2nd COPIGAL Workshop on Studies of Exotic Nuclei

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Correspondence between self-consistent and micro-macro predictions for very deformed & spin isomeric configurations.

Coworkers:

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Benoit Avez, Benjamin Bally, Jeremy Sadoudi (CENBG)

Exotic shapes and configurations in heavy & superheavy nuclei (SHN)

- These configurations may have larger half-lives and show particular patterns allowing for their experimental verification.
- In particular, spin isomers in SHN may be longer-lived.
- Orbits seen at super- and hyper-deformation in actinides are those occupied at normal shape in SHN; they can provide a test of a model. Experiments confirming predicted minima validate nuclear models.

Good methods should give similar predictions.

- Micro-macro, as a simpler one, is better tested/fitted against various data, eg. fission half-lives.
- Selfconsistent methods could (if constructed properly) give better extrapolations.But it is not guarateed at present. Hence, a prudent idea is to see whether both methods give similar results.

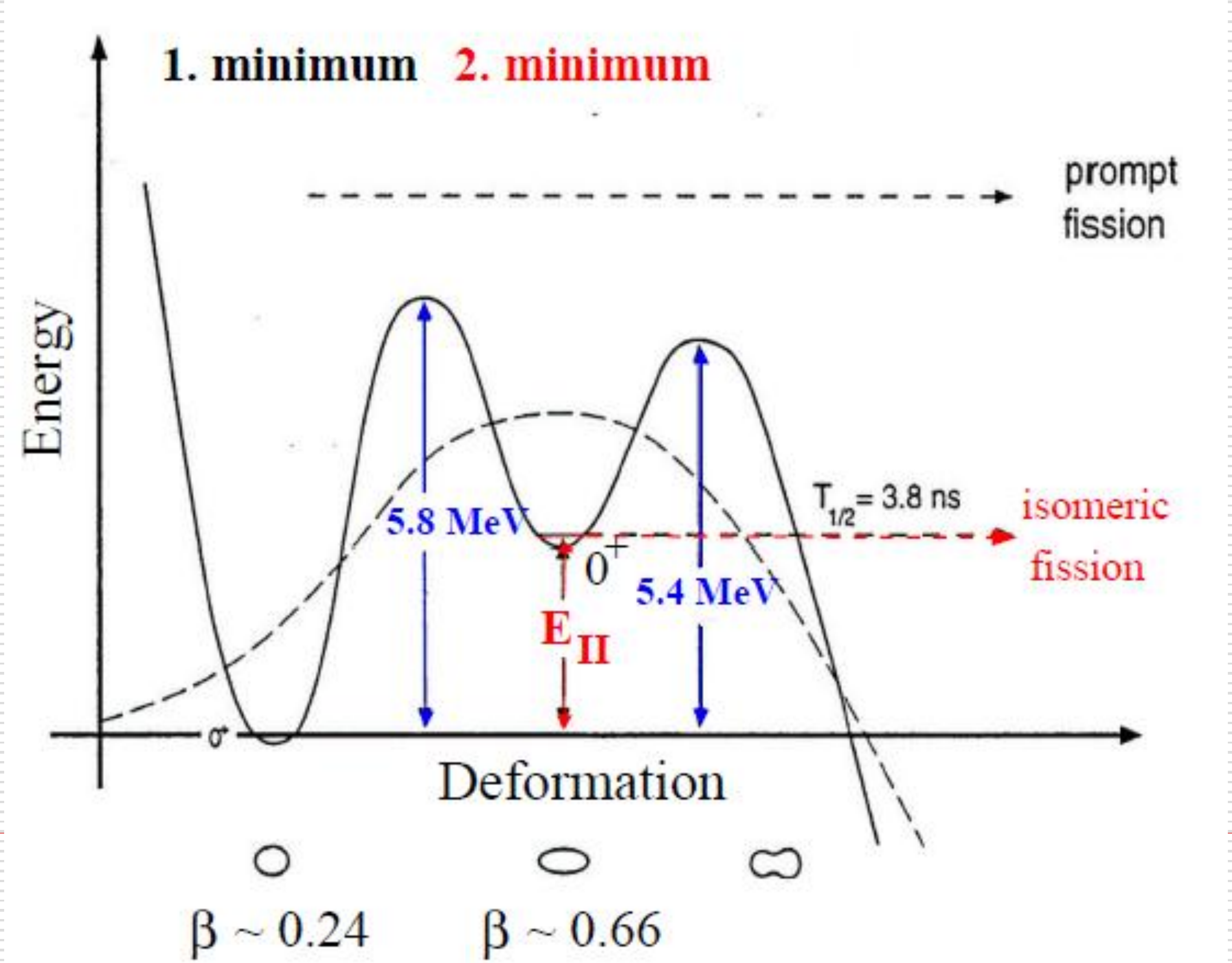
IIIrd minima in actinides - do they exist?

- M. Kowal, J. Skalski PRC, in press.

Planned activity:

- more detailed determination of 3rd barriers around Th (including odd nuclei);
- study of oblate configurations in SHN, including decay hindrance from K-isomerism;
- Importance of beyond-mean-field effects.

Polikanov et al. (1962) Discovery of isomeric fission
Strutinsky (1967) Calculated second minima
Specht et al. (1972) Identification of the rotational band with large moment of inertia in 240Pu



Third minima: Th,U

First predicted: P. Moller, S.G. Nilsson and R.K. Sheline (1972)

then Howard & Moller (1980) – rather shallow III-rd minima

S.Cwiok et al. – rather deep III-rd minima

some, not all, HF calculations give III-rd minima, BUT they often differ from macro-micro results

Experiments:

1)Studies of microstructure in the resonances of fission probability found using (n,f), (t,pf) and (d,pf) reactions

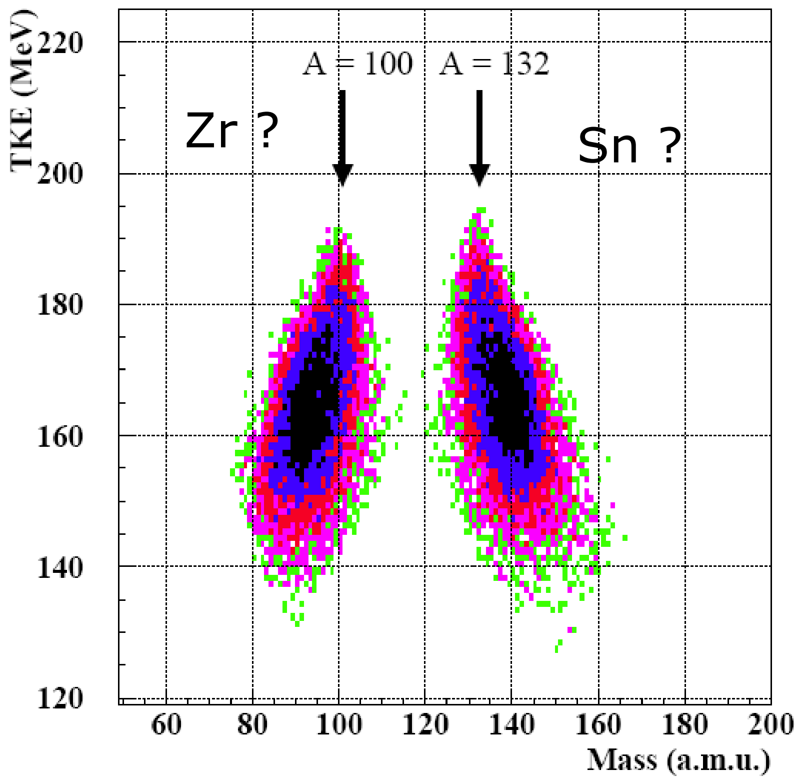
B.B. Back et al. (1972)

J. Blons et al. (1975)

recent claims of III-rd minima in 232,234,236U

2) Also observations of asymmetric angular distribution of light fission fragments around 232Th

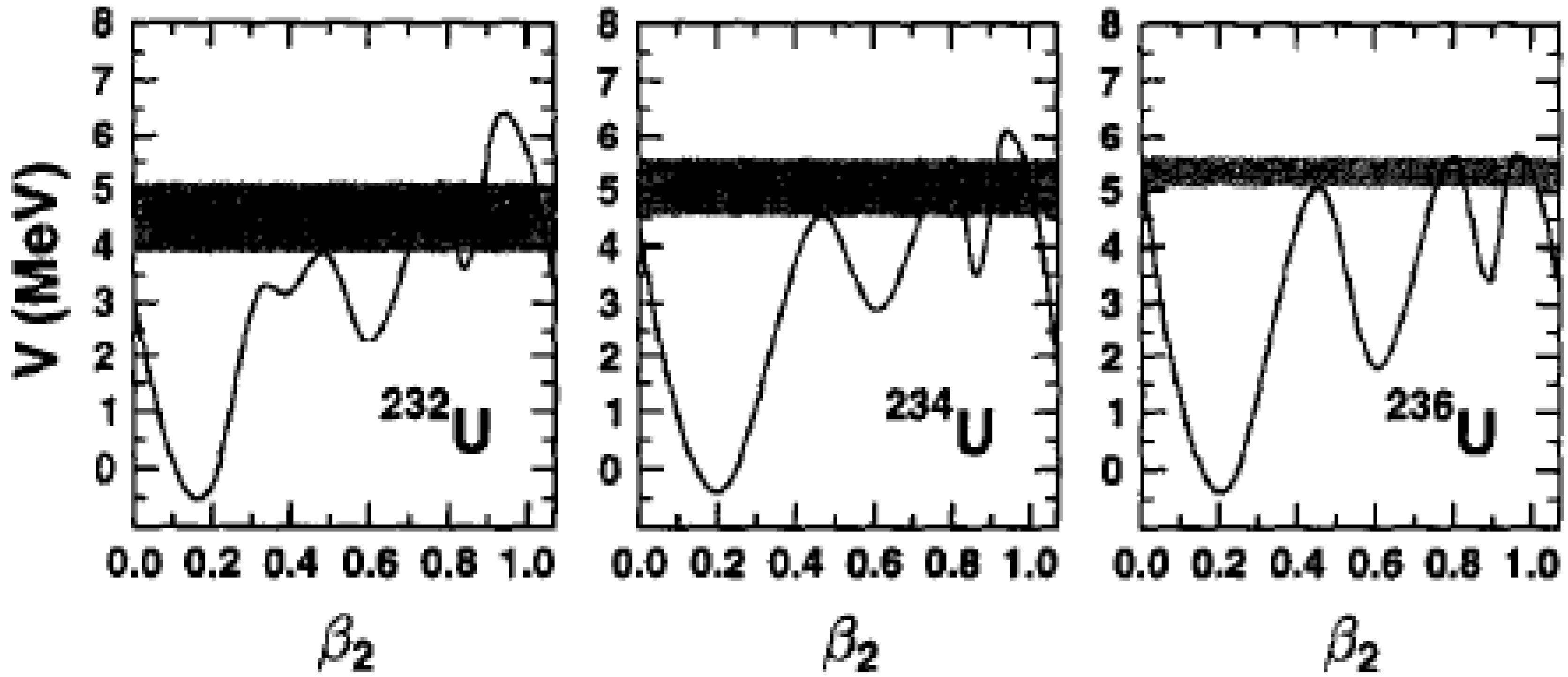
TKE



TKE as a function of the mass distribution of the fission fragments.

M. Csatlos et. al., Acta Phys. Pol. B Vol. 34, (2003).

P.G. Thirolf, D. Habs / Prog. Part. Nucl. Phys. 49 (2002) 325–402



Macroscopic-microscopic approach:

$$E = E_{tot}(\beta_{\lambda\mu}) - E_{MACRO}(\beta_{\lambda\mu} = 0)$$

$$E_{tot}(\beta_{\lambda\mu}) = E_{MACRO}(\beta_{\lambda\mu}) + E_{MICRO}(\beta_{\lambda\mu})$$

- $\mathbf{E_{MACRO}(\beta_{\lambda\mu})}$ = **Yukawa + exp**

- $\mathbf{E_{MICRO}(\beta_{\lambda\mu})}$ = **Woods – Saxon + pairing BCS**

Shape Parametrization:

$$R(\Theta,\Phi)=\{1+a_{20}Y_{20}+a_{40}Y_{40}+a_{60}Y_{60}+a_{80}Y_{80}$$

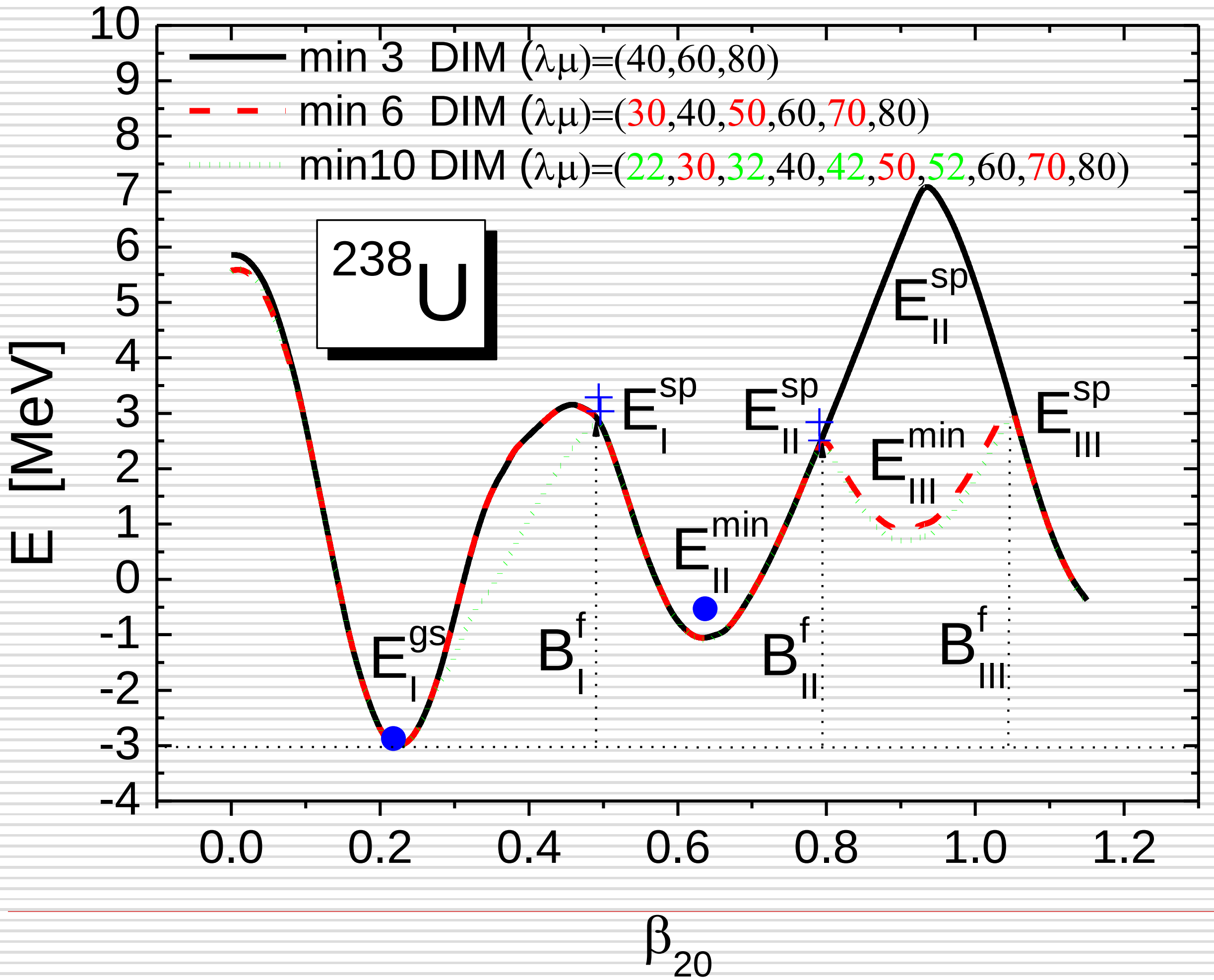
$$+a_{22}Y_{22}^{(+)}+a_{42}Y_{42}^{(+)}+a_{44}Y_{44}^{(+)}$$

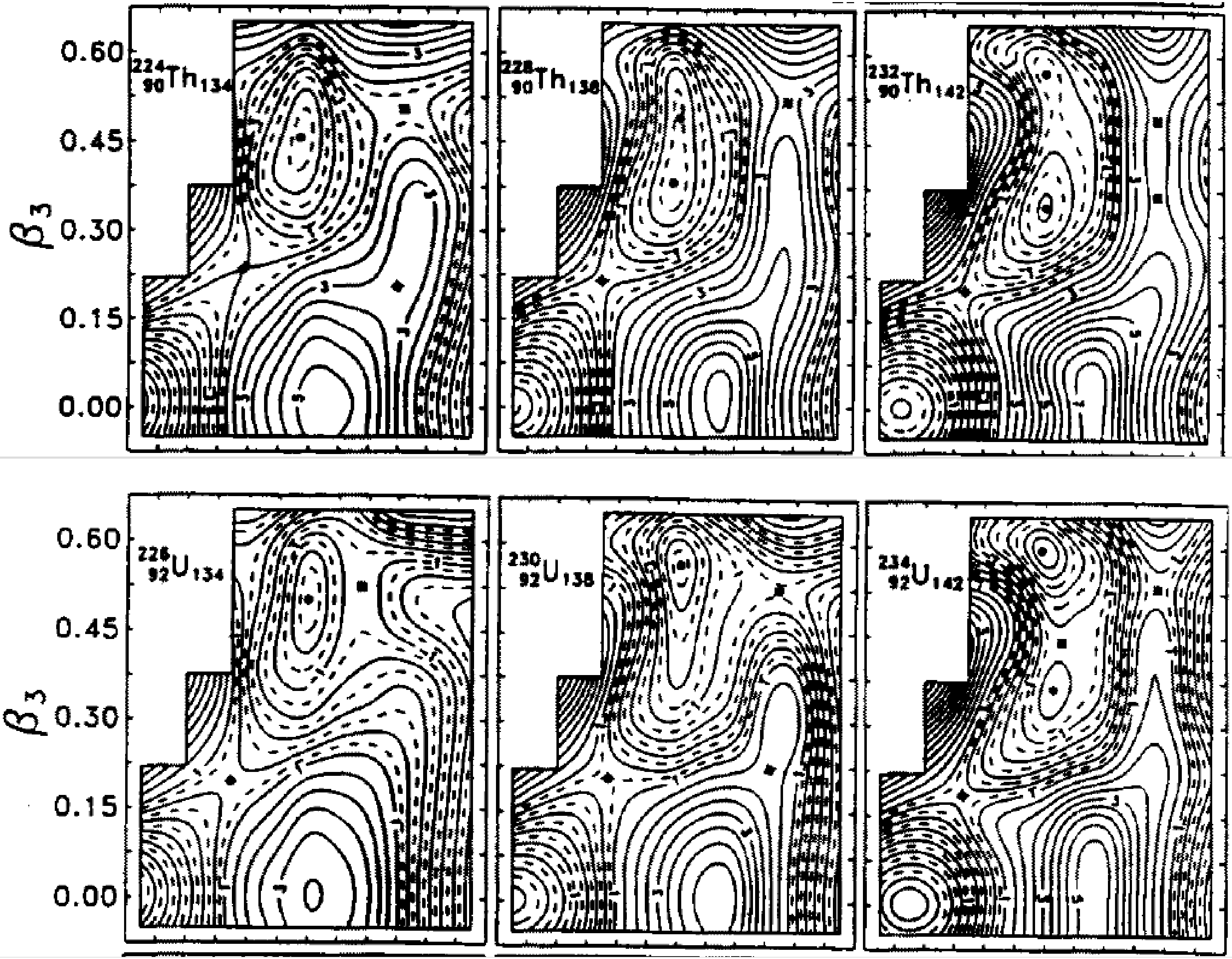
$$+a_{32}Y_{32}^{(+)}+a_{52}Y_{52}^{(+)}$$

$$+a_{30}Y_{30}+a_{50}Y_{50}+a_{70}Y_{70}\}$$

$$Y_{\lambda\mu}^{(+)}=\frac{1}{\sqrt{2}}(Y_{\lambda\mu}+Y_{\lambda-\mu})$$

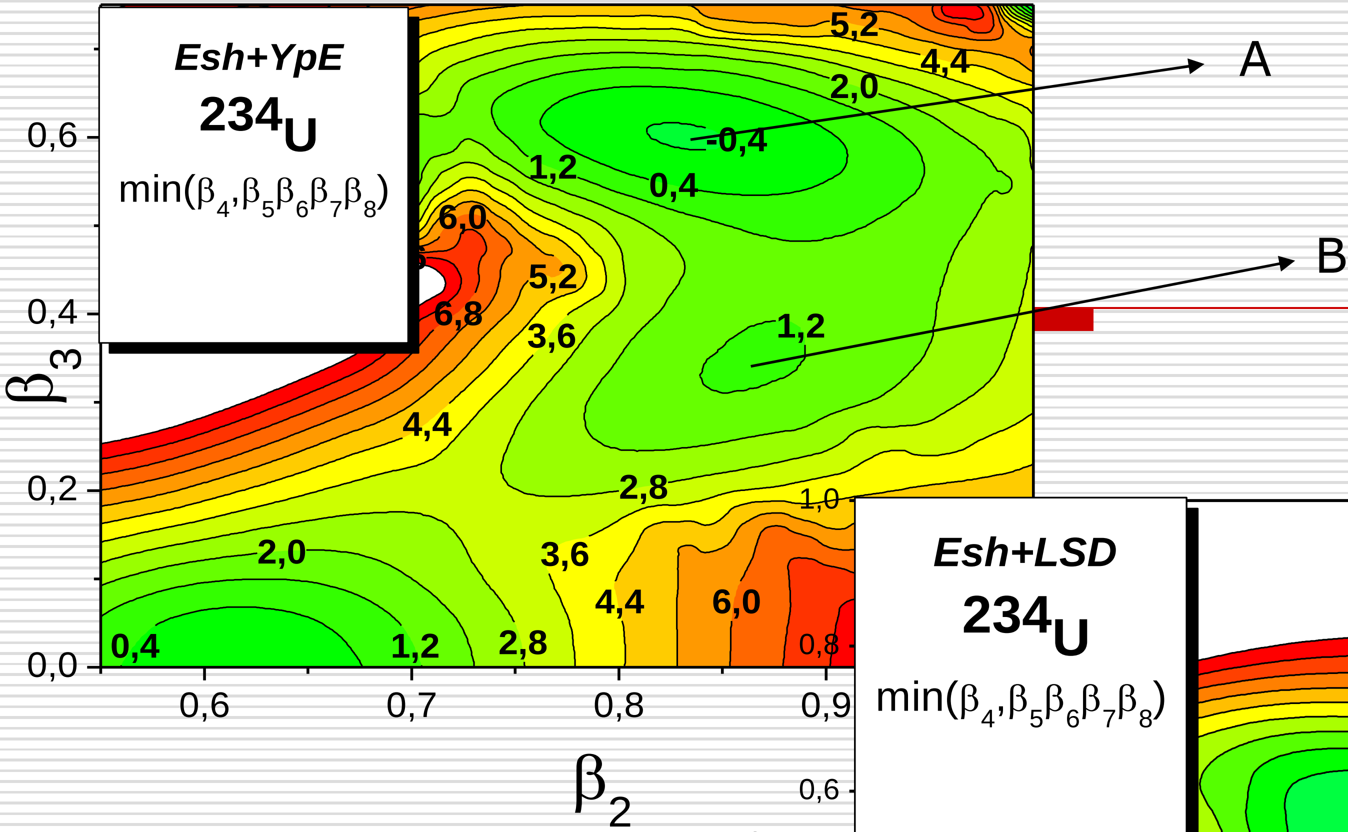
12-DIM !

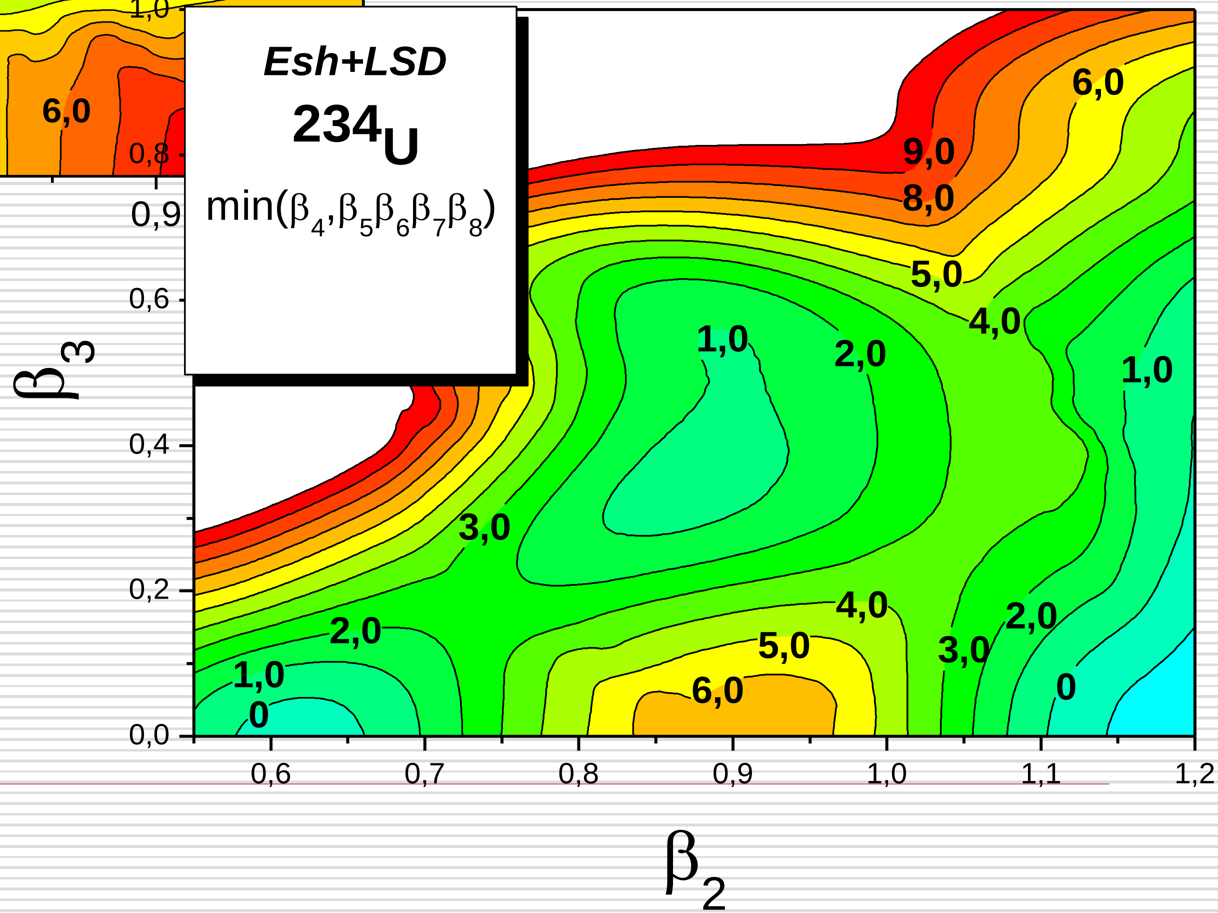

min 3 DIM (λμ)=(40,60,80)
min 6 DIM (λμ)=(30,40,50,60,70,80)
min10 DIM (λμ)=(22,30,32,40,42,50,52,60,70,80)
238U
E [MeV]
β20
E_I^gs
E_I^sp
B_I^f
E_II^min
E_II^sp
B_II^f
E_III^min
E_III^sp
B_III^f



0.60
0.45
0.30
0.15
0.00
β_3
$^{224}_{90}Th_{134}$
$^{228}_{90}Th_{138}$
$^{232}_{90}Th_{142}$
$^{226}_{92}U_{134}$
$^{230}_{92}U_{138}$
$^{234}_{92}U_{142}$

S.Cwiok at al

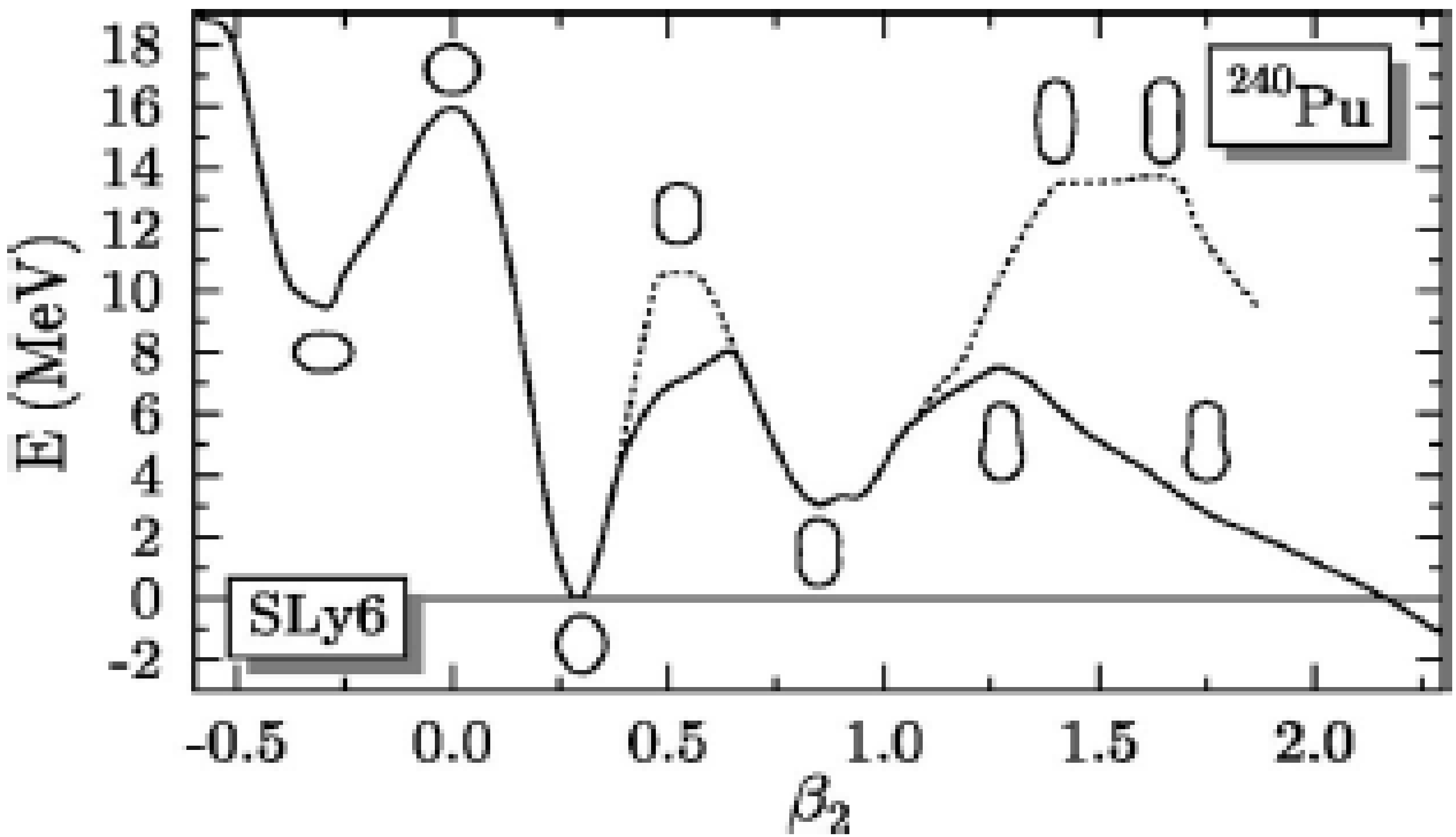




Repeated;
With LSD macro part
also deep minima

BÜRVENICH, BENDER, MARUHN, AND REINHARD

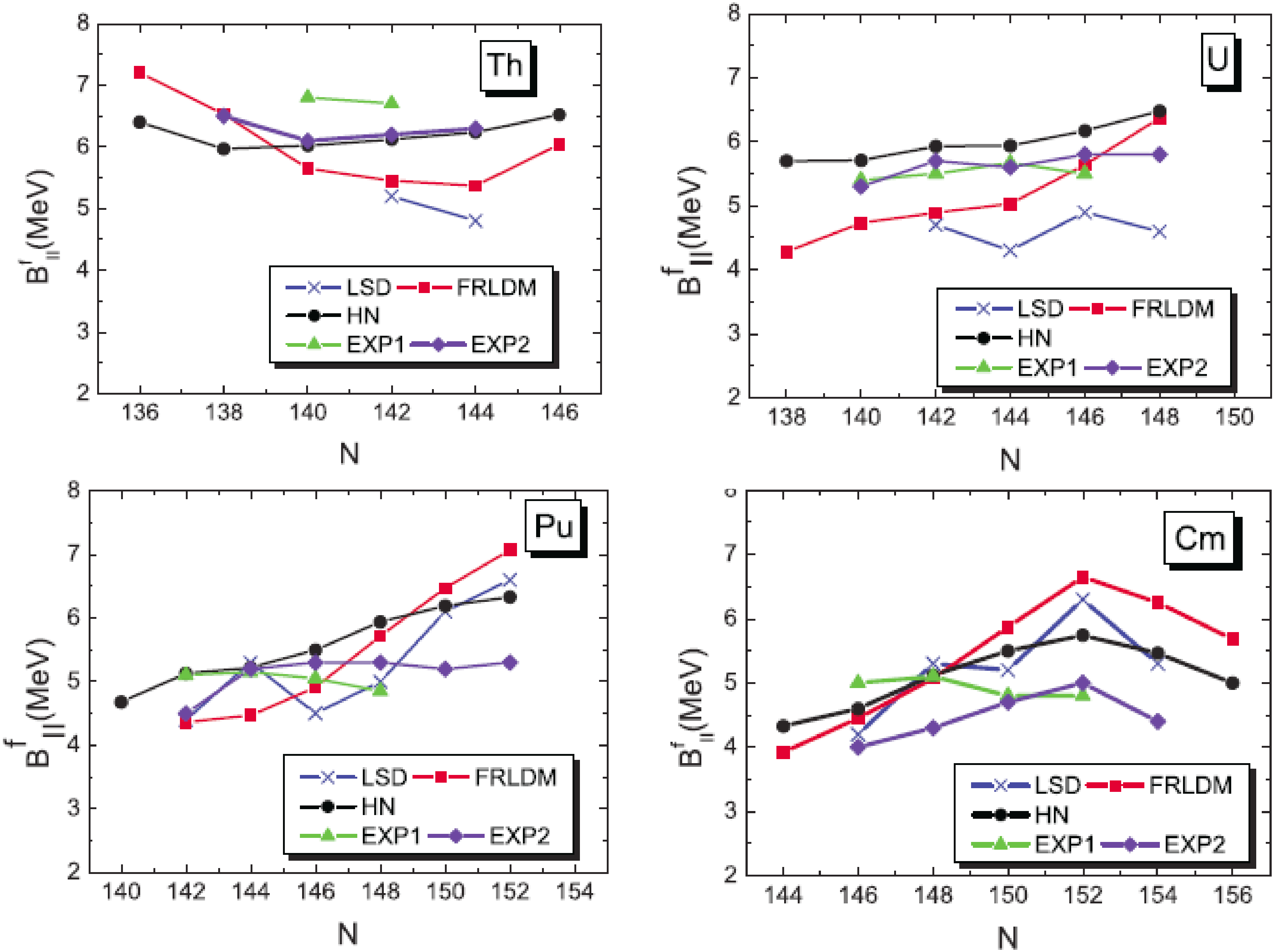
PHYSICAL REVIEW C 69, 014307 (2004)



Careful calculations for 234U by M. Bender do not show any 3rd minimum.

Performance of our model (HN)

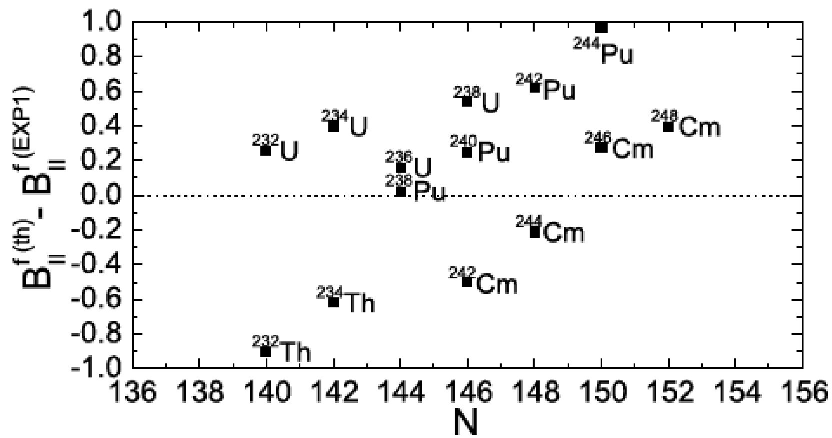
- Second barriers in actinides,
- Second minima in actinides,
- Fission barriers for SHN

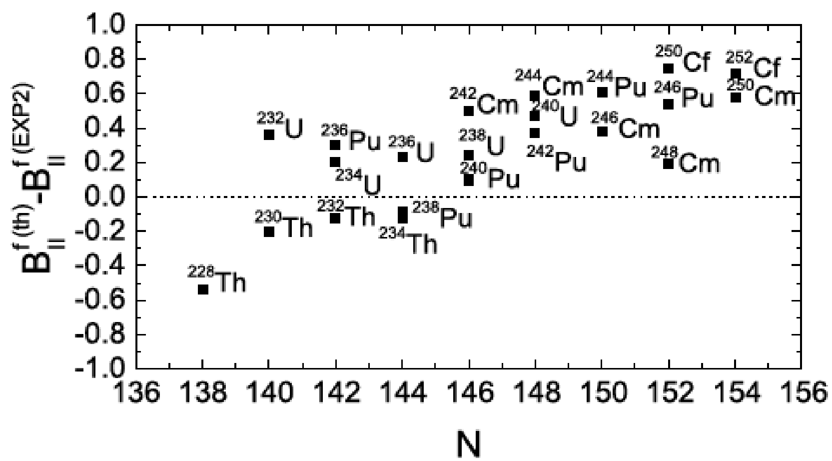


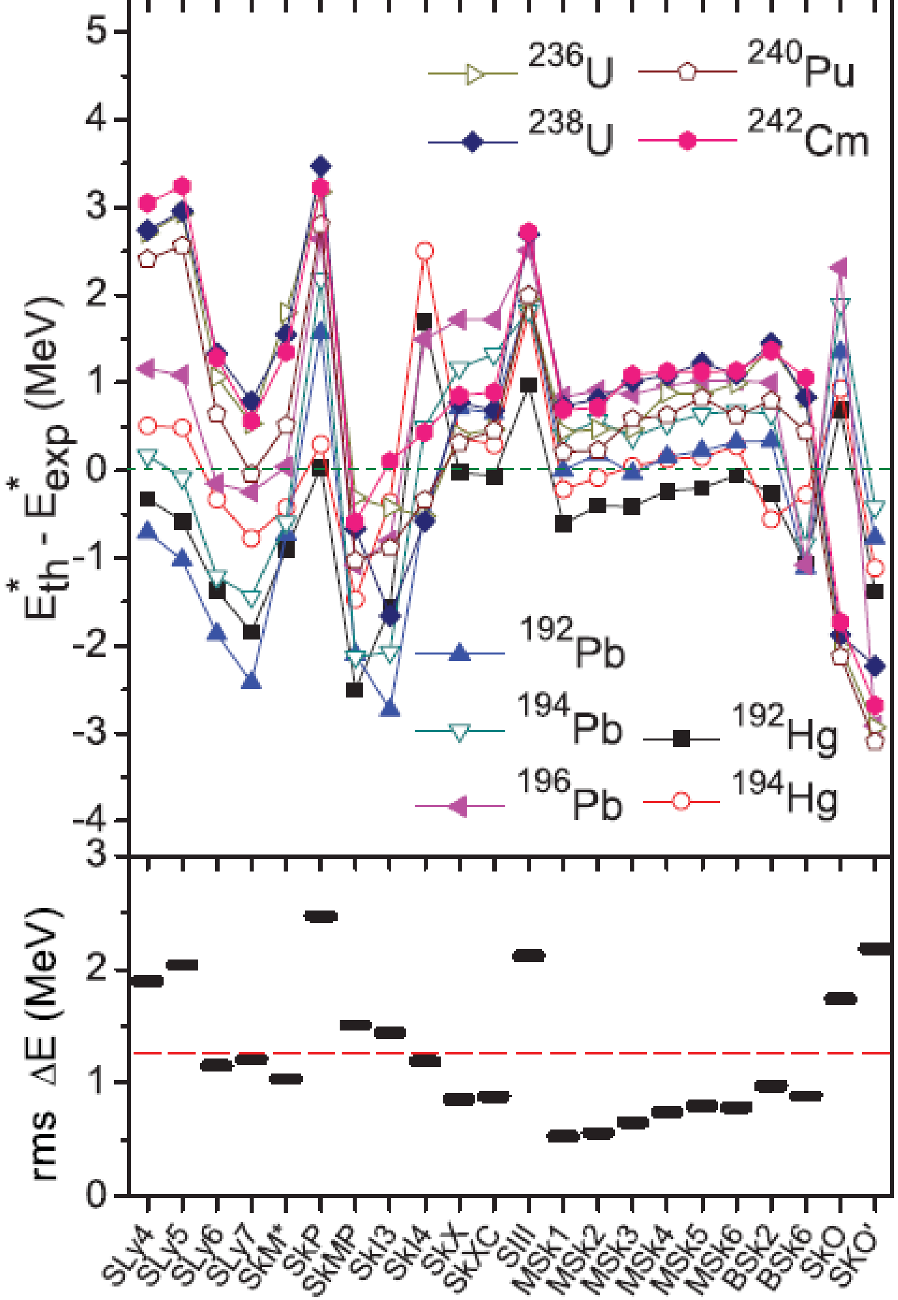
Th
LSD
FRLDM
HN
EXP1
EXP2
B^f_II(MeV)
N
U
Pu
Cm

Z	N	A	LSD	FRLDM	HN	EXP1	EXP2
90	136	226	–	7.20	6.26	–	–
	138	228	–	6.53	5.92	–	6.5
	140	230	–	5.65	5.97	6.80	6.1
	142	232	5.2	5.45	6.07	6.70	6.2
	144	234	4.8	5.37	6.07	–	6.3
	146	236	–	6.04	6.35	–	–
92	138	230	–	4.28	5.64	–	–
	140	232	–	4.73	5.66	5.40	5.3
	142	234	4.7	4.89	5.84	5.50	5.7
	144	236	4.3	5.03	5.78	5.67	5.6
	146	238	4.9	5.64	5.93	5.50	5.8
	148	240	4.6	6.37	6.04	–	5.8
	150	242	–	7.10	6.23	–	–
94	140	234	–	–	4.68	–	–
	142	236	4.4	4.36	5.06	–	4.5
	144	238	5.3	4.47	5.15	5.10	5.2
	146	240	4.5	4.91	5.28	5.15	5.3
	148	242	5.0	5.72	5.52	5.05	5.3
	150	244	6.1	6.47	5.63	4.85	5.2
	152	246	6.6	7.07	5.75	–	5.3
	154	248	–	–	5.42	–	–
96	144	240	–	3.92	4.25	–	–
	146	242	4.2	4.45	4.42	5.00	4.0
	148	244	5.3	5.07	4.72	5.10	4.3
	150	246	5.2	5.87	4.98	4.80	4.7
	152	248	6.3	6.65	5.14	4.80	5.0
	154	250	5.3	6.25	4.87	–	4.4
	156	252	–	5.68	4.31	–	–
98	150	248	–	5.18	4.14	–	–
	152	250	4.6	5.92	4.57	–	3.8
	154	252	–	5.83	4.36	–	3.5
	156	254	–	5.27	3.95	–	–

Theoretical models:	LSD		FRLDM		HN	
Experimental data:	[23]	[24]	[23]	[24]	[23]	[24]
N	12	18	14	22	14	22
$<\mid B_f^{th} - B_f^{exp} \mid>$	0.78	0.84	0.79	0.90	0.39	0.33
$Max \mid B_f^{th} - B_f^{exp} \mid$	1.50	1.50	1.85	2.33	0.83	0.86
δ_{RMS}	0.92	0.94	0.95	1.11	0.46	0.40



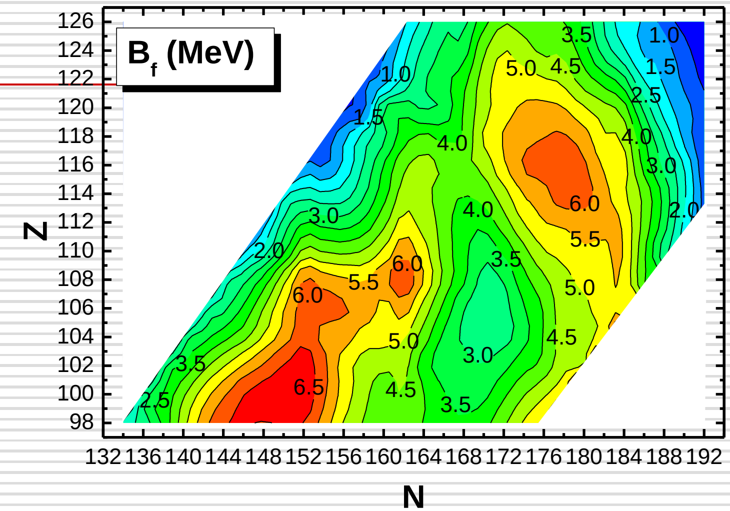


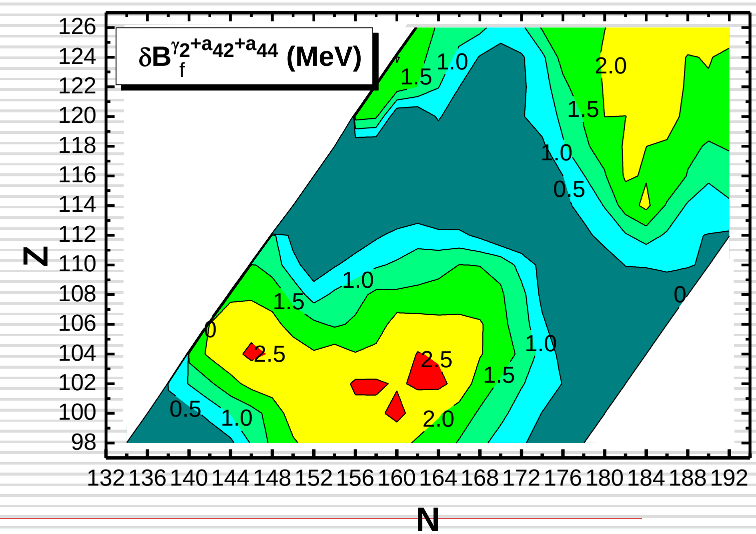


N	A	$E_{II}^{min}(th)^*$	$E_{II}^{min}(exp)^*$
144	236	2.04	2.75
146	238	1.94	2.56
142	236	2.43	3.00
144	238	2.05	2.40
146	240	1.95	2.80
148	242	1.99	2.20
144	240	1.69	2.00
146	242	1.64	1.90
148	244	1.68	2.20(?)

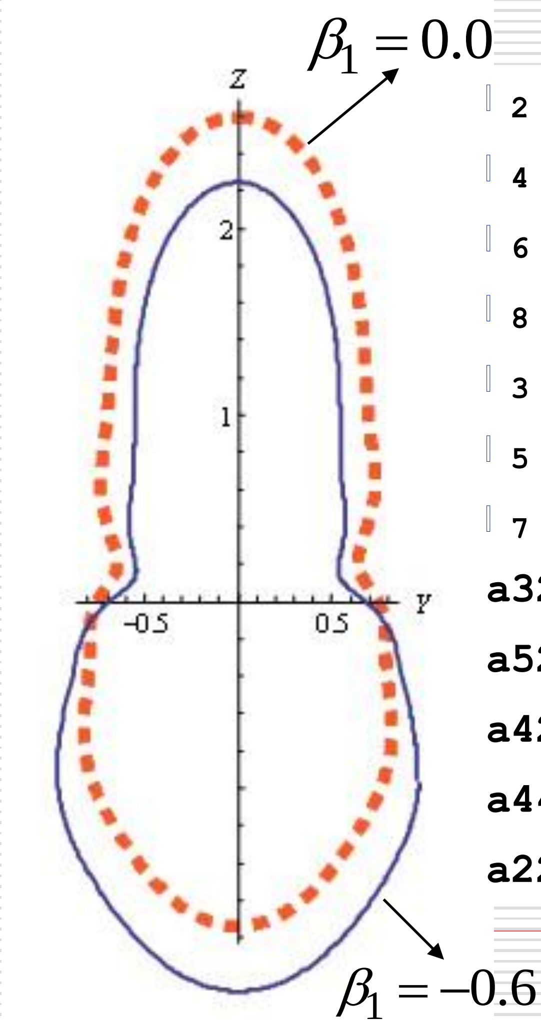
Barriers in SHN

Nucleus	SHF	FRLDM	ETFSI	HN	EXP
$^{284}112_{172}$	6.06	7.41	2.2	4.29	5.5
$^{286}112_{174}$	6.91	8.24	3.6	5.01	5.5
$^{288}114_{174}$	8.12	9.18	6.1	5.53	6.7
$^{290}114_{176}$	8.52	9.89	6.6	5.83	6.7
$^{292}114_{178}$	–	9.98	7.2	6.34	6.7
$^{292}116_{176}$	9.35	9.26	6.5	6.22	6.4
$^{294}116_{178}$	9.59	9.46	7.2	6.28	6.4
$^{296}116_{180}$	–	9.10	7.2	6.07	6.4
$^{294}118_{176}$	–	8.48	6.6	5.99	–
$^{296}118_{178}$	–	8.36	7.0	6.04	–
$^{298}118_{180}$	–	8.05	7.4	5.72	–
$^{296}120_{176}$	–	7.69	6.2	5.64	–
$^{298}120_{178}$	–	7.33	6.6	5.50	–
$^{300}120_{180}$	–	7.01	6.8	5.05	–
$^{302}120_{182}$	–	6.07	7.2	4.66	–
$^{304}120_{184}$	–	4.86	6.8	4.20	–





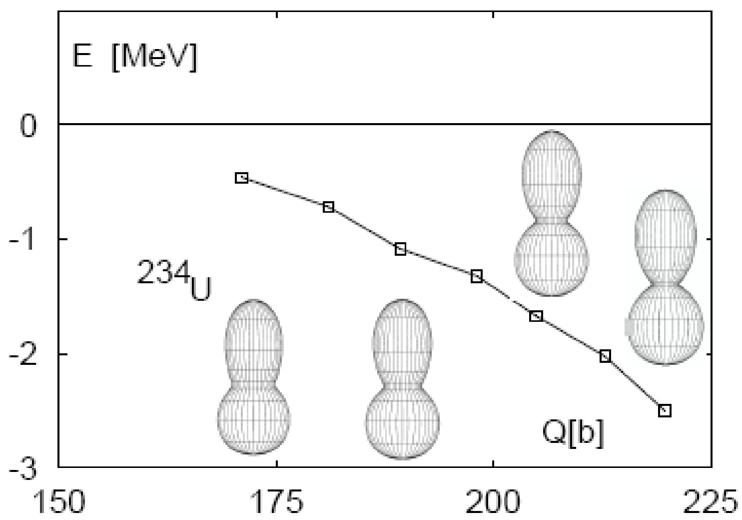
Back to IIIrd minima in actinides



β_2 = 1.1
β_4 = 0.3
β_6 = 0.1
β_8 = 0.1
β_3 = 0.3
β_5 = 0.1
β_7 = 0.1
a32 = 0.0
a52 = 0.0
a42 = 0.0
a44 = 0.0
a22 = 0.0

- The dipole deformation 1 is omitted there, as corresponding to a shift of the origin of coordinates which leaves energy (always calculated in the center of mass frame) invariant. However, this is true only for weakly deformed shapes. For large elongations, b1 acquires a meaning of a real shape variable.

IIIrd minima – type: A



One can nd continuous 8D paths start ing at the supposed IIIrd minimum and leading to scission, along which energy decreases gradually.

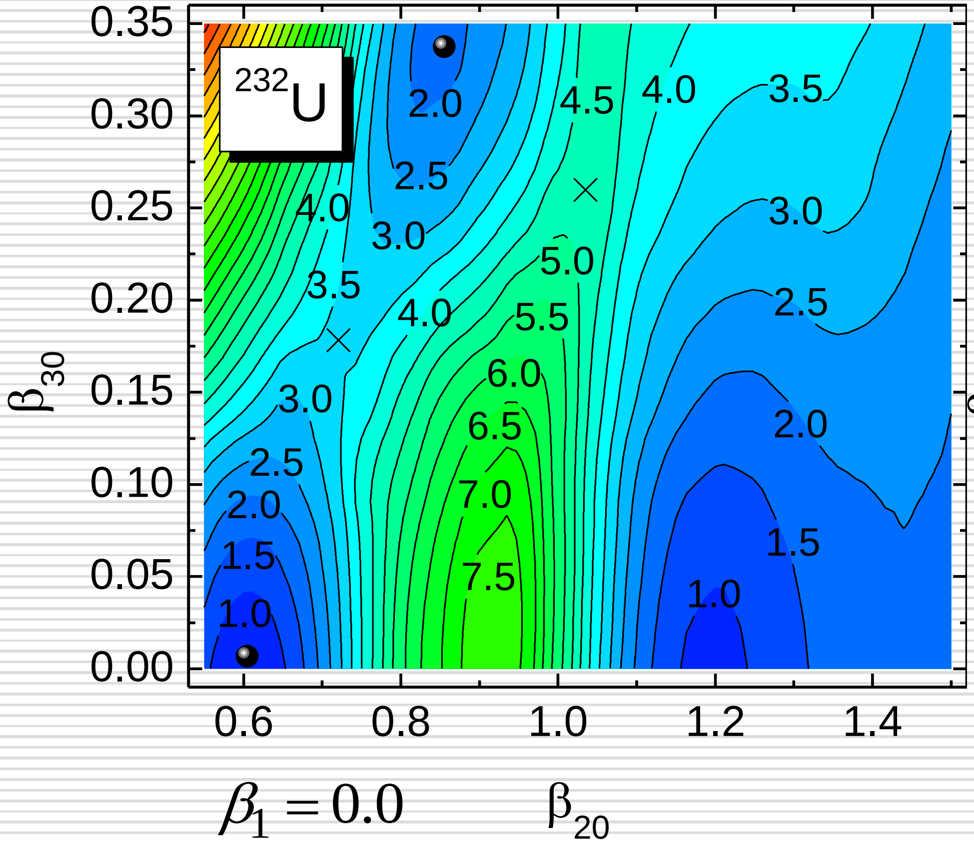
- minima with larger octupole deformations (A) have quadrupole moments Q 170 b, disturbingly close to the scission region.
- minima (A) are just intermediate congurations on the scission path, whose energy was calculated erroneously because of limitations of the admitted class of shapes.

M. Kowal, J. Skalski PRL 2012 (in press) arXiv:1203.4449

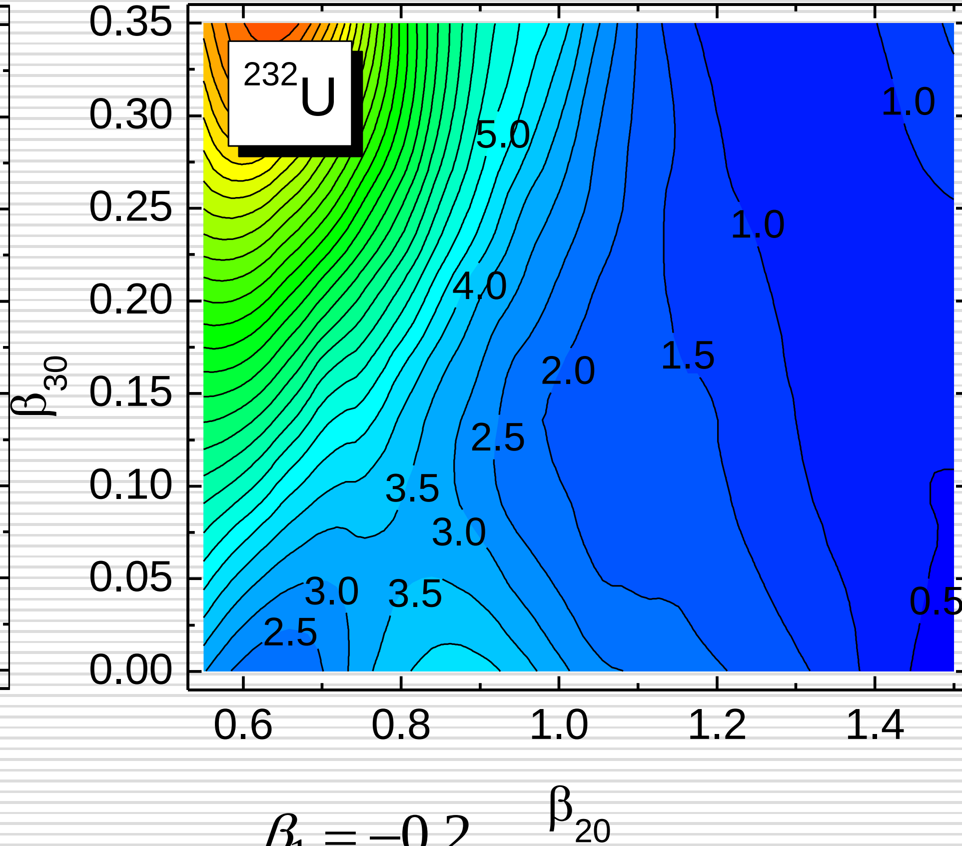
IIIrd minima – type: B

$-0.35 < \beta_1 < 0.00 \qquad -0.55 < \beta_2 < 1.50 \qquad 0.00 < \beta_3 < 0.35$

$-0.10 < \beta_4 < 0.35 \qquad -0.20 < \beta_5 < 0.20 \qquad -0.15 < \beta_6 < 0.15$

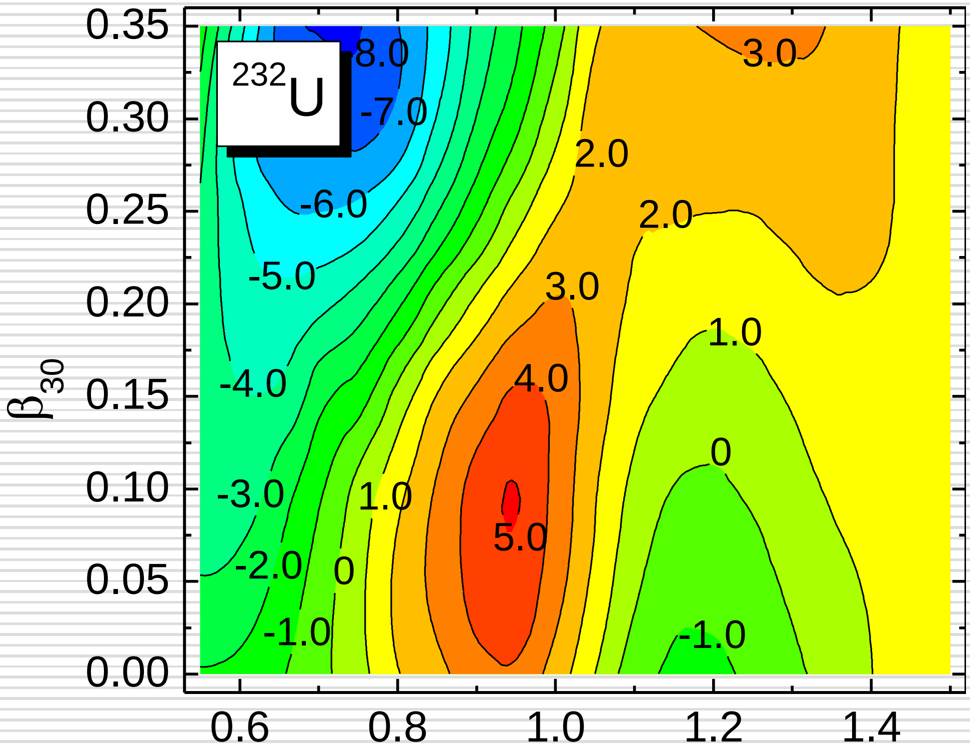


$\beta_1 = 0.0$



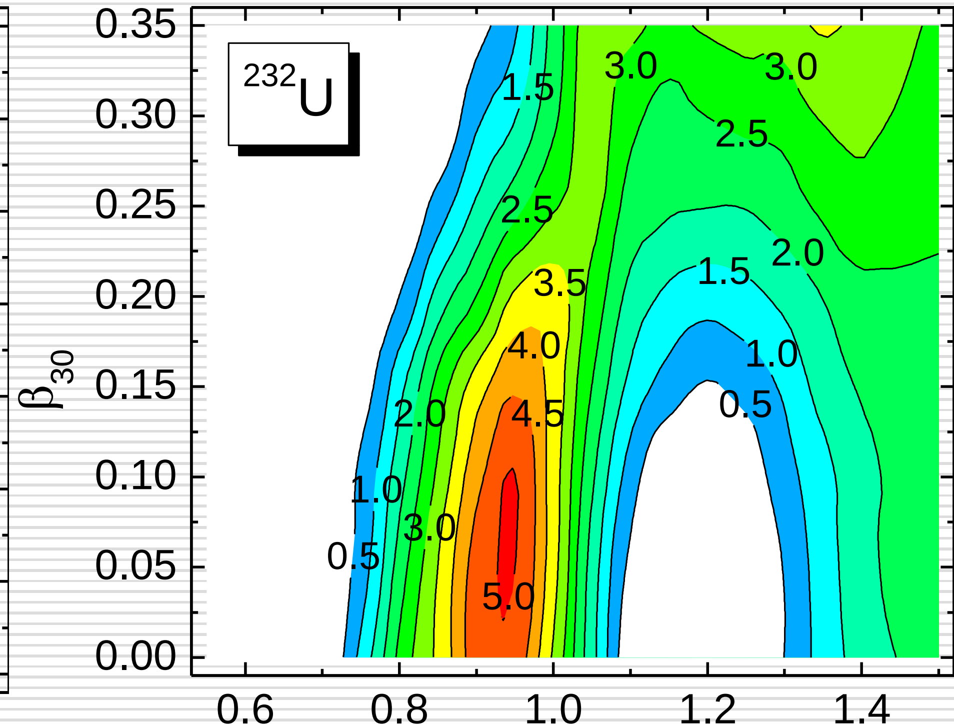
$\beta_1 = -0.2$

IIIrd minima – type: B
en. difference from beta1=0:



β20

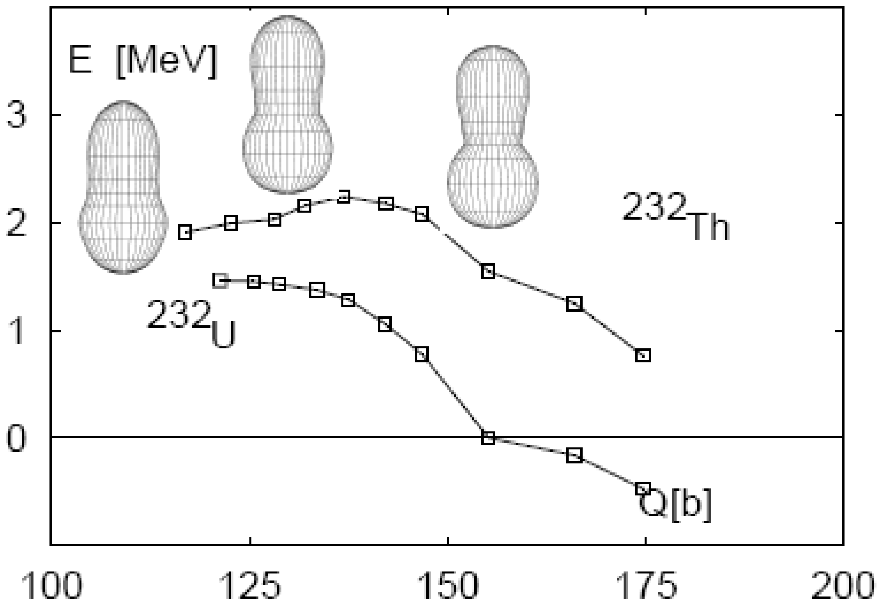
$\beta_1 = -0.2$



β20

$\beta_1 = \min$

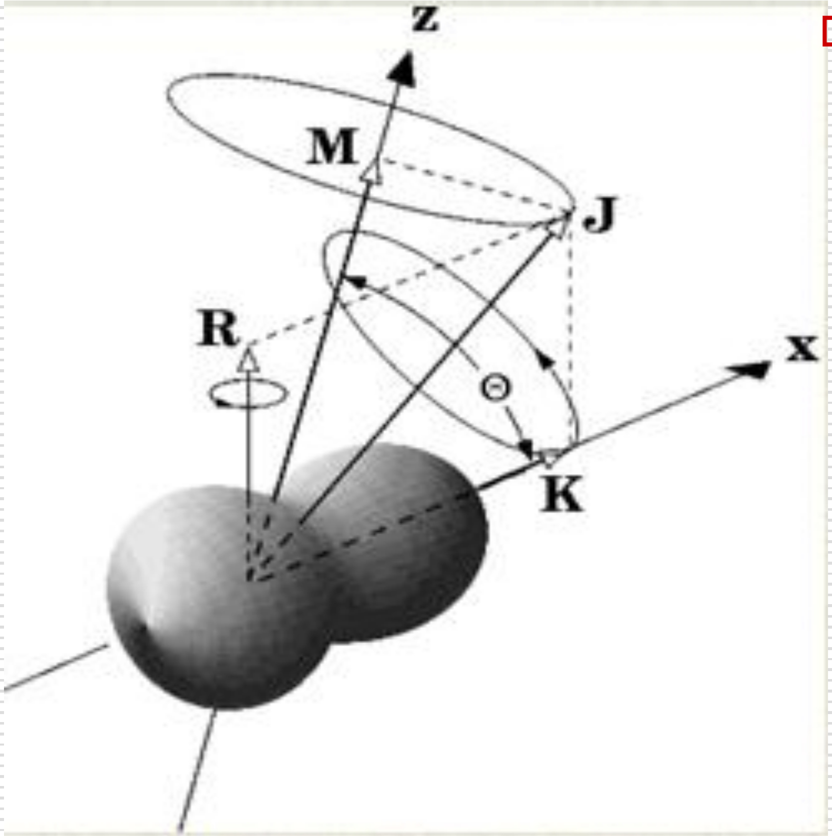
IIIrd minima – type: B



8D paths from the supposed IIIrd minima towards scission. Energies vs. quadrupole moments along such paths are shown

- the barrier vanishes in uranium and must be smaller than 330 keV in 232Th. The only other nonzero upper limit on the IIIrd barrier of 200 keV we nd in 230Th.

So, the Woods-Saxon model does not predict deep IIIrd minima.



Hyperdeformed shape

- We study the existence of third, hyperdeformed minima in a number of even-even Th, U and Pu nuclei using the Woods-Saxon microscopic-macroscopic model that very well reproduces first and second minima and fission barriers in actinides. Deep (3 4 MeV) minima found previously by Cwiok et al. are found spurious after sufficiently general shapes are included. Shallow third wells may exist in 230Th,232Th, with IIIrd barriers < 200 and 330 keV (respectively). Thus, a problem of qualitative discrepancy between microscopic-macroscopic and selfconsistent predictions is resolved. Now, an understanding of experimental results on the apparent third minima in uranium becomes an issue.