Shape evolution and Collectivity beyond ^{78}Ni: Lifetime measurements of low-lying states in neutron-rich Zn

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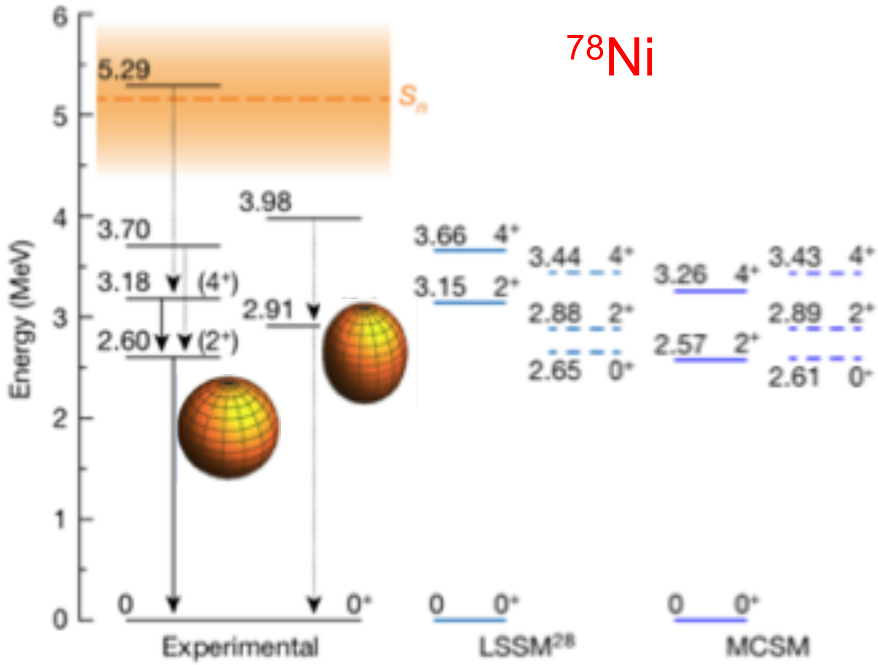
Motivation

- ❑ Collectivity && np - nh excitation
- ❑ ^{78}Ni(Z=28): doubly magic; prolate 2_2^+ state
- ❑ ^{79}Zn(Z=30): low-lying intruder state
- ❑ ^{80}Ge(Z=32): low-energy shape coexistence

First evidence: A. Gottardo *et al.*, PRL 116, 182501 (2016).
No evidence: F. H. Garcia *et al.*, PRL 125, 172501 (2020).

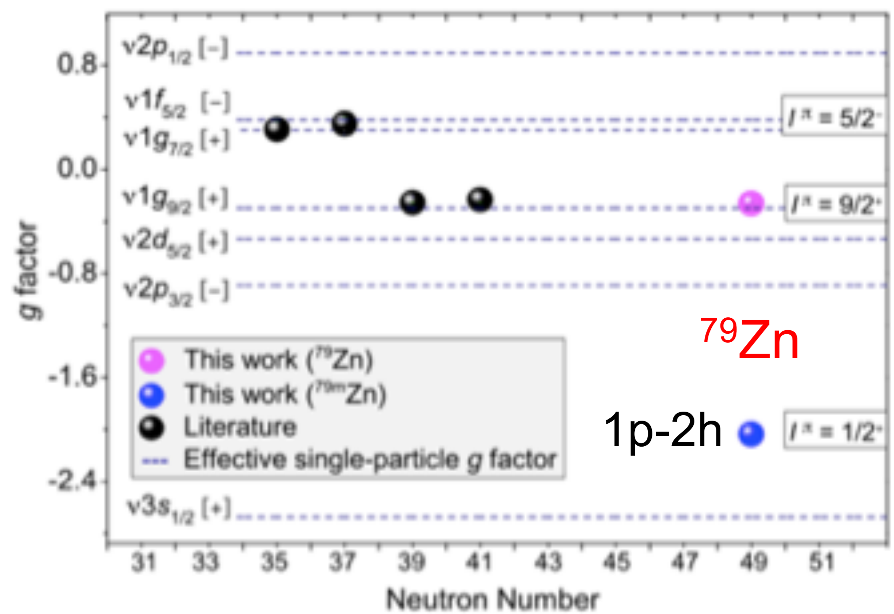
- ❑ N = 52 isotones: Shape transition from Z = 34(soft triaxial) to 32(prolate)

C. Delafosse et al., PRL 121, 192502 (2018).



R. Taniuchi *et al.*, Nature (London) 569, 53 (2019).

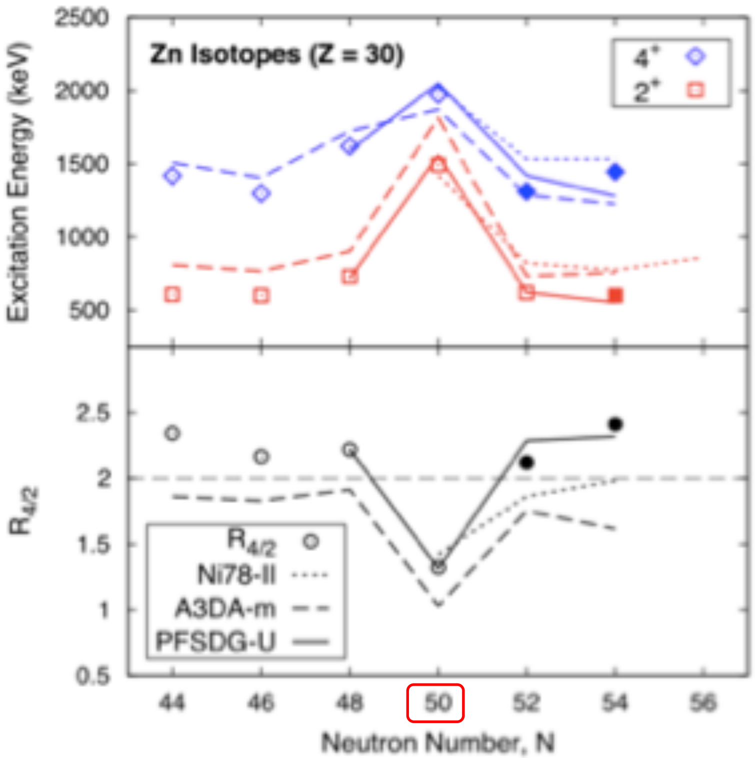
low-lying intruder state in ^{79}Zn



X. F. Yang *et al.*, Phys. Rev. Lett. 116, 219901 (2016).

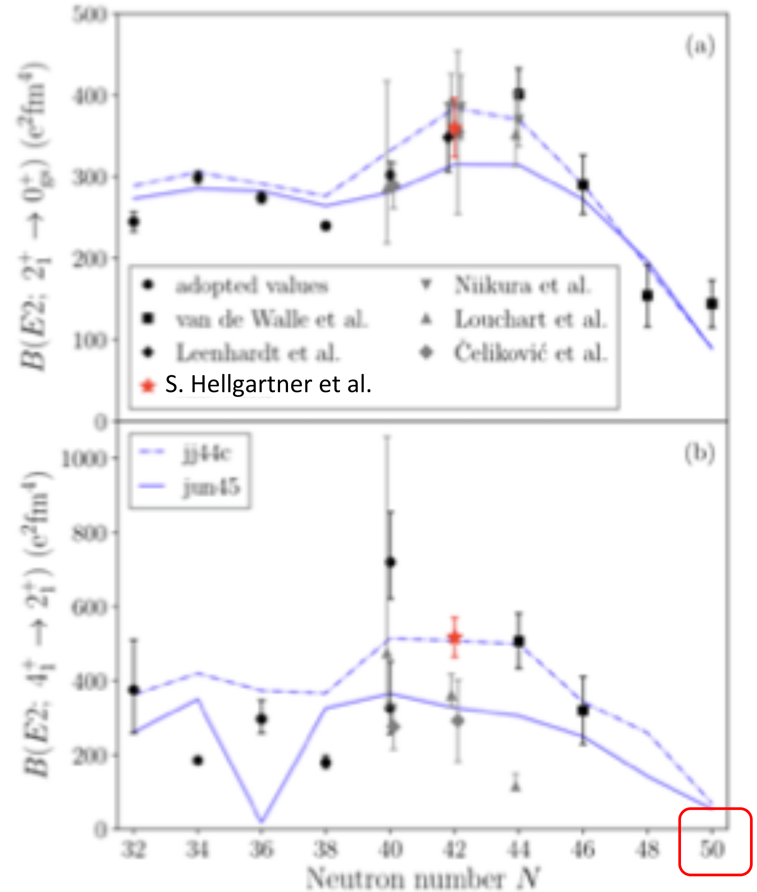
Deformation in even-even Zn isotopes

- Magicity confined to N = 50



Ni78-II: w/o core breaking
A3DA-m and PFSDG-U: w/ core breaking

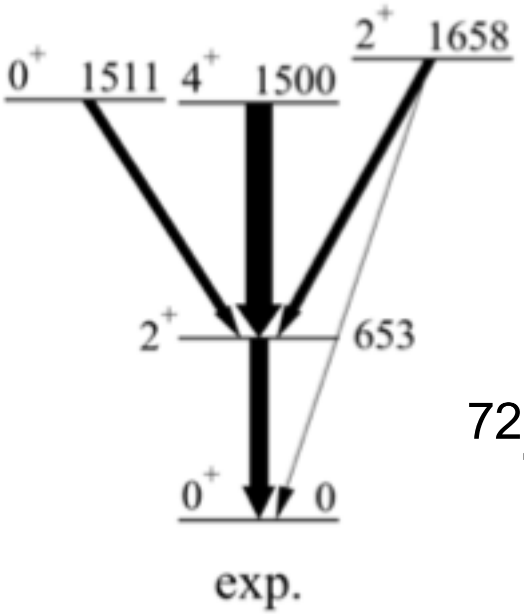
C.M. Shand et al., PLB 773, 492(2017).



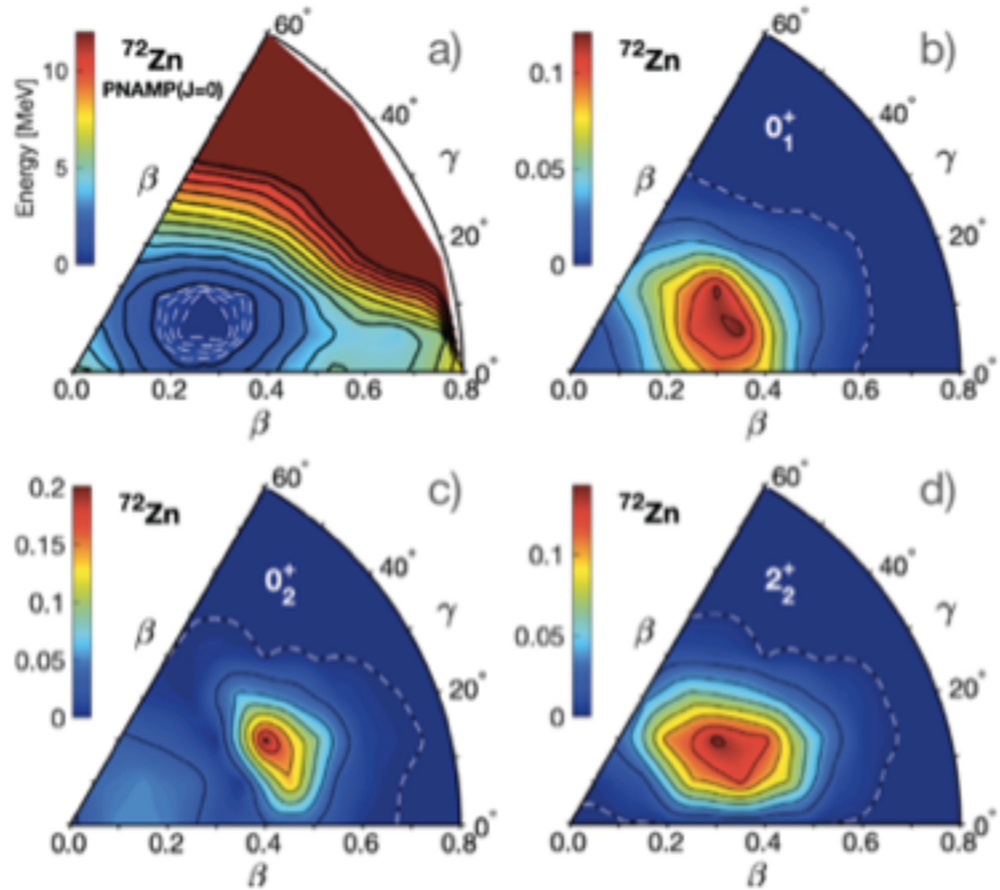
S. Hellgartner et al., PLB 841,137933(2023).

- An onset of deformation towards heavier Zn isotopes was predicted by SM.
- Lifetime of 4^+ and 2^+ states is unknown for heavier Zn isotopes.

Triaxial deformation in $^{72,74}Zn$



$^{72}Zn_{42}$



- ❑ Triaxial deformation
  - ○ $R_{22} = E(2_2^+)/E(2_1^+) = 2.54$
  - ○ Measured quadrupole moment

- ❑ Similar structure is also observed in ^{74}Zn.

M. Rocchini et al., PRL 130, 122502(2023).

S. Hellgartner et al., PLB 841,137933(2023).

- ❑ Evidence on triaxial deformation beyond N = 50 is still missing.

Previous study on $^{82}Zn_{52}$

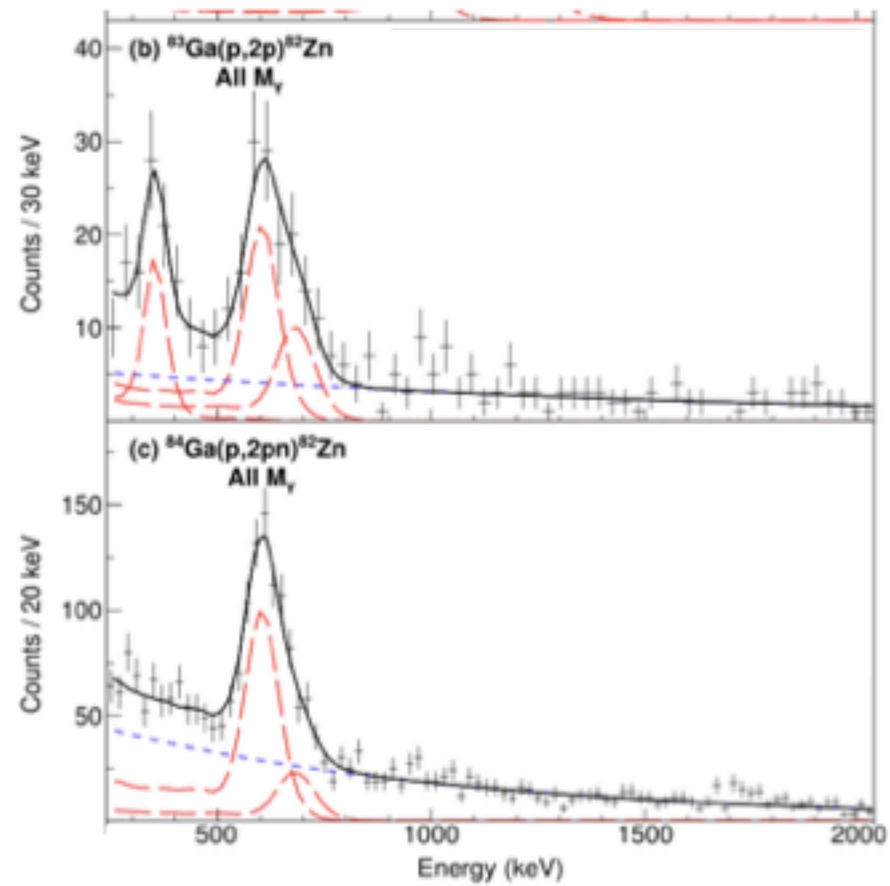
- ❑ First study: ^{9}Be(X,^{82}Zn+γ), DALI2
- ○ only 621(11)-keV γ transition was observed
- ○ 2^+ -> g.s.

Y. Shiga et al., PRC 93, 024320 (2016).

- ❑ Following up study: (p,2p), DALI2
- ○ three γ transitions were identified
- ○ 618(15), 2_1^+ -> g.s.
- ○ 692(12), 4_1^+ -> 2_1^+
- ○ 369(17), 0_2^+ -> 2_1^+

C.M. Shand et al., PLB 773, 492(2017).

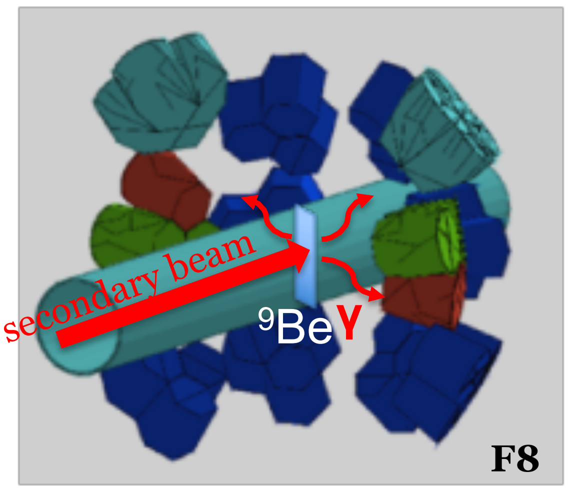
----- Simulated response functions

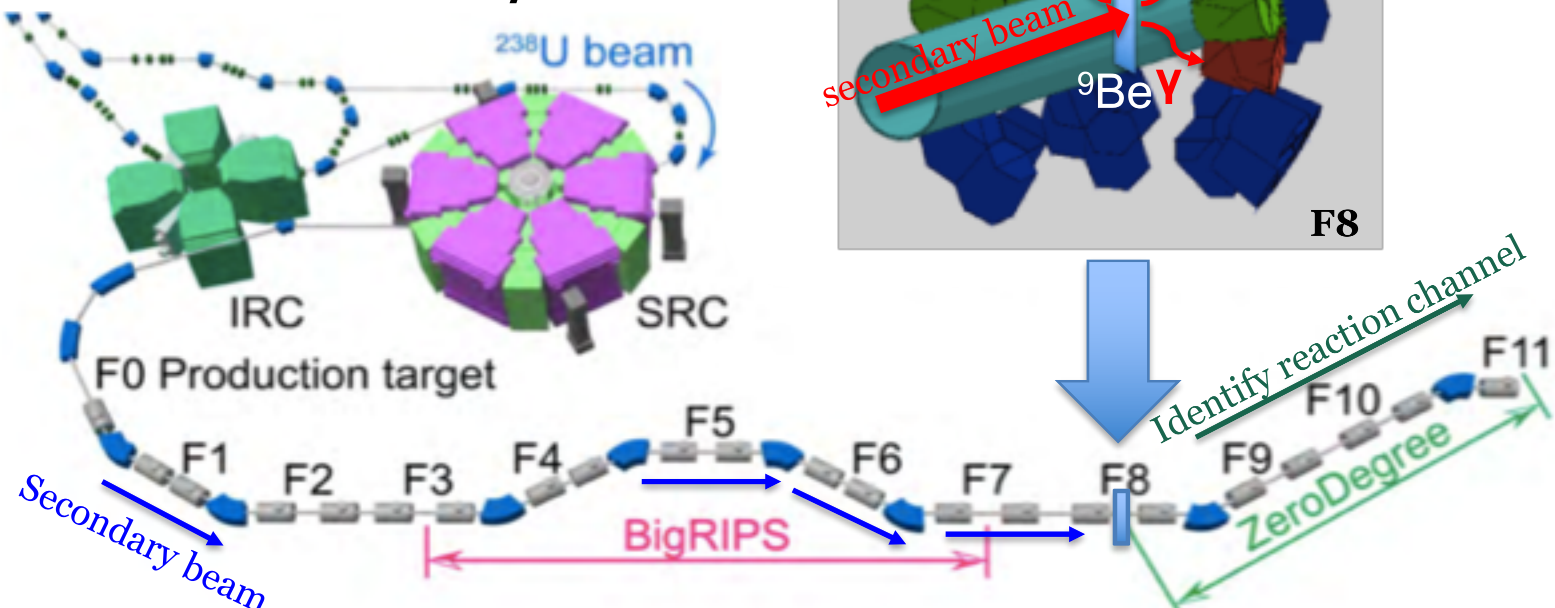


- ○ Precise energy measurement with detectors having better energy resolution is essential.

Experimental setup

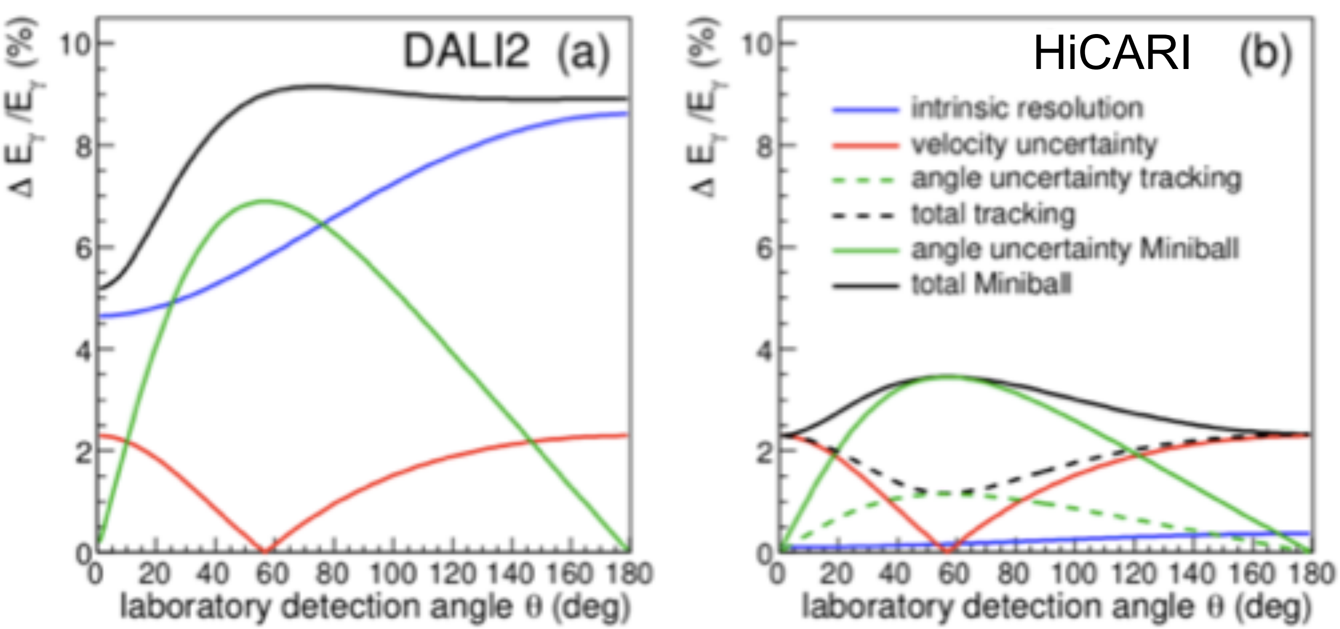
- ❑ HiCARI campaign @ RIKEN Nishina Center
- ○ 345MeV/u ^{238}U beam of 60 pnA; ~58 hours physical run
- ○ Primary target: ^{9}Be @F0
- ○ Reaction target: 6-mm ^{9}Be @F8
- ○ ^{82}Zn: ^{9}Be(^{83}Ga,^{82}Zn+γ)
- ○ Particle Identification: $\triangle E$ - $B\rho$ - TOF





High Resolution Cluster Array at RIBF(HiCARI)

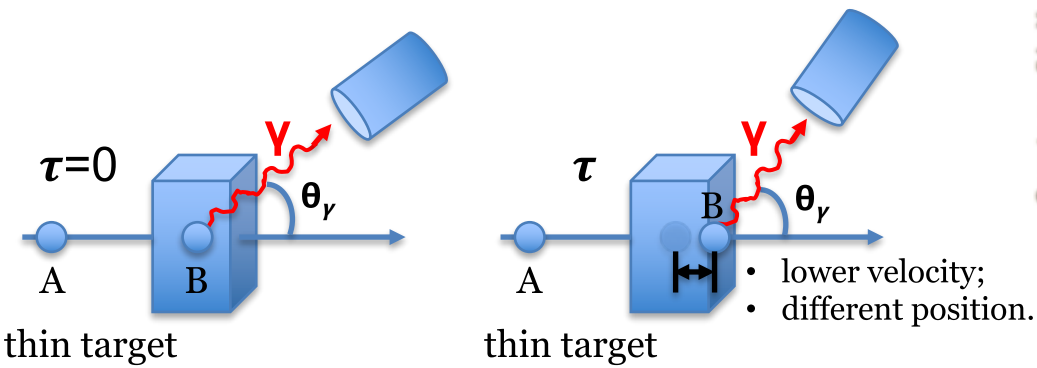
- ❑ HiCARI: highly segmented HPGe array
  - 6 Miniball triple clusters
  - 4 Clovers
  - RCNP Quad(GRETINA type)
  - LBNL triple(GRETINA type)
- ❑ Efficiency of ≈ 6% @1 MeV



Lifetime measurement

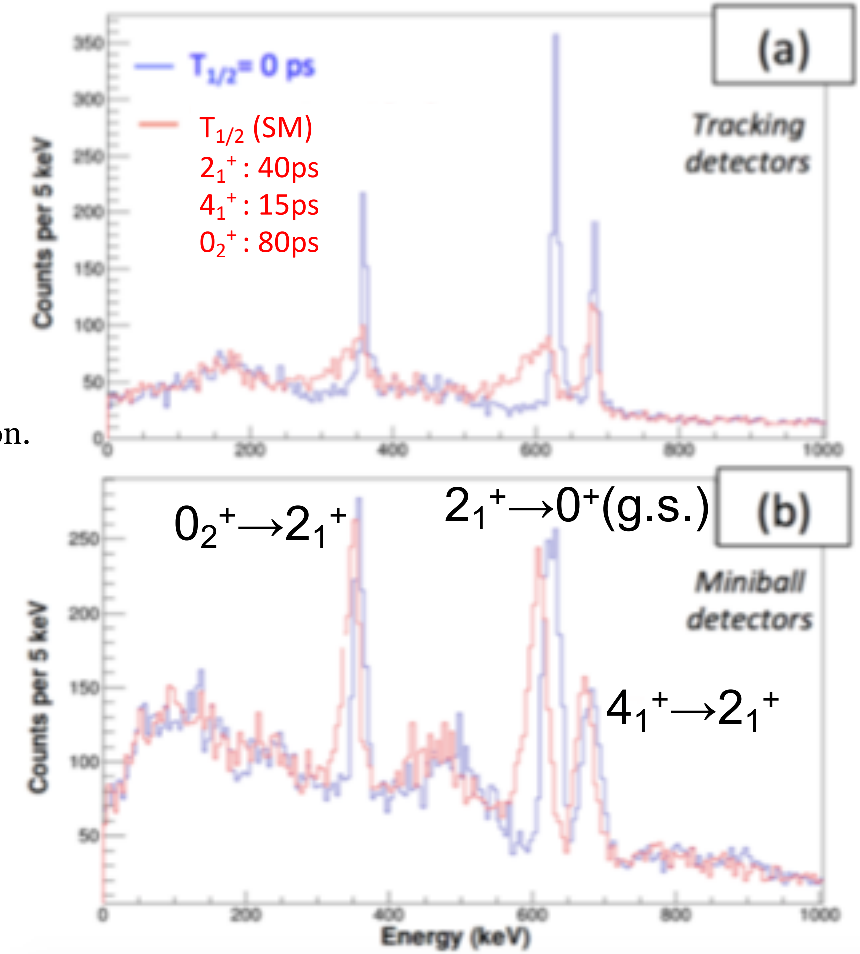
- ❑ γ-ray line-shape method

J. R. Terry *et al.,* Phys. Rev. C 77, 014316 (2008).
P. Doornenbal et al., NIMA 613, 218(2010).



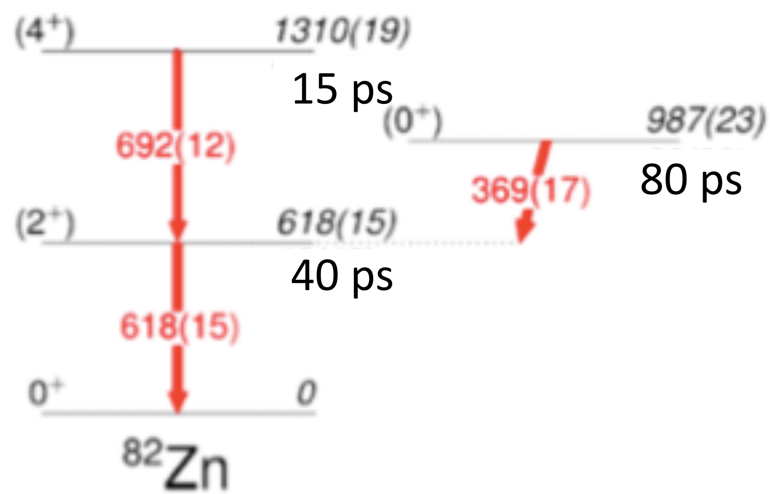
- ❑ τ could be deduced by using the least-χ^2 method.

Geant4 simulation for ^{82}Zn

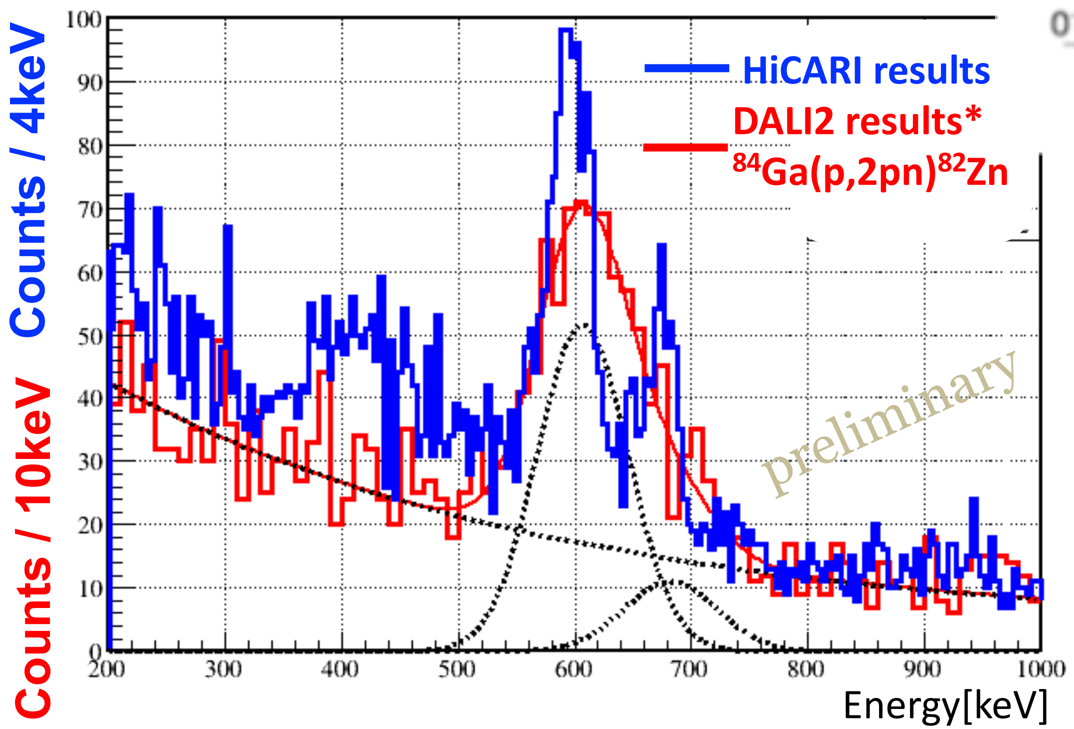


Doppler-corrected Spectra for ^{82}Zn

- ❑ HiCARI data:
  - ○ ^{9}Be(^{83}Ga,^{82}Zn+γ)
  - ○ only include MB and SC
  - ✓ much higher statistics
  - ✓ well separated peaks ~600keV
  - ○ peaks around 400keV, ambiguous



Half-lives are predicted by SM.



- ❑ Statistics of 2^{+} and 4^{+}states:
  - ○ DALI2* 1k counts
  - ○ HiCARI 2.6k counts

*C.M. Shand et al., PLB 773, 492(2017).

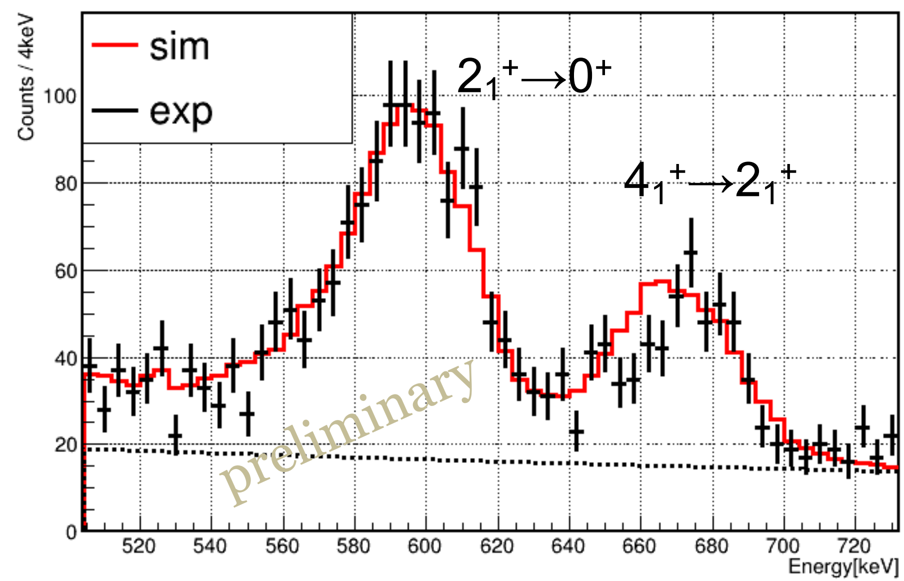
Lifetime results of 4^+ and 2^+ in ^{82}Zn

- 4^+ state
  - $E_\gamma(4^+ \rightarrow 2^+) = 678(1)$ keV

- 2^+ state
  - $E_\gamma(2^+ \rightarrow 0^+) = 608(1)$ keV
  - gamma feeding from 4^+ is included

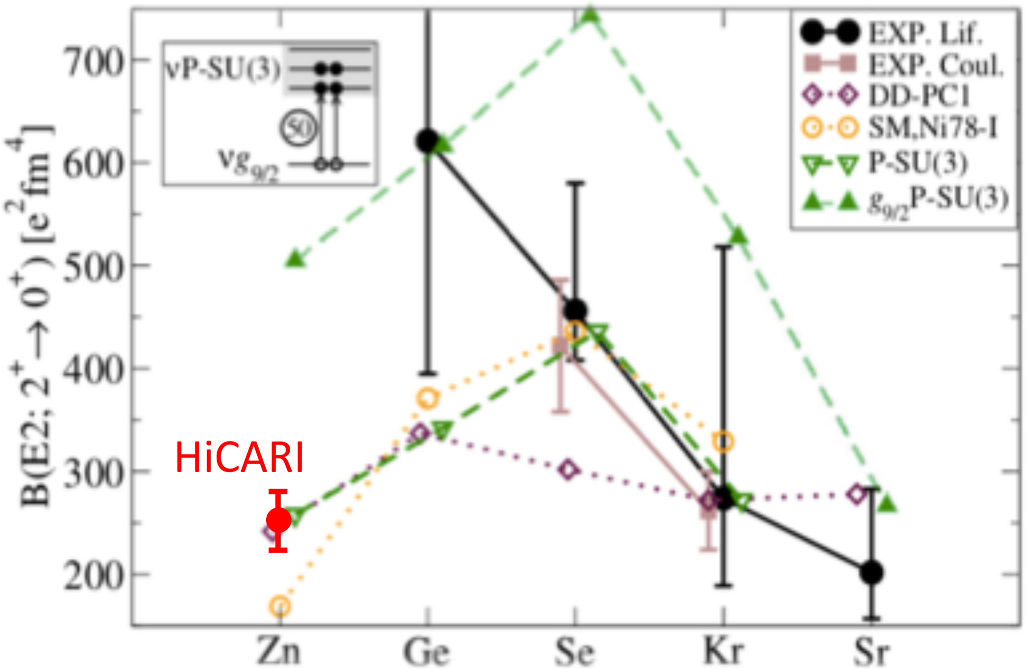
- Uncertainty estimation:
  - statistical part is underestimated now;
  - systematic uncertainty is not included.

C.M. Shand et al., PLB 773, 492(2017).



Exp B(E2) compared with calculations

B(E2) systematic of N=52 isotones



- DD-PC1: beyond meanfield calculations
- SM,Ni78-I: SM, ^{78}Ni as a core
- P-SU(3): pure P-SU(3)model
- $g_{9/2}$P-SU(3): with $g_{9/2}$ core breaking

C. Delafosse et al., PRL 121, 192502(2018).

❑ HiCARI data[e^2fm^4]:

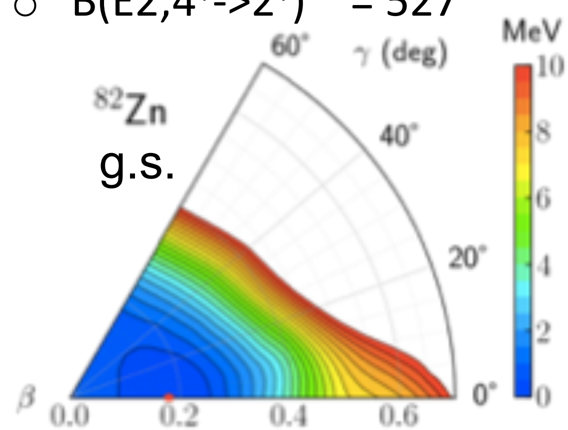
❑ Shell model(A3DA-m):

- B(E2;2^+->g.s.) = 156
- B(E2;4^+->2^+) = 237

Y. Tsunoda et al., PRC 89, 031301(2014).

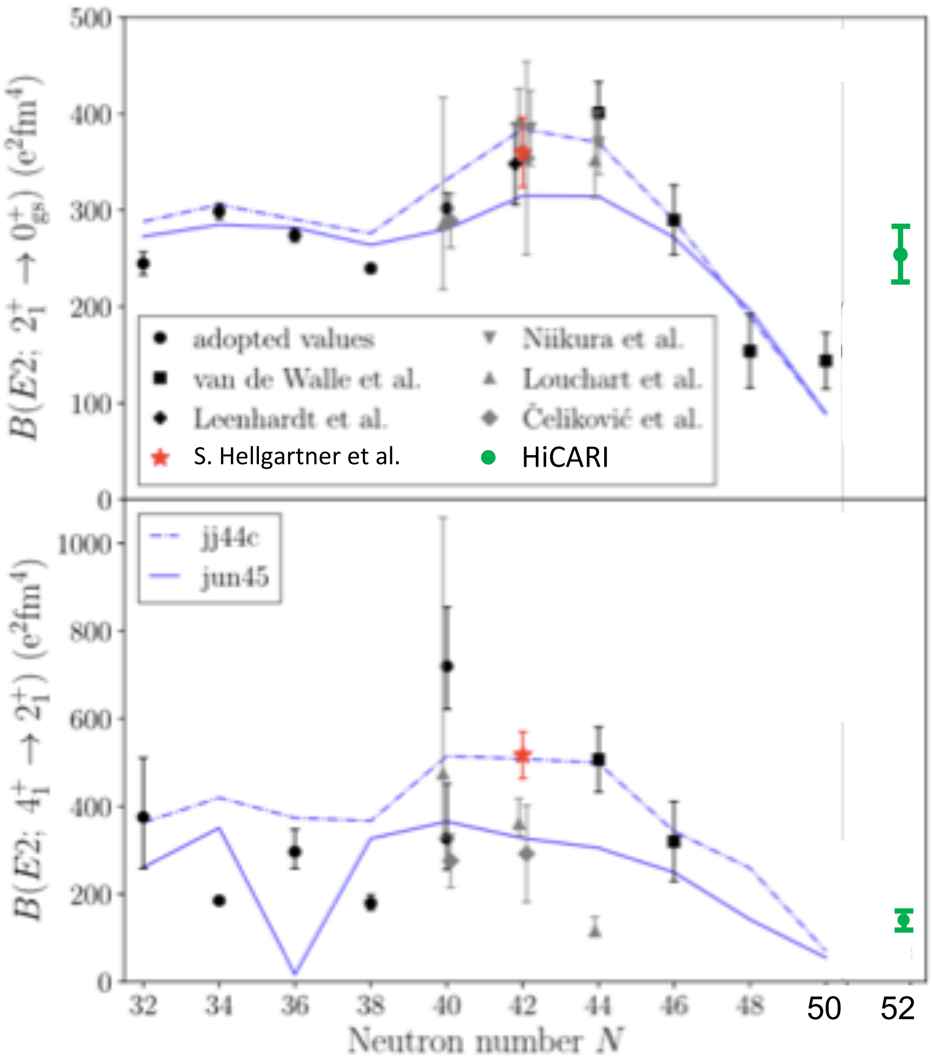
❑ Triaxial RHB + 5DCH calculation:

- B(E2;2^+->g.s.) = 281
- B(E2;4^+->2^+) = 527



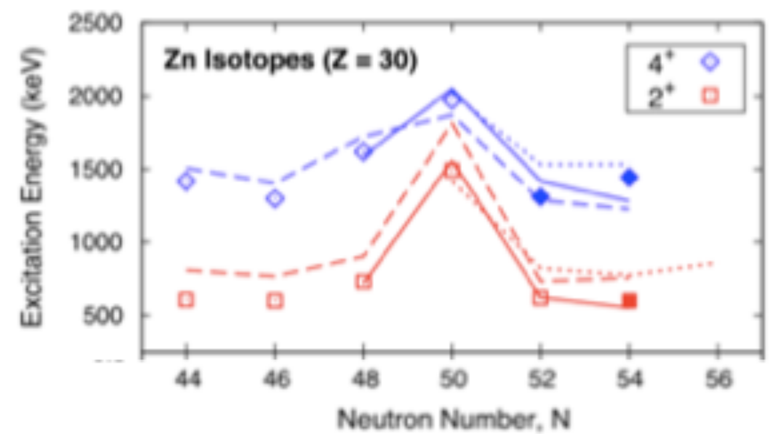
Yang et al., PRC 104, 054312(2021).
Yang et al., PRC 107, 024308(2023).

Systematics of B(E2) towards neutron-rich Zn



S. Hellgartner et al., PLB 841,137933(2023).

- B(E2;2^+ -> g.s.) increases rapidly from N = 50 to 52.



C.M. Shand et al., PLB 773, 492(2017).

- B(E2;4^+ -> 2^+) at N = 52 is close to B(E2) around N = 36 (neutron mid shell).
- Further discussion is still ongoing.

Summary

- Much attention has been attracted on the collectivity and shape evolution in ^{78}Ni region.
- An onset of deformation was predicted when moving towards neutron-rich Zn isotopes.
- A new experiment $^{9}Be(^{83}Ga,^{82}Zn+\gamma)$ to study the collectivity of ^{82}Zn was performed at RIKEN within the HiCARI campaign.
- The 2_1^+ and 4_1^+ states are well separated, for the first time, by using highly segmented HPGe detectors.
- Preliminary lifetime of 2_1^+ and 4_1^+ states is deduced and the B(E2) values are compared with different theoretical calculations.
- Further discussion on the current results is still ongoing.

Acknowledgement

RIBF-196 collaboration

Zs. Podolyák, F. Flavigny, M. Górska, M. Armstrong, J. Acosta, L. Achouri, H. M. Albers, A. Algora, N. Aoi, M. Assié, T. Arici, H. Baba, A. Banerjee, D. Beaumel, G. Benzoni, A . Blazhev, A. M. Bruce, F. Browne, M. Brunet, C. Campbell, R. Canavan, B. Cederwall, A. Corsi, M. L. Cortes, H. Crawford, C. Delafosse, F. Delaunay, Zs. Dombradi, P. Doornenbal, Z. Elekes, C. Fransen, P. Fallon, S. Franchoo, F. Galtarossa, J. Gerl, J. Gibelin, A. Gillibert, A. Gottardo, H.Grawe, F. Hammache, H. Hess, N.Hubbard, S. Iwazaki, S. Jazrawi, M.Juhasz, A. Jungclaus, J. Kim, A. Kohda, T. Koiwai, W. Korten, V. Lapoux, C. Lenain, T. Lokotko, M.Marques, A. Matta, D.Mengoni, A. Mistry, B. Mauss, B. Moon, T. L. Morrison, M. Niikura, N. Orr, L. Plagnol, T. Parry, M. Parlog, P.H.Regan, P. Reiter, J. Saiz, N. De Sereville, D. Sohler, D. Suzuki, S. Thiel, R. Taniuchi, J. J. Valiente Dobon, D. Verney, N. Warr, K. Wimmer, H. de Witte, Y. Yamamoto, and Y. Yasatuka.

Thanks for your attention!