New results from MTAS and the impact on the reactor anomaly

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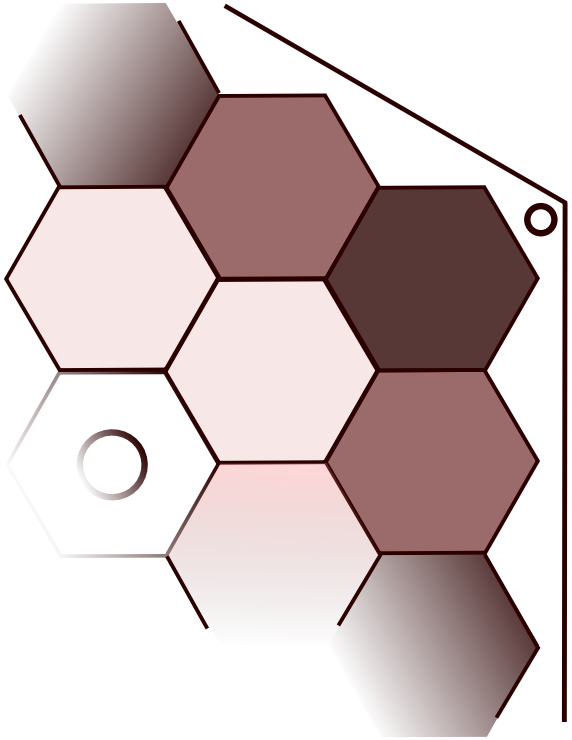
Outline



Reactor antineutrino anomaly

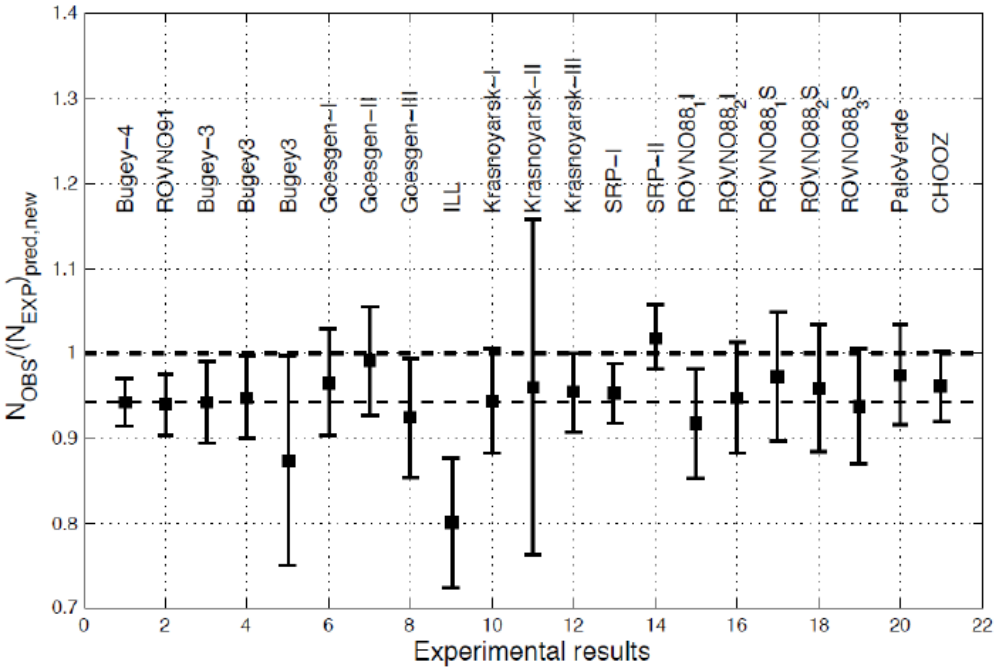
Experimental setup

- Modular Total Absorption Spectrometer

Data Analysis

Results and conclusions

Reactor antineutrino anomaly



$$N_{obs} / N_{cal} = 94.3\ (23)\%$$

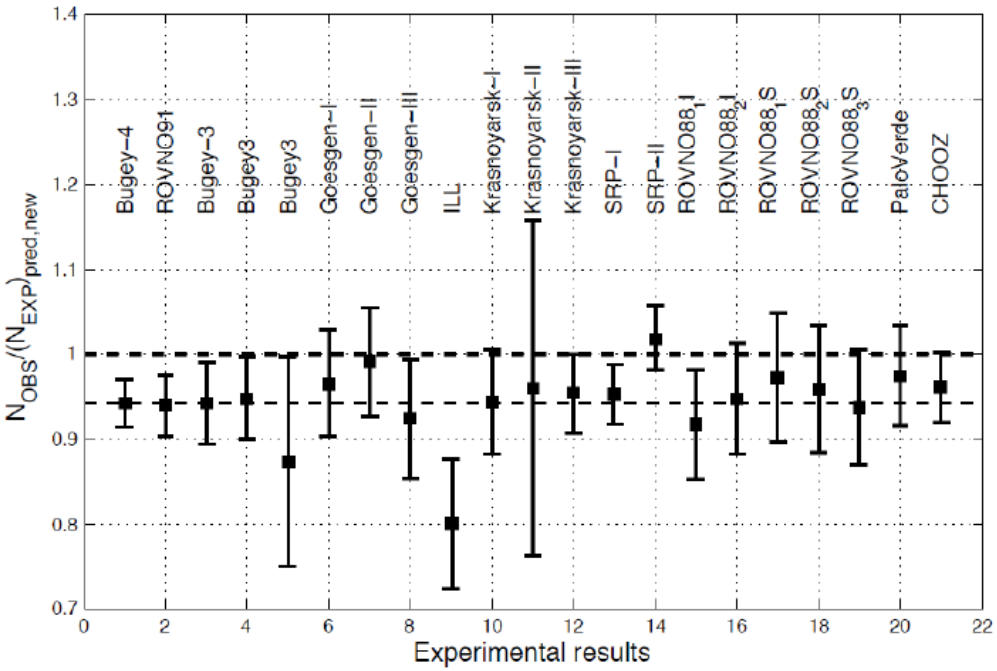
M. Fechner, G. Mention, T. Lasserre et al. arXiv:1101.2755 [hep-ex]

A nuclear reactor is a powerful source of electron antineutrinos. There are about 6 neutrinos per fission giving about 10^{20} ν_e/s per 1 GW of thermal power.

The measured reactor antineutrino spectra show only about 94(2)% of the total expected events. This might be caused by the presence of a fourth antineutrino type or incomplete decay data used for the antineutrino spectrum calculation.

Reactor antineutrino anomaly

STEP 1 - ab-initio method



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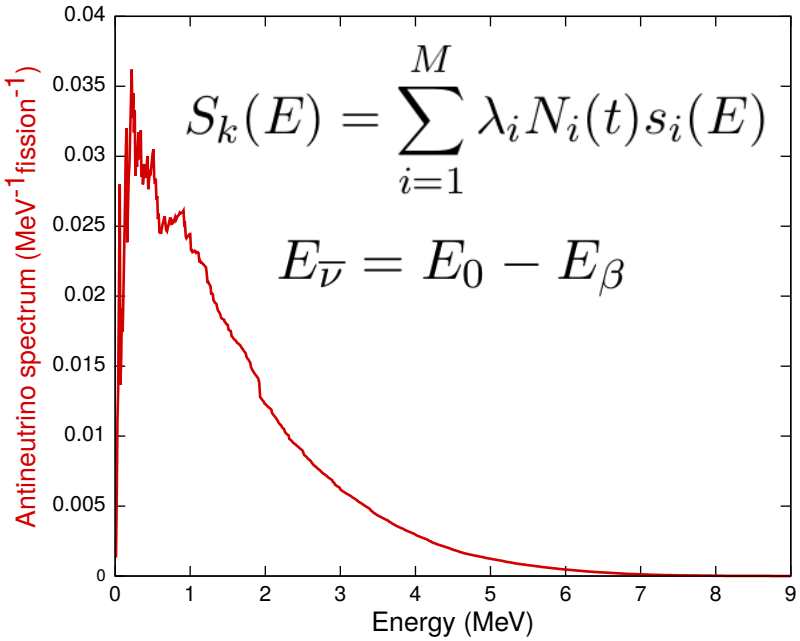
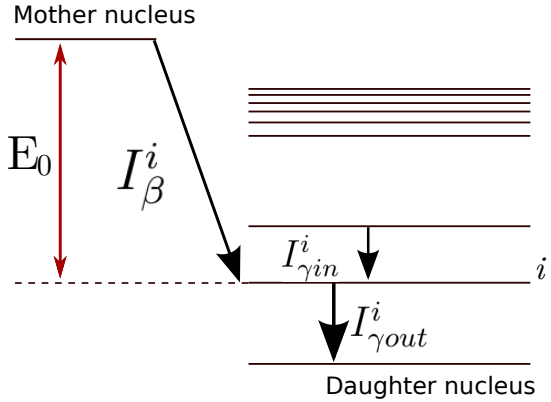
M. Fechner, G. Mention, T. Lasserre et al. arXiv:1101.2755 [hep-ex]

Sum over all known fission product



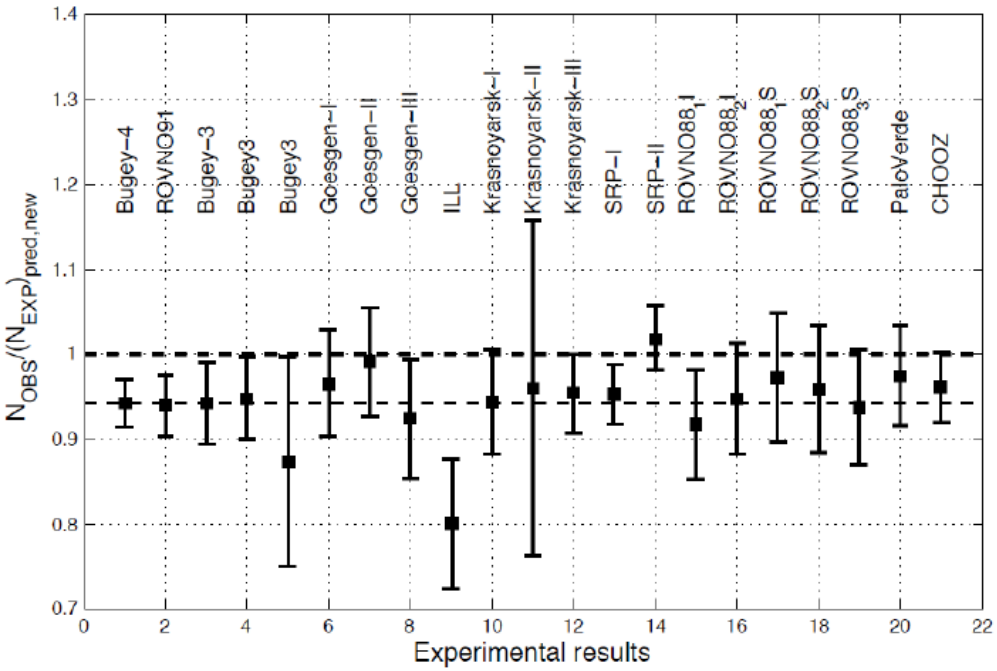
$$S_k(E) = \sum_{i=1}^{M} \lambda_i N_i(t) s_i(E)$$

$$E_{\overline{\nu}} = E_0 - E_\beta$$



Reactor antineutrino anomaly

STEP 2 - conversion method



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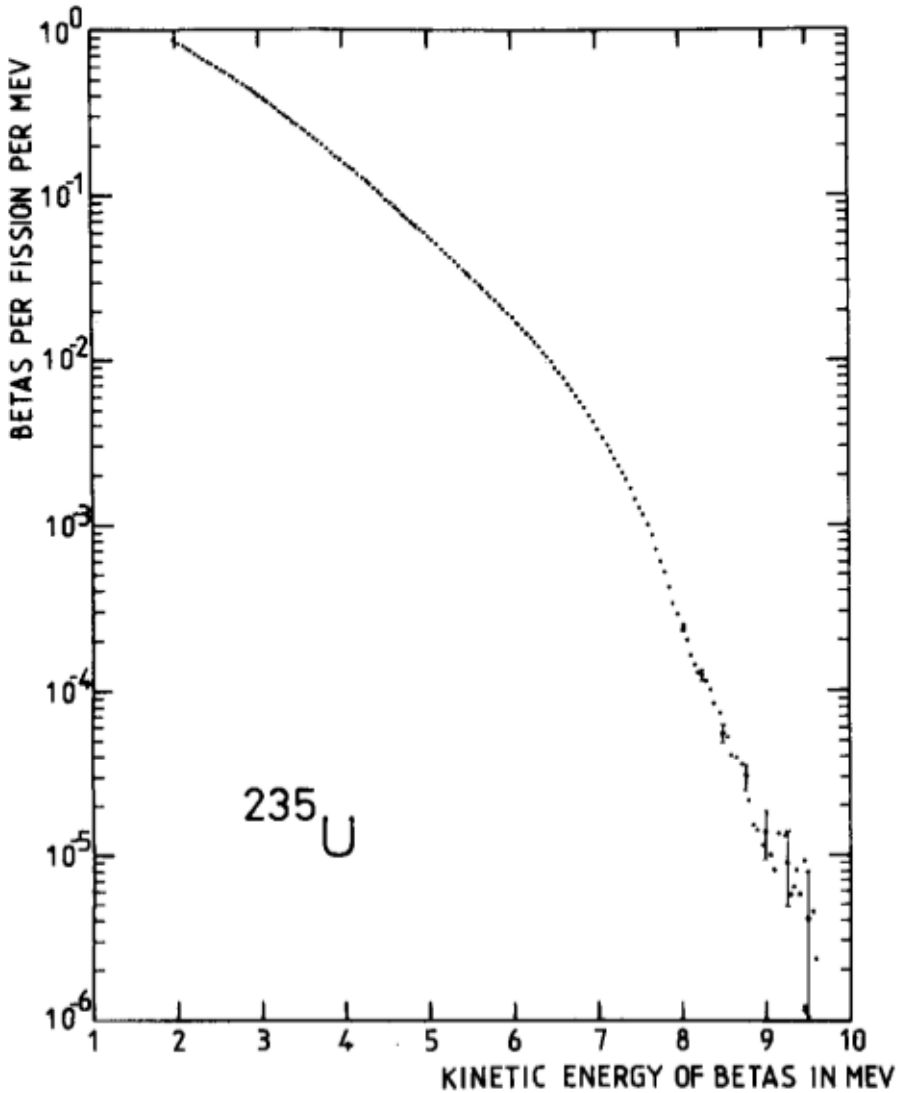
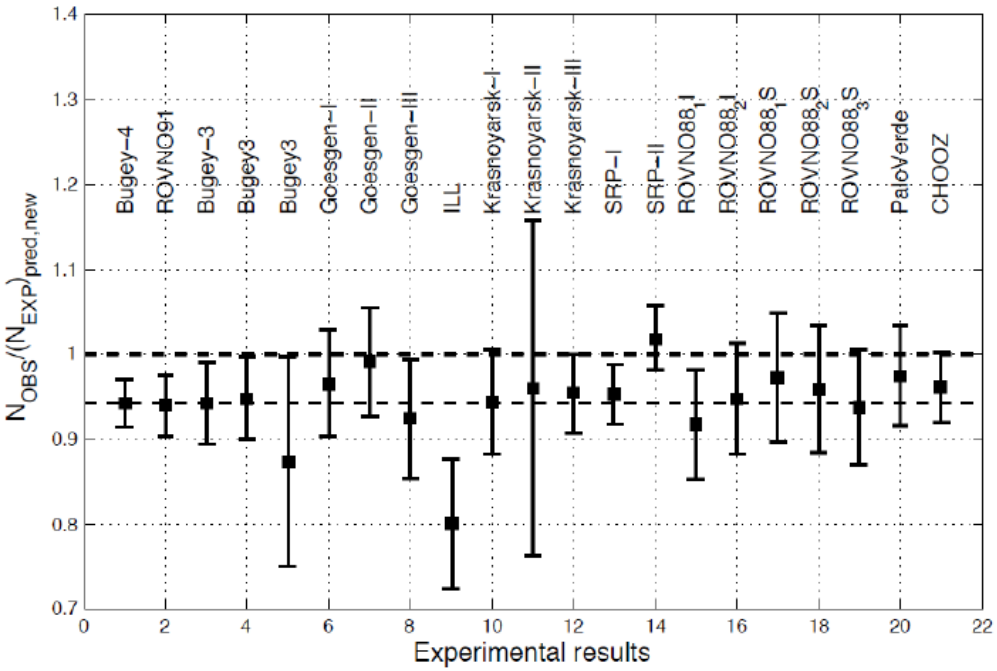
M. Fechner, G. Mention, T. Lasserre et al. arXiv:1101.2755 [hep-ex]

Integral electron spectrum from fission products in thermal-neutron induced fission of ^{235}U, ^{239}Pu and ^{241}Pu was "deconvoluted" into a set of five effective β branches with a nuclear charge of Z = 46.



Schreckenbach, Colvin, Gelletly,von Feilitzsch, Phys. Lett., 160B, 325, 1985

Reactor antineutrino anomaly



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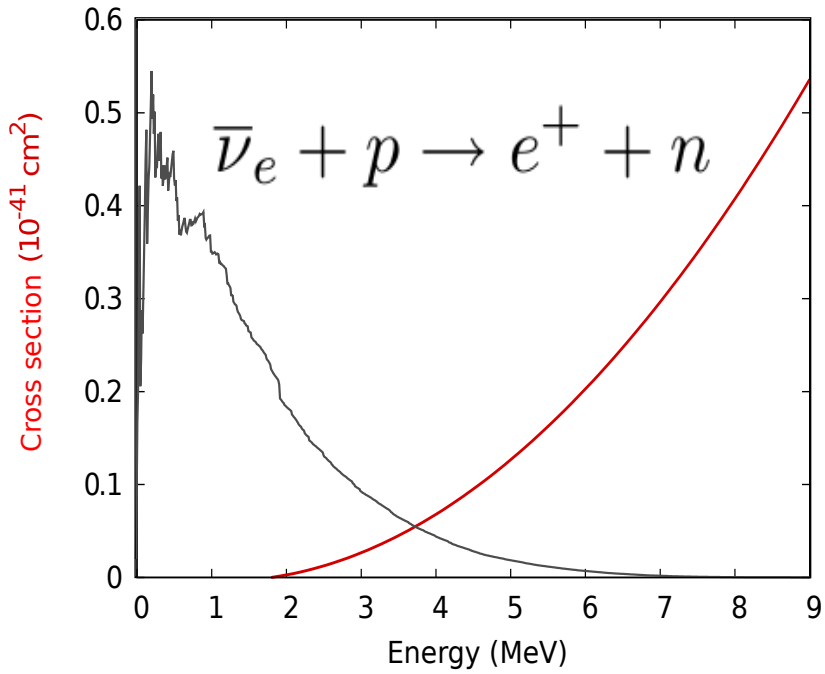
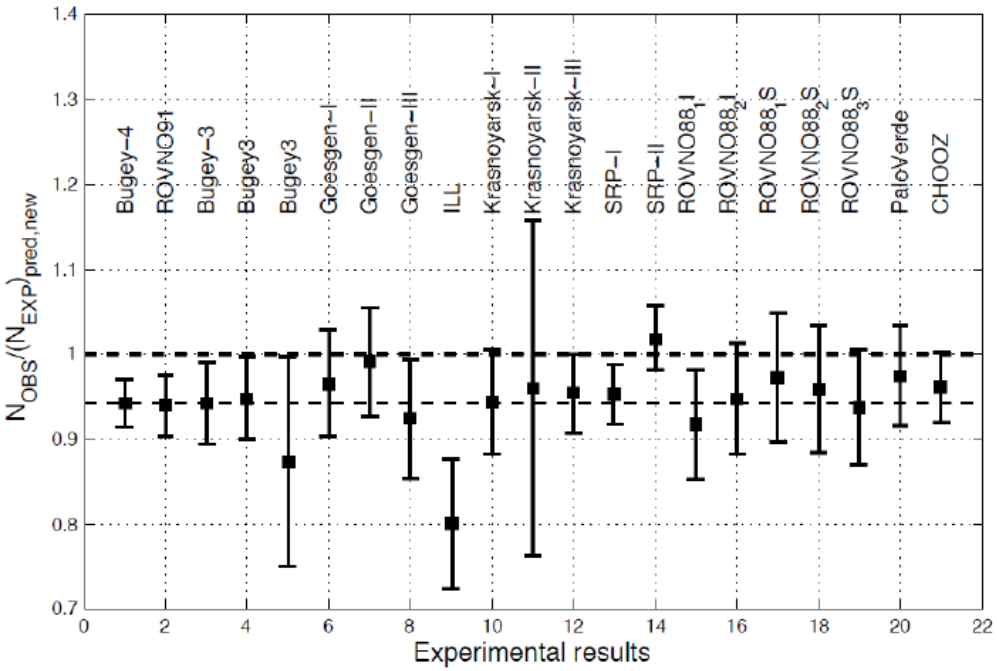
M. Fechner, G. Mention, T. Lasserre et al. arXiv:1101.2755 [hep-ex]

Inverse β-decay cross section



A Strumia, F Vissani
Precise quasielastic neutrino/nucleon cross section,
Phys.Lett.B564:42-54,2003

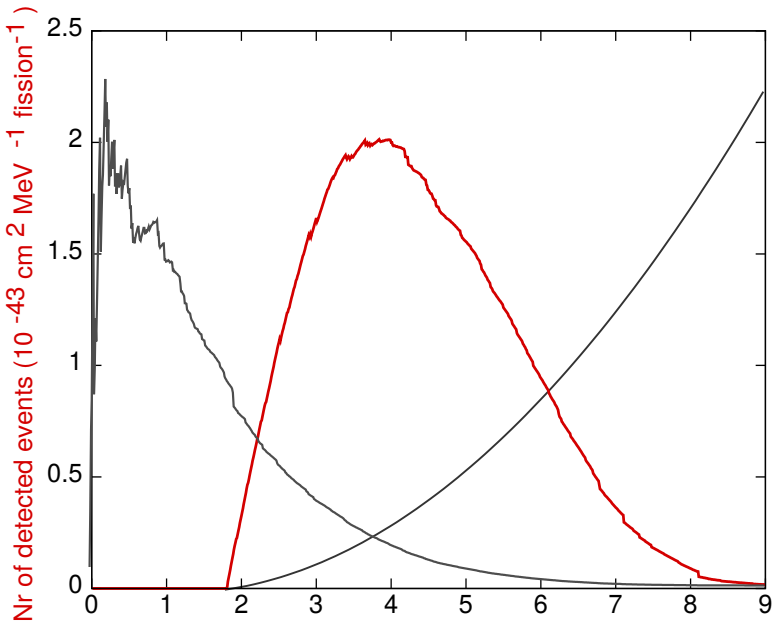
Reactor antineutrino anomaly



$$N_{obs} / N_{cal} = 94.3\ (23)\%$$

M. Fechner, G. Mention, T. Lasserre et al. arXiv:1101.2755 [hep-ex]

Number of detected events is integral to the product both curves



Reactor antineutrino anomaly

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M. Fechner, G. Mention, T. Lasserre et al. arXiv:1101.2755 [hep-ex]

$$S_k(E) = \sum_{i=1}^{M} \lambda_i N_i(t) s_i(E)$$

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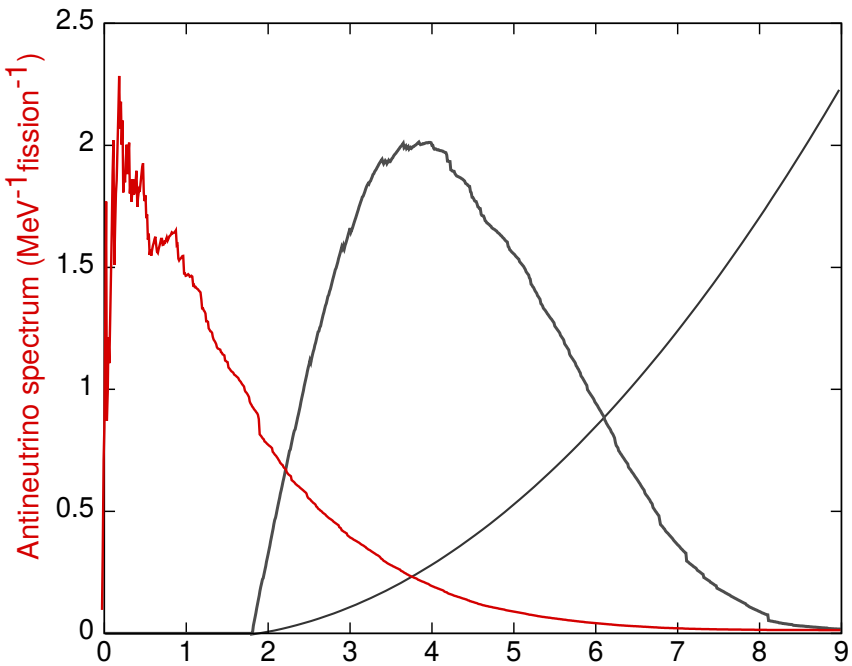

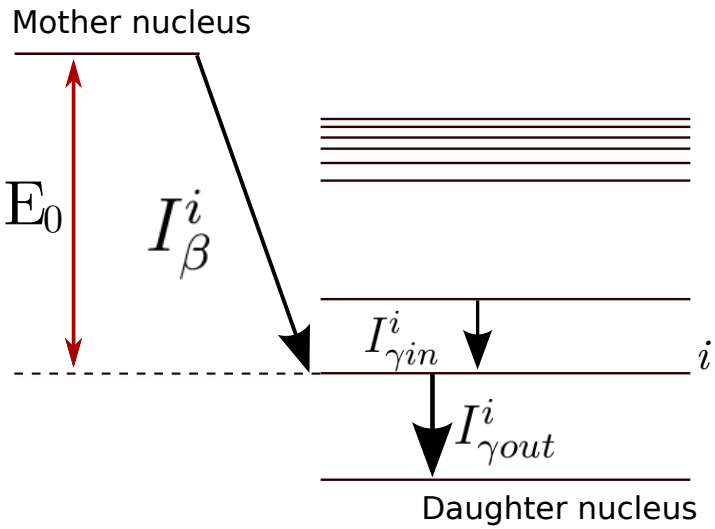

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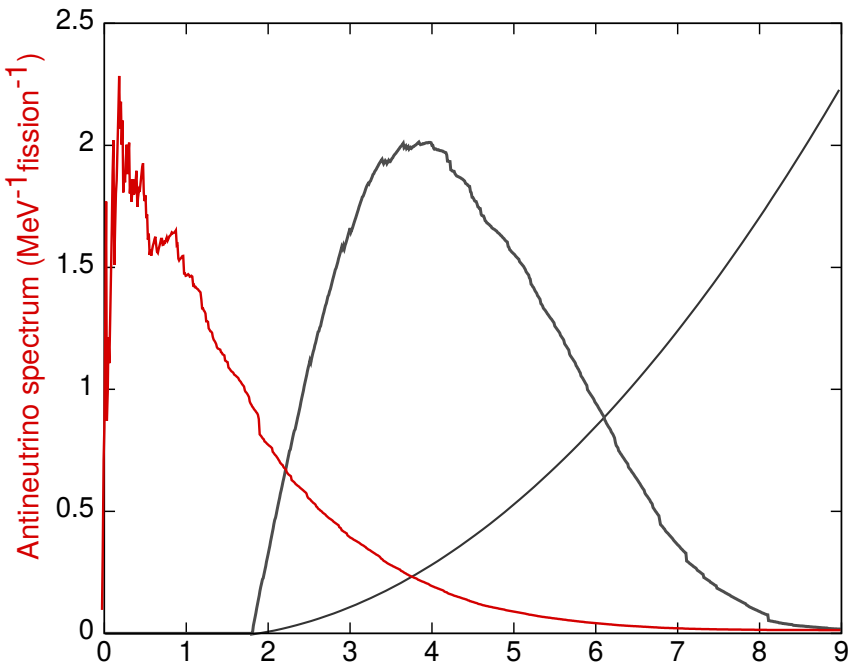

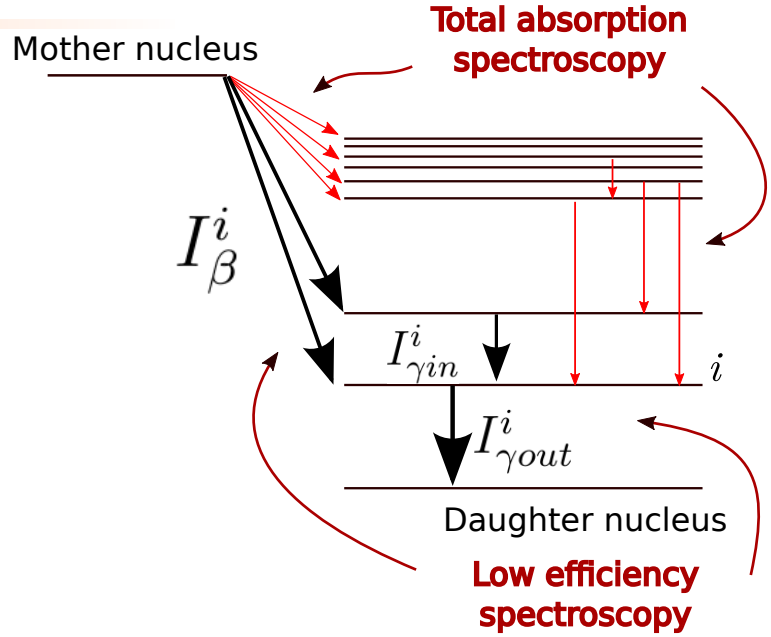

Pandemonium Effect

J. C. Hardy et al., Physics Letter B 71 (1977) 307-310

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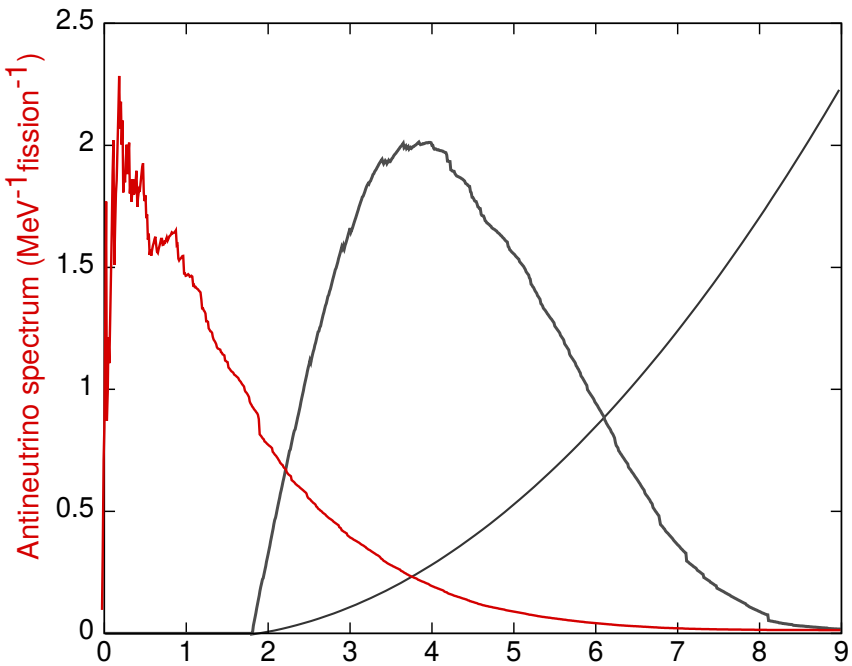
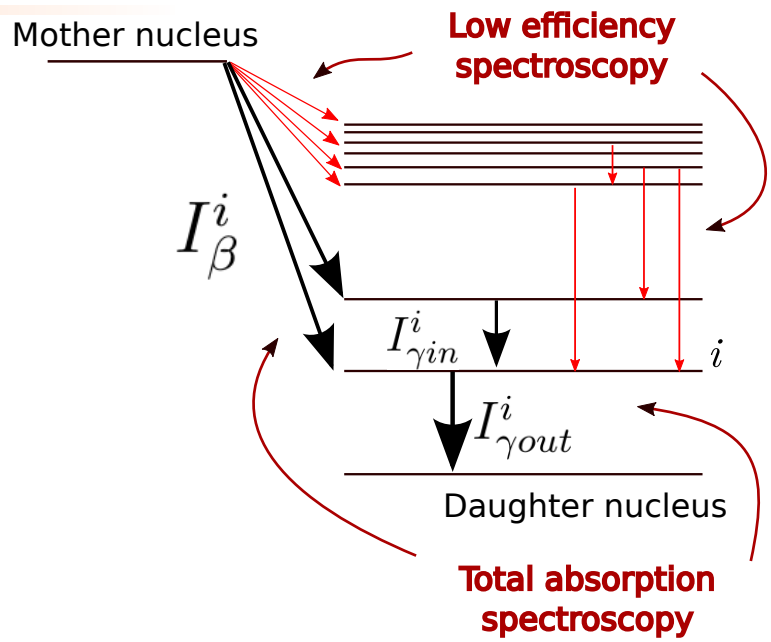




Pandemonium Effect

J. C. Hardy et al., Physics Letter B 71 (1977) 307-310

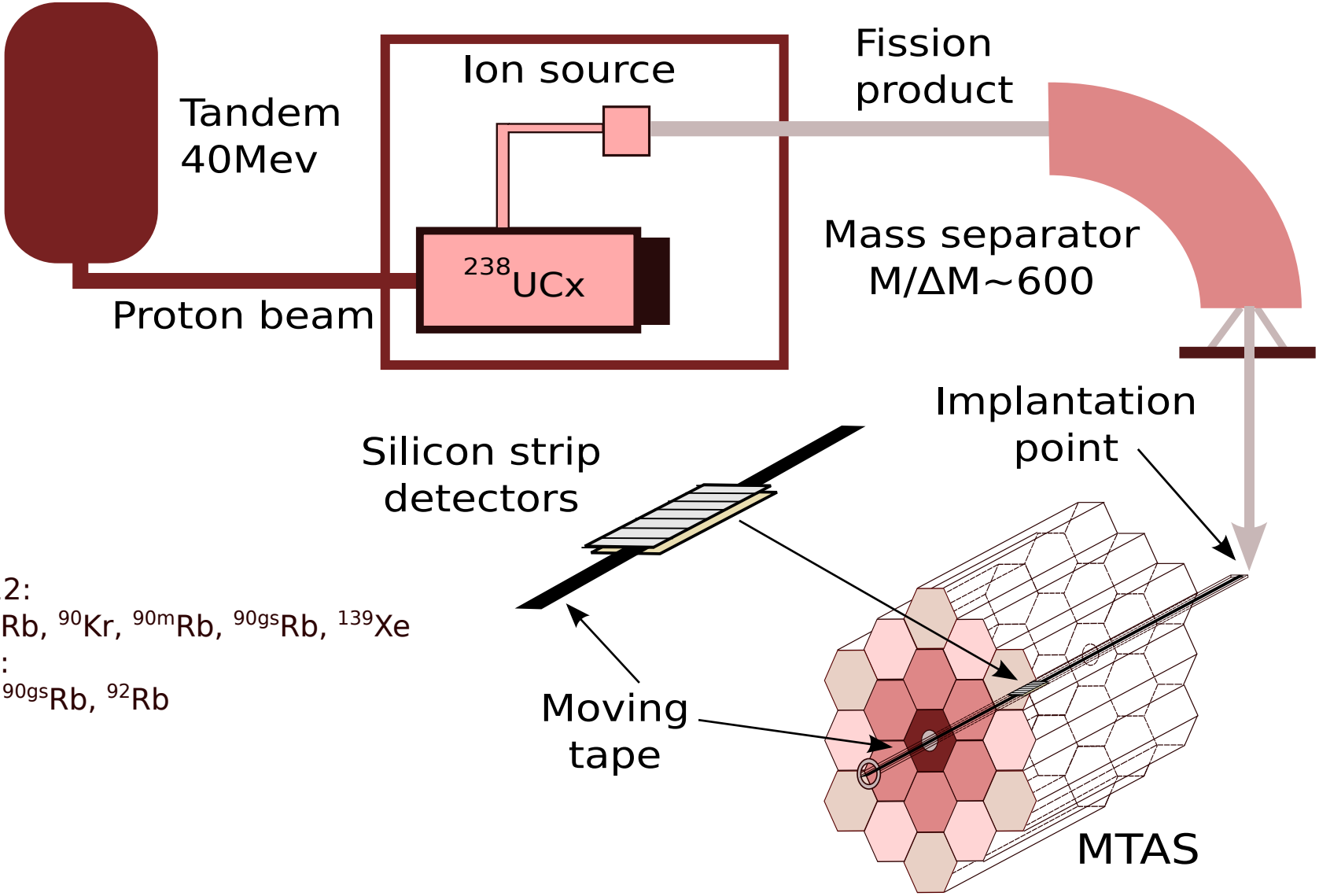
86Br, 89Rb, **89Kr**, **90Kr**, **90mRb**, **90gsRb, 92Rb**, **139Xe**

The list of the strongest contributors to the high energy part of reactor antineutrino spectra (5-7 MeV)
A.A. Sonzogni et al., Phys. Rev. C 91, 011301(R), 2015

Radionuclides recommended for TAGS measurements
Assessment of fission product, decay data for decay heat calculations, T. Yoshida, A.L. Nichols, OECD NEA, 2007

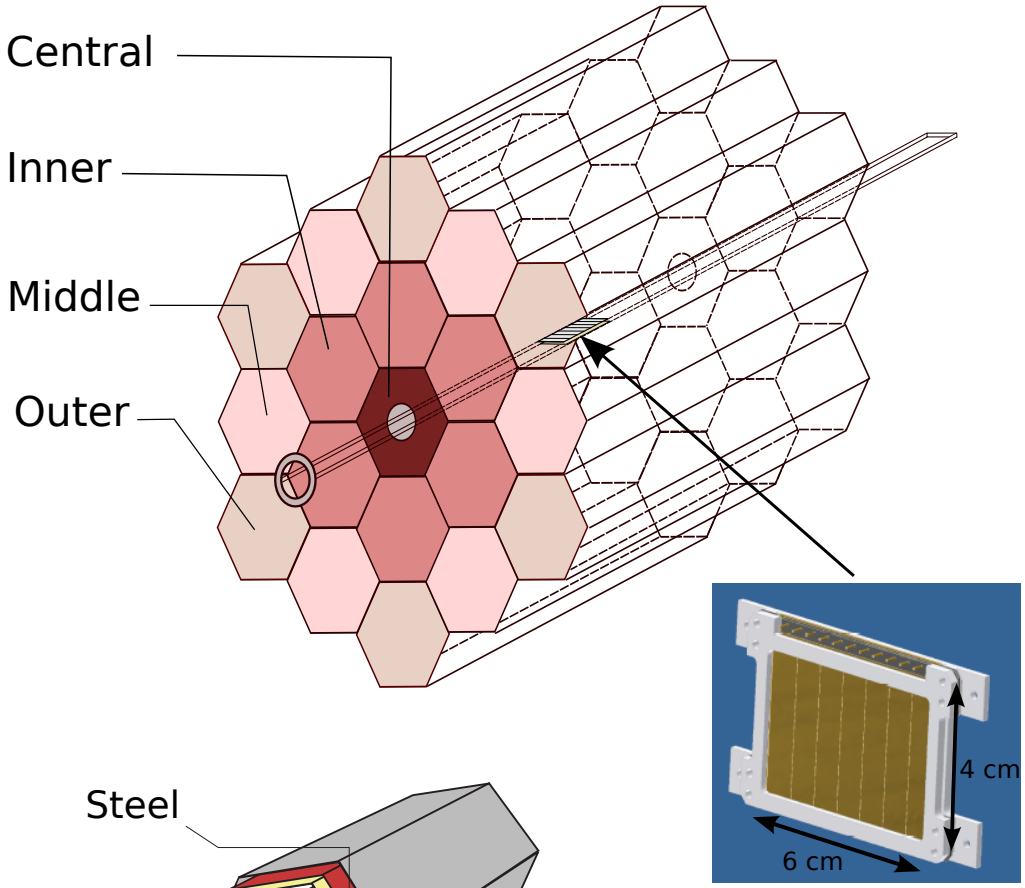
Experimental setup

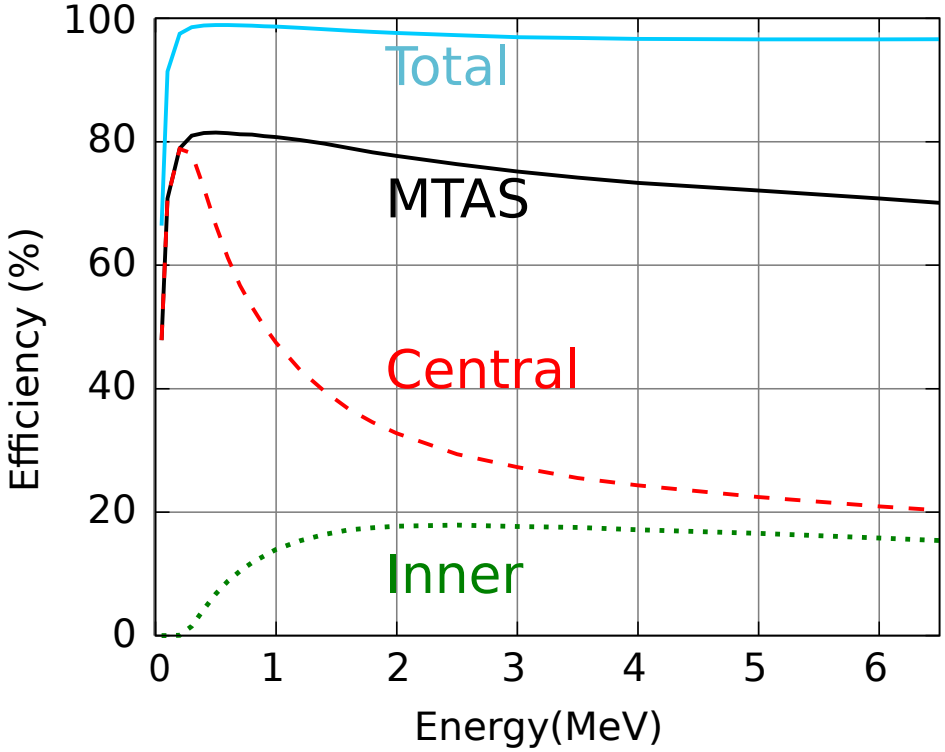
The experimental set-up consisted of the Modular Total Absorption Spectrometer (MTAS) coupled to the OnLine Test Facility (OLTF) at the Tandem accelerator of the Holifield Radioactive Ion Beam Facility (HRIBF) at ORNL.

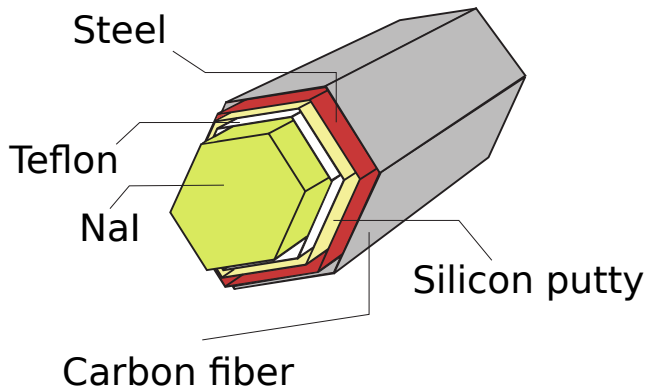


January 2012:
^{86}Br, ^{89}Kr, ^{89}Rb, ^{90}Kr, ^{90m}Rb, ^{90gs}Rb, ^{139}Xe
March 2015:
^{86}Br, ^{90m}Rb, ^{90gs}Rb, ^{92}Rb

Modular Total Absorption Spectrometer

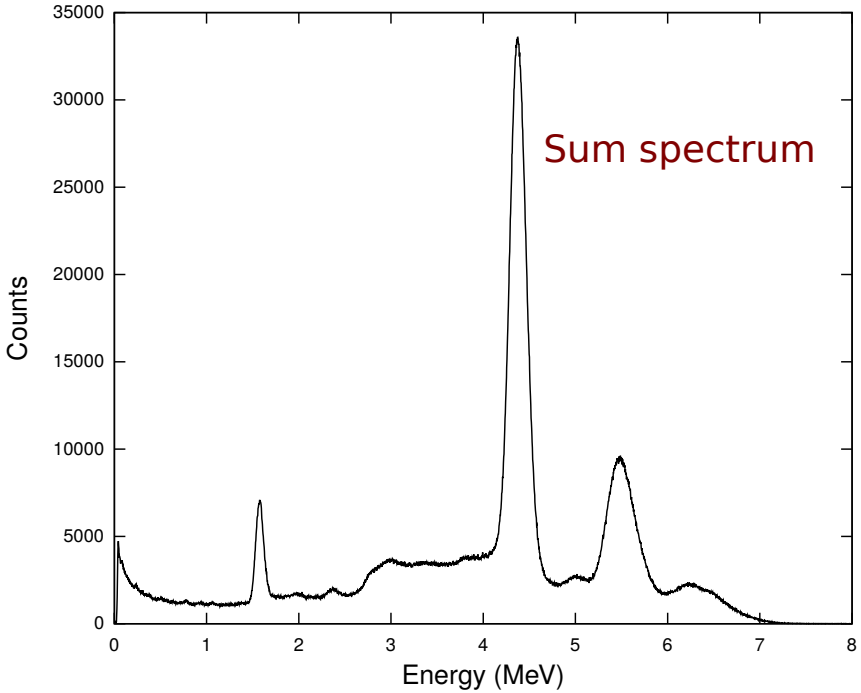


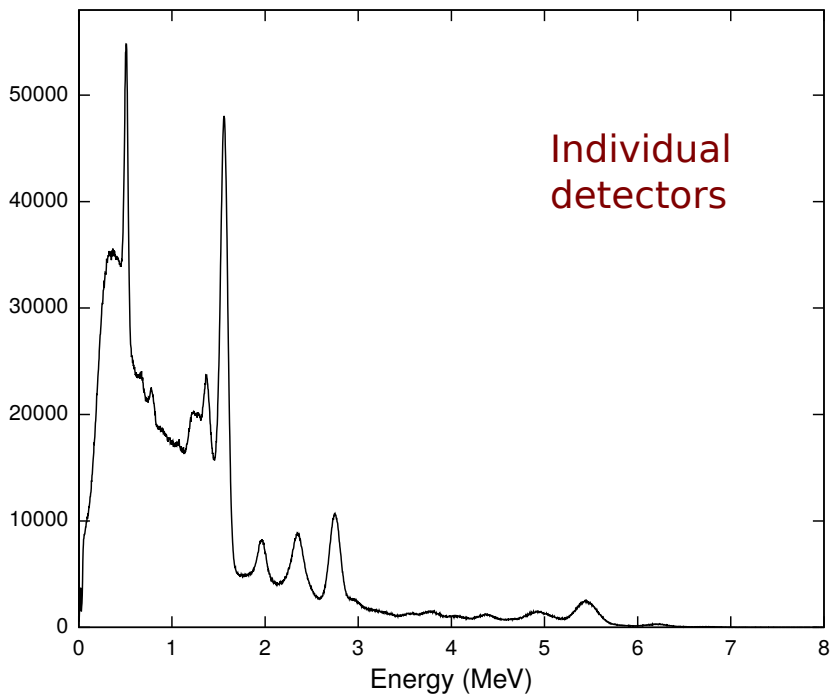


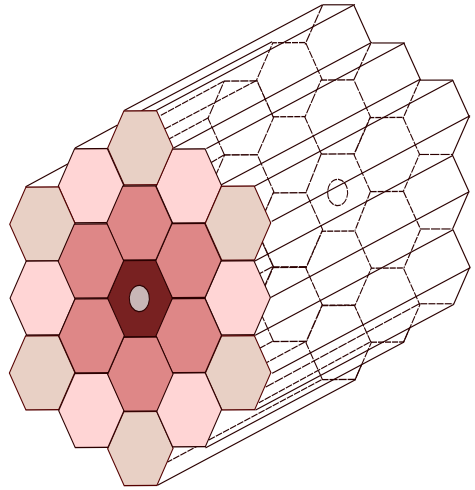


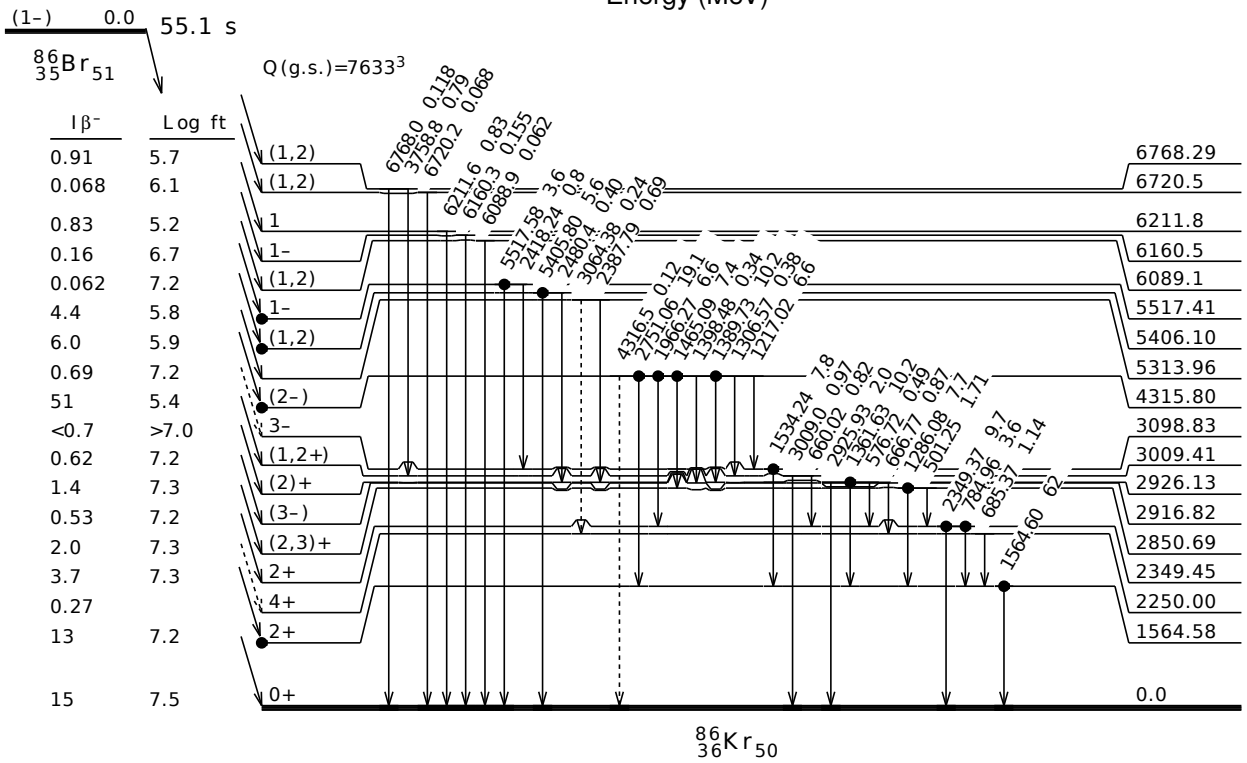
MTAS detector consists of 19 hexagonal modules 21” long and approximately 7” side-to-side placed in a honeycomb like structure.

Experimental spectrum, ^{86}Br

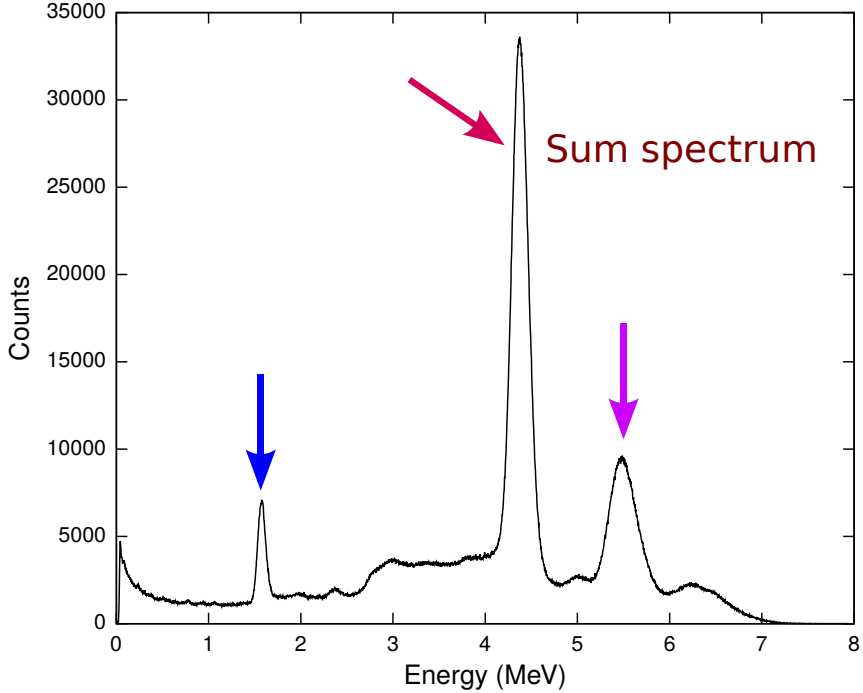


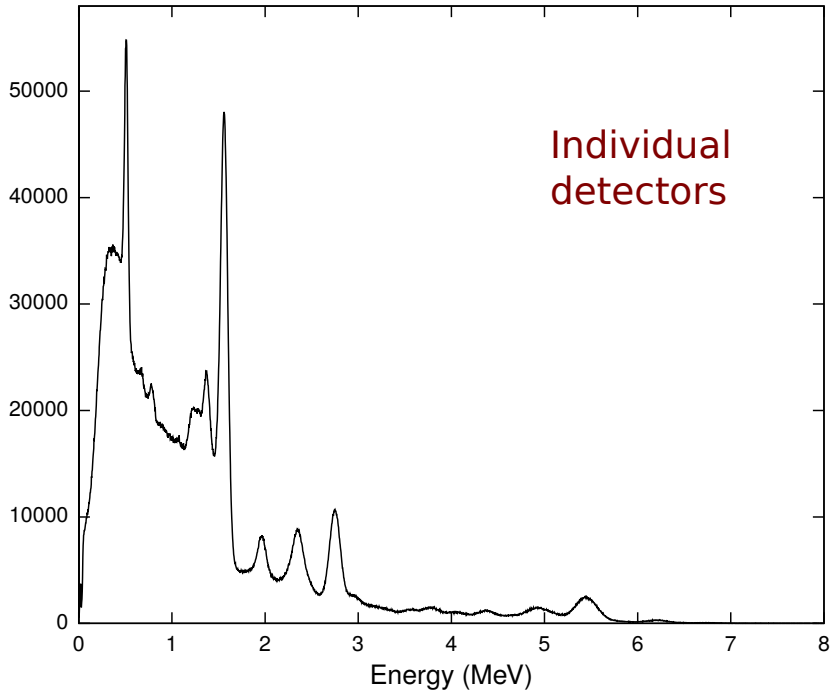


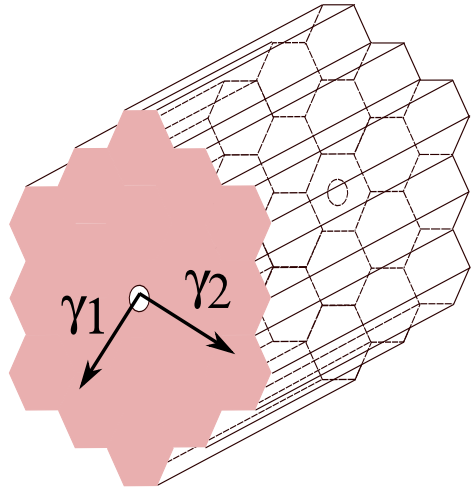


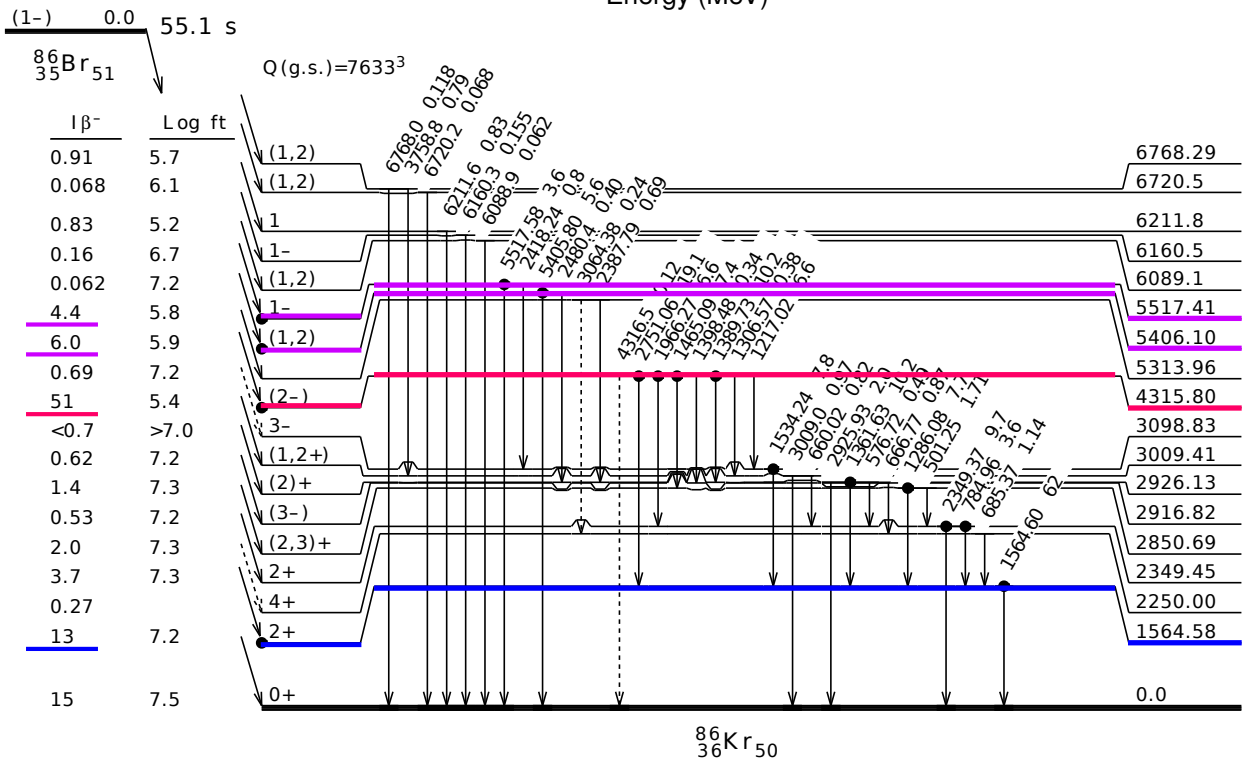


Experimental spectrum, ^{86}Br









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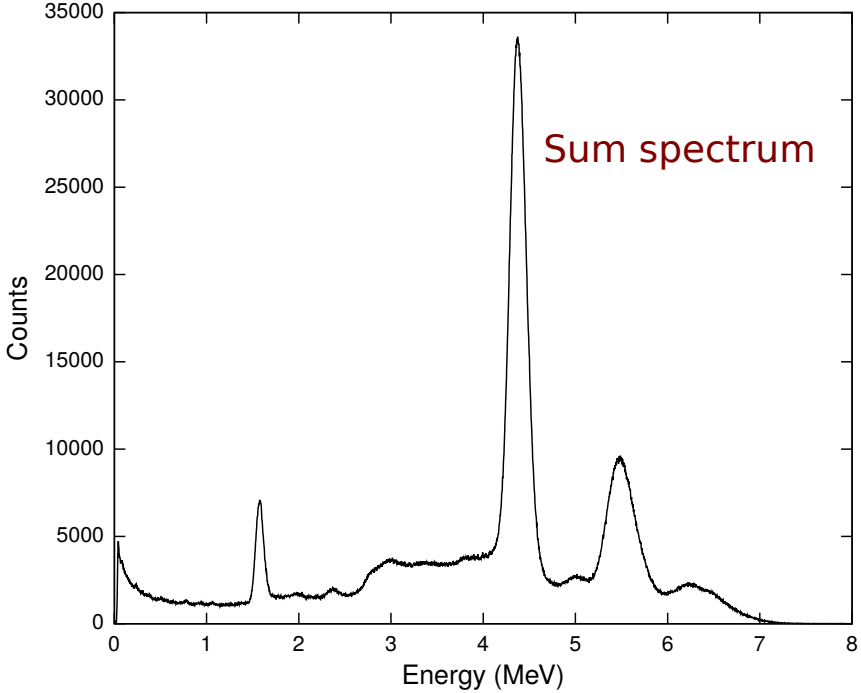
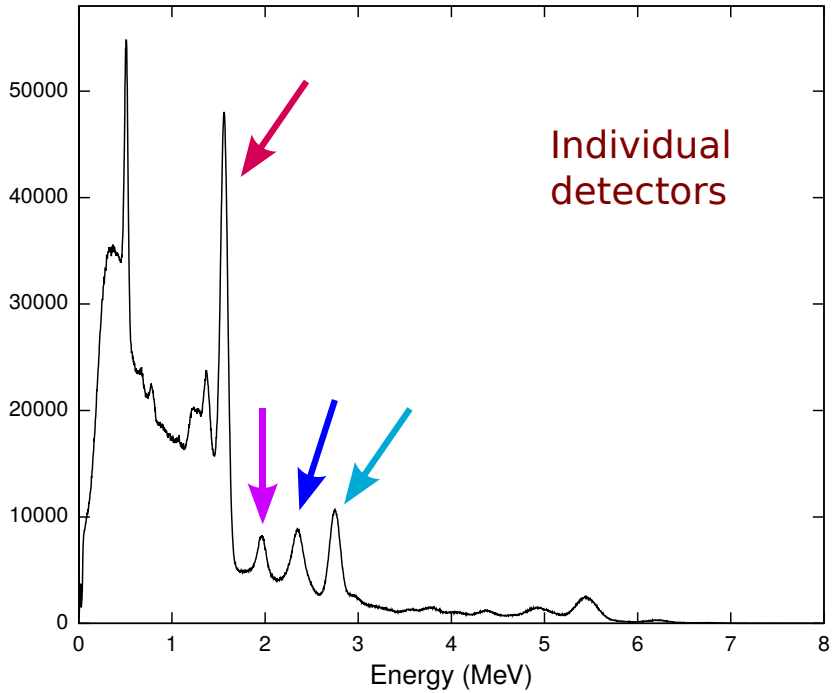
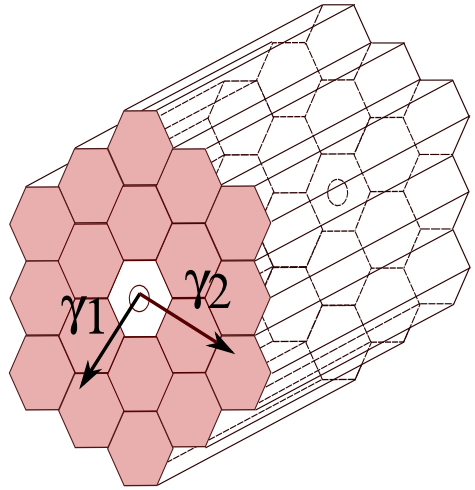
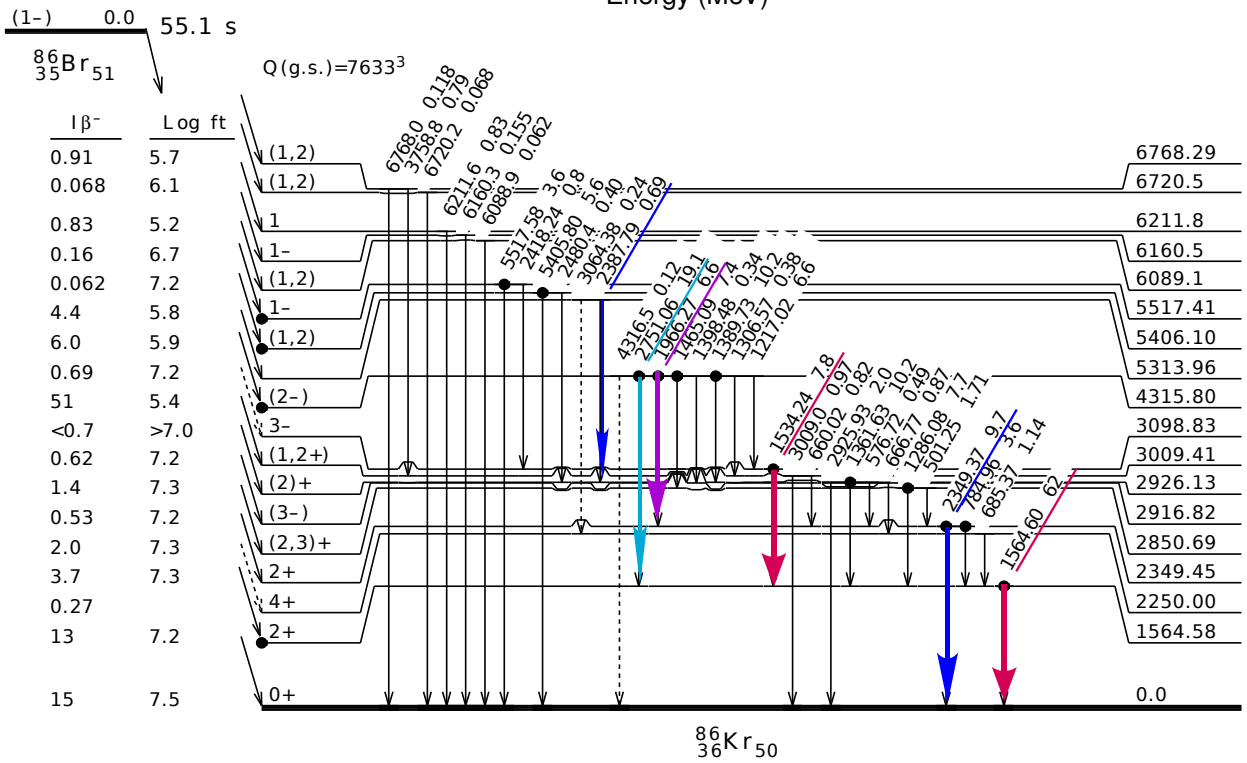




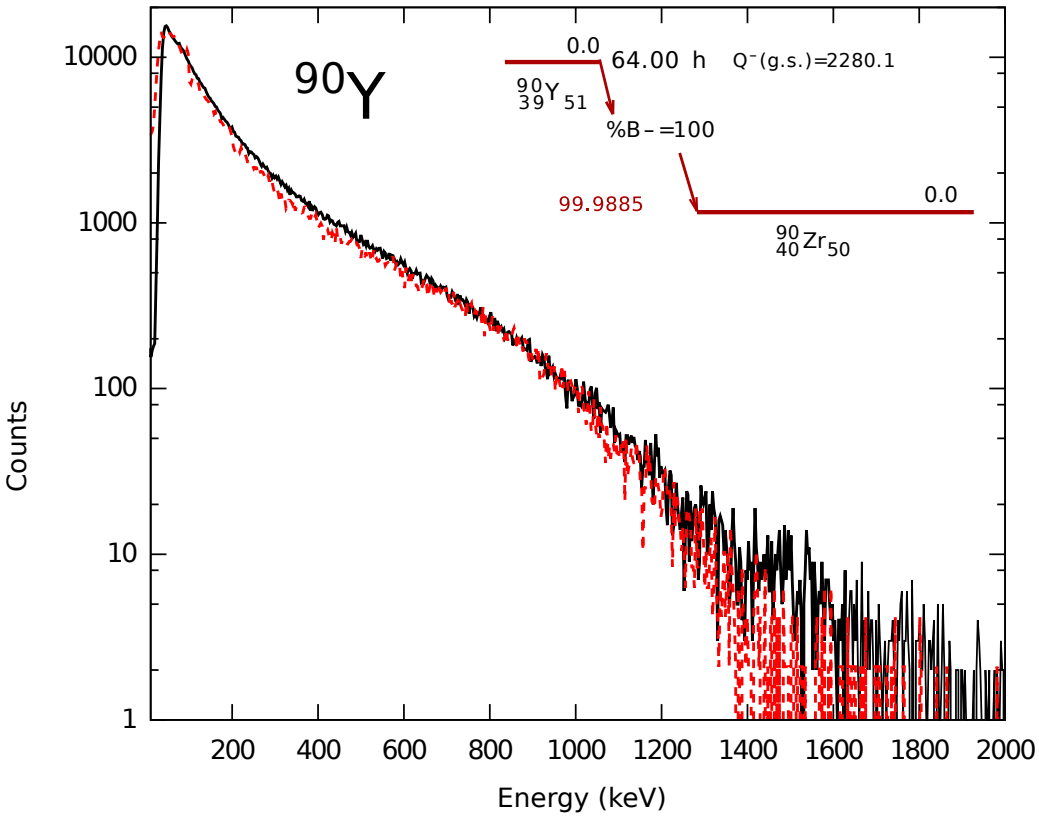


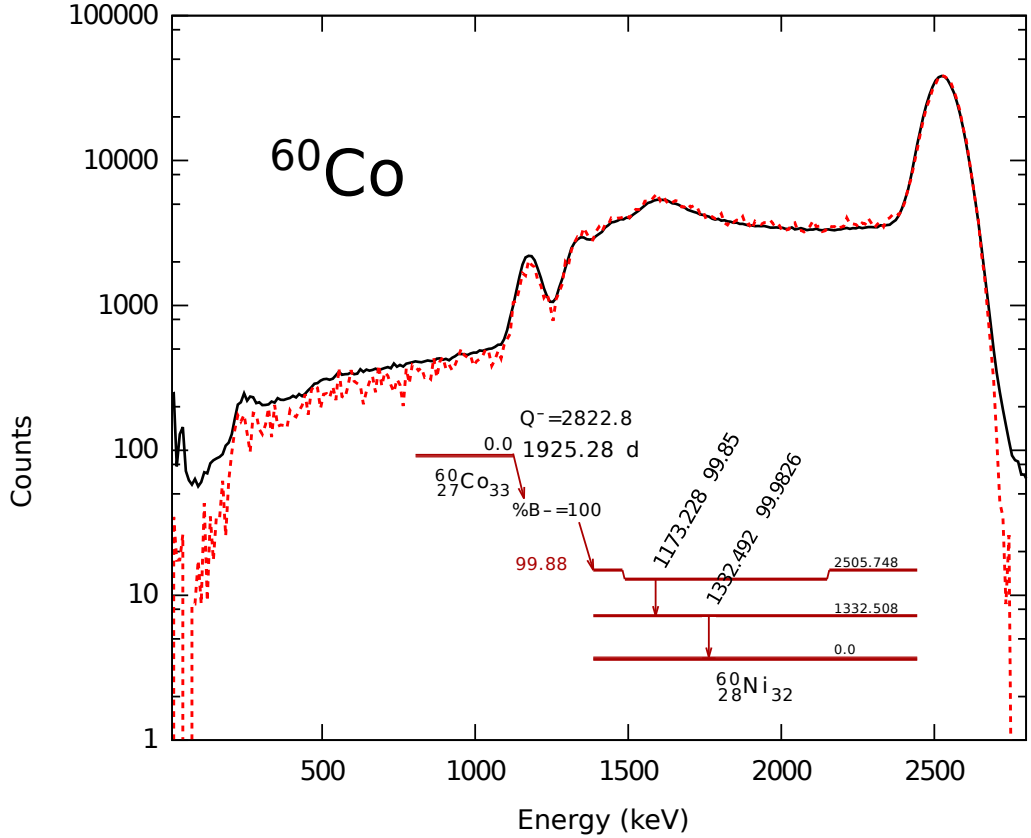


Simulation

Geant4 Simulation:
Over 200 volumes and more than 15 types of materials were developed including:
NaI(Tl) crystals with 4 layers housing, silicon strip detectors with cables, tape, ladder for tape and silicon detectors.

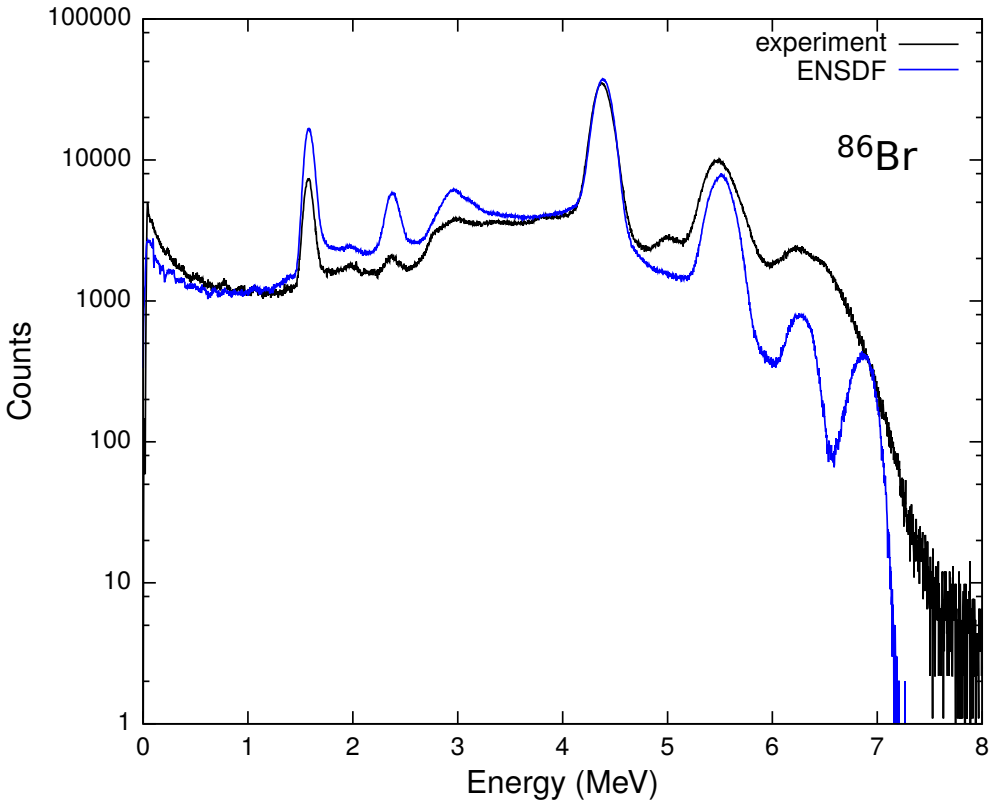
The simulations include the MTAS response for mono-energetic γ and β particles as well as for radioactive decay and pile-up events

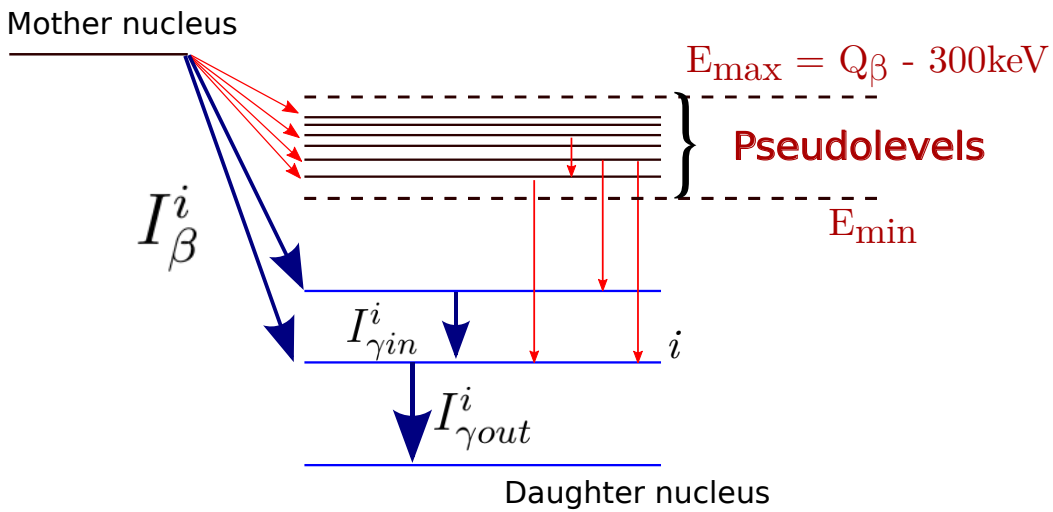




Analysis

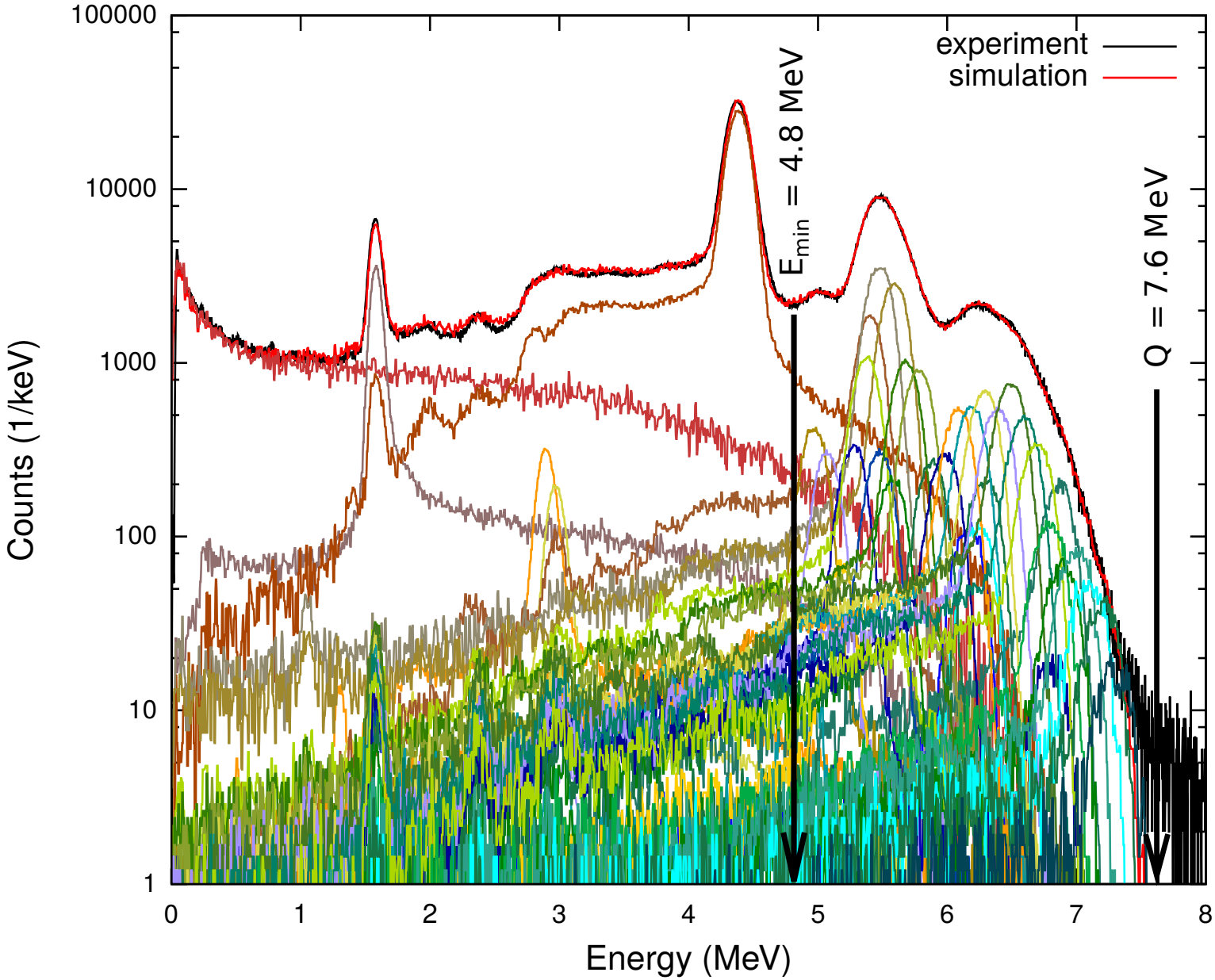
$$\mathbf{R} = \sum_{i=1}^{K} I_\beta^i \mathbf{r}_i$$



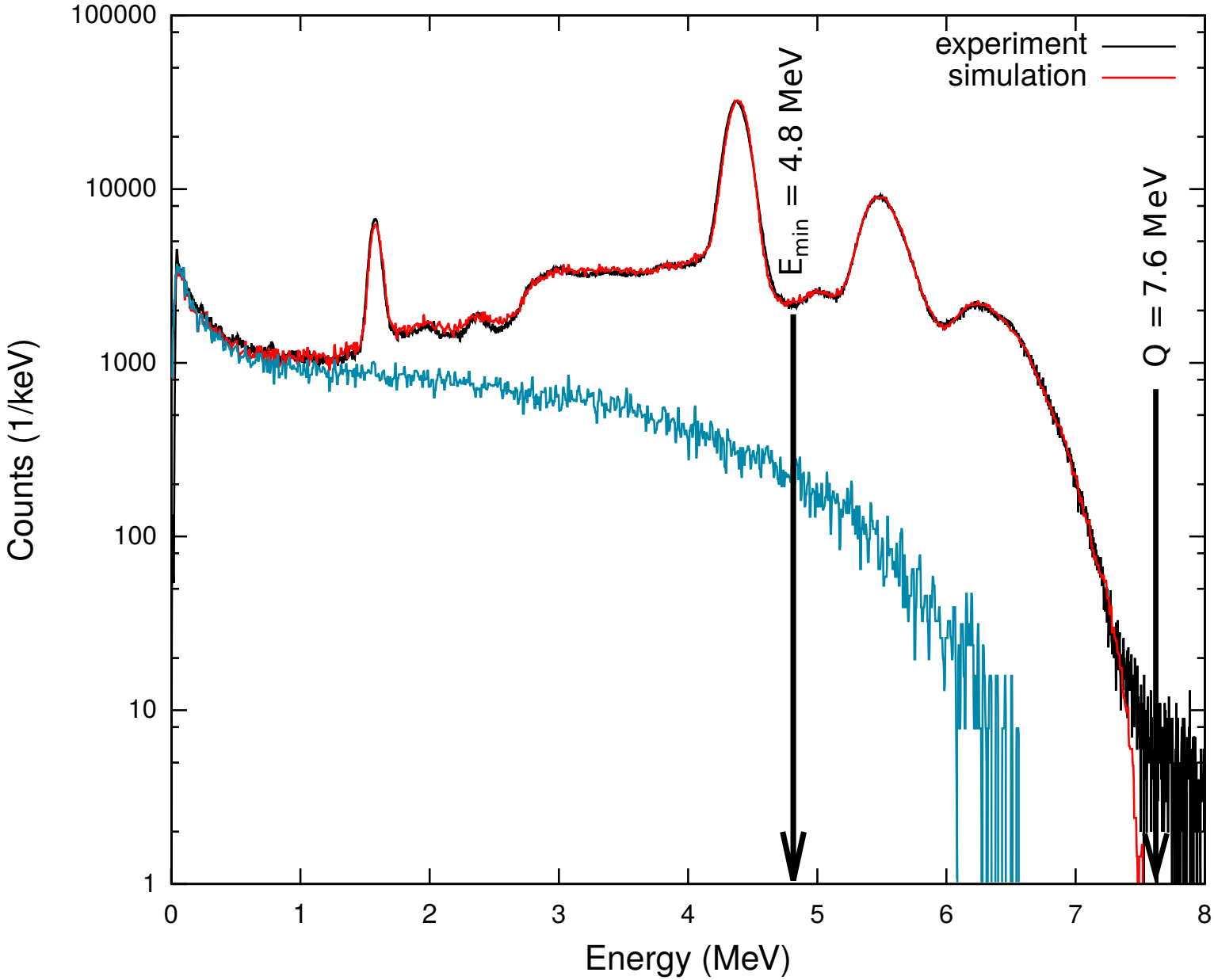


Pseudo-levels assumptions:
- levels added from E_{min} to $E_{max} = Q_\beta$ - 300keV every 100 keV
- Gamow–Teller transitions
- level density formula: A. Gilbert and W. Cameron. A composite nulcear-level density formula with shell corrections
- pseudolevels deexcite to "known" levels, only E1, E2, M1 and M2 transitions

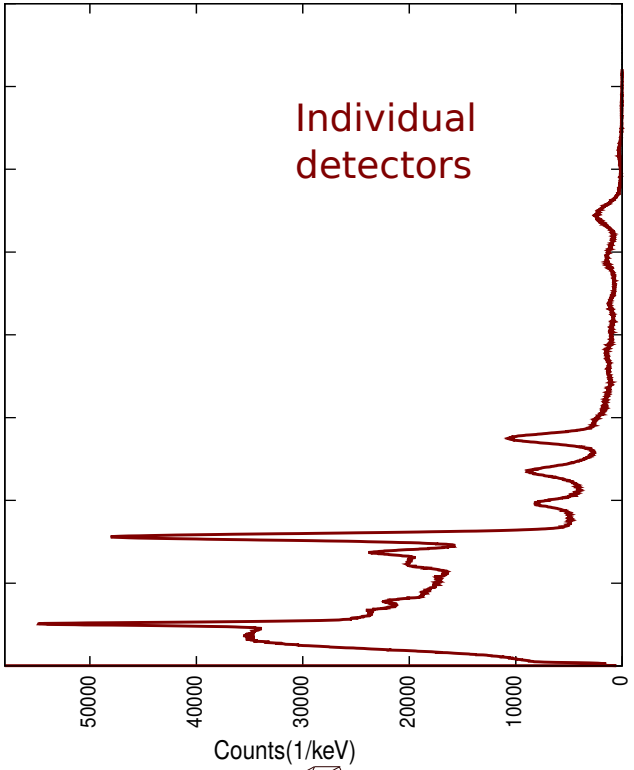
Analysis

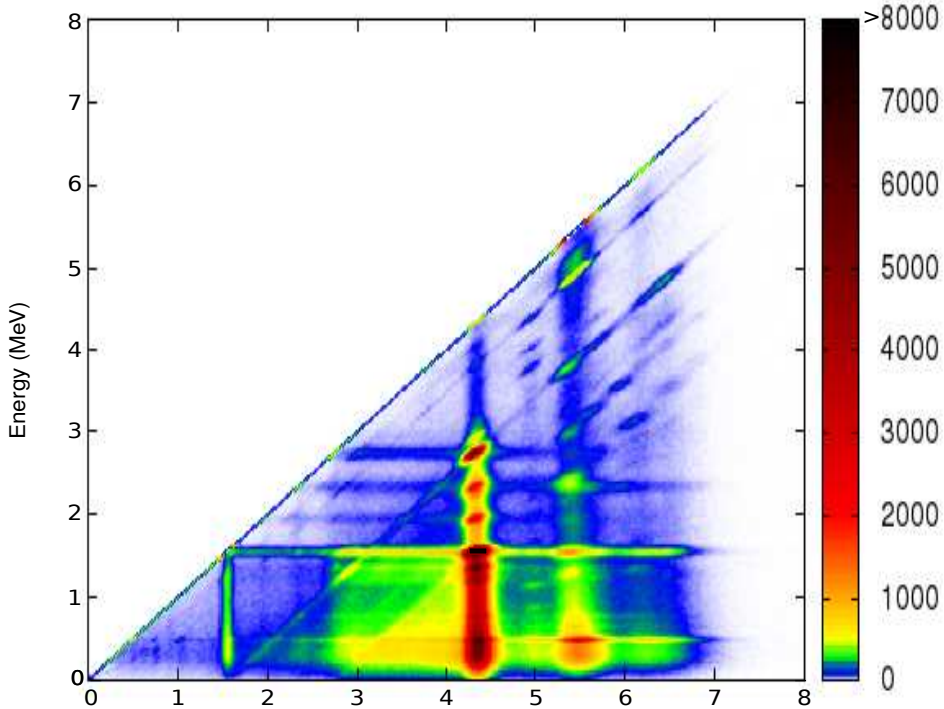

experiment
simulation
E_{min} = 4.8 MeV
Q = 7.6 MeV
Counts (1/keV)
Energy (MeV)
100000
10000
1000
100
10
1
0
1
2
3
4
5
6
7
8

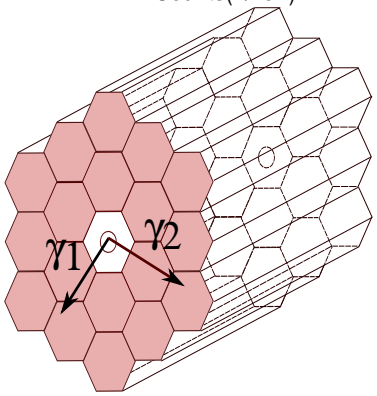
Ground state feeding

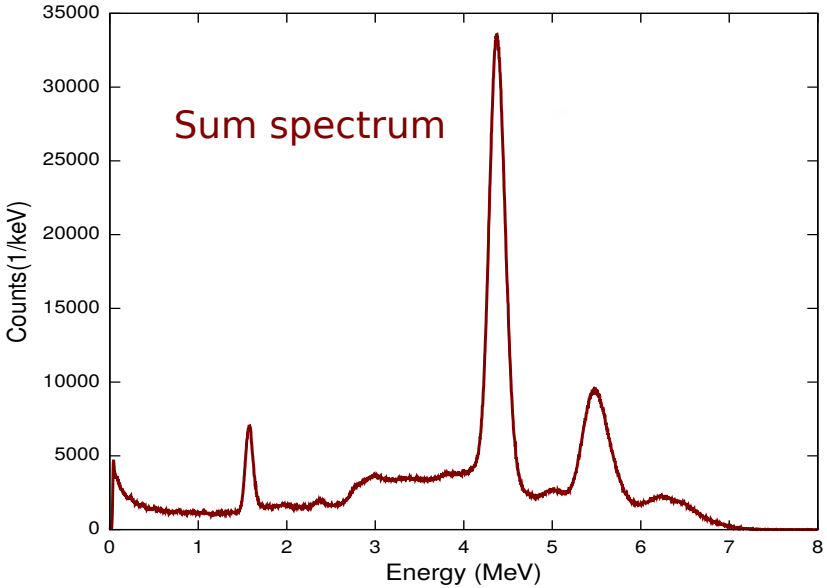


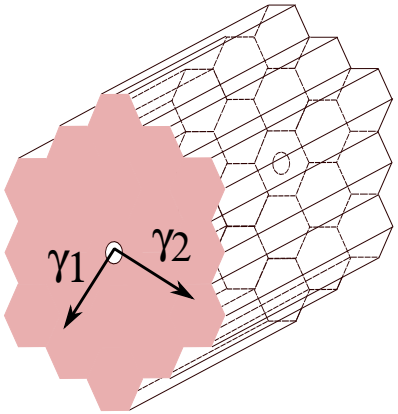
Analysis


Individual
detectors
Counts(1/keV)
50000
40000
30000
20000
10000
0

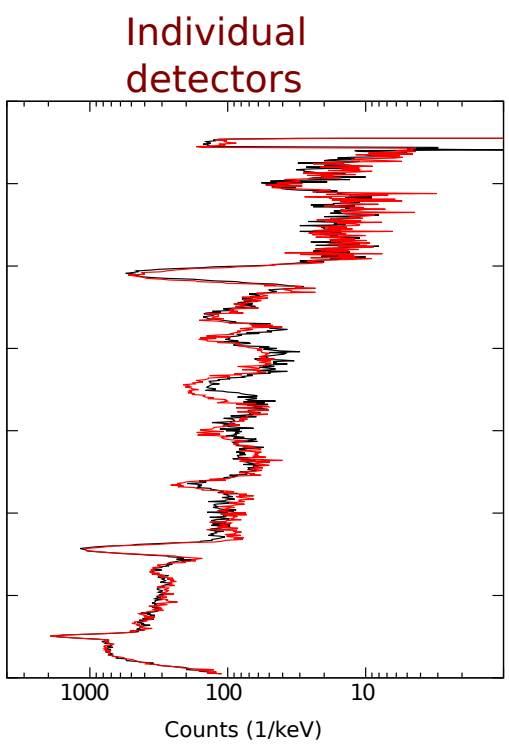

Energy (MeV)
0
1
2
3
4
5
6
7
8
>8000
7000
6000
5000
4000
3000
2000
1000
0

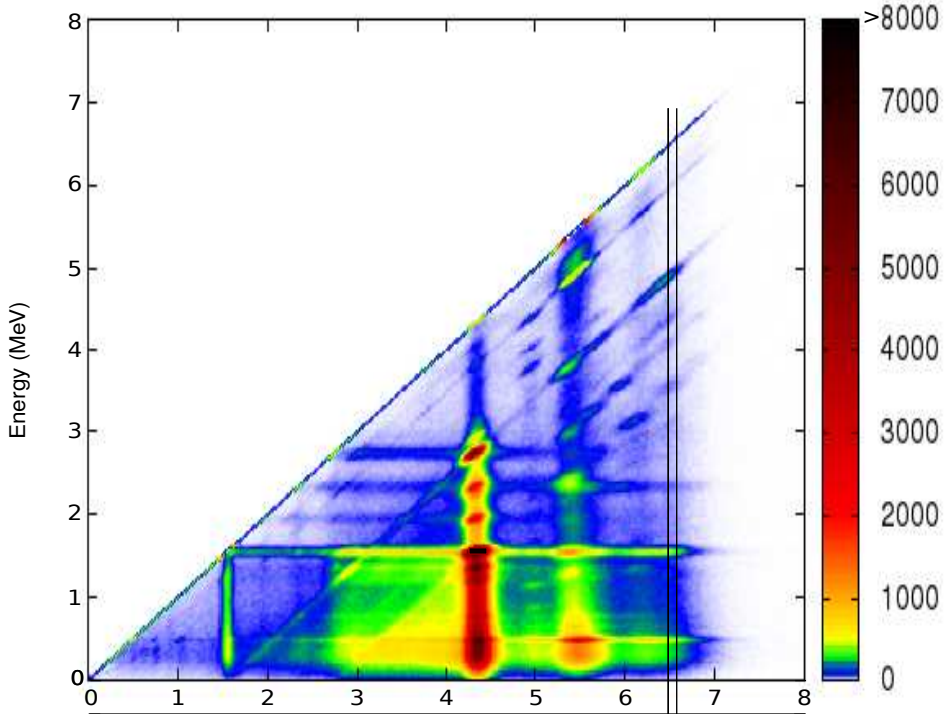

γ1
γ2

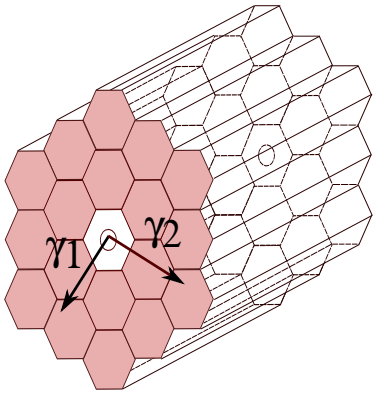

Sum spectrum
Counts(1/keV)
35000
30000
25000
20000
15000
10000
5000
0
Energy (MeV)
0
1
2
3
4
5
6
7
8

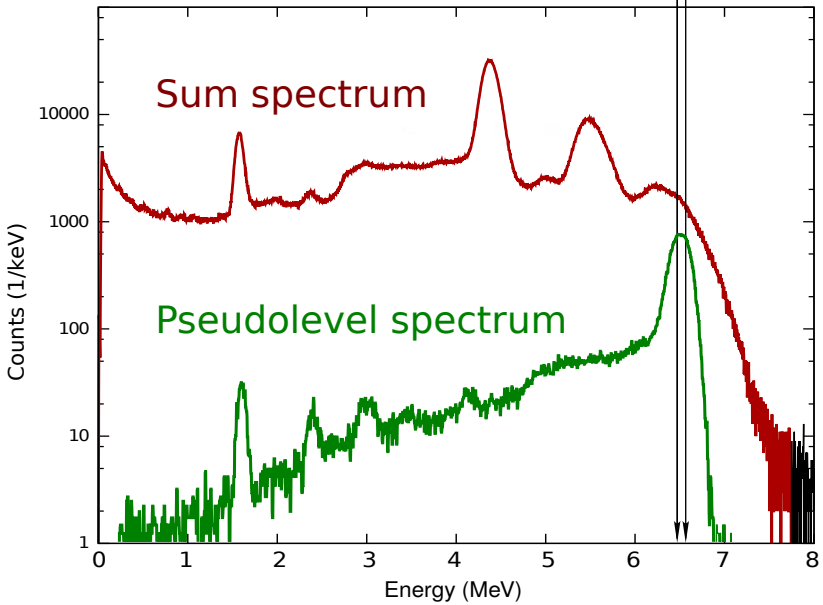

γ1
γ2

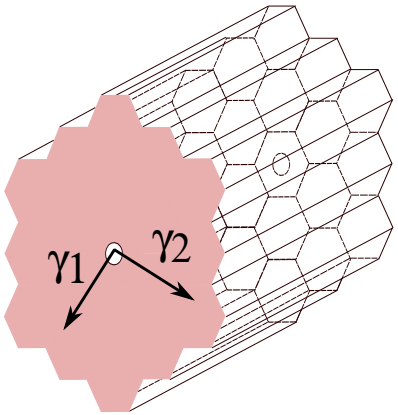
Analysis


Individual detectors
1000
100
10
Counts (1/keV)


Energy (MeV)
0
1
2
3
4
5
6
7
8
>8000
7000
6000
5000
4000
3000
2000
1000
0


γ1
γ2

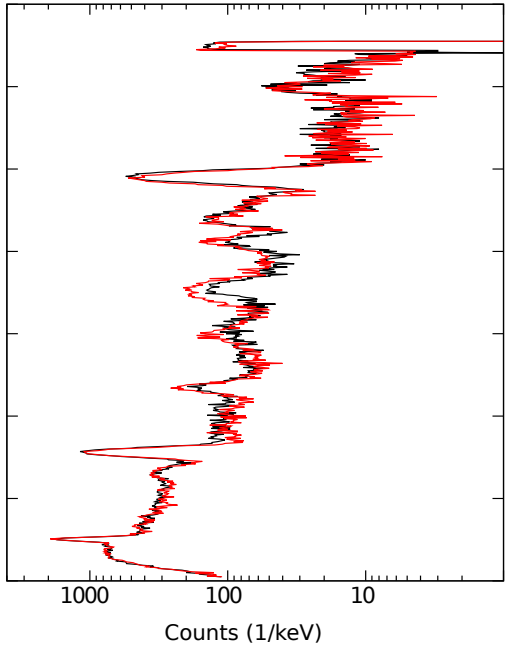

Sum spectrum
Pseudolevel spectrum
Counts (1/keV)
10000
1000
100
10
1
0
1
2
3
4
5
6
7
8
Energy (MeV)

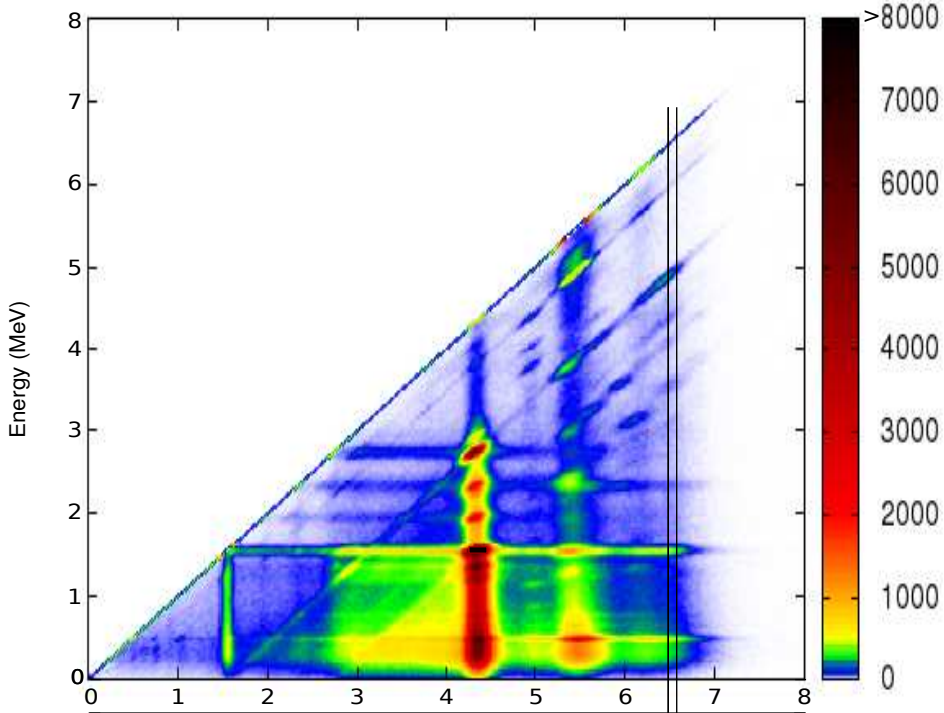

γ1
γ2

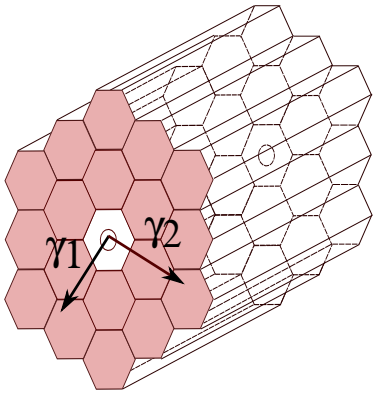
Analysis

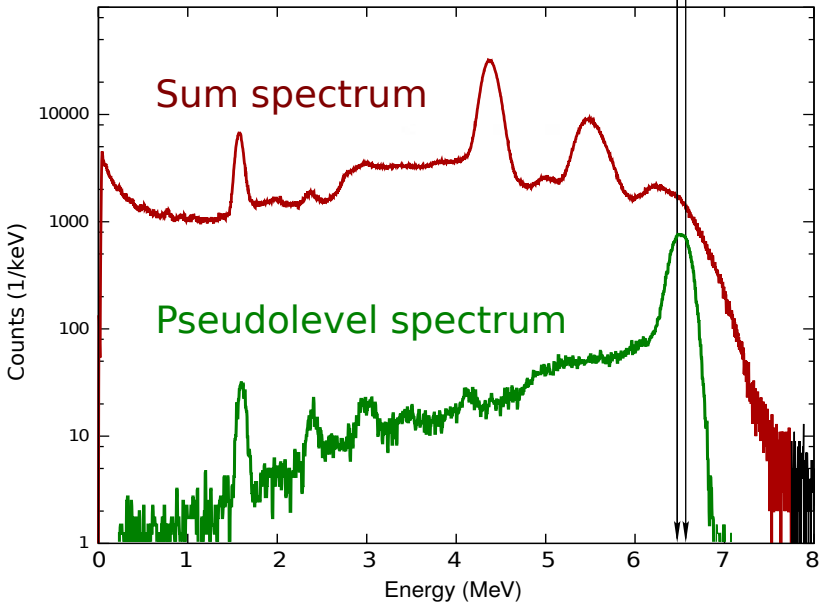
Checking pseudolevel deexcitation assumptions!!!

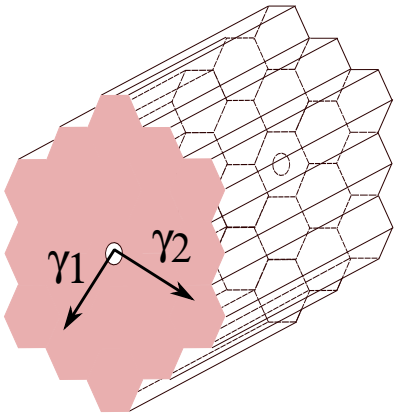
Individual detectors



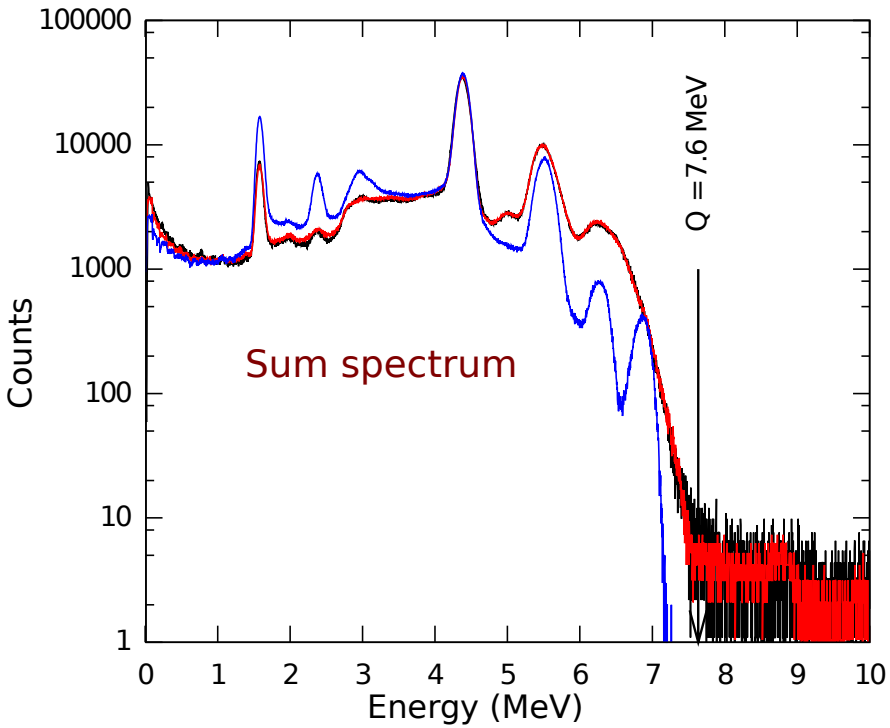


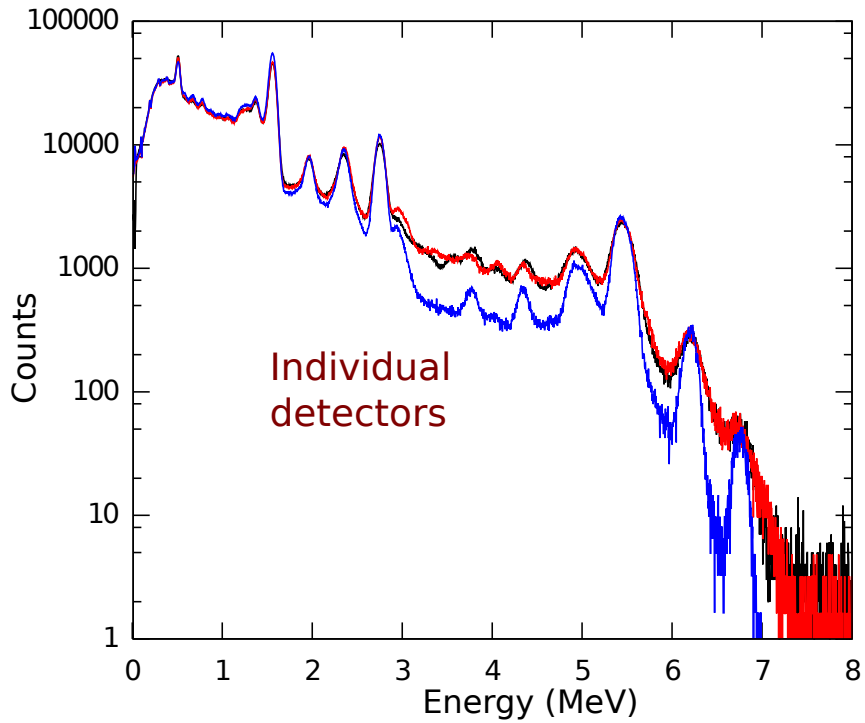




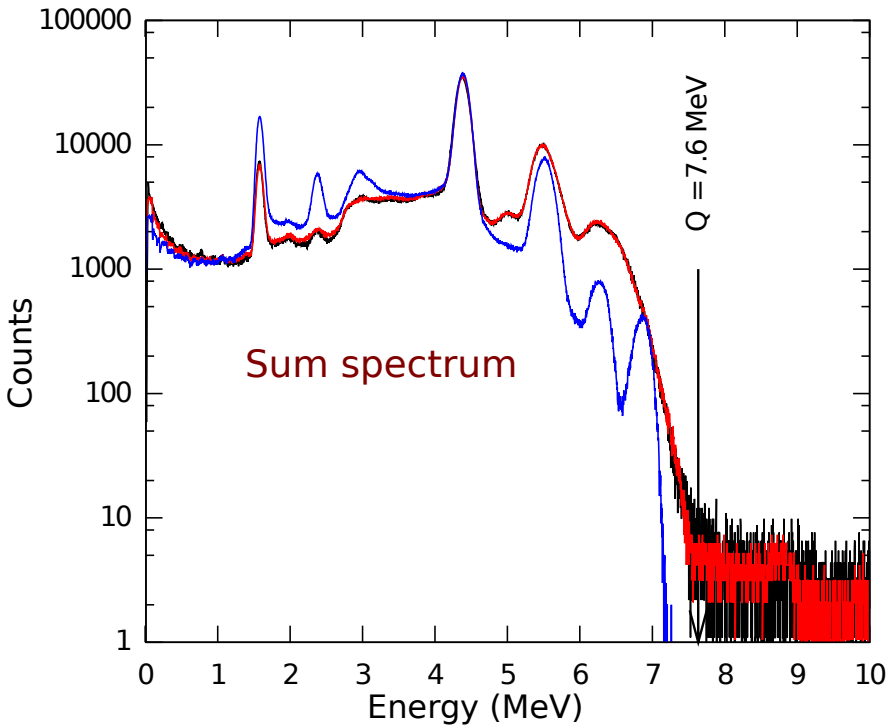


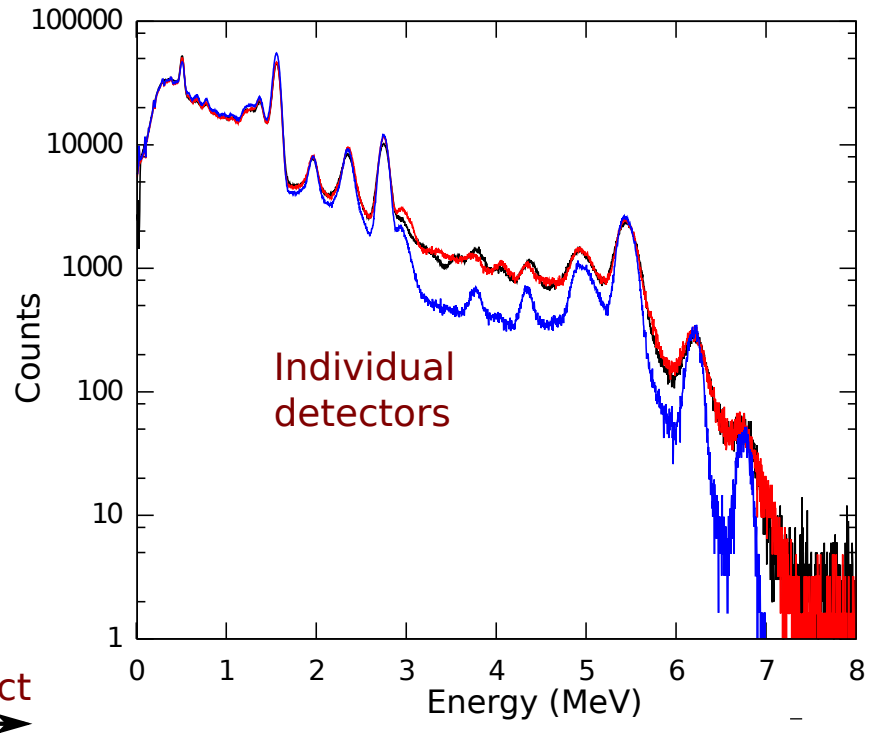
Results, ^{86}Br



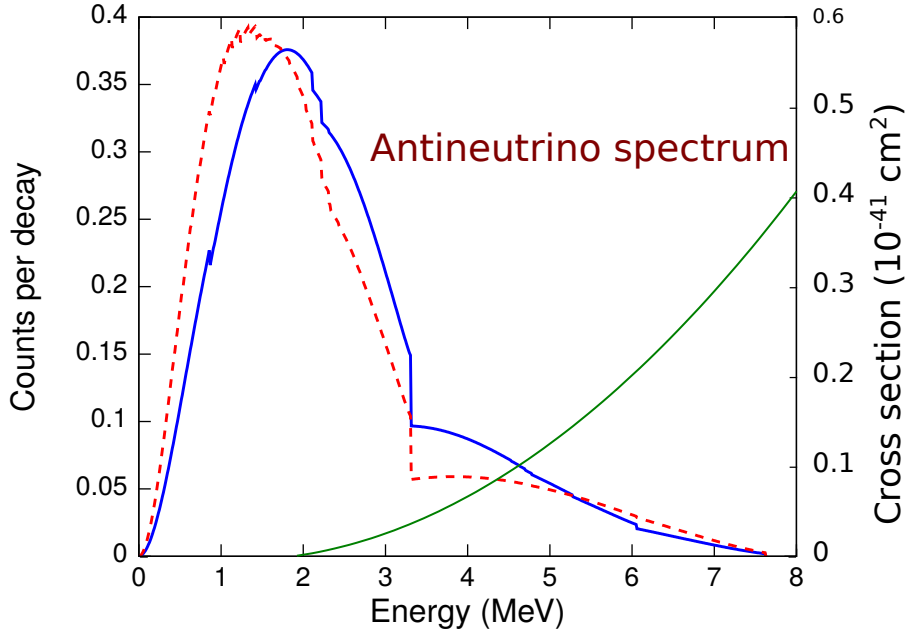


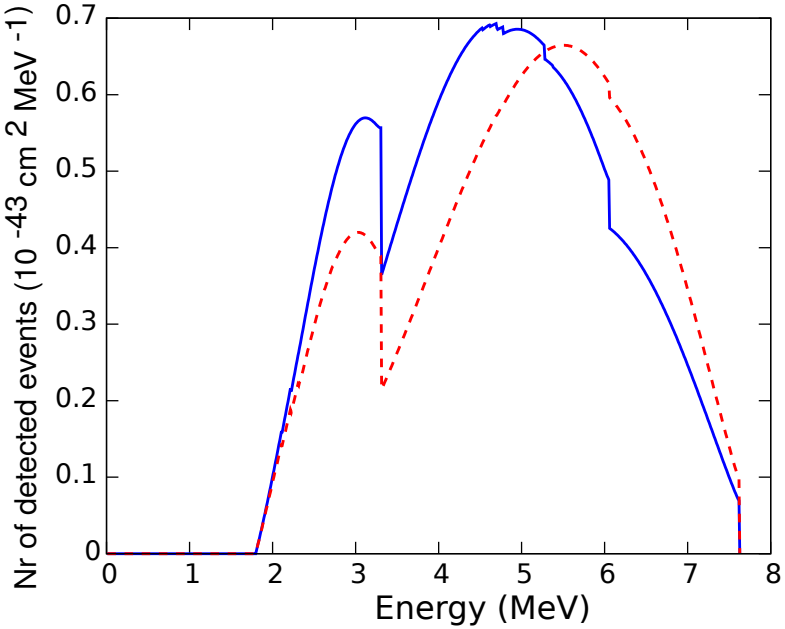
Results, ^{86}Br





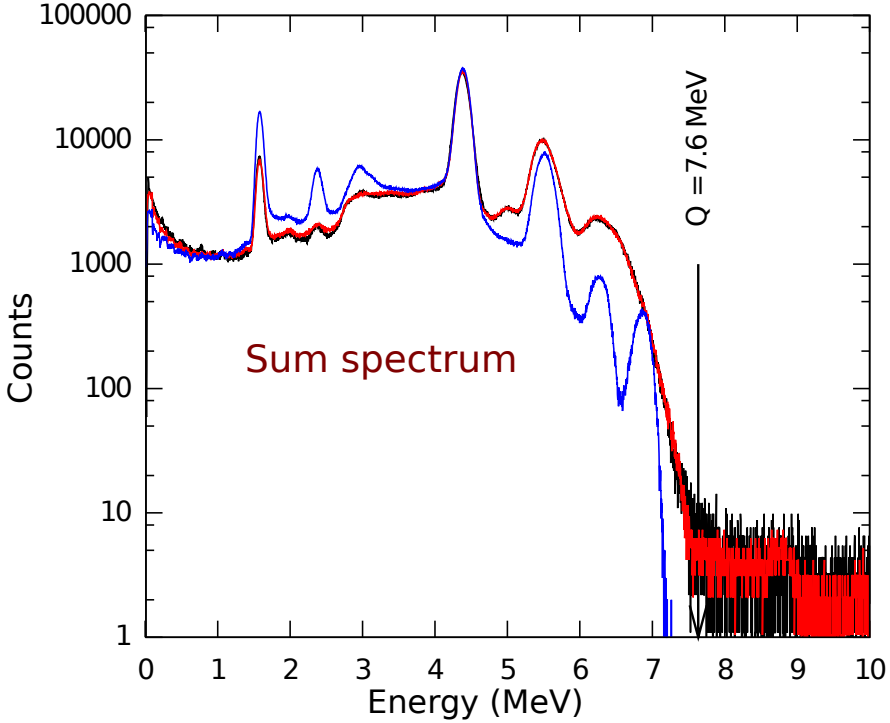
product

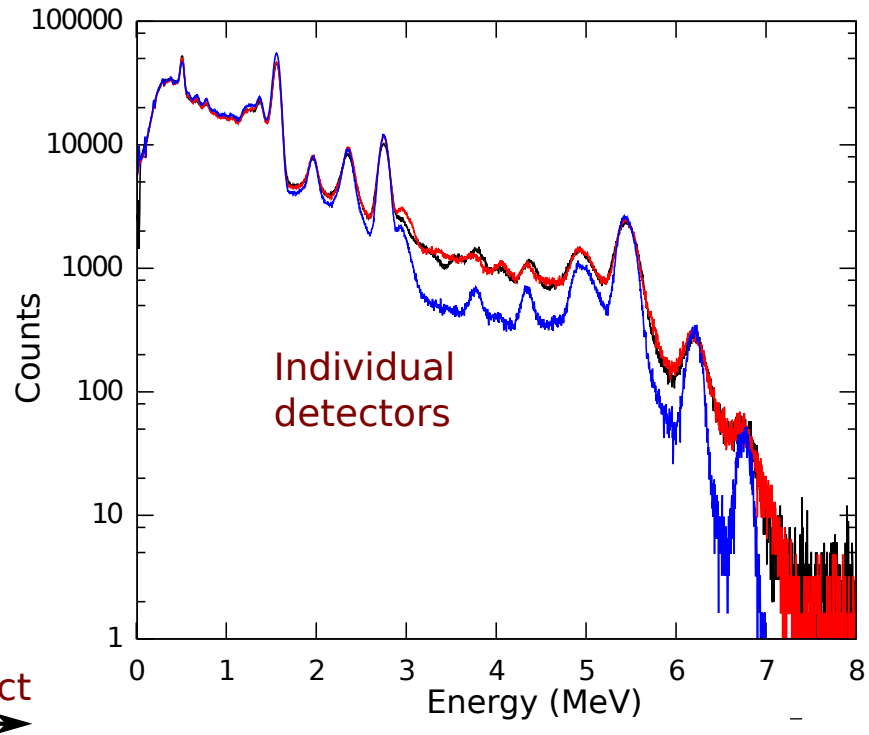




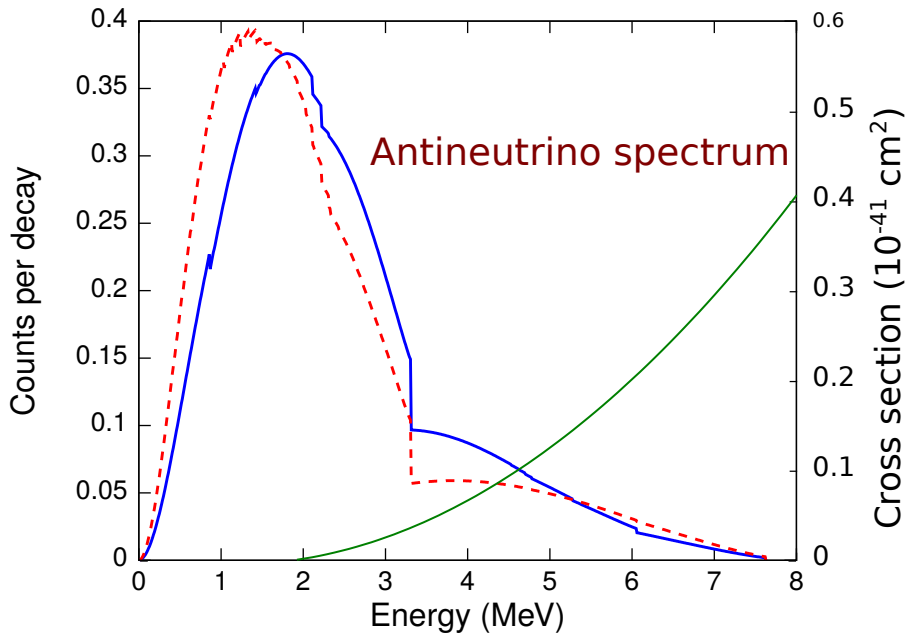
Results, ^{86}Br

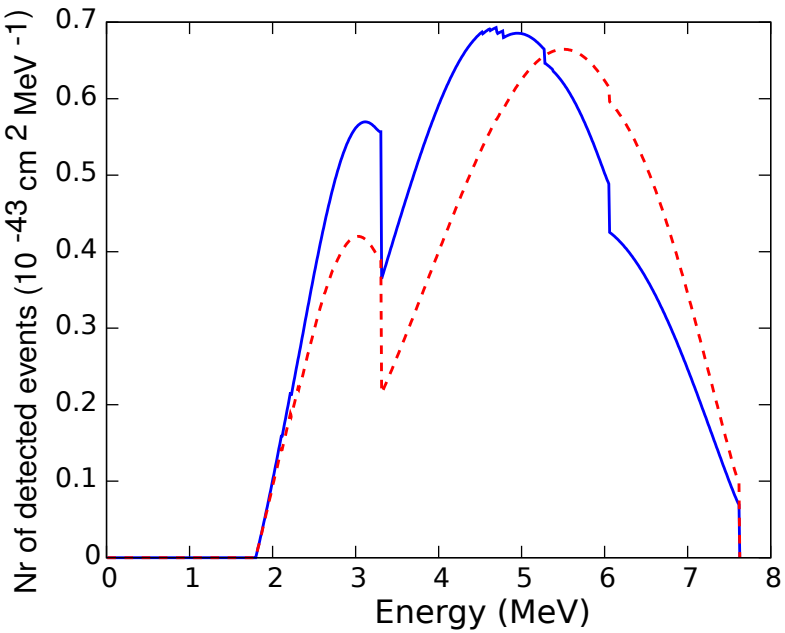
Eγ: from 3340(220) to 3717(83) keV (+11%)
Eβ: from 1900(300) to 1726(28) keV (-9%)
number of antineutrino interactions:
from 2,62(75) to 2,46(5) $\cdot 10^{-43}$ cm^2 (-6,5%)



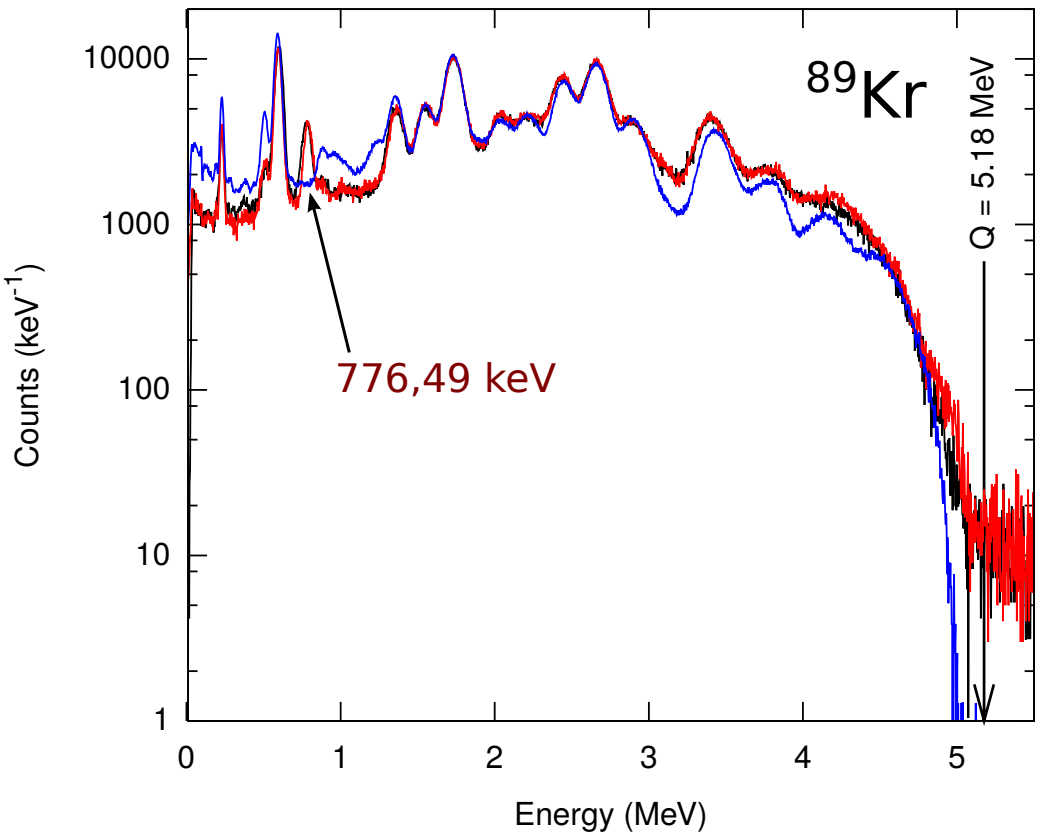


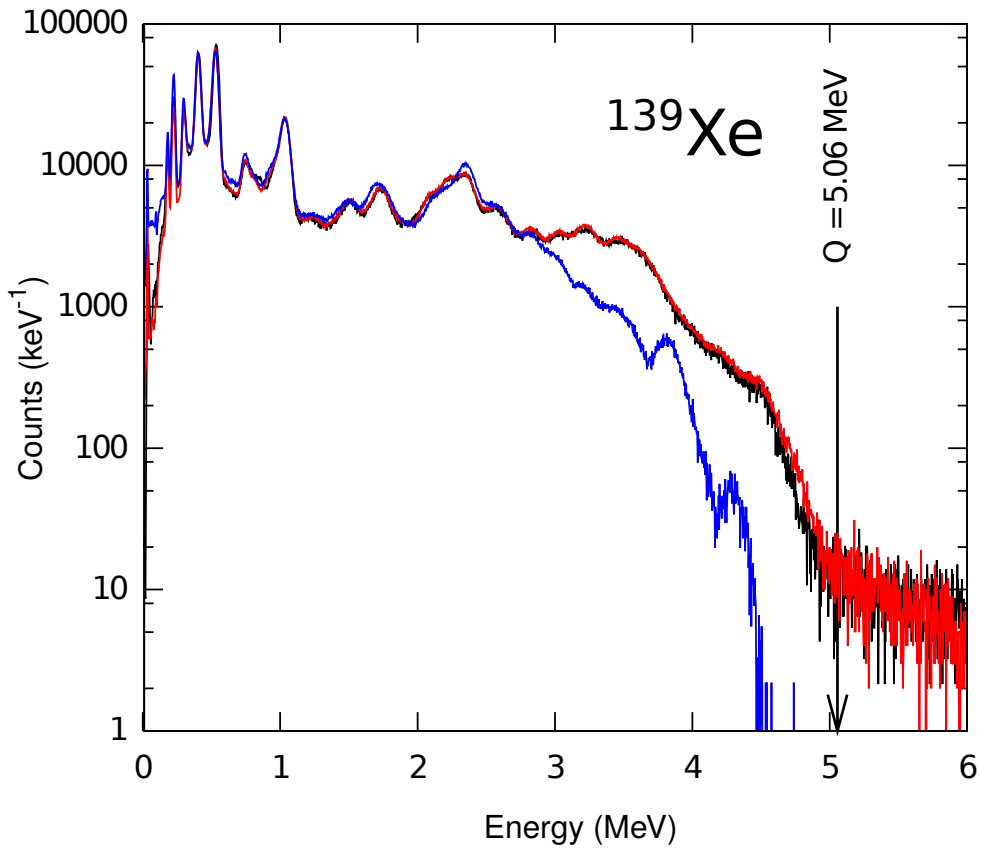
product





Results





Eγ: 1801(48) -> 2236(75) keV (+24%)
Eβ: 1460(100) -> 1254(35) keV (-14%)
number of antineutrino interactions:
1,17(13) -> 0,77(4) $\cdot 10^{-43}$ cm^2 (-35%)

Eγ: 935(59) -> 1343(31) keV (+31%)
Eβ: 1776(216) -> 1584(25) keV (-12 %)
number of antineutrino interactions:
1,87(29) -> 1,47(3) $\cdot 10^{-43}$ cm^2 (-21%)

All results

ENDF/B-VII.1

Izotope	$\sigma_{\overline{\nu}_e+p\rightarrow e^+ +n}$ $(10^{-43}\mathrm{cm}^2)$ ENSDF	MTAS	$\frac{\Delta_\sigma}{\sigma_{ENSDF}}$	$\frac{\Delta_\sigma}{\sigma_{ENSDF}} \cdot Y_{cum}$ (%) ^{235}U	^{238}U	^{239}Pu	^{241}Pu
^{86}Br	2,62(75)	2,450(55)	7%	0,10	0,08	0,03	0,03
^{89}Kr	1,18(13)	0,775(36)	35%	1,55	0,92	0,50	0,38
^{89}Rb	0,416(26)	0,386(30)	7%	0,34	0,20	0,12	0,09
^{90gs}Rb	3,33(27)	2,980(80)	11%	0,47	0,29	0,14	0,12
^{90m}Rb	1,24(19)	0,57(15)	54%	0,65	0,27	0,38	0,22
^{90}Kr	0,685(76)	0,322(15)	53%	2,58	1,64	0,69	0,64
^{92}Rb	10,50(8)	10,16(11)	3 %	0,16	0,14	0,06	0,06
^{139}Xe	1,87(29)	1,475(26)	21%	1,06	1,12	0,65	1,04

All results

Izotope	$\sigma_{\overline{\nu}_e+p\rightarrow e^+ +n}$ $(10^{-43}\mathrm{cm}^2)$ ENSDF	MTAS	$\frac{\Delta_\sigma}{\sigma_{ENSDF}}$	$\frac{\Delta_\sigma}{\sigma_{ENSDF}} \cdot Y_{cum}$ (%) ^{235}U	^{238}U	^{239}Pu	^{241}Pu
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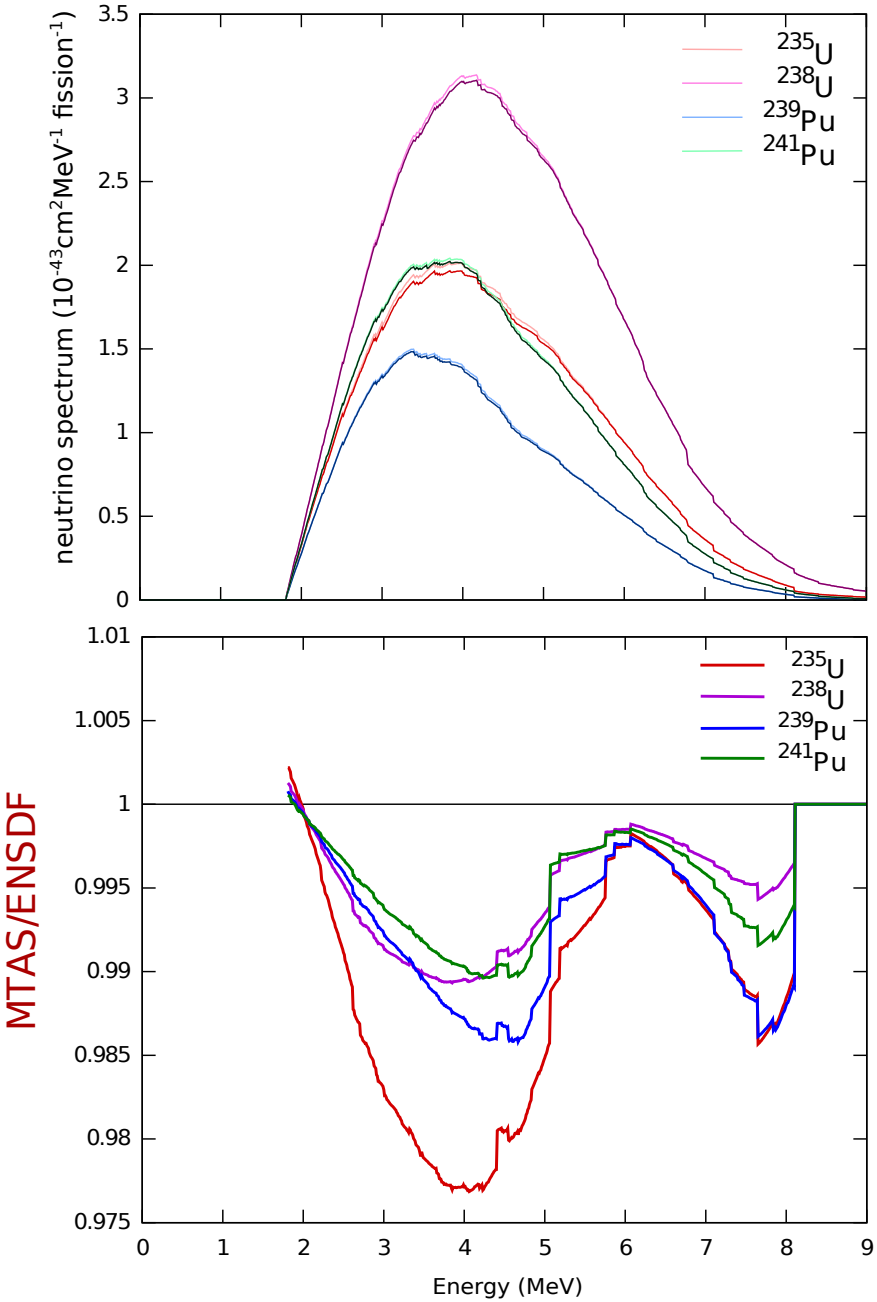
^{139}Xe	1,87(29)	1,475(26)	21%	1,06	1,12	0,65	1,04

Good agrement with TAGS results
R.C. Greenwood et al. NIM 390(1-2):95–154, 1997

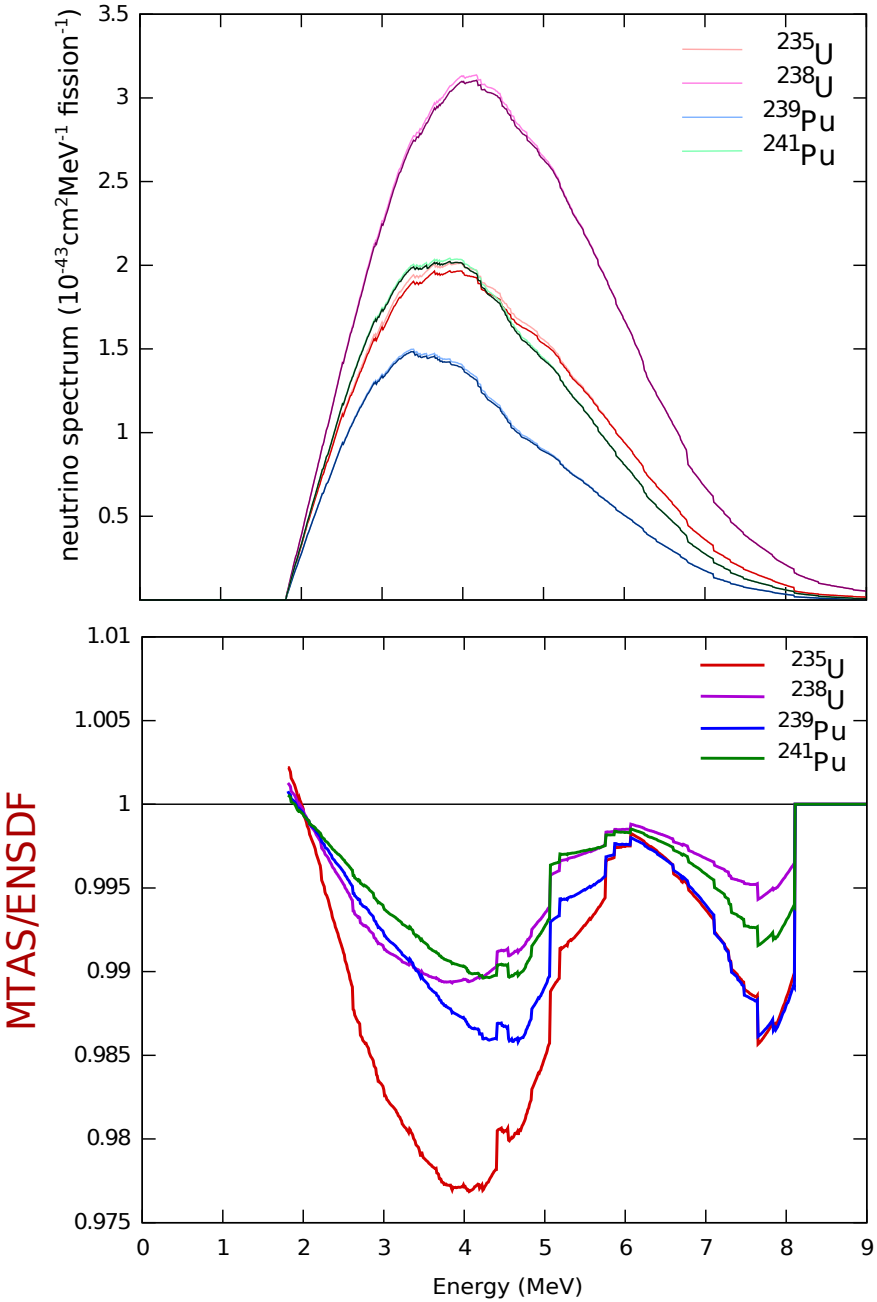
Reactor antineutrino



The relative change in the number of antineutrino interactions with matter:

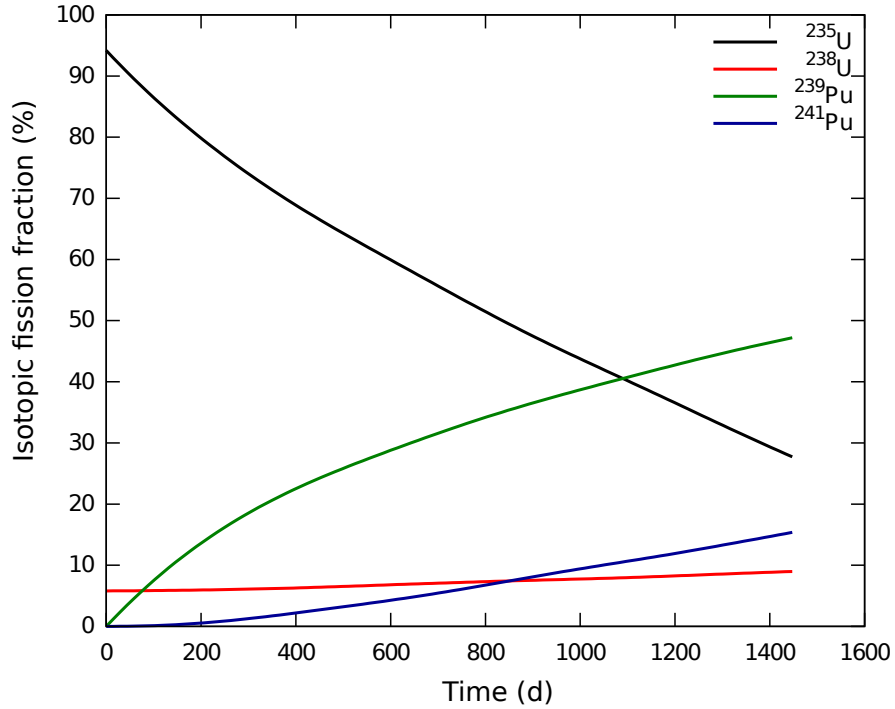
^{235}U	1,5%
^{238}U	0,7%
^{239}Pu	0,9%
^{241}Pu	0,6%

Reactor antineutrino



The relative change in the number of antineutrino interactions with matter:

^{235}U	1,5%	0 d	1,39%
^{238}U	0,7%	100 d	1,36%
^{239}Pu	0,9%	700 d	1,19%
^{241}Pu	0,6%	1400 d	1,00%



An example of PWR fuel composition. The starting enriched was 4.8% and power 38 MW.

Summary

8 important decays out of nearly 80 measured analyzed so far

A new method of data analysis which allows to obtain the information about pseudolevels deexcitation path has been performed

For all nuclides, with the exception of 89Rb, existing decay schemes have been modify, leading to the increase average γ energy, and decrease of average β and antineutrinos energy per decay

The average number of interactions reactor antineutrinos with matter has decreased by approx. 1%