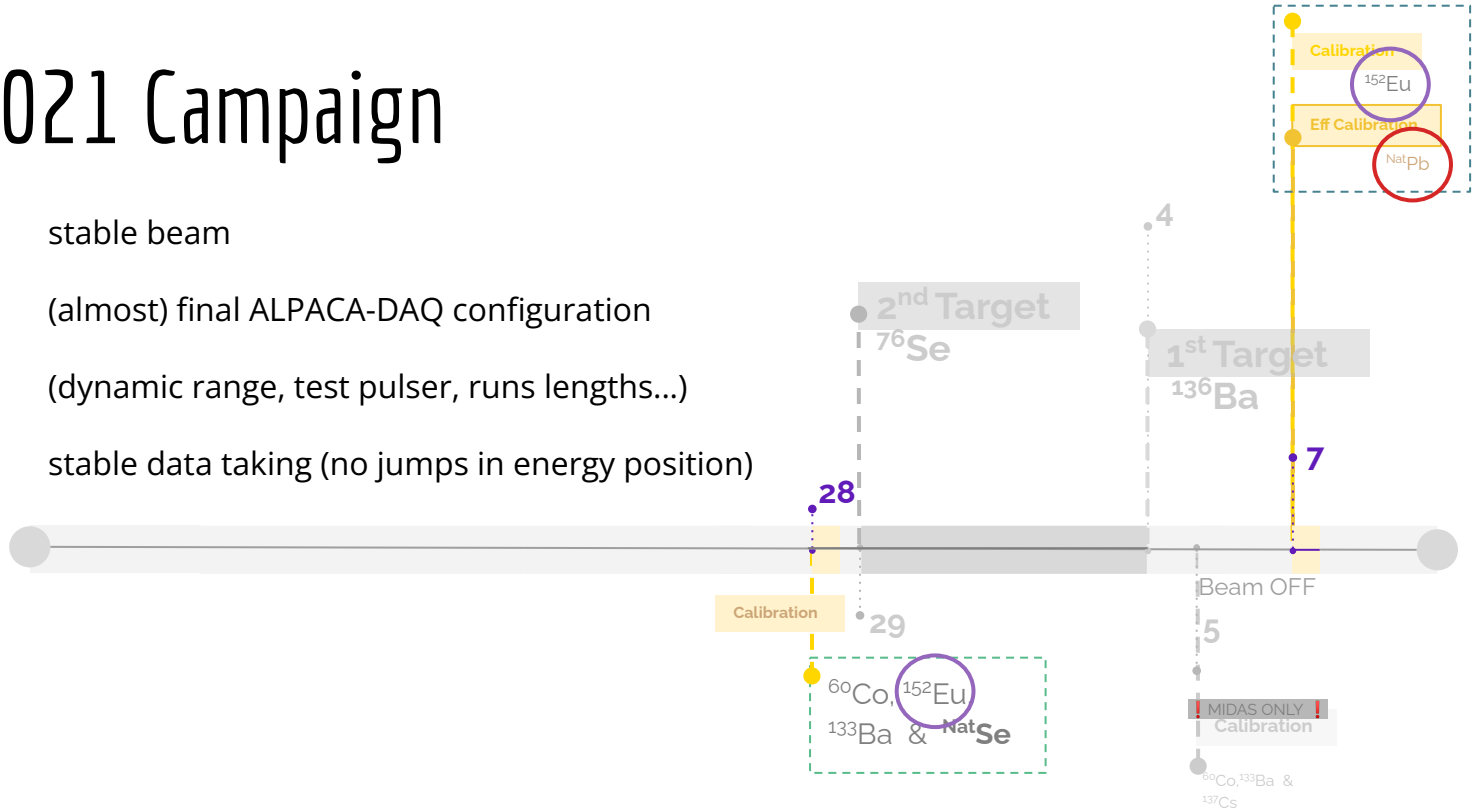
Efficiency at high Energy using ^{Nat}Pb

Elizabeth Mondragón | TUM

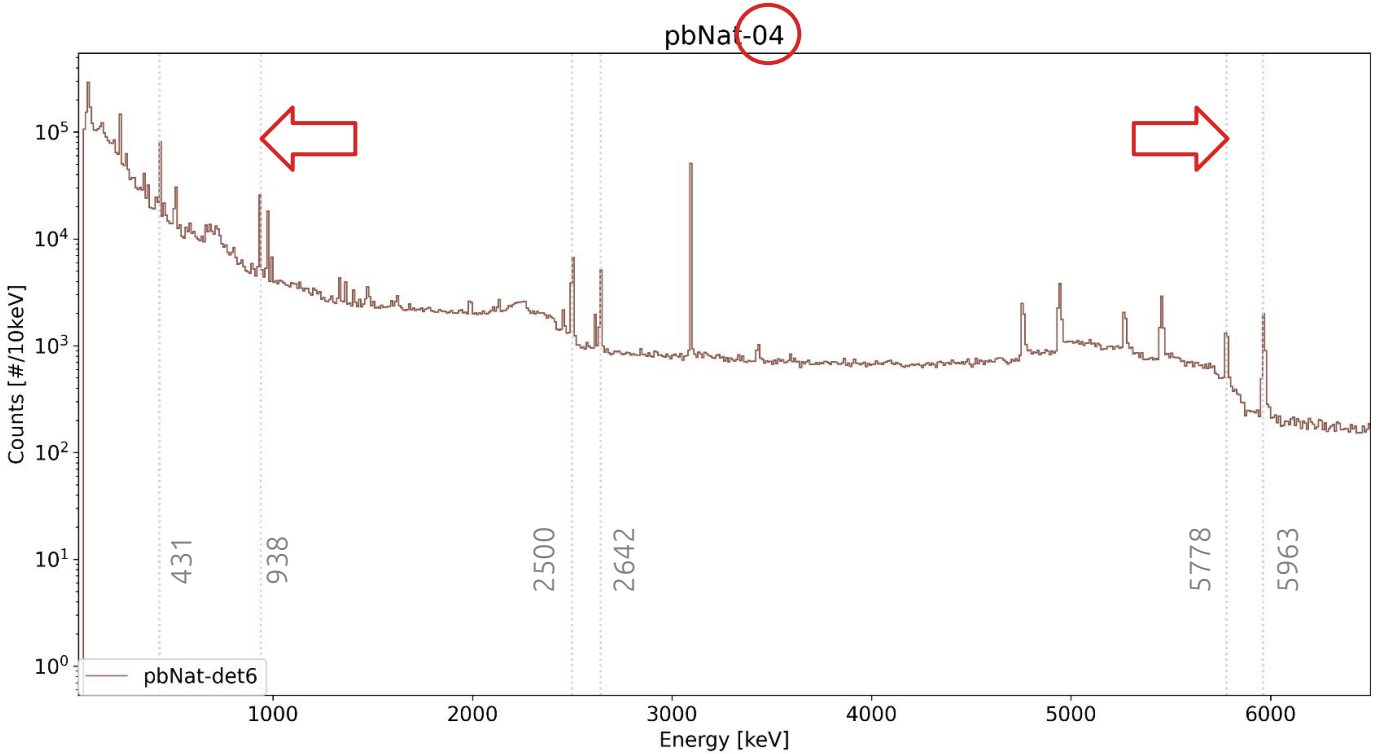
2021 Campaign

- stable beam
- (almost) final ALPACA-DAQ configuration

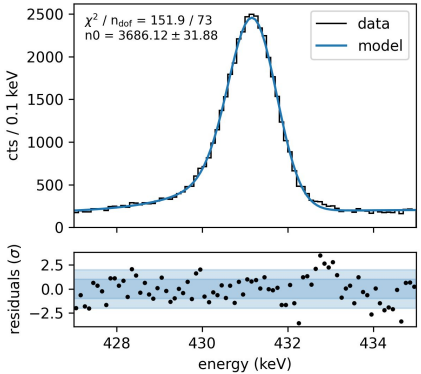
  (dynamic range, test pulser, runs lengths…)
- stable data taking (no jumps in energy position)

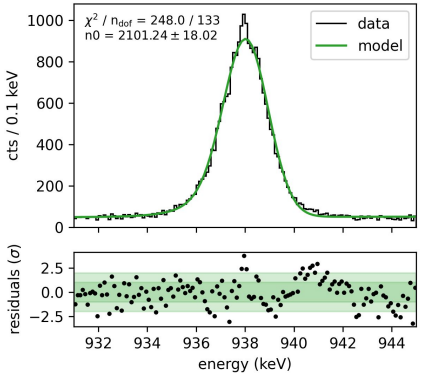


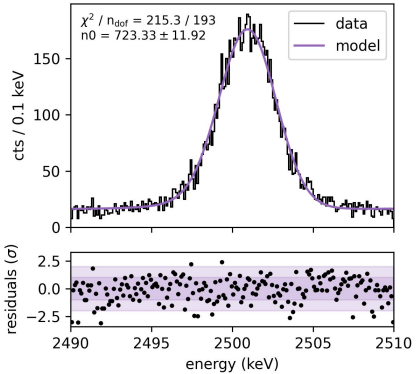
High intensity lines at different energies

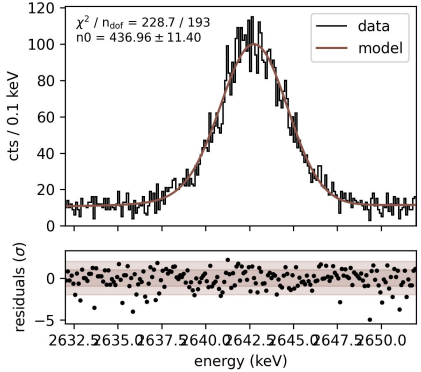


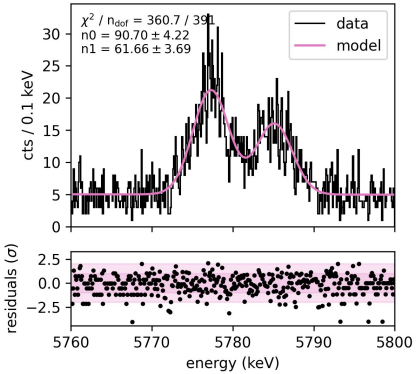
Peaks fits

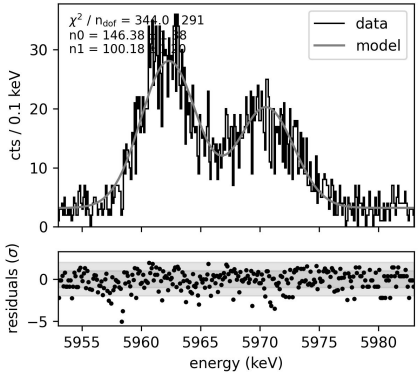

χ^2 / n_{dof} = 151.9 / 73
n0 = 3686.12 ± 31.88
data
model
cts / 0.1 keV
residuals (σ)
energy (keV)


χ^2 / n_{dof} = 248.0 / 133
n0 = 2101.24 ± 18.02
data
model
cts / 0.1 keV
residuals (σ)
energy (keV)


χ^2 / n_{dof} = 215.3 / 193
n0 = 723.33 ± 11.92
data
model
cts / 0.1 keV
residuals (σ)
energy (keV)


χ^2 / n_{dof} = 228.7 / 193
n0 = 436.96 ± 11.40
data
model
cts / 0.1 keV
residuals (σ)
energy (keV)


χ^2 / n_{dof} = 360.7 / 391
n0 = 90.70 ± 4.22
n1 = 61.66 ± 3.69
data
model
cts / 0.1 keV
residuals (σ)
energy (keV)


χ^2 / n_{dof} = 344.0 / 291
n0 = 146.38
n1 = 100.18
data
model
cts / 0.1 keV
residuals (σ)
energy (keV)

Branching ratios

SU7711702

E1 - 9580

V.S.Butsev, D.Chultem, V.Cojocaru, W.D.Fromm,
Dz.Ganzorig, T.Krogulski, H.-G.Ortlepp,
S.M.Polikanov, E.M.Sabirov, U.Schmidt

A12

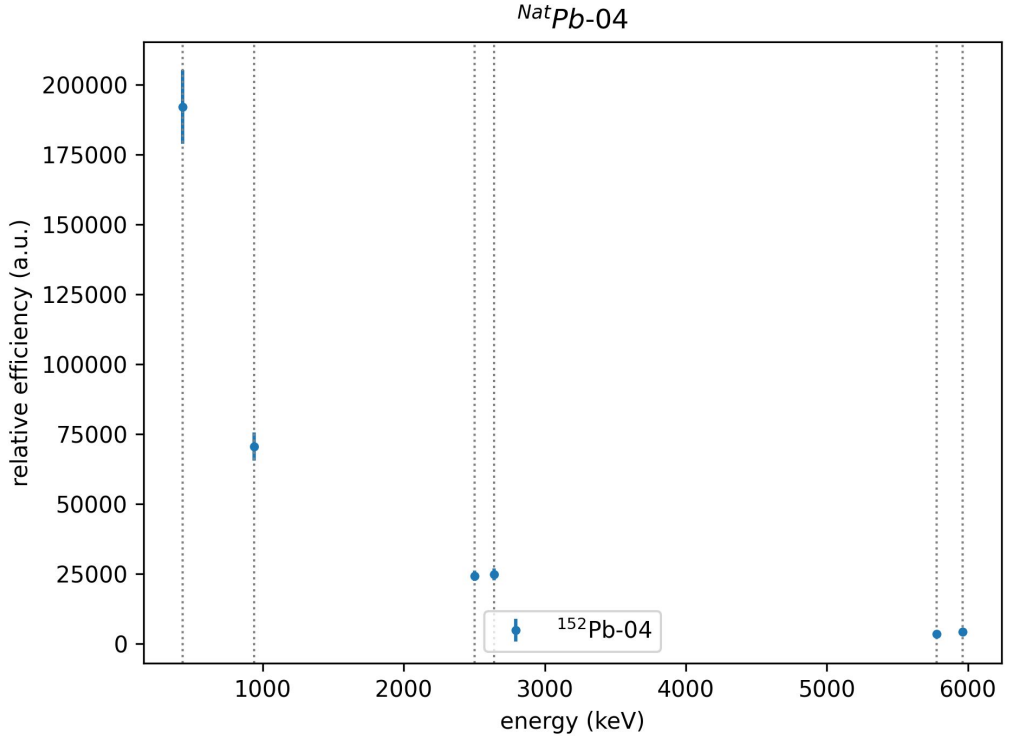
INTENSITIES OF MUONIC X RAYS IN LEAD, THORIUM AND URANIUM

Table 1

Intensities of radiative muonic transitions

	Pb(nat)			^{232}Th		^{238}U	
Transitions	E(keV)	I_{exp}	I_{calc} (α=-0.14)	E(keV)	I_{exp}	E(keV)	I_{exp}
Σ 7i-6h						166-182	0.367±0.025
9j-7i 9i-7h				181-191	0.034±0.004	190-200	0.040±0.004
8i-6h						285-295	0.043±0.007
Σ 6h-5g	230-237	0.436±0.035	0.405	274-291	0.315±0.022	285-304	0.391±0.027
7h-5g	370-375	0.060±0.005	0.075	443-456	0.035±0.003	464-477	0.050±0.006
$5g_{9/2}-4f_{7/2}$	429-432	0.265±0.016	0.239		0.176±0.014		0.228±0.016
$5g_{7/2}-4f_{5/2}$	437-441	0.192±0.013	0.211		0.139±0.009		0.173±0.010
Σ 5g-4f	429-441	0.457±0.032	0.450	514-535	0.315±0.022	537-560	0.401±0.026
6g-4f	662-673	0.055±0.005	0.080	794-816	0.033±0.004	831-854	0.048±0.005
$4f_{5/2}-3d_{5/2}$	929	0.024±0.003	0.016				
$4f_{7/2}-3d_{5/2}$	938	0.298±0.021	0.320	1115-1151	0.205±0.015	1170-1210	0.260±0.020
$4f_{5/2}-3d_{3/2}$	965-972	0.224±0.016	0.284	1174-1193	0.135±0.010	1230-1260	0.180±0.012
Σ 4f-3d		0.546±0.040	0.570		0.340±0.025		0.440±0.032
$3d_{5/2}-2p_{3/2}$	2501	0.298±0.022	0.435	2730-2740 2792-2825 2892-2927	0.074±0.012	2810-2850 2860-3035	0.142±0.020
$3d_{3/2}-2p_{1/2}$	2642	0.176±0.014	0.245	3088-3157	0.159±0.013	3215-3242	0.185±0.020
Σ 3d-2p		0.474±0.038	0.680		0.233±0.025		0.327±0.040
$2p_{1/2}-1s_{1/2}$	5781	0.259±0.026	0.295	6000-6120	0.230±0.024	6050-6200	0.312±0.030
$2p_{3/2}-1s_{1/2}$	5967	0.336±0.029	0.585	6280-6470	0.230±0.024	6380-6580	0.237±0.024
Σ 2p-1s		0.595±0.060	0.880		0.460±0.048		0.550±0.055

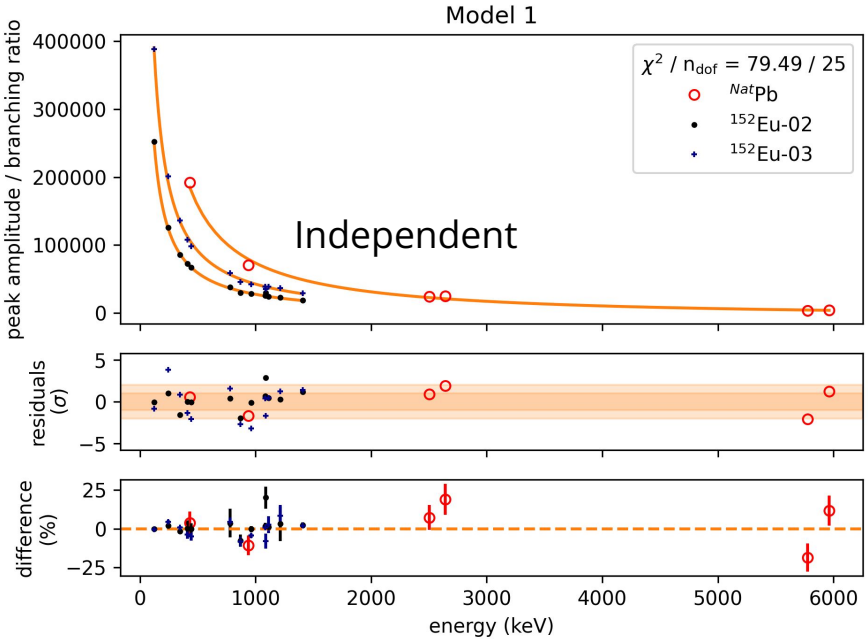
Efficiency values

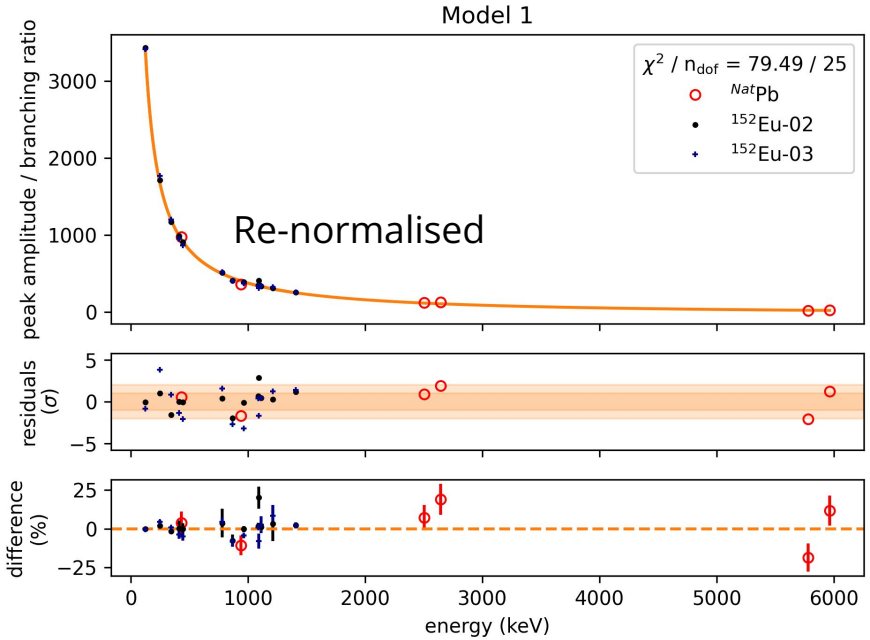


Efficiency fit

$$\epsilon(E) = \frac{1}{E} \cdot \sum_i C_i \ln(E)^i \ ^*$$

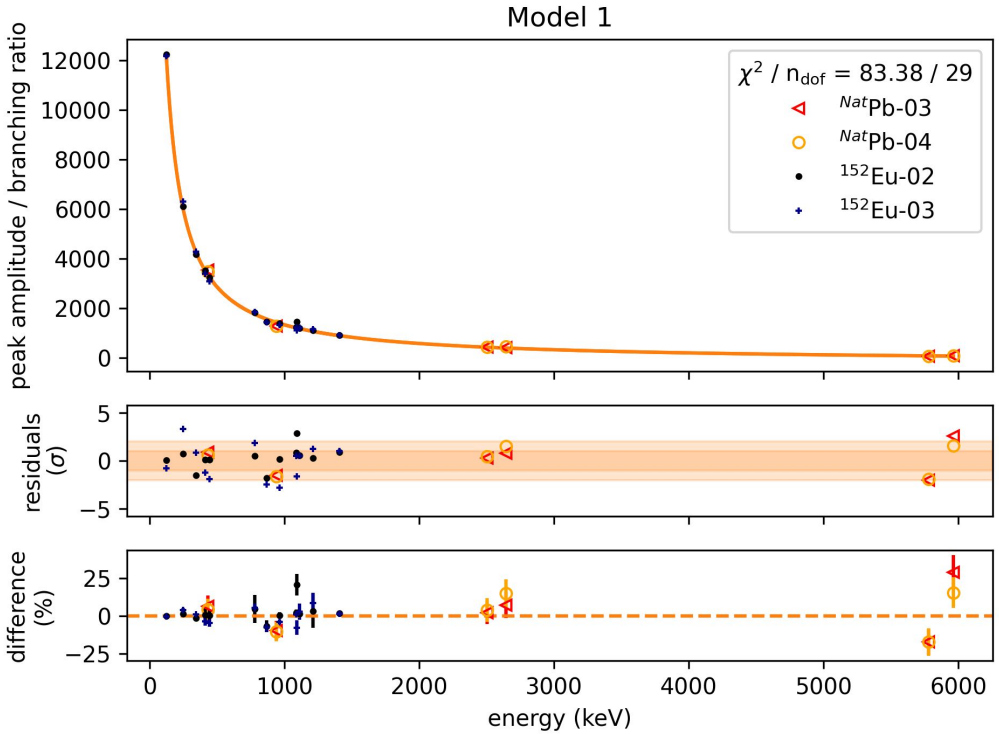
- χ^2 fit (Neyman) using iminuit



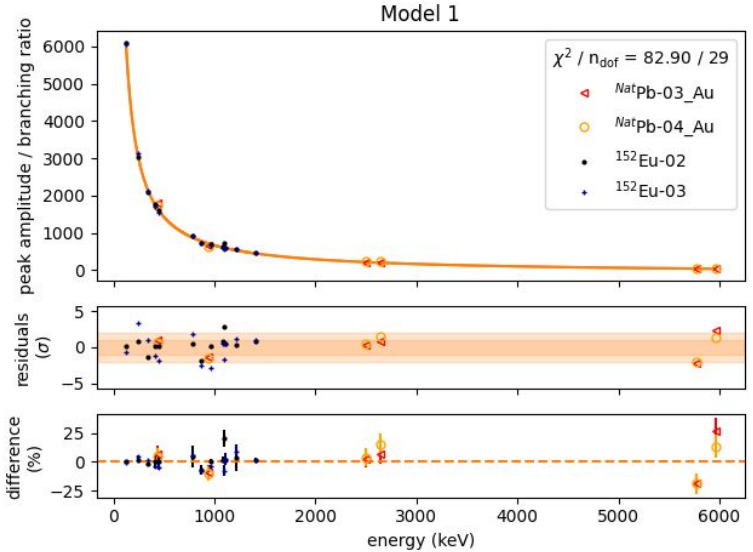


*AIP Conference Proceedings 1584, 38–44 (2014)

Adding other Pb calibration data



Considering an uncertainty on the energy position

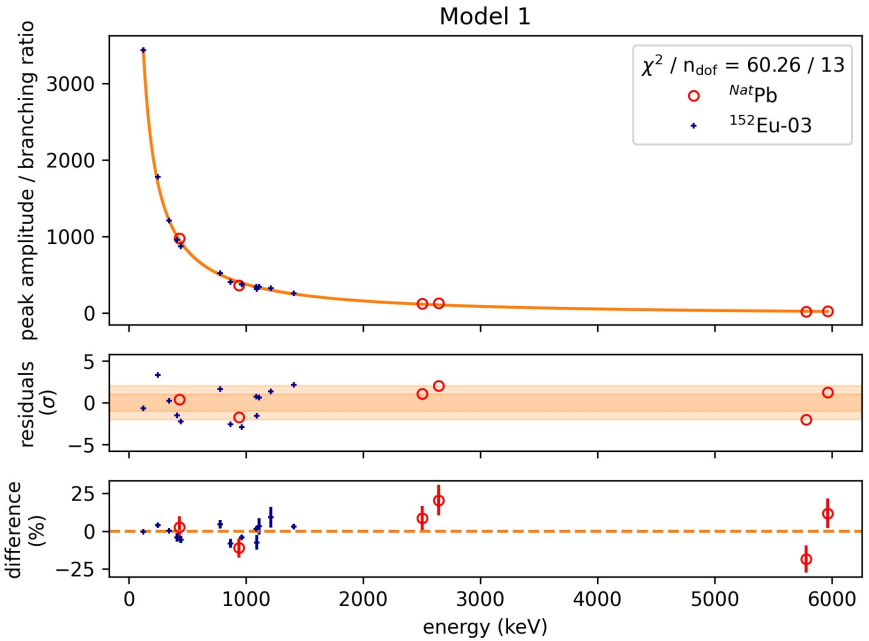


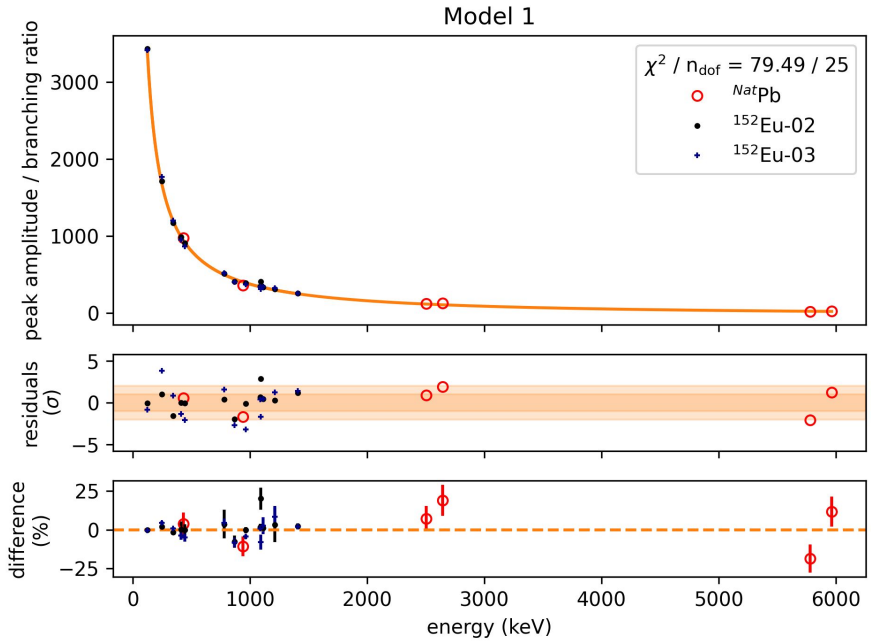
Conclusion

- Efficiency curve that covers most part of the energy spectrum
    - Residual acceptable, might add additional uncertainty
    - Branching ratios found in source worked out reasonably well for this detector
    - Needs to be re-checked when dealing with other detectors with more statistics
- It covers the energy range for the K-series μX-rays for ^{76}Se and ^{136}Ba
- Will serve to provide the $\sum I_{K\text{-series}}/\varepsilon$ term

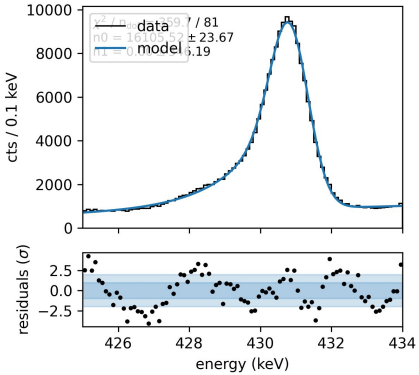
Backup

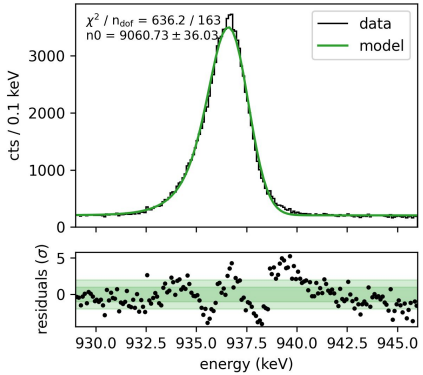
Backup

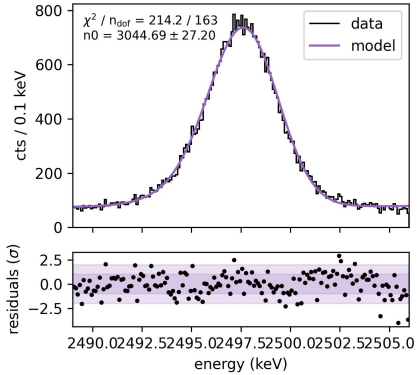

Model 1
χ^2 / n_{dof} = 60.26 / 13
^{Nat}Pb
^{152}Eu-03
peak amplitude / branching ratio
residuals (σ)
difference (%)
energy (keV)

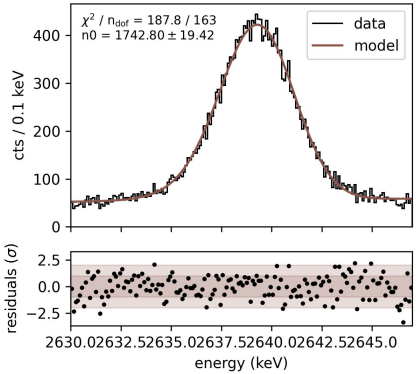

Model 1
χ^2 / n_{dof} = 79.49 / 25
^{Nat}Pb
^{152}Eu-02
^{152}Eu-03
peak amplitude / branching ratio
residuals (σ)
difference (%)
energy (keV)

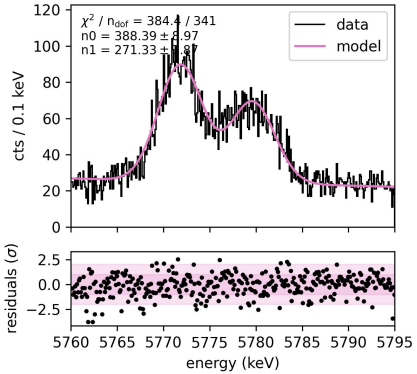
Backup (fits for Pb-03 data set)

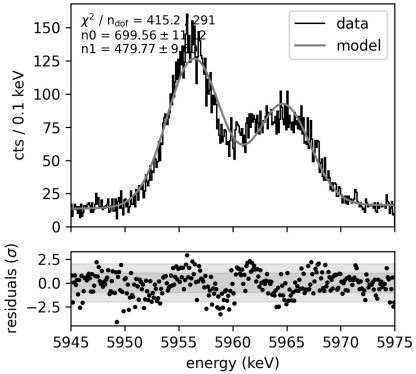












Backup

Table 8. Muonic x-rays in Au. Detailed intensity pattern, otherwise same as Table 7

Transition	Intensity	
	experimental	calc.
$2p_{1/2} \rightarrow 1s_{1/2}$	33.32 ± 1.86	
$2p_{3/2} \rightarrow 1s_{1/2}$	55.88 ± 3.22	
$2p_{3/2} \rightarrow 1s_{1/2}$ [a]	0.67 ± 0.28	
$3p \rightarrow 1s$	1.92 ± 0.24	1.68
$3d \rightarrow 1s$	2.59 ± 0.29	2.71 ± 0.31
$2s \rightarrow 2p$	2.65 ± 0.44	2.27
$3d \rightarrow 2p$	78.72 ± 2.62	82.51 ± 0.70
$3p \rightarrow 2s$	1.71 ± 0.46	1.51
$4d \rightarrow 2p$	3.96 ± 1.57	4.83
$4f \rightarrow 2p$	1.62 ± 0.65	1.59 ± 0.63

[a] With the nucleus left in the first excited state

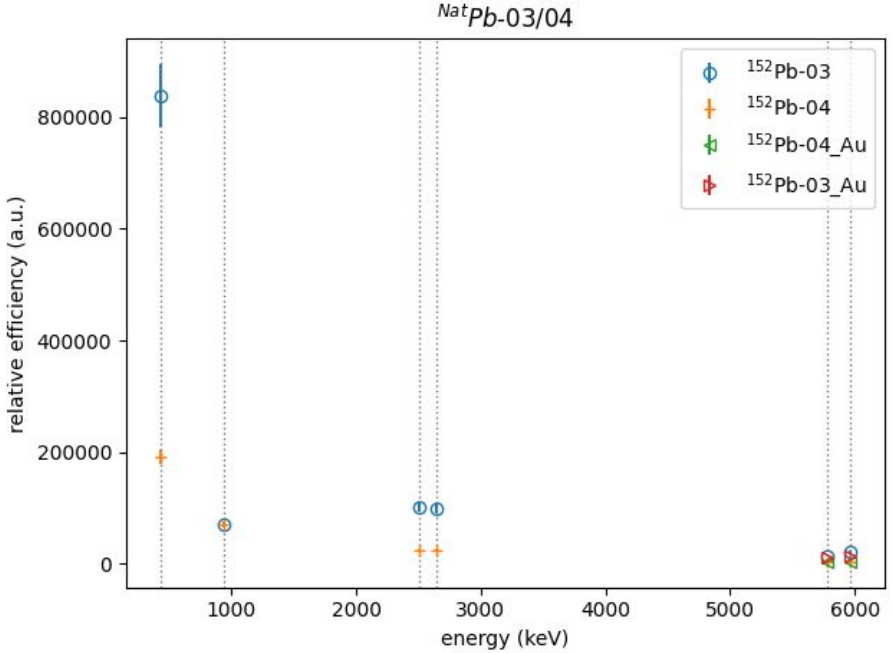
F. J. Hartmann et al., Z. Phys. A - Atoms and Nuclei 305,189-204 (1982)

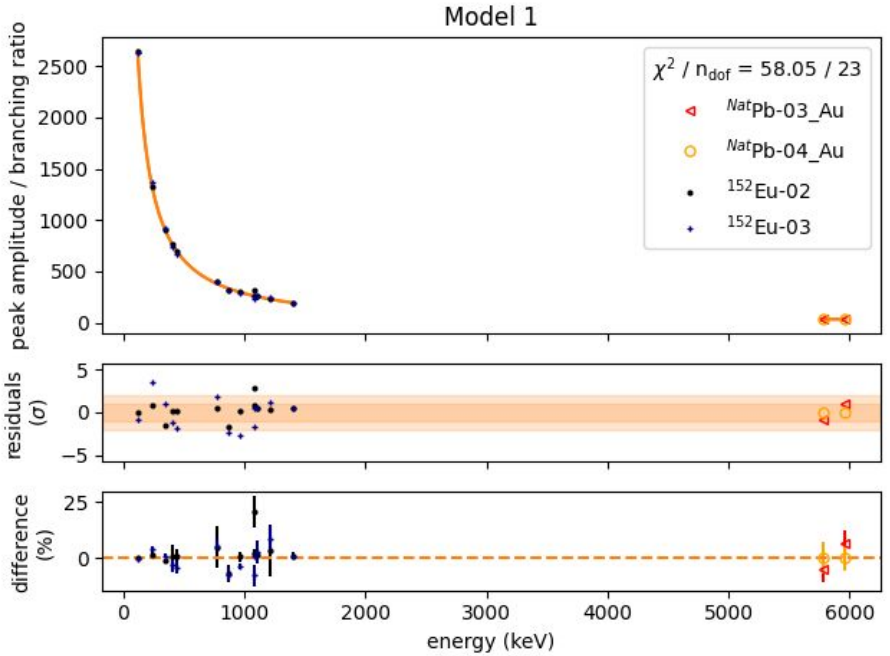
A. A. Skawran, PhD. Thesis [2021]

Transition	Anderson et al. [63]	Butsev et al. [120]	Hartmann et al. [49]
	$^{206}_{82}$Pb	Natural Lead	$^{197}_{79}$Au
	Fraction per μ capture	Fraction per μ capture	Fraction per μ capture
$2p_{3/2} - 1s_{1/2}$	0.421	0.336 ± 0.029	0.5655 ± 0.0323
$2p_{1/2} - 1s_{1/2}$	0.233	0.259 ± 0.026	0.3332 ± 0.0186
$2p - 1s$	0.654	0.595 ± 0.060	0.8987 ± 0.0372
$3d_{3/2} - 2p_{1/2}$	0.206	0.176 ± 0.014	
$3d_{5/2} - 2p_{3/2}$	0.348	0.298 ± 0.022	
$3d_{3/2} - 2p_{3/2}$	0.040		
$3d - 2p$	0.594	0.474 ± 0.038	0.7872 ± 0.0262
$4f_{5/2} - 3d_{3/2}$	0.197	0.224 ± 0.016	
$4f_{7/2} - 3d_{5/2}$	0.282	0.298 ± 0.021	
$4f_{5/2} - 3d_{5/2}$	0.015	0.024 ± 0.003	
$4f - 3d$	0.494	0.546 ± 0.040	

Table 3.10: Observed X-ray yield per captured muon in gold and lead.

Backup


^{Nat}Pb-03/04
^{152}Pb-03
^{152}Pb-04
^{152}Pb-04_Au
^{152}Pb-03_Au
relative efficiency (a.u.)
energy (keV)


Model 1
χ^2 / n_{dof} = 58.05 / 23
^{Nat}Pb-03_Au
^{Nat}Pb-04_Au
^{152}Eu-02
^{152}Eu-03
peak amplitude / branching ratio
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