

Insights into the statistical γ -decay behaviour of ^{108}Cd via radiative capture

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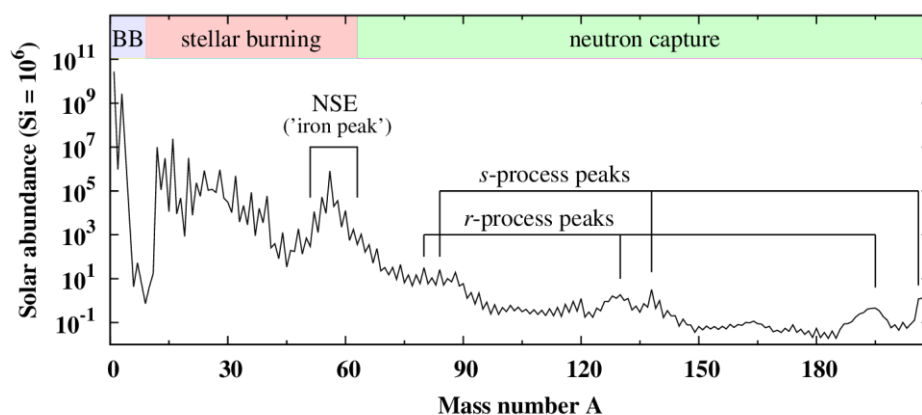
March 11th, 2019



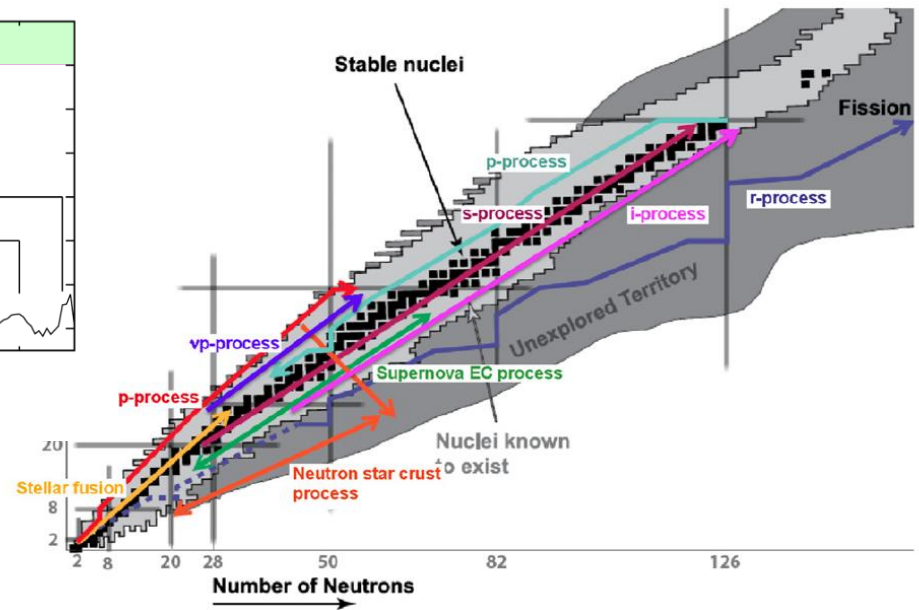
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Nuclear Physics and Astrophysics



Adopted from F. Käppeler, NIM Phys. Res. B **259** (2007) 663



H. Schatz, J. Phys. G: Nucl. Part. Phys. **43** (2016) 064001

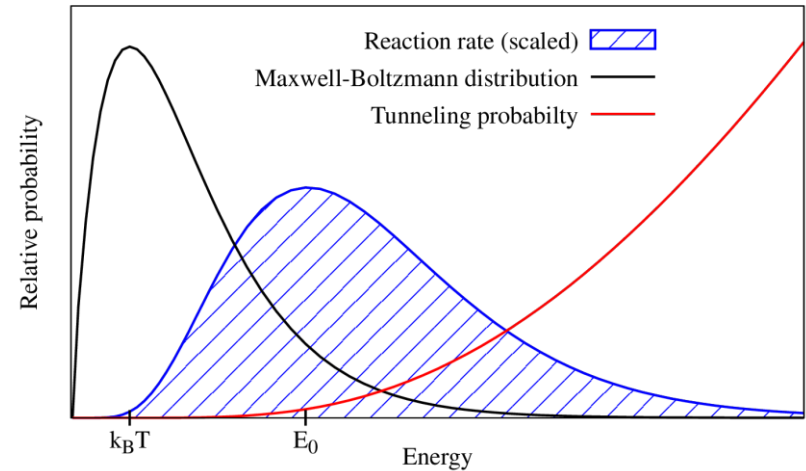
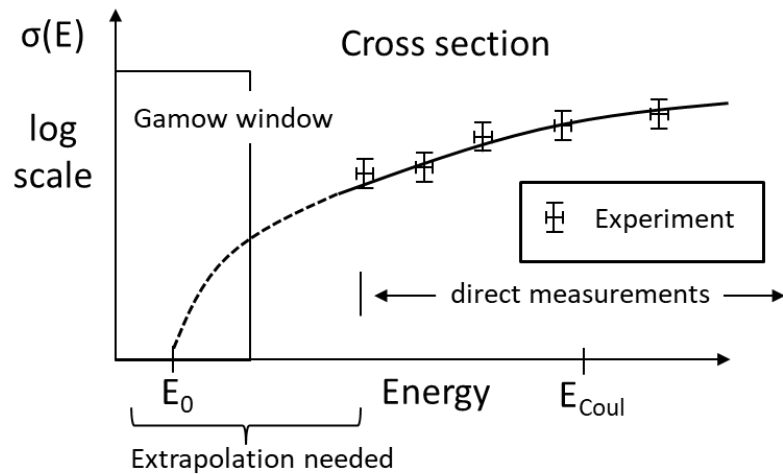
Astrophysics

- Temperatures
- Neutron densities
- Time scale of explosive scenarios

Nuclear Physics

- Cross sections and reaction rates
- Masses
- Half-lives

Astrophysically relevant cross sections

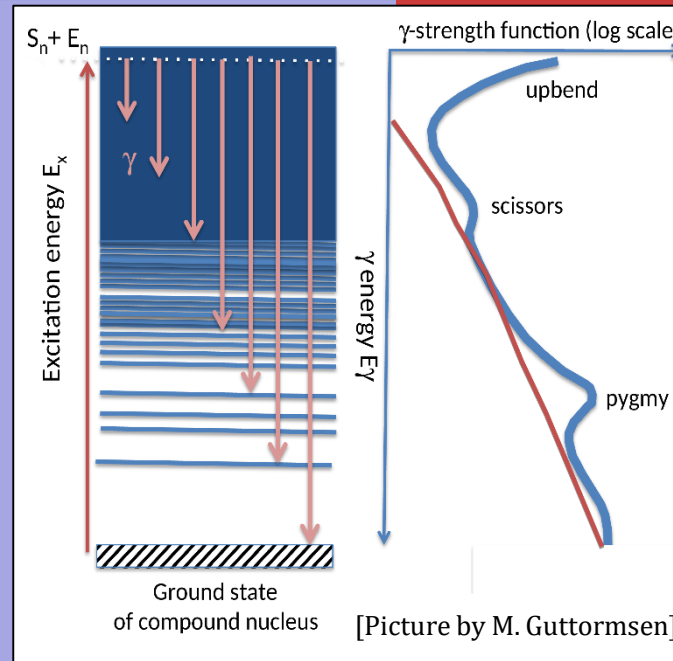


- Cross sections only inside the **Gamow window** are astrophysically relevant
→ Extrapolation using Statistical Model calculations needed (**Hauser-Feshbach**)
- Important input: **Optical-Model Potentials (OMPs)**, **Nuclear Level Density (NLD)**, **γ -ray strength functions (γ -SF)**

γ -ray SF and NLD

NLD:

- At high excitation energies the level spacing becomes much smaller than average resonance width
- Nuclear levels are given in $[\text{MeV}^{-1}]$ and cannot be counted separately
- NLD models describe the number of levels and provide a spin-parity distribution

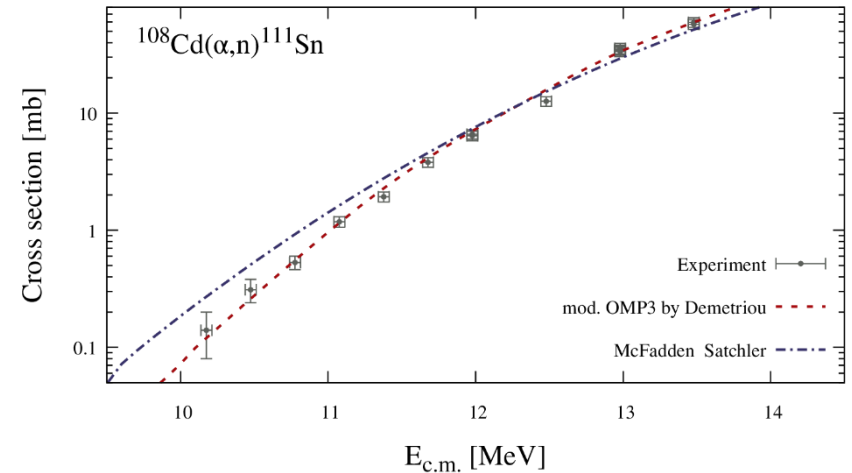


γ -ray SF:

- Holds the information about properties of the γ -emission channel
- Important for (n, γ) reactions in s - and r -process but also for p process nucleosynthesis within the γ process
- Different phenomena are observable and subject of current research: (“upbend”, “scissors modes”, PDR, GDR)

The $^{107}\text{Ag}(p,\gamma)^{108}\text{Cd}$ reaction

- The **α -OMP** in Sn-Cd region intensively studied in the last years
- Adjusted **α -OMP3**: Excellent agreement with experimental values
→ Appropriate model for **α -OMP** in mass region $A \approx 100-190$



[P. Scholz, F. Heim *et al.*, PLB **761** (2016) 247]

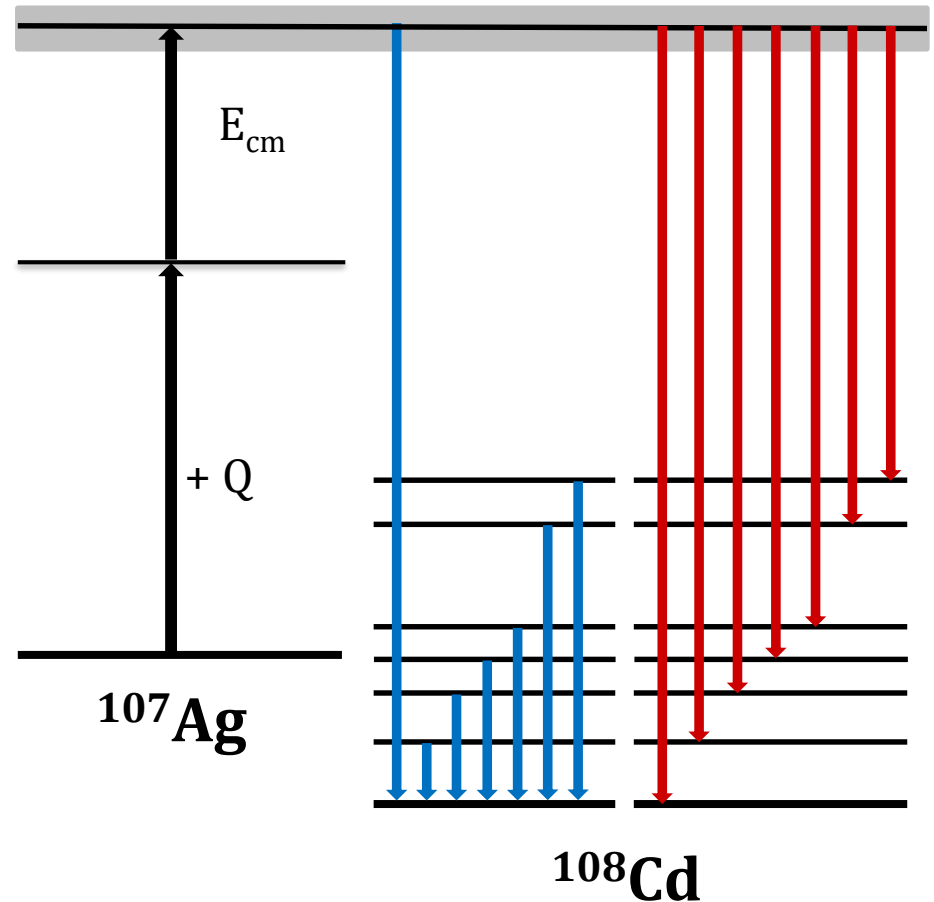
- Now: Detailed studies of **γ -ray strength function** and **NLD**
 - $E_p = 2.0 \text{ MeV to } 5.0 \text{ MeV}$
 - Determination of total and partial cross sections

	In 108 58.0 m	In 109 4.167 h	In 110 4.92 h	In 111 2.8063 d	In 112 14.88 m
48	Cd 107 6.50 h	Cd 108 0.0	Cd 109 461.6 d	Cd 110 12.49	Cd 111 12.80
	Ag 106 23.96 m	Ag 107 51.839	Ag 108 2.382 m	Ag 109 48.161	Ag 110 24.56 s
46	Pd 105 22.33	Pd 106 27.33	Pd 107 6.5 My	Pd 108 26.46	Pd 109 13.7012 h
	Rh 104 42.3 s	Rh 105 35.357 h	Rh 106 30.07 s	Rh 107 21.7 m	Rh 108 16.8 s
		60		62	

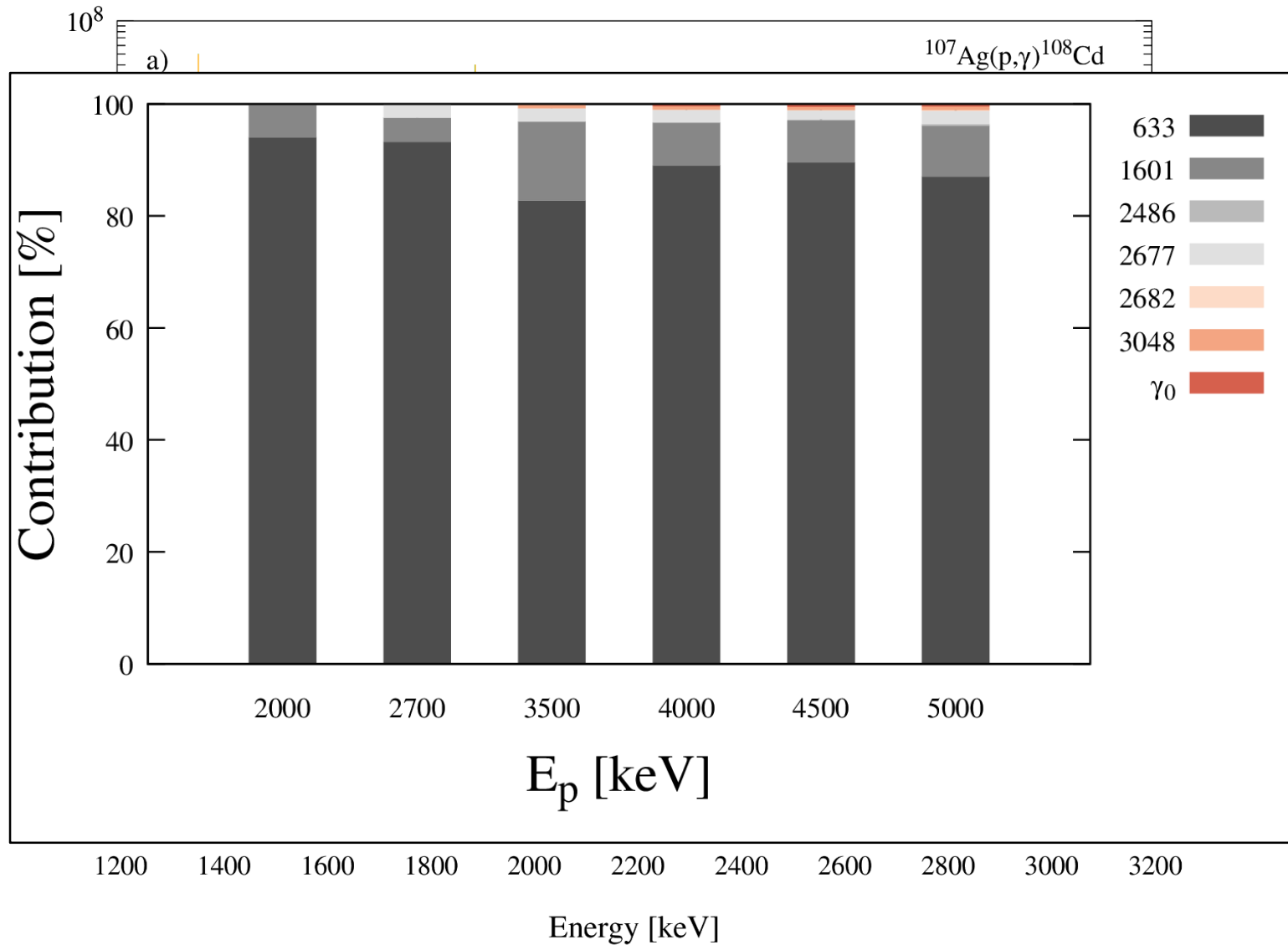
In-beam γ -ray spectroscopy

In-beam γ -ray spectroscopy

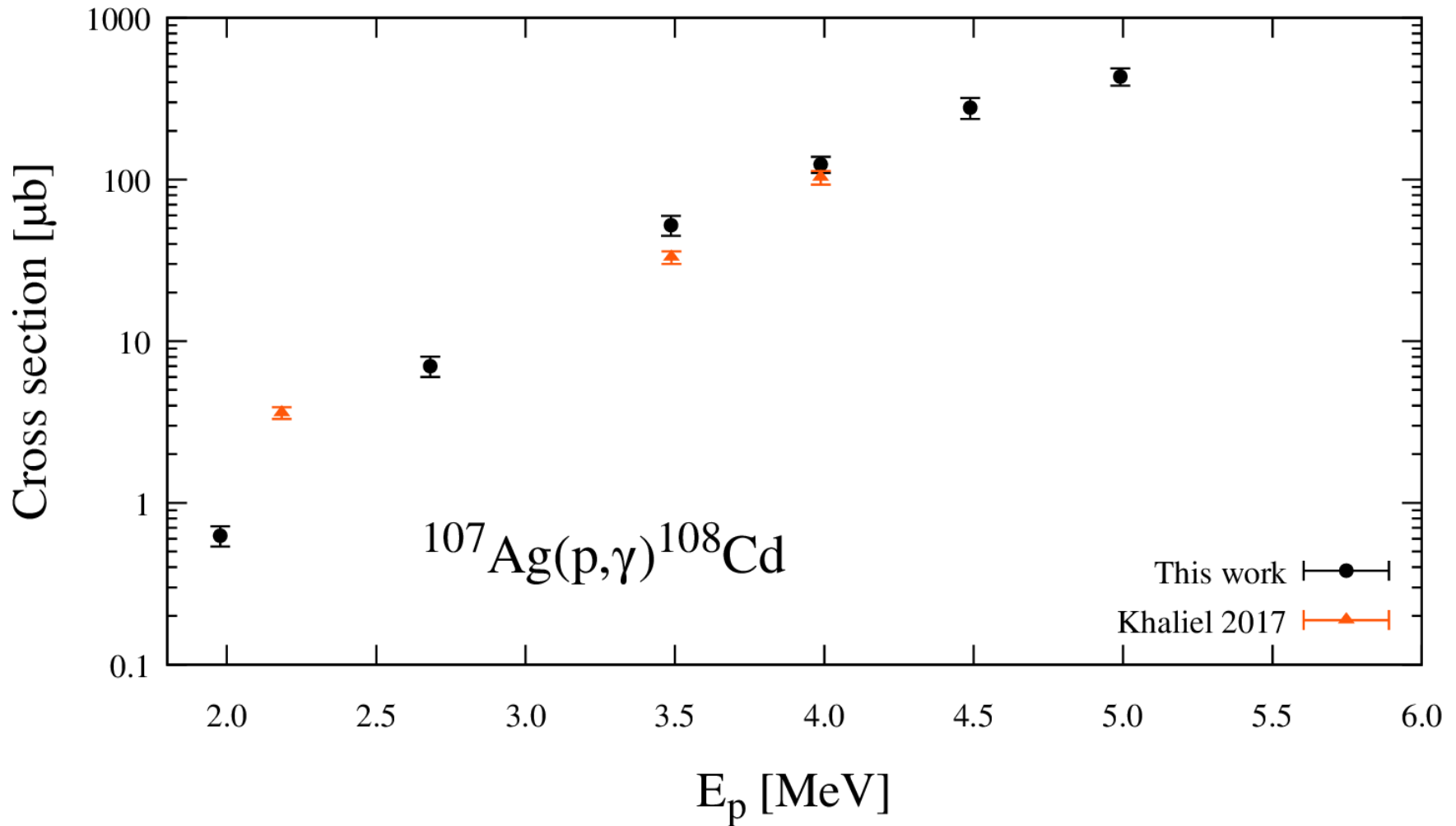
- **De-excitation of the entry state**
 - Determination of partial cross sections
 - **Sensitive to γ -ray strength function**
- **Transitions to the ground state**
 - Determination of the total cross section
 - **Can be used to deduce the Nuclear Level Density**



Results: γ -ray spectrum

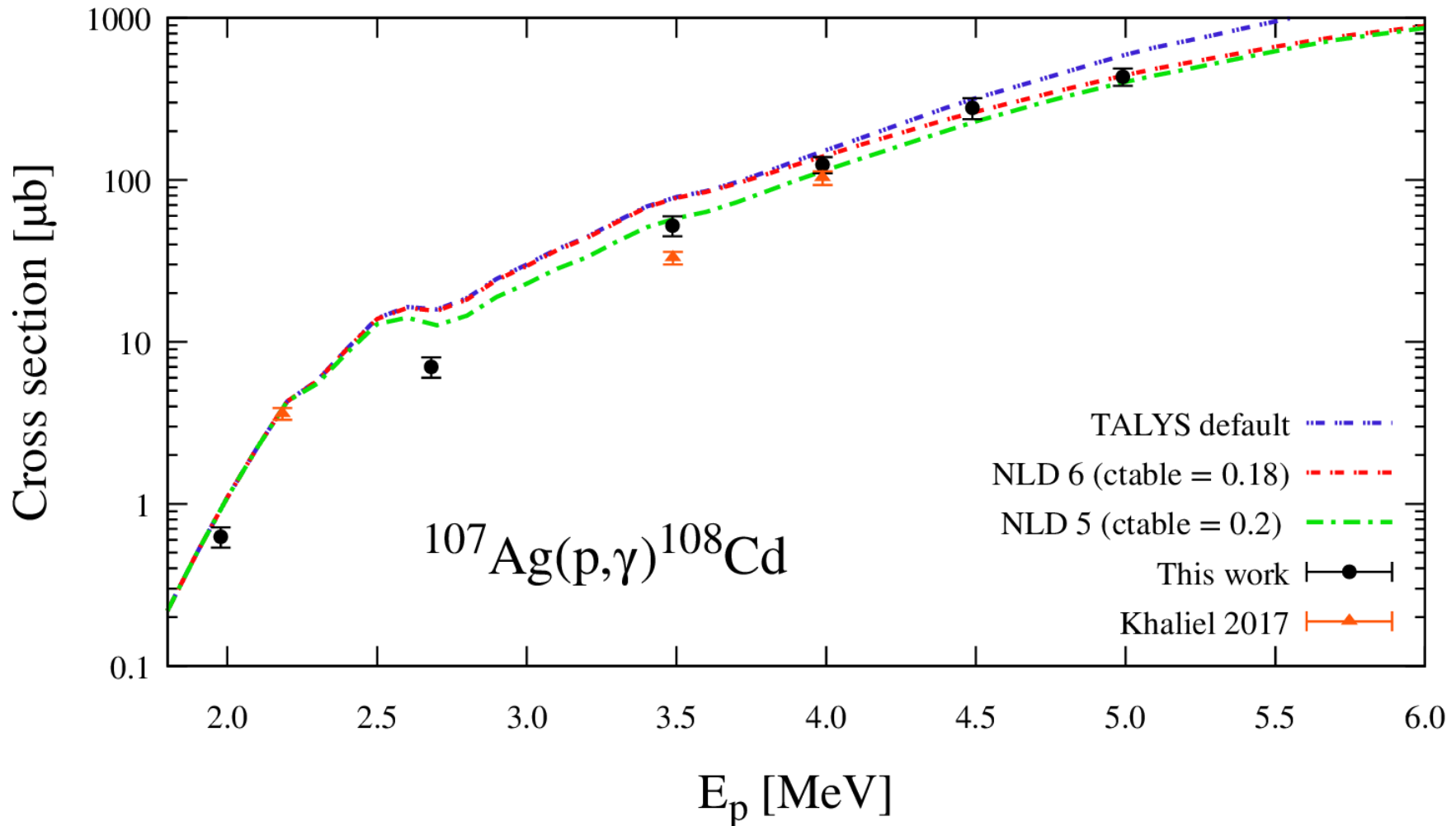


Total cross sections



[A. Khaliel *et al.*, PRC **96** (2017) 035806]

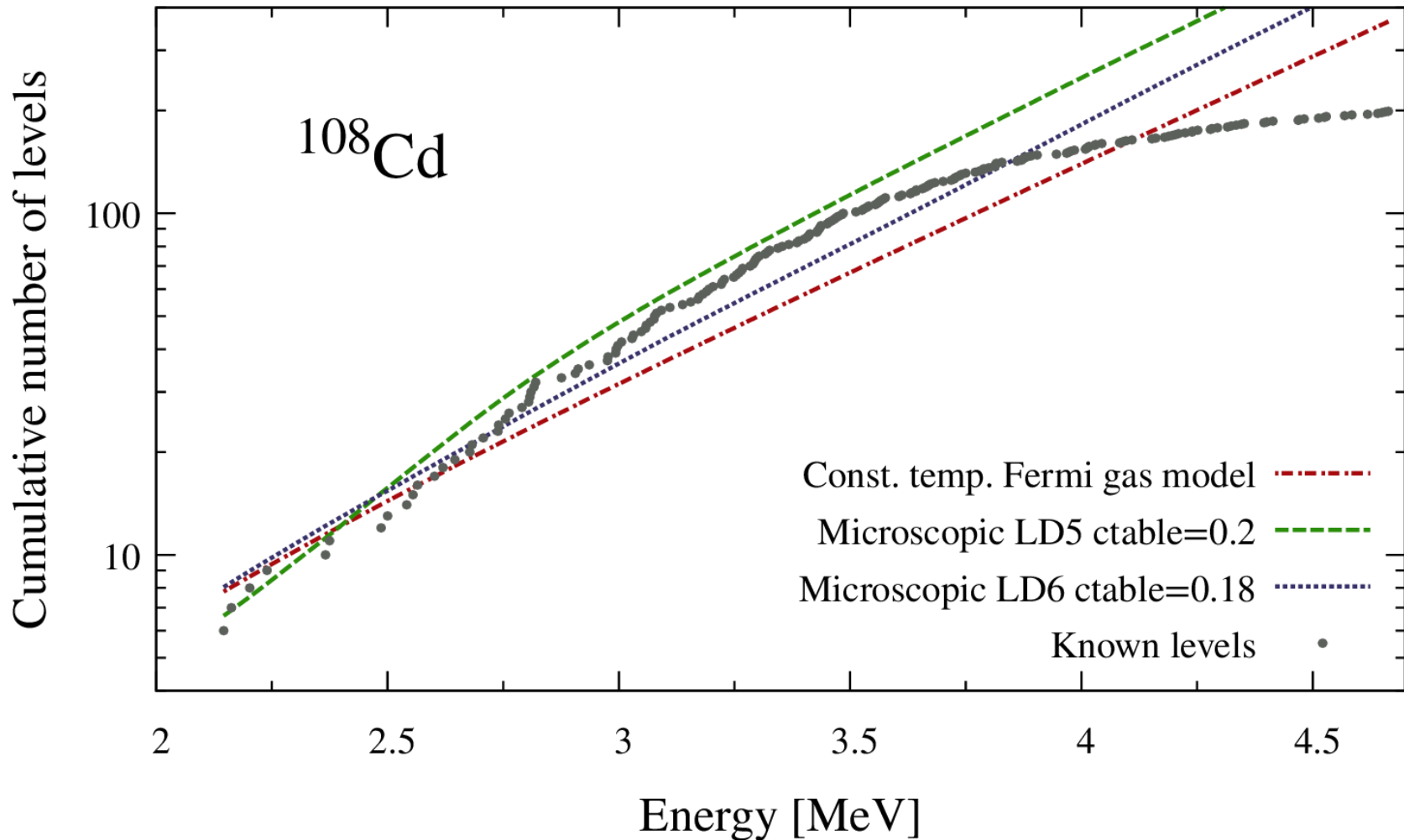
Total cross sections with adjusted NLD



NLD 5: [S. Hilaire, S. Goriely *et al.*, NPA **779** (2006) 63]
NLD 6: [S. Hilaire, S. Goriely *et al.*, PRC **86** (2012) 064317]

[A. Khaliel *et al.*, PRC **96** (2017) 035806]

Number of low-lying levels in ^{108}Cd



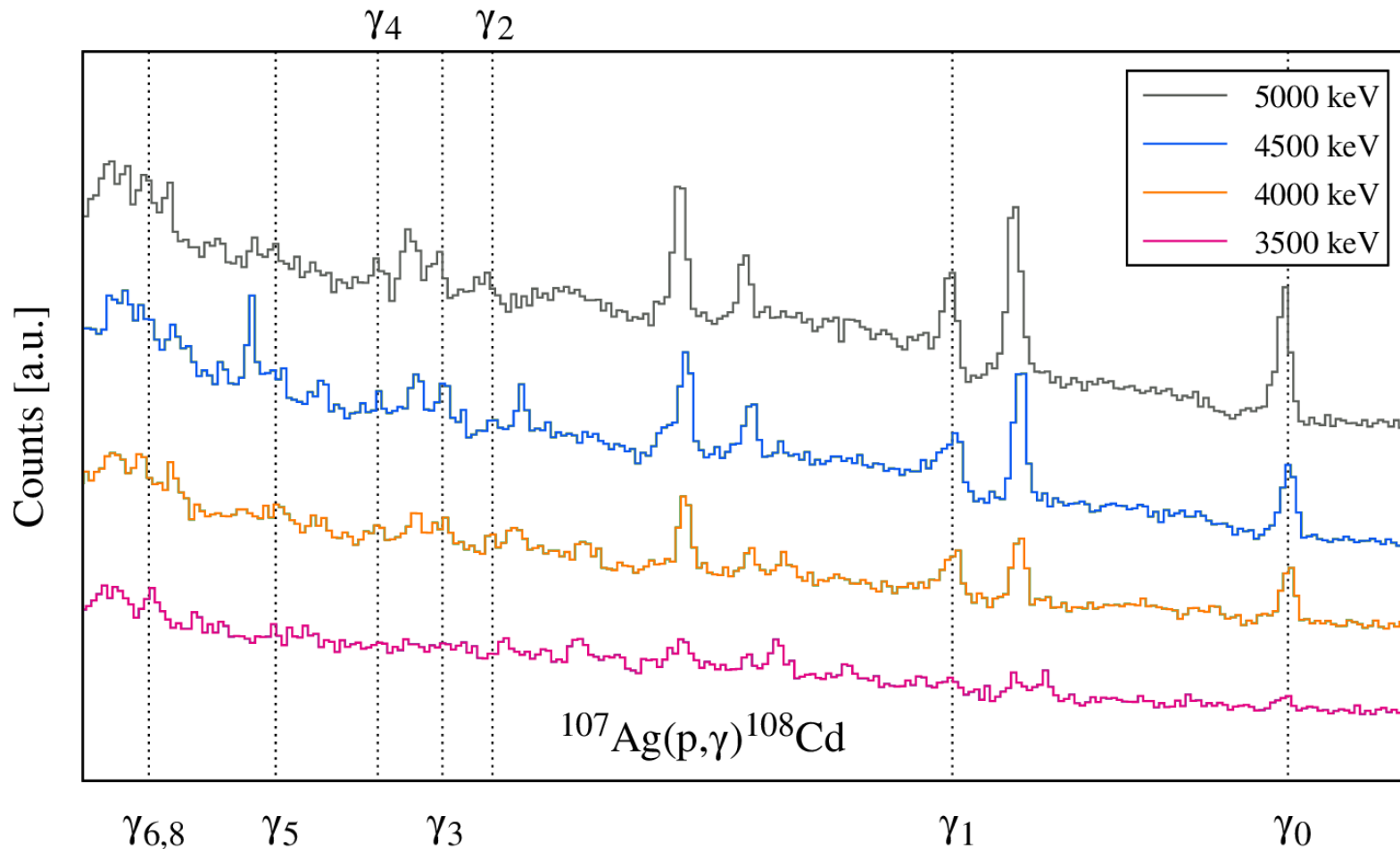
NLD 5: [S. Hilaire, S. Goriely *et al.*, NPA **779** (2006) 63]
NLD 6: [S. Hilaire, S. Goriely *et al.*, PRC **86** (2012) 064317]

CTM: [A. Gilbert *et al.*, Canadian Journal of Physics **43** (1965)(8) 1446]

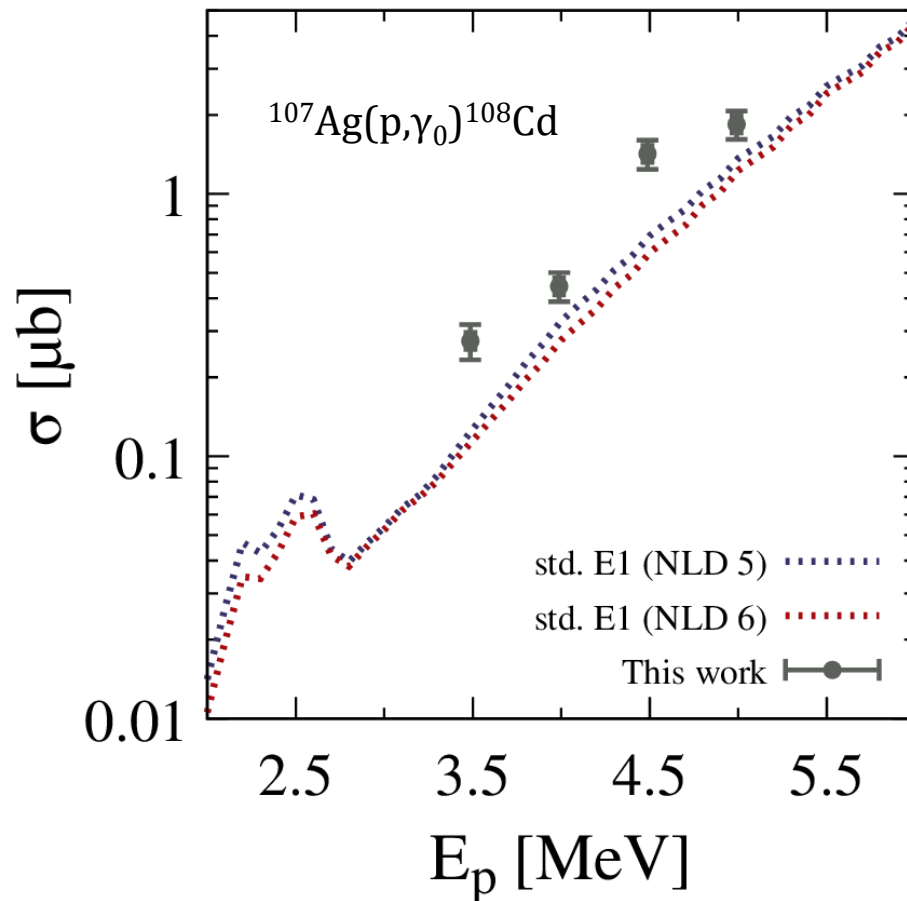
Results: Partial cross sections

$$E_{\gamma,x} = Q + E_{c.m.} - E_x$$

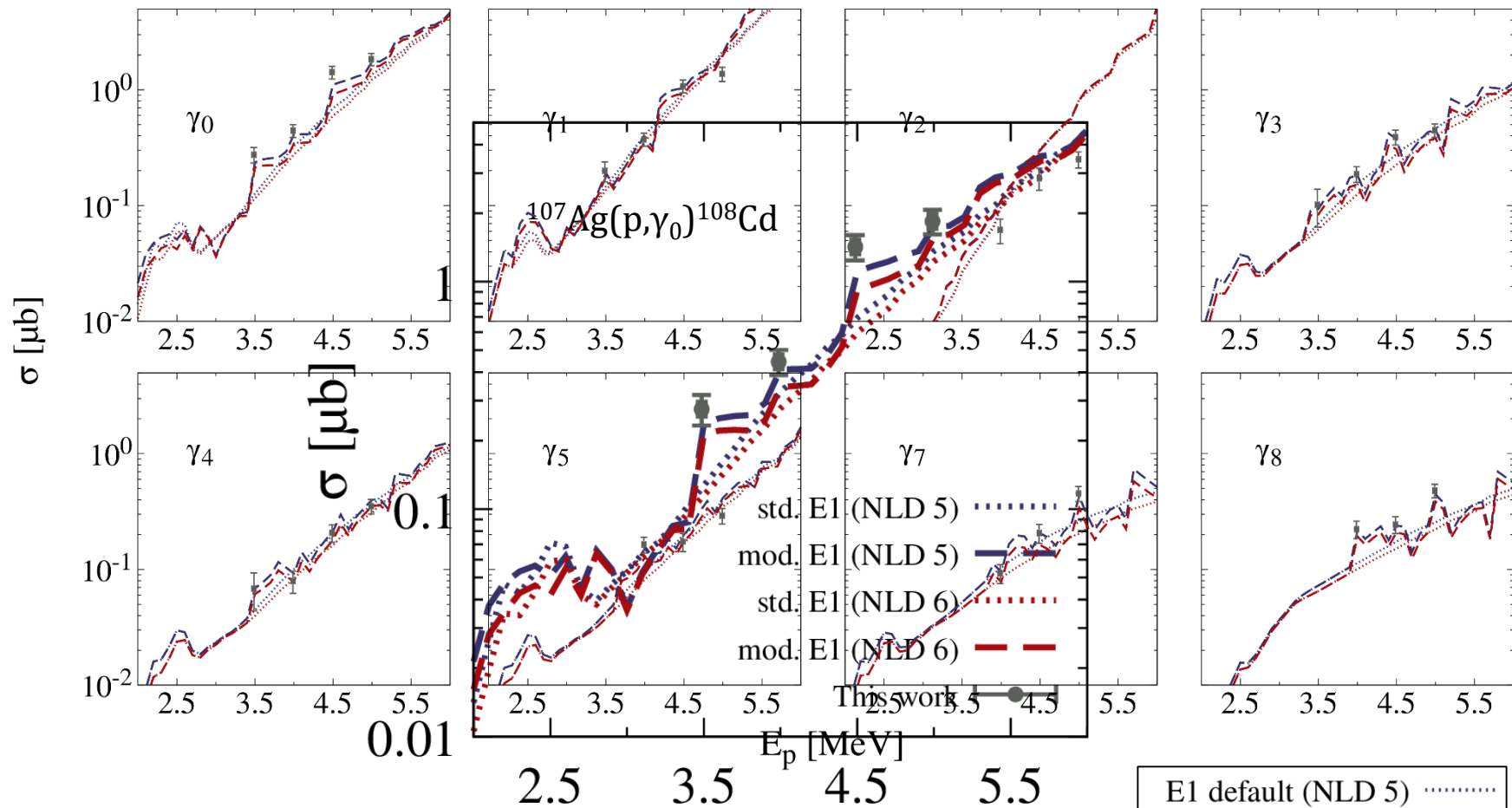
$$Q = 8134 \text{ keV}$$



Results: Partial cross sections



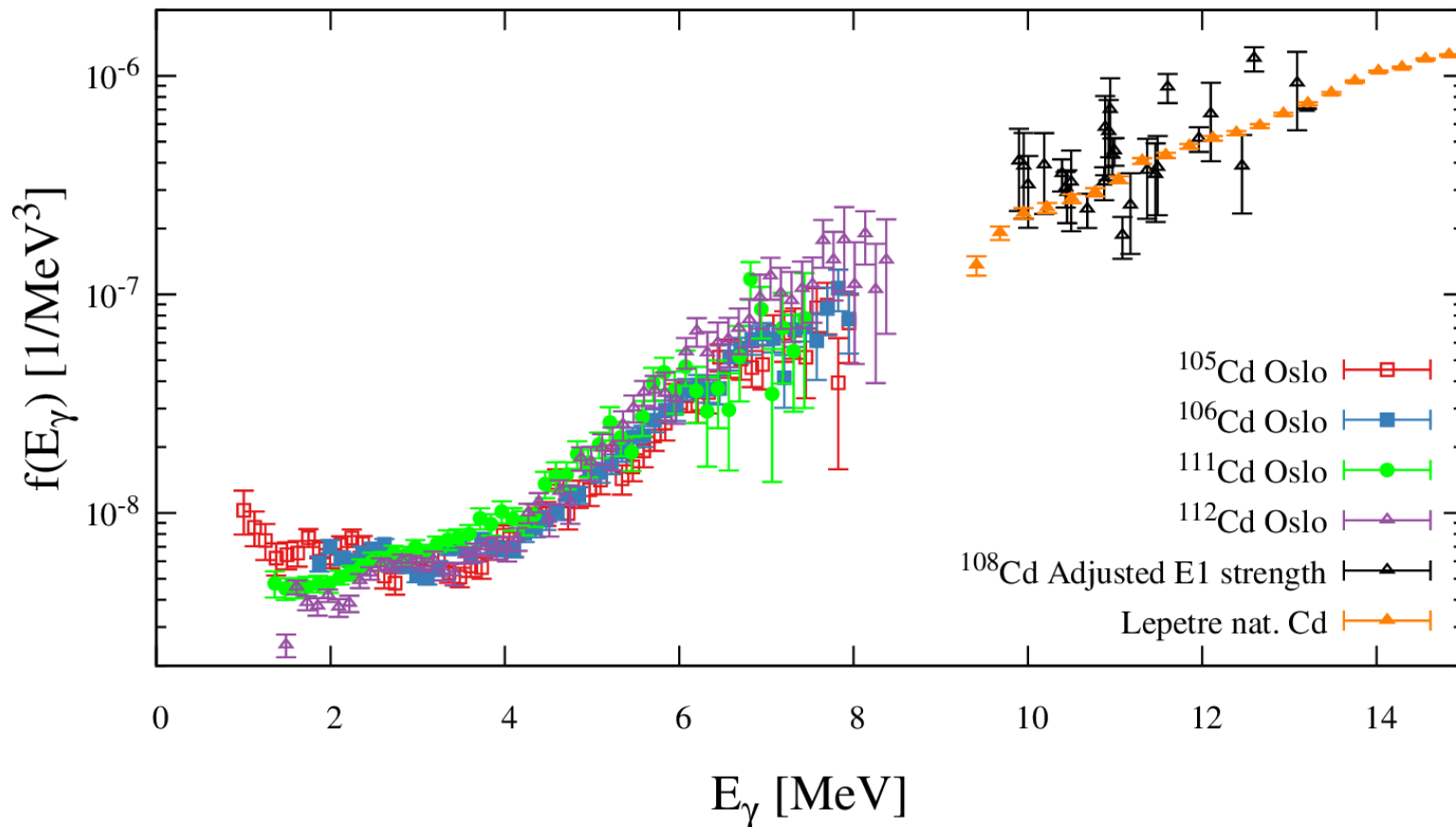
Partial cross sections with adjusted γ -ray strength function



**Adjusted dipole strength function
 based on Gogny D1M HFB+QRPA model**

[F. Heim, to be published]

Partial cross sections with adjusted γ -ray strength function

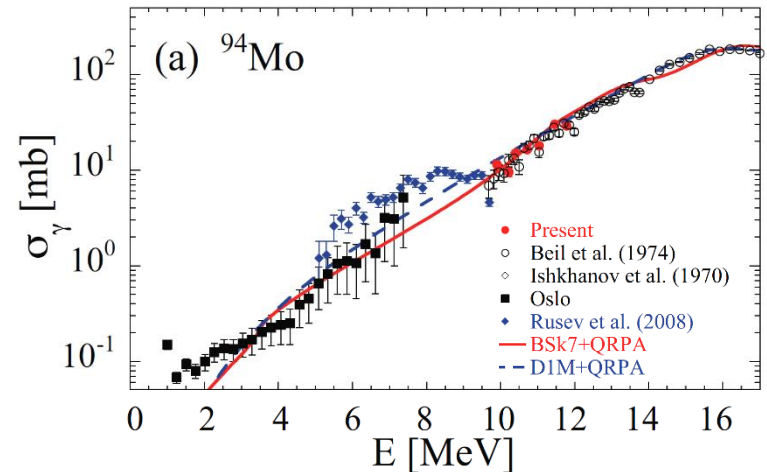


[F. Heim, *to be published*]

**Adjusted dipole strength function is
based on Gogny D1M HFB+QRPA model**

The $^{93}\text{Nb}(p,\gamma)^{94}\text{Mo}$ reaction

- The γ -SF in ^{94}Mo was already studied in other experiments: (γ,γ') , (γ,n) , Oslo method
- Oslo method also deduces **NLD**
 → Measurement of total and partial cross sections of the $^{93}\text{Nb}(p,\gamma)^{94}\text{Mo}$ reaction
 - $E_p = 3.0$ MeV and 3.5 MeV
- See next talk by Martin Müller



[H. Utsonomiya *et al.*, Phys. Rev. C. **88** (2013) 015805]

	Tc 93 2.75 h	Tc 94 293 m	Tc 95 20.0 h	Tc 96 4.28 d	Tc 97 4.21 My
42	Mo 92 14.53	Mo 93 4.0 ky	Mo 94 8.5	Mo 95 15.84	Mo 96 16.67
	Nb 91 680 y	Nb 92 34.7 My	Nb 93 100.	Nb 94 20.4 ky	Nb 95 34.991 d
40	Zr 90 51.45	Zr 91 11.22	Zr 92 17.15	Zr 93 1.61 My	Zr 94 17.38
	Y 89 100.	Y 90 64.00 h	Y 91 58.51 d	Y 92 3.54 h	Y 93 10.18 h
	50		52		54

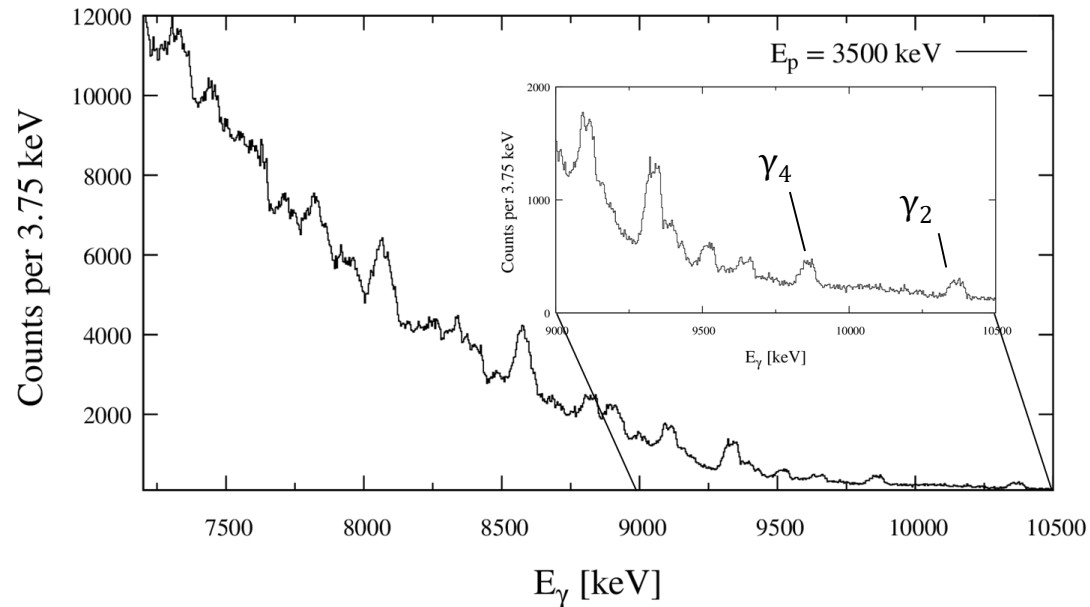
Primary γ -ray transitions

High-energy part of the γ -ray spectrum after the $^{93}\text{Nb}(p,\gamma)^{94}\text{Mo}$ reaction:

- Primary transitions need to be assigned to the corresponding state:

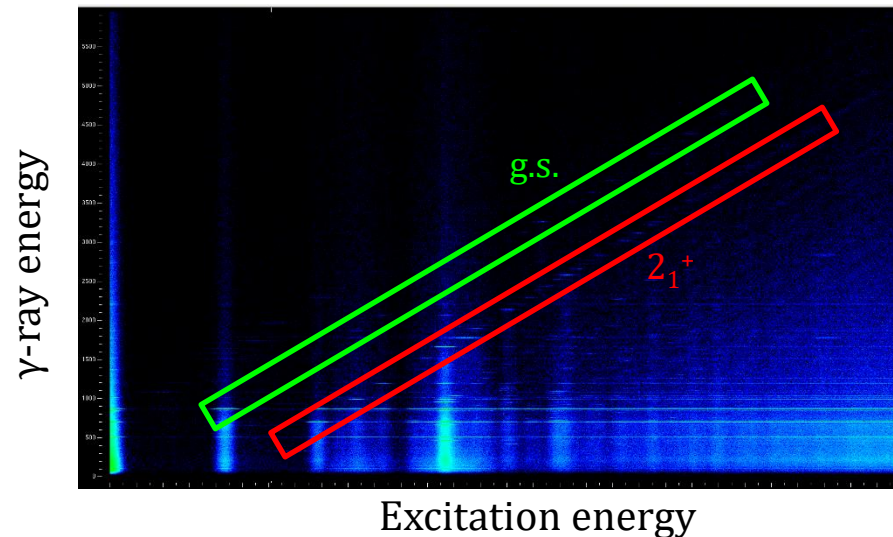
$$E_{\gamma,x} = Q + E_{c.m.} - E_x$$

$$Q = 8490 \text{ keV}$$



Precise knowledge of energy, spin and parity of states in the region around 3 to 4 MeV crucial

- $^{94}\text{Mo}(p,p'\gamma)^{94}\text{Mo}$ measured in Cologne
→ p- γ matrix available
- Gate on different excitation energies for identification of new states and transitions

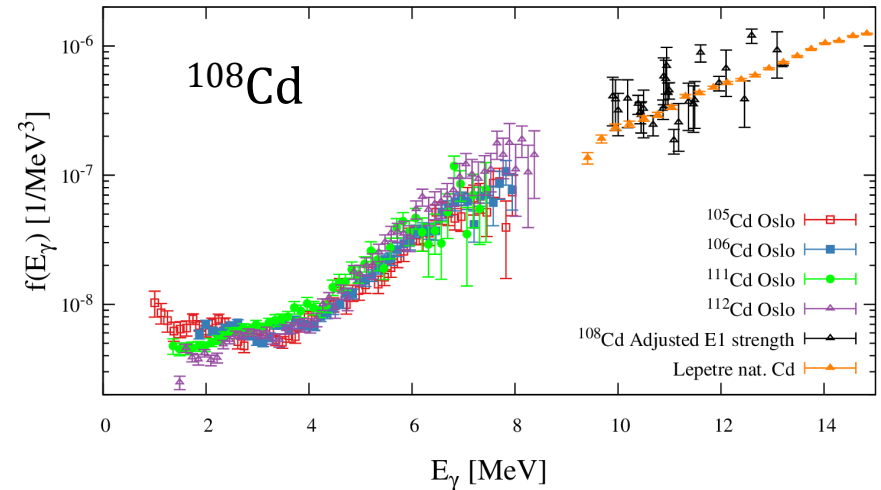


Summary and outlook

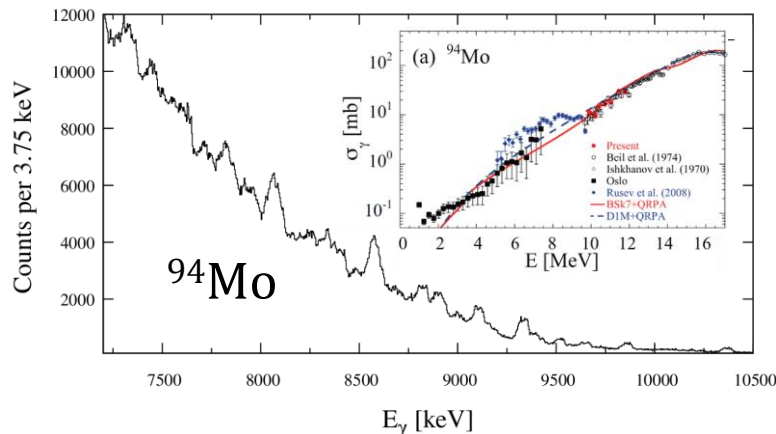
$^{107}\text{Ag}(p,\gamma)^{108}\text{Cd}$

- Total and partial cross section measurements allowed to obtain information about the statistical γ -decay behavior in ^{108}Cd
- Detailed study of γ -SF and NLD

[F. Heim, *to be published*]



$^{93}\text{Nb}(p,\gamma)^{94}\text{Mo}$



- Data analysis ongoing
- $^{94}\text{Mo}(p,p'\gamma)^{94}\text{Mo}$ data for completion of level scheme of ^{94}Mo
- γ -ray strength data from different methods available for comparison