

Appendix A

DETAILED RESULTS FOR ALL DECAY MODES

The main document concerned itself primarily with the $2\nu\beta\beta$ of ^{76}Ge to the 0_1^+ excited state. However, results are presented for all decay modes and energy peaks. This appendix will present figures and tables detailing the simulations, cuts, efficiencies and results for each decay mode and peak.

A.1 $2\nu\beta\beta$ to 0_1^+

Note that both the 559 and 563 keV peaks will be shown together since they use the same sets of cuts.

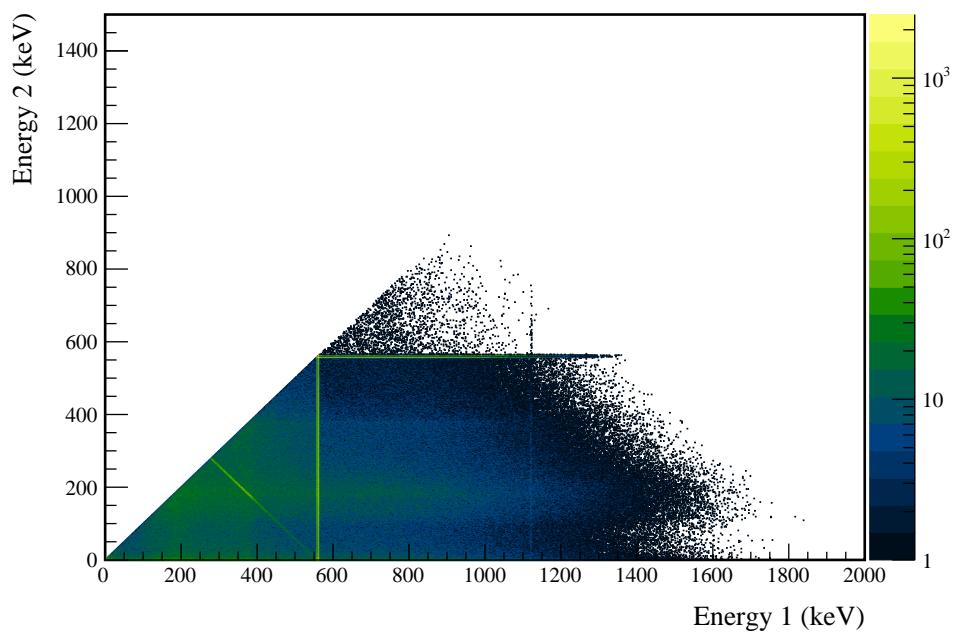


Figure A.1: Simulated multiplicity 2 energy spectrum of the $2\nu\beta\beta$ to 0_1^+ decay mode

Table A.1: Table of energy estimation uncertainties for the 559 and 563 keV peaks.

DS	E_{peak} (keV)	σ_{fit} (keV)	σ_{disfit} (keV)	σ (keV)	$f_{i,fit}$ (keV)	τ_{fit} (keV)	$\delta_{i,fit}$ (keV)	$\delta_{\mu,NL}$ (keV)	$\delta_{\mu,drift}$ (keV)	$\delta_{\mu,etalk}$ (keV)	$\delta_{\mu,peak}$ (keV)	δ_{μ} (keV)	FWHM (keV)	$\delta_{fwhm,fit}$ (keV)	$\delta_{fwhm,etalk}$ (keV)	$\delta_{fwhm,drift}$ (keV)	δ_{FWHM} (keV)	$\delta_{ROI,1}$ (keV)	$E_{ROI,2}$ (keV)	ϵ_{ROI}	$\sigma_{e,noi}$	
DS1	559.101	0.460	0.063	0.464	0.230	0.515	0.001	0.104	0.002	0.012	0.005	0.105	1.152	0.001	0.039	0.011	0.040	0.035	558.199	559.847	0.871	0.015
DS2	559.101	0.461	0.055	0.464	0.249	0.515	0.002	0.067	0.004	0.012	0.005	0.068	1.158	0.001	0.107	0.011	0.108	0.093	558.186	559.845	0.874	0.031
DS3	559.101	0.470	0.066	0.474	0.224	0.505	0.001	0.026	0.024	0.012	0.005	0.038	1.174	0.001	0.073	0.011	0.074	0.063	558.187	559.863	0.879	0.021
DS4	559.101	0.455	0.077	0.461	0.108	0.445	0.002	0.076	0.010	0.012	0.005	0.078	1.111	0.001	0.106	0.011	0.107	0.096	558.283	559.856	0.888	0.032
DS5a	559.101	0.560	0.085	0.567	0.106	0.855	0.002	0.079	0.005	0.012	0.005	0.080	1.367	0.002	0.055	0.011	0.056	0.041	558.098	560.022	0.875	0.014
DS5b	559.101	0.469	0.074	0.475	0.158	0.491	0.001	0.020	0.011	0.012	0.005	0.026	1.157	0.001	0.125	0.011	0.125	0.108	558.229	559.872	0.885	0.036
DS5c	559.101	0.460	0.085	0.468	0.174	0.489	0.001	0.037	0.030	0.012	0.005	0.050	1.145	0.001	0.162	0.011	0.162	0.142	558.231	559.860	0.883	0.046
DS6a	559.101	0.456	0.044	0.458	0.191	0.463	0.001	0.069	0.025	0.012	0.005	0.075	1.123	0.000	0.041	0.011	0.042	0.038	558.241	559.841	0.881	0.014
DS1	563.178	0.461	0.064	0.466	0.230	0.518	0.001	0.104	0.002	0.012	0.005	0.105	1.156	0.001	0.039	0.011	0.040	0.035	562.273	563.927	0.871	0.015
DS2	563.178	0.463	0.055	0.466	0.249	0.517	0.002	0.067	0.004	0.012	0.005	0.068	1.162	0.001	0.107	0.011	0.108	0.093	562.259	563.924	0.874	0.030
DS3	563.178	0.471	0.066	0.476	0.224	0.508	0.001	0.026	0.024	0.012	0.005	0.038	1.179	0.001	0.073	0.011	0.074	0.063	562.261	563.943	0.879	0.021
DS4	563.178	0.457	0.077	0.463	0.108	0.447	0.002	0.076	0.010	0.012	0.005	0.078	1.115	0.001	0.106	0.011	0.107	0.096	562.357	563.935	0.888	0.032
DS5a	563.178	0.562	0.086	0.569	0.106	0.858	0.002	0.079	0.006	0.012	0.005	0.080	1.372	0.002	0.055	0.011	0.056	0.041	562.172	564.103	0.875	0.014
DS5b	563.178	0.471	0.074	0.477	0.158	0.494	0.001	0.020	0.011	0.012	0.005	0.026	1.162	0.001	0.125	0.011	0.125	0.108	562.303	563.952	0.885	0.035
DS5c	563.178	0.462	0.086	0.470	0.174	0.492	0.001	0.037	0.030	0.012	0.005	0.050	1.149	0.001	0.162	0.011	0.162	0.141	562.305	563.939	0.883	0.046
DS6a	563.178	0.457	0.044	0.459	0.191	0.465	0.001	0.069	0.026	0.012	0.005	0.075	1.127	0.000	0.041	0.011	0.042	0.038	562.315	563.921	0.881	0.013

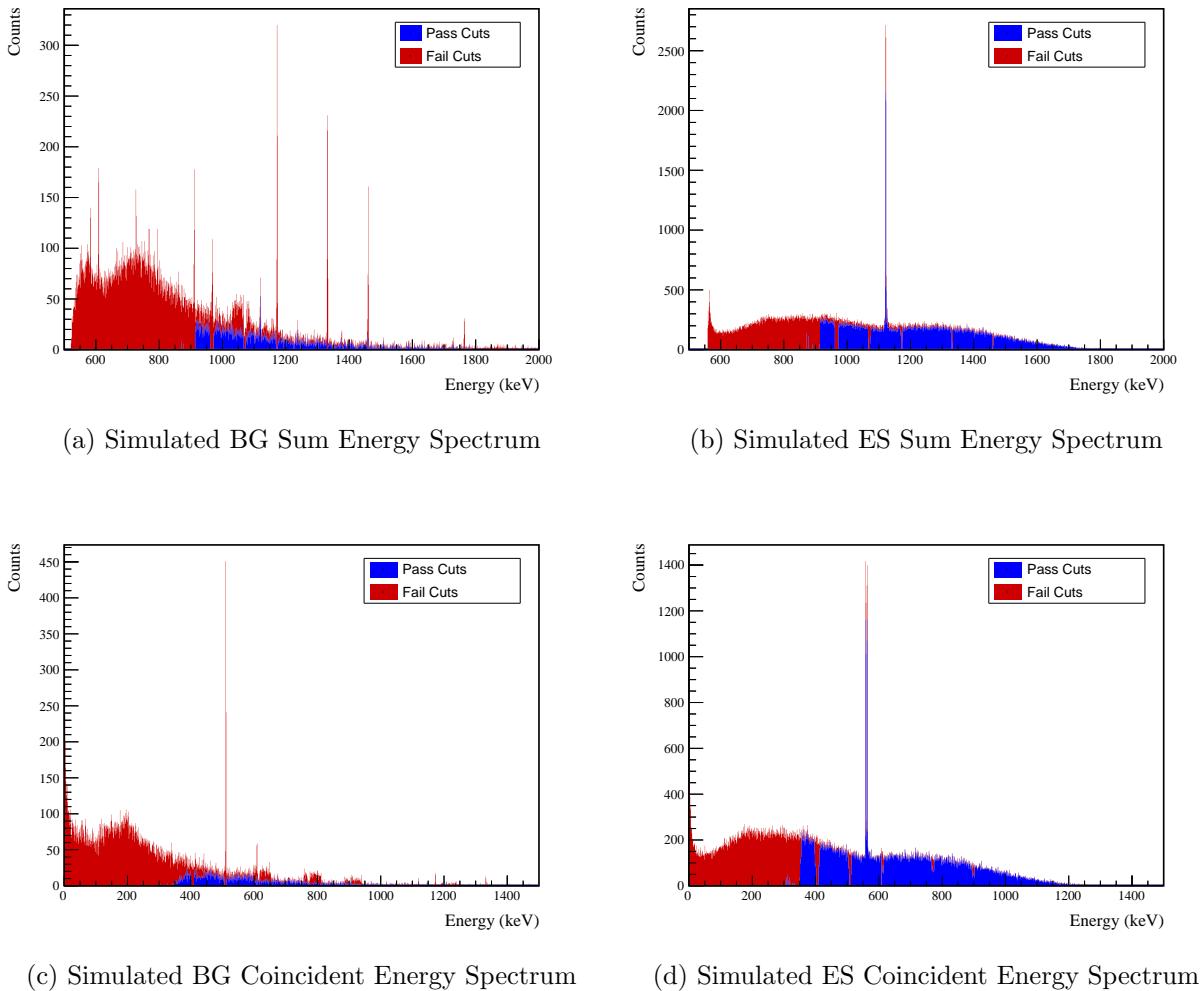


Figure A.2: Sum energy and coincident energy spectra for the 559 and 563 keV peaks.

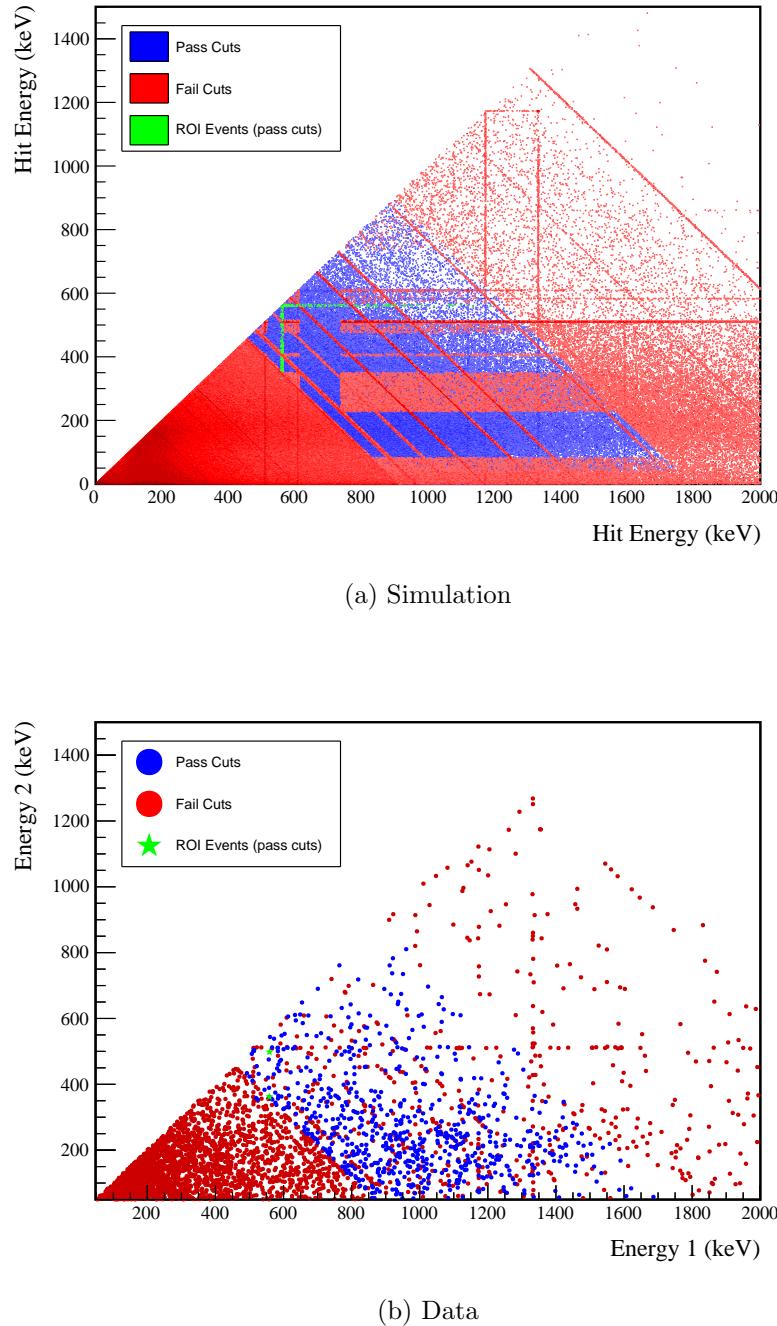
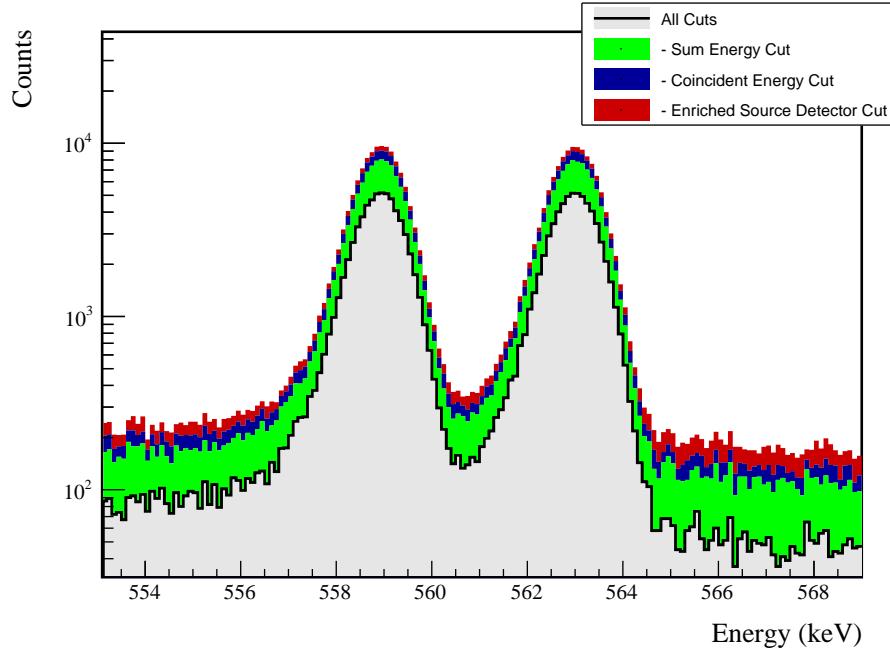


Figure A.3: Simulated and measured multiplicity 2 energy spectrum with sum and coincident energy cuts included for the 559 and 563 keV peaks.



(a) Effect of all cuts on ROI

Source	Module 1 efficiency	Module 2 efficiency
Multi-Detector with Full Energy γ	$5.9 \pm 0.2\%$	$3.2 \pm 0.5\%$
Region of Interest	$87.9 \pm 1.4\%$	$87.9 \pm 1.4\%$
Dead Layer	$74.5 \pm 4.3\%$	$65.7 \pm 6.0\%$
Detector Dead Times	$97.5 \pm 1.2\%$	$98.1 \pm 0.9\%$
Enriched Source Detector Cut	$96.8 \pm <0.1\%$	$89.4 \pm <0.1\%$
Coincident Energy Cut	$88.5 \pm 0.5\%$	$84.4 \pm 0.5\%$
Sum Energy Cut	$60.2 \pm 0.5\%$	$54.0 \pm 0.5\%$
Final Efficiency	$2.29 \pm 0.16\%$	$0.97 \pm 0.17\%$

(b) Table of efficiencies

Figure A.4: Plot showing effect of cuts applied sequentially on ROI peak and table of detection efficiencies for the 559 and 563 keV peaks.

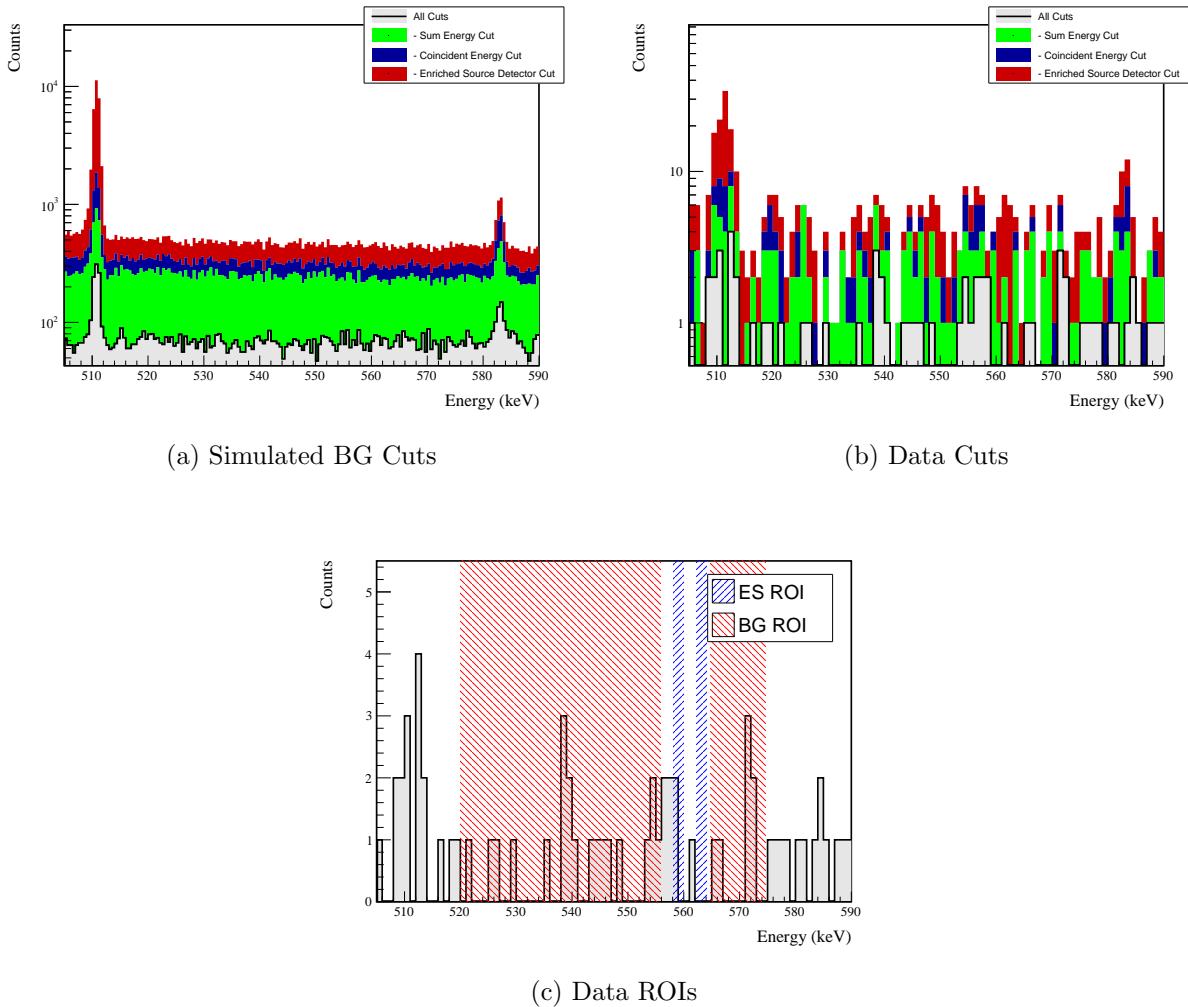


Figure A.5: Effect of all cuts applied to measured and simulated background data.

A.1. $2\nu\beta\beta$ TO 0_1^+

Cut Name	Cut Description	$\langle \epsilon_{total} \rangle$	$\hat{\epsilon}_{total}$	$\langle \epsilon_{unique} \rangle$	$\hat{\epsilon}_{unique}$	Sacrifice	ΔDP
Enriched Source		M1: 23.2 %	27.2 ^{+3.8} _{-3.5} %	2.2 %	2.0 ^{+1.5} _{-0.9} %	0.7 %	7%
Detector Cut	Any other detector: isEnr	M2: 42.7 %	62.8 ^{+7.0} _{-7.6} %	4.4 %	4.7 ^{+4.4} _{-2.3} %	2.1 %	
Coincident	No other detector: (((energy<40.6) (energy>402.6 && energy<409.6) (energy>506.8 && energy<512.4) (energy>608. && energy<610.2) (energy>1170.6 && energy<1175.) (energy>1235.)) && isEnr) ((energy<83.) (energy>228.2 && energy<350.6) (energy>475.2 && energy<516.8) (energy>566.6 && energy<613.4) (energy>737.4) && isEnr)	M1: 29.6 %	33.3 ^{+4.0} _{-3.8} %	4.4 %	4.8 ^{+2.1} _{-1.5} %	3.9 %	7%
Energy Cut		M2: 37.5 %	48.8 ± 7.5 %	4.2 %	2.3 ^{+3.6} _{-1.4} %	3.5 %	
Sum Energy Cut	Not: (sumE<870.) (sumE>870.6 && sumE<877.6) (sumE>878. && sumE<891.) (sumE>891.2 && sumE<913.8) (sumE>960.8 && sumE<972.) (sumE>1066.8 && sumE<1072.6) (sumE>1170.8 && sumE<1174.6) (sumE>1330. && sumE<1333.6) (sumE>1458.2 && sumE<1461.8) (sumE>1761.8 && sumE<1765.8) (sumE>1794.4)	M1: 75.0 %	74.8 ^{+3.4} _{-3.7} %	44.5 %	41.5 ^{+4.1} _{-4.0} %	31.8 %	20%
Combined Cuts		M1: 84.5 %	84.4 ^{+2.8} _{-3.2} %	—	—	44.9 %	27%
		M2: 89.5 %	95.3 ^{+2.3} _{-4.4} %	—	—	53.1 %	

Table A.2: Table of cut descriptions and efficiencies for simulated backgrounds and measured data for the 559 and 563 keV peaks.

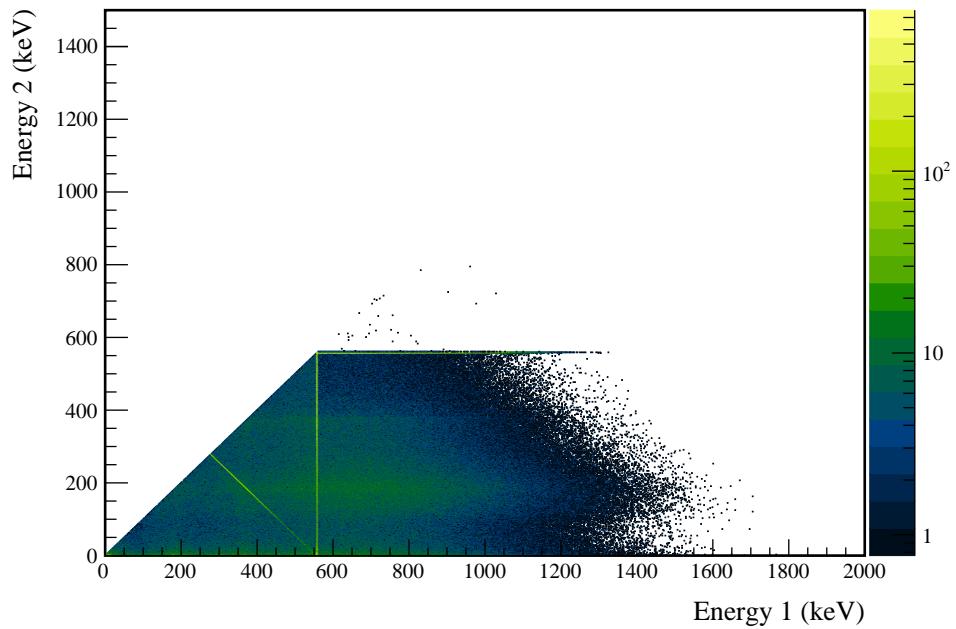
A.2 $2\nu\beta\beta$ to 2_1^+ Figure A.6: Simulated multiplicity 2 energy spectrum of the $2\nu\beta\beta$ to 2_1^+ decay mode

Table A.3: Table of energy estimation uncertainties for the 559 keV peak.

DS	E_{peak} (keV)	σ_{fit} (keV)	σ_{drift} (keV)	σ (keV)	$f_{i,fit}$	$f_{i,drift}$	τ_{fit} (keV)	τ_{drift} (keV)	$\delta_{\mu,NL}$ (keV)	$\delta_{\mu,fit}$ (keV)	$\delta_{\mu,drift}$ (keV)	δ_{peak} (keV)	δ_μ (keV)	FWHM	$\delta_{fwhm,fit}$ (keV)	$\delta_{fwhm,drift}$ (keV)	$\delta_{fwhm,peak}$ (keV)	δ_{FWHM} (keV)	δ_α	$E_{ROI,1}$ (keV)	$E_{ROI,2}$ (keV)	ϵ_{ROI}	$\sigma_{e_{ROI}}$
DS1	559.101	0.460	0.063	0.464	0.230	0.515	0.001	0.104	0.002	0.012	0.005	0.105	1.152	0.001	0.039	0.011	0.040	0.035	558.183	559.860	0.877	0.015	
DS2	559.101	0.461	0.055	0.464	0.249	0.515	0.002	0.067	0.004	0.012	0.005	0.068	1.158	0.001	0.107	0.011	0.108	0.093	558.169	559.858	0.880	0.030	
DS3	559.101	0.470	0.066	0.474	0.224	0.505	0.001	0.026	0.024	0.012	0.005	0.038	1.174	0.001	0.073	0.011	0.074	0.063	558.170	559.876	0.885	0.020	
DS4	559.101	0.455	0.077	0.461	0.108	0.445	0.002	0.076	0.010	0.012	0.005	0.078	1.111	0.001	0.106	0.011	0.107	0.096	558.269	559.869	0.893	0.031	
DS5a	559.101	0.560	0.085	0.567	0.106	0.855	0.002	0.079	0.005	0.012	0.005	0.080	1.367	0.002	0.055	0.011	0.056	0.041	558.081	560.038	0.881	0.014	
DS5b	559.101	0.469	0.074	0.475	0.158	0.491	0.001	0.020	0.011	0.012	0.005	0.026	1.157	0.001	0.125	0.011	0.125	0.108	558.214	559.886	0.891	0.035	
DS5c	559.101	0.460	0.085	0.468	0.174	0.489	0.001	0.037	0.030	0.012	0.005	0.050	1.145	0.001	0.162	0.011	0.162	0.142	558.216	559.873	0.888	0.045	
DS6a	559.101	0.456	0.044	0.458	0.191	0.463	0.001	0.069	0.025	0.012	0.005	0.075	1.123	0.000	0.041	0.011	0.042	0.038	558.226	559.854	0.886	0.013	

Cut Name	Cut Description	$\langle \epsilon_{total} \rangle$	$\hat{\epsilon}_{total}$	$\langle \epsilon_{unique} \rangle$	$\hat{\epsilon}_{unique}$	Sacrifice	ΔDP
Enriched Source		M1: 23.2 %	26.5 ^{+3.8} _{-3.5} %	4.5 %	4.1 ^{+2.0} _{-1.3} %	1.7 %	18%
Detector Cut	Any other detector: isEnv	M2: 42.7 %	62.8 ^{+7.0} _{-7.6} %	8.7 %	11.6 ^{+5.8} _{-4.0} %	4.1 %	
Multiplicity 2		M1: 15.4 %	16.3 ^{+3.3} _{-2.8} %	0.7 %	0.0 ^{+0.7} _{-0.0} %	0.0 %	
Cut	m==2	M2: 11.7 %	16.3 ^{+6.4} _{-4.9} %	0.7 %	0.0 ^{+2.3} _{-0.0} %	0.0 %	2%
Coincident	No other detector: (((energy<53.8) (energy>59.4 && energy<303.8) (energy>314.4 && energy<362.4) (energy>398.6 && energy<421.) (energy>506.2 && energy<512.2) (energy>1116.4 && energy<124.2) (energy>1147.8)) && isbnr)	M1: 59.2 %	55.8 ± 4.1 %	3.8 %	4.8 ^{+2.1} _{-1.5} %	0.3 %	12%
Energy Cut		M2: 44.9 %	30.2 ^{+7.4} _{-6.5} %	3.5 %	0.0 ^{+2.3} _{-0.0} %	0.3 %	
Sum Energy Cut	Not: (sumE<612.8) (sumE>618.4 && sumE<362.6) (sumE>873.4 && sumE<921.) (sumE>957.4 && sumE<979.6) (sumE>1064.8 && sumE<1070.8) (sumE>1171.6 && sumE<1174.6) (sumE>1330. && sumE<1333.6) (sumE>1457. && sumE<1462.4) (sumE>1675.2 && sumE<1684.8) (sumE>1706.4)	M1: 74.9 %	74.8 ^{+3.4} _{-3.7} %	6.3 %	5.4 ^{+2.2} _{-1.6} %	1.2 %	17%
Combined Cuts		M2: 75.6 %	76.7 ^{+5.8} _{-7.0} %	4.3 %	2.3 ^{+3.6} _{-1.4} %	1.2 %	
		M1: 89.9 %	89.1 ^{+2.3} _{-2.8} %	—	—	30.9 %	
		M2: 93.0 %	97.7 ^{+1.4} _{-3.6} %	—	—	34.0 %	79%

Table A.4: Table of cut descriptions and efficiencies for simulated backgrounds and measured data for the 559 keV peak.

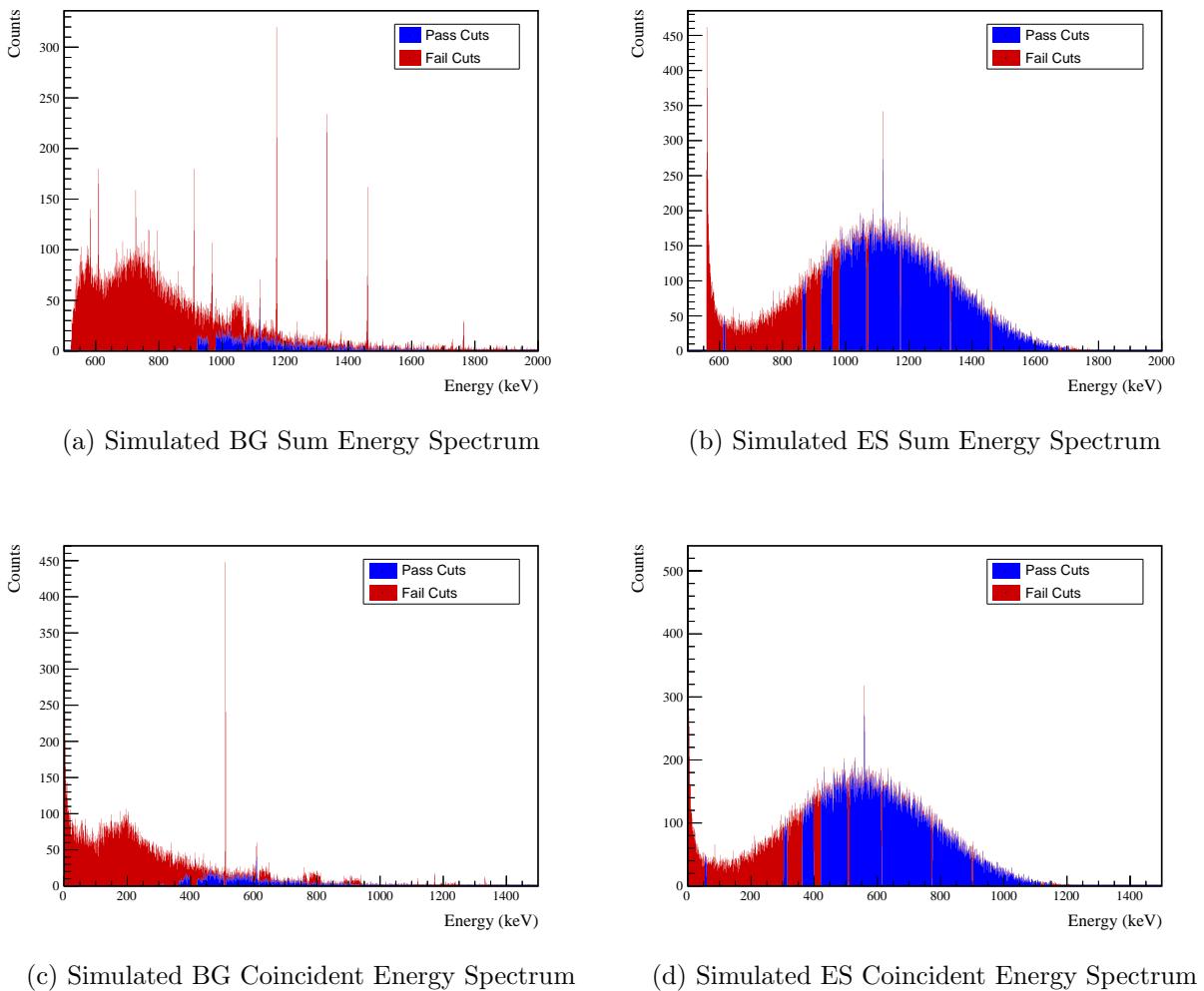


Figure A.7: Sum energy and coincident energy spectra for the 559 keV peak.

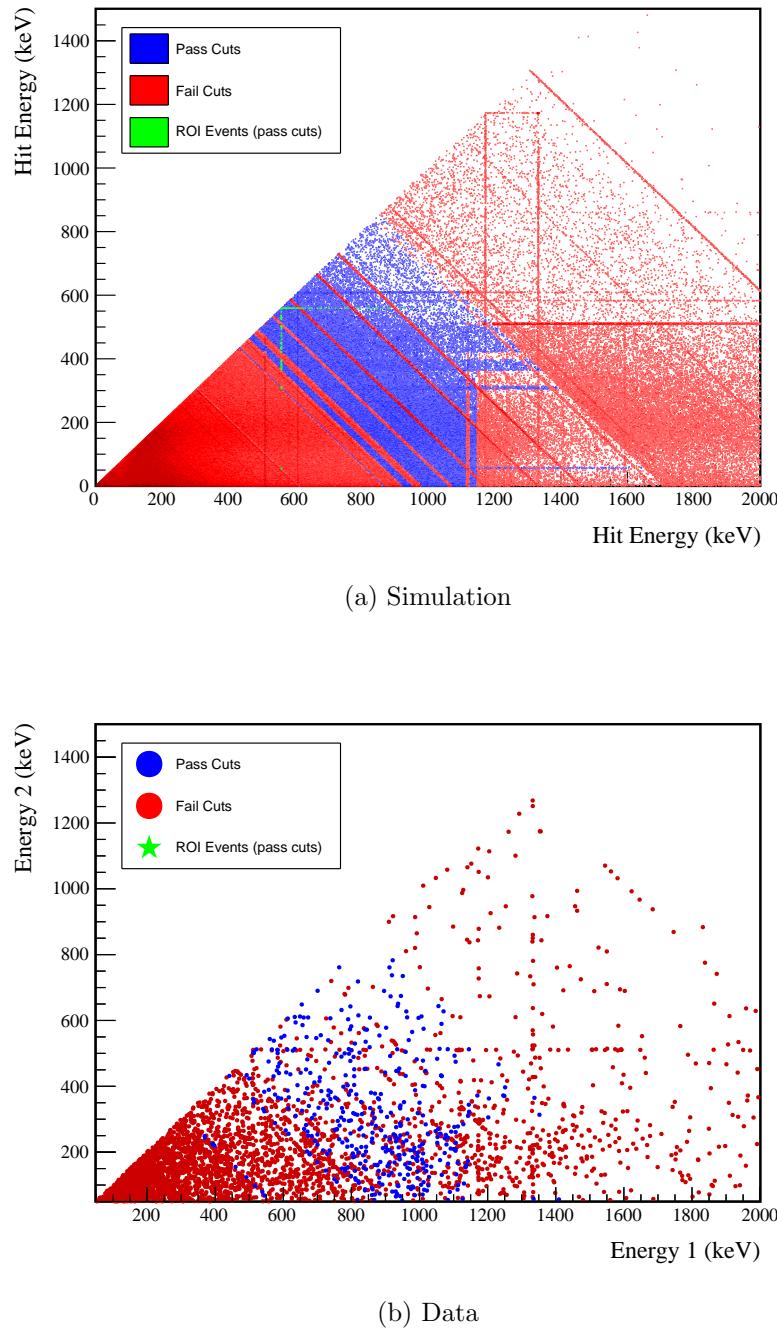
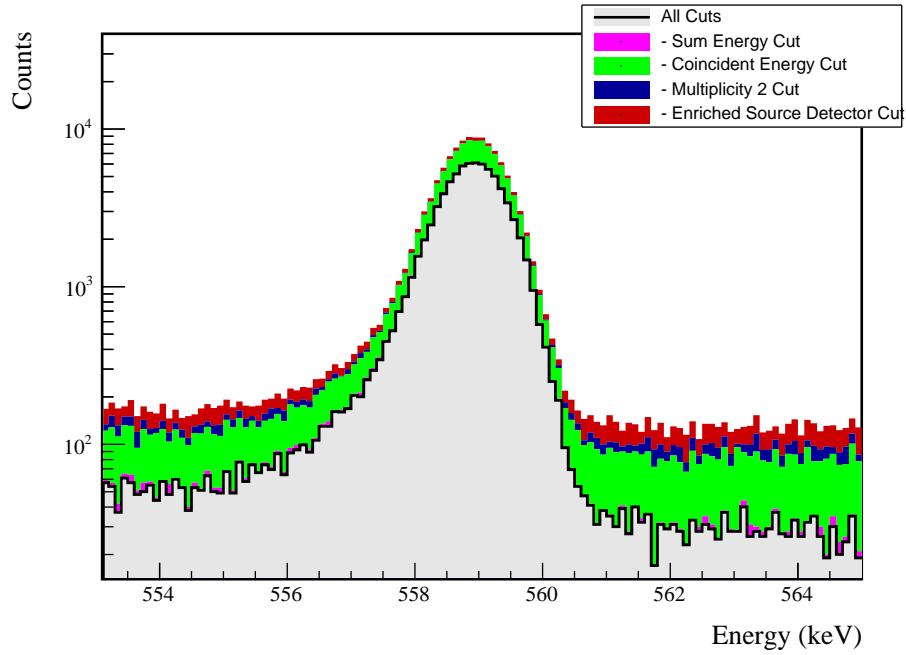


Figure A.8: Simulated and measured multiplicity 2 energy spectrum with sum and coincident energy cuts included for the 559 keV peak.



(a) Effect of all cuts on ROI

Source	Module 1 efficiency	Module 2 efficiency
Multi-Detector with Full Energy γ	$3.0 \pm 0.2\%$	$1.5 \pm 0.5\%$
Region of Interest	$88.4 \pm 2.0\%$	$88.4 \pm 2.0\%$
Dead Layer	$71.4 \pm 4.9\%$	$62.8 \pm 6.5\%$
Detector Dead Times	$97.5 \pm 1.2\%$	$98.0 \pm 0.9\%$
Enriched Source Detector Cut	$97.3 \pm <0.1\%$	$93.2 \pm <0.1\%$
Multiplicity 2 Cut	$99.5 \pm <0.1\%$	$99.7 \pm <0.1\%$
Coincident Energy Cut	$73.1 \pm 0.5\%$	$74.0 \pm 0.5\%$
Sum Energy Cut	$71.4 \pm 0.5\%$	$70.5 \pm 0.5\%$
Final Efficiency	$1.42 \pm 0.14\%$	$0.61 \pm 0.20\%$

(b) Table of efficiencies

Figure A.9: Plot showing effect of cuts applied sequentially on ROI peak and table of detection efficiencies for the 559 keV peak.

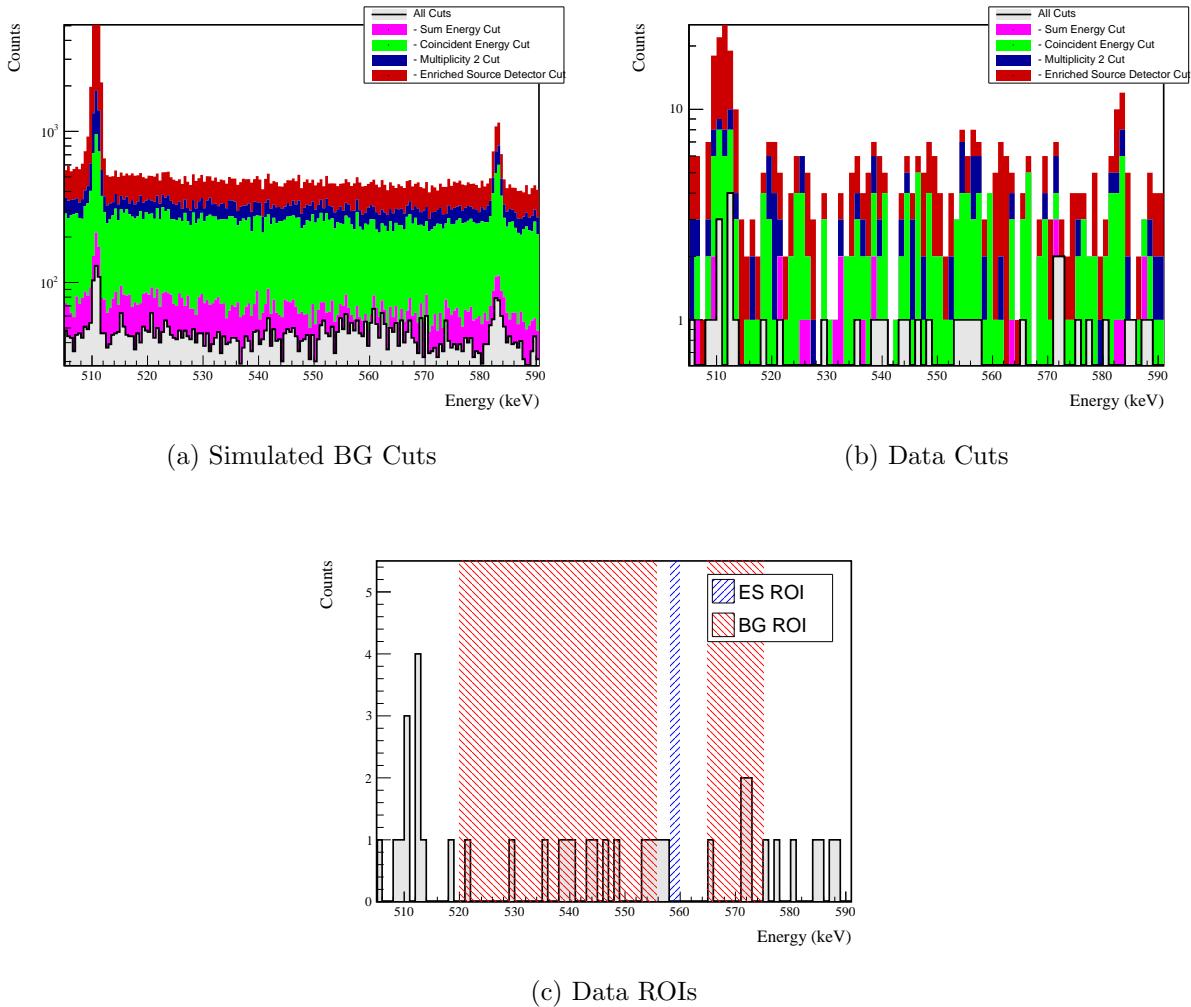


Figure A.10: Effect of all cuts applied to measured and simulated background data.

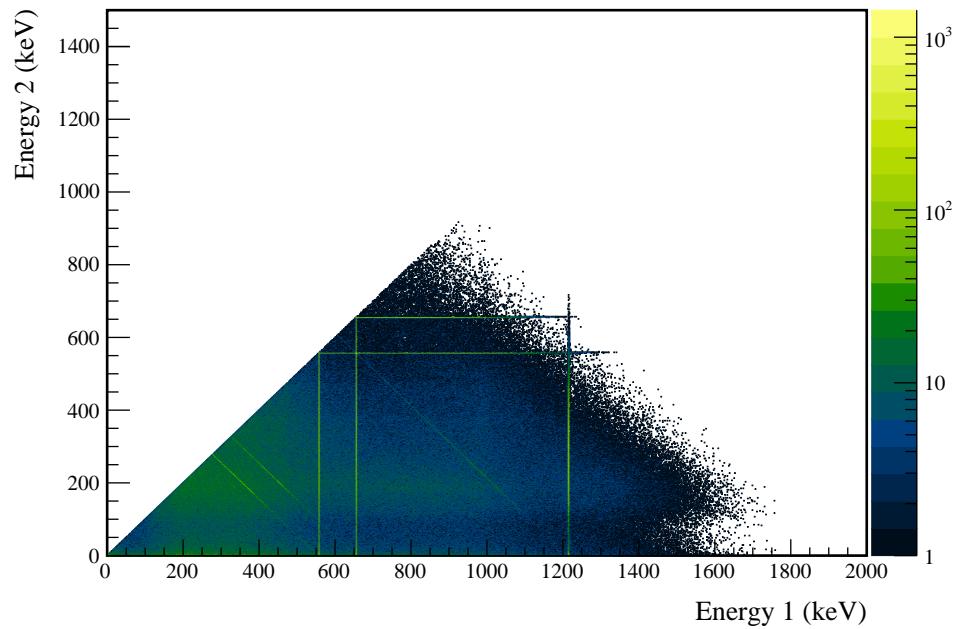
A.3 $2\nu\beta\beta$ to 2_2^+ 

Figure A.11: Simulated multiplicity 2 energy spectrum of the $2\nu\beta\beta$ to 2_2^+ decay mode

A.3.1 559 keV peak

Table A.5: Table of energy estimation uncertainties for the 559 keV peak.

DS	E_{peak} (keV)	σ_{fit} (keV)	σ_{drift} (keV)	σ (keV)	$f_{i,fit}$	$f_{i,drift}$	τ_{fit} (keV)	$\delta_{\mu,NL}$ (keV)	$\delta_{\mu,fit}$ (keV)	$\delta_{\mu,drift}$ (keV)	δ_{peak} (keV)	δ_μ (keV)	FWHM	$\delta_{fwhm,fit}$ (keV)	$\delta_{fwhm,drift}$ (keV)	$\delta_{fwhm,peak}$ (keV)	δ_{FWHM} (keV)	δ_α	$E_{ROI,1}$ (keV)	$E_{ROI,2}$ (keV)	ϵ_{ROI}	$\sigma_{e_{ROI}}$
DS1	559.101	0.460	0.063	0.464	0.230	0.515	0.001	0.104	0.002	0.012	0.005	0.105	1.152	0.001	0.039	0.011	0.040	0.035	558.218	559.832	0.864	0.016
DS2	559.101	0.461	0.055	0.464	0.249	0.515	0.002	0.067	0.004	0.012	0.005	0.068	1.158	0.001	0.107	0.011	0.108	0.093	558.206	559.830	0.867	0.032
DS3	559.101	0.470	0.066	0.474	0.224	0.505	0.001	0.026	0.024	0.012	0.005	0.038	1.174	0.001	0.073	0.011	0.074	0.063	558.206	559.847	0.872	0.021
DS4	559.101	0.455	0.077	0.461	0.108	0.445	0.002	0.076	0.010	0.012	0.005	0.078	1.111	0.001	0.106	0.011	0.107	0.096	558.299	559.841	0.881	0.033
DS5a	559.101	0.560	0.085	0.567	0.106	0.855	0.002	0.079	0.005	0.012	0.005	0.080	1.367	0.002	0.055	0.011	0.056	0.041	558.119	560.004	0.868	0.015
DS5b	559.101	0.469	0.074	0.475	0.158	0.491	0.001	0.020	0.011	0.012	0.005	0.026	1.157	0.001	0.125	0.011	0.125	0.108	558.247	559.857	0.878	0.037
DS5c	559.101	0.460	0.085	0.468	0.174	0.489	0.001	0.037	0.030	0.012	0.005	0.050	1.145	0.001	0.162	0.011	0.162	0.142	558.249	559.844	0.876	0.048
DS6a	559.101	0.456	0.044	0.458	0.191	0.463	0.001	0.069	0.025	0.012	0.005	0.075	1.123	0.000	0.041	0.011	0.042	0.038	558.259	559.826	0.874	0.014

Cut Name	Cut Description	$\langle \epsilon_{total} \rangle$	$\hat{\epsilon}_{total}$	$\langle \epsilon_{unique} \rangle$	$\hat{\epsilon}_{unique}$	Sacrifice	ΔDP
Enriched Source Detector Cut	Any other detector: isEnv	M1: 23.2 % M2: 42.7 %	26.5 _{-3.5} ^{+3.8} % 62.8 _{-7.6} ^{+7.0} %	6.1 % 11.8 %	6.1 _{-1.7} ^{+2.3} % 18.6 _{-5.2} ^{+6.6} %	1.7 % 5.2 %	10%
Coincident Energy Cut	No other detector: ((energy<41.) (energy>349.6 && energy<352.8) (energy>506.8 && energy<512.2) (energy>608.4 && energy<612.6) (energy>1307.4)) && isEnv) ((energy<42.) (energy>120.2 && energy>255.8) (energy>507.6 && energy<514.2) (energy>850.2)) && !isEnv) Not: ((sumE<810.2) (sumE>907.2 && sumE<912.4) (sumE>968. && sumE<969.2) (sumE>1064.8 && sumE<1070.) (sumE>1168.6 && sumE<1174.6) (sumE>1330.4 && sumE<1333.4) (sumE>1459.4 && sumE<1461.8) (sumE>1761.8 && sumE<1766.) (sumE>1906.)	M1: 28.8 % M2: 35.6 %	34.0 _{-3.8} ^{+4.0} % 48.8 ± 7.5 %	5.3 % 5.0 %	5.4 _{-1.6} ^{+2.2} % 7.0 _{-3.0} ^{+4.9} %	4.7 % 4.3 %	3%
Combined Cuts		M1: 74.4 % M2: 82.2 %	74.1 _{-3.8} ^{+3.4} % 88.4 _{-5.8} ^{+4.0} %	— —	— —	28.6 % 37.3 %	30%

Table A.6: Table of cut descriptions and efficiencies for simulated backgrounds and measured data for the 559 keV peak.

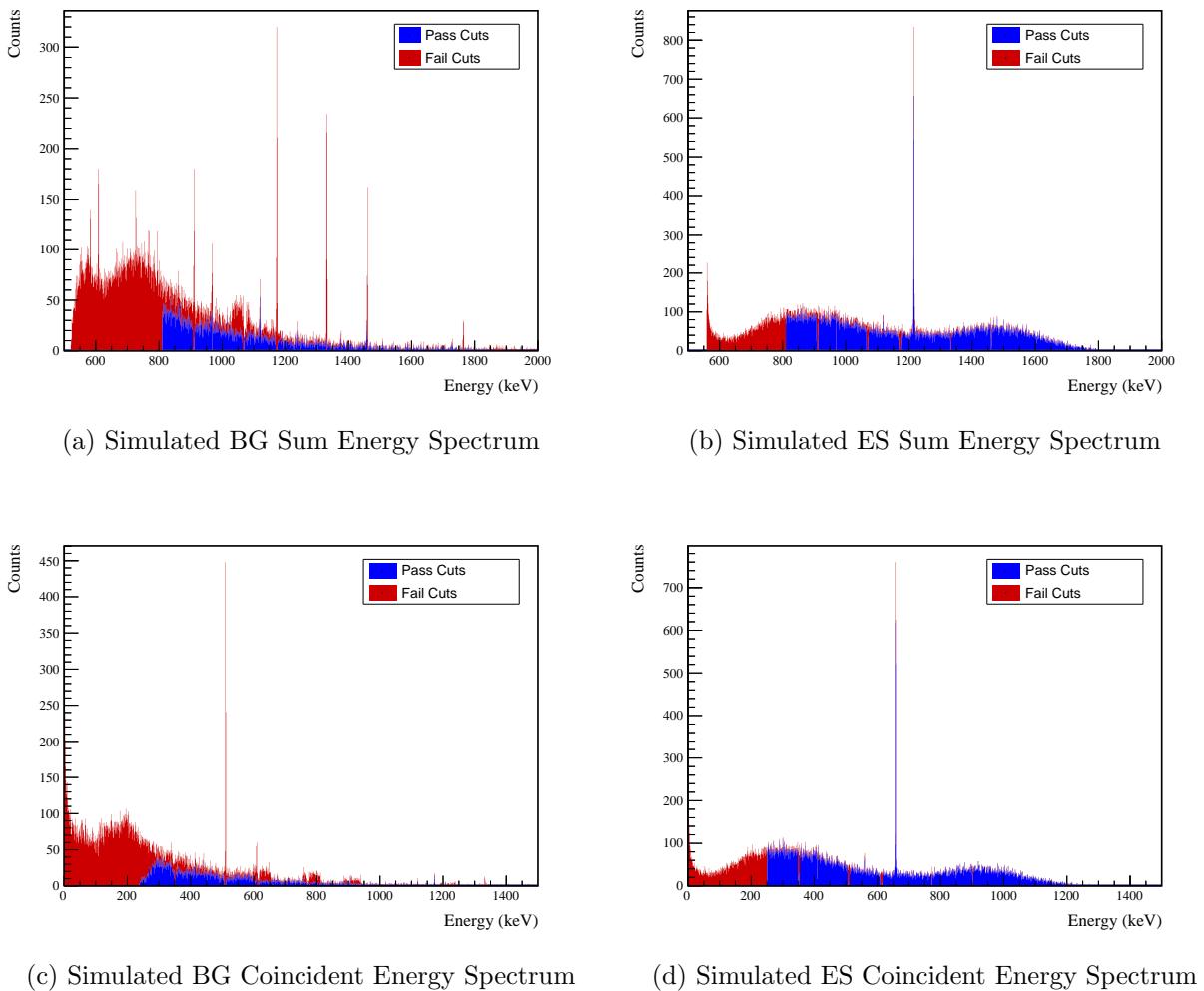


Figure A.12: Sum energy and coincident energy spectra for the 559 keV peak.

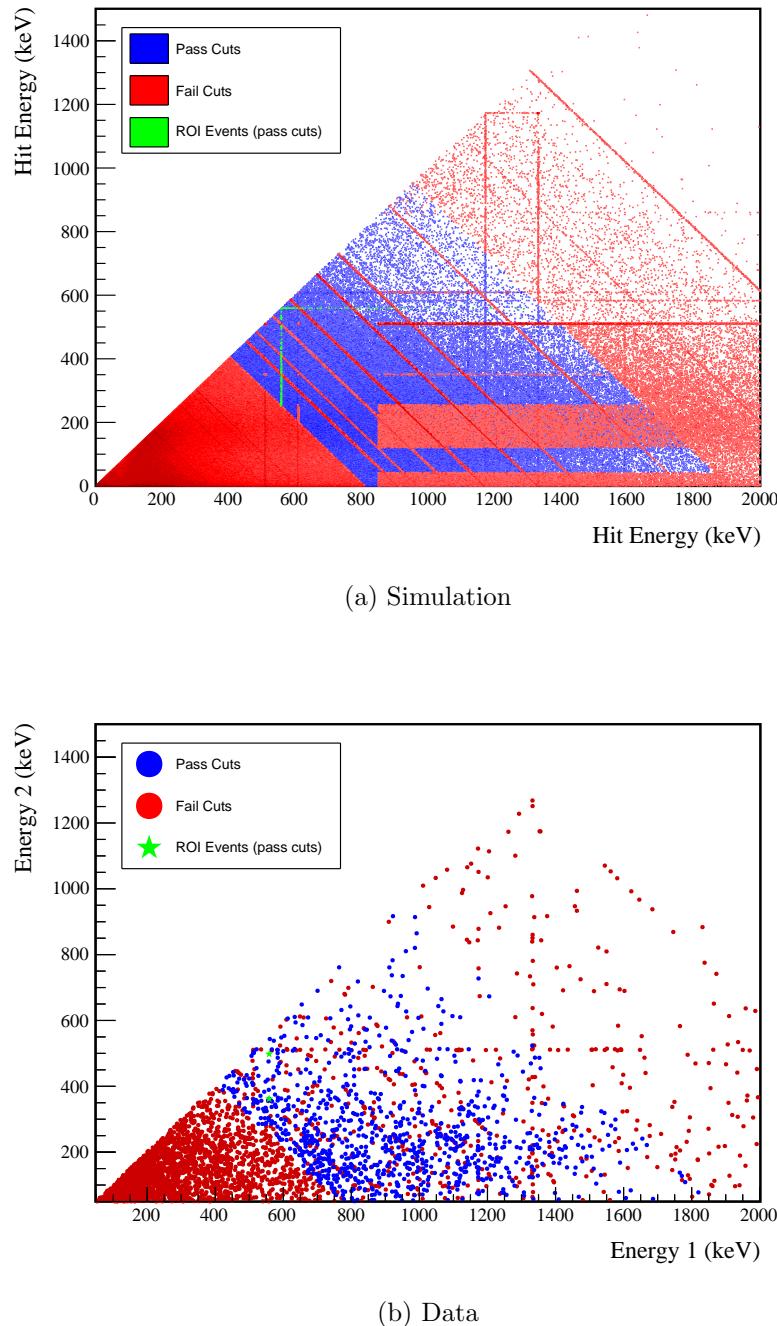
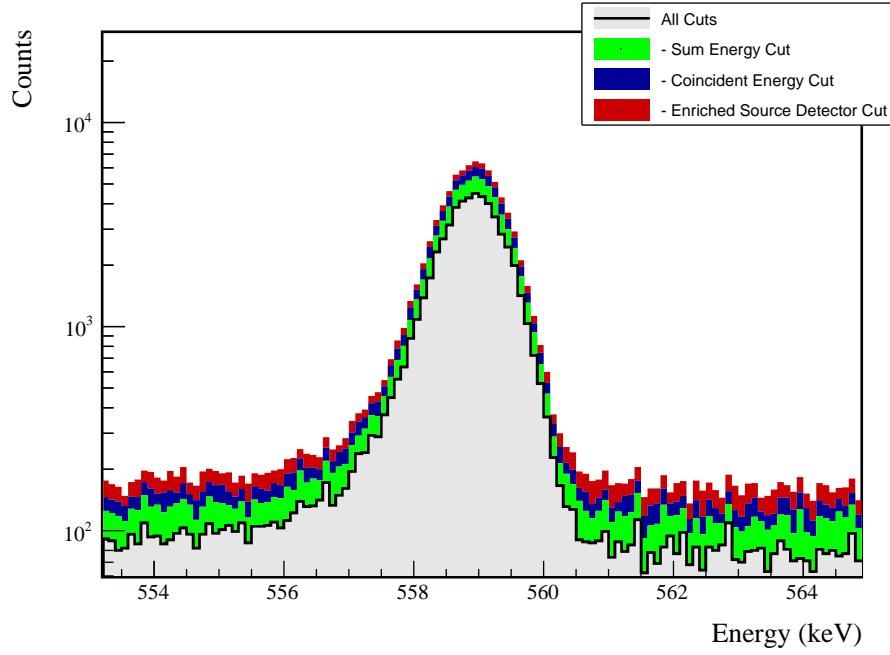


Figure A.13: Simulated and measured multiplicity 2 energy spectrum with sum and coincident energy cuts included for the 559 keV peak.



(a) Effect of all cuts on ROI

Source	Module 1 efficiency	Module 2 efficiency
Multi-Detector with Full Energy γ	$2.0 \pm 0.2\%$	$1.1 \pm 0.5\%$
Region of Interest	$87.1 \pm 2.1\%$	$87.1 \pm 2.1\%$
Dead Layer	$75.3 \pm 4.2\%$	$67.3 \pm 5.7\%$
Detector Dead Times	$97.6 \pm 1.1\%$	$98.2 \pm 0.9\%$
Enriched Source Detector Cut	$96.5 \pm <0.1\%$	$89.0 \pm <0.1\%$
Coincident Energy Cut	$89.7 \pm 0.5\%$	$85.9 \pm 0.5\%$
Sum Energy Cut	$78.3 \pm 0.5\%$	$73.3 \pm 0.5\%$
Final Efficiency	$0.99 \pm 0.12\%$	$0.44 \pm 0.20\%$

(b) Table of efficiencies

Figure A.14: Plot showing effect of cuts applied sequentially on ROI peak and table of detection efficiencies for the 559 keV peak.

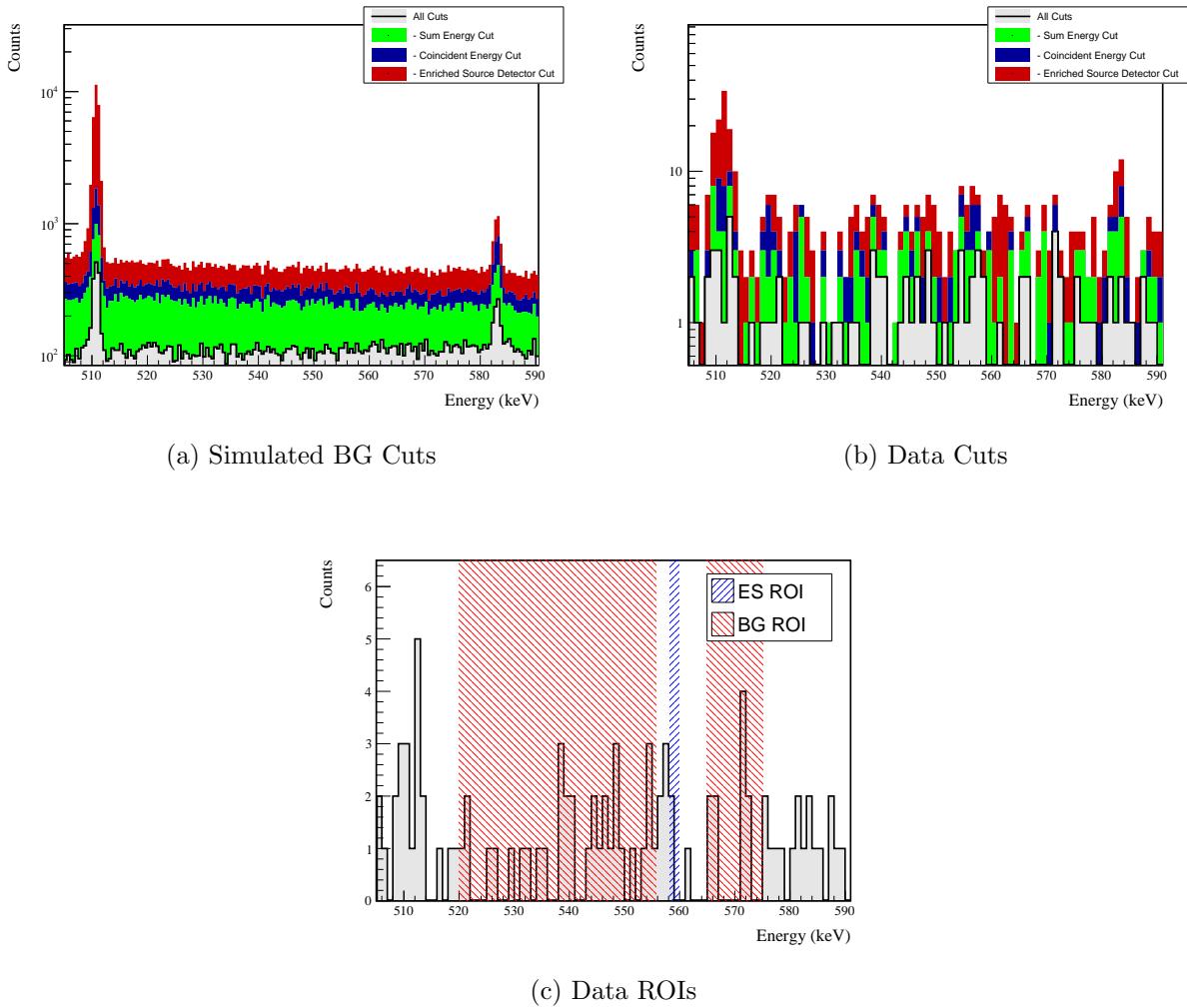


Figure A.15: Effect of all cuts applied to measured and simulated background data.

A.3.2 657 keV peak

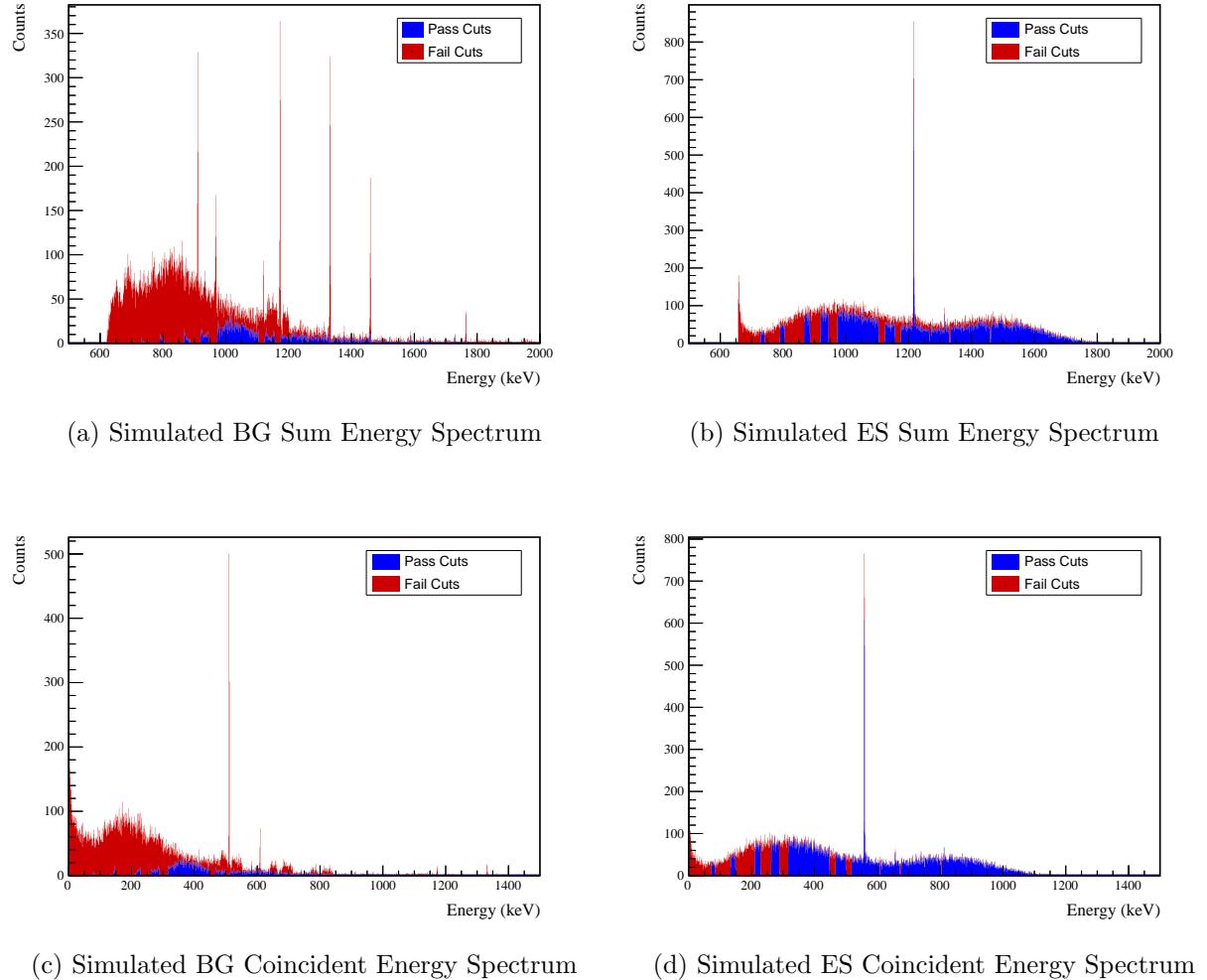


Figure A.16: Sum energy and coincident energy spectra for the 657 keV peak.

Table A.7: Table of energy estimation uncertainties for the 657 keV peak.

DS	E_{peak} (keV)	σ_{fit} (keV)	σ_{drift} (keV)	σ (keV)	$f_{i,fit}$	$f_{i,drift}$	τ_{fit} (keV)	$\delta_{\mu,NL}$ (keV)	$\delta_{\mu,drift}$ (keV)	$\delta_{\mu,peak}$ (keV)	δ_μ (keV)	FWHM (keV)	$\delta_{fwhm,fit}$ (keV)	$\delta_{fwhm,drift}$ (keV)	$\delta_{fwhm,peak}$ (keV)	$E_{ROI,1}$ (keV)	$E_{ROI,2}$ (keV)	ϵ_{ROI}	$\sigma_{e_{ROI}}$			
DS1	657.041	0.500	0.074	0.505	0.230	0.579	0.002	0.104	0.003	0.012	0.005	0.105	1.256	0.001	0.039	0.011	0.040	0.032	656.051	657.858	0.873	0.013
DS2	657.041	0.502	0.064	0.506	0.249	0.580	0.002	0.067	0.005	0.012	0.005	0.068	1.263	0.001	0.107	0.011	0.108	0.085	656.035	657.856	0.875	0.028
DS3	657.041	0.510	0.078	0.516	0.224	0.568	0.002	0.026	0.028	0.012	0.005	0.040	1.278	0.001	0.073	0.011	0.074	0.058	656.039	657.874	0.879	0.019
DS4	657.041	0.493	0.090	0.501	0.108	0.490	0.002	0.076	0.012	0.012	0.005	0.078	1.207	0.001	0.106	0.011	0.107	0.088	656.147	657.865	0.890	0.029
DS5a	657.041	0.606	0.100	0.614	0.106	0.924	0.002	0.079	0.006	0.012	0.005	0.080	1.481	0.002	0.055	0.011	0.056	0.038	655.948	658.045	0.878	0.013
DS5b	657.041	0.509	0.087	0.517	0.158	0.562	0.001	0.020	0.013	0.012	0.005	0.027	1.259	0.001	0.125	0.011	0.125	0.100	656.086	657.884	0.886	0.032
DS5c	657.041	0.500	0.100	0.510	0.174	0.555	0.002	0.037	0.035	0.012	0.005	0.053	1.247	0.001	0.162	0.011	0.162	0.130	656.087	657.872	0.883	0.042
DS6a	657.041	0.495	0.051	0.497	0.191	0.524	0.001	0.069	0.030	0.012	0.005	0.076	1.221	0.001	0.041	0.011	0.042	0.035	656.090	657.850	0.882	0.012

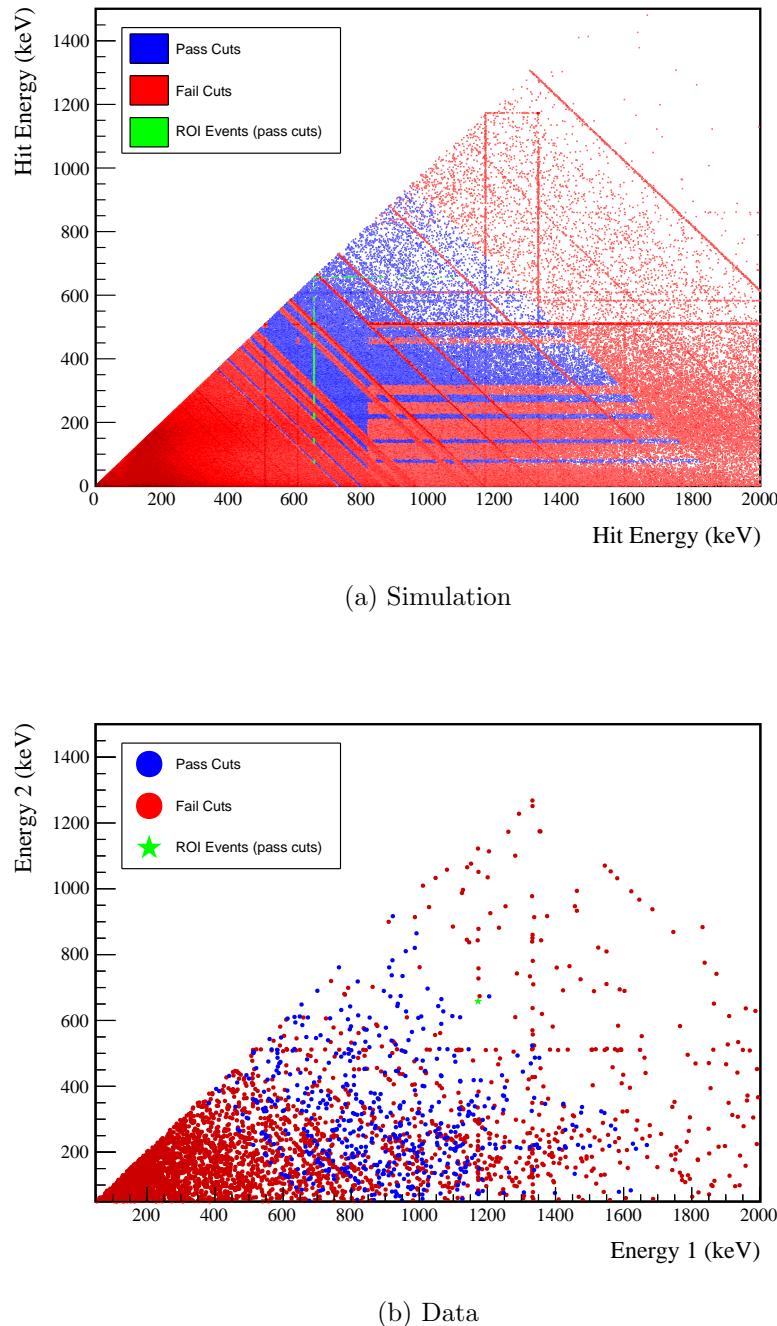
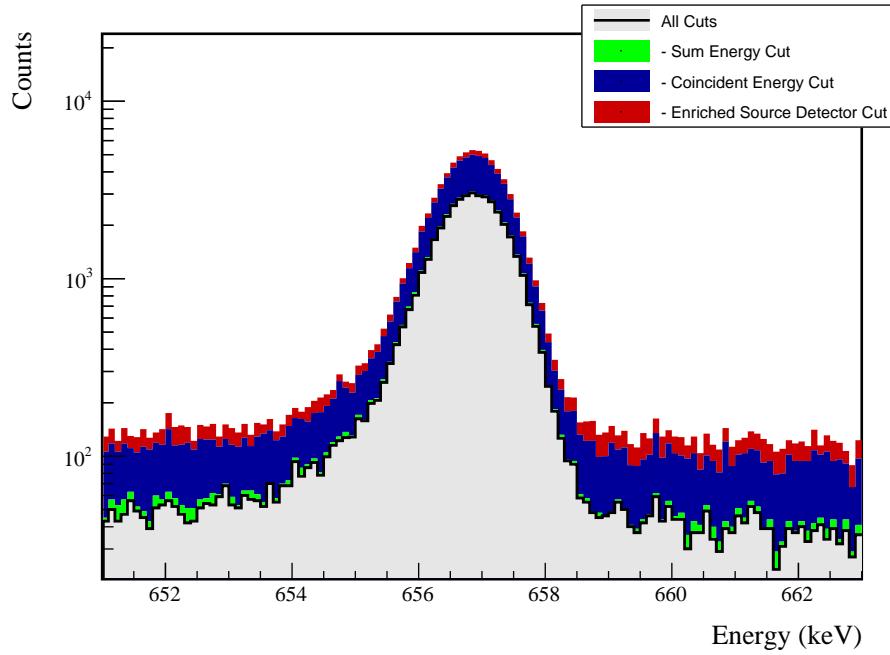


Figure A.17: Simulated and measured multiplicity 2 energy spectrum with sum and coincident energy cuts included for the 657 keV peak.



(a) Effect of all cuts on ROI

Source	Module 1 efficiency	Module 2 efficiency
Multi-Detector with Full Energy γ	$1.8 \pm 0.2\%$	$1.0 \pm 0.5\%$
Region of Interest	$88.0 \pm 1.8\%$	$88.0 \pm 1.8\%$
Dead Layer	$75.6 \pm 4.1\%$	$66.9 \pm 5.8\%$
Detector Dead Times	$97.8 \pm 1.0\%$	$98.2 \pm 0.8\%$
Enriched Source Detector Cut	$96.6 \pm <0.1\%$	$88.6 \pm <0.1\%$
Coincident Energy Cut	$62.2 \pm 0.5\%$	$65.6 \pm 0.5\%$
Sum Energy Cut	$73.7 \pm 0.5\%$	$68.9 \pm 0.5\%$
Final Efficiency	$0.75 \pm 0.10\%$	$0.35 \pm 0.17\%$

(b) Table of efficiencies

Figure A.18: Plot showing effect of cuts applied sequentially on ROI peak and table of detection efficiencies for the 657 keV peak.

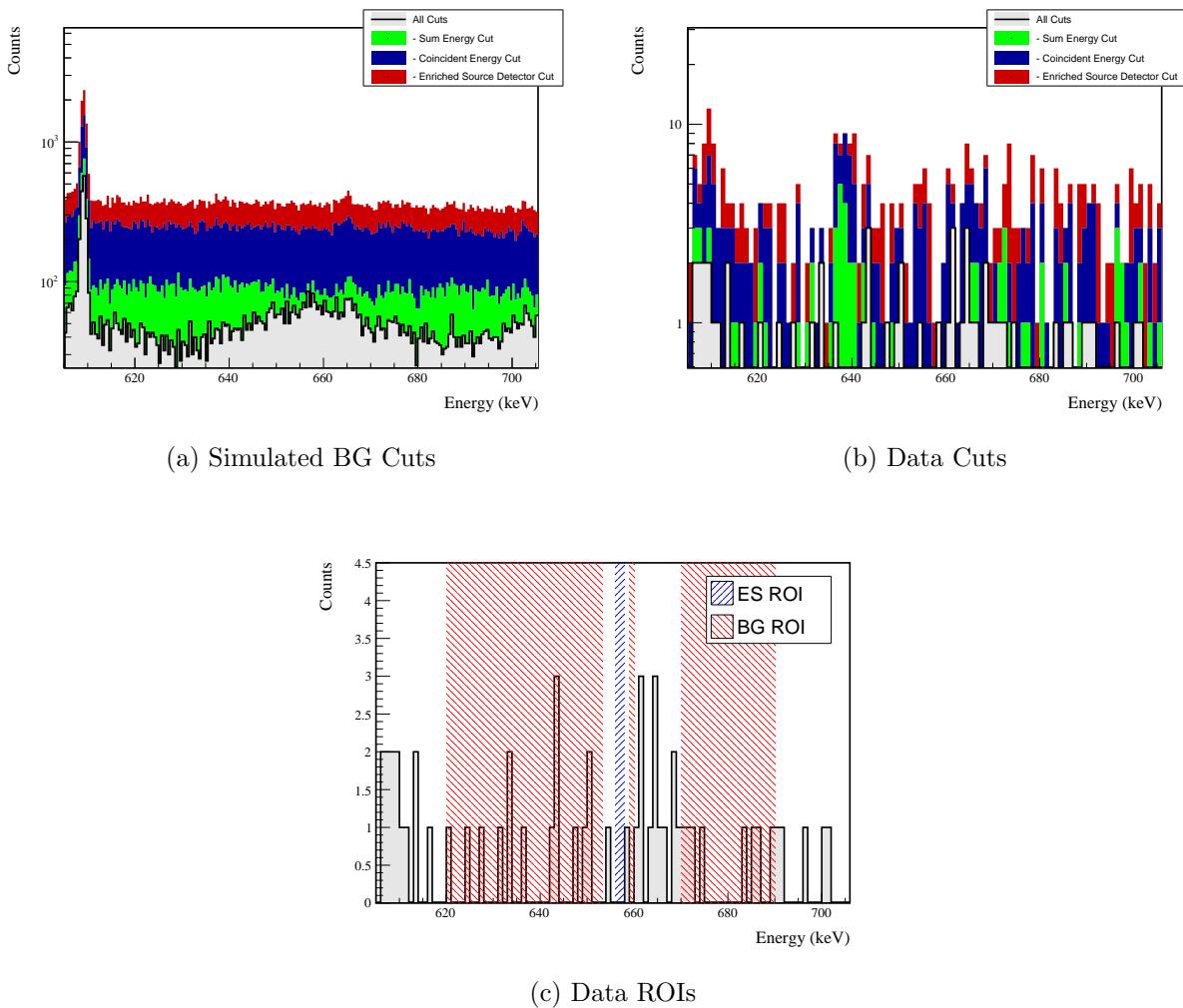
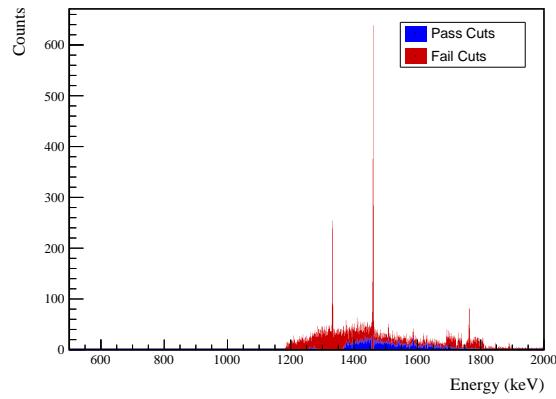


Figure A.19: Effect of all cuts applied to measured and simulated background data.

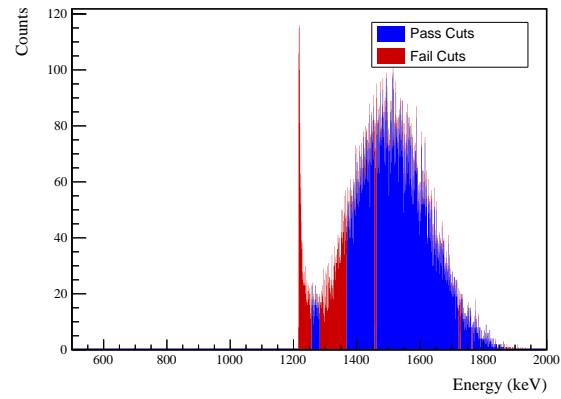
Cut Name	Cut Description	$\langle \epsilon_{total} \rangle$	$\hat{\epsilon}_{total}$	$\langle \epsilon_{unique} \rangle$	$\hat{\epsilon}_{unique}$	Sacrifice	ΔDP
Enriched Source Detector Cut	Any other detector: isEnr	M1: 23.9 % M2: 43.7 %	25.2 _{-3.5} ^{+3.9} % 60.4 _{-7.2} ^{+6.8} %	7.2 % 13.5 %	7.4 _{-2.0} ^{+2.6} % 14.6 _{-4.4} ^{+5.8} %	1.7 % 5.5 %	21%
Coincident Energy Cut	No other detector: ((energy<71.8) (energy>84.4 && energy<133.4) (energy>148.4 && energy>209.8) (energy>228.4 && energy>262.) (energy>288.4 && energy<316.2) (energy>447.4 && energy<467.2) (energy>499.6 && energy<512.8) (energy>607.6 && energy<610.4) (energy>1165.8 && energy<1175.6) (energy>1187.6) && isEnr) ((energy<55.2) (energy>503.6 && energy<516.4) (energy>820.)) && isEnr) Not: (sumE<729.) (sumE>741.8 && sumE<790.4) (sumE>805.4 && sumE<857.) (sumE>885.6 && sumE<919.8) (sumE>945. && sumE<973.2) (sumE>1104.4 && sumE<1123.8) (sumE>1156.4 && sumE<1174.8) (sumE>1328.8 && sumE<1333.6) (sumE>1458.8 && sumE<1461.8) (sumE>1762.4 && sumE<1766.) (sumE>1897.4)	M1: 54.0 % M2: 47.6 %	51.9 ± 4.3 % 37.5 _{-6.7} ^{+7.2} %	16.7 % 13.1 %	17.0 _{-3.0} ^{+3.5} % 10.4 _{-3.6} ^{+5.2} %	13.6 % 8.0 %	17%
Combined Cuts		M1: 86.5 % M2: 89.9 %	85.2 _{-3.3} ^{+2.8} % 93.8 _{-4.5} ^{+2.7} %	—	—	42.0 % 45.2 %	34%

Table A.8: Table of cut descriptions and efficiencies for simulated backgrounds and measured data for the 657 keV peak.

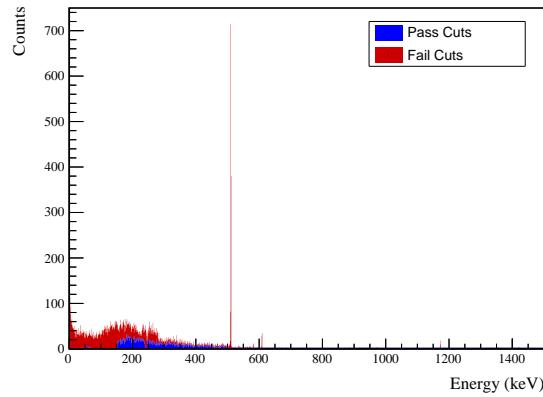
A.3.3 1216 keV peak



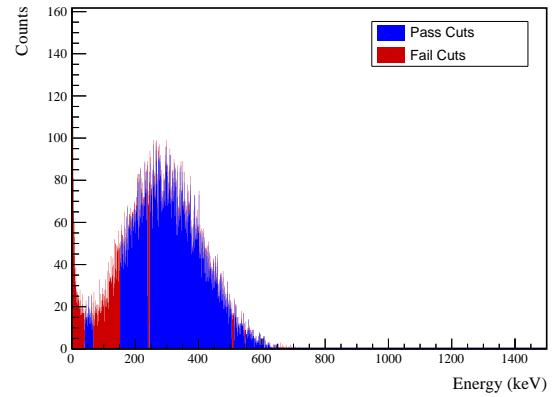
(a) Simulated BG Sum Energy Spectrum



(b) Simulated ES Sum Energy Spectrum



(c) Simulated BG Coincident Energy Spectrum



(d) Simulated ES Coincident Energy Spectrum

Figure A.20: Sum energy and coincident energy spectra for the 1216 keV peak.

Table A.9: Table of energy estimation uncertainties for the 1216 keV peak.

DS	E_{peak} (keV)	$\sigma_{t_{fit}}$ (keV)	$\sigma_{\mu,drift}$ (keV)	σ (keV)	$f_{t,fit}$ (keV)	τ_{fit} (keV)	$\delta_{t_{fit}}$ (keV)	$\delta_{\mu,NL}$ (keV)	$\delta_{\mu,drift}$ (keV)	$\delta_{t_{peak}}$ (keV)	δ_μ (keV)	FWHM (keV)	$\delta_{t_{width,fit}}$ (keV)	$\delta_{t_{width,drift}}$ (keV)	$\delta_{fwhm,xalk}$ (keV)	δ_{FWHM} (keV)	δ_α	$E_{ROI,1}$ (keV)	$E_{ROI,2}$ (keV)	ϵ_{ROI}	$\sigma_{t_{ROI}}$	
DS1	1216.104	0.705	0.137	0.718	0.230	0.945	0.003	0.104	0.005	0.012	0.020	0.107	1.787	0.001	0.039	0.011	0.040	0.023	1214.691	1217.262	0.868	0.008
DS2	1216.104	0.710	0.119	0.720	0.249	0.951	0.003	0.067	0.008	0.012	0.020	0.072	1.803	0.001	0.107	0.011	0.108	0.060	1214.663	1217.262	0.867	0.019
DS3	1216.104	0.715	0.144	0.729	0.224	0.925	0.003	0.026	0.051	0.012	0.020	0.062	1.812	0.001	0.073	0.011	0.074	0.041	1214.679	1217.281	0.872	0.013
DS4	1216.104	0.697	0.167	0.717	0.108	0.746	0.003	0.076	0.022	0.012	0.020	0.083	1.726	0.001	0.106	0.011	0.107	0.062	1214.529	1217.278	0.889	0.021
DS5a	1216.104	0.838	0.185	0.859	0.106	1.316	0.004	0.079	0.012	0.012	0.020	0.083	2.070	0.002	0.055	0.011	0.056	0.027	1214.581	1217.504	0.877	0.009
DS5b	1216.104	0.716	0.161	0.734	0.158	0.963	0.002	0.020	0.024	0.012	0.020	0.039	1.791	0.001	0.125	0.011	0.125	0.070	1214.743	1217.299	0.878	0.023
DS5c	1216.104	0.703	0.185	0.727	0.174	0.932	0.003	0.037	0.066	0.012	0.020	0.079	1.783	0.001	0.162	0.011	0.162	0.091	1214.738	1217.287	0.876	0.030
DS6a	1216.104	0.693	0.095	0.700	0.191	0.873	0.002	0.069	0.055	0.012	0.020	0.092	1.723	0.001	0.041	0.011	0.042	0.025	1214.771	1217.241	0.875	0.009

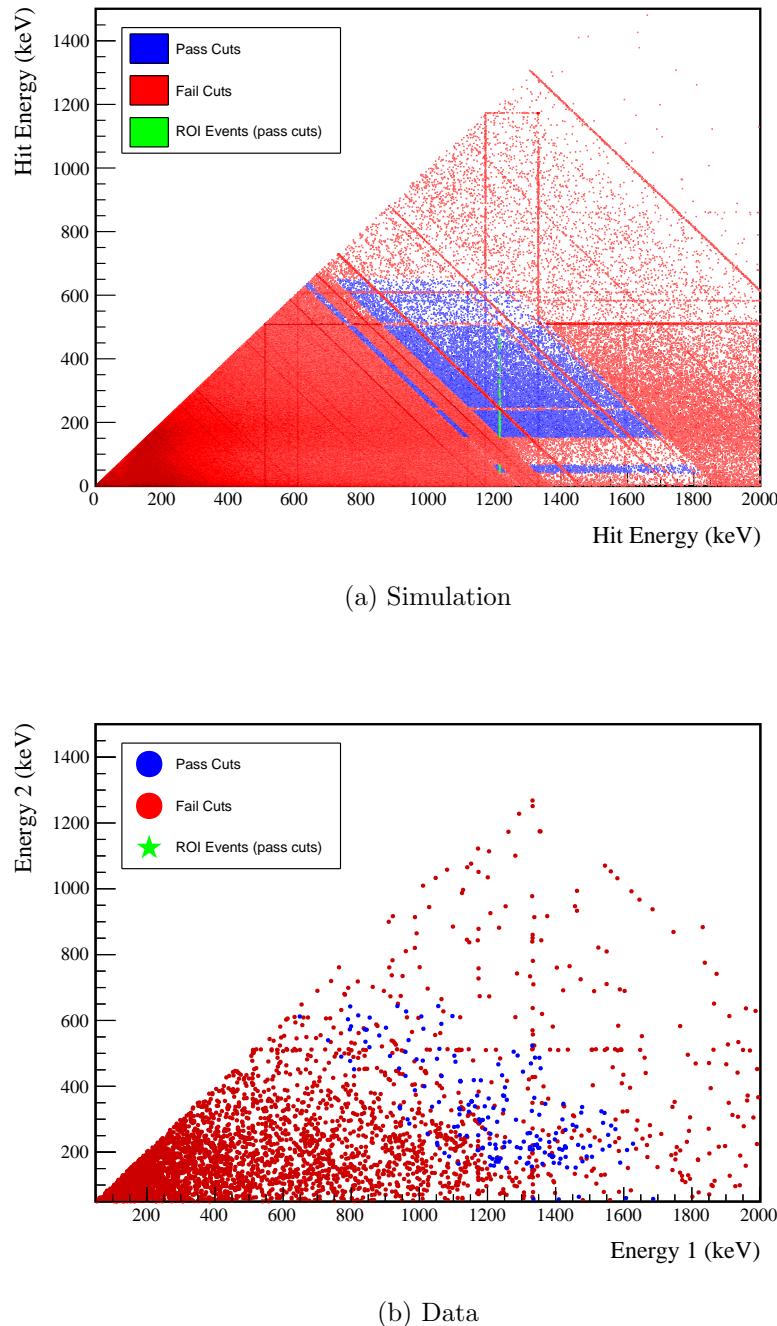
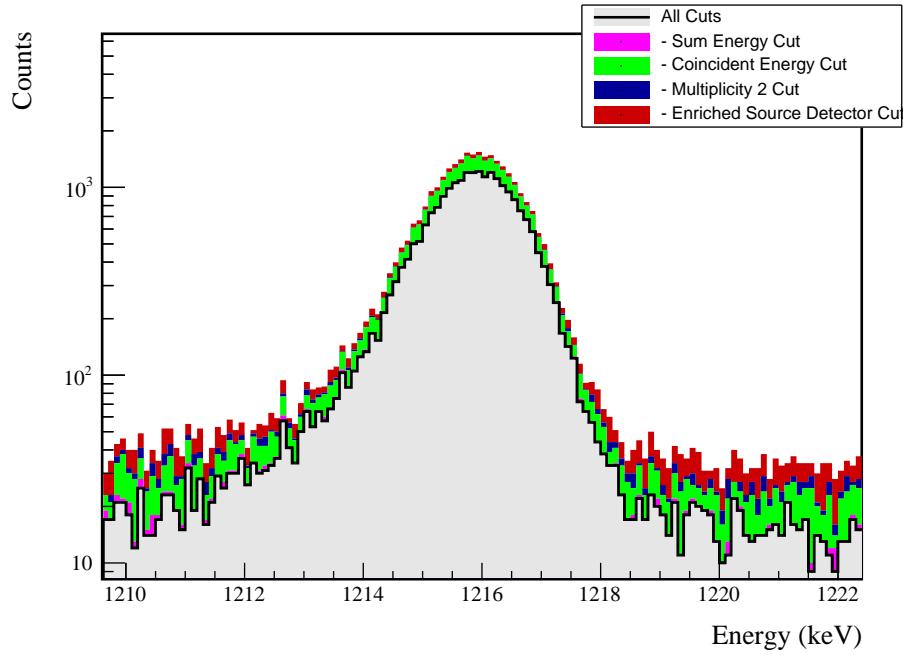


Figure A.21: Simulated and measured multiplicity 2 energy spectrum with sum and coincident energy cuts included for the 1216 keV peak.



(a) Effect of all cuts on ROI

Source	Module 1 efficiency	Module 2 efficiency
Multi-Detector with Full Energy γ	$0.8 \pm 0.2\%$	$0.4 \pm 0.5\%$
Region of Interest	$87.5 \pm 1.3\%$	$87.5 \pm 1.3\%$
Dead Layer	$73.9 \pm 4.4\%$	$63.6 \pm 6.4\%$
Detector Dead Times	$97.5 \pm 1.1\%$	$98.1 \pm 0.9\%$
Enriched Source Detector Cut	$97.0 \pm <0.1\%$	$92.5 \pm <0.1\%$
Multiplicity 2 Cut	$99.6 \pm <0.1\%$	$99.8 \pm <0.1\%$
Coincident Energy Cut	$83.5 \pm 0.5\%$	$84.2 \pm 0.5\%$
Sum Energy Cut	$82.9 \pm 0.5\%$	$82.4 \pm 0.5\%$
Final Efficiency	$0.43 \pm 0.11\%$	$0.18 \pm 0.22\%$

(b) Table of efficiencies

Figure A.22: Plot showing effect of cuts applied sequentially on ROI peak and table of detection efficiencies for the 1216 keV peak.

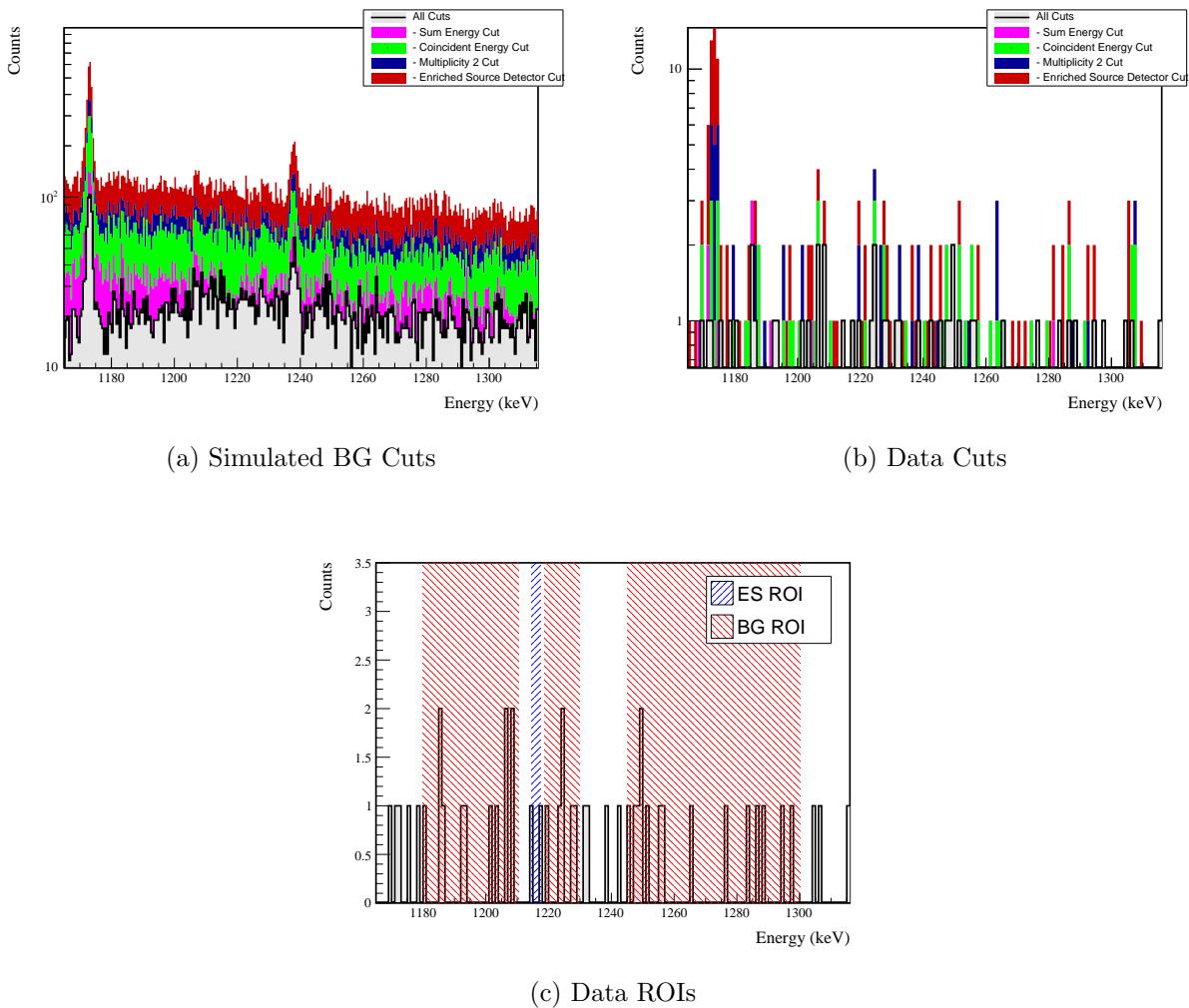


Figure A.23: Effect of all cuts applied to measured and simulated background data.

Cut Name	Cut Description	$\langle \epsilon_{total} \rangle$	$\hat{\epsilon}_{total}$	$\langle \epsilon_{unique} \rangle$	$\hat{\epsilon}_{unique}$	Sacrifice	ΔDP
Enriched Source	Any other detector: isEnv	M1: 26.9 %	16.9 ^{+4.5} _{-3.7} %	15.1 %	8.4 ^{+3.6} _{-2.6} %	2.4 %	23%
Detector Cut		M2: 43.9 %	61.9 ^{+9.8} _{-10.9} %	25.8 %	28.6 ^{+10.7} _{-8.7} %	5.8 %	
Multiplicity 2		M1: 15.3 %	16.9 ^{+4.5} _{-3.7} %	4.0 %	3.6 ^{+2.7} _{-1.6} %	0.1 %	5%
Cut	m==2	M2: 11.9 %	9.5 ^{+8.4} _{-4.7} %	3.2 %	0.0 ^{+4.5} _{-0.0} %	0.0 %	
Coincident	No other detector: ((energy<40.8) (energy>66.6 && energy<152.2) (energy>239.6 && energy>245.8) (energy>505.2 && energy<512.6) (energy>608.8 && energy<610.) (energy>650.8) && isEnv)	M1: 34.1 %	38.6 ^{+5.4} _{-5.2} %	10.8 %	8.4 ^{+3.6} _{-2.6} %	0.3 %	14%
Energy Cut		M2: 25.9 %	14.3 ^{+9.3} _{-6.0} %	9.3 %	4.8 ^{+7.0} _{-2.9} %	0.3 %	
Sum Energy Cut	Not: (sumE<1257.) (sumE>1283. && sumE<1367.4) (sumE>1455.2 && sumE<1462.) (sumE>1721.8 && sumE<1728.6) (sumE>1762. && sumE<1766.) (sumE>1845.6 && sumE<1851.2) (sumE>1866.6)	M1: 40.9 %	38.6 ^{+5.4} _{-5.2} %	10.5 %	4.8 ^{+2.9} _{-1.9} %	0.5 %	12%
Combined Cuts		M2: 35.9 %	42.9 ^{+10.9} _{-10.2} %	6.0 %	0.0 ^{+4.5} _{-0.0} %	0.5 %	
		M1: 77.1 %	65.1 ^{+5.0} _{-5.4} %	—	—	20.1 %	44%
		M2: 79.8 %	81.0 ^{+7.1} _{-9.9} %	—	—	23.8 %	

Table A.10: Table of cut descriptions and efficiencies for simulated backgrounds and measured data for the 1216 keV peak.

A.4 $0\nu\beta\beta$ **to** 0_1^+

Note that both the 559 and 563 keV peaks will be shown together since they use the same sets of cuts.

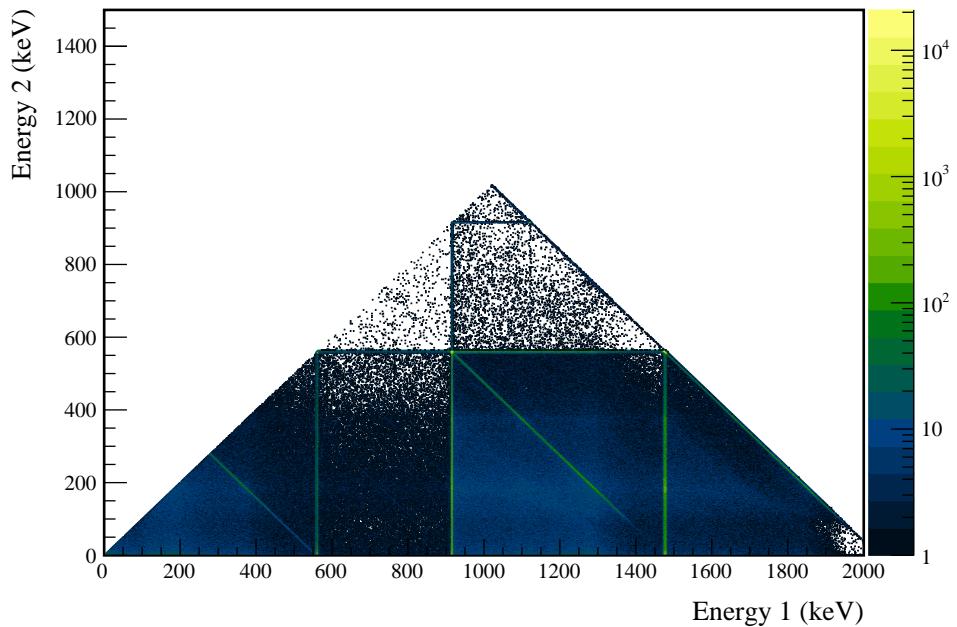


Figure A.24: Simulated multiplicity 2 energy spectrum of the $0\nu\beta\beta$ to 0_1^+ decay mode

Table A.11: Table of energy estimation uncertainties for the 559 and 563 keV peaks.

DS	E_{peak} (keV)	σ_{fit} (keV)	σ_{disfit} (keV)	σ (keV)	$f_{i,fit}$ (keV)	τ_{fit} (keV)	$\delta_{i,fit}$ (keV)	$\delta_{i,NL}$ (keV)	$\delta_{i,drift}$ (keV)	$\delta_{i,etalk}$ (keV)	$\delta_{i,peak}$ (keV)	δ_p (keV)	FWHM (keV)	$\delta_{fwhm,fit}$ (keV)	$\delta_{fwhm,etalk}$ (keV)	$\delta_{fwhm,drift}$ (keV)	δ_{FWHM} (keV)	$\delta_{ROI,1}$ (keV)	$E_{ROI,1}$ (keV)	ϵ_{ROI}	$\sigma_{e,roi}$	
DS1	559.101	0.460	0.063	0.464	0.230	0.515	0.001	0.104	0.002	0.012	0.005	0.105	1.152	0.001	0.039	0.011	0.040	0.035	558.083	559.935	0.907	0.012
DS2	559.101	0.461	0.055	0.464	0.249	0.515	0.002	0.067	0.004	0.012	0.005	0.068	1.158	0.001	0.107	0.011	0.108	0.093	558.066	559.934	0.910	0.025
DS3	559.101	0.470	0.066	0.474	0.224	0.505	0.001	0.026	0.024	0.012	0.005	0.038	1.174	0.001	0.073	0.011	0.074	0.063	558.071	559.953	0.914	0.017
DS4	559.101	0.455	0.077	0.461	0.108	0.445	0.002	0.076	0.010	0.012	0.005	0.078	1.111	0.001	0.106	0.011	0.107	0.096	558.186	559.943	0.922	0.026
DS5a	559.101	0.560	0.085	0.567	0.106	0.855	0.002	0.079	0.005	0.012	0.005	0.080	1.367	0.002	0.055	0.011	0.056	0.041	557.975	560.129	0.910	0.012
DS5b	559.101	0.469	0.074	0.475	0.158	0.491	0.001	0.020	0.011	0.012	0.005	0.026	1.157	0.001	0.125	0.011	0.125	0.108	558.122	559.962	0.919	0.029
DS5c	559.101	0.460	0.085	0.468	0.174	0.489	0.001	0.037	0.030	0.012	0.005	0.050	1.145	0.001	0.162	0.011	0.162	0.142	558.123	559.948	0.917	0.037
DS6a	559.101	0.456	0.044	0.458	0.191	0.463	0.001	0.069	0.025	0.012	0.005	0.075	1.123	0.000	0.041	0.011	0.042	0.038	558.134	559.928	0.916	0.011
DS1	563.178	0.461	0.064	0.466	0.230	0.518	0.001	0.104	0.002	0.012	0.005	0.105	1.156	0.001	0.039	0.011	0.040	0.035	562.156	564.015	0.907	0.012
DS2	563.178	0.463	0.055	0.466	0.249	0.517	0.002	0.067	0.004	0.012	0.005	0.068	1.162	0.001	0.107	0.011	0.108	0.093	562.139	564.014	0.910	0.025
DS3	563.178	0.471	0.066	0.476	0.224	0.508	0.001	0.026	0.024	0.012	0.005	0.038	1.179	0.001	0.073	0.011	0.074	0.063	562.144	564.033	0.914	0.017
DS4	563.178	0.457	0.077	0.463	0.108	0.447	0.002	0.076	0.010	0.012	0.005	0.078	1.115	0.001	0.106	0.011	0.107	0.096	562.260	564.023	0.922	0.026
DS5a	563.178	0.562	0.086	0.569	0.106	0.858	0.002	0.079	0.006	0.012	0.005	0.080	1.372	0.002	0.055	0.011	0.056	0.041	562.048	564.210	0.910	0.011
DS5b	563.178	0.471	0.074	0.477	0.158	0.494	0.001	0.020	0.011	0.012	0.005	0.026	1.162	0.001	0.125	0.011	0.125	0.108	562.196	564.042	0.919	0.029
DS5c	563.178	0.462	0.086	0.470	0.174	0.492	0.001	0.037	0.030	0.012	0.005	0.050	1.149	0.001	0.162	0.011	0.162	0.141	562.197	564.028	0.917	0.037
DS6a	563.178	0.457	0.044	0.459	0.191	0.465	0.001	0.069	0.026	0.012	0.005	0.075	1.127	0.000	0.041	0.011	0.042	0.038	562.208	564.008	0.915	0.011

Cut Name	Cut Description	$\langle \epsilon_{total} \rangle$	$\hat{\epsilon}_{total}$	$\langle \epsilon_{unique} \rangle$	$\hat{\epsilon}_{unique}$	Sacrifice	ΔDP
Enriched Source	Any other detector: isEur	M1: 23.2 % M2: 42.7 %	27.2 _{-3.5} ^{+3.8} % 62.8 _{-7.6} ^{+7.0} %	0.5 % 0.9 %	0.7 _{-0.4} ^{+1.1} % 7.0 _{-3.0} ^{+4.9} %	1.3 % 3.0 %	13%
Detector Cut	No other detector: ((energy<53.) (energy>469.6 && energy<525.2) (energy>587.8 && energy<853.2) (energy>1074.6 && energy<1079.2) (energy>1170.6 && energy<1175.) energy<1121.8) (energy>1331. && energy<1334.) (energy>1433.) && isEur) ((energy<44.8) (energy>508. energy<522.6) (energy>1385.6)) && !isEur)	M1: 28.8 % M2: 26.9 %	32.0 _{-3.7} ^{+4.0} % 23.3 _{-5.8} ^{+7.0} %	0.8 % 0.5 %	1.4 _{-0.7} ^{+1.3} % 7.0 _{-3.0} ^{+4.9} %	4.5 % 2.9 %	9%
Coincident	Not: (sumE<1472.) (sumE>1761.8 && sumE<1765.8) (sumE>2042.6)	M1: 97.1 % M2: 97.6 %	96.6 _{-1.8} ^{+1.2} % 86.0 _{-6.1} ^{+4.5} %	50.9 % 38.0 %	49.0 ± 4.1 % 27.9 _{-6.3} ^{+7.3} %	12.3 % 15.3 %	243%
Energy Cut	M1: 98.4 % M2: 99.1 %	98.6 _{-1.3} ^{+0.7} % 100.0 _{-2.3} ^{+0.0} %	— —	— —	— —	26.5 % 35.9 %	298%
Sum Energy Cut							
Combined Cuts							

Table A.12: Table of cut descriptions and efficiencies for simulated backgrounds and measured data for the 559 and 563 keV peaks.

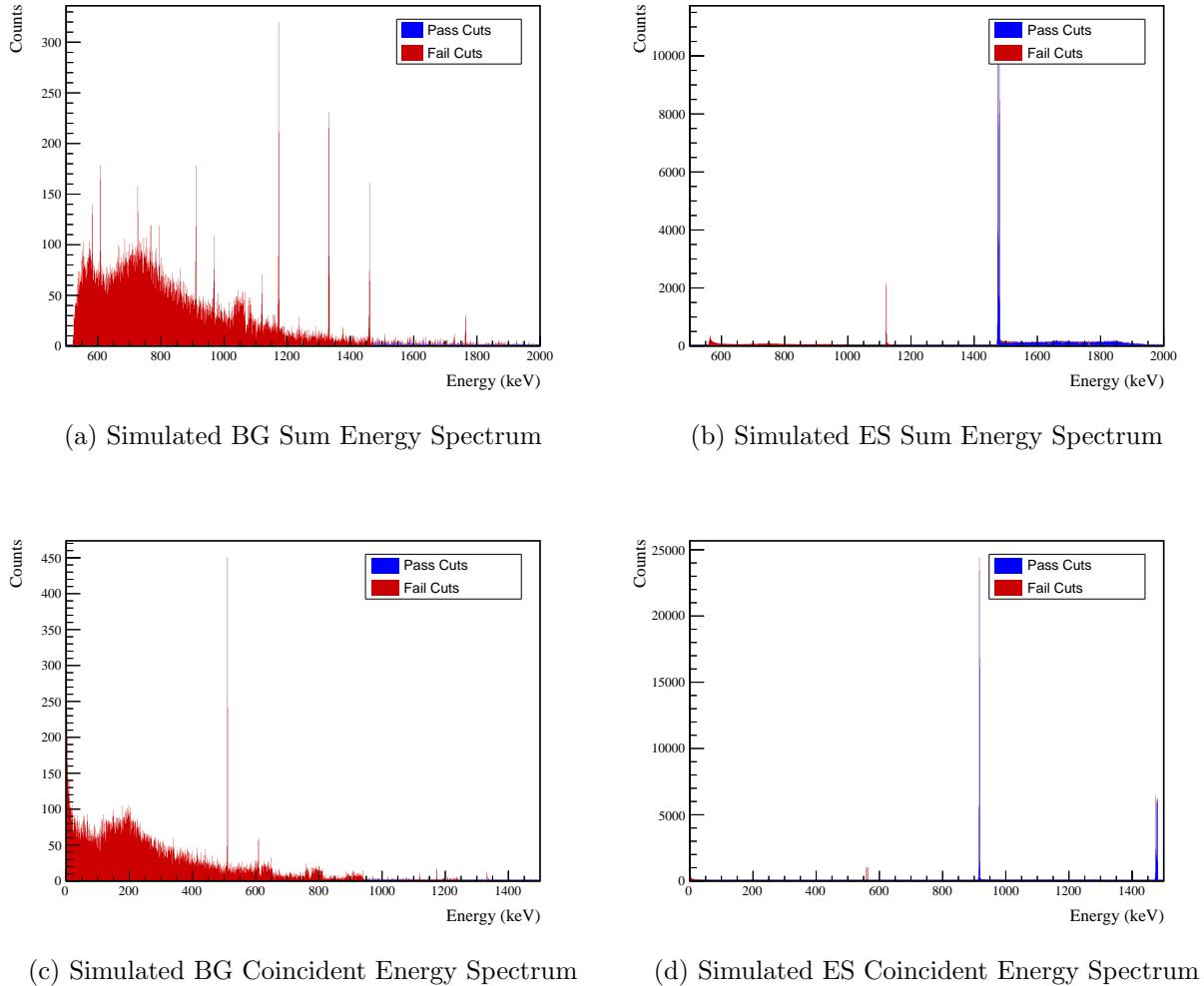


Figure A.25: Sum energy and coincident energy spectra for the 559 and 563 keV peaks.

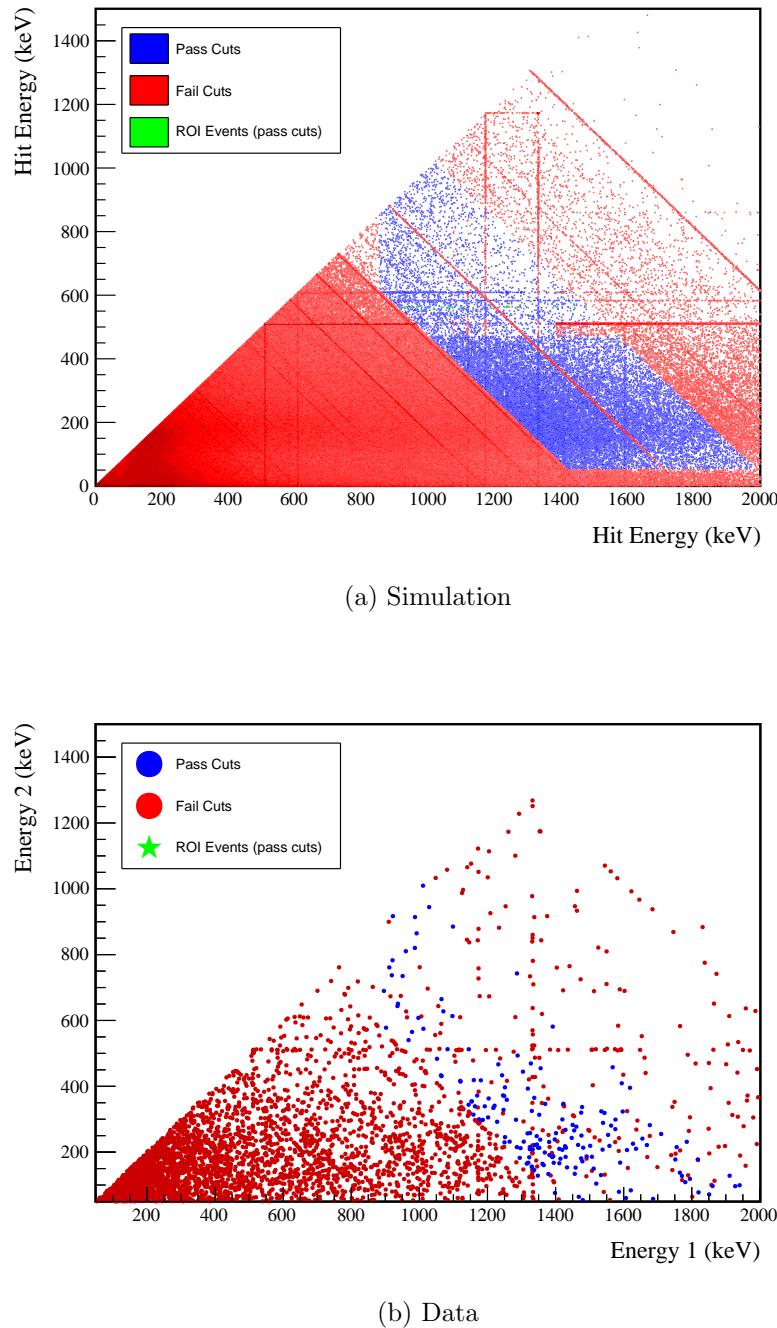
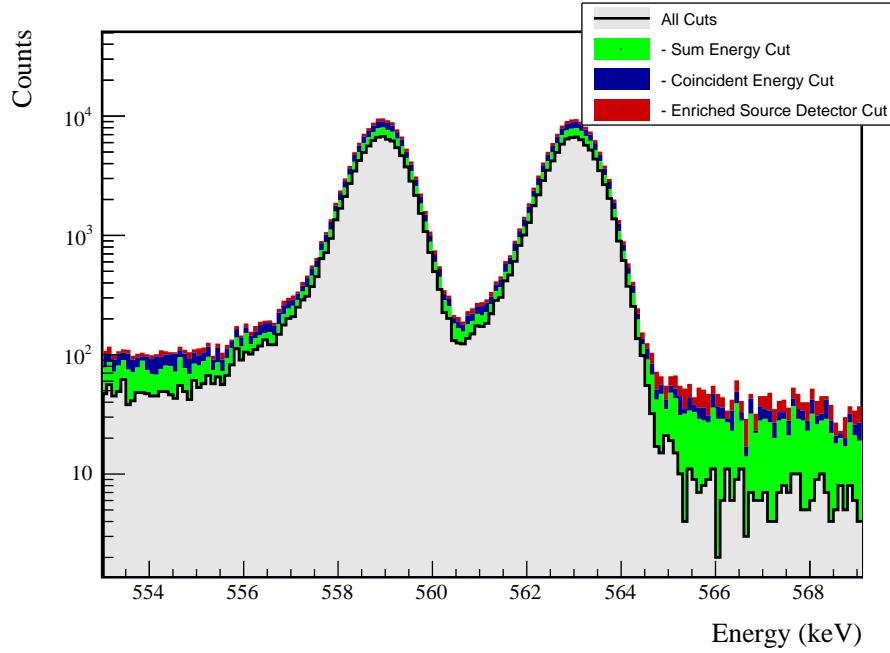


Figure A.26: Simulated and measured multiplicity 2 energy spectrum with sum and coincident energy cuts included for the 559 and 563 keV peaks.



(a) Effect of all cuts on ROI

Source	Module 1 efficiency	Module 2 efficiency
Multi-Detector with Full Energy γ	$5.8 \pm 0.2\%$	$3.1 \pm 0.5\%$
Region of Interest	$91.3 \pm 1.1\%$	$91.3 \pm 1.1\%$
Dead Layer	$69.3 \pm 5.2\%$	$60.7 \pm 6.9\%$
Detector Dead Times	$97.6 \pm 1.1\%$	$98.1 \pm 0.9\%$
Enriched Source Detector Cut	$97.0 \pm <0.1\%$	$90.2 \pm <0.1\%$
Coincident Energy Cut	$88.2 \pm 0.3\%$	$87.4 \pm 0.3\%$
Sum Energy Cut	$79.6 \pm 0.3\%$	$70.9 \pm 0.3\%$
Final Efficiency	$3.10 \pm 0.26\%$	$1.34 \pm 0.26\%$

(b) Table of efficiencies

Figure A.27: Plot showing effect of cuts applied sequentially on ROI peak and table of detection efficiencies for the 559 and 563 keV peaks.

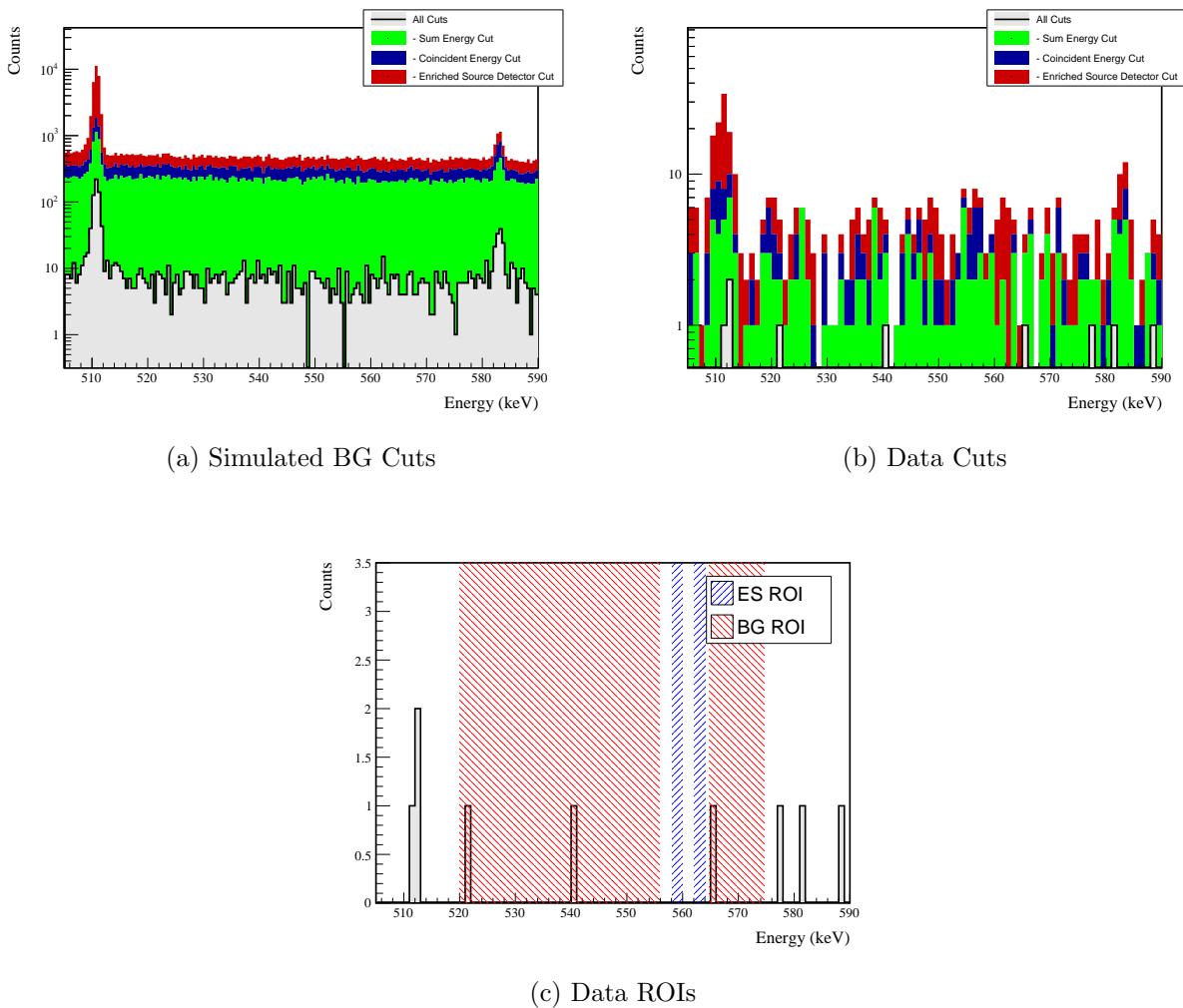


Figure A.28: Effect of all cuts applied to measured and simulated background data.

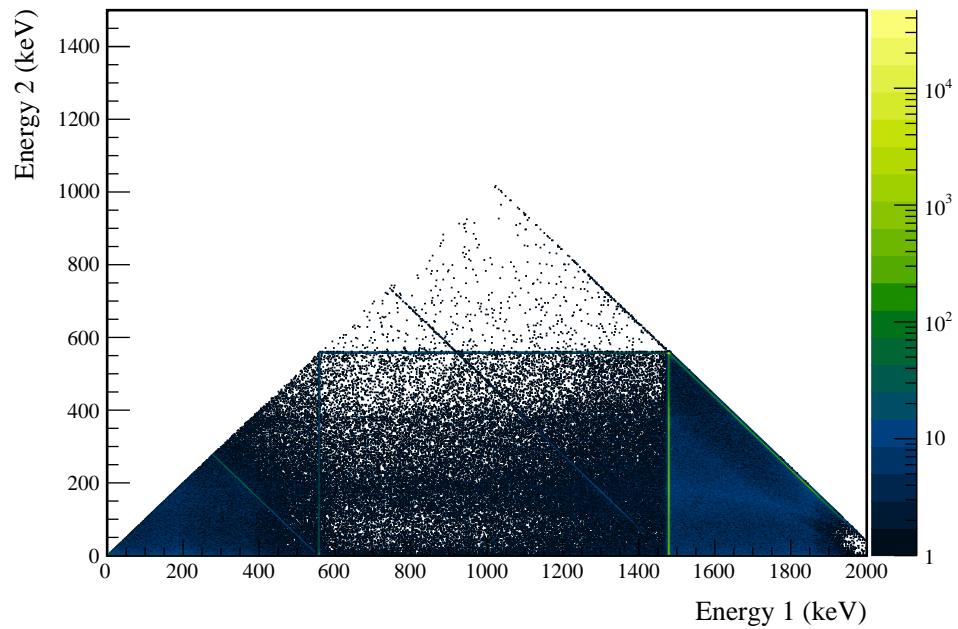
A.5 $0\nu\beta\beta$ **to** 2_1^+ 

Figure A.29: Simulated multiplicity 2 energy spectrum of the $0\nu\beta\beta$ to 2_1^+ decay mode

Table A.13: Table of energy estimation uncertainties for the 559 keV peak.

DS	E_{peak} (keV)	σ_{fit} (keV)	σ_{drift} (keV)	σ (keV)	$f_{i,fit}$	$f_{i,drift}$	τ_{fit} (keV)	$\delta_{\mu,NL}$ (keV)	$\delta_{\mu,drift}$ (keV)	$\delta_{\mu,peak}$ (keV)	δ_μ (keV)	FWHM	$\delta_{fwhm,fit}$ (keV)	$\delta_{fwhm,drift}$ (keV)	$\delta_{fwhm,peak}$ (keV)	δ_α (keV)	$E_{ROI,1}$ (keV)	$E_{ROI,2}$ (keV)	ϵ_{ROI}	$\sigma_{e_{ROI}}$		
DS1	559.101	0.460	0.063	0.464	0.230	0.515	0.001	0.104	0.002	0.012	0.005	0.105	1.152	0.001	0.039	0.011	0.040	0.035	558.032	559.959	0.915	0.011
DS2	559.101	0.461	0.055	0.464	0.249	0.515	0.002	0.067	0.004	0.012	0.005	0.068	1.158	0.001	0.107	0.011	0.108	0.093	558.035	559.957	0.917	0.023
DS3	559.101	0.470	0.066	0.474	0.224	0.505	0.001	0.026	0.024	0.012	0.005	0.038	1.174	0.001	0.073	0.011	0.074	0.063	558.039	559.977	0.921	0.016
DS4	559.101	0.455	0.077	0.461	0.108	0.445	0.002	0.076	0.010	0.012	0.005	0.078	1.111	0.001	0.106	0.011	0.107	0.096	558.161	559.966	0.929	0.024
DS5a	559.101	0.560	0.085	0.567	0.106	0.855	0.002	0.079	0.005	0.012	0.005	0.080	1.367	0.002	0.055	0.011	0.056	0.041	557.942	560.158	0.918	0.011
DS5b	559.101	0.469	0.074	0.475	0.158	0.491	0.001	0.020	0.011	0.012	0.005	0.026	1.157	0.001	0.125	0.011	0.125	0.108	558.094	559.986	0.927	0.027
DS5c	559.101	0.460	0.085	0.468	0.174	0.489	0.001	0.037	0.030	0.012	0.005	0.050	1.145	0.001	0.162	0.011	0.162	0.142	558.095	559.972	0.924	0.035
DS6a	559.101	0.456	0.044	0.458	0.191	0.463	0.001	0.069	0.025	0.012	0.005	0.075	1.123	0.000	0.041	0.011	0.042	0.038	558.106	559.951	0.923	0.010

Cut Name	Cut Description	$\langle \epsilon_{total} \rangle$	$\hat{\epsilon}_{total}$	$\langle \epsilon_{unique} \rangle$	$\hat{\epsilon}_{unique}$	Sacrifice	ΔDP
Enriched Source		M1: 23.2 %	$26.5^{+3.8}_{-3.5}\%$	0.0 %	$0.0^{+0.7}_{-0.0}\%$	2.1 %	-2%
Detector Cut	Any other detector: isEnv	M2: 42.7 %	$62.8^{+7.0}_{-7.6}\%$	0.0 %	$0.0^{+2.3}_{-0.0}\%$	4.5 %	
Multiplicity 2		M1: 15.4 %	$16.3^{+3.3}_{-2.8}\%$	0.0 %	$0.0^{+0.7}_{-0.0}\%$	0.0 %	0%
Cut	m==2	M2: 11.7 %	$16.3^{+6.4}_{-4.9}\%$	0.0 %	$0.0^{+2.3}_{-0.0}\%$	0.0 %	
Coincident		M1: 100.0 %	$100.0^{+0.0}_{-0.7}\%$	62.7 %	$59.9^{+4.0}_{-4.1}\%$	19.0 %	
Energy Cut	Any other detector: energy>1472.4 && energy<1483.3	M2: 100.0 %	$100.0^{+0.0}_{-2.3}\%$	47.8 %	$27.9^{+7.3}_{-6.3}\%$	20.5 %	808%
Combined Cuts		M1: 100.0 %	$100.0^{+0.0}_{-0.7}\%$	—	—	22.9 %	994%
		M2: 100.0 %	$100.0^{+0.0}_{-2.3}\%$	—	—	27.9 %	

Table A.14: Table of cut descriptions and efficiencies for simulated backgrounds and measured data for the 559 keV peak.

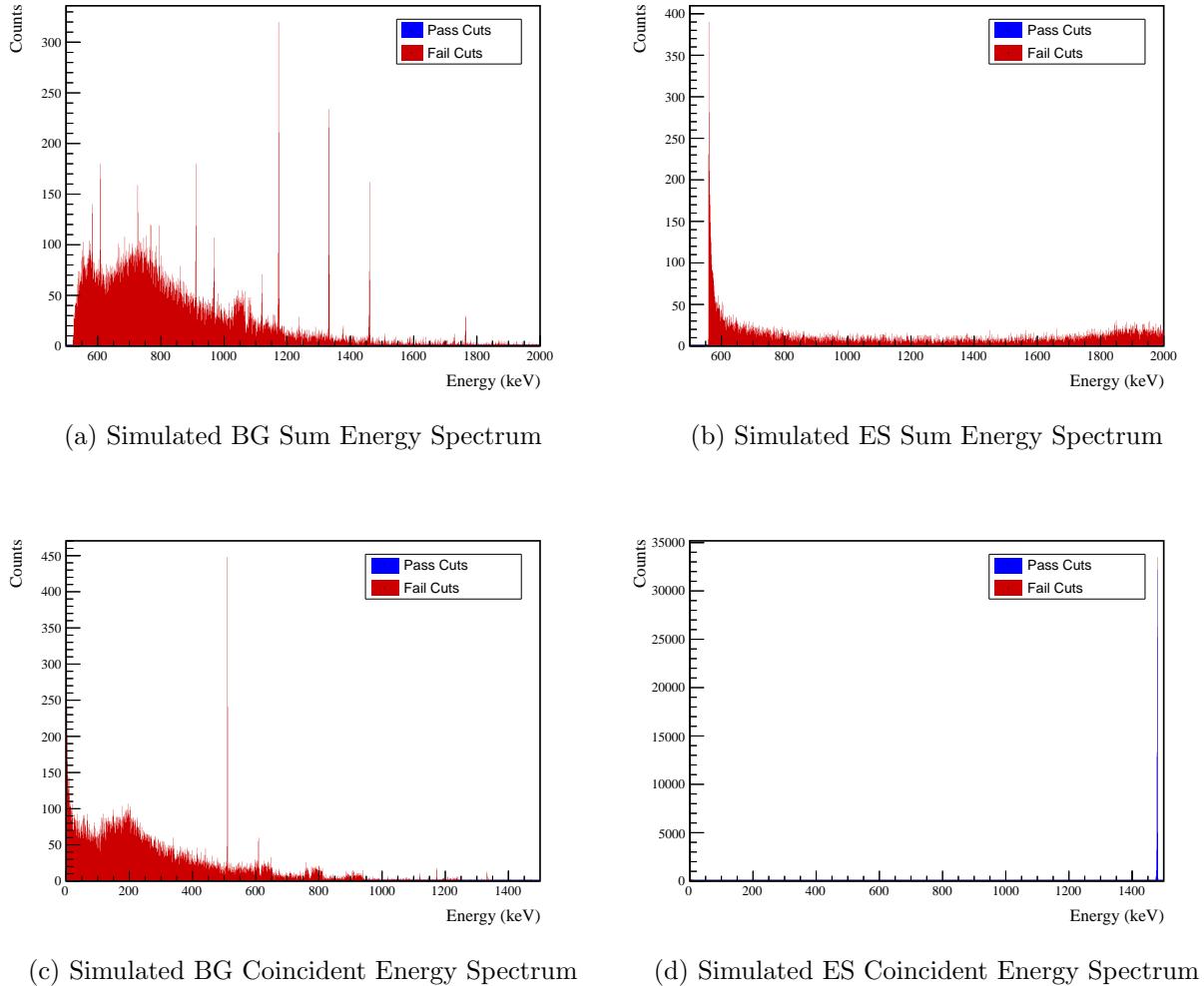


Figure A.30: Sum energy and coincident energy spectra for the 559 keV peak.

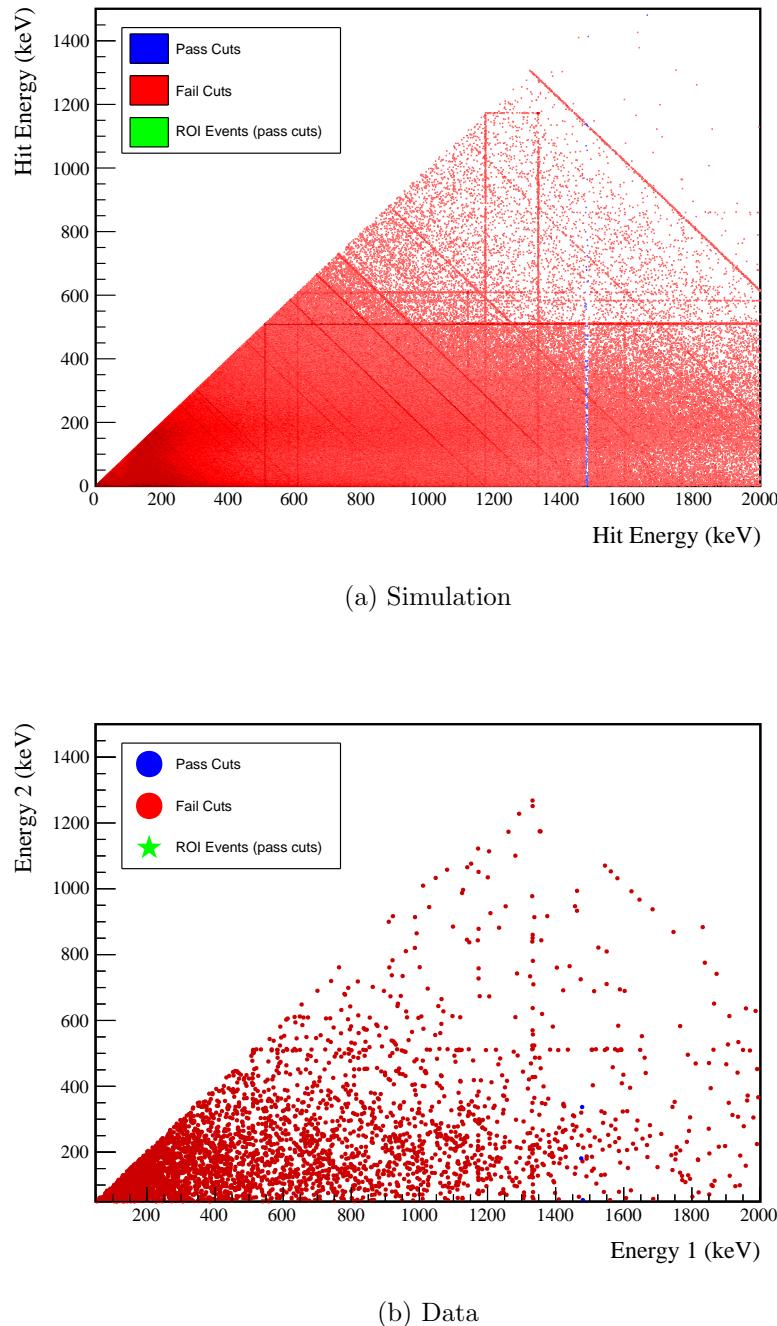
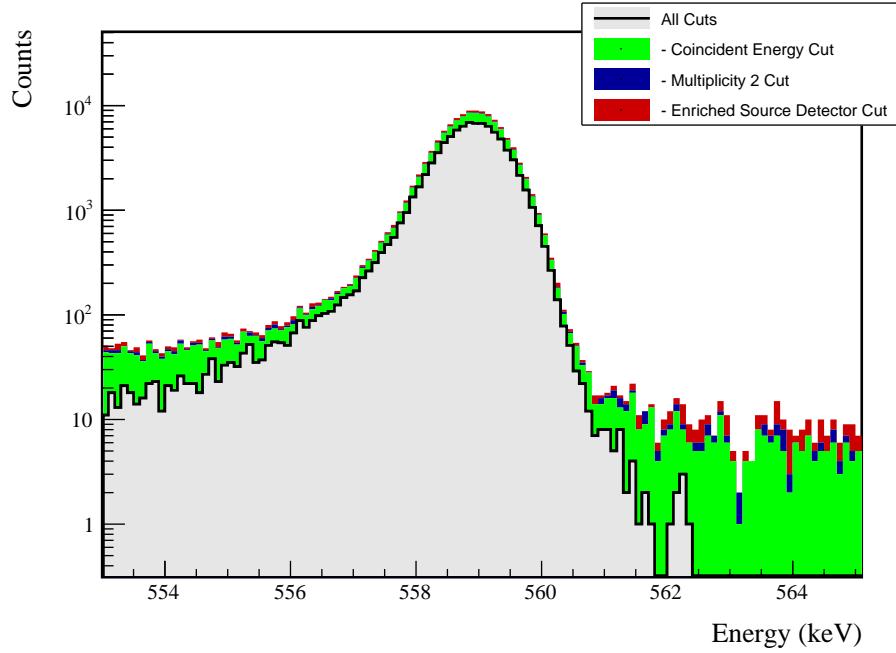


Figure A.31: Simulated and measured multiplicity 2 energy spectrum with sum and coincident energy cuts included for the 559 keV peak.



(a) Effect of all cuts on ROI

Source	Module 1 efficiency	Module 2 efficiency
Multi-Detector with Full Energy γ	$3.0 \pm 0.2\%$	$1.5 \pm 0.5\%$
Region of Interest	$92.1 \pm 1.5\%$	$92.1 \pm 1.5\%$
Dead Layer	$67.8 \pm 5.5\%$	$59.3 \pm 7.1\%$
Detector Dead Times	$97.5 \pm 1.1\%$	$98.0 \pm 0.9\%$
Enriched Source Detector Cut	$97.4 \pm <0.1\%$	$93.4 \pm <0.1\%$
Multiplicity 2 Cut	$98.6 \pm <0.1\%$	$99.2 \pm <0.1\%$
Coincident Energy Cut	$79.1 \pm 0.3\%$	$76.7 \pm 0.3\%$
Final Efficiency	$1.64 \pm 0.18\%$	$0.70 \pm 0.24\%$

(b) Table of efficiencies

Figure A.32: Plot showing effect of cuts applied sequentially on ROI peak and table of detection efficiencies for the 559 keV peak.

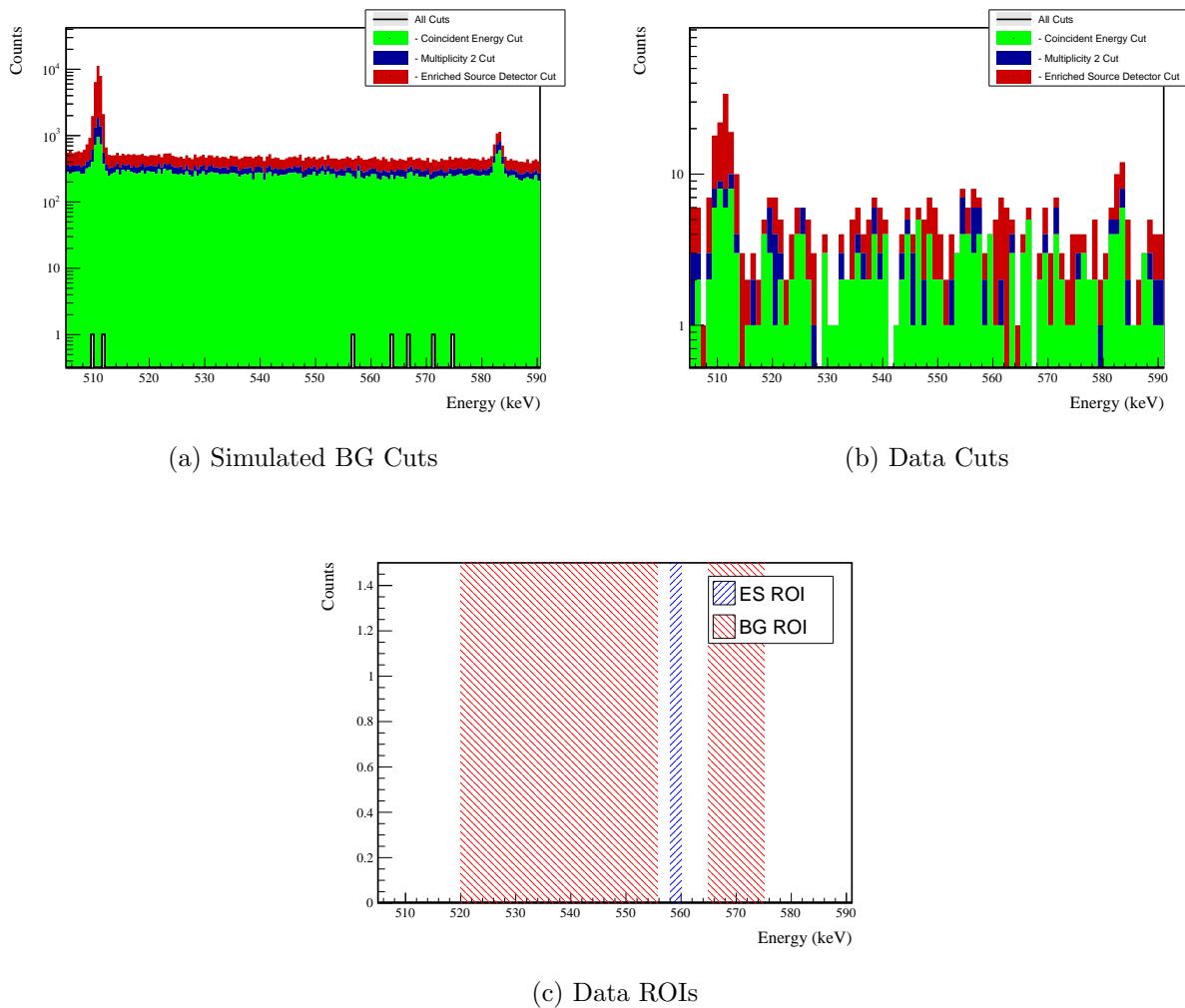


Figure A.33: Effect of all cuts applied to measured and simulated background data.

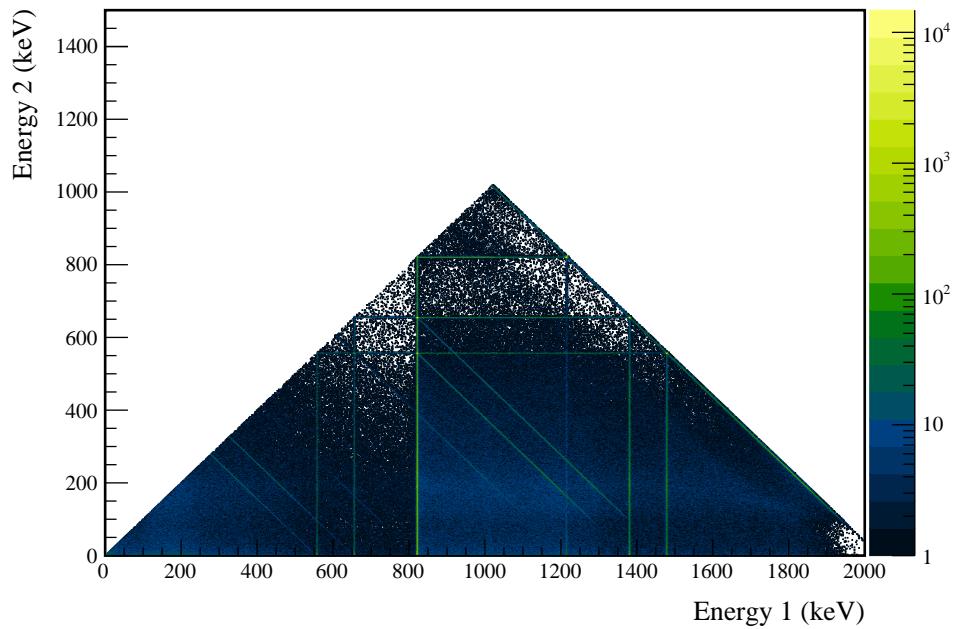
A.6 $0\nu\beta\beta$ to 2_2^+ 

Figure A.34: Simulated multiplicity 2 energy spectrum of the $0\nu\beta\beta$ to 2_2^+ decay mode

A.6.1 559 keV peak

Table A.15: Table of energy estimation uncertainties for the 559 keV peak.

DS	E_{peak} (keV)	σ_{fit} (keV)	σ_{drift} (keV)	σ (keV)	$f_{i,fit}$	$f_{i,drift}$	τ_{fit} (keV)	$\delta_{\mu,NL}$ (keV)	$\delta_{\mu,drift}$ (keV)	$\delta_{\mu,peak}$ (keV)	δ_μ (keV)	FWHM	$\delta_{fwhm,fit}$ (keV)	$\delta_{fwhm,drift}$ (keV)	$\delta_{fwhm,peak}$ (keV)	δ_α (keV)	$E_{ROI,1}$ (keV)	$E_{ROI,2}$ (keV)	ϵ_{ROI}	$\sigma_{e_{ROI}}$		
DS1	559.101	0.460	0.063	0.464	0.230	0.515	0.001	0.104	0.002	0.012	0.005	0.105	1.152	0.001	0.039	0.011	0.040	0.035	558.084	559.935	0.907	0.012
DS2	559.101	0.461	0.055	0.464	0.249	0.515	0.002	0.067	0.004	0.012	0.005	0.068	1.158	0.001	0.107	0.011	0.108	0.093	558.067	559.933	0.909	0.025
DS3	559.101	0.470	0.066	0.474	0.224	0.505	0.001	0.026	0.024	0.012	0.005	0.038	1.174	0.001	0.073	0.011	0.074	0.063	558.072	559.952	0.913	0.017
DS4	559.101	0.455	0.077	0.461	0.108	0.445	0.002	0.076	0.010	0.012	0.005	0.078	1.111	0.001	0.106	0.011	0.107	0.096	558.187	559.942	0.922	0.026
DS5a	559.101	0.560	0.085	0.567	0.106	0.855	0.002	0.079	0.005	0.012	0.005	0.080	1.367	0.002	0.055	0.011	0.056	0.041	557.976	560.128	0.910	0.012
DS5b	559.101	0.469	0.074	0.475	0.158	0.491	0.001	0.020	0.011	0.012	0.005	0.026	1.157	0.001	0.125	0.011	0.125	0.108	558.123	559.962	0.919	0.029
DS5c	559.101	0.460	0.085	0.468	0.174	0.489	0.001	0.037	0.030	0.012	0.005	0.050	1.145	0.001	0.162	0.011	0.162	0.142	558.124	559.948	0.917	0.037
DS6a	559.101	0.456	0.044	0.458	0.191	0.463	0.001	0.069	0.025	0.012	0.005	0.075	1.123	0.000	0.041	0.011	0.042	0.038	558.135	559.927	0.915	0.011

A.6. $0\nu\beta\beta$ TO χ_2^{\pm}

Cut Name	Cut Description	$\langle \epsilon_{total} \rangle$	$\hat{\epsilon}_{total}$	$\langle \epsilon_{unique} \rangle$	$\hat{\epsilon}_{unique}$	Sacrifice	ΔDP^{\pm}
Enriched Source	Any other detector: isErr	M1: 23.2 % M2: 42.7 %	26.5 ^{+3.8} _{-3.5} % 62.8 ^{+7.0} _{-7.6} %	0.5 % 0.9 %	0.7 ^{+1.1} _{-0.4} % 7.0 ^{+4.9} _{-3.0} %	1.4 % 3.3 %	10%
Detector Cut	No other detector: (((energy<65.6) (energy>504.4 && energy<516.4) (energy>591.4 && energy<637.8) (energy>801.8 && energy<868.6) (energy>1074.6 && energy<1078.4) (energy>1170.6 && energy<1175.) (energy>1205. && energy<1208.) (energy>1331. && energy<1334.) (energy>1482.6) && isErr) ((energy<44.8) (energy>507.8 && energy<524.6) (energy>1375.4) && !isErr))	M1: 25.2 % M2: 24.4 %	29.9 ^{+3.9} _{-3.6} % 25.6 ^{+7.2} _{-6.0} %	0.6 % 0.4 %	2.0 ^{+1.5} _{-0.9} % 7.0 ^{+4.9} _{-3.0} %	3.1 % 1.8 %	5%
Coincident	Not: (sumE<1214.) (sumE>1216.2 && sumE<1377.6) (sumE>333.6 && sumE<495.8) (sumE>1761.8 && sumE<1765.8) (sumE>2041.6)	M1: 97.1 % M2: 97.6 %	95.9 ^{+1.3} _{-2.0} % 86.0 ^{+4.5} _{-6.1} %	54.4 % 40.3 %	51.7 \pm 4.1 % 25.6 ^{+7.2} _{-6.0} %	18.3 % 20.4 %	192%
Energy Cut	M1: 98.3 % M2: 99.0 %	98.6 ^{+0.7} _{-1.3} % 100.0 ^{+0.0} _{-2.3} %	— —	— —	— —	31.5 % 40.6 %	226%
Sum Energy Cut							
Combined Cuts							

Table A.16: Table of cut descriptions and efficiencies for simulated backgrounds and measured data for the 559 keV peak.

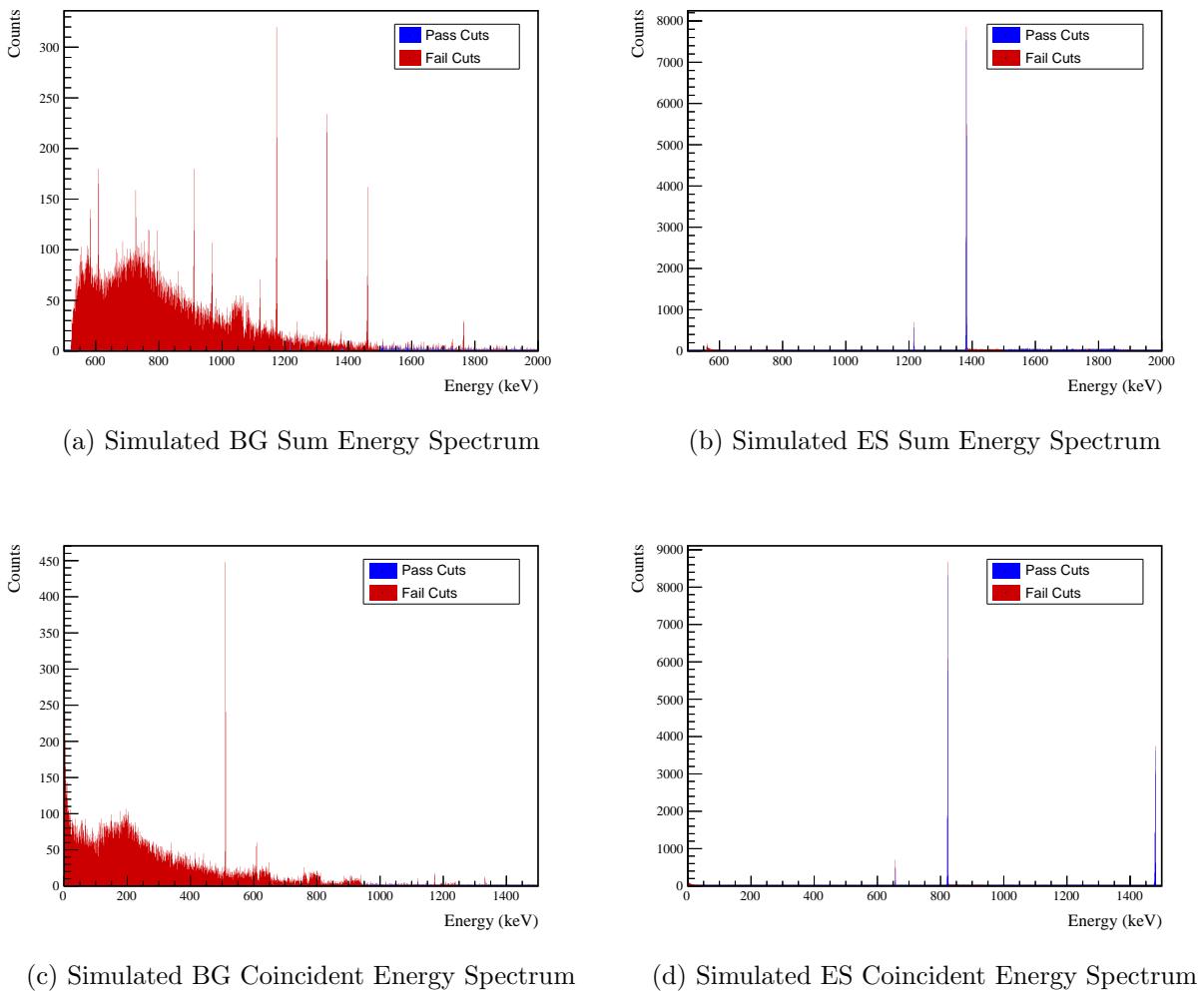


Figure A.35: Sum energy and coincident energy spectra for the 559 keV peak.

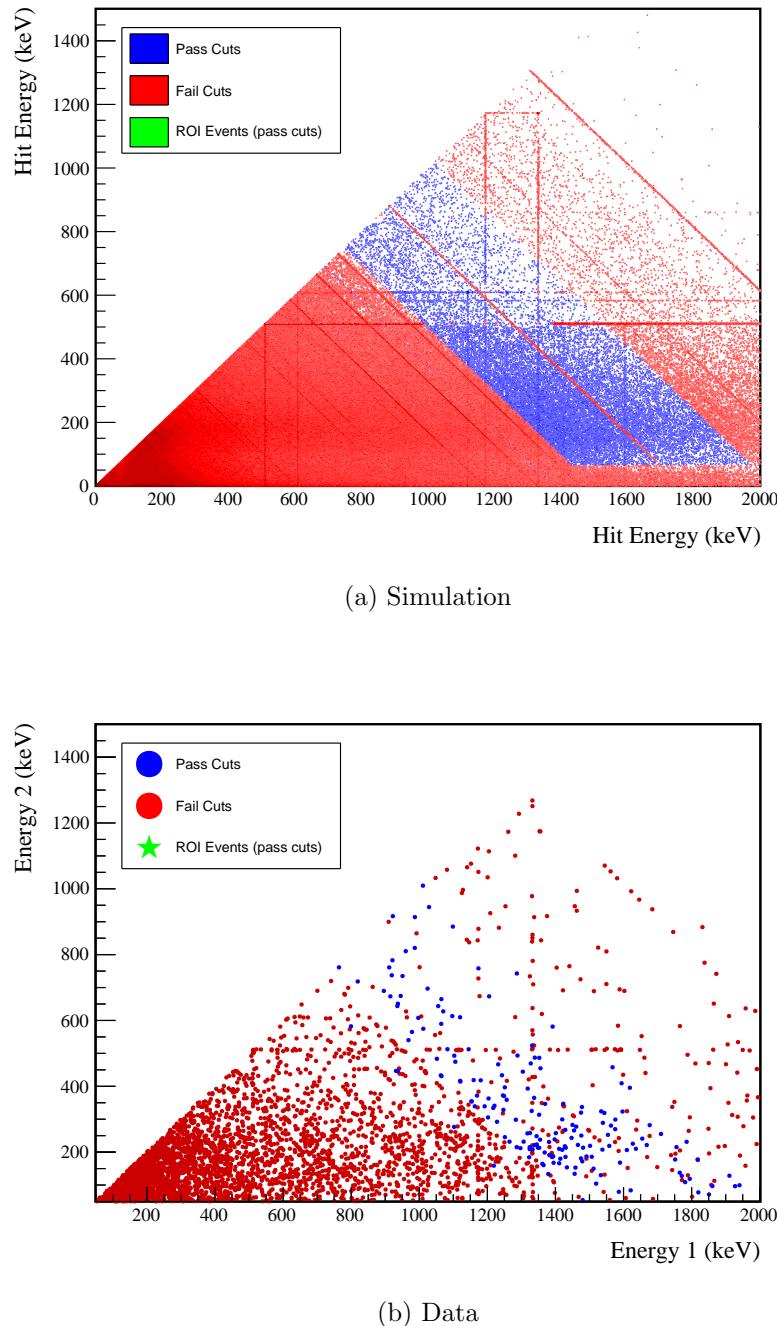
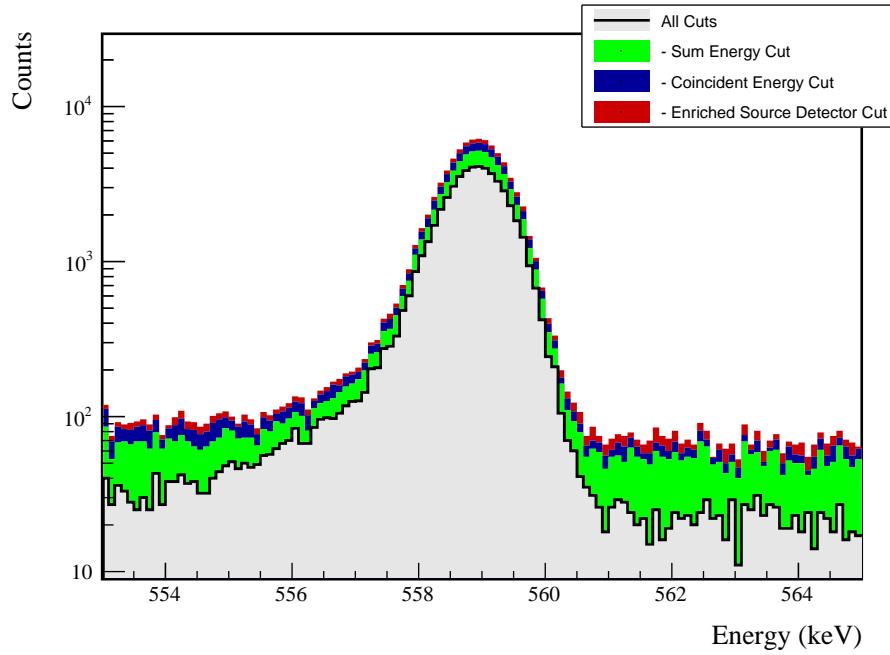


Figure A.36: Simulated and measured multiplicity 2 energy spectrum with sum and coincident energy cuts included for the 559 keV peak.



(a) Effect of all cuts on ROI

Source	Module 1 efficiency	Module 2 efficiency
Multi-Detector with Full Energy γ	$1.9 \pm 0.2\%$	$1.0 \pm 0.5\%$
Region of Interest	$91.3 \pm 1.6\%$	$91.3 \pm 1.6\%$
Dead Layer	$68.5 \pm 5.4\%$	$60.3 \pm 7.0\%$
Detector Dead Times	$97.6 \pm 1.1\%$	$98.1 \pm 0.9\%$
Enriched Source Detector Cut	$96.8 \pm <0.1\%$	$89.6 \pm <0.1\%$
Coincident Energy Cut	$89.5 \pm 0.3\%$	$88.6 \pm 0.3\%$
Sum Energy Cut	$73.2 \pm 0.3\%$	$65.3 \pm 0.3\%$
Final Efficiency	$0.98 \pm 0.13\%$	$0.42 \pm 0.20\%$

(b) Table of efficiencies

Figure A.37: Plot showing effect of cuts applied sequentially on ROI peak and table of detection efficiencies for the 559 keV peak.

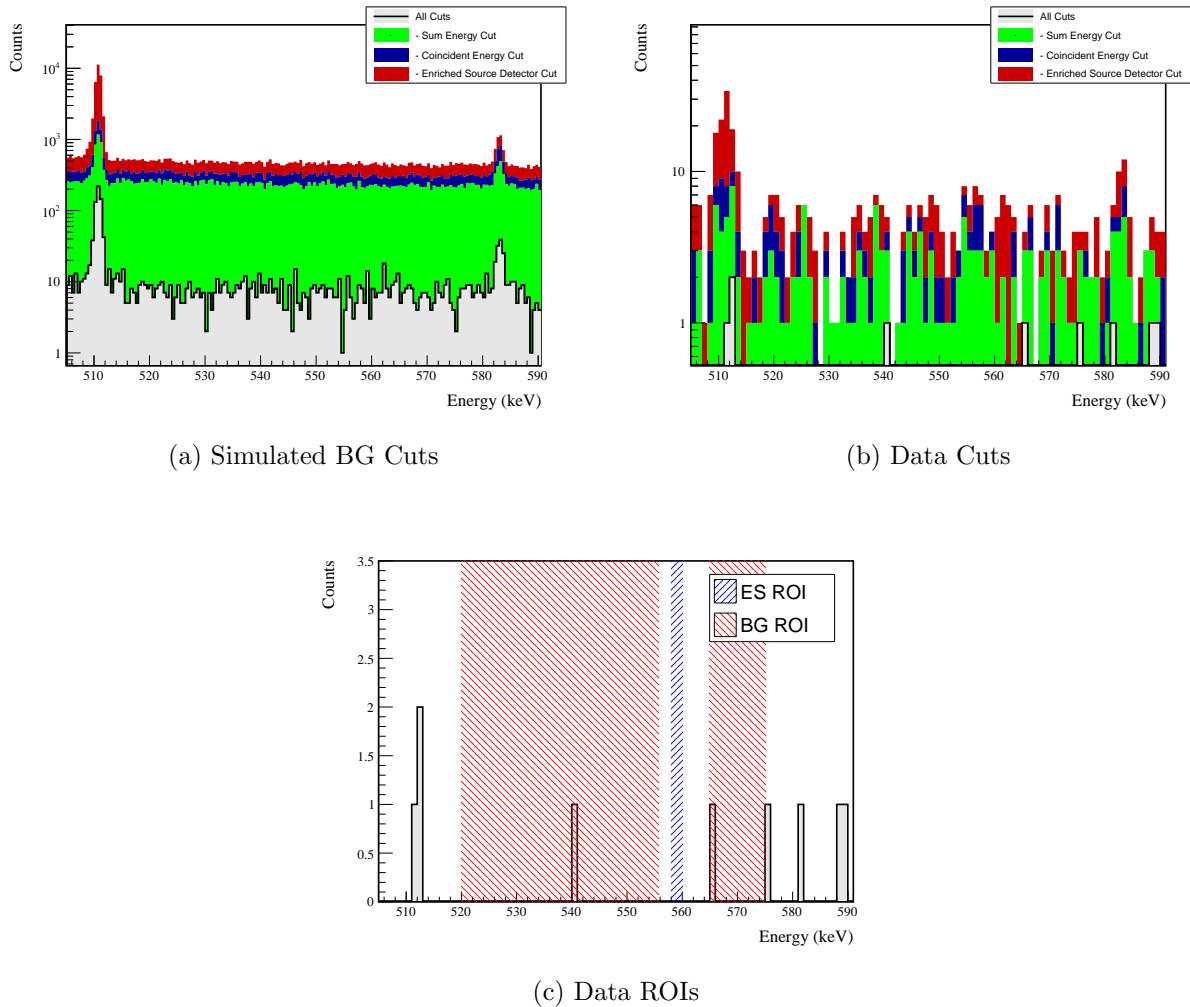
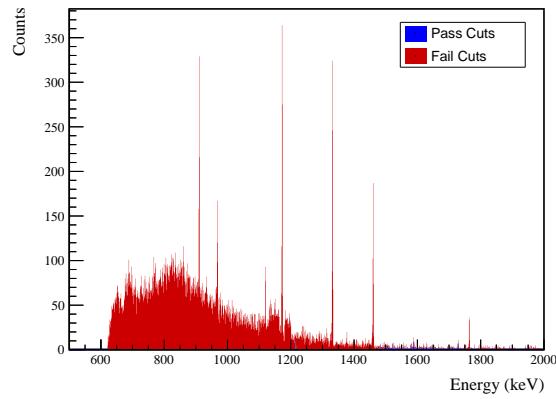
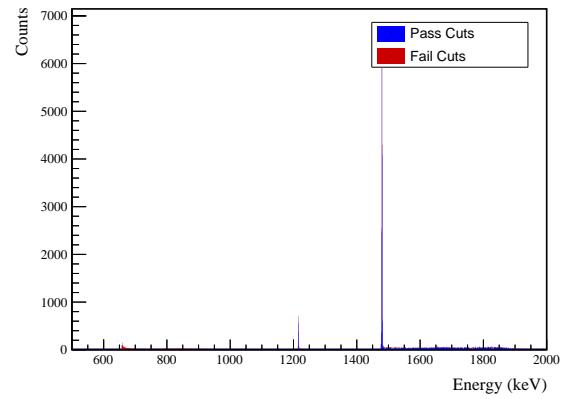


Figure A.38: Effect of all cuts applied to measured and simulated background data.

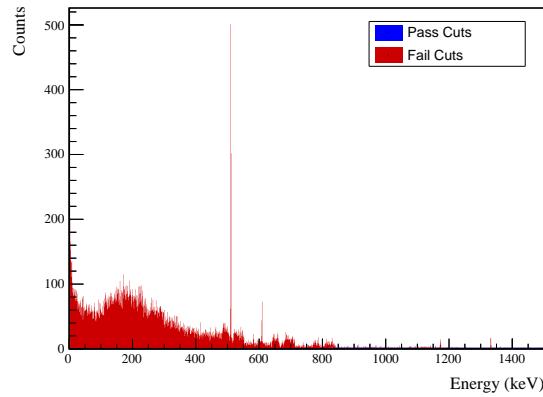
A.6.2 657 keV peak



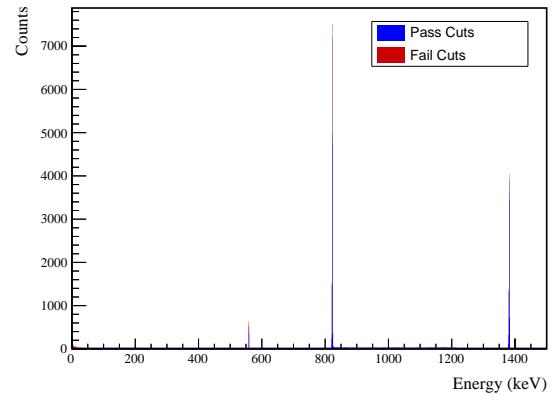
(a) Simulated BG Sum Energy Spectrum



(b) Simulated ES Sum Energy Spectrum



(c) Simulated BG Coincident Energy Spectrum



(d) Simulated ES Coincident Energy Spectrum

Figure A.39: Sum energy and coincident energy spectra for the 657 keV peak.

Table A.17: Table of energy estimation uncertainties for the 657 keV peak.

DS	E_{peak} (keV)	σ_{fit} (keV)	σ_{drift} (keV)	σ (keV)	$f_{i,fit}$	$f_{i,drift}$	τ_{fit} (keV)	$\delta_{\mu,NL}$ (keV)	$\delta_{\mu,drift}$ (keV)	$\delta_{\mu,peak}$ (keV)	δ_μ (keV)	FWHM	$\delta_{fwhm,fit}$ (keV)	$\delta_{fwhm,drift}$ (keV)	$\delta_{fwhm,peak}$ (keV)	$E_{ROI,1}$ (keV)	$E_{ROI,2}$ (keV)	ϵ_{ROI}	$\sigma_{e_{ROI}}$			
DS1	657.041	0.500	0.074	0.505	0.230	0.579	0.002	0.104	0.003	0.012	0.005	0.105	1.256	0.001	0.039	0.011	0.040	0.032	656.019	657.882	0.883	0.013
DS2	657.041	0.502	0.064	0.506	0.249	0.580	0.002	0.067	0.005	0.012	0.005	0.068	1.263	0.001	0.107	0.011	0.108	0.085	656.002	657.881	0.885	0.026
DS3	657.041	0.510	0.078	0.516	0.224	0.568	0.002	0.026	0.028	0.012	0.005	0.040	1.278	0.001	0.073	0.011	0.074	0.058	656.007	657.899	0.889	0.018
DS4	657.041	0.493	0.090	0.501	0.108	0.490	0.002	0.076	0.012	0.012	0.005	0.078	1.207	0.001	0.106	0.011	0.107	0.088	656.120	657.890	0.899	0.028
DS5a	657.041	0.606	0.100	0.614	0.106	0.924	0.002	0.079	0.006	0.012	0.005	0.080	1.481	0.002	0.055	0.011	0.056	0.038	655.915	658.075	0.887	0.012
DS5b	657.041	0.509	0.087	0.517	0.158	0.562	0.001	0.020	0.013	0.012	0.005	0.027	1.259	0.001	0.125	0.011	0.125	0.100	656.056	657.909	0.895	0.031
DS5c	657.041	0.500	0.100	0.510	0.174	0.555	0.002	0.037	0.035	0.012	0.005	0.053	1.247	0.001	0.162	0.011	0.162	0.130	656.057	657.896	0.893	0.040
DS6a	657.041	0.495	0.051	0.497	0.191	0.524	0.001	0.069	0.030	0.012	0.005	0.076	1.221	0.001	0.041	0.011	0.042	0.035	656.070	657.874	0.891	0.012

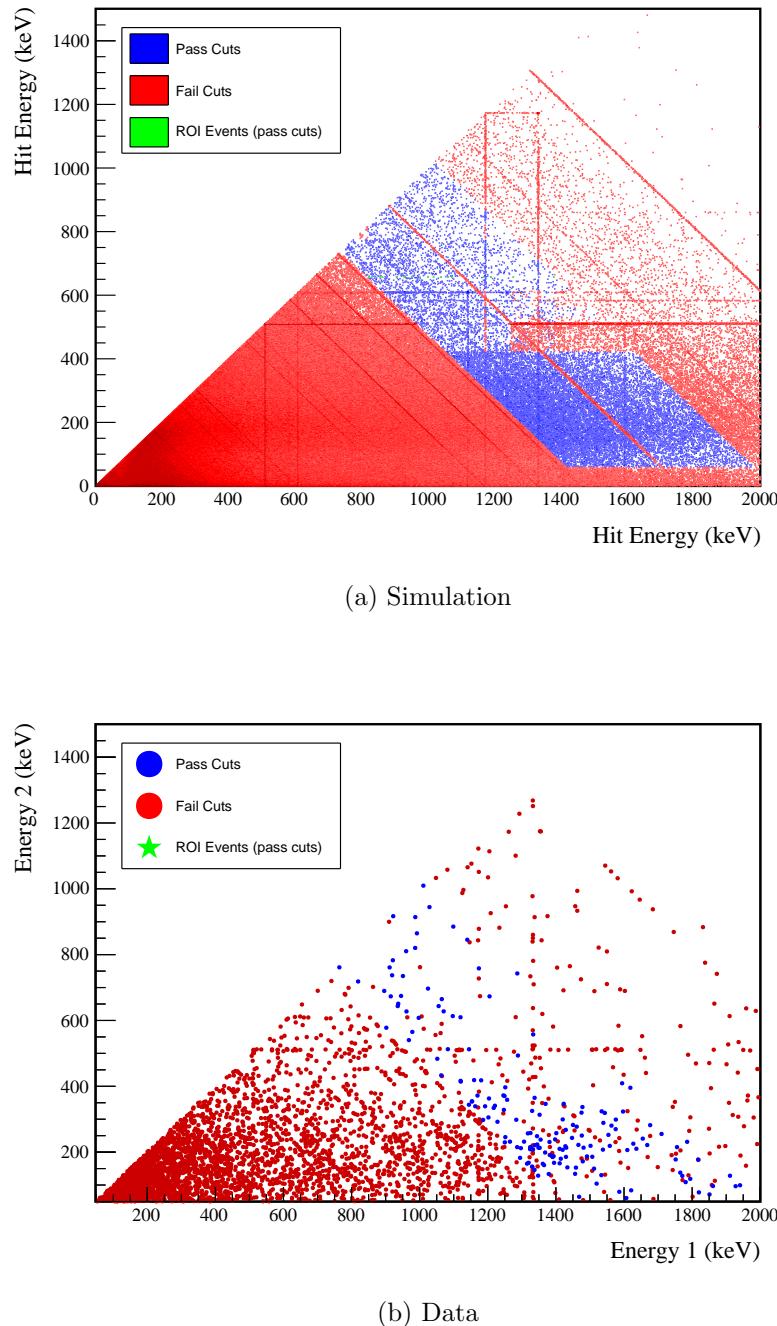
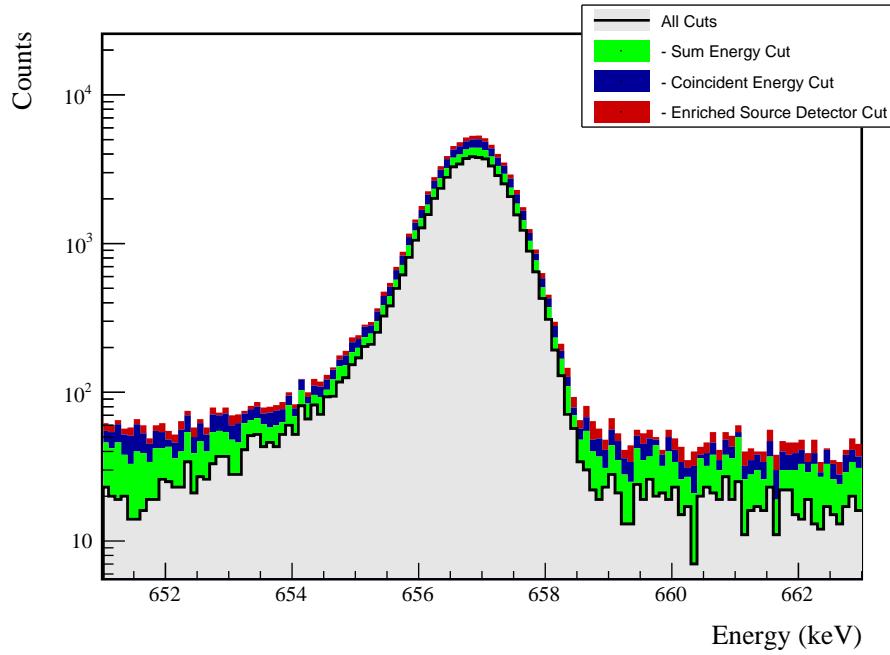


Figure A.40: Simulated and measured multiplicity 2 energy spectrum with sum and coincident energy cuts included for the 657 keV peak.



(a) Effect of all cuts on ROI

Source	Module 1 efficiency	Module 2 efficiency
Multi-Detector with Full Energy γ	$1.8 \pm 0.2\%$	$1.0 \pm 0.5\%$
Region of Interest	$89.0 \pm 1.7\%$	$89.0 \pm 1.7\%$
Dead Layer	$69.6 \pm 5.2\%$	$61.1 \pm 6.8\%$
Detector Dead Times	$97.6 \pm 1.1\%$	$98.1 \pm 0.9\%$
Enriched Source Detector Cut	$96.8 \pm <0.1\%$	$89.4 \pm <0.1\%$
Coincident Energy Cut	$88.4 \pm 0.3\%$	$87.1 \pm 0.3\%$
Sum Energy Cut	$80.9 \pm 0.3\%$	$72.9 \pm 0.3\%$
Final Efficiency	$0.95 \pm 0.13\%$	$0.41 \pm 0.21\%$

(b) Table of efficiencies

Figure A.41: Plot showing effect of cuts applied sequentially on ROI peak and table of detection efficiencies for the 657 keV peak.

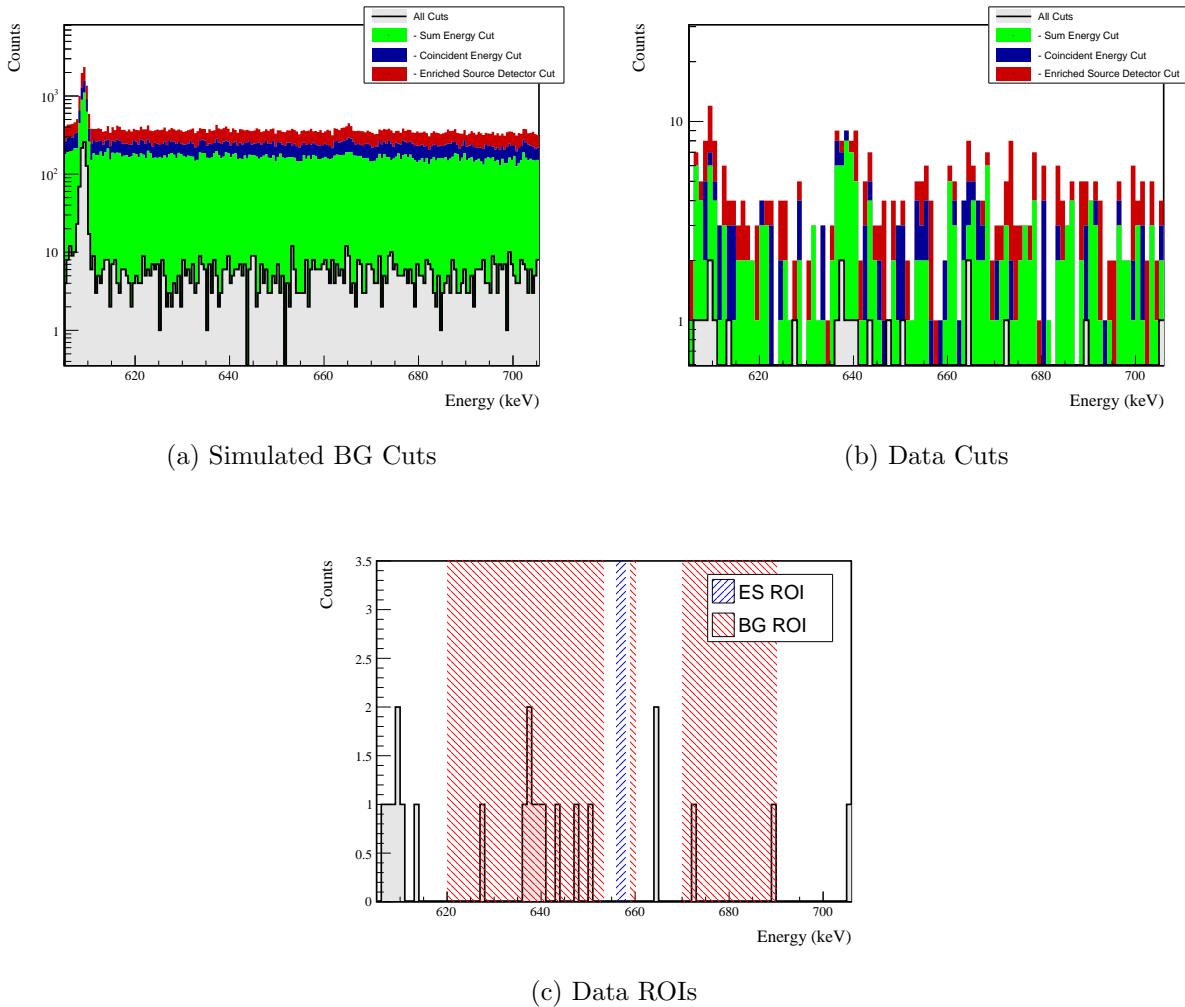
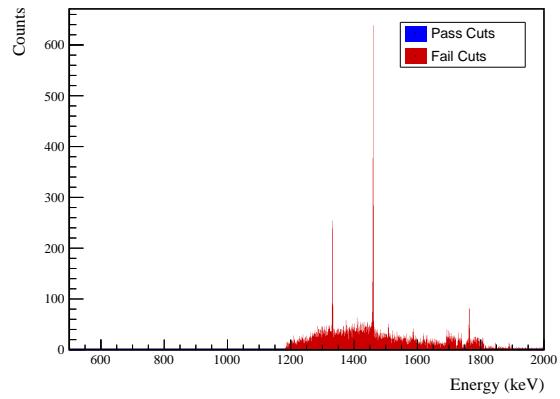


Figure A.42: Effect of all cuts applied to measured and simulated background data.

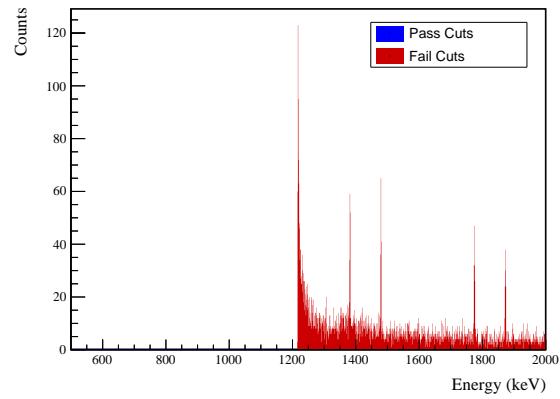
Cut Name	Cut Description	$\langle \epsilon_{total} \rangle$	$\hat{\epsilon}_{total}$	$\langle \epsilon_{unique} \rangle$	$\hat{\epsilon}_{unique}$	Sacrifice	ΔDP
Enriched Source	Any other detector: isEnv	M1: 23.9 %	25.2 _{-3.5} ^{+3.9} %	0.6 %	3.7 _{-1.3} ^{+2.0} %	1.4 %	12%
Detector Cut	No other detector: (((energy<59.) (energy>422.6 && energy<529.4) (energy>562.4 && energy<616.6) (energy>776.8 && energy<818.8) (energy>1169.6 && energy<1175.) (energy>1308. && energy<1333.2) (energy>1384.8) && isEnv) ((energy<52.2) (energy>491.6 && energy<554.8) (energy>1248.) && isEnv))	M2: 43.7 %	60.4 _{-7.2} ^{+6.8} %	1.2 %	4.2 _{-2.1} ^{+3.9} %	3.7 %	
Coincident		M1: 30.4 %	25.2 _{-3.5} ^{+3.9} %	0.8 %	2.2 _{-1.0} ^{+1.7} %	4.9 %	
Energy Cut		M2: 29.1 %	16.7 _{-4.7} ^{+6.0} %	0.6 %	2.1 _{-1.3} ^{+3.2} %	3.2 %	7%
Sum Energy Cut	Not: (sumE<1214.8) (sumE>1216.8 && sumE<1475.2) (sumE>1757.6 && sumE<1766.) (sumE>2042.6)	M1: 96.9 %	88.9 _{-3.0} ^{+2.4} %	49.8 %	48.9 \pm 4.3 %	11.6 %	207%
Combined Cuts		M2: 97.0 %	91.7 _{-4.9} ^{+3.2} %	36.9 %	27.1 _{-5.9} ^{+6.8} %	13.6 %	
		M1: 98.5 %	94.8 _{-2.3} ^{+1.6} %	—	—	25.7 %	
		M2: 99.0 %	97.9 _{-3.2} ^{+1.3} %	—	—	34.9 %	255%

Table A.18: Table of cut descriptions and efficiencies for simulated backgrounds and measured data for the 657 keV peak.

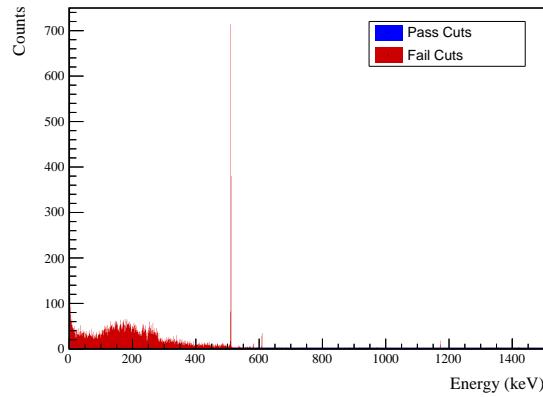
A.6.3 1216 keV peak



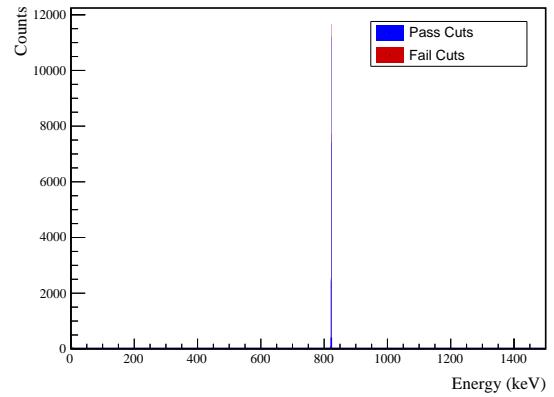
(a) Simulated BG Sum Energy Spectrum



(b) Simulated ES Sum Energy Spectrum



(c) Simulated BG Coincident Energy Spectrum



(d) Simulated ES Coincident Energy Spectrum

Figure A.43: Sum energy and coincident energy spectra for the 1216 keV peak.

Table A.19: Table of energy estimation uncertainties for the 1216 keV peak.

DS	E_{peak} (keV)	$\sigma_{T_{fit}}$ (keV)	$\sigma_{\mu, drift}$ (keV)	σ (keV)	$f_{t, fit}$ (keV)	T_{fit} (keV)	$\delta_{t, fit}$ (keV)	$\delta_{\mu, NL}$ (keV)	$\delta_{\mu, drift}$ (keV)	$\delta_{t, peak}$ (keV)	δ_μ (keV)	FWHM (keV)	$\delta_{f_{whm, drift}}$ (keV)	$\delta_{f_{whm, peak}}$ (keV)	$\delta_{f_{whm, drift}}$ (keV)	$\delta_{f_{whm, peak}}$ (keV)	δ_{FWHM} (keV)	δ_α	$E_{ROI, 1}$ (keV)	$E_{ROI, 2}$ (keV)	ϵ_{ROI}	$\sigma_{\epsilon_{ROI}}$
DS1	1216.104	0.705	0.137	0.718	0.230	0.945	0.003	0.104	0.005	0.012	0.020	0.107	1.787	0.001	0.039	0.011	0.040	0.023	1214.426	1217.449	0.914	0.006
DS2	1216.104	0.710	0.119	0.720	0.249	0.951	0.003	0.067	0.008	0.012	0.020	0.072	1.803	0.001	0.107	0.011	0.108	0.060	1214.387	1217.449	0.914	0.014
DS3	1216.104	0.715	0.144	0.729	0.224	0.925	0.003	0.026	0.051	0.012	0.020	0.062	1.812	0.001	0.073	0.011	0.074	0.041	1214.416	1217.470	0.917	0.010
DS4	1216.104	0.697	0.167	0.717	0.108	0.746	0.003	0.076	0.022	0.012	0.020	0.083	1.726	0.001	0.106	0.011	0.107	0.062	1214.621	1217.461	0.932	0.015
DS5a	1216.104	0.838	0.185	0.859	0.106	1.316	0.004	0.079	0.012	0.012	0.020	0.083	2.070	0.002	0.055	0.011	0.056	0.027	1214.323	1217.722	0.921	0.007
DS5b	1216.104	0.716	0.161	0.734	0.158	0.963	0.002	0.020	0.024	0.012	0.020	0.039	1.791	0.001	0.125	0.011	0.125	0.070	1214.506	1217.487	0.922	0.017
DS5c	1216.104	0.703	0.185	0.727	0.174	0.932	0.003	0.037	0.066	0.012	0.020	0.079	1.783	0.001	0.162	0.011	0.162	0.091	1214.497	1217.474	0.921	0.022
DS6a	1216.104	0.693	0.095	0.700	0.191	0.873	0.002	0.069	0.055	0.012	0.020	0.092	1.723	0.001	0.041	0.011	0.042	0.025	1214.535	1217.422	0.920	0.006

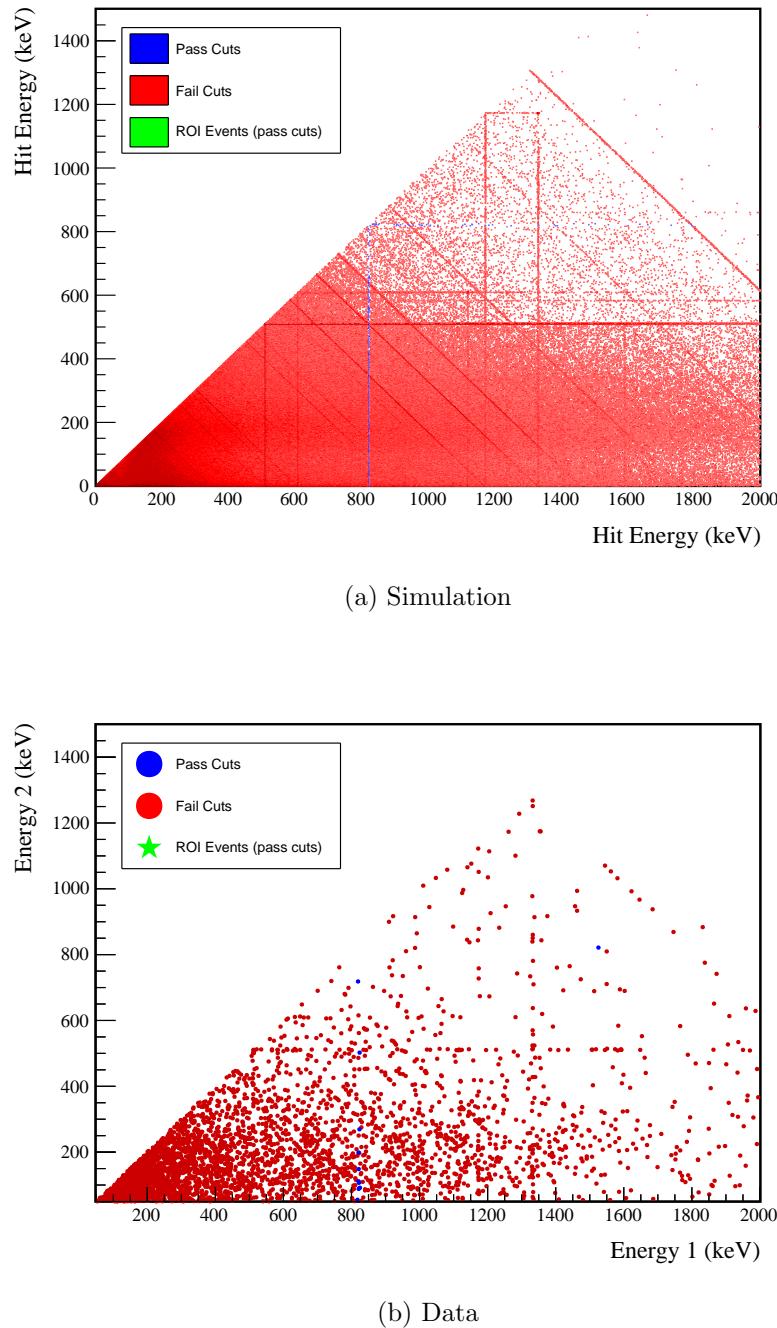
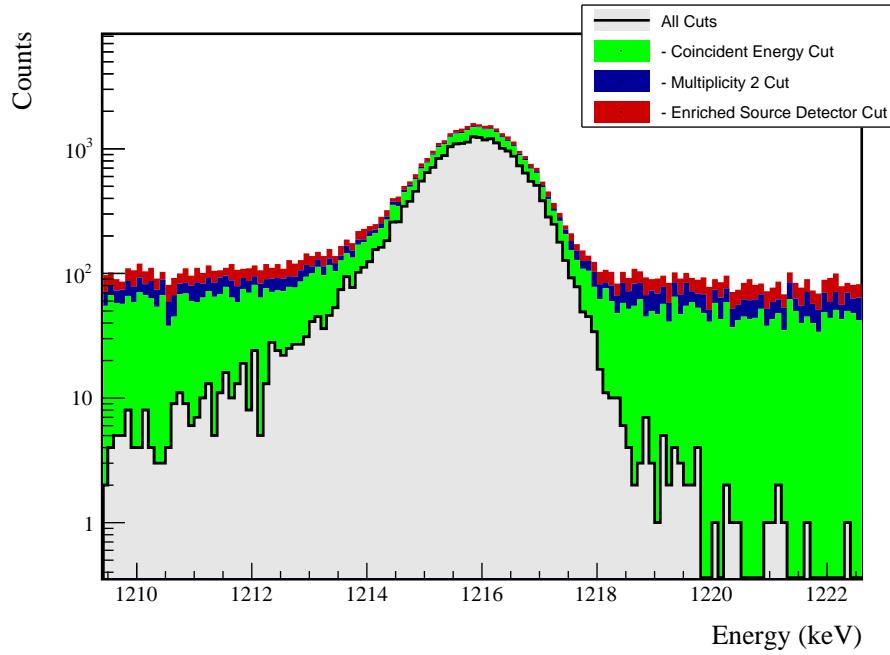


Figure A.44: Simulated and measured multiplicity 2 energy spectrum with sum and coincident energy cuts included for the 1216 keV peak.



(a) Effect of all cuts on ROI

Source	Module 1 efficiency	Module 2 efficiency
Multi-Detector with Full Energy γ	$0.8 \pm 0.2\%$	$0.4 \pm 0.5\%$
Region of Interest	$92.0 \pm 0.9\%$	$92.0 \pm 0.9\%$
Dead Layer	$68.8 \pm 5.3\%$	$61.2 \pm 6.8\%$
Detector Dead Times	$97.5 \pm 1.1\%$	$98.0 \pm 0.9\%$
Enriched Source Detector Cut	$96.1 \pm <0.1\%$	$90.8 \pm <0.1\%$
Multiplicity 2 Cut	$97.3 \pm <0.1\%$	$98.2 \pm <0.1\%$
Coincident Energy Cut	$76.9 \pm 0.3\%$	$75.7 \pm 0.3\%$
Final Efficiency	$0.44 \pm 0.12\%$	$0.19 \pm 0.22\%$

(b) Table of efficiencies

Figure A.45: Plot showing effect of cuts applied sequentially on ROI peak and table of detection efficiencies for the 1216 keV peak.

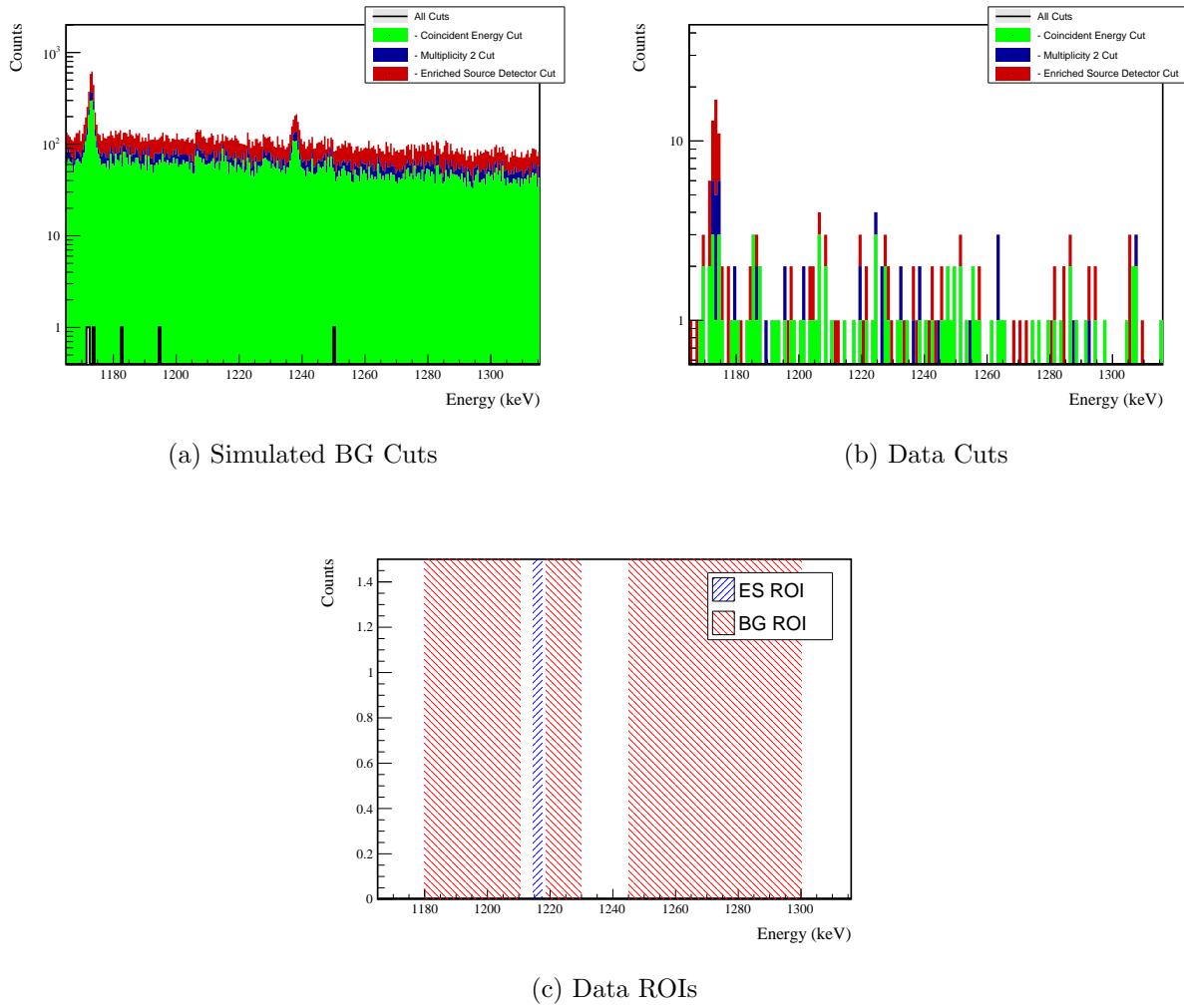


Figure A.46: Effect of all cuts applied to measured and simulated background data.

A.6. $0\nu\beta\beta$ TO 2_2^+

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Cut Name	Cut Description	$\langle \epsilon_{total} \rangle$	$\hat{\epsilon}_{total}$	$\langle \epsilon_{unique} \rangle$	$\hat{\epsilon}_{unique}$	Sacrifice	ΔDP
Enriched Source		M1: 26.9 %	$16.9^{+4.5}_{-3.7}\%$	0.0 %	$0.0^{+1.2}_{-0.0}\%$	2.0 %	-2%
Detector Cut	Any other detector: isEur	M2: 43.9 %	$61.9^{+9.8}_{-10.9}\%$	0.0 %	$0.0^{+4.5}_{-0.0}\%$	4.3 %	
Multiplicity 2		M1: 15.3 %	$16.9^{+4.5}_{-3.7}\%$	0.0 %	$0.0^{+1.2}_{-0.0}\%$	0.0 %	
Cut	m==2	M2: 11.9 %	$9.5^{+8.4}_{-4.7}\%$	0.0 %	$0.0^{+4.5}_{-0.0}\%$	0.0 %	0%
Coincident		M1: 100.0 %	$100.0^{+0.0}_{-1.2}\%$	59.6 %	$68.7^{+4.8}_{-5.3}\%$	18.7 %	555%
Energy Cut	Any other detector: energy>817.7 && energy<825.4	M2: 100.0 %	$100.0^{+0.0}_{-4.5}\%$	46.6 %	$33.3^{+10.8}_{-9.3}\%$	17.9 %	
Combined Cuts		M1: 100.0 %	$100.0^{+0.0}_{-1.2}\%$	—	—	25.2 %	669%
		M2: 100.0 %	$100.0^{+0.0}_{-4.5}\%$	—	—	28.7 %	

Table A.20: Table of cut descriptions and efficiencies for simulated backgrounds and measured data for the 1216 keV peak.