Attempts to infer the neutron inelastic cross sections using charged particle induced reactions

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Summary

1. Introduction
2. The $^{28}Si(n,n'\gamma)^{28}Si$ reaction @ GELINA, IRMM
3. The $^{25}Mg(\alpha,n\gamma)^{28}Si$ reaction @ Tandem, IFIN-HH
4. Results and discussion
5. Conclusions

Introduction: why? how?

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Introduction

The attempt to infer neutron induced cross sections from charged particle induced reactions

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Surrogate reactions: use a **direct reaction** at rather high energy to excite the nucleus then investigate the decay.

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Fairly successful when applied to **capture** and to **fission** cross sections.

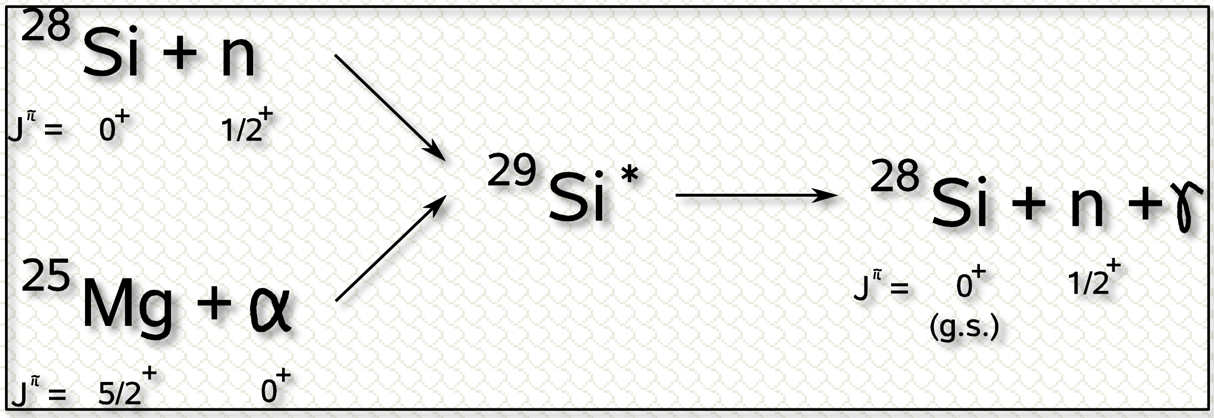
Can we do something similar for **neutron inelastic** cross sections?

Bohr hypothesis: Because the compound nucleus has a long lifetime compared to the time the projectile/ejectile needs to cross the nucleus, the decay channel should not depend – on a first approximation – on the input channel or otherwise formulated, the decay state forgets the way it was created. However it may work only for medium and heavy nuclei.

How and when this hypothesis is valid?

Can we use it to infer neutron-induced cross sections from charged particle-induced reactions?

Introduction



Compare **gamma production cross sections**.

Basic differences between the two reactions:

- Different **Q- value → upward or downward shift in excitation energy**
- The **Coulomb barrier present** in case of the alpha-induced reaction →additional shift, blackout zone
- Different **angular momenta** → different decaying states populated

$^{28}Si(n,n'\gamma)^{28}Si$

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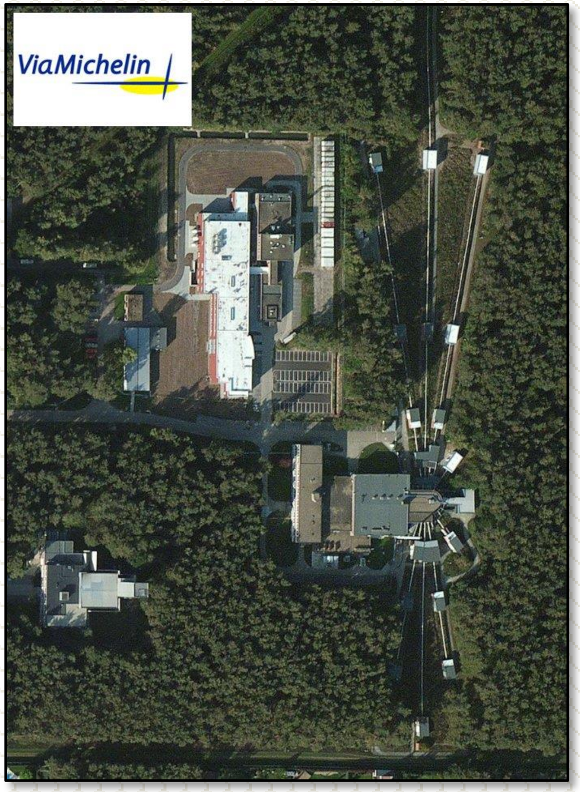
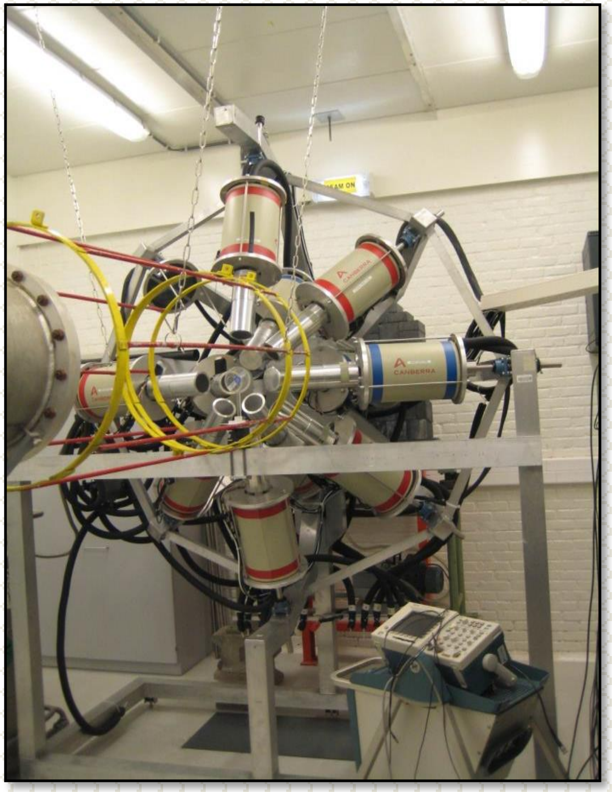
$^{28}Si(n,n'\gamma)^{28}Si$: The experimental setup



Neutron source: GELINA (white flux 100 keV – 20 MeV)
IRMM, Geel, Belgium

- TOF technique (200 m flight path):
  Amplitude ⇔ gamma energy
  Time ⇔ neutron energy



GAINS: Array of 12 HPGe detectors (ε=100%) used for highly precise neutron inelastic cross section measurements

- Beam monitoring: ^{235}U Fission chamber

$^{28}Si(n,n'\gamma)^{28}Si$: The analysis

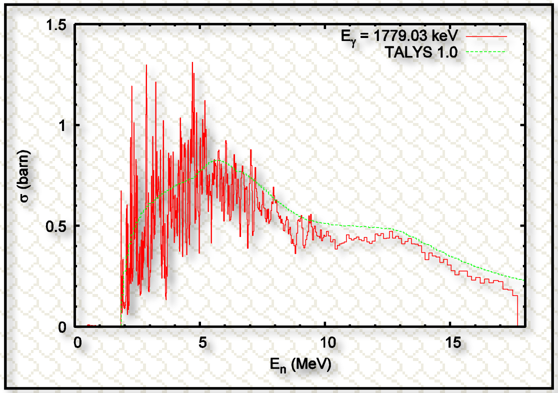
12 x HPGE yield

FC yield

HPGe Efficiency:
Monte-Carlo simulation

FC Efficiency

Gamma Production cross sections



NDS: level scheme

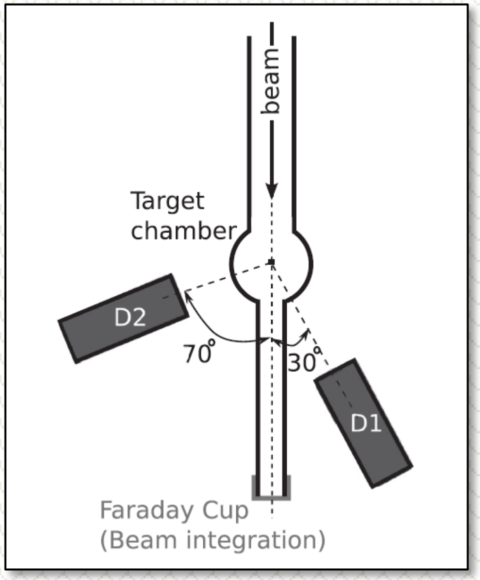
Total inelastic cross section
Level cross sections

IFIN-HH

$^{25}Mg(\alpha,n\gamma)^{28}Si$

$^{25}Mg(\alpha,n'\gamma)^{28}Si$: Experimental setup

The Tandem accelerator
IFIN-HH, Bucharest



2 HPGe Detection setup
Faraday cup

- E_{α}=5.6, 5.8, 6.0, 6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 6.8, 6.9, 7.0, 7.3, 7.6, 7.8, 8.0, 8.5, 9.0, 10.0, 12.0, 15.0 MeV

- HPGe efficiency calibration using a ^{152}Eu source (calibrated) + a ^{56}Co source (uncalibrated).

Results and discussion

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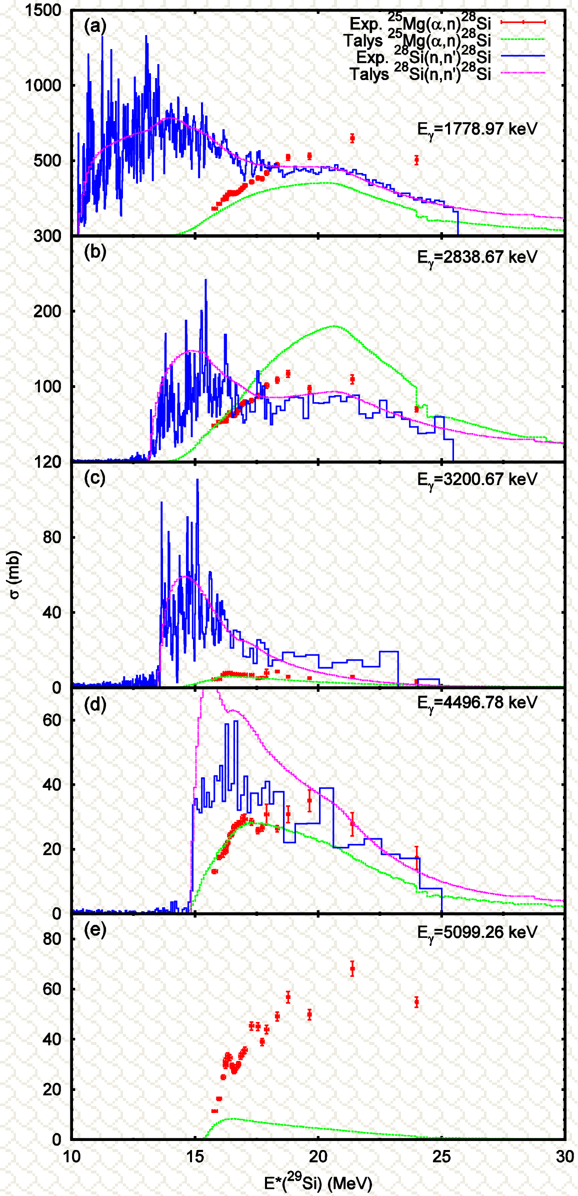
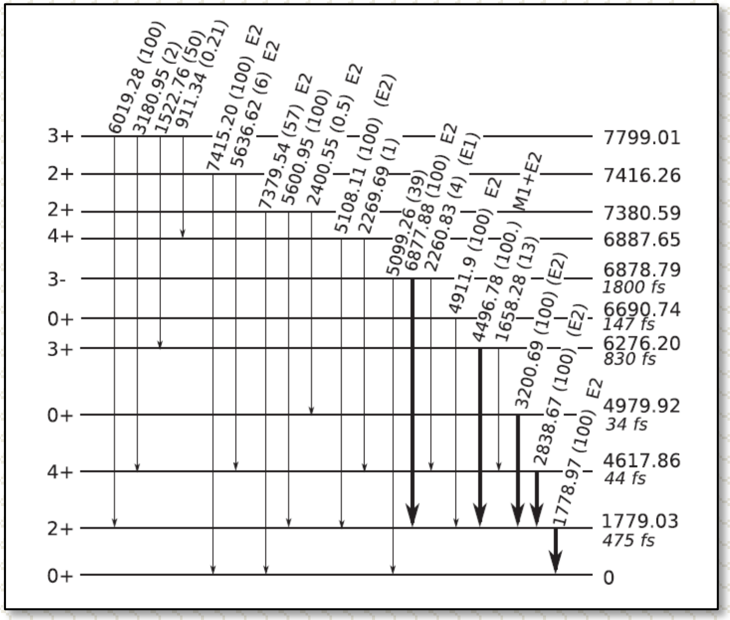
IFIN-HH

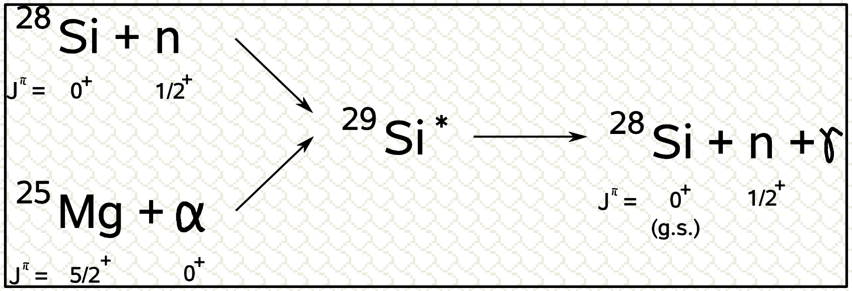
Results: γ production cross sections

Why are they so similar?
Why are they so different?

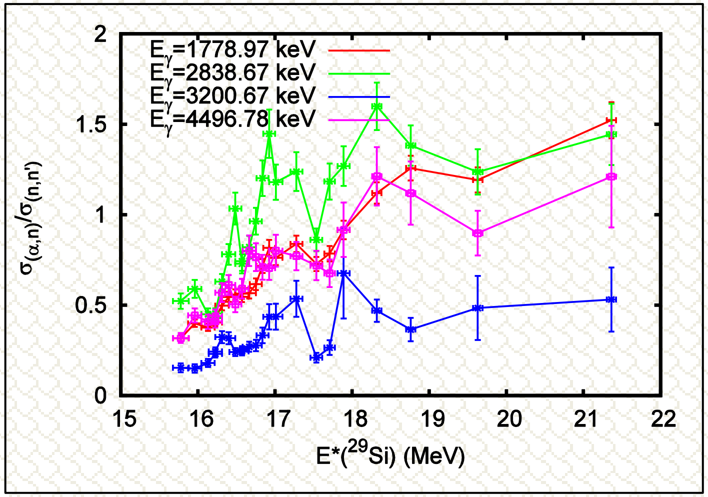




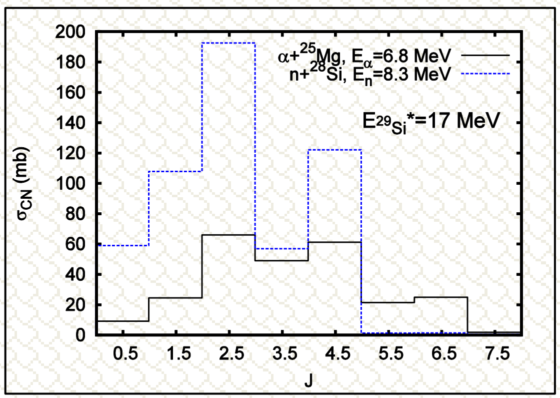
^{28}Si level scheme [ENSDF]



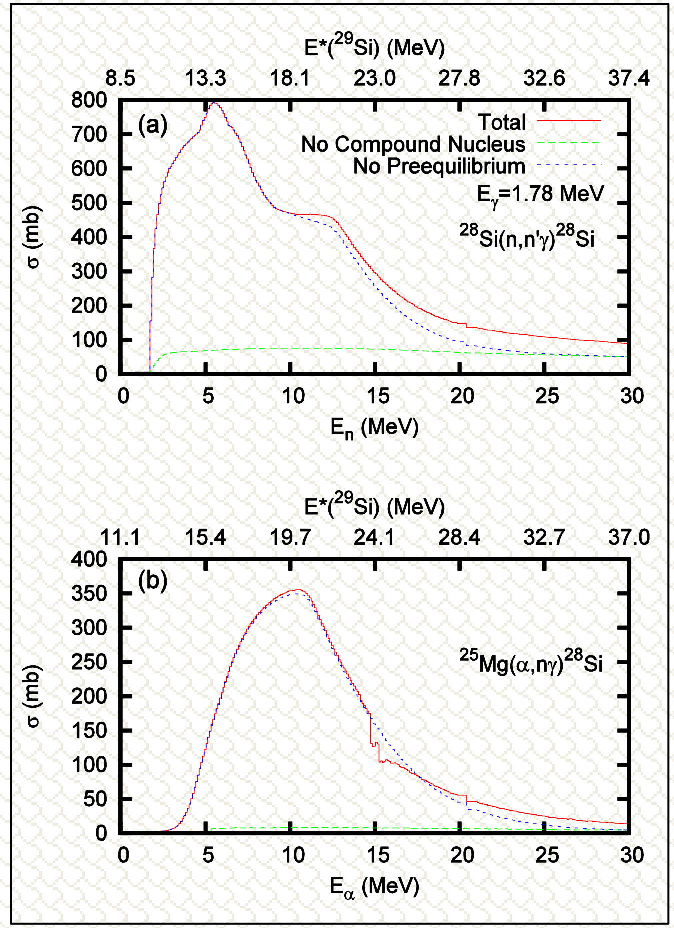
Discussion



EXP: Cross section ratios



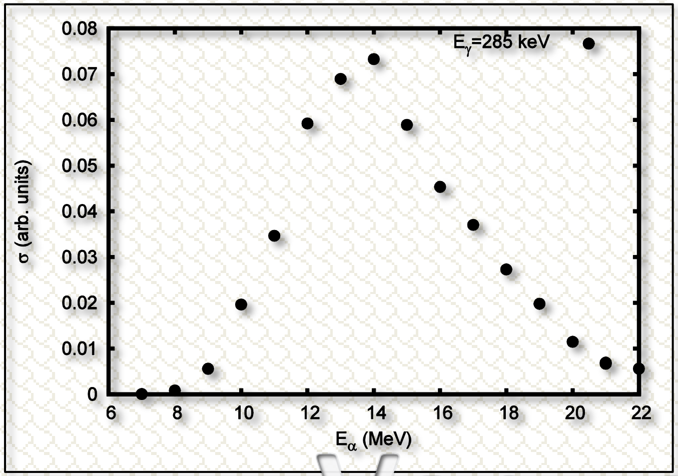
TALYS: Total angular momentum in the compound nucleus

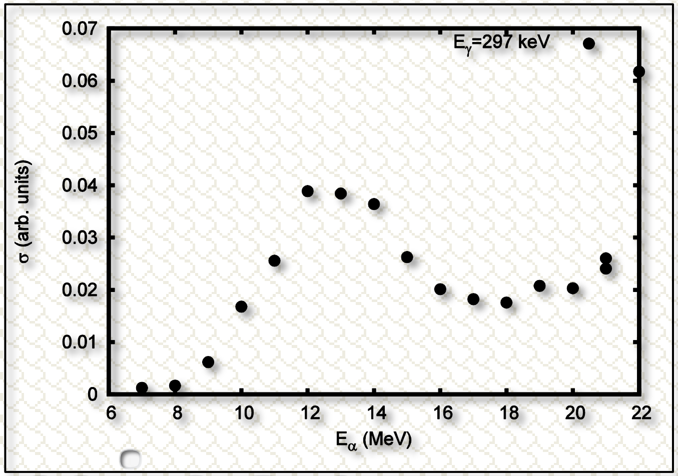


TALYS: Interplay of reaction mechanisms

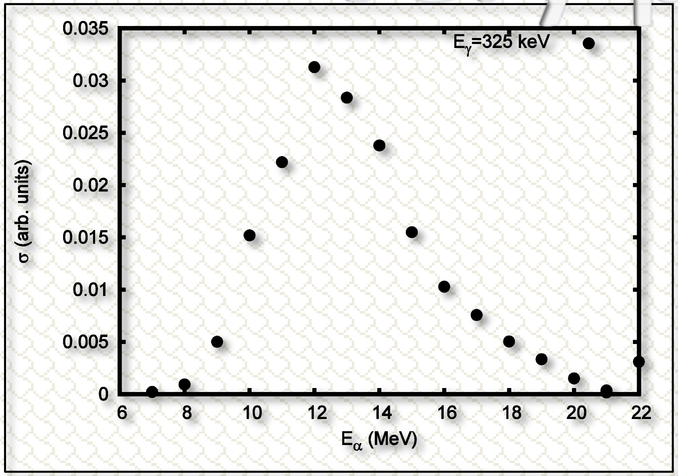
Next step: $^{70}Zn(\alpha,n\gamma)^{73}Ge$ @ the Tandem, IFIN-HH

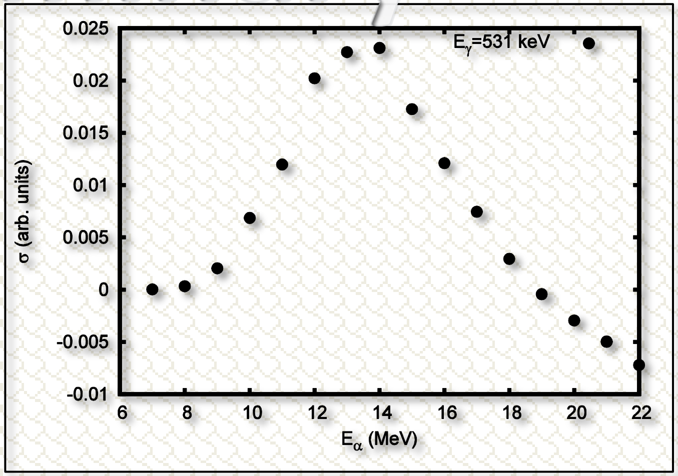
ERINDA experiment proposed by M. Kerveno *et al.*





Very preliminary





Other possibilities

- $^{232}Th + \alpha \rightarrow {}^{236}U^* \rightarrow {}^{235}U + n$ vs. ^{235}U (n,n') ^{235}U

Actinides, Bohr hypothesis should work, but:

Q=-11.12 MeV

Coulomb barrier: 22.7 MeV

- ^{28}Si(p,p') vs. ^{28}Si(n,n')

Mirror compound nuclei

Conclusions

Conclusions

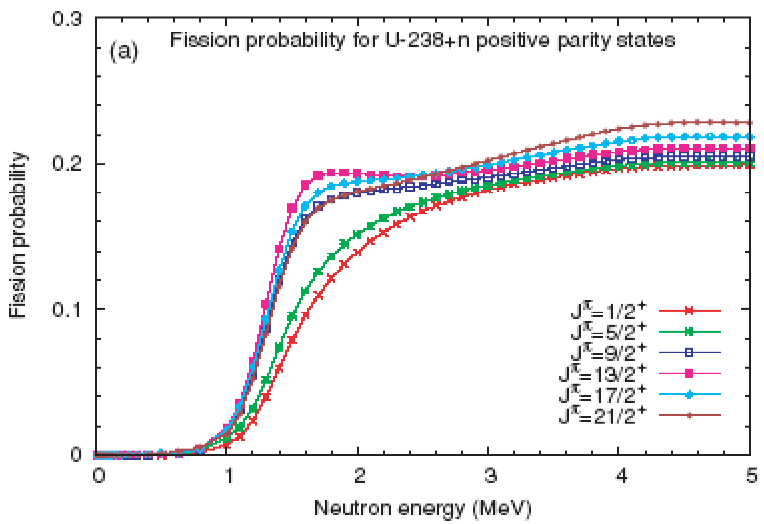
Phys. Rev. C88, 034604 (2013):

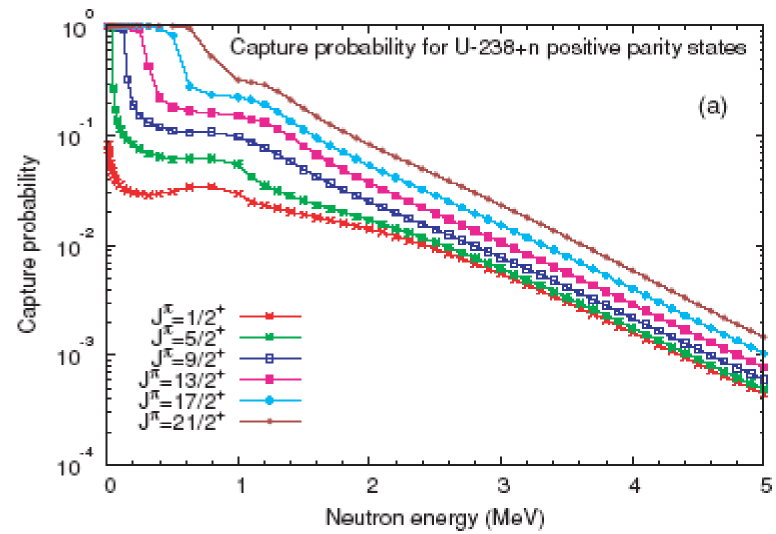
”The investigation of other cases should be performed before a clear experimental conclusion can be obtained regarding the comparison of the (*α, nγ*) and (*n, n'γ*) data. The present study shows that the *γ* production cross sections excited in the two reactions are of the same order of magnitude, while an attempt to directly derive one result from the other based on the Bohr hypothesis results in uncertainties of the order of at least 50%.”

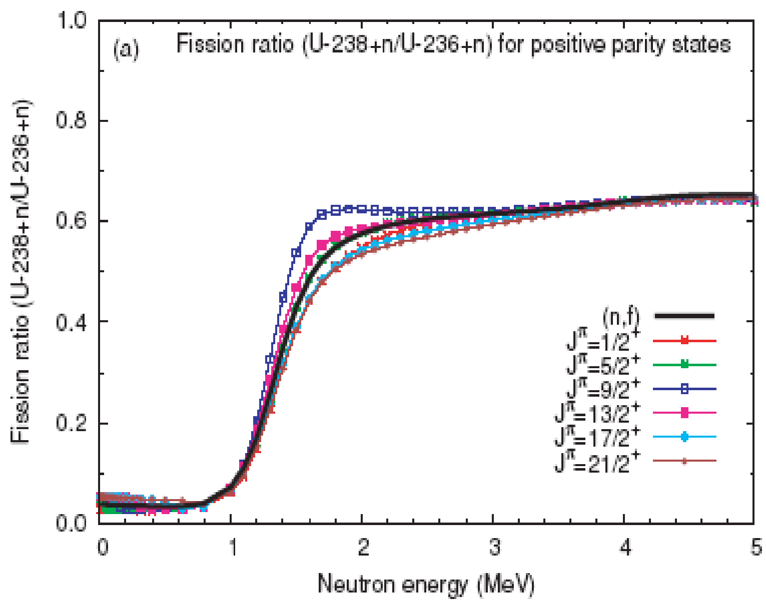
Can theoretically assisted corrections help to reliably improve the “predictions”?

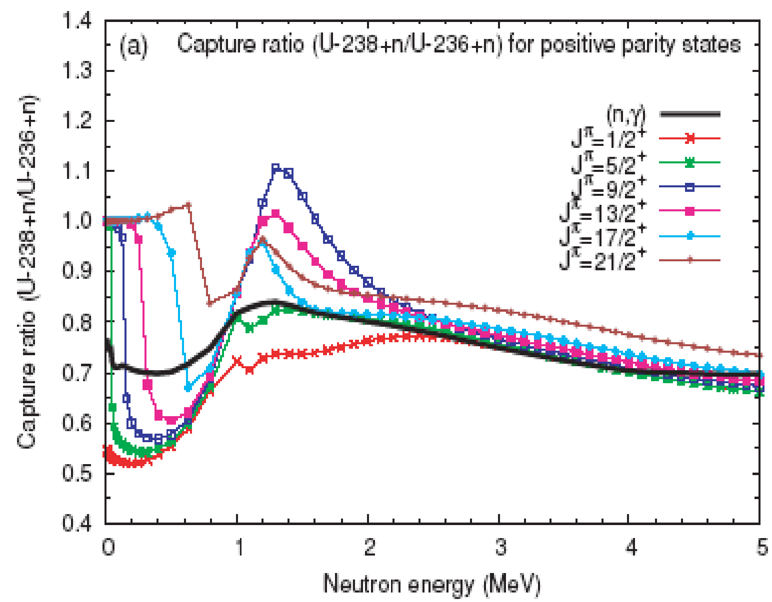
Theoretical “simulations” of the surrogate method show a better agreement in the case of fission and capture; can such assessment be made in the case of inelastic cross sections?

Thank you!


(a) Fission probability for U-238+n positive parity states
Fission probability
Neutron energy (MeV)
0
0.1
0.2
0.3
0
1
2
3
4
5
$J^\pi=1/2^+$
$J^\pi=5/2^+$
$J^\pi=9/2^+$
$J^\pi=13/2^+$
$J^\pi=17/2^+$
$J^\pi=21/2^+$


Capture probability for U-238+n positive parity states
(a)
Capture probability
Neutron energy (MeV)
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
1
2
3
4
5
$J^\pi=1/2^+$
$J^\pi=5/2^+$
$J^\pi=9/2^+$
$J^\pi=13/2^+$
$J^\pi=17/2^+$
$J^\pi=21/2^+$


(a) Fission ratio (U-238+n/U-236+n) for positive parity states
Fission ratio (U-238+n/U-236+n)
Neutron energy (MeV)
0.0
0.2
0.4
0.6
0.8
1.0
0
1
2
3
4
5
(n,f)
$J^\pi=1/2^+$
$J^\pi=5/2^+$
$J^\pi=9/2^+$
$J^\pi=13/2^+$
$J^\pi=17/2^+$
$J^\pi=21/2^+$


(a) Capture ratio (U-238+n/U-236+n) for positive parity states
Capture ratio (U-238+n/U-236+n)
Neutron energy (MeV)
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
0
1
2
3
4
5
(n,γ)
$J^\pi=1/2^+$
$J^\pi=5/2^+$
$J^\pi=9/2^+$
$J^\pi=13/2^+$
$J^\pi=17/2^+$
$J^\pi=21/2^+$