Shape mixing dynamics in the low-lying states of proton-rich Kr isotopes

Koichi Sato（Kyoto Univ./RIKEN)

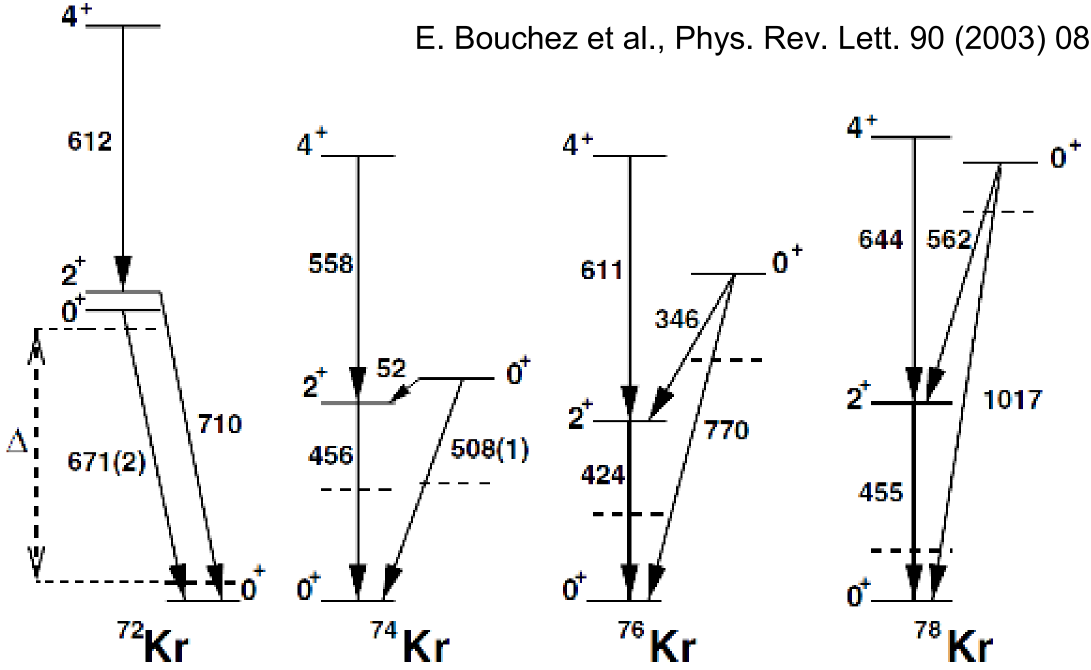
Nobuo Hinohara　(RIKEN)

Takashi Nakatsukasa (RIKEN)

Masayuki Matsuo (Niigata Univ.)

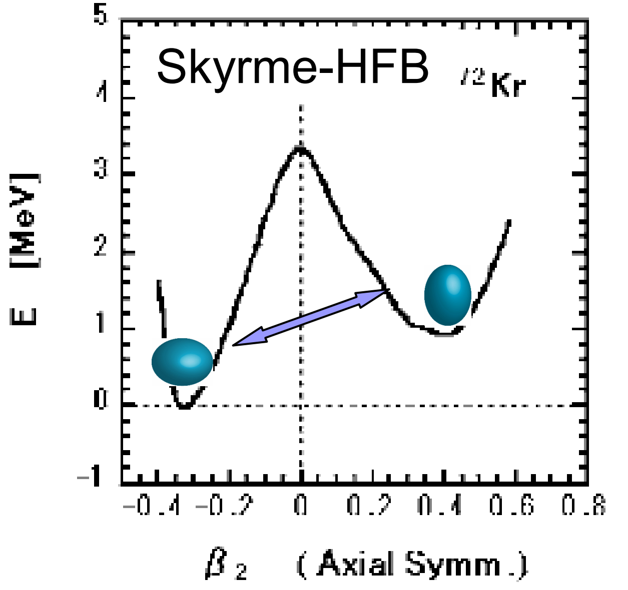
Kenichi Matsuyanagi (RIKEN/YITP)

Oblate- prolate shape coexistence phenomena in proton-rich Kr isotopes



E. Bouchez et al., Phys. Rev. Lett. 90 (2003) 082502

M. Yamagami et al.,NPA 693(2001) 579.



$\rho^2(E0)$	0.072(6)	0.085(19)	0.079(11)	0.047(13)

Shape mixing by tunneling between the local minima

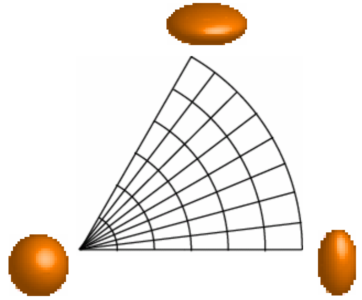
oblate ↔ **prolate**

- ◇ Low-lying excited 0+ states
- ◇ Spectroscopic quadrupole moments
- ◇ Irregularities of the excitation spectra
- ◇ Systematics of the excited 0+ energies and E0 transition strengths

Shape transition from the oblate ground state in 72Kr to the prolate ground state in 74,76,78Kr

We study oblate-prolate shape mixing in the low-lying state of 72,74,76Kr using

5D quadrupole collective Hamiltonian
(Generalized Bohr-Mottelson Hamiltonian) :



$$H = T_{\text{vib}} + T_{\text{rot}} + \boxed{V(\beta,\gamma)}$$

collective potential

$$T_{\text{vib}} = \frac{1}{2}\boxed{D_{\beta\beta}(\beta,\gamma)}\dot{\beta}^2 + \boxed{D_{\beta\gamma}(\beta,\gamma)}\dot{\beta}\dot{\gamma} + \frac{1}{2}\boxed{D_{\gamma\gamma}(\beta,\gamma)}\dot{\gamma}^2$$

vibrational inertial masses

$$T_{\text{rot}} = \sum_{k=1}^{3}\frac{1}{2}\boxed{\mathcal{J}_k}\omega_k^2$$

rotational moments of inertia

The collective Hamiltonian is derived microscopically by means of the "Constrained HFB+ Local QRPA"(CHFB+LQRPA) method, which we recently developed on the basis of the Adiabatic Self-consistent Collective Coordinate (ASCC) method

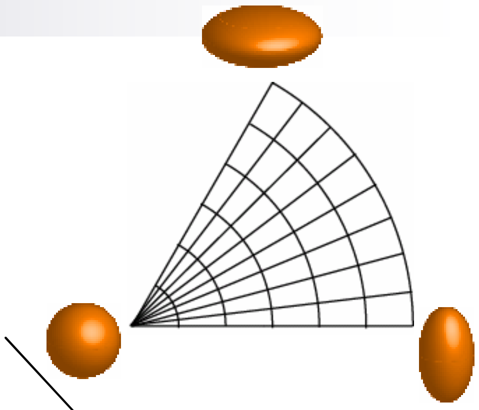
Matsuo, Nakatsukasa, and Matsuyanagi, Prog.Theor. Phys. 103(2000), 959.

Application of 1D ASCC to shape coexistence in Se and Kr

N. Hinohara, et al, Prog. Theor. Phys. 119(2008), 59; PRC 80 (2009),014305.

an approximation of the 2-dimensional ASCC method.

Constrained HFB + Local QRPA method:



Solve the constrained HFB eq. at each point on the (β , γ) plane

N,Z, β , γ ↓ $|\phi\,(\beta,\gamma)\rangle$ $\boxed{V(\beta,\gamma)}$ $\lambda\,(\beta,\gamma)$ $\mu(\beta,\gamma)$

Solve the local QRPA eqs. on top of each CHFB state $|\phi\,(\beta,\gamma)\rangle$

$\omega_\alpha^2\,(\beta,\gamma)$ $\hat{Q}^{(\alpha)}(\beta,\gamma)$ $\hat{P}^{(\alpha)}(\beta,\gamma)$

Local Thouless-Valatin eqs.

Calculate the vibrational masses

Local QRPA masses

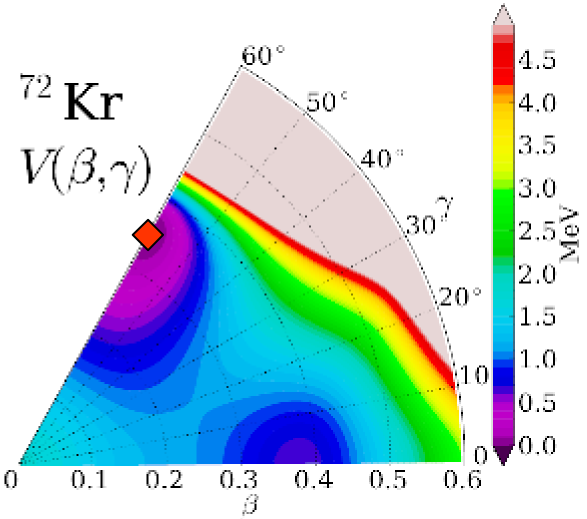
$$\boxed{D_{\beta\beta}(\beta,\gamma)\quad D_{\beta\gamma}(\beta,\gamma)\; D_{\gamma\gamma}(\beta,\gamma)\qquad \mathcal{J}_k(\beta,\gamma)}$$

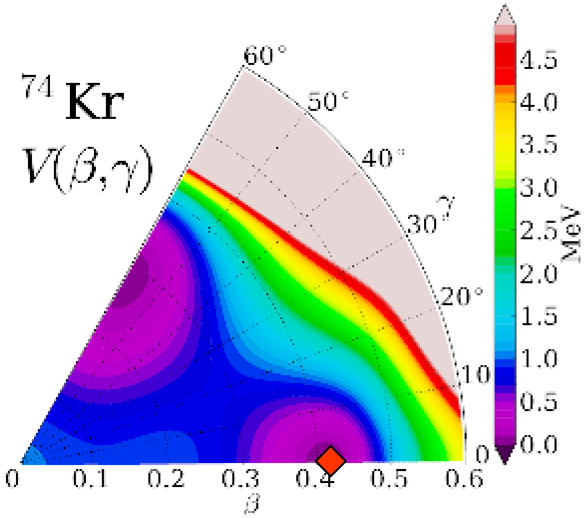
Include the contribution from the time-odd component of the mean field, unlike widely-used cranking masses

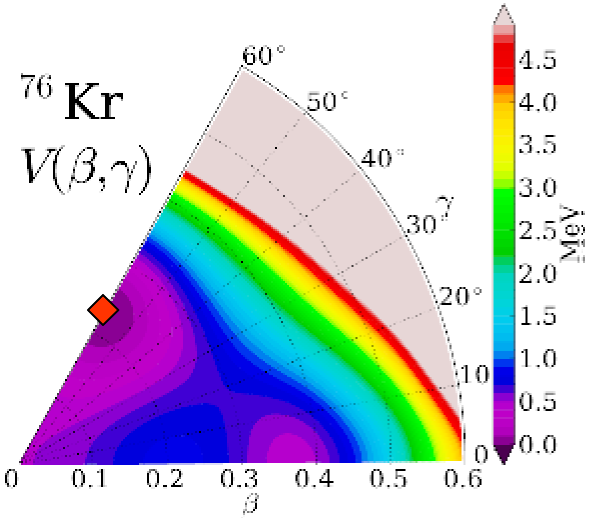
Diagonalize the 5D Quadrupole Hamiltonian to calculate the energy spectrum

Numerical results

Collective potential







◆: absolute minimum

oblate ↔ prolate

Shape transition?

oblate?

Dynamical effects beyond the mean field should be taken into account

Microscopic Hamiltonian:P+QQ model

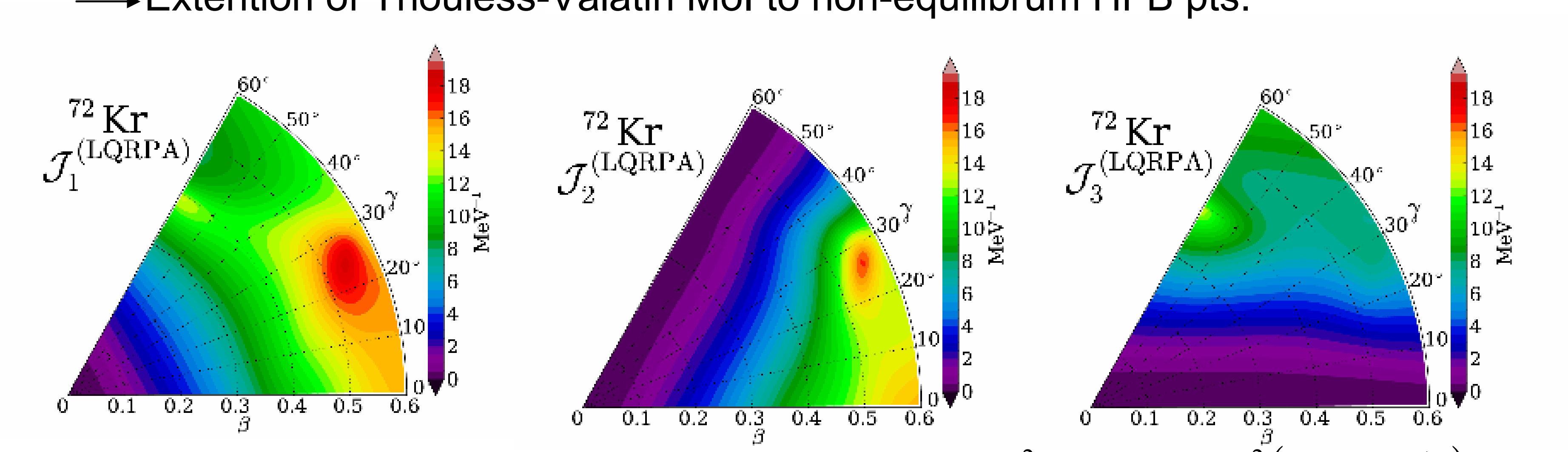
parameters are fitted to the pairing gap and the quadrupole deformation obtained with Skyrme-HFB by Yamagami et al.

M. Yamagami et al.,NPA 693(2001) 579.

^{72}Kr

LQRPA moments of Inertia

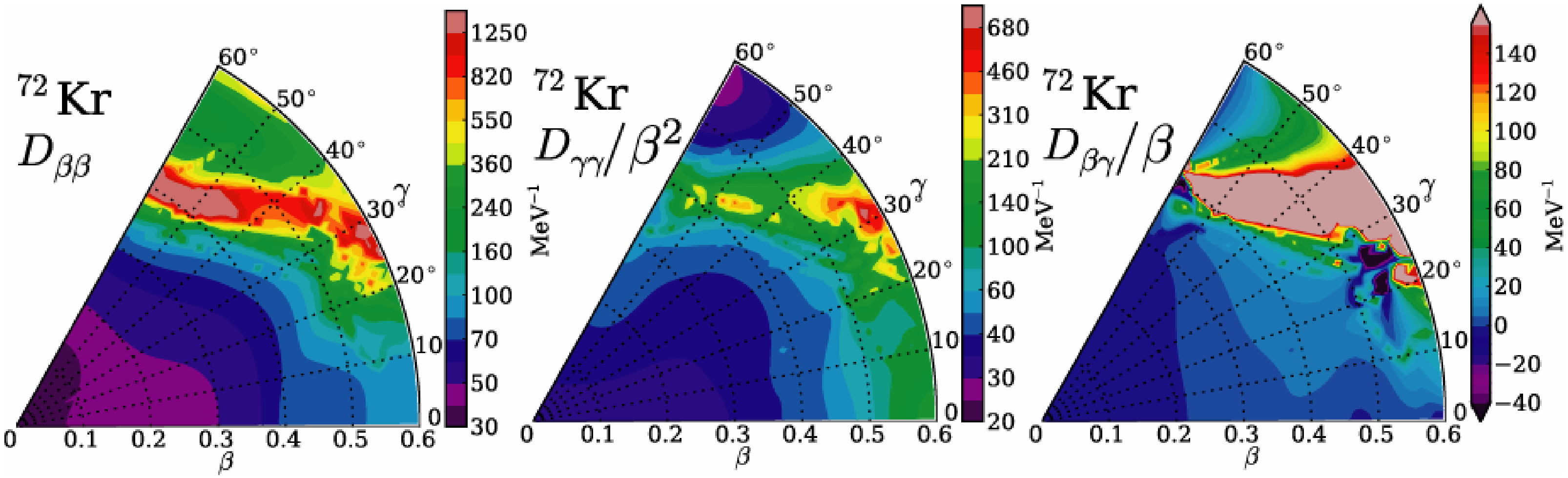
→ Extention of Thouless-Valatin MoI to non-equilibrum HFB pts.



$$\mathcal{J}_k(\beta,\gamma)=4\beta^2\underline{D_k(\beta,\gamma)}\sin^2\left(\gamma-2\pi k/3\right)$$

strongly dependent on (β , γ)

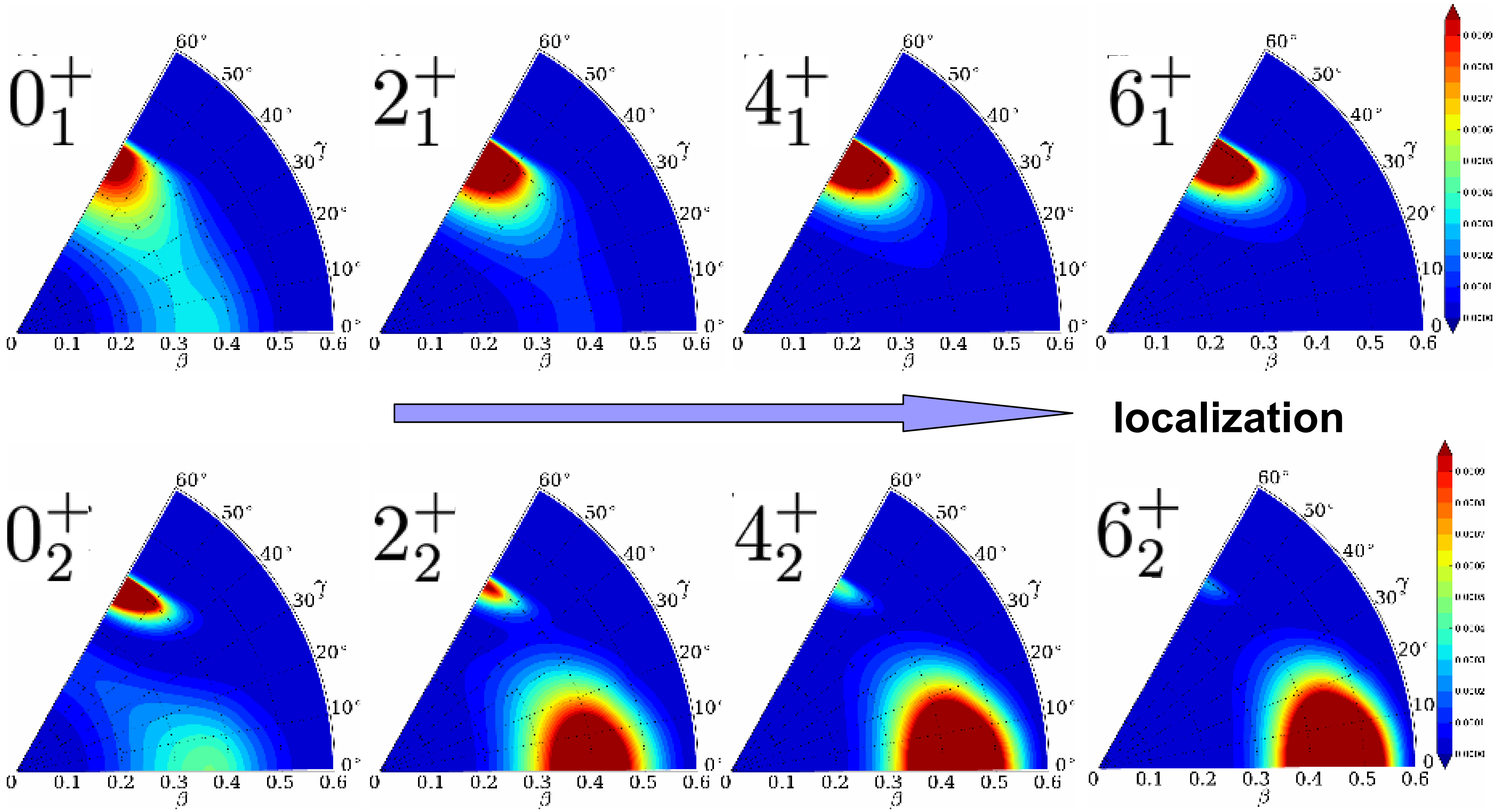
Local QRPA vibrational masses:



^{72}Kr

Collective wave functions squared for 72Kr

$$\beta^4 \sum_K |\Phi_{IKk}(\beta,\gamma)|^2$$



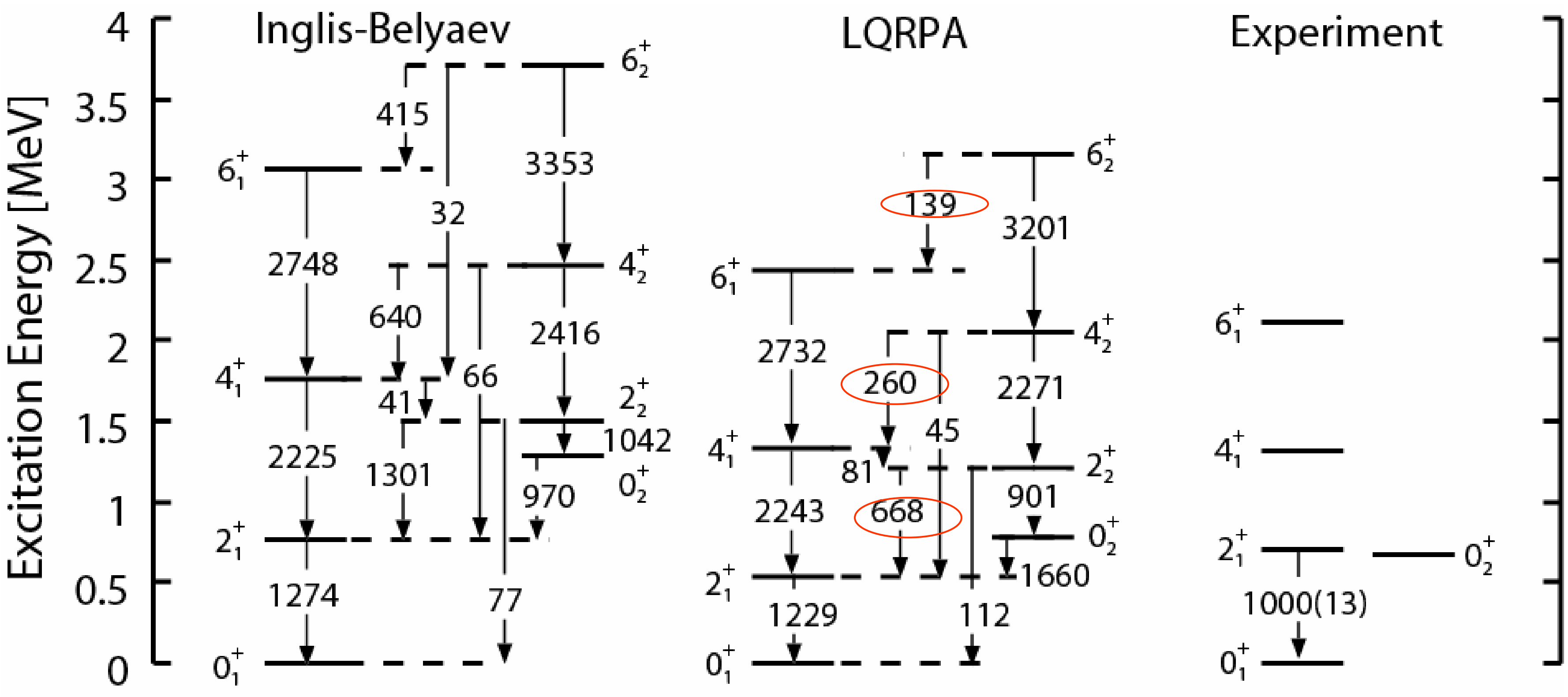
localization

Excitation Energies and B(E2)

EXP: Fischer et al., Phys.Rev.**C67** (2003) 064318,
Bouchez, et al., Phys.Rev.Lett.90 (2003) 082502.
Gade, et al., Phys.Rev.Lett.**95** (2005) 022502, **96** (2006) 189901

( ) …B(E2) e^2 fm^4

effective charge: e_{pol} =0.834



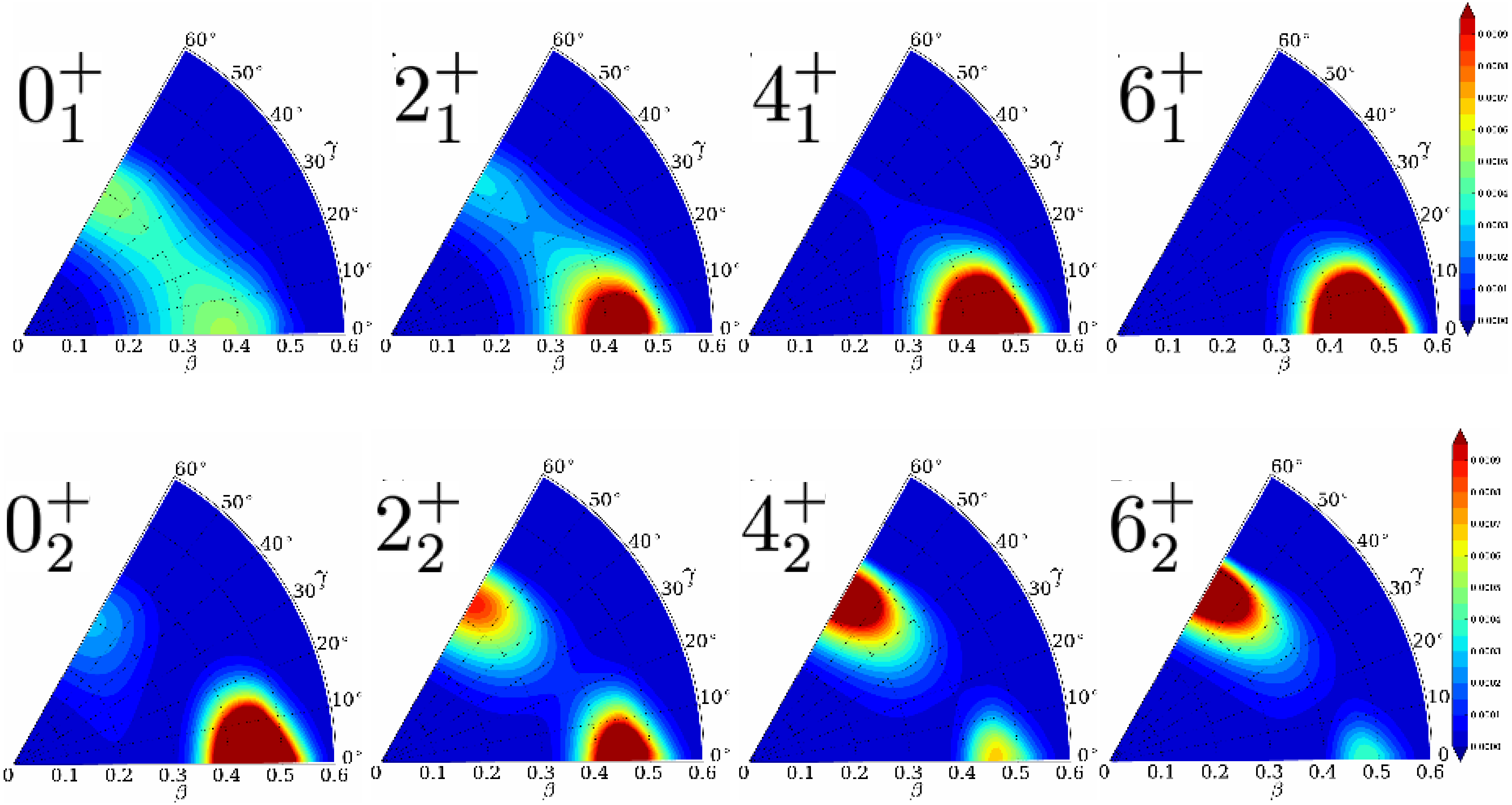
- The interband transitions become weaker as angular momentum increases.

  ⟷ development of the localization of w.f.

- The time-odd mean-field lowers the excitation energies.

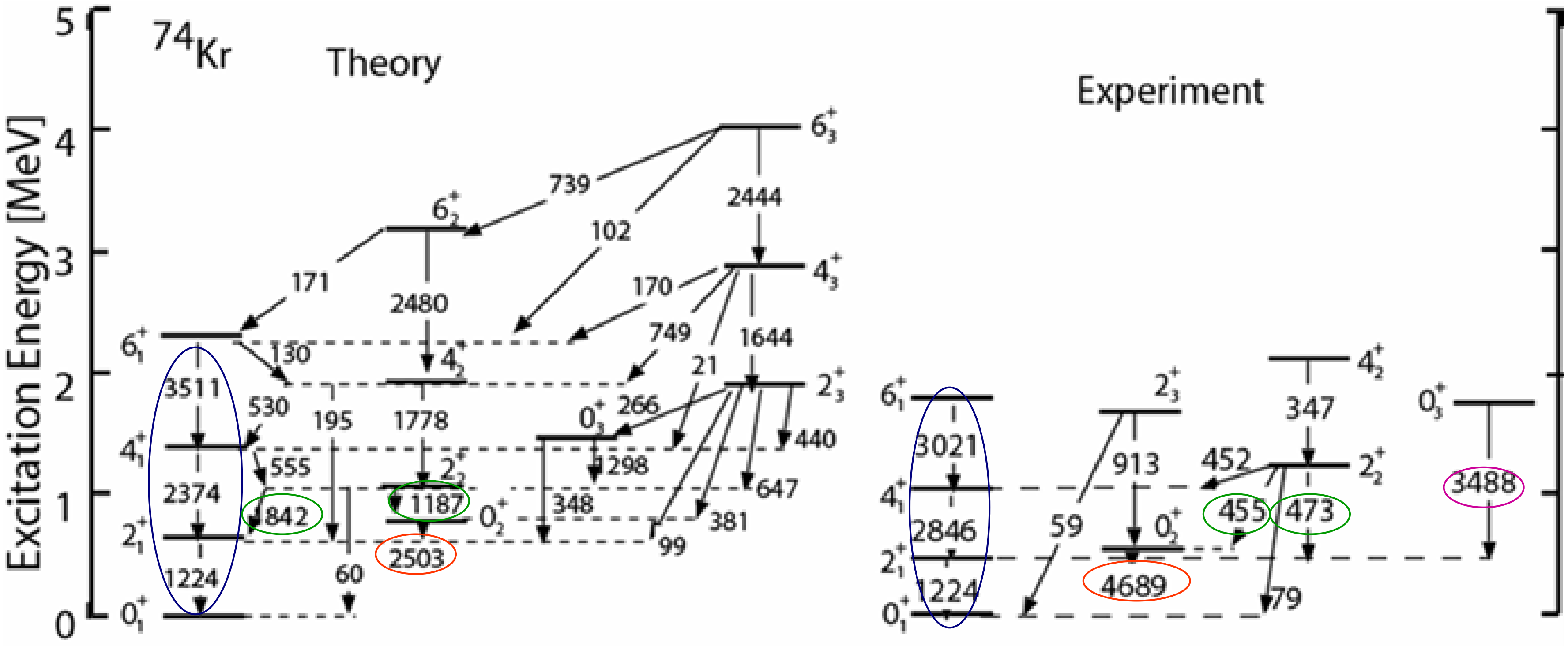
^{74}Kr

Collective wave functions squared for 74Kr $\beta^4 \sum_K |\Phi_{IKk}(\beta,\gamma)|^2$



Excitation Energies and B(E2) for 74Kr

EXP: E. Clément et al., PRC 75,054313 (2007).



Main features of the experimental data:

- ☺ Increasing tendency of B(E2) in the ground band ⬭
- ☺ Strong 0_2 -> 2_1 transition ⬭
- ☺ Equal strength of the 2_2 -> 2_1 and 2_2 -> 0_2 transitions ⬭

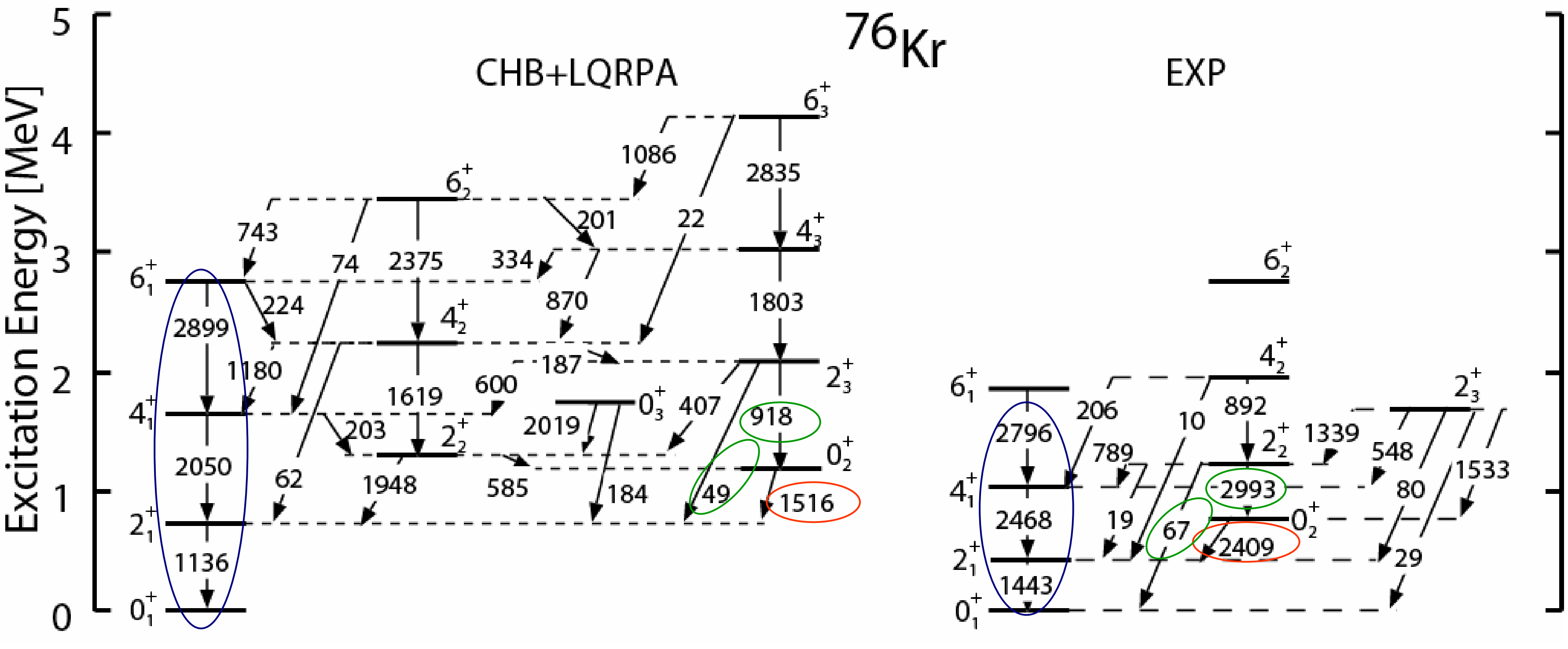
} well reproduced!

- ☹ Strong 0_3 -> 2_1 transition ⬭ not reproduced

Excitation Energies and B(E2) for 76Kr

( ) …B(E2) e^2 fm^4
effective charge: e_{pol} =0.834

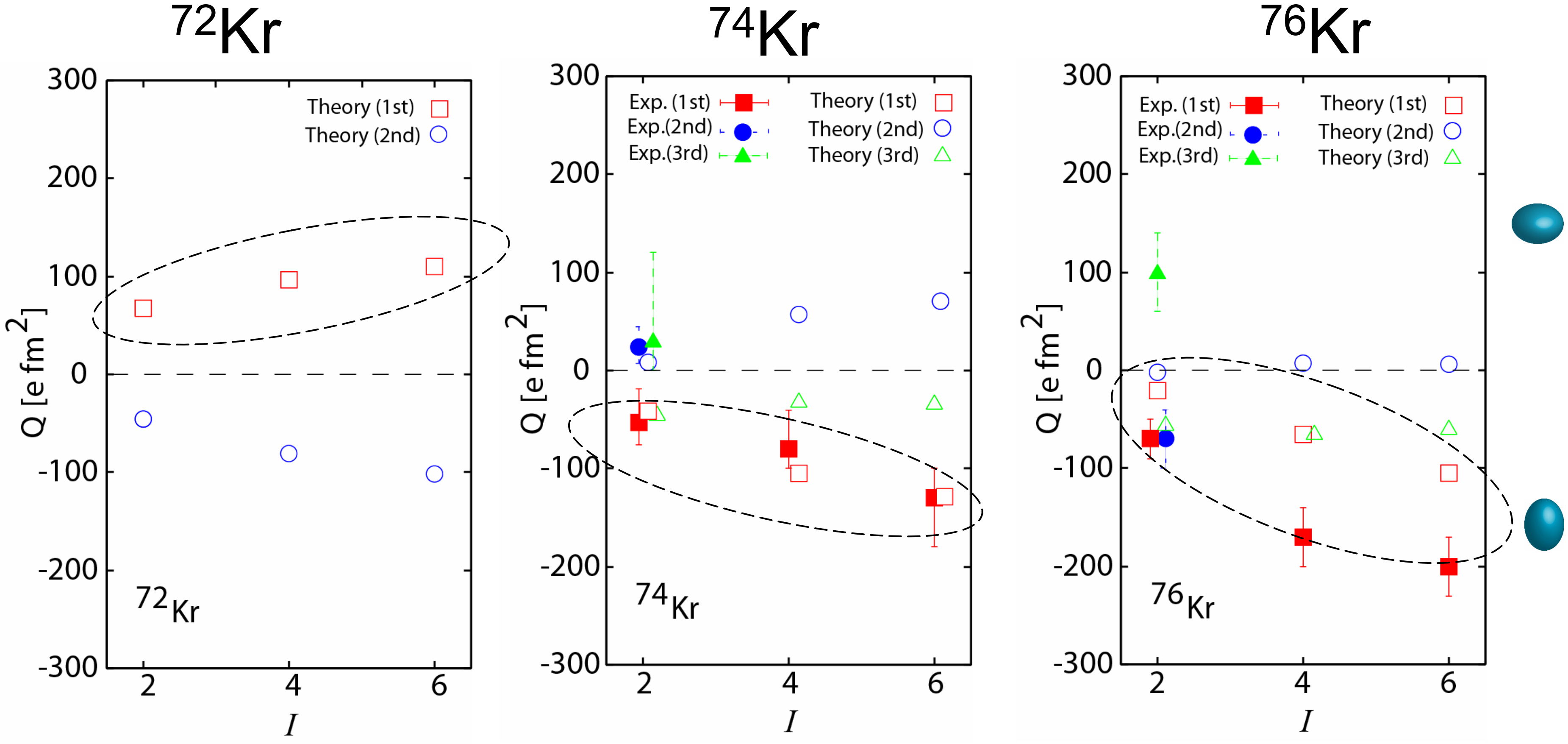
EXP: E. Clément et al., PRC 75,054313 (2007).



- Increasing tendency in the ground band ○
- Strong 0_2 -> 2_1 transition ○
- B(E2; 2_2 -> 0_2) >> B(E2; 2_2 -> 2_1) ○

} well reproduced!

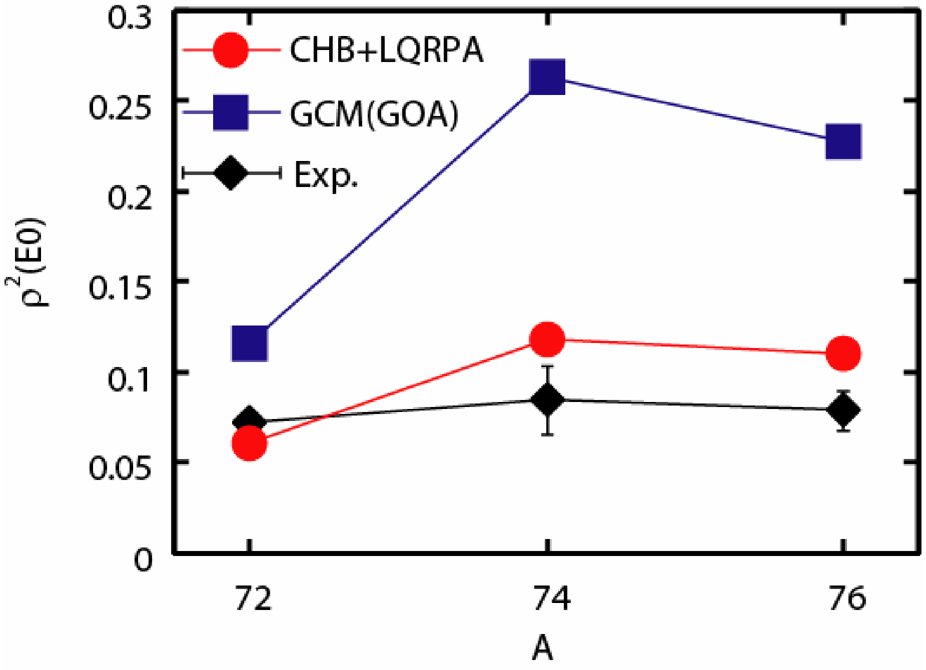
Spectroscopic quadrupole moments Q



Exp. (1st) :–■– Theory(1st): □
Exp.(2nd) :- ● - Theory(2nd):○
Exp. (3rd) :- ▲ - Theory(3rd): △

Shape transition from oblate in 72Kr to prolate in 74,76Kr was reproduced.

E0 transition strengths $\rho^2(E0;\, 0_2^+ \rightarrow 0_1^+)$



GCM(GOA):

HFB-based configuration mixing calculation using the Gogny D1S interaction

M. Girod et al., PLB 676 (2009) 39.

Exp: C. Chandler et al. PRC 56 (1997) 2924.
E. Bouchex et al., PRL 90 (2003) 082502.

The calculated result reproduces well the experimental data both qualitatively and quantitatively!

The ρ (E0) takes a maximal value at A=74, which reflects the shape transition.

Summary

- We have studied the shape coexistence/mixing in 72,74,76Kr using 5D quadrupole Hamiltonian derived by means of the CHFB+LQRPA method.
- Our results indicate a shape transition from the oblate ground state in 72Kr to the prolate one in 74,76Kr, which is consistent with the experiment.
- The basic features of the low-lying states in these nuclei are determined by the interplay of the large-amplitude shape fluctuation in the triaxial shape degree of freedom, the β -vibrational excitations and the rotational motions.
- The rotational motion plays an important role for the growth of the localization of the vibrational wave functions in the (β , γ) plane.

Outlook

More realistic interaction

Full 2D ASCC Method