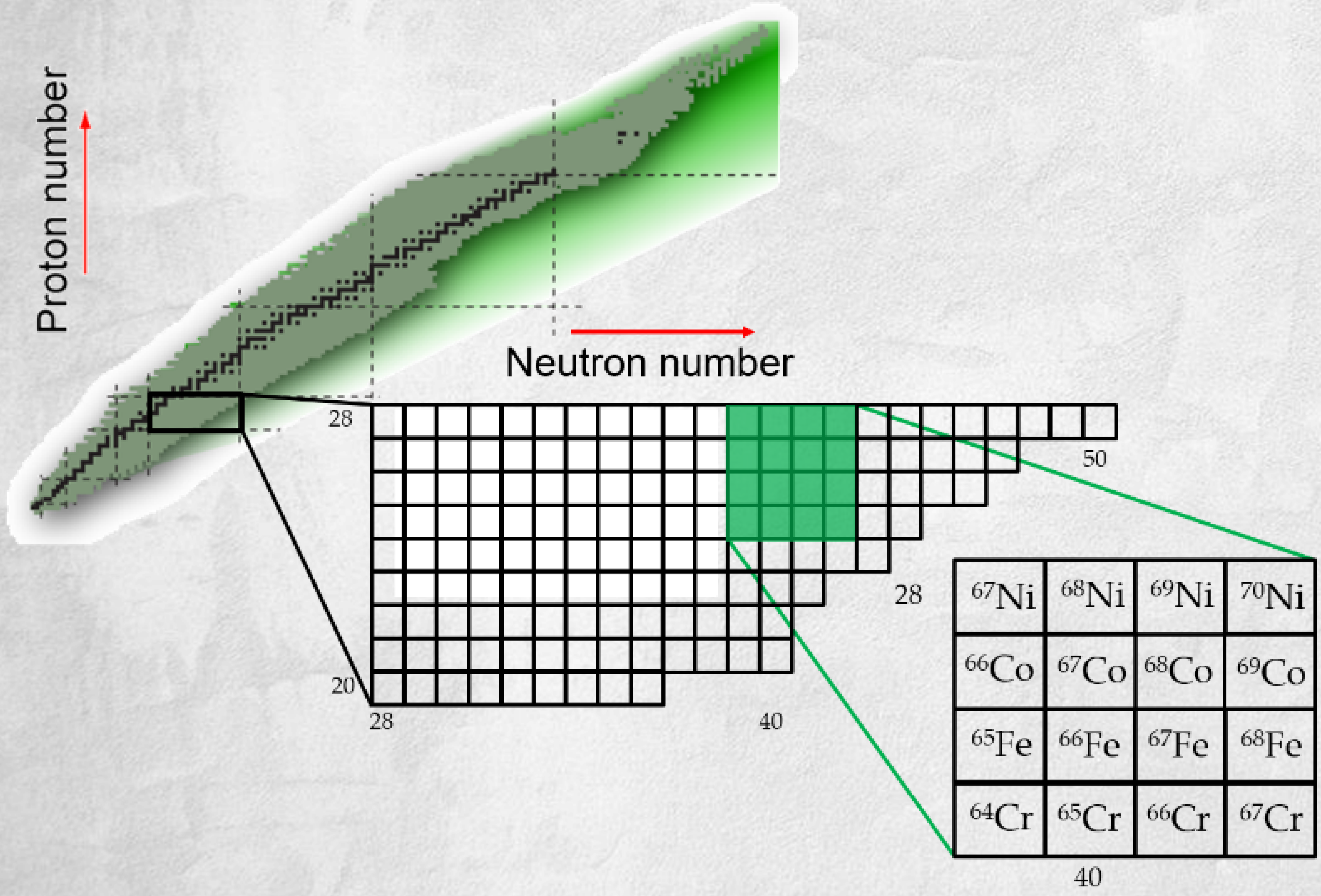
Exploring shape coexistence in neutron-rich nuclei near N=40 via lifetime measurements at NSCL

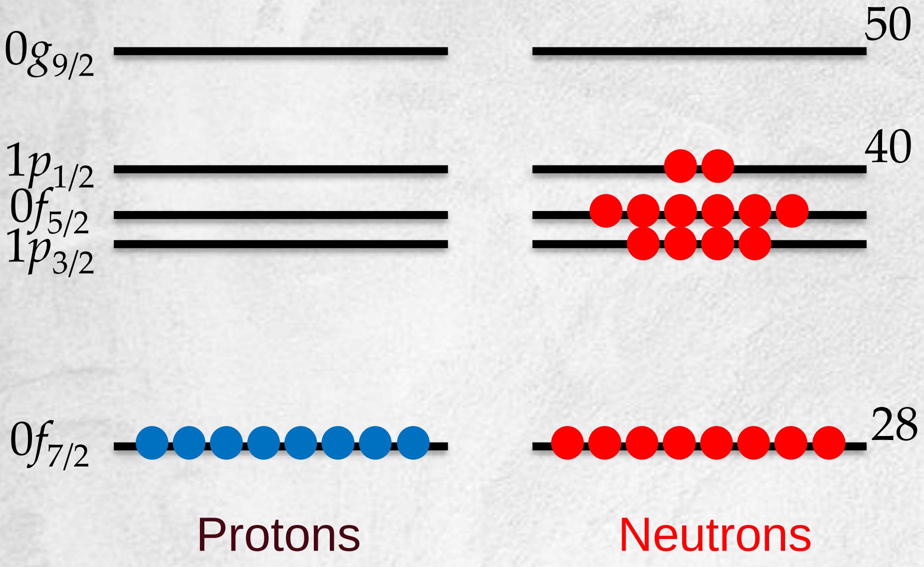
Ben Crider
NUSTAR Week 2017
September 29, 2017

Neutron-rich nuclei near N = 40

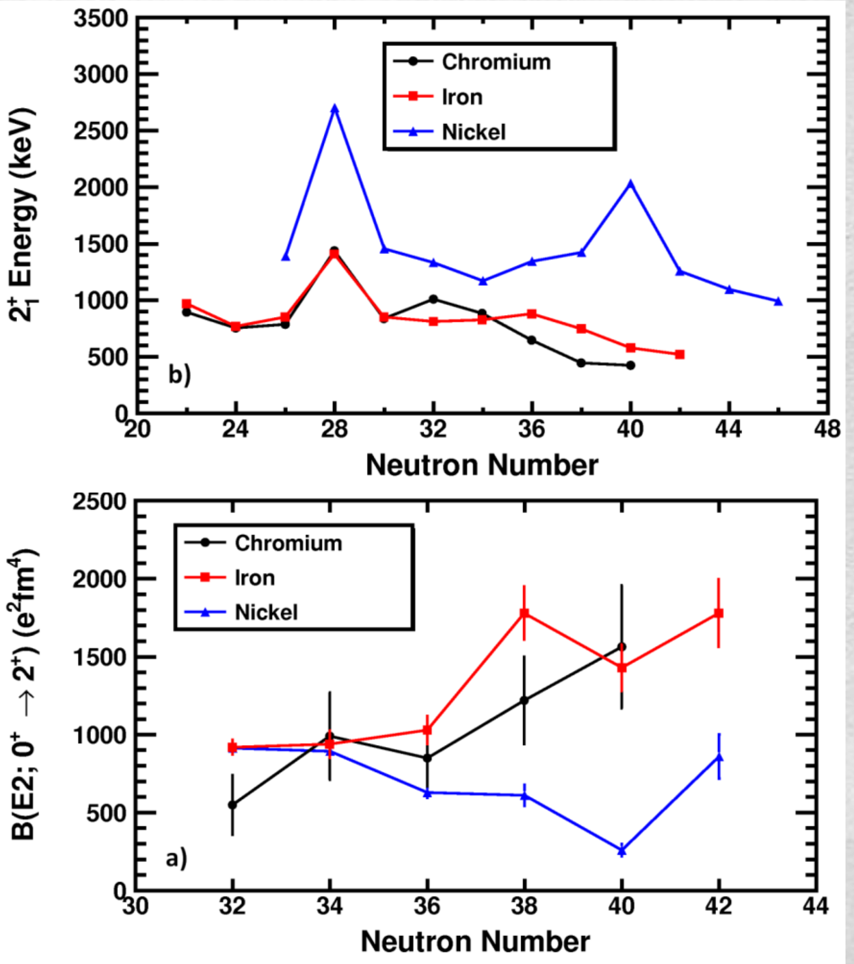


- Originally, the N = 40 subshell gap looked like a strong shell closure based on initial properties observed for ^{68}Ni.
- Neighboring nuclei do not share similar features

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



^{68}Ni



Bernas, M. *et al.*, Physics Letters B **113**, 279 (1982).
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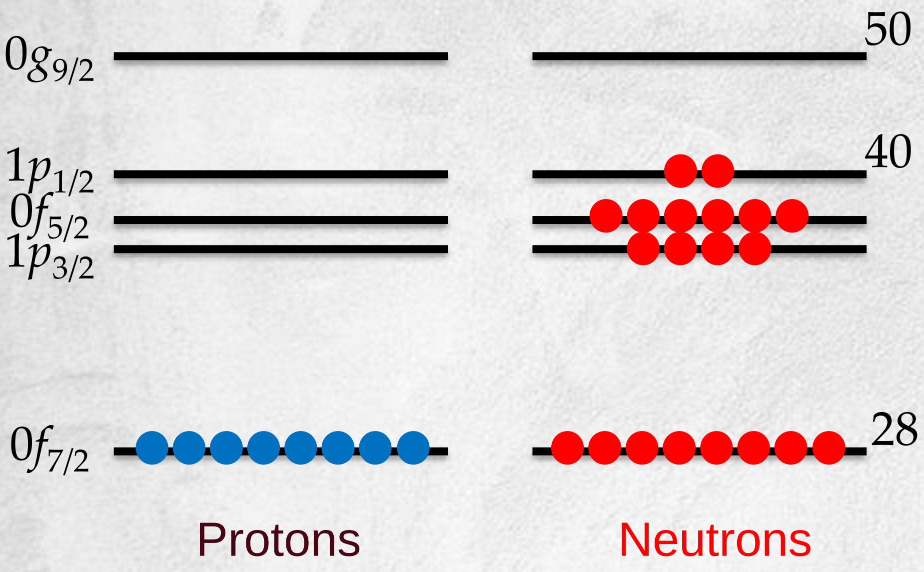
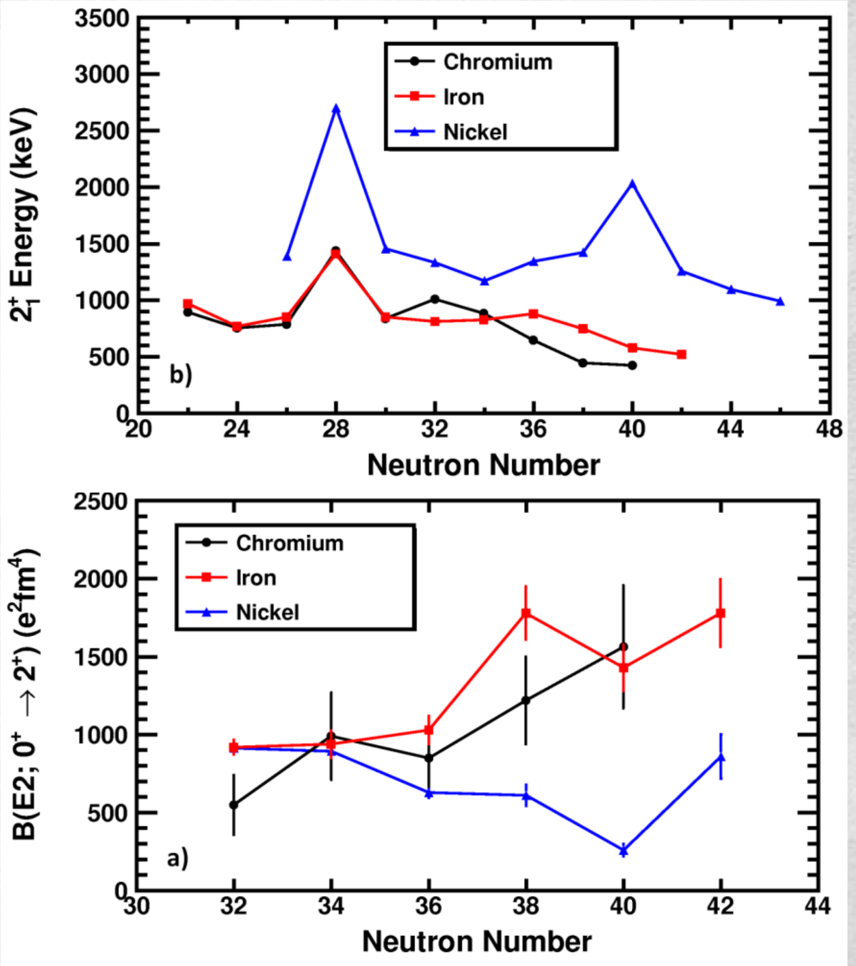
Crawford, H. *et al.*, Phys. Rev. Lett. **110**, 242701 (2013).

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



^{68}Ni

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



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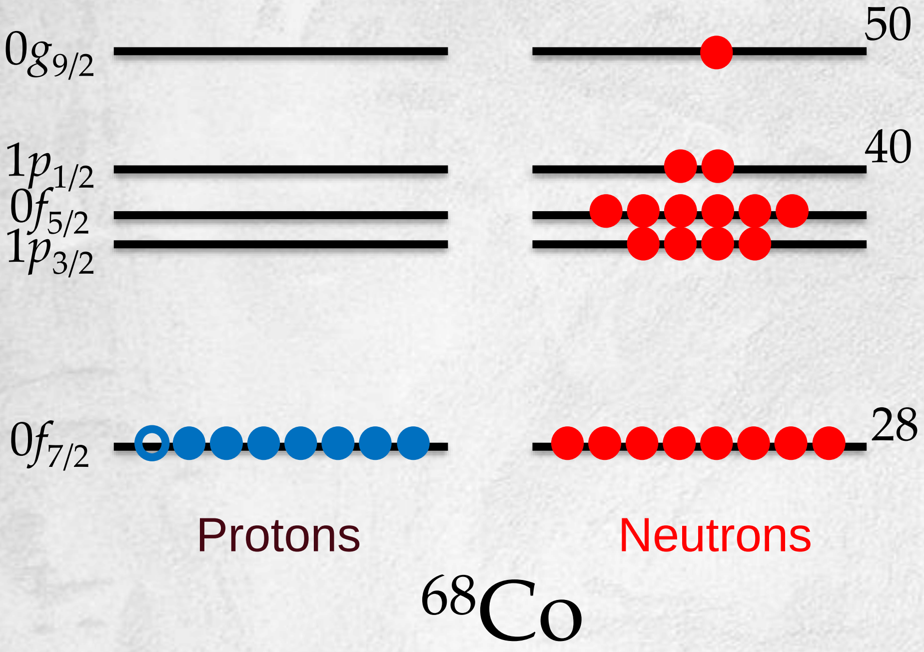
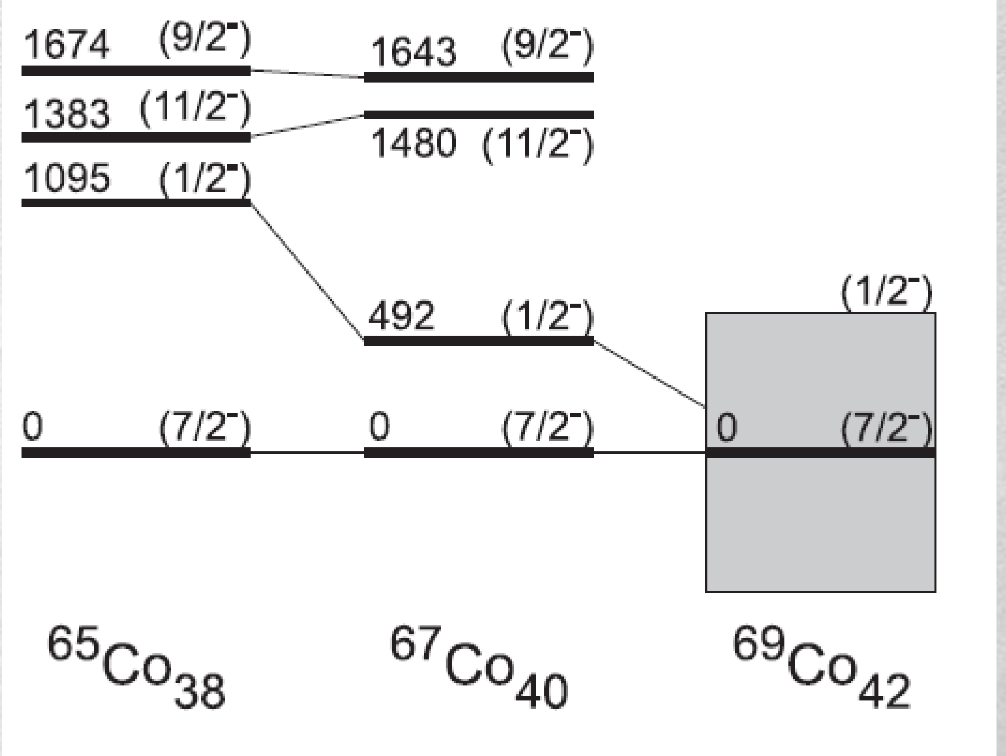
Crawford, H. *et al.*, Phys. Rev. Lett. **110**, 242701 (2013).

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



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

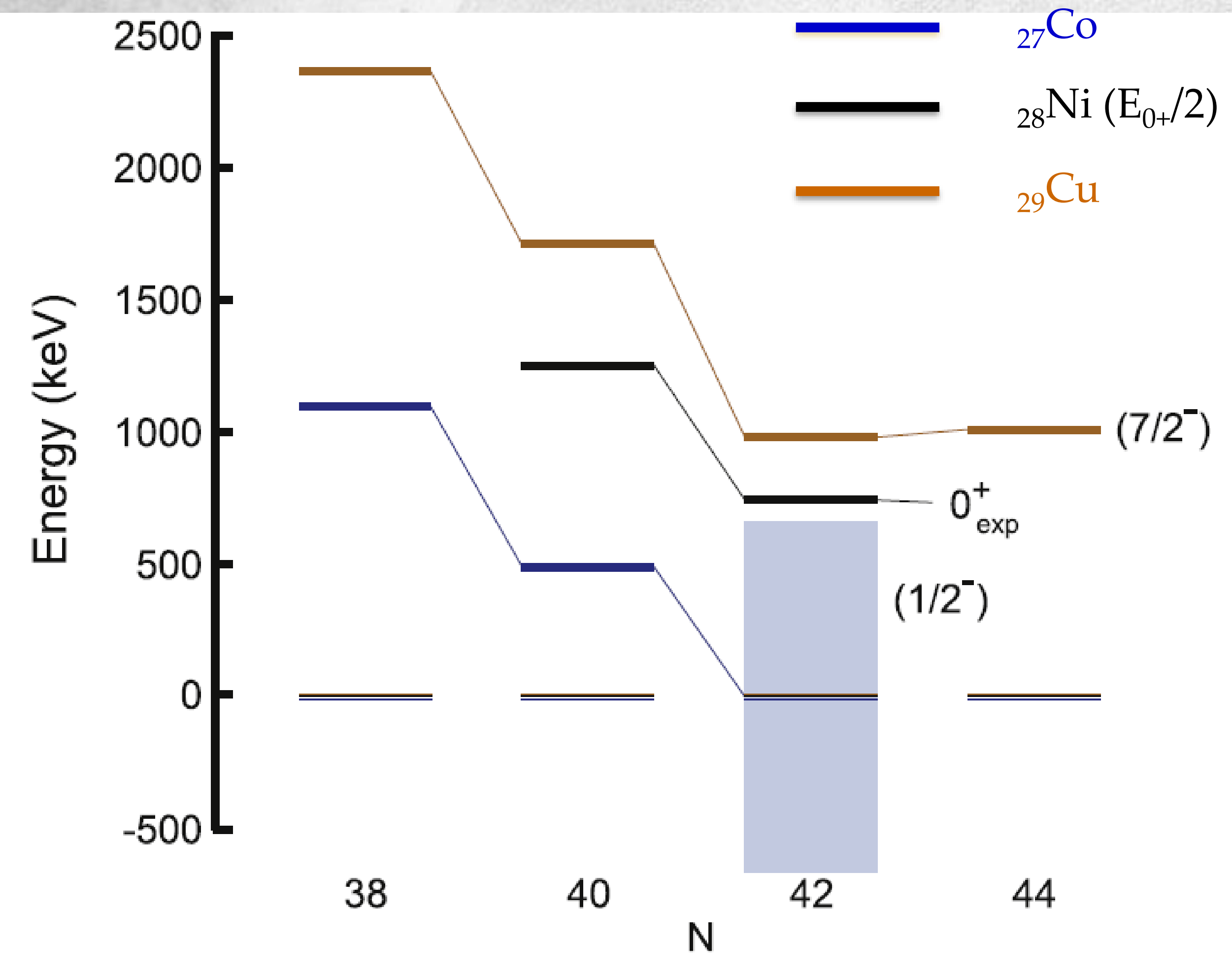


- How do these proton and neutron excitations affect the structure of ^{68}Co?

A. Gade and S. N. Liddick, J. Phys. G: Nucl. Part. Phys. **43** (2016) 024001.

S. M. Lenzi *et al.*, Phys. Rev. C **82**, 054301 (2010).

Systematics of deformed intruder states

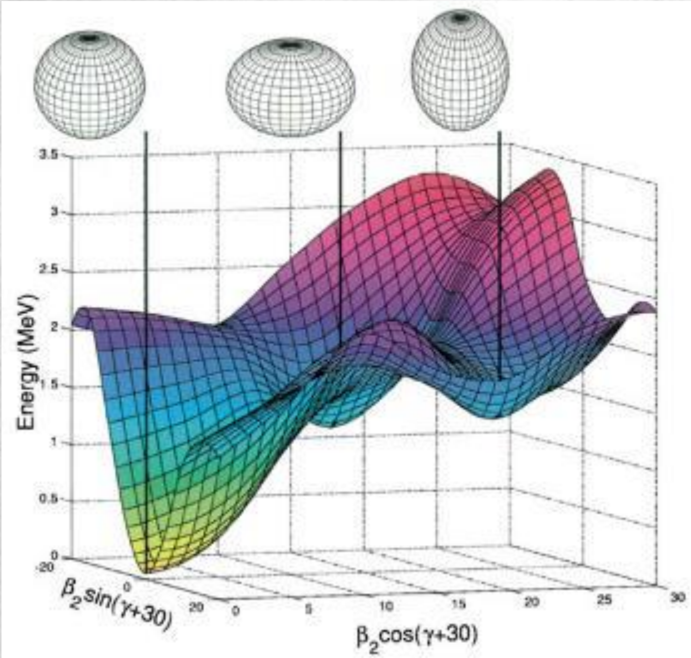


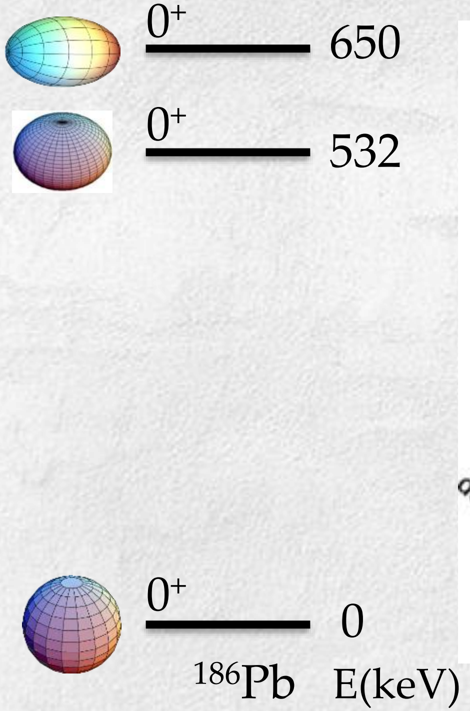
A. Gade and S. N. Liddick, J. Phys. G: Nucl. Part. Phys. **43** (2016) 024001.

- 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.

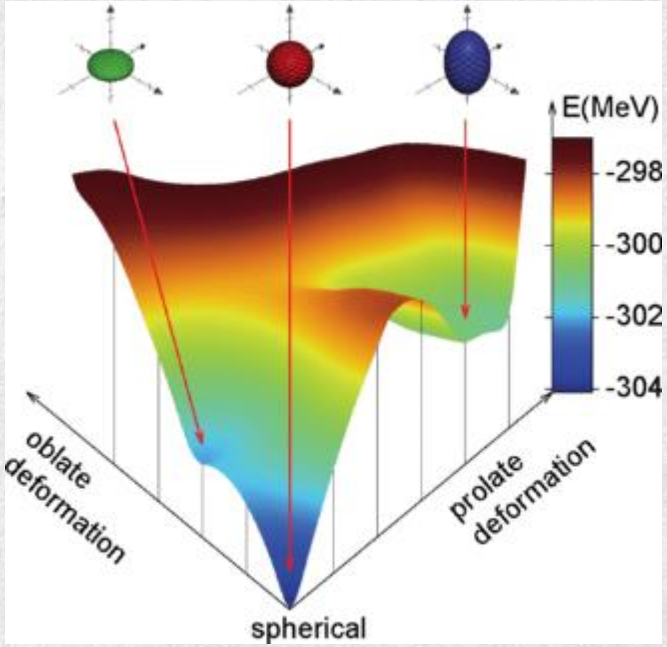
Nuclear Shape Coexistence

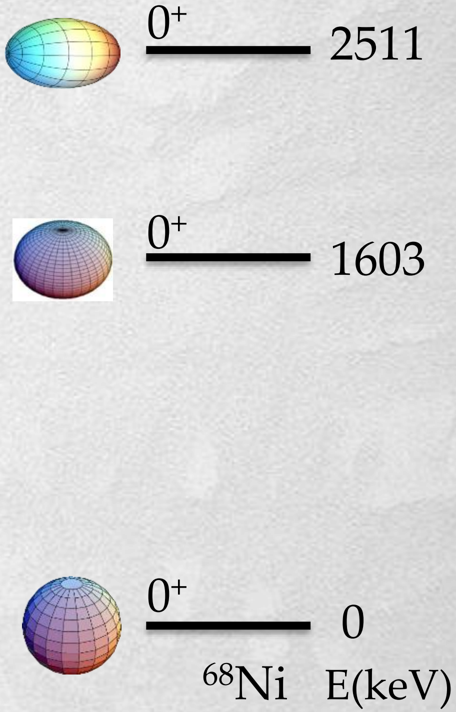
- Multiple states with different coexisting configurations at similar excitation energy
  - Hallmark of shape coexistence in even-even nuclei is multiple low-lying 0^+ states





A. N. Andreyev *et al.*, Nature **405**, 430 (2000).

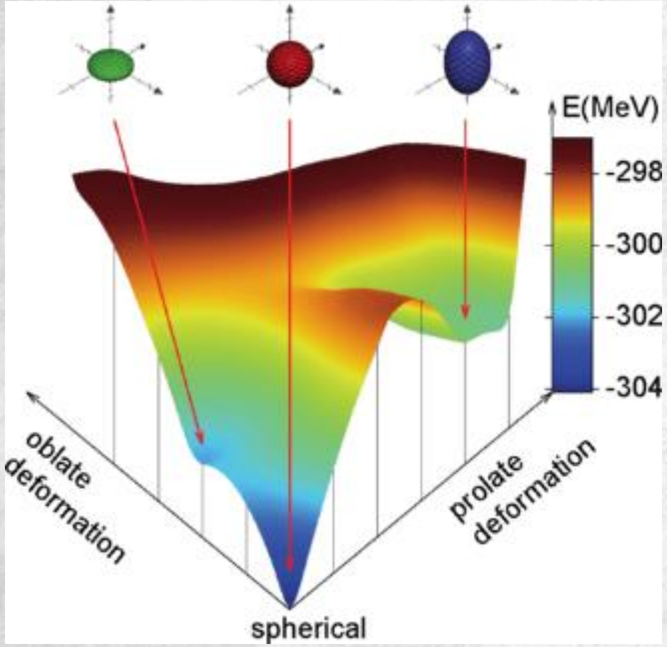


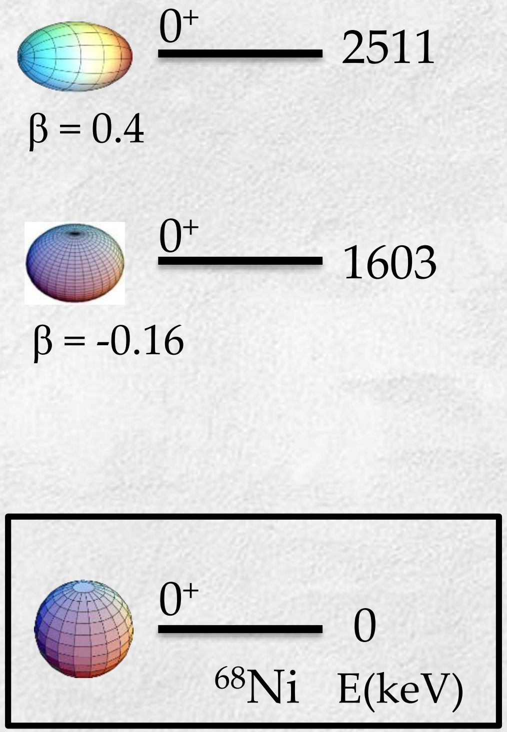


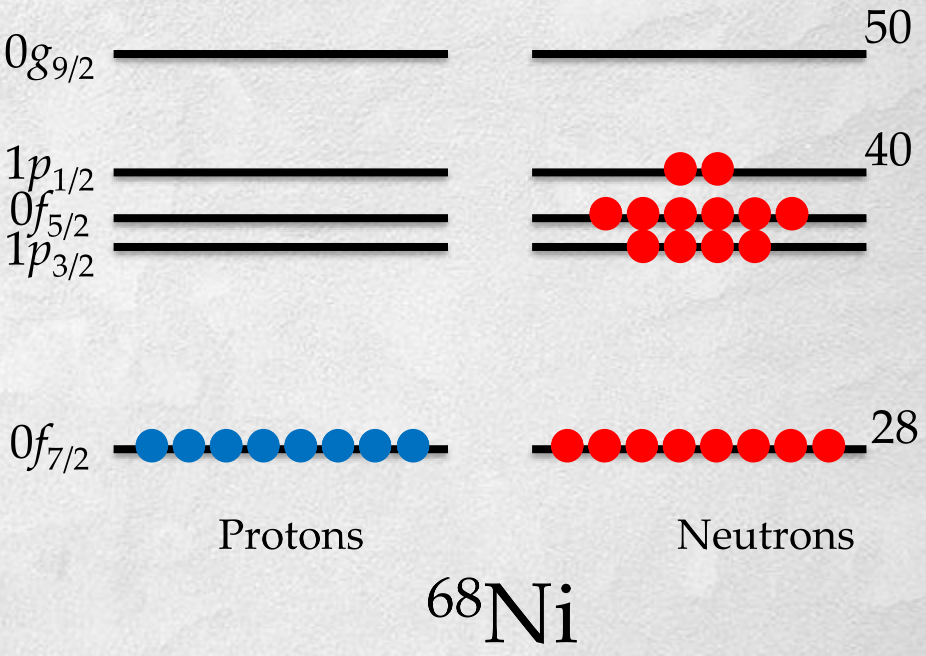
S. Suchyta *et al.*, Phys. Rev. C **89**, 021301(R) (2014).

Ni Shape Coexistence I

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



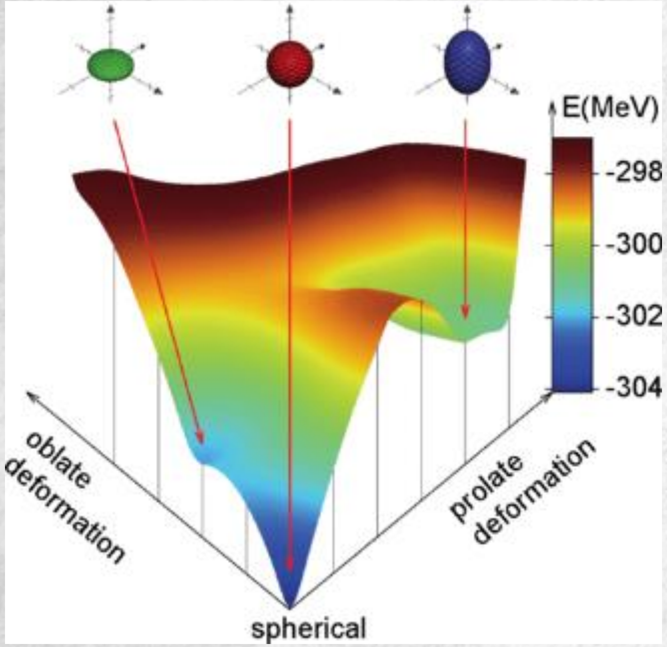


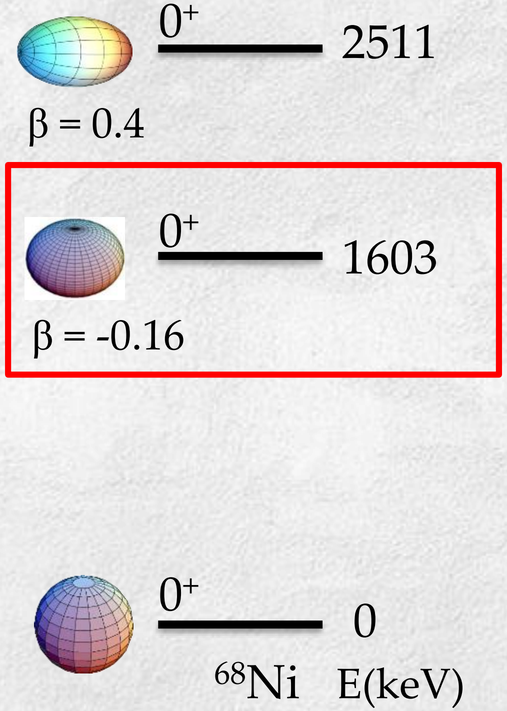


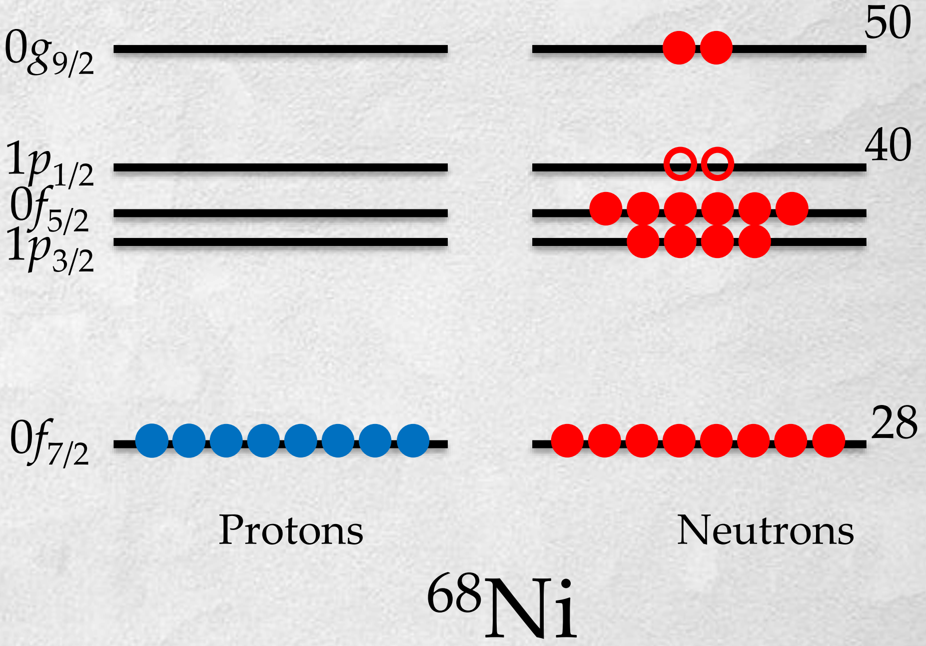
S. Suchyta *et al.*, Phys. Rev. C **89**, 021301(R) (2014).

Y. Tsunoda *et al.*, Phys. Rev. C **89**, 031301 (2014).
S. M. Lenzi *et al.*, Phys. Rev. C **82**, 054301 (2010).

Ni Shape Coexistence II







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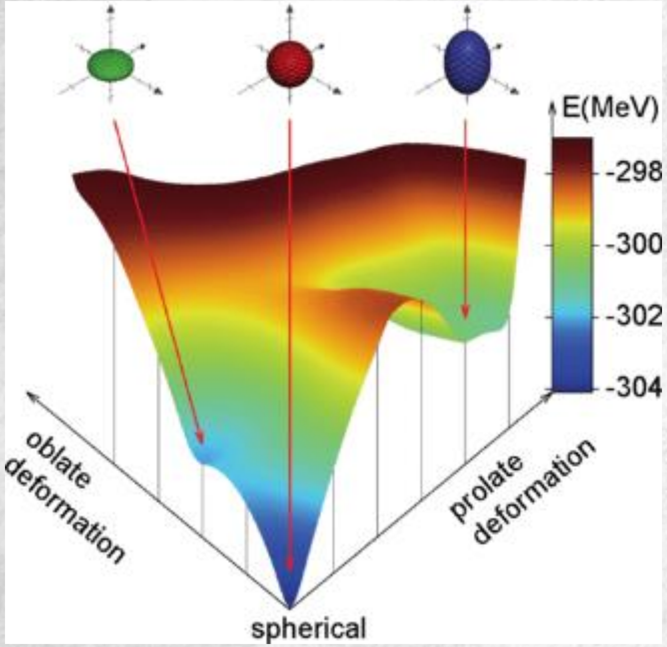
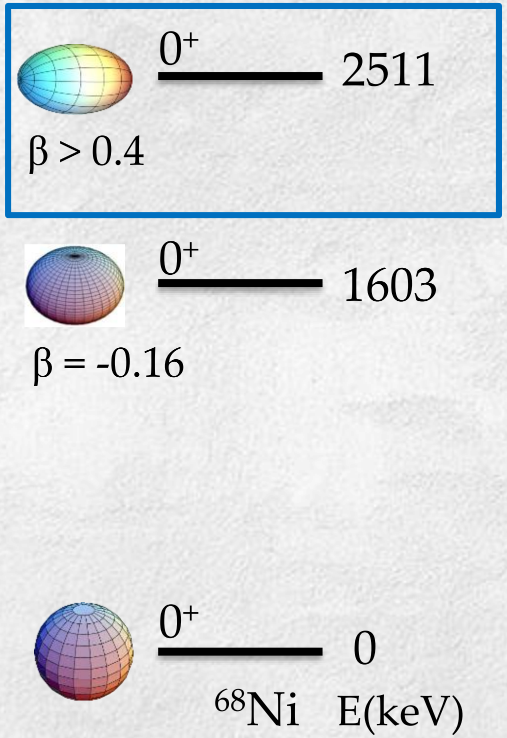
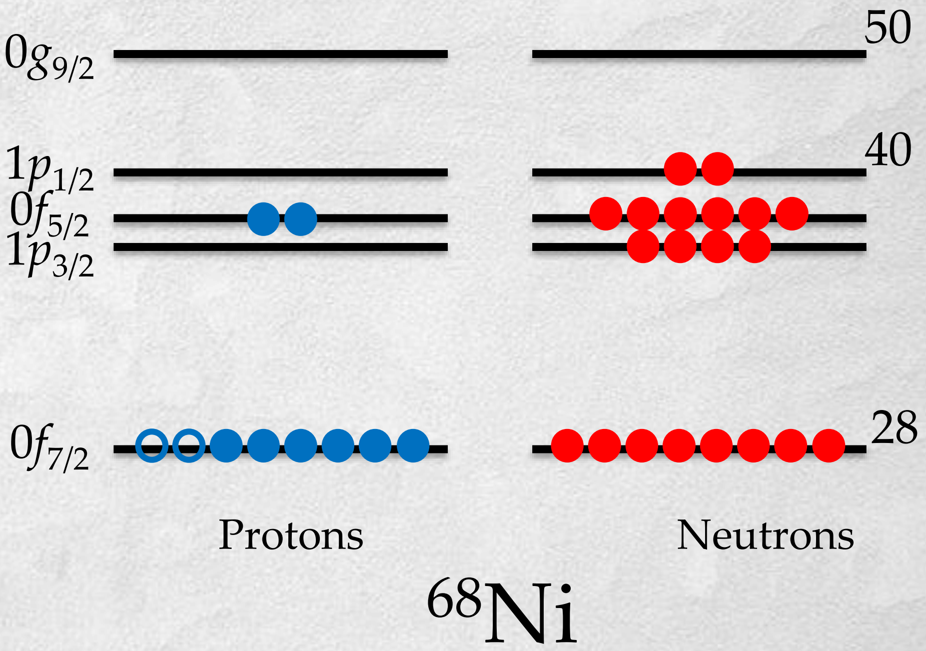
Ni Shape Coexistence III





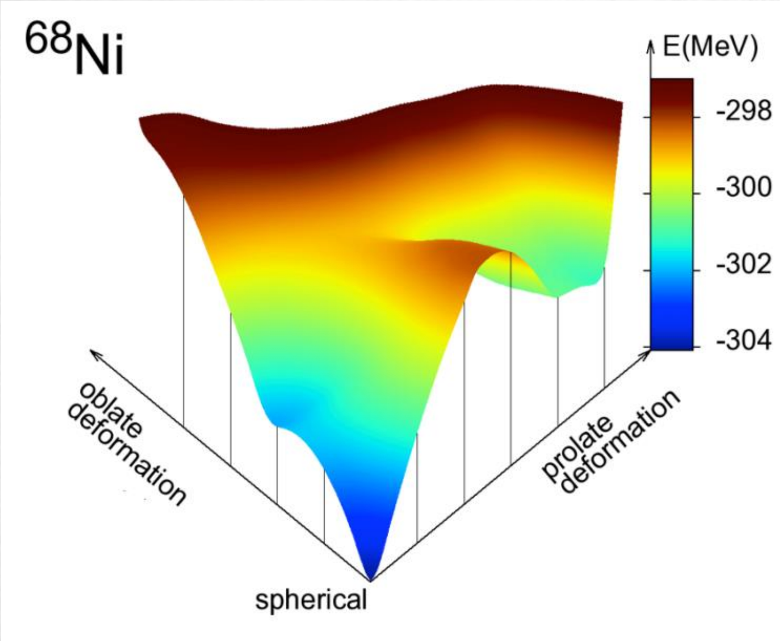


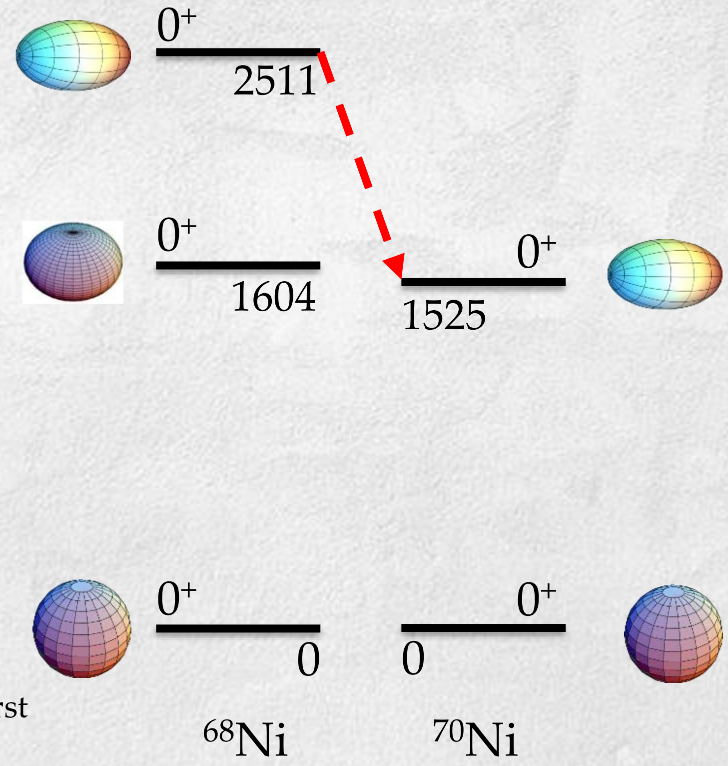
S. Suchyta *et al.*, Phys. Rev. C **89**, 021301(R) (2014).

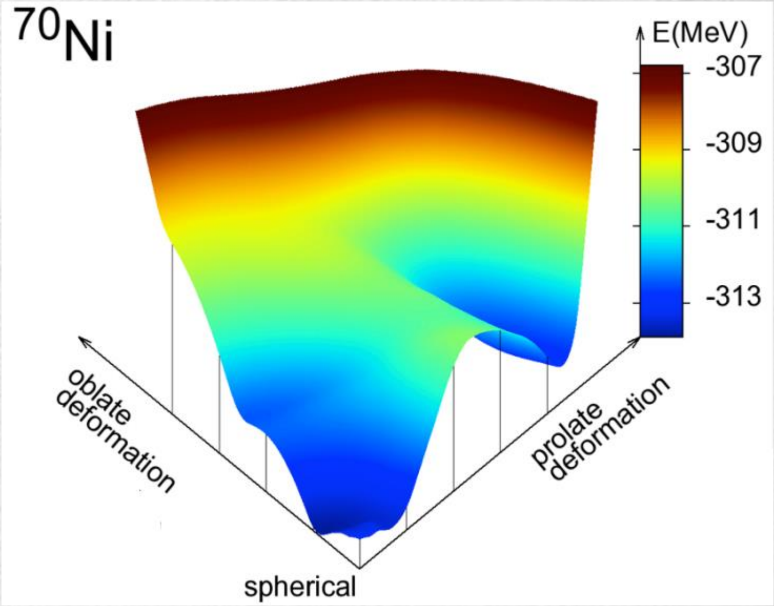
Y. Tsunoda *et al.*, Phys. Rev. C **89**, 031301 (2014).

Predicted Shape Coexistence in ^{70}Ni

- MCSM calculations also predict shape coexistence in ^{70}Ni
  - Deepening of the prolate potential well



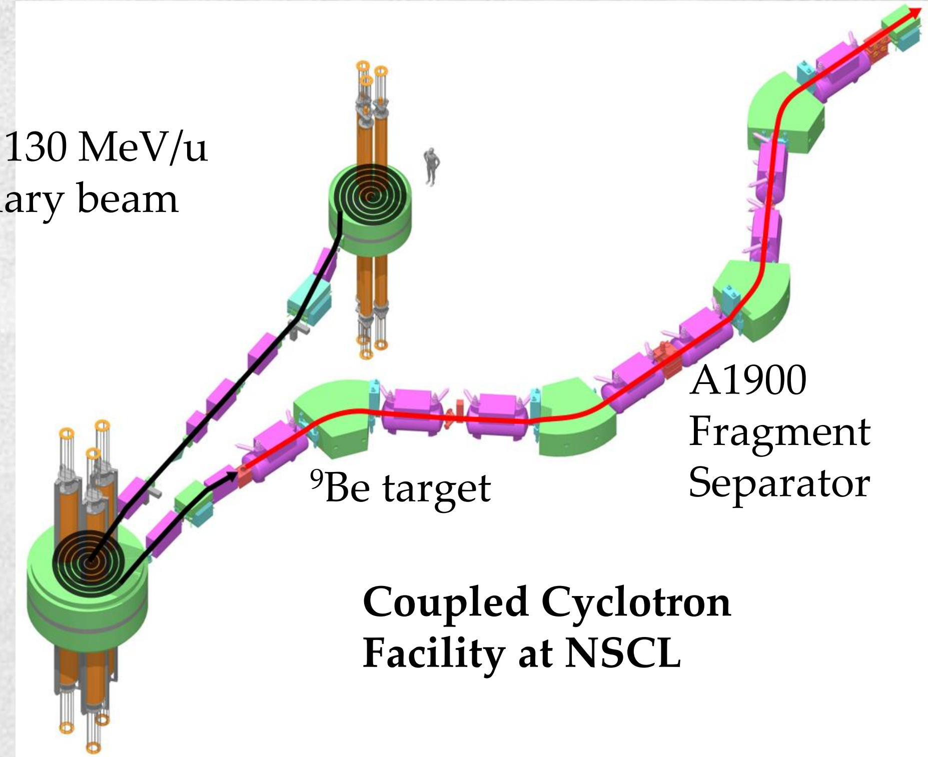




http://fustipen.ganil.fr/conferences/2014/workshops/understanding-nuclear-structure-and-reactions-microscopically-including-the-continuum-2/talks/otsuka_fustipen.pdf

National Superconducting Cyclotron Laboratory

Cocktail beam A~68 delivered to experimental end-station



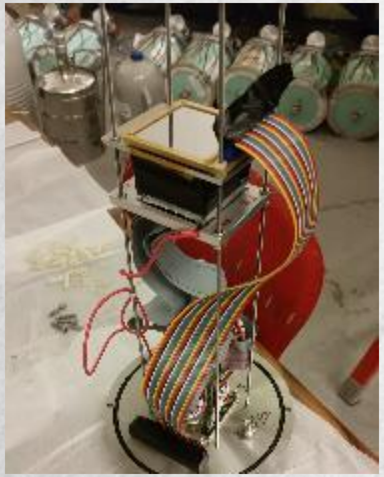
Fragmentation of a fast-moving, heavy, stable beam on a thin stable target

- ^{76}Ge beam at ~130 MeV/A
- 282 μg/cm^2 ^{9}Be target

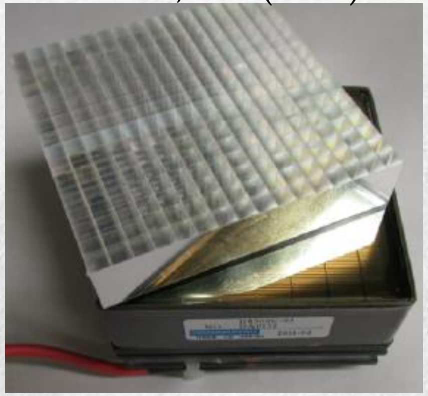
NSCL Experiment: Detection Systems

- 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



M. Alshudifat *et al.*, Physics Procedia **66**, 445 (2015).



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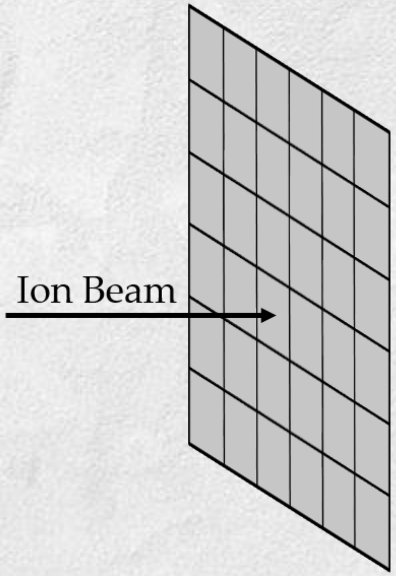
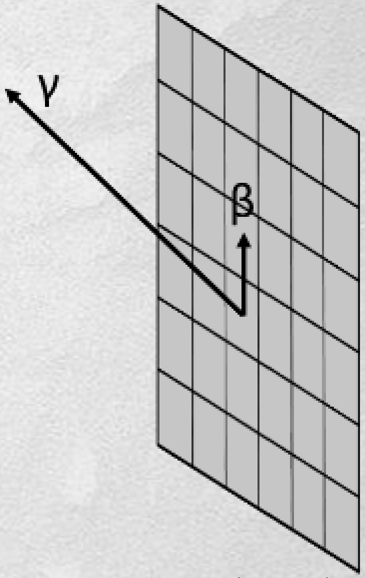
N. Larson *et al.*, Nucl. Instrum. Methods Phys. Res. A **727**, 59 (2013)
C. J. Prokop, *et al.*, Nucl. Instrum. Methods Phys. Res. A **741**, 163 (2014)

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

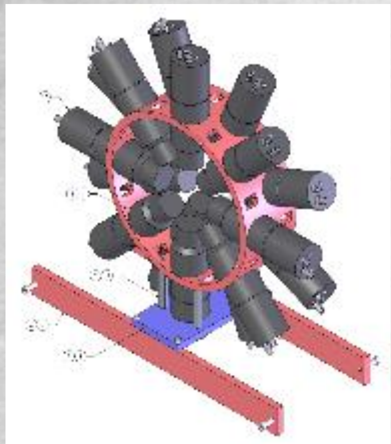


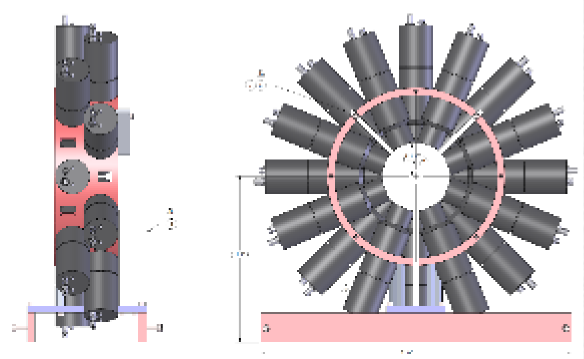
Some characteristic time later a decay is detected. Position and time of decay recorded.



- Decays are correlated to ions using spatial and temporal information
- Time scales: Beta decay: ~10^{-3} s, Gamma decay: ~10^{-15} to 10^{-9} s

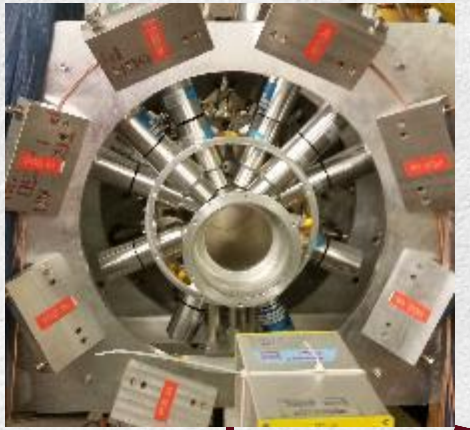
NSCL Experiment: Detection Systems



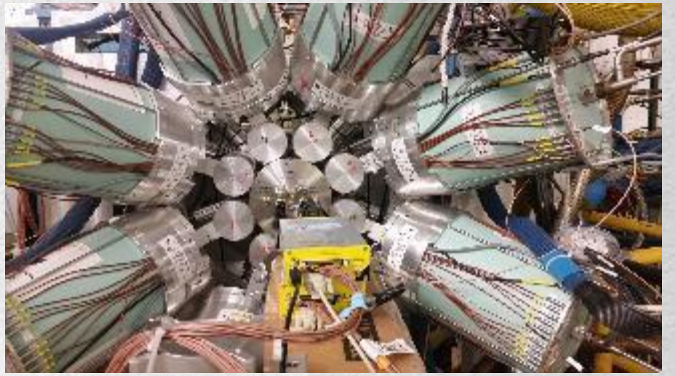


Gamma-ray Detectors

$LaBr_3(Ce)$ array



Half of 16 HPGe SeGA array



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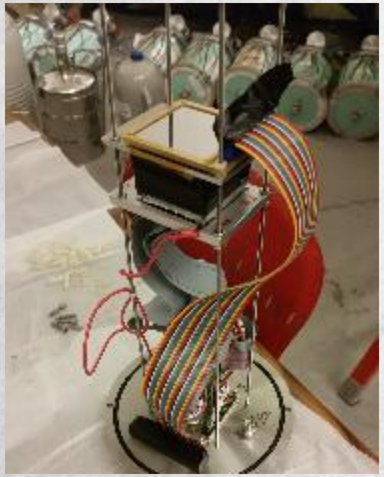

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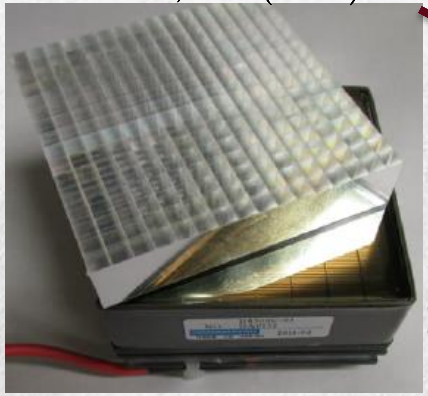

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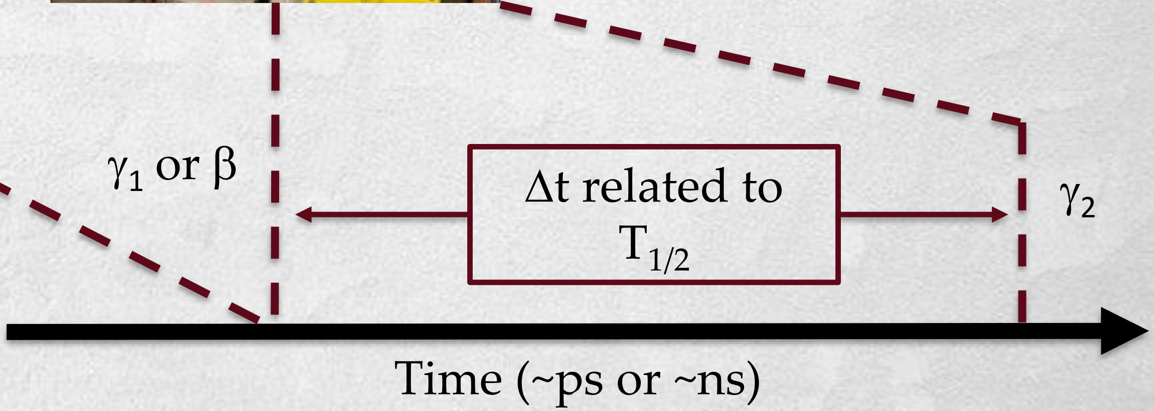

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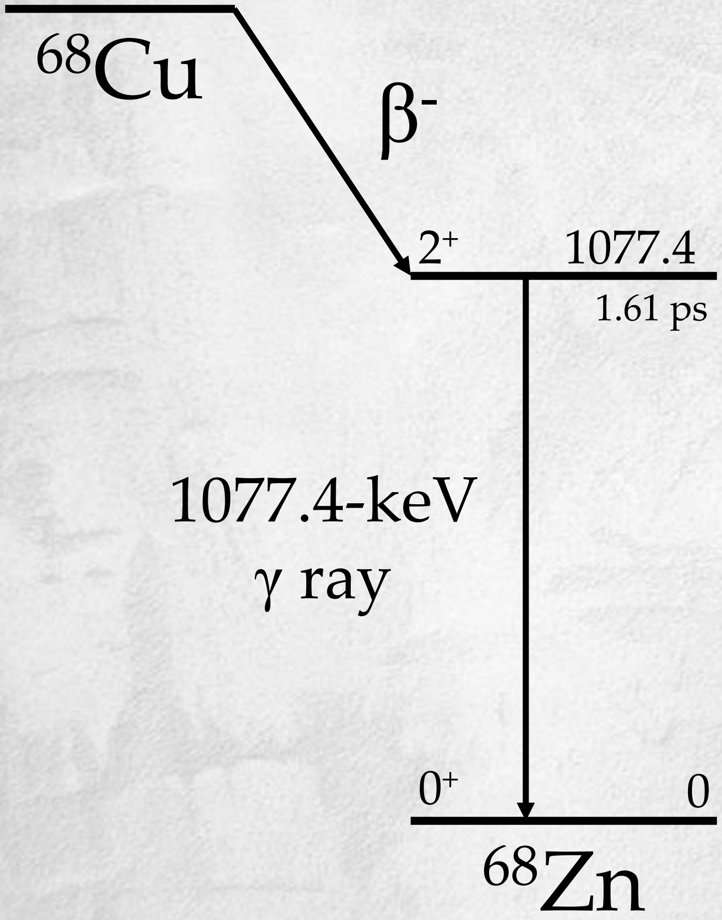
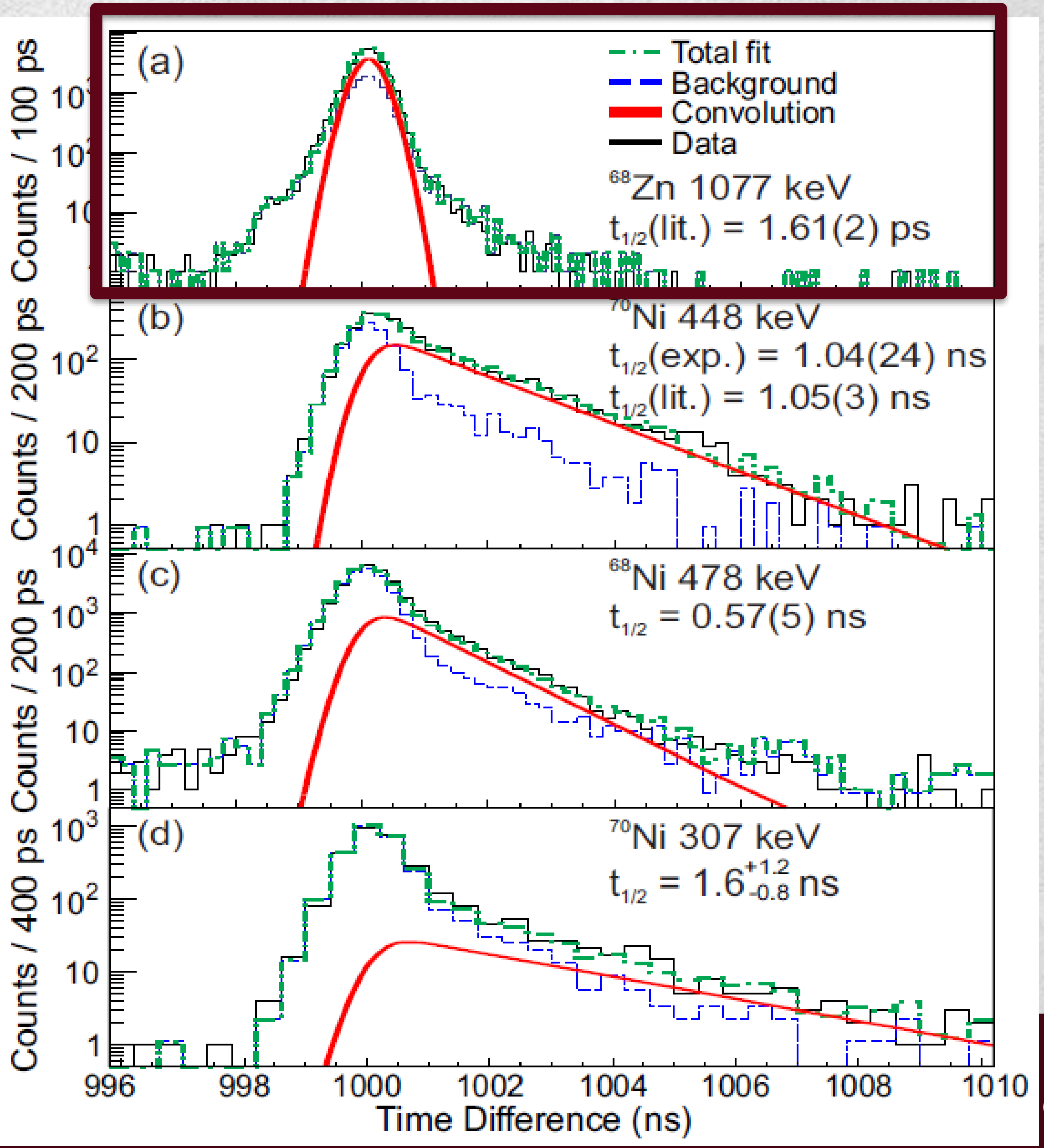
C. J. Prokop, *et al.*, Nucl. Instrum. Methods Phys. Res. A **741**, 163 (2014)

W. Mueller *et al.*, Nucl. Instrum. Methods Phys. Res. A **466**, 492 (2001)

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

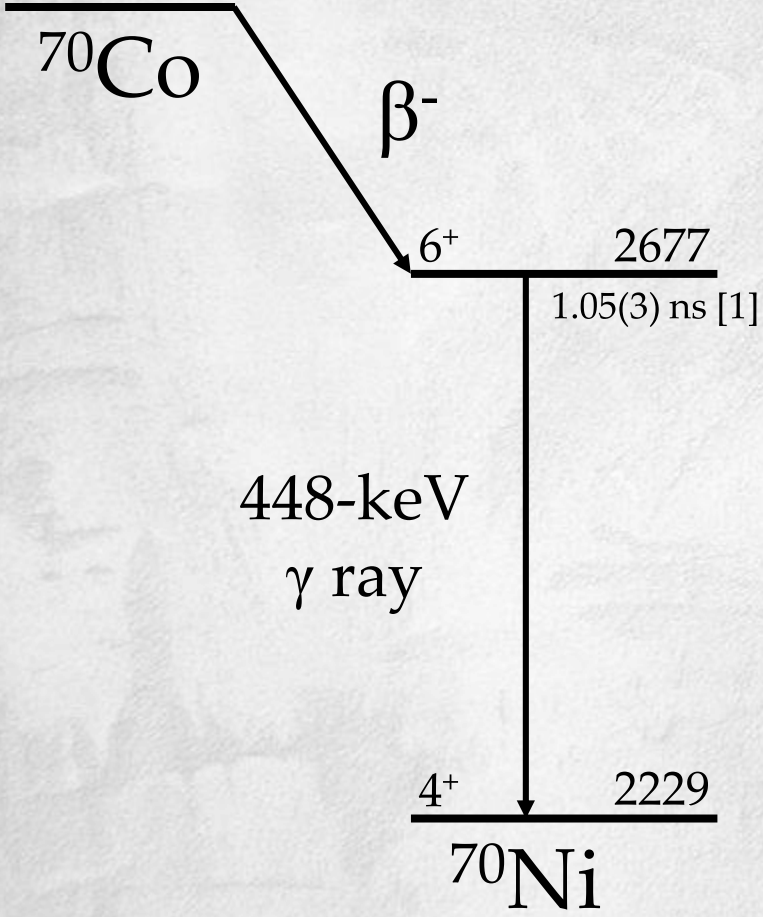
Lifetime Results

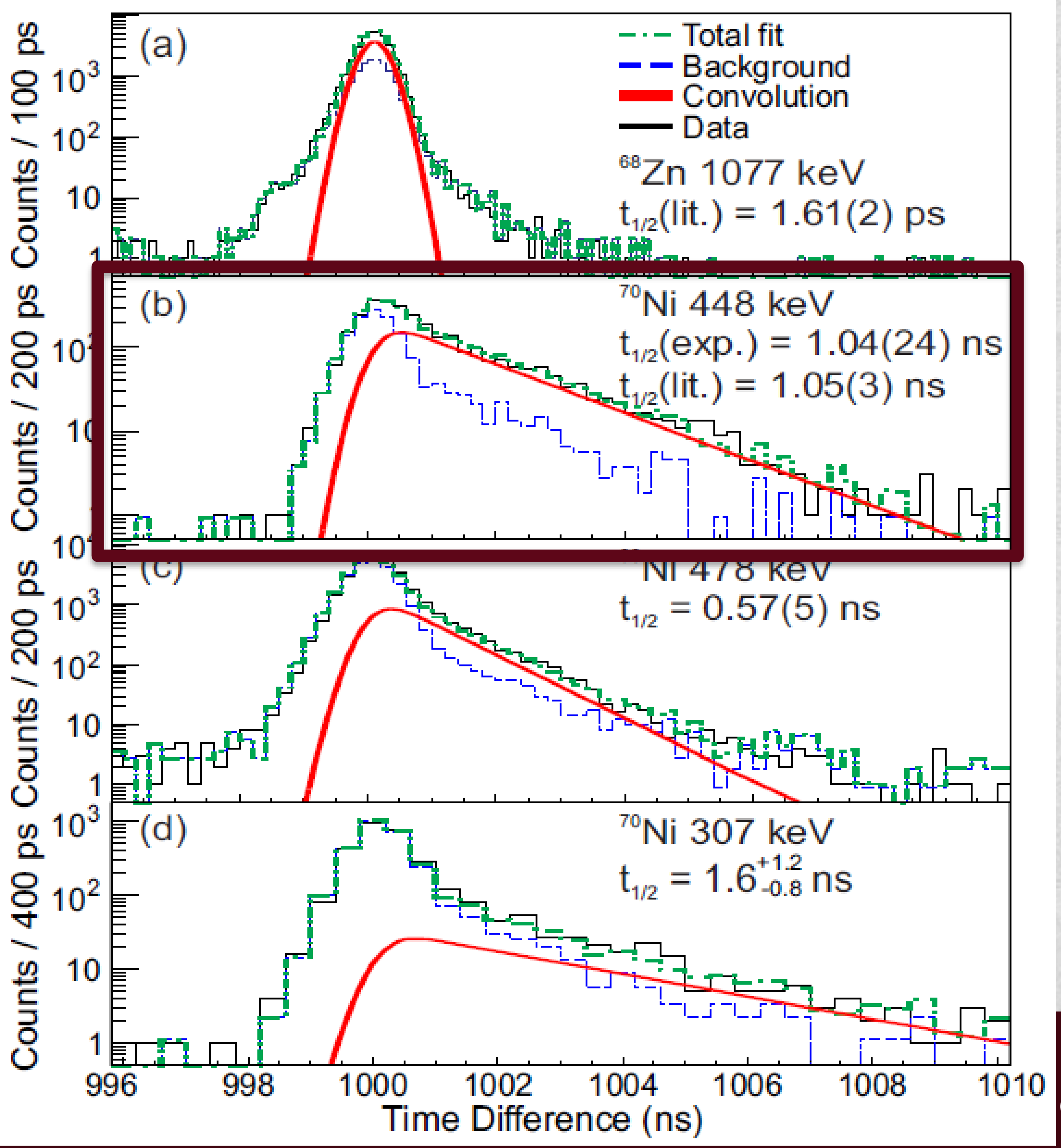




B. P. Crider *et al.*, Phys. Lett. B **763**, 108 (2016).

Lifetime Results



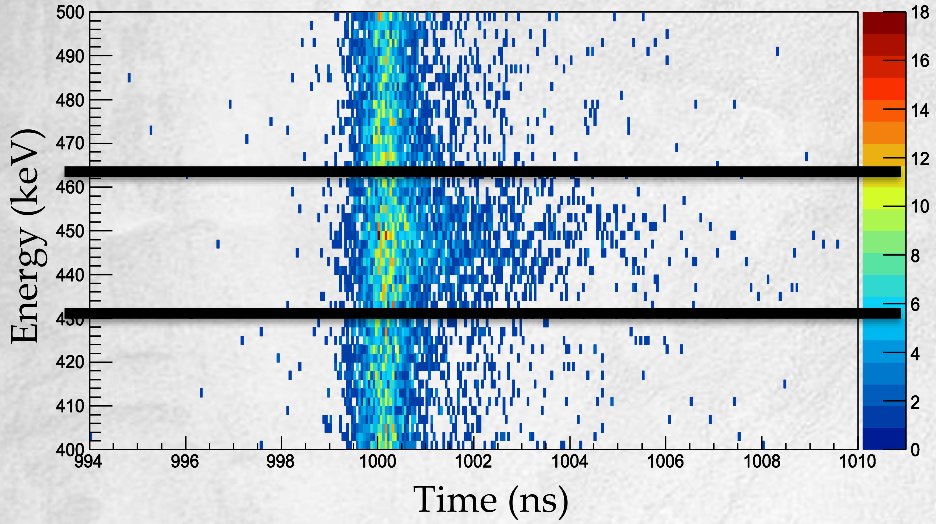


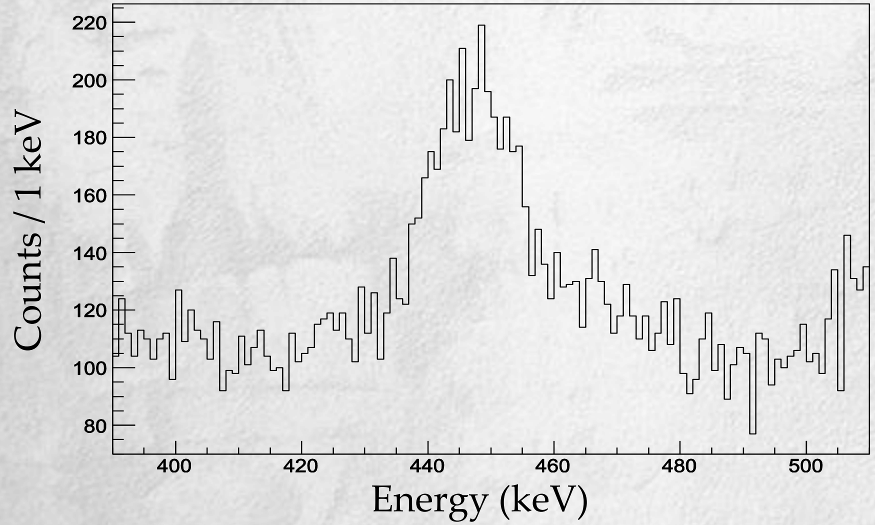
H. Mach *et al.*, Nucl. Phys. A **719**, C213 (2003).

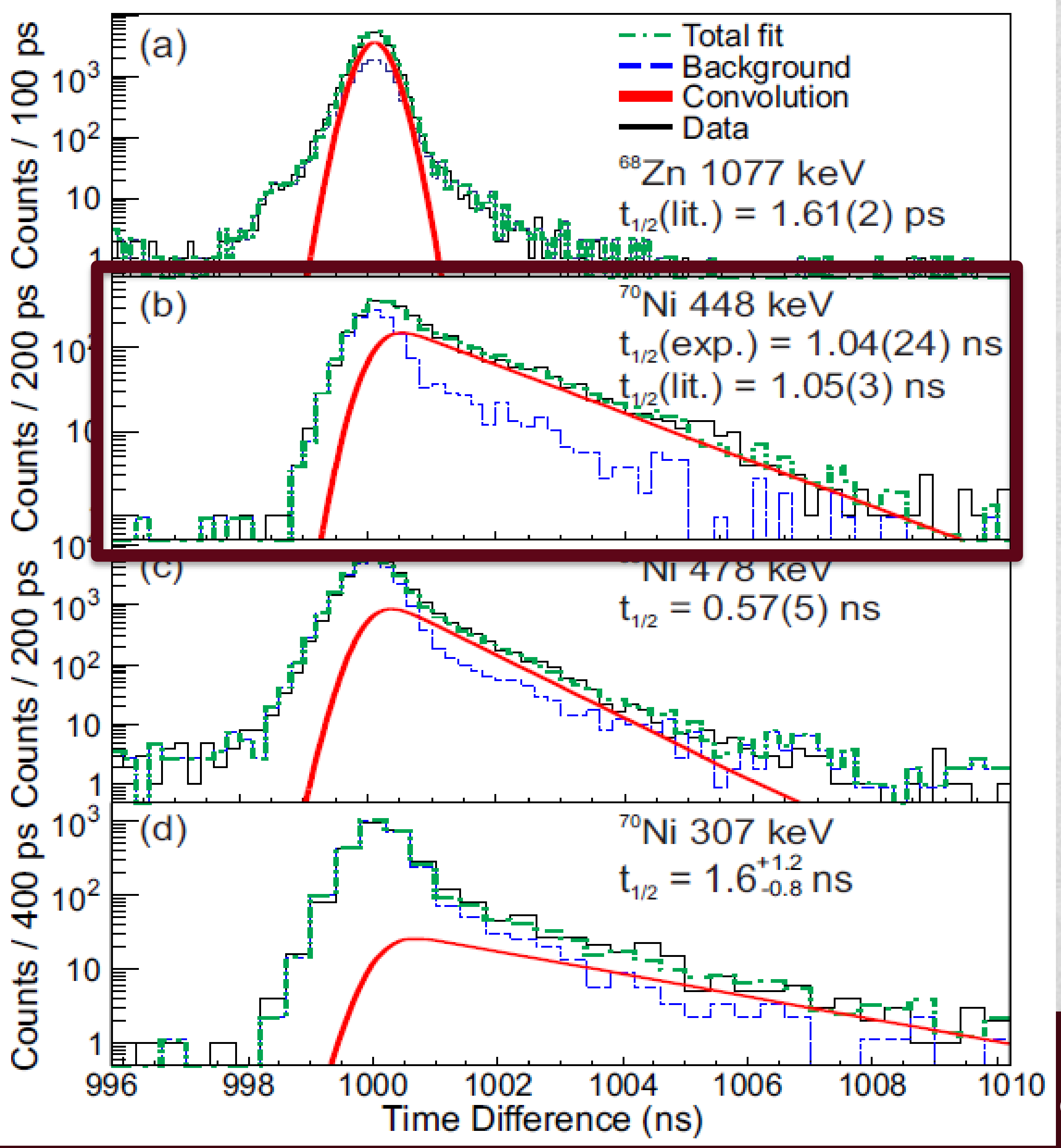
B. P. Crider *et al.*, Phys. Lett. B **763**, 108 (2016).

Lifetime Results

Correlated decays into ^{70}Ni







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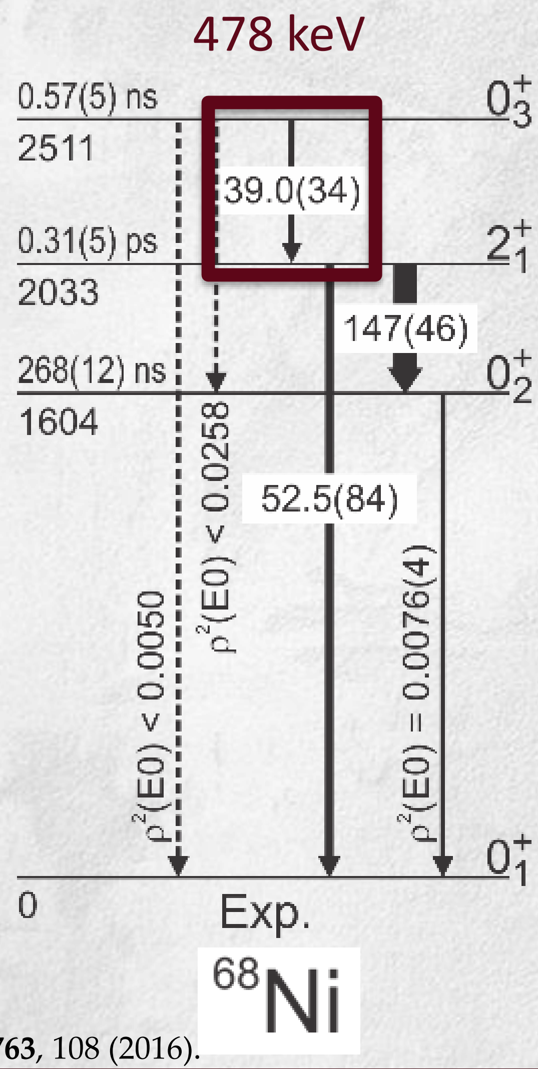

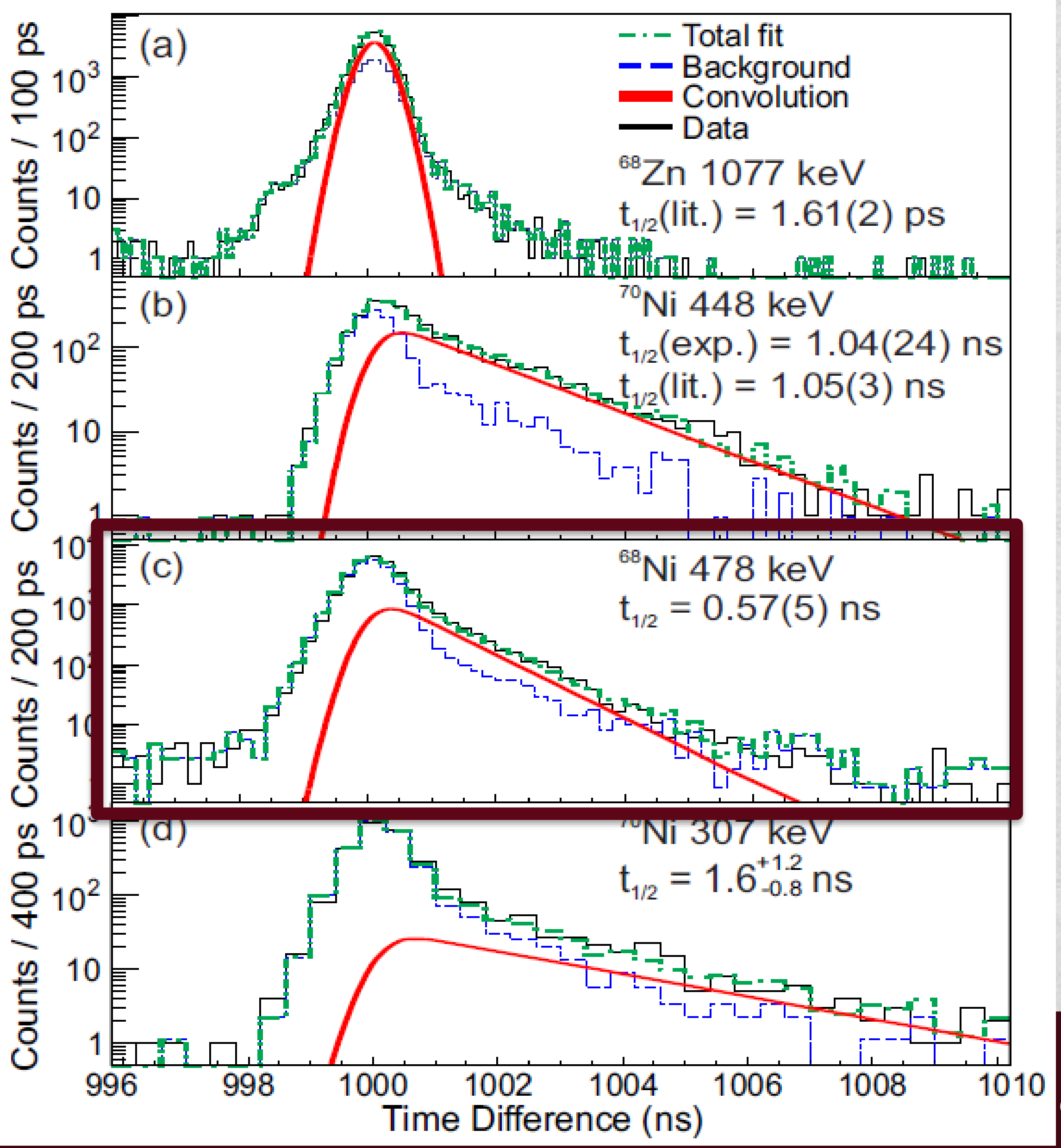

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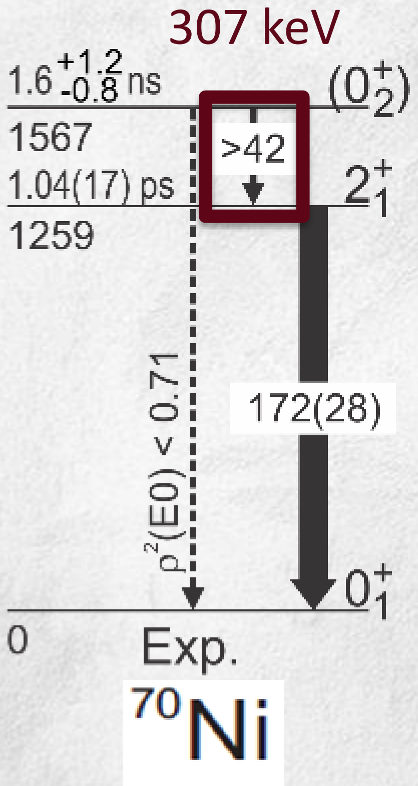
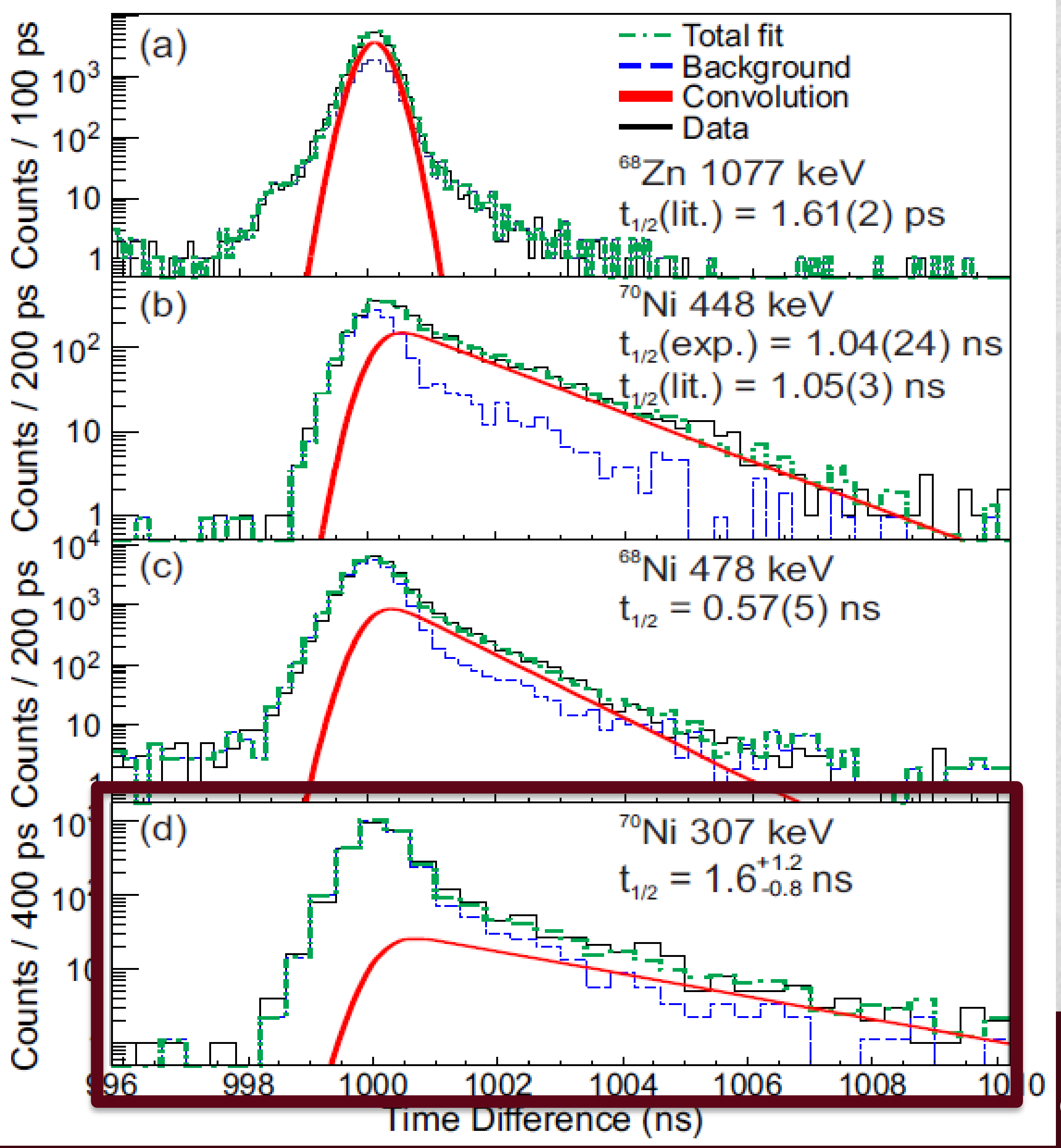
Lifetime Results





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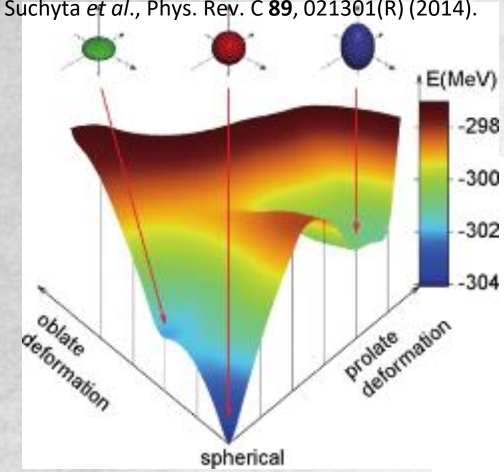
Putting it all together for ^{68,70}Ni…

S. Suchyta *et al.*, Phys. Rev. C **89**, 021301(R) (2014).



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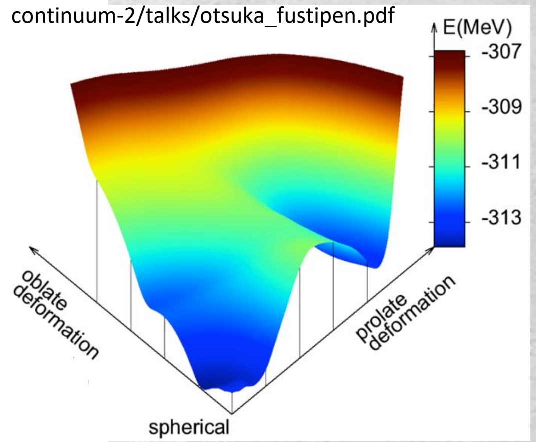

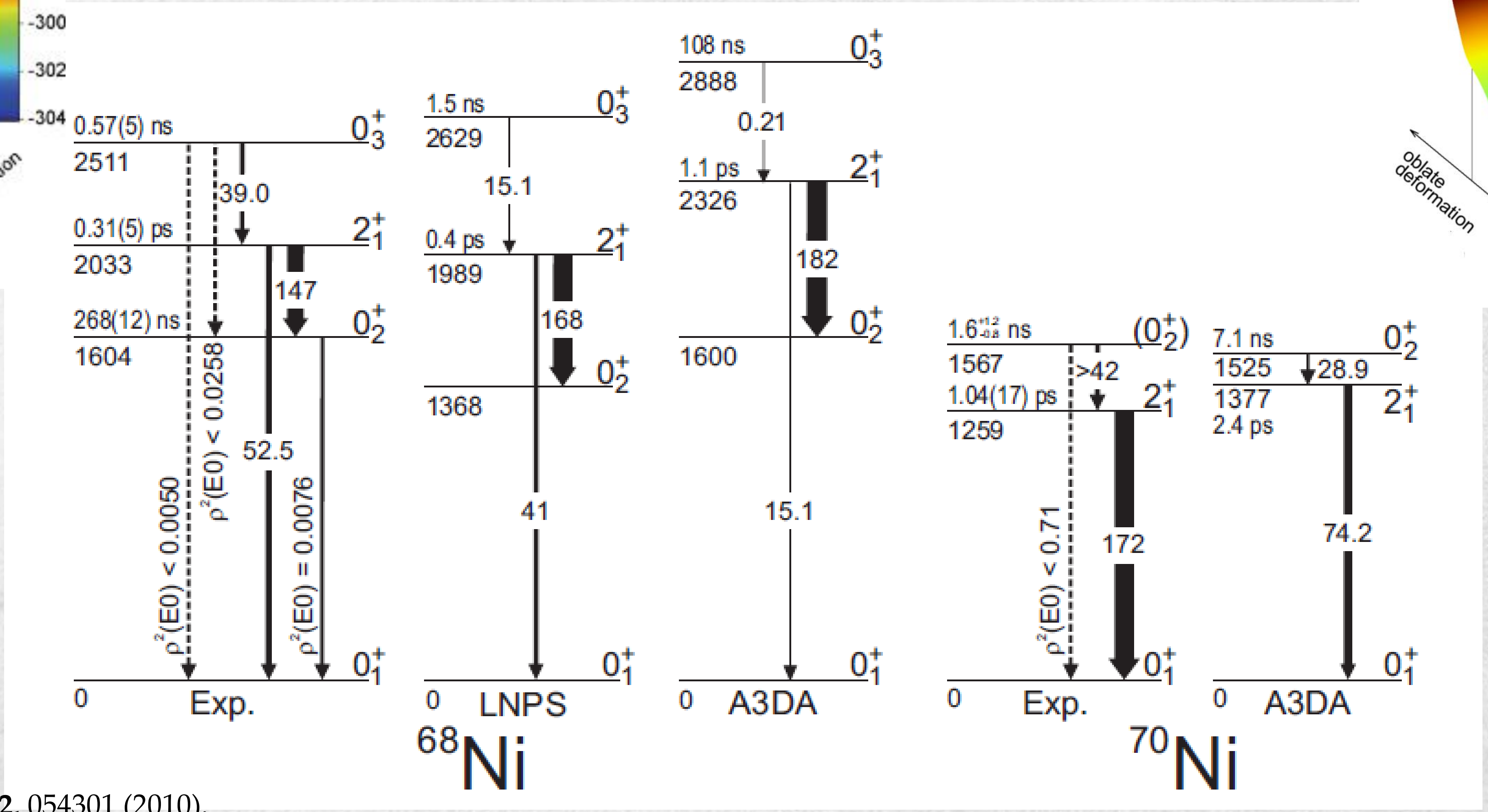

S. M. Lenzi *et al.*, Phys. Rev. C **82**, 054301 (2010).
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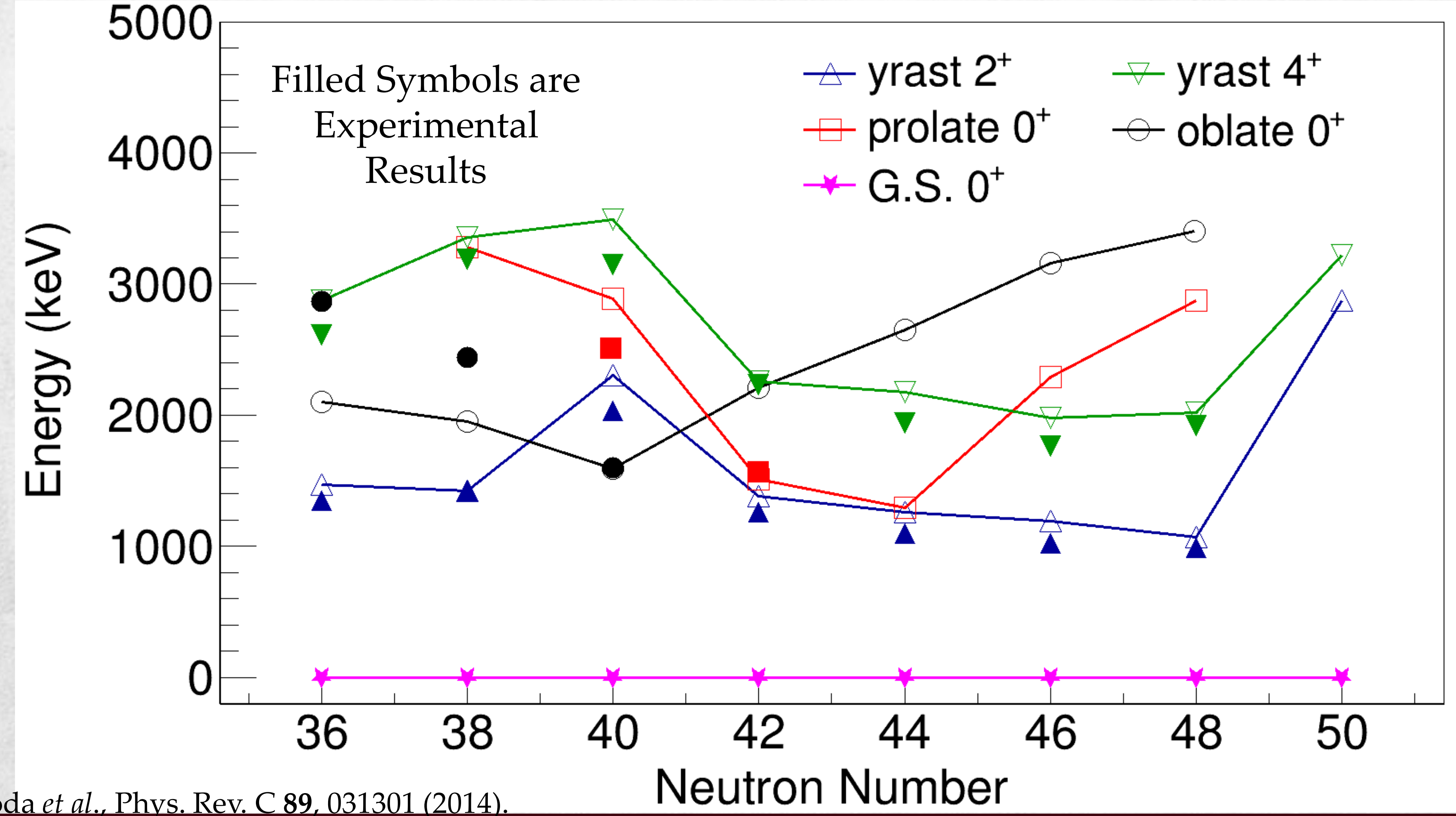

Y. Tsunoda *et al.*, Phys. Rev. C **89**, 031301 (2014).

Conclusions

- Evidence for shape coexistence is apparent in Ni nuclei in the neutron-rich N = 40 region. As for ^{68}Co…?
- A recent experiment at NSCL coupling fast-timing and high-resolution detection systems has enabled an expansion of the information in ^{68,70}Ni and ^{68}Co.
- $LaBr_3$ detectors enable clear determination of half-lives in the region > ~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,

ANL: A. D. Ayangeakaa, M. P. Carpenter, H. M. David, R. V. F. Janssens, T. Lauritsen, D. Seweryniak, and S. Zhu.

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

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