Shell structure and shape changes in neutron-rich krypton isotopes

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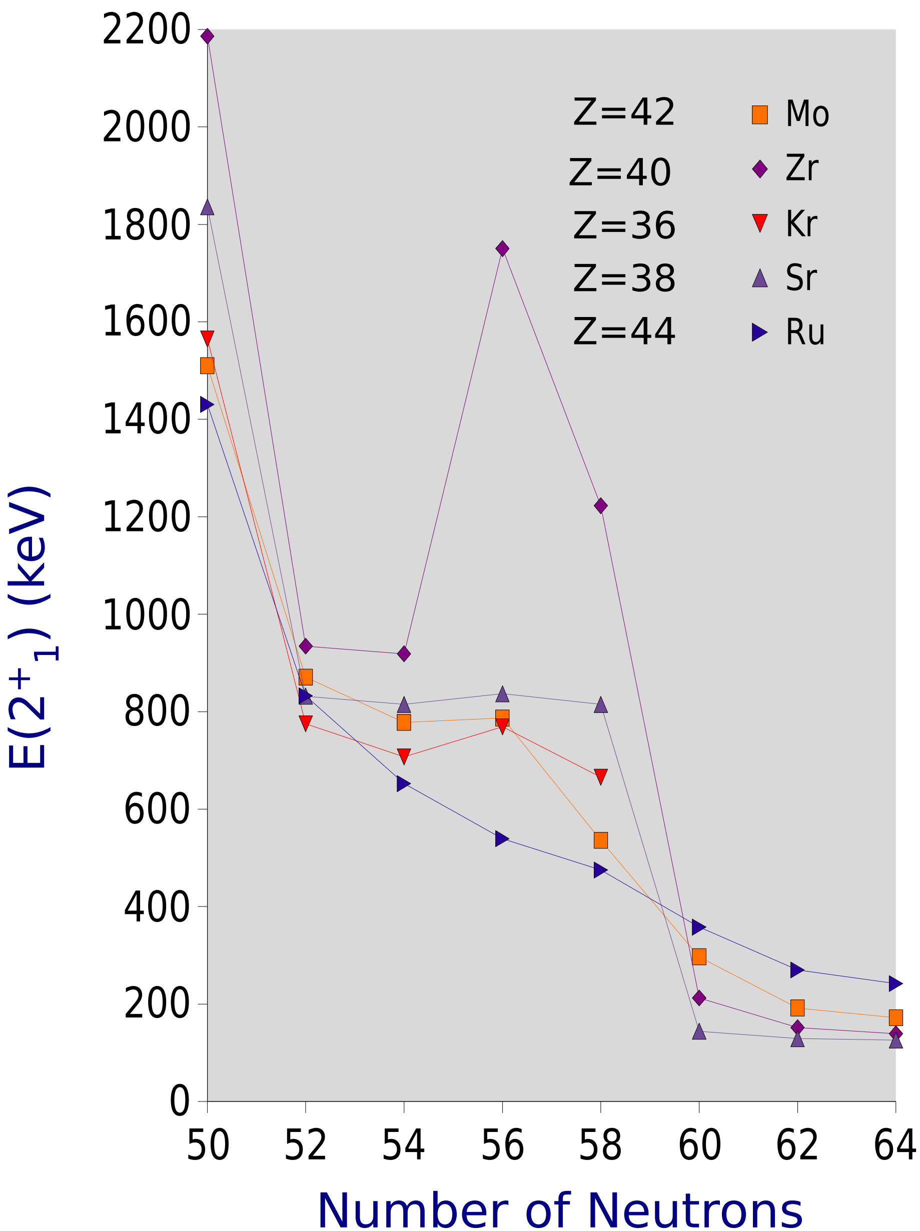
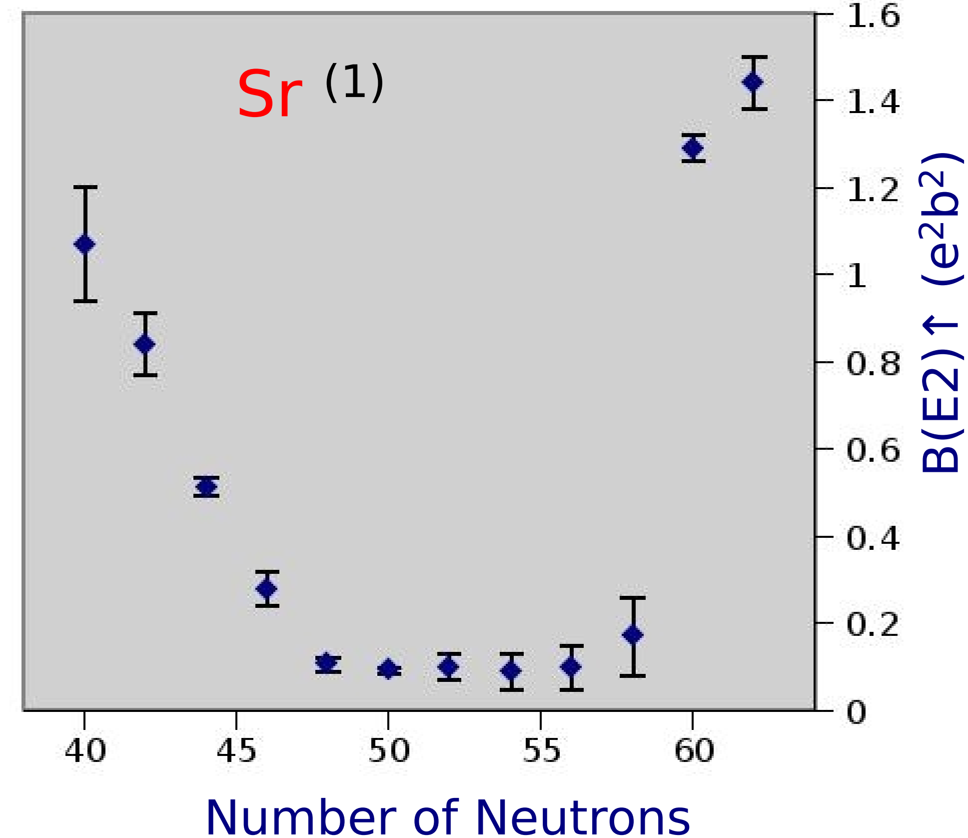
- Motivation: N=56 shell closure and octupole deformation in A=100
- Coulomb Excitation of ^{88}Kr and ^{92}Kr with MINIBALL @ ISOLDE
- Discussion: The nature of the N=56 subshell closure for Kr isotopes
- Determination of the Quadrupole Moment (prel.)
- Summary + Outlook

Systematics of the A≈100 Region





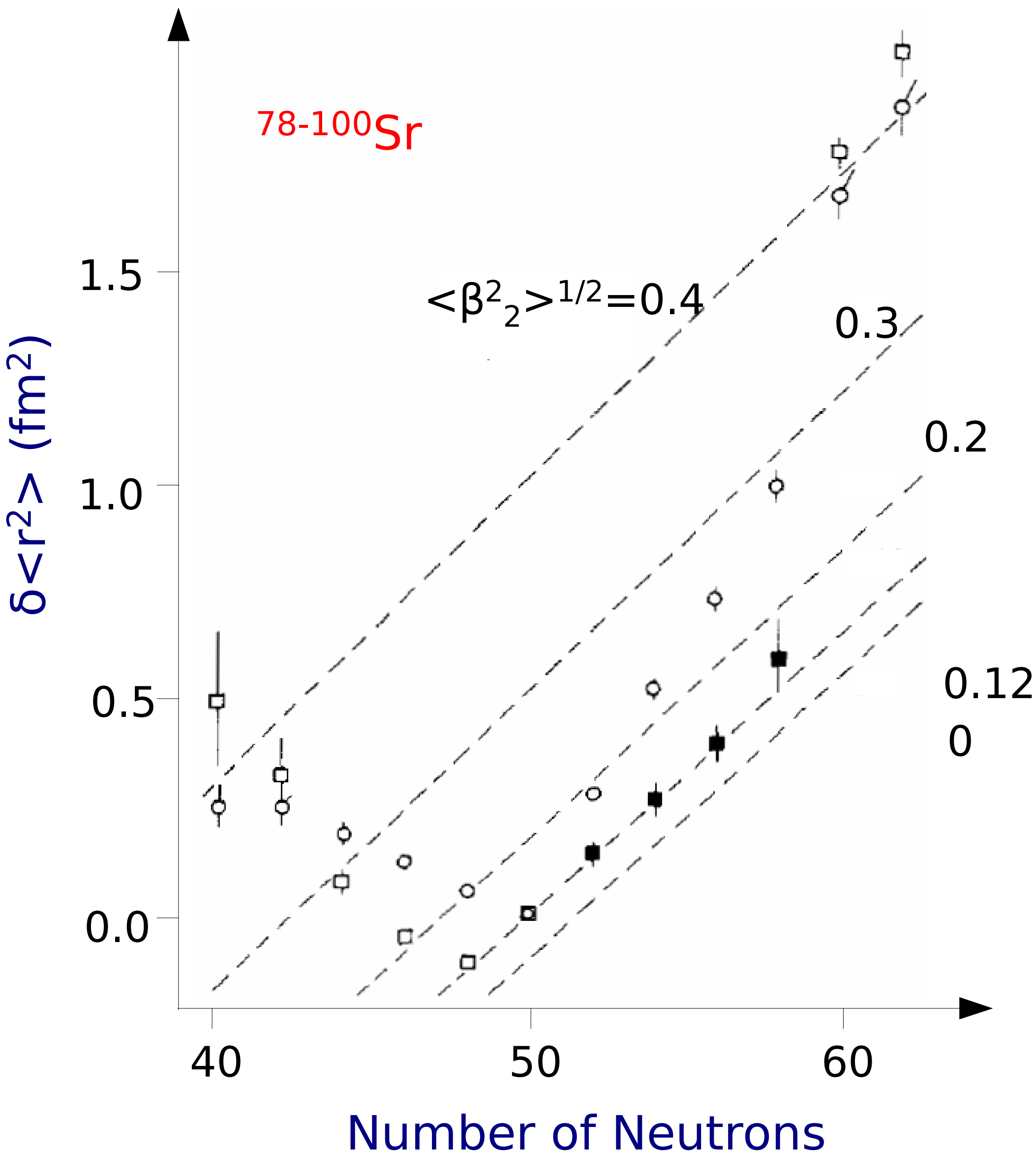
- strong influence of N=56 shell closure for Zr and Sr nuclei, but no evidence in Mo, Ru, Cd,...
- why peaks $E(2^+_1)$ for ^{92}Kr?
- ideas [1,2]: locally occuring deformed gap, quasi-spherical but soft against octupole deformation

(1): H. Mach et al./Nucl. Phys. A523 (1991) 197-227
(2): K.-L. Kratz et al./Atomic Nuclei 330, (1988)

Changes in mean-square charge radii, octupole deformation

Liquid drop model: $\delta\langle r^2\rangle = \frac{2}{3}C\delta A/A\langle r^2\rangle + (\frac{5}{4\pi}\langle r^2\rangle \sum_L \delta\langle\beta_L^2\rangle$

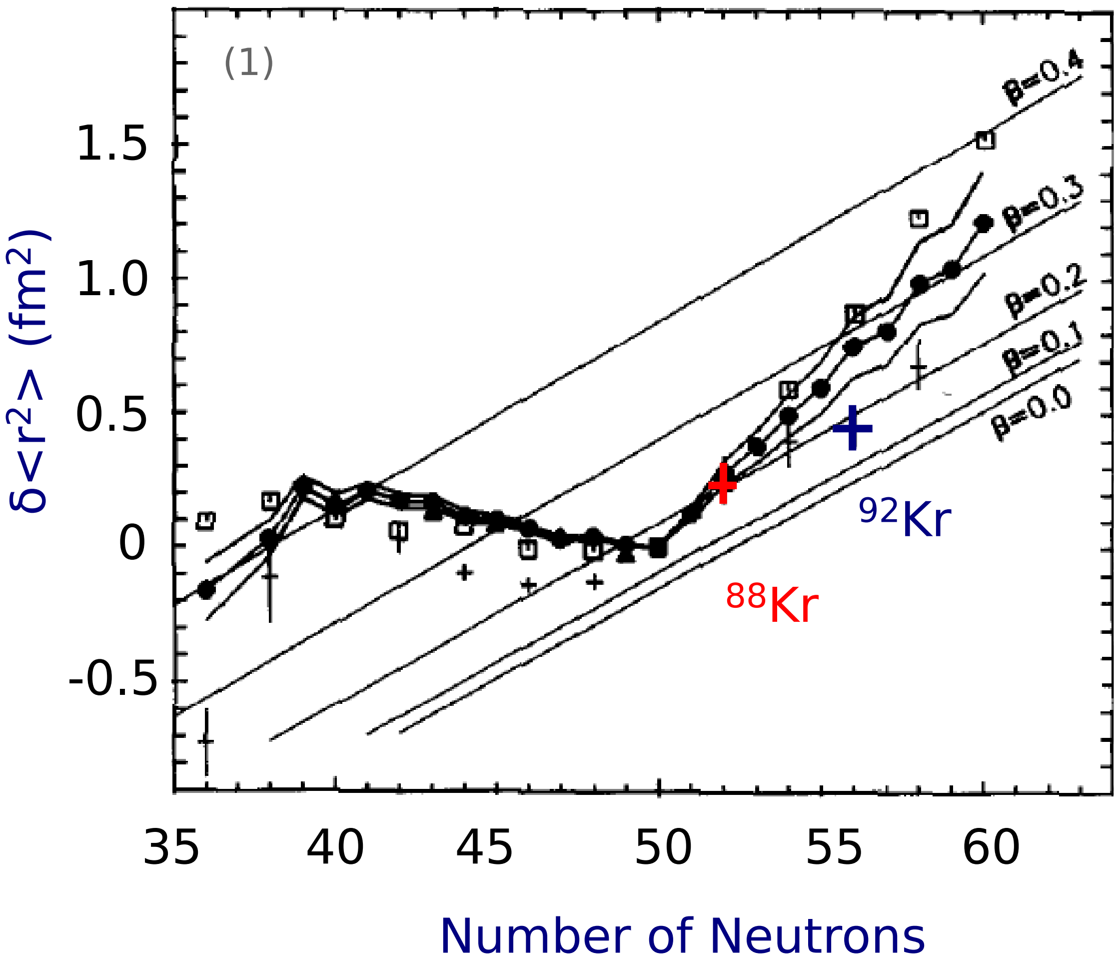
$$\langle\beta_L^2\rangle \sim \sum_f B(EL; 0_1^+ \rightarrow f)$$



- increase of radii contains additional contributions: „shell effect“
- e.g. Nazarewicz et al.: octupole softness
- sharp increase of charge radii at N=60: phase-transition-like behaviour

[(1)]: W. Nazarewicz et al./Nucl. Phys. A429 (1984) 269-295

Octupole deformation in Kr-Isotopes



- calculated values of radii show the same effects like in Sr isotopes
- B(E2) values: Grodzins Relation

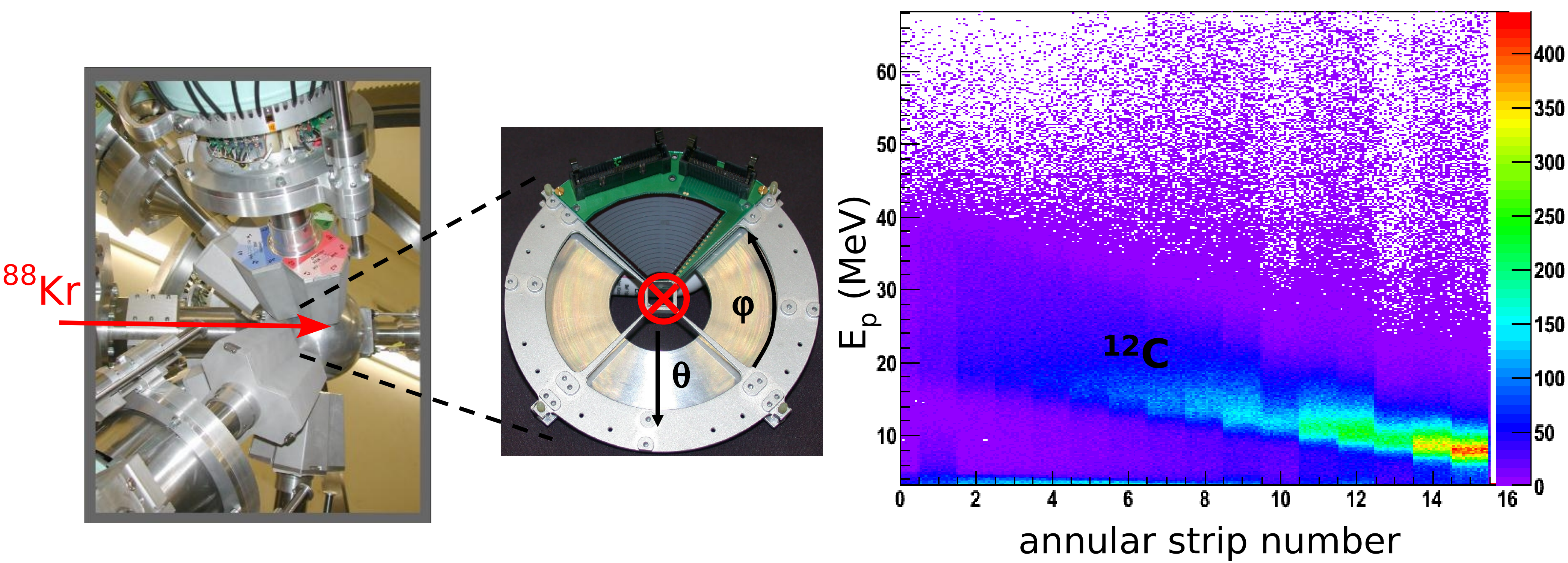
$$B(E2) = (12 \pm 4)\frac{Z^2}{A}\frac{1}{E_{2_1^+}}(keV \cdot e^2 b^2)$$

- no sharp increase of radii at N=60 was found

[(1)]: M. Keim et al./Nucl. Phys. A586 (1995) 219-239

Experiment on $^{(88,92)}$Kr @ REX-ISOLDE

- Beam energy: 2.19 MeV/u (broken 9 gap resonator)
- Beam intensity: 5 $*10^6$ particles/sec
- targets: 4 mg/cm² ^{109}Ag, 2 mg/cm² ^{109}Ag, 2mg/cm² ^{12}C
- 4 days beam time for ^{88}Kr and 2 days for ^{92}Kr
- MINIBALL spectrometer: 8 triple clusters+particle detector



Determination of B(E2) values

First order perturbation theory :
Alder & Winther : "Electromagnetic Excitation - Theory of Coulomb Excitation with Heavy Ions"
North-Holland, 1975, Amsterdam

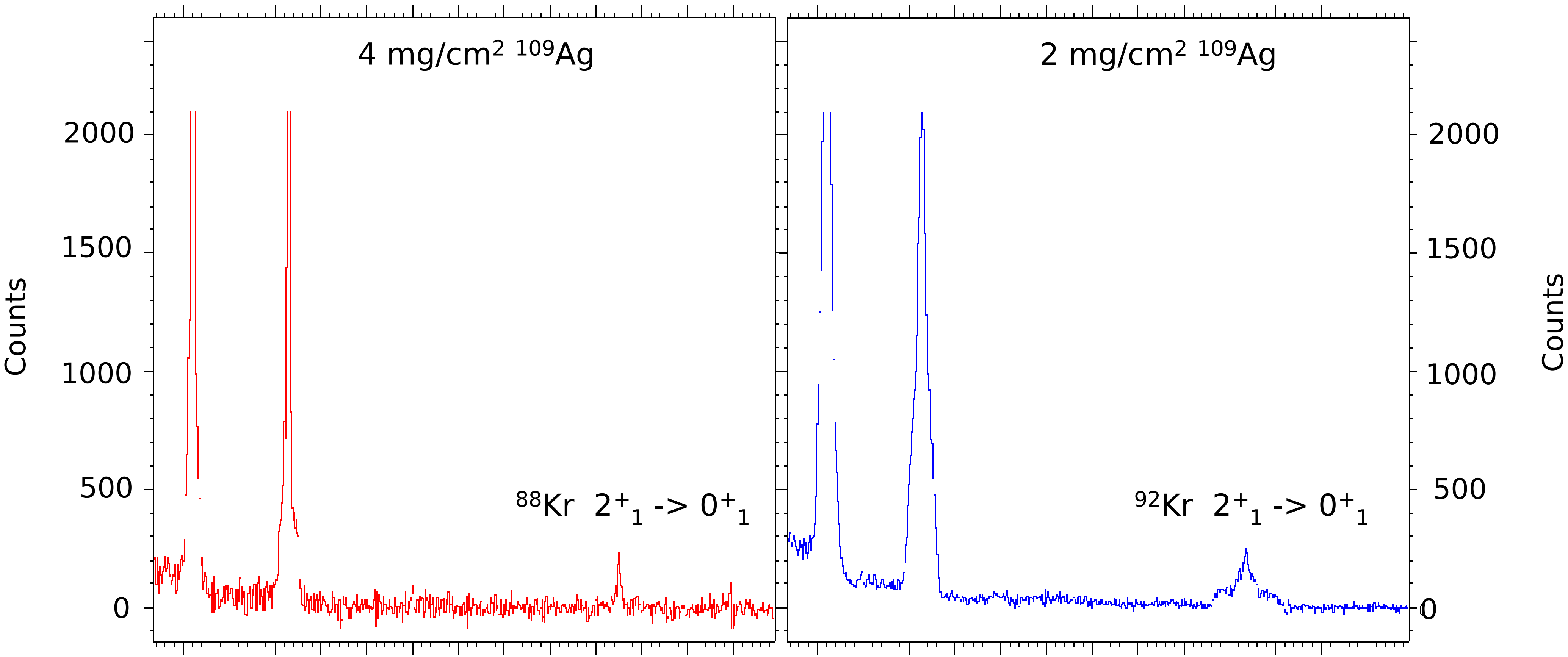
$$\sigma_{E2} = \left(\frac{Z_1 e}{\hbar v}\right)^2 a^{-2} B(E2, I_0 \rightarrow I_f) f_{E2}(\xi)$$

- Experimental method:

$$\sigma^{p}_{CE} = \frac{\epsilon^{t}_{\gamma}}{\epsilon^{p}_{\gamma}} \cdot \frac{b^{t}_{\gamma}}{b^{p}_{\gamma}} \cdot \frac{W^{t}_{\gamma}}{W^{p}_{\gamma}} \cdot \frac{N^{p}_{\gamma}}{N^{t}_{\gamma}} \cdot \sigma^{t}_{CE}$$

- used Coulomb Excitation codes:
  - CLX
    - ... calculates differential cross section, incl. energy loss
  - GOSIA (Rochester, Warsaw)
    - ... performs χ^2-fitting of matrix elements to the experimental data
    - ... handels projectile and target excitation simultaneously (GOSIA 2)
    - ... let the user to specify the experimental setup (8 cluster+part. det.)
    - ... calculates angular distributions
    - ... counts for the deorientation effect
    - ...

Spectra of ^{88}Kr and ^{92}Kr on ^{109}Ag Target

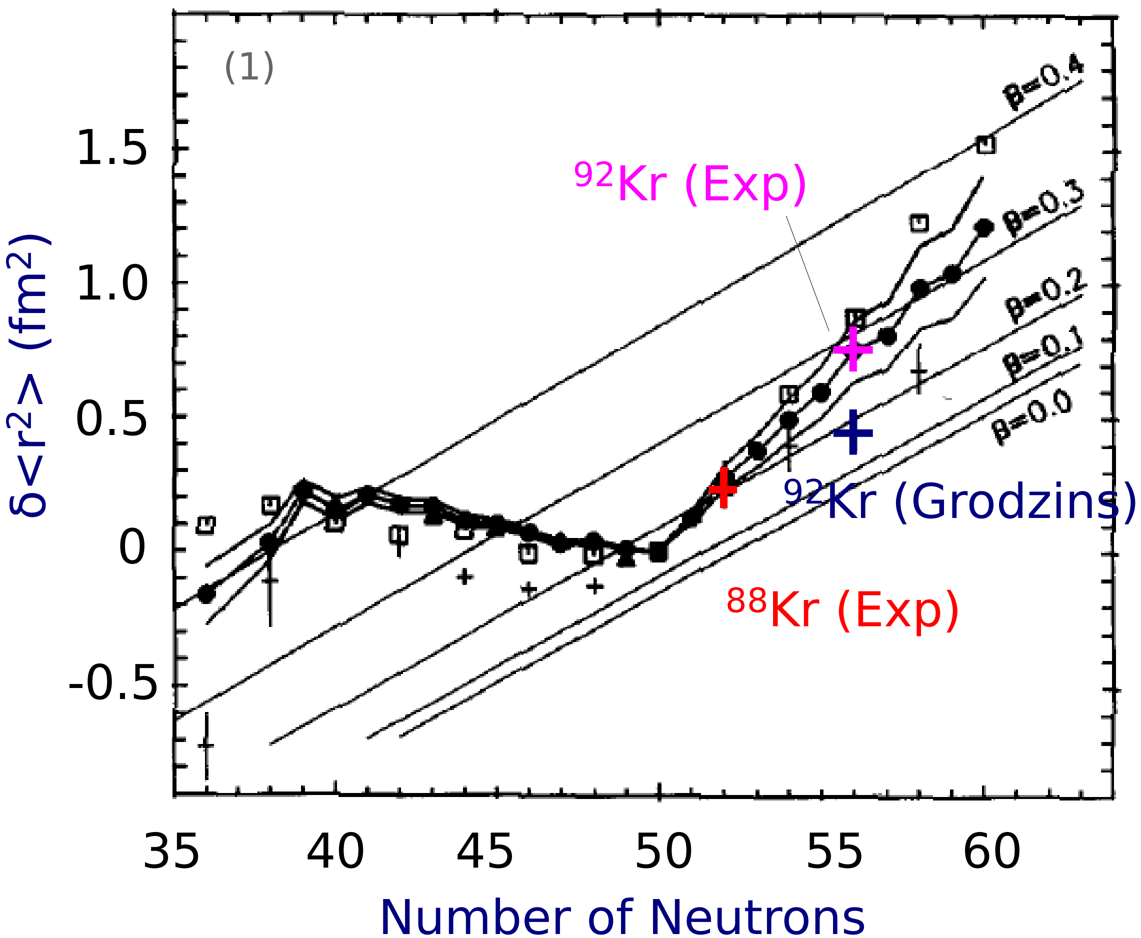


- when normalizing to target excitation: A(^{92}Kr,$2^+ \rightarrow 0^+$)≈2·A(^{88}Kr,$2^+ \rightarrow 0^+$) !!
- Exact calculation (integration over full CD range):

  ^{88}Kr: B(E2;$2^+_1 \rightarrow 0^+_1$)=7.7(8) W.u. (smaller error from ^{12}C data...)

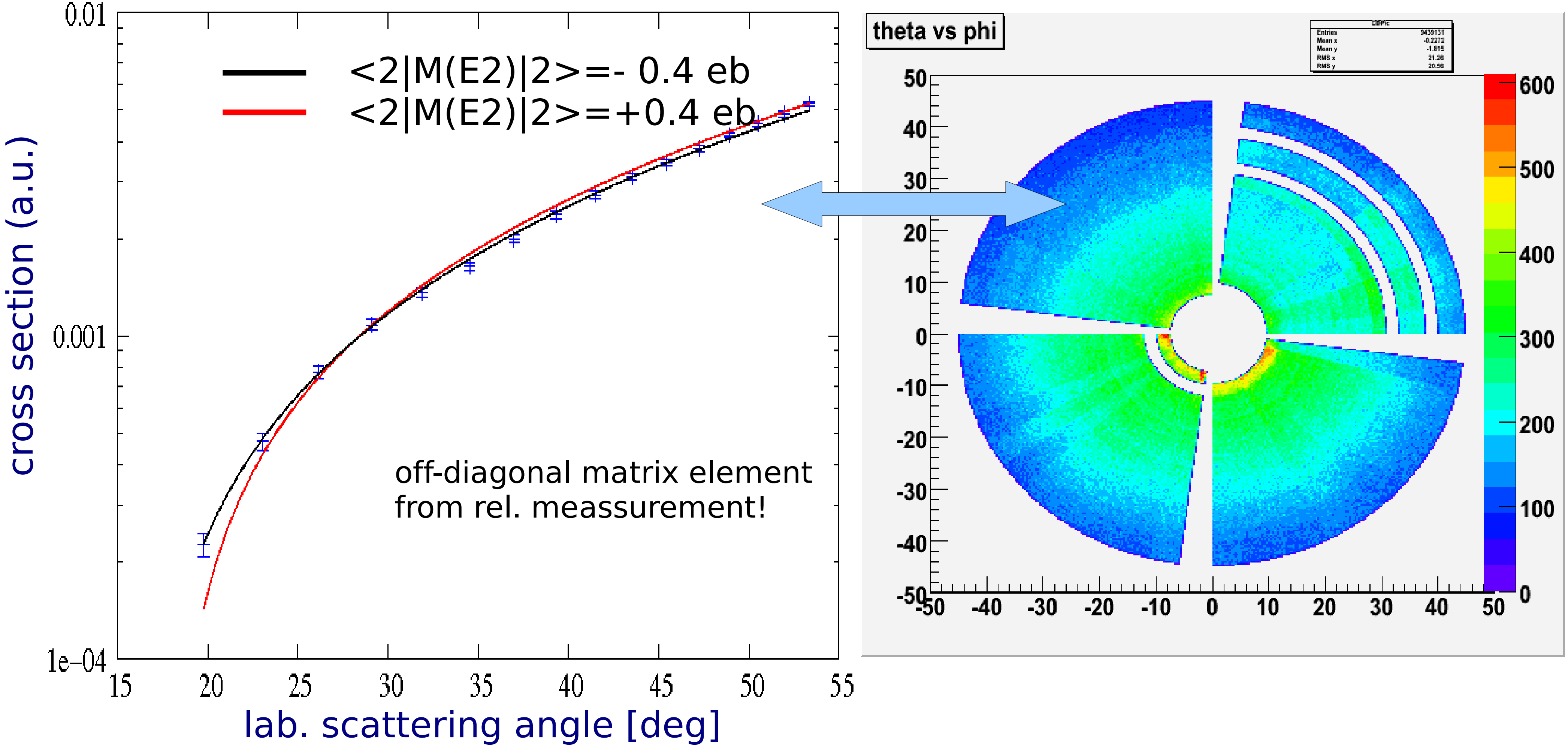
  ^{92}Kr: B(E2;$2^+_1 \rightarrow 0^+_1$)=16.9(5) W.u.

No octupole softness for ^{92}Kr



- Exp. B(E2) value gives new $\delta\langle r^2\rangle$
  -> no octupole softness !
- possible interpretation for high $E(2^+_1)$ energy: deformed gap (->Nilsson Model)
- evolution of deformation towards N=60?
  -> $^{(94,96)}$Kr @Isolde is possible

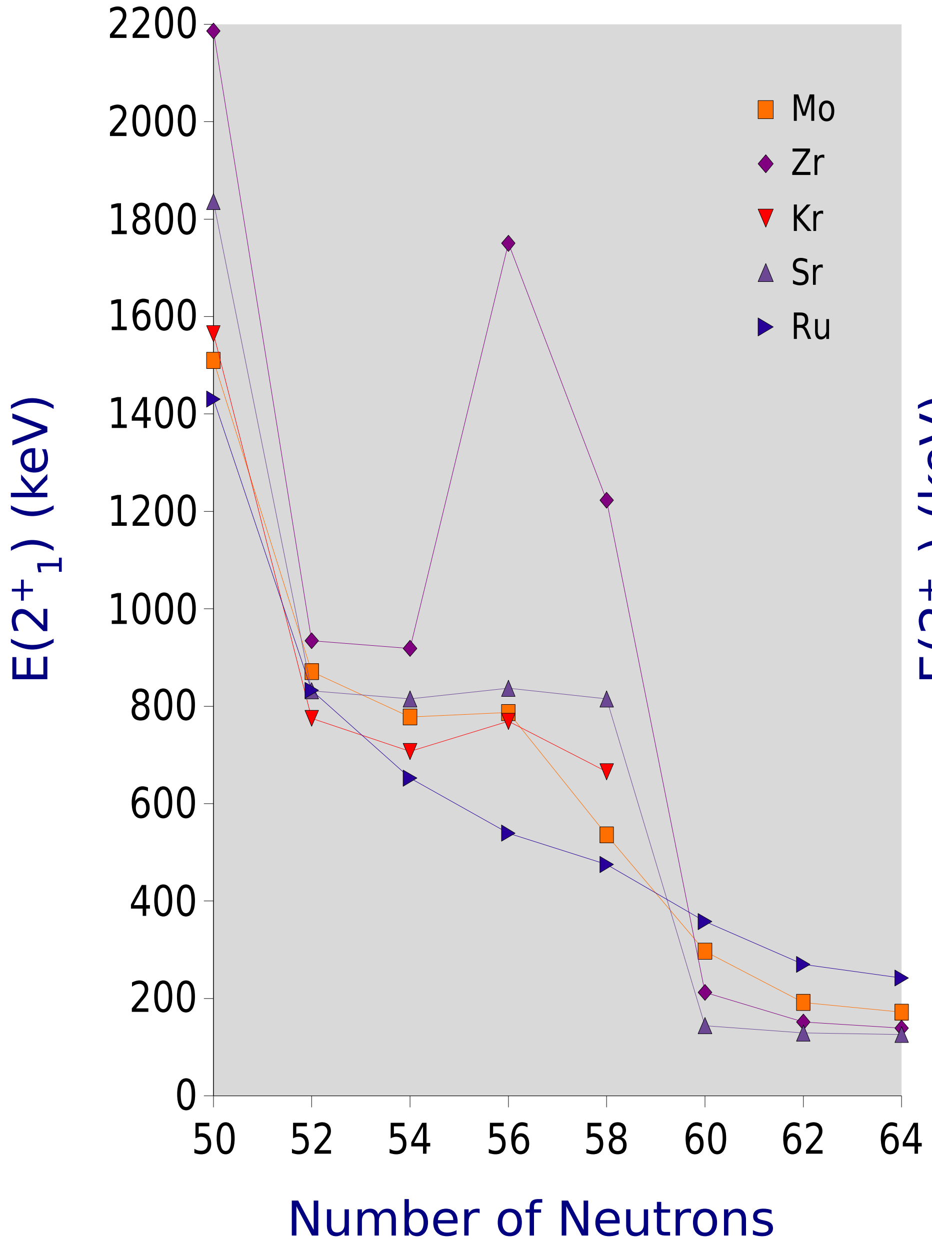
Quadrupole moment of ^{88}Kr

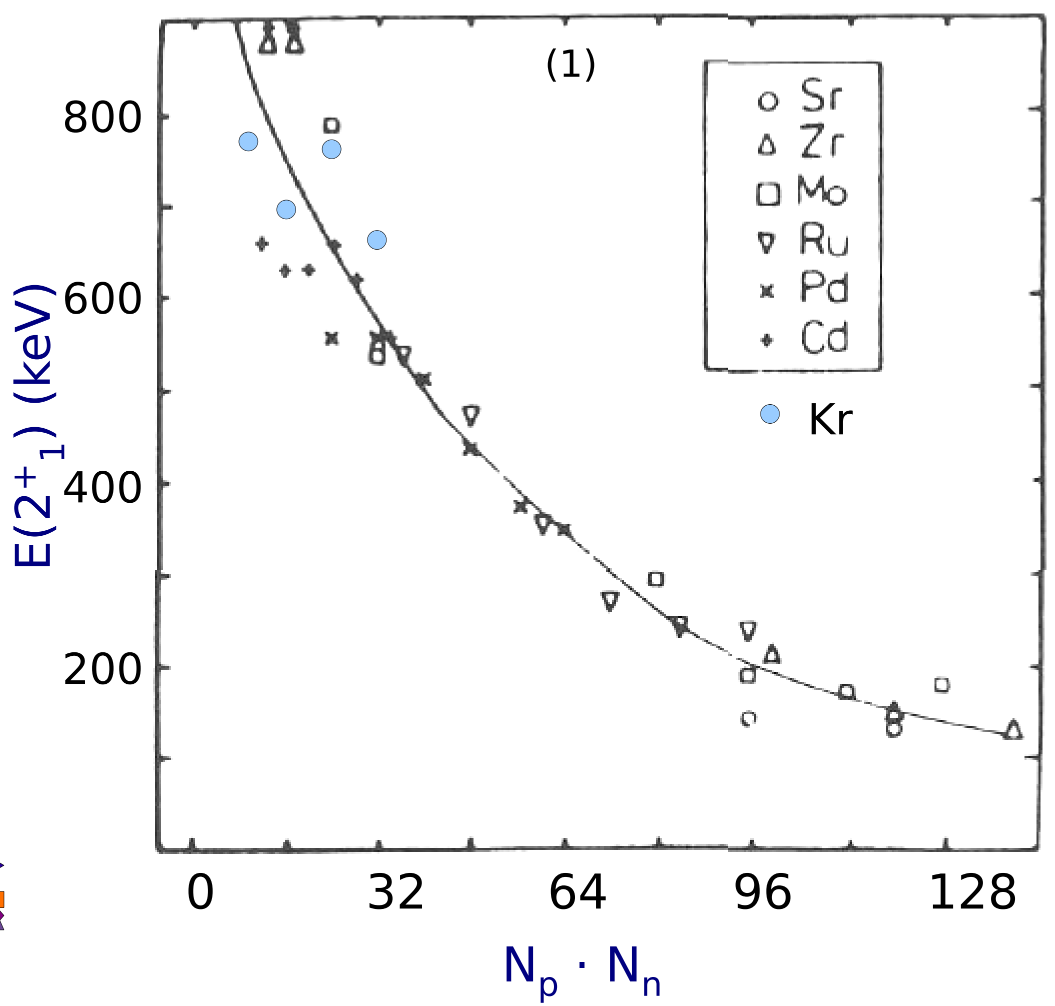


- a negative value for <2|M(E2)|2> fits better to the cross section
- due to defect strips only quater of the full statistics was used so far
- for ^{92}Kr: no separation of Target-and Projectile excitation -> Det. of Q not possible

  --> for future experiments: heavier and thinner targets !

The $N_p \cdot N_n$ scheme





(1): R.F. Casten/Nuclear Structure from a Simple Perspective

Summary and outlook

- The nuclear structure of the A=100 region shows a complex interplay between microscopic and macroscopic features: N=50,56,58 shell gaps vs phase transition to deformed nuclei for N>58
- In the past: Differences in mean square radii in Kr isotopes were explained by octupole softness
- We determined $B(E2;2^+_1\rightarrow0^+_1)$ values for ^{88}Kr and ^{92}Kr
- for ^{92}Kr deformation starts to set in and no octupole softness has to be assumed
- There is still the question why $E(2^+_1)$ peaks for ^{92}Kr !!
- The determination of the (sign of) the quadrupole moment is possible with RIB @Isolde
- For the future: evolution of deformation towards ^{96}Kr

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Thanks for your attention!