Skyrme-HFB description of shape phase transitions in even-even SHN

A. Staszczak, L. Próchniak

Natura non facit saltus

19th Nuclear Physics Workshop
"Marie & Pierre Curie"
Kazimierz 2012

The Segre Chart of the SHN

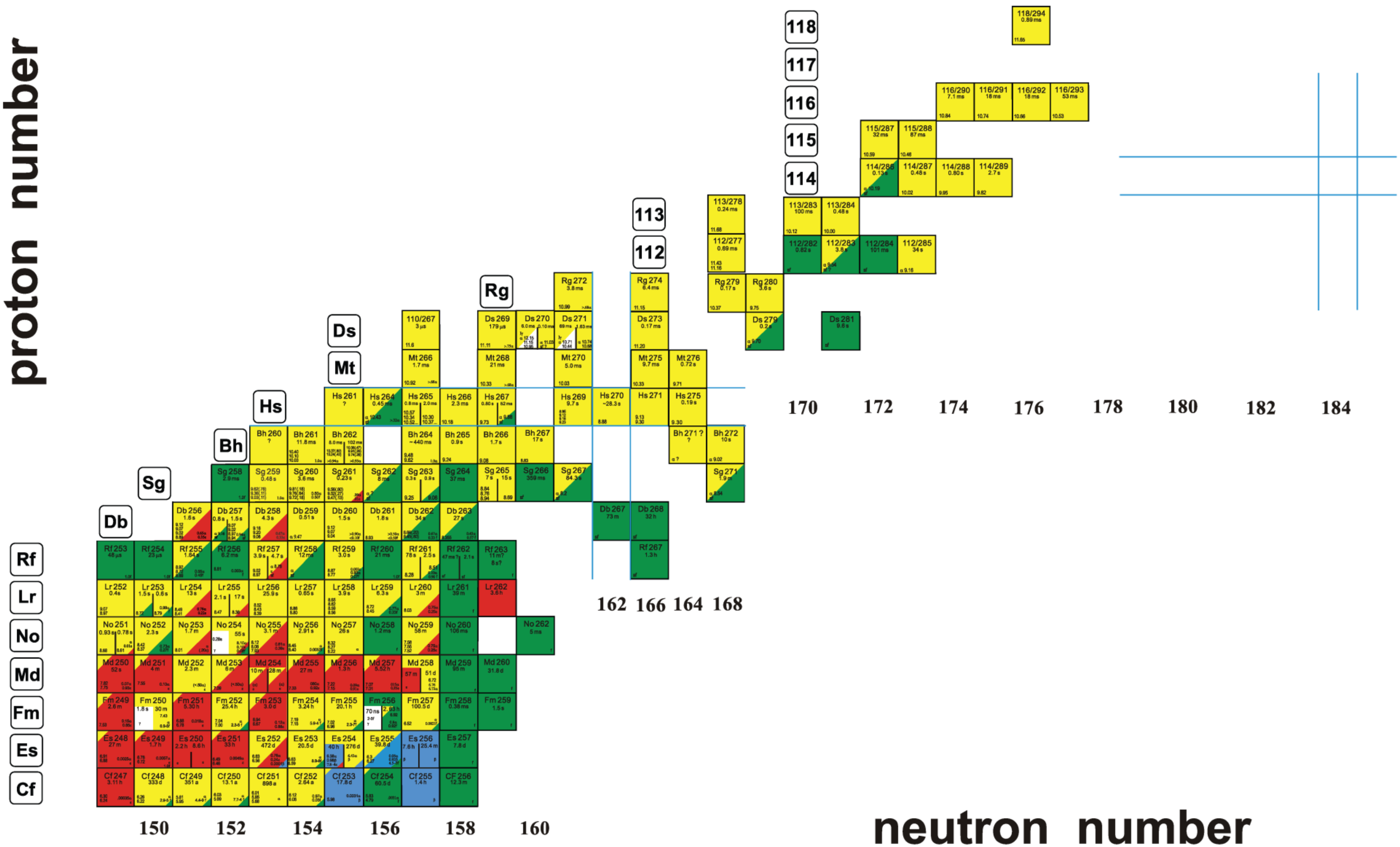


Fig. J. Dvořák (2007)

The Segre Chart of the SHN

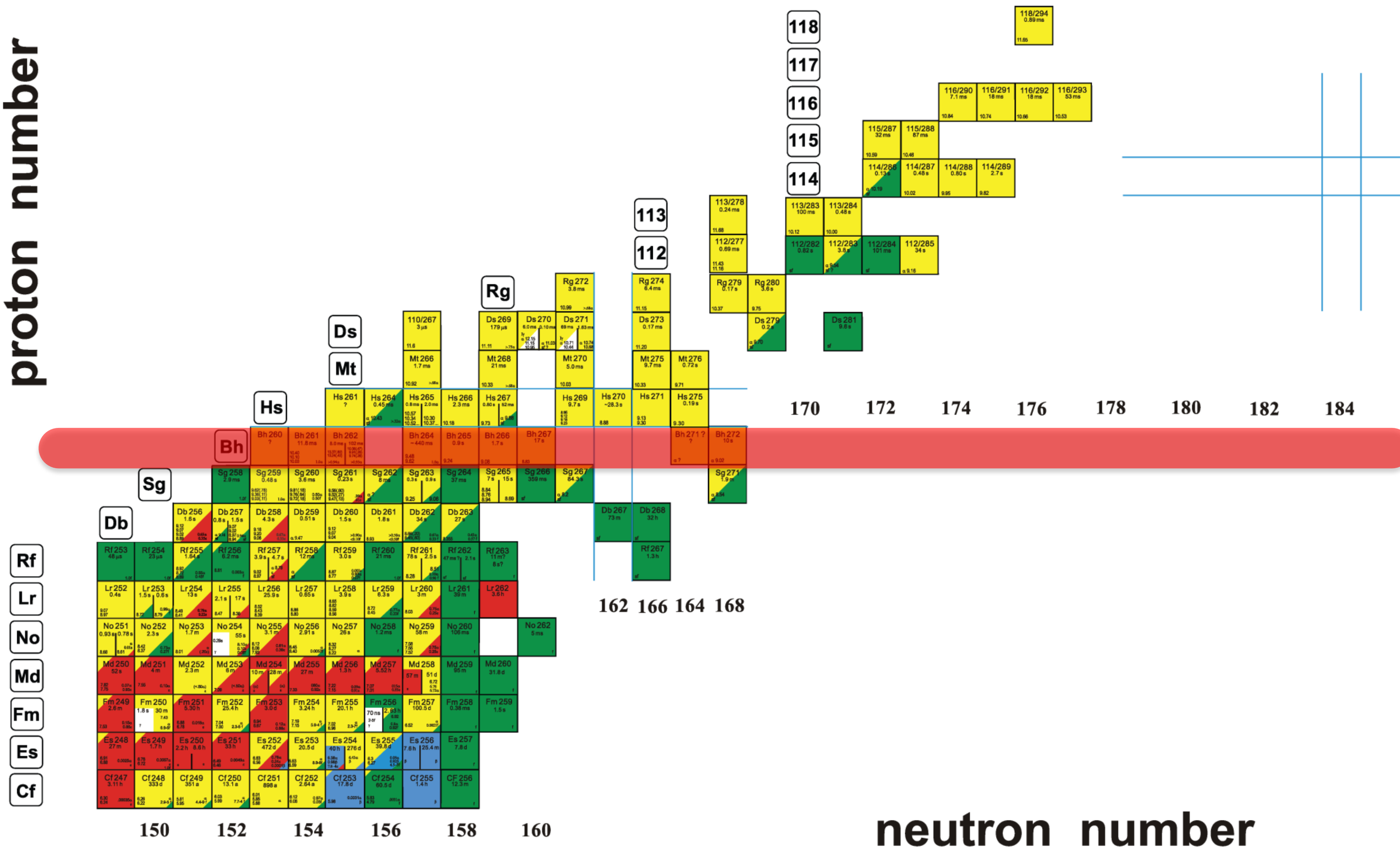
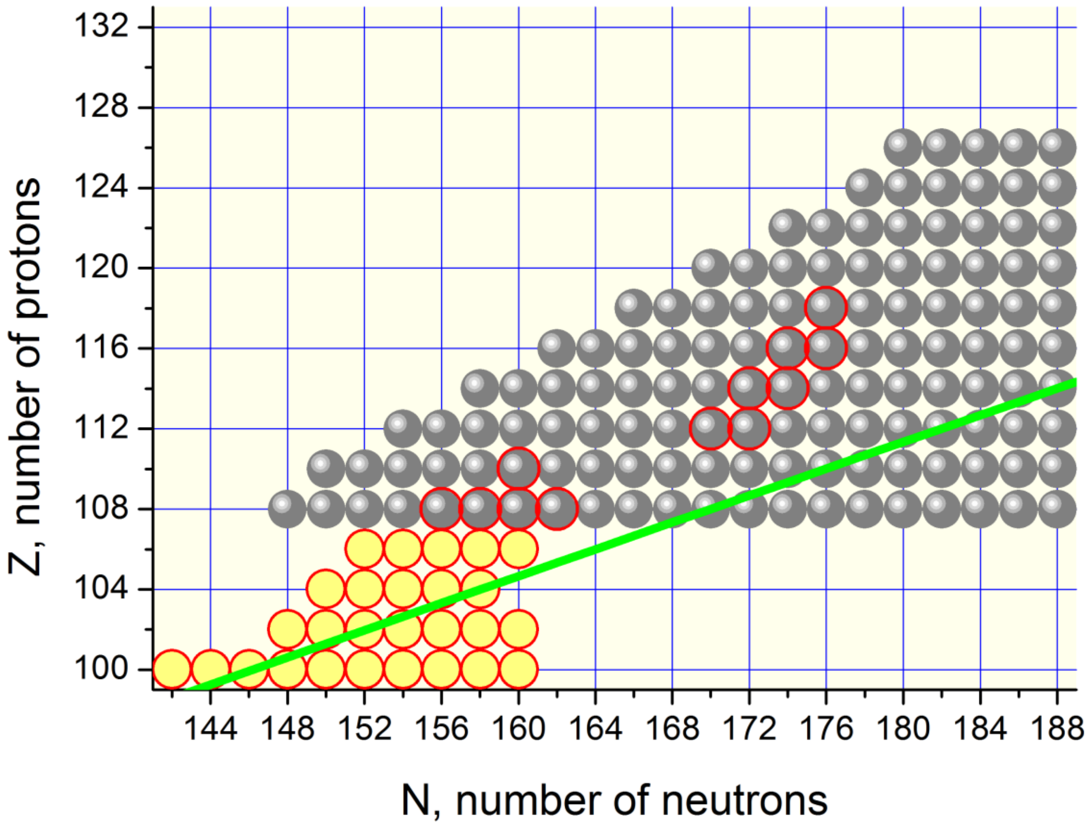


Fig. J. Dvořák (2007)

Model

The ground states properties of even-even super heavy nuclei (SHN), with $108 \leq Z \leq 126$ and $148 \leq N \leq 188$, were studied within Hartree-Fock-Bogoliubov (HFB) model with a zero-range Skyrme effective interaction.



130 e-e nuclei
$108 \leq Z \leq 126$
$148 \leq N \leq 188$

Model

The symmetry unrestricted code HFODD [1] and **an augmented Lagrangian method** [2] were used to solve constrained HFB equations with **SkM* Skyrme force** [3] in the particle-hole channel and **a density dependent mixed pairing** [4] interaction in the particle-particle channel.

To truncate the quasiparticle space of HFB, we adapted the quasiparticle cut-off value of 60 MeV in the equivalent energy spectrum. The pairing strengths were adjusted to reproduce the neutron and proton pairing gaps in ^{252}Fm [5]; the resulting values are V_{n0} = -268.9 MeV fm^3 and V_{p0} = -332.5 MeV fm^3.

The stretched harmonic oscillator basis of HFODD was composed of states having not more than N_0 = 26 quanta in either of the Cartesian directions, and not more than 1140 states in total.

---

[1] J. Dobaczewski and J. Dudek, Comput. Phys. Commun. **102**, 166 (1997); **102**, 183 (1997); **131**, 164 (2000); J. Dobaczewski and P. Olbratowski, **158**, 158 (2004); **167**, 214 (2005); J. Dobaczewski *et al*., **180**, 2361 (2009); *"HFODD (v2.40h) User's Guide"*, (2009), arXiv:0909.3626; N. Schunck *et al*., **183**, 166 (2012).

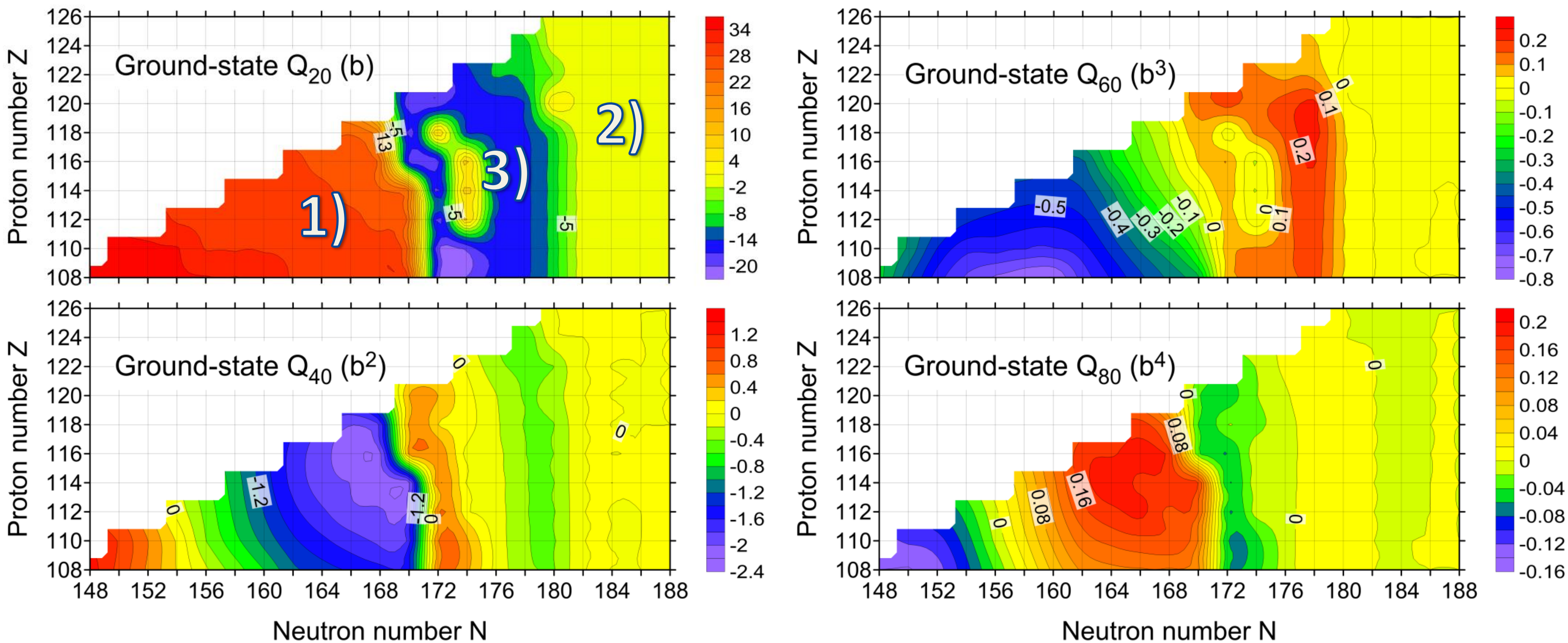
[2] A. Staszczak, M. Stoitsov, A. Baran, and W. Nazarewicz, Eur. J. Phys. A **46**, 85 (2010).

[3] J. Bartel *et al*., Nucl. Phys. A **386**, 79 (1982).

[4] J. Dobaczewski, W. Nazarewicz, and M. V. Stoitsov, Eur. J. Phys. A **15**, 21 (2002).

[5] A. Staszczak, A. Baran, J. Dobaczewski, and W. Nazarewicz, Phys. Rev. C **80**, 014309 (2009).

Groud state deformations

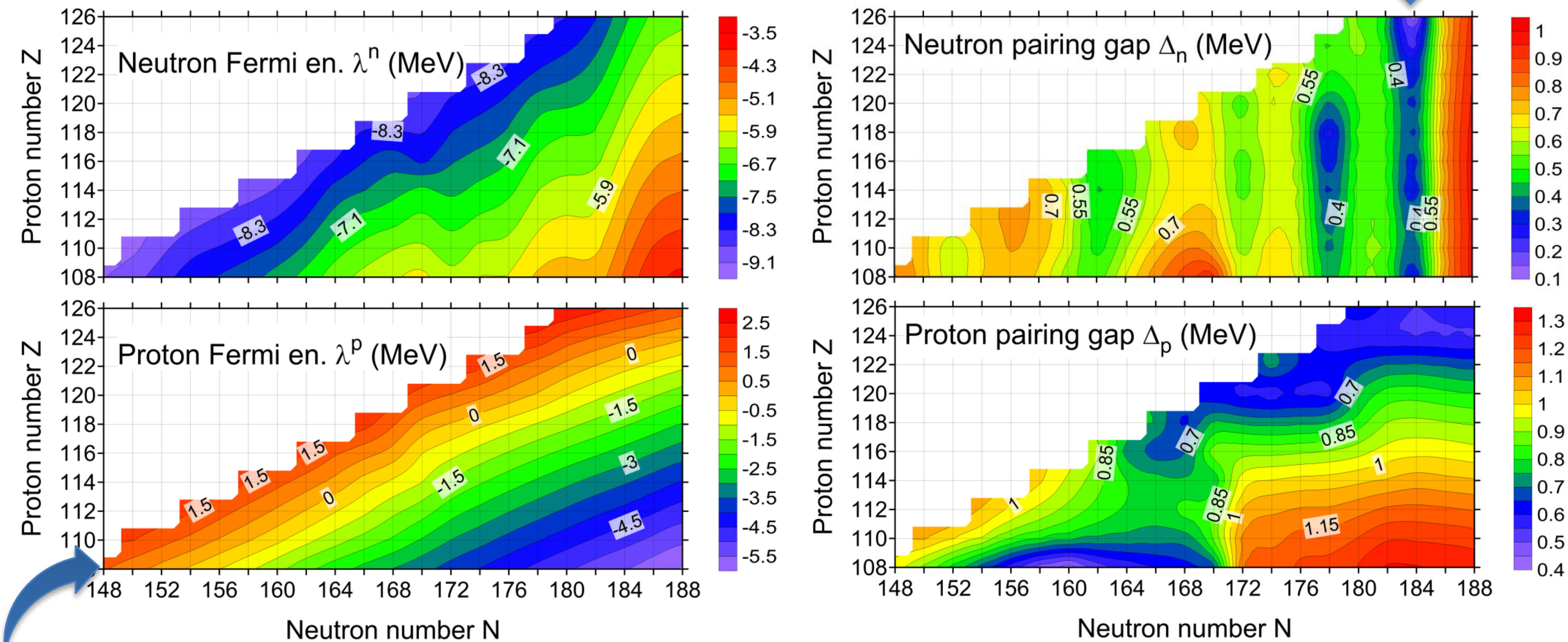


<u>The e-e SHN form three regions:</u>

1) a prolate-deformed (for N < 172),
2) spherical (N>180),
3) the transitional region (between the former two).

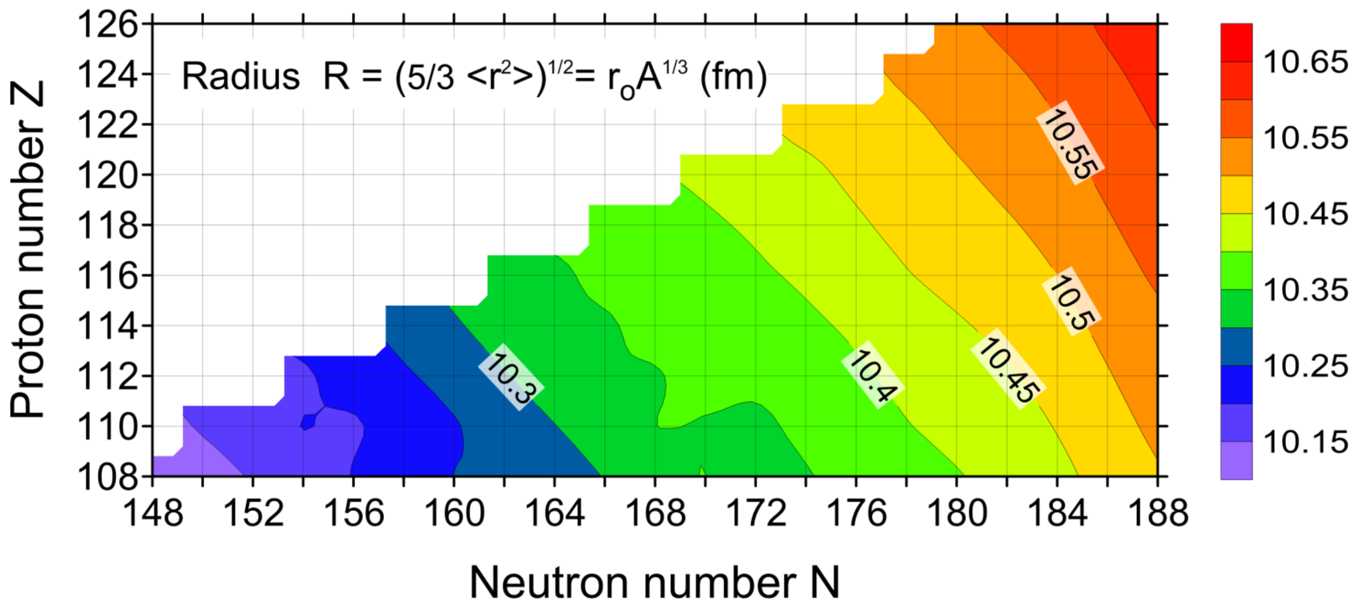
Ground state pairing properties of e-e SHN

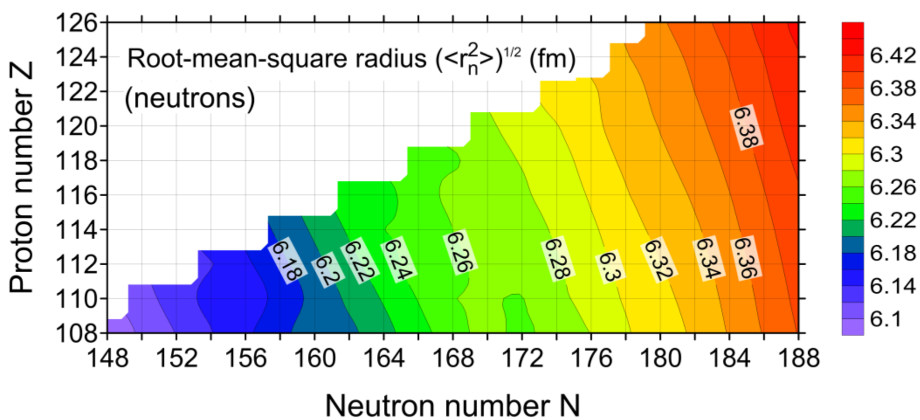
$\Delta_n \approx 0$ MeV for N = 184

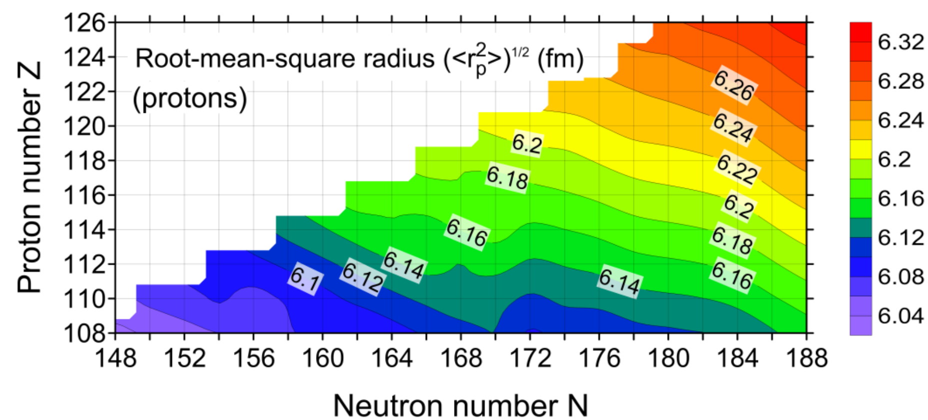


<u>Proton *drip line*:</u>
Fermi energy $\lambda^p \leq 2$ MeV.

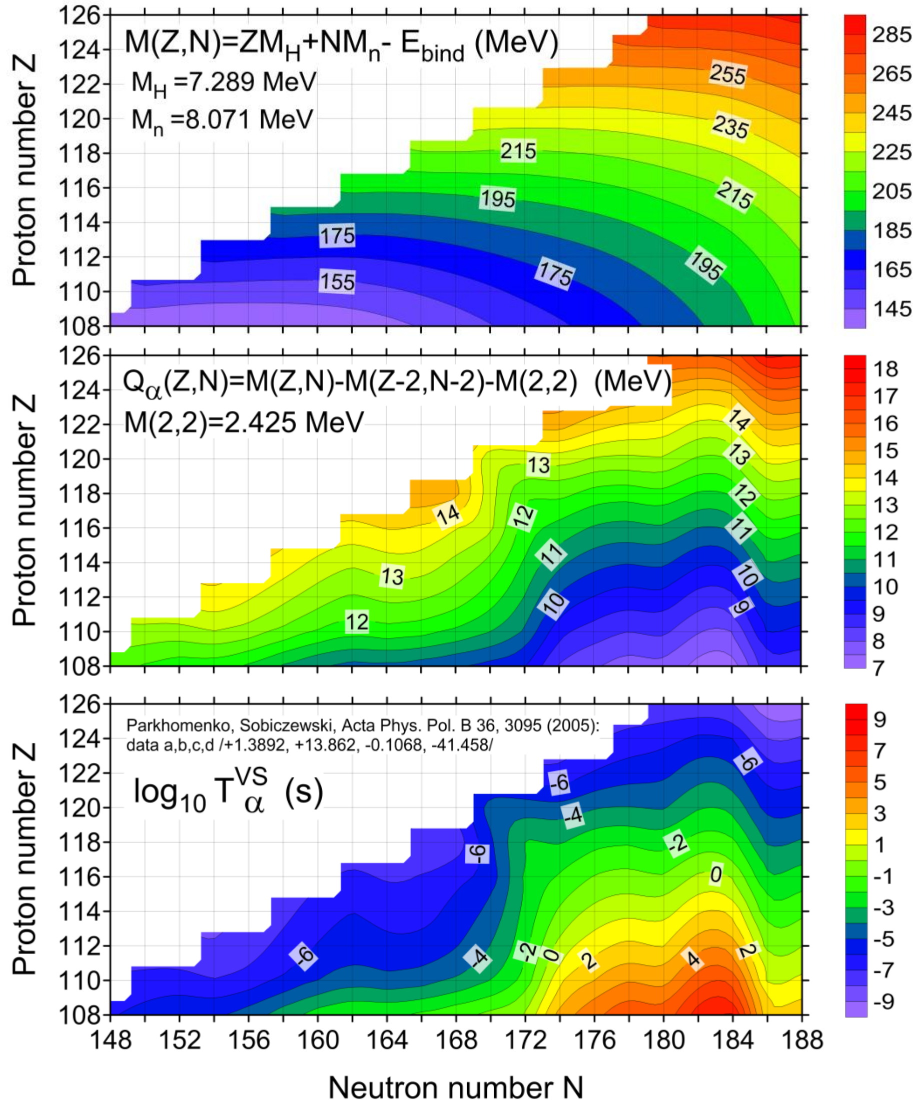
Geometric sizes



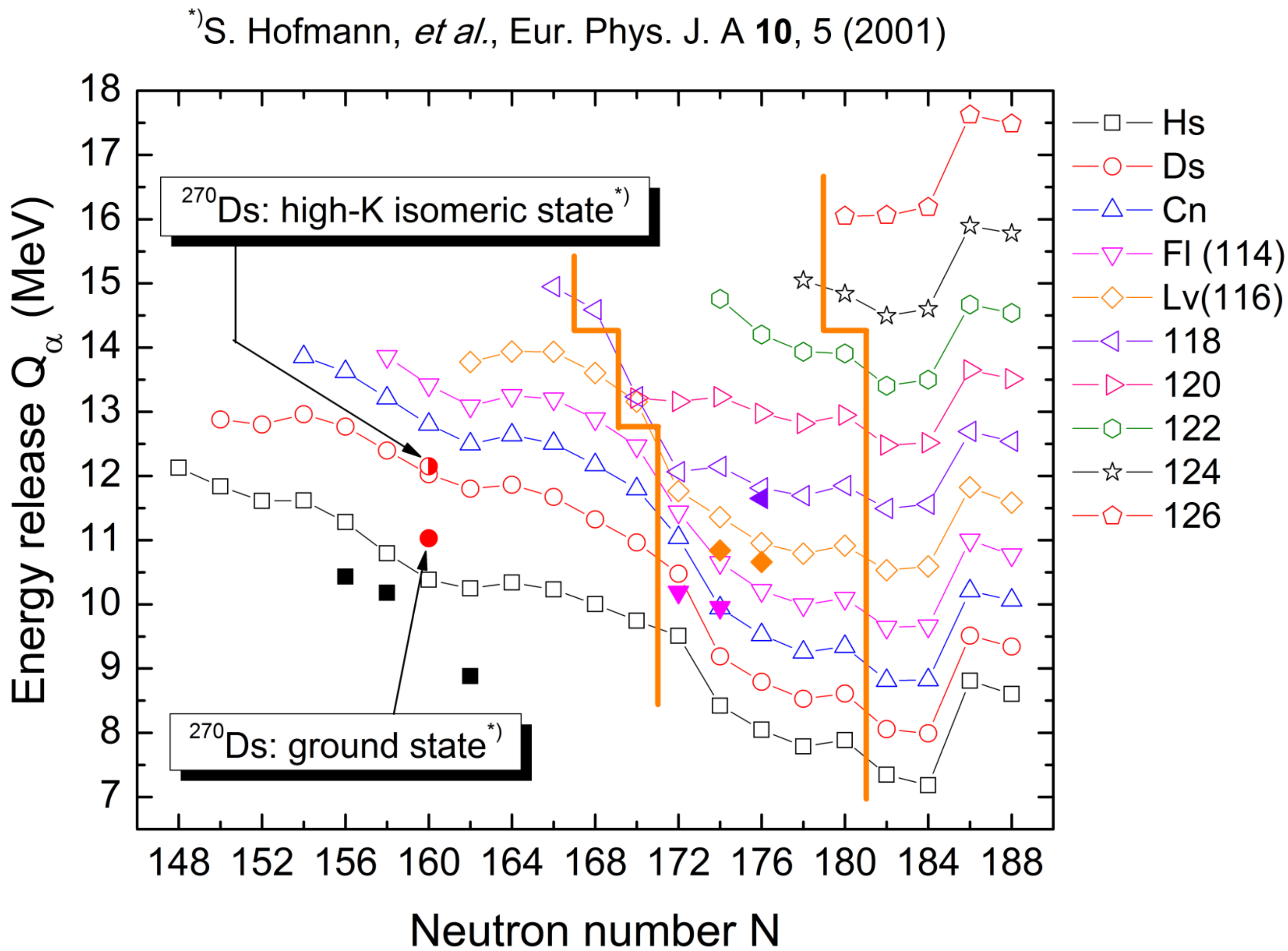




Alpha emission



Q $_\alpha$- values

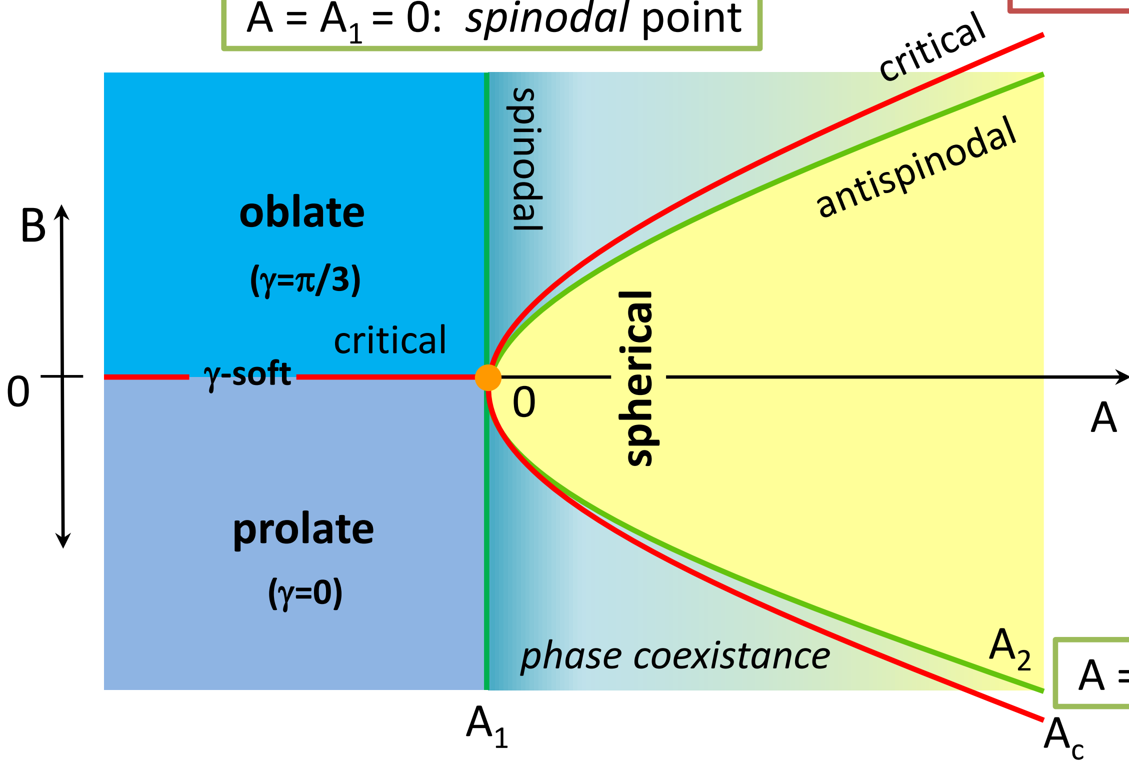


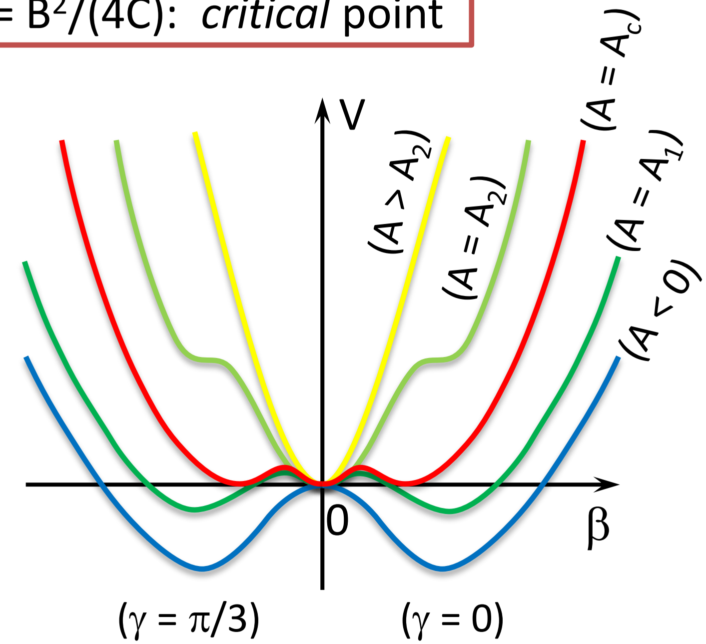
Geometric collective model (GCM) - A. Bohr (1952)

$$V(\beta,\gamma) = A\beta^2 + B\beta^3 \cos 3\gamma + C\beta^4, \quad (C>0)$$

$A = A_1 = 0$: *spinodal* point

$A = A_c = B^2/(4C)$: *critical* point





$A = A_2 = 9B^2/(32C)$: *antispinodal* point

$A = A_c$ $(B \neq 0)$ and $A < 0$ $(B = 0)$: *first-order* phase transition lines

$A = B = 0$: *second-order* phase transition point (*triple-point*)

Interacting boson approximation (IBA-1) – Arima, Iachello

$U(6) \supset U(5) \supset O(5) \supset O(3)$

$U(6) \supset SU(3) \supset O(3)$

$U(6) \supset O(6) \supset O(5) \supset O(3)$

$U(6) \supset \overline{SU(3)} \supset O(3)$

$U(6) \supset \overline{O(6)} \supset O(5) \supset O(3)$

Dynamical symmetries:

$U(5)$	(vibrational)
$SU(3), \overline{SU(3)}$	(rotational)
$O(6), \overline{O(6)}$	(γ-soft)

Critical-point solutions:

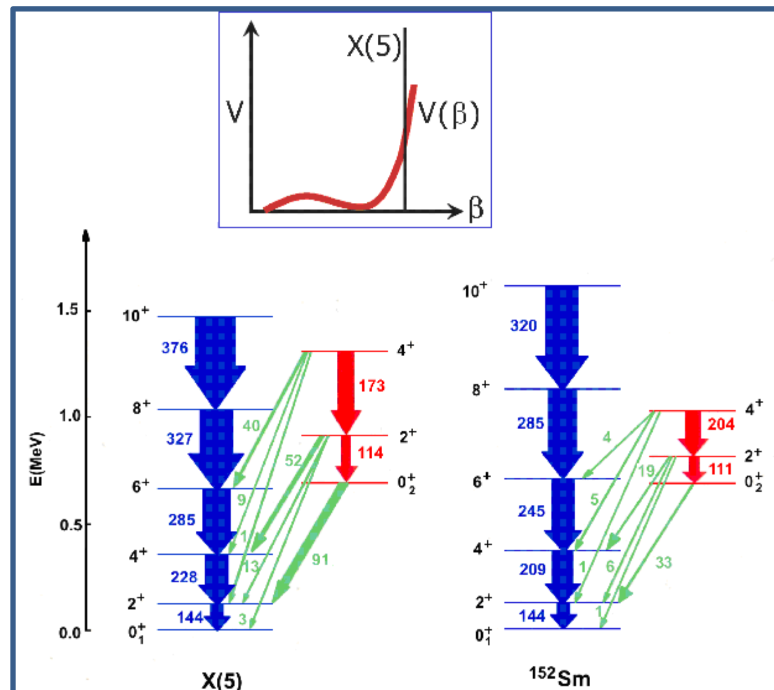
$$V(\beta,\gamma) = A\beta^2 + B\beta^3 \cos 3\gamma + C\beta^4$$

$$V(\beta,\gamma) \approx V_1(\beta) + V_2(\gamma)$$

$X(5)$: $\quad V_1 = V_{well}(\beta), \quad V_2 = c(\gamma-\gamma_o)^2, (c>0)$

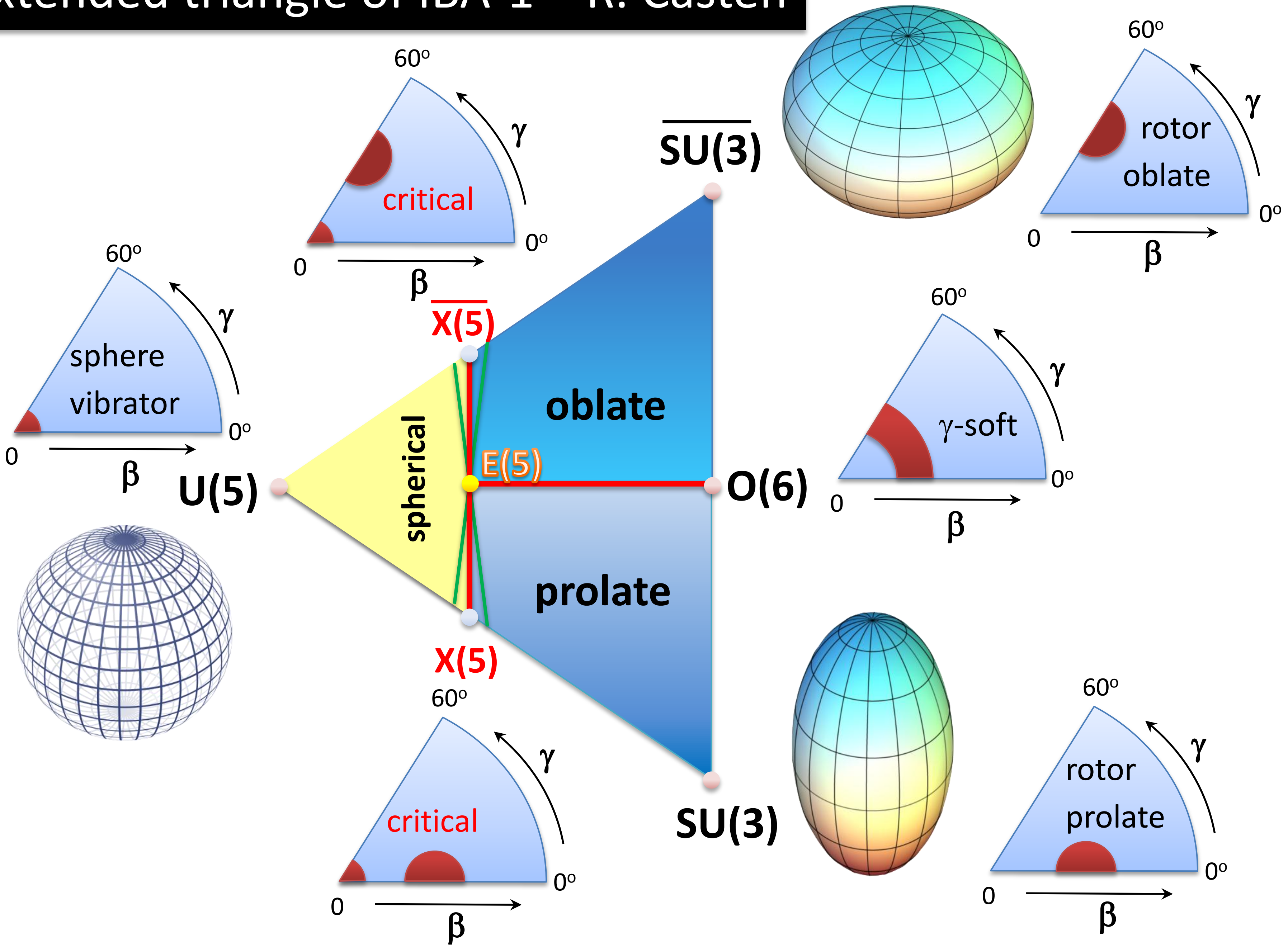
$E(5)$: $\quad V_1 = V_{well}(\beta), \quad V_2 \equiv 0$

F. Iachello, PRL **85**, 3580 (2000);
87, 052502 (2001).

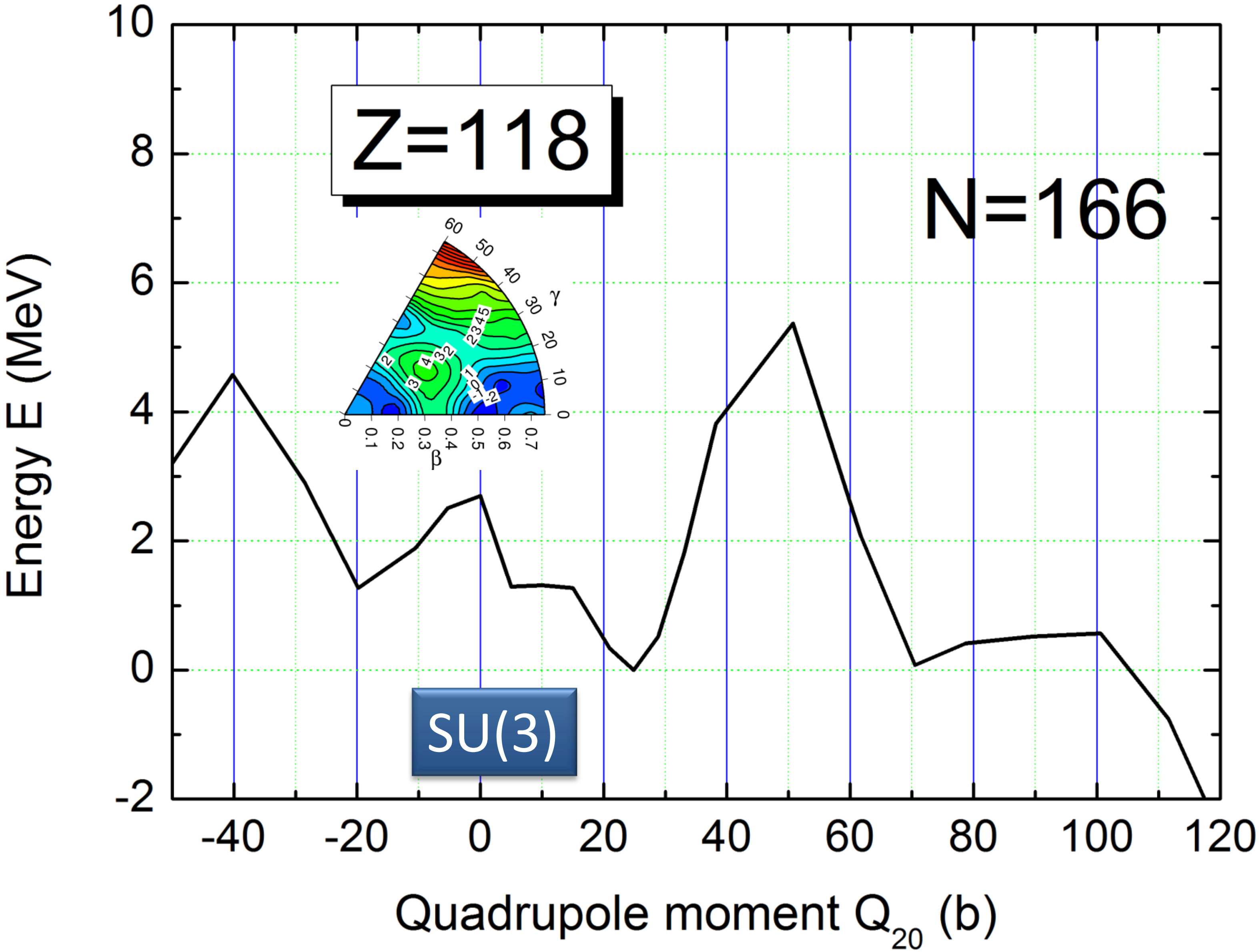


(Fig. Casten)

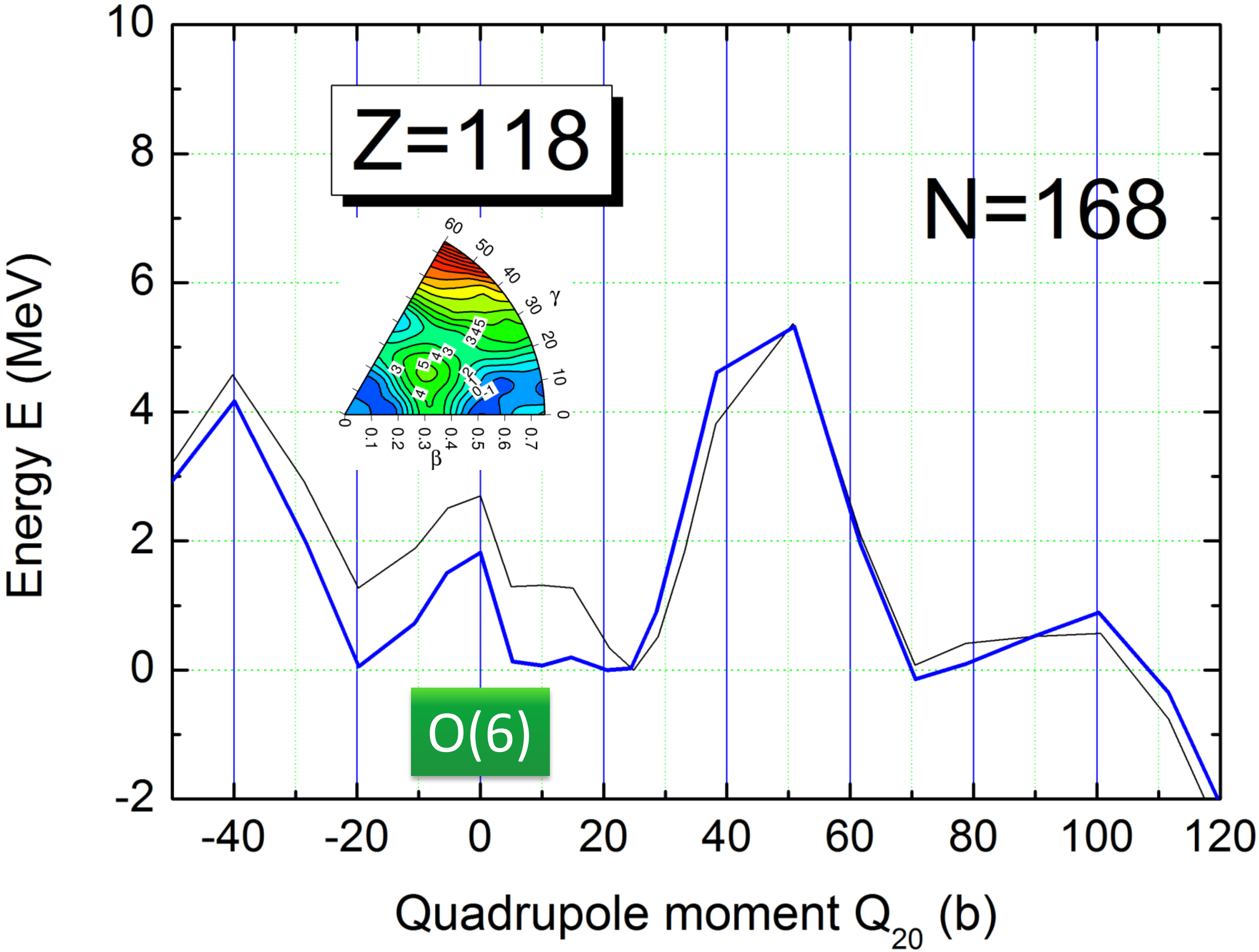
Extended triangle of IBA-1 – R. Casten



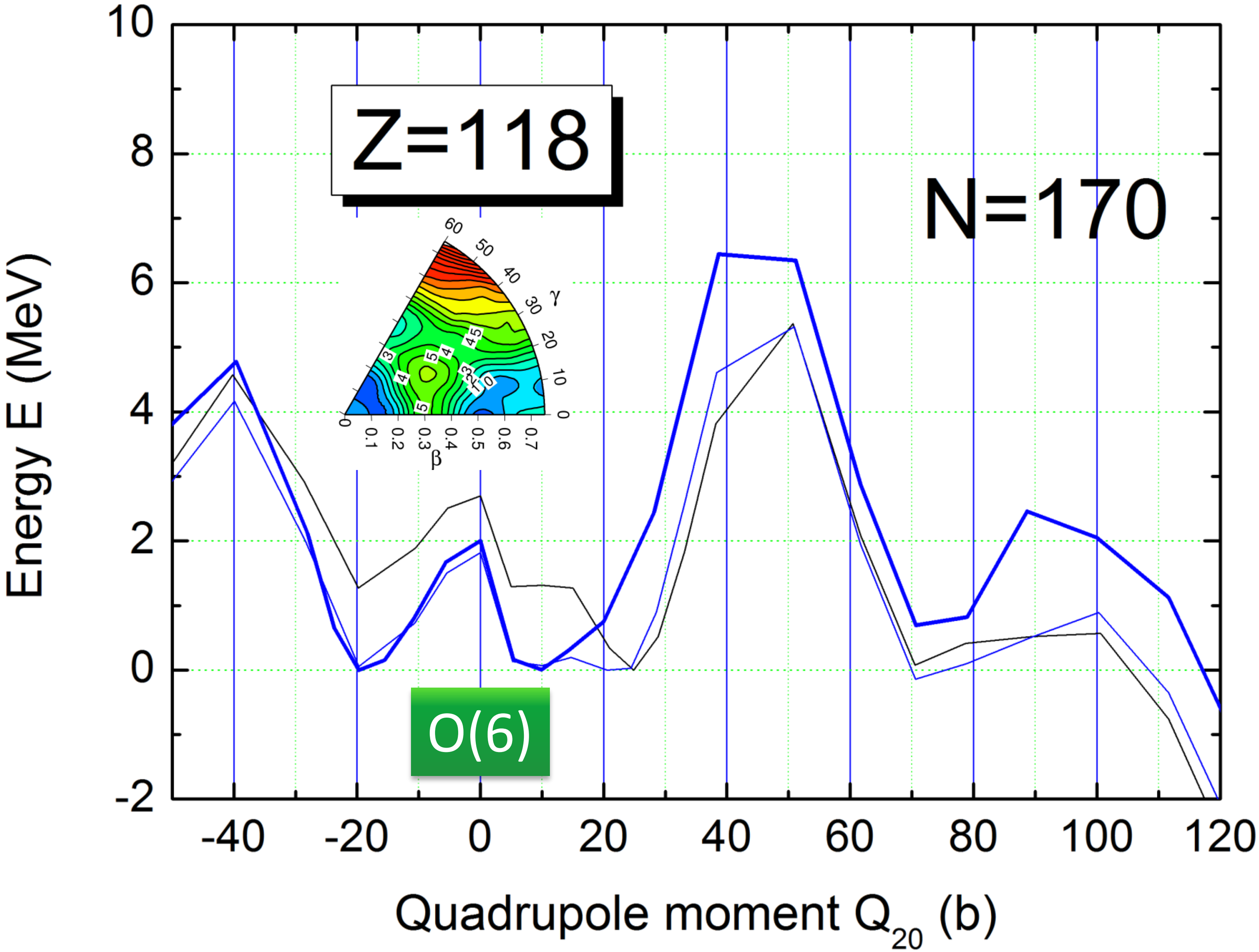
Nuclear shape phase transitions



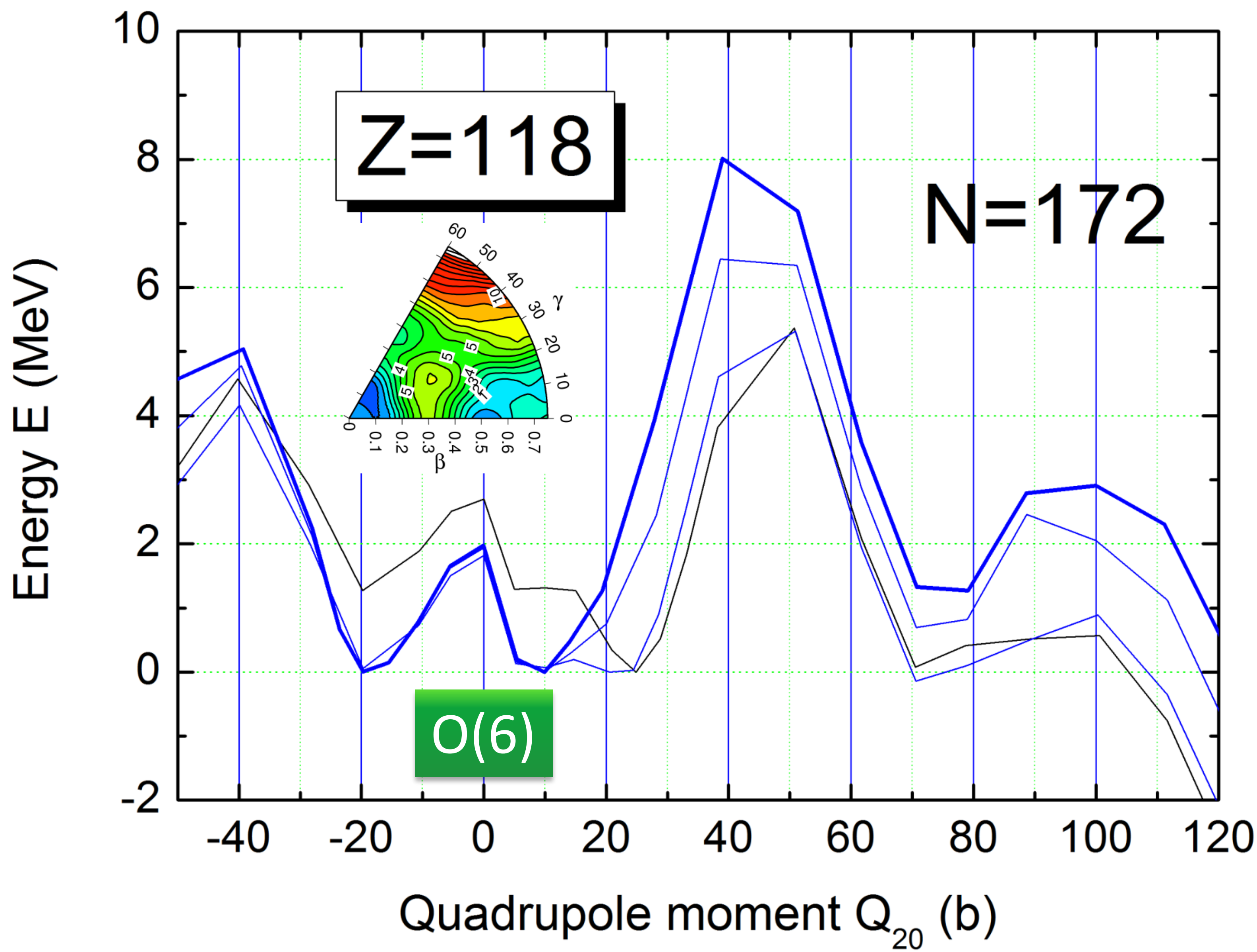
Second order phase transition O(6) – U(5)



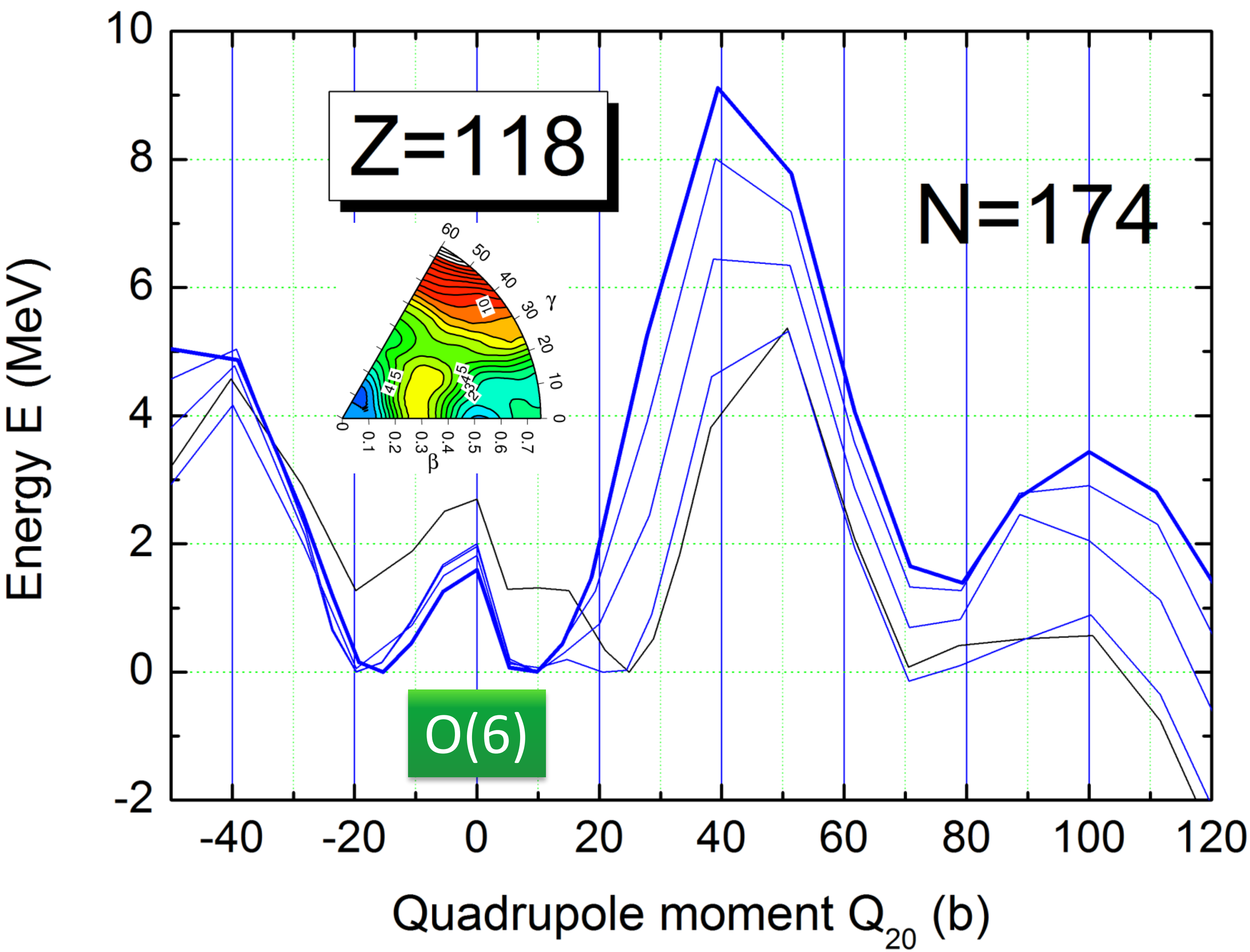
Second order phase transition O(6) – U(5)



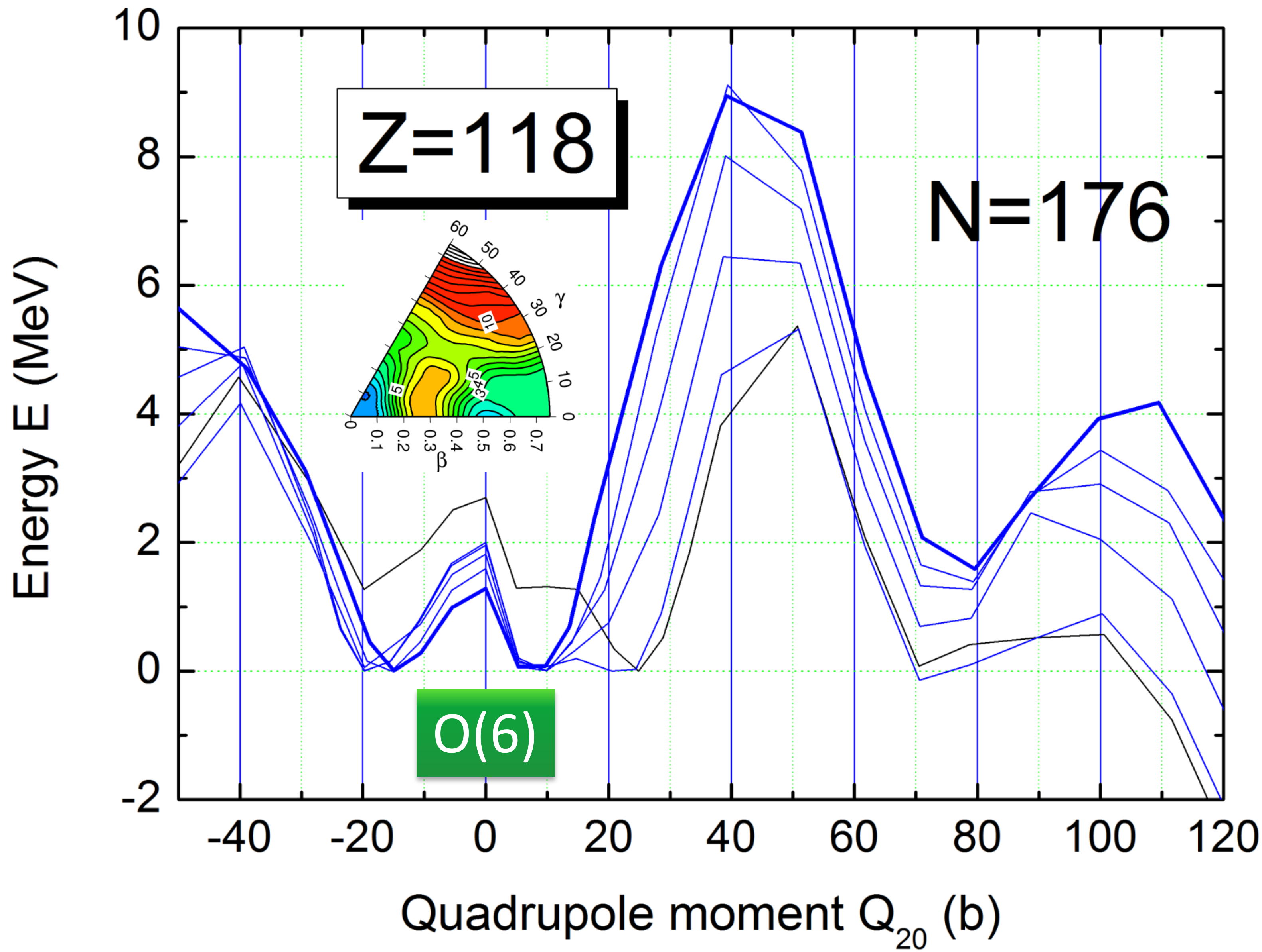
Second order phase transition O(6) – U(5)



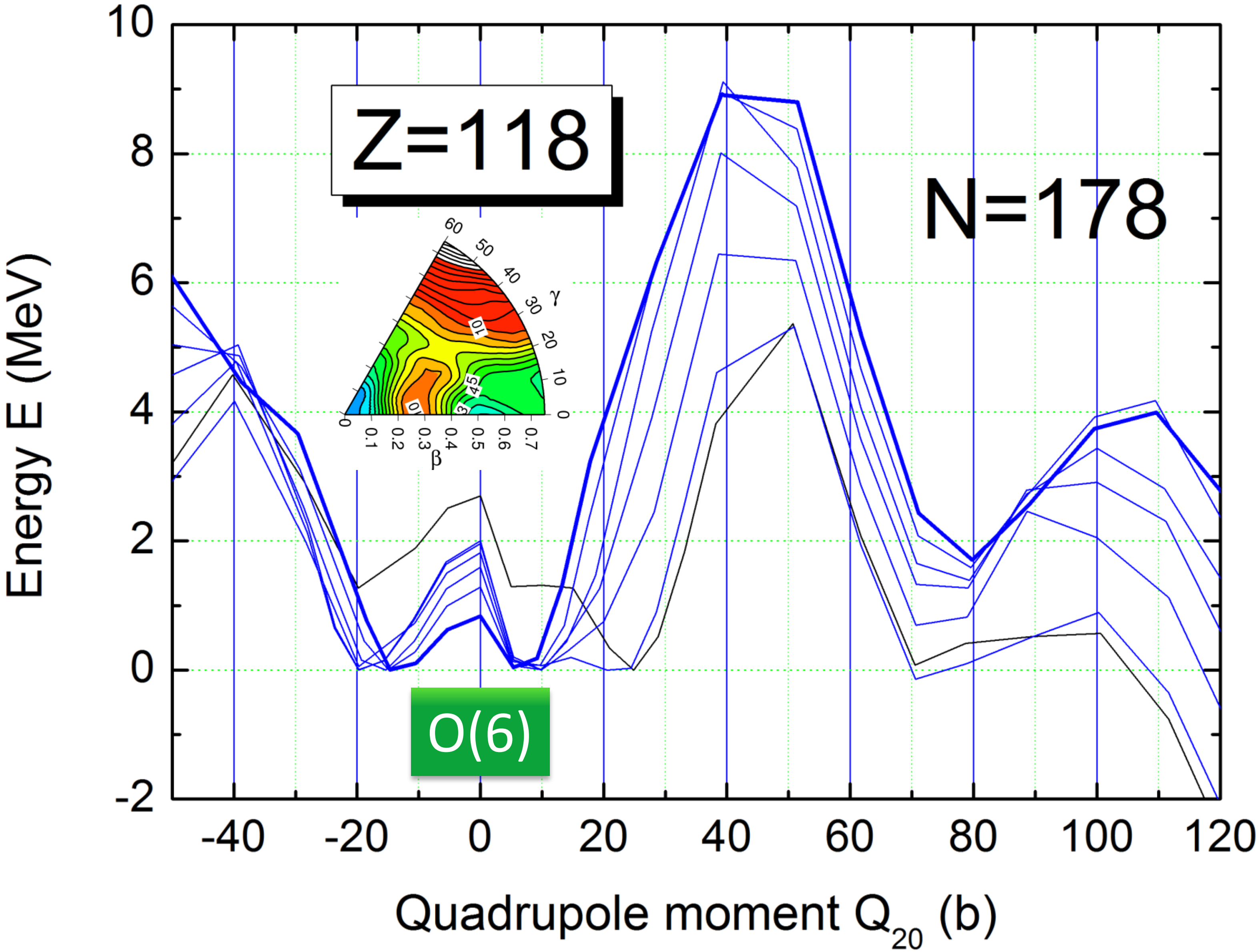
Second order phase transition O(6) – U(5)



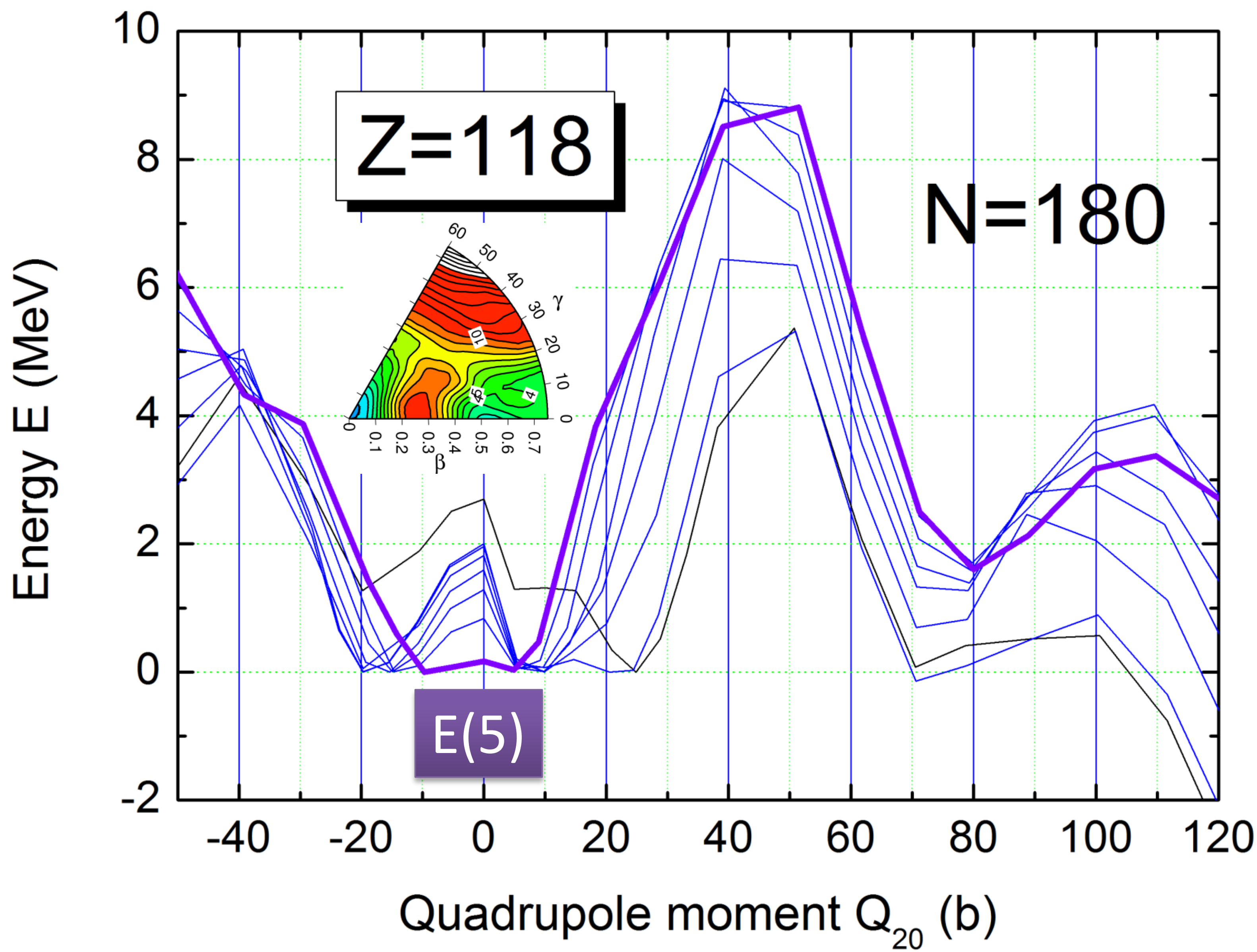
Second order phase transition O(6) – U(5)



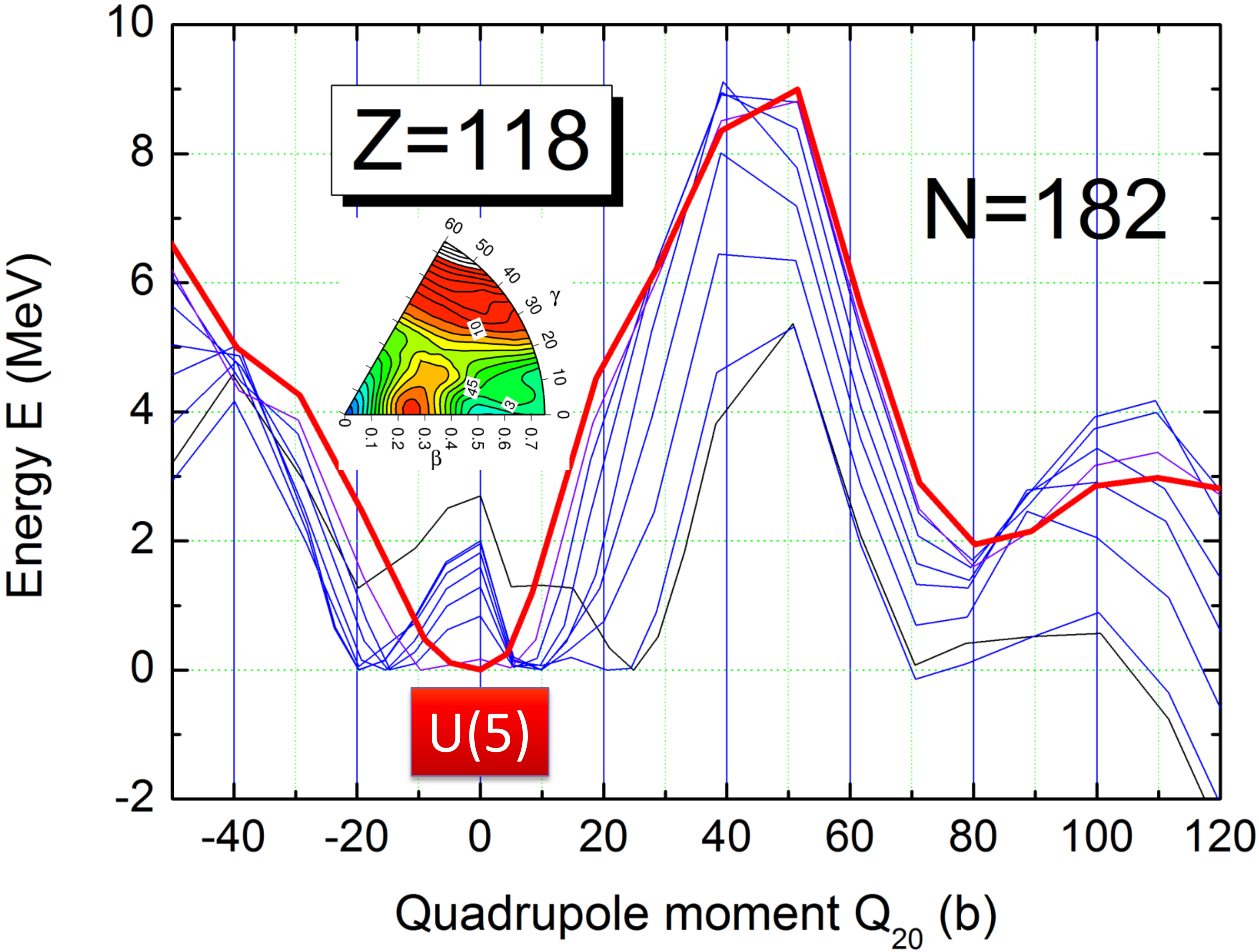
Second order phase transition O(6) – U(5)



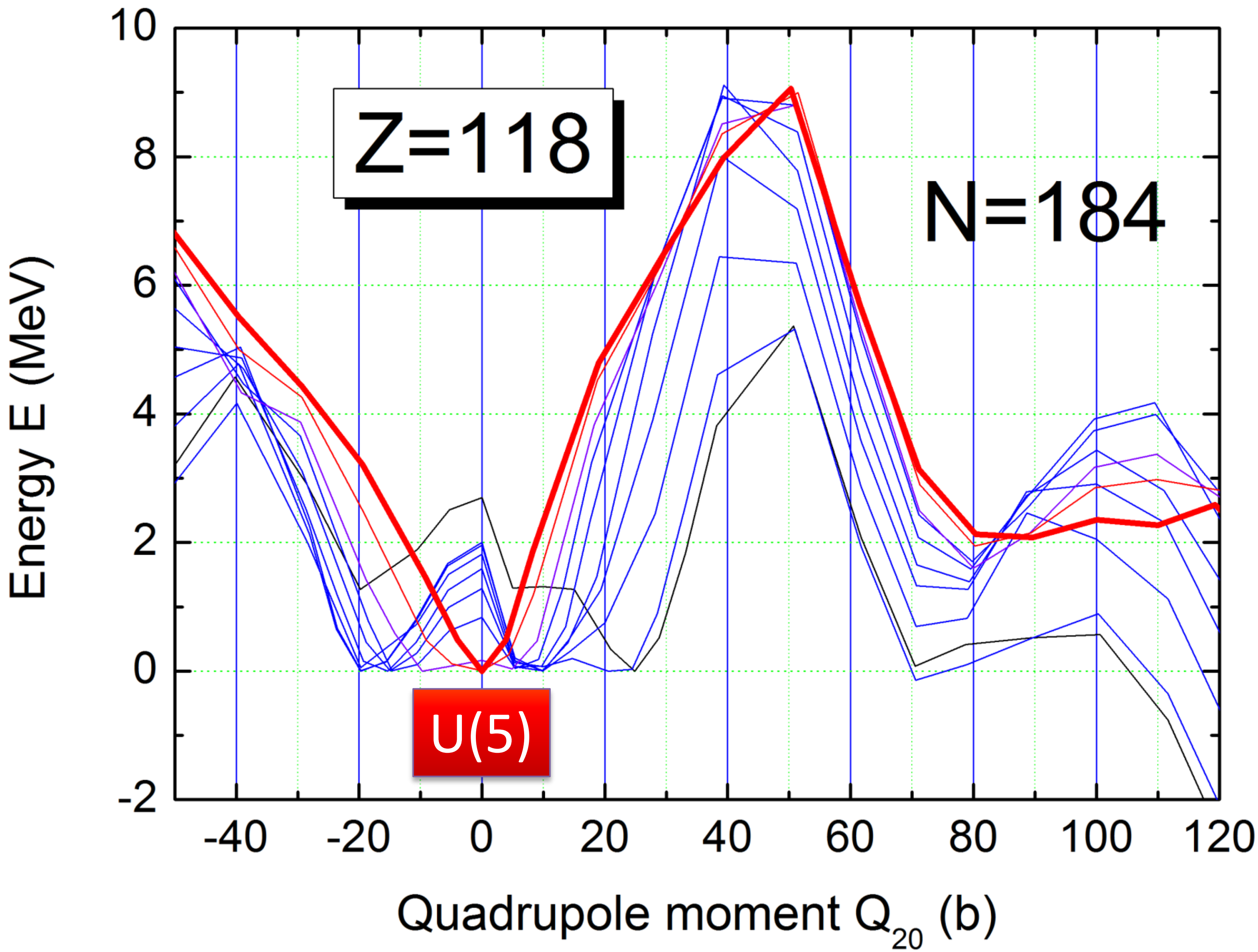
Critical (triple) point E(5)



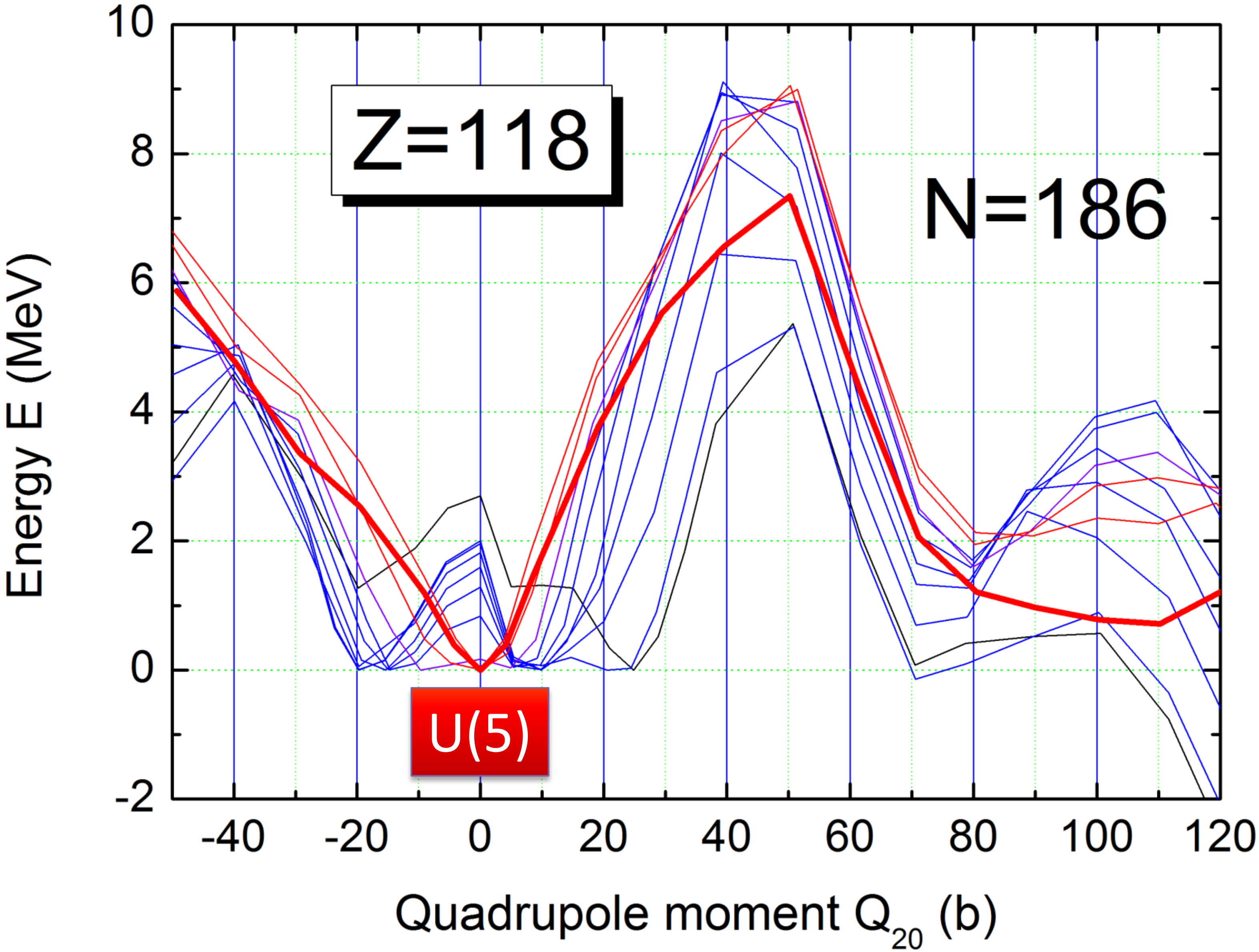
Second order phase transition O(6) – U(5)



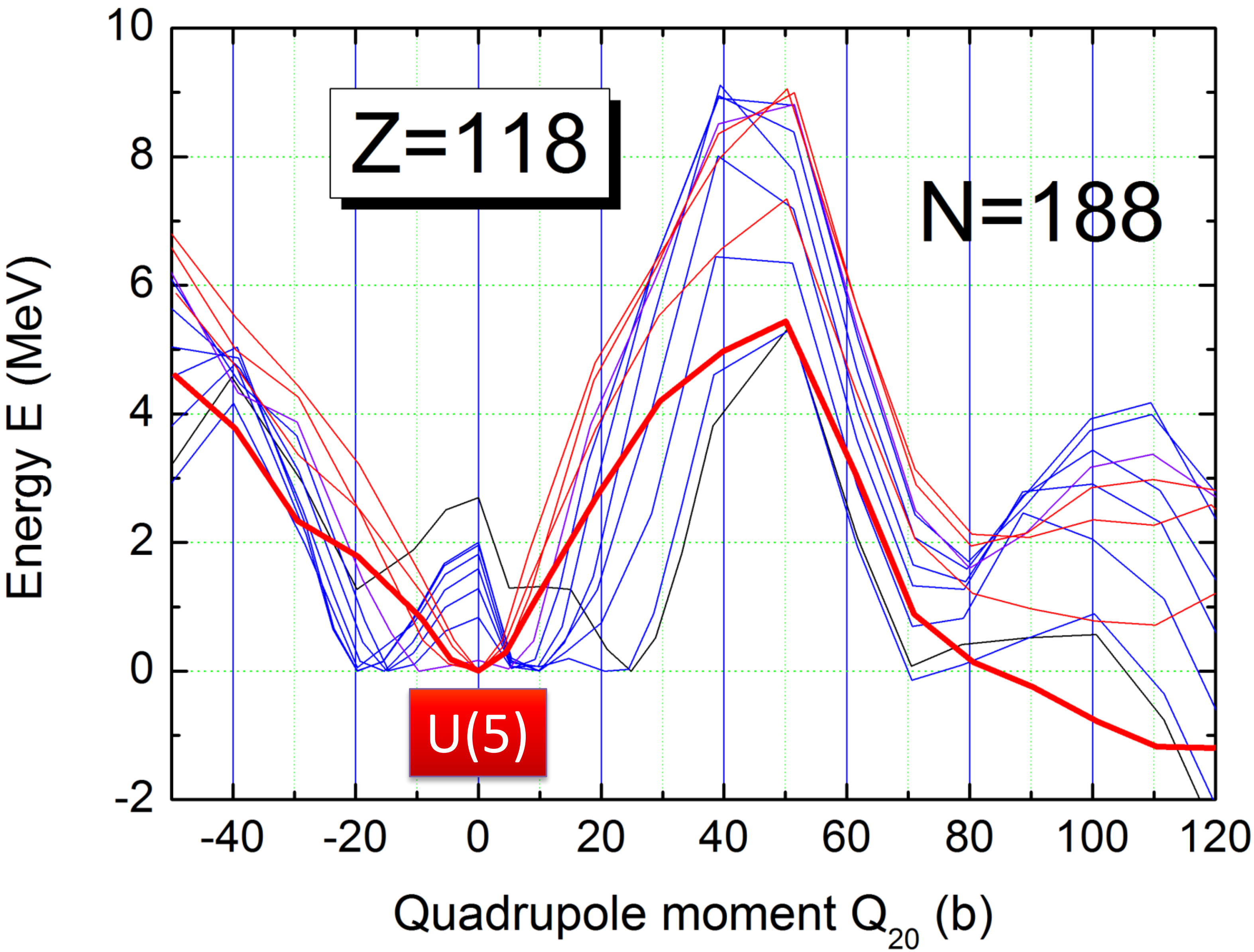
Second order phase transition O(6) – U(5)



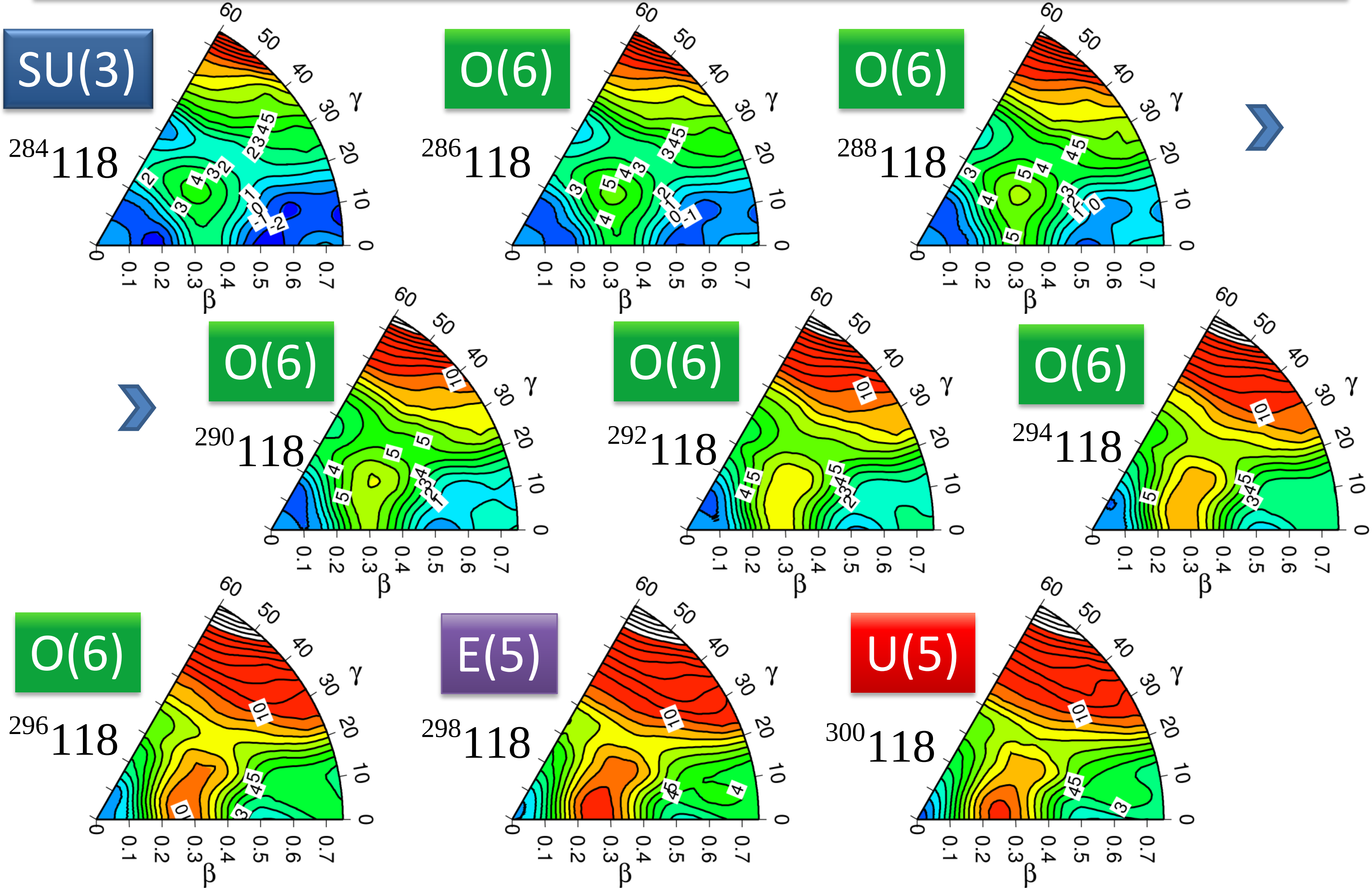
Second order phase transition O(6) – U(5)



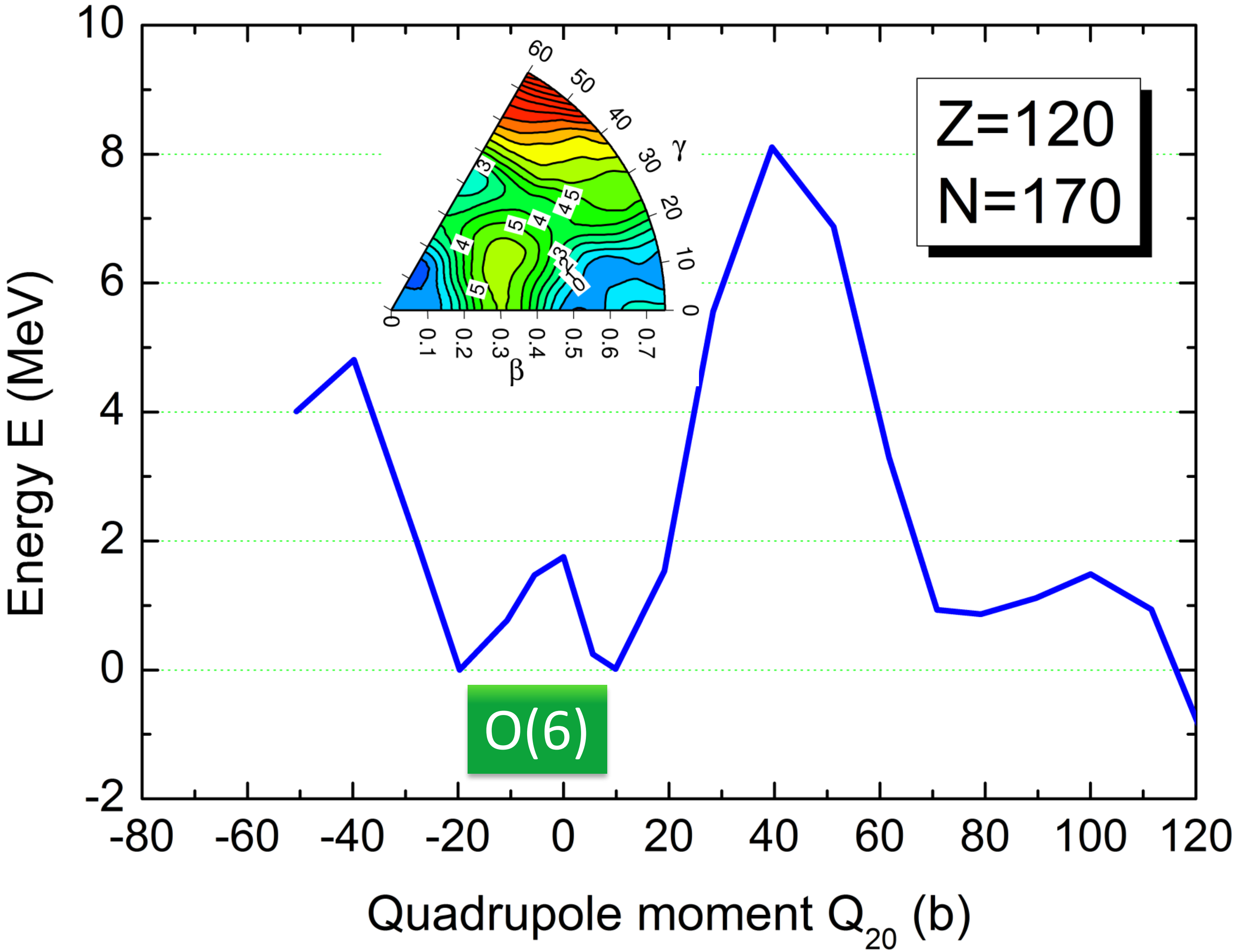
Second order phase transition O(6) – U(5)



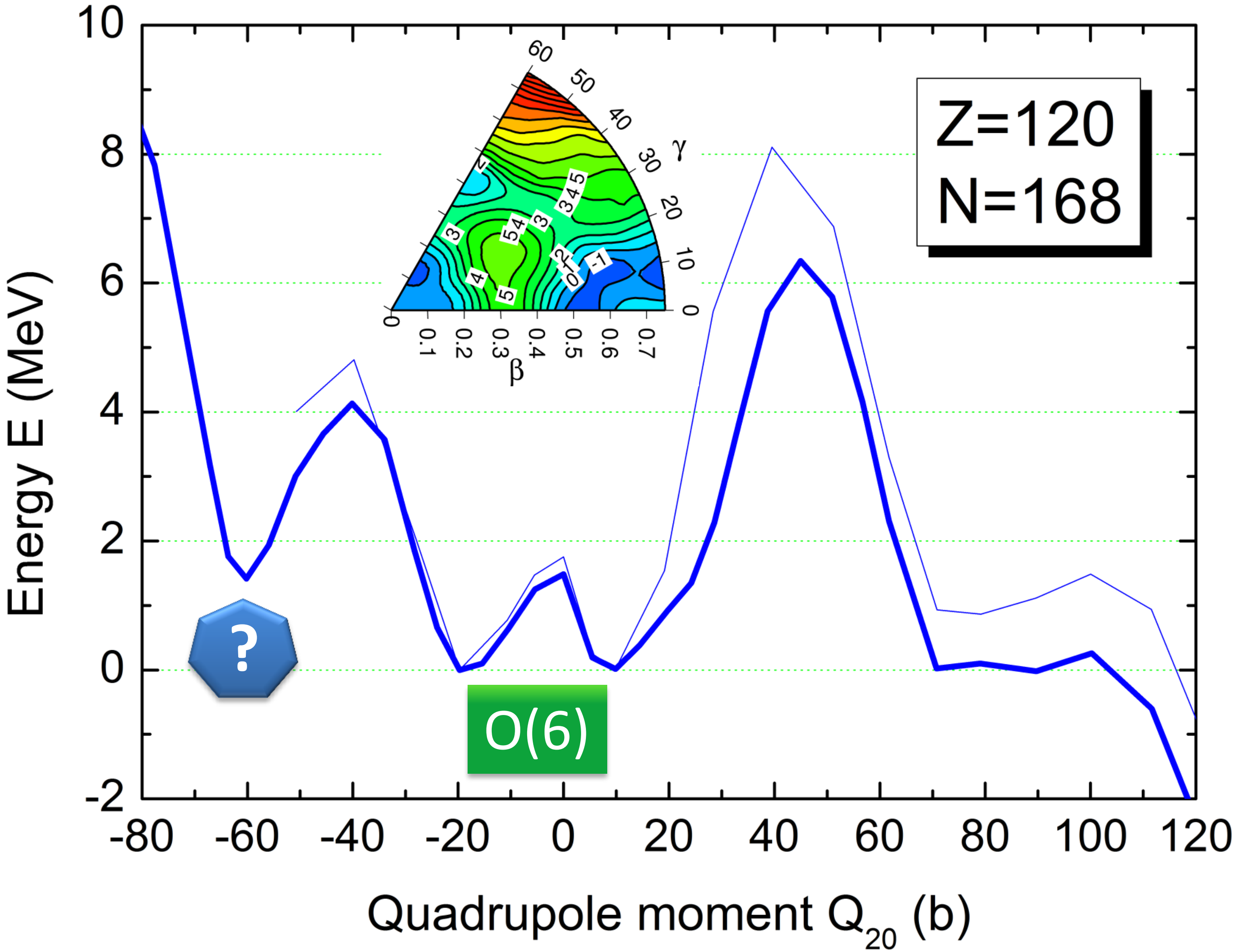
Second order phase transition O(6) – U(5)



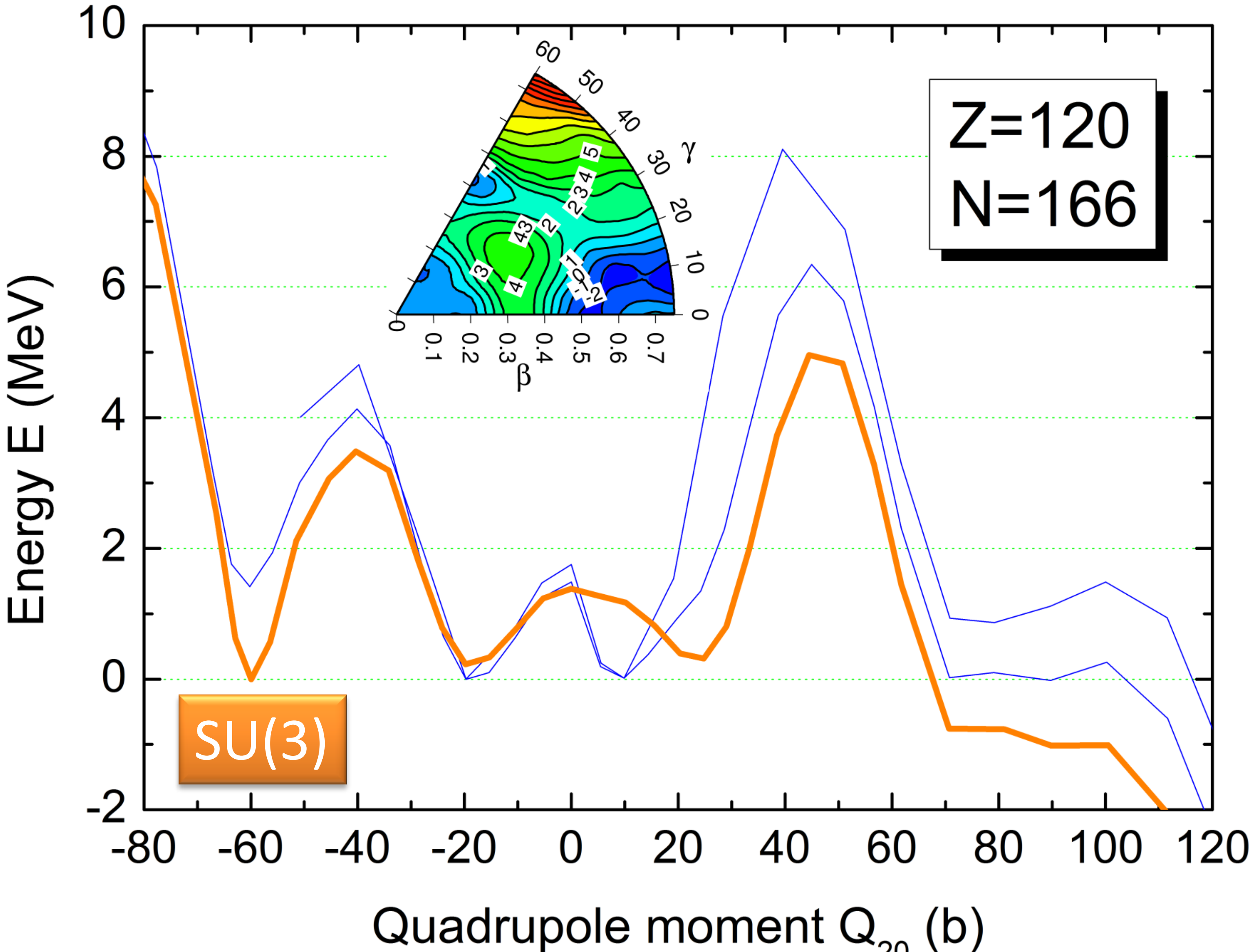
Superdeformed oblate (SDO) SHN?



Superdeformed oblate (SDO) SHN?

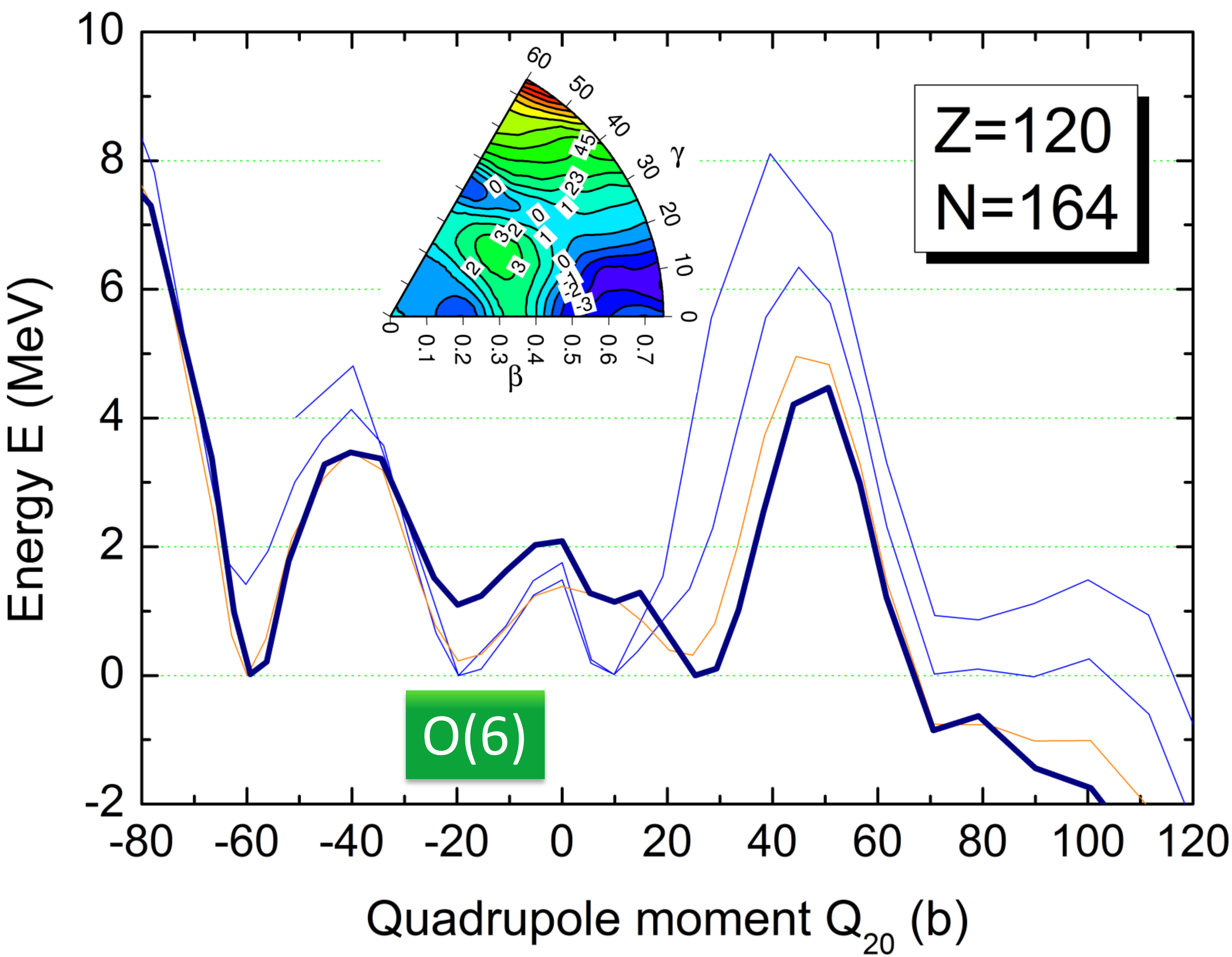


Superdeformed oblate (SDO*) SHN!

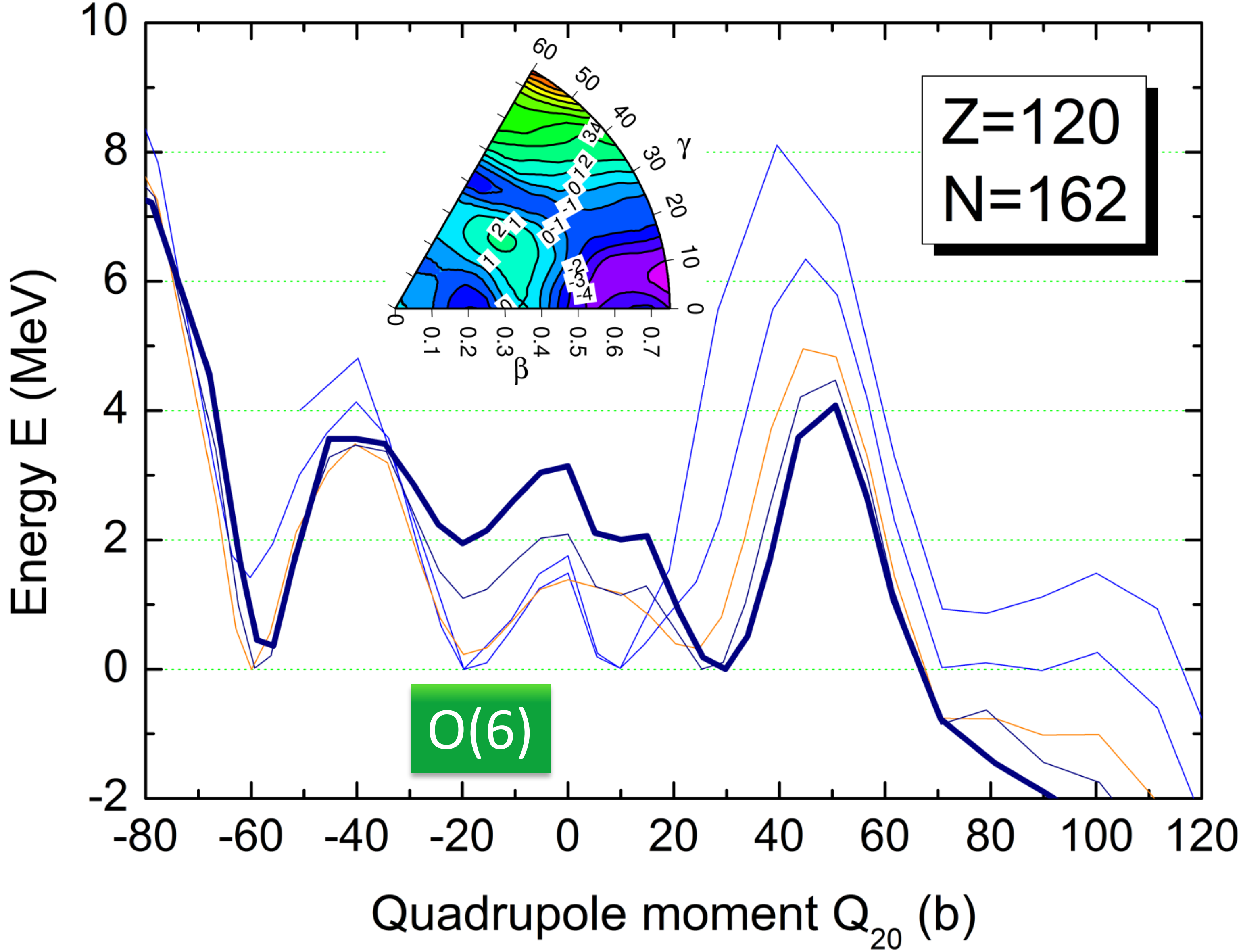


*P. Jachimowicz, M. Kowal, J. Skalski, Phys. Rev. C **83**, 054302 (2011)
L. Próchniak, A. S., ZAKOPANE 2012

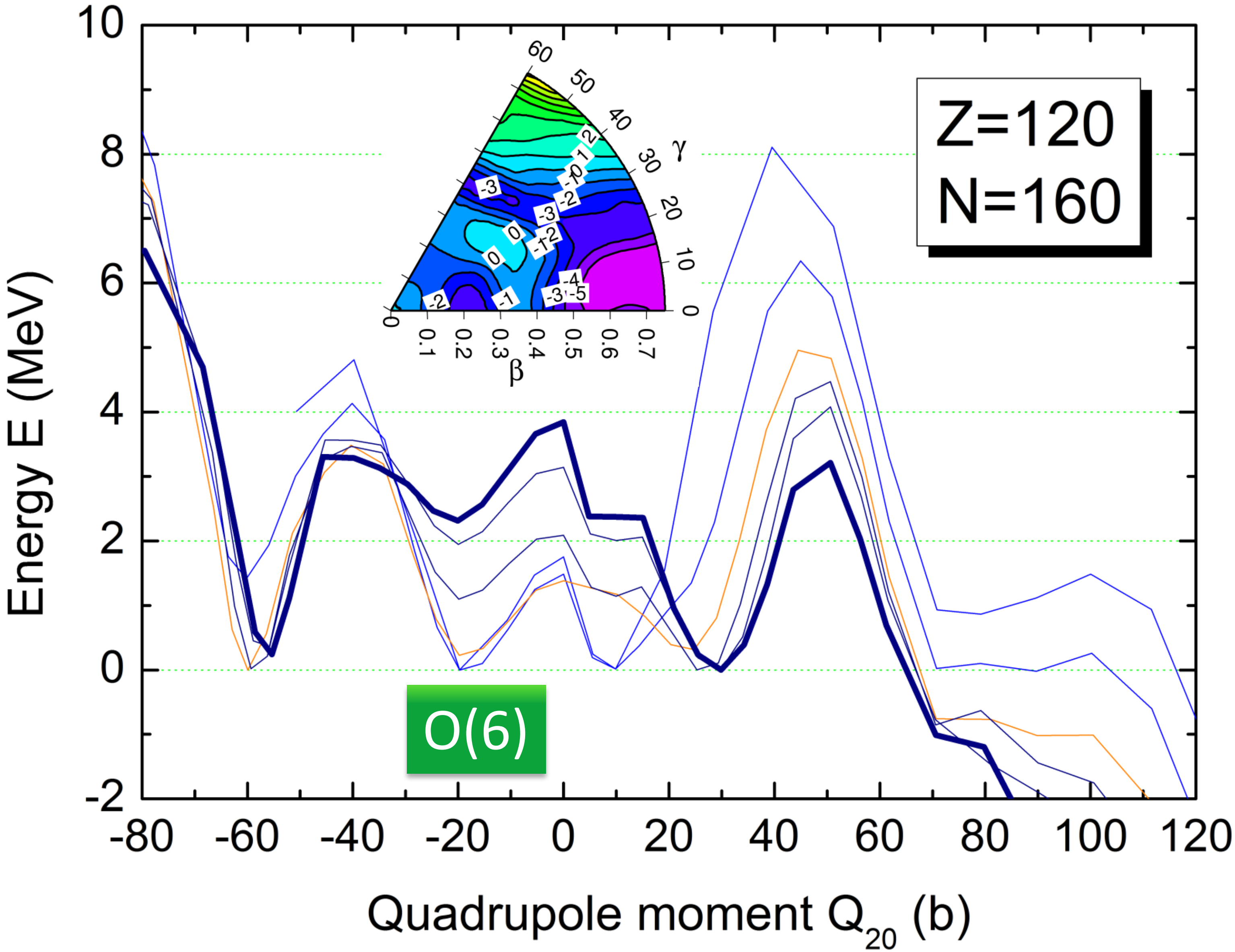
Superdeformed oblate (SDO) SHN



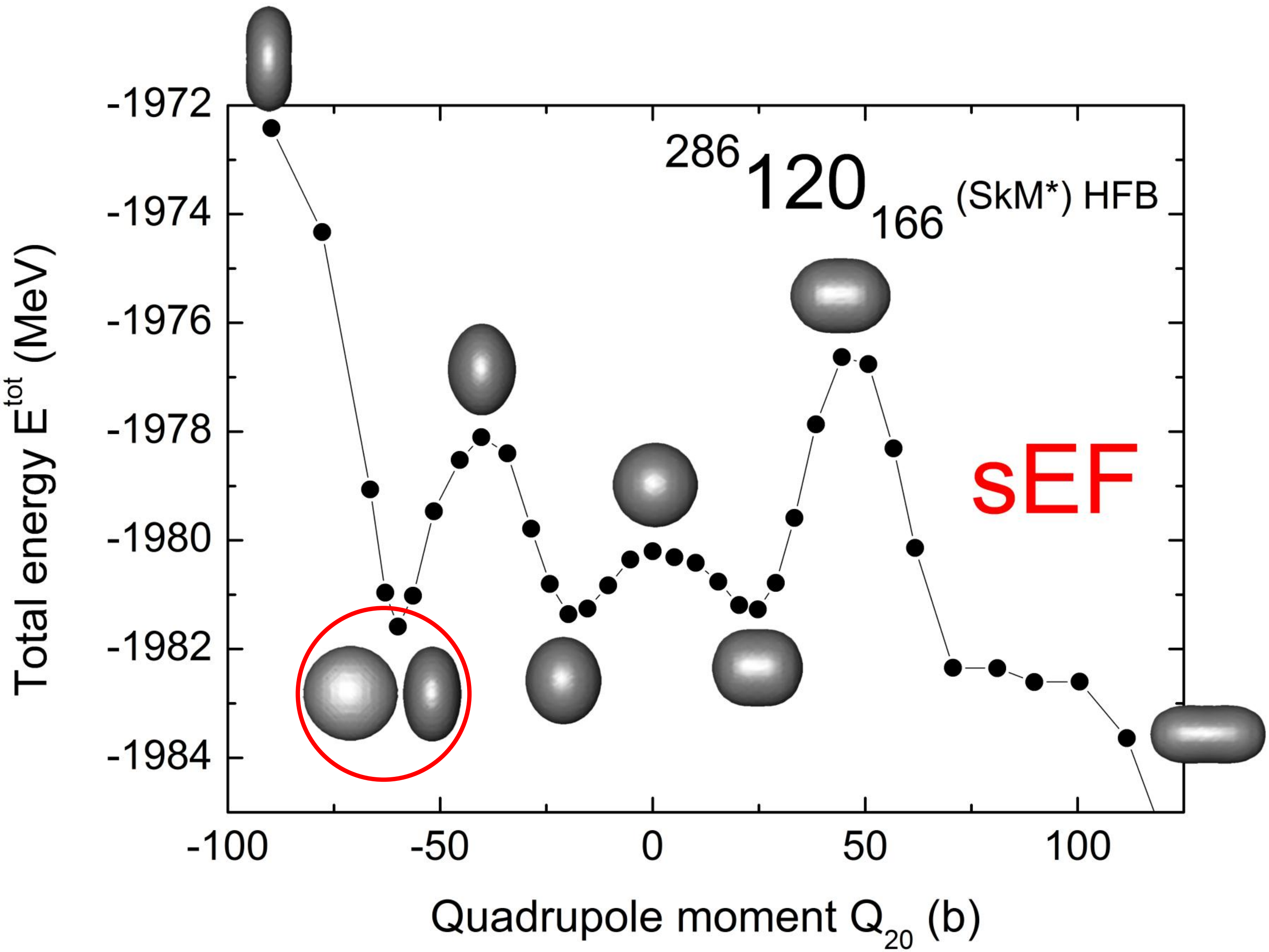
Superdeformed oblate (SDO) SHN



Superdeformed oblate (SDO) SHN

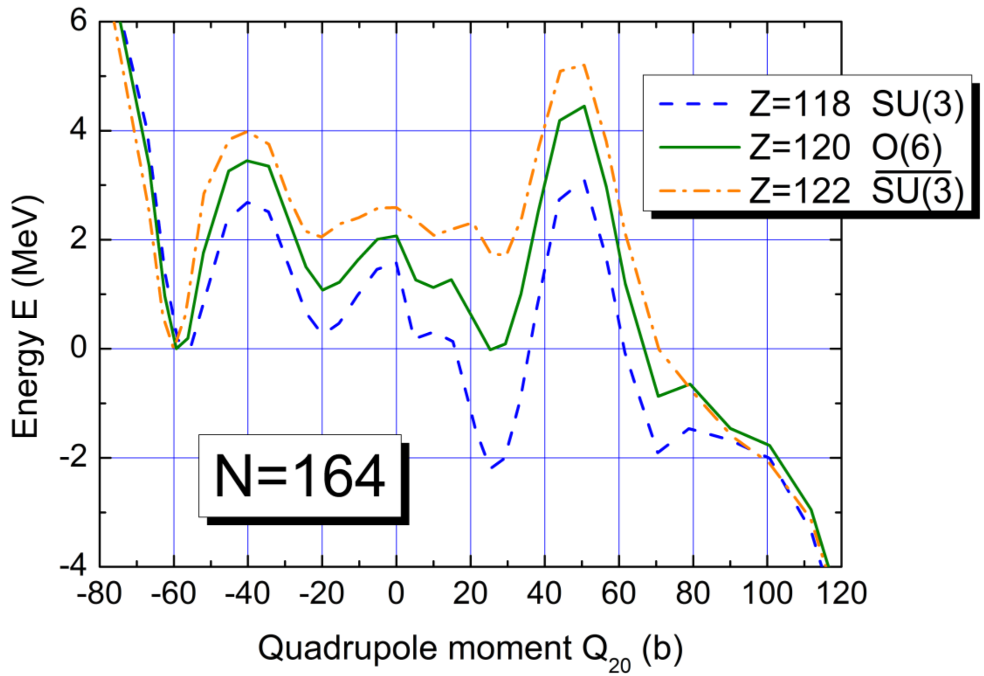


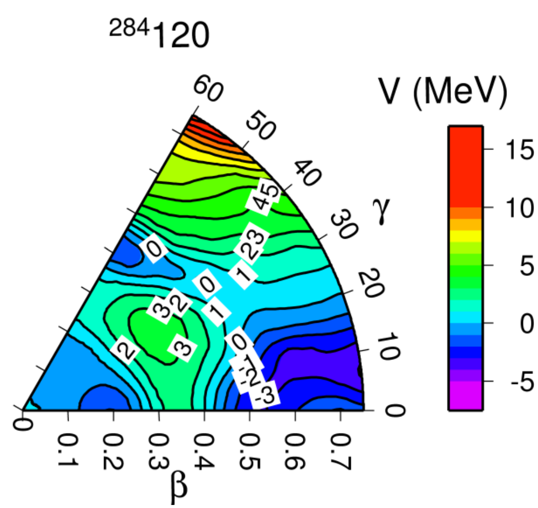
Superdeformed oblate (SDO) SHN

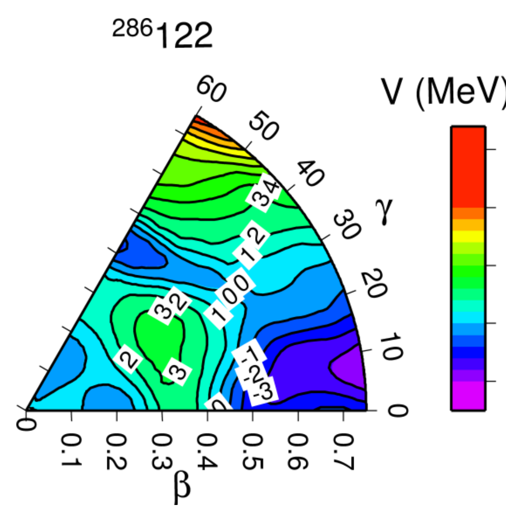


Prolate-oblate phase transition SU(3) - O(6) - $\overline{SU(3)}$

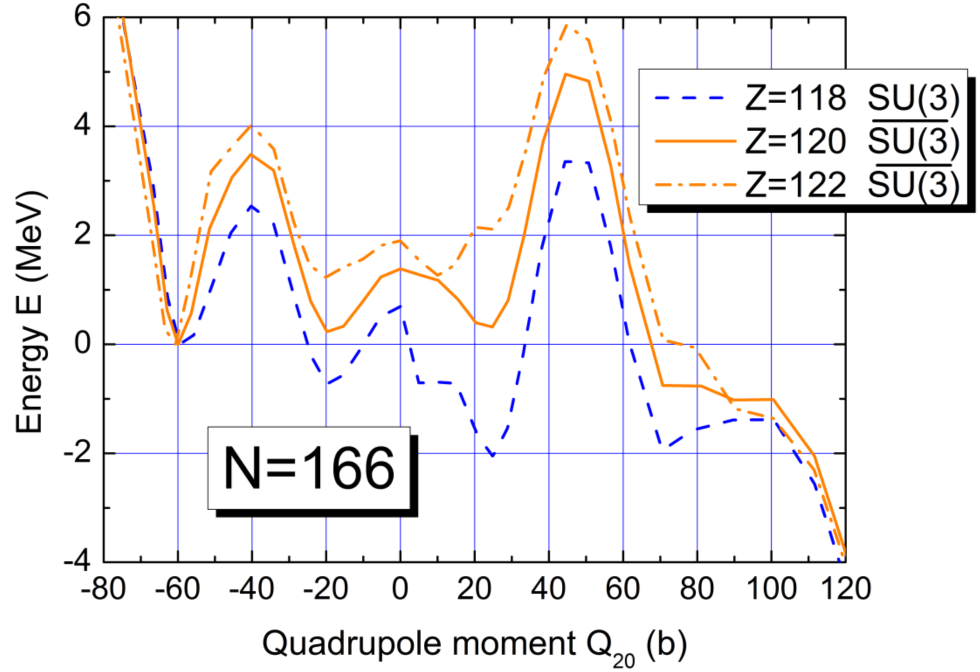
J. Jolie, R. Casten, P. von Brentano, V. Werner, PRL **87**, 162501 (2001).

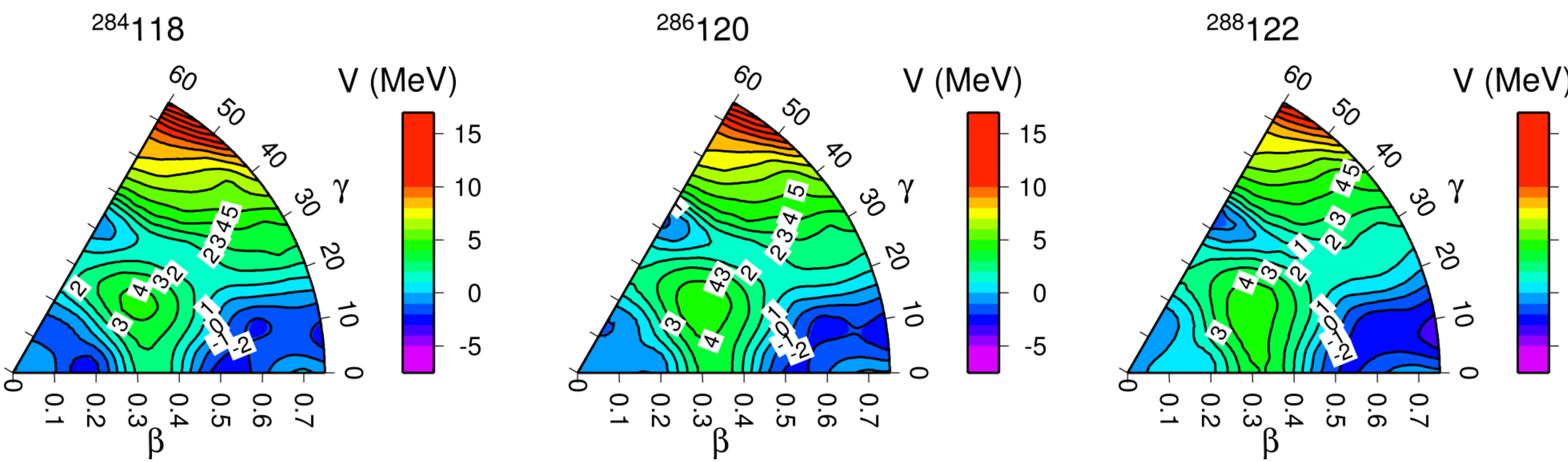




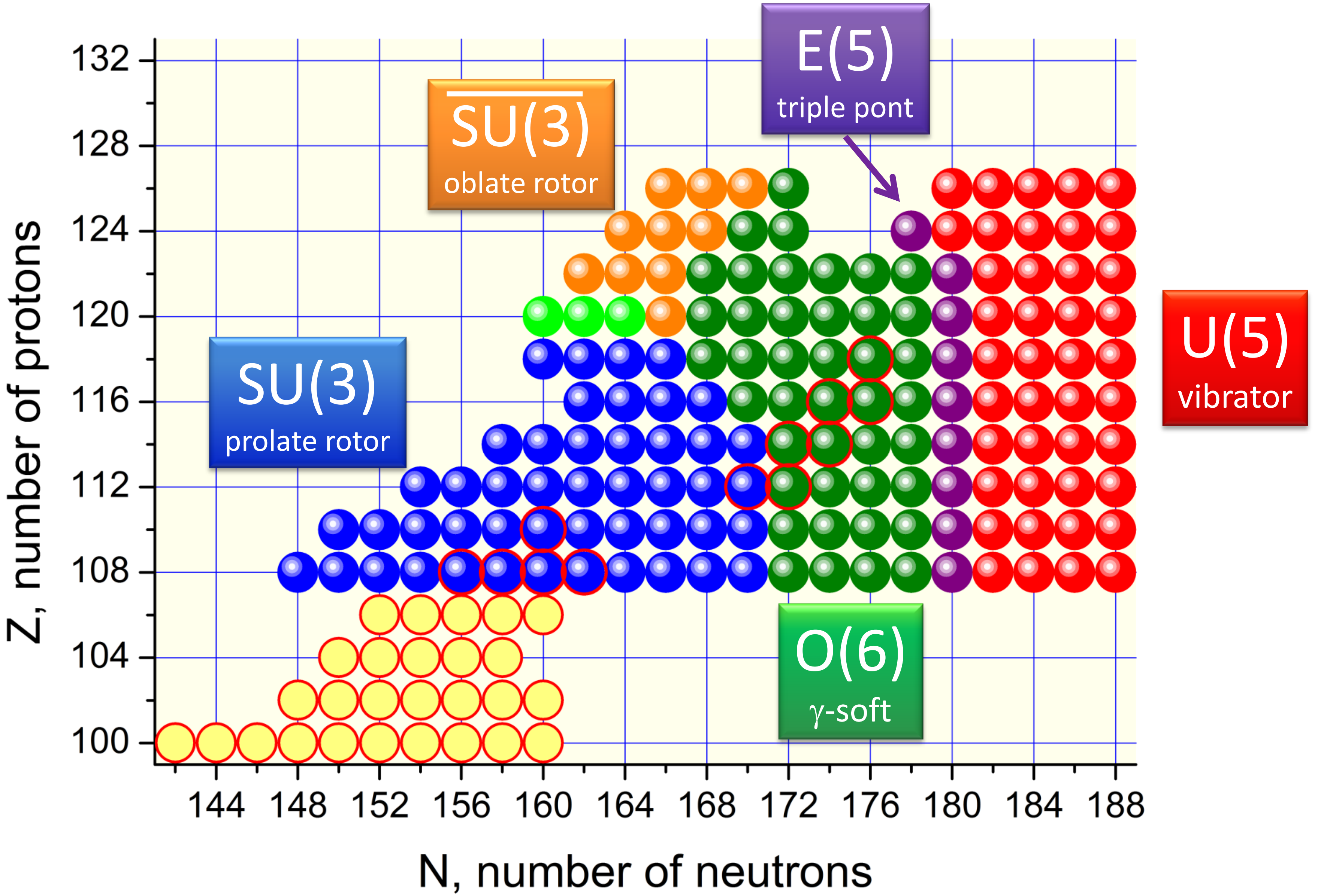


Prolate-oblate phase transition SU(3) - O(6) - $\overline{SU(3)}$





Natura non facit saltus



Conclusions

- ✓ The e-e SHN form three regions: the prolate-deformed SU(3) (for $N < 172$), spherical U(5) (for $N>180$), and transitional region (γ-soft) O(6) between the former two.
- ✓ On the border between the O(6) and U(5) regions (for $N = 180$) nuclei exhibit a rather flat potential bottom and acquire the triple-point solutions - E(5).
- ✓ The existence of superdeformed oblate (SDO) nuclei - $\overline{SU(3)}$ for $N \leq 166$ and $Z \geq 120$ was validated.
- ✓ The heaviest even-even nuclei produced by ^{48}Ca induced reactions on actinide targets fall into the class of O(6) γ-soft nuclei.

Thank you!

Ehrenfest classification, 1933:

The phase transition is of the *k*-th order if the *k*-th derivative of the thermodynamic free energy with respect to some thermodynamic variable changes discontinuously at the critical point.