

# **RIPL - Reference Input Parameter Library for Calculation of Nuclear Reactions and Nuclear Data Evaluations**

IAEA-CRP project (2017-2024)

**S. Goriely, R. Capote, ... (et al...)<sup>14</sup>**



# Reference Input Parameter Library

A major source of uncertainty in nuclear data evaluation comes from **the input parameters** needed to perform theoretical calculations



## RIPL Objective

Improve the methodology of nuclear data evaluation by increasing **predictive power, accuracy and reliability** of theoretical calculations by nuclear reaction model codes

1. **1994-1997: RIPL-1 starter file** (<http://www-nds.iaea.org/ripl/>)  
Electronic Starter File (known as Reference Input Parameter Library-1) developed and made available to users (**compilation**)

# Reference Input Parameter Library

2. **1998-2003: RIPL-2 database** (<http://www-nds.iaea.org/RIPL-2>)  
Second CRP on “Nuclear Model Parameter Testing for Nuclear Data Evaluation” Revision, extension and validation of the original RIPL-1 Starter File

## Main goals:

- Focus on Energy Applications at  $E < 20\text{MeV}$
- To **recommend** a rigorously **validated** reference library for use in nuclear reaction modeling
- To develop user-friendly retrieval **tools and interfaces** compatible with established nuclear reaction codes

Varenna (2000)



# Reference Input Parameter Library

3. **2003-2009: RIPL-3 database** (<http://www-nds.iaea.org/RIPL-3>)  
Third CRP: “Parameters for Calculation of Nuclear Reactions of Relevance to Non-Energy Nuclear Application

## Main goals:

- Extension to non-energy applications up to 200 MeV
- **Validation** of the RIPL-3 data through comprehensive calculations using major nuclear reaction codes and comparisons to experimental data.
- To estimate **uncertainties** and permissible parameter ranges.
- To develop **modular libraries** that can be interfaced with nuclear reaction codes.



# Reference Input Parameter Library

4. **2017-2024: RIPL-4 database** (<http://www-nds.iaea.org/RIPL-4>)  
Fourth CRP: “Recommended Input Parameter Library for Fission Cross Section Calculations”

## Main goals:

- to establish a comprehensive set of input parameters, including uncertainty estimates, for modeling **fission** cross sections using both phenomenological and microscopic approaches.
- Target photon- and nucleon-induced reactions on actinides at incident energies below 30 MeV.
- To **update all segments** of the RIPL database.





## Archive

[RIPL-1](#)  
[RIPL-2](#)

## Related Links

[Nuclear Data Services](#)  
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## Reference Input Parameter Library **RIPL-4**

<https://www-nds.iaea.org/RIPL-4><https://github.com/IAEA-NDS/RIPL-4>[Introduction](#)[MASSES](#)[LEVELS](#)[RESONANCES](#)[OPTICAL](#)[DENSITIES](#)[GAMMA](#)[FISSION](#)[CODES](#)[Contacts](#)

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### 7 different “segments”:

- Masses
- Levels
- Resonance parameters
- Optical model potentials
- Nuclear level densities
- Gamma-ray strength functions
- Fission

Website and Github not yet available...

Paper to be submitted to EPJA in April 2026



Archive

RIPL-1  
RIPL-2

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<https://github.com/IAEA-NDS/RIPL-4>

Introduction **MASSES** LEVELS RESONANCES OPTICAL DENSITIES GAMMA FISSION CODES Contacts

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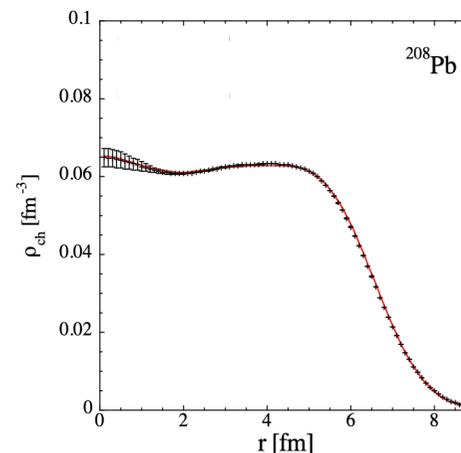
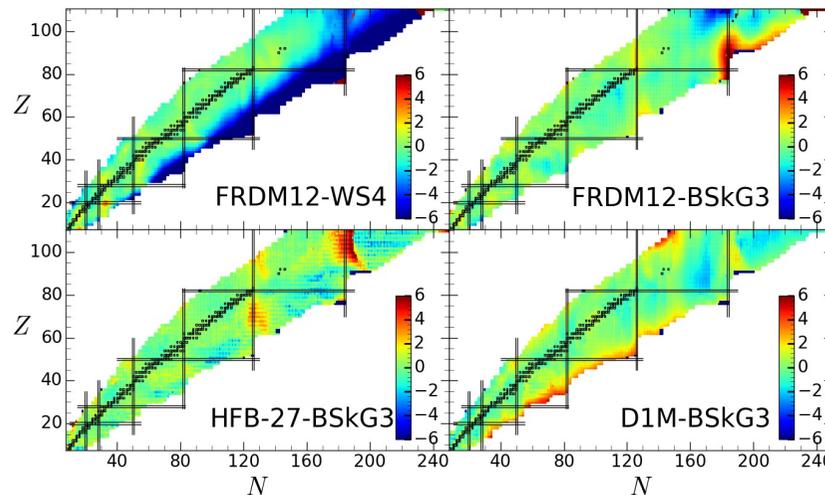
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### Segment 1: MASSES - Ground state properties

Ground-state properties:

- Atomic Mass Evaluation 2020 (2026 ?)
- Mass models ( $\sigma_{rms} < 0.8\text{MeV}$ )
  - Macroscopic-microscopic: FRDM, WS4
  - HFB mass models: HFB-27, BSkG3, D1M
- Nucleon densities (deformed): BSkG3, D1M





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### Segment 2: **LEVELS**

Discrete Level Scheme including  $J$ ,  $\pi$ ,  $\gamma$ -transition and branching for 118 isotopic chains:

- Essentially ENSDF (2022) levels and  $\gamma$ -ray scheme
- Absolute assignment (+ $X$ , + $Y$ ) when possible from NUBASE 2020 information
- Missing spins inferred uniquely for each level from spin distributions extracted from the existing data. Electromagnetic decay probabilities estimated accordingly.
- Estimate of the energy at which the level scheme is complete as in RIPL-3 (Cst-T NLD)

Updated by the IAEA every ~ 4y with NUBASE release

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### Segment 3: **RESONANCE PARAMETERS**

- average spacing of resonances  $\rightarrow$  NLD at  $U=S_n$
- neutron strength function  $\rightarrow$  OMP at low energy
- average radiative width  $\rightarrow$  Photon strength function

No major update with respect to RIPL-3

But

inclusion of BNL compilation published in 2018

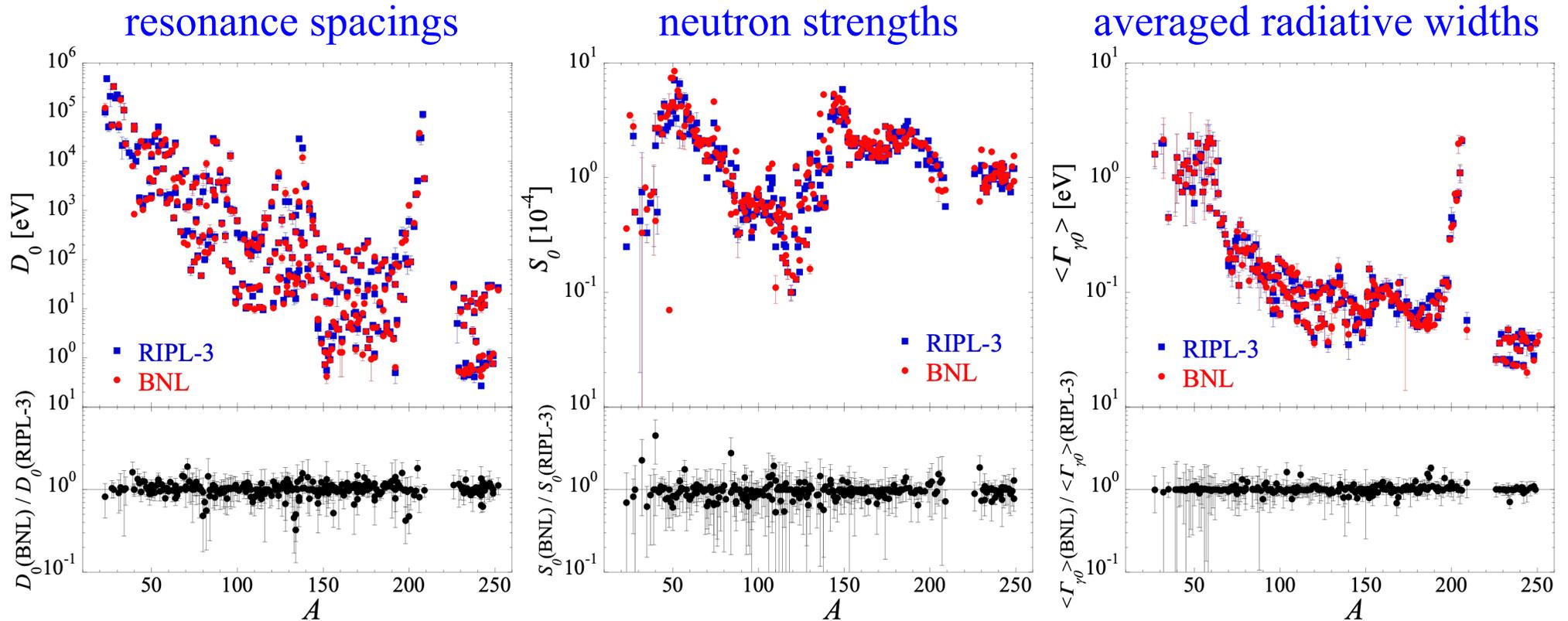
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# S-wave resonance parameters (~326 nuclei)



Good global agreement between both RIPL-3 & BNL, despite deviations by  $\sim 2$

Similar conclusions for p-wave resonance parameters ( $\sim 248$  nuclei)

Expected update coming soon with the IAEA-CRP on NLDs (2025-2028)



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### Segment 4: **OPTICAL MODEL POTENTIAL**

Grand total of 587 (494 in RIPL-3) well-documented, reproducible, and validated parameterizations for the OMPs used in calculations of nuclear data for applications

- 349 for incident **neutrons**
- 132 for incident **protons**
- 13 for incident **deuterons**
- 2 for incident **tritons**
- 3 for incident  **$^3\text{He}$  particles**
- 88 for incident **alpha particles**.

including many more **coupled-channel and dispersive OMPs**



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### Segment 4: OPTICAL MODEL POTENTIAL

Extension of RIPL-3 library of OMP, including in particular

- CC-OMP from Kunieda et al. (2007): 1keV-200MeV  $50 \leq A \leq 240$
- Rigid and soft rotor OMP for actinides: Martyanov et al. (2025); Sukhovitski et al. (2020)
- High-energy n/p OMP  $E < 3$  GeV  $A > 200$ : Yavshits et al. (2012)
- n-OMP: Whitehead et al. (2021) and Pruitt et al. (2023)
- d-OMP: JENDL/DEU (2020)
- t-,  $^3\text{He}$ -OMP: Xu et al. (2011, 2015)
- $\alpha$ -OMP: Su et al. (2015); Avrigeanu et al. (2014); Mohr et al. (2021)

including uncertainty quantification when available.



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### Segment 5: NUCLEAR LEVEL DENSITIES

- **Phenomenological (Fermi Gas type) approach: no major update**
  - EMPIRE: Composite GC Collective + EGSM Model
  - CCONE: Composite GC Model (Furutachi et al. 2019)
  - TALYS: Composite GC & BSFG (Koning et al. 2008)
- **Mean-Field + Combinatorial approach**
  - BSk14 + Combinatorial (Goriely et al. 2008)
  - D1M + Combinatorial (Hilaire et al. 2012)
  - BSkG3 + Combinatorial (Goriely et al. 2026)
  - QRPA+Boson Expansion (Hilaire et al. 2023)

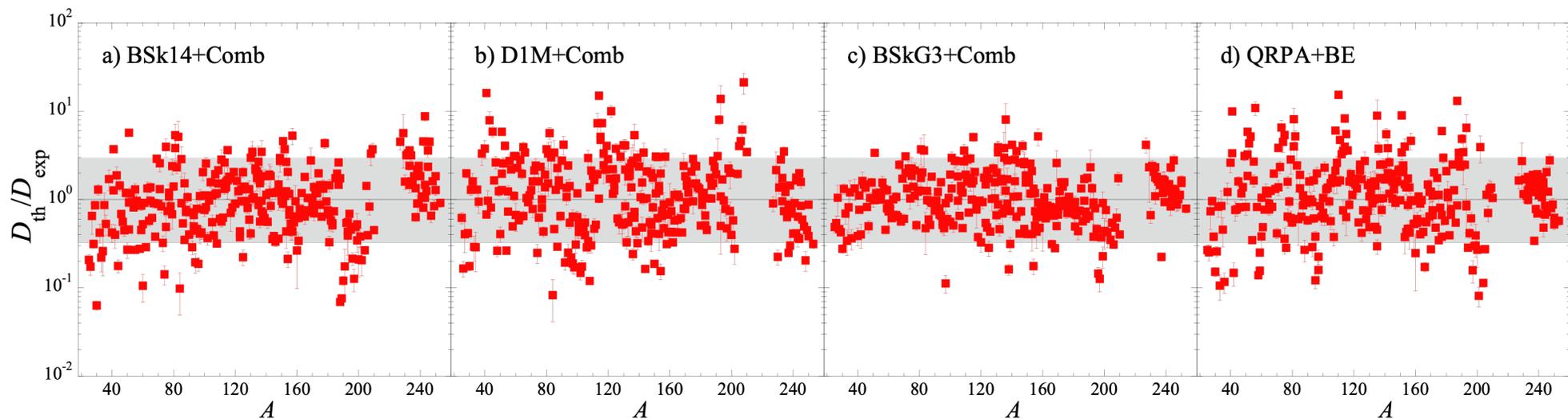
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# Mean-Field + Combinatorial approaches



RIPL-3 data	299 $D_0$		116 $D_1$	
	$f_{mean}^{D_0}$	$f_{rms}^{D_0}$	$f_{mean}^{D_1}$	$f_{rms}^{D_1}$
BSk14+comb	0.95	2.34	1.01	2.24
D1M +comb	1.11	2.58	1.62	4.38
BSkG3+comb	1.03	1.96	1.21	1.99
QRPA+BE	1.12	2.50	1.72	3.75

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

# IAEA-CRP on Nuclear Level Densities

“Updating Nuclear Level Densities for Applications” (2025–2028)

## This CRP aims

- to compile experimental NLD-related data including
  - level scheme
  - average resonance parameters (spacing)
  - Oslo data
  - evaporation spectra
  - fluctuation analyses (p,p'), (d,p $\gamma$ ), ...
- to recommend NLD models and parameters
- to provide microscopic tables



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### Segment 6: **GAMMA-RAY STRENGTH FUNCTION**

Major update with respect to RIPL-3  
within

The Photon Strength Function Database

IAEA CRP on PSF (2015-2018)

Regularly updated – latest version: 2025

- Extensive PSF-related experimental data
- Recommended E1/M1 PSF from large-scale calculation
  - SMLO model
  - D1M+QRPA model

Both “validated” according to CRP prescription

Cf Wiedeking’s talk

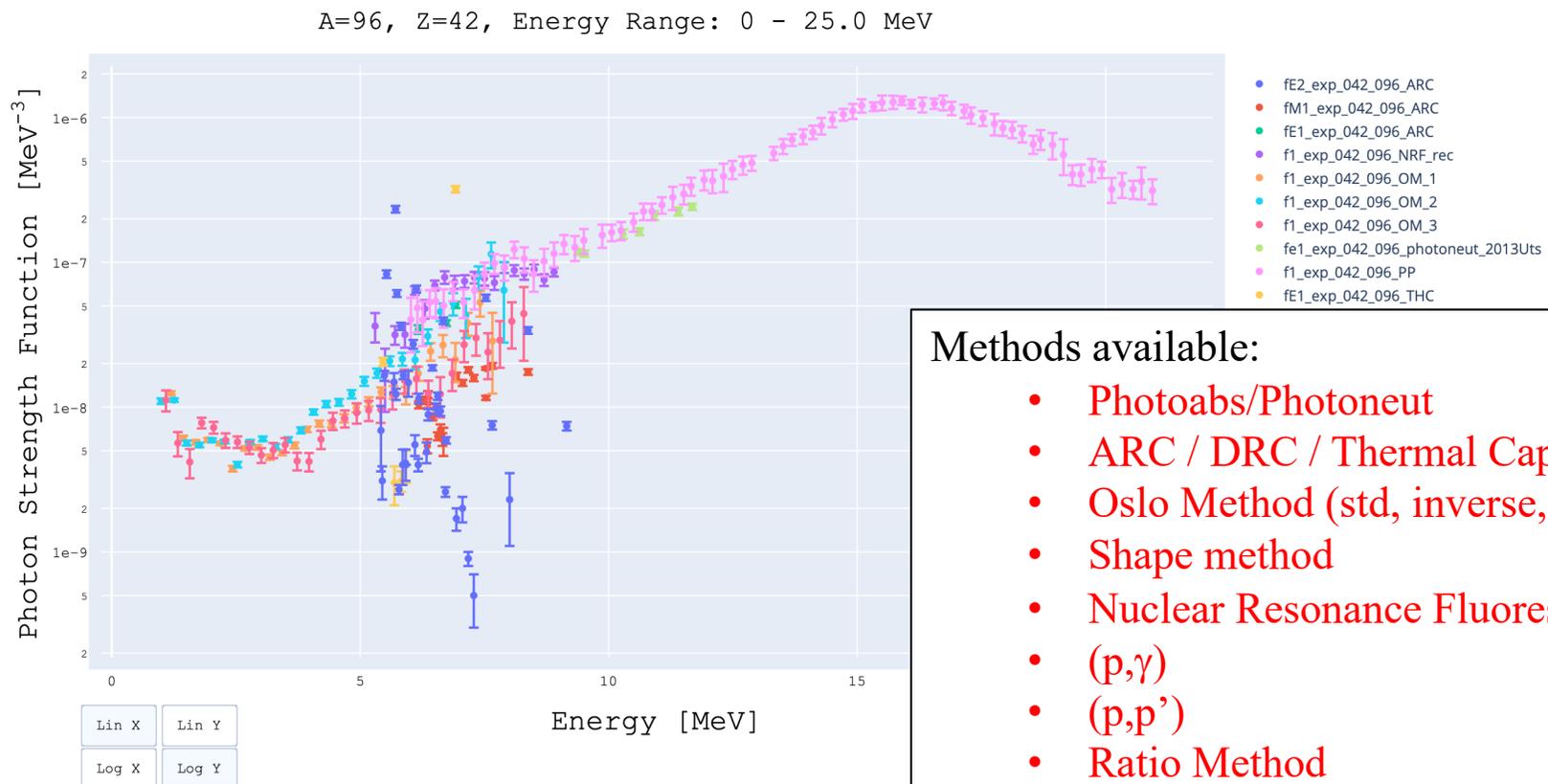
<https://www-nds.iaea.org/PSFdatabase>

Z:  A:  Energy from:  to:

XL:  Method:

For more detailed information, see the [Glossary](#).

11 Results



# Gogny-HFB + QRPA $E1$ and $M1$ strength functions

Theoretical  $E1$  and  $M1$  calculations  
 “validated” on direct and indirect  
 PSF-related experimental data

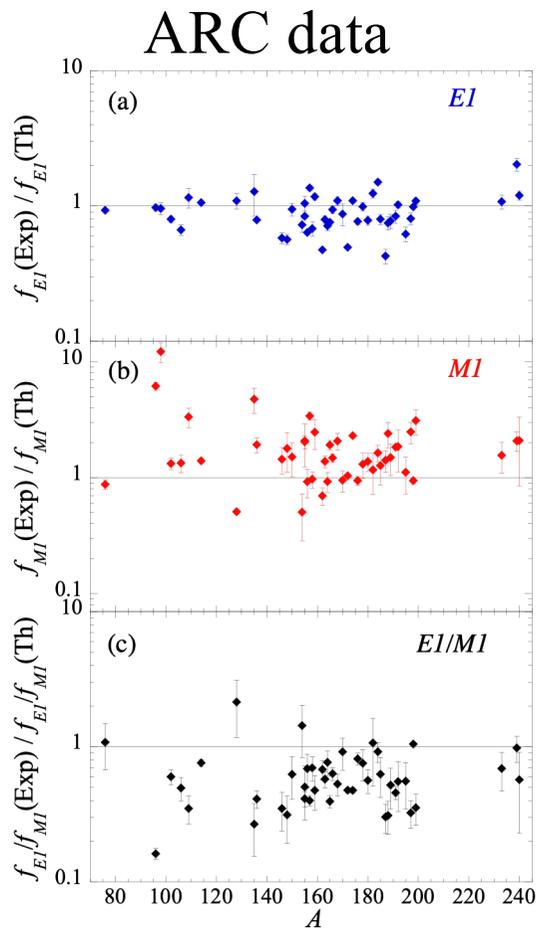
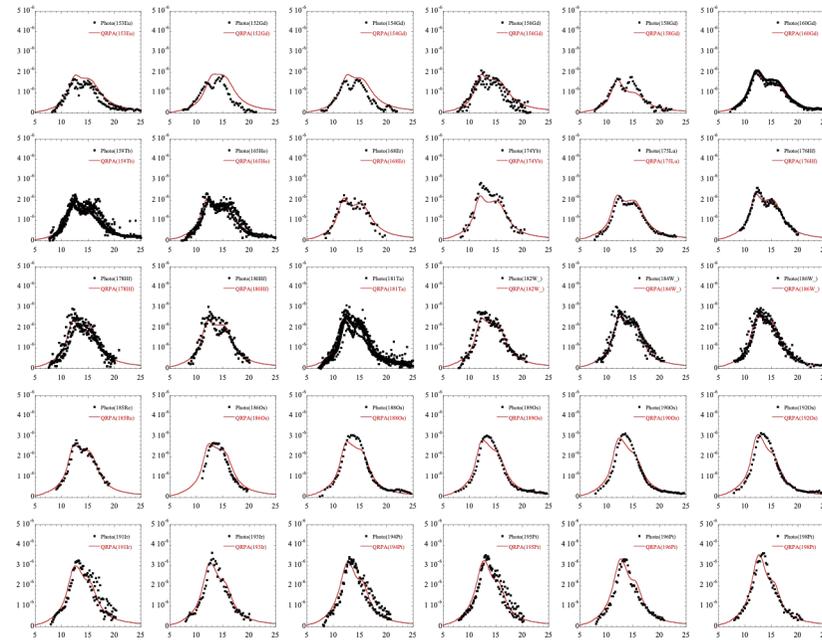
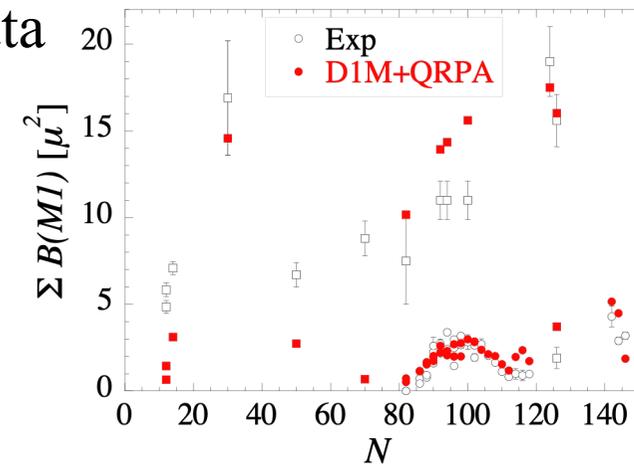


Photo data



$M1$  NRF data





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### Segment 7: **FISSION**

- **Energy applications:** ~ 3% accuracy in the cross sections  
→ Empirical input parameters
- **Non-energy applications:** exotic target tolerating larger uncertainties  
→ Global “microscopic” (mean-field-type) of inputs

Both require estimates of

- Fission barriers / paths
- Collective inertias
- Nuclear level densities at saddle points
- Transitions states
- Class II/III states

## Documents

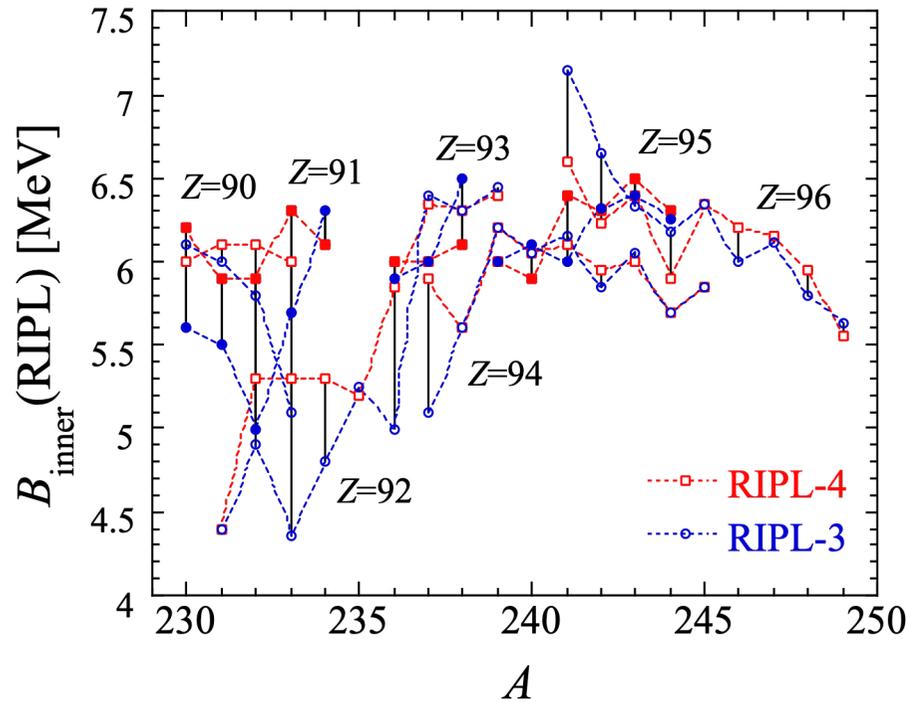
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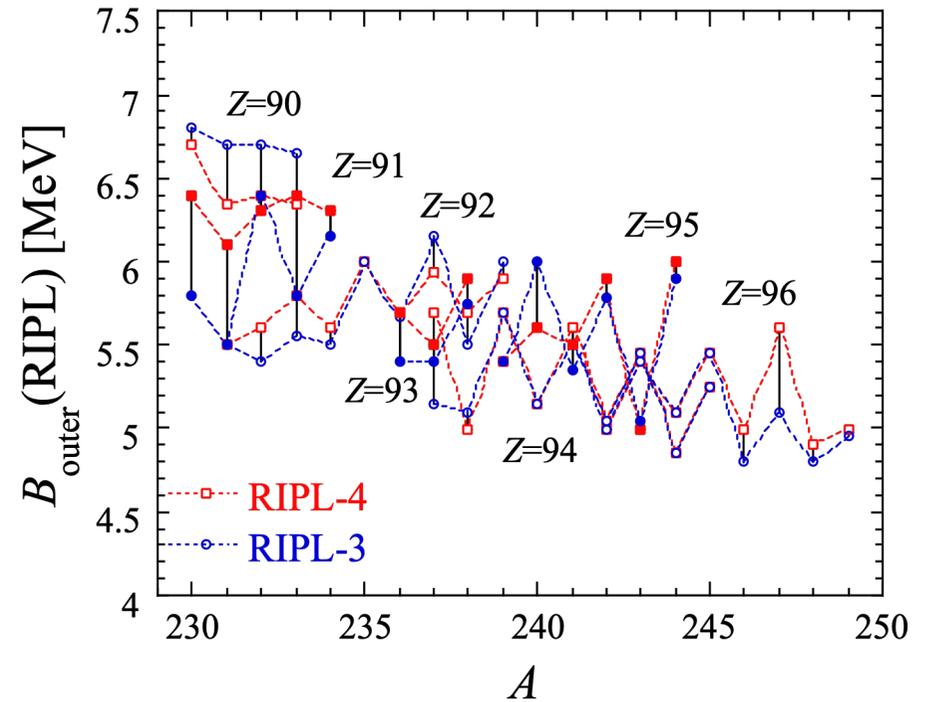
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# Updated determination of the empirical fission barriers for 45 actinides

Inner barriers



Outer barriers

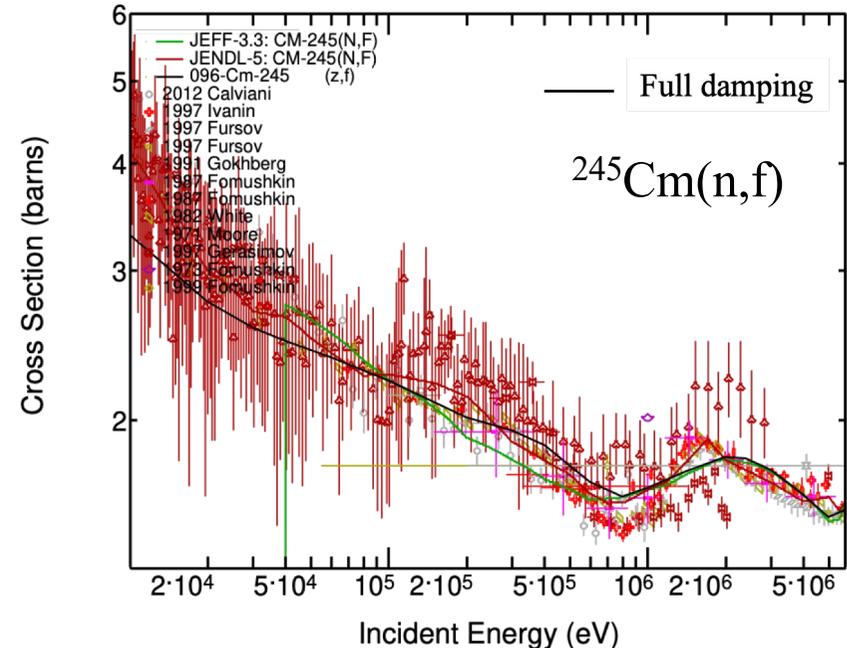
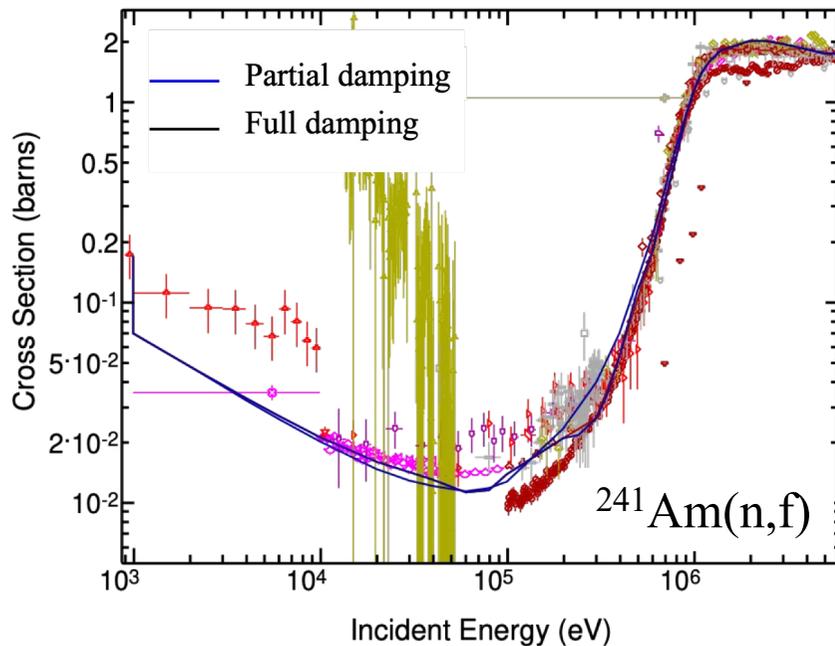
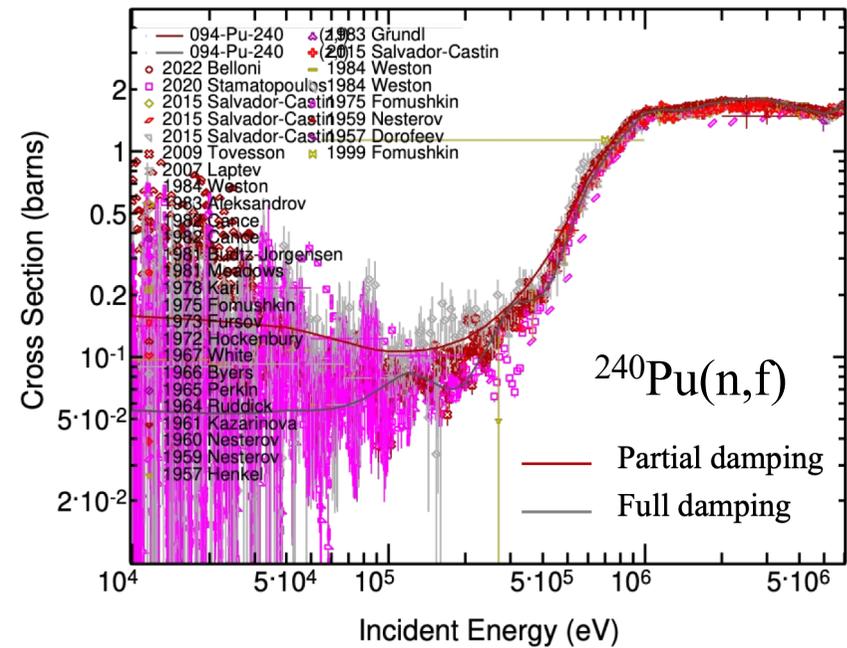
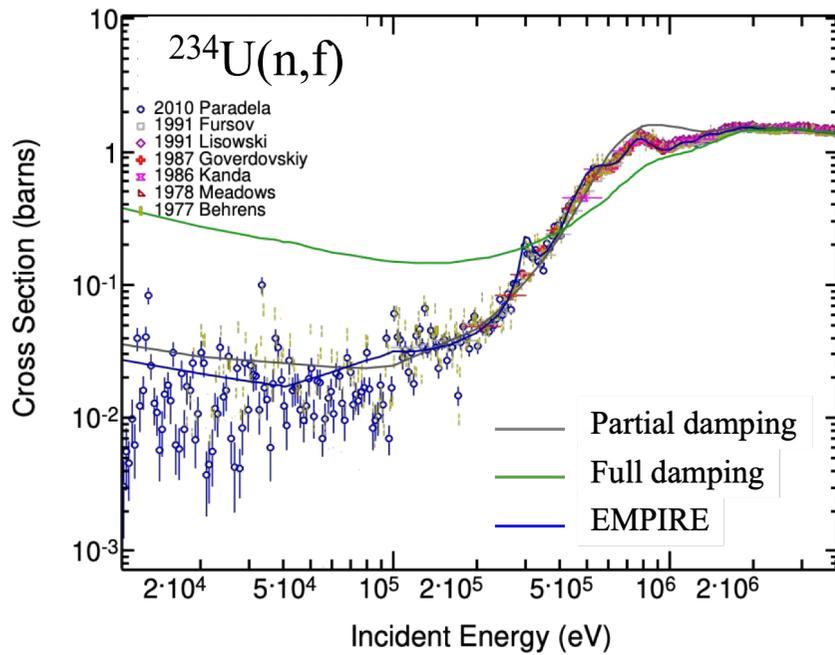


With new uncertainty estimates on barrier heights and widths ( $\delta B \sim 0.1-0.3$  MeV)

Estimation of triple-humped barriers for 7 light actinides

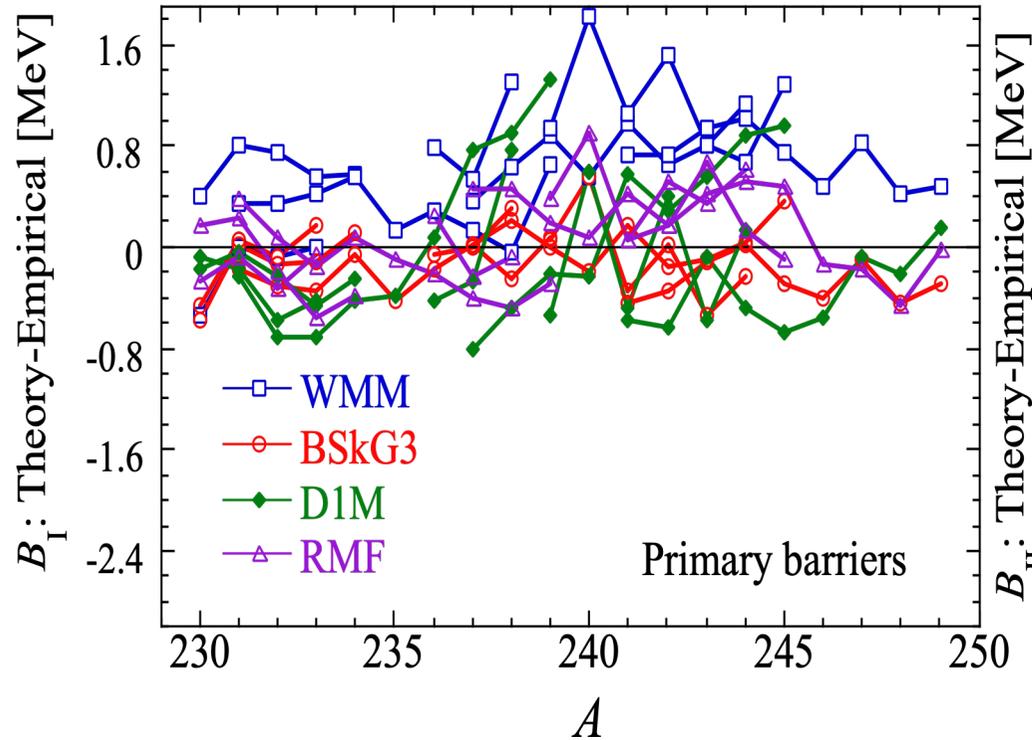
$Z$	$A$	Symb	Sym-A	$B_A$	$\delta B_A$	$\hbar\omega_A$	$B_B$	$\delta B_B$	$\hbar\omega_B$	$B_C$	$\delta B_C$	$E_{II}$	$\hbar\omega_{II}$	$E_{III}$	$\hbar\omega_{III}$
90	233	Th	S	5.82	0.3	1.0	6.35	0.1	1.3	6.45	0.1	2.12	1.0	5.65	1.0
91	232	Pa	S	5.92	0.3	0.5	6.3	0.1	1.2	6.45	0.1	1.90	1.0	5.40	1.0
92	233	U	S	4.7	0.2	0.7	6.06	0.1	1.4	5.7	0.2	1.7	1.0	5.05	1.0
92	234	U	S	4.6	0.2	0.6	5.9	0.2	1.3	5.2	0.2	1.6	1.0	4.7	1.0
92	235	U	S	4.8	0.2	0.6	6.1	0.1	1.45	5.78	0.2	1.6	1.0	5.1	1.0
92	236	U	S	4.6	0.3	0.6	5.9	0.2	1.45	5.64	0.2	1.6	1.0	4.9	1.0
92	237	U	GA	5.25	0.2	0.5	6.18	0.1	1.5	5.80	0.2	2.3	1.0	5.57	1.0

# “Validation” of the newly recommended Fission parameters

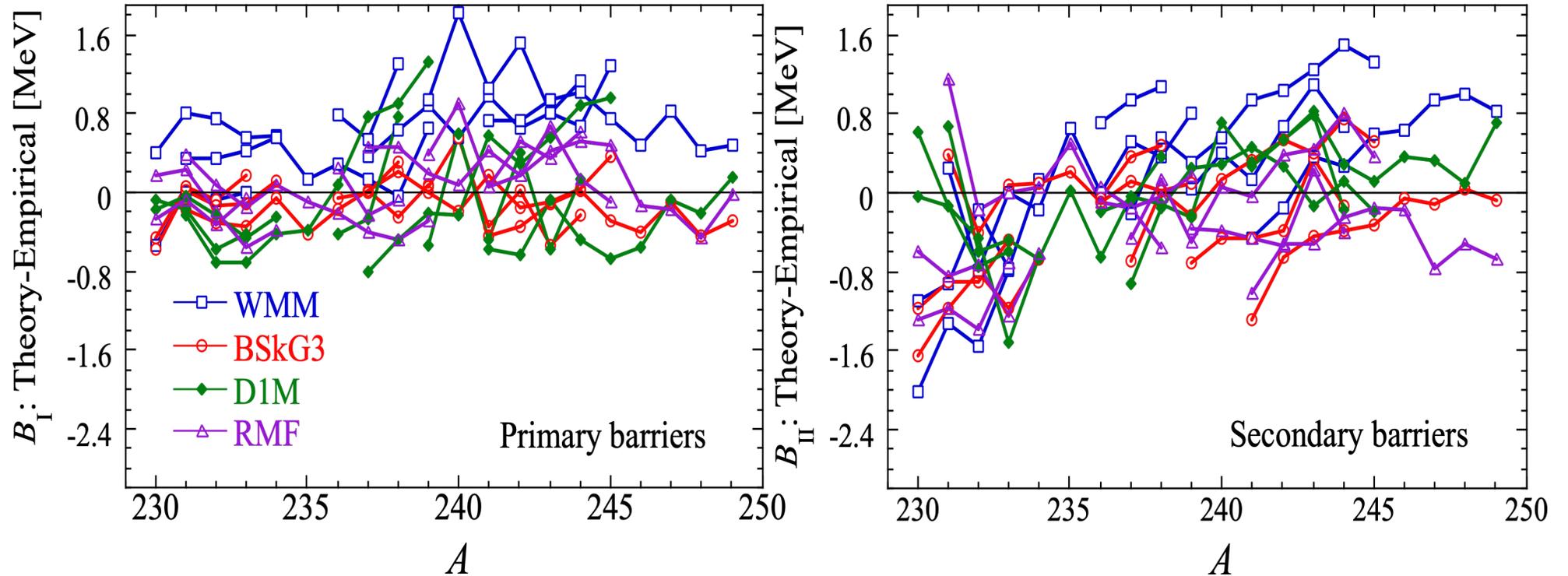


# Recommendation of 4 theoretical models

Primary barriers



Secondary barriers



rms (45 nuclei)	$\sigma(B_I)$ [MeV]	$\sigma(B_{II})$ [MeV]
Warsaw Macroscopic - Microscopic	0.77	0.82
BSkG3 – Skyrme- HFB	0.26	0.60
D1M – Gogny-HFB	0.54	0.50
PC-PK1 – MDC RMF	0.35	0.61

→ 1305 nuclei ( $89 \leq Z \leq 126$ )

→ 3500 nuclei ( $70 \leq Z \leq 118$ )

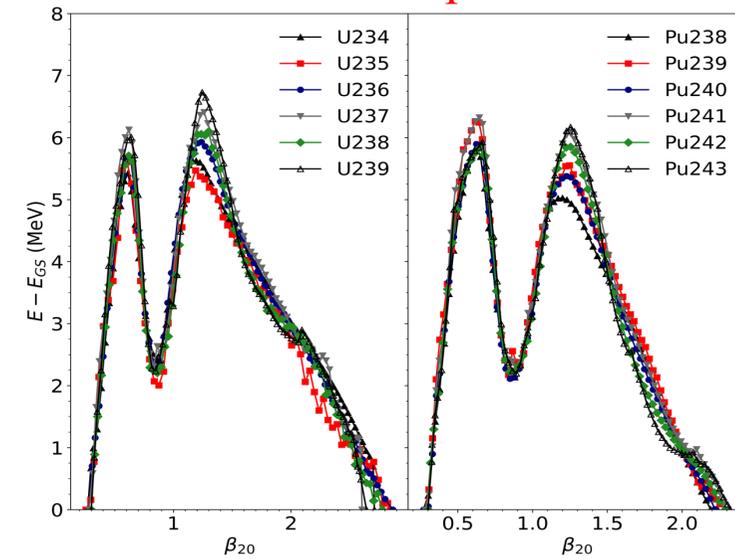
→ 45 nuclei ( $90 \leq Z \leq 96$ )

→ 45 nuclei ( $90 \leq Z \leq 96$ )

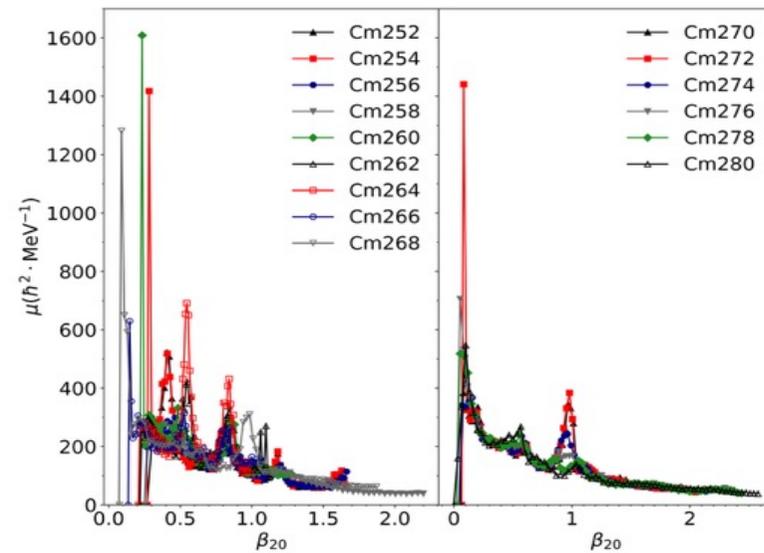
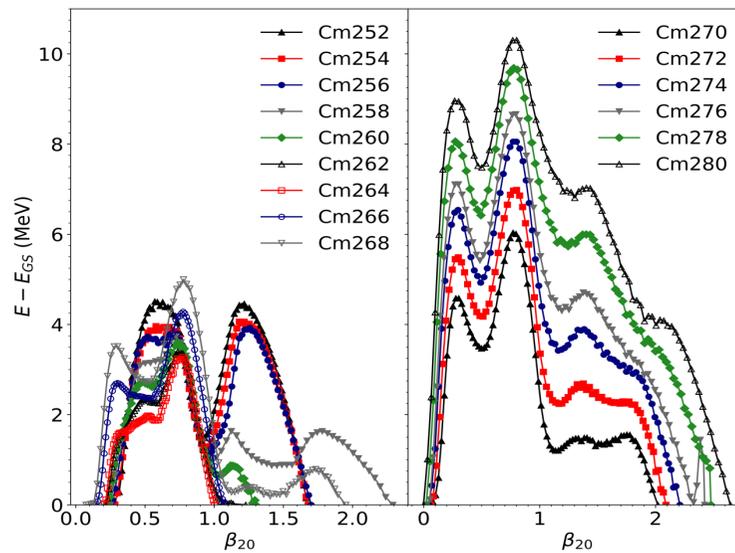
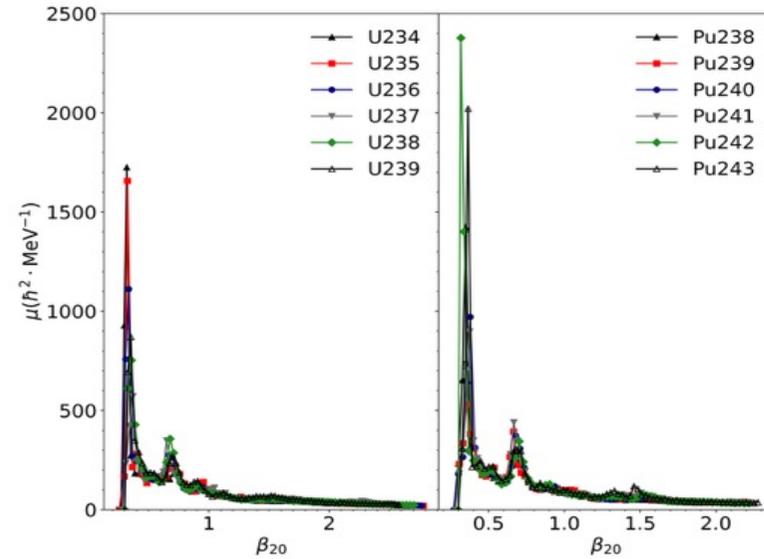
# BSkG3 prediction of fission paths and collective inertias for 3500 nuclei

cf A. Sanchez

## Fission paths

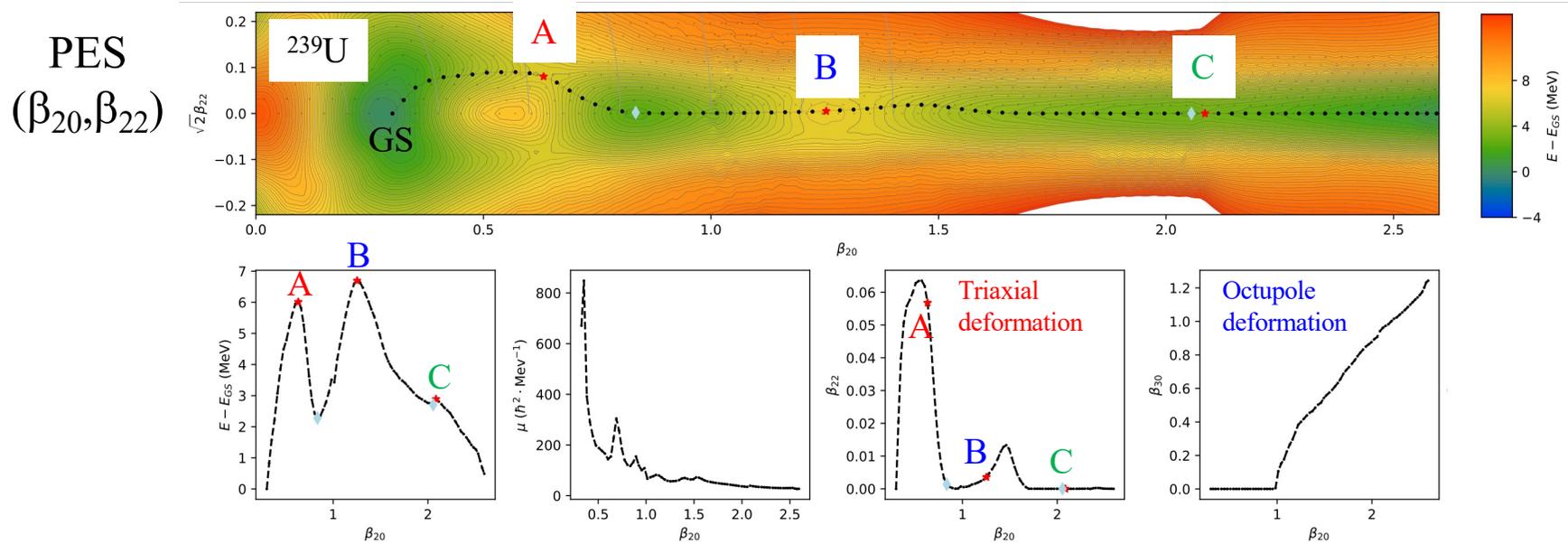


## Collective inertias

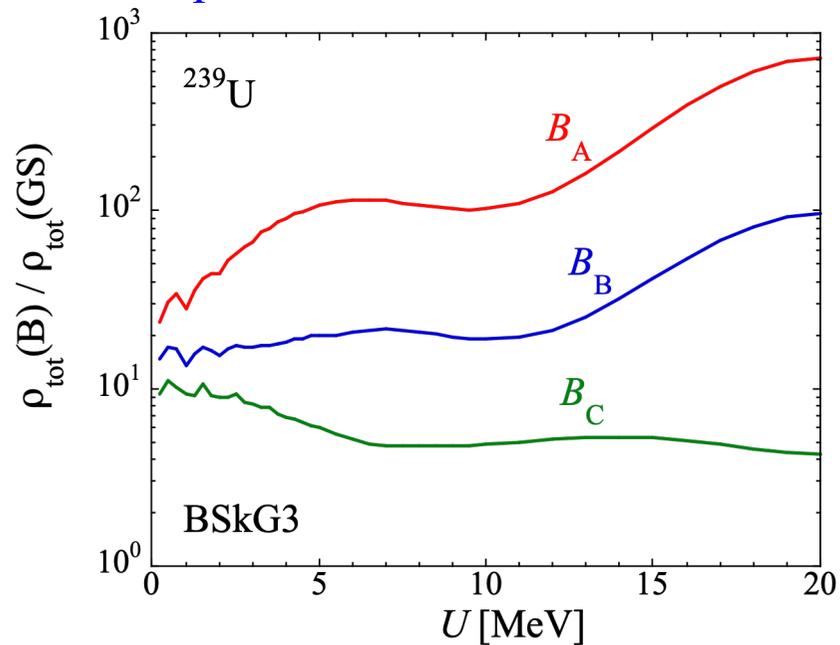


PC-PK1 and BSkG3 are the only MF calculations that consistently treat both octupolarity and triaxiality at the outer barrier

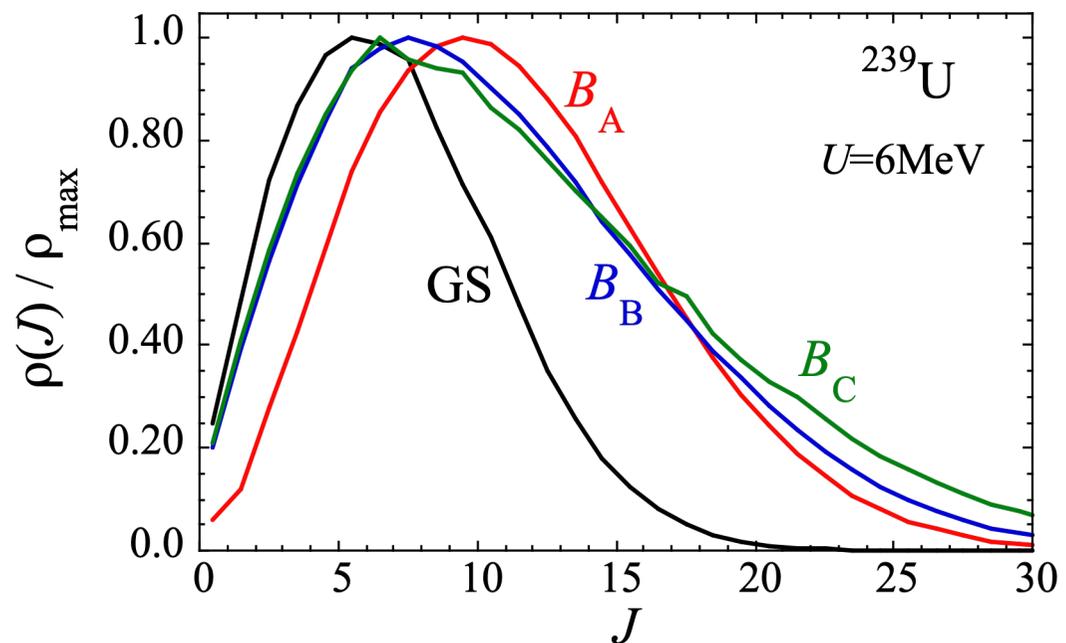
# BSkG3 prediction of NLDs at the fission saddle points for 3500 nuclei



*E*-dependent NLD at saddles wrt to GS

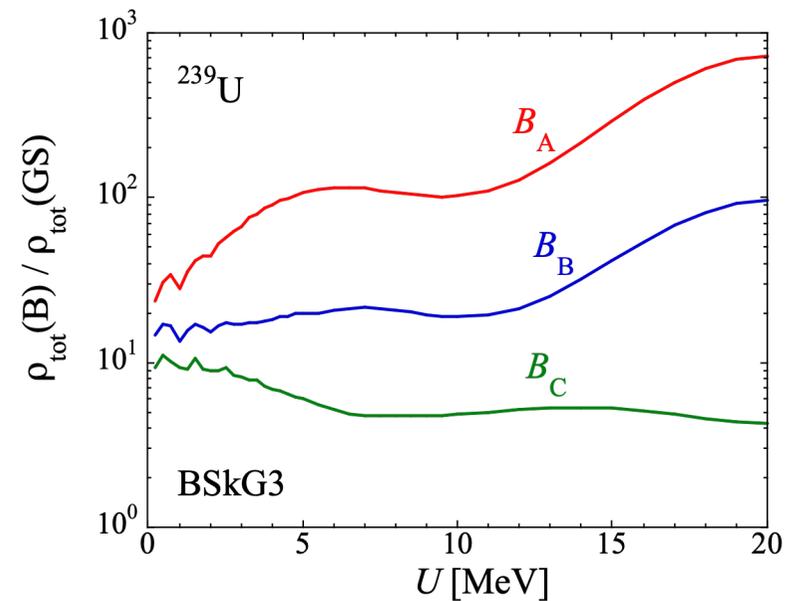
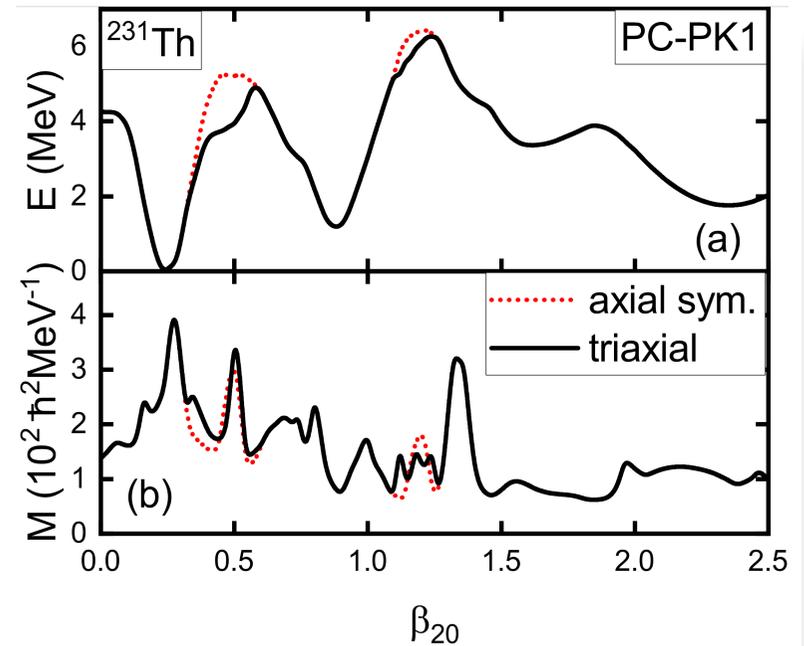


Spin distributions at saddles

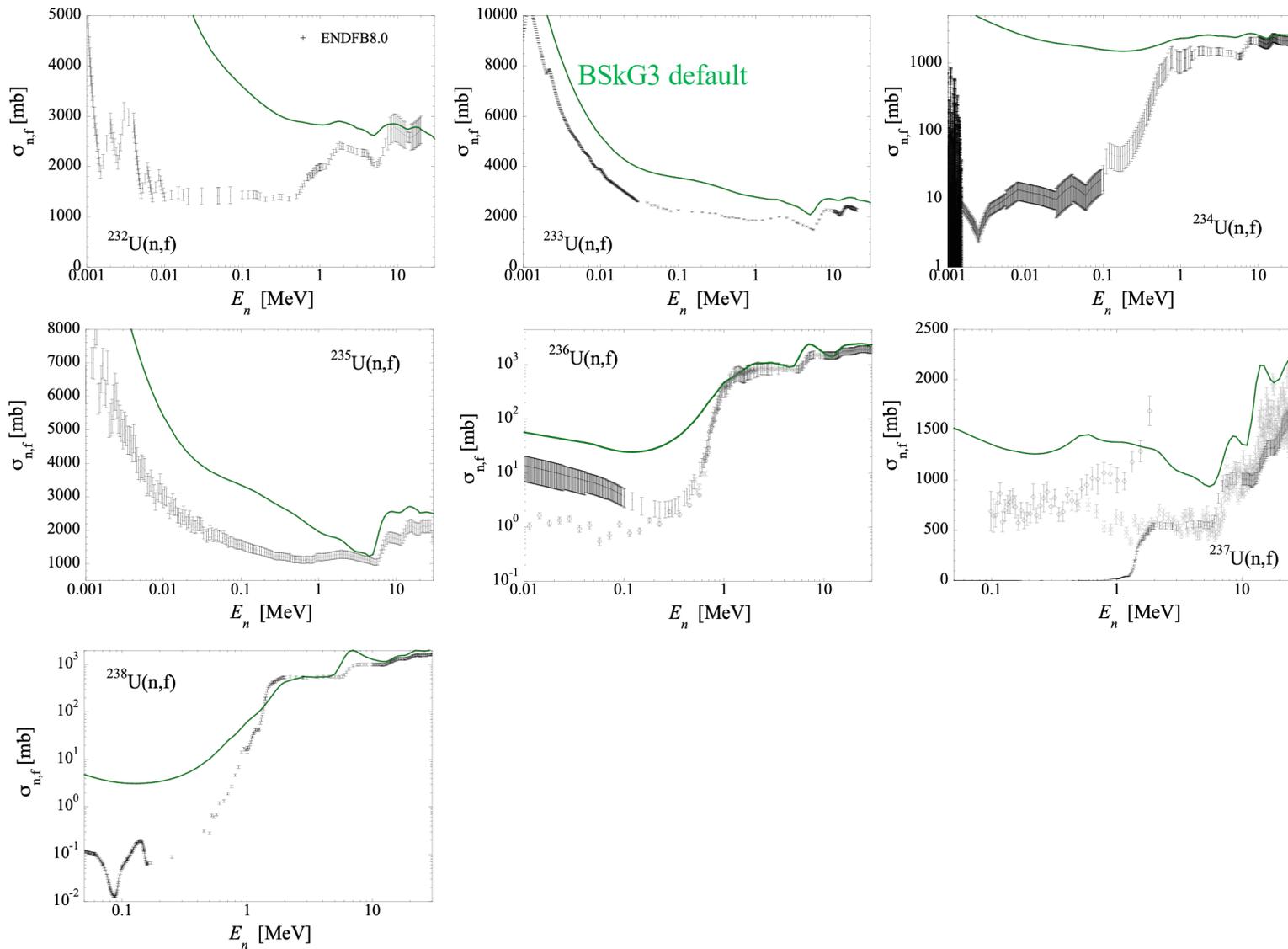


## Major outcomes from theoretical models

- 3 (or more) non-necessarily parabolic barriers along the fission path of many nuclei
- Triaxial inner barrier and octupole (and possibly triaxial) outer barrier
- Deformation-dependent collective inertias with strong structure effects along the fission path
- NLD at the fission saddle points significantly different from the GS ( $E$ - and  $J$ -distributions)



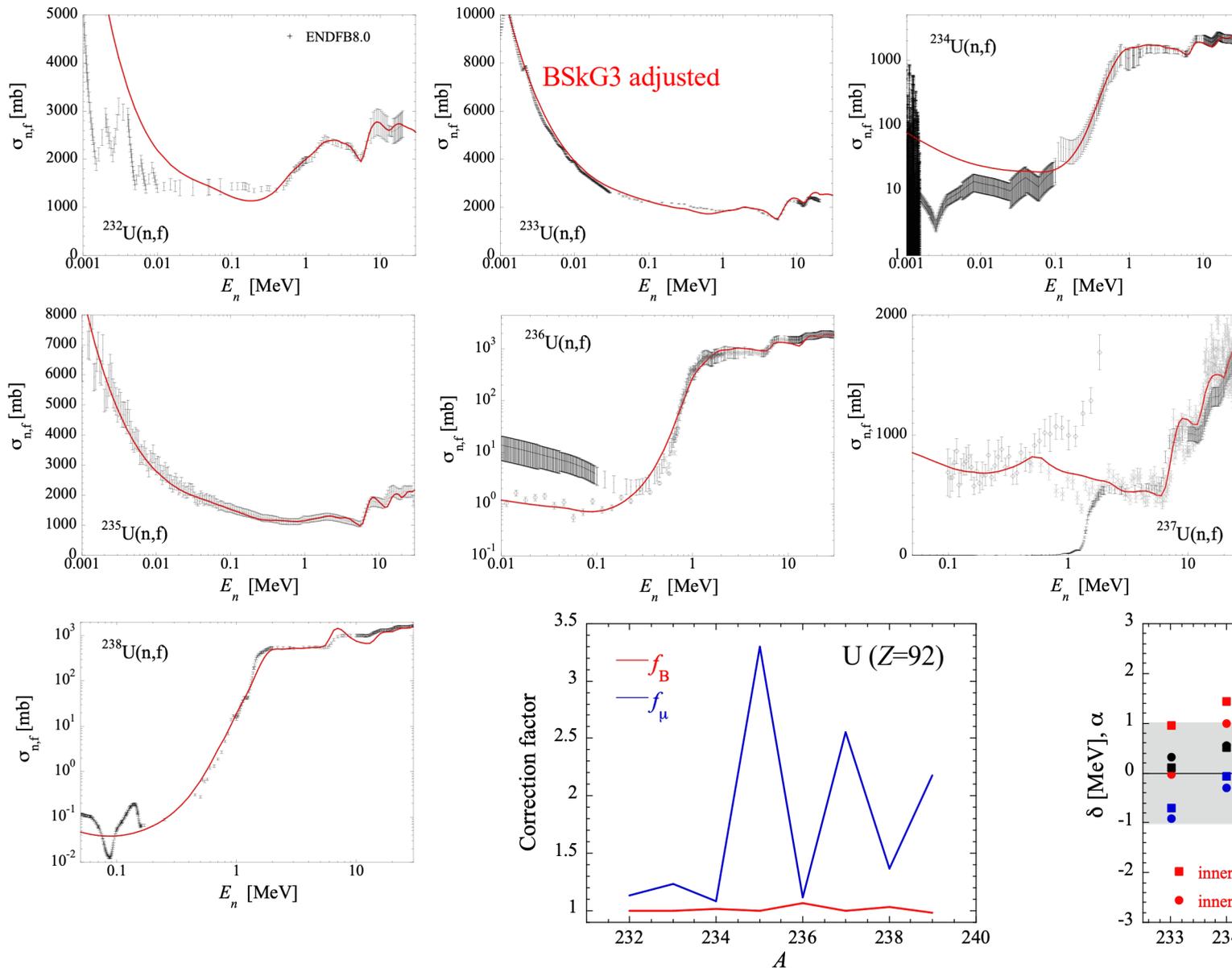
# Default calculation of $^{xxx}\text{U}(n,f)$ cross sections with BSkG3 fission paths $[E(\beta_{20}), \mu(\beta_{20})]$ and NLD at saddle points



No adjustment on any of U parameters:

- $f_B=1$
- $f_\mu=1$
- $\alpha=0, \delta=0$  inner  $B$
- $\alpha=0, \delta=0$  outer  $B$

# Coherent fit to $^{xxx}\text{U}(n,f)$ cross sections with BSkG3 fission path $[E(\beta_{20}), \mu(\beta_{20})]$ and NLD at saddle points



Adjustment for each U:

- $f_B$
- $f_\mu$
- $\alpha, \delta$  inner  $B$
- $\alpha, \delta$  outer  $B$

One unique set

$f_B, f_\mu, \alpha_i, \delta_i, \alpha_o, \delta_o$   
for each U isotope,  
irrespective of the  
channel

Full damping limit:

$$K_j = \pm \int_{a_j}^{b_j} \sqrt{2f_\mu \mu [f_B V(\beta_{20}) - E_{GS}] / \hbar^2 d\beta_{20}}$$

$$P_j(E) = \frac{1}{1 + \exp(2K_j)}$$

$$\rho^*(U) = e^{\alpha\sqrt{U-\delta}} \times \rho(U - \delta)$$

# Conclusions

RIPL has been a very successful IAEA project in providing a comprehensive set of recommended input parameters for theoretical calculation of reaction cross sections.

Still, it will require

- **Regular updates**
  - new measurements:  $M$ ,  $R_c$ ,  $E_x$ ,  $D$ ,  $S$ ,  $\langle \Gamma_\gamma \rangle$ , OMP,  $B_f$ , ...
  - theoretical developments
- **Improvements**
  - state-of-the-art "microscopic" developments that can compete with more phenomenological approaches
  - Uncertainty quantifications and propagation into reaction rates
  - Predicting fission cross section remains a challenge

Most probably no RIPL-5 to be expected... but some segments (Masses, Levels, NLD, PSF) will be regularly updated

# A special thank to

## RIPL-4 team



## Roberto





**THANK YOU  
FOR  
YOUR ATTENTION**