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

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

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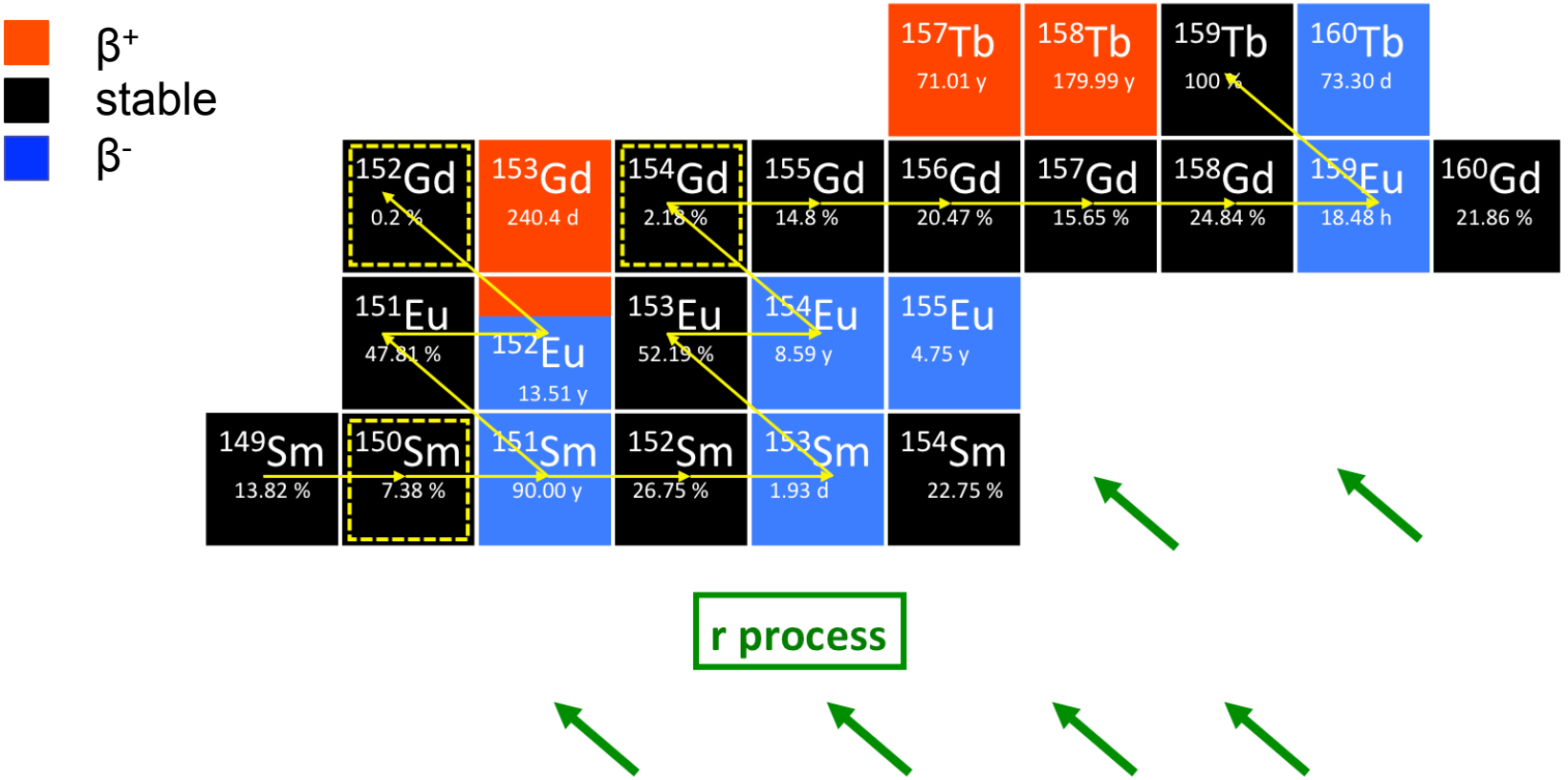
[S] **Spokesperson**

Technical coordinator: Oliver Aberle

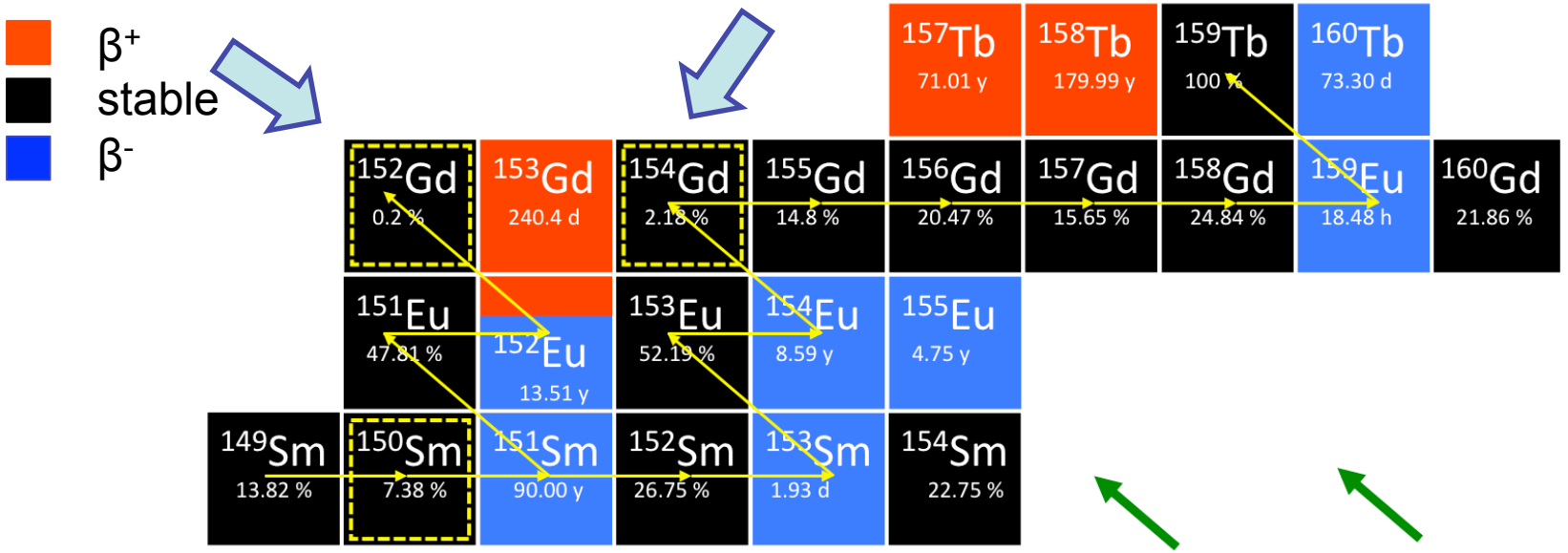
Outline

- Scientific Motivations
- Gd data in literature
- Proposed experimental setup
- Beam Time Request
- Conclusion

Scientific Motivations



Scientific Motivations

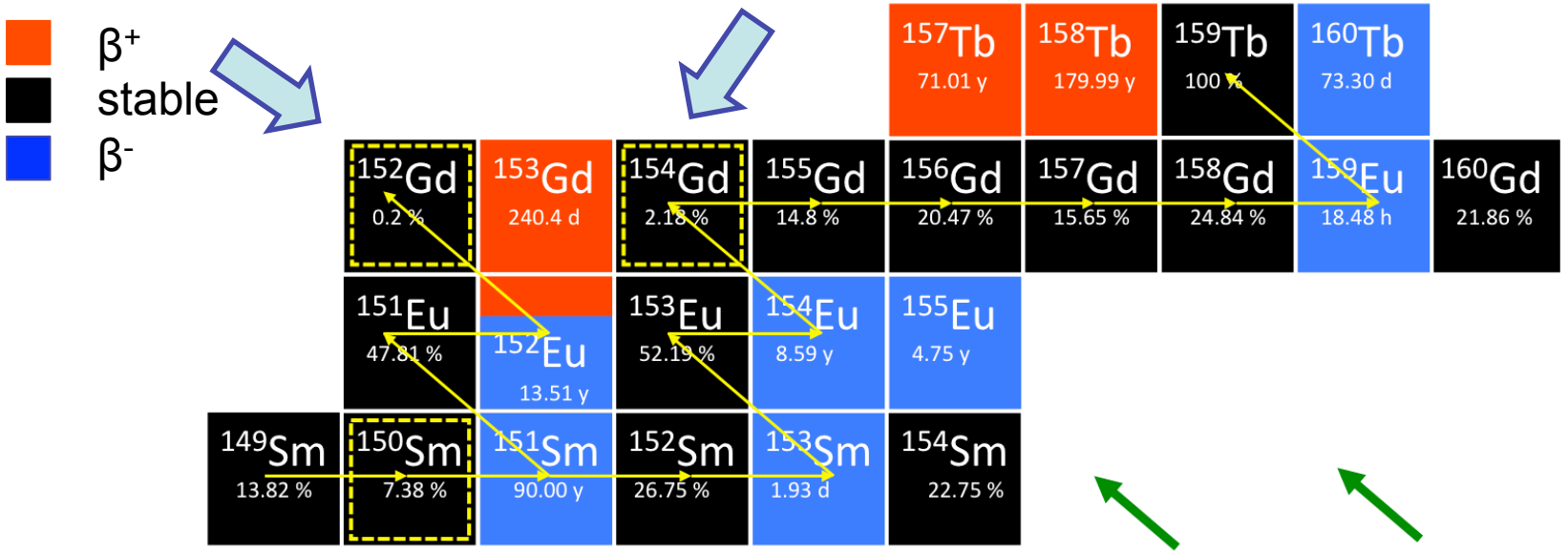


r process

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



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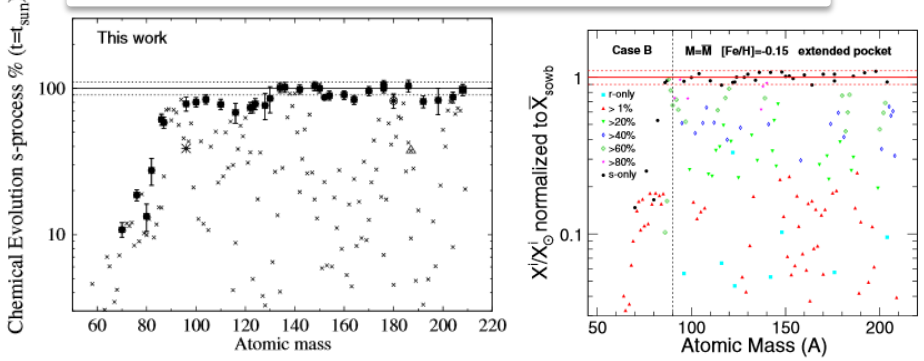
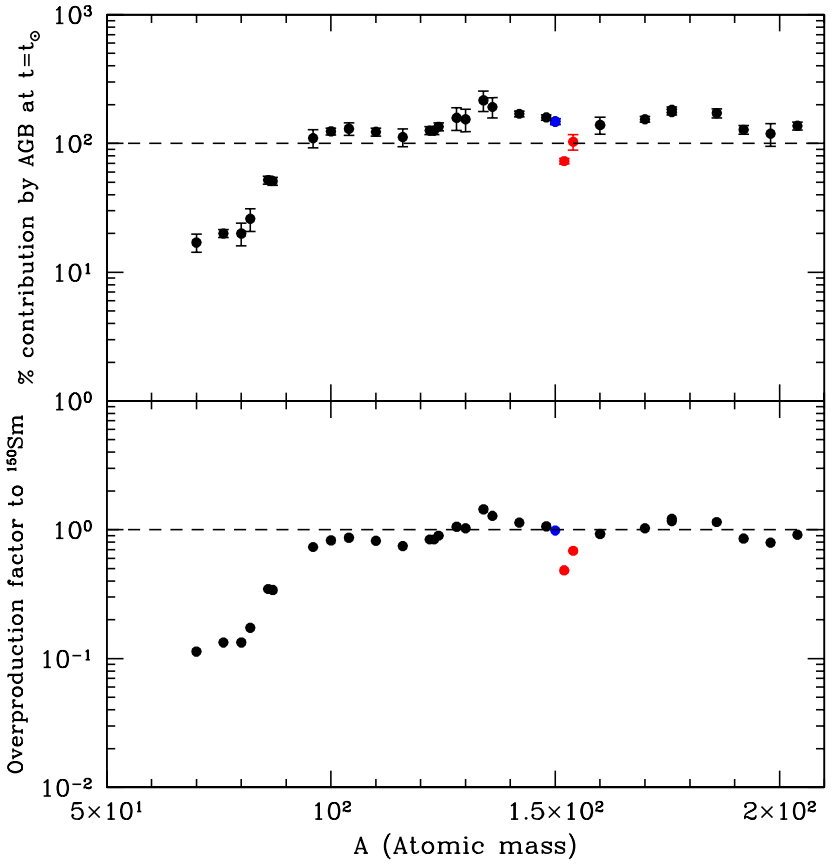
Proof of galactic chemical evolution (GCE) models

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

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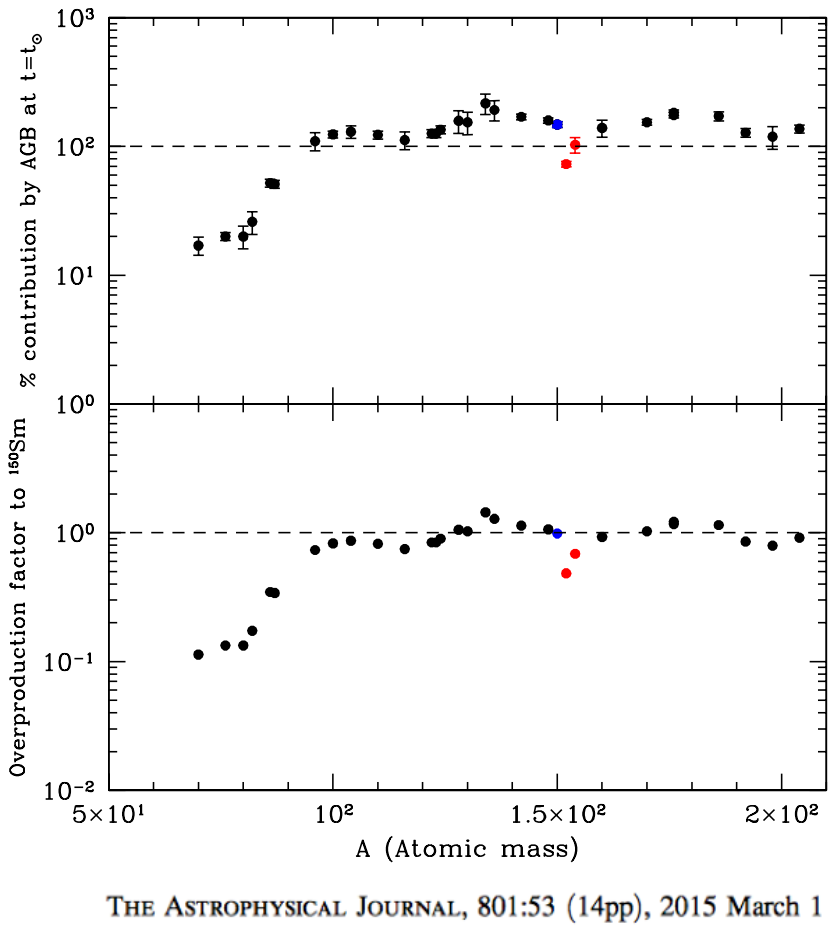
Scientific Motivations

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



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

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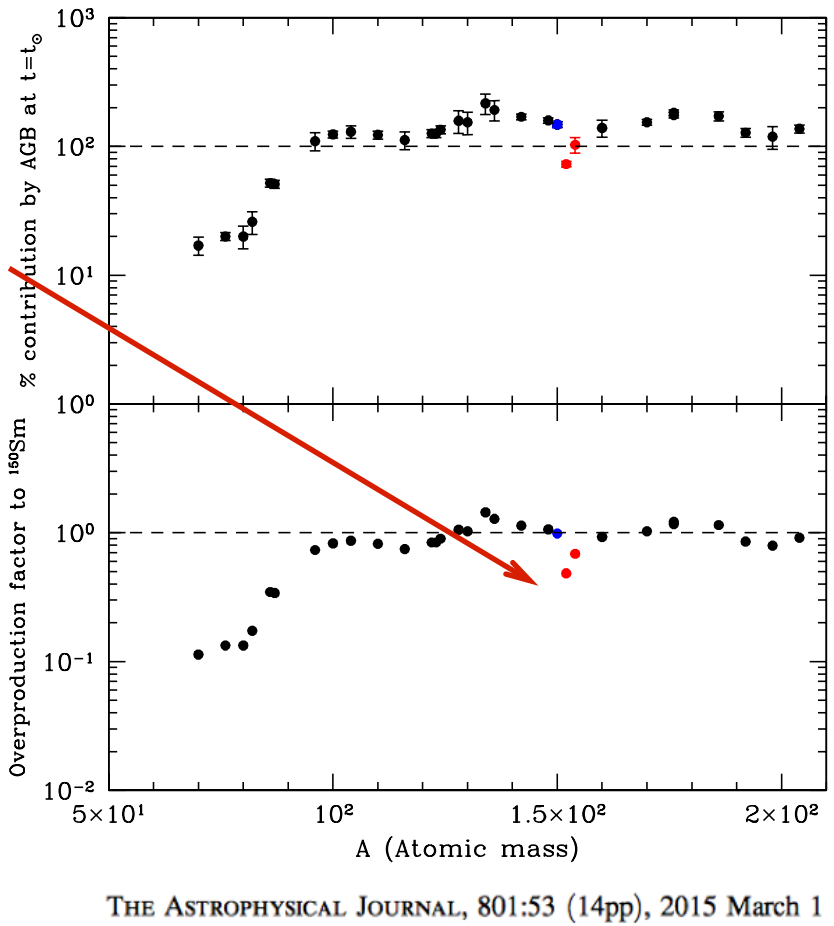
Disagreement of more than 20% between **observation** and **model calculation** of s-process abundances



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

more accurate nuclear data needed !!!

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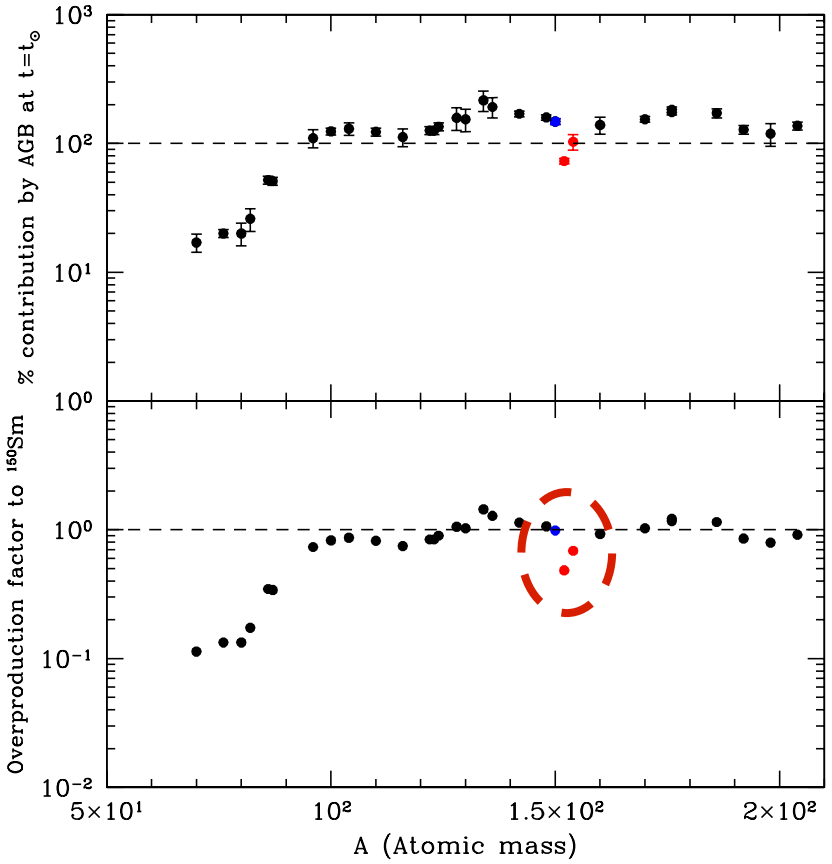

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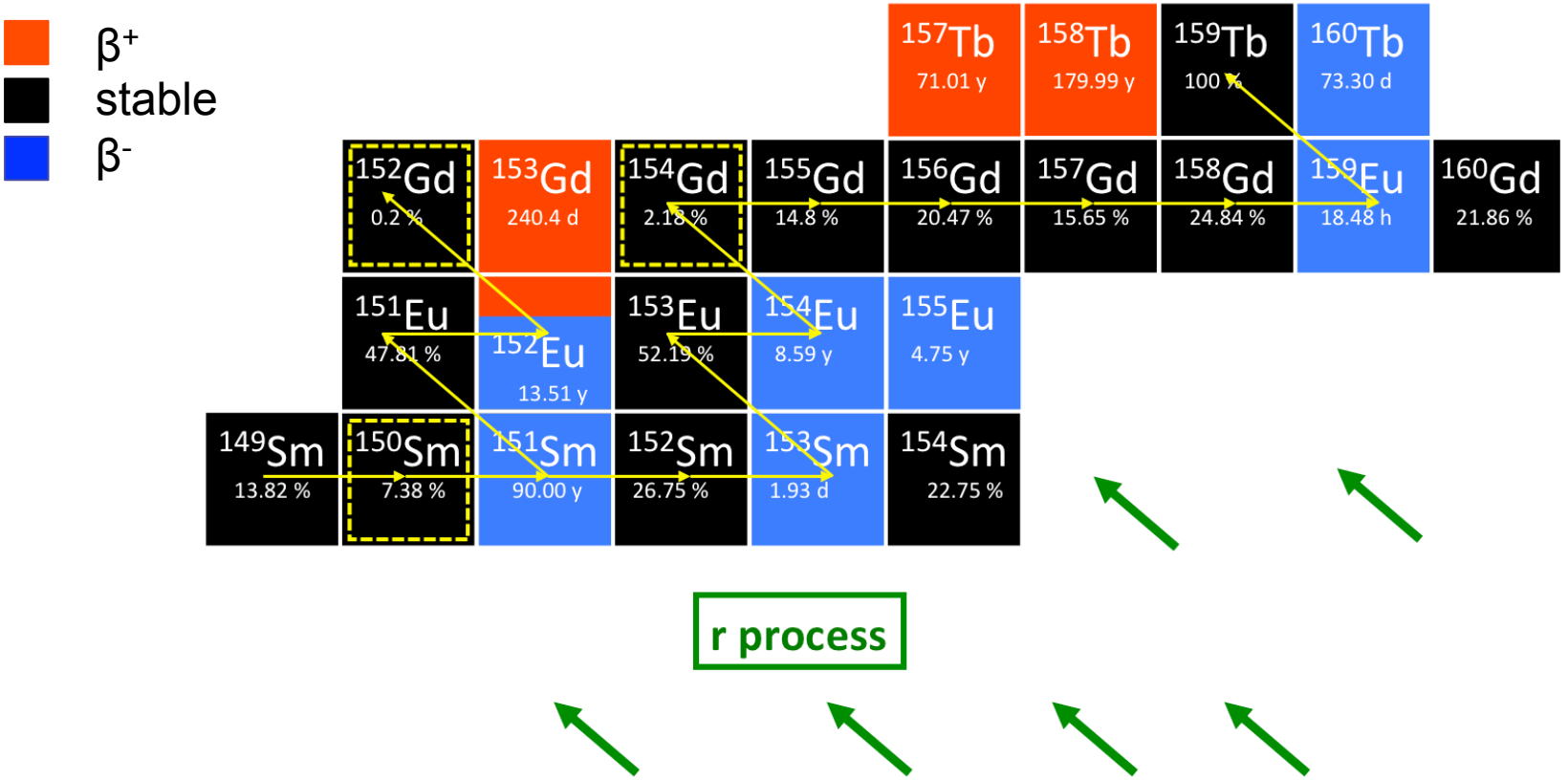

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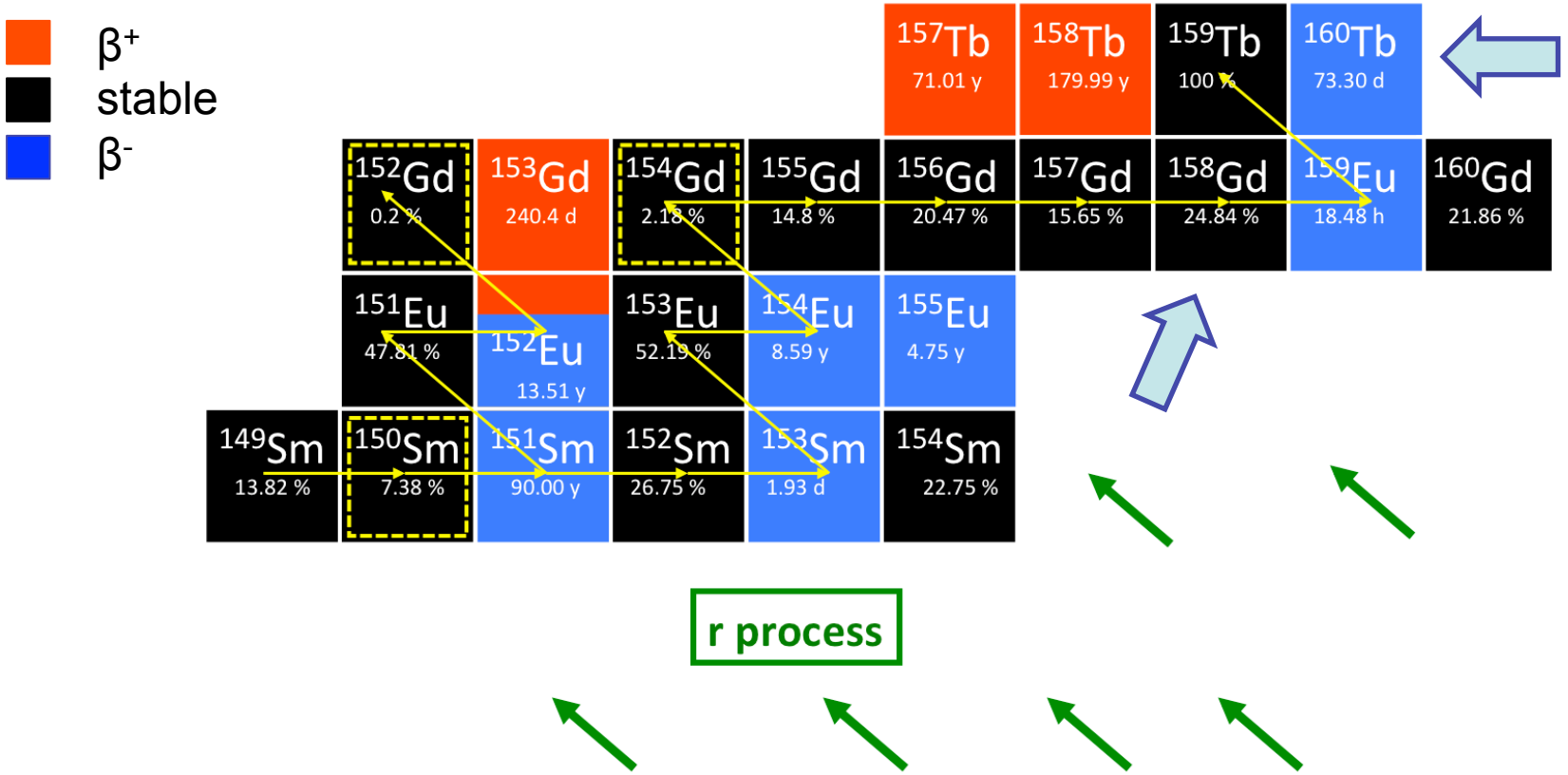
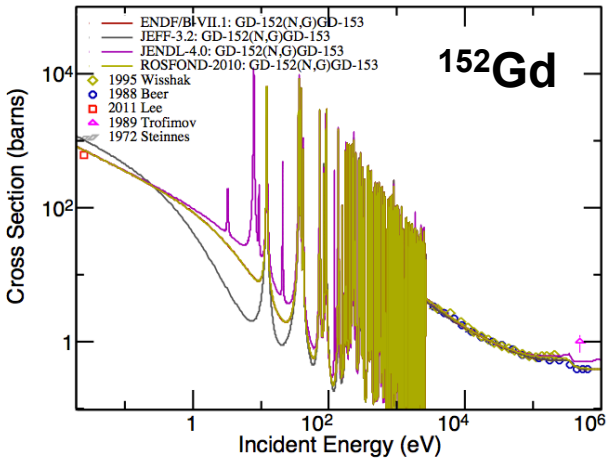


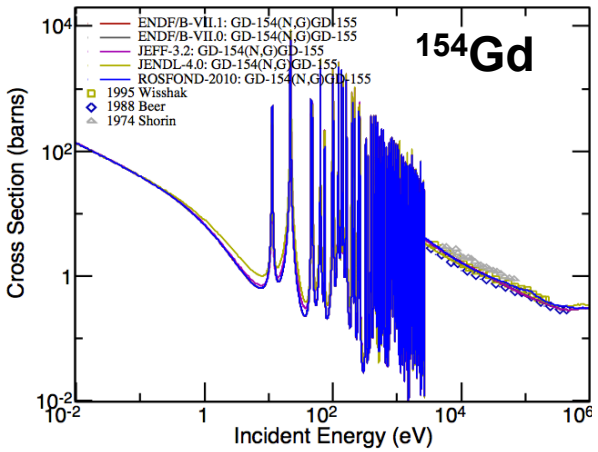
2) Capture cross section of ^{158}**Gd** drives the production of ^{159}**Tb**

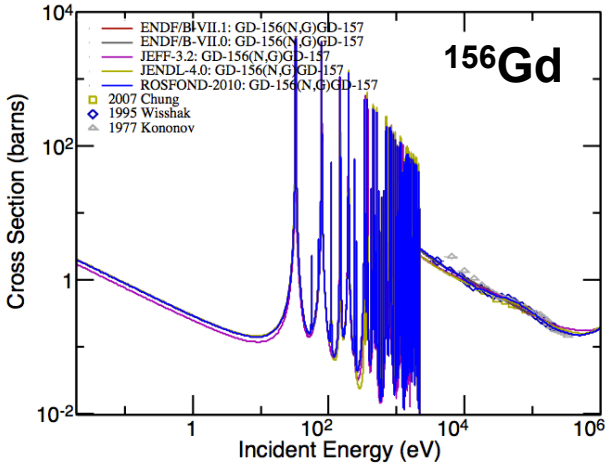
- the ratio of their observed abundances in **carbon-enhanced metal-poor** (CEMP) stars provides a constraint for the contribution of the s-process

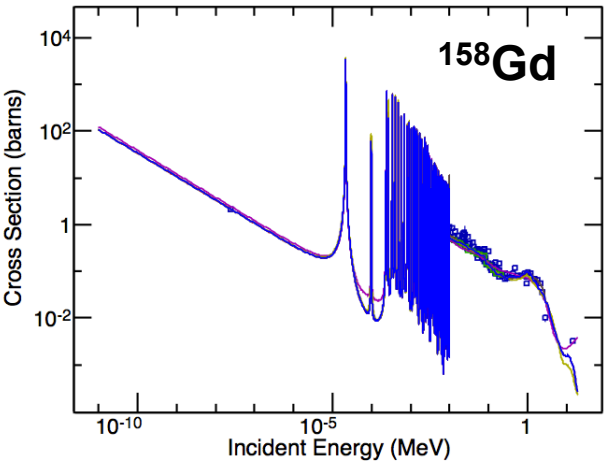
Gd data in literature

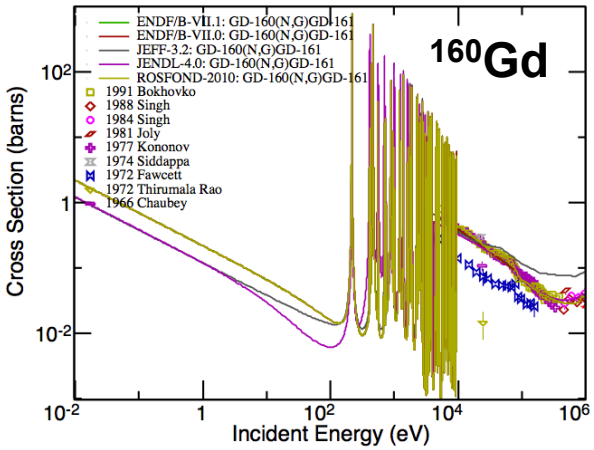
Unresolved Resonance Region











Main reference:
Wisshak and Kappeler

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

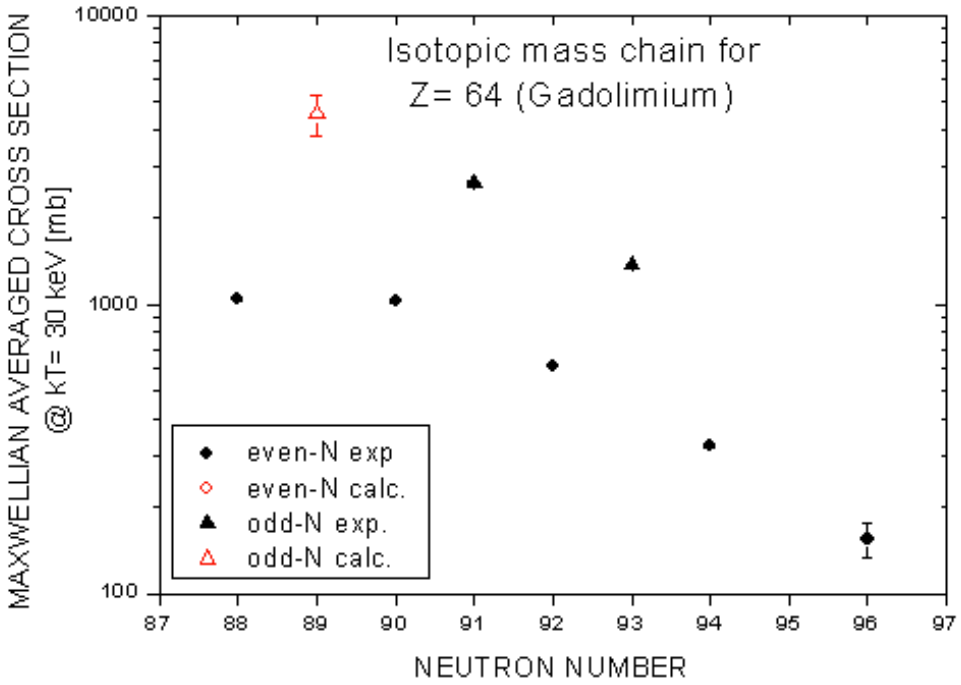
Gd data in literature

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 yes
^{158}Gd	Nevis Lab DUBNA	< 10 keV < 2.4 keV		NaI	yes

Gd data in literature

MACS from KADoNiS



Gd data in literature

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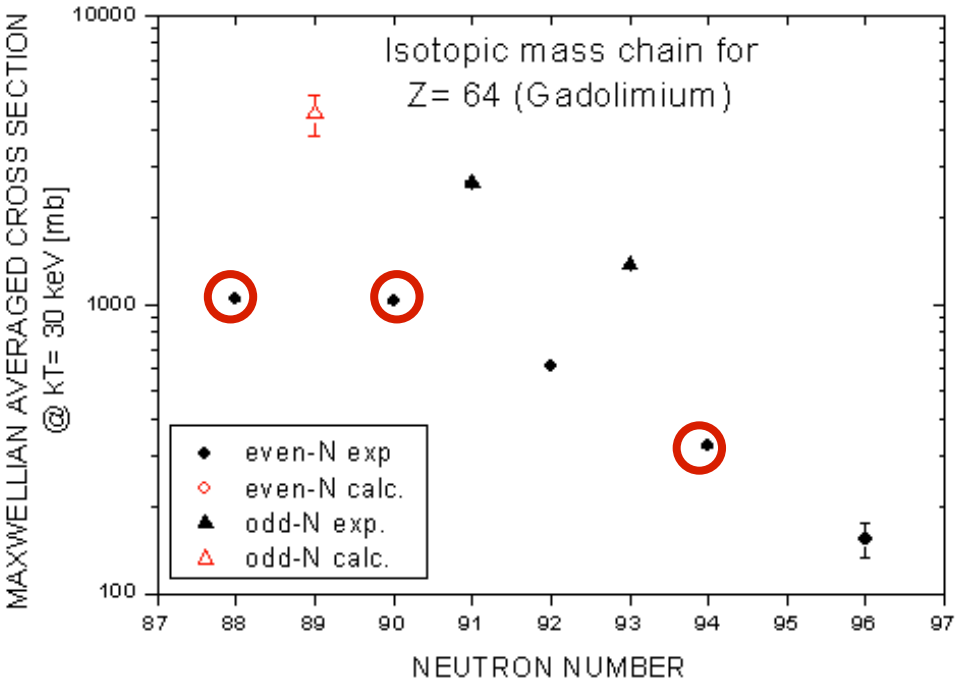
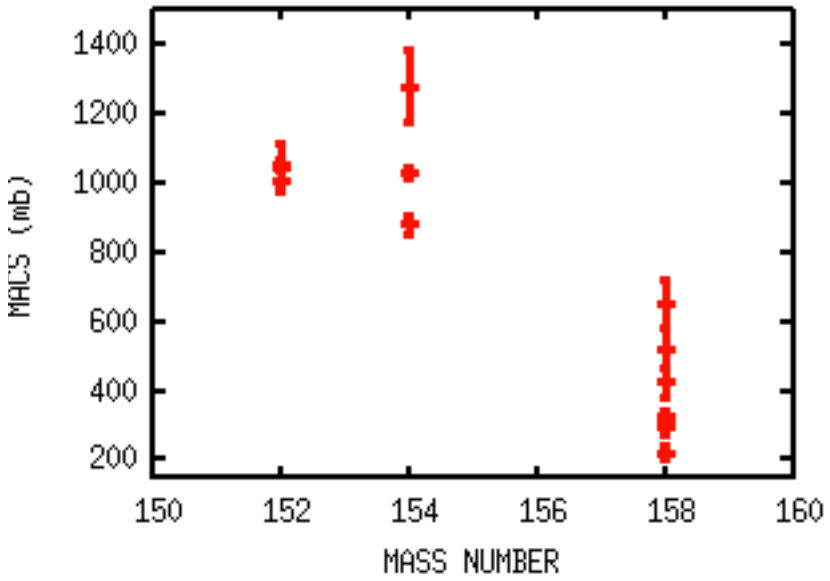
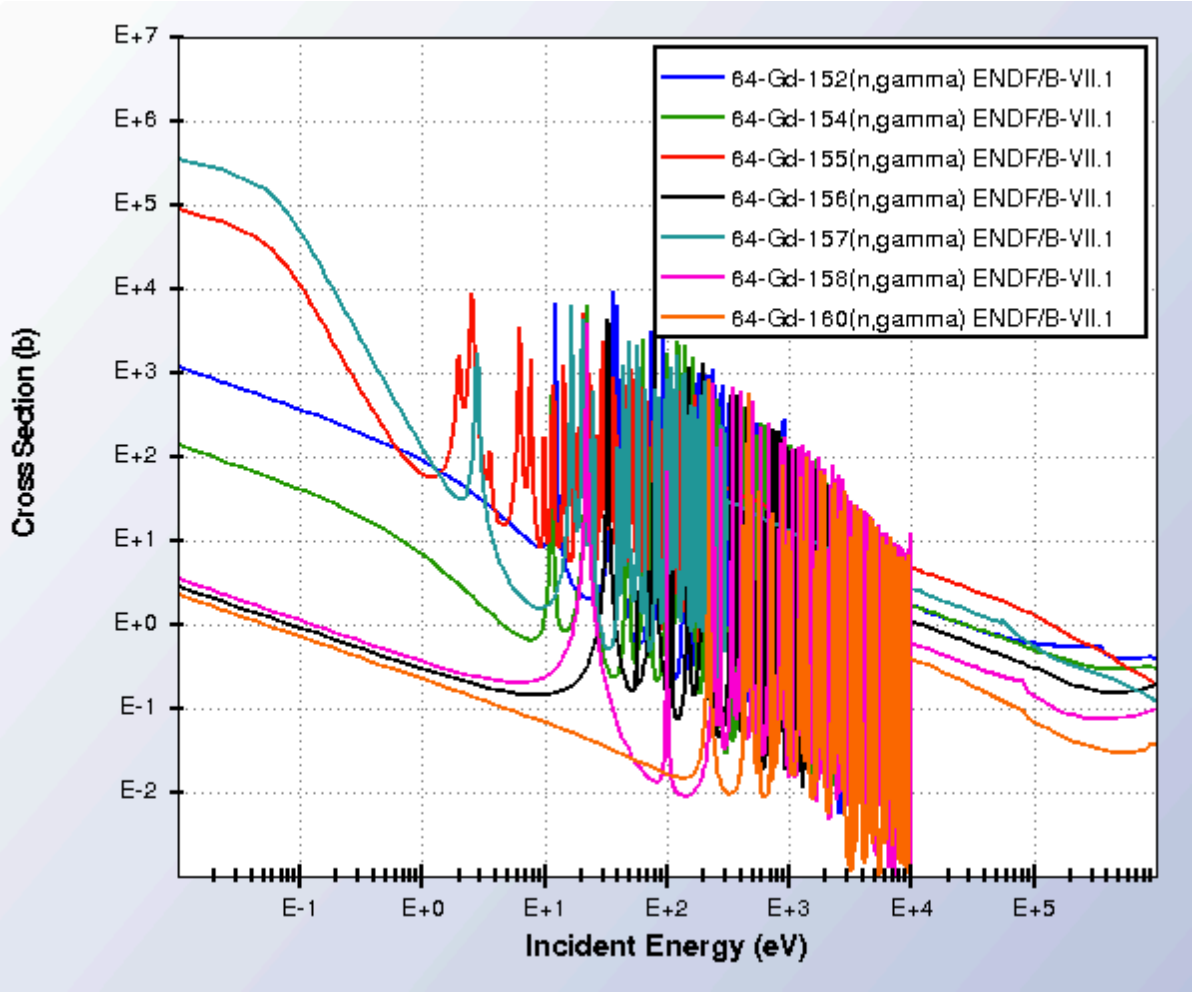




Large discrepancies in literature

Gd – Evaluation



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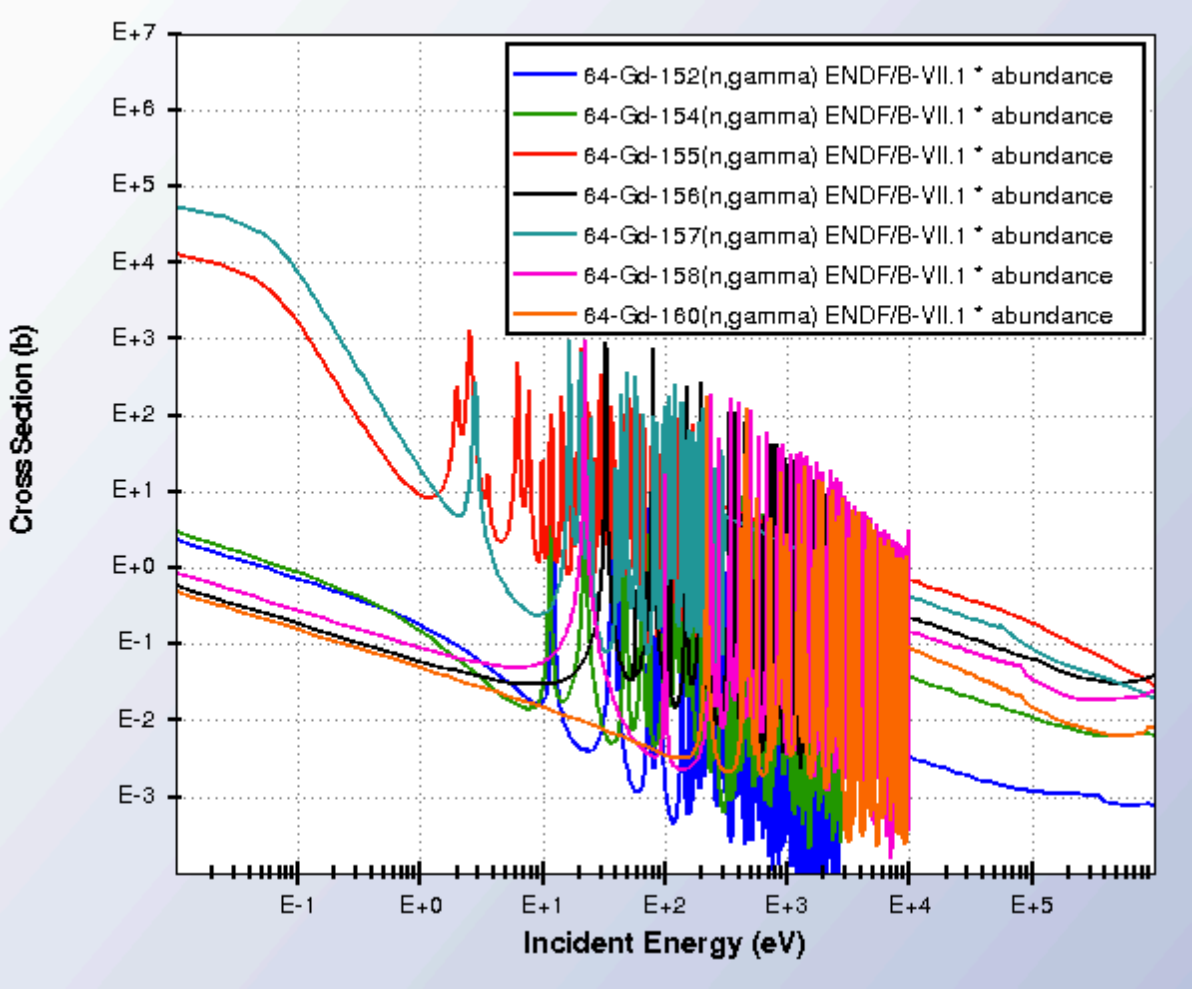
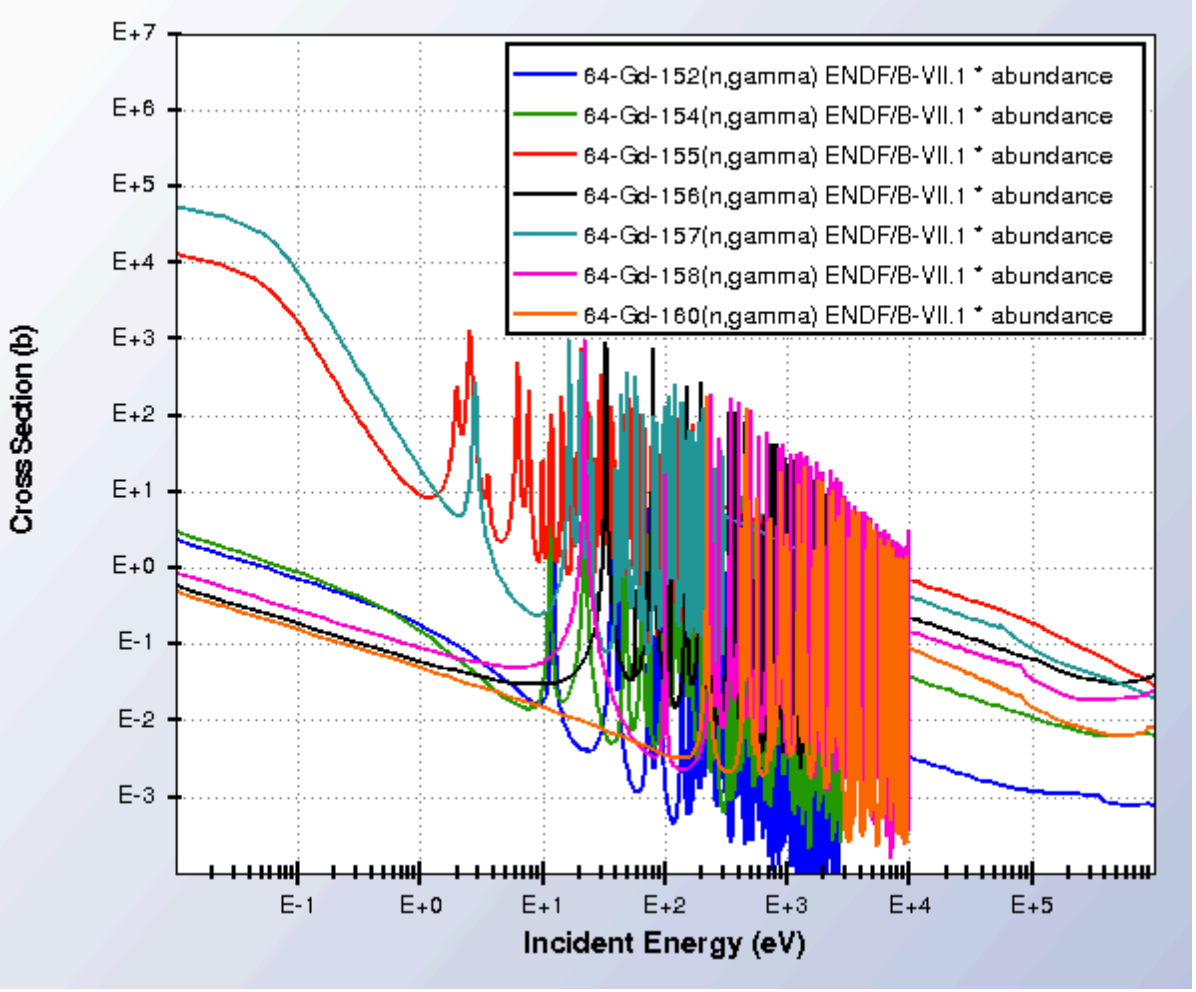


Natural abundance:

^{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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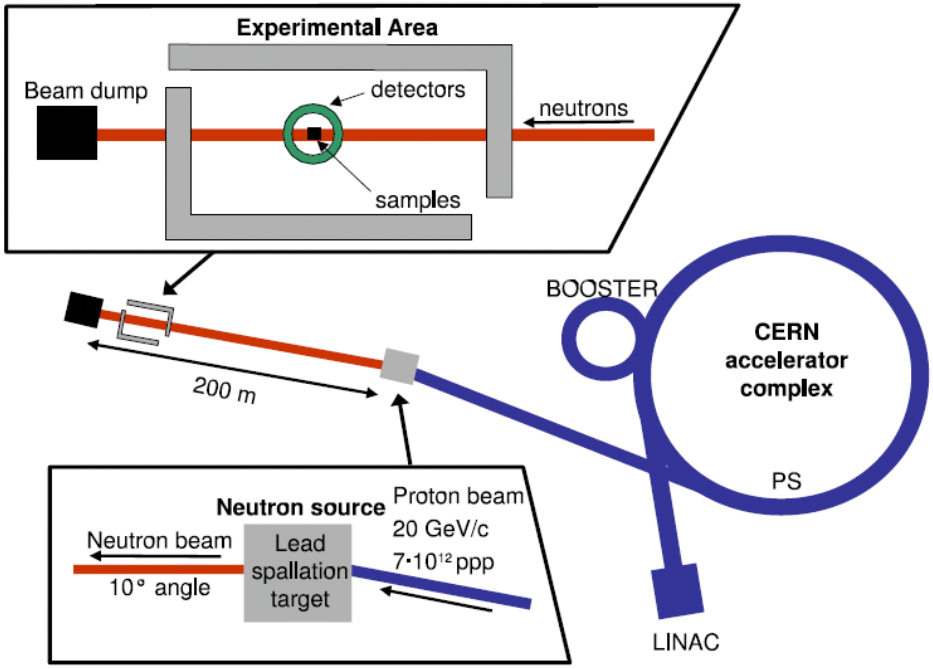
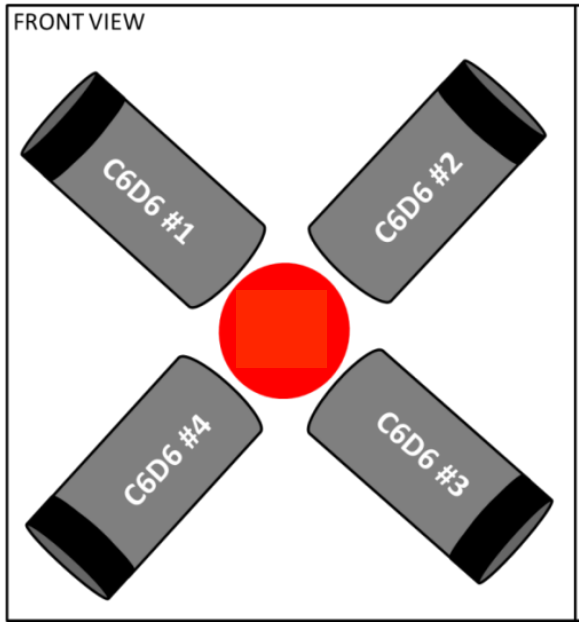
Enriched isotopes are needed

Simultaneous investigation of ALL Gd isotopes

Experimental setup



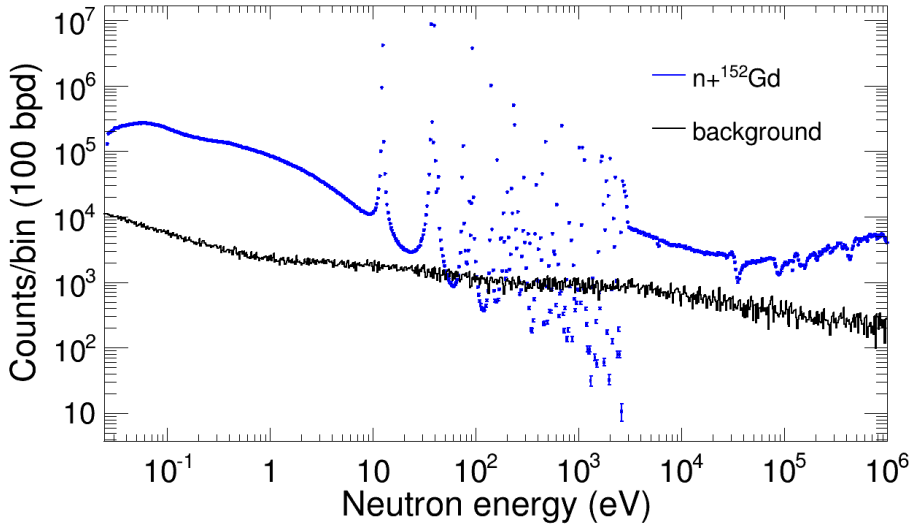
Mastinu et al., CERN-n_TOF-PUB-2013-002, "*New C_6D_6 detectors: reduced neutron sensitivity & improved safety*"

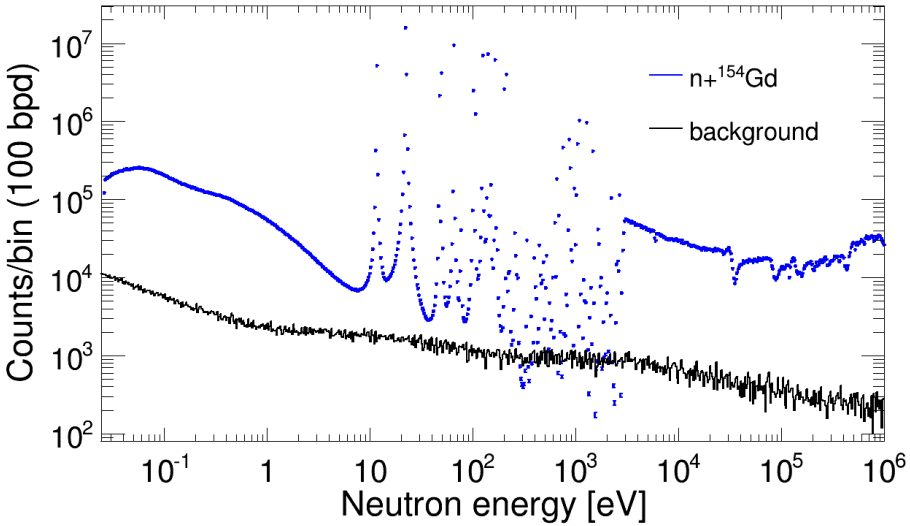


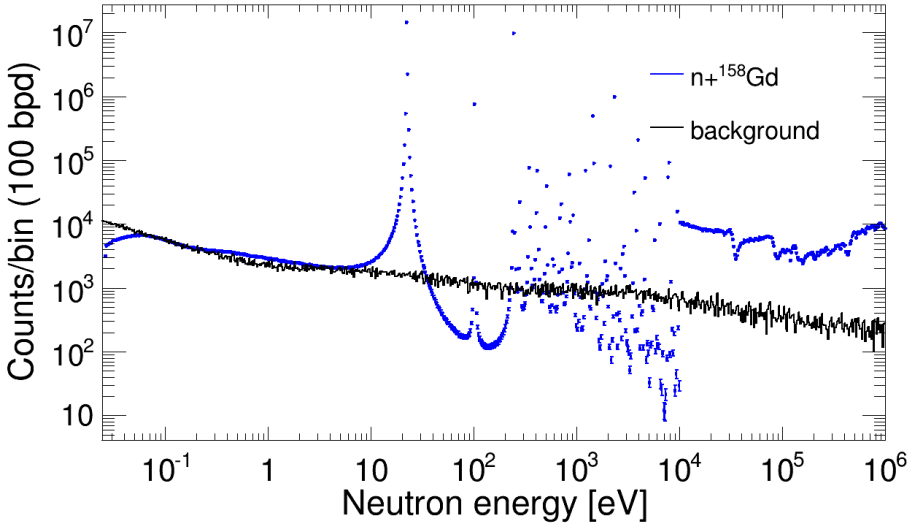
Requirements:
- Wide energy range
- Very good energy resolution
- Low neutron sensitivity

→ **EAR-1**
C_6D_6 detectors

Beam time request







Calculation for 500 mg of mono isotopic Gd (~6.2×10^{-4} at/b) 5×10^{17} protons per sample

SUMMARY

^{152,154,156,158,160}Gd samples

^{197}Au, ^{nat}Pb, ^{nat}C

3.3×10^{18} protons

Summary

Background: ^{152,154,158}**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 call for a more systematic and accurate study.

Idea: **simultaneous** investigation of Gd isotopes: measurement of capture cross section on enriched gadolinium samples(^{152,154,156,158,160}Gd) at **EAR-1** with an array of 4 C_6D_6 detectors. Taking advantage of the result of ^{155}Gd and ^{157}Gd capture measurements.

Goal: 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

Proton request: **3.3×10^{18}** protons

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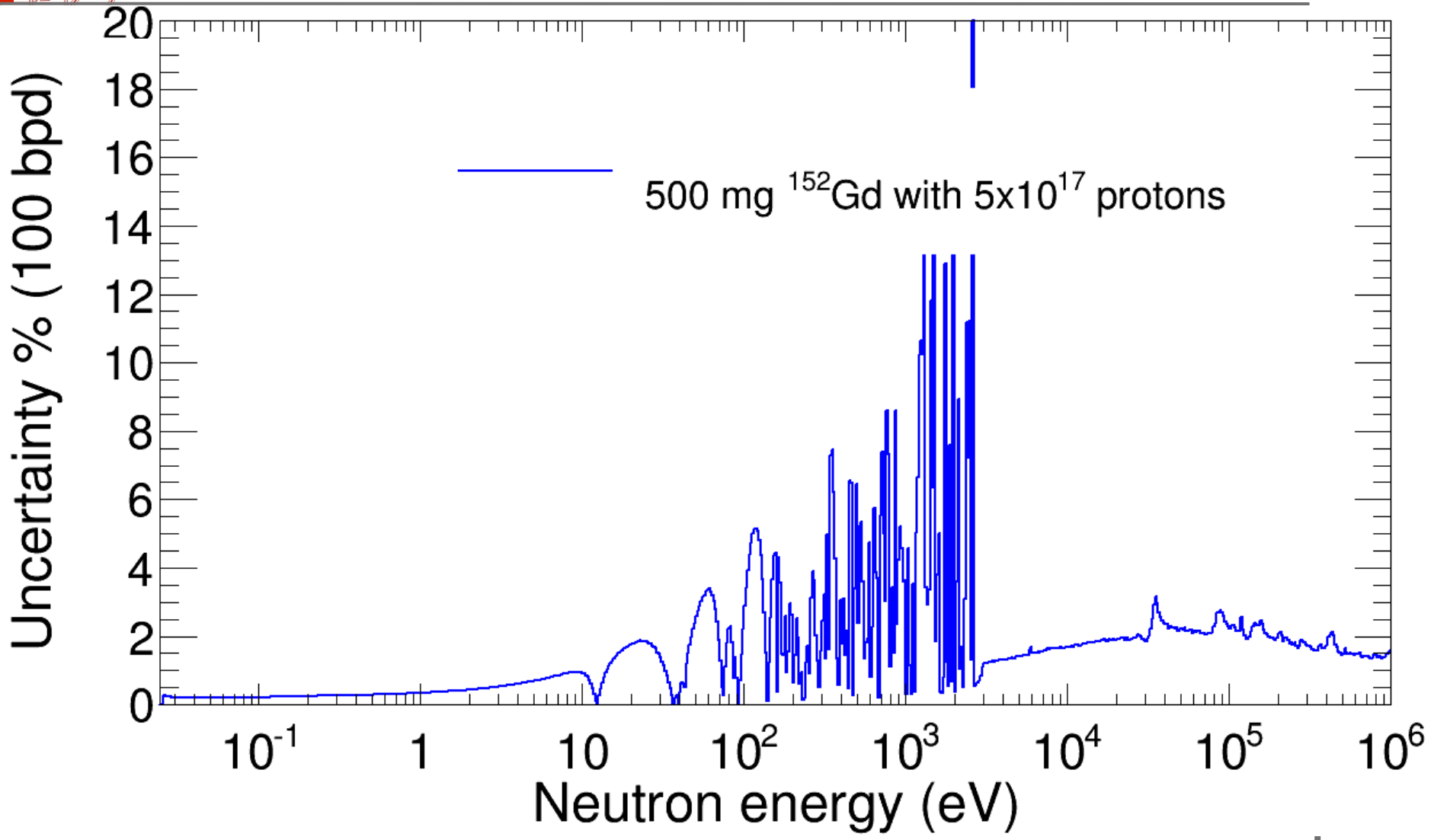
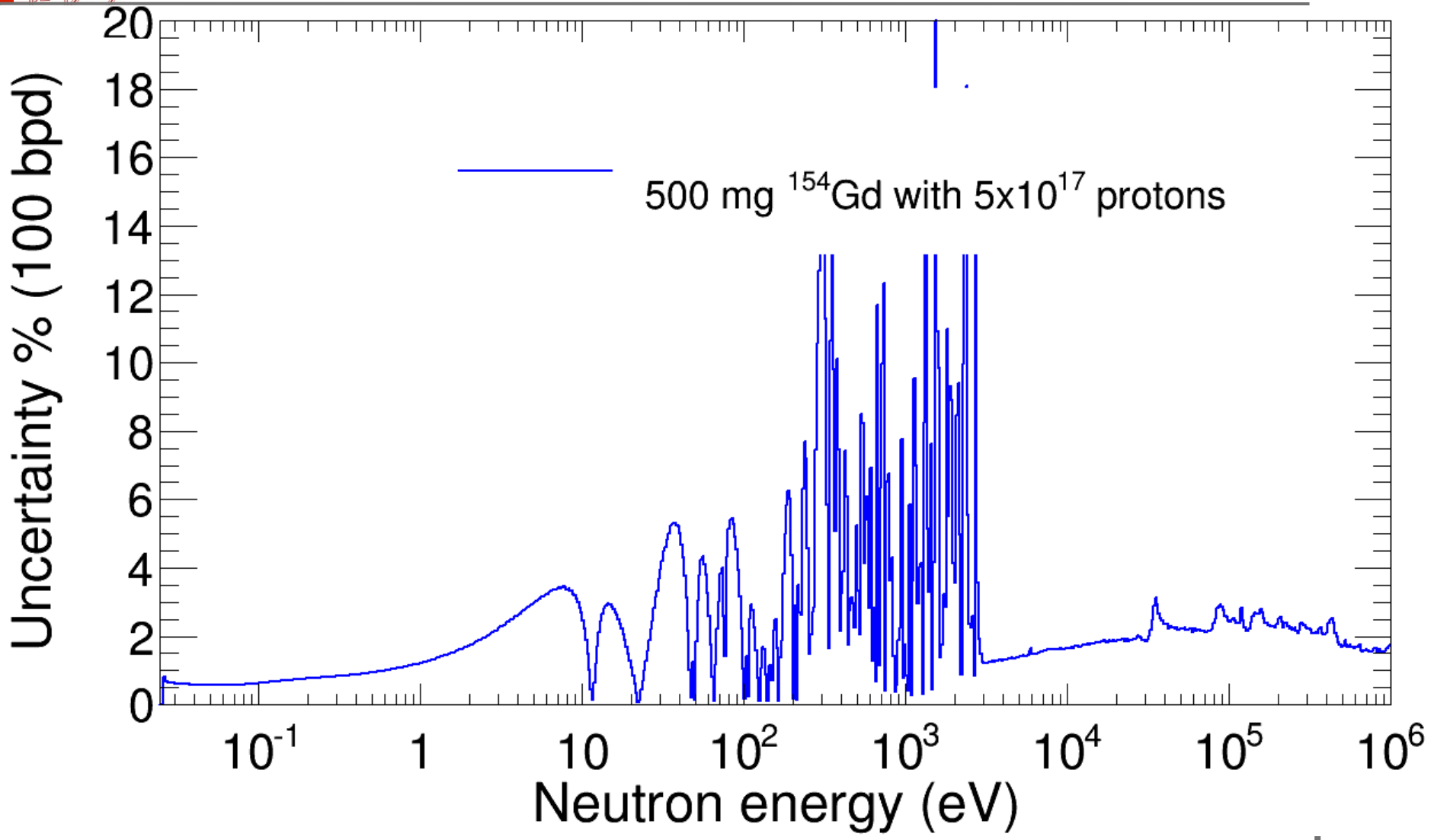
Table 1: Gadolinium isotopes

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	$95 - 98$


Uncertainty % (100 bpd)
20
18
16
14
12
10
8
6
4
2
0
500 mg ^{152}Gd with 5x10^{17} protons
10^{-1}
1
10
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
Neutron energy (eV)


Uncertainty % (100 bpd)
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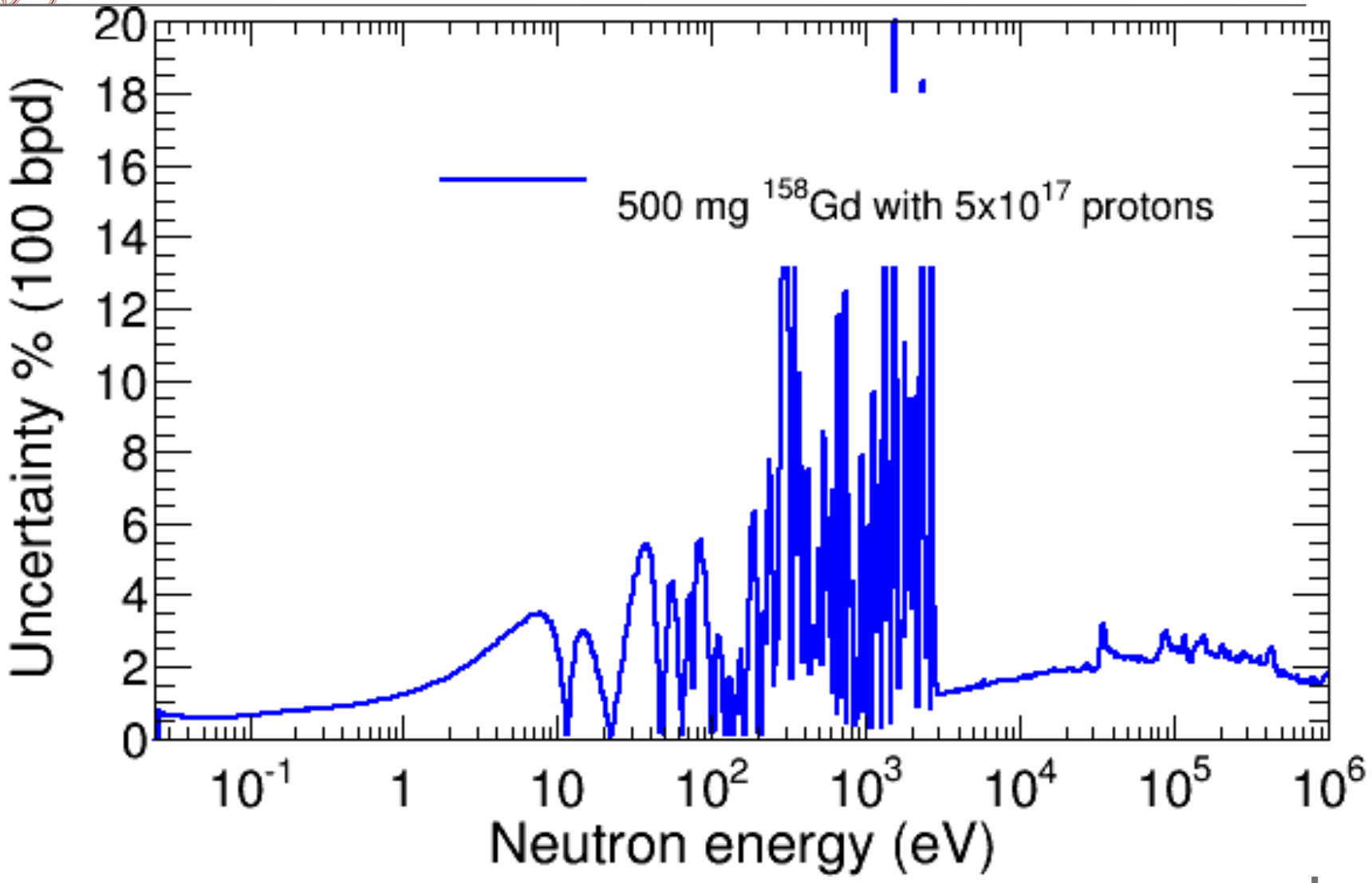
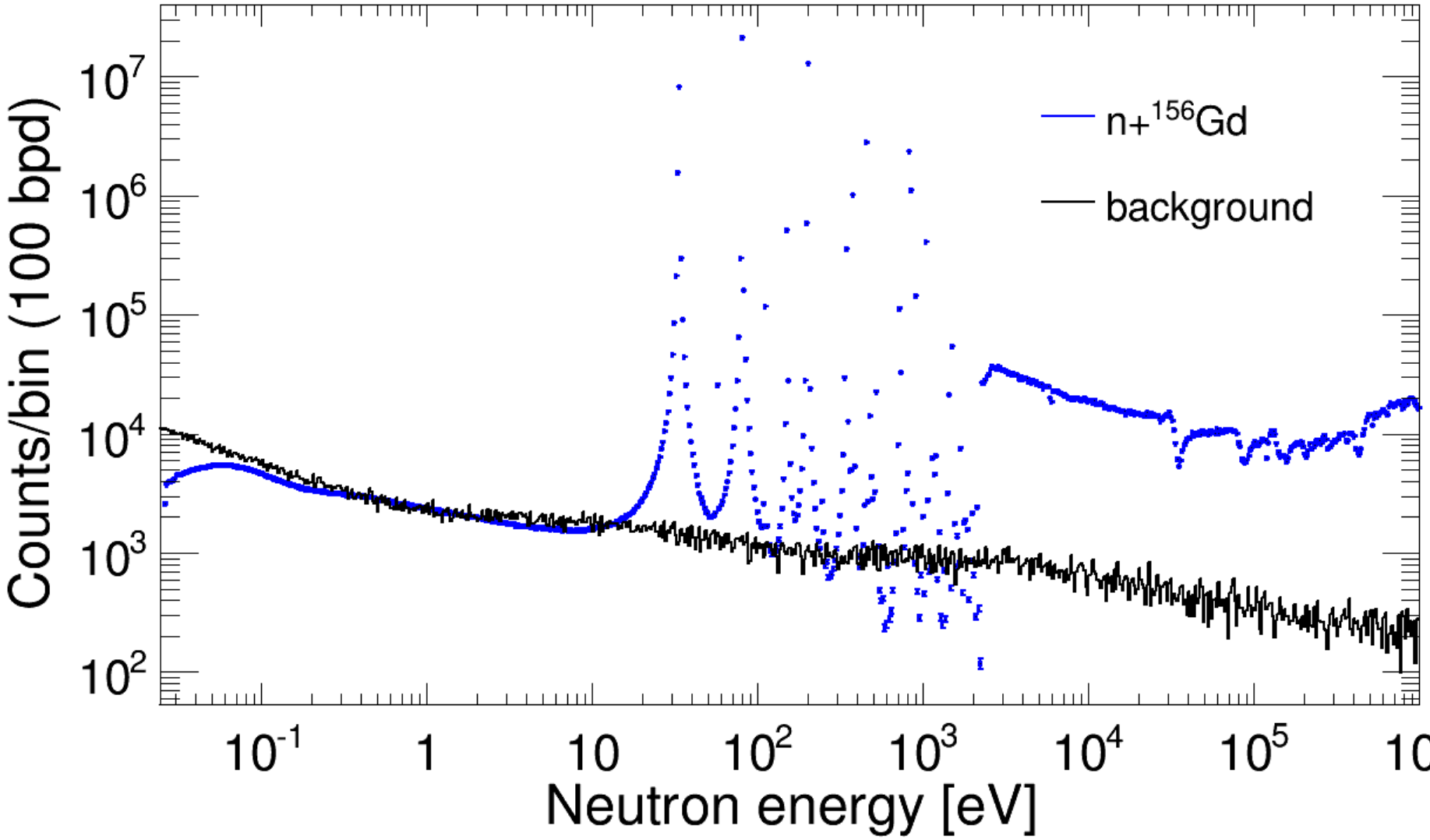
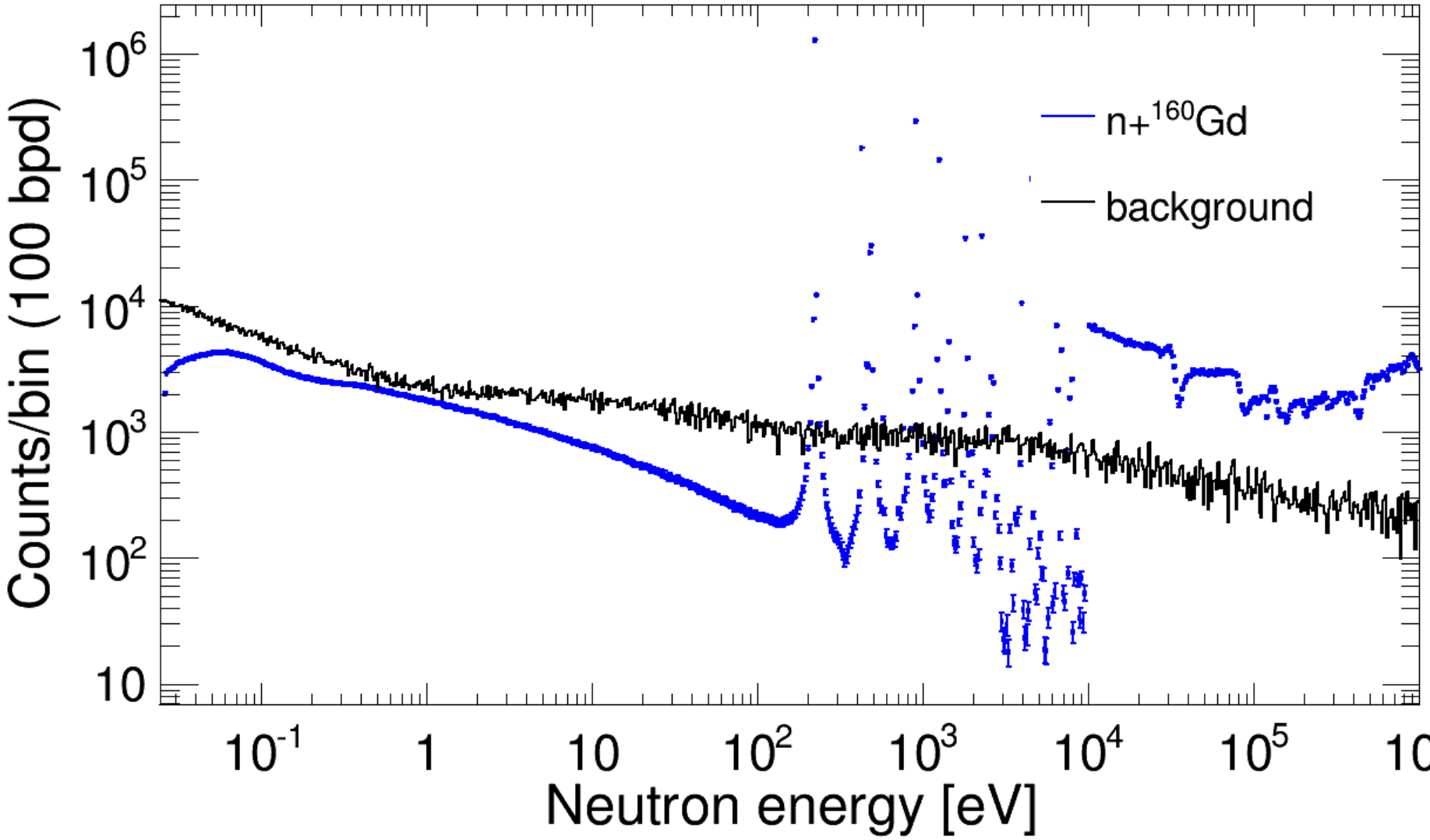
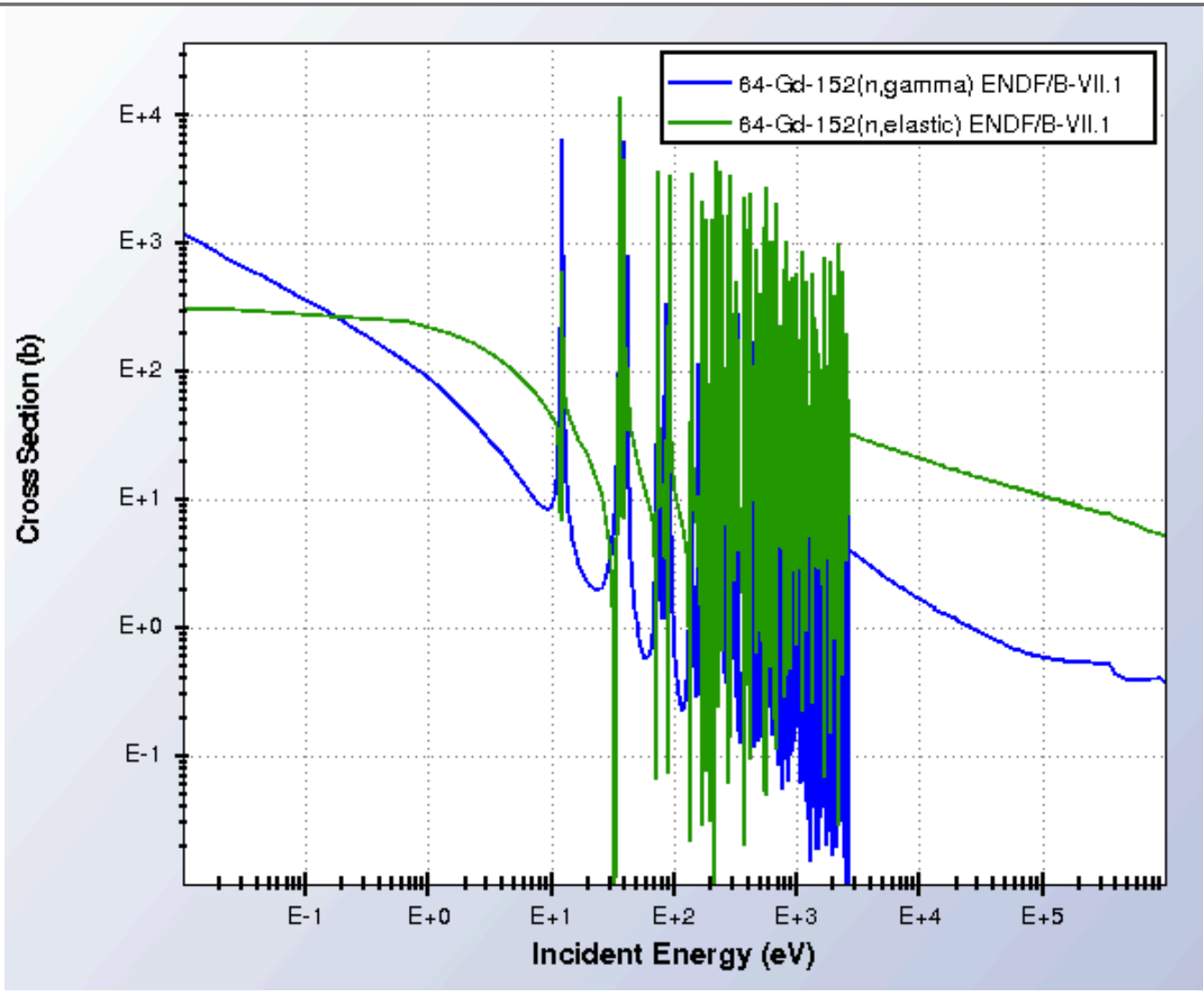
18
16
14
12
10
8
6
4
2
0
500 mg ^{154}Gd with 5x10^{17} protons
10^{-1}
1
10
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
Neutron energy (eV)


Uncertainty % (100 bpd)
Neutron energy (eV)
500 mg ^{158}Gd with 5x10^{17} protons
0
2
4
6
8
10
12
14
16
18
20
10^{-1}
1
10
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}


Counts/bin (100 bpd)
10^7
10^6
10^5
10^4
10^3
10^2
n+^{156}Gd
background
10^{-1}
1
10
10^2
10^3
10^4
10^5
10^6
Neutron energy [eV]


Counts/bin (100 bpd)
10^6
10^5
10^4
10^3
10^2
10
10^{-1}
1
10
10^2
10^3
10^4
10^5
10^6
Neutron energy [eV]
n+^{160}Gd
background

Gd data in literature



Gd data in literature