Exploring shape coexistence in neutron-rich nuclei near N=40 via lifetime measurements at NSCL

Ben Crider
NUSTAR Week 2017
September 29, 2017
Neutron-rich nuclei near N = 40

- Originally, the N = 40 subshell gap looked like a strong shell closure based on initial properties observed for $^{68}\text{Ni}$.

- Neighboring nuclei do not share similar features.
Nuclear structure near $N = 40$: $^{68}\text{Ni}$

$^{68}\text{Ni}$

$0g_{9/2}$  $50$

$1p_{1/2}$  $40$

$0f_{5/2}$

$1p_{3/2}$

$0f_{7/2}$  $28$

Protons  Neutrons


Nuclear structure near $N = 40$: $^{68}\text{Ni}$

- The low-lying structure of these nuclei can be strongly influenced by deformation-driving proton and neutron excitations across their respective shell gaps.

Nuclear structure near N = 40: odd-A Co isotopes

• We can look to the odd-A Co isotopes for some insight...

- How do these proton and neutron excitations affect the structure of $^{68}\text{Co}$?

$^{68}\text{Co}$


Systematics of deformed intruder states

- The decrease in energy of the deformed intruder state is consistent across all three isotopic chains.

- Systematics point to the coexistence of spherical and deformed configurations for many nuclei near N = 40, including $^{68}$Co.

- Need to go beyond systematics to measuring transition strengths and comparing with large-scale theoretical calculations.

Nuclear Shape Coexistence

- Multiple states with different coexisting configurations at similar excitation energy
  - Hallmark of shape coexistence in even-even nuclei is multiple low-lying $0^+$ states

Advanced shell model calculations using the full $fp g_{9/2}d_{5/2}$ model space for both protons and neutrons predict triple shape coexistence

$^{68}\text{Ni}$


Ni Shape Coexistence II


Ni Shape Coexistence III

$^{68}\text{Ni}$

$E(\text{keV})$

$\beta > 0.4$

$\beta = -0.16$


MCSM calculations also predict shape coexistence in $^{70}$Ni

- Deepening of the prolate potential well

Fragmentation of a fast-moving, heavy, stable beam on a thin stable target

- $^{76}$Ge beam at ~130 MeV/A
- 282 µg/cm² $^9$Be target
NSCL Experiment: Detection Systems

• Use beta decay to populate excited states of exotic nuclei near A = 68
• Combine detection systems to simultaneously achieve fast timing information and high-resolution energy measurements

Central Implantation Detectors: Implanted ions from beam and beta decays


Ions identified event-by-event are implanted. Position and arrival time recorded for all implanted ions

Some characteristic time later a decay is detected. Position and time of decay recorded.

• Decays are correlated to ions using spatial and temporal information
• Time scales: Beta decay: $\sim 10^{-3}$ s, Gamma decay: $\sim 10^{-15}$ to $10^{-9}$ s
Central Implantation Detectors: Implanted ions from beam and beta decays


C.J. Prokop, B.P. Crider, S.N. Liddick et al., (in prep.)

$^{68}\text{Cu}$

$\beta^-$

$2^+ \rightarrow 1077.4$-keV $\gamma$ ray

$1077.4$-keV $\gamma$ ray

$0^+ \rightarrow 0$

$^{68}\text{Zn}$

Lifetime Results

$^{70}\text{Co}$ $\beta^-$ $^{70}\text{Ni}$

$^{448}\text{keV}$ $\gamma$ ray

$6^+$ $\rightarrow$ $2677$ $1.05(3)$ ns [1]

$4^+$ $\rightarrow$ $2229$

$^{68}\text{Zn} 1077$ keV $t_{1/2}$ (lit.) = $1.61(2)$ ps

$^{70}\text{Ni} 448$ keV $t_{1/2}$ (exp.) = $1.04(24)$ ns
$t_{1/2}$ (lit.) = $1.05(3)$ ns

$^{70}\text{Ni} 478$ keV $t_{1/2} = 0.57(5)$ ns

$^{70}\text{Ni} 307$ keV $t_{1/2} = 1.6^{+1.2}_{-0.8}$ ns

Correlated decays into $^{70}\text{Ni}$

- $^{68}\text{Zn}$ 1077 keV
  - $t_{1/2}$ (lit.) = 1.61(2) ps

- $^{70}\text{Ni}$ 448 keV
  - $t_{1/2}$ (exp.) = 1.04(24) ns
  - $t_{1/2}$ (lit.) = 1.05(3) ns

- $^{70}\text{Ni}$ 478 keV
  - $t_{1/2} = 0.57(5)$ ns

- $^{70}\text{Ni}$ 307 keV
  - $t_{1/2} = 1.6^{+1.2}_{-0.8}$ ns
Lifetime Results

Lifetime Results

Putting it all together for $^{68,70}\text{Ni}$…


Putting it all together for $^{68,70}\text{Ni}$...

Conclusions

• Evidence for shape coexistence is apparent in Ni nuclei in the neutron-rich N = 40 region. As for $^{68}\text{Co}$…?

• A recent experiment at NSCL coupling fast-timing and high-resolution detection systems has enabled an expansion of the information in $^{68,70}\text{Ni}$ and $^{68}\text{Co}$.

• LaBr$_3$ detectors enable clear determination of half-lives in the region $> \sim 10^{-13}$ s.

• If branching ratios are also known, one can compare transition strength results with large-scale theoretical predictions.
Acknowledgements

Collaborators

NSCL: S. N. Liddick, C. J. Prokop, J. Chen, A. C. Dombos, N. Larson, R. Lewis, S. J. Quinn, and A. Spyrou,


ARL: J. J. Carroll and C. J. Chiara  

UMD: J. Harker and W. B. Walters

Padova: F. Recchia  

UTK: M. Alshudifat, S. Go, R. Grzywacz  

LBL: S. Suchyta

Funding

This work was supported in part by the National Science Foundation (NSF) under Contract No. PHY-1102511 (NSCL) and Grant No. PHY-1350234 (CAREER), by the Department of Energy National Nuclear Security Administration (NNSA) under Award No. DE-NA0000979 and Grant No. DE-NA0002132, by the U.S Department of Energy, Office of Science, Office of Nuclear Physics, under Contract No. DE-AC-06CH11357 (ANL) and Grant Nos. DE-FG02-94ER40834 (Maryland) and DE-FG02-96ER40983 (UT), and by the U.S. Army Research Laboratory under Cooperative Agreement W911NF-12-2-0019.