Search for shape coexistence in even-even stable molybdenum isotopes using Coulomb excitation method

Katarzyna Wrzosek

Heavy Ion Laboratory, Warsaw University

M. Zielińska, T. Czosnyka, J. Choiński, Y. Hatsukawa, J. Iwanicki, M. Kisieliński, M. Koizumi,

M. Kowalczyk, H. Kusakari, M. Matsuda, T. Morikawa, P. J. Napiorkowski, A. Osa, M. Oshima,

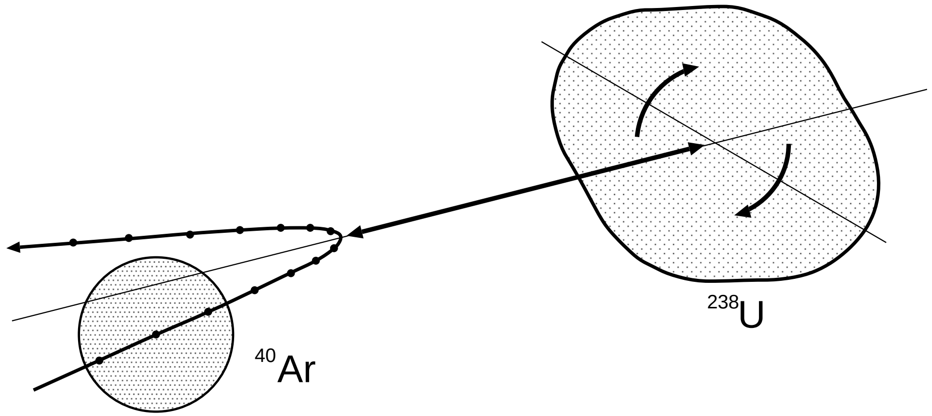
L. Reissig, T. Shizuma, J. Srebrny, M. Sugawara, K. Zając

Motivation

- Shape coexistence in medium mass nuclei was extensively studied during recent years.
- One of the interesting phenomena associated with shape coexistence is the occurence of low-lying 0^+ states in even-even nuclei. In extreme cases the second 0^+ state appears to be the first excited state.
- Among stable nuclei with $Z > 20$ only four of them have the 0^+ first excited state, namely ^{72}Ge, ^{90}Zr, ^{96}Zr and ^{98}Mo.
- Coulomb excitation method allows to determine deformation parameters of an excited nucleus independently for each level.
- Shape parameters of the two lowest 0^+ states in ^{96}Mo, ^{98}Mo, ^{100}Mo nuclei were inferred from Coulomb excitation data.

Coulomb excitation - basic facts

- Colliding nuclei do not interact via nuclear forces - if the distance between nuclear surfaces is at least 5 fm, the strong interaction can be neglected (Cline's empirical criterion).

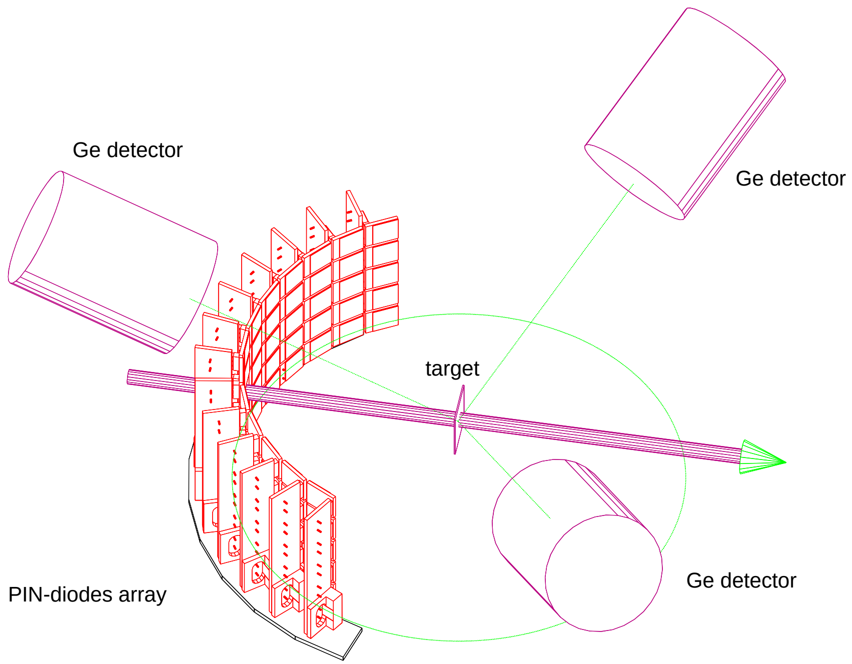


- Trajectories of scattered nuclei are described classically.
- Energy transfer is small compared to the energy of the projectile.
- The excitation strength strongly depends on charges and masses of the collision partners, on beam energy and scattering angle.
- γ-radiation emitted by the Coulomb-excited nuclei carries the information on their internal structure.

Coulomb excitation set-ups

The data were collected using two detection set-ups:

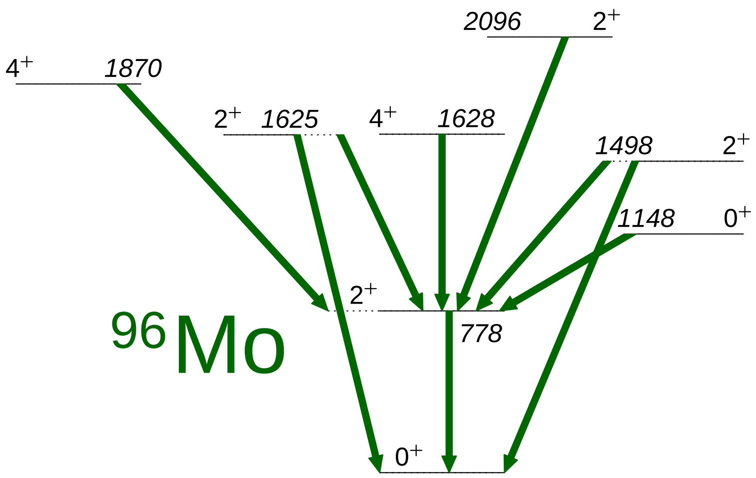
- CUDAC (Coulex Universal Detector Array Chamber) at **HIL** (Poland).

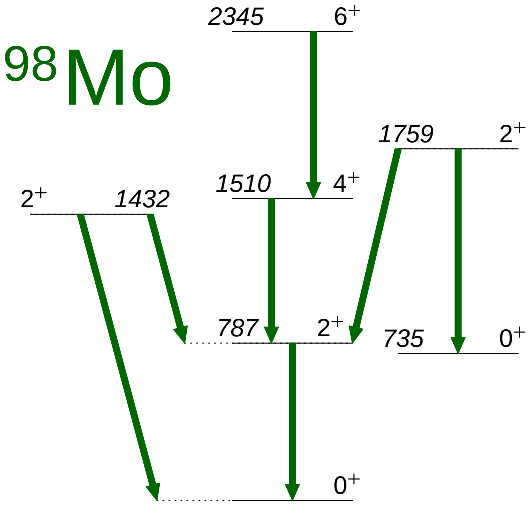


  - 30 particle detectors placed at backward angles.
  - 3 γ-ray detectors.
  - The deexcitation γ rays **measured in coincidence** with backscattered particles.

- GEMINI + LUNA detector array at **JAERI** (Tokai, Japan).

Experiments





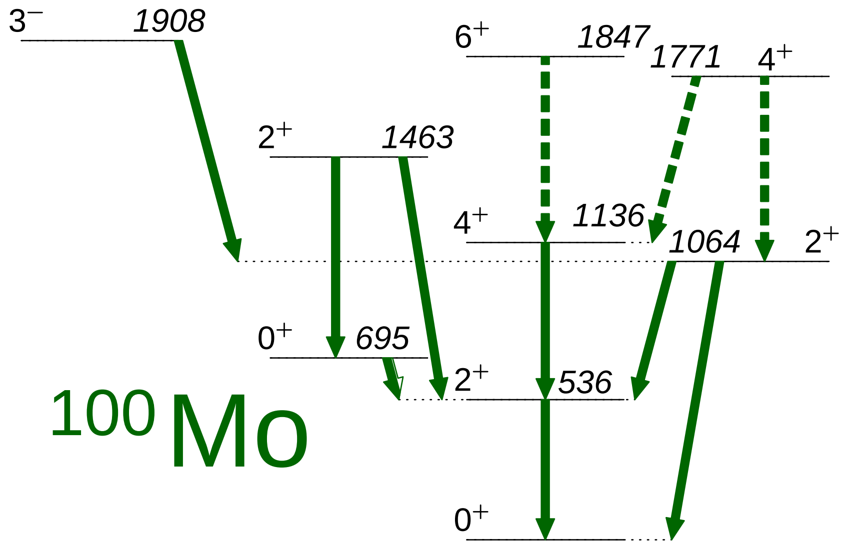
^{40}Ar + ^{96}Mo (**HIL**, Warsaw, Poland)
^{20}Ne + ^{96}Mo (**HIL**, Warsaw, Poland)
^{96}Mo + ^{nat}Pb (**JAERI**, Tokai, Japan)

^{20}Ne + ^{98}Mo (**HIL**, Warsaw, Poland)
^{84}Kr + ^{98}Mo (**JAERI**, Tokai, Japan)
^{136}Xe + ^{98}Mo (**JAERI**, Tokai, Japan)

Published:

M.Zielińska *et al.*, *Acta Phys. Pol.* **B33**, 515 (2002)
M.Zielińska *et al.*, *Nucl. Phys* **A712**, 79 (2002)
M.Zielińska *et al.*, *Acta Phys. Pol.* **B36**, 1289 (2005)
K. Zając, *Acta Phys. Pol.* **B34** 2241 (2003)
K. Zając, *Int. J. Mod. Phys.* **E13** 103 (2004)

Experiments

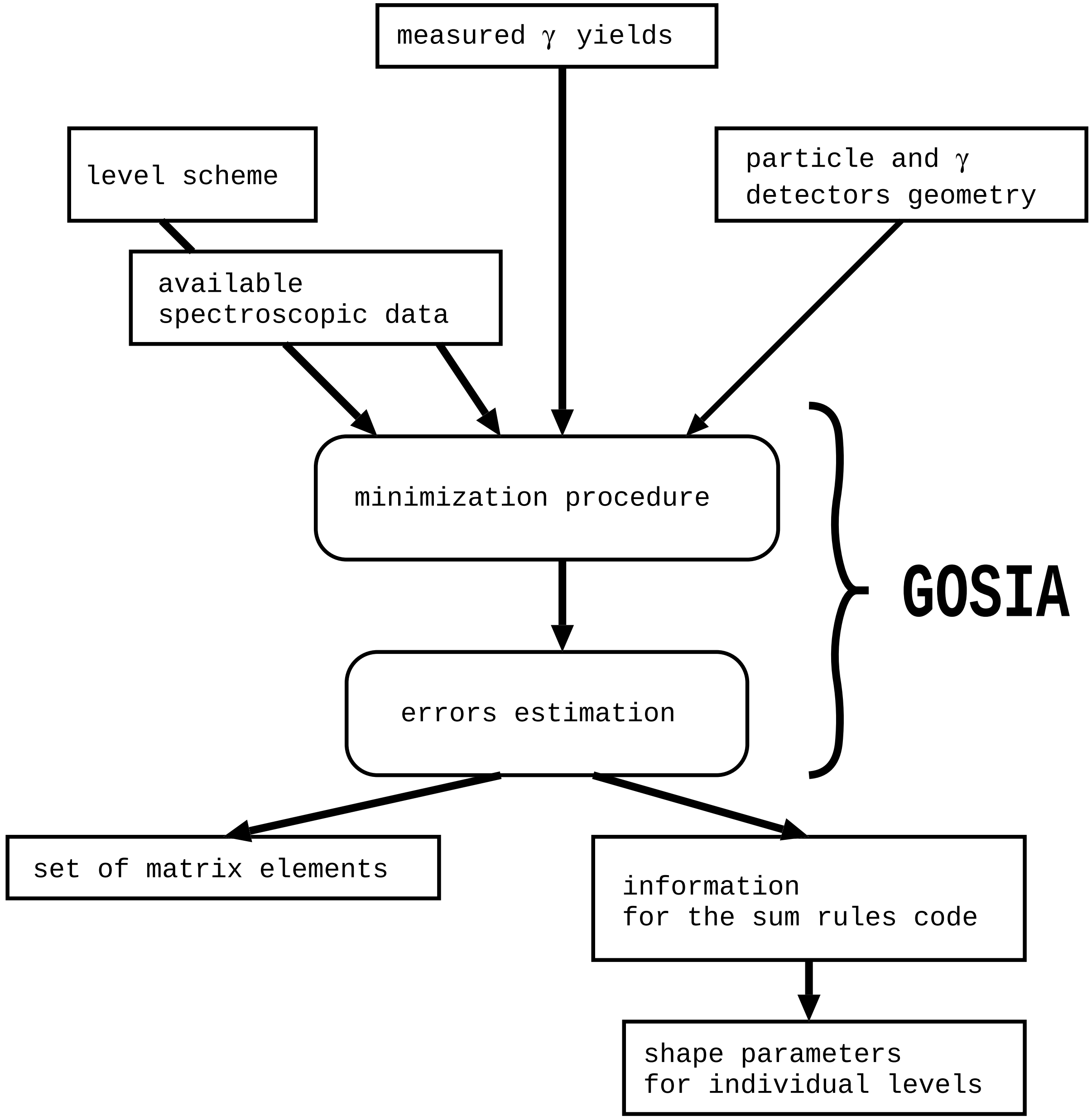


^{40}Ar + ^{100}Mo (**HIL**, Warsaw, Poland)
^{20}Ne + ^{100}Mo (**HIL**, Warsaw, Poland)

Published:

K.Wrzosek *et al.*, *Int. J. Mod. Phys.* **E14** 359 (2005)

Matrix elements determination

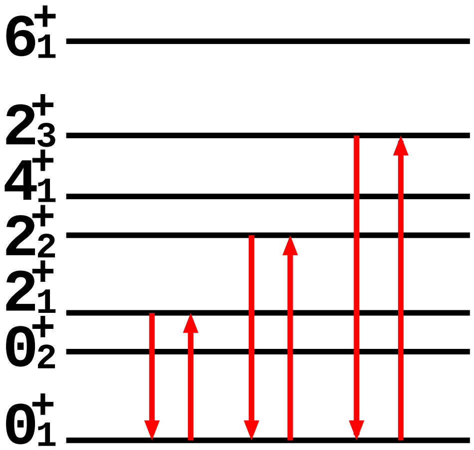


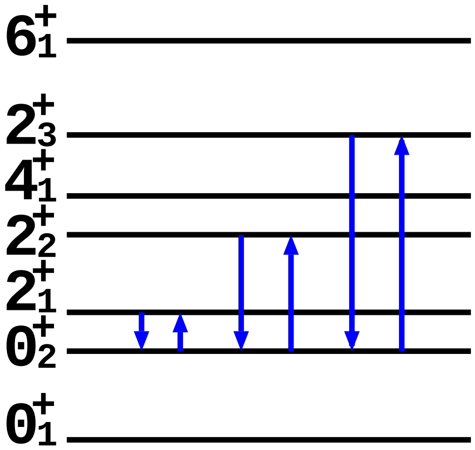
Quadrupole Sum Rules method

... is based on a fact, that zero–coupled products of E2 operators are **rotational invariants**. Operator products may be expressed using the intermediate state expansion formula:

$$\frac{\langle Q^2 \rangle}{\sqrt{5}} = \langle i \,|[E2 \times E2]_0|\, i \rangle =$$

$$= \frac{1}{\sqrt{(2I_i+1)}} \sum_t \langle i \| \mathrm{E2} \| t \rangle \langle t \| \mathrm{E2} \| f \rangle \left\{ \begin{array}{ccc} 2 & 2 & 0 \\ I_i & I_f & I_t \end{array} \right\}$$



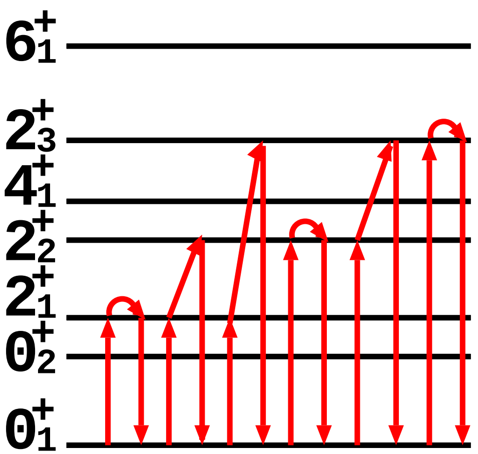


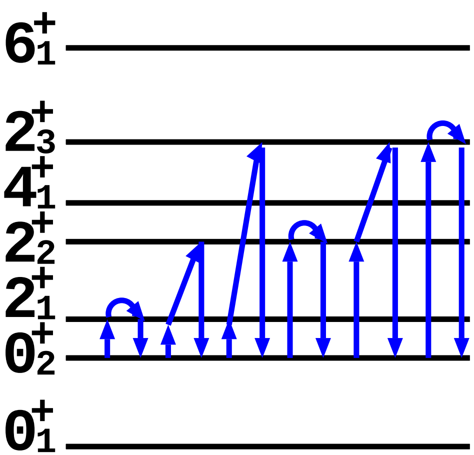
Quadrupole Sum Rules method

To get information on triaxiality the higher order invariant is needed:

$$\sqrt{\frac{2}{35}}Q^3\langle\cos 3\delta\rangle = \langle i\,|[E2\times E2]_2\times E2]_0|\,i\rangle =$$

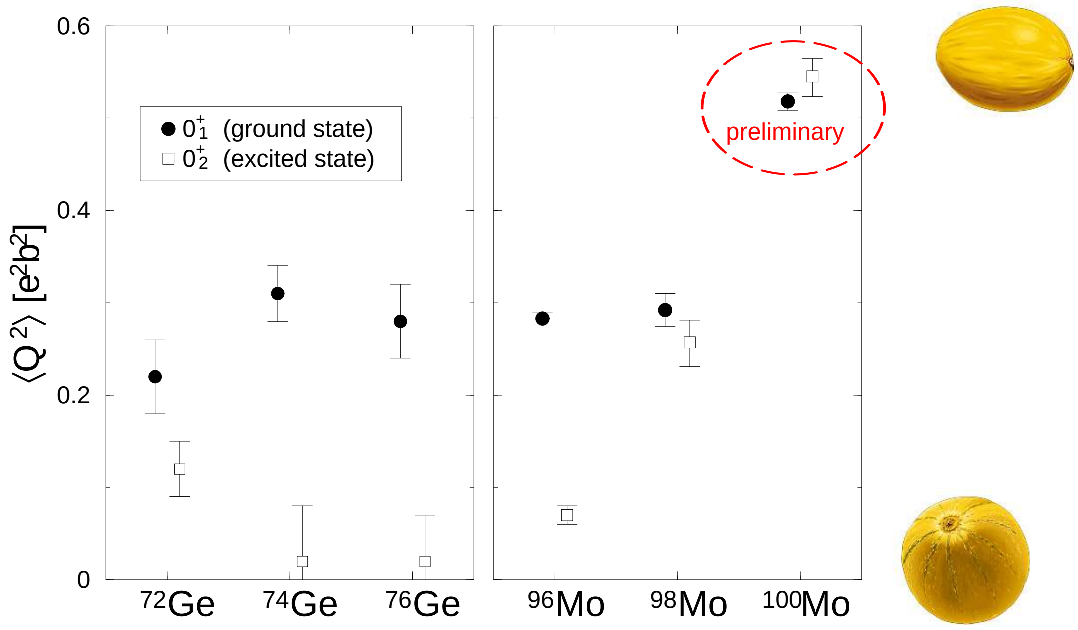
$$= \frac{1}{(2I_i+1)}\sum_{t,u}\langle i\|\mathrm{E2}\|u\rangle\langle u\|\mathrm{E2}\|t\rangle\langle t\|\mathrm{E2}\|i\rangle \left\{\begin{array}{ccc} 2 & 2 & 2 \\ I_i & I_t & I_u \end{array}\right\}$$





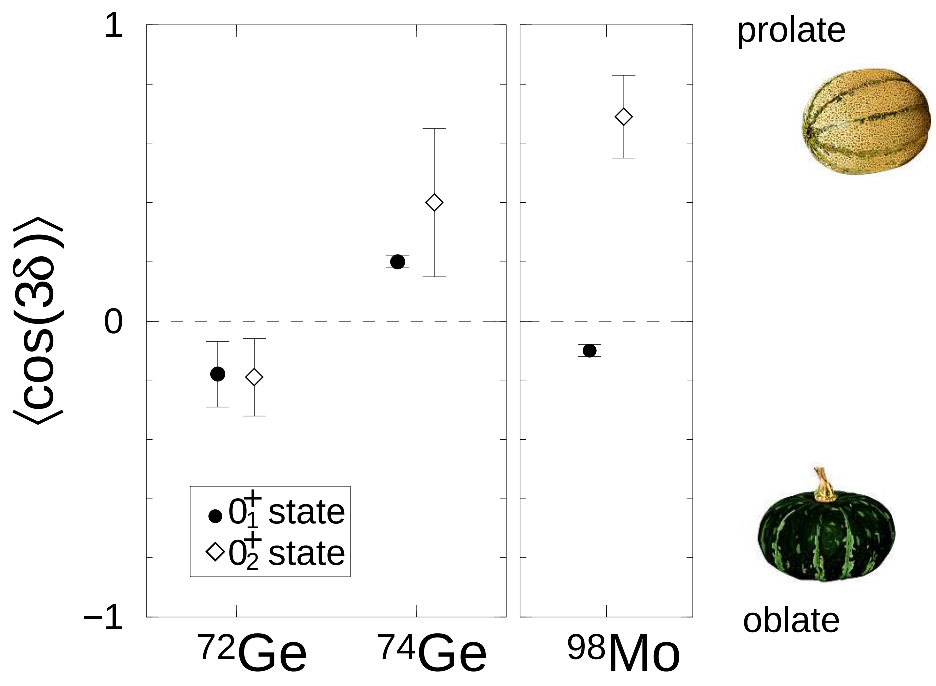
Shape coexistence

- ^{96}Mo: ground state 0_1^+ is deformed while the excited state 0_2^+ is almost spherical. This behaviour is similar to the one observed in Ge isotopes and ^{96}Zr.
- ^{98}Mo: the expectation value of Q^2 is almost the same for the ground state and for the fi rst excited state.
- ^{100}Mo: the preliminary results show similar trend as observed in case of the ^{98}Mo isotope: the expectation value of Q^2 is almost the same for both 0^+ states. Deformation of ^{100}Mo seems to be larger compared to other Mo isotopes.



Shape coexistence

- The triaxiality seems to be the same for each of Ge isotopes. On the contrary, the ground state (0_1^+) of ^{98}Mo is triaxial while the fi rst excited state (0_2^+) has a prolate shape.



Conclusions and future plans

- In case of ^{96}Mo and ^{98}Mo the resulting sets of matrix elements were rich and precise enough to determine shape parameters of the two 0^+ states.
- Data collected during two experiments performed at HIL were not sufficient for the difficult case of ^{100}Mo, therefore the presented deformation parameters for 0_1^+ and 0_2^+ states are preliminary.
- One more experiment with ^{100}Mo target using the new gamma and particle detection set-up (12 γ-ray detectors and about 50 particle detectors) is planned at HIL in the near future.
- The simulations performed point out that all doubts should be dispelled. We expect to determine the diagonal matrix elements with a higher accuracy.