Detector-response correction of two-dimensional γ-ray spectra from neutron capture

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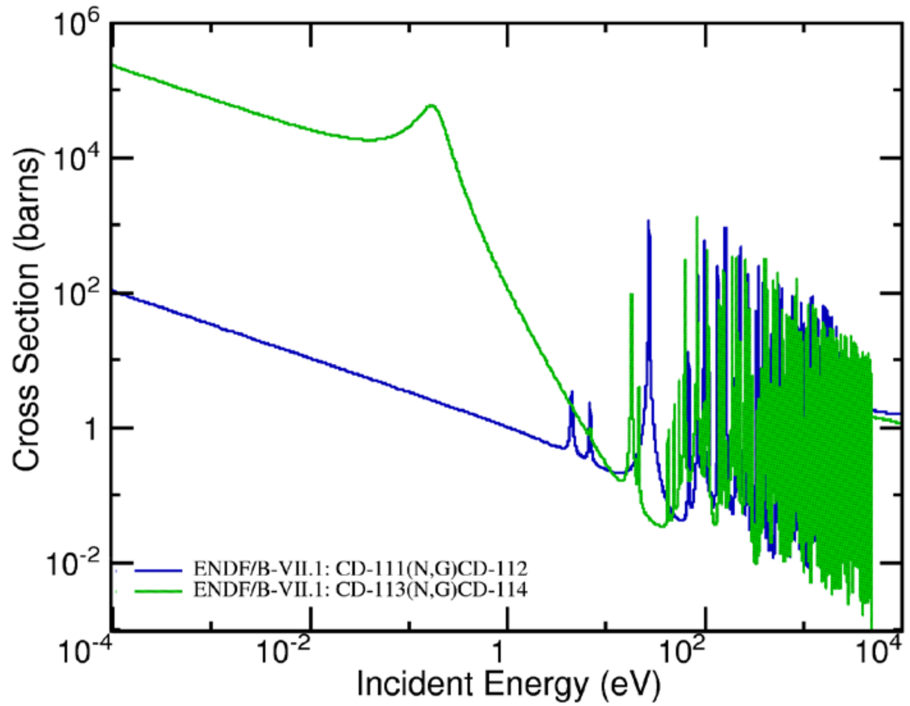
Motivation to study the γ-ray cascades from the ^{113}Cd(*n*,γ) reaction

- ^{113}Cd has one of the largest (*n*,γ) cross sections and is frequently used as a structural material for shielding or detectors.

- A good model for the intensity distribution of the neutron-capture γ rays is required for application of cadmium.

- Correlated data on M_γ vs. E_γ are desired for Monte Carlo transport simulations.

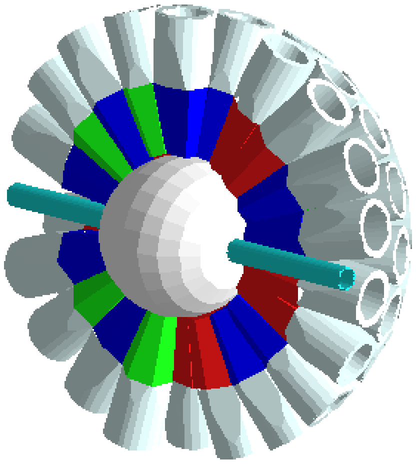


ENDF/B-VII.1 data for the (*n*,γ) cross section for ^{111}Cd (blue) and ^{113}Cd (green) target nuclei.

Detector for Advanced Neutron Capture Experiments

Characteristics of DANCE:

- 4π calorimeter → Q-value cut
- High granularity → $I_\gamma(E_\gamma,M_\gamma)$ measurement
- TOF → γ-ray cascades from a given (n,γ) resonance

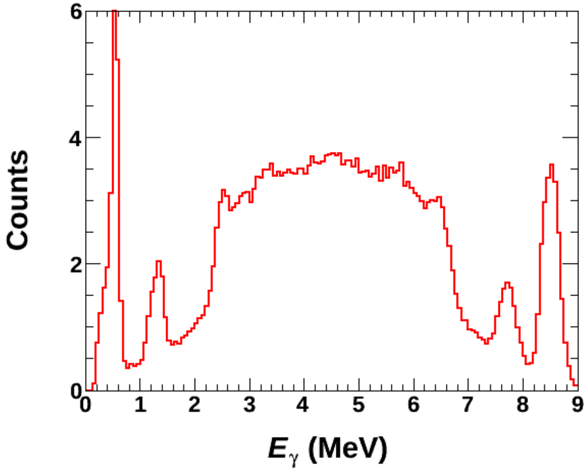


Our goal is to deduce the γ-ray cascades emitted by the nucleus at a given excitation energy (neutron-capture resonance).

Detector-response simulations for DANCE:

M. Jandel *et al.*, Nucl. Instr. and Methods B 261, 1117 (2007).

Trial and error approach



Predicted spectrum

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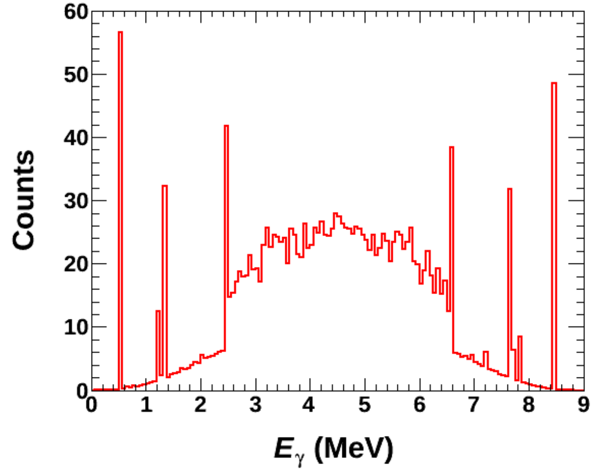
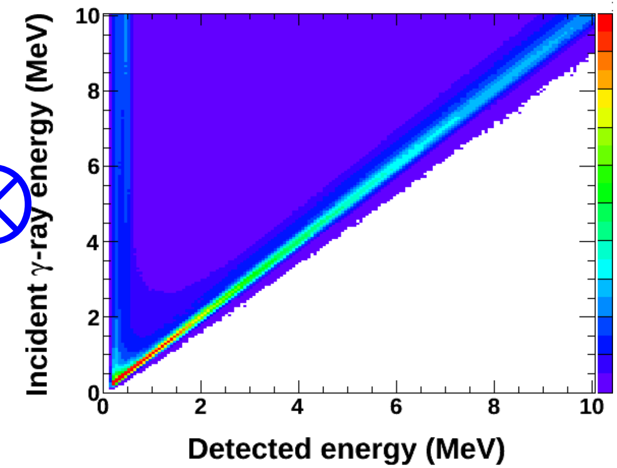


Simulated cascades
DICEBOX

$\otimes$



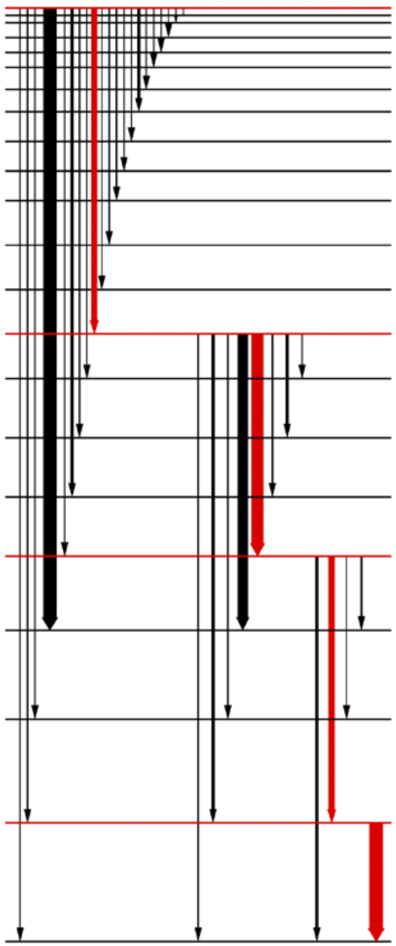
Detector-response matrix
GEANT 4

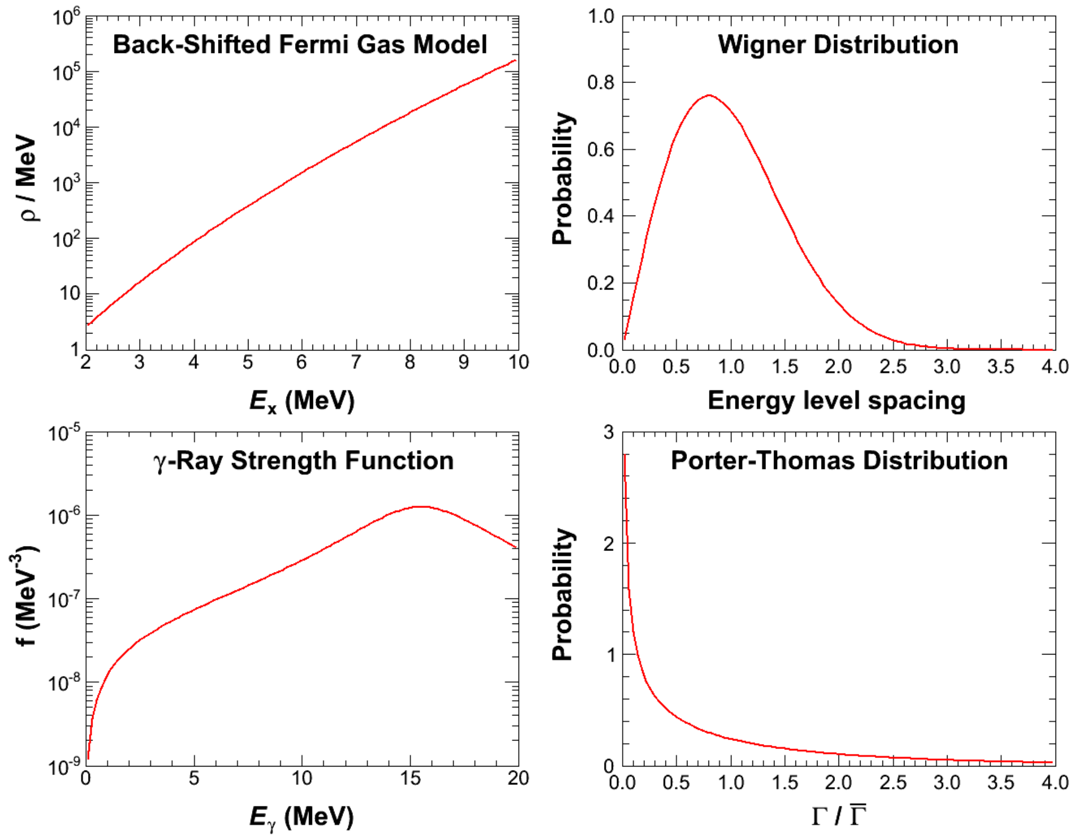
We produce a predicted spectrum by convolutions of cascades simulated with Dicebox for ^{114}Cd with the simulated DANCE response to γ-rays.

Dicebox: F. Bečvář, Nucl. Instr. and Methods A 417, 434 (1998).

DANCE response: M. Jandel *et al.*, Nucl. Instr. and Methods B 261, 1117 (2007).

Simulation of the γ-ray cascades

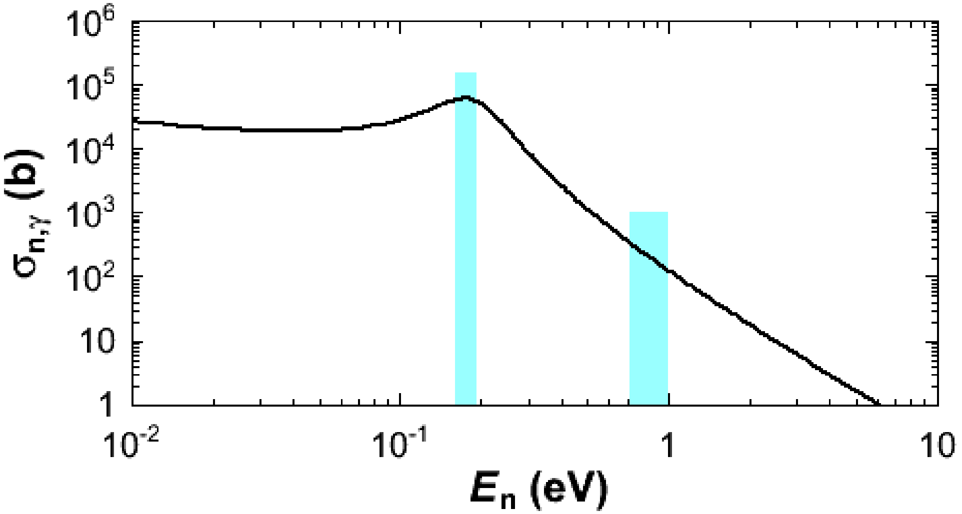




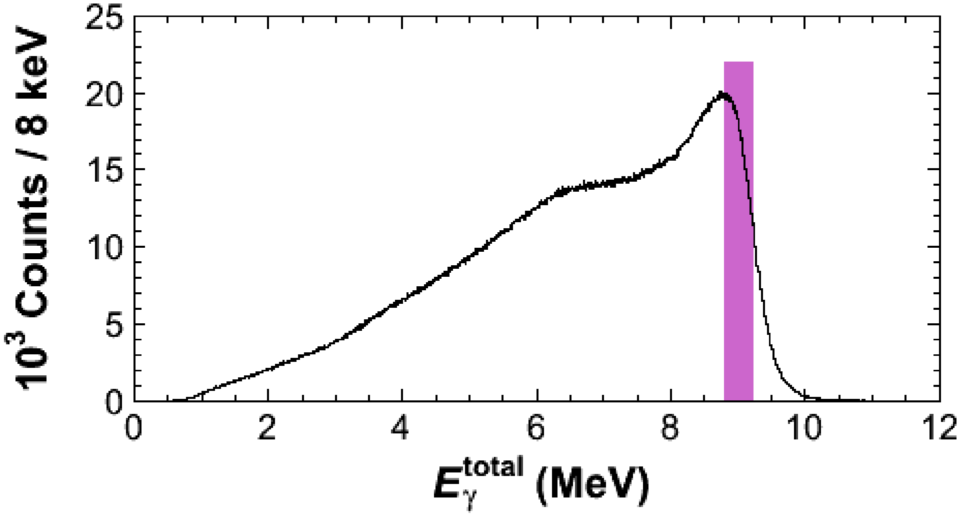
G. Rusev *et al.*, Phys. Rev C **87**, 054603 (2013).

Dicebox: F. Bečvář, Nucl. Instr. and Methods A 417, 434 (1998).

Time-of-flight and E^{total} spectra from ^{113}Cd

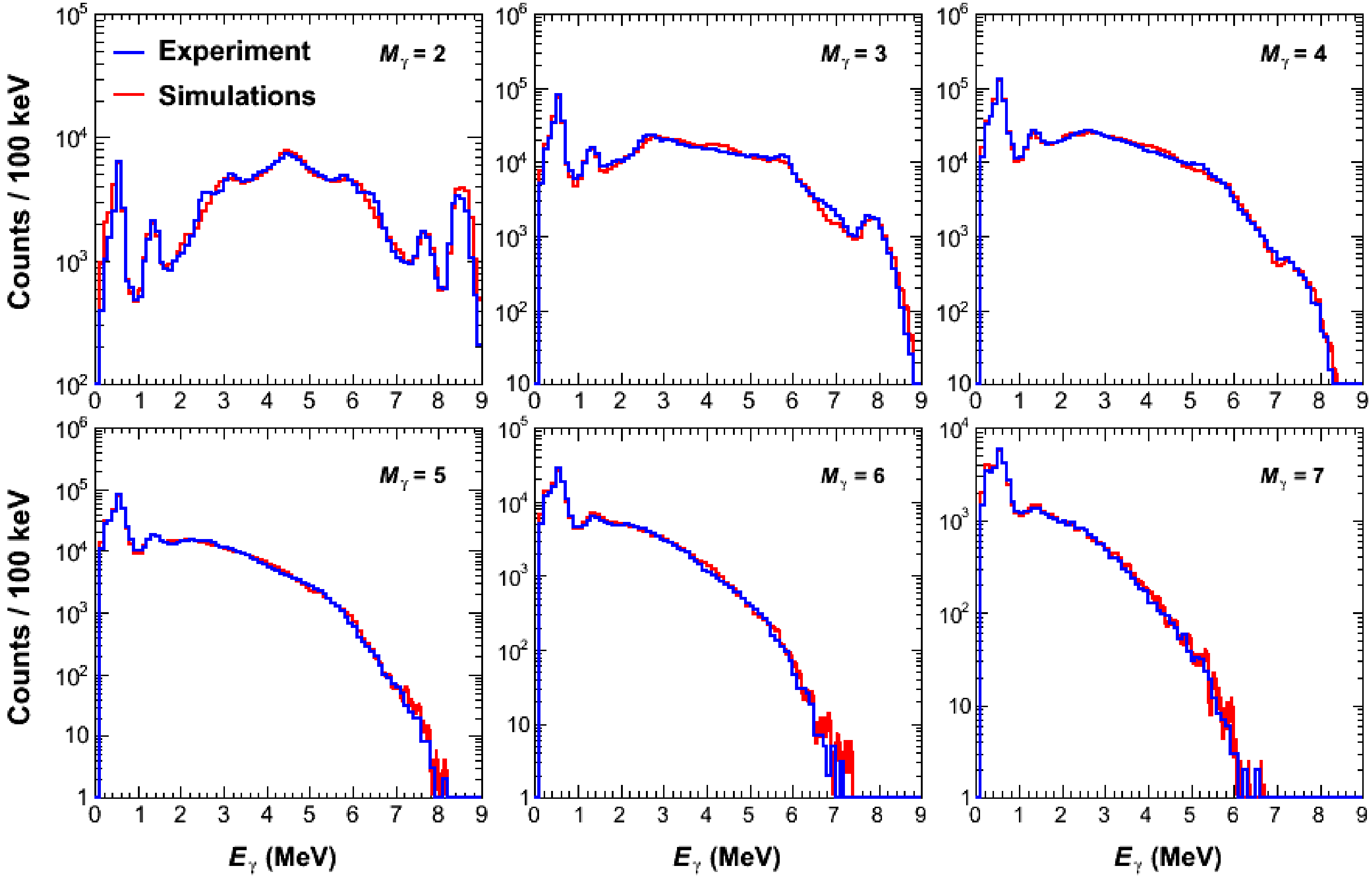


The data were collected in two TOF windows of 250 μs each. The γ rays in the second window were considered as background.



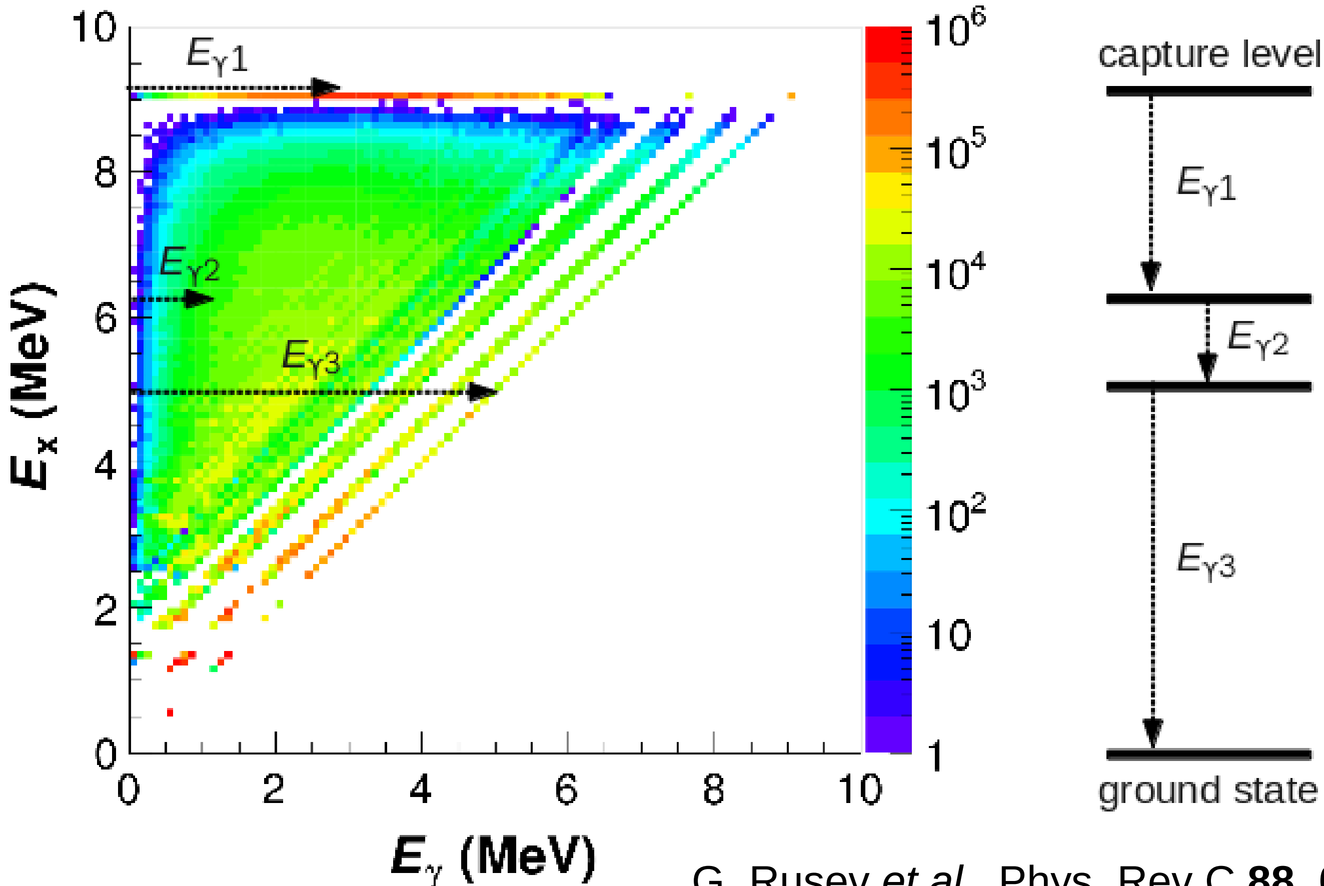
Further reduction of the background was achieved by applying *Q*-value gate to the E^{total} spectrum.

Gamma-ray spectra for different multiplicities



The best agreement of 10000 realizations is shown in red.

I_γ vs. E_x vs. E_γ distribution

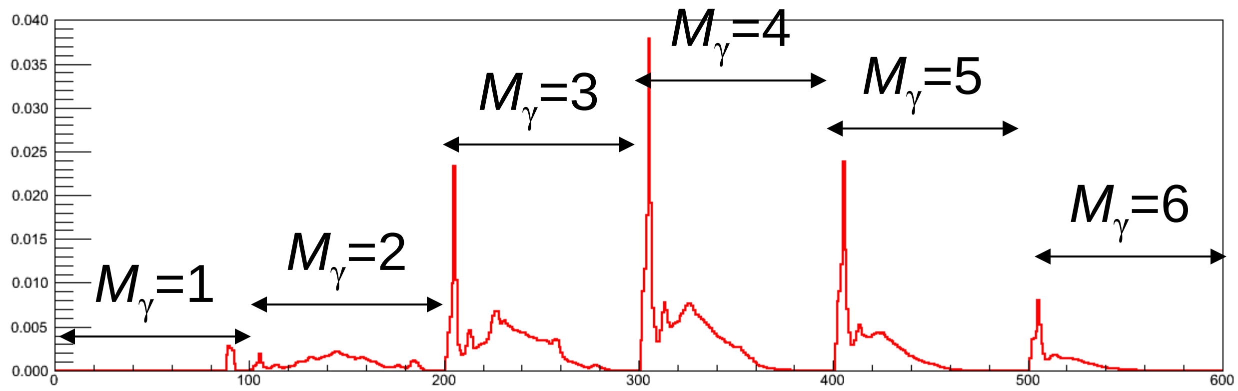


G. Rusev *et al*., Phys. Rev C **88**, 057602 (2013).

- Fully M_γ vs. E_γ correlated cascades
- We can build a new library for (n,γ) intensities

Decomposition of (n,γ) spectra

Linearization of the measured 2D spectrum:



$\boldsymbol{y} = \boldsymbol{R} \cdot \boldsymbol{x}$

y – measured spectrum

R – response matrix

x – source spectrum

$\boldsymbol{z} = \boldsymbol{A} \cdot \boldsymbol{x}$

$\boldsymbol{A} = \boldsymbol{R}^{\boldsymbol{T}}\boldsymbol{R}$

$\boldsymbol{z} = \boldsymbol{R}^{\boldsymbol{T}}\boldsymbol{y}$

iterative solution:

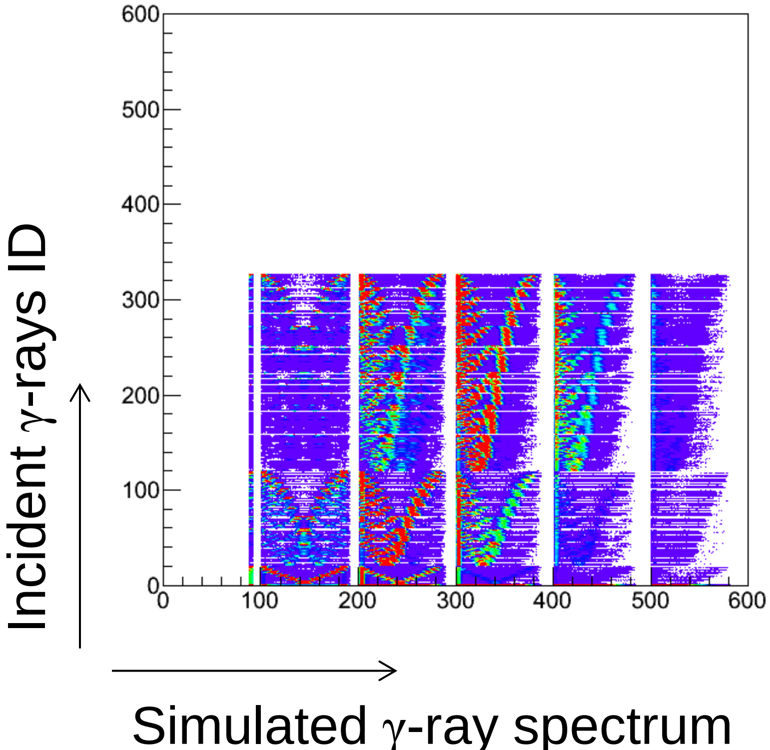
$$x_i{}^{(k+1)} = \frac{z_i}{\sum_{m=1}^{N} A_{im} x_m{}^{(k)}} x_i{}^{(k)}$$

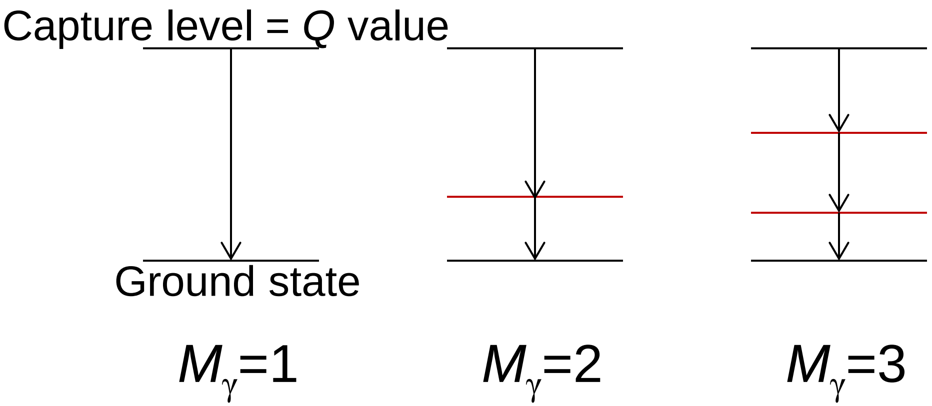
R. Gold, ANL-6984, 1964.
F. Sha *et al*., *Neural Computation* **19,** 2004 (2007).

Gammasphere application:
M. Jandel *et al*., NIM A 516 (2004) 172.

Decomposition of (*n*,γ) spectra

Building the response matrix:

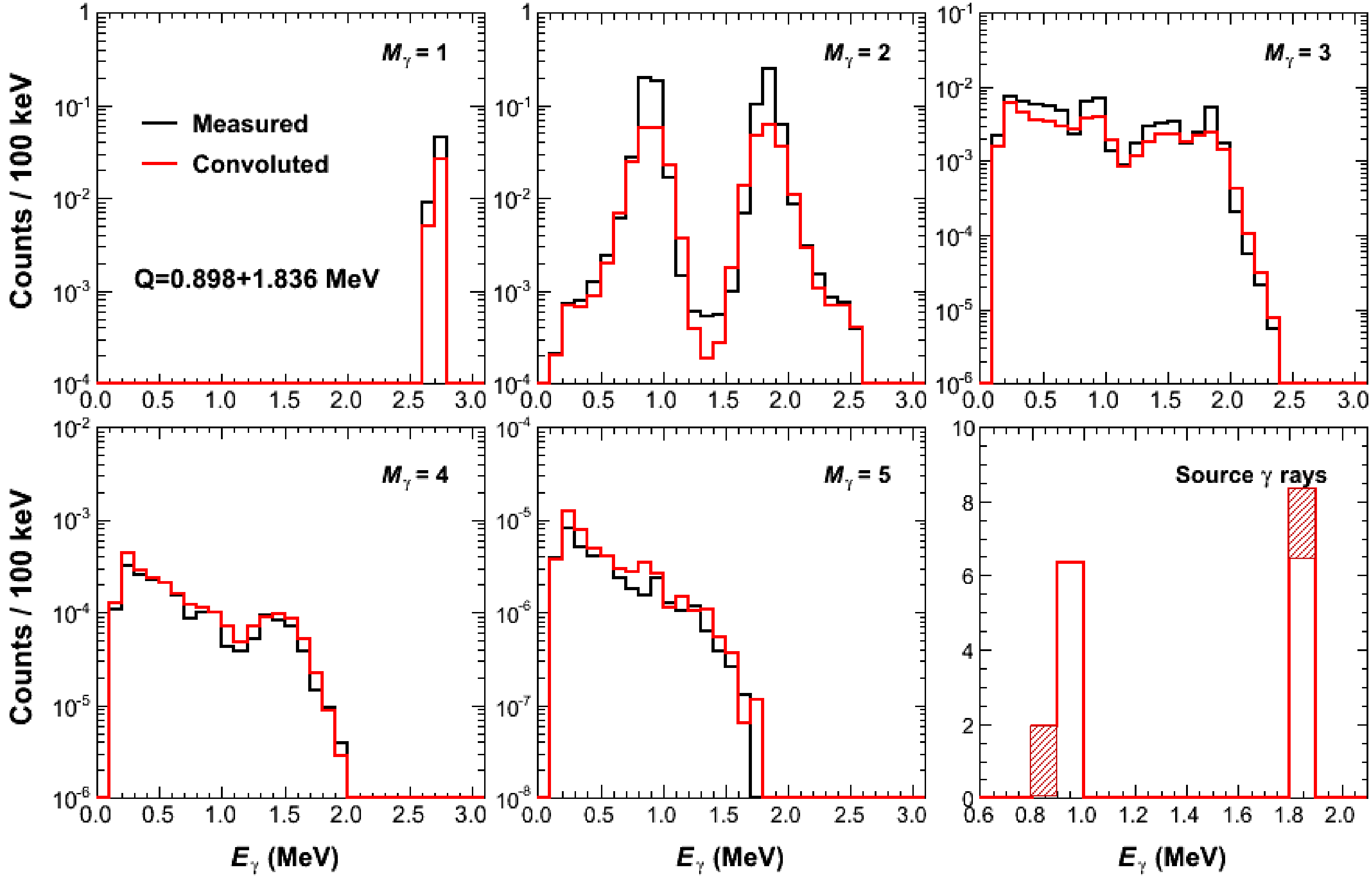




The IDs of the incident γ-rays define the energies of the γ rays emitted from the target: E_1, E_2, …, E_M:

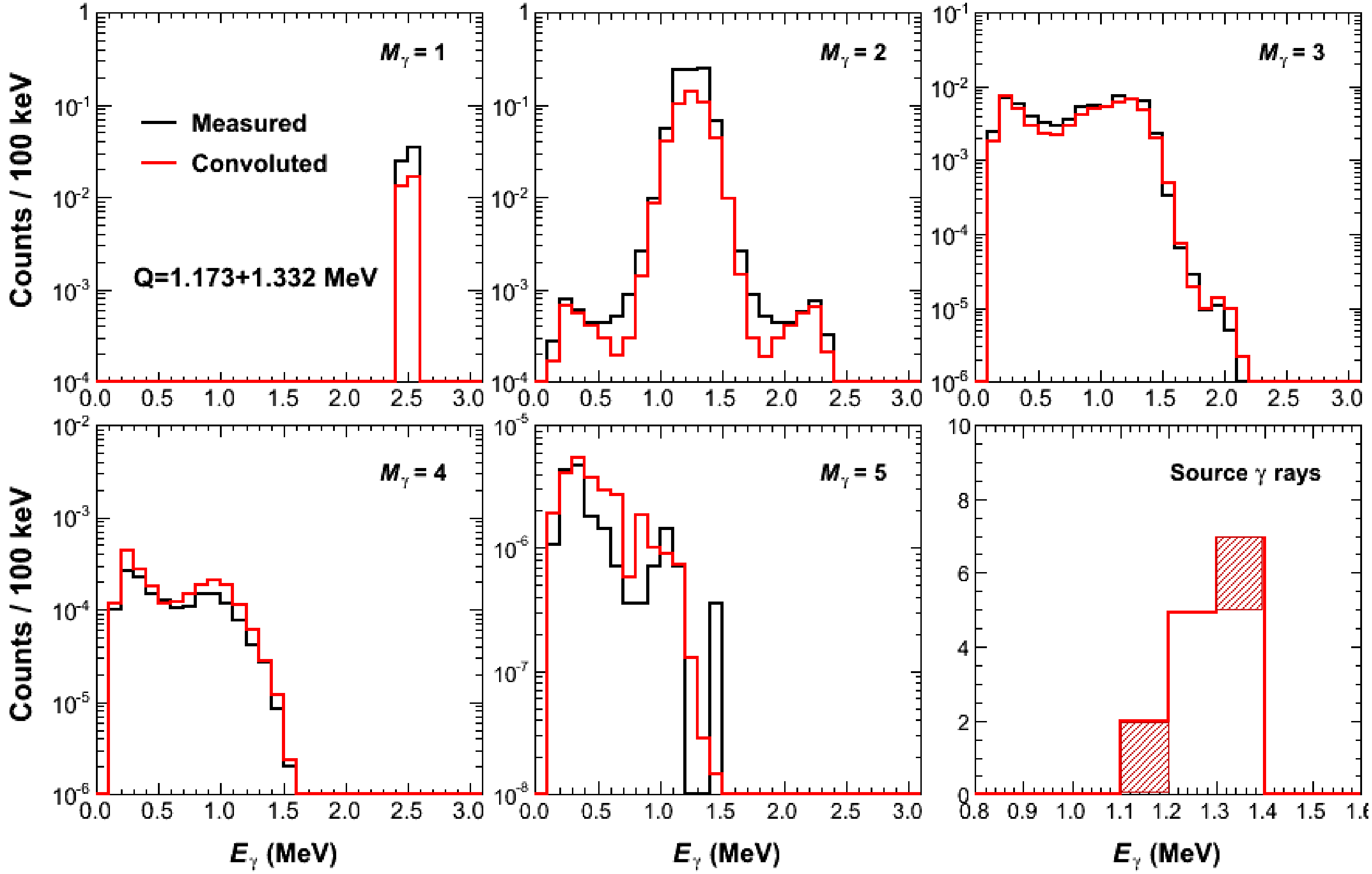
- $E_1+E_2+ \ldots +E_M = Q$
- $E_1 > E_2 > \ldots > E_M$
- E_1, E_2, …, E_M are discretized using a bin size ΔE

Decomposition of ^{88}Y spectra (a two-step cascade)



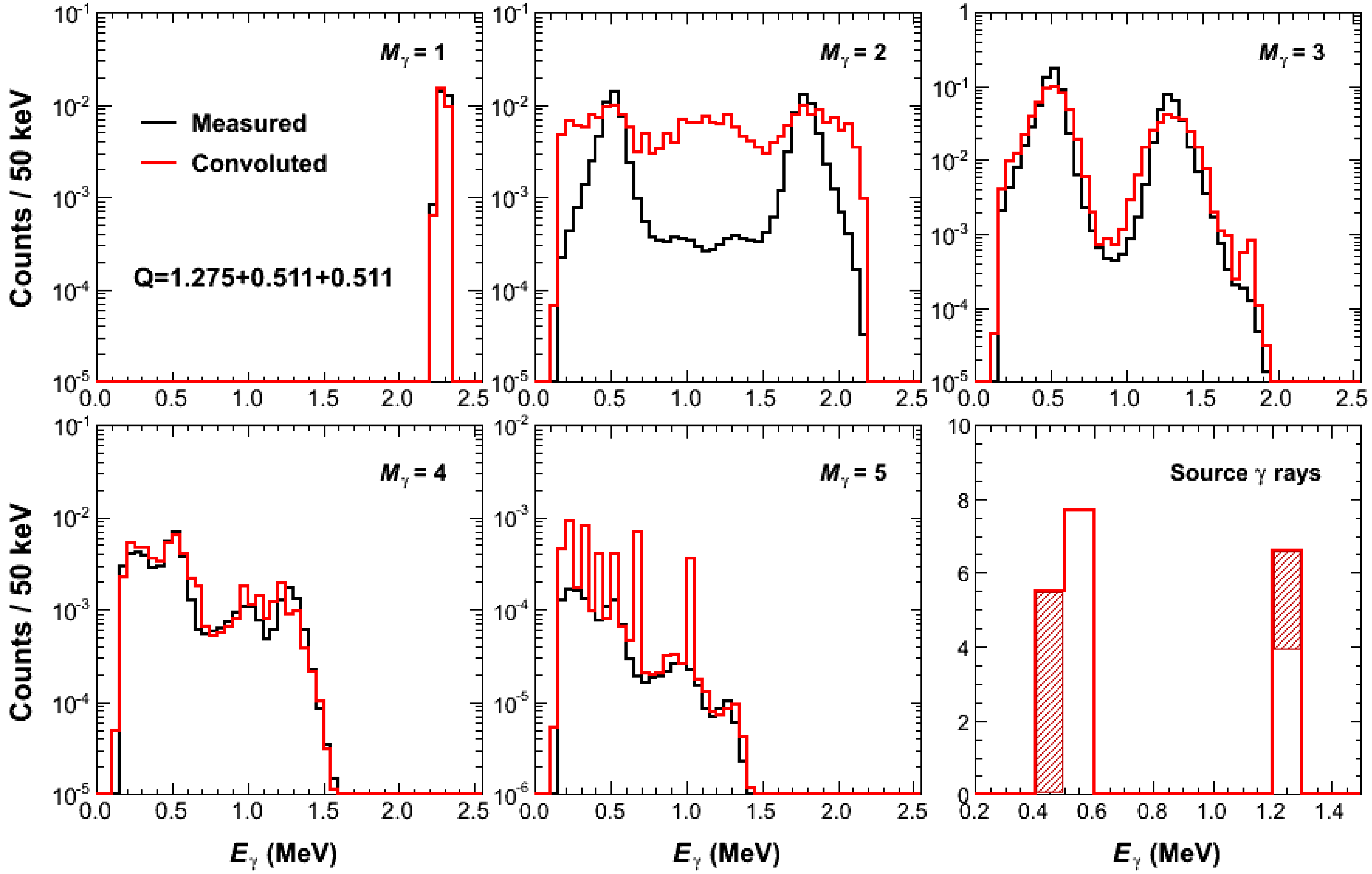
ID 11: 23%, E_1=0.8 MeV, E_2=1.8 MeV
ID 12: 77%, E_1=0.9 MeV, E_2=1.8 MeV

Decomposition of ^{60}Co spectra (a two-step cascade)



ID 3: 29%, E_1=1.1 MeV, E_2=1.3 MeV
ID 4: 71%, E_1=1.2 MeV, E_2=1.3 MeV

Decomposition of ^{22}Na spectra (a three-step cascade)



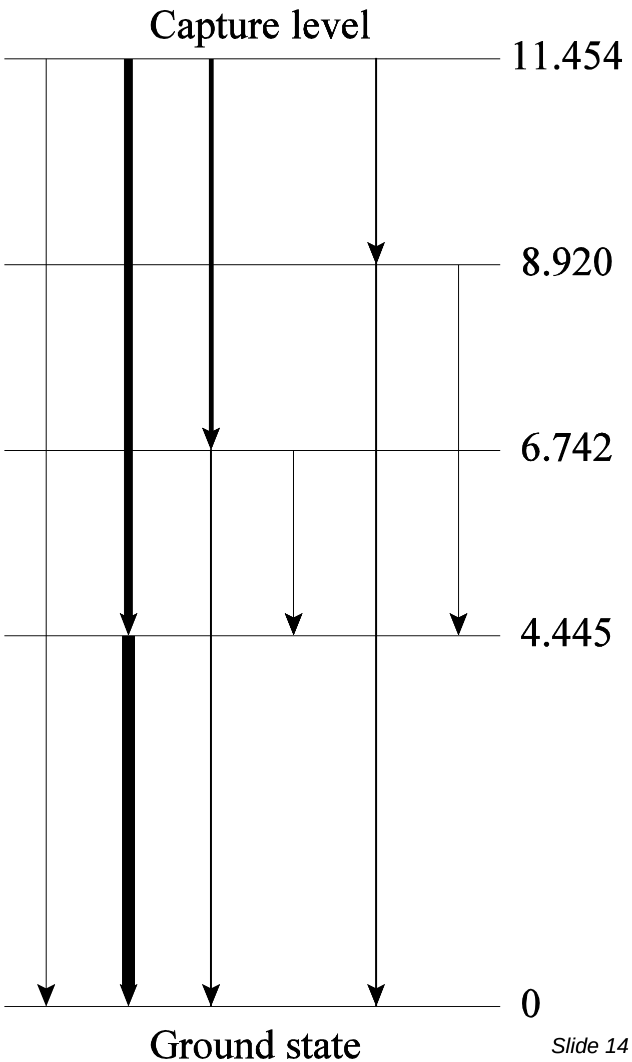
ID 68: 42%, E_1=0.4 MeV, E_2=0.4 MeV, E_3=1.2 MeV

ID 71: 58%, E_1=0.5 MeV, E_2=0.5 MeV, E_3=1.2 MeV

Decomposition of ^{10}B(n,γ) spectra

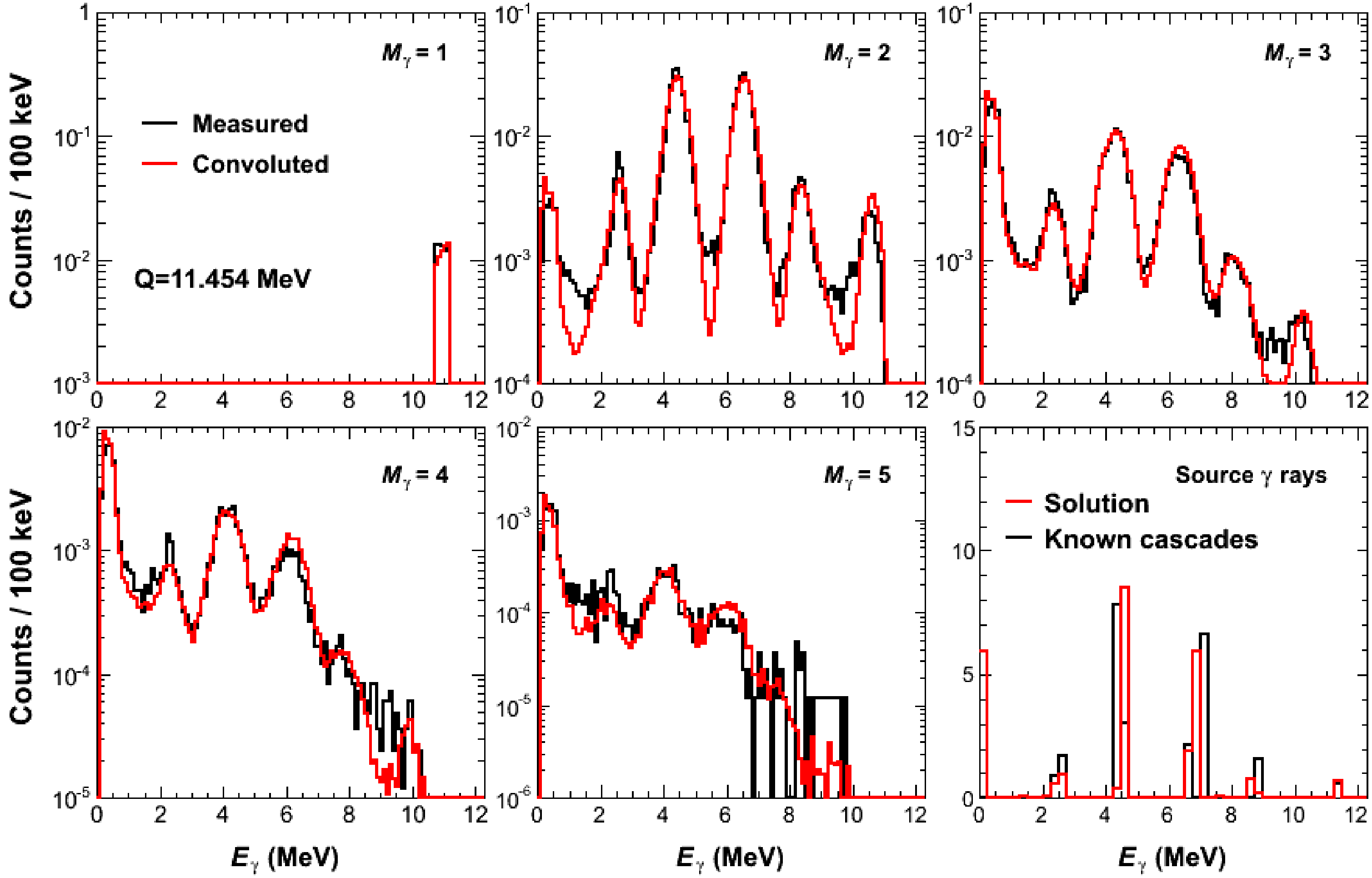
Cascades:

intensity	$E\gamma$ (MeV)
4.7%	11.447
55.3%	7.007+4.444
17.9%	4.711+6.740
13.4%	2.533+8.917
7.7%	4.711+2.297+4.444
1.0%	2.533+4.475+4.444

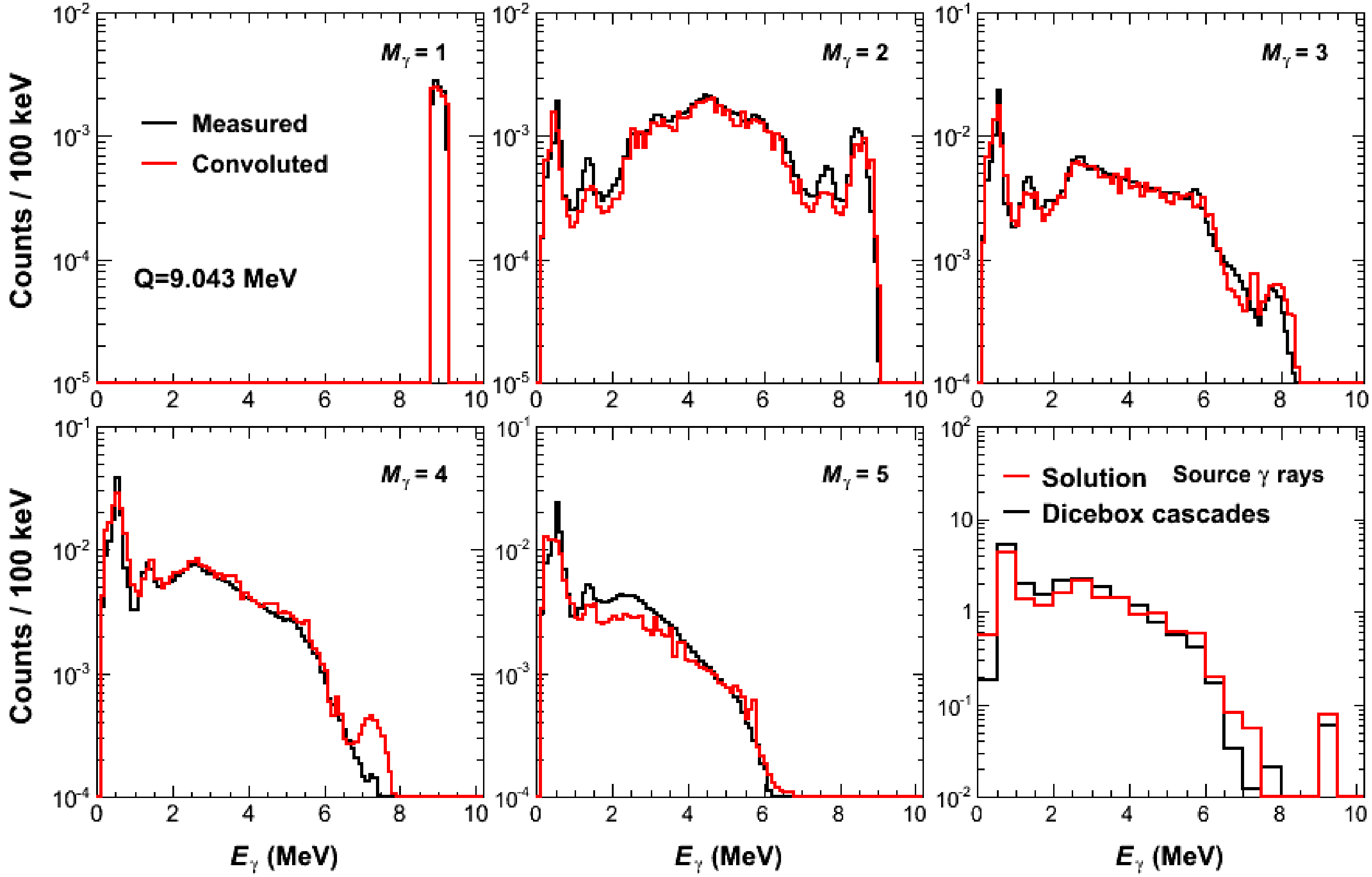


Competing reaction: ^{10}B(n,αγ)^{7}Li, E_γ=477 keV

Decomposition of $^{10}B(n,\gamma)$ spectra



Decomposition of ^{113}Cd(n,γ) spectra



Summary

- Trial and error approach: need to know the level density and gamma-ray strength functions accurately, very time consuming. The ^{113}Cd work was published in Phys. Rev. C **88**, 057602 (2013).

- Decomposition approach: the applicability of the method has been tested against source measurements and $^{10}B(n,\gamma)$ spectra. Future work: reducing the bin size and parallelization of the decomposition procedure.

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