Analysis of ^{77}Se(n,γ) Spectra

With Emphasis on Cascade Decays

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Motivation and Introduction

Why photon strength functions?

- photon strength functions and level densities are main ingredients for statistical treatment of photon nuclei interaction

Experiments for deducing strength functions

- in the past discrepancies between gamma strength deduced from neutron capture and photon scattering
- twin experiment ^{77}Se(n,γ) and ^{78}Se(γ,γ') to study photon strength function in the compound nucleus ^{78}Se
- s-wave neutron capture on ground state of ^{77}Se ($\frac{1}{2}^-$) and photo excitation of ground state of ^{78}Se (0^+) lead both to excited 1^- states in ^{78}Se
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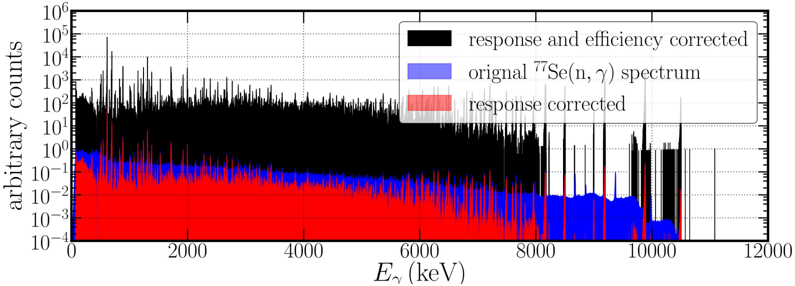
(n,γ) Experiment at the Budapest Research Reactor

- research reactor $P = 10\,\mathrm{MW}$
- $\Phi_{\mathrm{max}} = 2.2 \cdot 10^{14}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- neutron beam is guided to cold neutron source (CNS)
- beam size: $2\,\mathrm{cm} \times 2\,\mathrm{cm}$
- at the target: $\Phi = 5 \cdot 10^{7}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ in the cold range
- experiment performed in October 2009 with Anti-Compton shielded HPGe detector of FZD

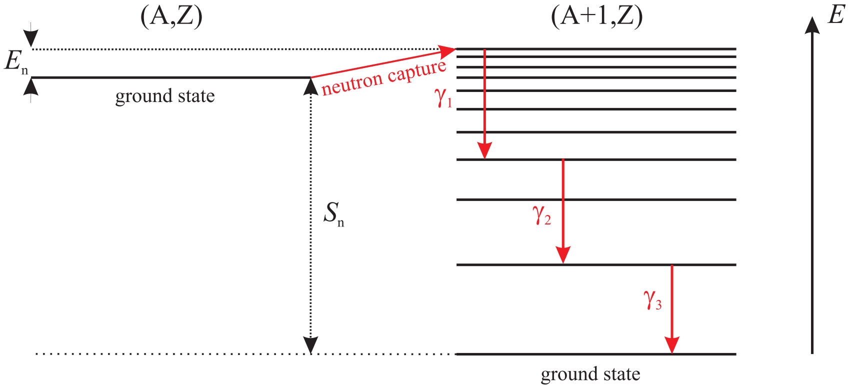
Figure: Budapest Research Reaktor `http://www.iki.kfki.hu/nuclear/images/BKR.jpg`

Response and Efficiency Correction

- detector efficiency and response correction is needed to analyse experimental spectra
- response of the BGO shielded HPGe detector was simulated with GEANT4 by Ralph Massarczyk
- efficiency correction done by Evert Birgersson



Gamma Cascades following Neutron Capture



- instead of decaying directly to the ground state, the excited compound nucleus deexcites mostly in a cascade, emitting more than one γ

Cascade Simulation

Why is a cascade simulation necessary?

- for deducing the neutron capture cross section from capture experiments, the average multiplicity of γ's is needed
- simulation can provide insight into the influence of gamma strength function and level density on the γ continuum

How to simulate a casacade?

- Monte Carlo simulation using the partial radiative widths Γ_{if} of an excited level i

Problem:

- up to $S_n \approx 300000$ nuclear levels in ^{78}Se
- only very few levels and Γ_{if} are known

$\Rightarrow$ statistical treatment using strength function and level density needed

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Statistical Treatment of γ Decay

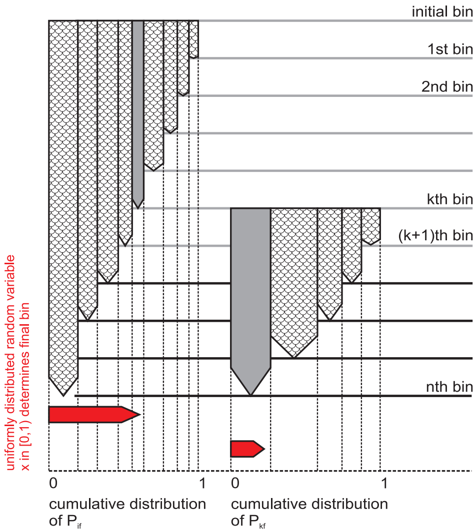
average spectral distribution per unit γ energy of primary γ's of type XL from an excited level λ with spin J
Bartholomew 1973 [Bartholomew et al., 1973]:

$$\nu^{J}_{i\lambda XL}(E_\gamma) = E_\gamma^{2L+1} \frac{f_{XL}(E_\gamma)}{\overline{\Gamma}_{\mathrm{tot},\lambda}} \frac{\sum\limits_{I=|J-L|}^{J+L} \varrho(E_\lambda - E_\gamma, I)}{\varrho(E_\lambda, J)} \tag{1}$$

f_{XL}	gamma strength function for XL transition
$\varrho(E, J)$	density of levels with spin J at energy E
$\Gamma_{\mathrm{tot},\lambda}$	total radiative width

Table: Symbols for average spectral distribution of primary γ's

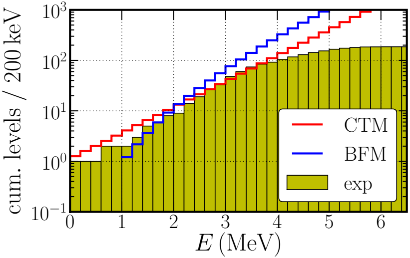
Scheme of the Simulation



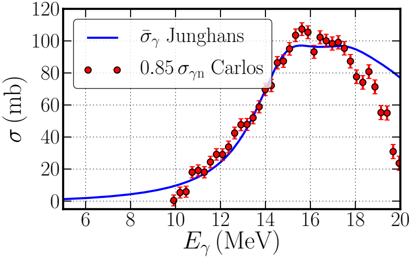
- algorithm similiar to DICEBOX of F.Becvar [Becvar, 1998]
- treat nucleus in energy bins
- calculate level density for all J in all bins
- use information of known discrete levels in lower bins up to E_{crit}
- calculate transition probabilities P_{if} for an excited bin i for all allowed transition to final bins f
- use $E1$, $M1$, $E2$ transitions, neglect levels with spins $J > 4$

Ingredients for Cascade Simulation

level density:
Constant Temperature Model
$\varrho(E,J) = f(J) \cdot \frac{1}{T} e^{(E-E_0)/T}$
$f(J) = e^{J^2/(2\sigma^2)} - e^{(J+1)^2/(2\sigma^2)}$
$T = 850\,\text{keV},\ E_0 = -140\,\text{keV}$

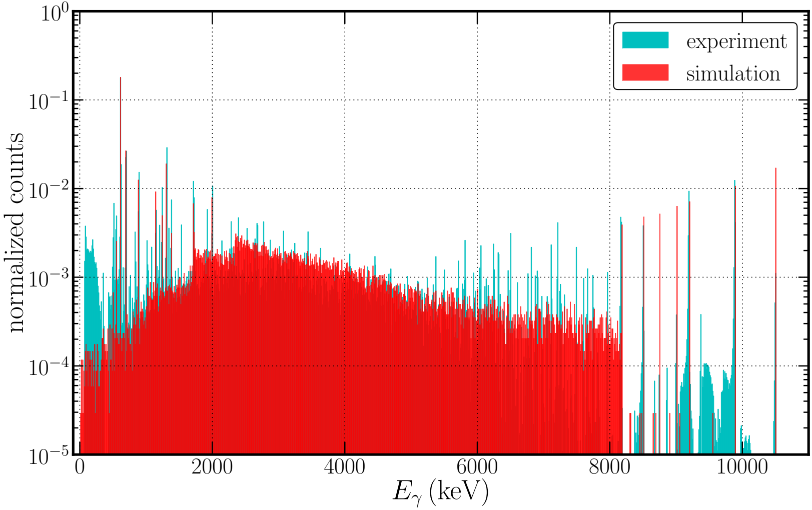


E1 strength:
Junghans et. al model
three Lorentzians
[Junghans et al., 2008]
$\beta = 0.271,\ \gamma = 27.1°$

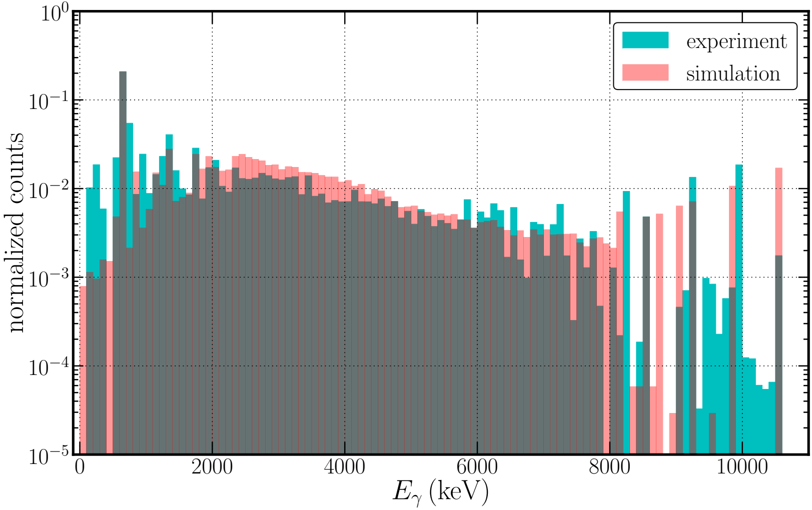


M1 strength:
three Gaussians
(deduced from K.Heyde data)

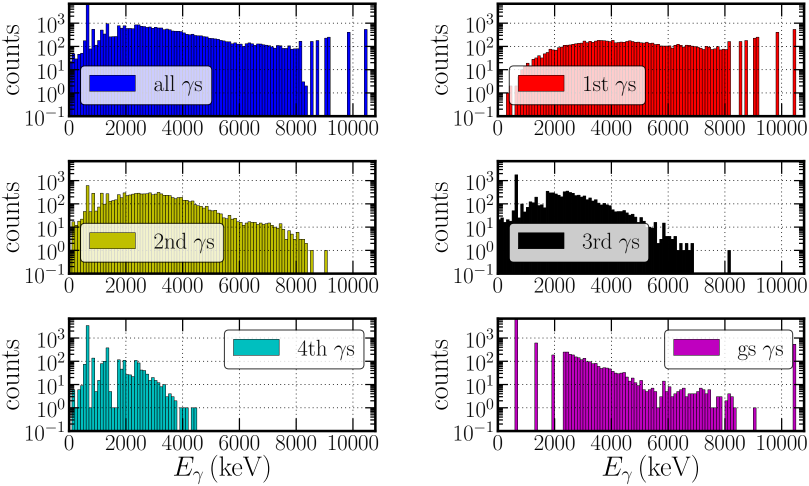
Simulated ^{77}Se(n,γ) Spectrum



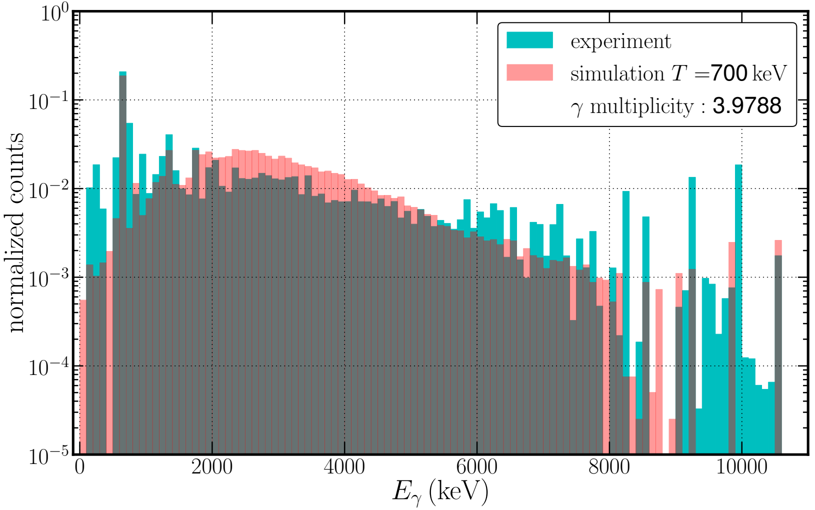
Simulated ^{77}Se(n,γ) Spectrum II



Simulated ^{77}Se(n,γ) Spectrum III



Influence of T on the Simulated Gamma Spectra



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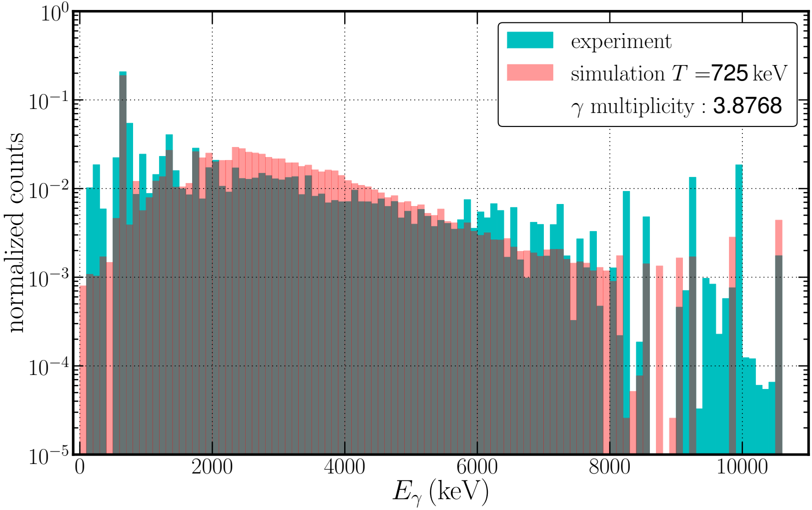

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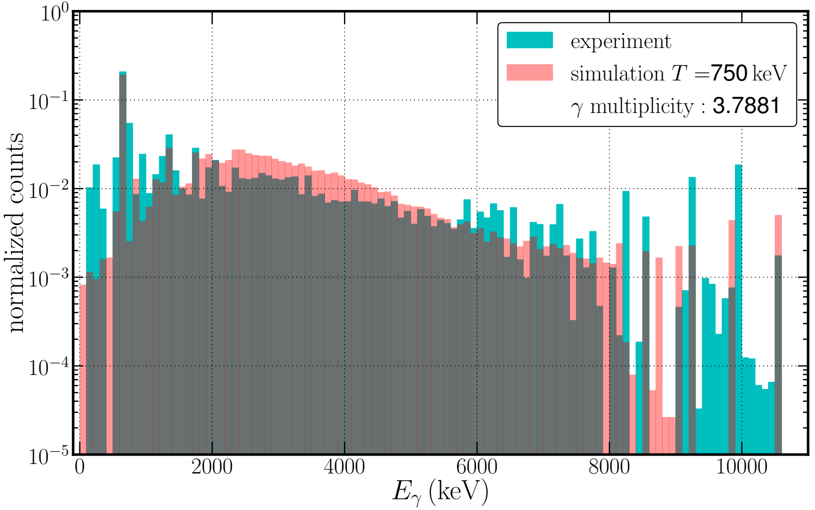

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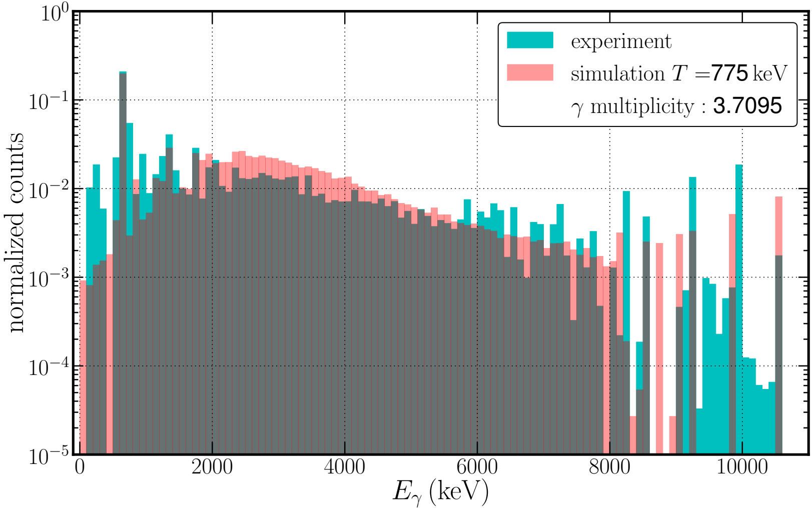

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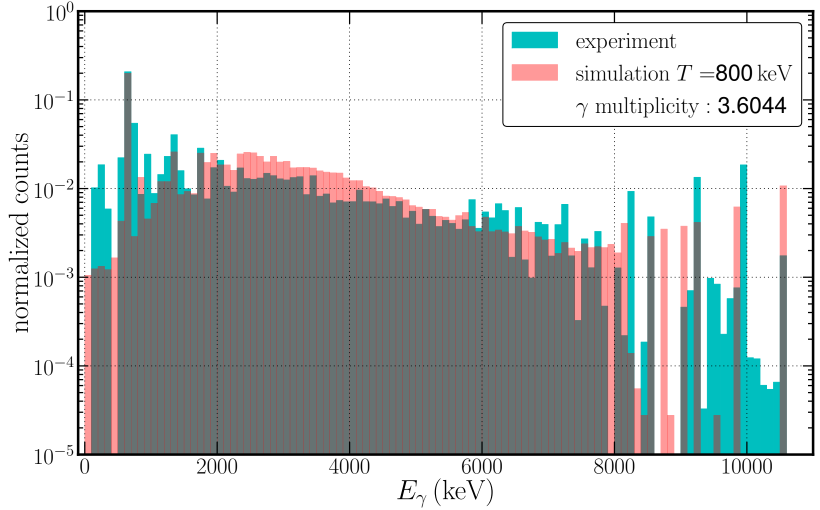

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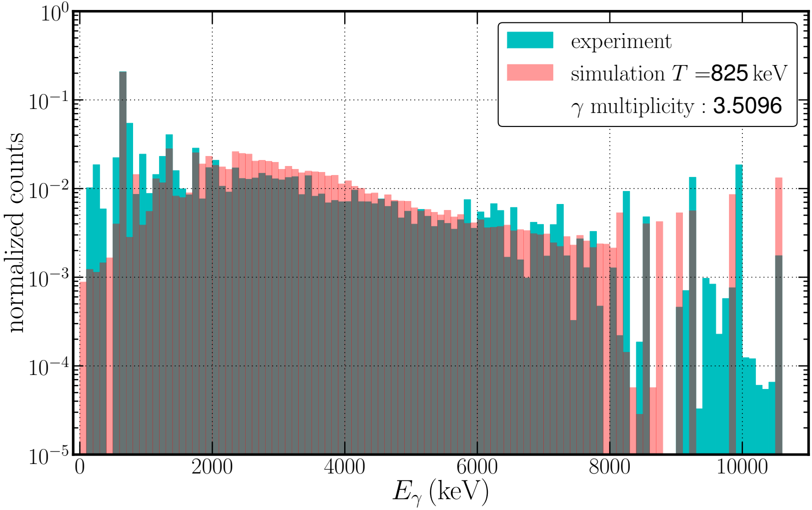

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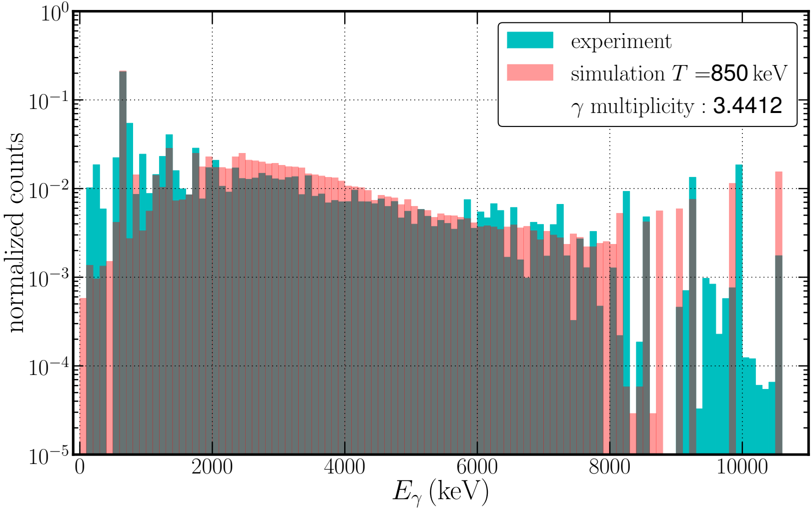

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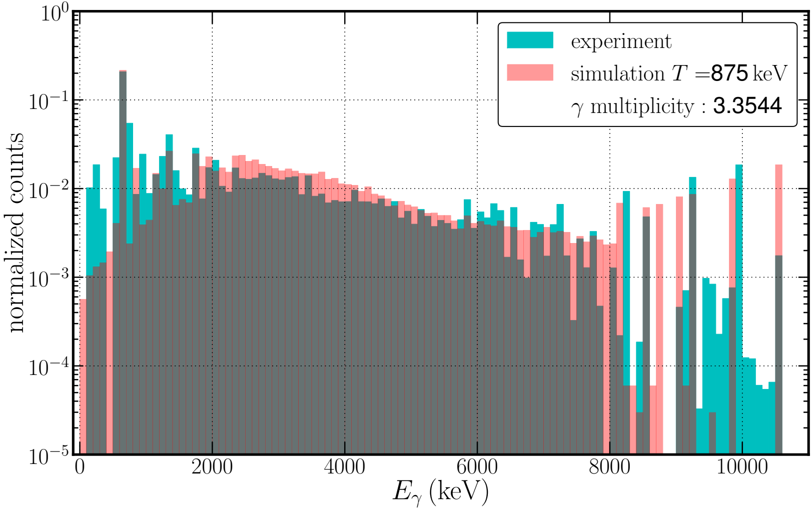

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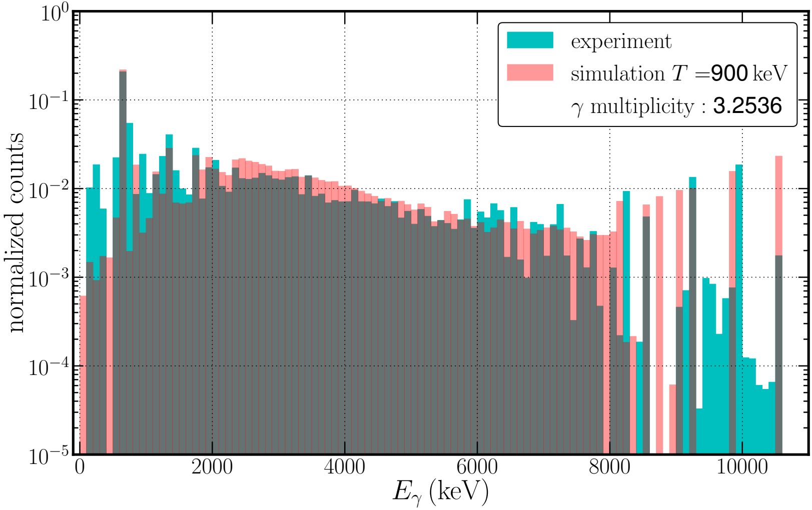

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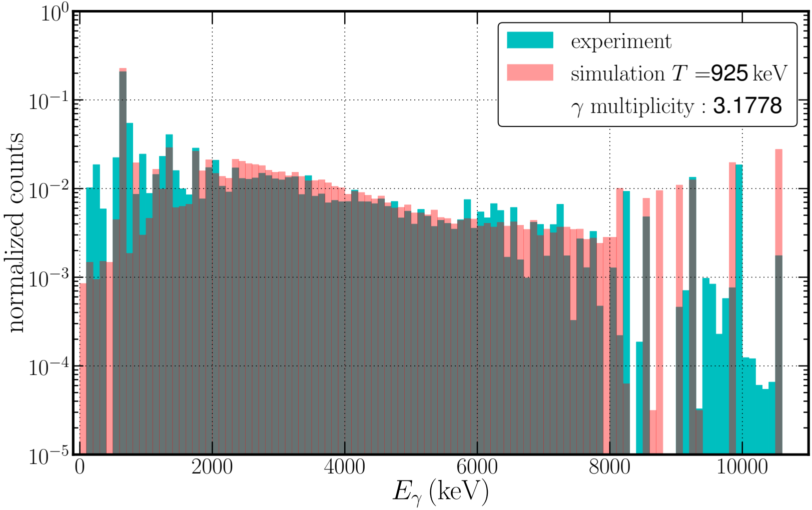

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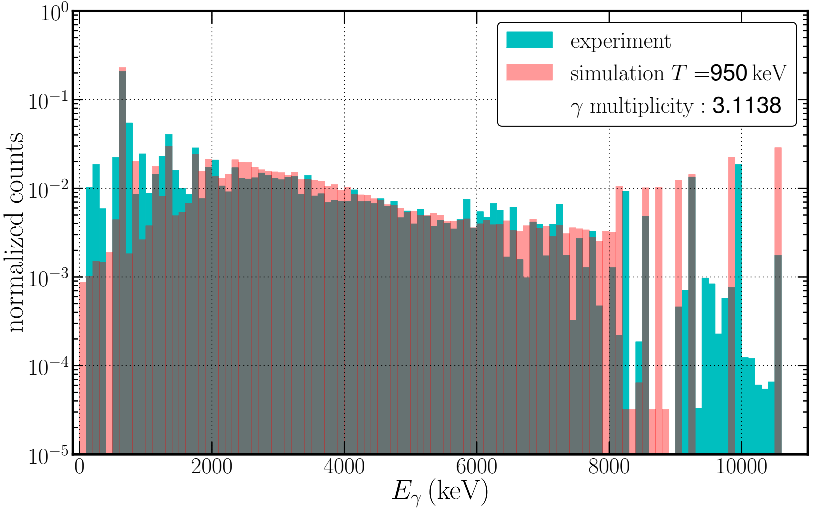

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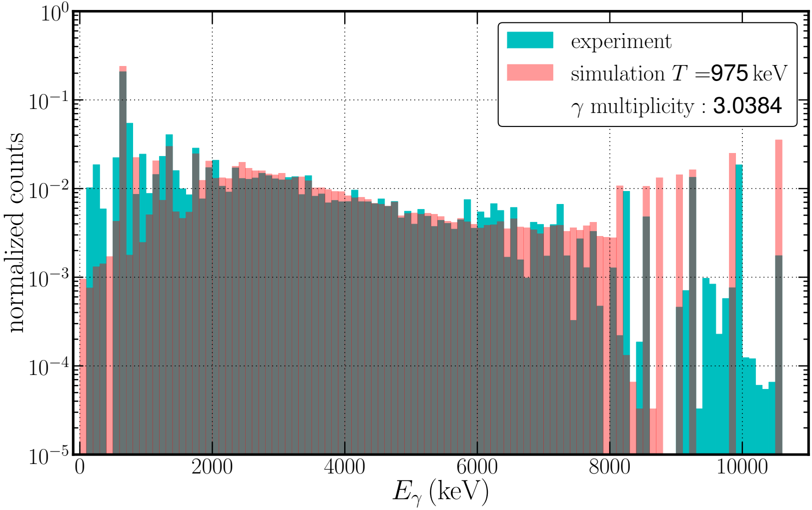

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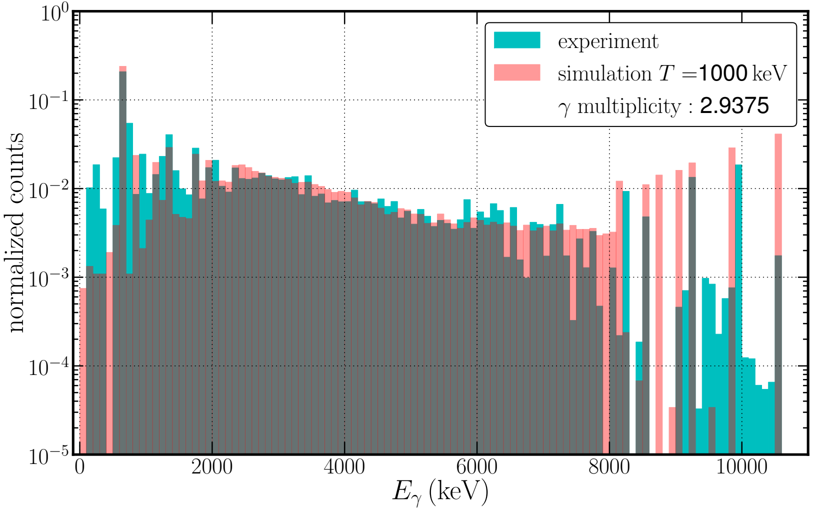

(n,γ) Cross Section

- knowing the total number of γ's in the spectrum and the γ multiplicity ($m = 3.44 \pm 0.5$), the $\sigma_{n\gamma}$ can be calculated

(n,γ) cross section

$$\sigma_{n\gamma} = 43.8\,\mathrm{b}$$

- uncertainty of $\sigma_{n\gamma}$ due to the uncertainty of m is approximately 15% (6.4 b)
- Atlas of Neutron Resonaces [Mughabghab, 2006]: $\sigma_{n\gamma} = 41.5 \pm 4.2\,\mathrm{b}$
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Summary and Outlook

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- With the help of a statistical γ cascade simulation using binned quantities, the ^{77}Se(n,γ) experiment was analysed.
- The comparison of simulated and experimental γ continuum gives insight about the level density (T).
- Using the simulated average multiplicity, the (n,γ) cross section could be calculated.

Outlook

- The simulation will be used to correct inelastic photon scattering experiments (γ,γ') to analyse the second part of the twin experiment.
- From ^{78}Se(γ,γ') a dipole strength function will be extracted which can be used to recheck the (n,γ) analysis.

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Bibliography

Bartholomew, G. et al. (1973).
Gamma ray strength functions.
Advances in Nuclear Physics, 7.

Becvar, F. (1998).
Simulation of cascades in complex nuclei with emphasis on assessment of uncertainties of cascade-related quantities.
Nuclear Instruments and Methods in Physics, A 417.

Junghans, A. et al. (2008).
Photon data shed new light upon the GDR spreading width in heavy nuclei.
Physics Letters B, 670.

Mughabghab, S. F. (2006).
Atlas of neutron resonances, volume 5.
Elsevier.