Shell structure and shape changes in neutron-rich krypton isotopes

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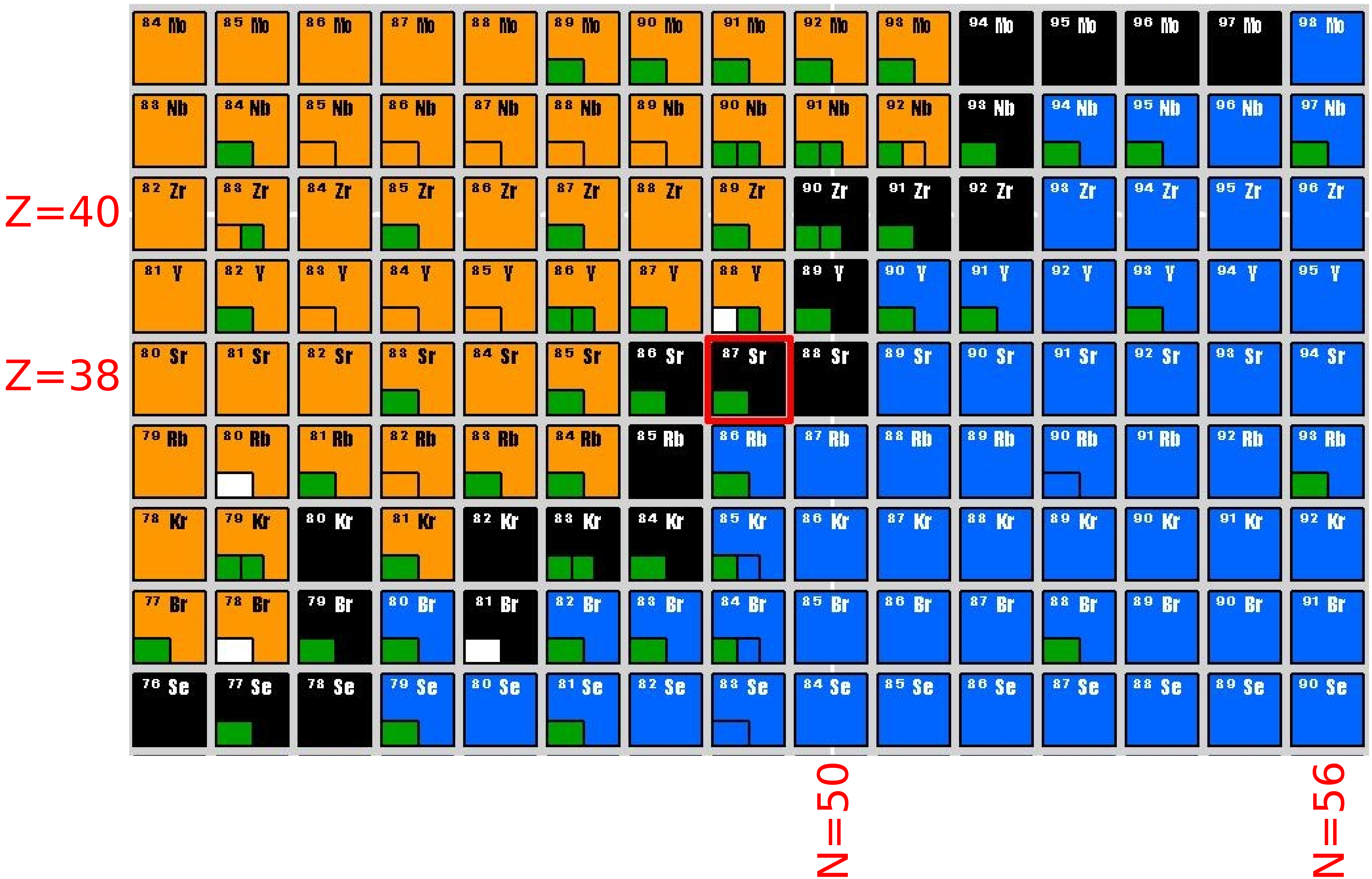
for the MINIBALL and REX_ISOLDE Collaboration

- Motivation: Shape changes in exotic krypton isotopes, N=56 @ Z=40
- Coulomb Excitation of ^{88}Kr and ^{92}Kr with MINIBALL @ ISOLDE
- conclusion on N=56 "subshell closure"
- consequence on deformation and octupole softness for neutron-rich Krypton isotope
- Quadrupole Moments from Coulomb Excitation data ? , GOSIA
- Conclusion and Outlook

Where we are ....



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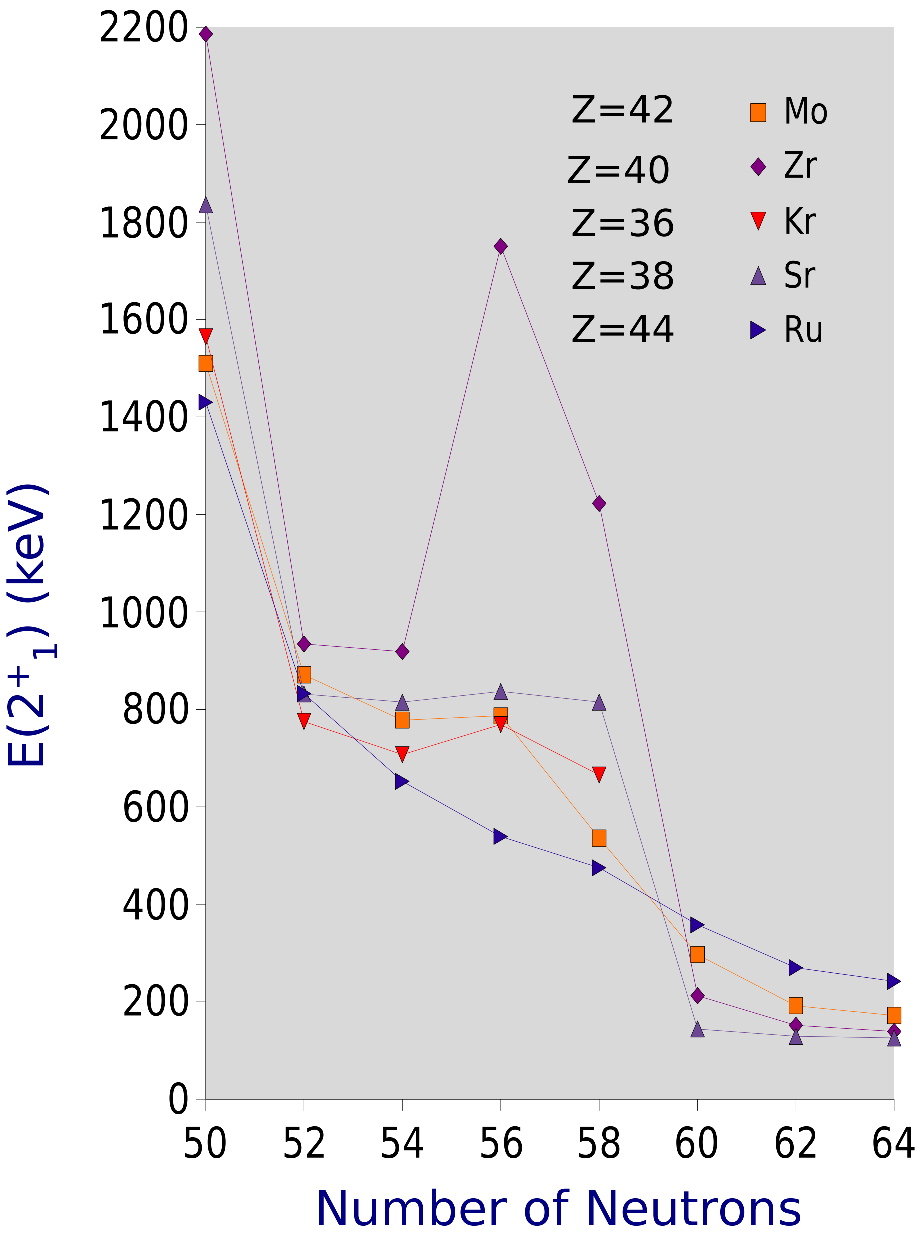
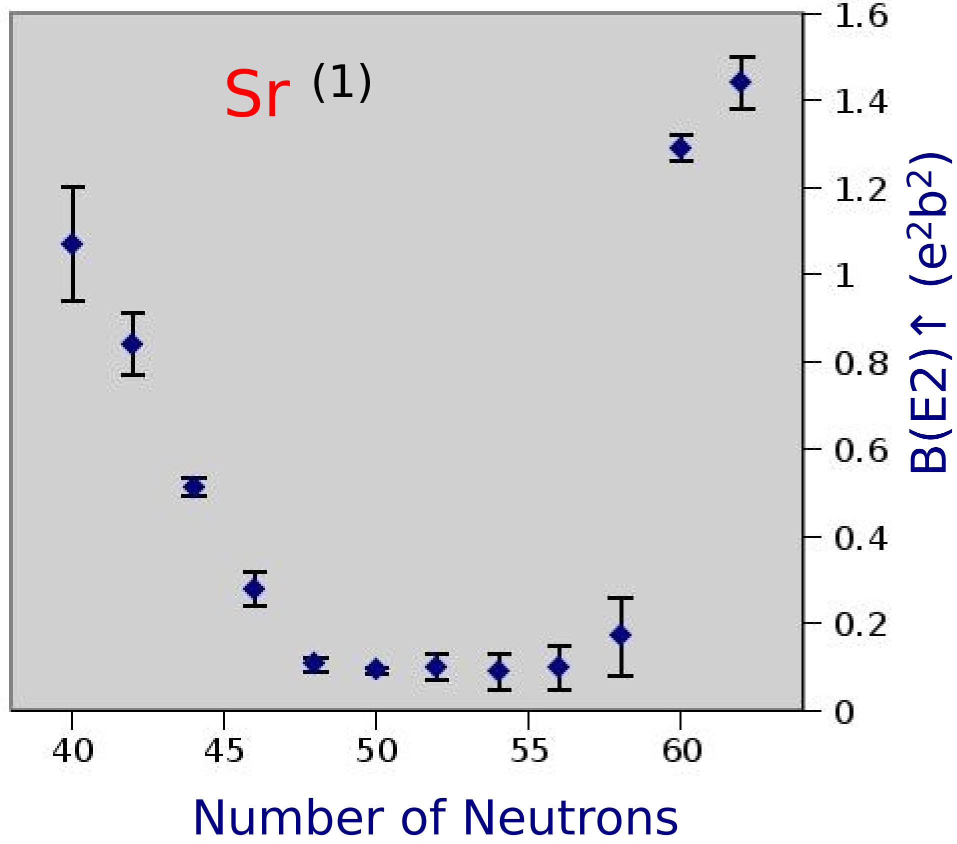
76 Se	77 Se	78 Se	79 Se	80 Se	81 Se	82 Se	83 Se	84 Se	85 Se	86 Se	87 Se	88 Se	89 Se	90 Se

N=56 subshell closure ?

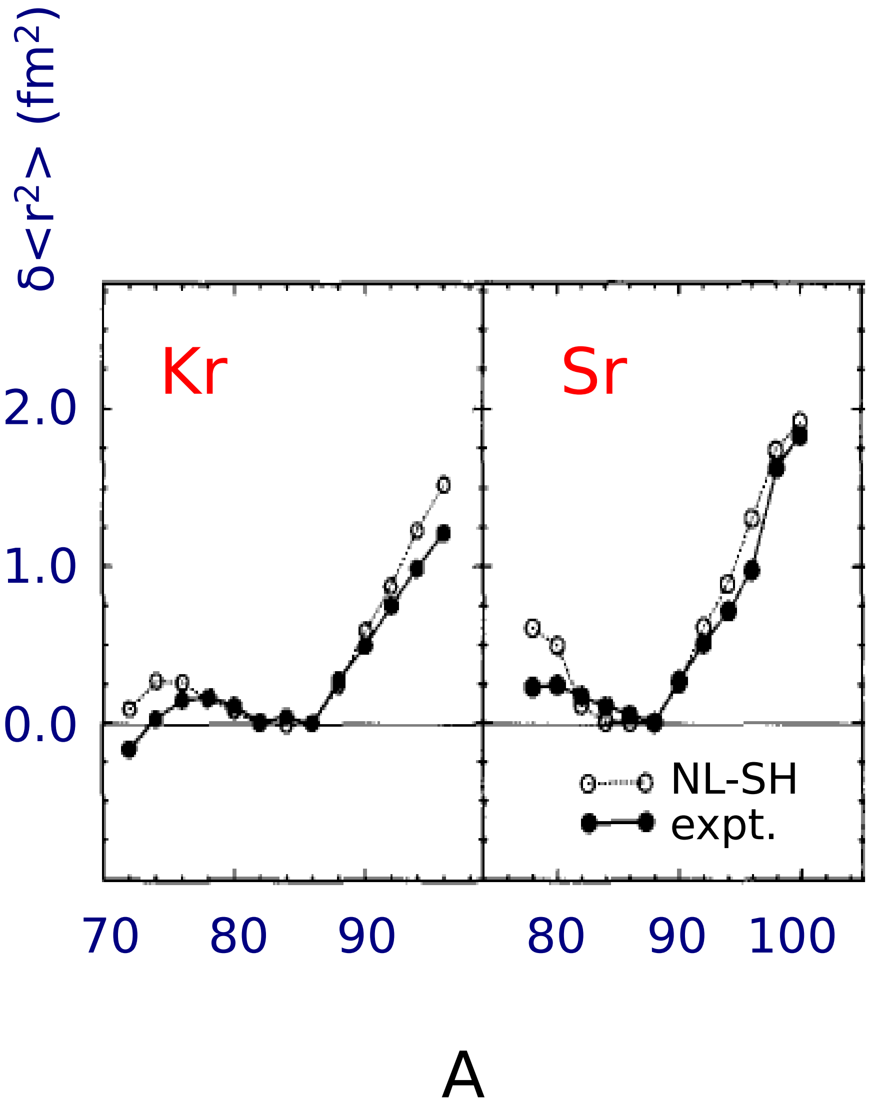


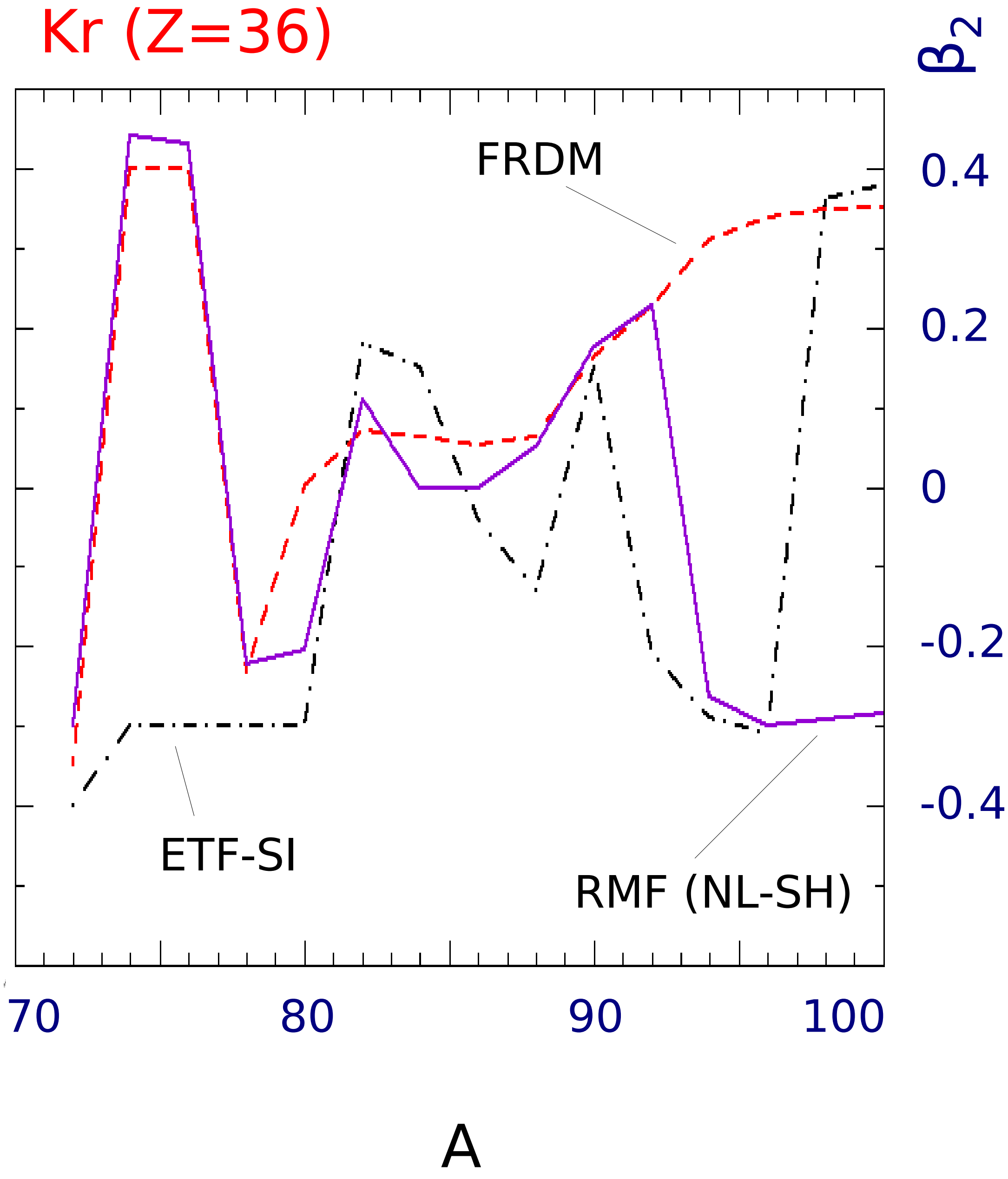


- strong influence of N=56 shell closure for Zr and Sr nuclei, but no evidence in Mo, Ru, Cd,...
- why peaks $E(2^+_1)$ for ^{92}Kr?
- ideas (1,2): locally occuring deformed gap , quasi-spherical but soft against octupole deformation

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

Deformation β_2 from Relativistic Mean-Field



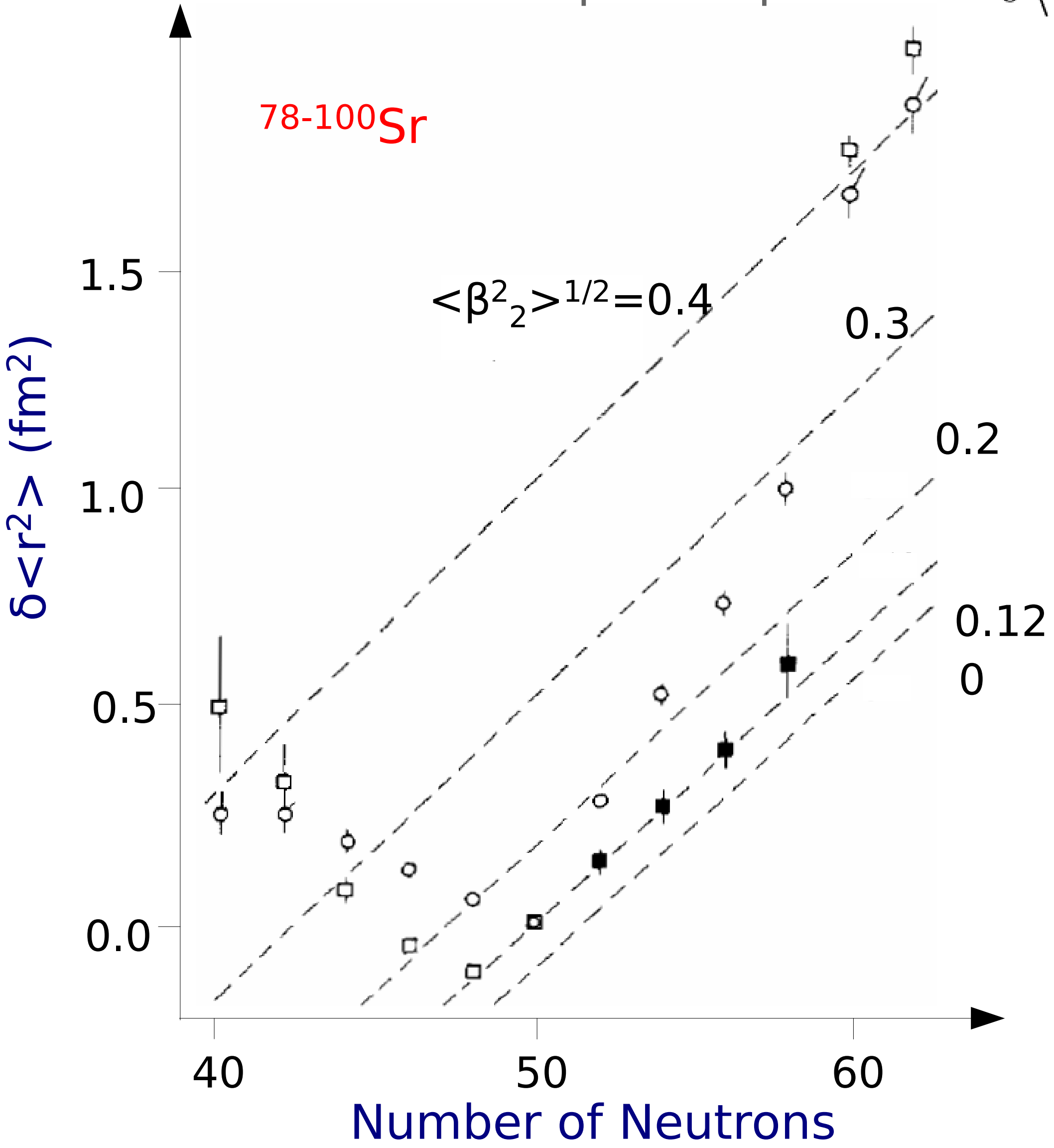


G.A. Lalazissis et al. Nucl. Phys. A586 (1995) 201-218

Changes in mean-square charge radii, octupole deformation

Description of isotope shifts: good description in RMF theory (1)

Liquid drop model:
$$\delta\langle r^2\rangle = \frac{2}{3}C\delta A/A\langle r^2\rangle + (\frac{5}{4\pi}\langle r^2\rangle \sum_L \delta\langle\beta_L^2\rangle$$
$$\langle\beta_L^2\rangle \sim \sum_f B(EL;0_1^+ \to f)$$



- increase of radii contains additional contributions: „shell effect“
- Strutinsky-type potential-energy calculations (2): "^{92}Kr is soft but stable with respect to octupole deformation"
- sharp increase of charge radii at N=60: phase-transition-like behaviour

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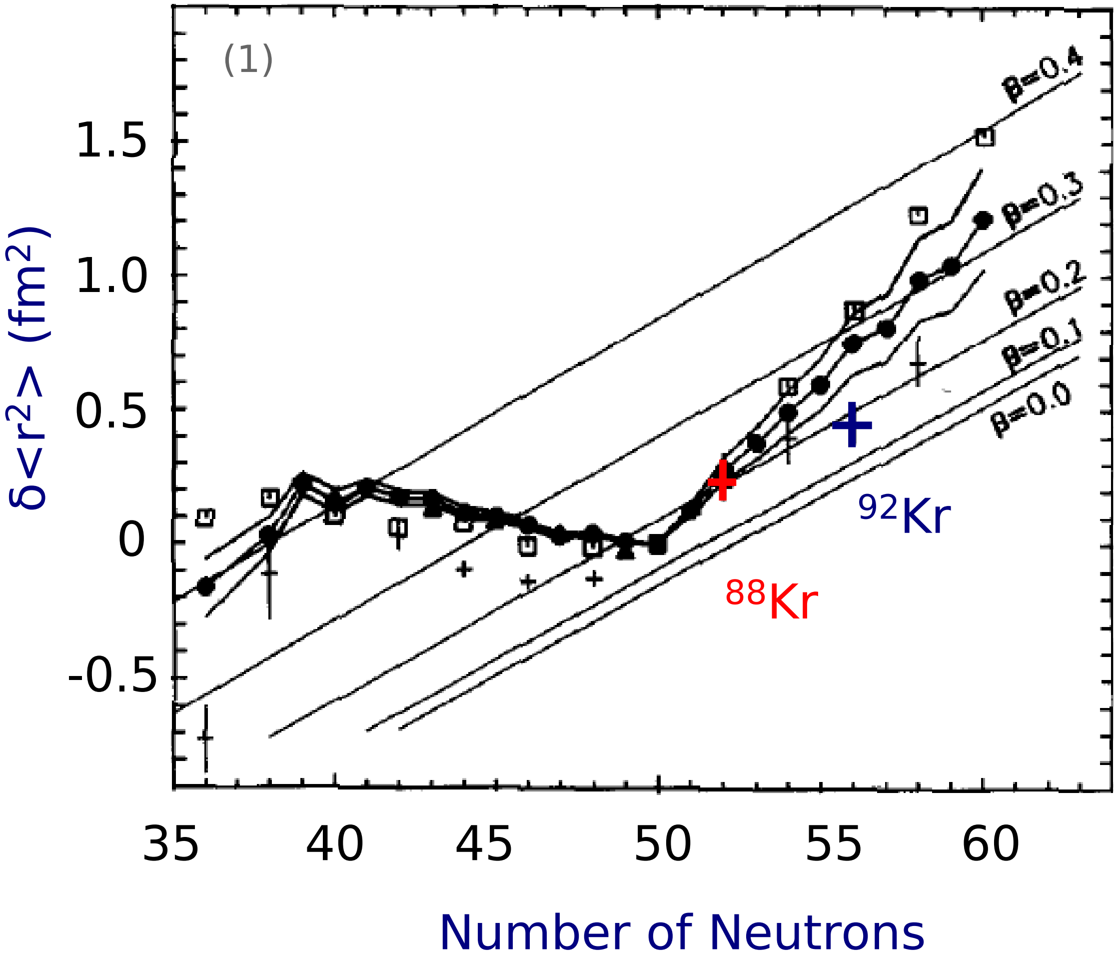
(1): G.A. Lalazissis et al. Nucl. Phys. A586 (1995) 201-218

(2): 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

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

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

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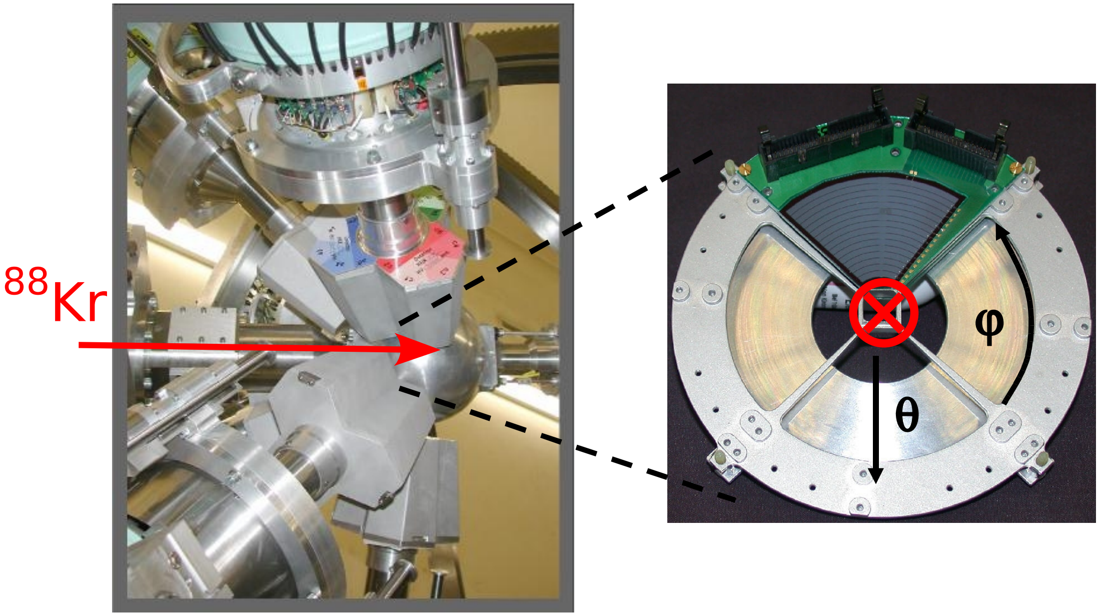
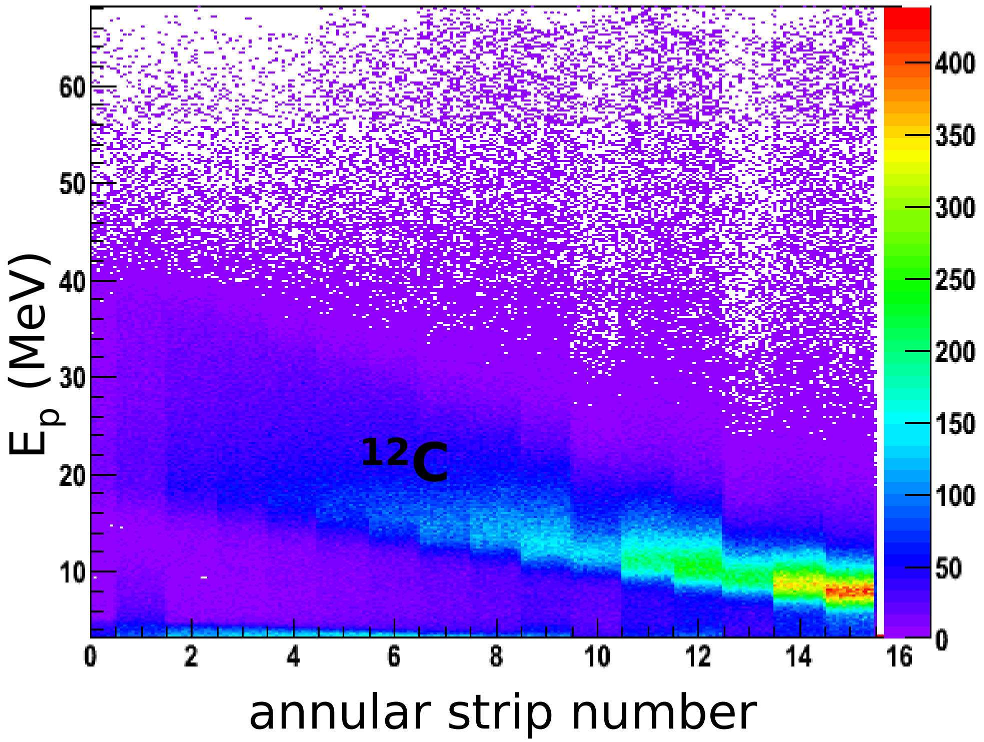
(1): M. Keim et al./Nucl. Phys. A586 (1995) 219-239

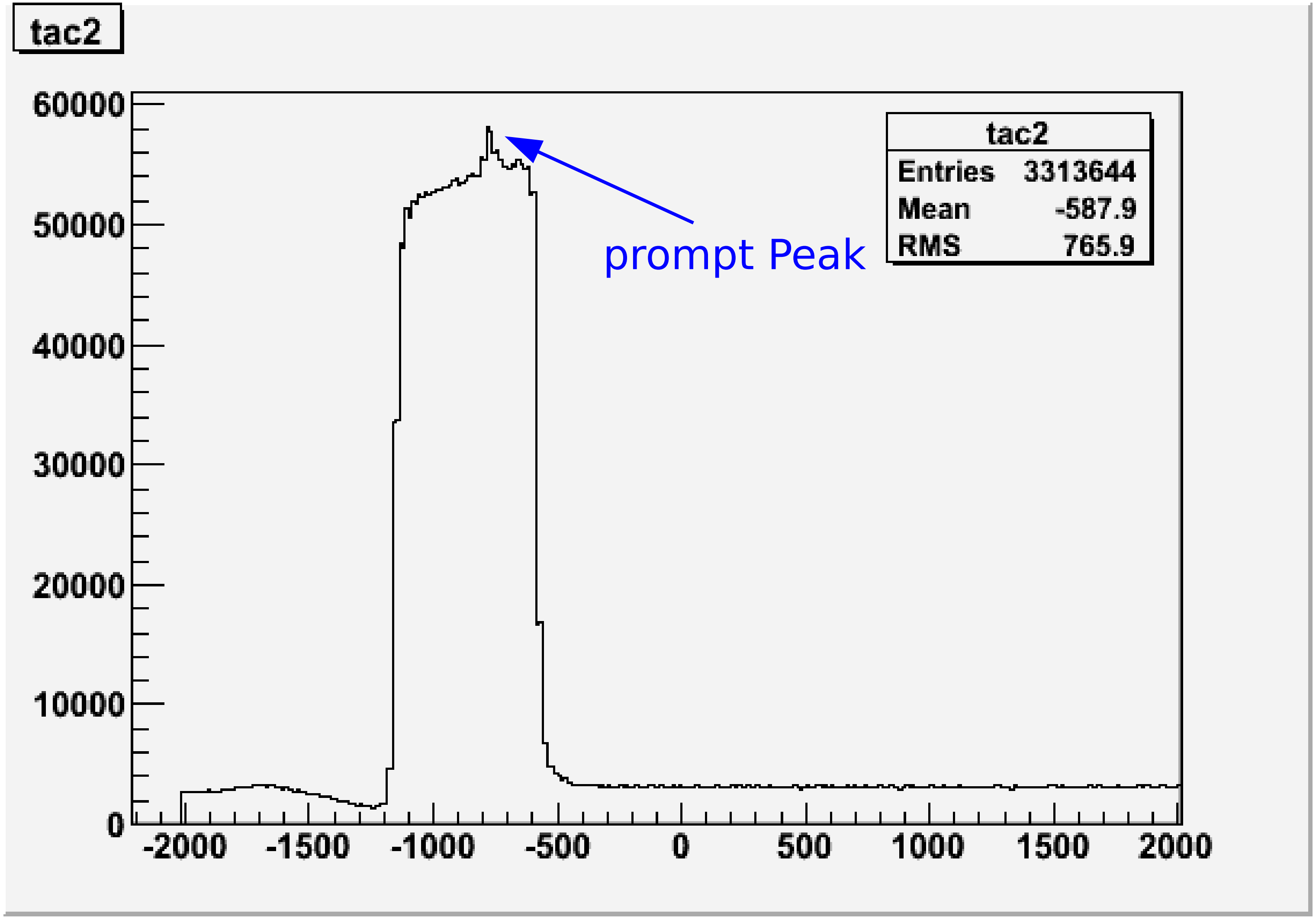
Experiment on $^{(88,92)}$Kr @ REX-ISOLDE

- 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



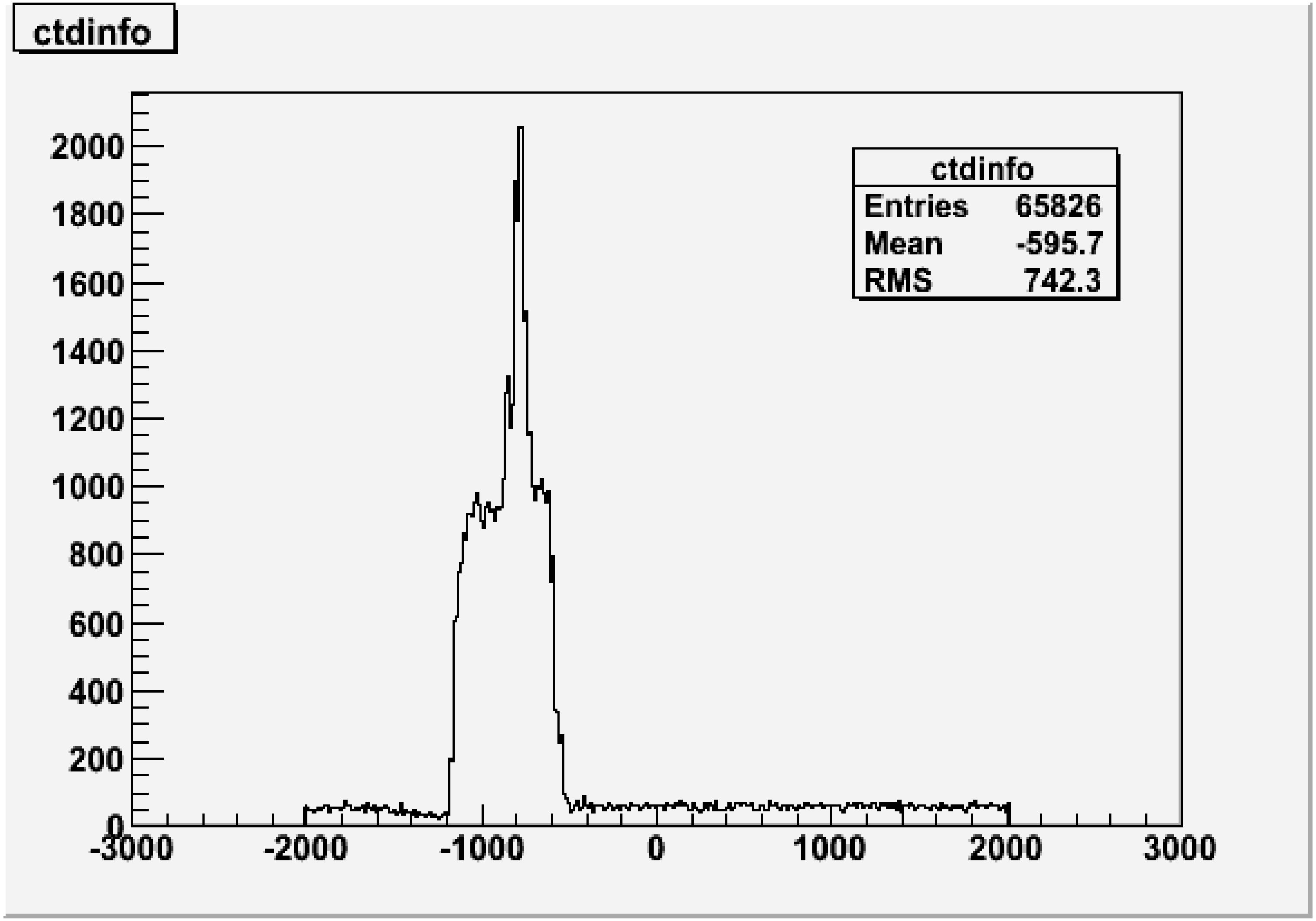


Particle-Gamma Time difference



tac2	
Entries	3313644
Mean	-587.9
RMS	765.9

Particle Gamma Time difference, gate on 2^+_1



Determination of B(E2) values

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

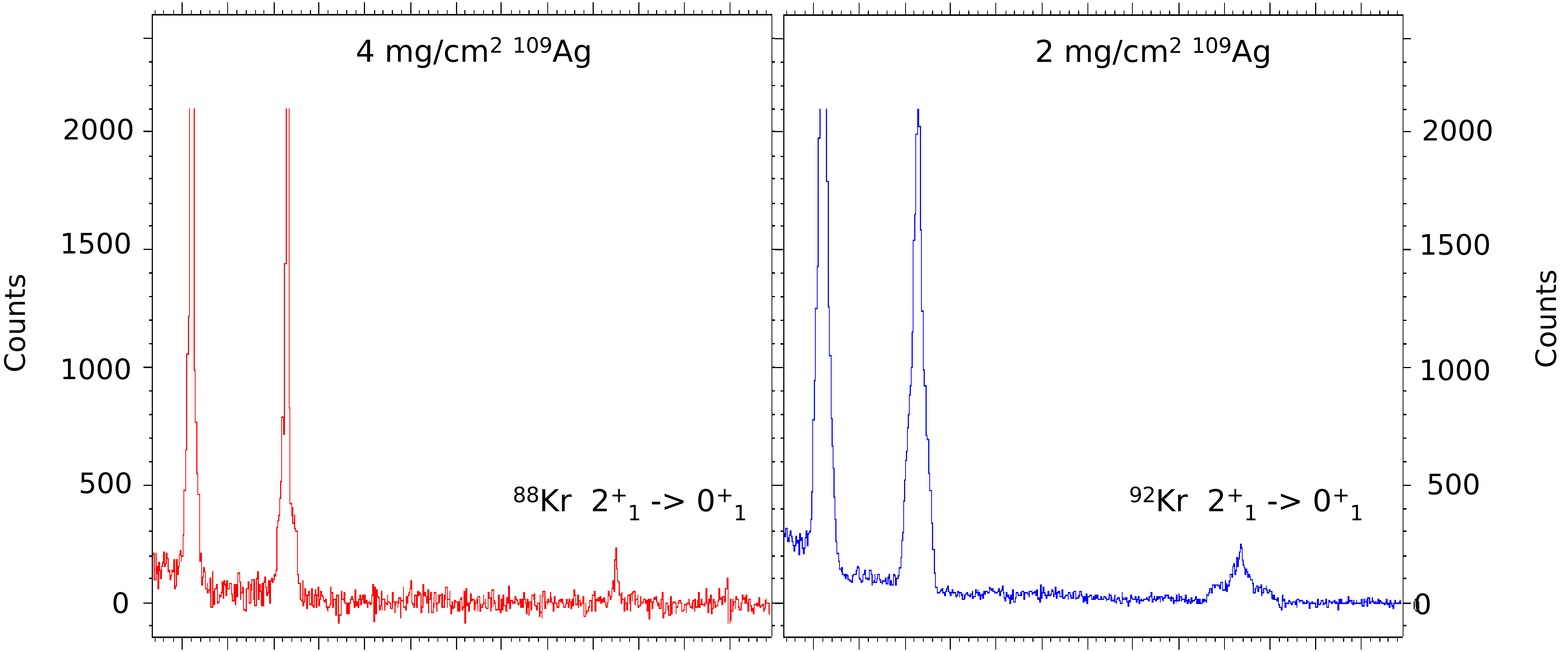
$$\sigma_{E2} = \left(\frac{Z_1 e}{\hbar v}\right)^2 a^{-2} B(E2, I_0 \rightarrow I_f) f_{E2}(\xi)$$

- Experimental method:

$$\sigma_{CE}^{p} = \frac{\epsilon_\gamma^t}{\epsilon_\gamma^p} \cdot \frac{b_\gamma^t}{b_\gamma^p} \cdot \frac{W_\gamma^t}{W_\gamma^p} \cdot \frac{N_\gamma^p}{N_\gamma^t} \cdot \sigma_{CE}^{t}$$

- 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

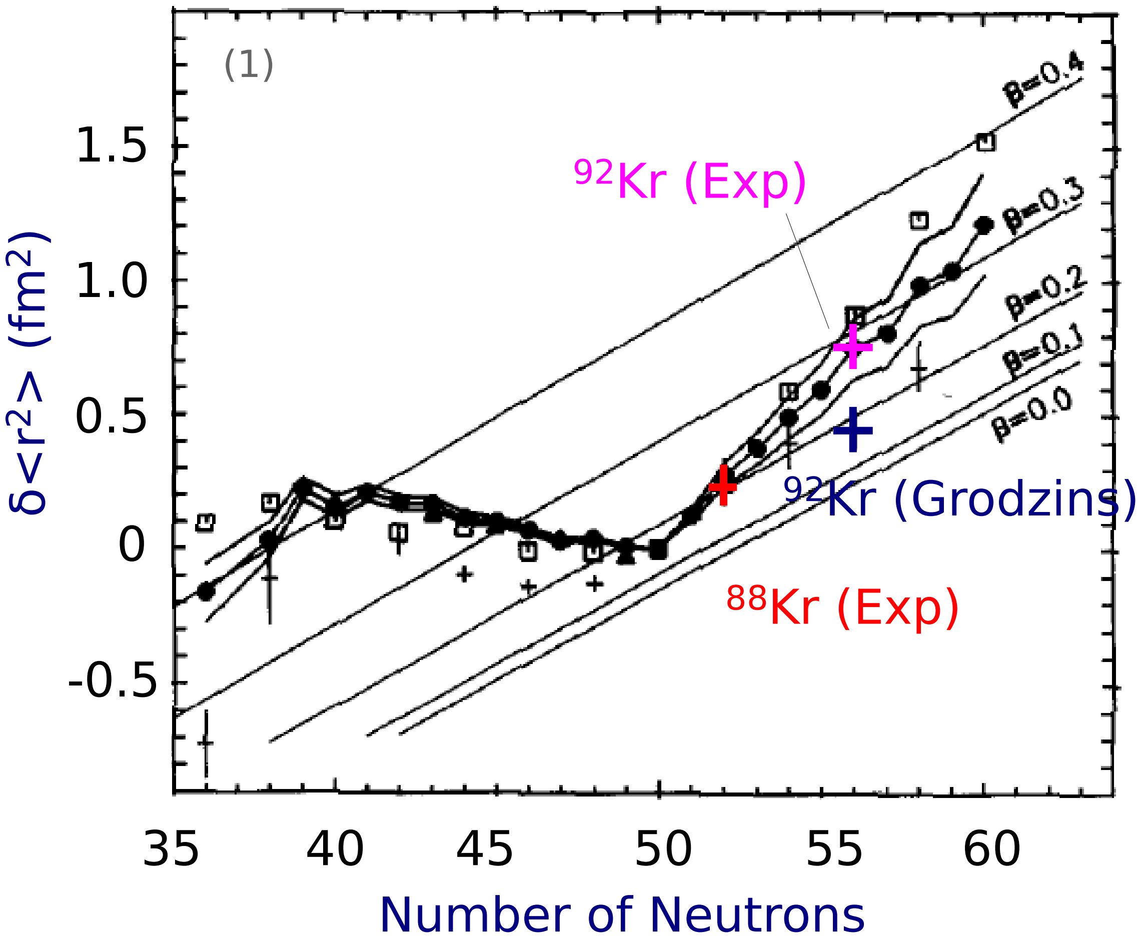


- Energy resolution after Doppler Correction: ~ 8 keV for ^{88}Kr on ^{12}C
- when normalizing to target excitation: A(^{92}Kr,$2^+ \to 0^+$)≈2·A(^{88}Kr,$2^+ \to 0^+$) !!
- Exact calculation (integration over full CD range):

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

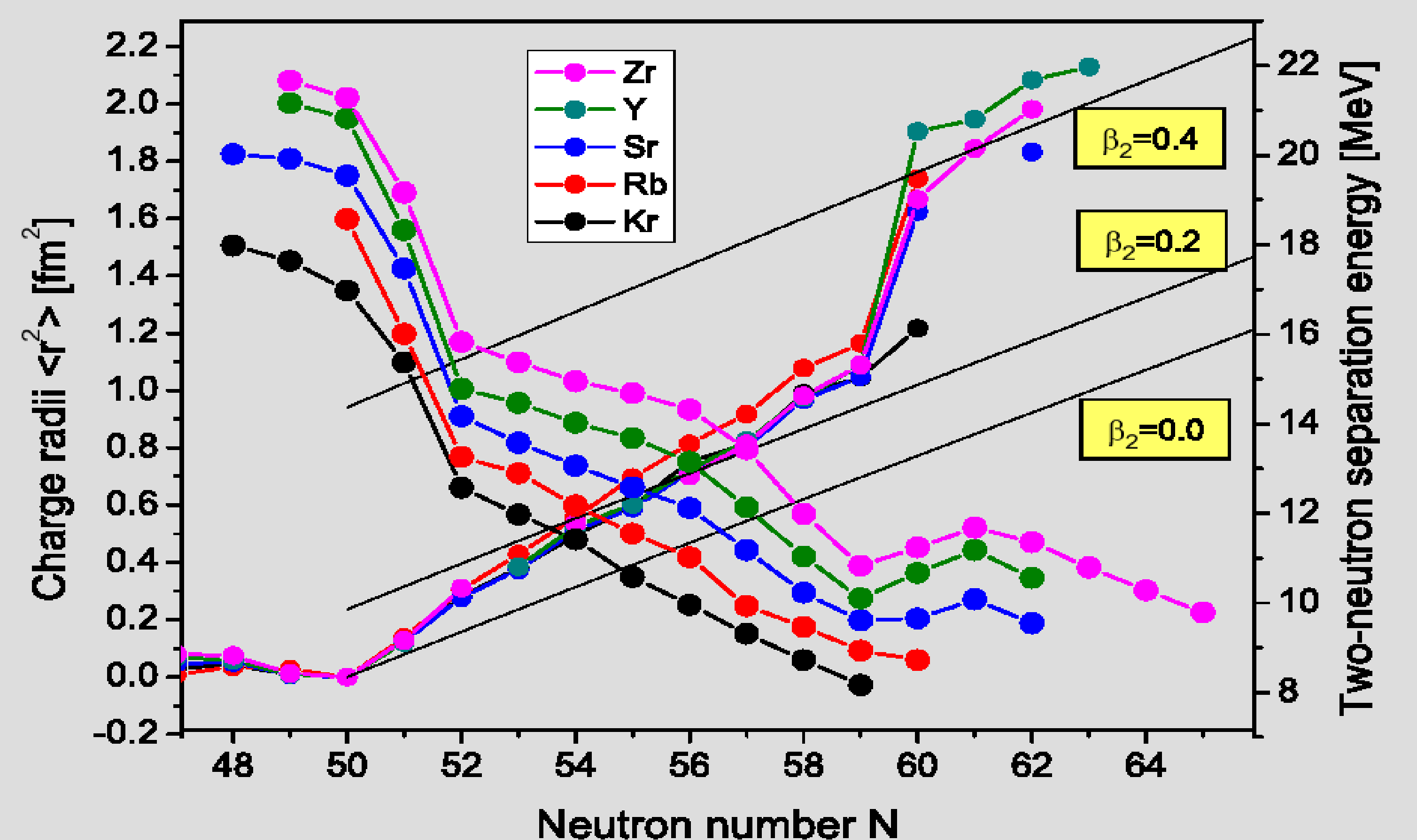
^{92}Kr: B(E2;2^+_1->0^+_1)=16.9(5) W.u.

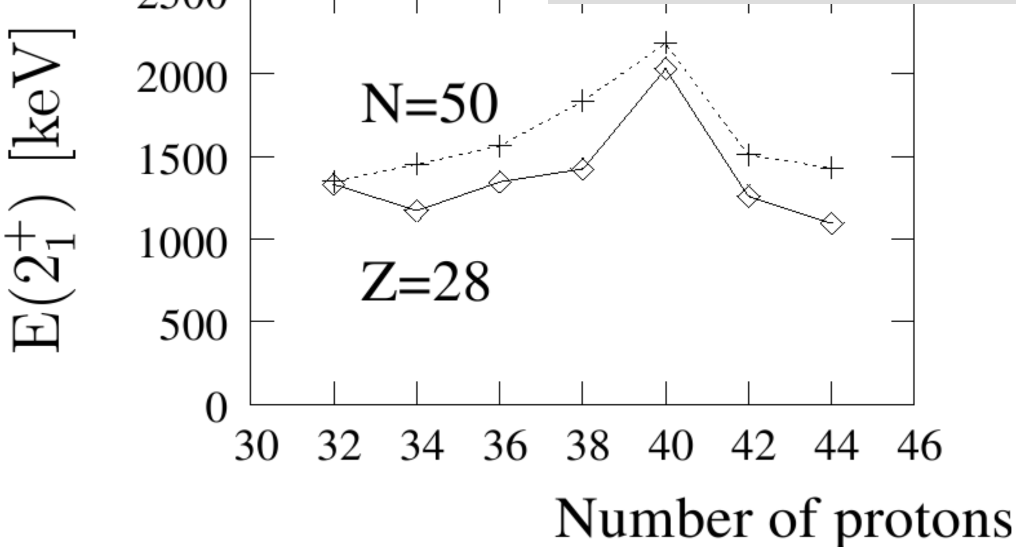
Consequences for nuclear structure in neutron-rich krypton isotopes



- B(E2) values do not follow Grodzins relation!
- Exp. B(E2) value gives new $\delta\langle r^2\rangle$ from liquid drop model and octupole degree of freedom has not to be included
- $E(2^+_1)$ in ^{92}Kr still a mystery, but deformation seems to set in smoothly, so N=56 is not active
- evolution of deformation towards N=60? -> $^{(94,96)}$Kr @Isolde ...

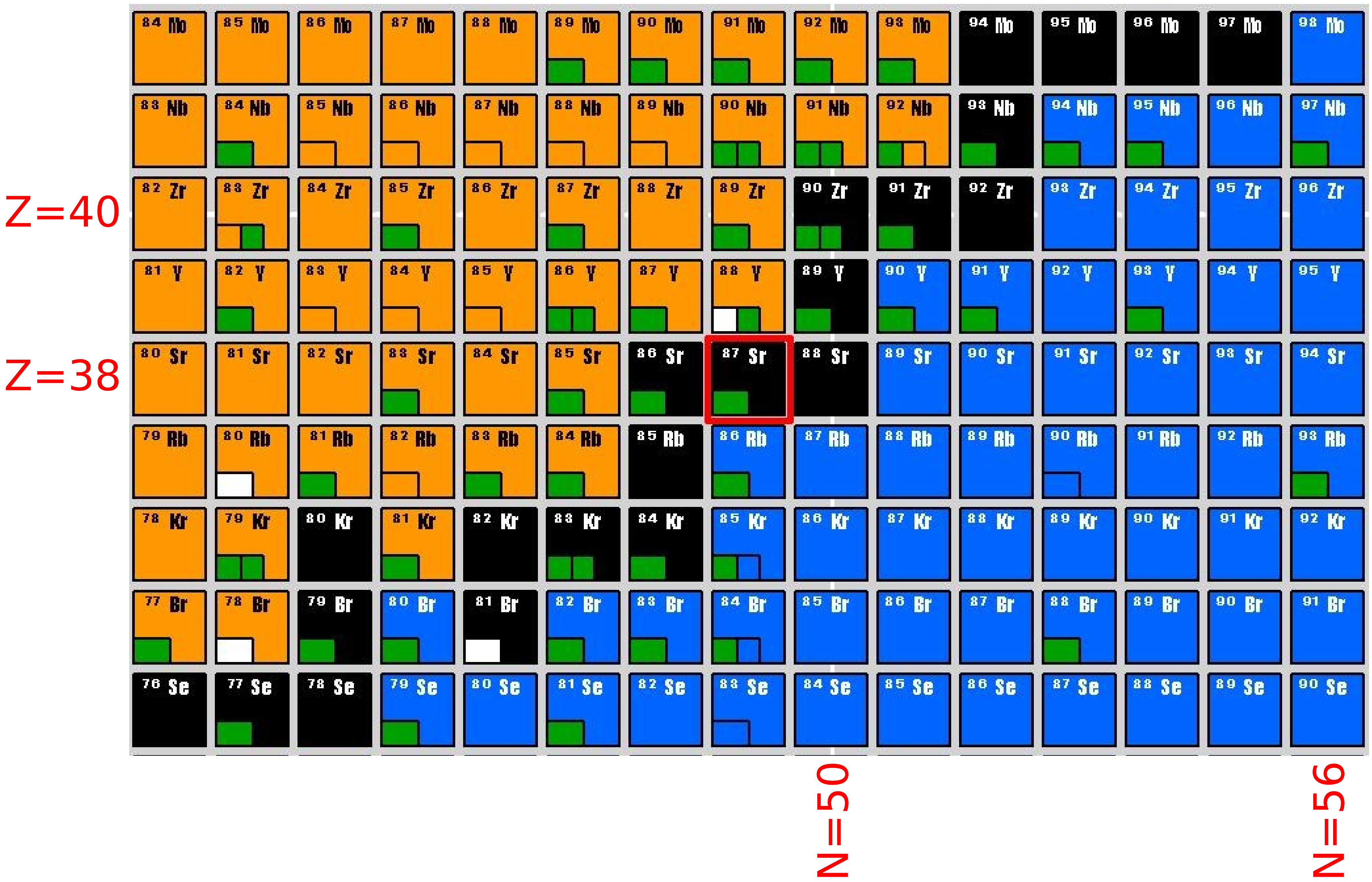
N=56 subshell closure...





Slide from Ari Jokinen

Where we are ....



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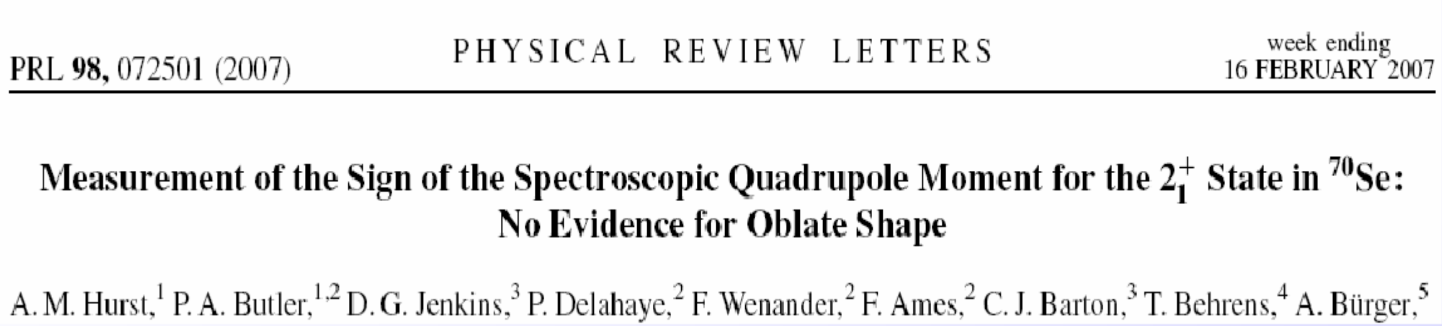
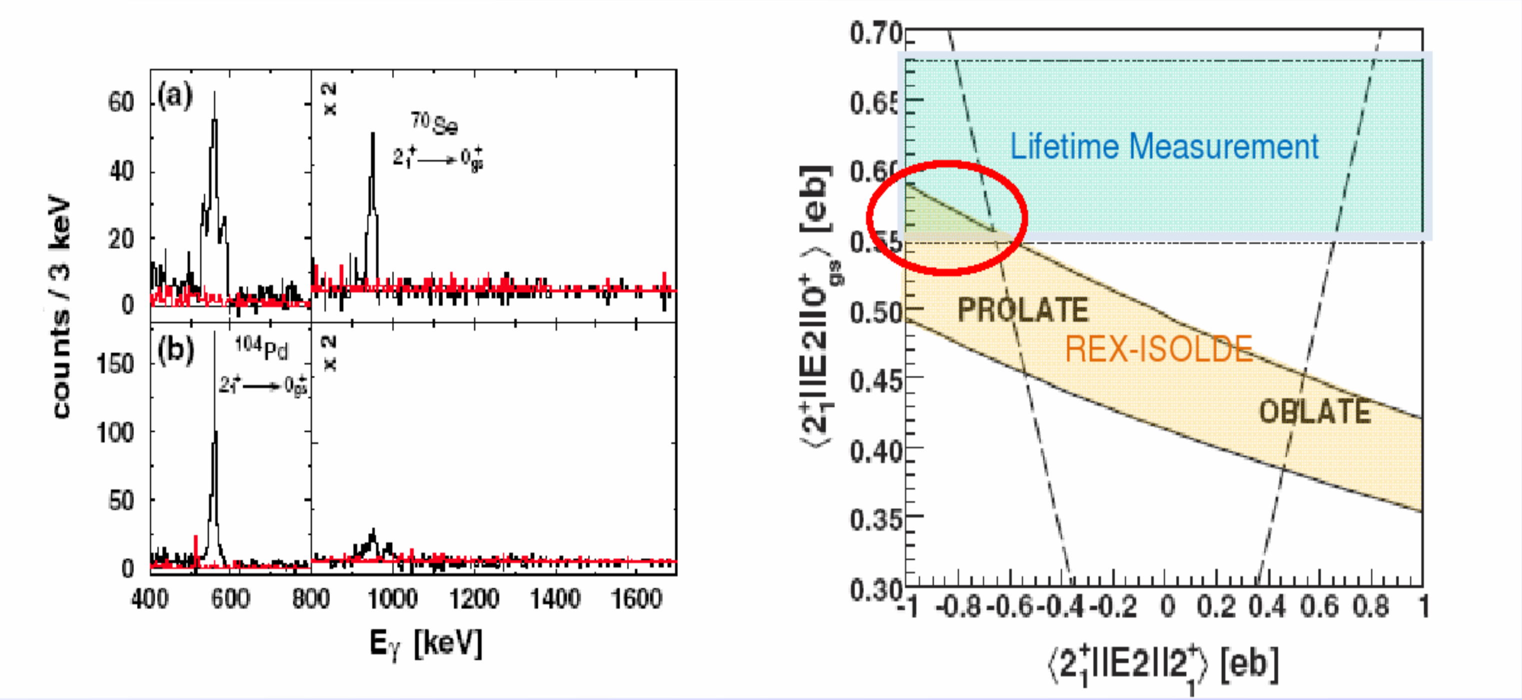
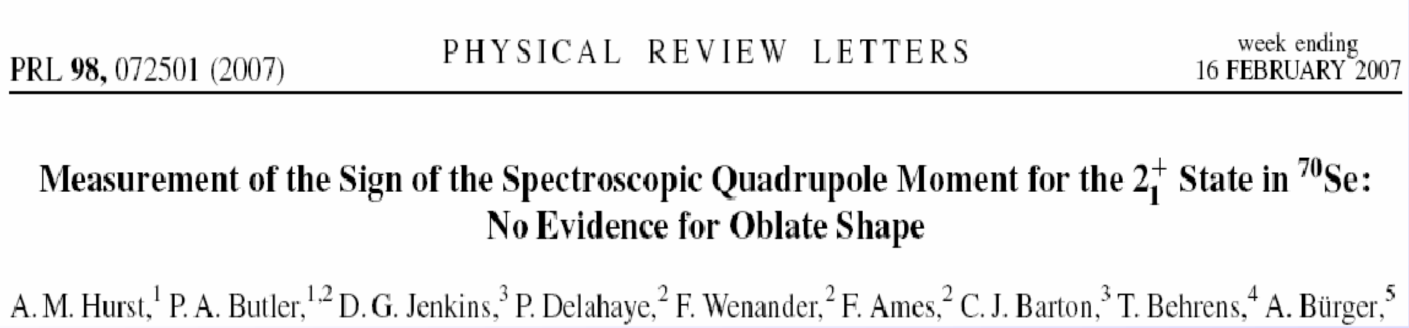


PRL **98,** 072501 (2007) PHYSICAL REVIEW LETTERS week ending 16 FEBRUARY 2007

Measurement of the Sign of the Spectroscopic Quadrupole Moment for the 2_1^+ State in ^{70}Se: No Evidence for Oblate Shape

A. M. Hurst,[1] P. A. Butler,[1,2] D. G. Jenkins,[3] P. Delahaye,[2] F. Wenander,[2] F. Ames,[2] C. J. Barton,[3] T. Behrens,[4] A. Bürger,[5]





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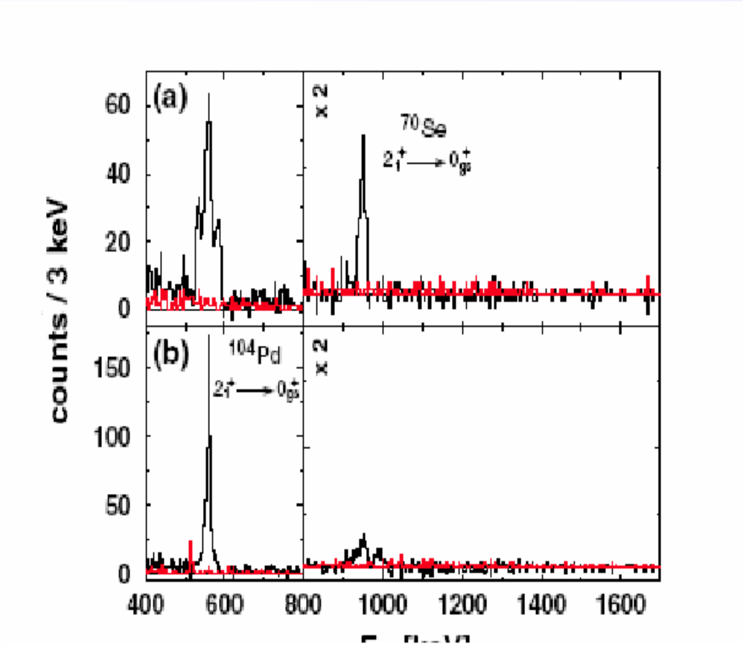

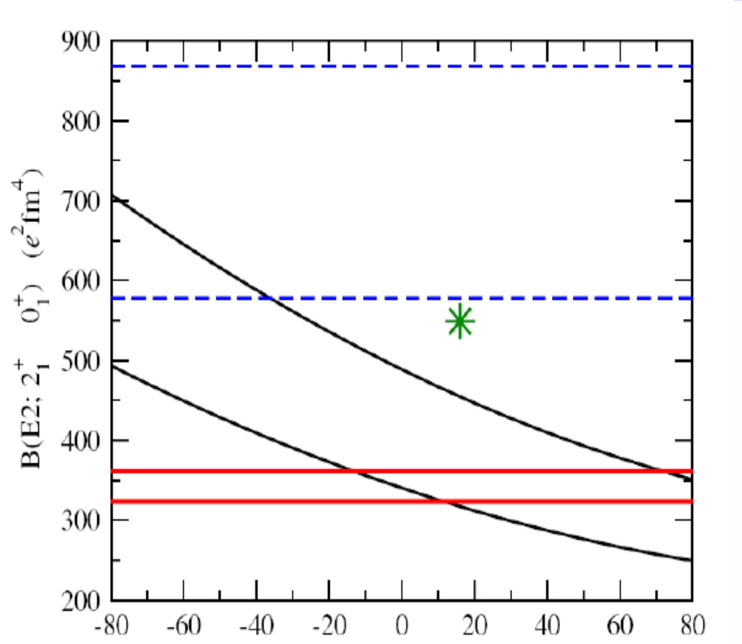

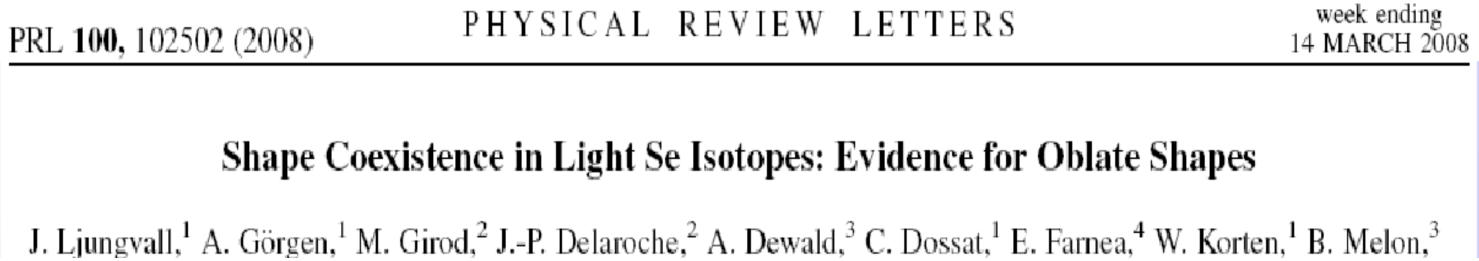

PRL **100,** 102502 (2008) PHYSICAL REVIEW LETTERS week ending 14 MARCH 2008

Shape Coexistence in Light Se Isotopes: Evidence for Oblate Shapes

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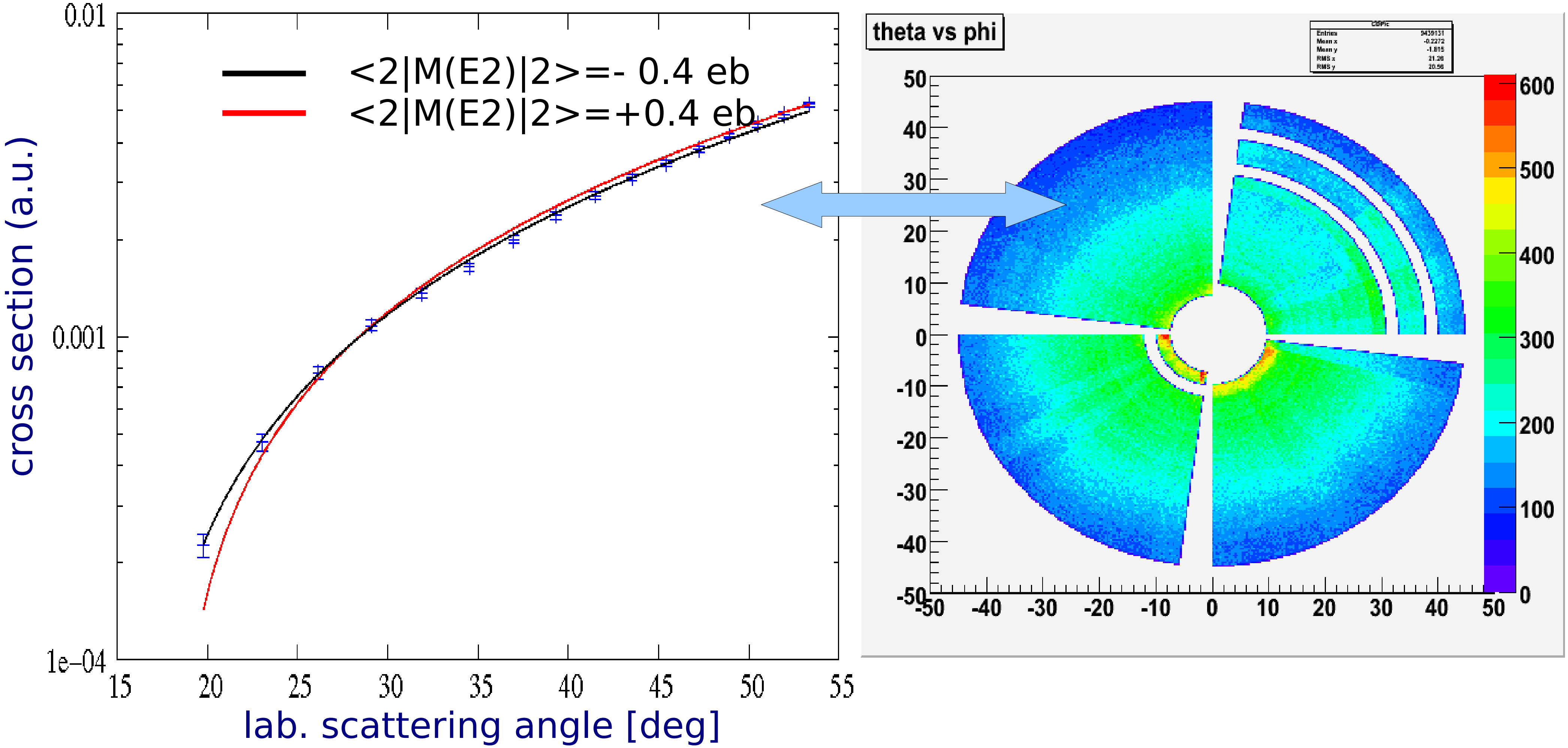
Quadrupole moment of ^{88}Kr

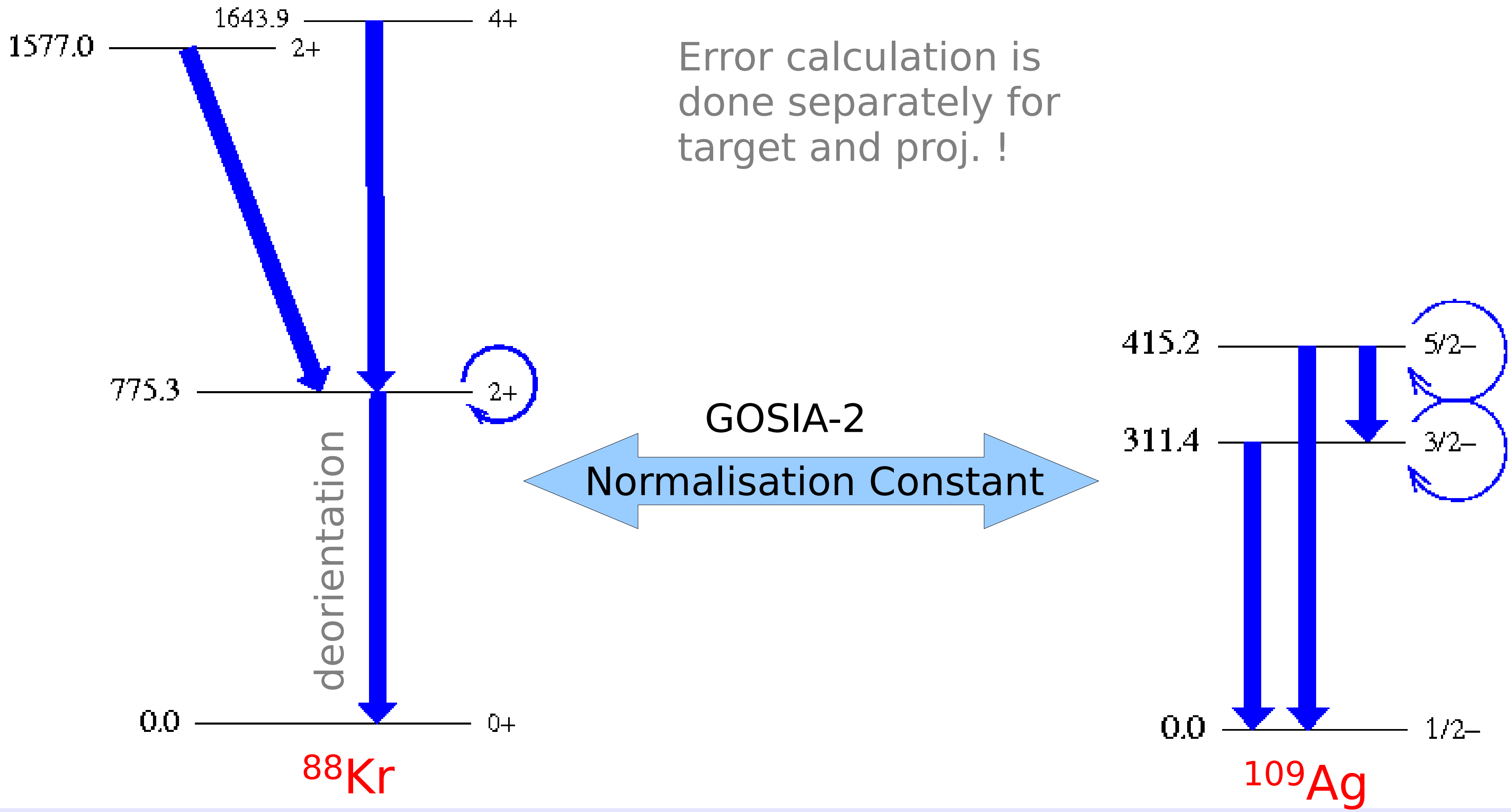


- a negative value for <2|M(E2)|2> fits better to the cross section
- due to defect strips only quater of the full statistics was used so far
- for ^{92}Kr: no separation of Target-and Projectile excitation -> Det. of Q not possible

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

Relative determination of matrix elements in GOSIA

Error calculation is done separately for target and proj. !



- dependencies of matrix elements: Minimization and error calculation with Gosia
- actuell problems: normalization constant can not be fixed and has no error!

  Problems when $A_{proj} > A_{target}$
- for the future: Gosia can make it possible to determine e.g. quadrupole moments without knowing the lifetimes, but we need an upgrade of GOSIA

Summary and outlook

- The nuclear structure of the A=100 region shows a complex interplay between microscopic and macroscopic features: N=50,56 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 $B(E2;2^+_1\text{->}0^+_1)$ 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 might be possible with RIB@Isolde without knowing lifetimes of the projectile, but we need an upgrade of GOSIA for this
- For the future: evolution of deformation towards ^{96}Kr

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Thanks for your attention!