Role of Hexadecupole Deformation in the Shape Evolution of Neutron-rich Nd Isotopes

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Collaborators

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Shape of atomic nuclei

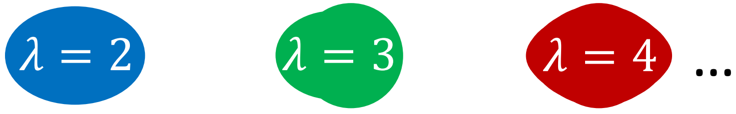
Atomic nuclei:

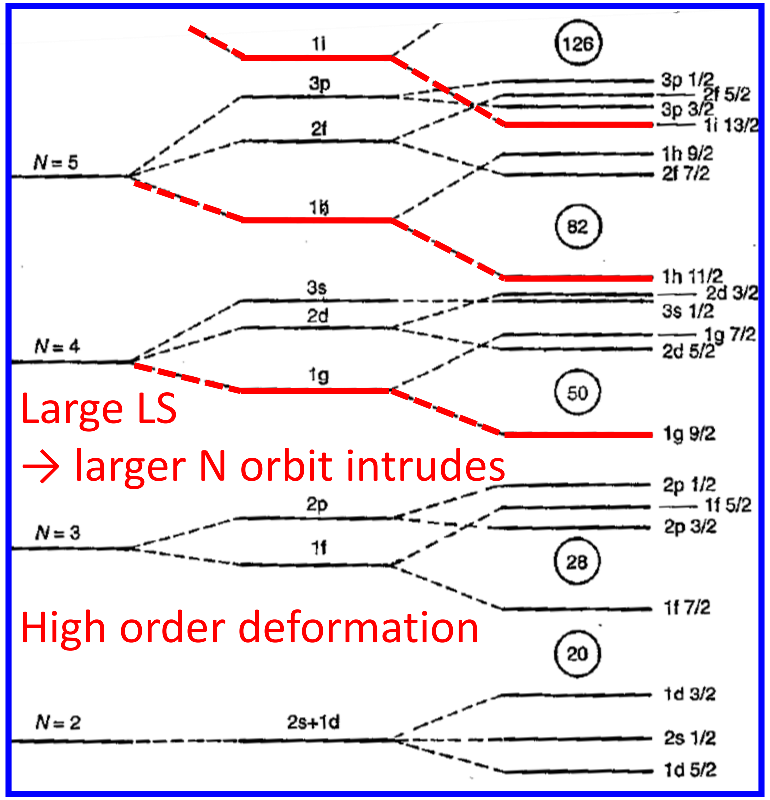
Finite quantum many-body system

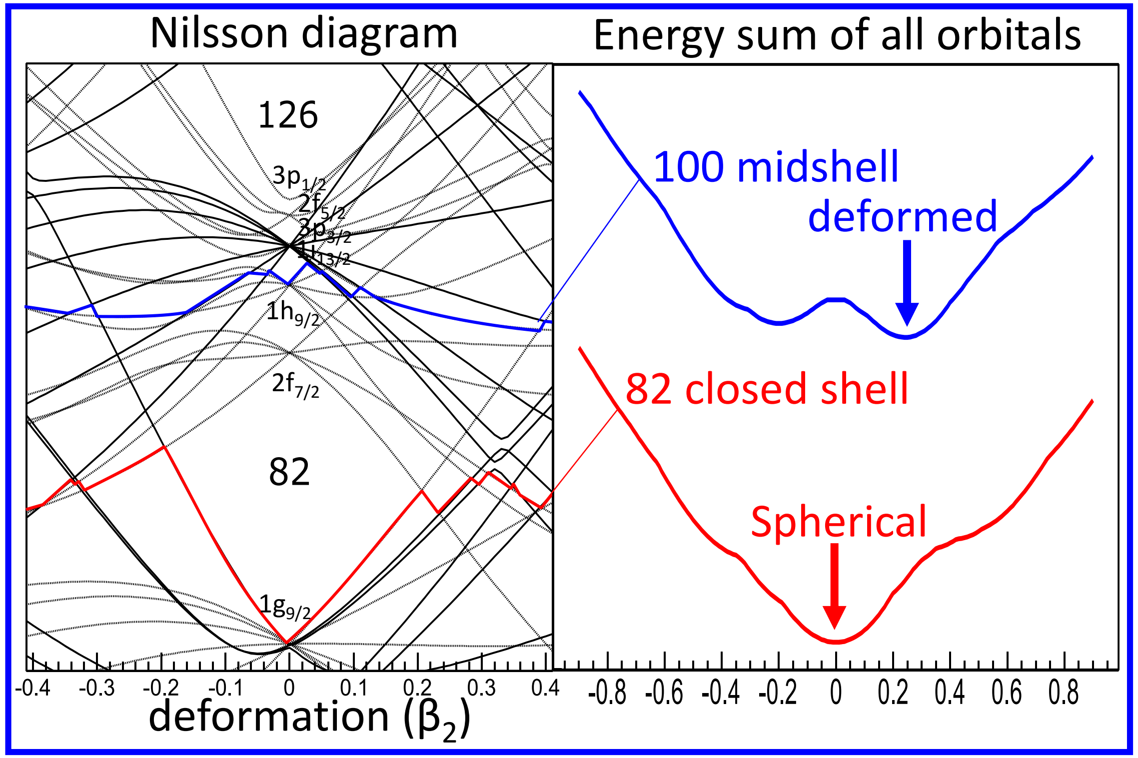
→ shell effect

Shell effect drives macroscopic shape

$$R(\theta, \phi) = R_0\{1 + \Sigma \alpha_{\lambda\mu} Y_{\lambda\mu}(\theta, \phi)\}$$







Experimental $E(2^+)$ on midshell nuclei

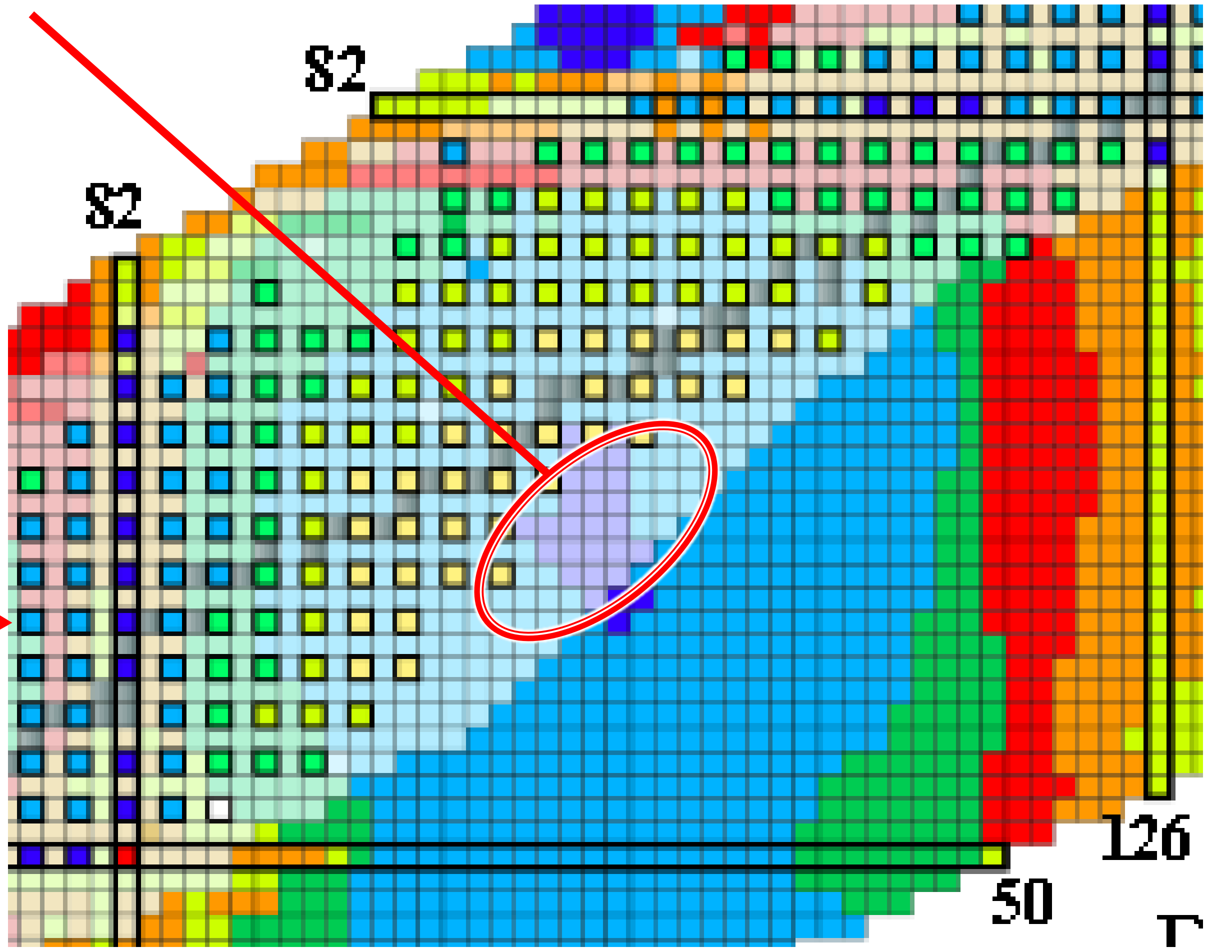
- E(2+) relates to deformation
- Lack of experimental data for neutron-rich midshell nuclei at N ~ 100, Z ~ 60

How does the shape evolve in (*N*, *Z*) plane?

Measurement of excited states

isomer & β-γ spectroscopy

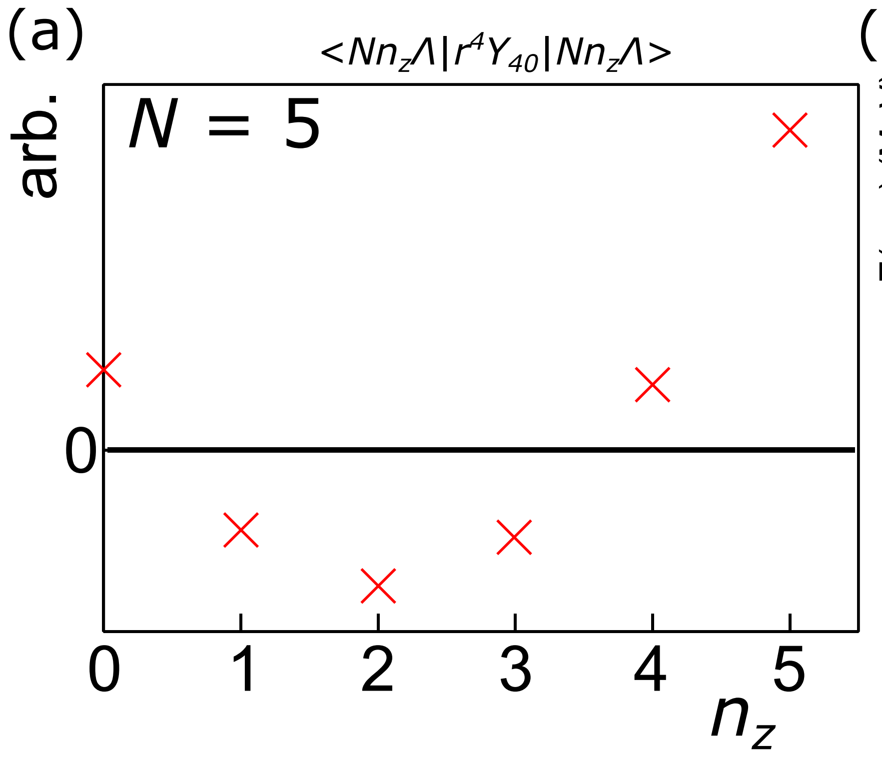
max. at *N*~102, Z~64 predicted



E(2+) plotted over the theoretical chart →

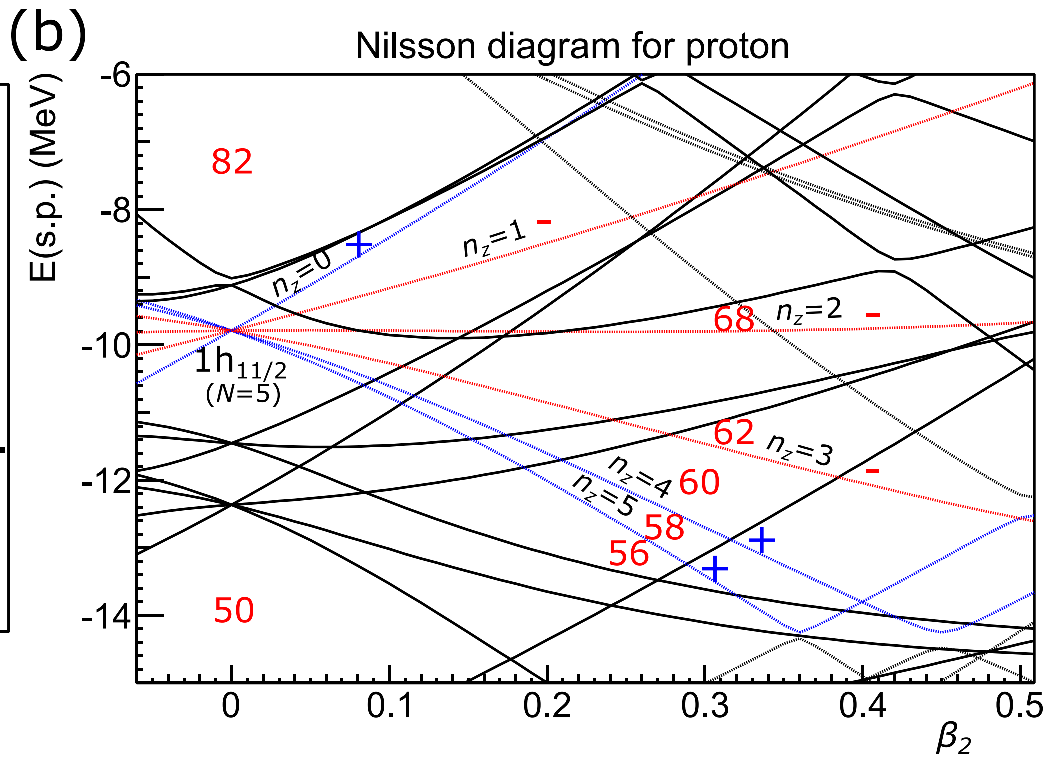
Hexadecupole deformation

$\langle Nn_z\Lambda|r^4Y_{40}|Nn_z\Lambda\rangle$ for $1h_{11/2}$ orbitals with deformed HO.



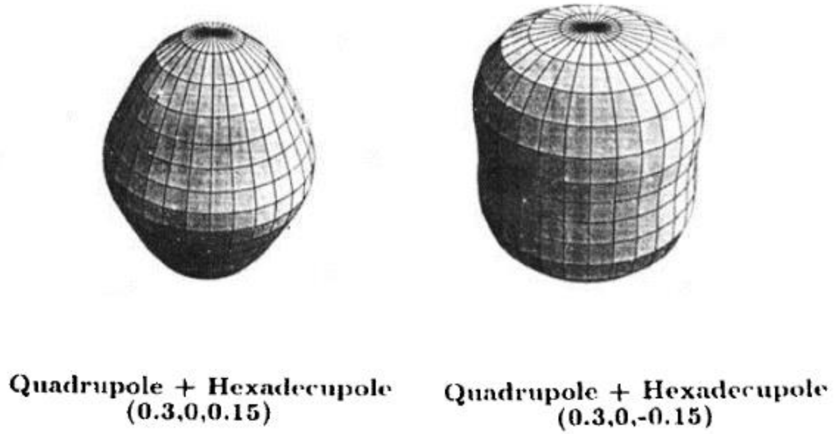
- Large n_z are responsible

Nilsson diagram for proton with deformed WS.



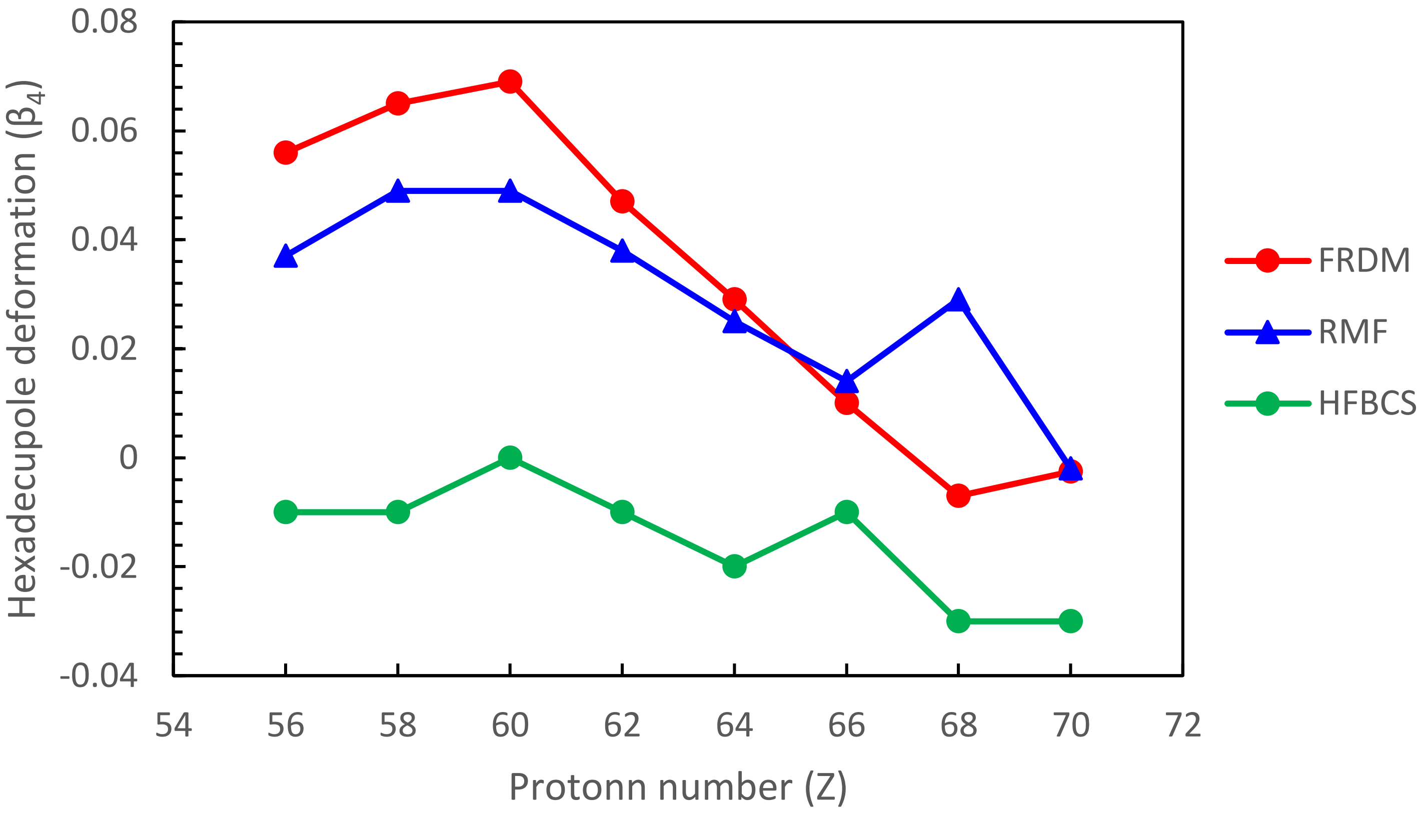
- When $\beta_2 \sim 0.3$, Z=60 (Nd) will have large hexadecupole moment

Hexadecupole deformation



- B(E4) measurement by Coulomb excitation
  - ^{152}Sm: β_4=0.06(3),
  - ^{148}Nd: β_4=0.07(2)
- No exp. data on unstable nuclide

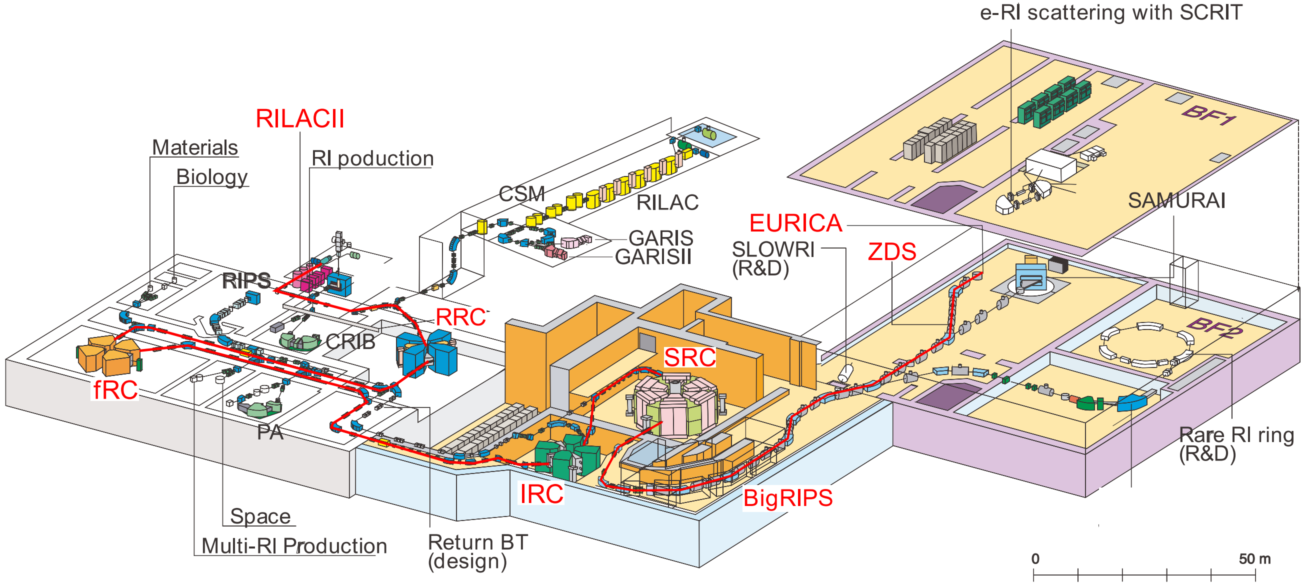
Comparison of theoretical β_4 values for N=100 isotopes



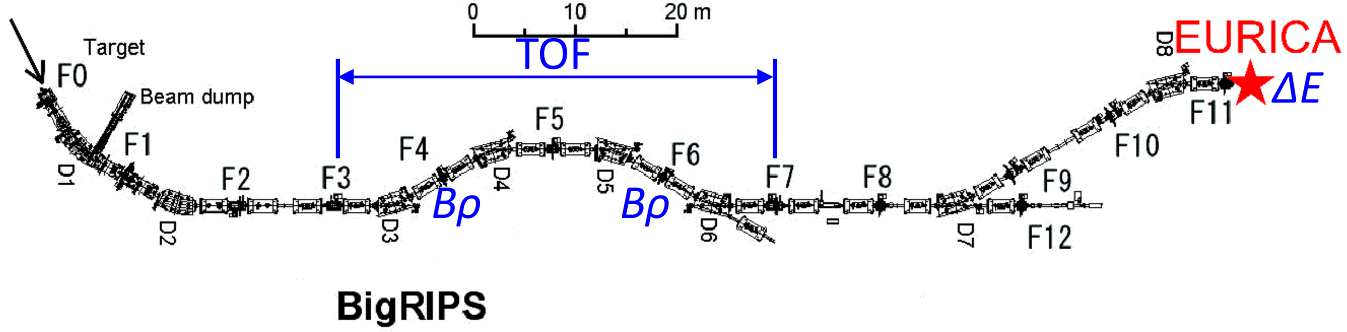
- Theoretical predictions on unstable nuclei differ in theories

Experimental investigations are necessary

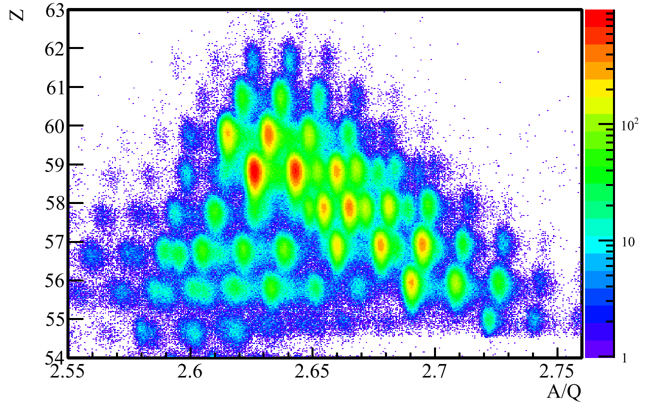
Production of neutron-rich nuclei at RIBF



Be target
in-flight fission

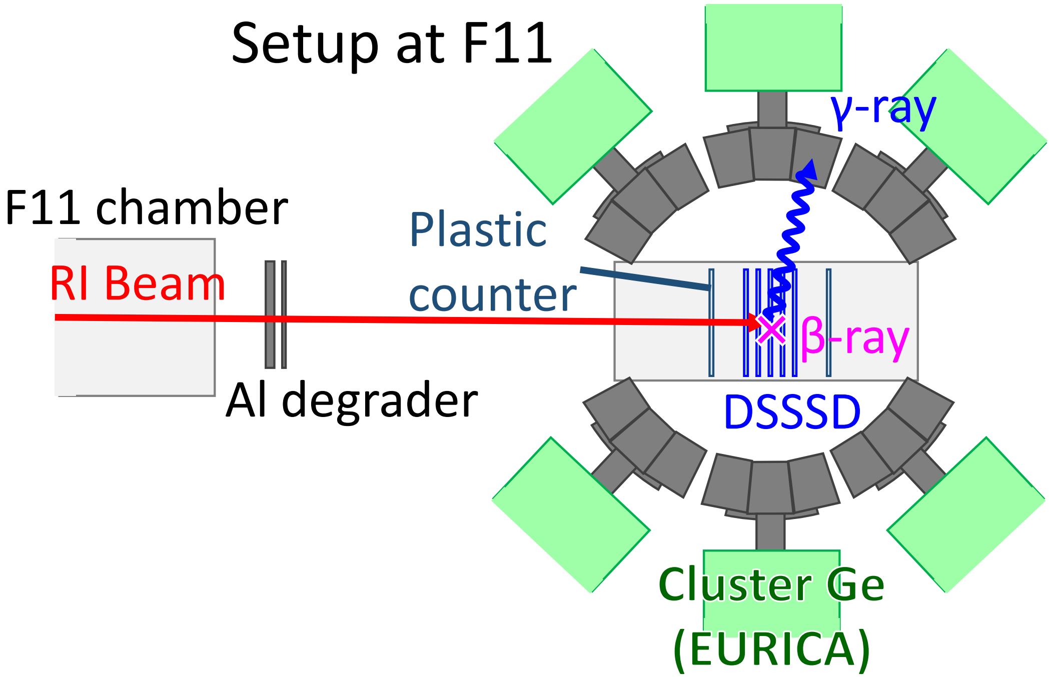


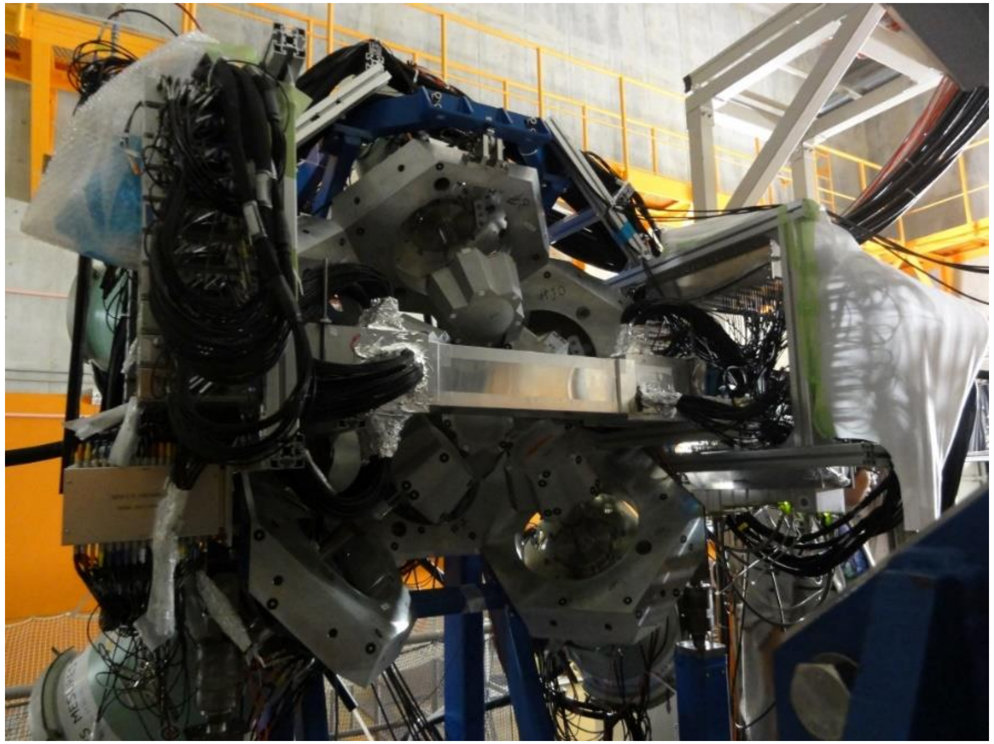
- 5 accelerators for 345 MeV/u ^{238}U beam
- Particle separation and identification at BigRIPS
- *Bρ*-TOF-*ΔE* method (event-by-event PI)



- transported to F11

Detector setups





- isomer and β-γ measurement
  - EURICA (Euroball Riken cluster array) with 84 Ge crystals
    - for γ-ray energies of isomer and β decay
  - WAS3ABi (Double sided Silicon strip detectors)
    - for position correlation between beam implantation and β-ray emission

Experimental results

Z:N	92	93	94	95	96	97	98	99	100	101	102	103	104	105
67	^{159}Ho	^{160}Ho	^{161}Ho	^{162}Ho	^{163}Ho	^{164}Ho	^{165}Ho	^{166}Ho	^{167}Ho	^{168}Ho	^{169}Ho	^{170}Ho	^{171}Ho	^{172}Ho
66	^{158}Dy	^{159}Dy	^{160}Dy	^{161}Dy	^{162}Dy	^{163}Dy	^{164}Dy	^{165}Dy	^{166}Dy	^{167}Dy	^{168}Dy	^{169}Dy	^{170}Dy	^{171}Dy
65	^{157}Tb	^{158}Tb	^{159}Tb	^{160}Tb	^{161}Tb	^{162}Tb	^{163}Tb	^{164}Tb	^{165}Tb	^{166}Tb	^{167}Tb	^{168}Tb	^{169}Tb	^{170}Tb
64	^{156}Gd	^{157}Gd	^{158}Gd	^{159}Gd	^{160}Gd	^{161}Gd	^{162}Gd	^{163}Gd	^{164}Gd	^{165}Gd	^{166}Gd	^{167}Gd	^{168}Gd	^{169}Gd
63	^{155}Eu	^{156}Eu	^{157}Eu	^{158}Eu	^{159}Eu	^{160}Eu	^{161}Eu	^{162}Eu	^{163}Eu	^{164}Eu	^{165}Eu	^{166}Eu	^{167}Eu	^{168}Eu
62	^{154}Sm	^{155}Sm	^{156}Sm	^{157}Sm	^{158}Sm	^{159}Sm	^{160}Sm	^{161}Sm	^{162}Sm	^{163}Sm	^{164}Sm	^{165}Sm	^{166}Sm	^{17}Sm
61	^{153}Pm	^{154}Pm	^{155}Pm	^{156}Pm	^{157}Pm	^{158}Pm	^{159}Pm	^{160}Pm	^{161}Pm	^{162}Pm	^{163}Pm	^{164}Pm	^{165}Pm	^{166}Pm
60	^{152}Nd	^{153}Nd	^{154}Nd	^{155}Nd	^{156}Nd	^{157}Nd	^{158}Nd	^{159}Nd	^{160}Nd	^{161}Nd	^{162}Nd	^{163}Nd	^{164}Nd	
59	^{151}Pr	^{152}Pr	^{153}Pr	^{154}Pr	^{155}Pr	^{156}Pr	^{157}Pr	^{158}Pr	^{159}Pr	^{160}Pr	^{161}Pr	^{162}Pr	^{163}Pr	
58	^{150}Ce	^{151}Ce	^{152}Ce	^{153}Ce	^{154}Ce	^{155}Ce	^{156}Ce	^{157}Ce	^{158}Ce	^{159}Ce	^{160}Ce			
57	^{149}La	^{150}La	^{151}La	^{152}La	^{153}La	^{154}La	^{155}La	^{156}La	^{157}La	^{158}La				
56	^{148}Ba	^{149}Ba	^{150}Ba	^{151}Ba	^{152}Ba	^{153}Ba	^{154}Ba	^{155}Ba	^{156}Ba					

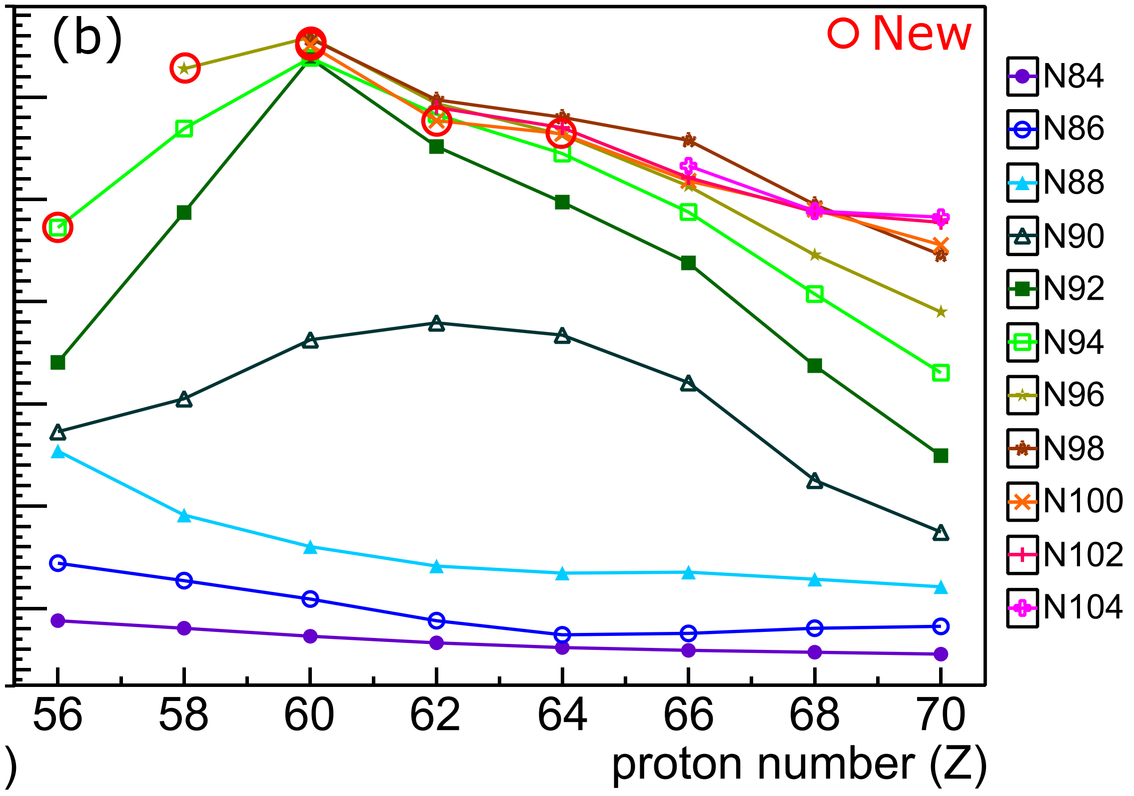
RIBF-86

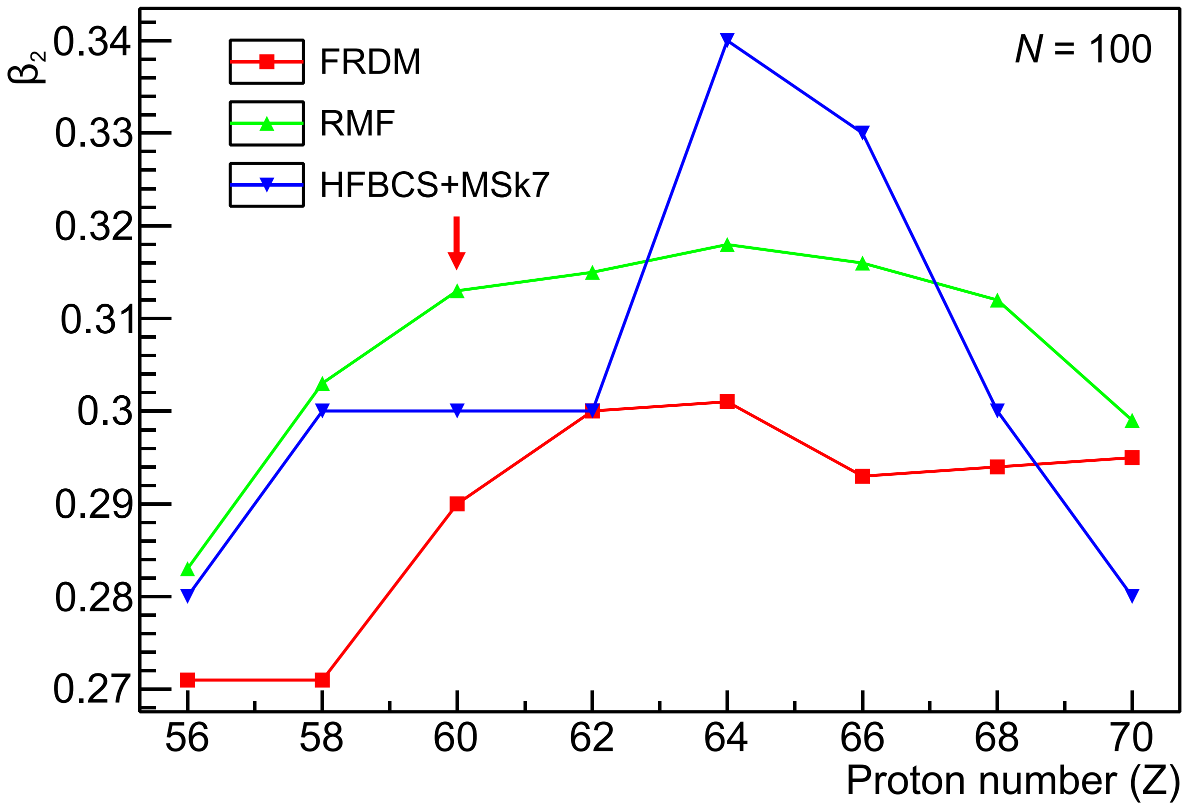
- ^{A}X Known isomer ($T_{1/2}$ >100 ns)
- ^{A}X New isomer
- ^{A}X No isomer (>10^4 implant)
- ^{A}X Octupole band
- ^{A}X stable nuclide
- ^{A}X New β-γ

- G.s. band systematics
  → quadrupole
- Isomers in *N*=100 and *N*=98 isotones
  → hexadecupole

Systematics of g.s. band

Moment of inertia of g.s. band from E(2+) of even-even nuclei

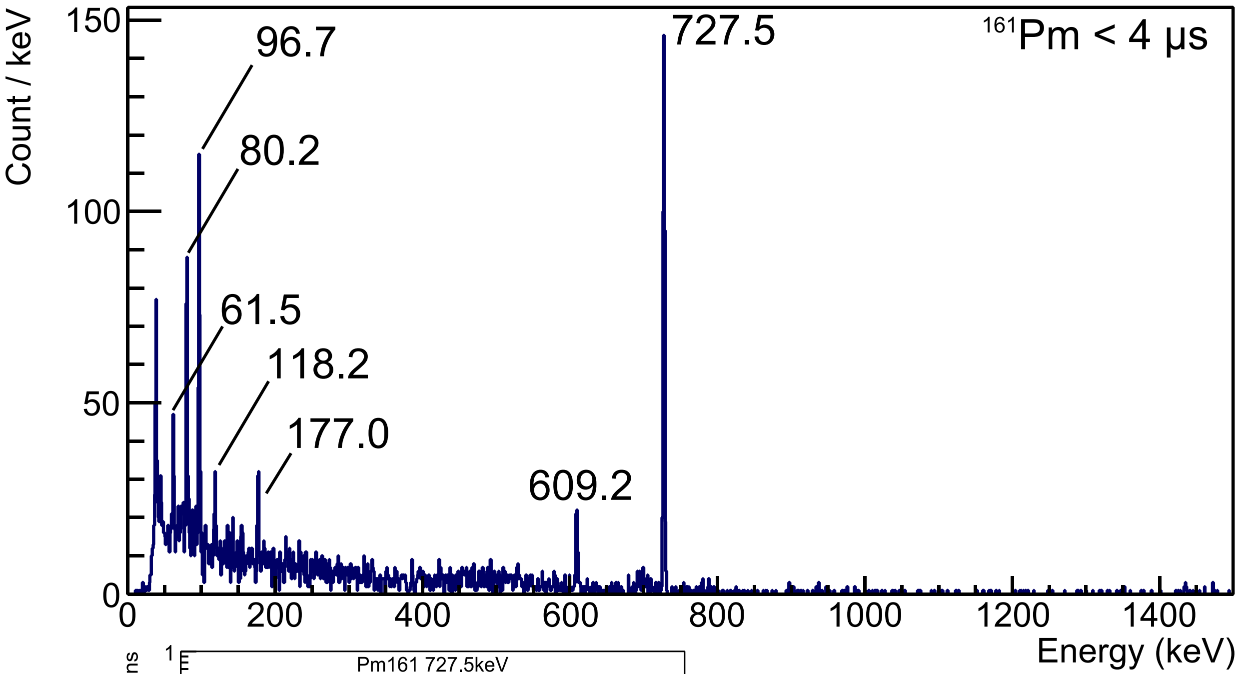


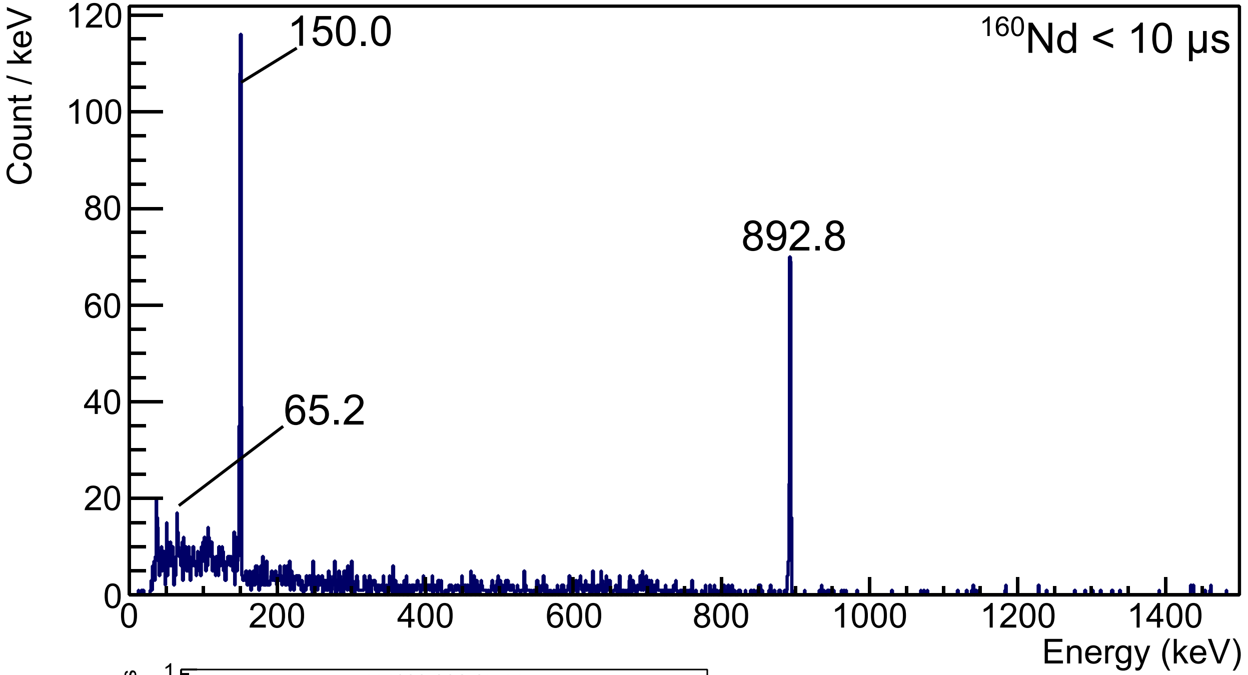


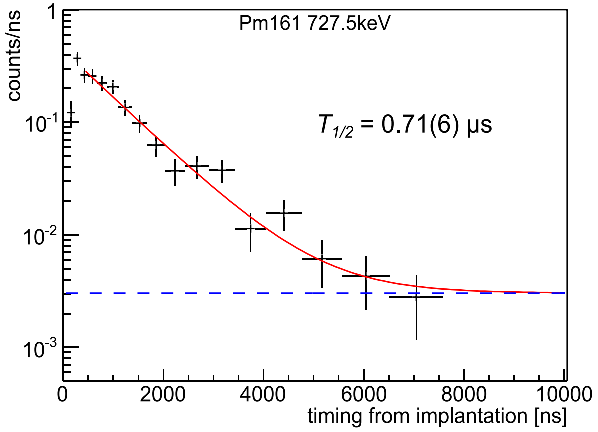
- Moment of inertia peaks at *Z*=60 (b)

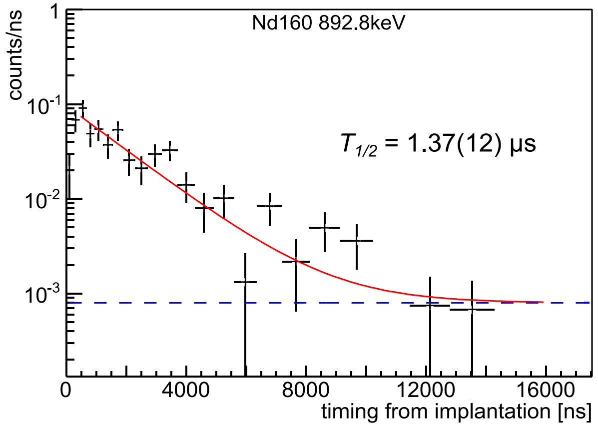
  → No calculation predicts deformation maximum at *Z*=60

Isomers in *N*=100 isotones: Energy and timing spectra

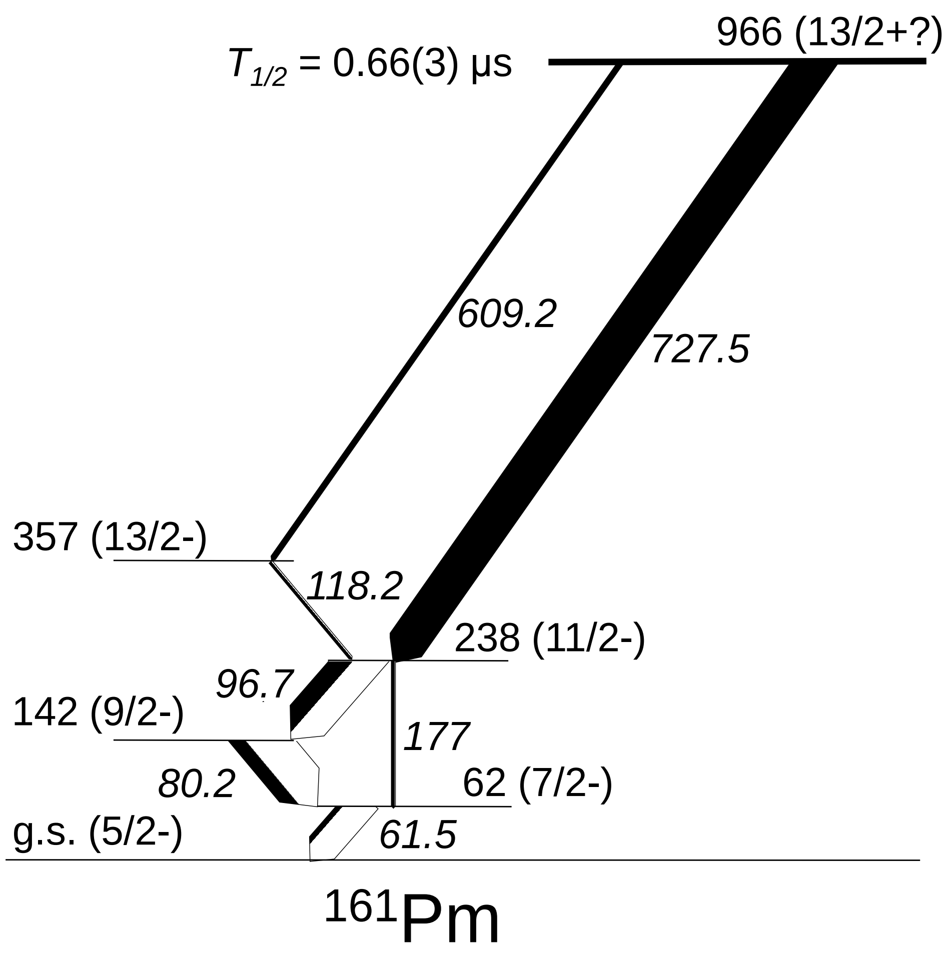


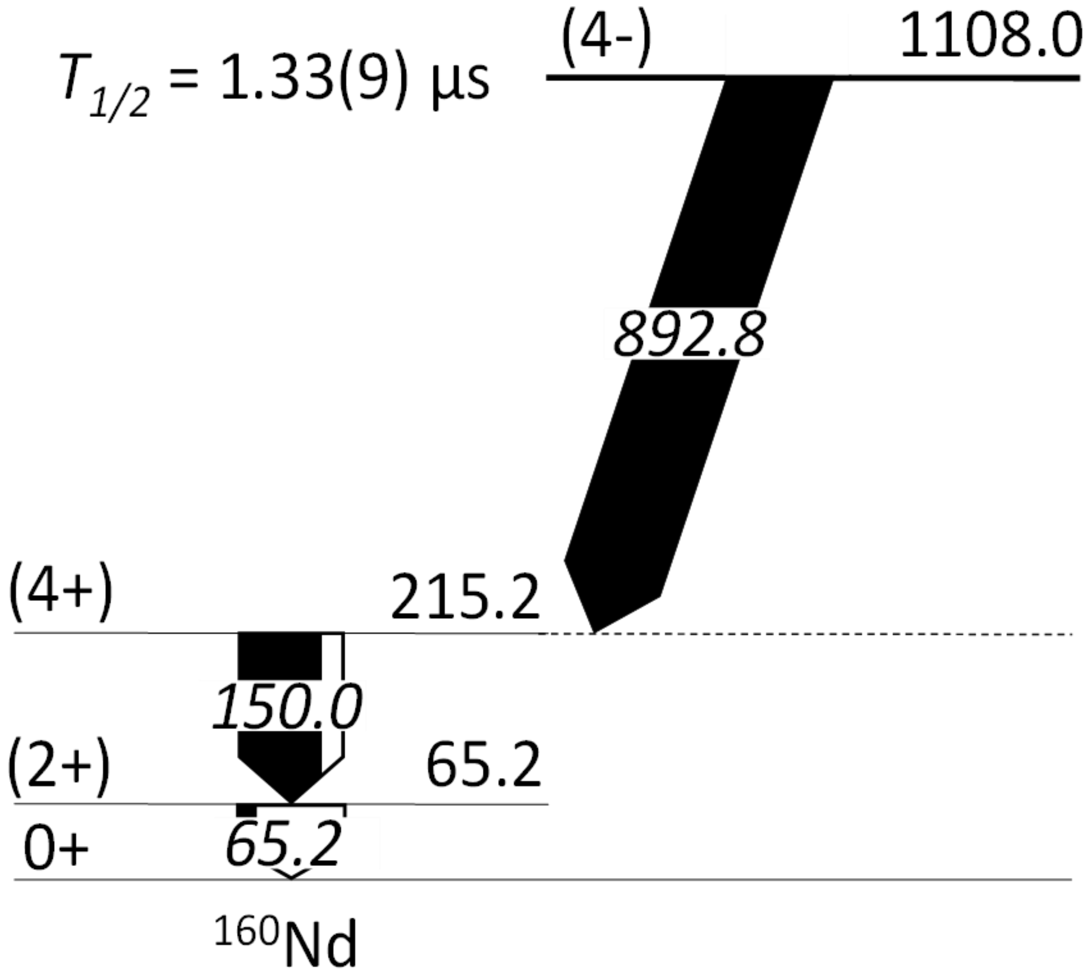




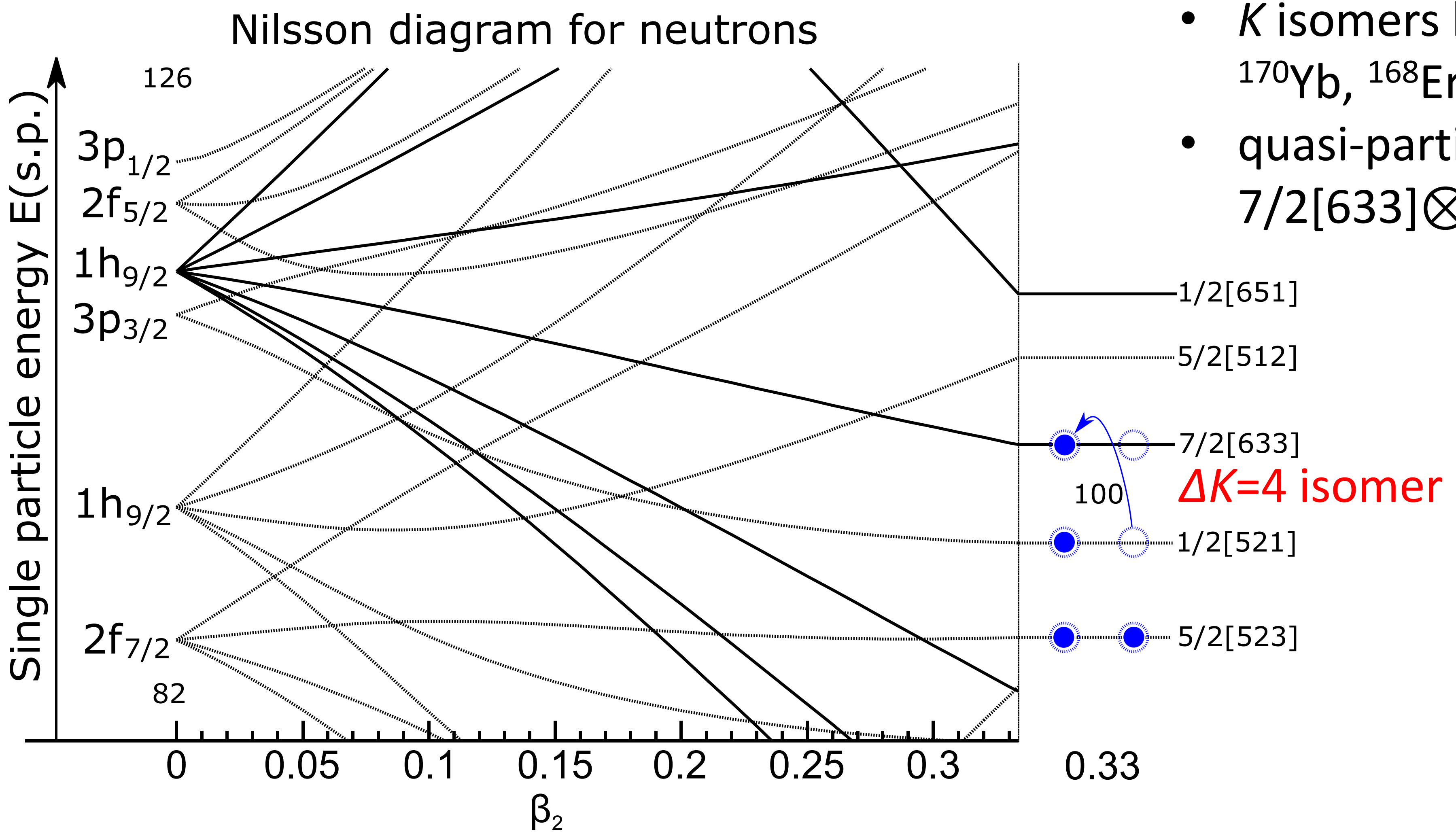


Isomers in N=100 isotones: Level schemes

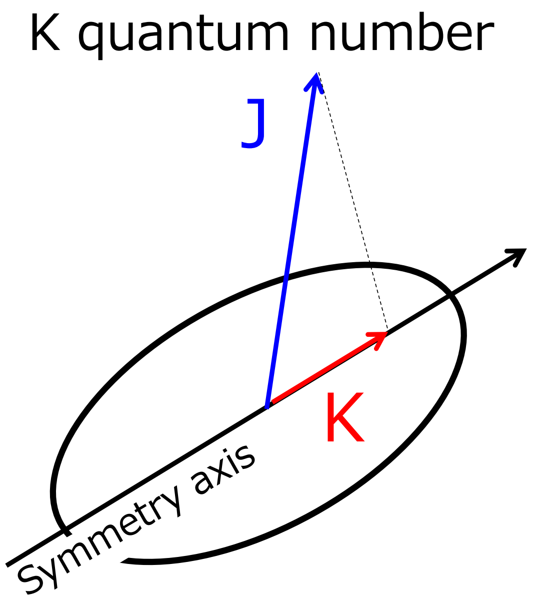




High-K isomers at N=100



- K isomers known in N = 100 isotones ^{170}Yb, ^{168}Er
- quasi-particle excitation: 7/2[633]⊗1/2[521]   ($\Omega[Nn_z\Lambda]$)



Isomers in N=100 isotones: Summary of isomer

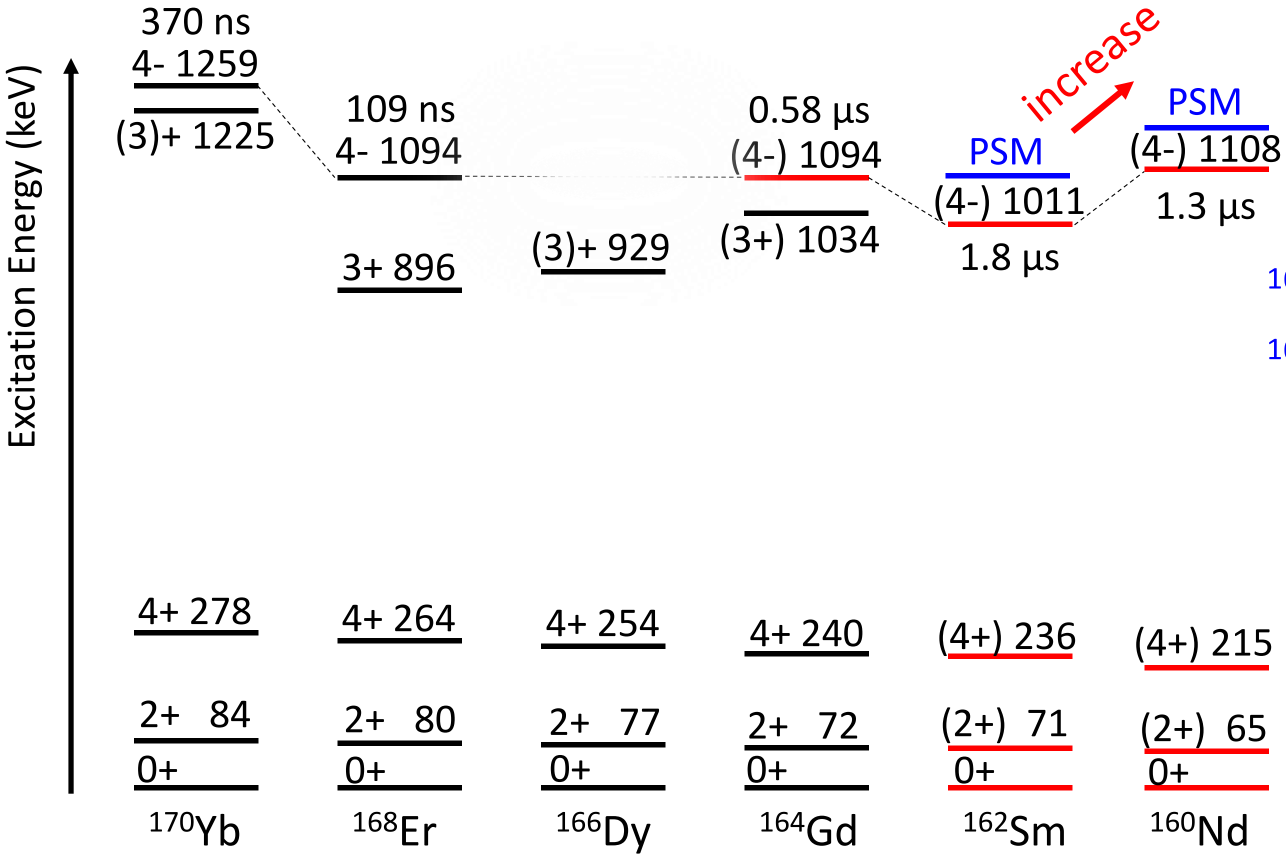
Nuclide		E_{isomer} (keV)	E_γ (keV)	$T_{\gamma 1/2}(exp.)$ (s)	F_w W.u.$^{-1}$
^{170}Yb		1259	981.1	3.7×10^{-7}	1.6×10^{9}
^{168}Er		1094	830.0	1.1×10^{-6}	2.9×10^{9}
^{164}Gd		1094	854.1	7.1×10^{-7}	2.0×10^{9}
^{163}Eu		964	674.9	9.1×10^{-7}	1.2×10^{9}
^{162}Sm		1010	774.5	1.8×10^{-6}	3.6×10^{9}
^{161}Pm	New	966	727.5	7.6×10^{-7}	1.3×10^{9}
^{160}Nd	New	1108	892.8	1.3×10^{-6}	4.0×10^{9}

ΔK=4

- All have 10^9 order of hindrance
- Expected same isomer configuration (neutron 2-qp K^π = 4$^-$)

known in ^{170}Yb and ^{168}Er

N=100 isomers



4- (ν7/2[633]⊗ν1/2[523])
Y. C. Yang et al., J. Phys. G **37** (2010) 085100

^{162}Sm: $\beta_2 = 0.318, \beta_4 = 0.008$

^{160}Nd: $\beta_2 = 0.332, \beta_4 = 0.032$

E(qp) calculation (MeV)

	$\beta_4 = 0.008$	$\beta_4 = 0.032$
^{162}Sm	1.03	1.12
^{160}Nd	1.01	1.15

- PSM (projected shell model) calculation reproduces the increase of E(4-) with large hexadecupole deformation in Nd

Conclusion

- New excited states found by isomer and β-γ spectroscopy
  - *K* isomers in *N*=100 ($K^{\pi}=4^{-}$), *N*=98 ($K^{\pi}=6^{-}$) isotones
  - Ground band of some even-even nuclei (^{150}Ba, ^{154}Ce, etc.…)
- Systematics of g.s. band
  - Moment of inertia peaks at *Z*=60 (disagree with FRDM, RMF, HFBCS calc.)
  - Small pairing correlation due to Z=60 gap may increase the moment of inertia
- Experimental indications on hexadecupole deformation in Nd (*Z*=60)
  - Energy increase of $K^{\pi}=4^{-}$ isomers
  - Change of isomer configuration ($K^{\pi}=5^{-}$ to $K^{\pi}=6^{-}$) in *N*=98 isotones
- Future perspective
  - Half-life measurement