Neutron Capture Measurement Status of ^{166}Er at n_TOF facility, CERN

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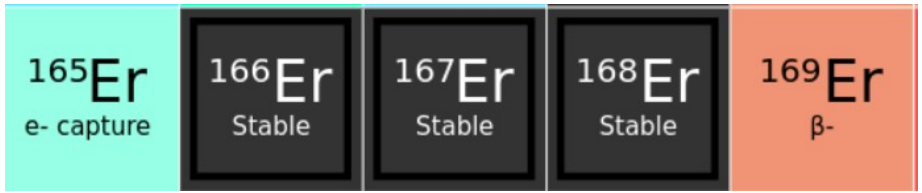
Outline

- Motivations of the measurements
- Comparison of the evaluated libraries
- Experimental set-up and ^{166}Er sample
- Calibrations of detectors: C6D6
- Measurements with ^{197}Au sample
- Neutron capture of ^{166}Er
- Measurements with Empty, C, Lead and Filters
- Background subtraction and yields calculations
- Comparison with R-matrix calculations

Motivations of Measurement

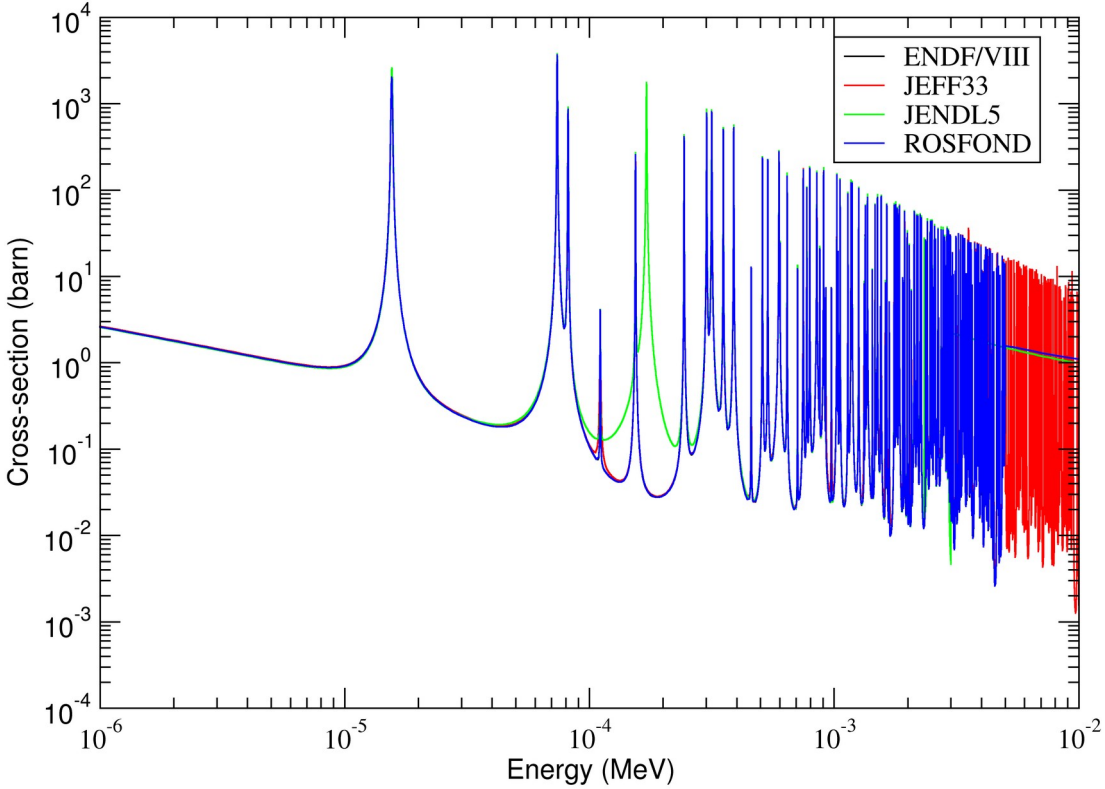


Rare earth element
Lanthanide series of the periodic table

- **Reactivity Control:** ^{166}Er serves as a key neutron absorber used to optimize reactor operations by finely tuning reactivity levels.
- **Stellar Insights:** Neutron capture data with ^{166}Er is crucial for accurate stellar modeling, especially in AGB stars for enhancing understanding of cosmic processes.
- **Refining Models:** Precise cross-section measurements of ^{166}Er will improve stellar models to explore its origins and natural abundances.

V. Alcayne, S. Amaducci, J. Andrzejewski et al. (the nTOF Collaboration), CERN-INTC-2023-015 / INTC-P-656
A. Guglielmelli, F. Rocchi, C. Massimi et al., Annals of Nuclear Energy 178, 109337 (2022)

Comparison between the Libraries

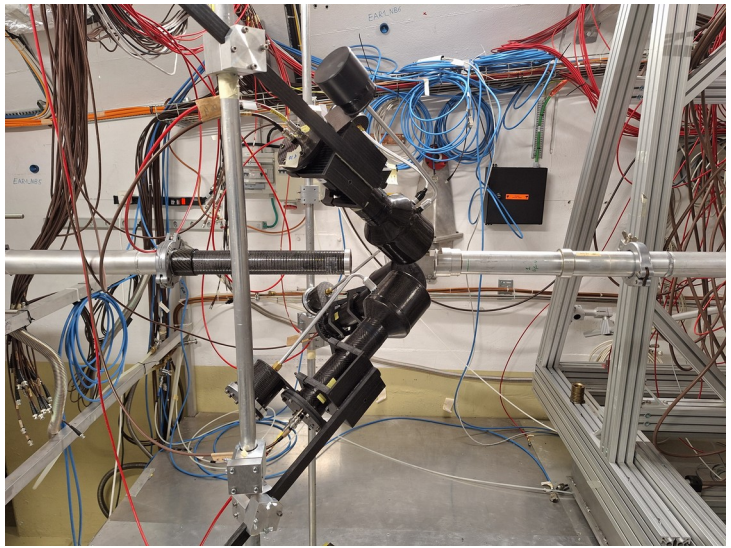


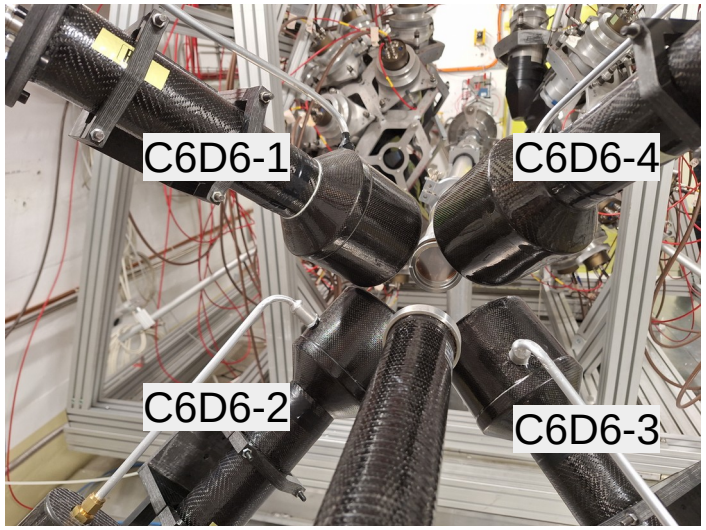
- ENDF & ROSFOND: Both libraries share similar structures and data sets.
- JEFF: Contains more detailed resonance data in the unresolved resonance regions.
- JENDL: Features unique data characteristics, differing from other nuclear libraries.

Ref: https://www.nndc.bnl.gov/endf/

Facility and Experimental Set-up

n_TOF facility at CERN@ EAR1



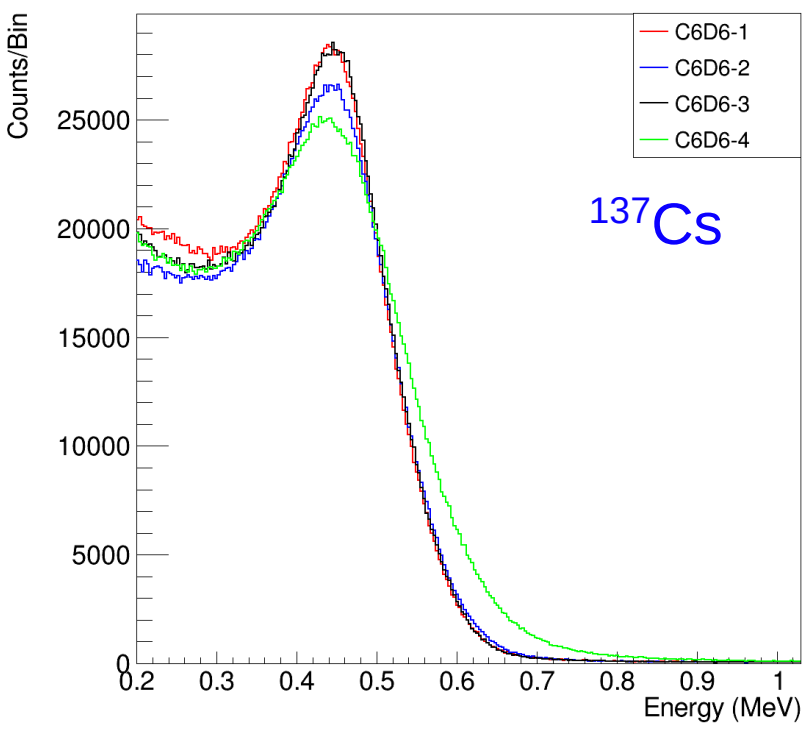


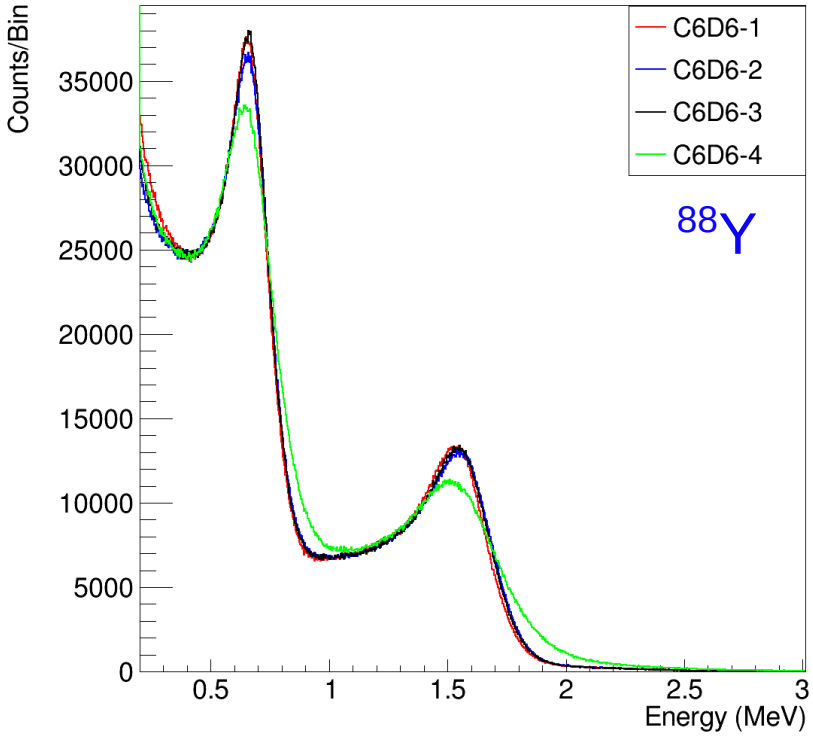
Er166
13mm-224.7mg

- **Neutron Generation:** bombarding high-energy 20 GeV/c proton beam on massive lead target.
- **Flux Monitoring:** SiMon detector via the $^{6}Li(n,^{3}H)^{4}He$ reaction.
- **Detection System:** 4 C6D6 detectors positioned 125^{0} to the beam

ISOTOPE	Er-166
ENRICHMENT	98.10(±0.10)%
ELEMENT WEIGHT	
FORM	Oxide (Er_2O_3)

Detector Calibrations

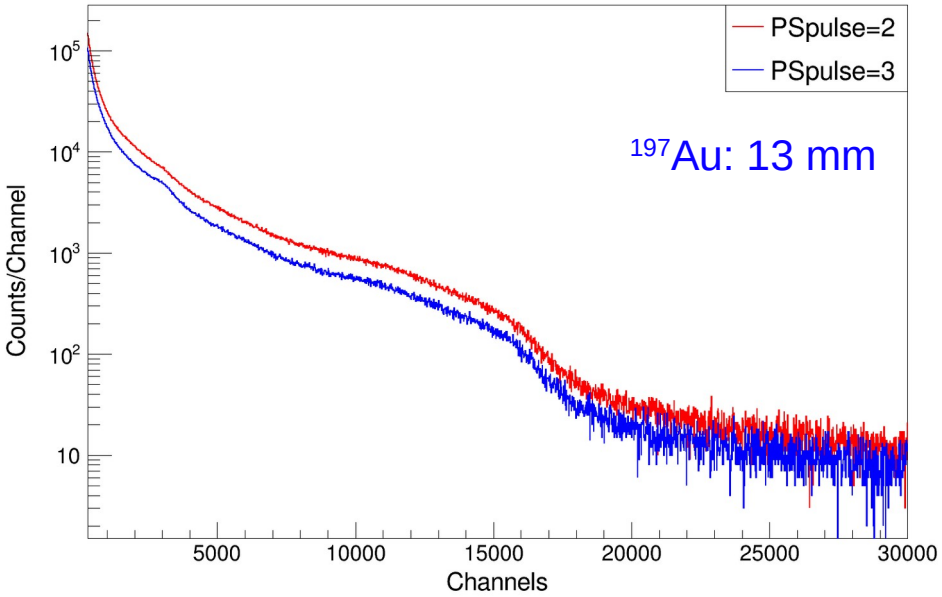




C6D6 detectors were calibrated using the sources: ^{88}Y, ^{137}Cs, AmBe, CmC

Measurements with ^{197}Au

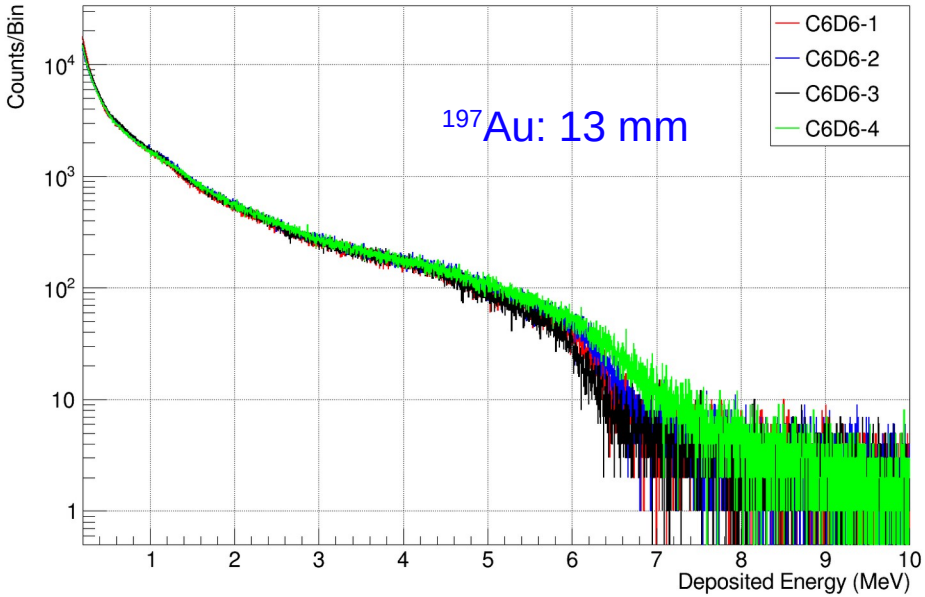
Dedicated and Parasitic Pulse



Dedicated: PSpulse=2
Parasitic: PSpulse =3

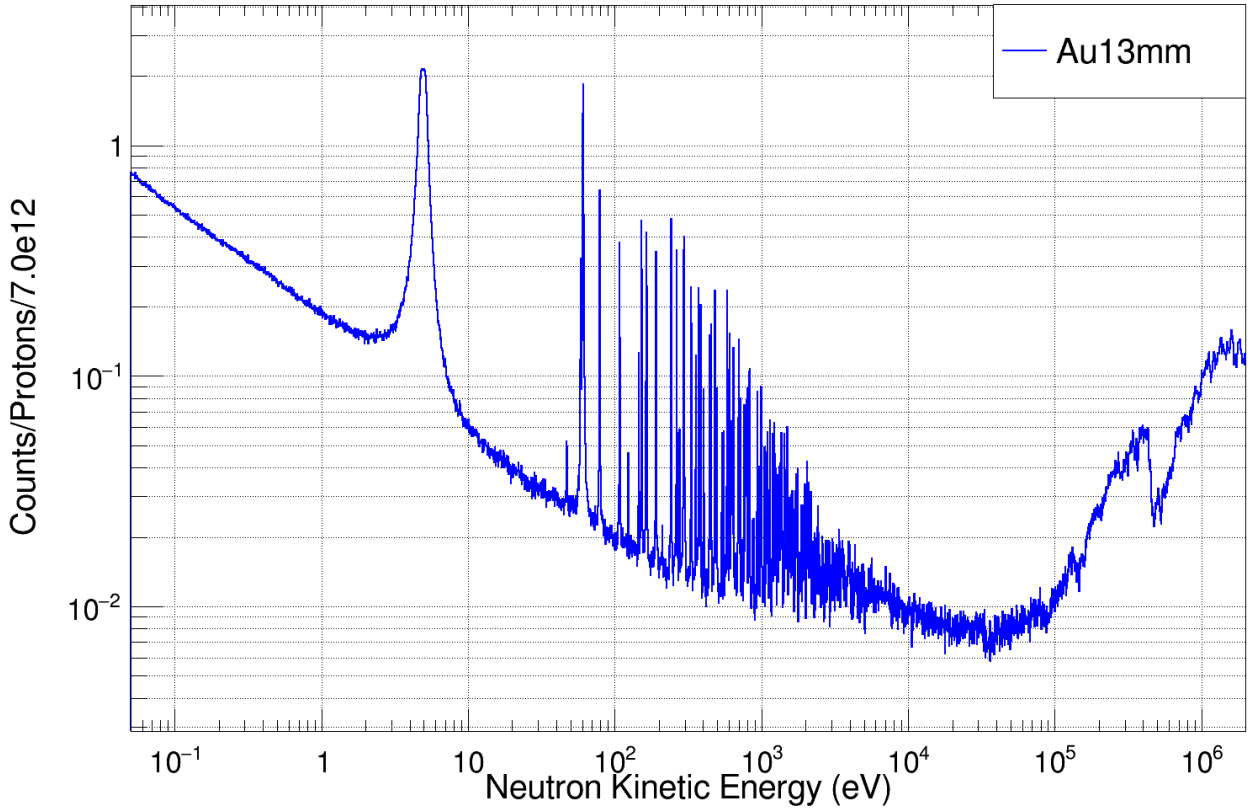
Shapes of both dedicated and parasitic pulses are same

C6D6 (1 to 4) detectors counts



Nice agreement between all the C6D6 detectors: shape and end-point of the ^{197}Au(n,γ) cascades on the saturated resonance

Neutron time of Flight Spectrum Converted to Energy

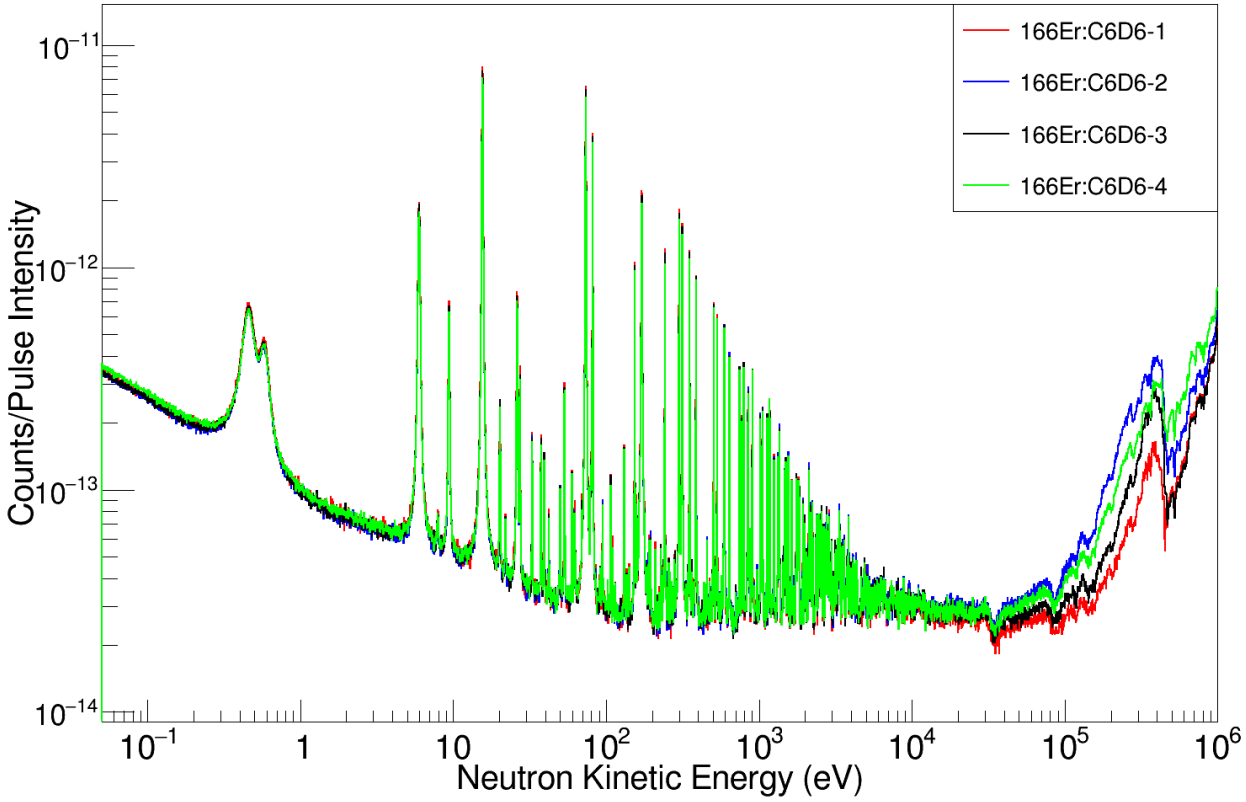


TOF is converted to energy

Distance from spallation source to EAR1(L) = 183.95 m

Saturated resonance falls in expected energy.

Measurements with ^{166}Er

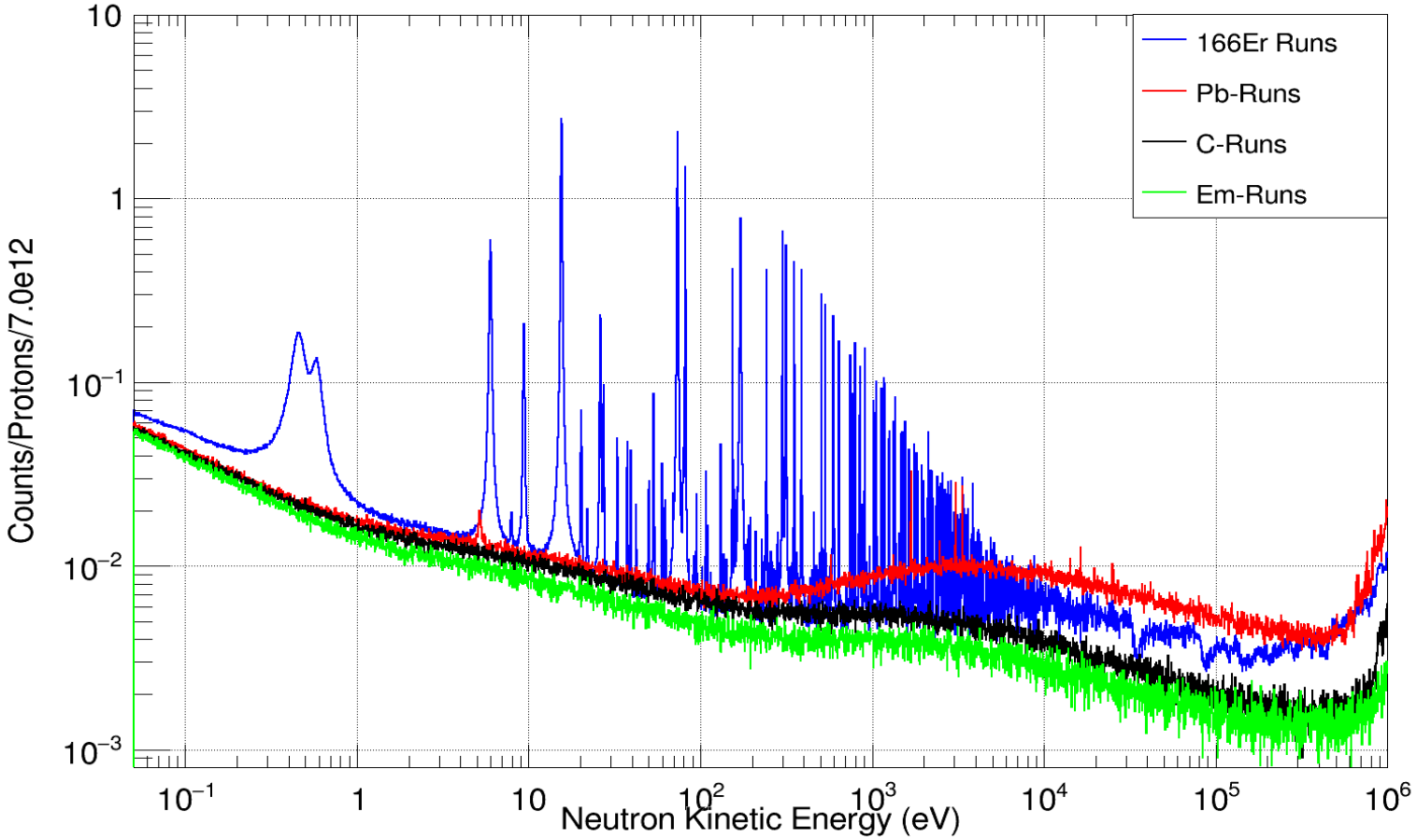


Distinct resonances, showcasing characteristic features of the isotope.

All detectors spectra exhibit a consistent structure.

Additional peaks are observed due contaminant in the sample.

Measurements with ^{166}Er, Empty, Pb and C

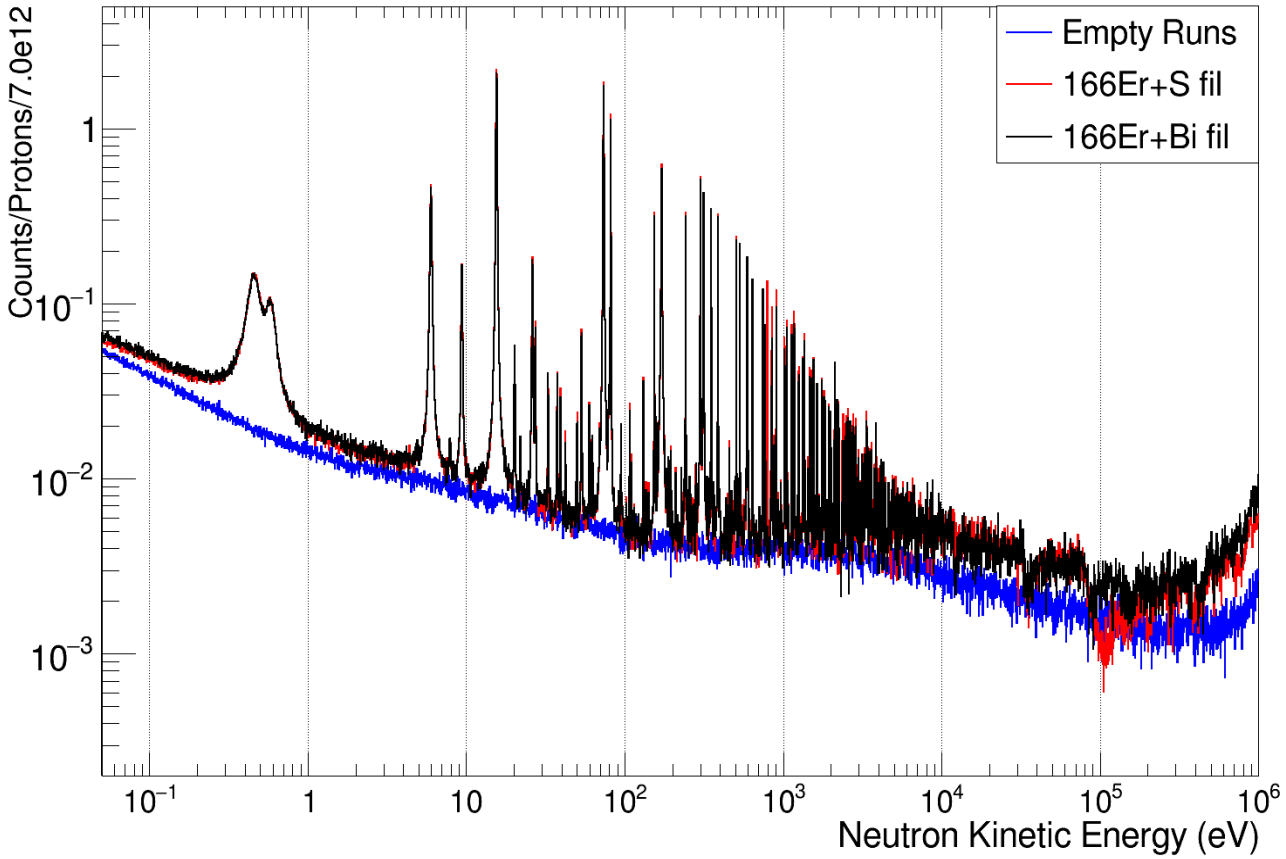


Measurements of ^{166}Er with S and Bi Filter

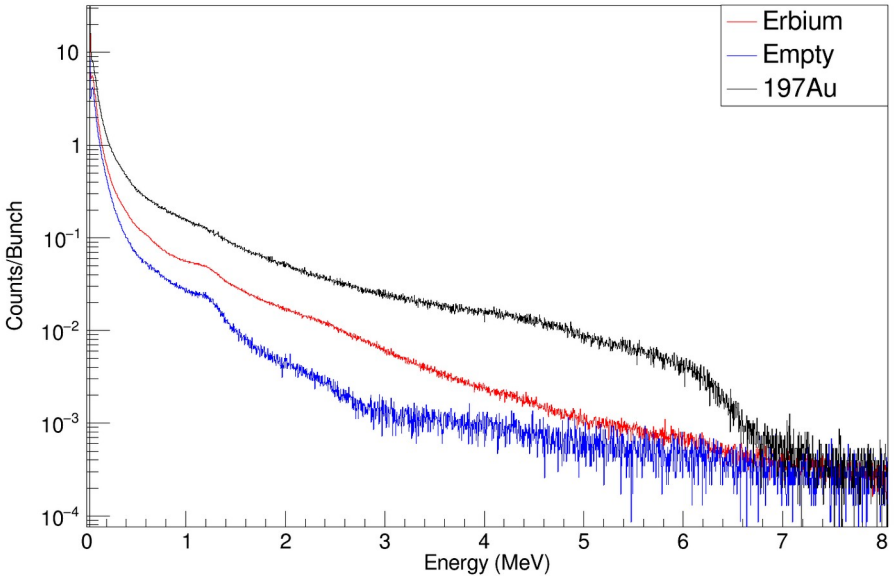
Filter measurements confirm accurate background levels.

At resonance energy, all neutrons are captured by the filters.

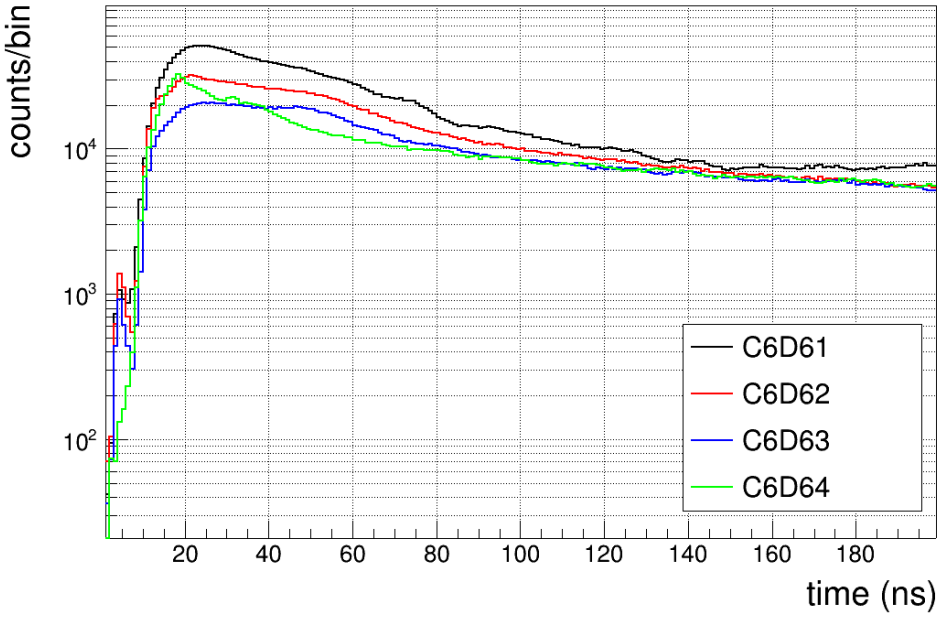
The resonance peaks seamlessly merge with the background spectrum.



Amp of Au, ^{166}Er, Empty: crossed at around 7 MeV



Comparison of Td plots of 4-C6D6 detectors



In the preliminary analysis, 8 MeV is used as maximum threshold and 150keV is used as minimum threshold. From this Td plots, 20 ns used as dead time.

Background Subtraction

Sources of Background:

Sample independent Bgr (depends on time) → Directly subtracted from the Samples

Sample dependent neutron scattering → Spectrum of the C scaled with density & elastic x-section

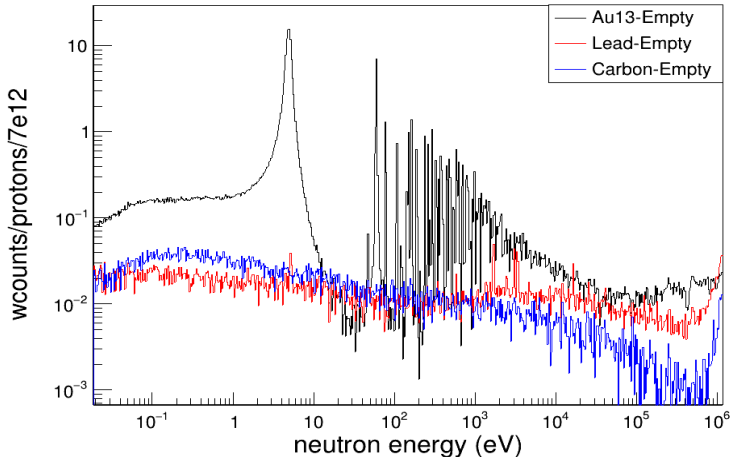
$$\frac{\sigma_{Er}^{el}}{\sigma_{C}^{el}}\frac{\rho_{Er}\left(atms/barn\right)}{\rho_{C}\left(atms/barn\right)}$$

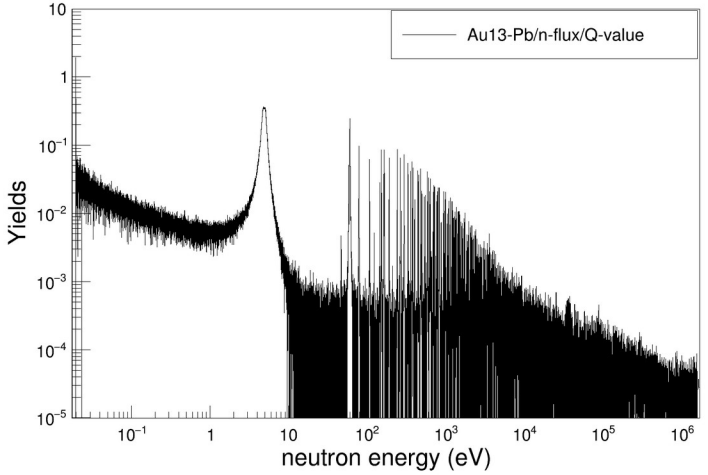
Sample dependent in-beam g-ray scattering → Spectrum of the Pb scaled with density and atomic number

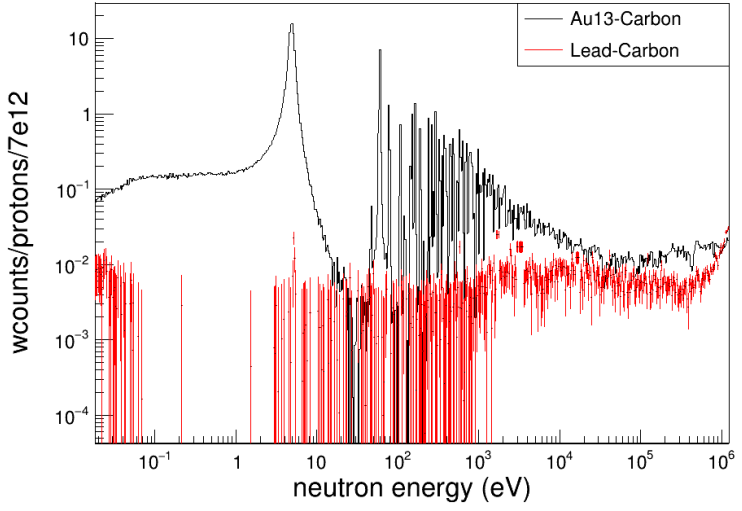
$$\frac{\sigma_{Pb}^{el}}{\sigma_{C}^{el}}\frac{\rho_{Pb}\left(atms/barn\right)}{\rho_{C}\left(atms/barn\right)}$$

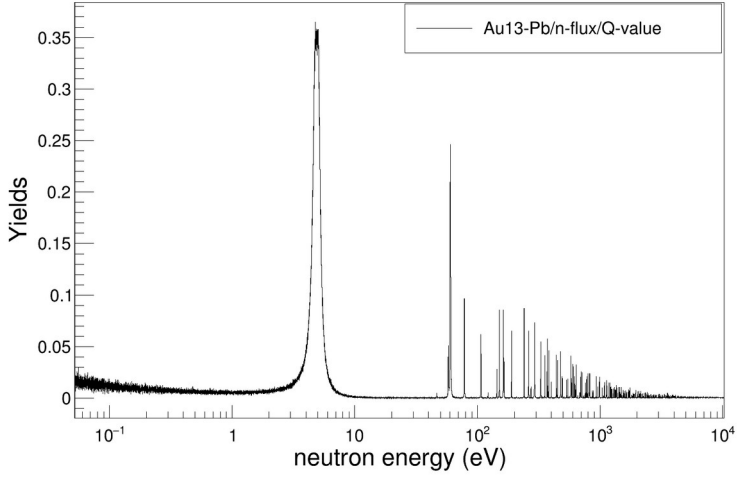
$$\frac{Z_{Er}}{Z_{Pb}}\frac{\rho_{Er}\left(atms/barn\right)}{\rho_{Pb}\left(atms/barn\right)}$$

^{197}Au-13 Yields

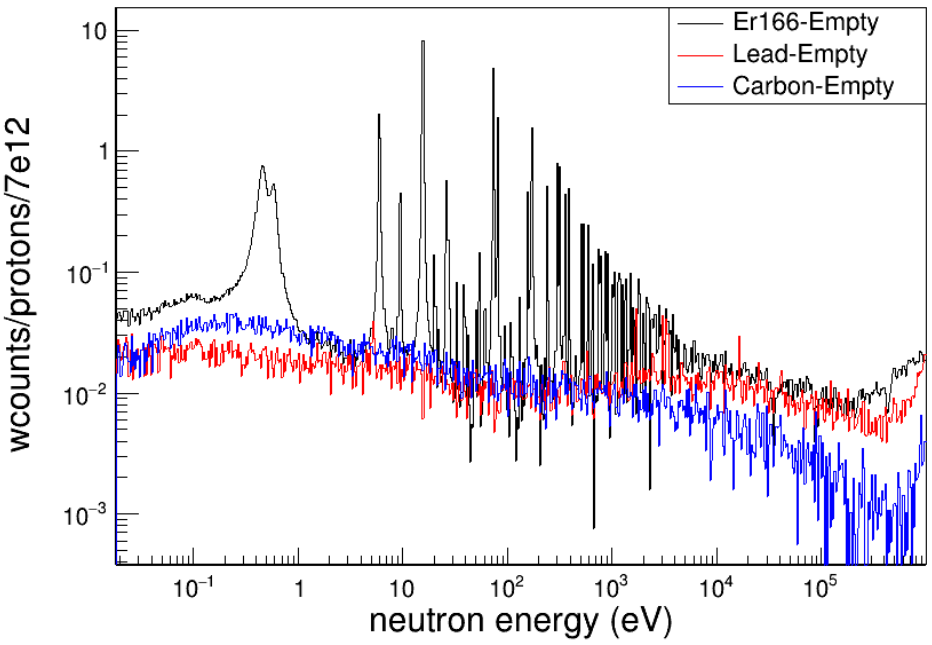


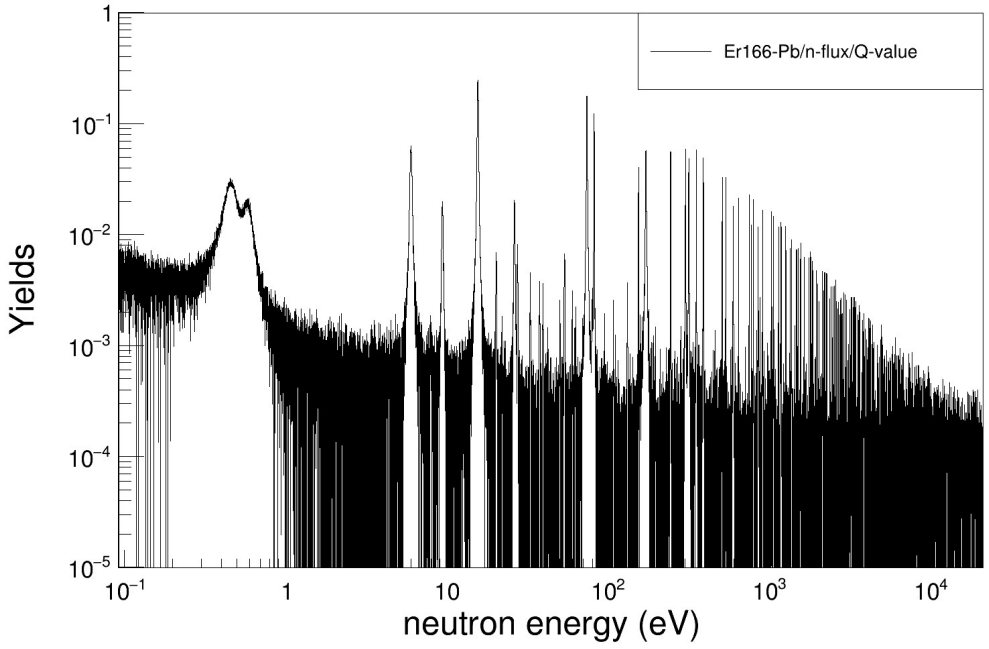




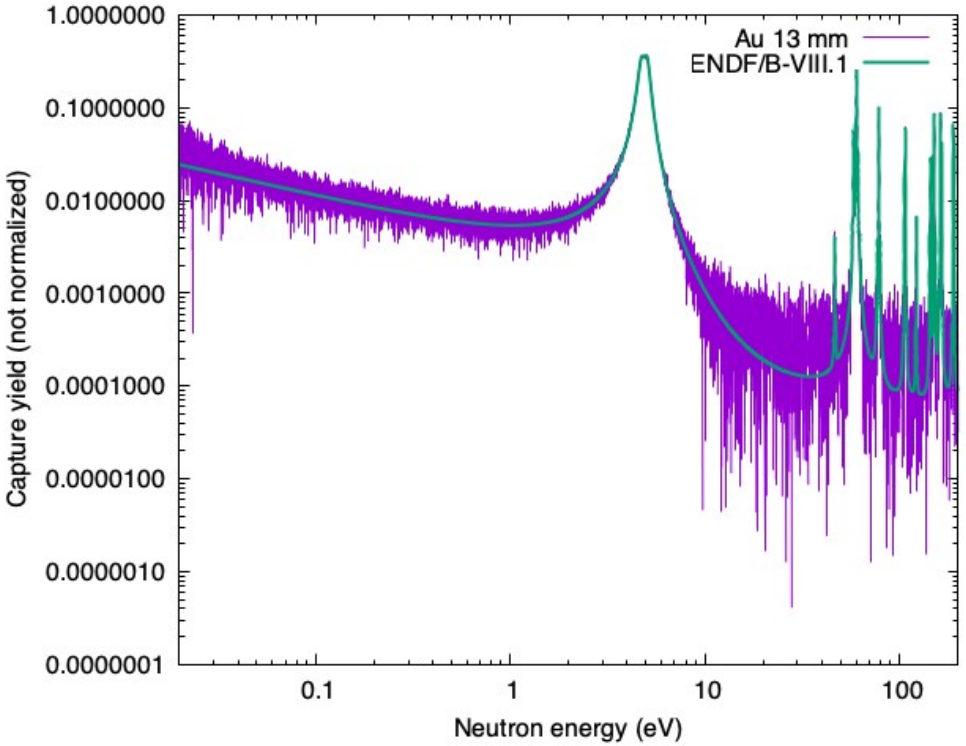


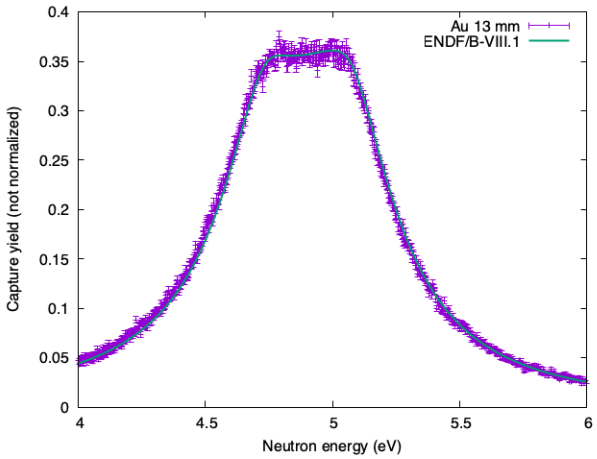
^{166}Er Yields Calculations

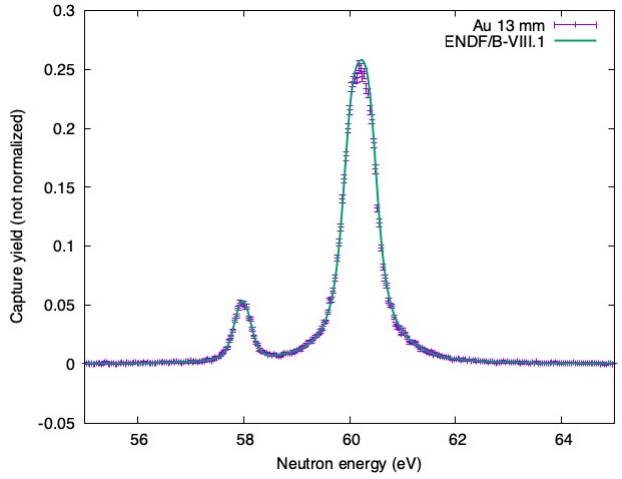




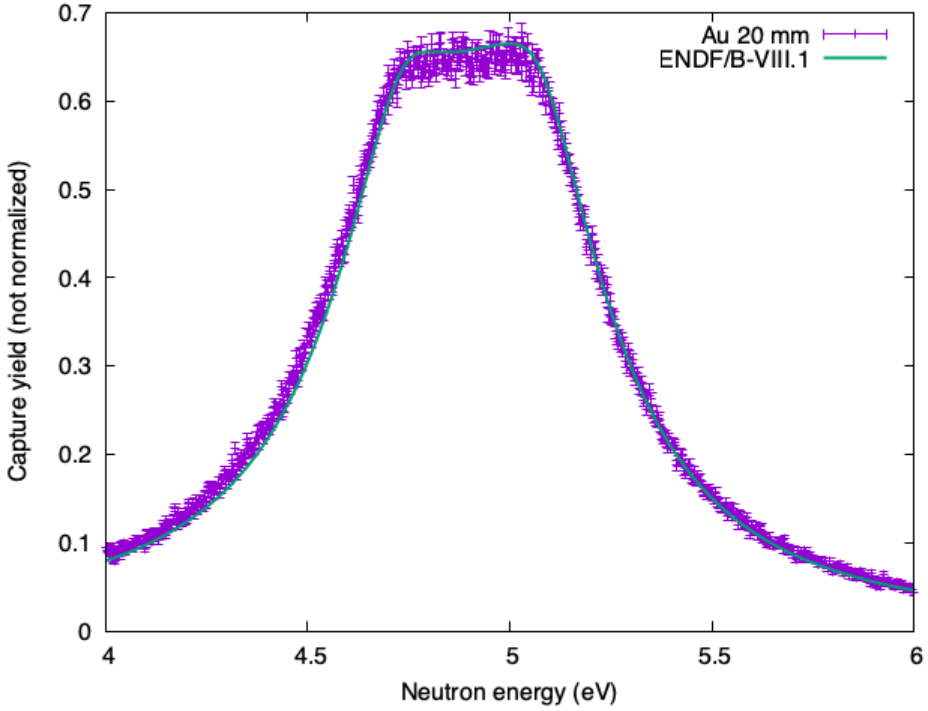
^{197}Au-13mm: Analysis with SAMMY-R-Matrix Calculations

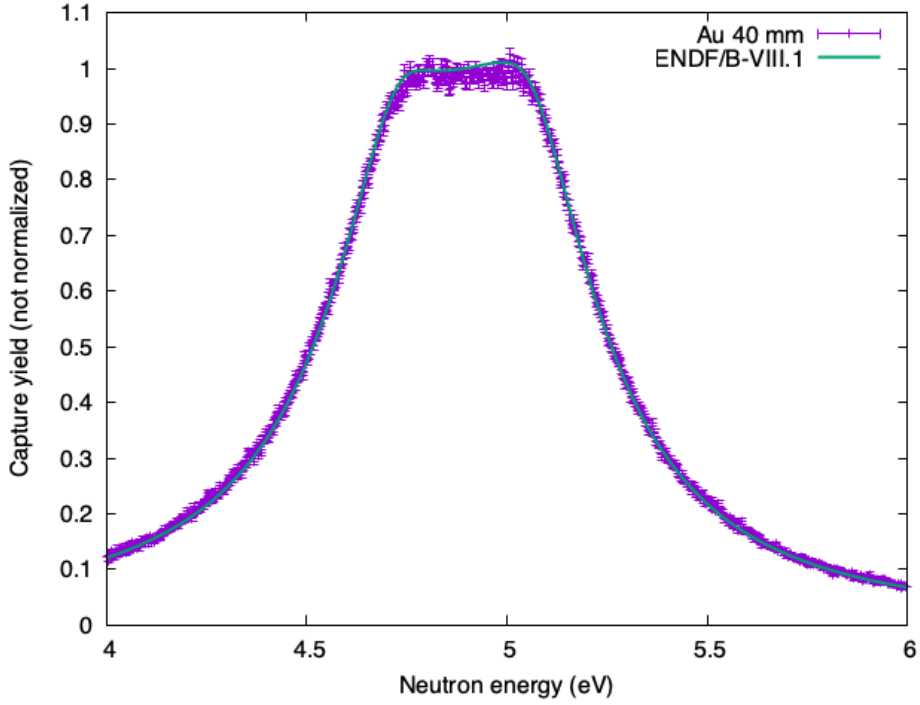




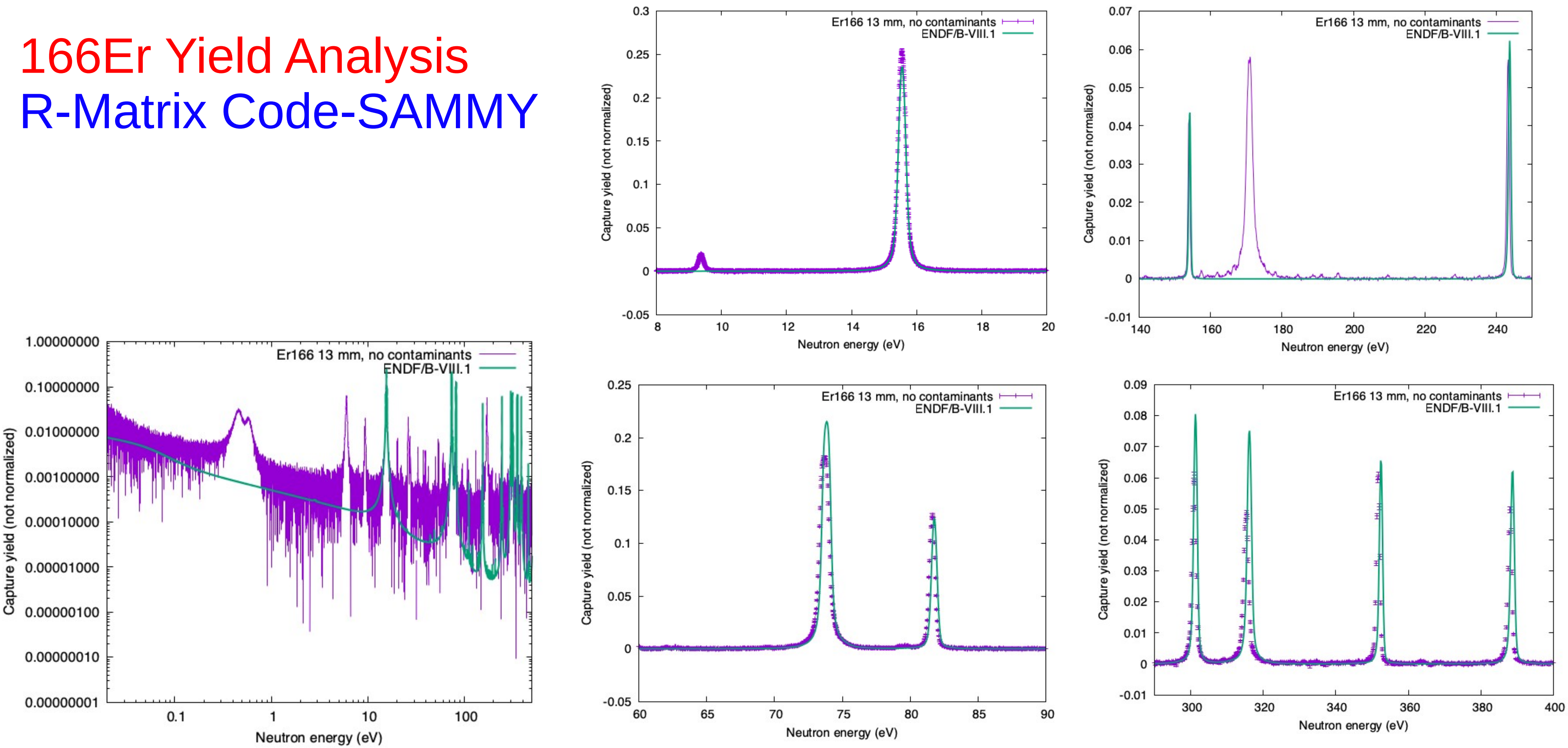


Saturated resonance of ^{197}Au:
Different Diameter: 20mm and 40mm

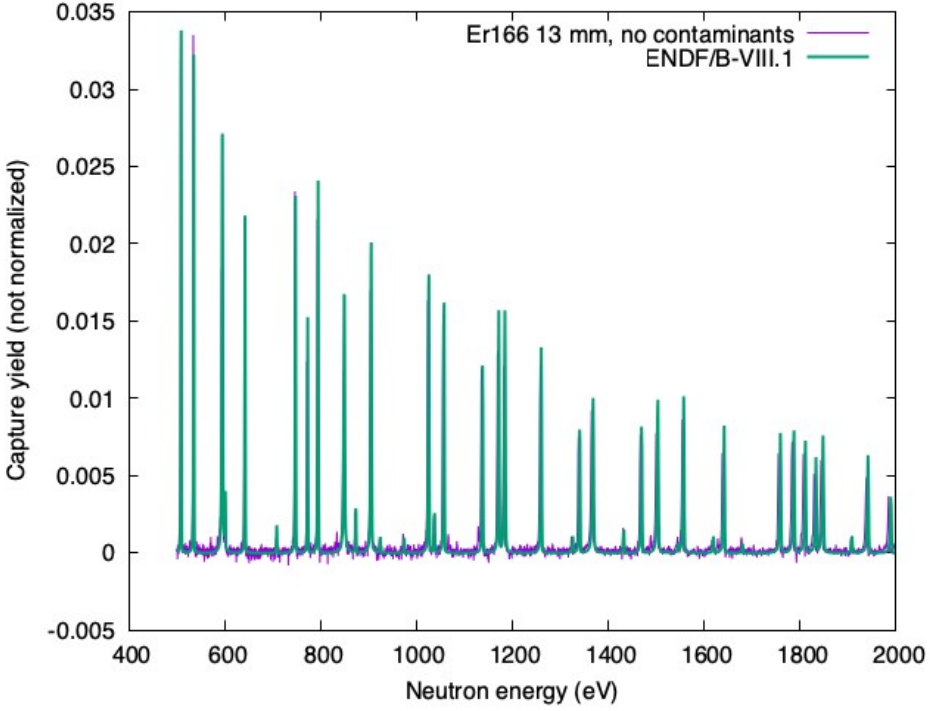




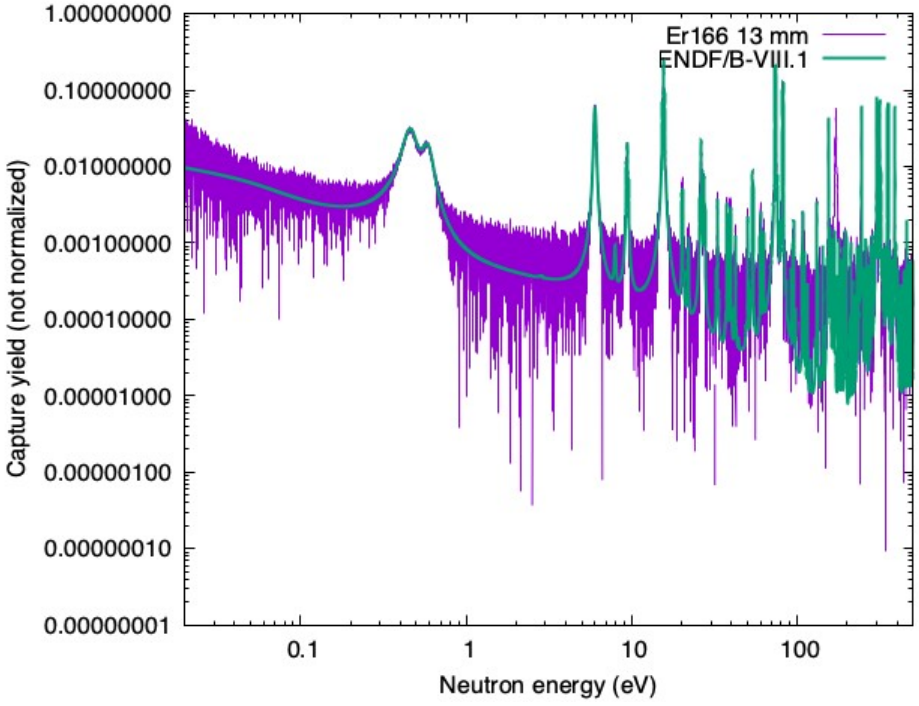
166Er Yield Analysis
R-Matrix Code-SAMMY



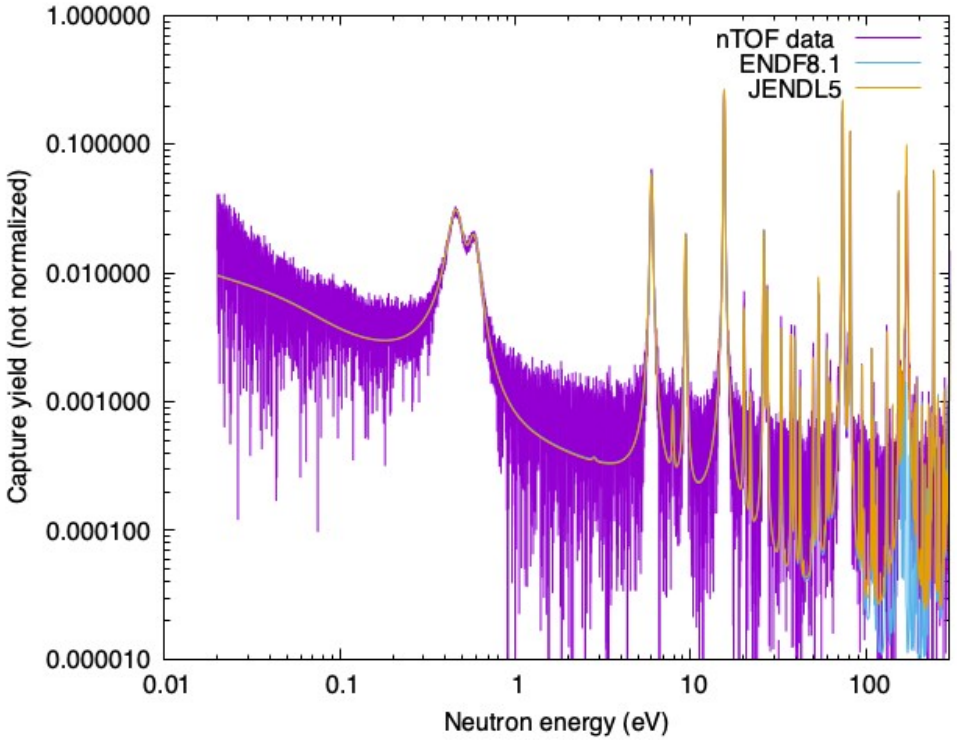
Resonances of ^{166}Er between 0.4 KeV to 2 KeV

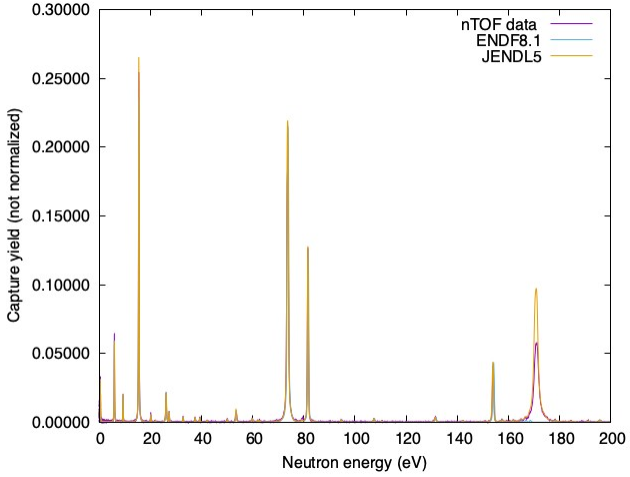


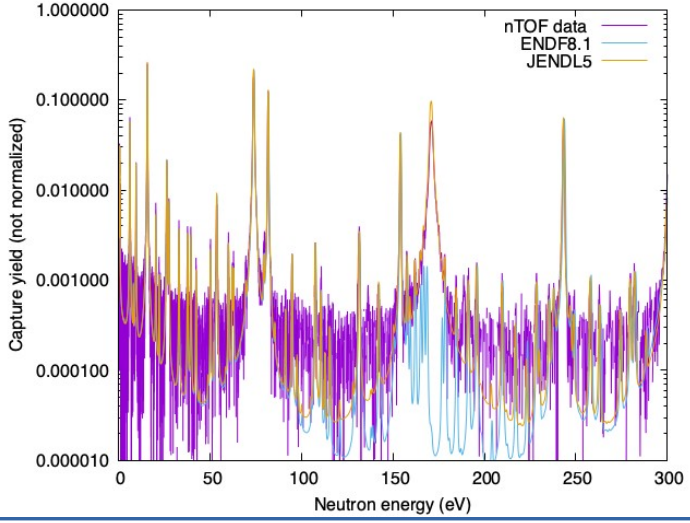
When ^{167}Er impurity included with ^{166}Er Analysis



Preliminary yields, R-matrix with calculations with ENDF and JENDL







Summary and Outlook

The experiment was successfully completed in June-July 2024.

Preliminary yield calculations have been performed.

Initial results indicate high-quality data.

Further data refinement is required to minimize errors.

The capture kernel will be calculated to determine the MACS.

Acknowledgments

Funding from INFN Bologna, Euro lab, and n_TOF collaborations

All the members and local team of n_TOF Collaborations

Thanks for your attention

ISOTOPE	Er-162	Er-164	Er-166	Er-167	Er-168	Er-170
CONTENT (%)	<0.01	0.02	98.10(±0.10)	1.33	0.45	0.10