IAEA 60 Years
Atoms for Peace and Development

Introduction to the TALYS nuclear model code

Arjan Koning, IAEA

Joint ICTP-IAEA Workshop on Simulation of Nuclear Reaction Data with the TALYS Code, October 16 - 20 2023, Trieste

Introduction

- TALYS
  - History
  - What it is used for
  - Worldwide use
  - What it can do
- Some nuclear models (very global)
- TALYS sample cases
- TALYS in a larger picture (applications)
- Conclusions

What is TALYS?

- Computer program to simulate nuclear reactions:
  - Open source, MIT license
  - Development sponsored by national and EU funding, and by private effort
  - Main development sites in Petten, Bruyères-le-Châtel, Brussels and Vienna

ULB UNIVERSITÉ LIBRE DE BRUXELLES

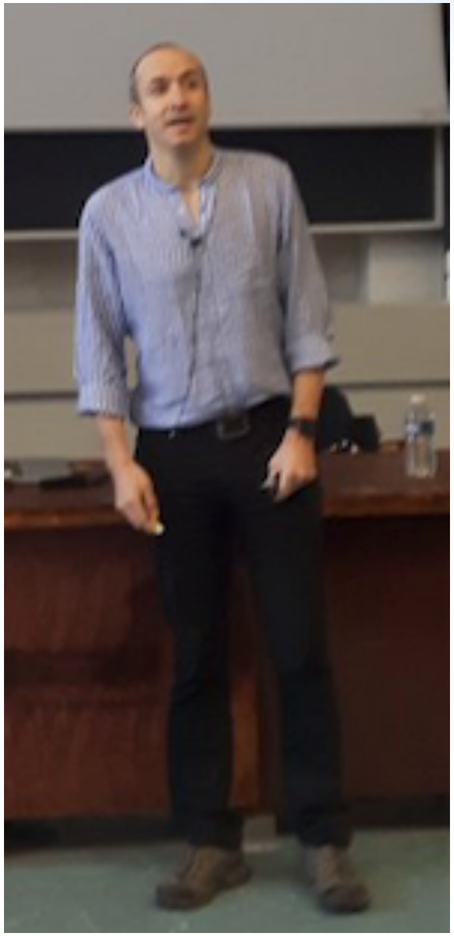
NRG

cea

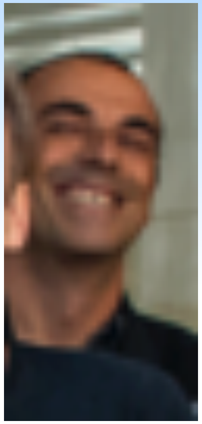
IAEA International Atomic Energy Agency

Who made TALYS?

Arjan Koning
Current: IAEA, Vienna



Stephane Goriely
Current: Univ. Libre Brussels



Stephane Hilaire
Current: CEA-DAM,
Bruyères-le-Châtel

Marieke Duijvestijn
Current: acupunctuurmarieke.nl

Special thanks

Dimitri Rochman

Jura Kopecky

Phil Young†

Olivier Bersillon†

Jacques Raynal†

TALYS

- Used for fundamental nuclear physics research
- Used to produce nuclear data for applications
- Projectiles: neutron, photon, proton, deuteron, triton, Helium-3, alpha particle
  - Also works for an excited nucleus as initial condition
- Targets: Z= 3-124, A=5-339
  - Reliability: Z > 9, A > 20
  - Also a natural element can be specified
- Incident energy: 1 meV - 1 GeV
  - Reliability: few keV - 200 MeV

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THE EUROPEAN PHYSICAL JOURNAL A

Check for updates

Review

TALYS: modeling of nuclear reactions

This is now the basic reference for TALYS

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[2] DIF, CEA, Arpajon 91297, France
[3] Université Paris-Saclay, CEA, LMCE, 91680 Bruyères-le-Châtel, France
[4] Institut d'Astronomie et d'Astrophysique, Université Libre de Bruxelles, Campus de la Plaine, CP-226, Brussels 1050, Belgium

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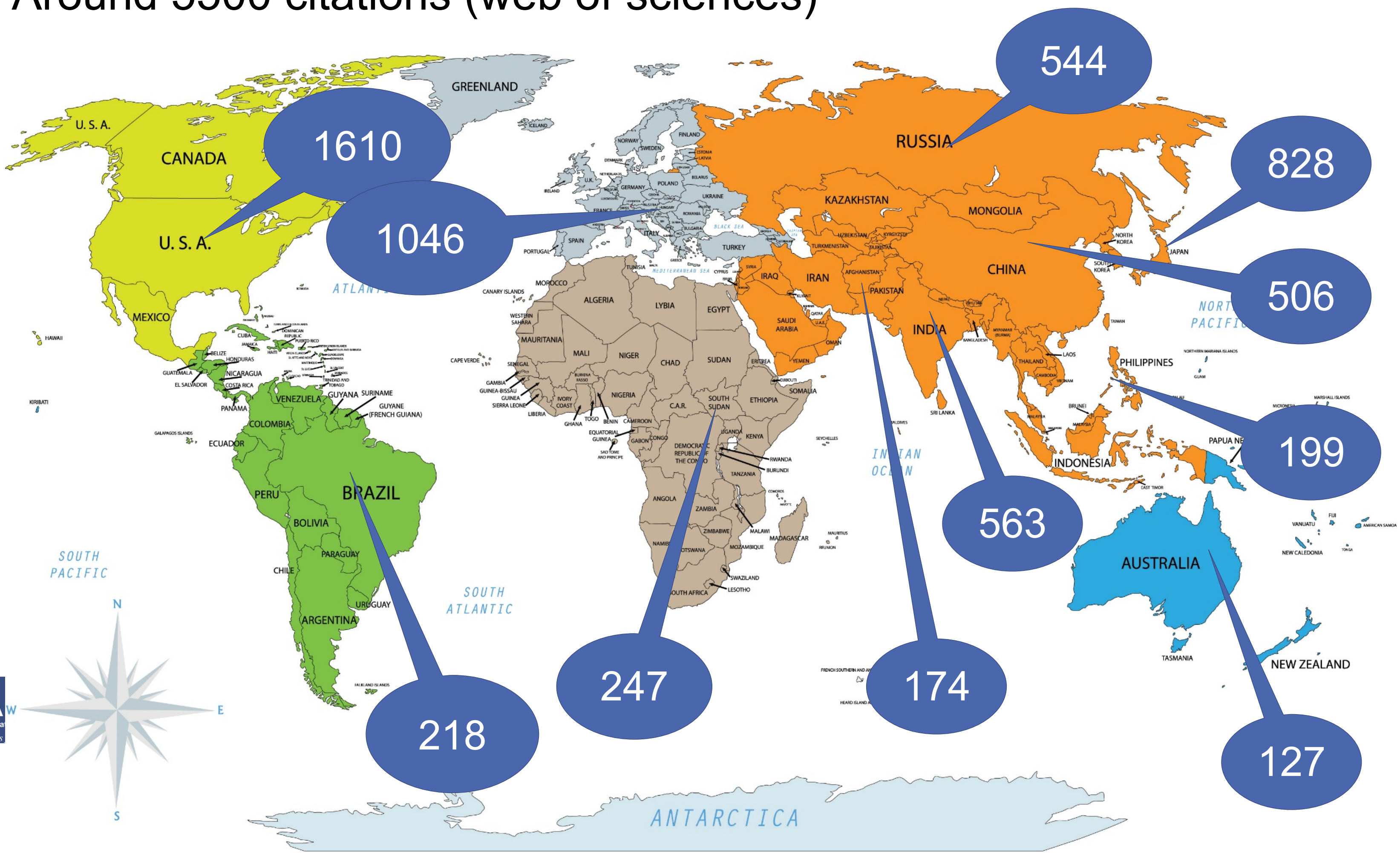
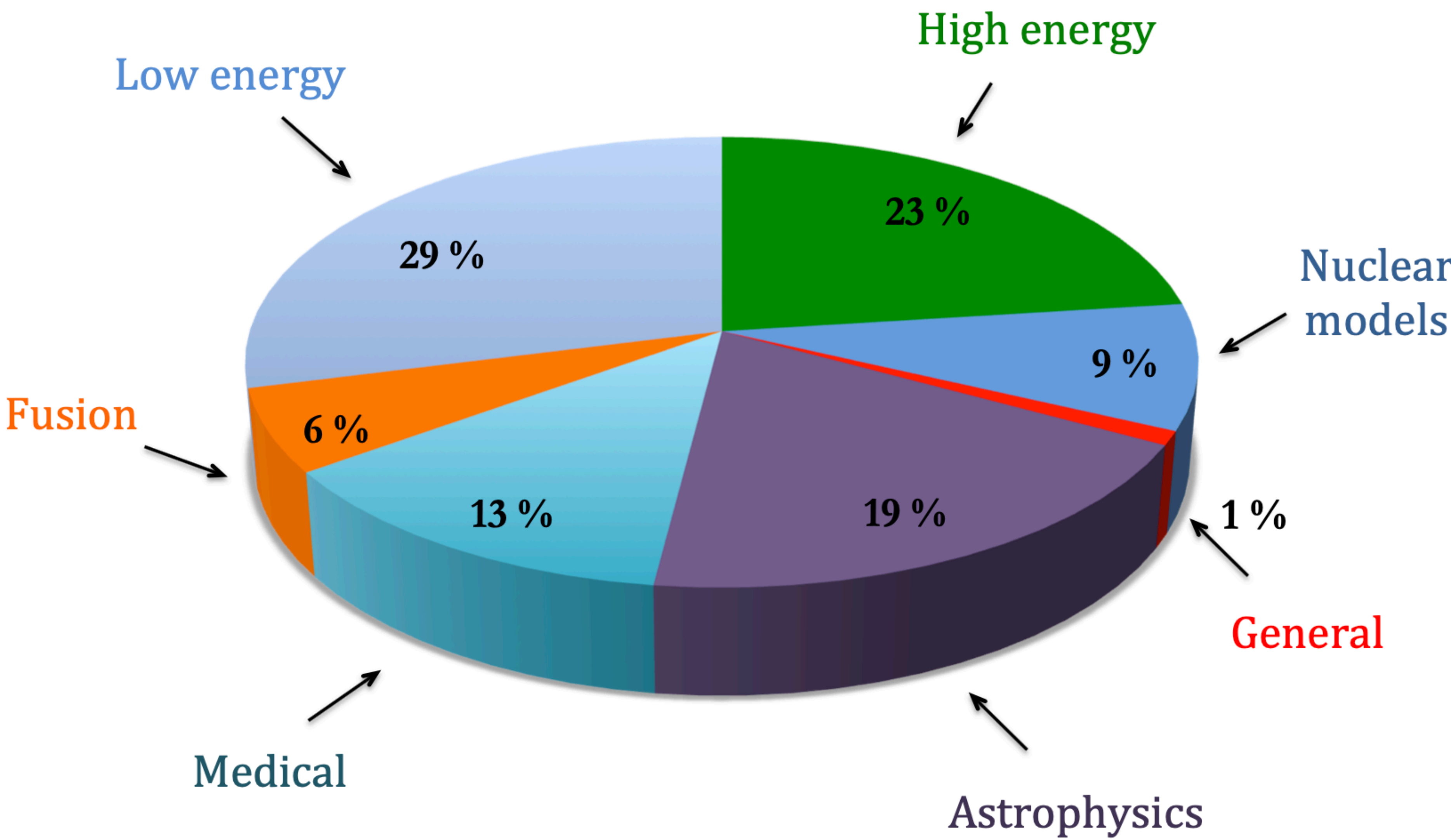
Communicated by Nicolas Alamanos

Abstract TALYS is a software package for the simulation of nuclear reactions below 200 MeV. It is used worldwide for the analysis and prediction of nuclear reactions and is based on state-of-art nuclear structure and nuclear reaction models. A general overview of the implemented physics and capabilities of TALYS is given. The general nuclear reaction mechanisms described are the optical model, direct reactions, compound nucleus model, pre-equilibrium reactions and fission. The most important nuclear structure models are those for masses, discrete levels, level densities, photon strength functions and fission barriers. A wide variety of nuclear reactions simulated with TALYS will be demonstrated, ranging from low-energy neutron cross sections, astrophysics, high-energy charged particle reactions and other reactions. TALYS is a nuclear reaction software which aims to give a complete description of nuclear reaction observables, and to be an important link between fundamental nuclear physics and applications.

TALYS around the World (status 2022)

- Around 5500 citations (web of sciences)

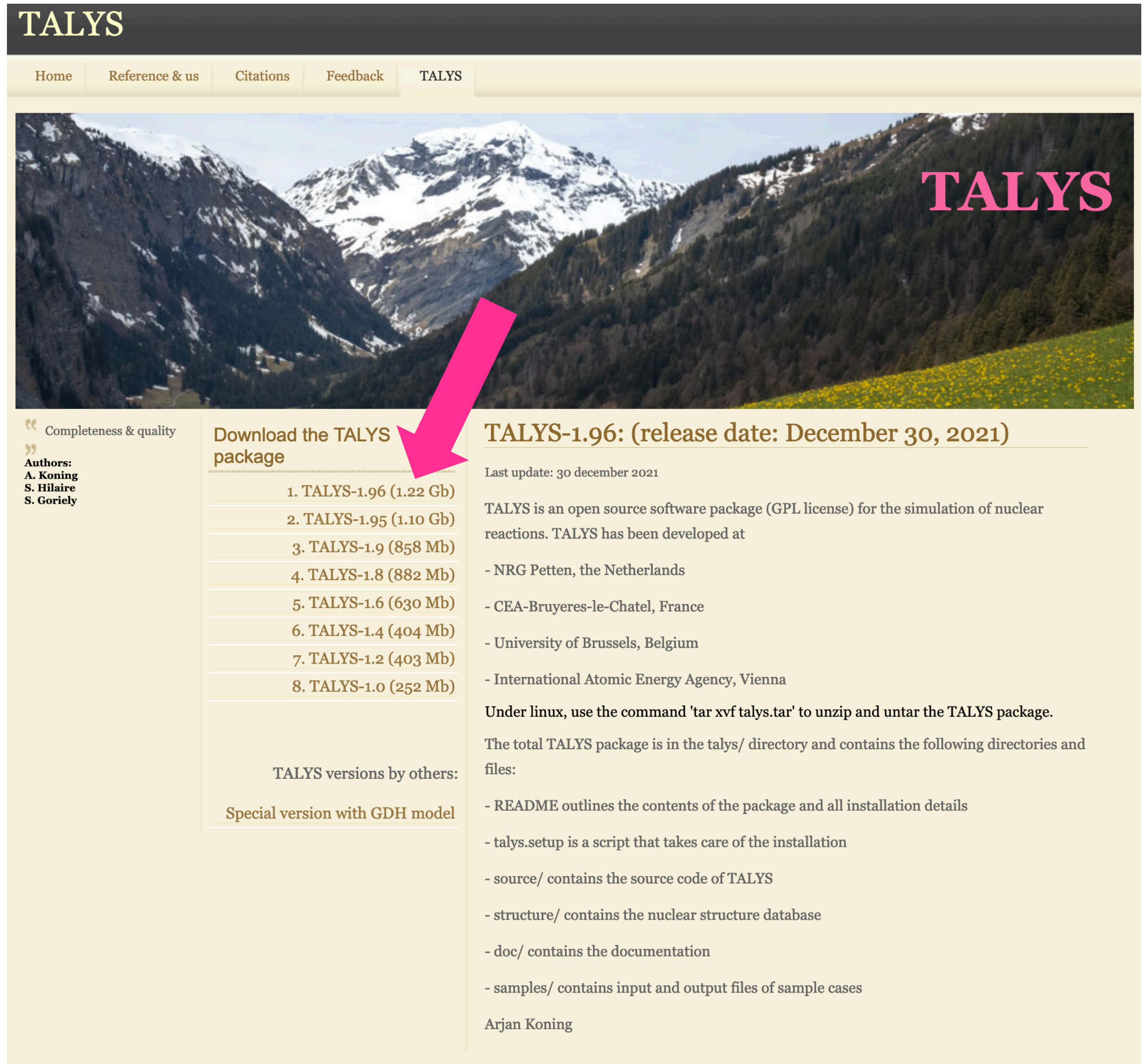



High energy
23 %
Low energy
29 %
Nuclear
models
9 %
Fusion
6 %
13 %
19 %
1 %
General
Medical
Astrophysics

Download TALYS

- Go to https://tendl.web.psi.ch/tendl_2021/talys.html

Scan to get URL



TALYS principles

We insist:
- Flawless and trivial software installation
- Complete and readable manual
- **Reproducibility**: you get the same results as we show, good or bad
- A large and diverse validation set
- TALYS does not crash

We aim:
- Physics as good as reasonably possible
- Adopting your innovations in our implementation: we are usually a few years behind the latest and greatest developments in nuclear physics

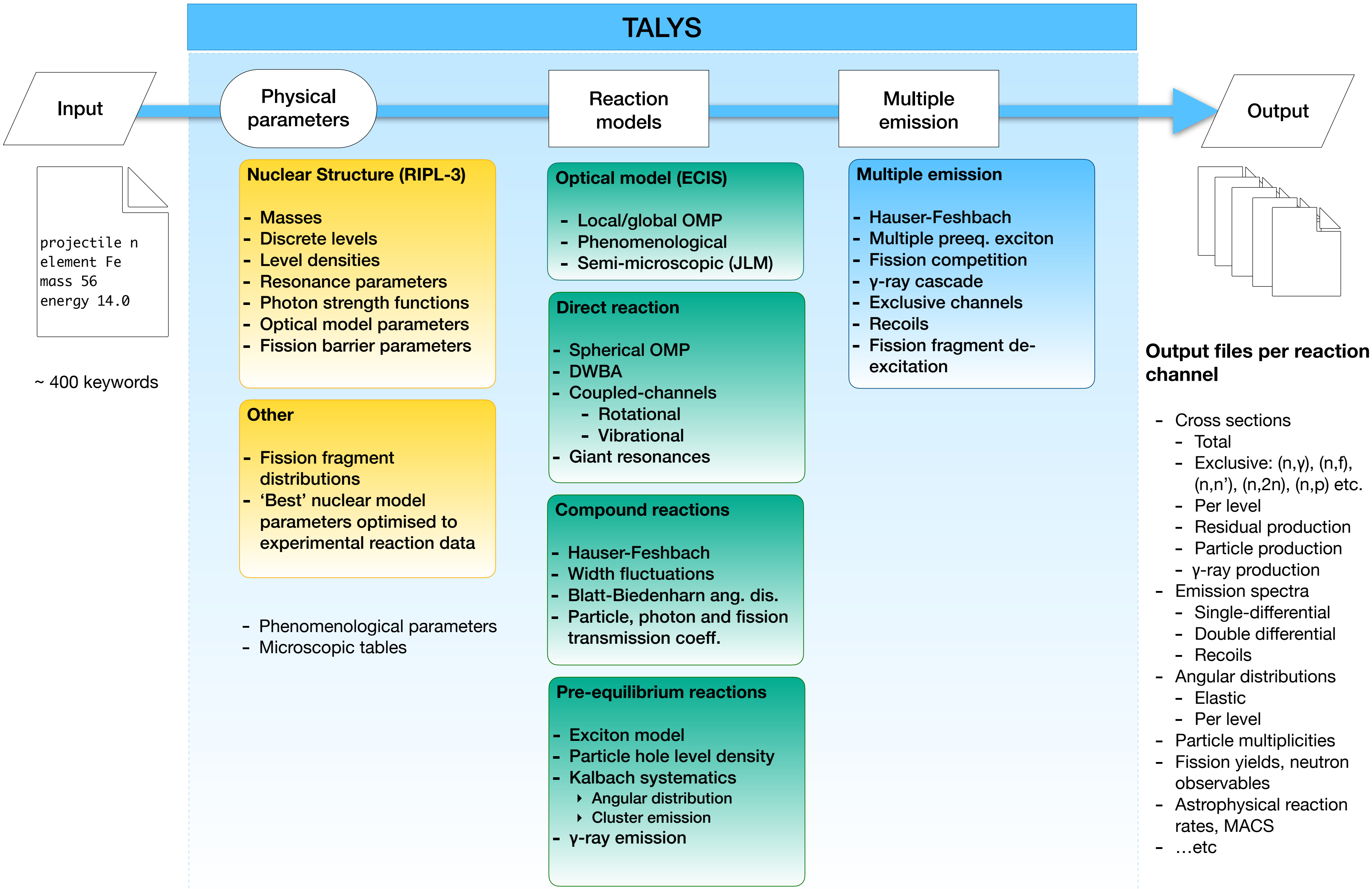
This enables:
- Thousands of analyses of experiments
- TALYS Evaluated Nuclear Data Library (TENDL)
- Total Monte Carlo (TMC) uncertainty quantification
- …and much more

Output of TALYS I

- Cross sections:
  - Total, reaction, elastic (shape & compound), non-elastic
  - Inelastic, per discrete level and total, similar for (n,p) etc.
  - Total particle production
  - Residual production + isomeric
  - Exclusive channel + isomeric
  - Gamma-ray production: per discrete level transition and total
- Angular distributions:
  - Elastic (shape + compound)
  - Inelastic per discrete level, similar for (n,p) etc.
  - Rutherford ratio for charged-particle elastic scattering
- Spectra:
  - Total particle production
  - Pre-equilibrium, multi pre-equilibrium and compound, per reaction stage
  - Exclusive channel
  - Double-differential

Output of TALYS II

- Fission observables:
  - Cross sections, total and by first, multi-chance stage
  - Fission fragment mass and isotopic yields (on input)
  - Fission product yields as function of charge, mass and isomer
  - Prompt fission neutron and gamma spectra
  - Neutron multiplicities, average (nubar), per fission fragment (nu(A)) and per neutron (P(nu))
- Miscellaneous:
  - Recoil spectra
  - Astrophysical reactions rates and Maxwellian-averaged cross sections (MACS)
  - Integral activation cross sections for standard neutron spectra
  - Statistical analysis of excitation functions
  - Data tables to prepare for ENDF formatting


TALYS
Input
Physical parameters
Reaction models
Multiple emission
Output
projectile n
element Fe
mass 56
energy 14.0
~ 400 keywords
Nuclear Structure (RIPL-3)
- Masses
- Discrete levels
- Level densities
- Resonance parameters
- Photon strength functions
- Optical model parameters
- Fission barrier parameters
Other
- Fission fragment distributions
- 'Best' nuclear model parameters optimised to experimental reaction data
- Phenomenological parameters
- Microscopic tables
Optical model (ECIS)
- Local/global OMP
- Phenomenological
- Semi-microscopic (JLM)
Direct reaction
- Spherical OMP
- DWBA
- Coupled-channels
- Rotational
- Vibrational
- Giant resonances
Compound reactions
- Hauser-Feshbach
- Width fluctuations
- Blatt-Biedenharn ang. dis.
- Particle, photon and fission transmission coeff.
Pre-equilibrium reactions
- Exciton model
- Particle hole level density
- Kalbach systematics
Angular distribution
Cluster emission
- γ-ray emission
Multiple emission
- Hauser-Feshbach
- Multiple preeq. exciton
- Fission competition
- γ-ray cascade
- Exclusive channels
- Recoils
- Fission fragment de-excitation
Output files per reaction channel
- Cross sections
- Total
- Exclusive: (n,γ), (n,f), (n,n'), (n,2n), (n,p) etc.
- Per level
- Residual production
- Particle production
- γ-ray production
- Emission spectra
- Single-differential
- Double differential
- Recoils
- Angular distributions
- Elastic
- Per level
- Particle multiplicities
- Fission yields, neutron observables
- Astrophysical reaction rates, MACS
- …etc

Nuclear Applications

Different possible approaches depending on the nuclear applications

PHENOMENOLOGICAL DESCRIPTIONS

ACCURACY
(reproduce exp.data)

Concern of applied physics

New concern of some applications

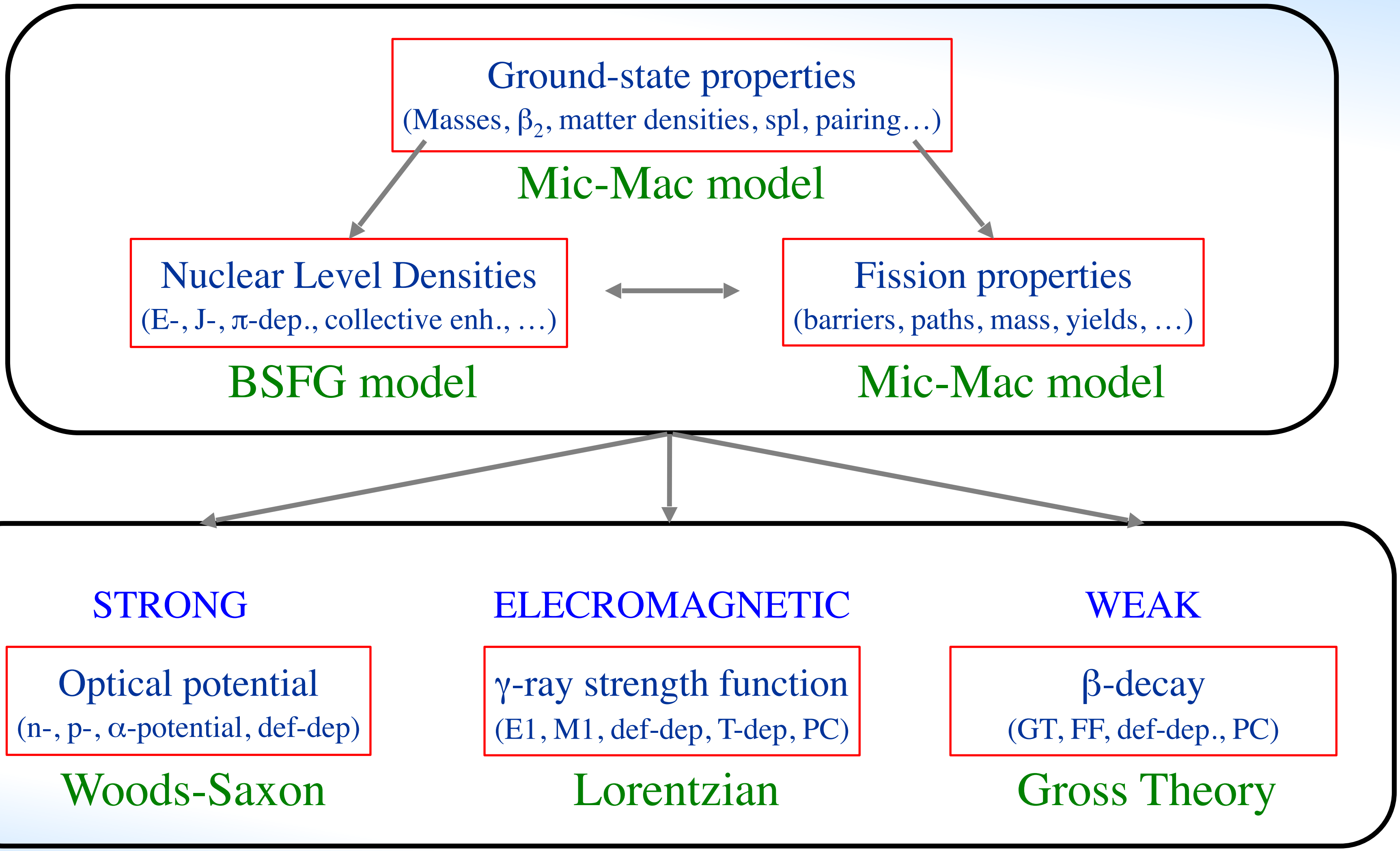
RELIABILITY
(Sound physics)

Concern of fundamental physics

Phenomenological models
(Parametrized formulas, Empirical Fits)
Classical models
(e.g Liquid drop, Droplet)
Semi-classical models
(e.g Thomas - Fermi)
mic-mac models
(e.g Classical with micro corrections)
semi-microscopic
(e.g microscopic models with phenomenological corrections)
fully microscopic
(e.g mean field, shell model, QRPA)

GLOBAL MICROSCOPIC DESCRIPTIONS

“Macroscopic” Nuclear Inputs



“Microscopic” Nuclear Inputs

Ground-state properties
(Masses, β_2, matter densities, spl, pairing…)
Mean-Field model

Nuclear Level Densities
(E-, J-, π-dep., collective enh., …)
HFB+Combinatorial

Fission properties
(barriers, paths, mass, yields, …)
HFB model

STRONG

Optical potential
(n-, p-, α-potential, def-dep)
BHF-type

ELECROMAGNETIC

γ-ray strength function
(E1, M1, def-dep, T-dep, PC)
HFB+QRPA

WEAK

β-decay
(GT, FF, def-dep., PC)
HFB+QRPA

Nuclear models

Only few slides per model.

See Stephane Hilaire and Stephane Goriely for more details

Optical model

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The optical model potential (OMP) is crucial for nuclear reaction physics and applications.

- Assumption: Approximate interaction between incident particle and nucleus by a complex mean-field potential $\mathcal{U}$.
- Complex potential $\mathcal{U}$ divides flux into (a) elastic channel, (b) all non-elastic channels
- Solve Schrödinger equation with $\mathcal{U}$ to give a wealth of nuclear information.

THE OPTICAL MODEL

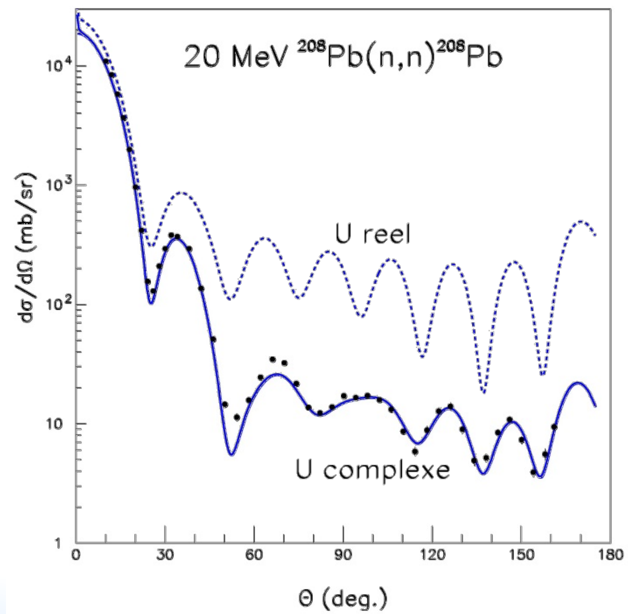
Direct interaction of a projectile with a target nucleus considered as a whole
Quantum model → Schrödinger equation

$$\left(-\frac{\hbar^2}{2\mu}\nabla^2 + U - E\right)\Psi = 0$$

Complex potential:

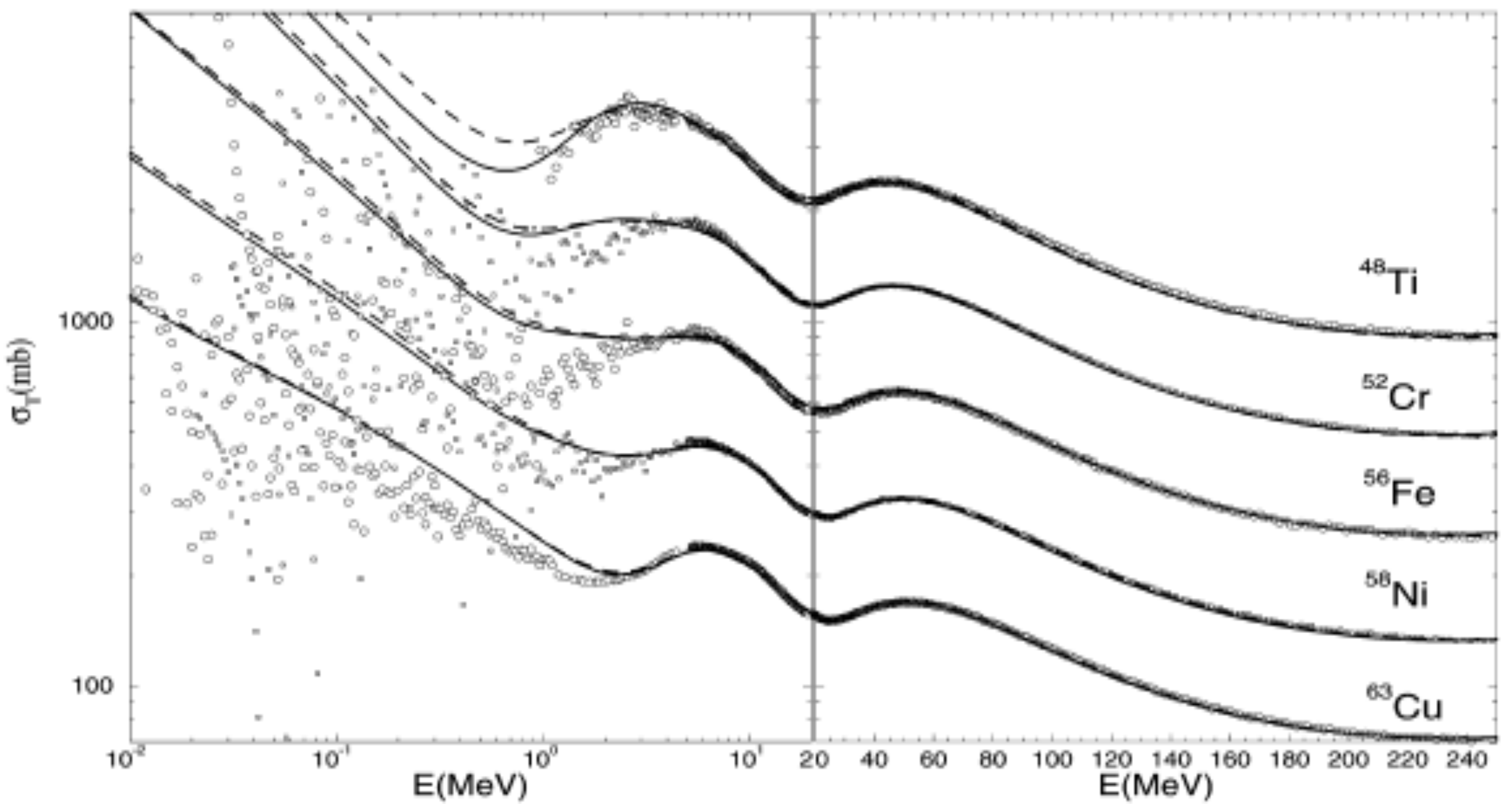
$$U = V + iW$$

Refraction (V) Absorption (iW)



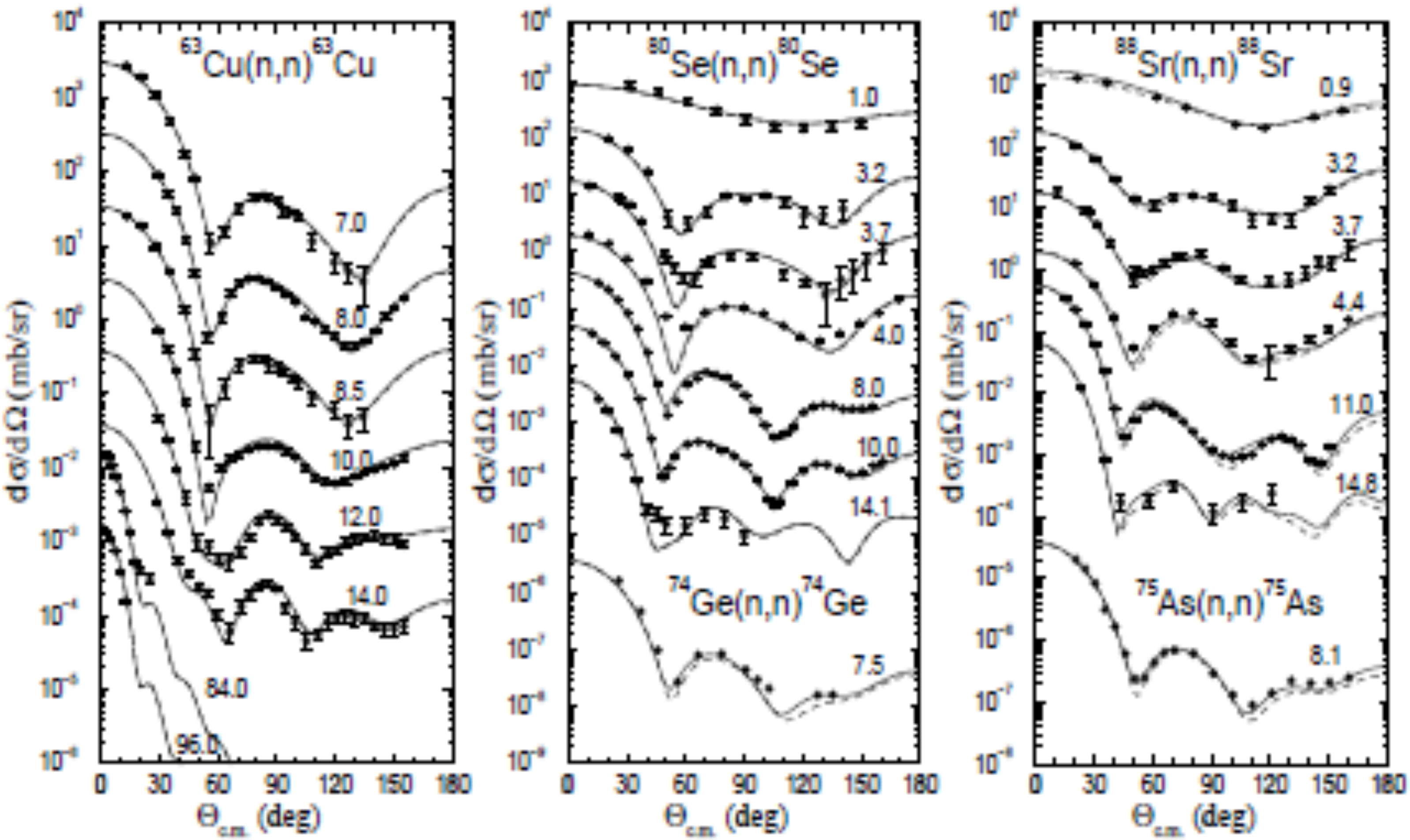
Neutron total cross sections

- A.J. Koning and J.P. Delaroche, KD03 OMP, Nucl. Phys. A713 (2003) 231

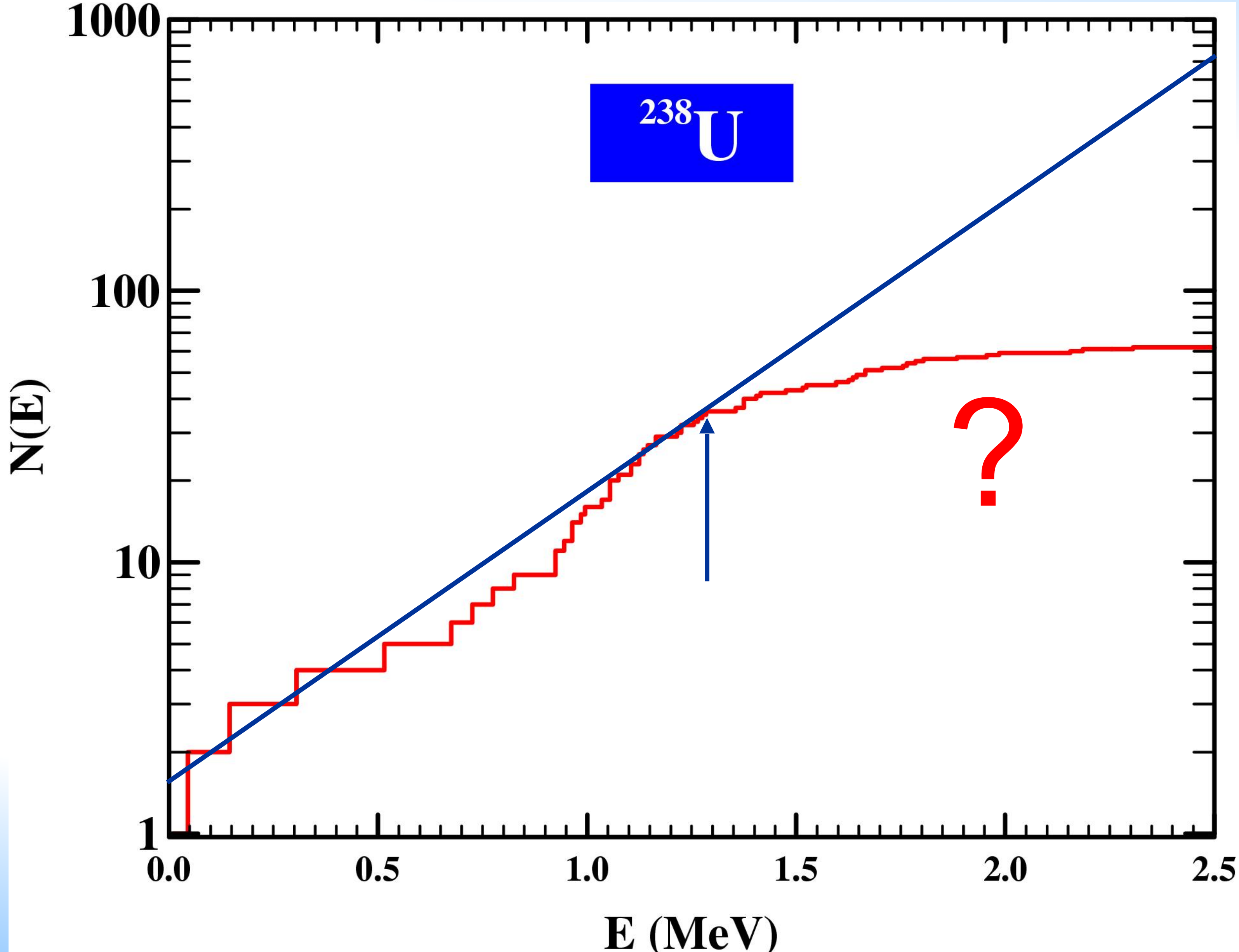


Neutron elastic scattering angular distributions

- A.J. Koning and J.P. Delaroche, KD03 OMP, Nucl. Phys. A713 (2003)



Level density



Level density definition

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Level density $\rho(E_x, J, \Pi)$: number of nuclear levels per MeV around an excitation energy E_x, for spin J and parity Π.
Total level density $\rho^{\mathrm{tot}}(E_x)$:

$$\rho^{\mathrm{tot}}(E_x) = \sum_J \sum_\Pi \rho(E_x, J, \Pi). \tag{1}$$

Phenomenological level density:

$$\rho(E_x, J, \Pi) = P(E_x, J, \Pi) R(E_x, J) \rho^{\mathrm{tot}}(E_x), \tag{2}$$

$P(E_x, J, \Pi)$: the parity distribution, $R(E_x, J)$: spin distribution.

$$P(E_x, J, \Pi) = \frac{1}{2}, \tag{3}$$

Fermi gas level density

Fermi gas level density:

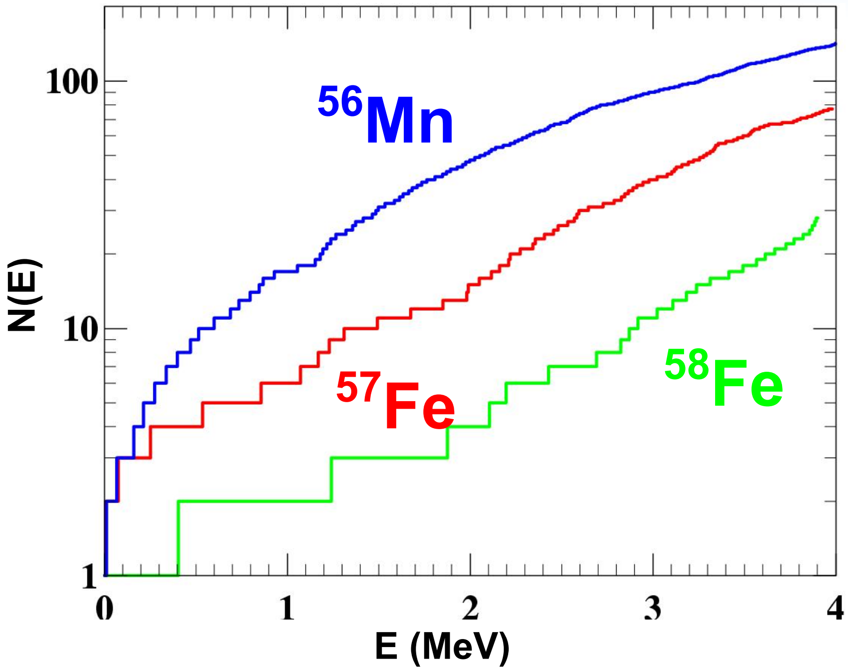
$$\rho_F(E_x, J, \Pi) = \frac{1}{2}\frac{2J+1}{2\sqrt{2\pi}\sigma^3}\exp\left[-\frac{(J+\frac{1}{2})^2}{2\sigma^2}\right]\frac{\sqrt{\pi}}{12}\frac{\exp\left[2\sqrt{aU}\right]}{a^{1/4}U^{5/4}}, \quad (4)$$

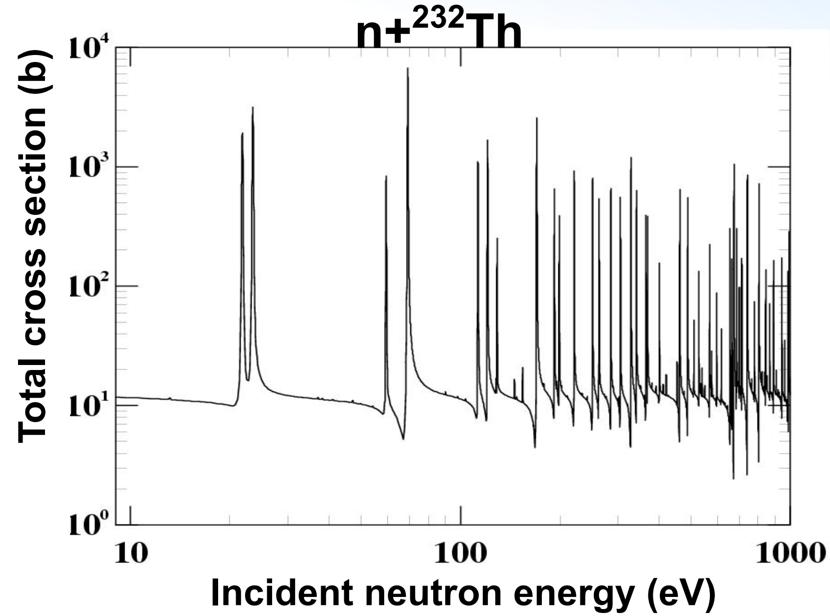
Summing $\rho_F(E_x, J, \Pi)$ over all spins and parities yields for the total Fermi gas level density

$$\rho_F^{\text{tot}}(E_x) = \frac{1}{\sqrt{2\pi}\sigma}\frac{\sqrt{\pi}}{12}\frac{\exp\left[2\sqrt{aU}\right]}{a^{1/4}U^{5/4}}, \quad (5)$$

Three parameters: level density parameter a, spin cut-off parameter σ^2 and pairing correction Δ.

THE LEVEL DENSITIES (Qualitative aspects 1/2)





- Exponential increase of the cumulated number of discrete levels N(E) with energy

⇒ $rho(E)=\frac{dN(E)}{dE}$ increases exponentially

⇒ odd-even effects

- Mean spacings of s-wave neutron resonances at B_n of the order of few eV

⇒ $rho(B_n)$ of the order of $10^4 – 10^6$ levels / MeV

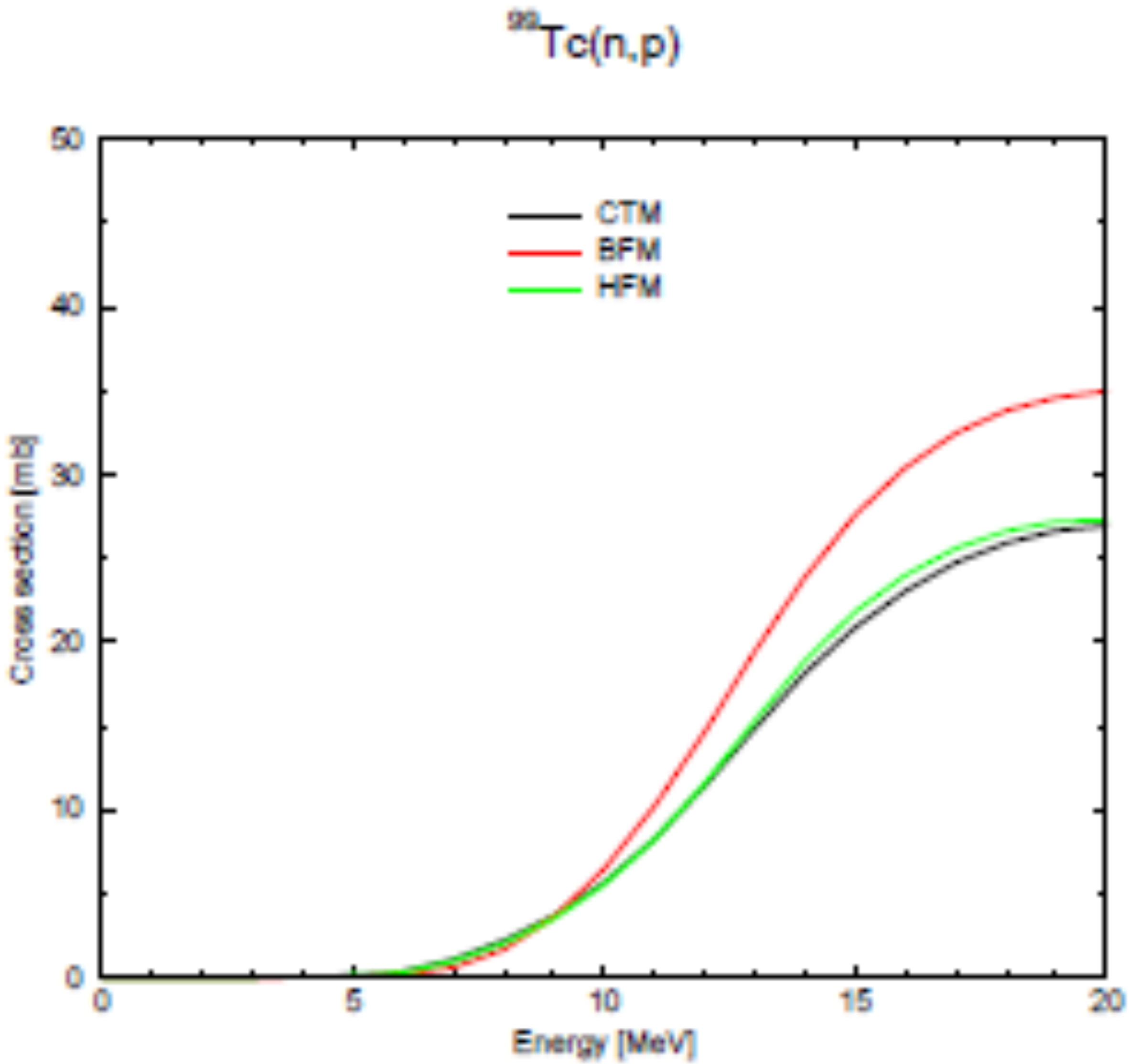
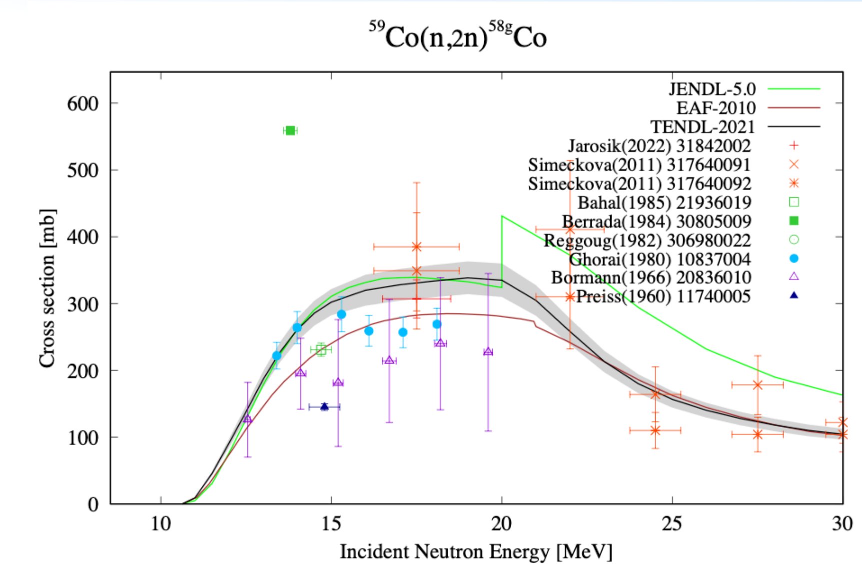


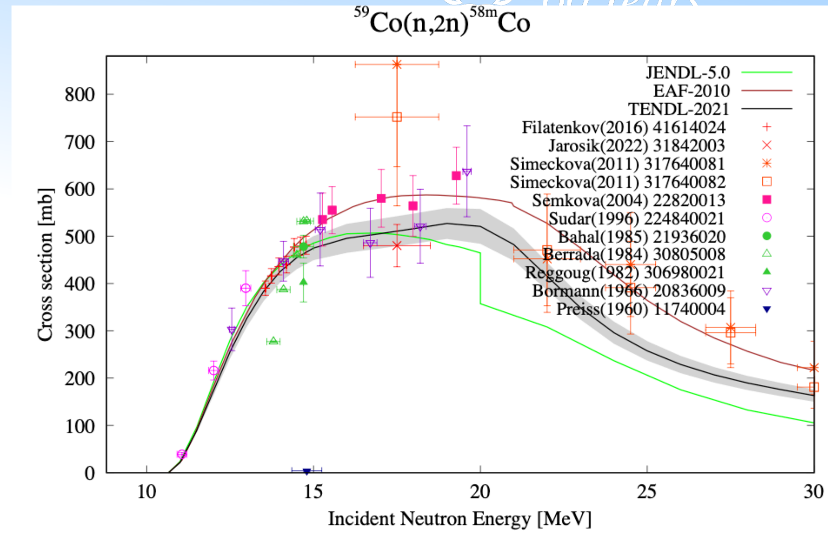
Figure 7.22: ^{99}Tc(n,p) cross section for different level density models.

Validation of level density spin distribution

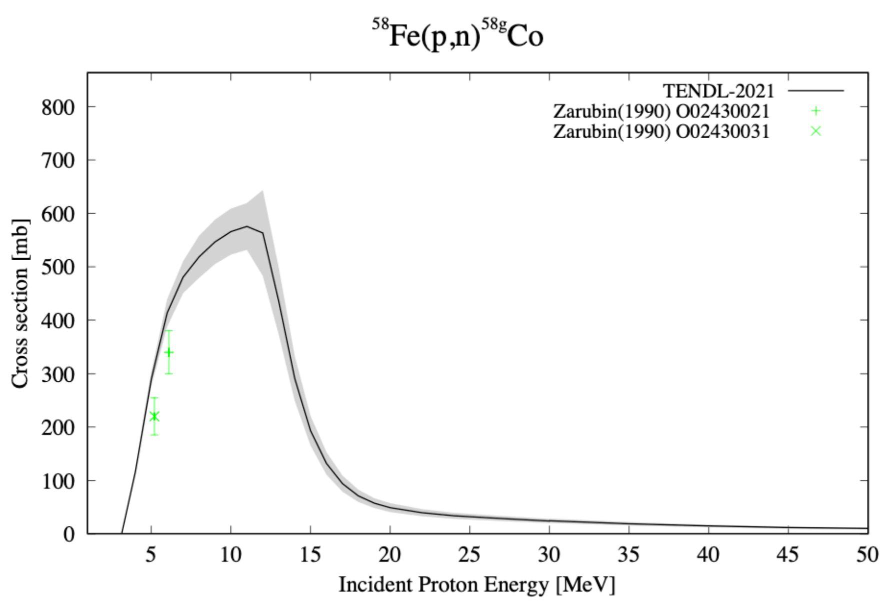
- Isomeric ratios of cross sections
- Gamma-ray production cross sections

Isomeric cross section ratios

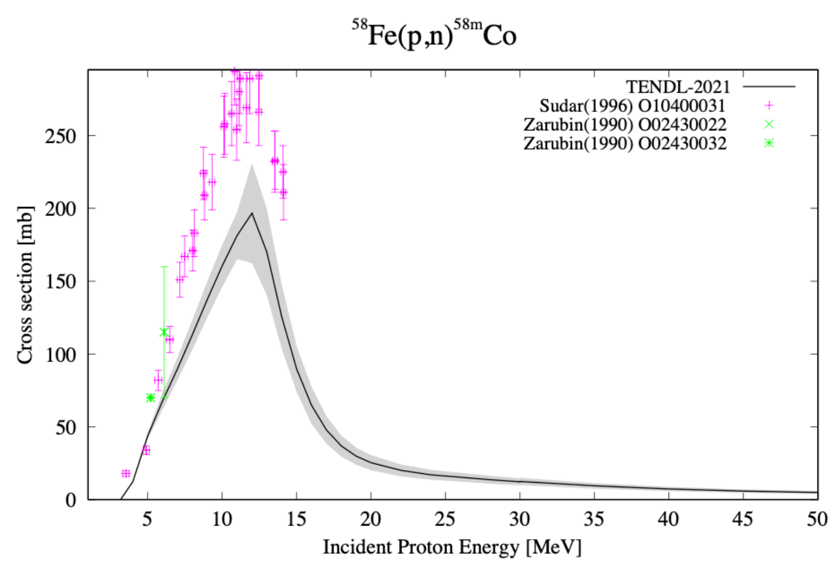




Good



Bad



Two sensitive inputs: 1. (Missing) spins and branching ratios of discrete level scheme
2. Width of the level density spin distribution

Gamma-ray production cross sections

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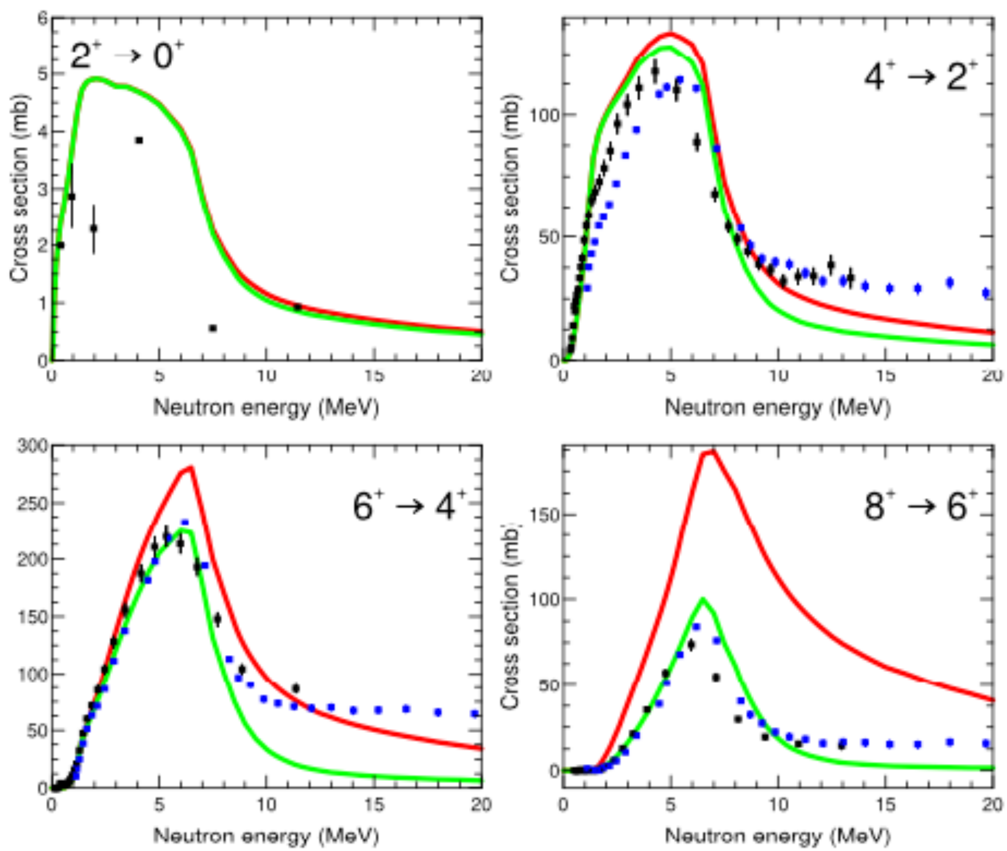


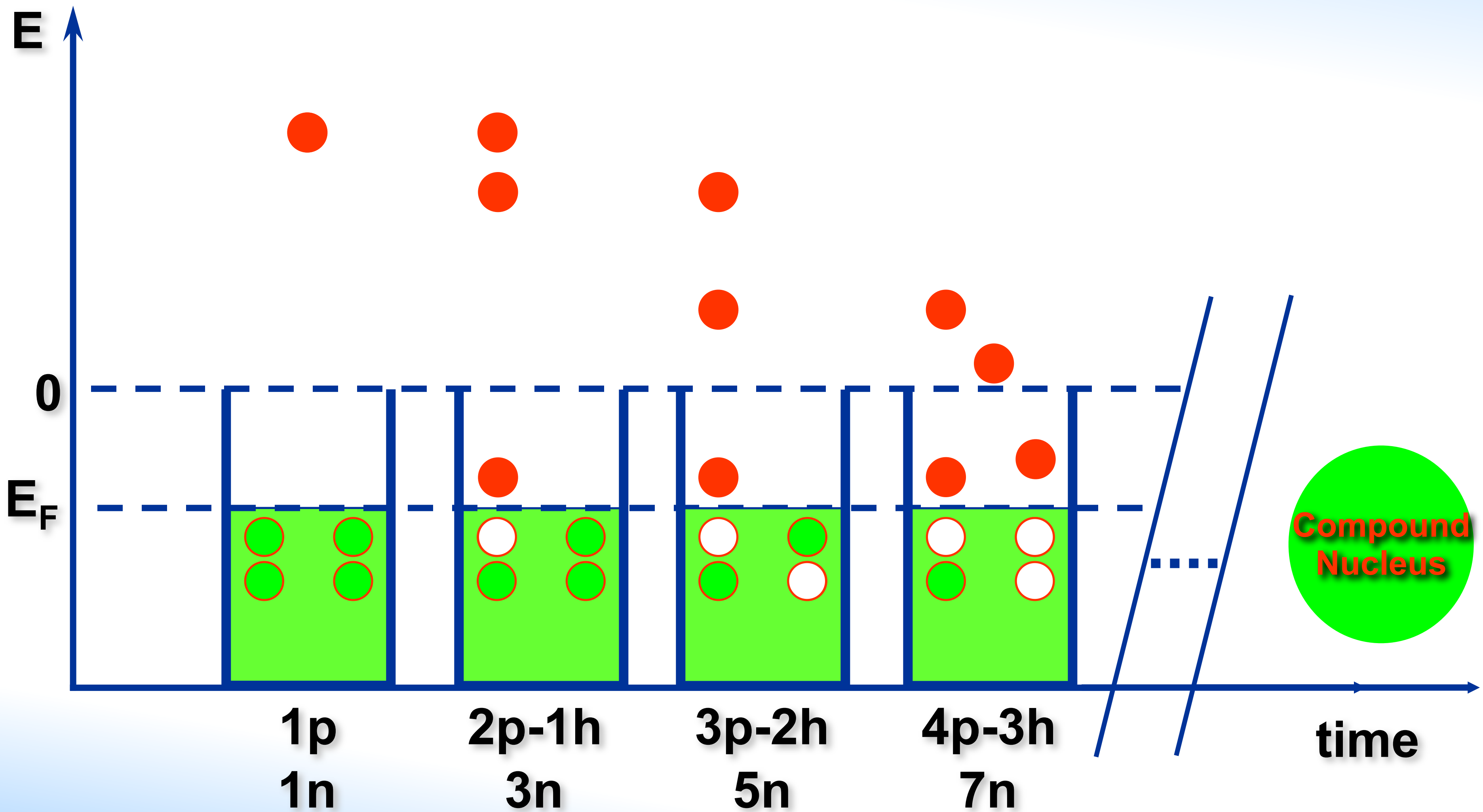
Fig. 33 $^{238}U(n, n'\gamma)$ cross sections for 4 transitions within the ground state rotational band. Spin and parity of the initial and final states are reported in each panel. Black and blue squares correspond to Ref. [93] and Ref. [211] respectively. The red and green lines correspond to two options for the pre-equilibrium spin distribution of the exciton model (see text for more details)

Two effects:

Particle-hole state density spin distribution (this example)

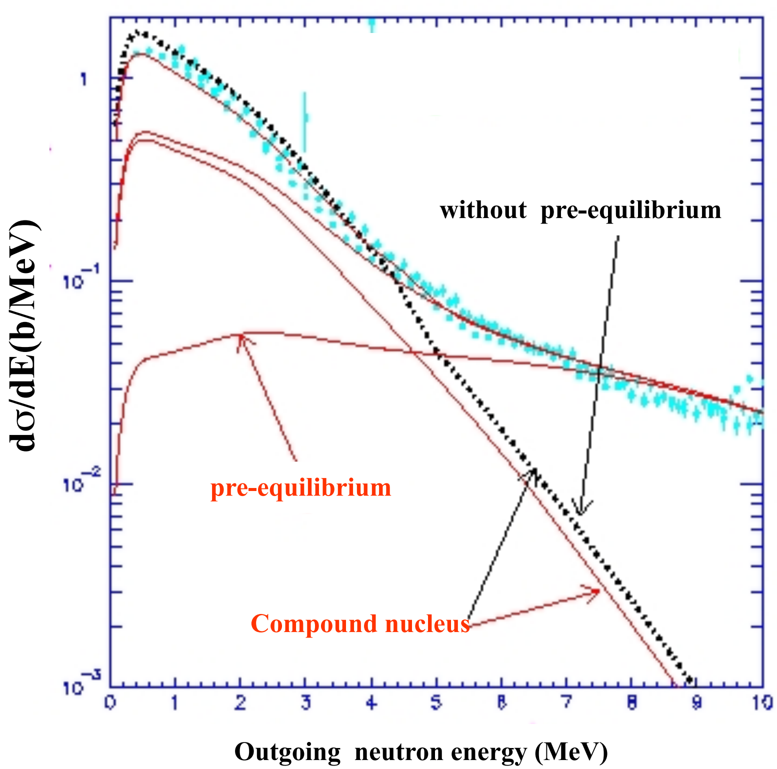
Total level density spin distribution

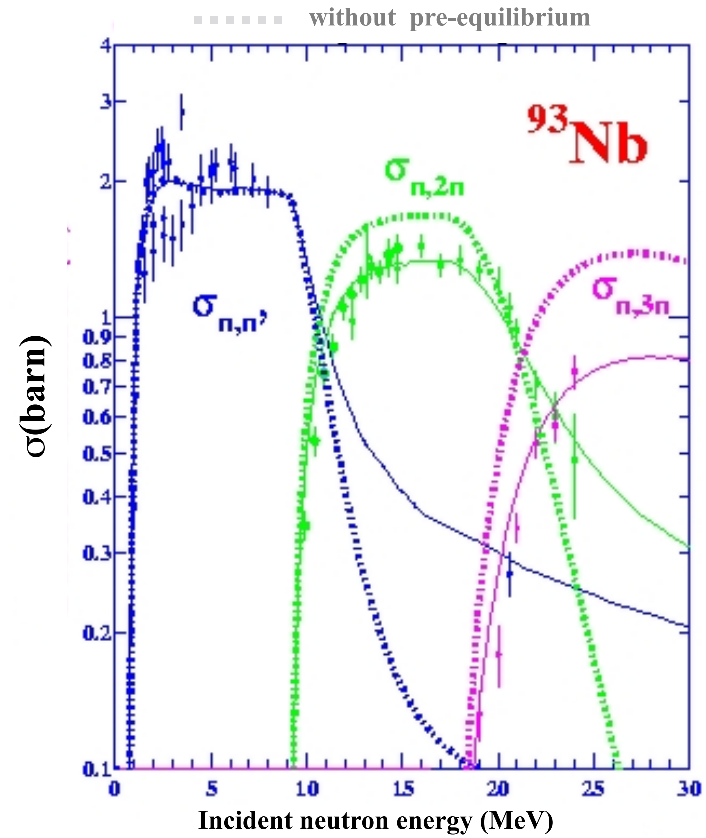
THE PRE-EQUILIBRIUM MODEL
(Exciton model principle)



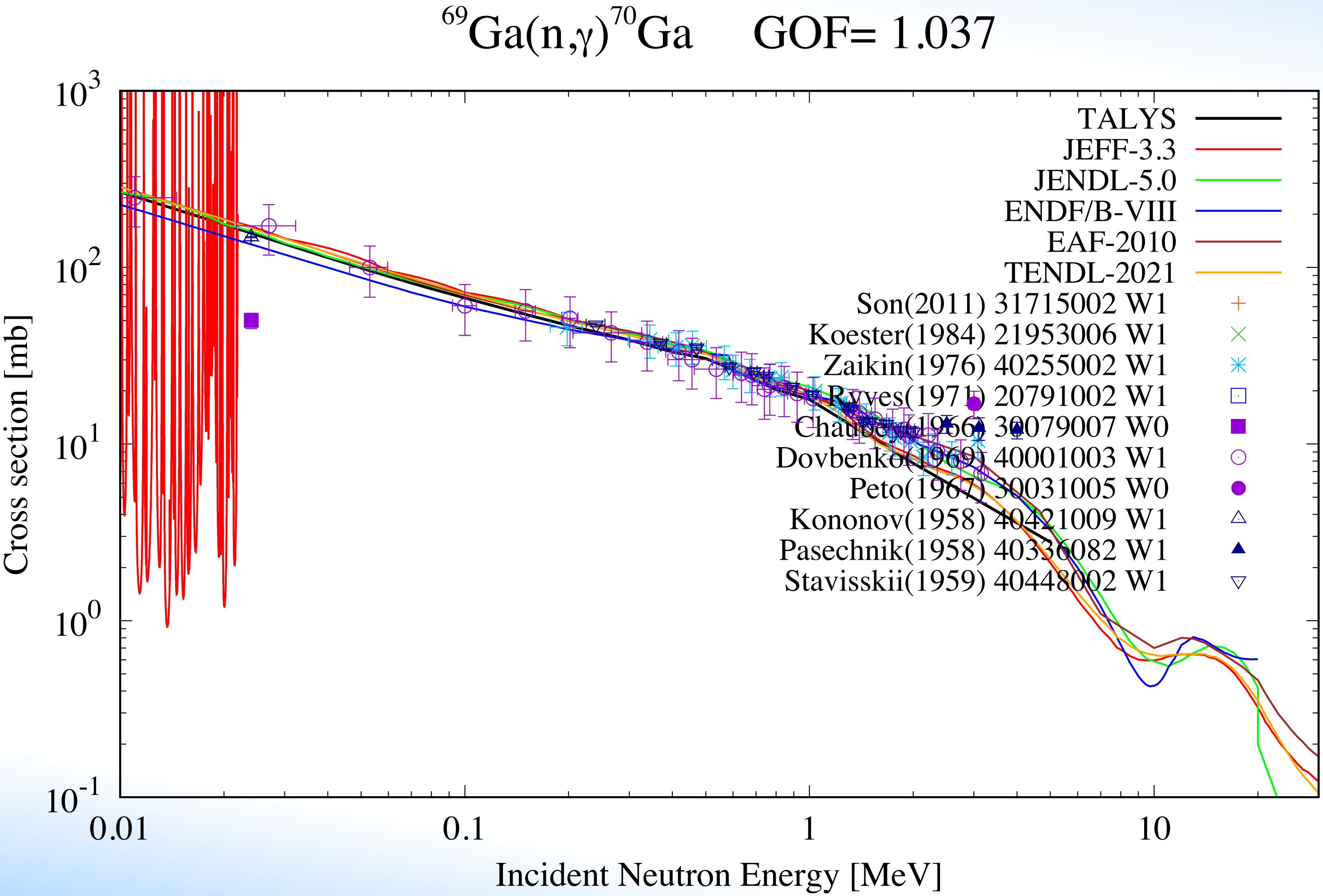
THE PRE-EQUILIBRIUM MODEL

14 MeV neutron + ^{93} Nb



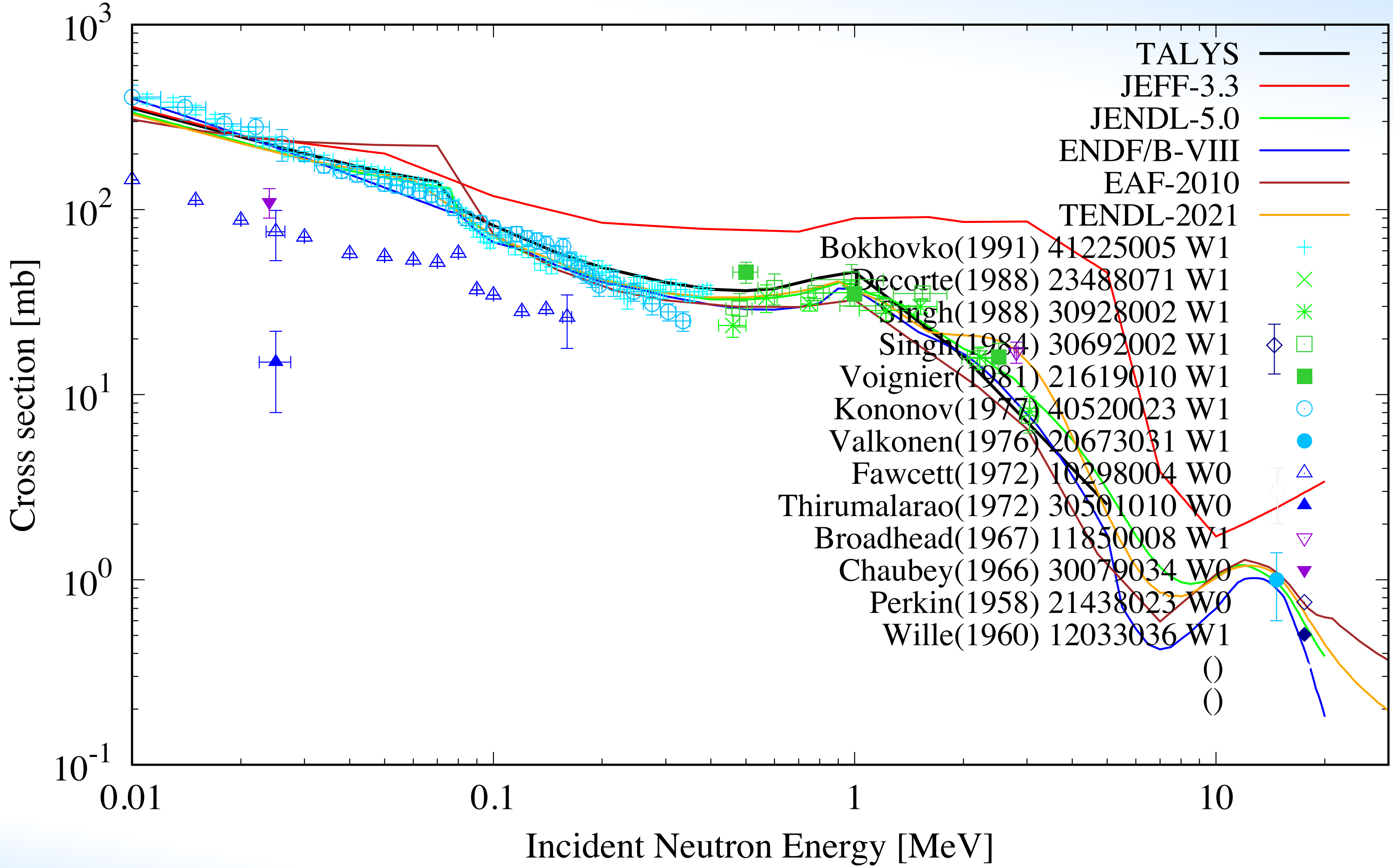


Optimization to included exp. data

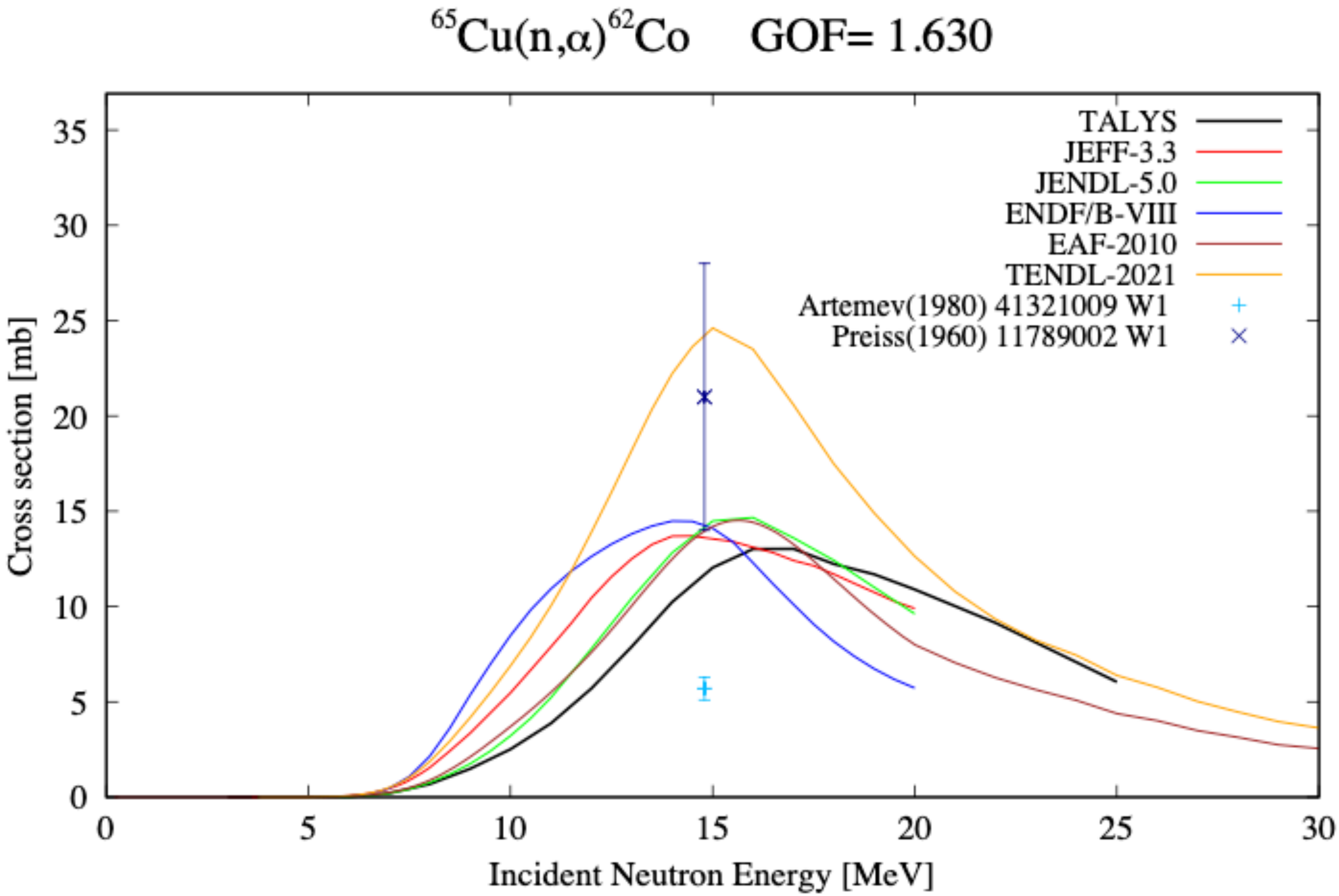


W0: weight 0

$^{160}Gd(n,\gamma)^{161}Gd$ GOF= 1.094

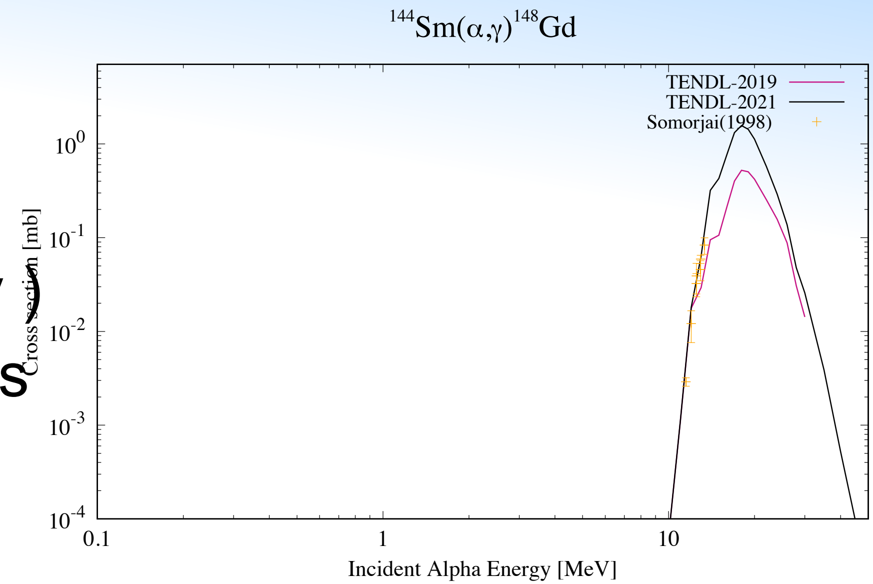


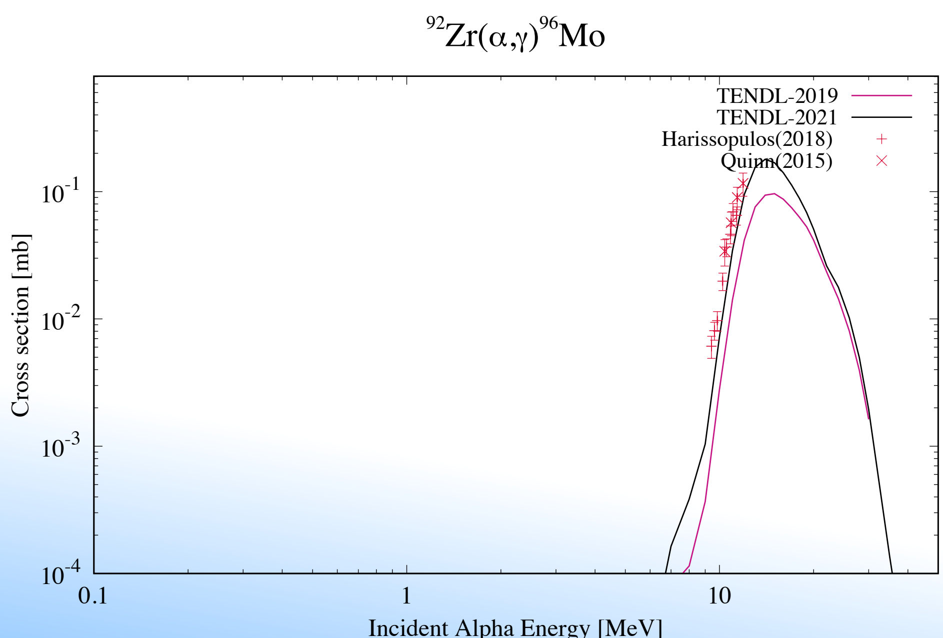
Segal's law: A man with a watch knows what time it is.
A man with two watches is never sure.

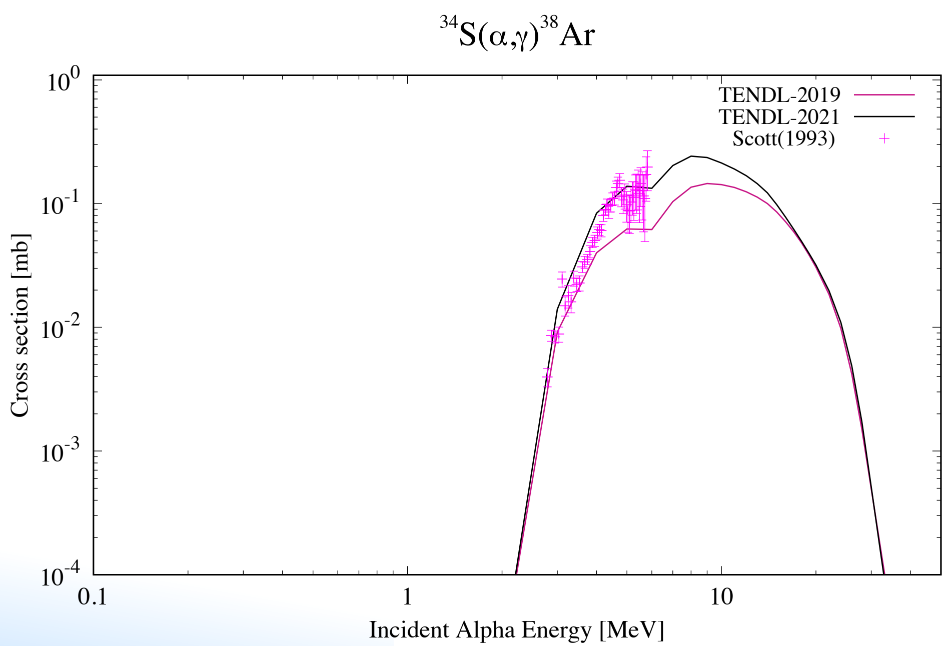


channel: (α , γ)

- New photon strength functions (Plujko & Goriely), SMLO, give better gamma-related data for all reaction channels, including (α ,γ)
- CRP on photon strength functions and photonuclear data, Dimitriou et al (IAEA 2019)







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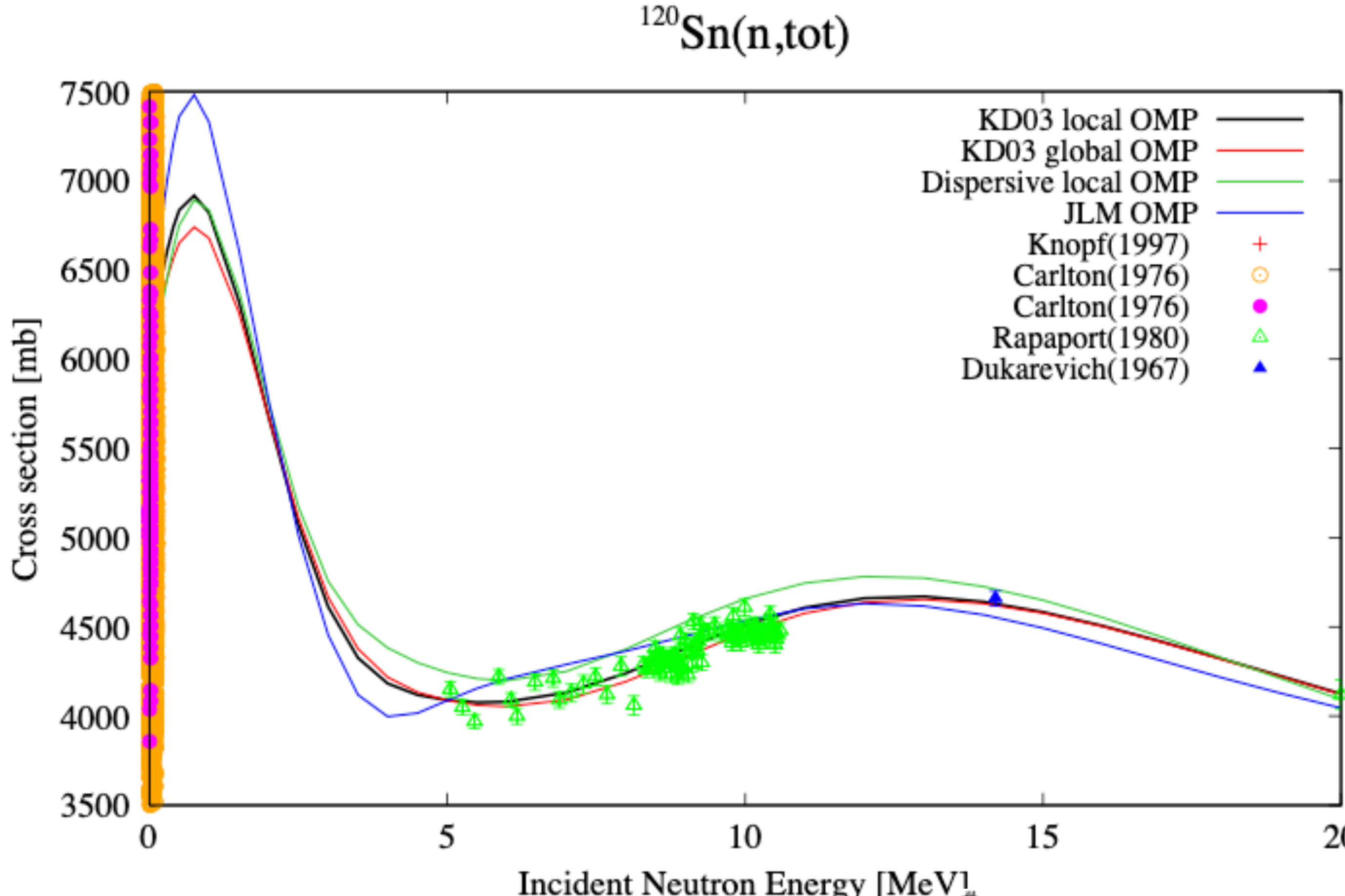


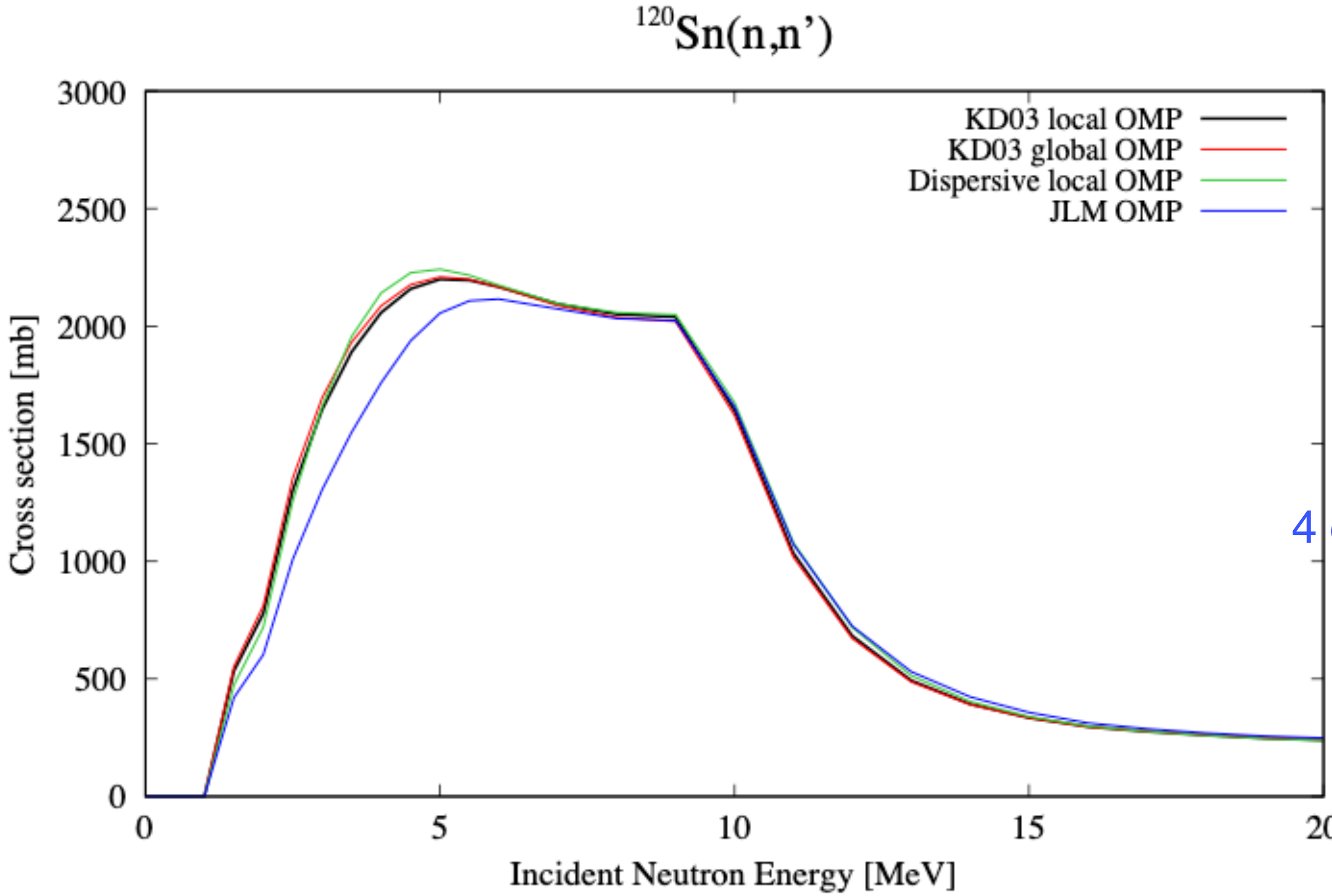
4 different input files

```
#
# n-Sn120-omp-KD03
#
# General
#
projectile n
element    sn
mass       120
energy     energies
```

```
#
# n-Sn120-omp-KD03global
#
# General
#
projectile n
element    sn
mass       120
energy     energies
#
# Parameters
#
localomp n
```

```
#
# n-Sn120-ompKD03disp
#
# General
#
projectile n
element    sn
mass       120
energy     energies
#
# Parameters
#
dispersion y
```

```
#
# n-Sn120-omp-JLM
#
# General
#
projectile n
element    sn
mass       120
energy     energies
#
# Parameters
#
jlmomp y
```



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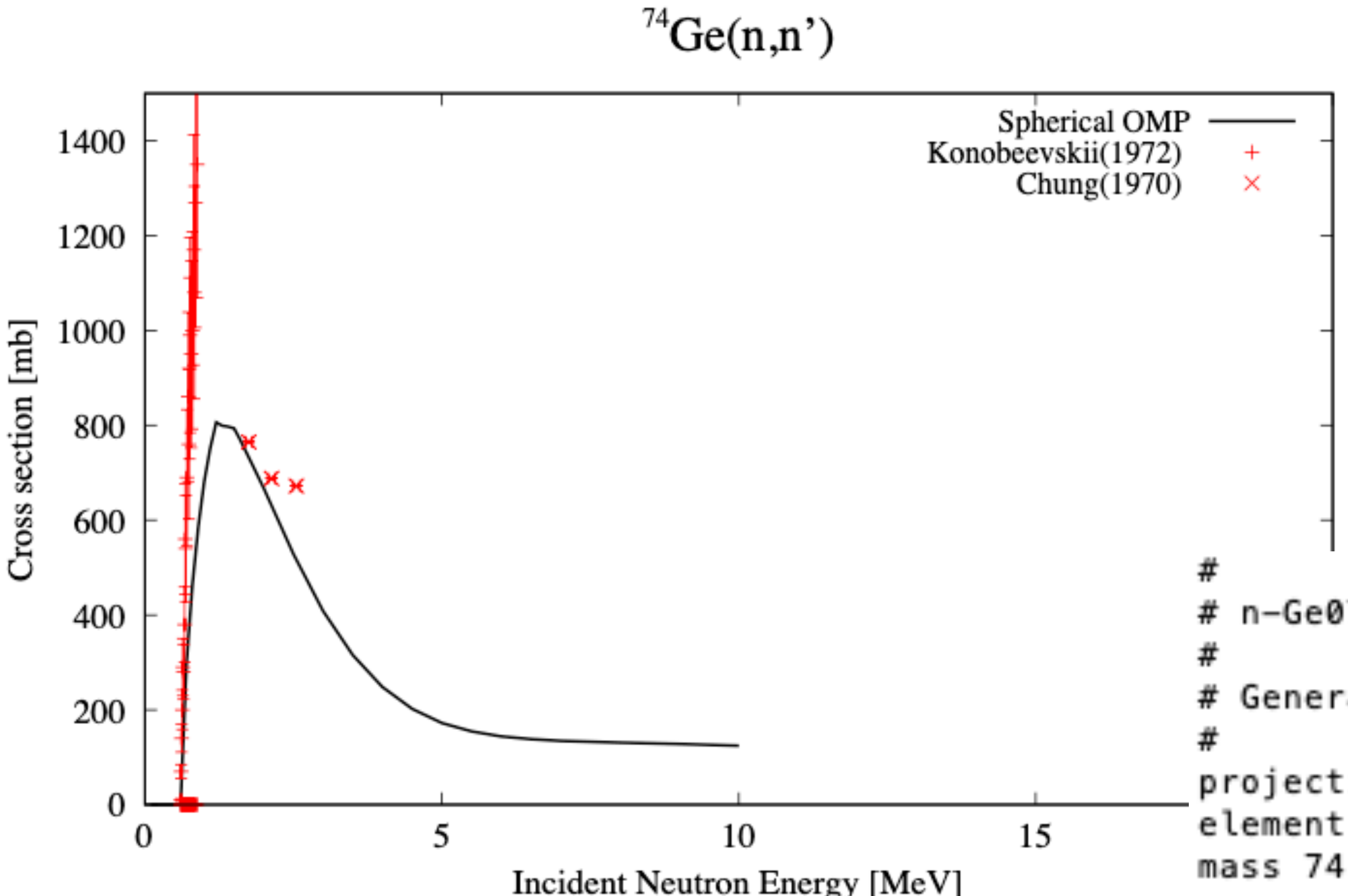
4 different input files

```
#
# n-Sn120-omp-KD03
#
# General
#
projectile n
element    sn
mass       120
energy     energies
```

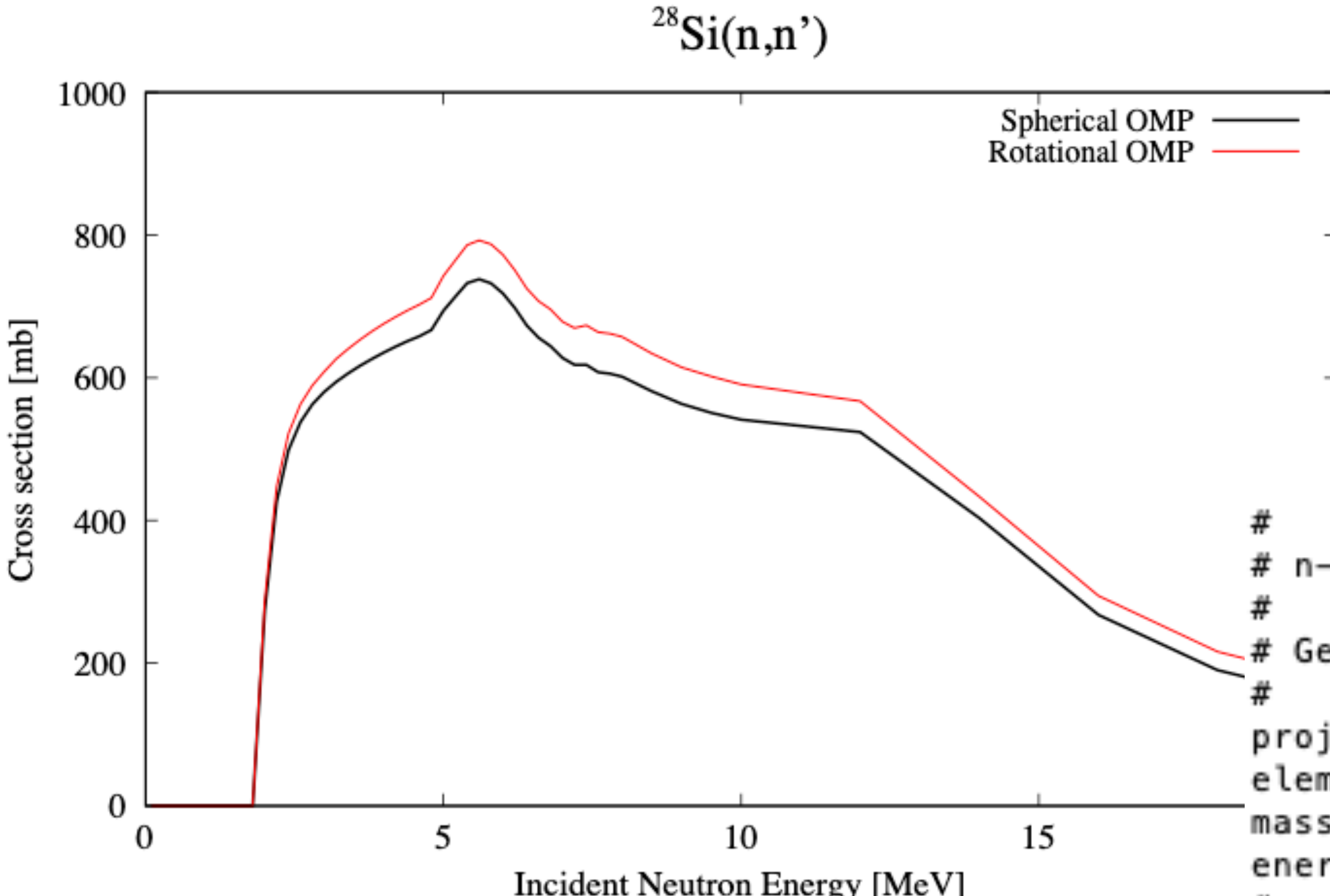
```
#
# n-Sn120-omp-KD03global
#
# General
#
projectile n
element    sn
mass       120
energy     energies
#
# Parameters
#
localomp n
```

```
#
# n-Sn120-ompKD03disp
#
# General
#
projectile n
element    sn
mass       120
energy     energies
#
# Parameters
#
dispersion y
```

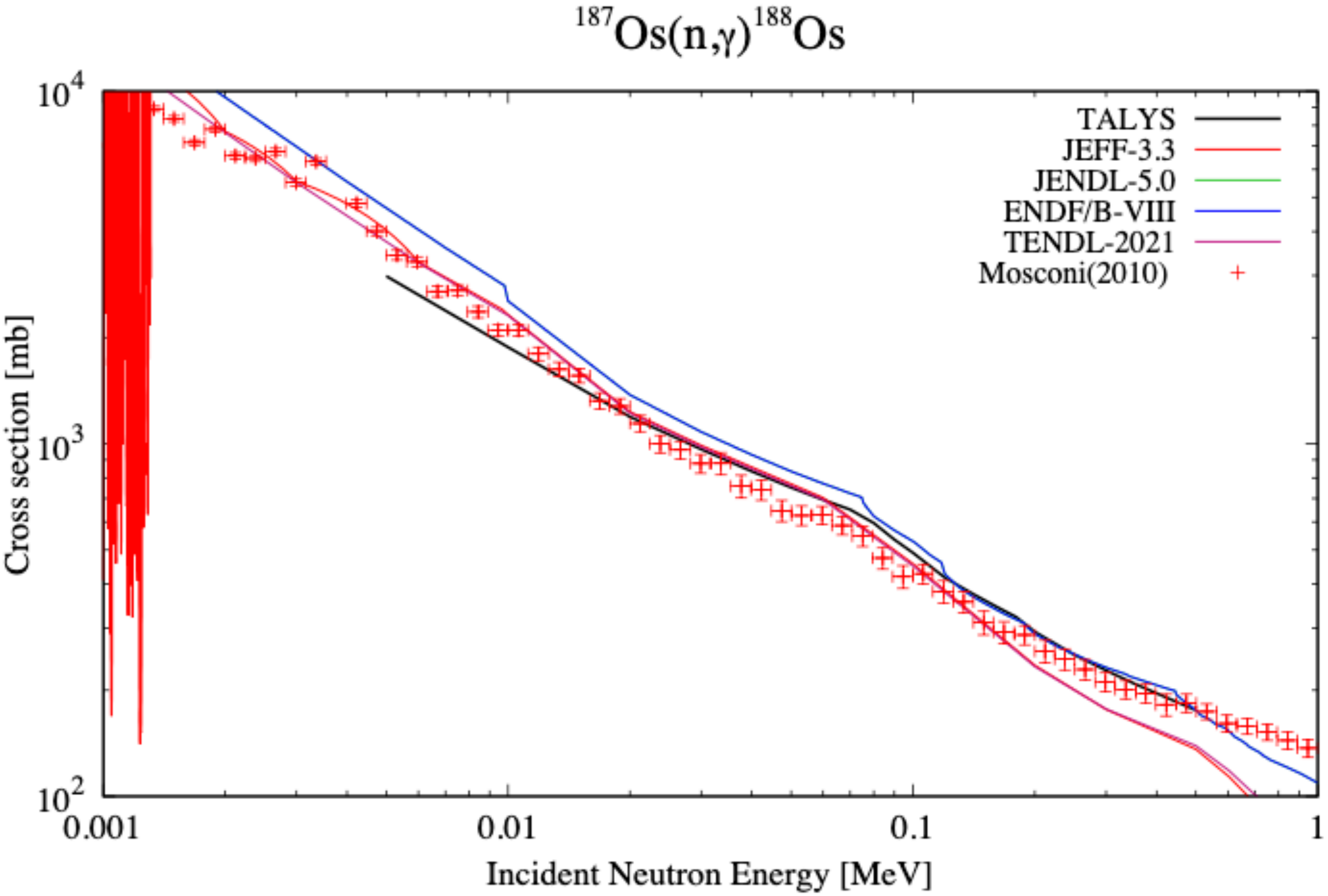
```
# n-Sn120-omp-JLM
#
# General
#
projectile n
element    sn
mass       120
energy     energies
#
# Parameters
#
jlmomp y
```




```
#
# n-Ge074-vib
#
# General
#
projectile n
element ge
mass 74
energy energies
#
# Output
#
outexcitation n
outdiscrete y
filediscrete 1
```




```
#
# n-Si028-cc
#
# General
#
projectile n
element si
mass 28
energy energies
#
# Parameters
#
spherical y
#
# Output
#
channels y
filechannels y
```



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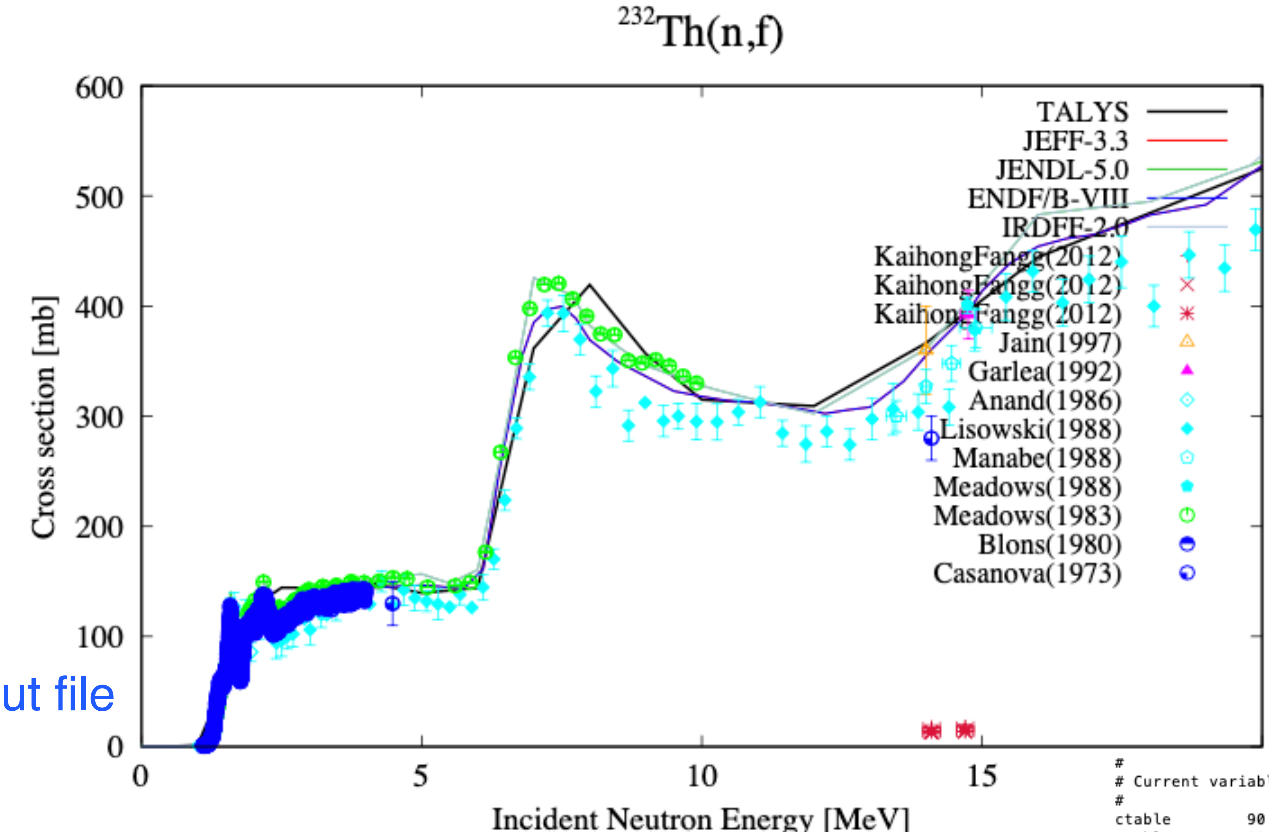
Cross section

```
#
# n-Os187-astro-ng
#
# General
#
projectile n
element    os
mass       187
energy     energies
channels y
filechannels y
#
# Parameters
#
ldmodel 1
strength 8
wtable         76 188    0.88 e1
```

Astro reaction rate

```
#
# n-Os187-astro-rate
#
# General
#
projectile n
element    os
mass       187
energy    1.
#
# Parameters
#
astro y
astrogs n
partable y
ldmodel 1
strength 8
wtable         76 188    0.88 e1
```

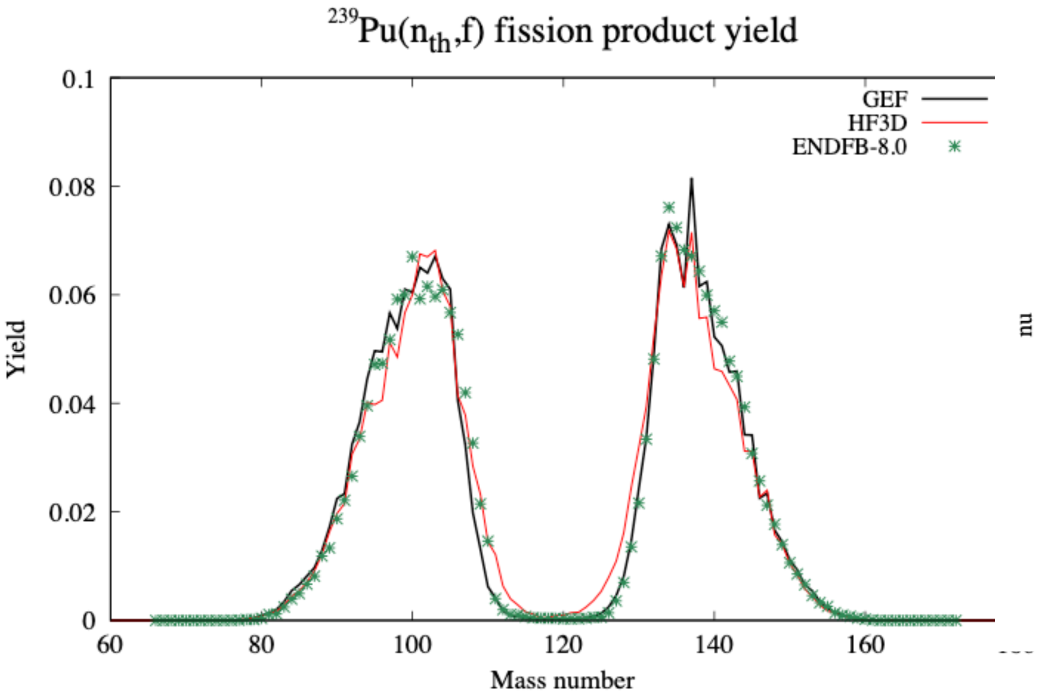


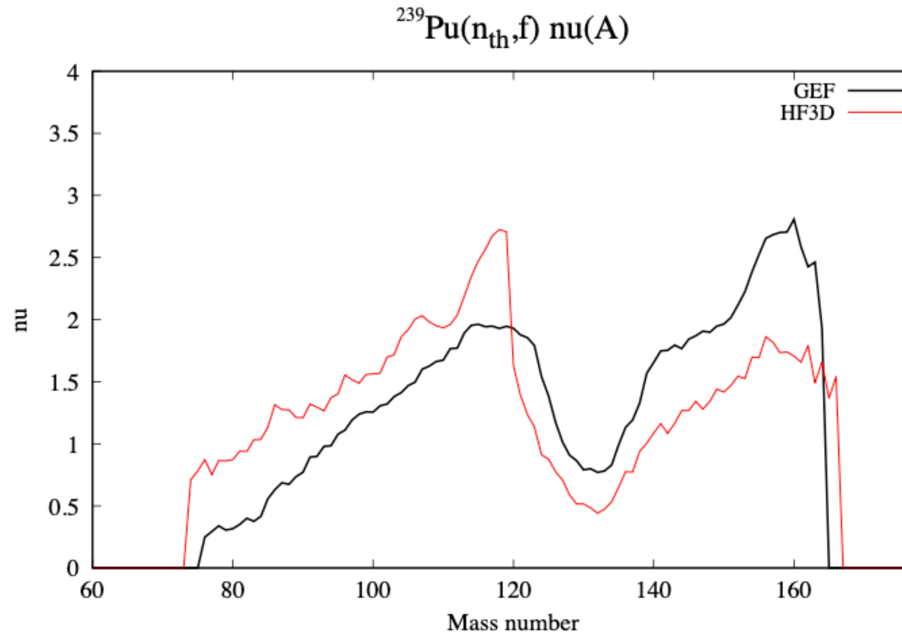
Large input file

```
#
# n-Th232-fis
#
# General
#
projectile n
element     Th
mass        232
ltarget     000
energy      energies
maxlevelstar     30
partable y
bins 40
ejectiles g n
#
# do not use best parameters from database
#
best n
#
# set multi-preequilibrium switch lower for actinides
#
multipreeq 6.
#
# output of extra channels
#
channels y
filechannels y
```

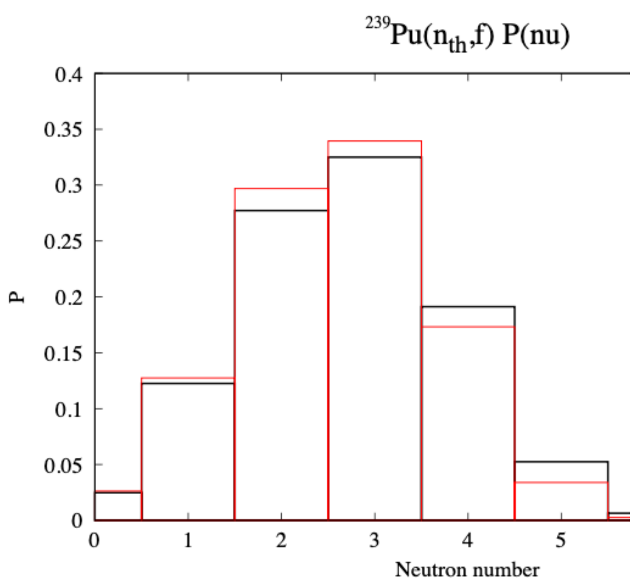
```
#
# reduce output for activation-only calculation
#
outspectra n
outangle n
ddxmode 0
outdiscrete n
maxrot 2
strength 9
strengthm1 3
ngfit y
upbend y
ldmodel 5
fismodel 5
fispartdamp y
hbstate n
class2 n
ecissave y
eciscalc y
inccalc y
outdiscrete y
riplrisk y
```

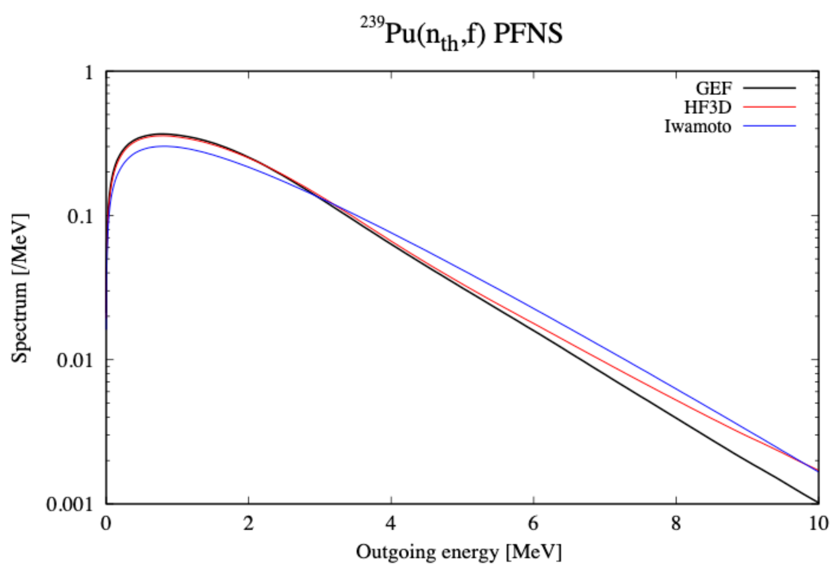
```
#
# Current variables of TASMAN Run:  2509
#
ctable       90 233    1.35146 1
ptable       90 233 -1.94808E+00 1
ctable       90 233 -9.41013E-01 2
ptable       90 233    1.01594 2
ctable       90 233    3.16960 3
ptable       90 233 -1.14439E+00 3
betafiscor   90 233    1.04349
vfiscor      90 233    0.71170
ctable       90 232    0.32630 1
ptable       90 232    2.77492 1
ctable       90 232    8.34473 2
ptable       90 232 -6.59883E+00 2
ctable       90 232    0.69898 3
ptable       90 232    0.75241 3
betafiscor   90 232    0.50505
vfiscor      90 232    0.84379
ctable       90 231  5.77646E-02 1
ptable       90 231 -2.67866E+00 1
ctable       90 231 -3.61946E+00 2
ptable       90 231 -2.25936E+00 2
ctable       90 231 -2.85851E+00 3
ptable       90 231    2.66753 3
betafiscor   90 231    1.58614
vfiscor      90 231    1.62104
ctable       90 230 -3.18402E+00 1
ptable       90 230 -4.20179E+00 1
ctable       90 230    1.13153 2
ptable       90 230 -5.43220E-01 2
ctable       90 230    1.01315 3
ptable       90 230 -2.80603E+00 3
betafiscor   90 230    1.66138
vfiscor      90 230    1.71450
```



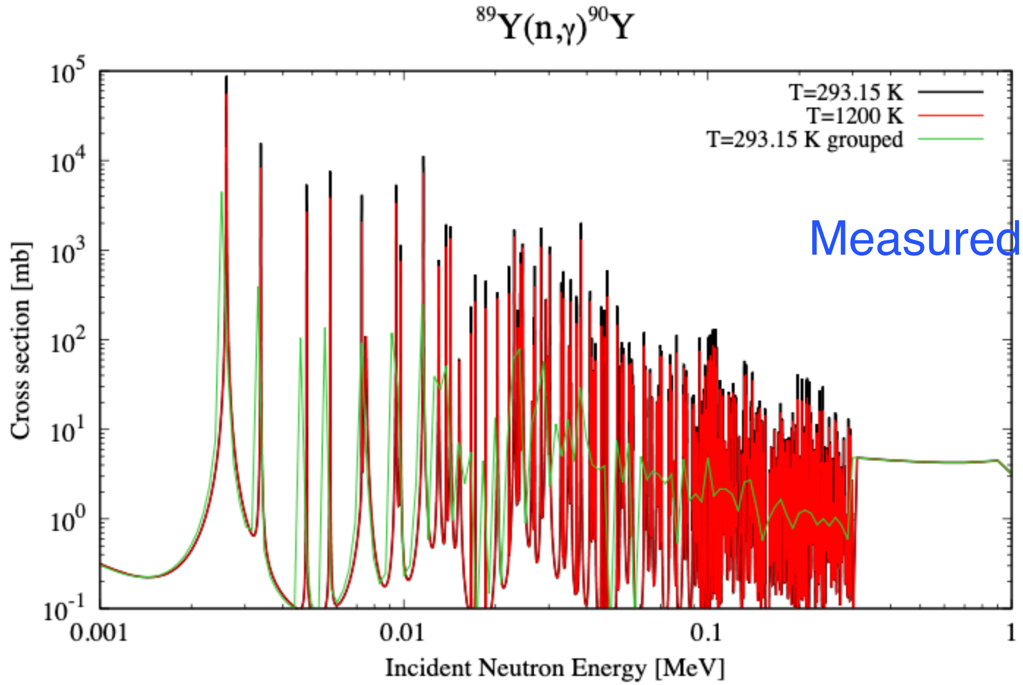


TALYS-2 only



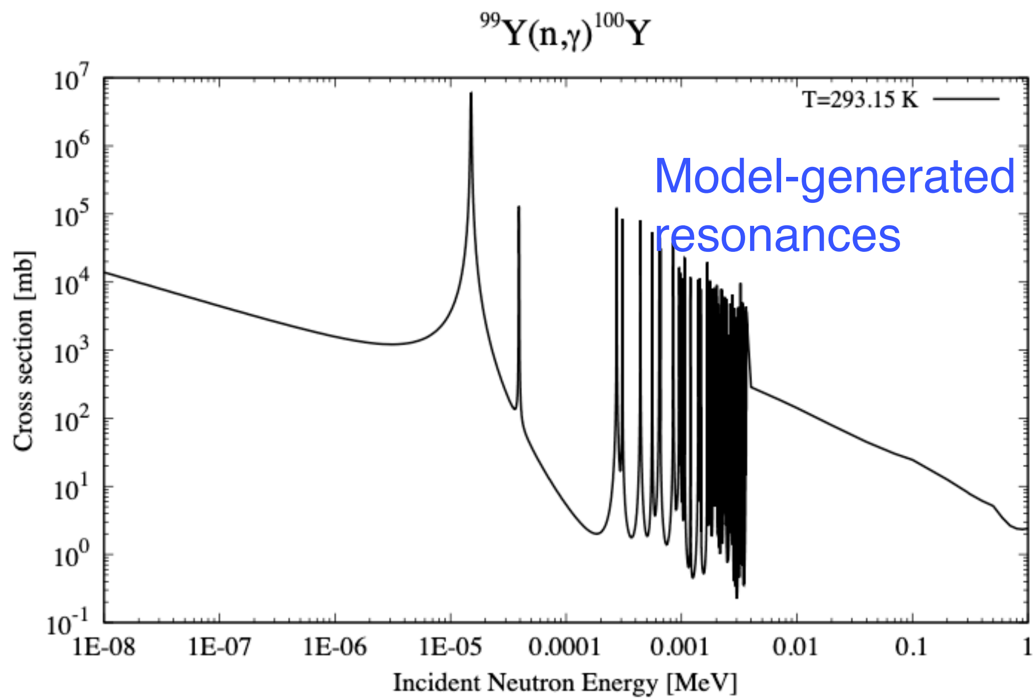



```
projectile n
element    Pu
mass       239
energy   2.53e-8
ejectiles g n
massdis y
fymodel 4
ffmodel 1
ldmodel 5
Rfiseps 1.e-5
outspectra y
bins 40
channels y
maxchannel 8
```



Measured resonances

```
#
# n-Y089-RRR-group
#
# General
#
projectile n
element Y
mass 89
energy energies
#
# Model
#
resonance y
group y
#
# Output
#
channels y
filechannels y
wtable 39 90 0.82 E1
```



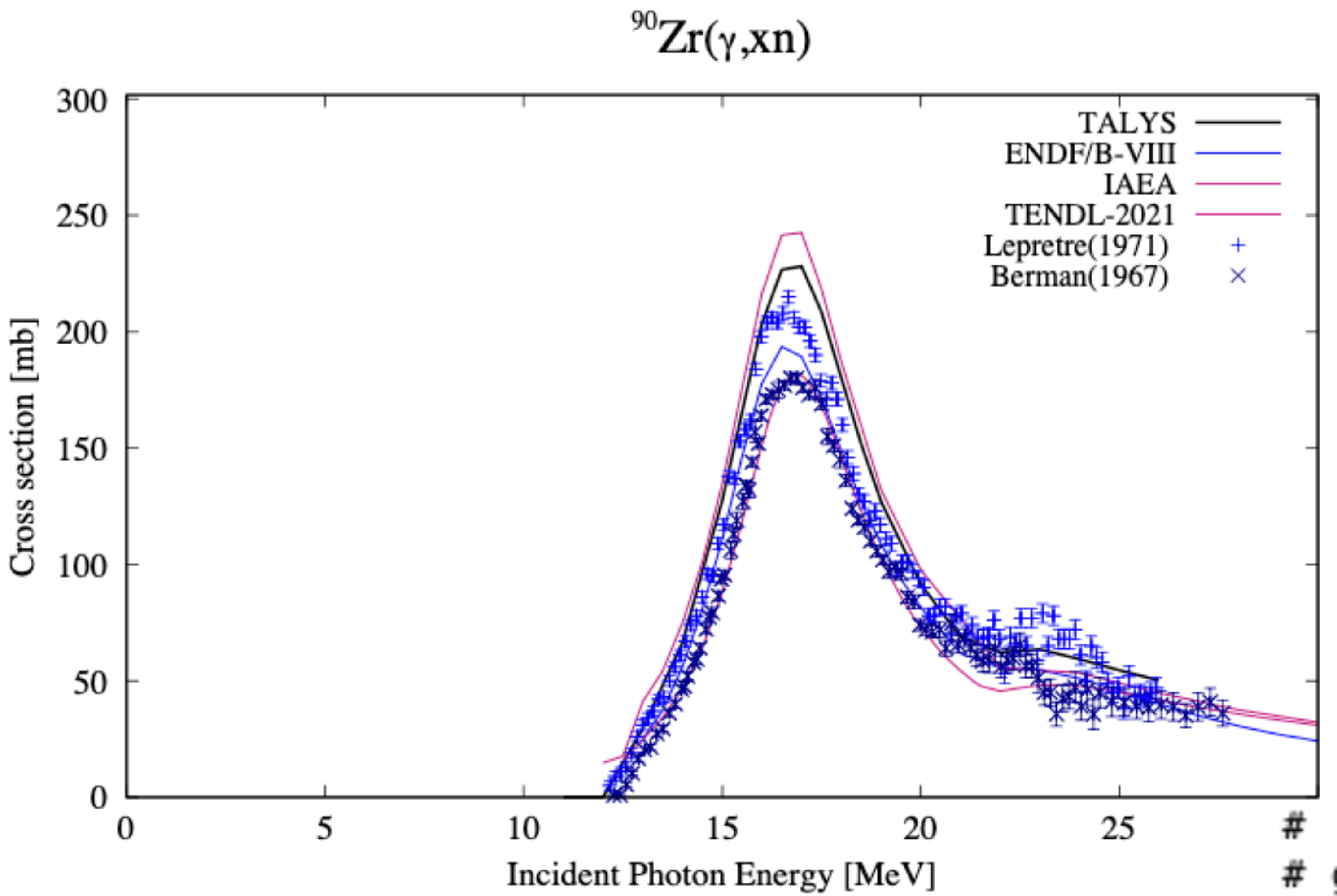
Model-generated resonances

TALYS simulates reactions in the resonance range:

reads resonance parameters, or

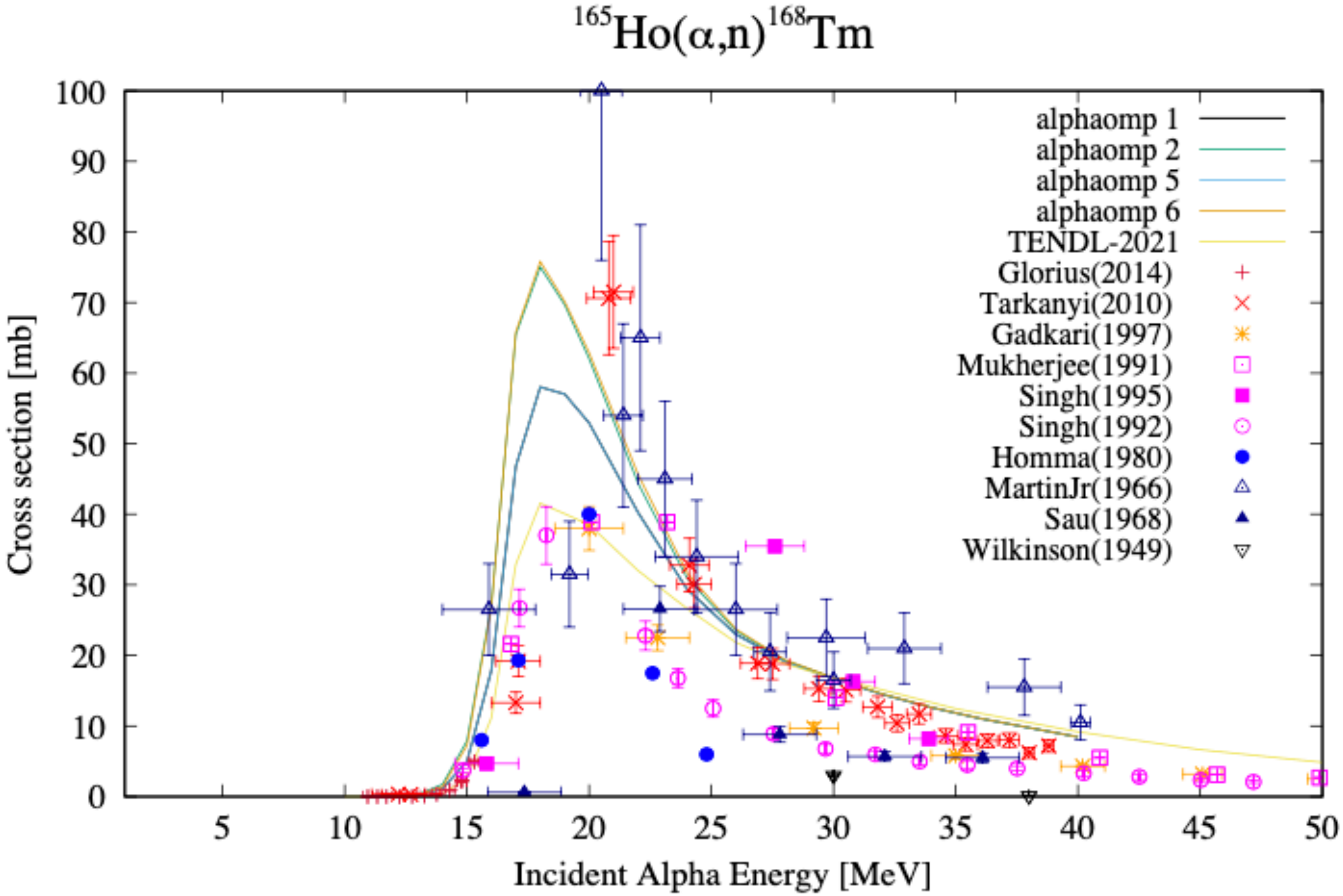
generates them from level densities and strength functions

uses PREPRO routines to turn them into point-wise cross sections

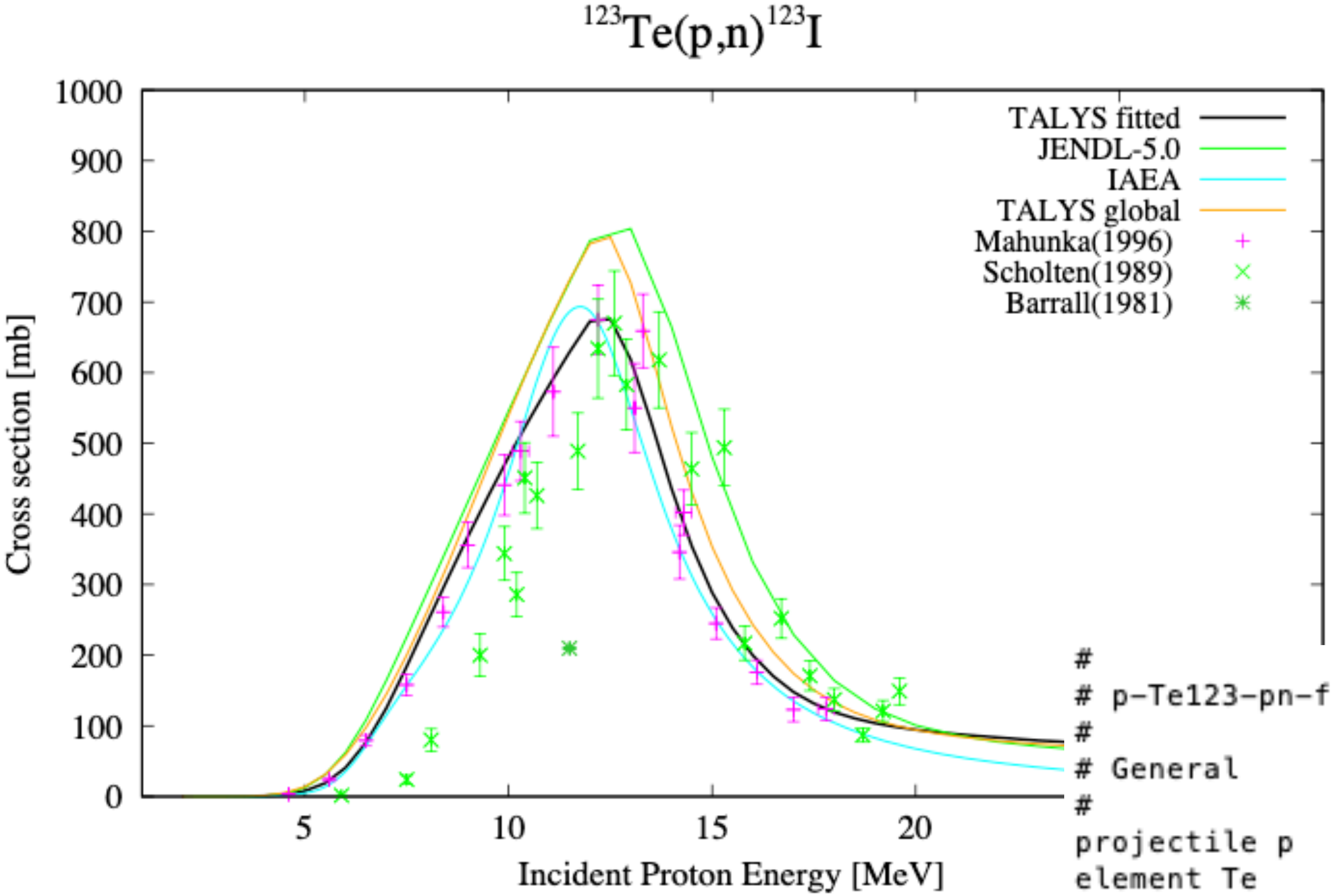


60 Years
Atoms for Peace and Development

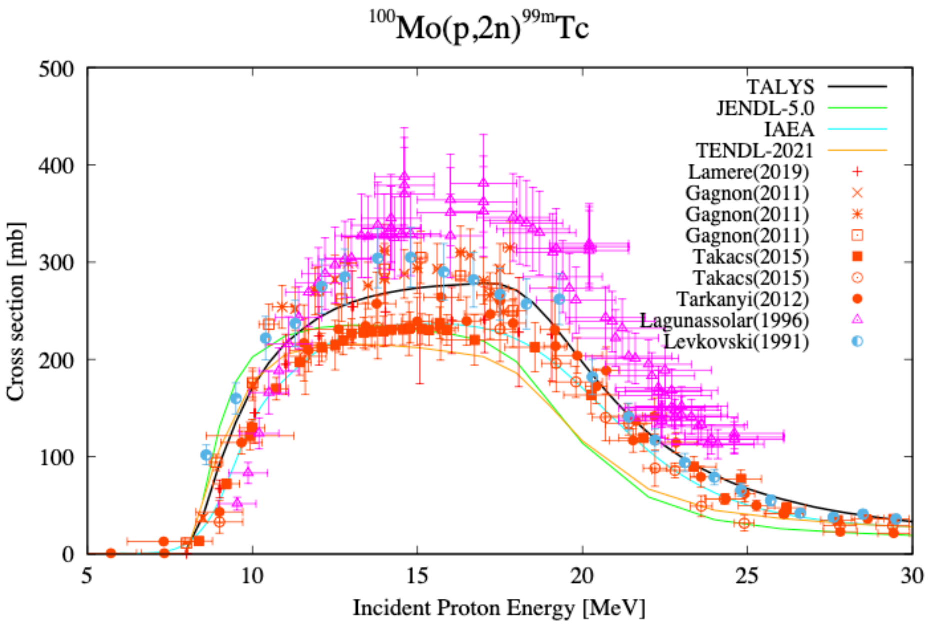
```
#
# g-Zr090-xs
#
# General
#
projectile g
element zr
mass 90
energy energies
```

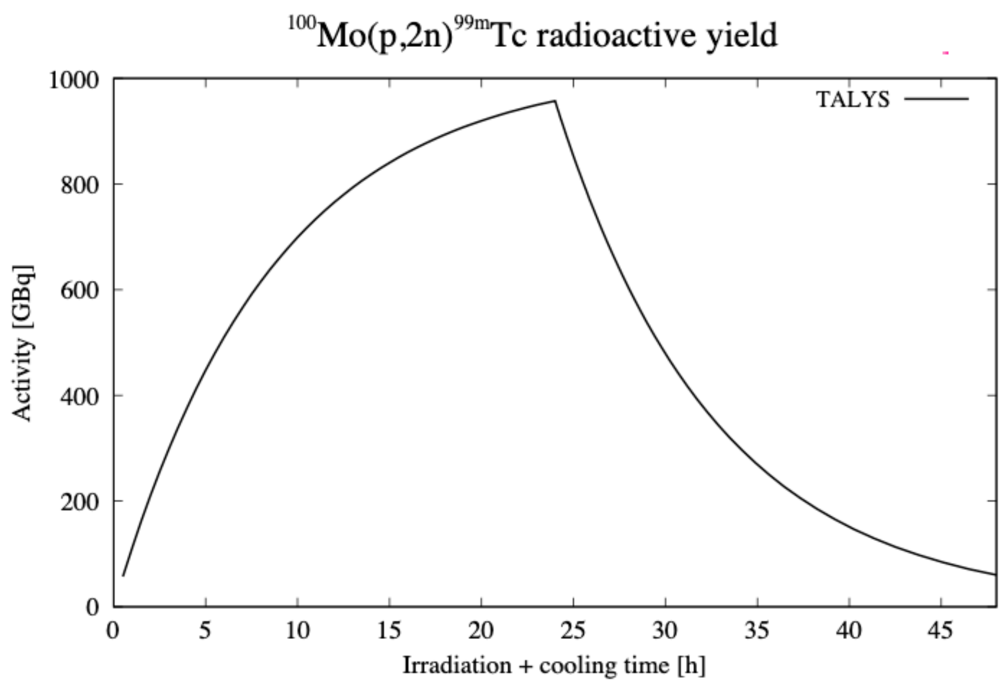



```
#
# a-Ho165-omp6
#
# General
#
projectile a
element Ho
mass 165
energy energies
#
# Model
#
alphaomp 6
#
# Output
#
outomp y
```




```
#
# p-Te123-pn-fit
#
# General
#
projectile p
element Te
mass 123
energy 1. 30. 0.5
#
# Adjusted parameters
#
rvadjust      p    0.95947
rwdadjust     p    0.93338
rvadjust      n    1.02377
gadjust        53 124    0.99089
gadjust        53 123    1.09408
ctableadjust   53 123 -2.54809E-01 0
```






```
#
# p-Mo100-medical
#
# General
#
projectile p
element    Mo
mass       100
energy     8. 30. 0.5
#
# Spherical OMP and adjusted parameters
#
spherical y
rvadjust      p    1.00676
rwdadjust     p    1.11091
rvadjust      n    1.04395
gadjust        43 101     1.22030
gadjust        43 100     1.04828
ctableadjust   43  99     1.34123 0
s2adjust       43  99     0.14784 0
#
# Medical isotope production
#
production y
Ibeam 0.15
Ebeam 24.
Eback 10.
```

TENDL-2023: Fission yields and fission neutron observables from TALYS

TALYS-1.96: reads distribution of excited fission fragments and evaporates them all with Hauser-Feshbach

Univ. Uppsala:
Ali Al-Adili
Fredrik Nordstroem

CEA-DAM Bruyeres:
Jean-Francois Lemaitre

Titech TOKYO:
Kazuki Fujio
Satoshi Chiba

LANL:
Toshihiko Kawano

IAEA:
Shin Okumura
Arjan Koning

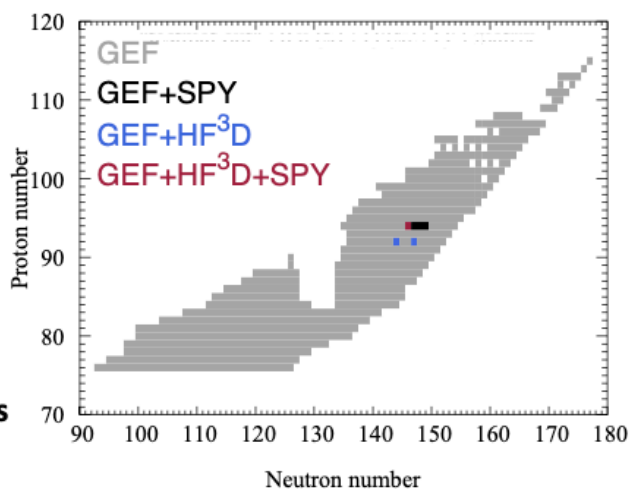
Fission fragment yield models stored in TALYS

GEF Designed with global fitting parameters based on experimental data
F. Nordström, Technical Report UPTEC ES21016, Uppsala university, 2021.
From $_{76}$Os to $_{115}$Mc, 737 nuclides

HF³D Designed with a fully deterministic technique with fitting functions
S. Okumura, T. Kawano, P. Jaffke, P. Talou, and S. Chiba, JNST, 55(9),1009–1023, 2018.
^{236}U, ^{239}U, and ^{240}Pu, 3 nuclides

SPY Designed with a statistical scission point model using microscopic calculation
J.-F. Lemaître, S. Goriely, S. Hilaire, and J.-L. Sida, PRC99, 034612, 2019.
^{240}Pu, ^{241}Pu, ^{242}Pu, and ^{243}Pu, 4 nuclides
(May 2022: 809 nuclides)

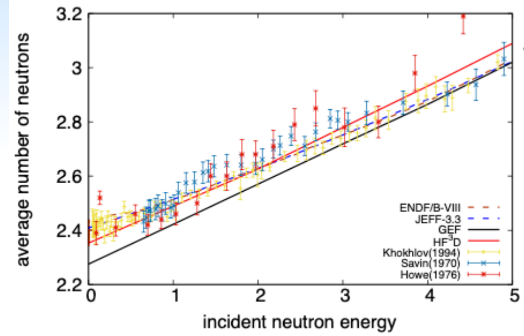
Arbitrary fission fragment data provided by users



We did:

calculations of the de-excitation process for ^{235}U+n with Hauser-Feshbach statistical decay theory and comparison with evaluated and experimental data

Fission observables for $^{235}U+n_{th}$ with TALYS



The energy dependence of average number of neutrons

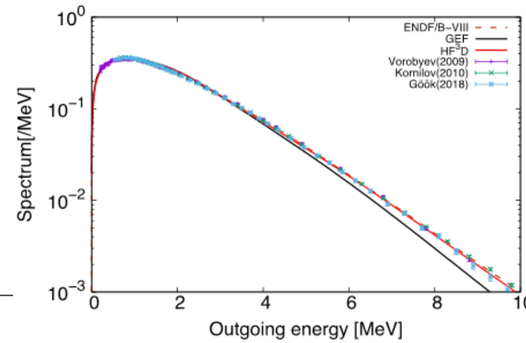
GEF is good agreement in after 4MeV

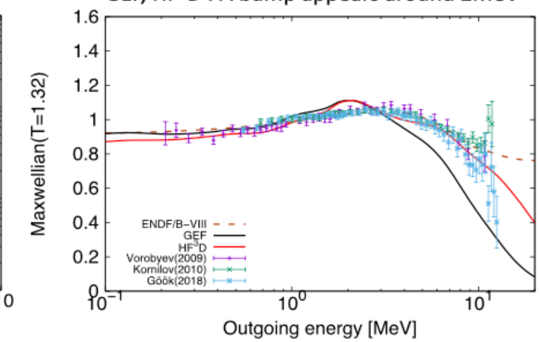
HF^3D is good agreement in low energy range

Prompt Fission Neutron Spectra

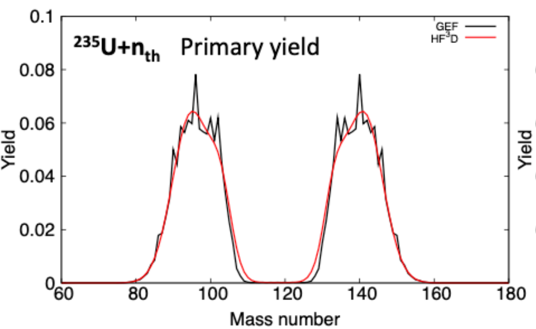
Ratios to Maxwellian

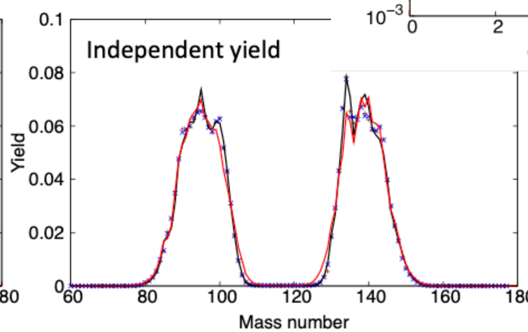
GEF, HF^3D : A bump appears around 2MeV

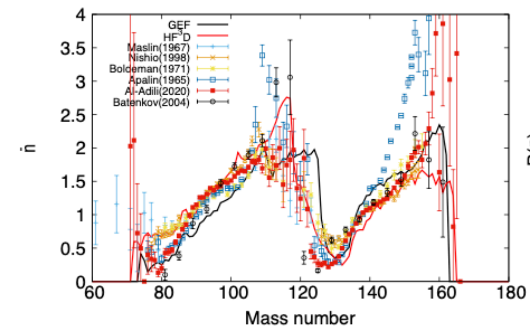


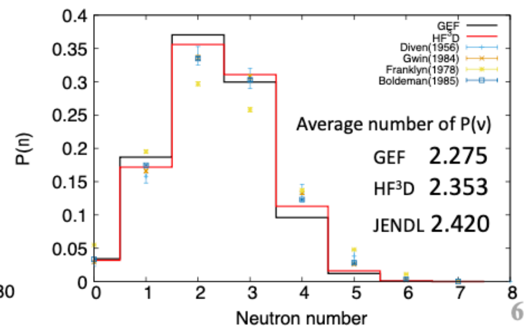


Fission observables for $^{235}U+n_{th}$ with TALYS









More initial FF distributions welcome!

FREYA

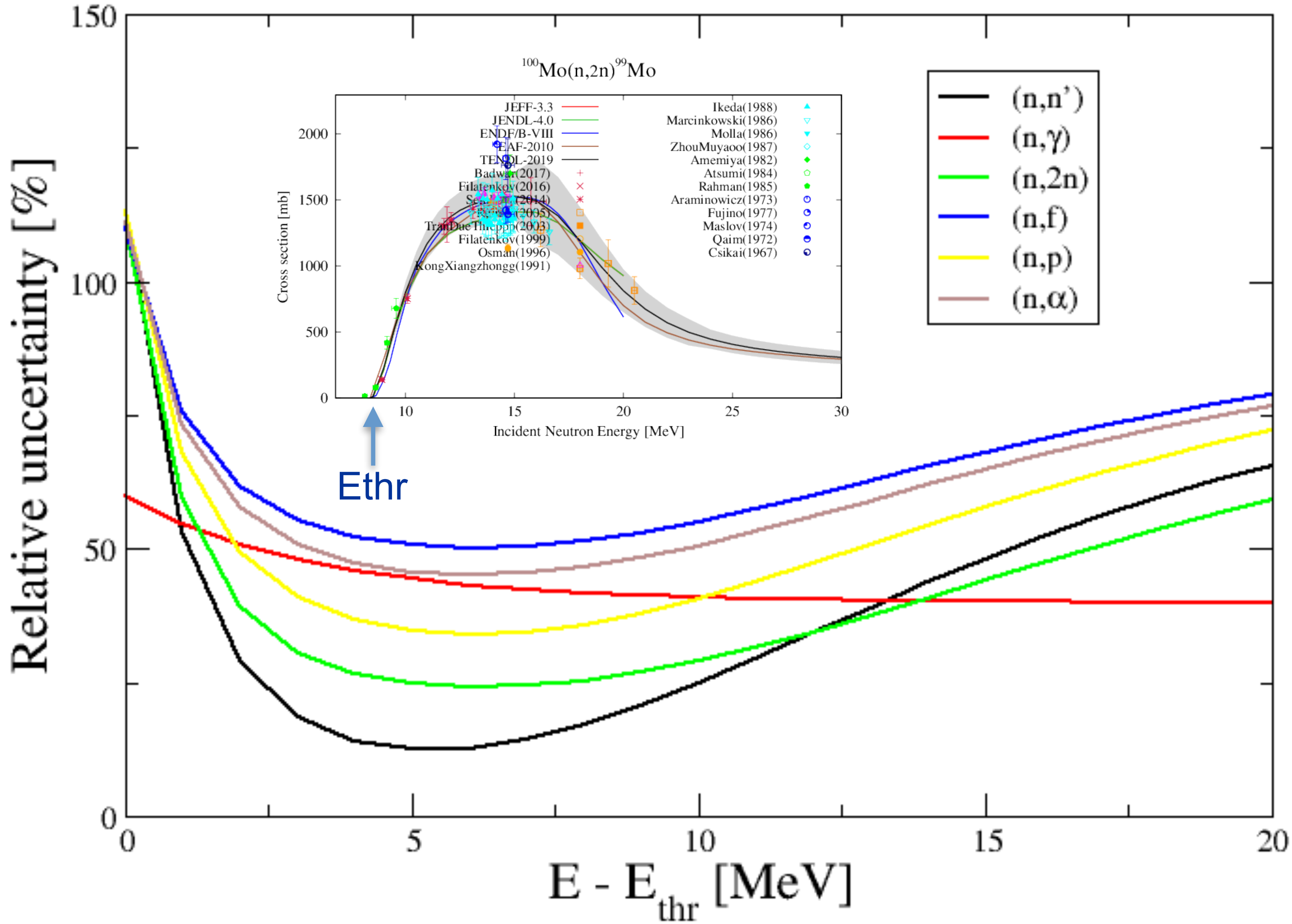
4D-Langevin

Next version of SPY

etc.

Global predictive power of TALYS

Based on all EXFOR cross sections, A-independent



TENDL-astro 2021

(n,g) cross sections, reaction rates and MACS for astrophysics

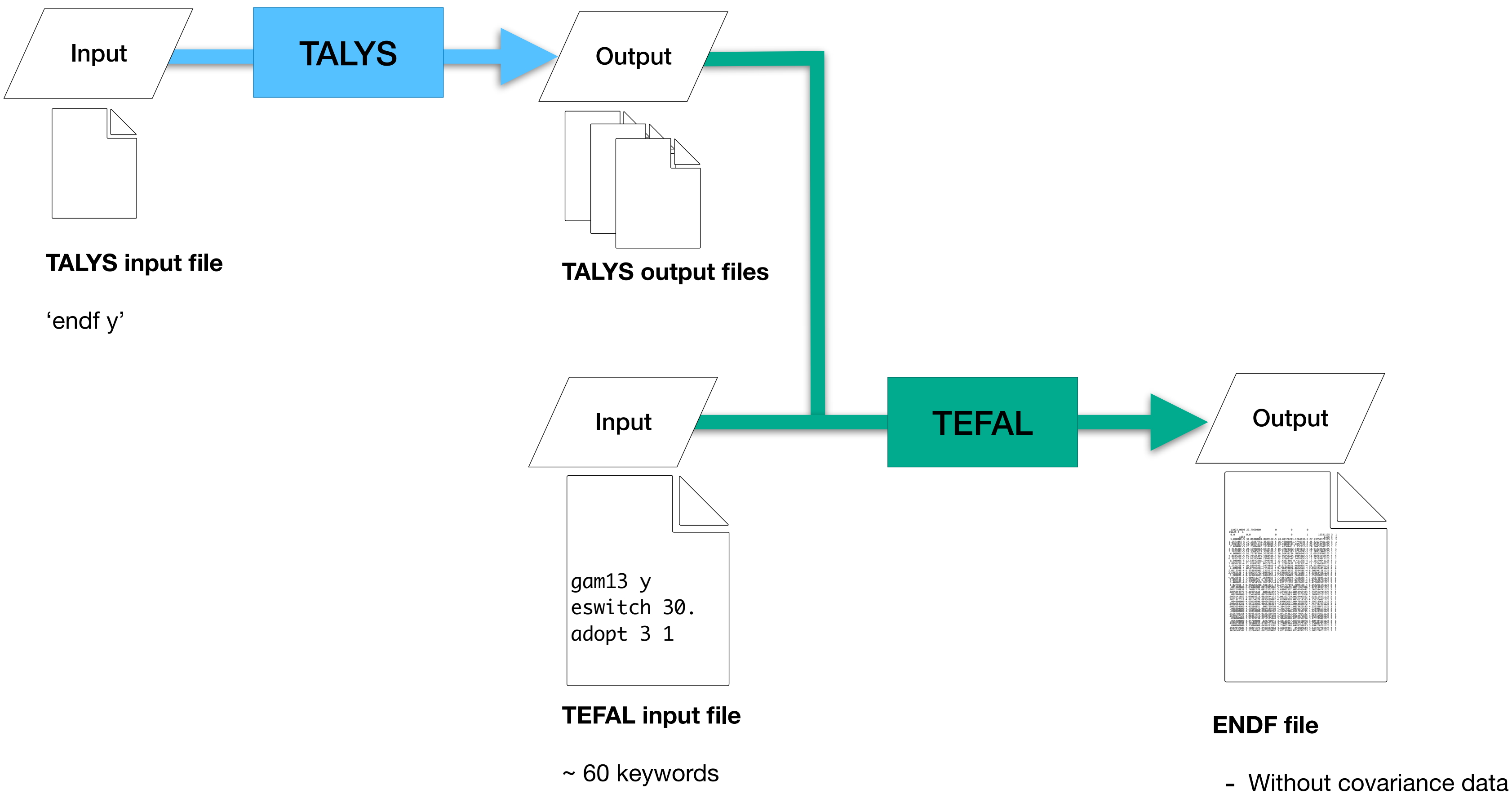
- Randomize models, not parameters
- 288 model combinations x 8892 isotopes:
  - Reaction rates + uncertainties

1. Gamma strength function (values 8 or 9): either Gogny D1M HFB+QRPA, or SMLO
2. Level density (values 1, 2 or 5): Constant temperature + Fermi gas model, or Back-shifted Fermi gas model, or Microscopic level densities (Skyrme force) from Hilaire's combinatorial tables
3. JLM microscopic optical model potential or KD optical model (values y or n)
4. Gamma strength function for M1 (values 3 or 8): Hartree-Fock BCS tables or Gogny D1M HFB+QRPA
5. Collective enhancement (values y or n): yes or no
6. Width fluctuation (values 0, 1 or 2): Moldauer model, or Hofmann-Richert-Tepel-Weidenmueller model
7. Mass model (values 0, 1, 2 or 3): Duflo-Zuker formula, Moeller table, Goriely HFB-Skyrme table, or HFB-Gogny D1M table (except for known masses, where the experimental value is used)

- https://tendl.web.psi.ch/tendl_2021/tar_files/astro/astro.html

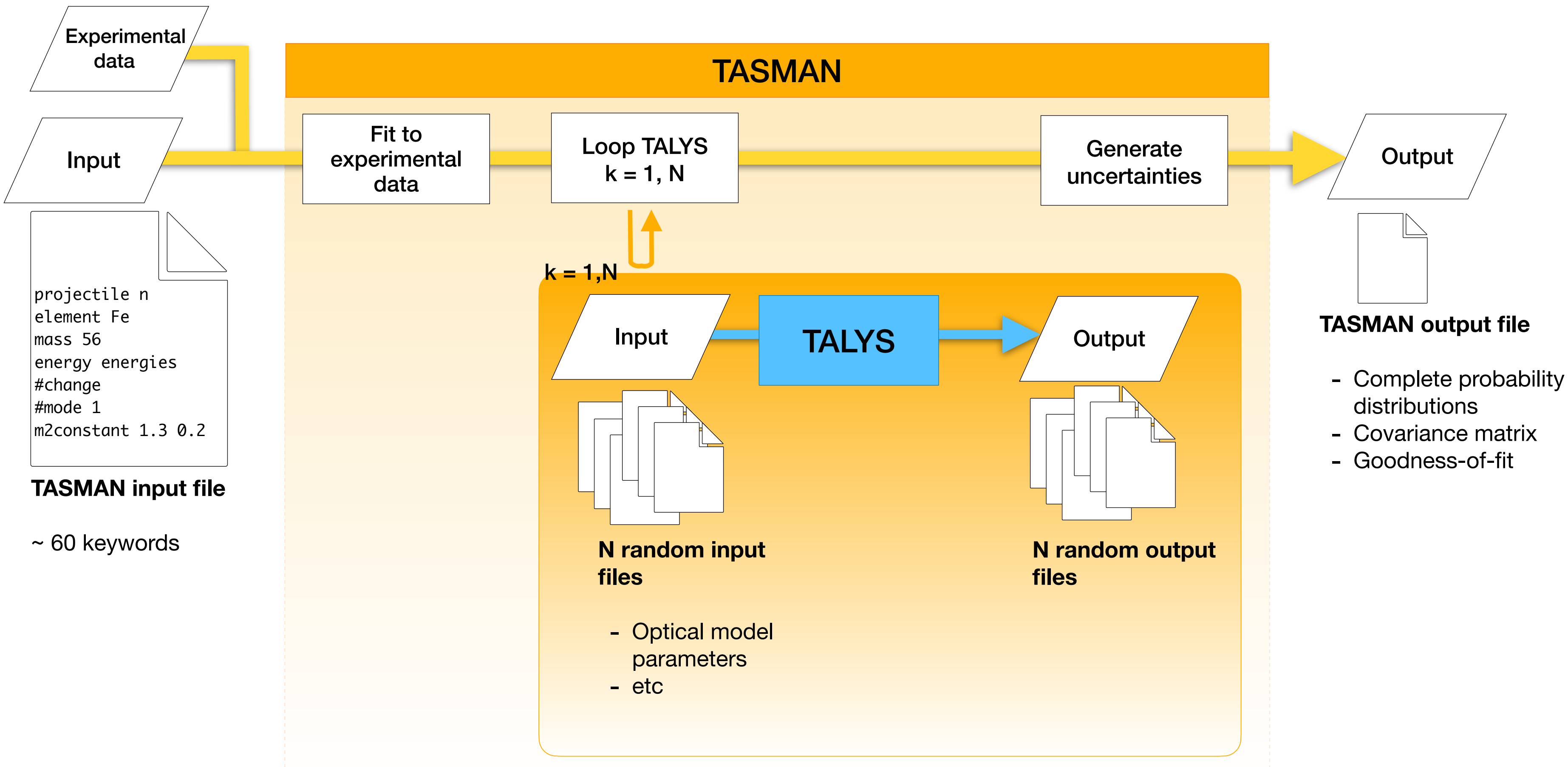
TEFAL + TALYS

- TEFAL processes the output of TALYS, and data from other sources, into an ENDF-6 data library



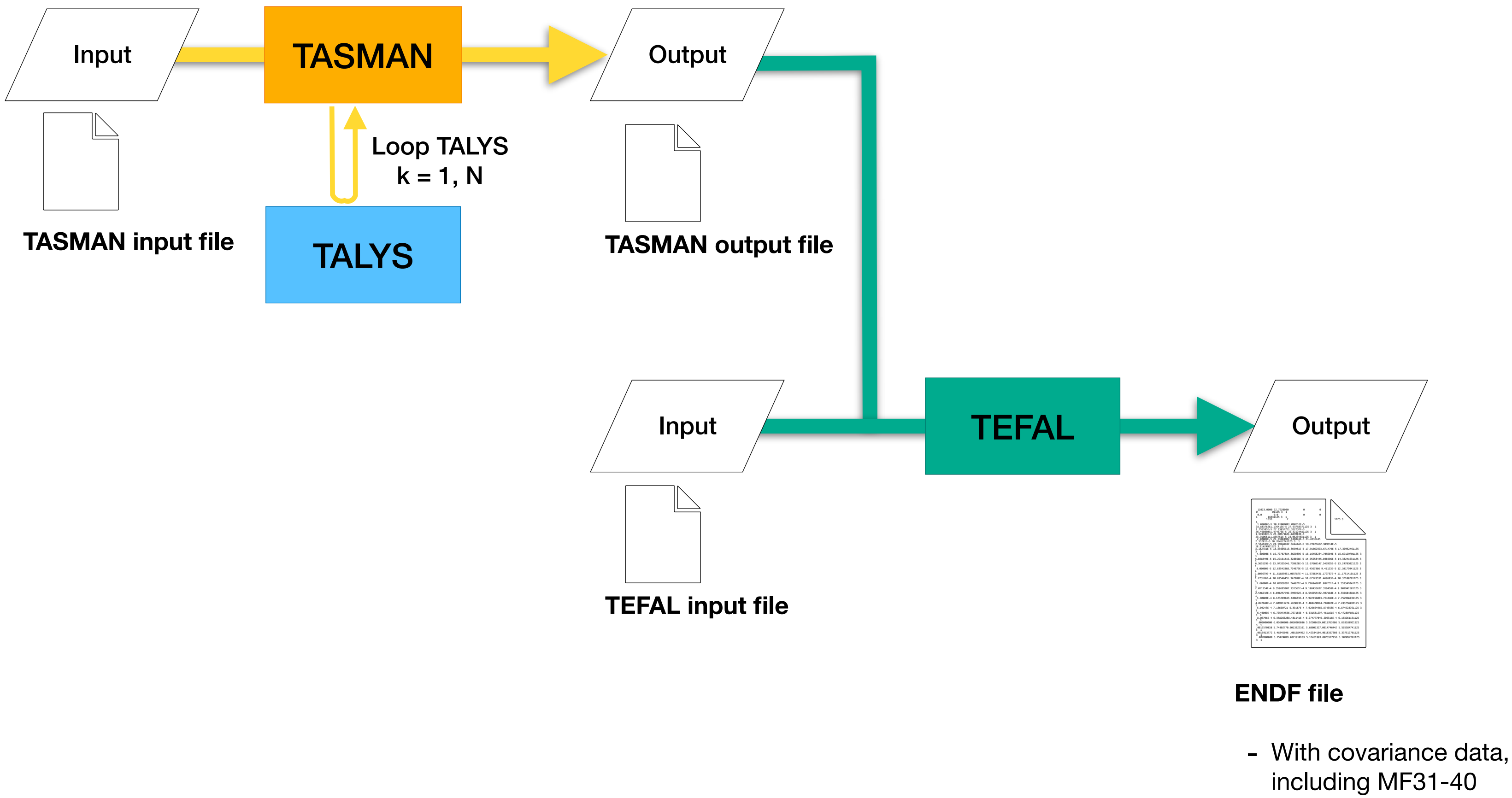
TASMAN + TALYS

- TASMAN produces uncertainty distributions based on input/output files of TALYS, and automatically fits experimental reaction data
- TASMAN generates random input N times and runs TALYS



TASMAN + TALYS + TEFAL 1: Covariance data

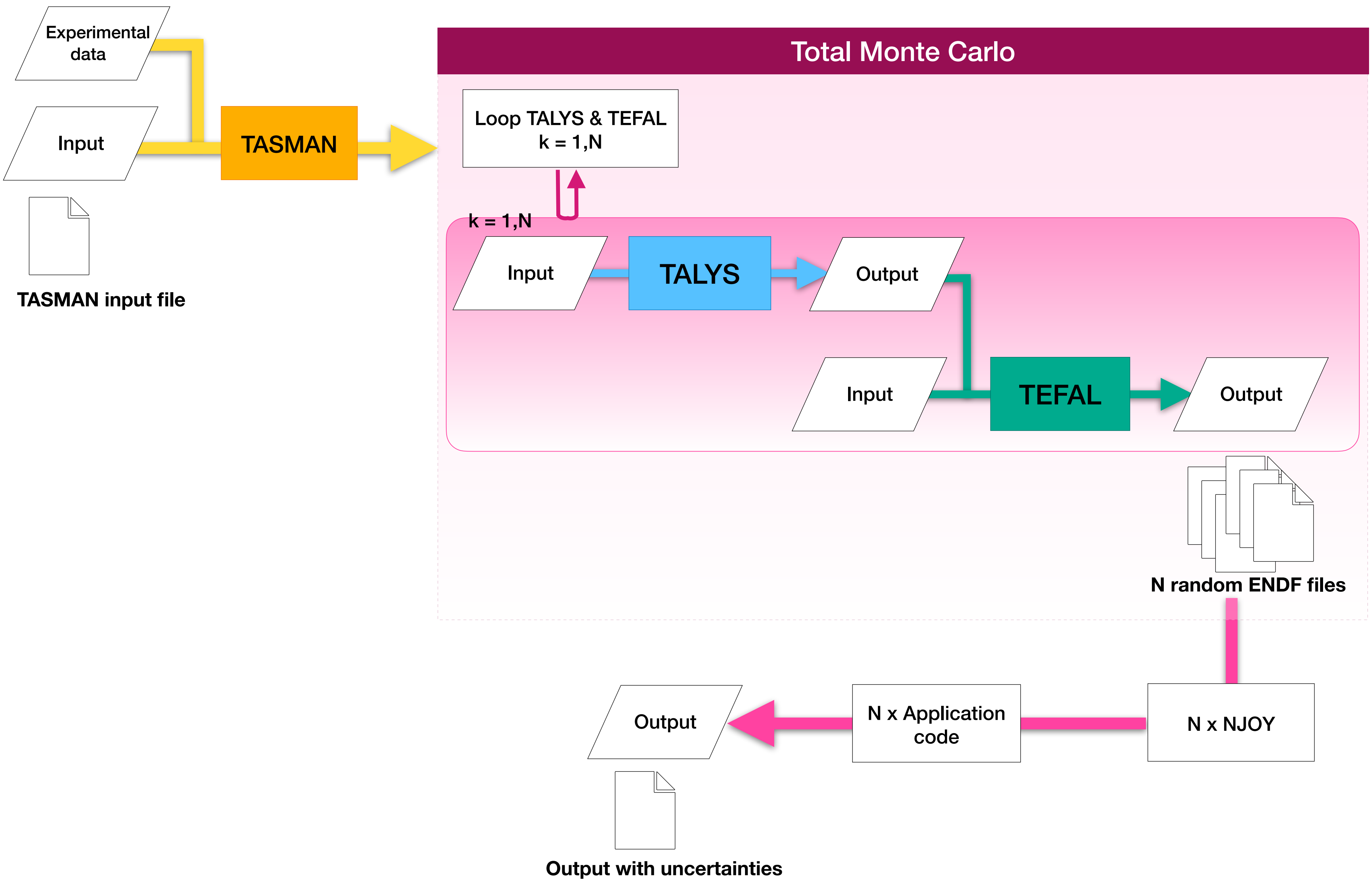
- TASMAN generates random input N times and runs TALYS



Loop the above over all nuclides = TENDL

TASMAN + TALYS + TEFAL 2: Total Monte Carlo

- TASMAN generates random input N times and runs TALYS and TEFAL for each 'k'



Conclusions

- TALYS a stable and well-tested (thanks to you!) tool for reasonable to good predictions nuclear reaction
- For nuclear reactions up to 200 MeV, TALYS is
  - the most versatile model code (subjective statement), and
  - most used model code in the world (objective statement)
- Exciting new nuclear structure developments can go straight into the code.
- The road to technology (nuclear data libraries) and applied science (astrophysics) is entirely automated.
- TALYS-2 will be released in December 2023
- Automated optimisation to many reaction channels with a relatively small number of TALYS parameters
  - Requires computational access to entire EXFOR database at once
  - Requires extensive outlier database
- TENDL-2023 will contain optimised excitation functions

IAEA

60 Years

Atoms for Peace and Development

Thank you!