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Microscopic description of fission properties:

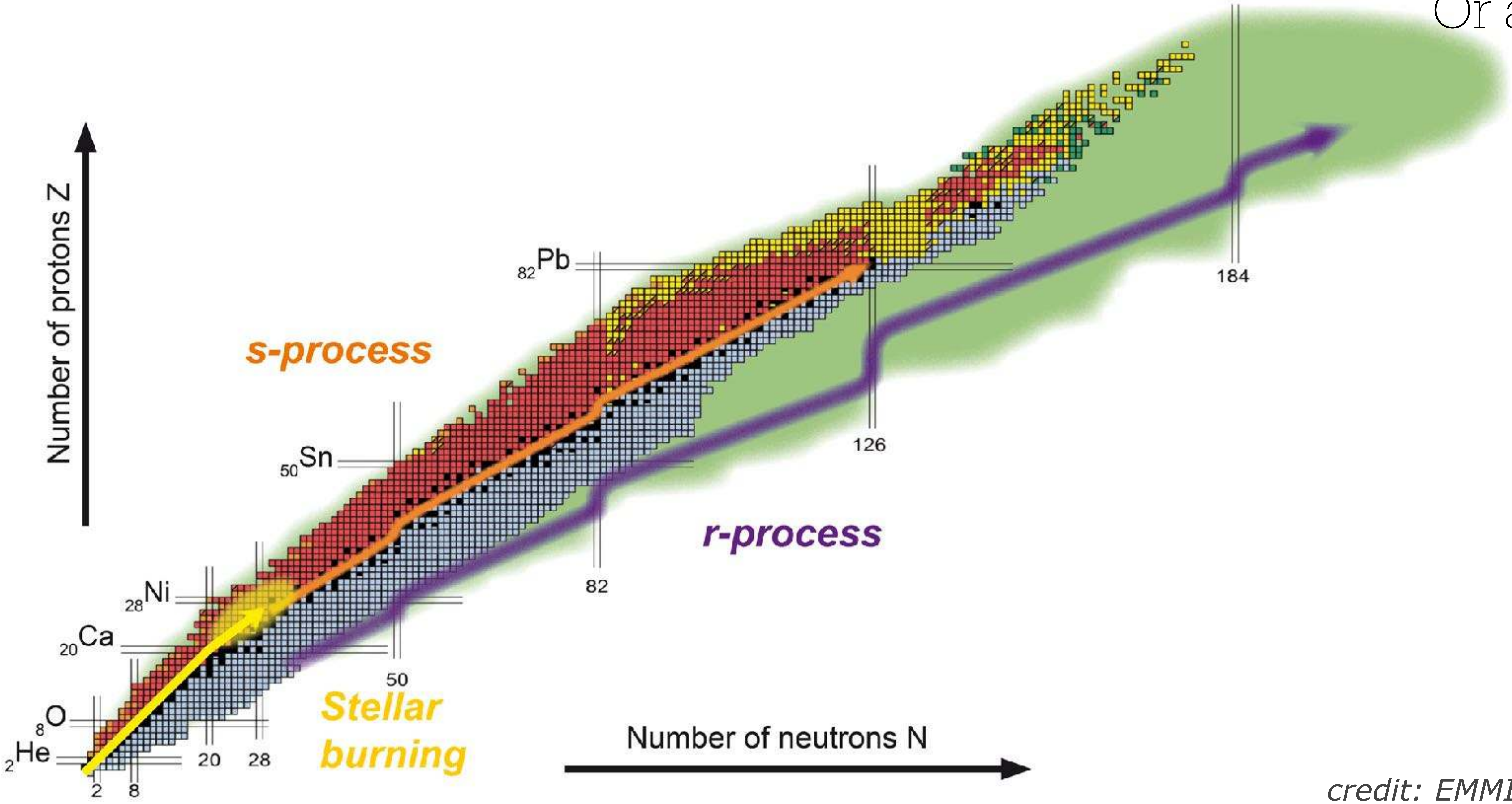
paving the way for large-scale data generation

Adrián Sánchez Fernández, Silvia Bara, Wouter Ryssens and Stéphane Goriely

Dynamics of Nuclear Fission (CEA Saclay). 19th of December, 2024.

The origin of the heaviest elements

Or at least half of them...



credit: EMMI, GSI/Different Arts

What we want

1. Mass abundances
2. Kilonovae light curves

Image credit: Dreamstime

What we need

1. Fission rates
2. Nuclear level densities
3. Fission fragments distributions

Our approach

Microscopic description of fission paths with (Skyrme) EDF

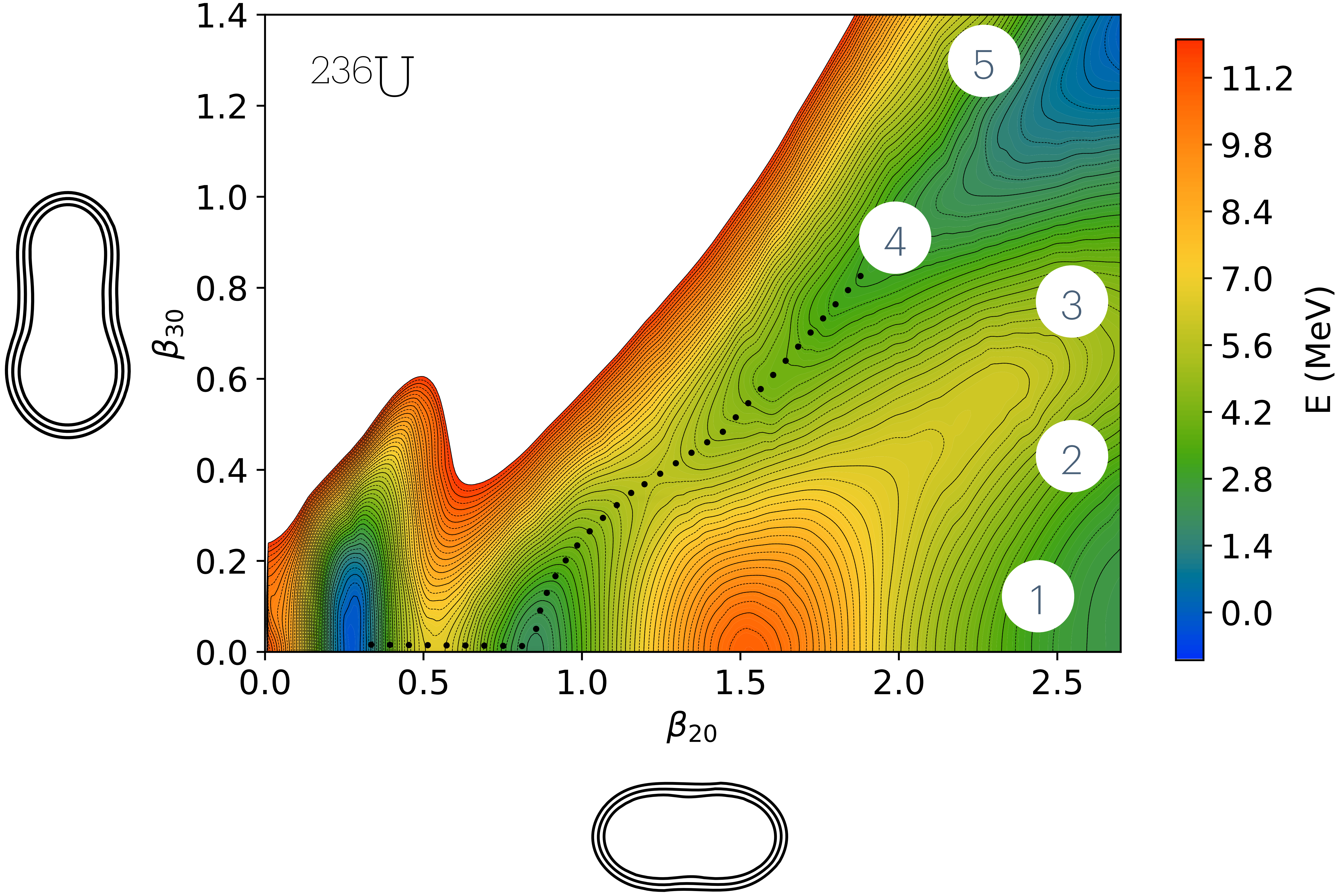
Integration MOCCa+PyNEB
(S. Bara, W. Ryssens and A. Sánchez-Fernández)

Step 1:

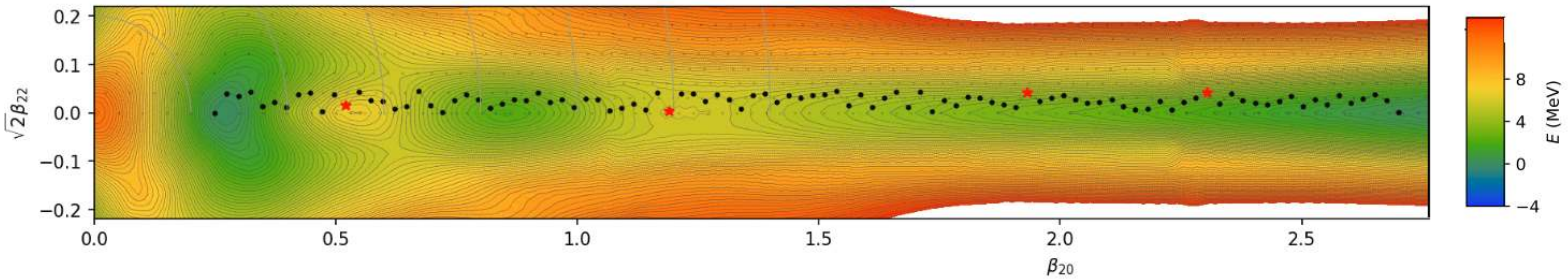
Mass symmetric or asymmetric?

Minimum energy path for different ending points

We chose the minimum action path



^{236}U (Least action* path)

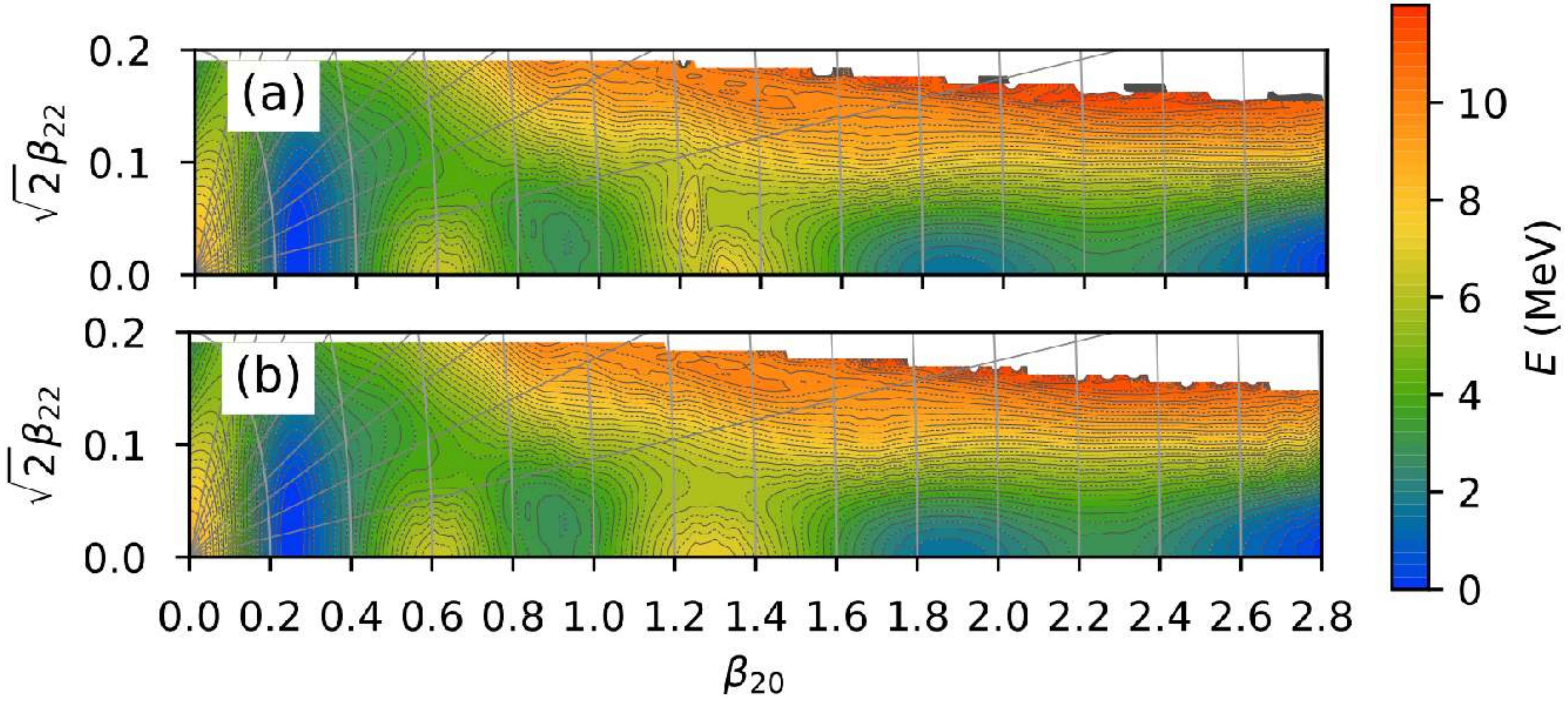


$$\mu(s) = \sum_{ij} B_{ij} \frac{dq_i}{ds} \frac{dq_j}{ds}$$

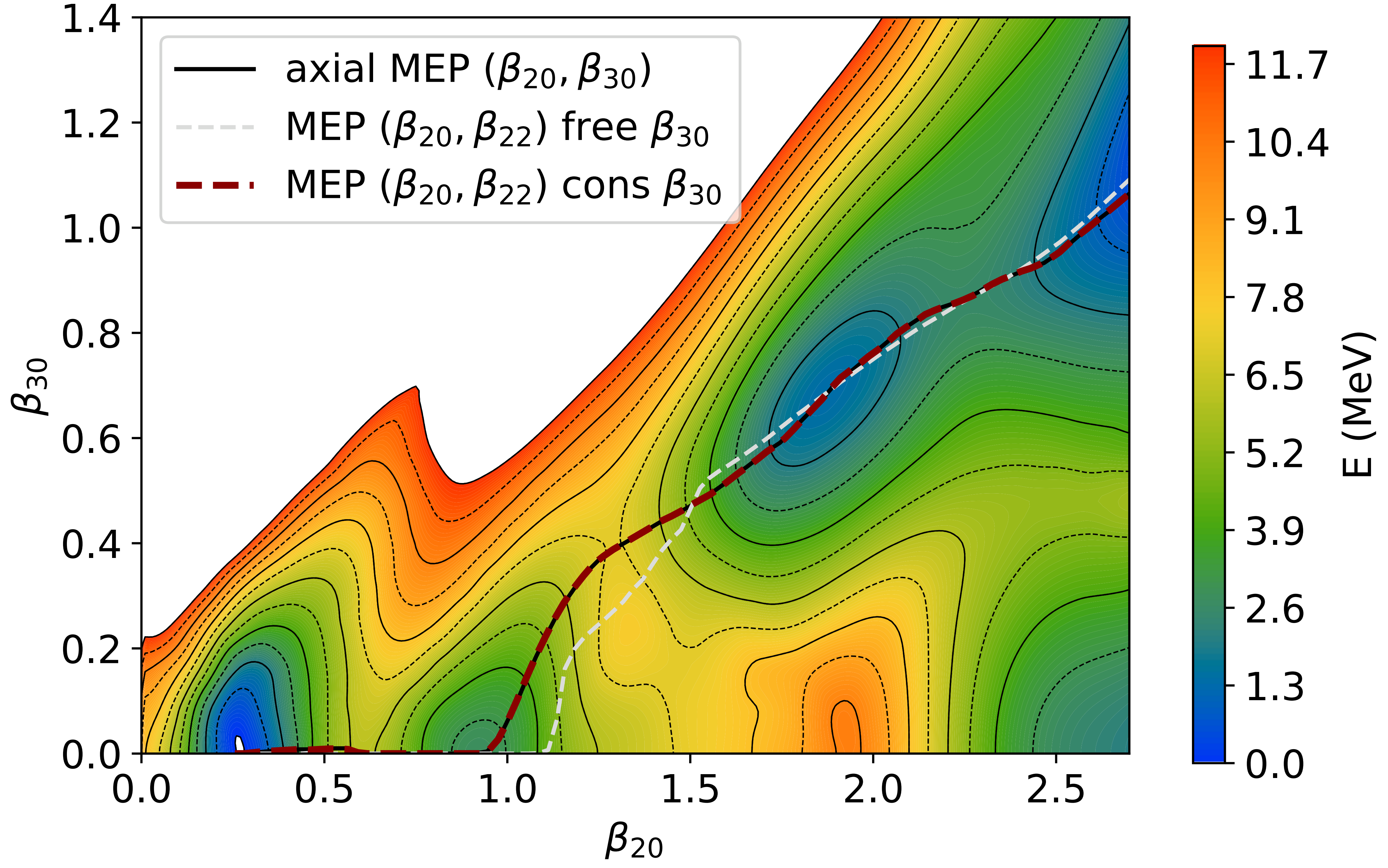
Step 2: Let us break axiality

$$^{*} \quad S = \int_{in}^{out} ds \sqrt{\mu(s)\,(V(s) - E_0)}$$

Showcase: Smoothing the ^{250}U fission PES



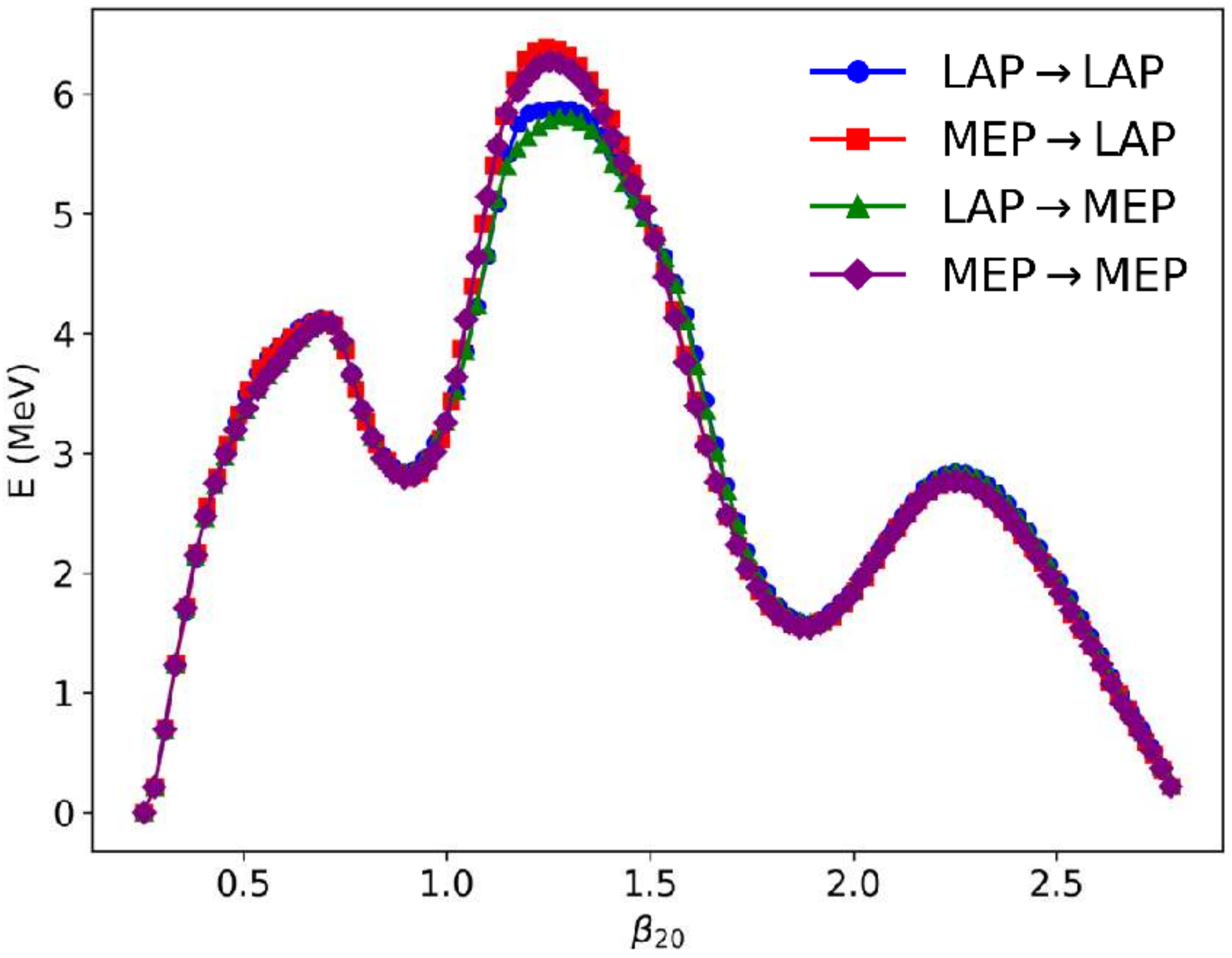
Showcase: Smoothing the ^{250}U fission PES

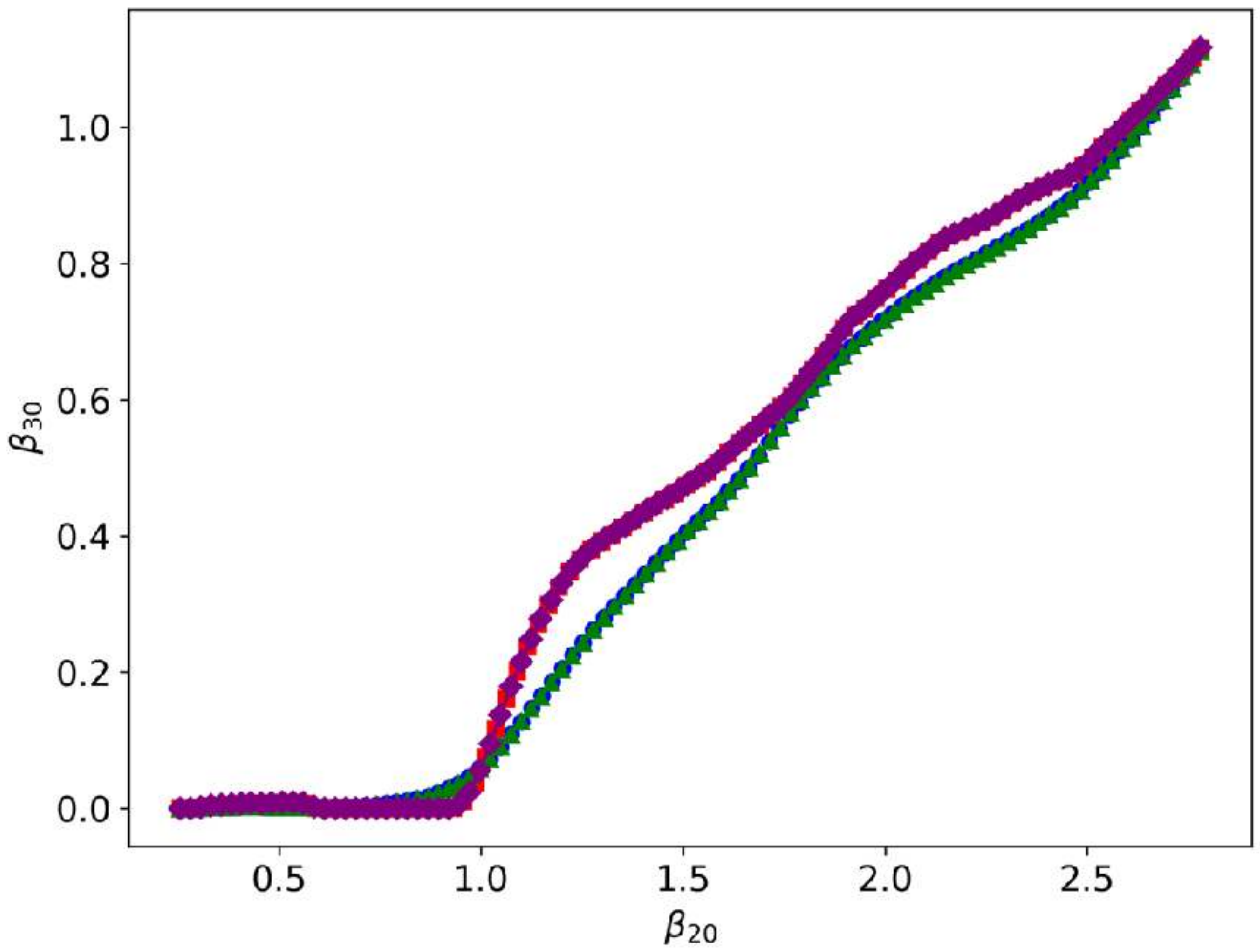


Benefits of the double-path calculation

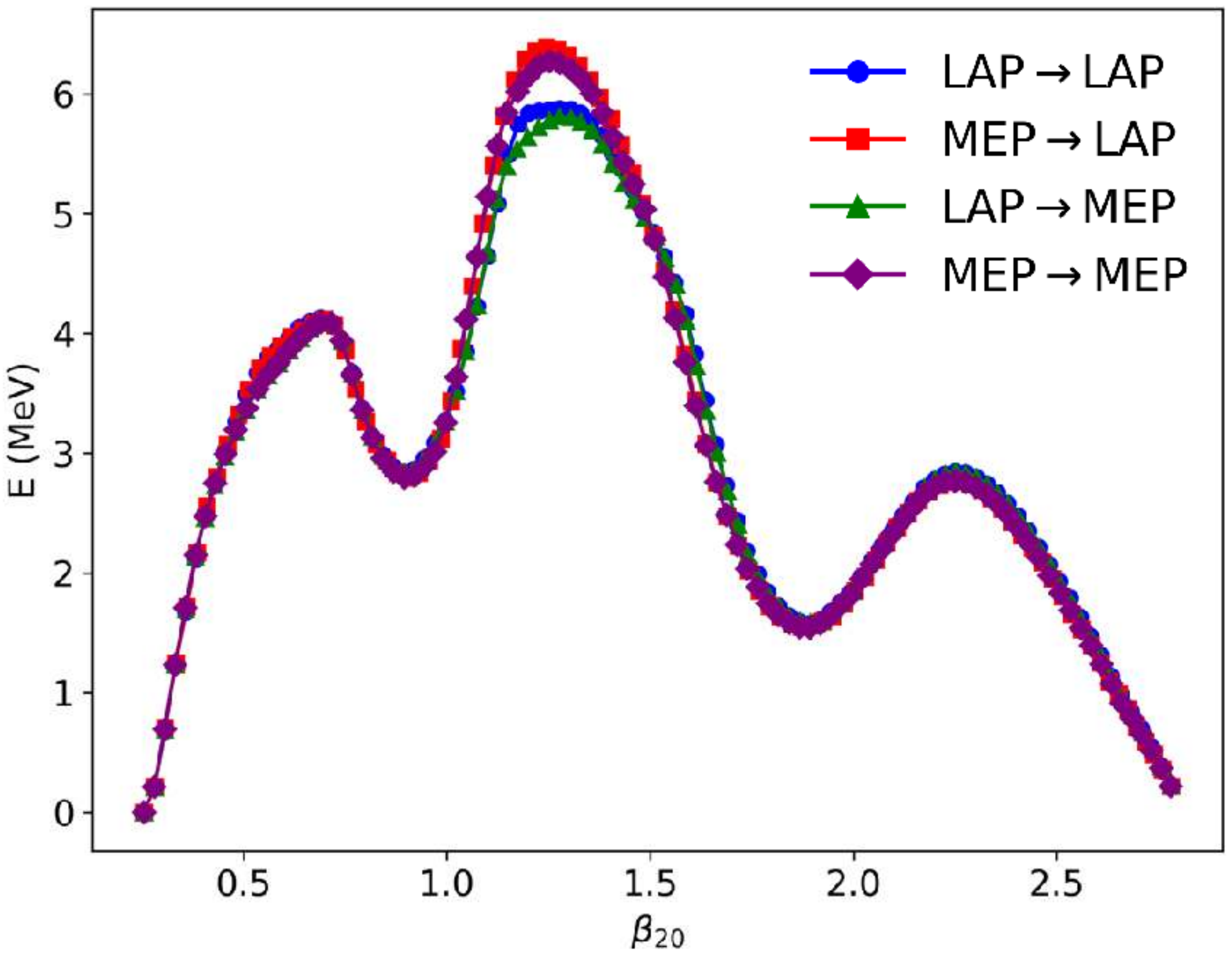
- We avoid usual discontinuities
- Identification of symmetric fission paths
- Fragment distribution analysis,

Showcase: Smoothing the ^{250}U fission PES





Showcase: Smoothing the ^{250}U fission PES



$$\Delta E_{out} \approx 0.6 \text{ MeV}$$

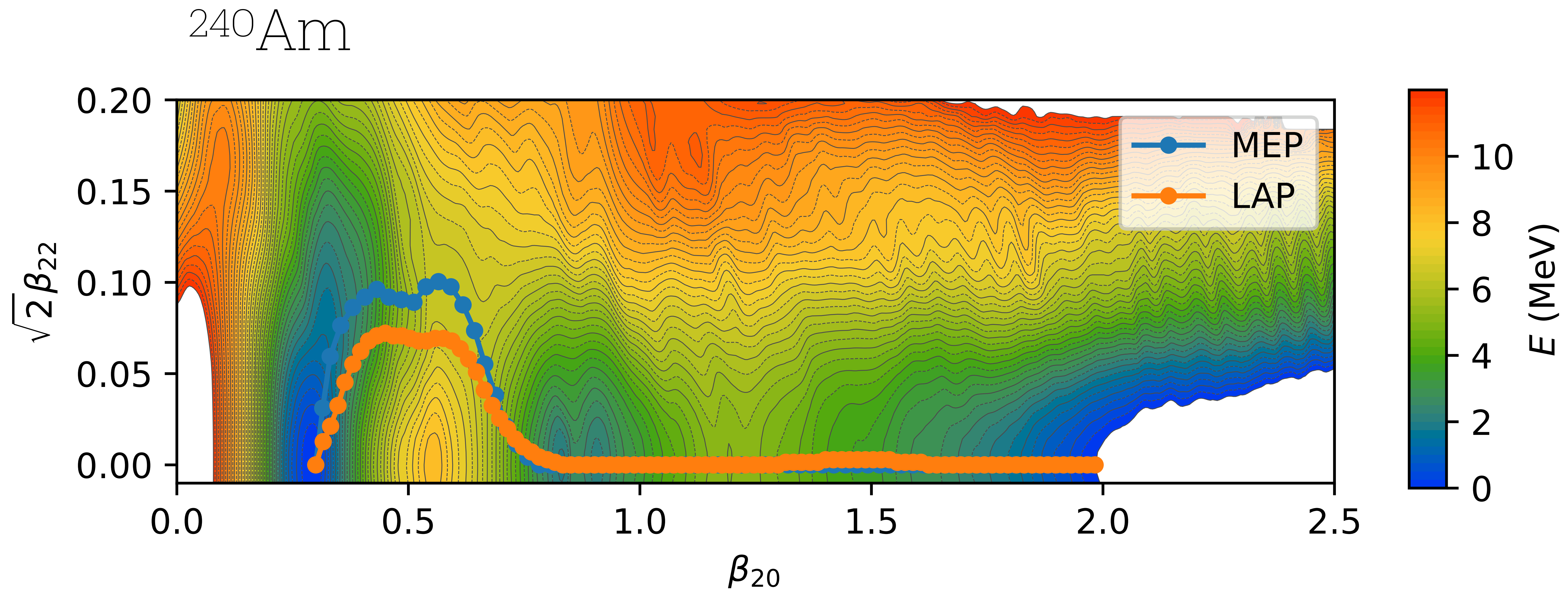
LAP->LAP:

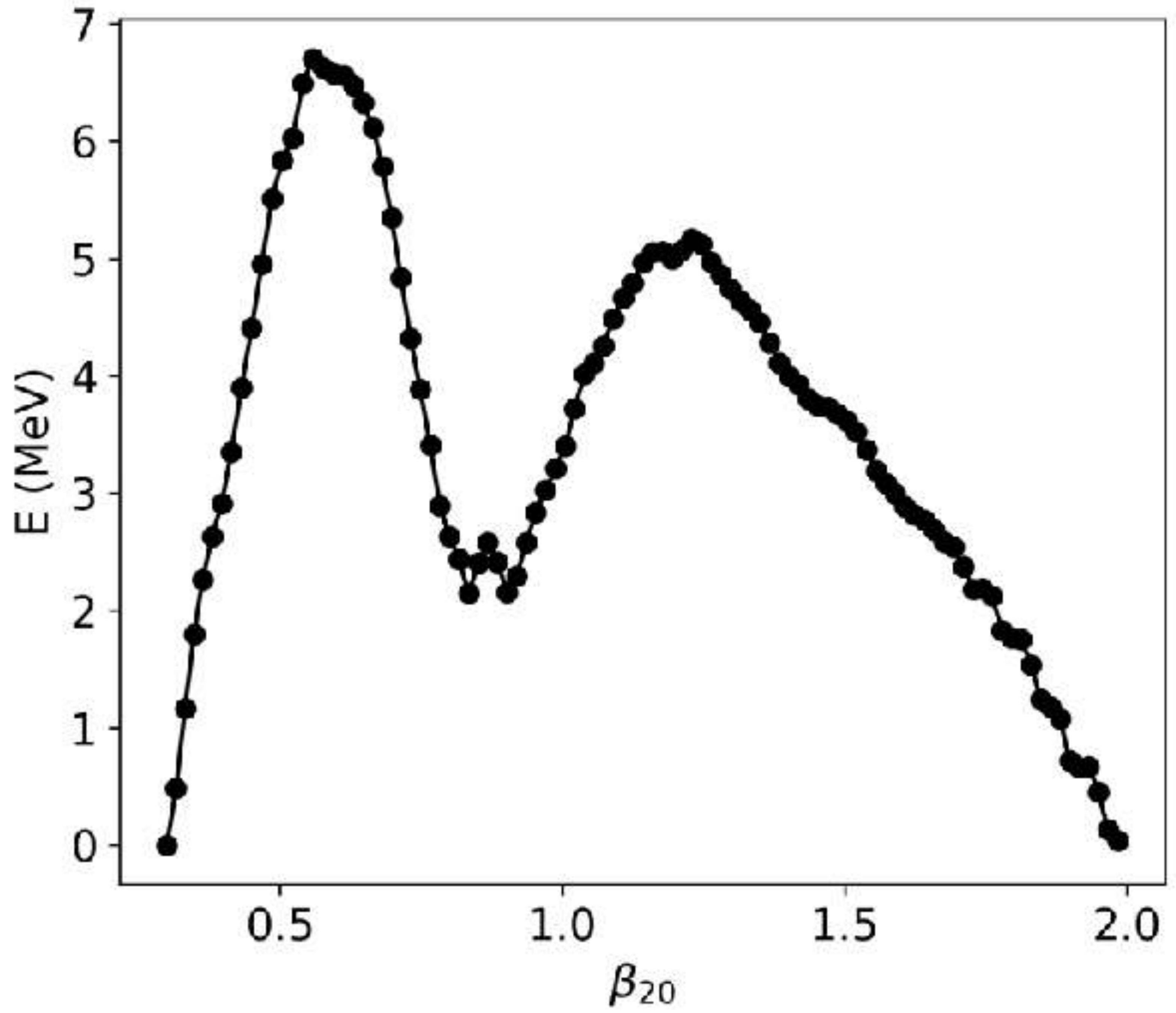
S=54,67 $\hbar$; $log[t_{1/2}^{SF}]$=26.94

MEP-> LAP

S=54,08 $\hbar$; $log[t_{1/2}^{SF}]$=26.43

The approach to odd/odd-odd nuclei

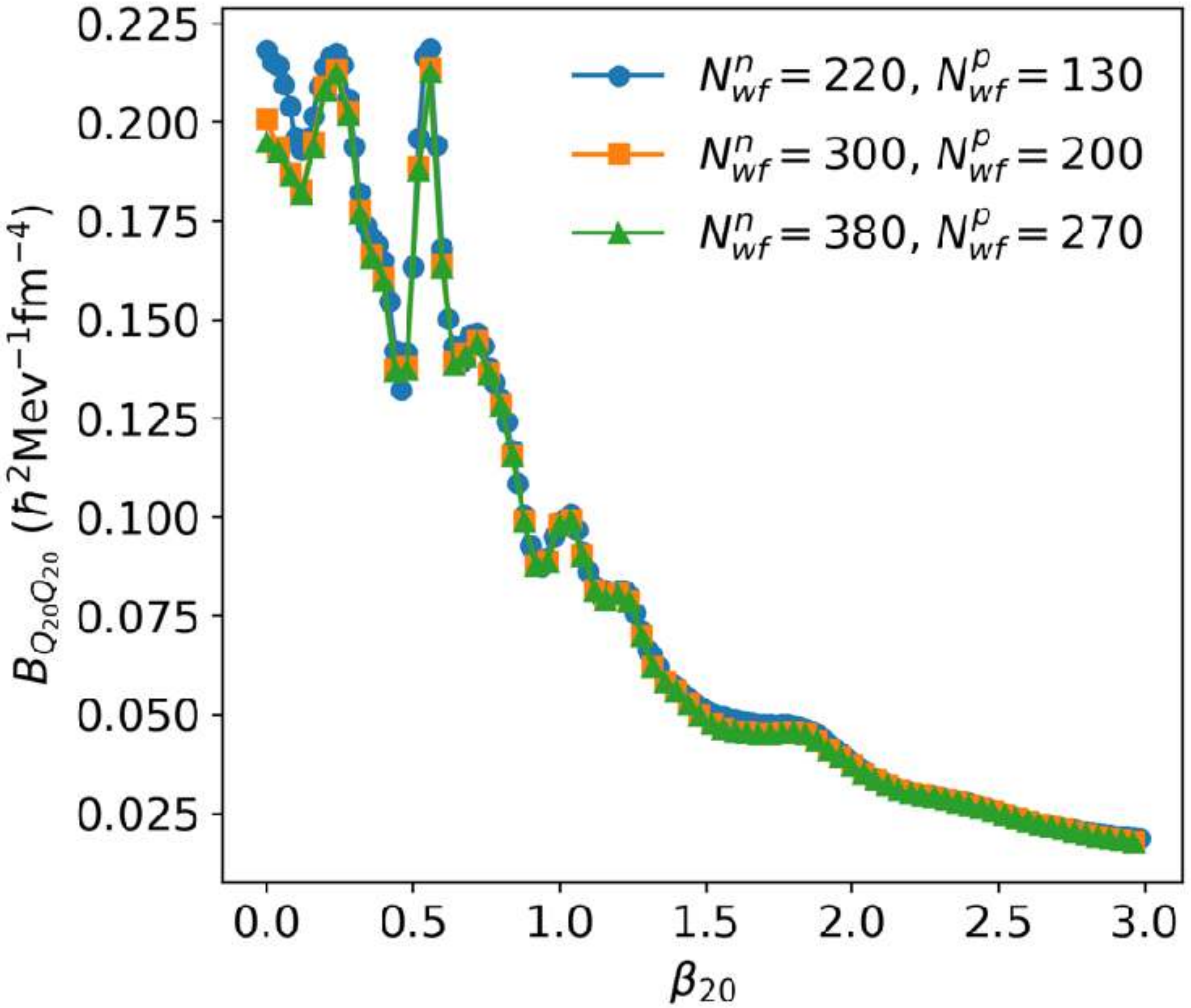


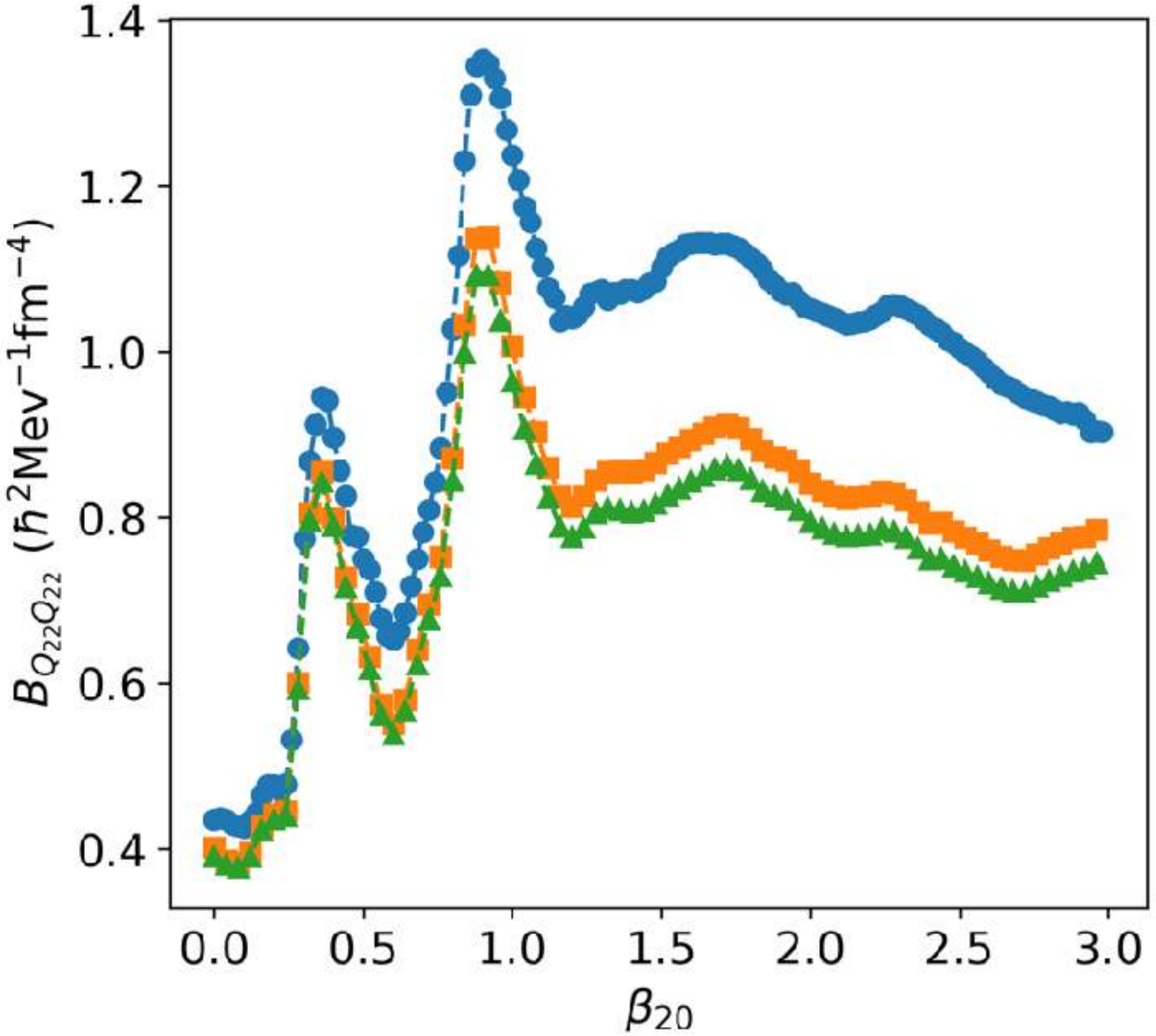


We choose the lowest energy blocked configuration

Step 2: Let us break axiality

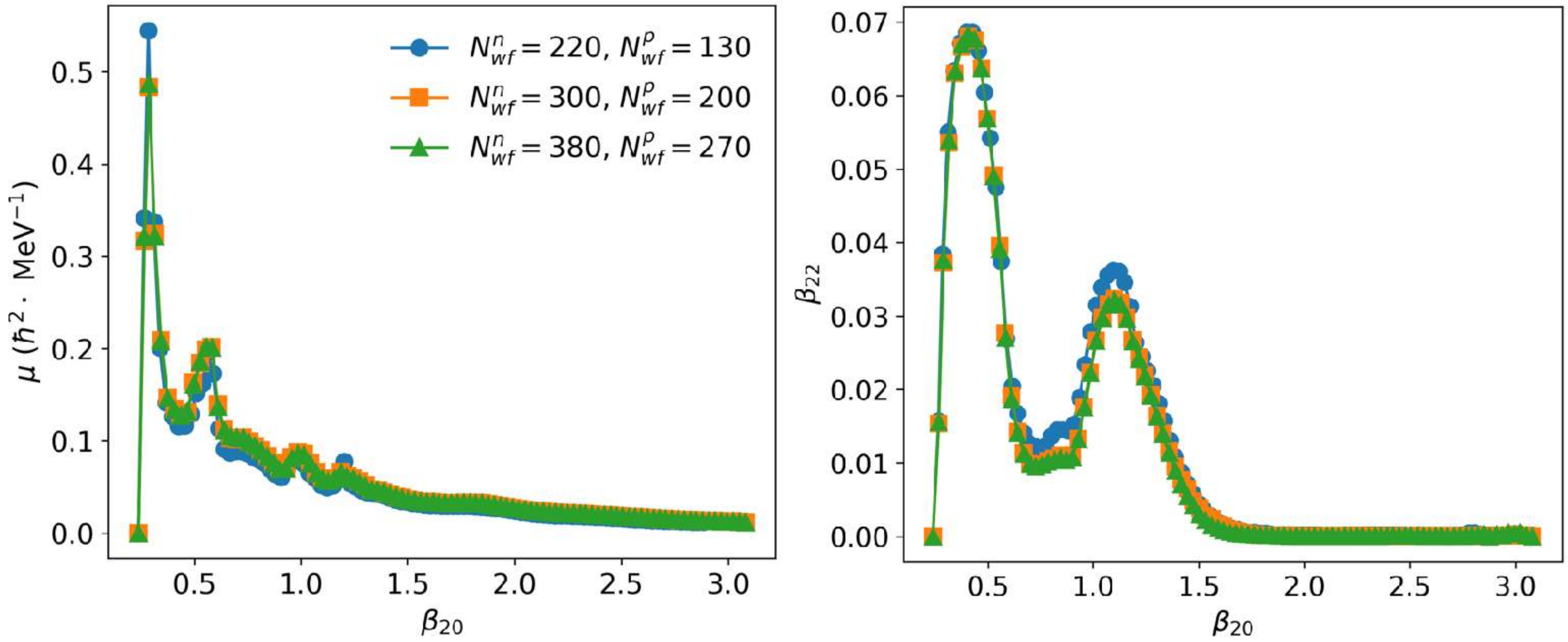
A key ingredient: the collective moments of inertia





Microscopic inertia tensor (diagonal terms) for ^{230}U

A key ingredient: the collective moments of inertia



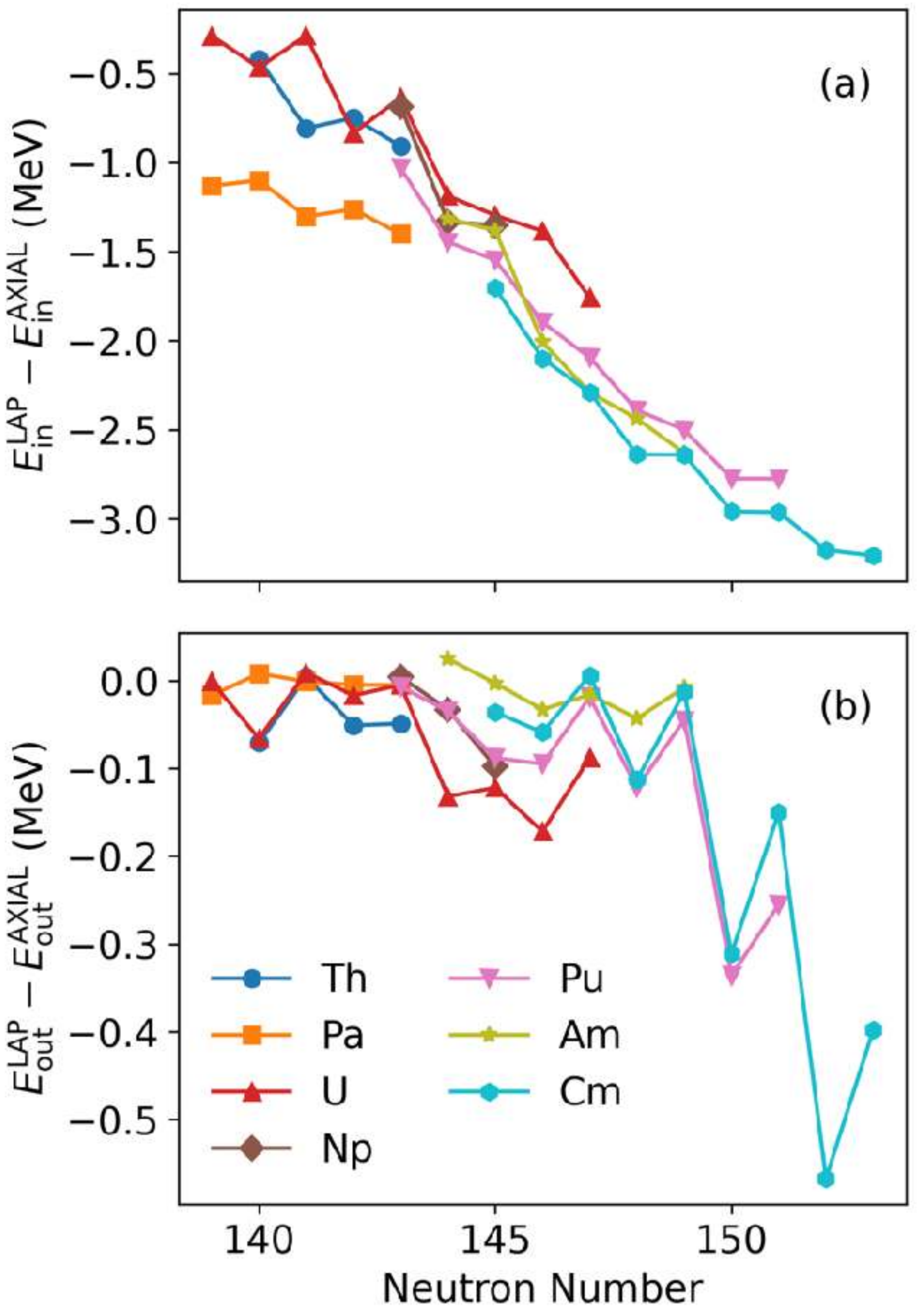
Effective inertia and triaxiality ^{230}U

What we got so far

45 reference nuclei (RIPL-3)

$\bar{\epsilon}(E)$	Inner (MeV)	Outer (MeV)
MEP	-1.70	-0.16
LAP	-1.66	-0.08

Energy mean-deviation triaxial-axial path



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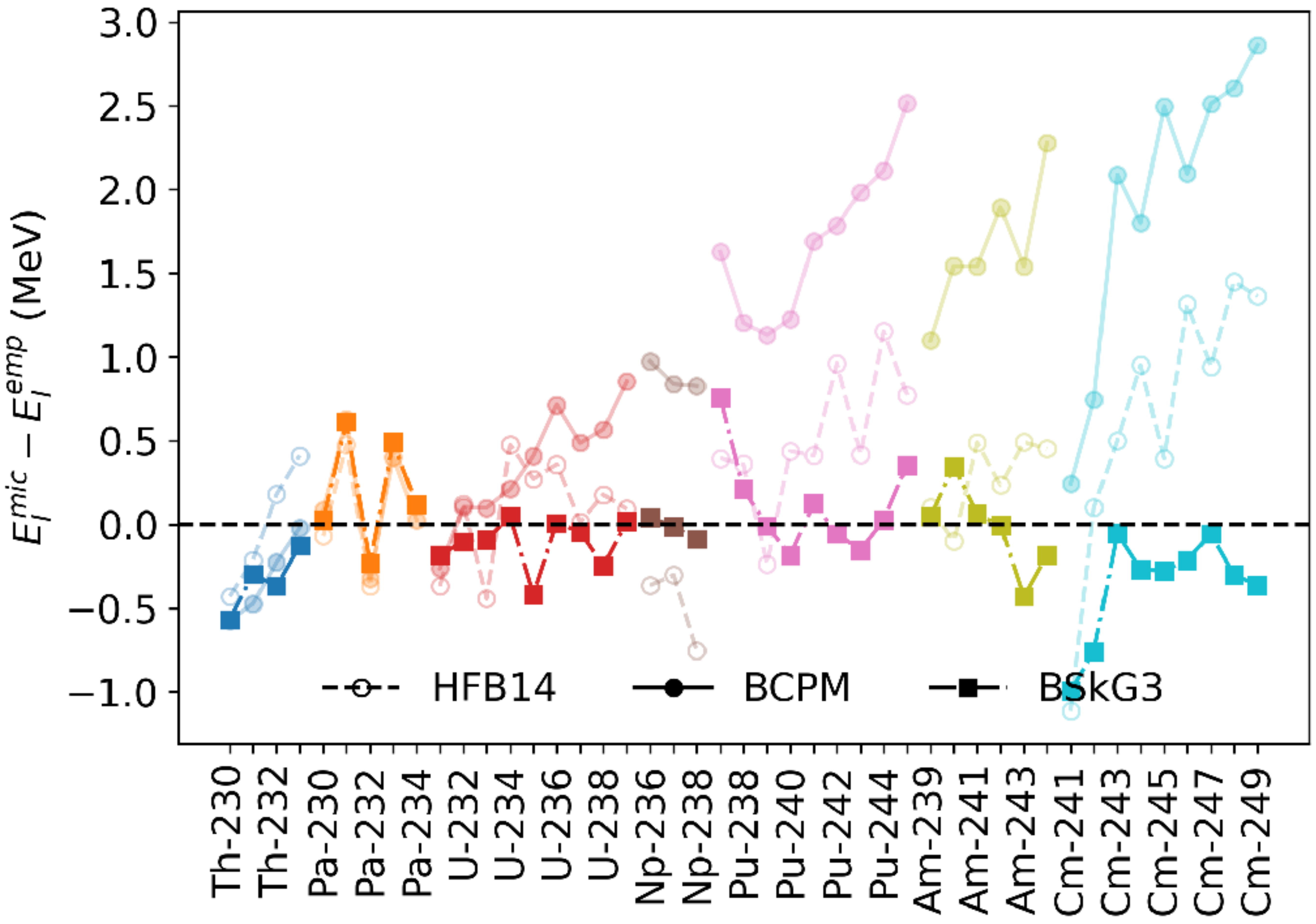
45 reference nuclei (RIPL-3)

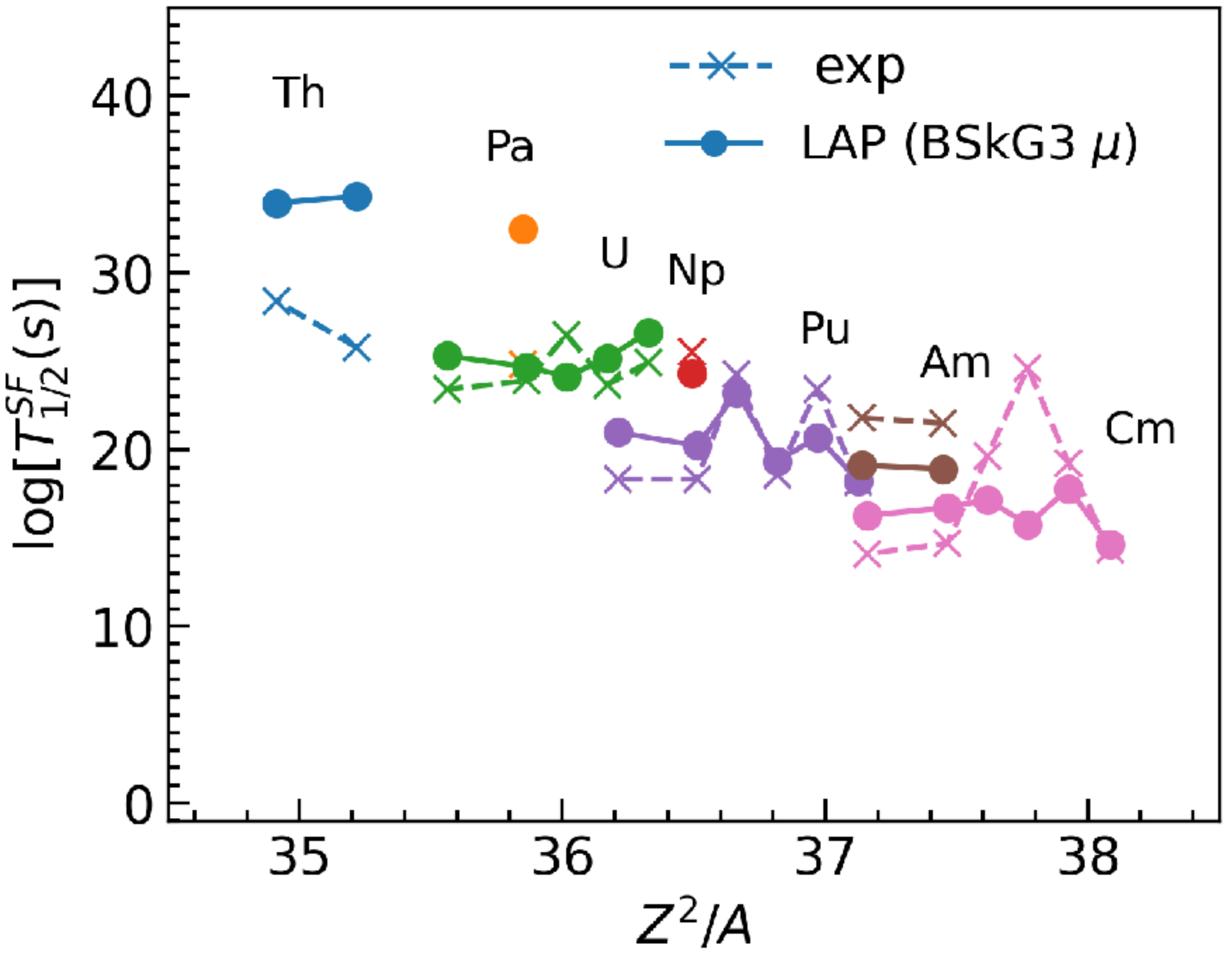
Primary barriers from MEP



	$\sigma(E_I)$
HFB14	0.601 MeV
BCPM	1.419 MeV
BSkG3	0.32 MeV

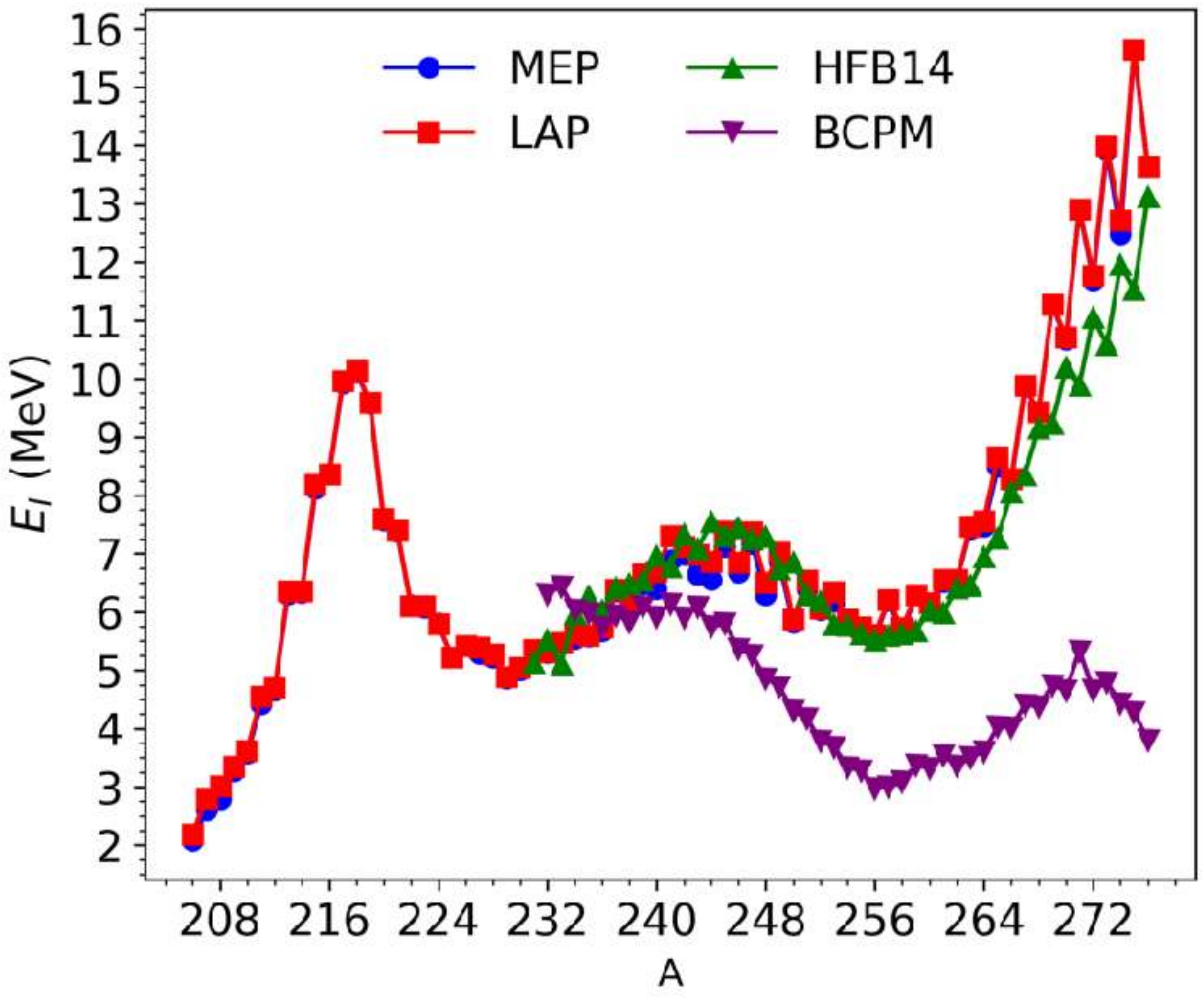
45 reference nuclei (RIPL-3)

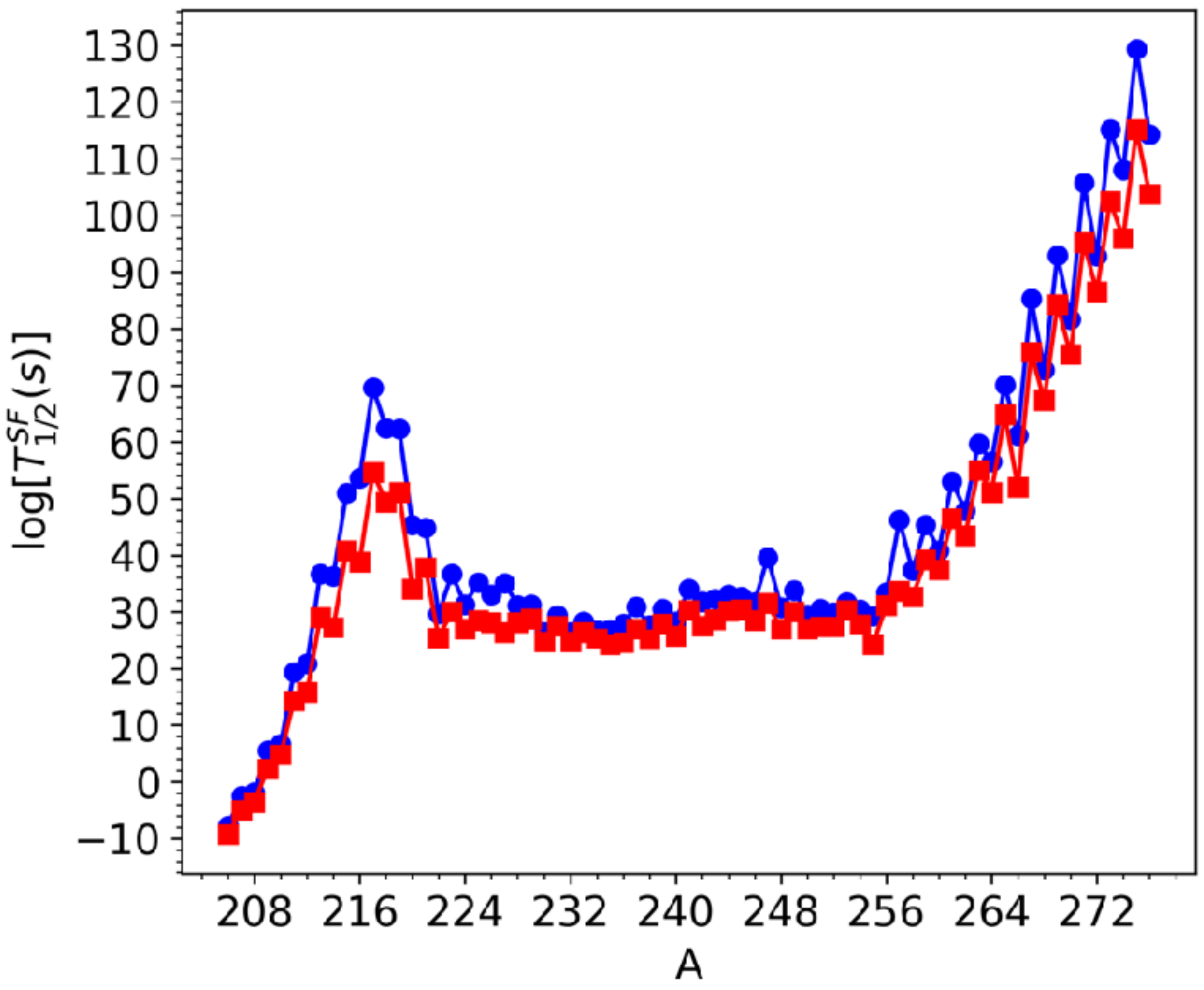
	$\bar{\epsilon}(\log[t_{1/2}^{SF}])$	$\sigma(\log[t_{1/2}^{SF}])$
MEP (μ con.)	12.33	13.42
MEP (μ mic.)	-2.78	4.44
LAP (μ mic.)	-0.53	3.66



Not-so-large scale: U-chain

Primary barrier and S.F. half-lives





Coming after Christmas

Comparison with all available experimental S.F. half-lives

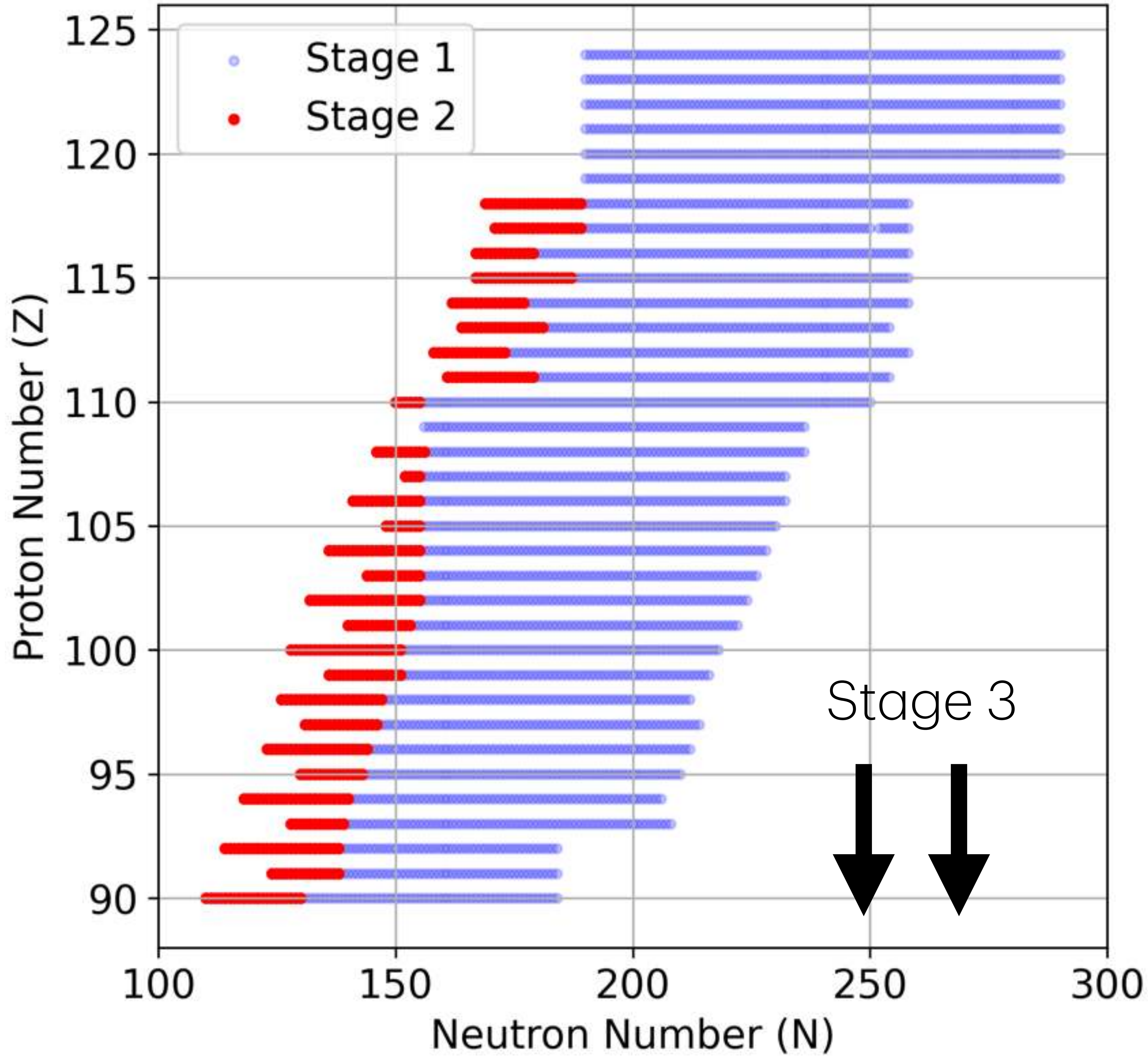
Requesting computing time in a Tier-0 cluster: the leap to the large-scale

5000 nuclei x 2 PESs = 10.000 PESs

10.000 PESs x 600 points = $6 \cdot 10^6$ points

$6 \cdot 10^6$ points x 4 h =

24 million hours of computation



Some conclusions

1. Unified microscopic framework for computing fission properties
2. Best EDF model to describe empirical fission barriers and S.F. half-lives
3. Even, odd and odd-odd nuclei "at the same price"
4. Tons of nuclei, I know… but it is feasible!
5. Results useful not only for astrophysics