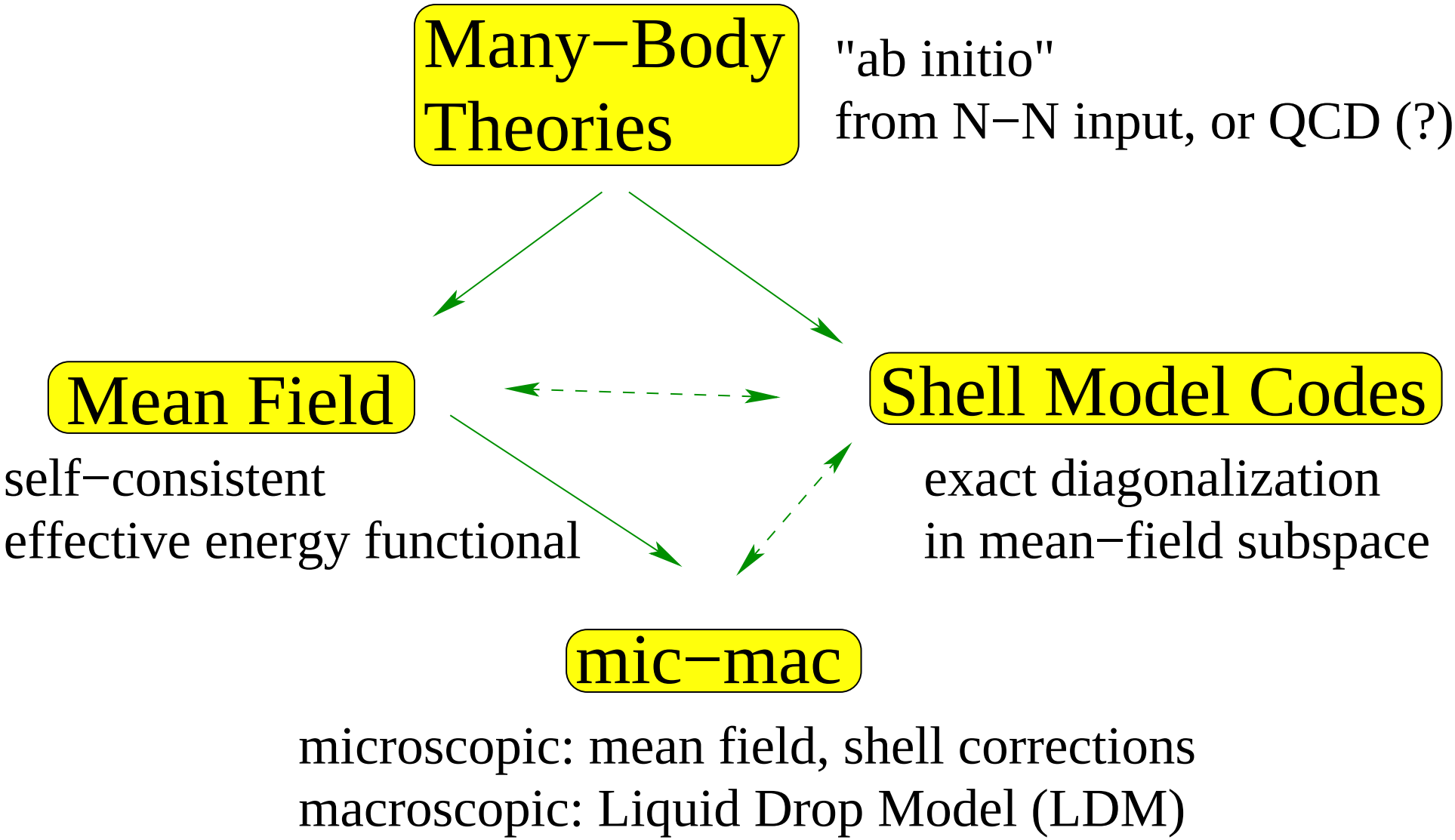
Mean-field models and exotic nuclei

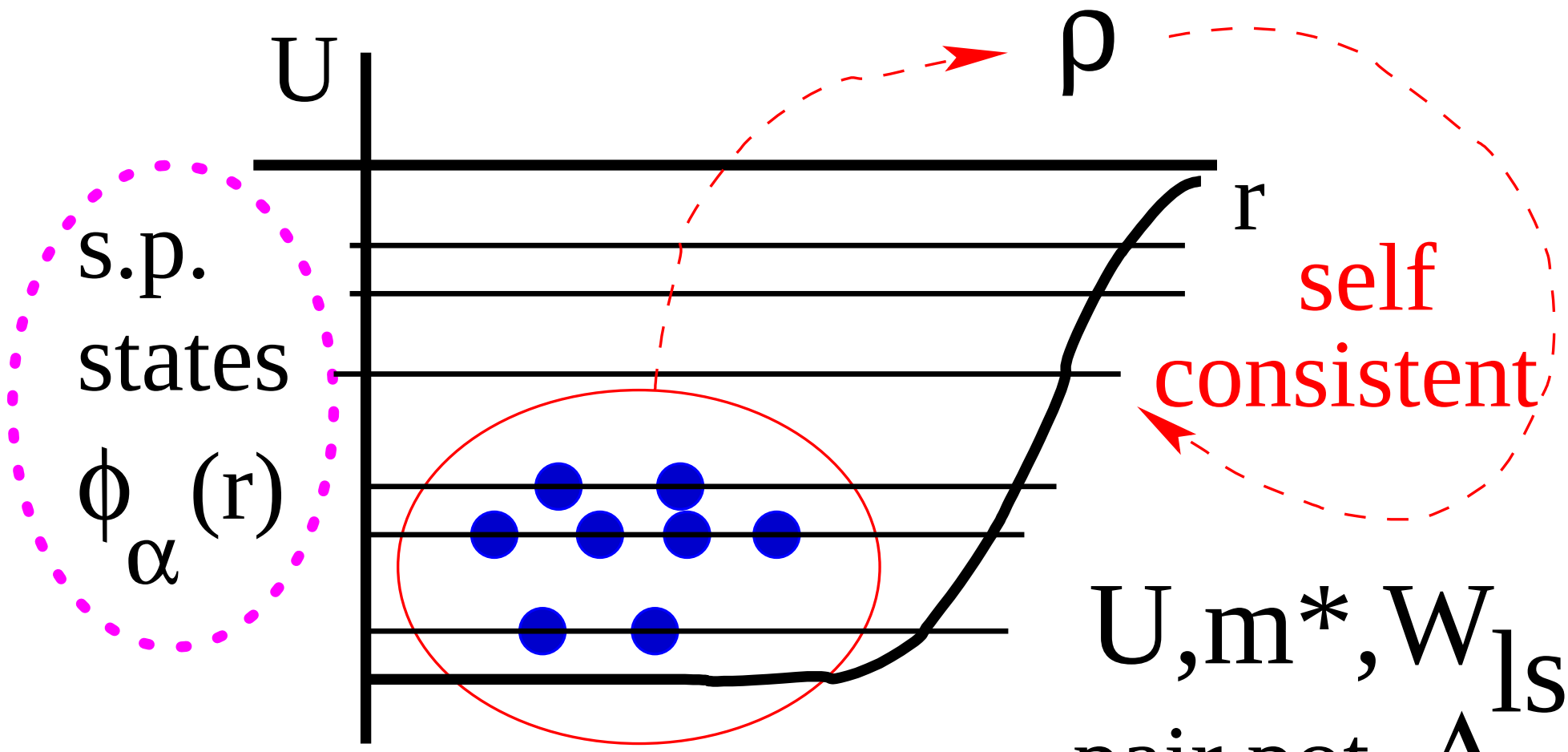
1) Formalities (energy functionals, observables, adjustment, correlations)
2) Basics (quality, nuclear matter, isovector, s.p. spectra)
3) Exotic nuclei – mean field (Sn chain, superheavy elements)
4) Exotic nuclei – collective Correlations (Sn chain, Pb chain)

Network:

M. Bender	Bruxelles
T. Bürvenich, D. Madland	Los Alamos
D. Dean, W. Nazarewicz, M.R. Strayer	Oak Ridge
T. Cornelius, J. Maruhn, W. Greiner	Frankfurt
P. Fleischer, P. Klüpfel, P.-G.R.	Erlangen


Many−Body Theories
"ab initio"
from N−N input, or QCD (?)
Mean Field
self−consistent
effective energy functional
Shell Model Codes
exact diagonalization
in mean−field subspace
mic−mac
microscopic: mean field, shell corrections
macroscopic: Liquid Drop Model (LDM)

Mean Field



ΔE~0.1−0.3% **fission**

Δr~ 0.5% **giant res.**

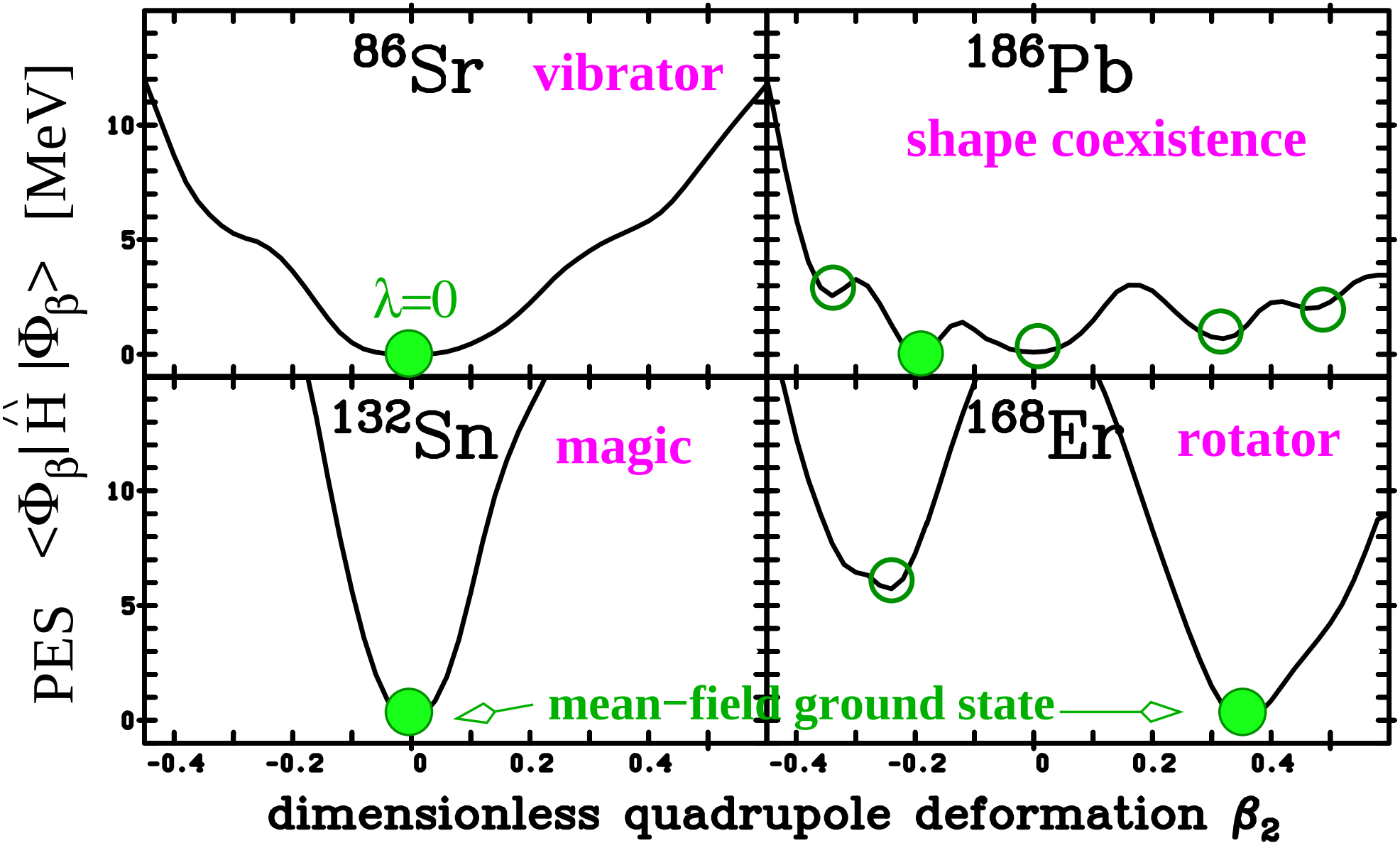
low E **...**

The Skyrme energy−density functional

$$E = E_{kin} + \int d^3r\, \mathcal{E}(\rho, \tau_{kin}, \boldsymbol{J}_{ls}, \tilde{\rho}, \tilde{\tau}_{kin}, \tilde{\boldsymbol{J}}_{ls}) + E_C + E_{pair} + E_{cm}$$

	isoscalar $T=0$	isovector $T=1$	
two−body	ρ^2	$\tilde{\rho}^2$	} *energy, density, asymmetry*
density dep.	$\rho^{2+\alpha}$	$\tilde{\rho}^2 \rho^{\alpha}$	
kinetic	$\rho\, \tau_{kin}$	$\tilde{\rho}\, \tilde{\tau}_{kin}$	*effective mass, sum rule enh.*
spin −orbit	$\rho\, \boldsymbol{J}_{ls}$	$(\tilde{\rho}\, \tilde{\boldsymbol{J}}_{ls})$	*spin−orbit splitting*
gradient cor.	$\rho \Delta \rho$	$\tilde{\rho} \Delta \tilde{\rho}$	*surface tension, surface asym.*

10 free parameters
adjusted to:
E_B, r_{ch} ,(ε_{ls}, $F_{ch}(q)$, r_n ...)
in 10... nuclei
→ *effective for all nuclei*


86Sr
vibrator
186Pb
shape coexistence
λ=0
132Sn
magic
168Er
rotator
mean−field ground state
PES <Φβ| Ĥ |Φβ> [MeV]
dimensionless quadrupole deformation β2
10
5
0
-0.4
-0.2
0
0.2
0.4

Examples from the variety of forces

Skyrme-Hartree-Fock:

SkM*	traditional benchmark
SkP	$m^*/m=1$
SLy4/6	isovector trends, neutron EoS
BSk1	energies E only in all stable nuclei

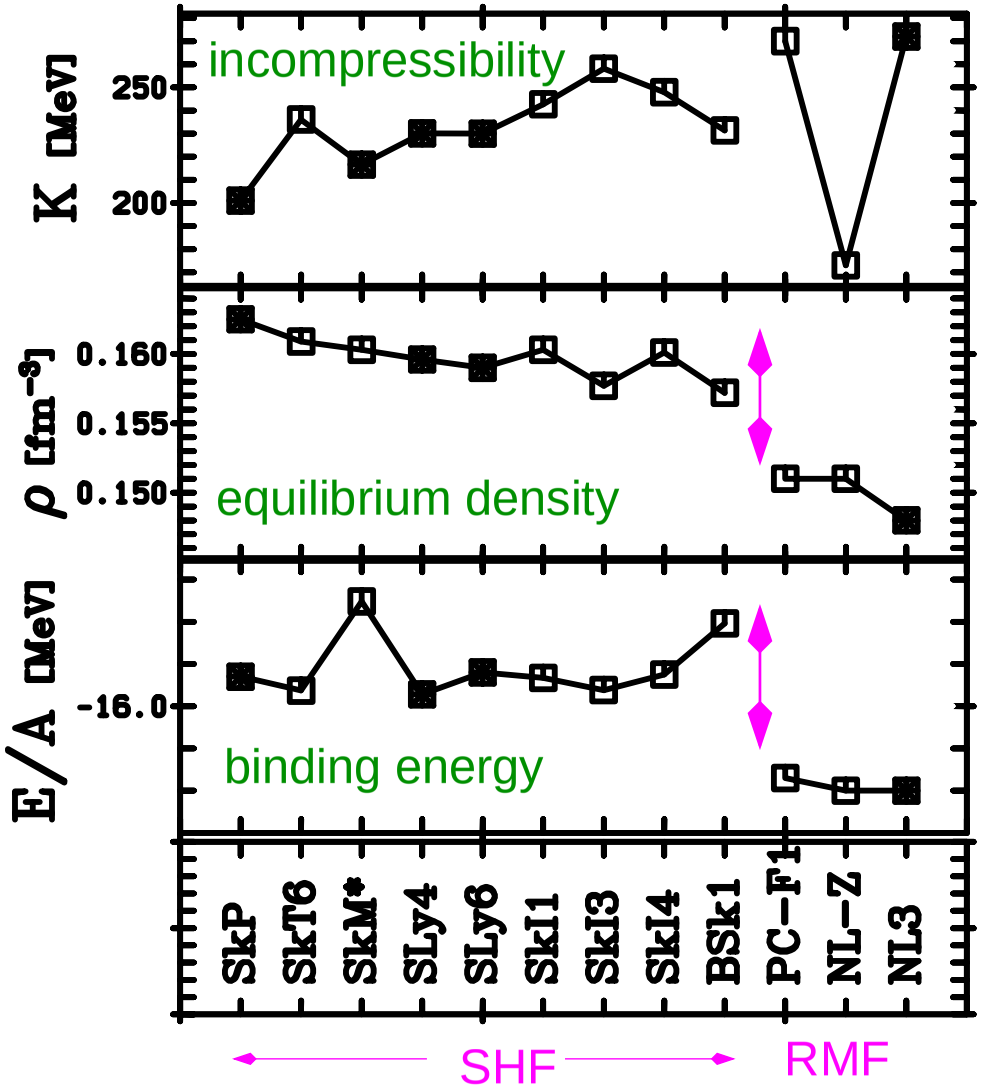
$l*s$ extended SHF:

SkI3/4	el.magn. formfactor, isotope shifts in Pb

Relativistic Mean Field model:

NL-Z2	el.magn. formfactor, surface prop.
NL3	isovector info
PC-F1	point coupling variant, fitted as NL-Z2

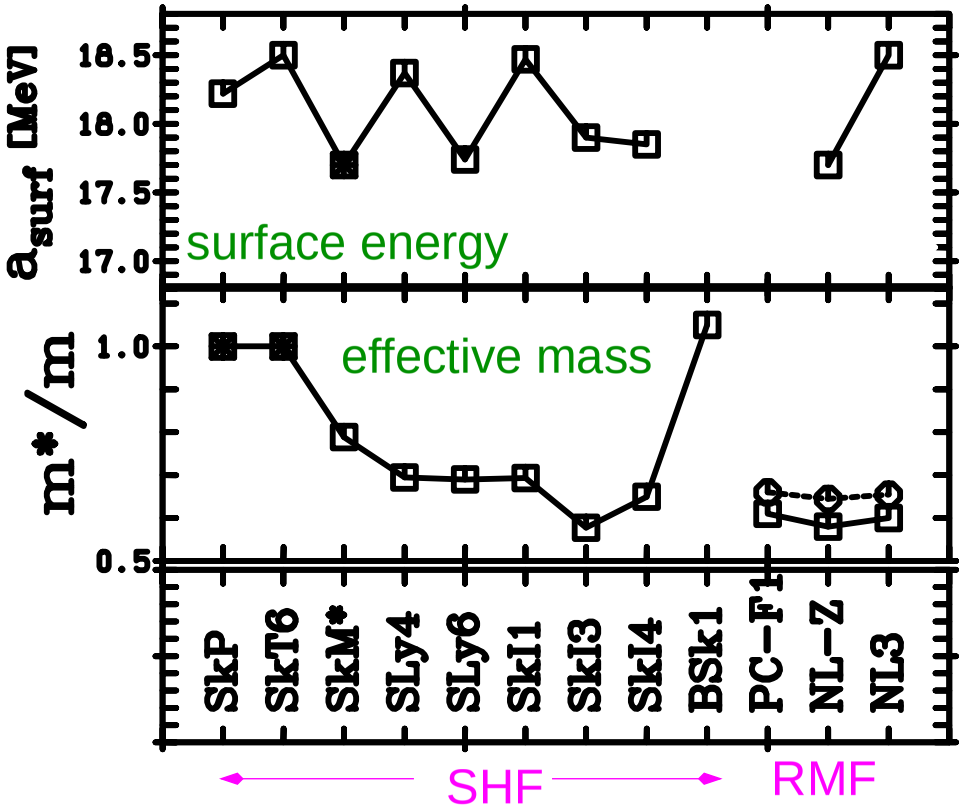
Nuclear matter properties: isoscalar



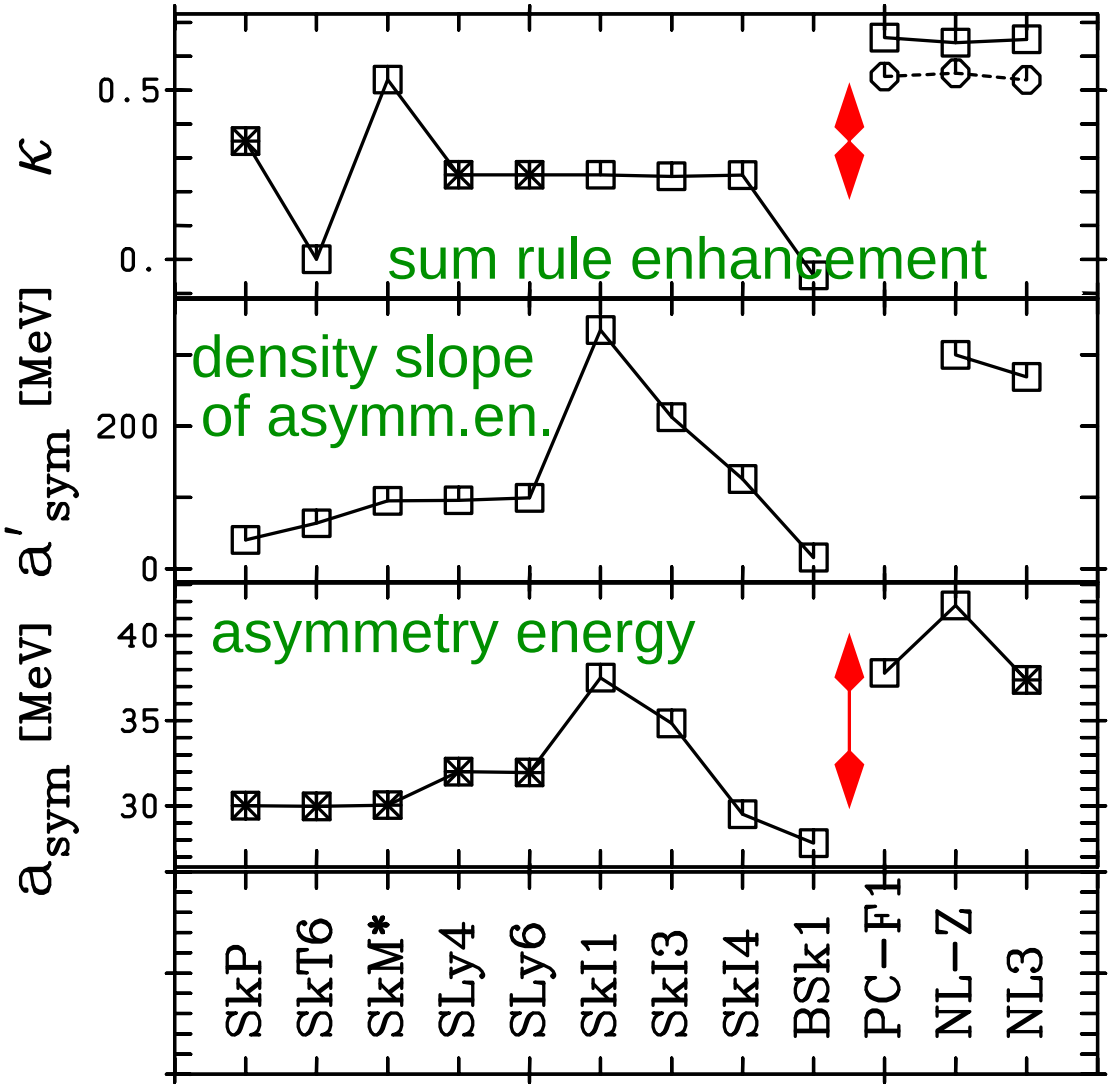
equilibrium point: RMF ≠ SHF

incompr., surface en.: both flexible

effective mass: SHF flexible, RMF low



Nuclear matter properties: isovector



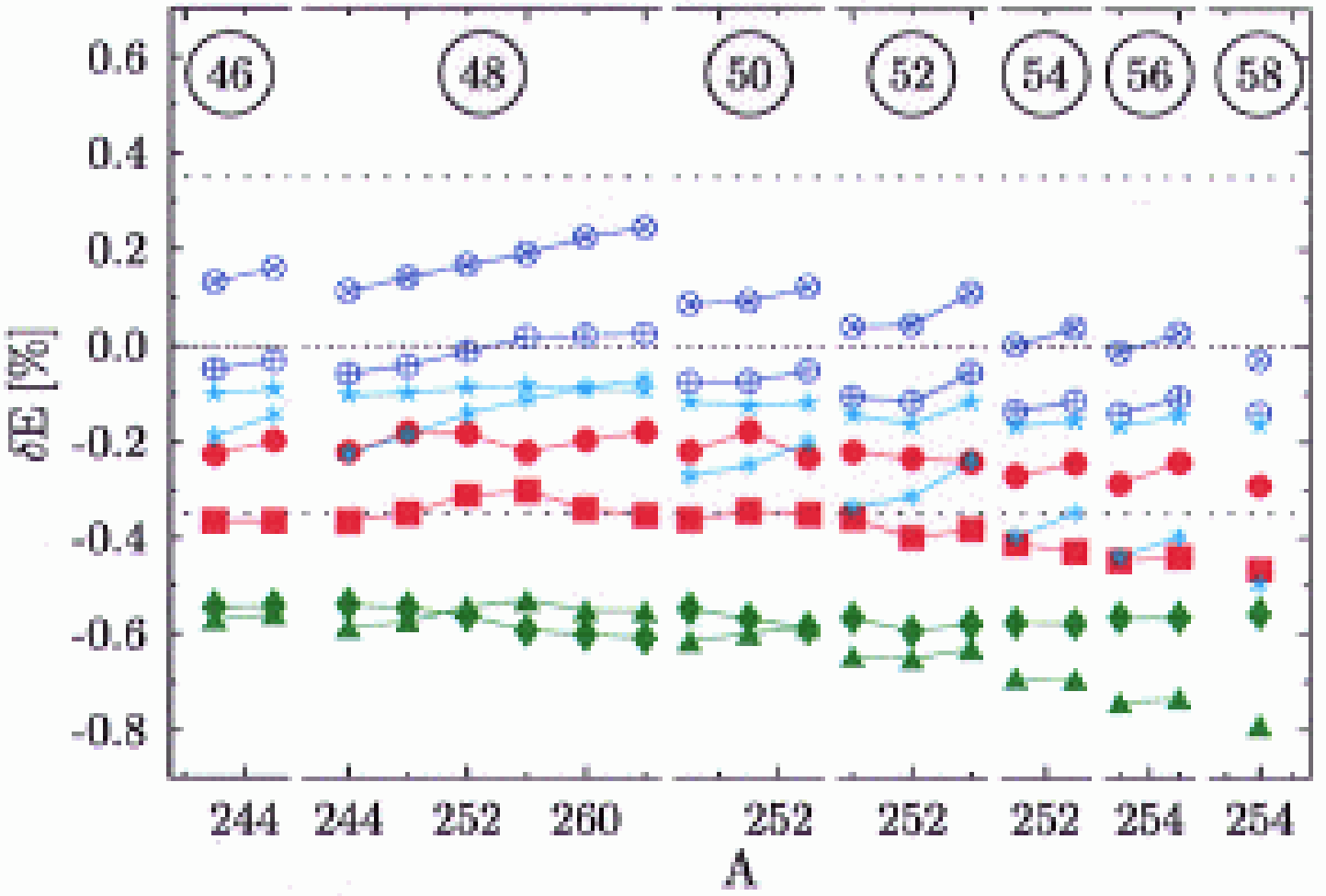
flexible in SHF, large in RMF

follows strictly the trends of asymmetry energy

Ω_{GDR} decreases with increasing a_{symm}

generally larger in RMF (good GDR together with large κ)

Quality of E_B in Superheavy Nuclei



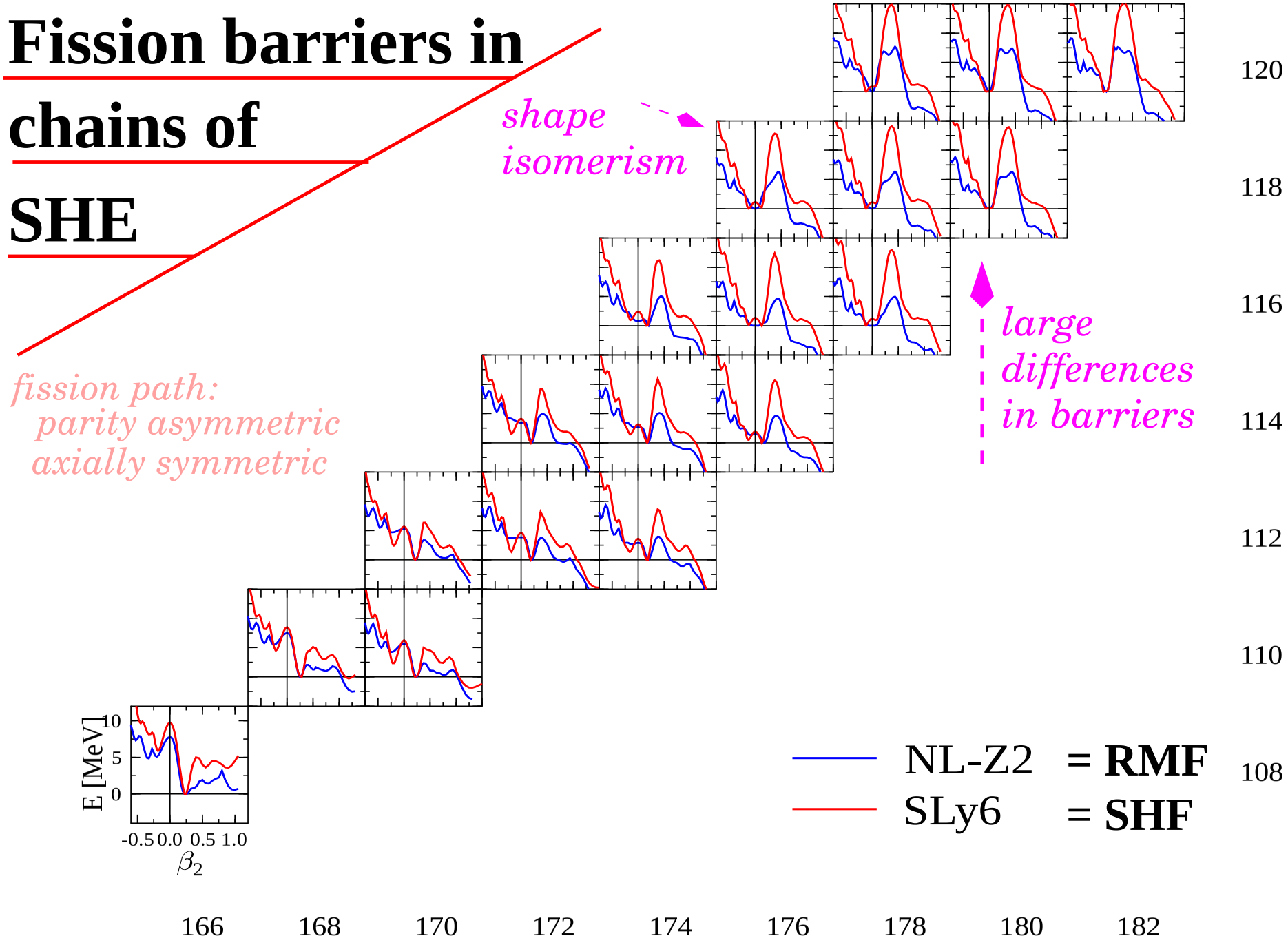
SkP
SLy6
SkI3
SkI4
} SHF

NL-Z2
NL3
P-LA
P-Fx
} RMF

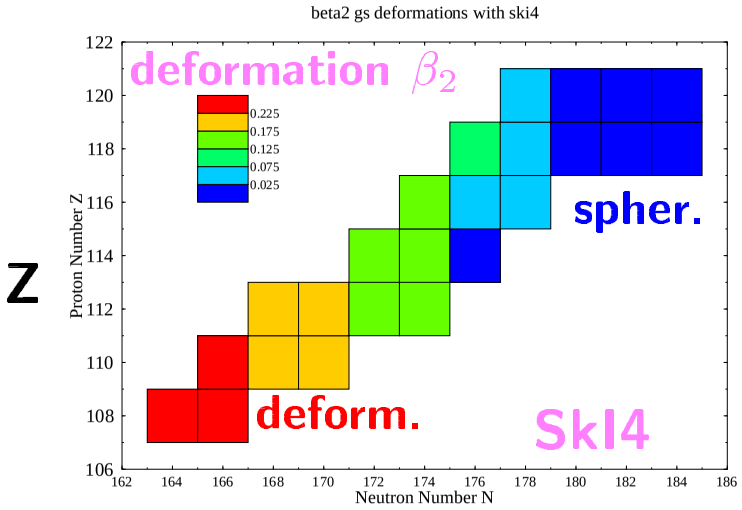
lower binding with increasing A

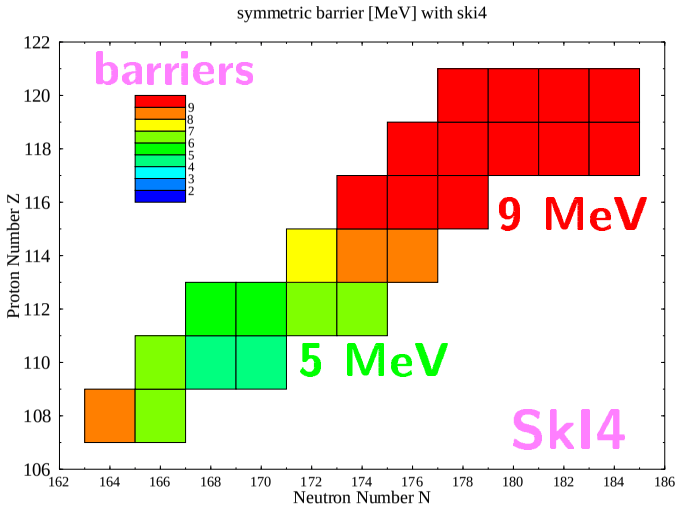
SHF generally less bound than RMF

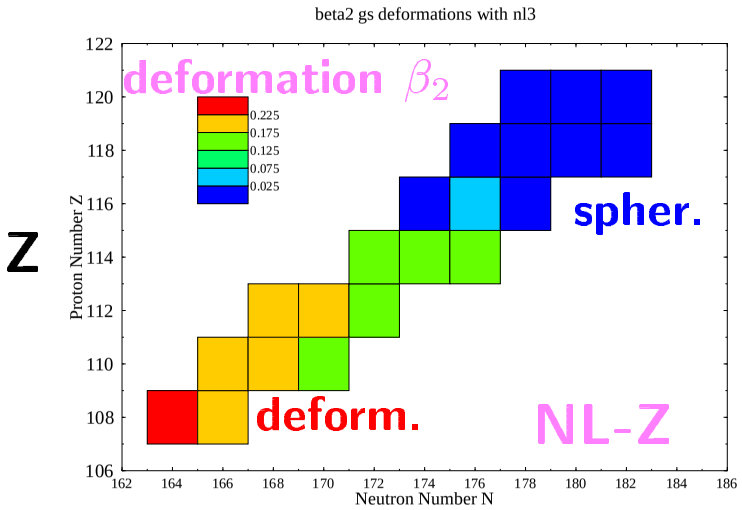
Fission barriers in chains of SHE

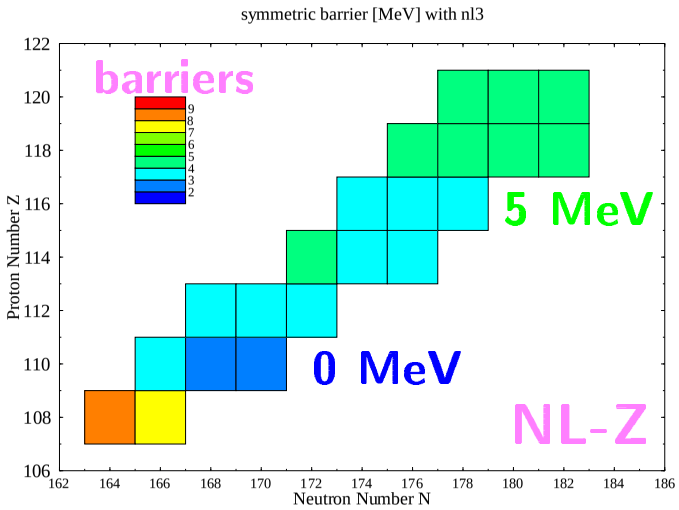


G.s. deformations and fission barriers









Z

N

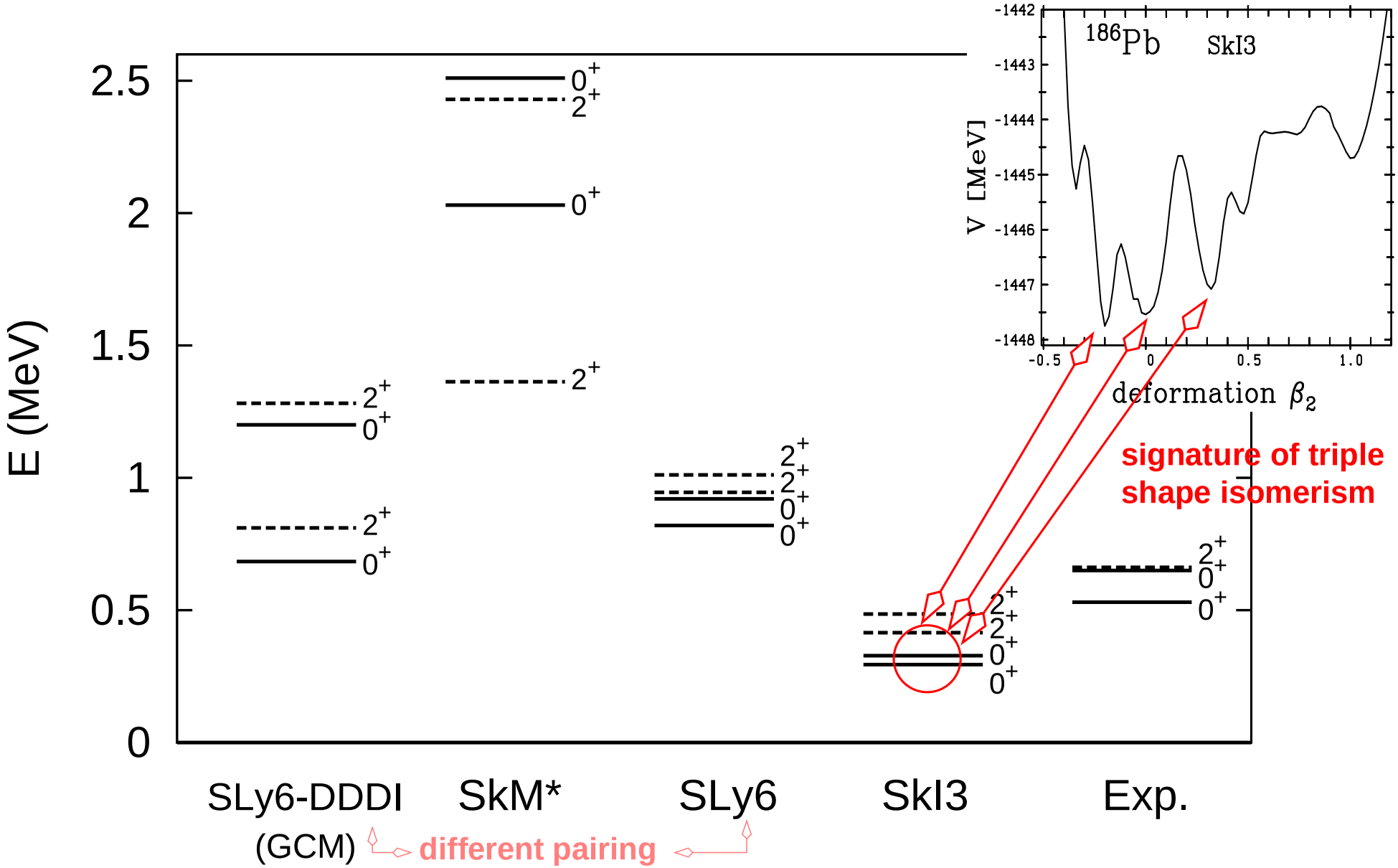
Z

N

SHF

RMF

Collective spectrum of ^{186}Pb



Conclusions

- **Self consistent mean field:**
  - excellent description of bulk properties in known nuclei, shapes without prejudices
  - universal parameters, but phenomenologically fitted
  - uncertainty in extrapolations ?, GDR in light nuclei ?, s.p. spectra ?
  - not yet fully fixed: pairing forces, isovector forces

- **Exotic nuclei:**
  - neutron radii $\leftrightarrow$ symm. energy, $E_B \leftrightarrow$ shell effects
  - superheavy elements: large islands of shell stabilization, fission barriers $\leftrightarrow$ forces
  - shape coexistence at bounds of stability

- **Collective ground state correlations:**
  - low energy excitations fairly well reproduced without free parameters,
  - problems: B(E2), vicinity of shell closures
  - large correlation effects for isotope shifts and energy differences (δ_{2p})
  - sensitive to pairing – but pairing yet to be fixed