Microscopic cross sections : an utopia ?

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Nuclear data : how ?

Nuclear data generally evaluated with analytic models

- Analytical OMP
- Analytical level densities
- Analytical strength function
- Analytical fission barriers …

} OK close to stability

But for exotic nuclei ?

Extrapolations, predictive power ?

→ **Predictive & Robust Nuclear models (codes) are essential to fill the gaps**

Contents

- General features of TALYS
- From phenomenological to microscopic predictions
- Few TALYS results
- What remains to be done

What TALYS does !

- Simulates a nuclear reaction between a projectile and a target

  projectiles : n,p,d,t,^{3}he, ^{4}he
  target : $3 \leq Z \leq 110$ or $5 \leq A \leq 339$

- Projectile energy from 1keV up to 200 MeV

- TALYS mantra : " Completeness then quality "

  - Optical, pre-equilibrium and statistical model implemented with sets of default parameters
  - All opened channels smoothly described
  - **Possibilities for future improvements anticipated**
    - Level densities (stored and interpolated)
    - Parity dependence
  - Still under development (improvement)

How TALYS works !

INPUT
- projectile n
- element Fe
- mass 56
- energy 14.

Loop over energies and isotopes

OPTICAL MODEL (ECIS)
- **Phenomenologic**
  - Local or global
- **Semi-Microscopic**
- **Tabulated**

STRUCTURE
- Abundances
- Discrete levels
- Deformations
- Masses
- Level densities
- Resonances
- Fission parameters
- Radial matter dens.

DIRECT REACTION
- **Spherical / DWBA**
- **Deformed / Coupled channel**
  - Rotational
  - Vibrational
- **Giant Resonances**
- **Pickup, stripping, exchange**

PRE-EQUILIBRIUM
- **Exciton model**
- **Partial densities**
- **Kalbach systematic**
  - Angular distributions
  - Cluster emissions
- **γ emission**
- **Approx DSD**

COMPOUND
- **Hauser-Feshbach**
- **Fluctuations**
- **Fission**
- **γ Emission**
- **Level densities**
  - GC + Ignatyuk
  - Tabulated
  - Superfluid Model

MULTIPLE EMISSION
- **Exciton model**
- **Hauser-Feshbach**
- **Fission**
- **γ cascade**
- **Exclusive channels**
- **Recoils**

OUTPUT
- XS
- Spectra
- Astro-rates
- Fission yields
- FF decay
- ENDF

Phenomenological ⇒ microscopic predictions ?

Can we calculate nuclear reaction cross sections starting from a nucleon-nucleon interaction ?

Yes we can but we need intermediate steps

Phenomenological ⇒ microscopic predictions ?

Experimentally known (deduced)		Theoretically predicted
Nuclear properties - Level properties (E, J^{π}, branching ratios) - deformations	⇒	**HFB + ν-ν interaction**
Level densities - Gilbert & Cameron - Back Shifted Fermi Gas - Generalized Superfluid Model - Williams + several corrections (p-h)	⇒	**Combinatorial method** - Total level densities - p-h level densities
Optical model - Koning & Delaroche - Soukhovistkii (actinides) - Tabulated	⇒	**Semi-microscopic JLM**
γ-strength functions - Kopecky-Uhl, Brink-Axel	⇒	**HFBCS or HFB Tables**
Fission paths - Hill-Wheeler	⇒	**HFB shapes with WKB penetrabilities**

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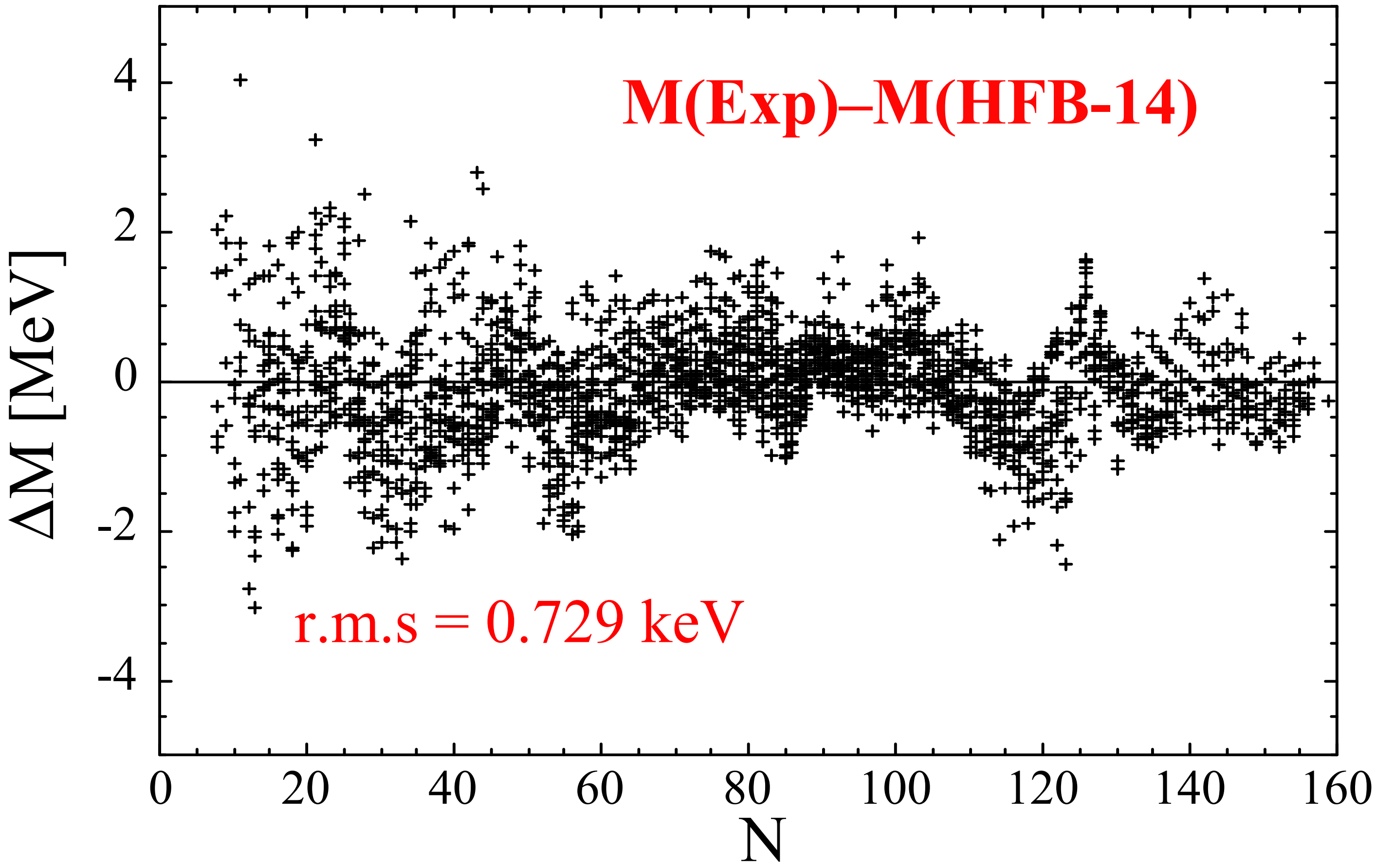
HFB + ν-ν interactions !

Comparison with experimental masses
(2149 nuclei: Audi, Wapstra & Thibault 2003)



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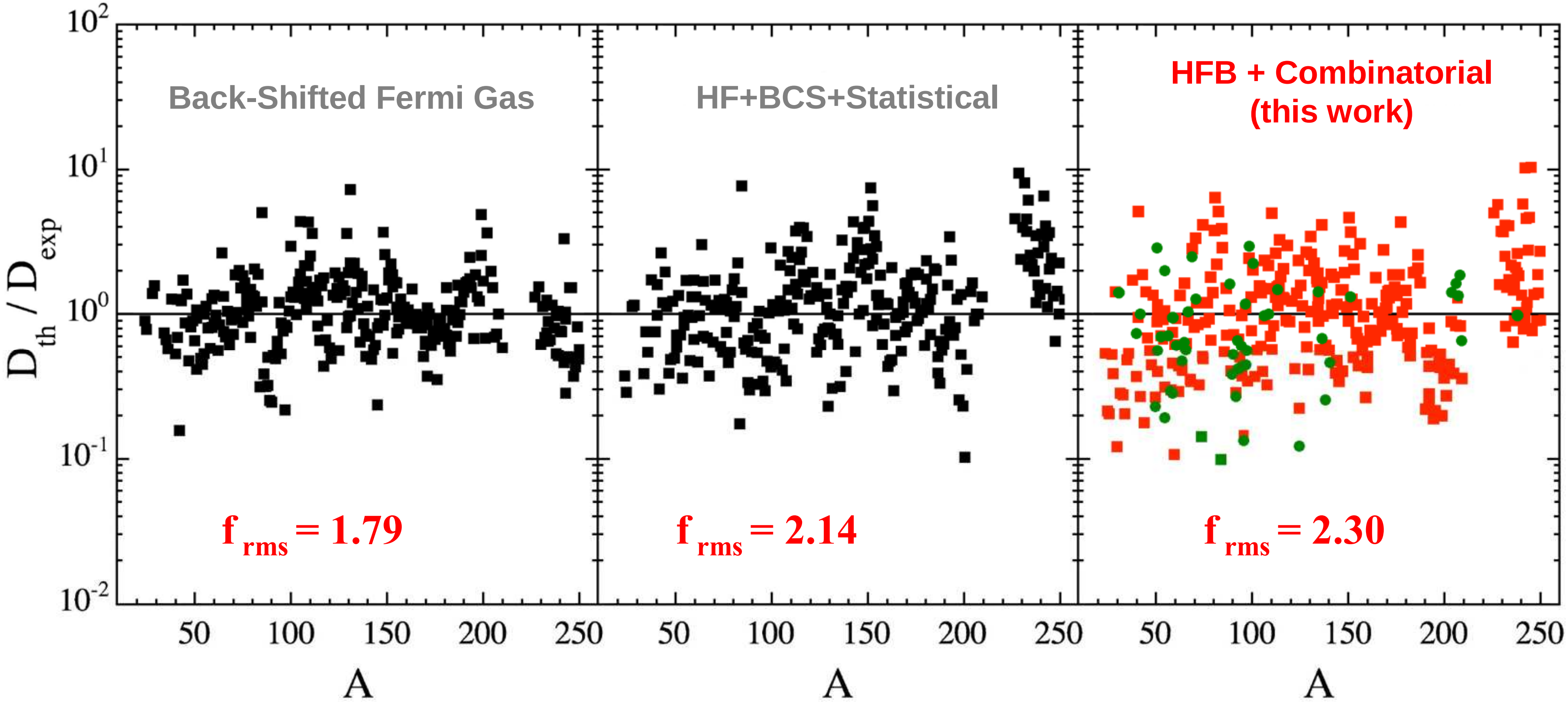
Results at B_n

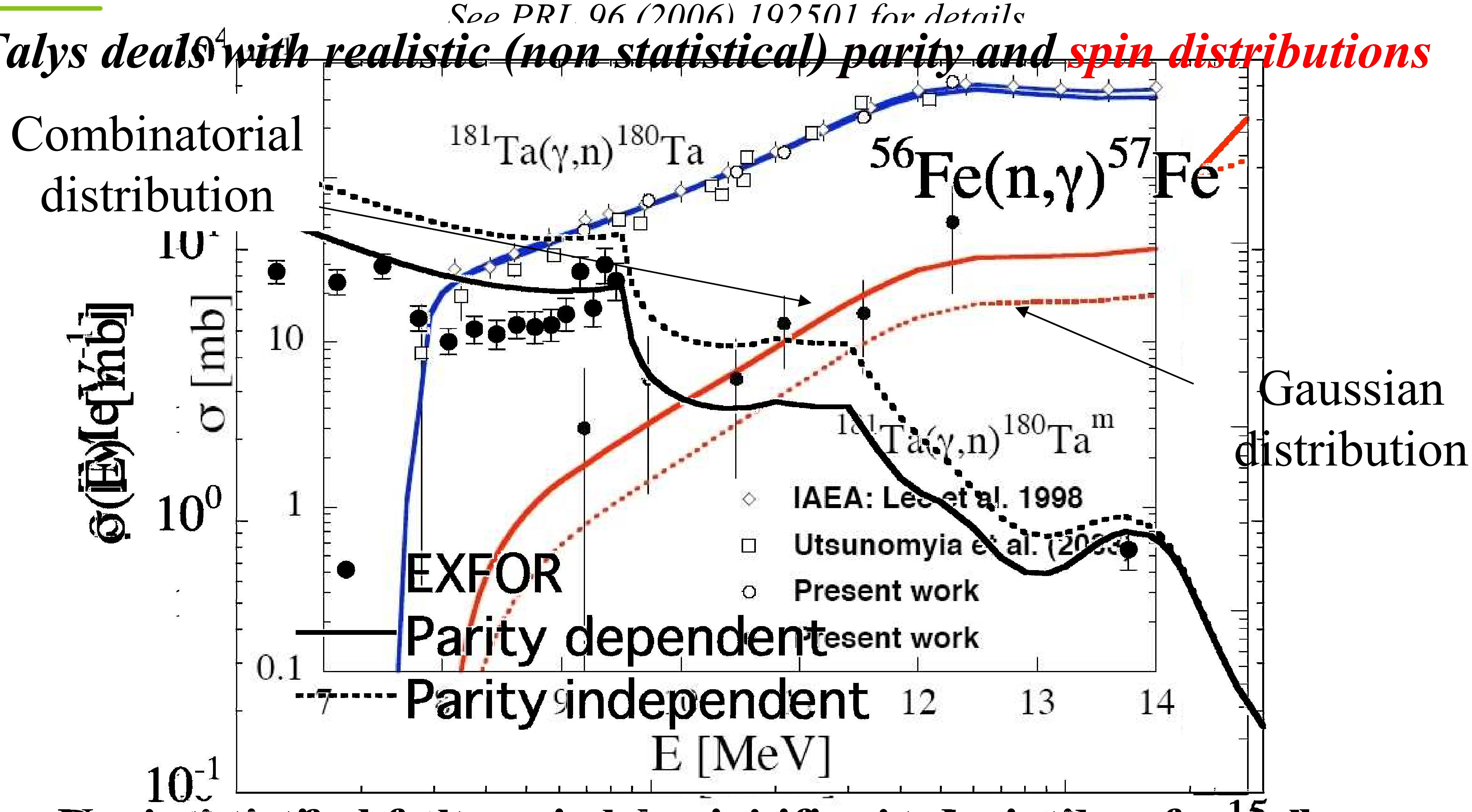
D values (s-waves & p-waves)



➡ **Description similar to that obtained with other global approaches**

Combinatorial level densities

Talys deals with realistic (non statistical) parity and spin distributions



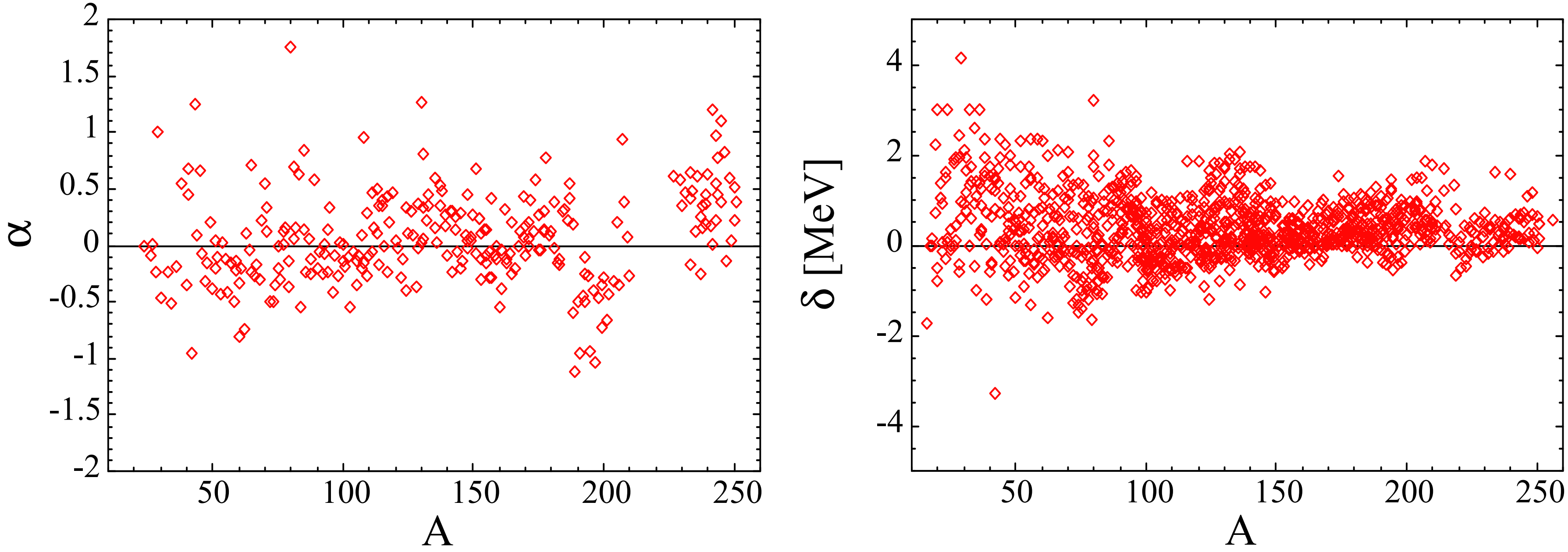
➡ **Non-statistical features imply significant deviations from the usual parity and spin dependent level densities / Non-statistical features can have large impact on reaction cross sections**

Global adjustment

See NPA 810 (2008) 13 for details

$$\rho_{\rm renorm}(U) = e^{\alpha \sqrt{(U-\delta)}} \rho_{\rm global}(U-\delta)$$

α and δ adjusted to fit discrete levels (≈ 1200 nuclei) and D_0's (≈ 300 nuclei) using the TALYS code



Phenomenological ⇒ microscopic predictions ?

Experimentally known (deduced) ⇒ Theoretically predicted

Nuclear properties ⇒ **HFB + ν-ν interaction**
- Level properties (E, J^{π}, branching ratios)
- deformations

Level densities ⇒ **Combinatorial method**
- Gilbert & Cameron
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Combinatorial method:
- Total level densities
- p-h level densities

Optical model ⇒ **Semi-microscopic JLM**
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Fission paths ⇒ **HFB shapes with WKB penetrabilities**
- Hill-Wheeler

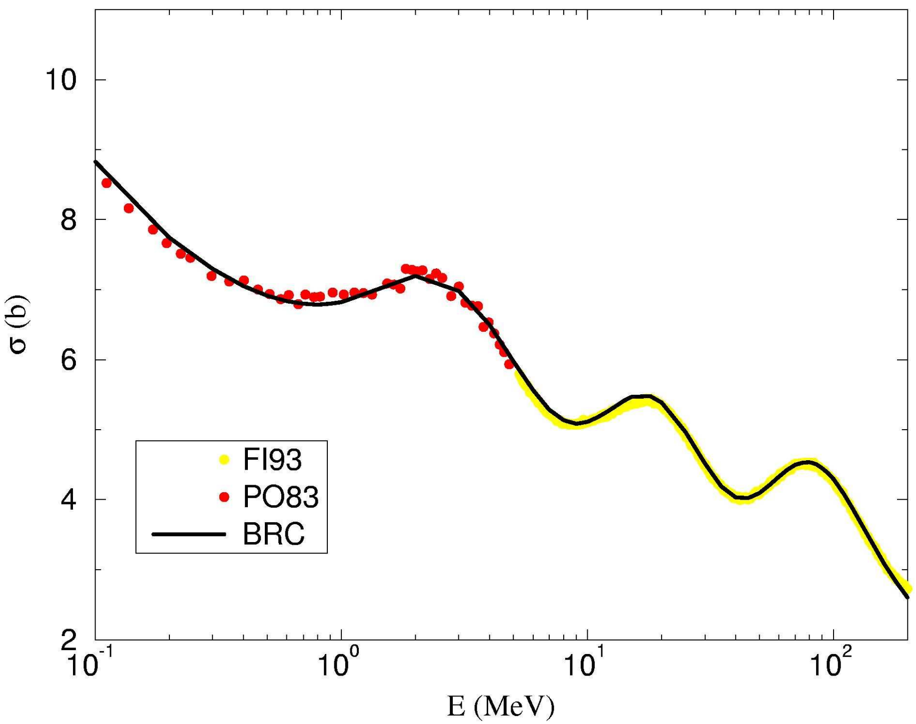
Approaches implemented in TALYS

Phenomenologic

Adjusted parameters
Weak predictive power
Very precise (≈ 1%)
Important work

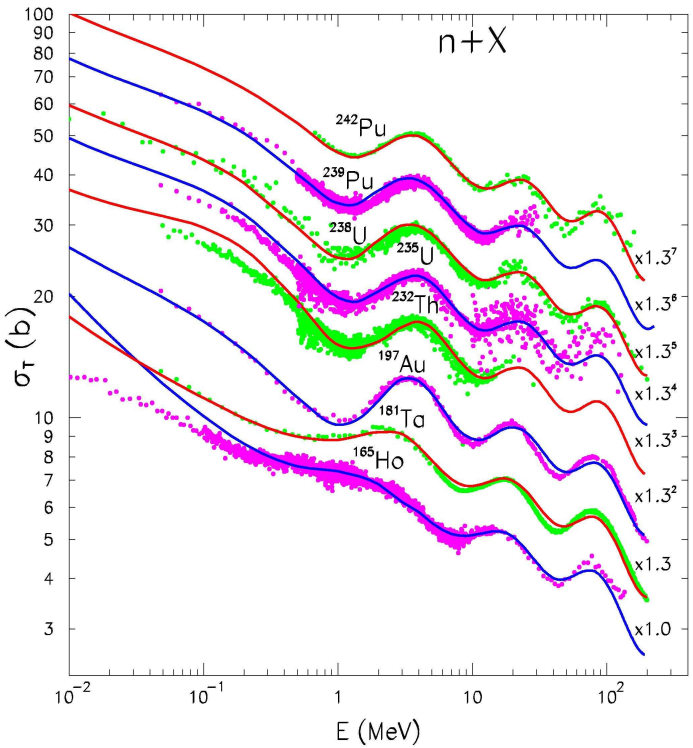
Semi-microscopic

No adjustable parameters
Usable without exp. data
Less precise (≈ 5-10 %)
Quasi-automated



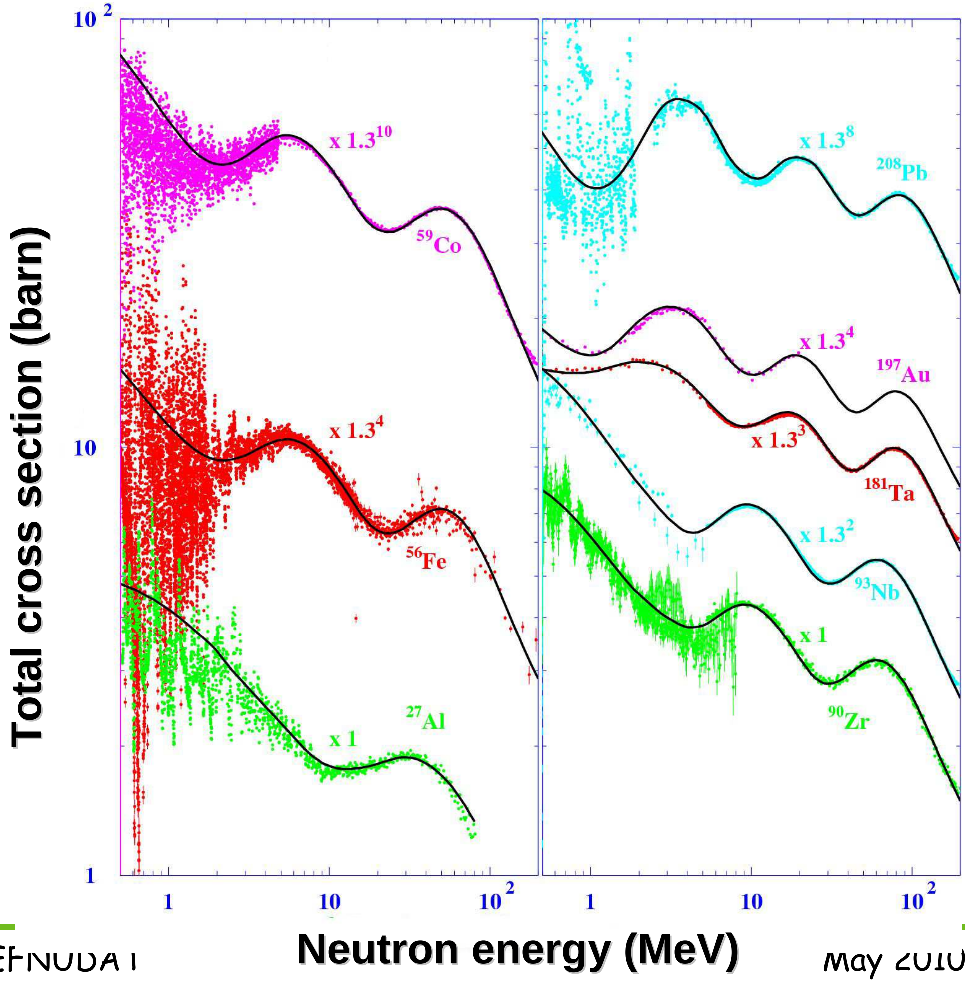
DAT

Total cross sections



Phenomenological OMP

- ≈ 20 adjusted parameters
- Very precise (1%)
- Relatively weak predictive power far away from stability

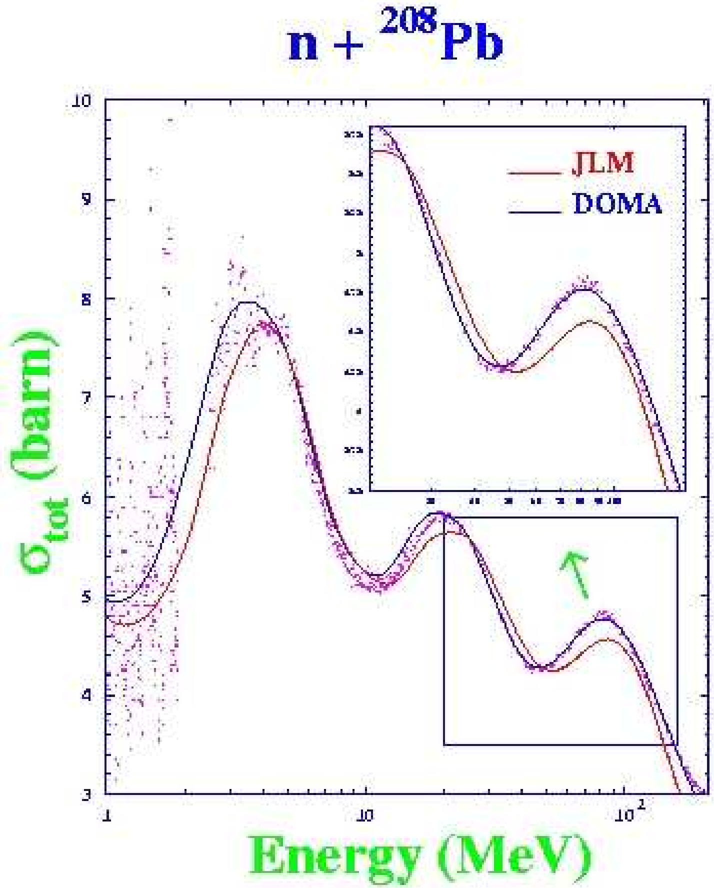


Semi-microscopic OMP

- **No adjustable parameters**
- **Based on nuclear structure properties**

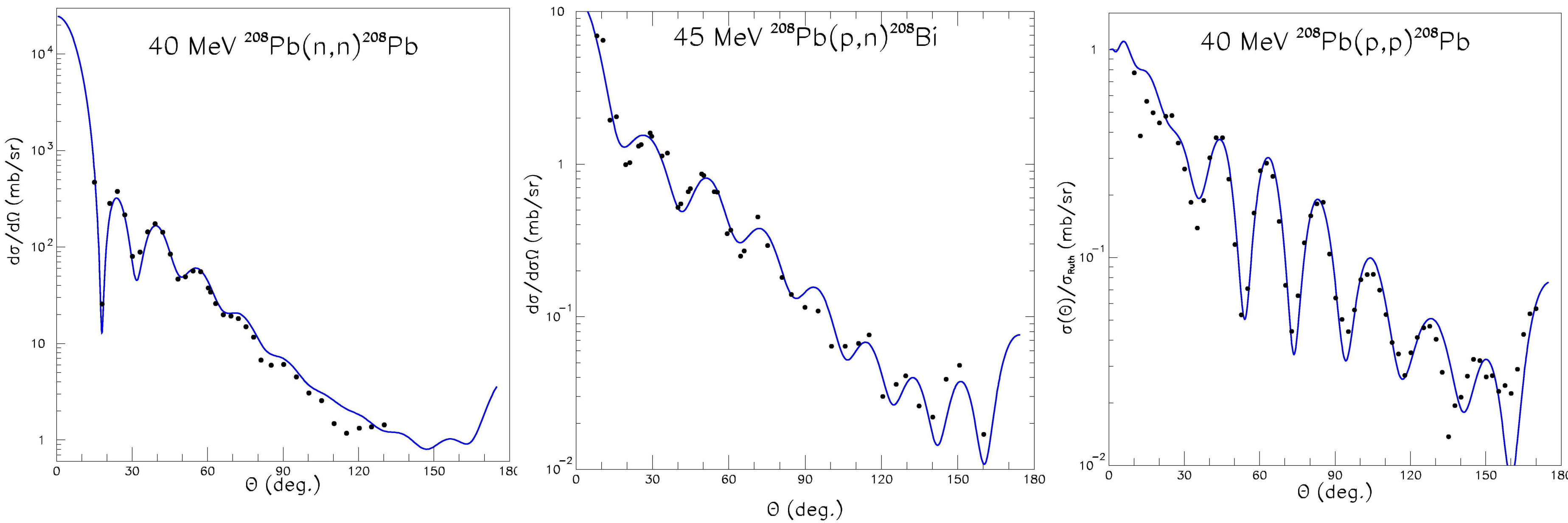
⇒ usable for any nucleus

- **Less precise than the phenomenological approach**



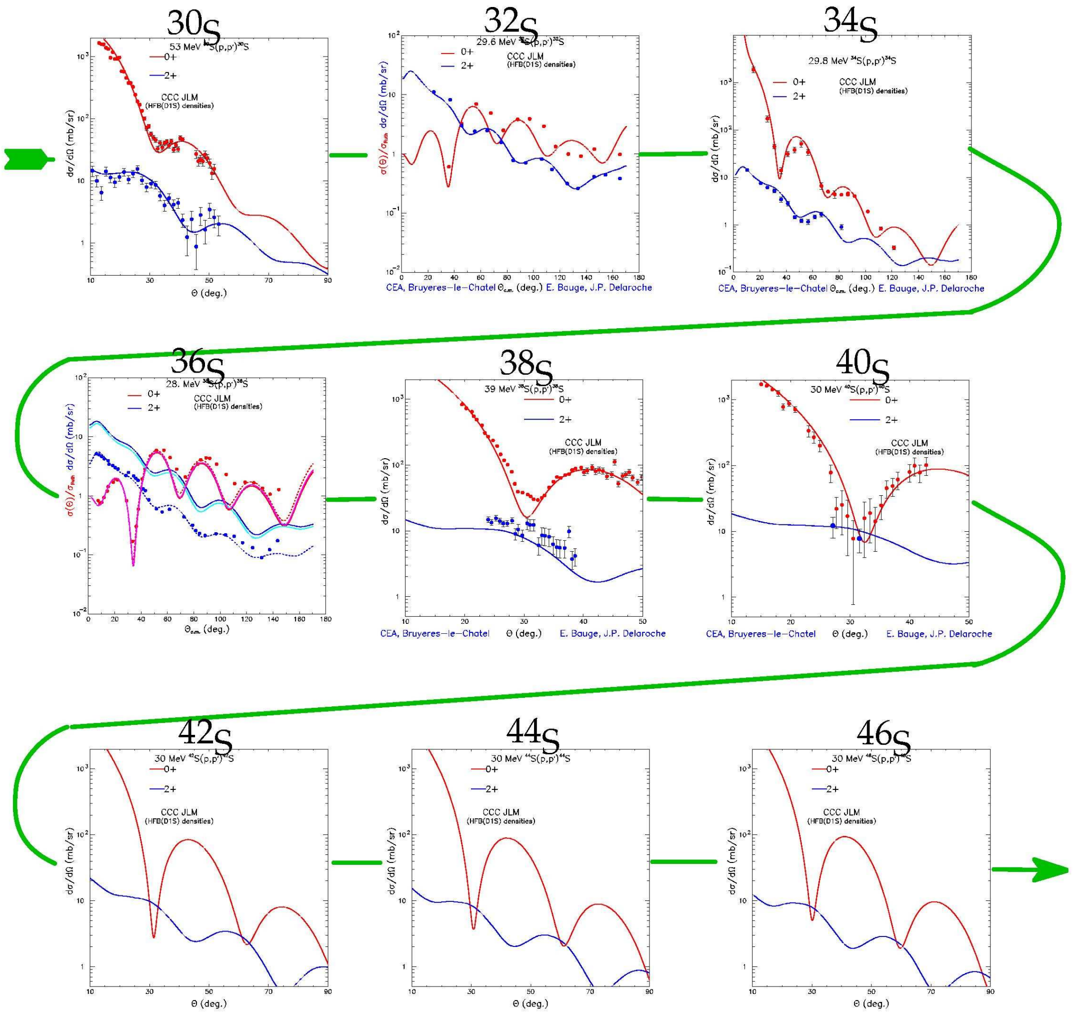
Semi-microscopic OMP

Unique description of elastic scattering (n,n), (p,p) et (p,n)



Semi-microscopic OMP

Enables to perform predictions for very exotic nuclei for which There exist no experimental data



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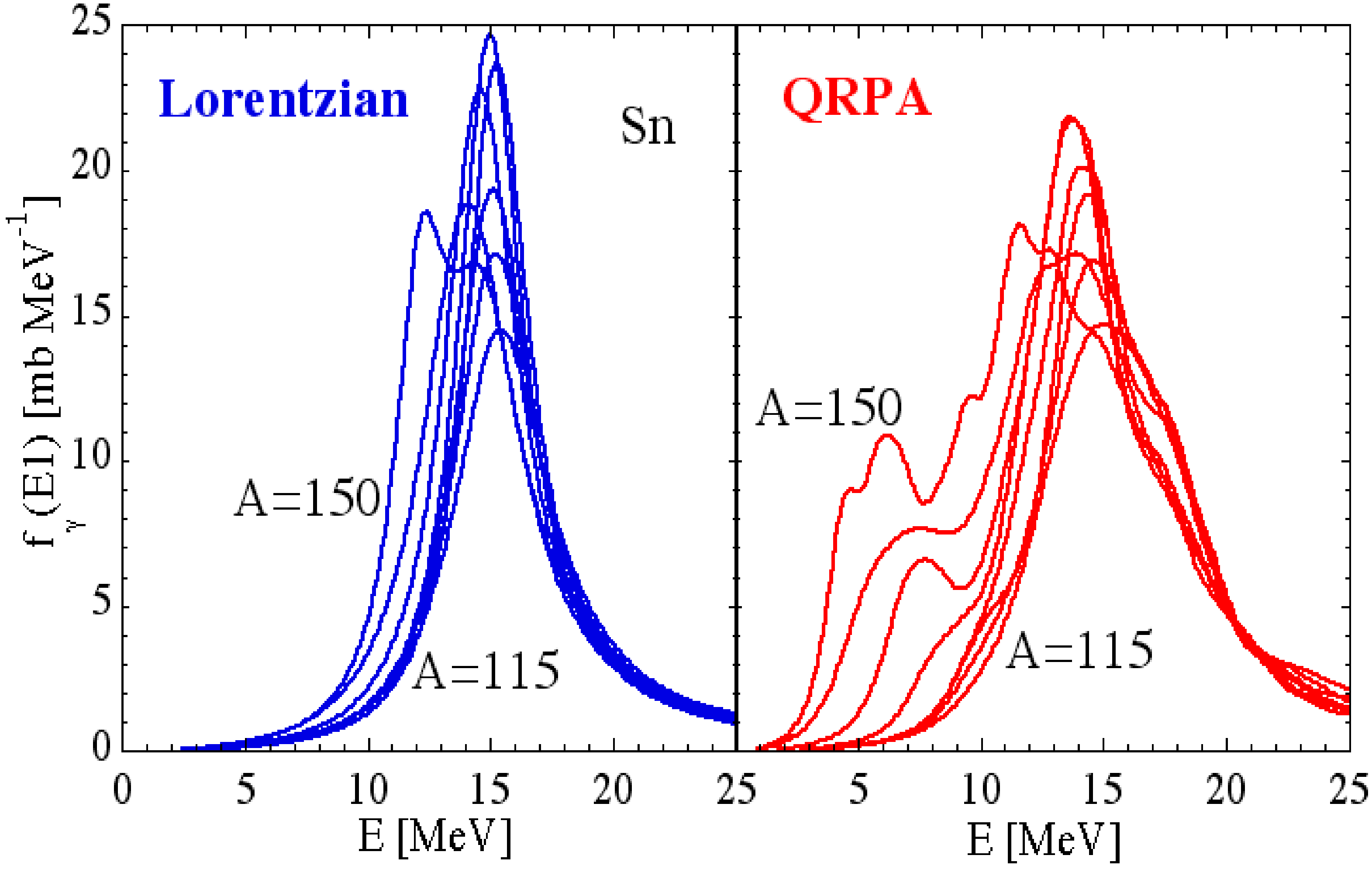
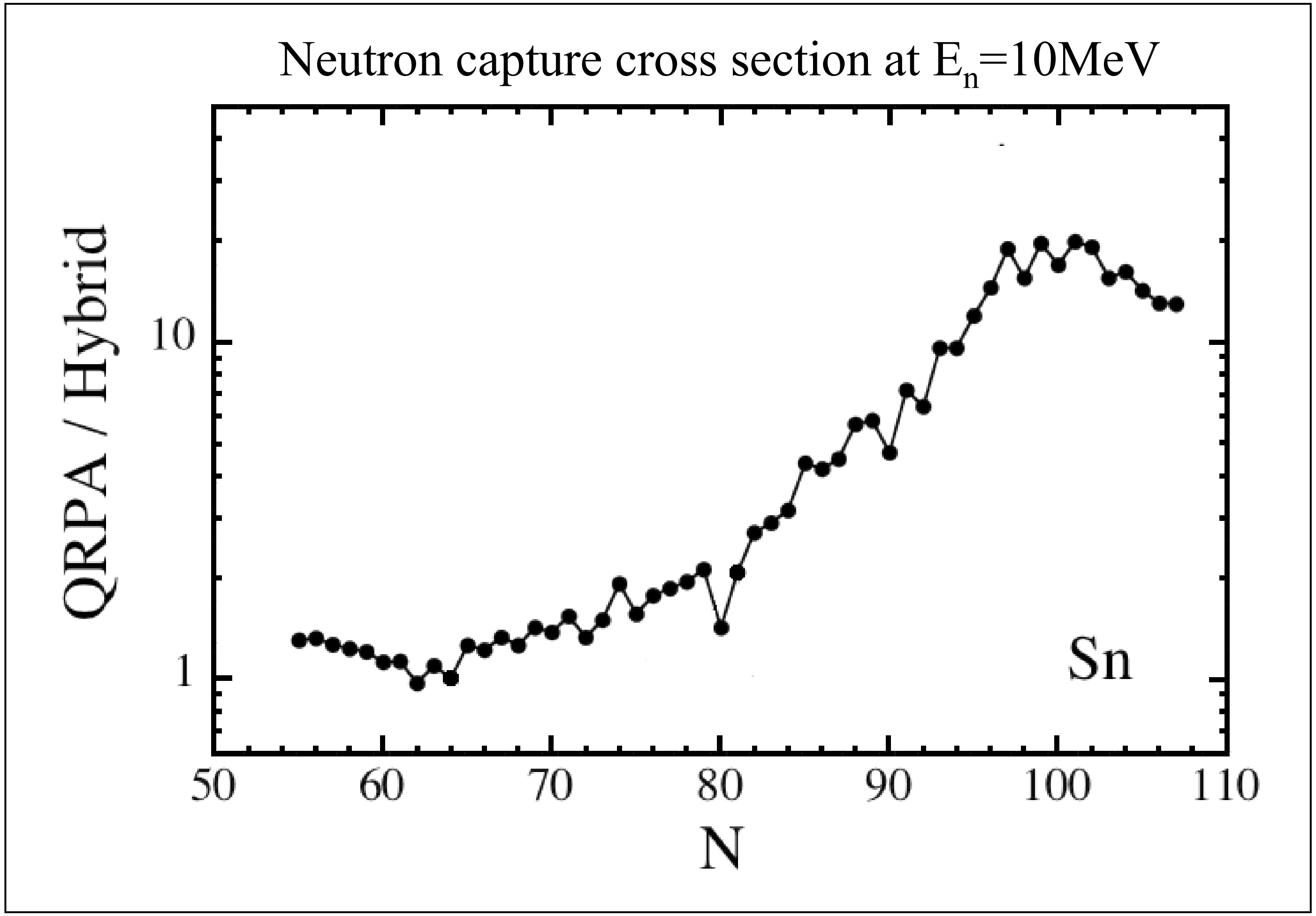
Microscopic γ-ray strength functions



⇒ **Good agreement with experimental data.**

⇒ **Significant differences for exotic nuclei.**

Microscopic vs Phenomenologic γ-ray strength functions and cross sections



⇒ **Impact not essential close to stability but crucial otherwise.**

Phenomenological ⇒ microscopic predictions ?

Experimentally known (deduced) ⇒ Theoretically predicted

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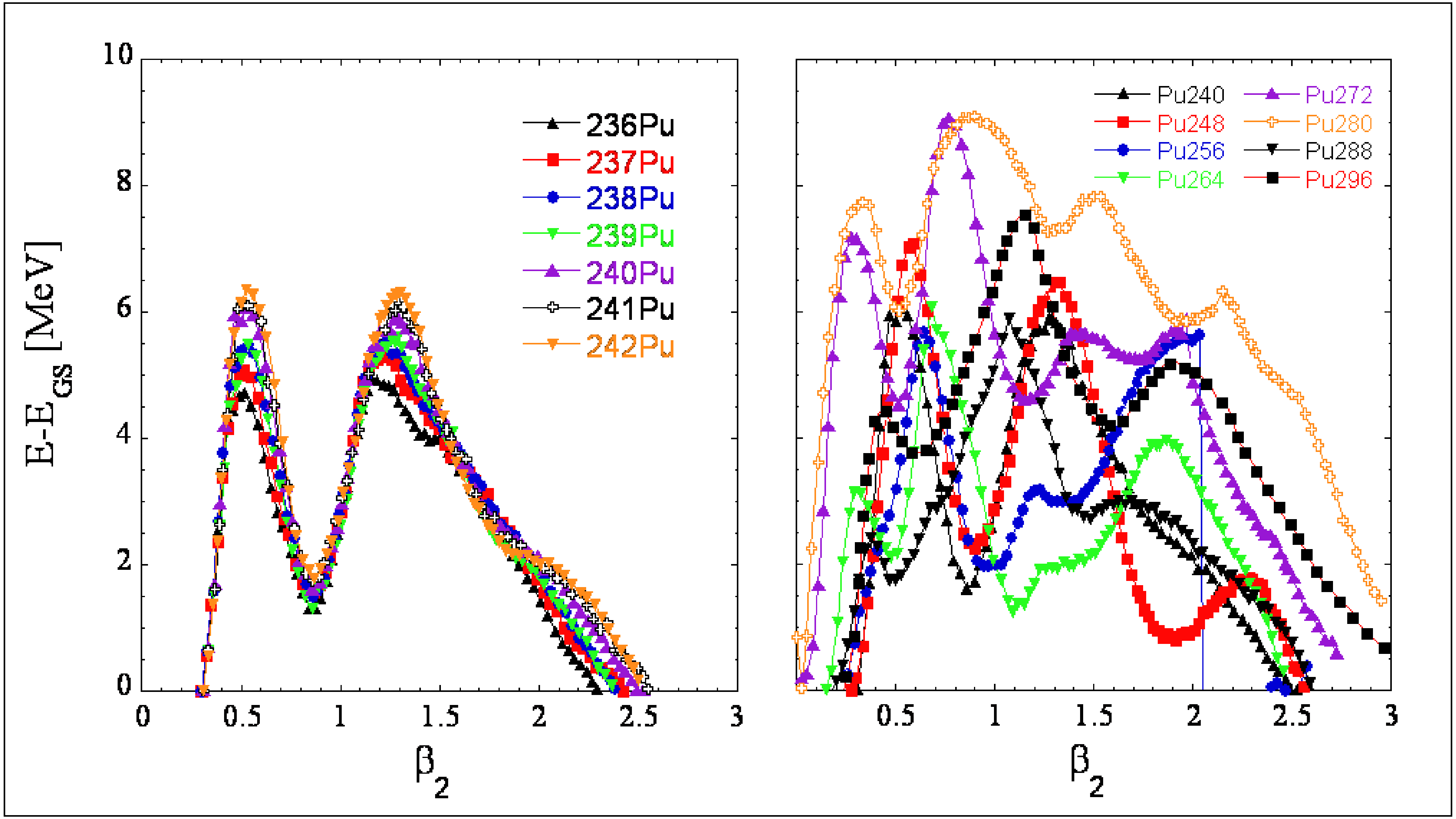
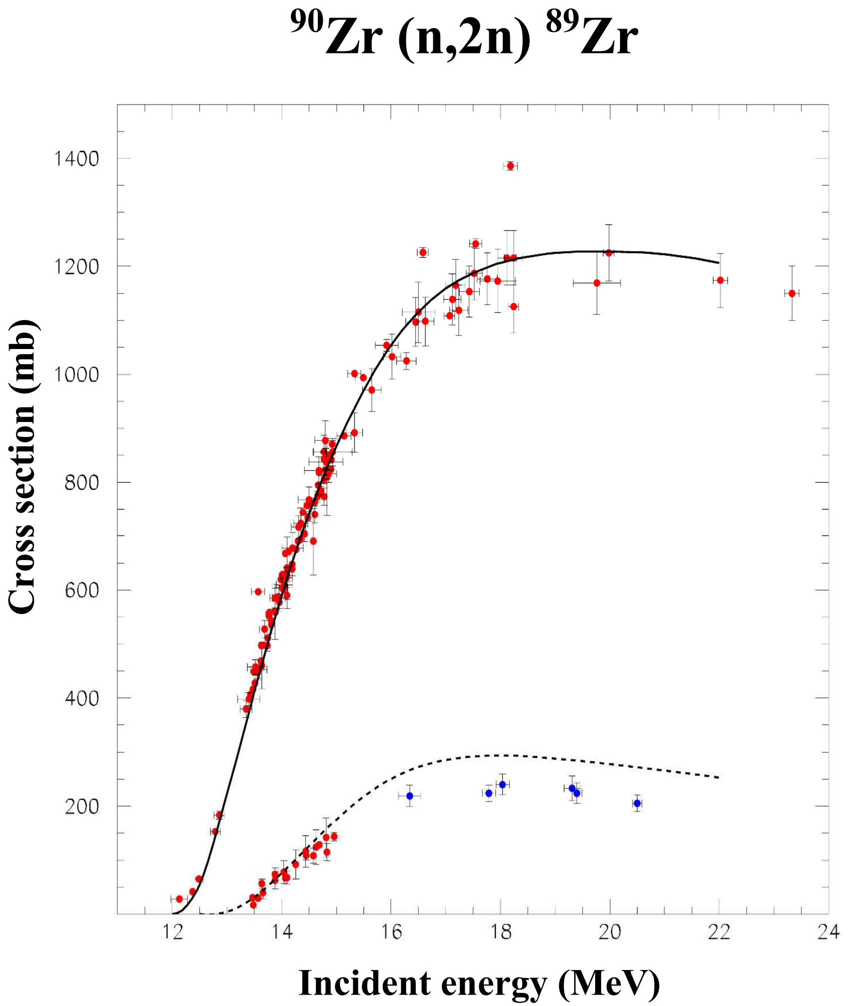
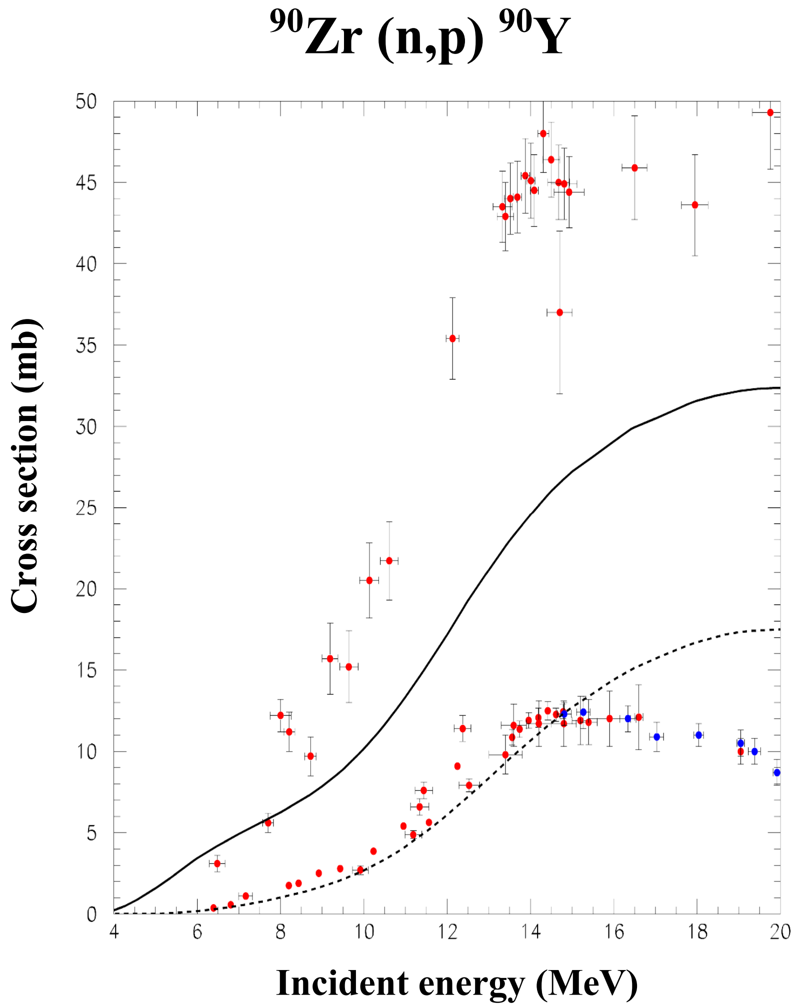
Microscopic fission barrier shapes



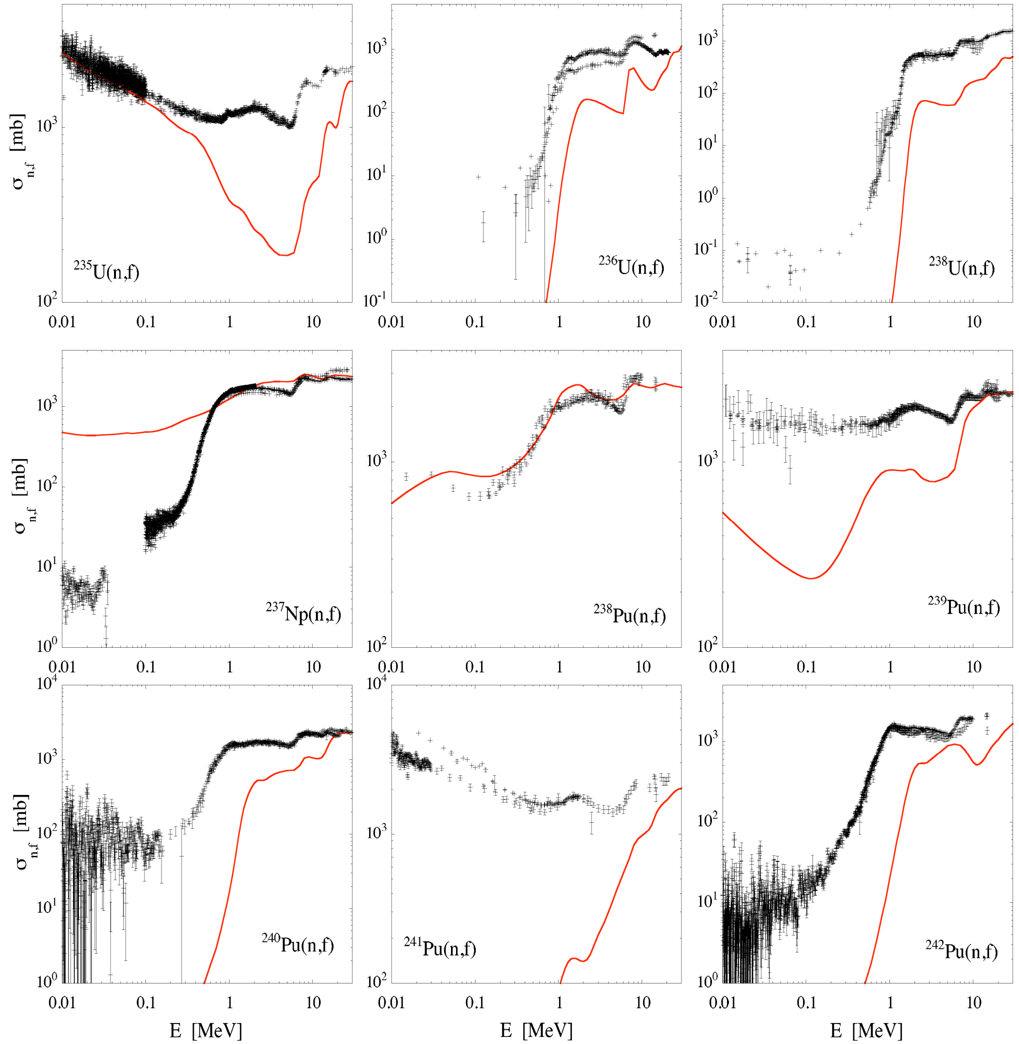
⇒ **For exotic nuclei : strong deviations from Hill-Wheeler.**

Fully (almost) microscopic cross section





Microscopic fission cross sections



⇒ **Default calculations after few adjustments:**
Not sufficient for applications.

Coherent fission cross sections with microscopic ingredients

HFB-14 predictions of fission barriers and NLD at saddle points, including renormalization (5 parameters) of

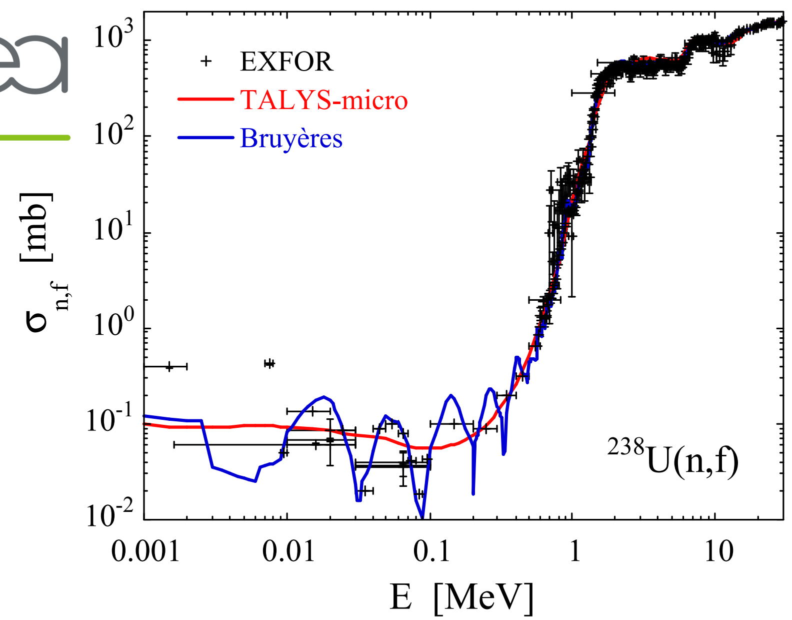
- fission path height: $B_f'(\beta_2) = B_f(\beta_2) \times v_{corr}$ $\Rightarrow$ no change of the topology !!
- NLD at 1st and 2d saddle points: $\rho'(U,J,P) = \rho(U-\delta,J,P)\,e^{\alpha\sqrt{U-\delta}}$

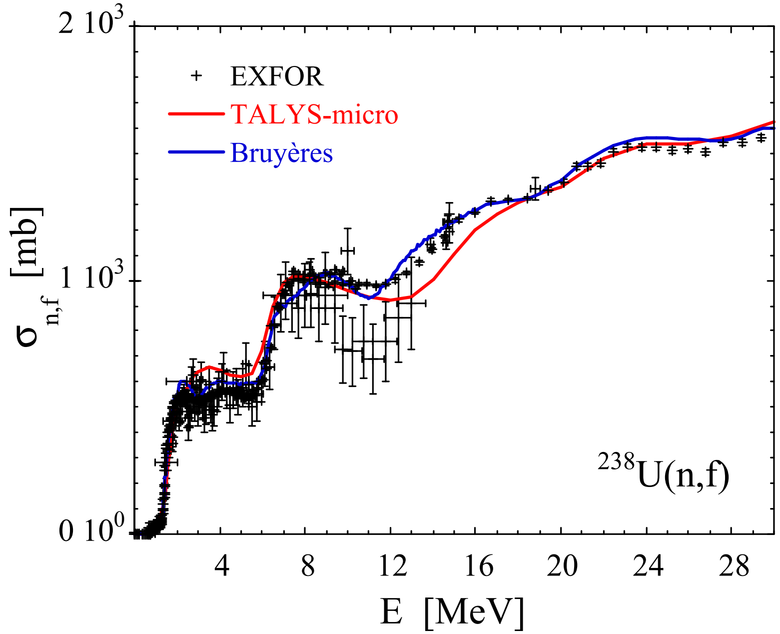
Additional nuclear inputs:

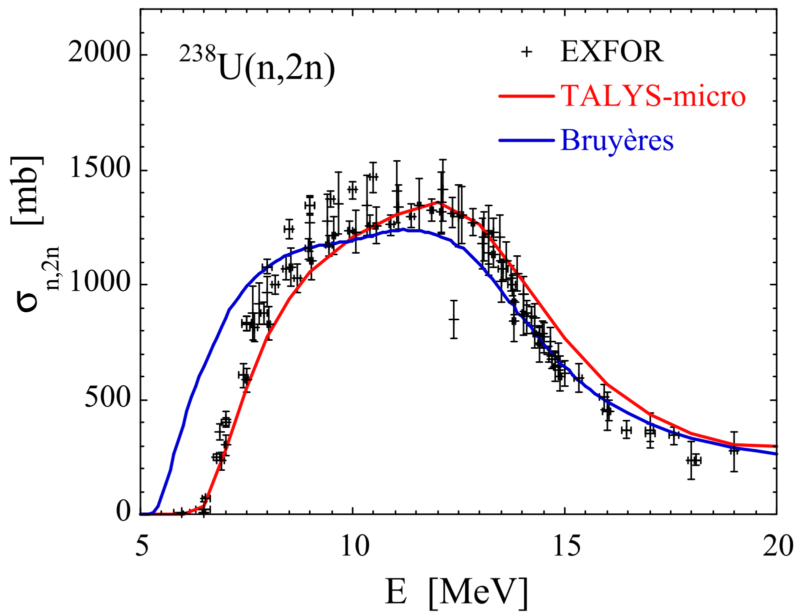
- Nuclear structure properties: HFB-14 (Goriely et al. 2007)
- Optical potential: Soukhovitskii et al. (2004)
- γ-ray strength: Hybrid model (Goriely, 1998)
- Equilibrium NLD: HFB-14 plus combinatorial model (Goriely et al., 2008) normalized on s-wave spacings and discrete levels

Note:

- no class 2 states included
- no discrete transition states included
- Experimental data in EXFOR only !


EXFOR
TALYS-micro
Bruyères
238U(n,f)
σn,f [mb]
E [MeV]
0.001
0.01
0.1
1
10
10-2
10-1
100
101
102
103


EXFOR
TALYS-micro
Bruyères
238U(n,f)
σn,f [mb]
E [MeV]
4
8
12
16
20
24
28
0 100
1 103
2 103


238U(n,2n)
EXFOR
TALYS-micro
Bruyères
σn,2n [mb]
E [MeV]
5
10
15
20
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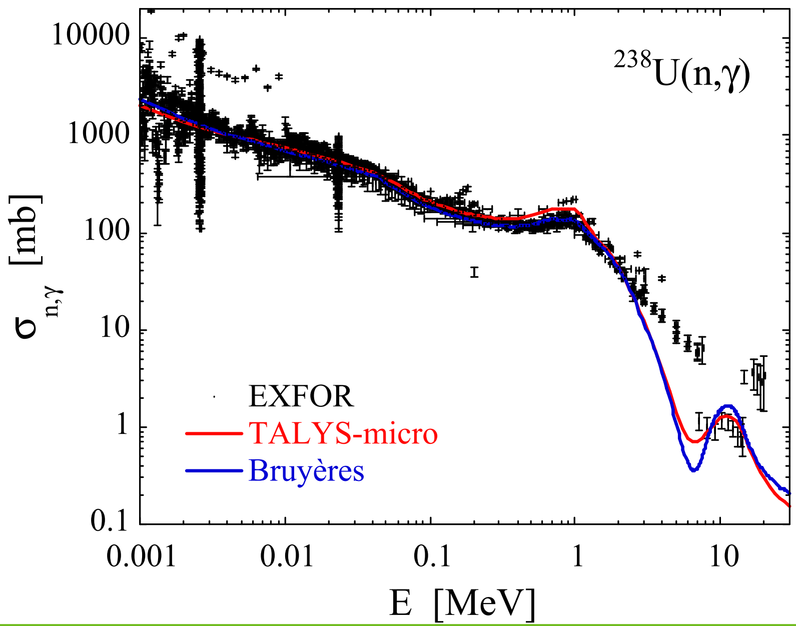
500
1000
1500
2000


238U(n,γ)
EXFOR
TALYS-micro
Bruyères
σn,γ [mb]
E [MeV]
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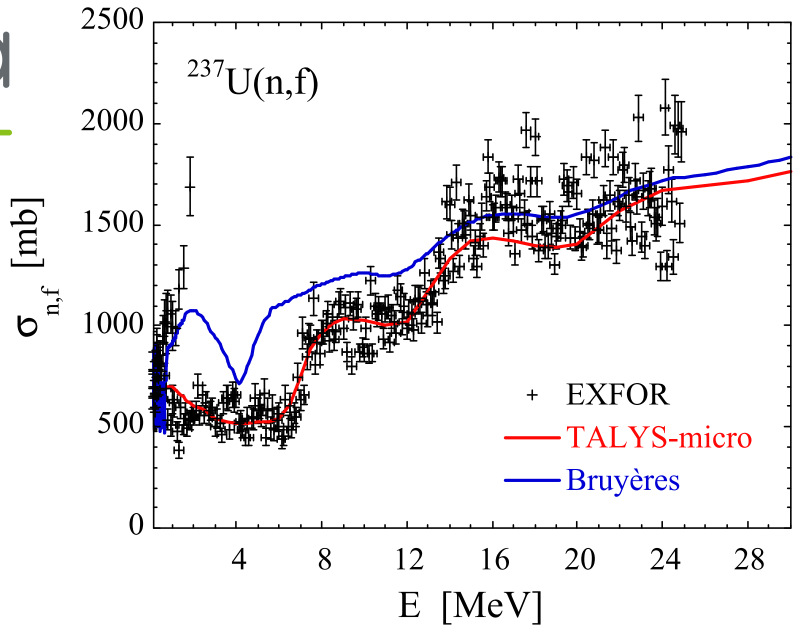

^{237}U(n,f)
EXFOR
TALYS-micro
Bruyères
$\sigma_{n,f}$ [mb]
E [MeV]
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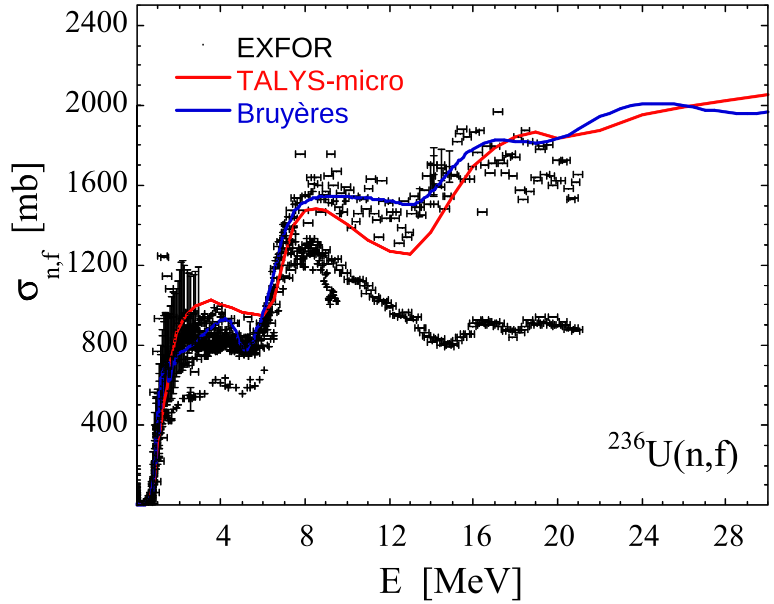

EXFOR
TALYS-micro
Bruyères
^{236}U(n,f)
$\sigma_{n,f}$ [mb]
E [MeV]
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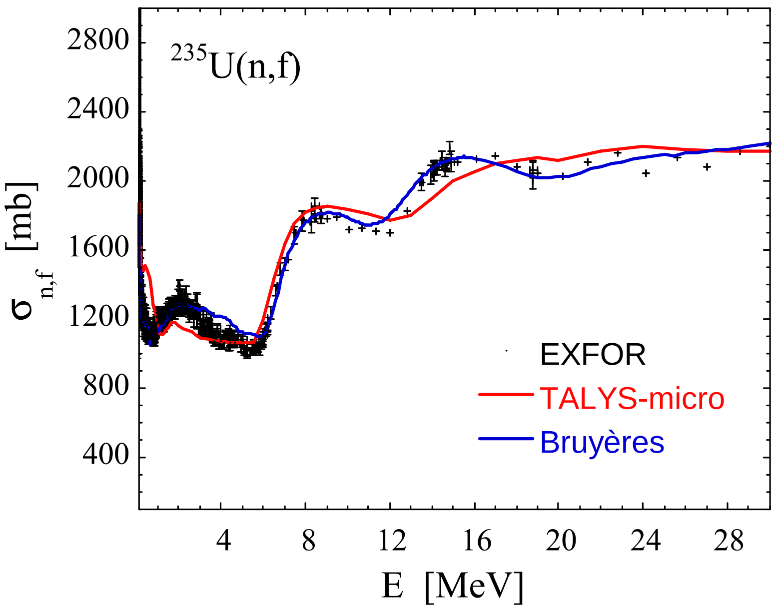

^{235}U(n,f)
EXFOR
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Bruyères
$\sigma_{n,f}$ [mb]
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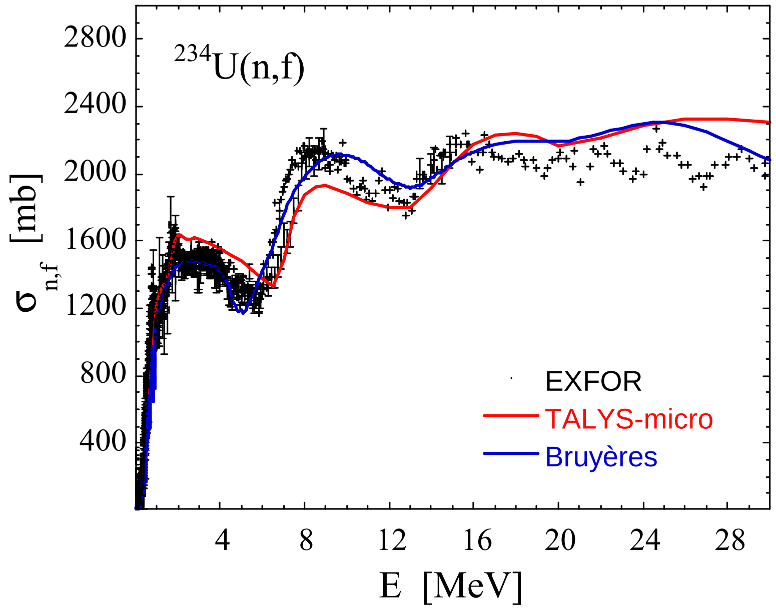

^{234}U(n,f)
EXFOR
TALYS-micro
Bruyères
$\sigma_{n,f}$ [mb]
E [MeV]
400
800
1200
1600
2000
2400
2800
4
8
12
16
20
24
28

Conclusions and prospects

- ***Cross section modeling quite easy for non fissile nuclei***

  Microscopic or Phenomenological OMP, Γ_γ, LDs

  ⇒ full microscopic calculation for non fissile nuclei almost possible

- ***Difficult but feasible cross section modeling for fissile nuclei***

- ***Web site opened in October 2006 : www.talys.eu***

  ⇒ All microscopic ingredients mentioned included in the distribution

• *Nev*

• *JLN*

• *Neu*

• *Mic* *ev.)*