Status of the measurement of the ^{176}Yb(n,γ) cross-section

Collaboration meeting
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Outline of the presentation

- Neutron Flux
  - Evaluated version available.
  - Thermal correction
- Analysis with Sammy
  - Residual background.
  - Assessment of contaminants.
  - Resonance analysis.
  - Neutron sensitivity correction.

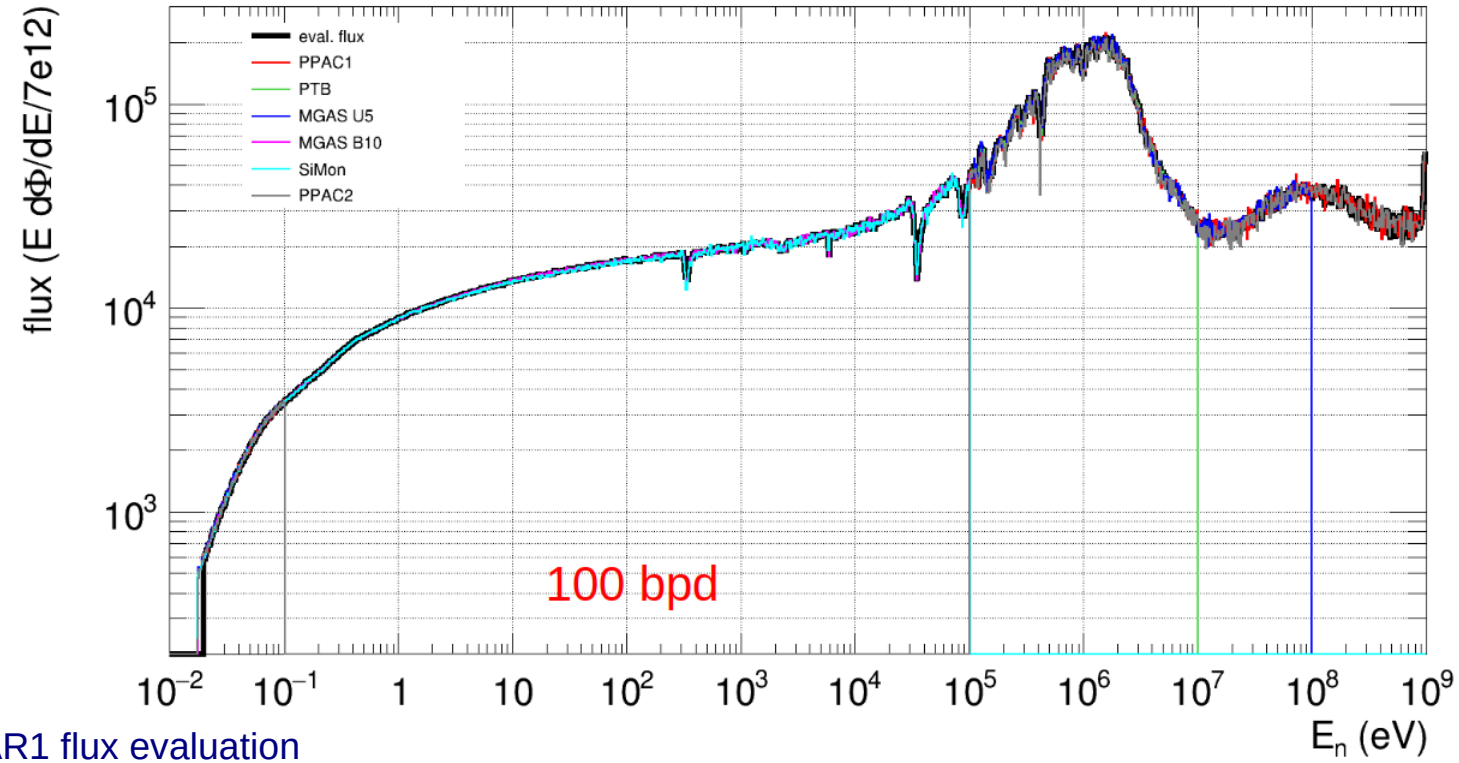
Previous talk:

- ***First Result of the capture measurement of 176Yb in EAR1***
- ***Status of the measurement of the 176Yb(n,γ) cross-section***
- ***WF Accuracy and background subtraction***

Neutron Flux

Evaluated version available

- The **evaluated flux for phase 4** in EAR1 is already available.
- The measurement was performed right after the commissioning campaign, and there is only a **two-month difference between the beginning of the experiment and the end of the commissioning flux campaign.**



Thanks Michi!!

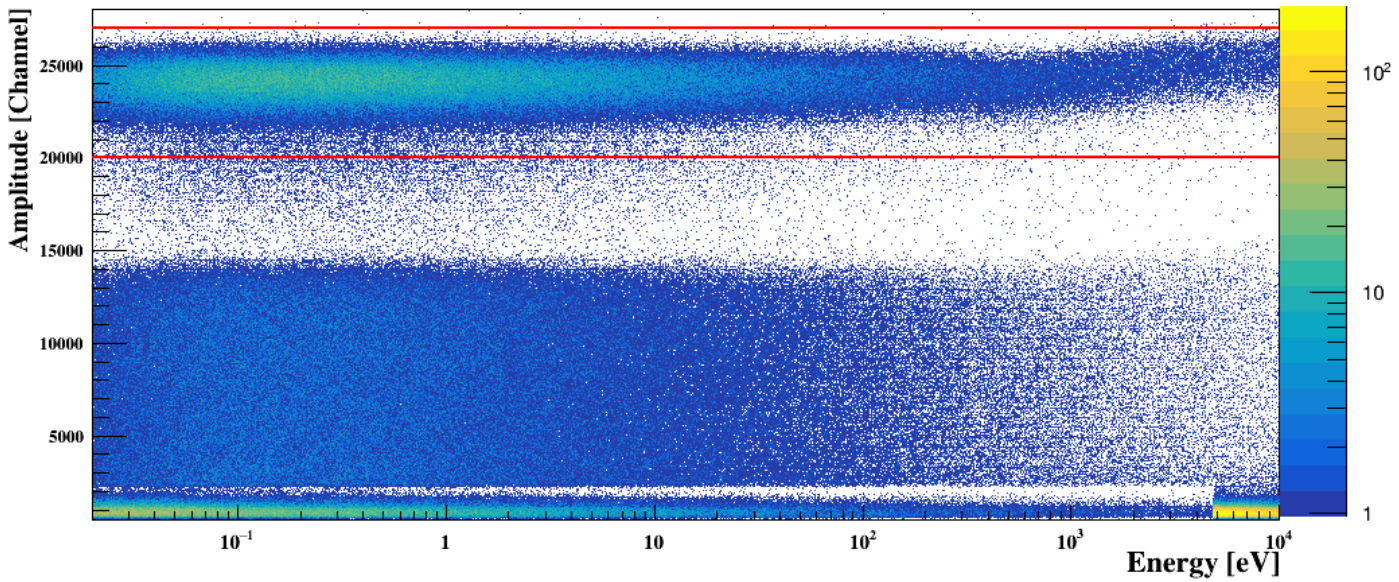
Link: Status of the Phase-4 EAR1 flux evaluation

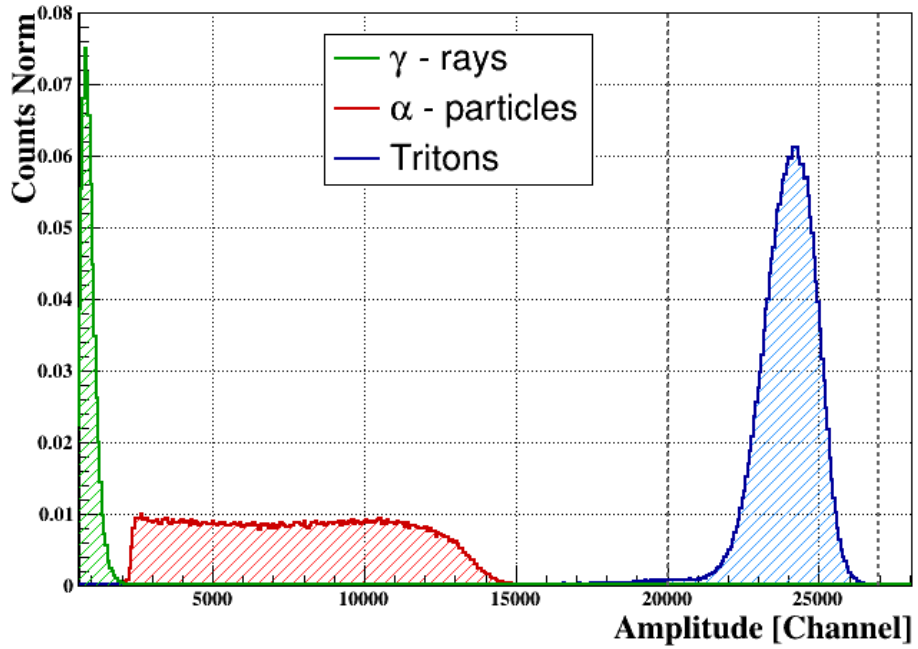
Evaluated version available

- The expected **flux has been reconstructed considering the thin target approximation**.

$$C(E_n) = \Phi_n(E_n)\,\varepsilon_X\, n\, \sigma_X(E_n)$$

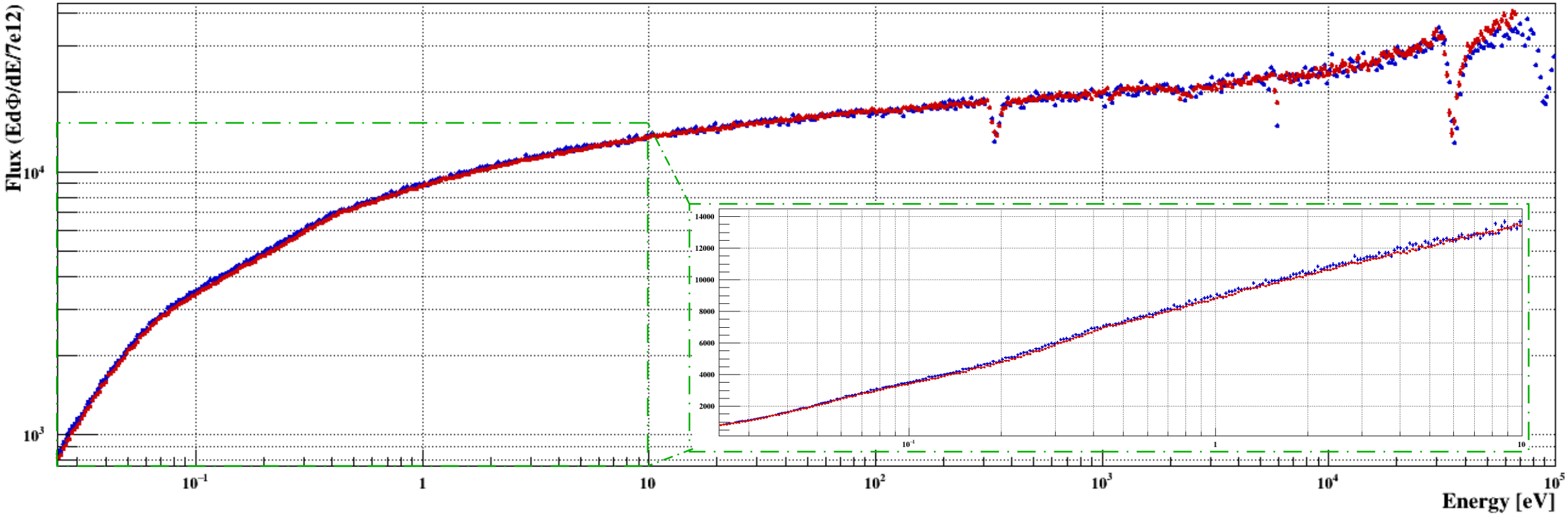
- The evaluated flux has been compared with the flux obtained from the SiMon monitors. **To obtain SiMon detector counts**, it is necessary to apply cuts in the amplitude, **only the triton signals have been considered**.





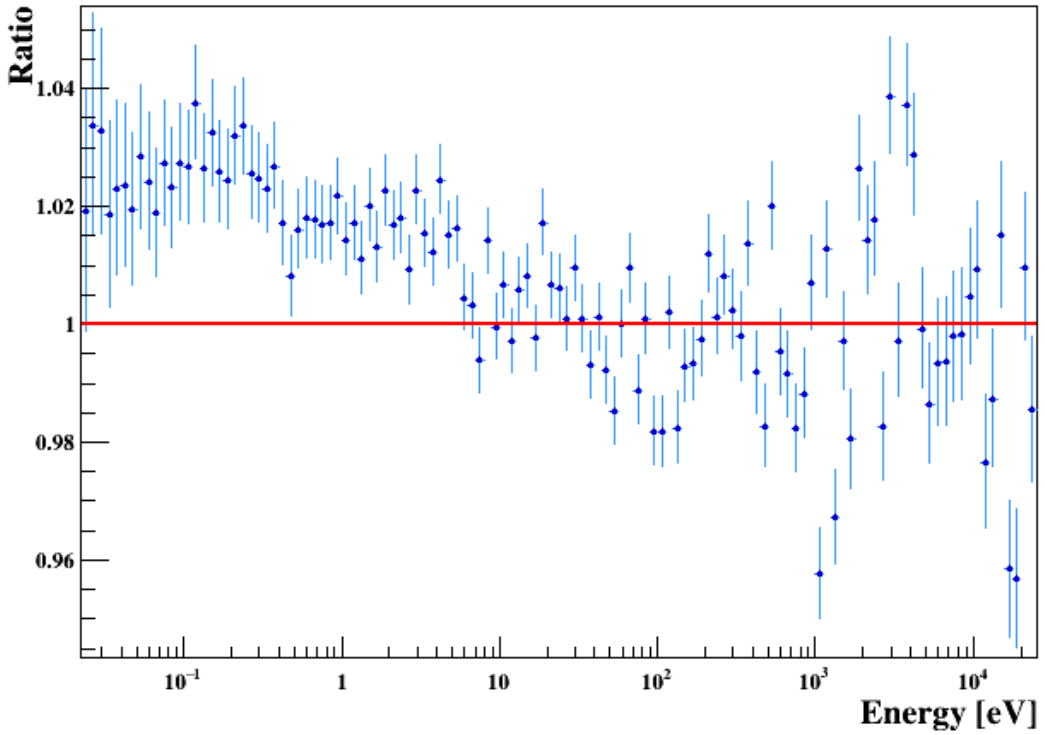
Evaluated version available

- The **flux obtained in this work has been normalized to the evaluated flux between 10-100 eV**. Below 10 eV, some **changes** can be expected **due to variations in the boron concentration** in the moderator.



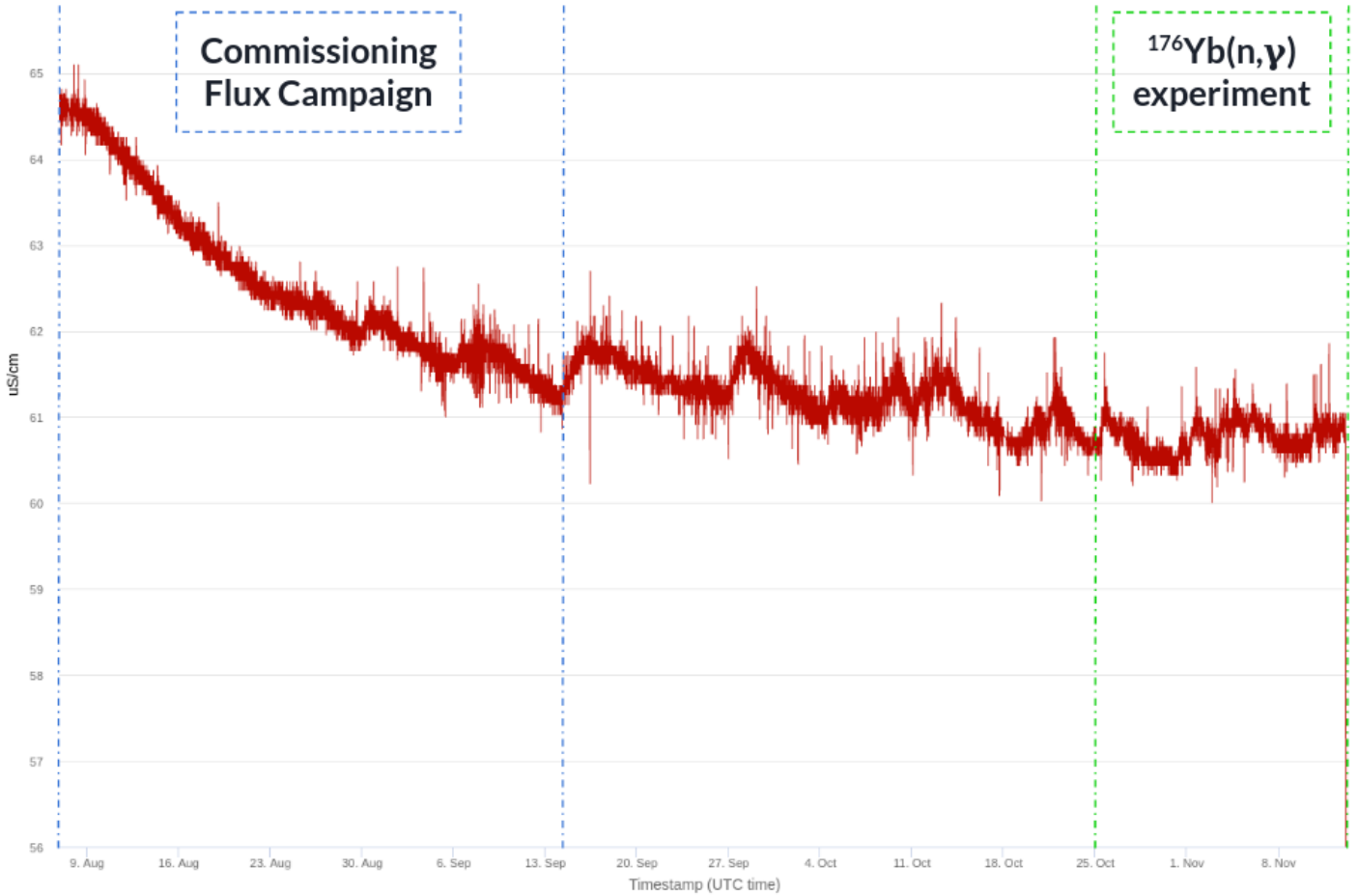
Evaluated version available

- The **differences are approximately 2.5%** between **0.025 and 1 eV** and around **1% between 1-10 eV**. **Between 10 eV and 10 keV**, the discrepancies remain **within 0.5%**, **increasing again above 10 keV**, where the reliability of the SiMon is compromised.



Energy Range [eV]	Variations [%]
0.025-0.1	2.47
0.1-1	2.22
1-10	1.12
10-100	0.01
100-1000	-0.31
1000-10000	0.18
10000-25000	-1.36

Evaluated version available



- The relationship between conductivity in a liquid and the concentration of mineral salts is based on the fact that mineral salts, when dissolved in water, dissociate into charged ions. Therefore, an increase in the concentration of mineral salts generally leads to an increase in the conductivity of the liquid.

$$\sigma = \lambda \cdot F \cdot C$$

Where:

- σ is the conductivity of the solution.
- λ is the molar conductivity(specific for each ion)
- F is the Faraday's constant.
- C is the concentration of ions in the solution

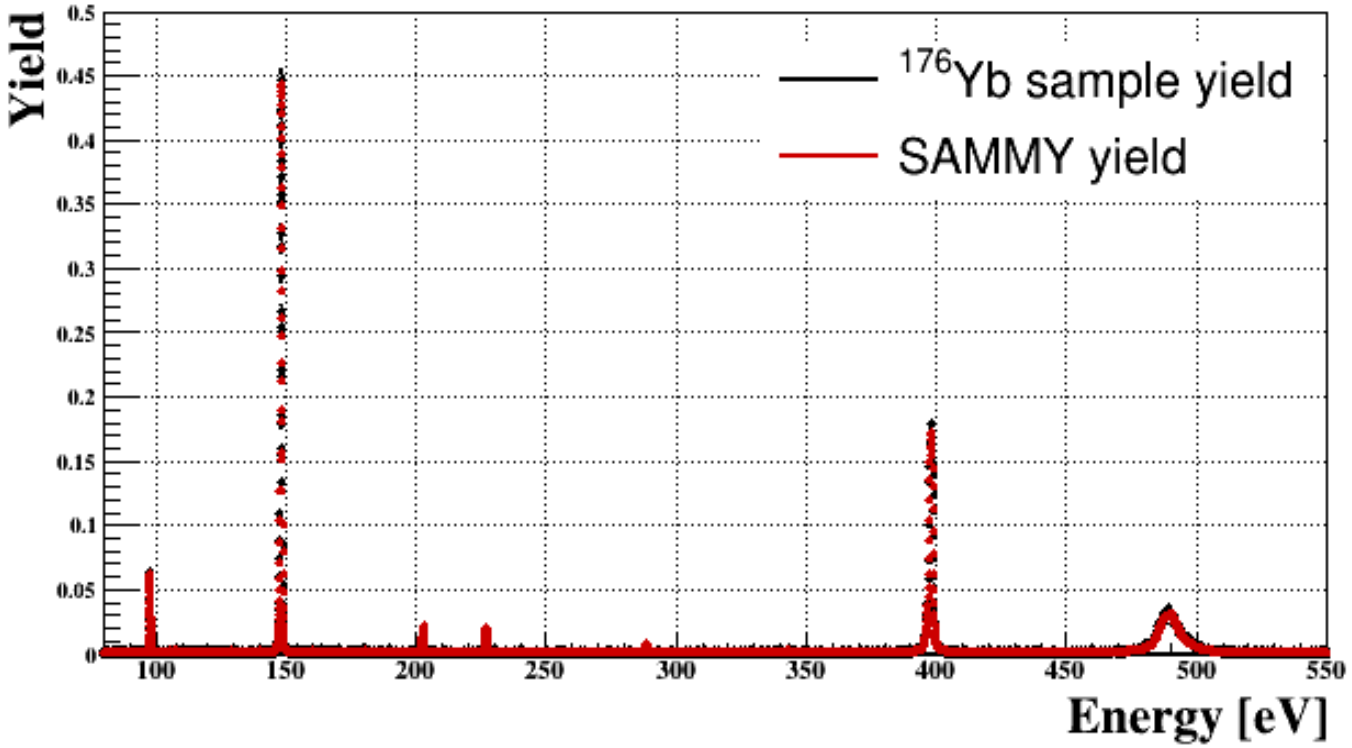
- The change in conductivity observed throughout the year is correlated with the discrepancies observed, as the conductivity at the beginning was higher. This implies a higher boron concentration, leading to a lower flux in the thermal region.

Thanks Michi for the help!!!

Analysis with Sammy

Previous transmission measurement

- There are **two transmission measurement** performed before this capture experiment
- The first transmission measurement was performed by **S. F. Mughabghab and R. E. Chrien**[1] in 1968, where **seven resonances were measured between 140 eV and 3000 eV** with high uncertainties. **Only Γ_n parameters** are provided in this work.
- The second transmission measurement was performed by **H. I. Liou et al**[2]**,** in 1973, where **68 resonances were measured between 80 eV and 20 keV**. **Only Γ_n parameters** are provided in this work, and **three resonances are candidates to be p-wave**.
- **In this work**, we have measure **165 resonances between 80 eV and 20 keV**. The details will be discussed during the presentation.

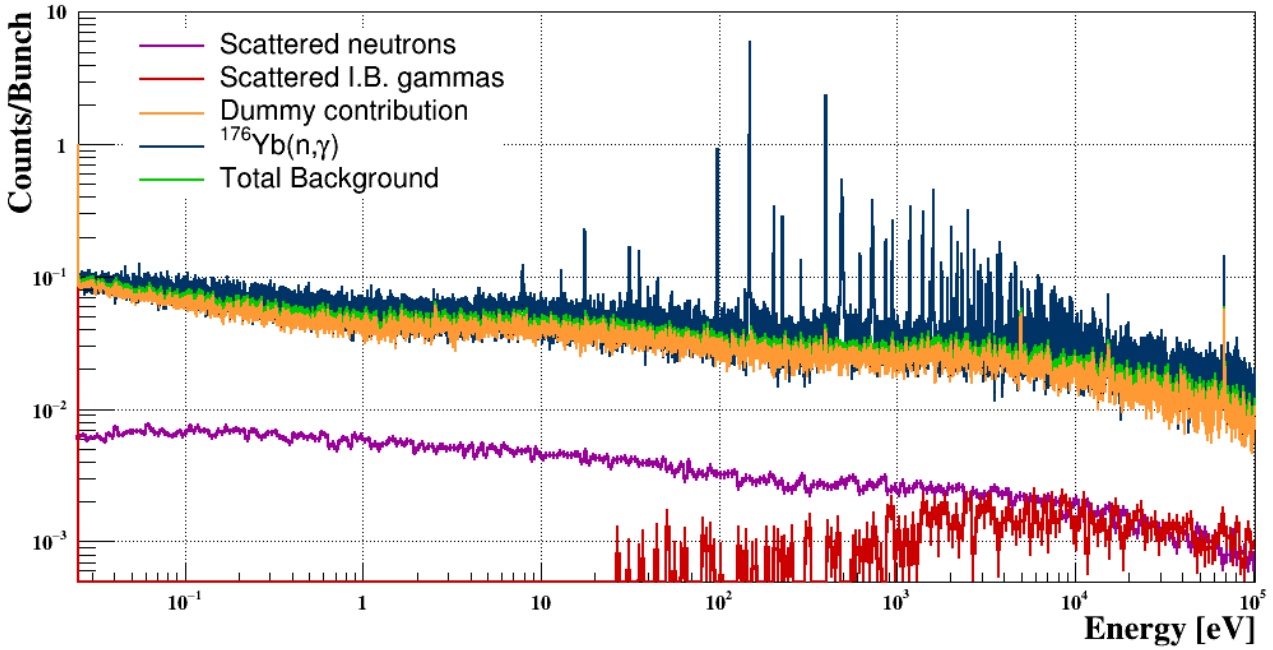


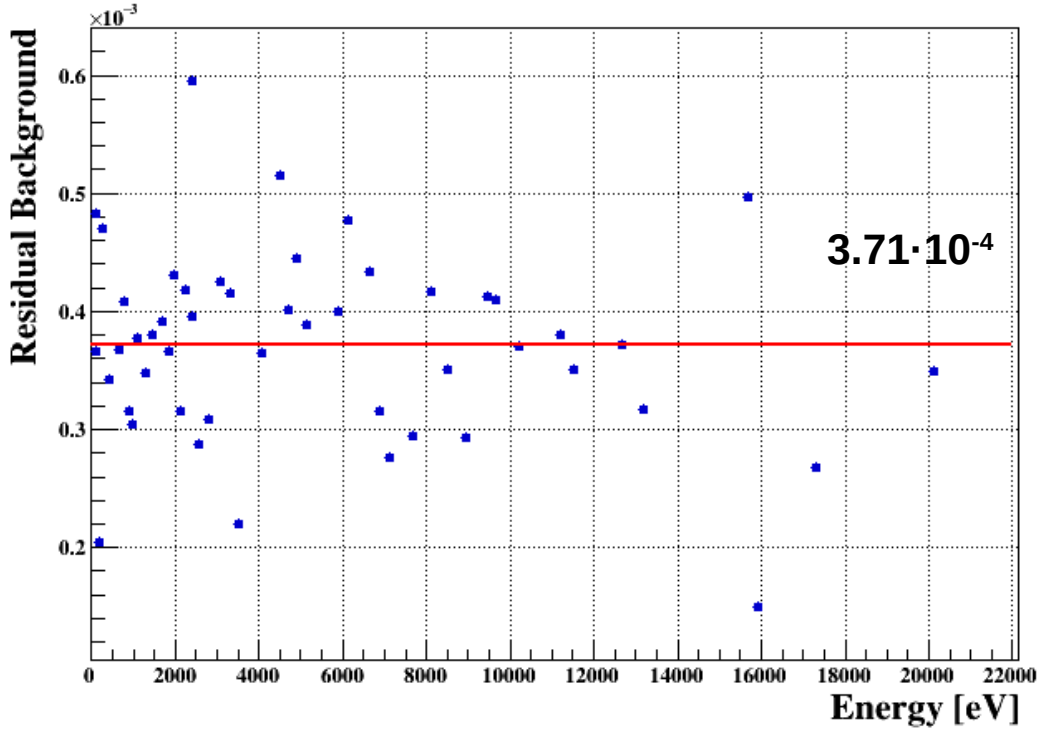
Residual Background

- **SAMMY** includes an **analytical form** to take into account the **residual background** in the yield.

$$B = B_0 + B_1/\sqrt{E} + B_2 \cdot \sqrt{E} + B_3 \cdot e^{-B_4 \cdot \sqrt{E}}$$

- **To evaluate the residual background** contribution, it **has been fitted near the individually analyzed resonances** throughout the entire energy range.





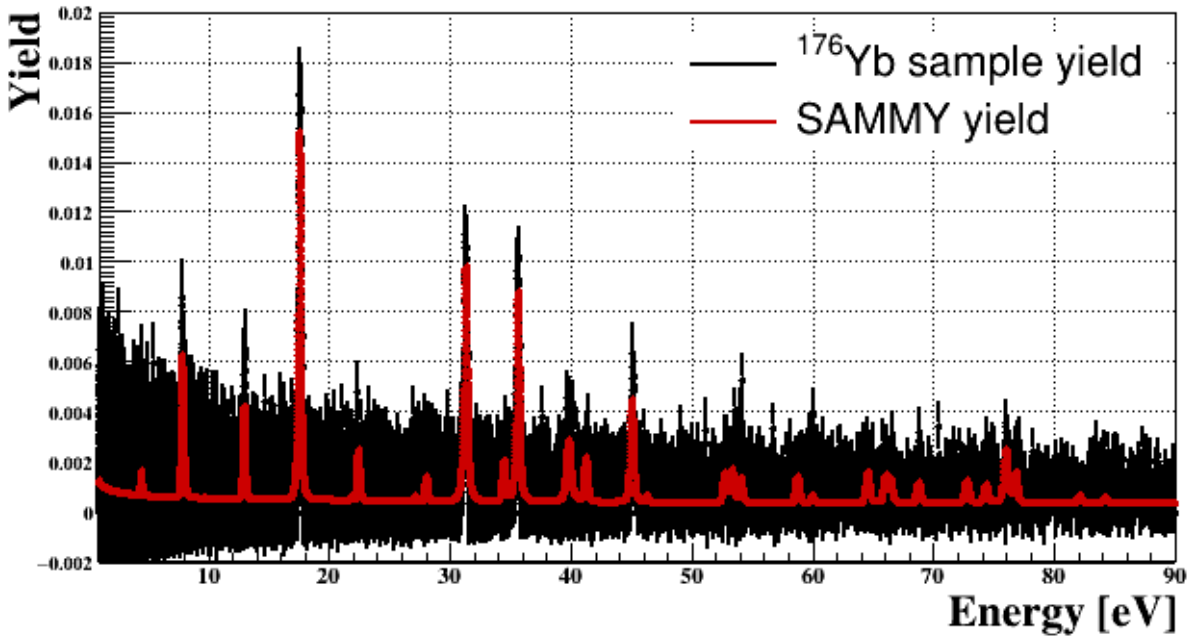
Available data detecting resonances

- The element **ytterbium** has **seven stable isotopes**: **^{168}Yb, ^{170}Yb, ^{171}Yb, ^{172}Yb, ^{173}Yb, ^{174}Yb and ^{176}Yb**.

Isotope	Natural abundance[3]	Abundance in the $^{176}Yb_2O_3$ enriched sample
^{168}Yb	0.13%	0.0061%
^{170}Yb	3.04%	0.0150%
^{171}Yb	14.28%	0.0747%
^{172}Yb	21.83%	0.1499%
^{173}Yb	16.13%	0.1090%
^{174}Yb	31.83%	0.3156%
^{176}Yb	12.76%	**99.430%**

- In order to assess the contribution of each isotopes, the **enrichement of the ^{176}Yb**, provided by R. Henkelmann and U. Koster,has been taken as a **reference.**

- To estimate the contribution of each isotope **the resonances parameters**, such as **Γ_n and Γ_γ**, have been fixed and the **isotopic abundance and the energy, E_0, have been fitted**.

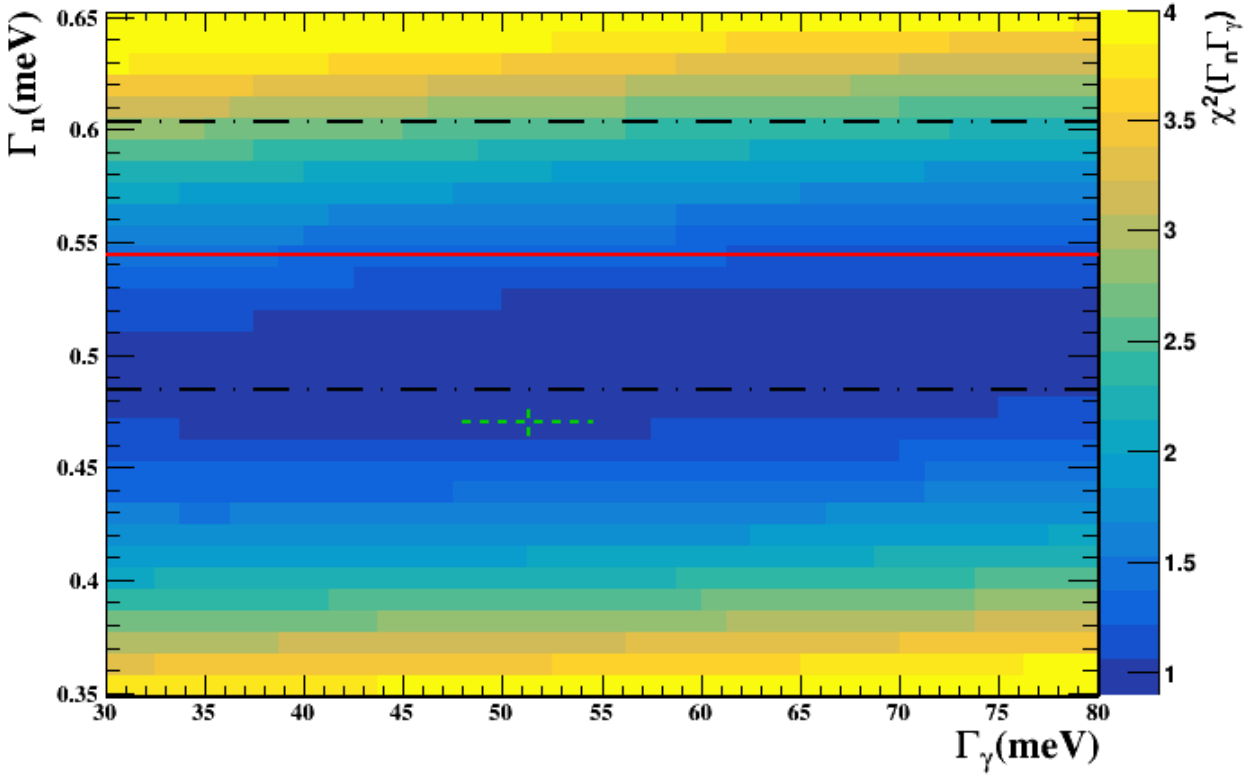


- **Two additional contaminants**, **^{152}Eu and ^{154}Eu**, were **measured in** a High Purity Germanium (**HPGe**) measurement at Isolde. **No resonance was detected** in either case.

First resonance at ~98eV

- The **first resonance** of the **^{176}Yb(n,γ) reaction** is found at **98.03 eV**. This resonance **was measured for first time by H. I. Liou** but not by Mughabghab. A correlation study was performed for the different spin group define for the **^{176}Yb isotope.**
- The **correlation** between Γ_n and Γ_γ has been performed for all the spin group define for the **^{176}Yb,** where the **best agreement** has been found for the **spind group with a $J^\pi=1/2^+$ and $J^\pi=1/2^-$.** *Nevertheless, no difference are observed in the resonance fit.*

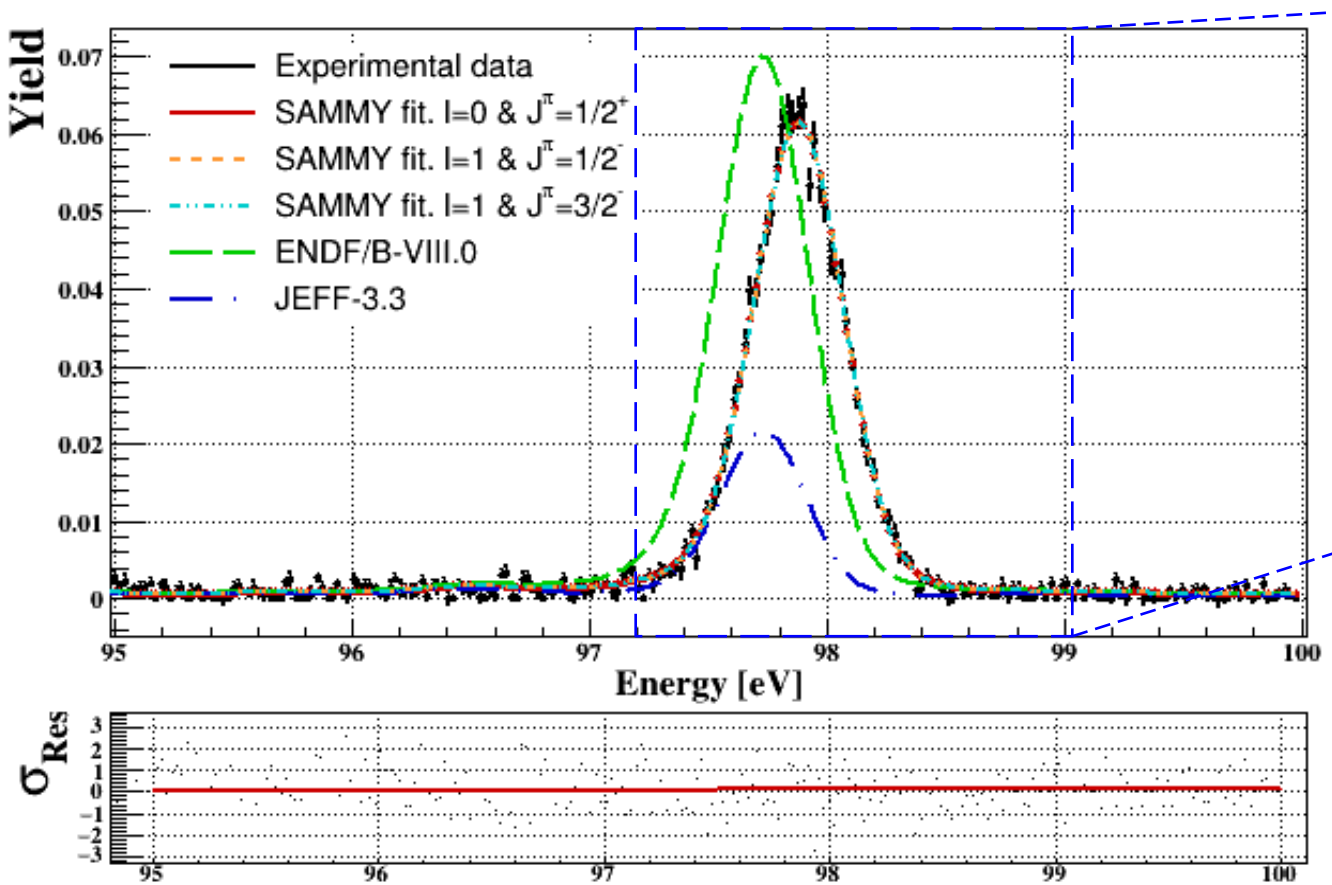
References	Energy [eV]	Γ_n [meV]	Γ_γ [meV]	J^π
Mughabghab[1]	—	—	—	—
H. Liou[2]	97.88±0.11	0.54±0.06	—	—
Mughabghab[4]	97.88±0.11	0.54±0.06	60	$1/2^+$
ENDF/B-VIII.0[5]	97.88	0.272	60	$3/2^-$
JEFF-3.3[6]	97.88	0.272	0.1	$3/2^-$
This work	98.03±0.002	0.470±0.005	51±3	$1/2^+$

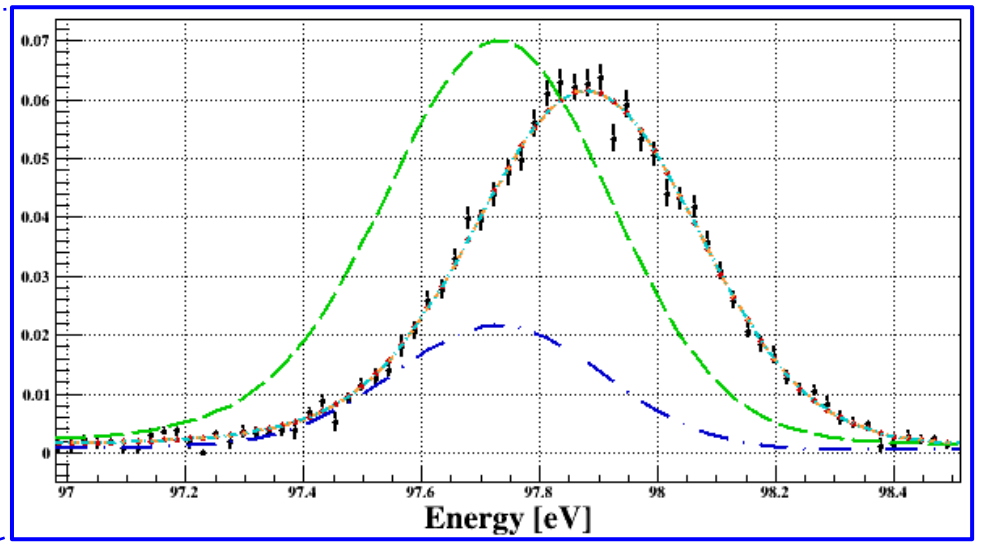


The correlation correspond to the **spin group l=0 and $J^\pi=1/2^+$**

First resonance at ~98eV

- The **first resonance** of the **^{176}Yb(n,γ) reaction** is found at ~**98 eV**. This resonance **was measured for first time by H. I. Liou** but not by Mughabghab.





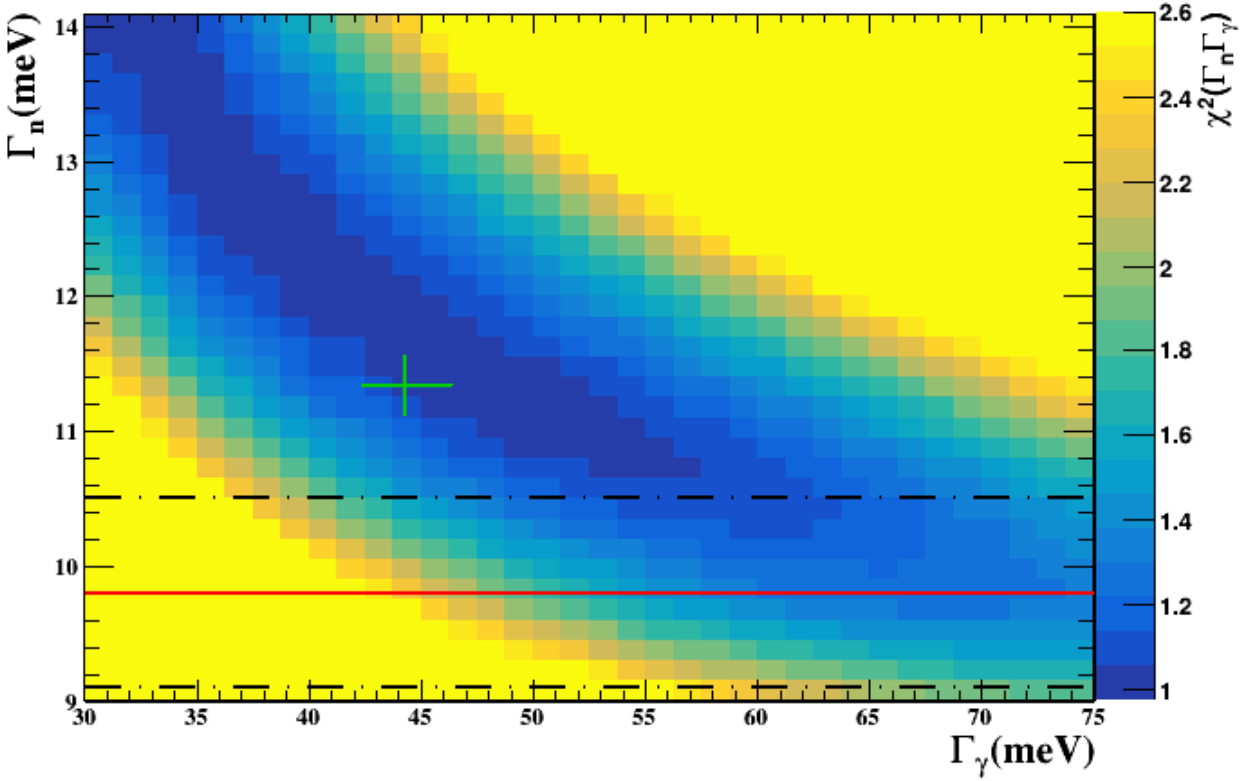
- No differences are oberved. The spin group has been choosen as the same one that the "Atlas of neutron" by Mughabghab, which correspond to **l=0 and J$^{\pi}$=1/2^{+}. According to the conclusions obtain in the correlation study.**

Second resonance at 148.5 eV

- The **second resonance** of the **^{176}Yb(n,γ) reaction** is found at **~148.5 eV**. This resonance **was measured for first time by Mughabghab and mesured again by H. I. Liou.**

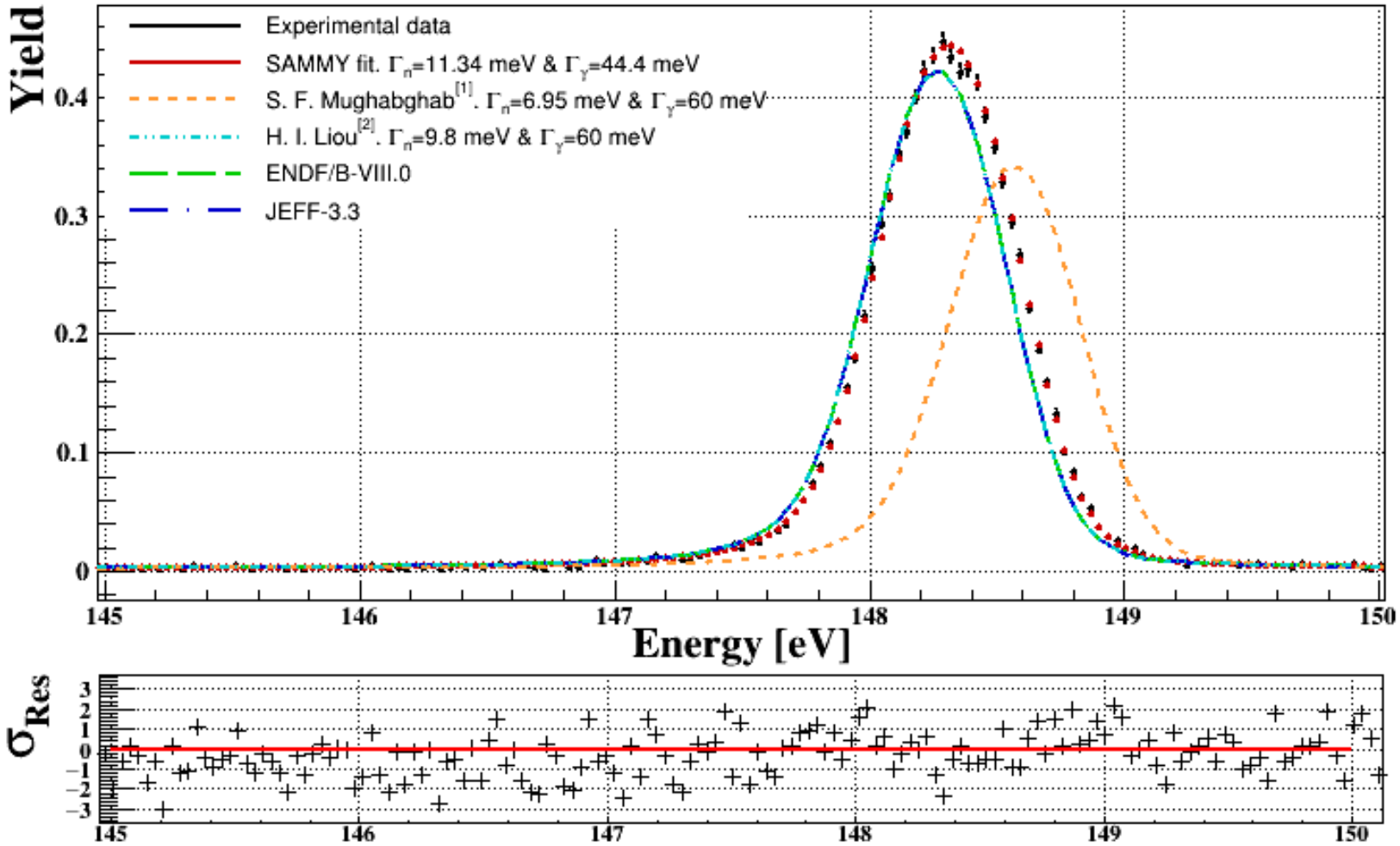
- The **correlation** between Γ_n and Γ_γ has been performed for the first spin group define for the **^{176}Yb.** A clear **correlation between both parameters are observed**, which has been observed when both paratemers have a similar value.

References	Energy [eV]	Γ_n [meV]	Γ_γ [meV]	J^π
Mughabghab[1]	148.8±1.7	6.95±1.04	—	—
H. Liou[2]	148.5±0.2	9.8±0.7	—	—
Mughabghab[4]	148.5±0.2	9.8±0.7	60	$1/2^+$
ENDF/B-VIII.0[5]	148.5	9.8	60	$1/2^+$
JEFF-3.3[6]	148.5	9.8	60	$1/2^+$
This work	148.54±0.01	11.34±0.17	44.4±2.1	$1/2^+$



The correlation correspond to the **spin group l=0 and J^π=1/2$^+$**

Second resonance at 148.5 eV



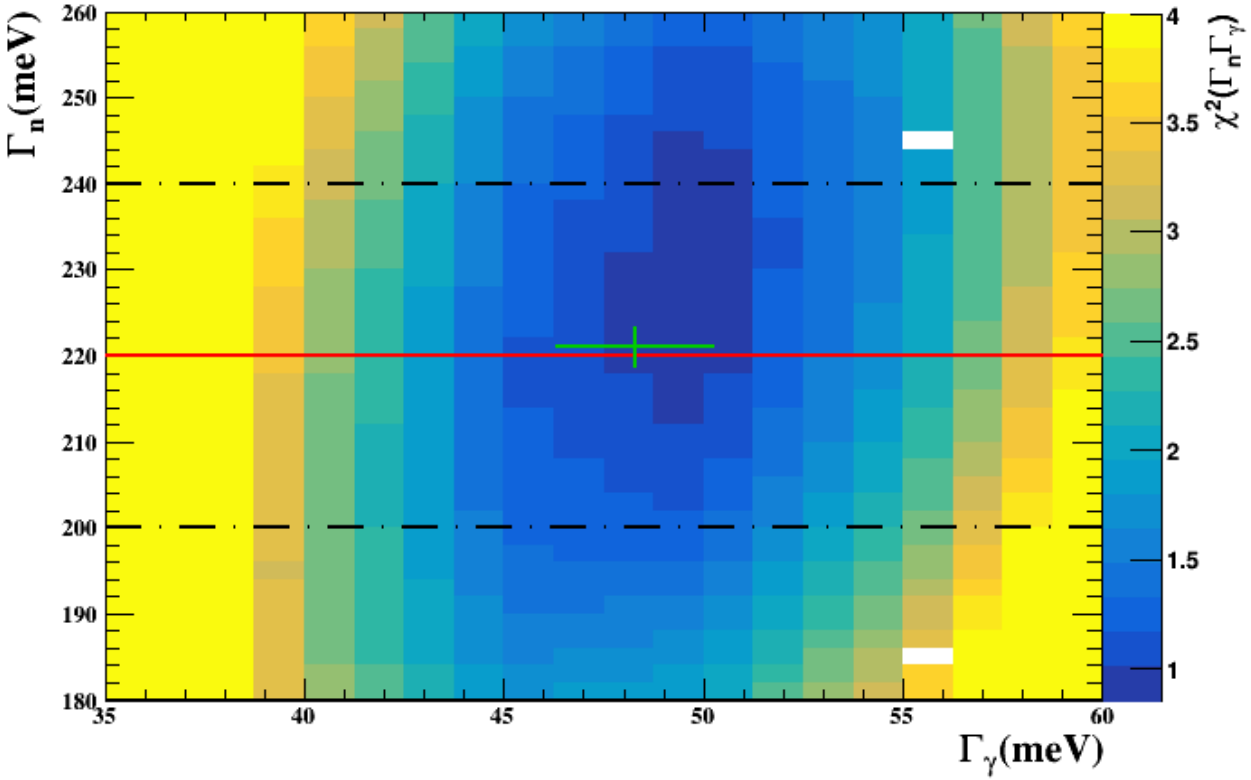
- The **second resonance** of the **^{176}Yb(n,γ) reaction** is found at **~148.5 eV**. This resonance **was measured for first time by Mughabghab and mesured again by H. I. Liou.**

Third resonance at 398.4 eV

- The **second resonance** of the **^{176}Yb(n,γ) reaction** is found at **~398.4 eV**. This resonance **was measured for first time by Mughabghab and mesured again by H. I. Liou.**

- The **correlation** between Γ_n and Γ_γ has been performed for the first spin group define for the **^{176}Yb.** For this resonance, **there is no correlation** between both parameters since they are significantly different in comparison with the previous one.

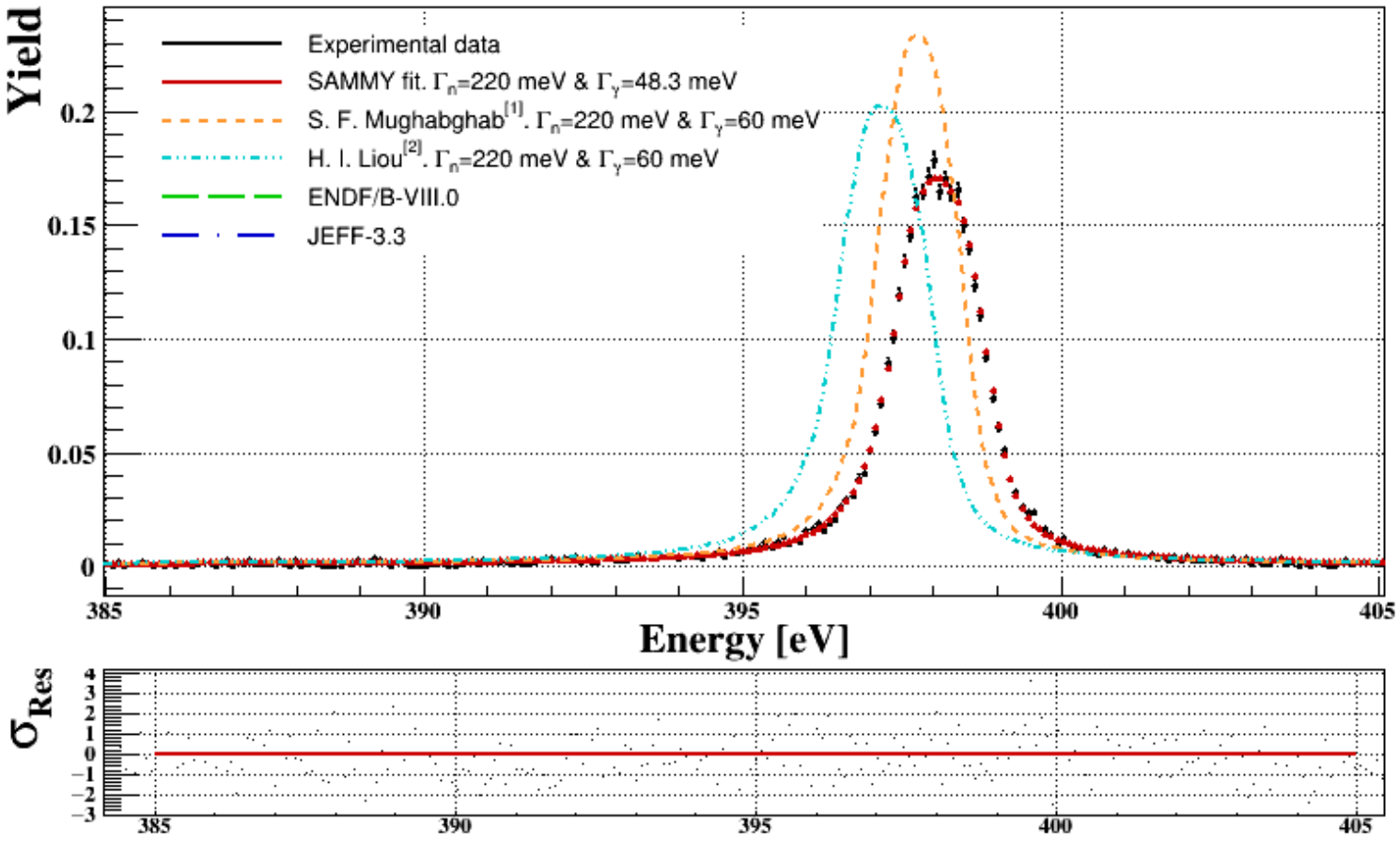
References	Energy [eV]	Γ_n [meV]	Γ_γ [meV]	J^π
Mughabghab	398.4±7.3	165±40	—	—
H. Liou	397.85±0.44	220±20	—	—
Mughabghab	397.85±0.44	220±20	60	$1/2^+$
ENDF/B-VIII.0	397.9	220	60	$1/2^+$
JEFF-3.3	397.9	220	60	$1/2^+$
This work	398.72±0.04	220.0±2.4	48.3±0.3	$1/2^+$

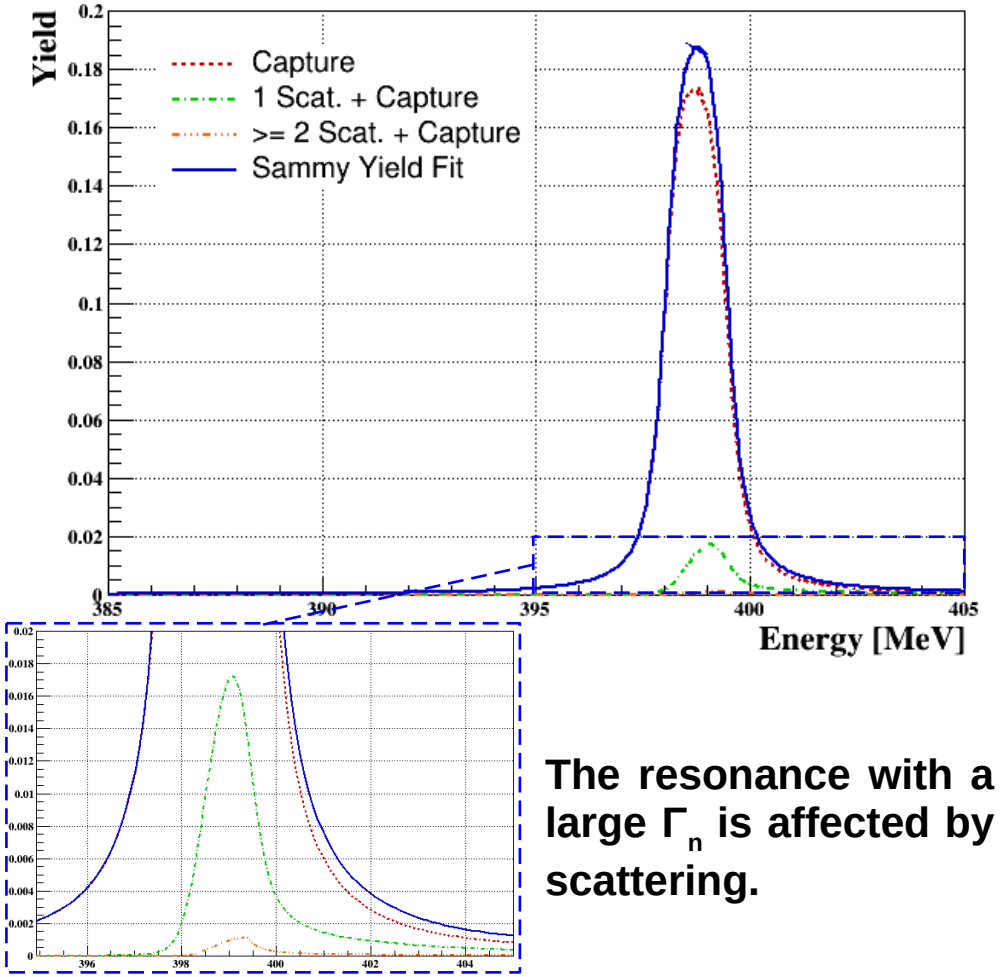


The correlation correspond to the **spin group l=0 and $J^\pi=1/2^+$**

Third resonance at 398.4 eV

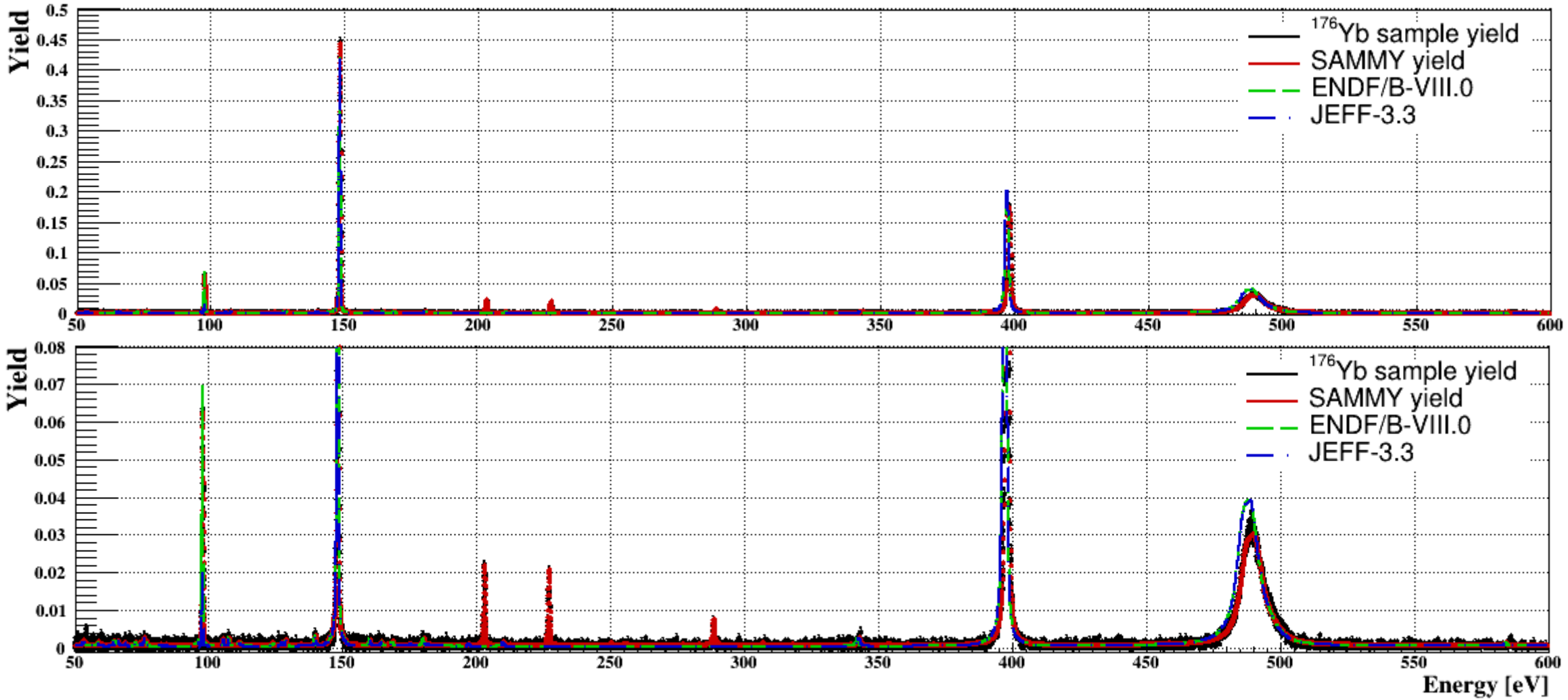
- The **second resonance** of the **^{176}Yb(n,γ) reaction** is found at **~148.5 eV**. This resonance **was measured for first time bv Mughabghab and mesured again by H. I. Liou.**



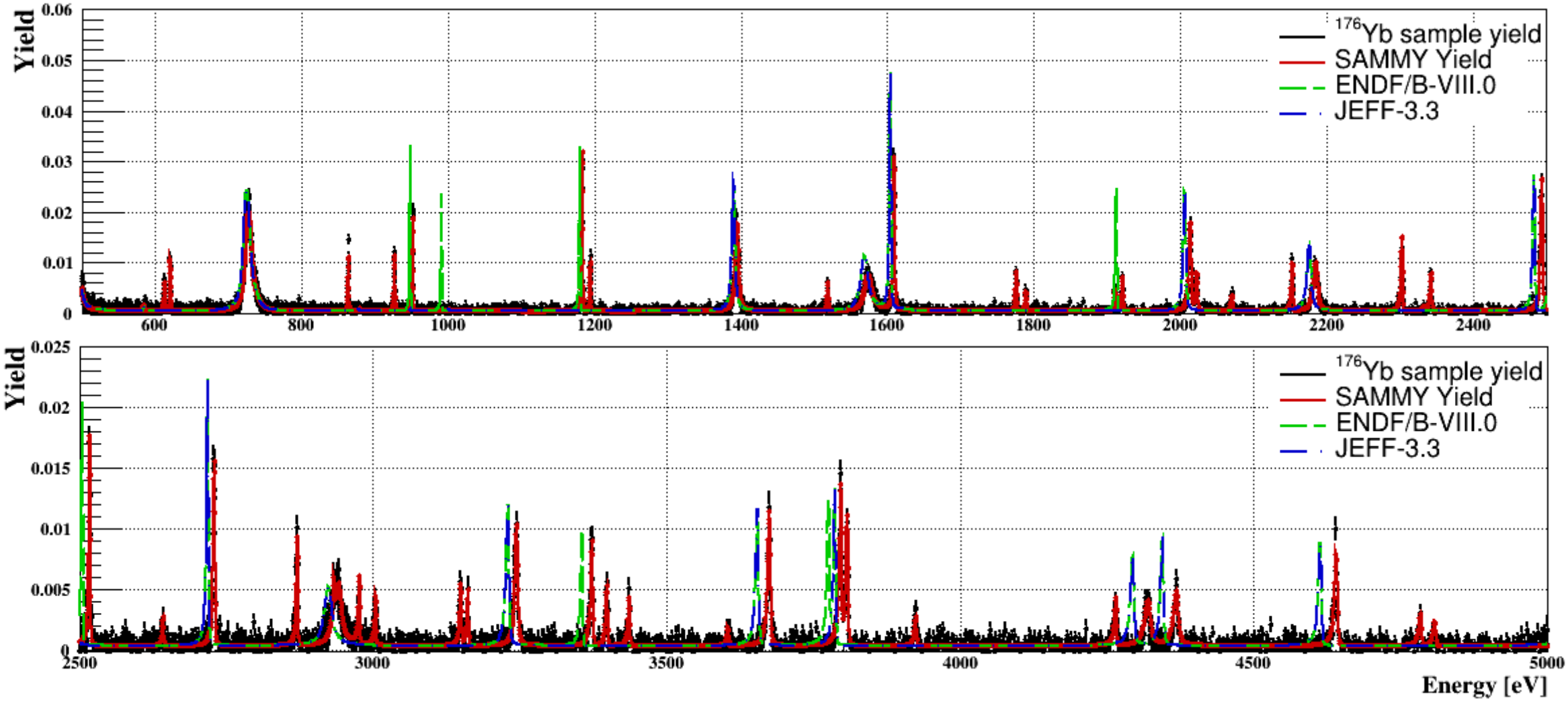


The resonance with a large Γ_n is affected by scattering.

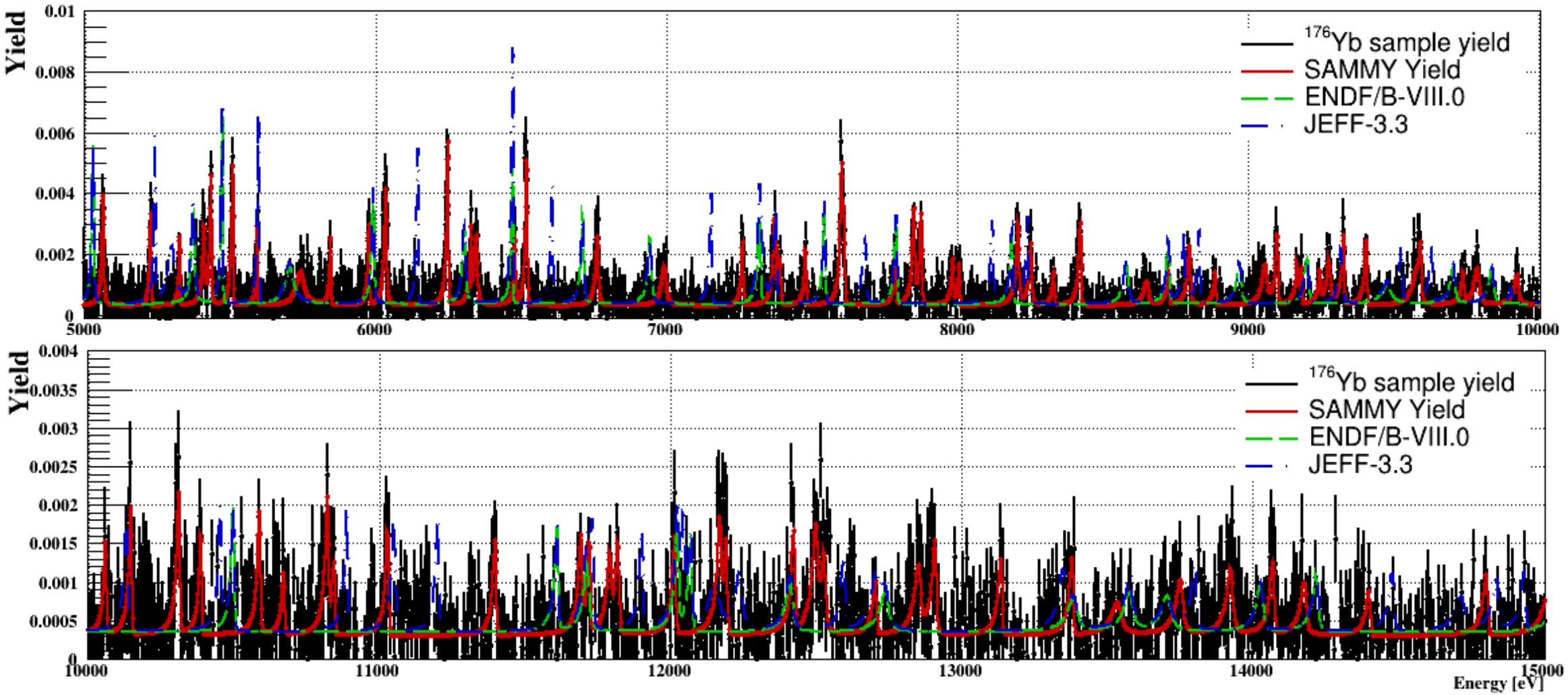
Resonance analysis from 50 eV up to 600 eV



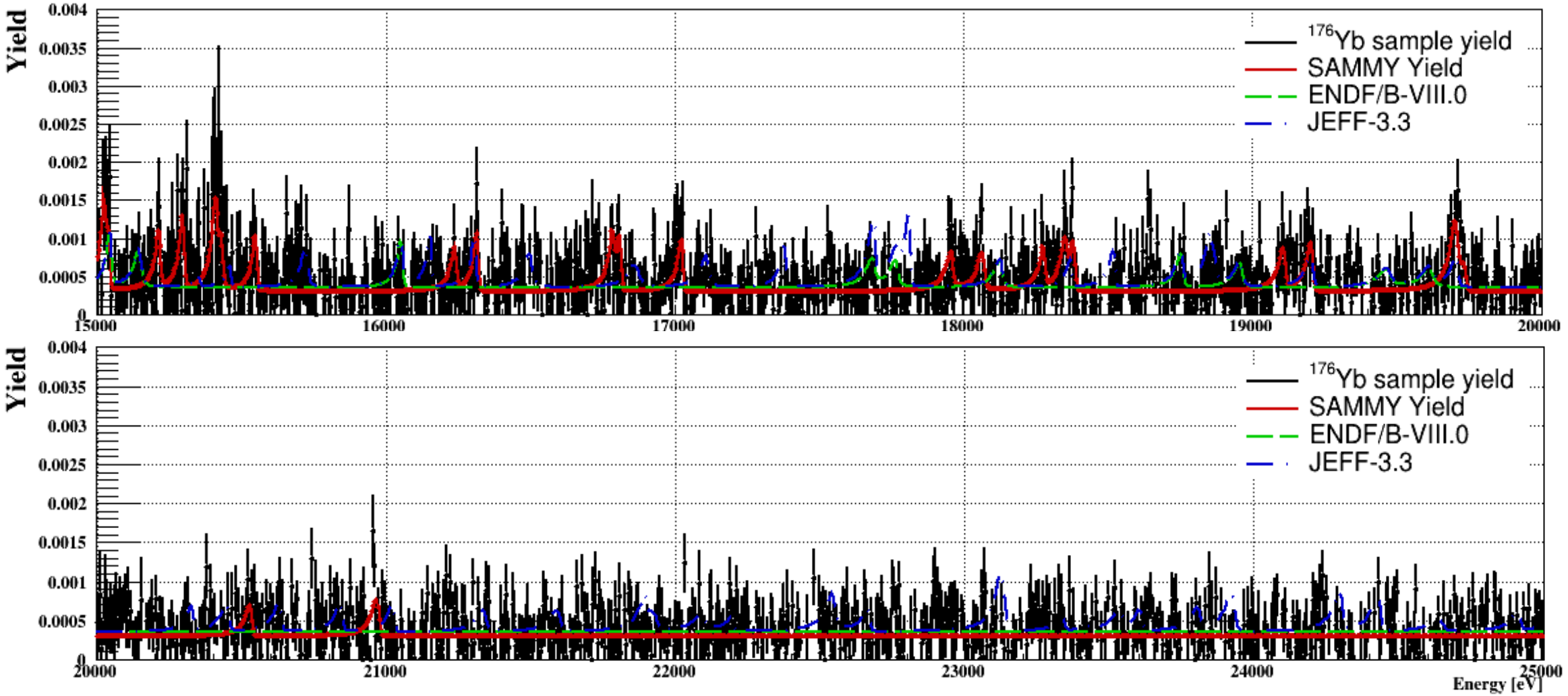
Resonance analysis from 500 eV up to 5 keV



Resonance analysis from 5 keV up to 15 keV



Resonance analysis from 15 keV up to 25 keV



Neutron Sensitivity

- The **last correction factor** is due to the neutron sensitivity:

$$f_{ns} = \frac{1}{1 + P_{ns}}$$

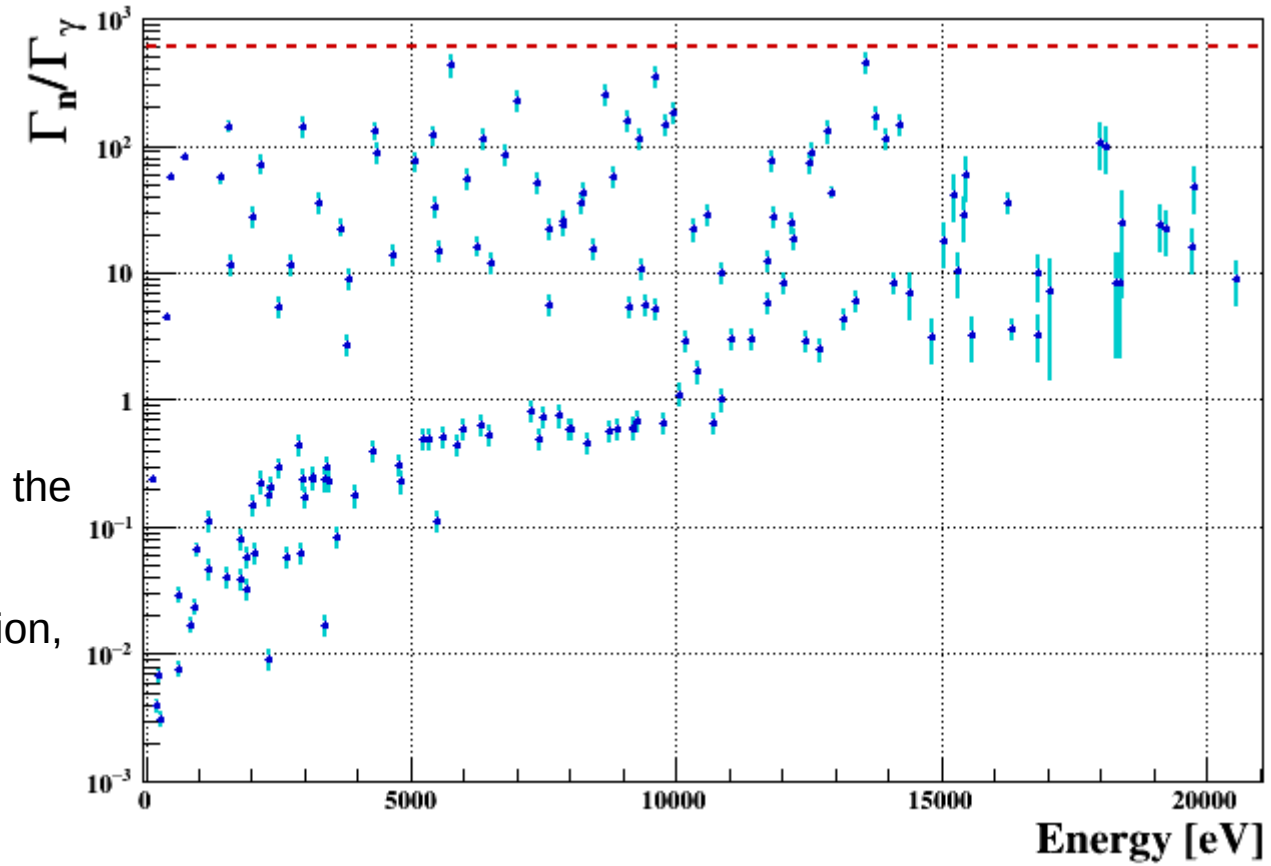
where

$$P_{ns} = \left(\frac{\varepsilon_n}{\varepsilon_c}\right)\frac{\Gamma_n}{\Gamma_\gamma} = \left(\frac{\varepsilon_n}{\varepsilon_\gamma}\right)\left(\frac{\varepsilon_\gamma}{\varepsilon_c}\right)\frac{\Gamma_n}{\Gamma_\gamma}$$

1 2

- The value of **1** has been extracted from the Ref [7], and the value is 2×10^{-5}
- The value of **2** has been extracted from the MC simulation, where a γ ray with 400 keV has been simulated, which value is 0.415
- All resonances are within the 0.5% in term of neutron sensitivity

The dash line represent a neutron sensitivity of 0.5%



Conclusions

Conclusions

- A total of **165 resonances** have been **measured** in an energy range **between 80 eV and 20 keV.**
- The results are **largely unaffected by neutron sensitivity**, and the **background appears to be correctly subtracted**, as evidenced by the results obtained when adjusting the residual background with SAMMY.
- Once the **analysis with SAMMY is completed**, a**ll corrections have been included**, and **uncertainties have to be evaluated**.
- Once the analysis is completely finished, **Monte Carlo simulations will be performed** to assess the **production of the radioisotope ^{177}Lu**, and the **MACS will be calculated** due to the **astrophysical implications**.

Thank you for your attention!!!
Questions or comments

References

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https://www-nds.iaea.org/amdc/ame2020/NUBASE2020.pdf

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[7] R. Plag et al. An optimized C 6 D 6 detector for studies of resonance-dominated (n,γ) cross-sections. Nuclear Instruments and Methods in Physics Research A, 496(2):425–436, January 2003.
https://doi.org/10.1016/S0168-9002(02)01749-7

Backup Slides

Residual background Systematic errors

Residual Background	R_k (meV) at E_n=98 eV	R_k (meV) at E_n=148.5 eV	R_k (meV) at E_n=398.7 eV	R_k (meV) at E_n=489.7 eV	R_k (meV) at E_n=728 eV	R_k (meV) at E_n=953.3 eV	R_k (meV) at E_n=1.58 keV
0.00068	0.455	9.342	39.21	47.03	47.34	2.548	41.70
0.00037	0.459	9.270	39.60	46.09	48.51	2.596	42.52
0.00018	0.463	9.245	39.91	45.01	49.50	2.646	43.13
Var. [%]	0.87	0.77	0.98	1.98	2	1.85	2.2

Residual Background	R_k (meV) at E_n=1.61 keV	R_k (meV) at E_n=2.16 keV	R_k (meV) at E_n=2.19 keV	R_k (meV) at E_n=489.7 eV	R_k (meV) at E_n=728 eV	R_k (meV) at E_n=953.3 eV	R_k (meV) at E_n=1.58 keV
0.00068	32.24	11.31	43.61				
0.00037	32.96	11.19	42.47				
0.00018	33.40	11.02	41.67				
Var. [%]	2.1	1.6	2.1				