“Mean-field” calculations for IoI

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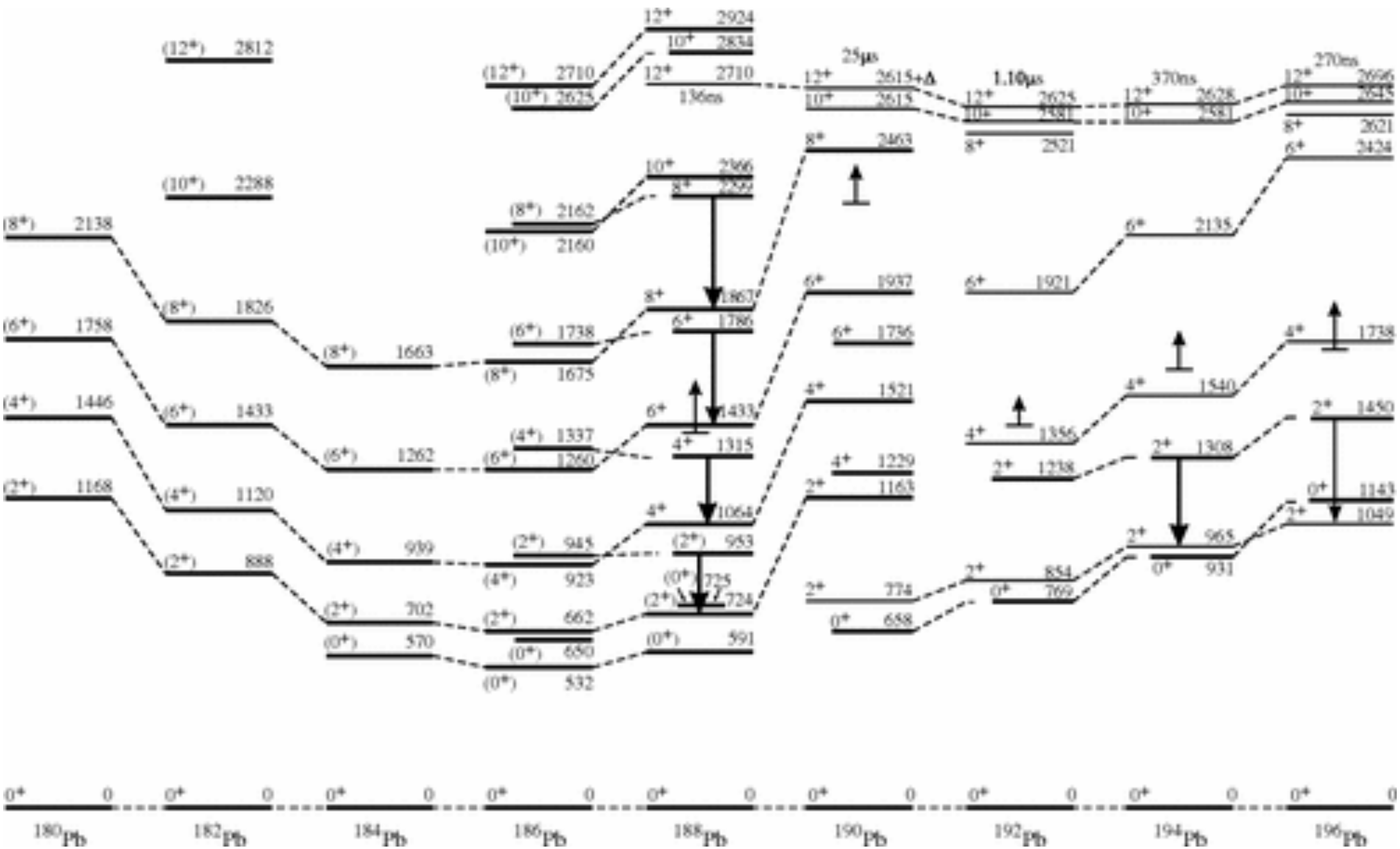
“Beyond mean-field” approaches based on the mean-field models

Ohta, Yabana, Nakatsukasa,
(method, stable nuclei) Phys. Rev. C70 (2004) 14301
(Mg isotopes) J. Phys. Conf. Ser. 20 (2005) 211

RIBF Discussion Plus! 2014.4.25

Singly-closed nuclei

Appearance of low-lying deformed states (intruder 0+)



Mean-field (density functional) approaches

- Minimization of the total energy automatically determines s.p. energies, (pair, def.) correlations, etc. for a given nucleus.

- Spherical shell gap at N=20 is about 4 MeV (SkM*)
  - Deformed H.F. ground state (SkM*)
  - Spherical H.F. ground state (SGII)
  - Correlation beyond the mean-field is important.

VAP on parity

Parity-projected wave function

$$\left|\Phi\right\rangle = \det\{\phi_1 \cdots \phi_n\}$$ **(Slater determinant)**

$$\left|\Phi^{(\pm)}\right\rangle = \left|\Phi\right\rangle \pm \hat{\mathrm{P}}\left|\Phi\right\rangle$$

Parity eigenstates

Energy functional

$$\mathrm{E}^{(\pm)} = \frac{\left\langle\Phi^{(\pm)}\middle|\hat{\mathrm{H}}\middle|\Phi^{(\pm)}\right\rangle}{\left\langle\Phi^{(\pm)}\middle|\Phi^{(\pm)}\right\rangle} = \frac{\left\langle\Phi\middle|\hat{\mathrm{H}}\middle|\Phi\right\rangle \pm \left\langle\Phi\middle|\hat{\mathrm{H}}\hat{\mathrm{P}}\middle|\Phi\right\rangle}{1 \pm \left\langle\Phi\middle|\hat{\mathrm{P}}\middle|\Phi\right\rangle}$$

Variation after projection

Orthonormalization

COM

$$\frac{\delta}{\delta\phi_i^*}\left[\frac{\left\langle\Phi^{(\pm)}\middle|\hat{\mathrm{H}}\middle|\Phi^{(\pm)}\right\rangle}{\left\langle\Phi^{(\pm)}\middle|\Phi^{(\pm)}\right\rangle} - \sum_{ij} e_{ij}\{\left\langle\phi_i\middle|\phi_j\right\rangle - \delta_{ij}\} - \vec{\eta}\cdot\left\langle\Phi\middle|\sum_i \vec{r}_i\middle|\Phi\right\rangle\right] = 0$$

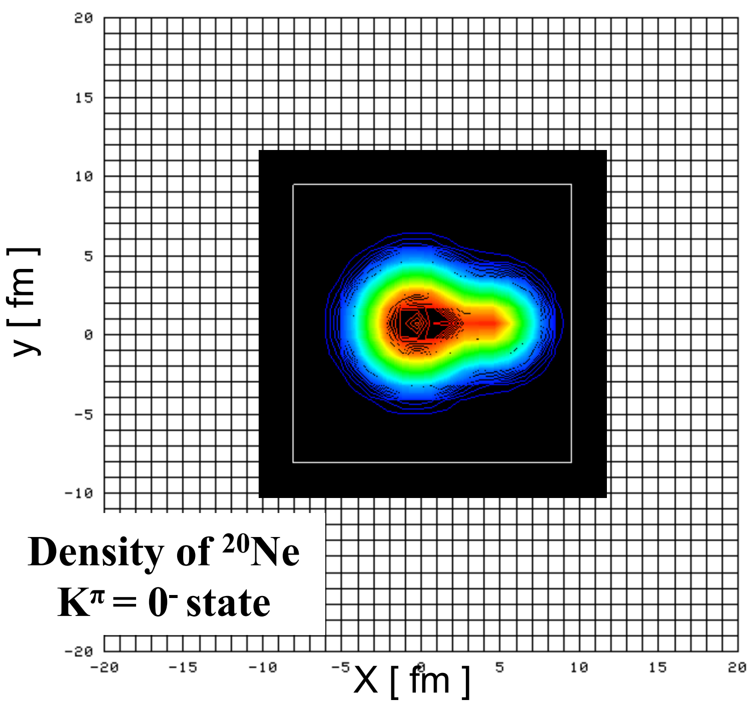
Parity-Projected Skyrme Hartree-Fock equation

$$(\hat{h}-\eta\cdot\vec{r})\phi_i \pm \langle\Phi|\hat{\mathrm{P}}|\Phi\rangle\{\hat{h}_P\tilde{\phi}_i - \sum_j \tilde{\phi}_j\langle\phi_j|\hat{h}_P|\tilde{\phi}_i\rangle\} + (\mathrm{E}^{(\pm)}-\mathrm{E}_1)\tilde{\phi} = \sum_j e_{ij}\phi_j$$

$$\mathrm{E}_1 = \langle\Phi|\hat{\mathrm{H}}|\Phi\rangle \qquad \tilde{\phi}_i(r) = \sum_{i=1}^{A}\phi_j(\vec{r})(\mathrm{B}^{-1})_{ij} \qquad \mathrm{B}_{ij} = \int d\vec{r}\,\phi_i(\vec{r})\phi_j(-\vec{r})$$

3D space is discretized in lattice

Single-particle orbital: $\phi_i(\mathbf{r}) = \{\phi_i(\mathbf{r}_k)\}_{k=1,\cdots Mr}, \quad i=1,\cdots,N$



Density of ^{20}Ne
$K^\pi = 0^-$ state

N: Number of particles

Mr: Number of mesh points

Spatial mesh size is 0.8 fm.

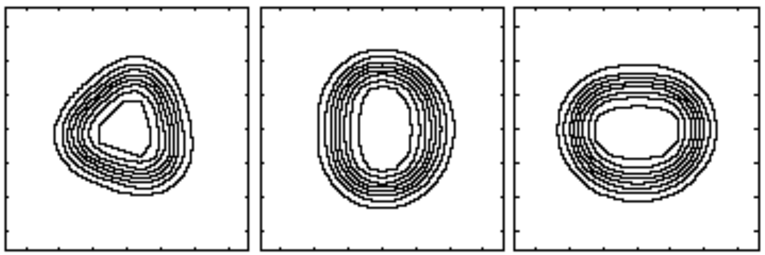
Ohta, Yabana, Nakatsukasa, Phys. Rev. C70 (2004) 14301

Density of ^{30}Mg (SGII)

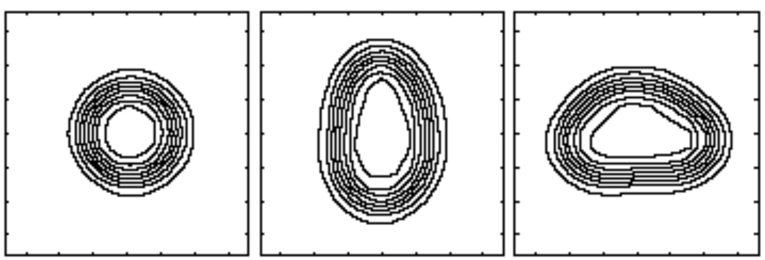
PPSHF ground solution

Even-parity

$K^{\pi} = 0^{+}$ (β_2= 0.223)

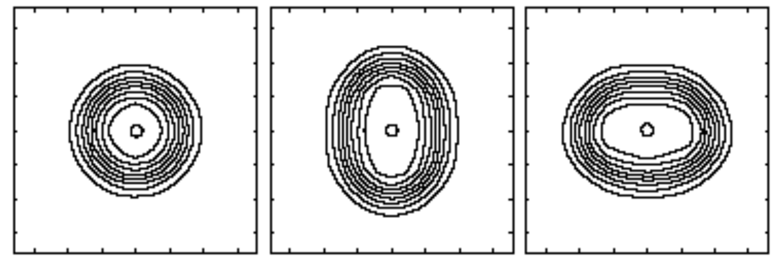


$K^{\pi} = 0^{+}$ (β_2= 0.578)

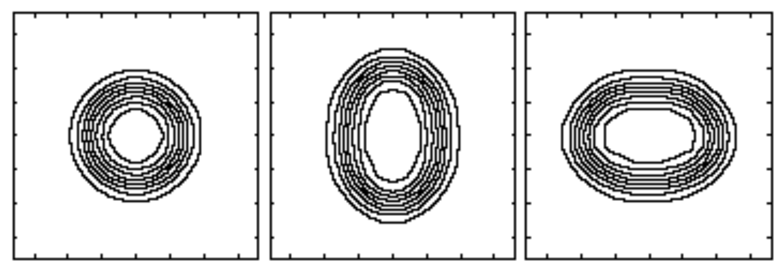


Odd-parity

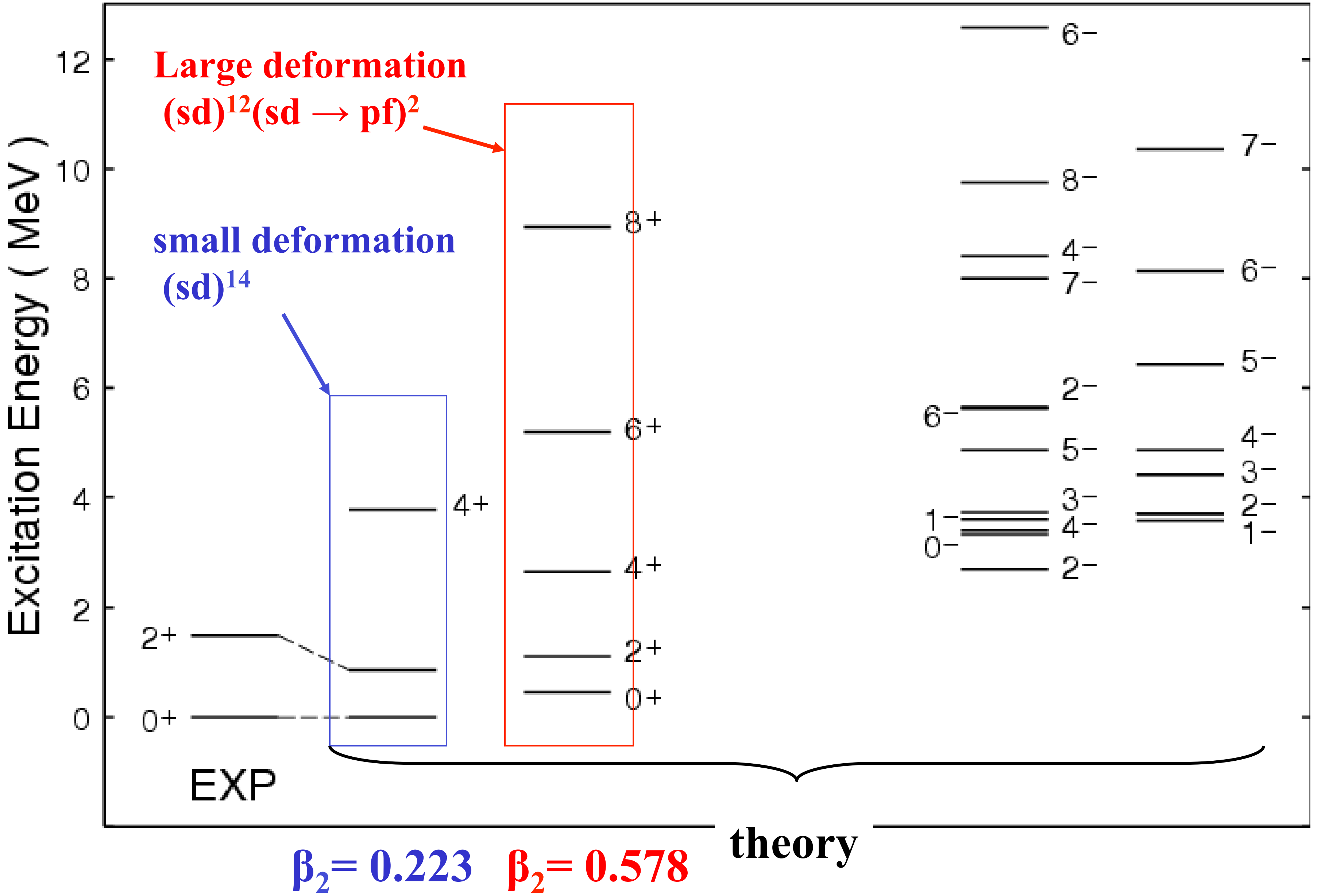
$K^{\pi} = 1^{-}, 0^{-}$ (80.2%, 19.7%)



$K^{\pi} = 1^{-}$



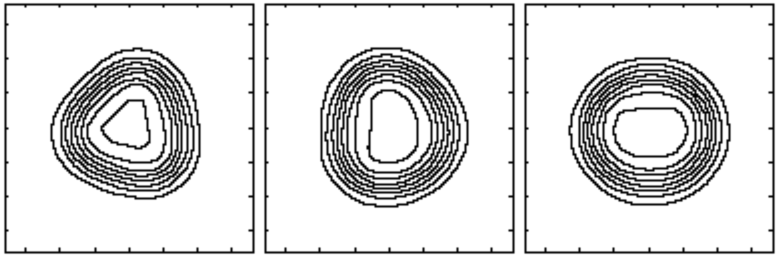
Spectra of ^{30}Mg (SGII)



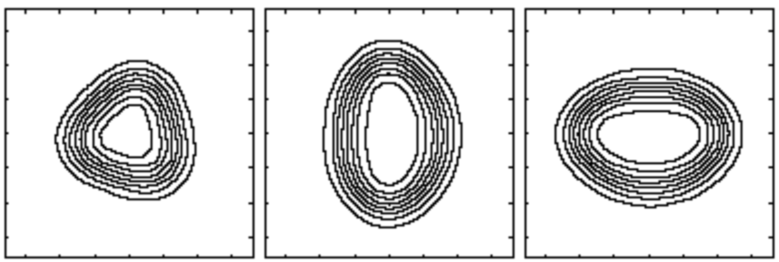
Density of ^{32}Mg (SGII)

PPSHF ground solution

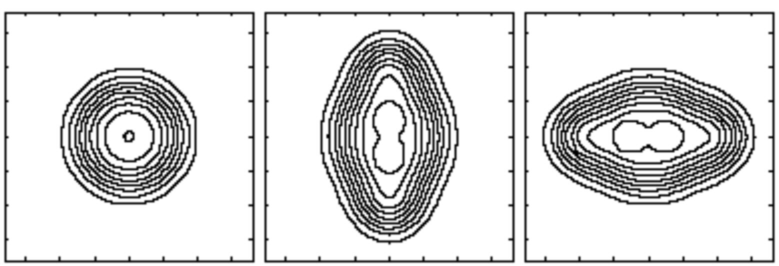
$K^{\pi} = 0^{+}$ ($\beta_2 = 0.095$)



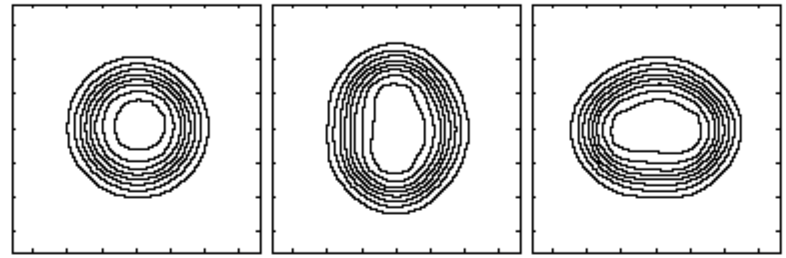
$K^{\pi} = 0^{+}$ ($\beta_2 = 0.438$)



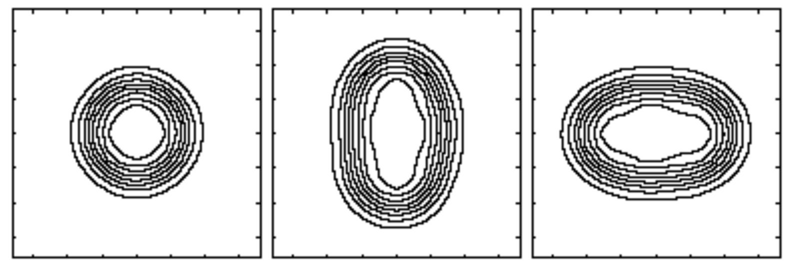
$K^{\pi} = 0^{+}$ ($\beta_2 = 0.679$)



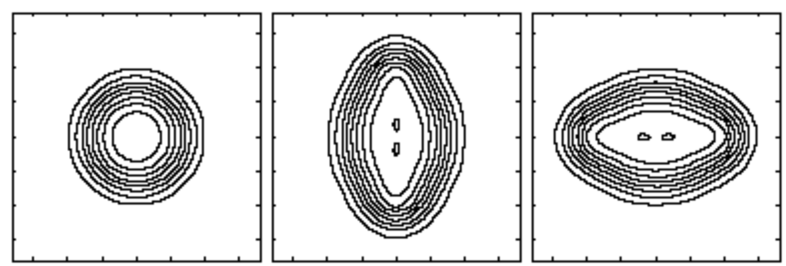
$K^{\pi} = 1^{-}$



$K^{\pi} = 2^{-}, 1^{-}$ (55.1%, 44.8%)

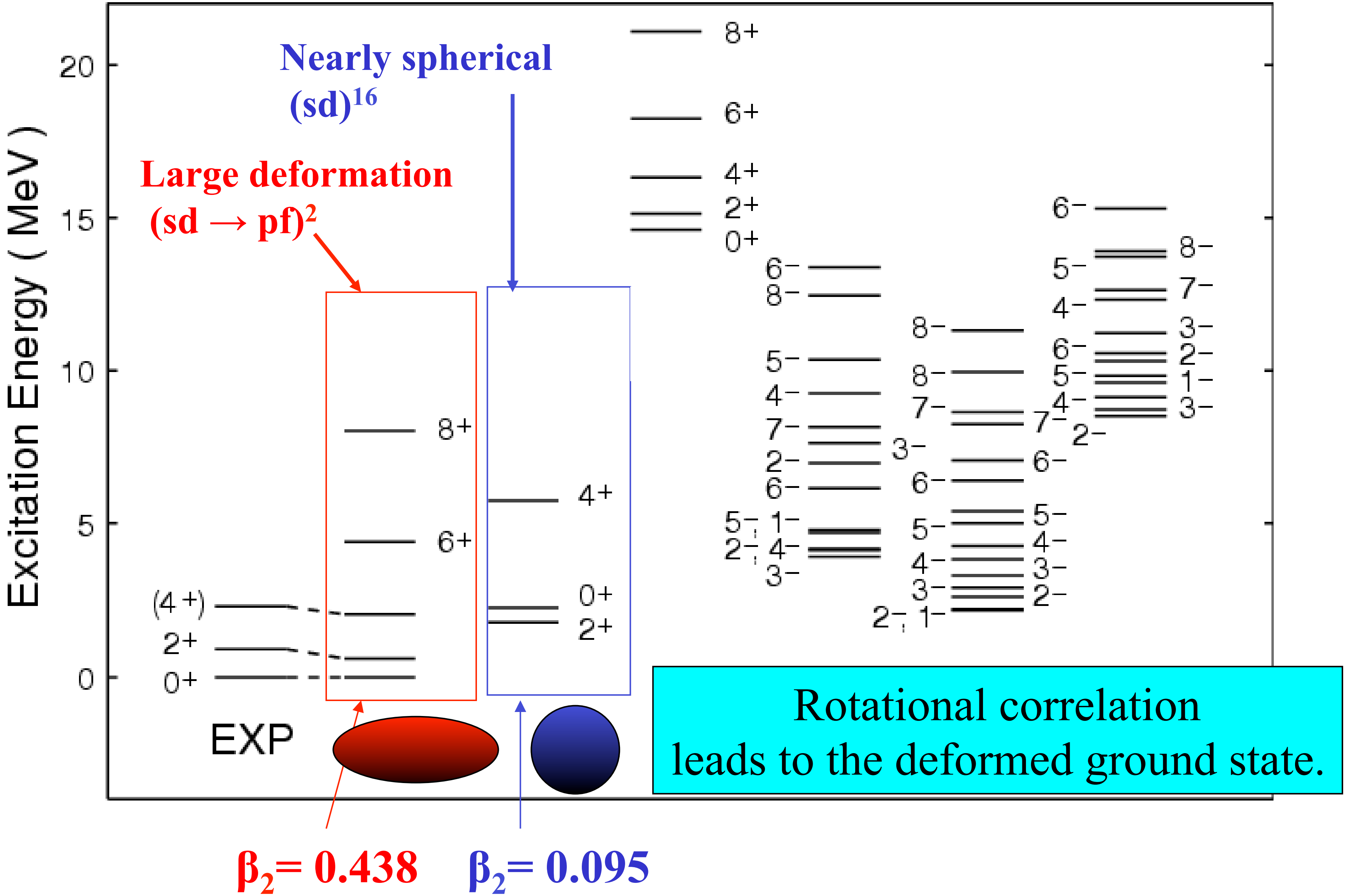


$K^{\pi} = 2^{-}$

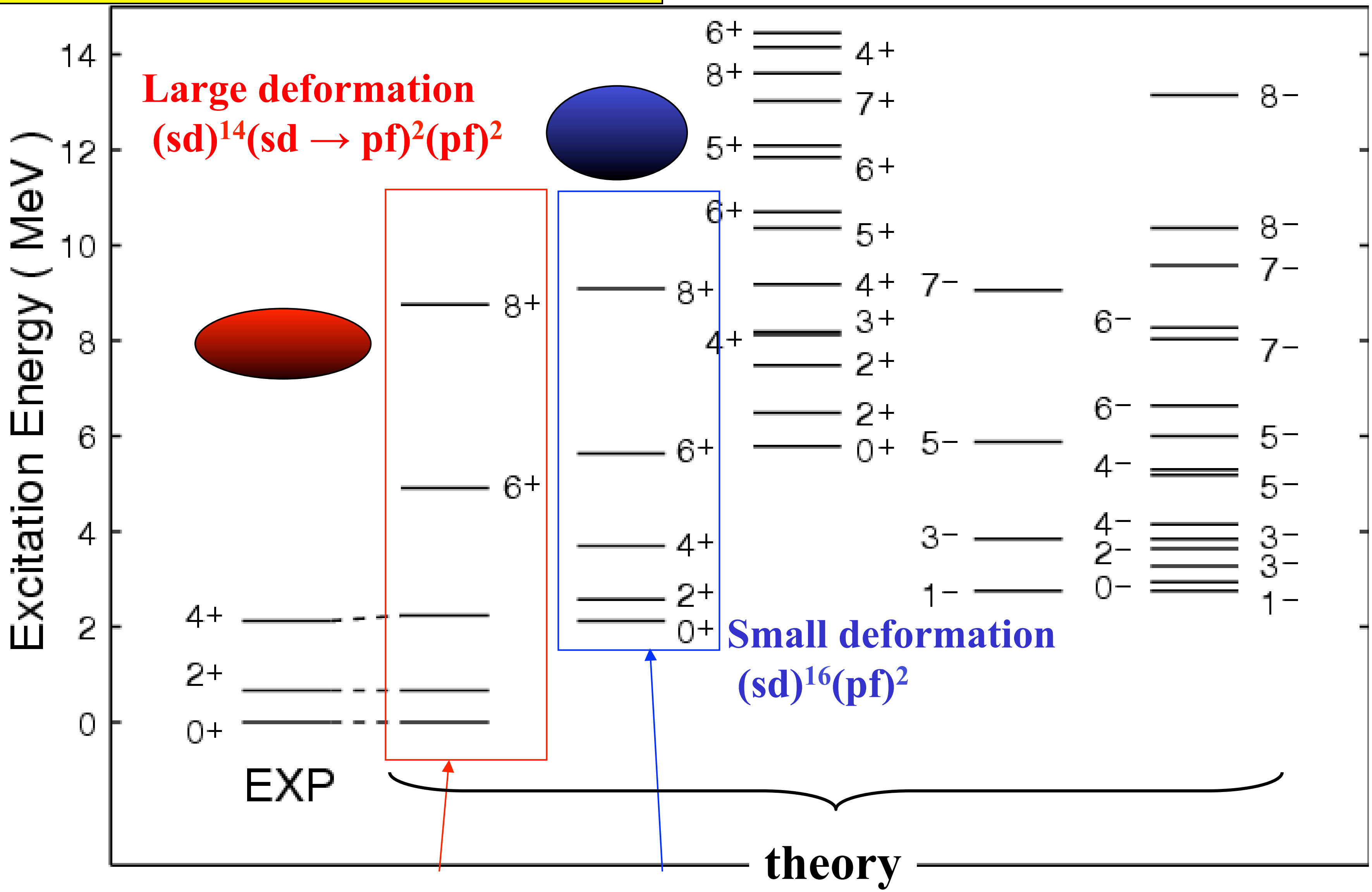


Spectra of ^{32}Mg (SGII)

Significant rotational correction

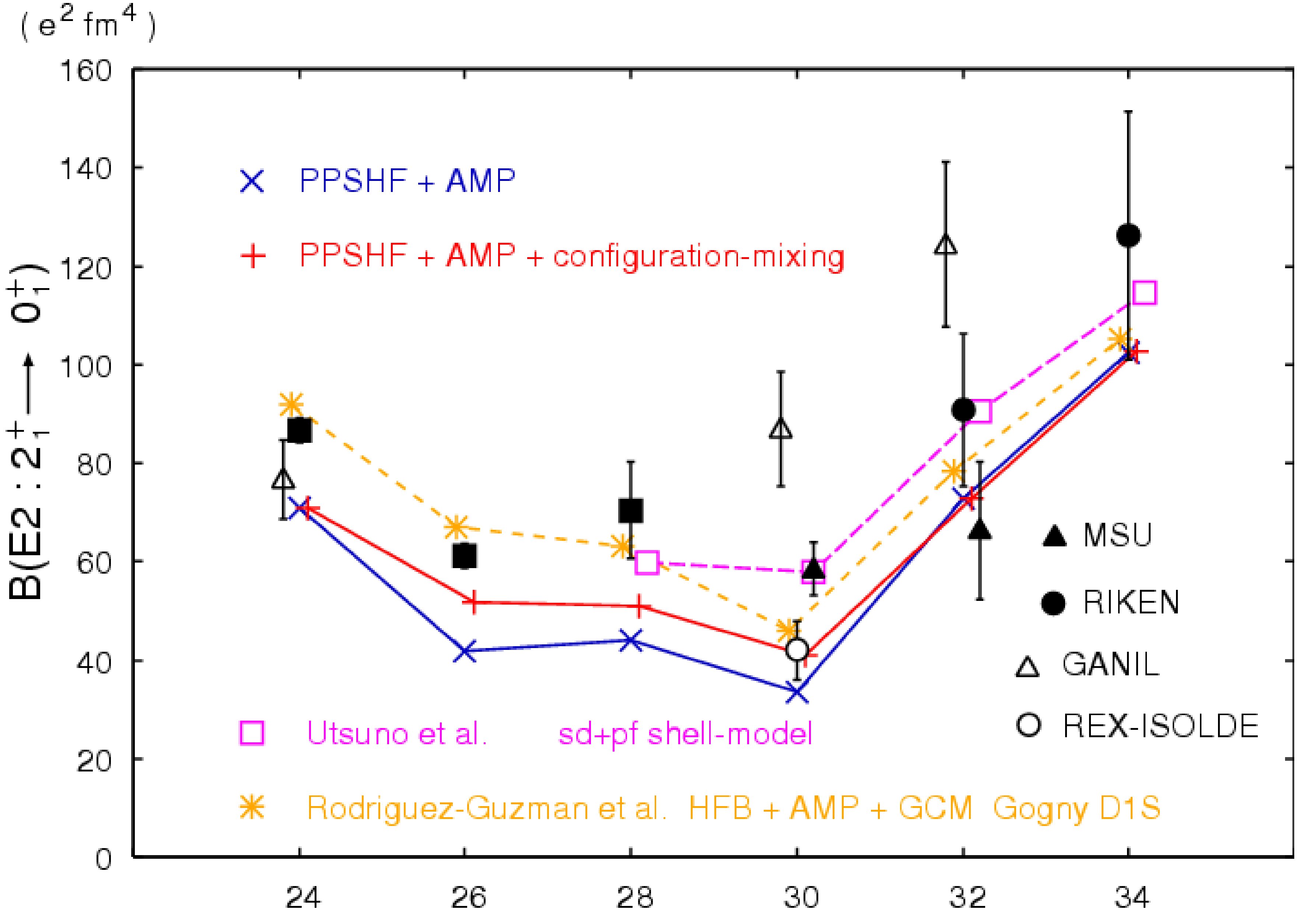


Spectra of ^{34}Mg (SGII)

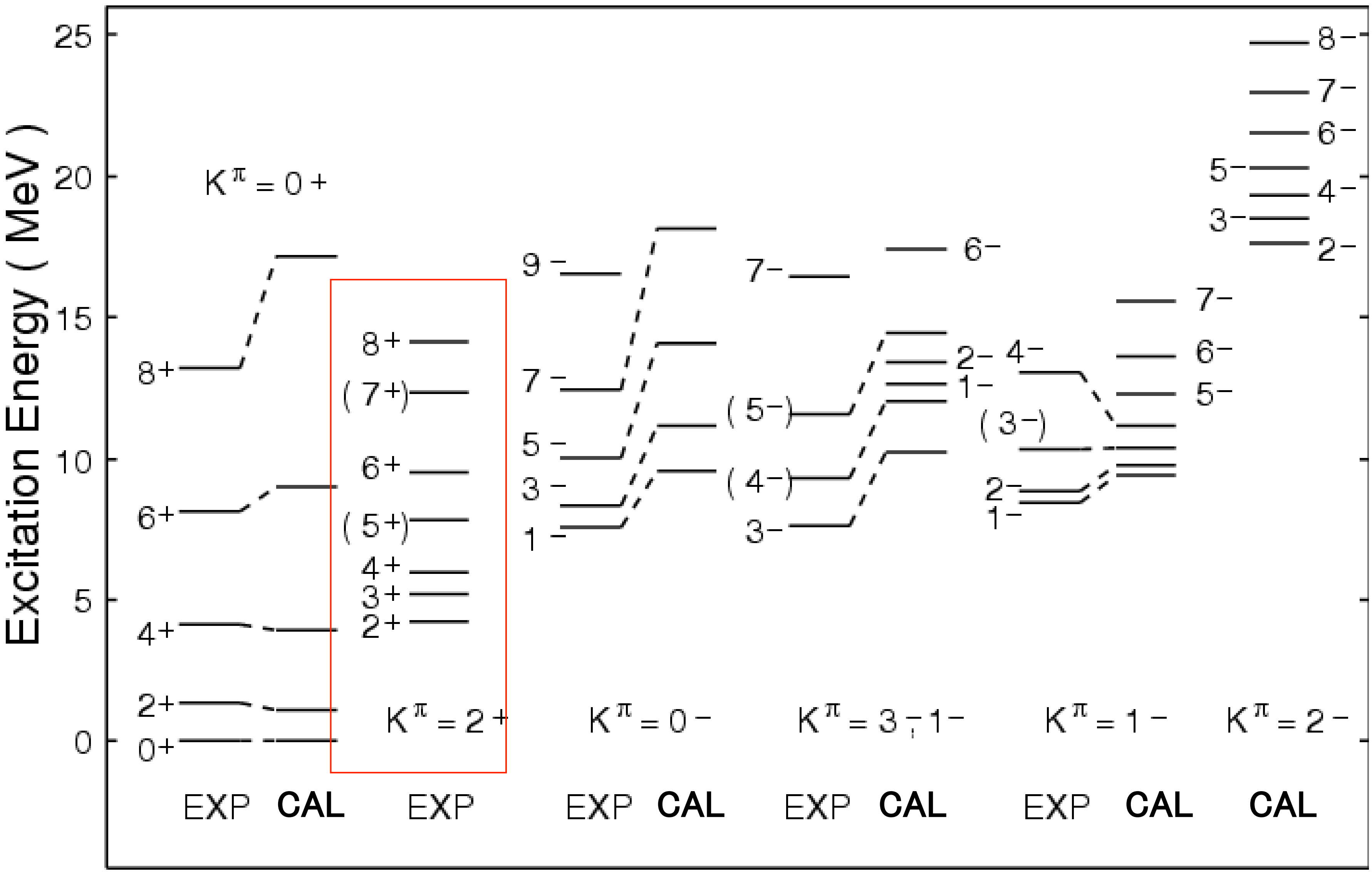


β_2= 0.534 β_2= 0.319

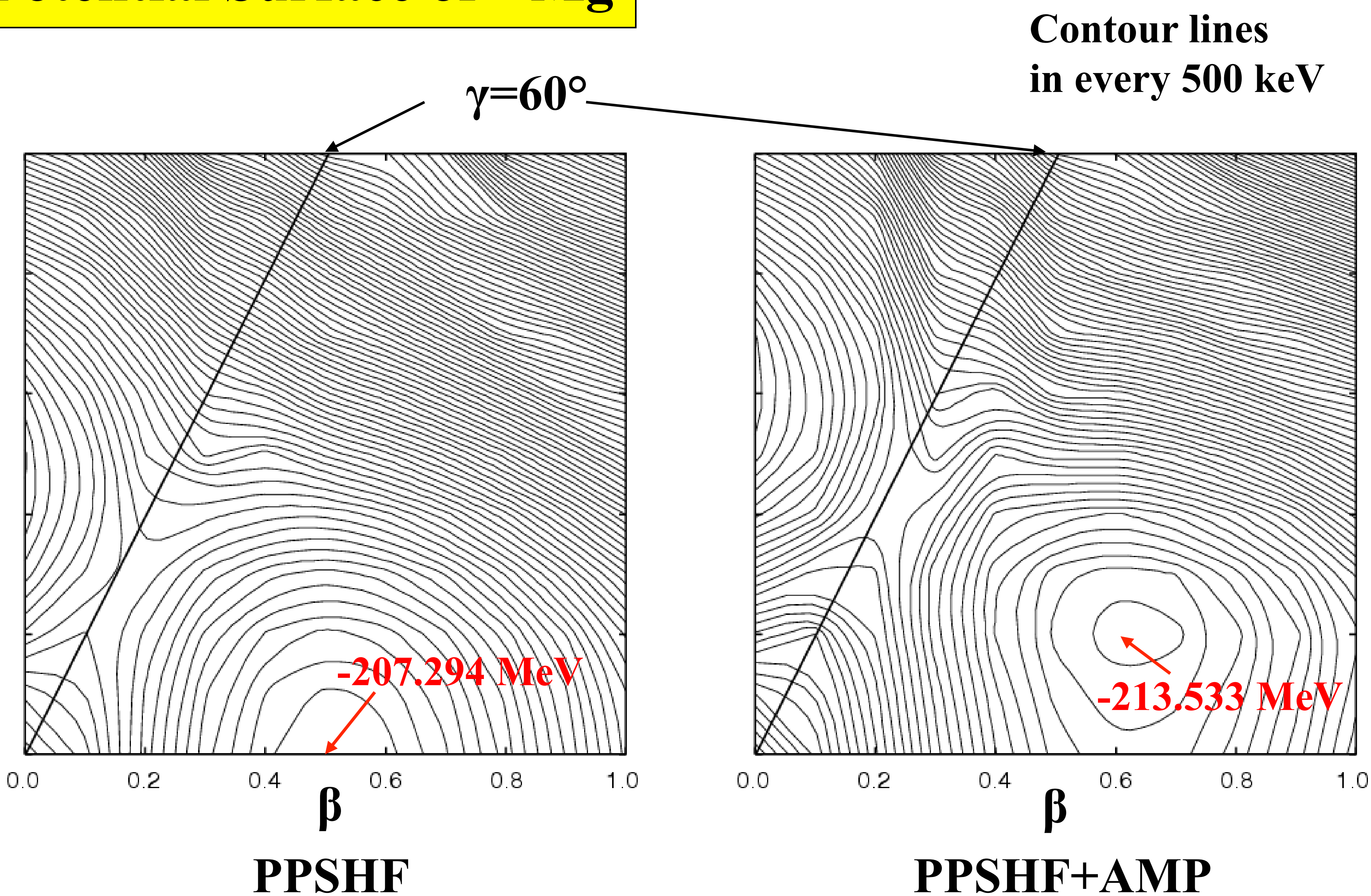
B(E2: $2^+_1 \rightarrow 0^+_1$) value of Mg isotopes (e^2fm^4)



VAP$^{\pi}$ cal. for ^{24}Mg (SGII parameter set)

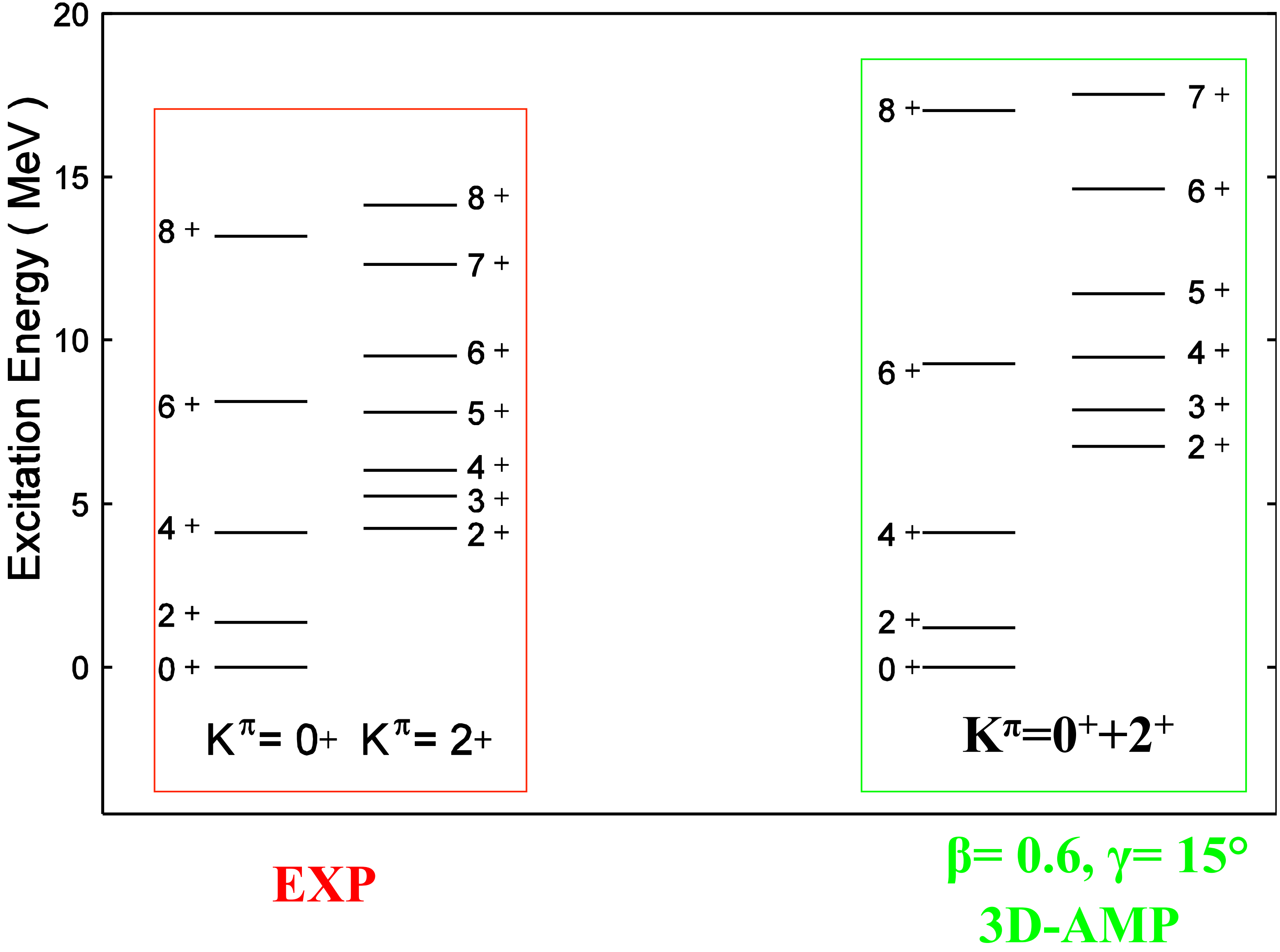


Potential Surface of ^{24}Mg



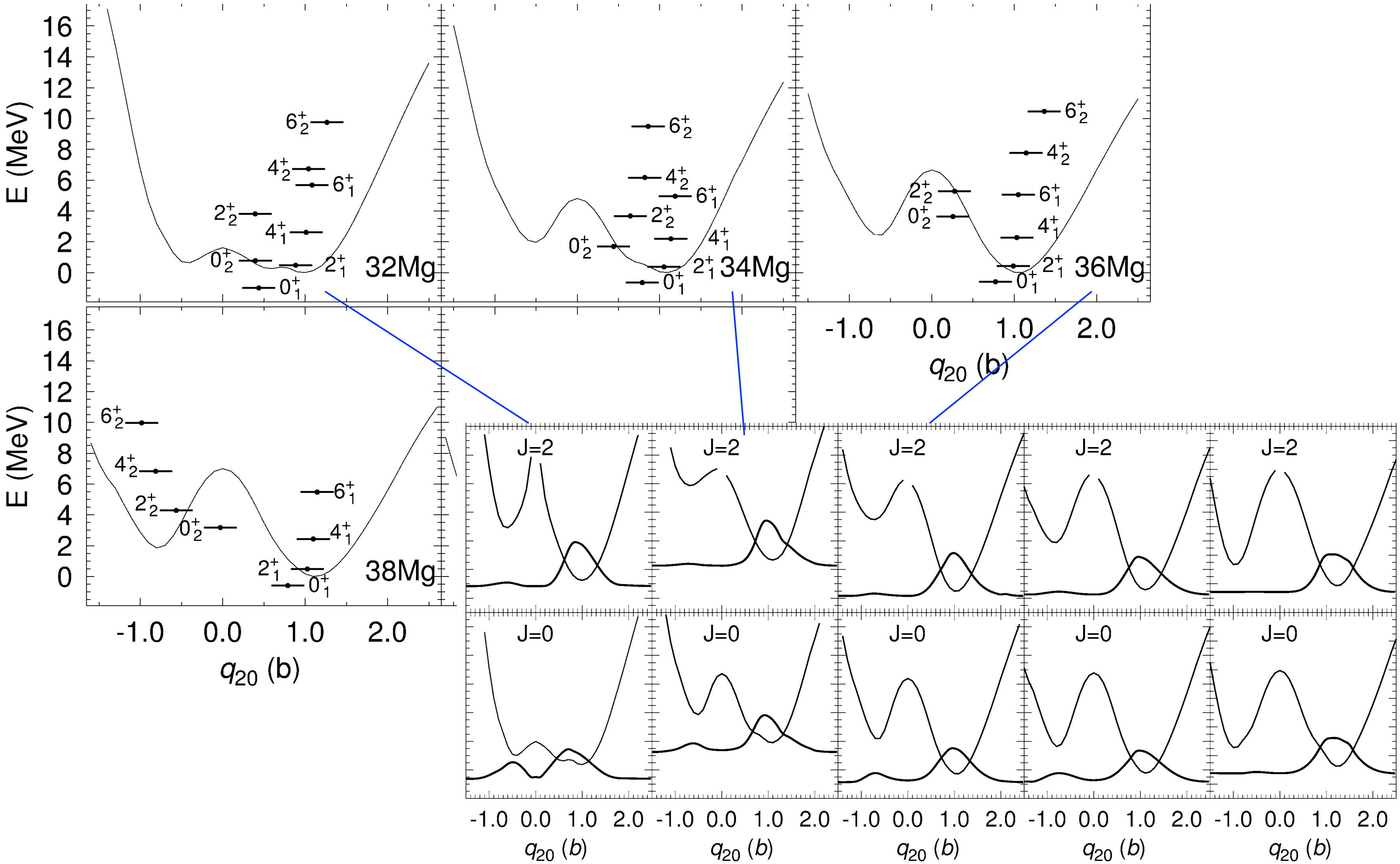
In PPSHF+AMP, the ground energy is 990 keV lower than minimum energy on symmetry axis.

VAP$^{\pi, I}$ for ^{24}Mg



Gogny-GCM (1D)

R. Rodriguez-Guzman J. L. Egido and L. M. Robeldo, Nucl. Phys. A709, 201 (2002)



- “Mean-field”-based approaches
  - Energy density functional is universal (no tuning involved)
  - GCM cal. with 2D real coordinates is a state-of-art technique
- Further developments
  - VAP on both parity and angular momentum
  - GCM with complex coordinates
- Insights into IoI (?)
  - Significant effect from rotational (def.) correlations in relatively light systems
  - Pairing & def. & rot. correlations can be “cooperative” in the shell closure.
  - Shape fluctuation effect