



β -Decay as a Window into Exotic Nuclei: Experimental Program at FRIB

Rebeka Sultana Lubna
lubna@frib.msu.edu



MICHIGAN STATE
UNIVERSITY

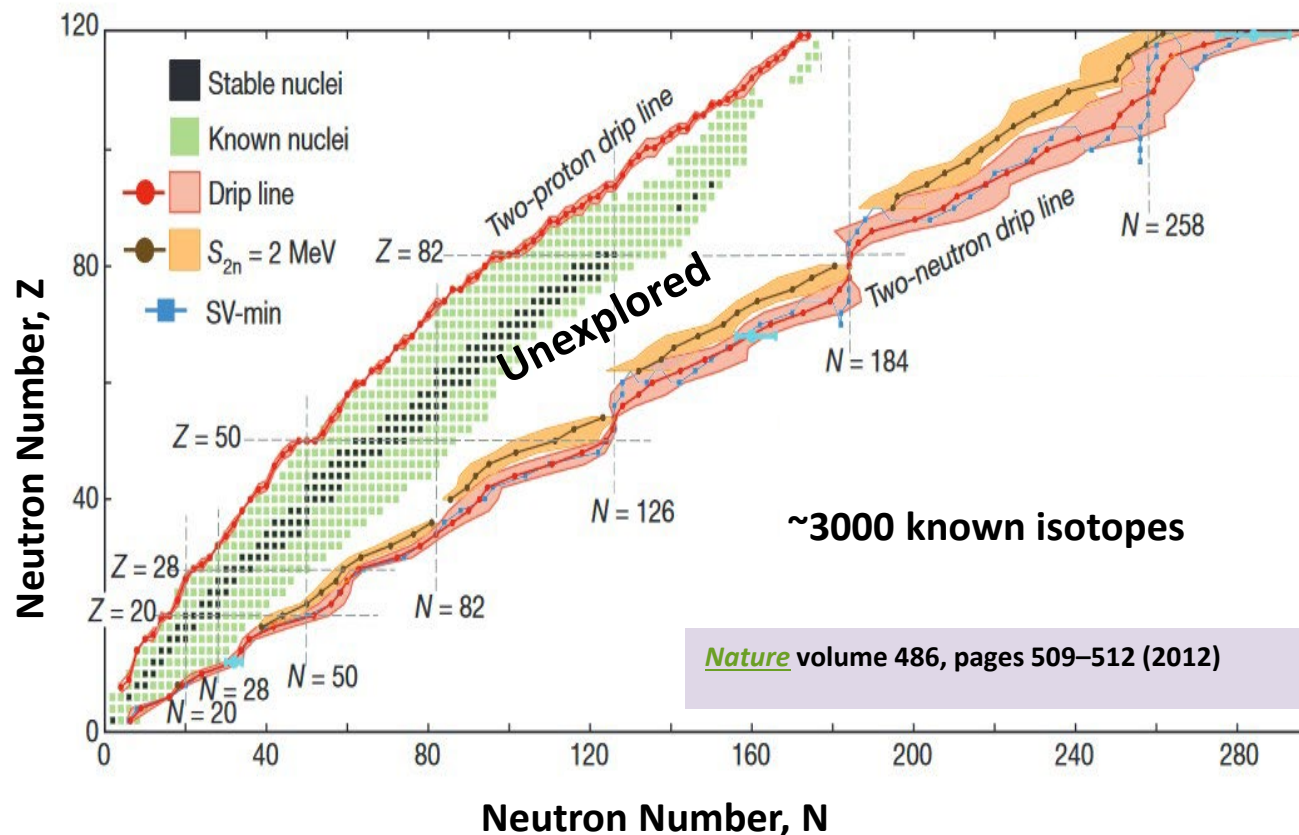


U.S. DEPARTMENT
of **ENERGY**

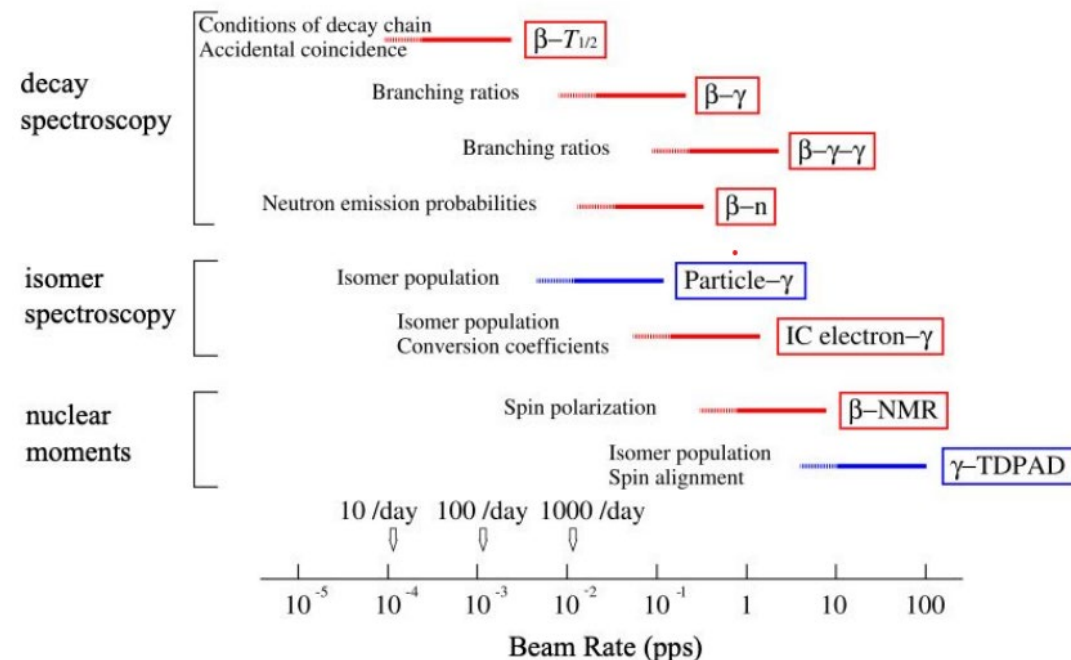
Office of
Science

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics and used resources of the Facility for Rare Isotope Beams (FRIB) Operations, which is a DOE Office of Science User Facility under Award Number DE-SC0023633.

Experimental Program on β decay at FRIB

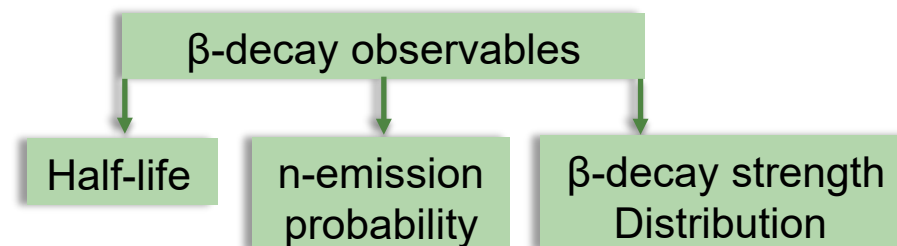
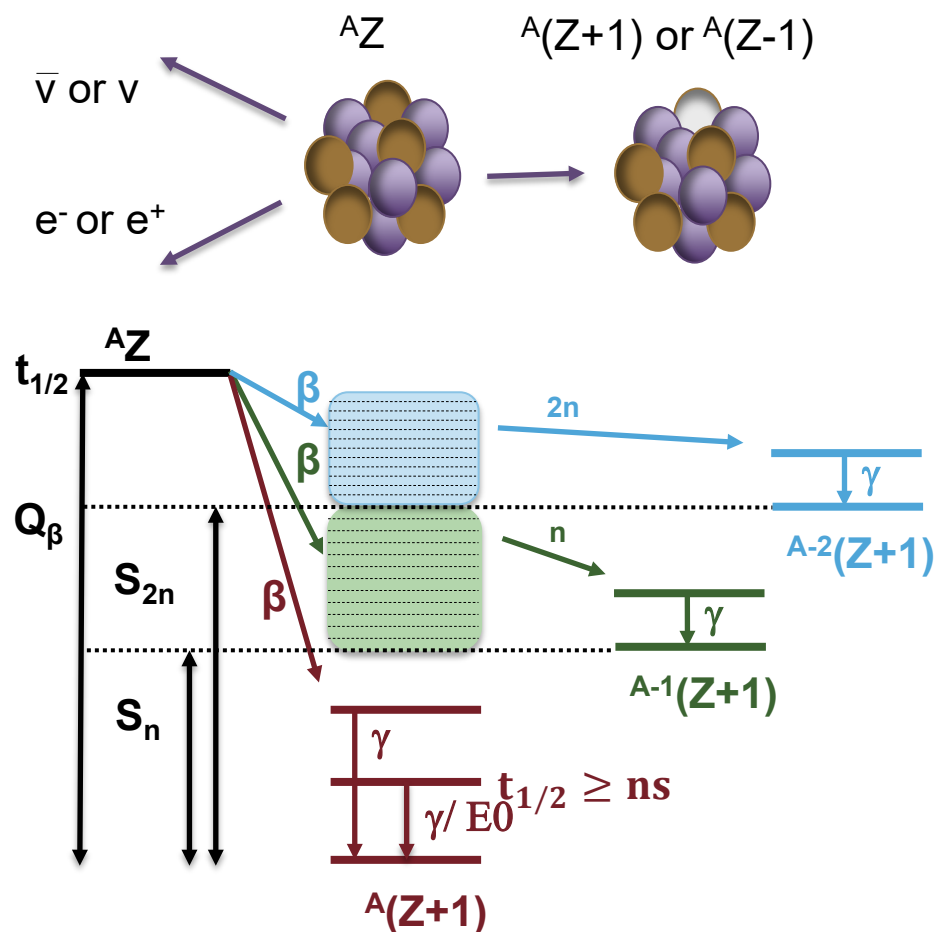


- The experimental program on beta decay at FRIB focuses on the extreme ends on isotopic chains in nuclear chart.



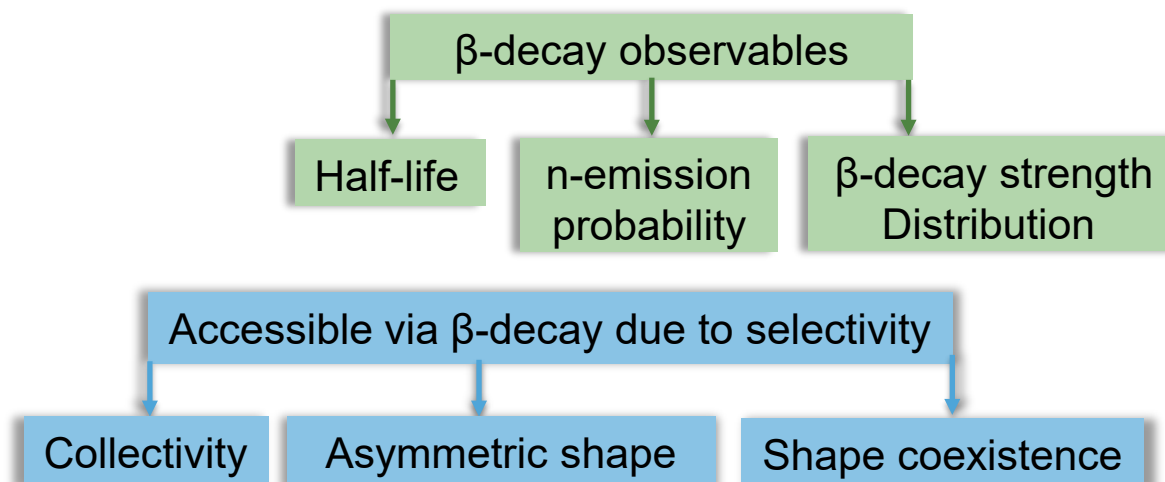
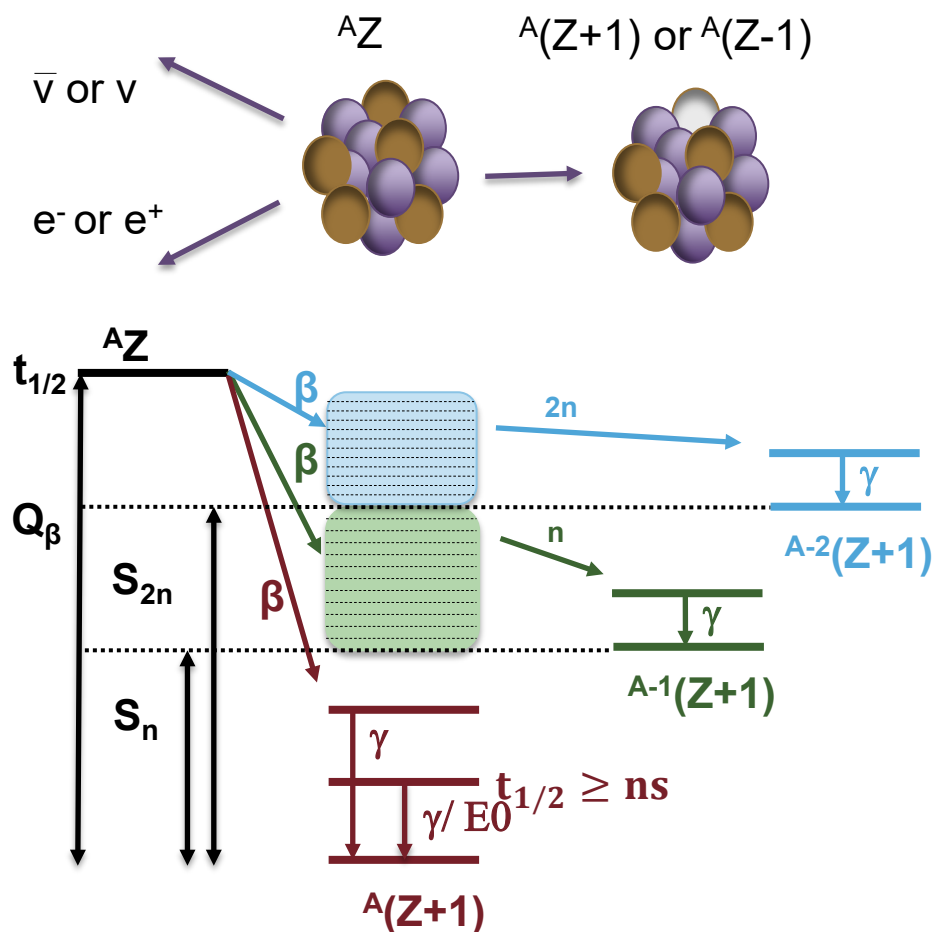
Experimental Program on β decay at FRIB

- The experimental program on beta decay at FRIB focuses on the extreme ends on isotopic chains in nuclear chart.



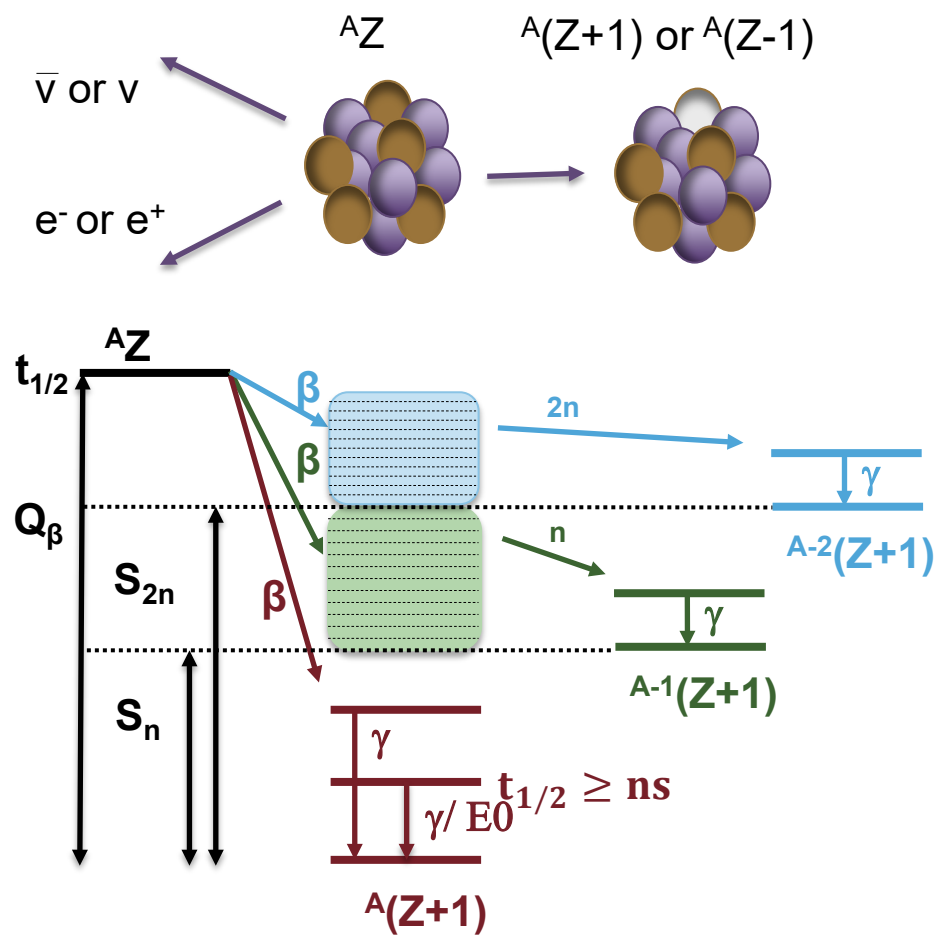
Experimental Program on β decay at FRIB

- The experimental program on beta decay at FRIB focuses on the extreme ends on isotopic chains in nuclear chart.



Experimental Program on β decay at FRIB

- The experimental program on beta decay at FRIB focuses on the extreme ends on isotopic chains in nuclear chart.



β -decay observables

Half-life

n-emission
probability

β -decay strength
Distribution

Accessible via β -decay due to selectivity

Collectivity

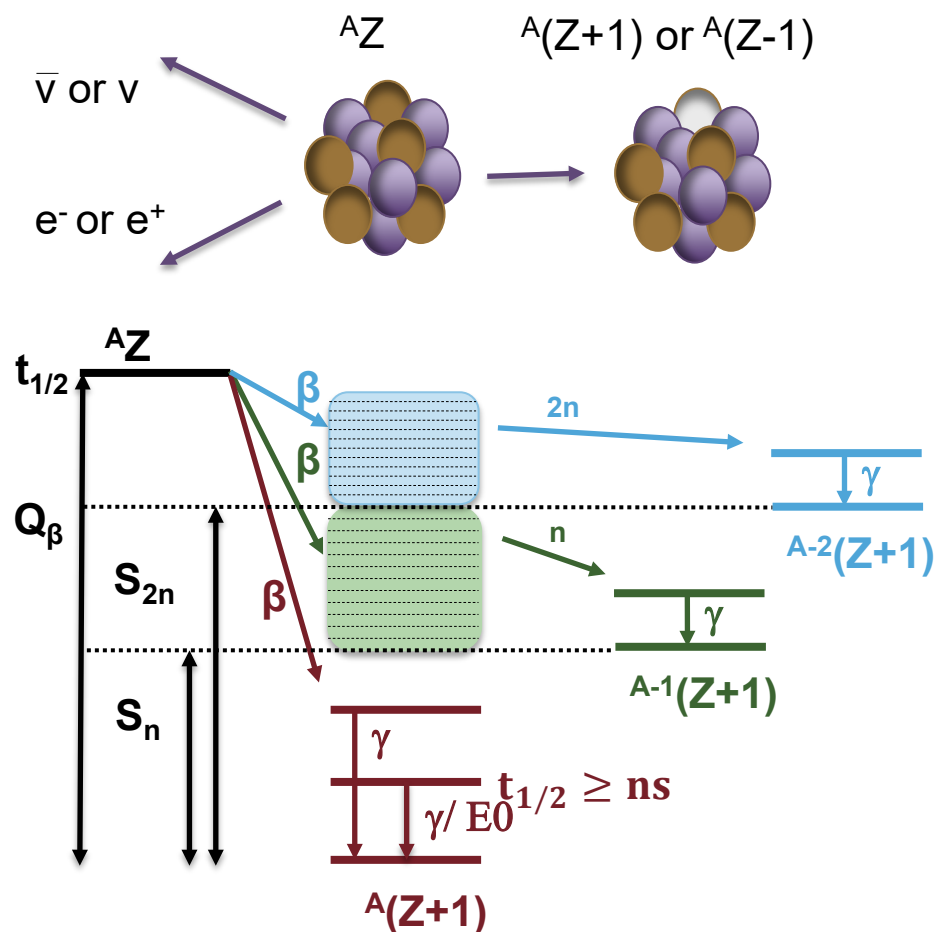
Asymmetric shape

Shape coexistence

Indirect reaction measurements via β decay

Experimental Program on β decay at FRIB

- The experimental program on beta decay at FRIB focuses on the extreme ends on isotopic chains in nuclear chart.



β -decay observables

Half-life

n-emission
probability

β -decay strength
Distribution

Accessible via β -decay due to selectivity

Collectivity

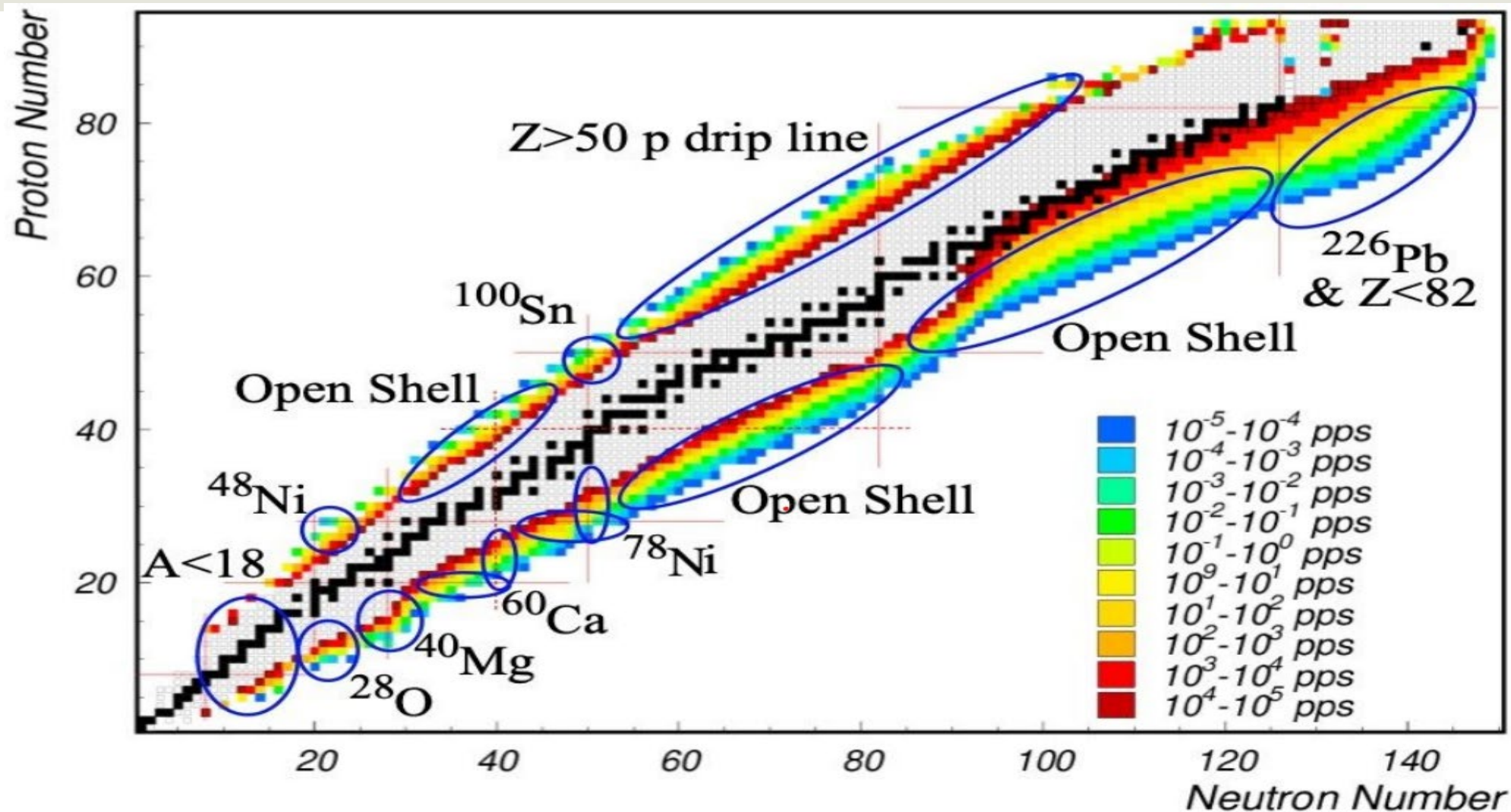
Asymmetric shape

Shape coexistence

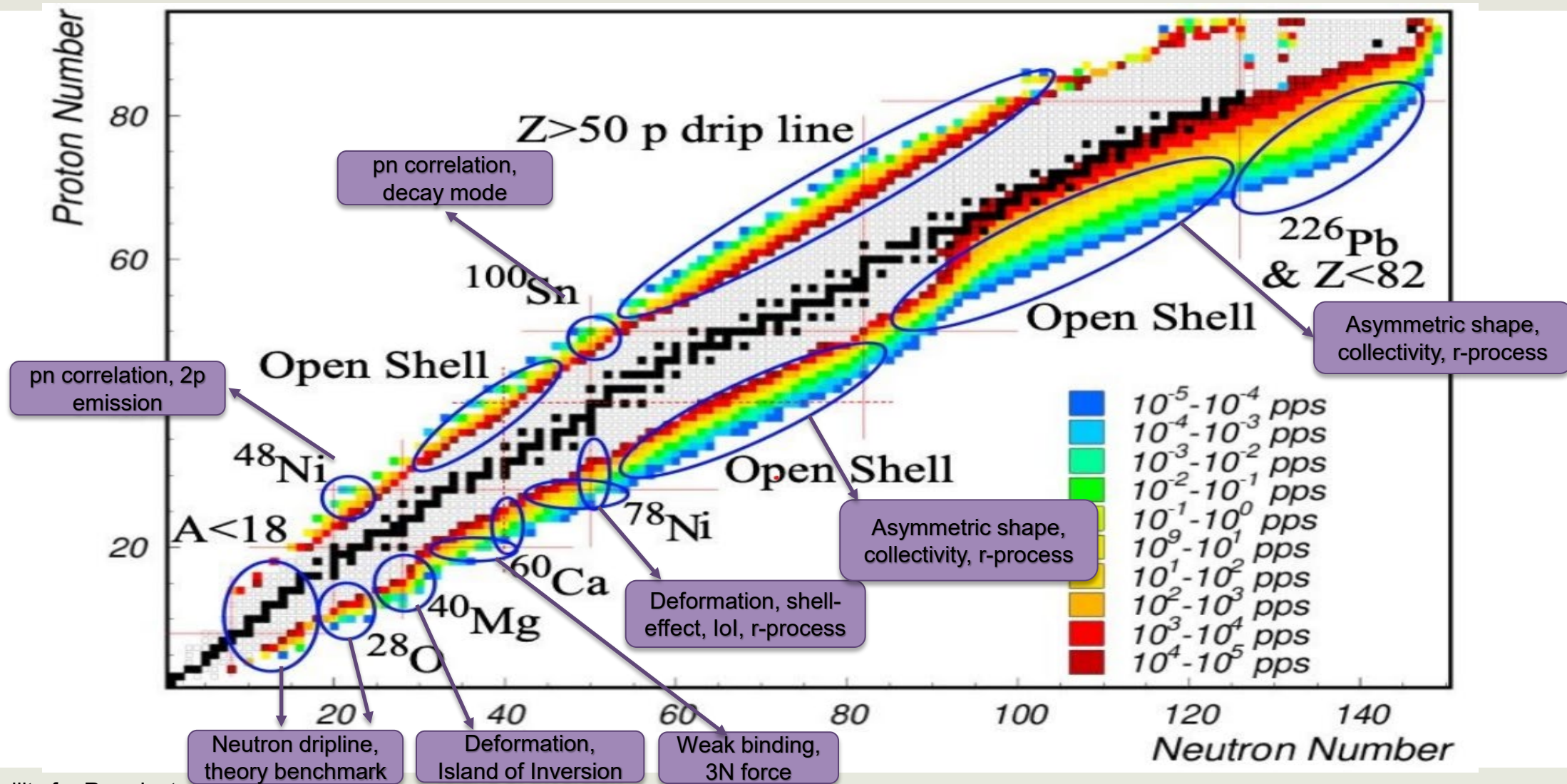
Indirect reaction measurements via β decay

Weak interaction, physics Beyond Standard Model (BSM)

Experimental Program on β decay at FRIB



Experimental Program on β decay at FRIB



FRIB Beta Decay Station (FDSi)

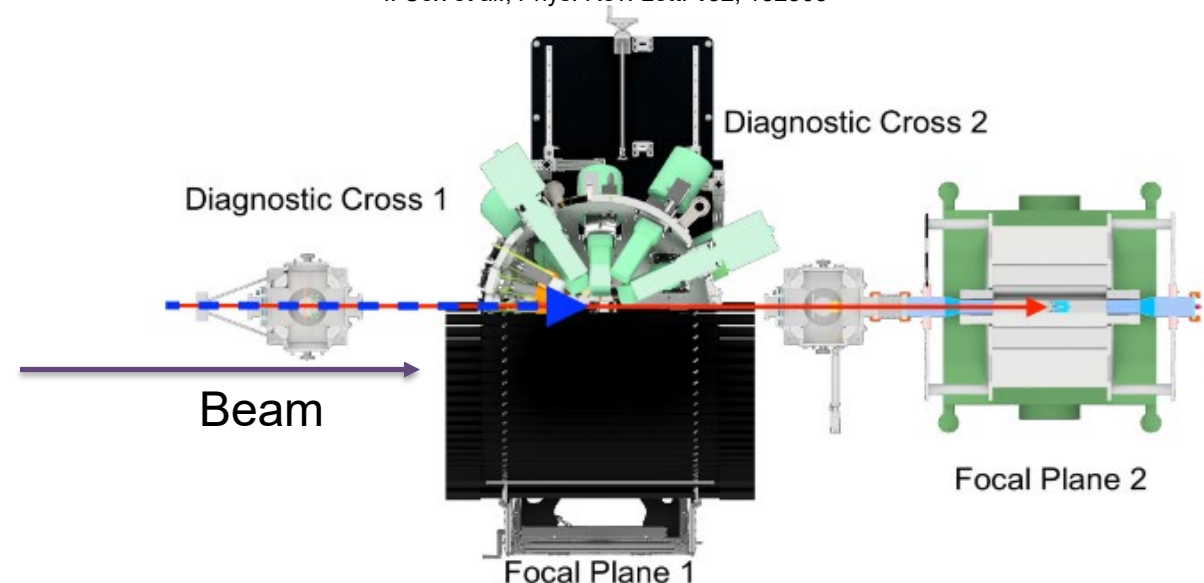
Focal plane 1: Discrete spectroscopy.

- Si PIN detectors for particle identification.
- Implant detector YSO, CeBr, XSiSi, GADGET.
- HPGe clover detectors: high energy resolution for γ .
- LaBr detectors: Good timing resolution.
- Neutron detector VANDLE.

Focal plane 2: Total absorption spectroscopy

- MTAS, SuN.
- Implantation detector at the center: YSO, GPS, DSSD.

I. Cox et al., Phys. Rev. Lett. **132**, 152503



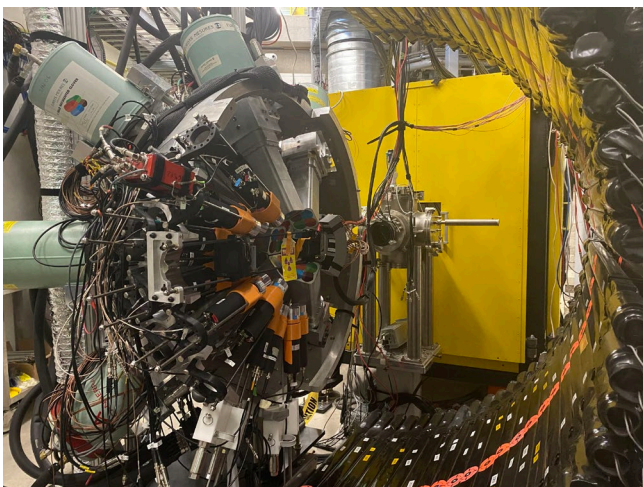
FRIB Beta Decay Station (FDSi)

Focal plane 1: Discrete spectroscopy.

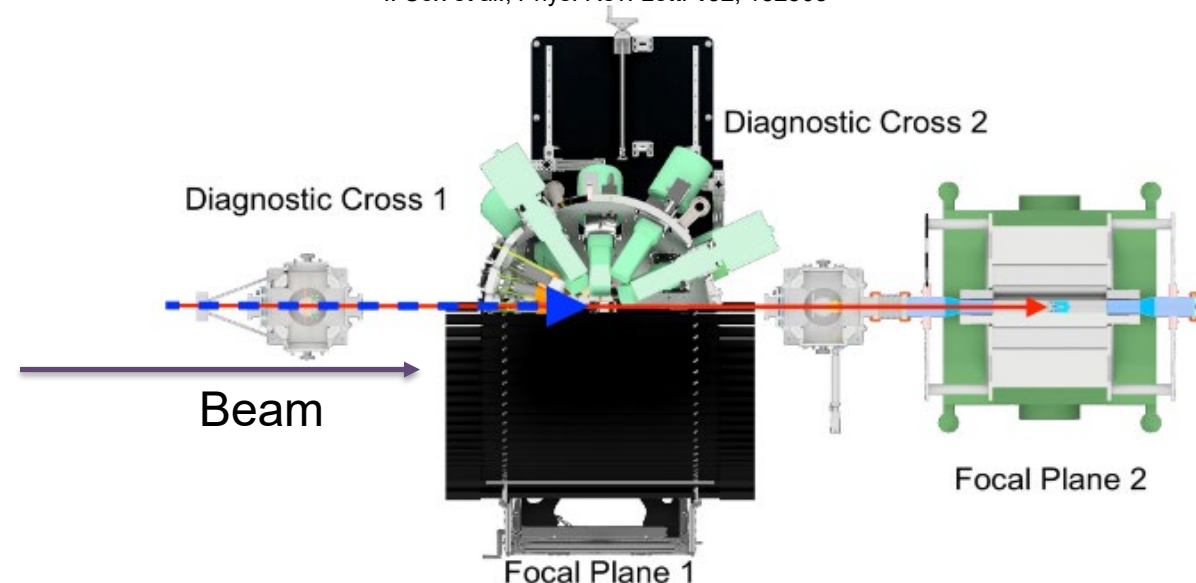
- Si PIN detectors for particle identification.
- Implant detector YSO, CeBr, XSiSi, GADGET.
- HPGe clover detectors: high energy resolution for γ .
- LaBr detectors: Good timing resolution.
- Neutron detector VANDLE.

Focal plane 2: Total absorption spectroscopy

- MTAS, SuN.
- Implantation detector at the center: YSO, GPS, DSSD.



I. Cox et al., Phys. Rev. Lett. **132**, 152503



FRIB Beta Decay Station (FDSi)

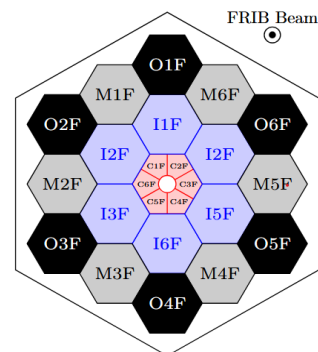
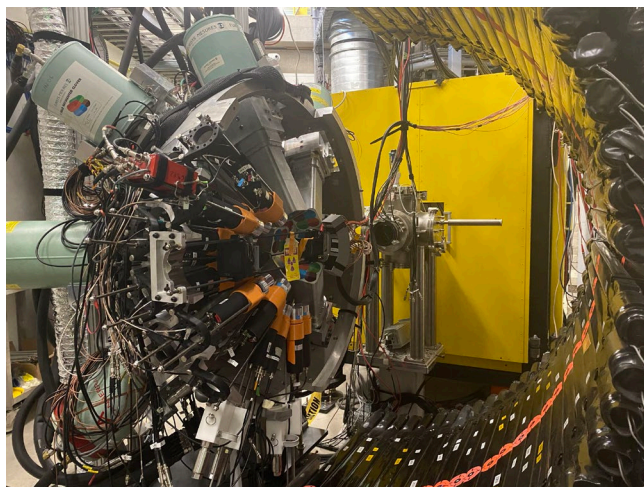
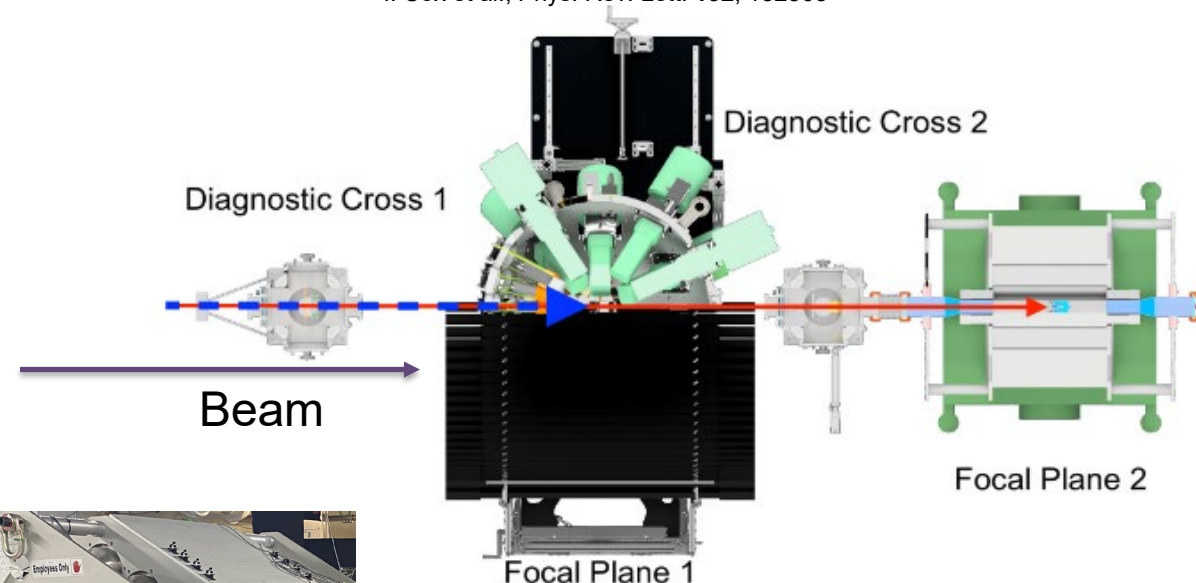
Focal plane 1: Discrete spectroscopy.

- Si PIN detectors for particle identification.
- Implant detector YSO, CeBr, XSiSi, GADGET.
- HPGe clover detectors: high energy resolution for γ .
- LaBr detectors: Good timing resolution.
- Neutron detector VANDLE.

Focal plane 2: Total absorption spectroscopy

- MTAS, SuN.
- Implantation detector at the center: YSO, GPS, DSSD.

I. Cox et al., Phys. Rev. Lett. **132**, 152503



Courtesy T. King, MTAS collaboration



FRIB Beta Decay Station (FDSi)

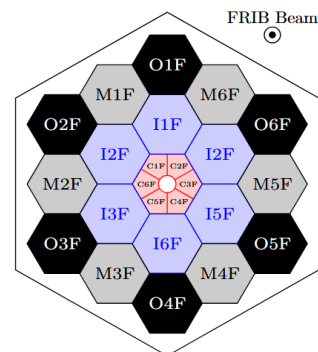
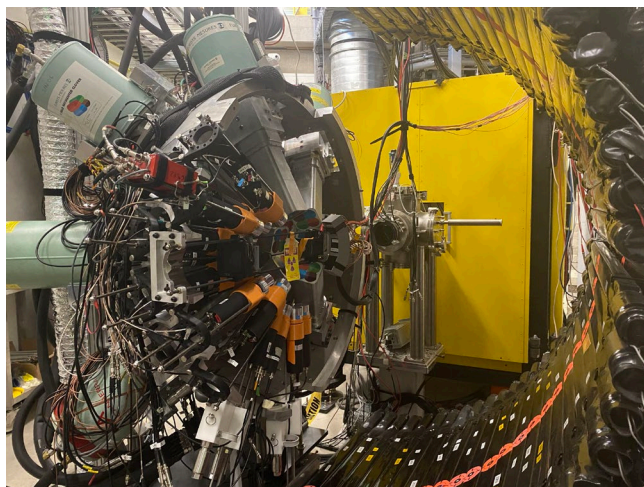
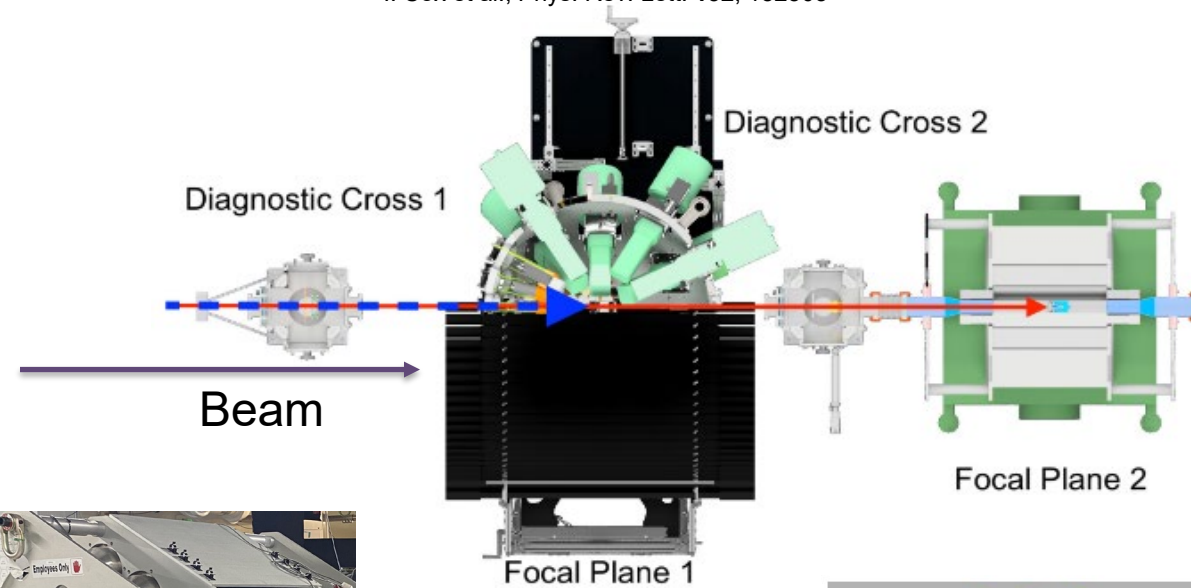
Focal plane 1: Discrete spectroscopy.

- Si PIN detectors for particle identification.
- Implant detector YSO, CeBr, XSiSi, GADGET.
- HPGe clover detectors: high energy resolution for γ .
- LaBr detectors: Good timing resolution.
- Neutron detector VANDLE.

Focal plane 2: Total absorption spectroscopy

- MTAS, SuN.
- Implantation detector at the center: YSO, GPS, DSSD.

I. Cox et al., Phys. Rev. Lett. **132**, 152503

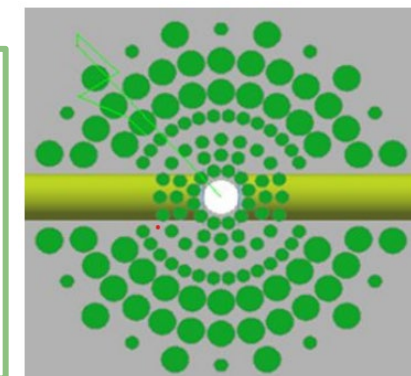


Courtesy T. King, MTAS collaboration



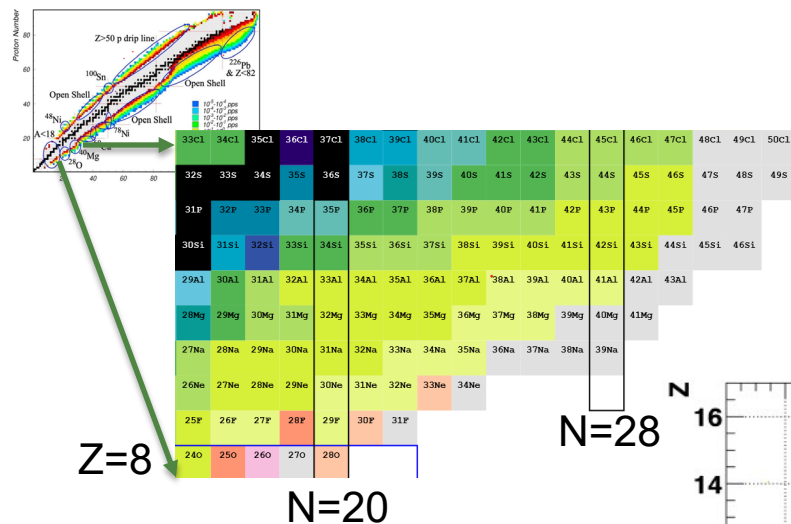
Focal plane 2:

- ^3He neutron detector.
- Ge detector.
- Multiple P_n measurement.



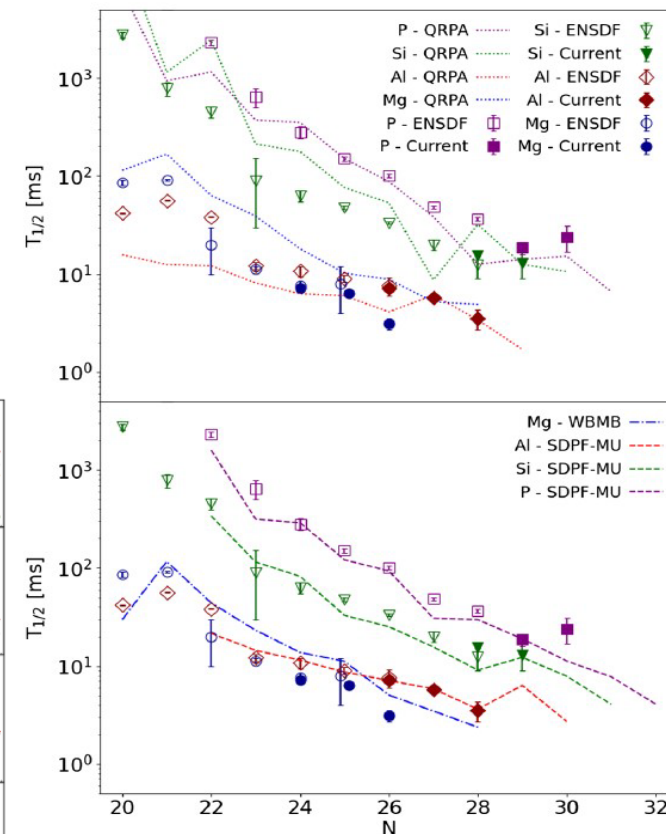
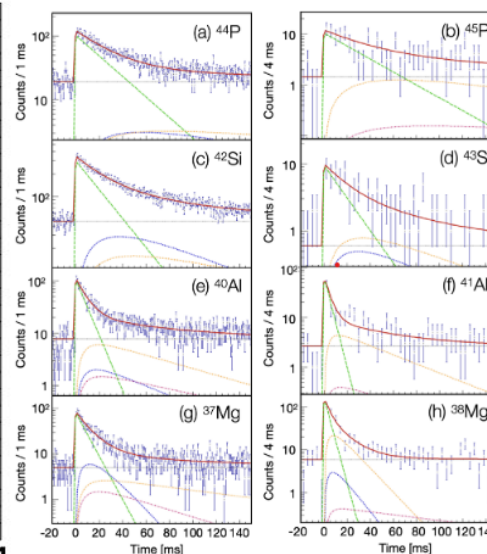
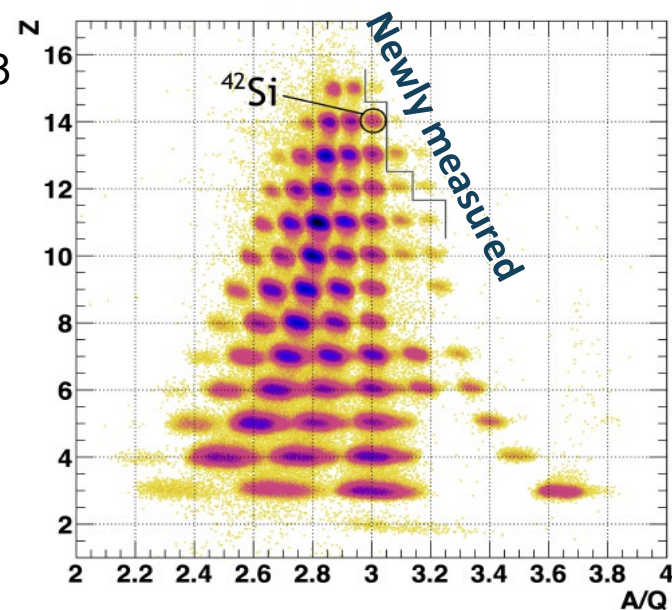
R. Grzywacz et al., Acta Physica Polonica, 45

Decay Properties at N~28 and Structural Change

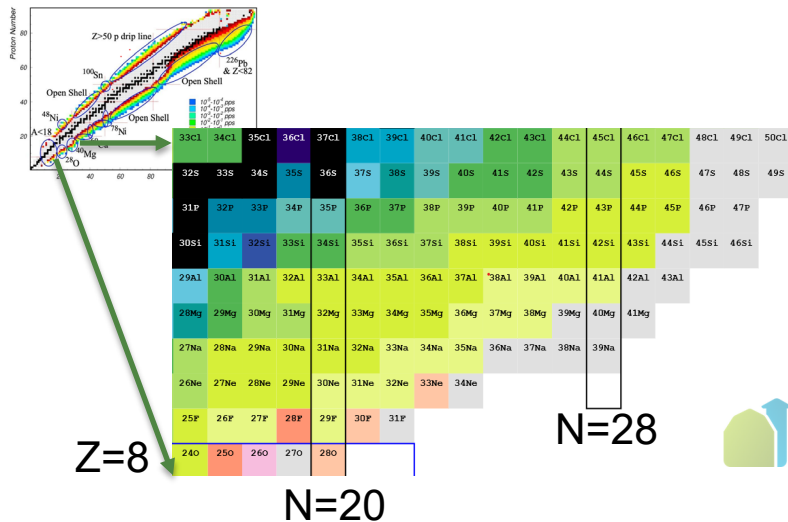


- More exotic half-lives.
- Measurement of neutron emission probabilities.
- β -decay strength.
- Need theoretical model for interpretation.

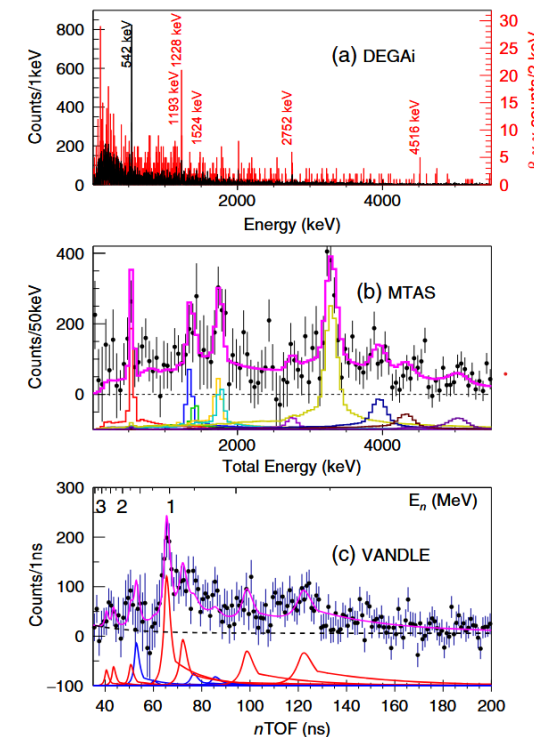
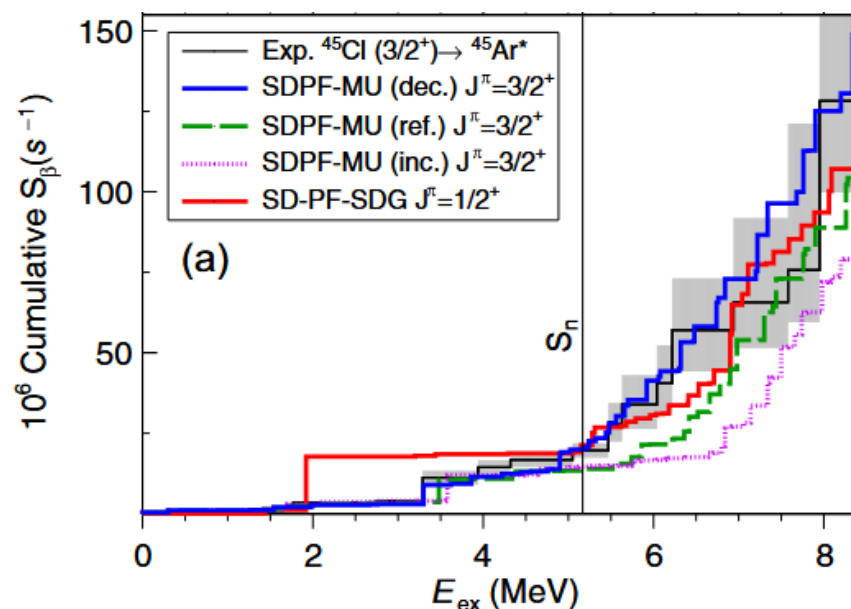
- The drop of ^{38}Mg half-life could not be explained.
- Measured $T_{1/2}$ of isotopes near drip line.



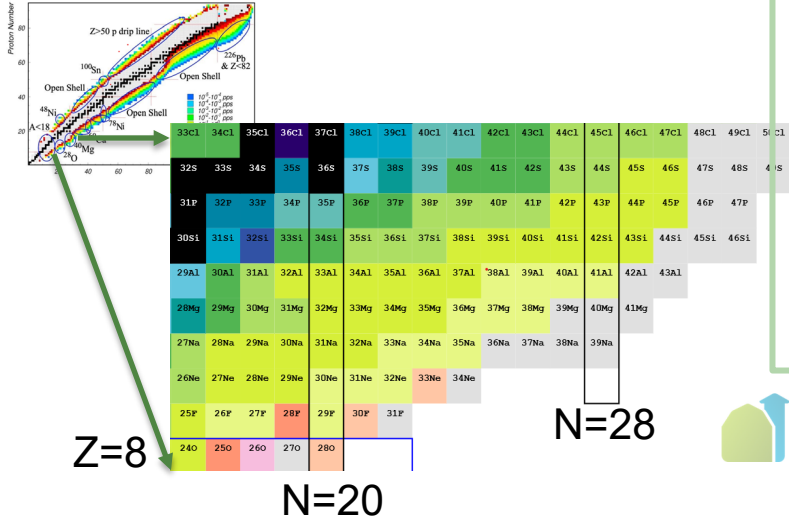
Decay Properties at N~28 and Structural Change



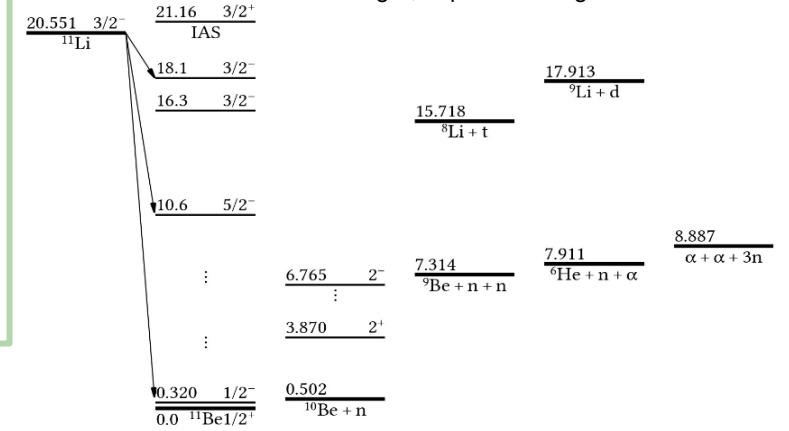
- β -decay strength distribution of ^{45}Cl was conducted up to 8 MeV.
- Extracted S_β above and below S_n of ^{45}Ar respectively.
- Increased S_β reported above S_n was interpreted due to the weakening of Z=20 shell gap.
- More experimental data needed for a robust test of the model.



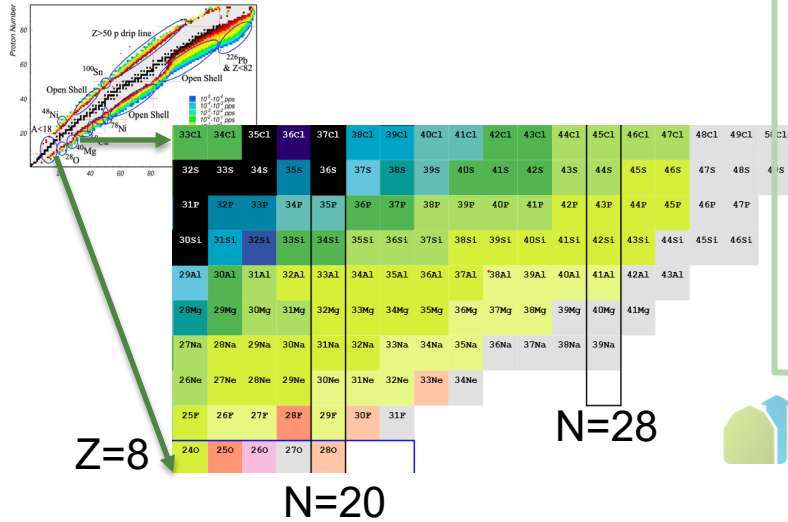
Dripline Properties via β decay



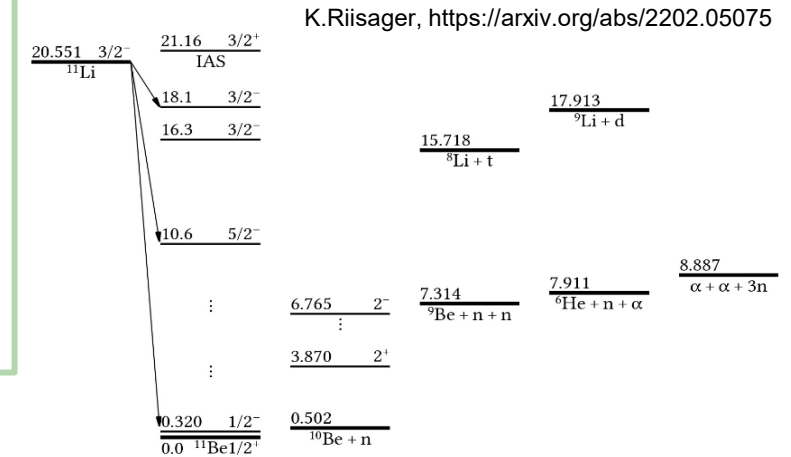
- Halo structure close to the dripline impacts the decay properties.
- β decay of 2-neutron halo ^{11}Li provide evidence of decaying to the continuum states via multiple particle emission.
- β -delayed multiple neutron emission channel will dominate in heavier systems.



Dripline Properties via β decay

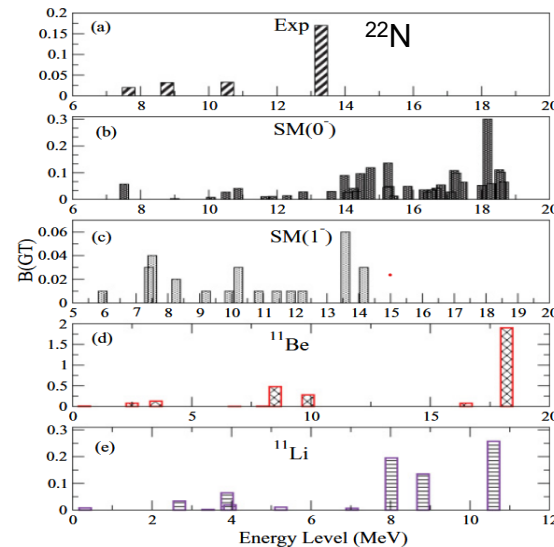


- Halo structure close to the dripline impacts the decay properties.
- β decay of 2-neutron halo ^{11}Li provide evidence of decaying to the continuum states via multiple particle emission.
- β -delayed multiple neutron emission channel will dominate in heavier systems.

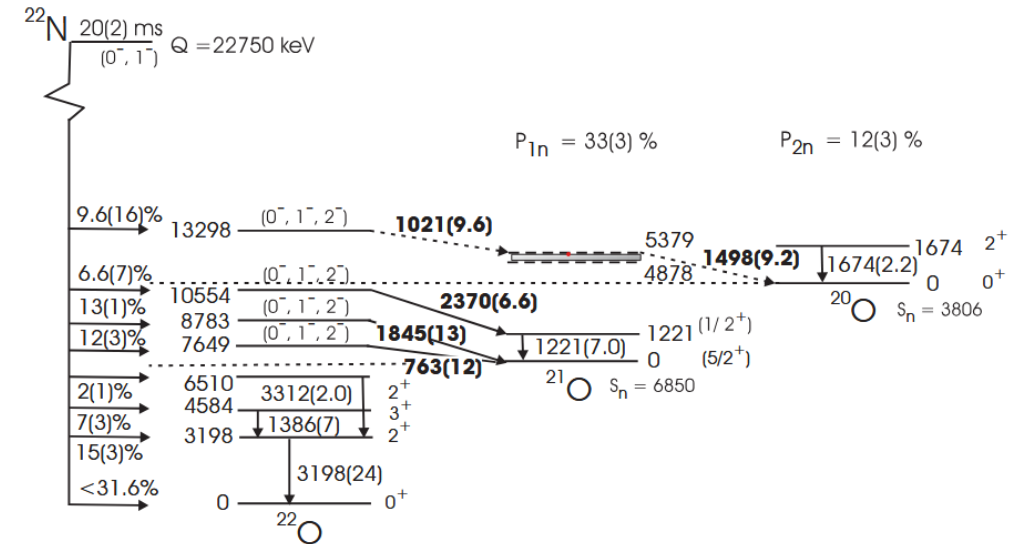


K.Riisager, <https://arxiv.org/abs/2202.05075>

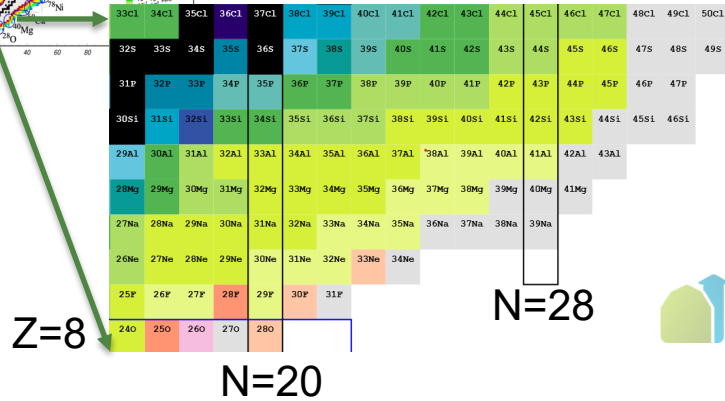
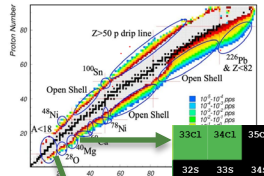
- Strong S_β distribution above S_n was observed in neutron halo nuclei.
- ^{22}N shows high S_β concentrated above S_n .



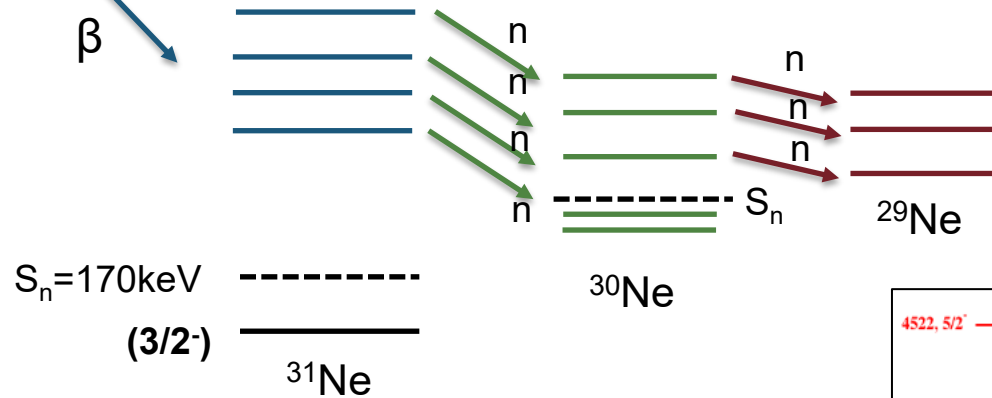
C.S.Sumithrarachchi et al., Phys. Rev. C **81**, 014302



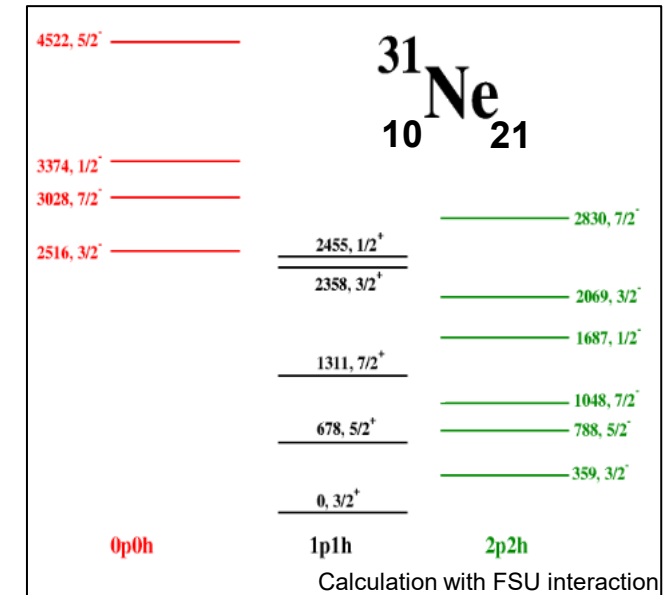
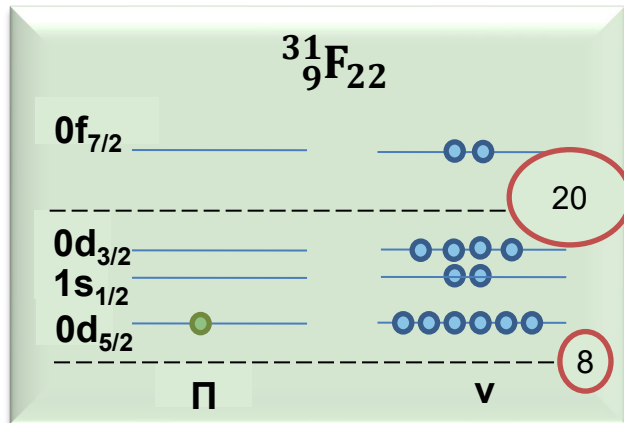
Dripline Properties via β decay



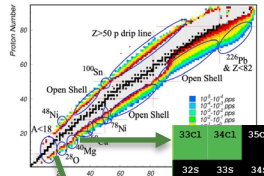
^{31}F , $Q_\beta = 25.6\text{MeV}$
($5/2^+$)



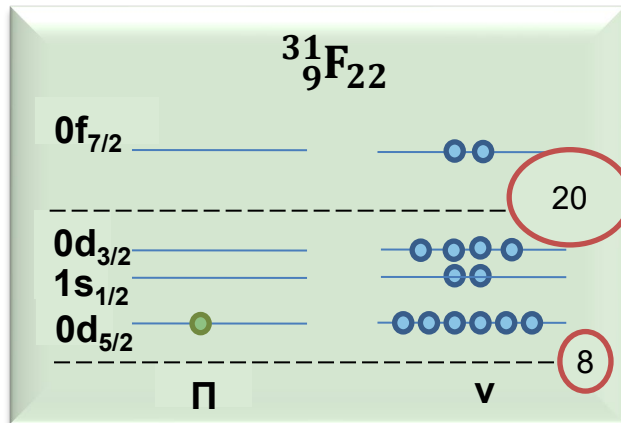
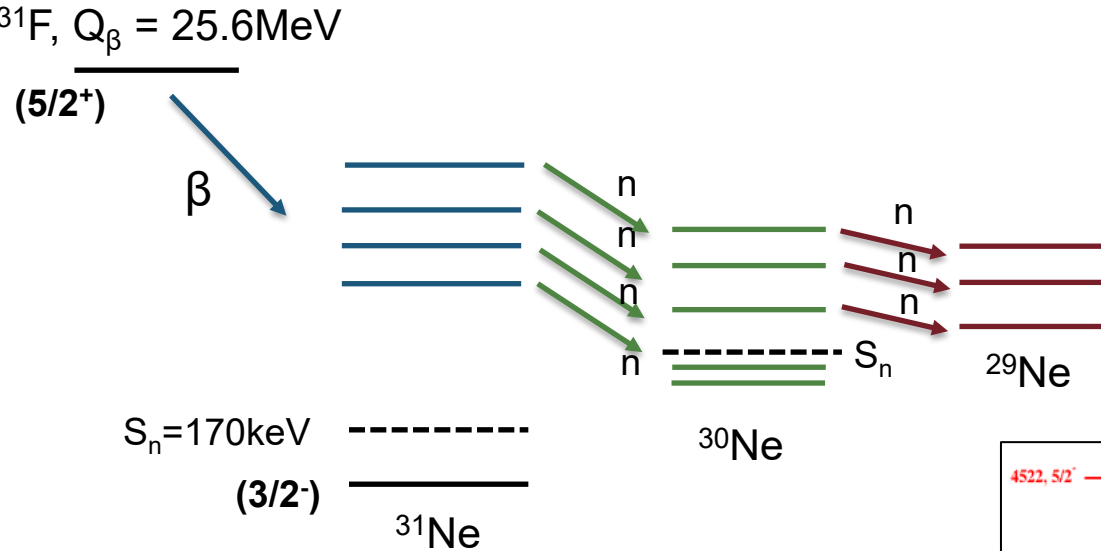
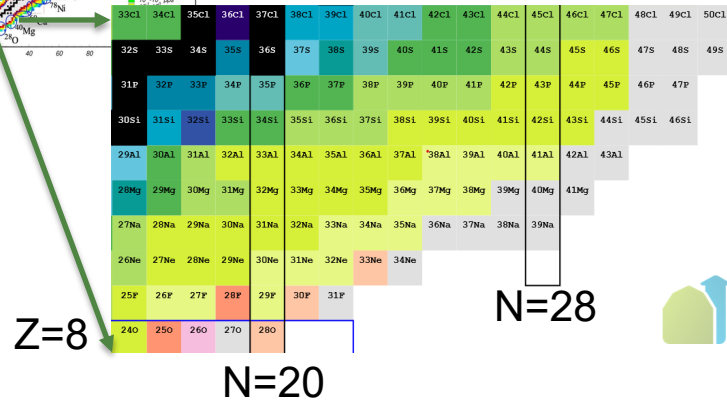
- S_n for ^{31}Ne is 170keV.
- β -decay will strongly populate the levels of ^{31}Ne above S_n .
- For a likely $5/2^+$ ground-state of ^{31}F , $3/2^+$, $5/2^+$, $7/2^+$ states in ^{31}Ne will be strongly populated via GT transition.
- S_β will reveal possible halo nature.



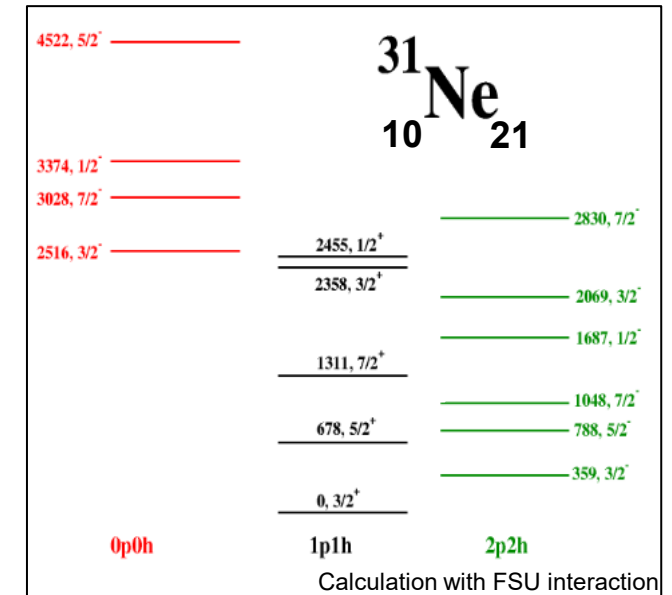
Dripline Properties via β decay



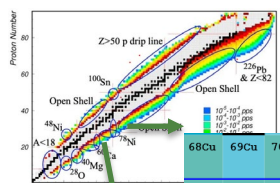
Approved e25079: ^{31}F , $Q_\beta = 25.6\text{MeV}$
M. Madurga et al.



- S_n for ^{31}Ne is 170keV.
- β -decay will strongly populate the levels of ^{31}Ne above S_n .
- For a likely $5/2^+$ ground-state of ^{31}F , $3/2^+$, $5/2^+$, $7/2^+$ states in ^{31}Ne will be strongly populated via GT transition.
- S_β will reveal possible halo nature.



Decay Spectroscopy at $N \sim 40$: Evolution towards $N=50$

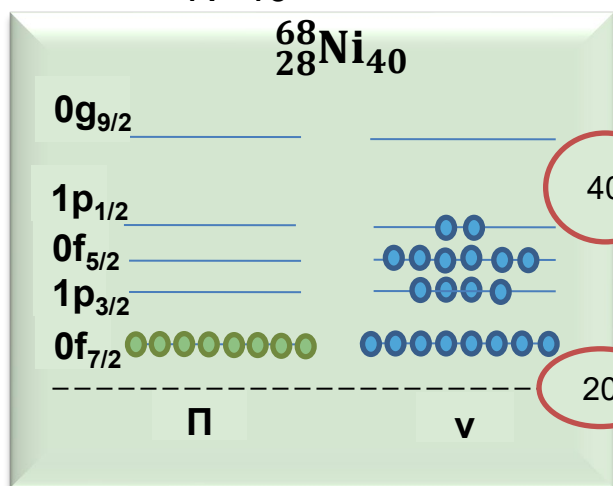


68Cu	69Cu	70Cu	71Cu	72Cu	73Cu	74Cu	75Cu	76Cu	77Cu	78Cu	79Cu
67Ni	68Ni	69Ni	70Ni	71Ni	72Ni	73Ni	74Ni	75Ni	76Ni	77Ni	78Ni
66Co	67Co	68Co	69Co	70Co	71Co	72Co	73Co	74Co	75Co	76Co	77Co
65Fe	66Fe	67Fe	68Fe	69Fe	70Fe	71Fe	72Fe	73Fe	74Fe	75Fe	76Fe
64Mn	65Mn	66Mn	67Mn	68Mn	69Mn	70Mn	71Mn	72Mn	73Mn		
63Cr	64Cr	65Cr	66Cr	67Cr	68Cr	69Cr	70Cr				
62V	63V	64V	65V	66V	67V						
61Ti	62Ti	63Ti	64Ti	65Ti							
60Sc	61Sc	62Sc	63Sc								

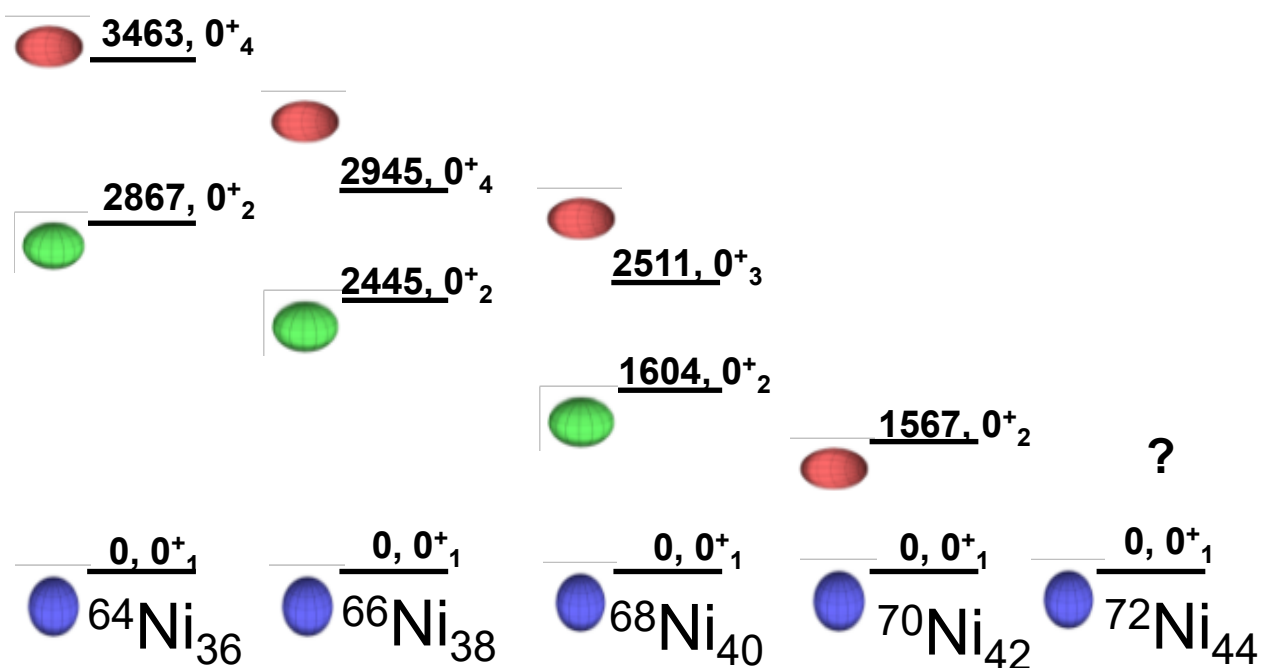
 $Z=28$

N=50

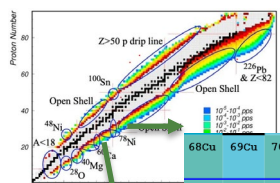
N=40



- Shape coexistence in proton closed shell Ni isotopes is well established at N~40.
- Adding neutrons to $g_{9/2}$ orbital can result in dramatic structural change.
- Extreme shape coexistence was reported in ^{70}Cu recently.
- Moving towards more exotic isotopes will shed light on the evolution towards the possible N=50 Island of Inversion.



Decay Spectroscopy at N~40: Evolution towards N=50

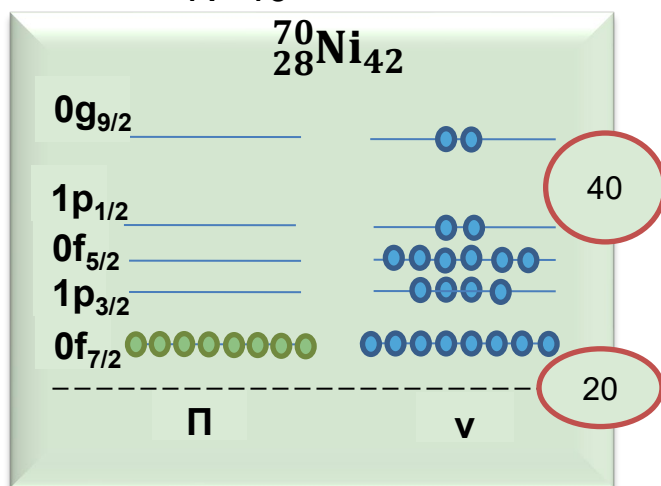


68Cu	69Cu	70Cu	71Cu	72Cu	73Cu	74Cu	75Cu	76Cu	77Cu	78Cu	79Cu
67Ni	68Ni	69Ni	70Ni	71Ni	72Ni	73Ni	74Ni	75Ni	76Ni	77Ni	78Ni
66Co	67Co	68Co	69Co	70Co	71Co	72Co	73Co	74Co	75Co	76Co	77Co
65Fe	66Fe	67Fe	68Fe	69Fe	70Fe	71Fe	72Fe	73Fe	74Fe	75Fe	76Fe
64Mn	65Mn	66Mn	67Mn	68Mn	69Mn	70Mn	71Mn	72Mn	73Mn		
63Cr	64Cr	65Cr	66Cr	67Cr	68Cr	69Cr	70Cr				
62V	63V	64V	65V	66V	67V						
61Ti	62Ti	63Ti	64Ti	65Ti							
60Sc	61Sc	62Sc	63Sc								

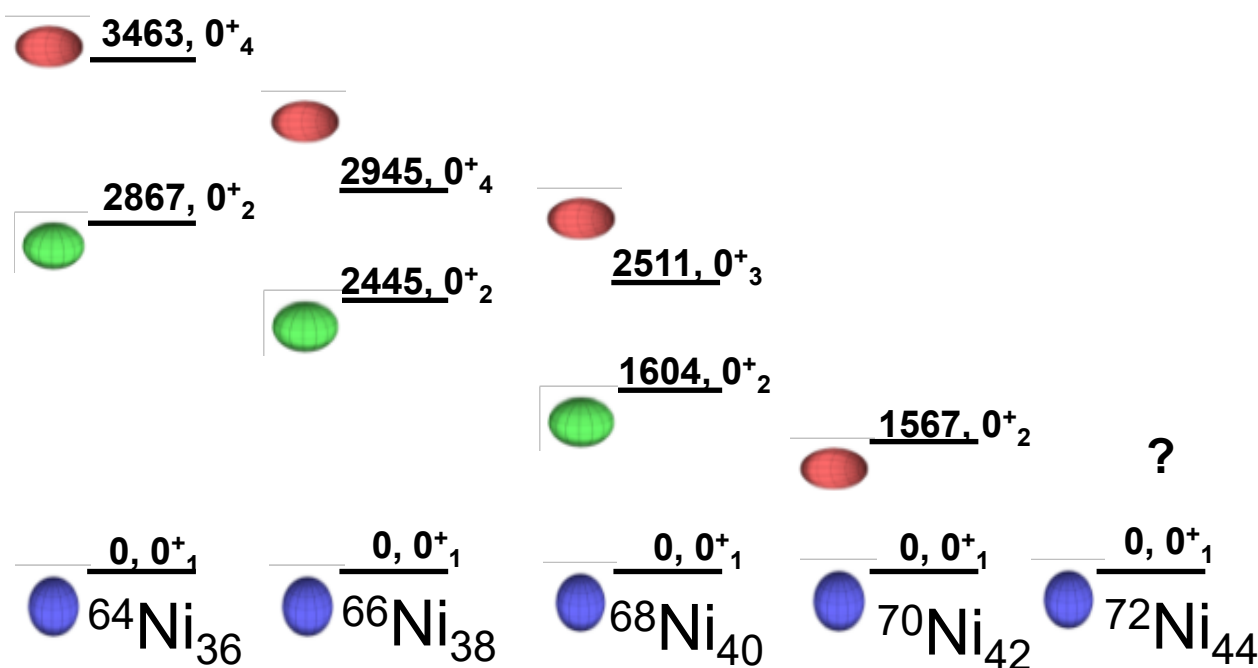
Z=28

N=50

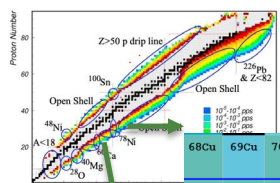
N=40



- Shape coexistence in proton closed shell Ni isotopes is well established at N~40.
- Adding neutrons to $g_{9/2}$ orbital can result in dramatic structural change.
- Extreme shape coexistence was reported in ^{70}Cu recently.
- Moving towards more exotic isotopes will shed light on the evolution towards the possible N=50 Island of Inversion.



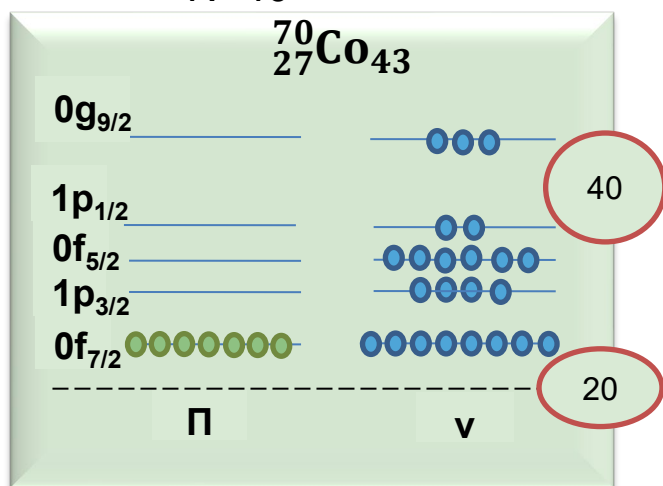
Decay Spectroscopy at N~40: Evolution towards N=50



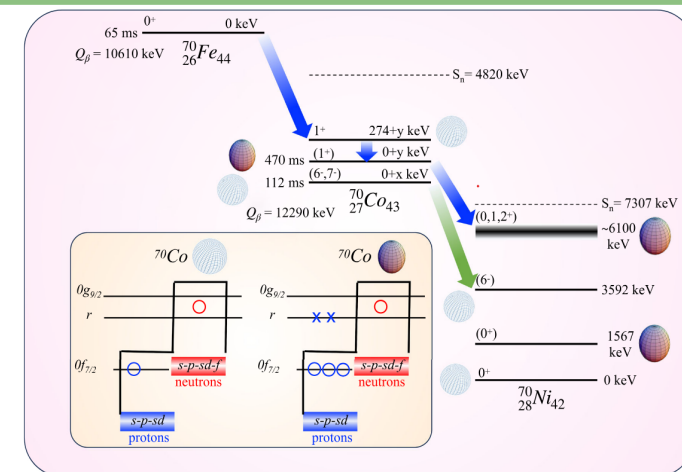
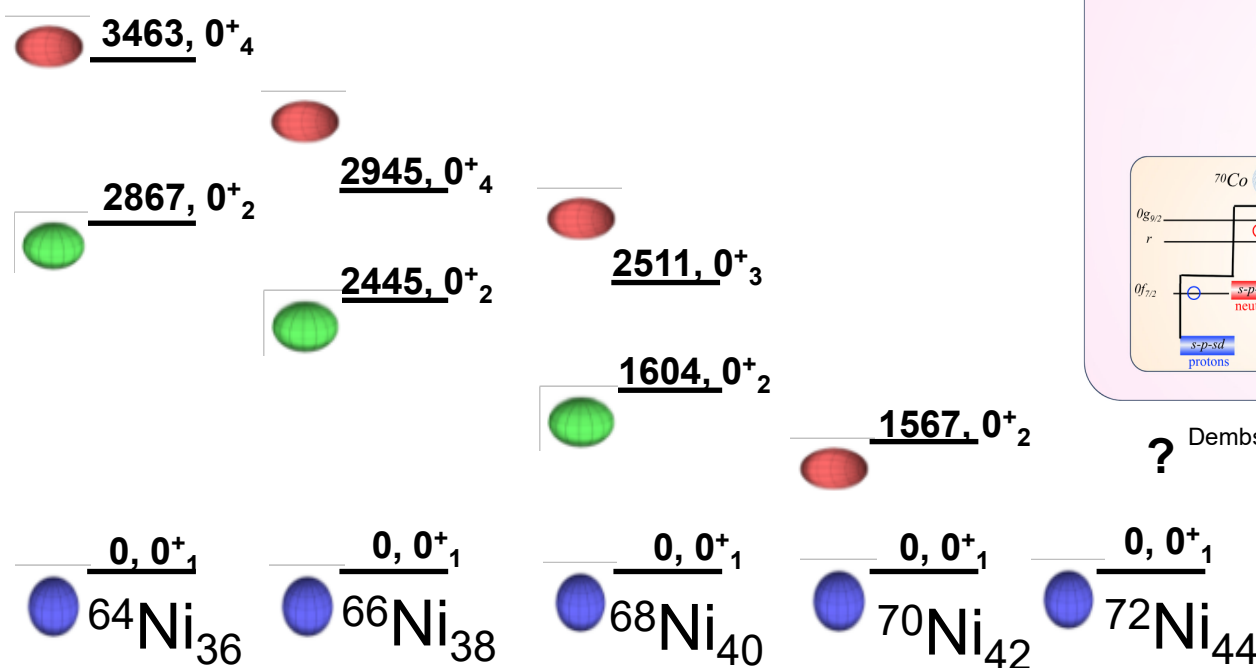
Z=28

N=50

N=40

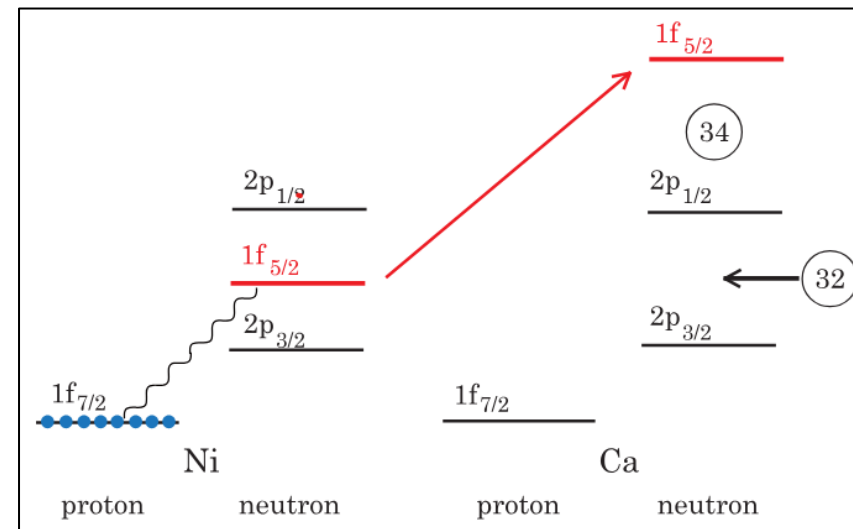
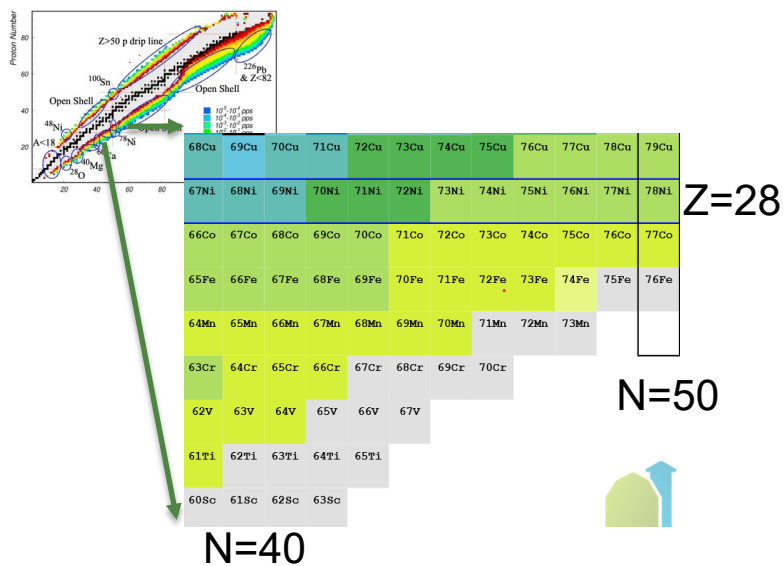


- Shape coexistence in proton closed shell Ni isotopes is well established at N~40.
- Adding neutrons to $g_{9/2}$ orbital can result in dramatic structural change.
- Extreme shape coexistence was reported in ^{70}Cu recently.
- Moving towards more exotic isotopes will shed light on the evolution towards the possible N=50 Island of Inversion.



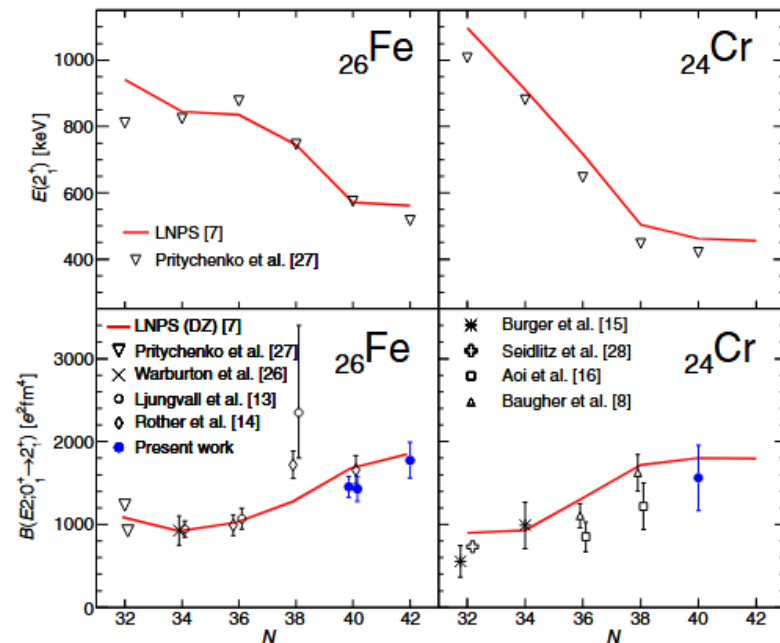
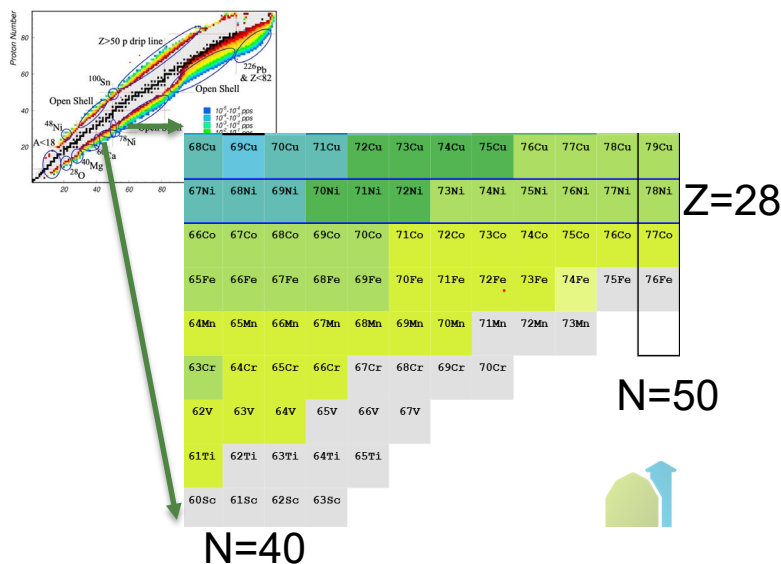
? Dembski, C. et al., *Commun Phys* 8, 77 (2025)

Decay Spectroscopy at N~40: Evolution towards N=50

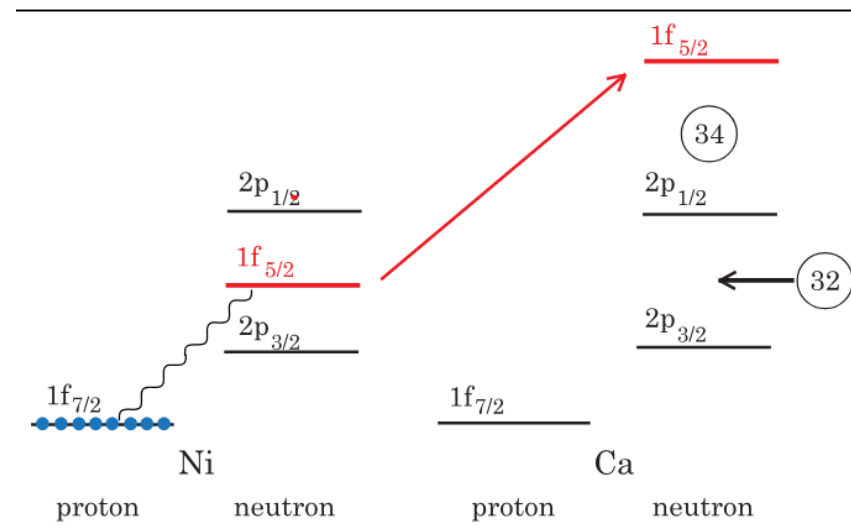


T.Otsuka, Y. Tsunoda, J. Phys. G: Nucl. Part. Phys. 43 (2016) 024009

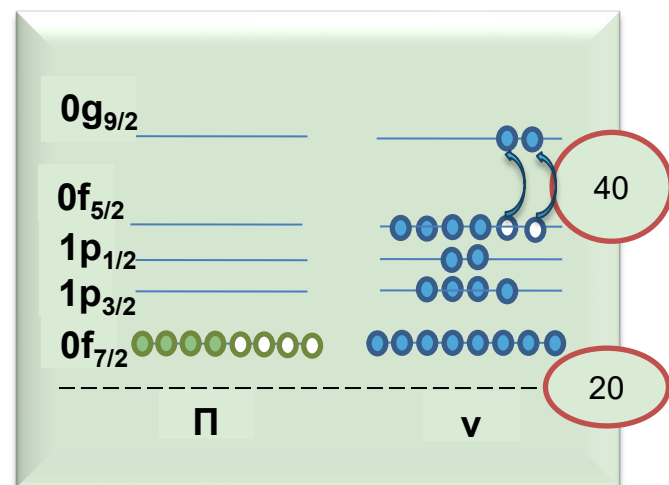
Decay Spectroscopy at N~40: Evolution towards N=50



H.L. Crawford et al., Phys. Rev. Lett. **110**, 242701

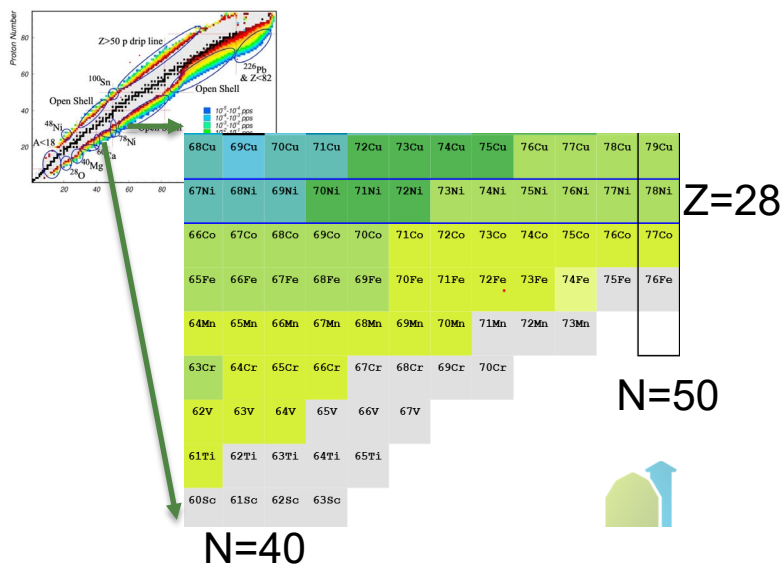


T.Otsuka, Y. Tsunoda, J. Phys. G: Nucl. Part. Phys. **43** (2016) 024009

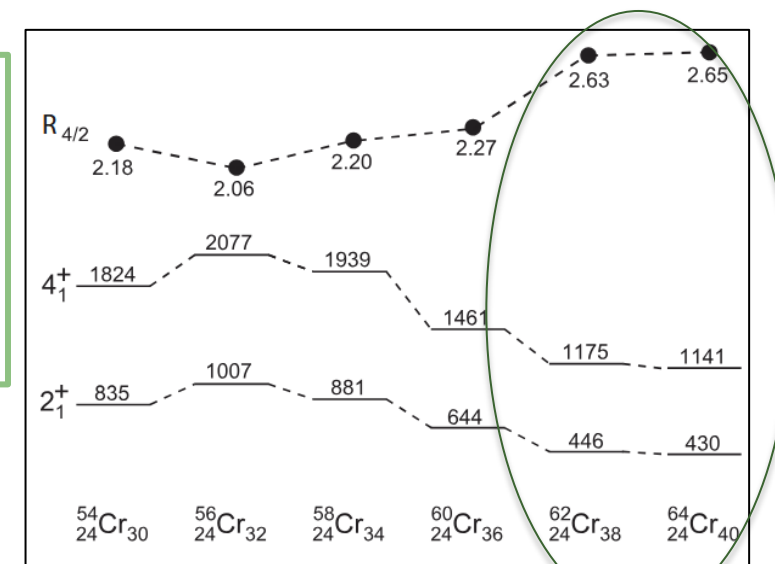


- For N~40 as protons are removed from $f_{7/2}$, attractive monopole interaction between $\pi f_{7/2}$ - $\nu f_{5/2}$ decreases.
- Structurally similar as N=20 Island of Inversion.
- Including the $\nu g_{9/2}$ orbital in the shell-model description seems to explain the collective properties in Fe, Cr near N~40.

Decay Spectroscopy at N~40: Evolution towards N=50

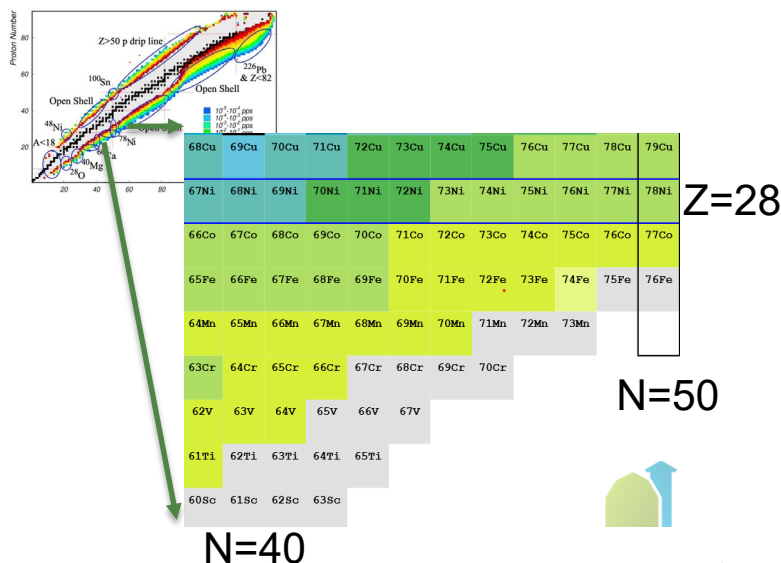


- Systematics of Cr isotopes reveal the evolution from spherical to deformed shape.
- N=32 appears to be a sub-shell gap.
- Maximum deformation reported in ^{64}Cr at N=40 in a β -decay experiment.

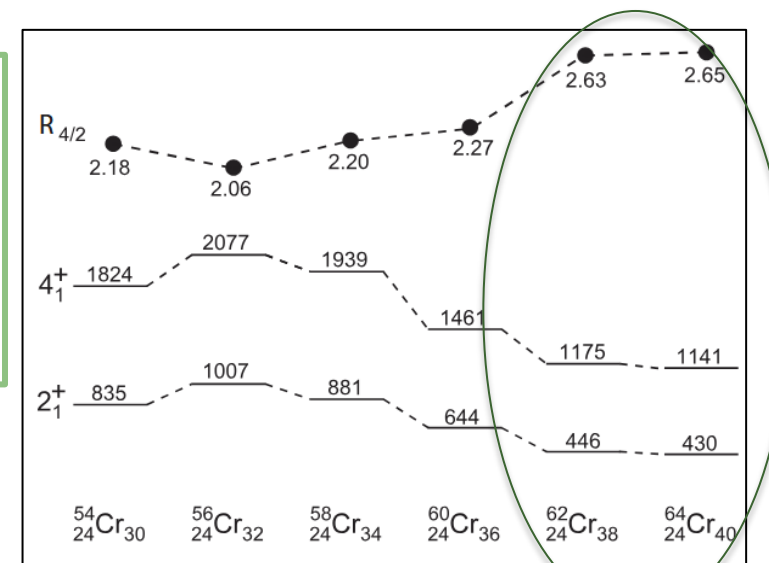


S. Suchyta et al, Phys. Rev. C **89**, 067303

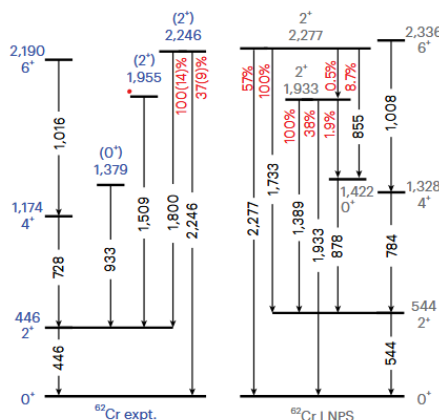
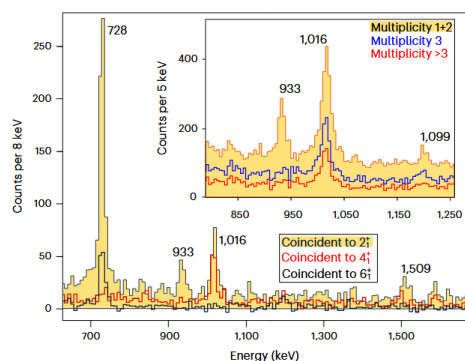
Decay Spectroscopy at N~40: Evolution towards N=50



- Systematics of Cr isotopes reveal the evolution from spherical to deformed shape.
- N=32 appears to be a sub-shell gap.
- Maximum deformation reported in ^{64}Cr at N=40 in a β -decay experiment.



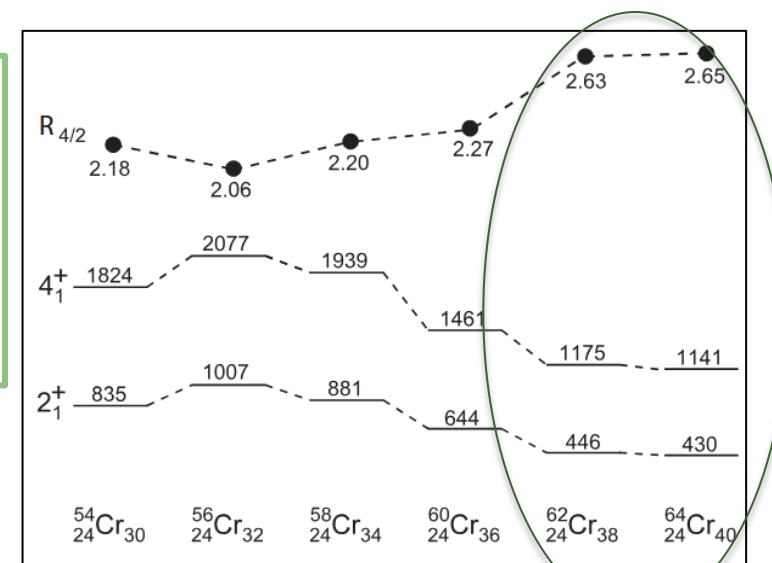
S. Suchyta et al, Phys. Rev. C **89**, 067303



- Shape coexistence was reported in ^{62}Cr through the observation of 0^+ excited state.
- $0^+_{1/2}$ was discussed to be dominated by 4p4h and $0^+_{2/2}$ was by 2p2h.
- Established ^{62}Cr as the portal of the N=40 'Island of Inversion'.
- The decay experiment in this region will push toward more neutron-rich for Cr, Fe and Ni isotopes.

A. Gade et al., *Nature Physics* volume **21**, pages 37–42 (2025)

- Experiment e23055: B. Crider et al.



The figure displays two energy level diagrams for the ^{62}Cr and ^{63}Cr LNPS systems. The left diagram represents the ^{62}Cr expt. data, and the right diagram represents the ^{63}Cr LNPS data. Both diagrams show energy levels in cm^{-1} and corresponding transition probabilities and branching ratios.

^{62}Cr expt. Data:

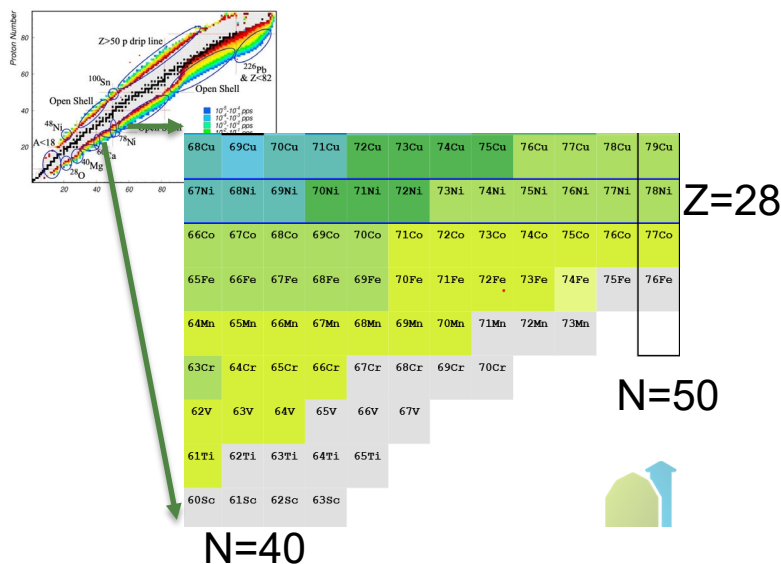
- Energy levels: 0^+ , 2^+ (446), 4^+ (1,174), 6^+ (2,190).
- Transitions and Probabilities:
 - $0^+ \rightarrow 2^+$: 446
 - $2^+ \rightarrow 4^+$: 728
 - $4^+ \rightarrow 6^+$: 1,016
 - $0^+ \rightarrow 4^+$: 1,379 (0%)
 - $2^+ \rightarrow 6^+$: 1,509 (100%)
 - $4^+ \rightarrow 6^+$: 1,800 (100%)
 - $2^+ \rightarrow 6^+$: 1,955 (37%)

^{63}Cr LNPS Data:

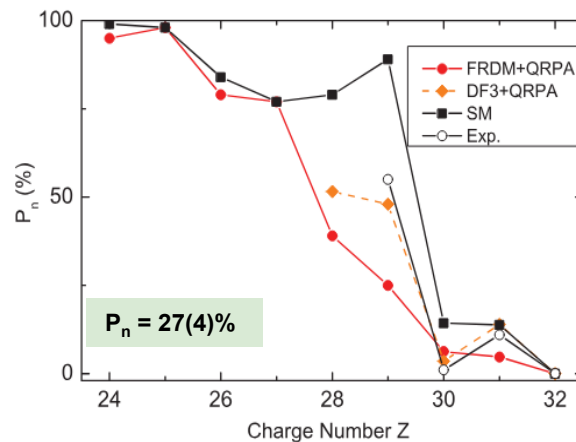
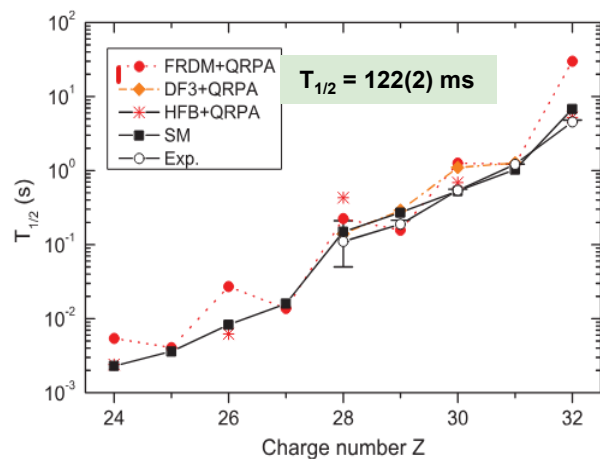
- Energy levels: 0^+ , 2^+ (544), 4^+ (1,328), 6^+ (2,336).
- Transitions and Probabilities:
 - $0^+ \rightarrow 2^+$: 544
 - $2^+ \rightarrow 4^+$: 784
 - $4^+ \rightarrow 6^+$: 1,008
 - $0^+ \rightarrow 4^+$: 1,422 (0%)
 - $2^+ \rightarrow 6^+$: 1,733 (57%)
 - $4^+ \rightarrow 6^+$: 1,933 (38%)
 - $2^+ \rightarrow 6^+$: 1,933 (100%)
 - $4^+ \rightarrow 6^+$: 855 (8.7%)
 - $2^+ \rightarrow 6^+$: 2,277 (100%)

- A. Gade et al.,
- Nature Physics*
- volume 21, pages 37–42 (2025)

β Decay of ^{78}Ni , $N=50$

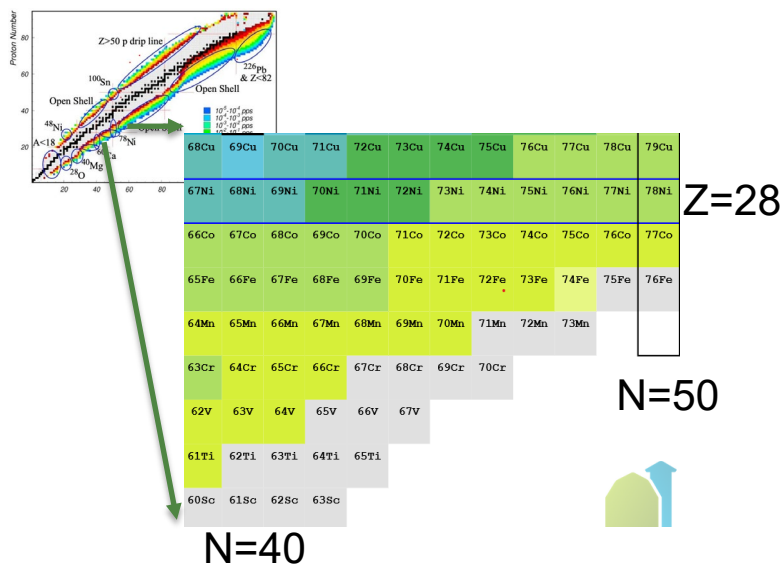


- $T_{1/2}$ well predicted by including the GT+FF; impact of FF transition on r-process is inevitable.
- Theory overpredicted P_n .
- β -decay strength distribution to the states of ^{78}Cu will provide critical test for theoretical models.

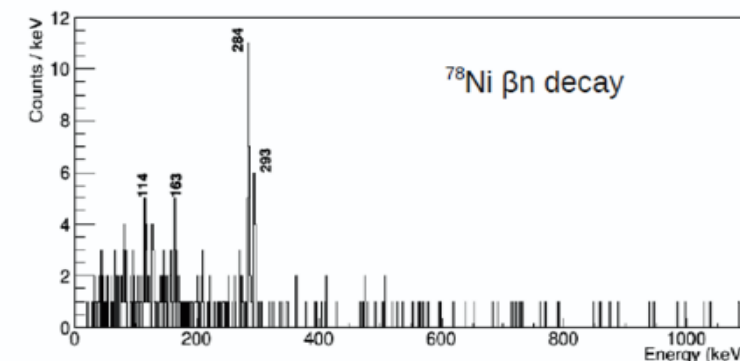
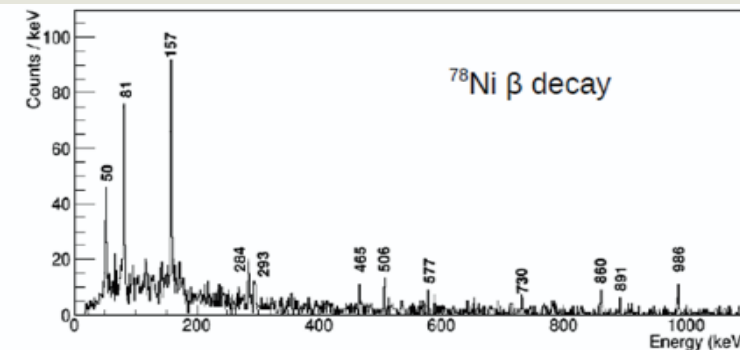


Q. Zhi et al., Phys. Rev. C **87**, 025803

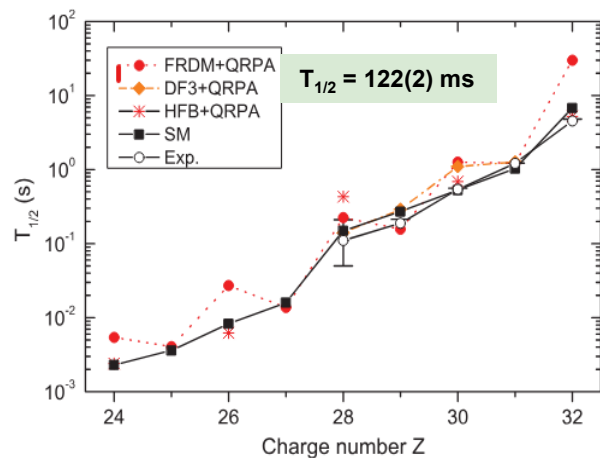
β Decay of ^{78}Ni , $N=50$



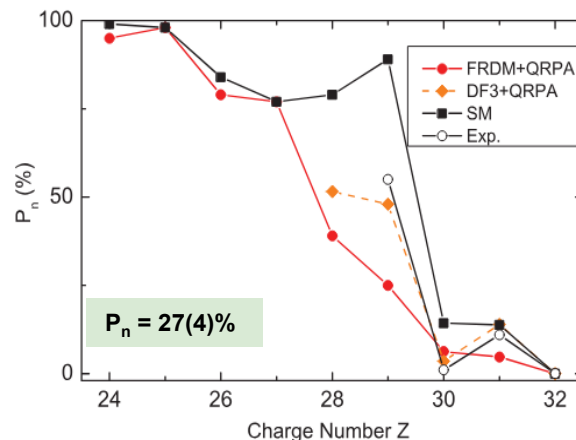
- $T_{1/2}$ well predicted by including the GT+FF; impact of FF transition on r-process is inevitable.
- Theory overpredicted P_n .
- β -decay strength distribution to the states of ^{78}Cu will provide critical test for theoretical models.



K. Rykaczewski et al., RIKEN Accelerator Report 51

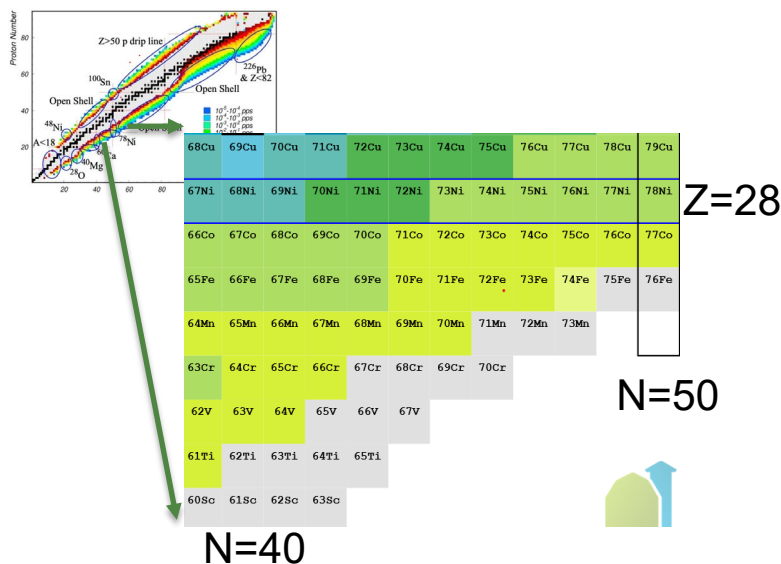


Q. Zhi et al., Phys. Rev. C **87**, 025803

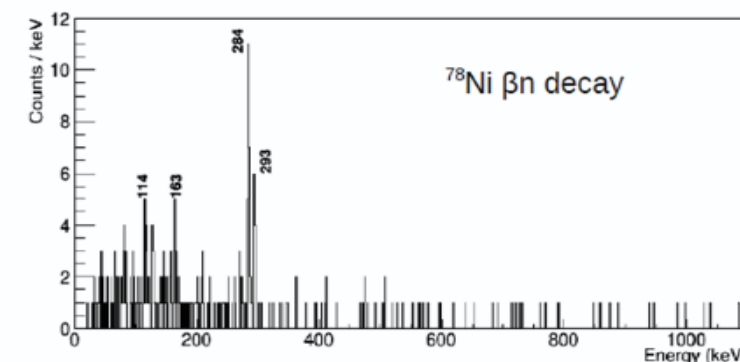
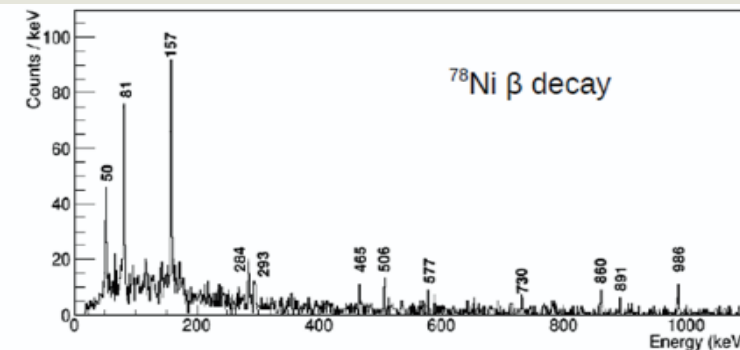


- Allowed GT transition of ^{78}Ni will populate 1^+ states in ^{78}Cu .
- No known 1^+ states in ^{78}Cu .
- High resolution γ -ray spectroscopy identified three low-energy transitions.

β Decay of ^{78}Ni , $N=50$

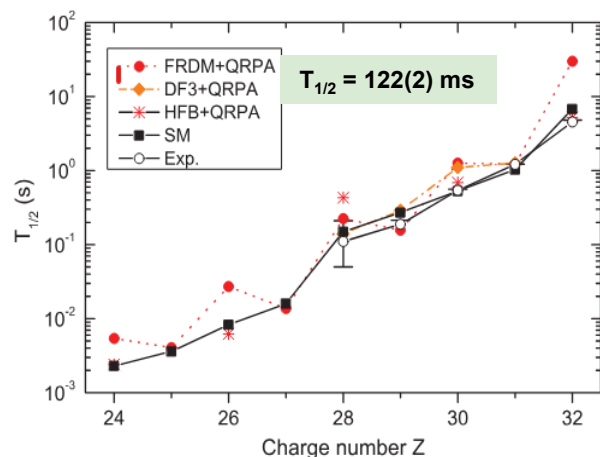


- $T_{1/2}$ well predicted by including the GT+FF; impact of FF transition on r-process is inevitable.
- Theory overpredicted P_n .
- β -decay strength distribution to the states of ^{78}Cu will provide critical test for theoretical models.

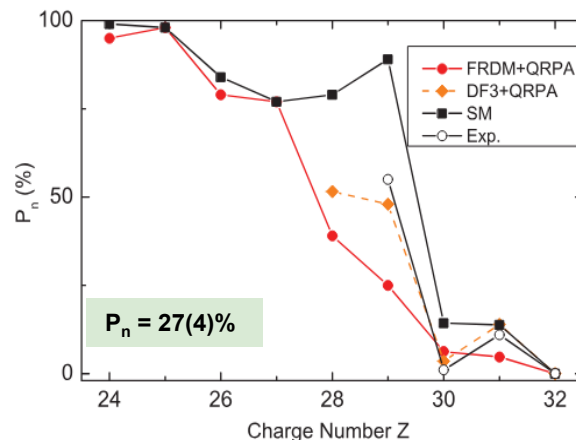


K. Rykaczewski et al., RIKEN Accelerator Report 51

Experiment e21027: K. Rykaczewski.



Q. Zhi et al., Phys. Rev. C **87**, 025803

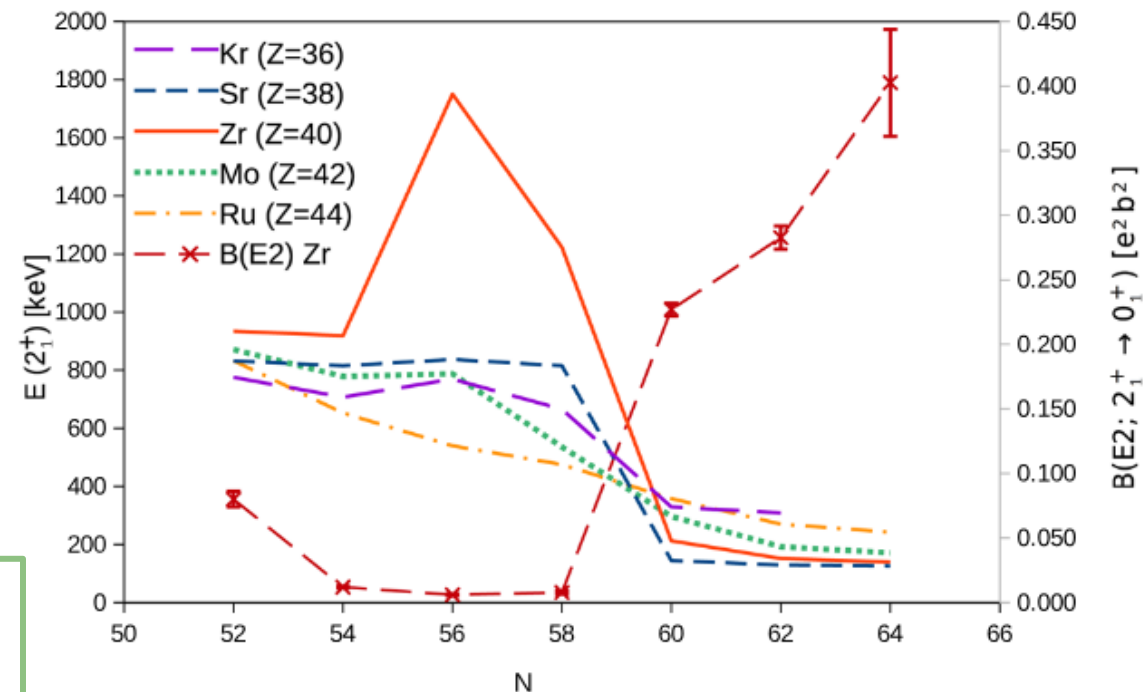


- Allowed GT transition of ^{78}Ni will populate 1^+ states in ^{78}Cu .
- No known 1^+ states in ^{78}Cu .
- High resolution γ -ray spectroscopy identified three low-energy transitions.

Shape Evolution at $A > 100$ $_{40}\text{Zr}$ - $_{46}\text{Pd}$ Region



- A~100, Zr-Pd region offers insight into the shape evolution.
- Collectivity evolves drastically in Zr at N>98.
- Sudden drop of $E(2^+_1)$ and increase in $B(E2)$ in ^{100}Zr .
- Strong residual interaction between $0\pi g_{9/2}$ - $0\nu g_{7/2}$ nucleons was discussed to be responsible for the deformation.

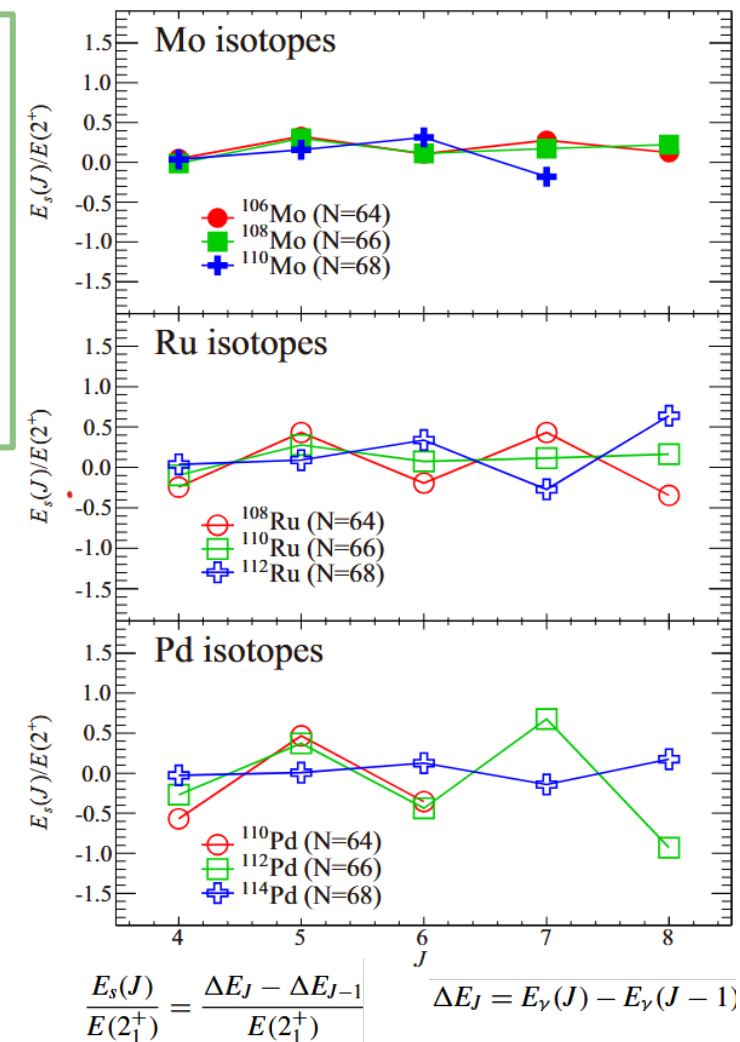


G.Pasqualato et al., EPJ A Vol. 59, article No. 276, (2023)

Shape Evolution at $A > 100$ $_{40}\text{Zr}$ - $_{46}\text{Pd}$ Region



- γ -vibrational band: flat pattern
- γ -soft band: staggering with lower values for even J
- Rigid triaxial rotor: staggering with lower values for odd J.

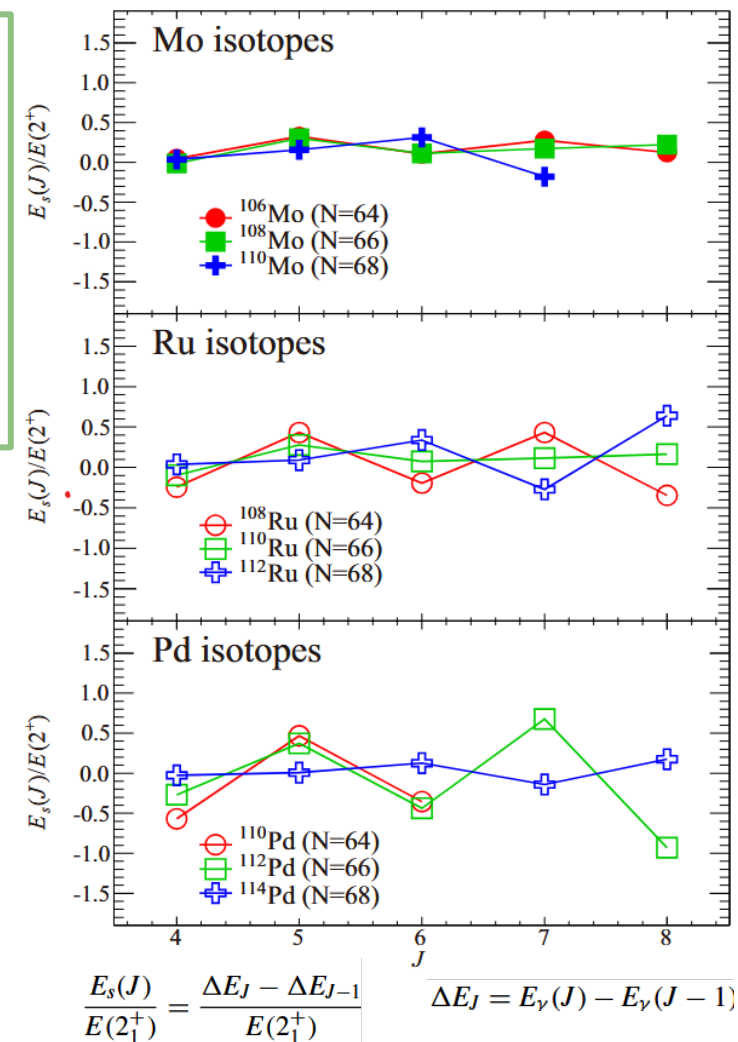
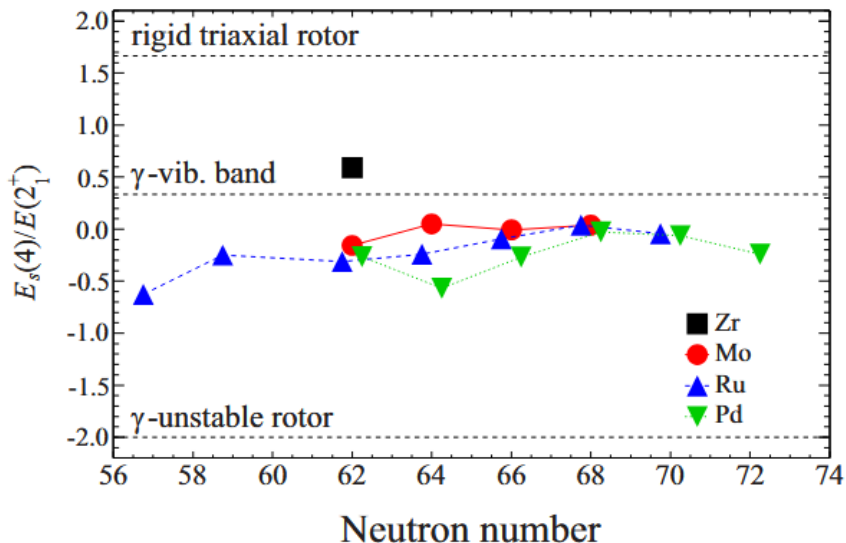


Shape Evolution at $A > 100$ $_{40}\text{Zr}$ - $_{46}\text{Pd}$ Region



- $^{106,108,110}\text{Mo}$ assigned to have gamma vibrational band.
- As the neutron number increases, $\nu_{h11/2}$ starts playing role.

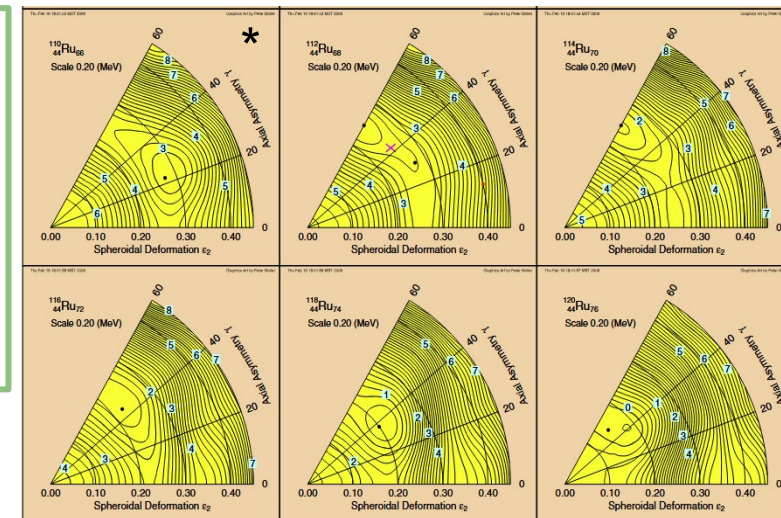
- γ -vibrational band: flat pattern
- γ -soft band: staggering with lower values for even J
- Rigid triaxial rotor: staggering with lower values for odd J.



Shape Evolution at $A > 100$ $_{40}\text{Zr}$ - $_{46}\text{Pd}$ Region

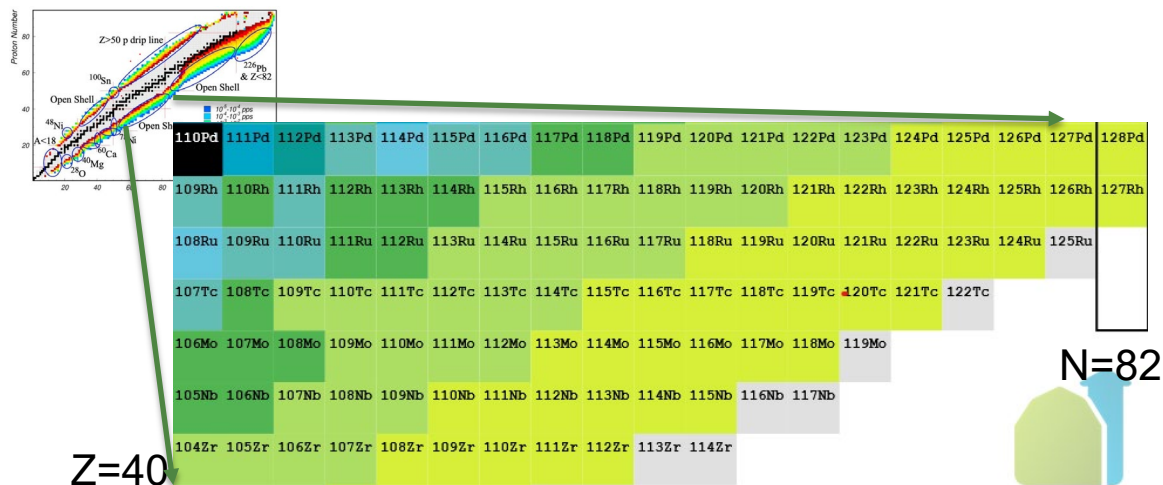


- ^{110}Ru predicted to have strong triaxial deformation.
- Anticipated influence of triaxiality on nuclear binding energy.

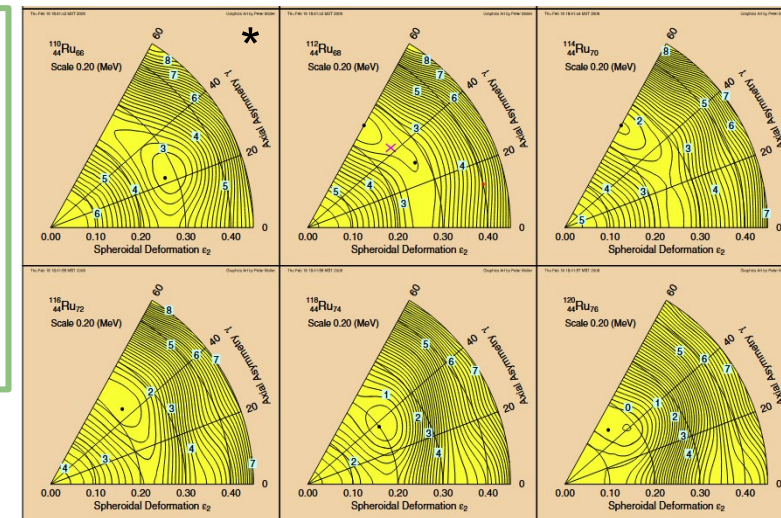


P. Moller et al., Atomic Data and Nuclear Data Tables 94

Shape Evolution at $A > 100$ $_{40}\text{Zr}$ - $_{46}\text{Pd}$ Region

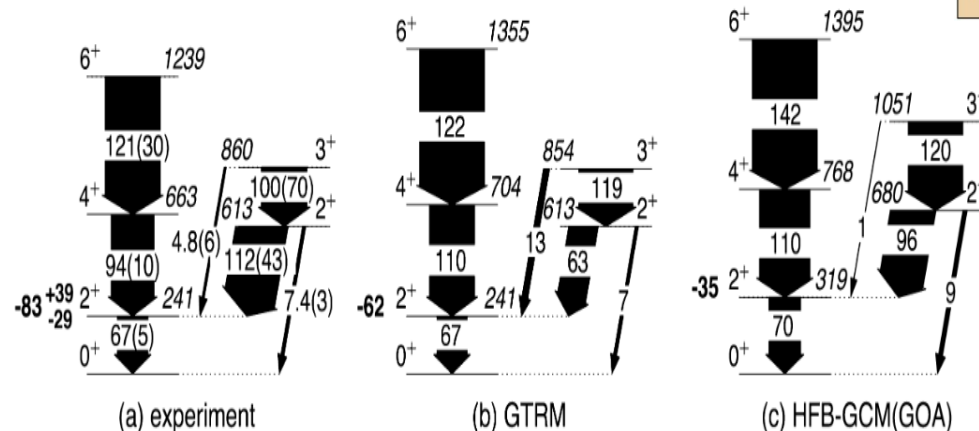


- ^{110}Ru predicted to have strong triaxial deformation.
- Anticipated influence of triaxiality on nuclear binding energy.



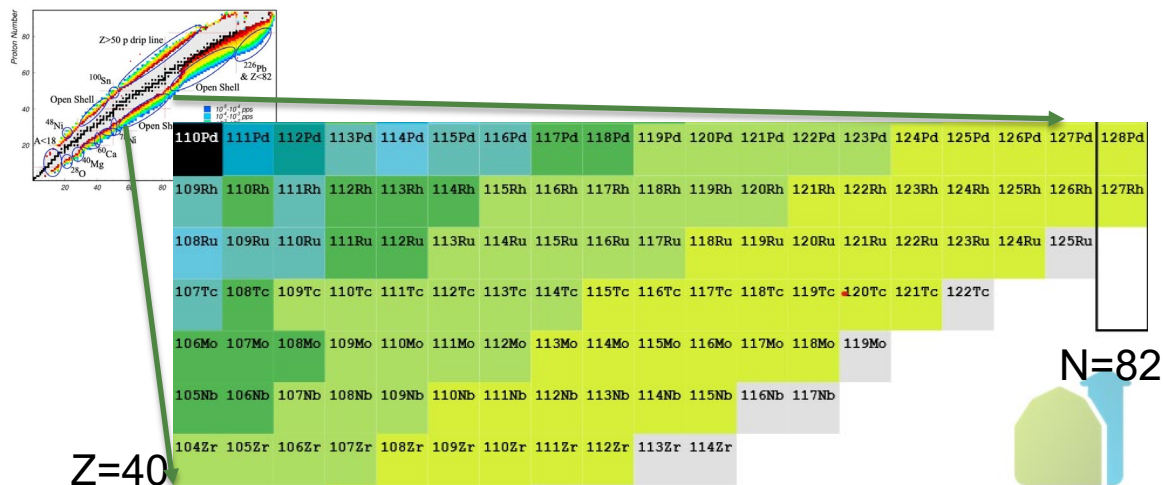
P. Moller et al., Atomic Data and Nuclear Data Tables 94

- A multi-step Coulomb excitation provided evidence of triaxial deformation in ^{110}Ru .
- Strong branching between 2^+_2 - 2^+_1 and weak branching between 2^+_2 - 0^+_1 .
- $E(3_1)=E(2_1)+E(2_2)$.

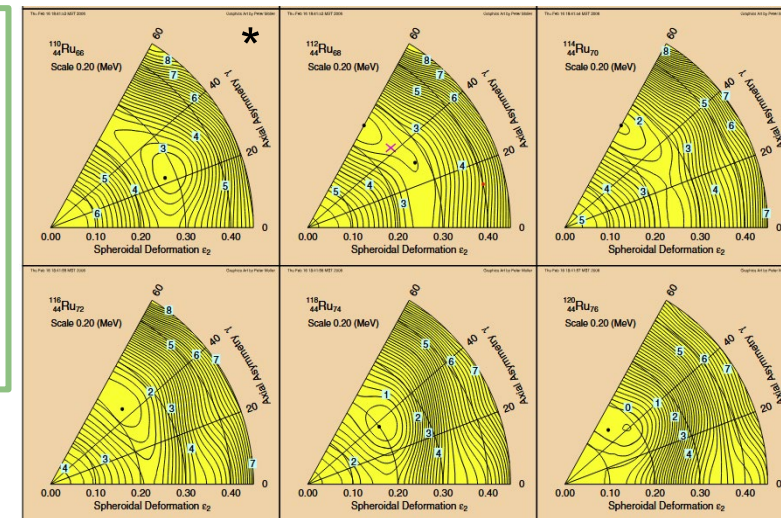


D.T.Doherty et al., Physics Letters B 766 (2017) 334–338

Shape Evolution at $A > 100$ $_{40}\text{Zr}$ - $_{46}\text{Pd}$ Region

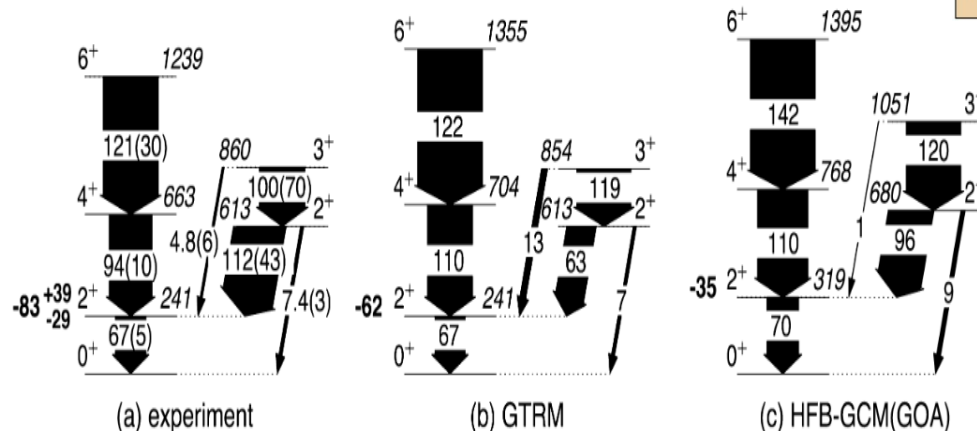


- ^{110}Ru predicted to have strong triaxial deformation.
- Anticipated influence of triaxiality on nuclear binding energy.



P. Moller et al., Atomic Data and Nuclear Data Tables 94

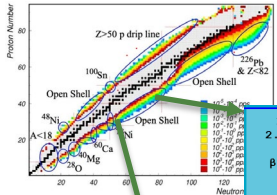
- A multi-step Coulomb excitation provided evidence of triaxial deformation in ^{110}Ru .
- Strong branching between 2^+_2 - 2^+_1 and weak branching between 2^+_2 - 0^+_1 .
- $E(3_1) = E(2_1) + E(2_2)$.



D.T.Doherty et al., Physics Letters B 766 (2017) 334–338

Experiment e21035: M. J. Allmond

Constraining Neutron Capture Rates via β Decay

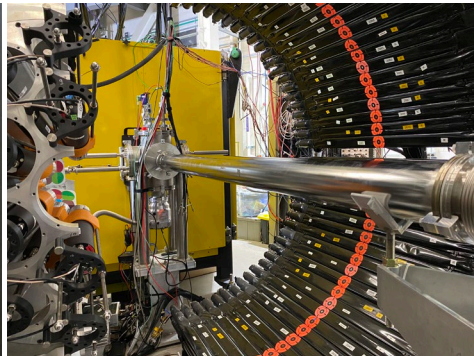
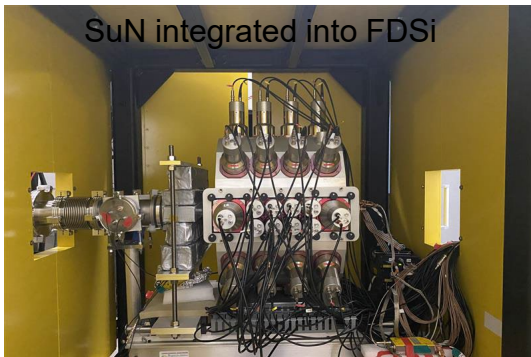
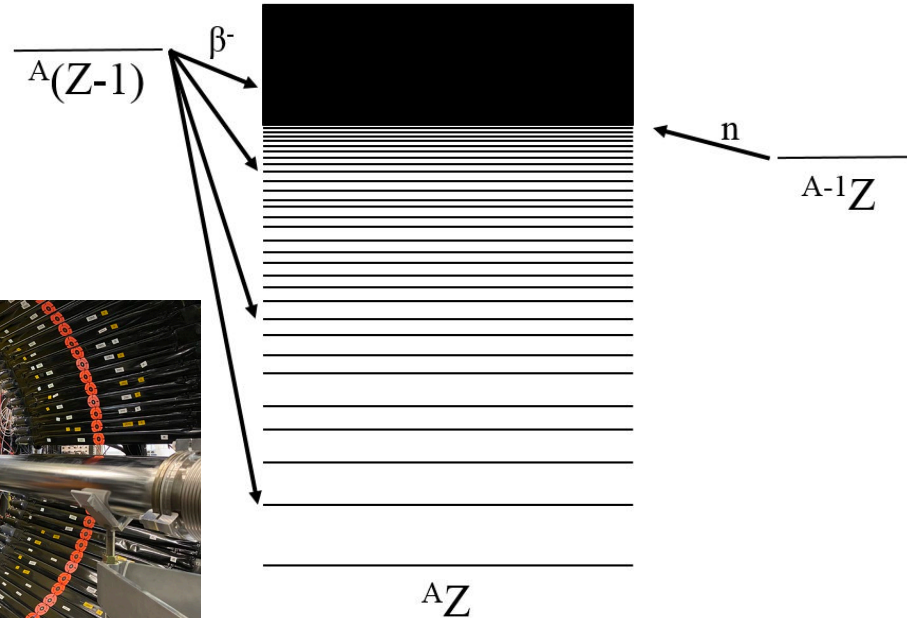


Z=47

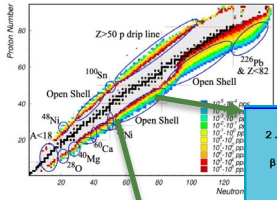
129Sn 2.23 min β^- =100%	130Sn 3.73 min β^- =100%	131Sn 56 s β^- =100%	132Sn 39.7 s β^- =100%	133Sn 1.38 s β^- =100% $\beta^-n=2.94e-2\%$
128In 0.84 s β^- =100% $\beta^-n=0.038\%$	129In 629 ms β^- =100% $\beta^-n=0.228\%$	130In 277 ms β^- =100% $\beta^-n=0.93\%$	131In 261 ms β^- =100% $\beta^-n=2.3\%$	132In 200 ms β^- =100% $\beta^-n=12.3\%$ $\beta^-2n?$
127Cd 0.45 s β^- =100% $\beta^-n<1.2\%$	128Cd 245.9 ms β^- =100% $\beta^-n=1.9\%$	129Cd 151 ms β^- =100% $\beta^-n=1.84\%$	130Cd 129 ms β^- =100% $\beta^-n=3\%$	131Cd 98 ms β^- =100% $\beta^-n=3.5\%$ $\beta^-2n?$
126Ag 52 ms β^- =100% $\beta^-n=3.8\%$	127Ag 89.1 ms β^- =100% $\beta^-n=5.5\%$	128Ag 66.6 ms β^- =100% $\beta^-n=9.3\%$ $\beta^-2n?$	129Ag 52 ms β^- =100% $\beta^-n=17.9\%$	130Ag 41 ms β^- =100% $\beta^-n?$ $\beta^-2n?$
125Pd 64.2 ms β^- =100% $\beta^-n=3.7\%$	126Pd 48.6 ms β^- =100% $\beta^-n=4.9\%$	127Pd 38 ms β^- =100% $\beta^-n=9\%$ $\beta^-2n?$	128Pd 36 ms β^- =100% $\beta^-n=10\%$	129Pd 31 ms β^- =100% $\beta^-n?$ $\beta^-2n?$

N=82

- β -decay to constrain neutron capture reactions in exotic isotopes.
- Extract nuclear level density (NLD) and γ strength function (γ SF) using total absorption spectroscopy.
- Test models for nuclear structure and nuclear astrophysics.
- FRIB experiment e21073: A. Spyrou et al.



Constraining Neutron Capture Rates via β Decay

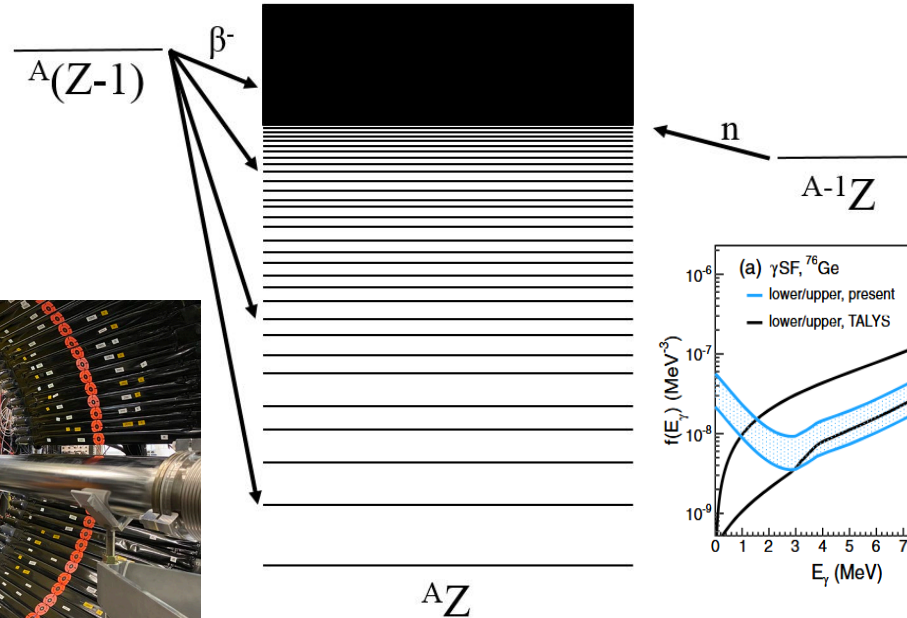


129Sn 2.23 min β^- =100%	130Sn 3.73 min β^- =100%	131Sn 56 s β^- =100%	132Sn 39.7 s β^- =100%	133Sn 1.38 s β^- =100% $\beta^-n=2.94e-2\%$
128In 0.84 s β^- =100% $\beta^-n=0.038\%$	129In 629 ms β^- =100% $\beta^-n=0.228\%$	130In 277 ms β^- =100% $\beta^-n=0.93\%$	131In 261 ms β^- =100% $\beta^-n=2.3\%$	132In 200 ms β^- =100% $\beta^-n=12.3\%$ $\beta^-2n=?$
127Cd 0.45 s β^- =100% $\beta^-n<1.2\%$	128Cd 245.9 ms β^- =100% $\beta^-n=1.9\%$	129Cd 151 ms β^- =100% $\beta^-n=1.84\%$	130Cd 129 ms β^- =100% $\beta^-n=3\%$	131Cd 98 ms β^- =100% $\beta^-n=3.5\%$ $\beta^-2n=?$
126Ag 52 ms β^- =100% $\beta^-n=3.8\%$	127Ag 89.1 ms β^- =100% $\beta^-n=5.5\%$	128Ag 66.6 ms β^- =100% $\beta^-n=9.3\%$ $\beta^-2n=?$	129Ag 52 ms β^- =100% $\beta^-n=17.9\%$	130Ag 41 ms β^- =100% $\beta^-n=?$ $\beta^-2n=?$
125Pd 64.2 ms β^- =100% $\beta^-n=3.7\%$	126Pd 48.6 ms β^- =100% $\beta^-n=4.9\%$	127Pd 38 ms β^- =100% $\beta^-n=9\%$ $\beta^-2n=?$	128Pd 36 ms β^- =100% $\beta^-n=10\%$	129Pd 31 ms β^- =100% $\beta^-n=?$ $\beta^-2n=?$

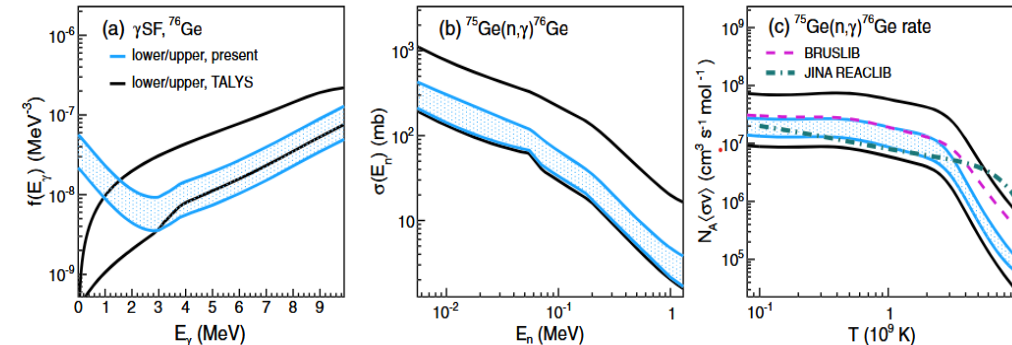
Z=47

N=82

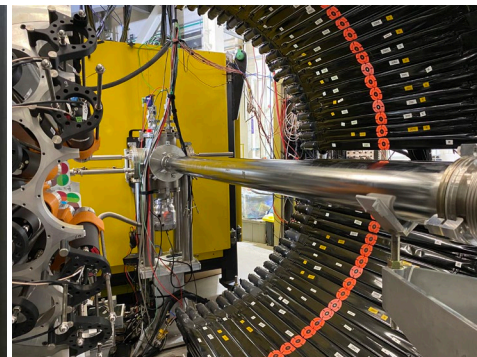
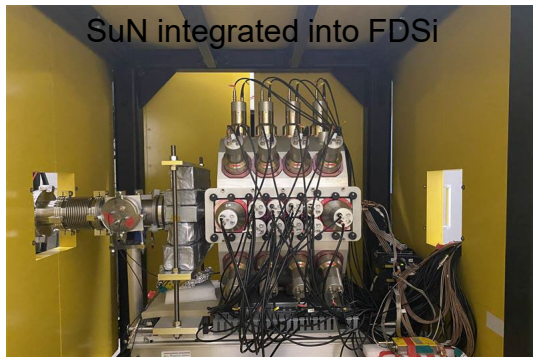
- β -decay to constrain neutron capture reactions in exotic isotopes.
- Extract nuclear level density (NLD) and γ strength function (γ SF) using total absorption spectroscopy.
- Test models for nuclear structure and nuclear astrophysics.
- FRIB experiment e21073: A. Spyrou et al.



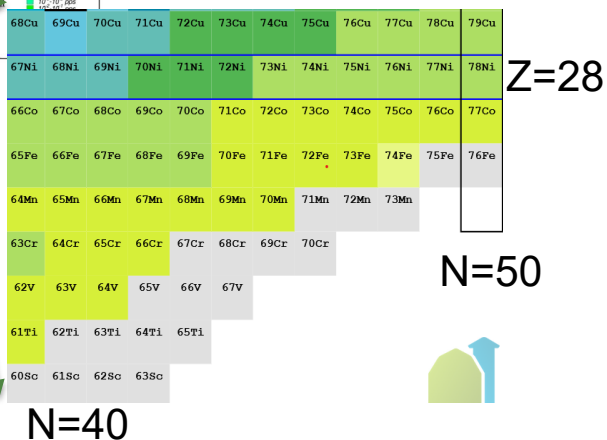
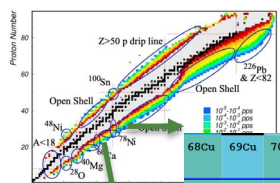
- $^{75}\text{Ge}(n, \gamma)^{76}\text{Ge}$ reaction rate was constrained utilizing β decay of ^{76}Ga .



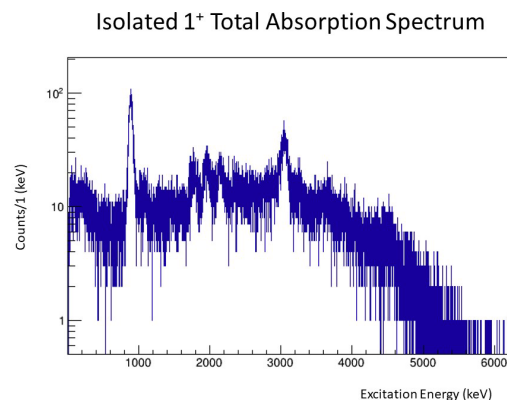
A.Spyrou et al., Phys. Rev. Lett. **113**, 232502



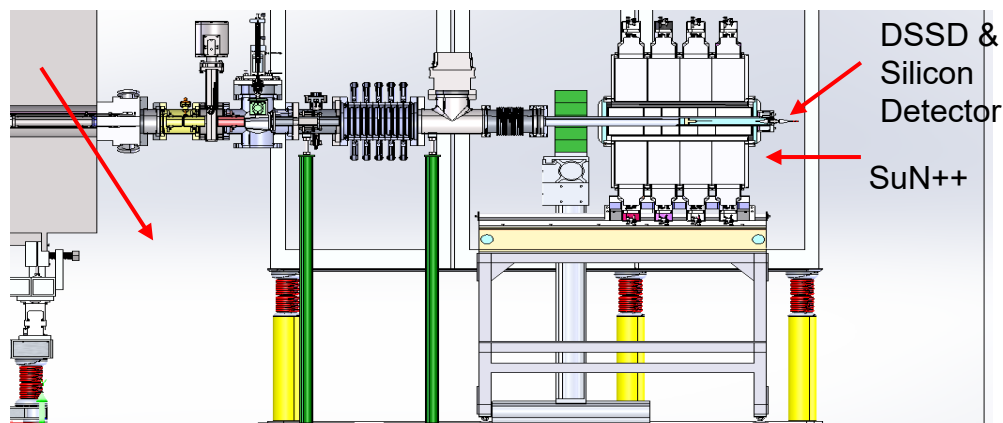
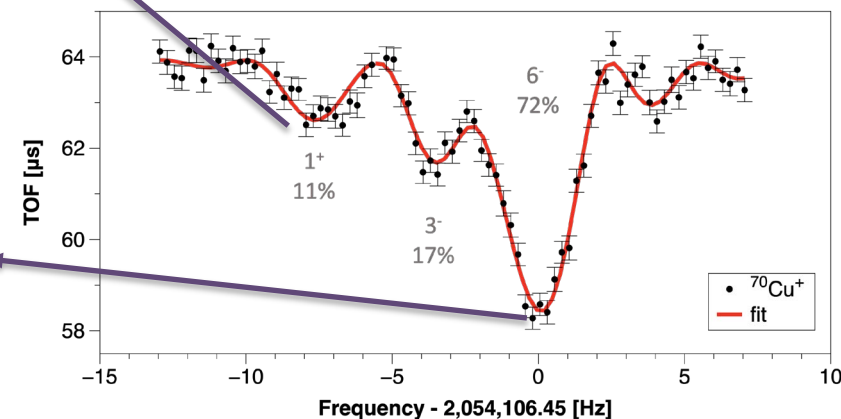
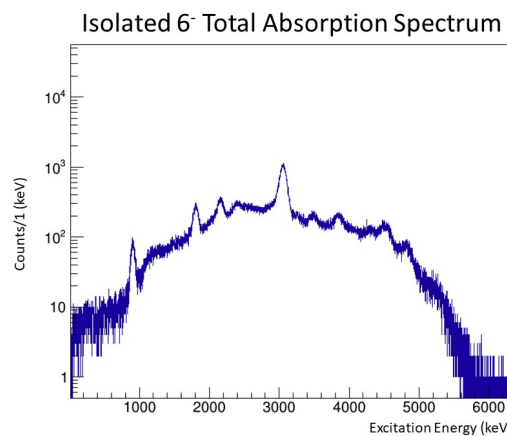
Constraining Neutron Capture Rates via β Decay



- Test models for nuclear structure and nuclear astrophysics.
- FRIB experiment e23004: E. Ronning et al.

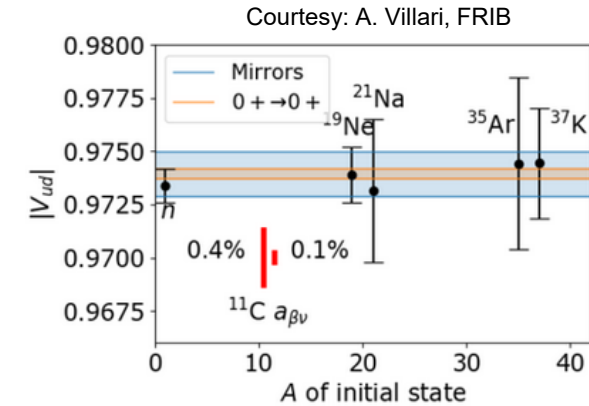


- LEBIT can separate the β -decaying isomeric states.
- Ground and isomeric states of different spins will populate different levels of descendent nuclei.
- Test the spin independence of GBA hypothesis.



β -decay Measurements to Search new Physics

- Superconducting Array for Low-Energy Radiation (SALER).
- Uses a Superconducting Tunnel Junction (STJ) array detector.
- Search for physics Beyond Standard Model (BSM).
- Study of beta-neutrino correlation $a_{\beta\nu}$ by measuring beta and sub-keV recoil.
- $a_{\beta\nu}$ is sensitive to V_{ud} , a component of CKM matrix.
- Led by K. Leach, Colorado School of Mines.



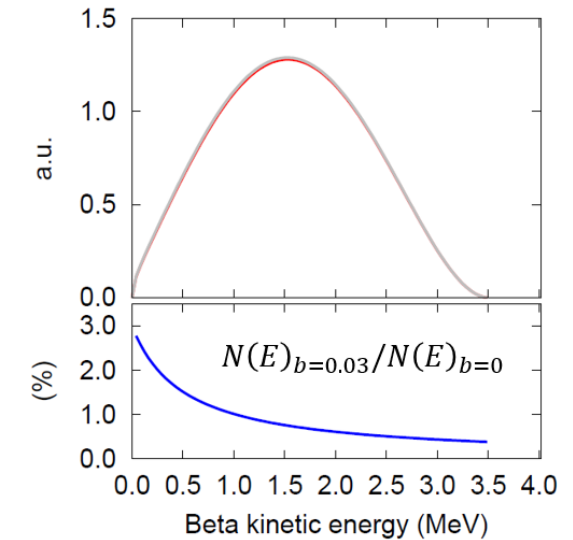
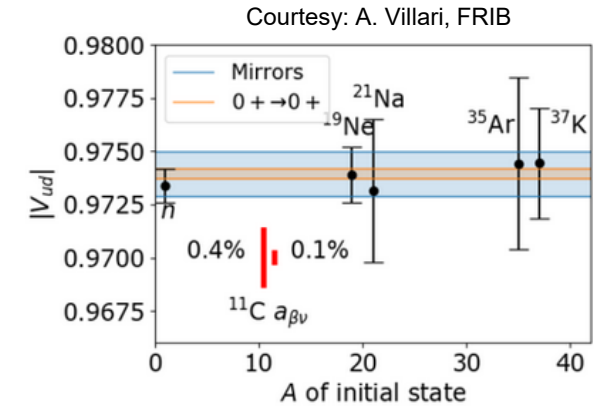
β -decay Measurements to Search new Physics

- Superconducting Array for Low-Energy Radiation (SALER).
- Uses a Superconducting Tunnel Junction (STJ) array detector.
- Search for physics Beyond Standard Model (BSM).
- Study of beta-neutrino correlation $a_{\beta\nu}$ by measuring beta and sub-keV recoil.
- $a_{\beta\nu}$ is sensitive to V_{ud} , a component of CKM matrix.
- Led by K. Leach, Colorado School of Mines.

- Determine Fierz term from β energy spectrum.

$$N(E) \propto (1 + \eta)pE(E - E_0)^2 \left(1 + \frac{m}{E} b_{GT}\right)$$

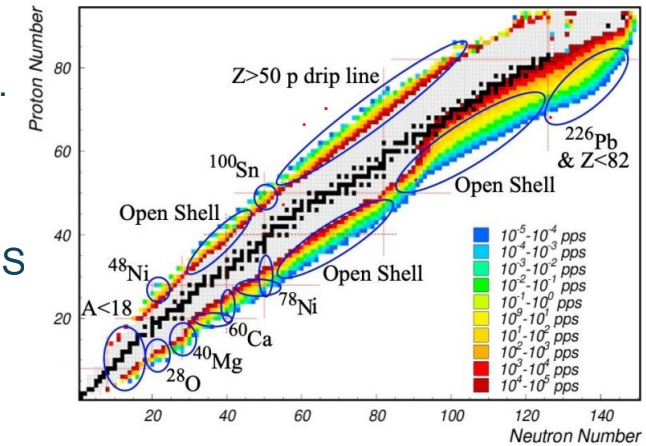
- $b_{GT} \rightarrow$ sensitivity of the Fierz term.
- $b_{GT} = 0$ in Standard Model
- A non-zero b_{GT} will provide indication of deviation from SM.
- Led by O. Naviliat-Cuncic, MSU, FRIB.



Courtesy: O. Naviliat-Cuncic, FRIB, MSU

Approved Experiments

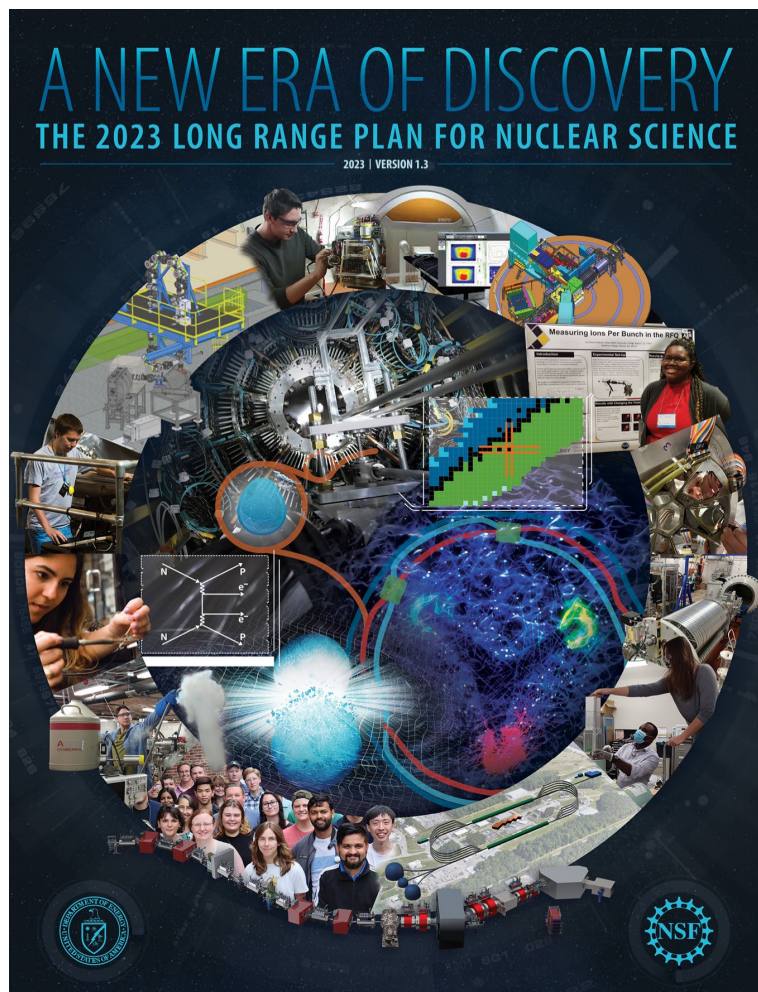
- e21027 Decoding the doubly magic stronghold - decay spectroscopy of ^{78}Ni .
- e21035 Correlation of Triaxial Deformation with Inertial Dynamics, Masses and r-Process Nucleosynthesis.
- e21062 Decay Spectroscopy Near $N=28$: Shell Structure, Shapes and Weak Binding.
- e21073 Constraining neutron capture rates for the r-process.
- e21021 Complete decay spectroscopy of ^{100}Sn and its neighbors.
- e21069 Decay spectroscopy of the $N=35$ nuclei ^{55}Ca , ^{54}K and ^{53}Ar and the search for dripline nucleus ^{50}S
- e21080 Decay spectroscopy in the vicinity of the $N=126$ shell closure.
- e21072 Strength of the key $^{15}\text{O}(\alpha, \gamma)^{19}\text{Ne}$ resonance in X-ray bursts.
- e23004 The last piece of Generalized Brink Axel Hypothesis Puzzle.
- e23035 Is there a NiCu Cycle in X-ray Bursts?
- e23055 Decay Spectroscopy Near $N = 40$: toward the $N = 50$ island of inversion near ^{78}Ni .
- e23064 Seniority Isomers and Single-Particle Evolution in 218-222Pb Region: New Isotopes, Isomers, and Half Lives.
- e23071 The Study of Proton-Rich Isotopes Along the Proton Drip-Line above ^{100}Sn .
- e23076 Intersections of nuclear structure and statistical model in βn -decays of cobalt isotopes and isomers.
- e25046 Measuring $^{57}\text{Ni}(p, \gamma)^{58}\text{Cu}$ reaction rate through β -decay of ^{58}Zn .
- e25052 $^{34}\text{Cl}(p, \gamma)^{35}\text{Ar}$ reaction rate in classical novae: Measurement of ^{35}K decay with GADGET I.
- e25058 Strength of the key $^{15}\text{O}(\alpha, \gamma)^{19}\text{Ne}$ resonance in X-ray bursts: Run 2.
- e25065 Exploring the Drip-Line Around ^{60}Ca : Insights into Nuclear Stability.
- e25072 Role of nuclear structure and statistical effects on beta-delayed neutron emission.
- e25077 Constraining the nucleosynthesis of ytterbium by the r-process.
- e25079 Beta-decay of ^{31}F in the drip line of the island of inversion.
- e25084 Demonstrating new methods for beta-delayed fission.



Summary and Outlook

- β -decay experimental program at FRIB is broad, explore everywhere possible in the nuclear chart.
- Addresses issues on nuclear structure, nuclear astrophysics, physics beyond Standard Model.
- Measurements at the extreme ends on the nuclear chart will reveal the nature of nuclear force, shed light on the elemental formation in the stellar environment and enrich our understanding on the models of fundamental interaction.
- Increasing beam power will allow access to more exotic isotopes and help resolving outstanding puzzles.

The 2023 NSAC Long Range Plan



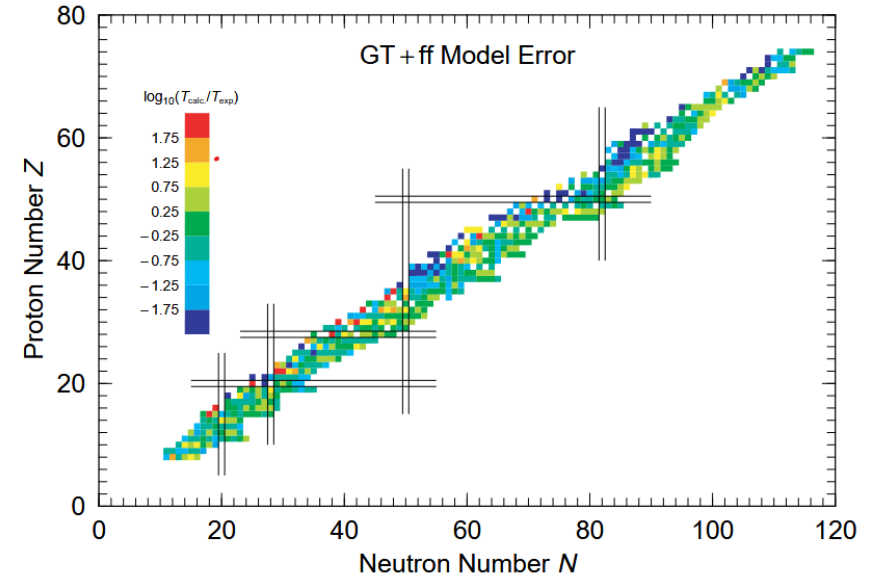
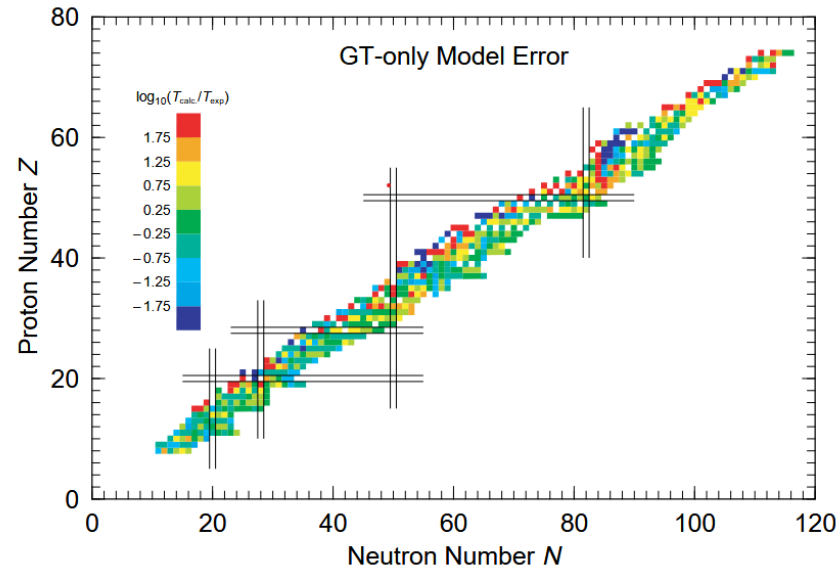
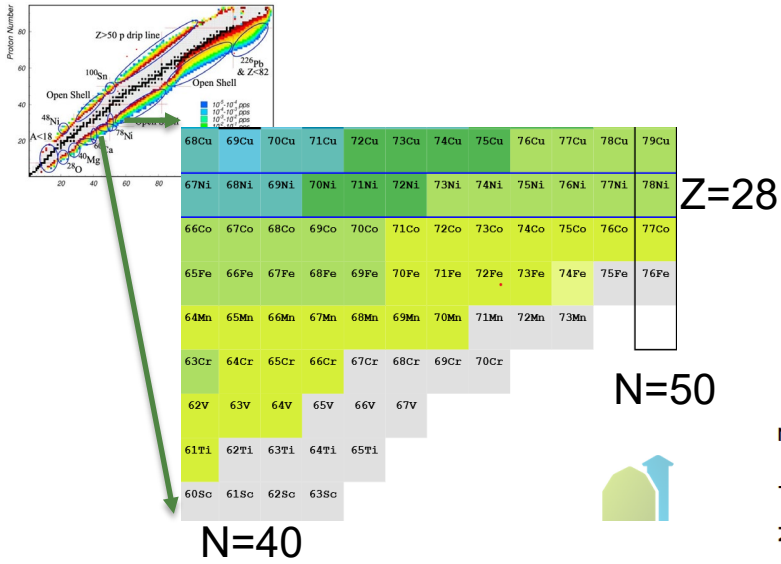
- “**The field of nuclear structure** and reactions is **at the brink of a new age of discovery** with exciting opportunities at the **newly operational FRIB**, upgrades to the ATLAS facility, the complementary unique capabilities of the university-based laboratories...”
- “**The scientific challenges for both experiment and theory lie in producing and modeling the most neutron-rich nuclei that can exist.**”
- **The highest priority** of this Long-Range Plan is to capitalize on the extraordinary opportunities for **scientific discovery made possible by recent investments.**

Thank you

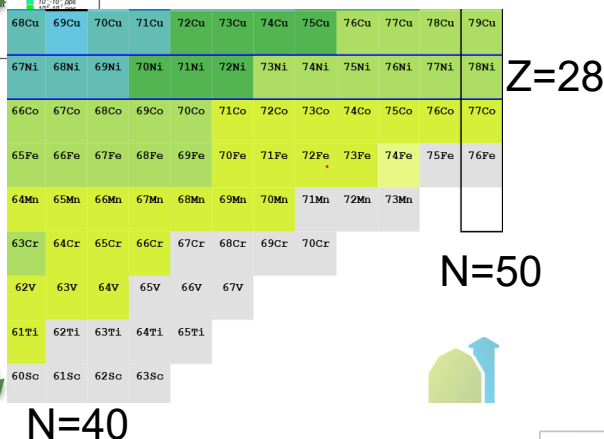
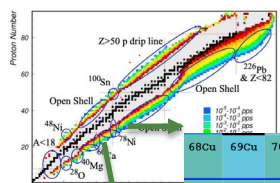
Work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Grant No DE-SC0020451 (FRIB)

Back up

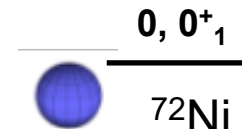
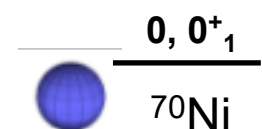
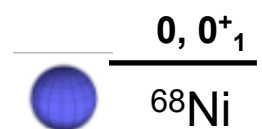
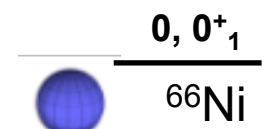
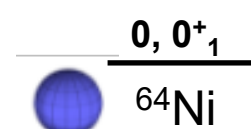
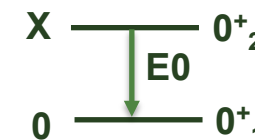
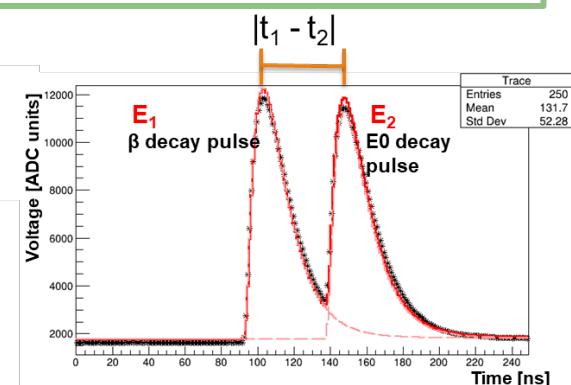
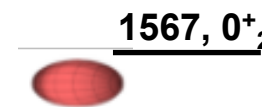
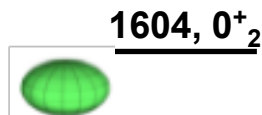
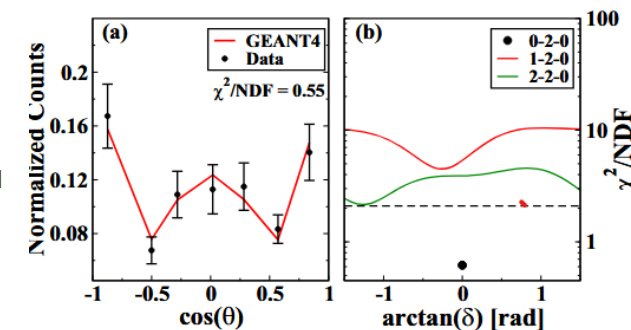
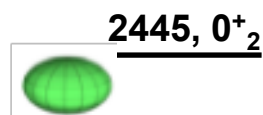
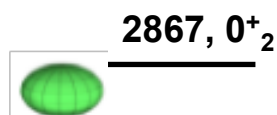
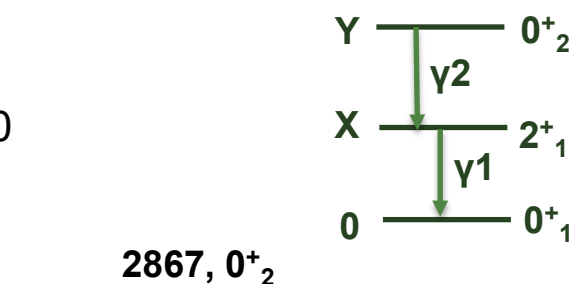
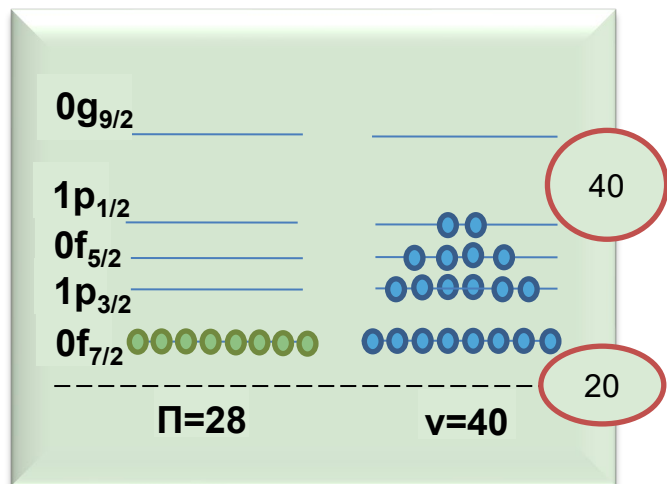
- Fifth Island of Inversion (Iol) at N=50 and ^{78}Ni β -decay.

P. Moler et al., Phys. Rev. C **67**, 055802

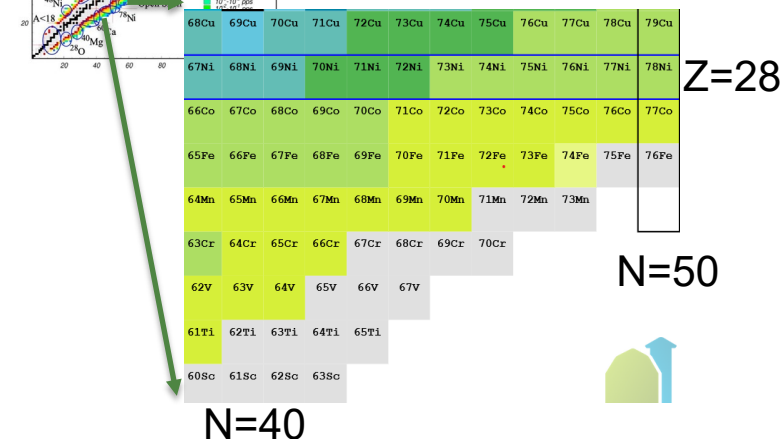
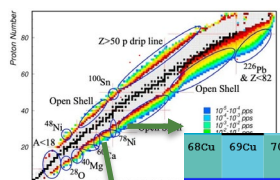
Decay Spectroscopy at N~40: Evolution towards N=50



- Shape coexistence in proton closed shell Ni isotopes is well established at N~40.
- Adding neutrons in $g_{9/2}$ orbitals can attribute to dramatic structural change.
- Moving towards more exotic isotopes will shed light on the evolution towards the possible N=50 Iol.



Decay Spectroscopy at N~40: Evolution towards N=50



- Understanding the states of the odd-mass isotopes at N~40 will shed light on the nature of the excited 0^+ states.
- Can predict for more exotic Ni isotopes.

