DE LA RECHERCHE À L'INDUSTRIE

Beyond mean field : the Bohr Hamiltonian

S. Hilaire
CEA,DAM,DIF

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What's the point of using it ?

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GENERAL MOTIVATION

Providing nuclear reaction models with **« credible and coherent »** microscopic inputs

- makes (really) senses when dealing with unmeasured target
- the sounder the underlying physics the better the predictive power
- no direct link between xs and n-n interaction for **all nuclei**
- **many inputs** needed
  - . Discrete levels properties (masses, J, p, deformation etc …)
  - . Nuclear level densities up to 200MeV
  - . Gamma strength functions
  - . Fission properties (barriers, broken symetries, = path)
  - . Optical potential (spherical and deformed)
- all this can be derived from nuclear structure more or less directly
- all this can be used mostly through tables
- robust codes needed
- robust methodolodgy (recipes)
  - . to reduce human intervention while producing tables
  - . to fill gaps (even-even limitation for instance)

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All this has been done with Skm for all nuclei (S. Goriely) !

Let's do it with Gogny !

. Optical potential (spherical and deformed)

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PLAN

- Motivation
- The starting point : nuclear masses
- Spectroscopy
- Nuclear Reaction inputs
- Conclusions & Perspectives

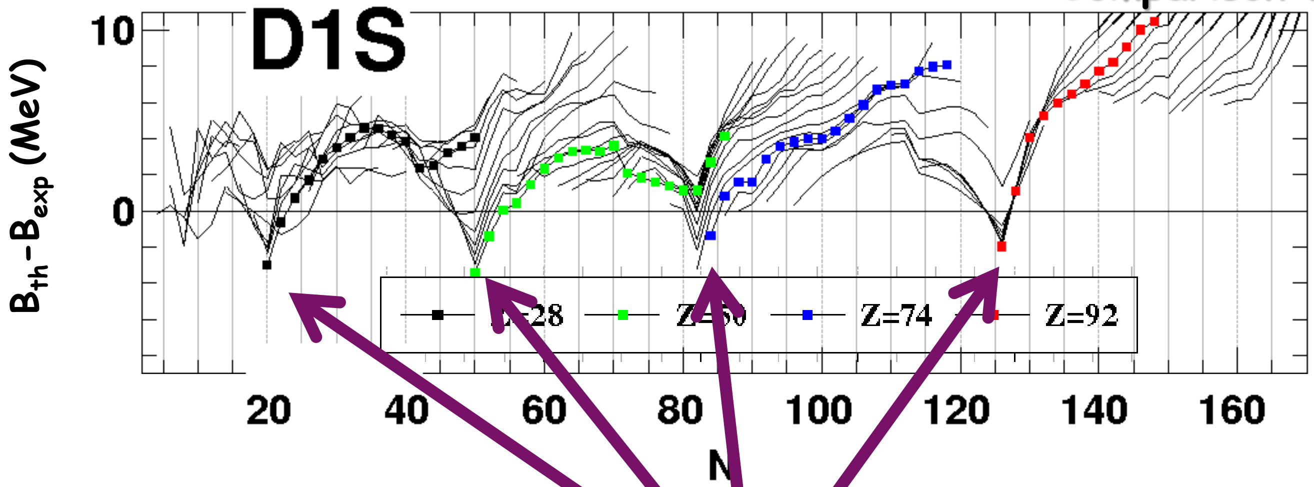
THE STARTING POINT :

Nuclear masses

Nuclear masses with D1S

D1S

Comparison with 2149 Exp. Masses



- $E_{th} = E_{HFB}$

r.m.s ~ 4.4 MeV

Discussion with M. Girod :
We forgot to estimate infinite basis effect
⇒ Overbinding of 1-3 MeV

How can we compute binding energies ?

$$B = B(N_0) + \Delta_\infty$$

➲ Infinite basis correction : code AMEDEE

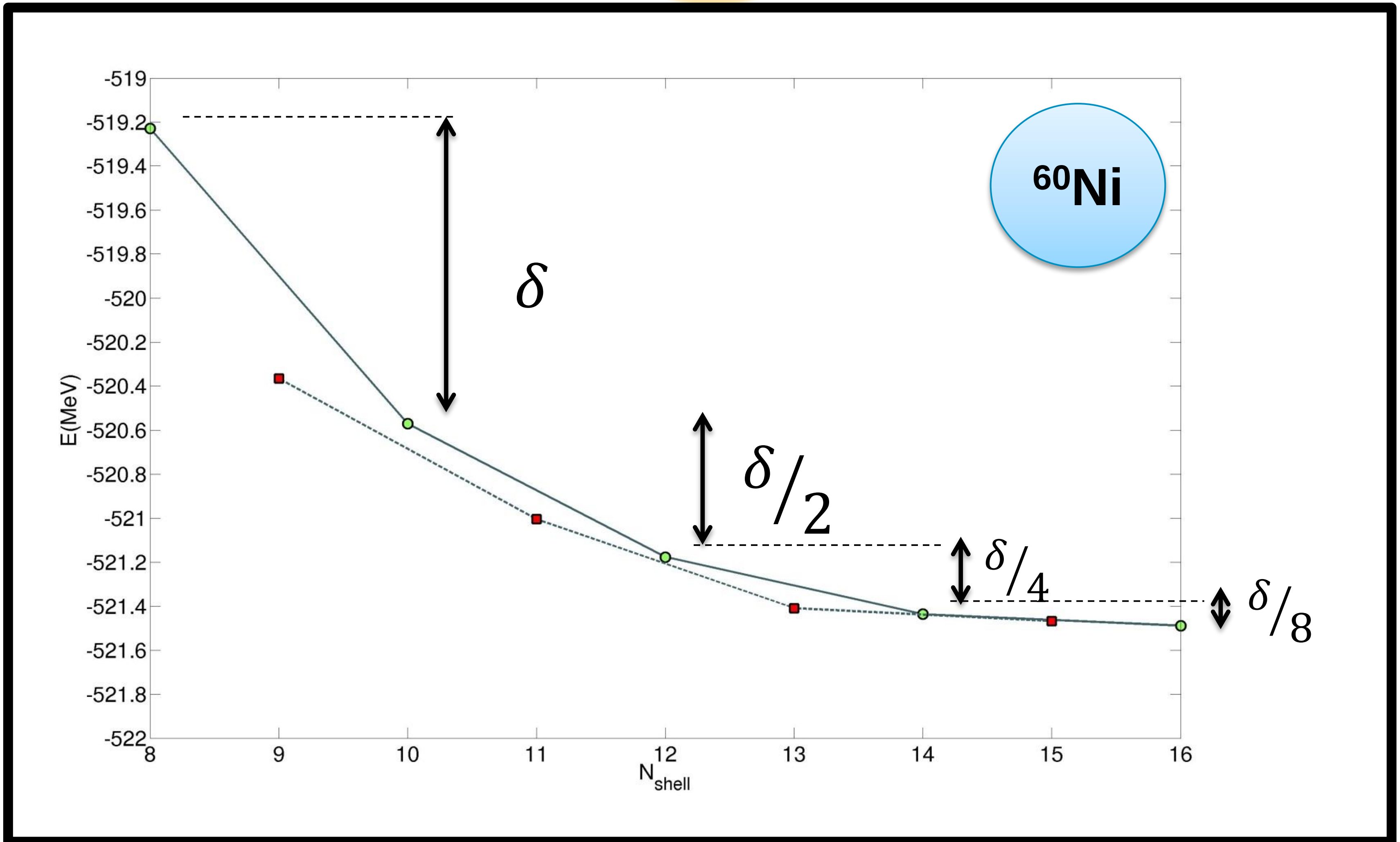
$$\Delta_\infty = E(N_0) - E(N = +\infty)$$

➲ Assumption

$$\Delta_\infty = 2[E(N_0) - E(N_0 + 2)]$$

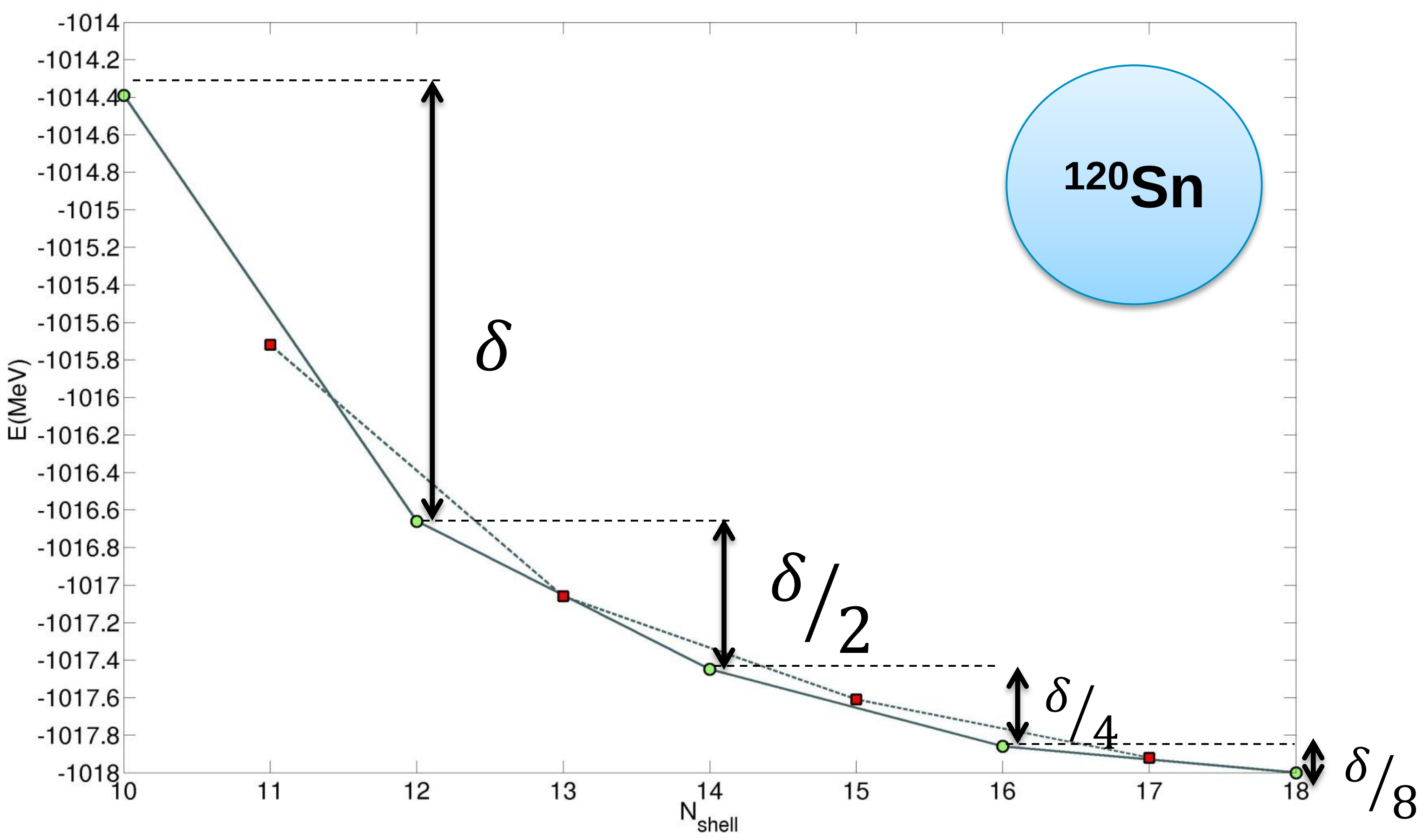
How can we compute binding energies ?

$$B = B(N_0) + \Delta_\infty$$



How can we compute binding energies ?

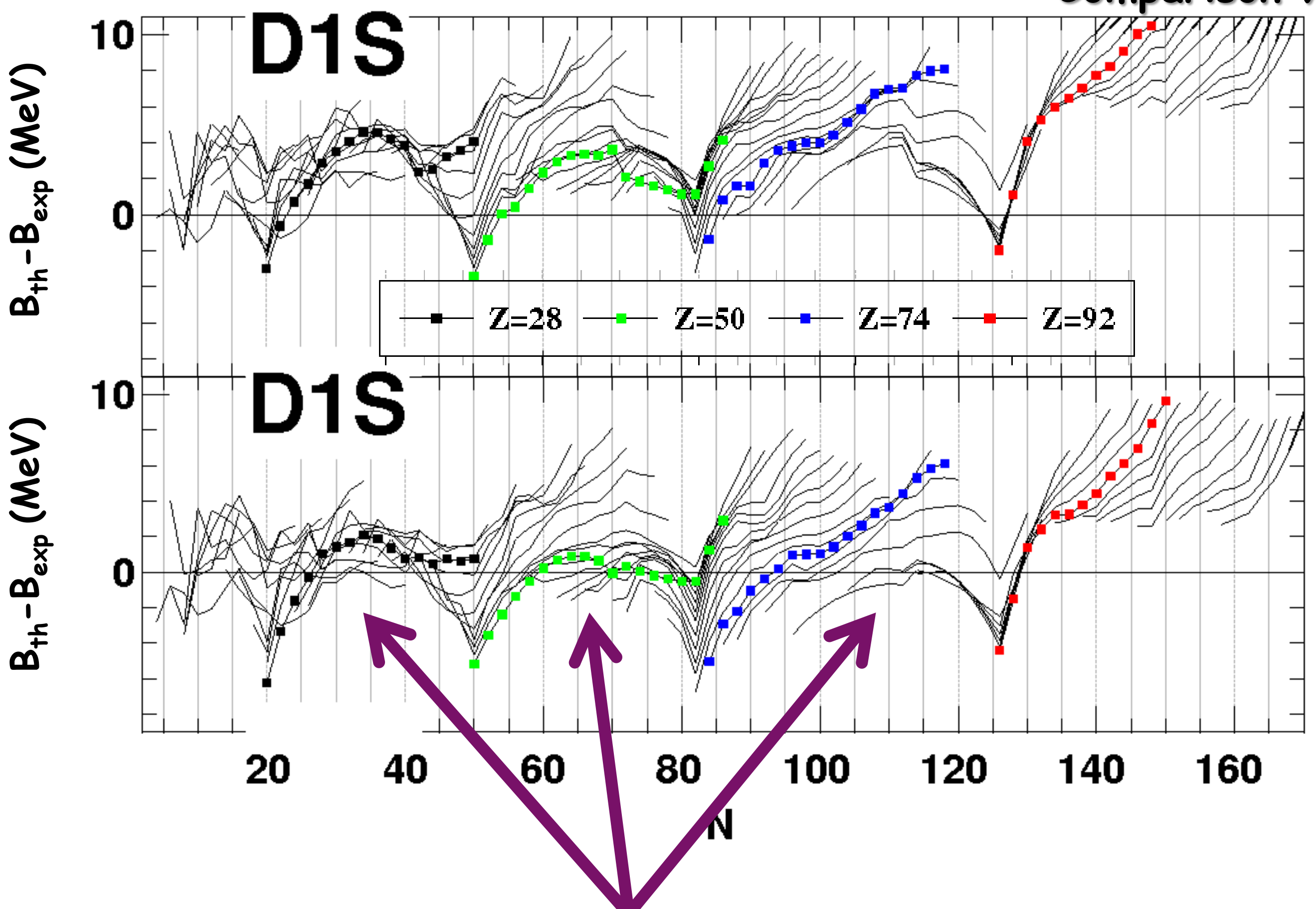
$$B = B(N_0) + \Delta_\infty$$



Consequences illustrated with D1S

D1S

Comparison with 2149 Exp. Masses



- $E_{th} = E_{HFB}$

  r.m.s ~ 4.4 MeV

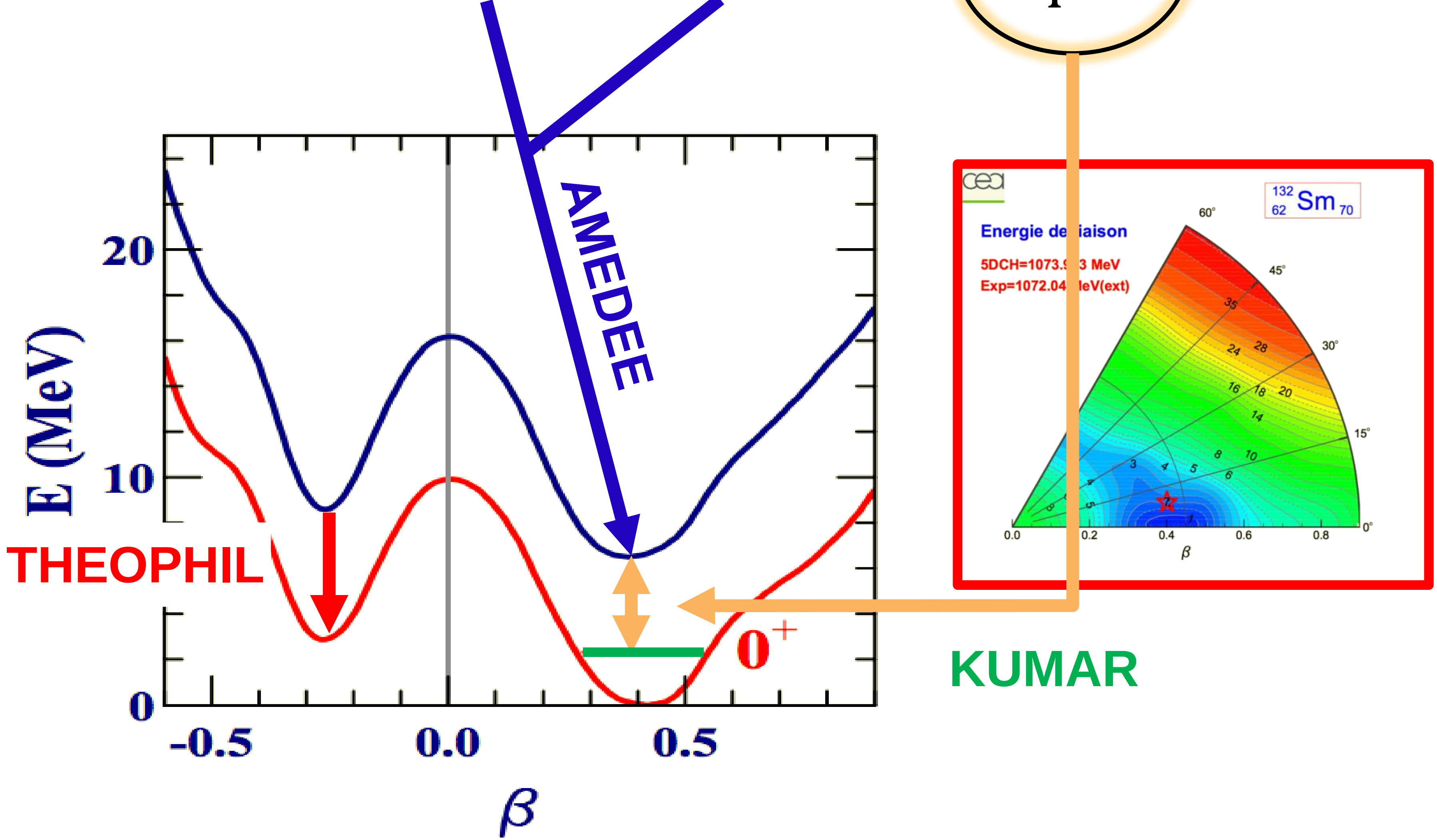
- $E_{th} = E_{HFB} - \Delta_\infty$

  r.m.s ~ 2.6 MeV

Discussion with Girod :
You forgot to include bmf (quadrupole) correlations
$\Rightarrow$ Arches between magic nuclei

How can we compute binding energies ?

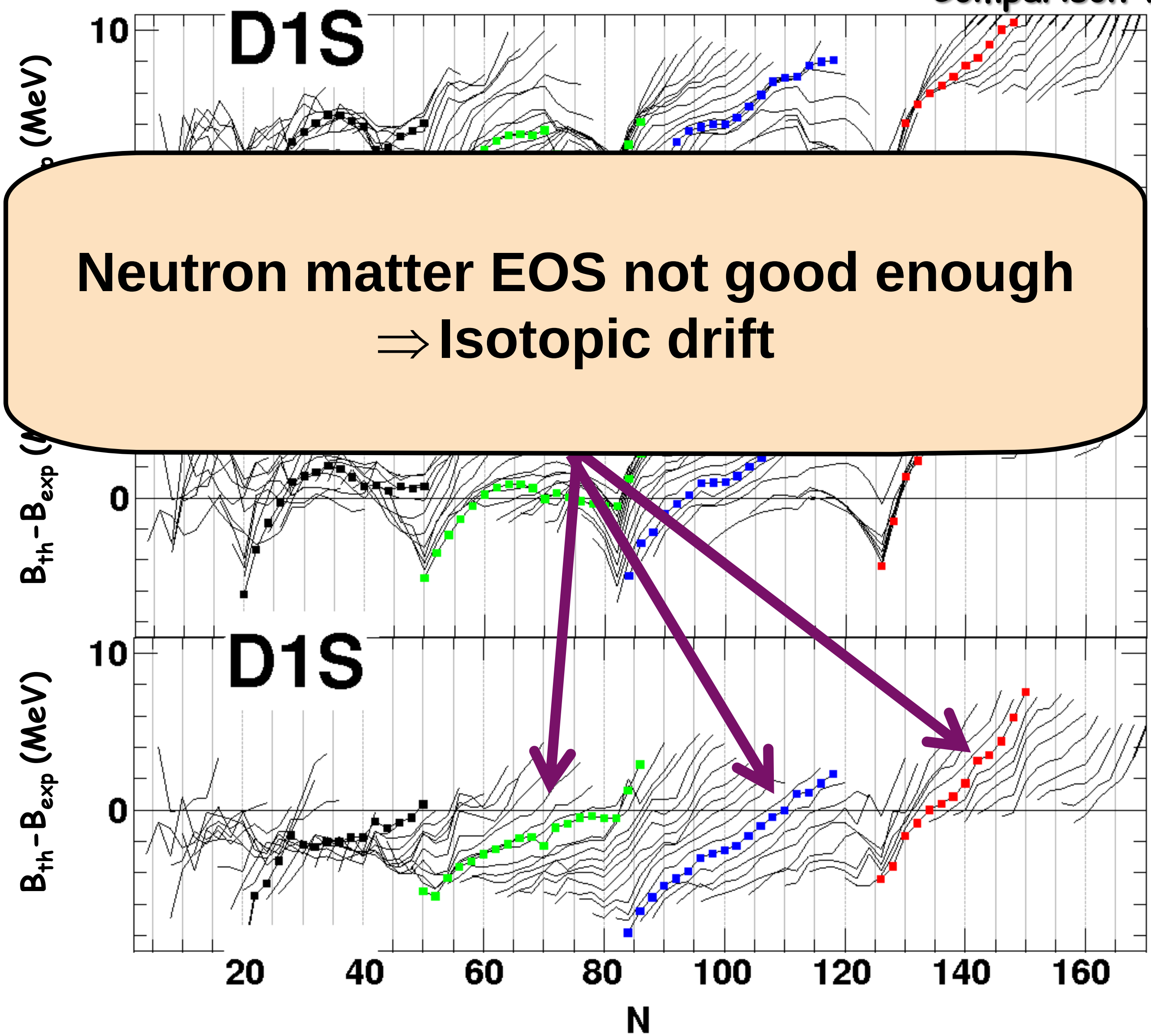
$$B = B(N_0) + \Delta_\infty + \Delta_{\text{quad}}$$



Consequences illustrated with D1S

D1S

Comparison with 2149 Exp. Masses



- $E_{th} = E_{HFB}$

  r.m.s ~ 4.4 MeV

- $E_{th} = E_{HFB} - \Delta_{\infty}$

  r.m.s ~ 2.6 MeV

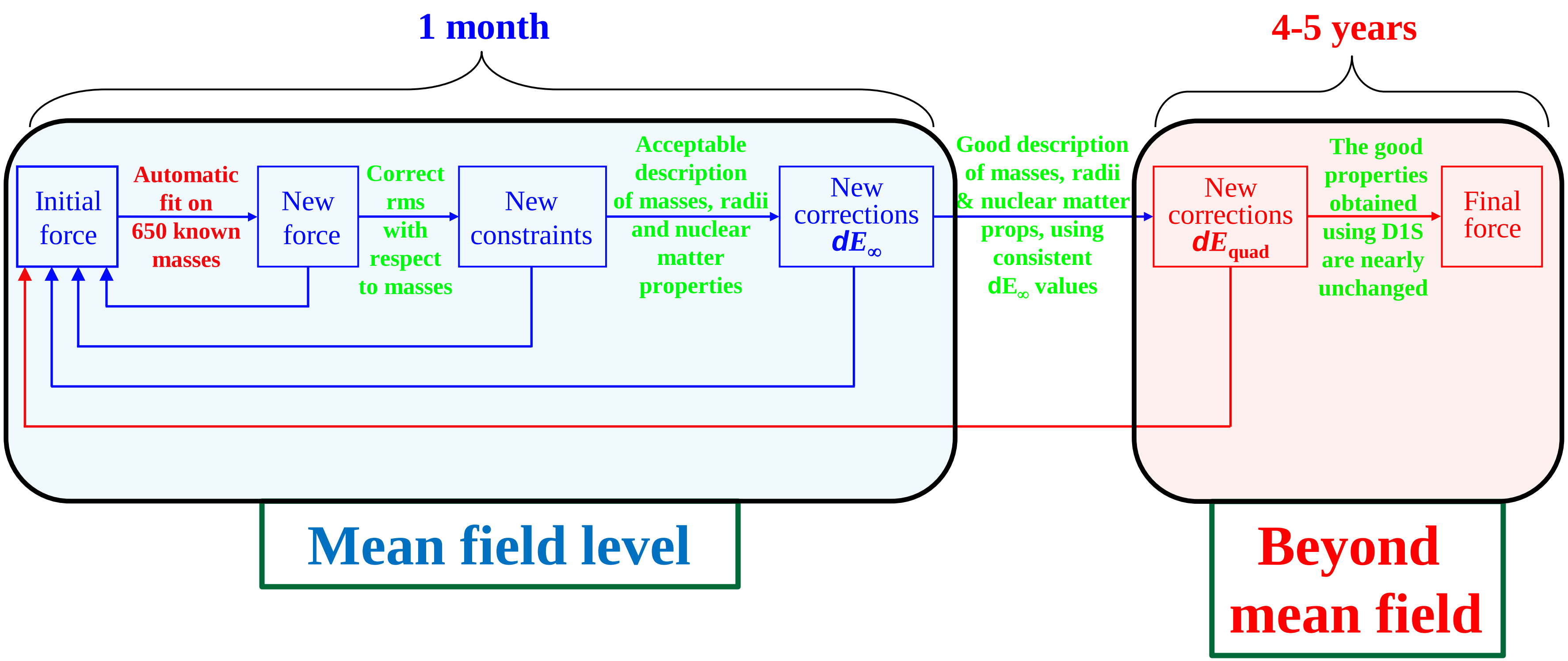
- $E_{th} = E_{HFB} - \Delta_{\infty} - \Delta_{quad}$

  r.m.s ~ 2.9 MeV

BASIC STRUCTURE PROPERTIES
HFB Mass models

Most advanced theoretical approach = multireference level

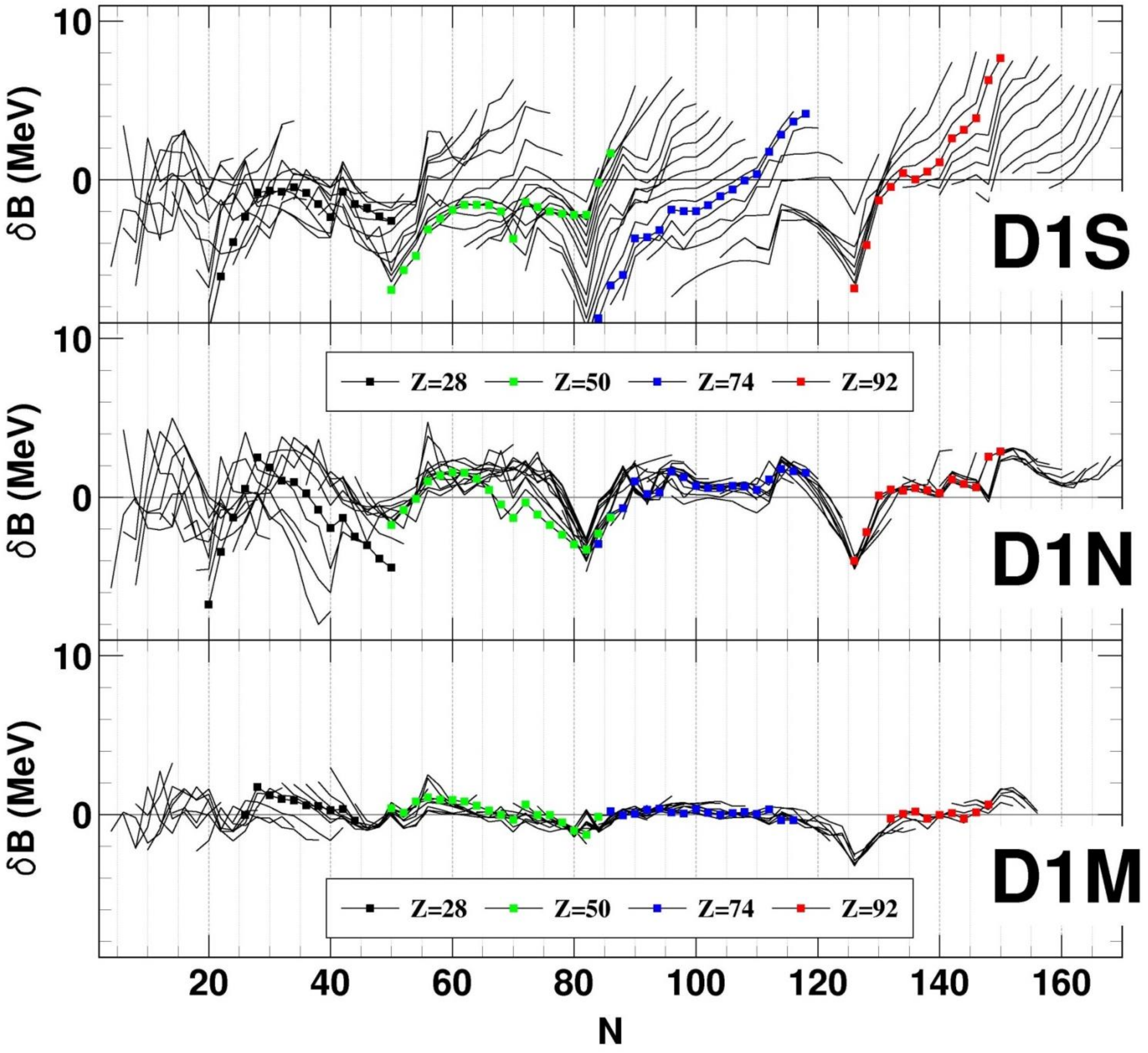
- Methodology : $E = E_{mf} + dE_{\infty} + dE_{quad}$



* Additional filters

- Collective properties (0+,2+, BE2), RPA modes, backbending properties, pairing properties, fission properties, gamma strength functions, level densities

Major goal reached : first Gogny mass model !



r.m.s ~ 3 MeV

r.m.s ~ 1 MeV

r.m.s = 0.798 MeV

SPECTROSCOPY

- Several tens of papers with D1S

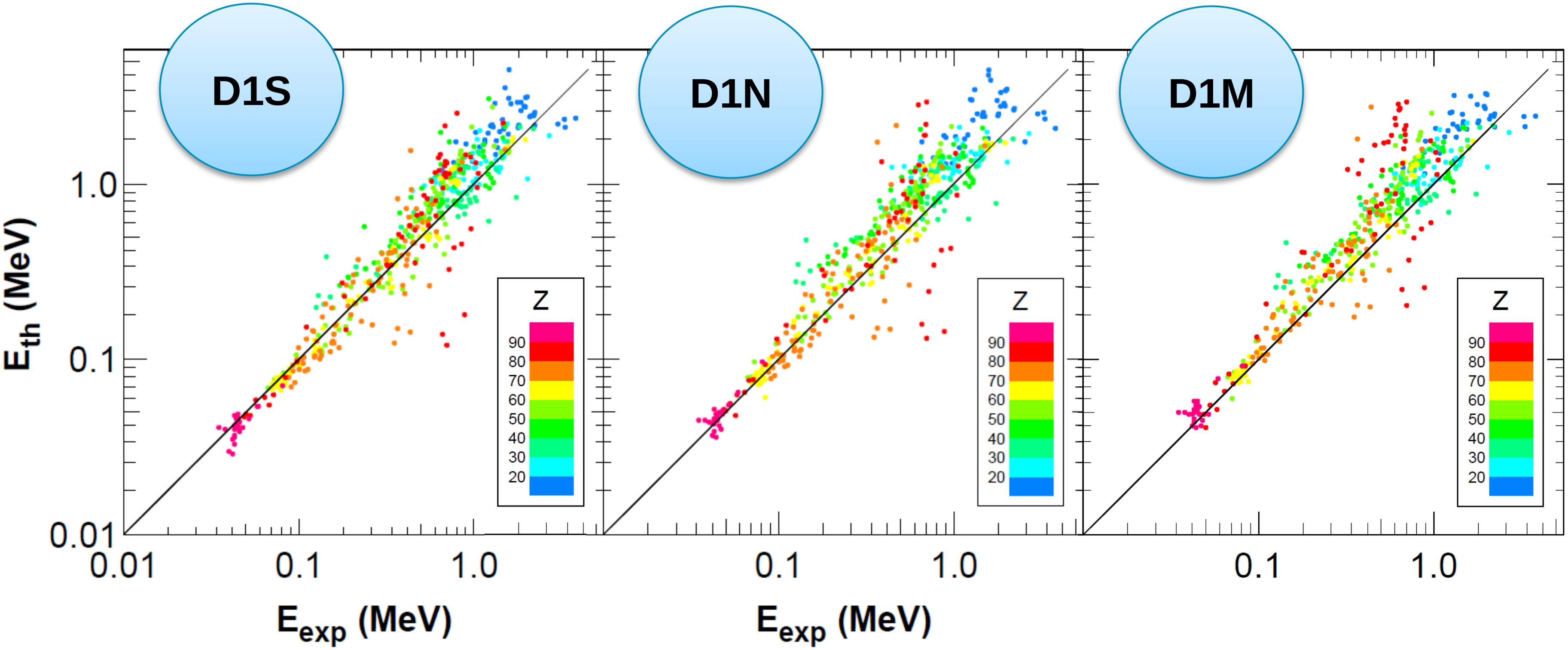
  - Collective states spectroscopy (rotations and vibrations)
  - Shape coexistence & mixing
  - Transition strengths
  - Drip lines (through mass differences)
  - Improved nuclear deformations (radii, β and γ Bohr parameters)

$\Rightarrow$ Showing the predictive power of the D1S effective interaction

- Global systematics published in PRC81 (2010) 014303 with D1S
  - not with Kumar/Girod code but with J. Libert one

- Web site : www.phynu.cea.fr (D1S now, D1M soon)

Excitation energies of the first 2^+ for 519 e-e nuclei



SPECTROSCOPY

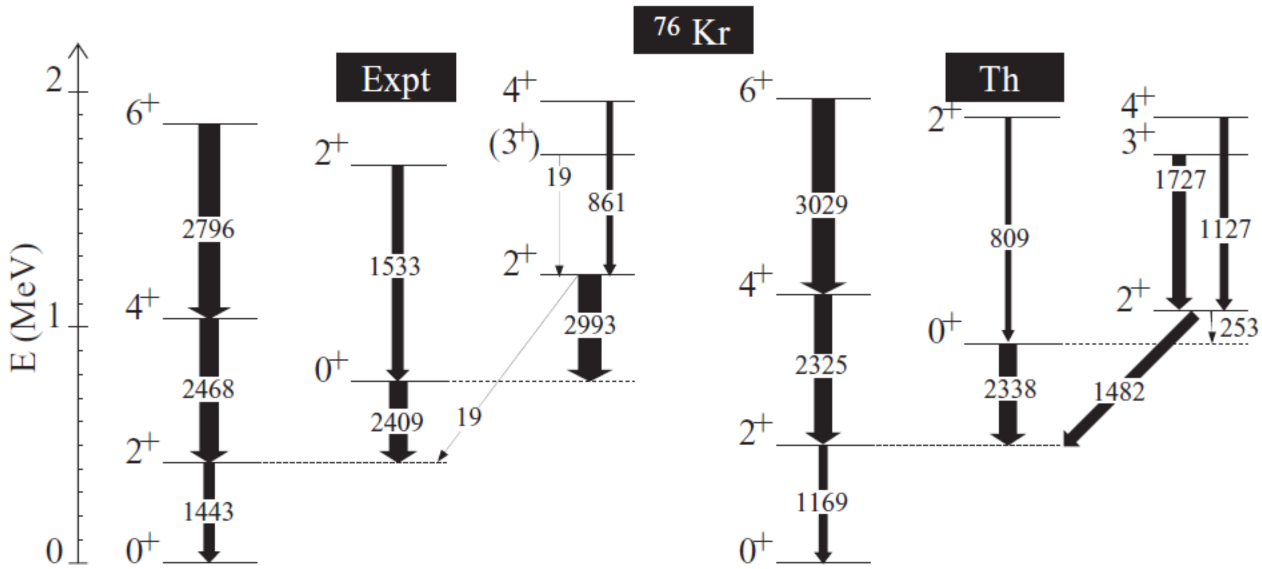


FIG. 1. Experimental and theoretical spectra (MeV) and transition strengths (e^2 fm^4) of ^{76}Kr showing the excitations that we examine in the present global study. The experimental spectrum, on the left, is from Ref. [23] as well as from data repository for the 3^+ and 4^+ members of the γ band [24]. Calculated values are those from Ref. [23].

NUCLEAR REACTION INPUTS

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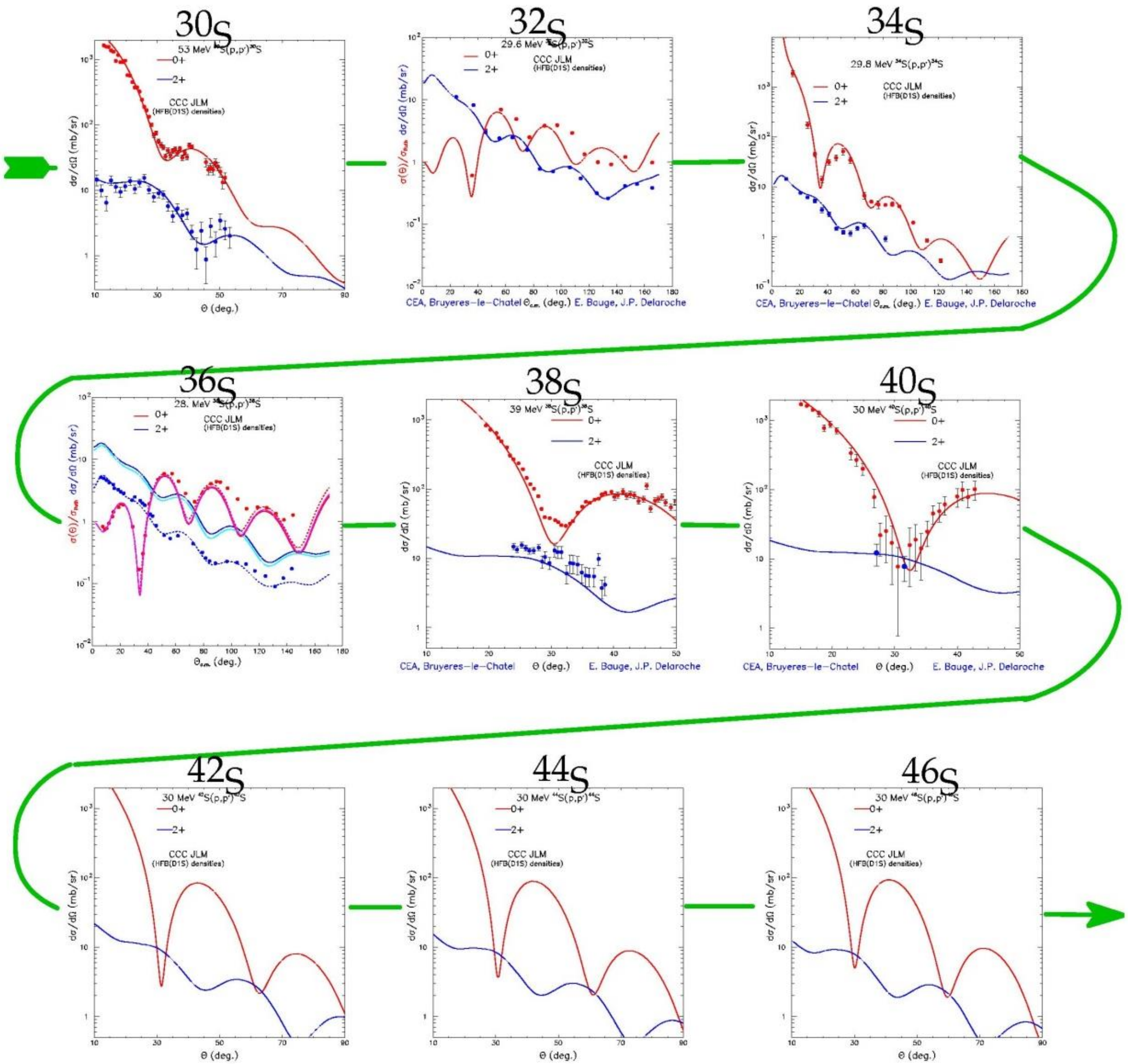
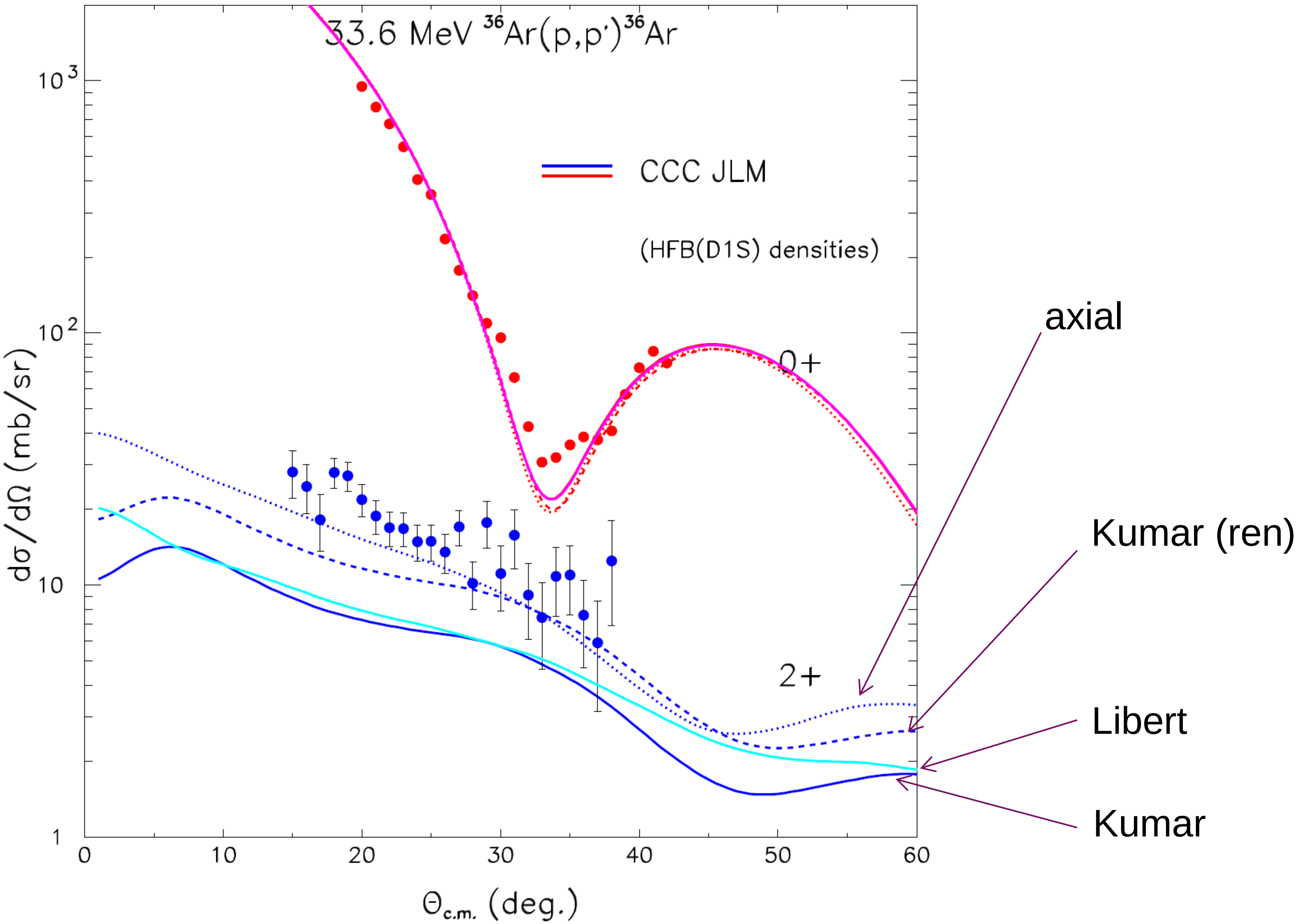
Optical model



Optical model



LEVEL DENSITIES
(The combinatorial method)

See PRC 78 (2008) 064307 and PRC 86 (2012) 064317 for details

- **TDHFB + effective nucleon-nucleon interaction**
  ⇒ temperature (energy) dependent single particle level schemes

- **Combinatorial calculation ⇒ intrinsic p-h and total state densities ω_{ph} (U, K, π)**

- **Collective effects ⇒ from state to level densities ρ(U, J, π)**

  1) folding of intrinsic states and vibrational states : $\omega = \omega_{ph} * \omega_{vib}$

  2) construction of rotational bands for deformed nuclei

$$\rho(U, J, \pi) = \sum_K \omega(U - E^{JK}_{rot}, K, \pi)$$

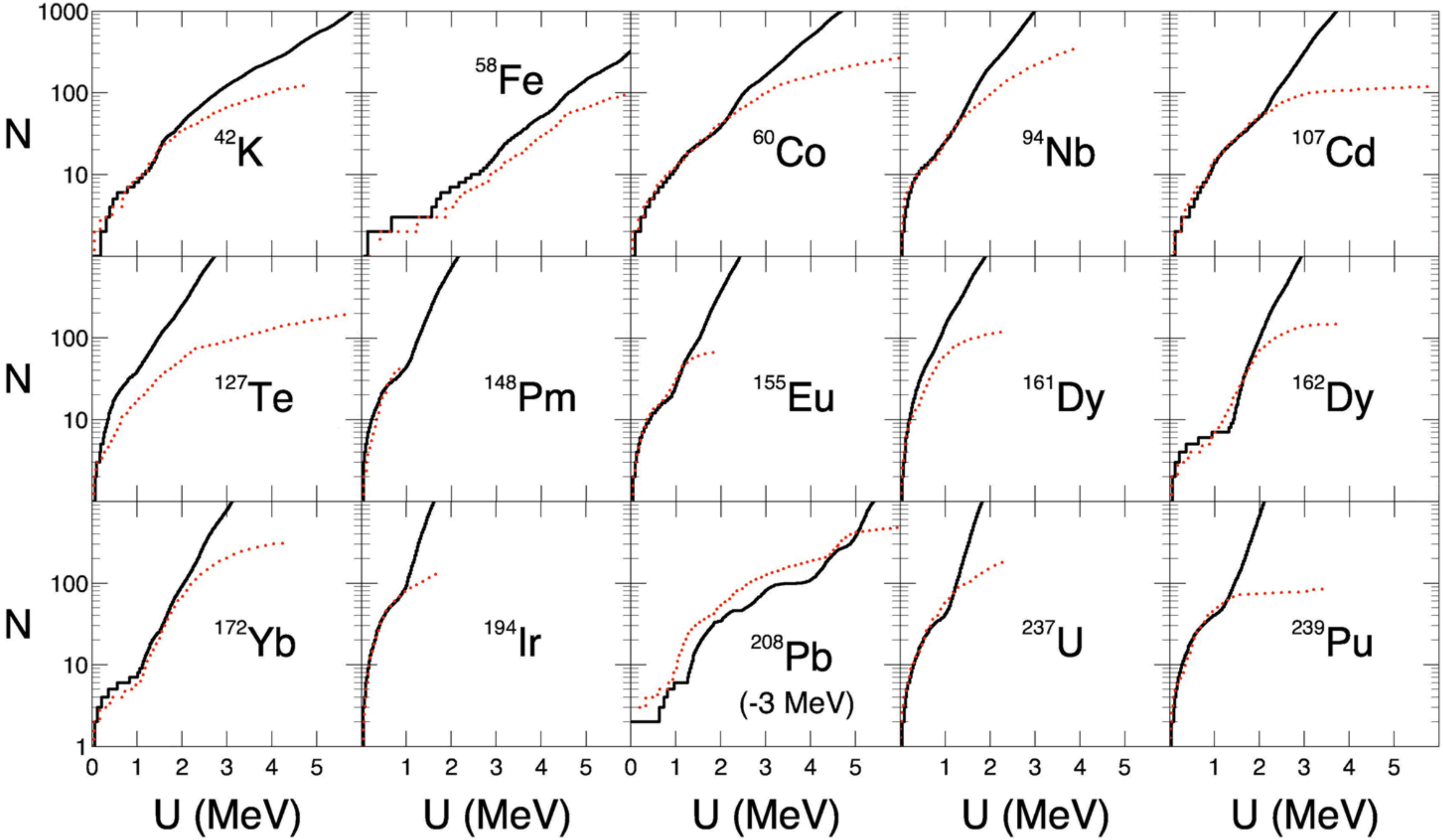
Predicted within the same theoretical framework (coherence)

trivial relation for spherical nuclei

$$\rho(U, J, \pi) = \omega(U, K=J, \pi) - \omega(U, K=J+1, \pi)$$

- **Phenomenological mixing of spherical and deformed densities for small deformations**

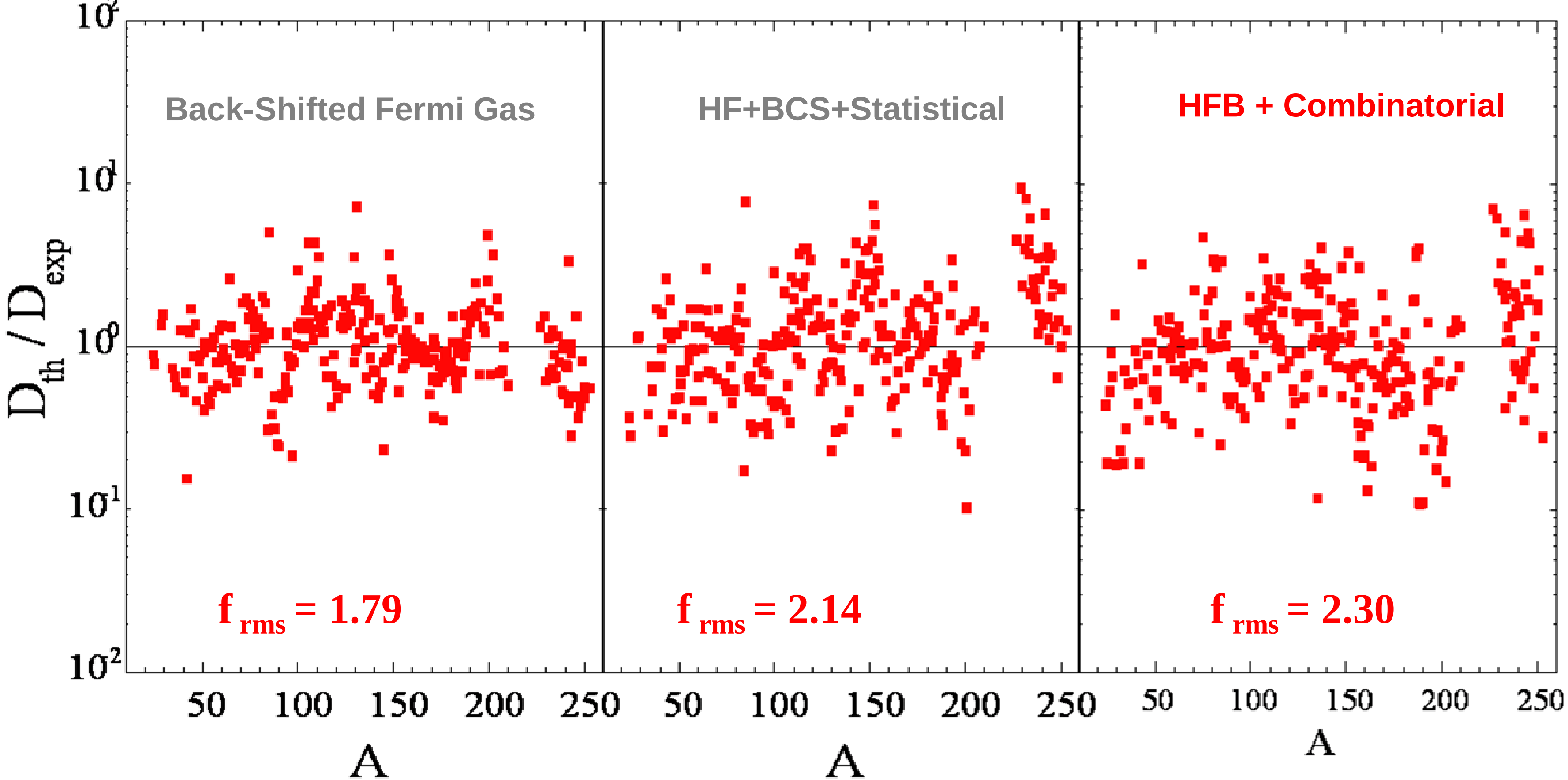
LEVEL DENSITIES
(The combinatorial method)



➡ **Structures typical of non-statistical feature**

LEVEL DENSITIES
(The combinatorial method)

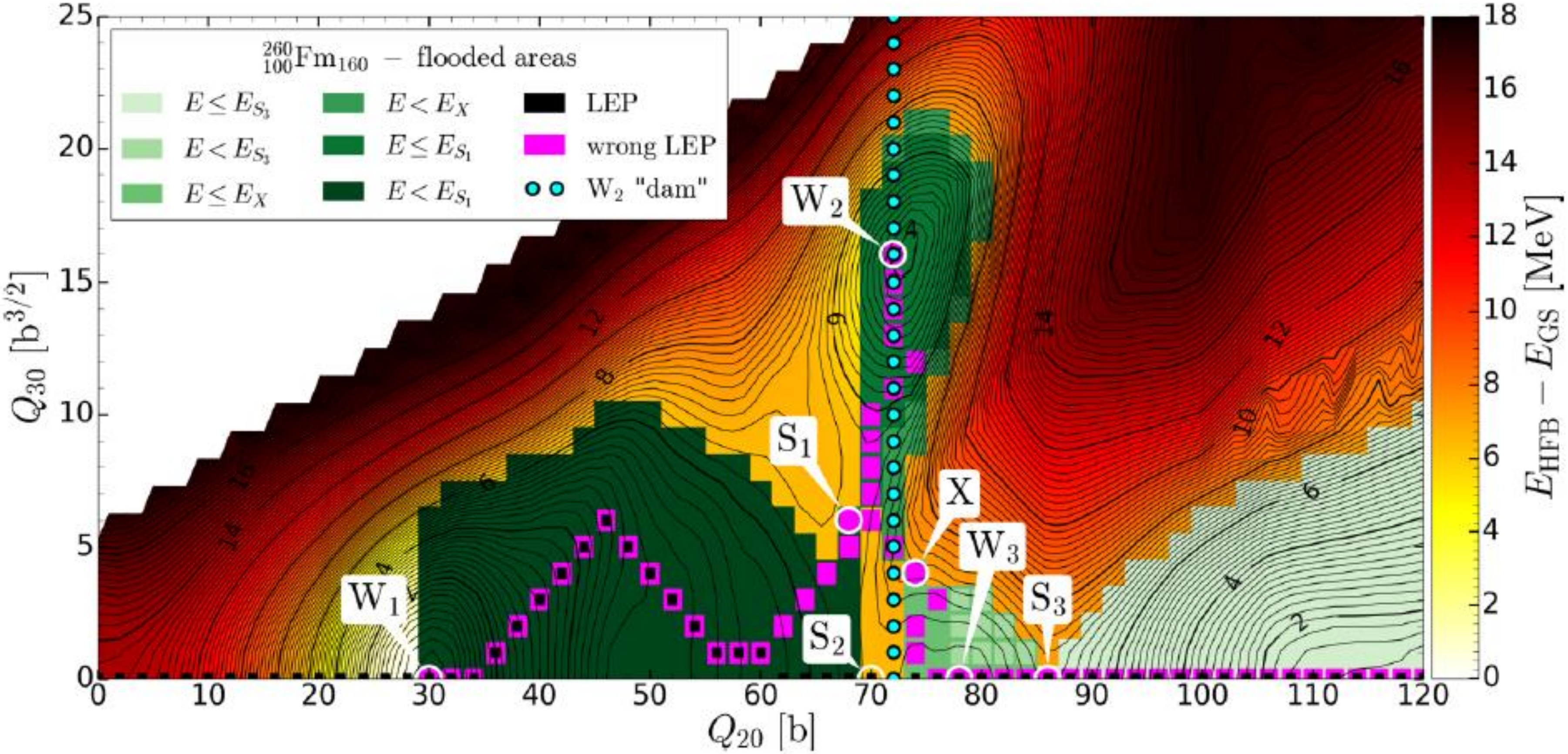
D_0 values (s-waves & p-waves)



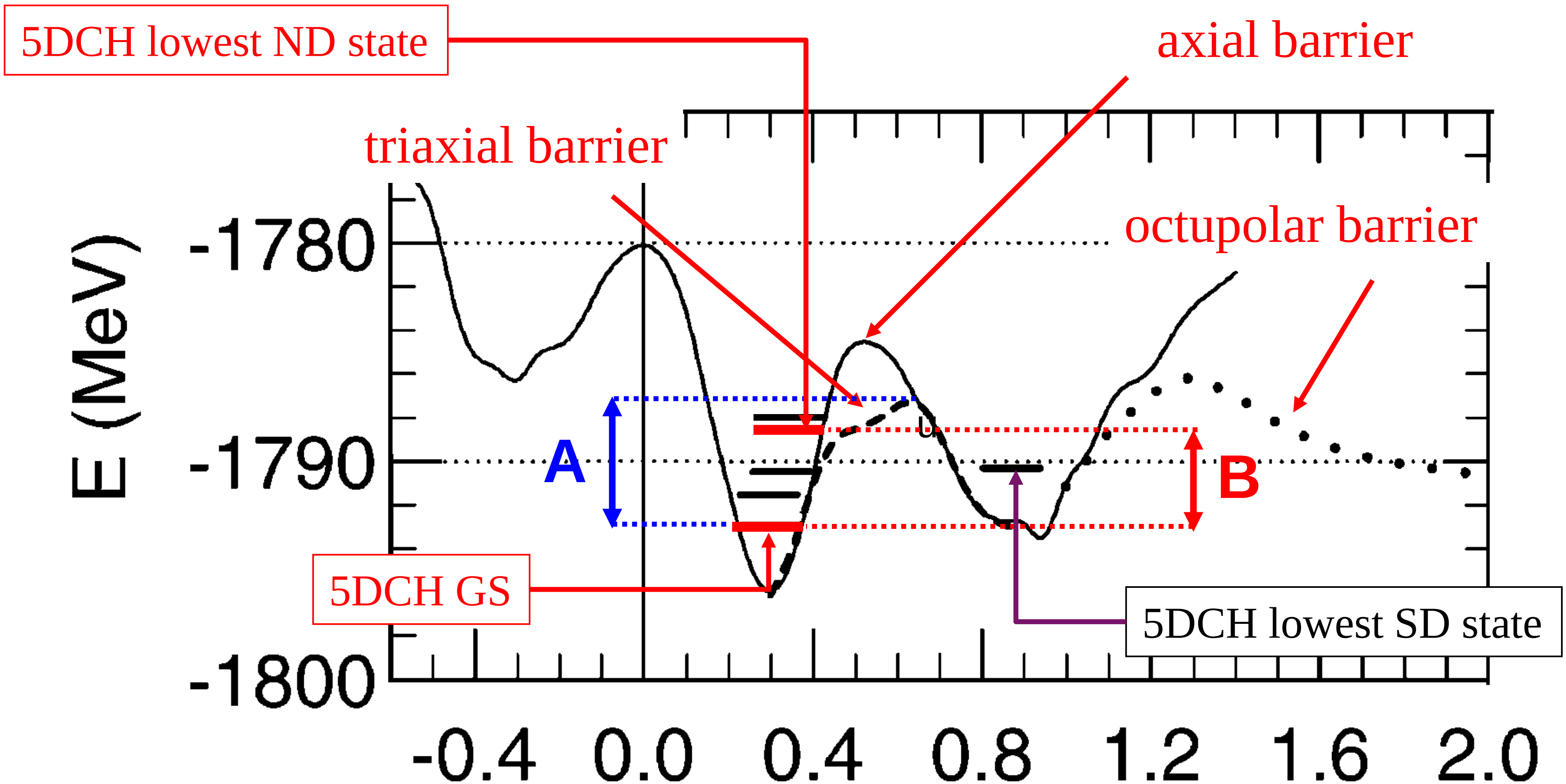
➡ **Descrip** ... **vith other**
global a

$$f_{\mathrm{rms}} = \exp\left[\frac{1}{N_e}\sum_{i=1}^{N_e}\ln^2\frac{D^i_{\mathrm{th}}}{D^i_{\mathrm{exp}}}\right]^{1/2}$$

Fission paths

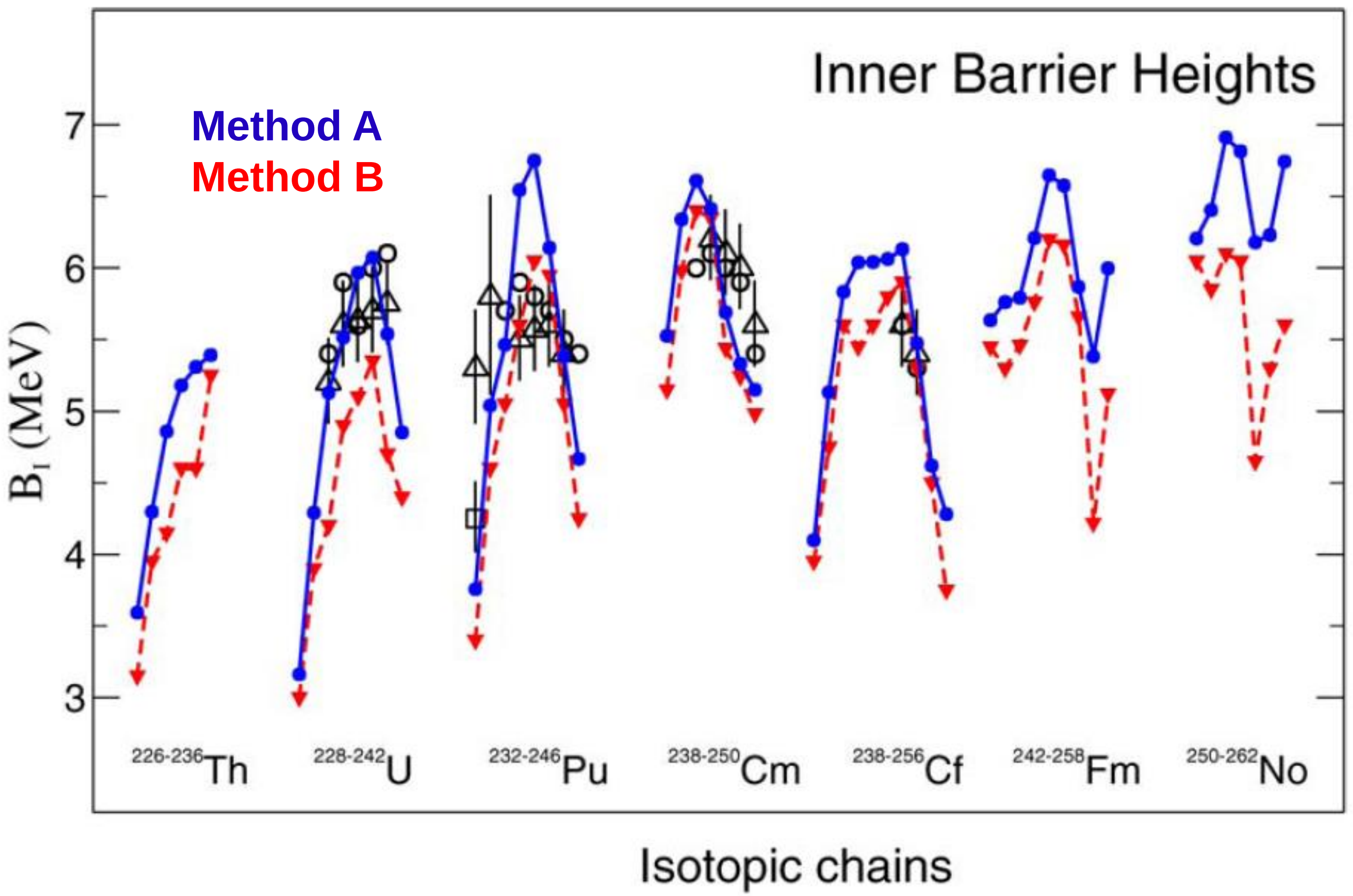


Fission barriers



Determining a fission is a complex task depending on the considered degrees of freedom

Fission barrier heights



CONCLUSIONS & PROSPECTS

5DCH powerfull approach for systematic approach : robust and fast

Provides usefull nuclear reaction input on top of pure structure data

There is a clear need to maintain the know how and even push the approach further

Perspectives :

- Develop new codes with « young » staff members
- HFB3 project started
- Update of FELIX (TDGCM+GOA into GCM+GOA) under consideration