Shape dynamics in the A=100 mass region: Collectivity at neutron number N=54

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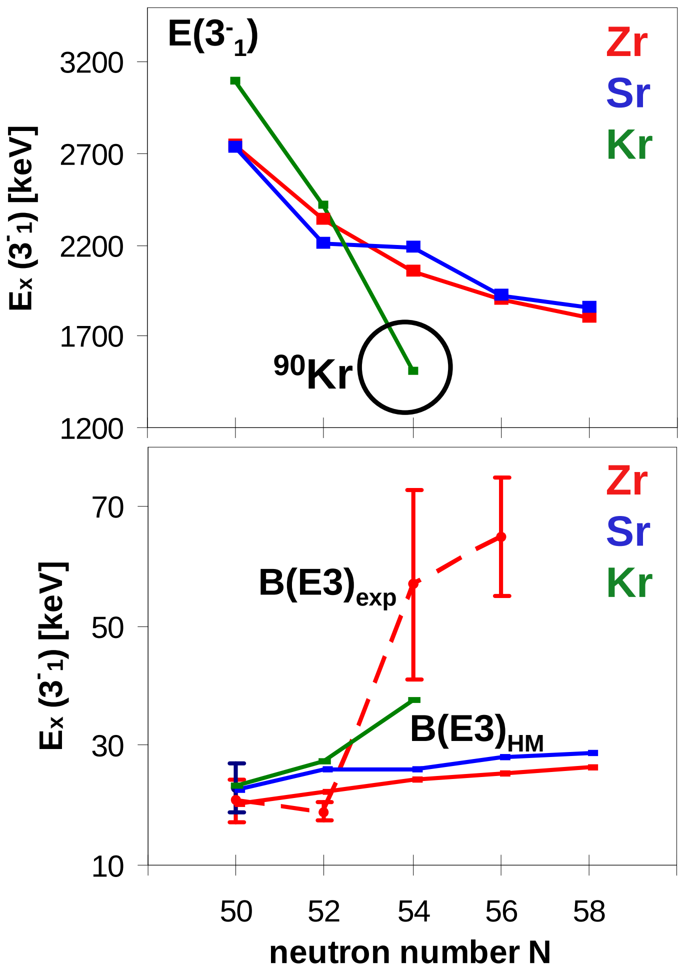
Enhanced octupole collectivity in Zr isotopes



${}^{94}_{40}Zr^{54}$, ${}^{96}_{40}Zr^{56}$ exhibit enhanced B(E3) values [1,2] compared to ${}^{92}_{40}Zr^{52}$ [3] which is inconsistent with simple harmonic vibrations[4]

$$B(E3)_{HM} = C \cdot Z^2 \cdot E^v A^{1/3} \qquad \begin{matrix} C=3.2(5) \\ v=-0.68(14) \end{matrix}$$

This phenomenon was discussed as coherent superposition of proton ($p_{3/2} \rightarrow g_{9/2}$) and neutron ($d_{5/2} \rightarrow h_{11/2}$) particle-hole exc.

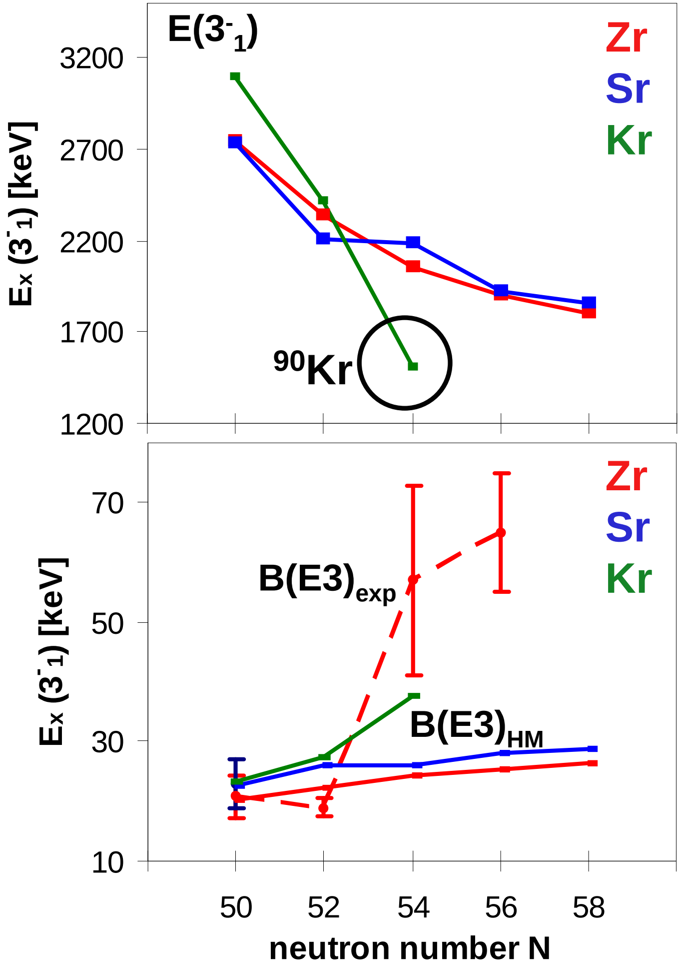
Low excitation energy of the 3^-_1 state in ${}^{90}_{36}Kr^{54}$ [5] (in fact the lowest-lying 3^- state in this mass region) indicating enhanced octupole collectivity in this nucleus

Experiment GS1462 (P2) at ATLAS was approved to measure B(E3) transition strengths in ^{90}Kr using

- Gammasphere
- CHICO2 (forward shell)
- ^{90}Kr beam provided by the new CARIBU source
- ^{196}Pt target ($2 mg/cm^2$)
- Extraction of matrix elements using GOSIA(2)[6]

[1]: Y. Toh et al., AIP Conf. Proc. 1090, 189 (2009)a.r.t.
[2]: H. Mach et al., Phys. Rev. C 42, 811(R) (1990)
[3]: A.S. Obeid et al., J. Phys. Conf. Series 205, 012040 (2010)
[4]: D.J. Horen et al., Phys. Rev. C 48, 2131(R) (1993) a.r.t.
[5]: T. Rzaca-Urban et al., Eur. Phy. J A9, 165 (2000)
[6]: T. Czosnyka, D. Cline, and C.Y. Wu. Bull. Am. Phys. Soc., 28:745, 1983.
A. Winther and J. de Boer, Coulomb Excitation, (Academic, New York, 1965)

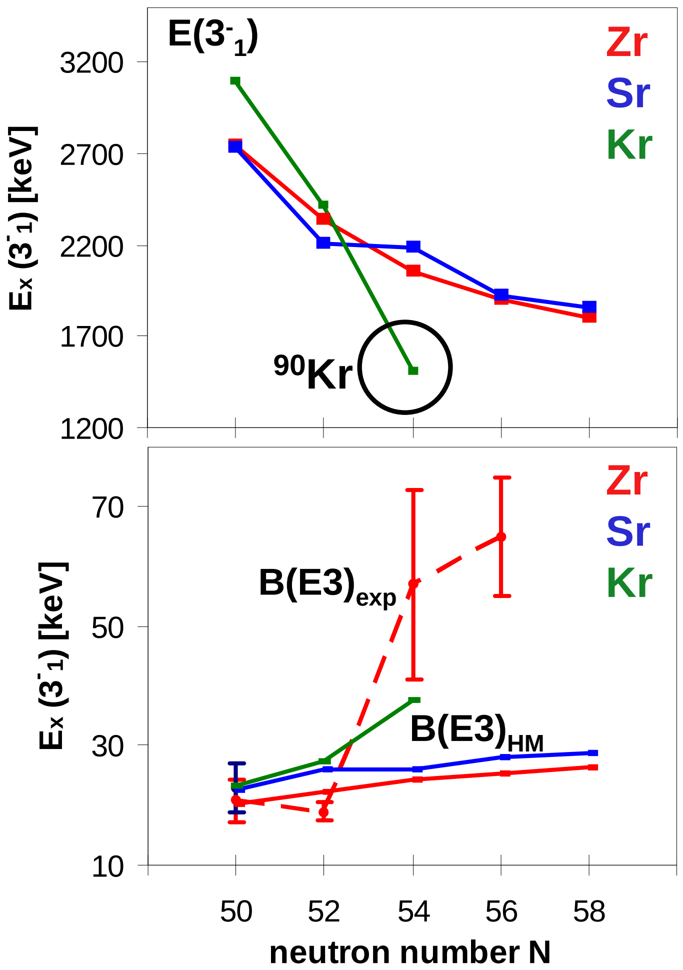
Enhanced octupole collectivity in ^{90}Kr
Experiment GS1462



- Gammasphere for γ-ray detection
- CHICO2 (only forward shell)
- 1400 pps ^{90}Kr beam @ 405 MeV (~88% of Coulomb barrier)
- CARIBU: 340 mCi
- ^{196}Pt target (2mg/cm^2)
- matrix elements calculated using *Rachel* and *Gosia*

Transition	E_γ	Estimated B(EL)		Estimated
in ^{90}Kr	[keV]	[W.u.]		count rate
$2^+_1 \rightarrow 0^+_1$	707	E2	(10)	244
$2^+_2 \rightarrow 2^+_1$	655	E2	(15)	6.7
$4^+_1 \rightarrow 2^+_1$	1057	E2	(15)	6.6
$3^-_1 \rightarrow 0^+_1$	1508	E3	(60)	---
$3^-_1 \rightarrow 2^+_1$	801	E1	(0.00123)	14.6
Transition	E_γ	Known B(EL)		Estimated
in ^{196}Pt	[keV]	[W.u.]		count rate
$2^+_1 \rightarrow 0^+_1$	356	E2	40.6(2)	740
$2^+_2 \rightarrow 2^+_1$	333	E2	57.7(8.8)	62
$4^+_1 \rightarrow 2^+_1$	521	E2	60.0(9)	82

Enhanced octupole collectivity in ^{90}Kr
Experiment GS1462



- **GRETINA** → similar γ–ray detection efficiency
  improved peak-to-total ratio
  improved Doppler correction

- **CARIBU**: 340 mCi → stronger source will (hopefully) arrive in September 2013
  → increase of the beam intensity (x1-3)

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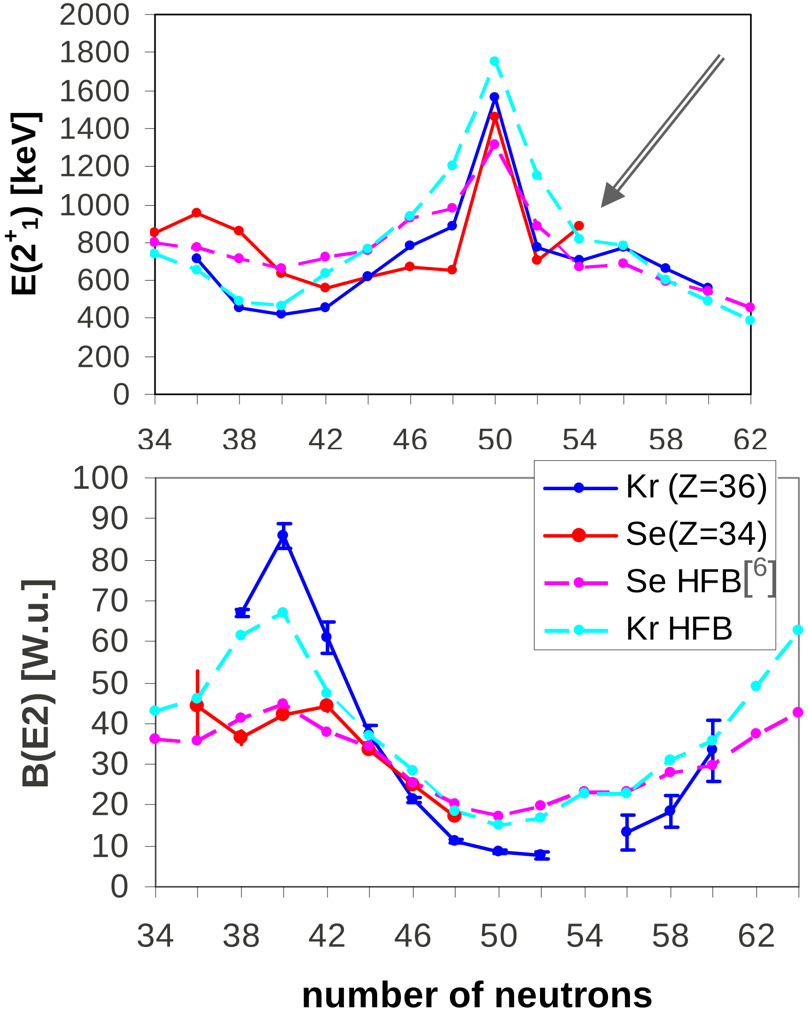
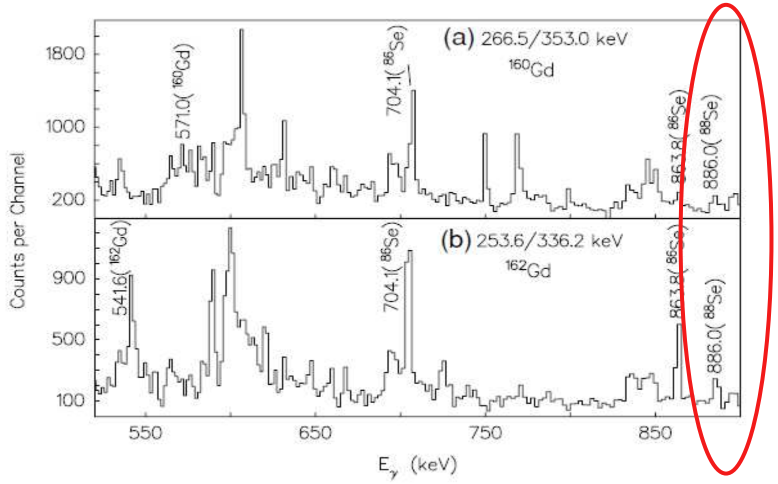
High-lying 2^+_1 state in ^{88}Se?



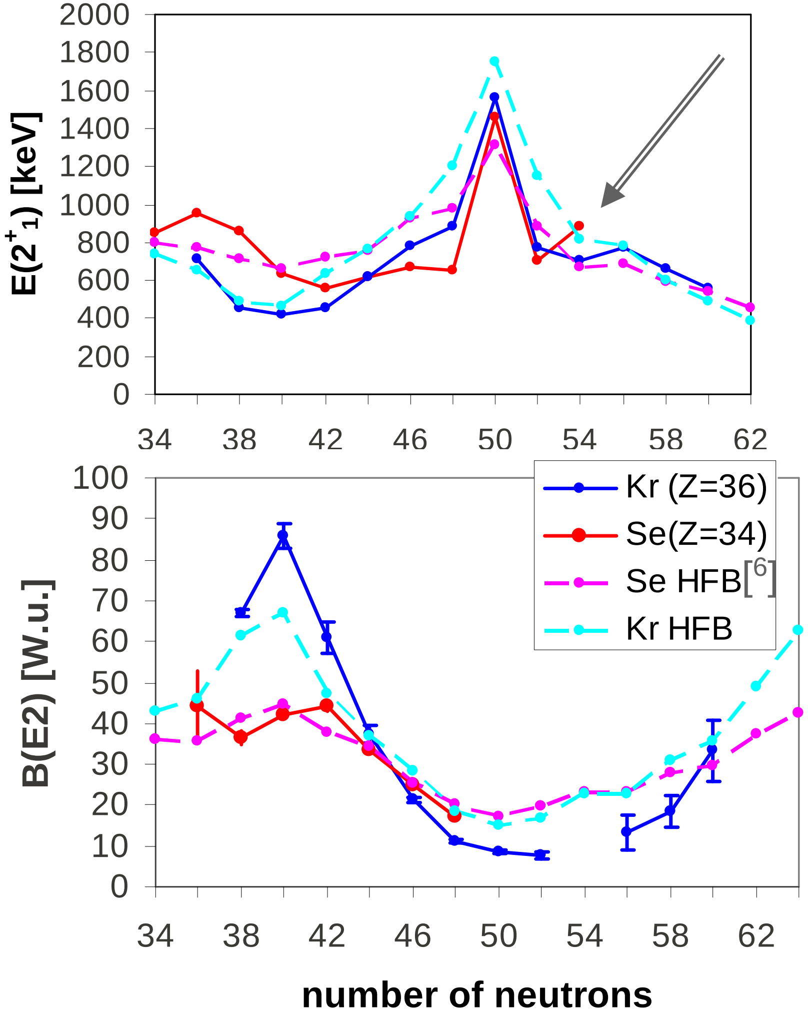
- [1]: Spontaneous fission of ^{252}Cf
- γ rays detected with Gammasphere
- Assignment of γ transitions by gating on transitions in the respective partner nuclei
- 886 keV γ ray was assigned to the $2^+_1 \rightarrow 0^+_1$ transition in ^{88}Se
- Explanation: 0^+ mixing of a spherical ground state and deformed 0^+_2 state leading to a repulsion between both states [1]



- But: spherical gs in ^{88}Se would imply a strong subshell closure in ^{90}Se (N=56), which is incompatible with QRPA calculations and recent results on β decay half lifes [2-5]

[1]: E.F. Jones et al., Phys. Rev. C73, 017301 (2006)
[2]: M. Quinn et al., Phys. Rev. C85, 035807 (2012)
[3]: P. Moeller et al., At. Data Nucl. Data Tables 59, 185 (1995)
[4]: P. Moeller et al., At. Data Nucl. Data Tables 66, 131 (1997)
[5]: P. Moeller et al., Phys. Rev. C67, 0558-2 (2003)
[6] S. Hilaire and M. Girod. Eur. Phys. J. A, 33:237, 2007

High-lying 2^+_1 state in ^{88}Se?



Possible experiment:

- ^{88}Se beam provided by CARIBU (340mCi)
    - E=384 MeV
    - I=130 pps
    - ^{196}Pt target (2mg/cm^2)
- matrix elements calculated using *Rachel* and *Gosia*

Transition	E_γ	Estimated B(EL)		Estimated Count rate
in ^{88}Se	[keV]	[W.u.]		per day
$2^+_1 \rightarrow 0^+_1$	886	E2	(10)	27

Transition	E_γ	Known B(EL)		Estimated
in ^{196}Pt	[keV]	[W.u.]		count rate
$2^+_1 \rightarrow 0^+_1$	356	E2	40.6(2)	96
$2^+_2 \rightarrow 2^+_1$	333	E2	57.7(8.8)	8
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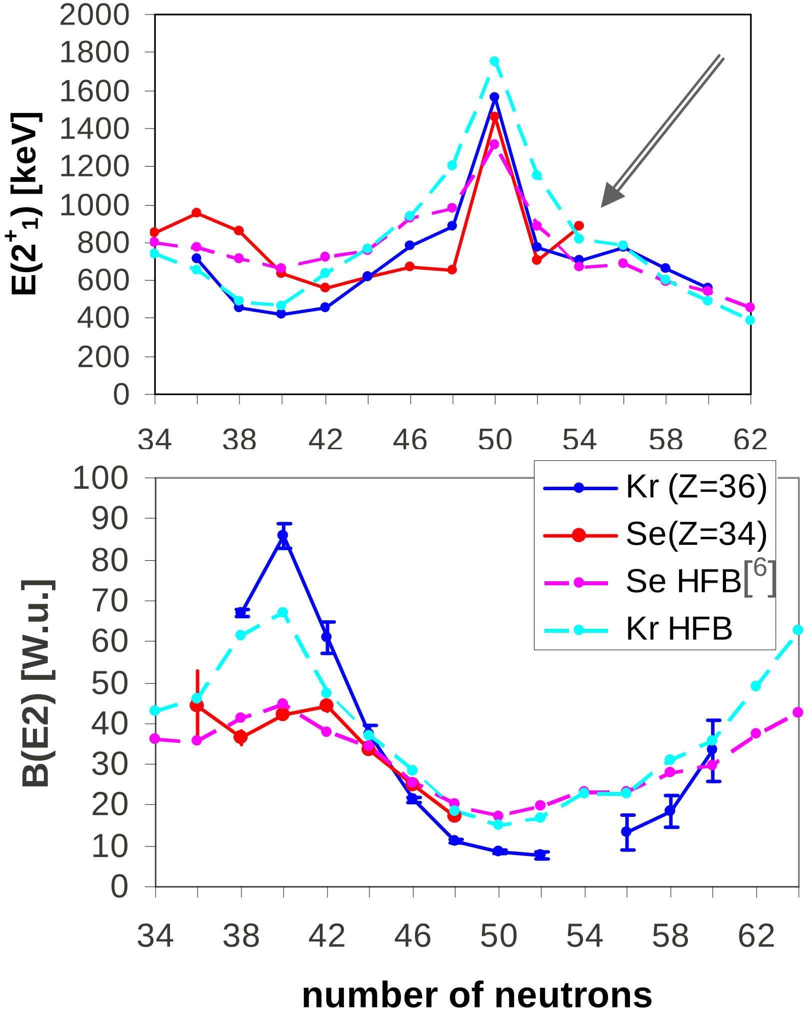
High-lying 2^+_1 state in ^{88}Se?



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in ^{88}Se	[keV]	[W.u.]		per day
$2^+_1 \rightarrow 0^+_1$	886	E2	(10)	27
$2^+_1 \rightarrow 0^+_1$	~700	E2	(20)	50
$4^+_1 \rightarrow 2^+_1$	~750	E2	(40)	5
$3^-_1 \rightarrow 0^+_1$	~1500	E3	(60)	---
$3^-_1 \rightarrow 2^+_1$	~800	E1	(0.001)	1.5
Transition	E_γ	Known B(EL)		Estimated
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$2^+_1 \rightarrow 0^+_1$	356	E2	40.6(2)	96
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Summary

- Coulomb excitation is a powerful tool for studying low-energy nuclear structure in exotic radioactive nuclei using CARIBU beams
- The high efficiency and high peak-to-total ratio of GRETINA will allow a high precision measurement of deexciting γ rays
- CHICO2 is suitable for a high-resolution measurement of scattered beam-like and target-like particles
- Employing the coupled-channels Coulomb excitation computer code GOSIA will allow the model-independent extraction of transitional and diagonal matrix elements from the experimental data
- The combination of the new experimental setup at ATLAS with powerful analysis tools will allow the study of collectivity in exotic nuclei, in particular octupole collectivity in ^{90}Kr and quadrupole collectivity in ^{88}Se.

Acknowledgements

Collaborators:

Argonne National Laboratory: R.V.F. Janssens, M. Alcorta, S.J. Almaraz-Calderon, M.P. Carpenter, C.J. Chiara, C.R. Hoffman, F.G. Kondev, T. Lauritsen, O. Nusair, G. Savard, D. Seweryniak, S. Zhu

University of Rochester: D. Cline, A. Hayes

Lawrence Livermore National Laboratory: A. Chyzh, E. Kwan, C.Y. Wu

A.W. Wright Nuclear Structure Laboratory: V. Werner, C. Bernards, F. Naqvi

Thank you for your attention!

Determination of matrix elements: GOSIA(2)

- projectile level scheme
- Particle + γ ray detector geometry
- All available experimental data (lifetimes, mixing ratios, etc.)
- Start parameter for projectile matrix elements
- Efficiency corrected experimental γ-ray yields
- Target and projectile level schemes
- Target matrix elements

GOSIA*:

Varying the projectile matrix elements; based on those matrix elements theoretical γ-ray yields are calculated and compared to the experimental ones.

χ^2 test qualifies the calculations

Lowest χ^2 yields the matrix elements

GOSIA1: Normalization on known matrix element (i.e., $B(E2;2^+_1 \rightarrow 0^+_1)$ is known)

GOSIA2: Normalization on target transition

Rachel: Graphical User Interface (A. Hayes *et al.*)

[*]: T. Czosnyka, D. Cline, and C.Y. Wu. Bull. Am. Phys. Soc., 28:745, 1983.
A. Winther and J. de Boer, Coulomb Excitation, (Academic, New York, 1965)

Quadrupole collectivity in neutron-rich Kr isotopes