$^{155, 157}$Gd(n, γ) cross sections measured at n_TOF

M. Mastromarco on behalf of the n_TOF Collaboration

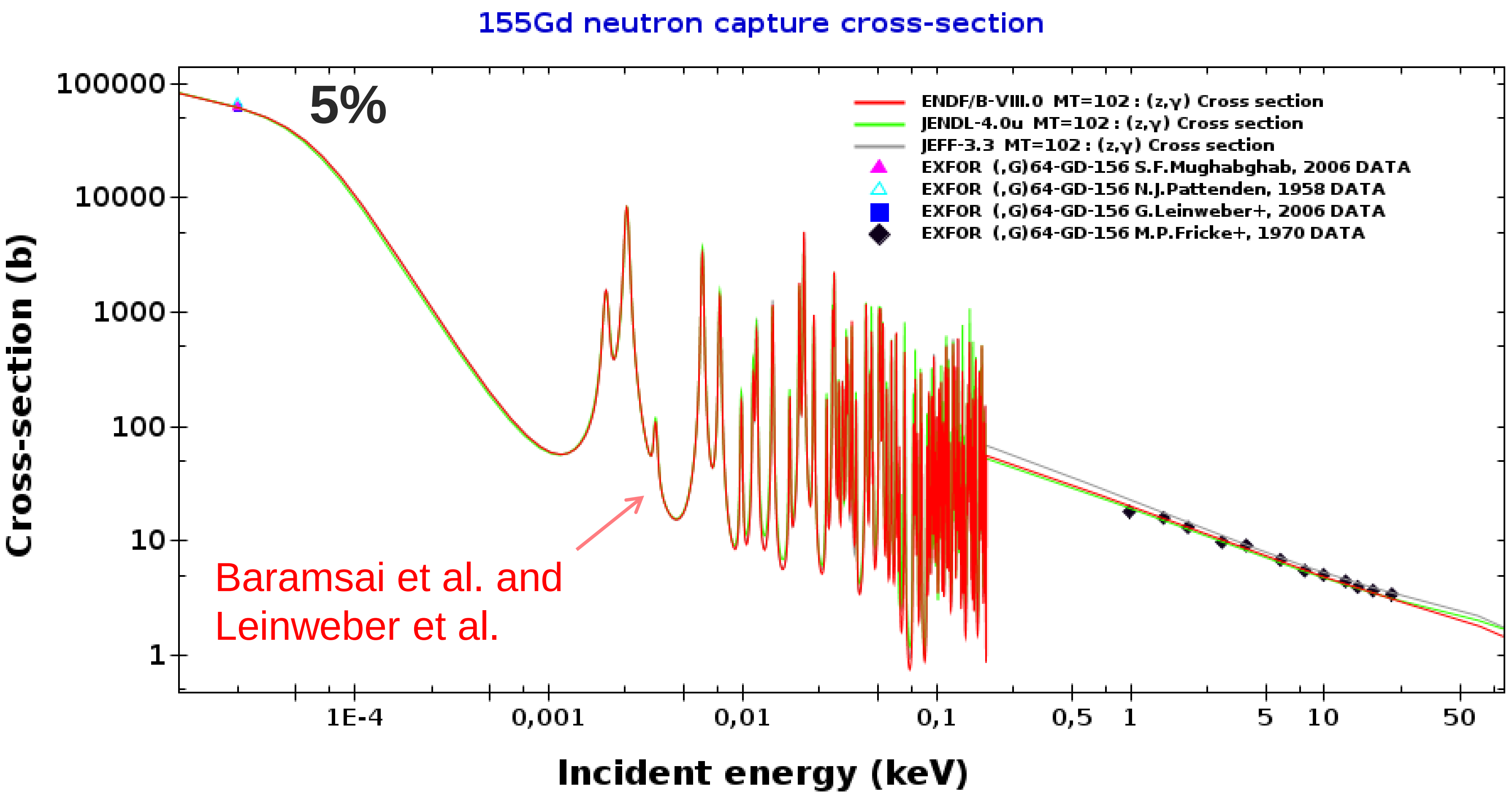
Main motivation

- ✓ **FAs** of current **Light Water Reactor** make extensive use of the so-called **“burnable neutron poisons”** characterized by a neutron capture cross section comparable or higher than **^{235}U(n, f);**

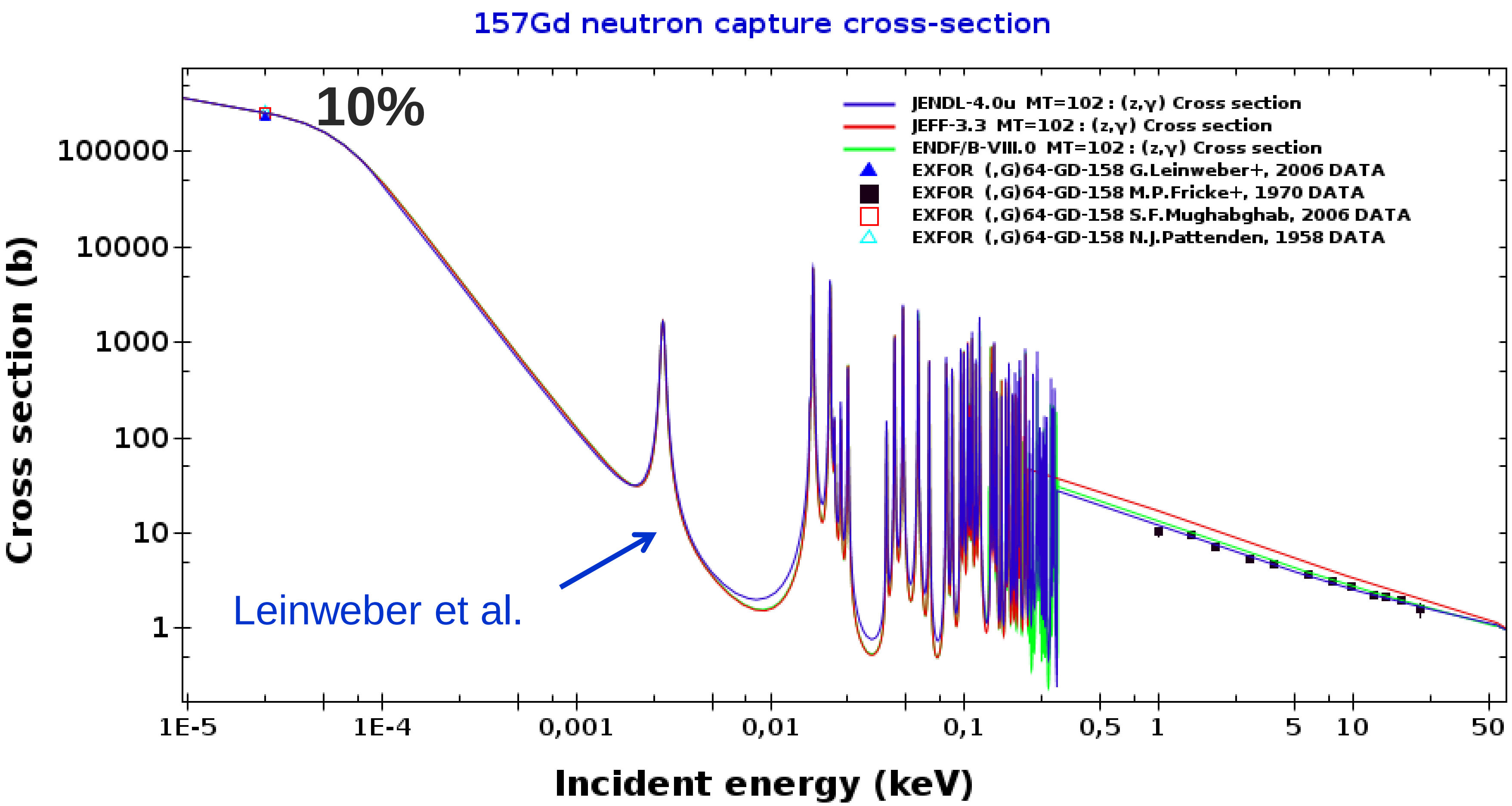
- ✓ Among these isotopes **the most common is Gadolinium**, taking advantage of the very large capture cross section at neutron energies below 1 eV of the two odd isotopes: **^{155}Gd** and **^{157}Gd**;

- ✓ Accurate predictions about their burning rate are fundamental for **safety reasons** and predicting the **appearance of FAs reactivity peak** and its intensity;

State of the Art: ^{155}Gd

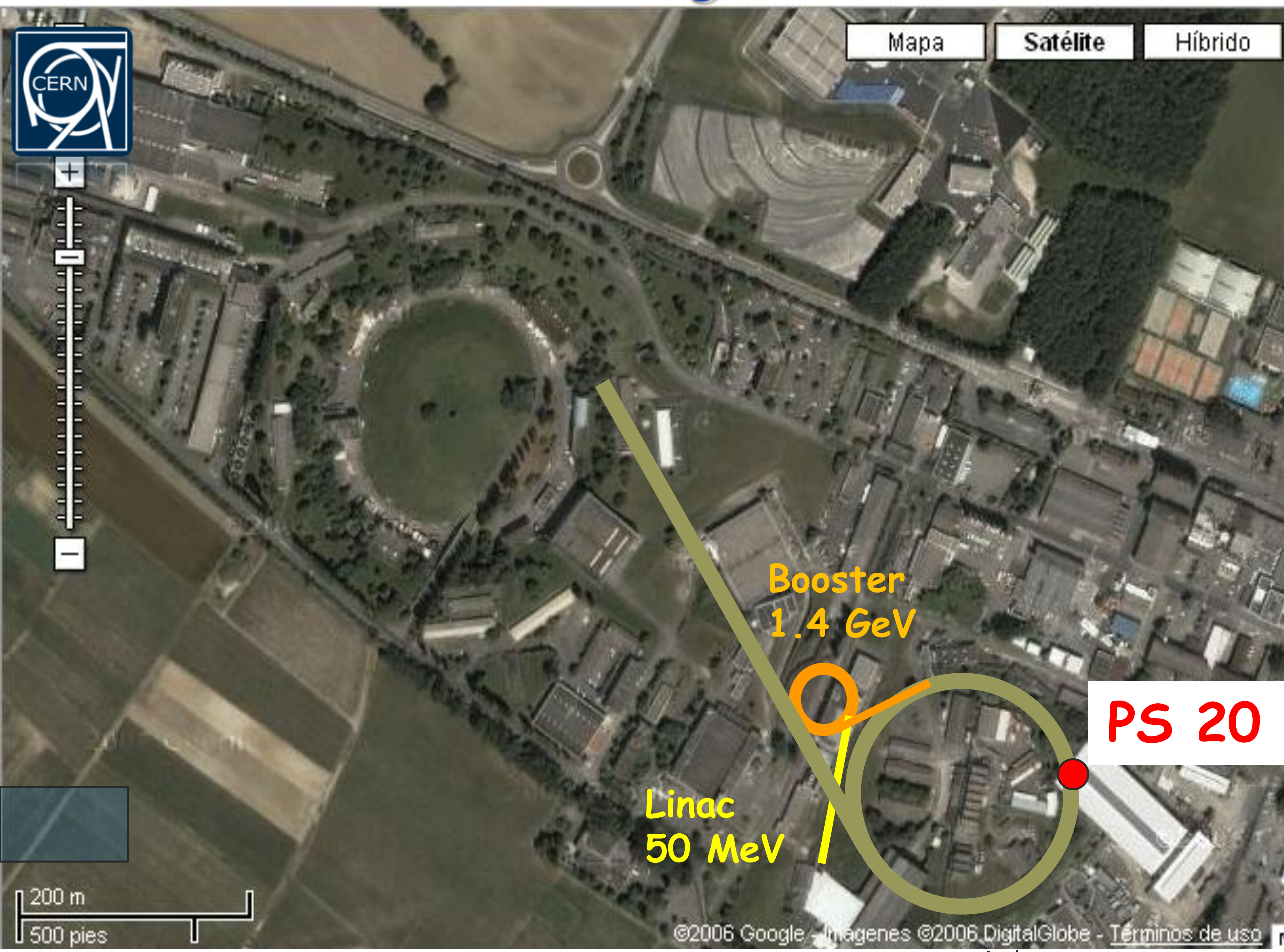


State of the Art: ^{157}Gd



n_TOF facility @ CERN

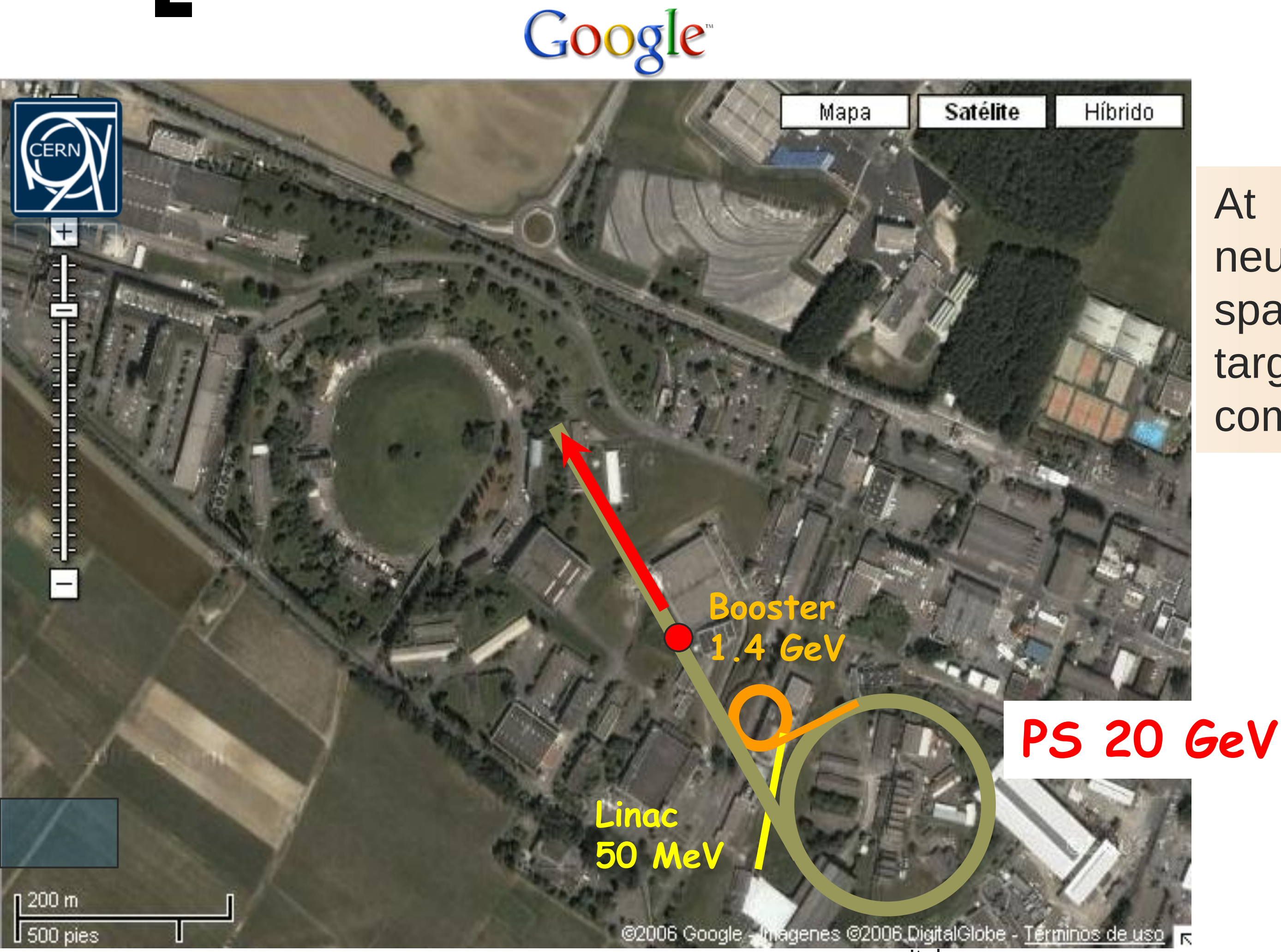
Google



At the n_TOF facility neutrons are produced by spallation, on a Lead target, of **20 GeV protons** coming from the PS

Italy

n_TOF facility @ CERN



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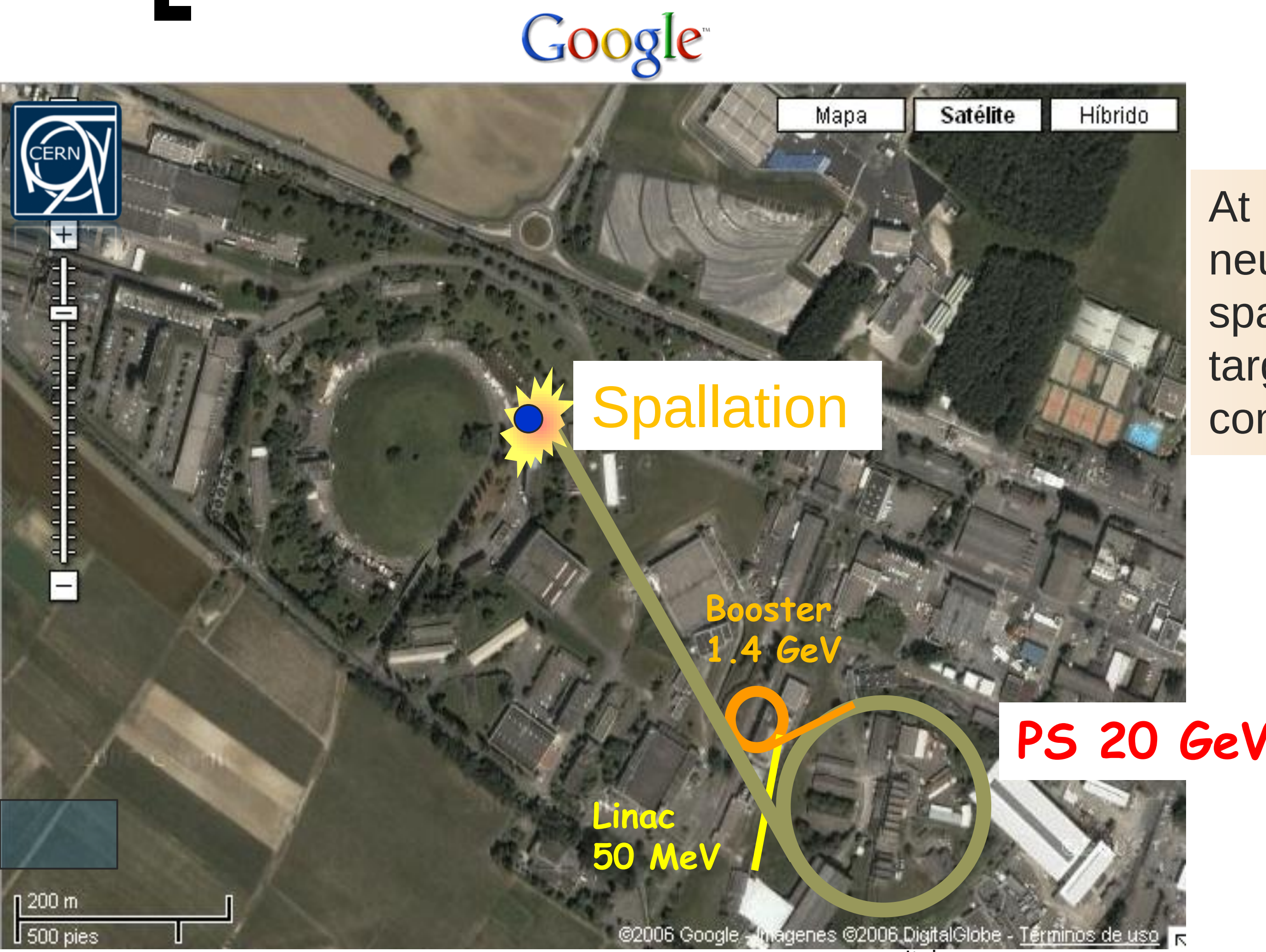

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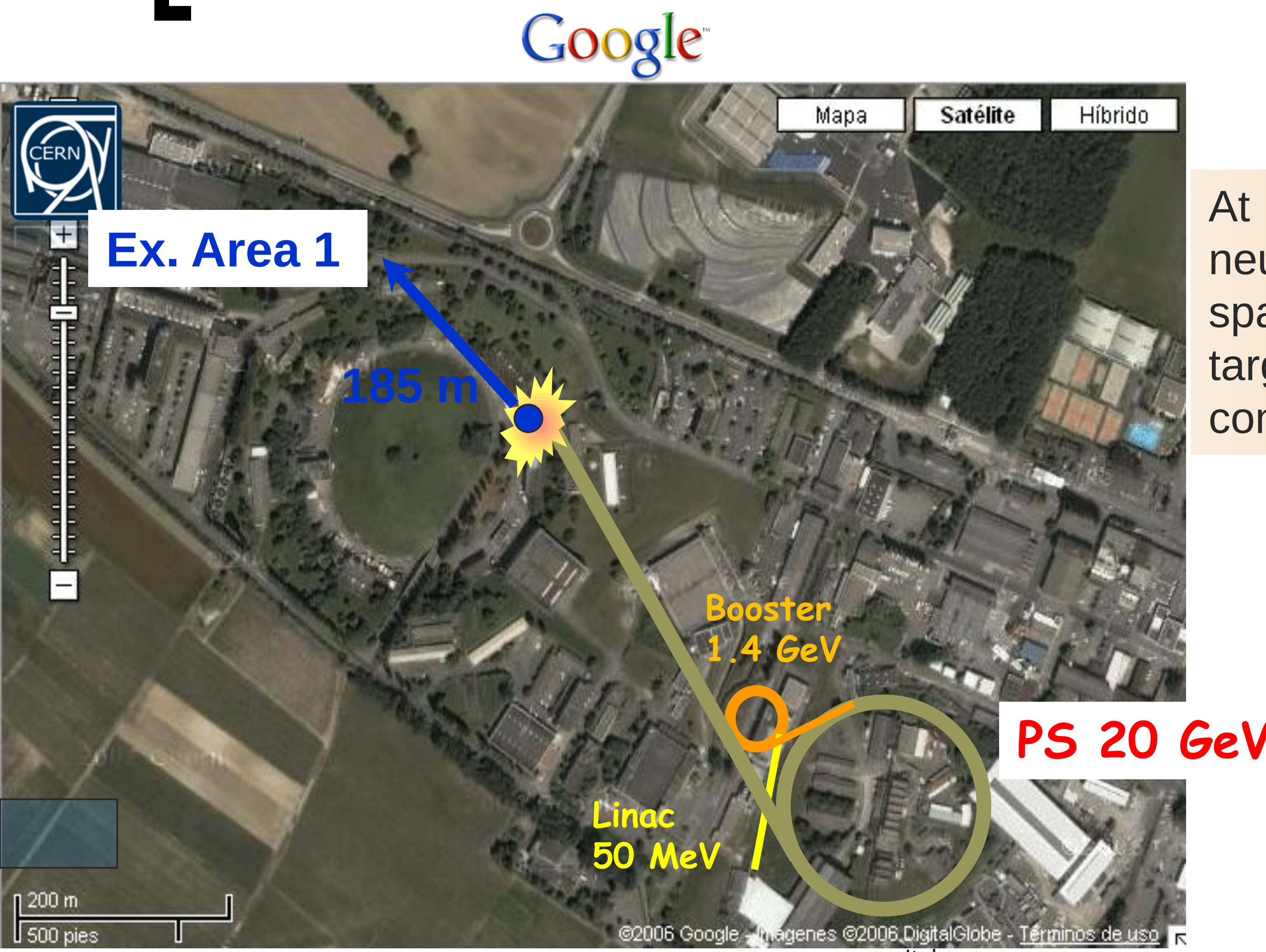
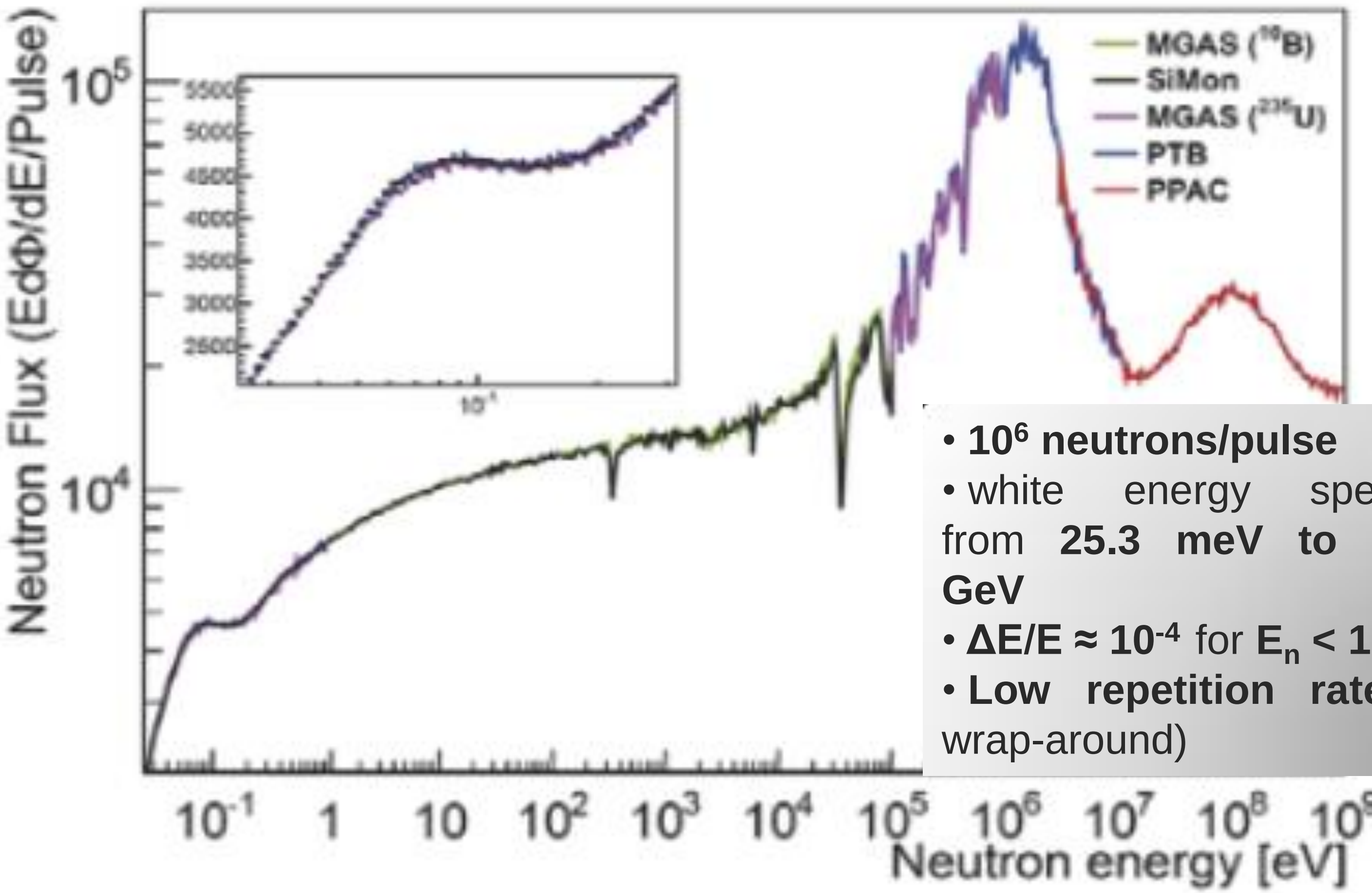


At the n_TOF facility neutrons are produced by spallation, on a Lead target, of **20 GeV protons** coming from the PS

n_TOF facility @ CERN: neutron flux characteristics

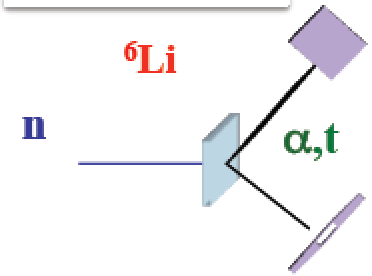


- **10^6 neutrons/pulse**
- white energy spectrum from **25.3 meV to some GeV**
- **ΔE/E ≈ 10^{-4}** for **E_n < 1 keV**
- **Low repetition rate** (no wrap-around)

Neutron flux during the Gd campaing

$^{6}Li(n, t)^{4}He$

SiMon – EAR1



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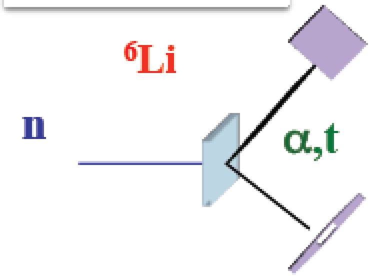

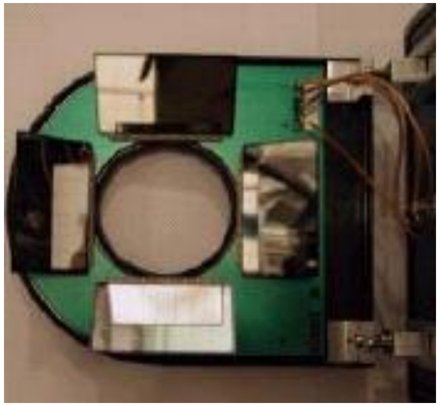

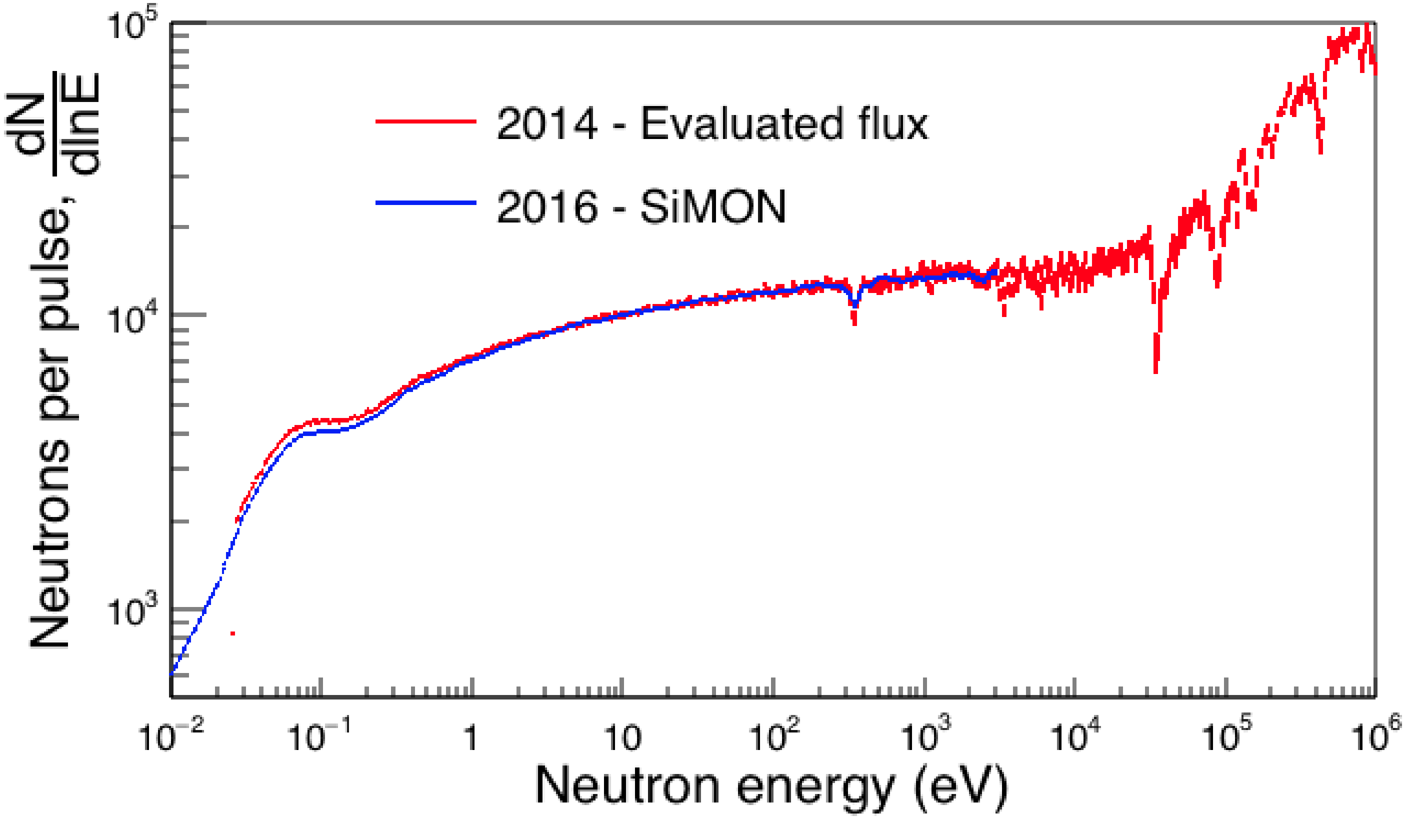

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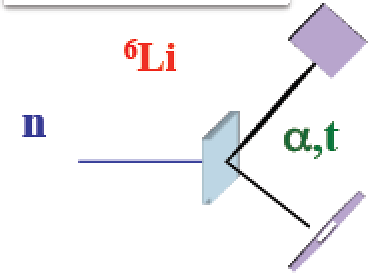

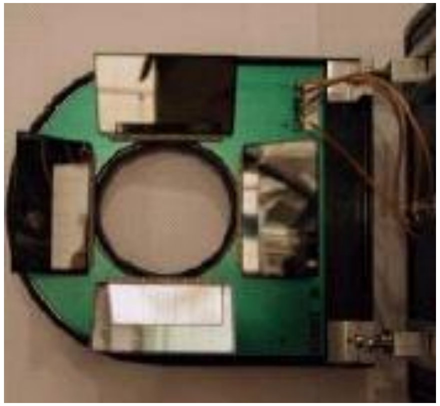

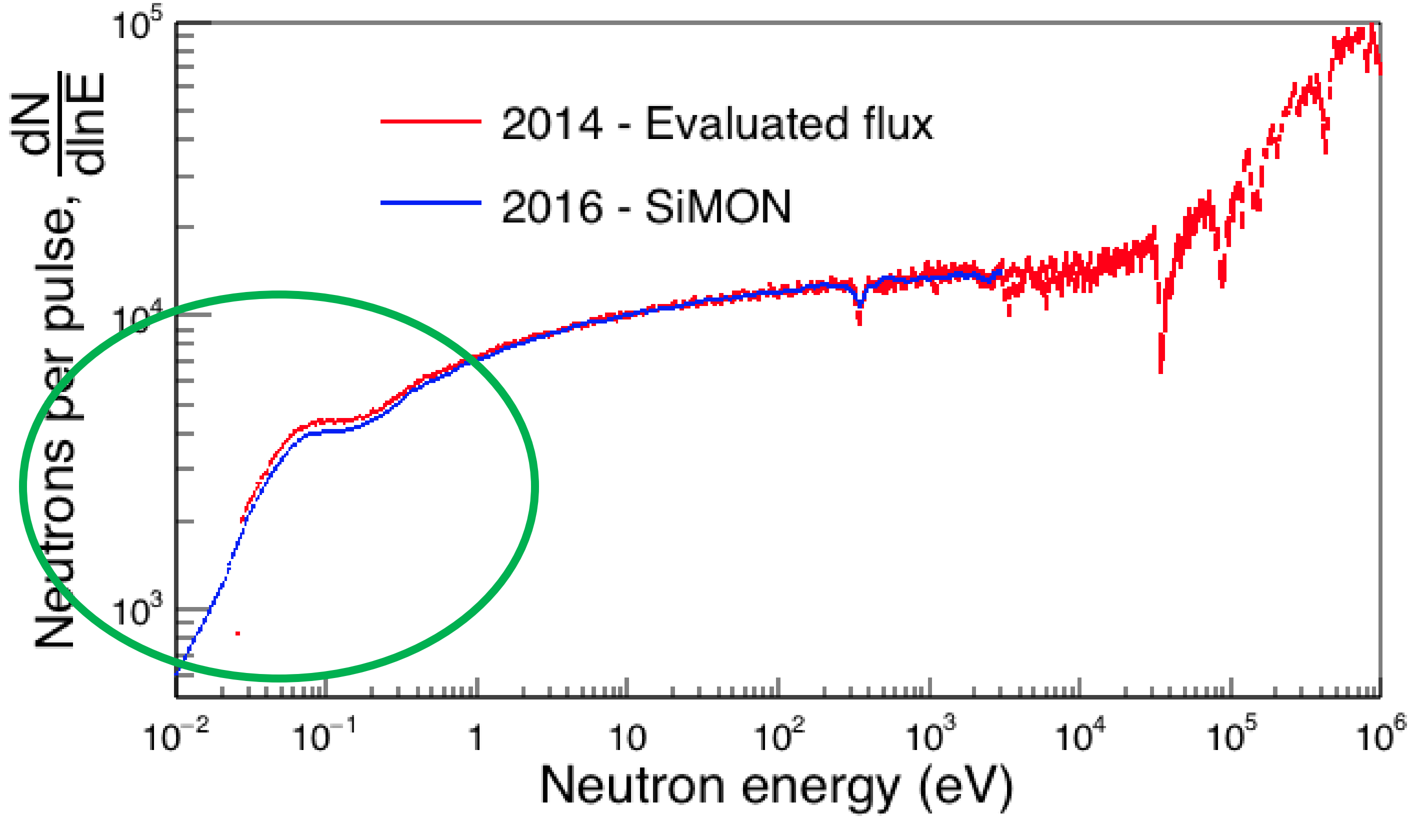

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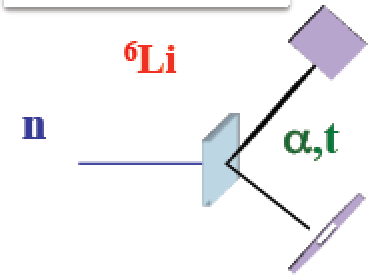
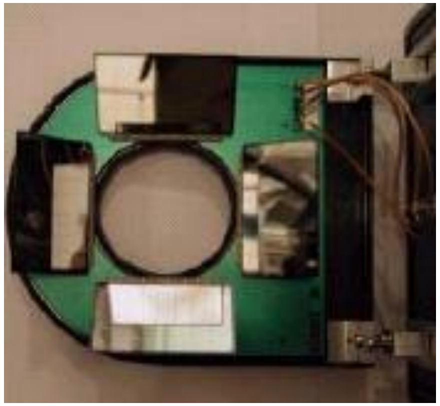
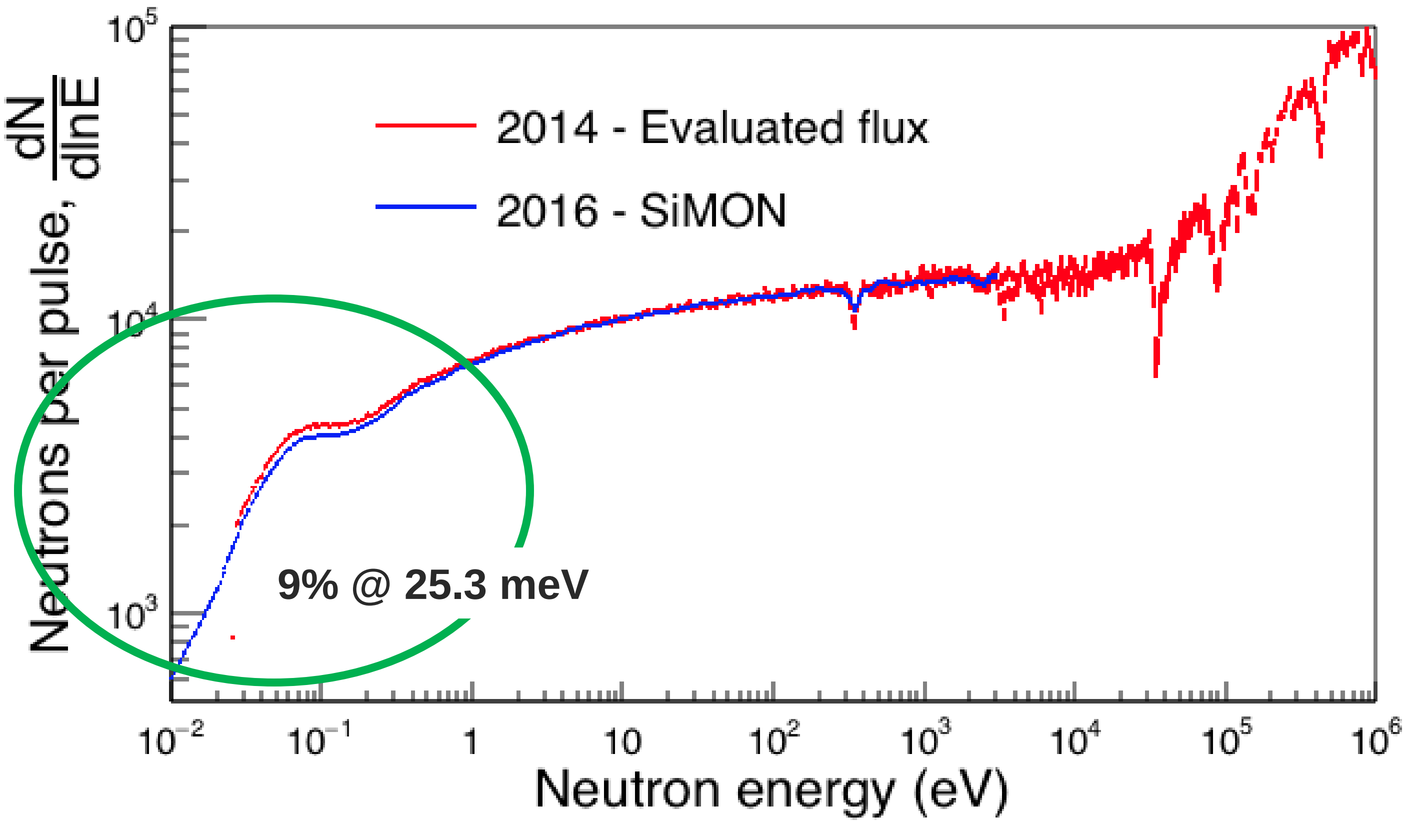




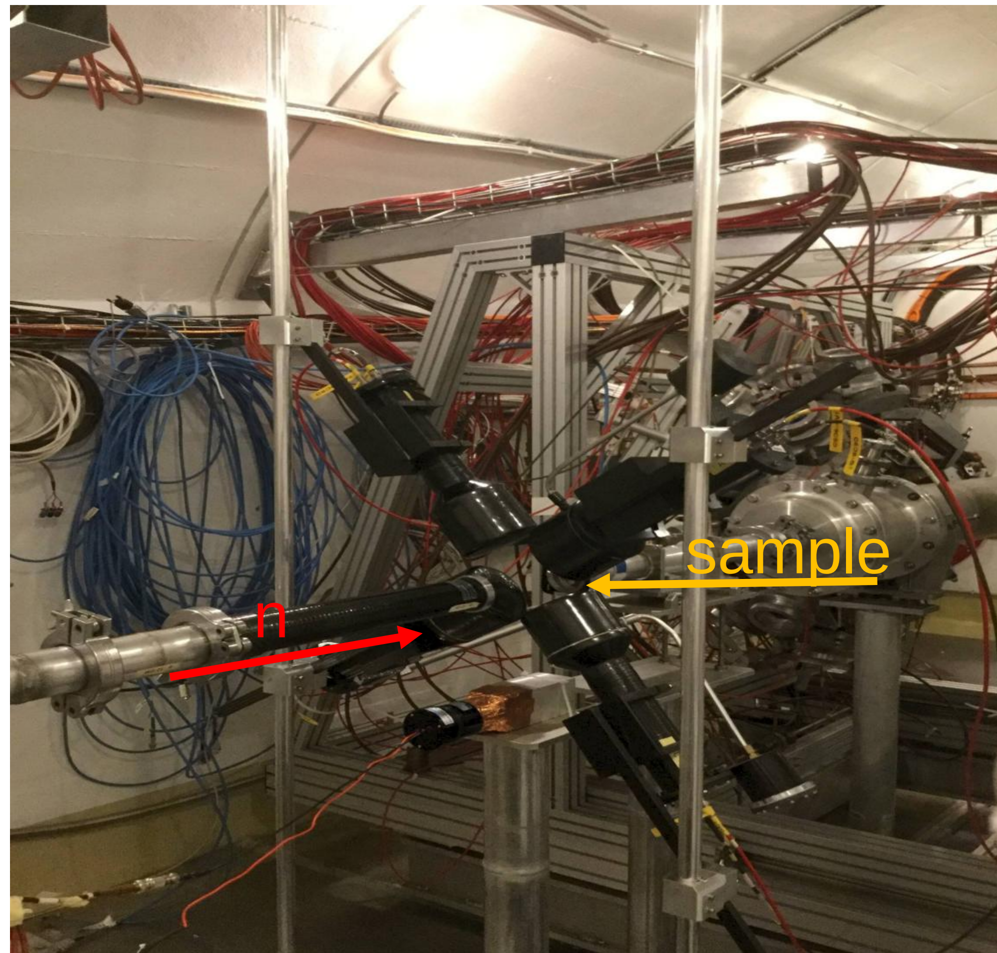


Experimental setup

4 deuterated benzene C_6D_6 liquid scintillator detectors placed at 90° with respect to each other and in front of the sample.

The **total energy detection principle** was used by combining the detection system described above with the so-called **Pulse Height Weighting Technique (PHWT)** (see Ref. [1] and [2])

- Two sample of ^{157}Gd:
  - **thin** sample of 4.7 mg
  - **thick** sample of 191.6 mg
- Two sample of ^{155}Gd:
  - **thin** sample of 10 mg
  - **thick** sample of 100.6 mg
- **Empty and natPb:** background
- **Gold**: normalization



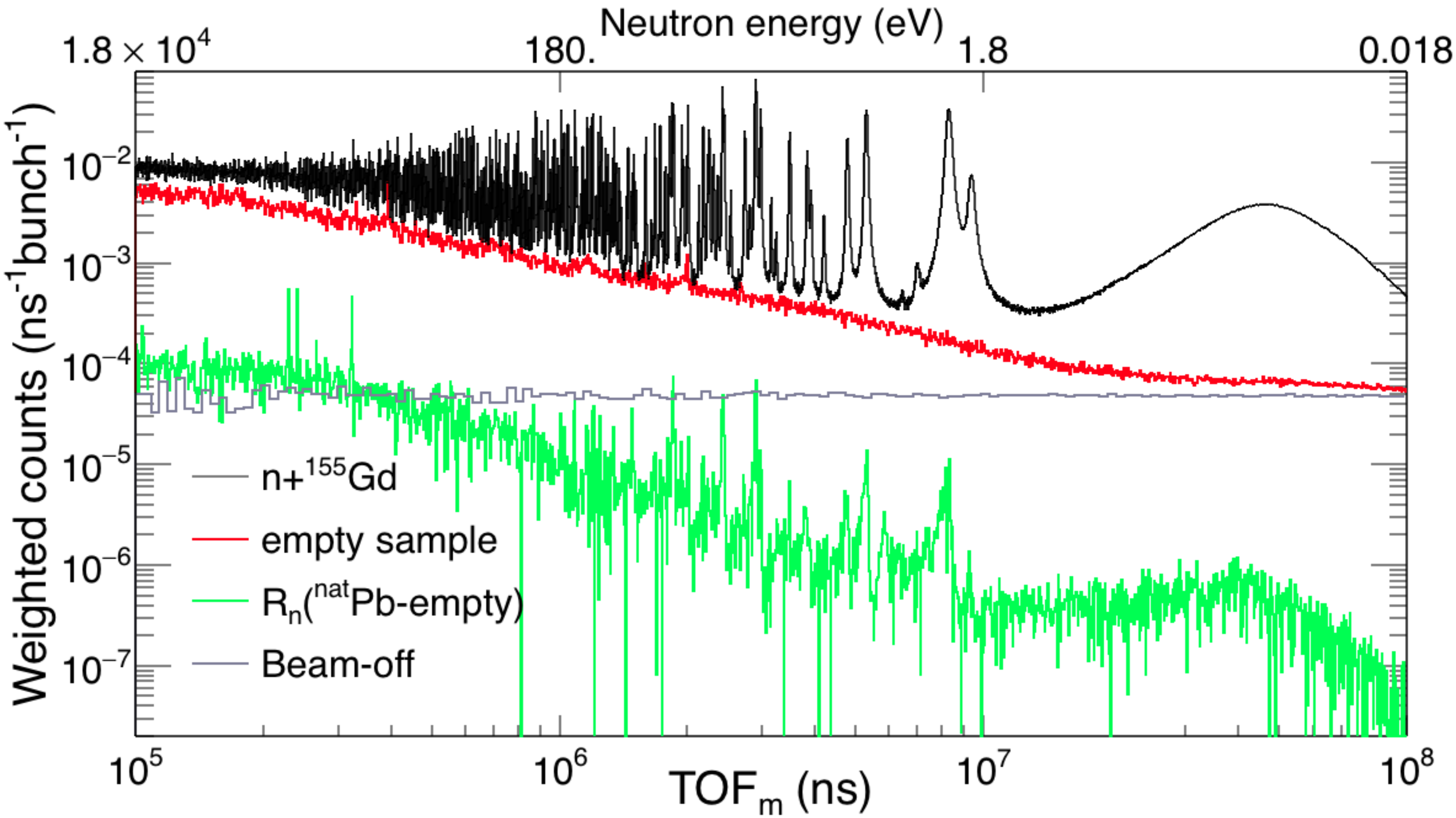
[1] P. Schillebeeckx, et al., Nucl. Data Sheets 113 (2012) 3054
[2] A. Borella, et al., Nucl. Instrum. & Methods A 577 (2007) 626

Yield calculation

$$Y(E_n) = \frac{N}{S_n + E_n \frac{A}{A+1}} \frac{C_w(E_n) - B_w(E_n)}{\varphi_n(E_n) f_{BIF}(E_n)}$$

N	Normalization factor
$C_w(E_n) - B_w(E_n)$	Sample counts background subtracted
$S_n + E_n \frac{A}{A+1}$	Energy of the compound nucleus
$\varphi_n(E_n) f_{BIF}(E_n)$	Flux fraction intercepted by the sample

Background



Neutron energy (eV)
1.8 × 10^4
180.
1.8
0.018
Weighted counts (ns^-1bunch^-1)
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
n+155Gd
empty sample
Rn(natPb-empty)
Beam-off
10^5
10^6
10^7
10^8
TOFm (ns)

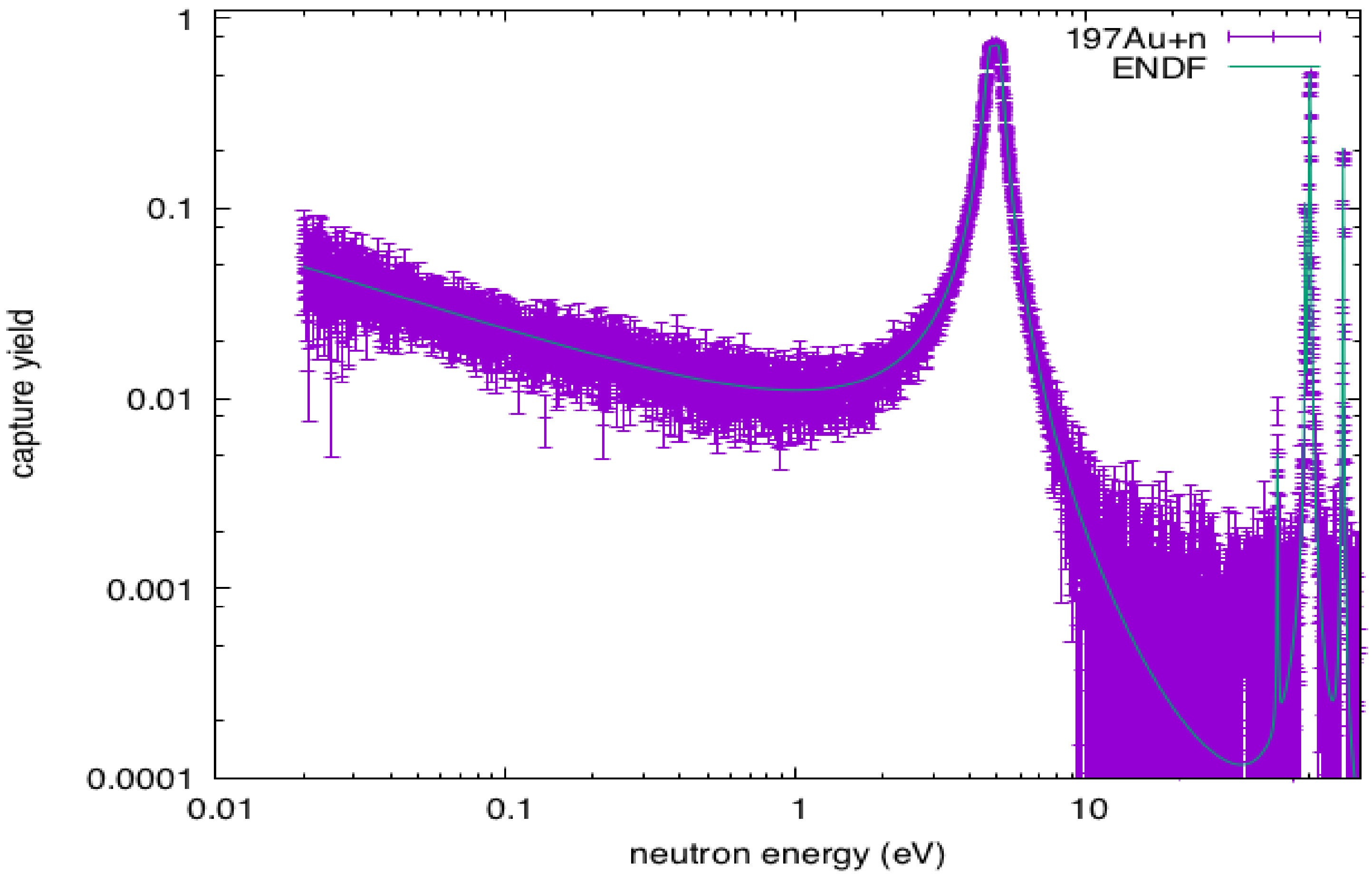
Quality check: Calibrations + WF

- Calibrations:
  1. Linear
  2. Quadratic

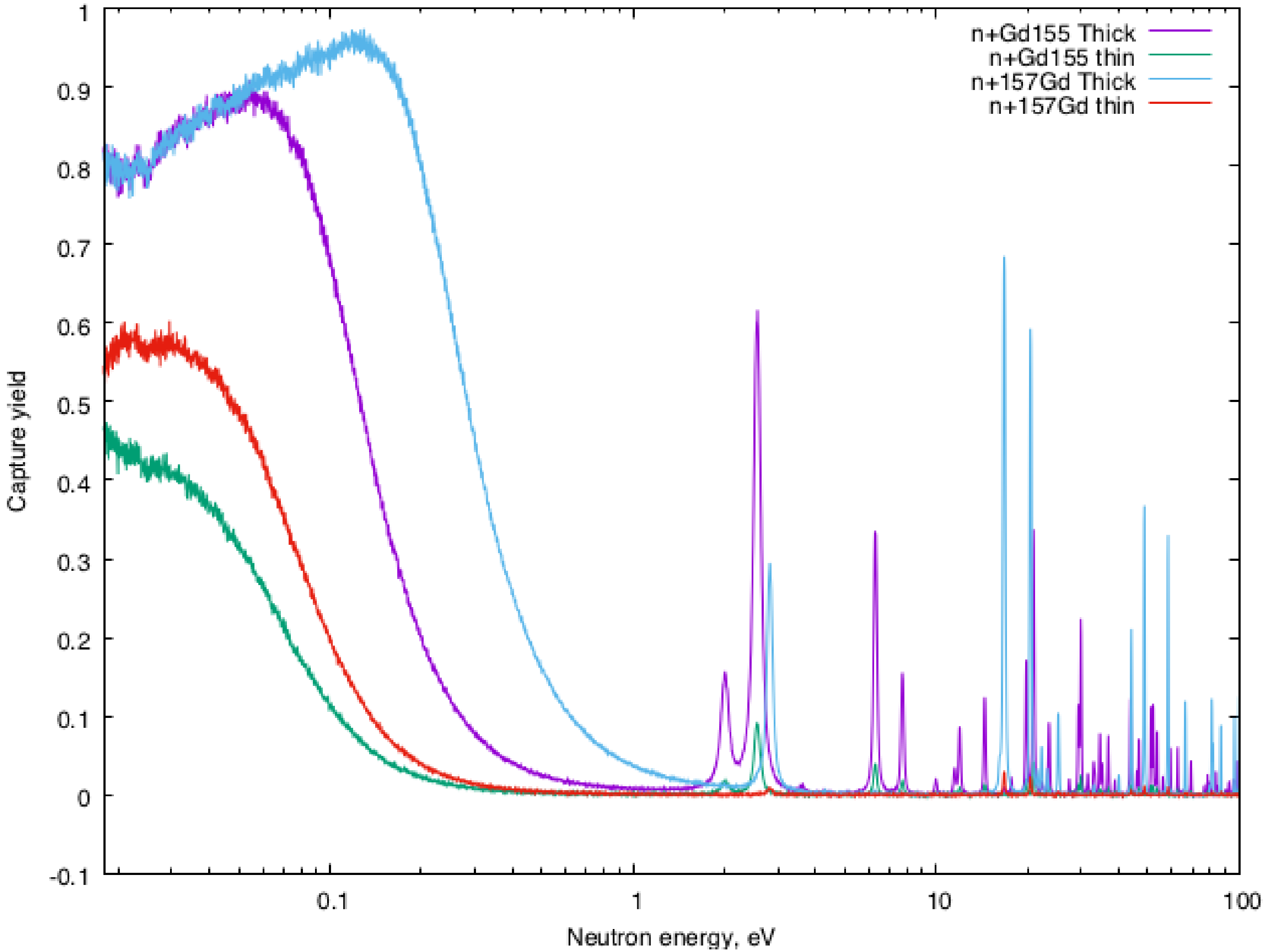
- Weighting Functions:
  1. Exponential emission (7 cases) and omogeneous, threshold 150, 175 and 200 keV

Yields in agreement within 1.5 %

Yield: Gold Normalization @ 4.9 eV



Yield: thermal region

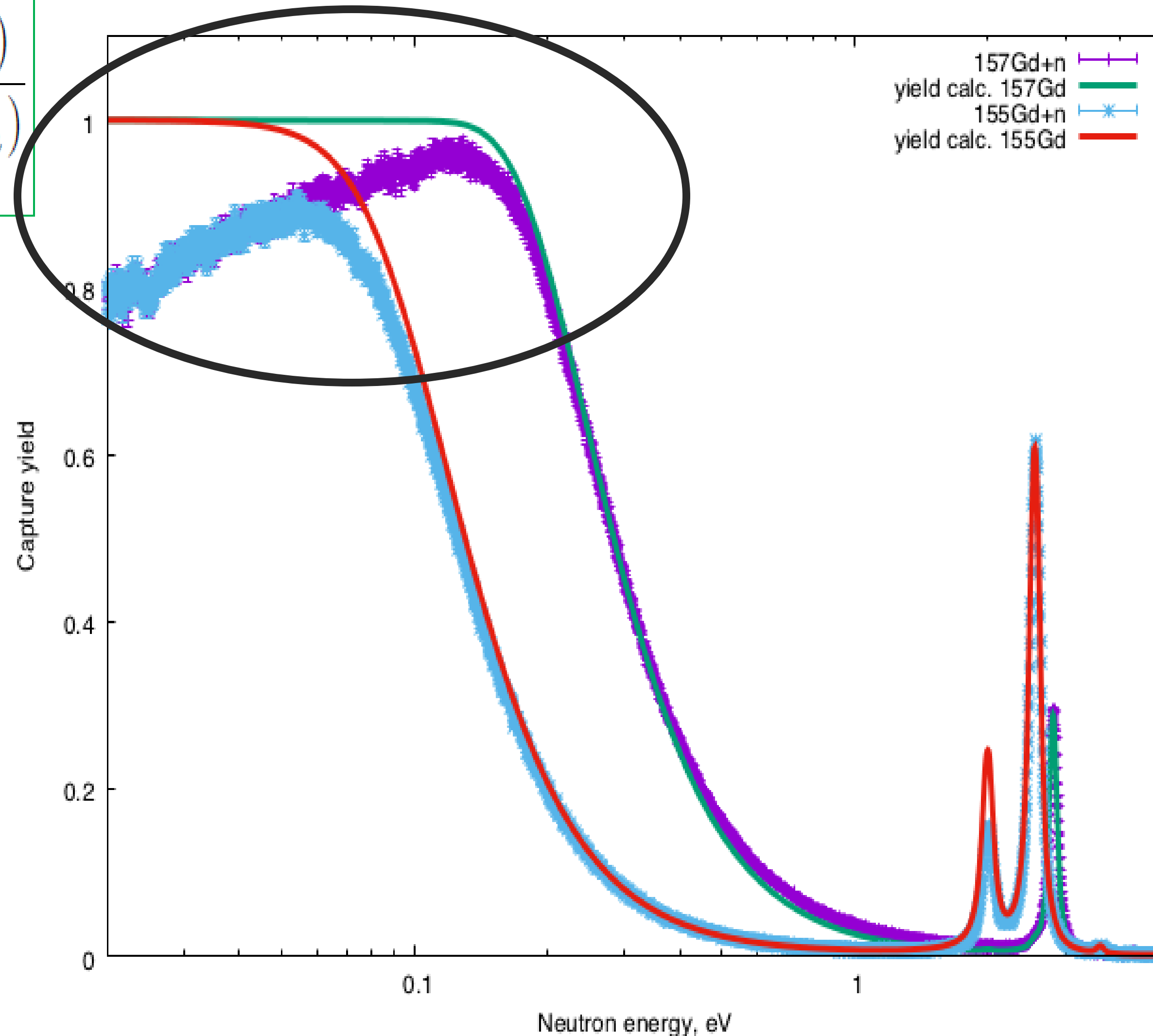


Yield: thermal region, the expected yield

$$Y(E_n) = \left(1 - e^{-n\sigma_{tot}(E_n)}\right)\frac{\sigma_\gamma(E_n)}{\sigma_{tot}(E_n)}$$

$$n\sigma_{tot}(E_n) >> 1$$

$$Y(E_n) \approx \frac{\sigma_\gamma(E_n)}{\sigma_{tot}(E_n)} \approx 1$$



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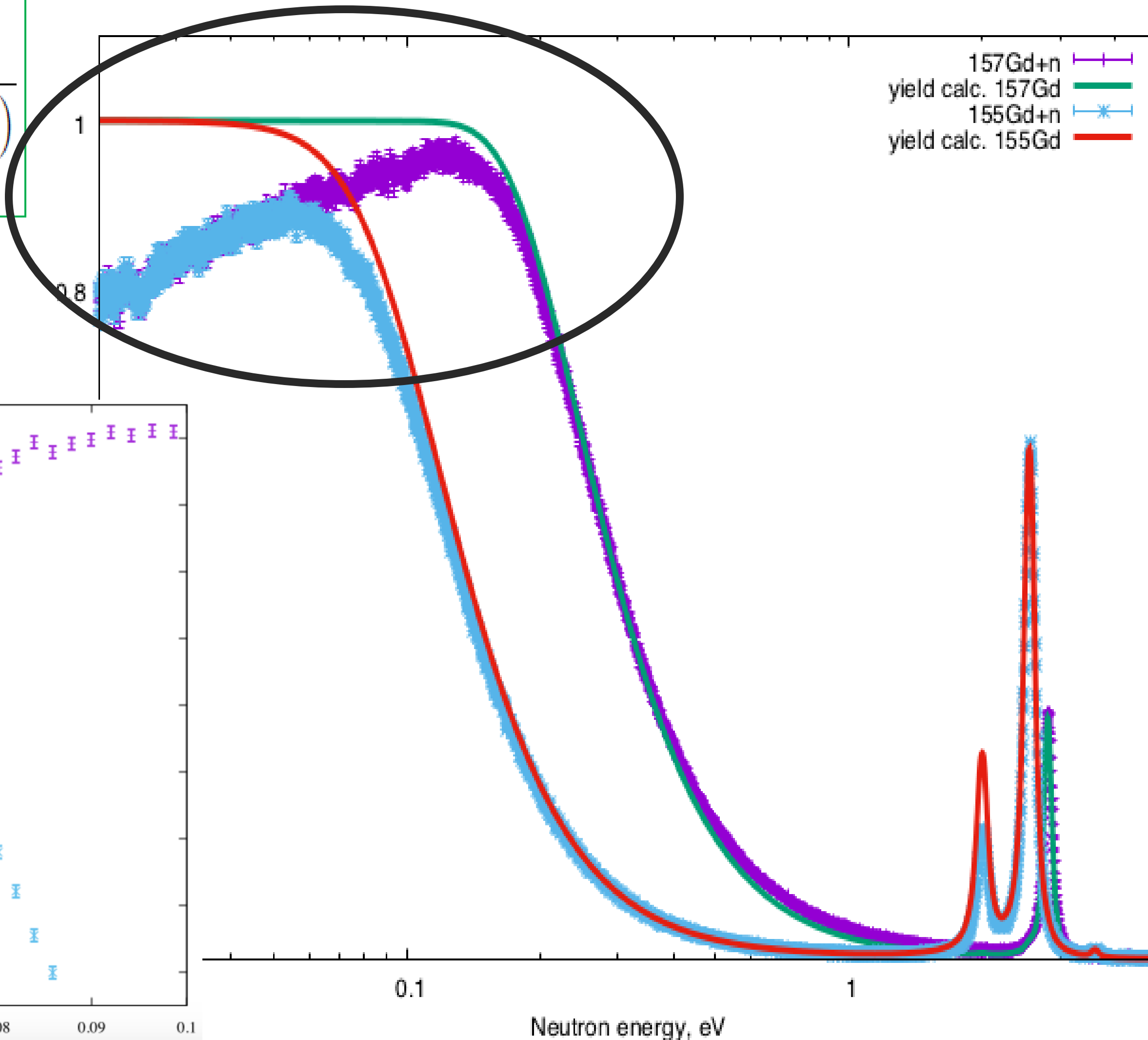
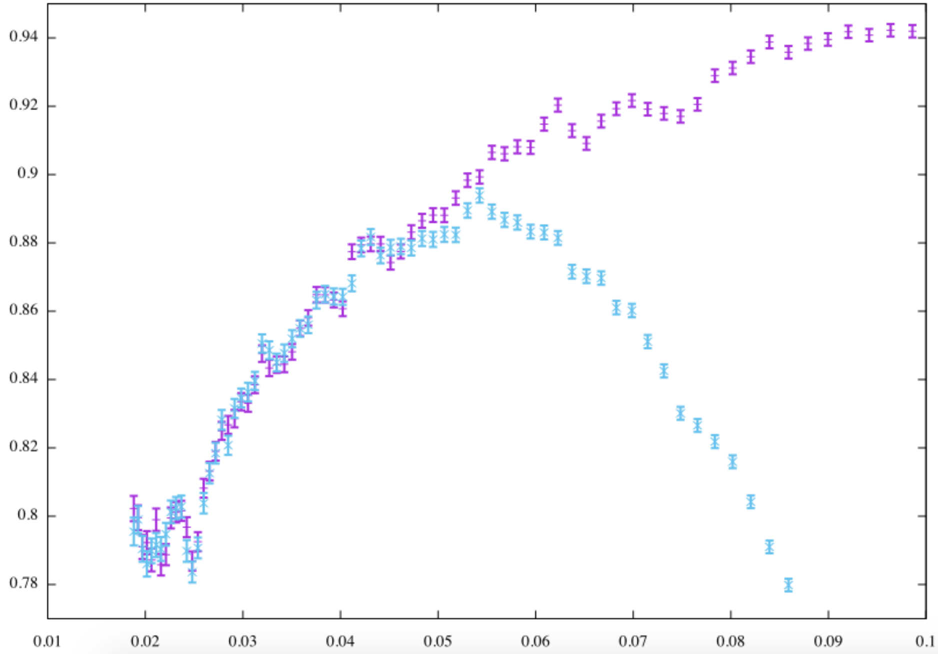
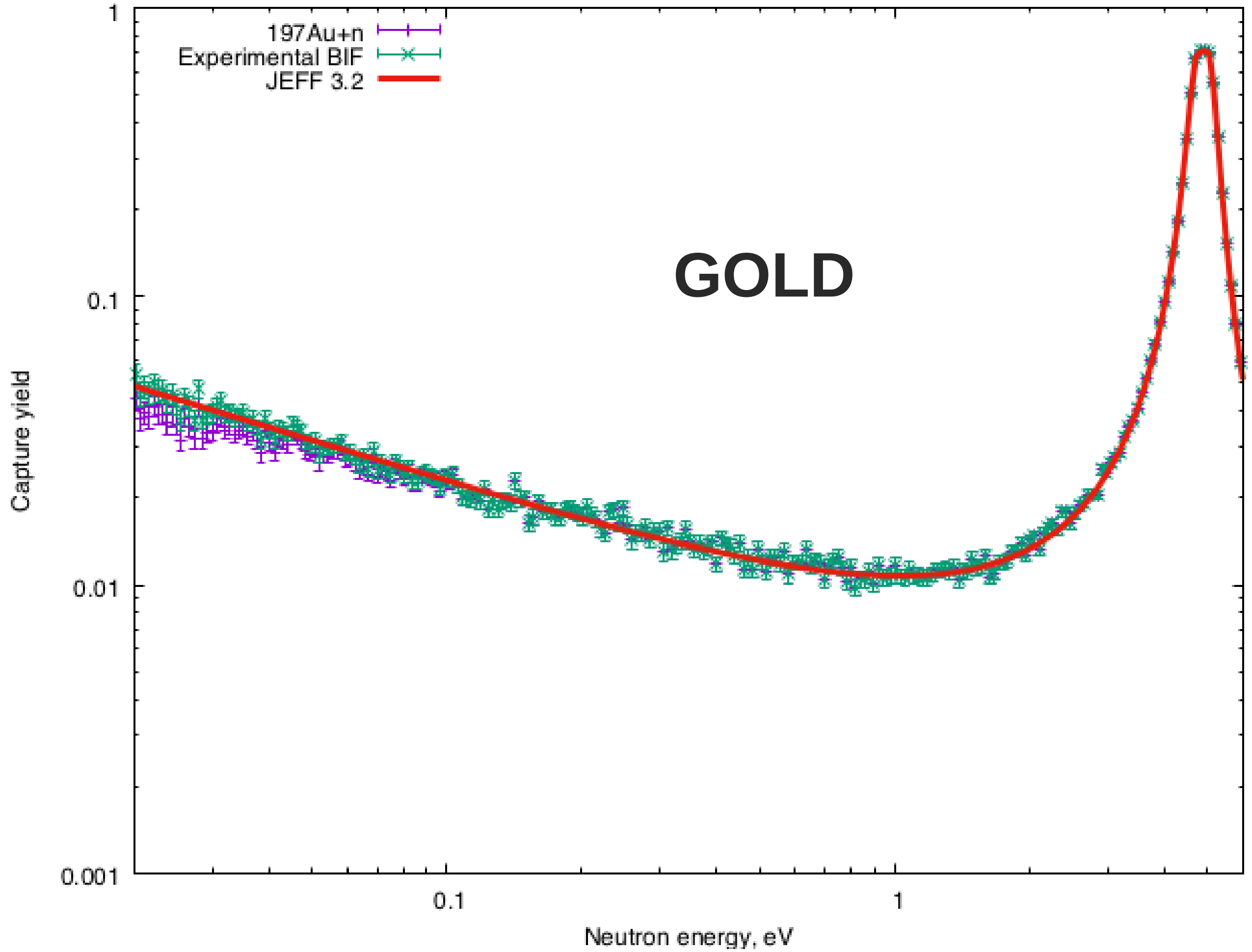




Yield: BIF correction



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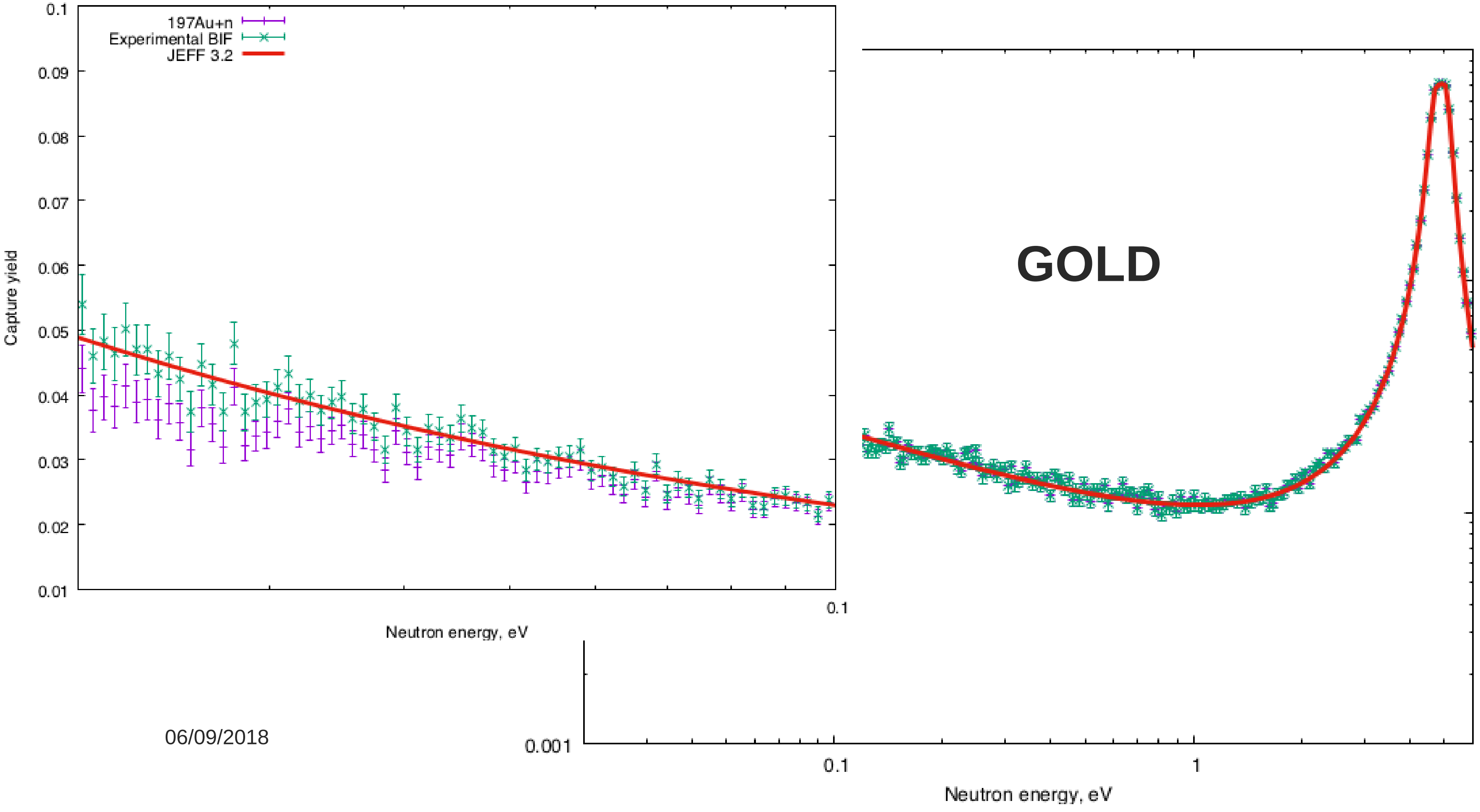

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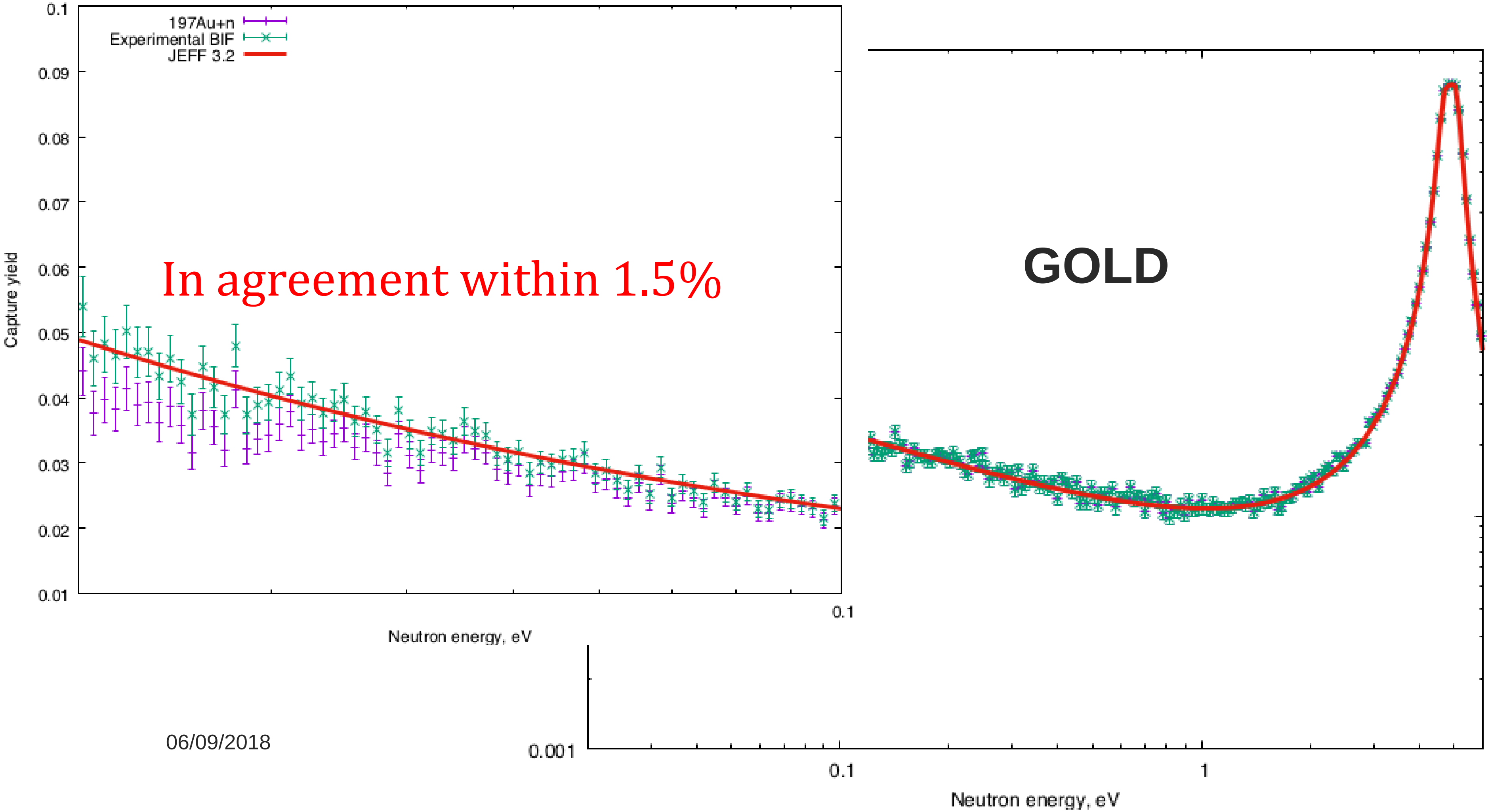
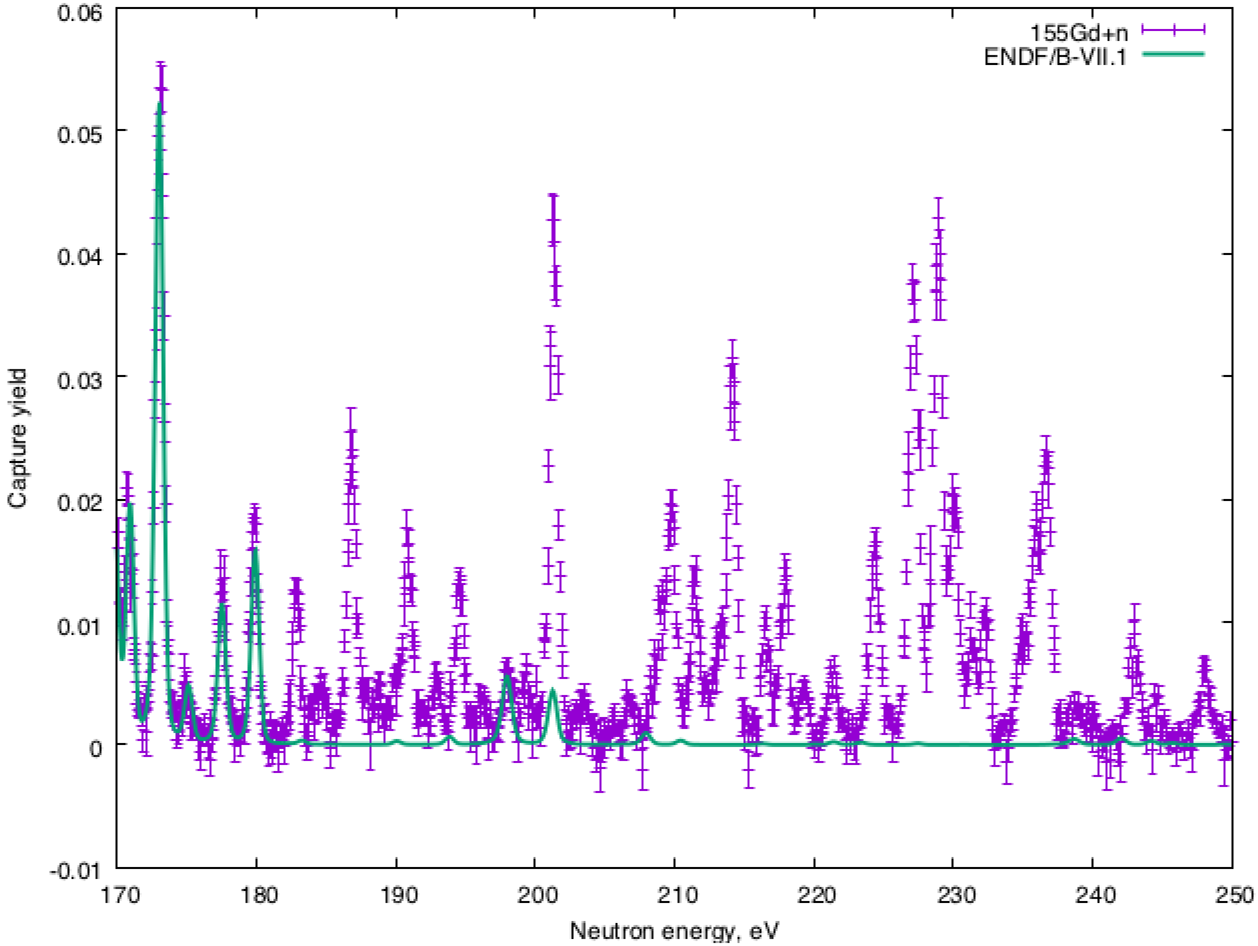


Systematic uncertainties

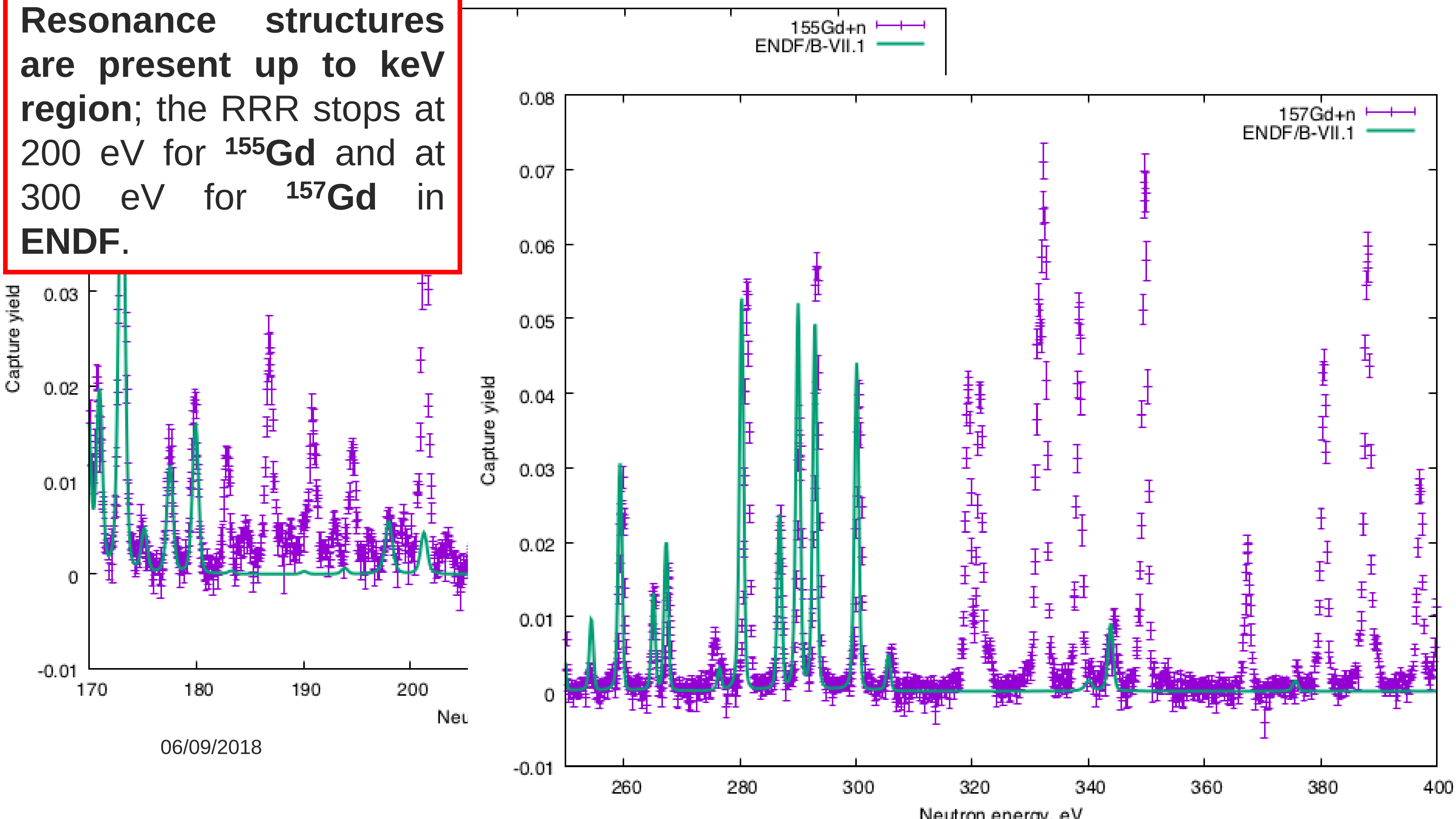
Source of uncertainty	^{155}Gd(n,γ) near thermal	^{155}Gd(n,γ) resonance region	^{157}Gd(n,γ) near thermal	^{157}Gd(n,γ) resonance region
PHWT	1.5%	1.5%	1.5%	1.5%
Normalization	1.5%	1.5%	1.5%	1.5%
Background	1.4%	$\approx$ 1%	1.0%	$\approx$ 1%
Sample mass	1.0%	$<$ 0.1%	2.1%	$<$ 0.1%
BIF	2.0%		2.0%	
Flux	1.0%	1.0%	1.0%	1.0%
Total	**3.5%**	**2.5%**	**3.9%**	**2.5%**

$^{155,\,157}$Gd thick: resolved region (ENDF Upper Limit)

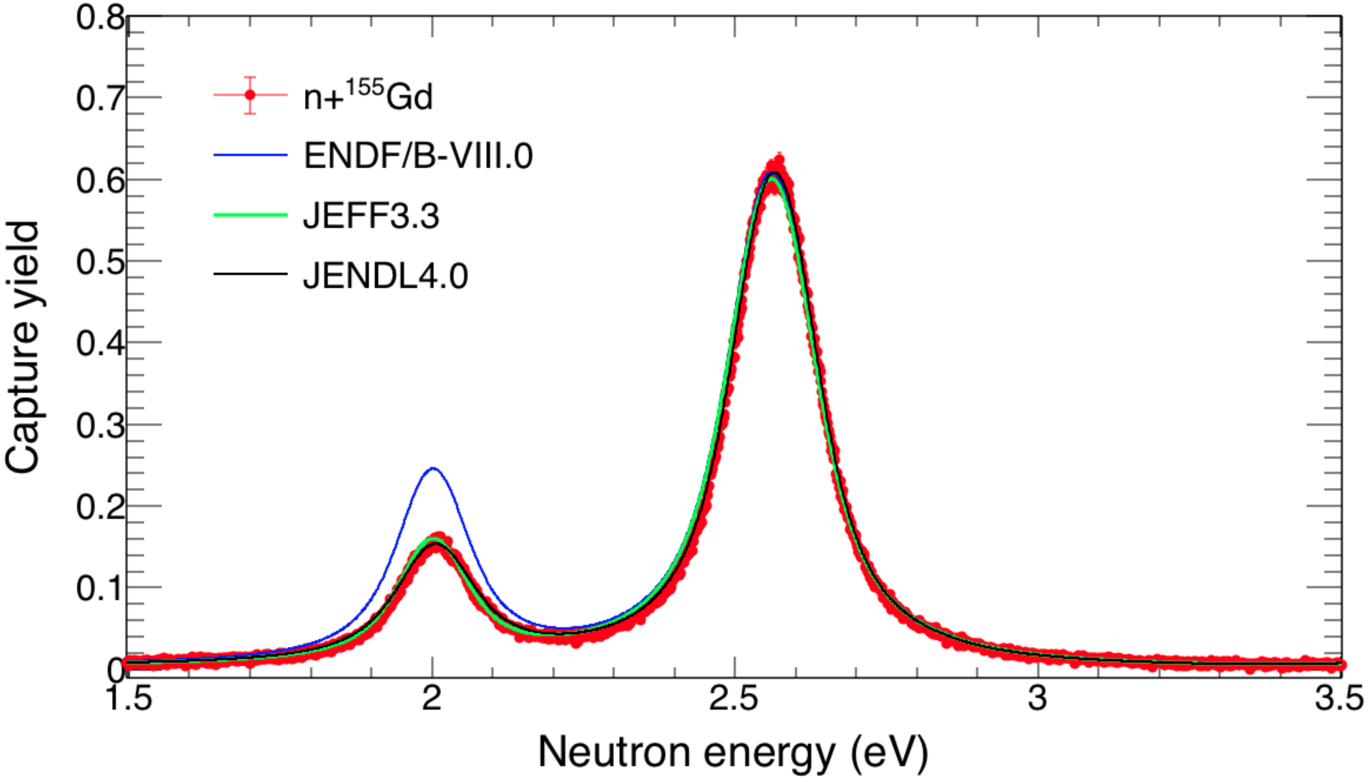


$^{155,\,157}$Gd thick: resolved region (ENDF Upper Limit)

Resonance structures are present up to keV region; the RRR stops at 200 eV for ^{155}**Gd** and at 300 eV for ^{157}**Gd** in **ENDF**.



^{155}Gd: RSA by SAMMY code



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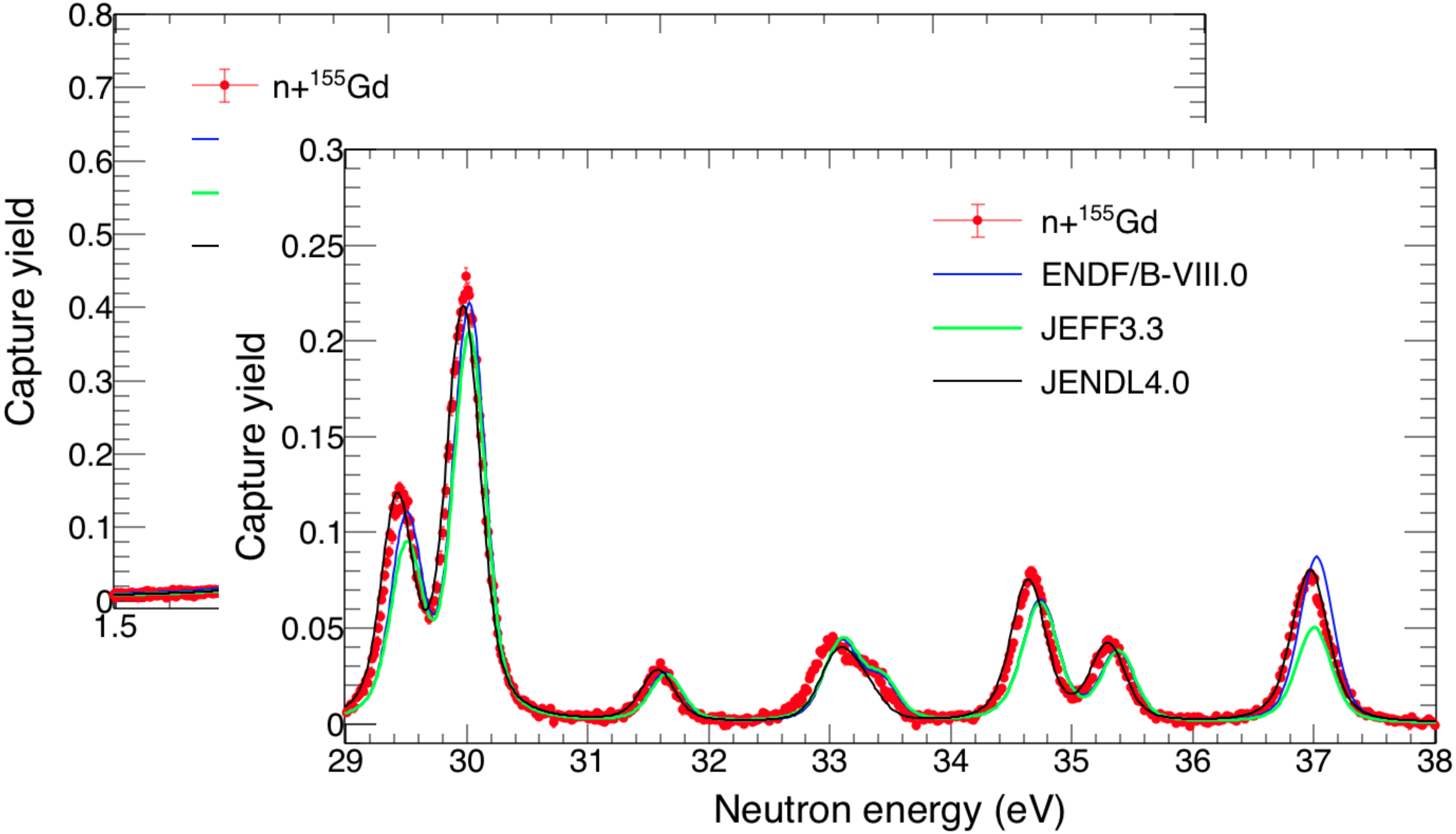

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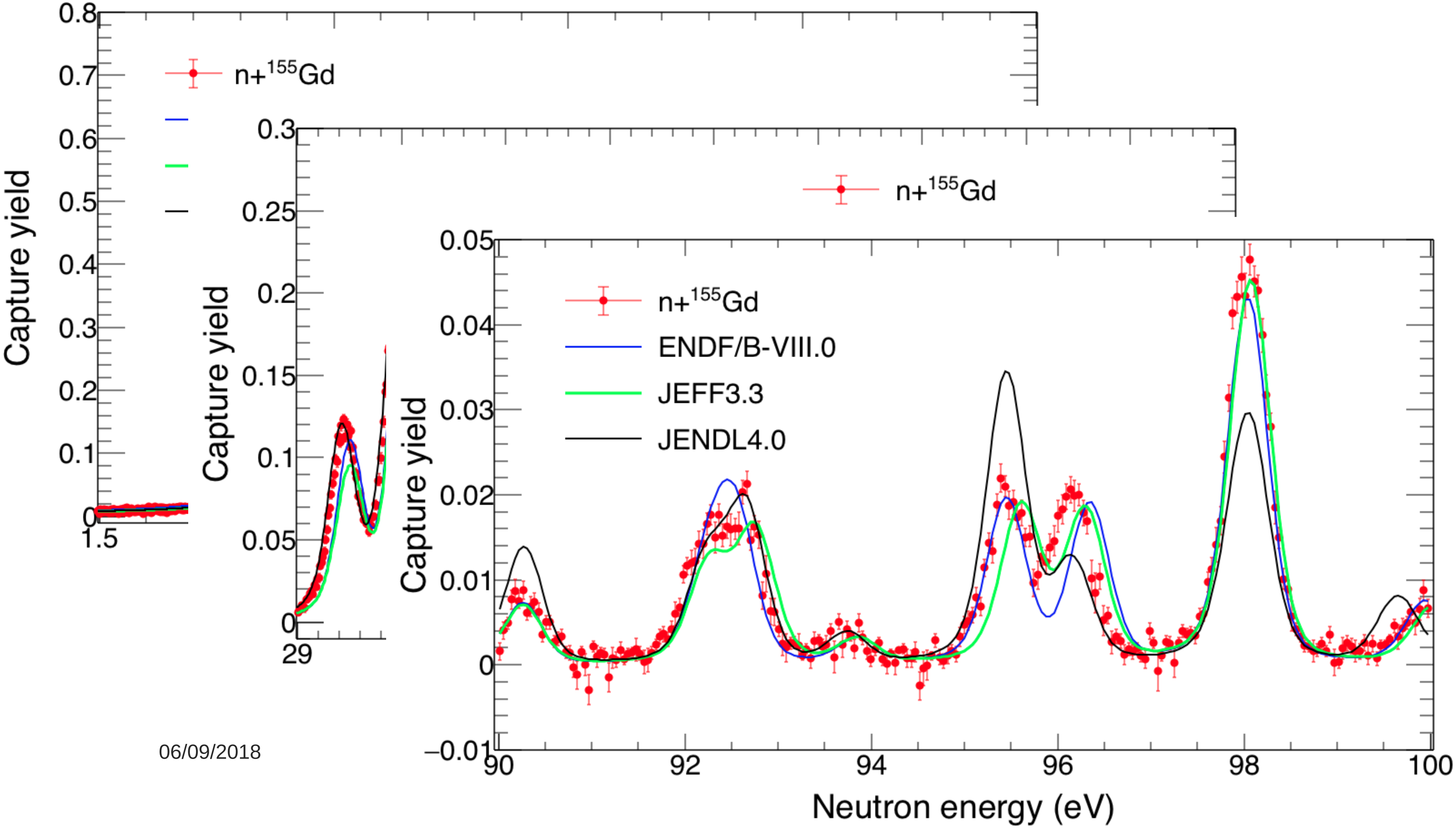
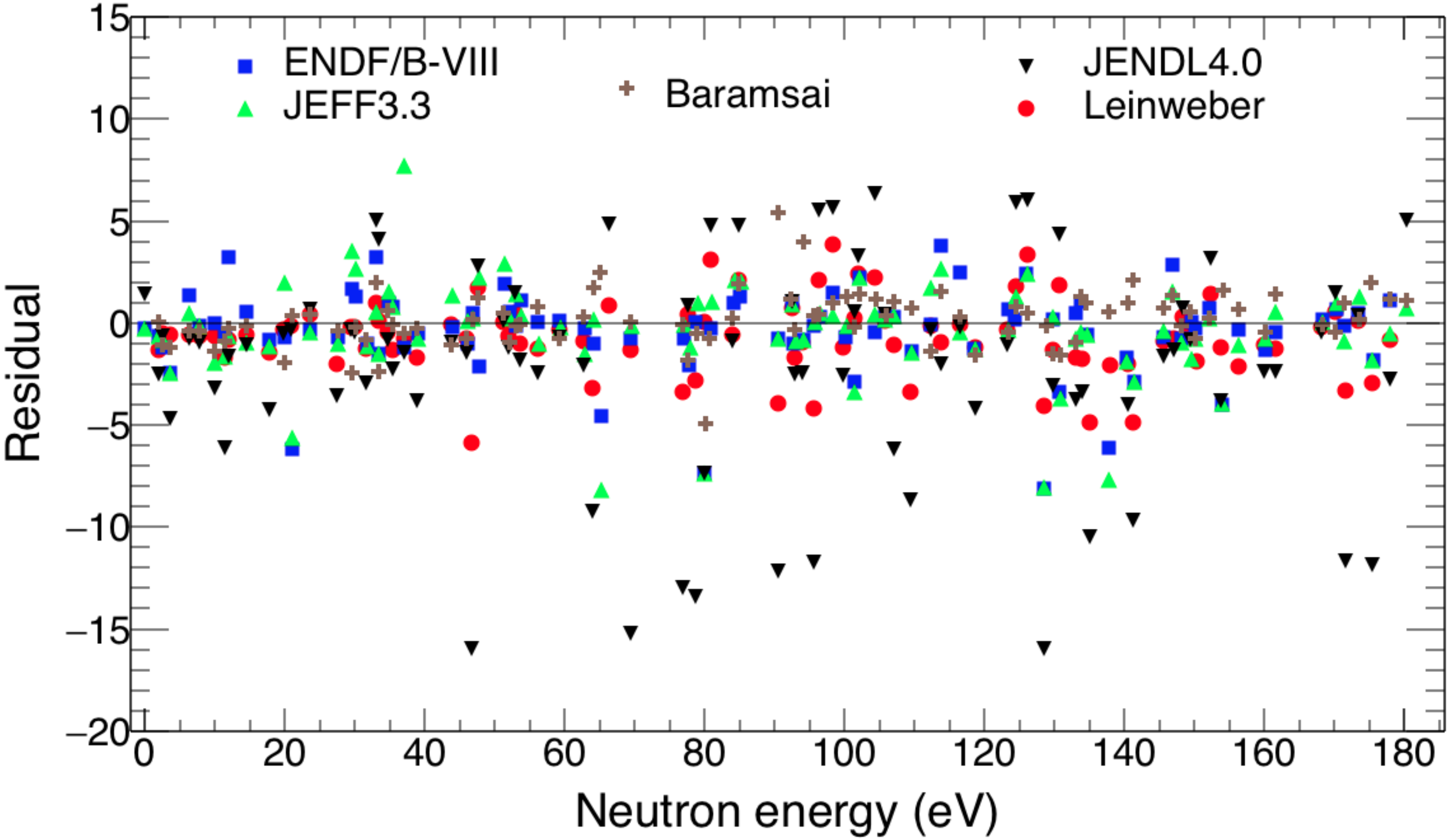
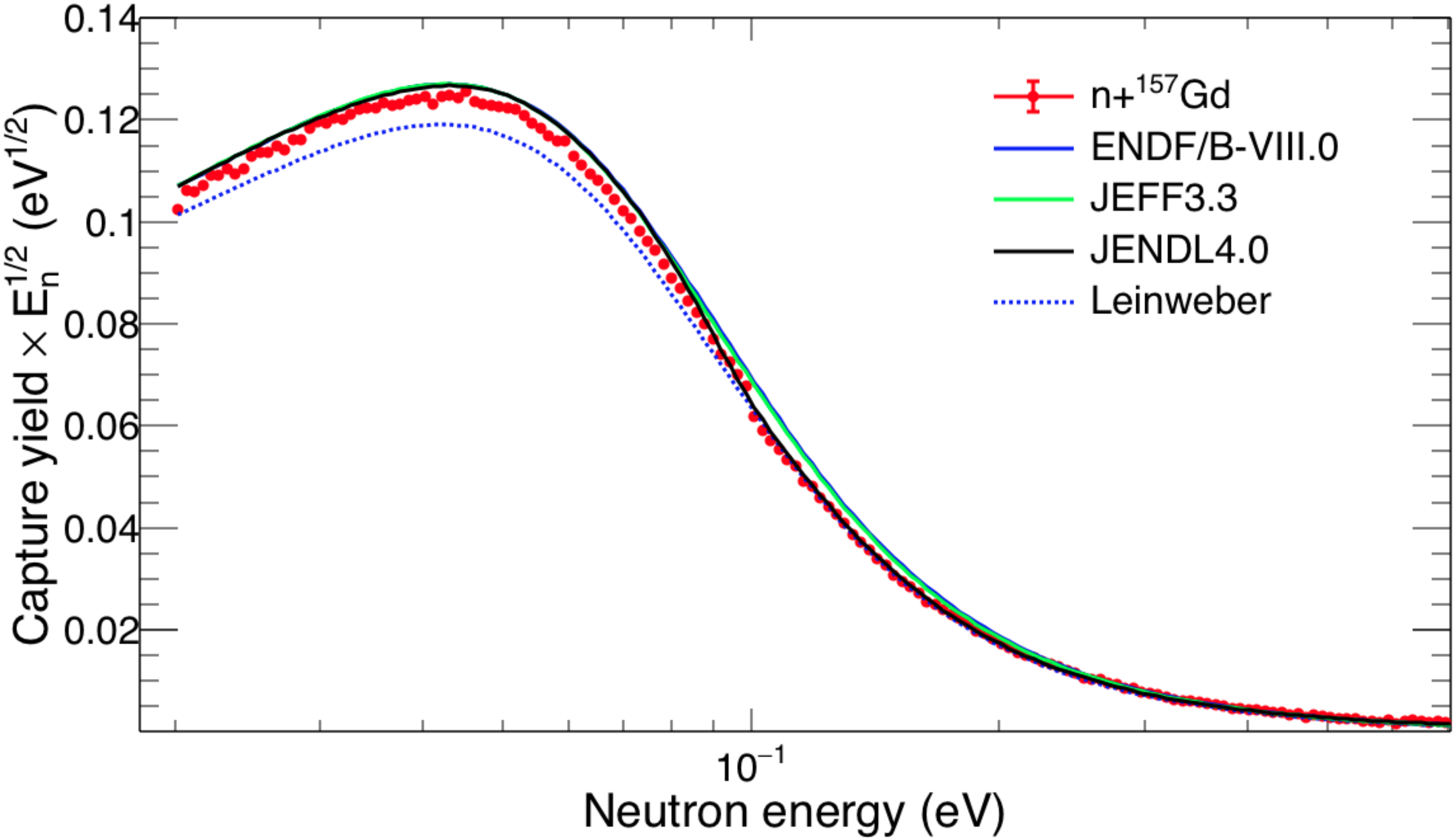


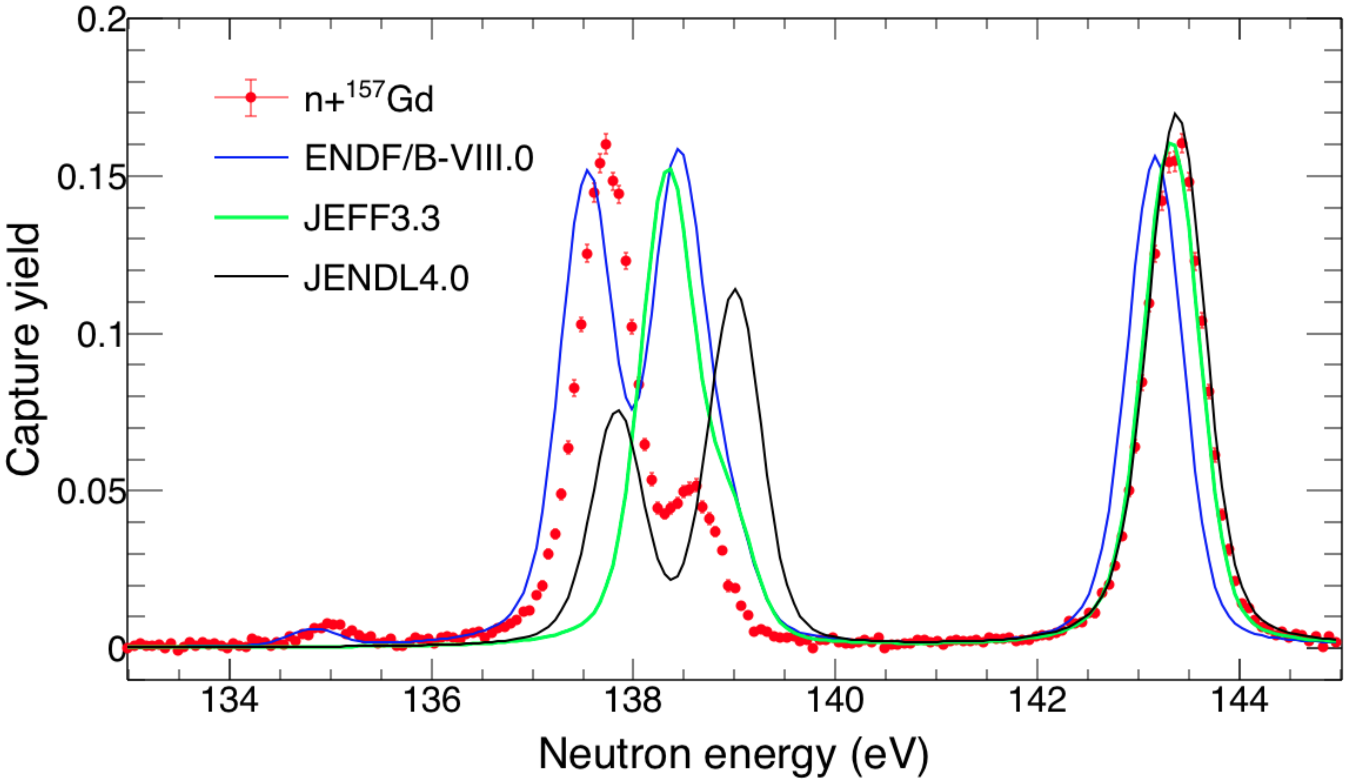
^{155}Gd: Resonance kernels



^{157}Gd: thermal region



^{157}Gd: RSA by SAMMY code



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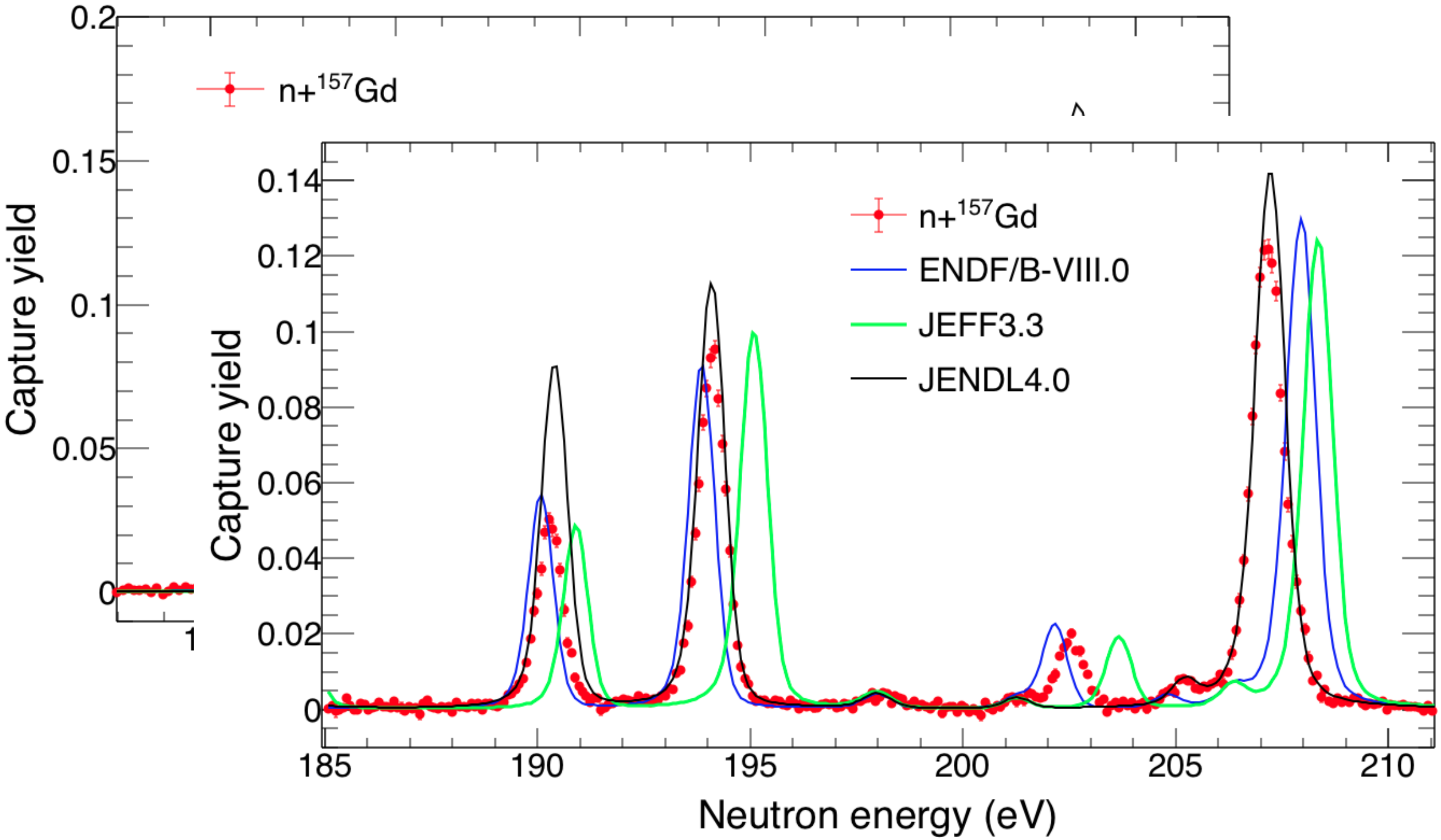

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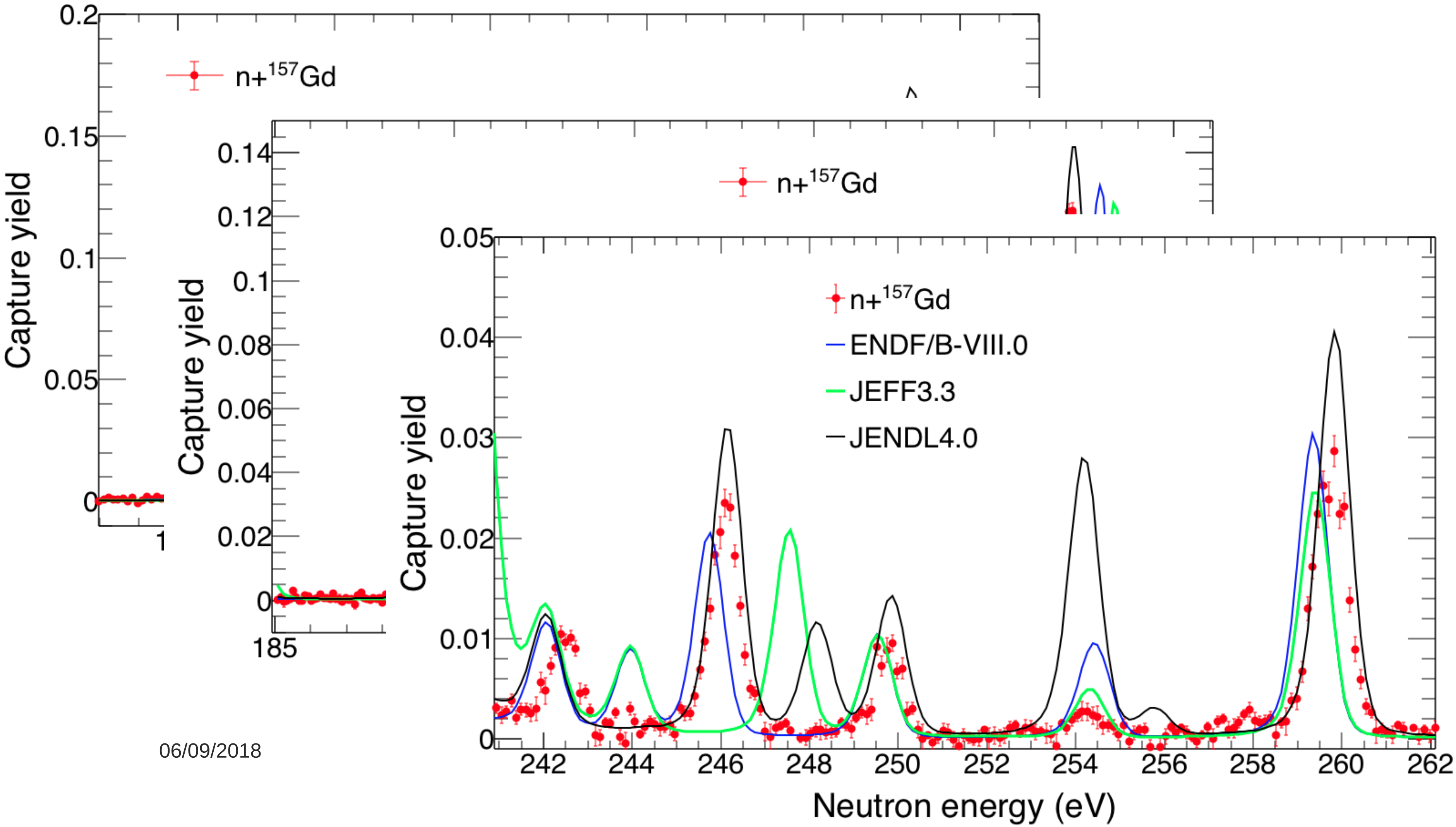

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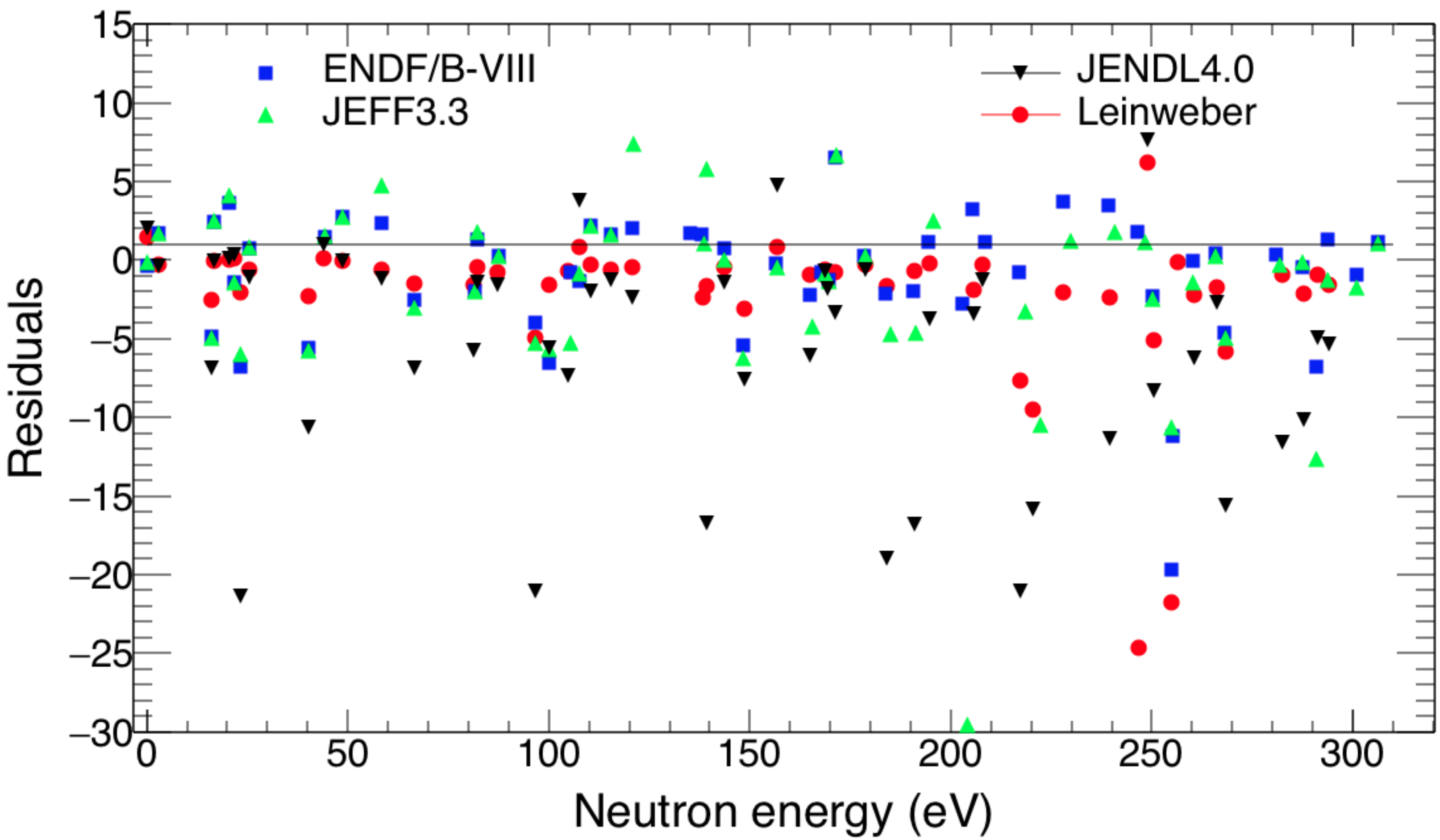
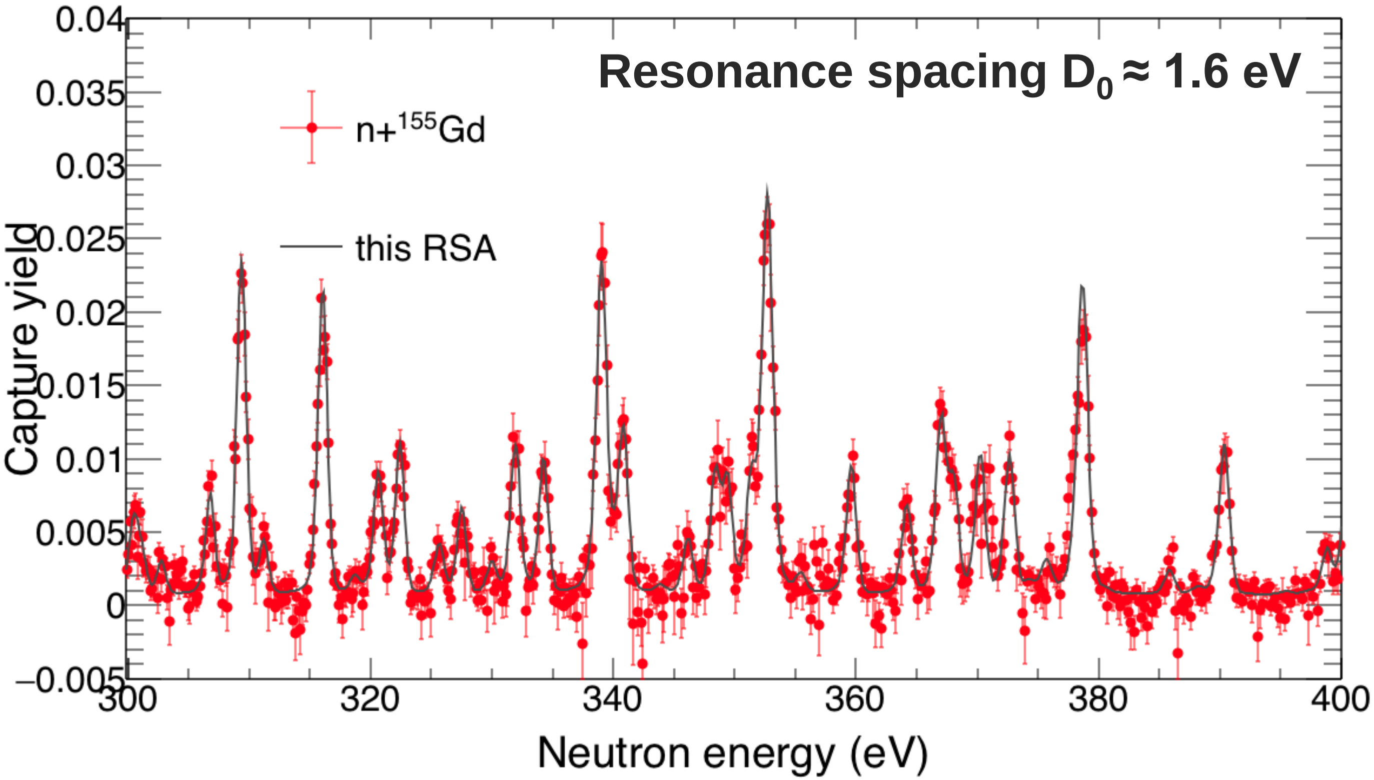


RSA: Above the upper limit



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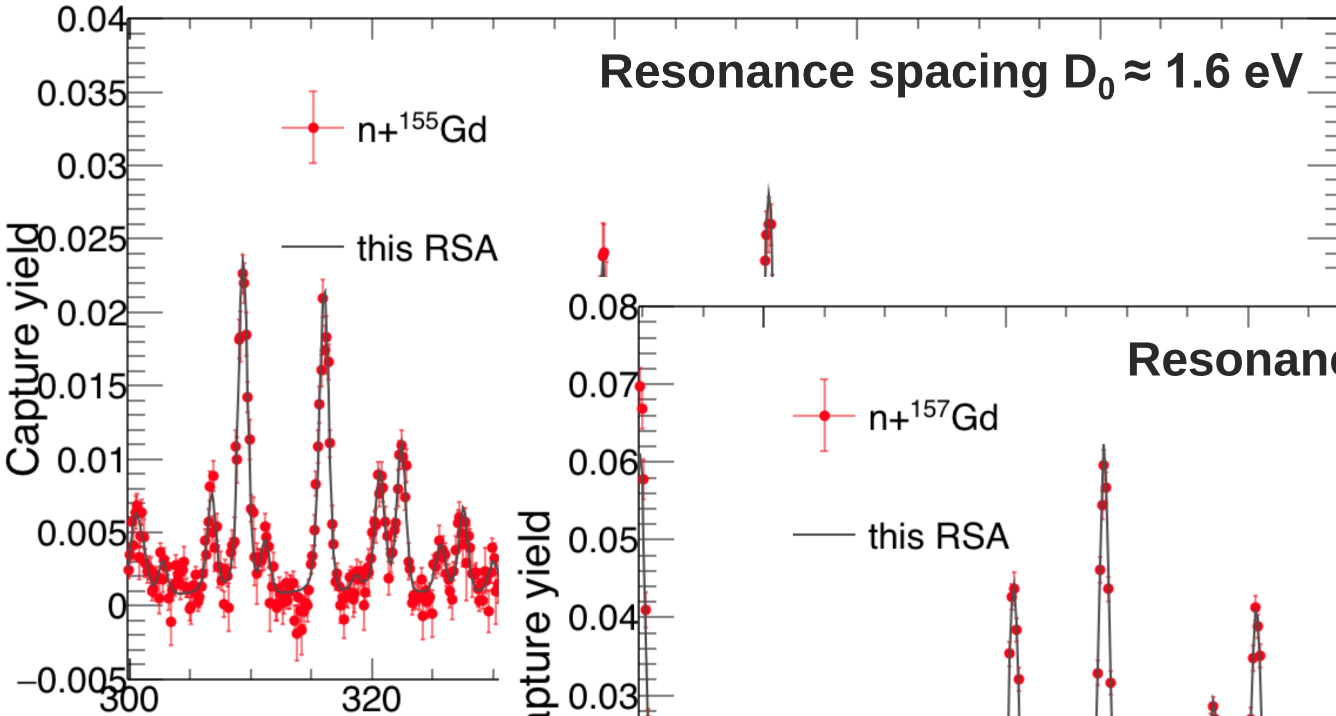

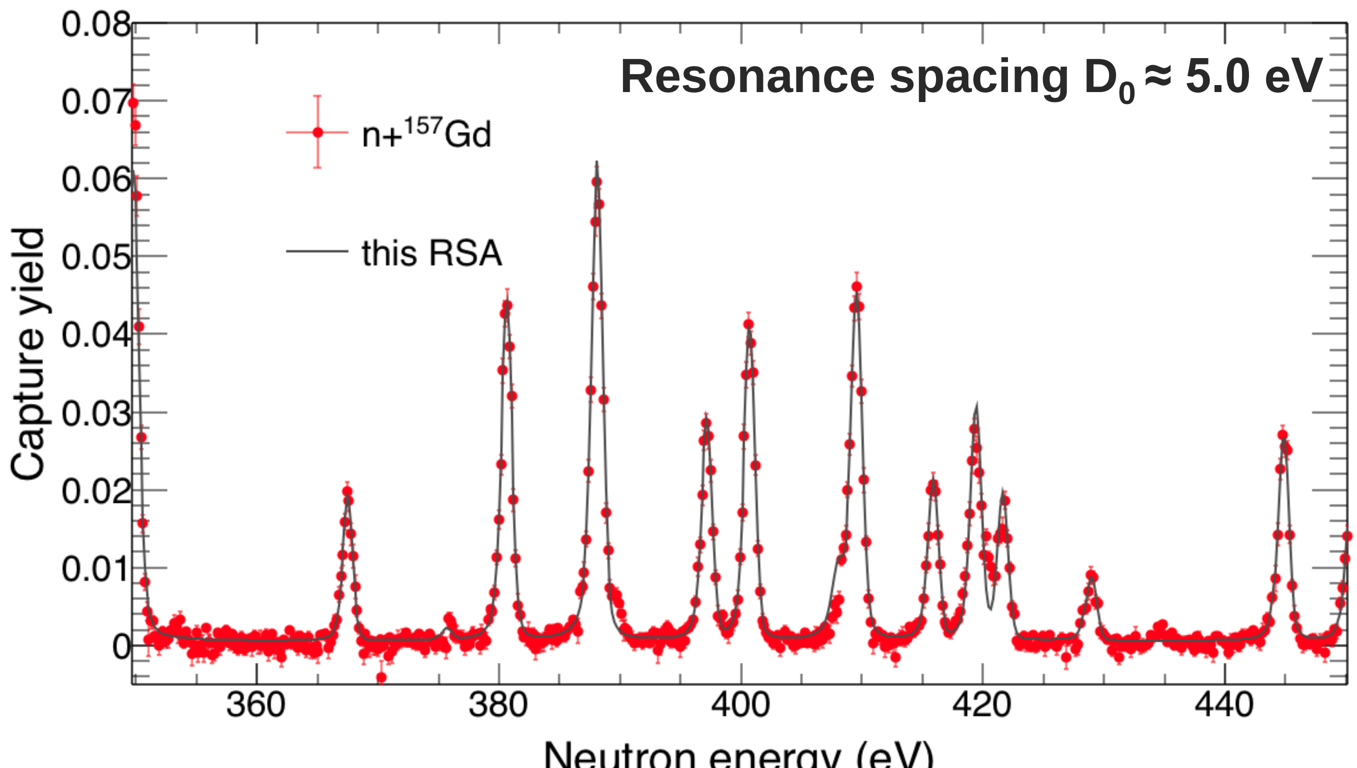

Conclusions

- **The ^{155,157}Gd(n,ɣ) reaction has been analyzed up to 1 keV**; from RSA by R-matrix code the cross-section has been extracted from thermal to about 1 keV;
- **These data sets can be used for future evaluations** combining with the results of a new transmission measurement;
- **In the RRR** the comparisons with **ENDF/B-VIII.0 and JEFF-3.3** data libraries show a fair agreement whereas sizable differences are present with **Leinweber *et al.*** data and with **JENDL-4.0** evalutation;
- **The thermal cross-sections** in this work are about **2% higher for ^{155}Gd** and **6% smaller for ^{157}Gd** than those reported in nuclear data libraries;
- Paper submitted (**https://arxiv.org/abs/1805.04149v1**).