Off-line Data Analysis: ^{136}Ba

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$^{136}Ba(\mu^-,\nu)^{136}Cs$

E (keV)	A_0(X') (10^6 h^{-1})	N_0(X') (10^8)	$T_{1/2}$ (d)	$T_{1/2}$ (ref.) (d)
66.9	0.77	3.51	13.1	13.01
86.4	0.72	3.30	13.3	
109.7	1.18	4.94	12.1	
153.2	1.49	6.72	13.0	
163.9	1.48	6.60	12.9	
166.6	1.20	5.34	12.8	
176.6	2.24	9.86	12.7	
187.3	1.19	4.85	11.8	

E: energy of the peak
A_0: initial activity when the muon irradiation stopped
N_0: initial number of isotopes when the muon irradiation stopped
$T_{1/2}$: half-life

E (keV)	A_0(X') (10^6 h^{-1})	N_0(X') (10^8)	$T_{1/2}$ (d)	$T_{1/2}$ (ref.) (d)
273.6	1.35	6.04	12.9	13.01
319.9	1.58	7.03	12.9	
340.5	1.45	6.48	12.9	
507.2	1.46	***8.86***	***17.5***	
818.5	1.47	6.51	12.8	
1048.1	1.43	6.35	12.8	
1235.4	1.39	6.15	12.8	
1321.6	***90.2***	***392***	12.5	

- For **low energy** region (< 120 keV), A_0(X') is relatively lower.
- There's a **fluctuation** of A_0(X') around **166-187 keV** (possibly due to efficiency).
- A **relatively long** $T_{1/2}$ was calculated for **507.2 keV** (the fitting error is expected to be large since the peak **overlapped** with another peak of ^{132}Cs at 505.8 keV).
- The A_0(X') and its uncertainty for **1321.6 keV** is **unusually high** hence it is excluded from averaging.

$^{136}Ba(\mu^-, \nu 2n)^{134}Cs$

E (keV)	A_0(X') (10^4 h^{-1})	N_0(X') (10^8)	$T_{1/2}$ (y)	$T_{1/2}$ (ref.) (y)
563.2	4.79	***142***	***23.4***	2.0652
569.3	**negative decay constant**			
604.7	6.10	***52.1***	***6.75***	
795.9	6.35	***2.87***	***0.36***	
802.0	**negative decay constant**			
1365.2	**negative decay constant**			

- None of the peak has a $T_{1/2}$ that close to reference value (some peaks even "grow" instead of decay).
- The decay curve is **too flat** to overcome the fluctuation caused by uncertainty of N(X').
- However, the A_0(X') of all peaks are at the **same magnitude of 10^4**.

$^{136}Ba(\mu^-, \nu 4n)^{132}Cs$

E (keV)	A_0(X') (10^5 h^{-1})	N_0(X') (10^8)	$T_{1/2}$ (d)	$T_{1/2}$ (ref.) (d)
464.5	10.2	2.11	6.01	6.48
505.8	8.22	1.03	3.62	
630.2	5.78	1.10	5.51	
667.7	9.62	2.14	6.41	
1317.9	7.48	1.43	5.51	

- The A_0(X') of all peaks are between 5.78-10.2 x 10^5.
- Except 505.9 keV, $T_{1/2}$ of all the peaks are close to reference value.
- The 505.8 keV peak has **relatively short $T_{1/2}$** due to **overlapping** with ^{136}Cs at 507.2 keV.

$^{136}Ba(\mu^-, \nu 7n)^{129}Cs$

E (keV)	$A_0(X')$ (10^4 h^{-1})	$N_0(X')$ (10^6)	$T_{1/2}$ (h)	$T_{1/2}$ (ref.) (h)
371.9	9.09	4.32	33.0	32.06
411.5	10.7	4.07	26.5	

- For ^{129}Cs, two of the most prominent peaks from this isotope are observed successfully.

$^{136}Ba(\mu^-, vp)^{135}Xe$

E (keV)	A_0(X') (10^4 h^{-1})	N_0(X') (10^5)	$T_{1/2}$ (h)	$T_{1/2}$ (ref.) (h)
249.8	5.13	6.16	8.32	9.14

$^{136}Ba(\mu^-, vp2n)^{133}Xe$

E (keV)	A_0(X') (10^4 h^{-1})	N_0(X') (10^6)	$T_{1/2}$ (d)	$T_{1/2}$ (ref.) (d)
81.0	2.72	7.22	7.67	5.2475
233.2	5.60	5.11	2.63	2.198

- For emission channels with 1 proton, the prominent peaks from ^{135}Xe and ^{133}Xe are observed successfully.
- The N_0 of both ^{135}Xe and ^{133}Xe are less than ^{136}Cs and ^{134}Cs by a magnitude of 2 or 3.

$^{136}Ba(\mu^-, \nu\alpha n)^{131}I$

E (keV)	A_0(X') (10^3 h^{-1})	N_0(X') (10^6)	$T_{1/2}$ (d)	$T_{1/2}$ (ref.) (d)
364.5	5.90	1.75	8.58	8.0252

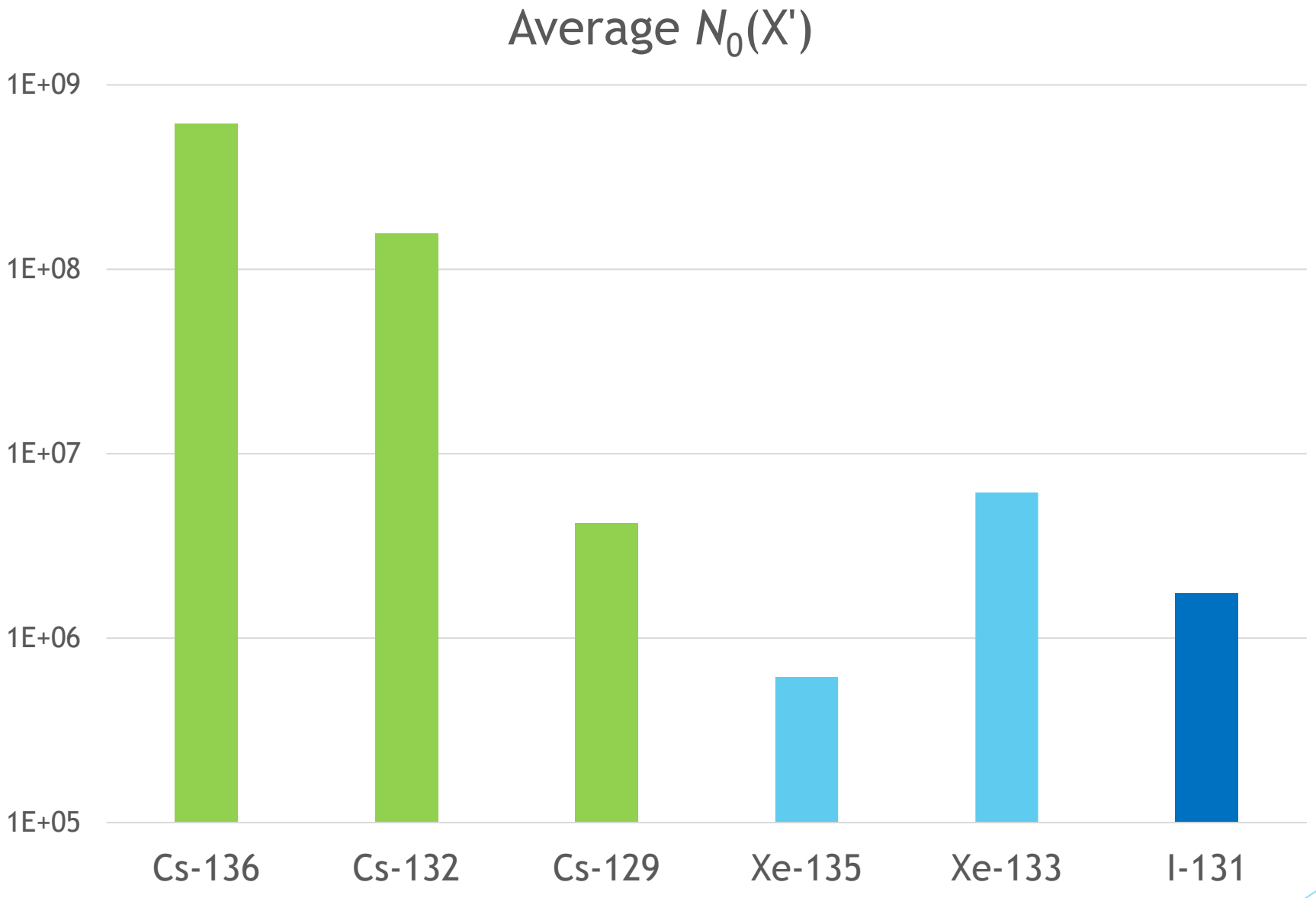
- The most prominent ^{131}I ($1\alpha 1n$) peak at 364.5 keV is observed which confirm the alpha emission from OMC of ^{136}Ba.
- The $N_0(^{131}I)$ is less than half of ^{133}Xe, but more than ^{135}Xe.

Average $N_0(X')$

Isotope	$N_0(X')$	Ratio to ^{136}Cs
^{136}Cs (0n)	6.17×10^8	1
^{135}Cs (1n)	-	-
^{134}Cs (2n)	-	-
^{133}Cs (3n)	-	-
^{132}Cs (4n)	1.56×10^8	0.25
^{131}Cs (5n)	-	-
^{130}Cs (6n)	-	-
^{129}Cs (7n)	4.20×10^6	0.007

Isotope	$N_0(X')$	Ratio to ^{136}Cs
^{135}Xe (1p)	6.16×10^5	0.001
^{134}Xe (1p1n)	-	-
^{133}Xe (1p2n)	6.17×10^6	0.01
^{132}Xe (1p3n)	-	-
^{131}Xe (1p4n)	-	-

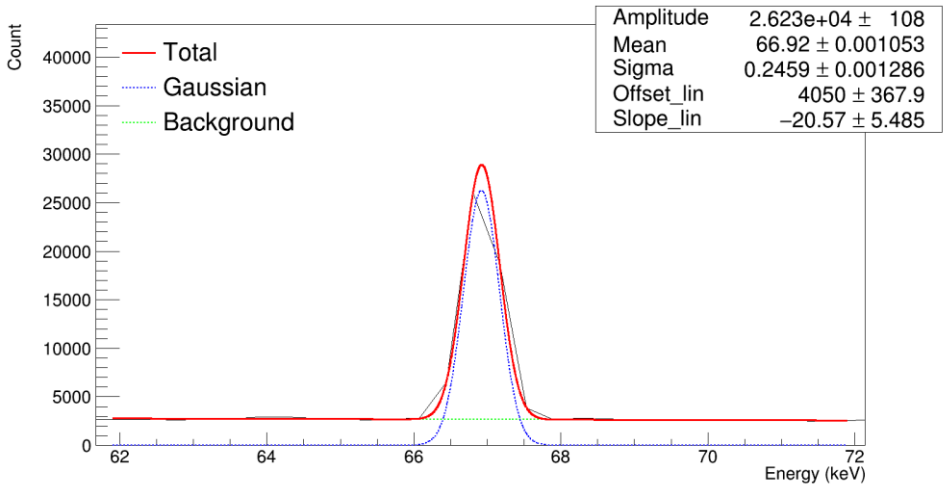
Isotope	$N_0(X')$	Ratio to ^{136}Cs
^{132}I (1α)	-	-
^{131}I (1α1n)	1.75×10^6	0.003
^{130}I (1α2n)	-	-

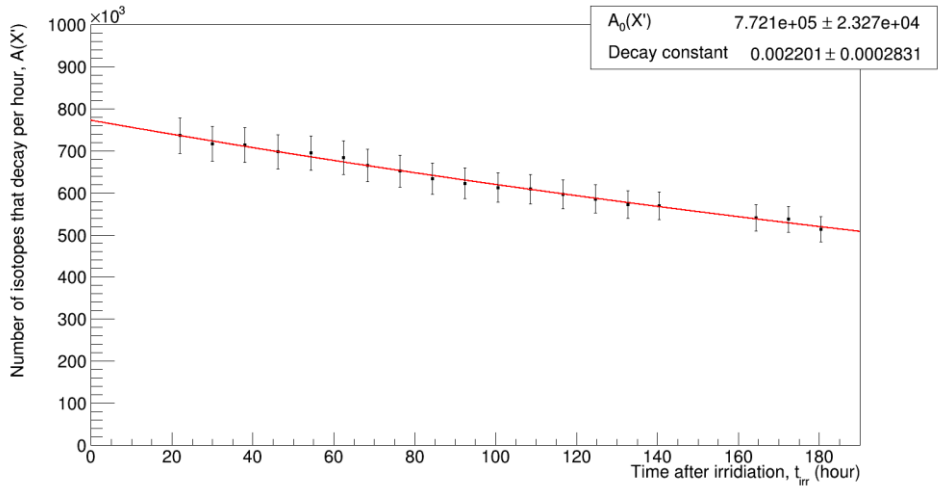

Average $N_0(X')$
1E+09
1E+08
1E+07
1E+06
1E+05
Cs-136
Cs-132
Cs-129
Xe-135
Xe-133
I-131

APPENDIX A:

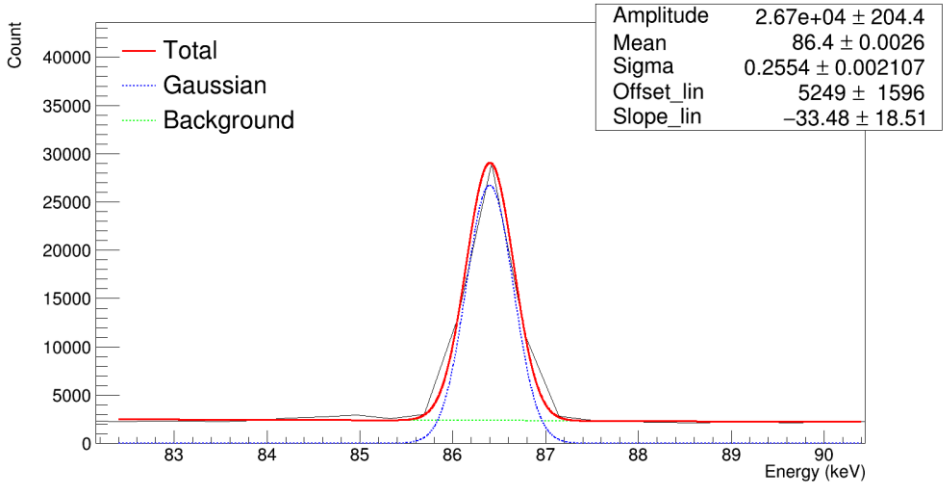
Spectra and $A(X')$ vs t_{irr} plots of $^{136}Ba(\mu^-,\nu)^{136}Cs$ peaks

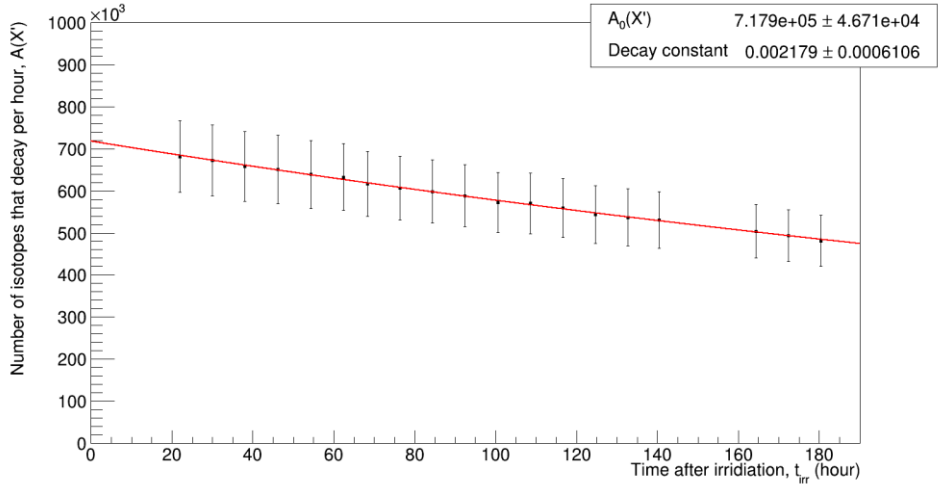
66.9 keV



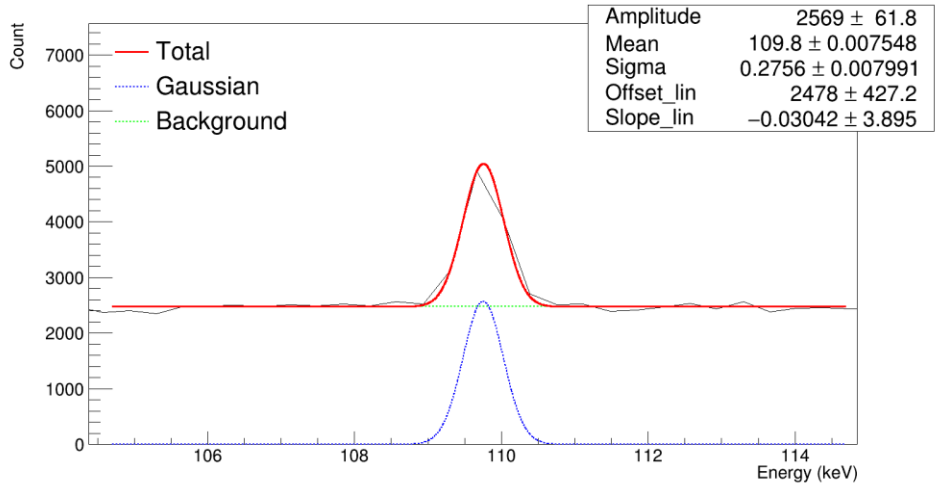


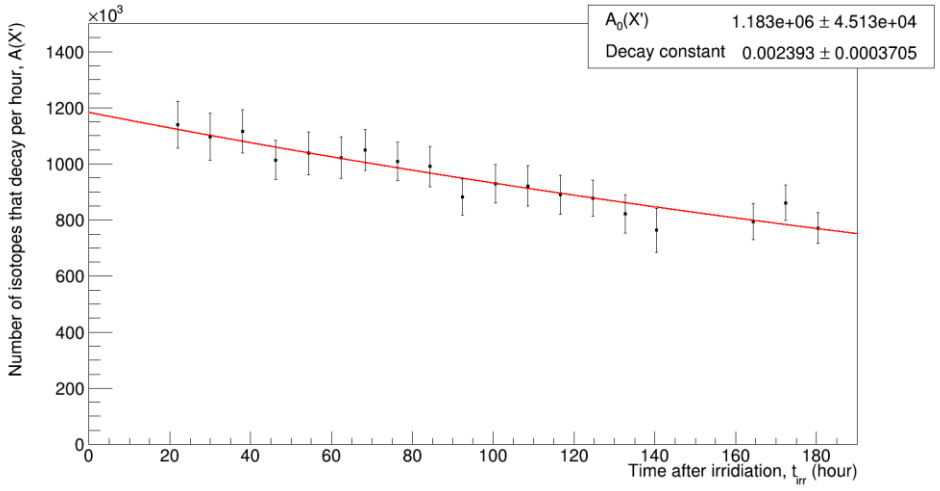
86.4 keV



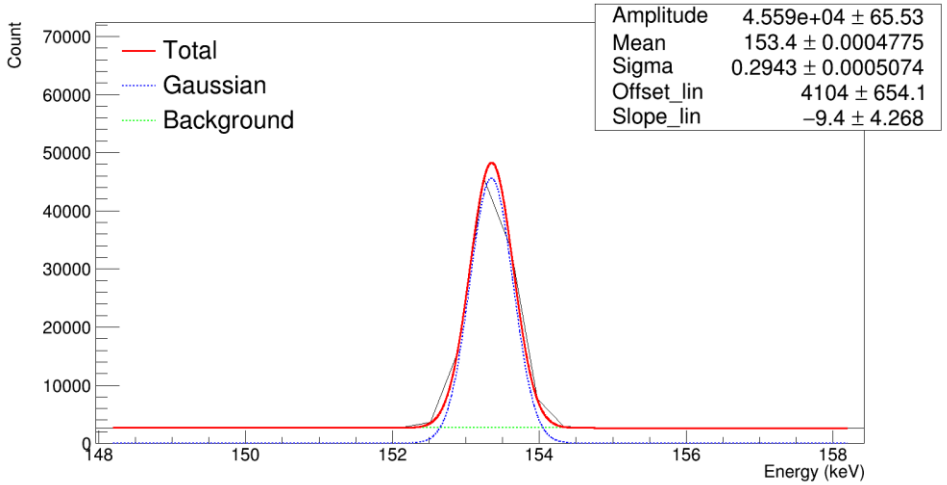


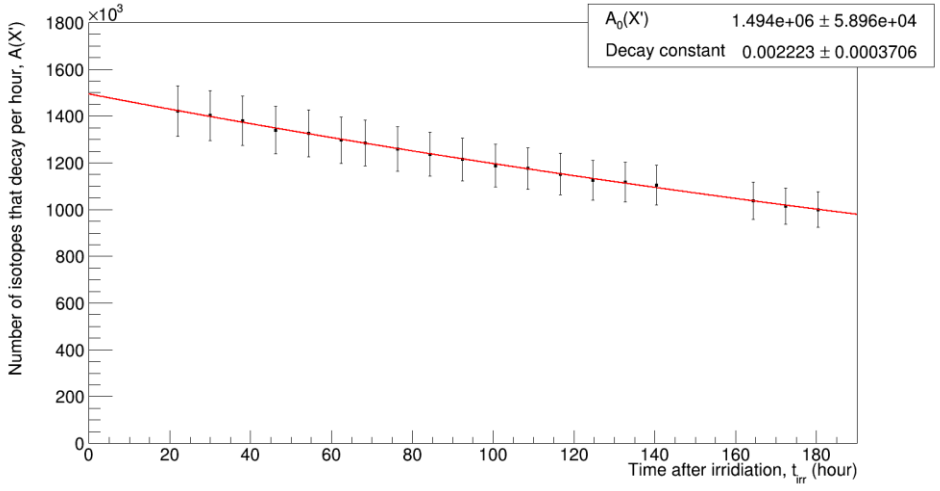
109.7 keV

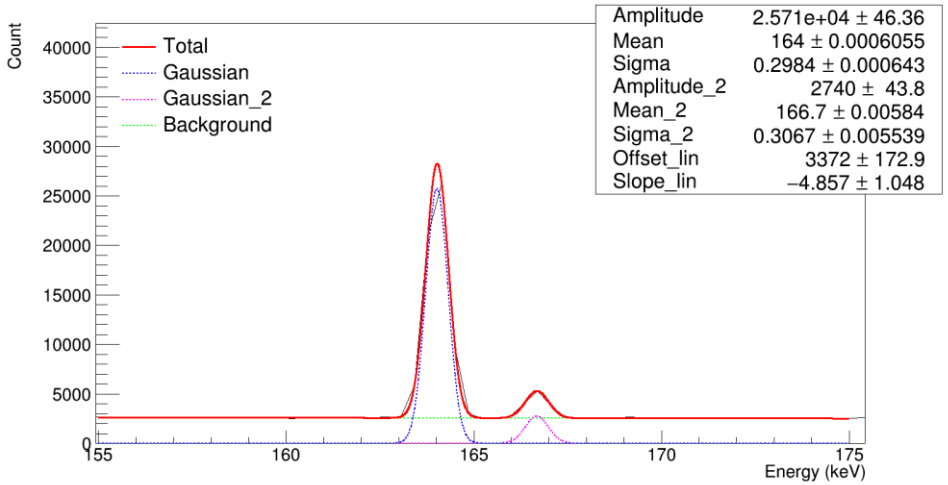




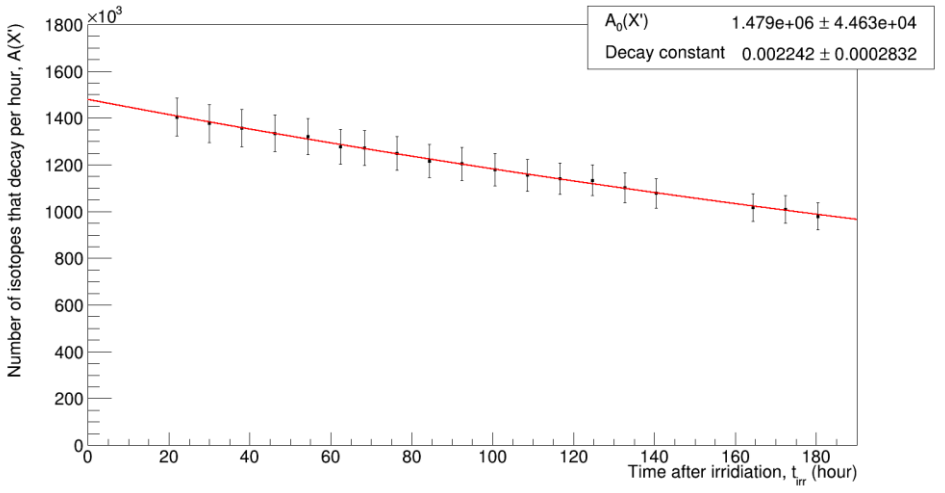
153.2 keV



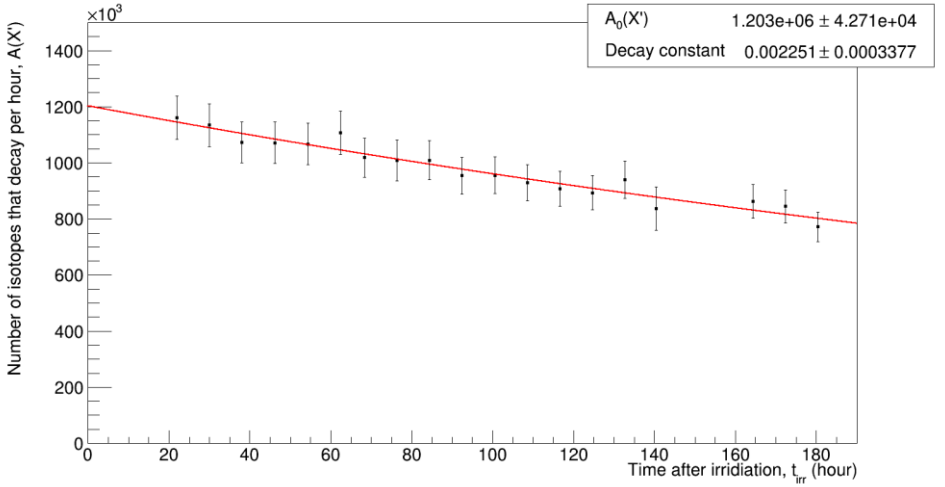




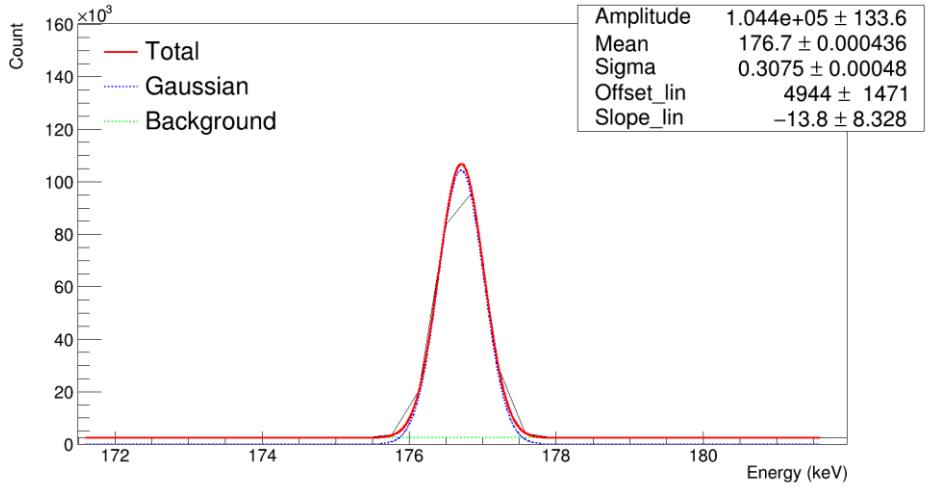
163.9 keV

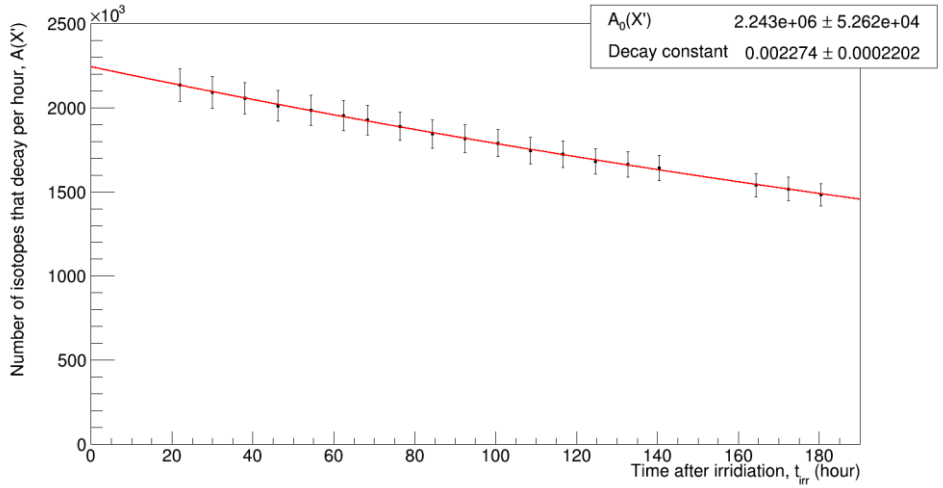


166.6 keV

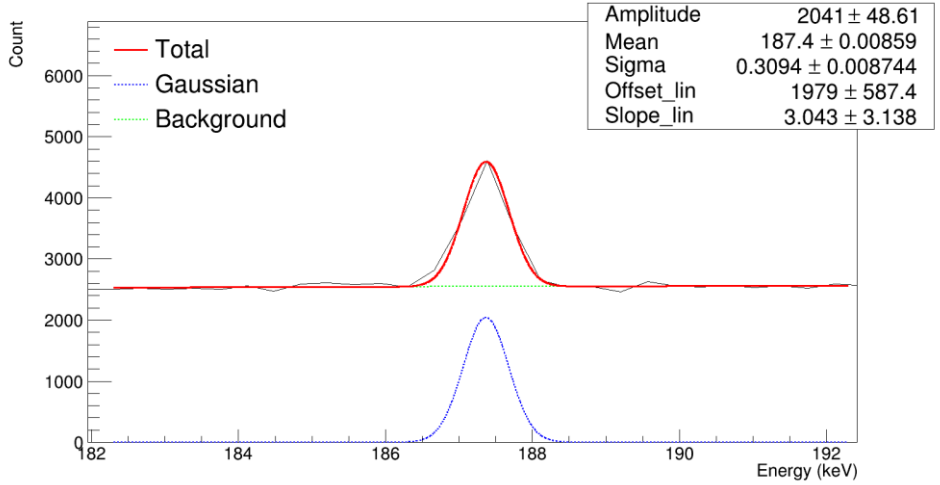


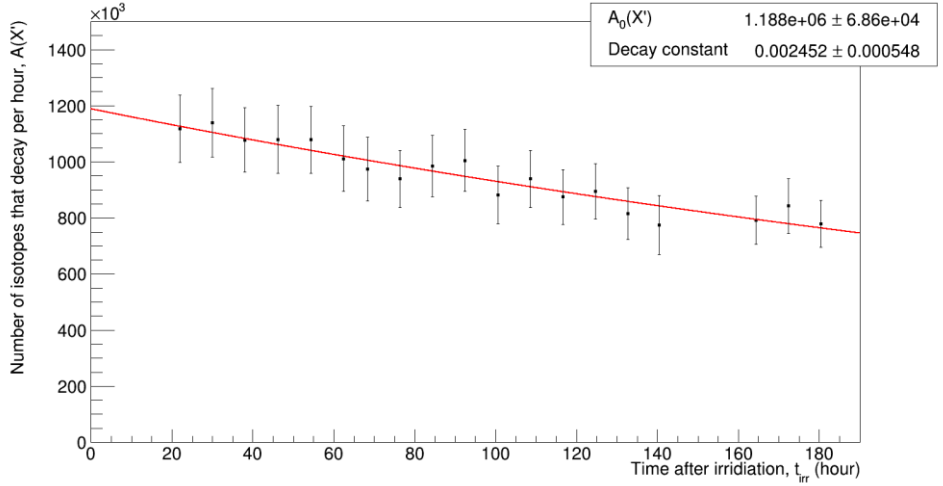
176.6 keV



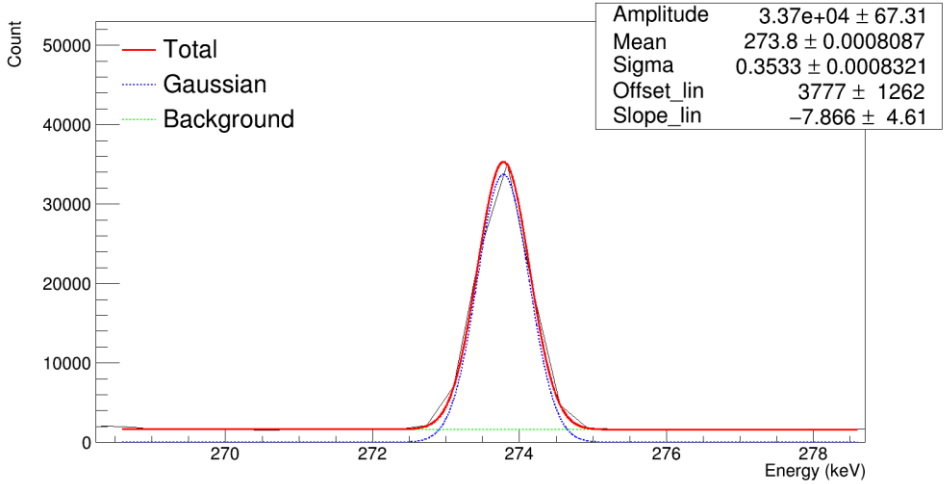


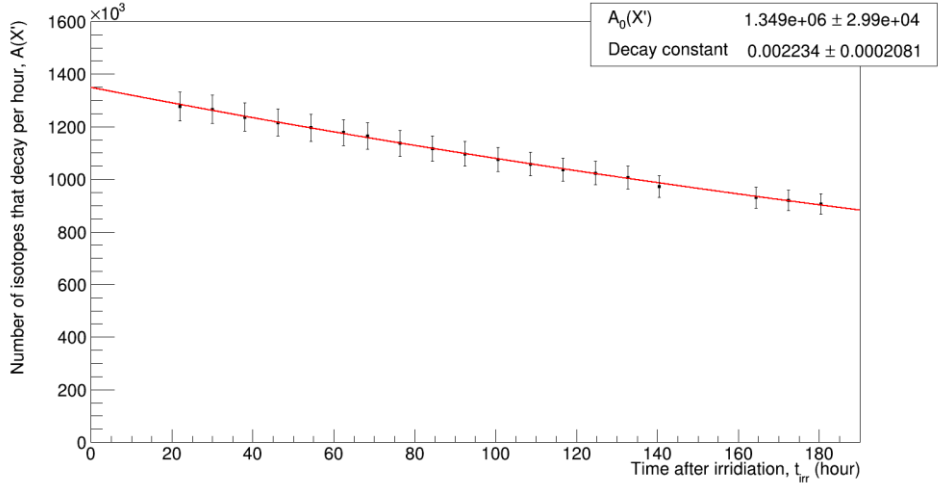
187.3 keV



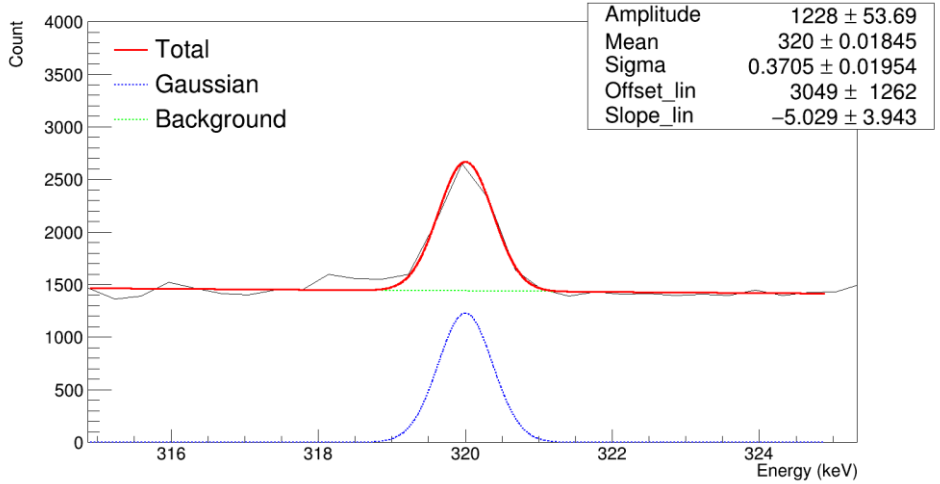


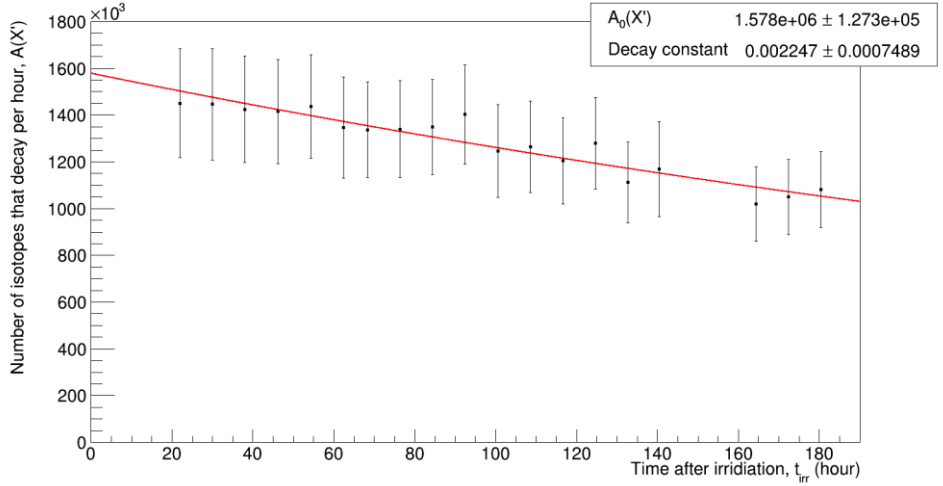
273.6 keV



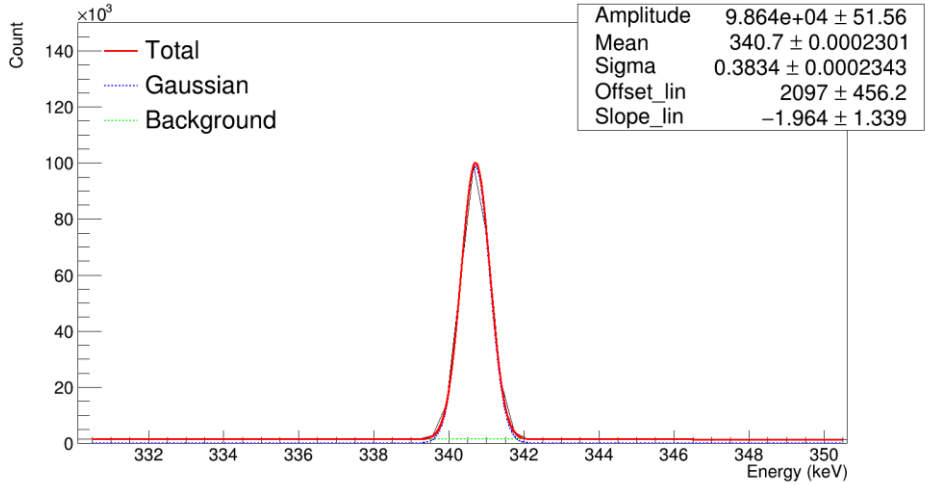


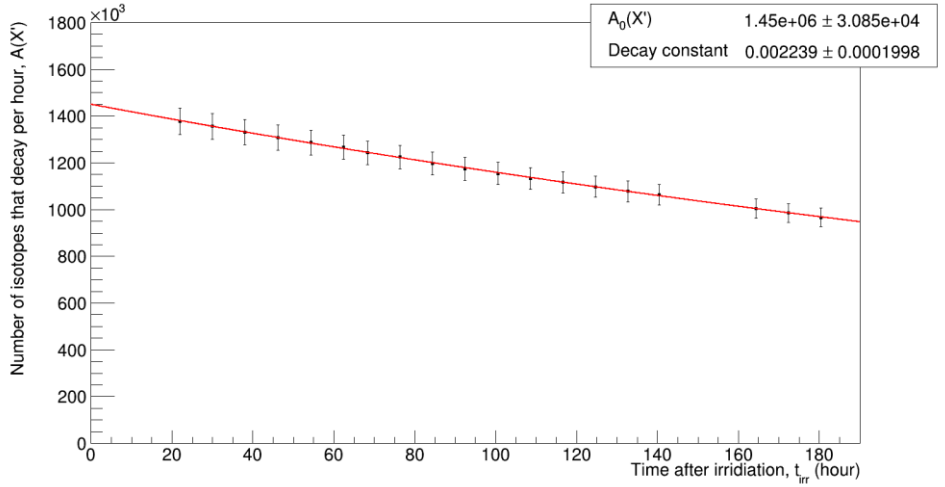
319.9 keV



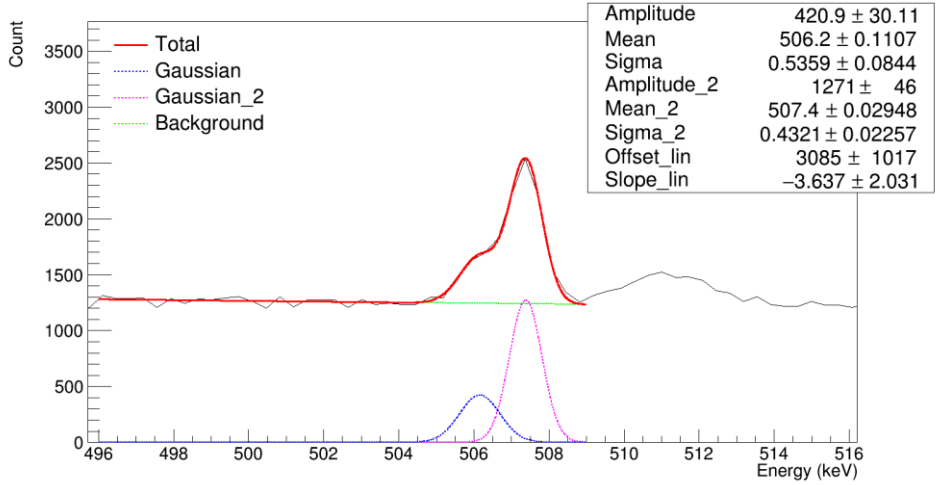


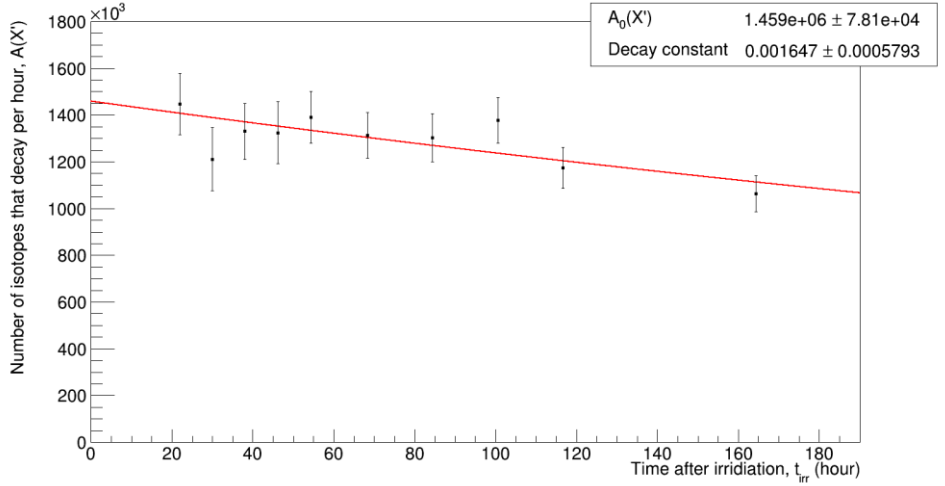
340.5 keV



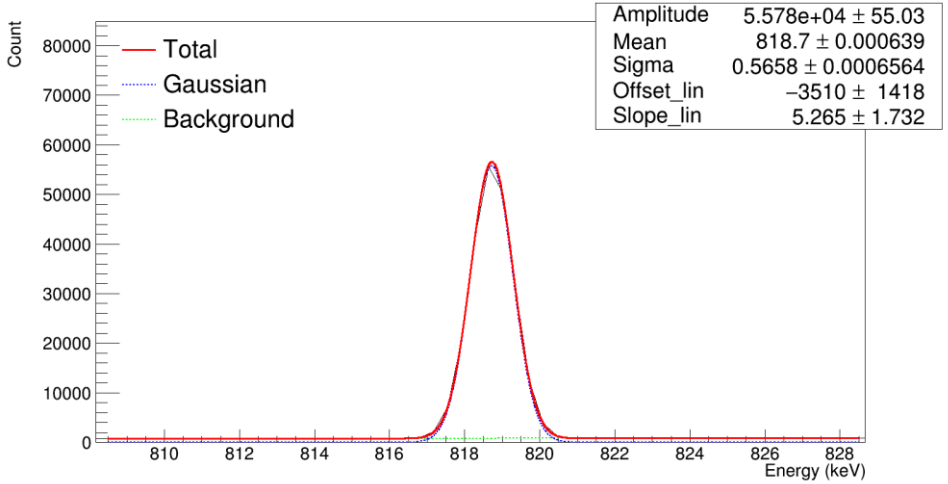


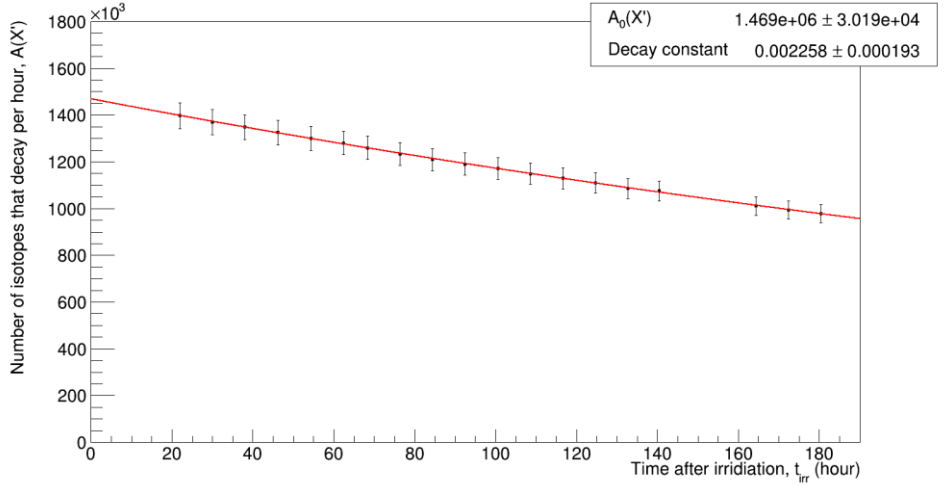
507.2 keV



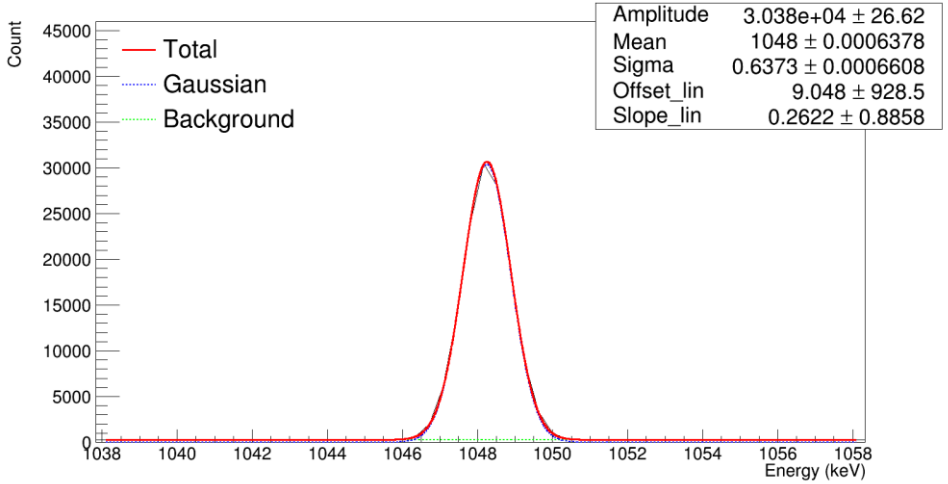


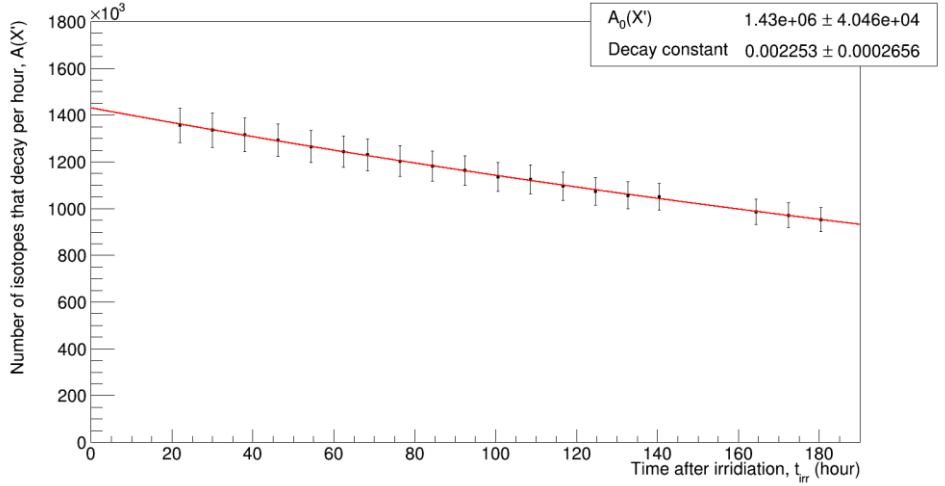
818.5 keV



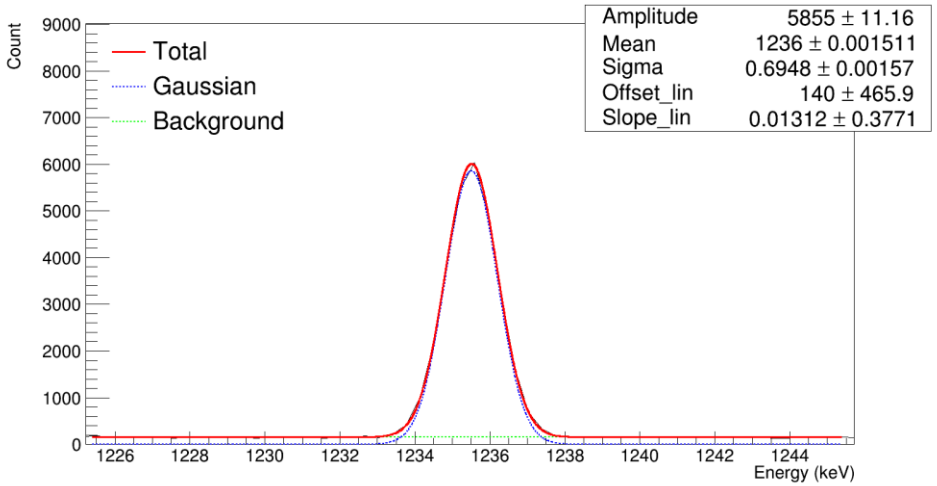


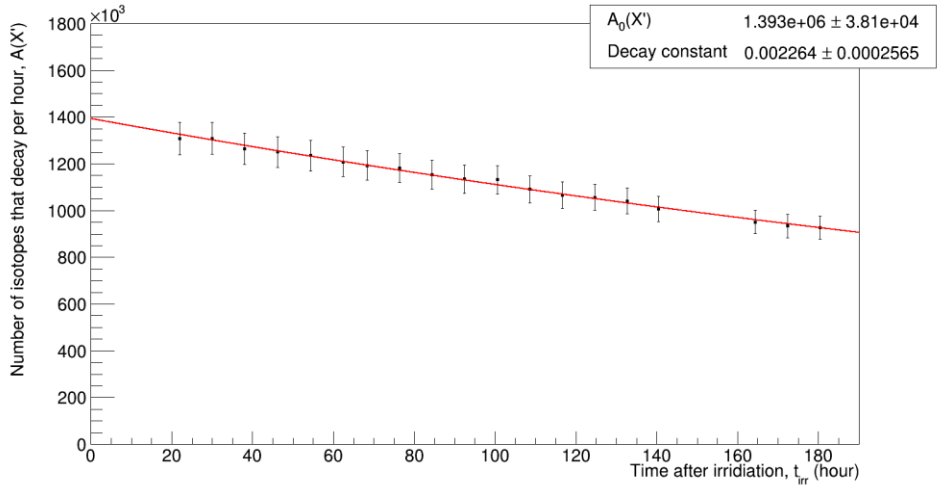
1048.1 keV



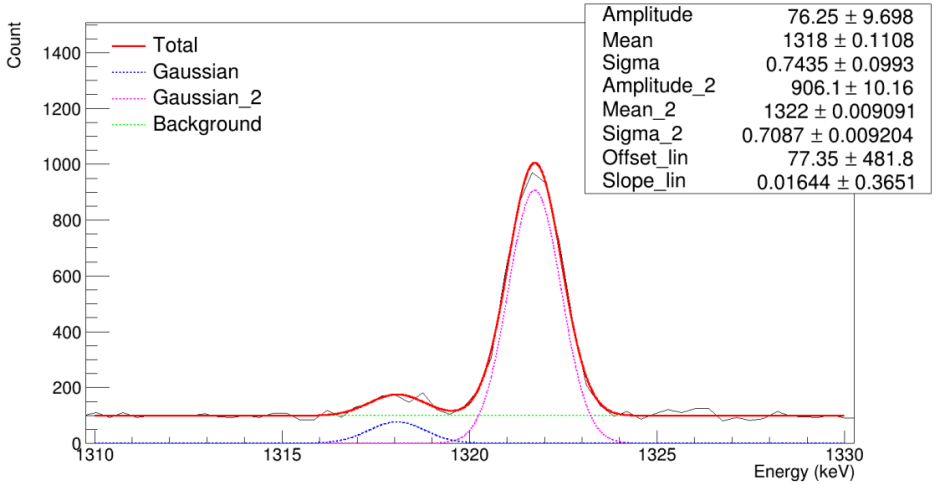


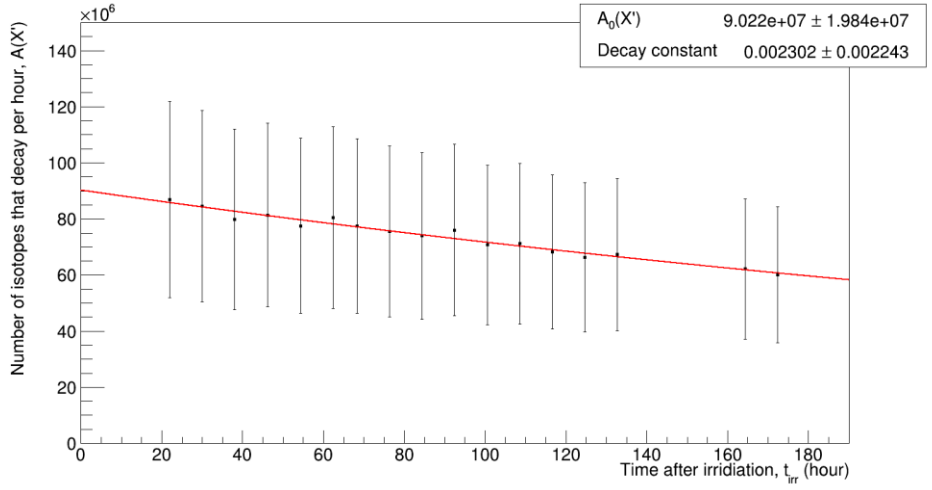
1235.4 keV





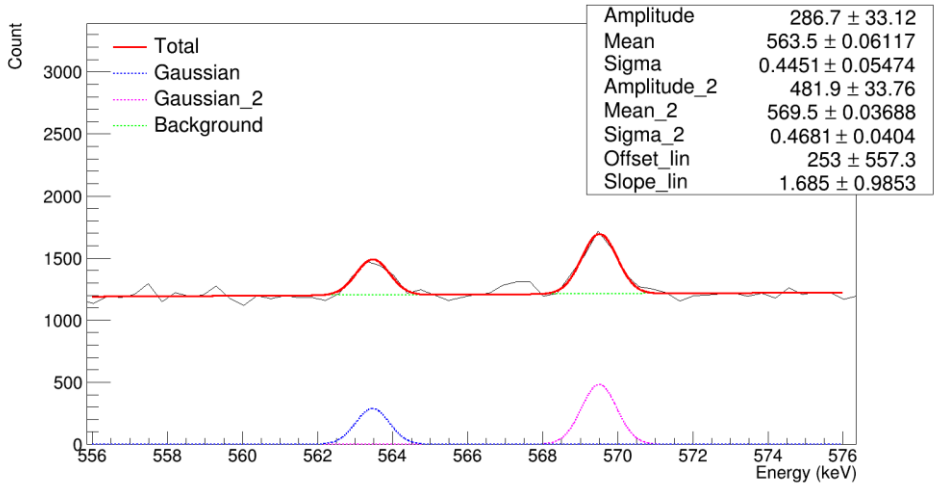
1321.6 keV



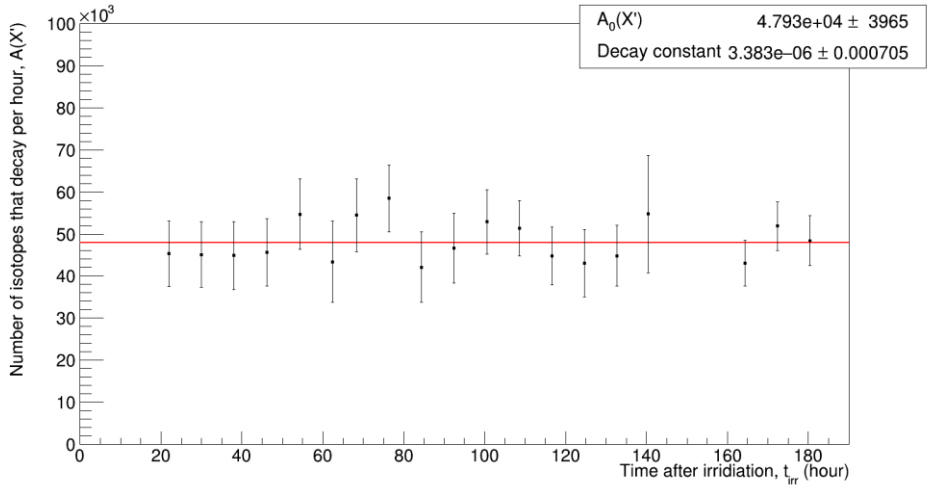


APPENDIX B:

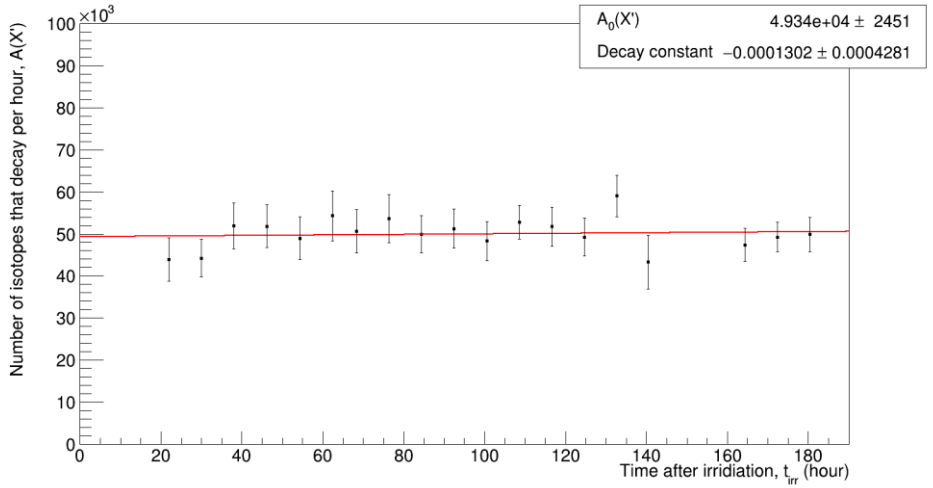
Spectra and $A(X')$ vs t_{irr} plots of $^{136}Ba(\mu^-,\nu 2n)^{134}Cs$ peaks



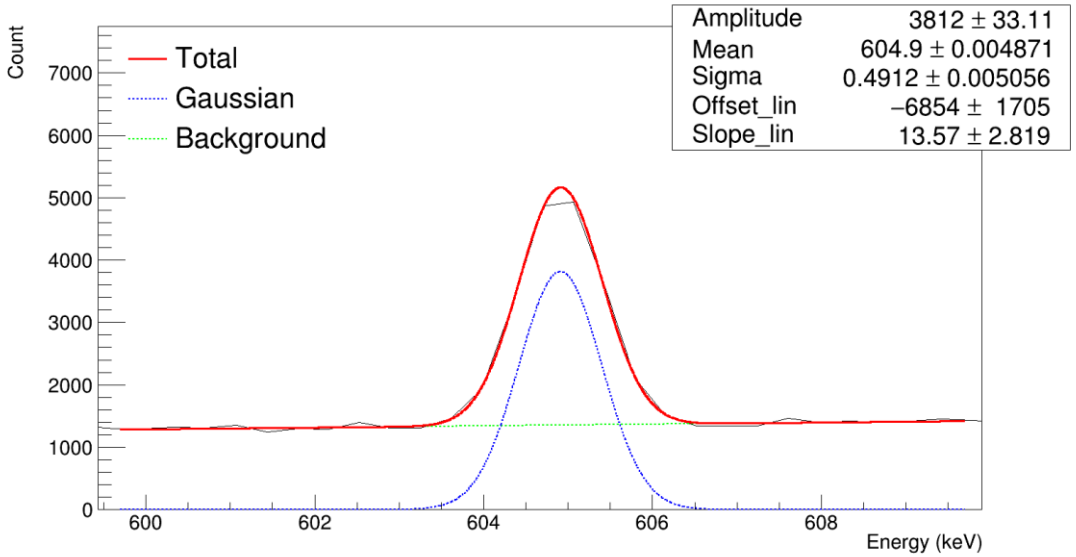
563.2 keV

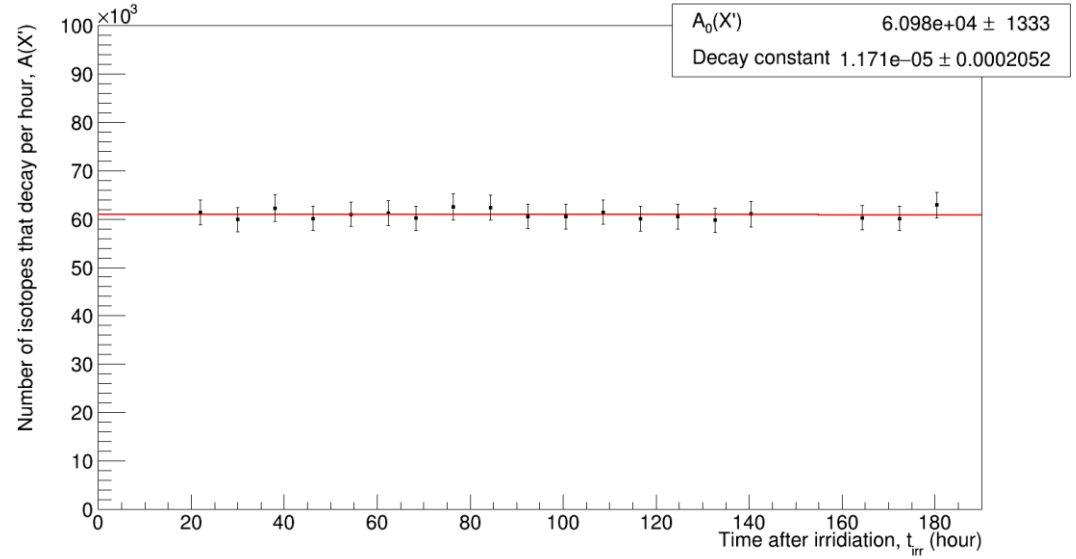


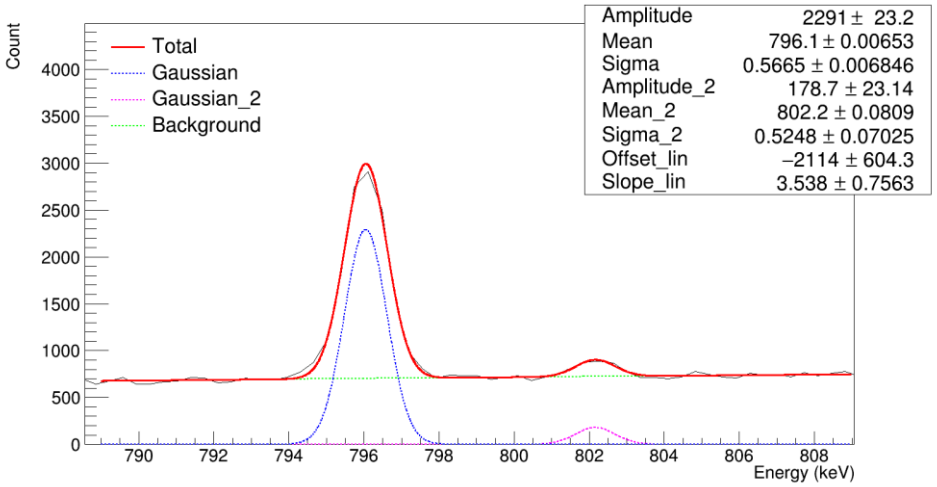
569.3 keV



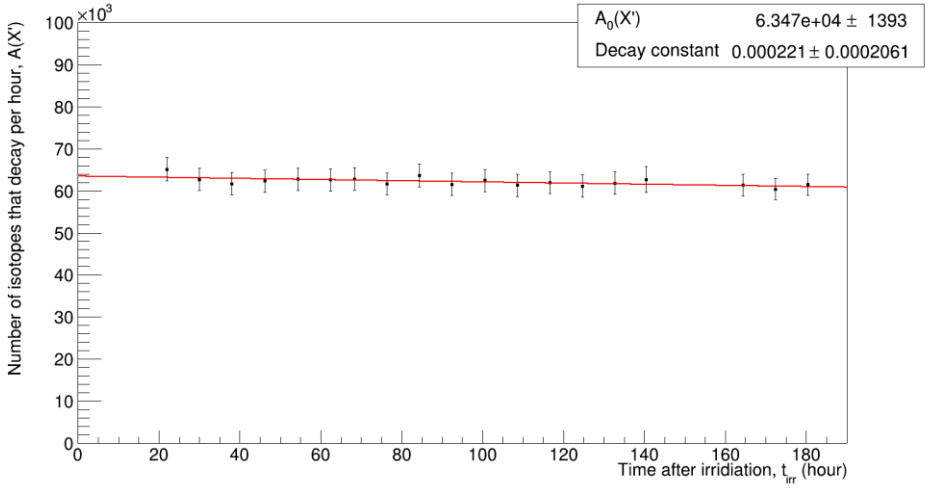
604.7 keV


Count
Total
Gaussian
Background
Amplitude 3812 ± 33.11
Mean 604.9 ± 0.004871
Sigma 0.4912 ± 0.005056
Offset_lin −6854 ± 1705
Slope_lin 13.57 ± 2.819
Energy (keV)

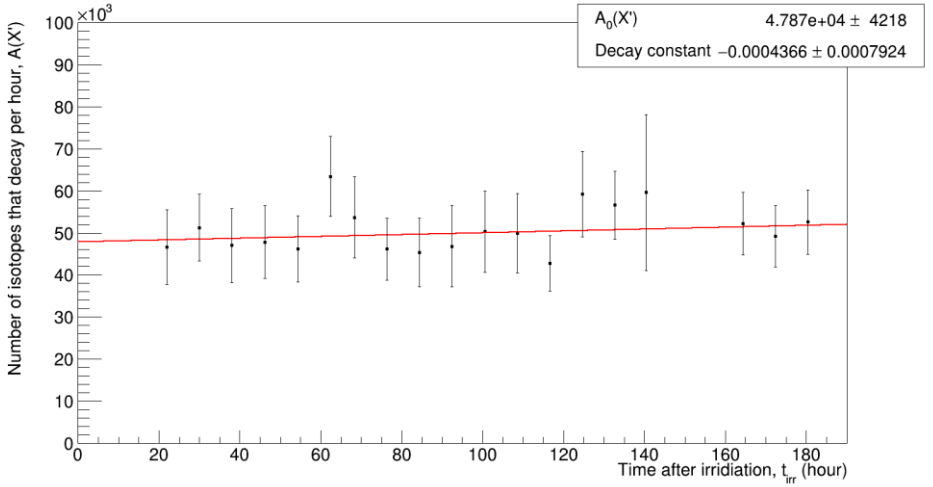

Number of isotopes that decay per hour, A(X')
×10^3
A0(X') 6.098e+04 ± 1333
Decay constant 1.171e−05 ± 0.0002052
Time after irridiation, t_irr (hour)



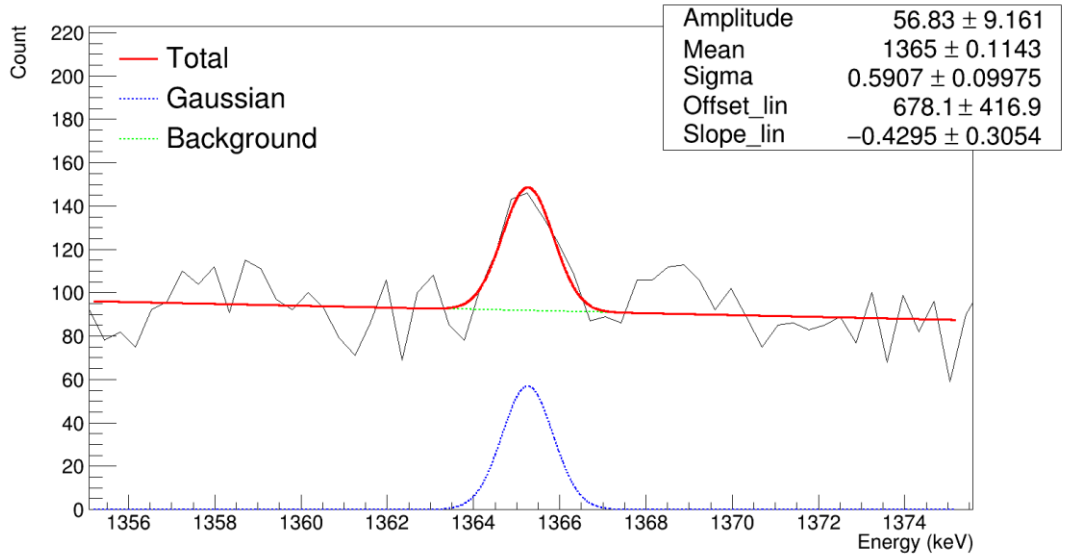
795.9 keV

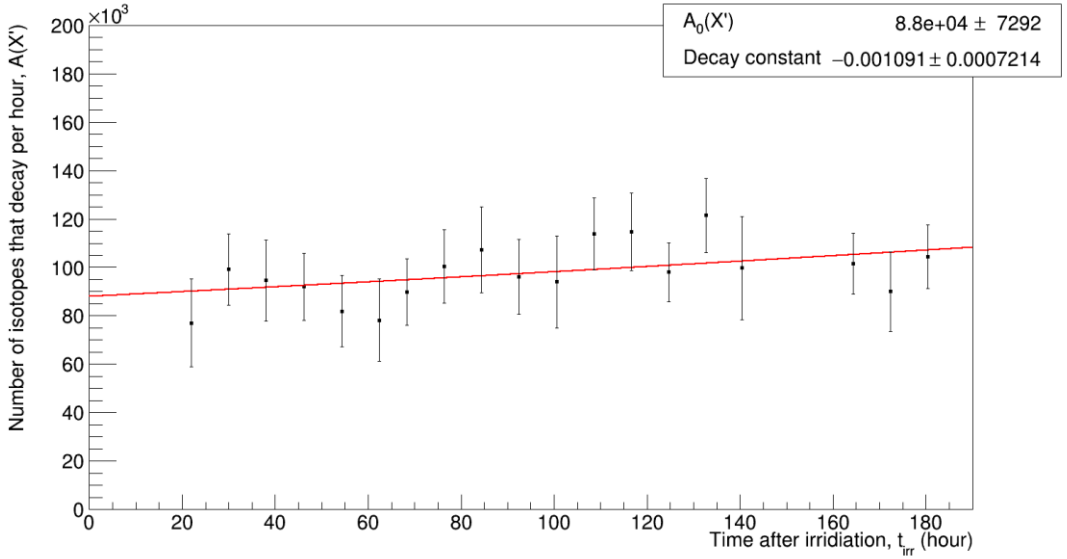


802.0 keV



1365.2 keV

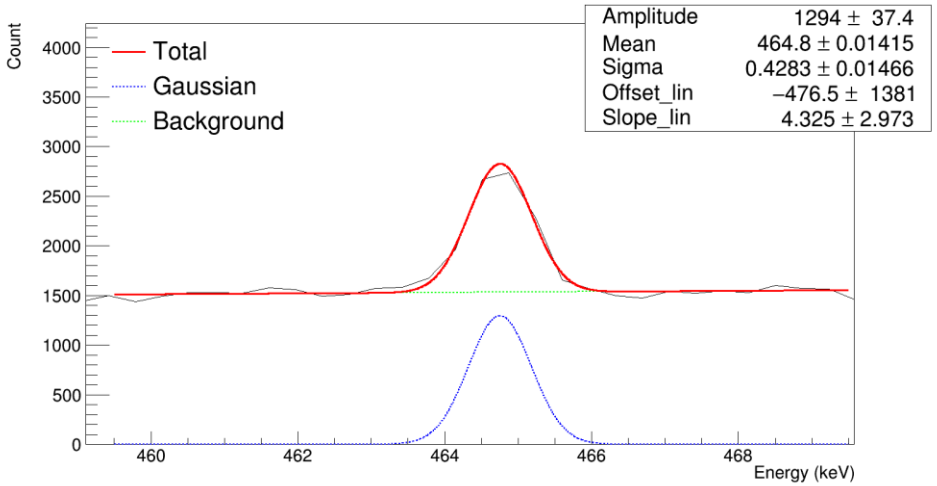

Count
Total
Gaussian
Background
Amplitude 56.83 ± 9.161
Mean 1365 ± 0.1143
Sigma 0.5907 ± 0.09975
Offset_lin 678.1 ± 416.9
Slope_lin −0.4295 ± 0.3054
Energy (keV)

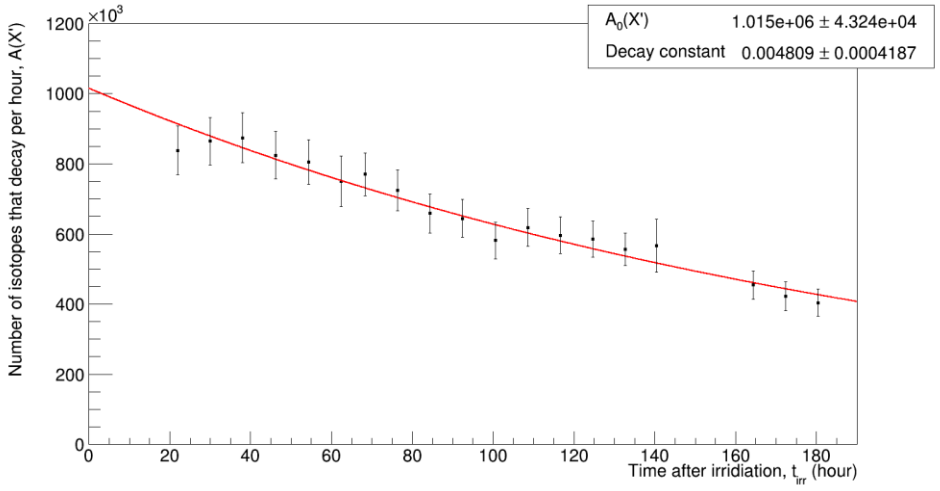

×10^3
Number of isotopes that decay per hour, A(X')
A0(X') 8.8e+04 ± 7292
Decay constant −0.001091 ± 0.0007214
Time after irridiation, t_irr (hour)

APPENDIX C:

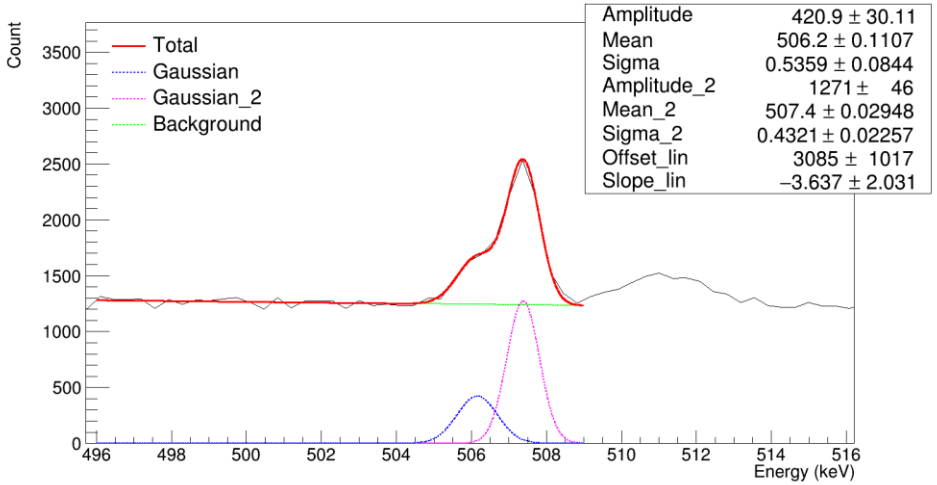
Spectra and $A(X')$ vs t_{irr} plots of $^{136}Ba(\mu^-,\nu 4n)^{132}Cs$ peaks

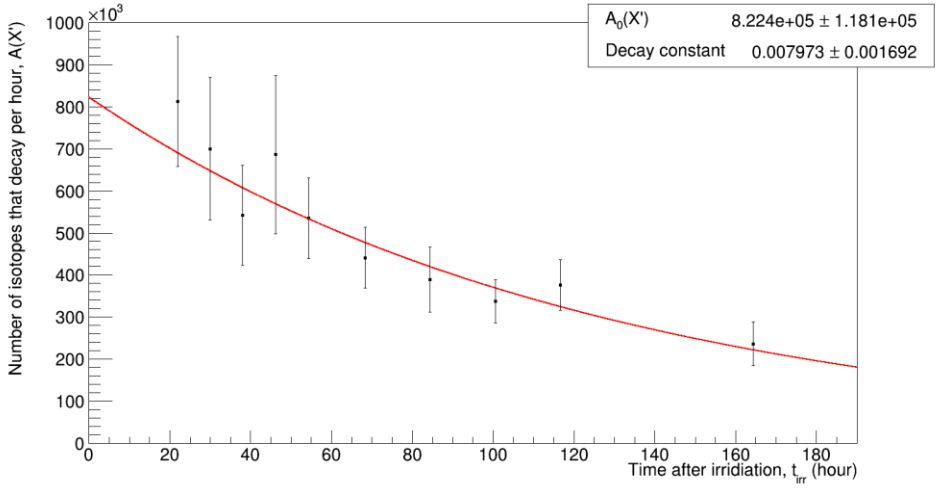
464.5 keV



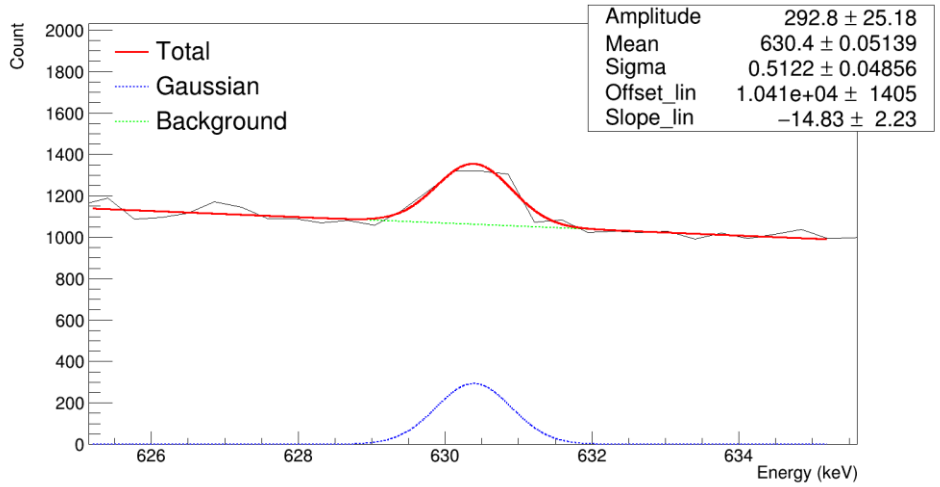


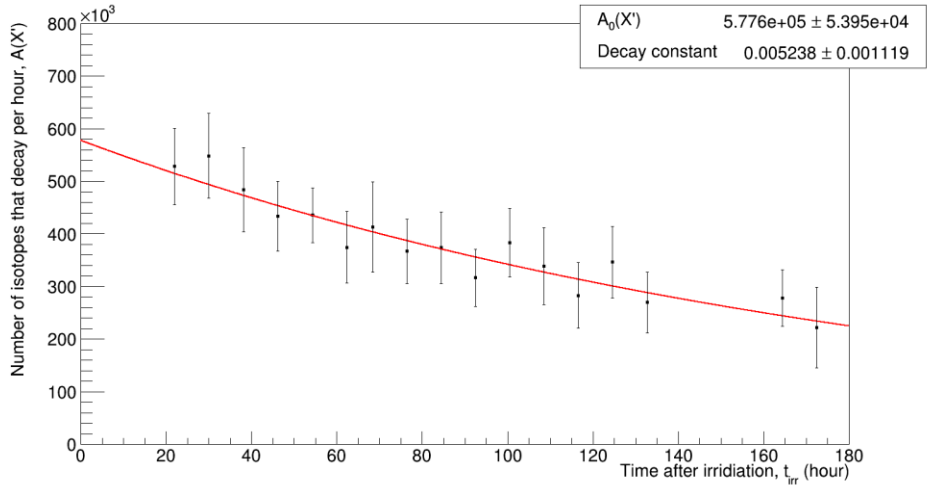
505.8 keV



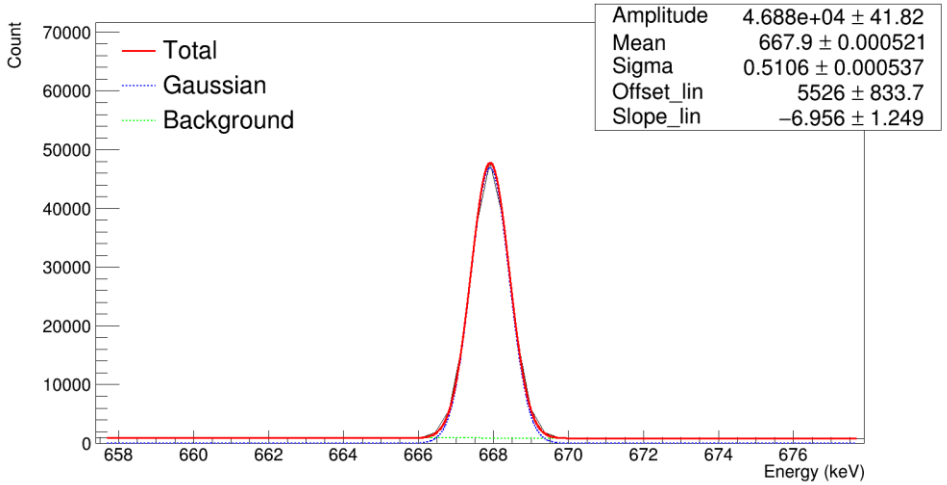


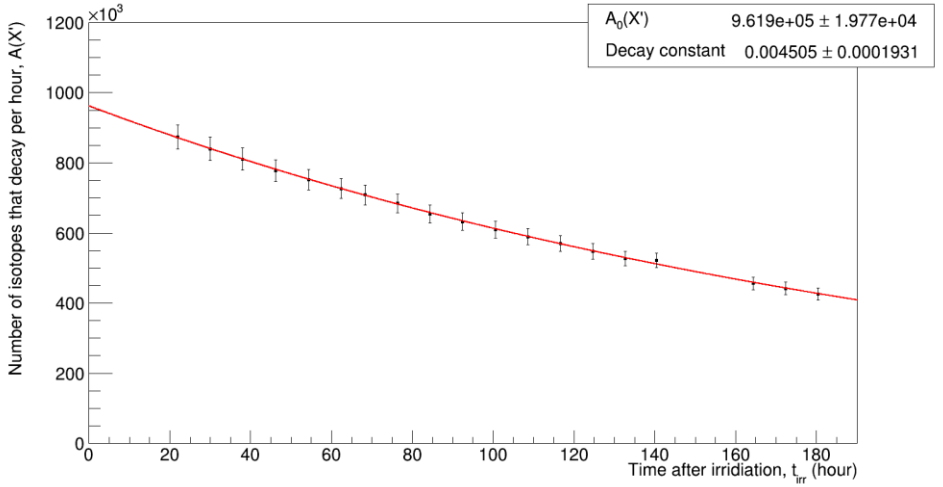
630.2 keV



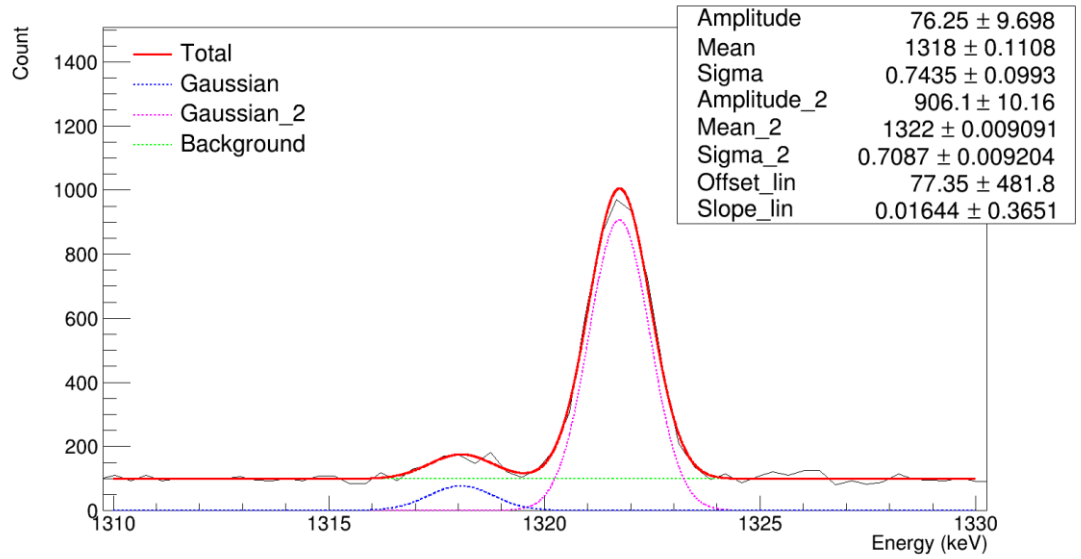


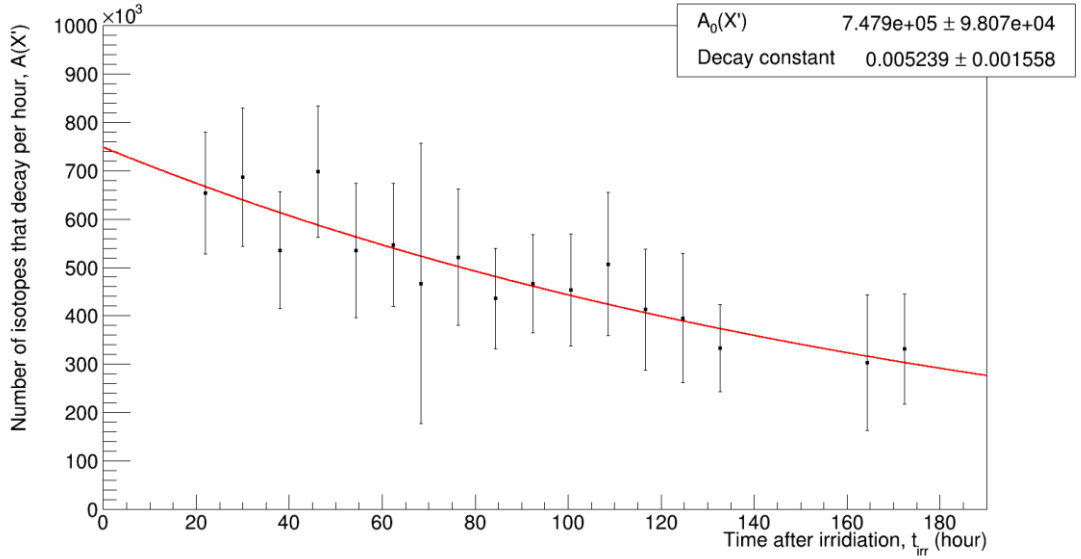
667.7 keV





1317.9 keV

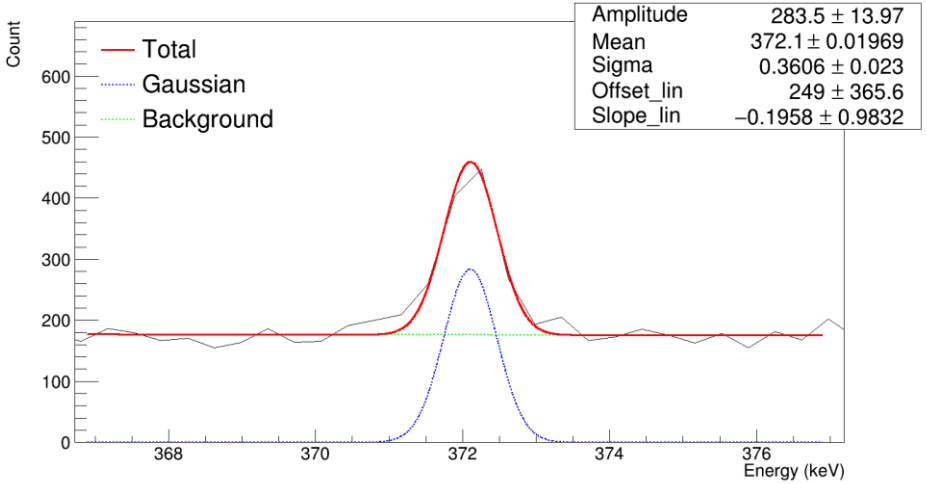

Count
Total
Gaussian
Gaussian_2
Background
Amplitude 76.25 ± 9.698
Mean 1318 ± 0.1108
Sigma 0.7435 ± 0.0993
Amplitude_2 906.1 ± 10.16
Mean_2 1322 ± 0.009091
Sigma_2 0.7087 ± 0.009204
Offset_lin 77.35 ± 481.8
Slope_lin 0.01644 ± 0.3651
Energy (keV)

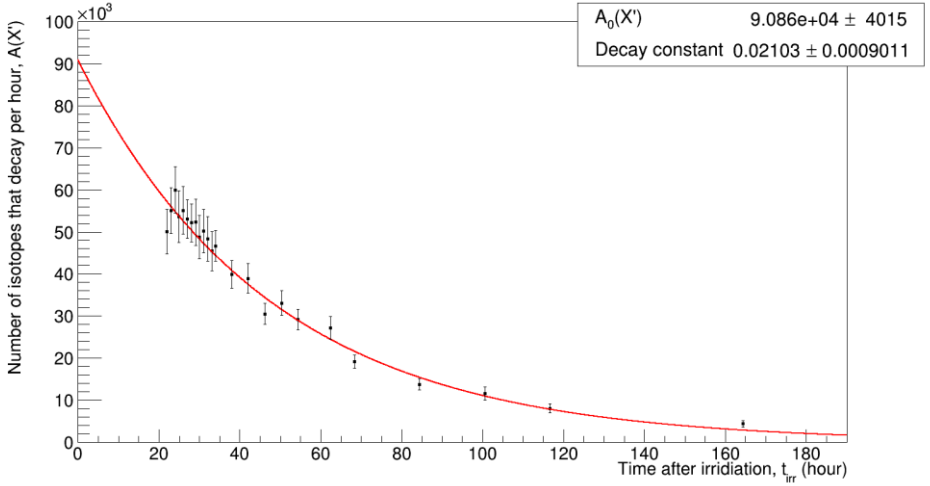

×10^3
A0(X') 7.479e+05 ± 9.807e+04
Decay constant 0.005239 ± 0.001558
Number of isotopes that decay per hour, A(X')
Time after irridiation, t_irr (hour)

APPENDIX D:

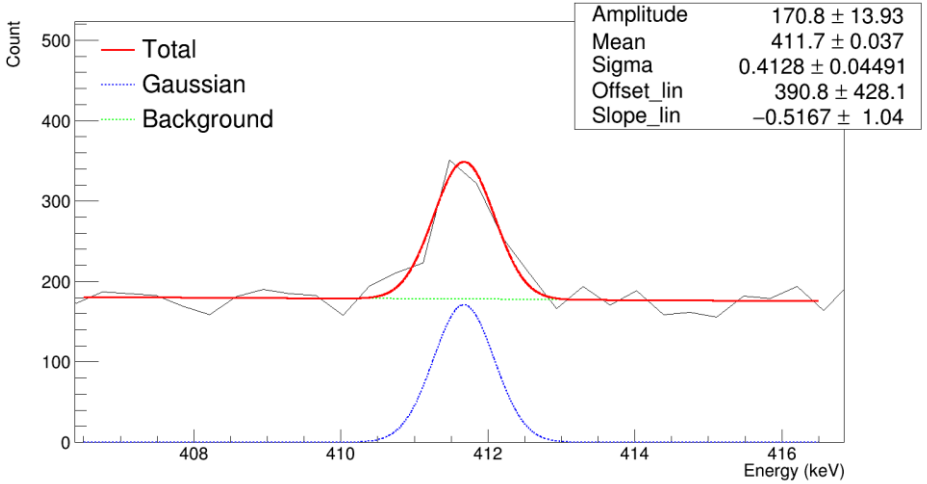
Spectra and $A(X')$ vs t_{irr} plots of $^{136}Ba(\mu^-,\nu 7n)^{129}Cs$ peaks

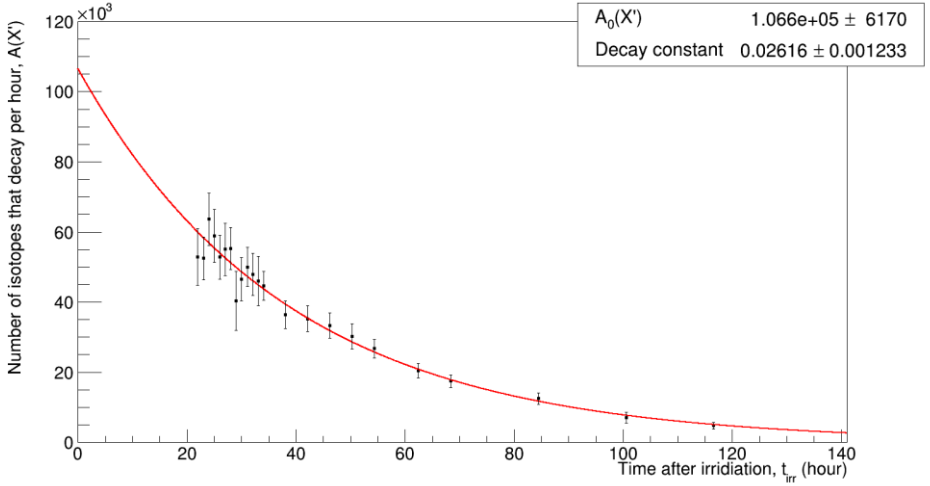
371.9 keV





411.5 keV

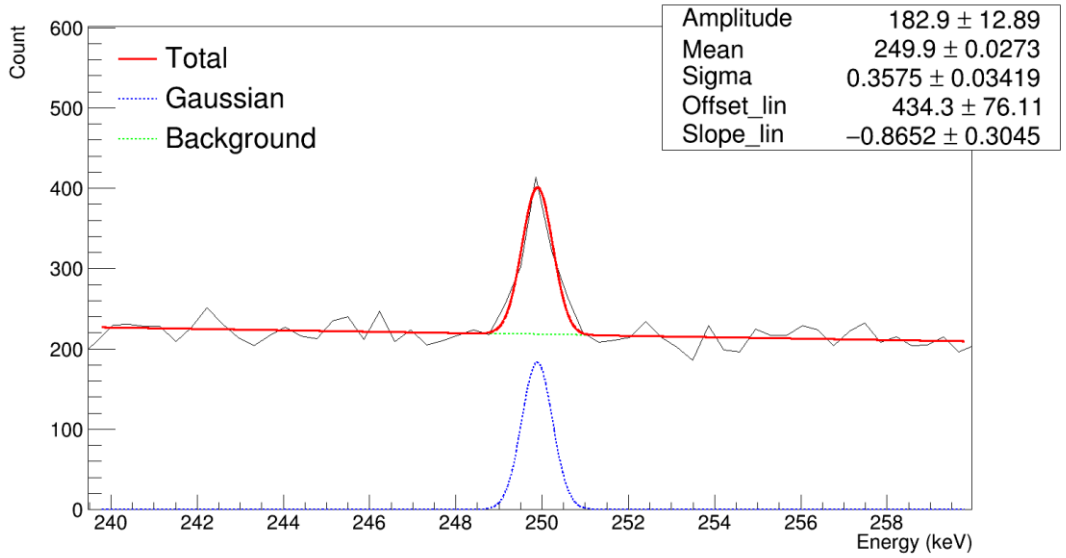


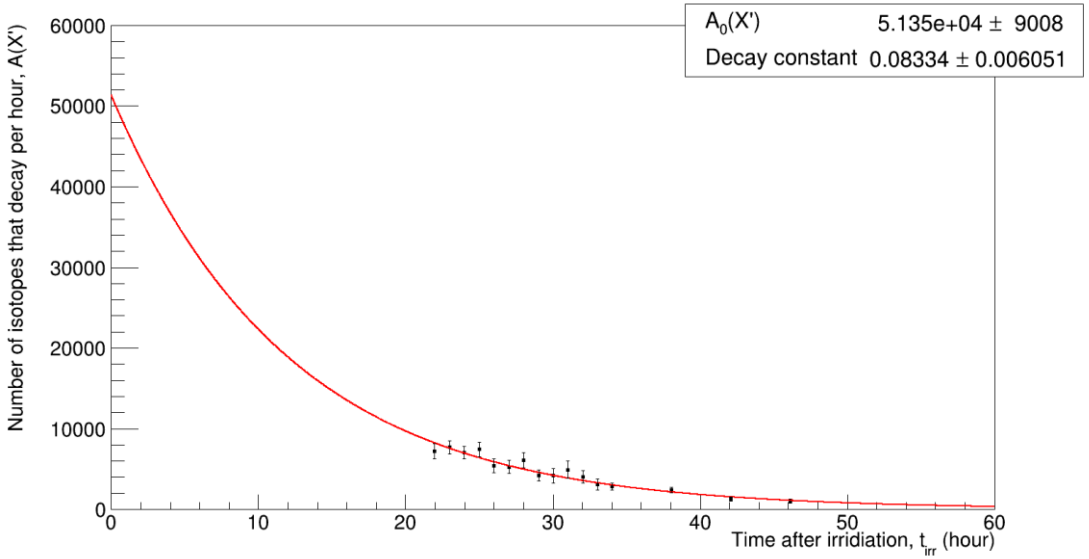


APPENDIX E:

Spectra and $A(X')$ vs t_{irr} plots of $^{136}Ba(\mu^-,\nu p)^{135}Xe$ peaks

249.8 keV

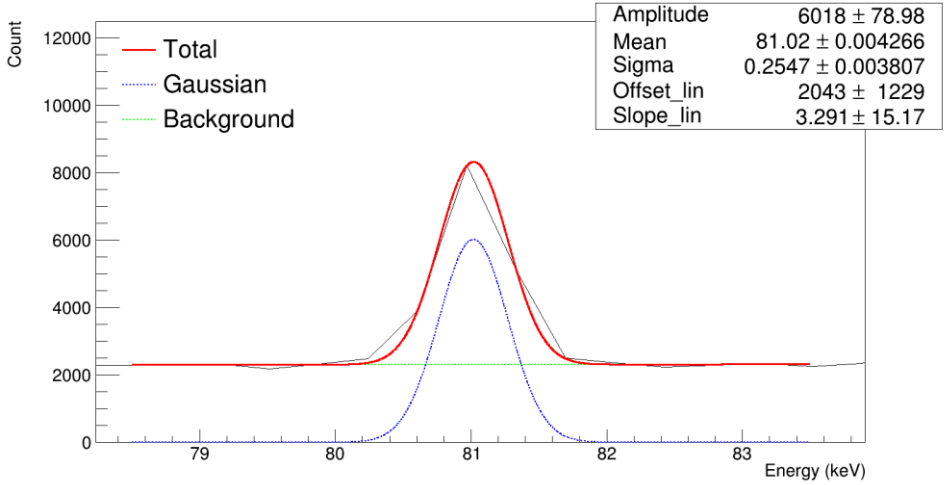

Count
Total
Gaussian
Background
Amplitude 182.9 ± 12.89
Mean 249.9 ± 0.0273
Sigma 0.3575 ± 0.03419
Offset_lin 434.3 ± 76.11
Slope_lin −0.8652 ± 0.3045
Energy (keV)

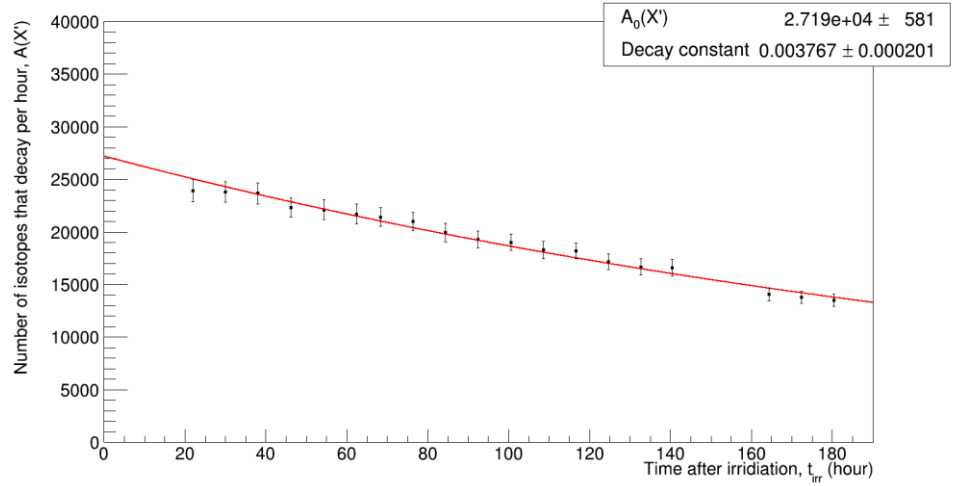

Number of isotopes that decay per hour, A(X')
A0(X') 5.135e+04 ± 9008
Decay constant 0.08334 ± 0.006051
Time after irridiation, tirr (hour)

APPENDIX F:

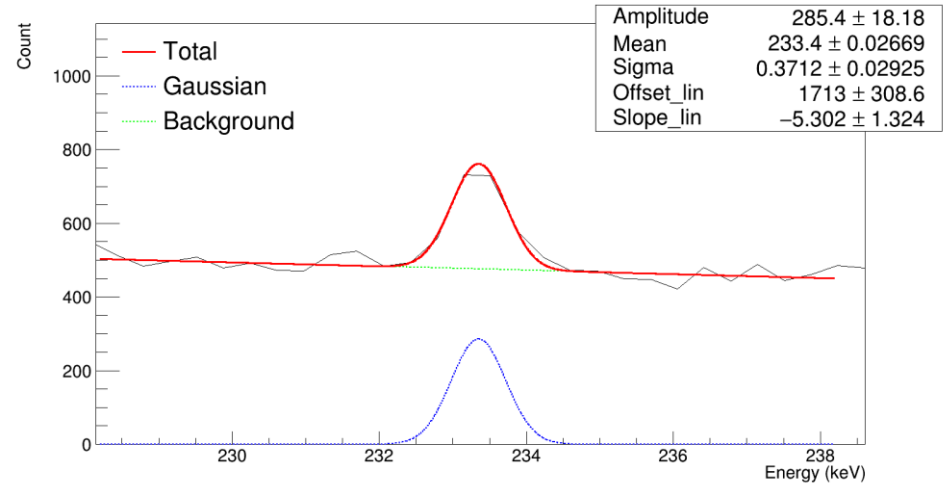
Spectra and $A(X')$ vs t_{irr} plots of $^{136}Ba(\mu^-,vp2n)^{133}Xe$ peaks

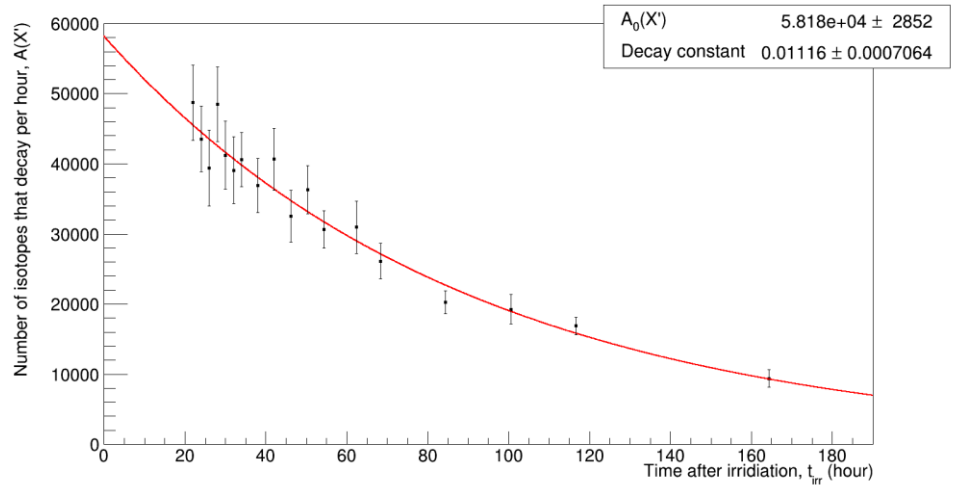
81.0 keV





233.2 keV

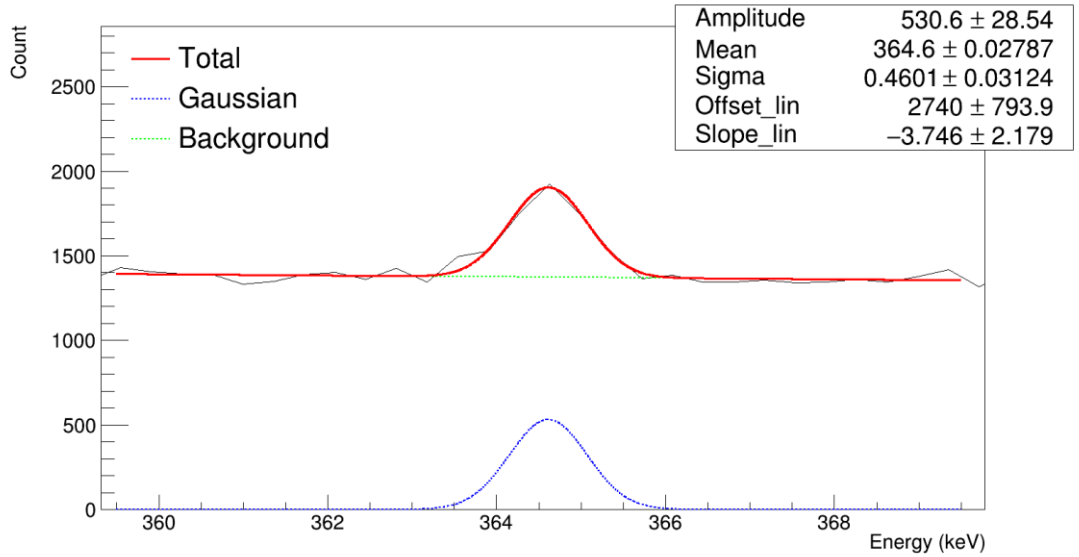


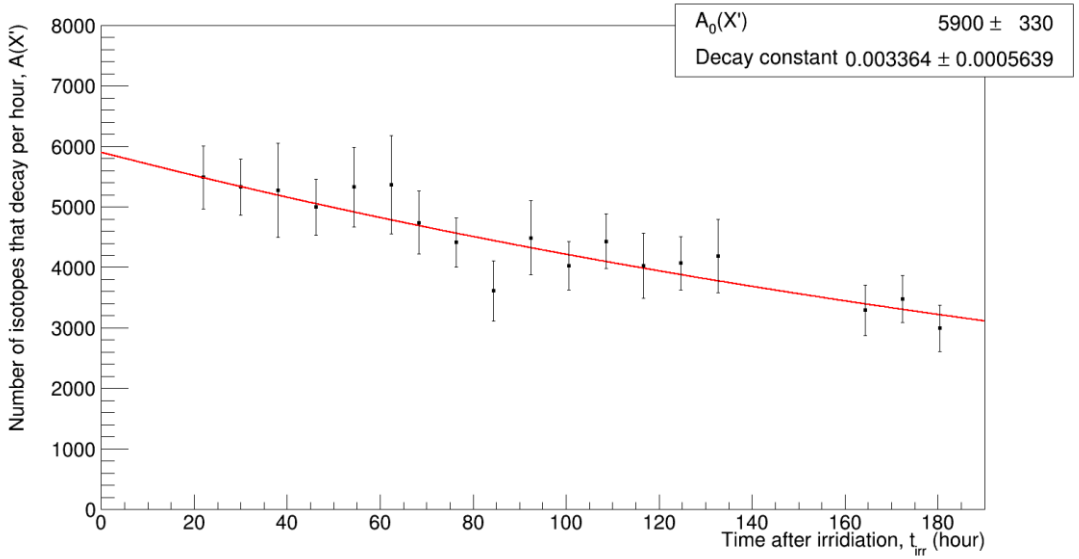


APPENDIX G:

Spectra and $A(X')$ vs t_{irr} plots of $^{136}Ba(\mu^-,\nu\alpha n)^{131}I$ peaks

364.5 keV


Count
Total
Gaussian
Background
Amplitude 530.6 ± 28.54
Mean 364.6 ± 0.02787
Sigma 0.4601 ± 0.03124
Offset_lin 2740 ± 793.9
Slope_lin −3.746 ± 2.179
2500
2000
1500
1000
500
0
360
362
364
366
368
Energy (keV)


Number of isotopes that decay per hour, A(X')
$A_0(X')$ 5900 ± 330
Decay constant 0.003364 ± 0.0005639
8000
7000
6000
5000
4000
3000
2000
1000
0
0
20
40
60
80
100
120
140
160
180
Time after irridiation, t_{irr} (hour)