Three-step gamma cascades following the neutron capture in ^{161}Dy

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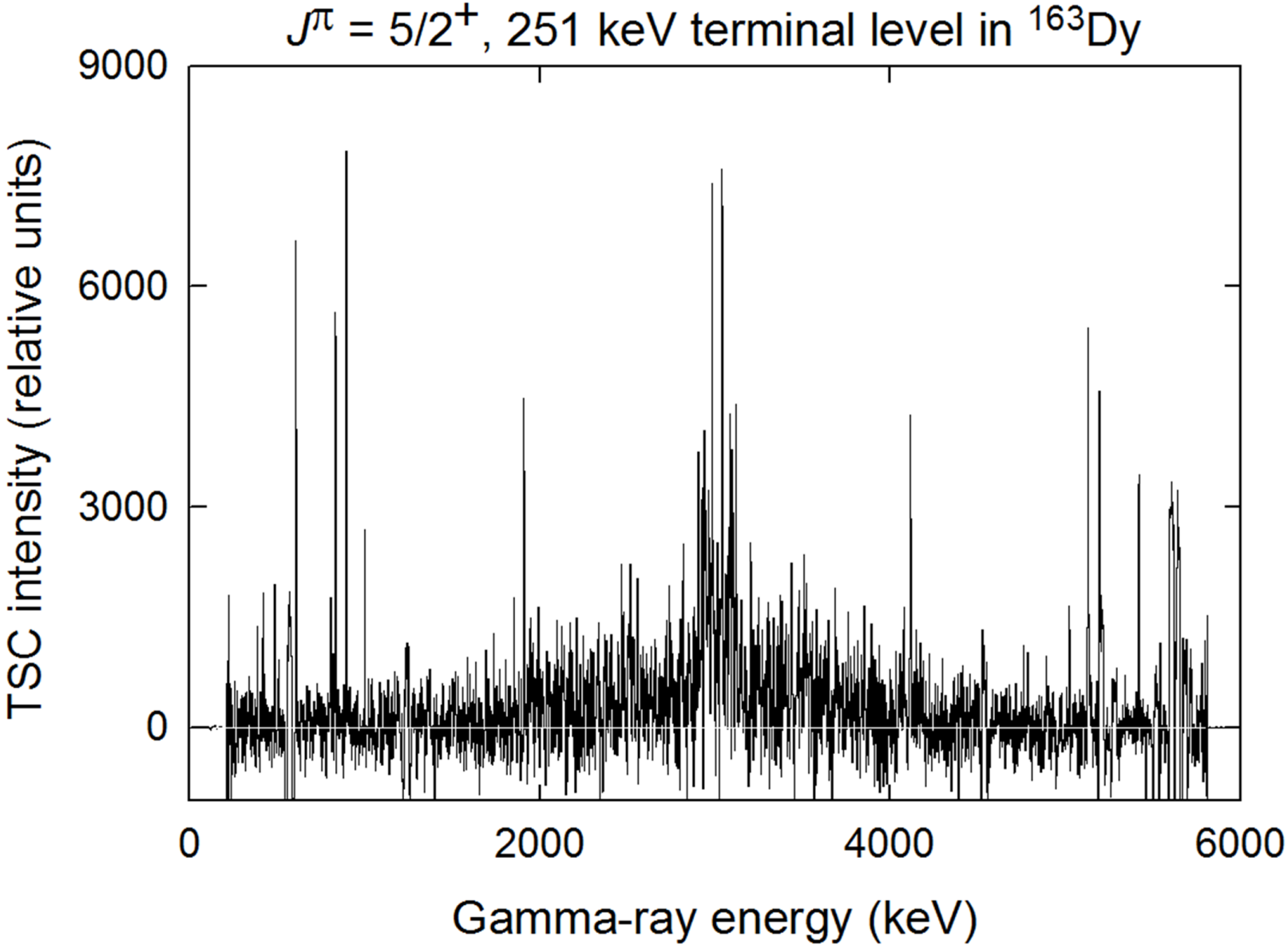
Motivation

Results of TSC experiment in 2004 with reaction ^{162}Dy$(n_{th},\gamma)^{163}$Dy showed necesity of postulating the scissors mode (SM) with these properties:

- $E_{SM} \approx 3$ MeV, $\Gamma_{SM} \approx 0.6$ MeV, $\sum B(M1) \uparrow = 6.2\mu_N^2$
- above all states up to $\approx$ 4MeV of excitation energy
- follows Brink hypothesis

Motivation


$J^{\pi} = 5/2^{+}$, 251 keV terminal level in ^{163}Dy
TSC intensity (relative units)
9000
6000
3000
0
0
2000
4000
6000
Gamma-ray energy (keV)

Motivation

What happens with SM at higher excitation energies?
How is the SM fragmented?
Can we get this information from TSC-like experiment?

The answer is (hopefully) YES, but one needs:

- suitable pair of nuclei $\surd$ $^{161}\mathrm{Dy}(\mathrm{n_{th}},\gamma)^{162}\mathrm{Dy}$
- suitable aparatus $\surd$ EXOGAM @ ILL
- beam time $\surd$

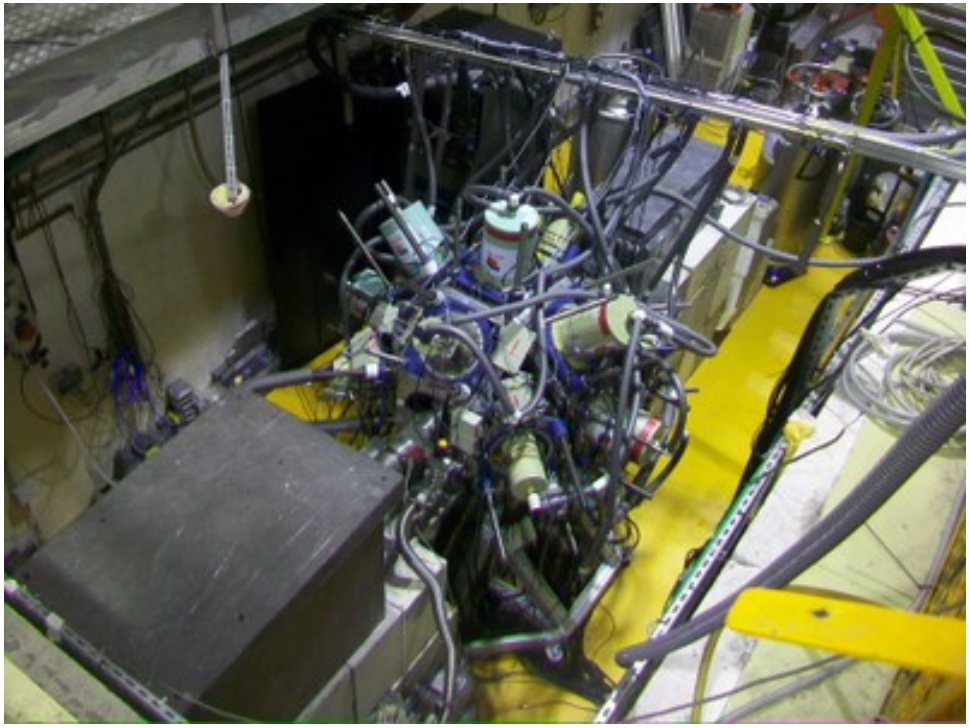
Why $^{161}Dy(n_{th},\gamma)^{162}Dy$?

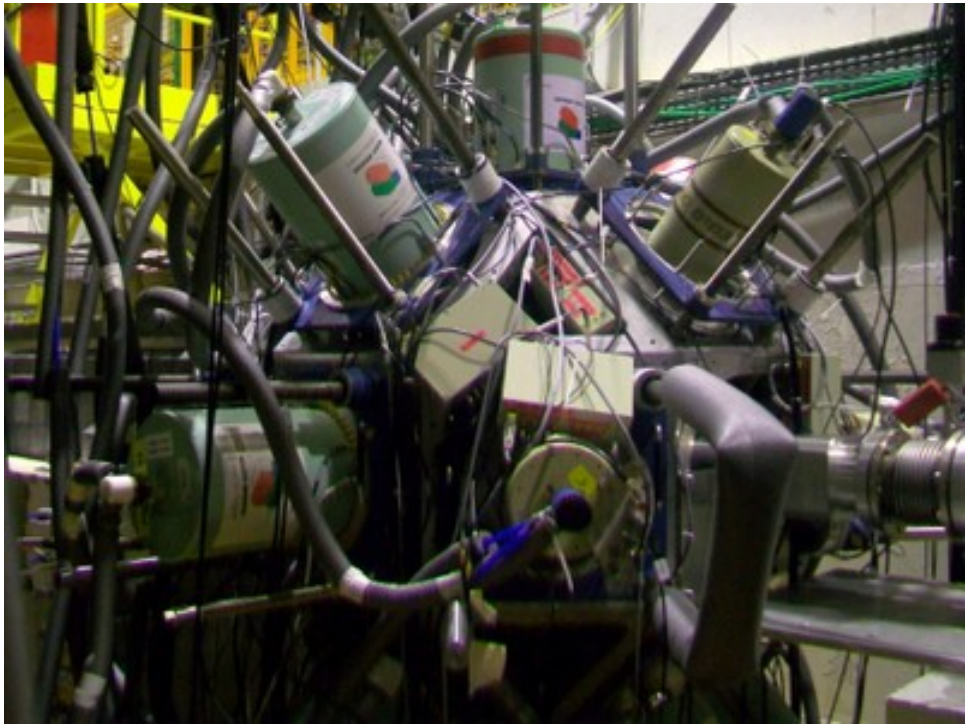
- stable target with reasonable σ and stable well-deformed product
- $S_n = 8.197$ MeV - not that lower than $3 \times E_{SM}$
- suitable spins and parities of levels involved in decay:
  - capturing state $J^\pi = 3^-$
  - low lying states of both parities and spins from 0 to 6
- available target enriched to $> 90\%$

$\Rightarrow$ possible three step cascades M1-M1-M1 (and other combinations)
$\Rightarrow$ possible two step cascades of all combinations

EXOGAM @ ILL = EXILL Campaign

EXOGAM was borrowed to ILL for 2 reactor cycles during 2012-2013.

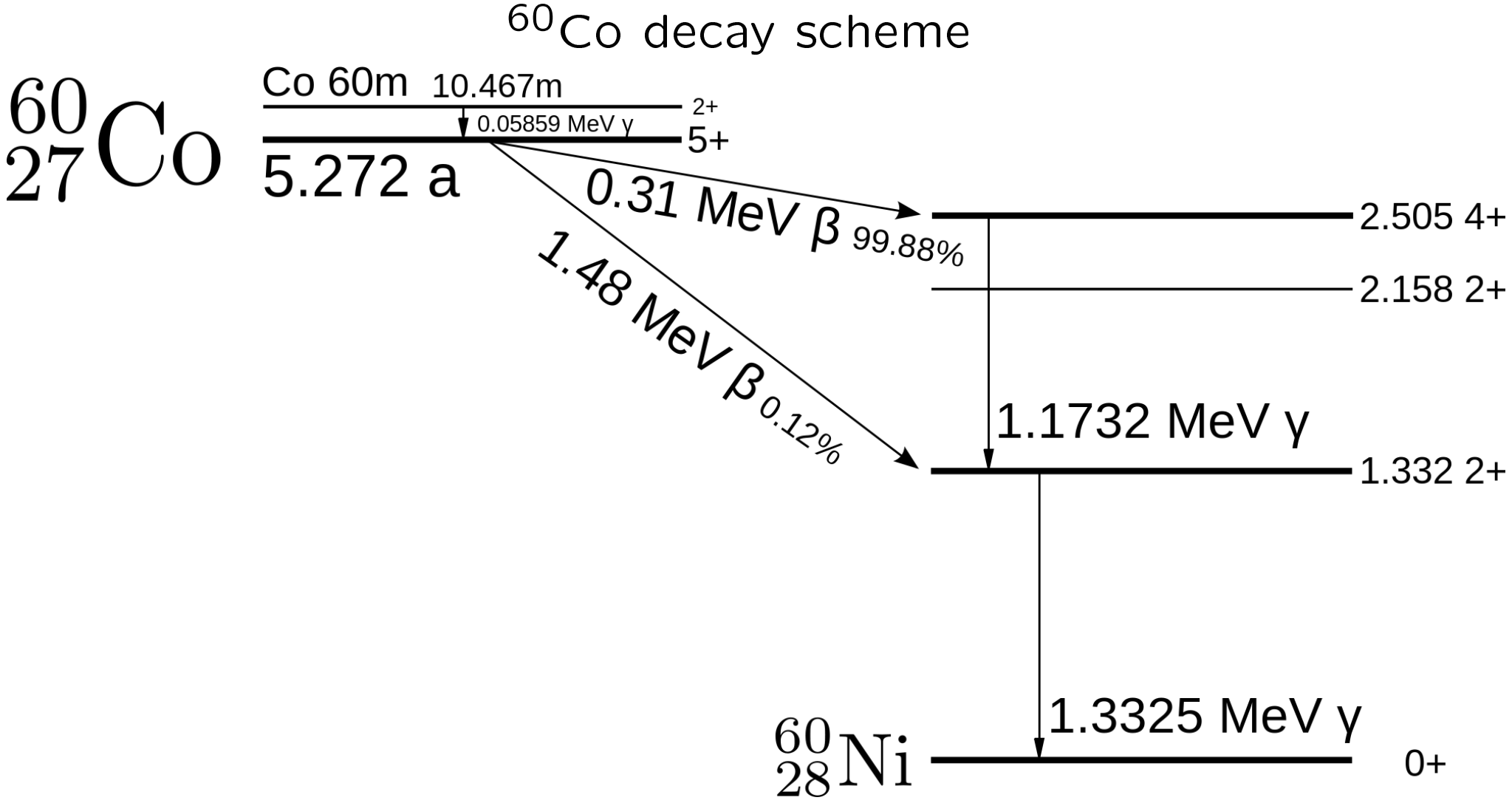


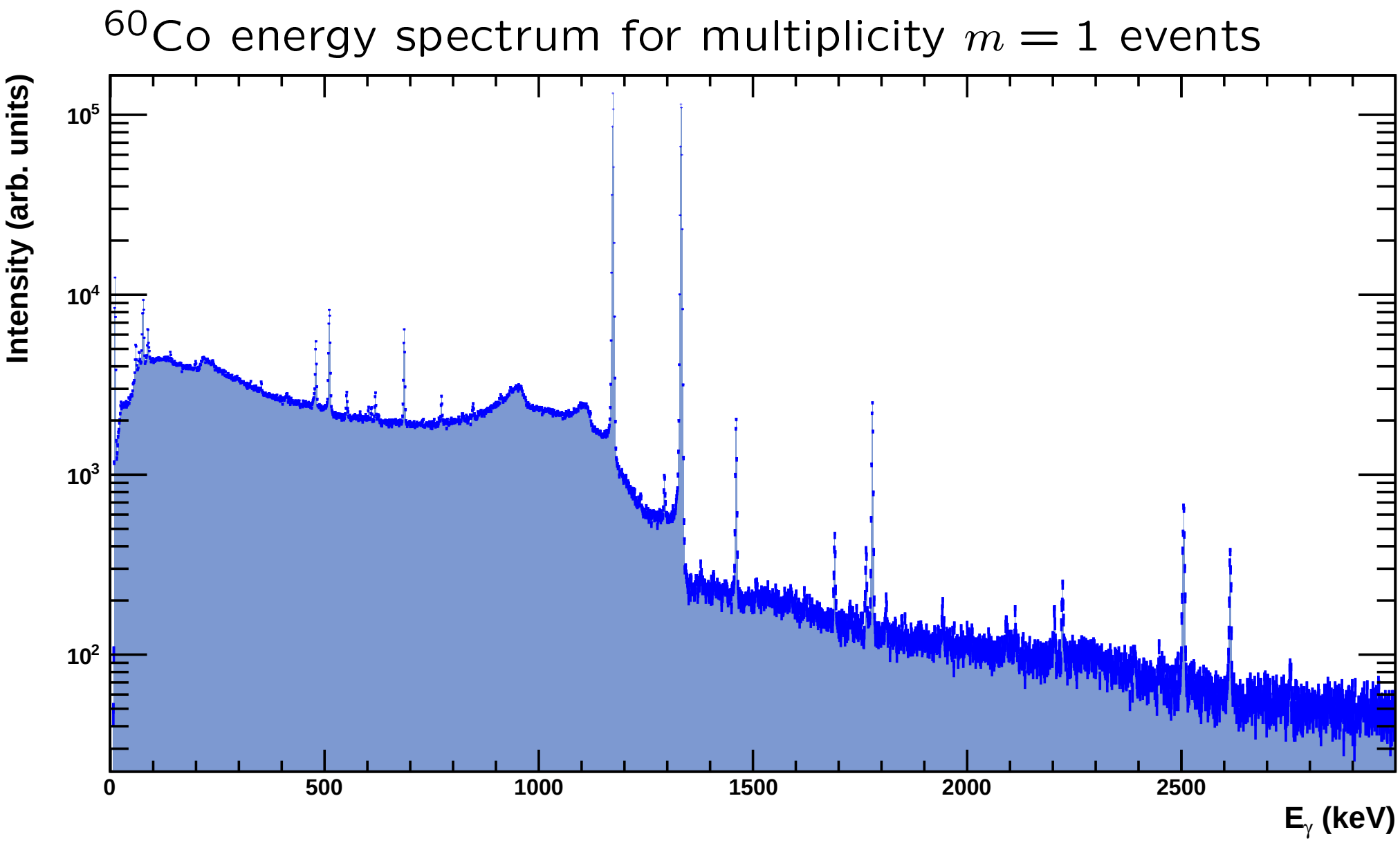


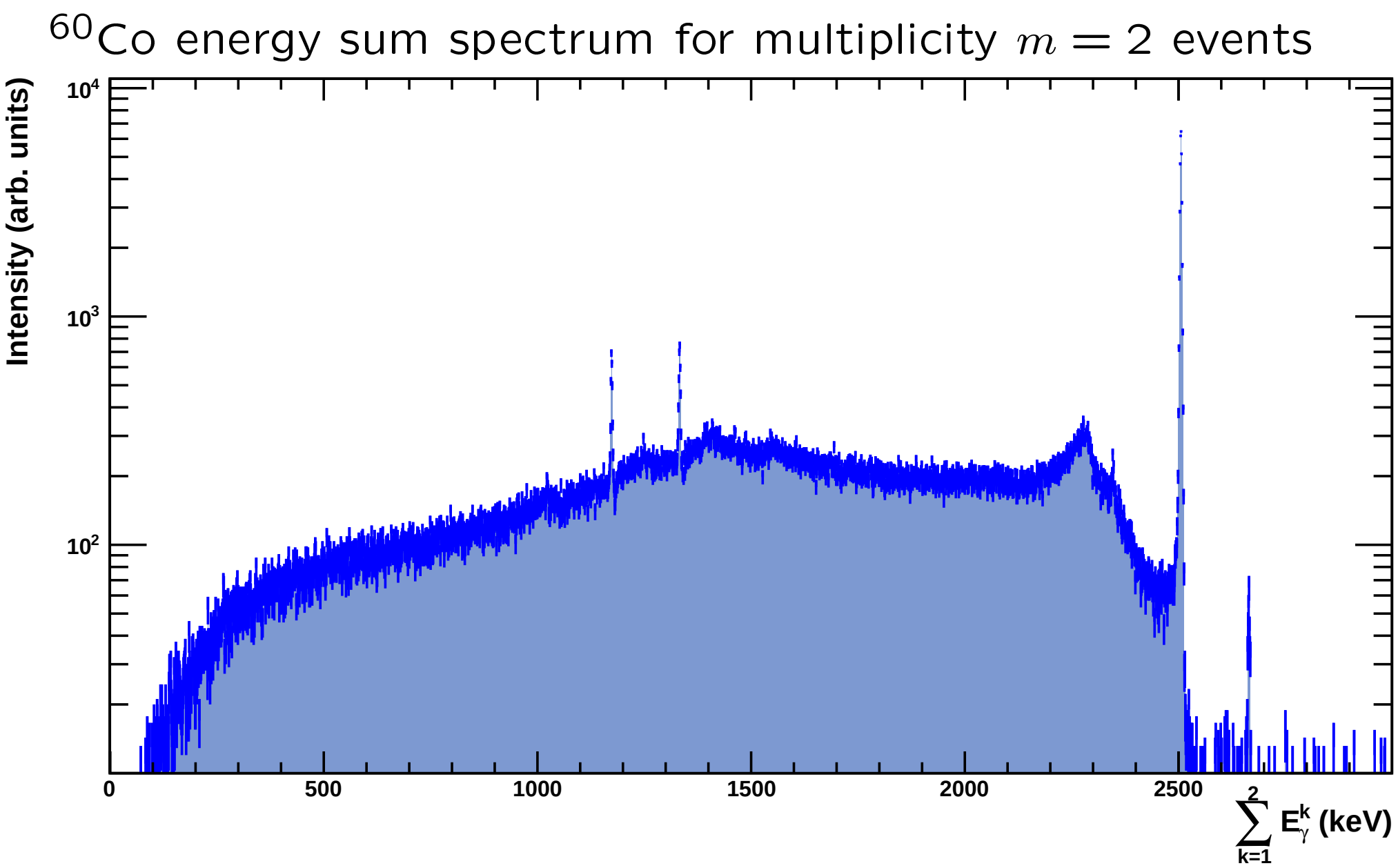
Our experiment was granted 2.5 days of data taking (list mode, several TB) in the end of first cycle in December 2012.

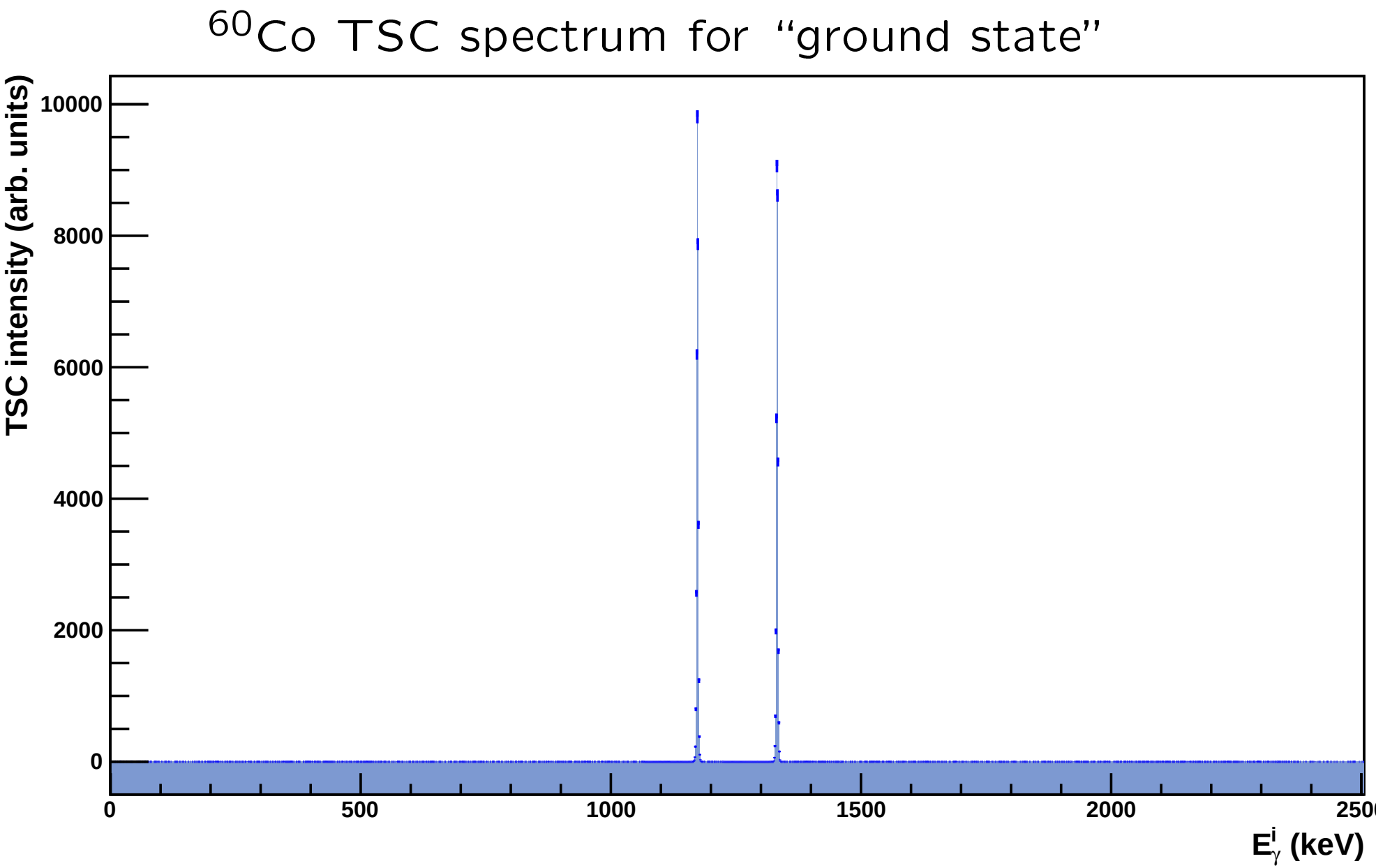
What has been measured and it's use

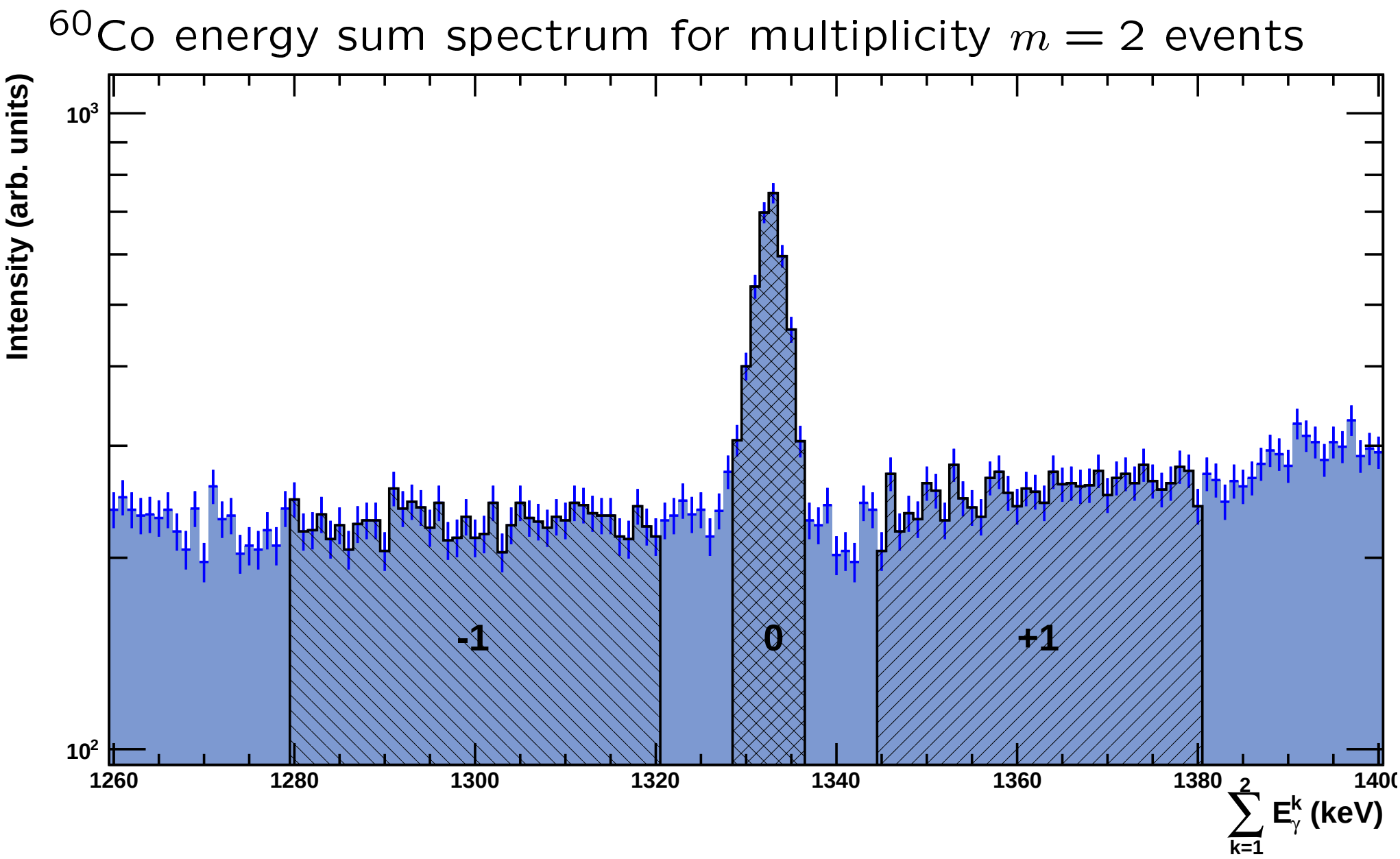
- ^{60}Co - channel to energy, total & peak efficiency, data reduction checks
- ^{152}Eu - channel to energy, peak efficiency, checks of event builder for higher multiplicities
- (n,γ)^{36}Cl - channel to energy, peak efficiency, data reduction checks, time aligment
- (n,γ)^{162}Dy


60Co decay scheme
60 27 Co
Co 60m 10.467m
0.05859 MeV γ
2+
5+
5.272 a
0.31 MeV β 99.88%
1.48 MeV β 0.12%
2.505 4+
2.158 2+
1.1732 MeV γ
1.332 2+
1.3325 MeV γ
60 28 Ni
0+

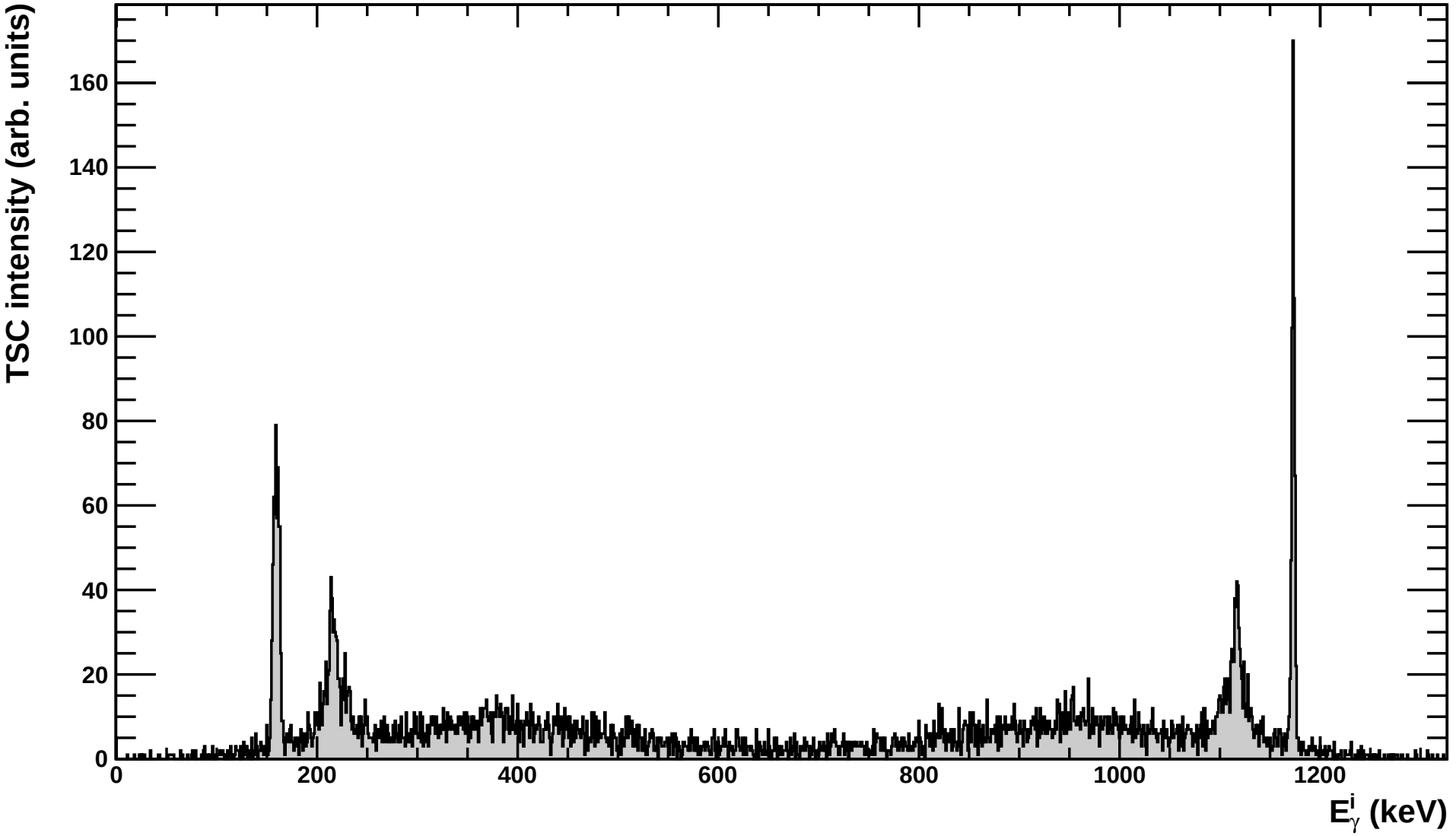

^{60}Co energy spectrum for multiplicity $m = 1$ events
Intensity (arb. units)
10^5
10^4
10^3
10^2
0
500
1000
1500
2000
2500
E_γ (keV)

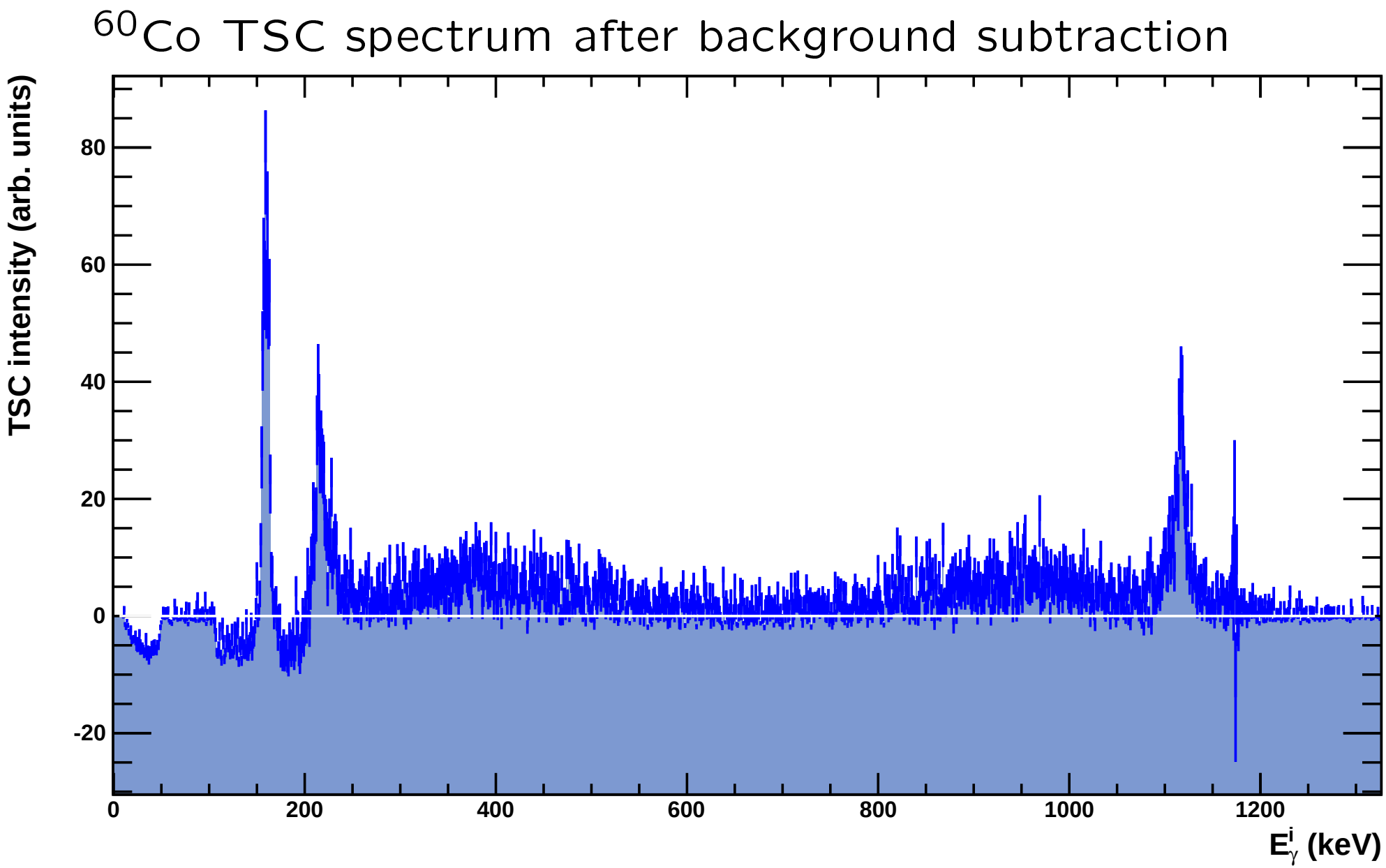

^{60}Co energy sum spectrum for multiplicity $m = 2$ events
Intensity (arb. units)
10^4
10^3
10^2
0
500
1000
1500
2000
2500
$\sum_{k=1}^{2} E_\gamma^k$ (keV)


^{60}Co TSC spectrum for "ground state"
TSC intensity (arb. units)
10000
8000
6000
4000
2000
0
0
500
1000
1500
2000
2500
E_γ^i (keV)

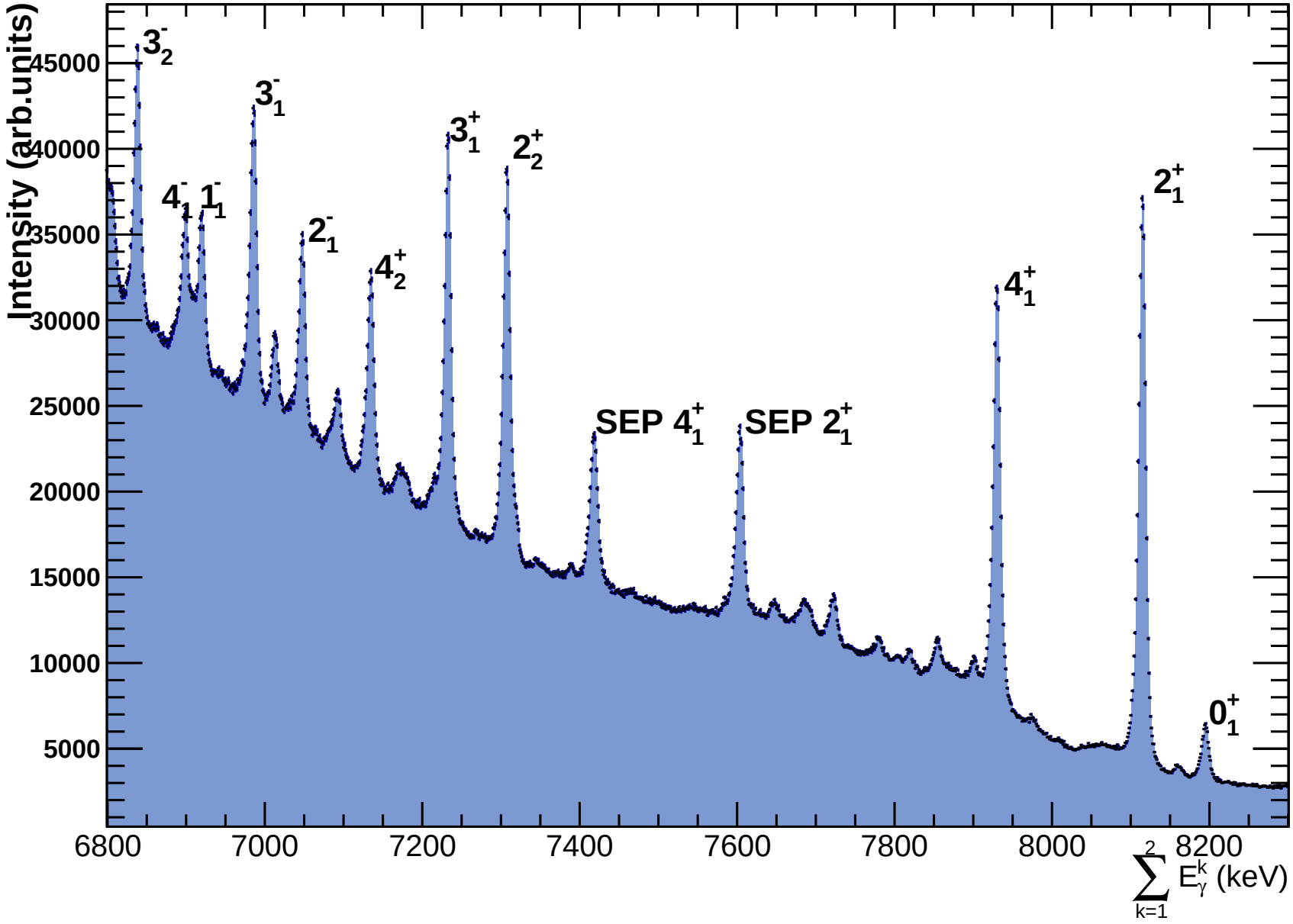

^{60}Co energy sum spectrum for multiplicity $m = 2$ events
Intensity (arb. units)
10^3
10^2
-1
0
+1
1260
1280
1300
1320
1340
1360
1380
$\sum_{k=1}^{2} E_\gamma^k$ (keV)

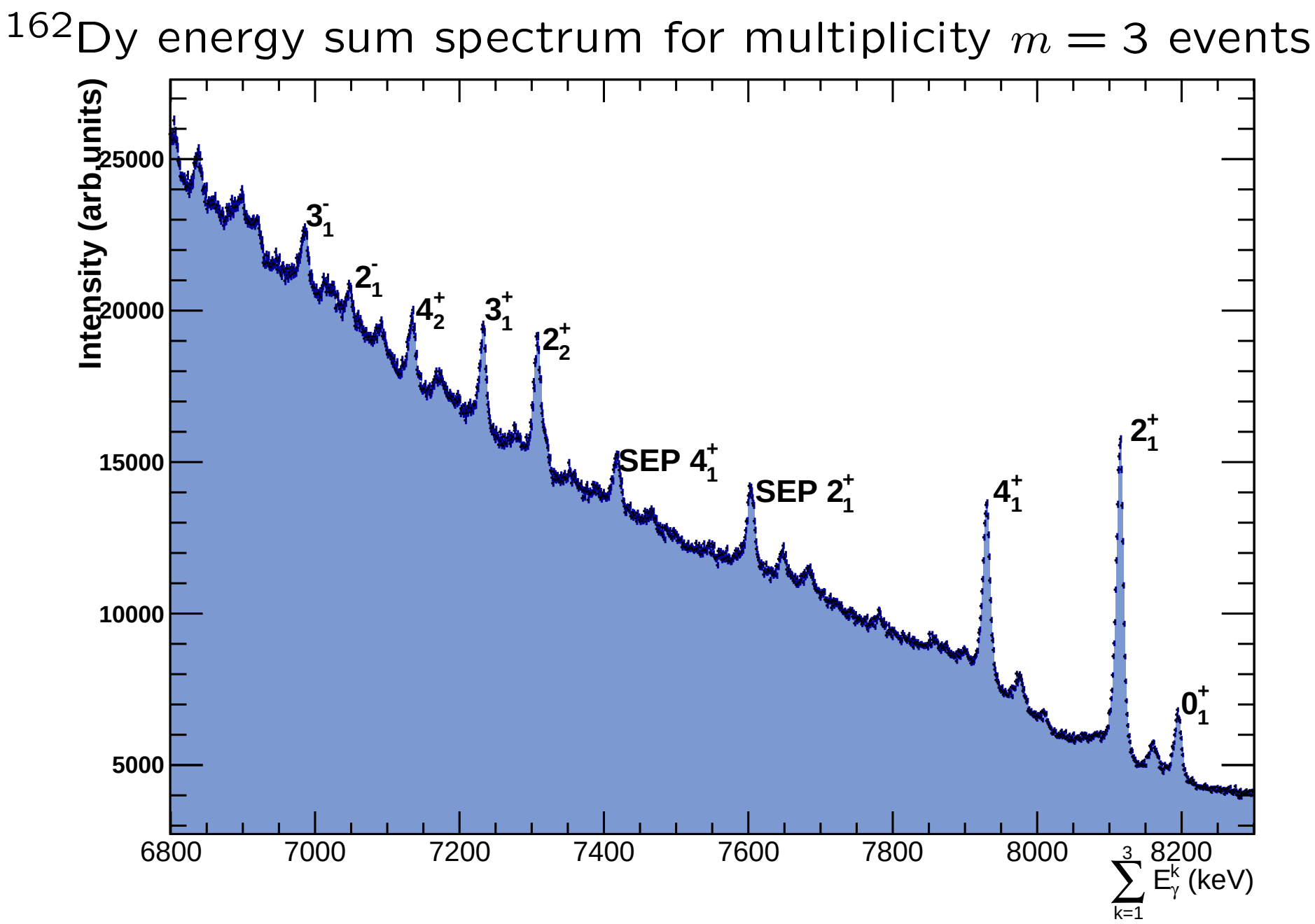
^{60}Co "TSC" spectrum from central ("0") part of energy sum spectrum

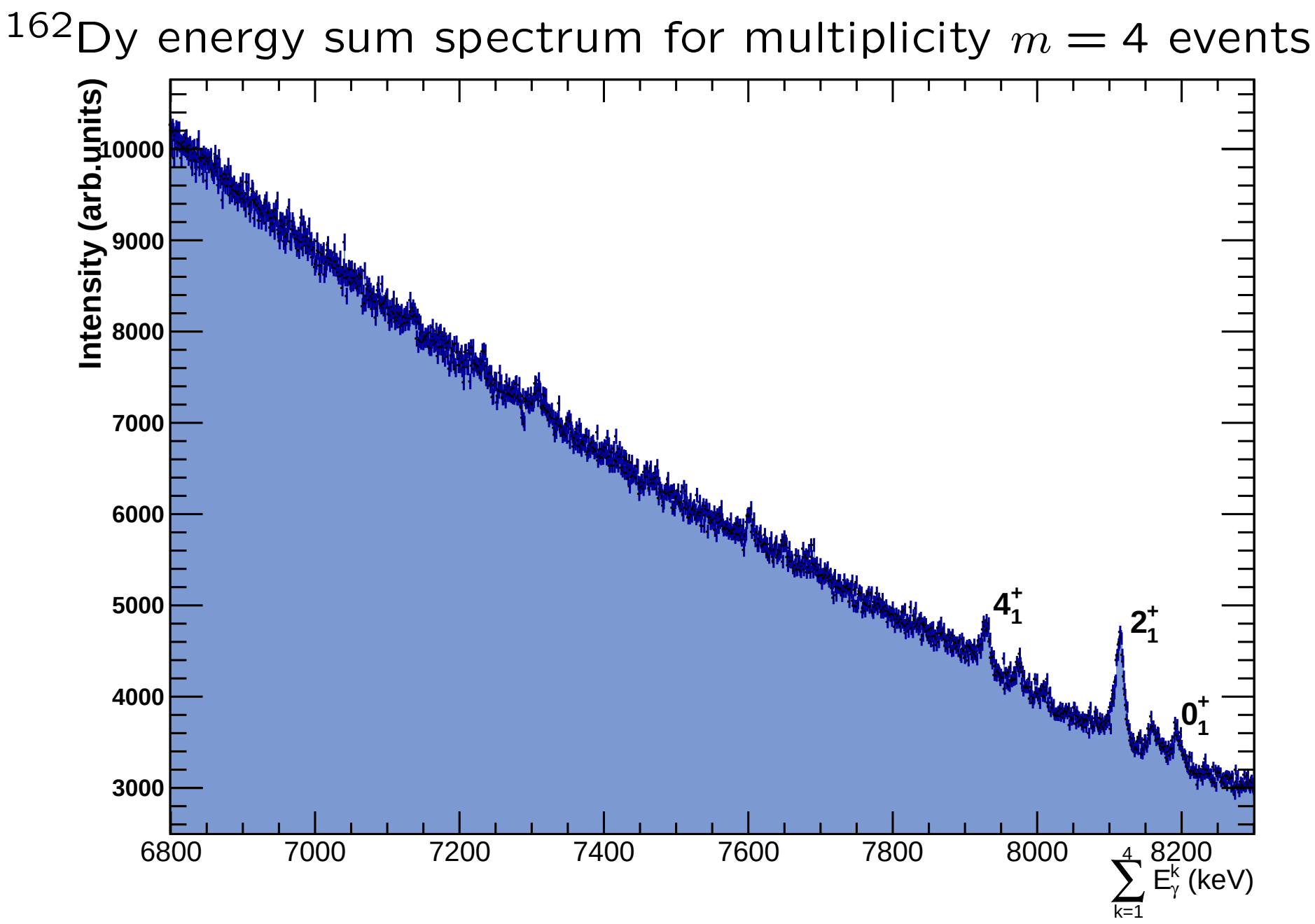



^{60}Co TSC spectrum after background subtraction
TSC intensity (arb. units)
80
60
40
20
0
-20
0
200
400
600
800
1000
1200
E_γ^i (keV)

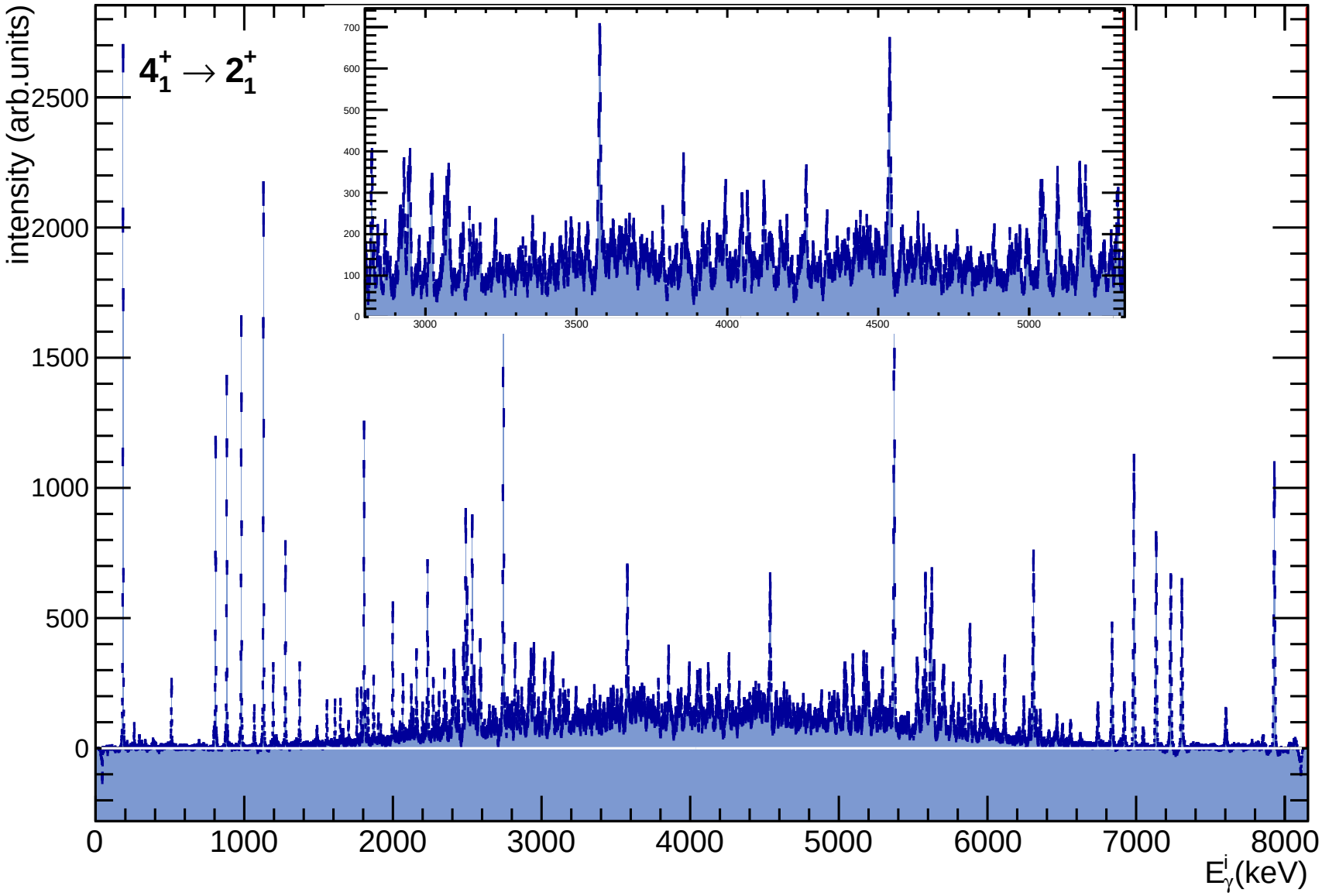
^{162}Dy energy sum spectrum for multiplicity $m = 2$ events



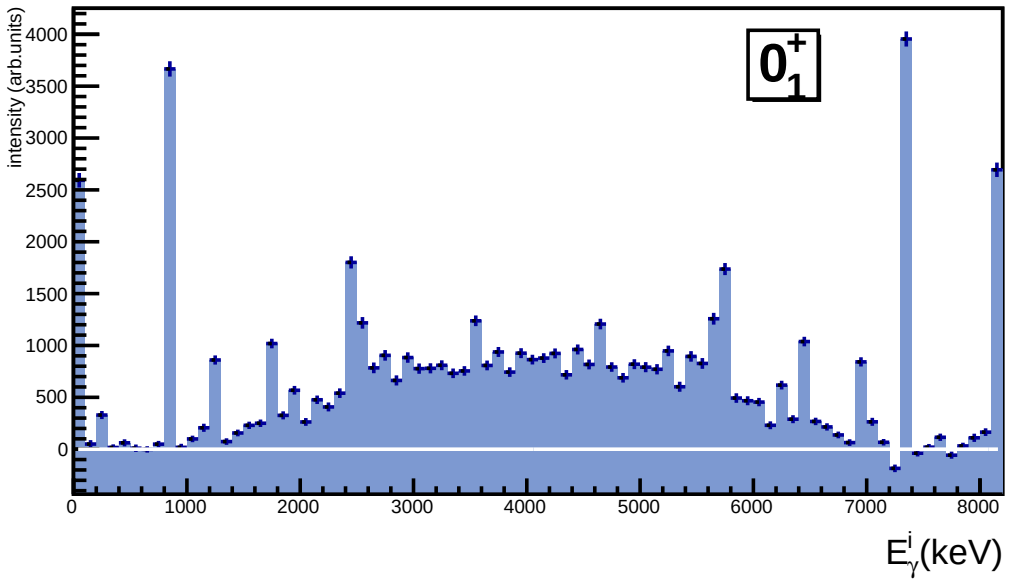

^{162}Dy energy sum spectrum for multiplicity $m = 3$ events
Intensity (arb. units)
25000
20000
15000
10000
5000
6800
7000
7200
7400
7600
7800
8000
8200
$\sum_{k=1}^{3} E_\gamma^k$ (keV)
3_1^-
2_1^-
4_2^+
3_1^+
2_2^+
SEP 4_1^+
SEP 2_1^+
4_1^+
2_1^+
0_1^+

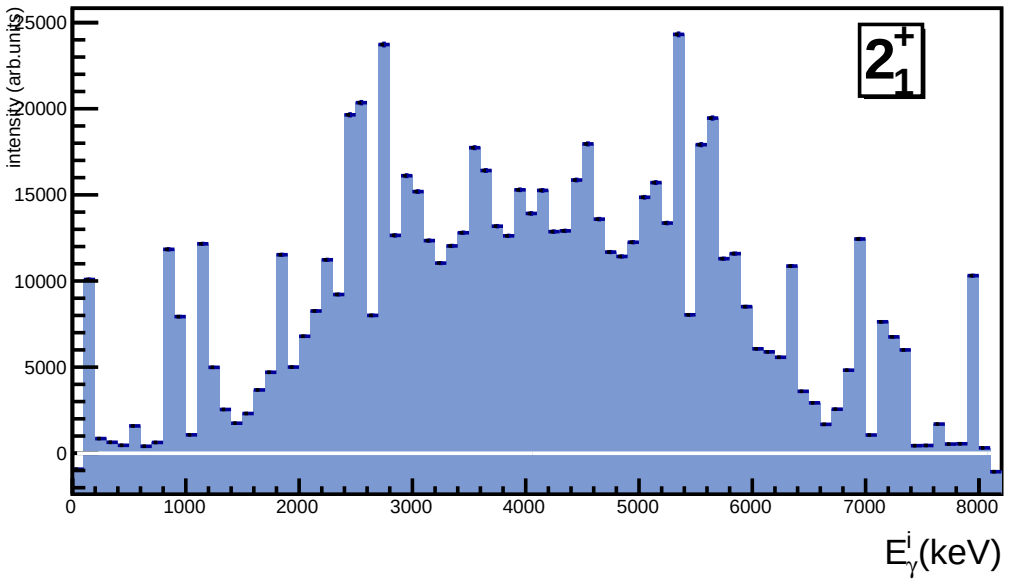

^{162}Dy energy sum spectrum for multiplicity $m = 4$ events
Intensity (arb.units)
10000
9000
8000
7000
6000
5000
4000
3000
6800
7000
7200
7400
7600
7800
8000
8200
4_1^+
2_1^+
0_1^+
$\sum_{k=1}^{4} E_\gamma^k$ (keV)

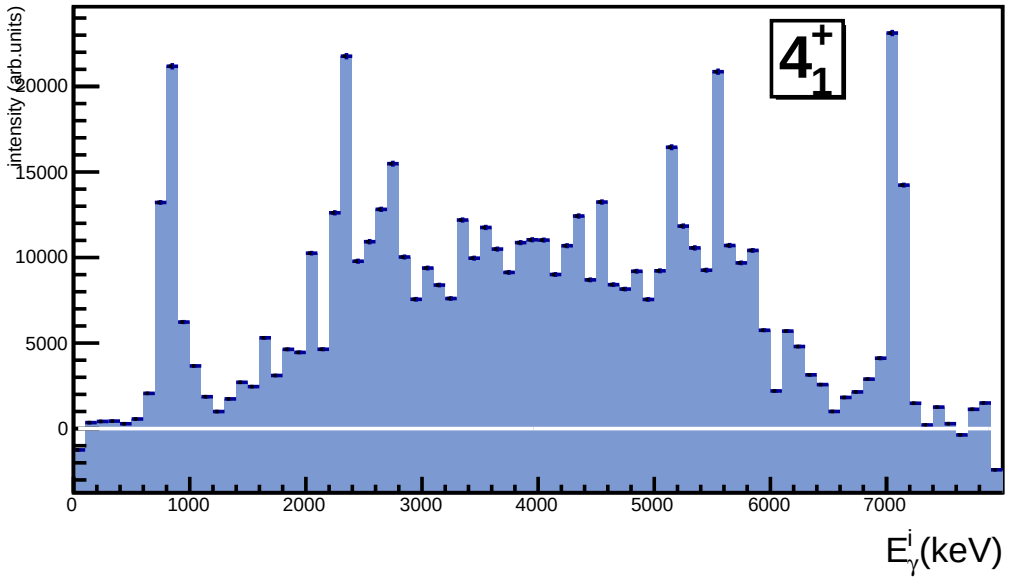
^{162}Dy TSC spectrum for 2_1^+ state

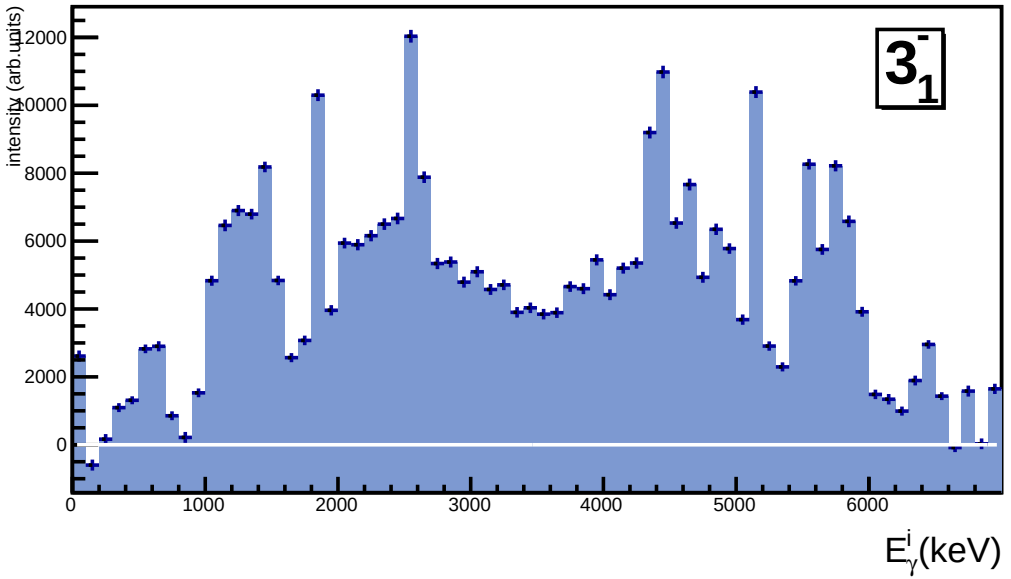


^{162}Dy binned TSC spectra

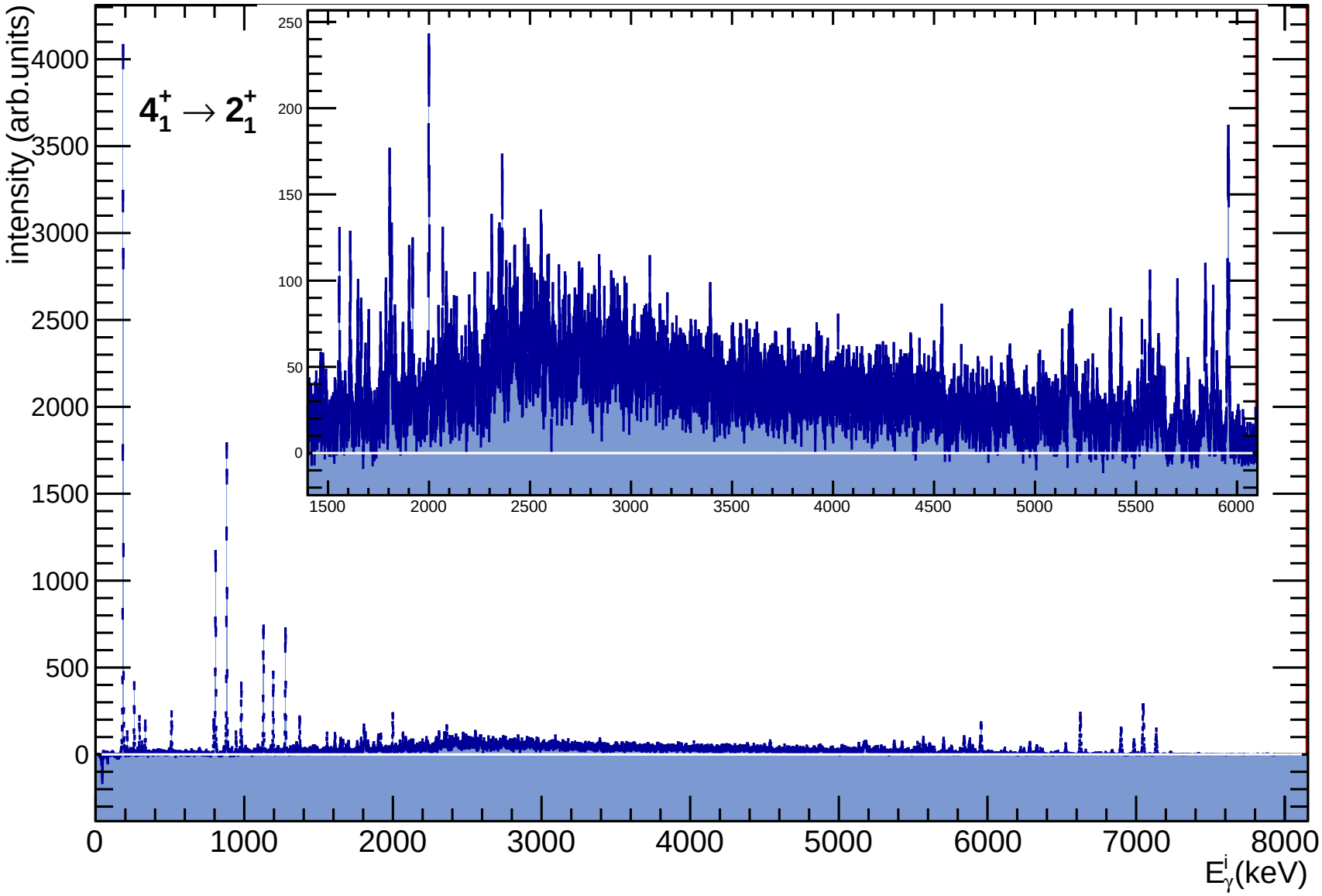




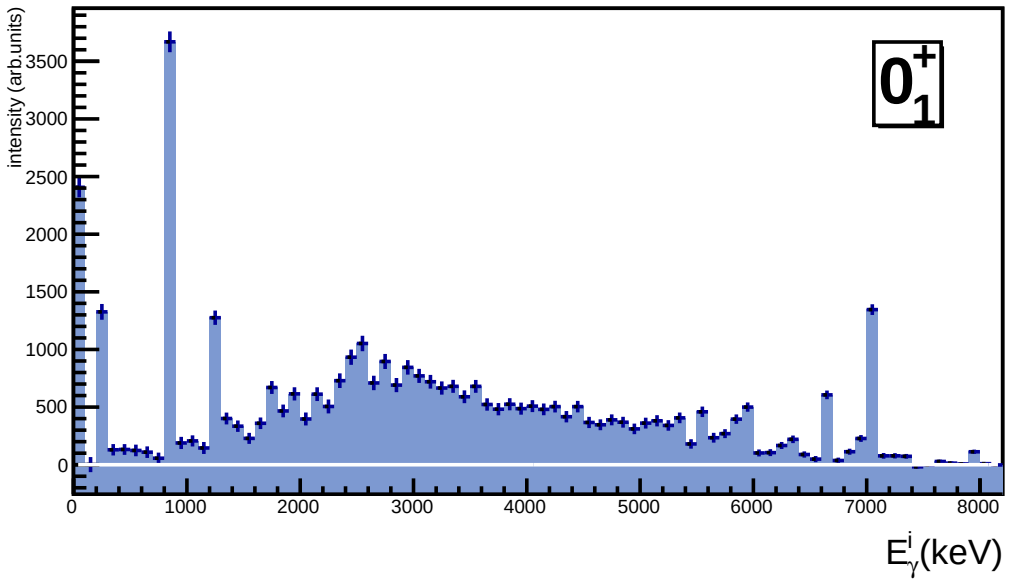


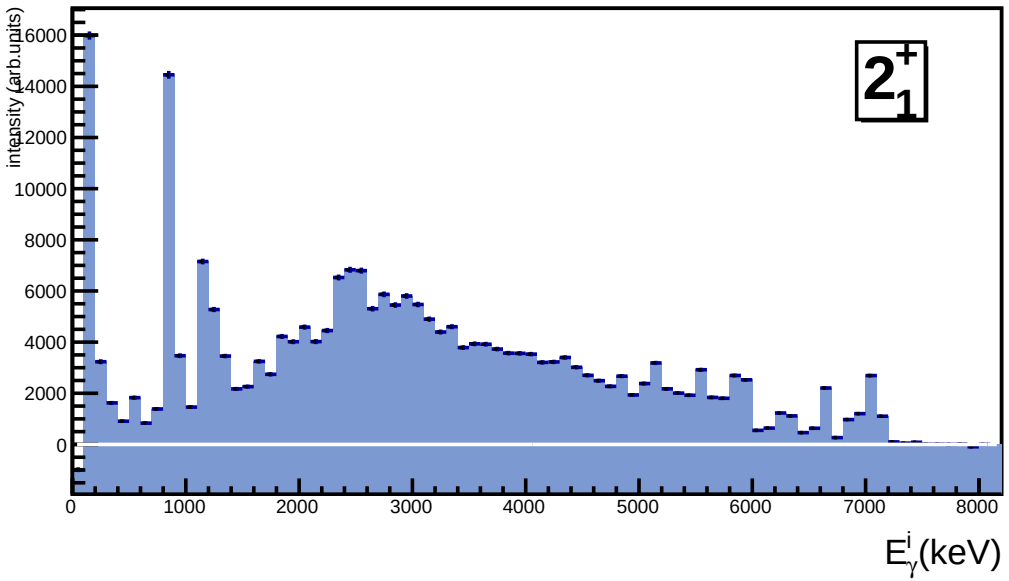


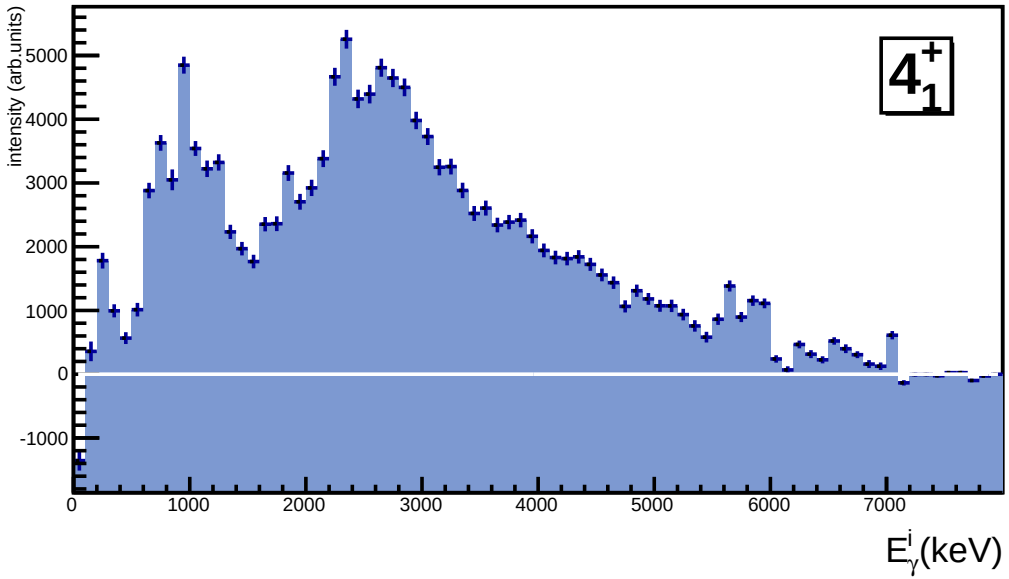
^{162}Dy 3SC spectrum for 2_1^+ state

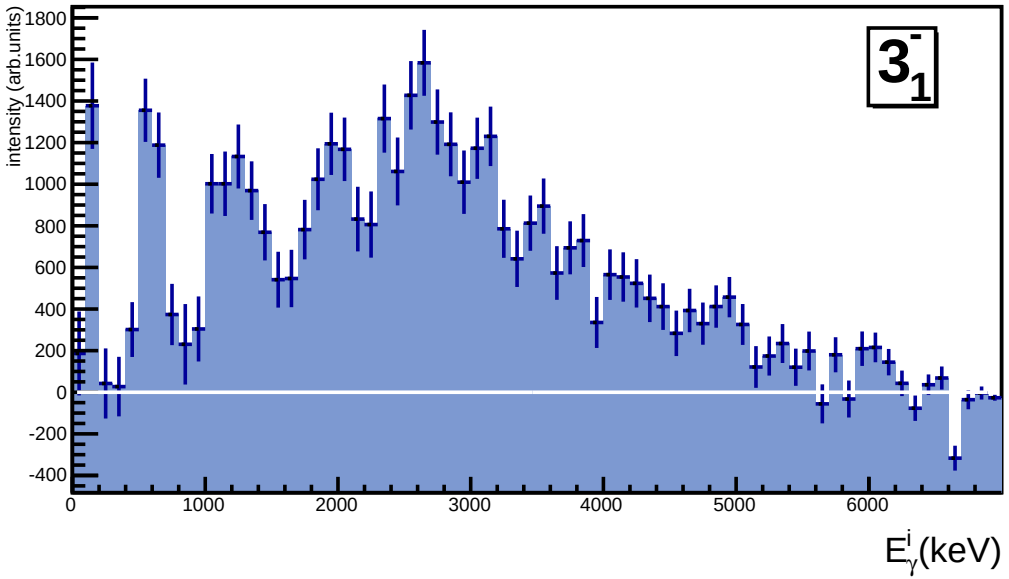


^{162}Dy binned 3SC spectra



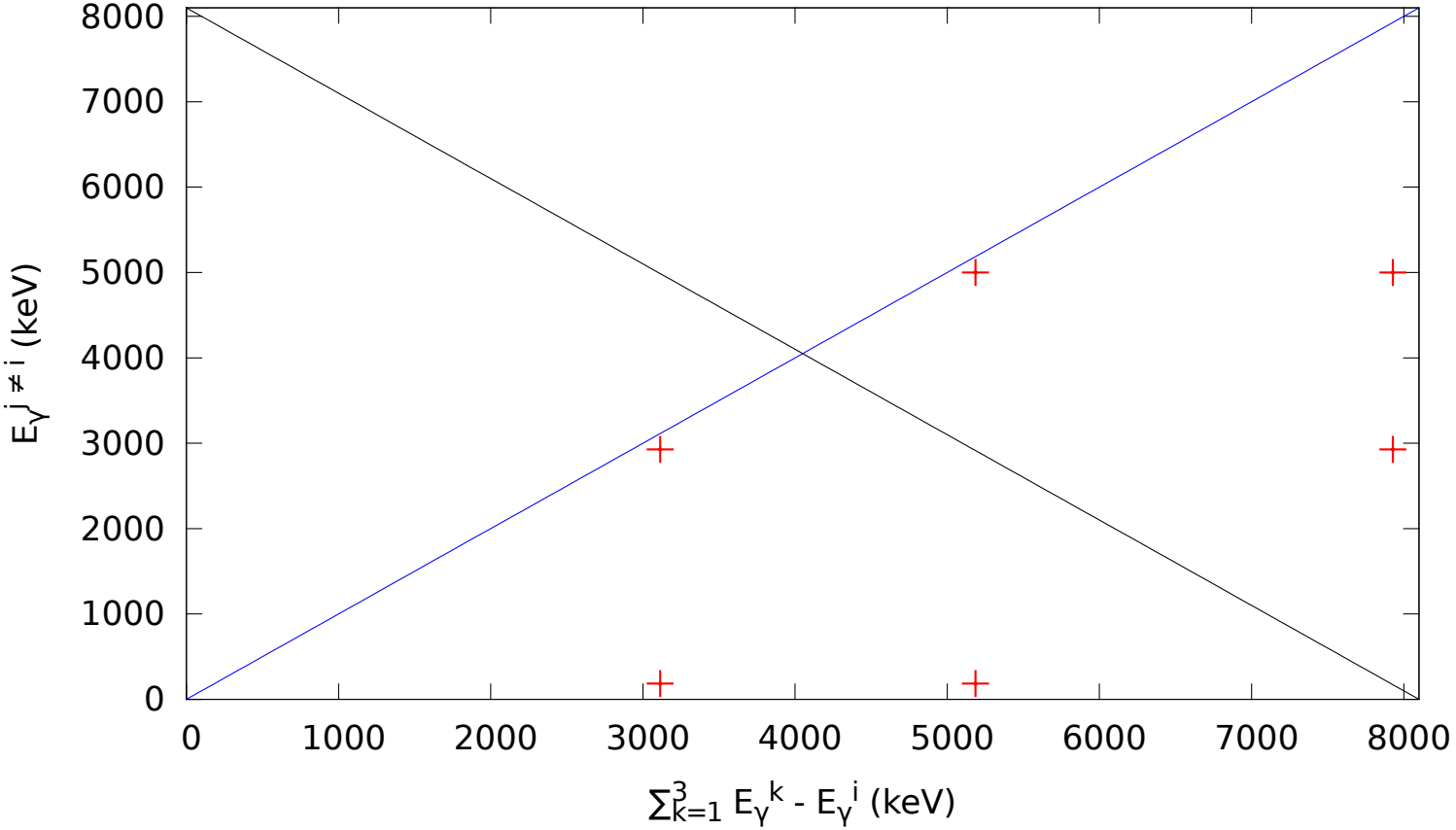


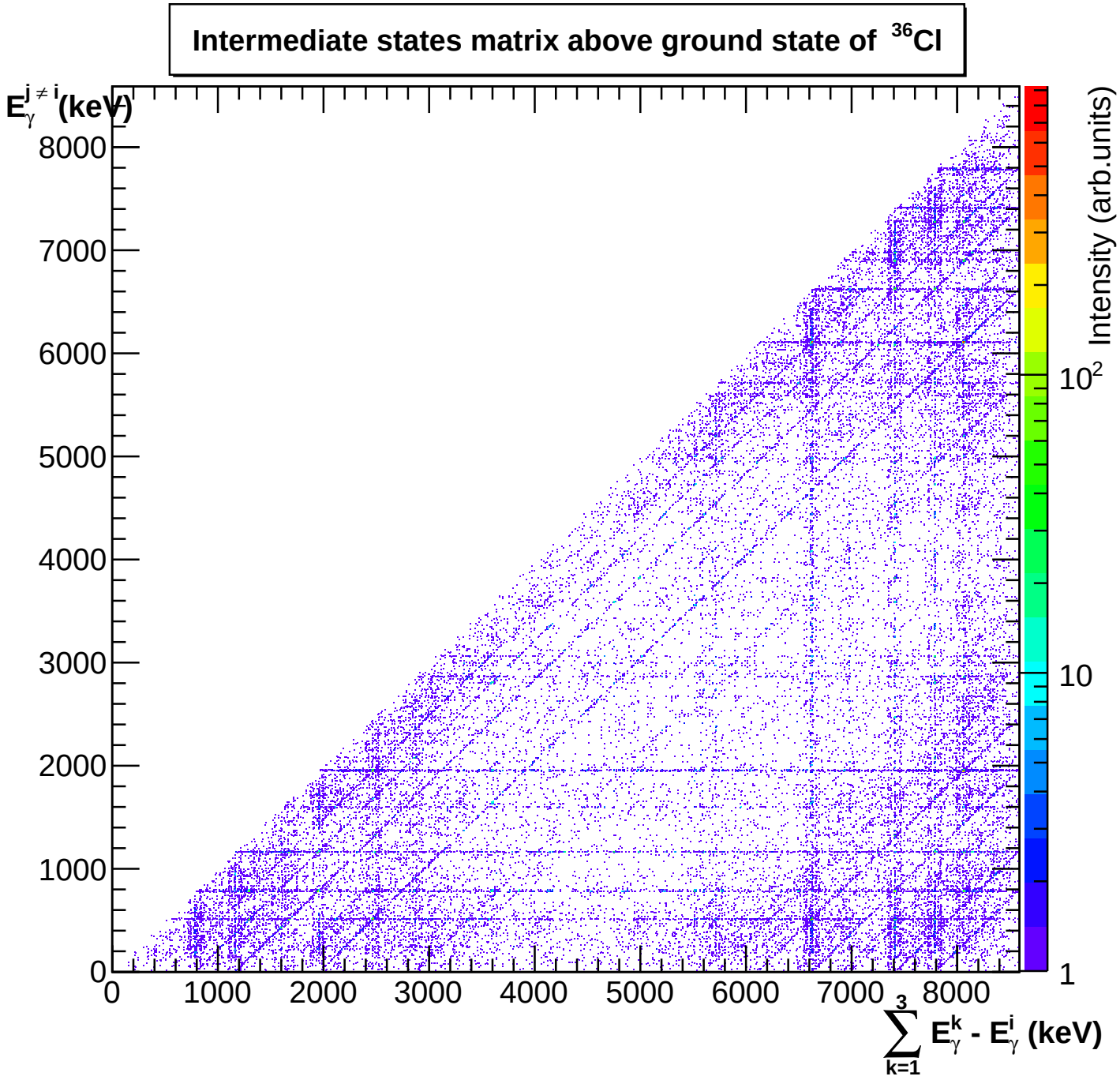


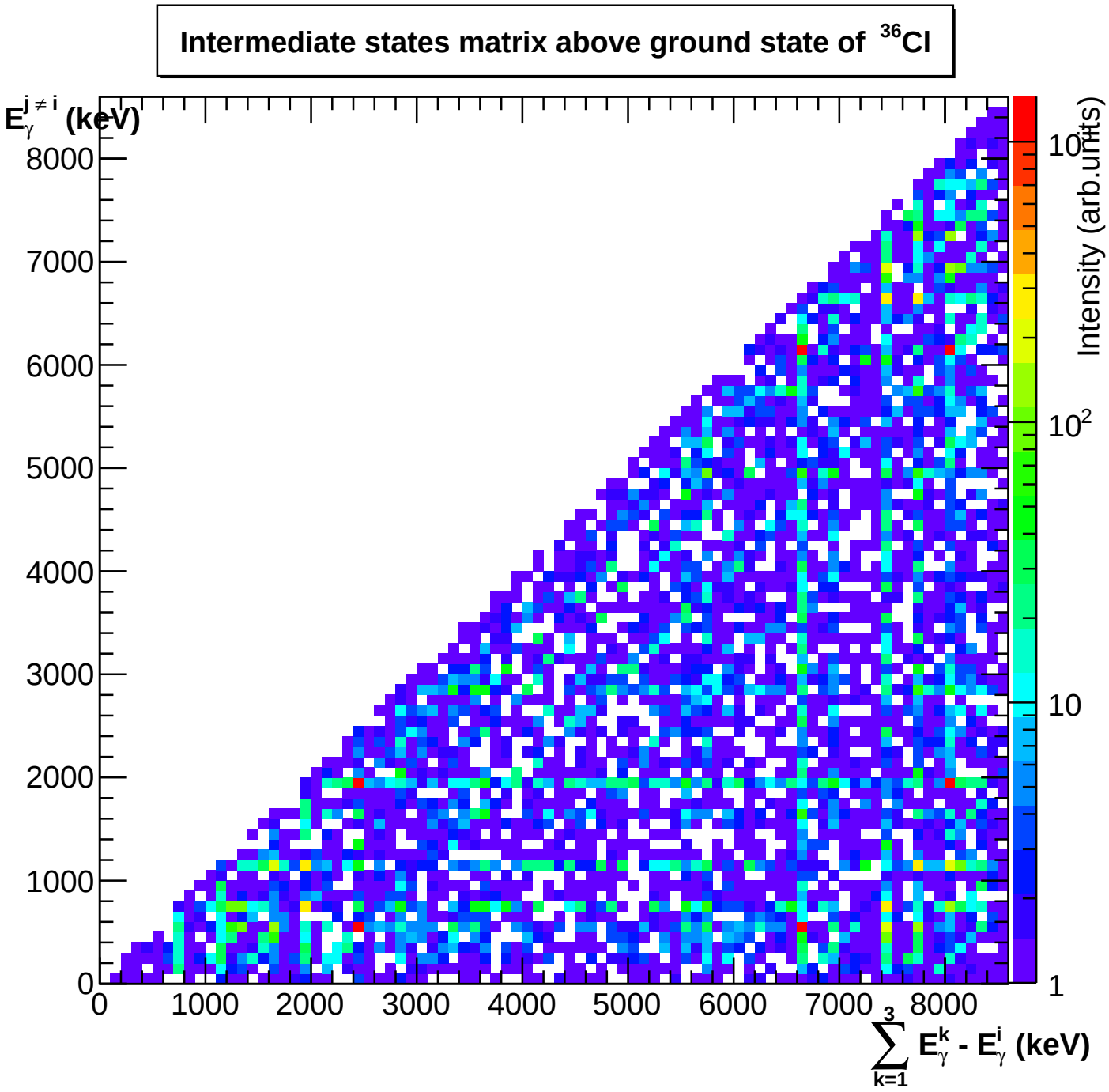


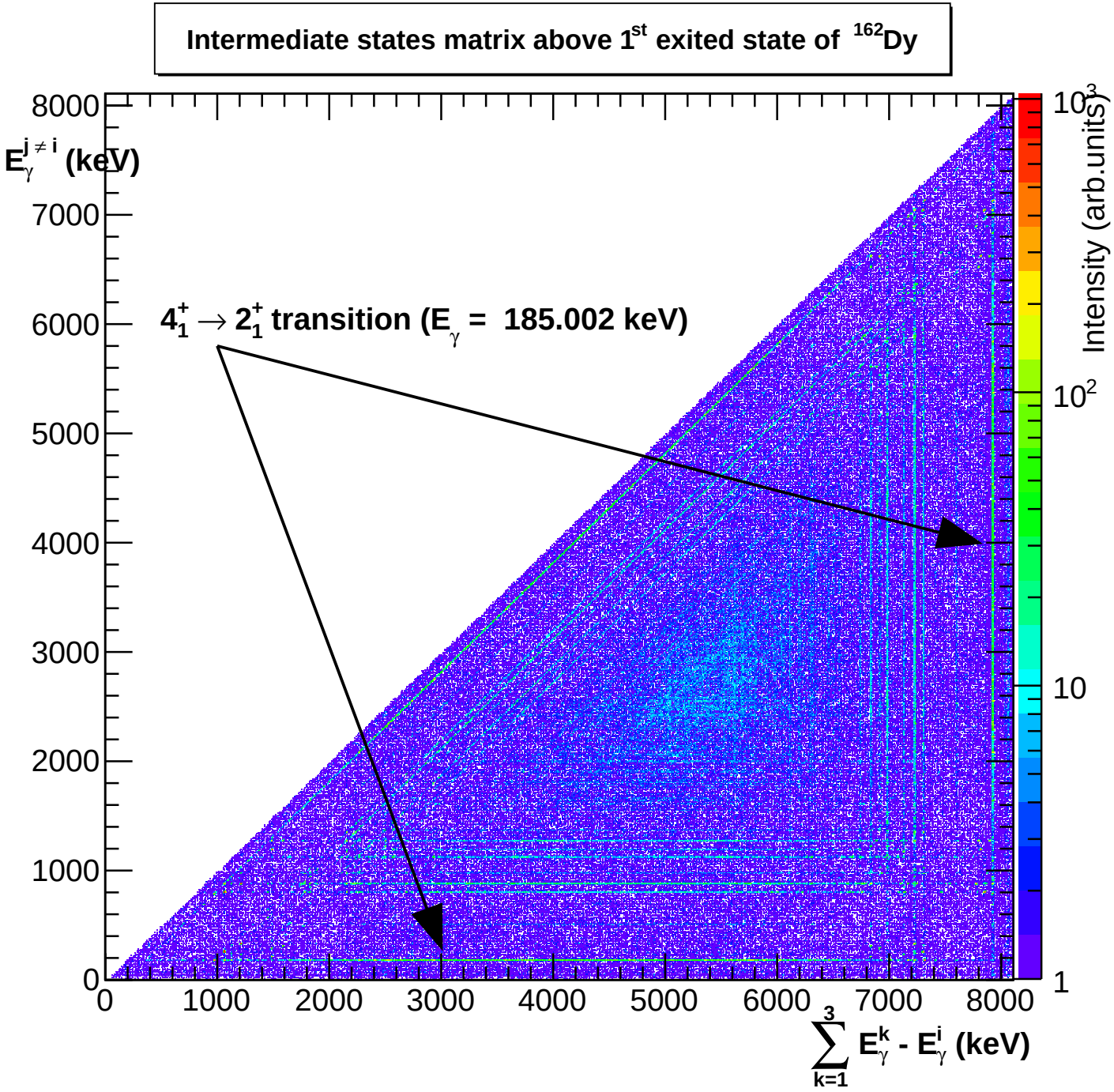
Intermediate states matrix

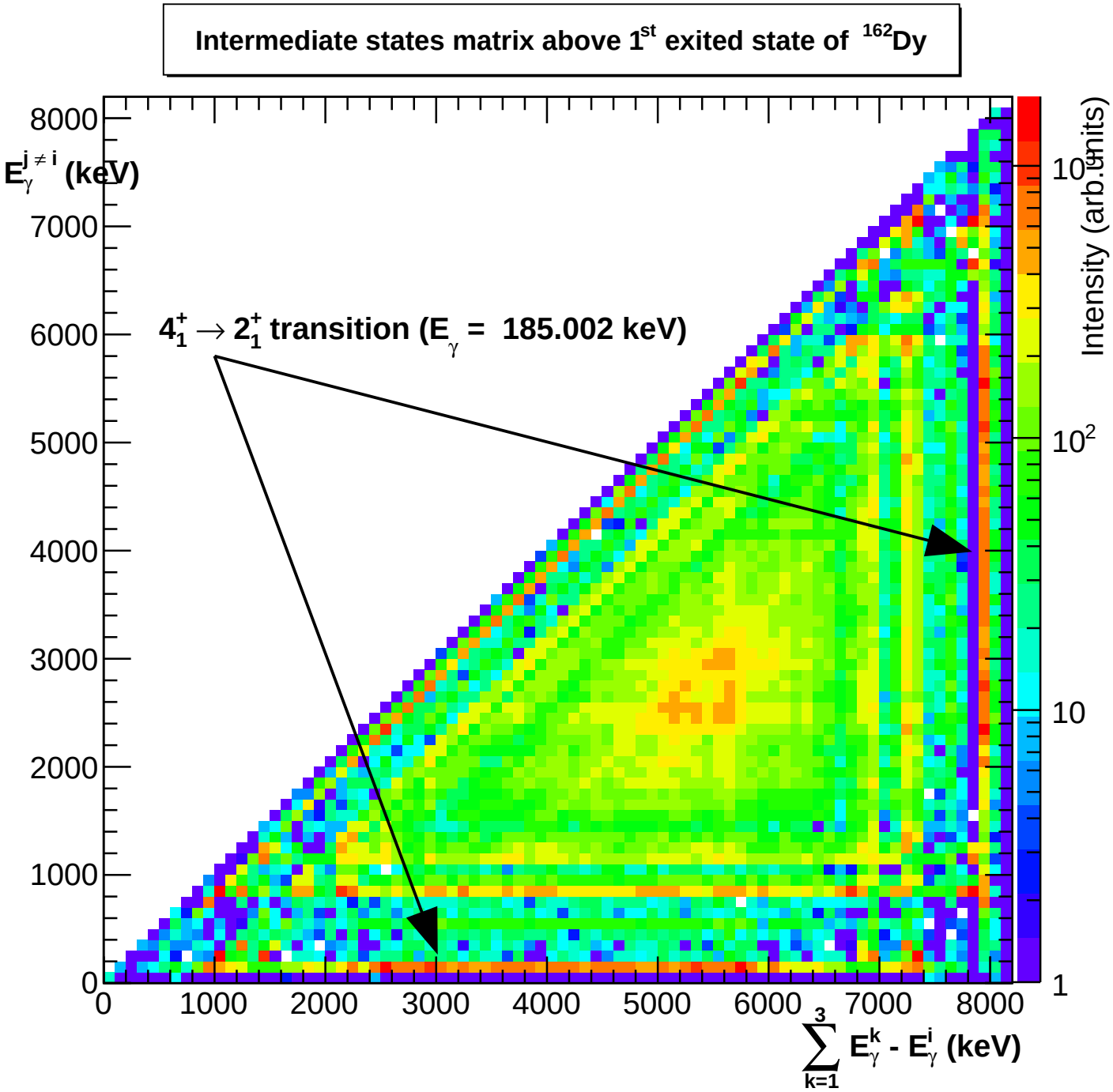
Imagine you get a cascade of 3 photons of 5MeV, 2.9MeV and 185 keV from simulations. You directly know the energies of intermediate states. You might see same cascade in the experimental data but generally You cannot be sure about the order. Why not plot all 6 combinations?




Intermediate states matrix above ground state of ^{36}Cl
$E_\gamma^{j \neq i}$ (keV)
8000
7000
6000
5000
4000
3000
2000
1000
0
0
1000
2000
3000
4000
5000
6000
7000
8000
$\sum_{k=1}^{3} E_\gamma^k - E_\gamma^i$ (keV)
Intensity (arb.units)
10^2
10
1

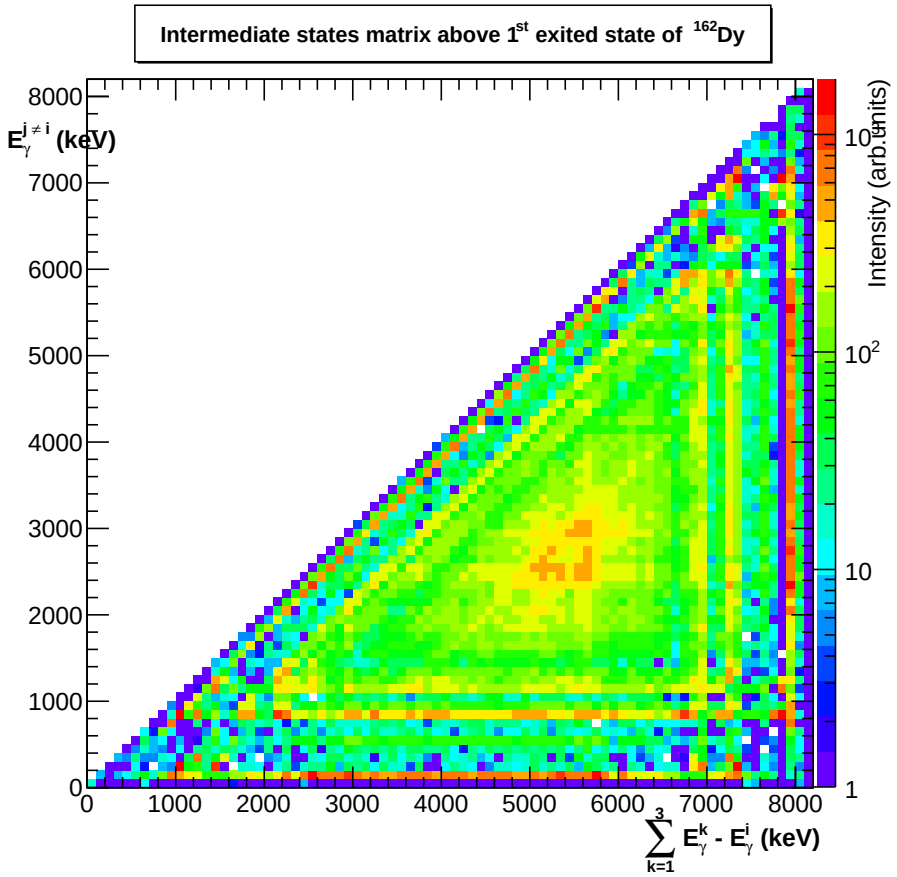

Intermediate states matrix above ground state of ^{36}Cl
$E_\gamma^{j \neq i}$ (keV)
8000
7000
6000
5000
4000
3000
2000
1000
0
0
1000
2000
3000
4000
5000
6000
7000
8000
$\sum_{k=1}^{3} E_\gamma^k - E_\gamma^i$ (keV)
Intensity (arb.units)
10^2
10
1

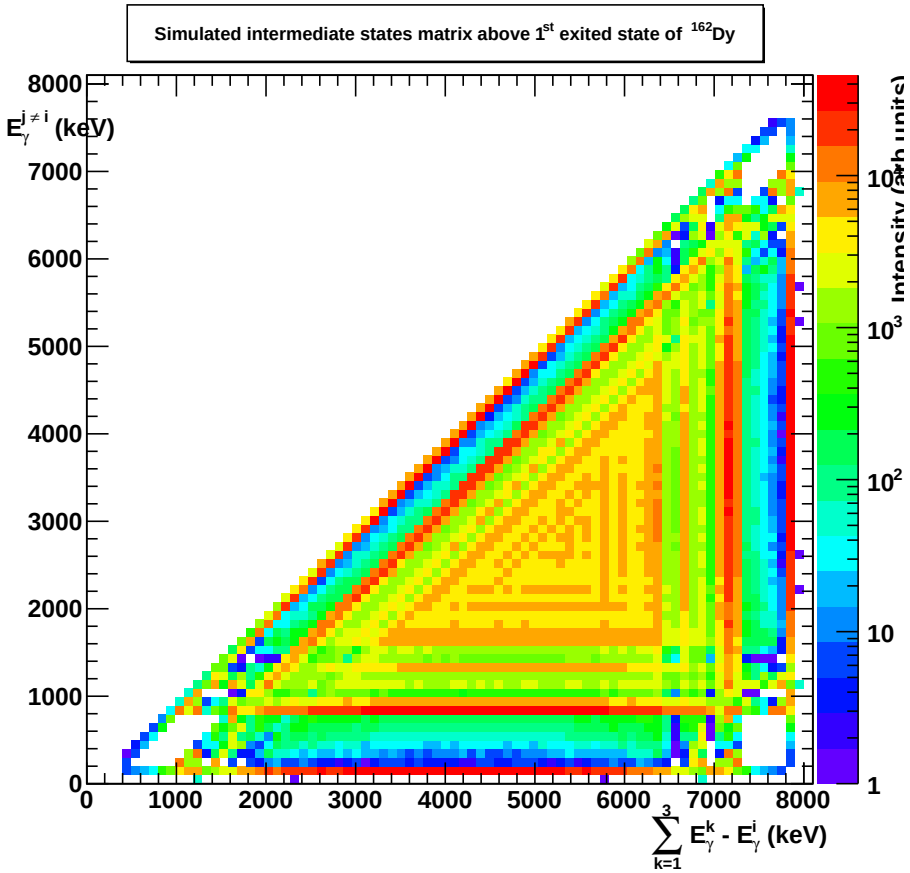

Intermediate states matrix above 1st exited state of 162Dy
$E_\gamma^{j \neq i}$ (keV)
$4_1^+ \rightarrow 2_1^+$ transition (E_γ = 185.002 keV)
$\sum_{k=1}^{3} E_\gamma^k - E_\gamma^i$ (keV)
Intensity (arb.units)
0
1000
2000
3000
4000
5000
6000
7000
8000
1
10
10^2
10^3


Intermediate states matrix above 1st exited state of 162Dy
$E_\gamma^{j \neq i}$ (keV)
$4_1^+ \rightarrow 2_1^+$ transition (E_γ = 185.002 keV)
$\sum_{k=1}^{3} E_\gamma^k - E_\gamma^i$ (keV)
Intensity (arb.units)
0
1000
2000
3000
4000
5000
6000
7000
8000
1
10
10^2

What input to DICEBOX simulation will translate to that?

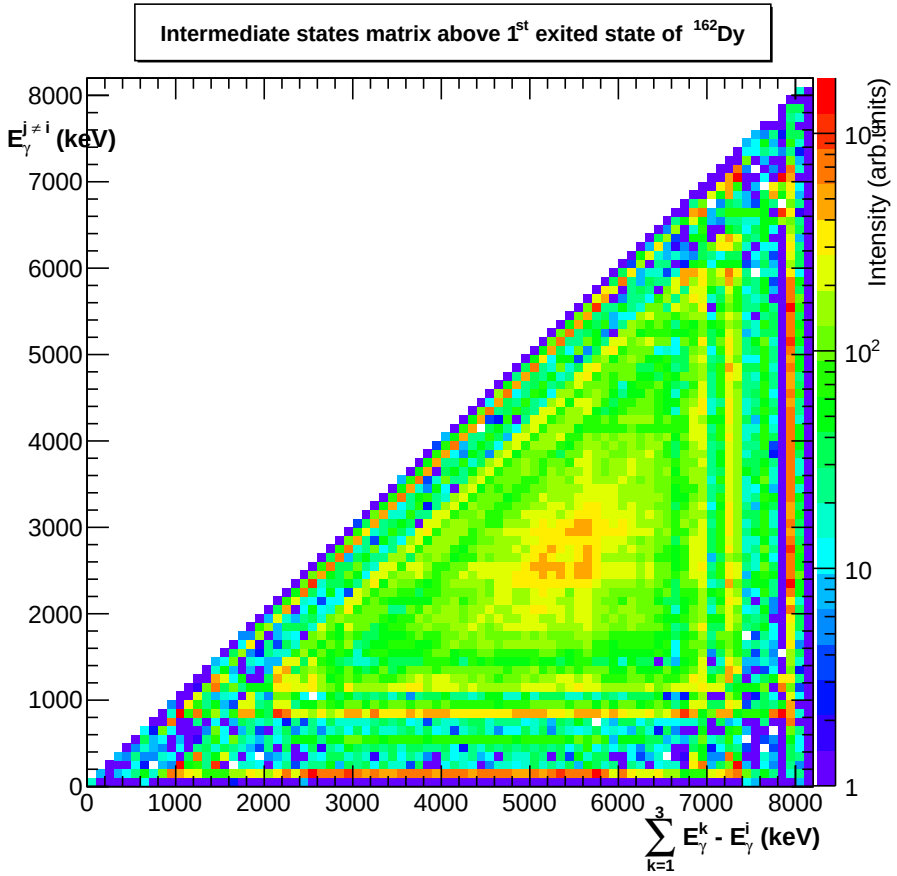
no SM at all?

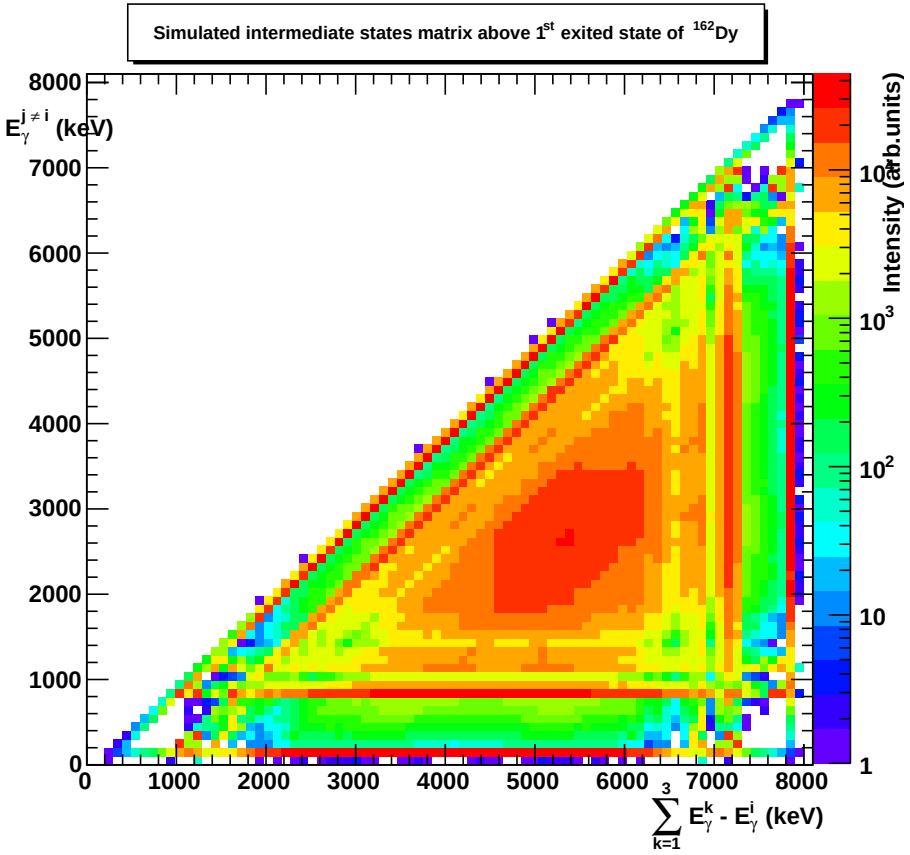




What input to DICEBOX simulation will translate to that?

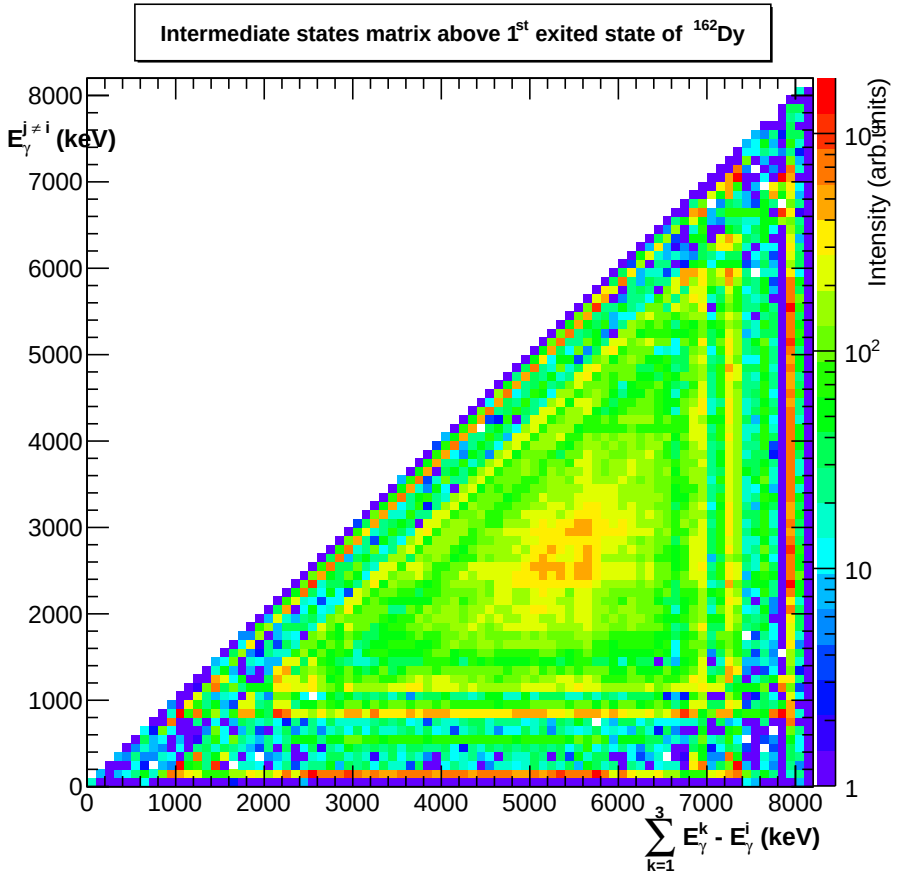
no SM above 3 MeV of excitation energy?

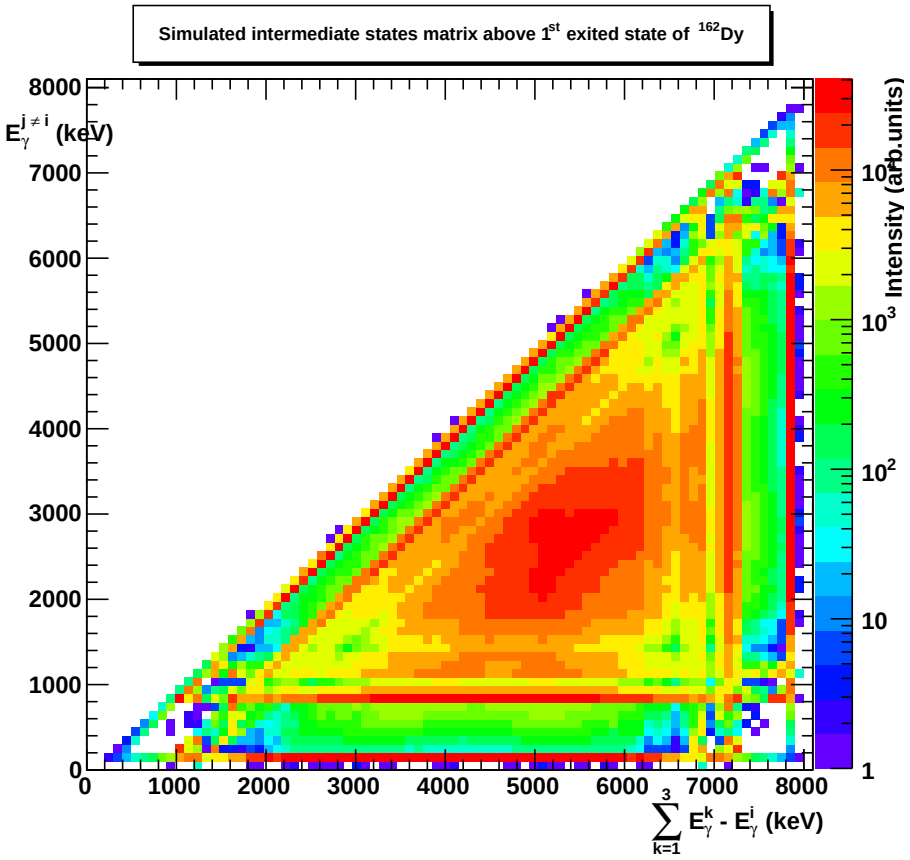




What input to DICEBOX simulation will translate to that?

SM built on all states?





TODO list:

- GEANT simulations of detectors:
  - total efficiency for higher E_γ
  - parasitic efects = crosstalk
- simulations under various assumptions
- compare the experimental spectra with simulations
- comparison with other results
- talk at 5^{th} Workshop on NLD and GS in Oslo 2015

Comparison with other data