Level Density, γ-ray strength function of ^{240}Pu and the ^{239}Pu fast neutron capture cross-section

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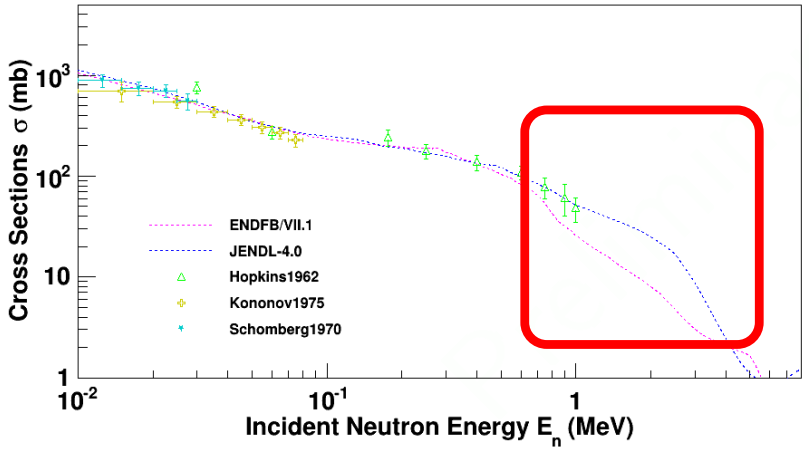
ND2016, Brugge

- Fundamental nuclear structures and dynamics
- Get σ from Hauser-Feshbach calc.
  - Safeguards & Verification
  - Astrophysics: nucleosynthesis of heavy elements
  - Reactor physics
    - Advanced nuclear reactors
    - waste management
  - ...

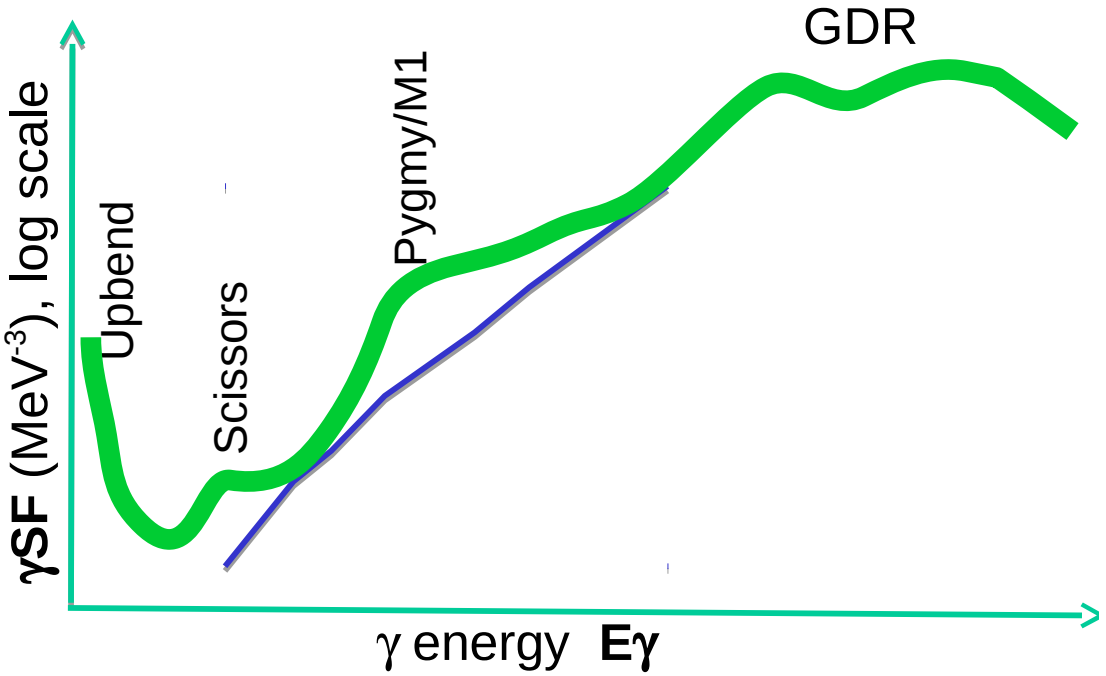
→ Surrgoate rection + Oslo Method

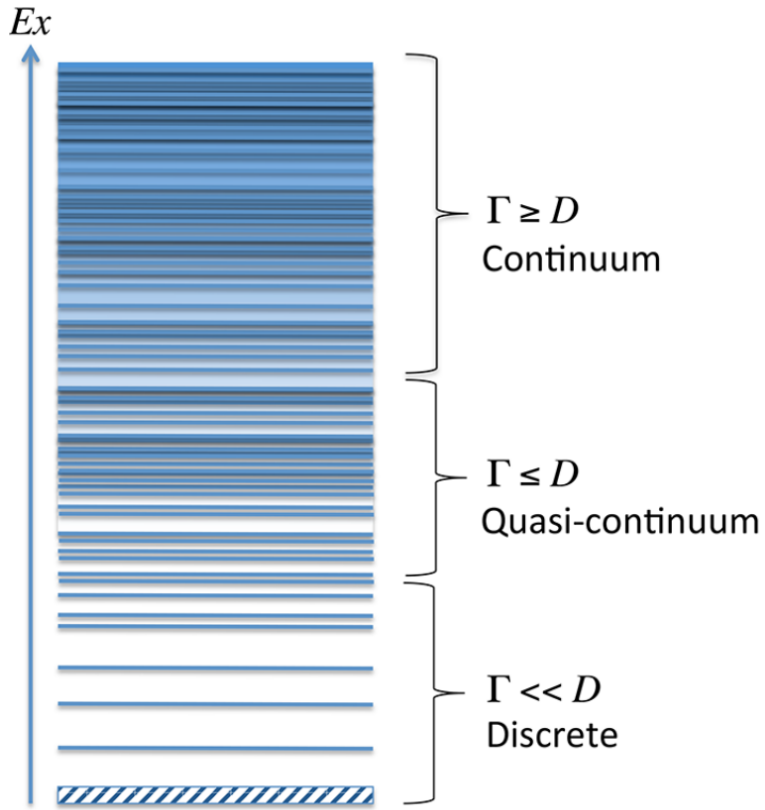
[Pixabay.com]



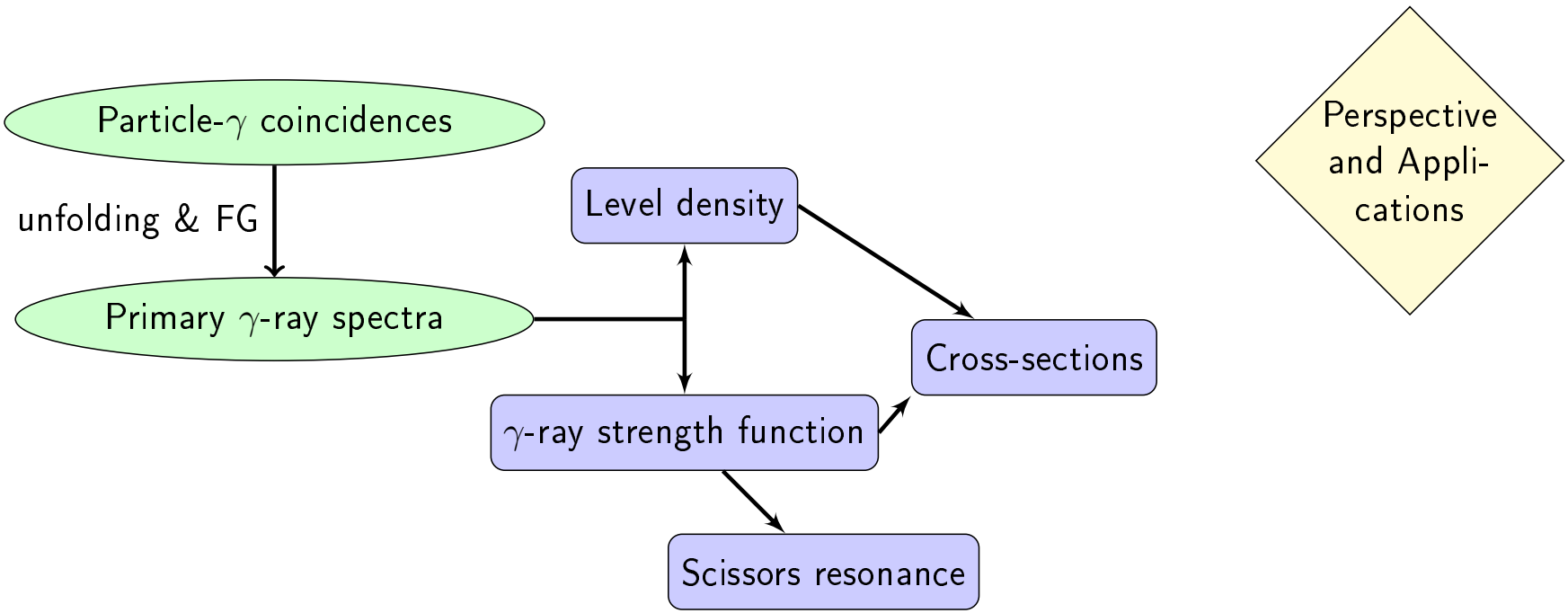
$^{239}\mathrm{Pu}(n,\gamma)^{240}\mathrm{Pu}$

$^{239}\mathrm{Pu}(\mathrm{n},\gamma)$: "[t]hese reactions are so important that should new assessments, based on new measured data, lead to significant changes in these evaluated cross sections, there will be significant implications for nuclear applications, for example in our criticality calculations."
Chadwick et. al. "ENDF/B-VII.1 Nuclear Data" NDS, 112(12):2887–2996, Dec 2011



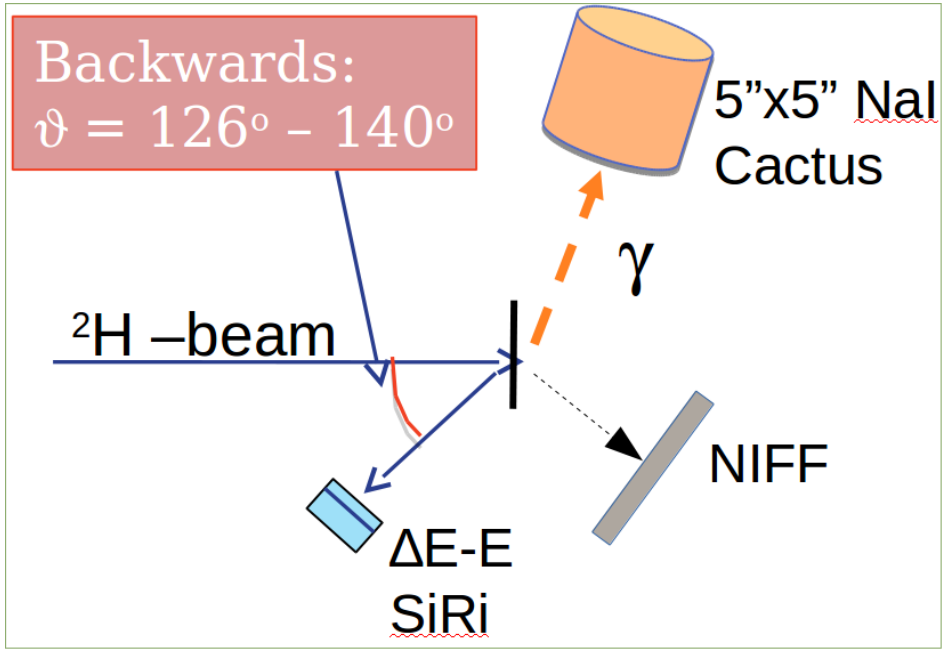


[Guttormsen et al., Europ. Phys. J. A 51 (2015)]


Particle-γ coincidences
unfolding & FG
Primary γ-ray spectra
Level density
γ-ray strength function
Cross-sections
Scissors resonance
Perspective and Appli-cations

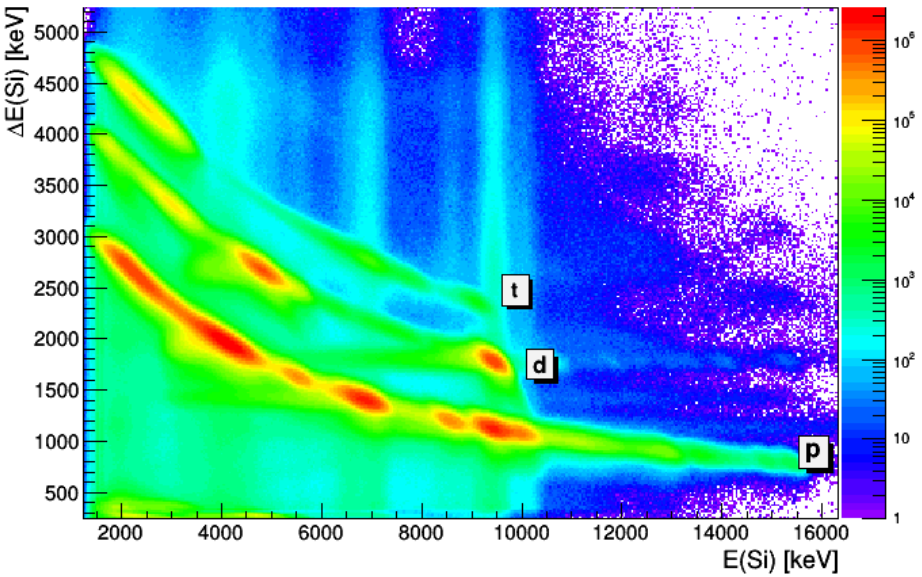
Set-up

- Beam time: June 2014
- 12 MeV deuterons on ^{239,242}Pu (0.4 mg/cm^2 on 1.8 mg/cm^2 Be backing)
- Measurements
  - particle-γ coincidence
  - Fission coincidence with NIFF

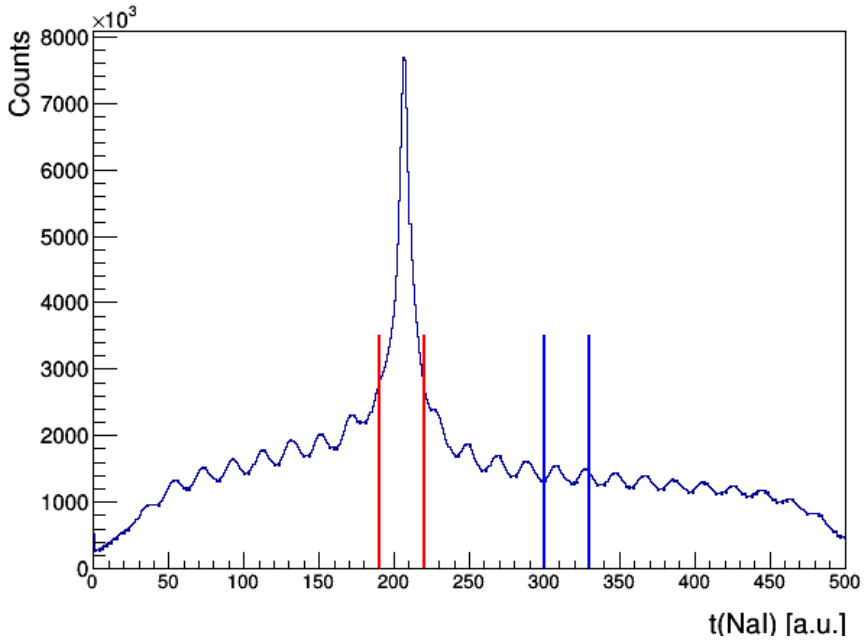


Calibration: The Particle Spectra

(d,x)



(d,pγ)



Calibration: Reaction kinematics

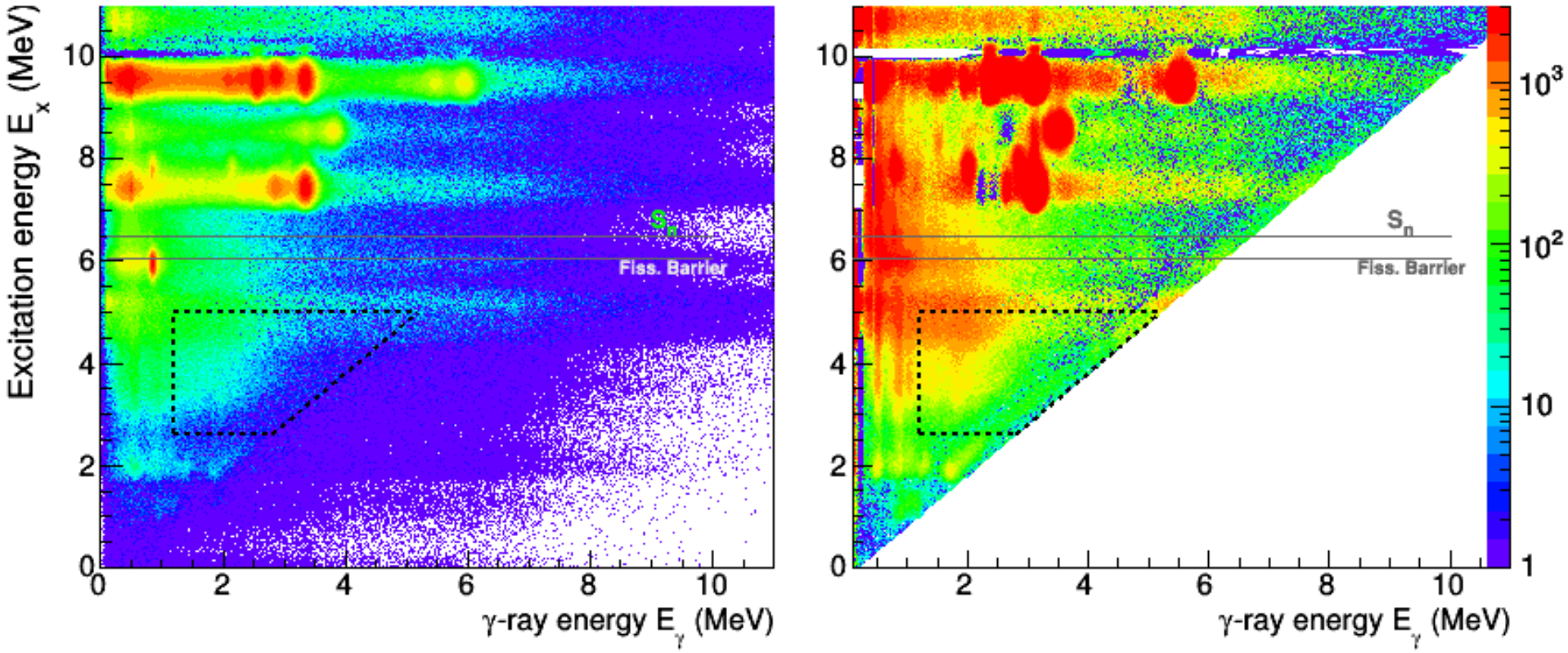
Gate on

- particles "bananas" $\rightarrow$ e.g. (d,p)
- time: true vs. random coincidences

The particle-γ coincidences

raw spectrum

unfolded



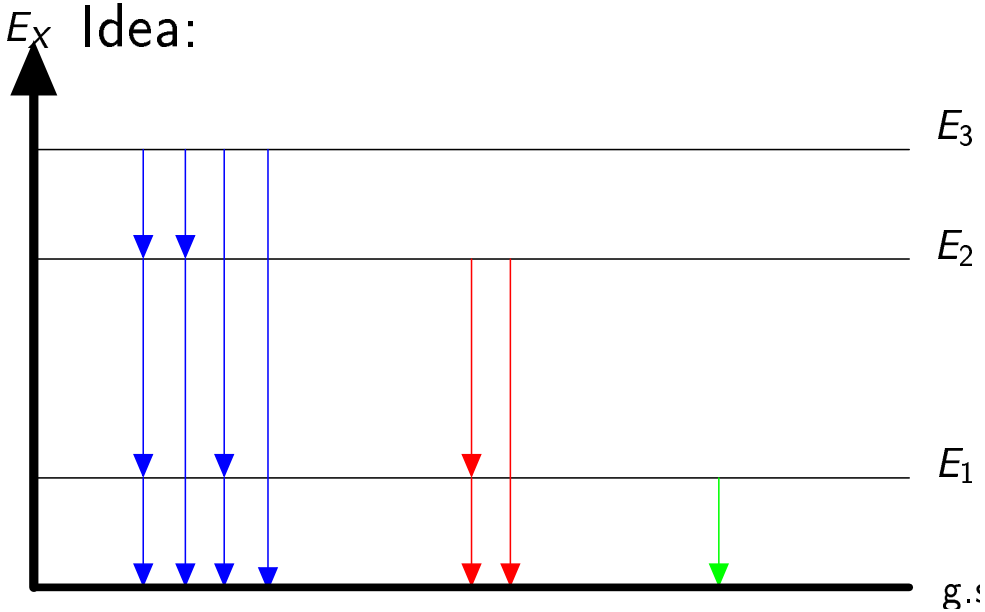
- Unfolding with smoothed Compton background:
  M. Guttormsen et al., *NIM A*, **374** 371 (1996)

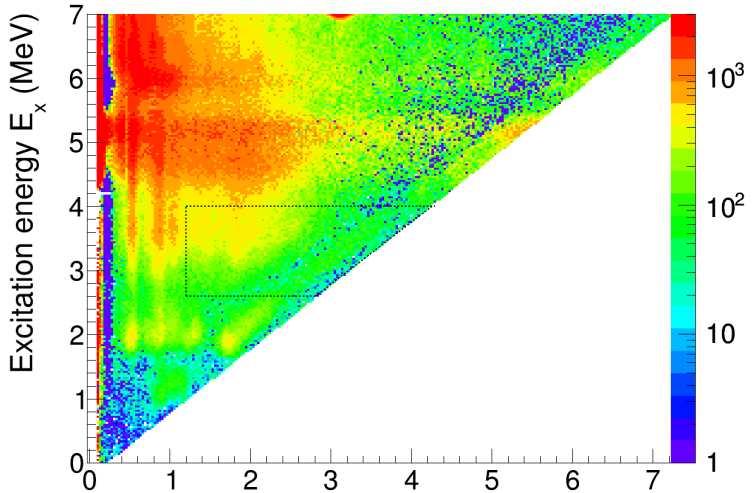
Fasten your seatbelts!

The Oslo Method

First-Generations Martix

Goal: (d,pγ) spectra $\rightarrow$ primary γ-rays





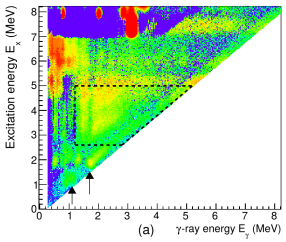
Assupmtion:

- Same population of (d,p) then γ-decay

Method: M. Guttormsen, et al., *NIM A*, 255 518 (1987)

How does it work?

First generations



Golden Rule

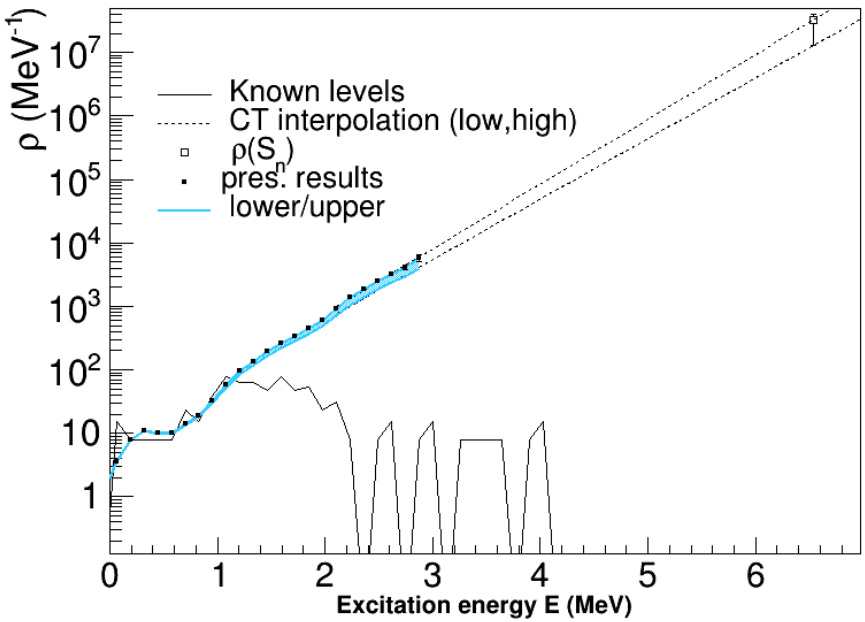
$$P(E_x, E_\gamma) \propto \rho(E_f)\mathscr{T}(E_\gamma, E_f) \propto \rho(E_f) \times \mathscr{T}(E_\gamma)$$

Brink-Axel hypothesis

ToDo: Normalization

Method: A. Schiller, et al., *NIM A*, 447 498 (2000)

Level Density



Normalization: level spacing D_0 [RIPL3]

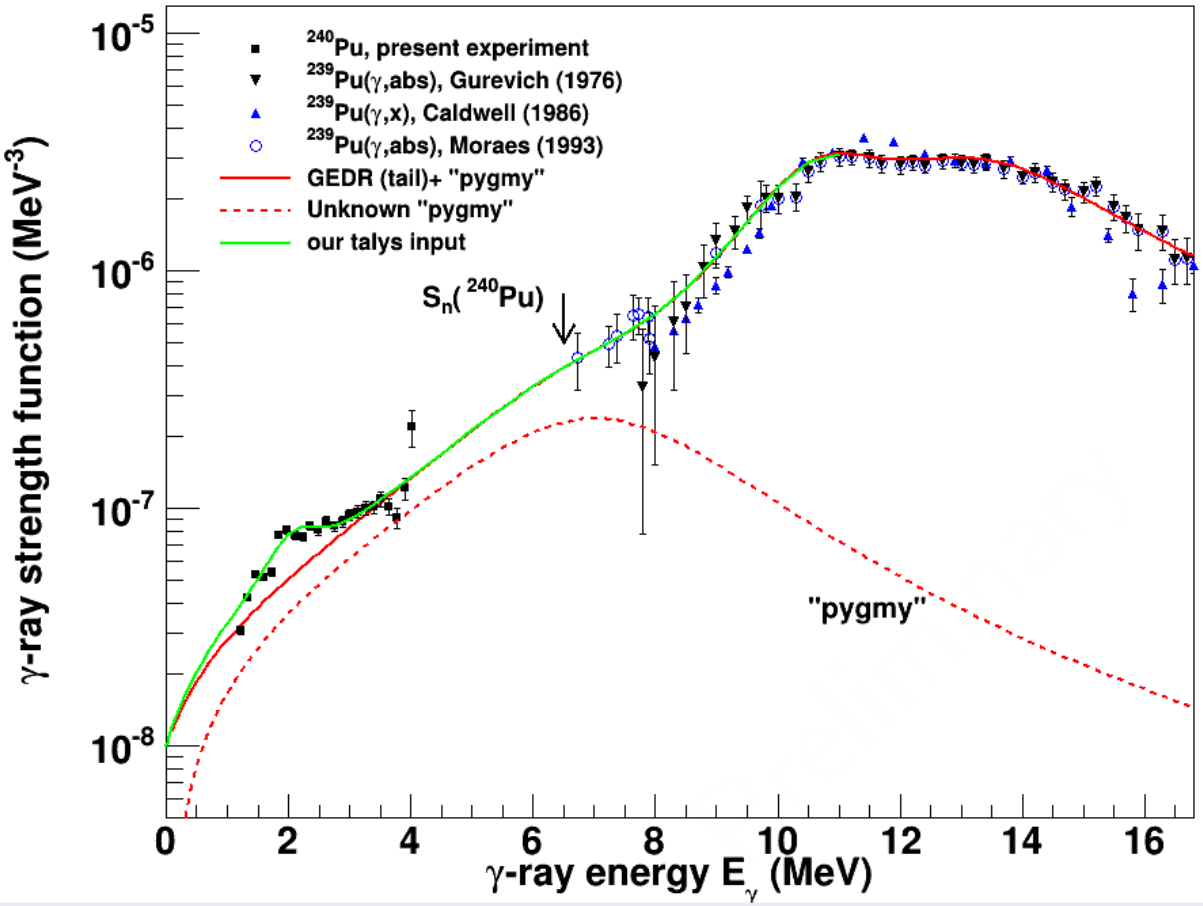
Additional assumptions:

- Spin distribution [EB06]
- Parity distribution

ρ_{red}
(d,p) spin transfer

Gamma Strength Function

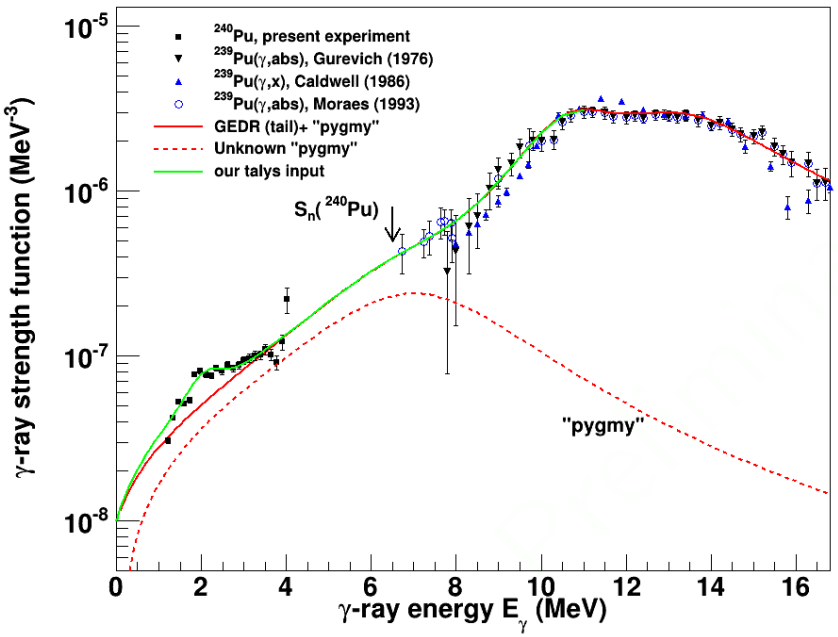
A never ending story...



$$f(E_\gamma) = \frac{1}{2\pi}\frac{\mathscr{T}(E_\gamma)}{E_\gamma^{2L+1}} \overset{\text{L=1 transition}}{=} \frac{1}{2\pi}\frac{\mathscr{T}(E_\gamma)}{E_\gamma^{3}}.$$

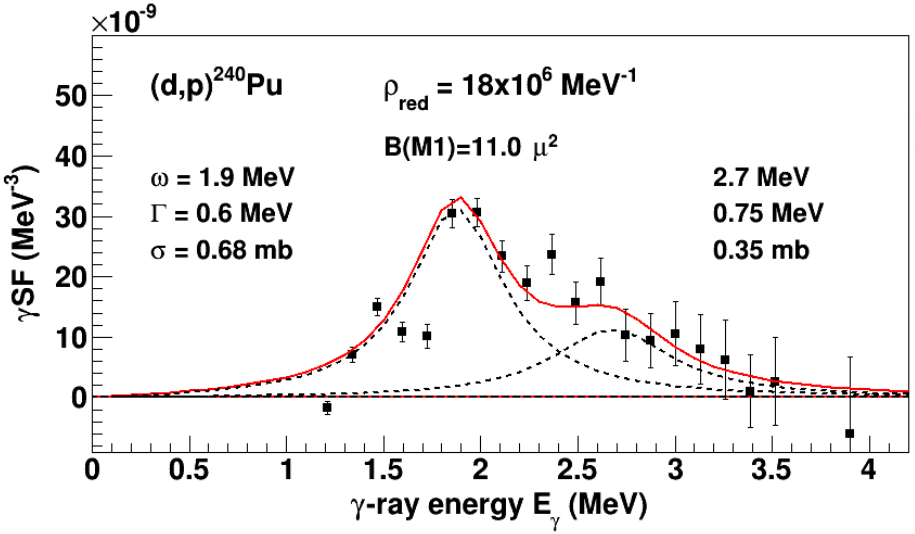
Gamma Strength Function

A never ending story...



Data: $2.6\text{MeV} \leq E_\text{x} \leq 4\text{MeV}$

Scissors Resonance

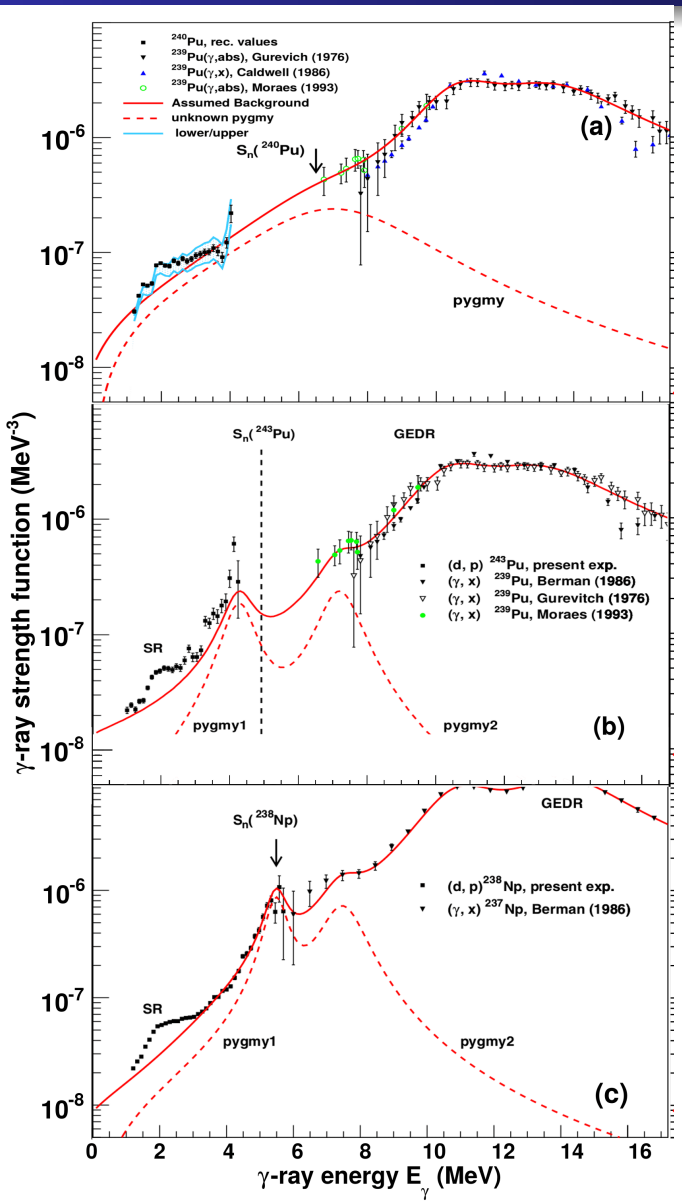


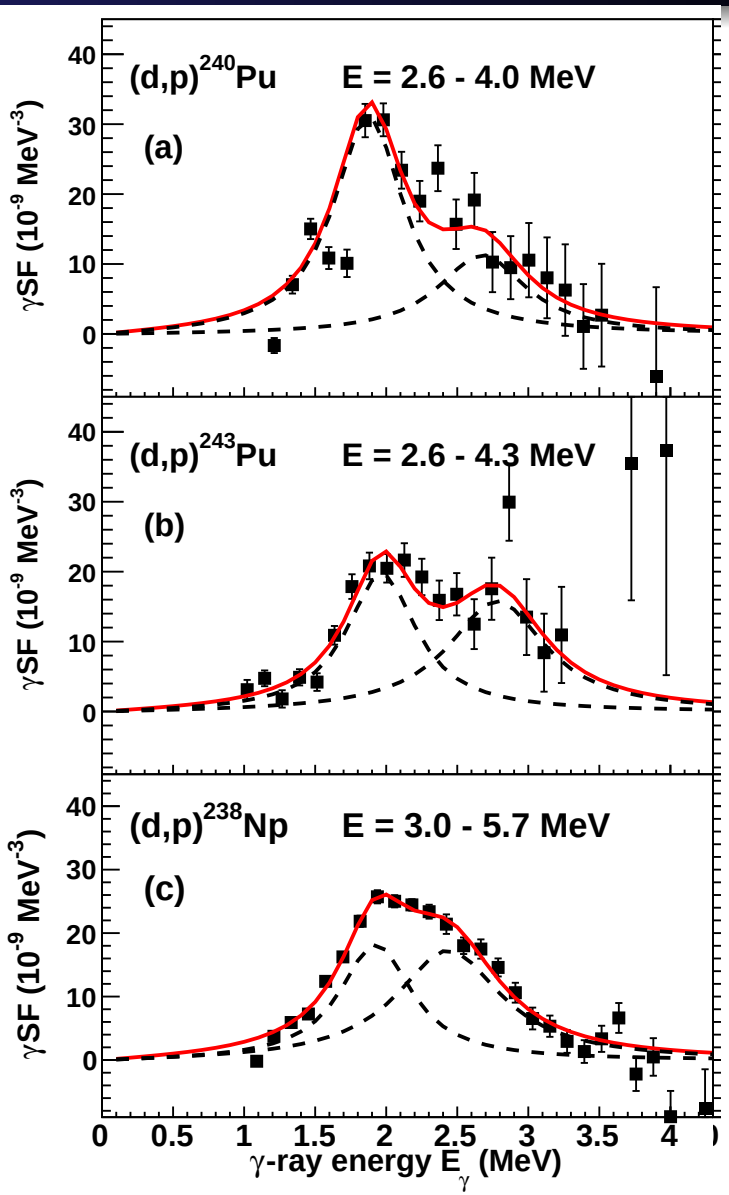
$B(M1) = 11.0(16)\ \mu_{\text{N}^2}$

Caution:

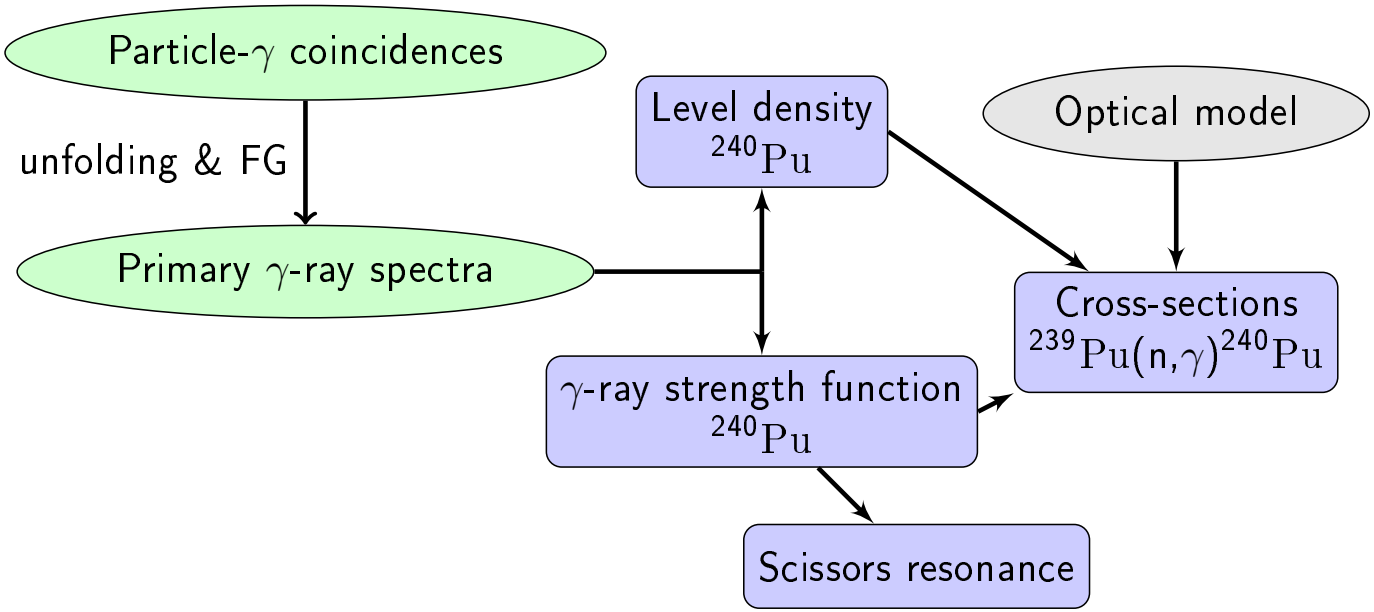
Uncertainty in spin and background estimation

Comparison



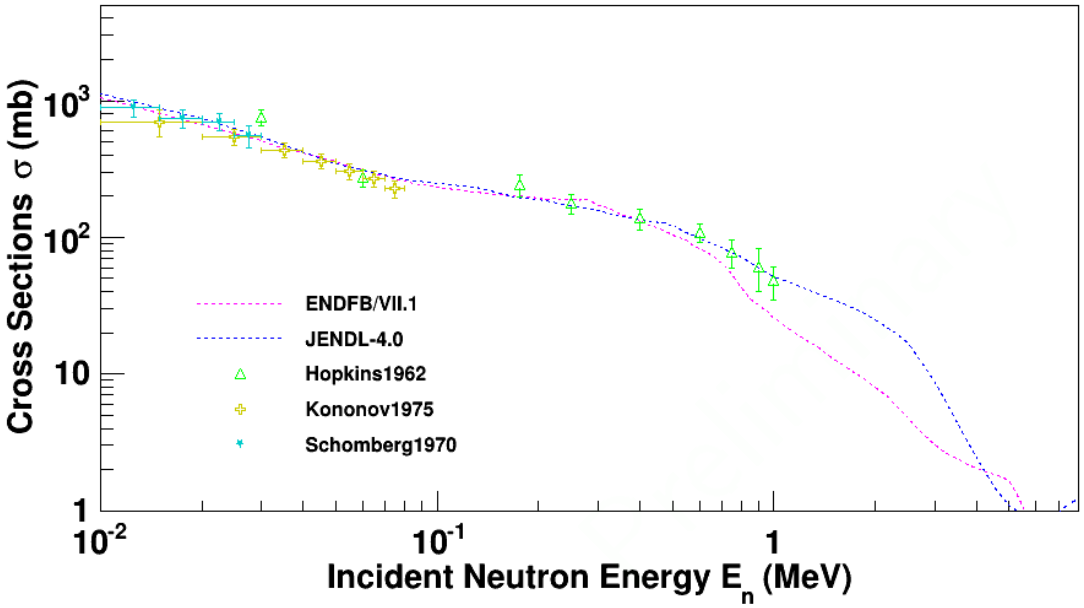


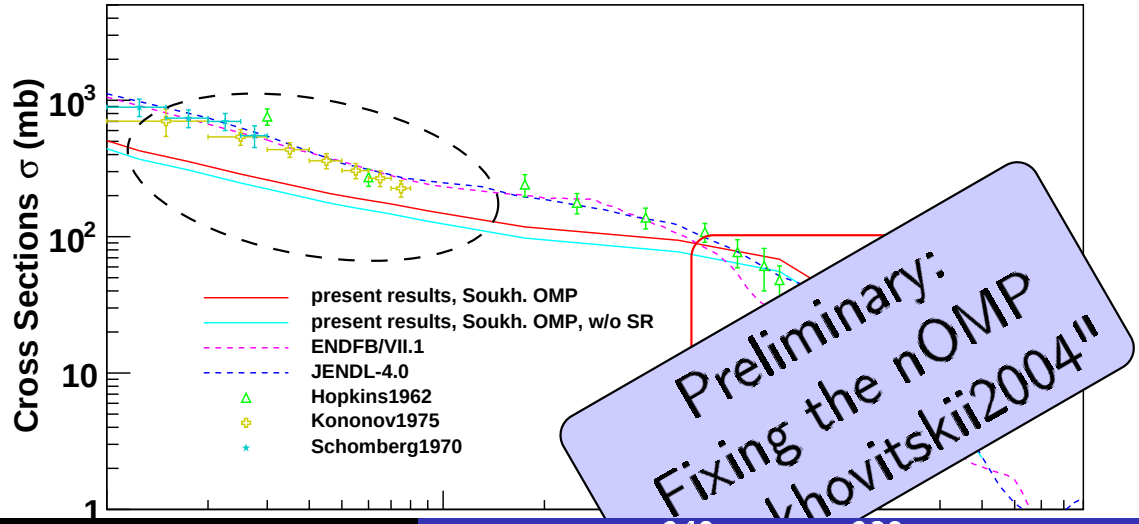
(b): ^{243}Pu, T. Laplace et al., *Phys. Rev.C*, **93** 014323 (2016).
(c): ^{238}Np, T. G. Tornyi et al., *Phys. Rev.C*, **89** 044323 (2014).

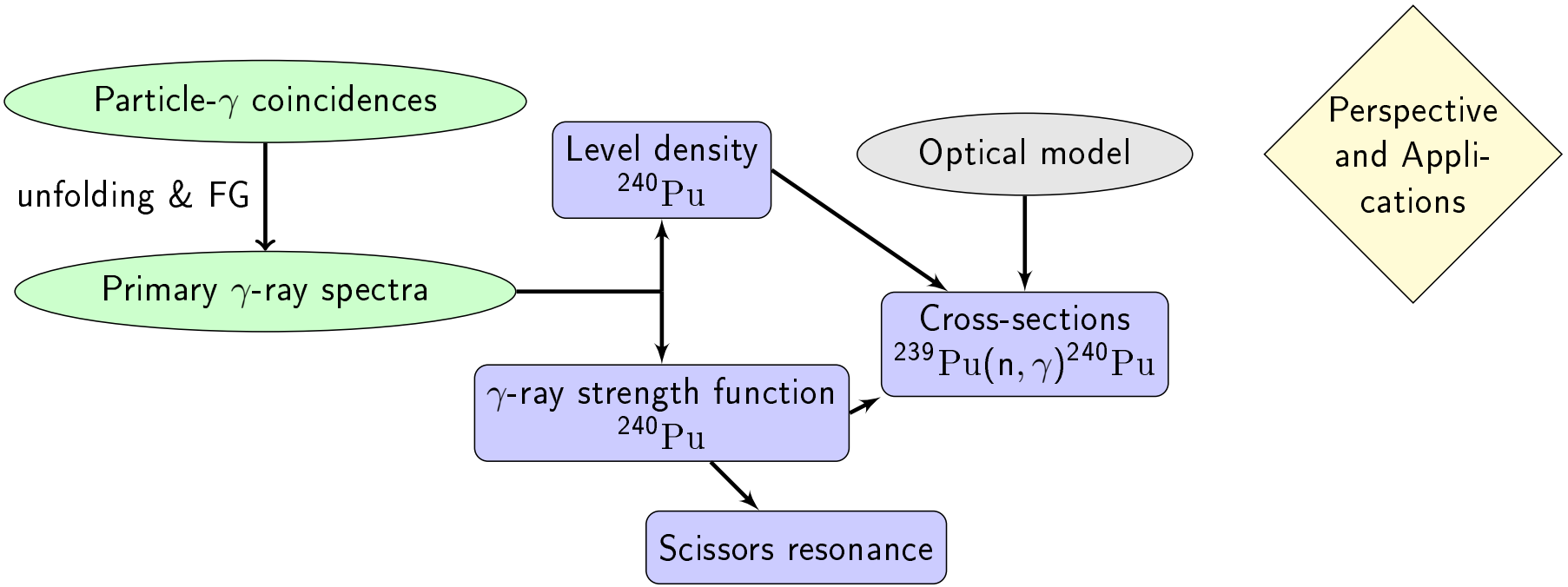


Predictive powers of the data?

Talys: Neutron Capture Cross Sections



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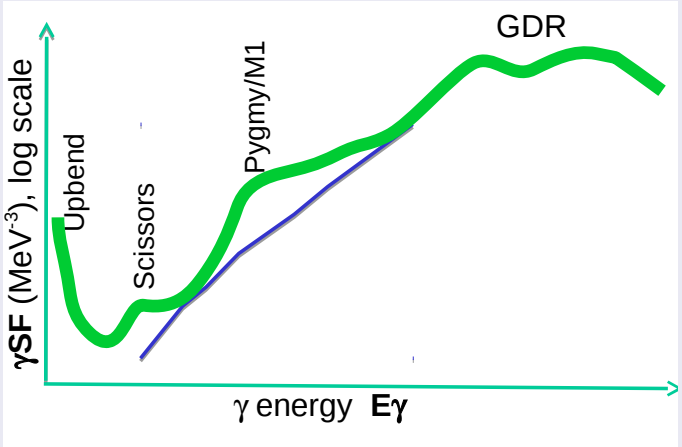
Perspective and Applications

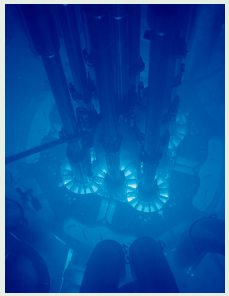
Applications

Test of nuclear models



Nuclear Reactors

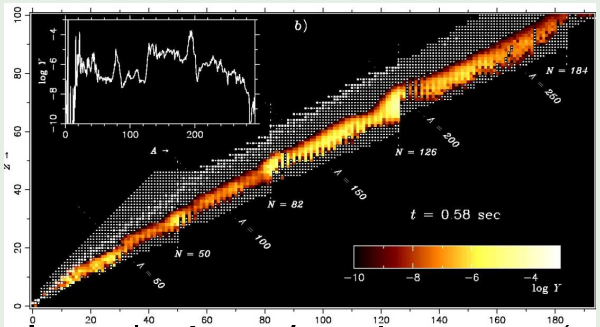
- Effect of new σ incl. SR on k_{eff}, ...



[wikipedia:cherenkov]

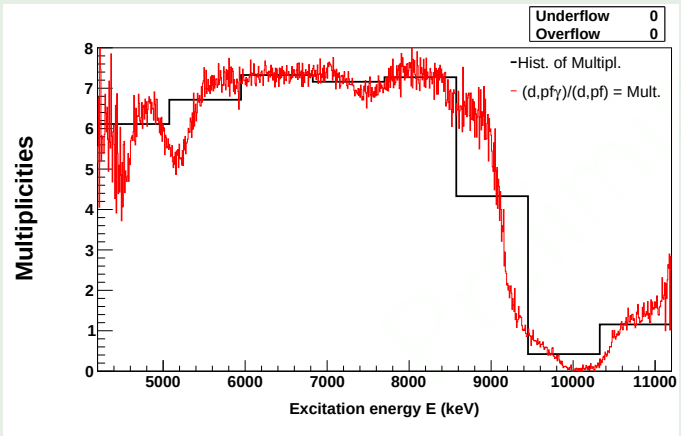
Astrophysics

- SR in the nucleosynthesis
- Effects on r-capture rates & "Concurrence" (50.000 reaction rates)

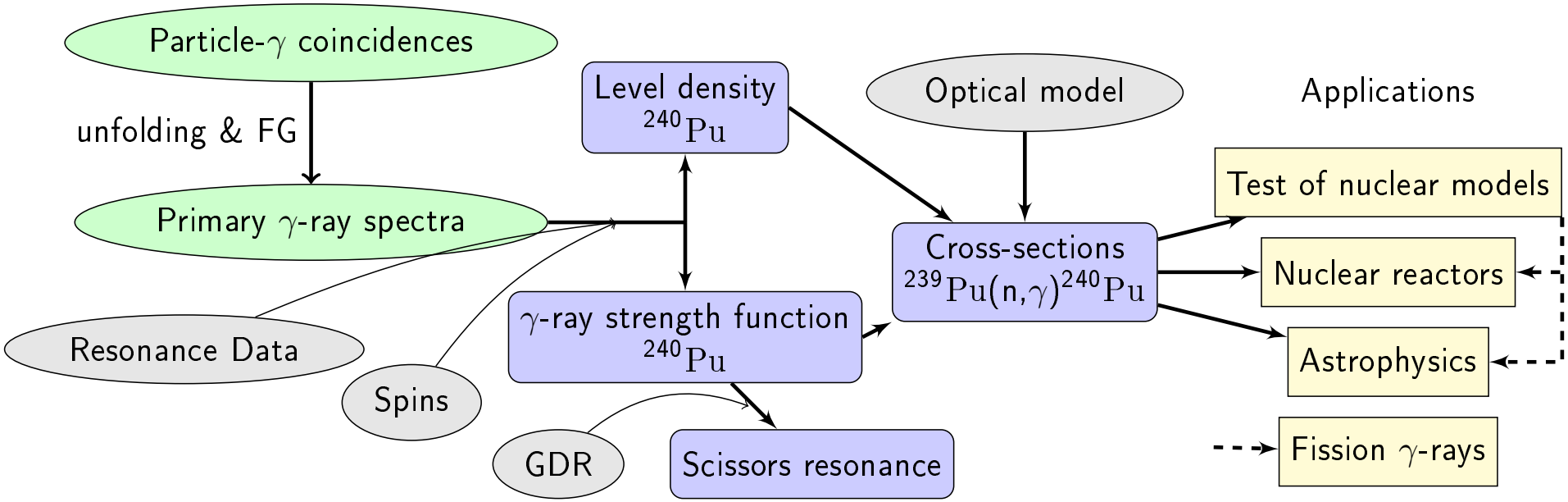


[S. Wanajo et al., *Astrophys. J.*, 577 853 (2002)]

Fission γ-ray multiplicities



$$\frac{\#(\mathrm{d},\mathrm{pf}\gamma)}{\#(\mathrm{d},\mathrm{pf}f)}$$



Outlook

- Spin distribution for (d,p) reaction
- Impact of LD and γSF on σ *despite* varying nOMP parameters
- For systematics: ^{240}Pu and ^{244}Pu waiting for beamtime
- New $LaBr_3$ detectors: Better resolution

Thanks to ..

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& The cyclotron engineers!

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