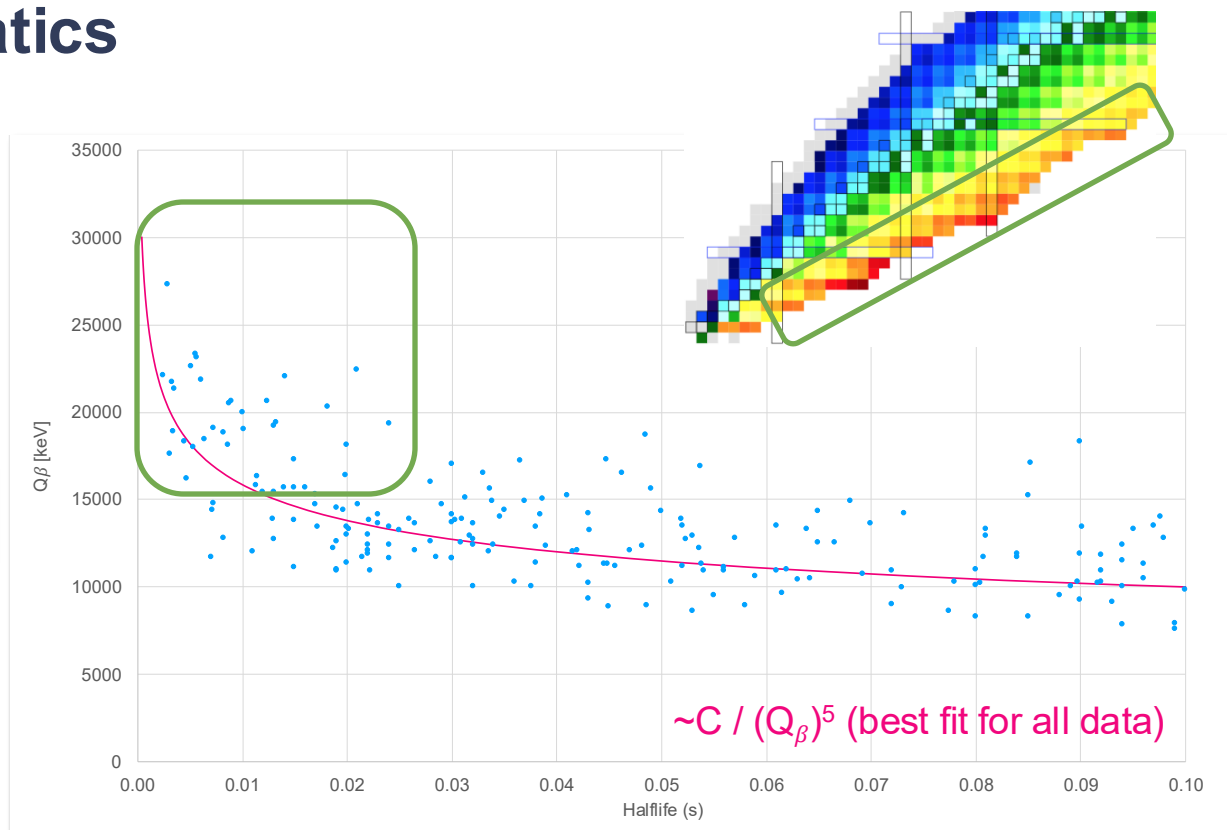
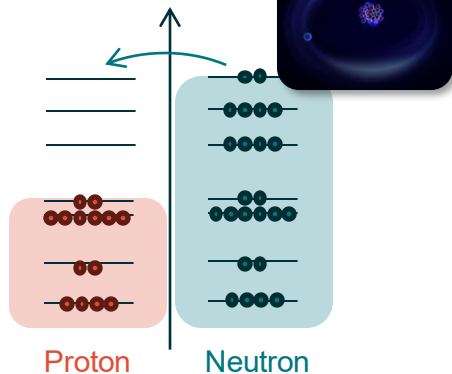
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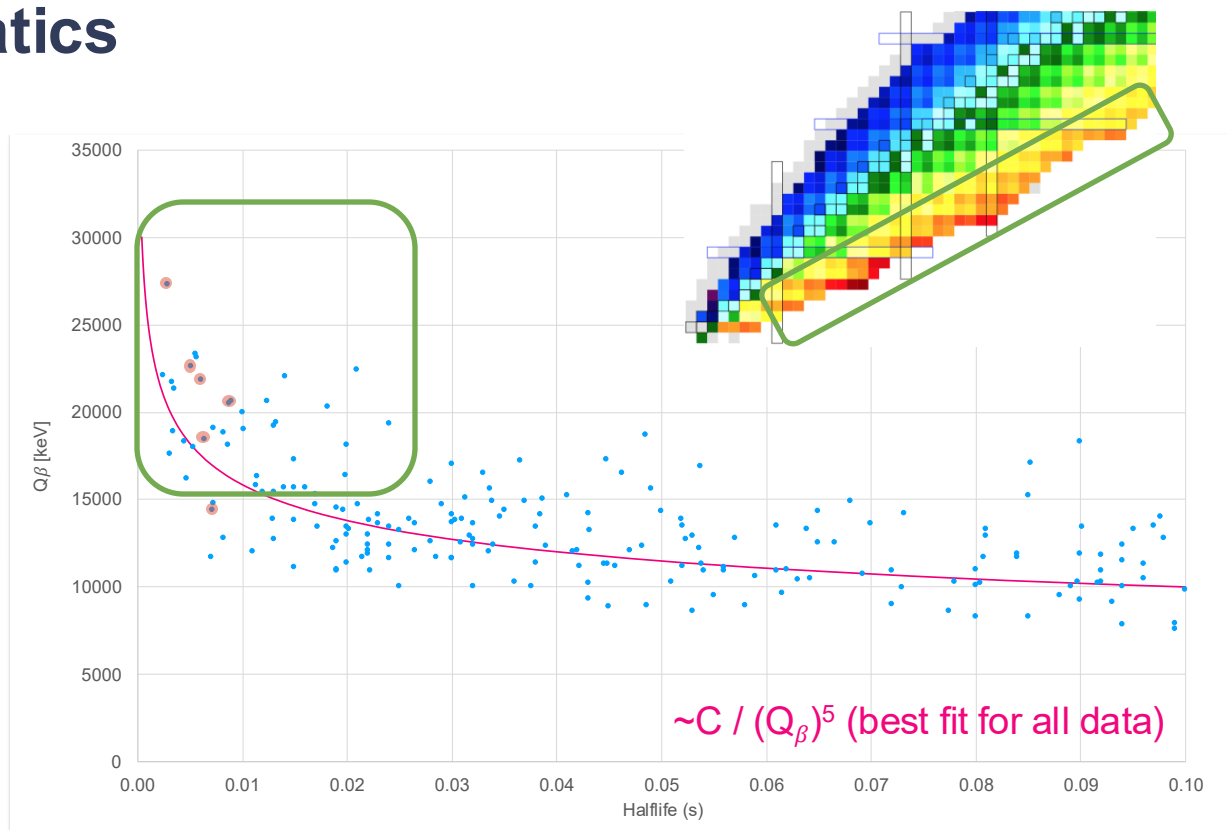
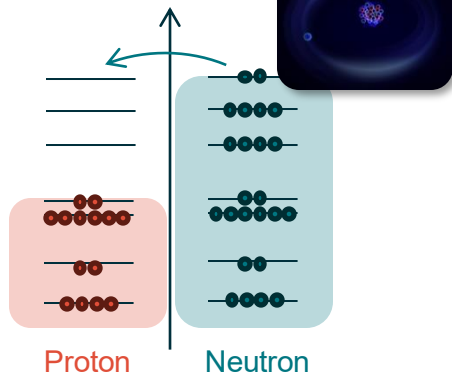
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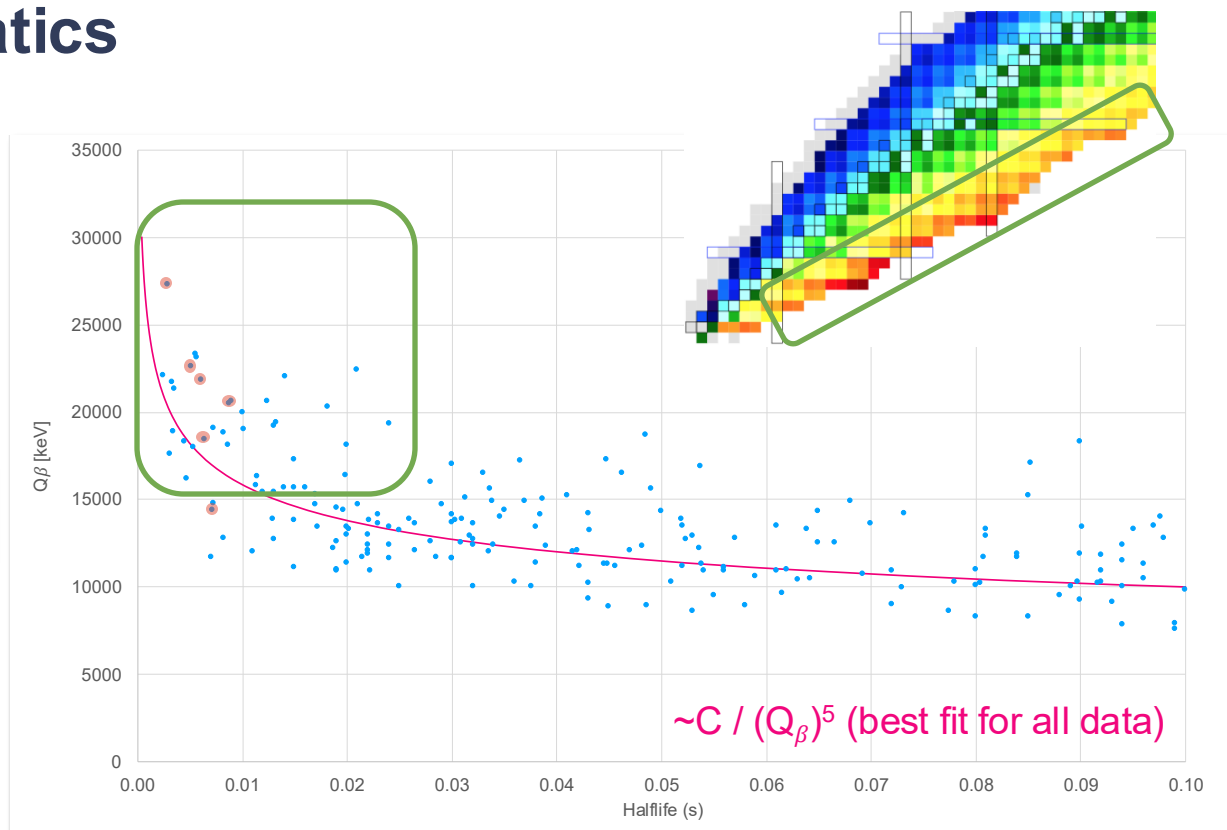
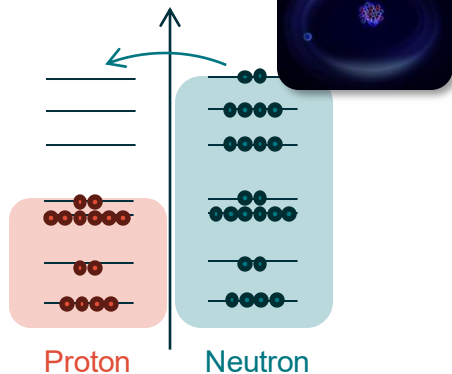
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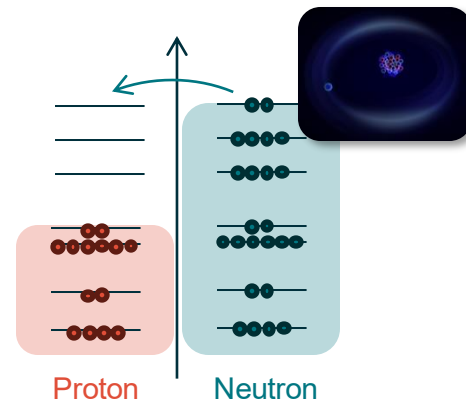
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Is there a general way to understand what should dominate $T_{1/2}$? Is there a lower limit to β -decay half-lives?

β Decay in Halo Systems

- For halo (v. weakly bound) systems, decay branches for delayed neutron (or particle) emission are expected to be enhanced due simply to Q_β , but also due to halo nature

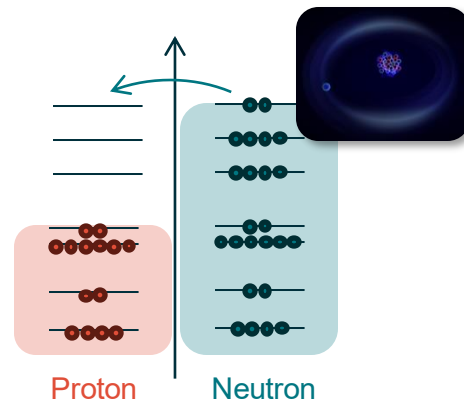


K. Riisager, arXiv:2202.05075

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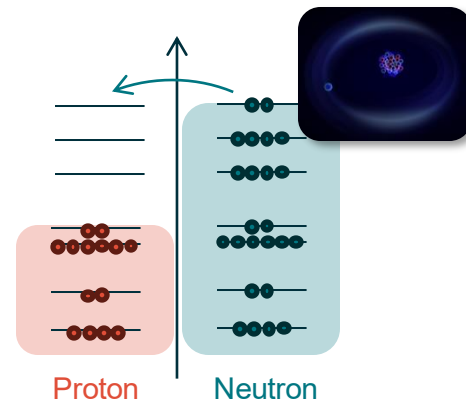
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Much more on β -delayed neutrons tomorrow (Grzywacz & Xu)



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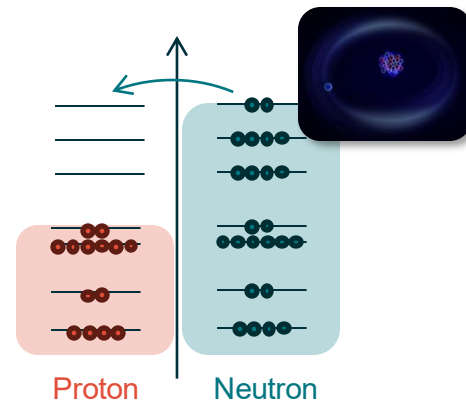
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- Neutron halo systems can be ~ thought of as either core decay + spectator halo neutron OR inert core + decay of halo neutron



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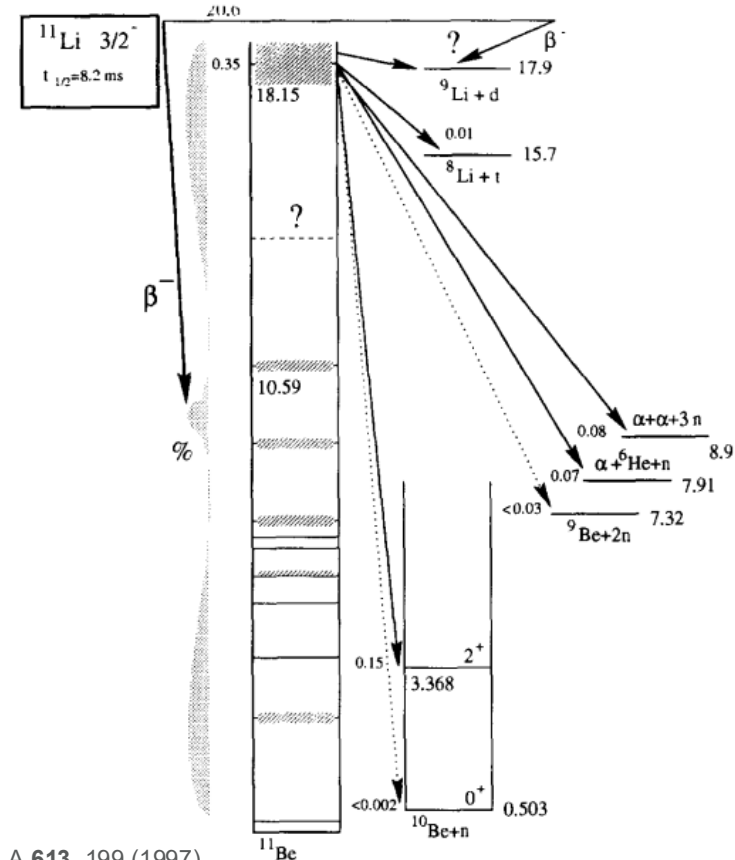
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- Neutron halo systems can be ~ thought of as either core decay + spectator halo neutron OR inert core + decay of halo neutron
- Extended spatial extent of the halo state will reduce overlap to 'normal' bound states, but increasing overlap to continuum states – impact on the half-life is not simple

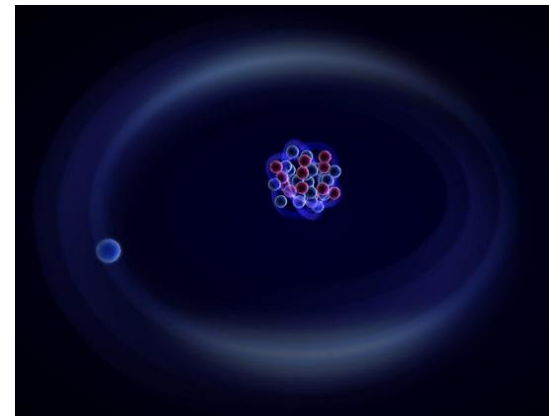
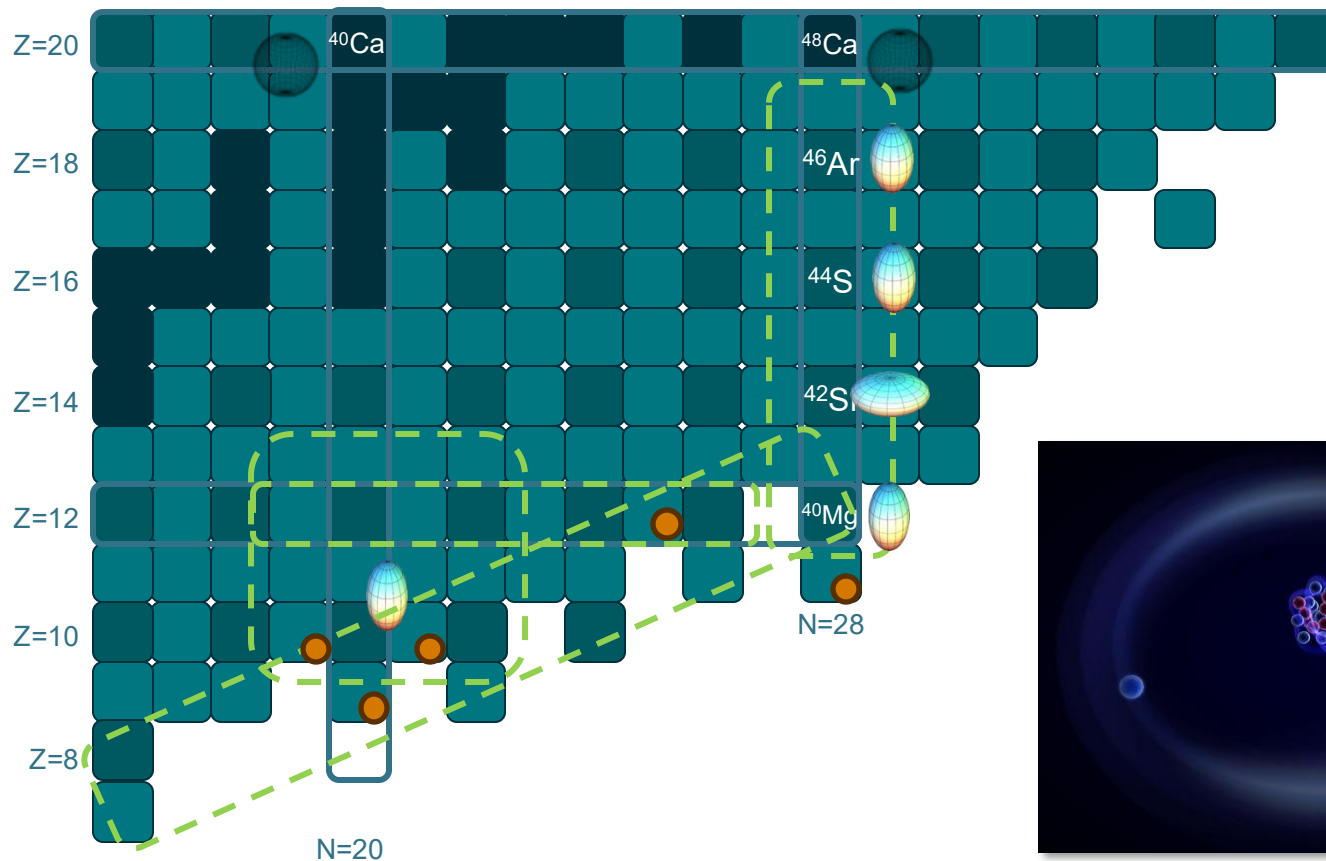


β Decay of ^{11}Li Halo

- For halo (v. weakly bound) systems, decay branches for delayed neutron (or particle) emission are expected to be enhanced due simply to Q_β , but also due to halo nature
- ^{11}Li is experimentally the best studied halo beta-decay, with strong βn , $\beta 2n$ and charged particle emission channels
- The population of the $0+$ and $2+$ states in the βn daughter ^{10}Be can even provide insight into the $(p_{1/2})^2$ vs. $(s_{1/2})^2$ components of the ^{11}Li wavefunction



Why This Region? Halo Structures



Getting to ^{40}Mg

- For halo (v. weakly bound) systems, decay branches for delayed neutron (or particle) emission are expected to be enhanced due simply to Q_β
- ^{40}Mg was one of the objectives for E21062, but didn't end up being part of the beam cocktail

Getting to ^{40}Mg

- For halo (v. weakly bound) systems, decay branches for delayed neutron (or particle) emission are expected to be enhanced due simply to Q_β
- ^{40}Mg was one of the objectives for E21062, but didn't end up being part of the beam cocktail
- Another proposal was submitted to FRIB PAC 3 focusing on ^{40}Mg , emphasizing the impact of a potential 2n halo ($S_n = 1.3(7)$ MeV)
- Proposed measurement of βn , $\beta 2n$, ... branches for $^{38,40}\text{Mg}$ using Super-3Hen initiator to look for halo influence (and determine half-life)

“While the PAC noted the potentially rich physics taking place in ^{40}Mg , the arguments relied largely on a single theory paper. Hence, the proposal could be further strengthened by adding predictions from other theoretical methods.”

Summary

- Decay spectroscopy is a powerful tool for both first information into nuclear structure, and detailed level-scheme building depending on the isotope beam rate
- The first experiment at FRIB focused on decay in the region of $N=28$ below Ca, exploring nuclei where we expect different shapes/deformations, possible influence from weak-binding/halo structures
- Half-life in ^{38}Mg drops substantially compared to ^{37}Mg , beyond expectation of just energy systematics
- It **seems** that half-lives of the isotopes with very large Q_β are longer than expected based on broader systematics – is there a way to understand this generally?
- Halo nuclei will manifest signatures in their decay – enhanced $\beta n/\beta 2n/\dots$ branches, but calculations for comparison are needed; impact on half-life is unclear

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C. Morse

LANL

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