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FLNP FRANK LABORATORY OF NEUTRON PHYSICS

Measurement of gamma decay properties of compound states of ^{176}Lu and ^{177}Lu

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Outline

- Literature Review
- Experiments
- Raw data analysis
- Preliminary results
- Future plans

Literature Review

- In the papers [Wasson O.A. et al.,1970] and [Becvar F. et al., 1987] for the reaction ^{175}Lu(n,γ)^{176}Lu it had been measured the intensities of E1 and M1 gamma-transitions from the limited sets of the neutron resonances to many low lying exited states of ^{176}Lu nucleus belonging different rotational or vibrational bands.
- The results were obtained for only four and seven neutron resonances with $J^{\pi} = 4^{+}$ and $J^{\pi} = 3^{+}$ respectively as well as for the set of final states $J^{\pi} K = 2^{\pm}0$ to $5^{-}5$.
- In the work [Becvar F. et al., 1987], the effect of K mixing was investigated for very limited number of compound states 176Lu nucleus.
- The aim of initial proposal and two experiment runs at the CSNS Back-n neutron beam were to increase the number of studied neutron resonances ^{176}Lu and ^{177}Lu compound nuclei and to obtain more informative set of partial radiation gamma widths.
- So our performed new measurements of $^{175\text{-}176}$Lu(n,γ)$^{176\text{-}177}$Lu reaction was aimed at improving essentially the results of above mentioned experiments.

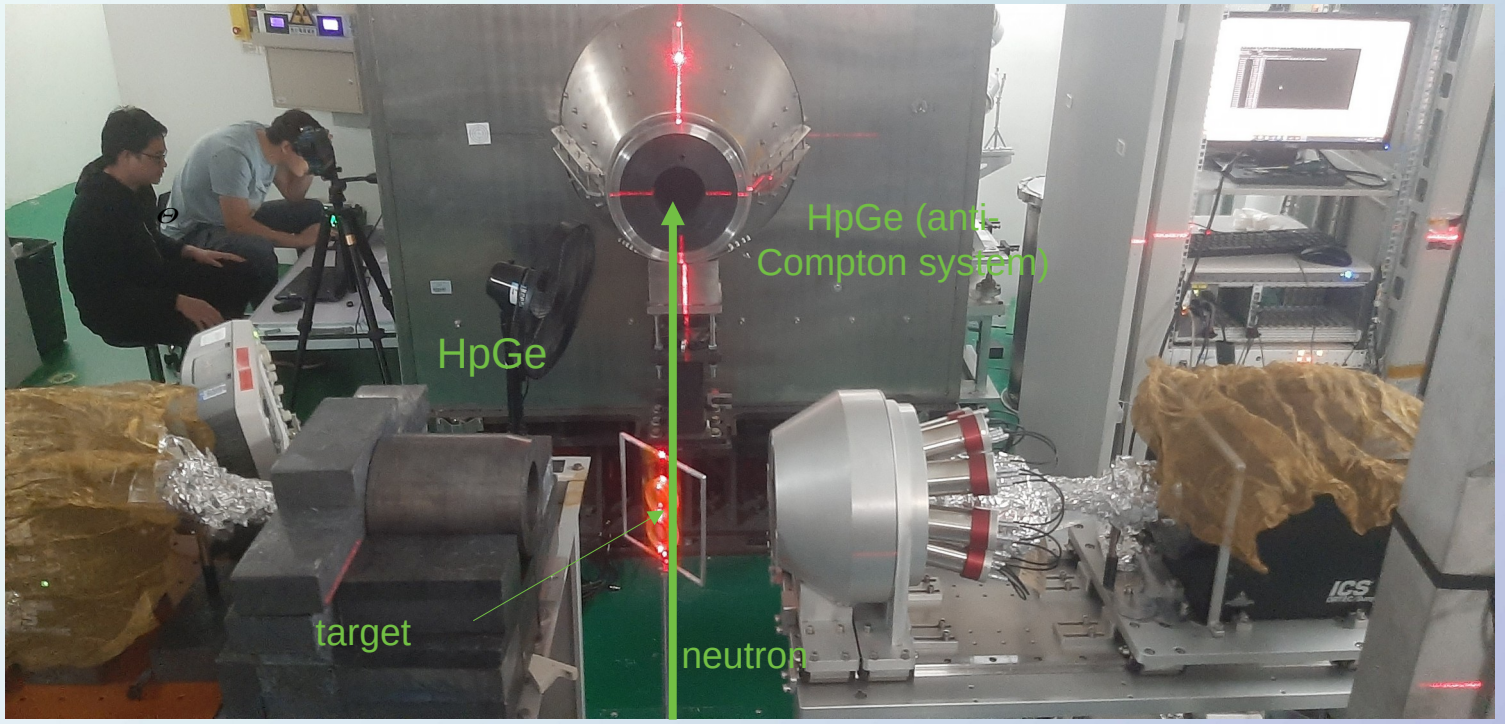
Wasson O.A. and Chrien R.E., Phys. Rev., 1970, v. C2, p. 675
F. Becvar, Ya. Gonzatko, M.E. Monte-Cabrero, S.A. Telezhnikov and Huynh Thuong Hiep, Study of photon strength functions of ^{174}Yb and ^{176,177}Lu by means of (n,γ) reaction in isolated resonances, Journal of Nuclear Physics, 1987, v. 46, p. 392 – 399
M.S. BASUNIA, Nuclear Data Sheets for A=176 // Nuclear Data Sheets 107 (2006) 791–1026*
F.G. KONDEV, Nuclear Data Sheets for A=177 // Nuclear Data Sheets 159, 1 (2019)*

Experiments

The experiments took place in the CSNS experimental hall, where the flight path from the spallation target to the measurement position (ES#2) is 76 meters. The experiments were performed twice, accumulating approximately 400 hours of data, including time for setup and optimization.

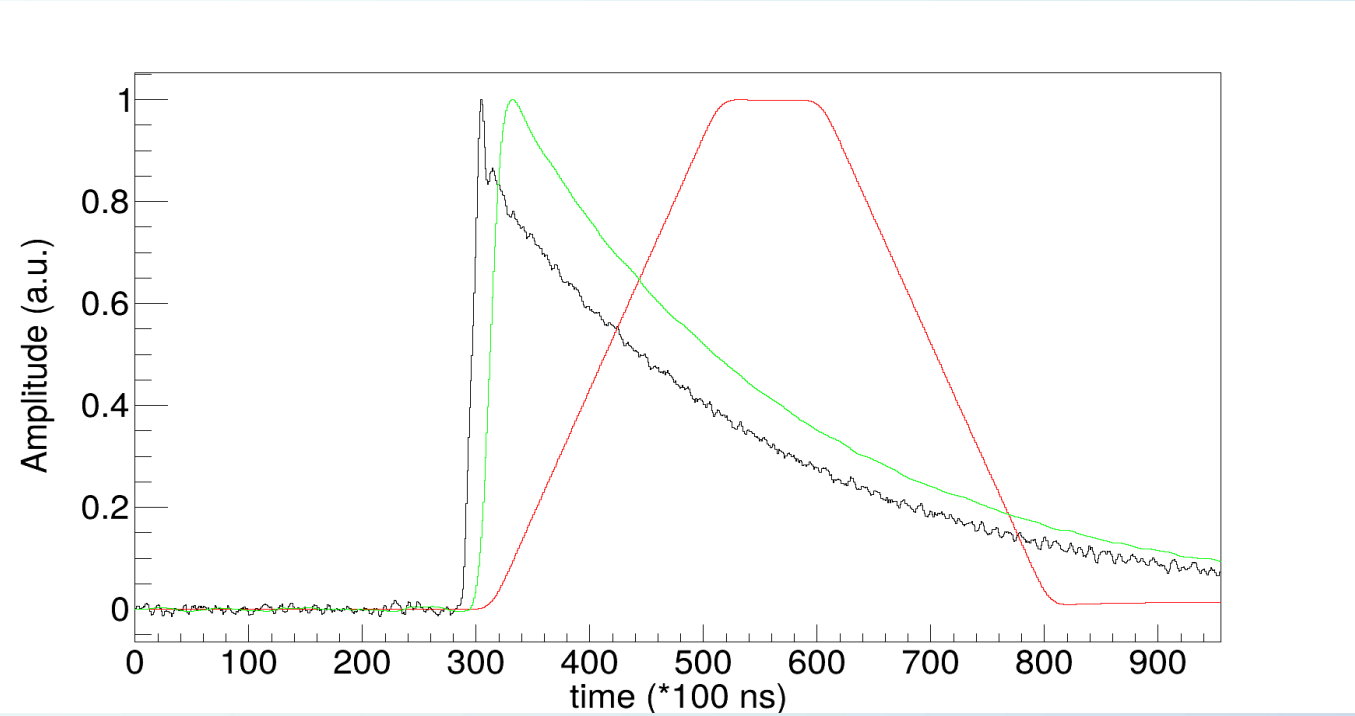
1. First experiment was done with two HpGe gamma detectors. One of them was with anti-Compton system and other one without. Distance between target and one of them is 20 cm. The experiment was performed with 7.4 g metallic ^{nat}Lu for about 200 hours. It was used a spectrometric amplifier with 3 us shaping time after preamplifier of HpGe detector.

2. Second experiment was performed one HpGe gamma detectors anti-Compton system. Distance between target and one of them is 20 cm. Pure measurement time was approximately 200 hours and 50 hours including time for setup and optimization. Metallic ^{nat}Lu targets with 60 g (60*2.2 mm) with 99.9 % purity was employed. It was used new preamplifier for HpGe detector.



Data analysis

Data proceeding was done offline using C++ based ROOT package. Single signal from a HPGe detector is shaped, analyzed and graphed. The result of this analysis will be the relative energy of the incident gamma ray which produced the signal. The digitized signal was sampled at a rate of 10 MHz. Comparison of waveforms obtained from analysis is shown below.



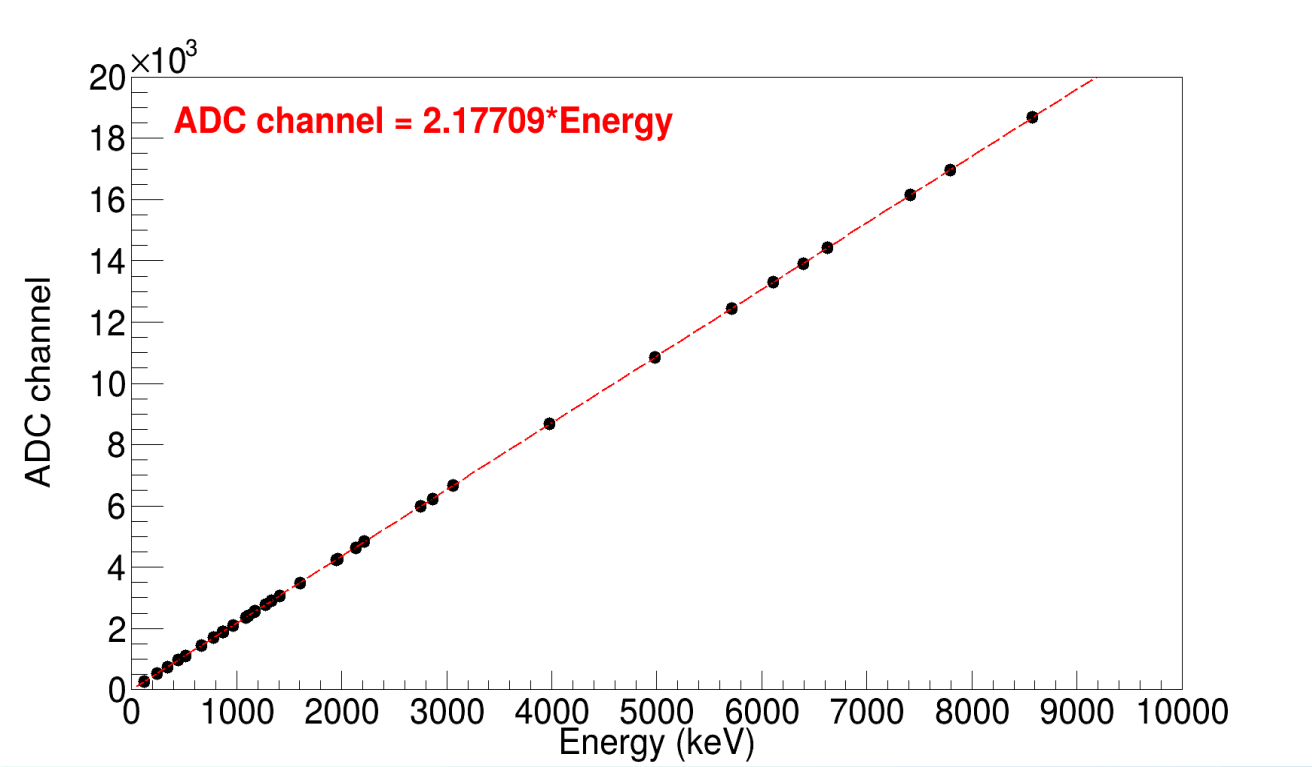
1. Waveform from HpGe detector

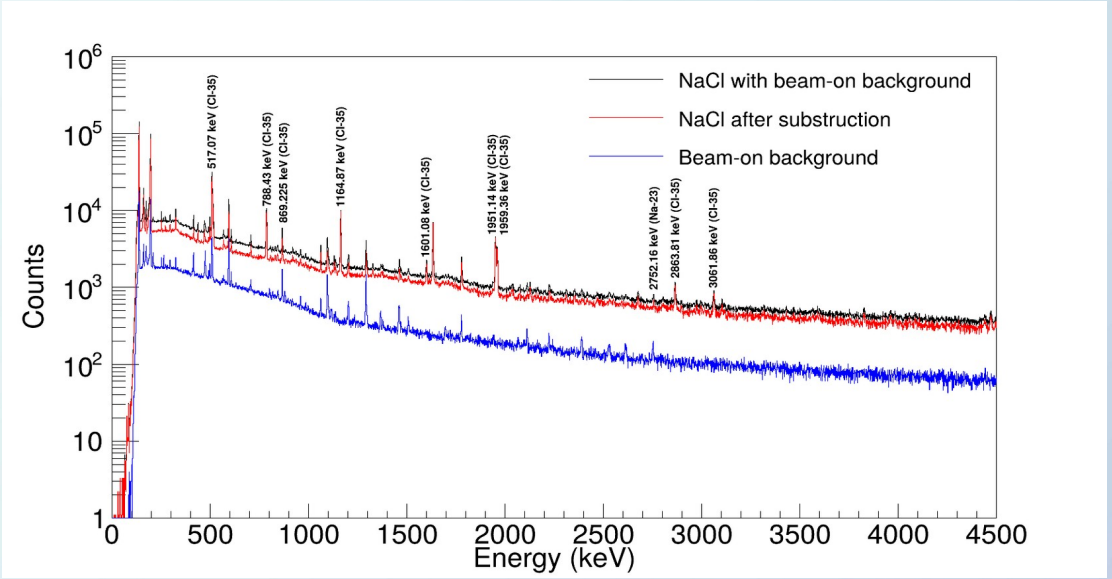
2. Energy resolution in detectors is often about distinguishing small variations in signal amplitude corresponding to different energy levels. The Butterworth filter helps in smoothing out noise without significantly distorting the signal, making it easier to differentiate between these small variations. The 4th-order Butterworth filter gives good energy resolution because it effectively suppresses noise while maintaining a flat frequency response in the passband, offers a smooth transition to the stopband, and introduces minimal phase distortion.

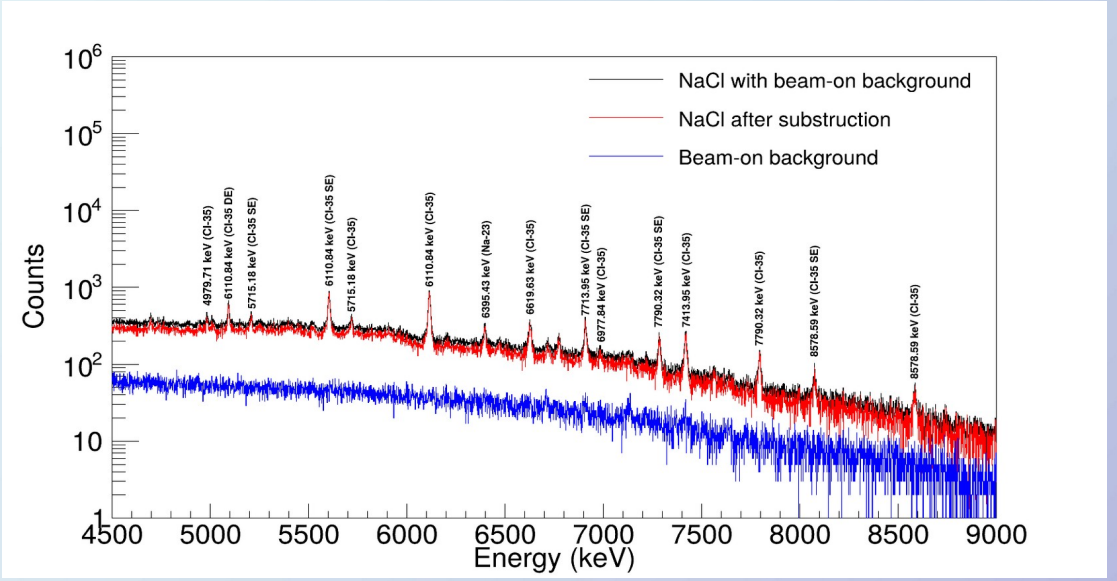
3. Second filter which helps to improve energy resolution is trapezoidal filter. The trapezoidal filter is designed to transform the preamplifier's raw pulse into a trapezoid-shaped pulse. This shape is achieved by combining integration (summing the signal over time) and differentiation (subtracting delayed signals). The trapezoidal filter is characterized by two main time constants: rise time (τ) and flat top time (T).

Energy calibration

In our measurement we interested in energy region up to 8000 keV. Therefore, energy calibration of HpGe detector was done with point calibration sources (Co^{60}, Eu^{152}, Cs^{137} and Na^{22}) and measuring gamma lines from NaCl (n,g) reaction. In the right spectrum was shown a spectrum from NaCl(n, g) reaction. As shown in the right spectrum, dependence of ADC channel on energy is linear up-to to 9000 keV. This results is also used for efficiency calibration.

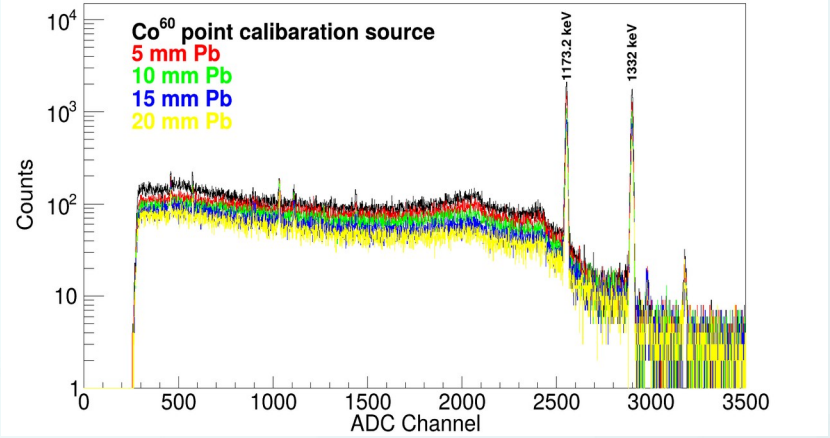


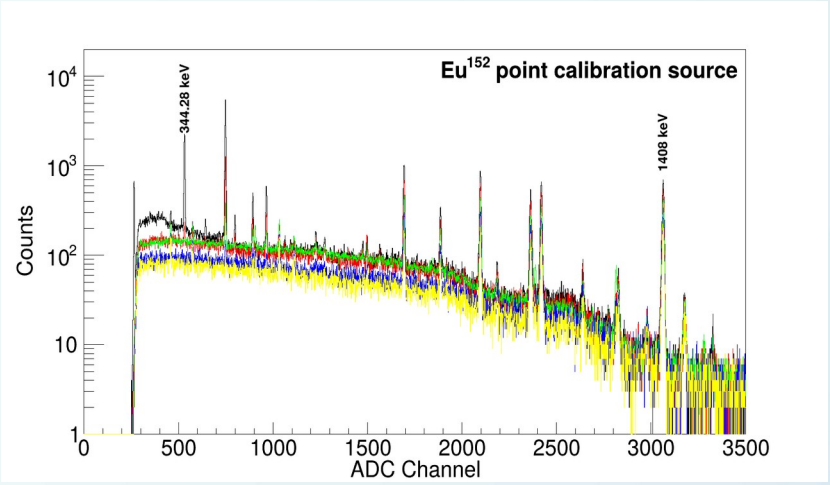


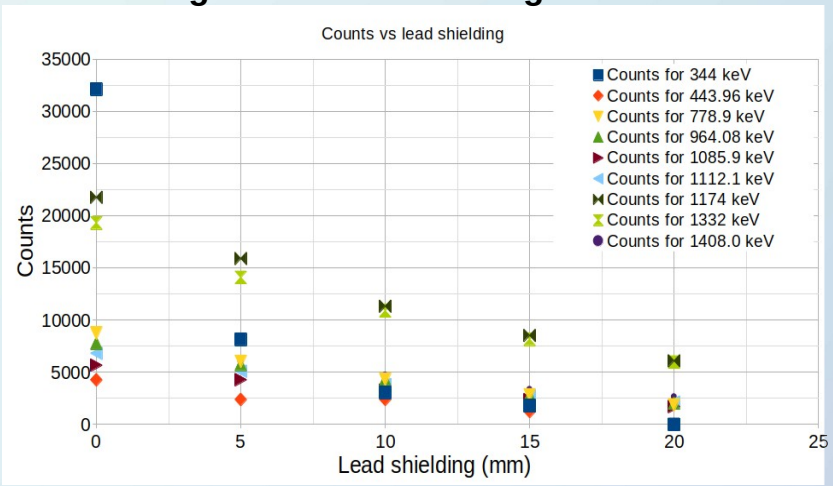


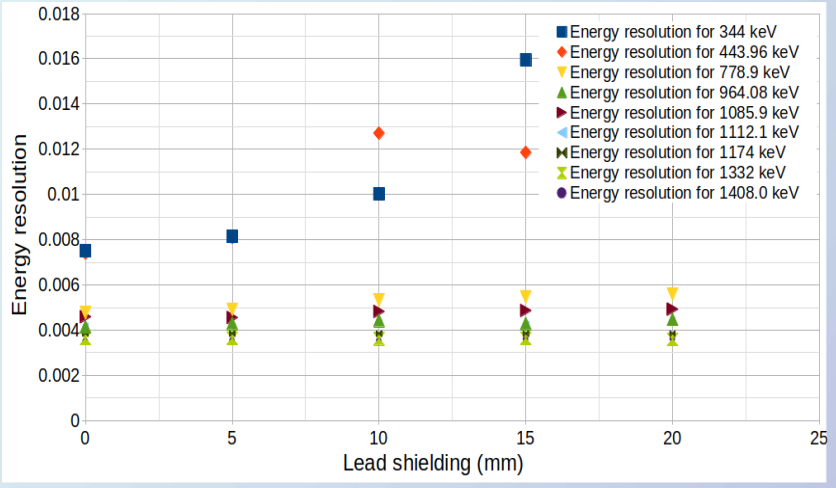
Pb shielding measurement

As is well known, HPGe detectors are relatively slow detection systems. Consequently, as the count rate increases, the likelihood of pulse pile-up also increases. HPGe detectors exhibit higher efficiency for low-energy gamma rays, with efficiency improving as the gamma-ray energy decreases. To reduce the pile-ups, we conducted experiments using Pb shielding. Our measurements indicate that a 10 mm Pb shield is optimal for our experiment. The pulse height spectra for ^{60}Co and ^{152}Eu sources, with varying thicknesses of Pb shielding, are shown on the left. The figures on the right illustrate the energy resolution and count rate dependencies. The results demonstrate that the energy resolution is unaffected by the thickness of the Pb shielding. However, the count rate decreases by a factor of 1.7 for 1 MeV gamma rays when using 10 mm Pb shielding.









TOF spectrum from ^{nat}Lu(n,g)

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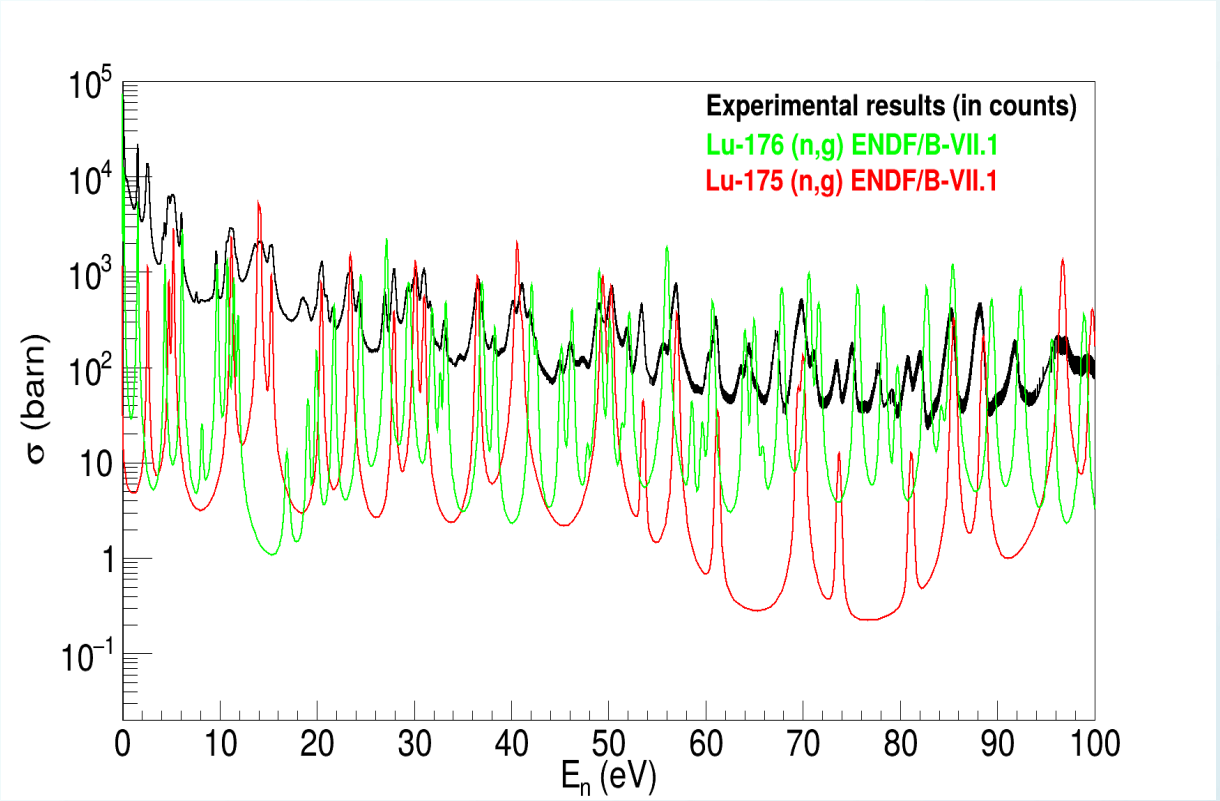
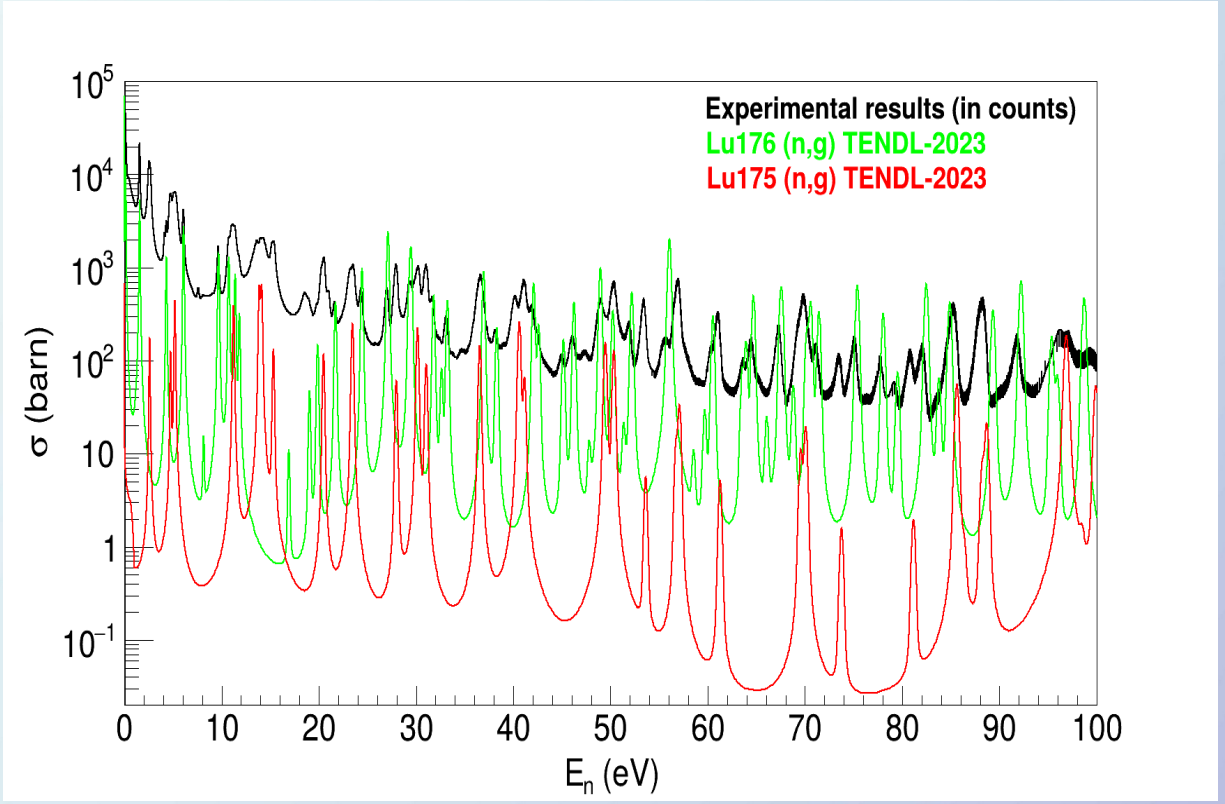
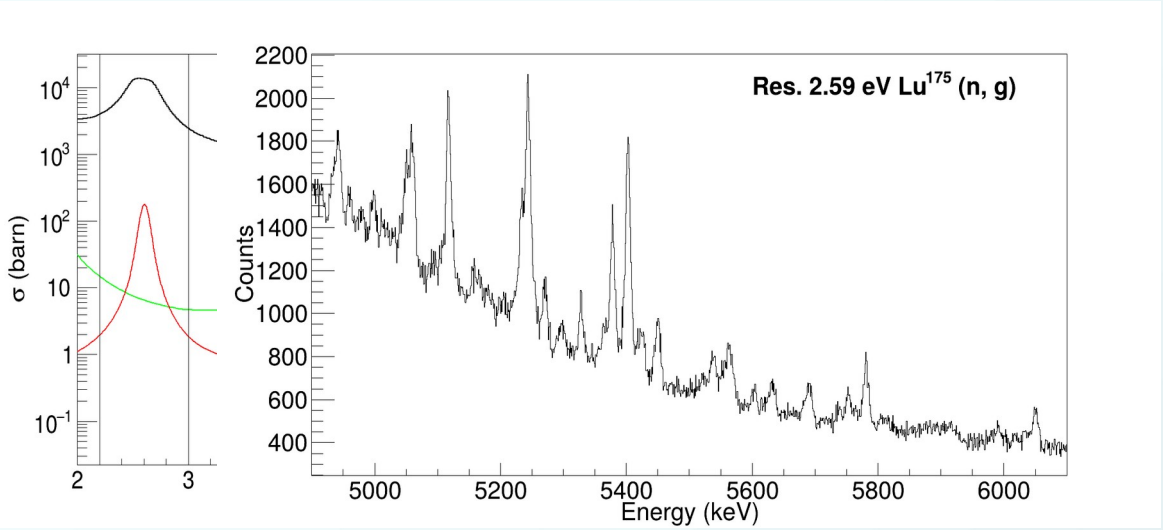
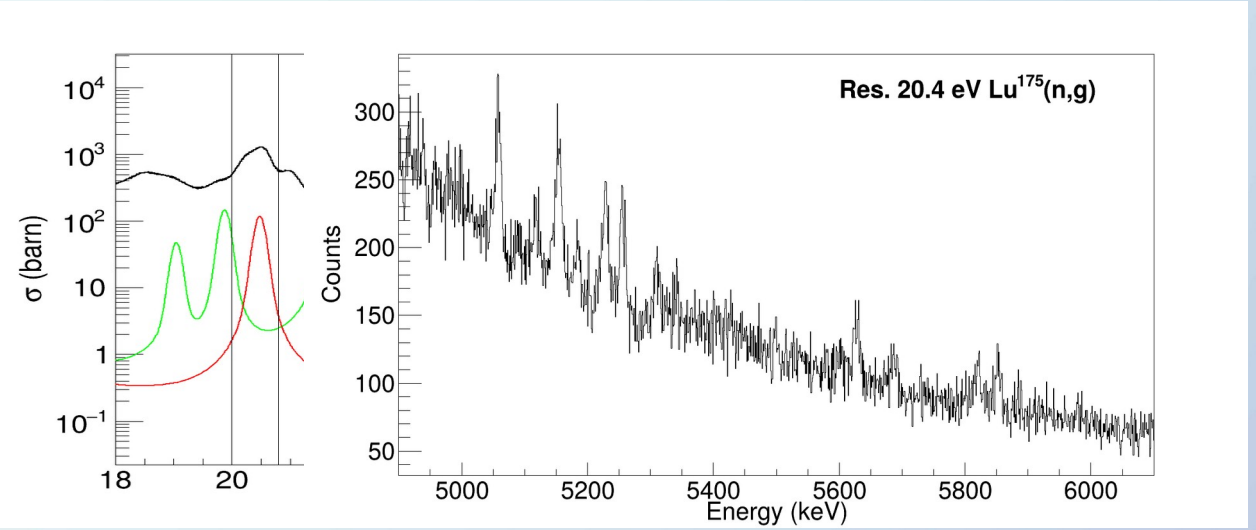
Comparison of experimental obtained resonance spectrum (from 1 eV up-to 100 eV) with (n,g) cross-section for Lu^{175} and Lu^{176} isotopes from TENDL-2023 and ENDF/B-VII. It has measured in the energy range of 1-1000 eV, in where up-to 100 eV statistics allow to study decay properties. Literature shows that Lu^{175} and Lu^{176} has been studied up to 50 eV, with intensities of E1 and M1 gamma-transitions from limited neutron resonances to numerous low-lying excited states belonging to different rotational or vibrational bands. Energy spectrum is for 205 hours for all resonances.

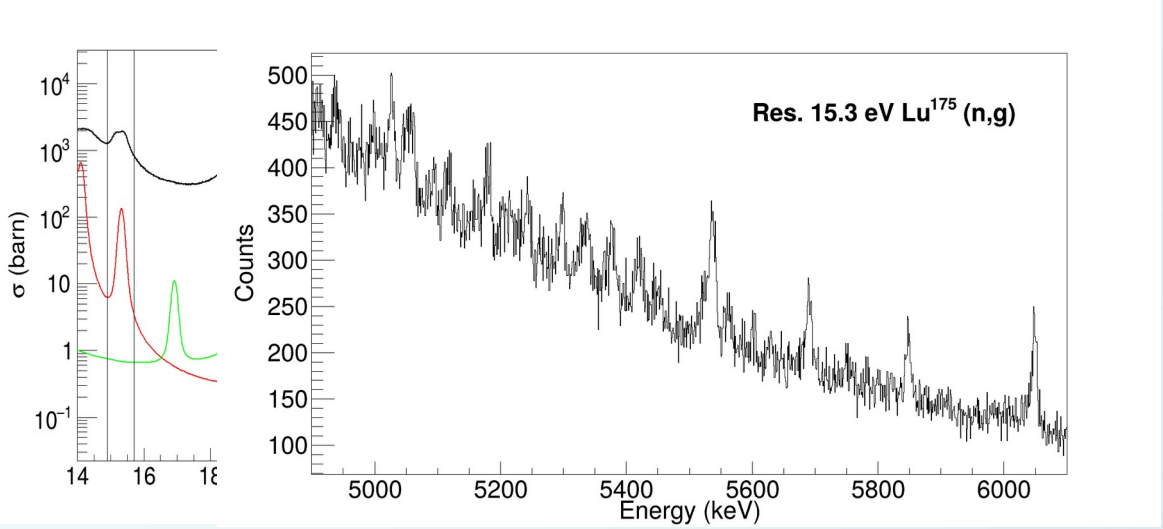


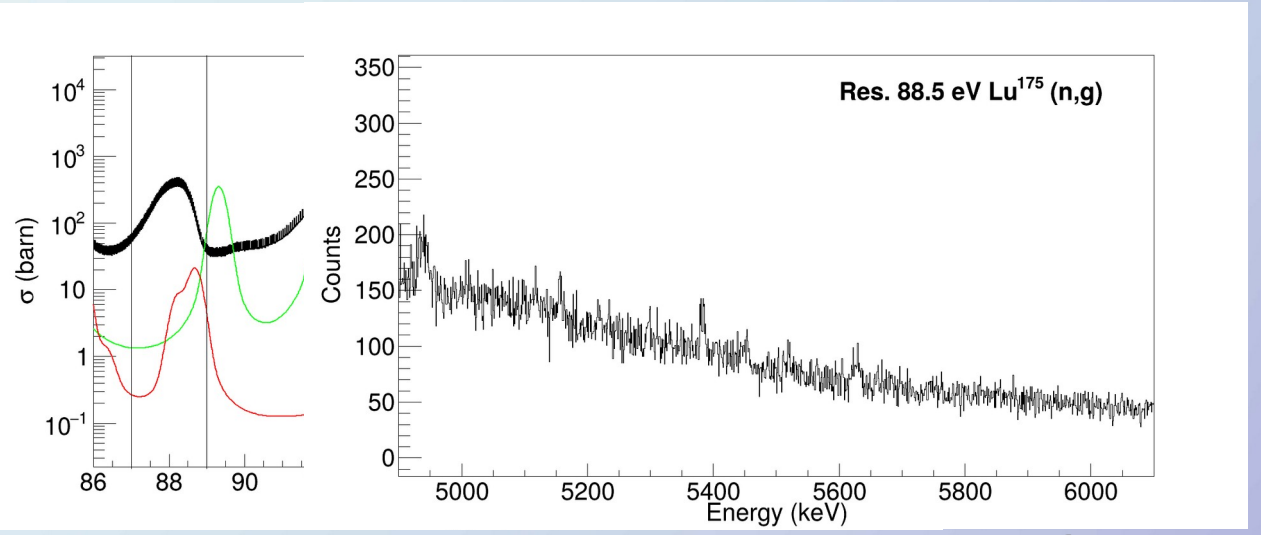


Energy spectra related to neutron resonance energies for Lu^{175}

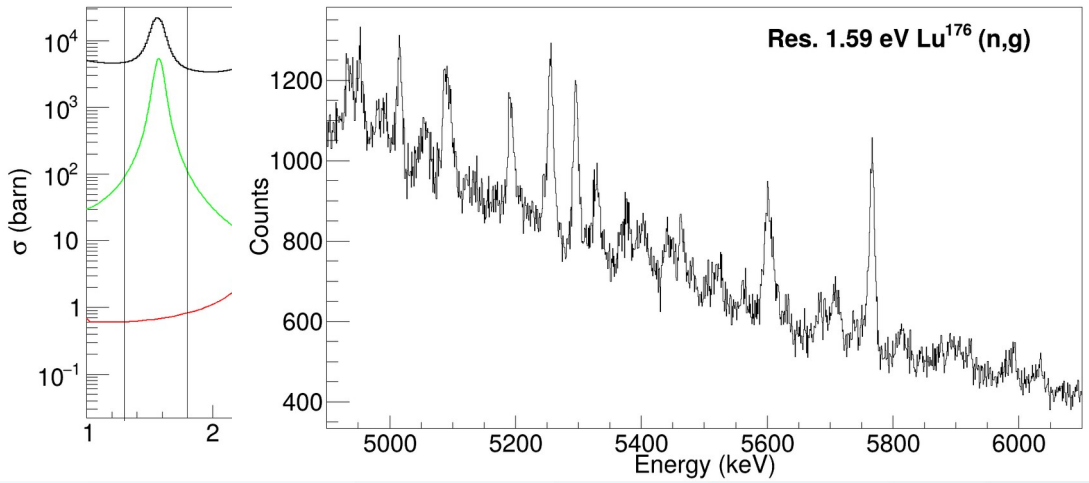


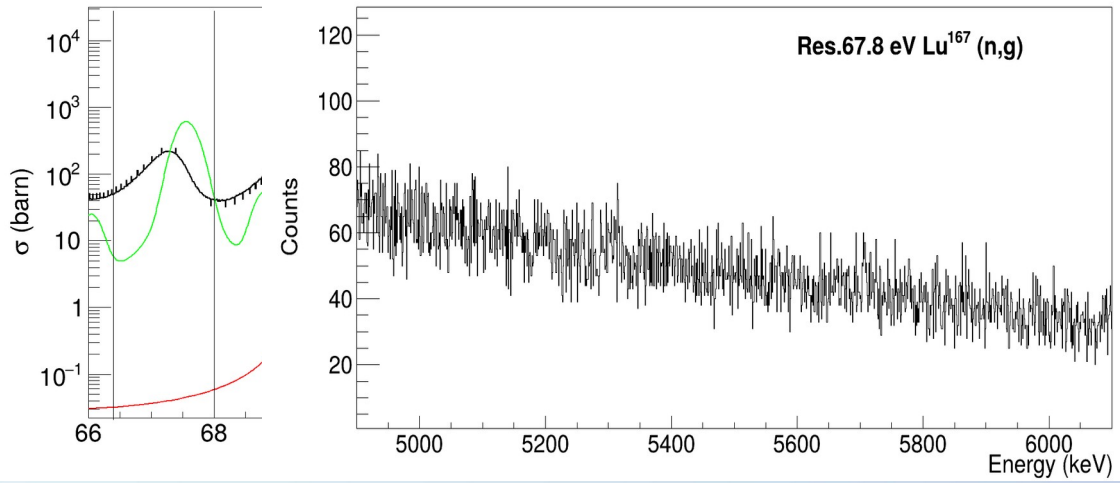


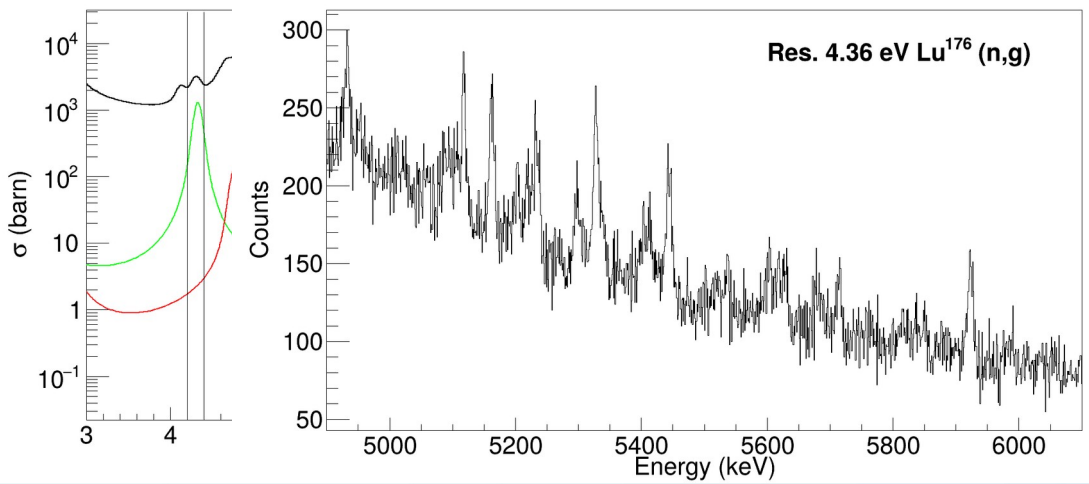


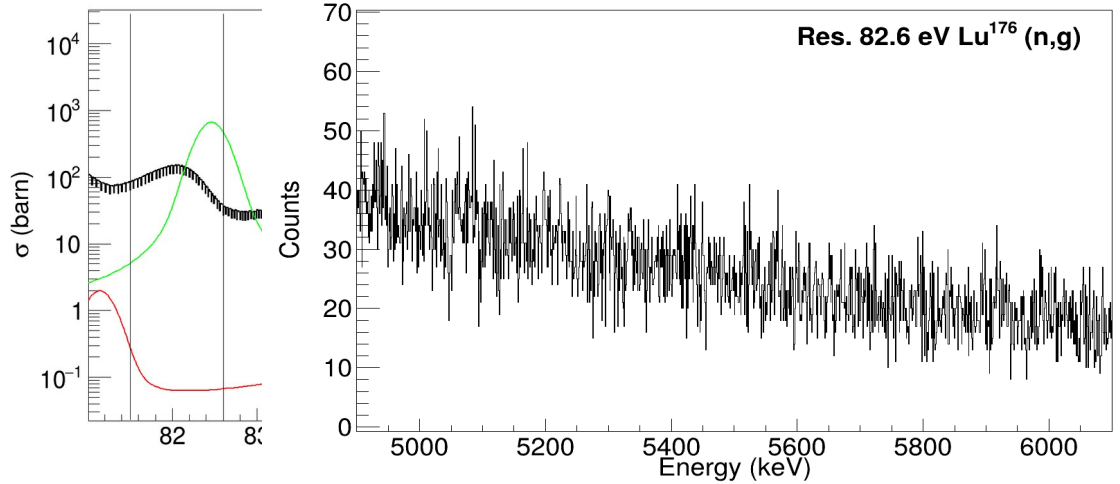


Energy spectra related to neutron resonance energies for Lu^{176}









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Preliminary results and future plans

1) Compared to the first experiment, which utilized a standard spectrometric amplifier, the second experiment achieved improved energy resolution by employing C++-based Butterworth and trapezoidal filters. The energy resolution for the 1173.2 keV gamma rays was enhanced to 0.25%, compared to 0.38% in the initial experimental run.
2) The statistics of the second experiment were improved due to an increase in the target mass, which was 60 g compared to 7.4 g in the first experiment.
3) Pule-ups were reduced by using 10 mm of lead (Pb) shielding.
4) Preliminary analysis of the obtained experimental data indicates that gamma transitions are observable in the relevant gamma- spectra at neutron resonance energies above 50 eV for ^{175}Lu and for ^{176}Lu target nuclei. This is notable despite low abundance of ^{176}Lu isotope (2.59%) in our target.
5) The data analysis is still ongoing. However, the results of preliminary analysis definitely indicate that new results for partial gamma width will be obtained. Achieved accuracy of gamma-transition intensities aslo indicates possible perspective for future experiments using state-of art experimental methods and present neutron beam flux.
6) We expect that the results obtained from this experiments are suitable for publication, as they provide improvements over existed published results.

Thank you very much
for your attention and time!