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

Collaboration meeting
Edinburgh (Scotland)
13/14-12-2022

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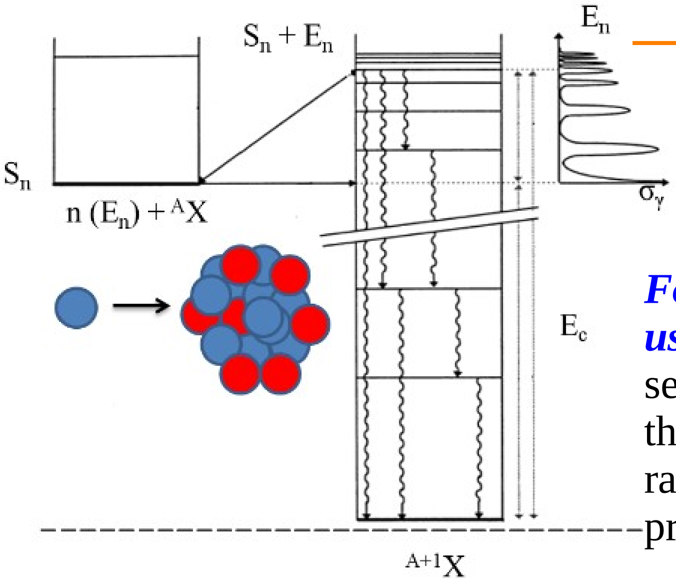
Outline of the presentation

- Measurement at n_TOF Facility
  - Measure, Experimental Set-Up and ^{176}Yb Sample.
- Preliminary Yield
  - Preliminary yield presented in the ND Conference.
- Check in the analysis
  - Channel to Energy calibration.
  - Resolution of the detector.
  - WF application
  - Cascade analysis with NuDEX

Measure, Experimental Set-Up and ^{176}Yb sample

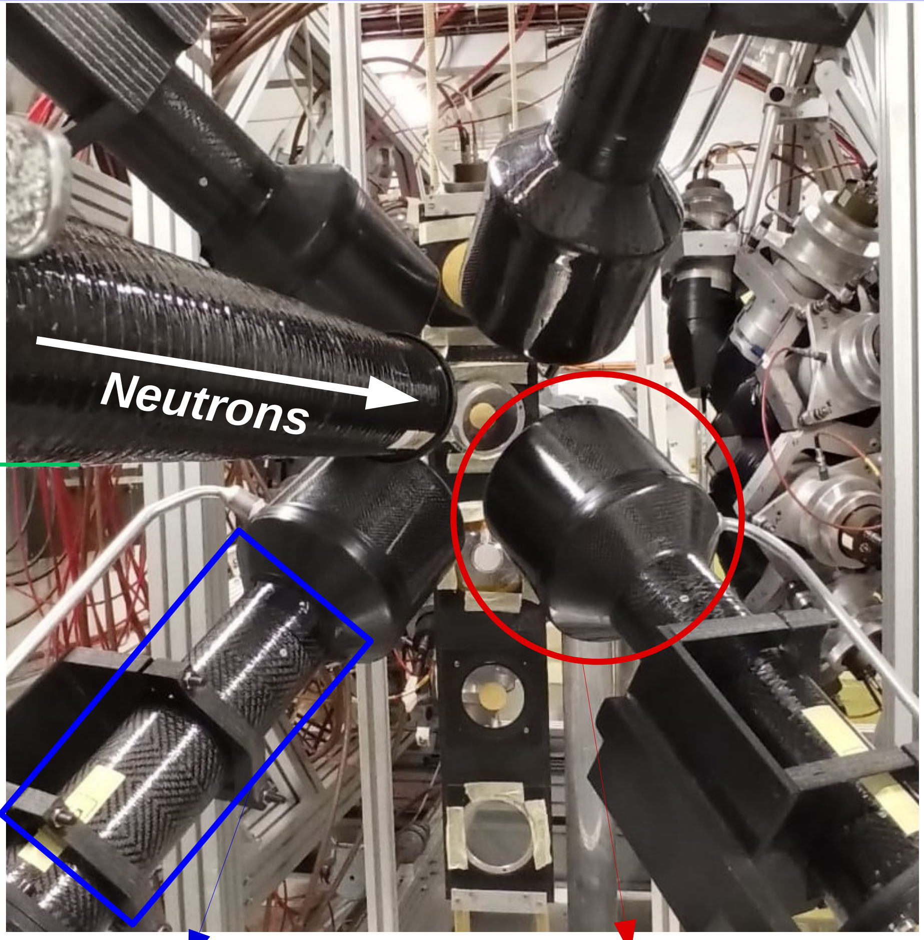


Sketch of the ***compound nucleus formation when a neutron of energy E_n interacts with ^{A}X nucleus***. The quasi-stationary states on the compound nucleus above the neutron separation energy S_n lead to resonances in the cross section.

Four custom C6D6 scintillation detectors were used, optimized for an extremely low neutron sensitivy. These detectors are positioned at 125° to the beam position to reduce the in beam gamma rays background and minimize the effects of the primary radiation angular distribution [1,2].

The sample is a ***^{176}Yb oxide powder***, (***1.5976 g and 99.43% purity***) ***pressed in a 19 mm Ø quartz and 2mm thickness***.

Kindly ***provided by Richard Henkelmann*** (ITG company) ***and Ulli Koester*** (ILL). This sample will be recycled for radioisotope production at ITG. ***ITG supplies of ^{177}Lu to hospitals***. As mentioned, new routes are of high interest to produce radioisotopes.



PMT and VD

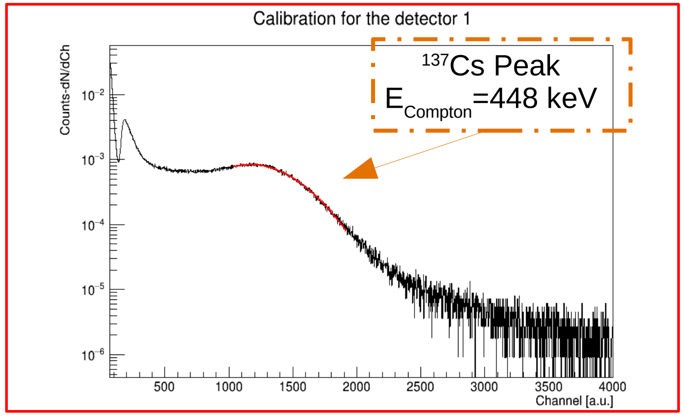
Deuterated Benzene

Measurement time from ***25/10/2021*** to ***14/11/2021***

Previous Results

- **Results presented in previous meetings**

- **3 Source and 4 Peak used for the calibration.**
- **4 set of calibration have been compared.**



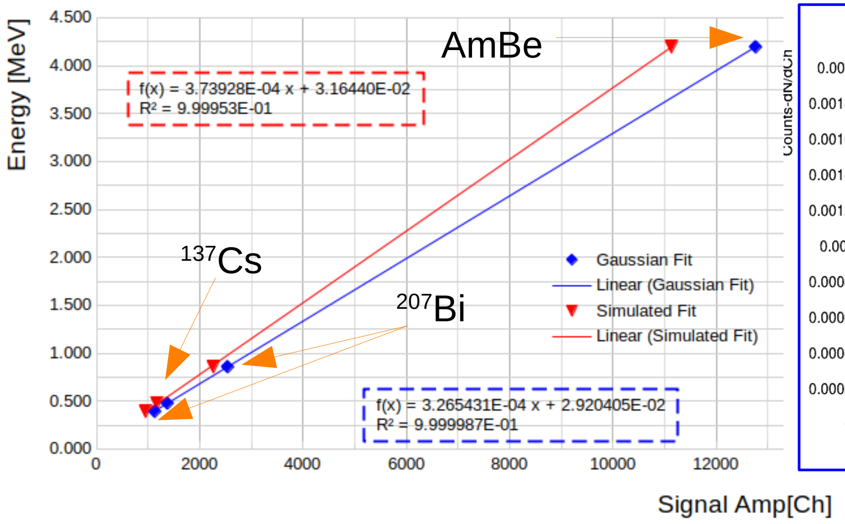
First calibrations

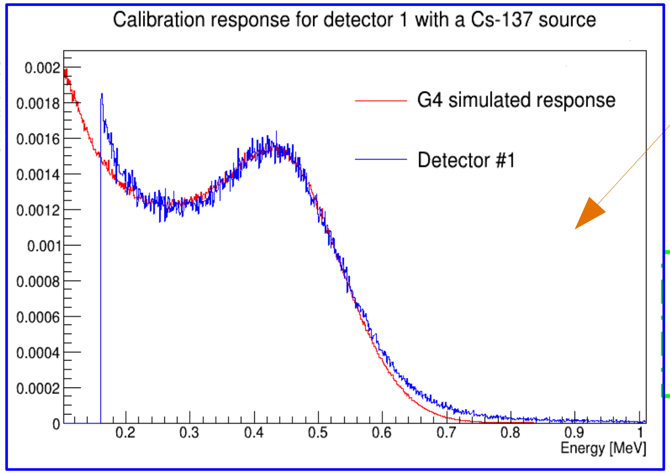
- **The first simulations were performed using a Gaussian fit of the Compton peak**
- **No simulations were performed**

Second calibrations

- **Simulations have been carried out in GEANT4**

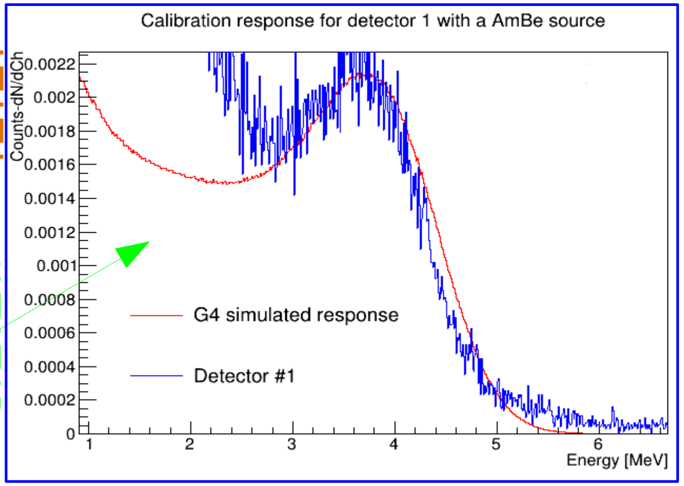
Source	Photo Peak [MeV]	Compton Peak [MeV]
^{207}Bi Peak	0.569	0.369
^{137}Cs Peak	0.662	0.448
^{207}Bi Peak	1.064	0.806
AmBe Peak	4.438	3.944





^{137}Cs Peak
$E_{Compton}$=448 keV

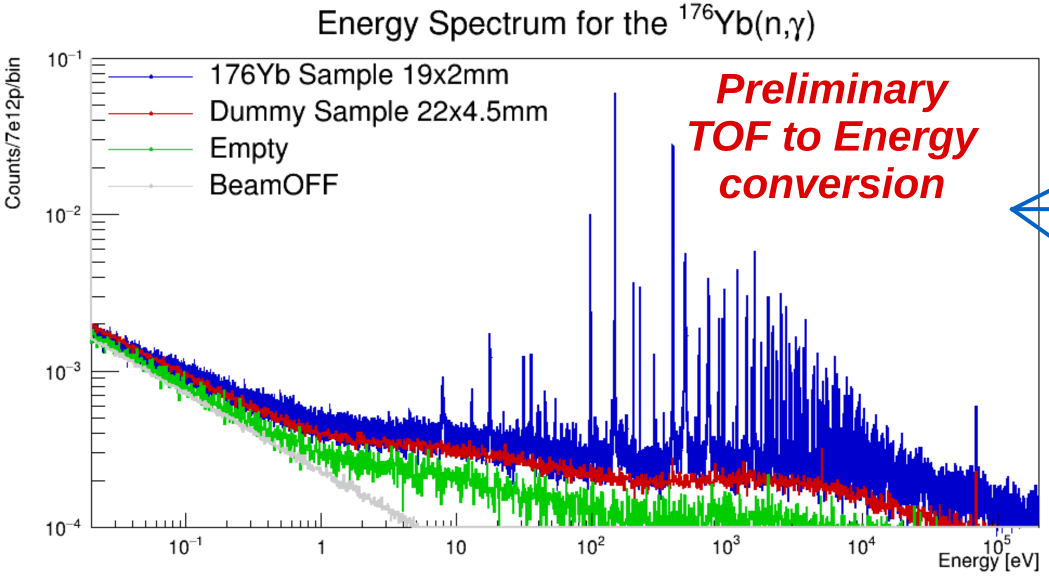
AmBe Peak
$E_{compton}$=3.944 MeV



Thanks to Victor Babiano, Adriá and Jorge for providing me with the GEANT4 simulation code with the implemented geometry.

Results presented in the ND conference

Experimental Data



First steps of the analysis:

Transmission measurement[5]

Detector Calibration: Amplitud (Channel) to Energy Deposited (keV)

Stability Study: Monitoring of the neutron beam during the measurement.

Threshold Study: Cuts applied to the energy deposited in the detectors due to rebounds in the signals. The cutoffs applied depend on the response of each detector. Therefore, they are different for each of them.

Pulse Height Weighting Tecnique[3,4]

Very Low Efficiency

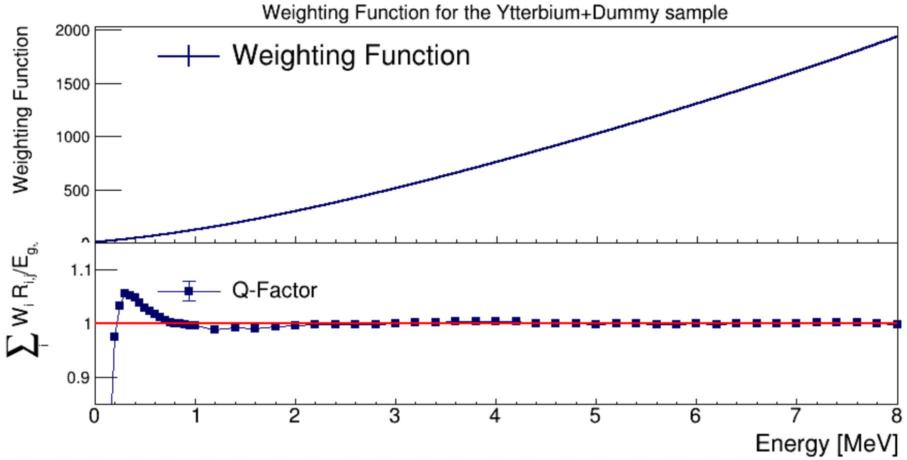
$$\varepsilon^{\gamma} \ll 1$$

Proportionality condition

$$\varepsilon^{\gamma} = \alpha E^{\gamma}$$

$$\varepsilon_C = \alpha E_C$$

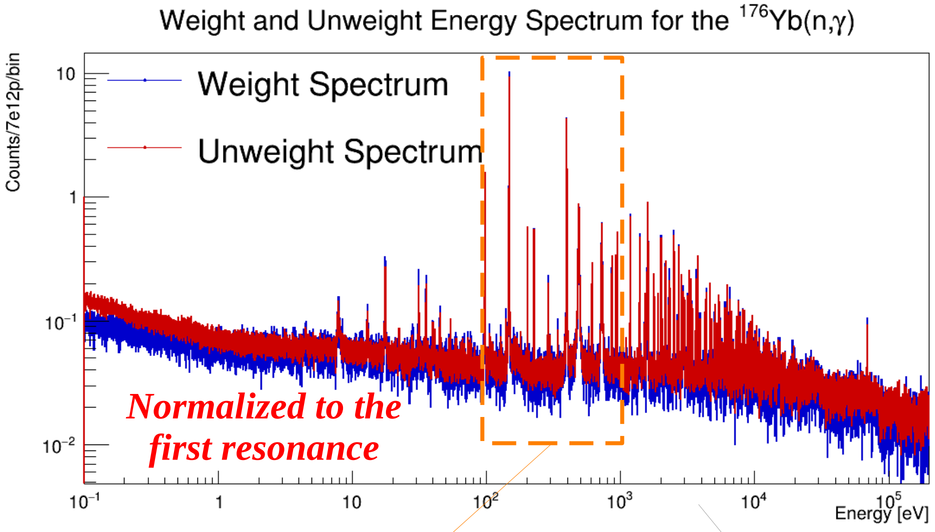
WF obtained through Geant4 simulations



Fulfilling these two conditions, we obtain that ***the efficiency is proportional to the energy of the cascade***, and therefore, ***independent of the de-excitation path***.

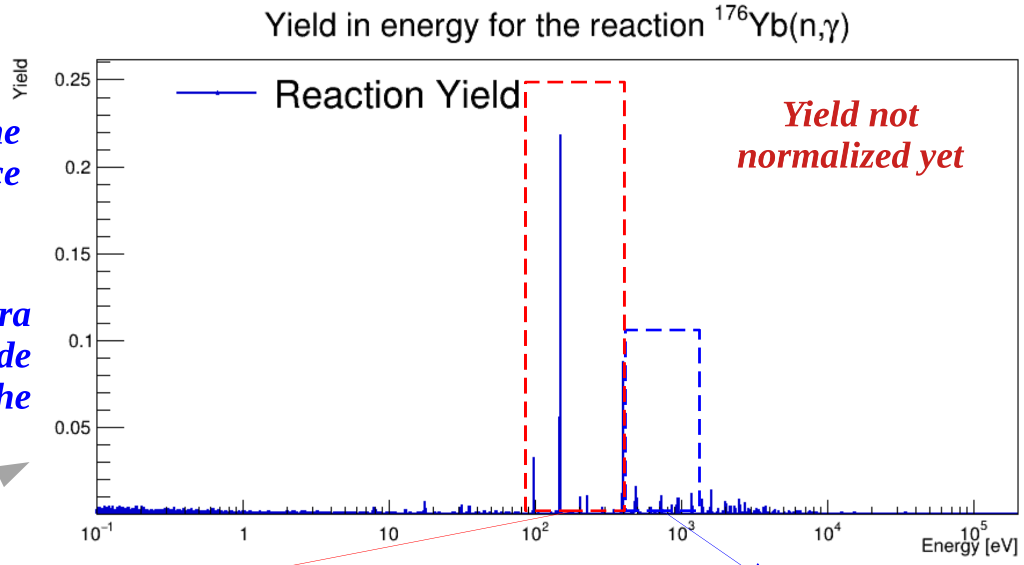
Many thanks to César Domingo for helping me and providing the WF code[4].

Experimental Data



For normalization, the gold saturated resonance method will be used.

In addition, some extra corrections must be made to the calculation of the yield.



Signal/Background improvement¿?

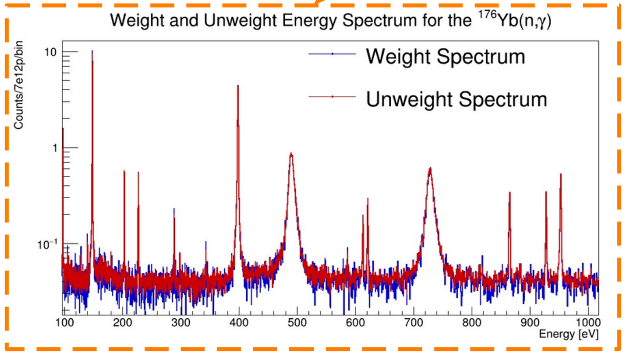
YIELD

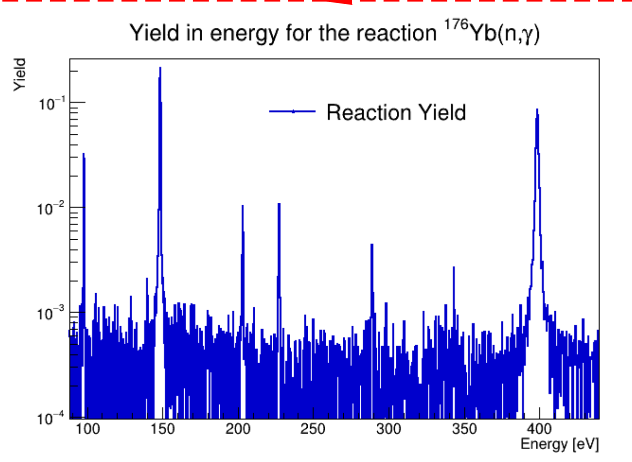
$$Y_{exp}(E_n) = f_{corr.}\,\frac{C_w(E_n) - B_w(E_n)}{\phi_n(E_n)\cdot(S_n + E_n)}$$

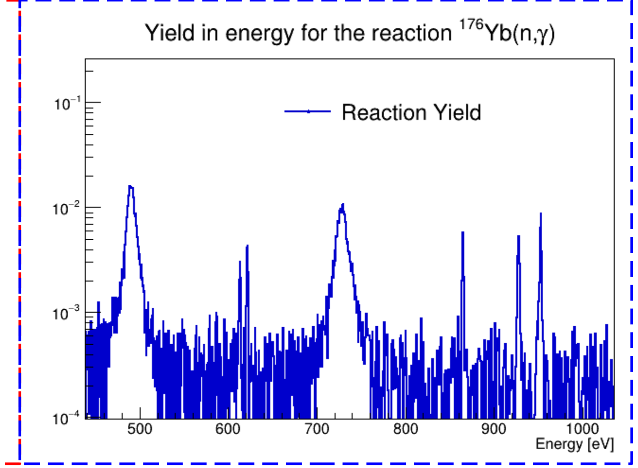
Correction factor (not applied yet)

Cascade energy 5.5664 MeV

Experimental flux not available, the simulated one has been used

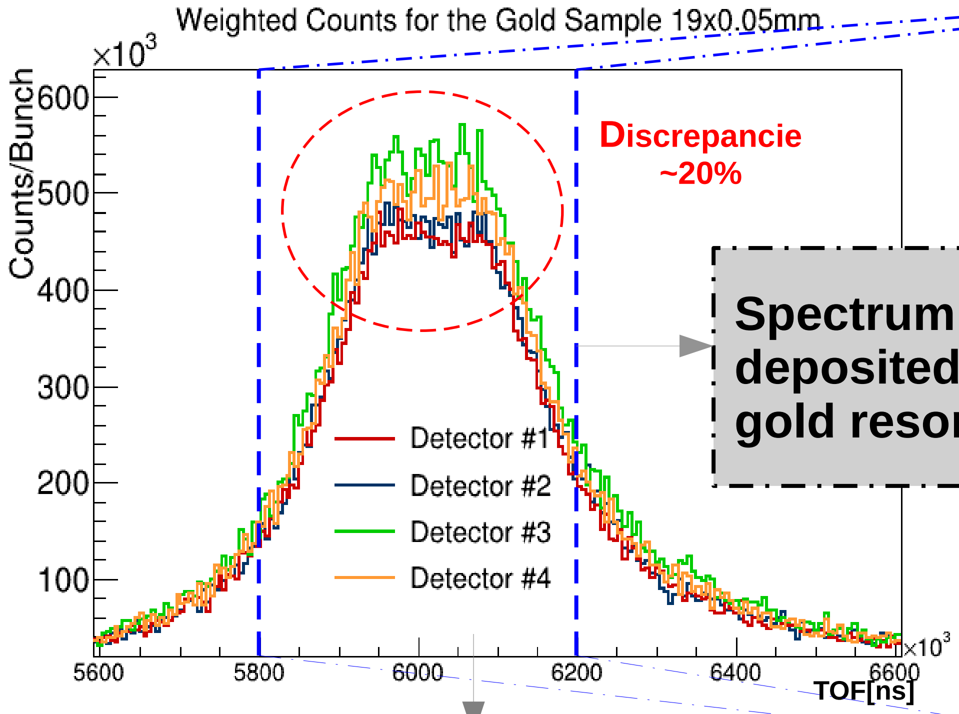




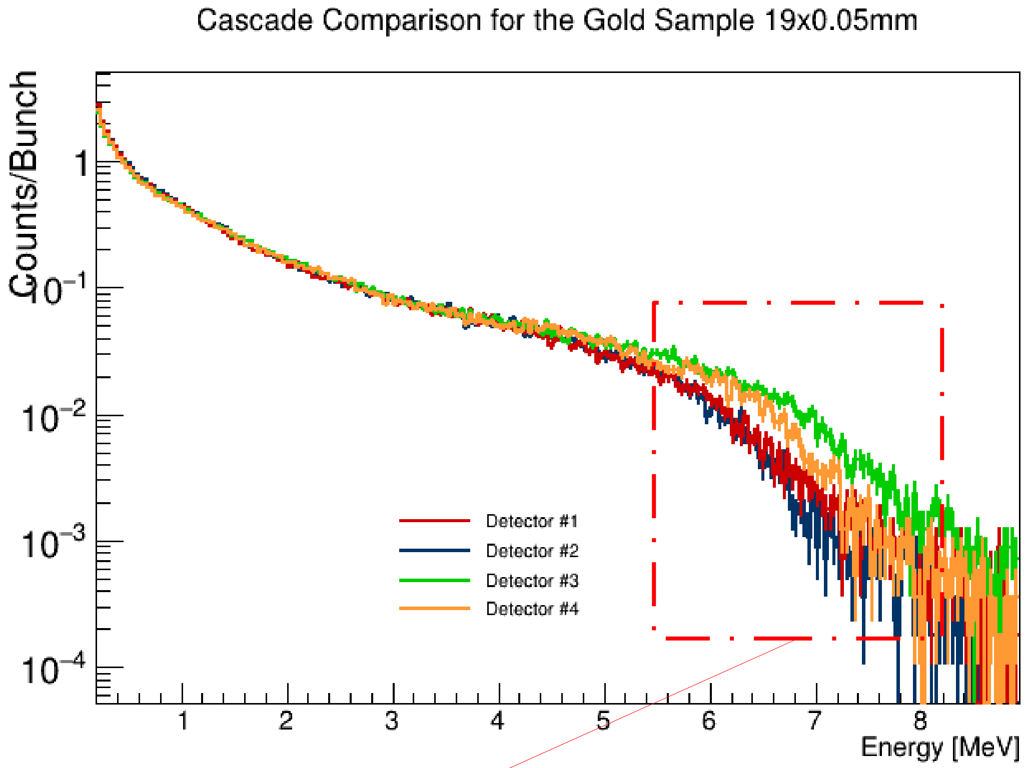


Corrections applied after ND conference

Gold Check Validation



Spectrum of energy deposited in the gold resonance



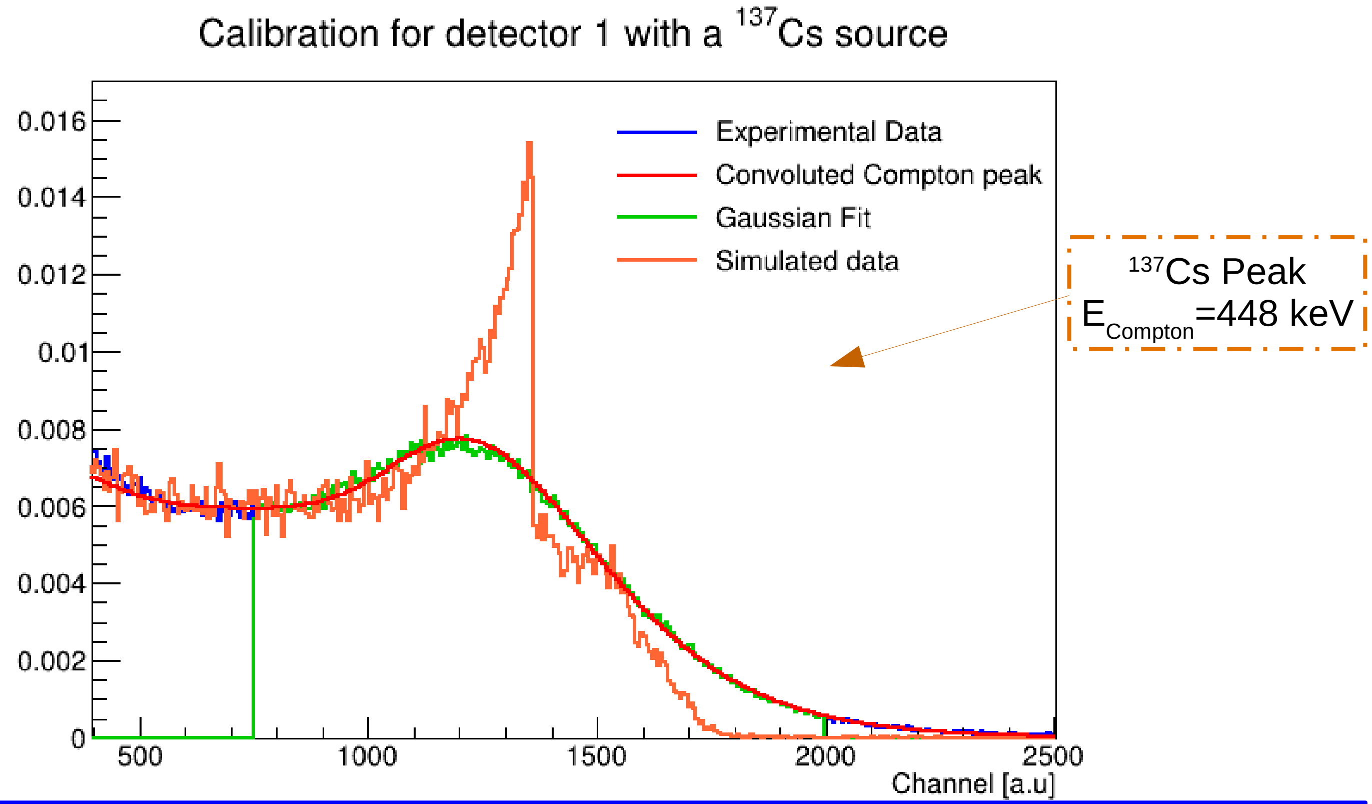
- **Geometric problems**
  - **Different distances from detectors**
  - **sample misalignment**
- **Calibration problems**
- **Different threshold**

An improved calibration has been performed to solve the discrepancy.

Detector ReCalibration

To calibrate at higher energies, the gold cascade itself will be taken into account.

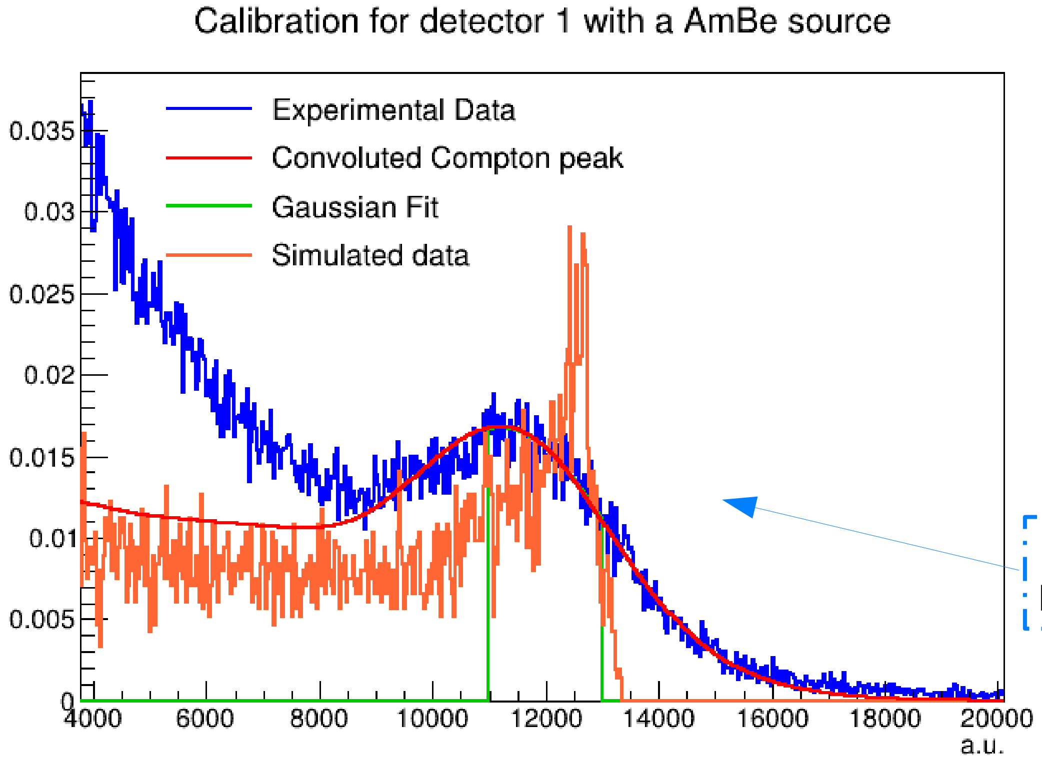
Source	Photo Peak [MeV]	Compton Peak [MeV]
^{207}Bi Peak	0.569	0.369
^{137}Cs Peak	0.662	0.448
^{207}Bi Peak	1.064	0.806
AmBe Peak	4.438	3.944
Gold Cascade peak	6.512	6.236



The binding energy of ^{177}Yb is 5.566 *MeV*. Therefore, taking the gold cascade as the calibration point would be sufficient to be able to analyze ^{177}Yb without problems.

The simulated spectrum has been convoluted taking into account the fit of channels to energy, as well as the resolution of the detector. The spectrum has been convolved by modifying the parameters until the best possible fit is obtained.

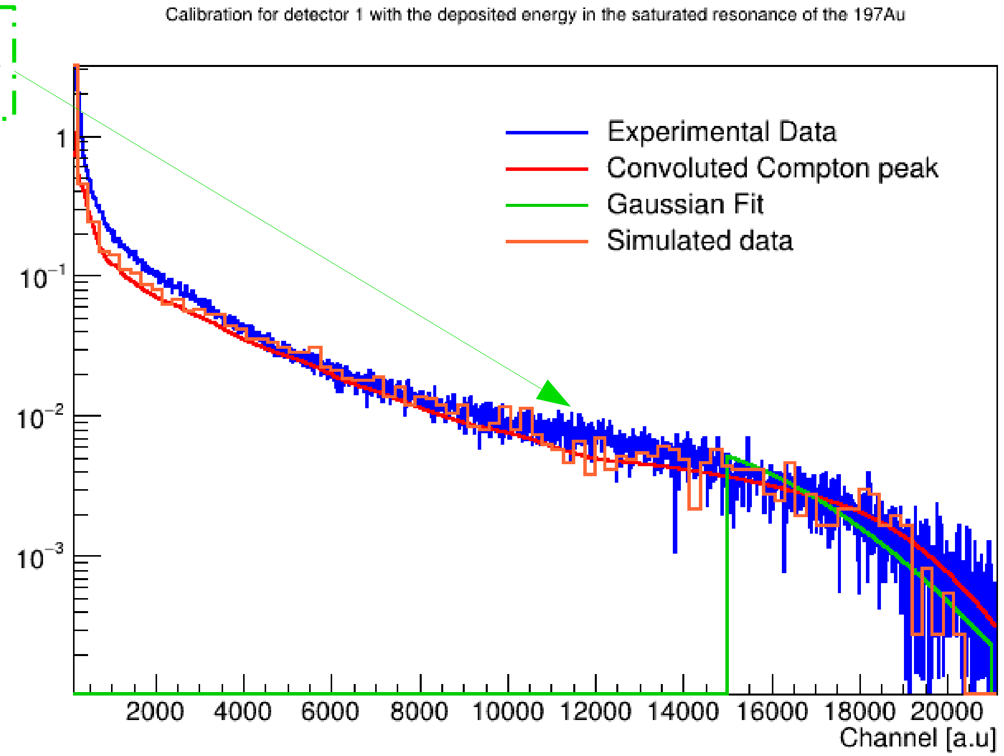
Detector ReCalibration



Gold cascade has been fitted with the TAC parameters. Cascades obtained by Carlos Guerrero with "DECAYGEN" (program by J.L. Taín)[6].

Gold Peak
$E_{compton}$=6236 keV

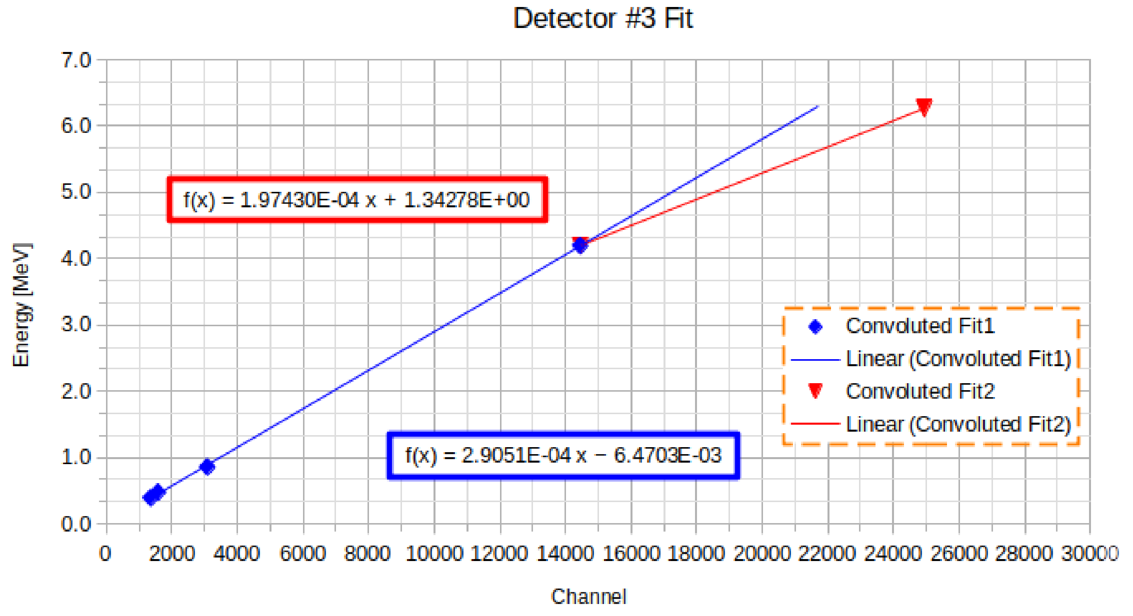
AmBe Peak
$E_{compton}$=3944 keV



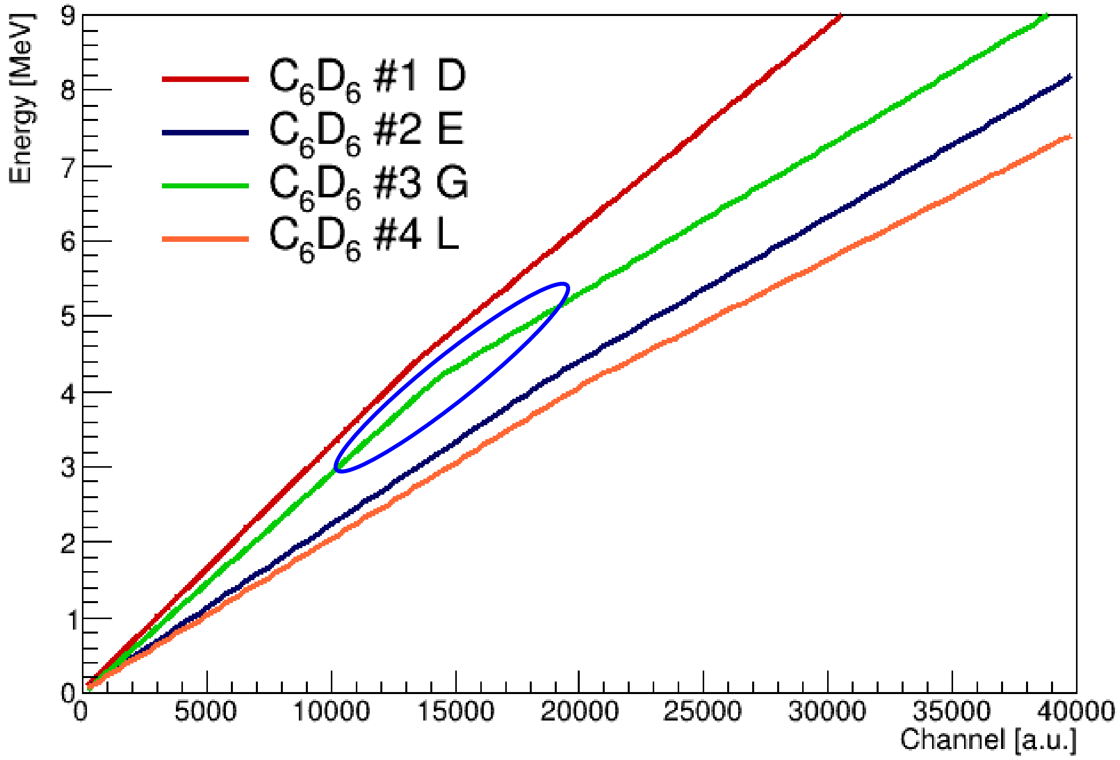
For the ^{137}Cs and ^{207}Bi source, it is possible to simulate the complete decay of the radioisotope. But the AmBe source is not reproducible, so the most energetic gamma emitted has been simulated.

Thanks to Victor Alcayne and Adriá Casanovas for providing me with the parameters and helping me with the problem mentioned above.

Detector ReCalibration



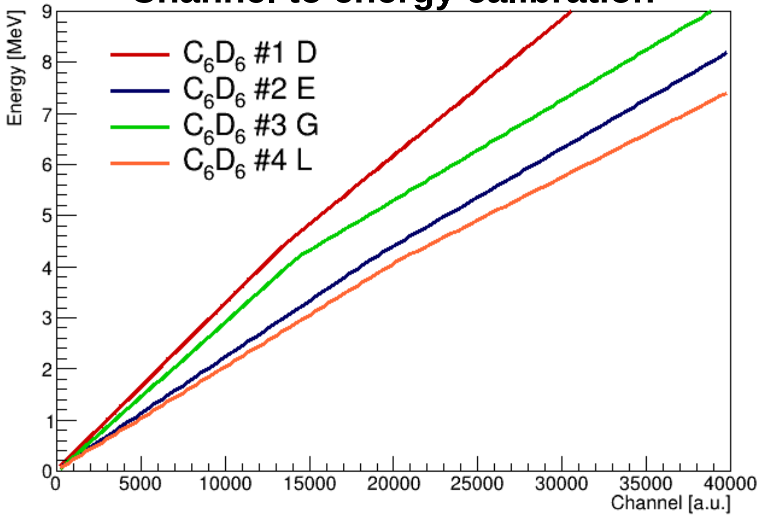
At first, double linear calibration was taken as valid. For detector #3, this variation is observed in the calibration at high energies. This explains the difference observed above.



The change in the fit trend is evident

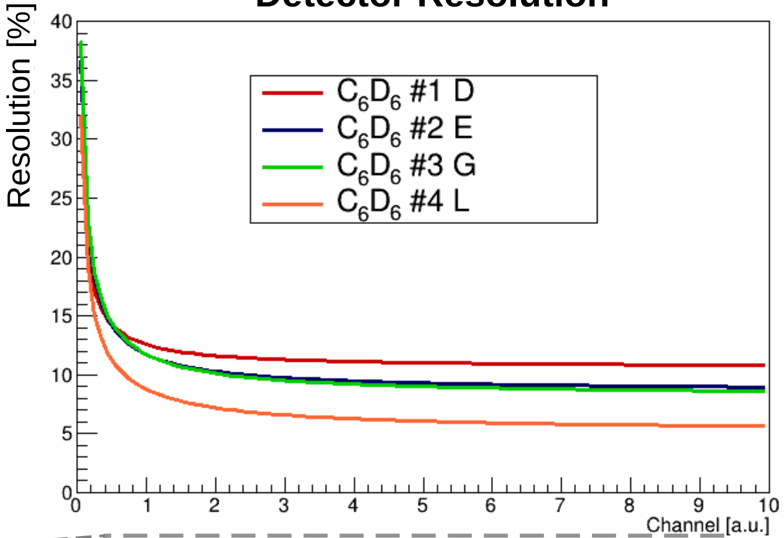
Detector ReCalibration

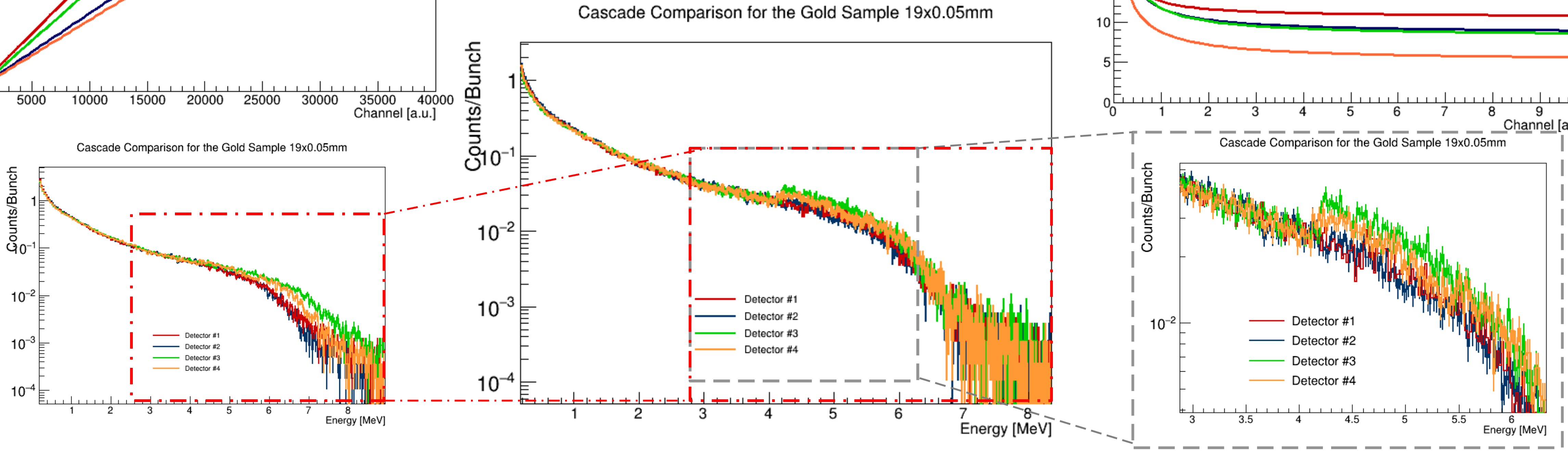
Channel to energy calibration



Better agreement is observed in the cascade, but due to the double linear fit some artifacts are observed in the results

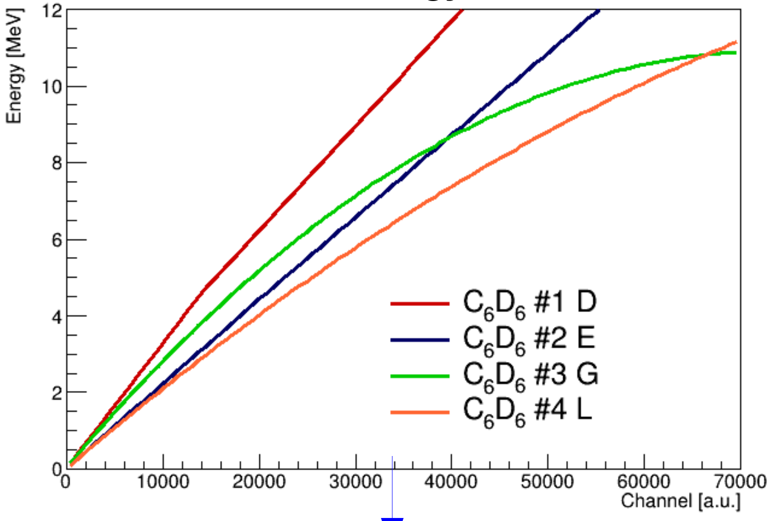
Detector Resolution





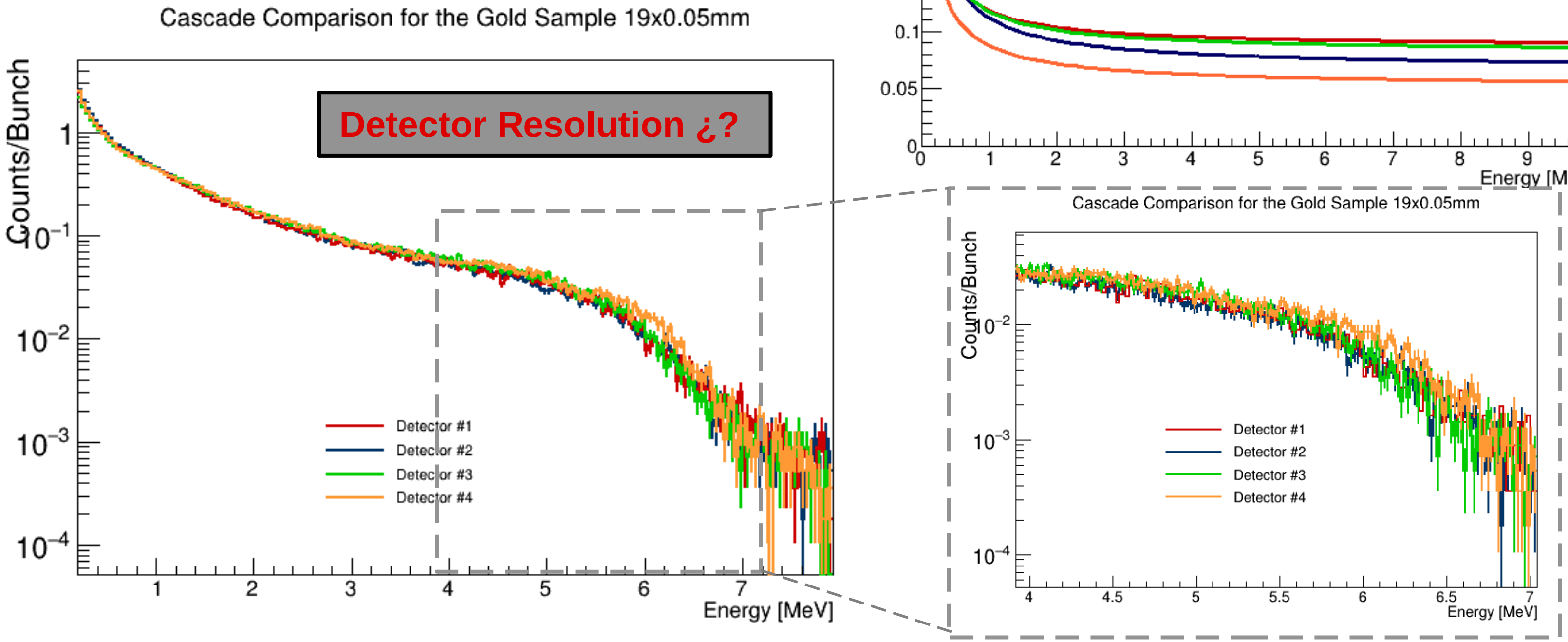
Detector ReCalibration

Channel to energy calibration

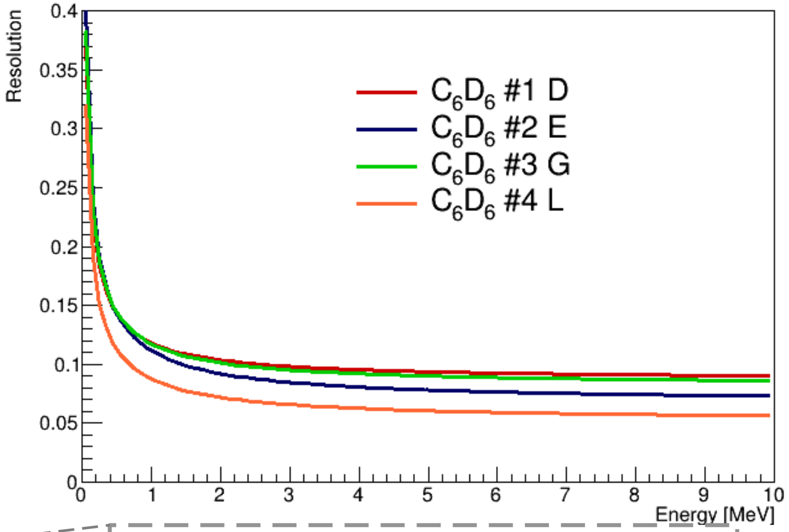


Taking into account the trend of the detector 3 calibration curve, it has been ensured that the trend does not change until at least 10 MeV. It is at this energy that the results at high energies are being cut.

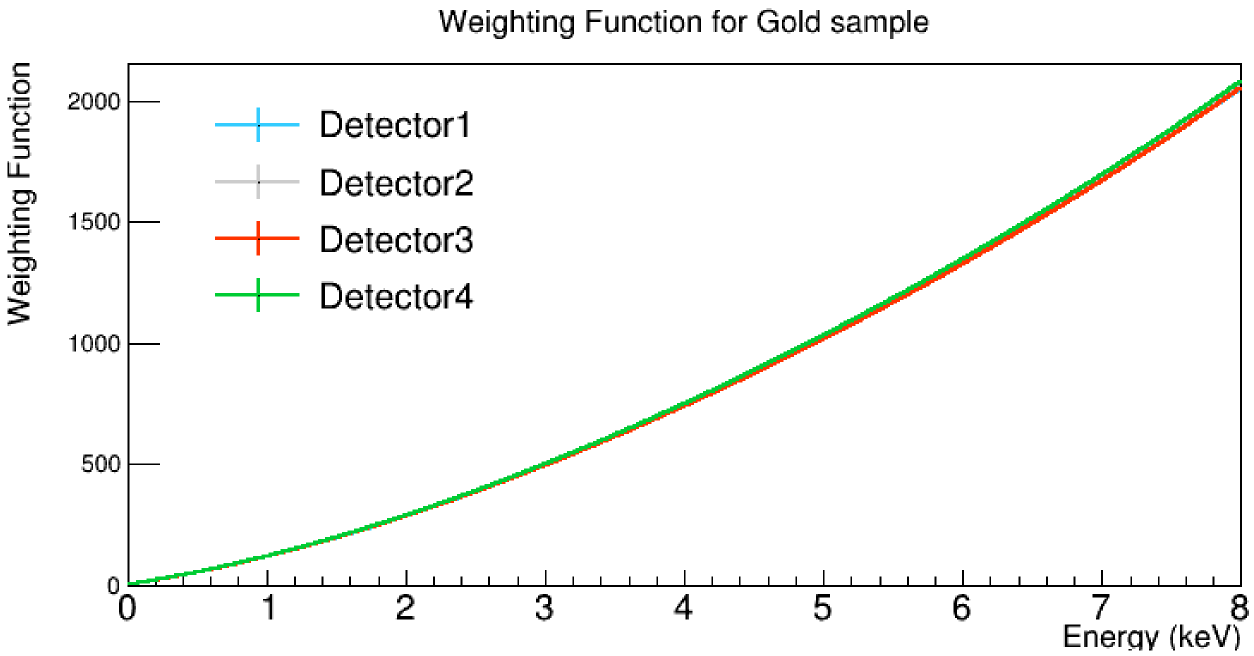
Finally, a good agreement has been reached between the gold cascades. Considering a double linear fit for detectors #1 and #2, and a second order fit for detectors #3 and #4.

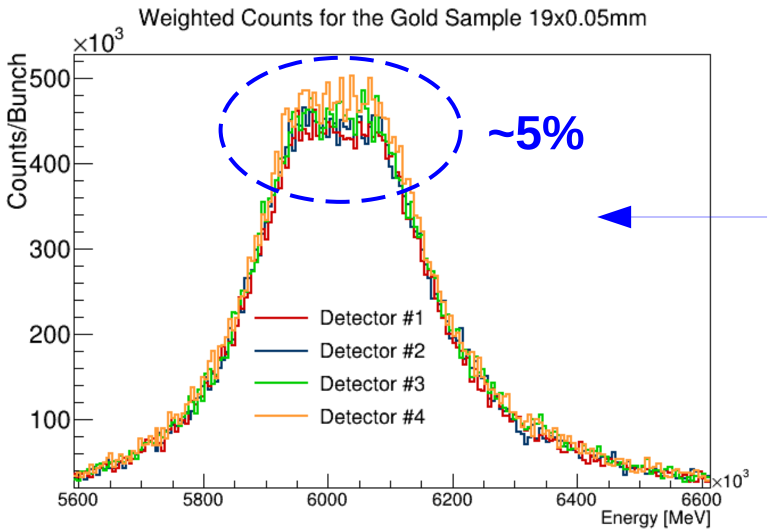


Detector Resolution



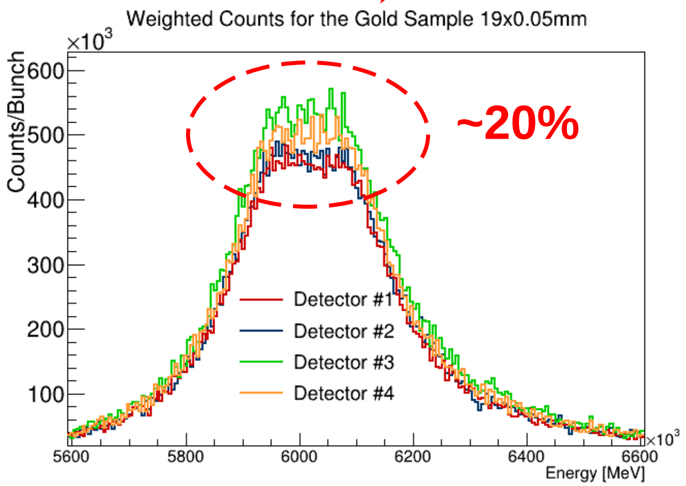
Weigthing Function





Double linear plus second degree fit

Linear fit



The WF has been recalculated, since it depends on the resolution of the detectors. Better agreement has been obtained on the saturated resonance of gold, but there are still some discrepancies. This may be due to other corrections that have not been applied yet.

- **Deposited Energy Threshold**
- **Gamma summing**
- **Electrons conversion**

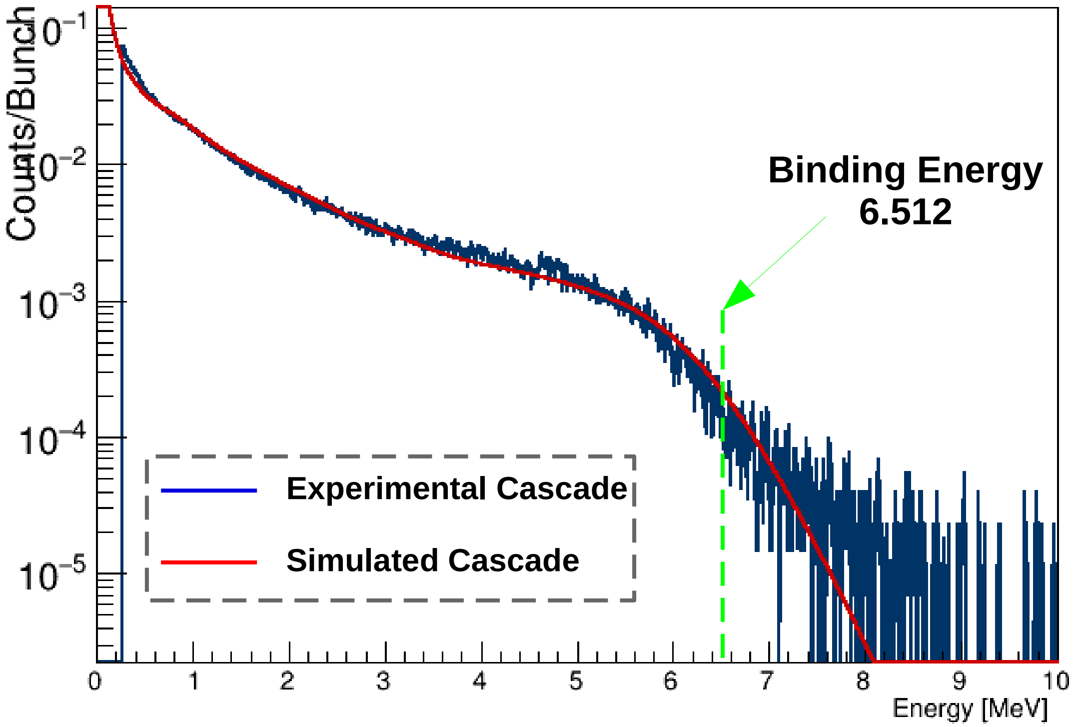
^{176}Yb(n,g) Cascades Simulations

Gold Cascades simulations

The first step has been to calculate the cascades for the saturated resonance of gold. The parameters have been obtained by Carlos Guerrero with "DECAYGEN" (program by J.L. Taín)[6].

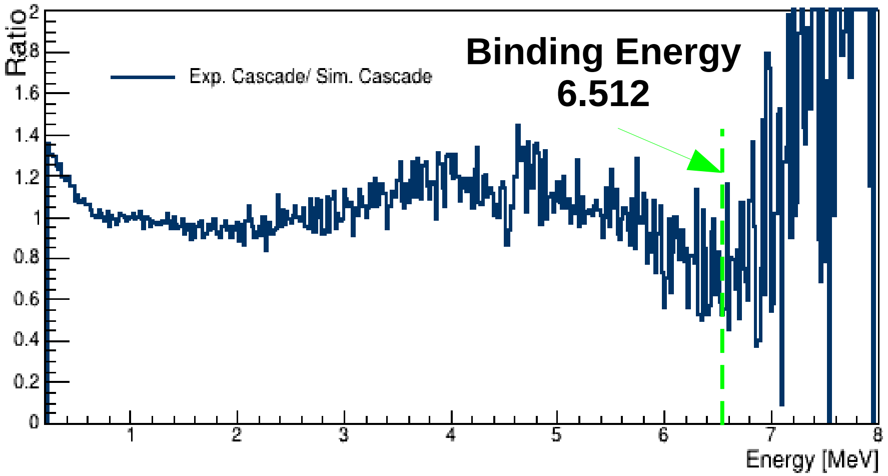
The ratio shows good agreement between the simulated cascades and the experimental gold cascades.

Below the binding energy, 6.512 MeV, the discrepancies remain around ~5%, except at low energies where it increases, and well above the binding energy.



Experimental Cascade

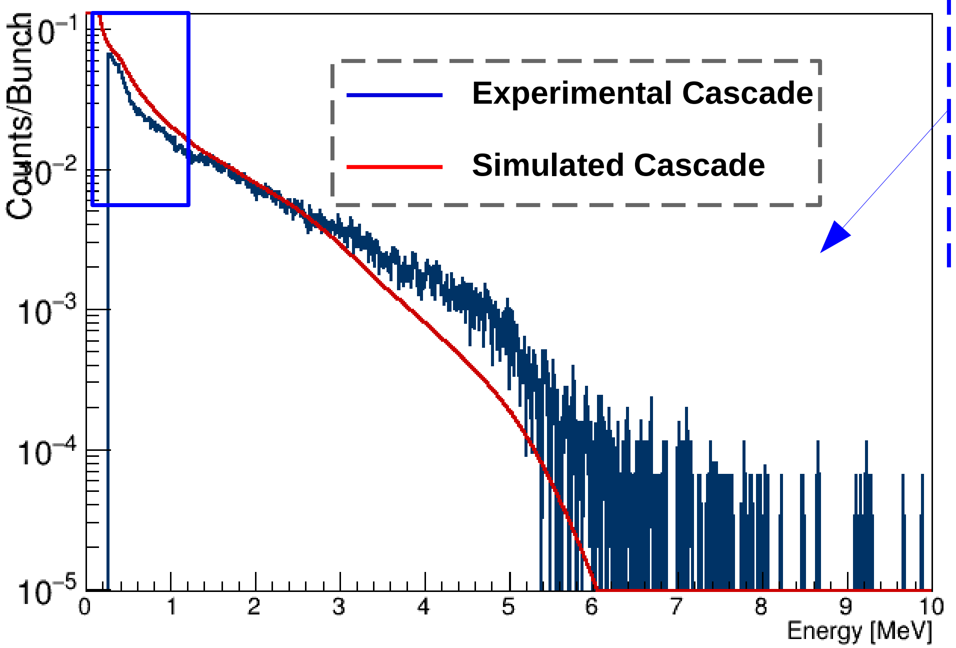
Simulated Cascade



^{176}Yb(n,g) Cascades simulations

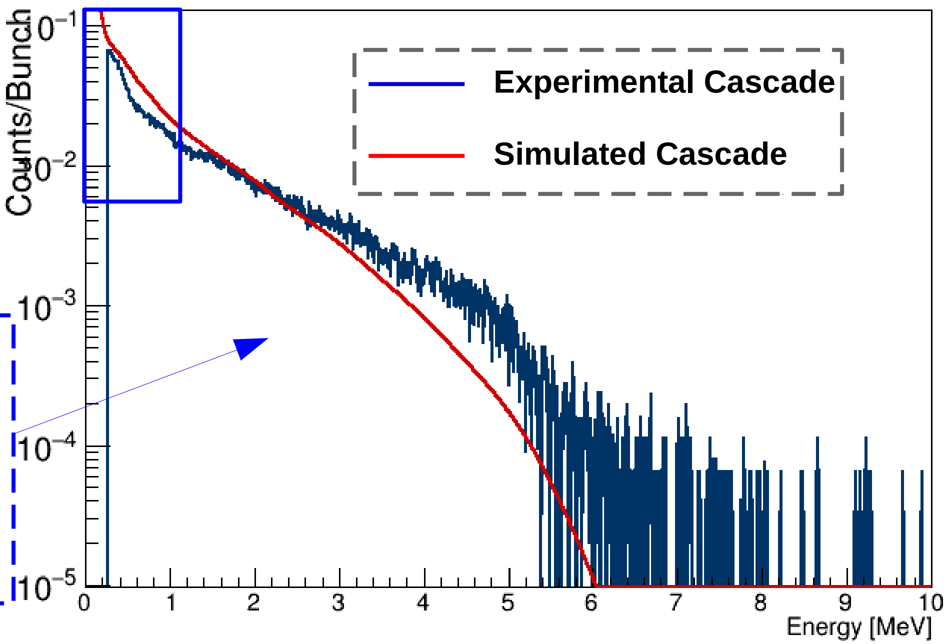
For the simulated ^{177}Yb cascades, the first step has been to carry out the simulations with the different libraries and models. In this way, we have a first idea of the shape of the cascades simulated with GEANT4 with the NuDEX parameters.

First of all, many thanks to Emilio Mendoza for helping me and providing NuDEX for the simulation of the cascades. Thanks also to Victor Alcayne for help with NuDEX.



LD "Back-Shifted-Fermi-Gas"
Photon Strength Function "IAEA PSF models and database"[8]

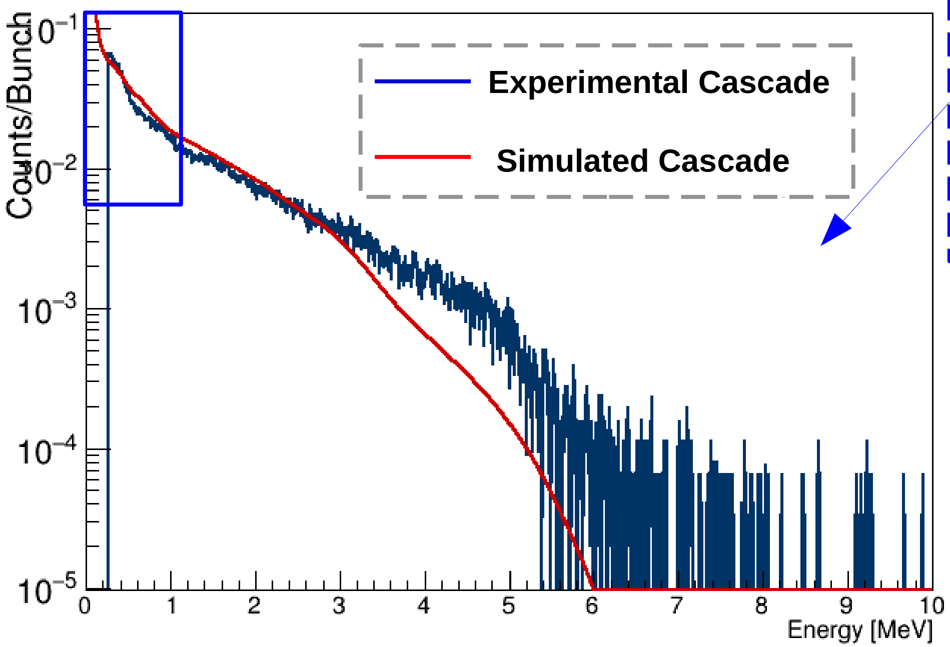
LD "Gilbert-Cameron model"
Photon Strength Function "IAEA PSF models and database"[8]



In view of the first results it has been considered to take for the model of the LD "Back-Shifted-Fermi-Gas" and for the PSF "RIPL-3 PSF models and database".

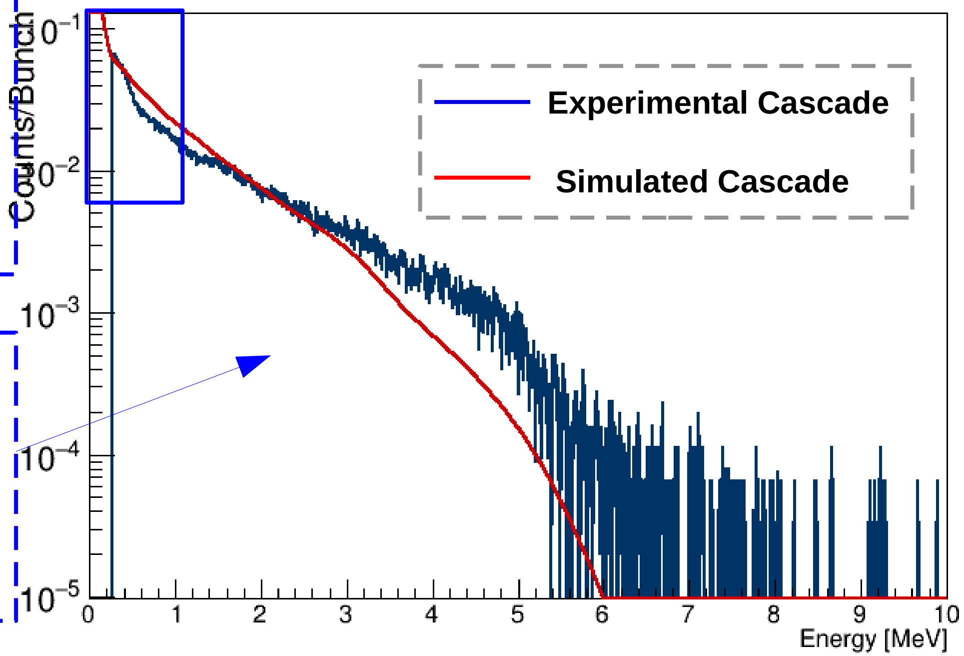
^{176}Yb(n,g) Cascades simulations

For the simulated ^{177}Yb cascades, the first step has been to carry out the simulations with the different libraries and models. In this way, we have a first idea of the shape of the cascades simulated with GEANT4 with the NuDEX parameters.



LD "Back-Shifted-Fermi-Gas" Photon Strength Function "RIPL-3 PSF models and database"[9]

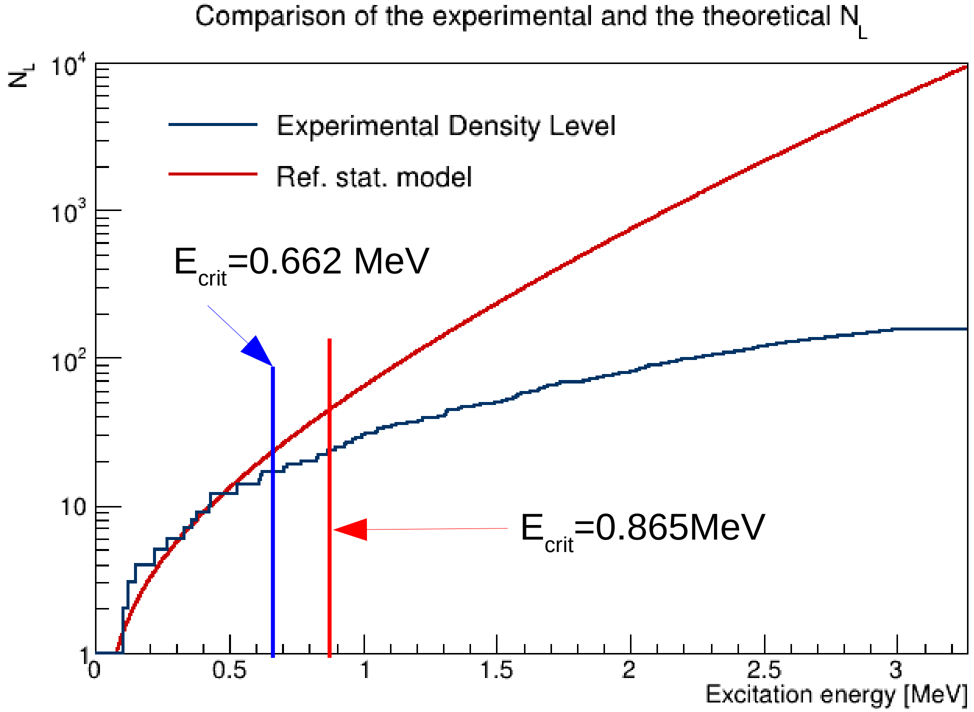
LD "Gilbert-Cameron model" Photon Strength Function "RIPL-3 PSF models and database"[9]

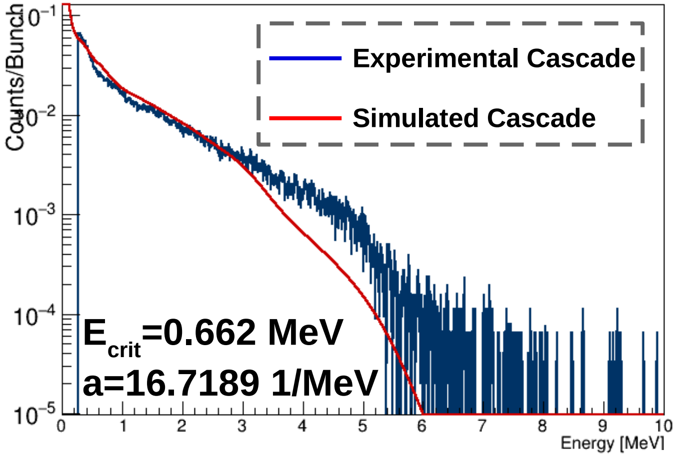


In view of the first results it has been considered to take for the model of the LD "Back-Shifted-Fermi-Gas" and for the PSF "RIPL-3 PSF models and database".

^{176}Yb(n,g)Cascades simulations

Therefore, the next step is to find the best agreement between the number of experimental levels and the levels we consider in the model.



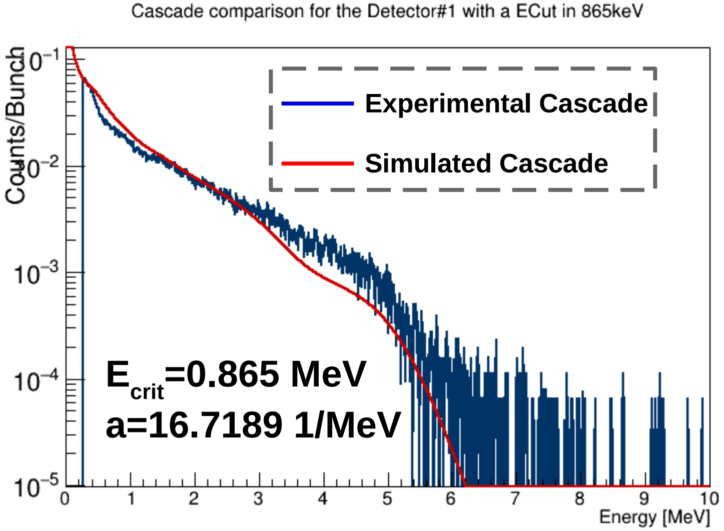


Tabulated parameters[9]	
E_{crit} [MeV]	0.662
a [MeV^{-1}]	16.7189
E_1 [MeV]	-0.47346
A	177

For the Back-Shifted-Fermi-Gas, the corresponding equation is[10, 11]:

$$\rho_{tot}(E)=\frac{\exp\left(2\sqrt{a(E-E_1)}\right)}{12\sqrt{2}\,\sigma_c\,a^{1/4}(E-E_1)^{5/4}}$$

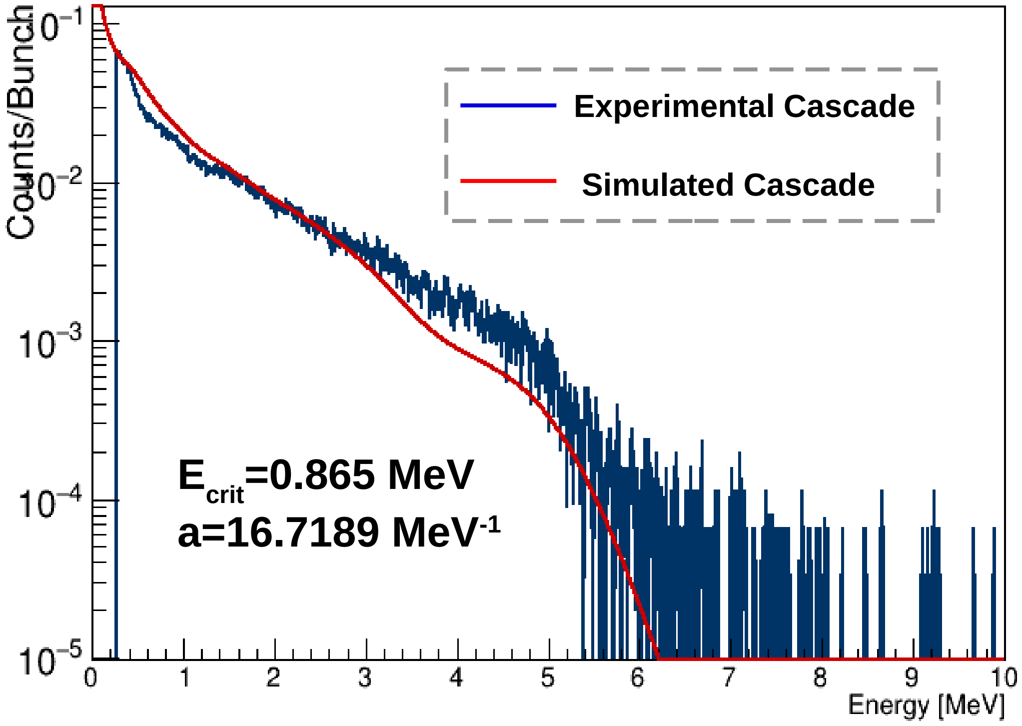
$$\sigma_c=0.0146\,A^{5/3}\frac{1+\sqrt{1+4a(E-E_1)}}{2a}$$

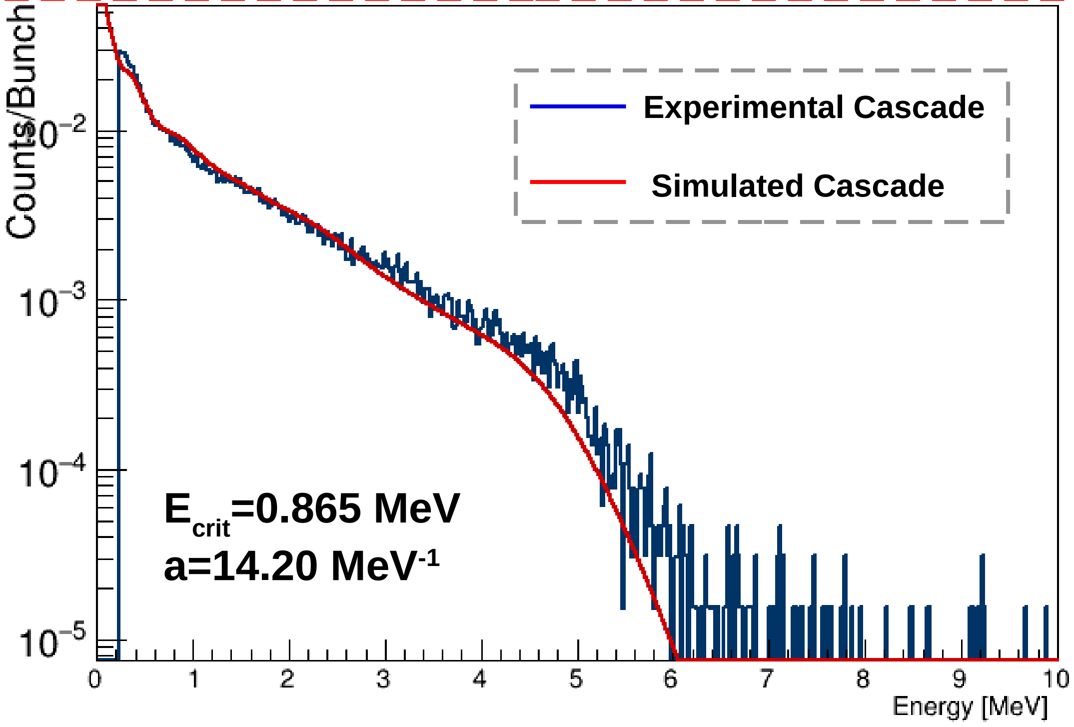


^{176}Yb(n,g) Cascades simulations

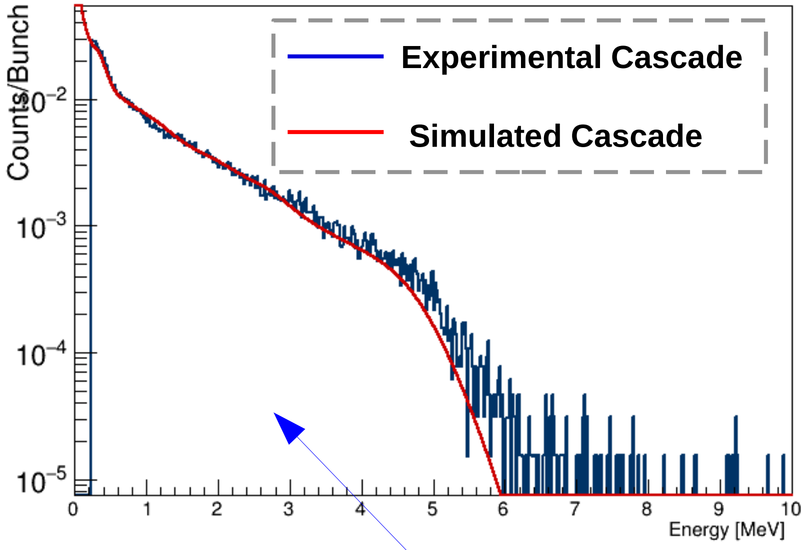
From the above results, we can preliminarily conclude that the model is overestimating the number of experimental levels.

It should be noted that up to now, all the fits have been made for the resonance with the highest cross section of the ^{176}Yb(n,γ) reaction, E_{res}=148.5 eV, and for the detector #1

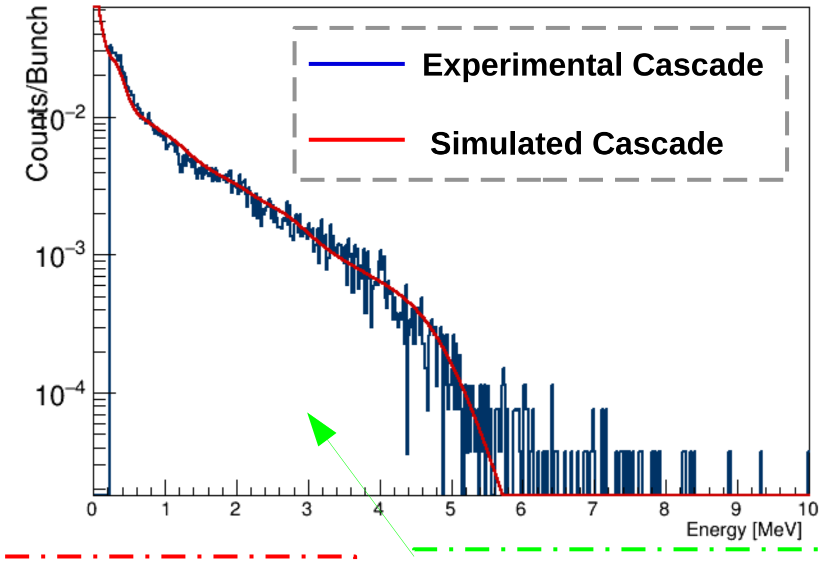




^{176}Yb(n,g) Cascades simulations

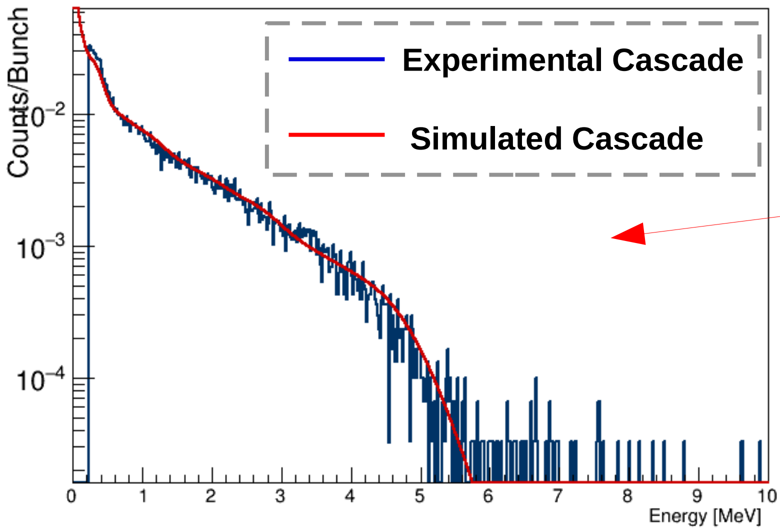


The last parameter that has been modified is the incident energy of the neutron. The purpose is to understand how it affects the shape of the cascade.



E_{crit} = 865 keV
a = 14.2 MeV^{-1}
E_n= 0.9499 keV

Each cascade has been simulated with the same incident neutron energy E_n=0.9499 keV.



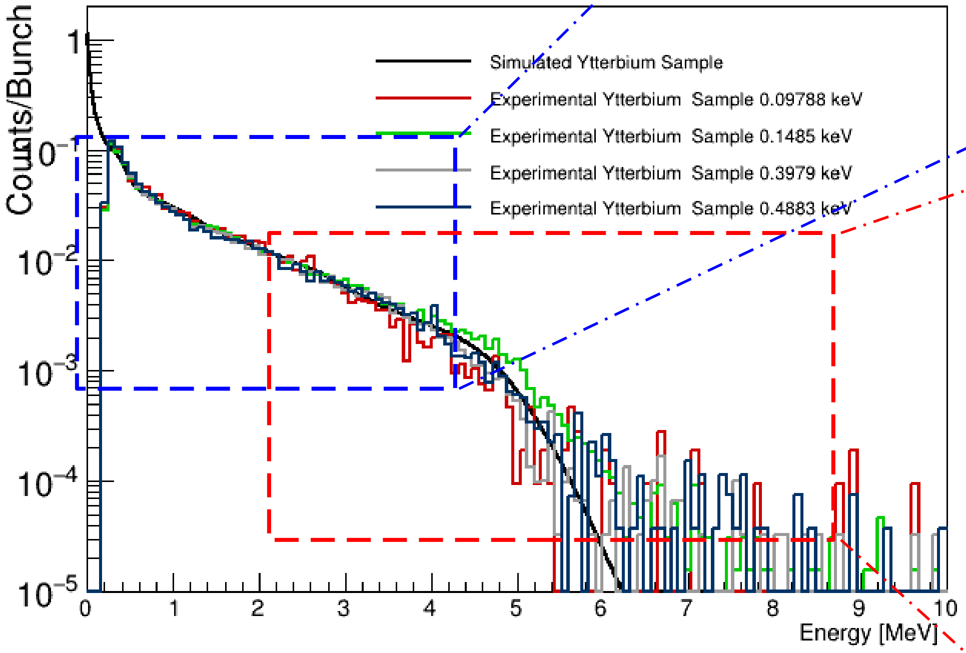
E_{crit} = 865 keV
a = 14.2 MeV^{-1}
E_n= 0.9499 keV

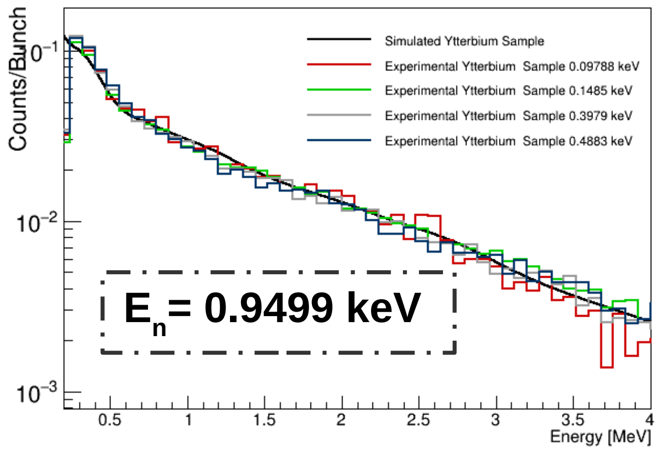
E_{crit} = 865 keV
a = 14.2 MeV^{-1}
E_n= 0.9499 keV

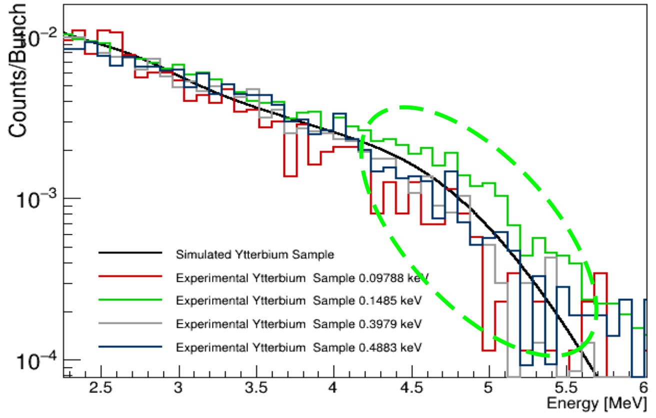
A good agreement is found. The first seven resonances have been simulated, finding a good agreement between all of them.

^{176}Yb(n,g) Cascades simulations

All the results obtained are very preliminary, but a good agreement has been found between the simulations and the experimental values.







At low energies a good agreement is found between the simulations and the experimental results. Agreement between simulations and experimental data holds up to 4.5 MeV.

Tabulated[9] vs experimental parameters		
E_{crit} [MeV]	0.662	0.865
a [MeV^{-1}]	16.7189	14.2
E_1 [MeV]	-0.47346	-0.47346

Why these differences in the resonances?

At high energies certain discrepancies are observed in the experimental data. One of the resonances presents a different cascade. This happens on all detectors

Conclusions

A preliminary yield of the results has been obtained. For the first time resonances have been resolved.

To apply the corrections to the results obtained, the measured gold sample has been analyzed. The results have shown some discrepancies in the energy deposited between the different detectors. The calibrations of all the detectors have been redone.

By means of double linear and second degree fit, a good agreement has been found in the gold cascade for all the detectors..

The next step has been to start the simulations of the Ytterbium cascades. The preliminary results show a good agreement between simulations and experimental data. Some issues remain to be resolved, such as the experimental differences in the cascades.

Therefore, the next step will be to finish the simulations of the cascades and apply the different corrections mentioned above. Once this part of the analysis is finished, the background analysis will begin.

Thank you for your attention!!!
Questions or comments

References

[1] *P. F. Mastinu et al.; New C6D6 detectors: reduced neutron sensitivity and improved safety, (The n_TOF Collaboration), CERN-n TOF-PUB-2013-002 (2013).*

[2] *C. Domingo-Pardo et al., Resonance capture cross section of ^{207}Pb, PHYSICAL REVIEW C 74, 055802 (2006).* *https://journals.aps.org/prc/pdf/10.1103/PhysRevC.74.055802*

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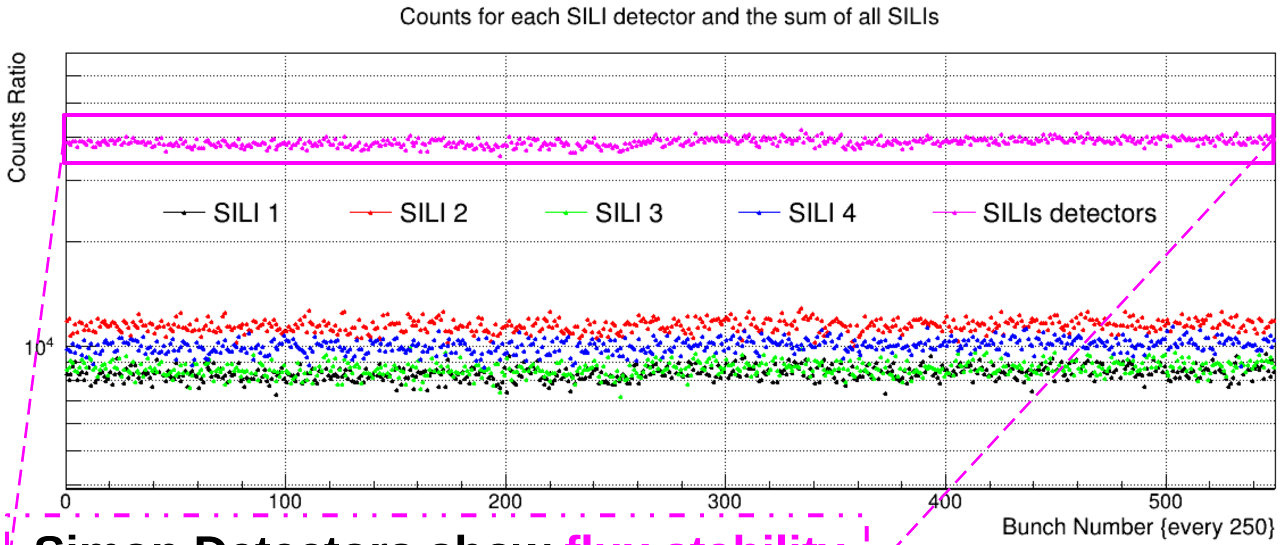
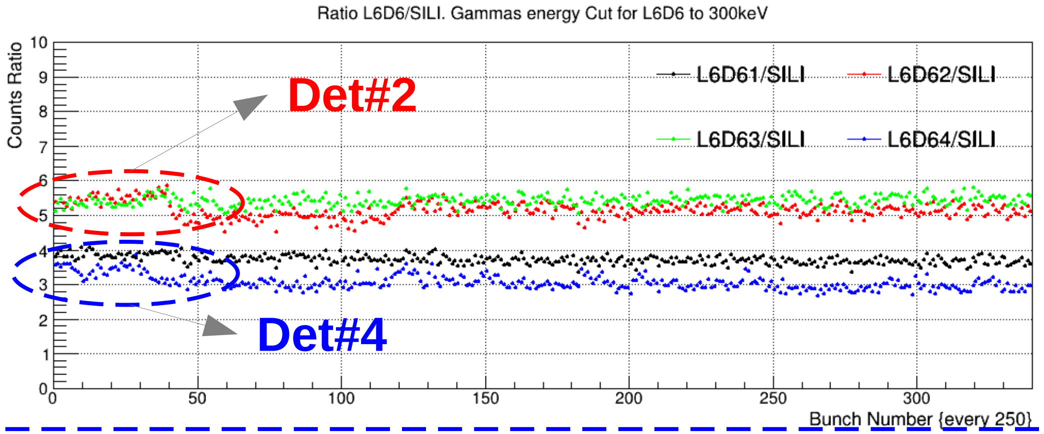
https://dspace.cuni.cz/bitstream/handle/20.500.11956/177739/140104891.pdf?sequence=1&isAllowed=y

Backup Slides

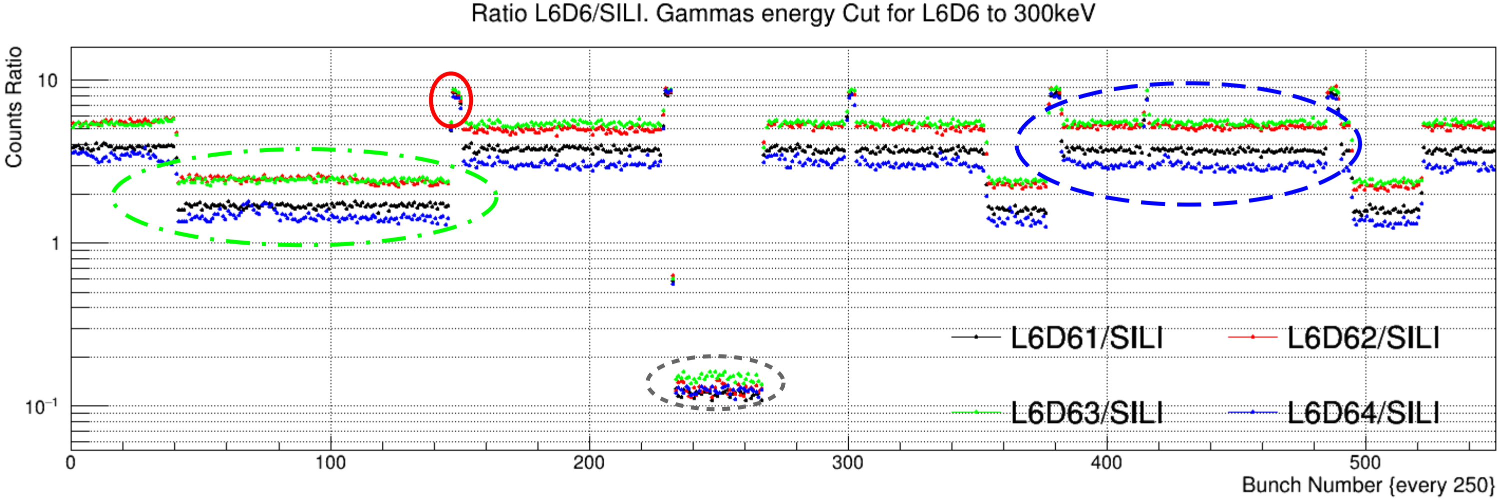
Stability of the detector





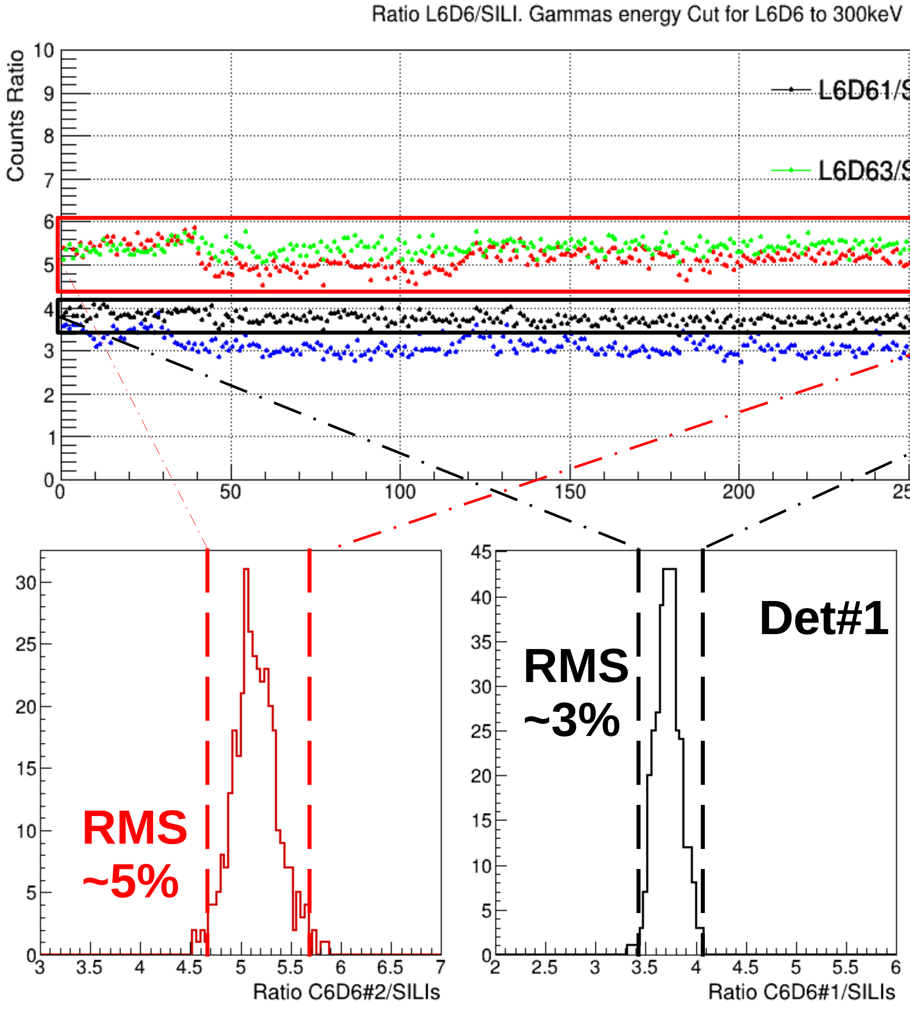
Gain changes are observed **during ytterbium measurement** that are not due to flux changes

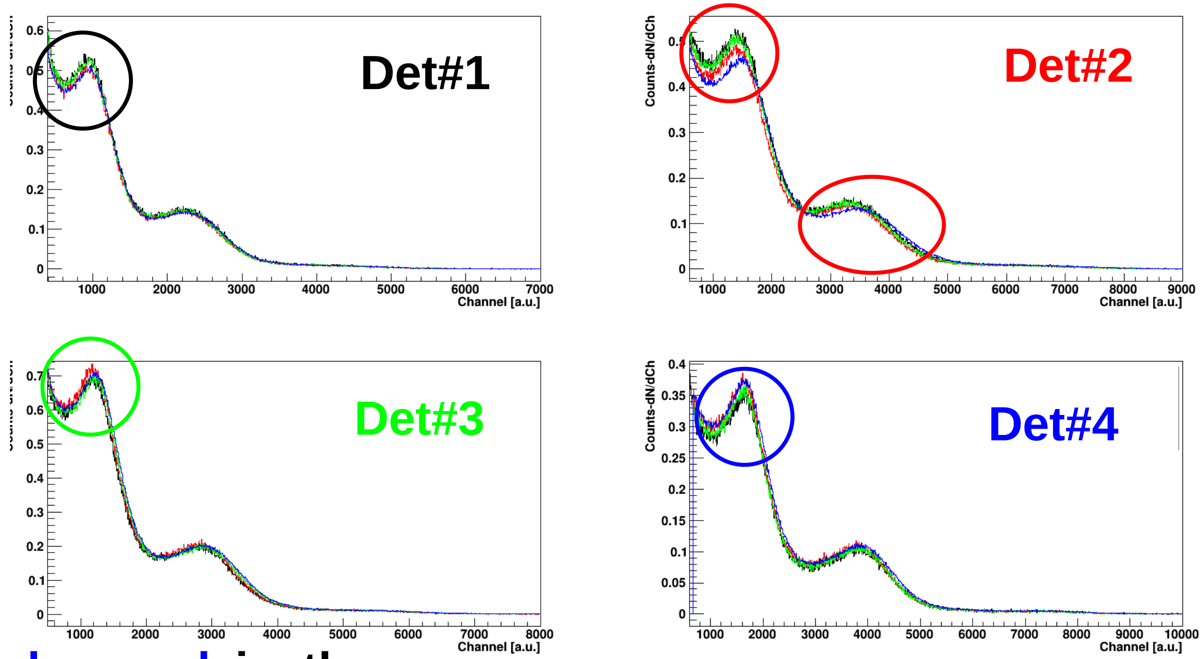
Simon Detectors show flux stability throughout the whole experiment



- Ytterbium Sample 19x2mm
- Quartz (Dummy) 22x4.5mm
- BackGround (BeamOn)
- Gold Sample 19x0.05mm

Threshold correction





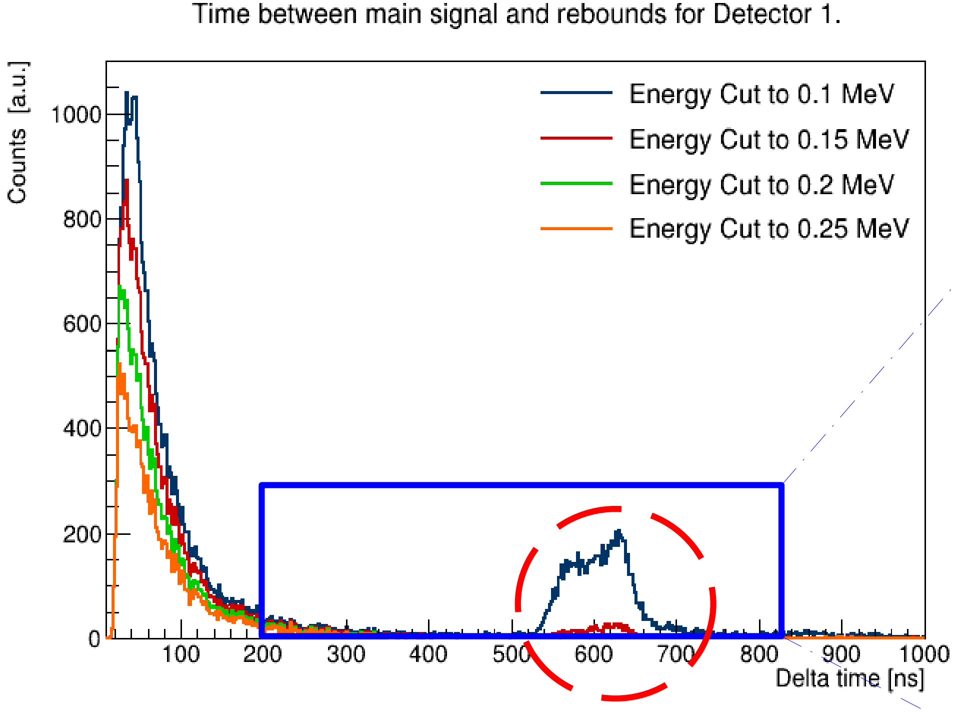
Gain shift are observed in the projections, as well as in the calibrations made during the measure. To solve the problem, all calibrations will be used, instead of taking one as a reference.

- **First Calibration 25/10/21**
- **Second Calibration 01/11/21**
- **Third Calibration 10/11/21**
- **Forth Calibration 15/11/21**

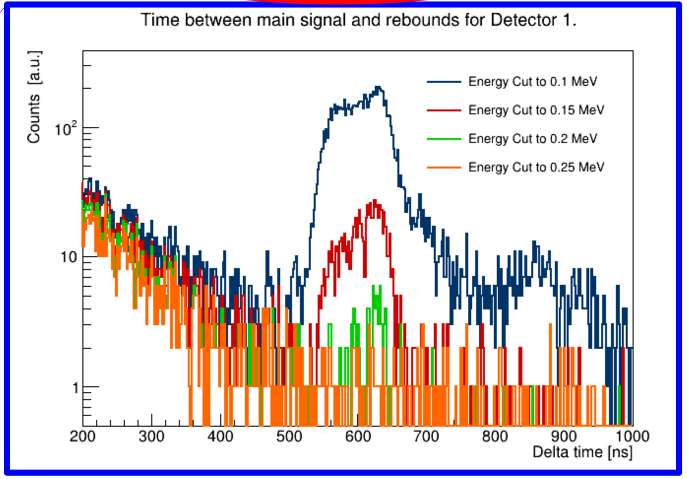
Threshold correction

To apply a **threshold** **to the detectors, the** **rebounds of the signals** **for the detectors have been studied.**

First, the time between two consecutive signals has been calculated.

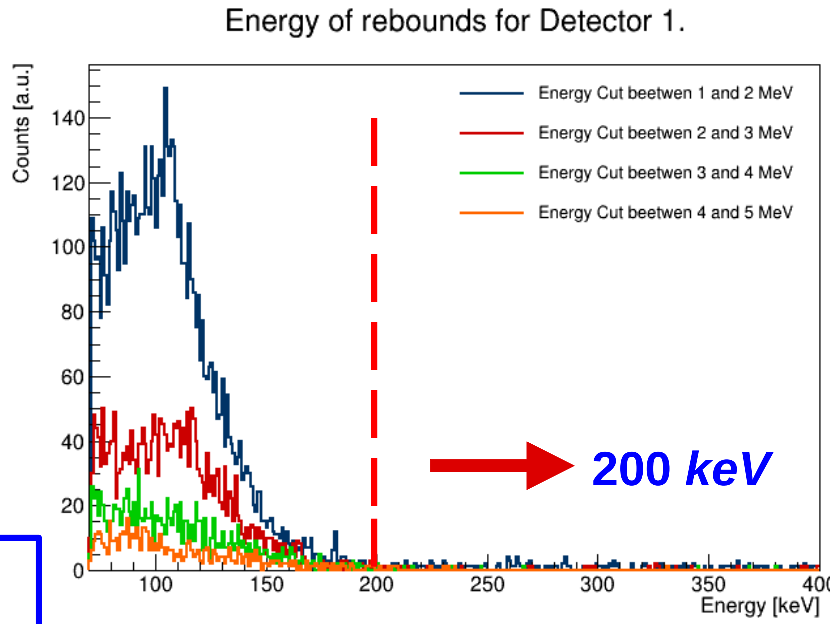


Rebounds!!



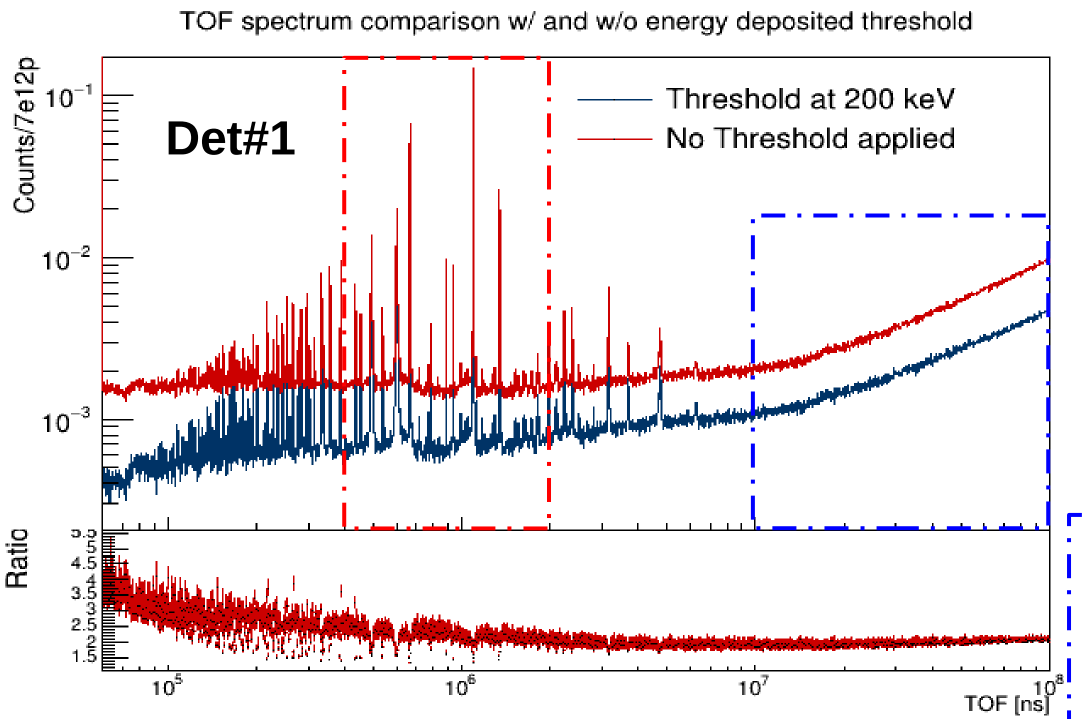
In view of the results, the energy deposited by the rebound structure found has been calculated, depending on the amplitude of the main signal.

No rebound signals above ~200 keV for detector 1

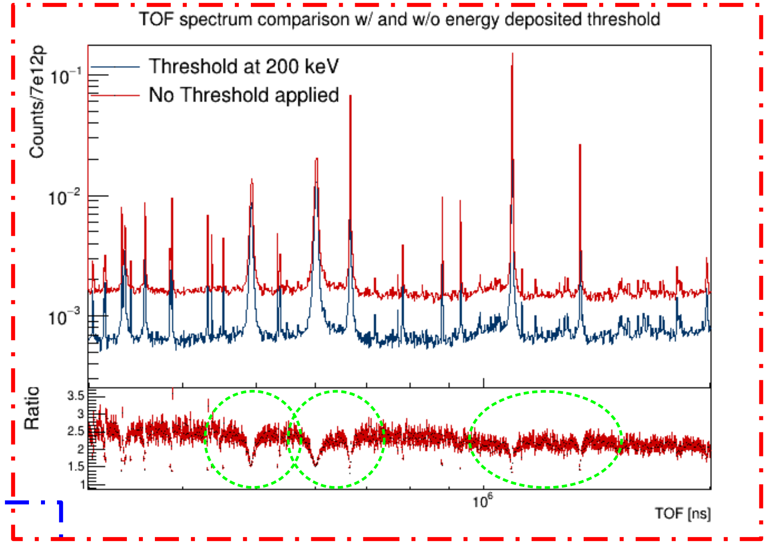


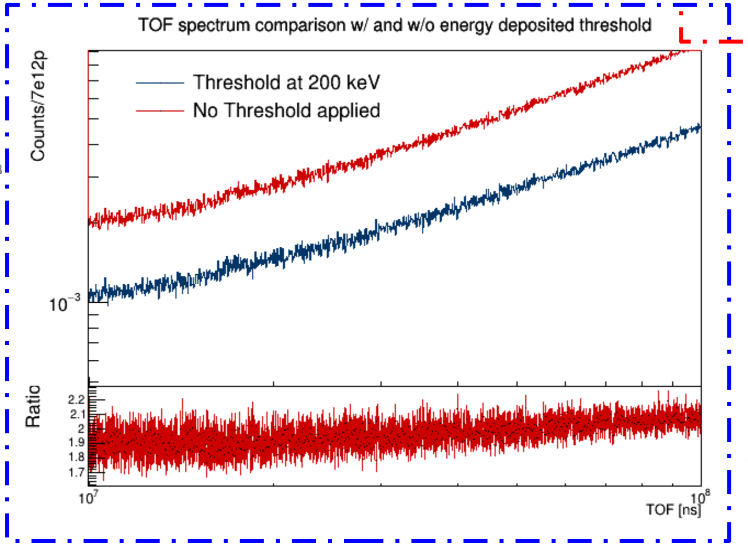
Detector	Threshold [keV]
1	200
2	220
3	280
4	300

Threshold correction



The conclusions obtained for det#1 are equivalent for the four detectors.
(See extra slide)





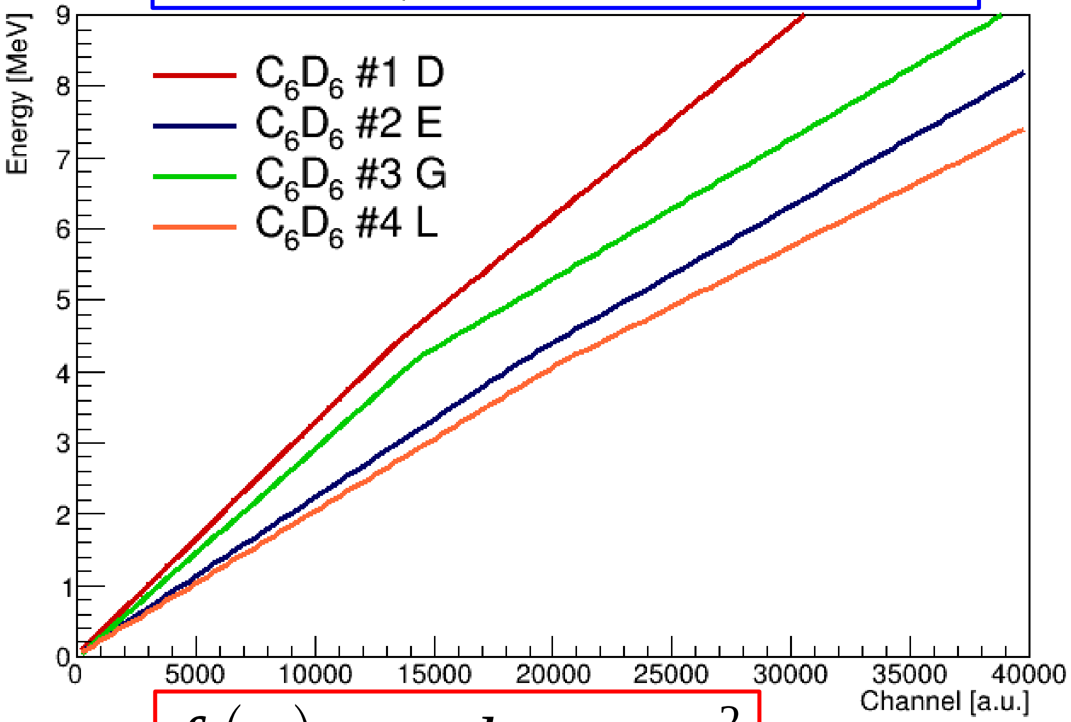
These cuts are necessary to remove the signals that do not come from the sample and are produced by the detector. But they must be corrected, estimating the number of gammas that are being lost due to the cuts introduced.

In the resonances it is observed that the ratio is lower, since the energy deposited is dominated by the ^{176}Yb cascade. An increase in the ratio is observed in the valley of the resonances as well as at low energies.

Detector Calibration

Final parameters obtained with ROOT Double Linear Fit		
Parameters	Detector #1	Detector #2
b	0.0296	0.0331
a	0.000326	0.000220
d	0.000272	0.000214
e	0.7899	0.1548
c	14084.7	20258.1

$$f(x)=\begin{cases} a\cdot x+b & if \quad x\leq c \\ d\cdot x+e & if \quad x>c \end{cases}$$



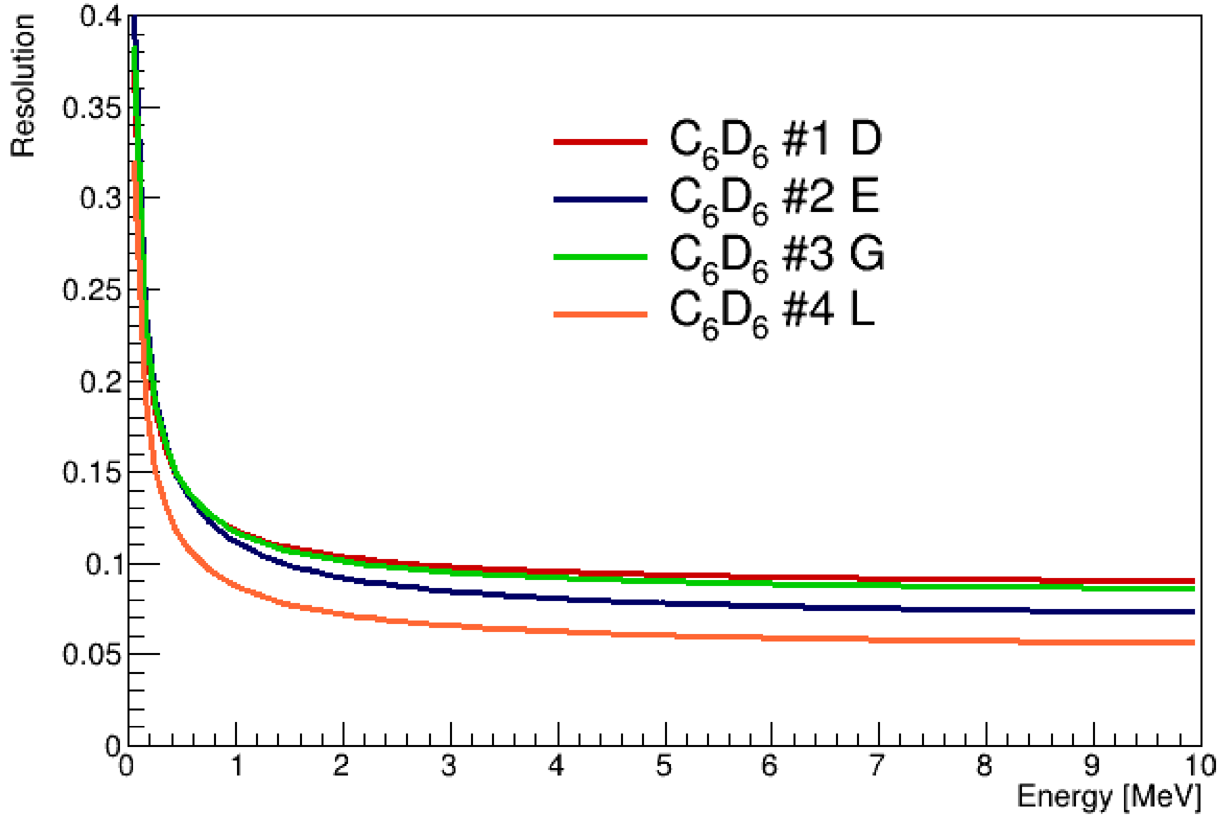
$$f(x)=a+b\cdot x+c\cdot x^2$$

Final parameters obtained with ROOT Second Degree Fit		
Parameters	Detector #3	Detector #4
a	-0.10835	-0.02857
b	0.000352	0.000225
c	-3.848e-9	-1.044e9

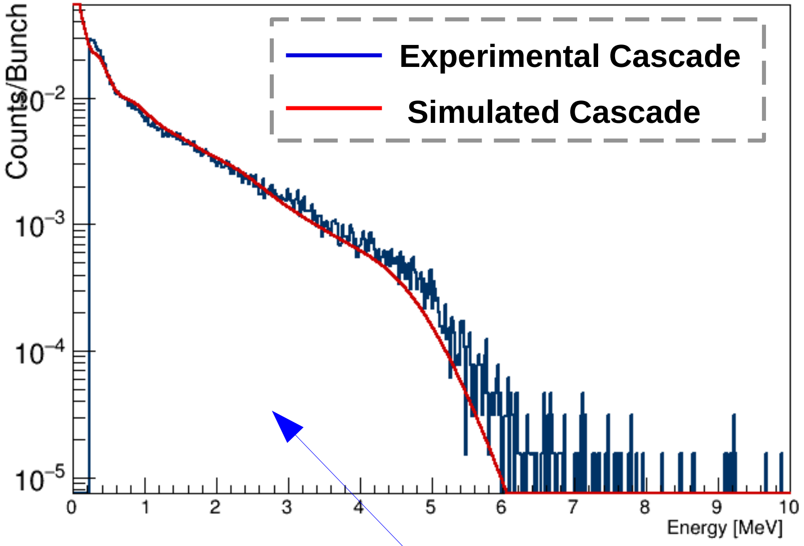
Detector Calibration

Final parameters obtained with ROOT Resolution Parameters		
Parameters	Detector #1	Detector #2
a	0.00744	0.00447
b	0.00644	0.00784
Parameters	Detector #3	Detector #4
a	0.00665	0.00266
b	0.00704	0.00501

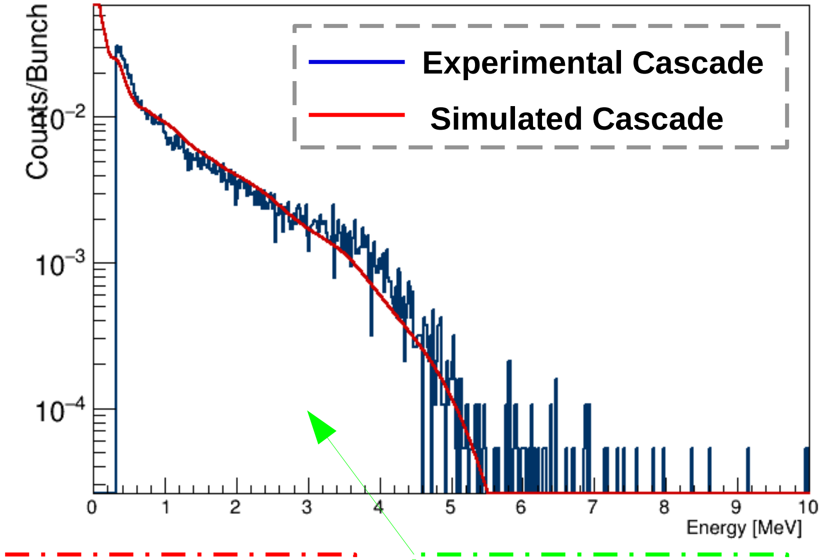
$$\sigma=\sqrt{a\cdot E+b\cdot E^2}$$



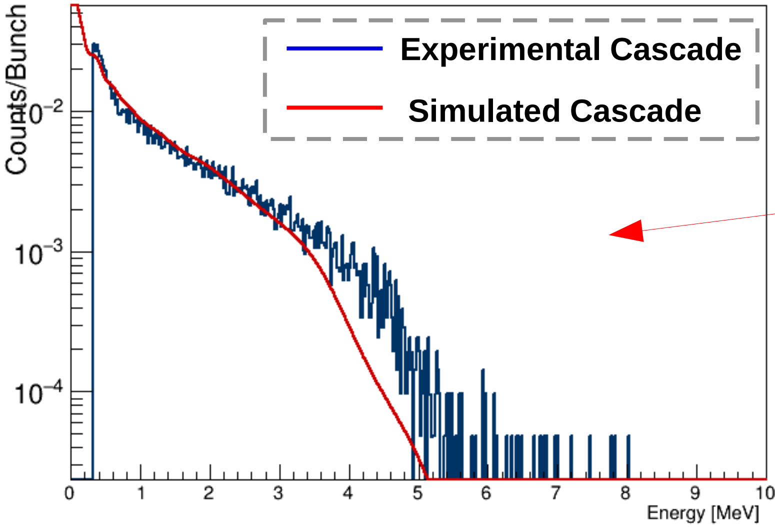
Cascades simulations



The last parameter that has been modified is the incident energy of the neutron. The purpose is to understand how it affects the shape of the cascade.



E_{crit} = 865 keV
a = 14.2 1/MeV
E_n= 0.1485 keV



E_{crit} = 865 keV
a = 14.2 1/MeV
E_n= 0.3979 keV

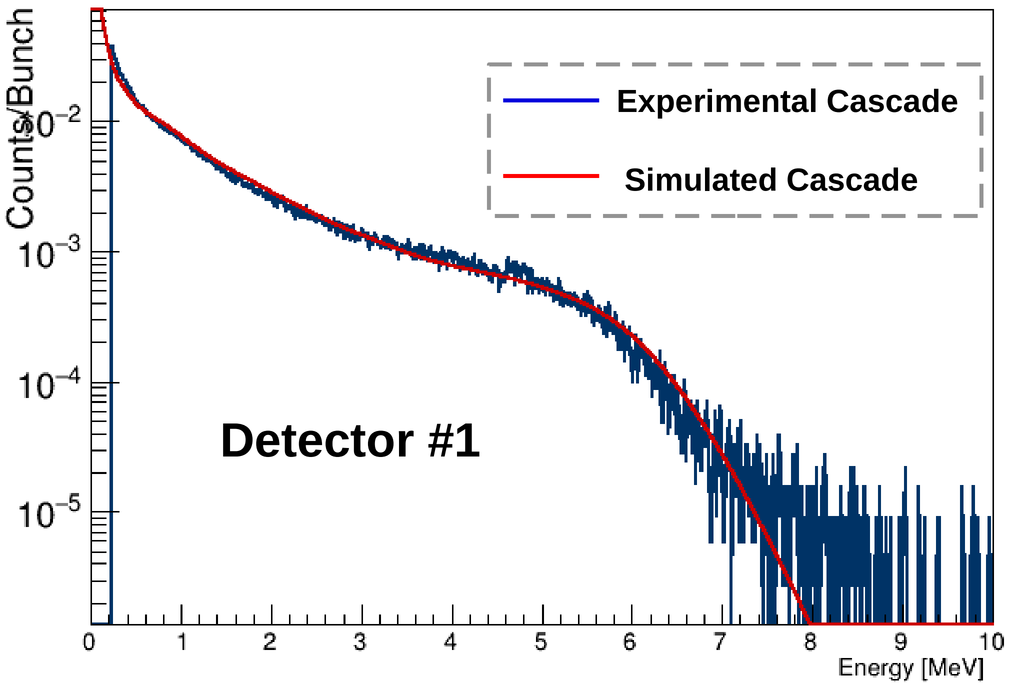
E_{crit} = 865 keV
a = 14.2 1/MeV
E_n= 0.4883 keV

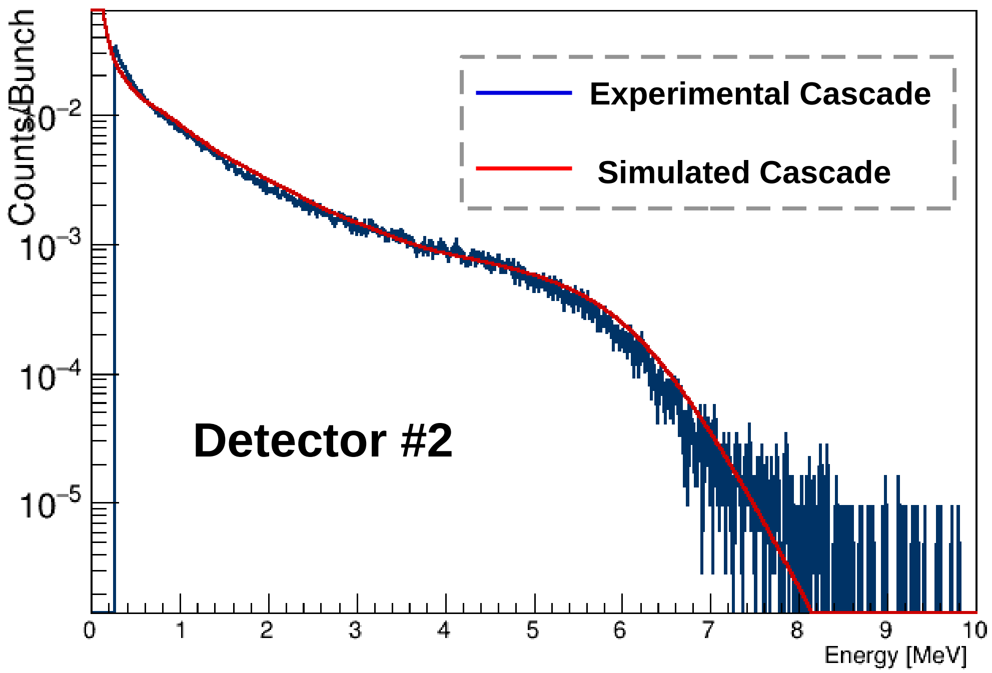
Each cascade has been simulated with a incident neutron energy corresponding to the resonance.

A good agreement is found except for an energy of E=0.3979keV. The first seven resonances have been simulated, finding a good agreement between all of them.

Cascades simulations

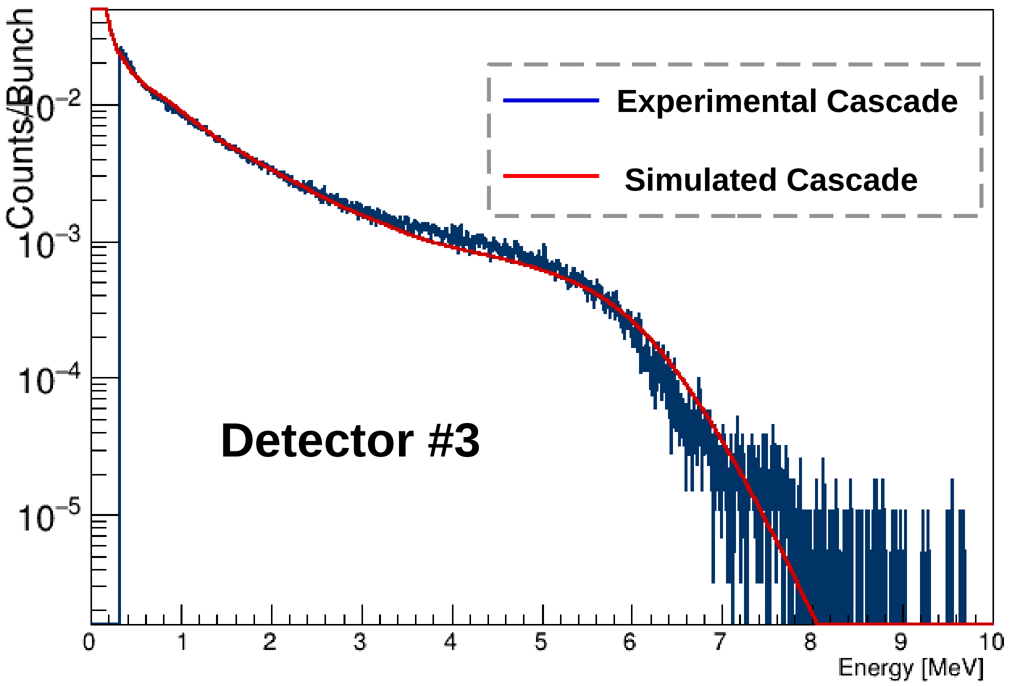
Comparison between the simulations and the experimental results in the saturated resonance of gold.

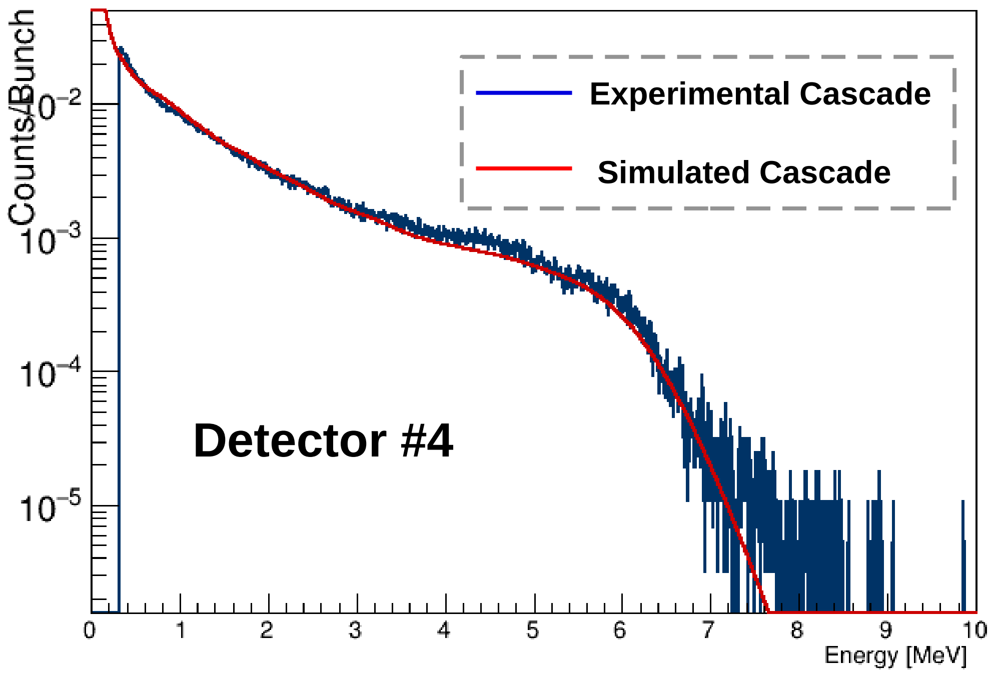




Cascades simulations

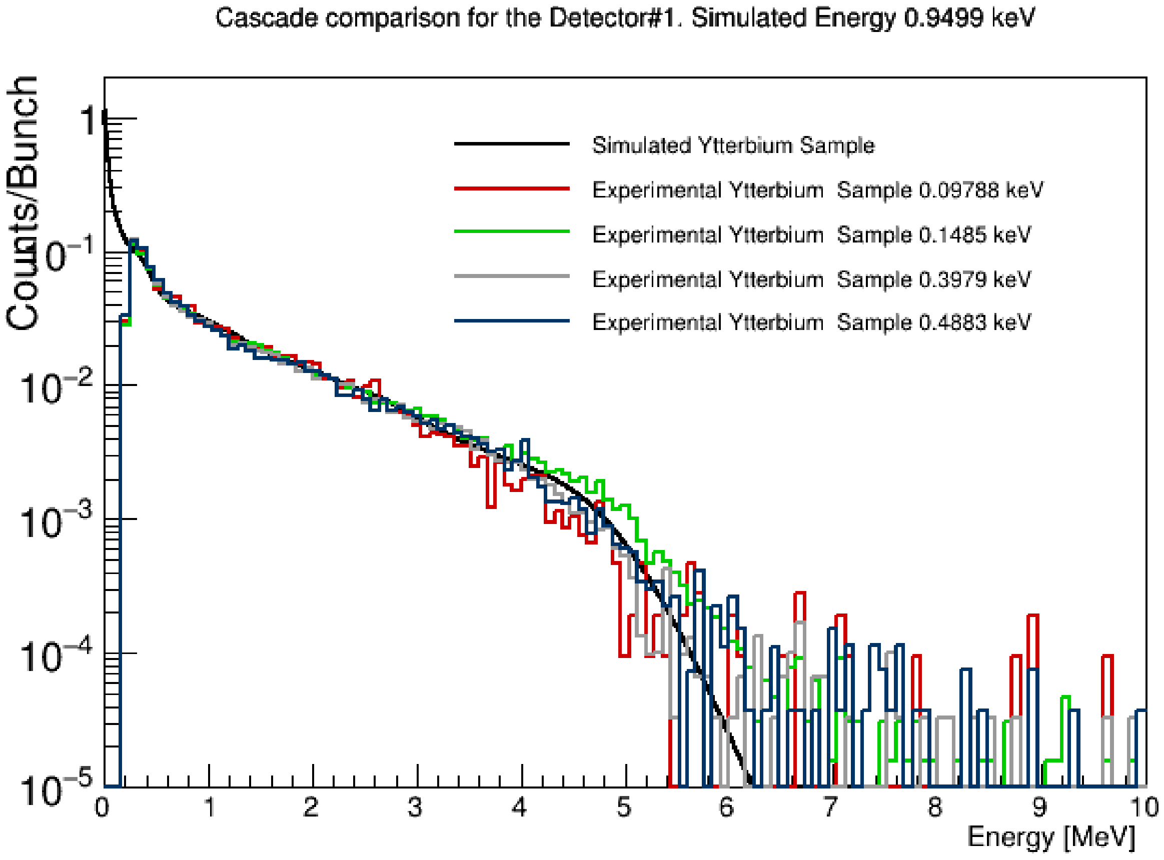
Comparison between the simulations and the experimental results in the saturated resonance of gold.

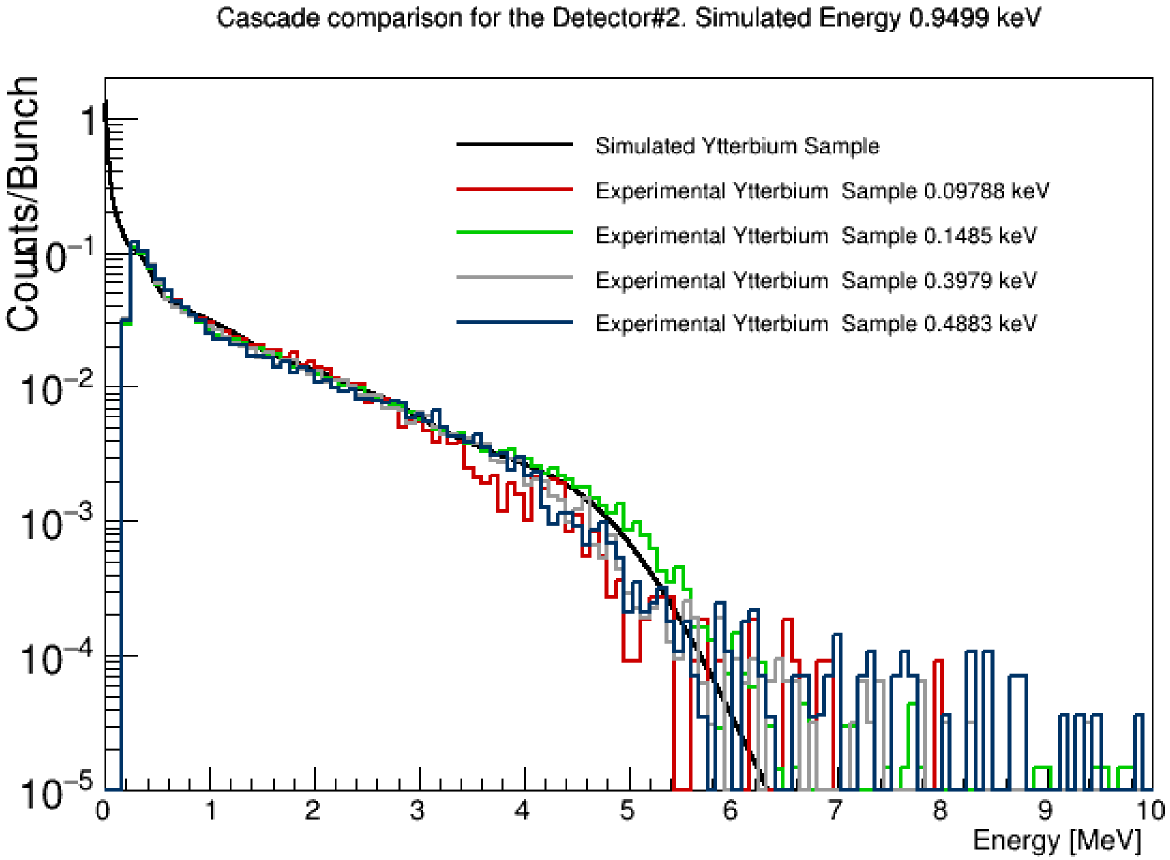




Cascades simulations

Comparison between simulations and experimental results for the cascades of the first four resonances of the 176Yb(n,γ) reaction.





Cascades simulations

Comparison between simulations and experimental results for the cascades of the first four resonances of the 176Yb(n,γ) reaction.