Dynamical shape coexistence in ^{60}Ca

Kouhei Washiyama (CCS, Univ. Tsukuba, Japan)

筑波大学
計算科学研究センター
Center for Computational Sciences

Collaborator: Kenichi Yoshida (RCNP, Osaka Univ., Japan)

Bohr-Mottelson collective model

Shape coexistence

Excited 0^+ state—Dynamical shape coexistence

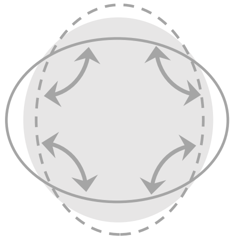
Bohr--Mottelson collective model

Five-dimensional collective Hamiltonian (5DCH) method

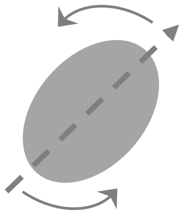
$$\mathcal{H} = T_{\rm vib} + T_{\rm rot} + V(\beta,\gamma)$$

Vibrational mass

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



$$T_{\rm rot} = \frac{1}{2}\sum_{k=1}^{3}\mathcal{J}_k(\beta,\gamma)\omega_k^2$$



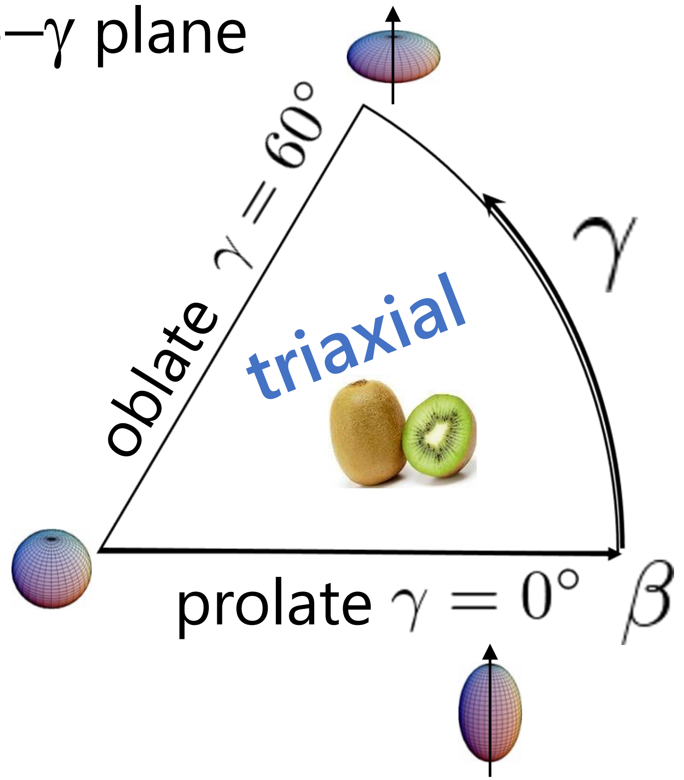
Moment of inertia

Representation of β, γ deformation parameters

Quadrupole deformation

$$Q_{2m} = \langle r^2 Y_{2m}(\hat{r}) \rangle = \int r^2 Y_{2m}(\hat{\boldsymbol{r}}) \rho(\boldsymbol{r}) d^3 r$$

β–γ plane



β Size of deformation

γ Degree of non-axial shape

$$\beta \cos\gamma \propto Q_{20}$$

$$\beta \sin\gamma \propto (Q_{22} + Q_{2-2})$$

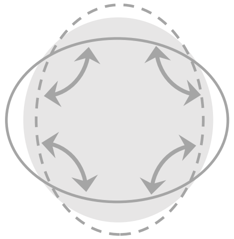
Bohr--Mottelson collective model

Five-dimensional collective Hamiltonian (5DCH) method

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

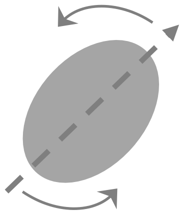
Vibrational mass

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



$$T_{\mathrm{rot}} = \frac{1}{2}\sum_{k=1}^{3} \mathcal{J}_k(\beta,\gamma)\omega_k^2$$

Moment of inertia



$V(\beta,\gamma) \Leftarrow E[\rho]$ Constrained DFT

$D_{\beta\beta},\ D_{\beta\gamma},\ D_{\gamma\gamma},\ \mathcal{J}_k$ **DFT + Local QRPA (FAM)**

Inertia ⟺ Quadrupole collectivity

Quantize Hamiltonian

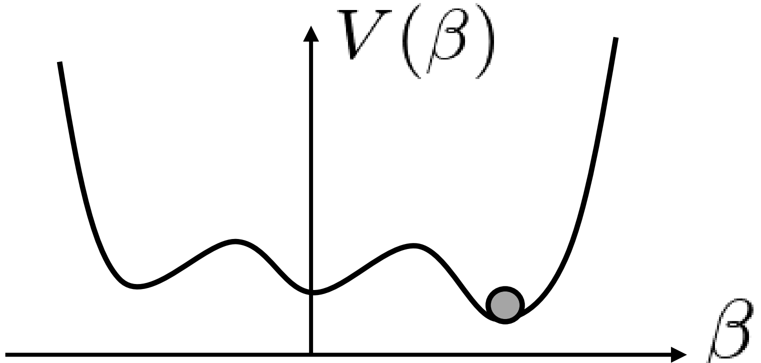
$$\hat{H}\Psi_{\alpha IM}(\beta,\gamma,\Omega) = E_{\alpha I}\Psi_{\alpha IM}(\beta,\gamma,\Omega)$$

$E_{\alpha I}$, transition probability B(E2)

Washiyama, Hinohara, Nakatsukasa, Phys. Rev. C 109, L051301(2024)

Shape coexistence in nuclei

Shape coexistence



Signatures

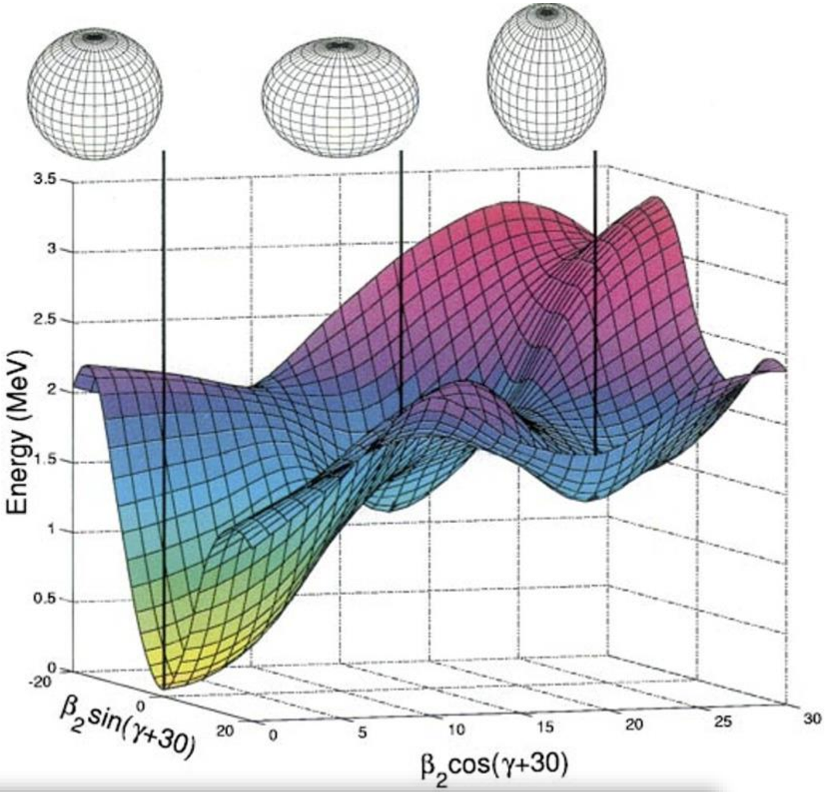
- Low-lying $I^\pi = 0^+$ states
- Bands associated with 0^+ states

+ Theoretical interpretation

^{16}O, ^{40}Ca

^{186}Pb
Andreyev et al., Nature (2000)

$^{74,76}Kr$
Clement et al., PRC(2007)



Heyde, Wood, RMP83,1467(2011)
Garrett, Zielinska, Clement, PPNP124, 103931(2022)

In this talk,

“Dynamical” shape coexistence

Candidate : ^{60}Ca

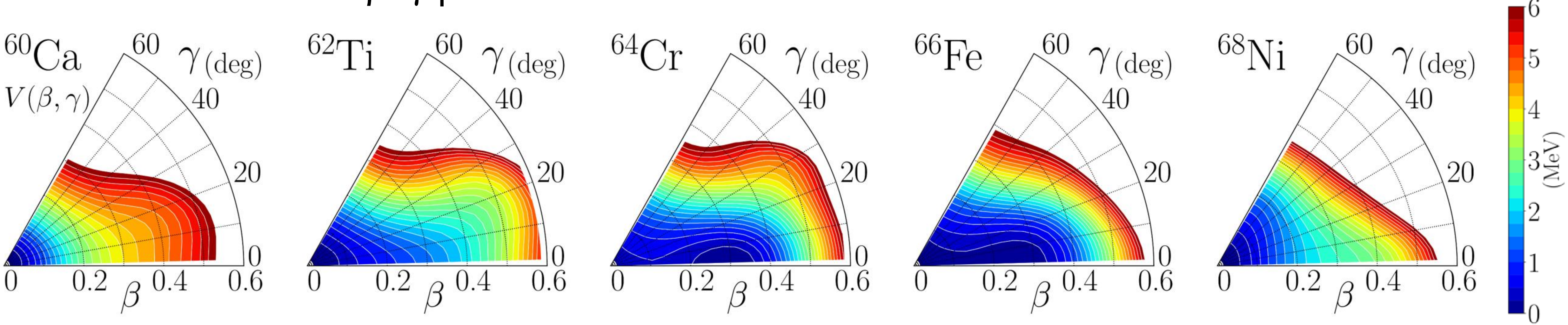
Purpose of the present work

To analyze low-lying states in N=40 nuclei

To analyze an emergence of dynamical shape coexistence in ^{60}Ca

Result: potential energy surface in N=40 isotones

Constrained DFT in β–γ plane



Z=20 Z=22 Z=24 Z=26 Z=28

Shape transition in mean-field level

Spherical → Prolate → Spherical

0 < β < 0.6

0 < γ < 60°

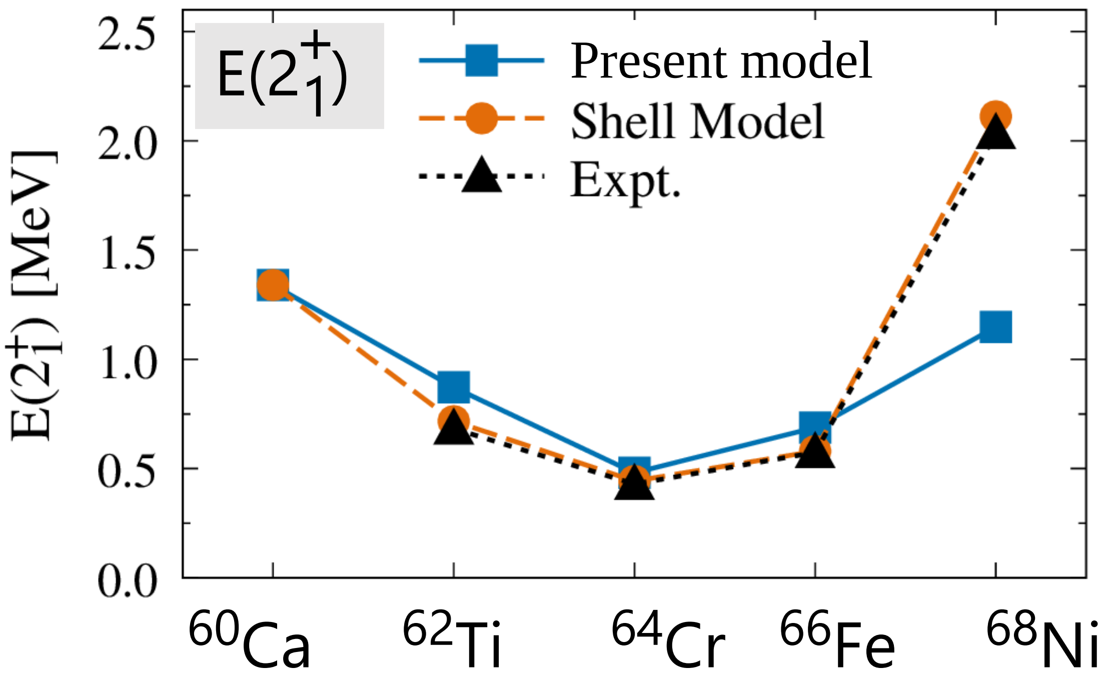
~100 mesh points

SkM*

Volume pairing

Washiyama & Yoshida, in preparation

Systematics on the 2_1^+ energy in N=40



Shell model : Lenzi et al., PRC82,054301 (2010)

Expt.: Cortés et al., PLB 800, 135071 (2020) +NNDC

Good on 2_1^+ energy

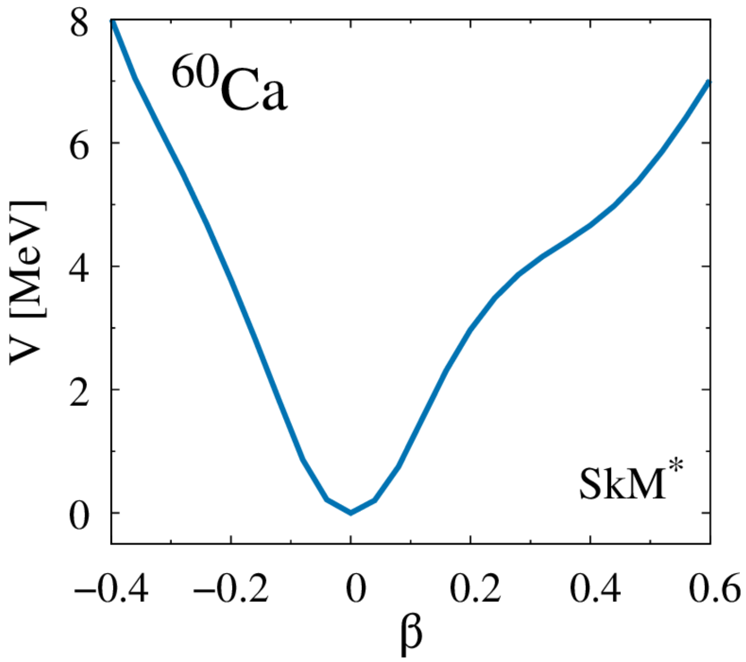
Large deviation in ^{68}Ni

(good description by shell model)

Washiyama & Yoshida, in preparation

Discussion: low-lying 0_2^+ state in ^{60}Ca

Potential



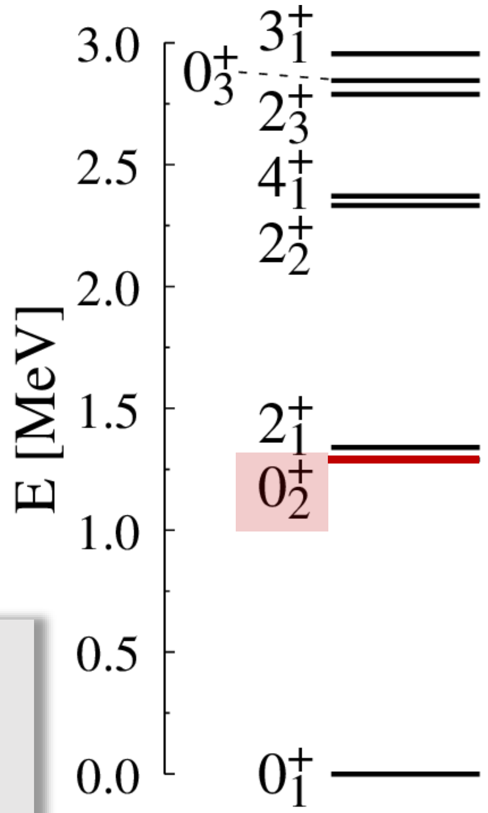
cf. Spherical harmonic vibrator limit

$4_1, 2_2, 0_2$

2_1

0_1

Low-lying spectra in ^{60}Ca



$R_{0/2} = E(0_2) / E(2_1)$

$= 0.96$

What is the origin of low $R_{0/2}$?

Discussion: Role of inertial functions in the 0_2 state

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

Test a constant mass *D*

$$T_{\mathrm{vib}} = \frac{1}{2}D_{\beta\beta}(\beta,\gamma)\dot{\beta}^2 + \dots$$
$$\rightarrow \frac{1}{2}D\dot{\beta}^2 + \dots$$

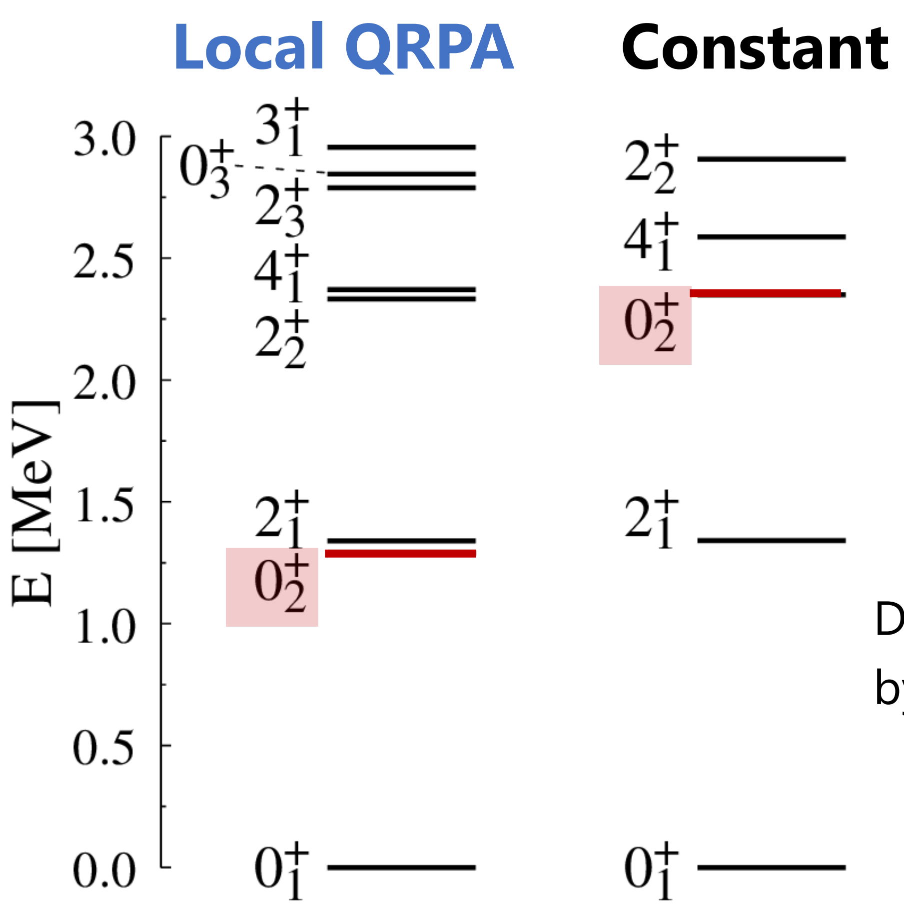
Ignore β–γ dependence of Local QRPA inertial functions

Low $R_{0/2}$ ~~←~~ potential

← inertial functions

= **dynamical correlations**

Low-lying spectra in ^{60}Ca

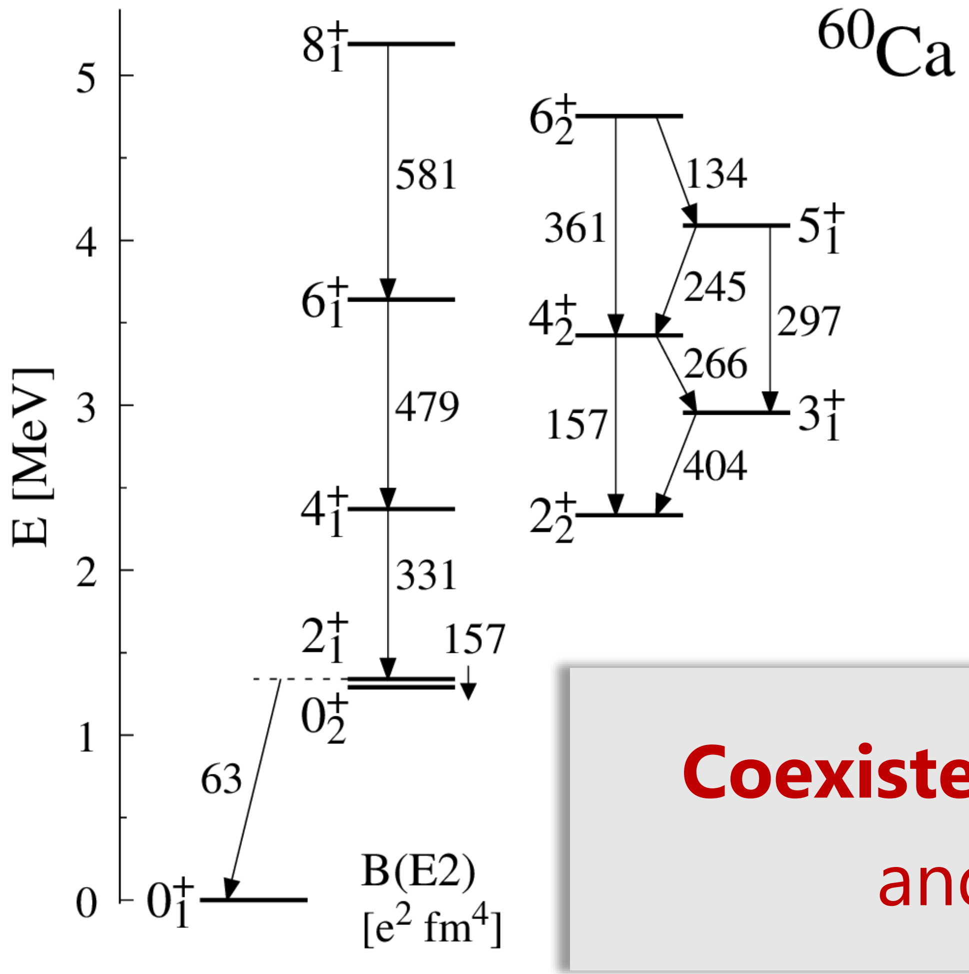


$R_{0/2}$ = 0.96   1.75

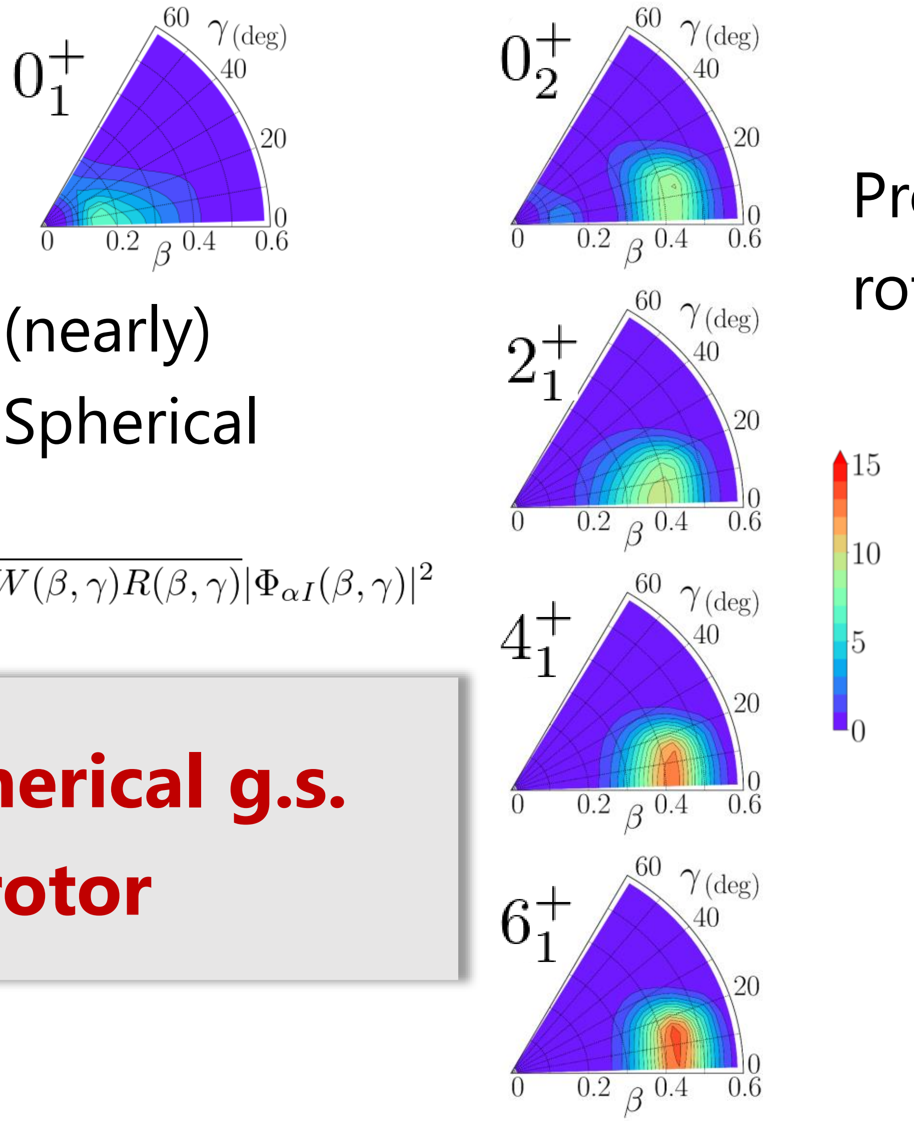
D is determined by fitting to $E(2_1)$

Dynamical shape coexistence in ^{60}Ca

Band structure in ^{60}Ca



Collective wave functions



(nearly) Spherical

$$\beta^4\sqrt{W(\beta,\gamma)R(\beta,\gamma)}|\Phi_{\alpha I}(\beta,\gamma)|^2$$

Prolate rotor

Coexistence of spherical g.s.
and **prolate rotor**

Summary

Low-lying spectra in N=40 neutron-rich nuclei

Dynamical shape coexistence in ^{60}Ca

Potential: Spherical-vibrator-like potential

Dynamical correlations in the kinetic energies

→ generate low 0_2^+ state

→ spherical-like ground state and prolate-rotor 0_2^+ band

This research used computational resources of Wisteria/BDEC-01 Odyssey (Univ. Tokyo),
provided by the Multidisciplinary Cooperative Research Program in CCS, Univ. Tsukuba.