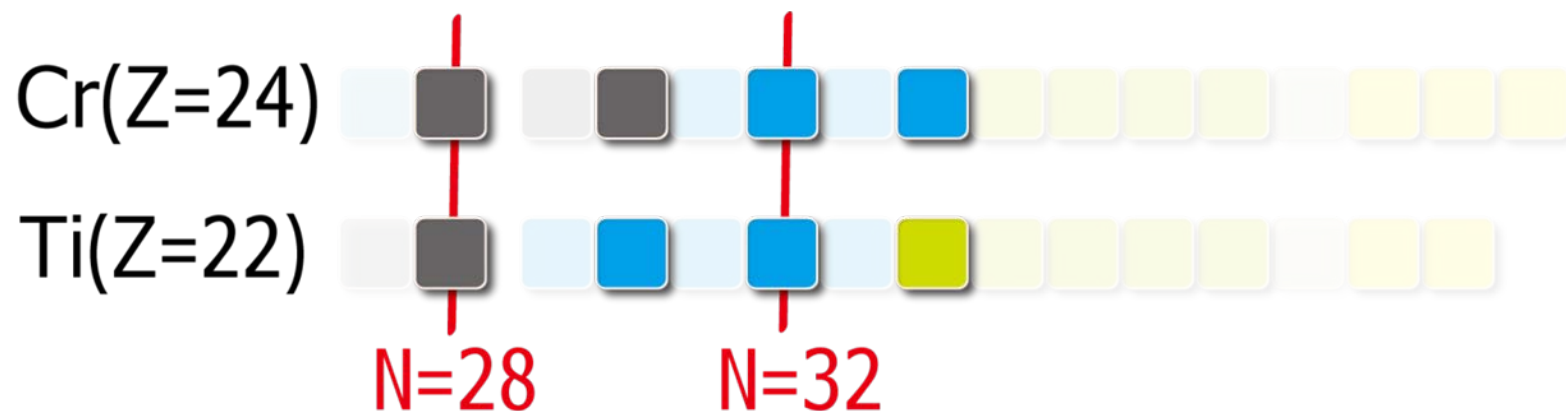# Shape coexistence and Triaxial deformation in Cr isotopes studied by AMD-HFB model

Masaaki Kimura (Hokkaido Unaiv.)

Introduction: 2+ and B(E2) of Ti and Cr

Cr(Z=24)

Ti(Z=22)

N=28   N=32

Characteristic behavior of 2+ and B(E2) is reported by exp
- New magic number in N≠Z nucleus
- Change of deformation depends on neutron number
- Shape coexistence and triaxial deformation are expected

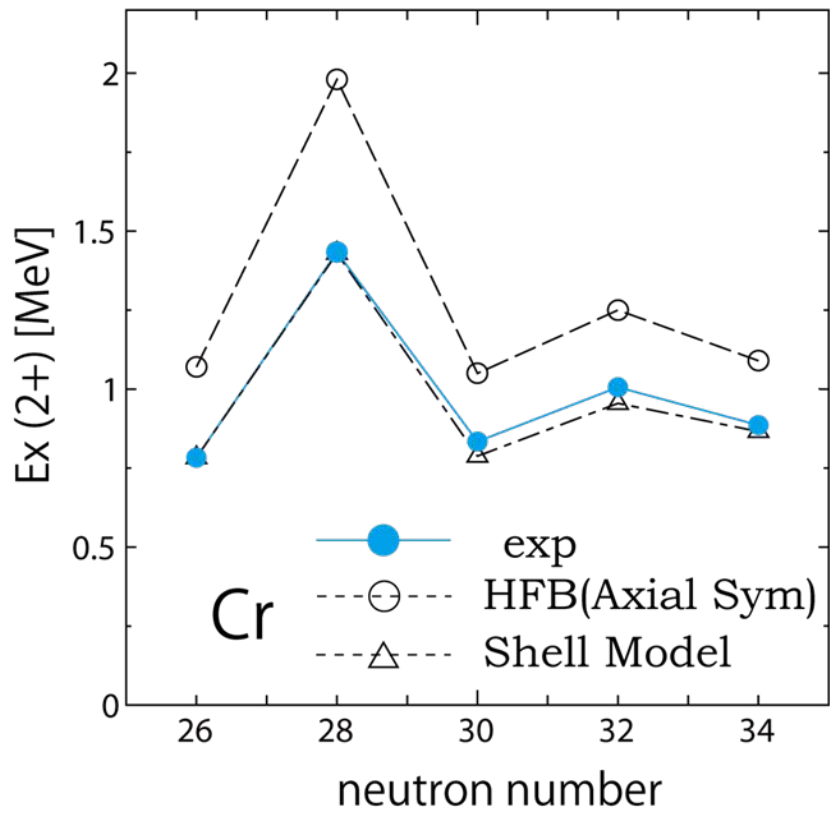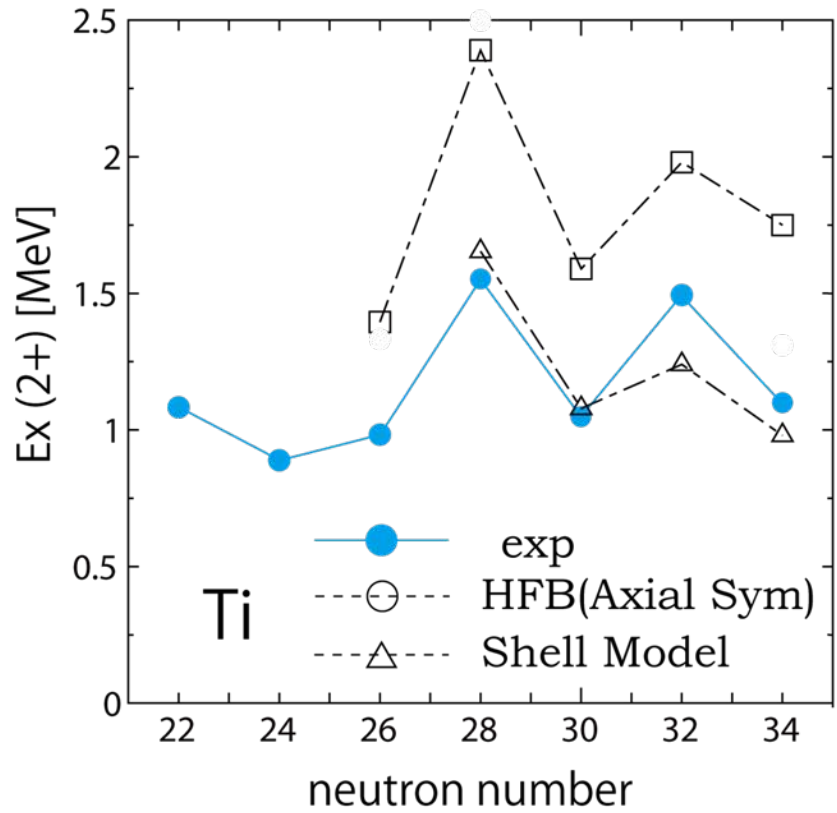Shell model : T. Otsuka et al., Eur. Phys. J. A 15, 151 (2002).
HFB+GCM: T.R. Rodriguez, et. al. PRL99, 062501(2007).

Introduction: Excitation energy of Ti and Cr 2^+ states

- Staggering behavior of observed 2^+ energies
- Shell model and HFB calculations reproduces this behavior
    Shell model: GXPF1A interaction
    HFB: Axial symmetry, Beyond mean-field (N, J projection, GCM)

Introduction: $B(E2)$ of Ti and Cr

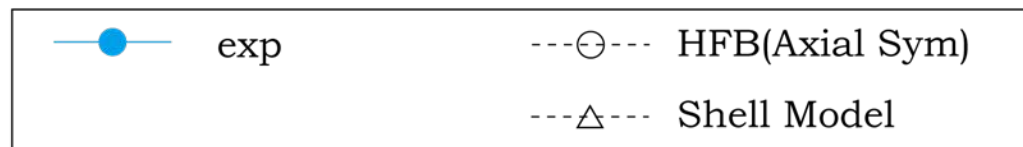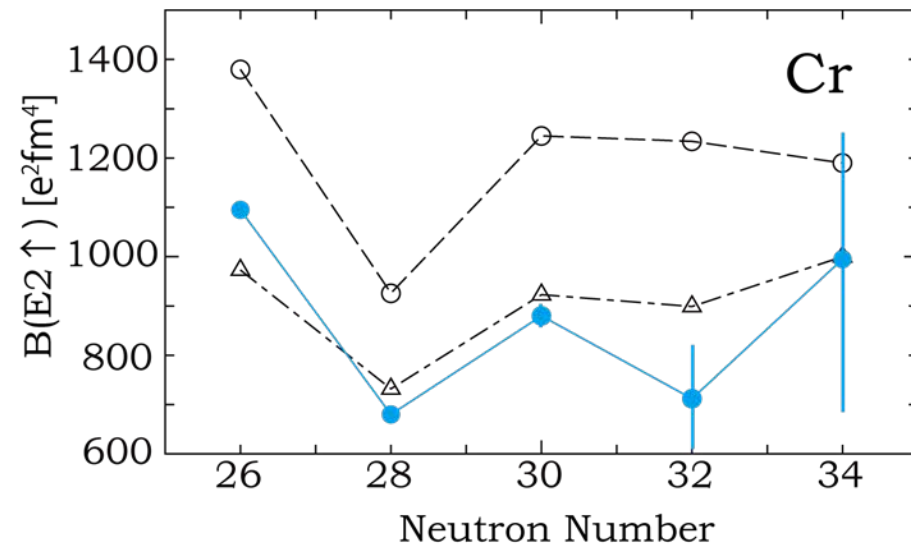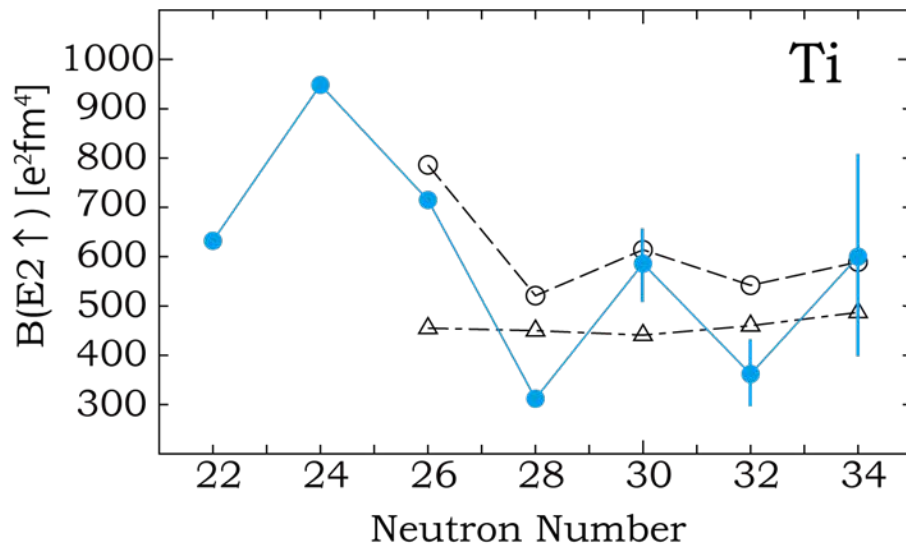- Staggering behavior of observed B(E2) (Magicity of N=32?)
- Ti

  Shell model: Almost constant B(E2) (constant effective charge)

  HFB+GCM: Staggering behavior is reproduced

- Cr

  Shell model: Staggering behavior is reproduced

  HFB+GCM: Overestimation for all isotopes

Introduction: Aim of the study

Structure of Ti and Cr isotopes

Shell model : T. Otsuka et al., Eur. Phys. J. A 15, 151 (2002).
HFB: T.R. Rodriguez, et. al. PRL99, 062501(2007).

• Change of deformation depending on neutron number

• Coexistence of prolate and oblate deformation

• Importance of particle number projection to describe zigzag behavior

• Possibility of triaxial deformation

⟹   Investigation of deformation of Ti and Cr isotopes

Construction of theoretical model that can treat

• deformation of nucleus without assumption on its symmetry

• beyond mean-field calculations (N, J projections, GCM,…)

• Clustering phenomena
    (extention of Antisymmetrized Molecular Dynamics)

Framework: AMD+HFB

Hamiltonian: $\hat{H} = \hat{T} + \hat{V}_N + \hat{V}_C - \hat{T}_g$

Effective interaction: Gongy D1S

Wave function: HFB type wave function (uses localized Gaussian as basis

$$|\Psi\rangle = \prod_{i=1}^{M} \beta_i |0\rangle$$

$$\beta_i = U_{pi}^* a(Z_p) + V_{pi}^* a^\dagger(Z_p)$$

$$\langle \vec{r} | a^\dagger(Z_p) | 0 \rangle = \left(\frac{2v}{\pi}\right)^{3/4} \exp\left\{-v\left(\vec{r} - \frac{\vec{Z}_p}{\sqrt{v}}\right)^2 + \frac{1}{2} Z_p^2\right\}$$

$$\{a_i(\vec{Z}_p), a_j^\dagger(\vec{Z}_q)\} = b(\vec{Z}_p, \vec{Z}_q)$$

AMD

$$|\Psi\rangle = a^+(Z_1)...a^+(Z_A)|0\rangle$$

HFB with H.O. basis

$$|\Psi\rangle = \prod_{i=1}^{M} \beta_i |0\rangle,$$

$$\langle r | a^+_i | 0 \rangle = \phi_{njm}(r)$$

Variational calculation:

• Variation of U and V: ordinary HFB equations (gradient method)

• Variation of basis wave function Z: AMD like equation
  (equation of motion for wave packets)

Number and J projection and GCM

• Numerical Integration is required. Small number of basis wave function reduces CPU time

Framework: AMD+HFB

Energy Surface of ^{20}Ne(0^+)

AMD+HFB

α-th

HFB (HO)

α-th

^{20}Ne
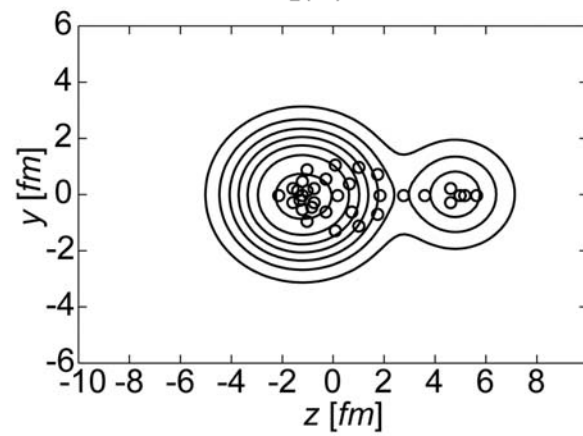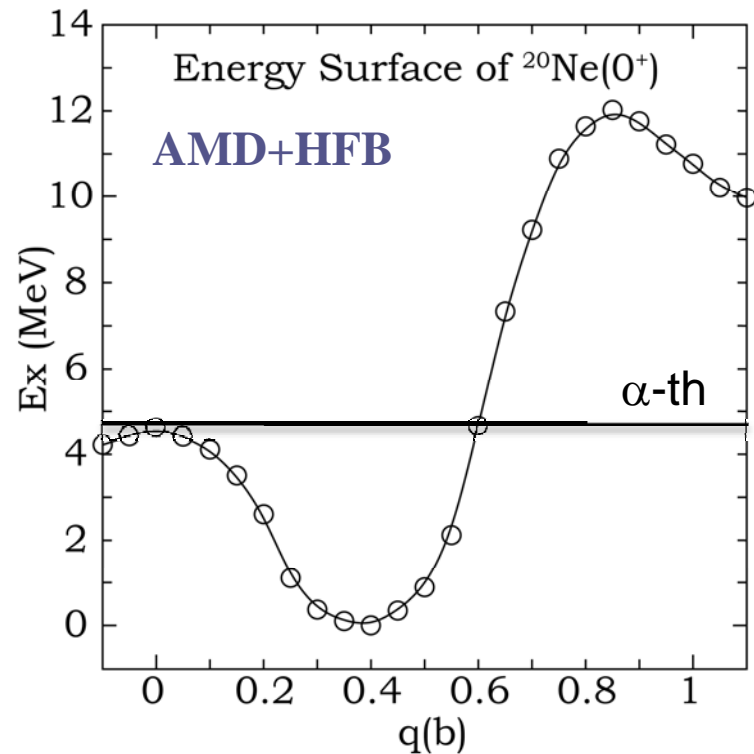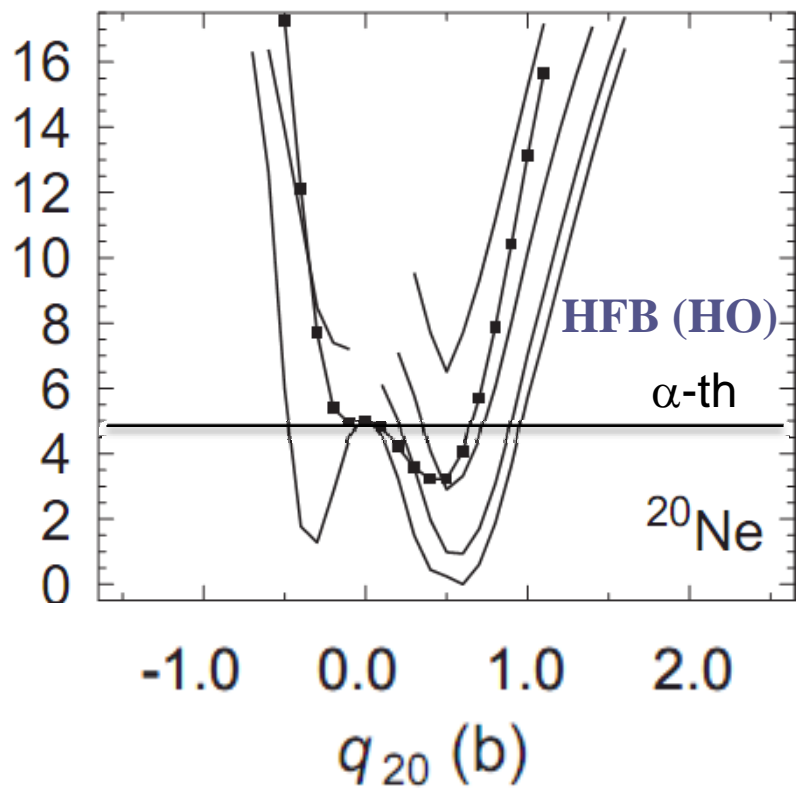
Results: Energy surface for β deformation

**Results of axial symmetric calculation
(Projected to $J^{\pi}=0^{+}$ and N projection)**
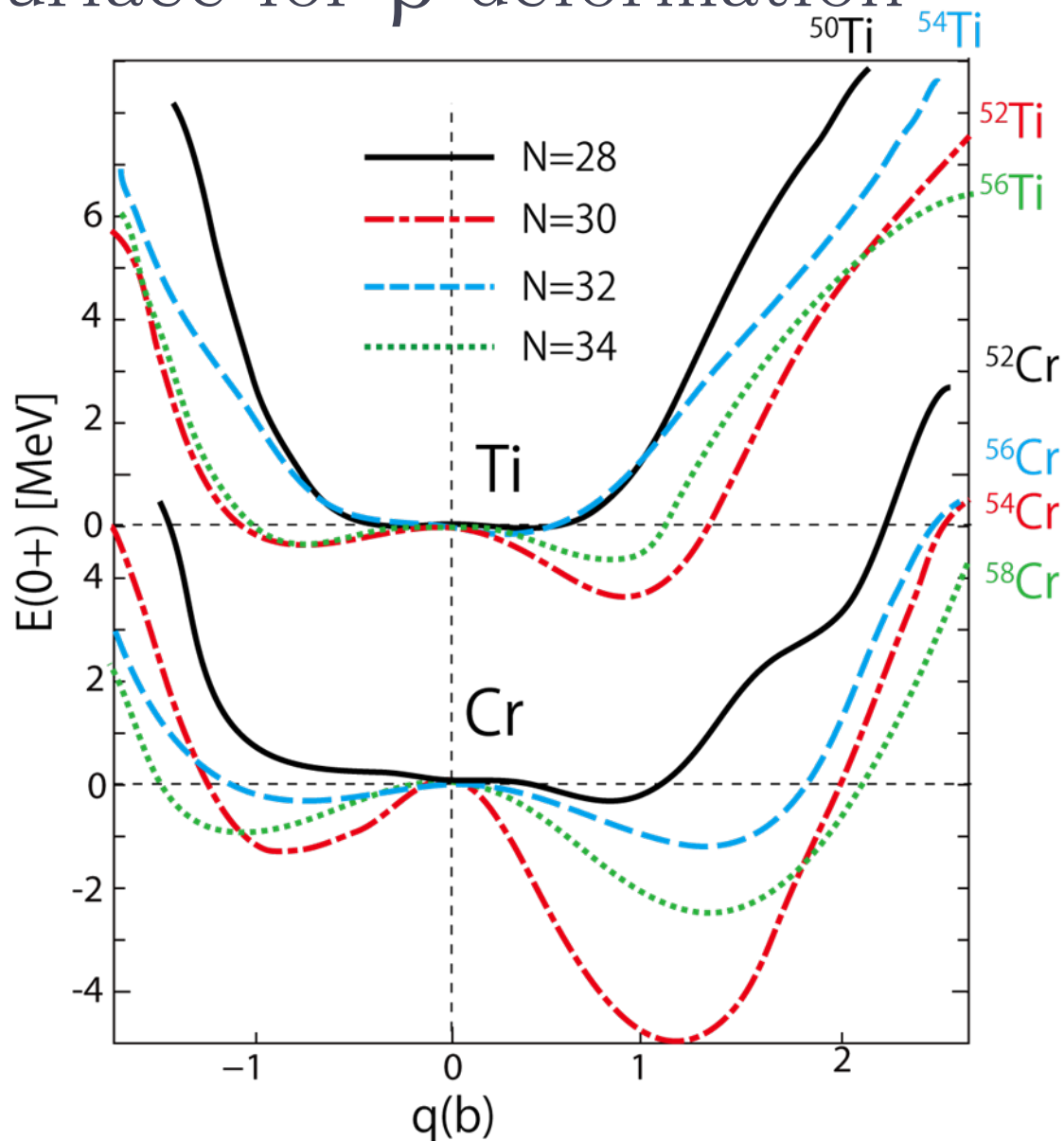
• Change of energy surface depending on neutron number

N=30, 34 :
Well developed prolate minimum.
Coexistence of prolate and oblate minimum.
N=28, 32 :
Shallower prolate minimum
 or spherical

• Larger deformation of Cr than Ti

Results: Energy surface for γ deformation

Results of triaxial calculation g=15 and 45 degree (Projected to $J^{\pi}=0^{+}$ and N projection)

- Intrinsic energy (Energy before projection) is higher than axial case
- After the J projection, triaxial state is more deeply bound than axial states in ^{54}Cr and ^{58}Cr

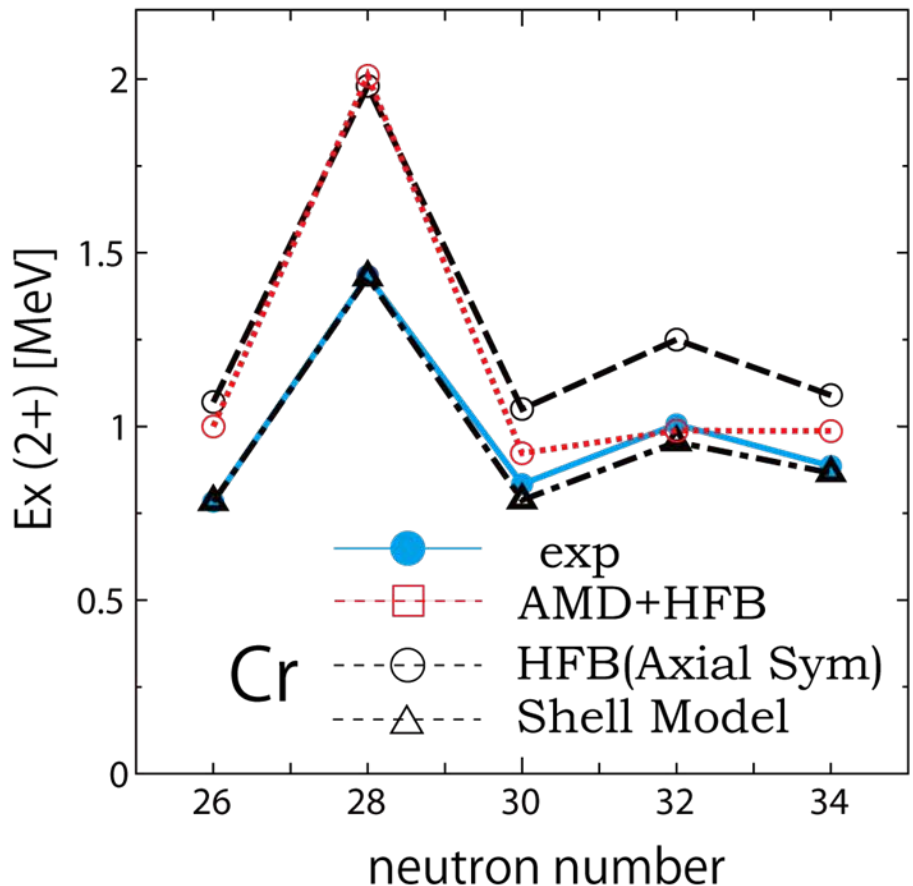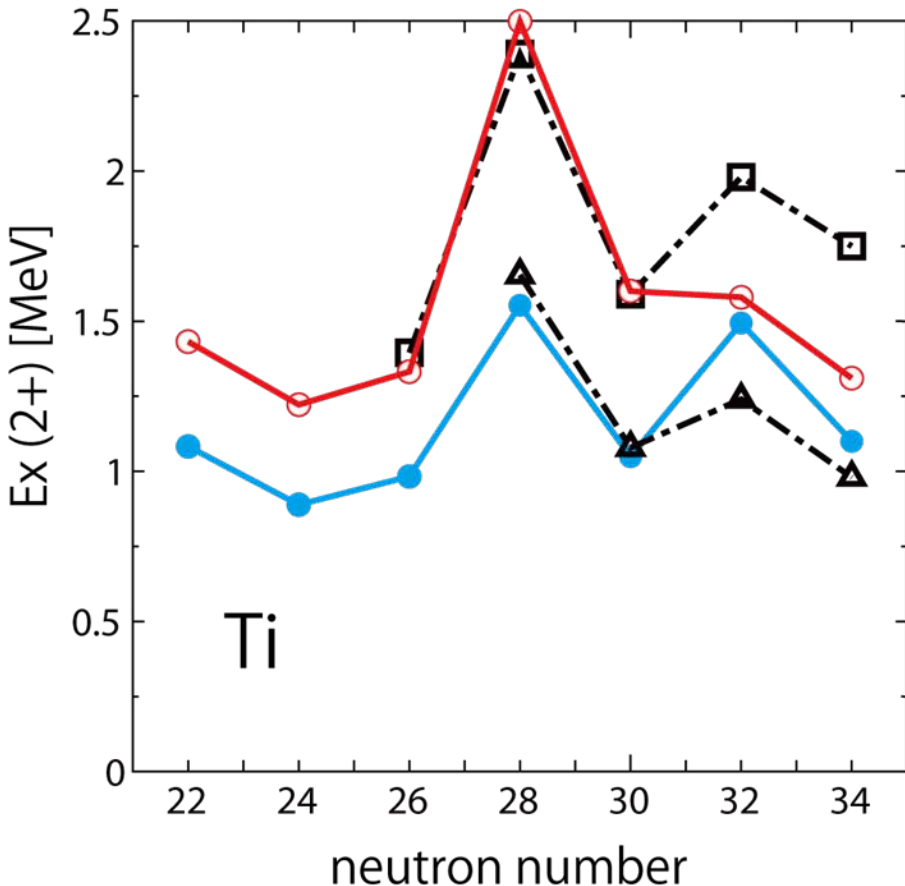This leads to the mixing of prolate, oblate and triaxial states after GCM calculation
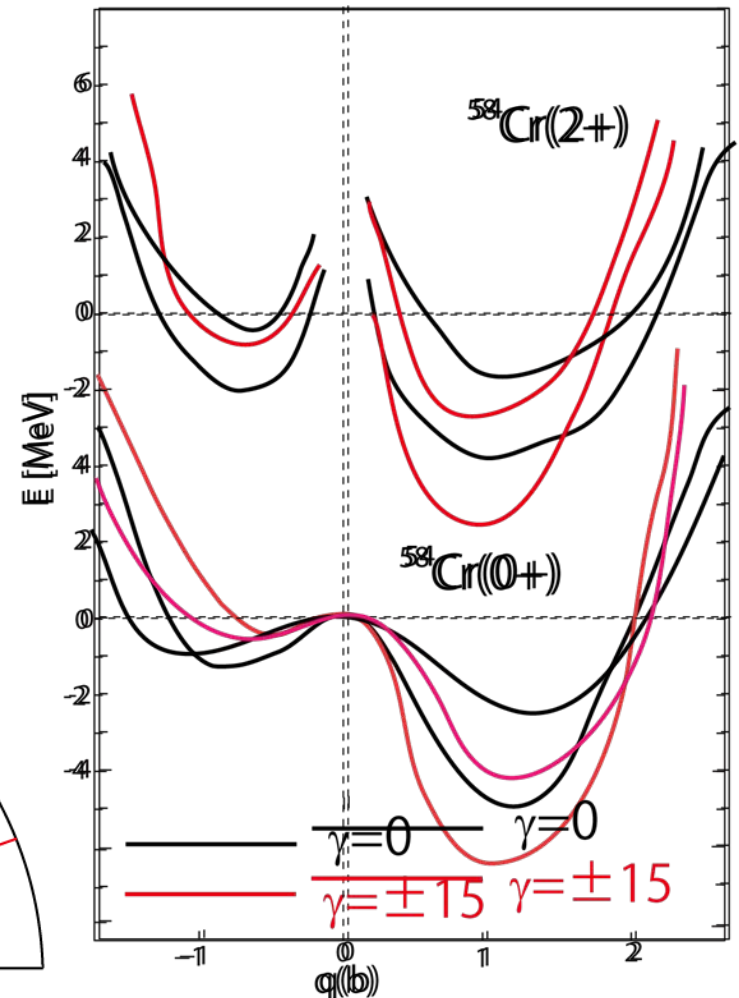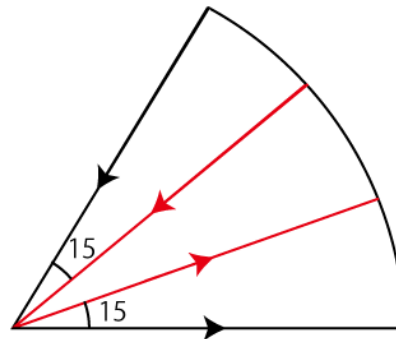
Results: Excitation energy of 2^+ states of Ti and Cr

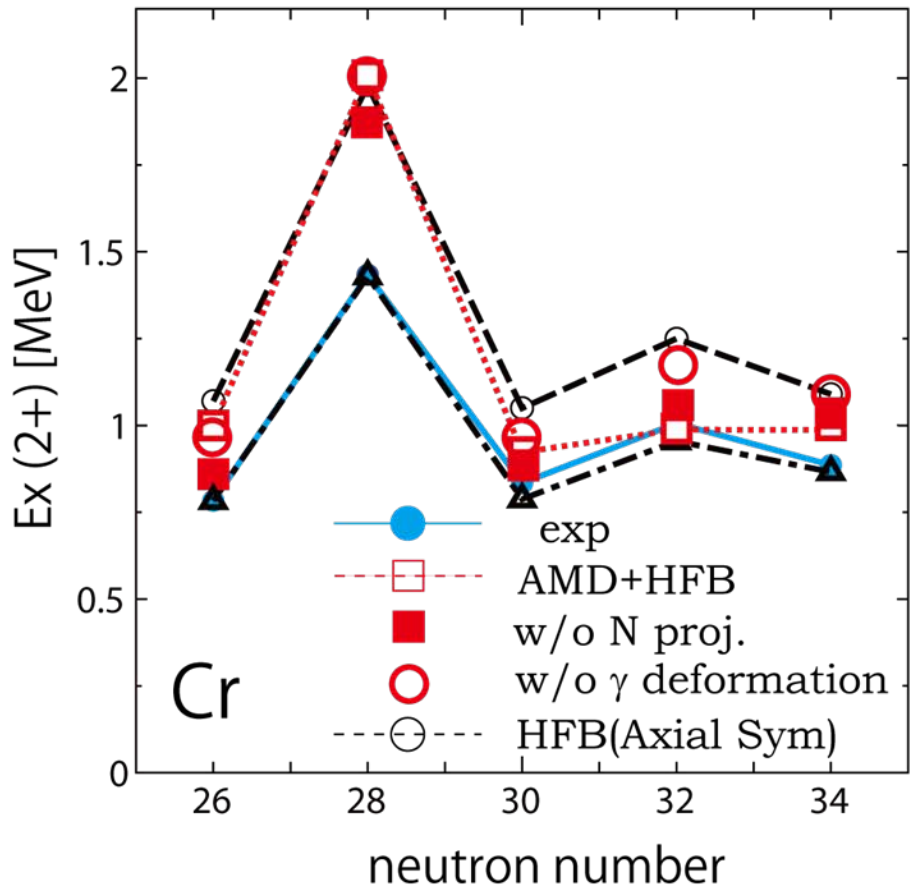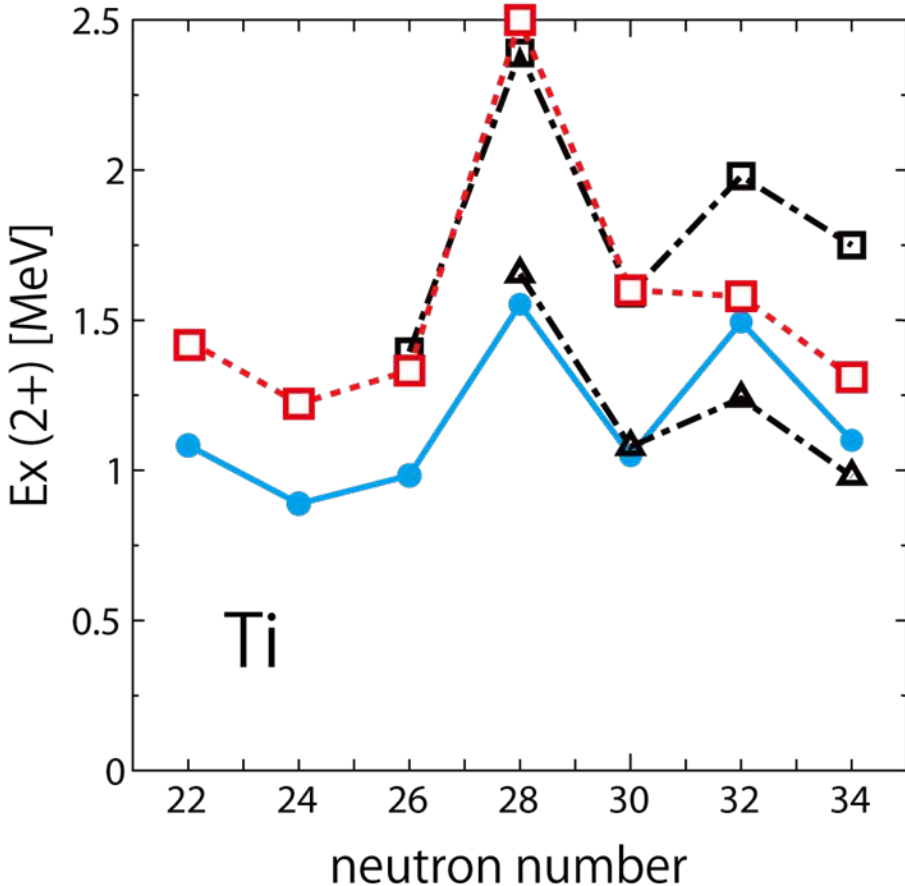## Results of triaxial calculation (projection and GCM)

- 2^+ energies are improved for N=30, 32, and 34 systems
- Triaxial deformation reduces 2^+ energies
- Energy gain by the triaxial deformation is rather small.

Results: Effect of N proj. and triaxality to 2+ energy

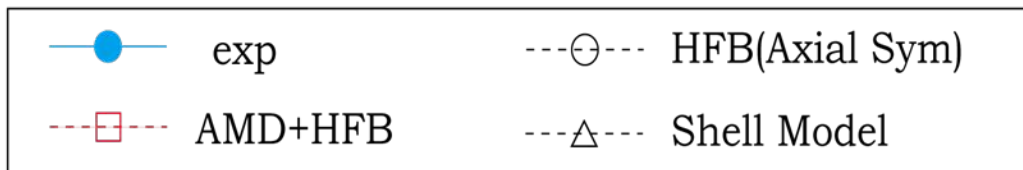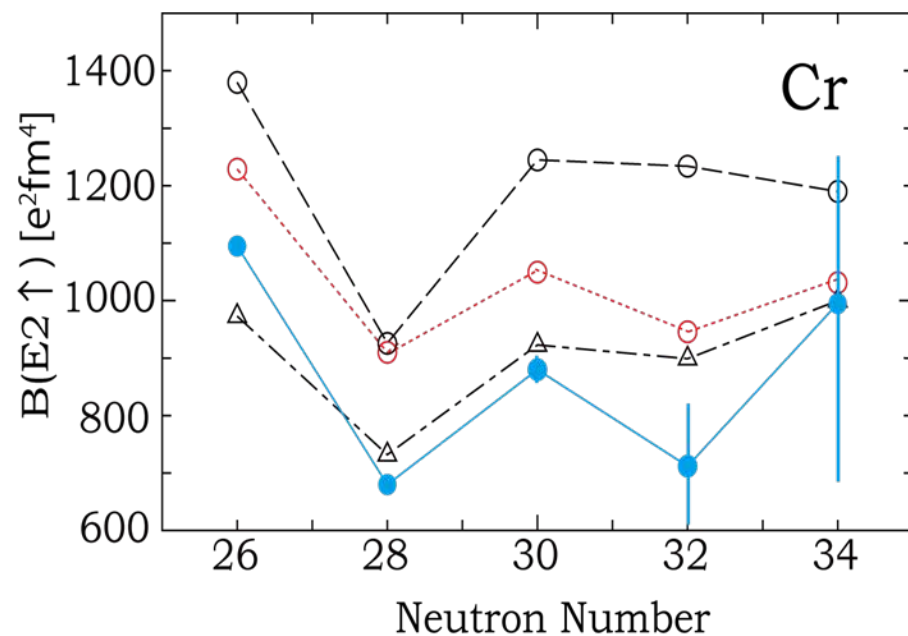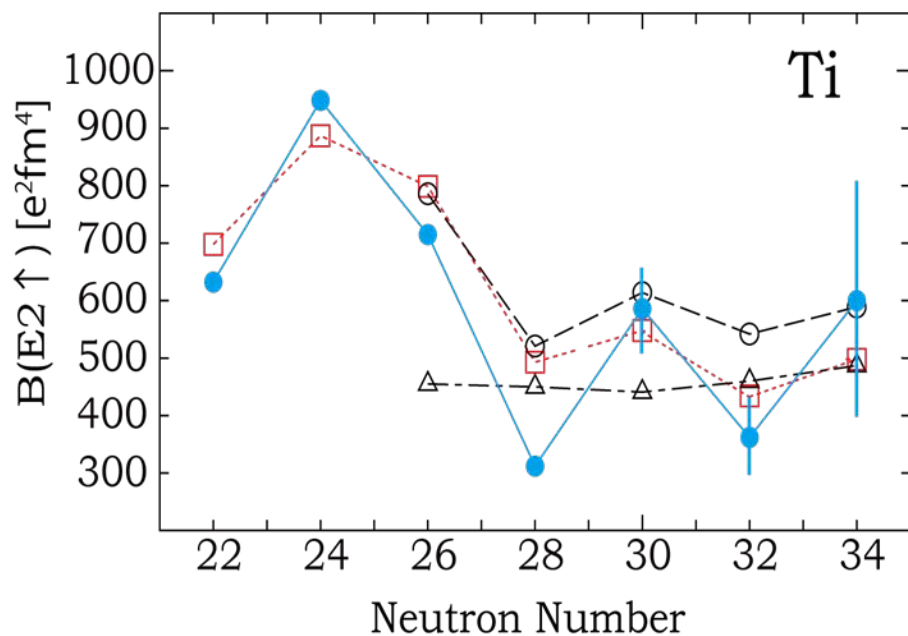Comparison of axial v.s. triaxial and N projected and unprojected calculations
- N projection has weaker effect on 2^+ energies
- Triaxial deformation lowers 2+ energies by a 200~300 keV

Results: B(E2) of Ti and Cr

Results of triaxial calculation (projection and GCM)

- Reduction of B(E2) in N=30, 32 and 34 System
- Cr isotopes have larger reduction due to their larger triaxial effect
  that is most apparent in ^{56}Cr(N=32)

Results: B(E2) of Ti and Cr

Comparison of axial v.s. triaxial and N projected and unprojected calculations
- N projection does not have large effect
- Triaxial deformation greatly reduces B(E2) of ^{54,56,58}Cr (N=30, 32,34)
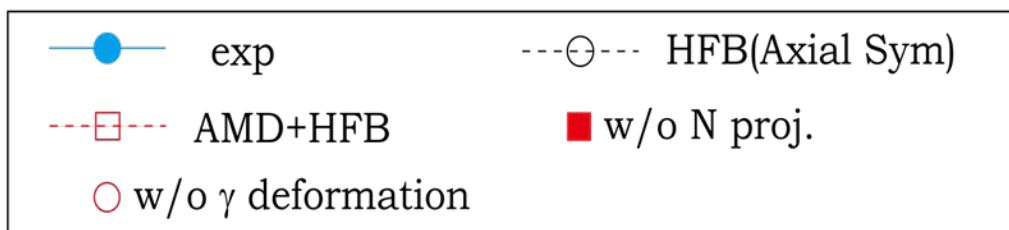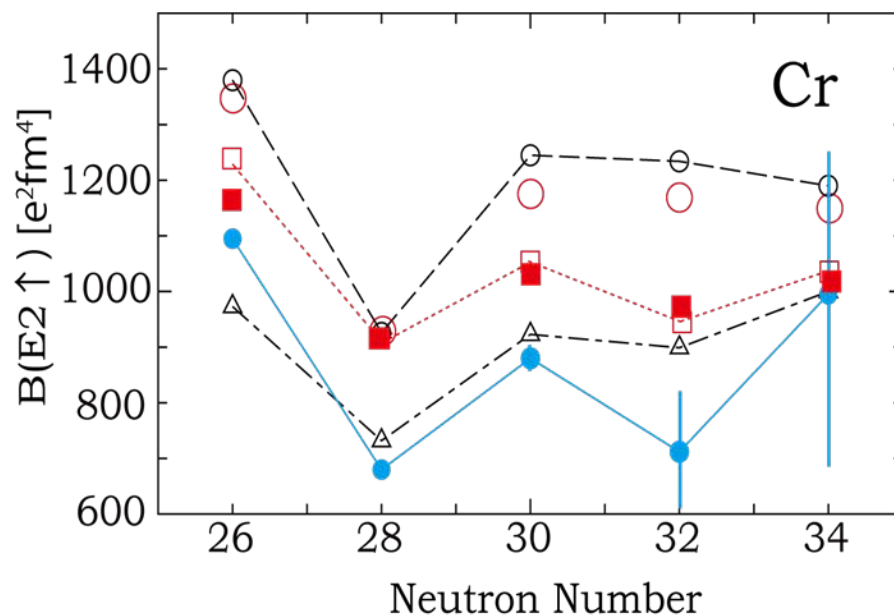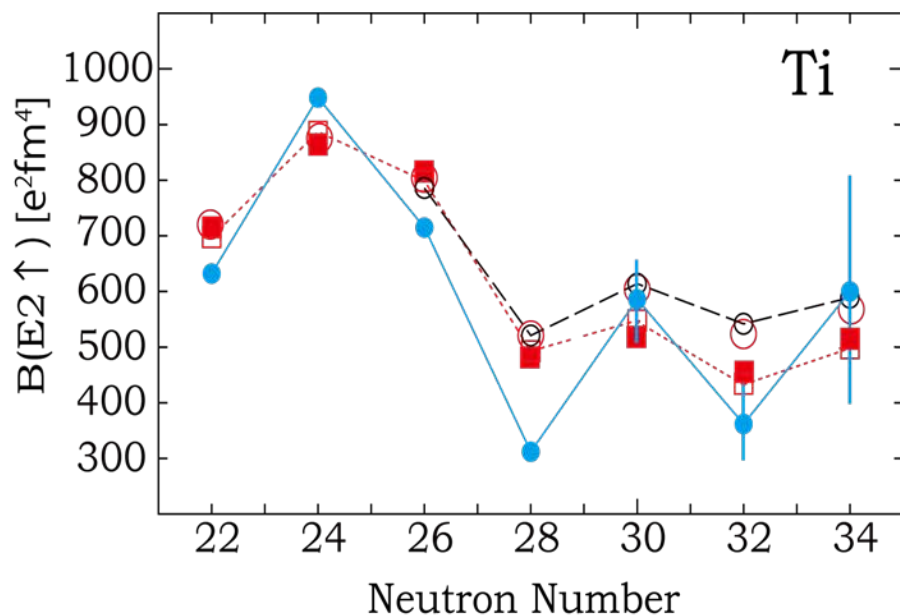
Summary & Outlook

Theoretical Framework of AMD+HFB is suggested

• Deformation of nucleus without assumption on its symmetry

• Beyond mean-field calculations (N, J projections, GCM,…)

• Clustering phenomena
   (extention of Antisymmetrized Molecular Dynamics)

Behavior of 2+ and B(E2) of Ti and Cr isotopes

• Coexistence of prolate and oblate deformation

• Development of triaxial deformation
   (most prominent in ^{54}Cr and ^{58}Cr)

• Mixing of prolate, oblate and triaxial wave functions

• This mixing greatly reduces the B(E2) of Cr isotopes (N $\geqq$ 30)

Outlook

Triaxial deformation and shape coexistence in ^{43}S