Collective and single-particle motion in beyond-mean-field approaches

Tomás R. Rodríguez

Nuclear Structure and Astrophysical Applications

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Acknowledgments

M. Borrajo (UAM-Madrid)
J. L. Egido (UAM-Madrid)

Acknowledgments

Congratulations, Xavier!

Acknowledgments

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Acknowledgments

Cincuenta Aniversario
1968 2018
UAM

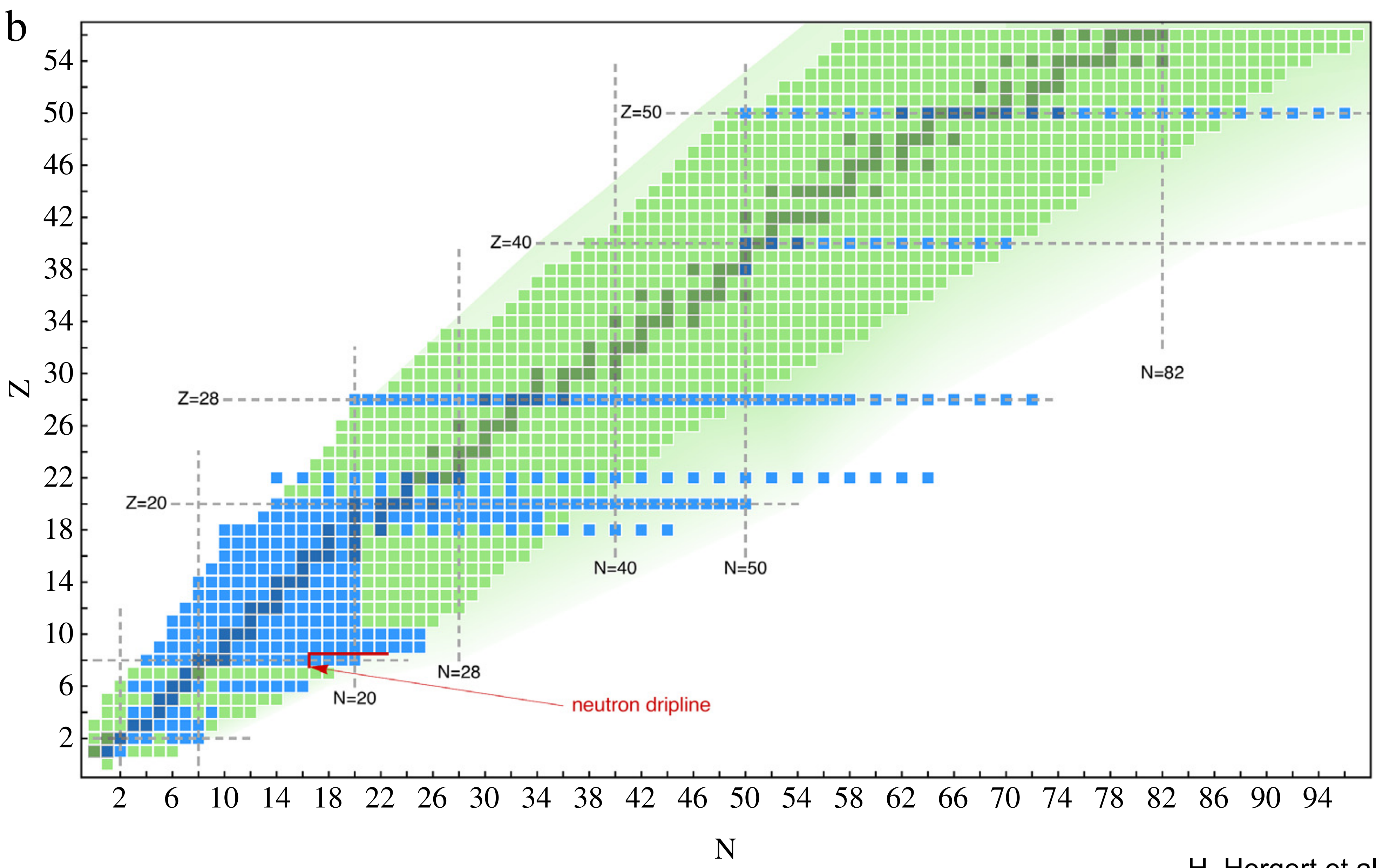
Congratulations, Xavier!

Outline

1. Introduction
2. SCCM with cranking
3. Collective and Single-particle states in ^{44}S
4. Summary and Outlook

Ab initio world

- First-principle calculations based on EFT+SRG interactions and different many-body methods can be nowadays performed in a large amount of nuclei.

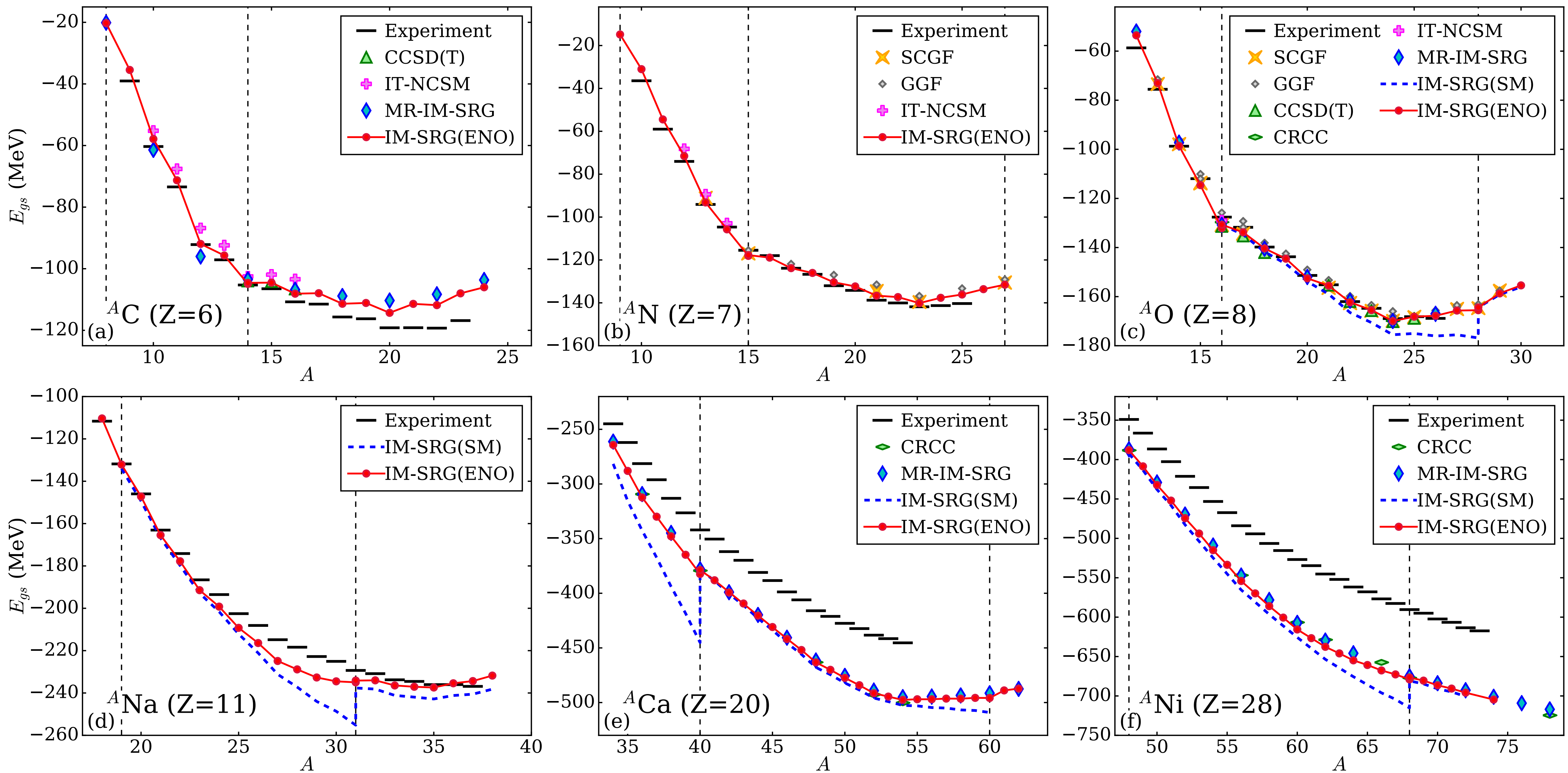


philosopher's stone

H. Hergert et al., Phys. Rep. 621, 165 (2016)

Ab initio world

- Still some problems in reproducing some basic observables in heavier systems.



S. R. Stroberg et al., Phys. Rev. Lett. 118, 032502 (2017)

Phenomenological world

- Use of phenomenological interactions (adjusted to data in finite nuclei) is necessary to obtain precise predictions/descriptions of ground state, spectroscopic and reaction data.

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- Exact diagonalizations within a valence space.
- Effective interactions adapted to the valence space and adjusted to reproduce the evolution of single particle energies (monopoles).
- Very precise description of spectroscopy and transitions of nuclei.
- Limited by the combinatorial increase of the number of configurations.
- Defined in the laboratory frame→Intrinsic shapes can only be inferred from the spectra and electromagnetic moments

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SELF-CONSISTENT MEAN FIELD

- Variational approach with simple trial wave functions (HFB) using 'universal' functionals (applicable to the whole nuclear chart).
- Parameters of the functional fitted to bulk properties and masses and radii of finite nuclei.
- Very precise description of ground state properties and collective phenomena.
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- **Spectroscopy with beyond mean-field techniques (GCM, QRPA, ...)**

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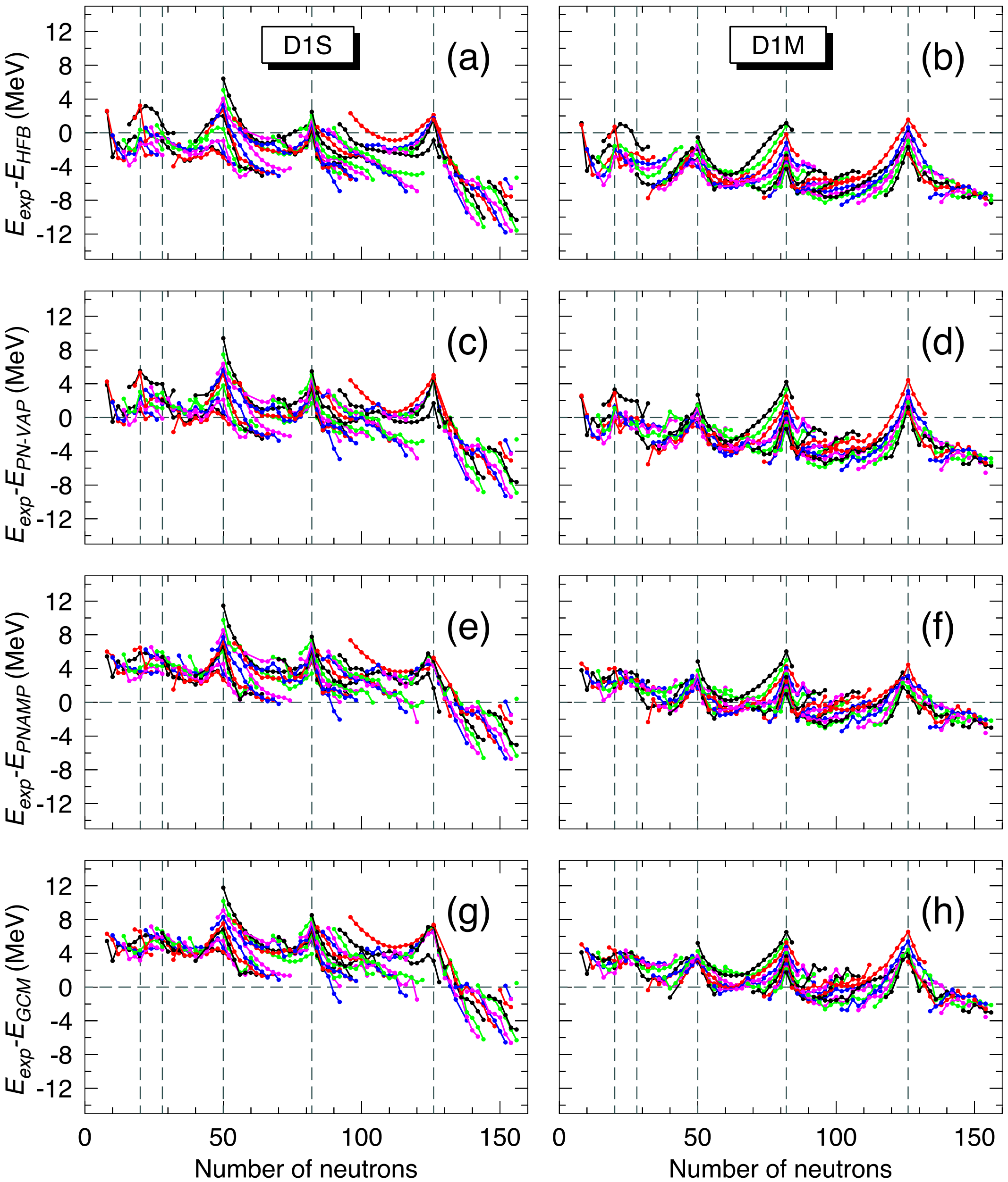
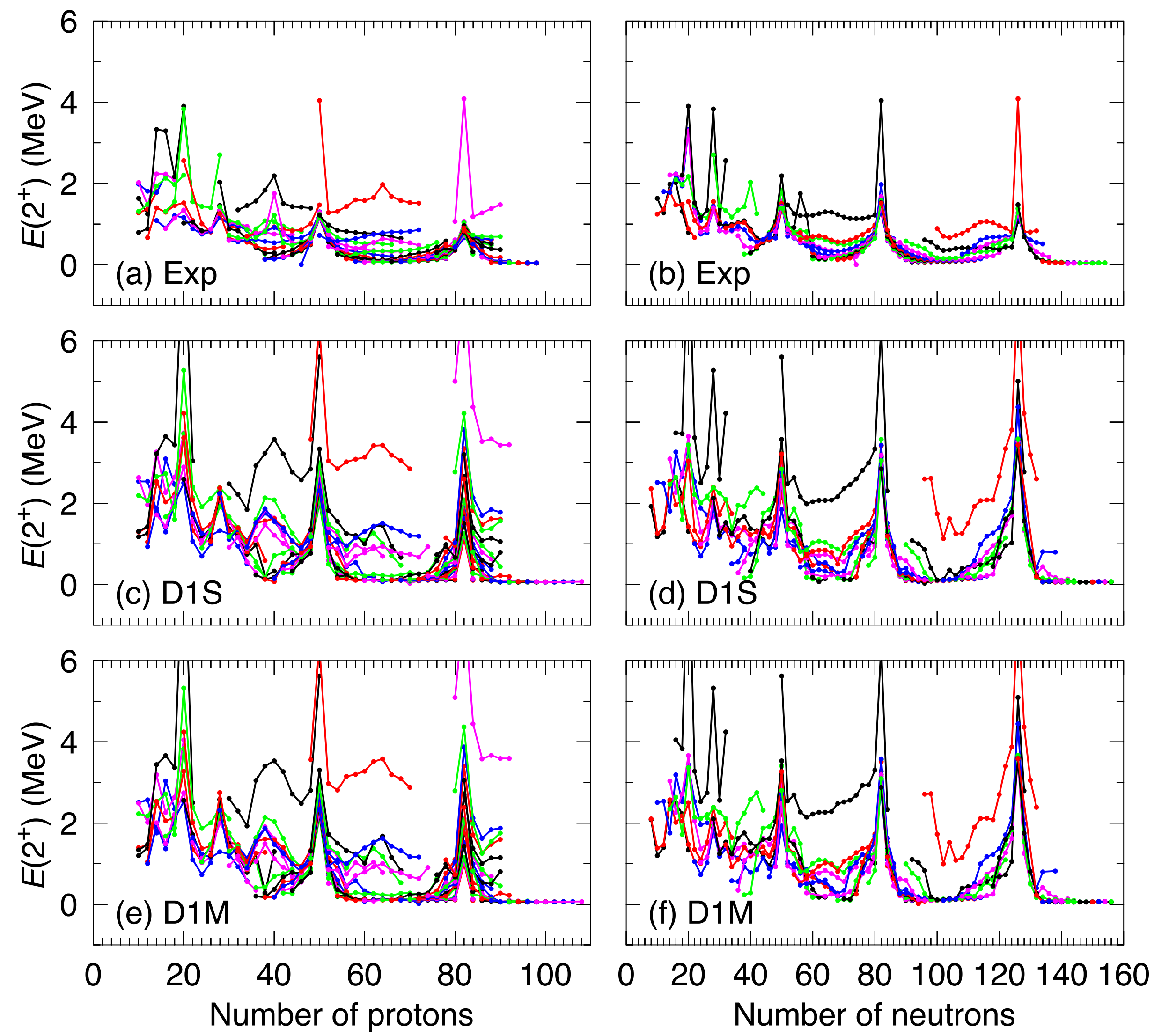
Example of the performance of Gogny D1S/D1M interactions

Global study of nuclear masses and 2^+ excitation energies





Physical Review C 91, 044315 (2015)

Gogny interaction

Effective nucleon-nucleon interaction: Gogny force (D1S/D1M)

$$V(1,2) = \sum_{i=1}^{2} e^{-(\vec{r}_1-\vec{r}_2)^2/\mu_i^2} \left(W_i + B_i P^\sigma - H_i P^\tau - M_i P^\sigma P^\tau\right)$$

$$+iW_0(\sigma_1+\sigma_2)\vec{k}\times\delta(\vec{r}_1-\vec{r}_2)\vec{k} + V_{\mathrm{Coulomb}}(\vec{r}_1,\vec{r}_2)$$

$$+t_3(1+x_0P^\sigma)\delta(\vec{r}_1-\vec{r}_2)\rho^\alpha\left((\vec{r}_1+\vec{r}_2)/2\right)$$

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Density dependent term

- Other alternatives: Skyrme, relativistic Lagrangians, BCPM, ...

Gogny EDF with cranked states

- Initial intrinsic states: PN-VAP

$$E^{N,Z}[\Phi] = \frac{\langle\Phi|\hat{H}_{2b}\hat{P}^{N}\hat{P}^{Z}|\Phi\rangle}{\langle\Phi|\hat{P}^{N}\hat{P}^{Z}|\Phi\rangle} + \varepsilon_{DD}^{N,Z}(\Phi) - \lambda_{q_{20}}\langle\Phi|\hat{Q}_{20}|\Phi\rangle - \lambda_{q_{22}}\langle\Phi|\hat{Q}_{22}|\Phi\rangle - \omega\langle\Phi|\hat{J}_{x}|\Phi\rangle$$

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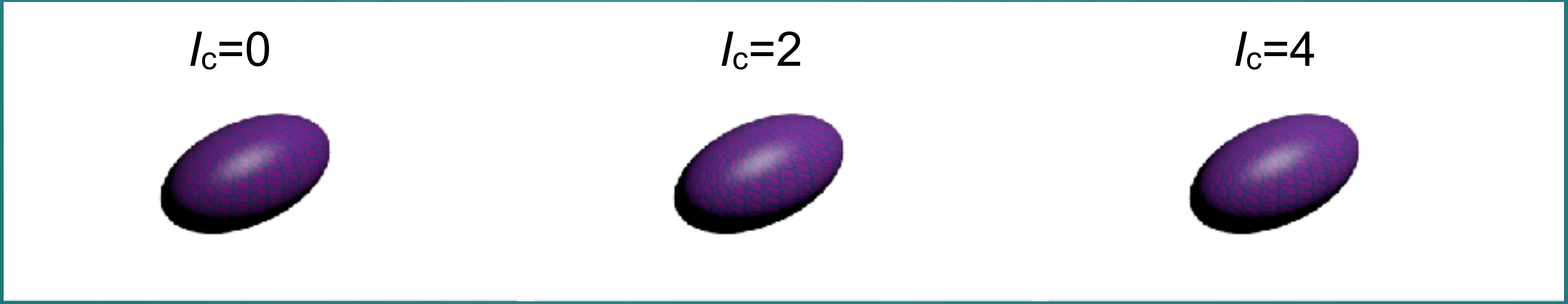

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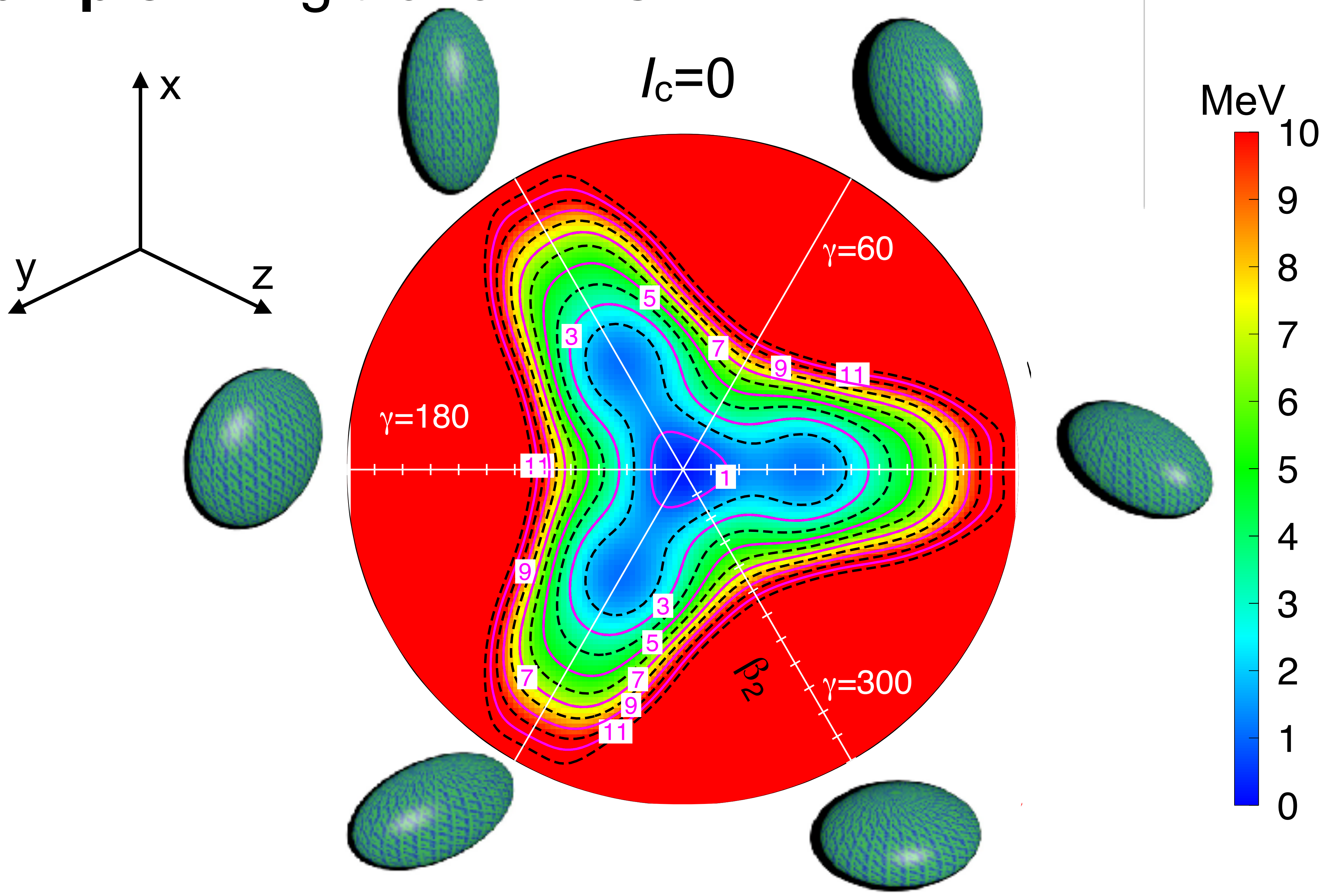
- Intermediate Particle Number and Angular Momentum Projected states

$$|IMK;NZ;\beta\gamma;\omega\rangle = \frac{2I+1}{8\pi^2}\int \mathcal{D}^{I*}_{KK'}(\Omega)\hat{R}(\Omega)\hat{P}^N\hat{P}^Z|\Phi(\beta,\gamma,\omega)\rangle d\Omega$$

- Final GCM states $|IM;NZ;\sigma\rangle = \sum_{K\beta\gamma\omega} f^{I;NZ;\sigma}_{K\beta\gamma\omega}|IMK;NZ;\beta\gamma;\omega\rangle$

$$\sum_{K'\beta'\gamma'\omega'}\left(\mathcal{H}^{I;NZ}_{K\beta\gamma\omega;K'\beta'\gamma'\omega'} - E^{I;NZ;\sigma}\mathcal{N}^{I;NZ}_{K\beta\gamma\omega;K'\beta'\gamma'\omega'}\right) f^{I;NZ;\sigma}_{K'\beta'\gamma'\omega'} = 0$$

Example: ^{32}Mg triaxial+TRSB



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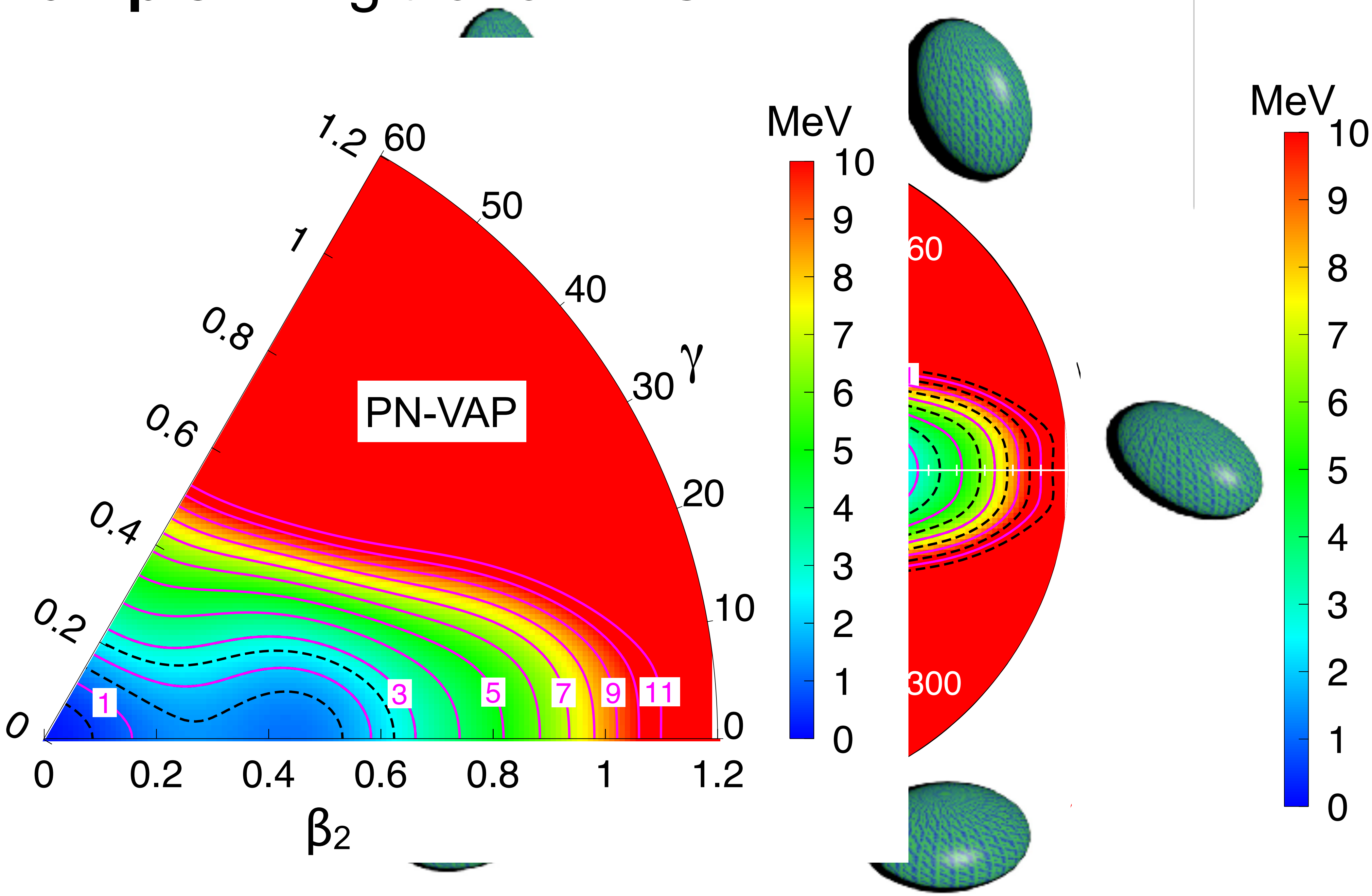

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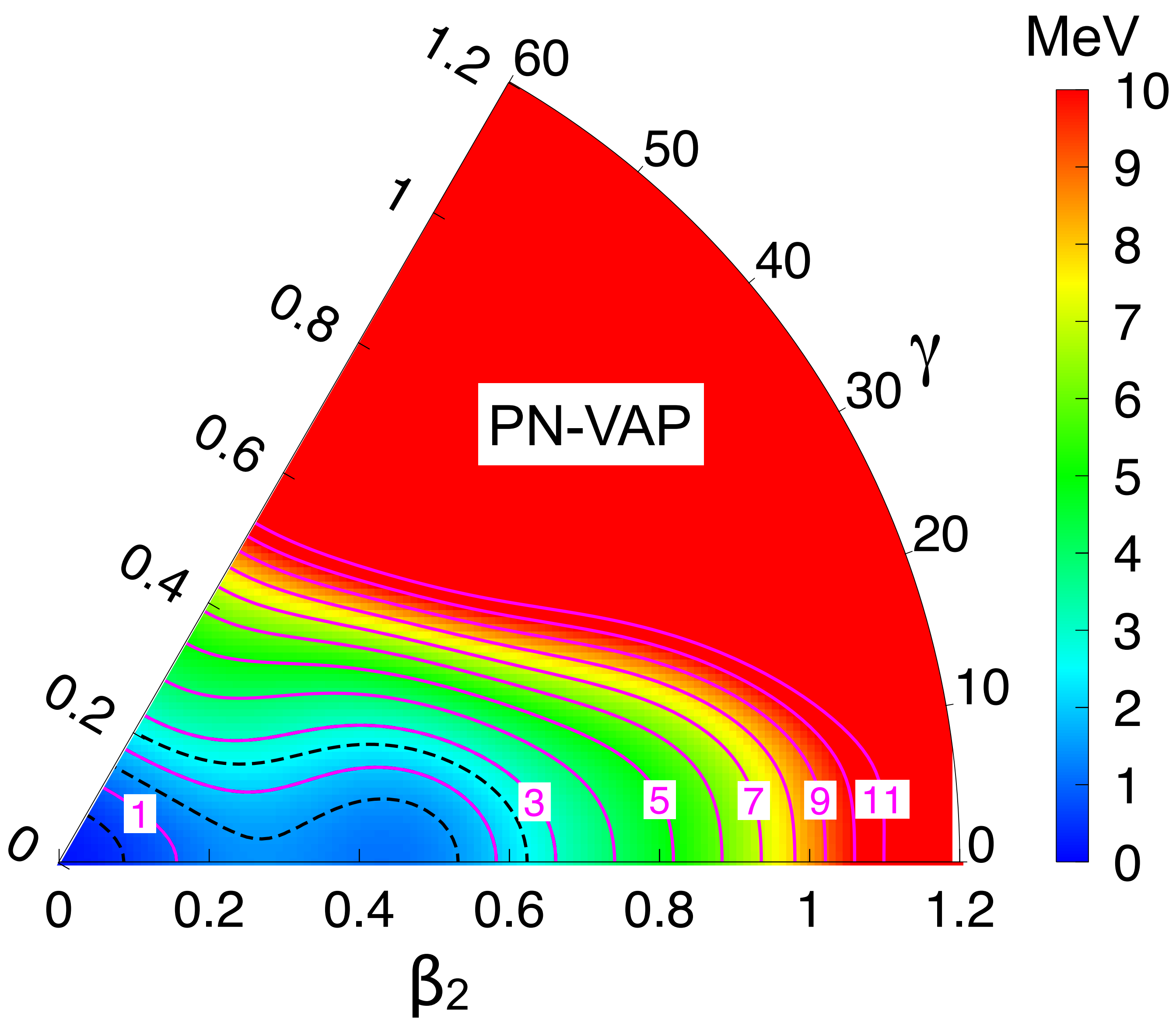

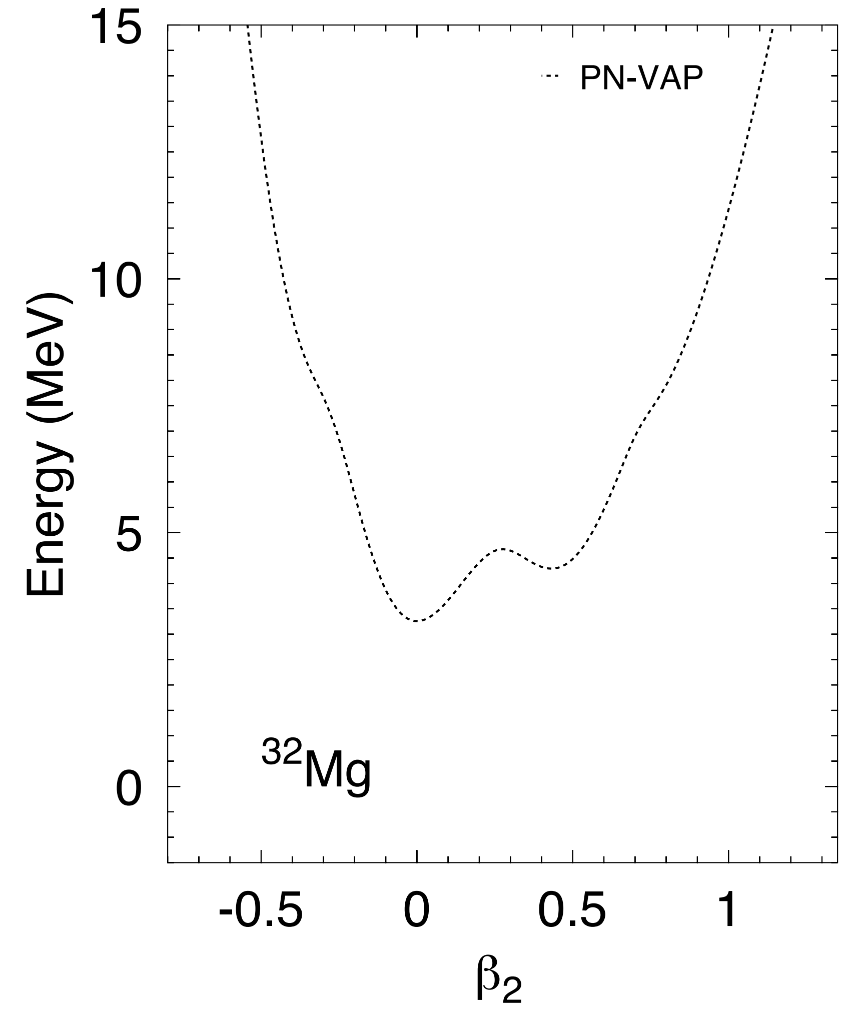

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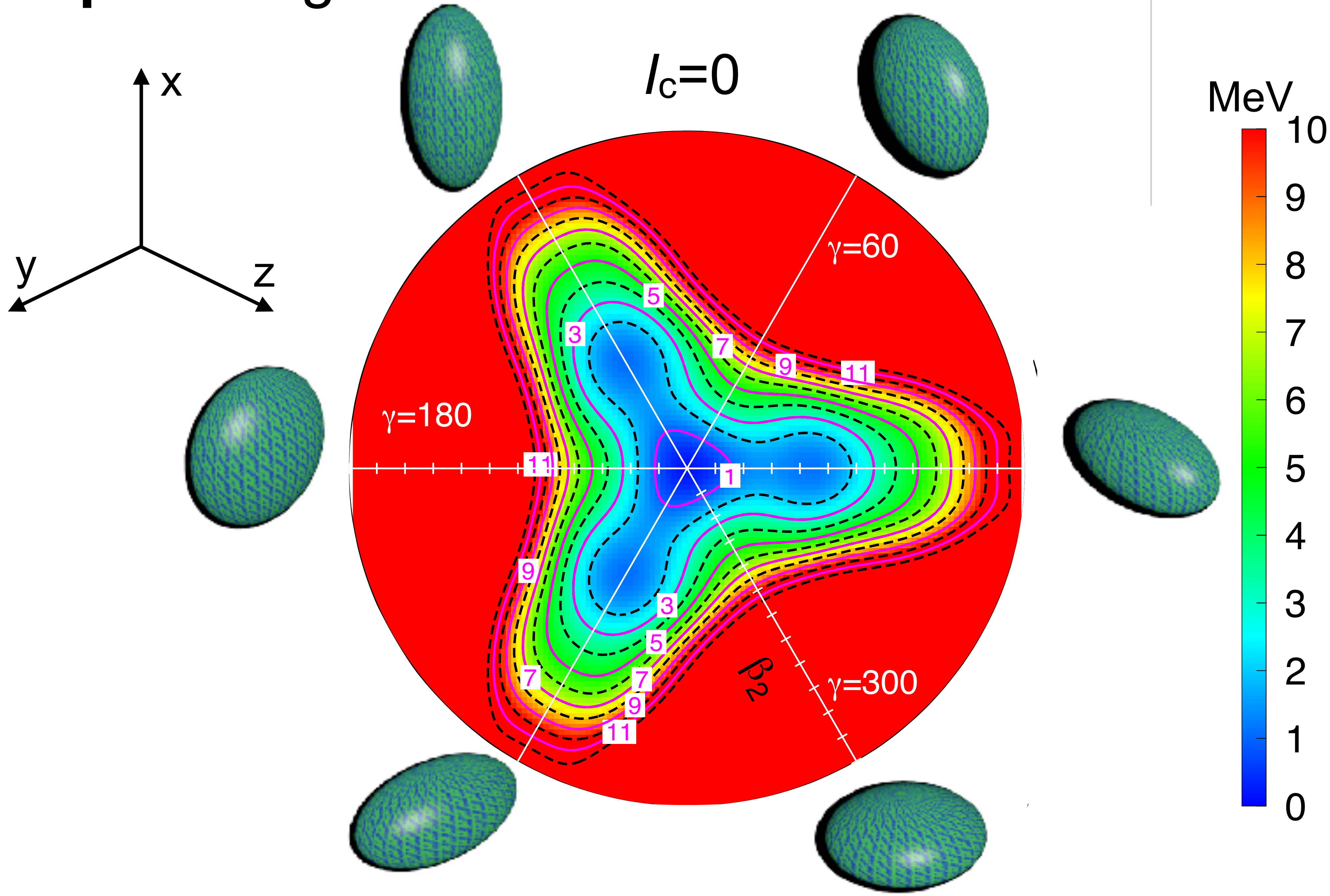

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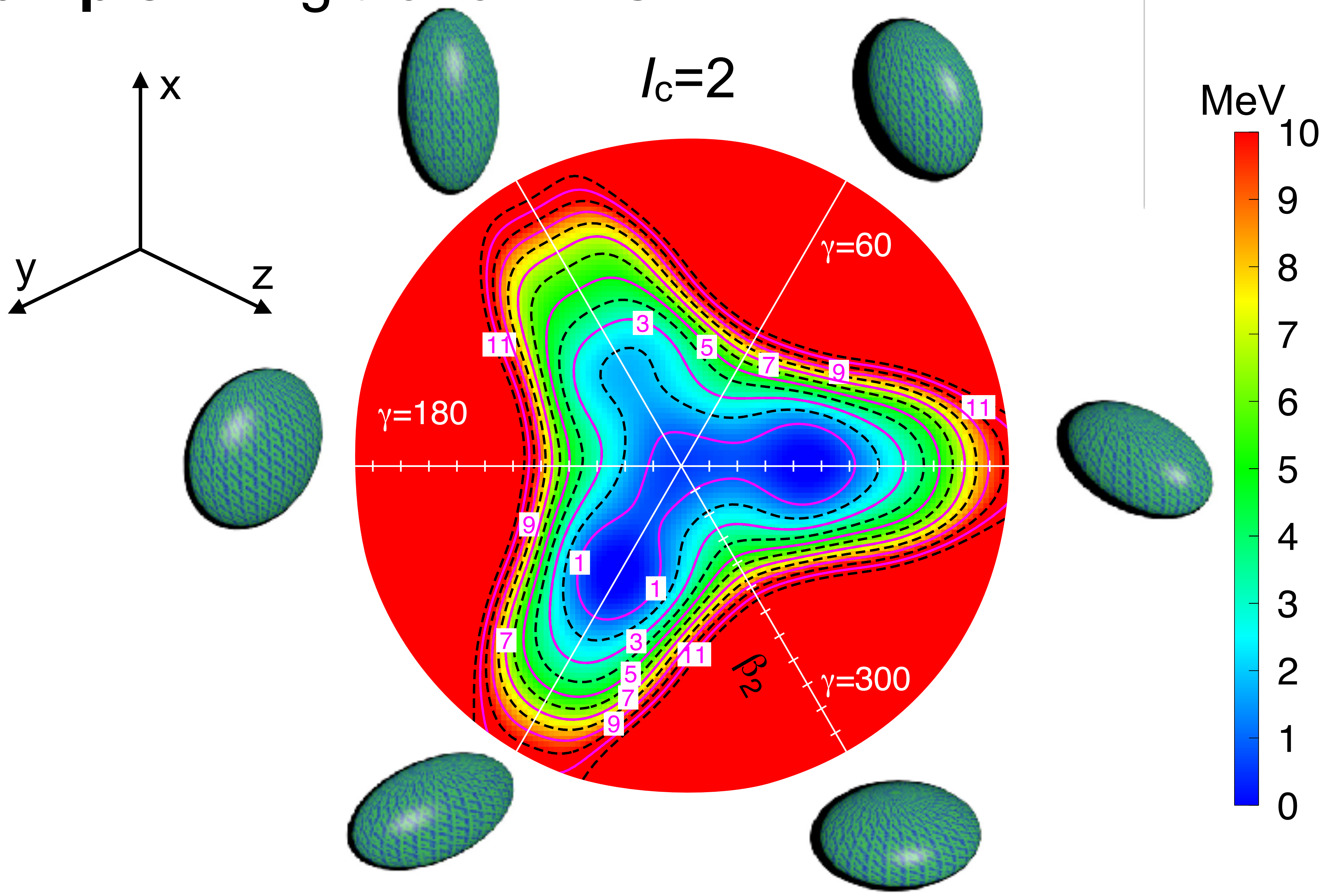

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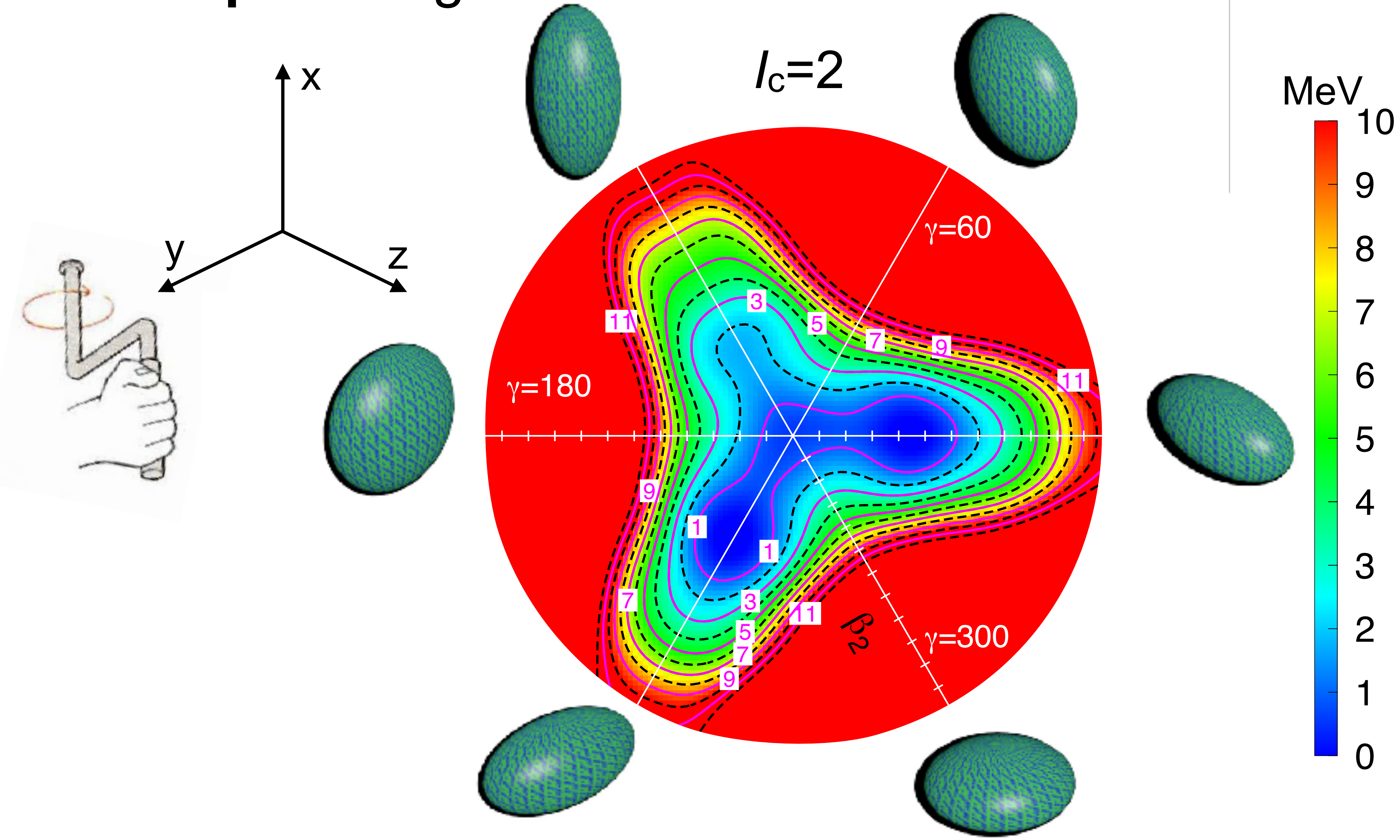

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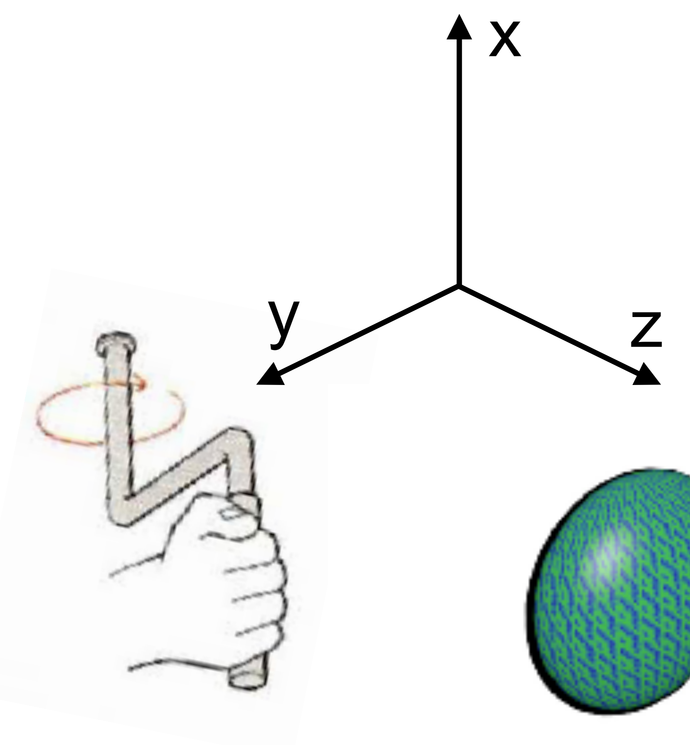

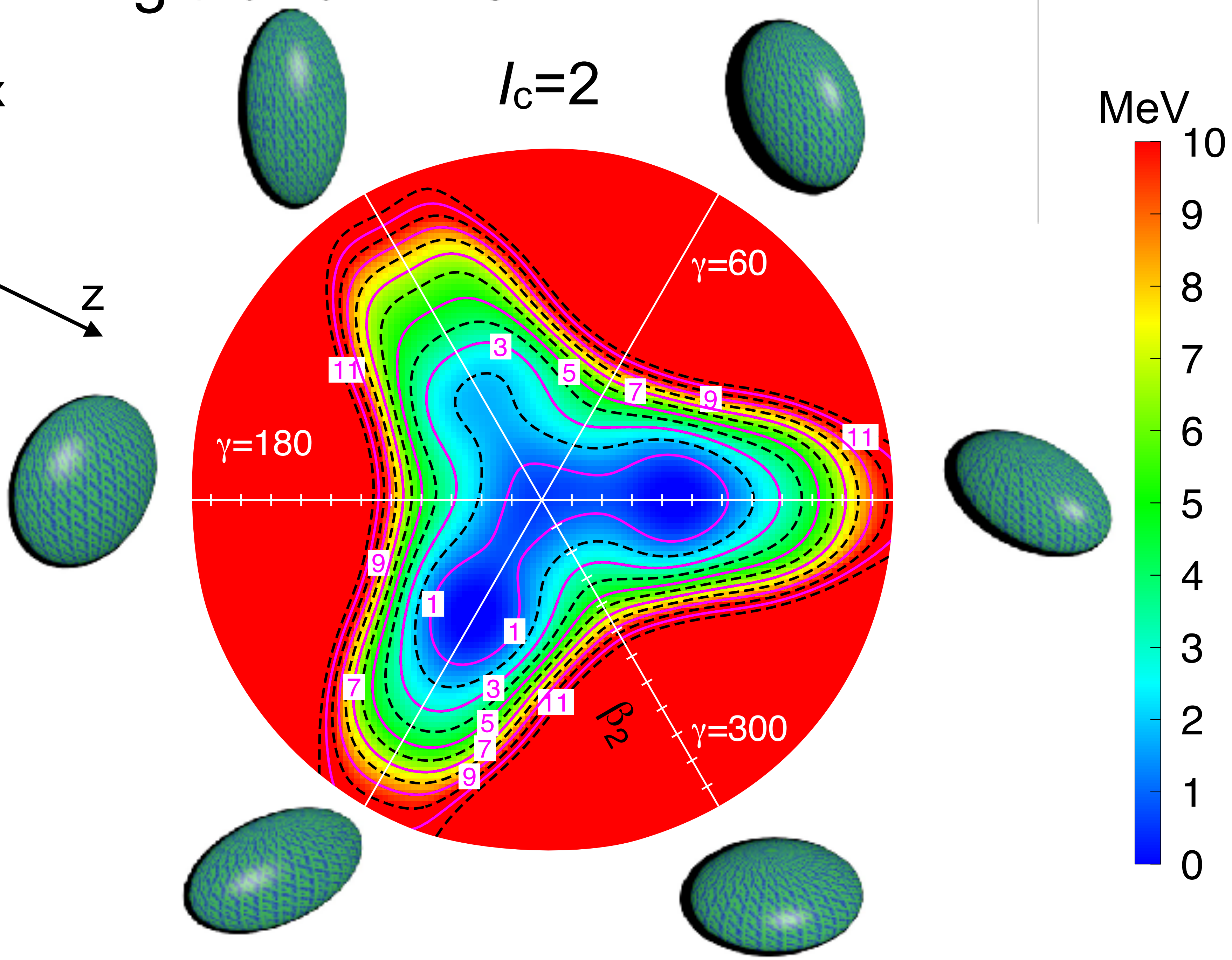

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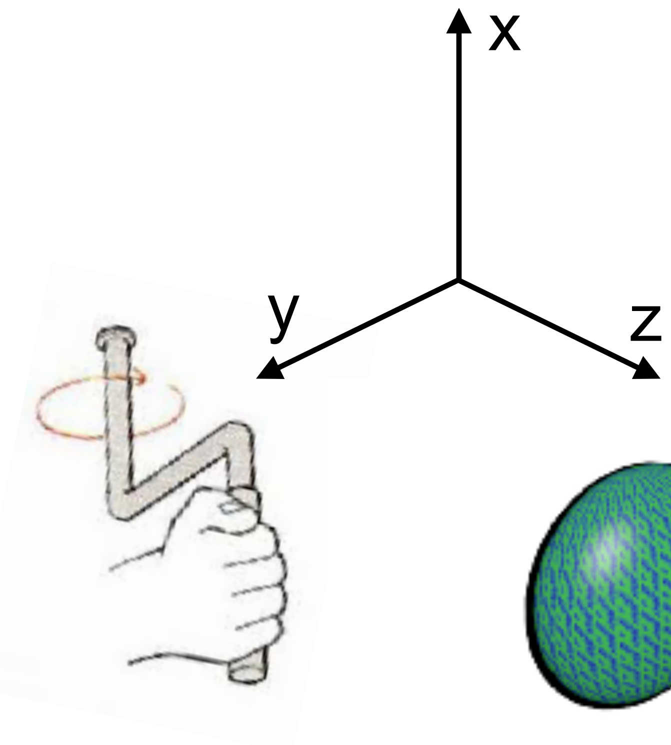

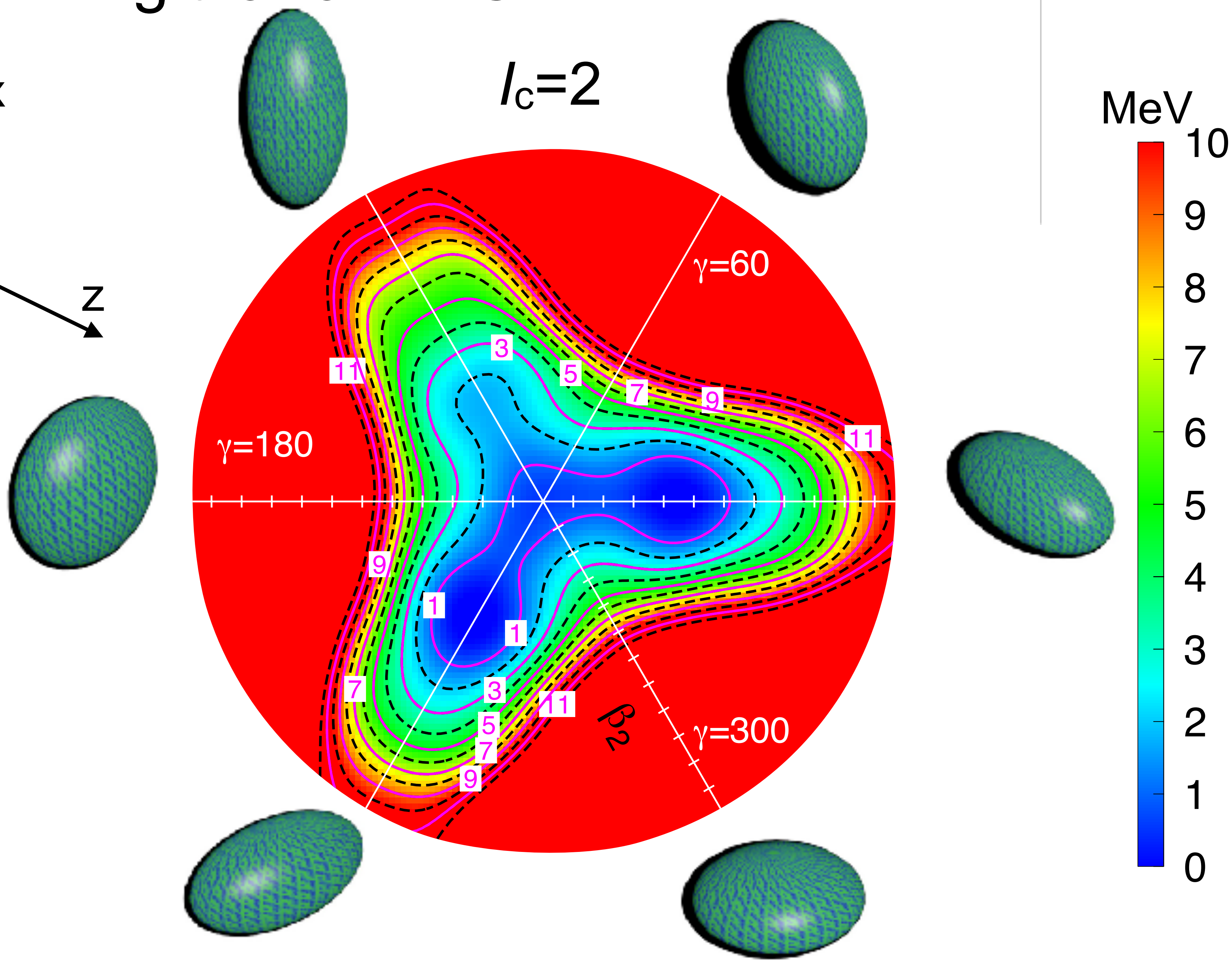

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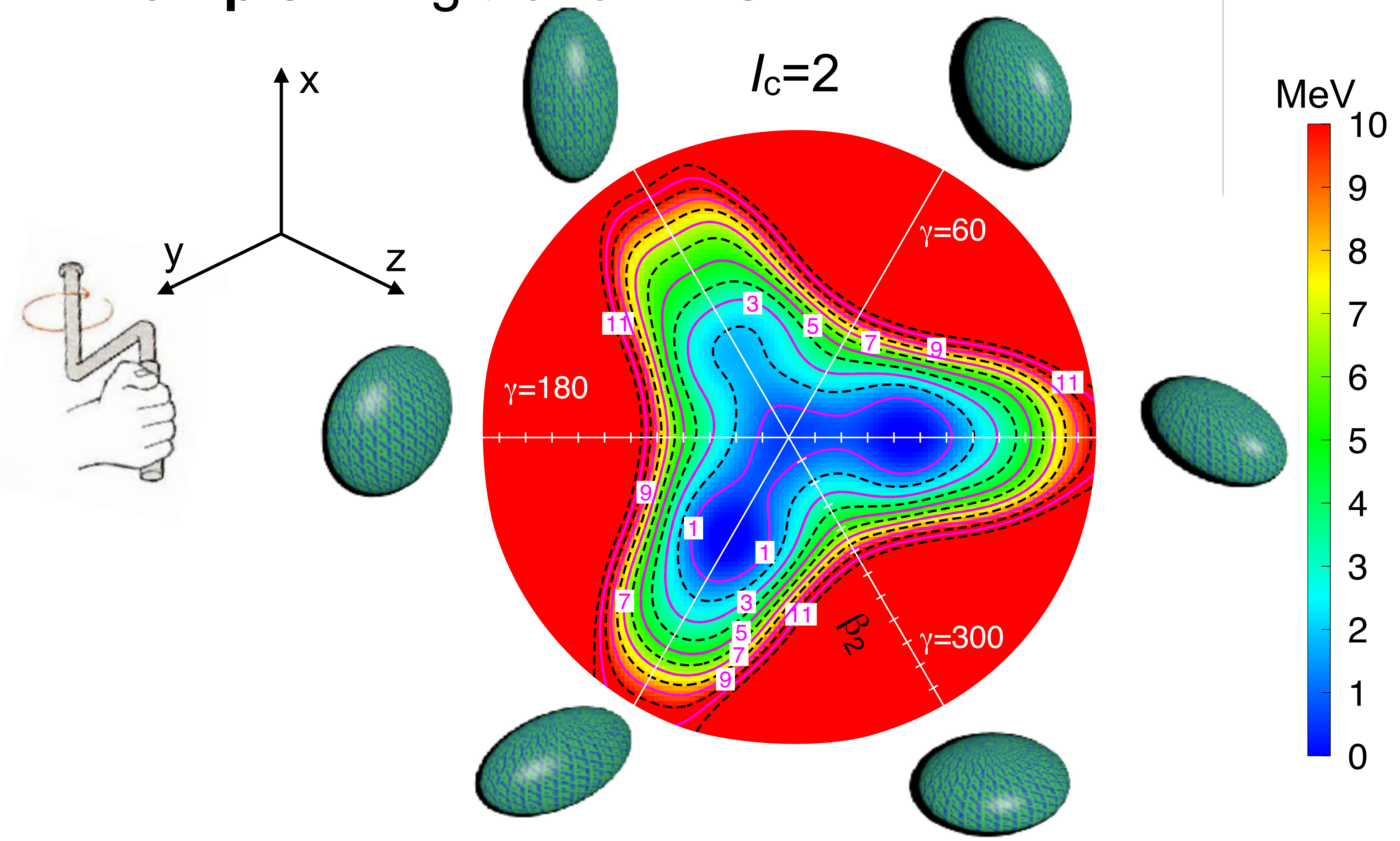

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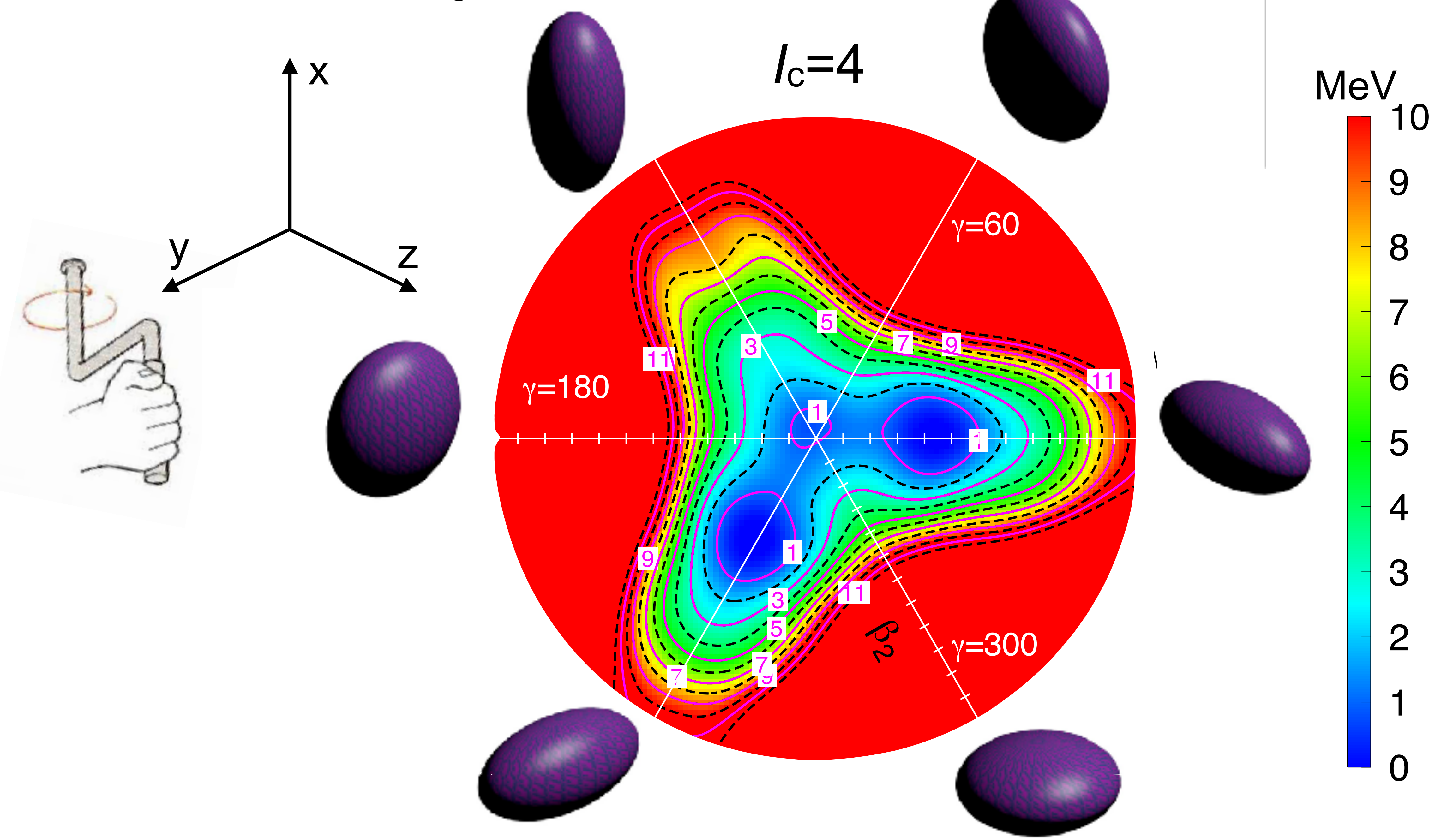

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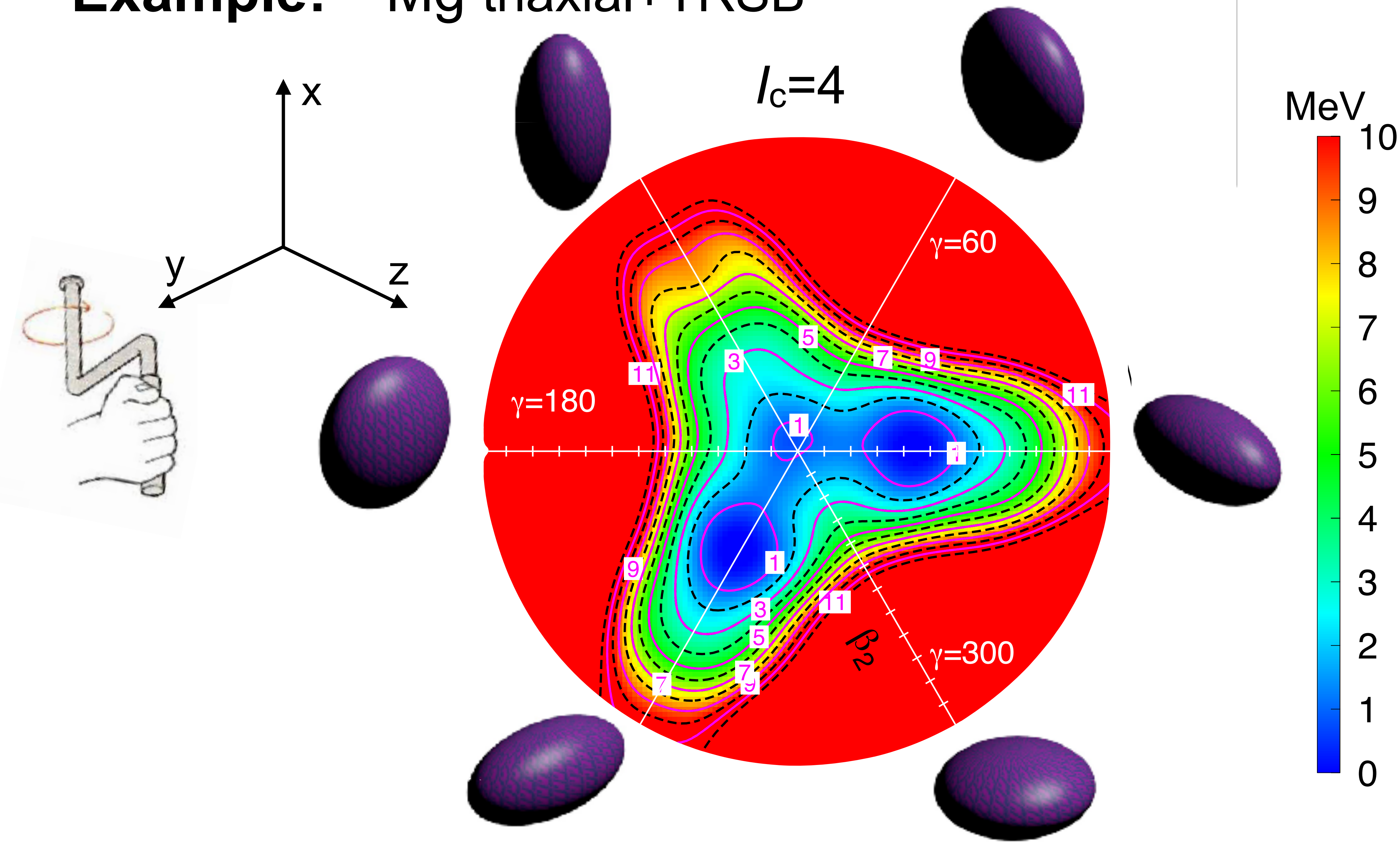
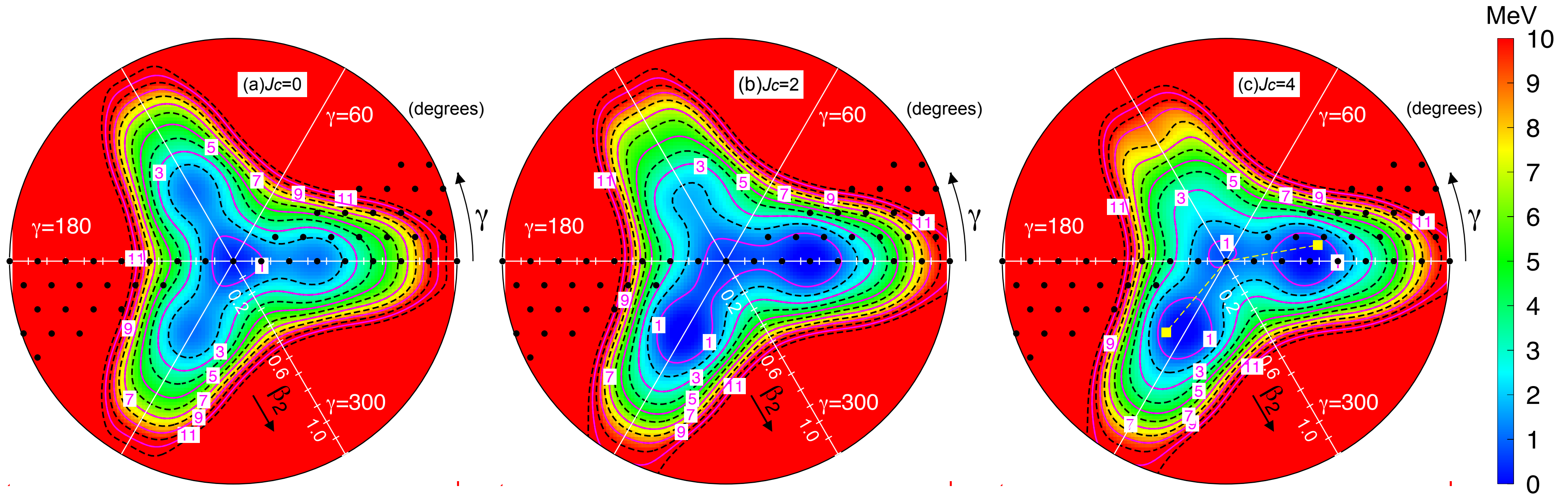


EDF with cranked states

Example: ^{32}Mg; Effect on the energies



M. Borrajo, T.R.R, J.L. Egido, PLB 746, 341 (2015)

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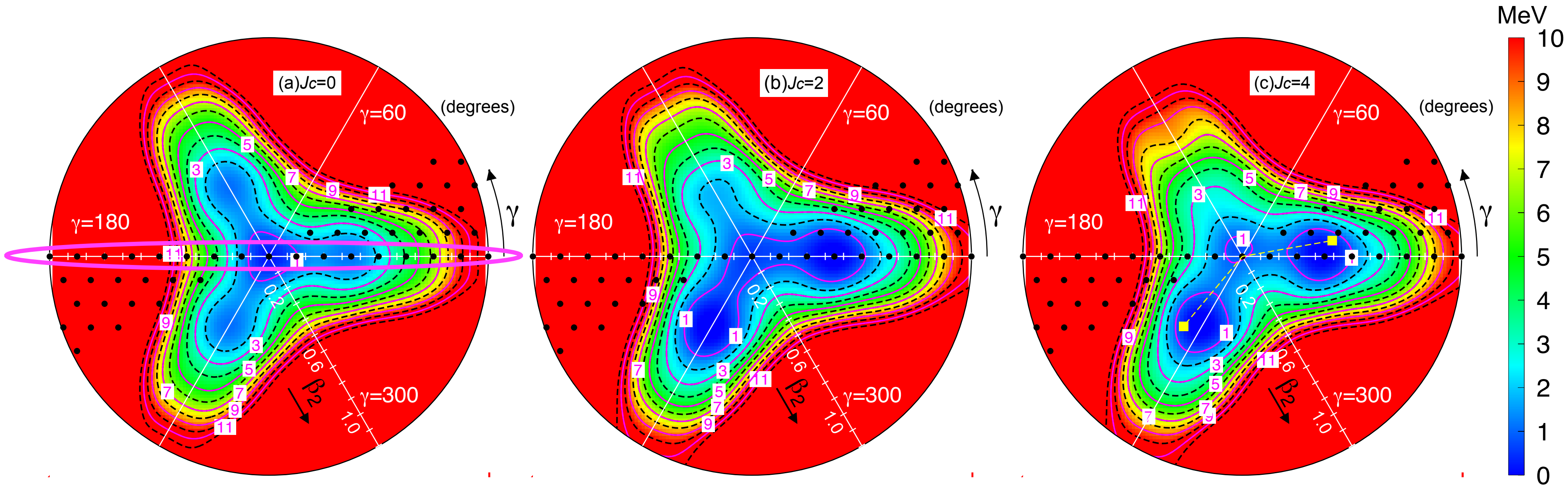

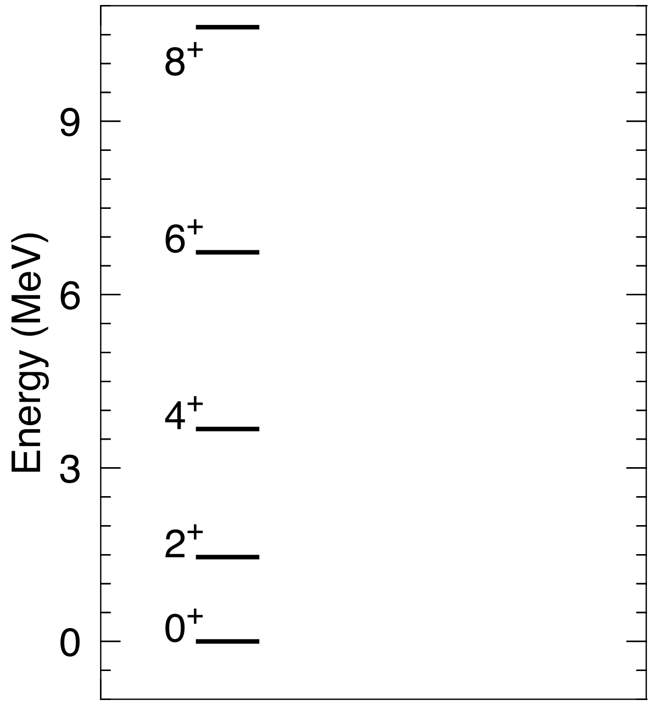

ONLY AXIAL SHAPES AND NO-TIME-REVERSAL-SYMMETRY BREAKING

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EDF with cranked states

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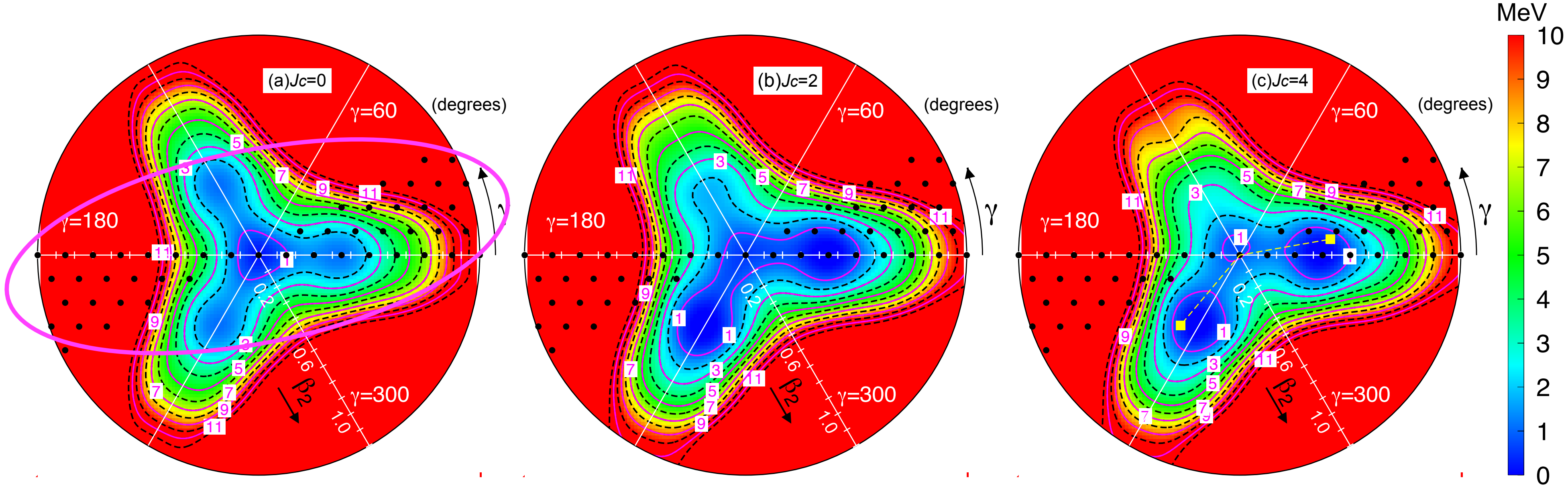

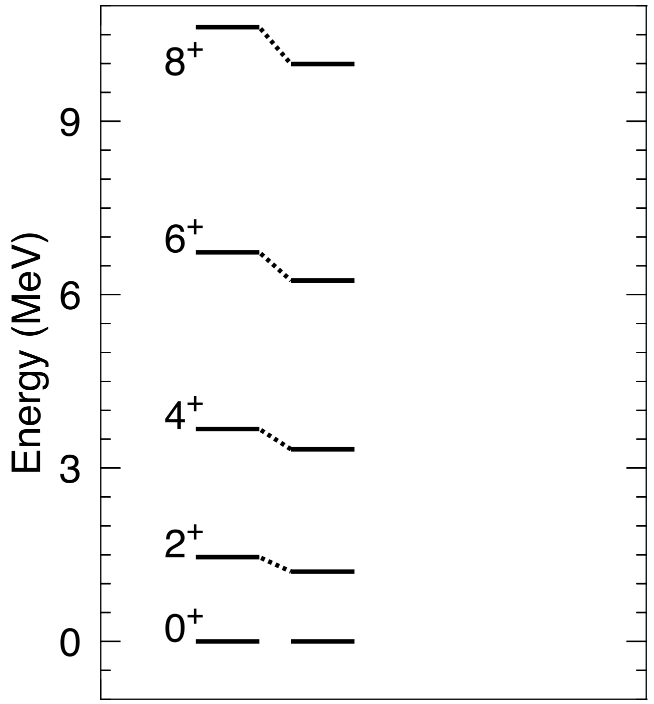

AXIAL+TRIAXIAL *SHAPES AND NO-TIME-REVERSAL-SYMMETRY BREAKING*

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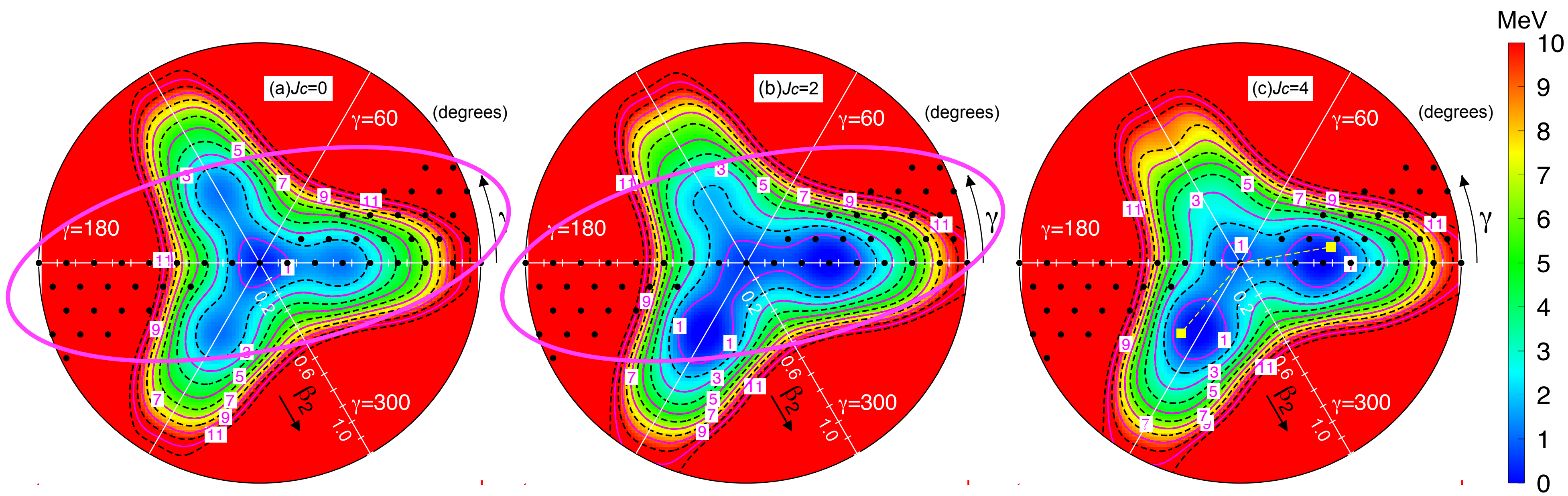

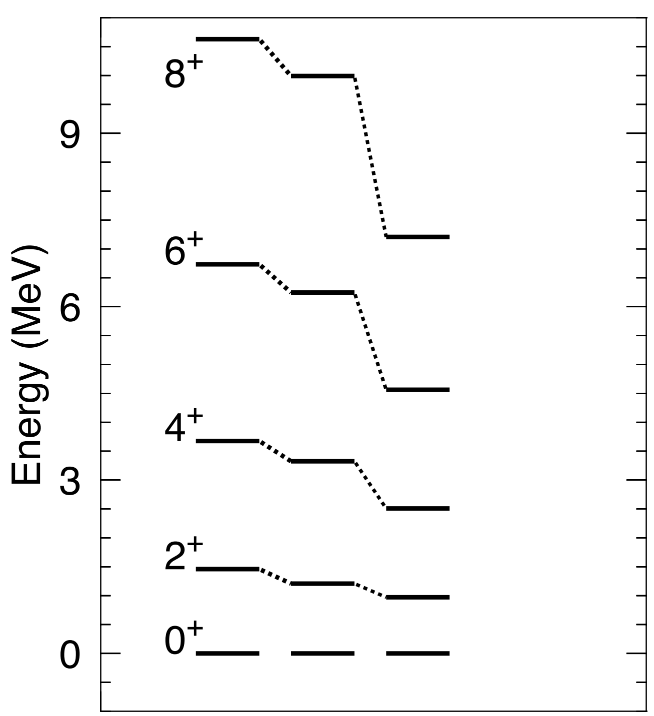

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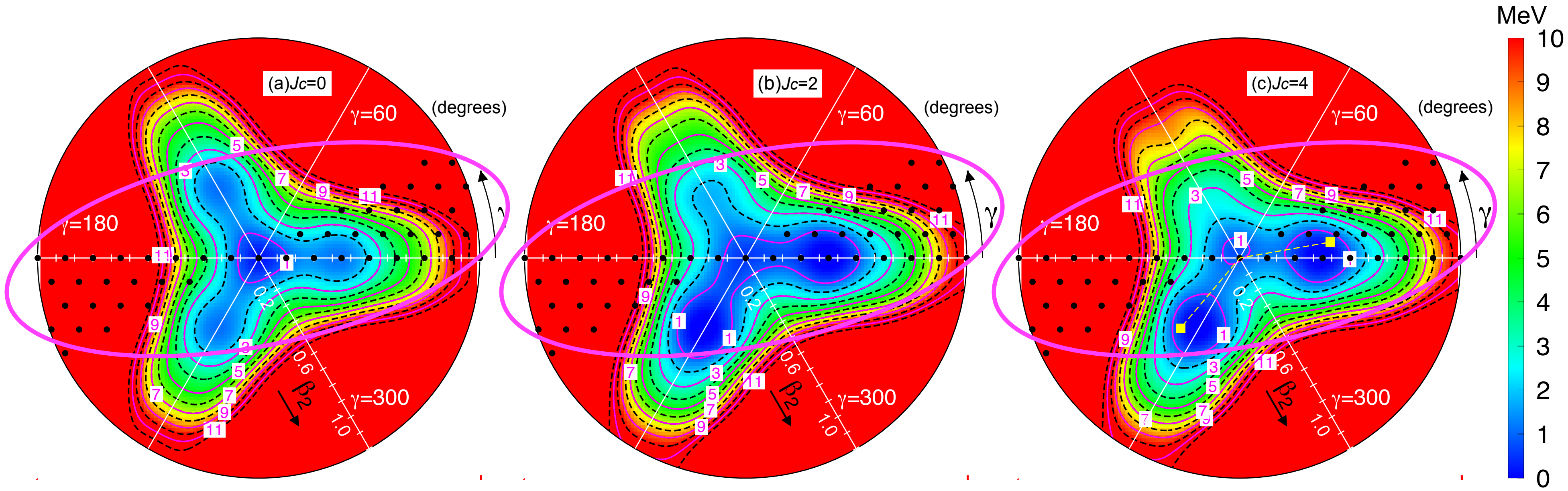

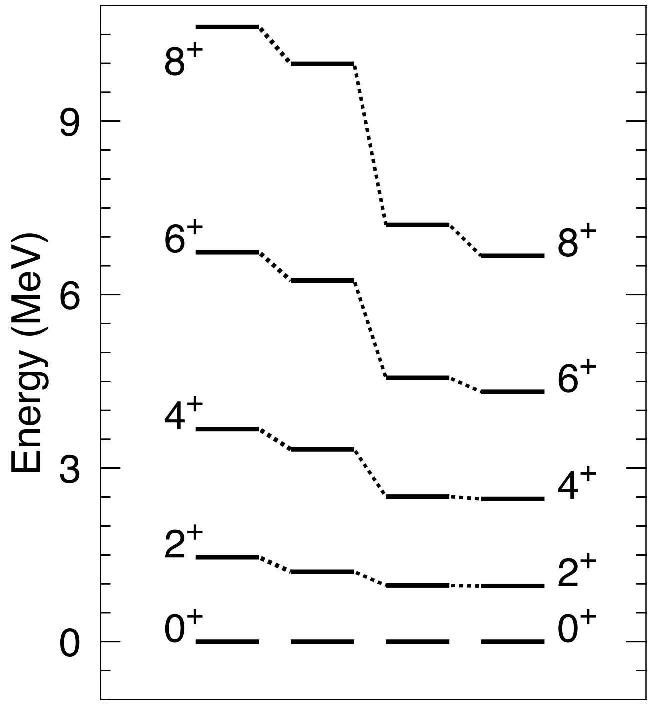

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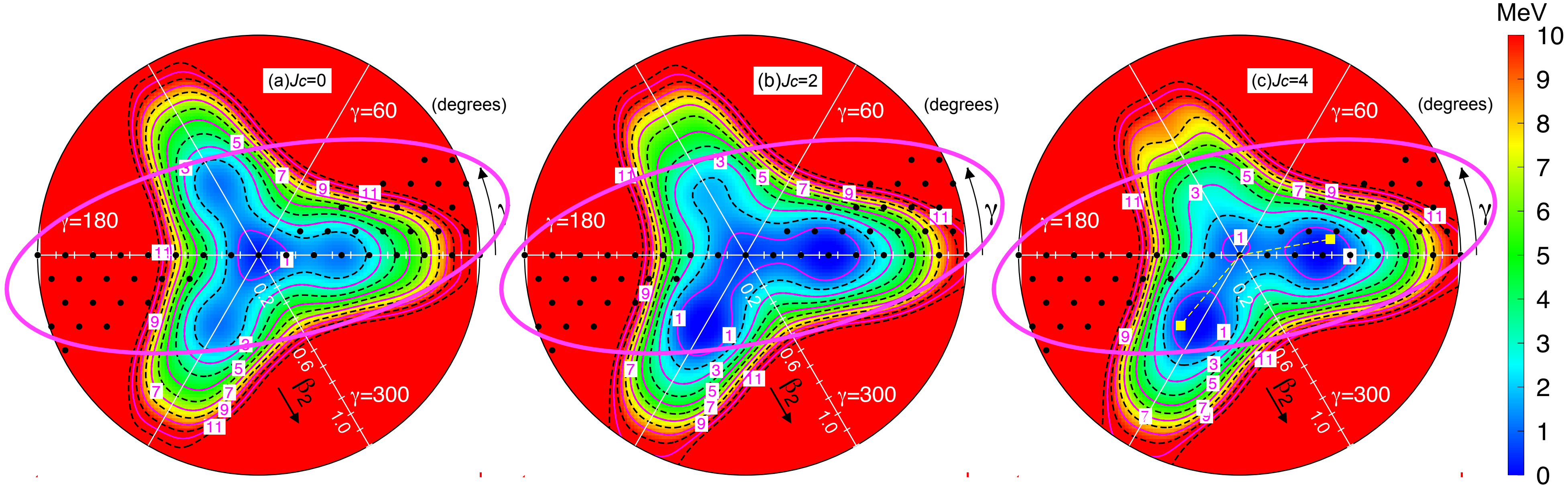

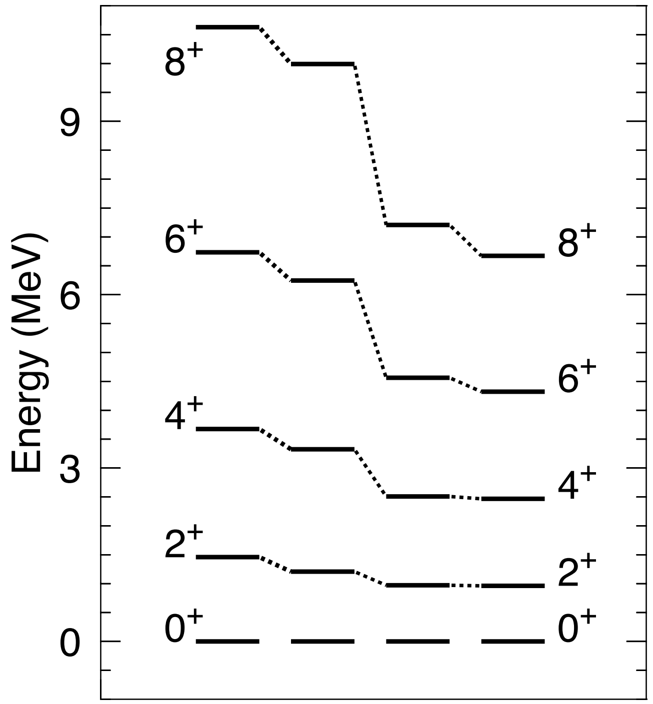

- ✓ Compression of the spectrum is observed.
- ✓ Convergence of the energies of the ground and lowest excited states is obtained.
- ✓ Only one-sextant is included.

E (g.s.)=-253.056,-253.477,-253.486,-253.498 MeV

M. Borrajo, T.R.R, J.L. Egido, PLB 746, 341 (2015)

EDF with cranked states

Example: ^{32}Mg; Comparison to SM and experiment

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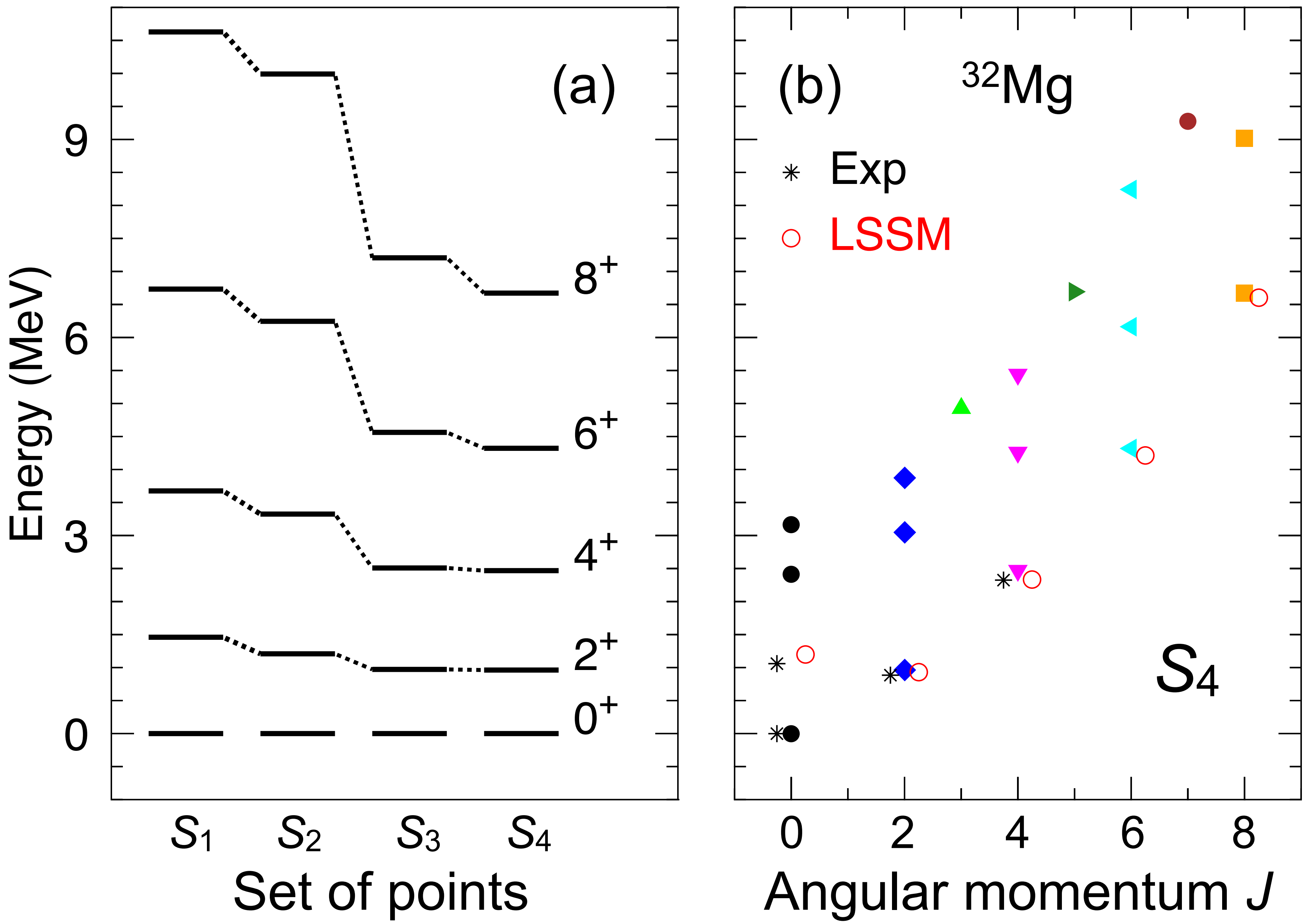

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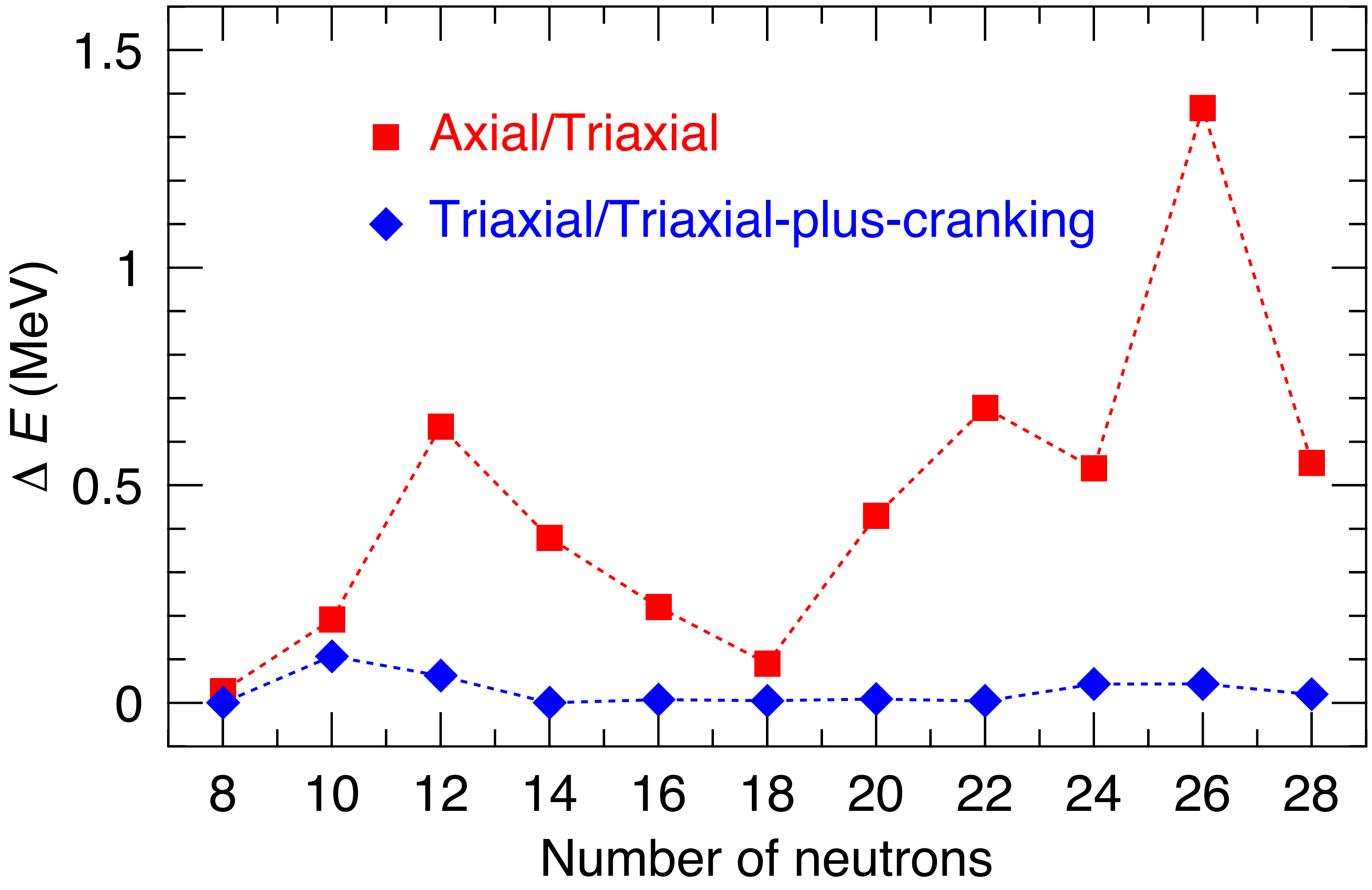
Systematics in the Magnesium isotopic chain



✓ Convergence of the energies of the ground states

T. R. R., Eur. Phys. J. A 52, 190 (2016)

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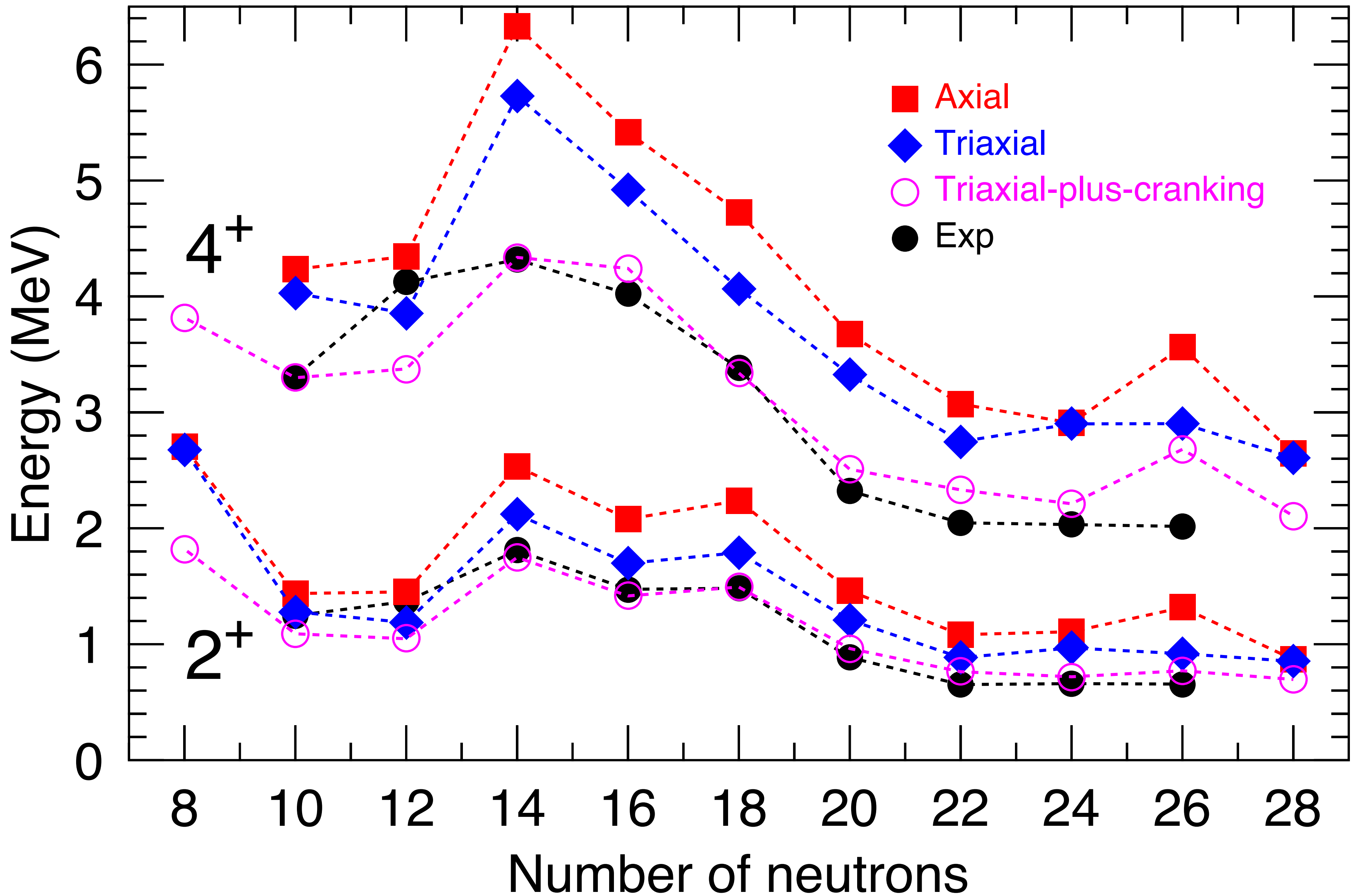

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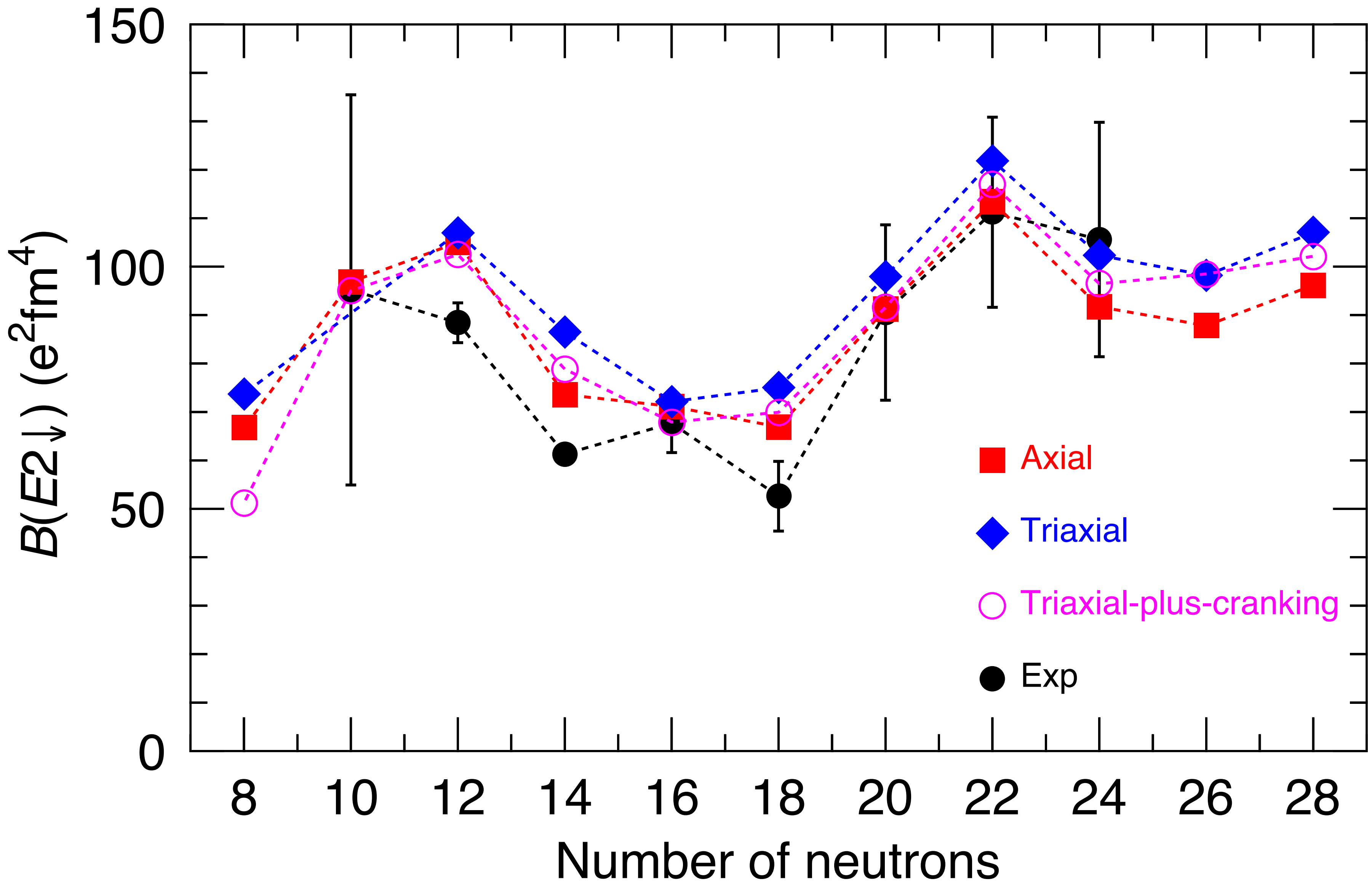
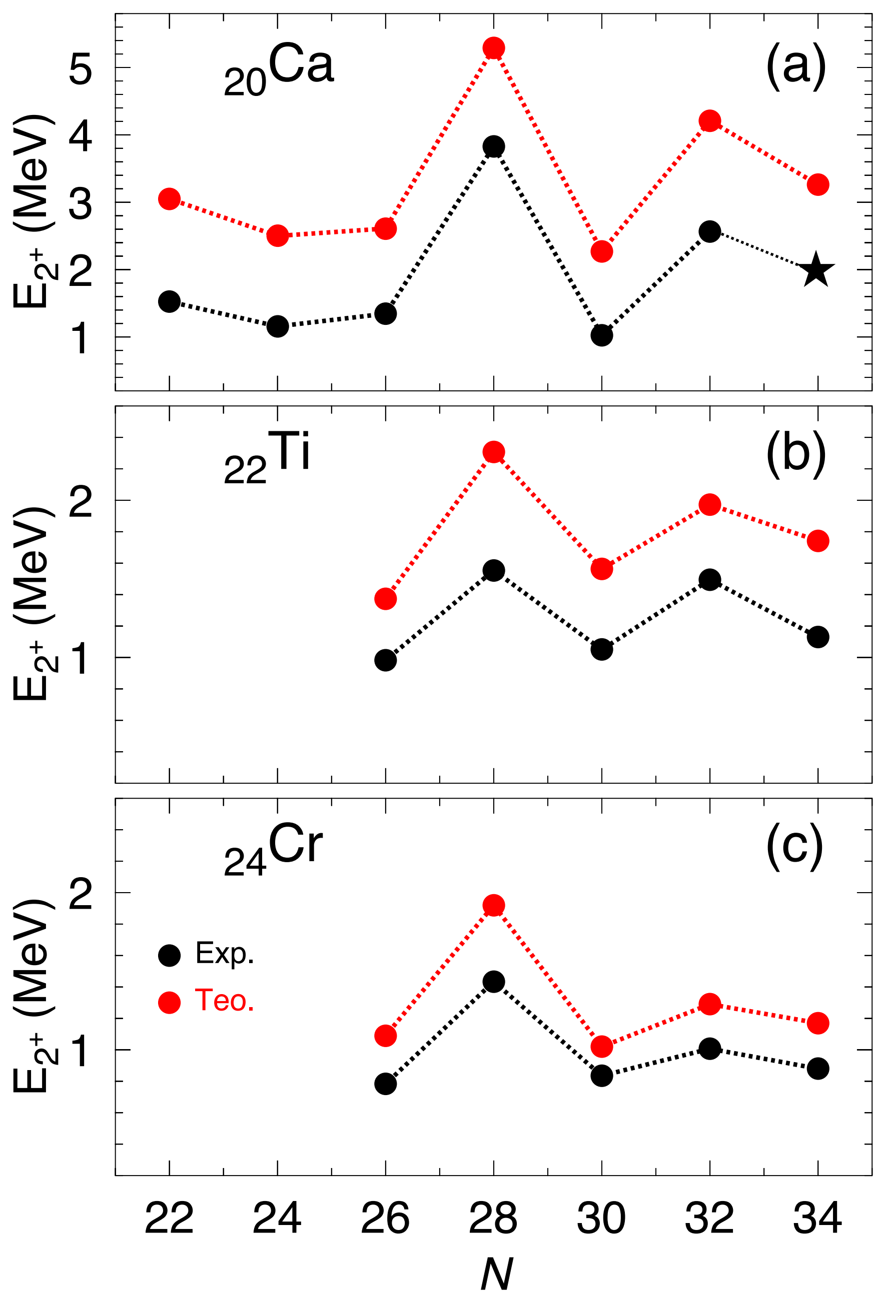
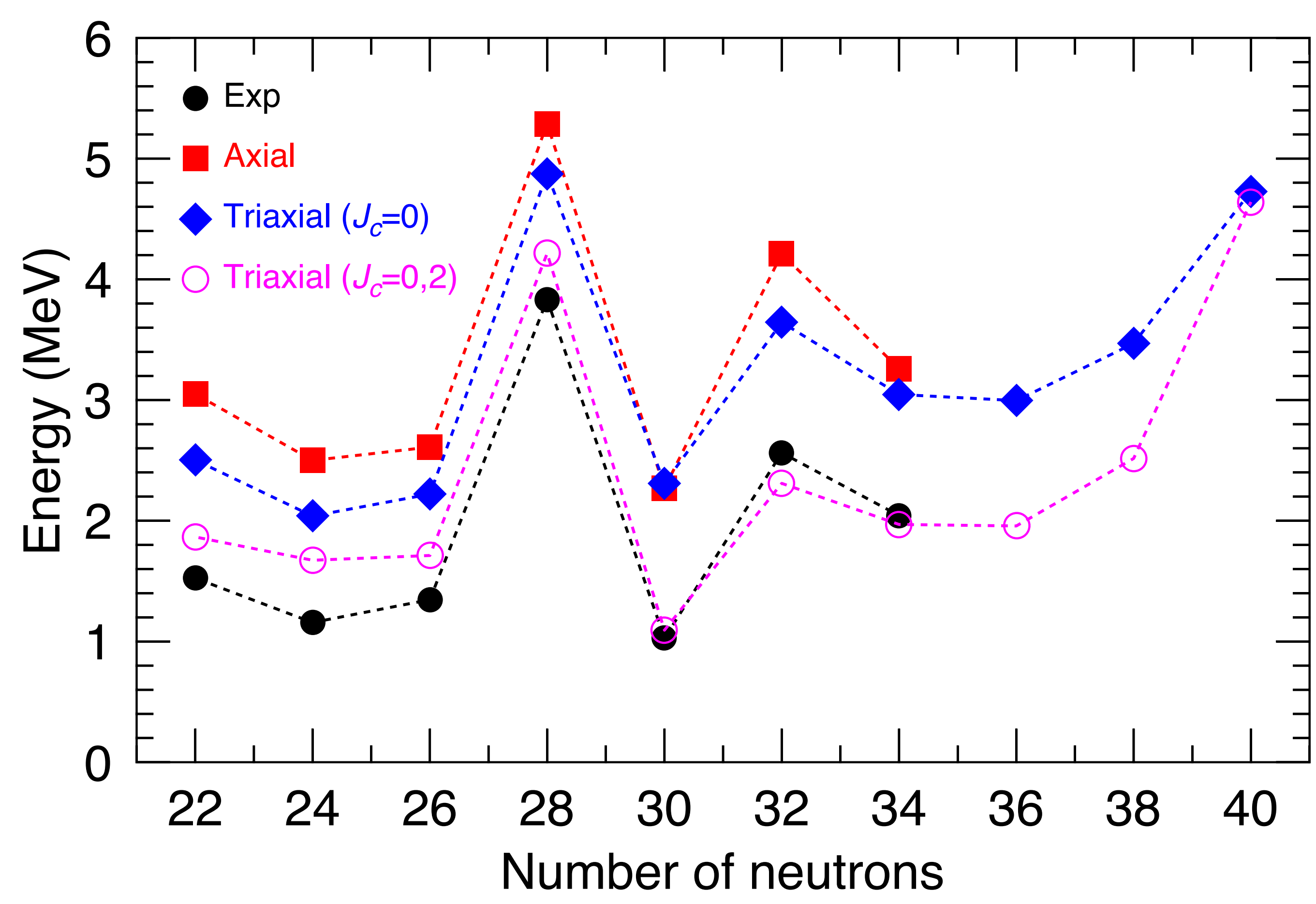


EDF with cranked states

N=32 and/or *N*=34 in Ca, Ti and Cr isotopes.



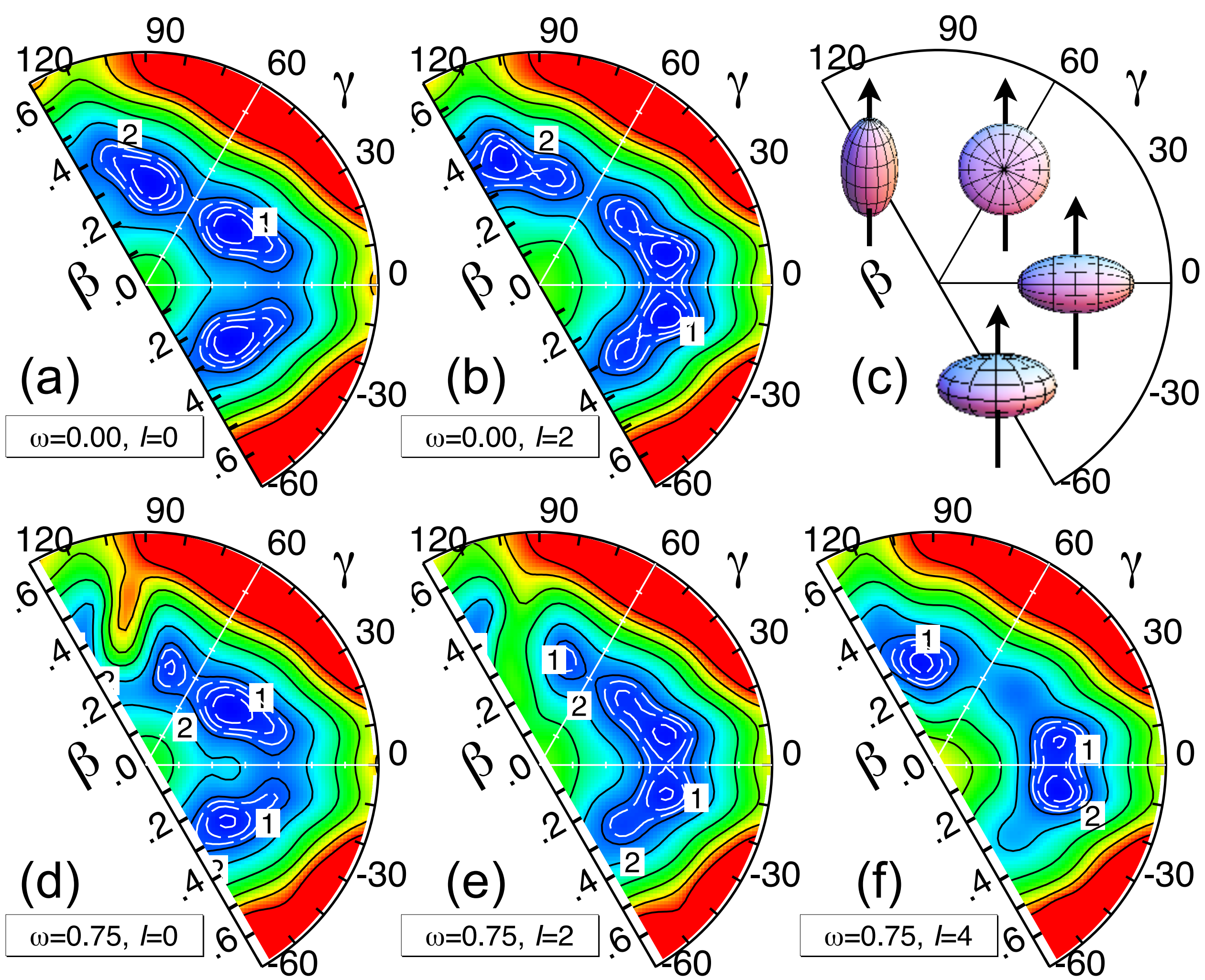


T.R.R, M. Borrajo, J.L. Egido, unpublished

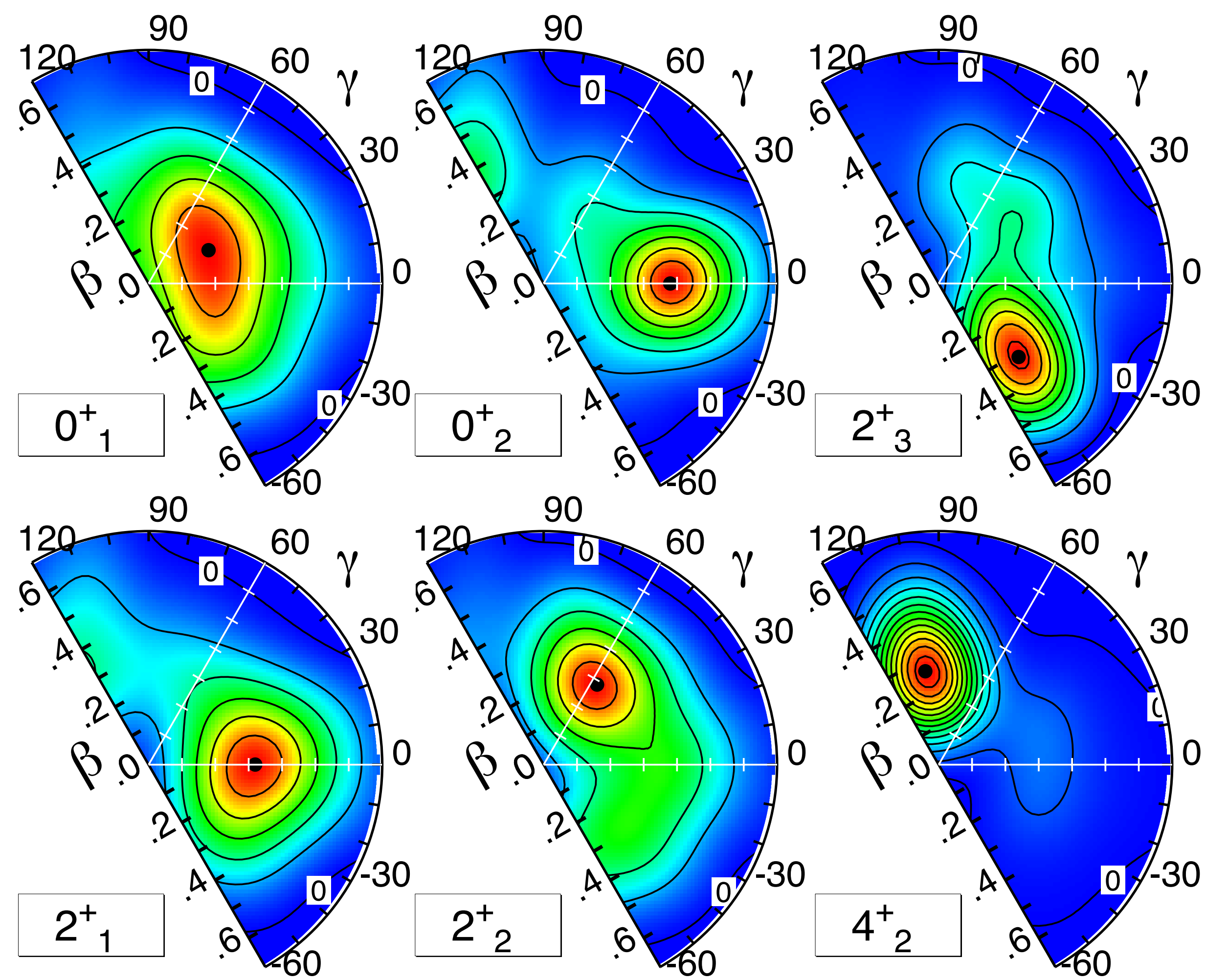
EDF with cranked states

^{44}S

Potential energy surfaces



Collective wave functions



J.L. Egido, M. Borrajo, TRR, PRL 116, 054319 (2016)

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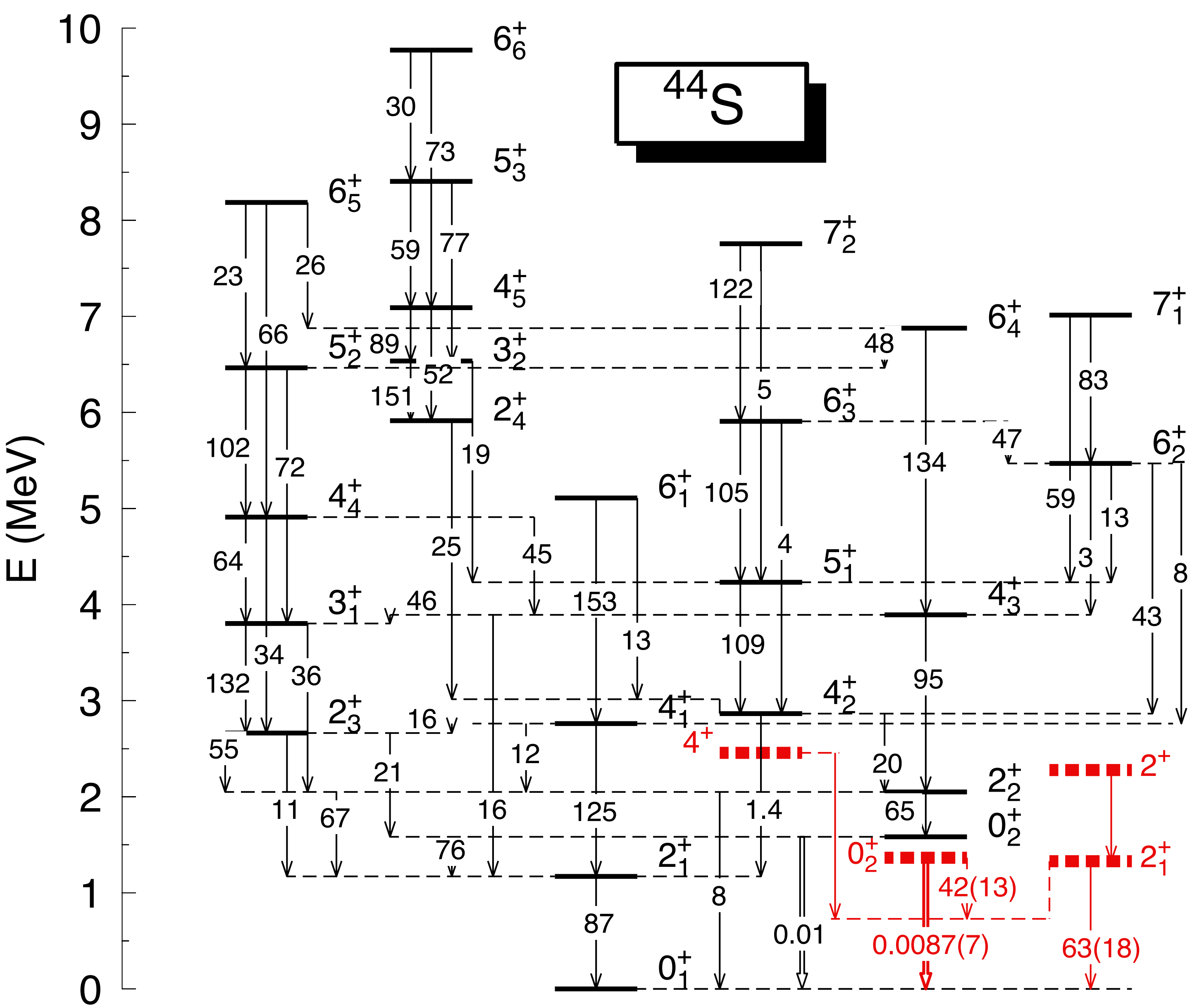

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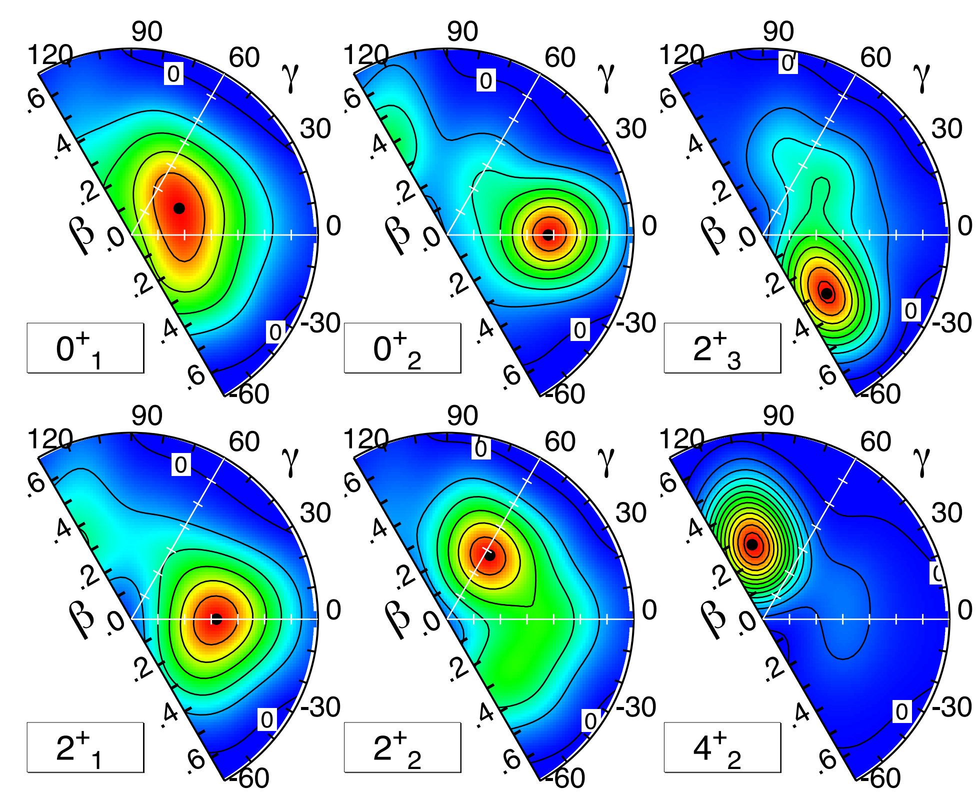

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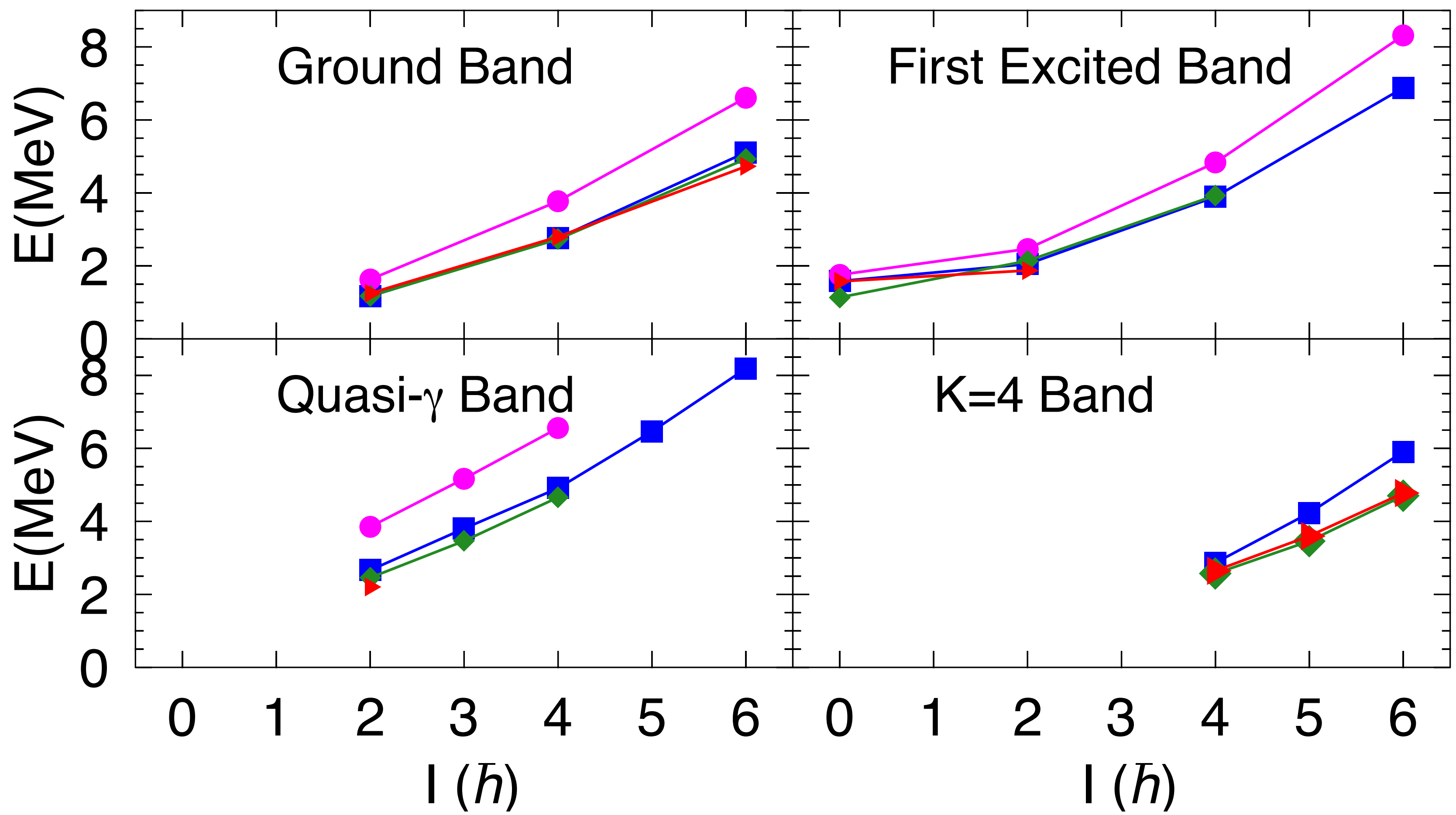


FIG. 4: (Color online) Comparison of several theories: Triangles, red lines, Tokyo group [22]; diamonds, green lines, Madrid-Strasbourg collaboration [31]; boxes, blue lines, this work; circles, magenta lines, our former work without angular frequency dependence [20].

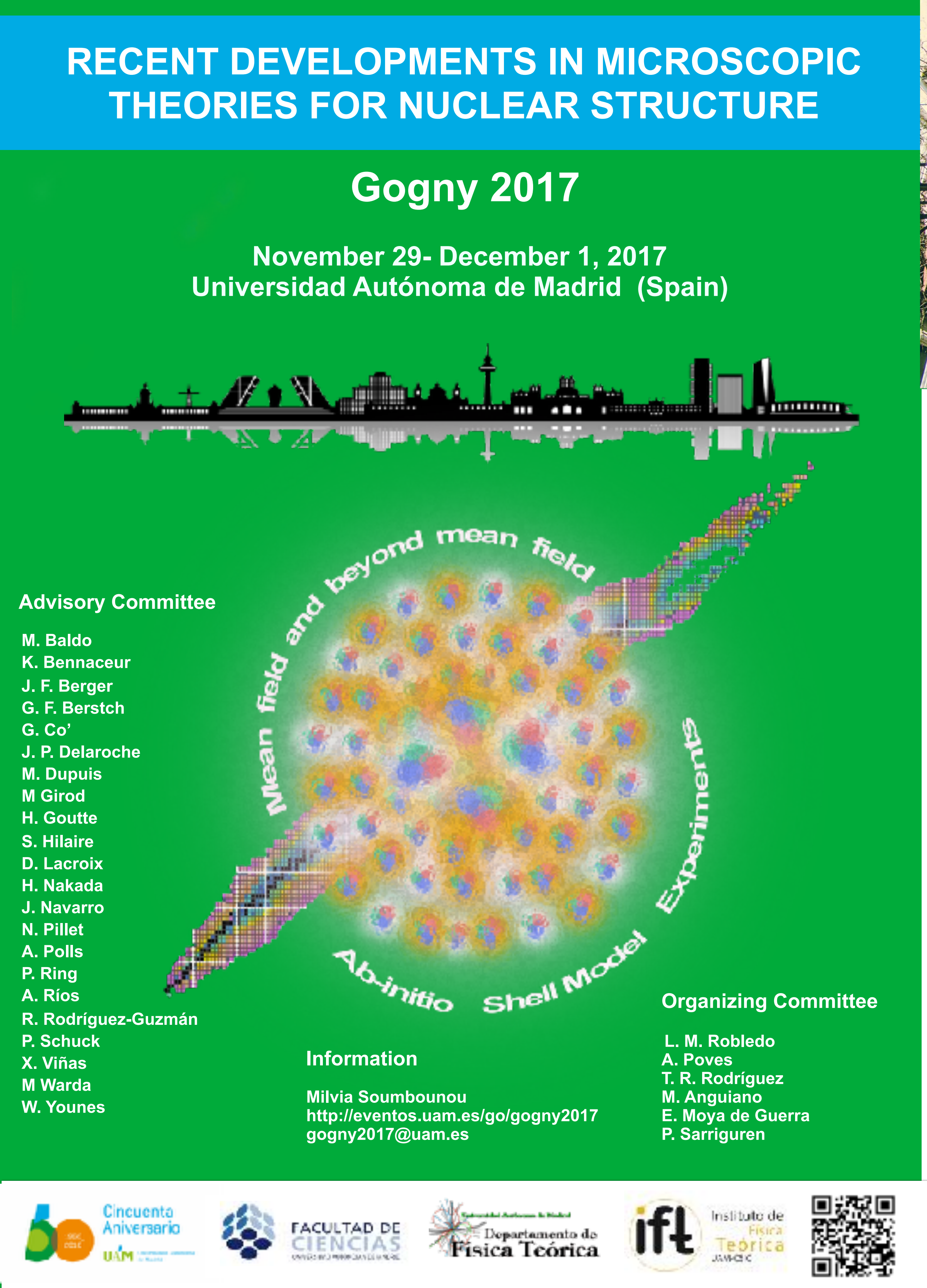
J.L. Egido, M. Borrajo, TRR, PRL 116, 054319 (2016)

Summary and outlook

Time-reversal symmetry (cranking states) allows for a quantitative agreement with the experimental energy spectra.

Outlook

- Quasiparticle states:
  - Odd-nuclei. (Bally-Bender-Heenen, Borrajo-Egido, …)
  - Single-particle excitations. (Qi-Egido, …)
- T_z=0 pairing, pn pairing.
- Isospin projection. (Satula et al., …)
- Parameters of the next generation of functionals should be fitted taking into account beyond-mean-field effects and/or extracted from *ab initio* methods (…).



We look forward to welcoming you in Madrid!

http://eventos.uam.es/go/gogny2017