^{166}Er Neutron Capture Measurement at n_TOF facility

Rudra N Sahoo
INFN Postdoc Fellow
INFN Bologna, Italy

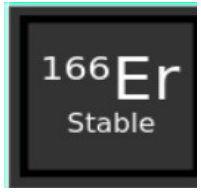
Cristian Massimi (Advisor)

V. Alcayne, S. Amaducci, D. Cano-Ott, A. Casanovas, D. M. Castelluccio, S. Cristallo, G.Grasso, E. González-Romero, A. Guglielmelli, A. Manna, T. Martínez, E. Mendoza, R. Mucciola, A. Sánchez-Caballero, P. Schillebeeckx, D. Vescovi, A. Perez de Rada and the n_TOF collaboration

Outline

- Recap of the Previous Presentation
  - Experimental Set-up
  - Measured Data
- Yield Evaluation
  - ^{197}Au with 13mm, 20mm and 40mm diameter
  - ^{166}Er and ^{Nat}Er
- R-Matrix Analysis with SAMMY
- Interpretations of the Kernel
- Summary and Next Plans

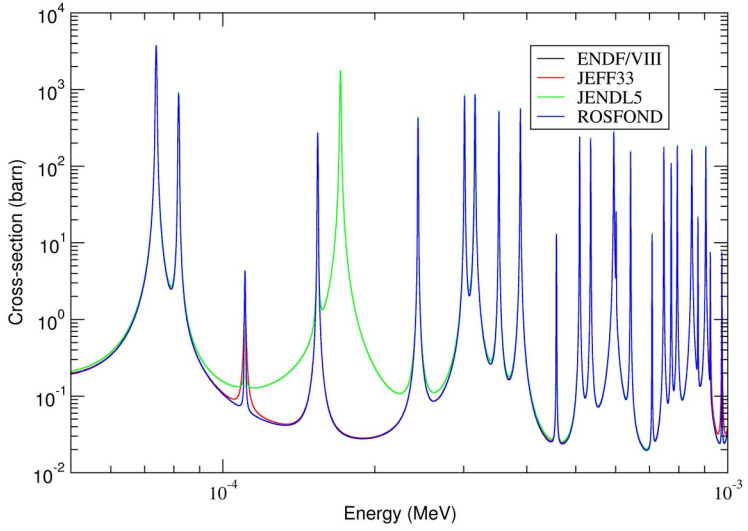
Recap of the Previous Talk



Introduction

Rare earth element, Lanthanide series of the periodic table

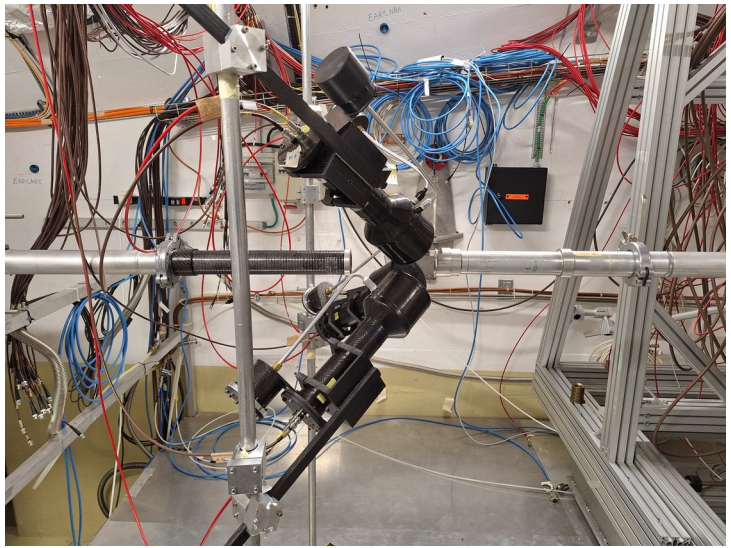
- **Reactivity Control:** ^{166}Er serves as a key neutron absorber used to optimize reactor operations.
- **Stellar Insights:** Accurate neutron capture data will be used for stellar modeling.

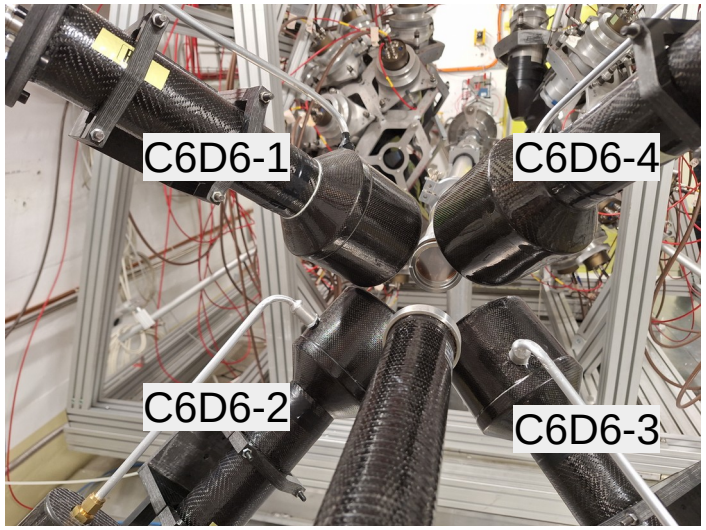


V. Alcayne, S. Amaducci, J. Andrzejewski et al. (the nTOF Collaboration), CERN-INTC-2023-015 / INTC-P-656
A. Guglielmelli, F. Rocchi, C. Massimi et al., Annals of Nuclear Energy 178, 109337 (2022)

Experimental Set-up

n_TOF facility at CERN@ EAR1



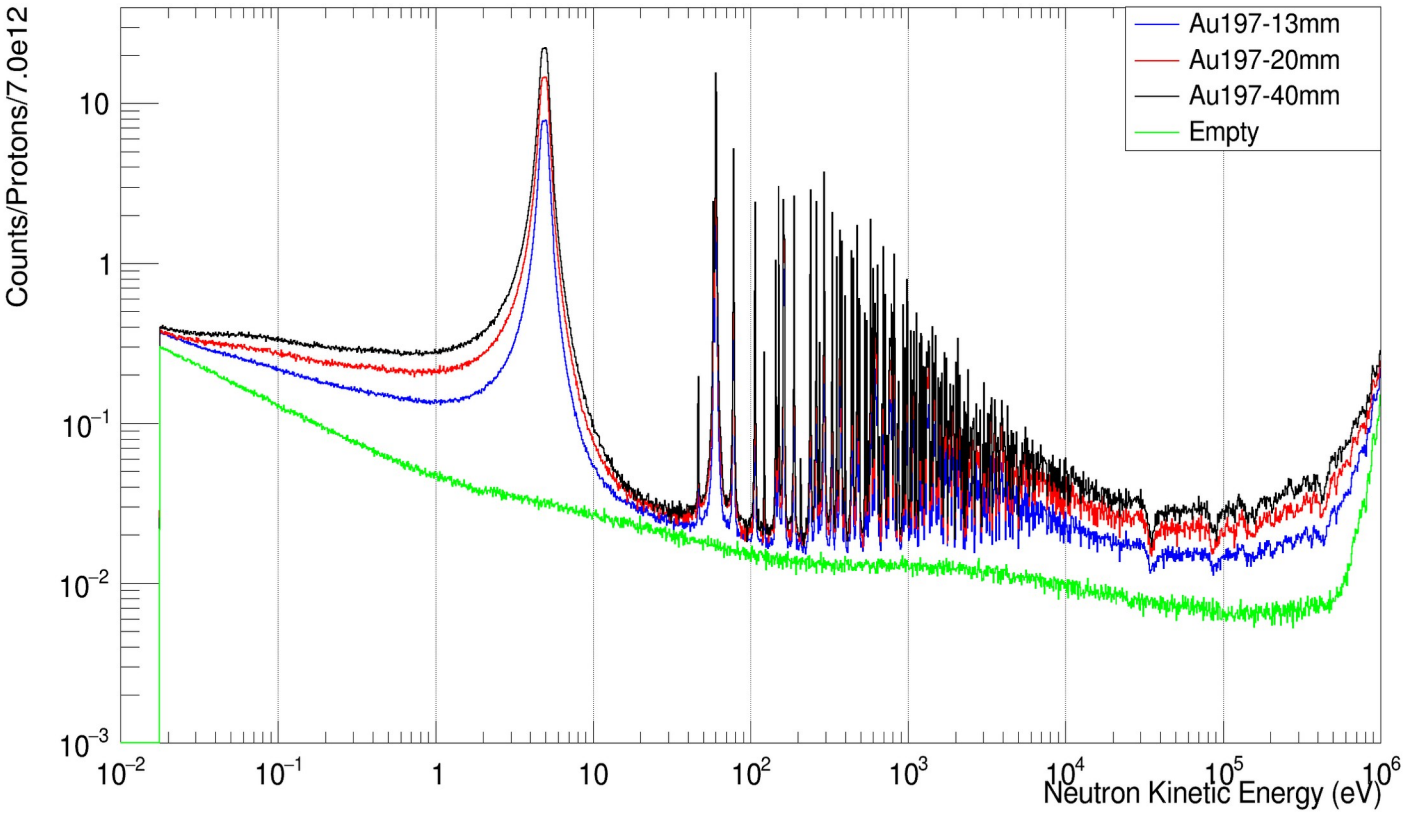


Er166
13mm-224.7mg

- **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

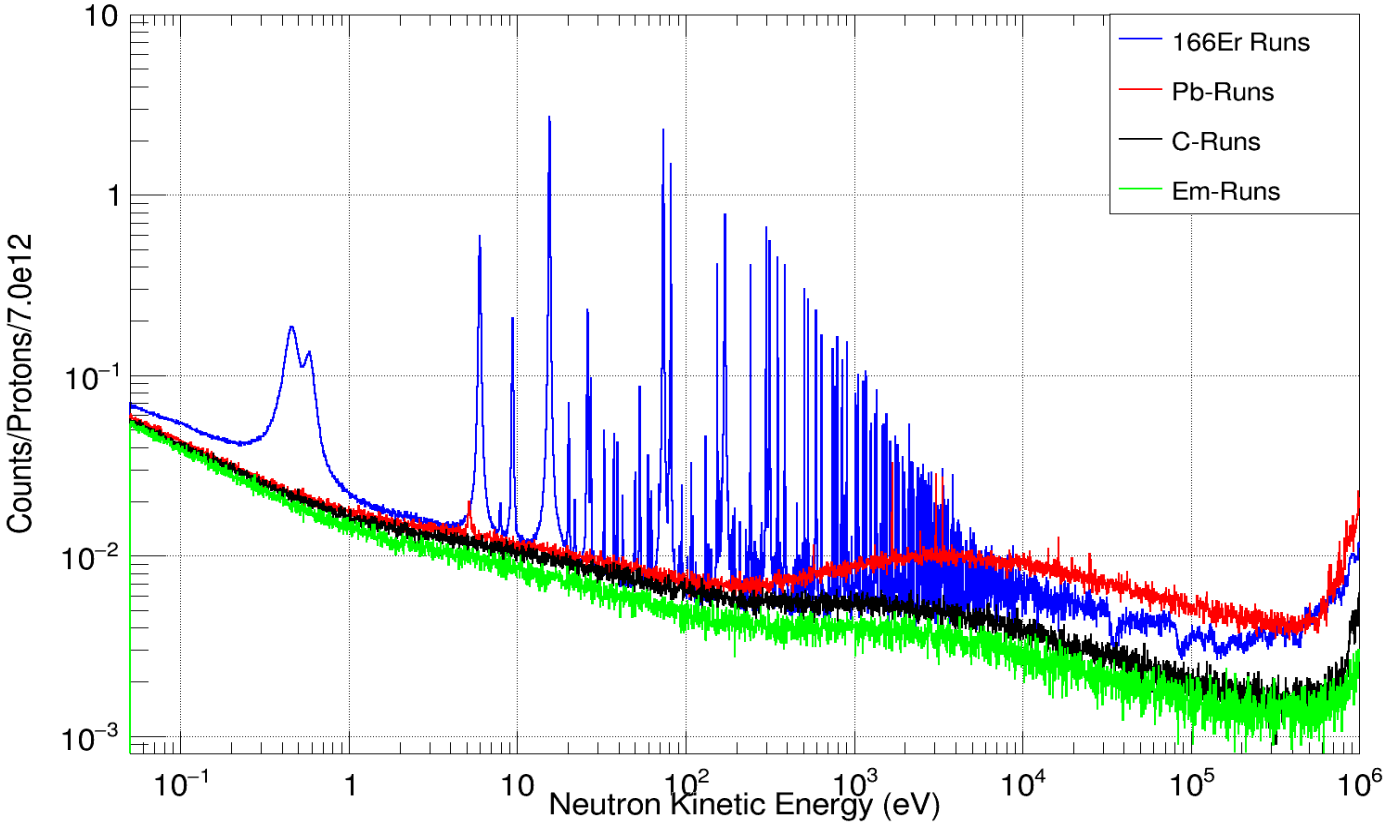
ISOTOPE	Er-166
ENRICHMENT	98.10(±0.10)%
ELEMENT WEIGHT	
FORM	Oxide (Er_2O_3)

^{197}Au-Samples- Normalization



- Calibration, tflash position, parasitic and dedicated ratio, consistency in measurements,and dead time- presented.
- n+^{197}Au has been measured with different diameter to estimate the beam correction factor

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



- n+^{166}Er has been measured. In addition to that Pb and C has been measured to subtract background.
- The measurements are done with also different Bismuth and Sulfer filters to recheck and validate the measured data

Background Subtraction

Sources of Background:

Sample independent (depends on time)

Directly subtracted (empty) from the Samples

Sample dependent neutron scattering

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

Spectrum of the C scaled with density & elastic x-section

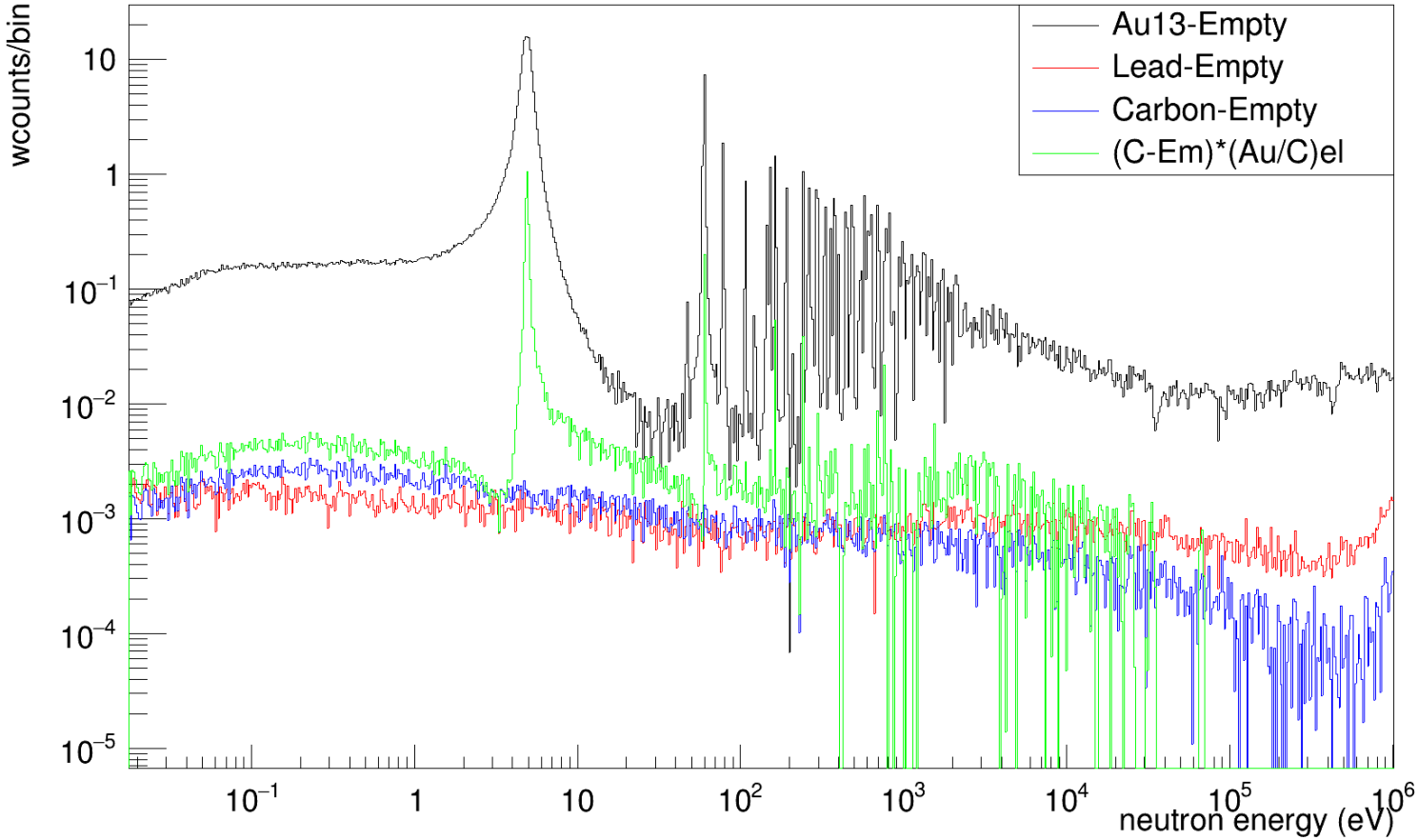
Sample dependent in-beam g-ray scattering

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

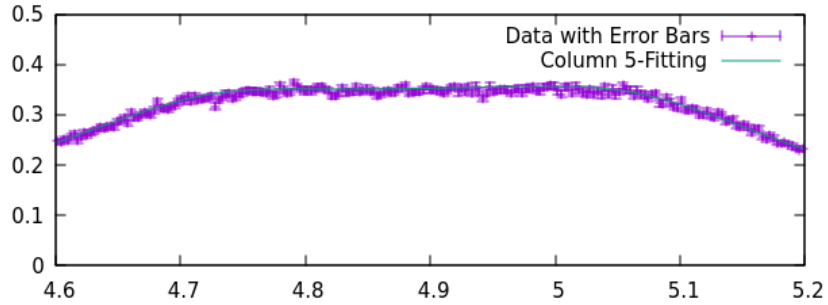
$$\frac{Z_{Er}}{Z_{Pb}}\frac{\rho_{Er}\left(atms/barn\right)}{\rho_{Pb}\left(atms/barn\right)}$$

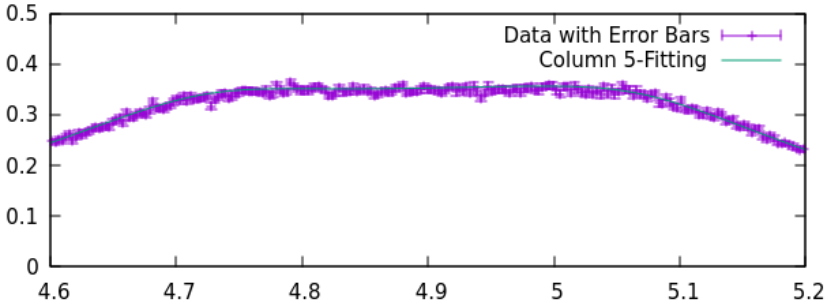
Spectrum of the Pb scaled with density and atomic number

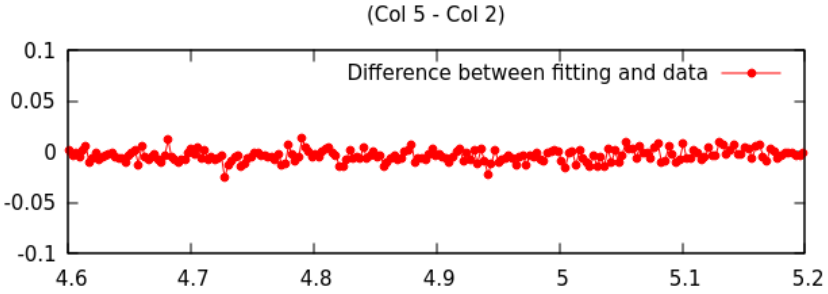
13mm-^{197}Au: Measured Data-Background Subtraction

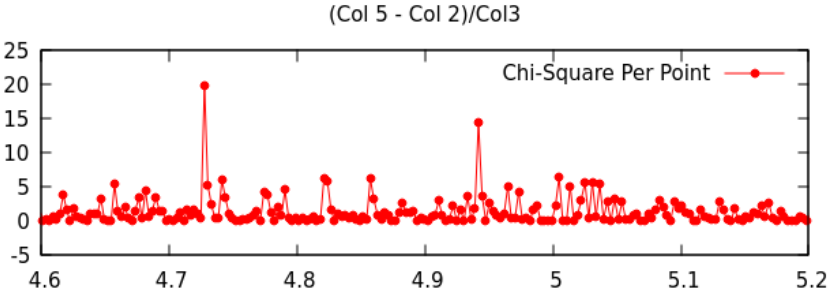


13mm-Au: Saturated Resonance







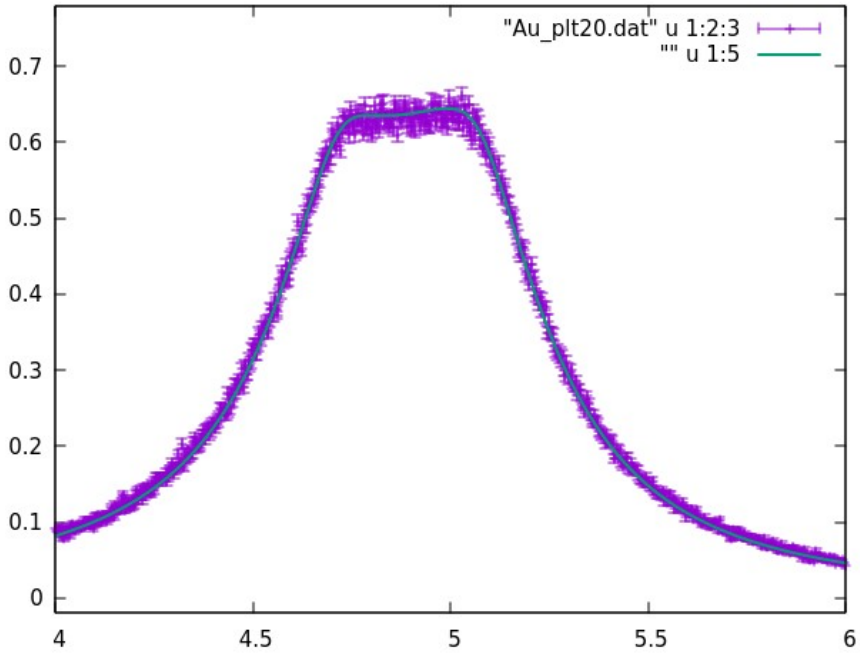


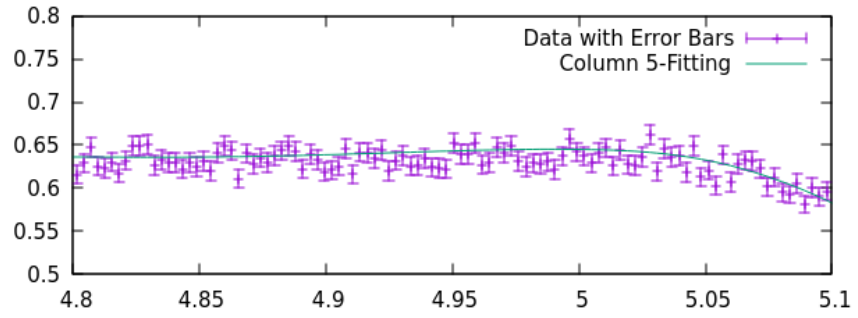
Normalization

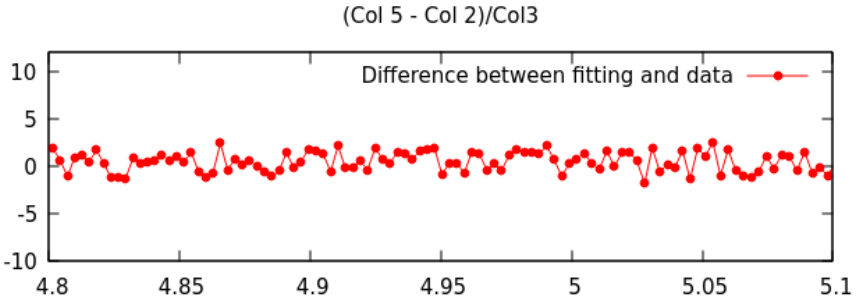
.360838729 0. 0. 0. 0. 0. 1 0 0 0 0 0

1.00000000 .01000000 1.00000-6 1.00000-8 0. 0.

20mm-197Au: Analysis with SAMMY



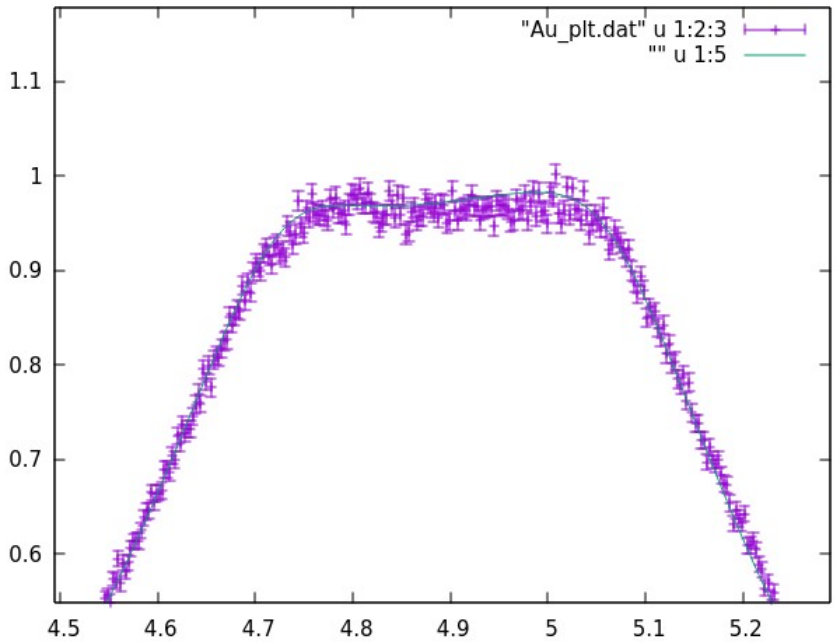


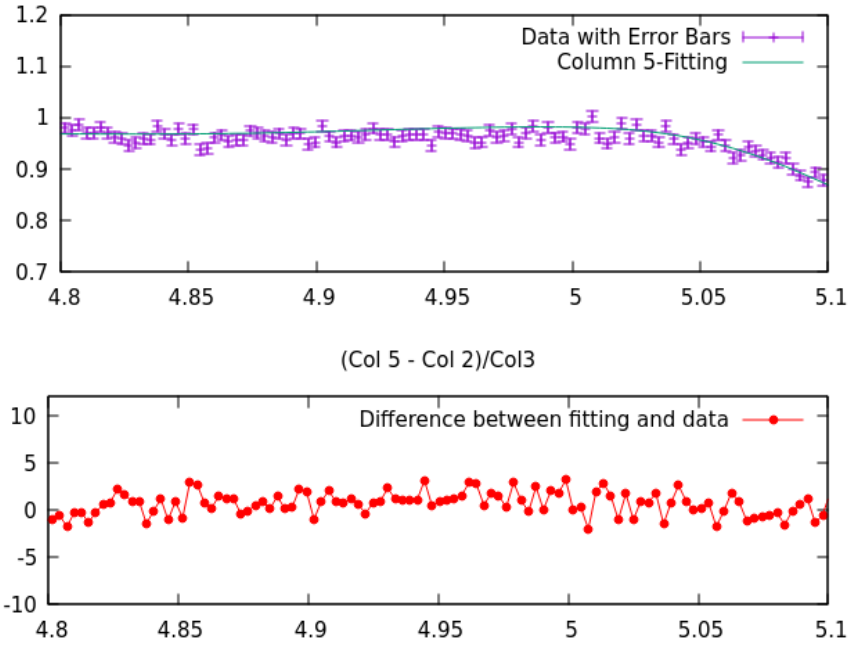


Normalization

.659649322 4.00815-5 0. 0. 0. 0. 1 0 0 0 0 0
1.00000000 .00010000 1.00000-6 1.00000-8 0. 0.

40mm-197Au: Analysis with SAMMY

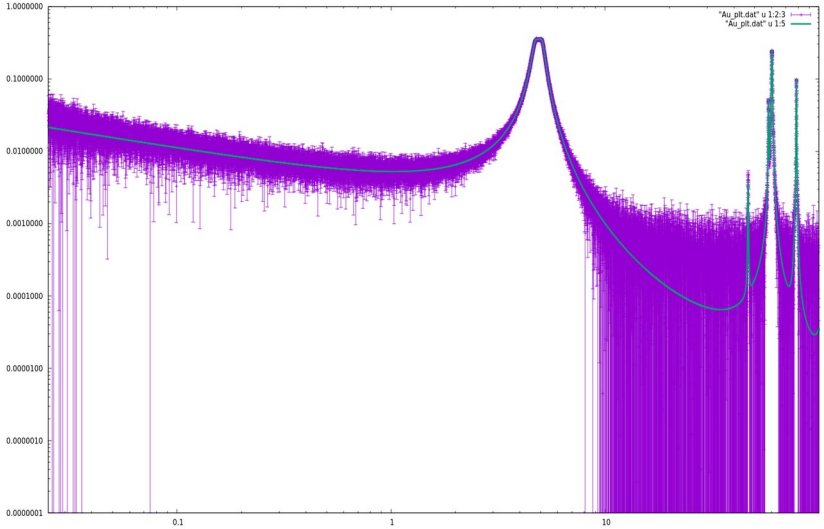


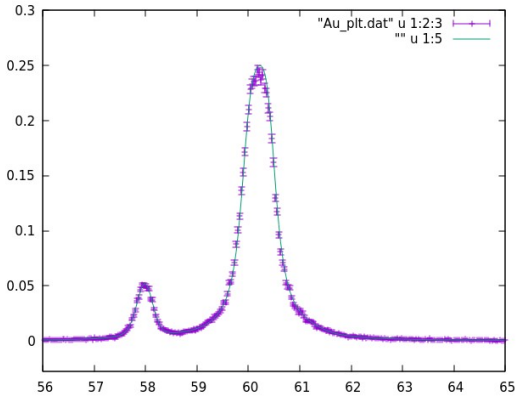


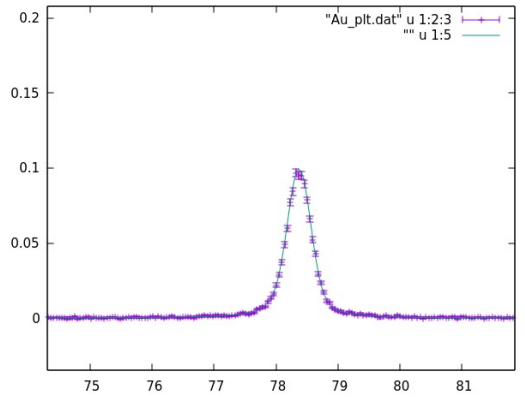
Normalization

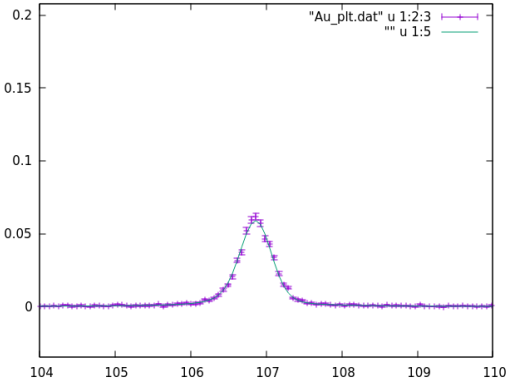
.994966003 9.10286-5 0. 0. 0. 0. 0 1 0 0 0 0
1.00000000 .00010000 1.00000-6 1.00000-8 0. 0.

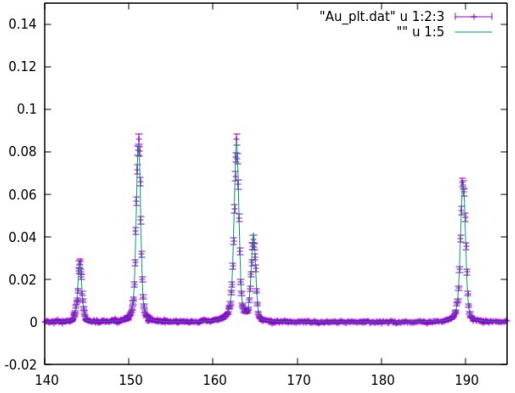
13mm-197Au: Analysis with SAMMY





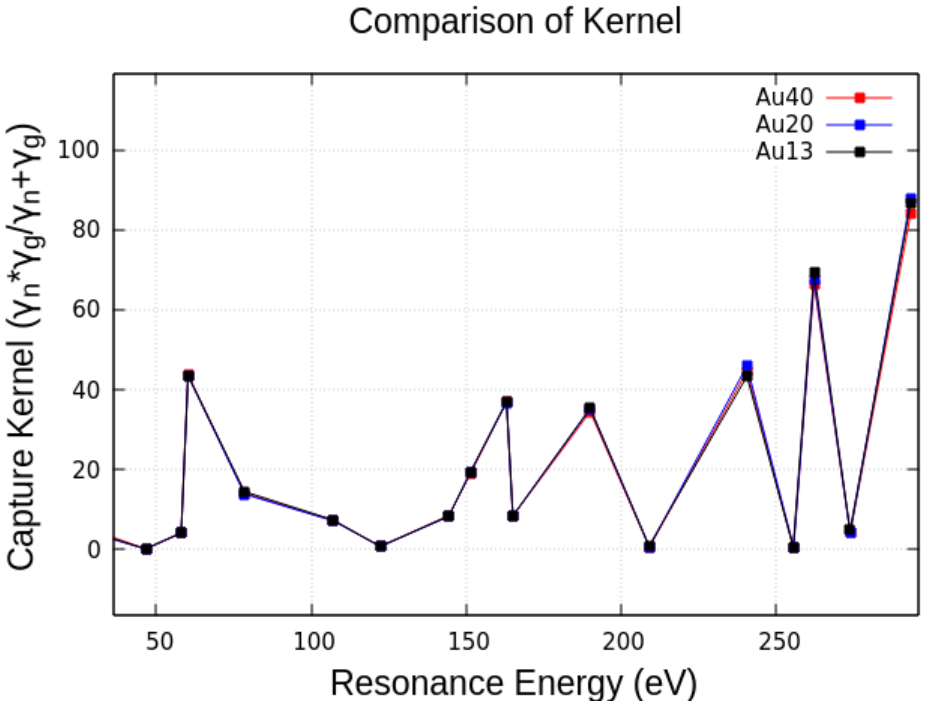


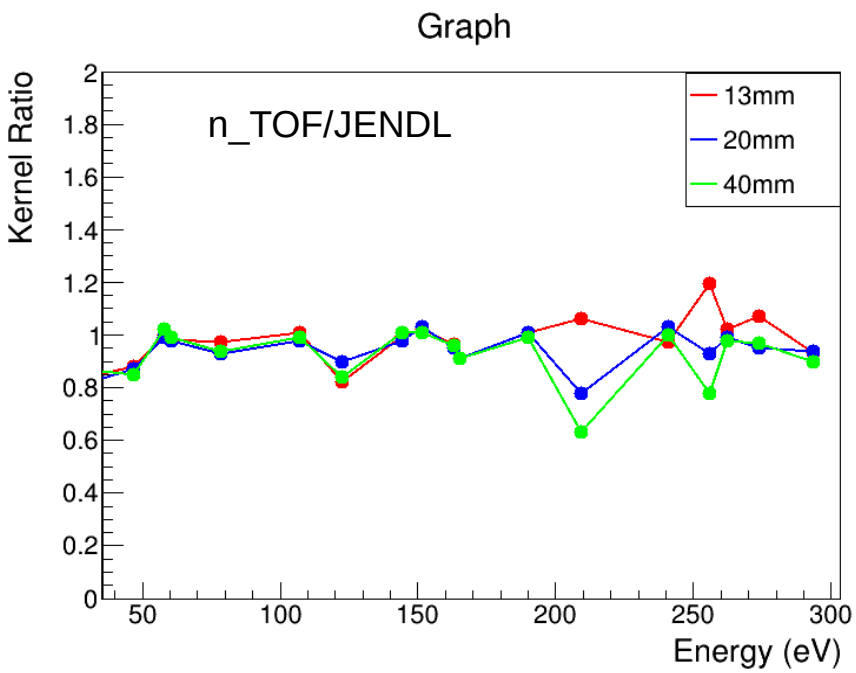




Note: 0.360 normalization used.
Resonances are well fitted with chi squire = 1.15

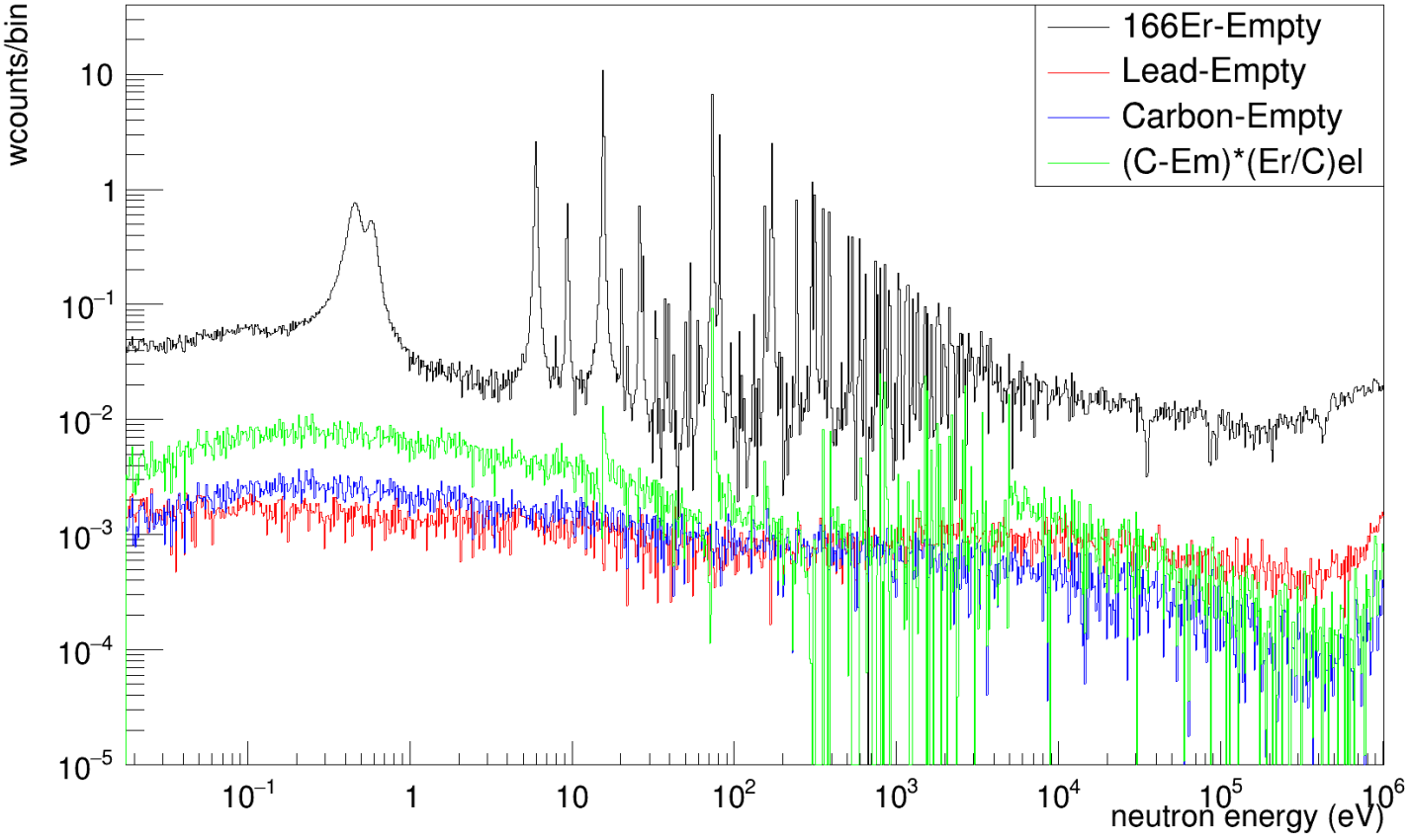
Comparison of 3-Gold Samples with Different Diameter





The kernel of the three gold samples are consistent to each other
Experimental and Lib kernel ratio also consistent with slight deviation
The Normalization factor 0.360 have been considered for Analysis of ^{166}Er and ^{Nat}Er

Yield Evaluation of ^{166}Er- after Background Subtraction

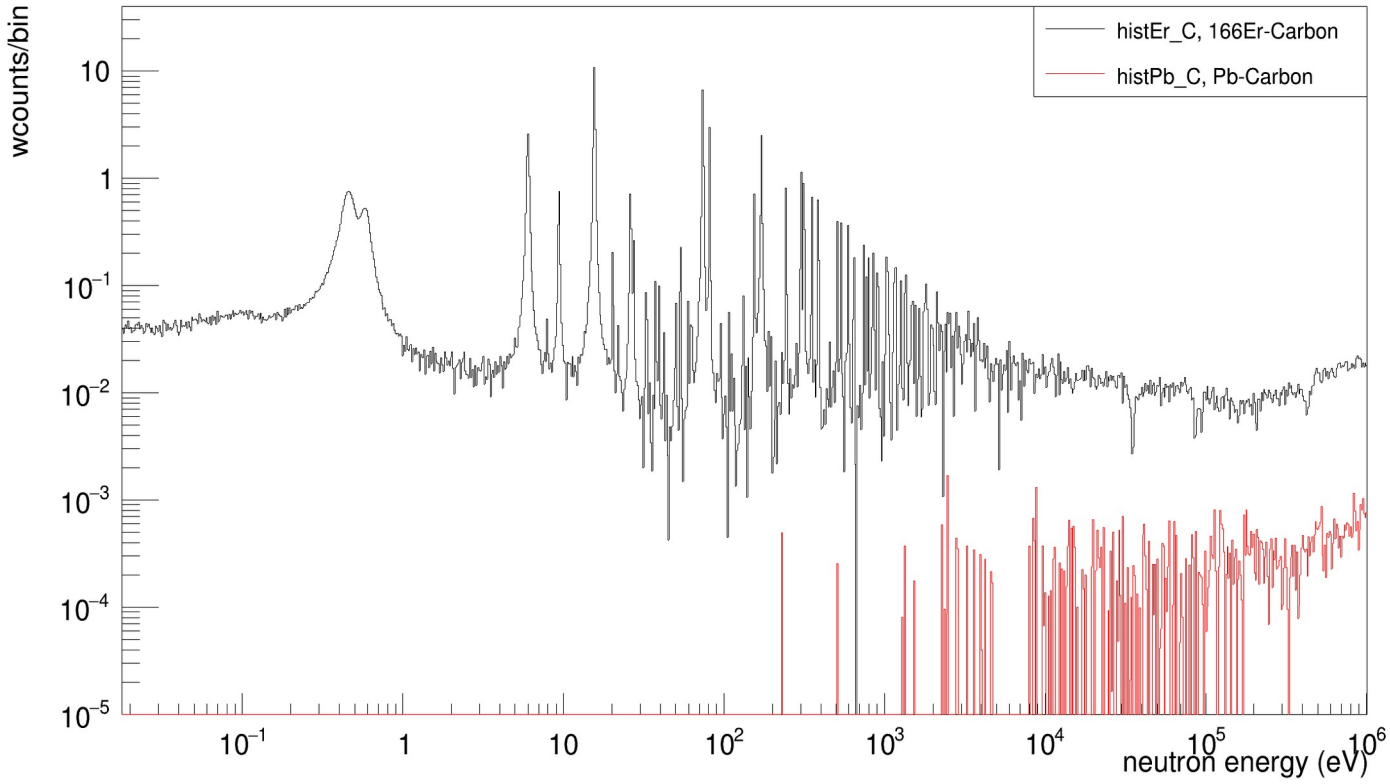


Unit = atom/barn
rho_C = 4.51e-3
rho_C20 = 8.72e-3
rho_Au = 6.15e-4
rho_Pb = 3.37e-4
rho_Er = 6.14e-4

The in beam g-ray has been subtracted in following procedure

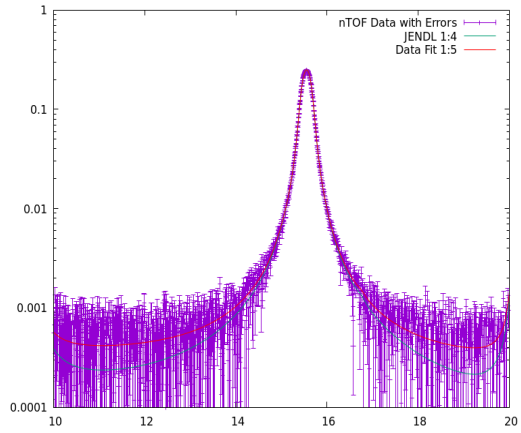
histPb->Scale(0.829);

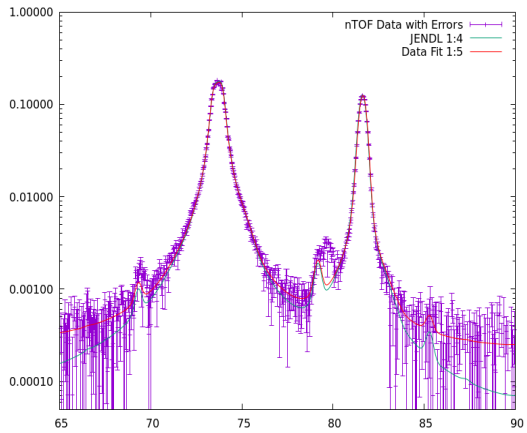
histPb->Scale(rho_Er/rho_Pb);

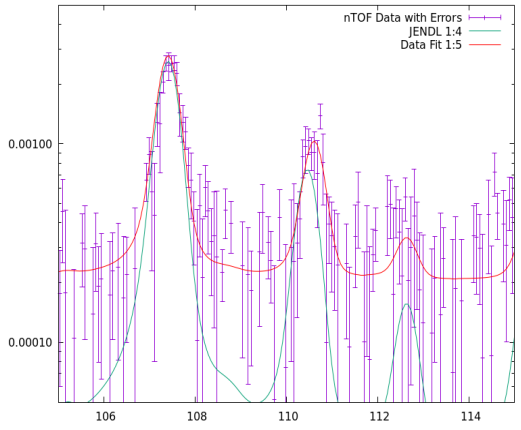


R-Matrix- (0.360)Resonances of ^{166}ER

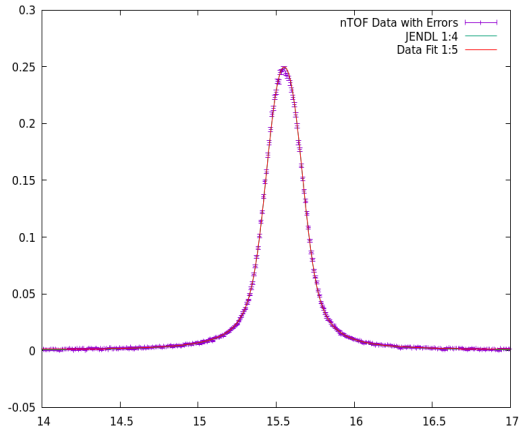
Log Scale

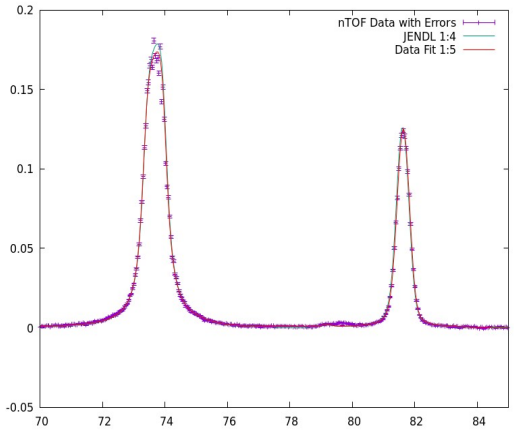


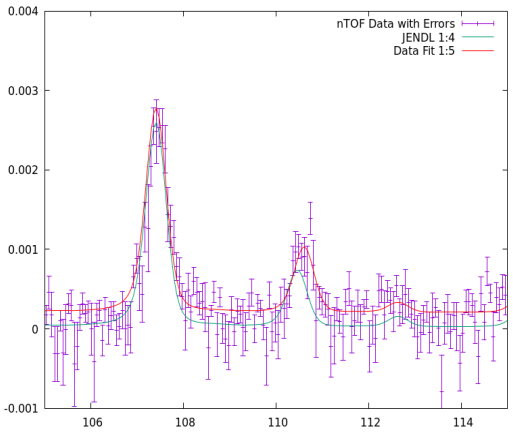




Lin Scale

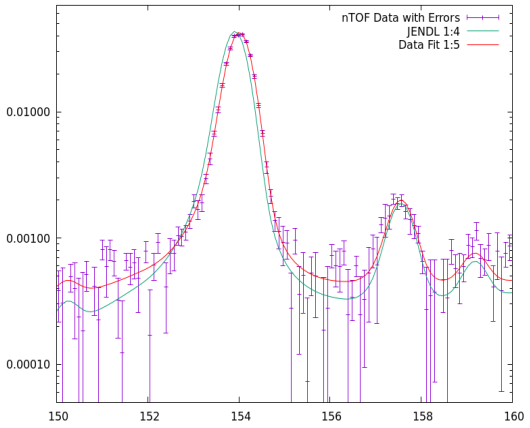


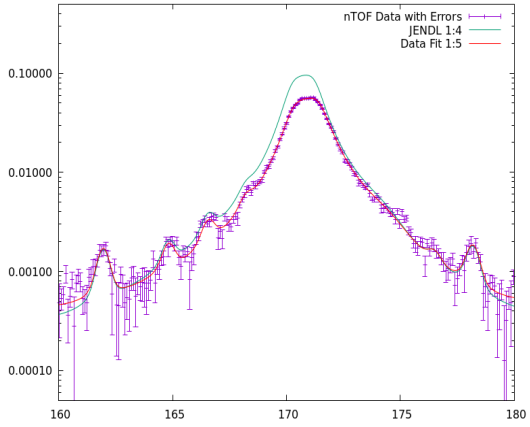


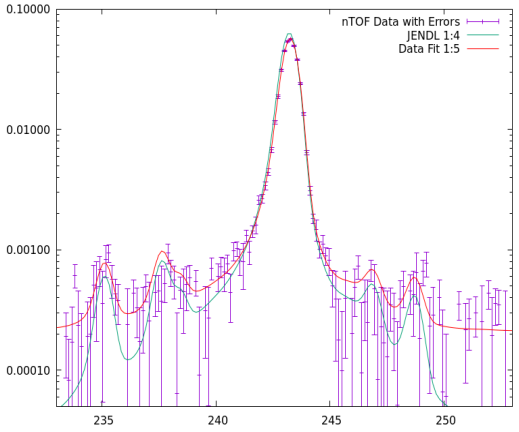


Few more **Resonances** of ^{166}ER

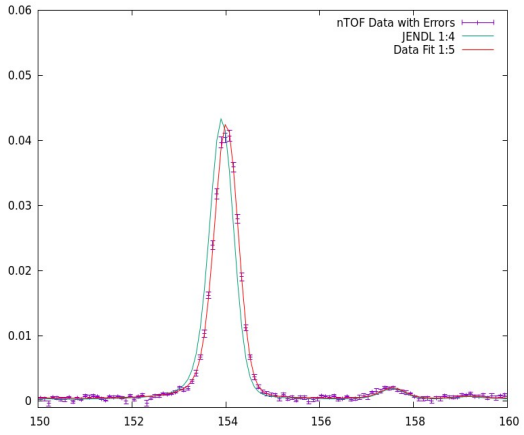
Log Scale

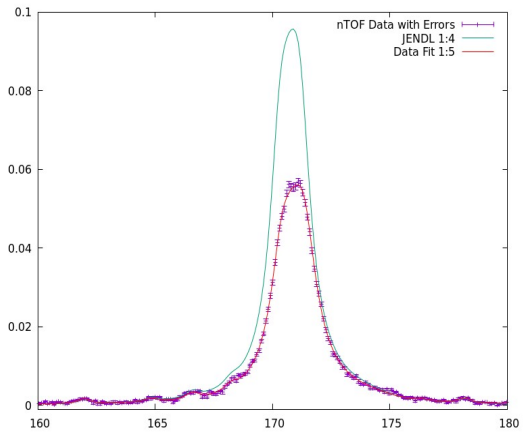


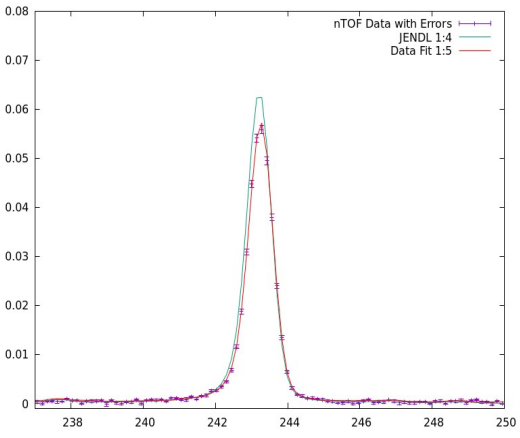




Lin Scale

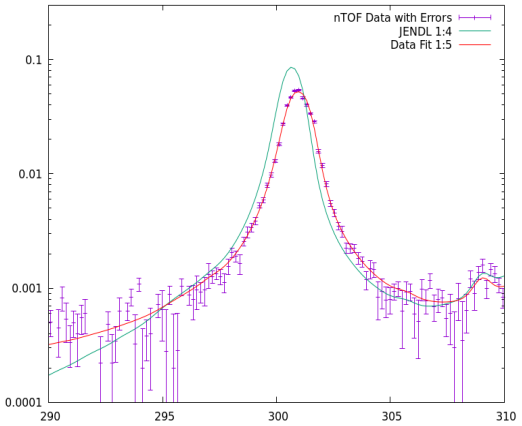


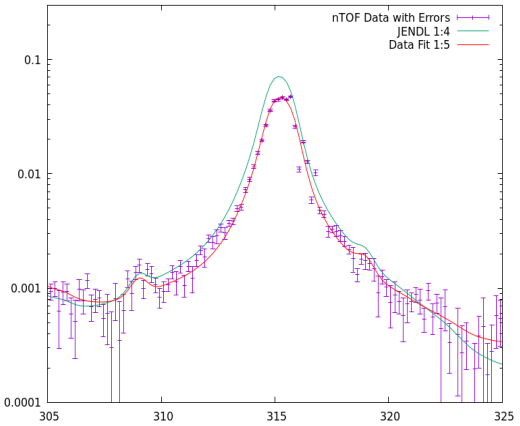


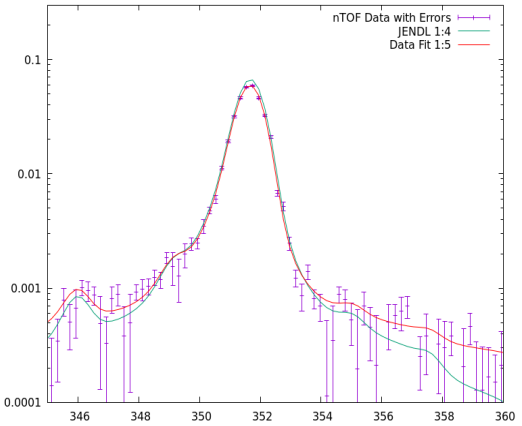


Few more **Resonances** of ^{166}ER

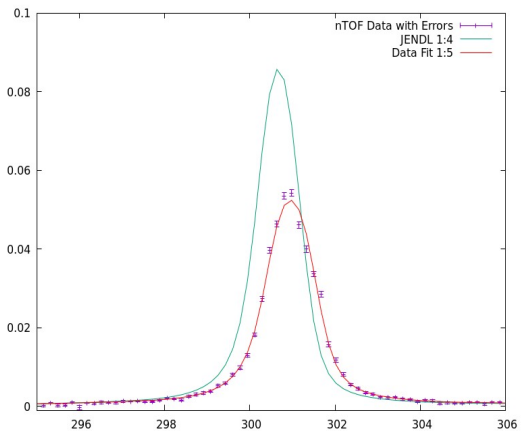
Log Scale

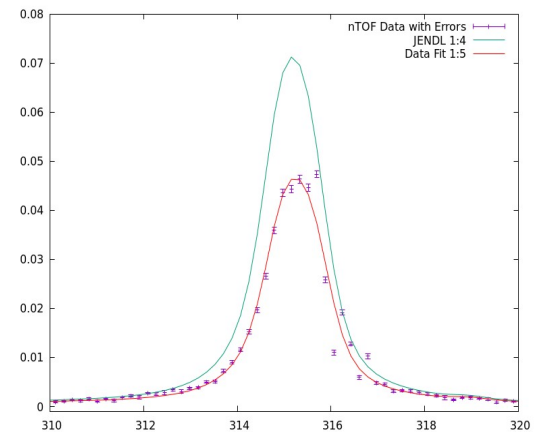


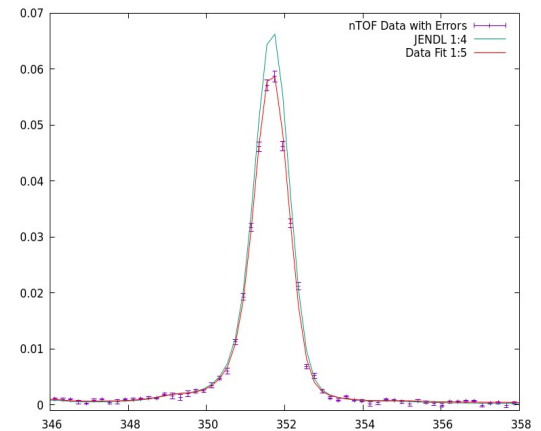




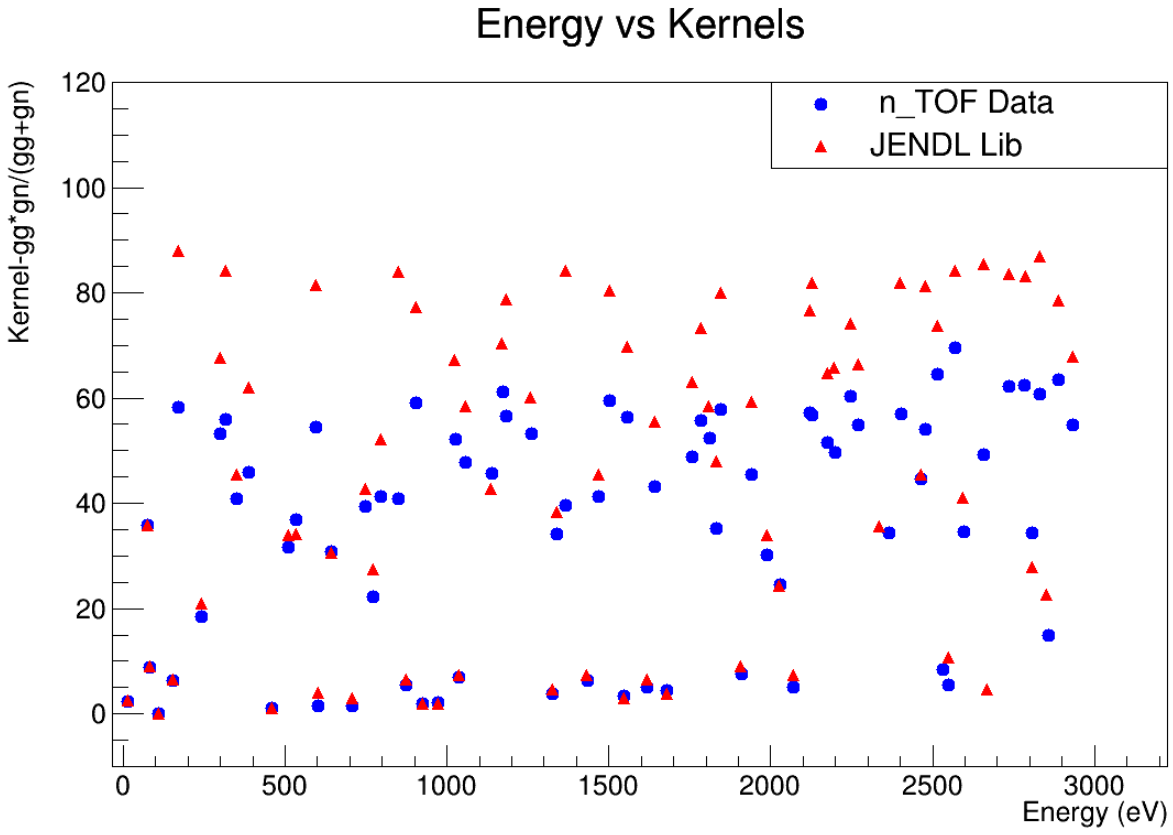
Lin Scale





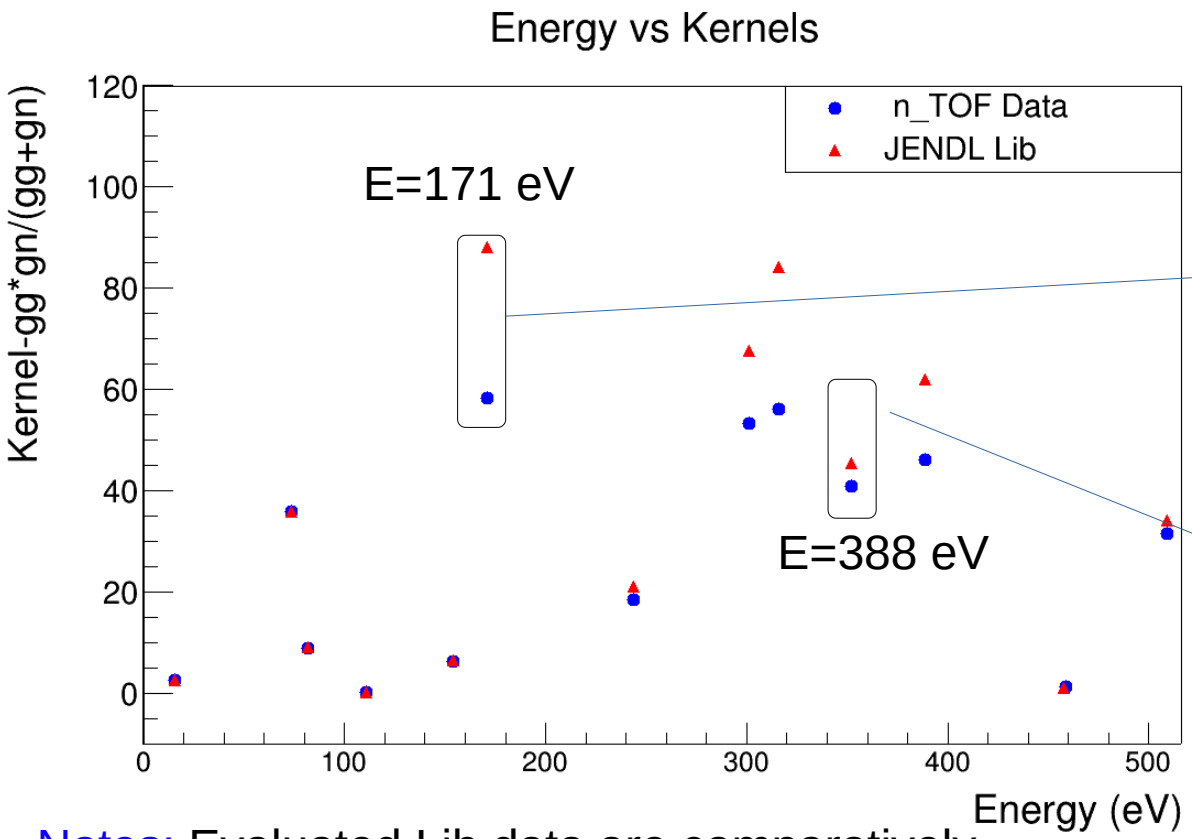


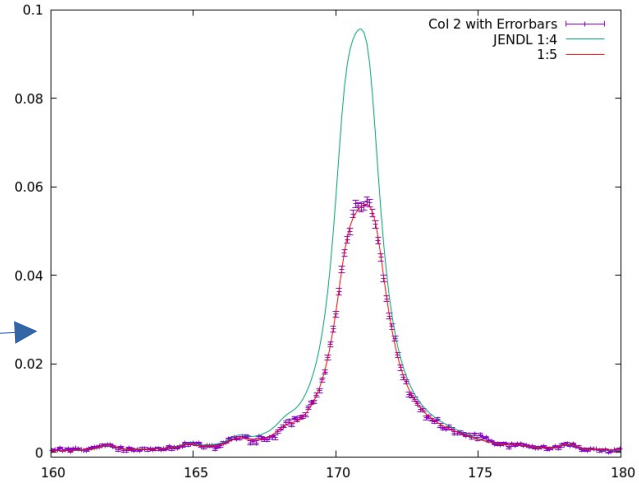
Kernel comparison of the n_TOF Data with JENDL Lib

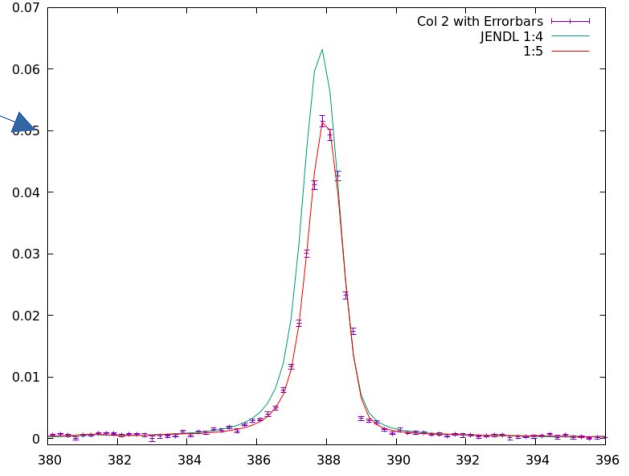


- The experimental kernels are 25% lesser compared to the Lib data
- Few Resonances are matching exactly with Lib evaluation

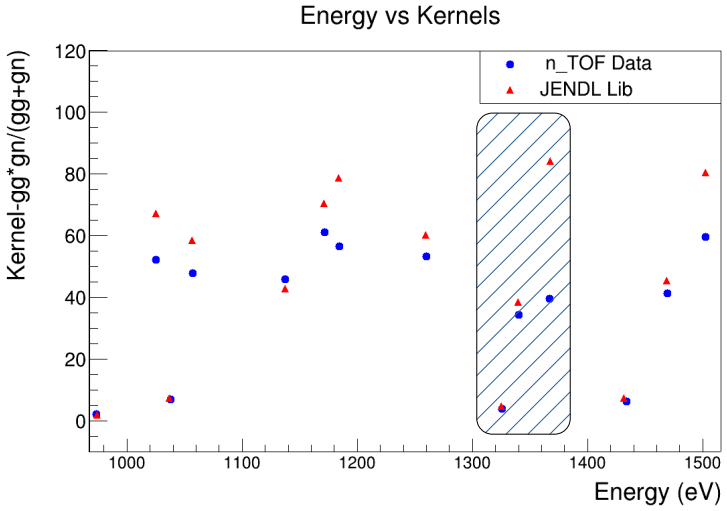
Energy Range: 0-500 eV

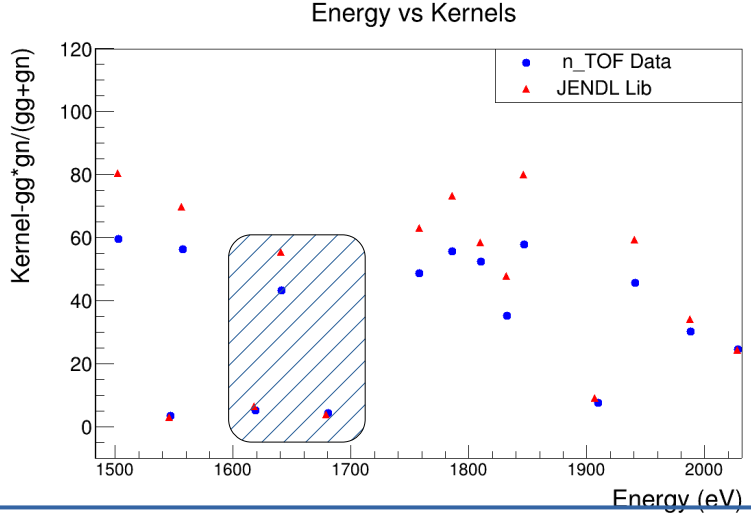


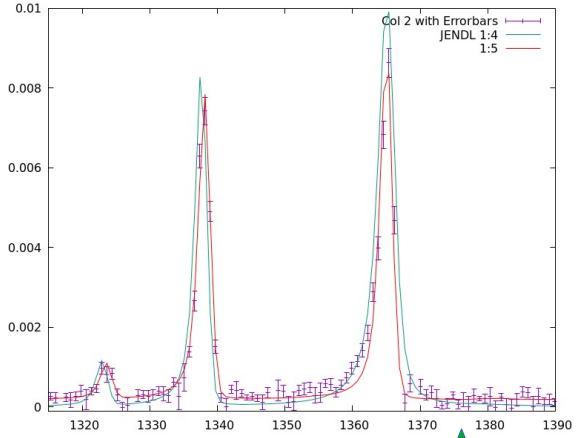


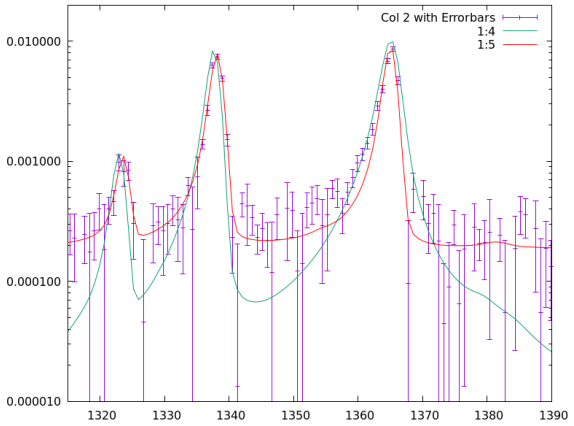


Notes: Evaluated Lib data are comparatively higher compared to measured data



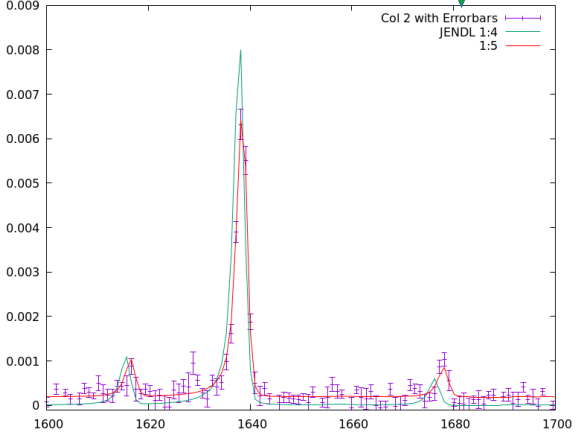


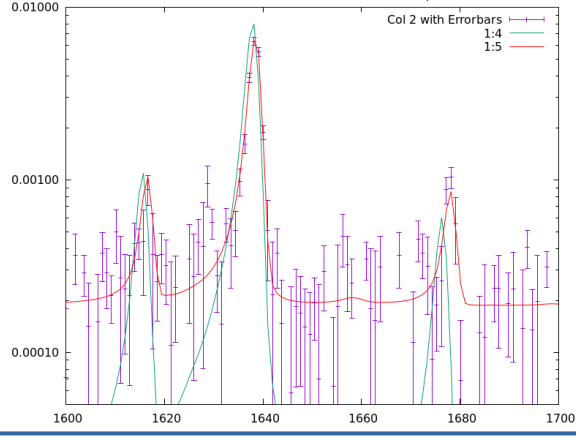




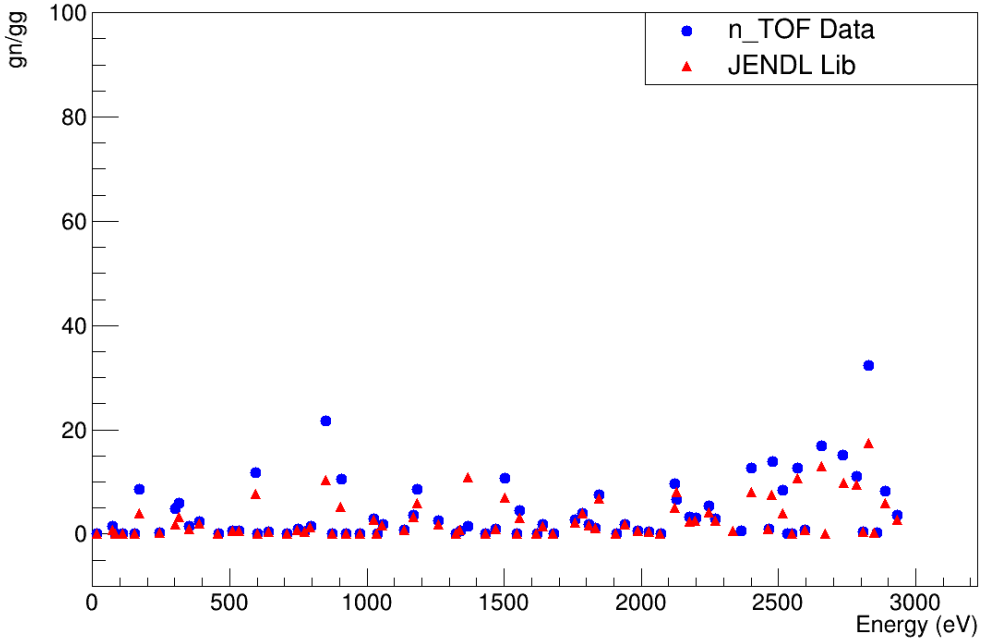
Linear Scale

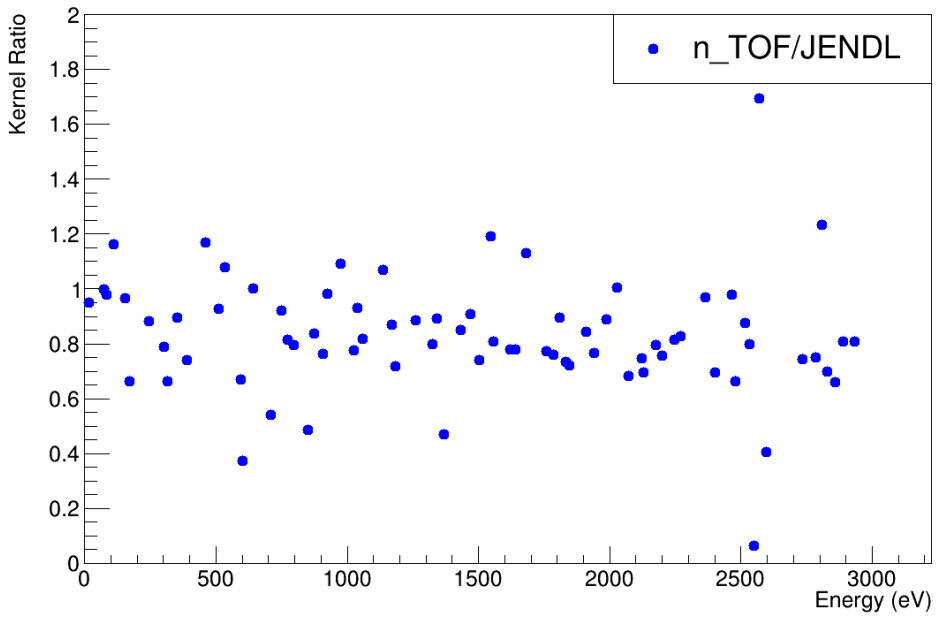
Log Scale





Analysis

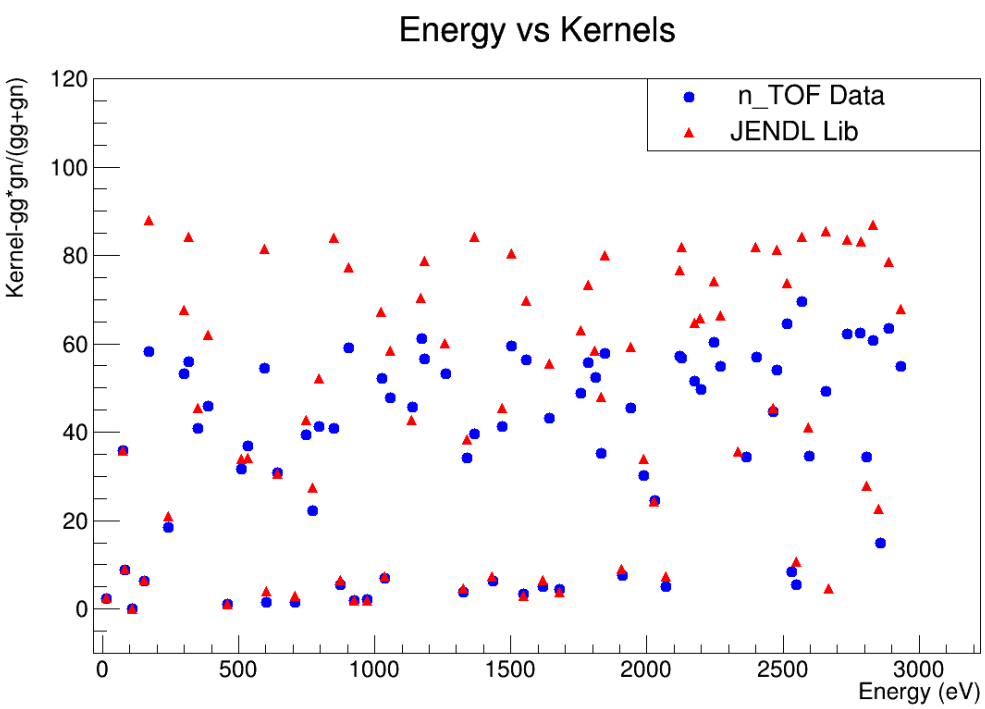


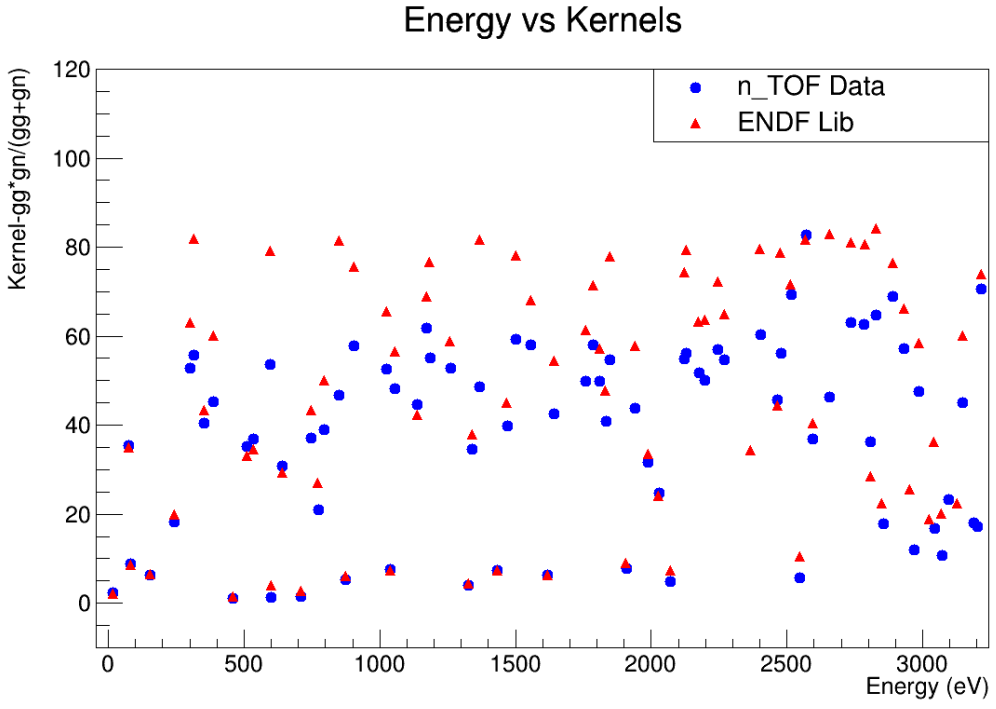


Left-The neutron width and gamma width of resonances of measured data and evaluated data are compared

Right: The Kernel Ratio of the Measured data and the Evaluated from JENDL Lib

Comparison JENDL and ENDF with measured data by n_TOF



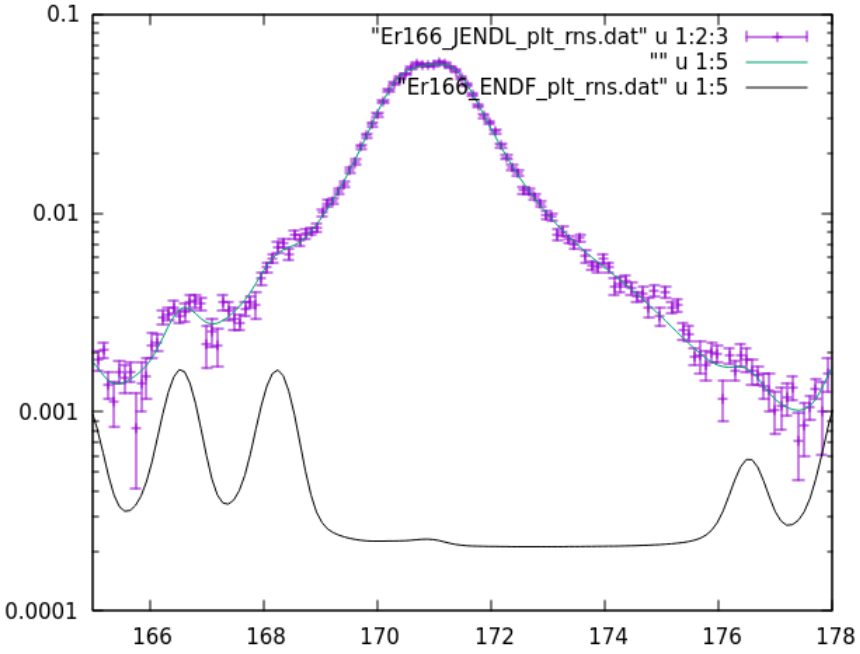


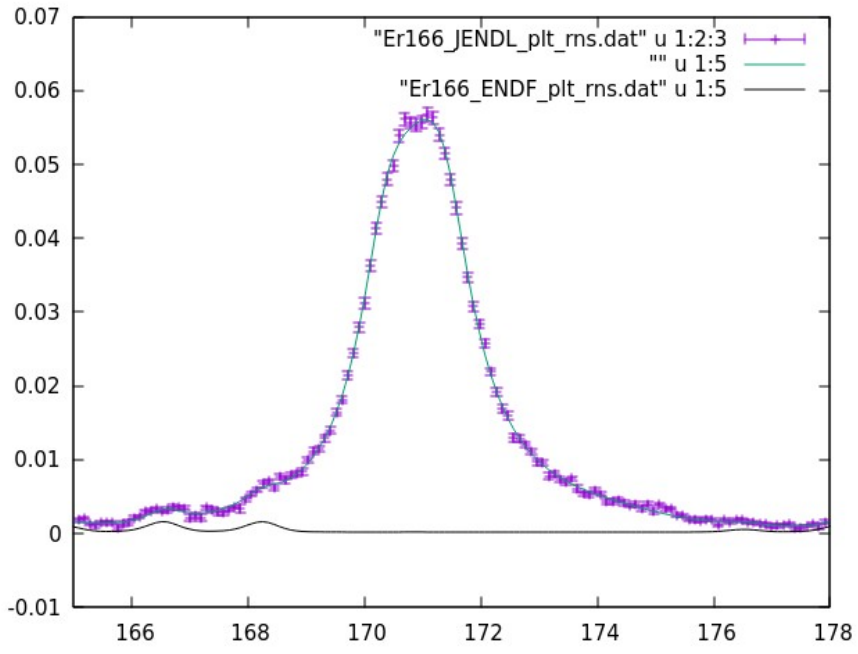
Within 3000 eV, JENDL has 7-Resonances, which are not present in the ENDF.

Resonance not found in ENDF

110.77, 171.11, 924.76, 973.49, 1547.0, 1680.6, and 2531.5

171.11eV Resonance is not present in ENDF but JENDL evaluation Lib

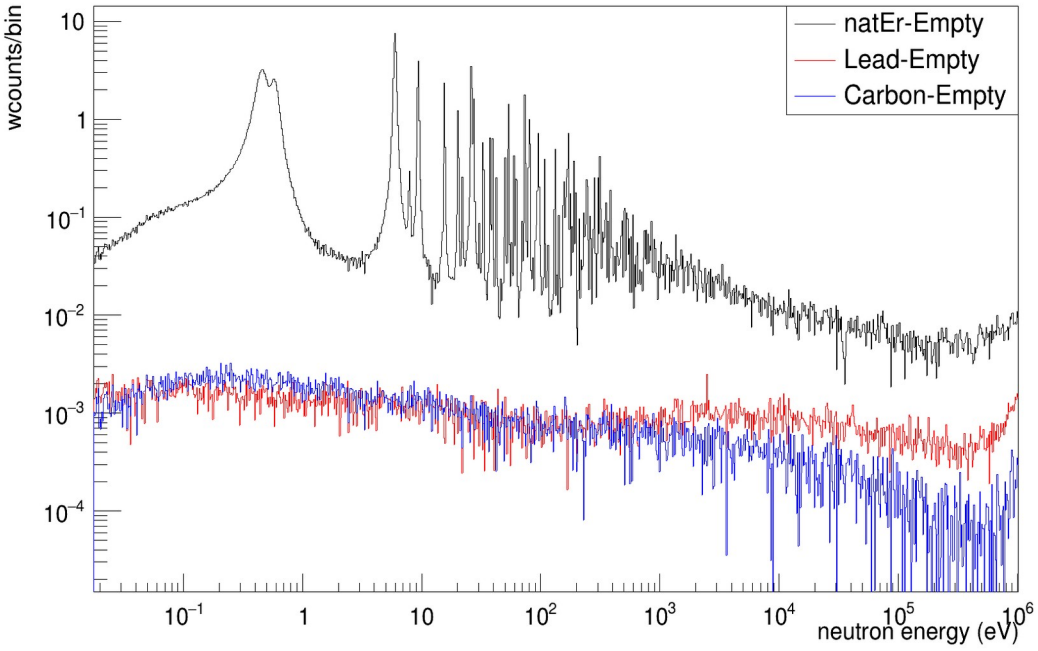


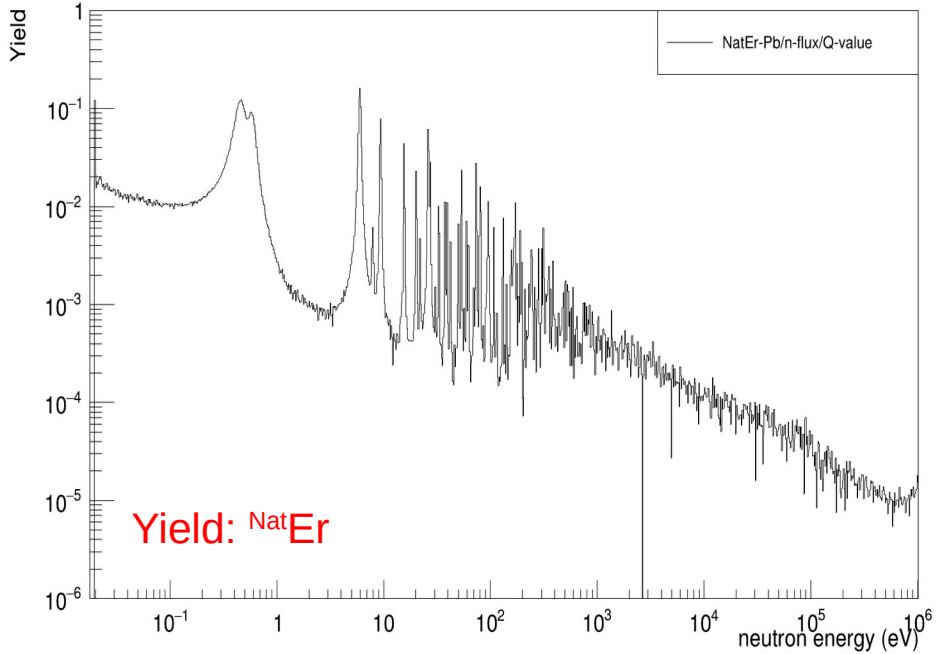


Yield Evaluation of ^{Nat}Er- after Background Subtraction

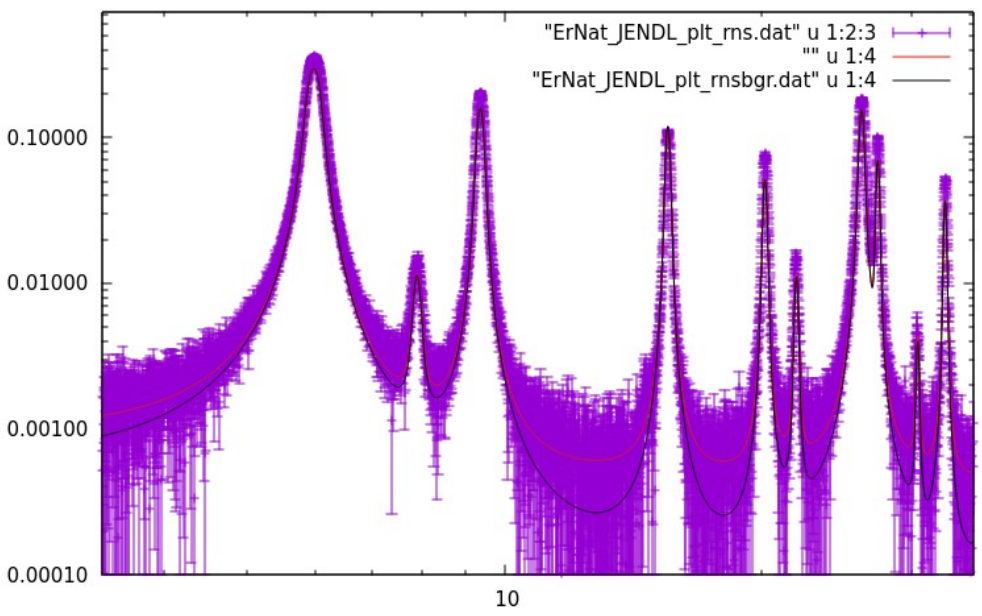
histC->Scale(rho_C/rho_C20);
hist3C->Scale(rho_NatEr/rho_C)

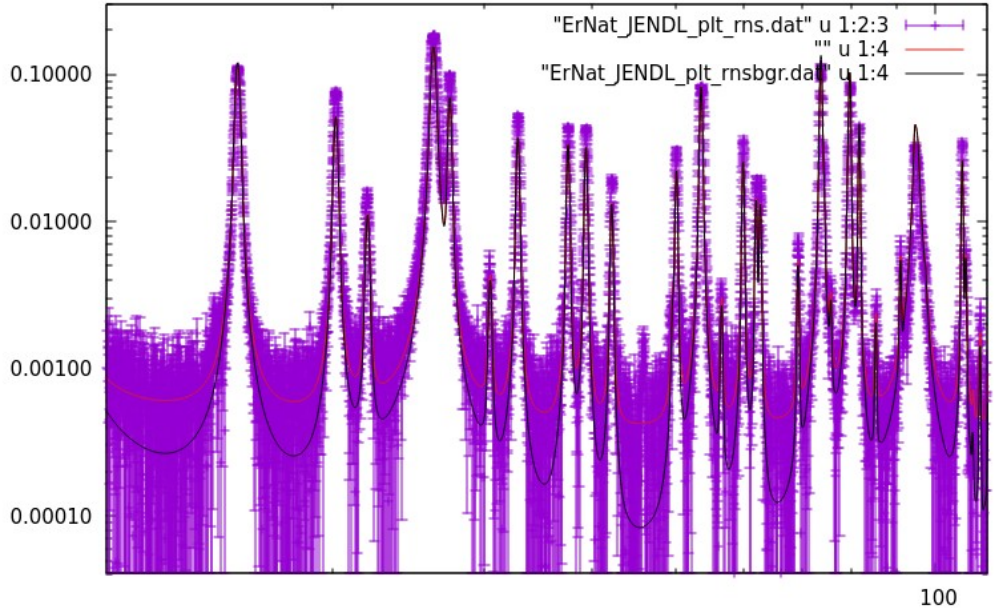
hist2→Scale(rho_Pb/rho_C);
rho_natEr = **5.34E-04**





Resonances of ^{Nat}Er



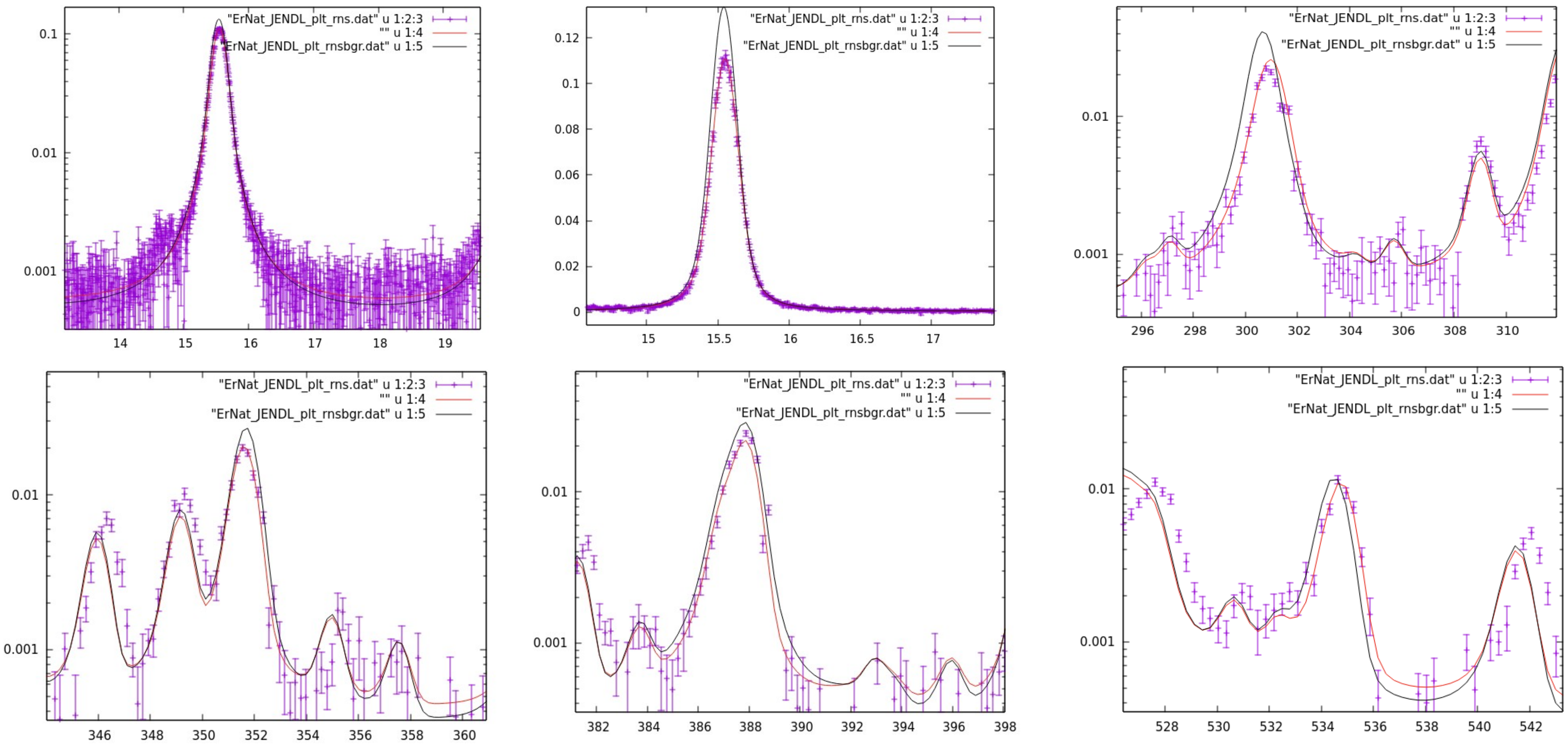


Experimental data with Background

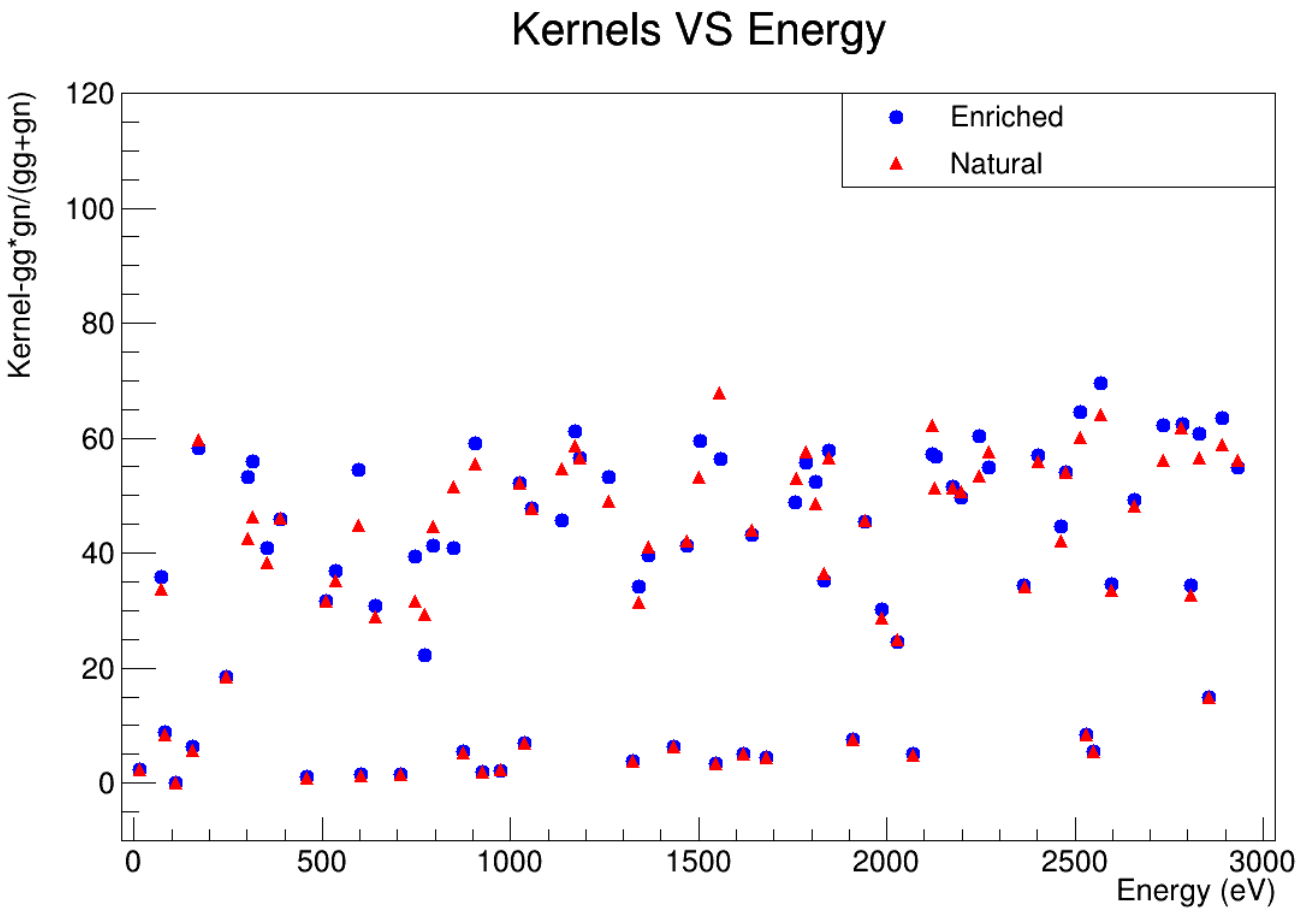
Normalization factor 0.360 have been considered for Analysis of ^{Nat}Er

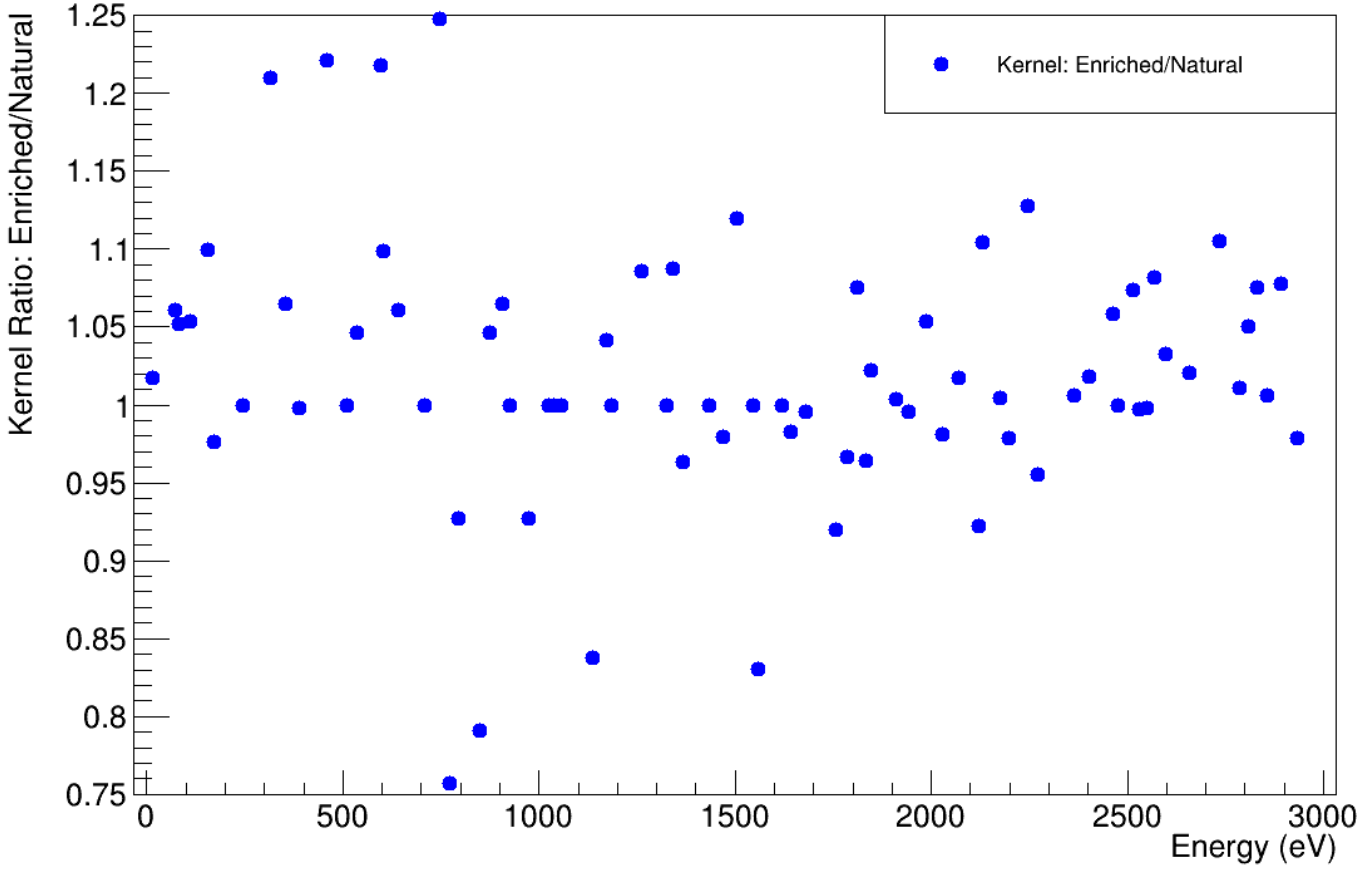
Few Fitted resonances are given in the next transparency

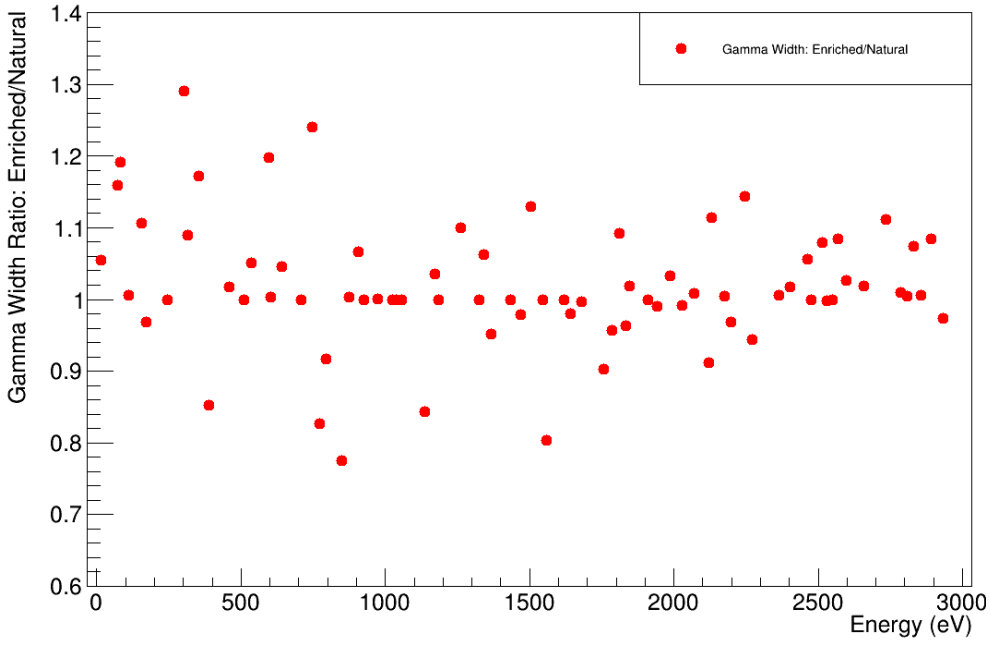
Some fitted **Resonances** of ^{Nat}ER

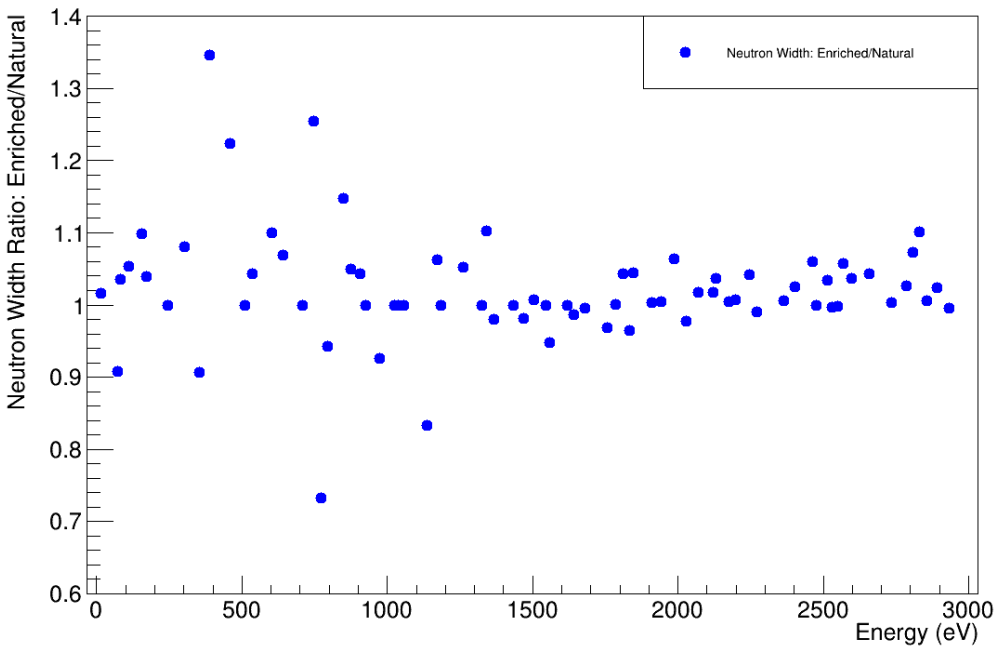


Kernel Comparison of ^{166}Er and ^{Nat}Er




Kernel: Enriched/Natural
Kernel Ratio: Enriched/Natural
Energy (eV)
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0
500
1000
1500
2000
2500
3000


Gamma Width: Enriched/Natural
Gamma Width Ratio: Enriched/Natural
Energy (eV)
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0
500
1000
1500
2000
2500
3000


Neutron Width: Enriched/Natural
Neutron Width Ratio: Enriched/Natural
Energy (eV)
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0
500
1000
1500
2000
2500
3000

Summary and Outlook

- The experiment was successfully completed in June-July 2024.
- Yields of Au13, Au20, Au40, ^{166}Er and ^{Nat}Er has been evaluated
- Data are Analyzed with R-Matrx Code Sammy and capture kernel are studied.

To be Done:

- Evaluation of Uncertainty,
- Maxwellian Average Cross Section Determination

Acknowledgments

Thanks for your attention