This project has received funding from the HORIZON-EURATOM-2023-NRT-01-06 call under grant agreement No 101164596.

APRENDE

# Experiment: continuum range (GAINS@GELINA)

## Insights in the GAINS data analysis procedure

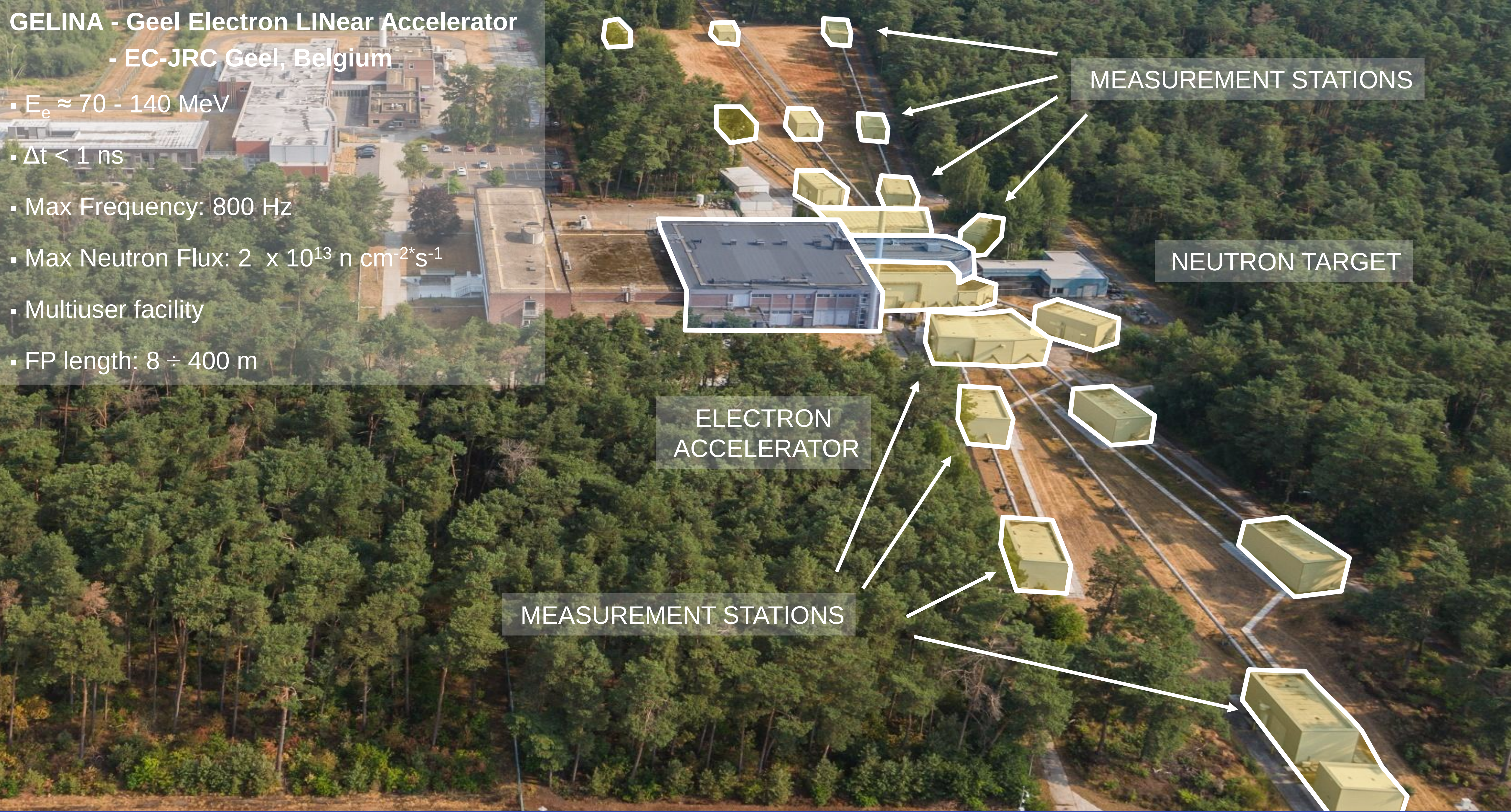
26 - 27/02/2025
APRENDE Experimentalists-Evaluators workshop (WP2-WP4)

Adina Coman, IFIN-HH

Funded by the European Union

## GELINA - Geel Electron LINear Accelerator
## - EC-JRC Geel, Belgium

- $E_e \approx 70 - 140$ MeV
- $\Delta t < 1$ ns
- Max Frequency: 800 Hz
- Max Neutron Flux: $2 \times 10^{13}$ n $cm^{-2*}s^{-1}$
- Multiuser facility
- FP length: 8 ÷ 400 m



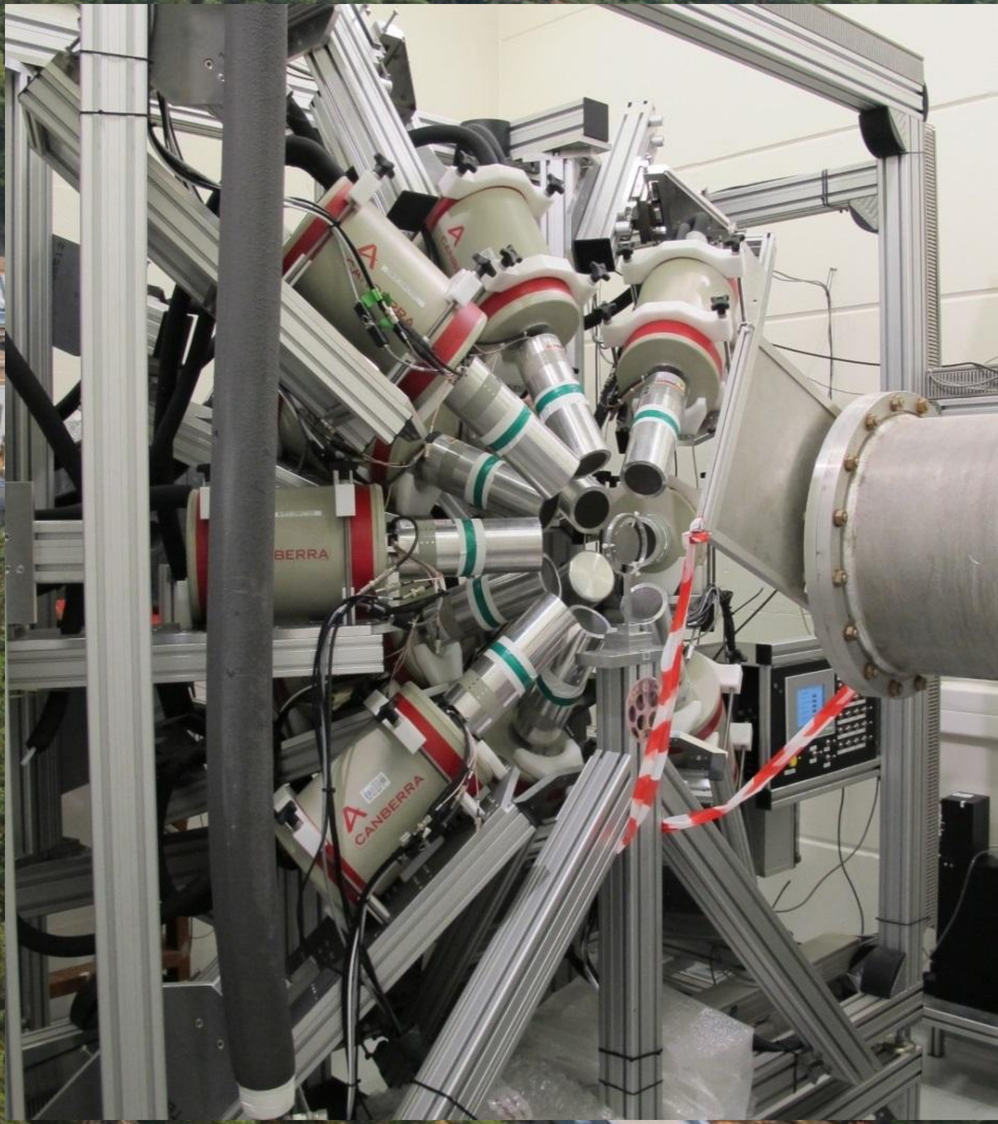
## GAINS Spectrometer

Gamma Array for Inelastic Neutron Scattering

- 12 large-volume HPGe detectors:
  - 4 @ 110°
  - 4 @ 150°
  - 4 @ 125°

  100% relative efficiency

  2.3 keV energy resolution for 1332 keV of 60Co

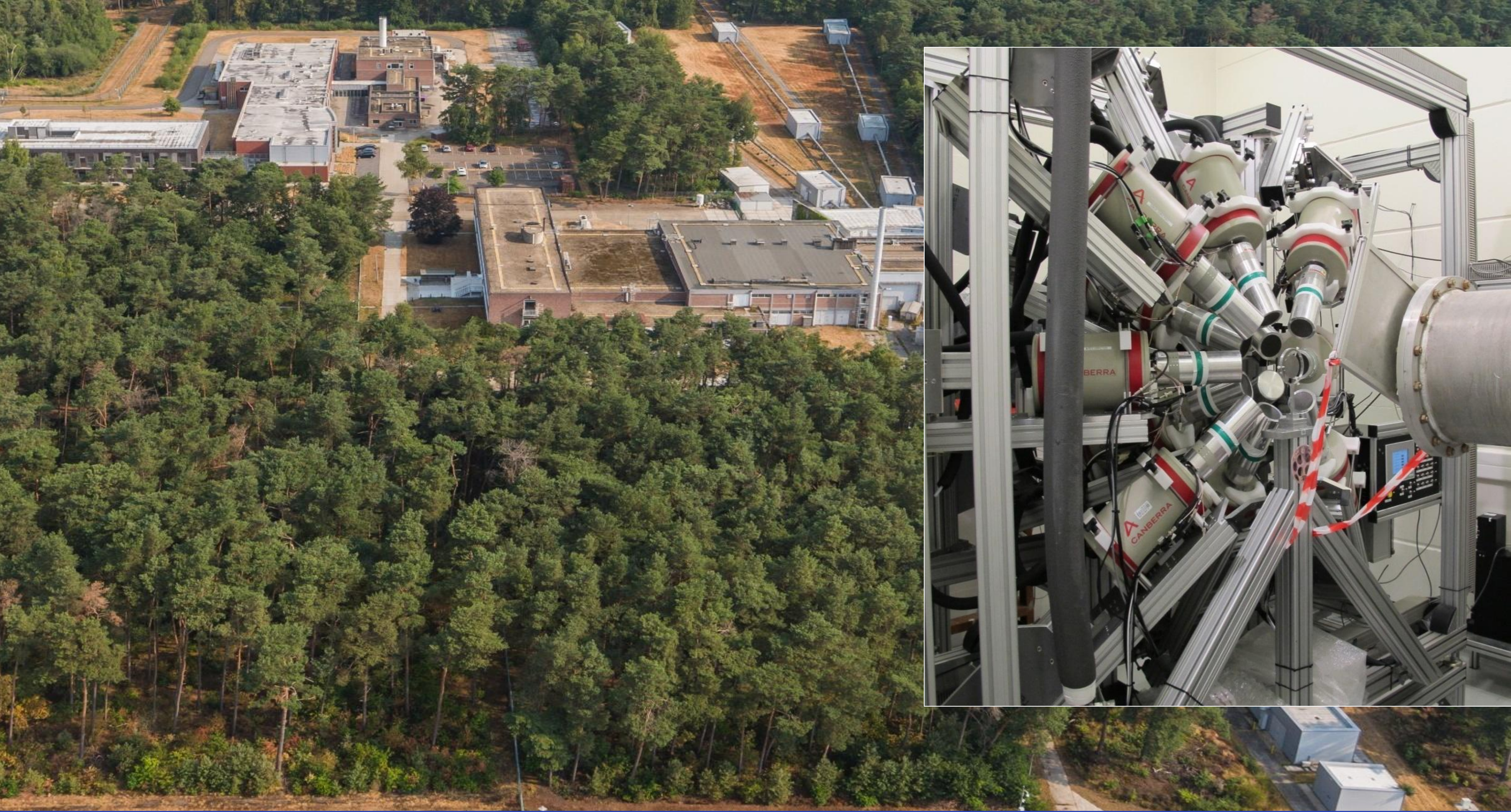



## $^{235}$U Fission chamber for beam monitoring

- $E_n$ range: $E_{th}$ – 20 MeV
- Neutron flux ~1000 n/cm$^2$s
- Neutron energy resolution:

  3 keV @ 1MeV

  80 keV @ 10 MeV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PHYSICAL REVIEW C **88**, 034604 (2013)

## Cross sections for inelastic scattering of neutrons on $^{28}$Si and comparison with the $^{25}$Mg$(\alpha, n)^{28}$Si reaction

A. Negret,[1,*] C. Borcea,[1] D. Bucurescu,[1] D. Deleanu,[1] Ph. Dessagne,[2] D. Filipescu,[1] D. Ghita,[1] T. Glodariu,[1] M. K
N. Marginean,[1] R. Marginean,[1] C. Mihai,[1] S. Pascu,[1] A. J. M. Plompen,[3] T. Sava,[1] and L. Stroe[1]
[1] *"Horia Hulubei" National Institute for Physics and Nuclear Engineering, 077125 Bucharest-Măgurele, Romania*
[2] *CNRS, Université de Strasbourg, UMR7178, IPHC, 23 rue du Loess, 67037 Strasbourg, France*
[3] *European Commission, Joint Research Center, Institute for Reference Materials and Measurements, B-2440 Geel, Belgi*
(Received 29 May 2013; published 11 September 2013)

The inelastic scattering of neutrons on $^{28}$Si was investigated using the $(n, n'\gamma)$ technique. The $\gamma$ production cross sections were measured and the level and total inelastic cross sections were determined with high accuracy. $^{28}$Si was also excited through the $^{25}$Mg$(\alpha, n\gamma)^{28}$Si reaction and a comparison of the $\gamma$ production cross sections determined for various incident energies was performed.

5.−e, 24.87.+y

## Cross section measurements for neutron inelastic scattering and the $(n, 2n\gamma)$ reaction on $^{206}$Pb

A. Negret,[1,*] L. C. Mihailescu,[1,2,†] C. Borcea,[1] Ph. Dessagne,[3,4] K. H. Guber,[5] M. Kerveno,[3,4] A. J. Koning,[6] A. Olacel,[1,7] A. J. M. Plompen,[2] C. Rouki,[2] and G. Rudolf[3,4]
[1] *"Horia Hulubei" National Institute for Physics and Nuclear Engineering, R-077125 Bucharest-Măgurele, Romania*
[2] *European Commission, Joint Research Centre, Institute for Reference Materials and Measurements, B-2440 Geel, Belgium*
[3] *Université de Strasbourg, IPHC, F-67037 Strasbourg, France*
[4] *CNRS, UMR7178, F-67037 Strasbourg, France*
[5] *Reactor and Nuclear Systems Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA*
[6] *Nuclear Research Group Petten, NL-1755 ZG Petten, The Netherlands*
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(Received 27 May 2015; published 30 June 2015)

Excitation functions for $\gamma$ production associated with the neutron inelastic scattering and the $(n, 2n)$ reactions on $^{206}$Pb were measured from threshold up to 18 MeV for about 40 transitions. Two independent measurements were performed using different samples and acquisition systems to check consistency of the results. The neutron flux was determined with a $^{235}$U fission chamber and a procedure that were validated against a fluence standard. For incident energy higher than the threshold for the first excited level and up to 3.5 MeV, estimates are provided for the total inelastic and level cross sections by combining the present $\gamma$ production cross sections with the level and decay data of $^{206}$Pb reported in the literature. The uncertainty common to all incident energies is 3.0% allowing overall uncertainties from 3.3% to 30% depending on transition and neutron energy. The present data agree well with earlier work, but significantly expand the experimental database while comparisons with model

PHYSICAL REVIEW C **93**, 024610 (2016)

luction cross section following inelastic
ring by $^7$Li

irovano,[1] A. J. M. Plompen,[1] and C. Rouki[1]
*tute for Reference Materials and Measurements,*
*40 Geel, Belgium*

PHYSICAL REVIEW C **90**, 034603 (2014)

## Neutron inelastic cross-section measurements for $^{24}$Mg

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[1] *Horia Hulubei National Institute for Physics and Nuclear Engineering, Reactorului 30, 077125 Bucharest-Mă*
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(Received 24 June 2014; published 8 September 2014)

The $\gamma$ production cross sections from neutron inelastic scattering on $^{24}$Mg were measured for neutron up to 18 MeV at GELINA (the Geel Linear Accelerator), the neutron source operated by EC-JRC Belgium. The level cross section and the total inelastic cross section were determined. We used the (Gamma Array for Inelastic Neutron Scattering) spectrometer with seven large-volume high-purity ger

PHYSICAL REVIEW C **96**, 024620 (2017)

## Cross-section measurements for the $^{57}$Fe$(n,n\gamma)^{57}$Fe and $^{57}$Fe$(n,2n\gamma)^{56}$Fe reactions

A. Negret,[1,*] M. Sin,[2] C. Borcea,[1] R. Capote,[3] Ph. Dessagne,[4] M. Kerveno,[4] N. Nankov,[5] A. Olacel,[1] A. J. M. Plompen,[5] and C. Rouki[5]
[1] *Horia Hulubei National Institute for Physics and Nuclear Engineering, 077125 Bucharest-Magurele, Romania*
[2] *University of Bucharest, Faculty of Physics, 077125 Bucharest-Magurele, Romania*
[3] *Nuclear Data Section, Inte*
[4] *Université de Strasbourg*
[5] *European Commission*
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A neutron inelastic scattering experim
Linear Accelerator neutron source using t
$\gamma$-production cross sections were determ
steadily increased $\gamma$ background at h
a and carefully tuned theoretical calcu

PHYSICAL REVIEW C **106**, 024609 (2022)

## Nucleon-induced inelastic cross sections on $^{nat}$Ni

A. Olacel,[1] C. Borcea,[1] M. Boromiza,[1,*] S. Calinescu,[1] C. Clisu,[1] C. Costache,[1] Ph. Dessagne,[2] I. Dinescu,[1] D. Filipescu,[1] N. Florea,[1] I. Harca,[1] G. Henning,[2] A. Ionescu,[1] M. Kerveno,[2] R. Lica,[1] A. Matei,[1] C. Mihai,[1] R. Mihai,[1] A. Mitu,[1] A. Negret,[1] C. Nita,[1] M. Nyman,[3] A. Oprea,[1] C. Petrone,[1] A. J. M. Plompen,[3] C. Sotty,[1] L. Stan,[1] L. Stoica,[1,4] G. Suliman,[1,5] A. Turturica,[1] and S. Ujeniuc[1]
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(Received 8 June 2022; accepted 26 July 2022; published 17 August 2022)

This paper reports on the results of $(n, n'\gamma)$ and $(p, p'\gamma)$ cross section measurements on nickel performed at the Geel Electron Linear Accelerator of the European Commission, Joint Research Centre (Geel) and at the 9-MV Tandem Accelerator of Horia Hulubei National Institute for Physics and Nuclear Engineering (Bucharest-Magurele), respectively. The main goal was to reliably measure with small uncertainty the most intense transitions arising from the inelastic channel. Comparisons are performed between the extracted results, nuclear reaction model calculations using default parameter values, and previously reported measurements, if available. The broader goal of this paper is related to our study on the possibility of inferring neutron inelastic cross sections from the proton-induced ones, in this case for $^{58}$Ni. We show that—by making use of the Lane consistency of the nucleon optical model potential and of the constraints offered by the proton data—one can extract a neutron-target potential that better describes the experimental data, as compared to the calculation with default neutron parameters. We also discuss relevant issues and still open questions of our calculations along with future plans for mitigation.

DOI: 10.1103/PhysRevC.106.024609

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PHYSICAL REVIEW C **96**, 014621 (2017)

## Neutron inelastic scattering measurements on the stable isotopes of t

A. Olacel,[1,*] F. Belloni,[2] C. Borcea,[1] M. Boromiza,[1,3] P. Dessagne,[4] G. Henning,[4] M. Kerveno,[4] A. E. Pirovano,[2] and A. J. M. Plompen[2]
[1] *Horia Hulubei National Institute for Physics and Nuclear Engineering, Reactorului 30, 077125 Bucharest*
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(Received 24 May 2017; published 31 July 2017)

The results of a neutron inelastic scattering experiment performed at the Geel Electron Linear pulsed white neutron source of the European Commission Joint Research Centre are reported. The n energies up to 18 MeV interacted with a $^{nat}$Ti sample and the $\gamma$ rays resulting from inelastic scattering the stable isotopes were detected using the Gamma Array for Inelastic Neutron Scattering (GAINS) s We were able to measure the $\gamma$-production cross sections for 21 transitions in the five stable Ti is these, the level cross sections and the total inelastic cross sections were determined. Our experiment compared with theoretical calculations performed using the TALYS 1.8 code, evaluated nuclear data l also with previously reported results.

DOI: 10.1103/PhysRevC.96.014621

Eur. Phys. J. A (2018) **54**: 183
DOI 10.1140/epja/i2018-12619-x

Regular Article – Experimental Physics

## Neutron inelastic scatt

A. Olacel[1,a], C. Borcea[1], M. Boromiza[1,
M. Nyman[5], and A.J.M. Plompen[5]
[1] Horia Hulubei National Institute for Physi
[2] University of Bucharest, Faculty of Physic
[3] Université de Strasbourg, CNRS, IPHC UMR 7178,
[4] Institut de Radioprotection et de Sûreté Nucléaire,
[5] European Commission, Joint Research Centre, Reti

Received: 9 July 2018 / Revised: 17 Septem
Published online: 30 October 2018

Communicated by A. Orbetelli

**Abstract.** A neutron inelastic scattering exp
neutron source using an enriched $^{54}$Fe sampl
Gamma Array for Inelastic Neutron Scatter
the $\gamma$-production cross section for incident e
to 18 MeV. Using these primary data we als
total inelastic cross section. Our experiment
nuclear data libraries and theoretical calcu
of the optical model parameters allowed sig
results leading to interesting conclusions re

eno,[2,3] N. Marginean,[1]
,[5] C. Sotty,[1] G. Suliman,[4]
est-Măgurele, Romania
[4] *Horia Hulubei National Institute for Physics and Nuclear Engineering, ELI-NP, Reactorului 30, 077125 Bucharest-Magurele, Romania*
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(Received 13 September 2019; revised manuscript received 25 November 2019; accepted 16 December 2019; published 10 February 2020)

This paper reports cross-section measurements of the $(n, n')$ and $(p, p')$ reactions on $^{16}$O and $^{28}$Si at Geel Electron Linear Accelerator and at the 9-MV Tandem Accelerator of Horia Hulubei National Institute for Physics and Nuclear Engineering, respectively. The main purpose was to measure the neutron- and proton-induced inelastic $\gamma$-production cross sections for all observed transitions in $^{16}$O and $^{28}$Si, followed by the calculation of the corresponding total inelastic cross section. The results are compared with theoretical calculations performed using the TALYS 1.9 code, evaluated nuclear data, and previously reported experimental data. The broader goal of this work is to study whether and to what extent the neutron-induced inelastic cross sections of these nuclei can be inferred from those obtained using suitable charged particle reactions. We show that, by making use of the formal similarities between the neutron- and the proton-target optical model potentials and isospin symmetry in mirror nuclei, one can develop a procedure that combines experimental proton-induced inelastic cross sections with theoretical calculations to infer neutron inelastic cross sections. For $^{16}$O and $^{28}$Si, the precision associated with this procedure is around 10–20% for most of the incident energy range.

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PHYSICS

Nuclear Physics A 786 (2007) 1–23

## High resolution measurement of neutron inelastic scattering and $(n, 2n)$ cross-sections for $^{52}$Cr

L.C. Mihailescu[a,b], C. Borcea[a,b], A.J. Koning[c], A.J.M. Plompen[a,*]
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[b] *"Horia Hulubei" National Institute for Physics and Nuclear Engineering, P.O. Box MG-6, 76900 Bucharest, Romania*
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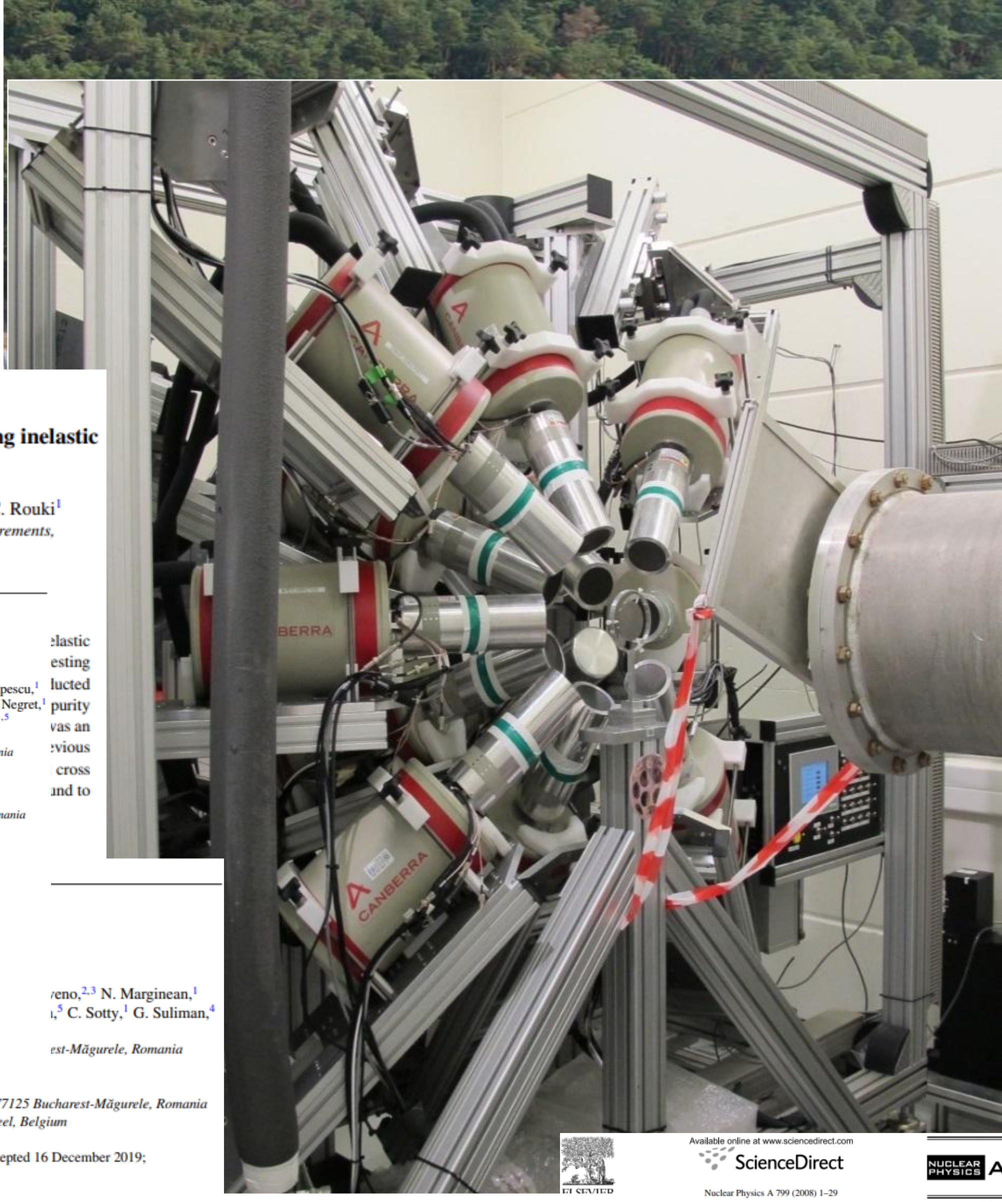
Received 17 November 2006; received in revised form 15 December 2006; accepted 8 January 2007
Available online 12 January 2007




PHYSICAL REVIEW C **90**, 034602 (2014)

### Cross-section measurements for the $^{56}$Fe$(n, xn\gamma)$ reactions

A. Negret,[1,*] C. Borcea,[1] Ph. Dessagne,[2] M. Kerveno,[2] A. Olacel,[1,3] A. J. M. Plompen,[4] and M. Stanoiu[1]
[1] *"Horia Hulubei" National Institute for Physics and Nuclear Engineering, 077125, Bucharest-Măgurele, Romania*
[2] *CNRS, Université de Strasbourg, UMR7178, IPHC, 23 rue du Loess, 67037, Strasbourg, France*
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*ropean Commission, Joint Research Centre, Institute for Reference Materials and Measurements, B-2440, Geel, Belgium*
(Received 23 June 2014; revised manuscript received 12 August 2014; published 5 September 2014)

A measurement was performed at the white neutron source Geel Linear Accelerator (GELINA) of the Institute for Reference Materials and Measurements to determine the cross sections for the $(n, n'\gamma)$ and $(n, 2n'\gamma)$ reactions on $^{56}$Fe. The Gamma Array for Inelastic Neutron Scattering (GAINS) was used. The results are scaled to the neutron-induced fission cross section of $^{235}$U. The paper emphasizes the multiple checks performed to assure the consistency of the results. $\gamma$ production cross sections, total inelastic cross sections, and level production cross sections were determined. A good agreement exists with previous measurements. Theoretical calculations were performed with the TALYS 1.6 reaction code using default parameters, but also using a microscopic approach. These calculations are discussed in comparison to the experimental data.

DOI: 10.1103/PhysRevC.90.034602 PACS number(s): 25.40.Fq, 29.30.Kv, 27.40.+z

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NUCLEAR PHYSICS A
Nuclear Physics A 799 (2008) 1–29
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solution measurement of neutron inelastic
ring and $(n, 2n)$ cross-sections for $^{209}$Bi

ihailescu[a,b], C. Borcea[a,b], A.J. Koning[c], A. Pavlik[d],
A.J.M. Plompen[a,*]
*mmission, Joint Research Centre, Institute for Reference Materials and Measurements, B-2440 Geel, Belgium*
*Hulubei" National Institute for Physics and Nuclear Engineering, PO Box MG-6, 76900 Bucharest, Romania*
*ar Research Group Petten, Westerduinweg 3, 1755 ZG Petten, The Netherlands*
*lty of Physics, University of Vienna, Währinger Straße 17, 1090 Wien, Austria*

# Data analysis procedure

- γ spectroscopy measurements

- Differential γ–production cross sections @ 110º & 150º: primary results

$$\frac{d\sigma}{d\Omega}(\theta_i, E_k) = \frac{1}{4\pi} \frac{Y_j(E_k)}{Y_{FC}(E_k)} \frac{\varepsilon_{FC}\,\sigma_U(E_k)}{\varepsilon_j} \frac{t_U}{t_S} \frac{A_S}{A_U} \frac{1}{c_{ms}(E_k)}$$

Funded by the European Union

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# Data analysis procedure

HPGE detectors's data reduction

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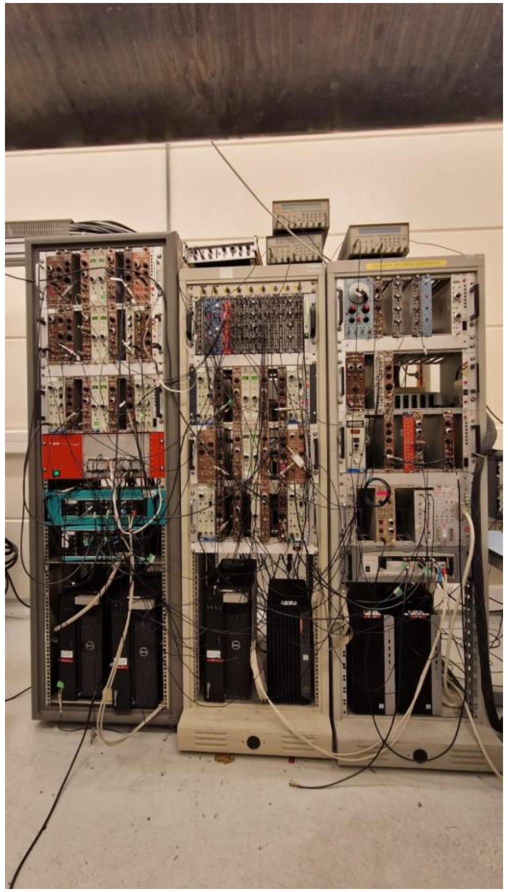
the European Union

- Differential γ–production cross sections

$$\frac{d\sigma}{d\Omega}(\theta_i, E_k) = \frac{1}{4\pi}\frac{Y_j(E_k)}{Y_{FC}(E_k)}\frac{\varepsilon_{FC}}{\varepsilon_j}\frac{\sigma_U(E_k)}{}\frac{t_U}{t_S}\frac{A_S}{A_U}\frac{1}{c_{ms}(E_k)}$$

- ➢ Time-amplitude listfiles recorded for 2h

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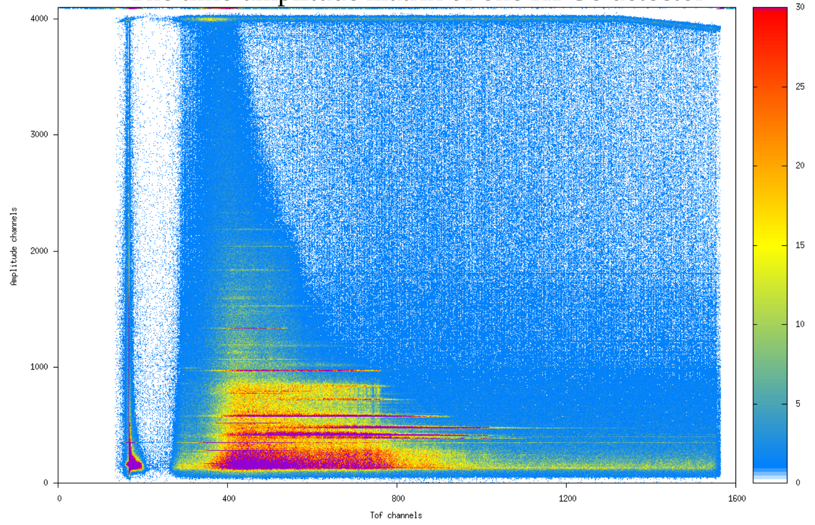
The time-amplitude matrix of one HPGe detector

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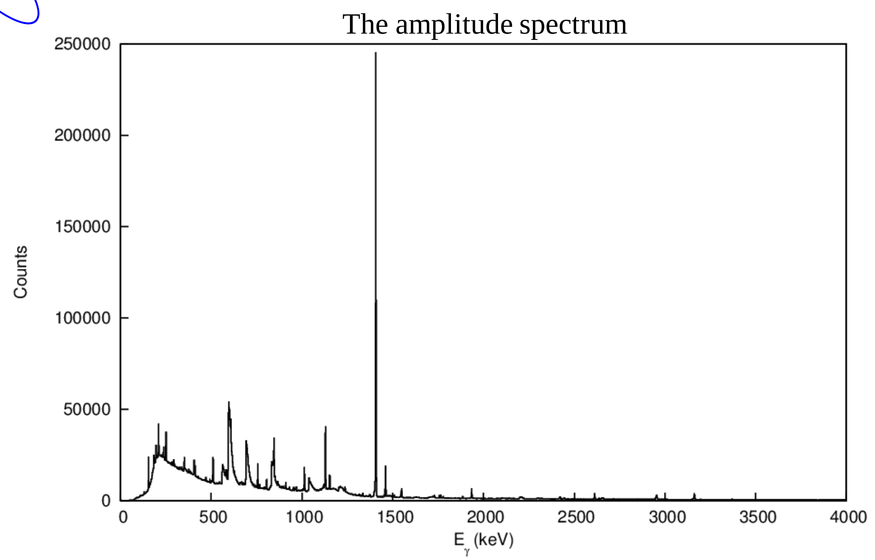


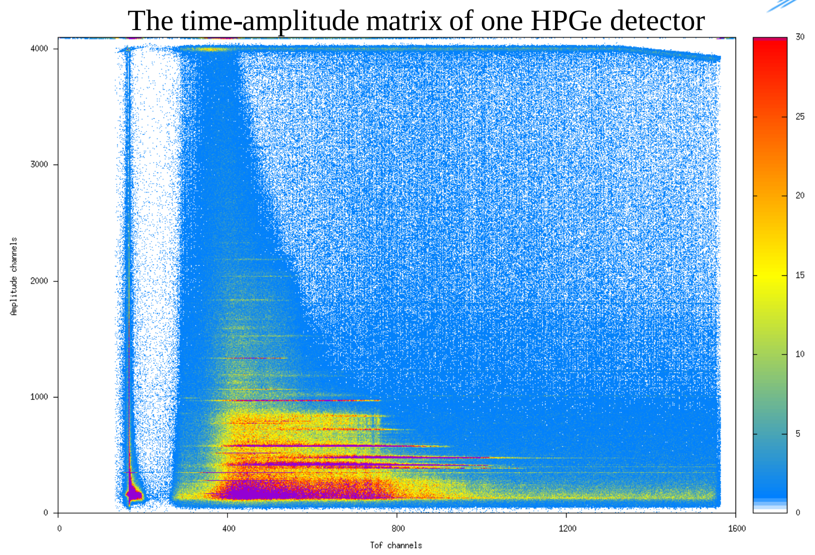


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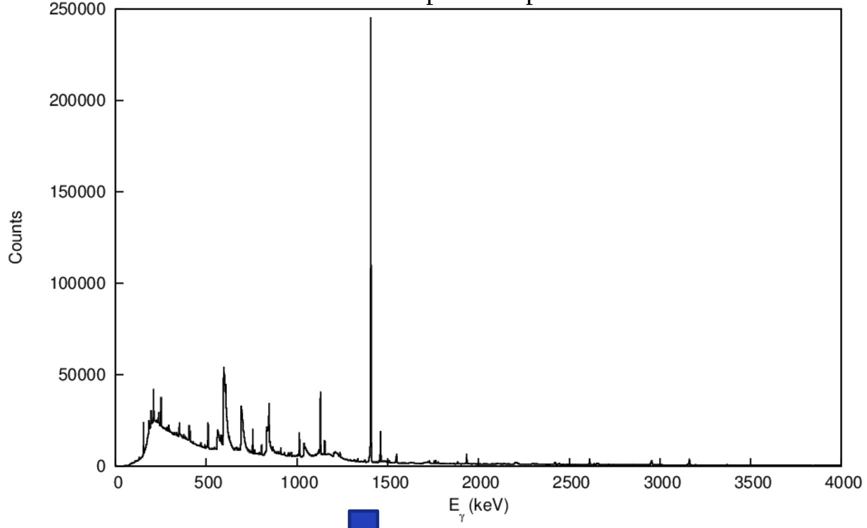
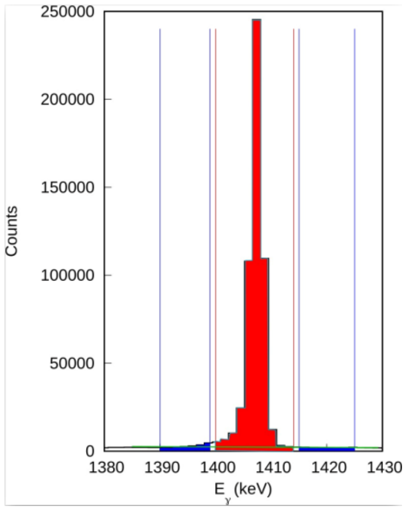
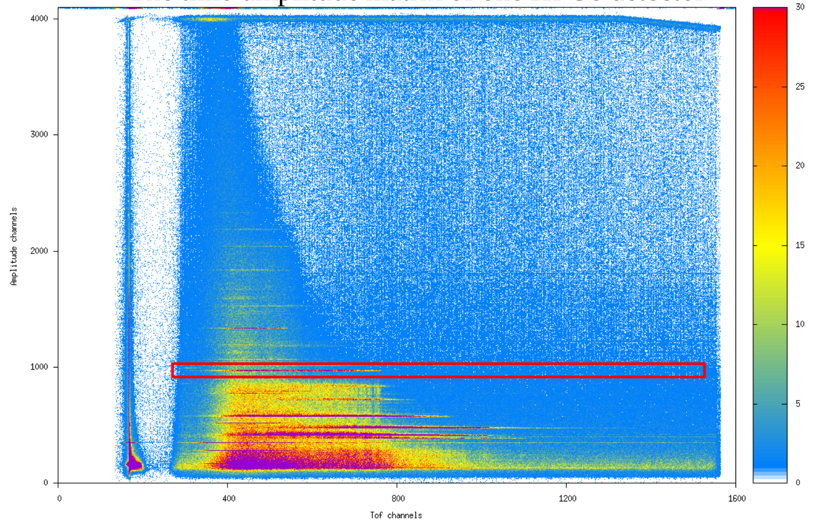
The amplitude spectrum




The time-amplitude matrix of one HPGe detector

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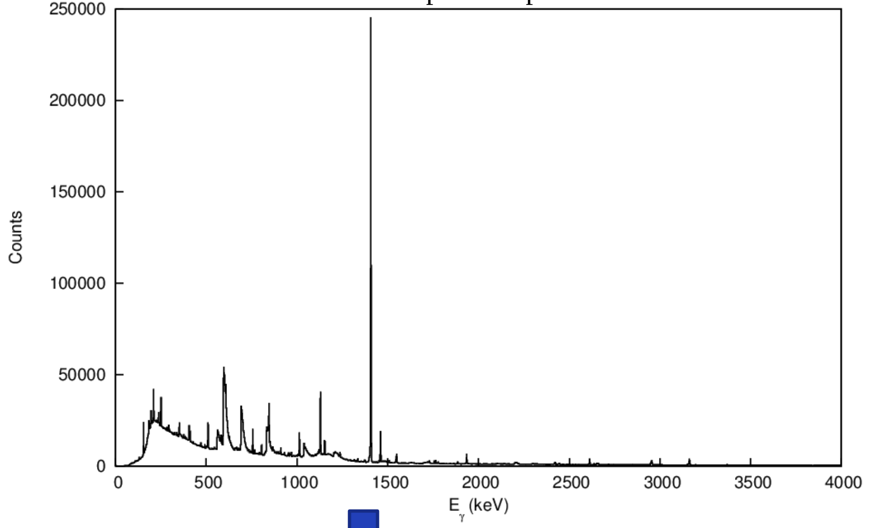
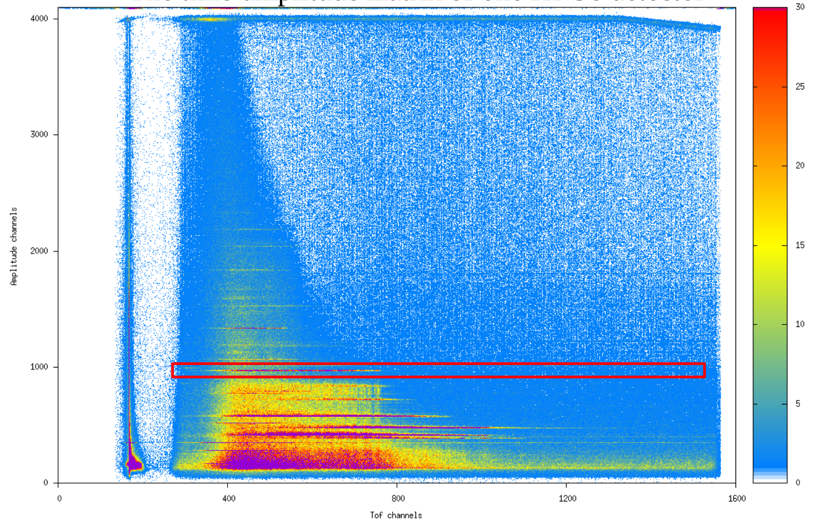
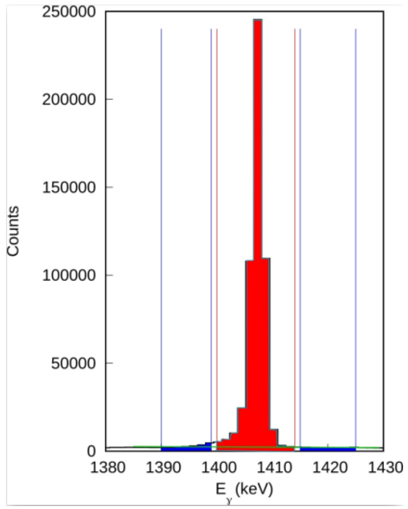
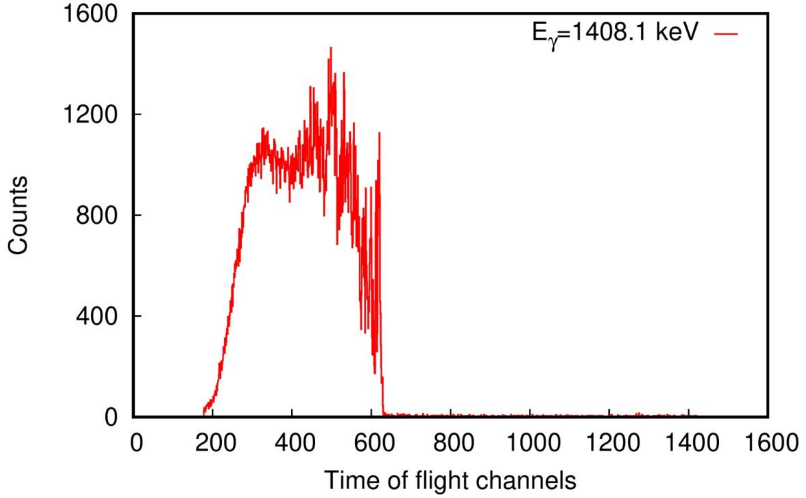
The amplitude spectrum




The time-amplitude matrix of one HPGe detector





Funded by
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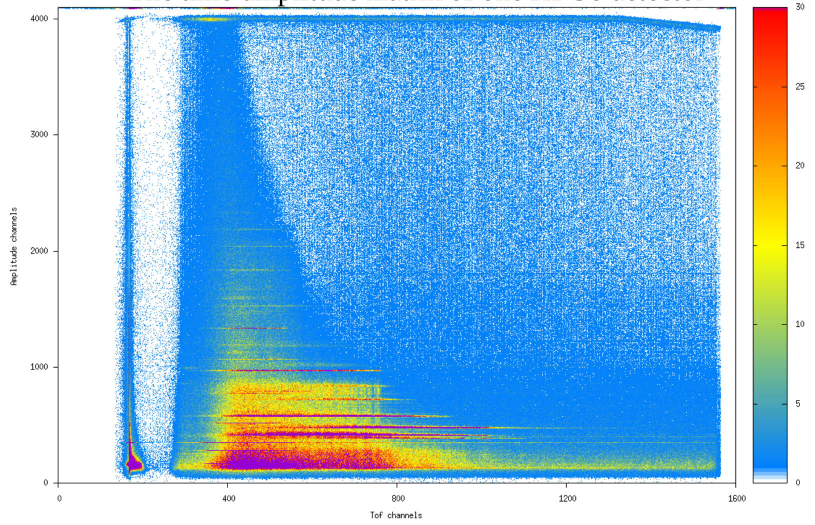
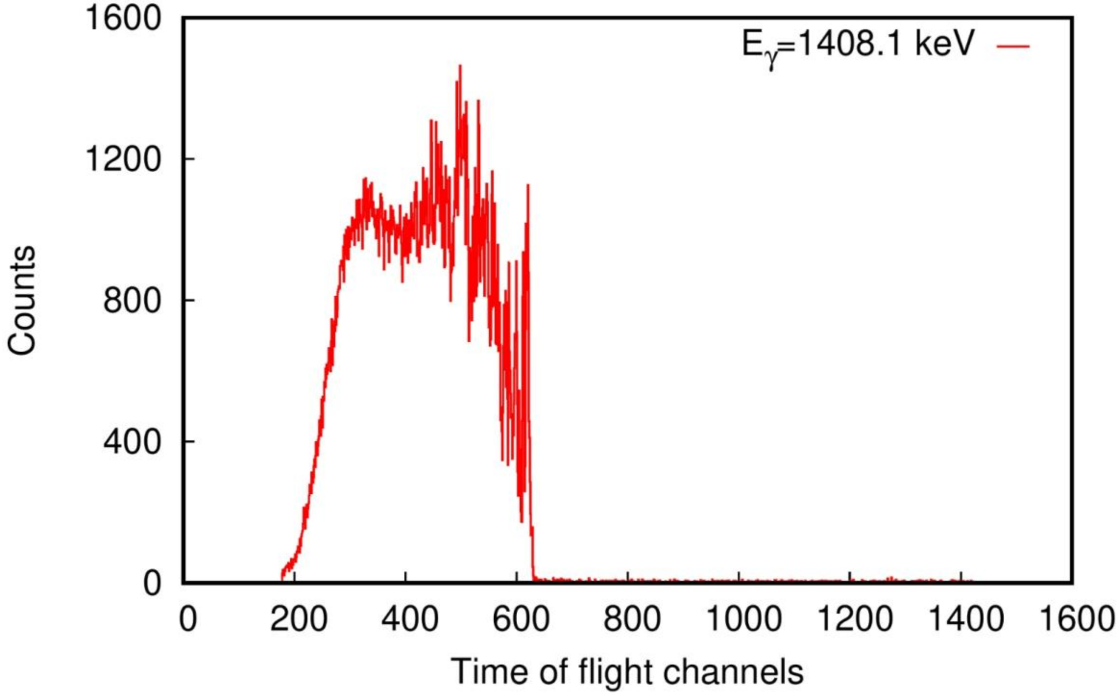
The time-amplitude matrix of one HPGe detector

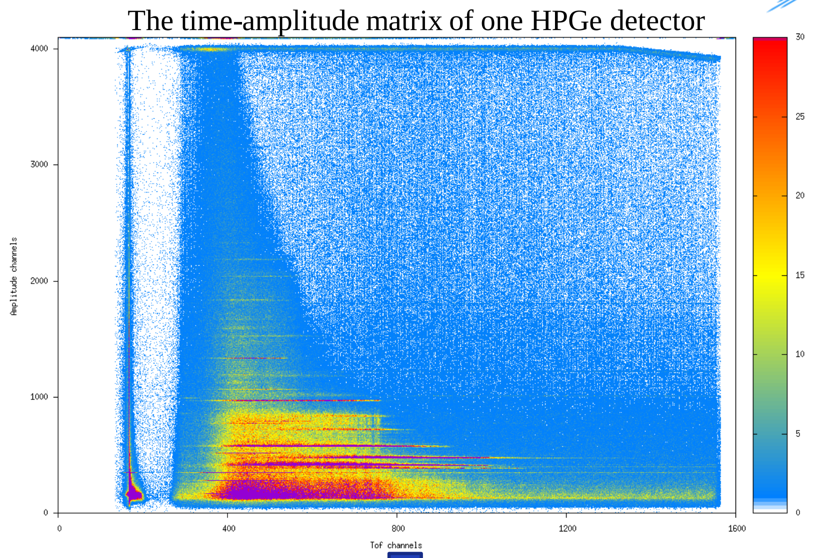


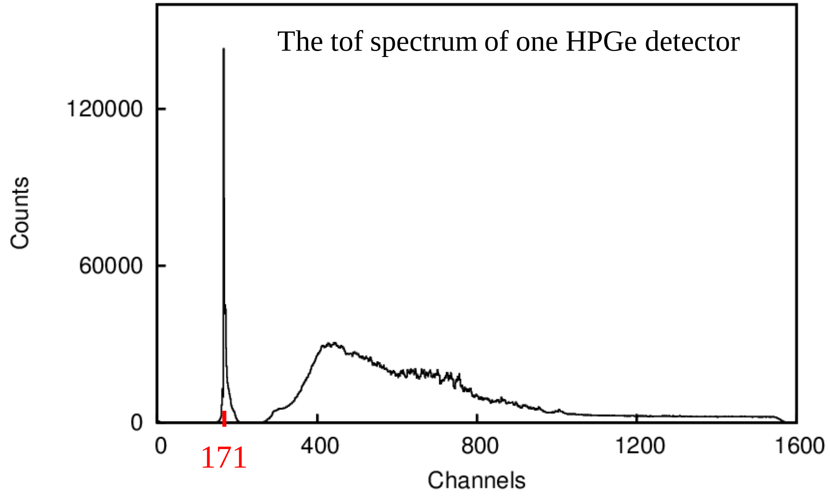
$$t_{\gamma-flash} = \frac{d_{flight\ path}}{c} = \frac{9967.55\ cm}{29.979\ cm/ns} = 332.484\ \text{ns}$$

- calibration in time of flight

$$tof\,(ns) = [tof\,(channels) - \gamma\text{–}flash(channels)] * 9.5238\ ns - t_{\gamma-flash}$$





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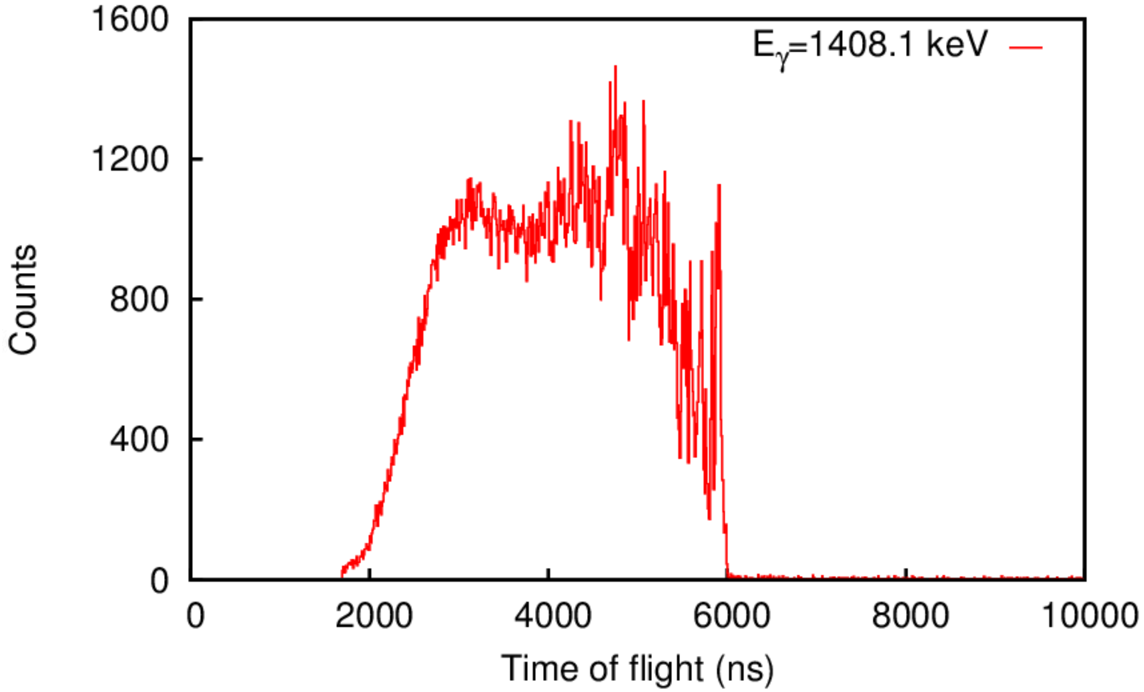
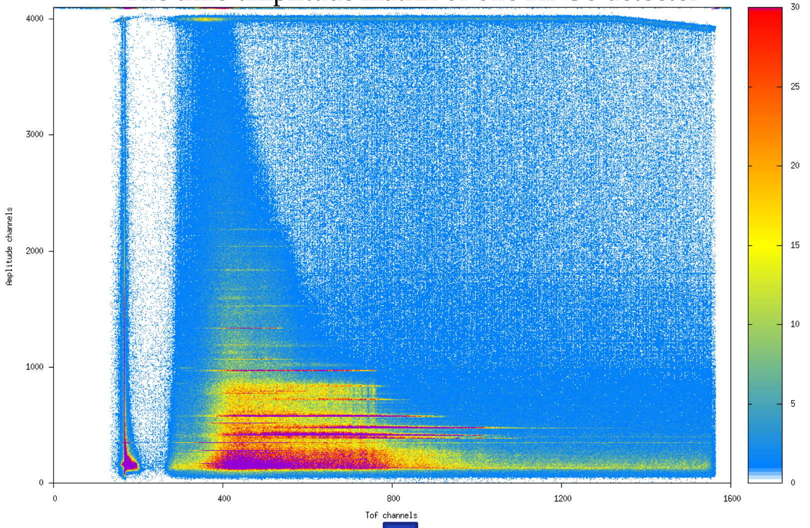
$$t_{\gamma-flash} = \frac{d_{flight\ path}}{c} = \frac{9967.55\ cm}{29.979\ cm/ns} = 332.484\ \text{ns}$$

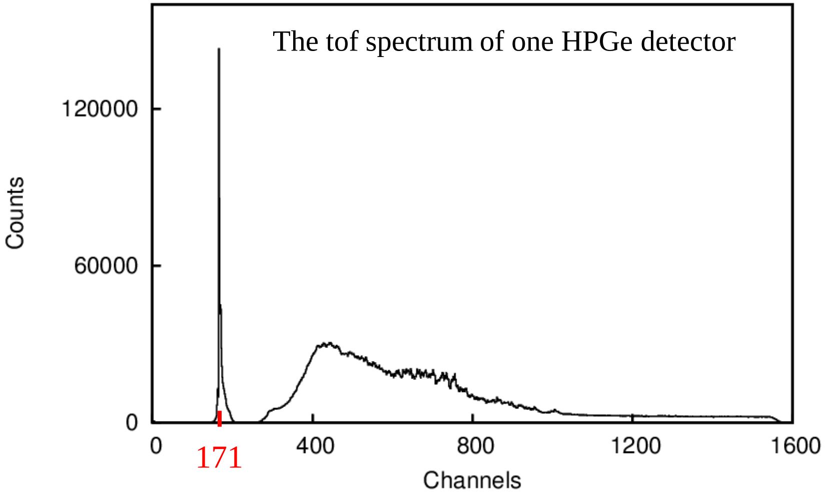
- calibration in time of flight

$$tof\,(ns) = [tof\,(channels) - \gamma\text{–}flash(channels)] * 9.5238\ ns - t_{\gamma-flash}$$




The time-amplitude matrix of one HPGe detector







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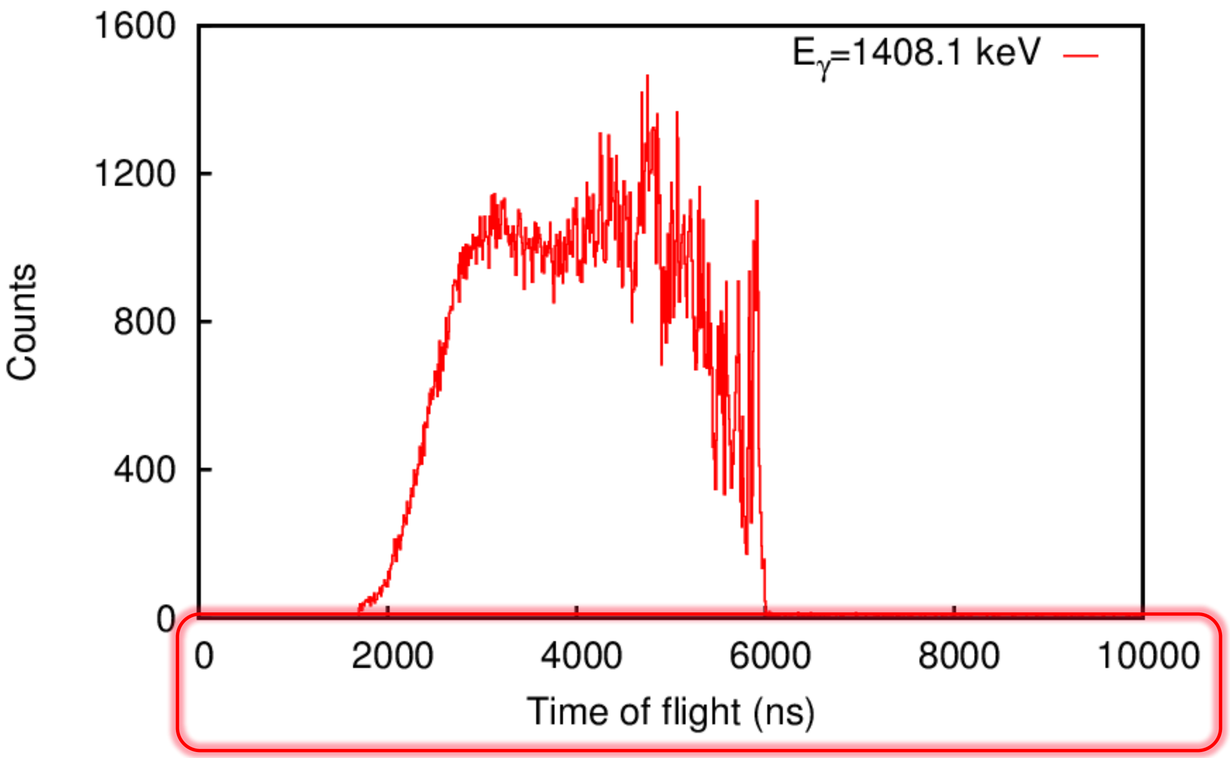
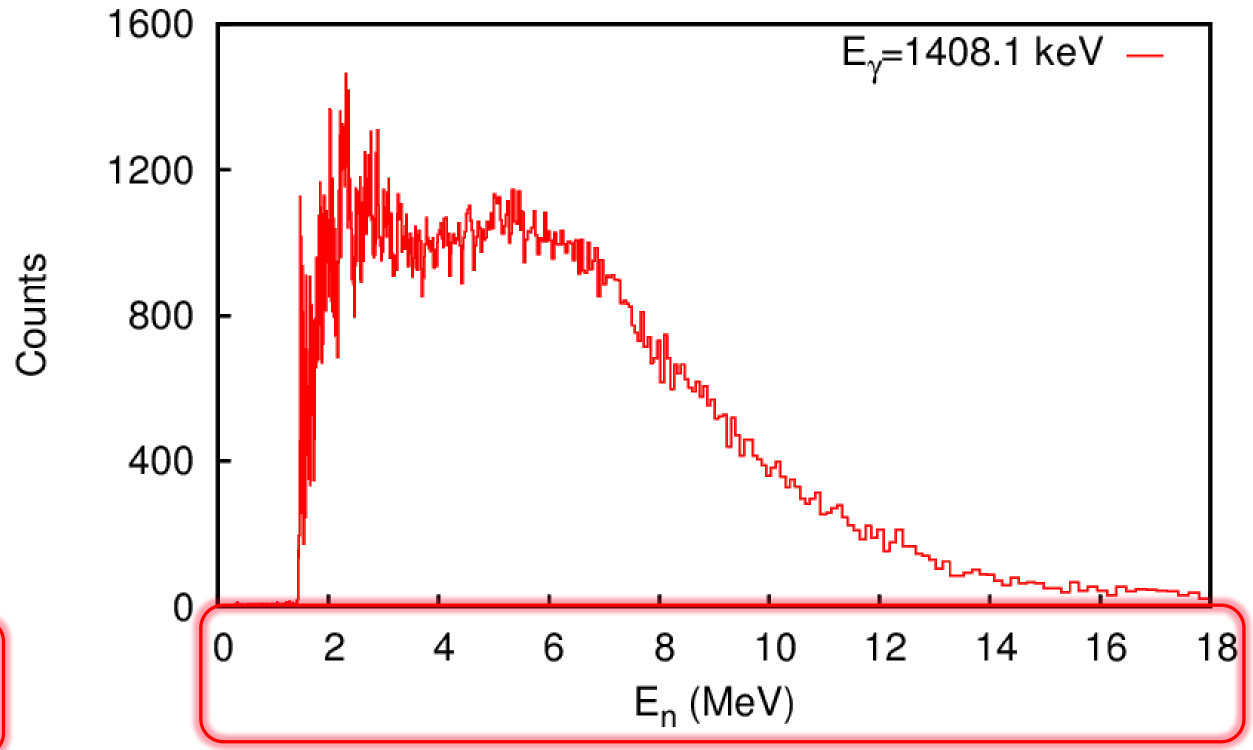
$$E_n = m_0 c^2 \left[ \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} - 1 \right]$$

& ToF-tehnique

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- Differential γ–production cross sections

$$\frac{d\sigma}{d\Omega}(\theta_i, E_k) = \frac{1}{4\pi}\frac{Y_j(E_k)}{Y_{FC}(E_k)}\frac{\varepsilon_{FC}\ \ \sigma_U(E_k)}{\varepsilon_j}\frac{t_U}{t_S}\frac{A_S}{A_U}\frac{1}{c_{ms}(E_k)}$$

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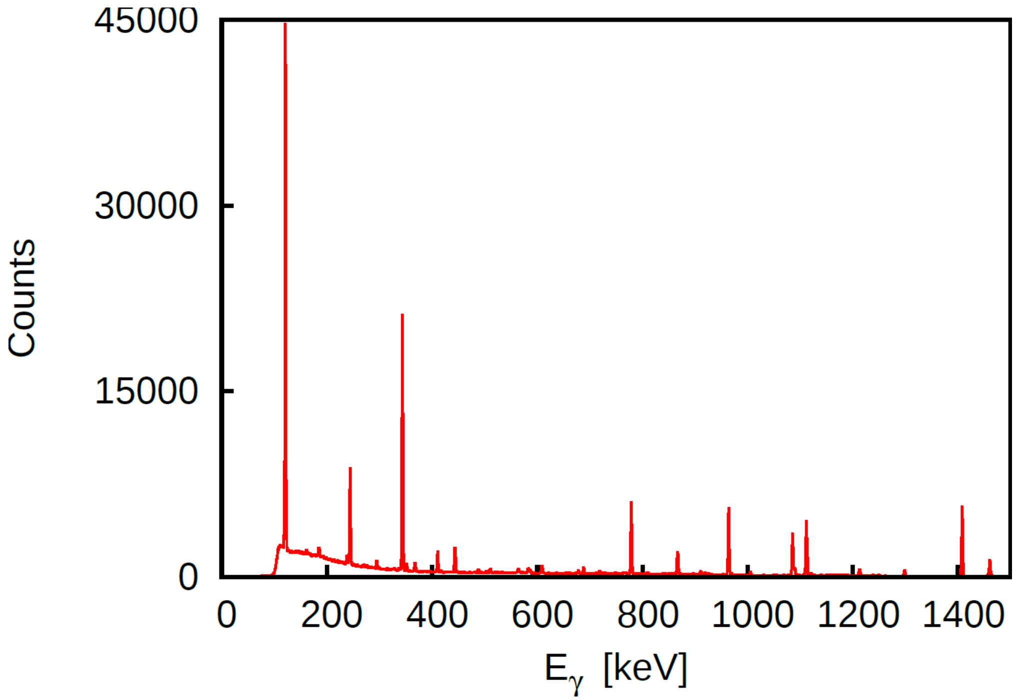
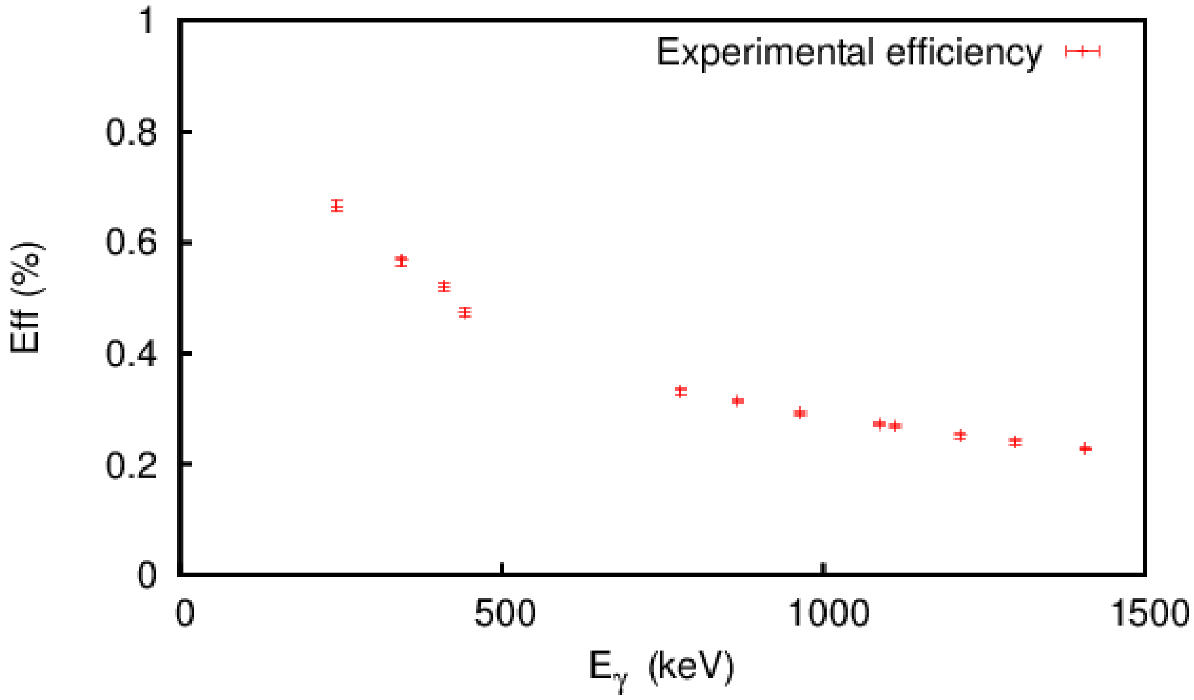
- The efficiency of the HPGe detectors

Two important steps:
1. Experimental efficiencies using a $^{152}$Eu point-like source.
2. Real efficiencies which take into account our extended sample (using MCNP6).

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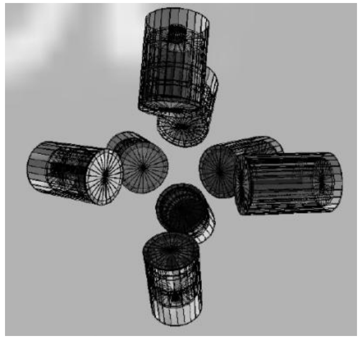

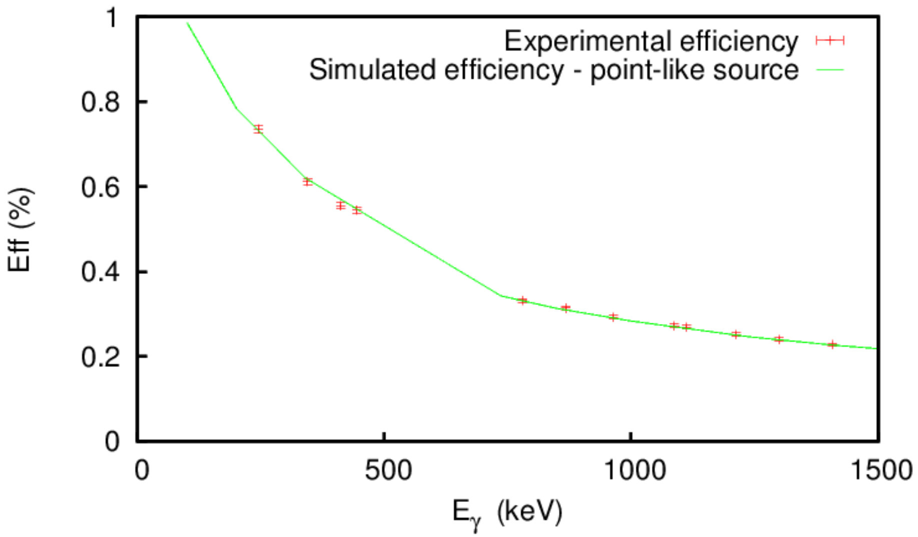


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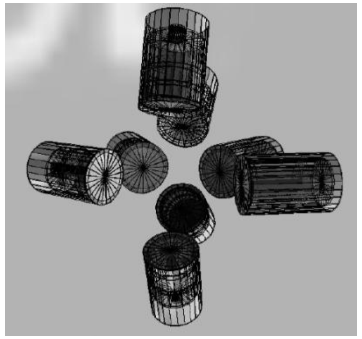

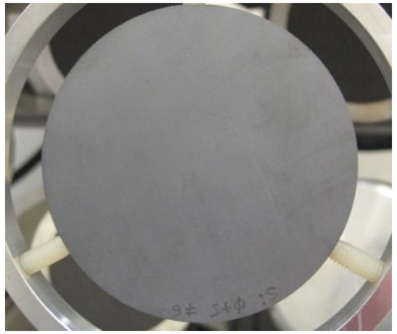

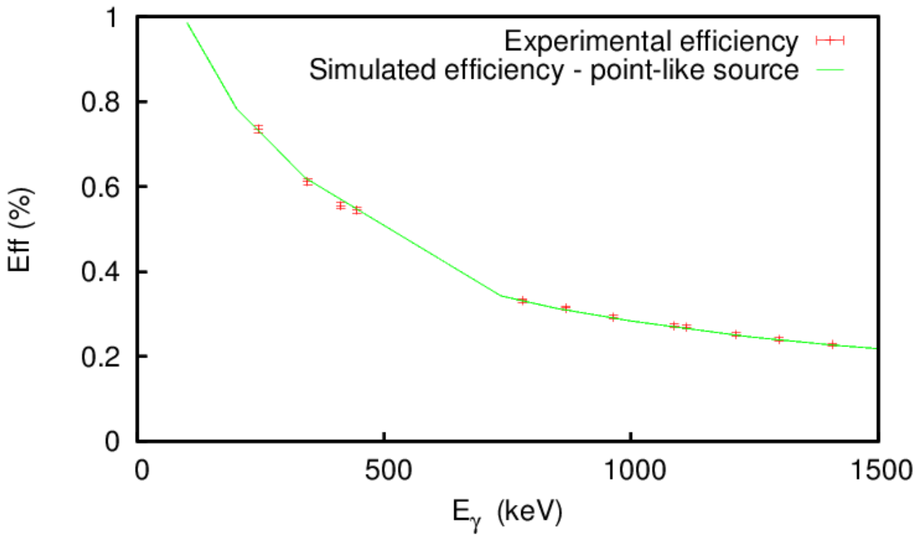


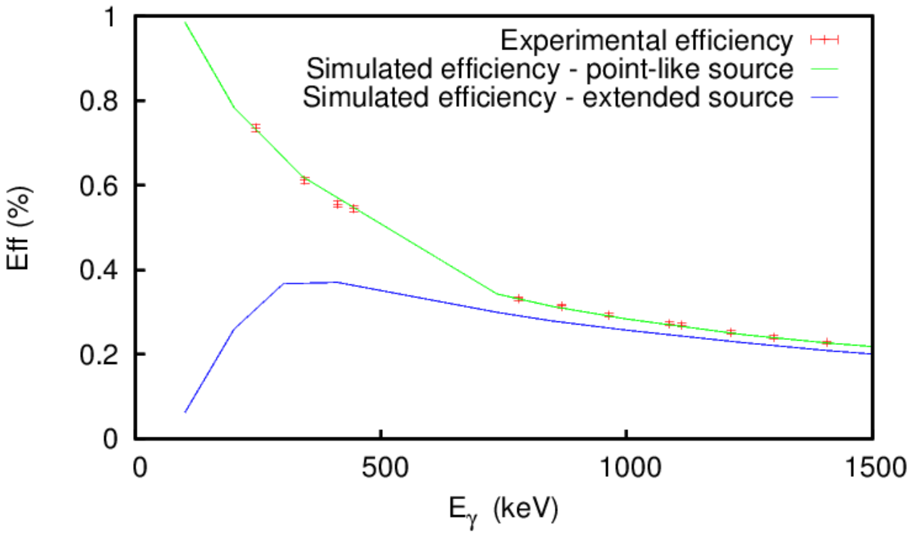


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# Data analysis procedure

Fission chamber data reduction

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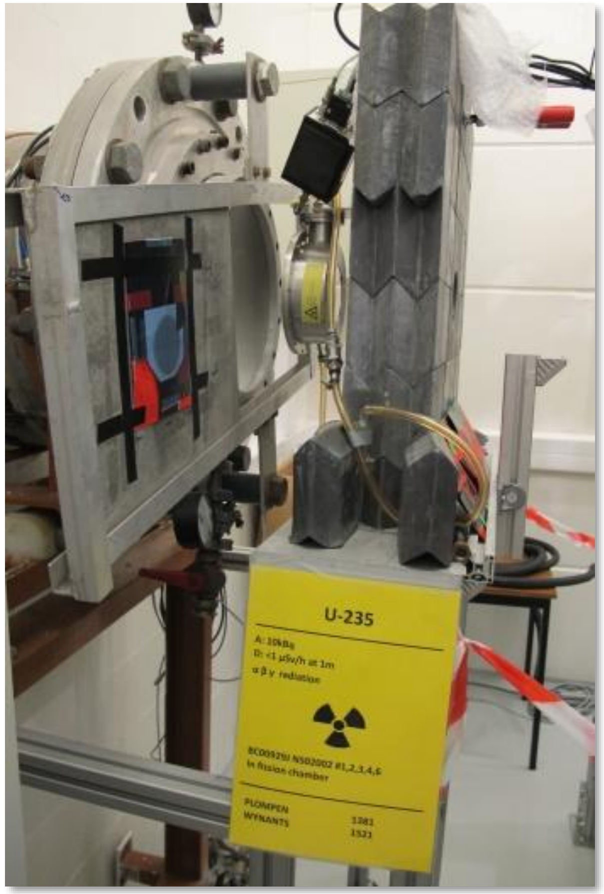
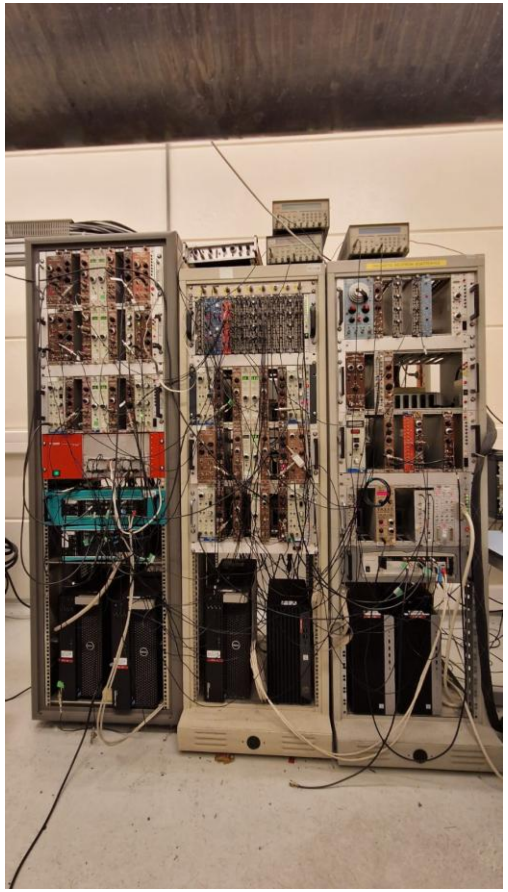
➢ Differential γ–production cross sections

$$\frac{d\sigma}{d\Omega}(\theta_i, E_k) = \frac{1}{4\pi}\frac{Y_j(E_k)}{Y_{FC}(E_k)}\frac{\varepsilon_{FC}\;\;\sigma_U(E_k)}{\varepsilon_j}\frac{t_U}{t_S}\frac{A_S}{A_U}\frac{1}{c_{ms}(E_k)}$$



- Time-amplitude listfiles recorded for 2h

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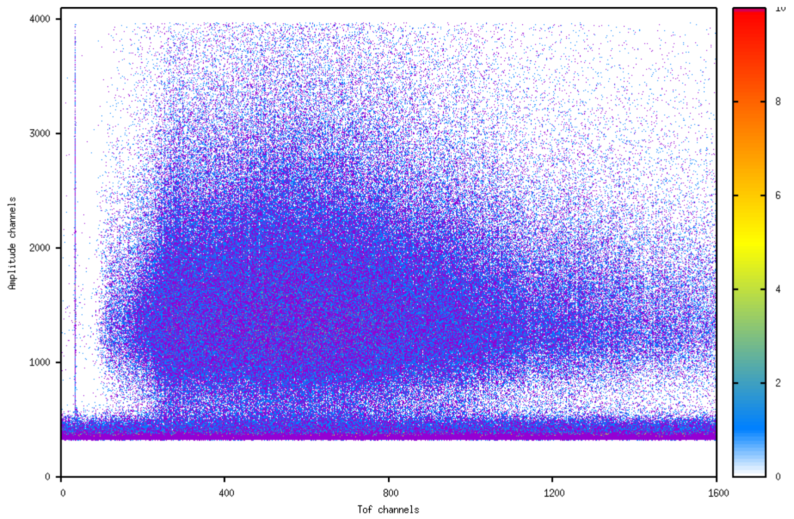
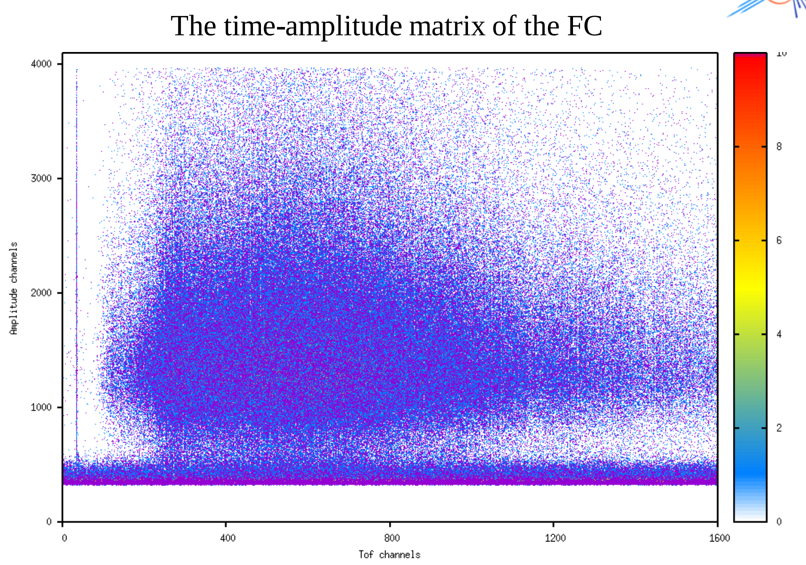
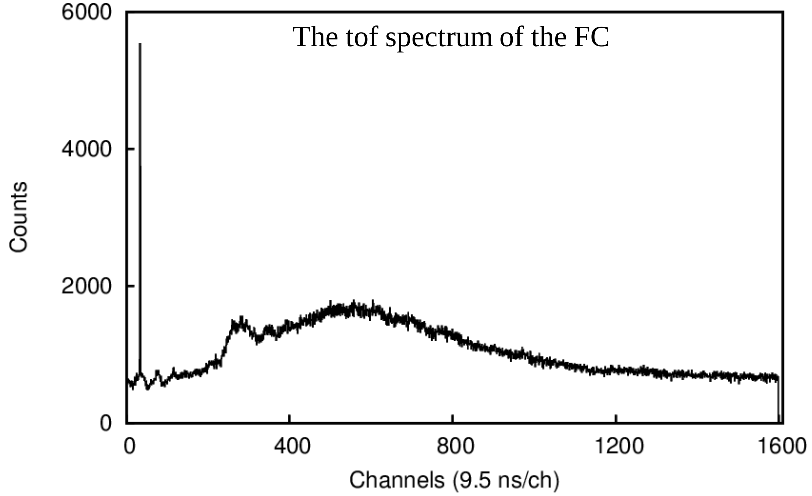
The time-amplitude matrix of the FC



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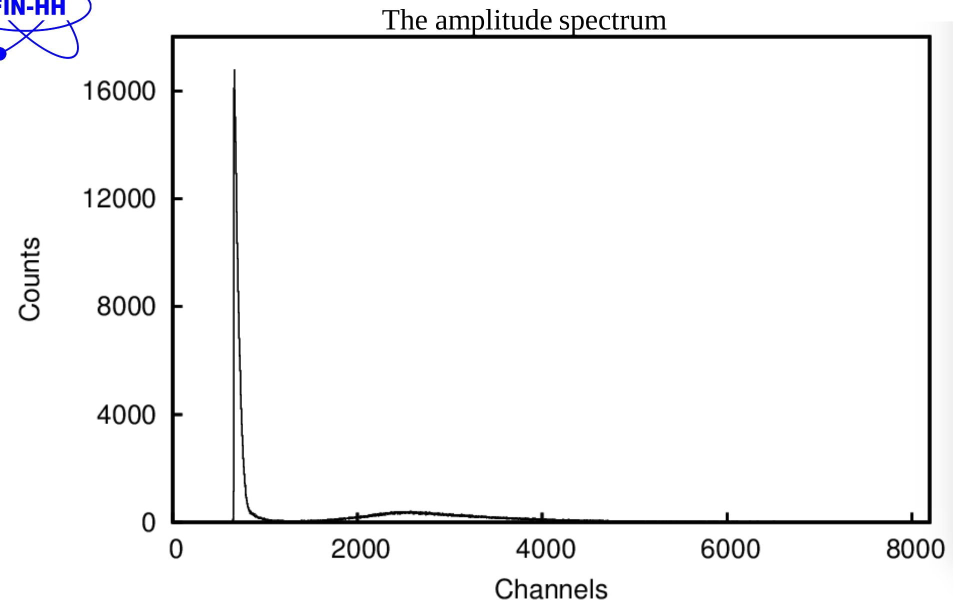


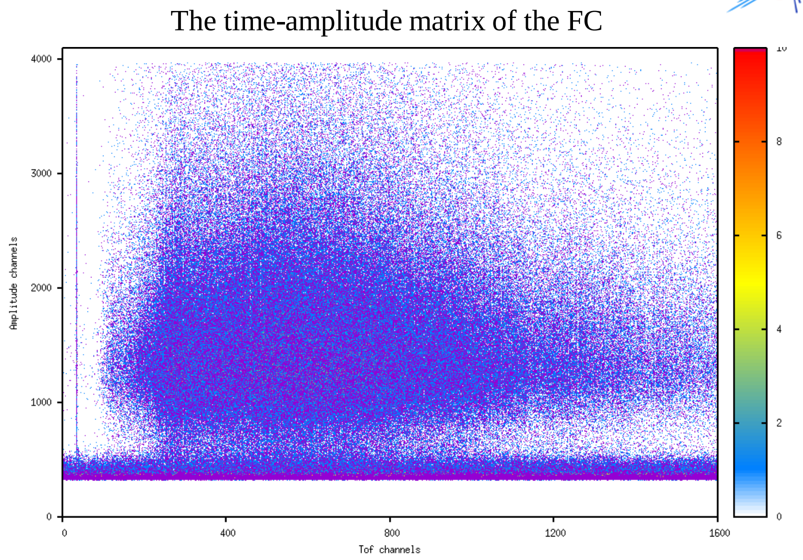


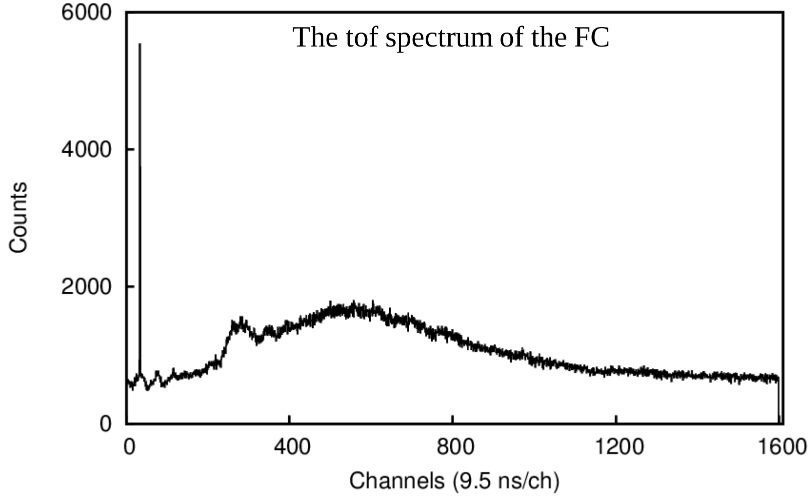


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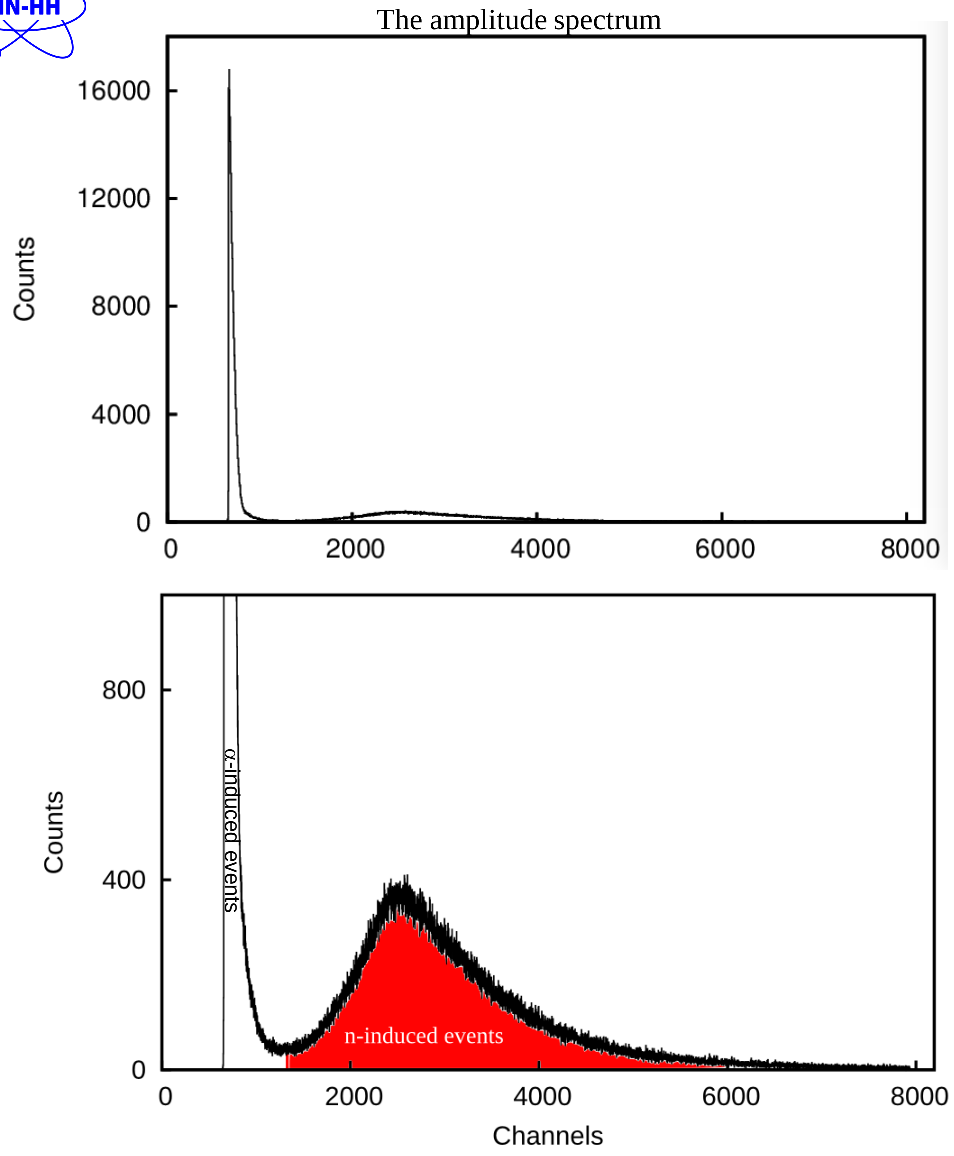


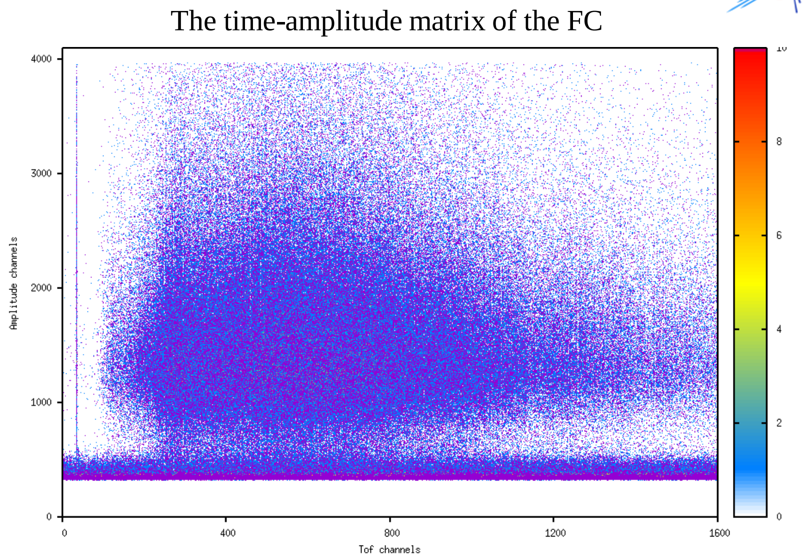


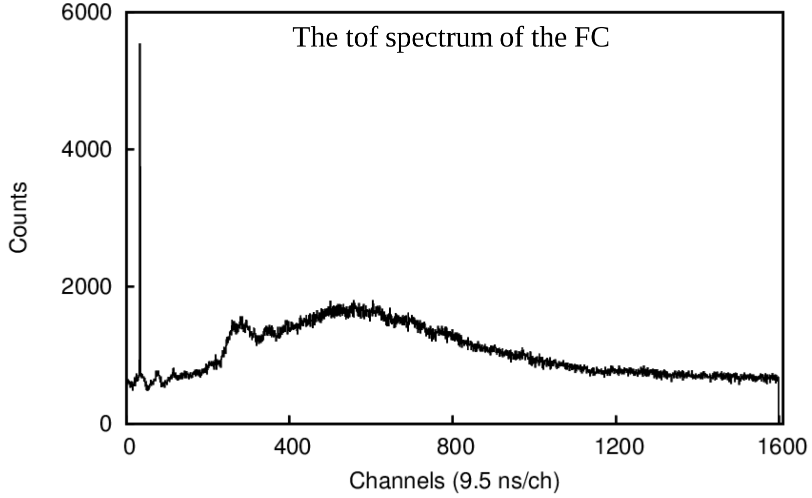


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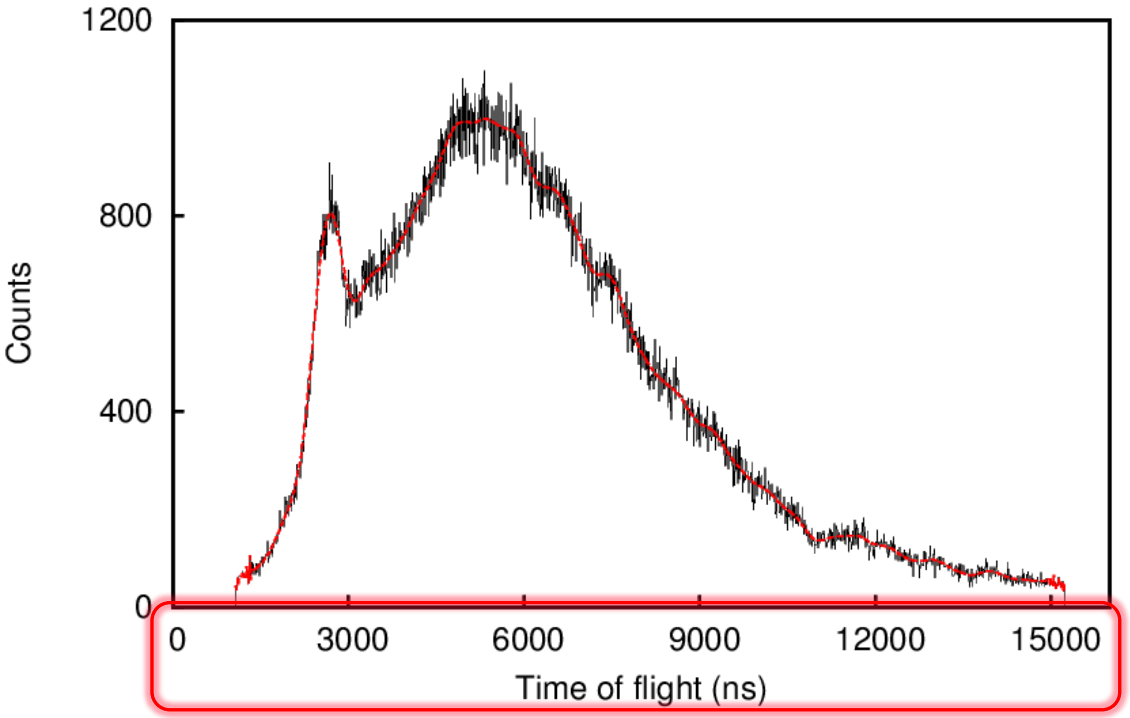


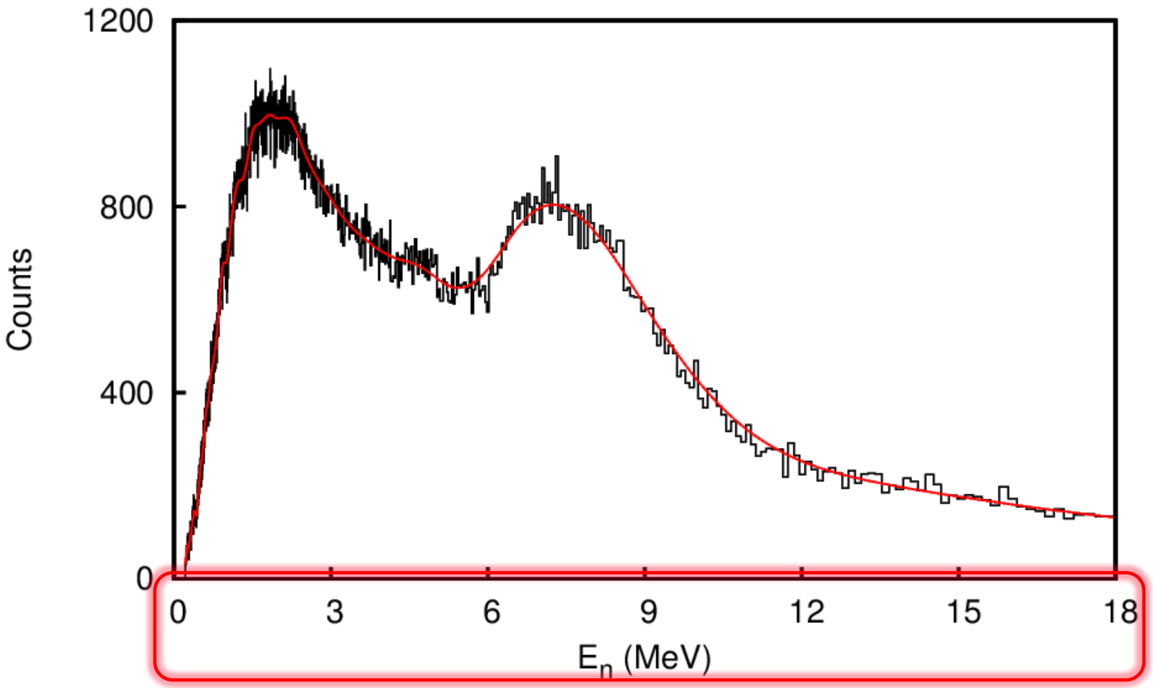


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- Differential γ–production cross sections

$$\frac{d\sigma}{d\Omega}(\theta_i, E_k) = \frac{1}{4\pi}\frac{Y_j(E_k)}{Y_{FC}(E_k)}\frac{\varepsilon_{FC}\ \sigma_U(E_k)}{\varepsilon_j}\frac{t_U}{t_S}\frac{A_S}{A_U}\frac{1}{c_{ms}(E_k)}$$

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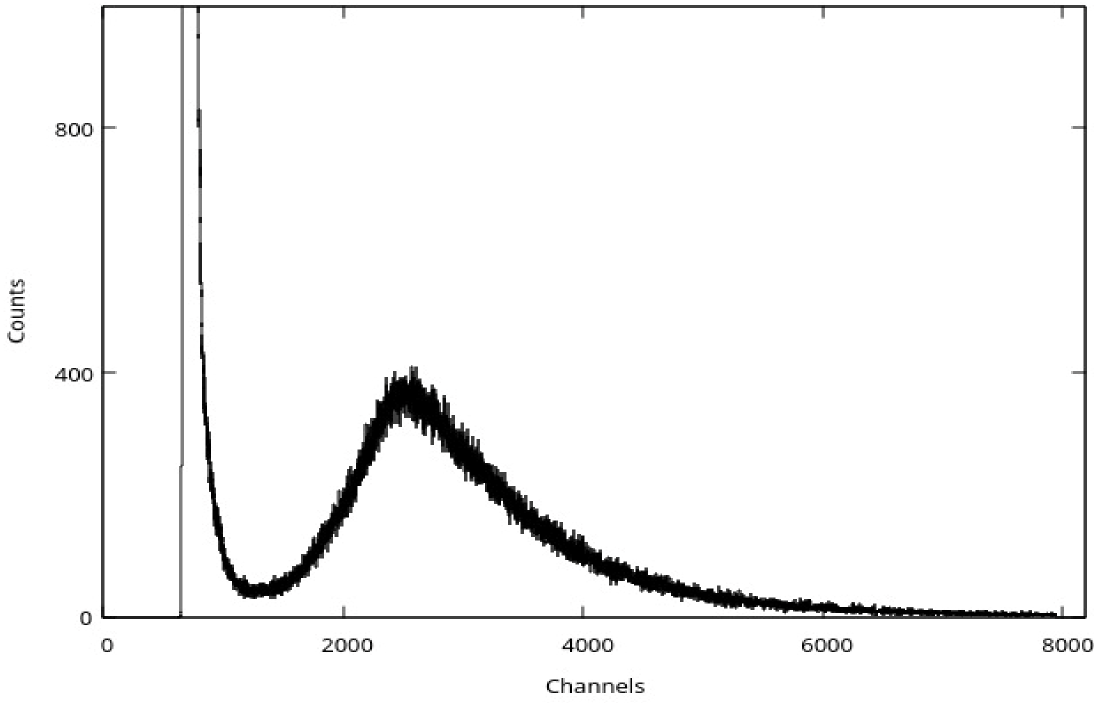
## ➢ The efficiency of the fission chamber

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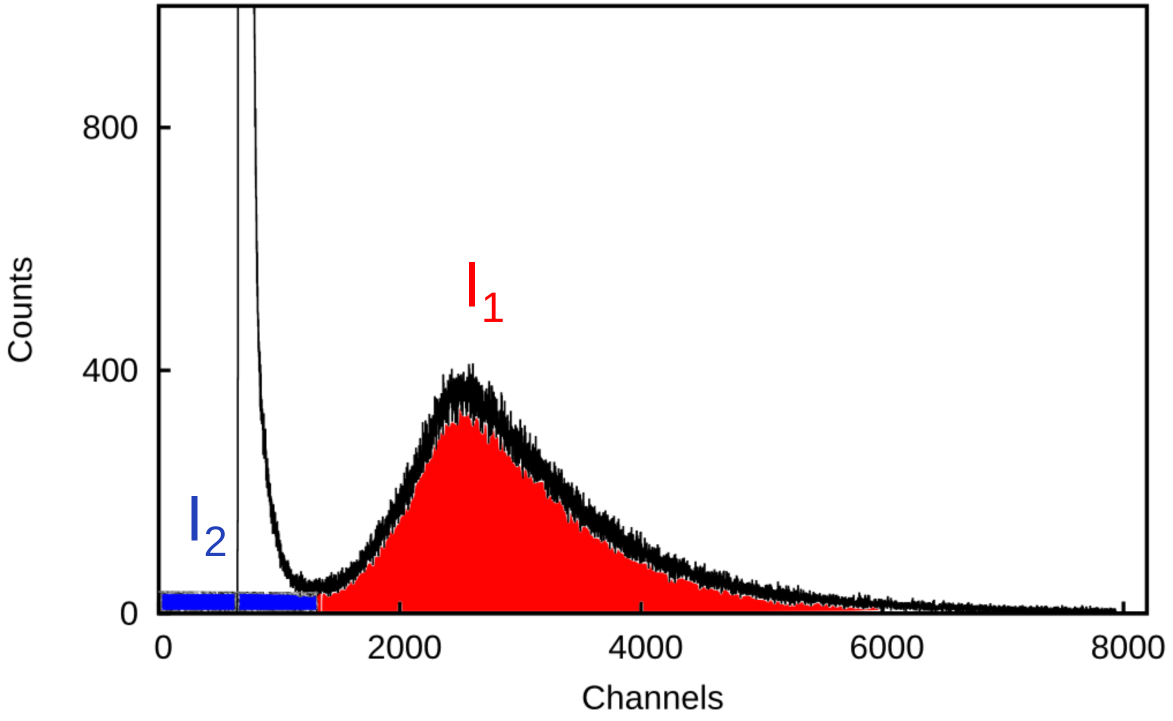
## ➢ The efficiency of the fission chamber

$$\varepsilon_1 = \frac{I_1}{I_1 + I_2} = 0.920^*$$




* experimental value

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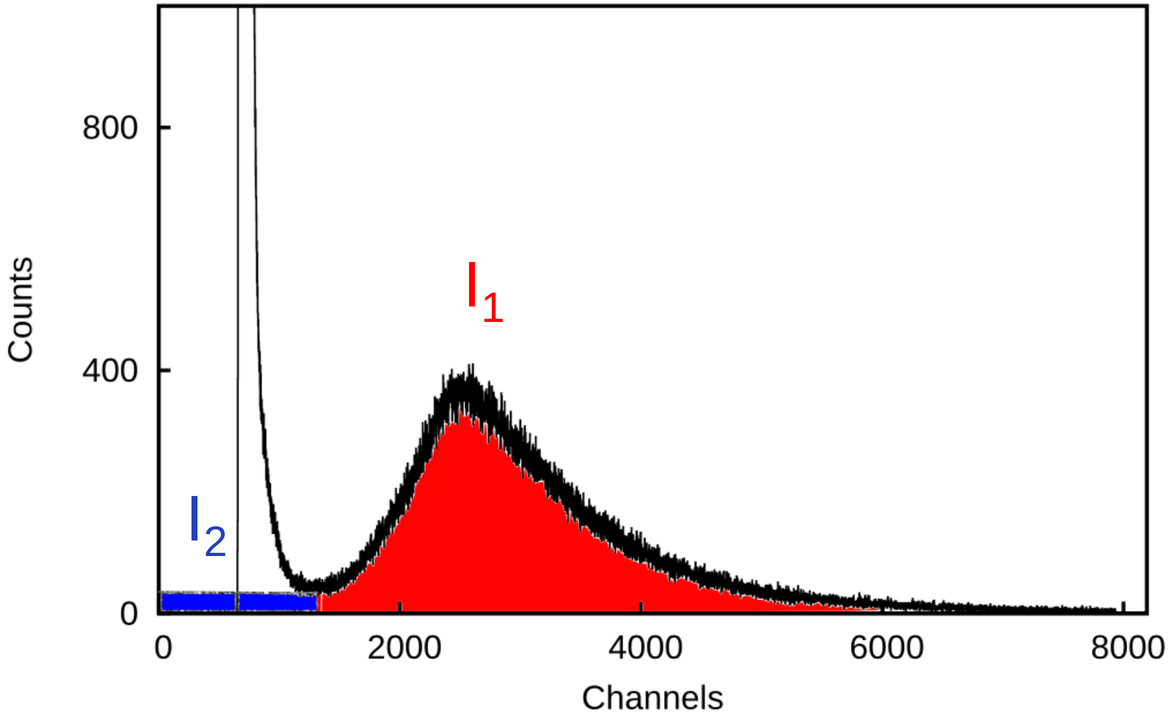
## ➢ The efficiency of the fission chamber

$$\varepsilon_1 = \frac{I_1}{I_1 + I_2} = 0.920^*$$

$$\varepsilon_2 = 0.982^{**}$$




* experimental value

** accounts for the number of the fission fragments that stop in the deposits

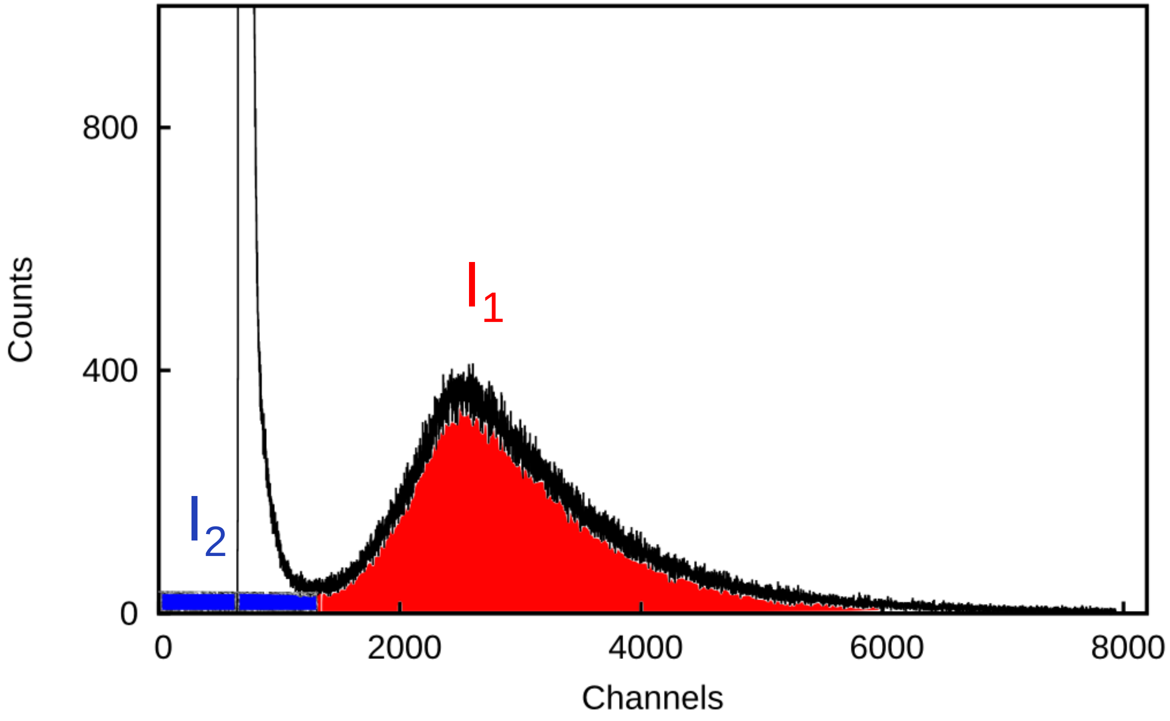
➢ The efficiency of the fission chamber

$$\varepsilon_1 = \frac{I_1}{I_1+I_2} = 0.920^{*}$$

$$\varepsilon_2 = 0.982^{**}$$

$$\varepsilon_3 = 0.947^{***}$$

$$\boldsymbol{\varepsilon_{FC}} = \varepsilon_1 \cdot \varepsilon_2 \cdot \varepsilon_3 = 0.855$$




[*] experimental value

[**] accounts for the number of the fission fragments that stop in the deposits

[***] accounts for the inhomogeneity of the $UF_4$ deposits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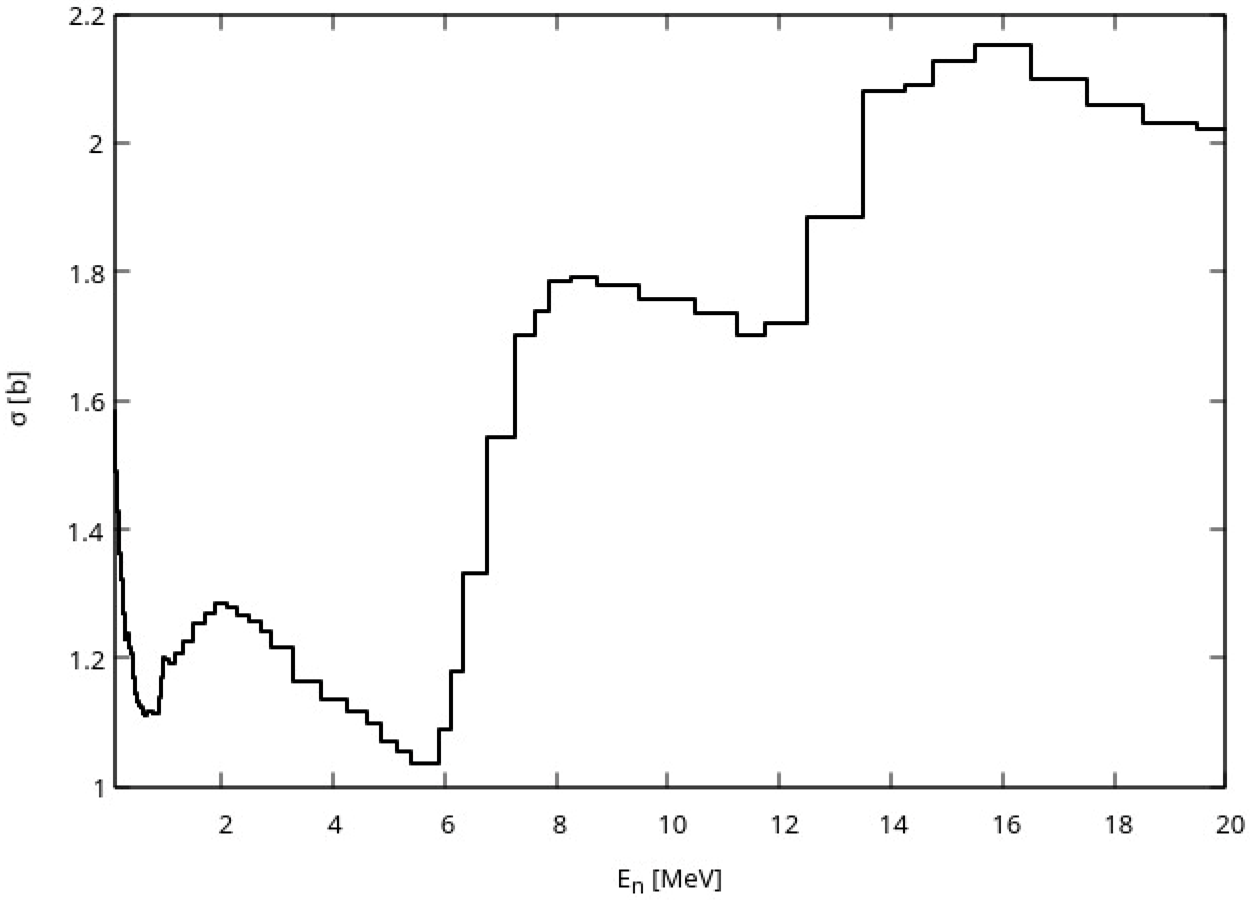
- Differential γ–production cross sections

$$\frac{d\sigma}{d\Omega}(\theta_i, E_k) = \frac{1}{4\pi} \frac{Y_j(E_k)}{Y_{FC}(E_k)} \frac{\varepsilon_{FC} \quad \sigma_U(E_k)}{\varepsilon_j} \frac{t_U}{t_S} \frac{A_S}{A_U} \frac{1}{c_{ms}(E_k)}$$

## ➢ The standard $^{235}U(n,f)$ cross section used as a reference

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## Constants:

- Areal density of the $^{235}U$ deposit ($t_U$=3.089 x$10^{-3}$ g/$cm^2$)
- Areal density of the sample ($t_S$= 0.933 g/$cm^2$)
- Atomic mass of $^{235}U$ ($A_U$=235.043 a.m.u)
- Atomic mass of sample ($A_S$=53.939 a.m.u)

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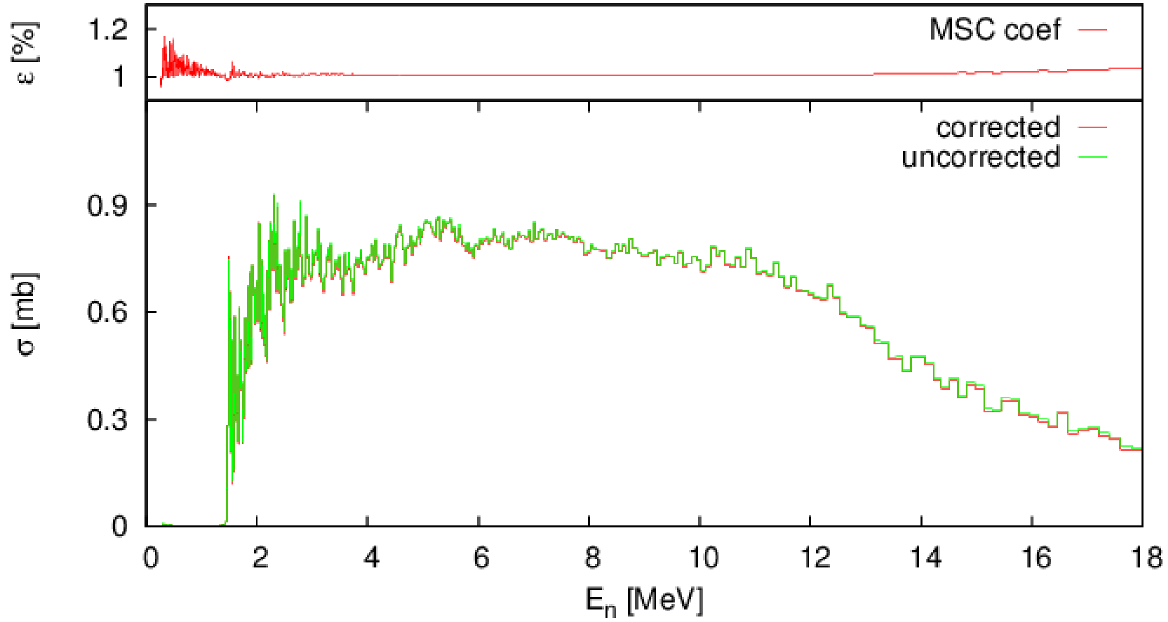
# ➢ Neutron multiple scattering and attenuation corrections (using MCNP6)

- take into account the effects in the sample and in the surrounding materials.
- important because if a neutron undergoes multiple scattering or is attenuated the flux is altered and also the time of the (n, n'γ) event will not correspond to the energy of the incident neutron.

- simultaneously taken into account via MCNP 6 simulations




Steps:

1. Geometry description
2. Measured γ-production cross section used as a dose card
3. Reaction rates calculated both for full geometry and for void after fission chamber
4. Correction factor determined by the ratio of the two reaction rates for each γ-production cross section

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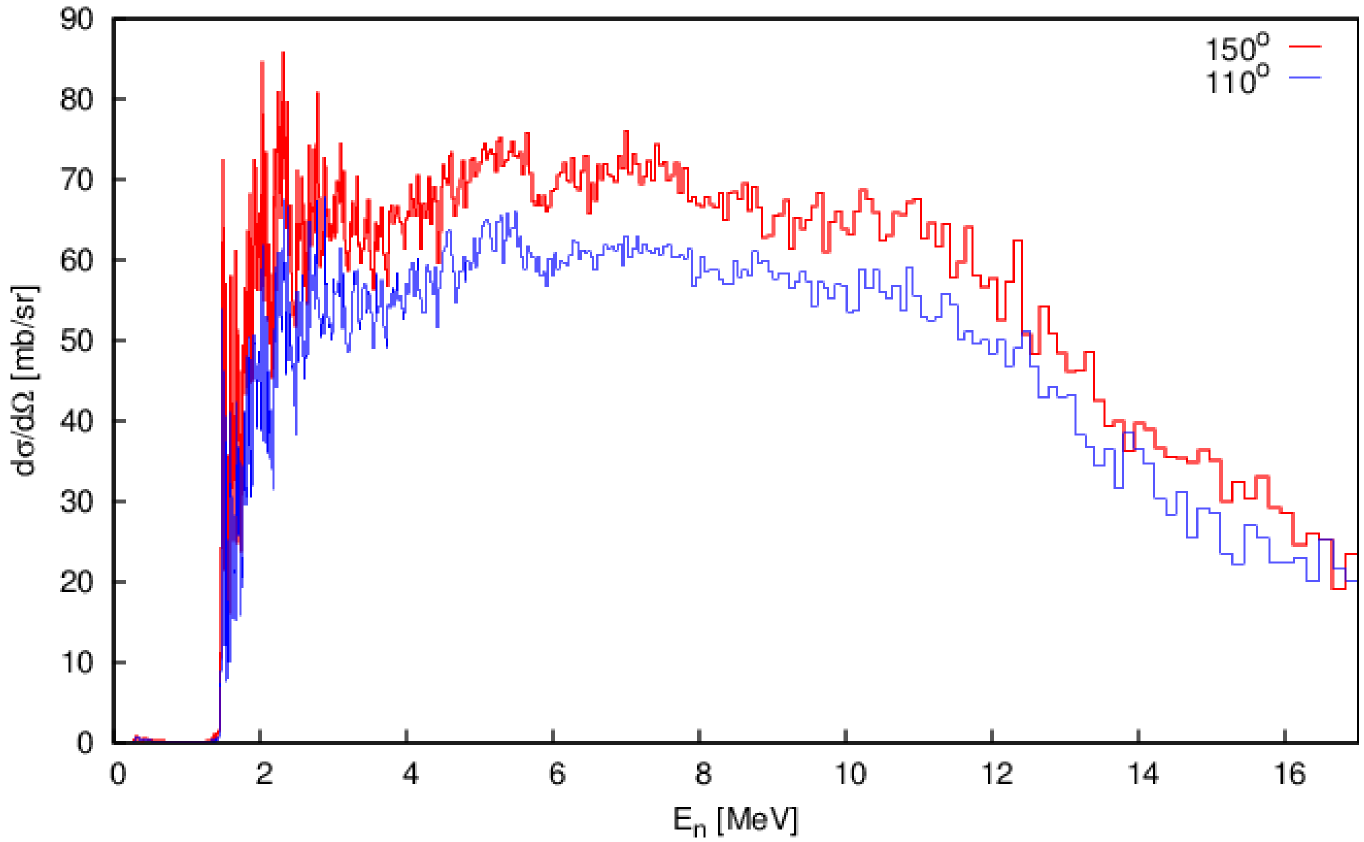




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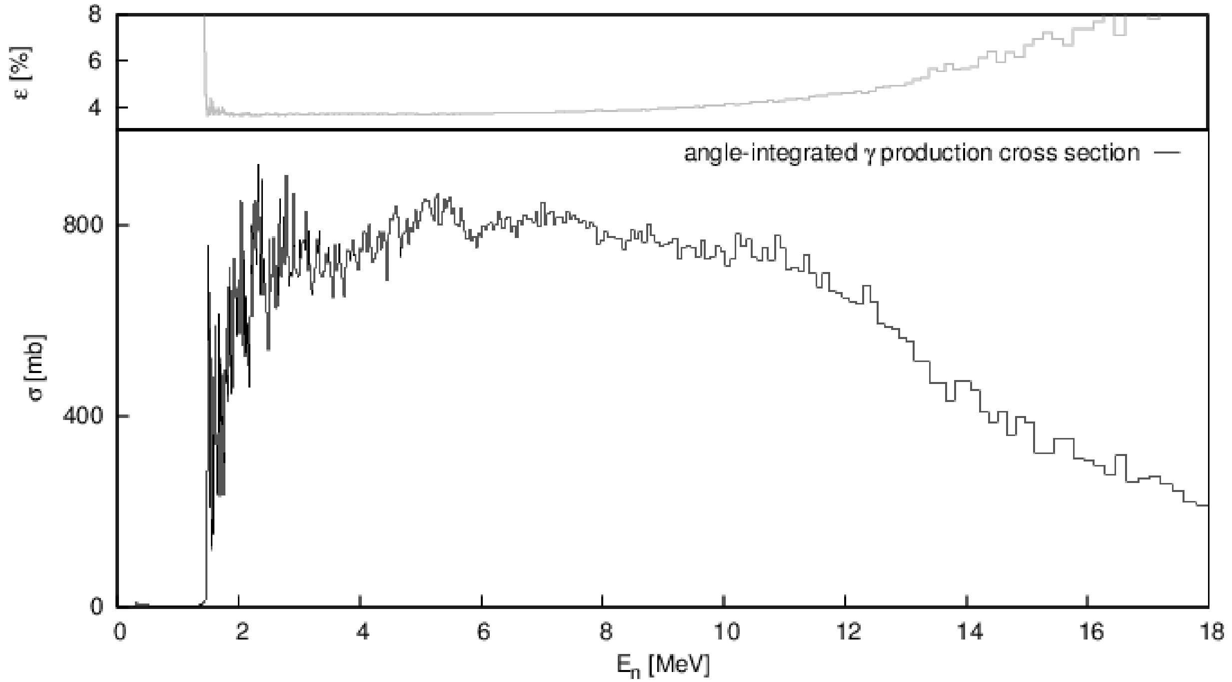
## ➢ Angle-integrated γ–production cross sections

- Calculated using the gaussian quadrature method
- Writing the differential cross sections in terms of Legendre polynomials
- cos(110°) and cos(150°) are notes of the 4th order Legendre polynomial

$$\sigma(E_k) = 2\pi[w_{110^o} \frac{d\sigma}{d\Omega}(110^o, E_k) + [w_{150^o} \frac{d\sigma}{d\Omega}(150^o, E_k)]$$

$w_{110^o}$ = 1.30429 $w_{150^o}$ = 0.69571

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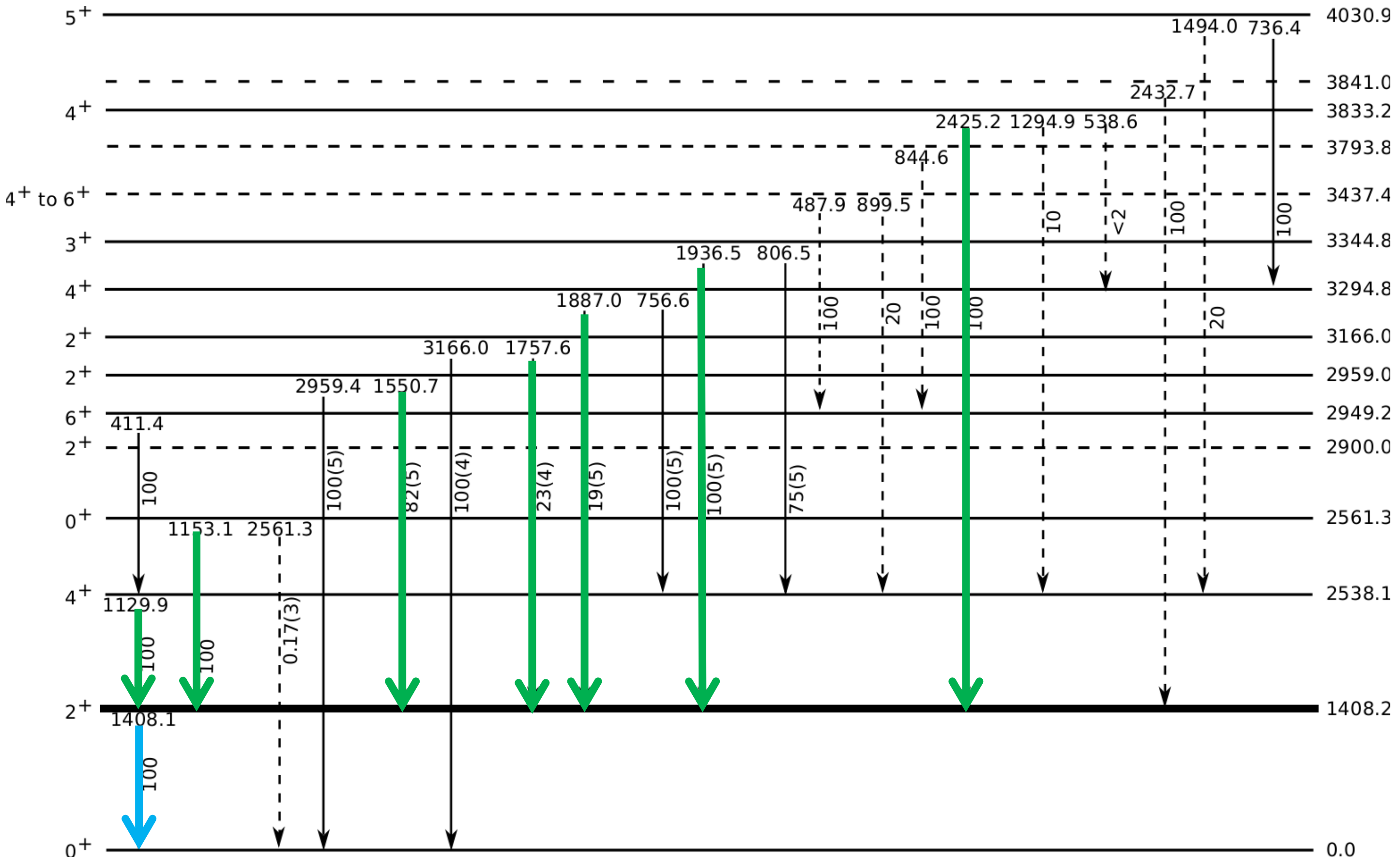
# ➢ Level cross sections

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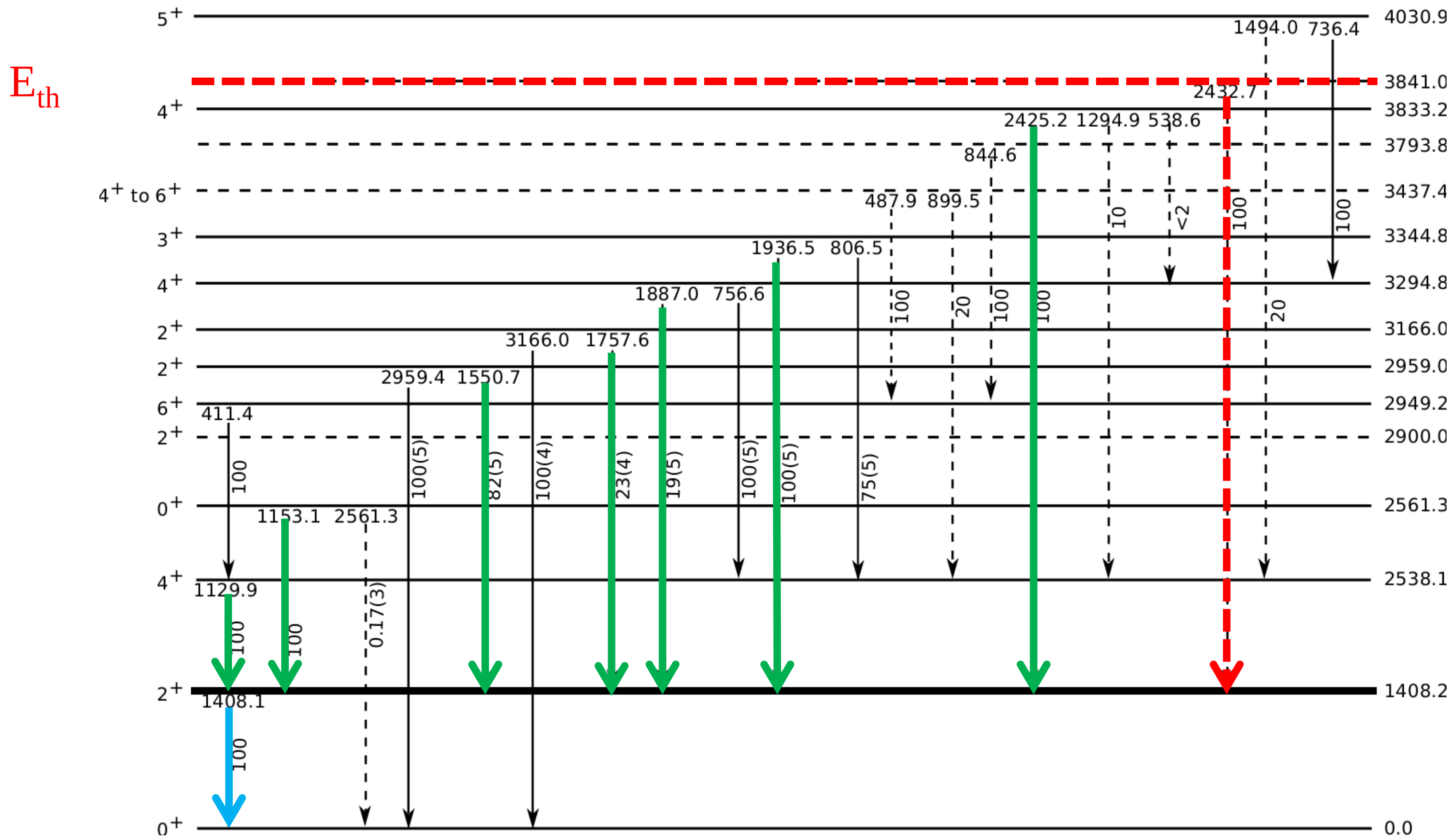
## ➢ Level cross sections

- Limited by our detection possibility.



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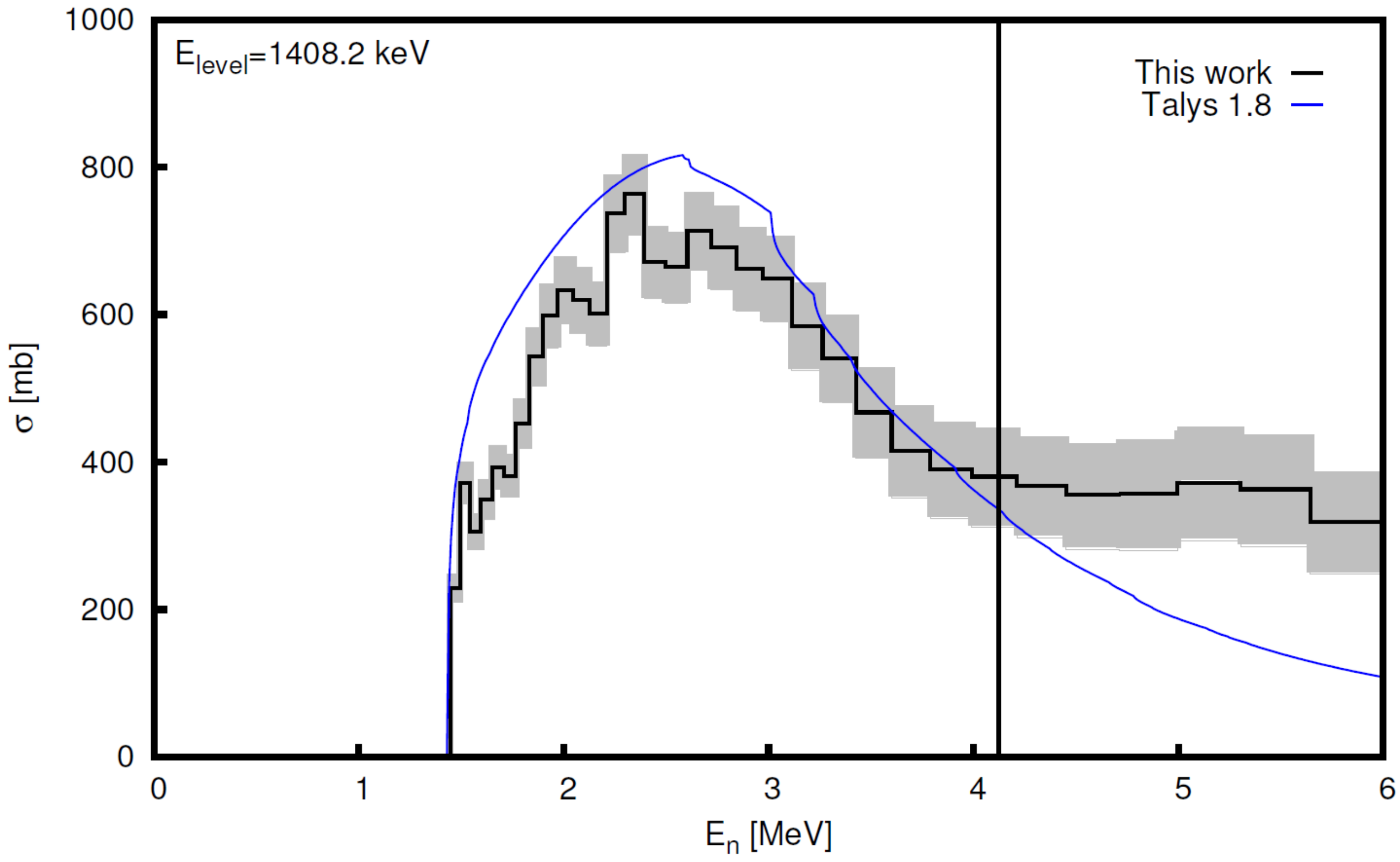


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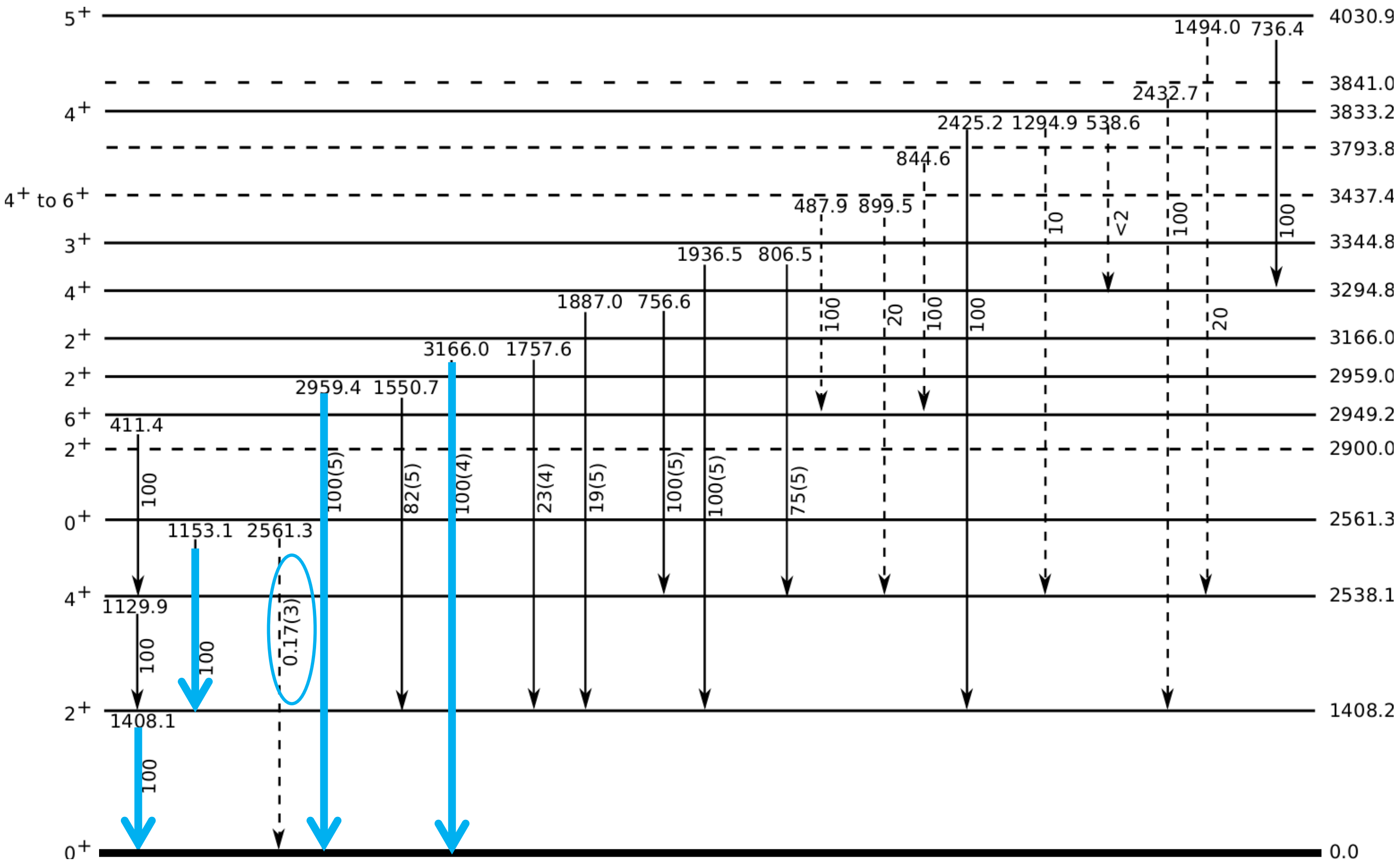
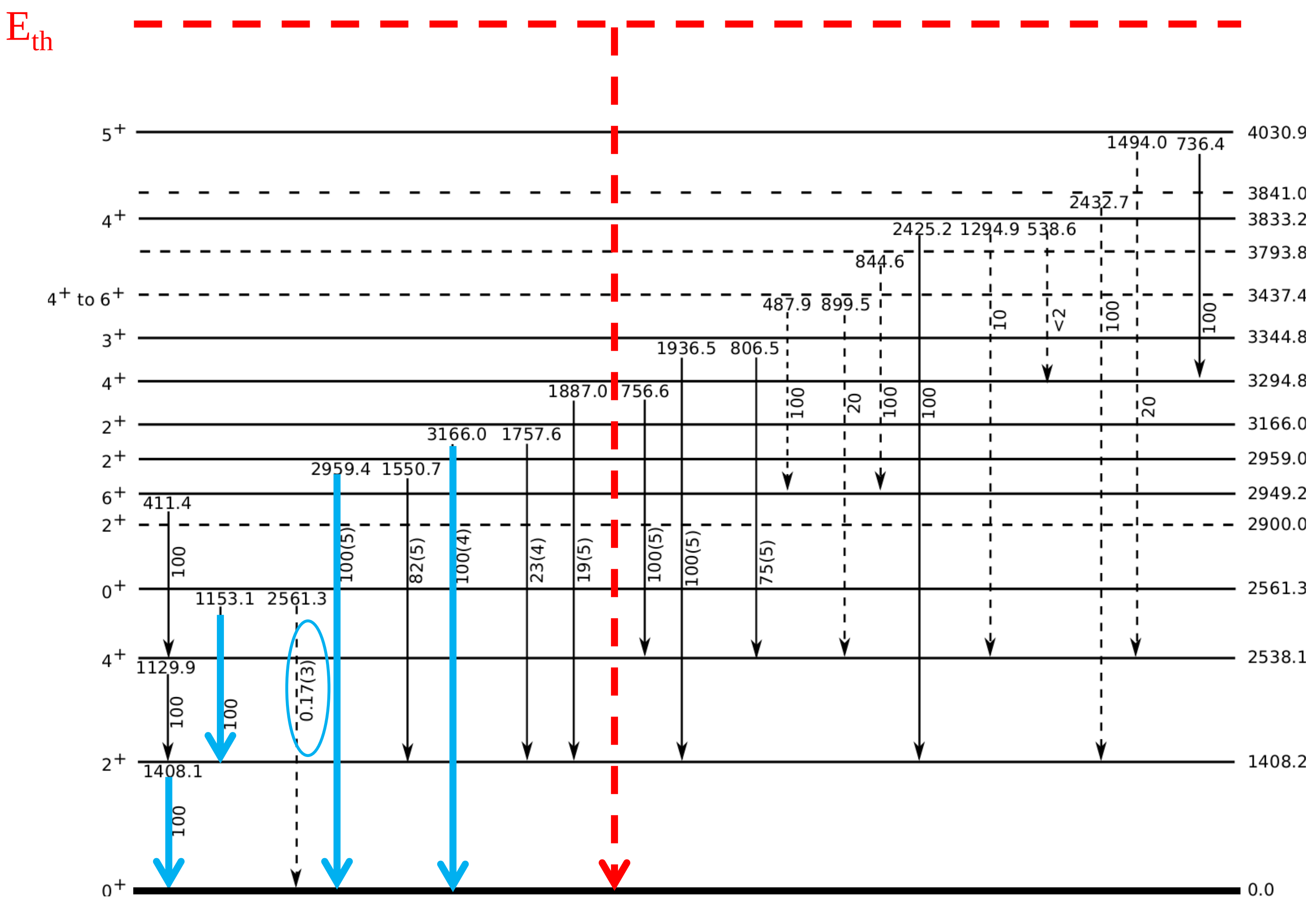
## ➢ Total inelastic cross sections



## ➢ Total inelastic cross sections

- Limited by our detection possibility.



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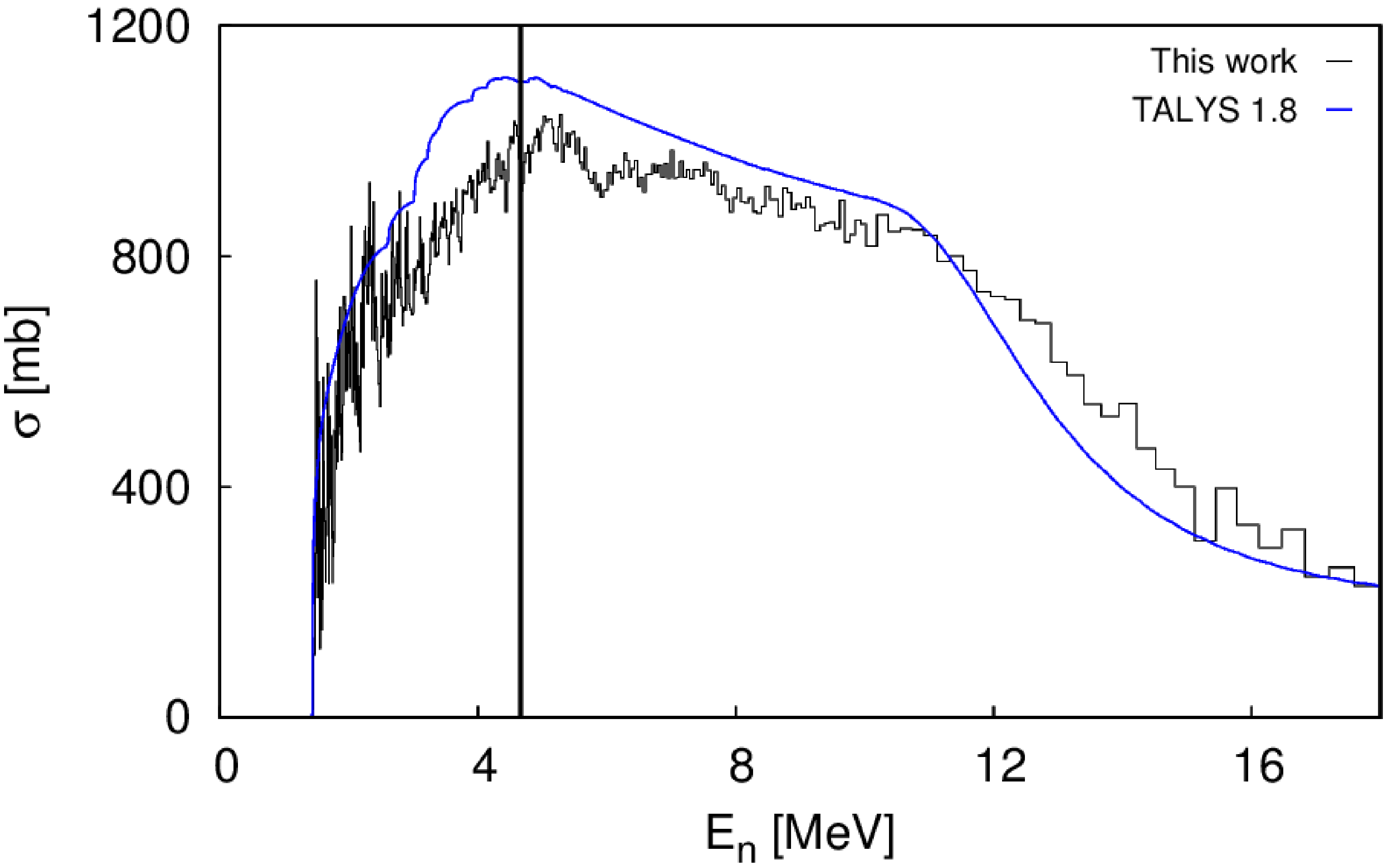



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# Data analysis procedure

Uncertainty calculation

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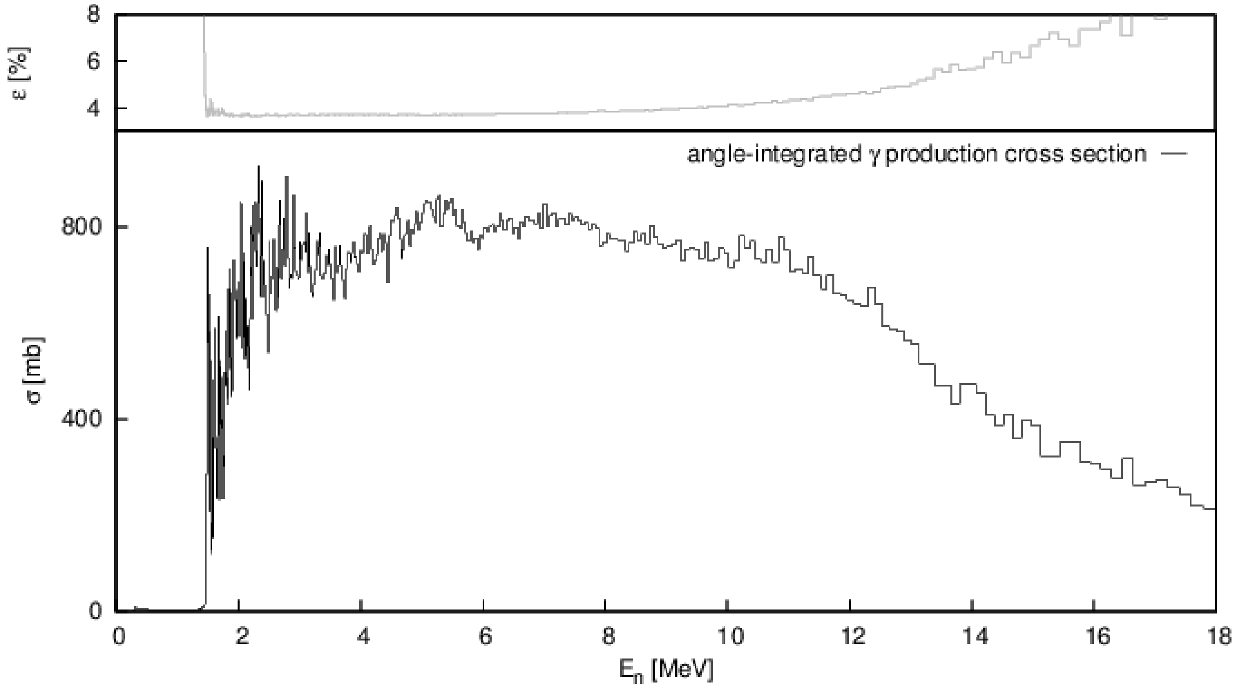
## Differential γ–production cross sections: primary results

$$\frac{d\sigma}{d\Omega}(\theta_i, E_k) = \frac{1}{4\pi}\frac{Y_j(E_k)}{Y_{FC}(E_k)}\frac{\varepsilon_{FC}\ \ \sigma_U(E_k)}{\varepsilon_j}\frac{t_U}{t_S}\frac{A_S}{A_U}\frac{1}{c_{ms}(E_k)}$$

## Angle-integrated γ–production cross sections: main reported results

$$\sigma(E_k) = 2\pi[w_{110^o}\frac{d\sigma}{d\Omega}(110^o, E_k) + [w_{150^o}\frac{d\sigma}{d\Omega}(150^o, E_k)]$$

| Parameter | Value (%) |
|---|---|
| $Y_j(E_k)$ | ≅1% ($E_n$<10 MeV) ≅5% ($E_n$=10÷20 MeV) |
| $Y_{FC}(E_k)$ | 3% |
| $\varepsilon_{FC}$ | 2% |
| $\varepsilon_j$ | 2% |
| $\sigma_U(E_k)$ | <1% |
| $c_{ms}(E_k)$ | <1% |
| $t_U$ | <1% |
| $t_S$ | 2% |

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➢ Differential γ–production cross sections: primary results

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➢ Angle-integrated γ–production cross sections: main reported results

$$\sigma(E_k) = 2\pi[w_{110^o}\frac{d\sigma}{d\Omega}(110^o, E_k) + [w_{150^o}\frac{d\sigma}{d\Omega}(150^o, E_k)]$$

| Parameter | Value (%) |
|---|---|
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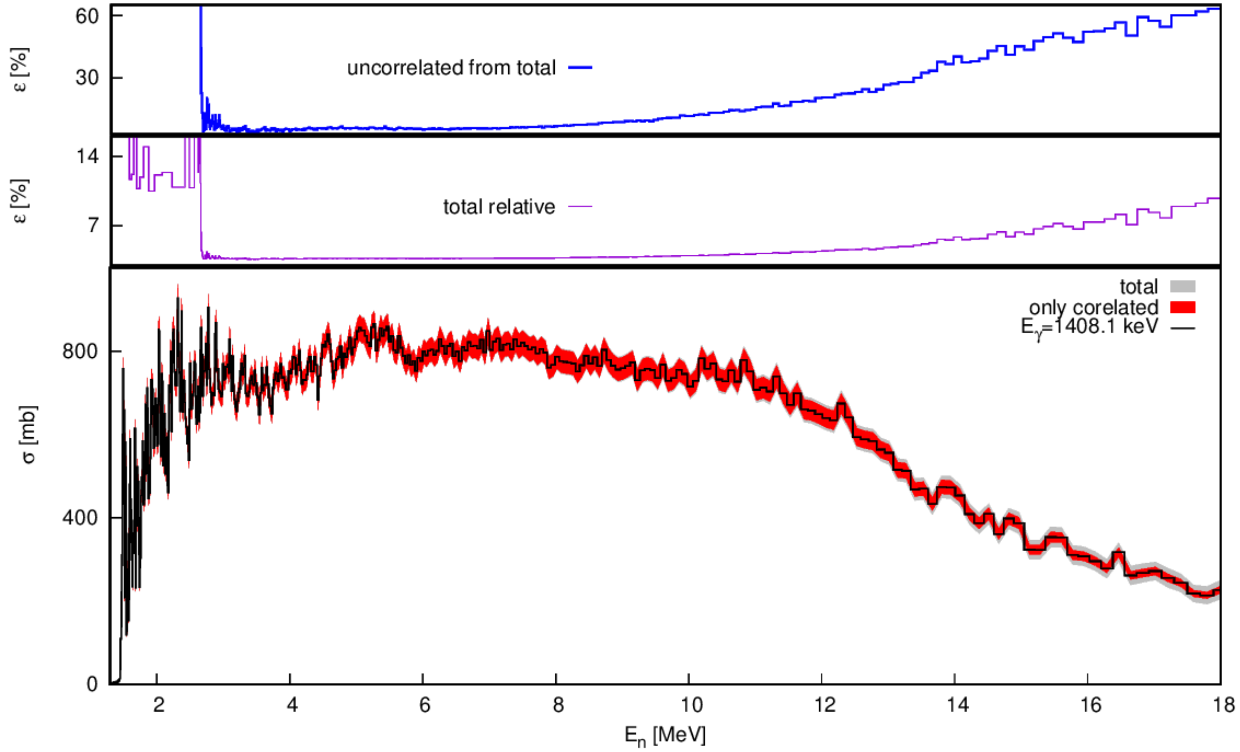
| $Y_{FC}(E_k)$ | 3% |
| $\varepsilon_{FC}$ | 2% |
| $\varepsilon_j$ | 2% |
| $\sigma_U(E_k)$ | <1% |
| $c_{ms}(E_k)$ | <1% |
| $t_U$ | <1% |
| $t_S$ | 2% |

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APRENDE

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# Thank you!

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