^{154}Gd(n, γ) and ^{nat}Gd(n, γ) cross section measurement at the n_TOF facility

A. Manna and many others

15th Russbach School on Nuclear Astrophysics, 21 March 2018

Outline

- Scientific Motivations
  - and data in literature
- Gd samples
- Experiment (Aug 2017)
- First data

nice

INTC 2015

Measurement of the neutron capture cross section of gadolinium even isotopes relevant to Nuclear Astrophysics

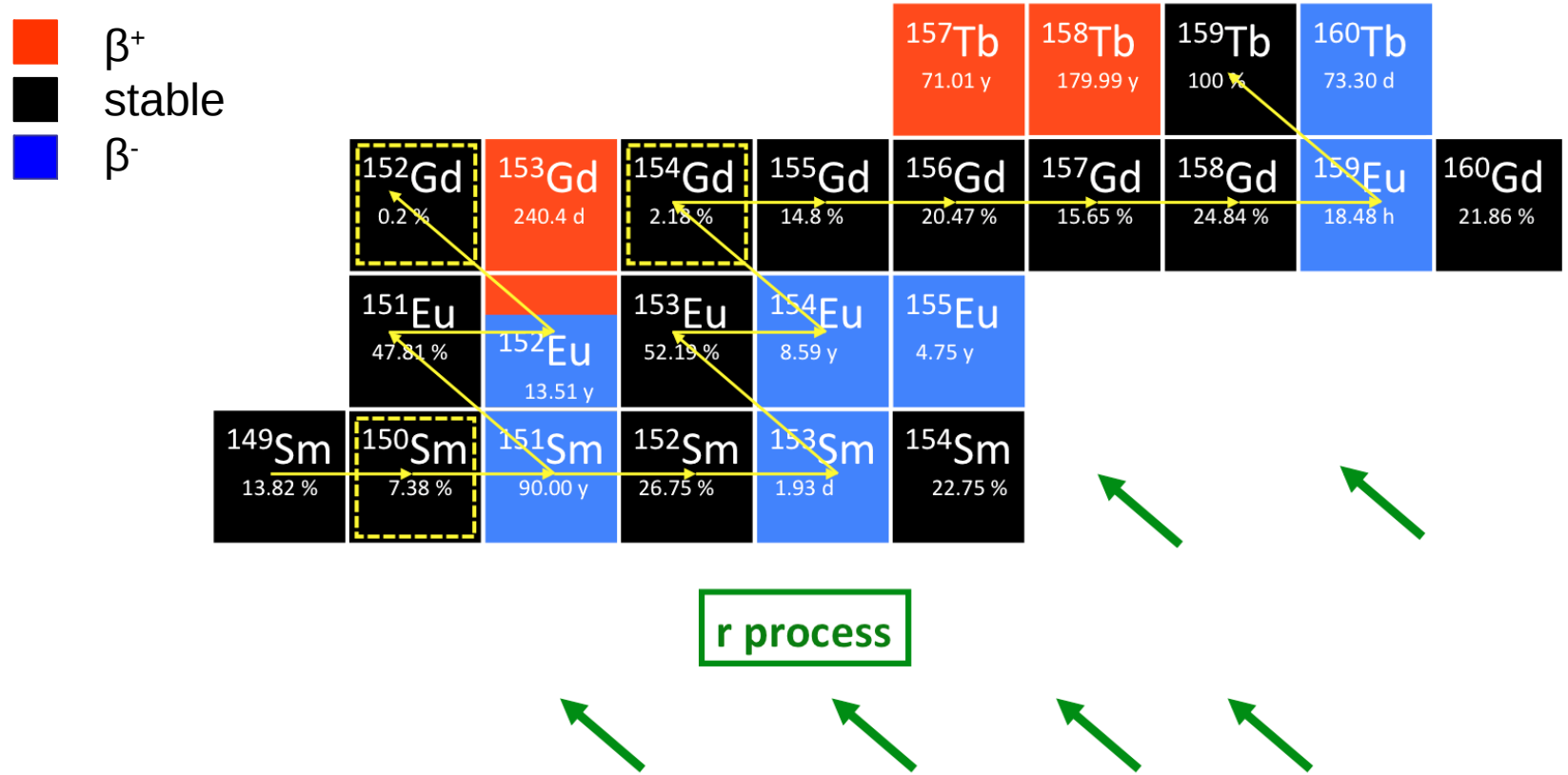
50th Meeting of the INTC, 1 – 2 July 2015

C. Massimi[1,2,s], F. Mingrone[1,s], S. Cristallo[3], E. Berthoumieux[4], D.M. Castelluccio[1,5], N. Colonna[6], M. Diakaki[4], R. Dressler[7], E. Dupont[4], F. Gunsing[4,8], N. Kivel[7], S. Lo Meo[1,5], P.M. Milazzo[9], A. Musumarra[10], D. Schumann[7], G. Tagliente[6], G. Vannini[1,2], V. Variale[6]

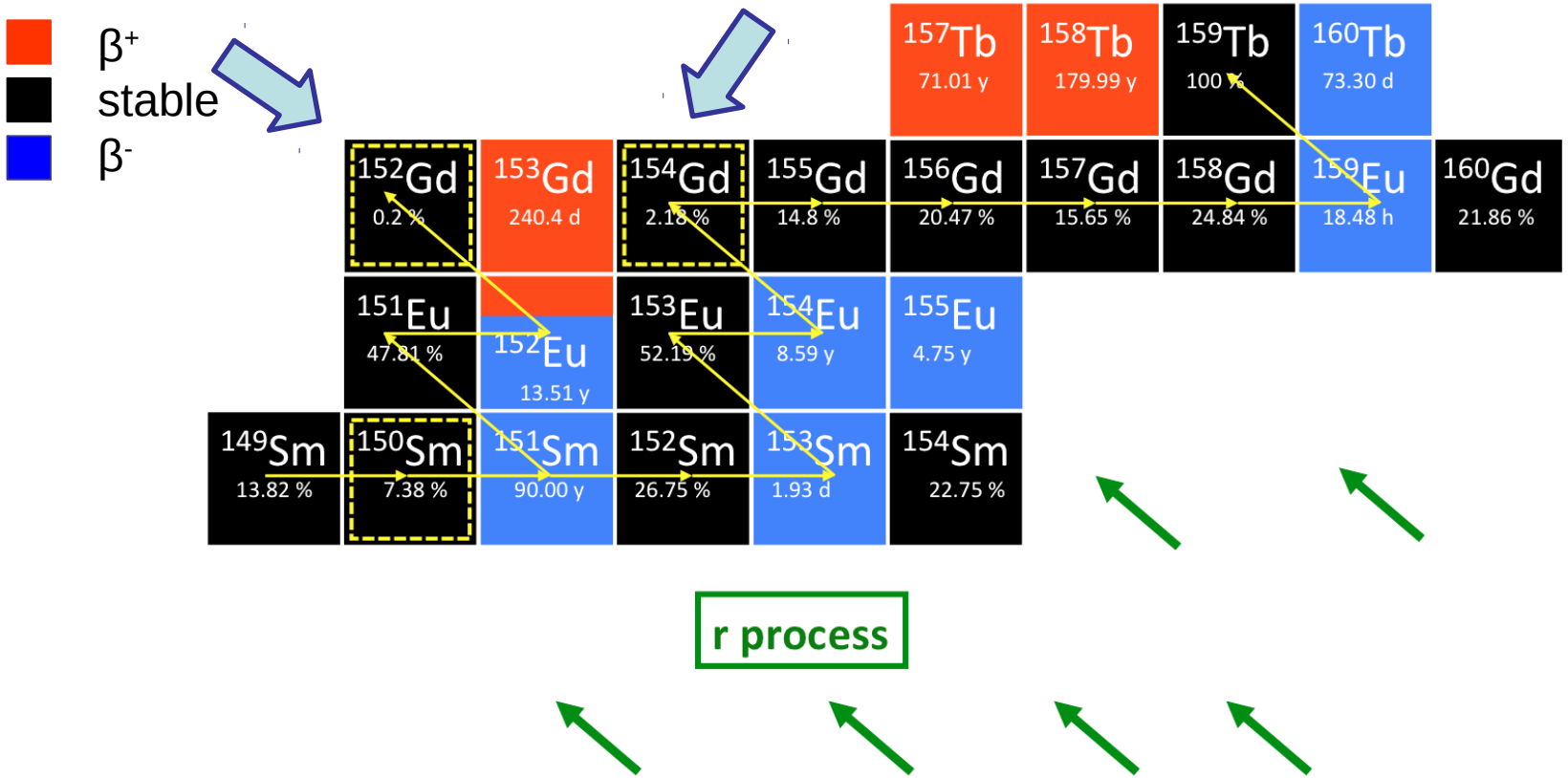
[1] INFN Section of Bologna, Bologna - Italy
[2] Dipartimento di Fisica e Astronomia, Universit`a di Bologna, Bologna - Italy
[3] INAF - Osservatorio Astronomico di Collurania, TERAMO - Italy
[4] CEA, Saclay, Irfu/SPhN, Gif-sur-Yvette - France
[5] ENEA Research Centre E. Clementel, Bologna - Italy
[6] INFN Section of Bari, Bari - Italy
[7] Paul Scherrer Institute, Villigen - Switzerland
[8] European Organization for Nuclear Research (CERN), Geneva - Switzerland
[9] INFN Section of Trieste, Trieste - Italy
[10] INFN Section of Catania, Catania – Italy
[s] **Spokesperson**

Technical coordinator: Oliver Aberle

Scientific Motivations



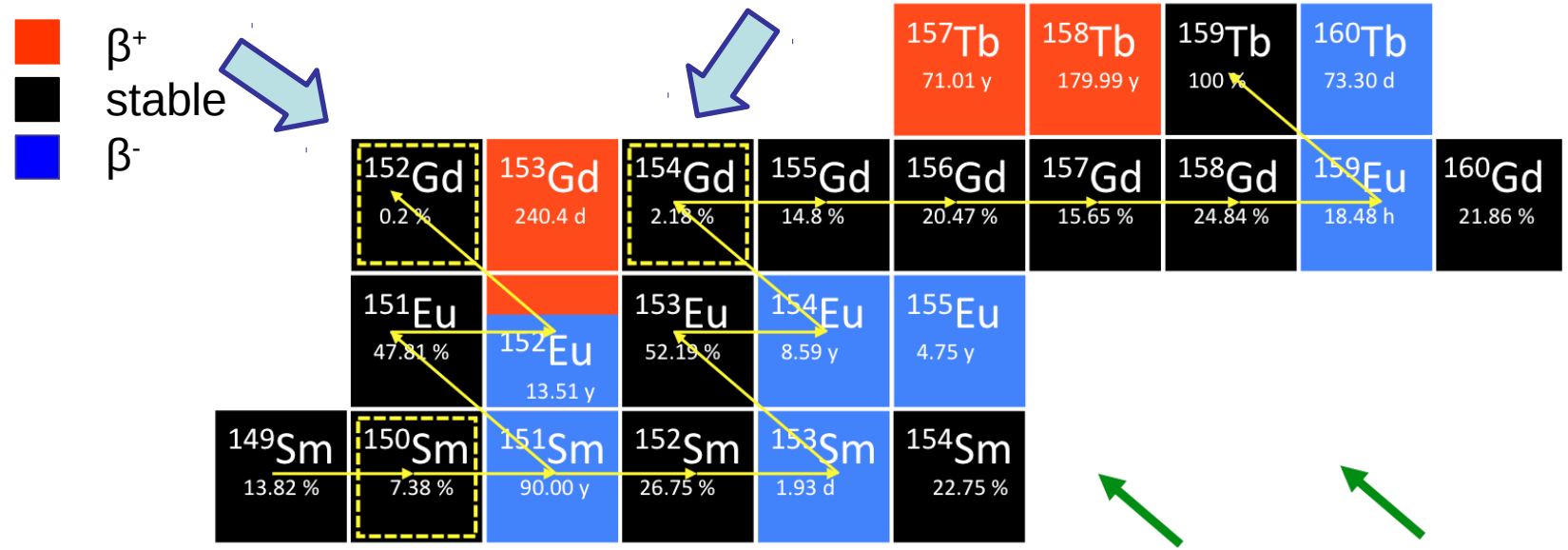
Scientific Motivations



1) **^{152}Gd** and **^{154}Gd** are **s-only** isotopes

- they can be produced only via s process because they are shielded against the β- decay chains from the r-process region by the isobars samarium

Scientific Motivations



r process

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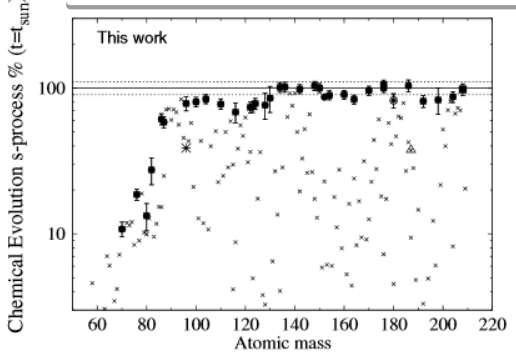
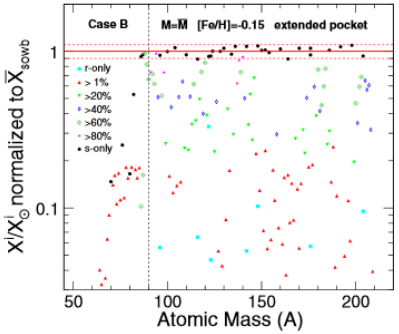
→ Proof of galactic chemical evolution (GCE) models

Scientific Motivations

3 very recent and **independent** studies:

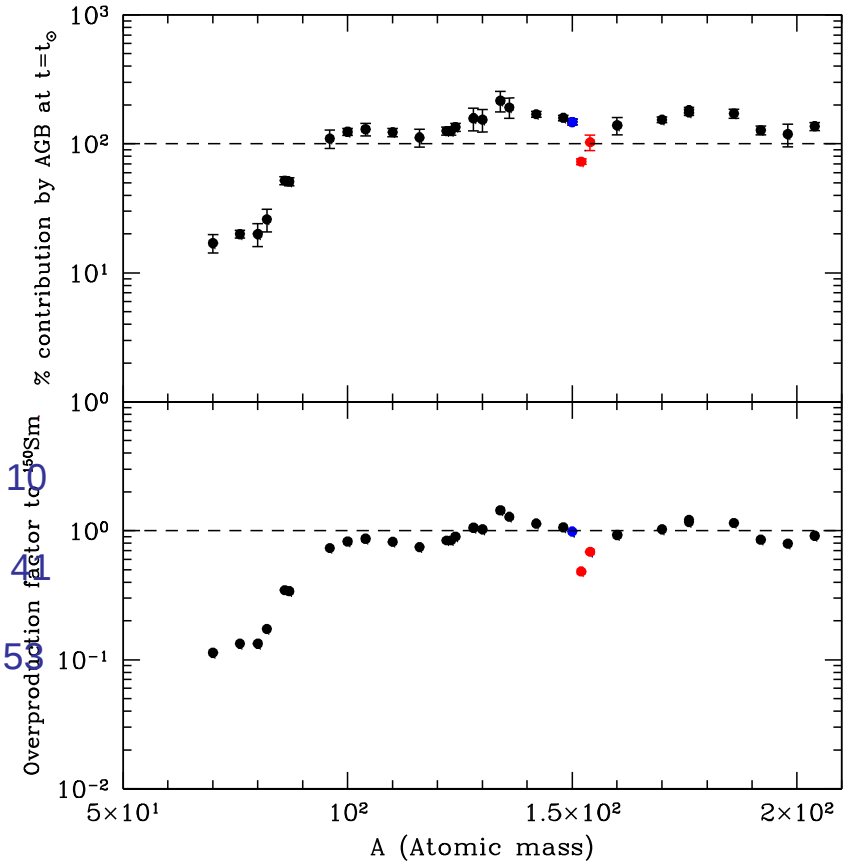




S. Bisterzo, *et al.*, The Astrophysical Journal **787** (2014) 10

C. Trippella, *et al.*, The Astrophysical Journal **787** (2014) 41

S. Cristallo, *et al.*, The Astrophysical Journal **801** (2015) 53



THE ASTROPHYSICAL JOURNAL, 801:53 (14pp), 2015 March 1

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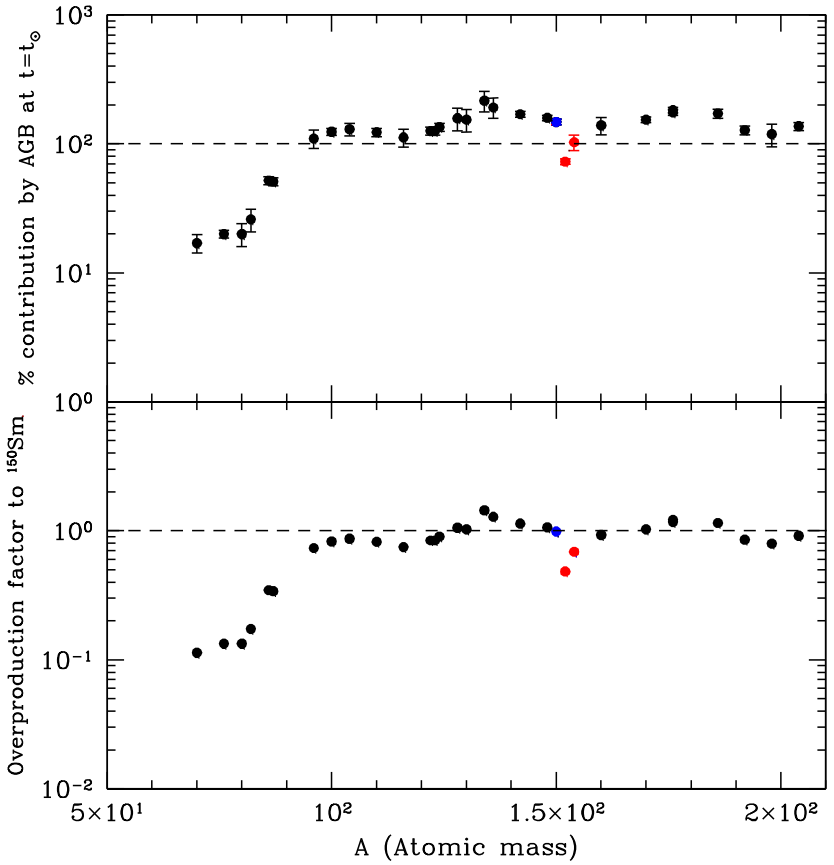
Scientific Motivations

Constraints for the ^{13}C pocket, i.e. the main neutron source of the s process



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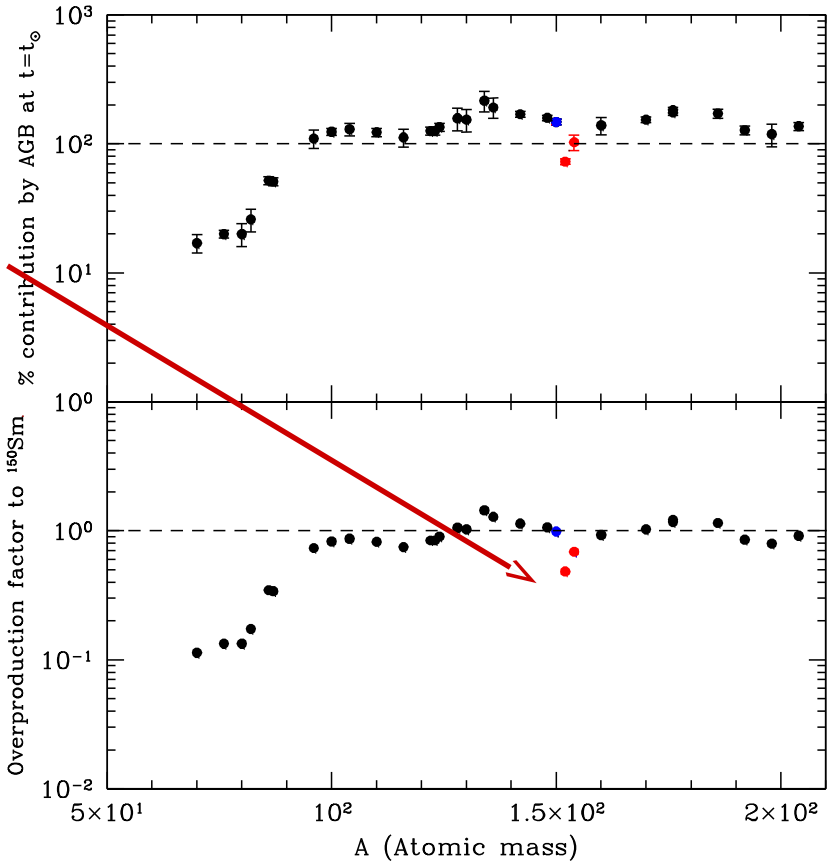
Disagreement of more than 20% between **observation** and **model calculation** of s-process abundances



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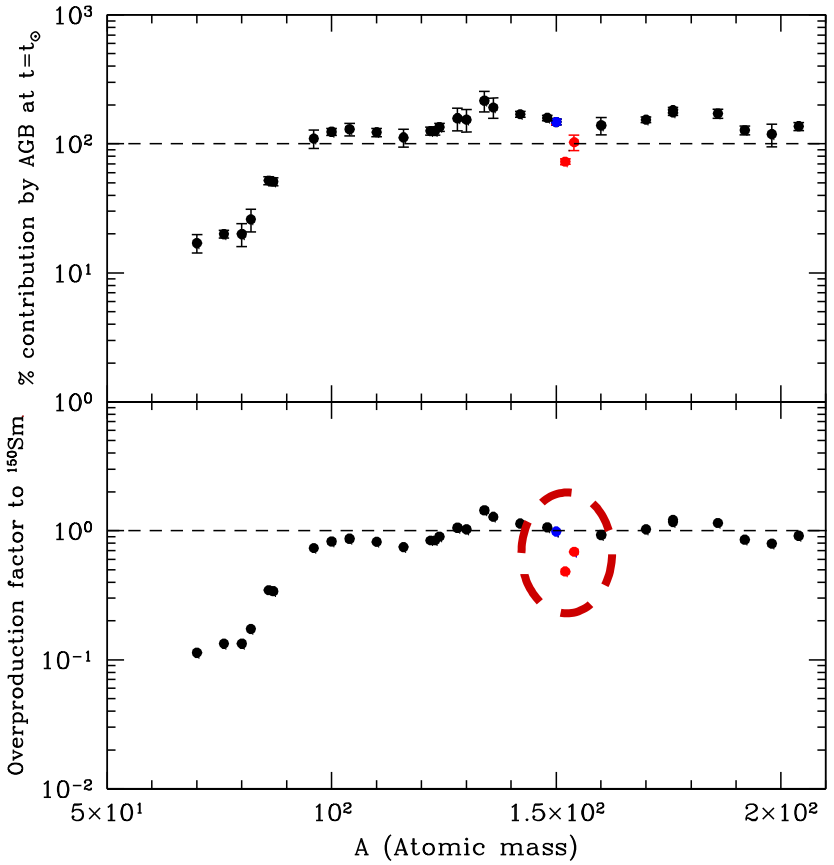
So far, no conclusive identification of the causes of the disagreement:

more accurate nuclear data needed !!!



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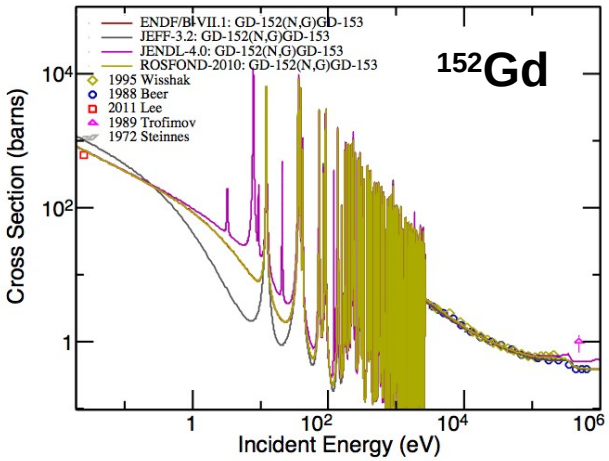
Gd data in literature

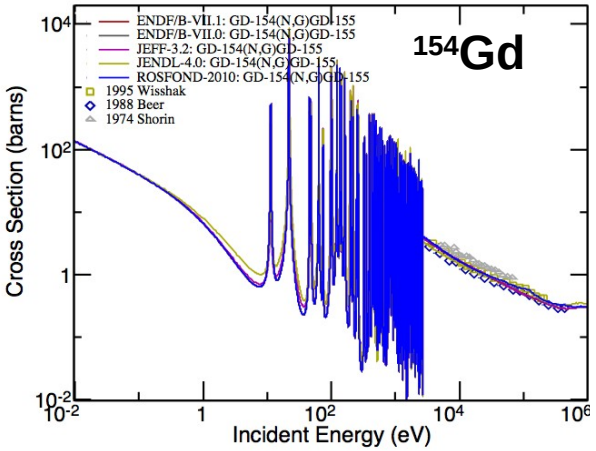
Resolved Resonance Region

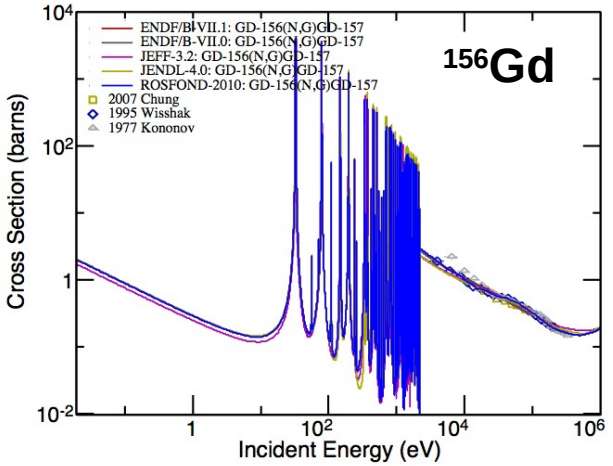
Isotope	Facility	Energy	Enrichment	Capture Detector	Transmission ?
^{152}Gd	ORELA DUBNA	< 2.6 keV < 235 eV	32% 36%	C_6F_6 NaI	yes yes
^{154}Gd	Nevis Lab ORELA DUBNA	< 1 keV < 2.6 keV < 224 eV	66 %	C_6F_6 NaI	yes

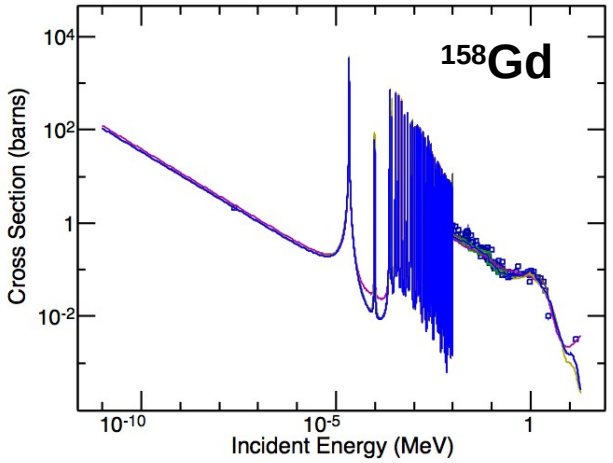
Gd data in literature

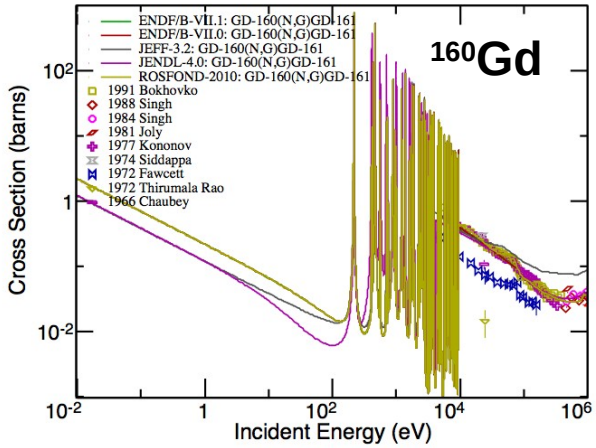
Unresolved Resonance Region









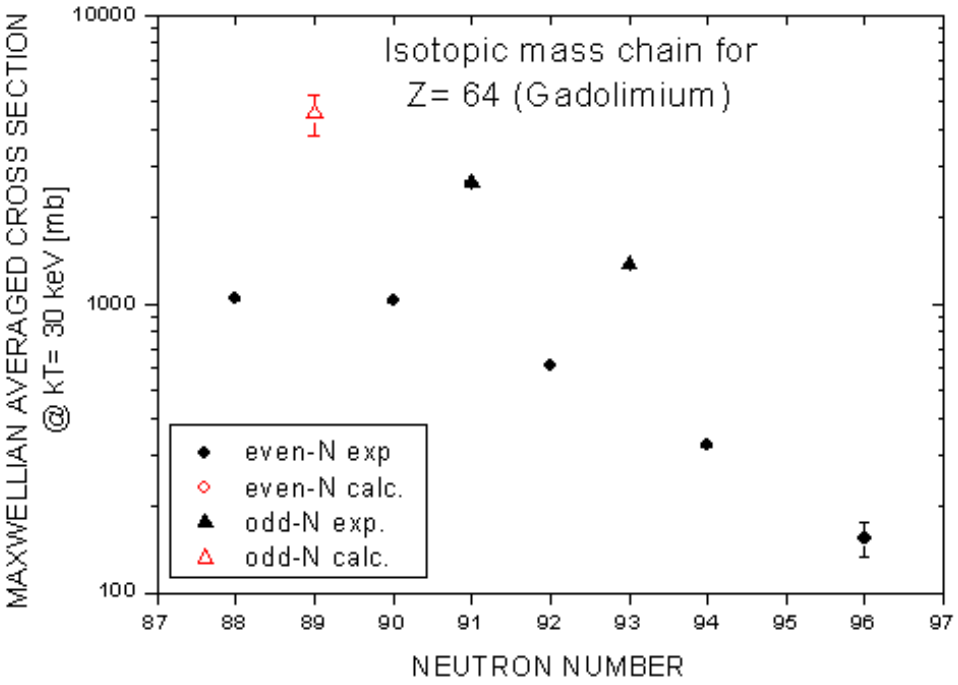


Main reference:
Wisshak and Kappeler

- $3 < E_n < 100$ keV
- Neutron flux from $^{197}Au(n,\gamma\gamma)$
- **4π BaF_2**

Gd data in literature

MACS from KADoNiS



Gd data in literature

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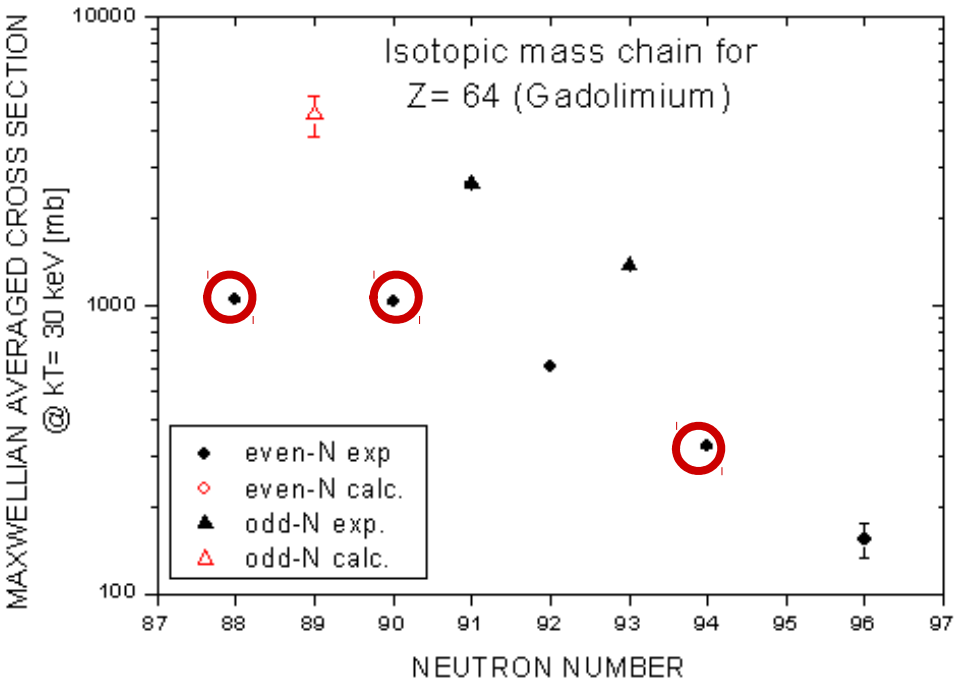
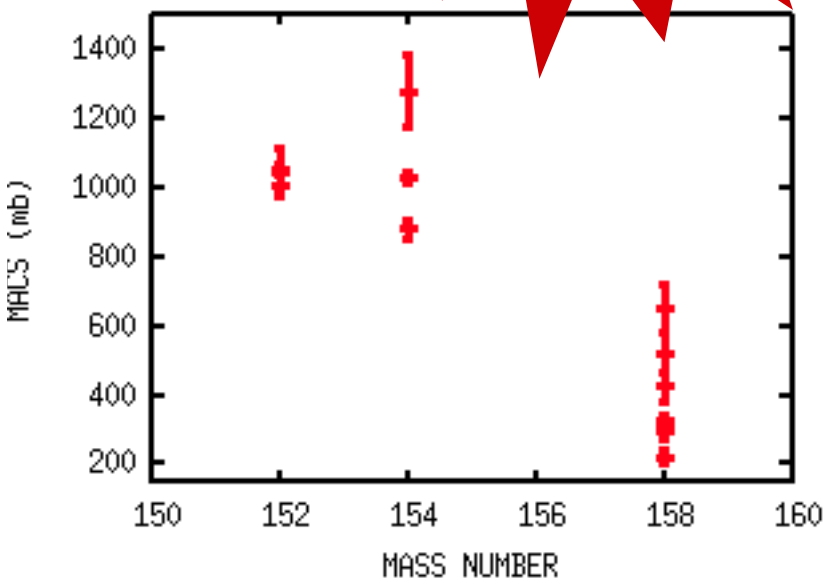
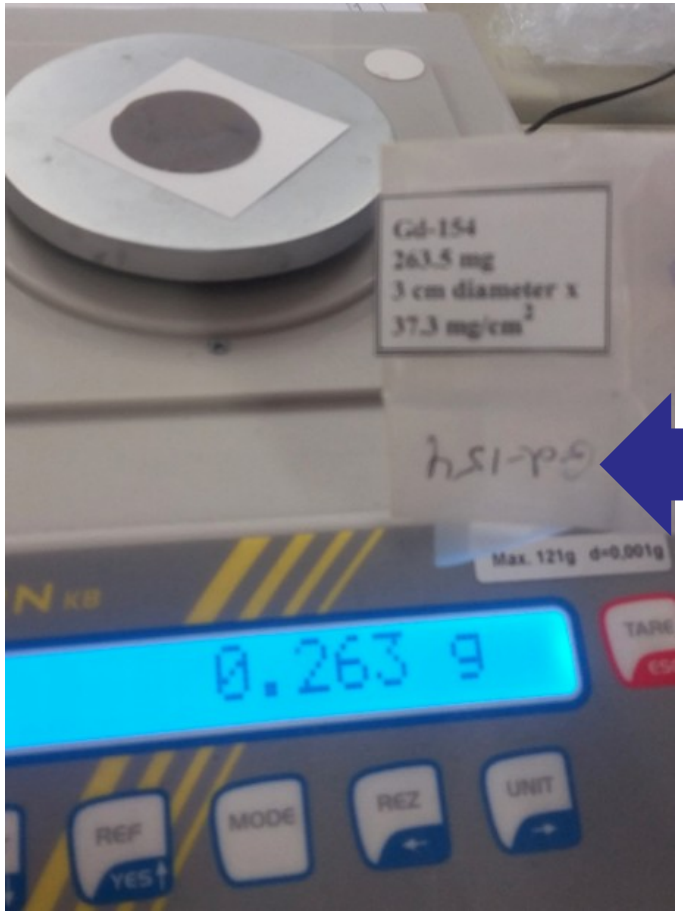


Largest disagreement for ^{154}Gd



Large discrepancies in literature

Gd Samples



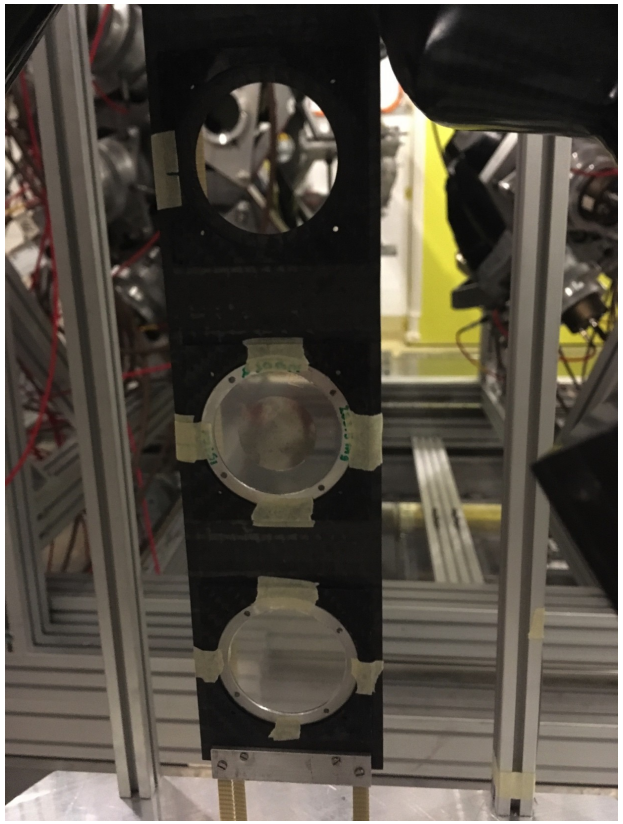
ORNL
0.263 g (~ 17 kE !)
Gd metal
^{154}Gd ~ 66,78 %

Goodfellow
8.749 g
Natural Gd

National Isotope Development Center

Radius = 1.5 cm

Gd Samples

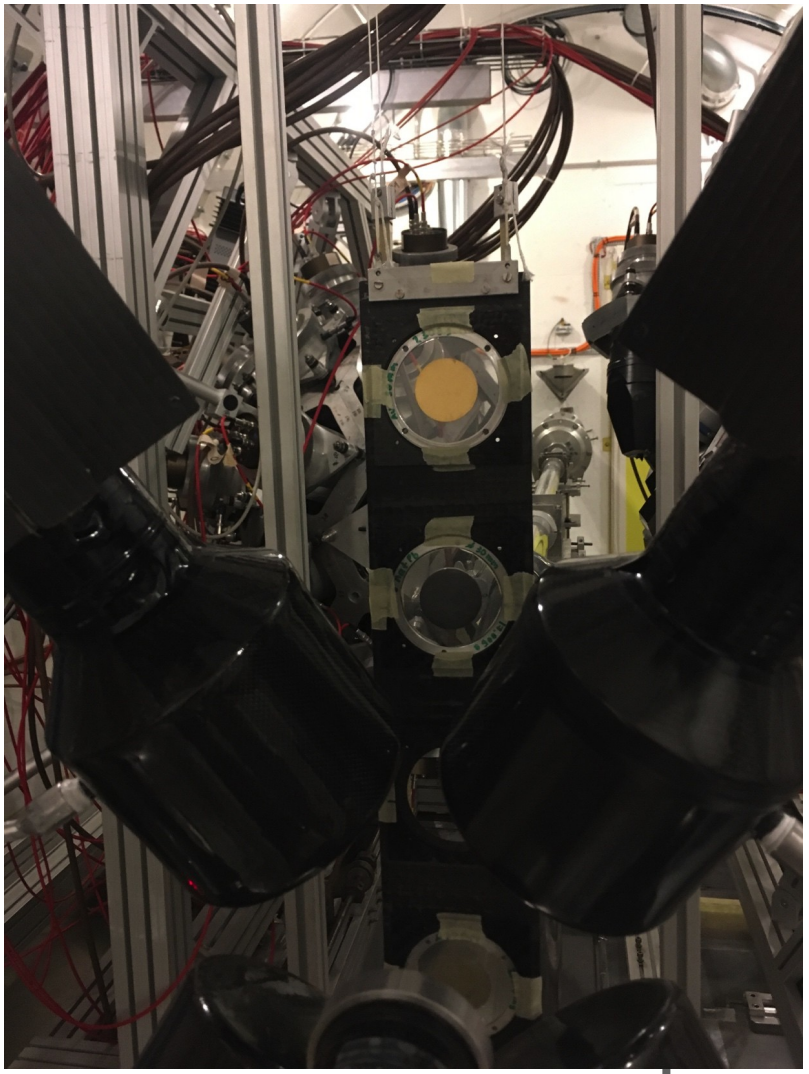


Other samples:

- ^{197}Au (1.308 g)
- Carbon (6.24 g)
- Lead (17.00 g)

R = 1.5 cm

EAR-1
C_6D_6 detectors



Experiment

Isotope	Protons	note
^{197}Au	4×10^{16}	Cyclic – after calibration
^{154}Gd	$\mathbf{1.88 \times 10^{18}}$	
^{nat}Gd	2.3×10^{17}	
Carbon	4×10^{16}	From ^{88}Sr and ^{89}Y campaign
Lead	1.2×10^{17}	
Empty	3.5×10^{17}	
Others	2.0×10^{17}	Filters bkg

2.6×10^{18}

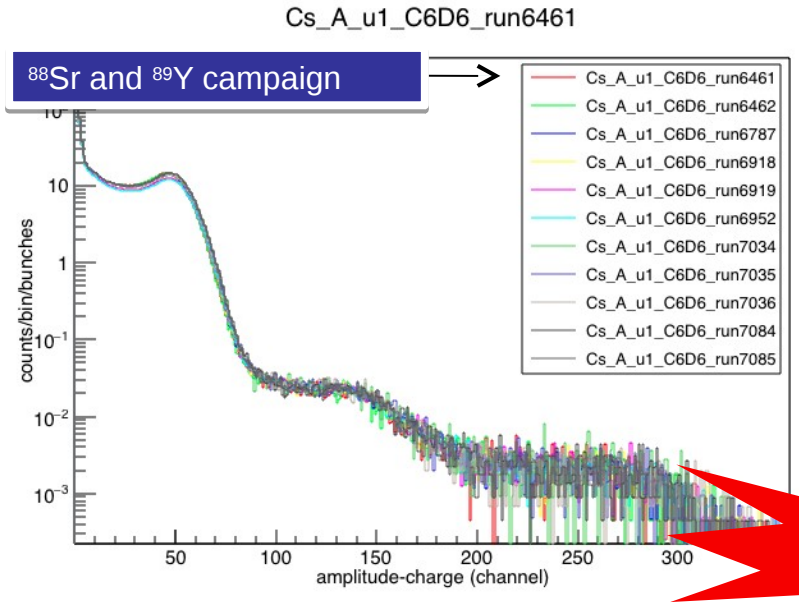
Full calibration (^{137}Cs, ^{88}Y, Am-Be and Cm-C composite γ-ray source) **every week !!!**

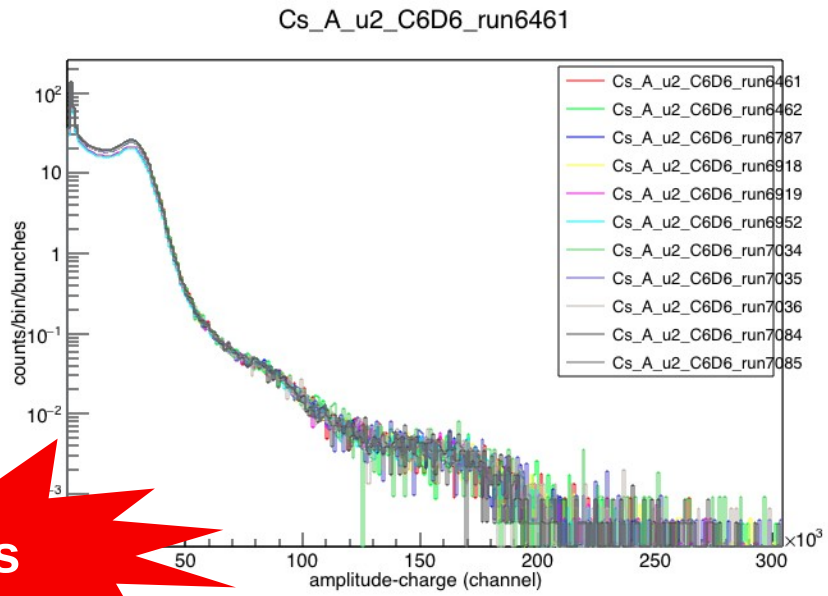
14th August 2017
10th September 2017

Experiment

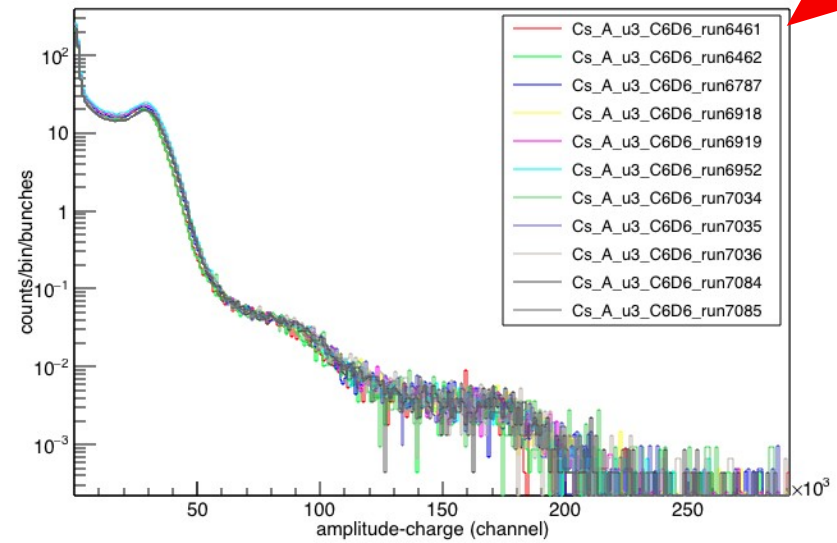
Istituto Nazionale di Fisica Nucleare

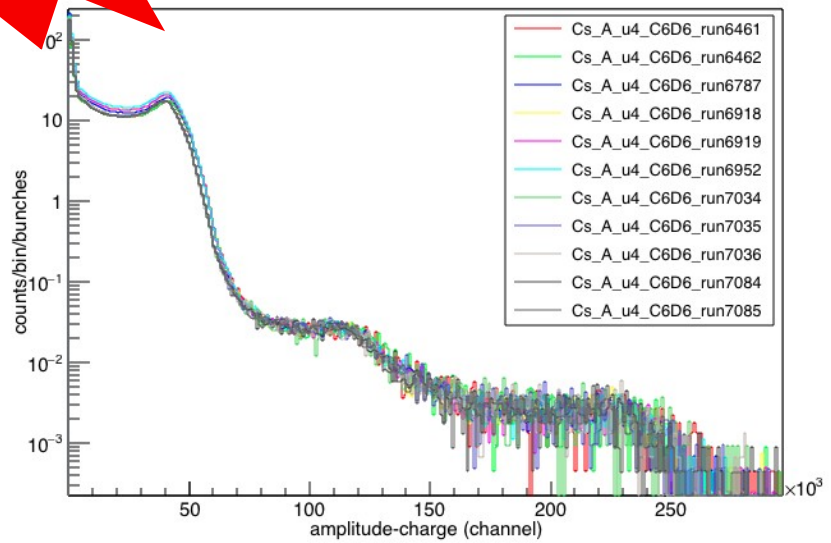
^{88}Sr and ^{89}Y campaign





^{137}Cs

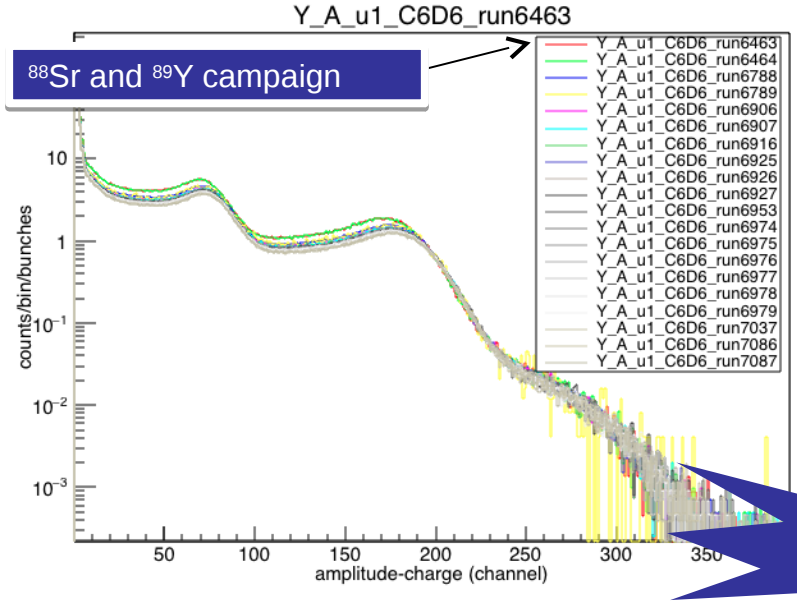


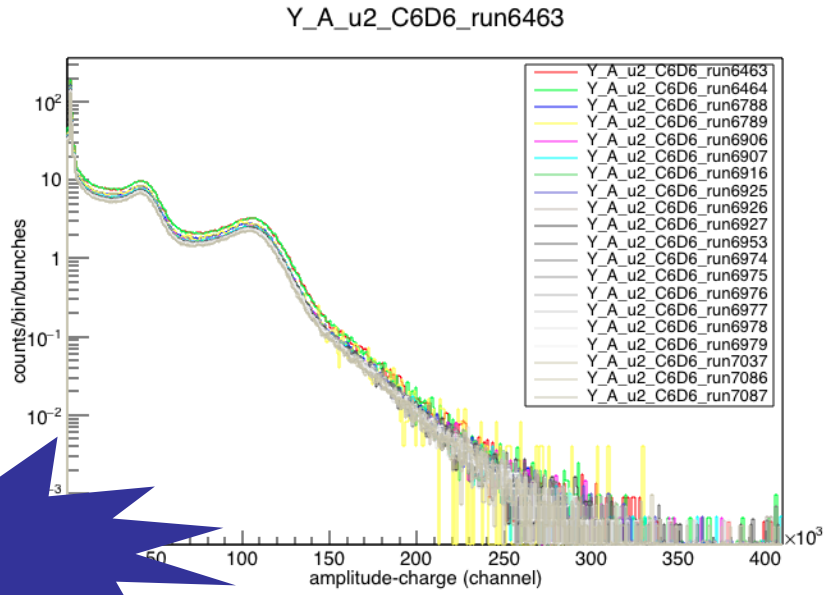


Experiment

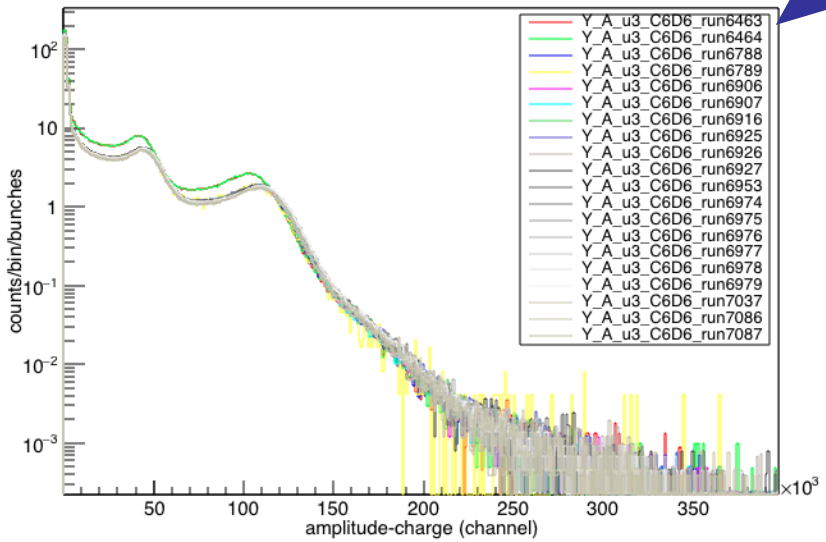
Istituto Nazionale di Fisica Nucleare

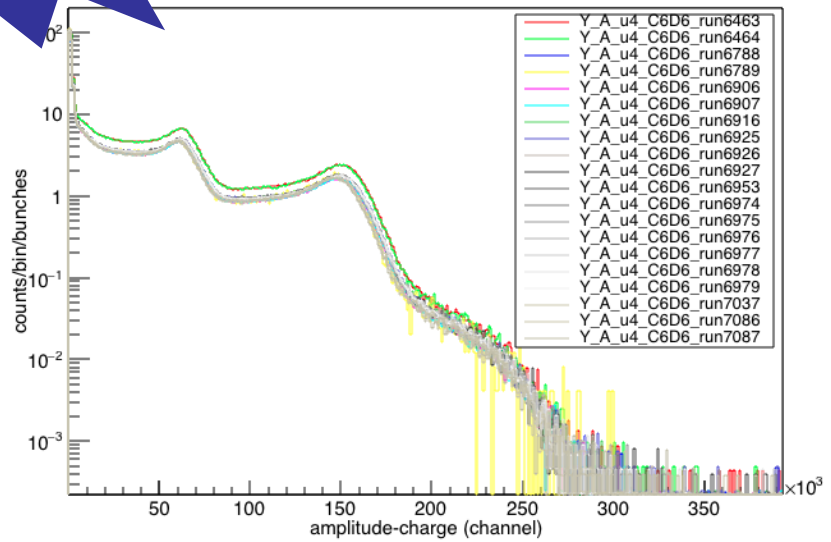
^{88}Sr and ^{89}Y campaign





^{88}Y

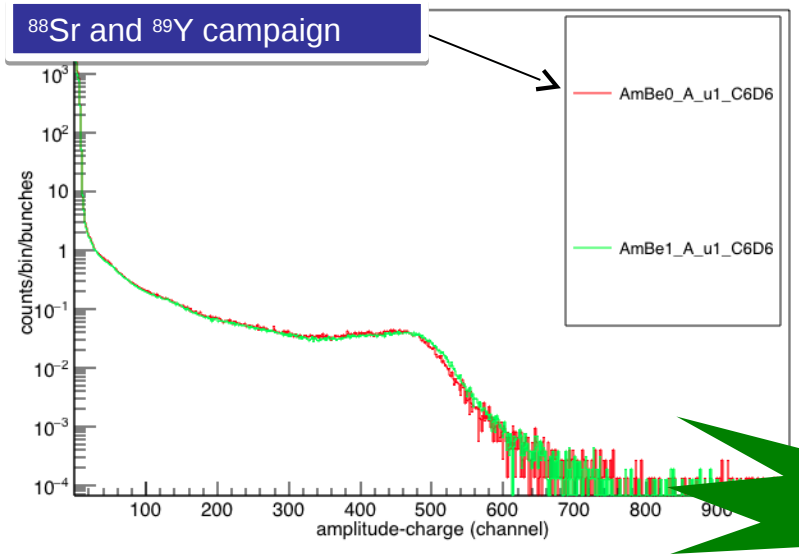




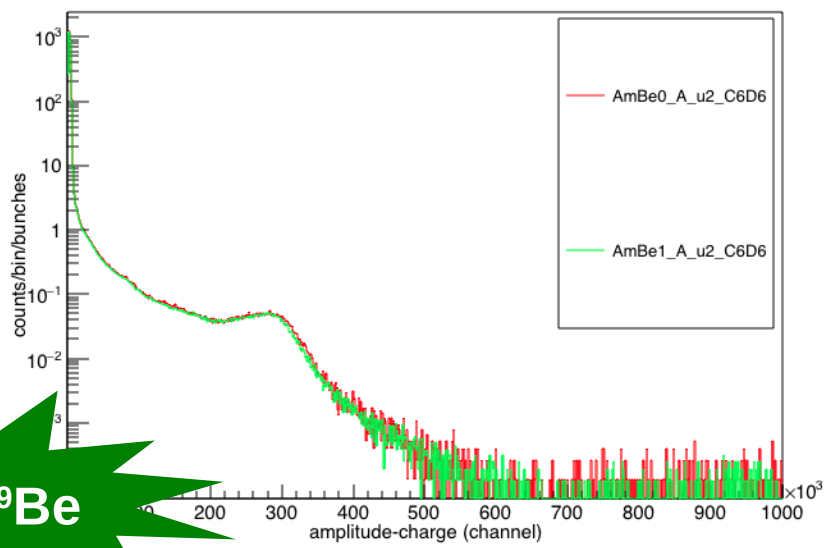
Experiment

AmBe0_A_u1_C6D6

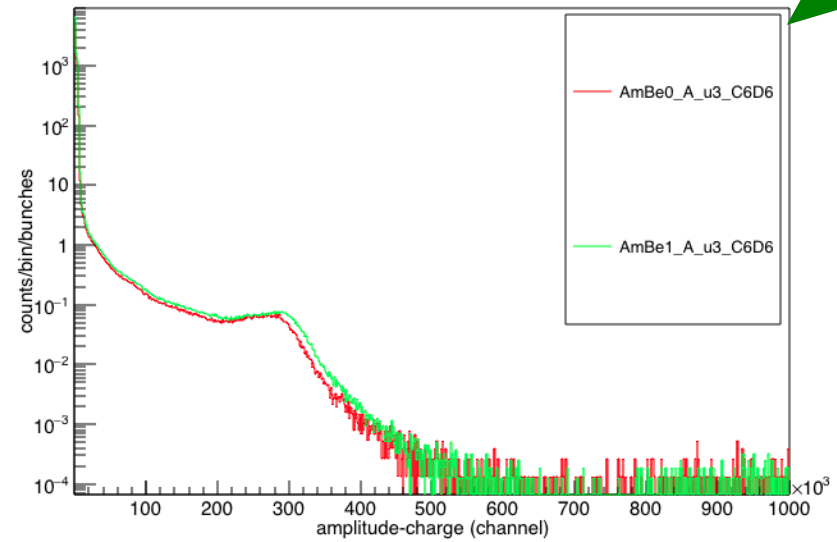
^{88}Sr and ^{89}Y campaign

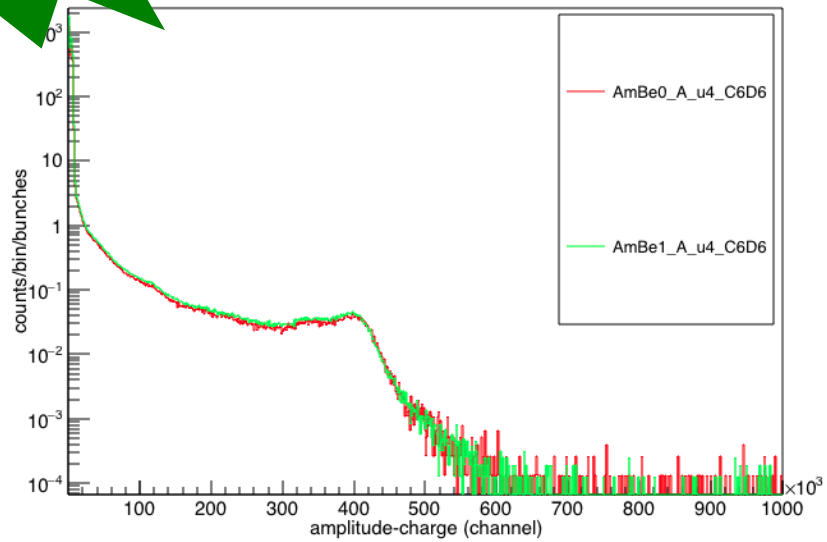


AmBe0_A_u2_C6D6



^{241}Am-^{9}Be

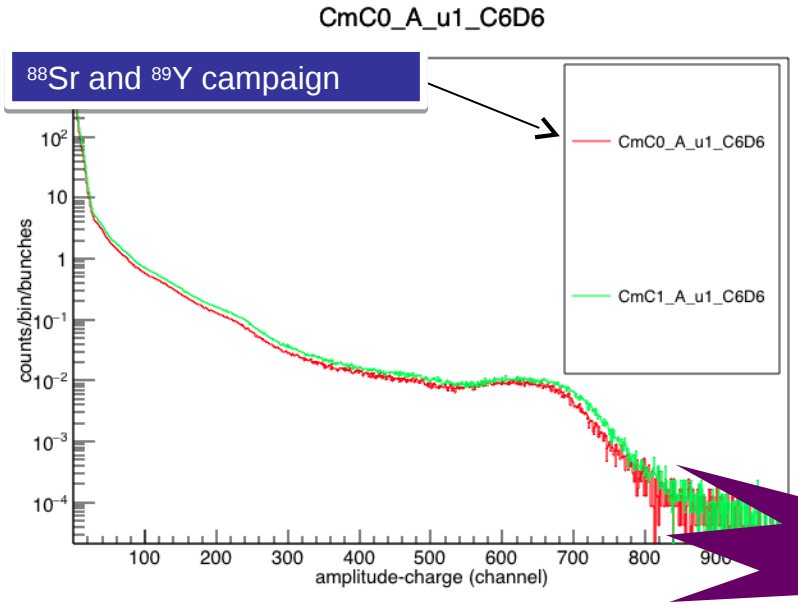


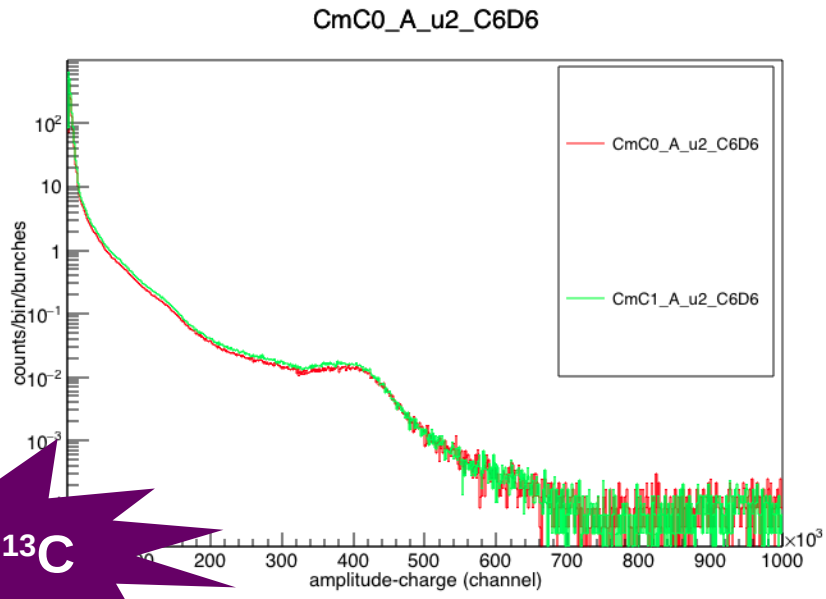


Experiment

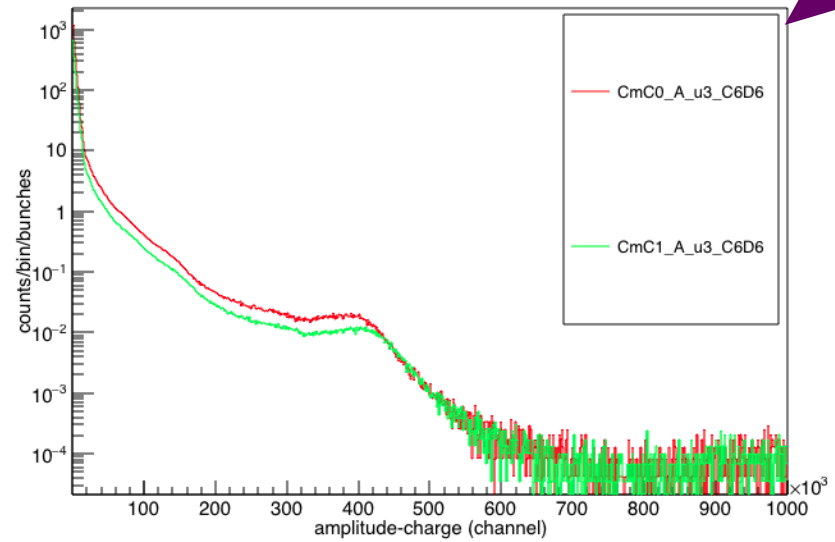
Istituto Nazionale di Fisica Nucleare

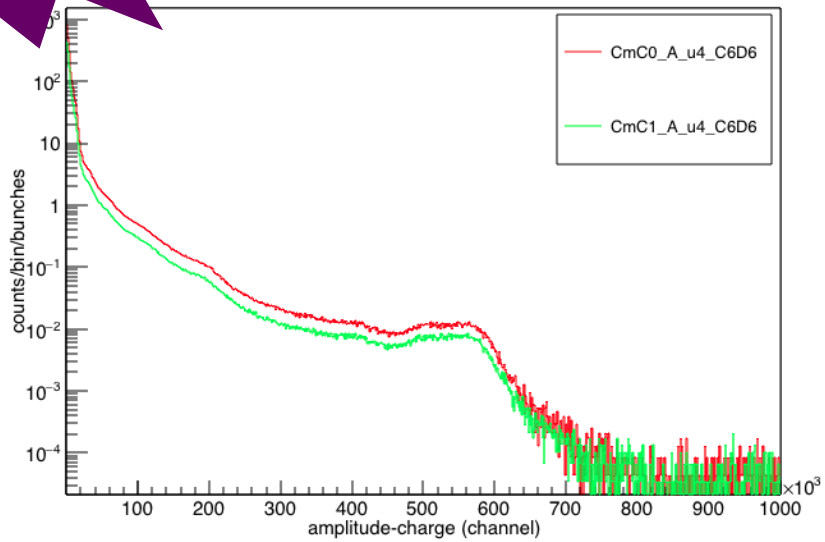
^{88}Sr and ^{89}Y campaign





^{244}Cm-^{13}C

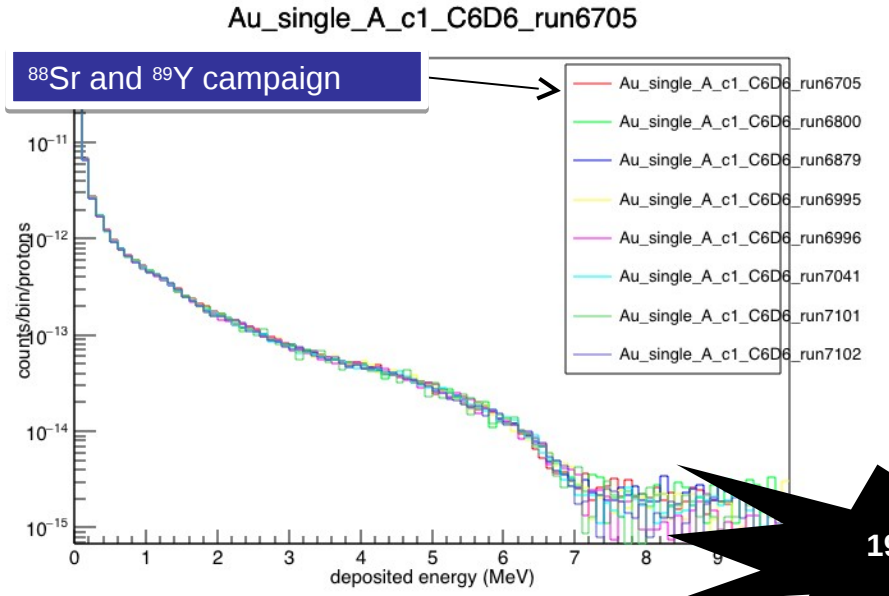


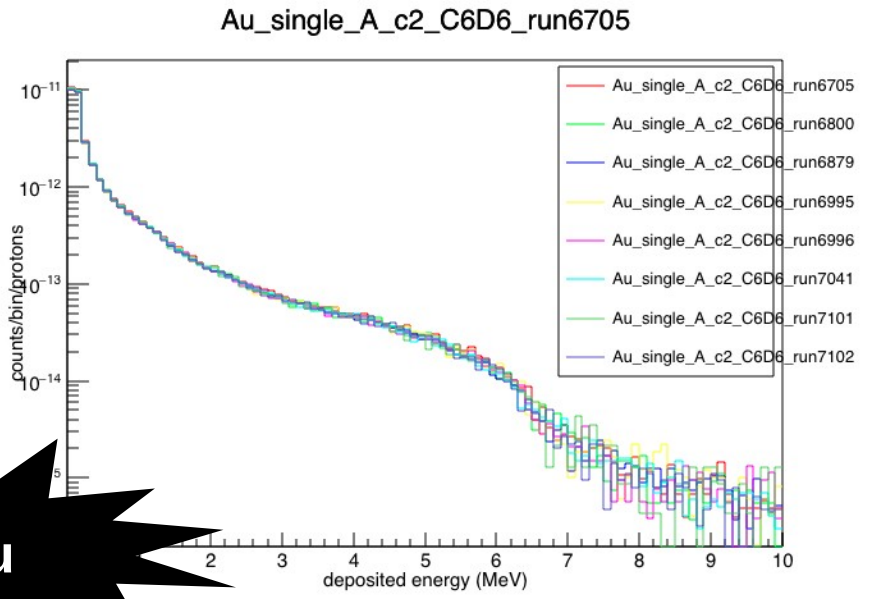


Experiment

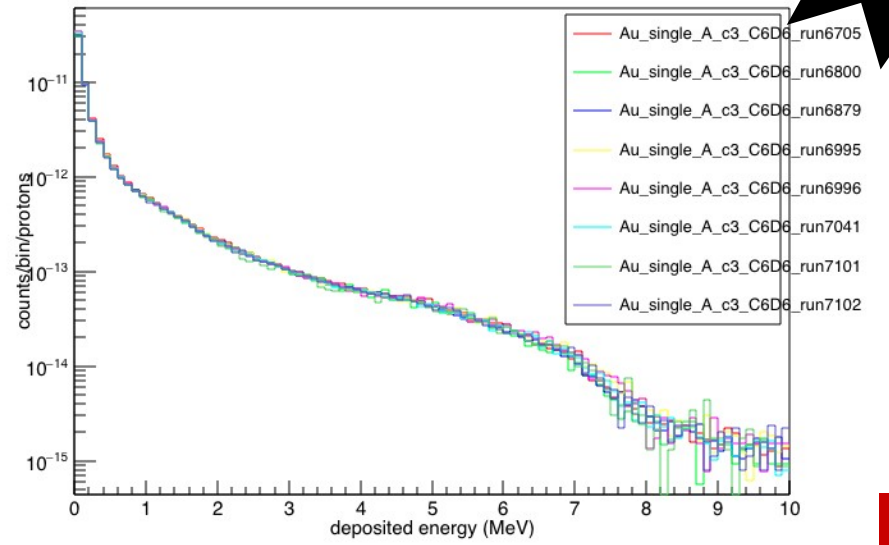
Istituto Nazionale di Fisica Nucleare

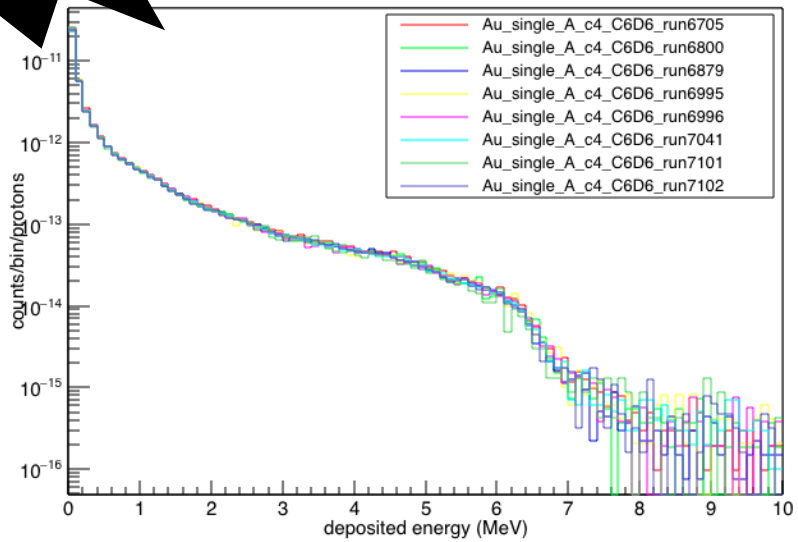
^{88}Sr and ^{89}Y campaign



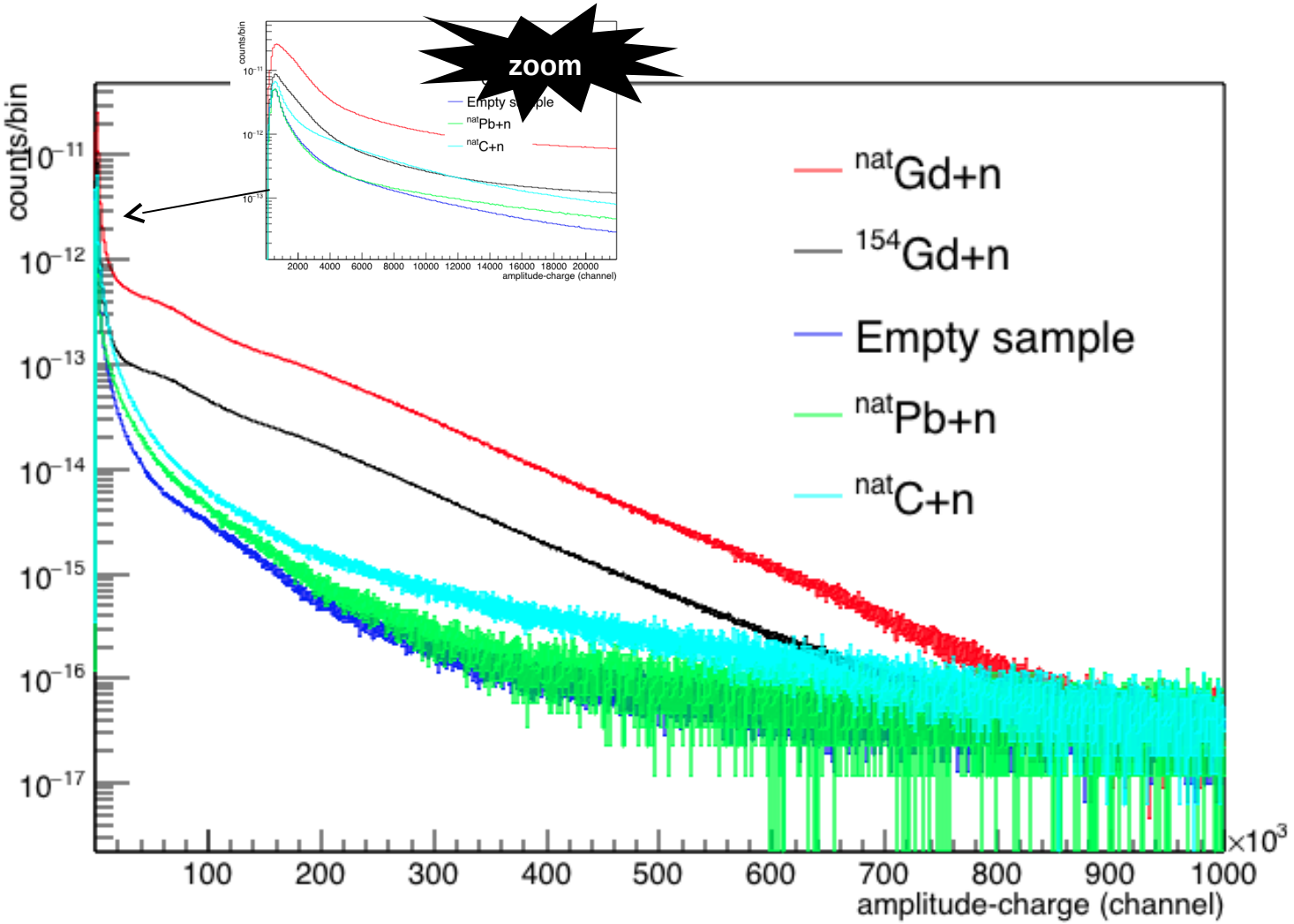


^{197}Au

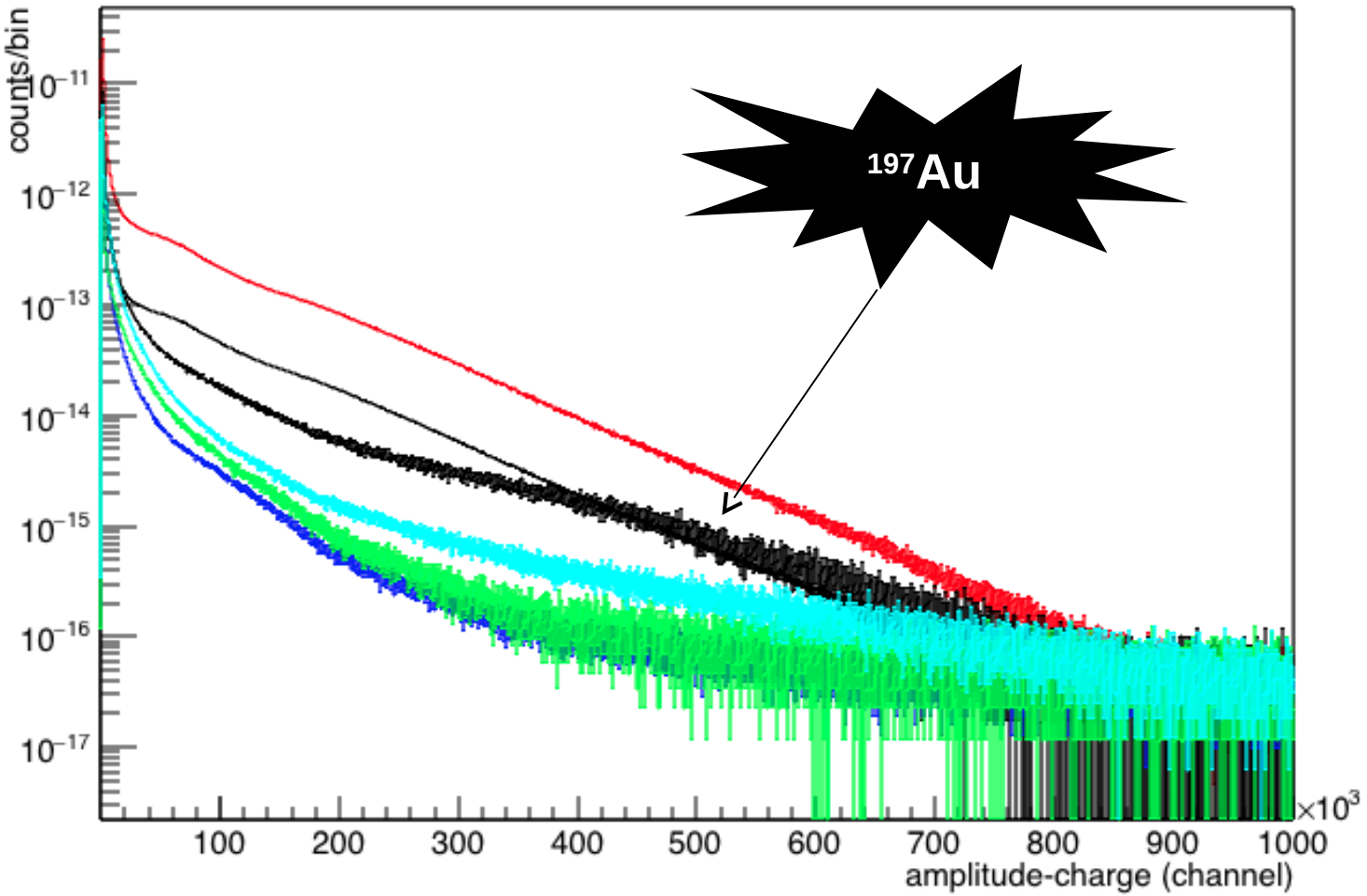




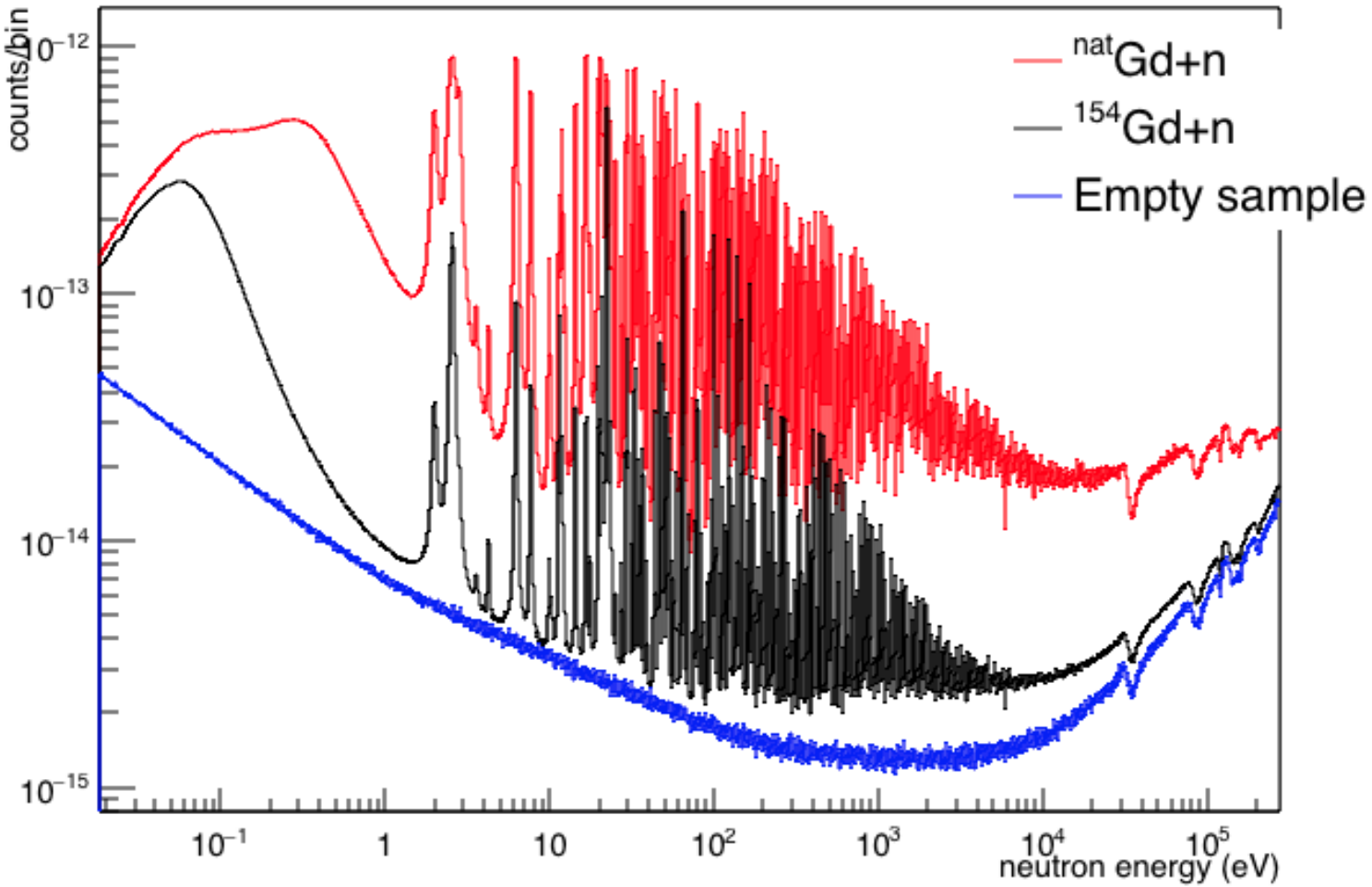
Experiment


zoom
counts/bin
amplitude-charge (channel)
^{nat}Gd+n
^{154}Gd+n
Empty sample
^{nat}Pb+n
^{nat}C+n
×10^3

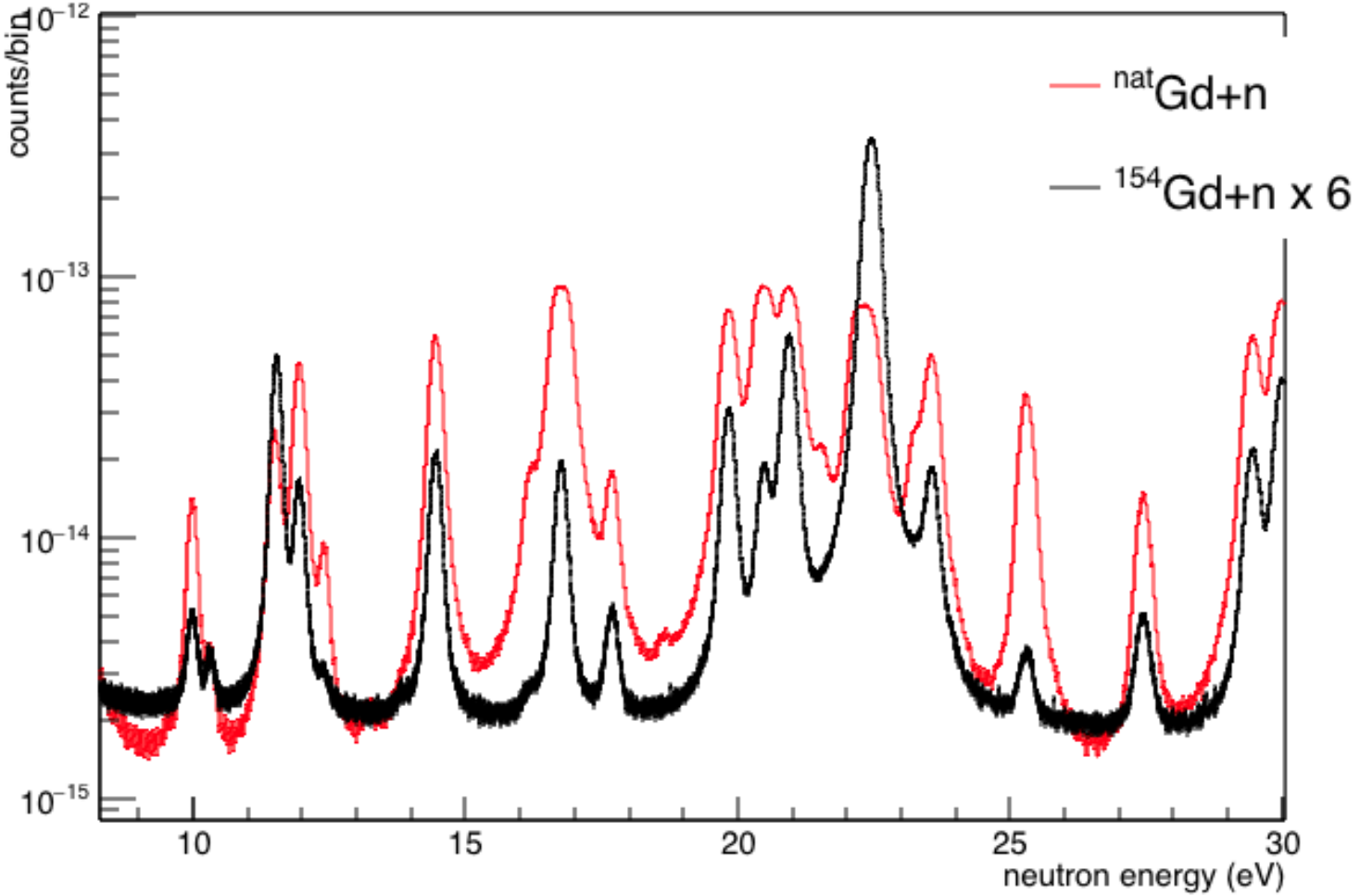
Experiment


counts/bin
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
^{197}Au
100
200
300
400
500
600
700
800
900
1000
×10^3
amplitude-charge (channel)

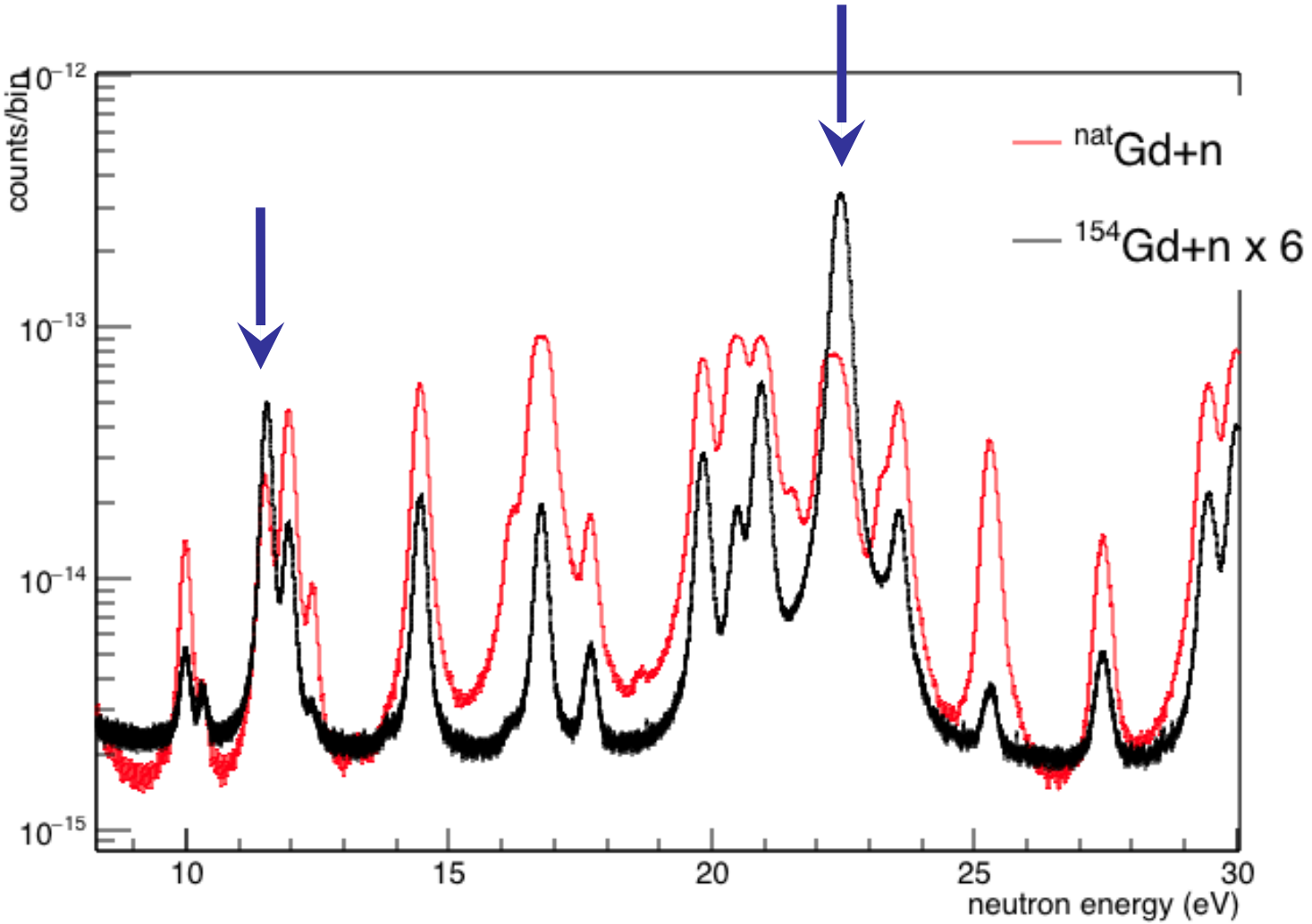
Experiment


counts/bin
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-1}
1
10
10^{2}
10^{3}
10^{4}
10^{5}
neutron energy (eV)
^{nat}Gd+n
^{154}Gd+n
Empty sample

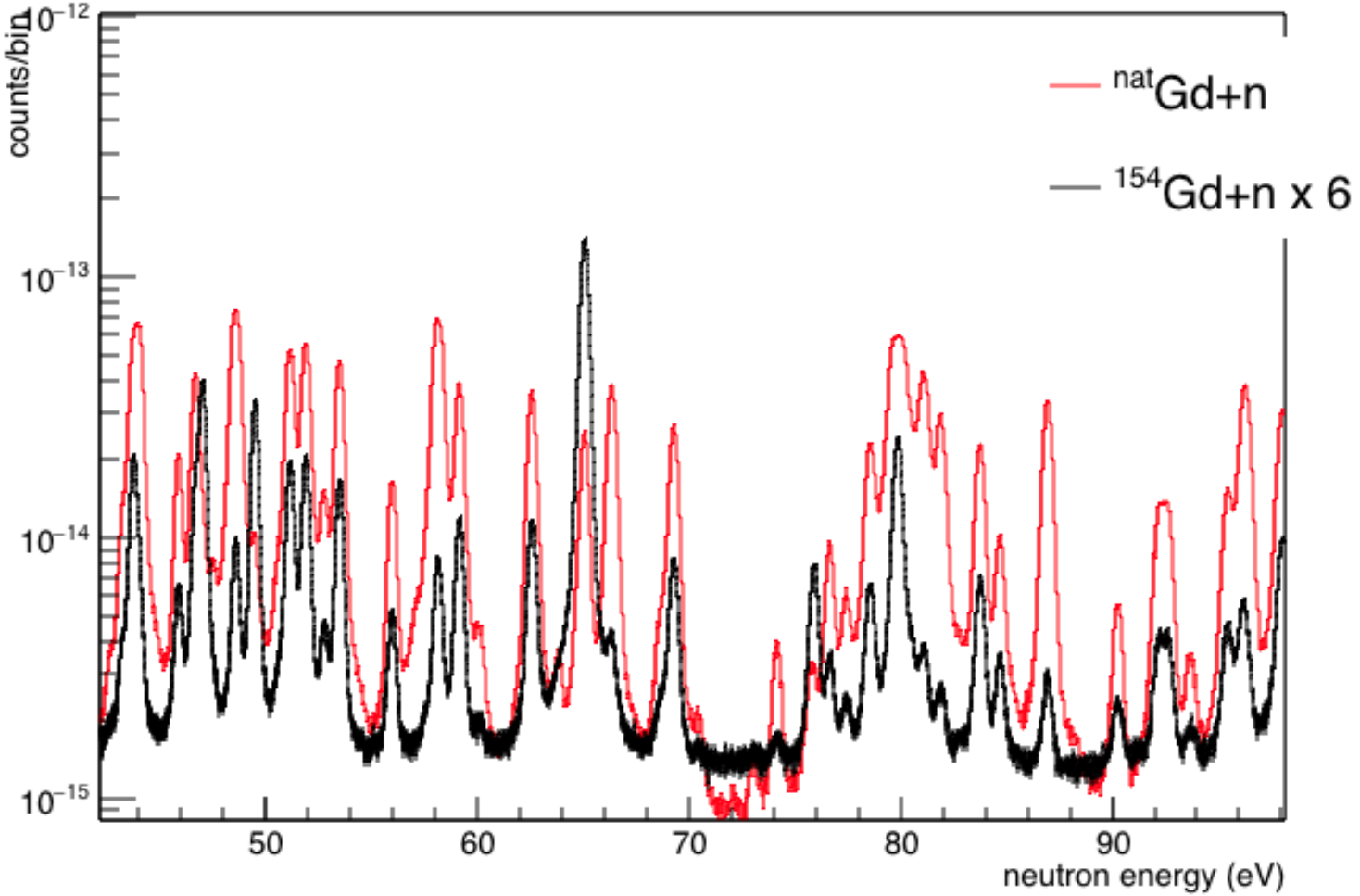
Experiment


counts/bin
10^{-12}
10^{-13}
10^{-14}
10^{-15}
^{nat}Gd+n
^{154}Gd+n x 6
10
15
20
25
30
neutron energy (eV)

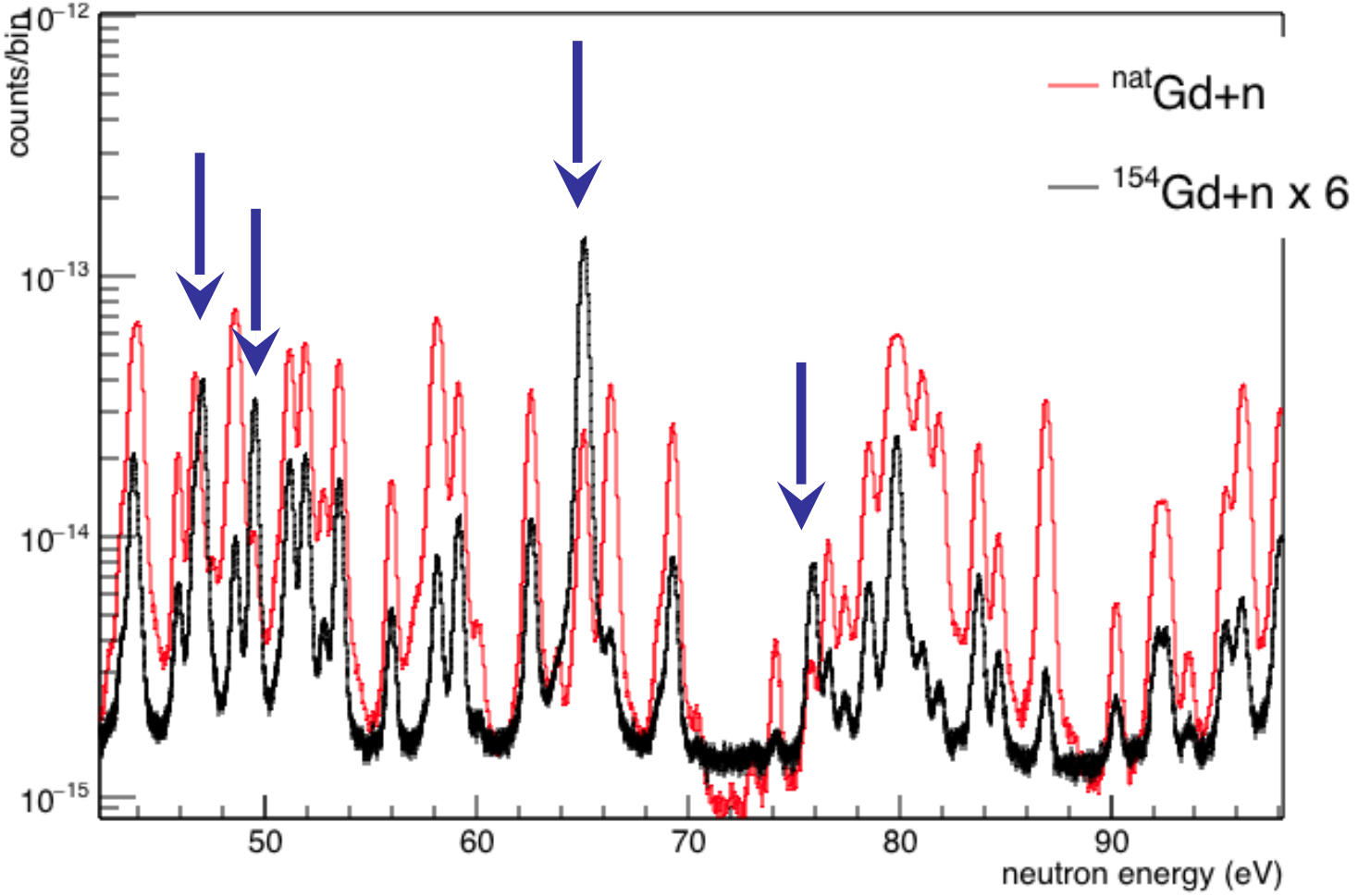
Experiment


counts/bin
10^{-12}
10^{-13}
10^{-14}
10^{-15}
^{nat}Gd+n
^{154}Gd+n x 6
10
15
20
25
30
neutron energy (eV)

Experiment


counts/bin
10^{-12}
10^{-13}
10^{-14}
10^{-15}
^{nat}Gd+n
^{154}Gd+n x 6
50
60
70
80
90
neutron energy (eV)

Experiment


counts/bin
10^{-12}
10^{-13}
10^{-14}
10^{-15}
^{nat}Gd+n
^{154}Gd+n x 6
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60
70
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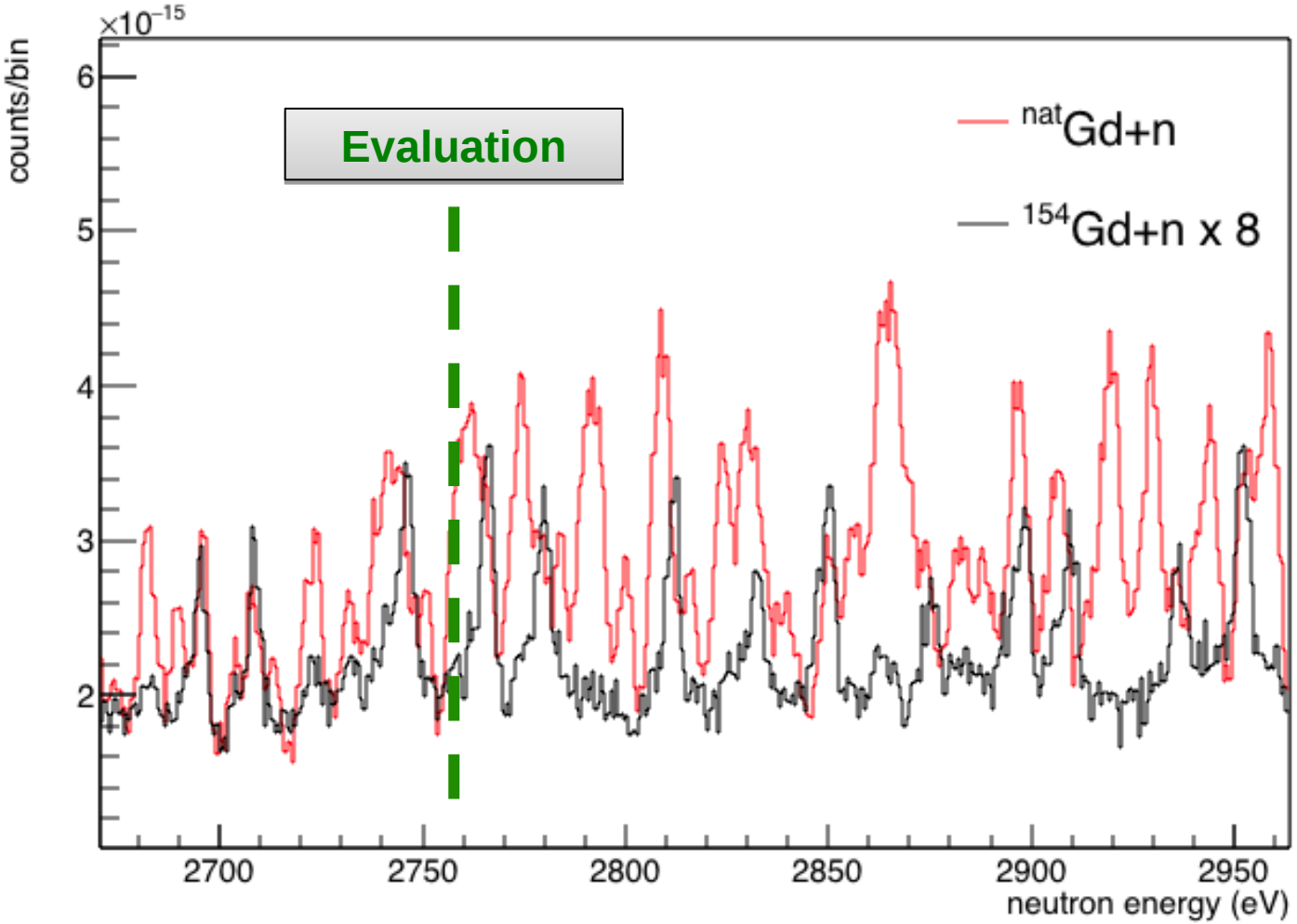
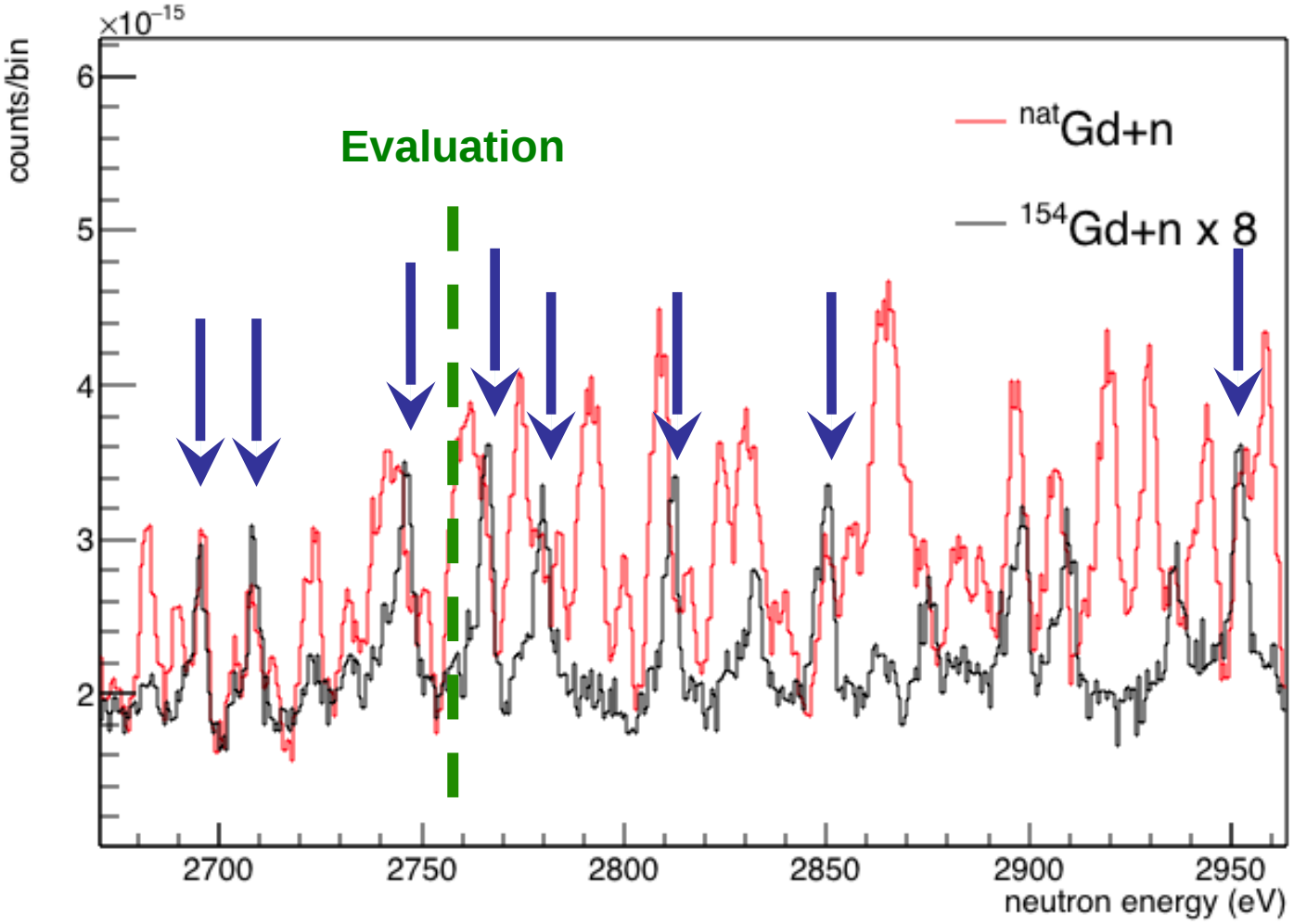
neutron energy (eV)

Experiment


×10⁻¹⁵
counts/bin
6
5
4
3
2
Evaluation
natGd+n
154Gd+n x 8
2700
2750
2800
2850
2900
2950
neutron energy (eV)

Experiment


×10⁻¹⁵
counts/bin
6
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4
3
2
Evaluation
natGd+n
154Gd+n x 8
2700
2750
2800
2850
2900
2950
neutron energy (eV)

Summary

Background: ^{152,154}**Gd** are relevant in the study of *s process* because of their impact on **s-process abundances**. Measurements are present in literature, however large **discrepancies** are still present and called for a more systematic and accurate study.

Experiment: **capture cross section** measurement successfully performed in August 2017 at **EAR-1** with an array of 4 C_6D_6 detectors.

Goal: **Improve resonance parameters** of ^{154}Gd (and perhaps few strong ^{152}Gd neutron resonances) for an accurate determination of **stellar cross sections** with overall uncertainty below **5%** for thermal energies of interest to *s process*, from few keV to about kT = 100 keV, *i.e.* 20 meV < E_n < 1 MeV

… data seem promising

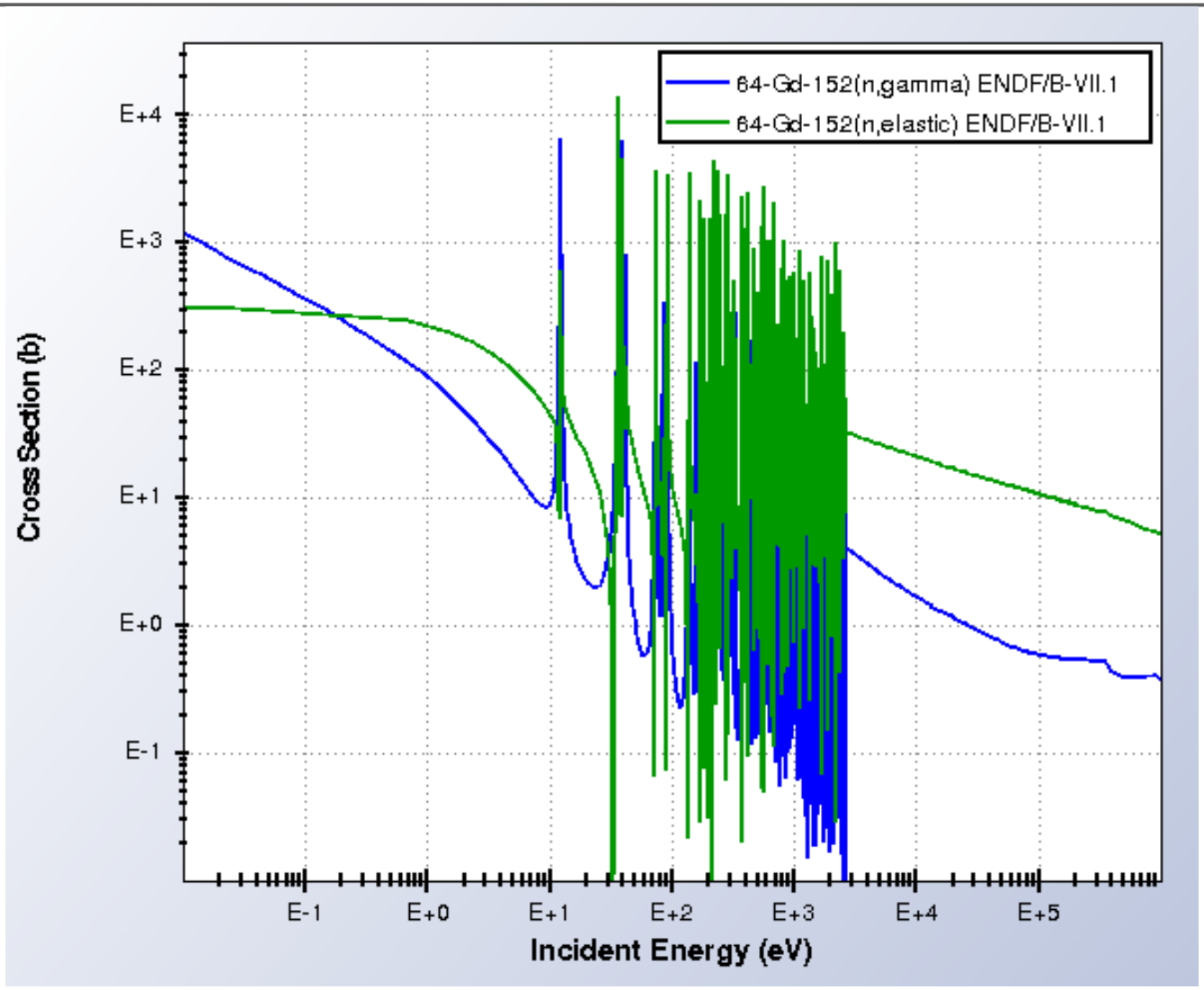
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Alice Manna - alice.manna2@unibo.it

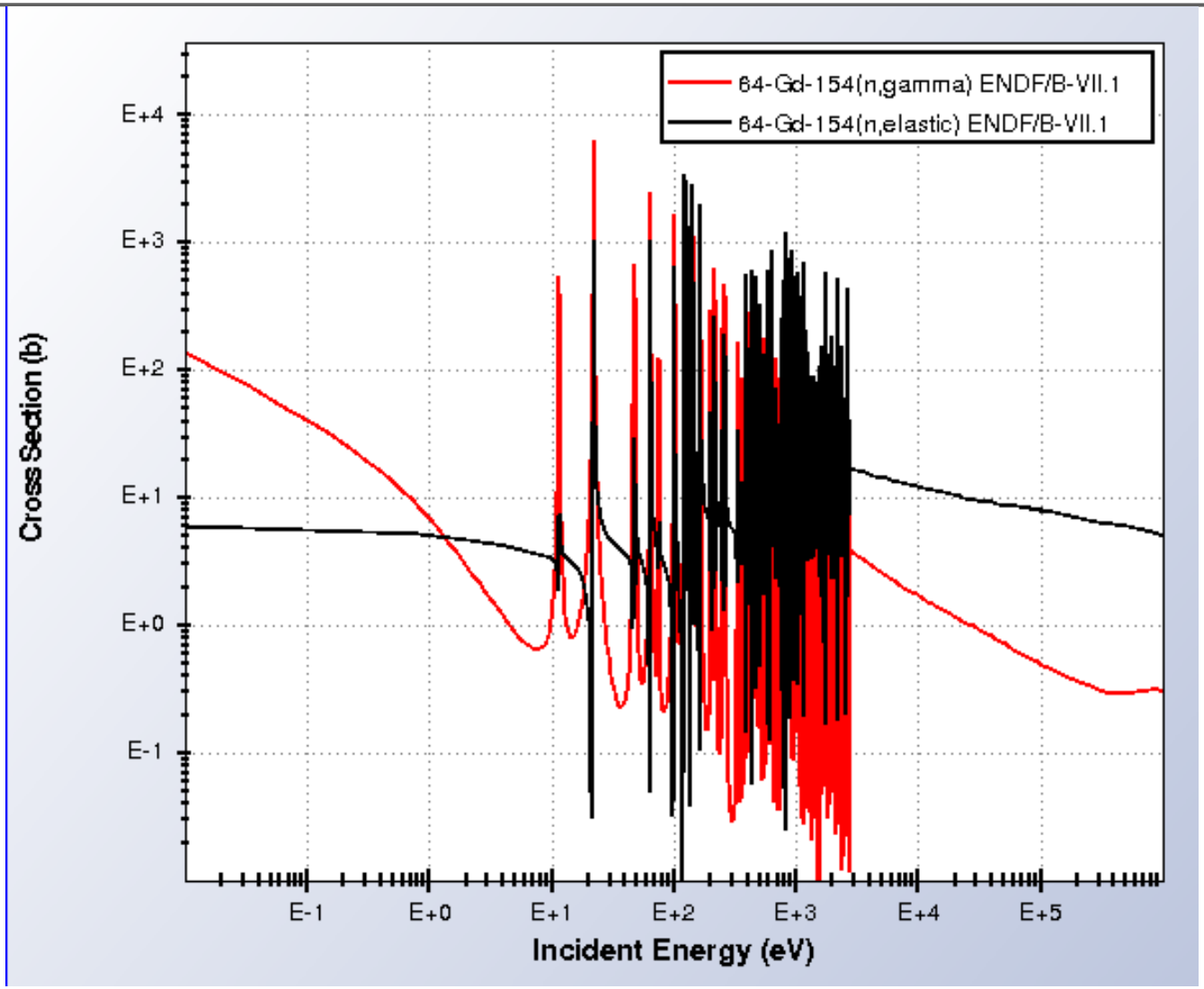
Table 1: Gadolinium isotopes

Isotope	Binding energy (MeV)	Natural abundance %	ORNL enrichment %
^{152}Gd	6.25	0.20	$32 - 51$
^{154}Gd	6.44	2.15	> 66 and 99.3
^{155}Gd	8.54	14.73	> 90
^{156}Gd	6.36	20.47	$93 - 99$
^{157}Gd	7.94	15.68	> 90
^{158}Gd	5.94	24.87	> 95
^{160}Gd	5.64	21.9	$95 - 98$

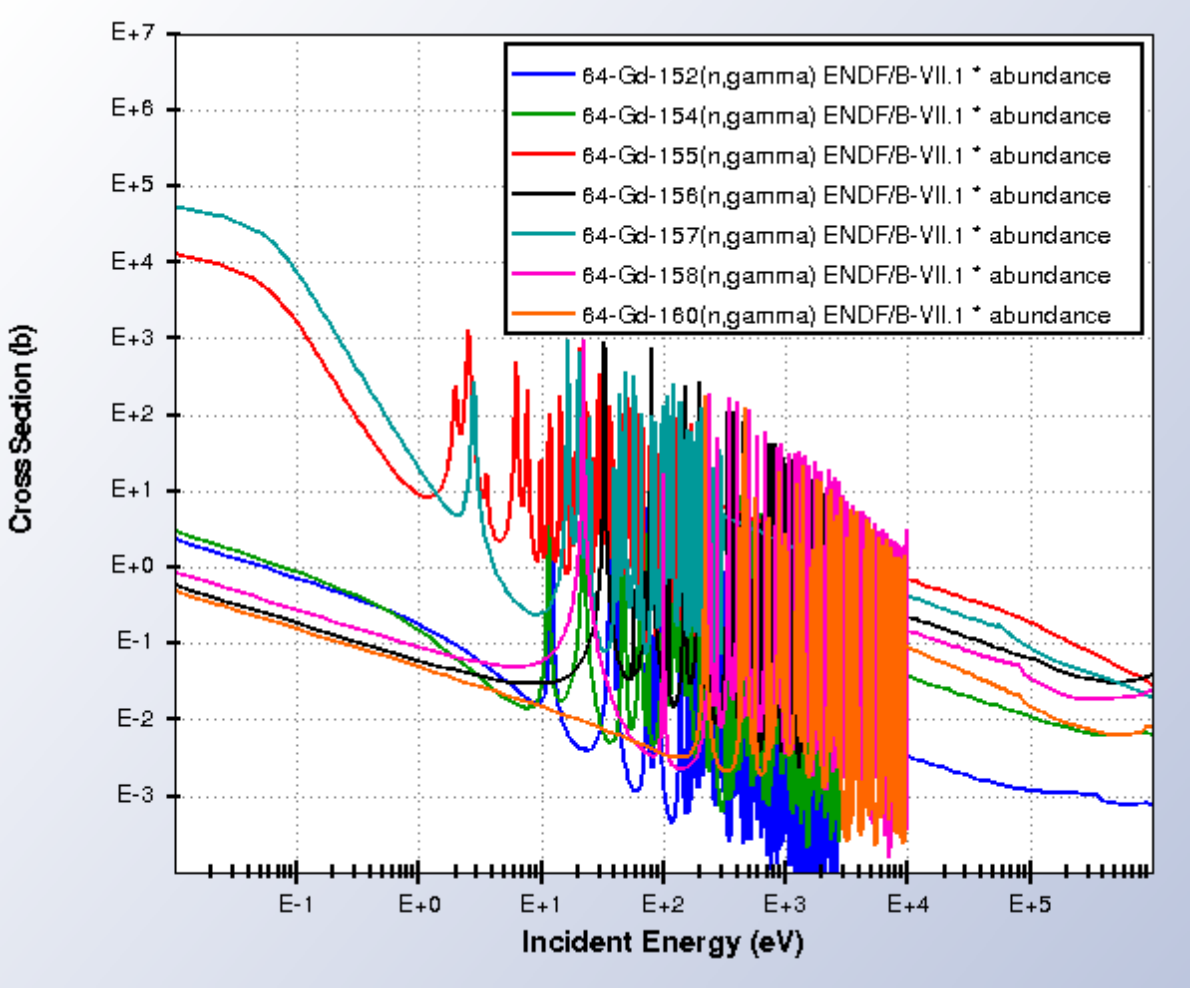
Gd data in literature



Gd data in literature



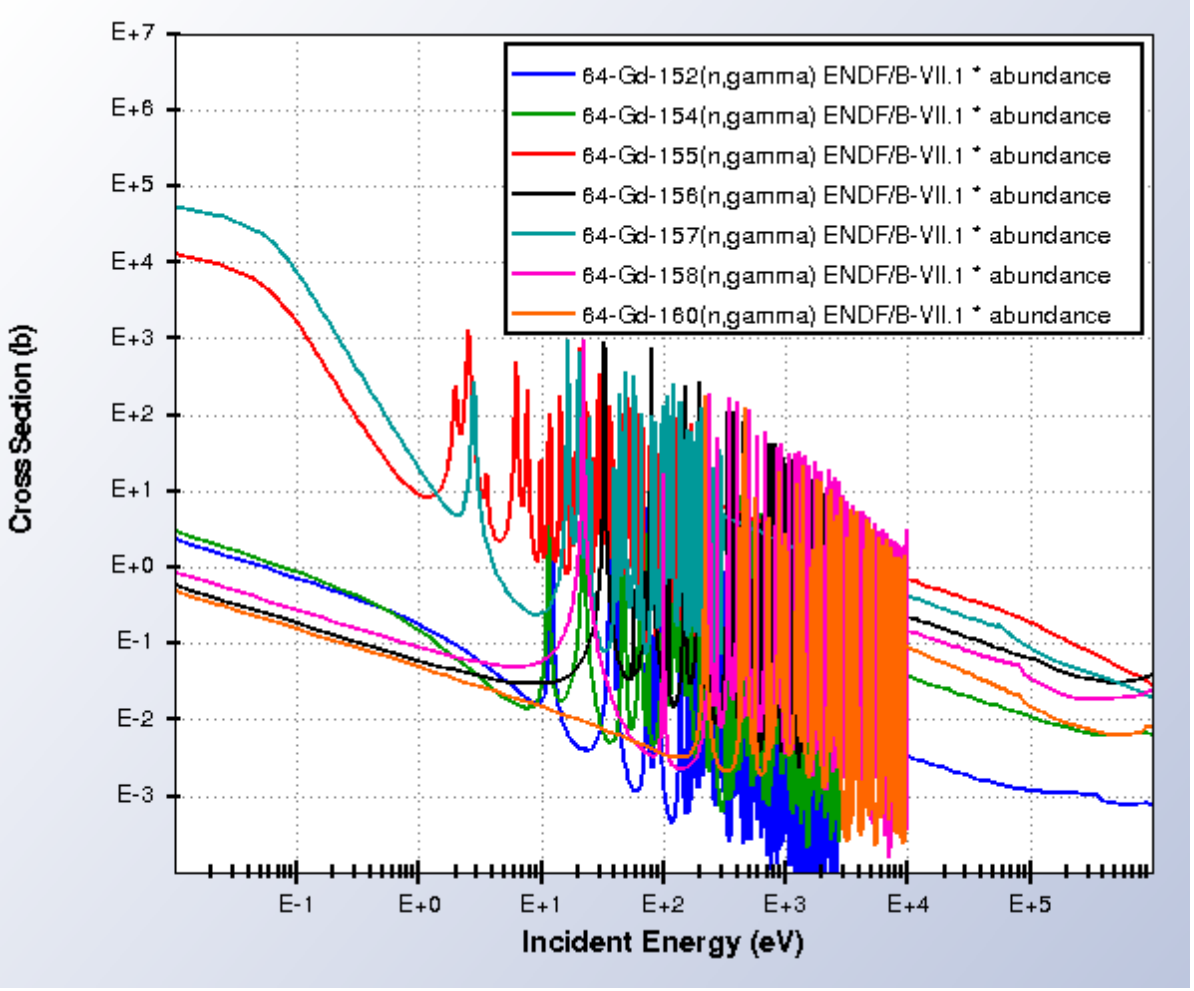
Gd – Evaluation



Natural abundance:

^{152}Gd ~ 0.20%
^{154}Gd ~ 2.15%
^{155}Gd ~ 14.73%
^{156}Gd ~ 20.47%
^{157}Gd ~ 15.68%
^{158}Gd ~ 24.87%
^{160}Gd ~ 21.90%

Gd – Evaluation



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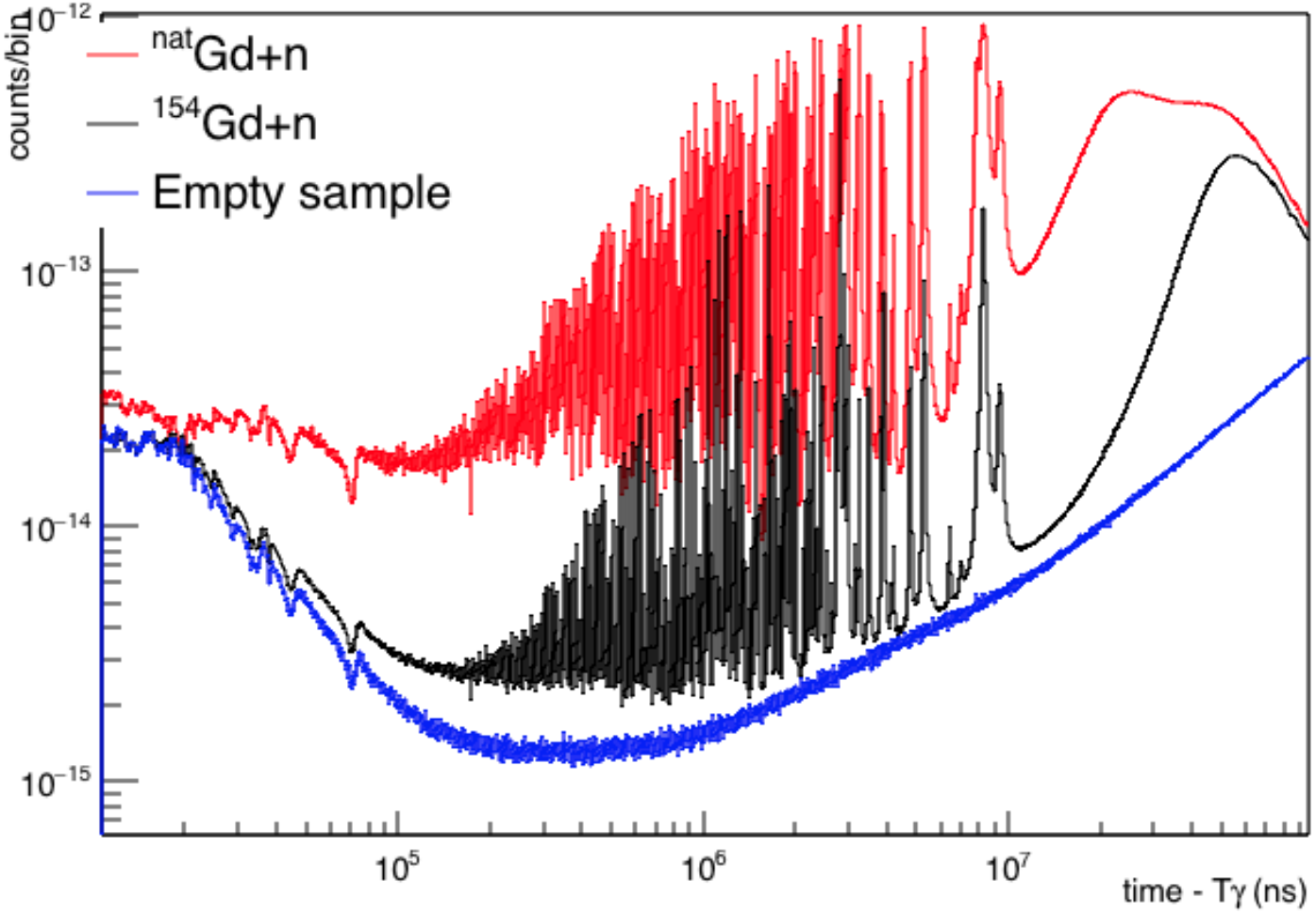
^{157}Gd ~ 15.68%
^{158}Gd ~ 24.87%
^{160}Gd ~ 21.90%

Enriched isotopes are needed

Simultaneous investigation of ALL Gd isotopes

Experiment


counts/bin
10^{-12}
10^{-13}
10^{-14}
10^{-15}
^{nat}Gd+n
^{154}Gd+n
Empty sample
10^{5}
10^{6}
10^{7}
time - Tγ (ns)