Neutron capture and total cross measurements on ^{94,95,96}Mo at n_TOF and GELINA

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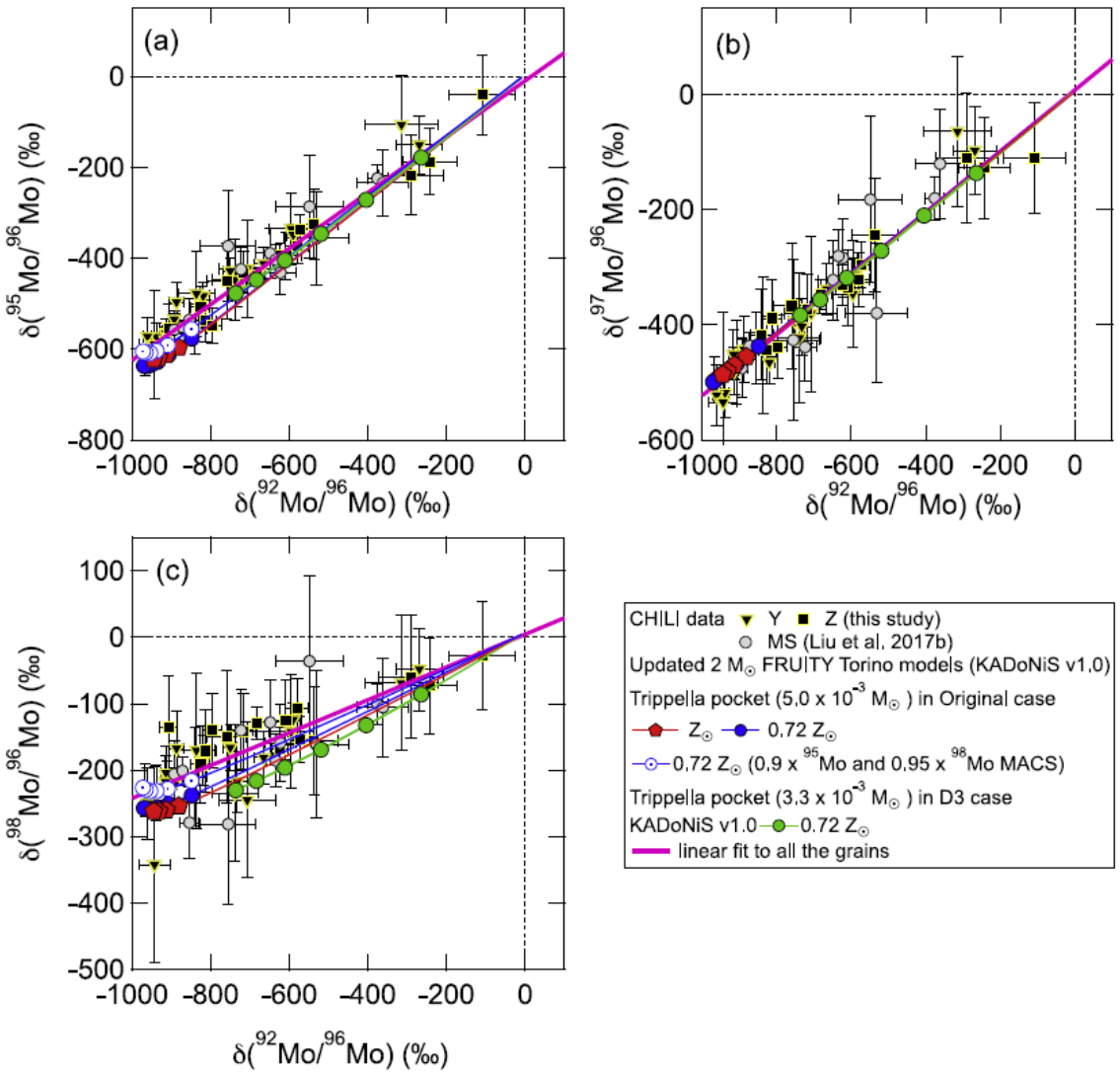
Importance of molybdenum

- Fission product in nuclear power plants;
- Nucleosynthesis of heavy elements: pollution in presolar SiC grains;
- Transport casks, irradiated fuel storage;
- Research reactors and Accident Tolerant Fuels.

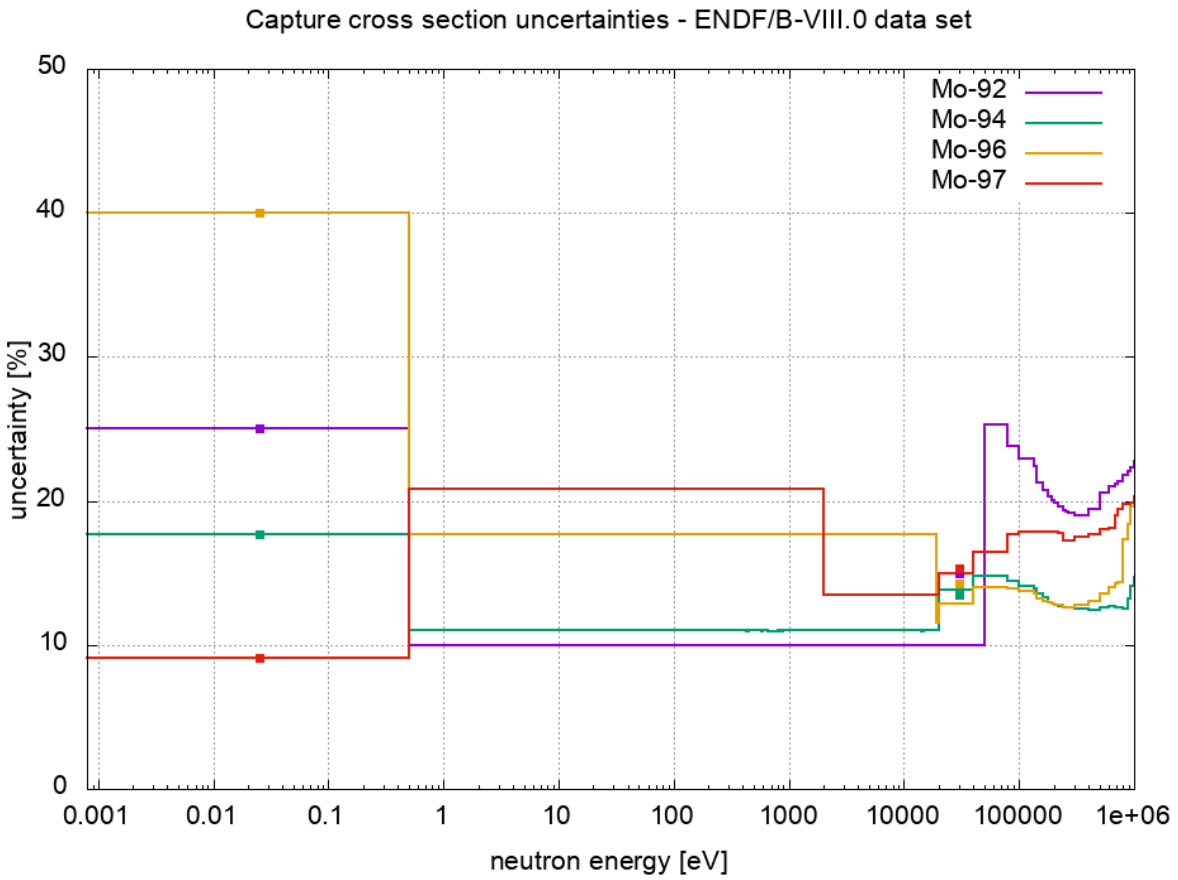
Presolar grain composition

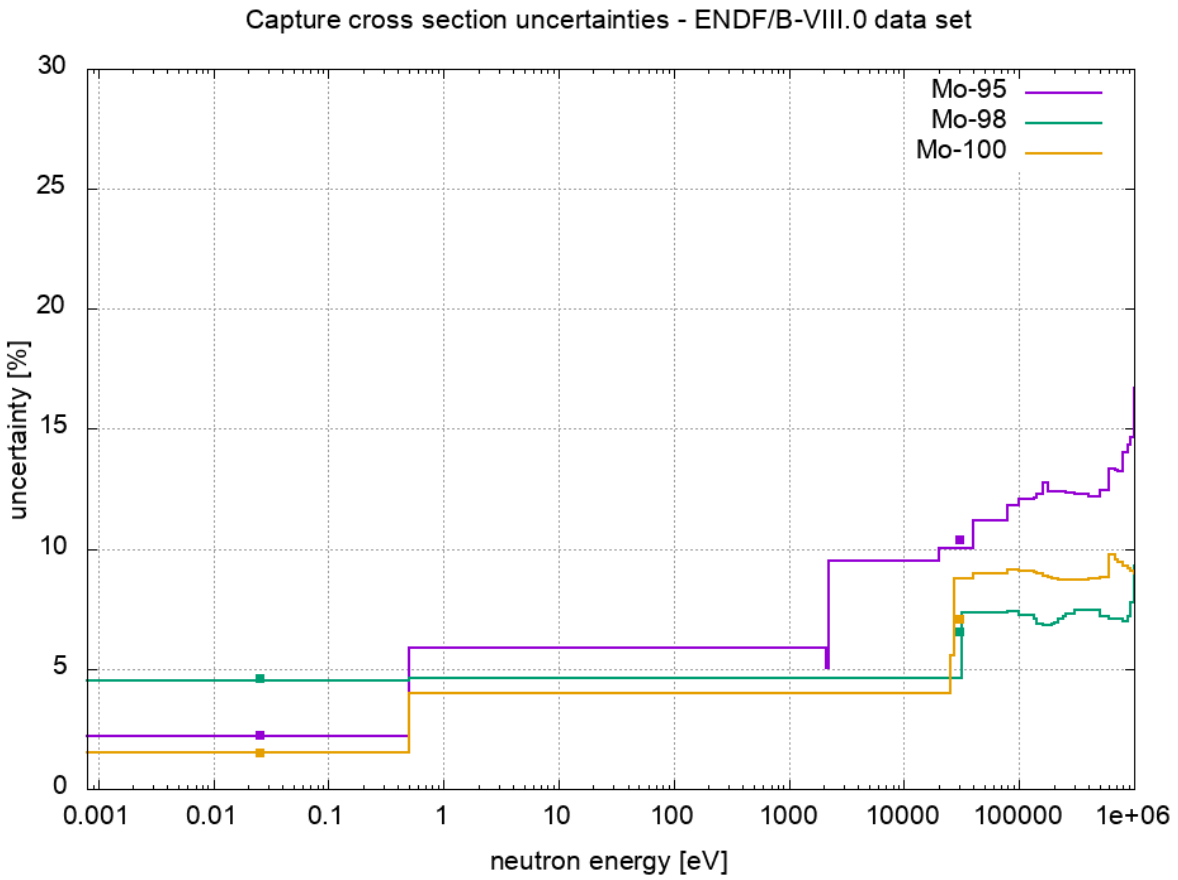


- Comparison of SiC grains composition versus stellar model (FRUITY Torino model)
- MACS form KADoNiS v1.0
- Slight discrepancy between model and isotopic composition
- Possible overestimation of MACS in KADoNiS.

N. Liu, et al., ApJ 881 (2019) 28.

Cross section uncertainties in ENDF/B-VIII





Improved RP for ^{94,95,96,nat}Mo

1) Study transmission and capture data for Mo reported in the literature:
   - compilation of resonance parameters based on these data
2) Transmission cross section measurements using ^{nat}Mo samples at 50m GELINA:
   - adjust the compiled resonance parameter file by RSA with REFIT
3) Experiments with enriched ^{94,95,96}Mo samples:
   - Transmission and capture measurements at GELINA
   - Capture measurements at n_TOF

- Final resonance parameter file by a simultaneous analysis of GELINA and n_TOF data

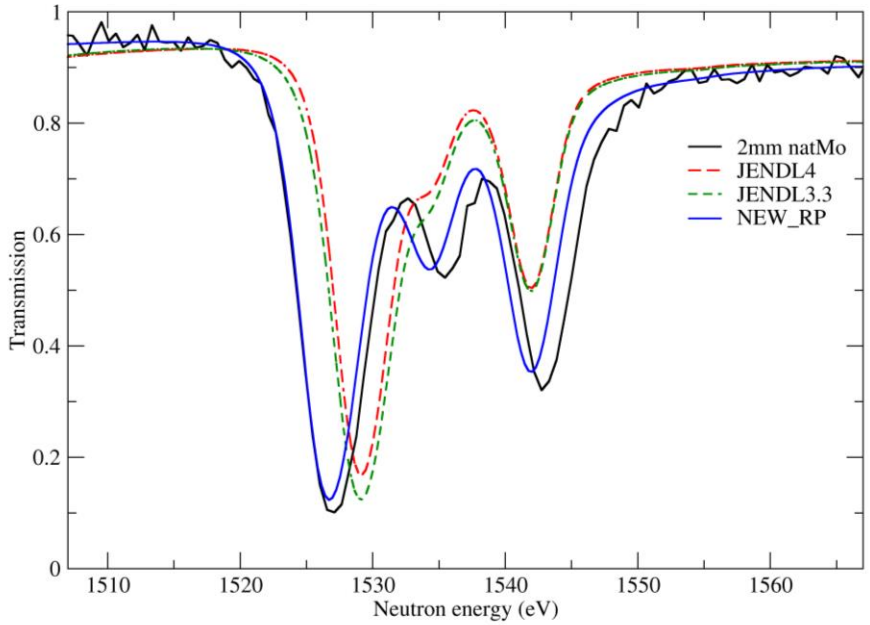
Resonance parameters evaluation

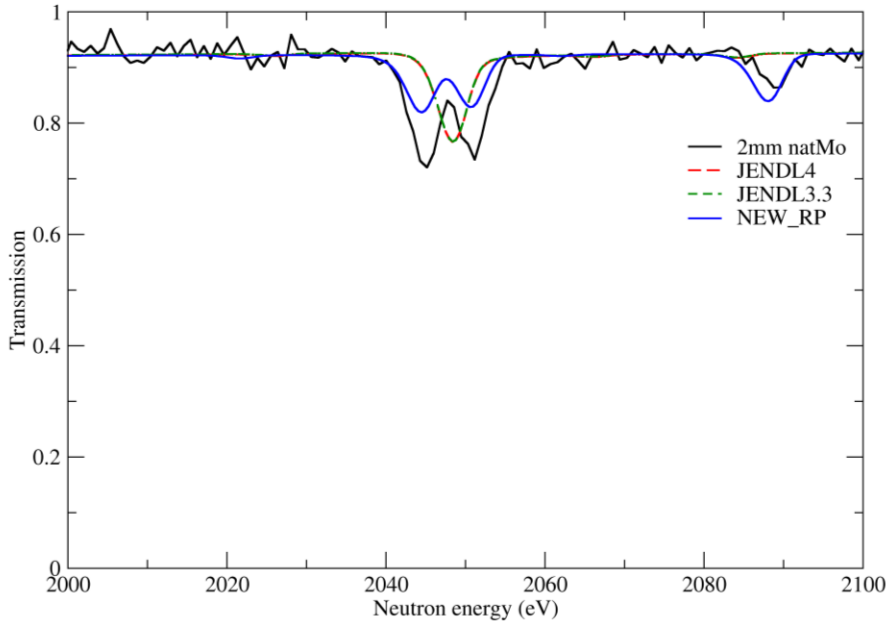
RP compilation from literature

1) Define consistent energy scale:
   Weigmann et al. (capture experiments at GELINA)
2) Select $g\Gamma_n$ reference:
   E < 2keV: Leinweber
   E > 2keV: Whynchank
3) Select $\frac{g\Gamma_\gamma\Gamma_n}{\Gamma}$ reference:
   Weigmann
   Musgrove for odd isotopes and E>3keV

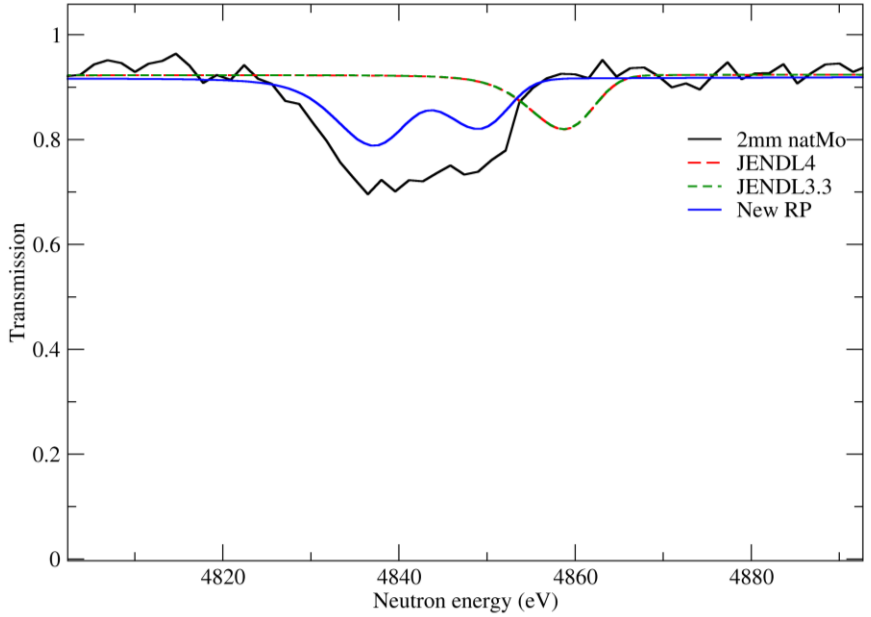
- Compilation of RP file from literature data
- ^{nat}Mo transmission measurements at GELINA to validate and improve RP file

Validation of compiled RP file

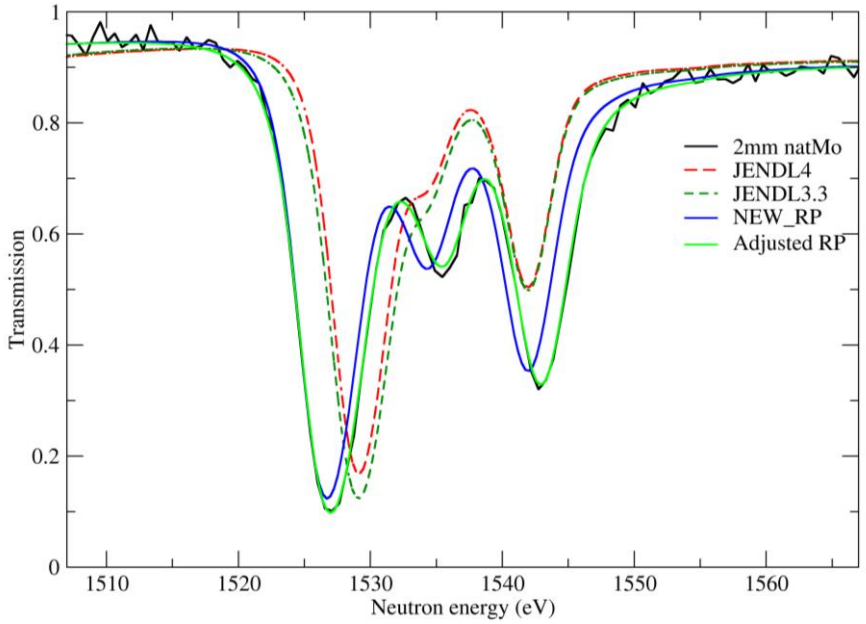




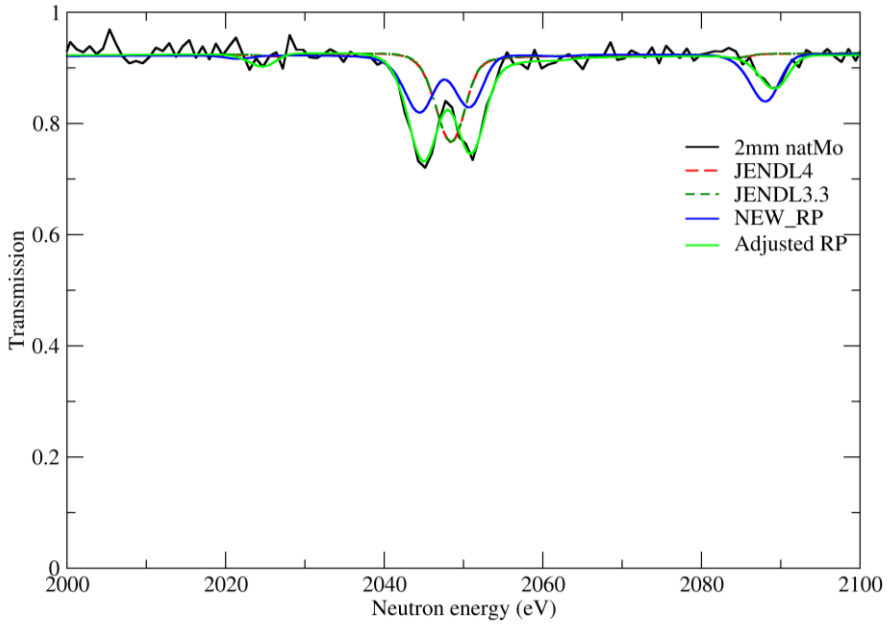
- RP file verified by transmission data (50 m) of 2mm and 5mm thick ^{nat}Mo samples
- Missing resonances in libraries reported in literature data
- Literature parameters more consistent with transmission data
- **New RP file improve data description**.

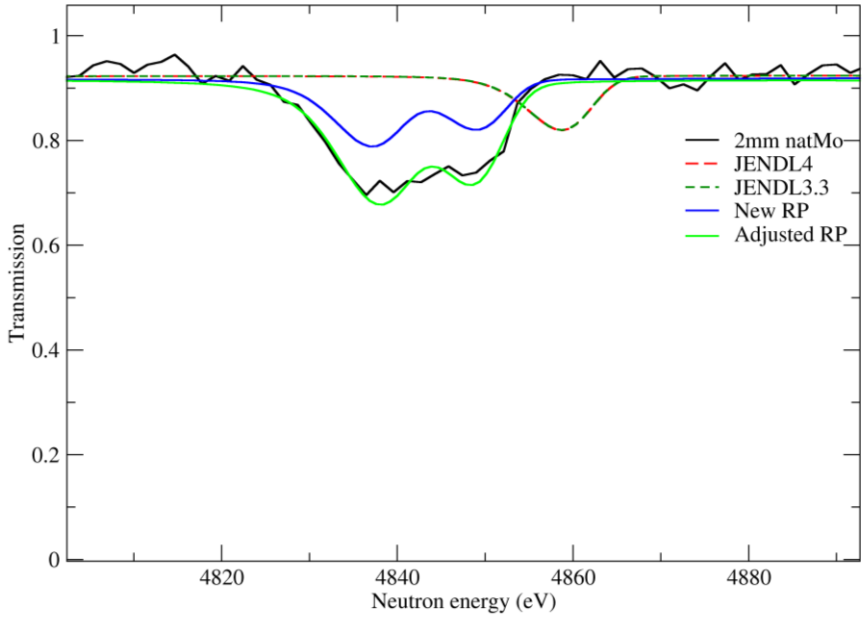


Improvement of RP file



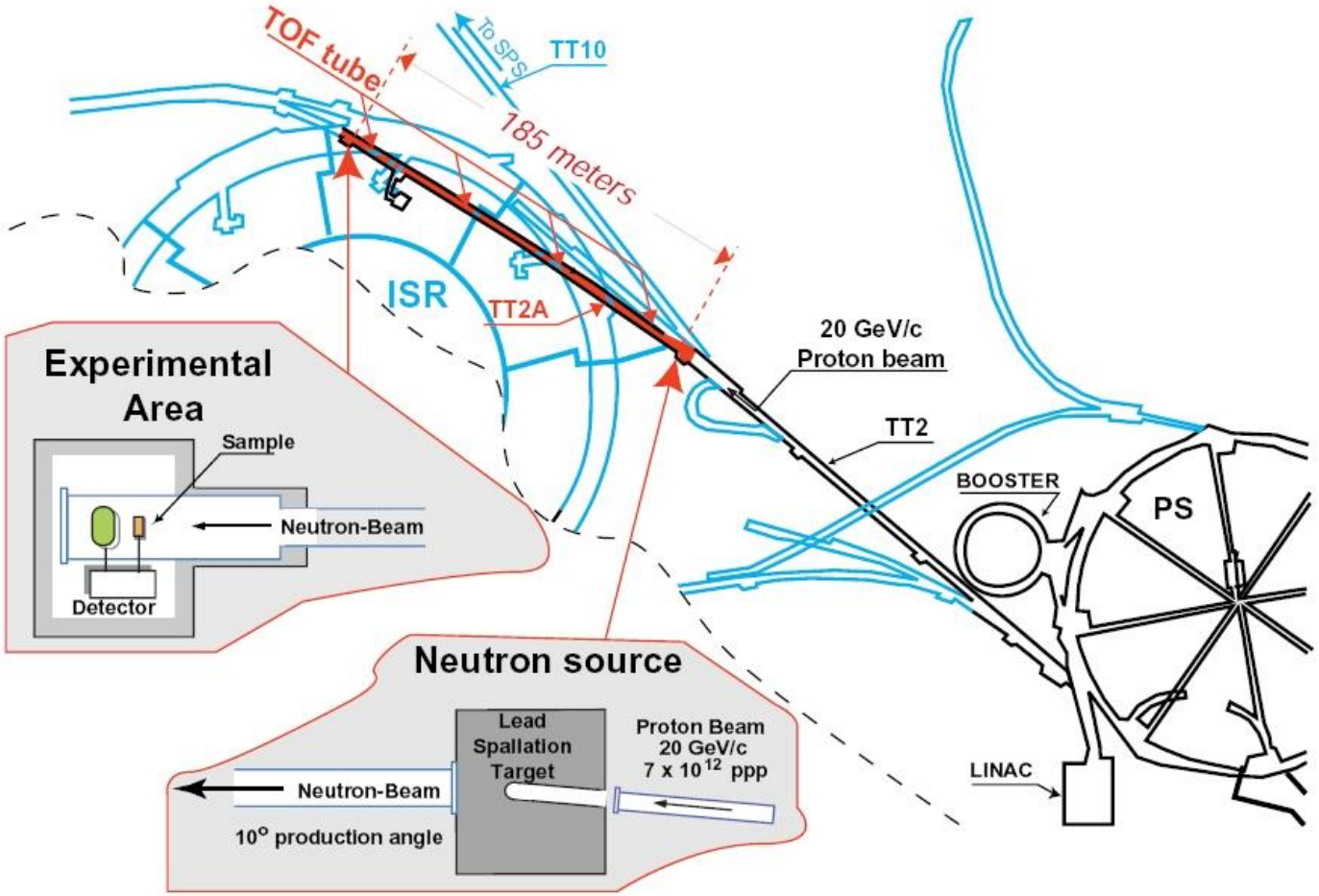
- RP file improved by an adjustment to transmission data using REFIT
- Fit of resonances up to 5 keV
- Full procedure in R. Mucciola et al., NIMB 531 (2022) 100





Enriched samples campaign

n_TOF



- Located at CERN
- Neutron beam produced using PS proton on lead target
- Production of neutrons via spallation
- Pulsed neutron source (10 meV < E < 1 GeV)
- Three experimental areas (EAR1, EAR2 and NEAR)

Mo powder @ EAR2

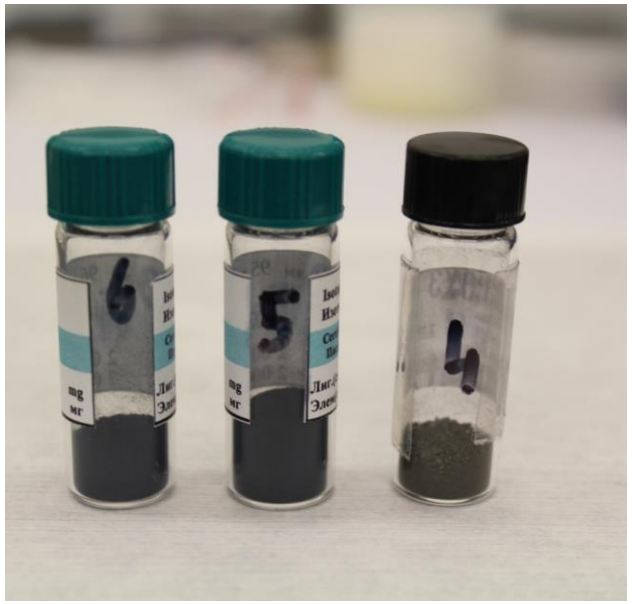
- Metallic powder in metallic capsules;
- Capsule fixed to mylar disk using Kapton foil;
- 2g of powder available for each isotope;
- Capture measurements performed at n_TOF in October 2021.

Enriched pellets preparation

- Pressed pellets prepared using enriched powder
- Pellets prepared at JRC-Geel
- Self sustaining pellets of ~ 2g
- Additional ^{nat}Mo samples prepared using powder with different grain sizes
- Samples used in EAR1 and EAR2 2022 measurements at n_TOF and transmission at GELINA

Samples prepared

^{94}Mo	^{95}Mo	^{96}Mo
99%	95%	96%

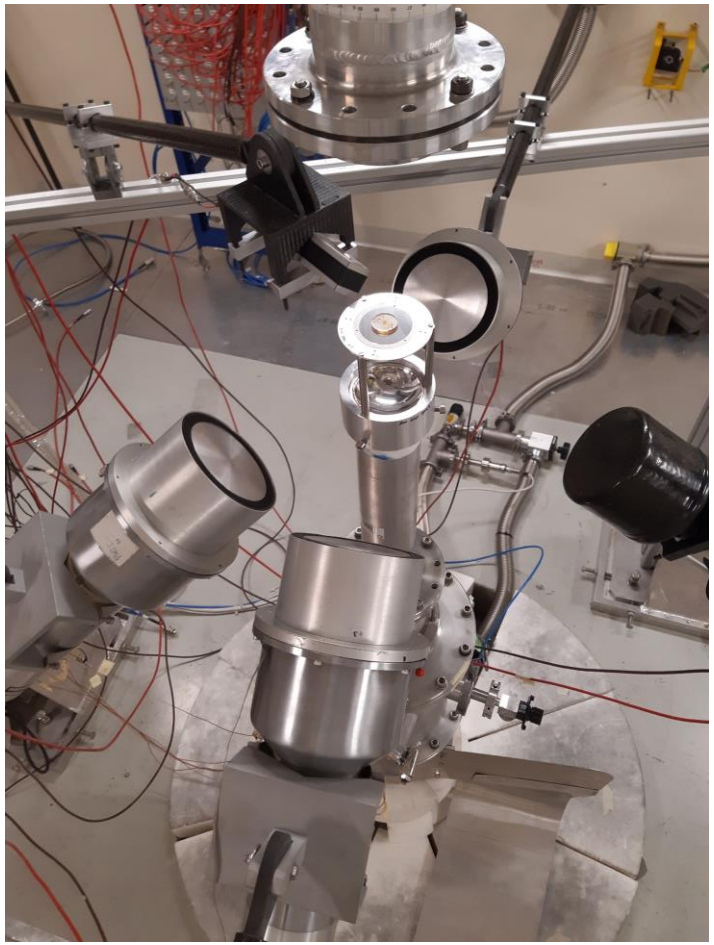


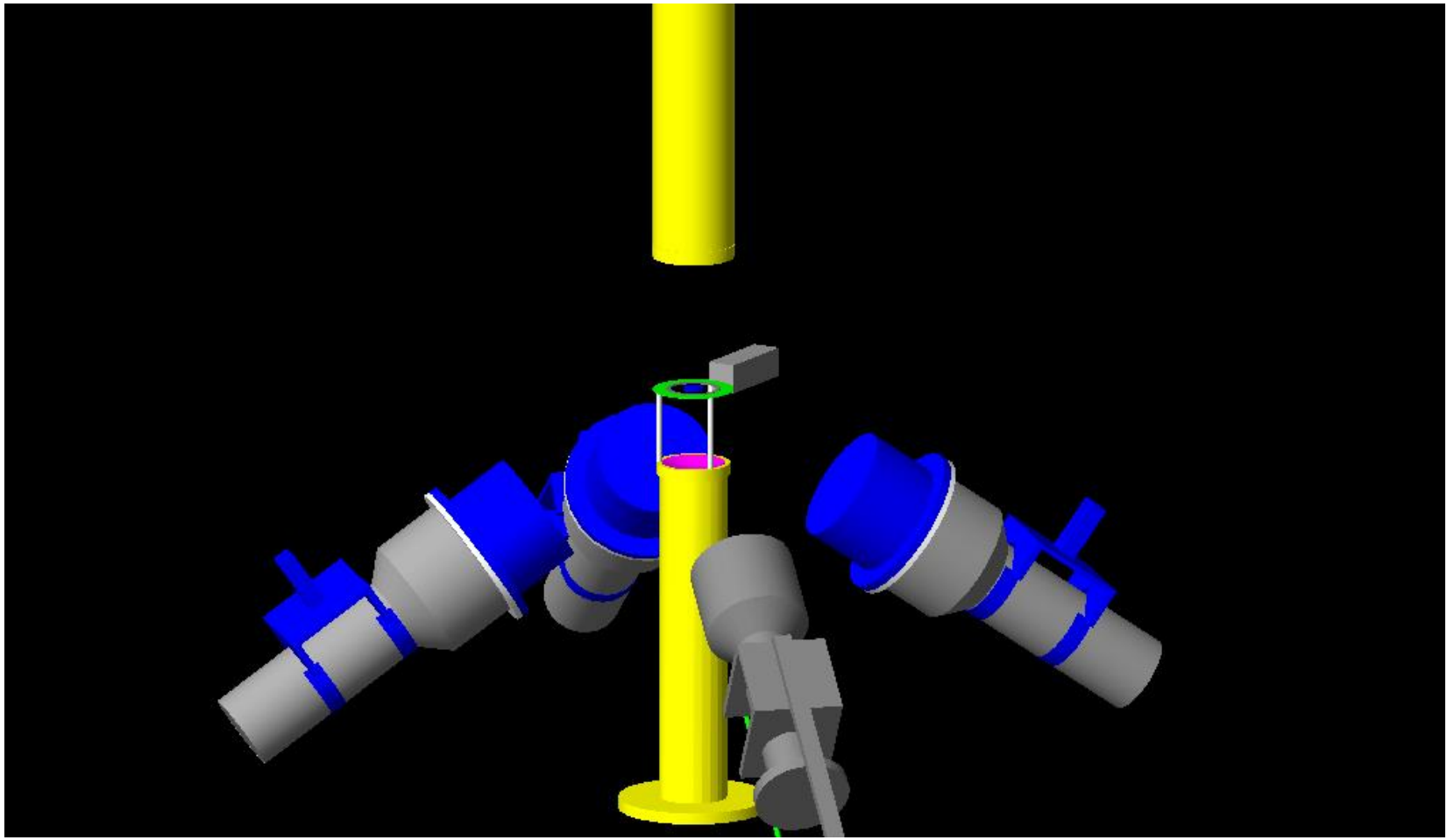
Mo samples

Atomic %	^{92}Mo	^{94}Mo	^{95}Mo	^{96}Mo	^{97}Mo	^{98}Mo	^{100}Mo
^{94}Mo	0,63%	98,97%	0,36%	0,01%	0,01%	0,01%	0,01%
^{95}Mo	0,31%	0,69%	95,40%	2,24%	0,51%	0,65%	0,20%
^{96}Mo	0,28%	0,24%	1,01%	95,90%	1,00%	1,32%	0,25%

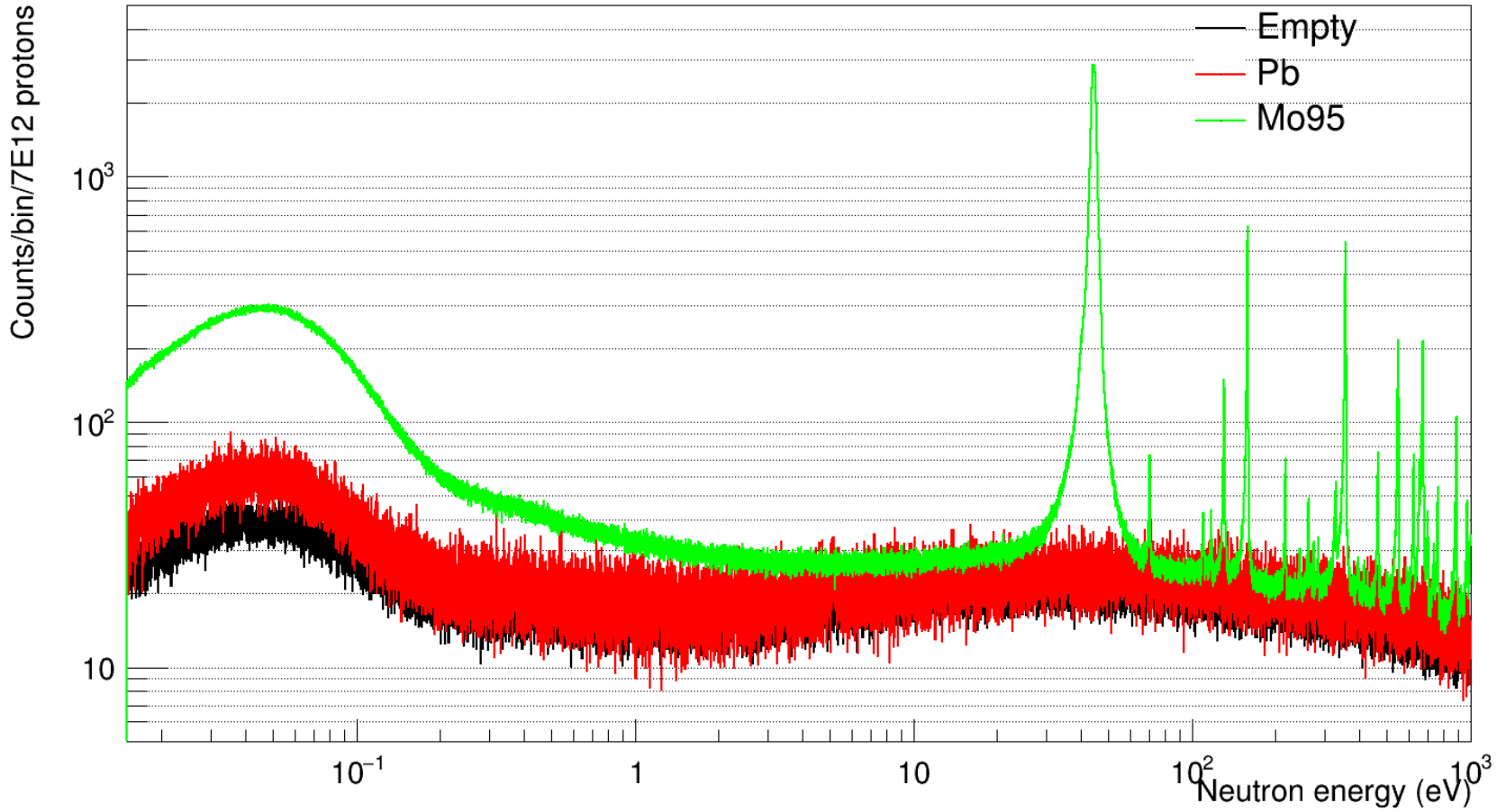
Isotope	Mass (g)	Areal density (atoms/b)
^{94}Mo	1,9526	3,9592E-03
^{95}Mo	1,9745	3,9558E-03
^{96}Mo	1,9175	3,8064E-03
^{nat}Mo-5 μm	2,014	4,0059E-03
^{nat}Mo-350 μm	1,989	3,9584E-03

EAR2 simulation - Setup



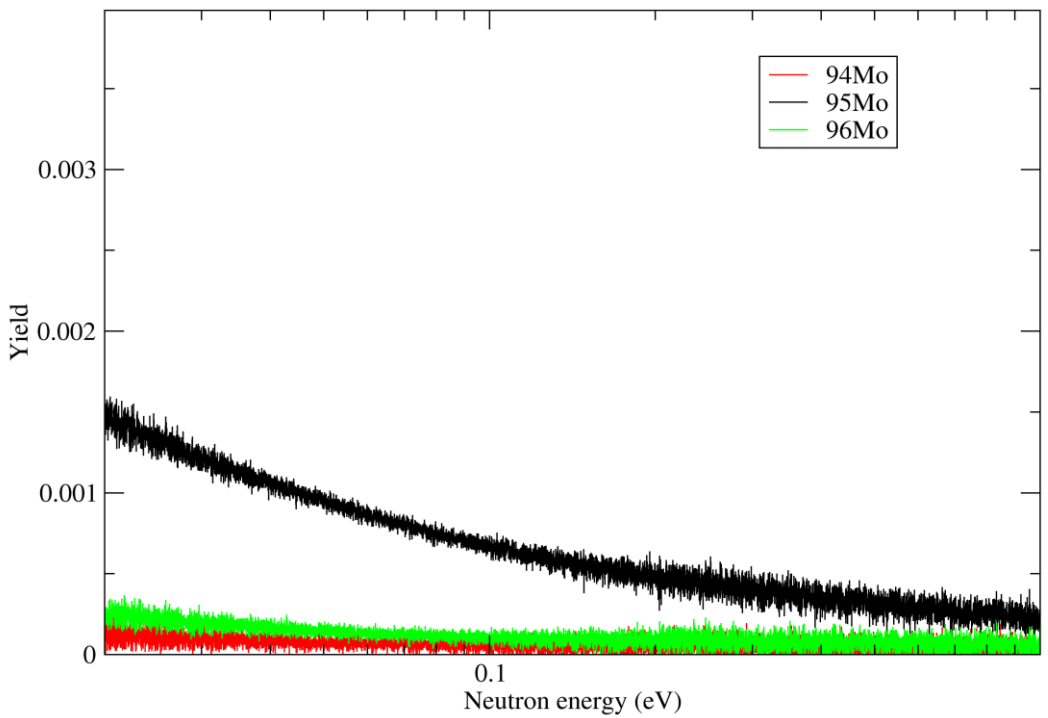


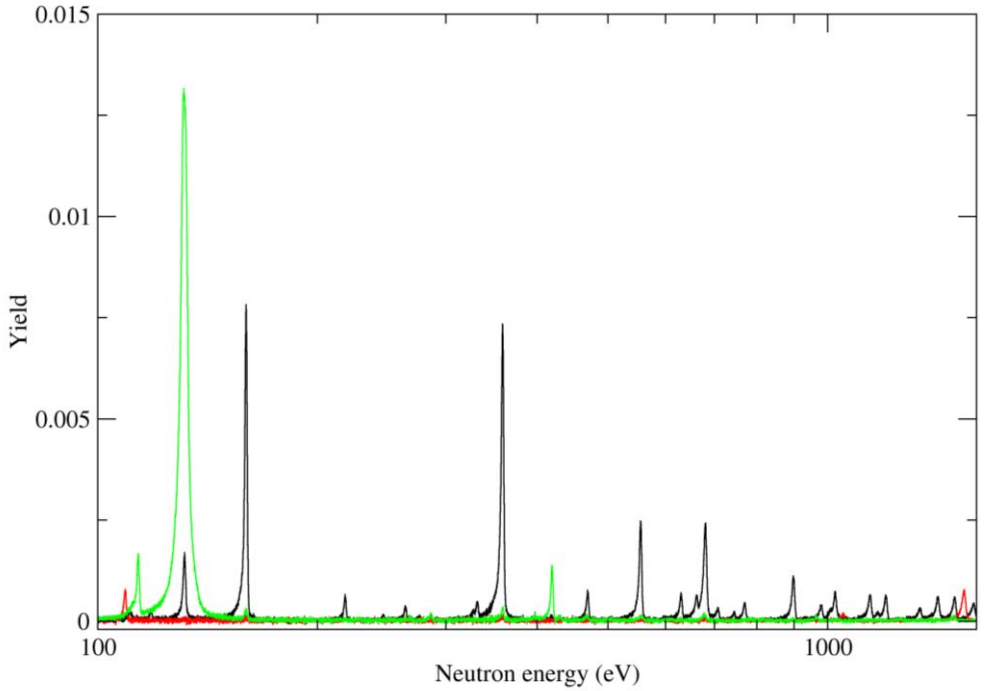
EAR2 measurements



Good resolution up to few keV

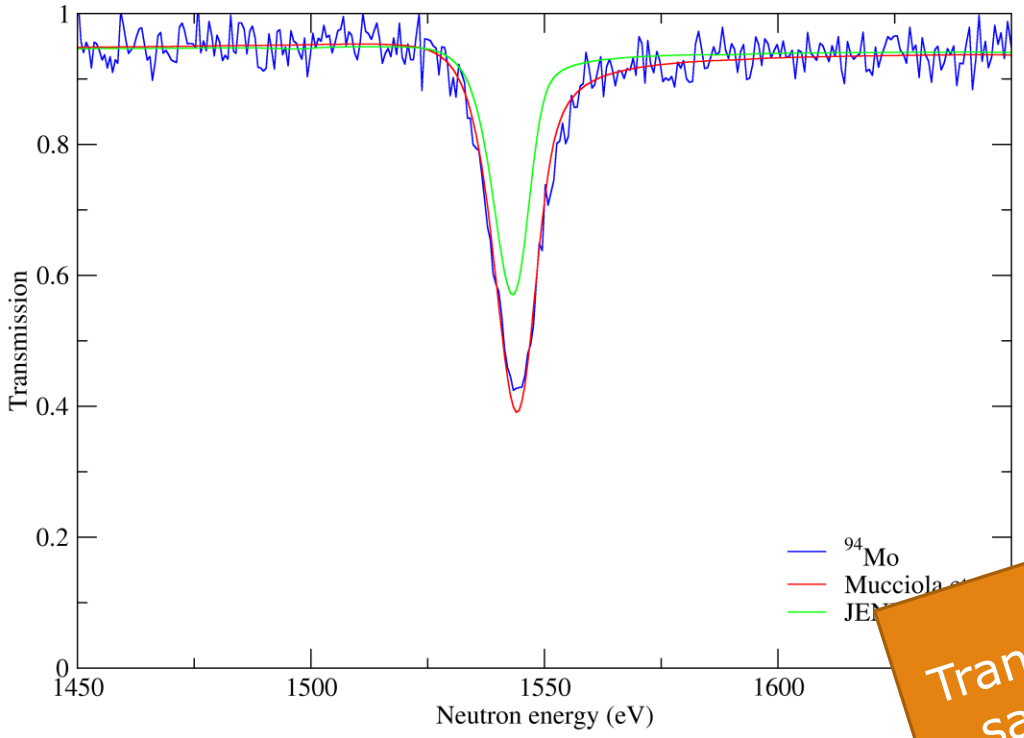
EAR2 2021 – Preliminary yield



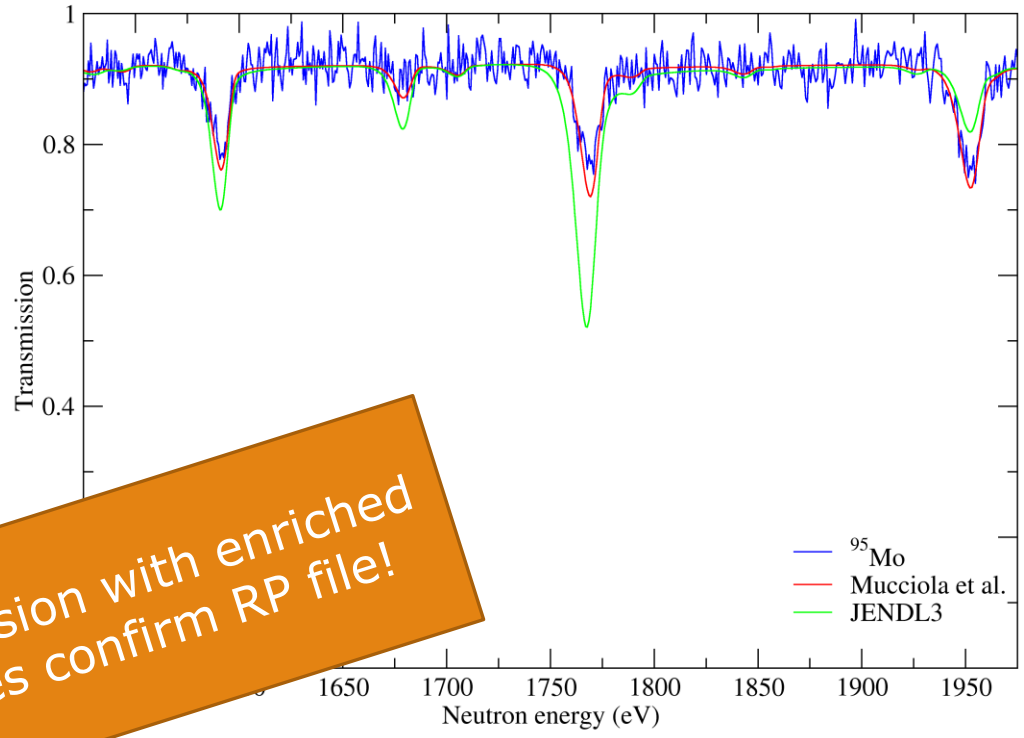


Transmission with enriched Mo

^{94}MO TRANSMISSION

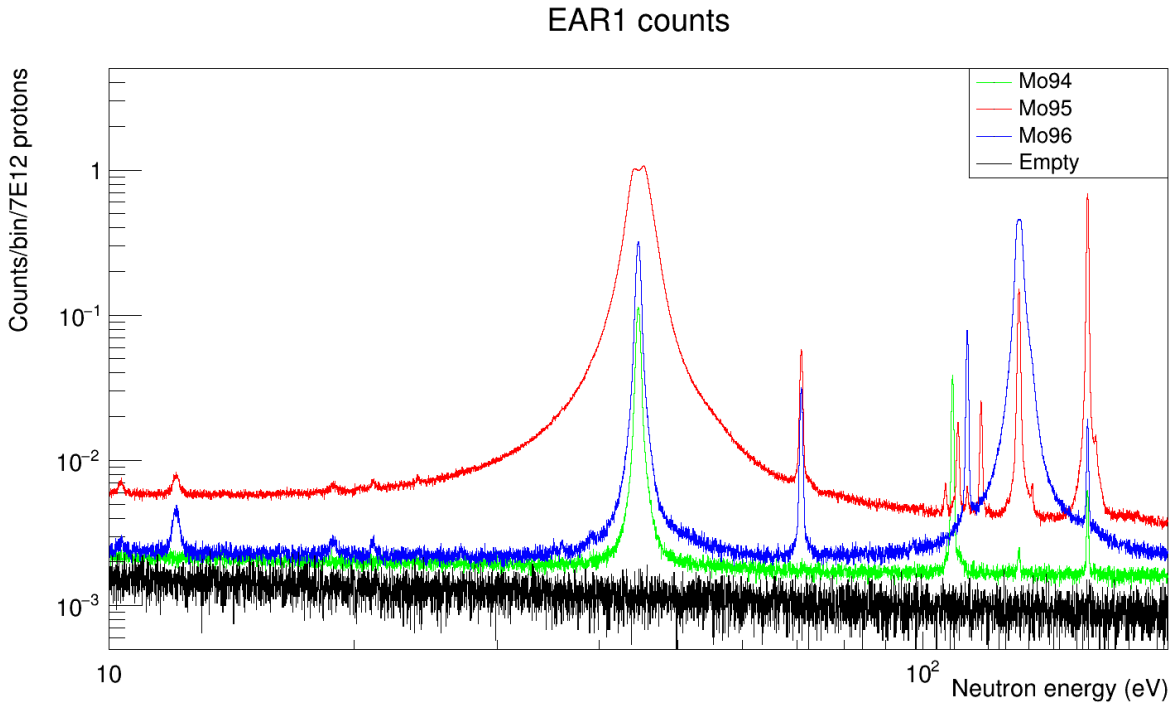


^{95}MO TRANSMISSION



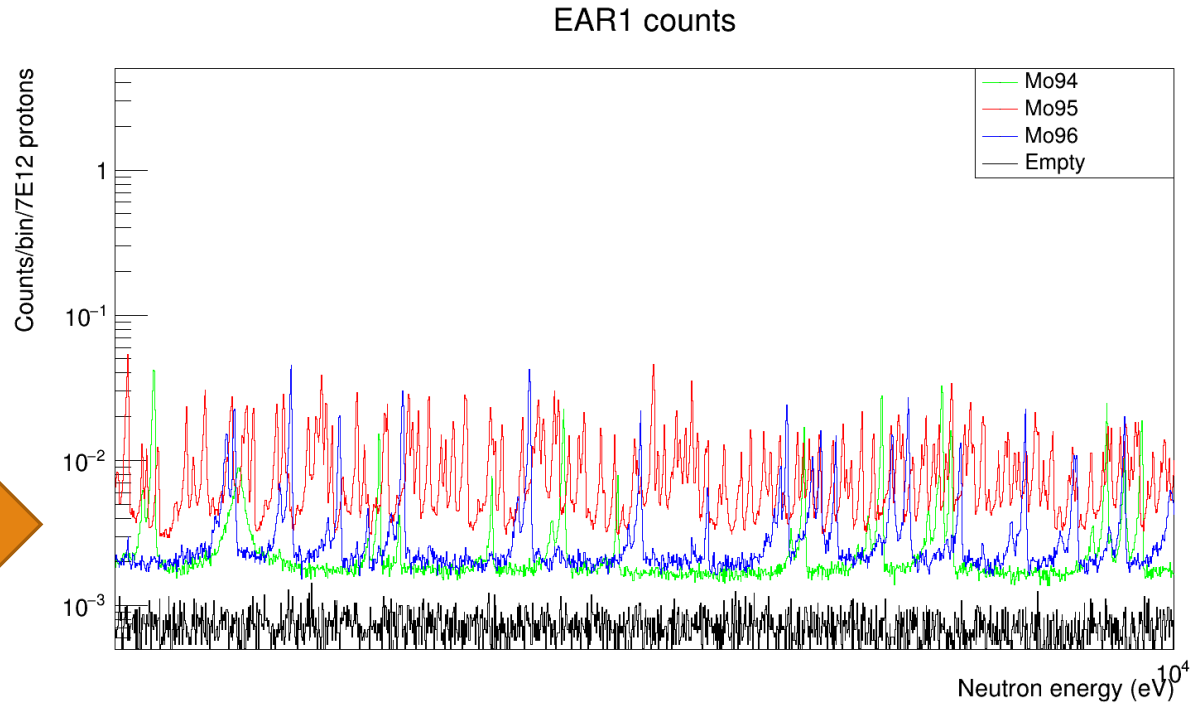
Transmission with enriched samples confirm RP file!

EAR1 counts

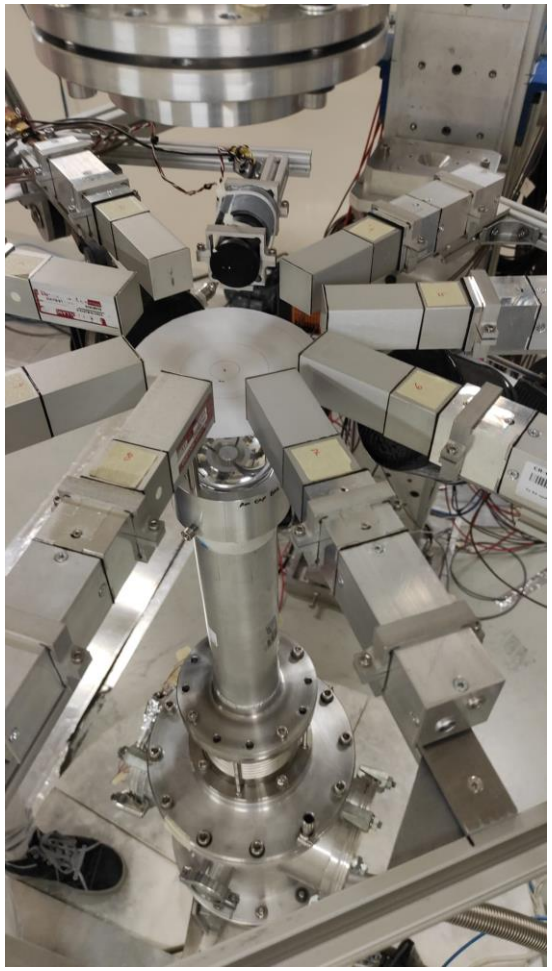


4 C6D6
~1.5 E18 protons/sample

Good resolution up to tens of keV



EAR2 – 2022 measurements



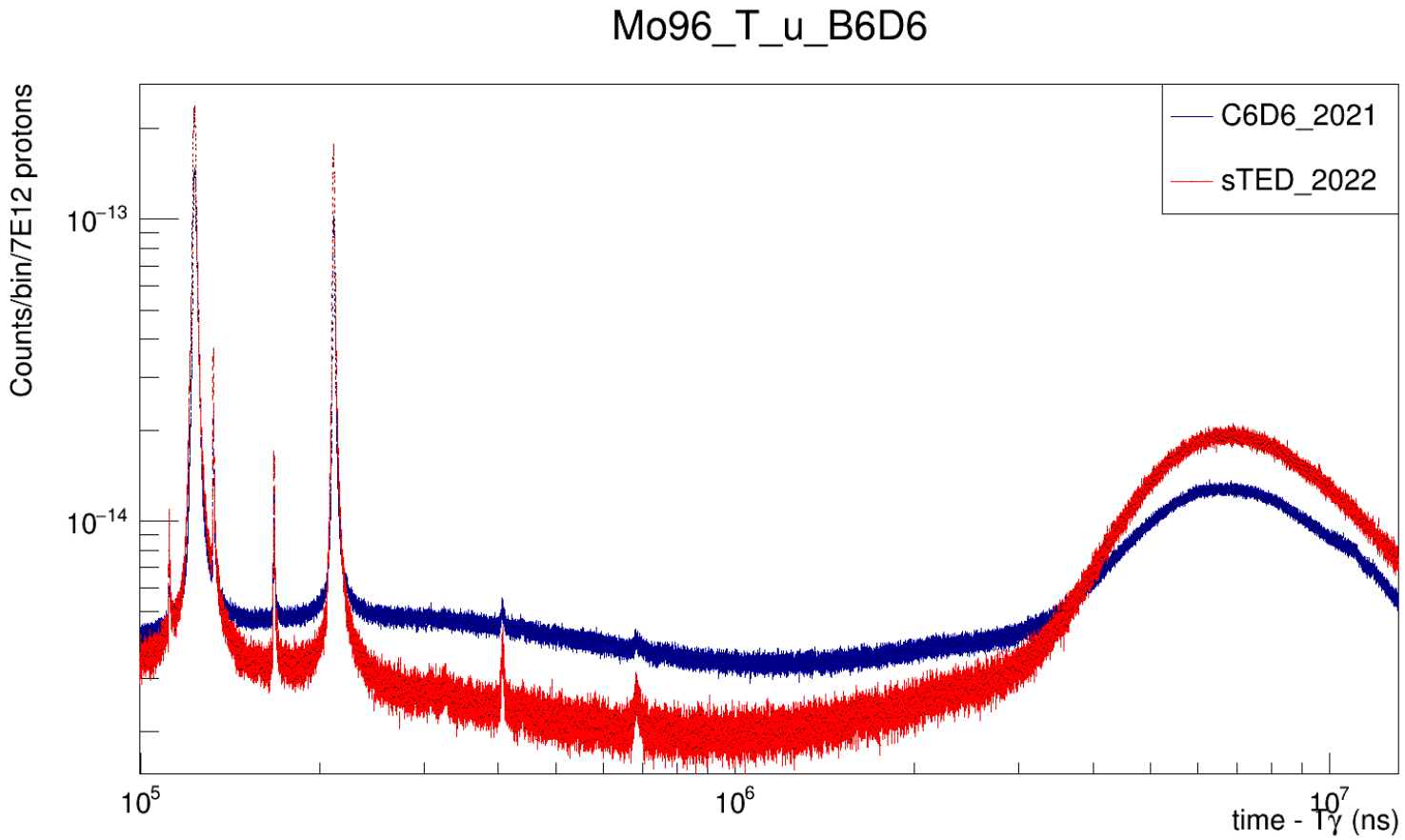
Setup:

- 8 sTED,
- 2 C6D6,
- 1 Stilbene.

Enriched pellets

~ 4E17 protons/sample

EAR2 – 2022 measurements



Setup:

- 8 sTED,
- 2 C6D6,
- 1 Stilbene.

Better SN ratio with the sTED

Summary and outlook

What is done:

- Compilation and validation of new resonance parameters file for all molybdenum isotopes
- Article describing the recommended resonance parameters
- Capture measurements at n_TOF and transmission measurements at GELINA using enriched samples
- Analysis of transmission and 2021 EAR2 data

What is left to do:

- Full analysis of n_TOF data from 2022
- Simultaneous analysis of transmission and capture data
- Preparation of results for EXFOR submission

Thank you for your attention!

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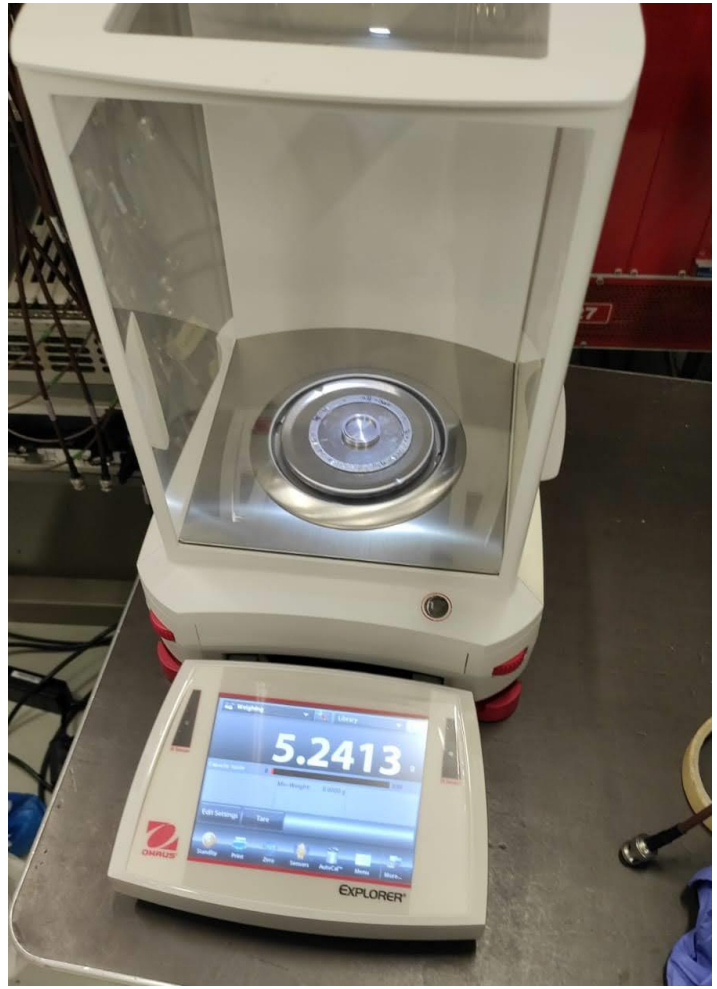
Backup

Backup - ^{nat}Mo abundances

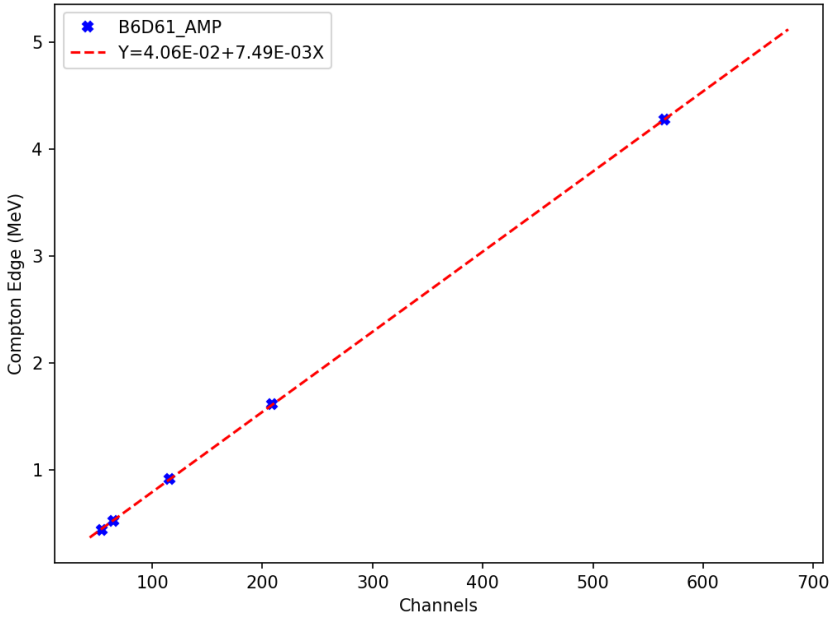
Isotope	Abundance
^{92}Mo	14.84%
^{94}Mo	9.25%
^{95}Mo	15.92%
^{96}Mo	16.68%
^{97}Mo	9.55%
^{98}Mo	24.13%
^{100}Mo	9.63%

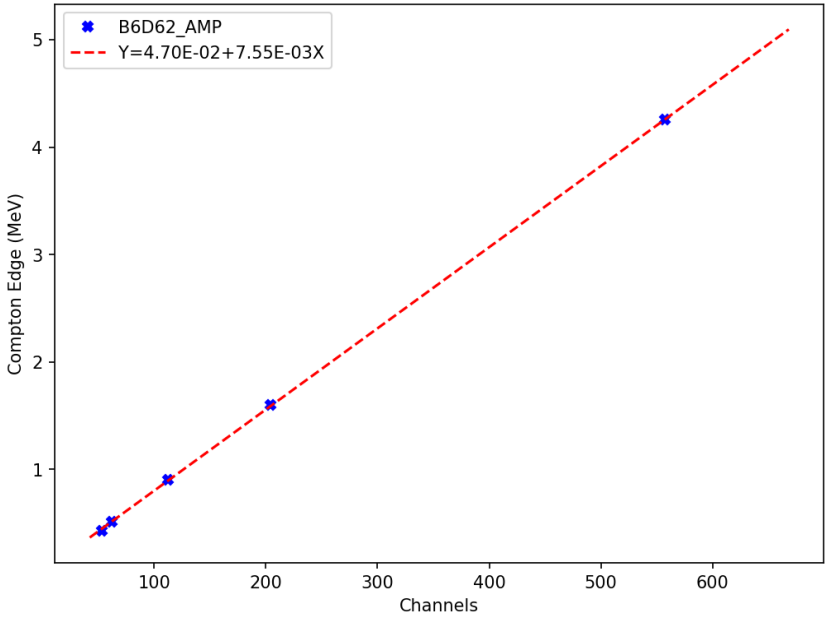
Backup - EAR2 samples

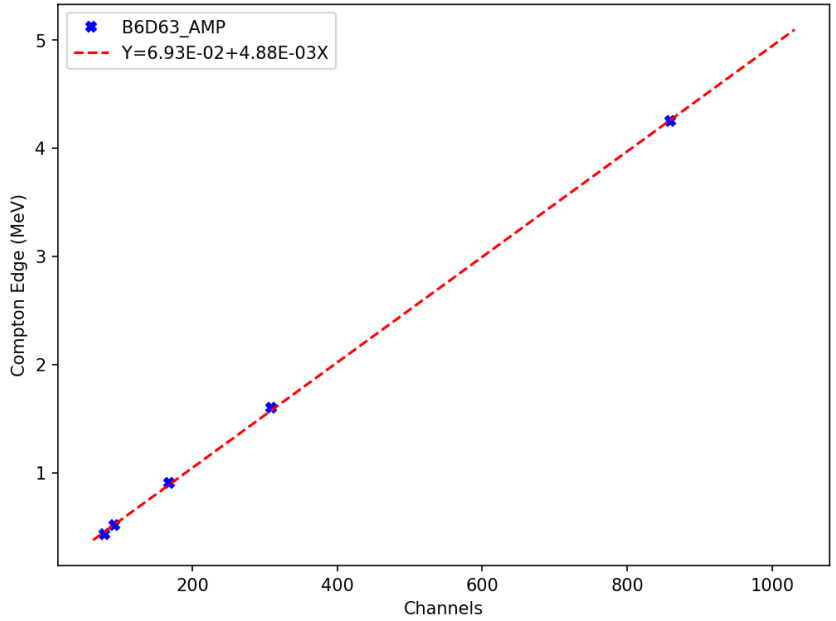
Sample	Mass	Areal density
^{94}Mo	1737,5 mg	3,47E-3
^{95}Mo	929,2 mg	1,86E-3
^{96}Mo	1611 mg	3,22E-3
^{nat}Mo pellet	2003,3 mg	4,00E-3
^{nat}Mo powder	985,7 mg	1,97E-3

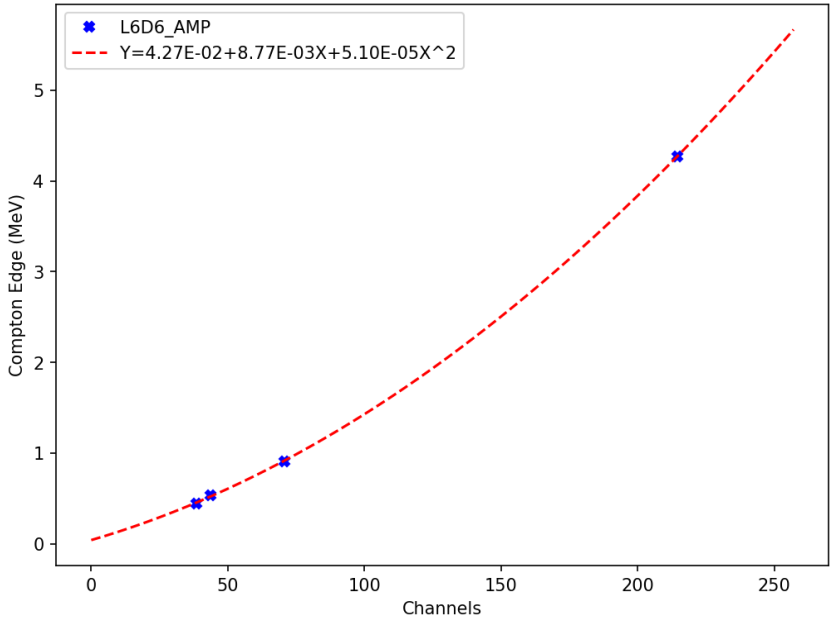


EAR2 2021 Calibration

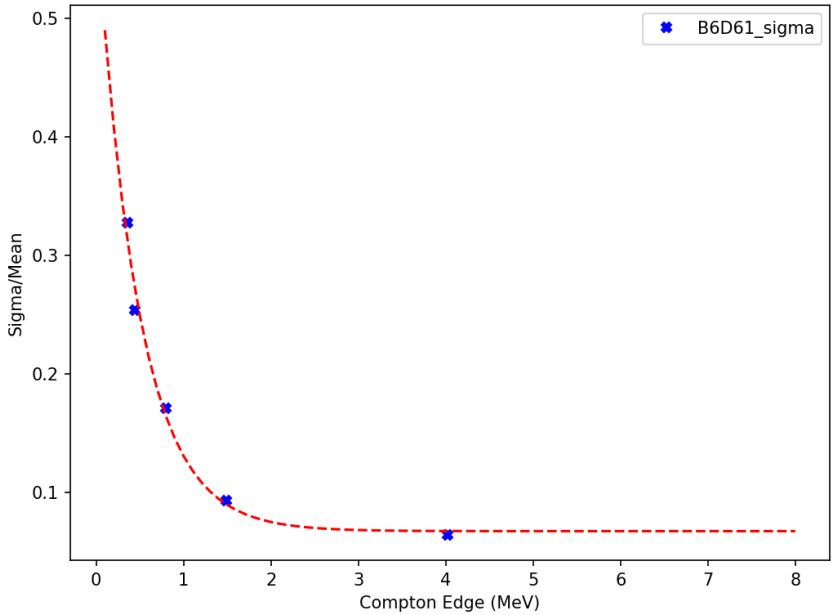


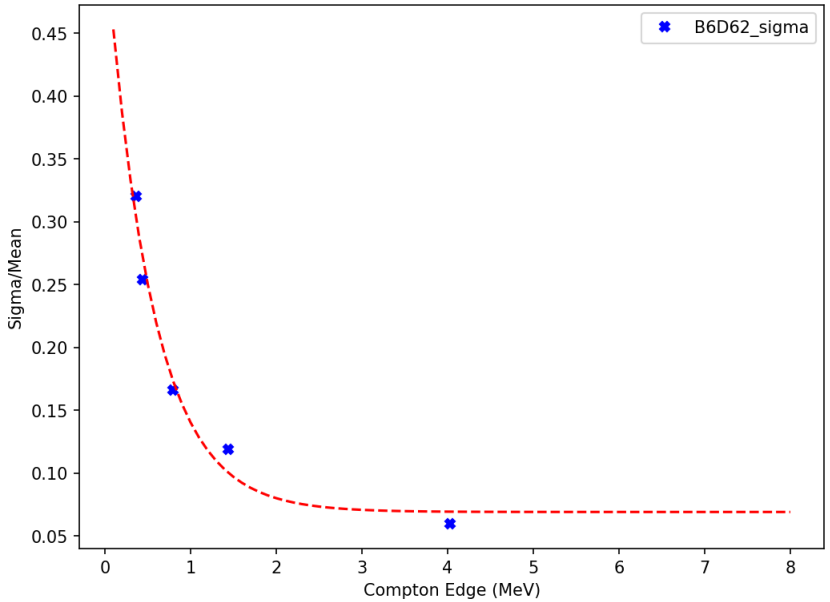


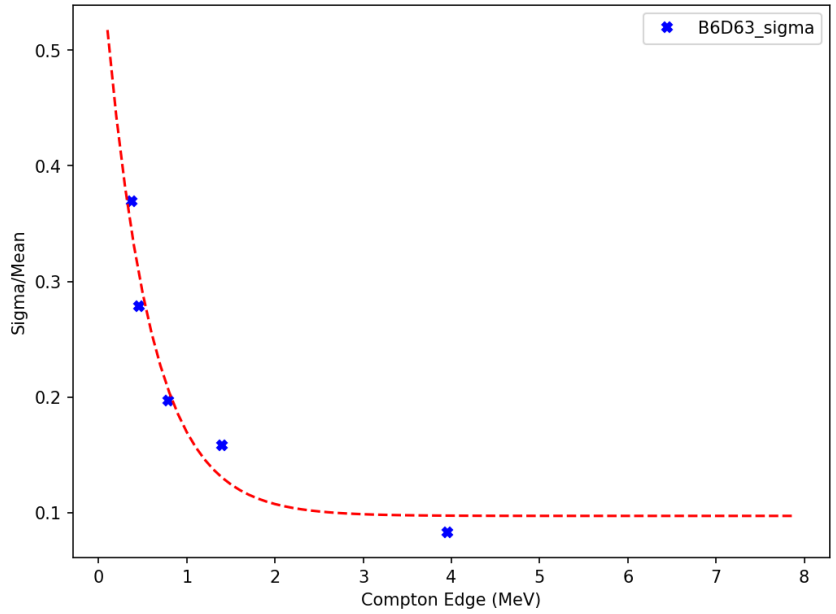


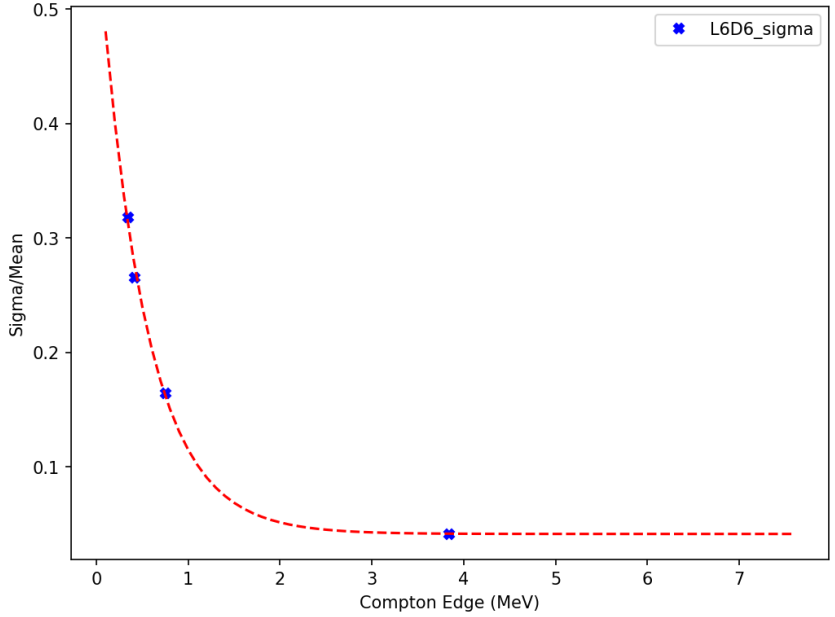


EAR2 2021 Resolution

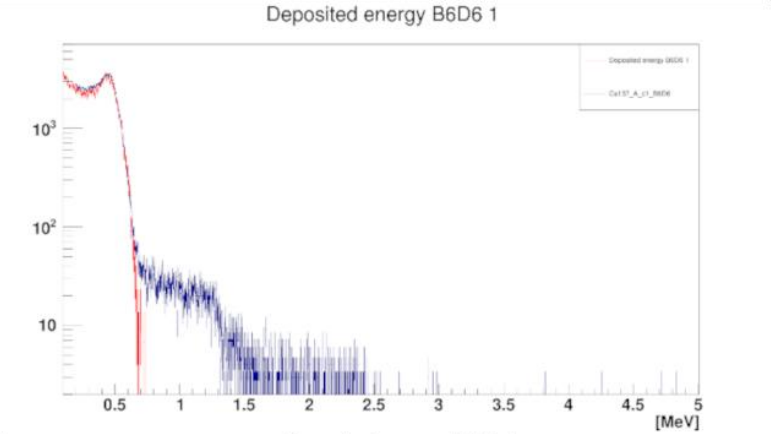


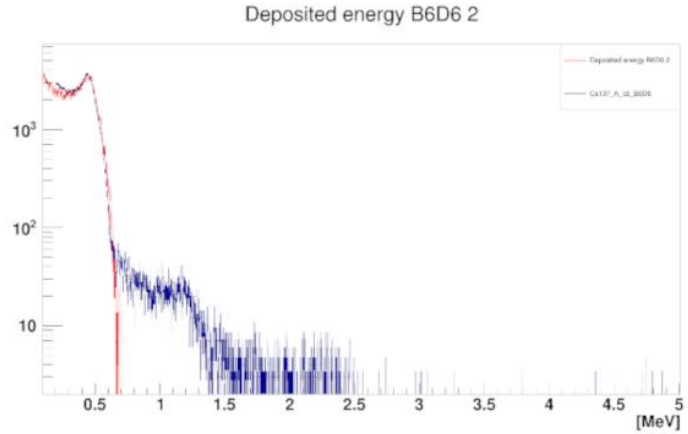


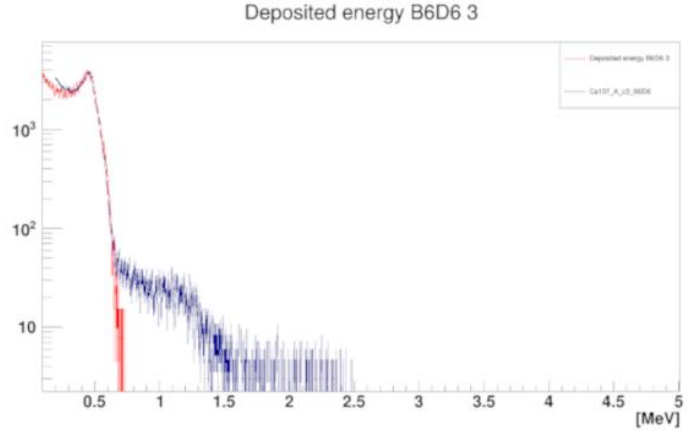


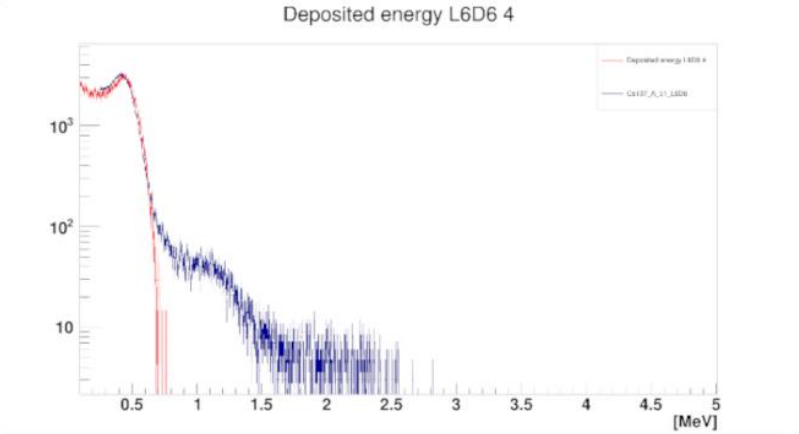


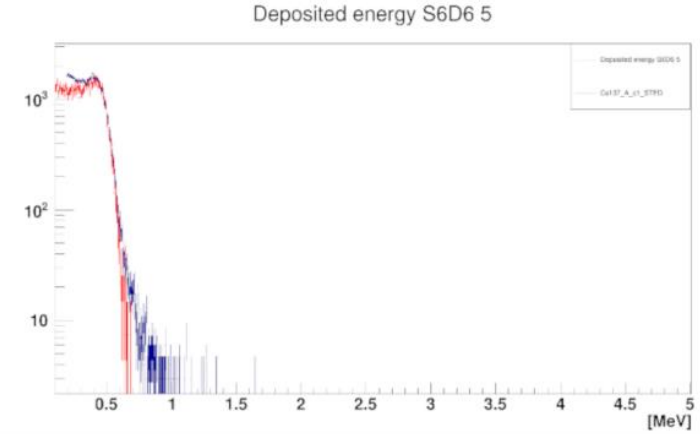
EAR2 simulation – Sources Cs











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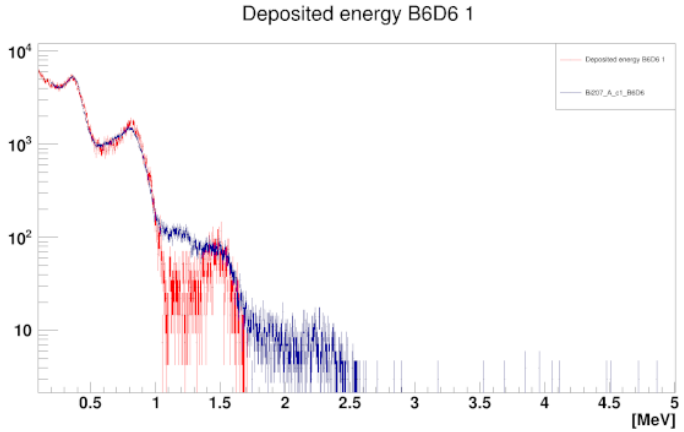

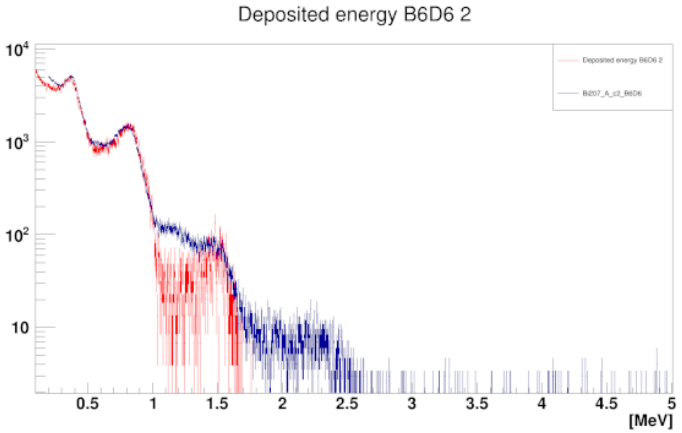

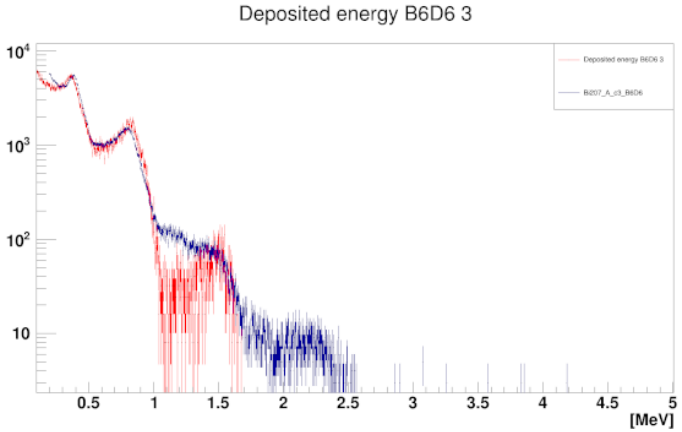

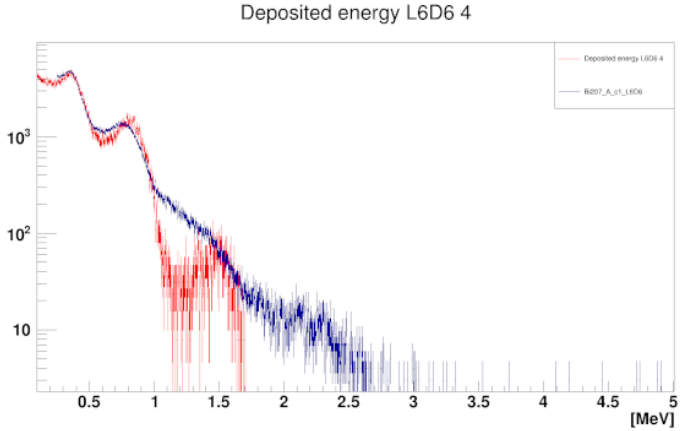

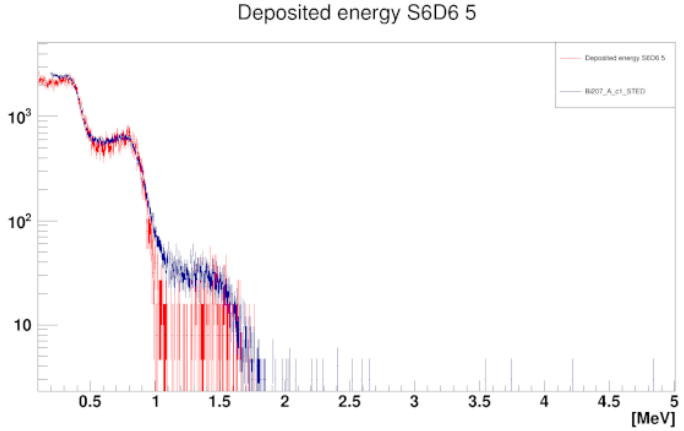

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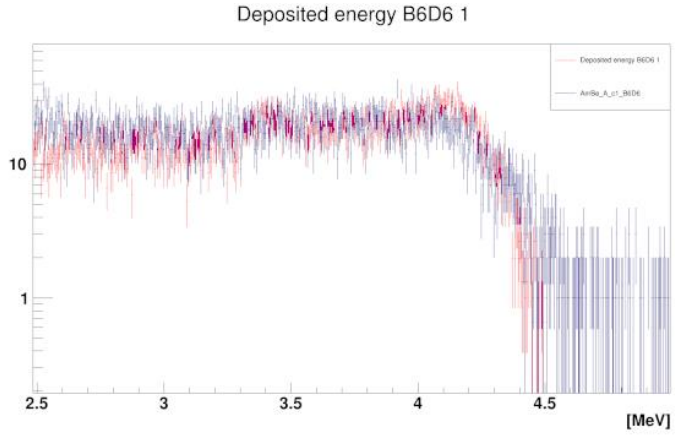
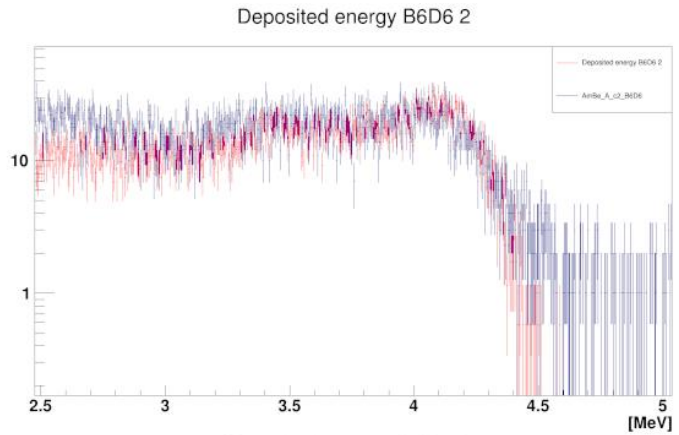
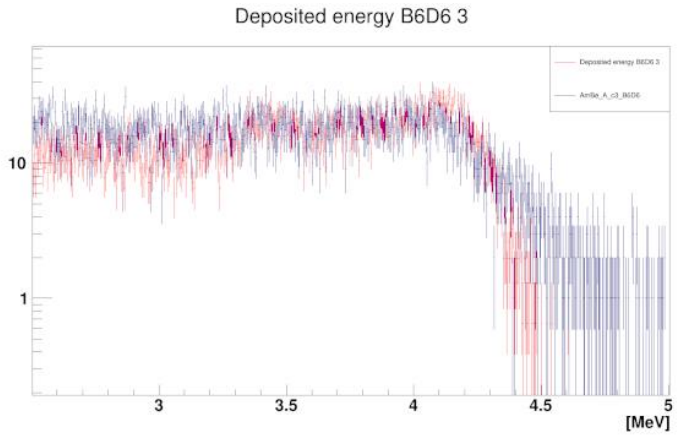
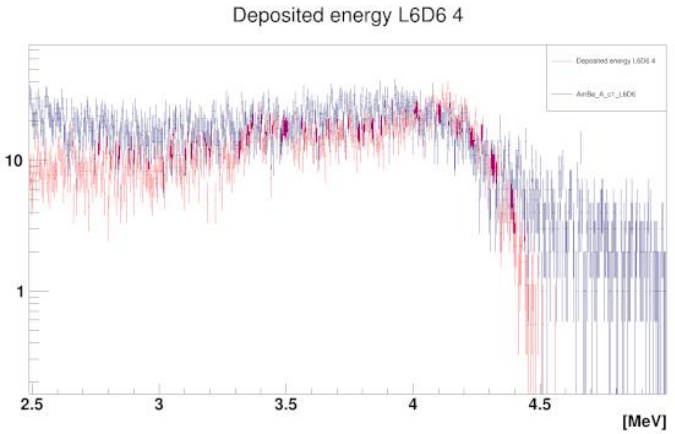
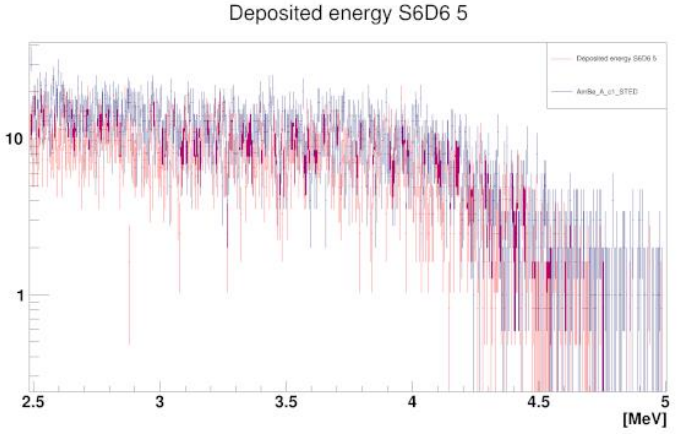


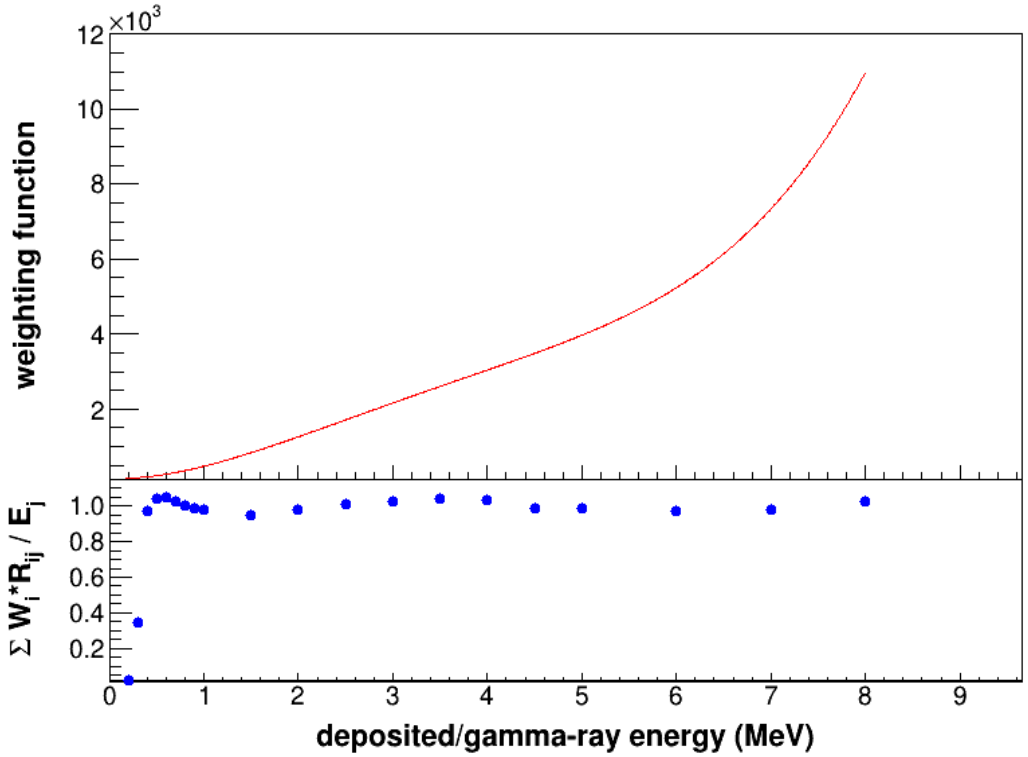


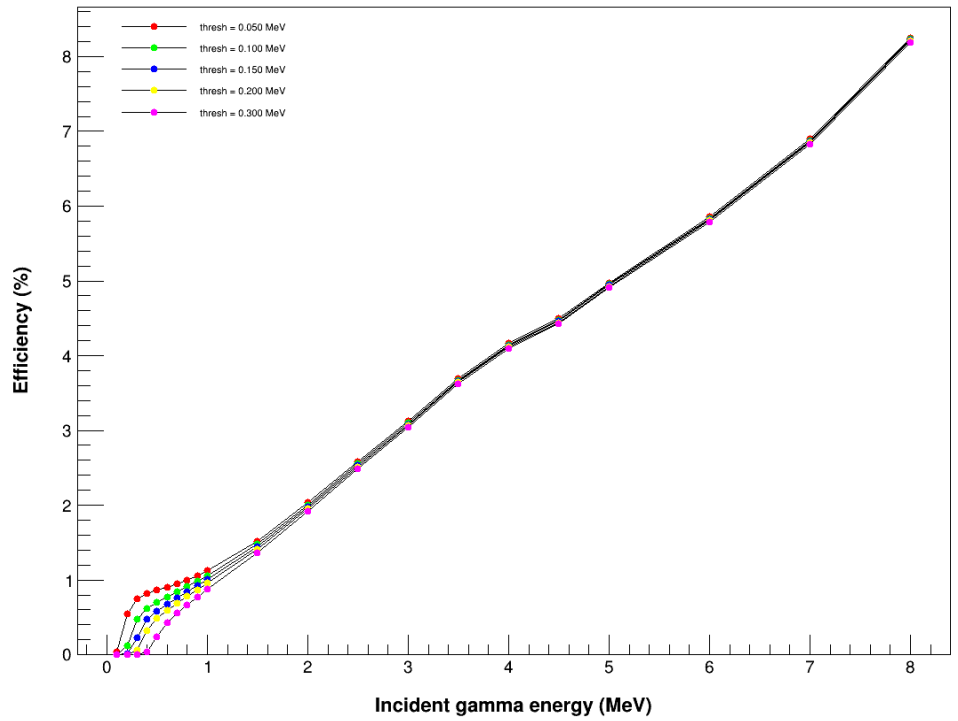




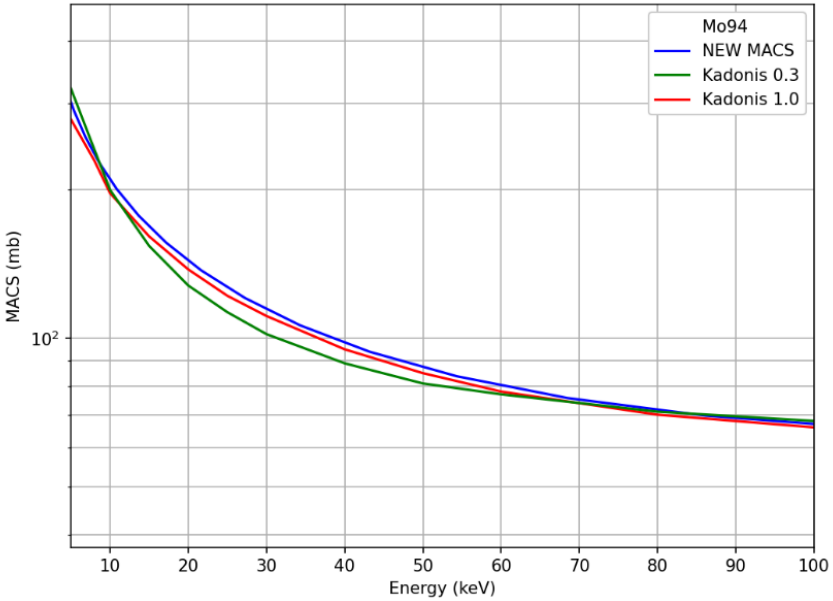


EAR2 2021 WF

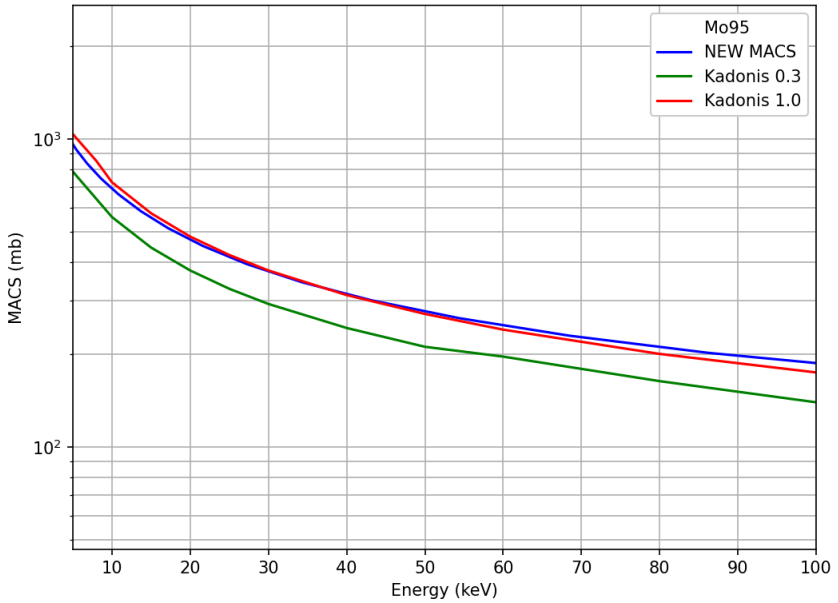

×10^3
weighting function
Σ W_i*R_ij / E_j
deposited/gamma-ray energy (MeV)

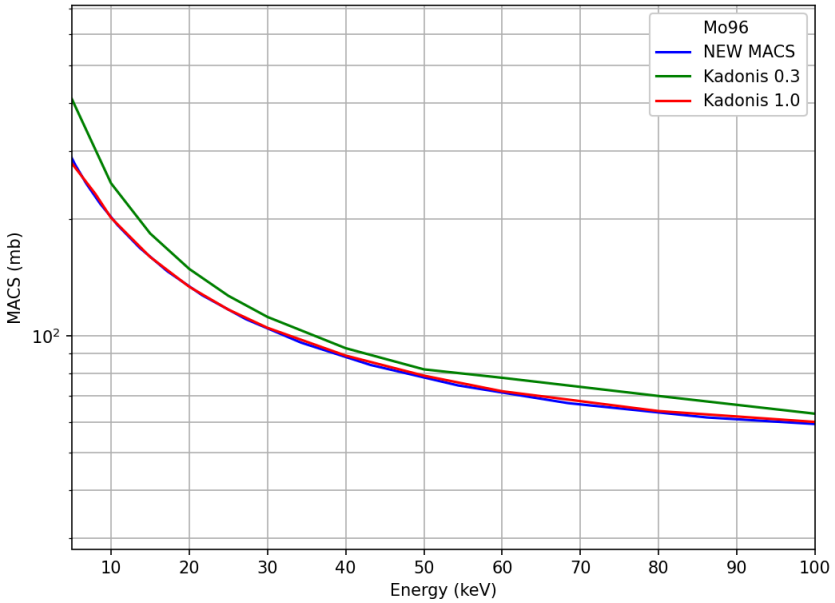

thresh = 0.050 MeV
thresh = 0.100 MeV
thresh = 0.150 MeV
thresh = 0.200 MeV
thresh = 0.300 MeV
Efficiency (%)
Incident gamma energy (MeV)

Updated MACS



New MACS for all Mo isotopes using parameters from RP file





NEWTON calculation