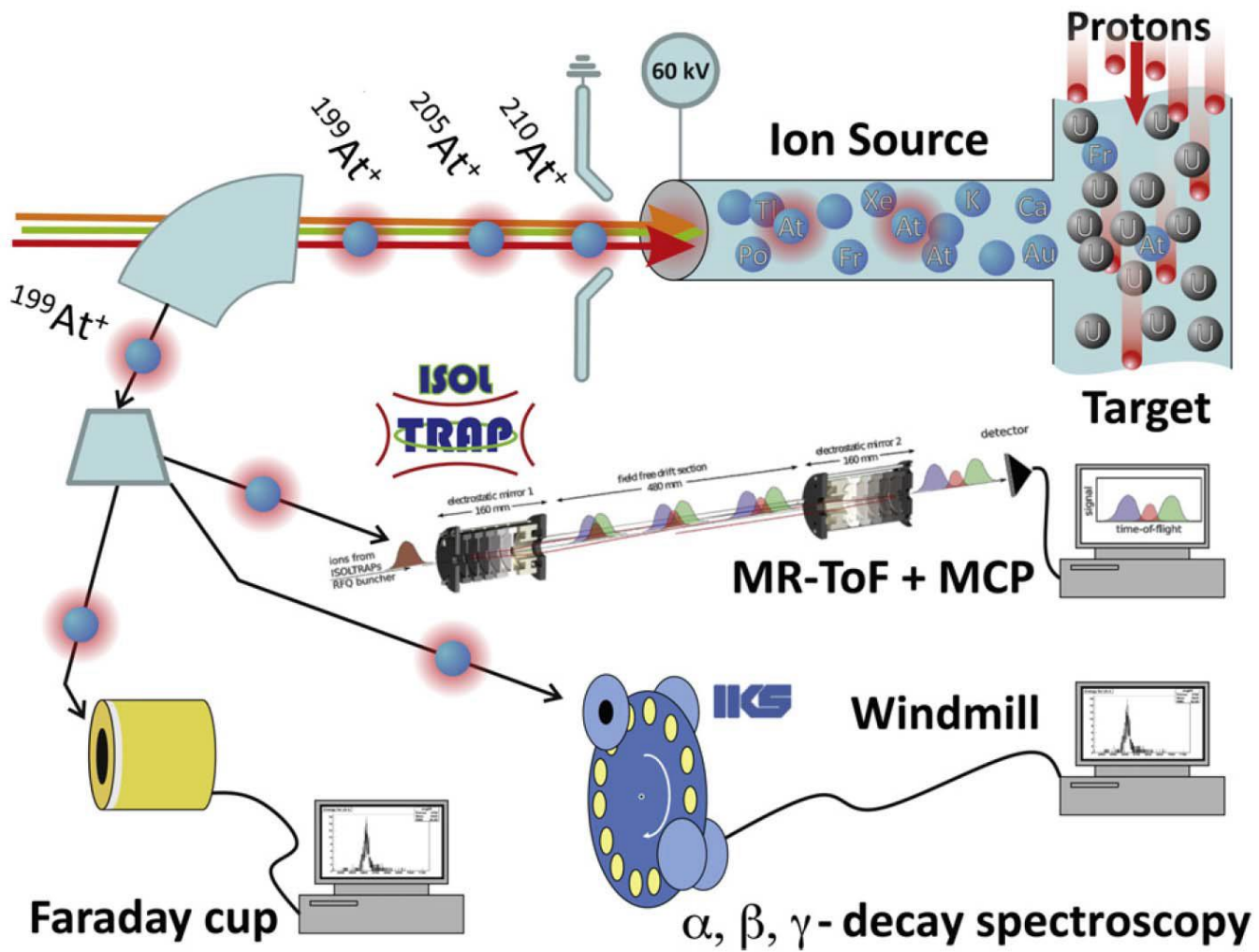
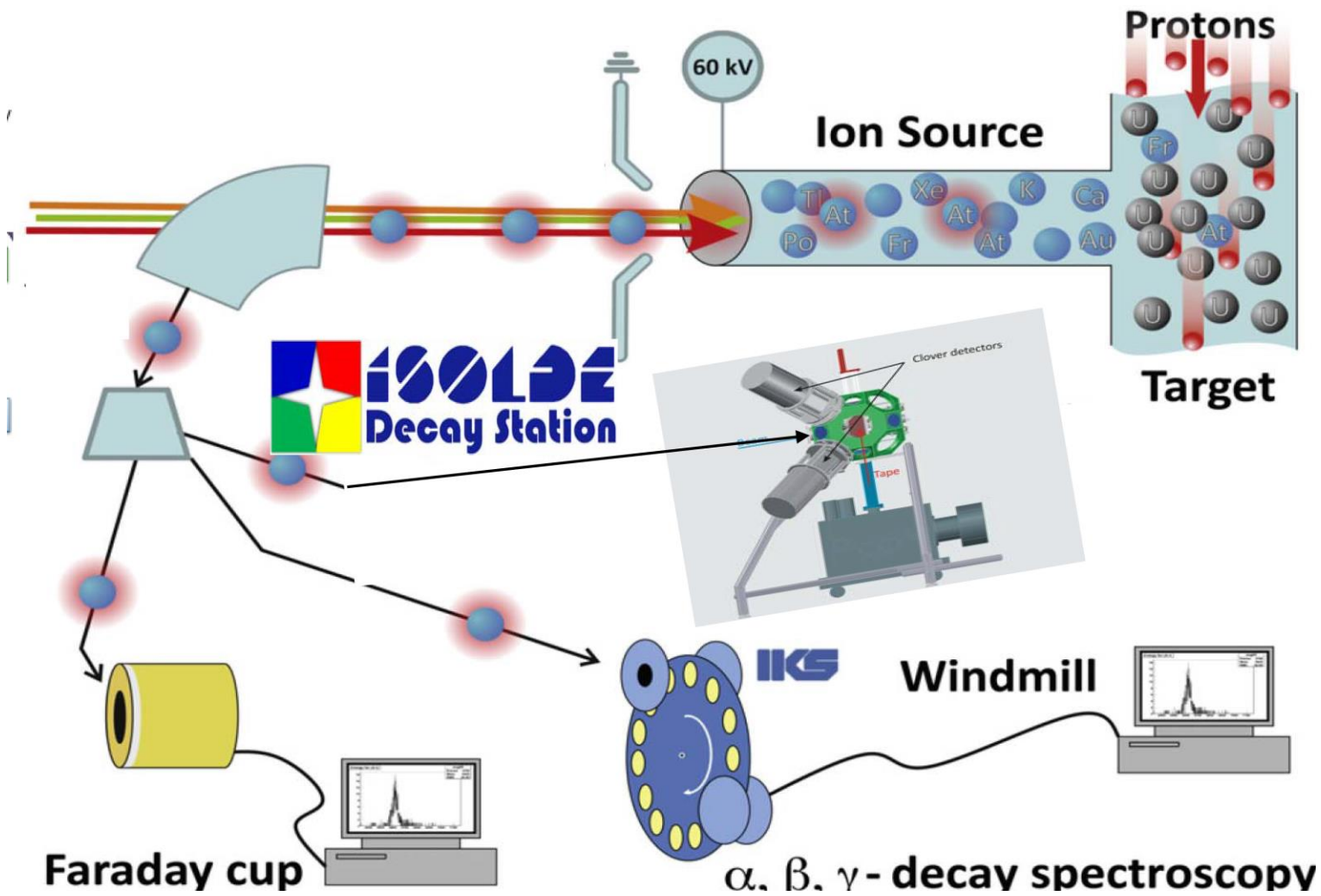


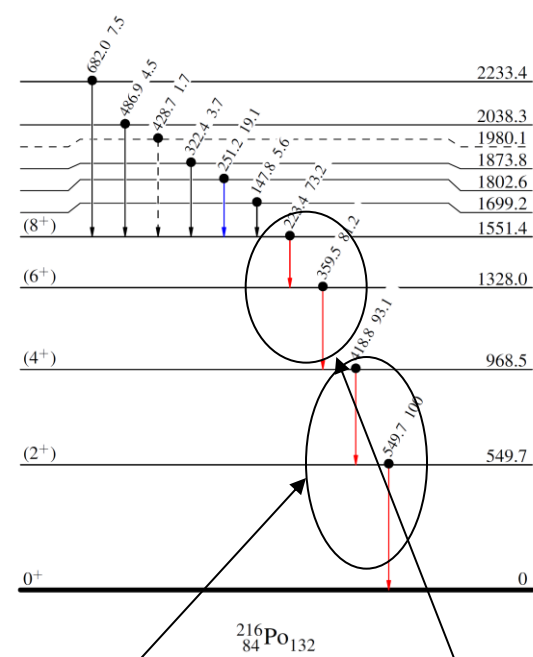
Изотонические зависимости зарядовых радиусов  
и границы области октупольной деформации ядер при  
 $Z > 82$  (CERN; *RILIS-IDS collaboration*)

А. Е. Барзах, П. Л. Молканов, М. Д. Селиверстов, Д. В. Федоров





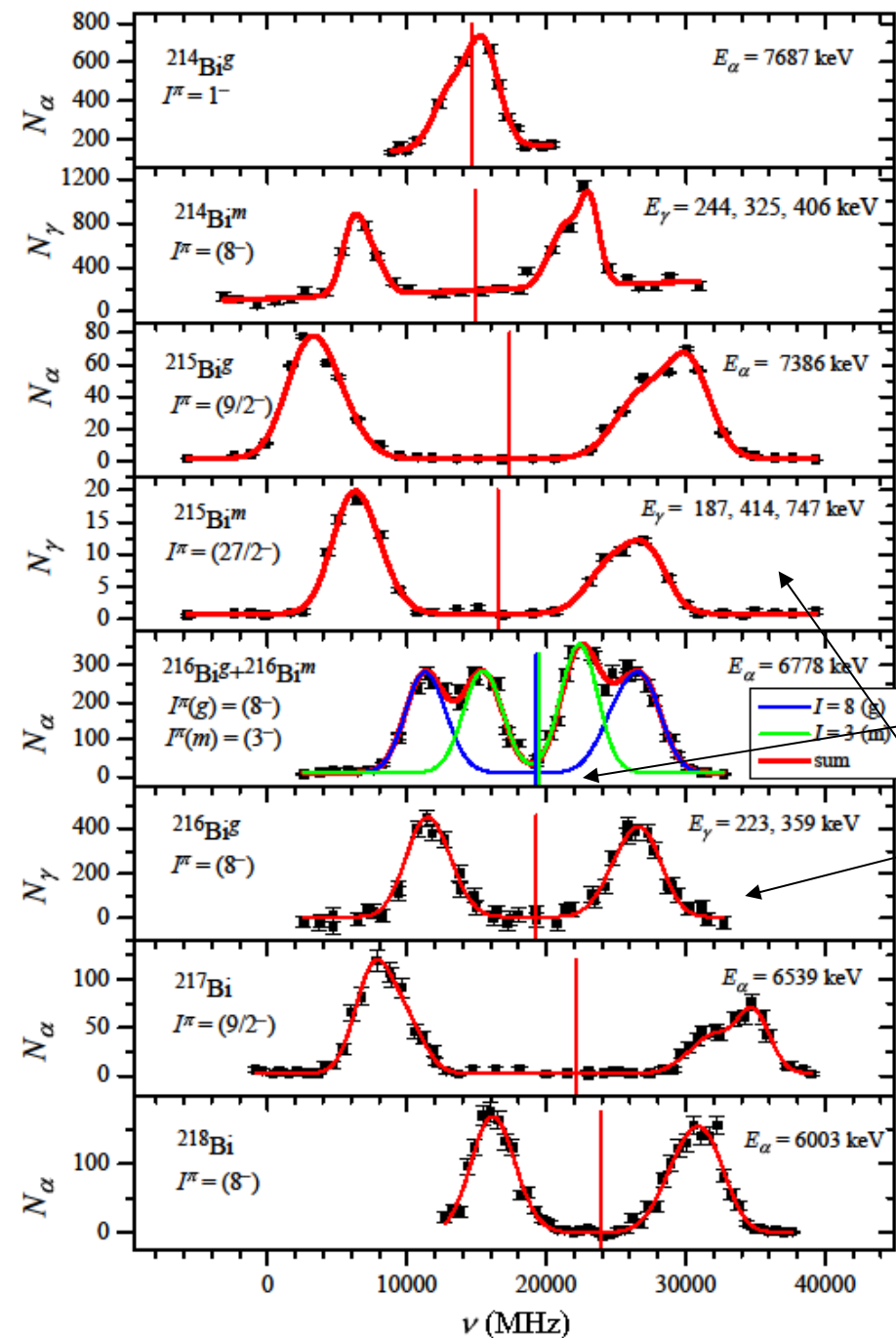
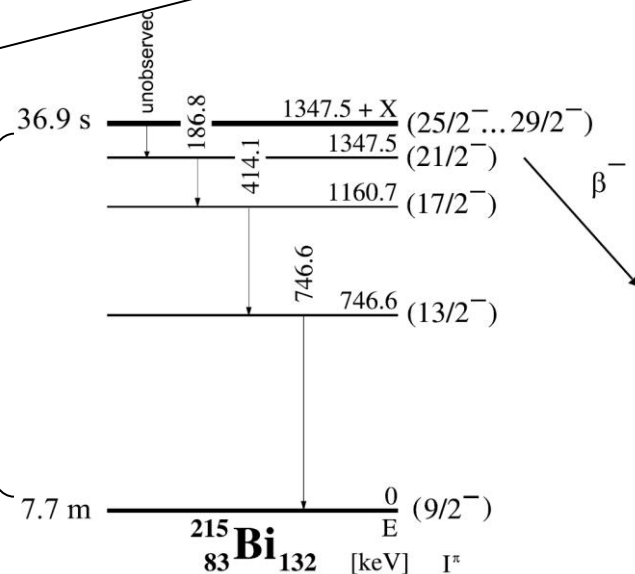
# IDS

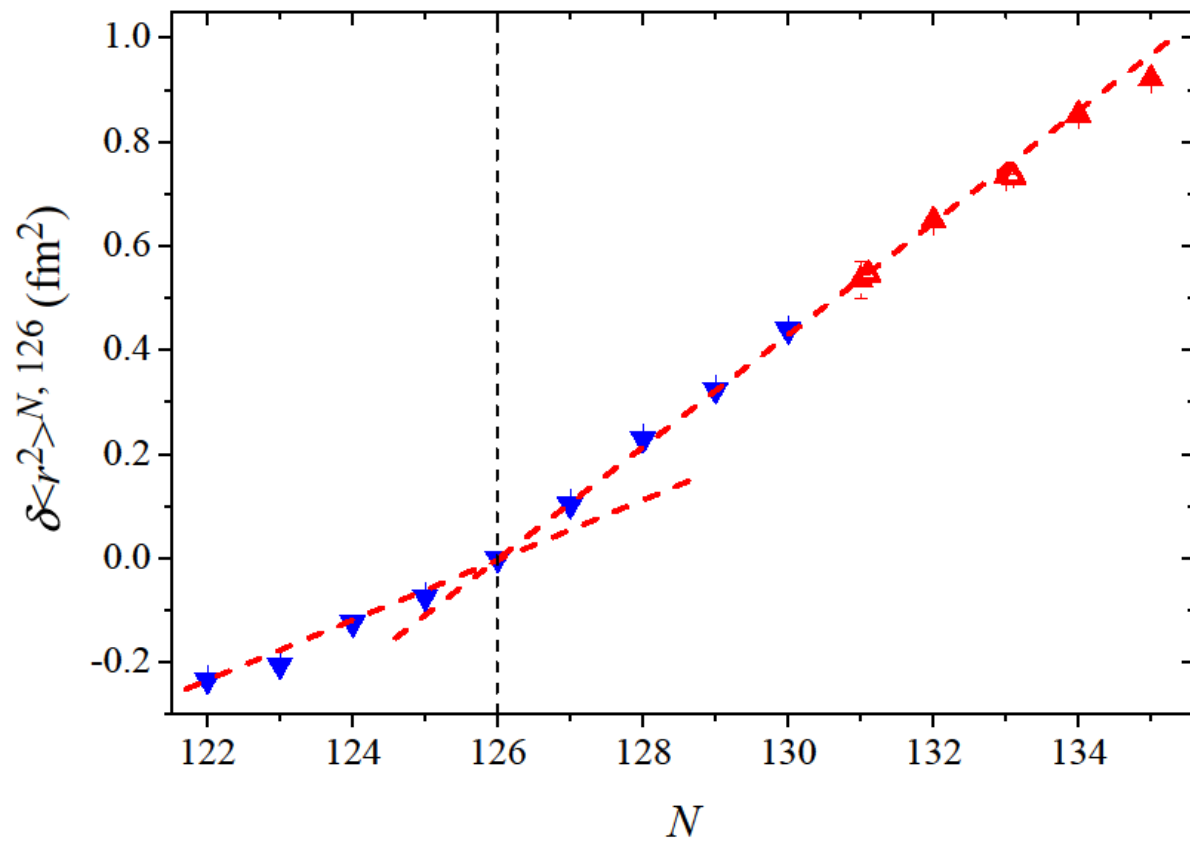


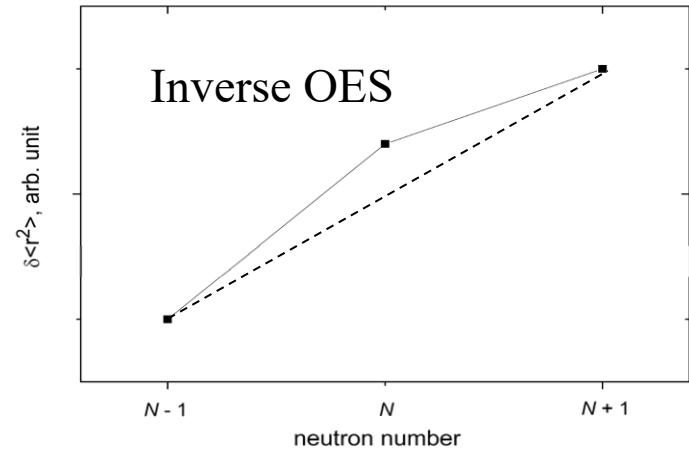
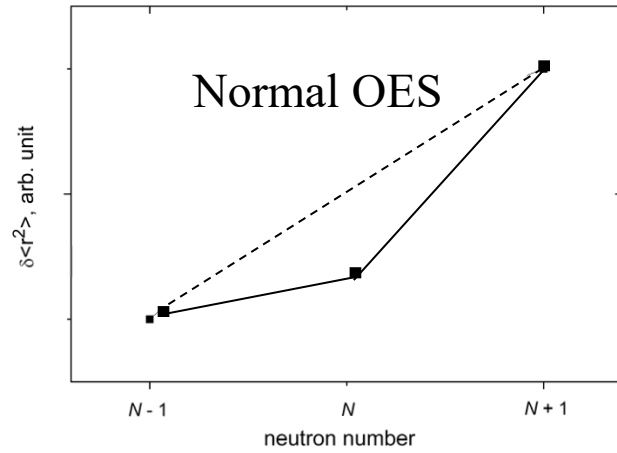
Mixed hs ( $I = 8^-$ ) & ls ( $I = 3^-$ )

Pure hs ( $I = 8^-$ )

Pure isomer  
IT

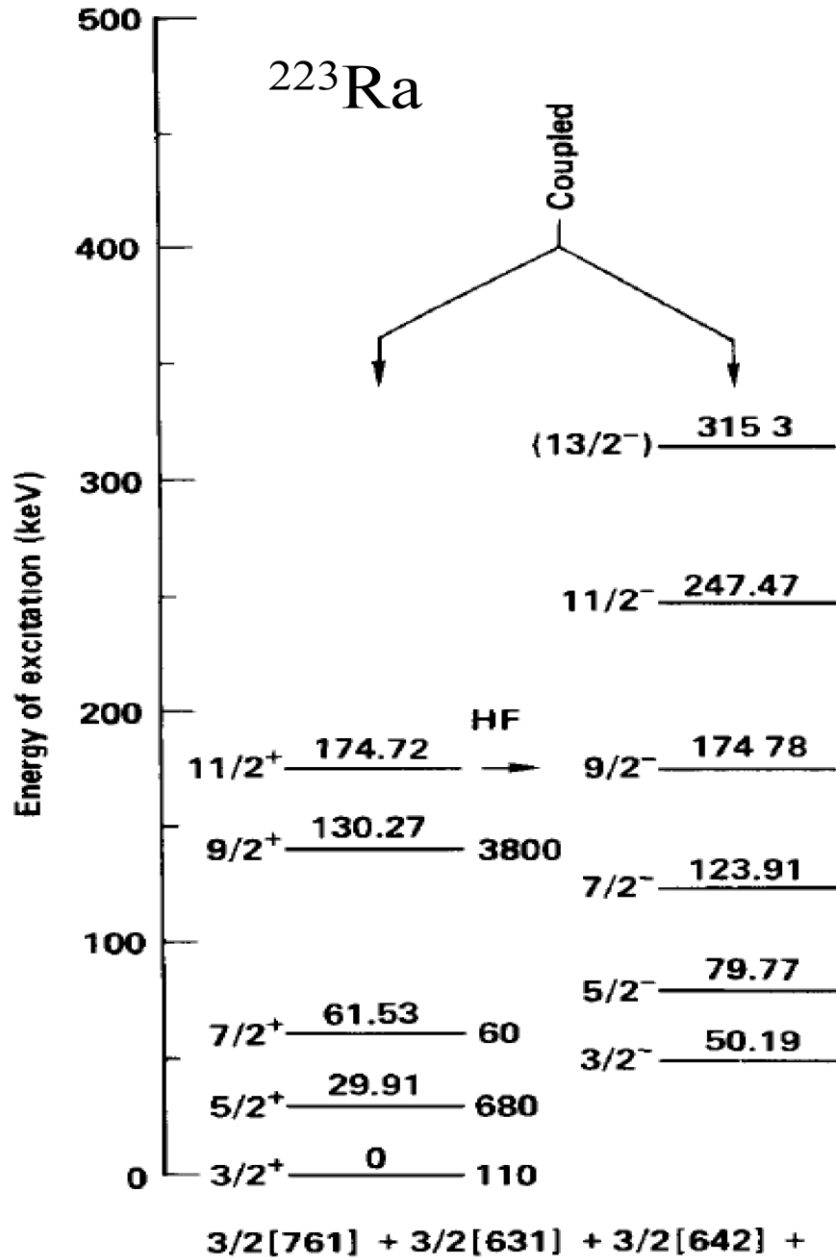




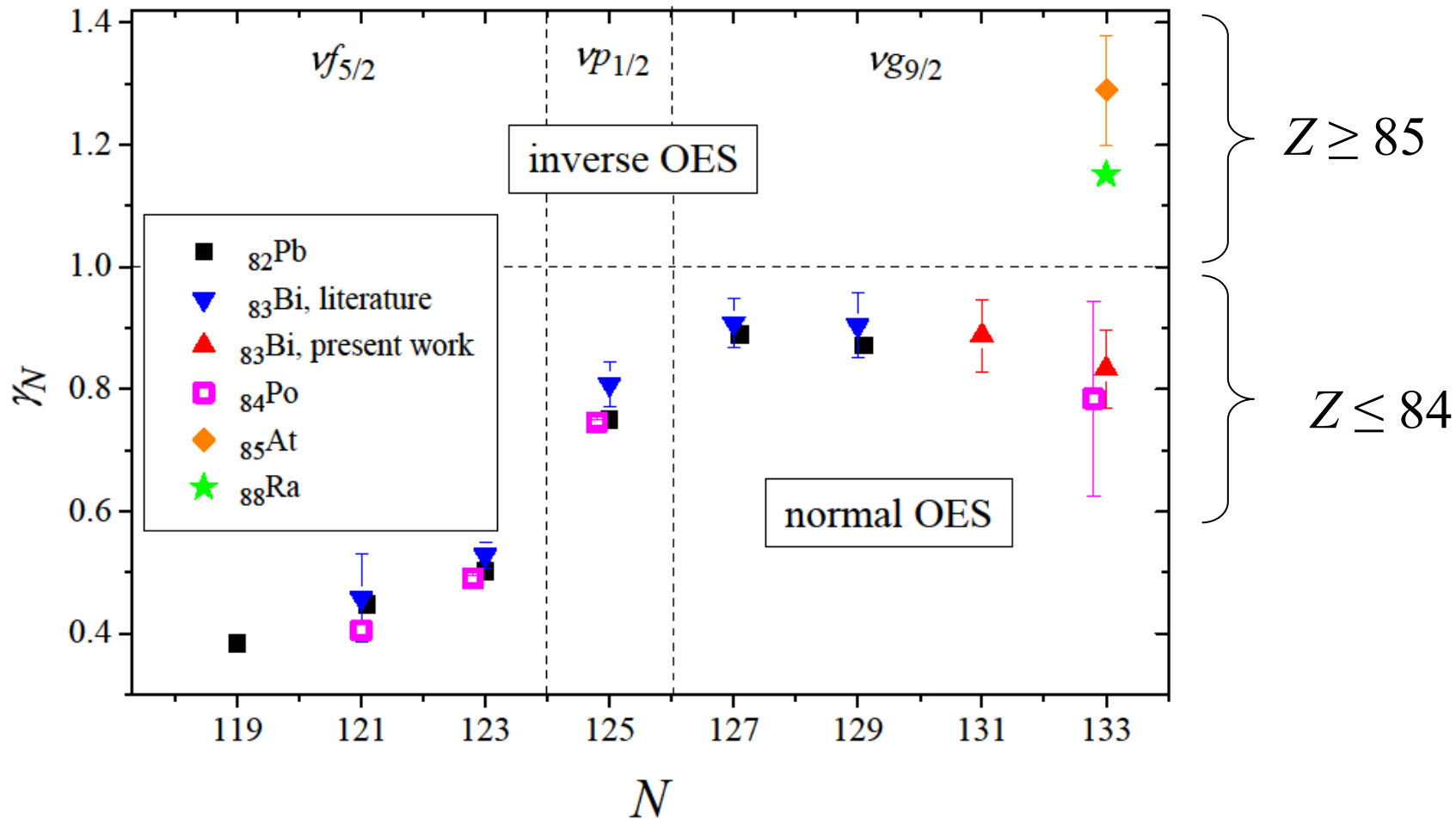


Inverse OES is observed for nuclei where octupole collectivity is expected

# Parity doublets

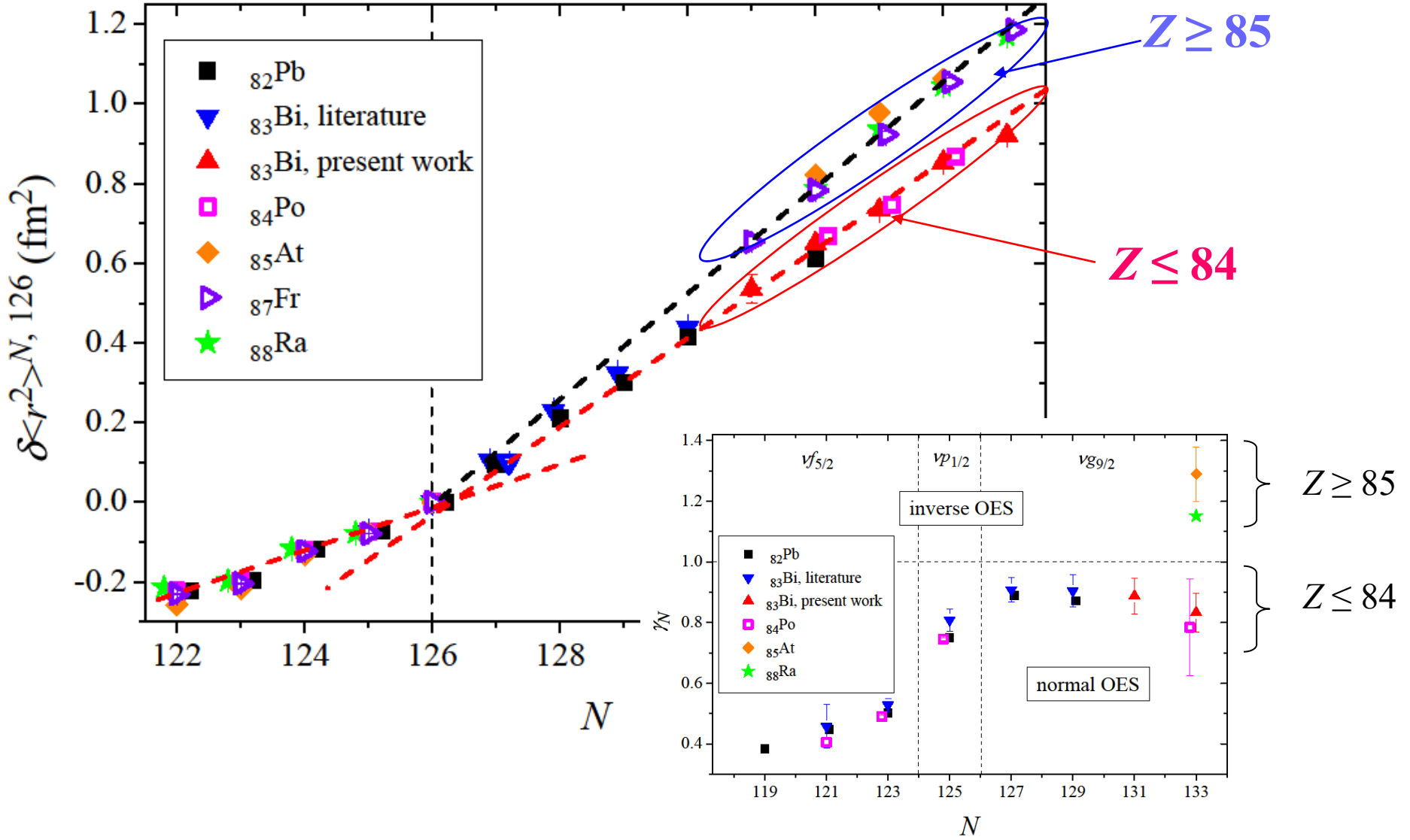


$$\gamma_N = \frac{2\delta\langle r^2 \rangle_{N-1, N}}{\delta\langle r^2 \rangle_{N-1, N+1}} \quad \gamma < 1 \rightarrow \text{normal OES}; \quad \gamma > 1 \rightarrow \text{inverse OES}$$



Possible explanation: increase of  $\beta_3$  for odd-N isotopes in comparison with their even-N neighbors

$$\langle r^2 \rangle = \langle r^2 \rangle_0 \left[ 1 + \frac{5}{4\pi} (\langle \beta_2^2 \rangle + \langle \beta_3^2 \rangle) \right]$$



$$\delta\nu_{A,A'} = \delta\nu_{A,A'}^F + \delta\nu_{A,A'}^M,$$

$$\delta\nu_{A,A'}^F = F\delta\langle r^2 \rangle_{A,A'},$$

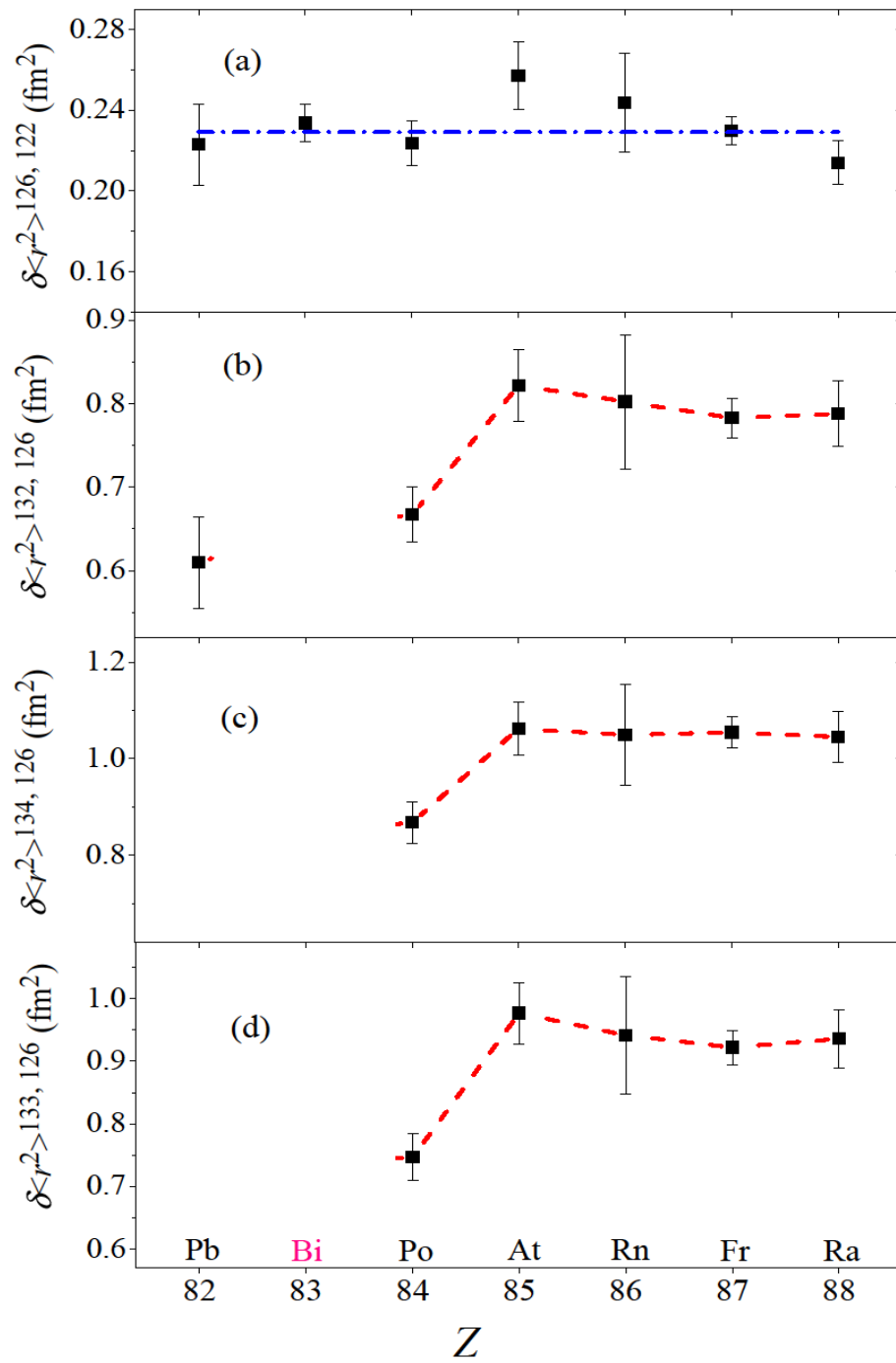
$$\delta\nu_{A,A'}^M = \frac{M(A - A')}{AA'},$$

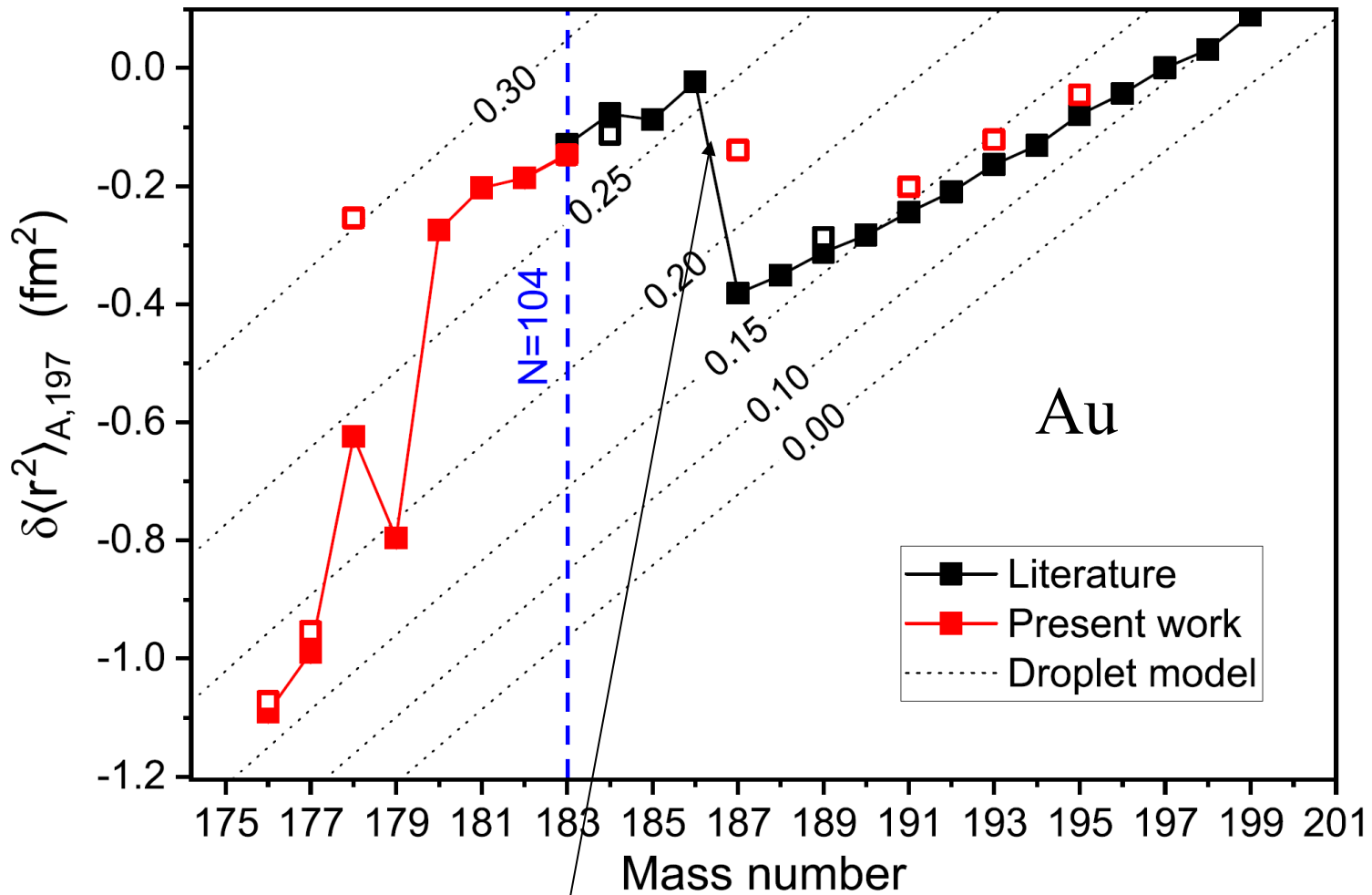
| $Z$ | $\lambda(\text{nm})$ | $F(\text{GHz fm}^{-2})$ | Uncertainty of $\delta\langle r^2 \rangle$ (%) | Ref.    |
|-----|----------------------|-------------------------|--|---------|
| 82  | 283                  | 20.3                    | 9  | [51,58] |
| 83  | 307                  | 23.8                    | 5  | [32]    |
| 84  | 843                  | -12.8                   | 5  | [52,53] |
| 85  | 795                  | -11.6                   | 5  | [54]    |
| 86  | 745                  | -19.2 <sup>a</sup>      | 10   |         |
| 87  | 718                  | -20.8                   | 3  | [55,56] |
| 88  | 468                  | -39.8                   | 5  | [57]    |

<sup>a</sup>Corrected semiempirical  $F$  factor from Refs. [15,18] (see Appendix B for details).

Semiempirical Goudsmit-Fermi-Segre method or/and single-electron approximation for hfs constant in s atomic states give for Rn  $F = -22.1 \text{ GHz/fm}^2$ . Correction 15(10)%.

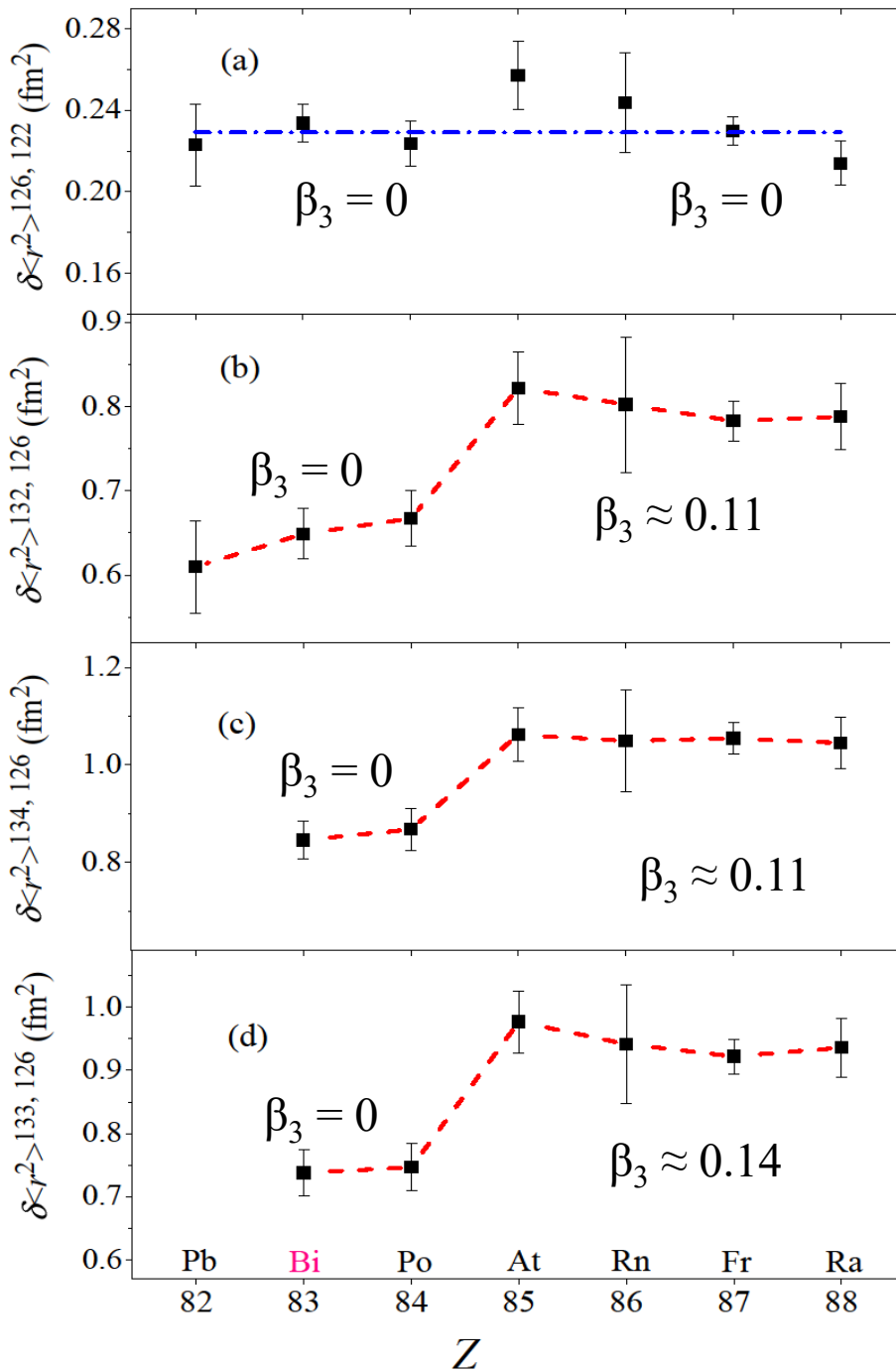
$F$  factor for Po was corrected to avoid double counting of higher moments contribution. Correction 7%.





Jump in isotopic dependency is explained by the jump in quadrupole deformation  $\beta_2$  (from 0.15 to 0.25)

$$\langle r^2 \rangle = \langle r^2 \rangle_0 \left[ 1 + \frac{5}{4\pi} (\langle \beta_2^2 \rangle + \langle \beta_3^2 \rangle) \right]$$



Jump at  $Z_1=85, Z_2=84$ :

$$J_{132}(\text{expt}) = 0.16(5) \text{ fm}^2$$

$$J_{133}(\text{expt}) = 0.23(6) \text{ fm}^2$$

$$\beta_3(126) = 0, \quad \beta_3(132) \approx \text{const} = 0.11$$

$$J_{132} = \delta\langle r^2 \rangle_{132,126}(Z_1) - \delta\langle r^2 \rangle_{132,126}(Z_2) = \frac{5}{4\pi} \langle r^2 \rangle \left( \delta\langle \beta_3^2 \rangle_{132,126}(Z_1) - \delta\langle \beta_3^2 \rangle_{132,126}(Z_2) \right) =$$

$$0.16 \text{ fm}^2$$

$$\beta_3(126) = 0, \quad \beta_3(133) = 0.14$$

$$J_{133} = J_{133}(\text{expt}) = 0.23(6) \text{ fm}^2$$

The parity doublets are experimentally found to be more closely spaced in the odd nuclei than in their even neighbours.  $\implies$

$\beta_3(\text{odd}) > \beta_3(\text{even}) \implies$  inverse OES

These values are compatible with the  $\beta_3$  value ( $\beta_3 = 0.10$ ) ascribed to the odd- $A$  Rn, Fr, Ra, Ac, and Th isotopes with  $131 \leq N \leq 140$ :

G. A. Leander and Y. S. Chen, Phys. Rev. C **37**, 2744 (1988)

In the framework of the macroscopic-microscopic calculations, similar values ( $|\beta_3| = 0.12\text{--}0.13$ ) were predicted in the region  $131 \leq N \leq 136$  and  $85 \leq Z \leq 88$ :

P. Möller et al., At. Data Nucl. Data Tables **94**, 758 (2008)

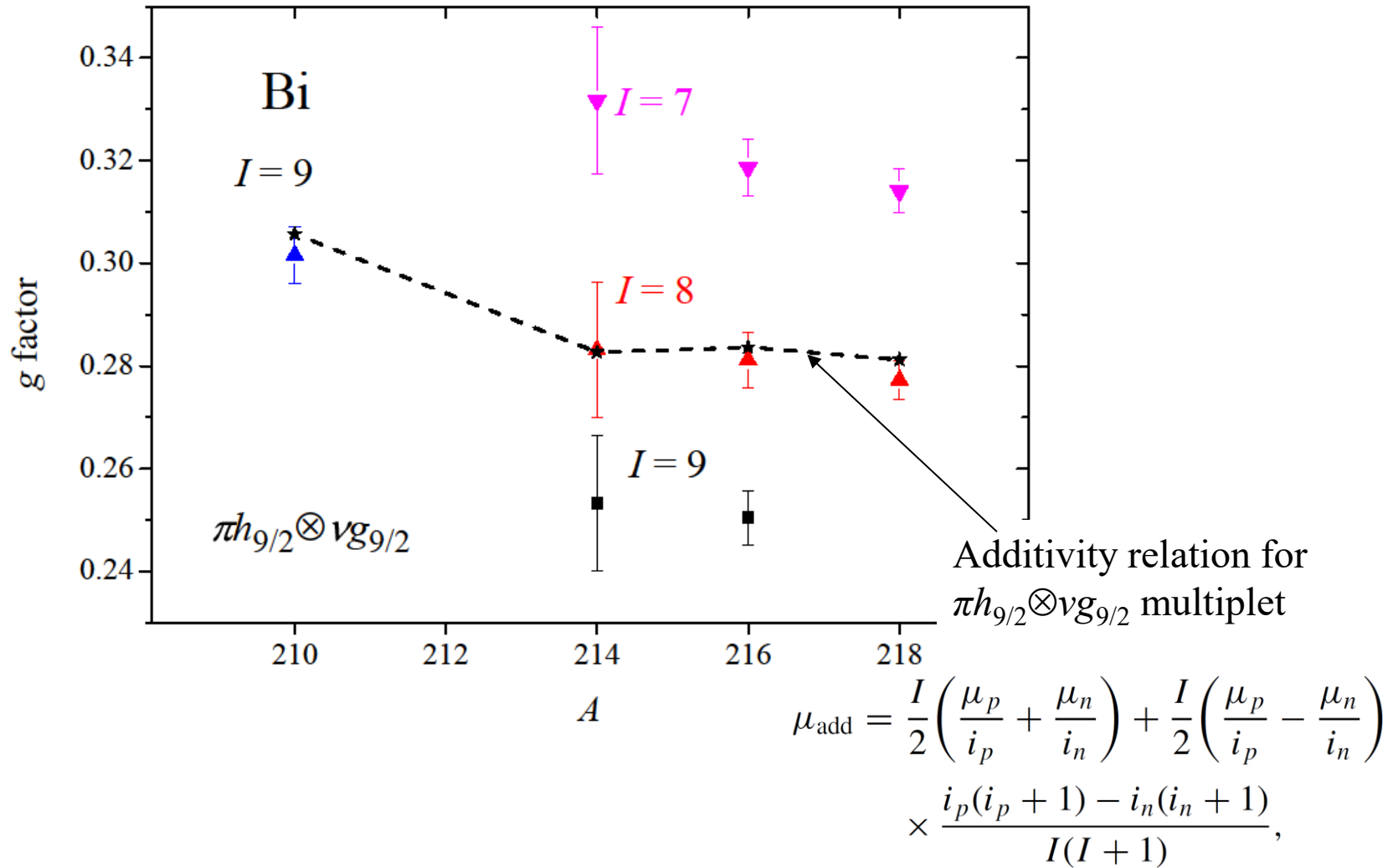
P. Möller et al., At. Data Nucl. Data Tables **59**, 185 (1995).

Recent calculations with five Skyrme energy-density functionals also predict  $\beta_3 \approx 0.10$  for radium and radon isotopes with  $N = 132$  and  $134$ :

Y. Cao, S. E. Agbemava, A. V. Afanasjev, W. Nazarewicz, and E. Olsen, Phys. Rev. C **102**, 024311 (2020).

In all these calculations/analysis  $\beta_3 \approx \text{const}$  at  $N = 131\text{--}137$ . This constancy is confirmed by isotone dependencies.

# $\mu$ for hs states in odd-odd Bi nuclei ( $^{214}\text{Bi}^m, ^{216}, ^{218}\text{Bi}^g$ )



| A                                  | N   | $I^\pi$ | $\mu_{\text{expt}}(\mu_N)$ | $\mu_{\text{add}}(\mu_N)$   |                              |                              |
|------------------------------------|-----|---------|----------------------------|-----------------------------|------------------------------|------------------------------|
|                                    |     |         |                            | $ph_{9/2} \otimes ng_{9/2}$ | $ph_{9/2} \otimes ni_{11/2}$ | $pi_{11/2} \otimes ng_{9/2}$ |
| <b><math>^{83}\text{Bi}</math></b> |     |         |                            |                             |                              |                              |
| 214                                | 131 | $8^-$   | 2.25(12)                   | 2.26                        |                              |                              |
| 216g                               | 133 | $8^-$   | 2.25(6)                    | 2.27                        |                              |                              |
| 216m                               | 133 | $3^-$   | 0.98(3)                    | 0.87                        |                              |                              |
| <b><math>^{85}\text{At}</math></b> |     |         |                            |                             |                              |                              |
| 216                                | 133 | $3^-$   | 1.25(12)                   | 0.87                        | 0.6                          |                              |
| 216                                | 133 | $3^+$   | 1.25(12)                   |                             |                              | 6.1                          |

## Isomer shift

214m-g 0.006(15) fm<sup>2</sup>

216m-g 0.007(8) fm<sup>2</sup>

Zero isomer shift supports inference on the same (pure) configuration (from  $\pi h_{9/2} \otimes \nu g_{9/2}$  multiplet) in the ground and isomeric states in Bi with  $126 < N < 134$

|                  | 126     | 127       | 128       | 129       | 130     | 131            | 132       | 133       | 134                  | 135       | 136         | 137       | 138         | 139     | 140                  |
|------------------|---------|-----------|-----------|-----------|---------|----------------|-----------|-----------|----------------------|-----------|-------------|-----------|-------------|---------|----------------------|
| $^{82}\text{Pb}$ |         | $9/2^+$   |           | $9/2^+$   |         |                |           |           |                      |           |             |           |             |         |                      |
| $^{83}\text{Bi}$ | $9/2^-$ |           | $(9/2)^-$ |           | $9/2^-$ |                |           |           |                      |           |             |           |             |         |                      |
| $^{84}\text{Po}$ |         | $(9/2^+)$ |           | $9/2^+$   |         | $(9/2)^+$      |           |           |                      |           |             |           |             |         |                      |
| $^{85}\text{At}$ | $9/2^-$ |           | $9/2^-$   |           | $9/2^-$ |                | $9/2^-$   |           |                      |           |             |           |             |         |                      |
| $^{86}\text{Rn}$ |         | $9/2^+$   |           | $(9/2^+)$ |         | $9/2^+$        |           | $5/2^+$   |                      | $7/2$     |             |           |             |         |                      |
| $^{87}\text{Fr}$ | $9/2^-$ |           | $9/2^-$   |           | $9/2^-$ |                | $(9/2)^-$ |           | $5/2^-$<br>$K=1/2^-$ |           | $3/2^{(-)}$ |           | $3/2^{(-)}$ |         | $1/2$                |
| $^{88}\text{Ra}$ |         | $9/2^+$   |           | $9/2^+$   |         | not<br>$9/2^+$ |           | $5/2^+$   |                      | $3/2^+$   |             | $1/2^+$   |             | $3/2^+$ |                      |
| $^{89}\text{Ac}$ | $9/2^-$ |           | $9/2^-$   |           | $9/2^-$ |                |           | $5/2^-$   |                      | $3/2^-$   |             | $3/2^-$   |             |         | $(3/2^+)$            |
| $^{90}\text{Th}$ |         |           |           | $(9/2^+)$ |         | not<br>$9/2^+$ |           | $(5/2^+)$ |                      | $3/2^+$   |             | $1/2^+$   |             | $5/2^+$ |                      |
| $^{91}\text{Pa}$ |         |           |           |           |         |                |           |           |                      | $(5/2^-)$ |             | $(5/2^+)$ |             |         | $3/2^-$<br>$K=1/2^-$ |
| $^{92}\text{U}$  |         |           |           |           |         |                |           |           |                      |           | $3/2^+$     |           | $(5/2)$     |         |                      |
| $^{93}\text{Np}$ |         |           |           |           |         |                |           |           |                      |           |             | $(5/2)$   |             |         | $(5/2^+)$            |

1. Измерены  $\mu$ ,  $Q$ ,  $\delta\langle r^2 \rangle$  для изотопов и изомеров  $^{214-218}\text{Bi}$ . Использование IDS позволило в ряде случаев получить чистые пучки изомеров.
2. Впервые удалось систематически исследовать изотонические зависимости радиусов. Скачок в этих зависимостях при переходе от  $Z = 84$  к  $Z = 85$  объясняется скачкообразным ростом октупольной деформации от  $\beta_3 \approx 0$  к  $\beta_3 \approx 0.1$ .
3. Для изотопов  $\text{Bi}$  при  $N < 135$  наблюдается нормальный OES. Показано, что переход от нормального к инверсному OES происходит при переходе от  $Z = 84$  к  $Z = 85$ , что подтверждает скачок октупольной деформации при этих значениях  $Z$ .
4. Рост величины скачка в радиусах при нечетных  $N$  соответствует росту октупольной деформации для нечетно-нейтронных ядер по сравнению с соседними четно-нейтронными ядрами (от  $\beta_3 \approx 0.11$  к  $\beta_3 \approx 0.14$ ), что проявляется также в инверсном OES.
5. Подтверждены спины и конфигурации нечетно-нечетных изотопов  $\text{Bi}$ . Хорошее описание  $\mu$  для этих ядер в рамках соотношения аддитивности подтверждает отсутствие октупольности у ядер  $\text{Bi}$  с  $N < 136$ .
6. Полученные данные позволяют расширить границы области октупольной деформации.

A. Barzakh *et al.* *Charge radii and electromagnetic moments of  $^{214-218}\text{Bi}$ : Exploring the “southern” border of the  $Z > 82$  octupole-deformation region*, Phys. Rev. C **112**, 034304 (2025)