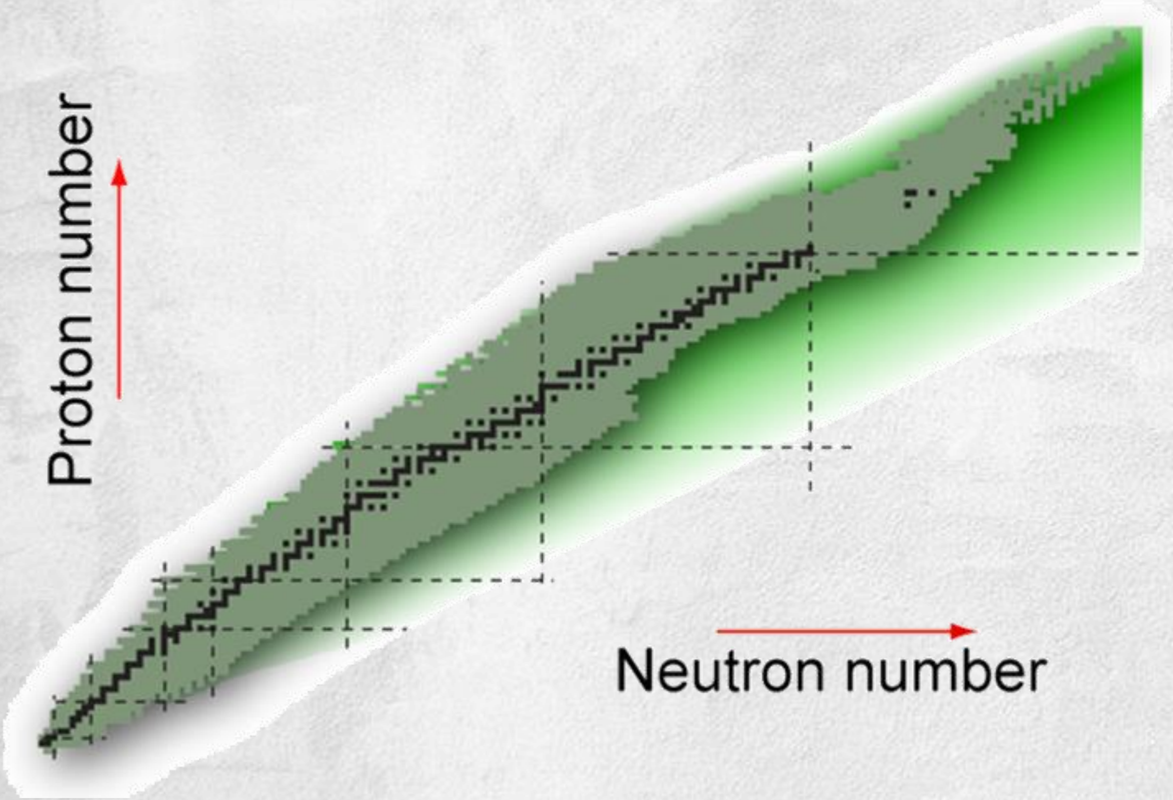
Lifetime measurements with fast-timing arrays

Ben Crider

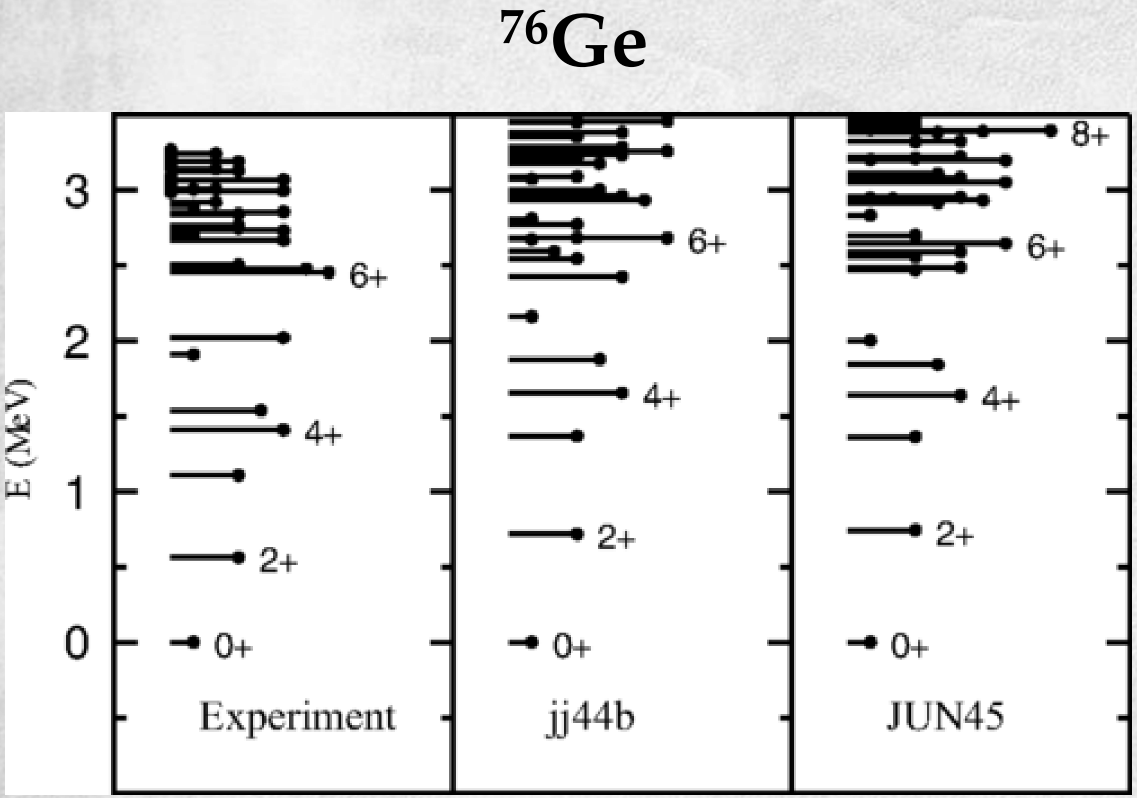
FRIB Decay Workshop
January 25-26, 2018

Overview



- Shell structure helps lay out a roadmap of interesting structural features
- Experimentally determined properties described in terms of shell structure
- Large-scale shell model calculations and ab initio calculations (NCSM, IM-SRG, and their merger) have exciting prospects as they move towards expanding our understanding of medium-mass nuclei

Overview

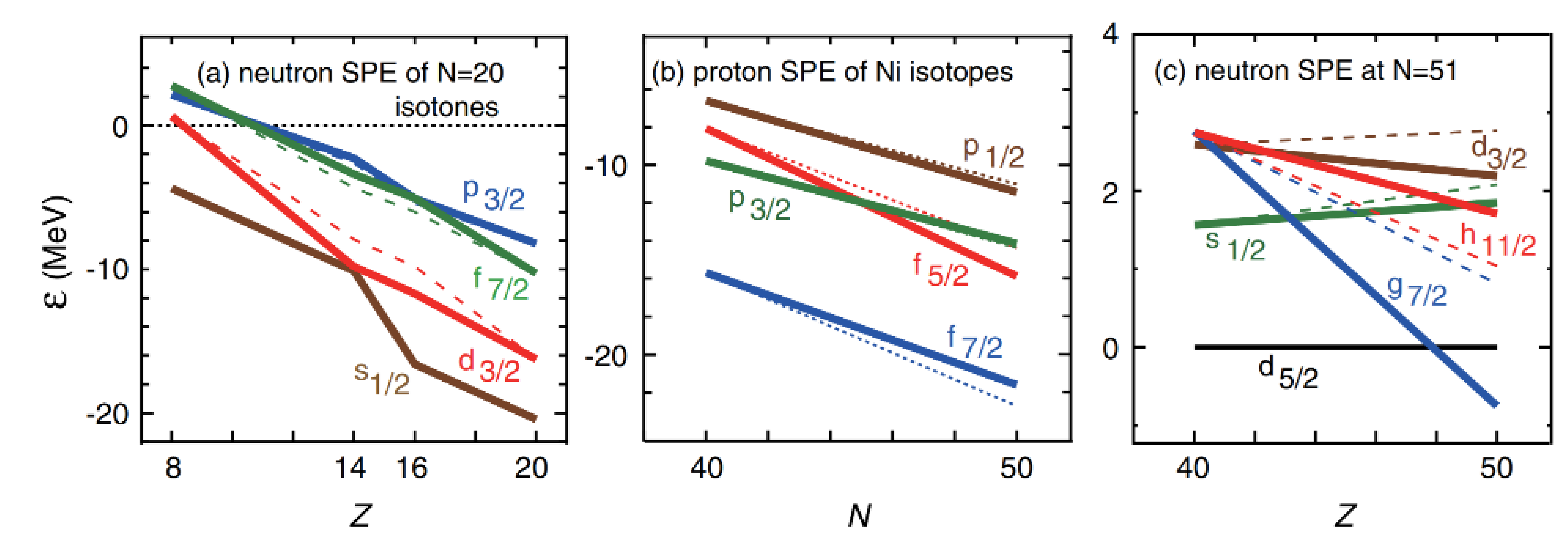


S. Mukhopadhyay *et al*, Phys. Rev. C **95**, 014327 (2017)

- Shell structure helps lay out a roadmap of interesting structural features
- Experimentally determined properties described in terms of shell structure
- Large-scale shell model calculations and ab initio calculations (NCSM, IM-SRG, and their merger) have exciting prospects as they move towards expanding our understanding of medium-mass nuclei

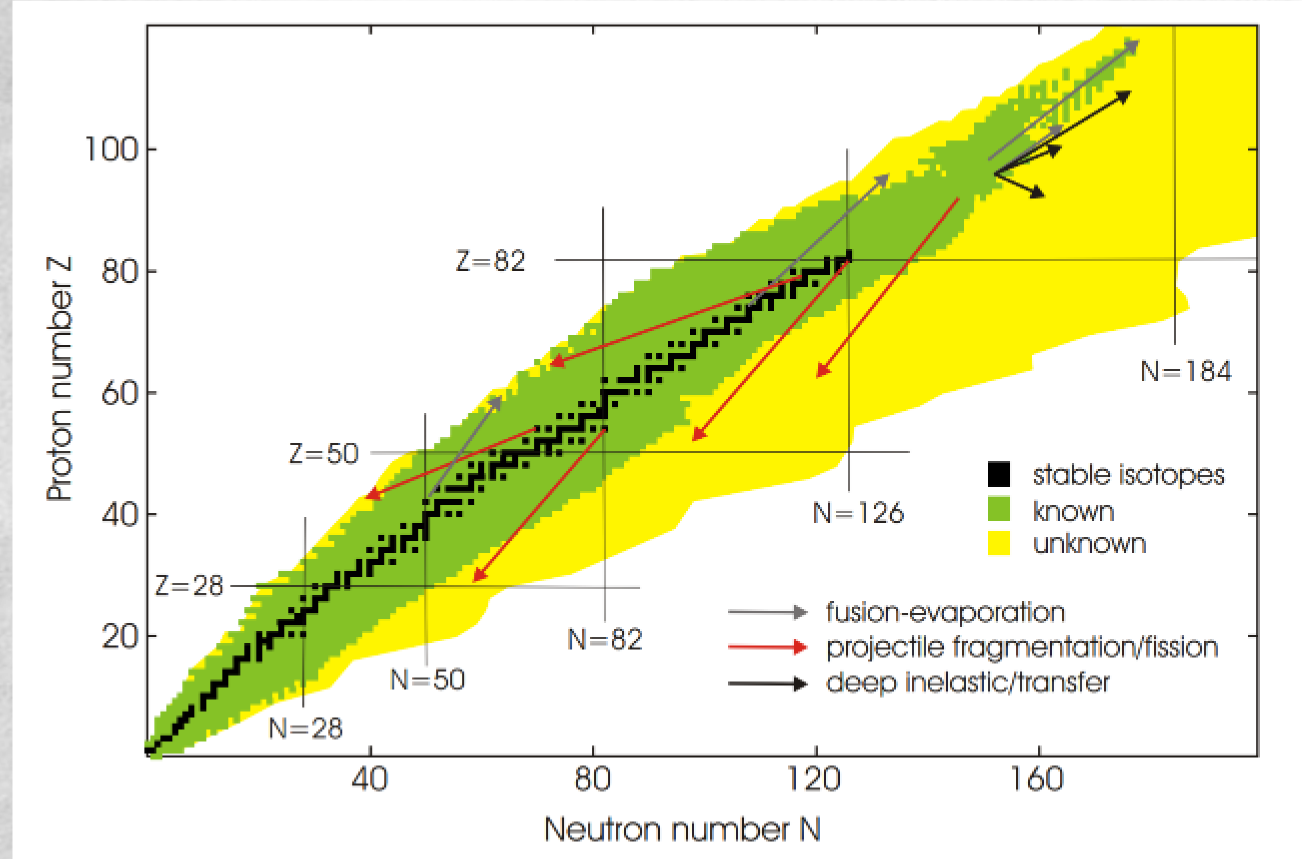
Shell Evolution

- Many shell model calculations predict a modified shell structure in nuclei away from the β-stability line



T. Otsuka *et al*., Phys. Rev. Lett. **104**, 012501 (2010)

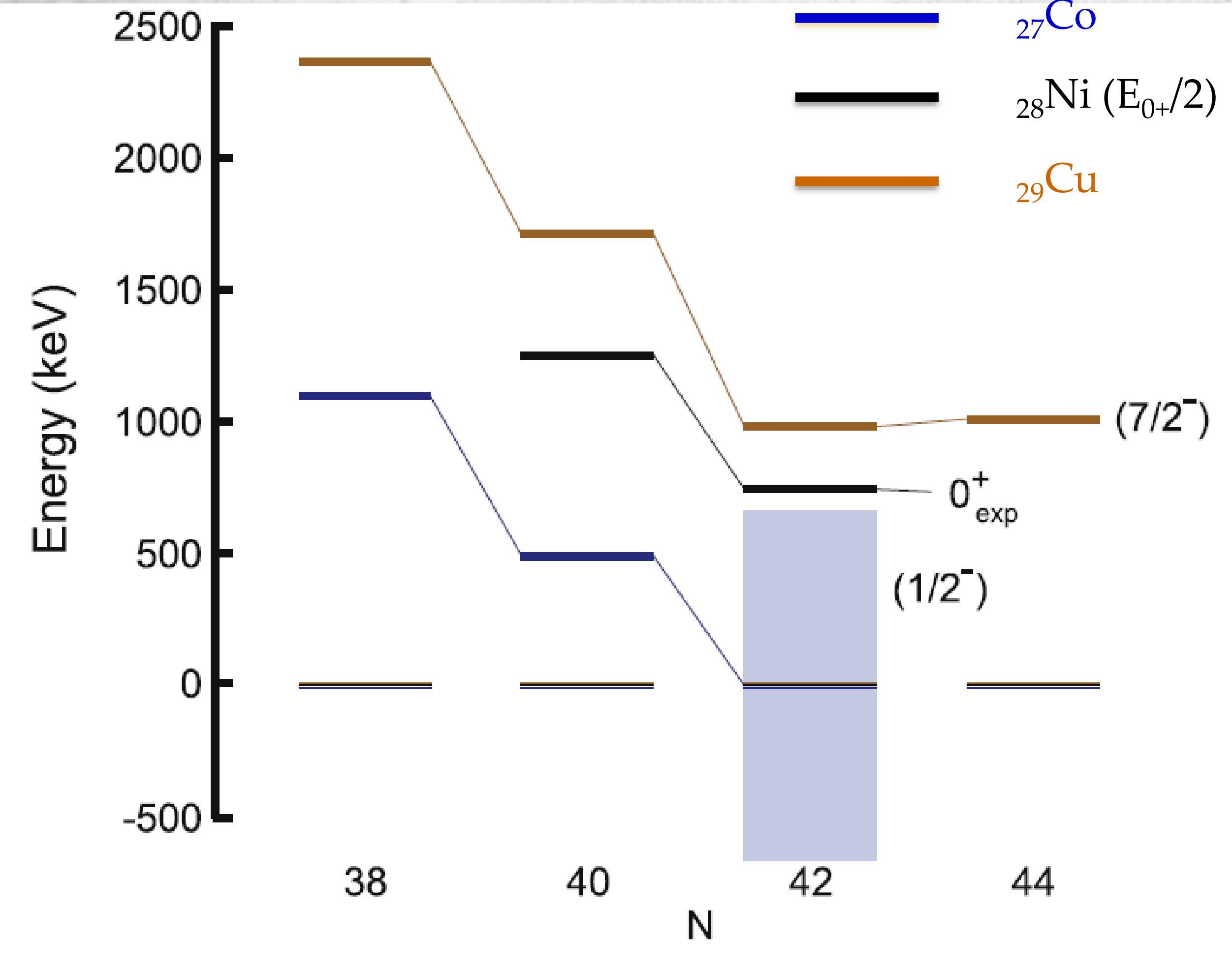
FRIB Nuclei



M. Thoennessen, Nuclear Data Sheets **118**, 85 – 90 (2014)

- FRIB will enable the study of many exotic nuclei
- Even for nuclei near the extremes of the FRIB production rates, β-decay studies are a viable means for determining their low-lying properties

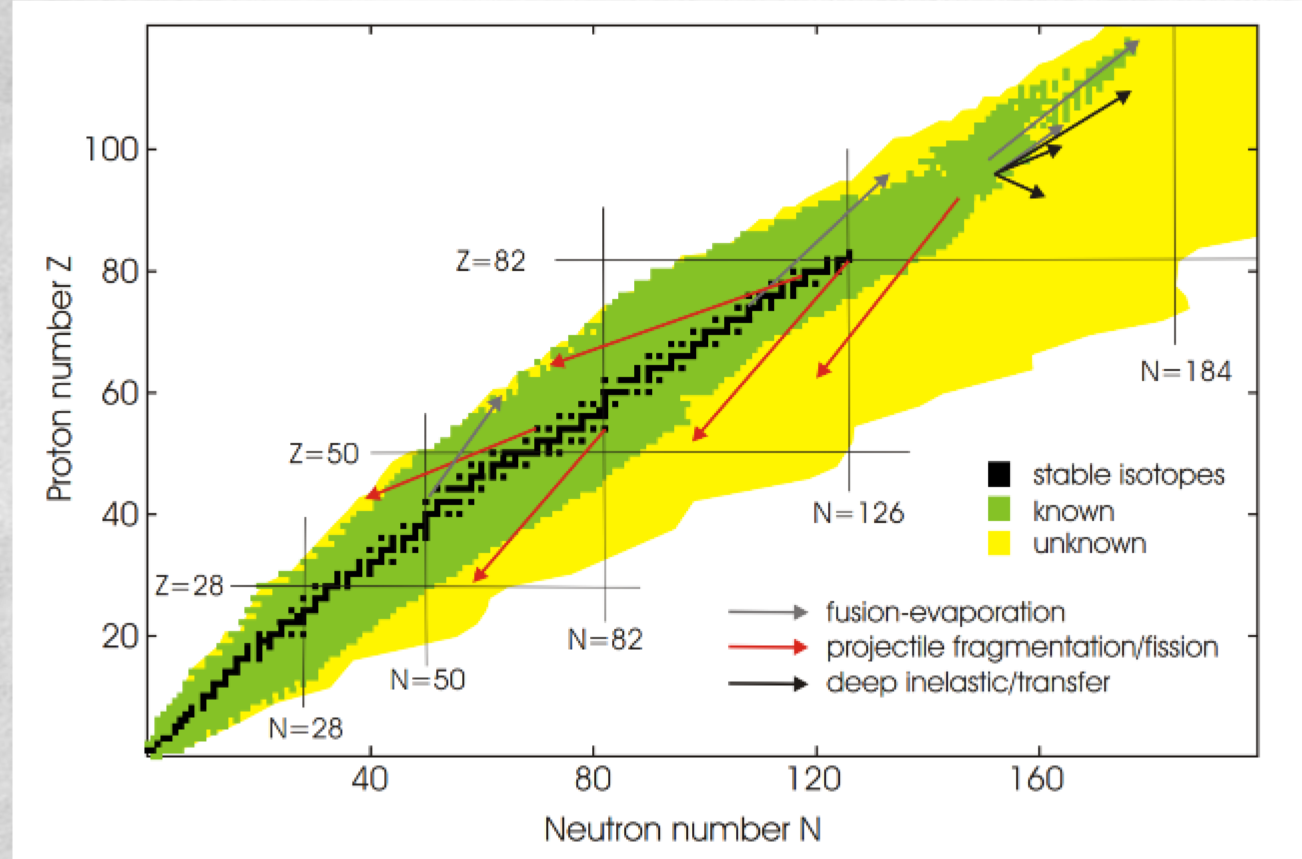
Energy Systematics



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

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

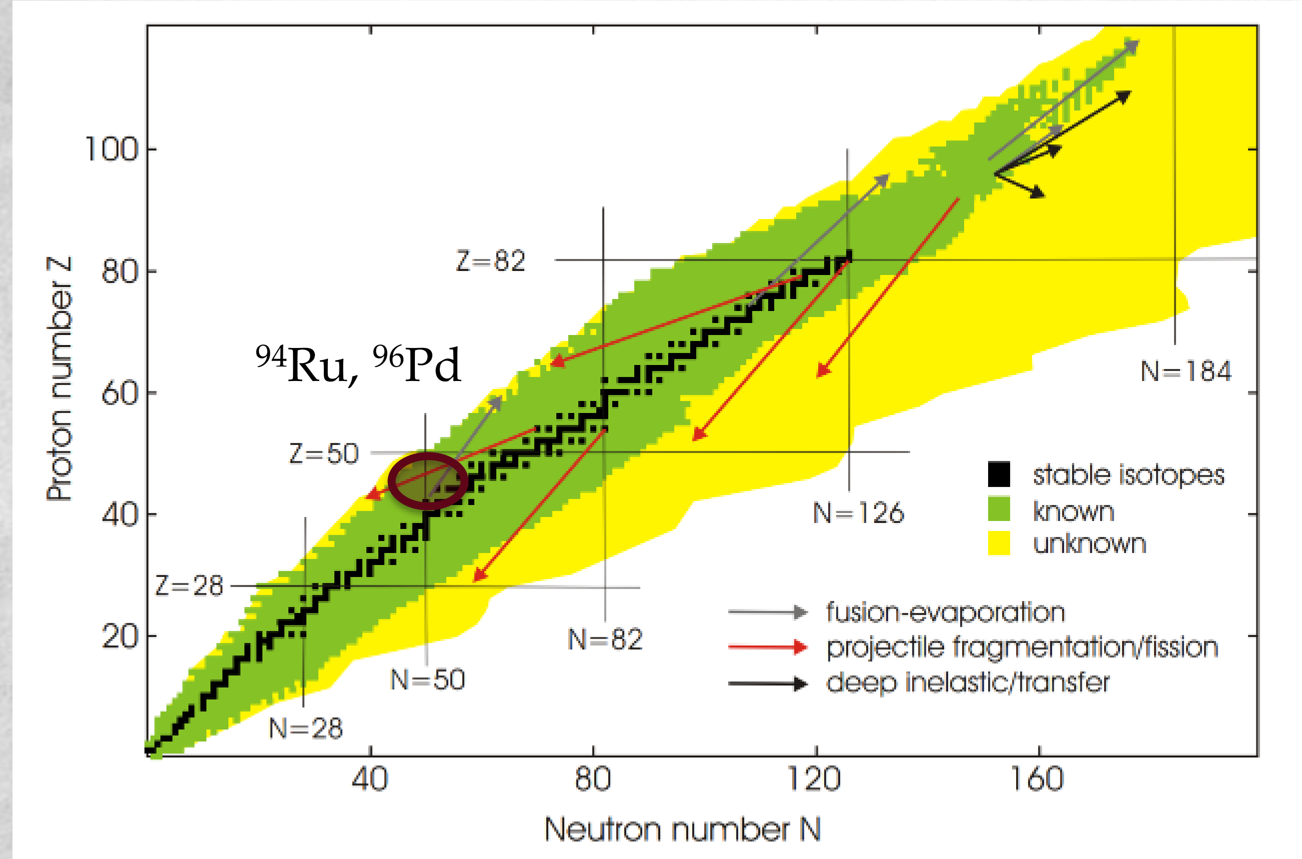
Lifetimes around the nuclear chart



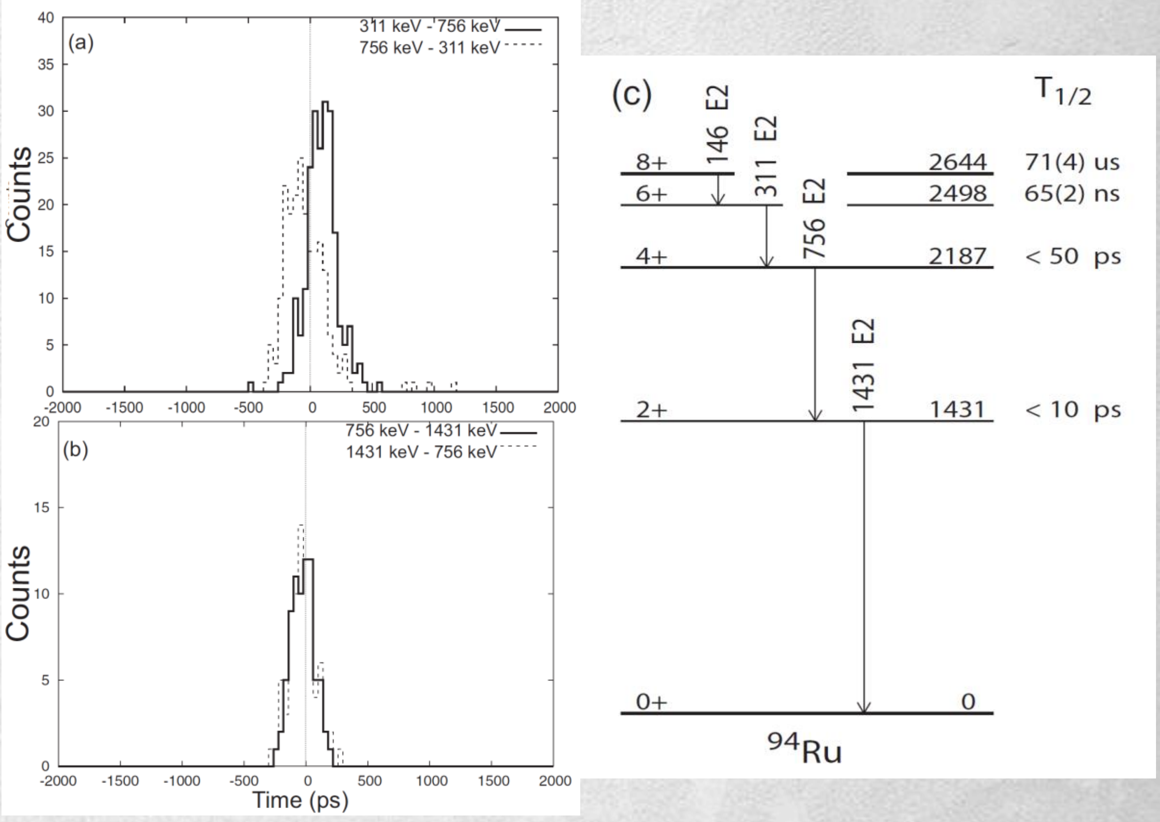
M. Thoennessen, Nuclear Data Sheets **118**, 85 – 90 (2014)

- A lot of useful information can be determined through measuring lifetimes all throughout the nuclear chart

Lifetimes of proton-rich nuclei

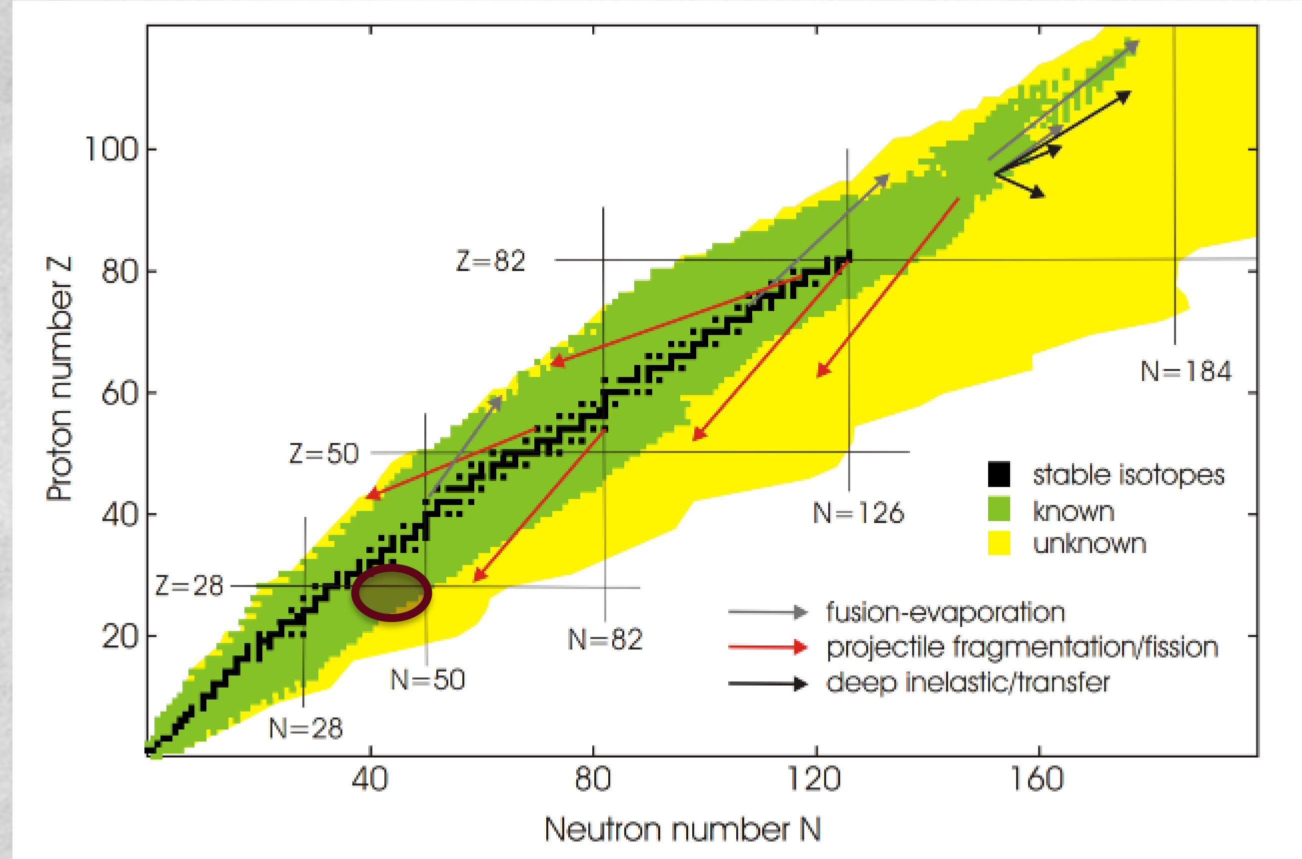


M. Thoennessen, Nuclear Data Sheets **118**, 85 – 90 (2014)



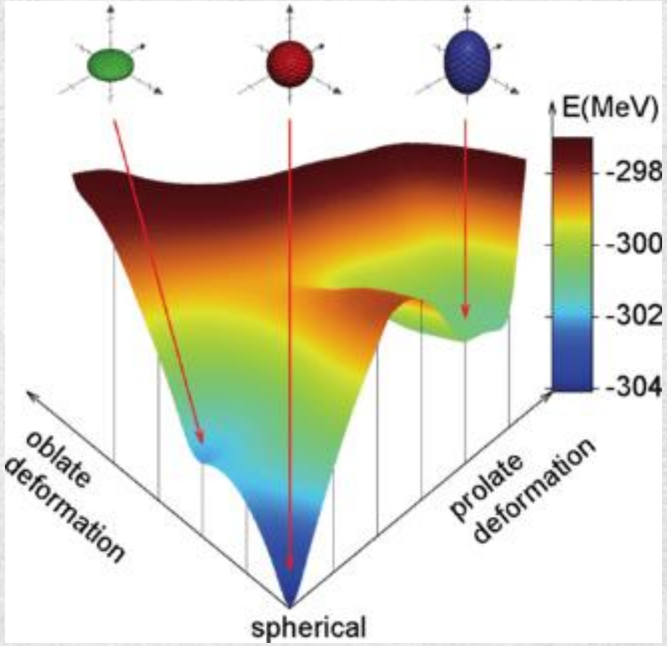
H. Mach *et al.*, Phys. Rev. C **95**, 014313 (2017)

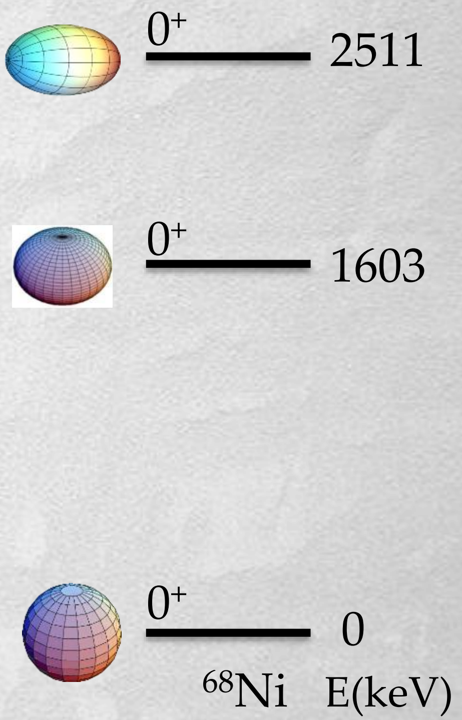
Lifetimes of neutron-rich nuclei



M. Thoennessen, Nuclear Data Sheets **118**, 85 – 90 (2014)

^{68}Ni

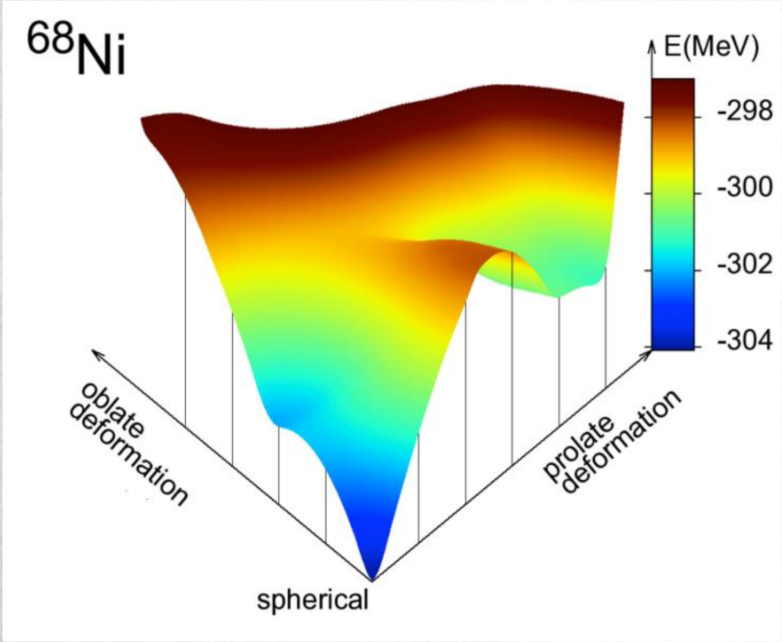


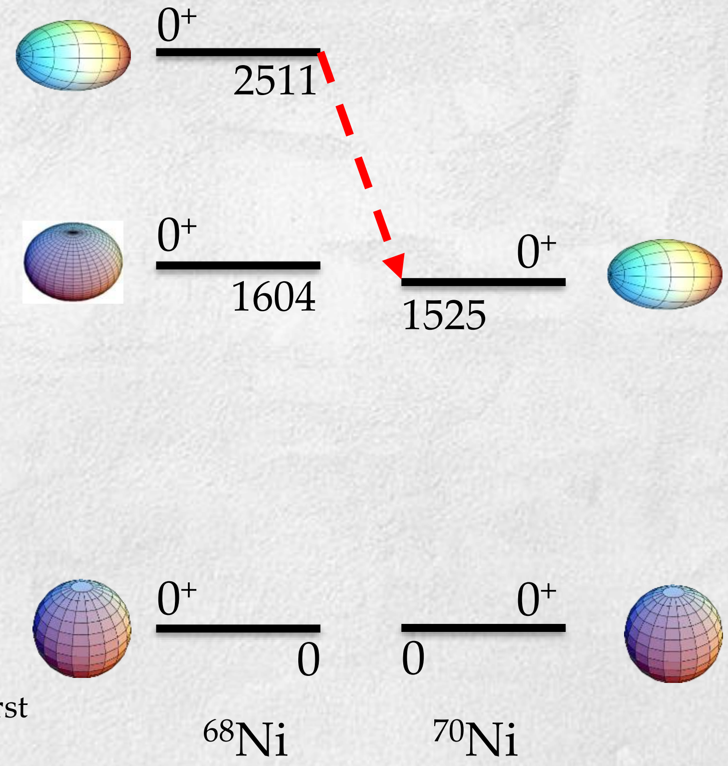


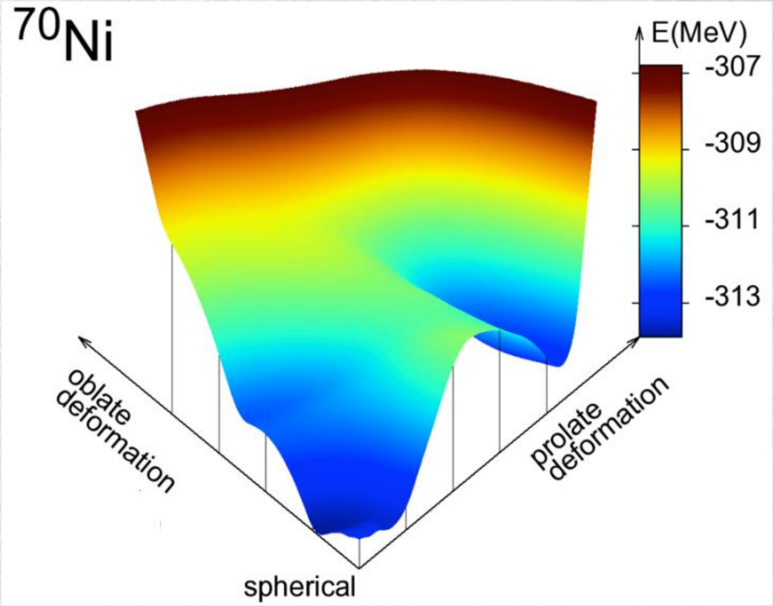
S. Suchyta *et al.*, Phys. Rev. C **89**, 021301(R) (2014)

Predicted Shape Coexistence in ^{70}Ni

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



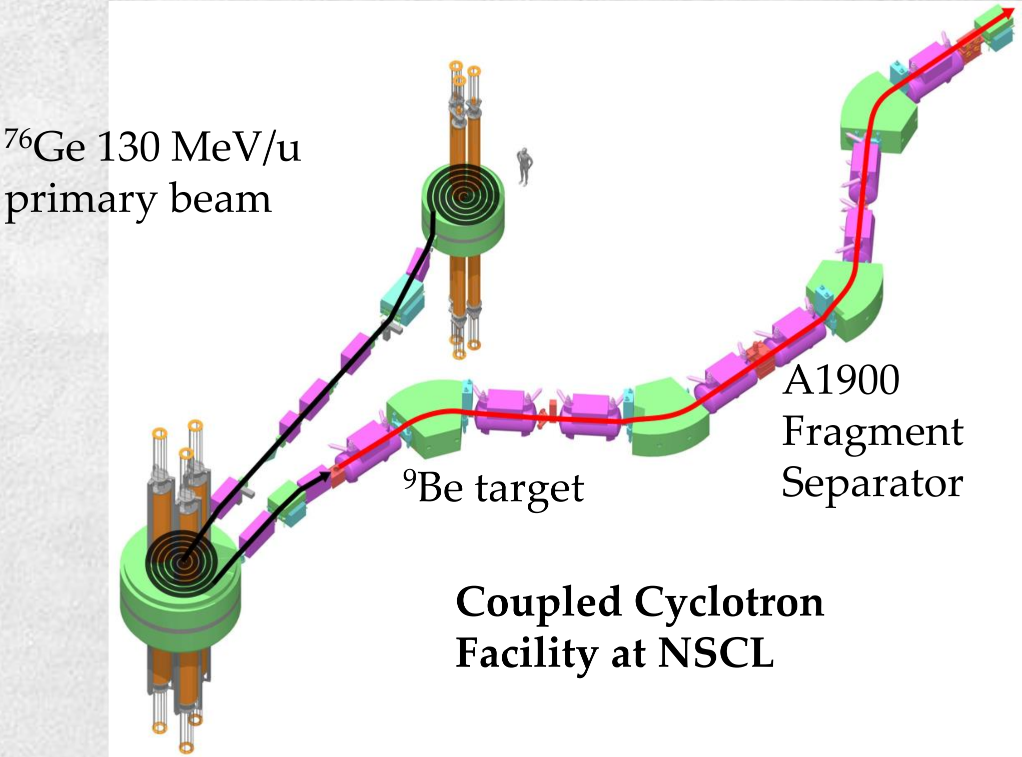




http://fustipen.ganil.fr/conferences/2014/workshops/understanding-nuclear-structure-and-reactions-microscopically-including-the-continuum-2/talks/otsuka_fustipen.pdf

National Superconducting Cyclotron Laboratory

Cocktail beam A~68 delivered to experimental end-station



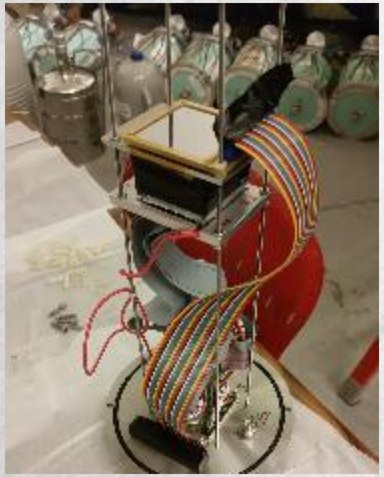
Fragmentation of a fast-moving, heavy, stable beam on a thin stable target

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

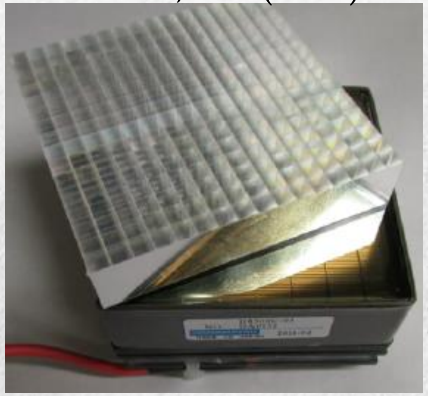
NSCL Experiment: Detection Systems

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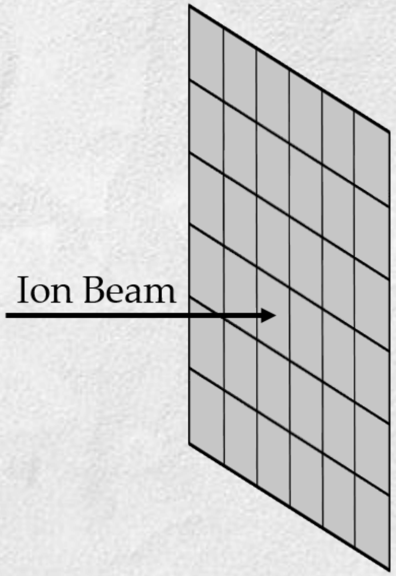
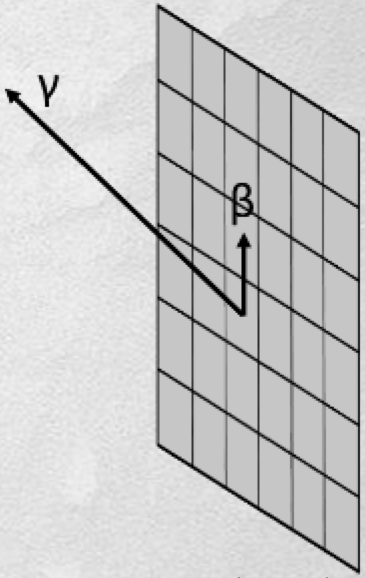
N. Larson *et al.*, Nucl. Instrum. Methods Phys. Res. A **727**, 59 (2013)
C. J. Prokop, *et al.*, Nucl. Instrum. Methods Phys. Res. A **741**, 163 (2014)

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

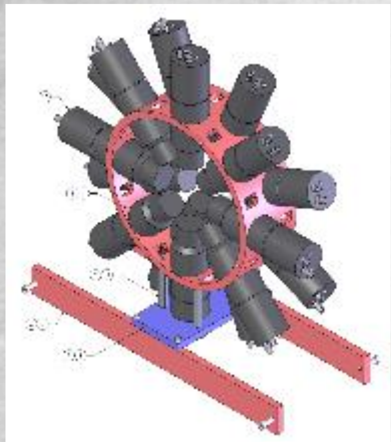


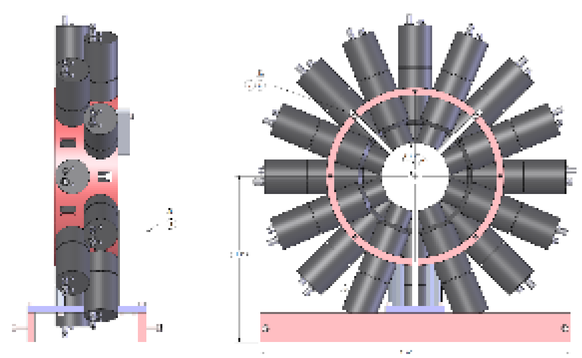
Some characteristic time later a decay is detected. Position and time of decay recorded.



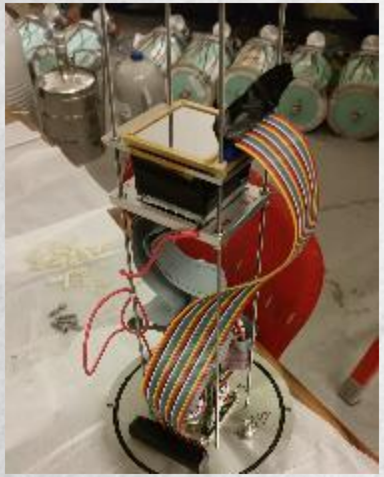
- Decays are correlated to ions using spatial and temporal information
- Time scales: Beta decay: ~10^{-3} s, Gamma decay: ~10^{-15} to 10^{-9} s

NSCL Experiment: Detection Systems





Central Implantation Detectors: Implanted ions from beam and beta decays



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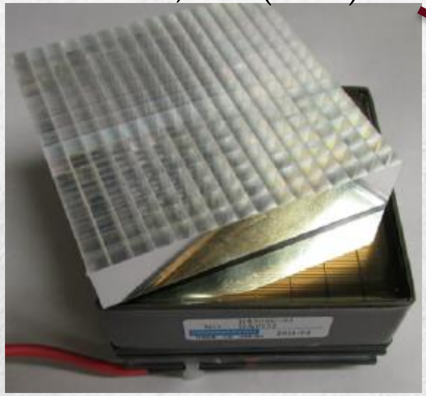

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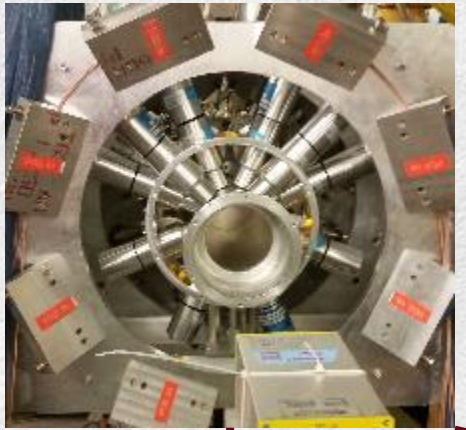
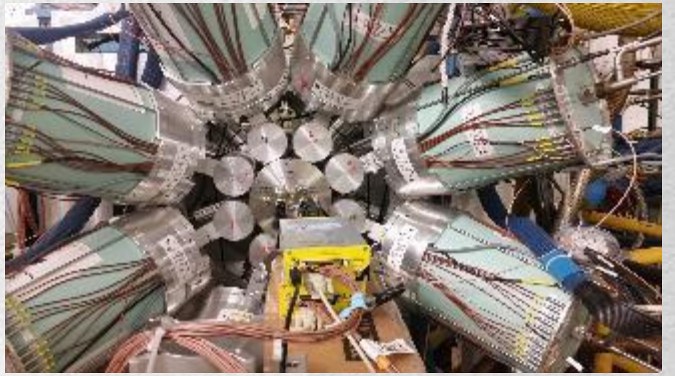
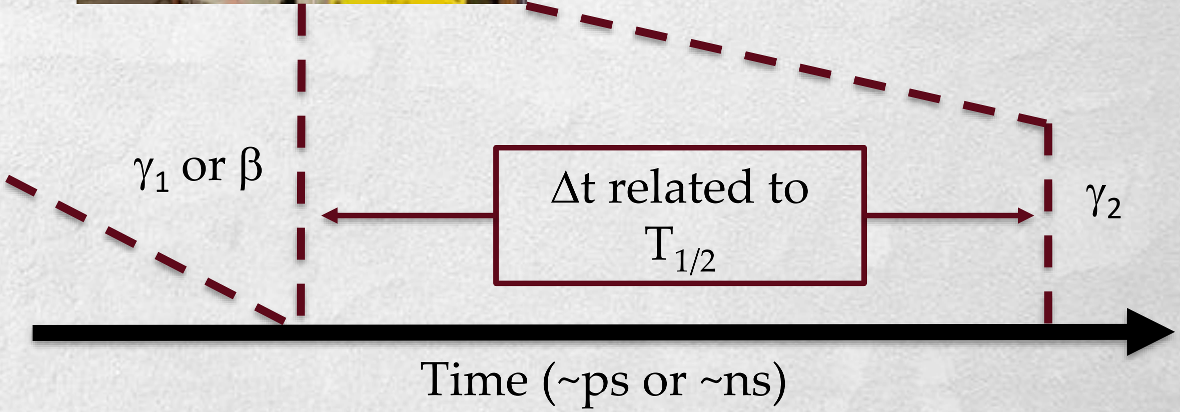
Gamma-ray Detectors

$LaBr_3$(Ce) array



Half of 16 HPGe SeGA array



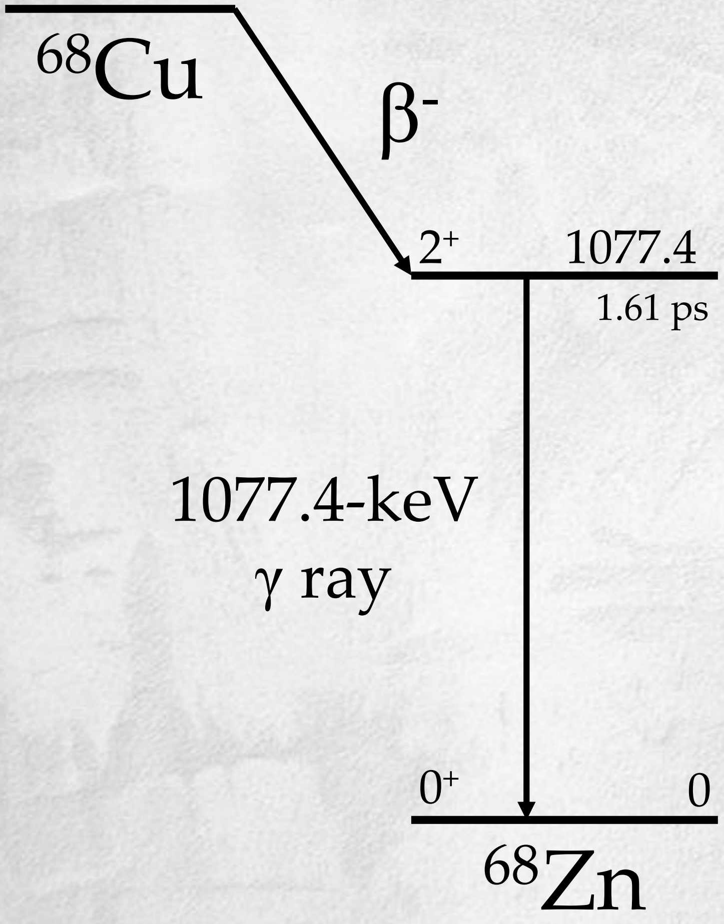


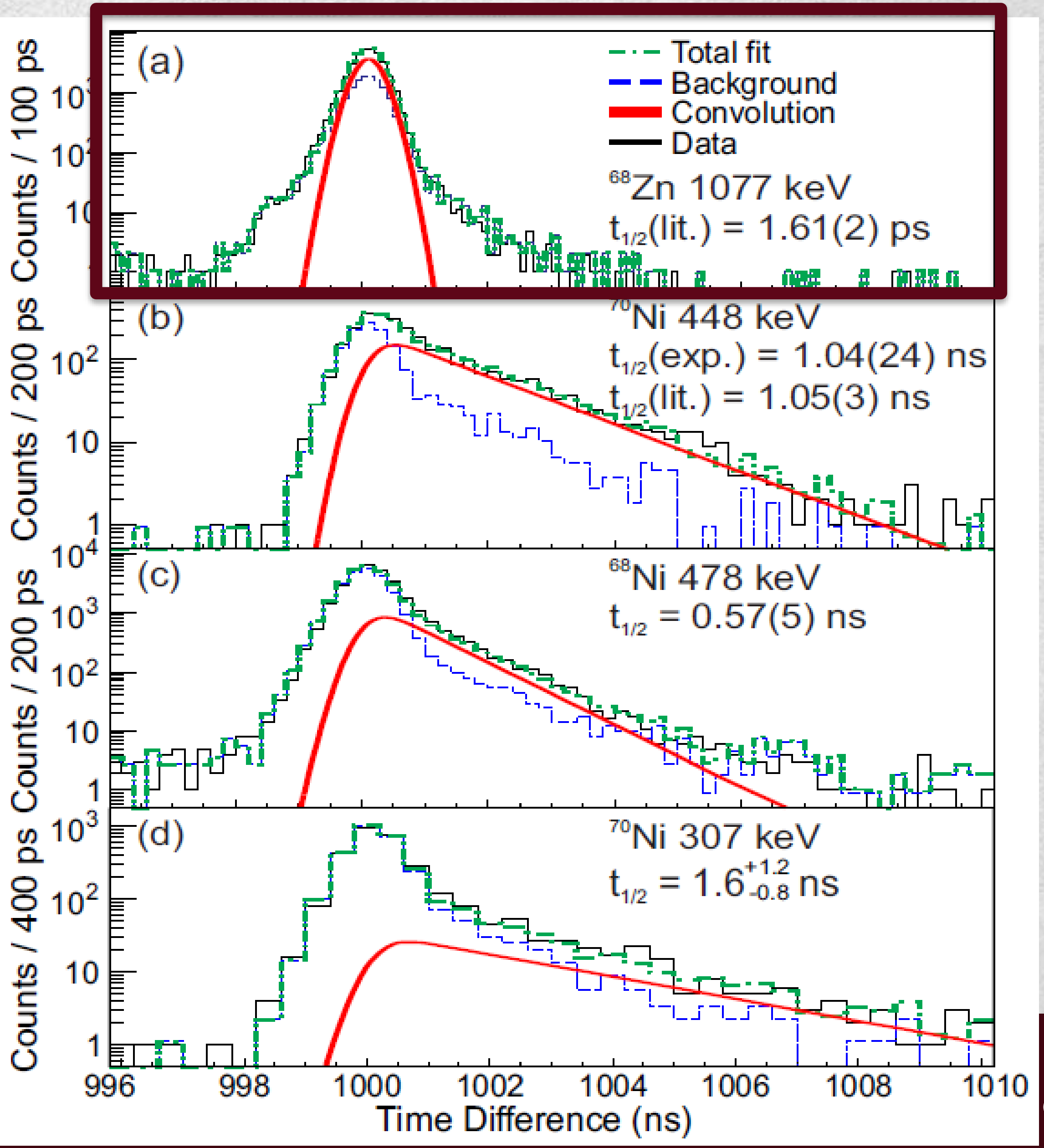
N. Larson *et al.*, Nucl. Instrum. Methods Phys. Res. A **727**, 59 (2013)
C. J. Prokop, *et al.*, Nucl. Instrum. Methods Phys. Res. A **741**, 163 (2014)

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

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

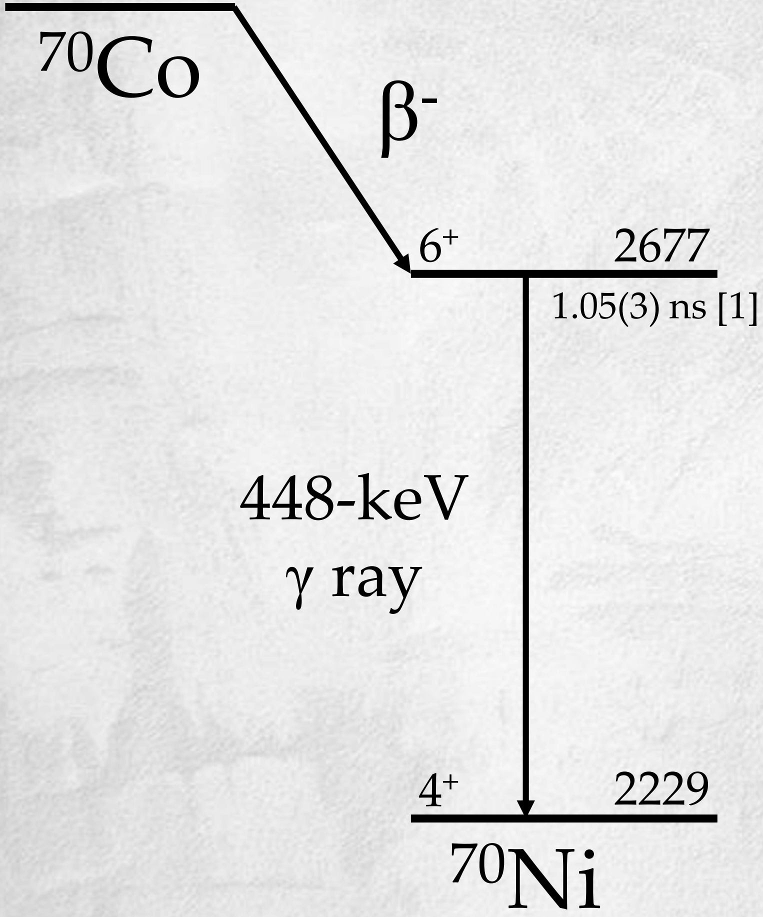
Lifetime Results

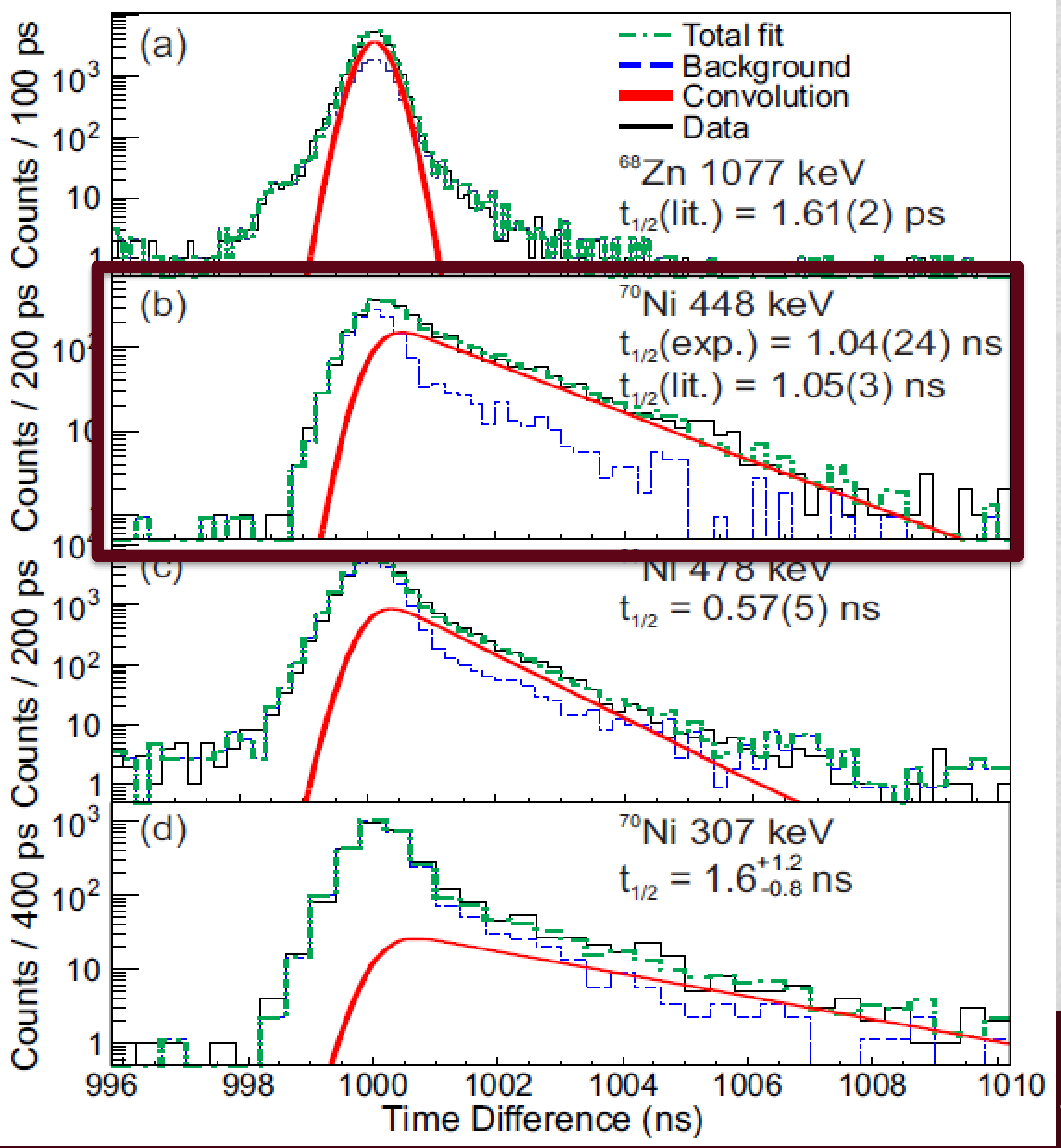




B. P. Crider *et al.*, Phys. Lett. B **763**, 108 (2016).

Lifetime Results



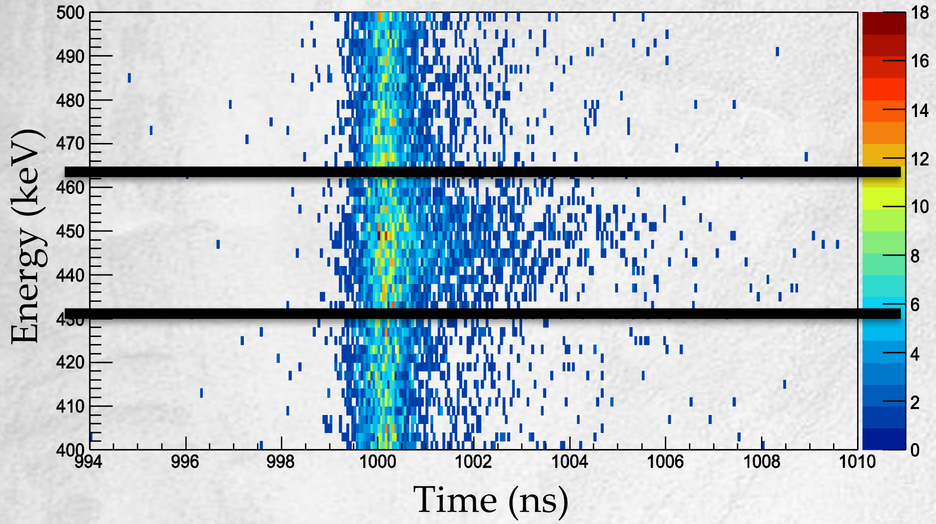


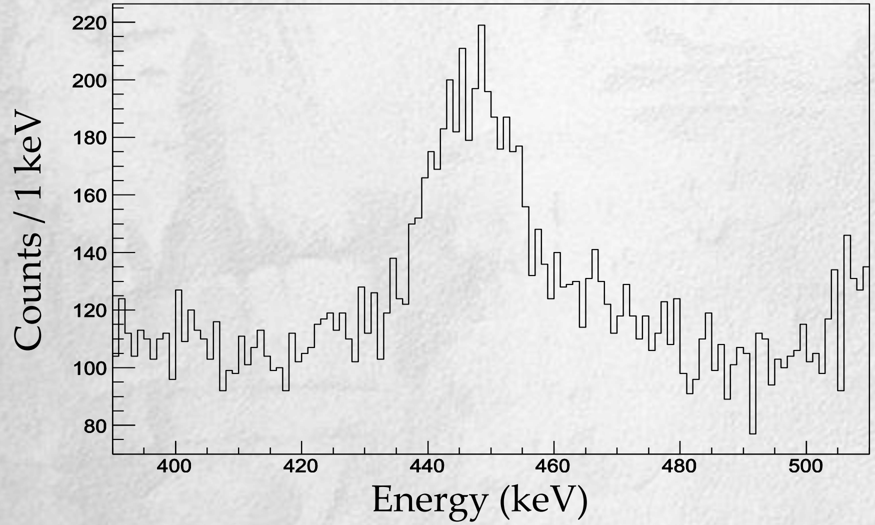
H. Mach *et al.*, Nucl. Phys. A **719**, C213 (2003)

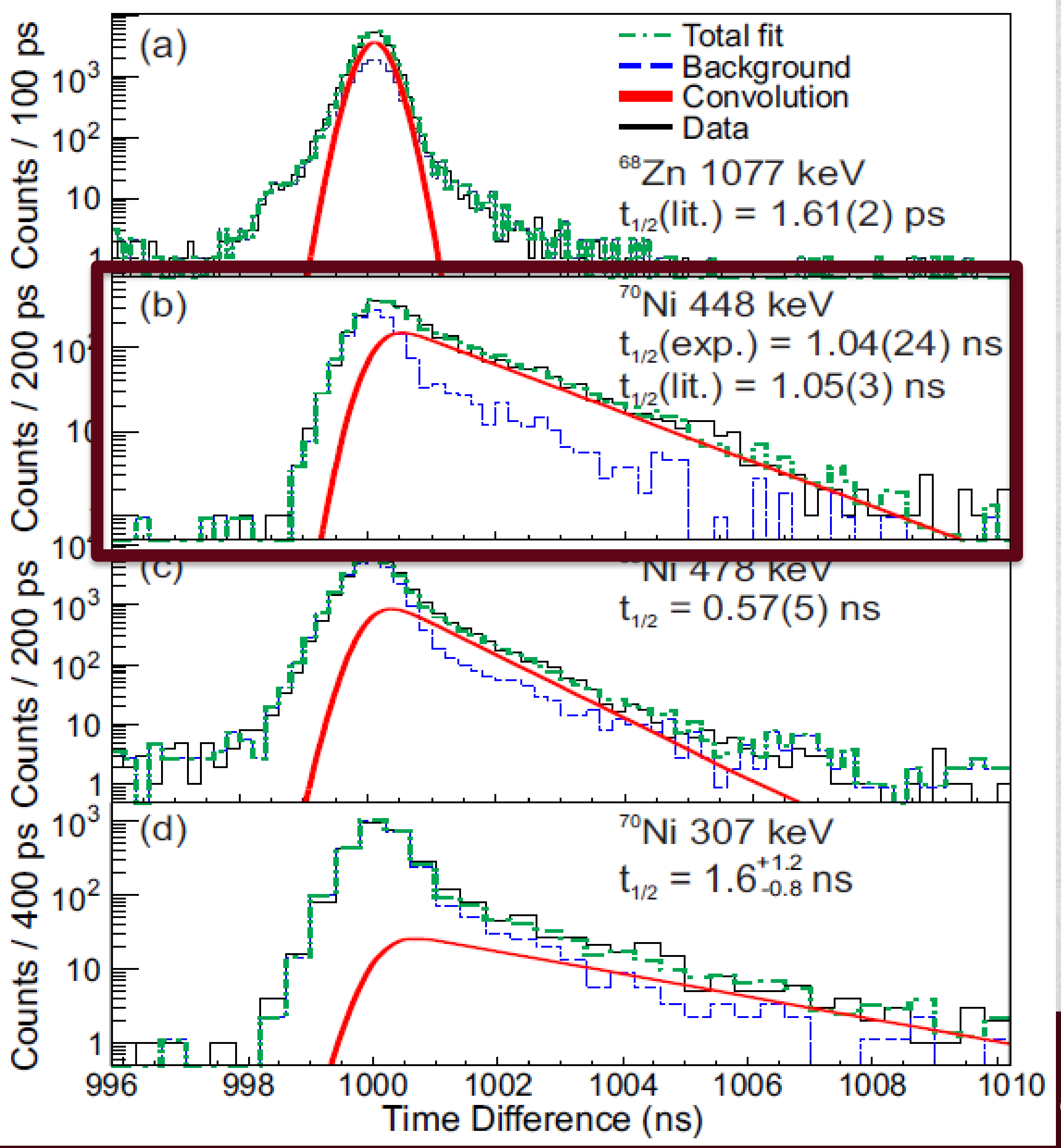
B. P. Crider *et al.*, Phys. Lett. B **763**, 108 (2016)

Lifetime Results

Correlated decays into ^{70}Ni







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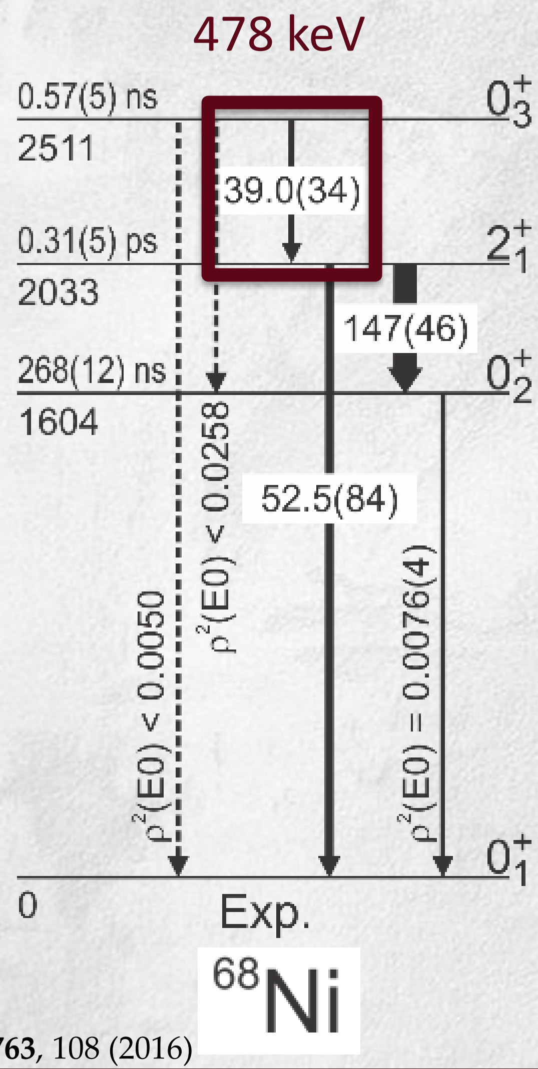
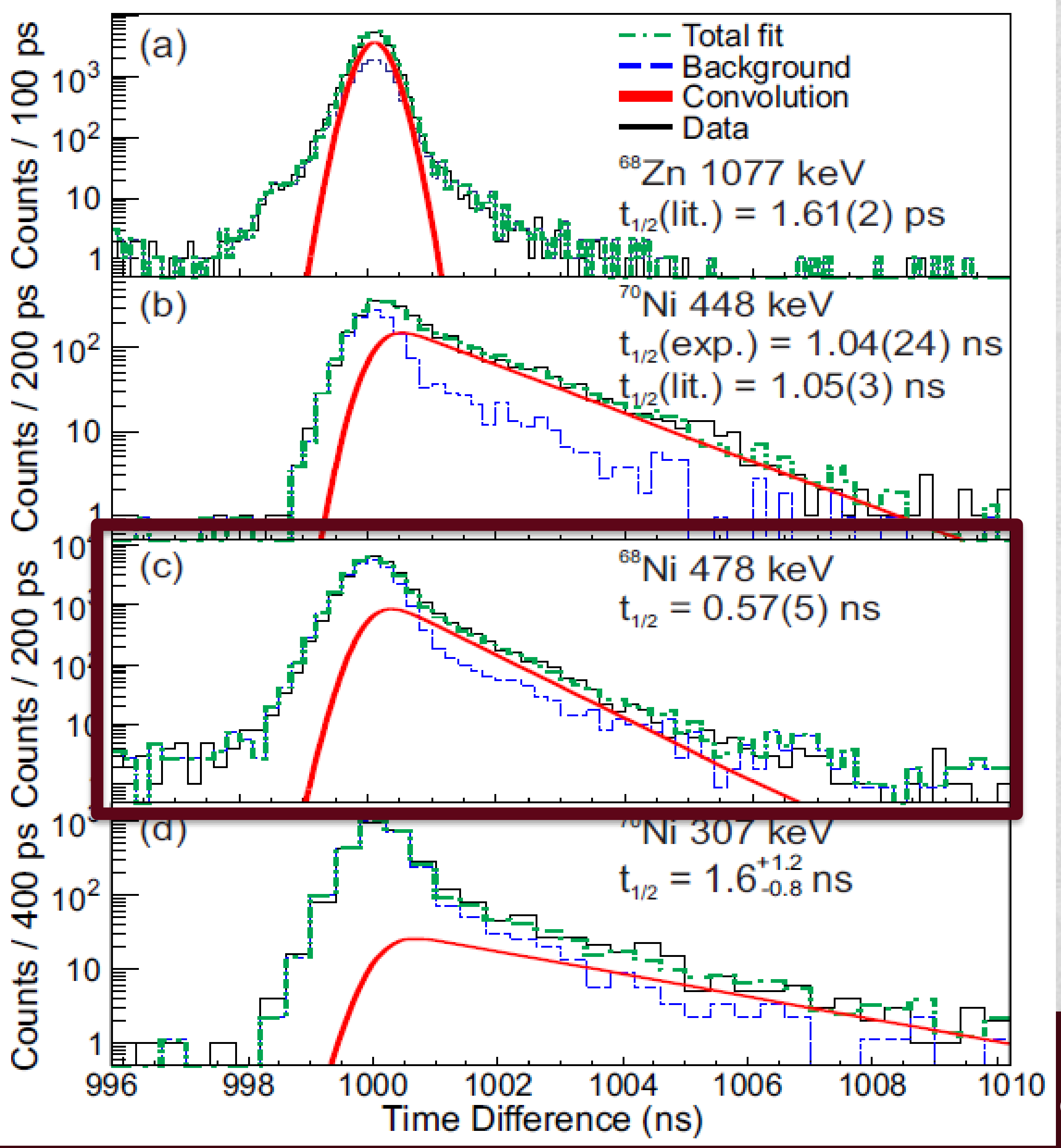


B. P. Crider *et al.*, Phys. Lett. B **763**, 108 (2016)



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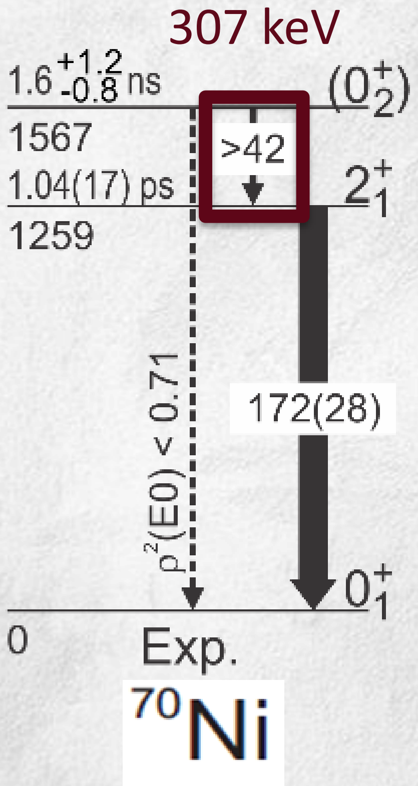
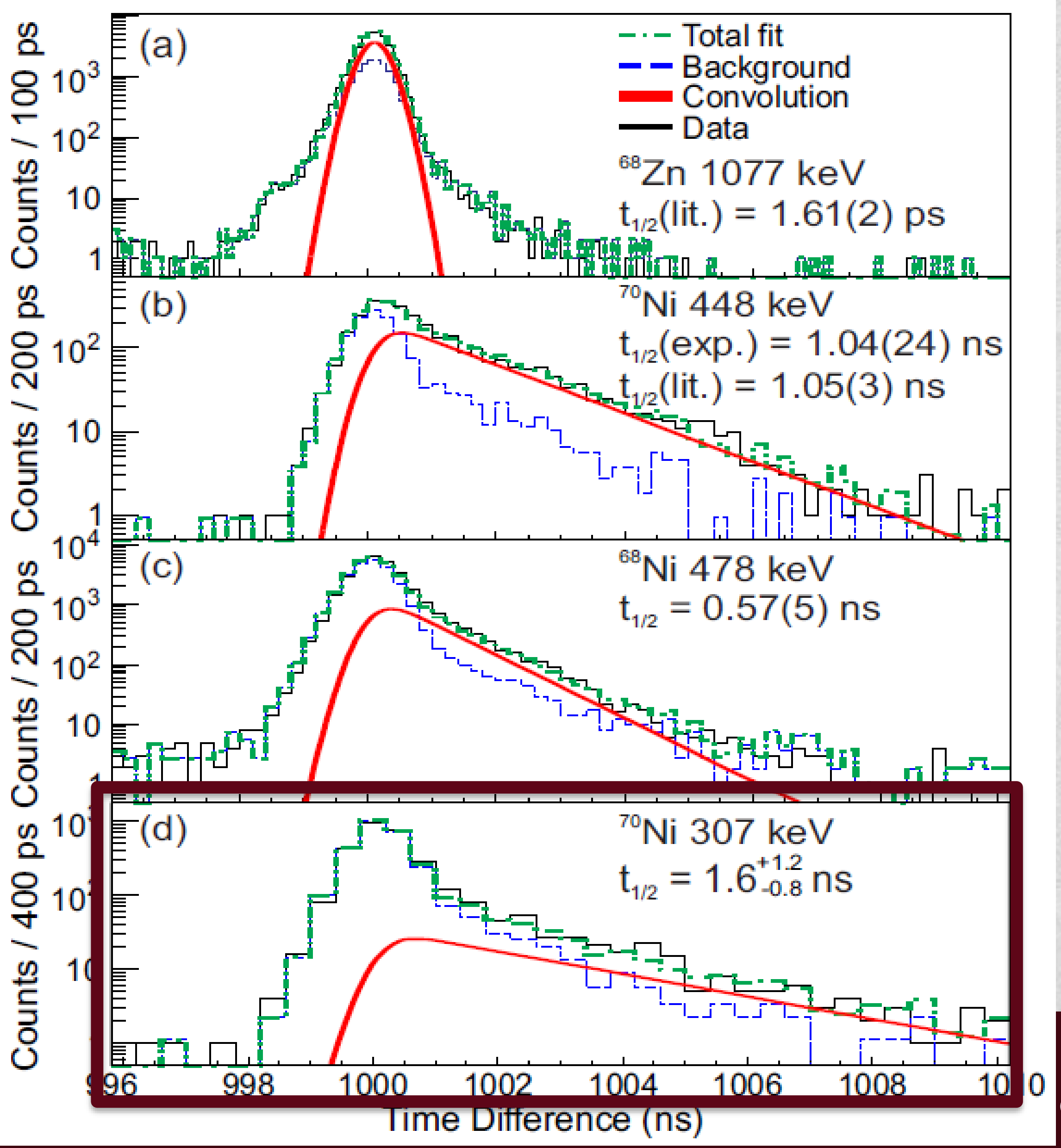
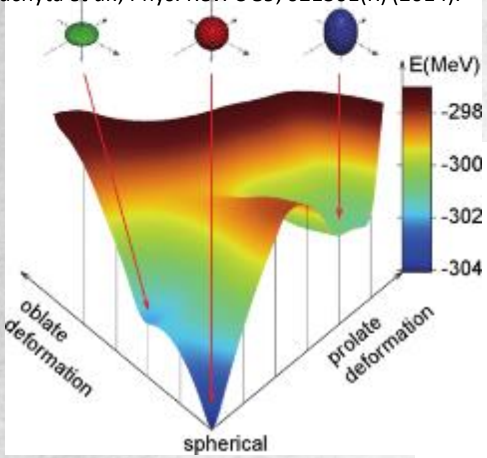




B. P. Crider *et al.*, Phys. Lett. B **763**, 108 (2016)

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

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



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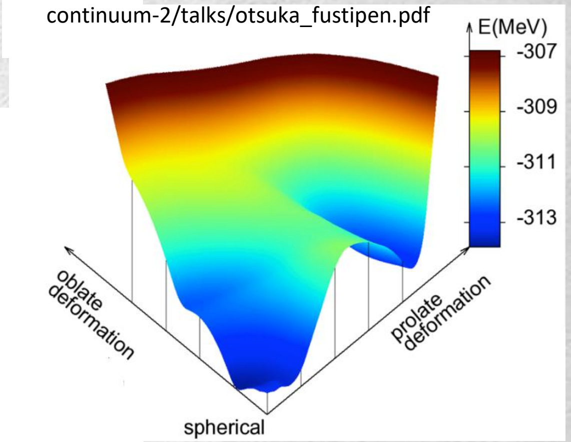

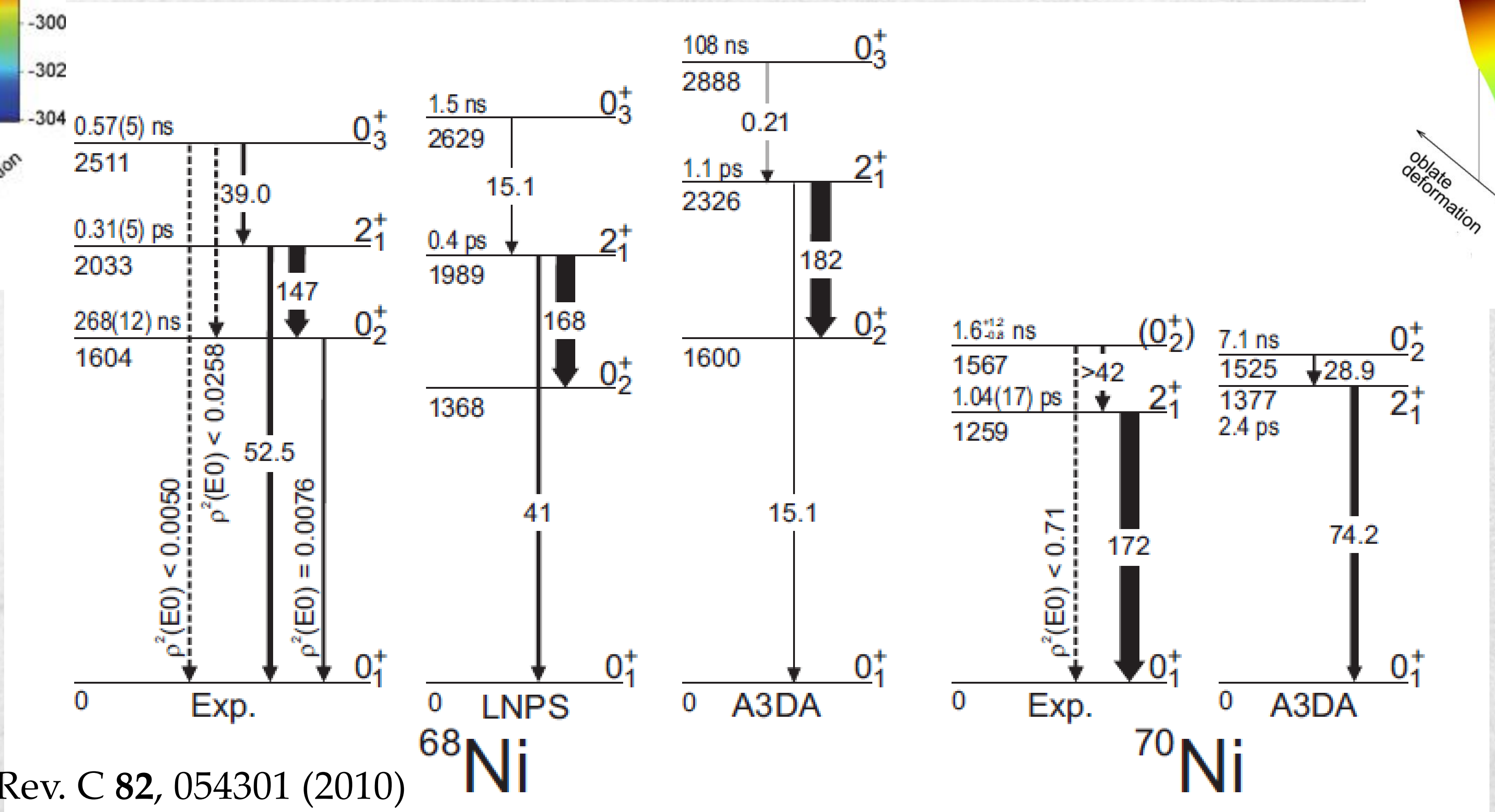

S. M. Lenzi *et al.*, Phys. Rev. C **82**, 054301 (2010)
B. P. Crider *et al.*, Phys. Lett. B **763**, 108 (2016)

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

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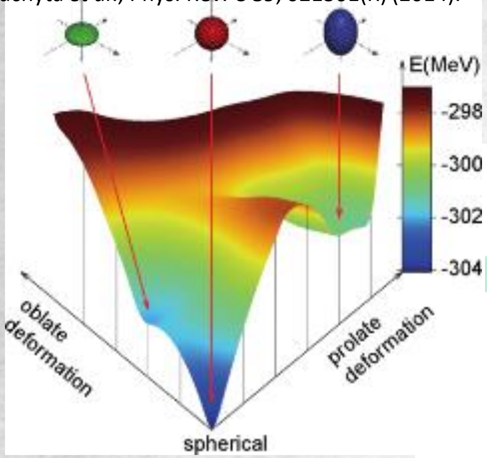

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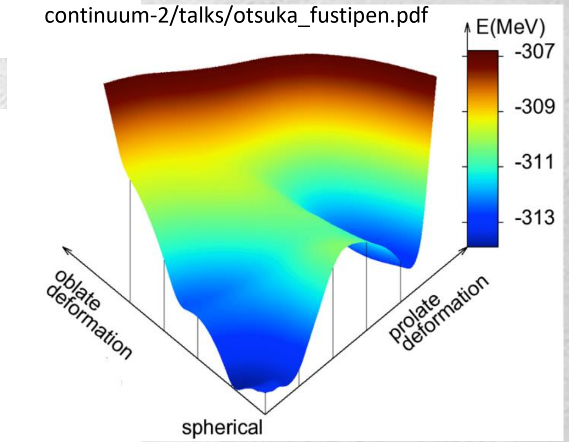
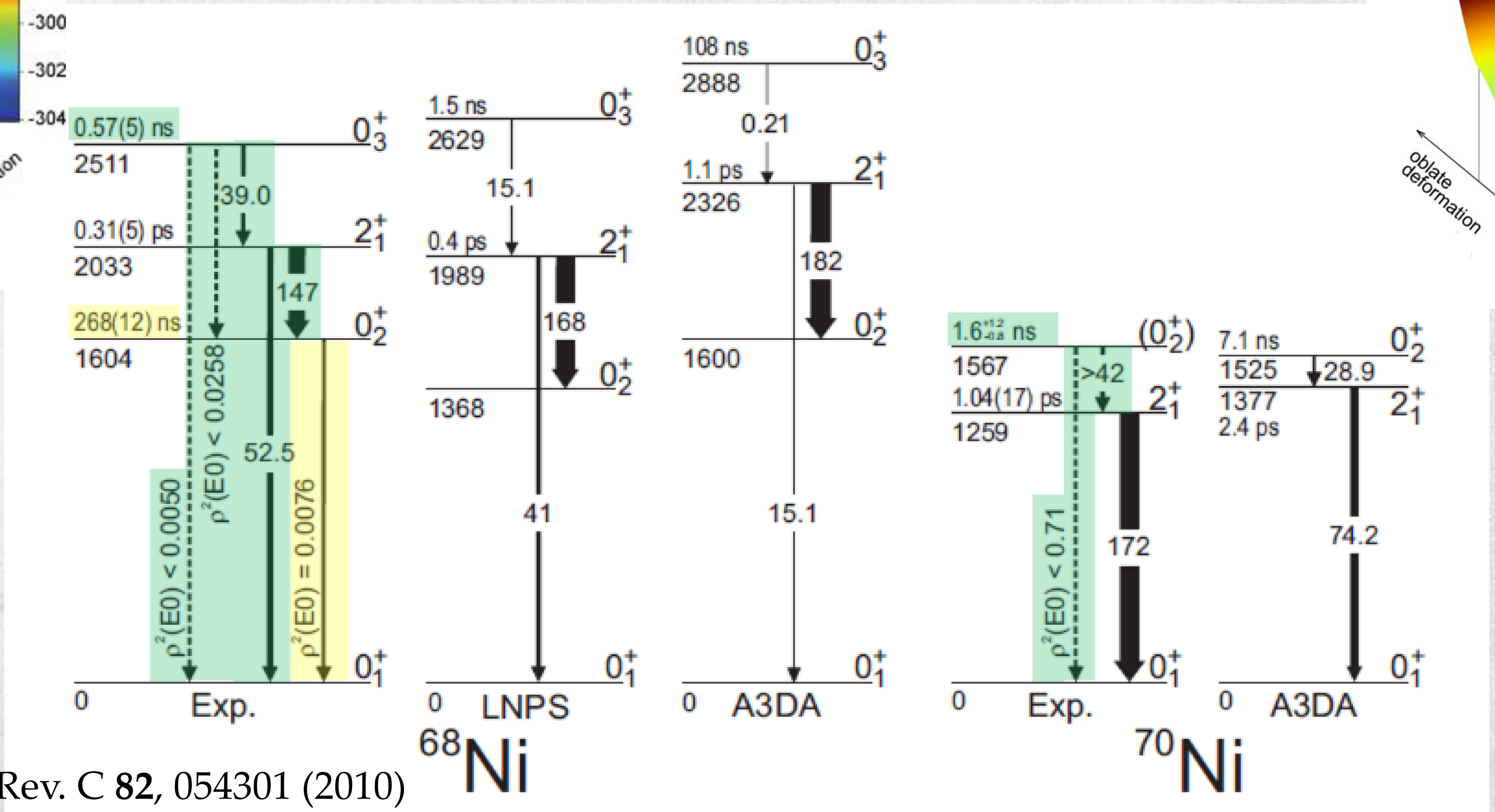
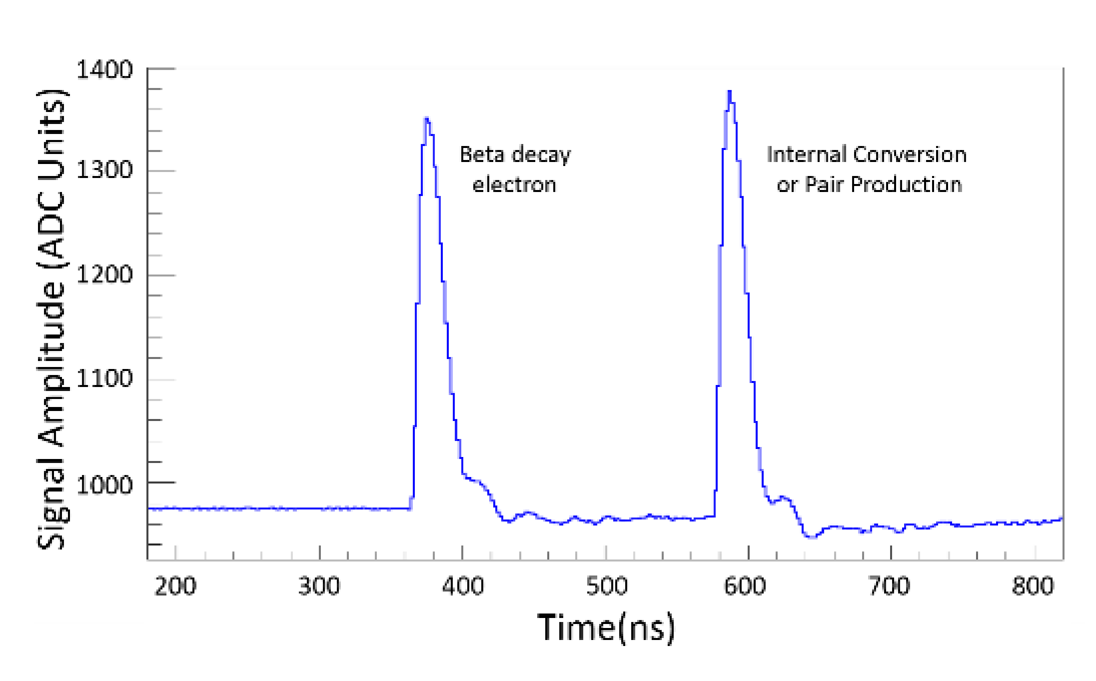


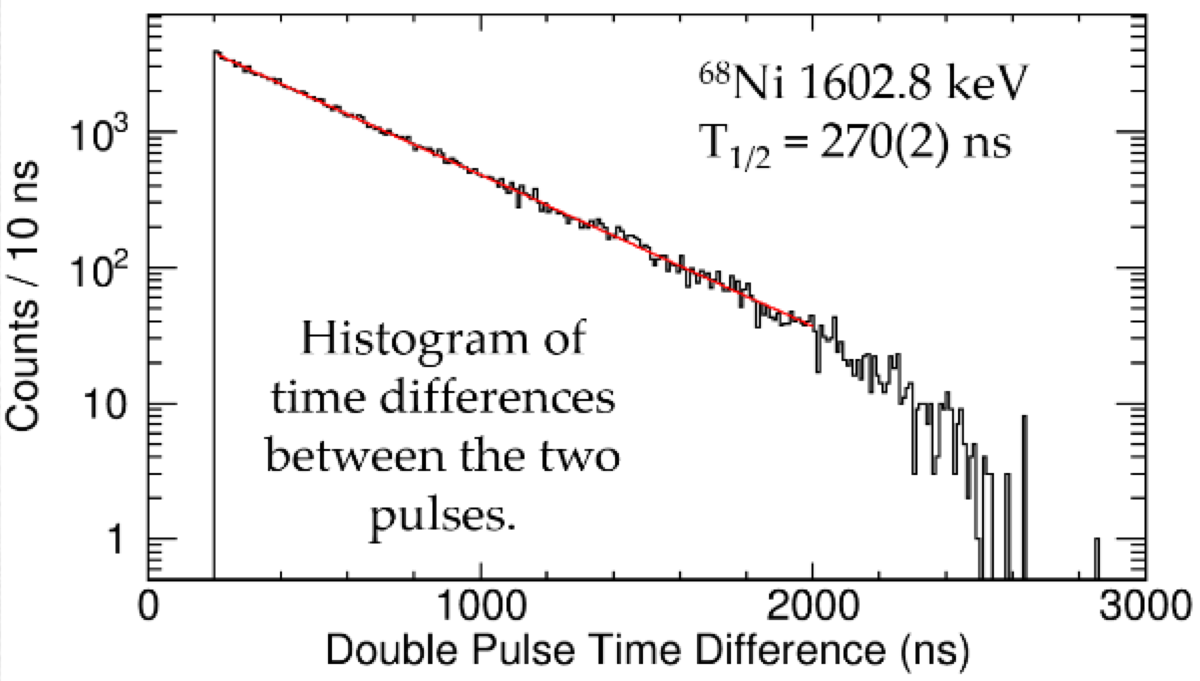


S. M. Lenzi *et al.*, Phys. Rev. C **82**, 054301 (2010)
B. P. Crider *et al.*, Phys. Lett. B **763**, 108 (2016)

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

Lifetime of the 0_2^+ in ^{68}Ni





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

Conclusions

- FRIB opens up a large number of nuclei for which β-decay experiments can provide many details on their low-lying structure
- Lifetime measurements leading to transition strength determinations are critical for understanding the underlying configurations of excited nuclear states.
- A recent experiment at NSCL coupling fast-timing and high-resolution detection systems has enabled an expansion of the information in ^{68,70}Ni.

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

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.