JOINT INSTITUTE FOR NUCLEAR RESEARCH

FLNP FRANK LABORATORY OF NEUTRON PHYSICS

Primary gamma transitions in ^{176}Lu and ^{177}Lu after resonance neutron capture

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Outline

- Literature review and motivation
- Experiment
- ToF spectrum and comparison with the libraries
- Results
- Summary

Literature review and motivation

- In the papers [Wasson O.A. et al.,1970], [Becvar F. et al., 1987] and [Basunia M.S. 2006] 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 ^{176}Lu nucleus.
- These studies were primarily limited to the 0–50 eV energy range, focusing on E1 and M1 gamma transitions from a select number of resonances. These investigations predominantly examined decays to low-lying excited states, frequently associated with rotational or vibrational band structures.

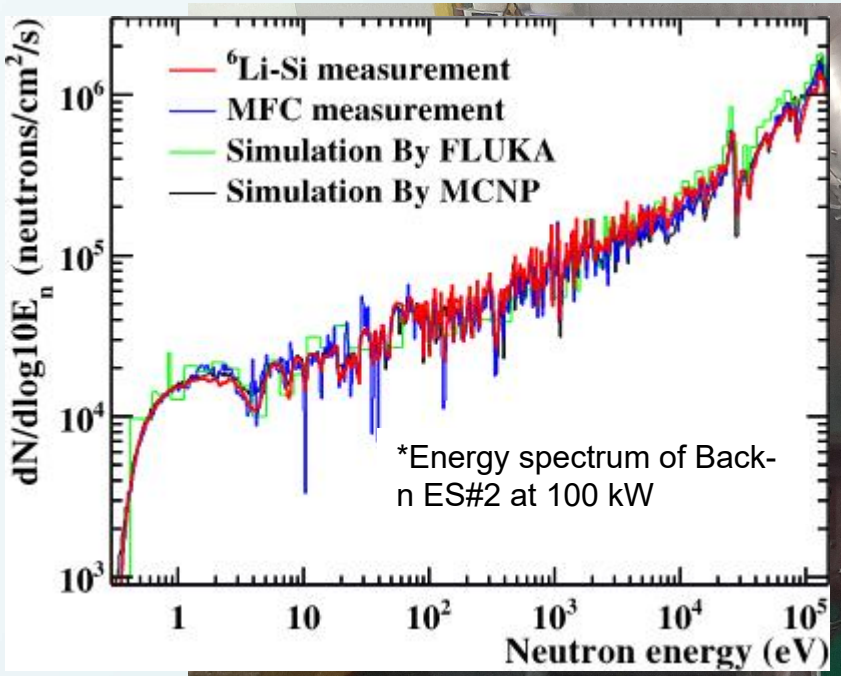
• Motivation

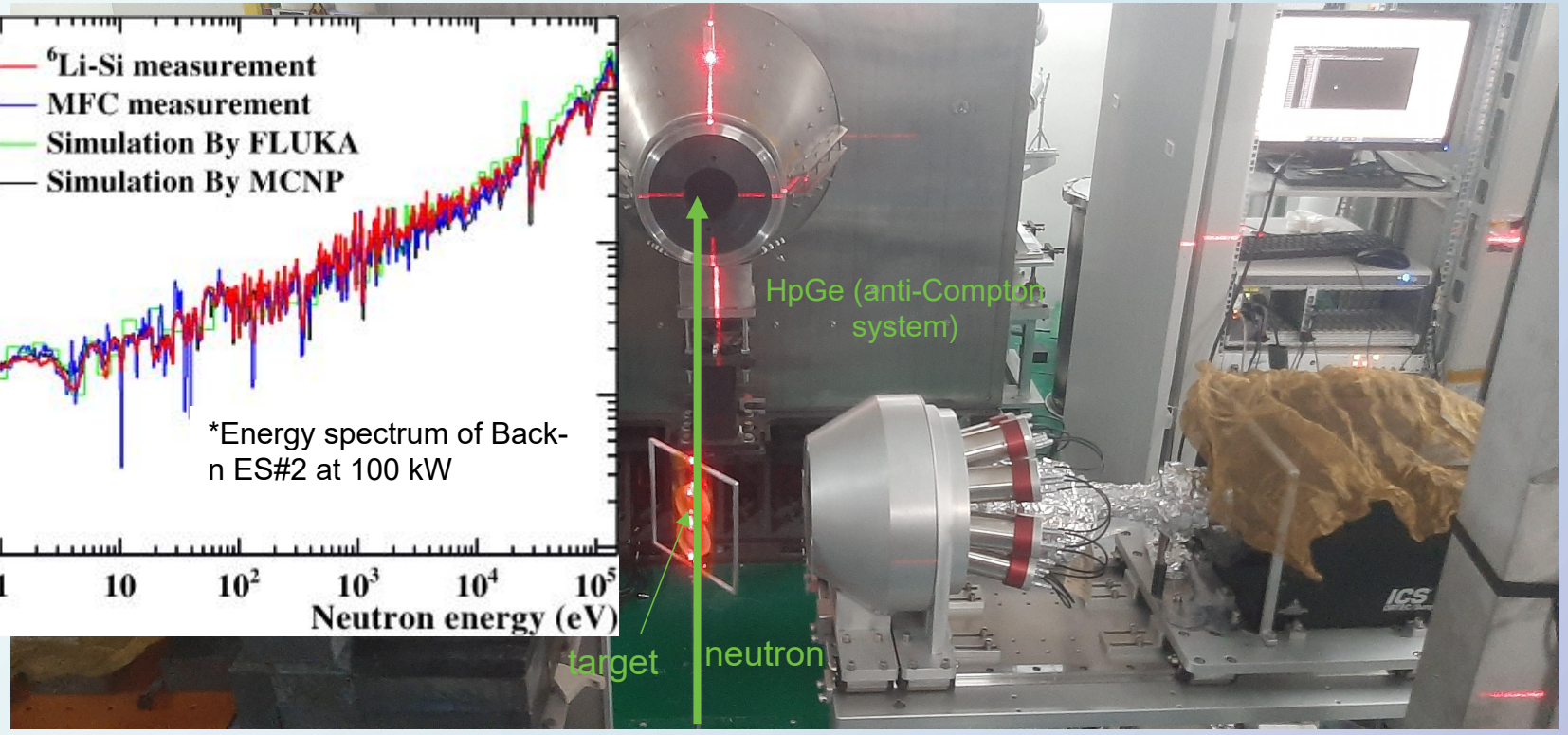
Our measurements of $^{175\text{-}176}$Lu(n,γ)$^{176\text{-}177}$Lu reaction are aimed at increasing the number of studied neutron resonances of ^{176}Lu and ^{177}Lu compound nuclei and to obtain more informative set of partial radiation gamma widths. This talk focused on primary gamma transitions in ^{176}Lu after resonance neutron capture.

1) *Wasson O.A. and Chrien R.E., Phys. Rev., 1970, v. C2, p. 675*
2) *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*
3) *M.S. BASUNIA, Nuclear Data Sheets for A=176* // Nuclear Data Sheets 107 (2006) 791–1026*
4) *F.G. KONDEV, Nuclear Data Sheets for A=177* // Nuclear Data Sheets 159, 1 (2019)*

Experiment

- The experiments were conducted at the CSNS ES#2 measurement hall, located 76 meters from the spallation target along the neutron flight path.
- A total of 200 hours of data were accumulated, with an additional 50 hours allocated for experimental setup and optimization.
- Measurements were carried out using a high-purity germanium (HPGe) gamma detector equipped with an anti-Compton system. The detector was positioned 20 cm from the target. A newly developed preamplifier was employed to enhance the performance of the HPGe detector.
- The target material consisted of metallic natural lutetium (natLu), with a mass of 60 grams (60 × 2.2 mm) and a purity of 99.9%.
- Measurements were performed in the low-energy neutron region at the ES#2 experimental hall, with the accelerator operating at a beam power of 160 kW.

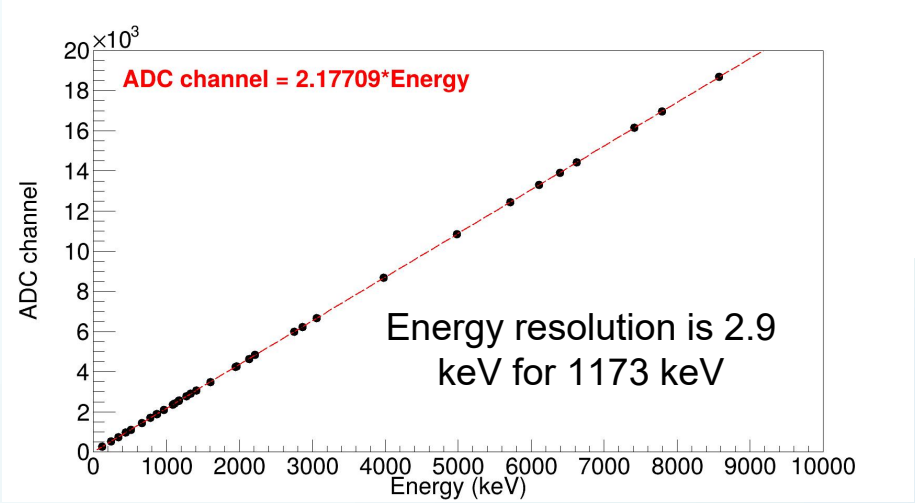


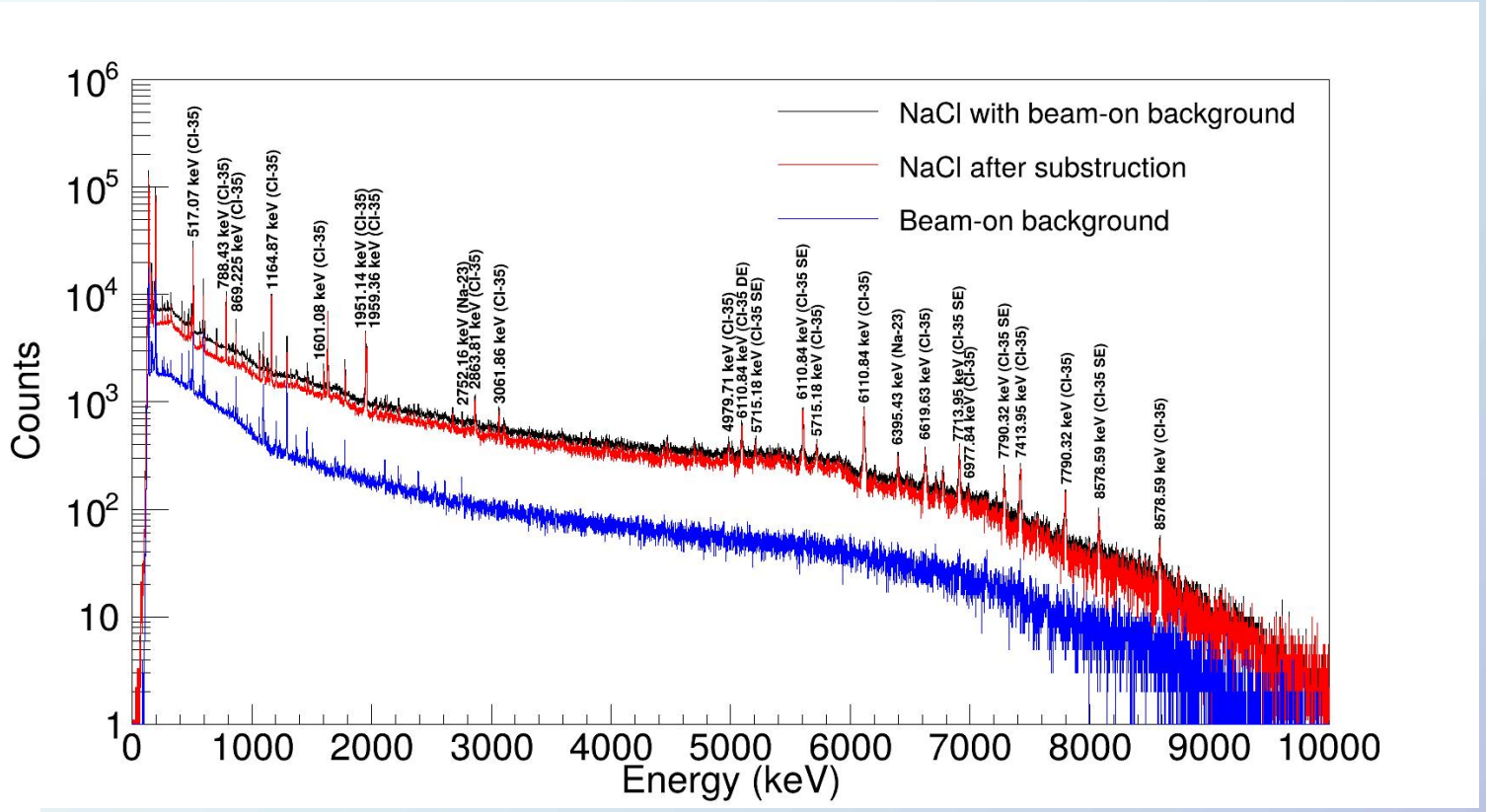


*Chen, Y., Luan, G., Bao, J. et al. Eur. Phys. J. A 55, 115 (2019)
*Yijia Qiu, Yonghao Chen, Qiang Li et al., NIMA Volume 1075, June 2025, 170383

Experiment: energy calibration of HpGe detector

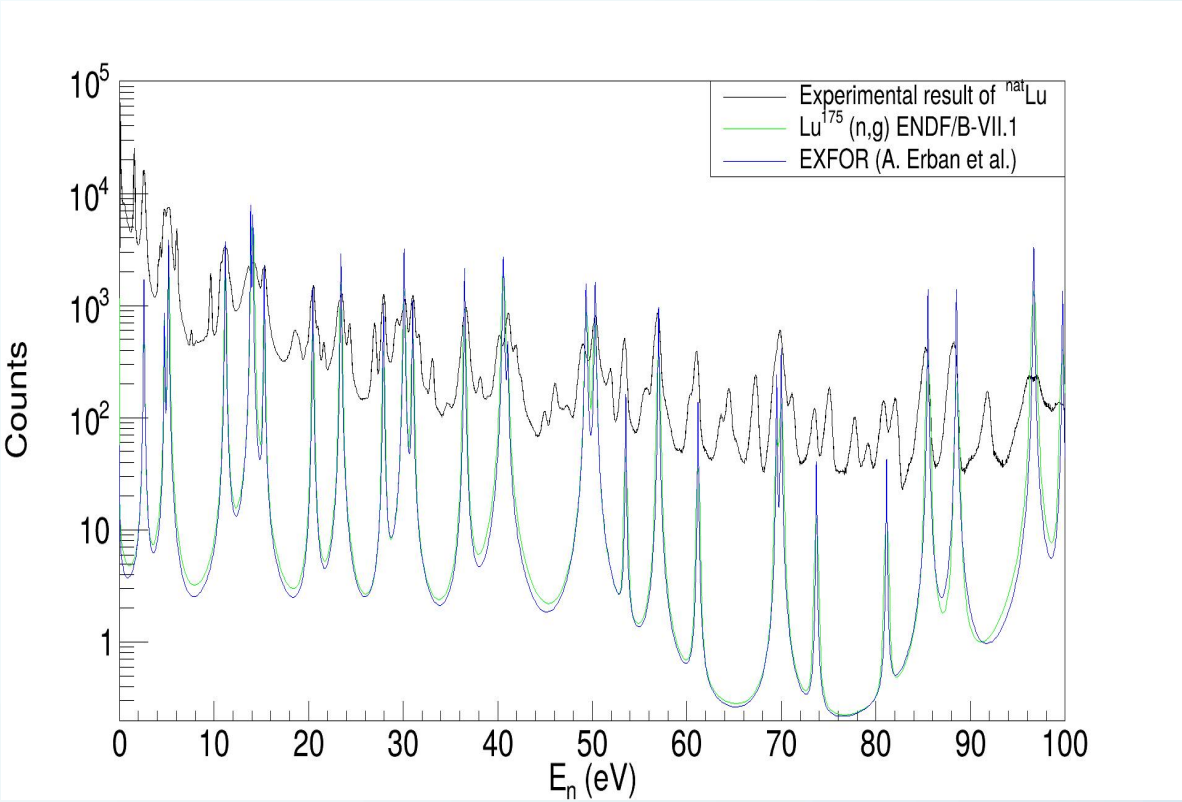
- **Energy vs. channel calibration curve is important for accurate identification of unknown gamma energies in subsequent measurements. To calibrate the detector across a broad energy range (0–10000 keV), we used standard gamma sources (Cs-137, Co-60, Na-22, Eu-152) to identify known photopeaks and construct an energy-channel calibration curve. Additionally, a NaCl sample was measured to extend calibration to higher energies using characteristic gamma lines from sodium and chlorine. The NaCl spectrum and resulting calibration curve are shown below.**

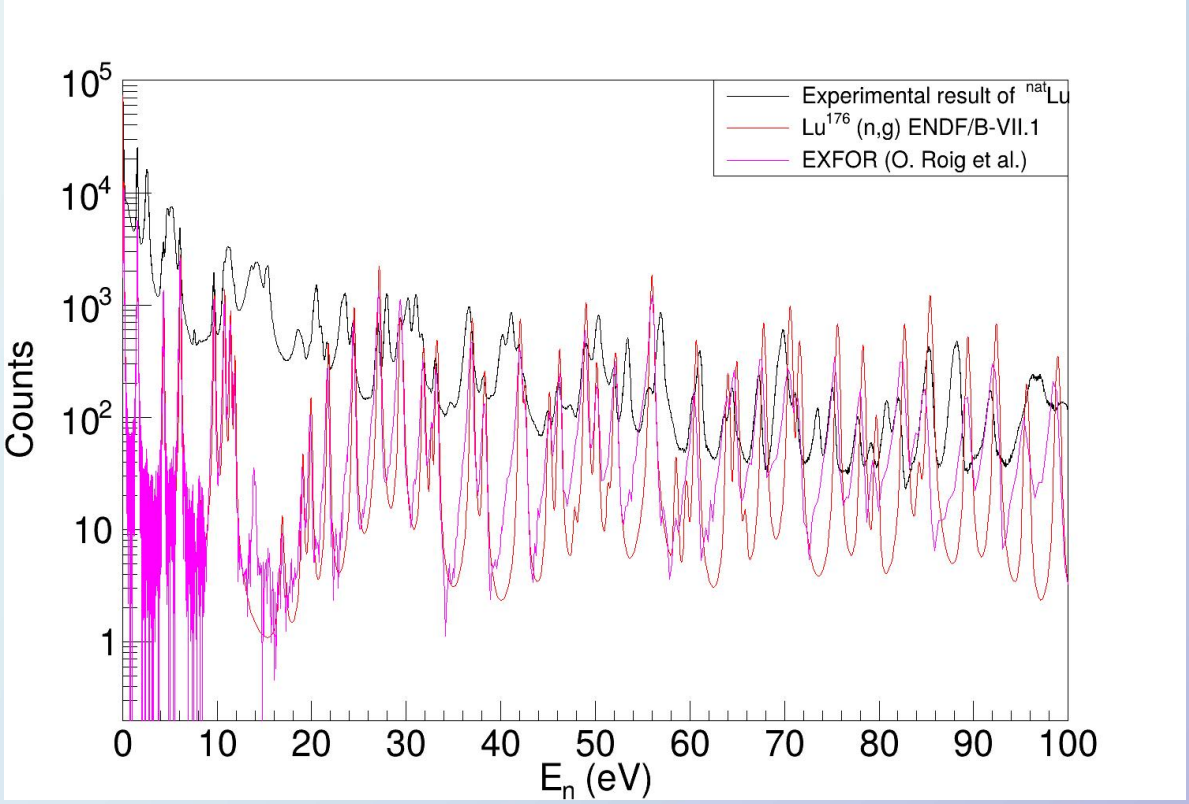




TOF spectrum from ^{nat}Lu(n,g)

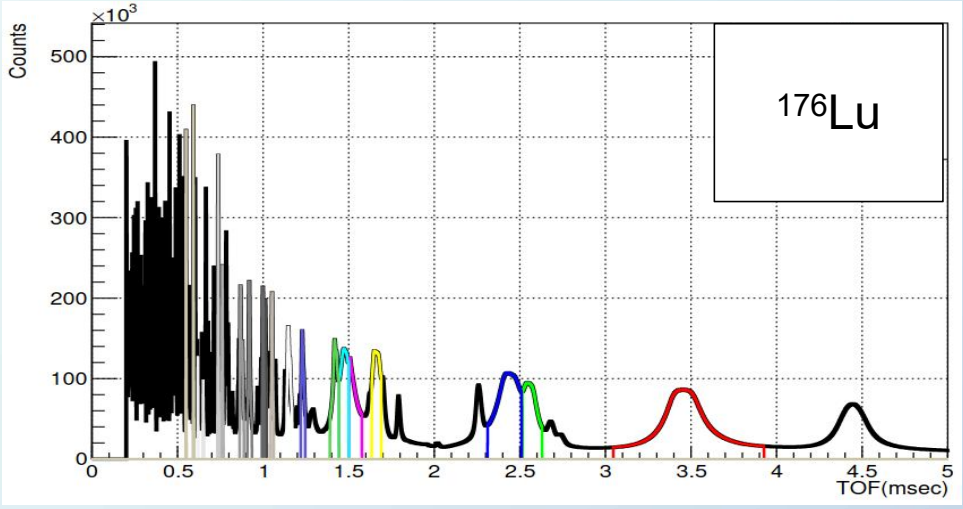
- The figure shows the experimentally measured resonance spectrum from 1 eV to 100 eV, compared with the (n,γ) cross-sections of ^{175}Lu and ^{176}Lu from ENDF/B-VII and EXFOR libraries.
- Measurements were performed in the energy range of 1–700 eV, with sufficient statistics up to 100 eV to study transition energies.
- In the energy range (1–100 eV), the measured resonance positions show good agreement with libraries, confirming consistency and reliability.
- Some deviations in peak widths and fine structures are observed due to experimental conditions

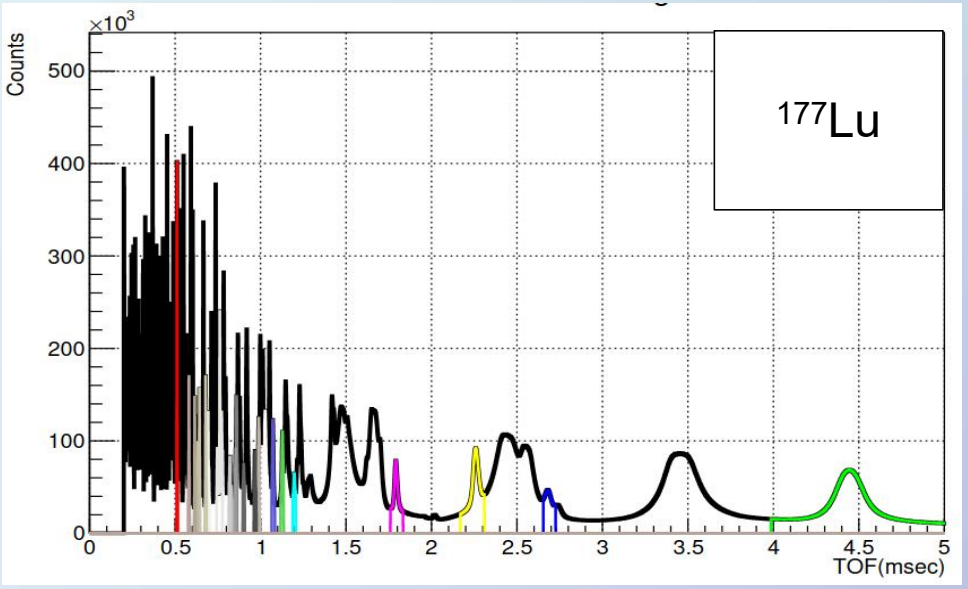




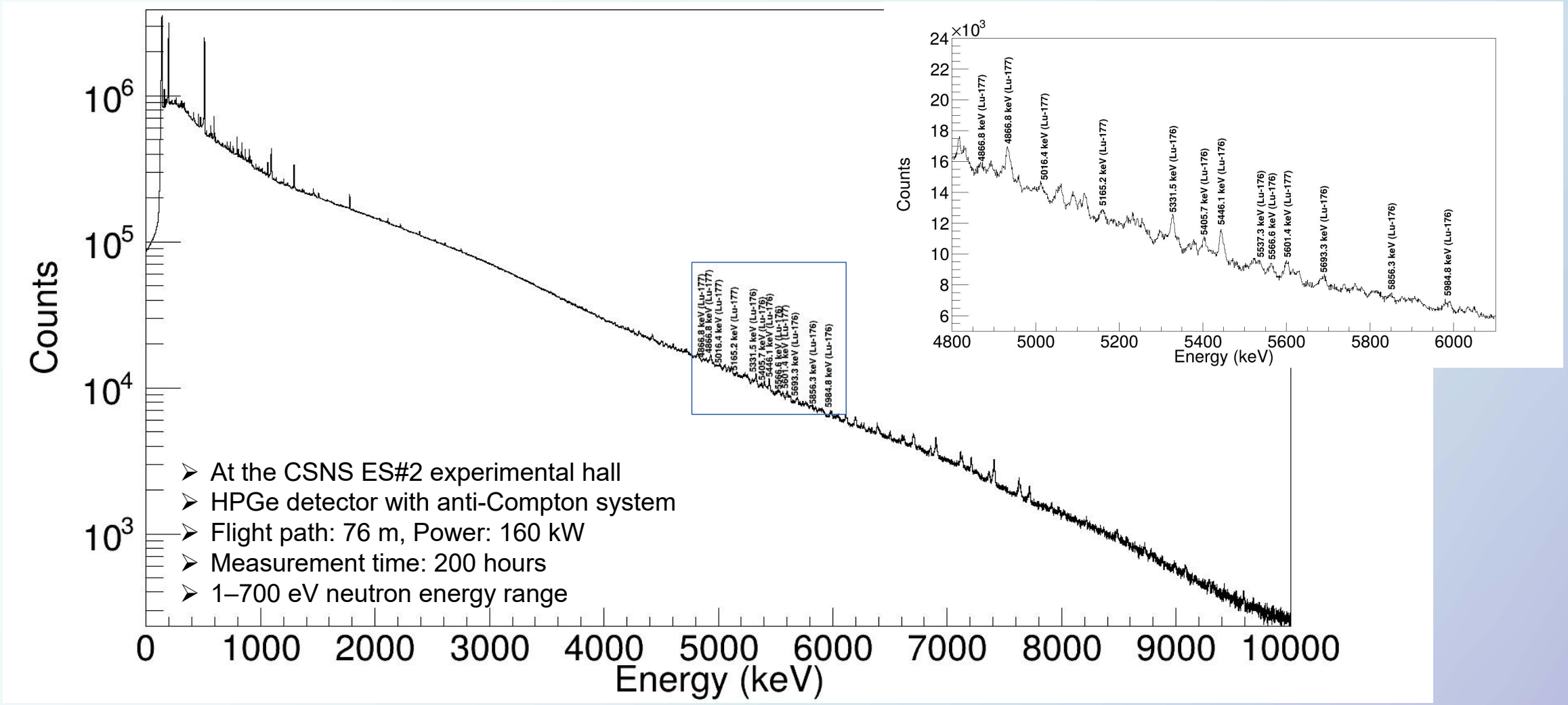
Analyzed resonances

Lu-176			Lu-177		
En(eV)	cut1	cut2	En(eV)	cut1	cut2
2.6	2	3.34	1.57	1.17	1.95
4.8	4.48	4.9	4.3	4.17	4.4
4.2	4.92	5.8	6.1	5.81	6.59
11.2	10.85	11.6	9.6	9.22	10.01
13.8	12.46	13.7	21.7	21.3	21.96
14.1	13.77	14.88	24.4	24.05	24.83
15.4	14.88	16.03	27.0	26.39	27.32
20.7	19.97	20.82	29.4	28.8	29.65
23.7	22.65	23.95	31.8	31.41	32.09
27.9	27.48	28.42	33.1	32.57	33.58
30.1	29.72	30.61	38.2	37.63	38.62
36.5	35.5	37.6	42.0	41.61	42.25
40.6	39.33	41.54	42.5	42.27	42.92
53.5	52.5	54.15	45.1	44.3	45.43
57.0	56.14	57.61	46.2	45.46	46.72
73.6	72.3	74	52.2	51.38	56.12
81.1	80.2	81.25	63.9+64.7	62.66	65.63
88.5	86.98	88.9	67.5	66.22	68.27

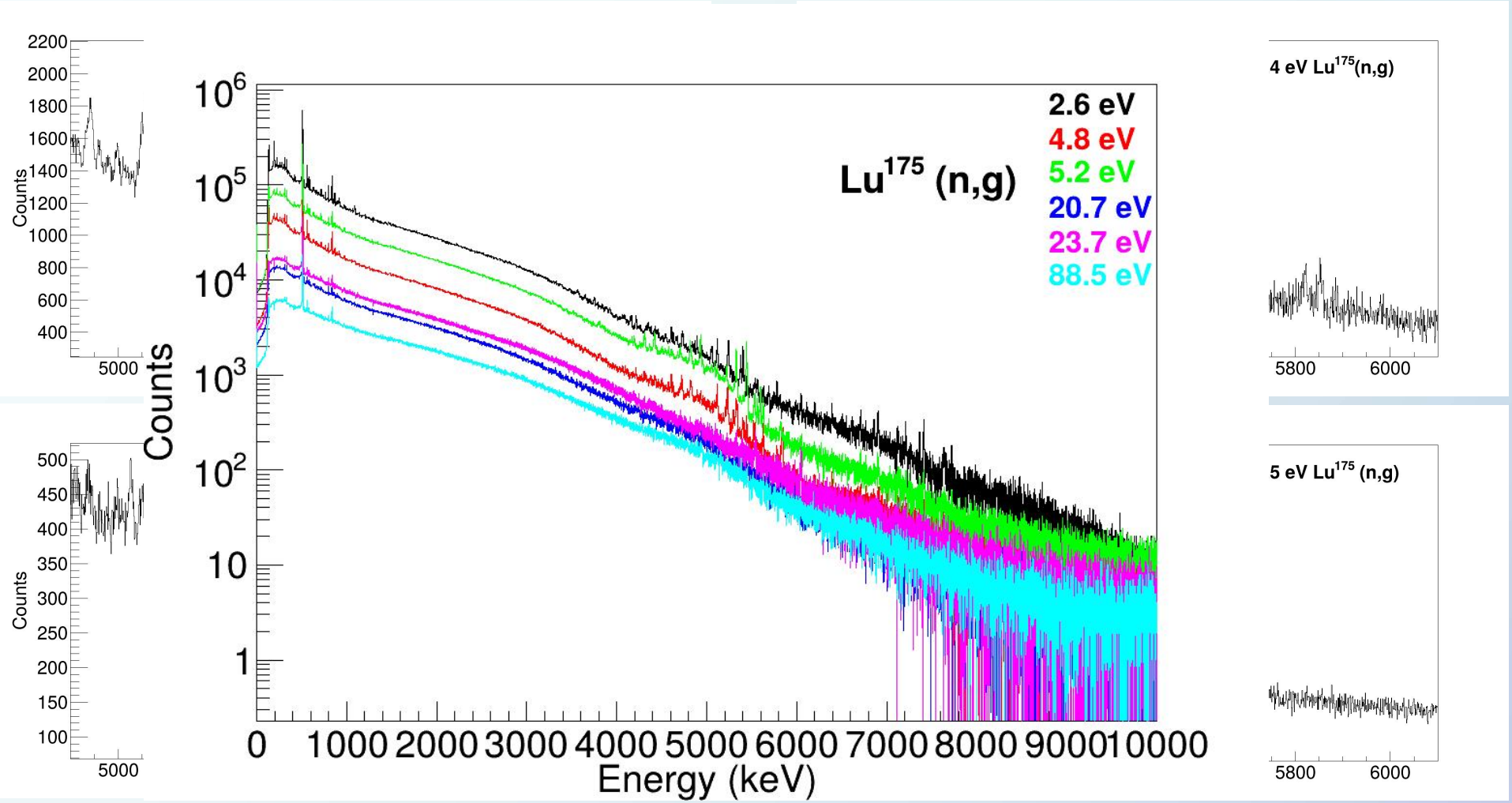




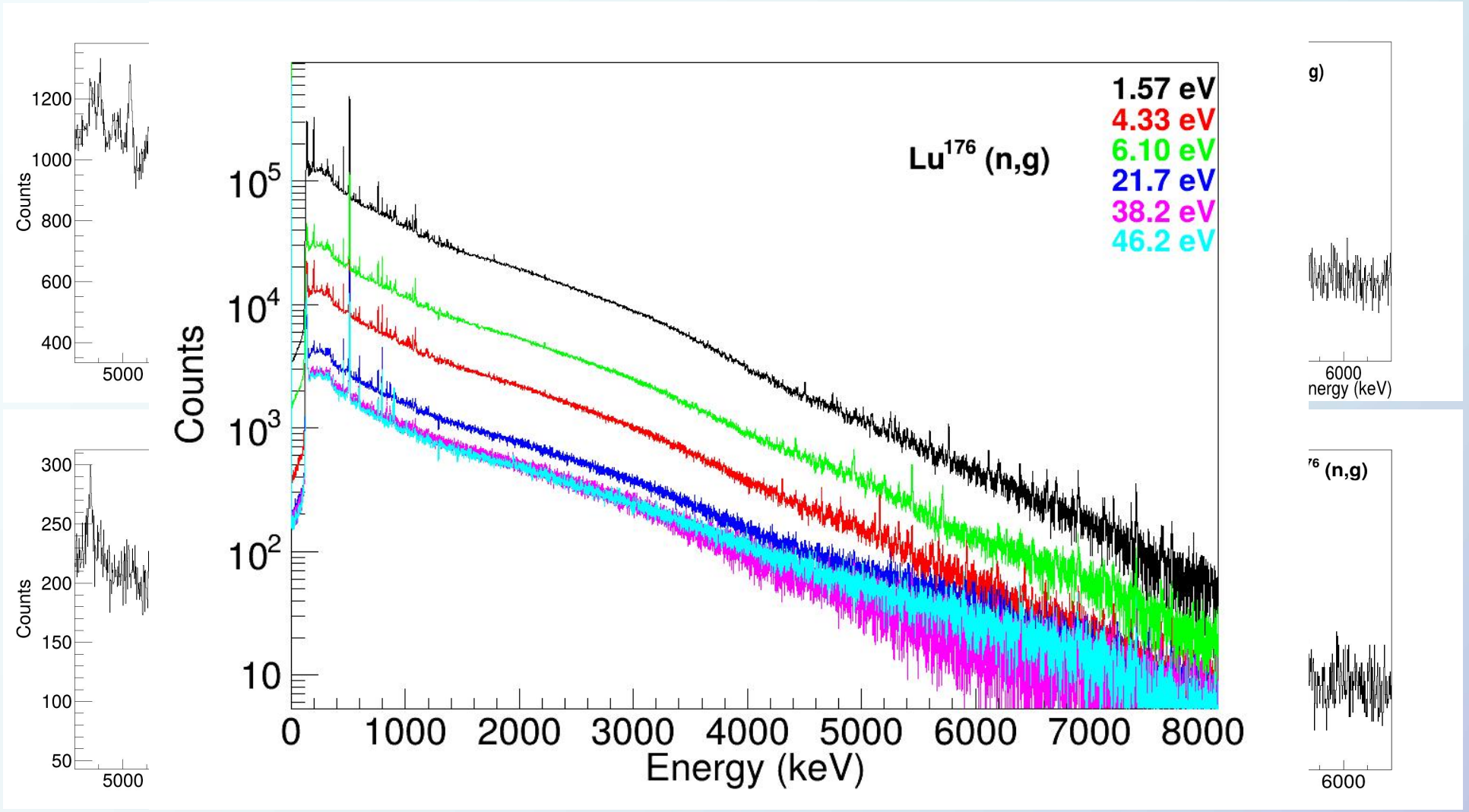
Full energy spectra for ^{nat}Lu



Gamma-ray emission spectra for ^{176}Lu for different resonances



Gamma-ray emission spectra for ^{177}Lu for different resonances

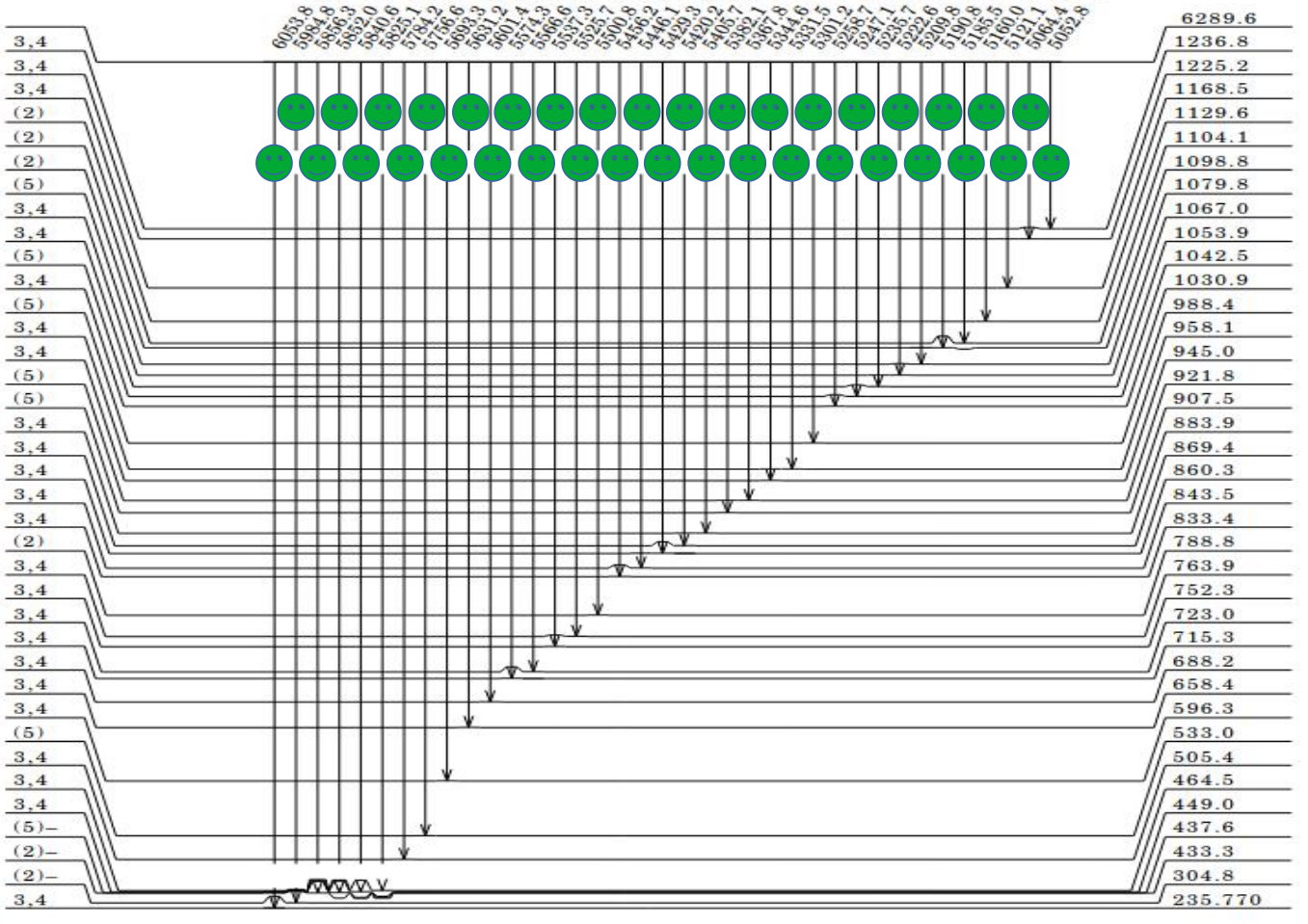


Measured E_g for primary γ rays

Gamma transition energies were measured for 15 neutron resonances in ^{175}Lu, spanning the energy range from 2.6 eV to 73.6 eV (for some resonances even higher energies). The experimental results show good agreement with existing literature data.

E_g (keV)	E_n (eV)
6053.927(329)	2.6, 4.8, 13.8, 20.7, 23.7, 36, 40.6, 57
5982.199(799)	2.6, 4.8, 5.2, 15.4, 23.7, 31, 40.6, 57
5851.520(191)	2.6, 4.8, 5.2, 14.1, 15.4, 53.2
5838.954(673)	4.8, 5.2, 11.2, 20.7, 36, 40.6
5824.802(456)	4.8, 5.2, 11.2, 20.7, 27.9, 36, 40.6, 57, 73.6
5783.612(685)	2.6, 4.8, 5.2, 11.2, 13.8, 14.1, 23.7, 27.9
5692.059(341)	2.6, 5.2, 13.8, 15.4, 23.7, 27.9
5573.021(587)	2.6, 11.2, 13.8, 27.9
5418.824(762)	4.8, 15.4, 36, 40.6, 53.5
5331.521(326)	2.6, 4.8, 5.2, 11.2, 13.8, 15.4,23.7, 27.9, 36, 40.6, 57, 116.4
5301.760(731)	2.6, 4.8, 11.2, 15.4, 31, 76.3
5120.283(348)	2.6, 4.8, 11.2, 13.8, 15.4, 23.7, 27..9, 31, 57, 73.6
5053.612(929)	2.6, 4.8, 13.8, 15.4, 36, 40.6, 57, 81

[1]Level scheme



[1]*M.S. BASUNIA, Nuclear Data Sheets for A=176* // Nuclear Data Sheets 107 (2006) 791–1026*

Summary

- ✓ Resonance neutron-induced (n,γ) reaction on natural lutetium (^{nat}Lu) was conducted at the Back-n neutron source (CSNS) at 160 kW power for 200 hours in 2024.
- ✓ 16 resonances of ^{175}Lu were studied, with primary gamma transitions identified and compared with existing literature.
- ✓ Despite its low natural abundance (2.6%), clear resonances for ^{176}Lu were analyzed. Data interpretation is ongoing.
- ✓ Digital filters (Butterworth & Trapezoidal) enhanced energy resolution for 1173.2 keV γ-rays: 0.25% (vs. initial 0.38%) and 6000 keV γ-rays: 0.11%
- ➢ Using additional HPGe detectors and advanced signal processing techniques can improve both the accuracy and statistical reliability of the measurements. Furthermore, increasing the target mass could enhance counting statistics, particularly for higher resonances.

Thank you very much
for your attention and time!