Development of a Monte Carlo model for the Argonne Total Absorption Gamma-ray Spectrometer (TAGS)

Michael L. Smith
PhD student
Department of Nuclear Physics, ANU
and
[Nuclear Engineering Division, ANL]

THE AUSTRALIAN NATIONAL UNIVERSITY

Argonne NATIONAL LABORATORY

People

THE AUSTRALIAN NATIONAL UNIVERSITY

Dr. Greg Lane

Prof. George Dracoulis

Argonne NATIONAL LABORATORY

Dr. Filip Kondev

Dr. C. J. (Kim) Lister

UMASS LOWELL

Prof. Partha Chowdhury

Funding:

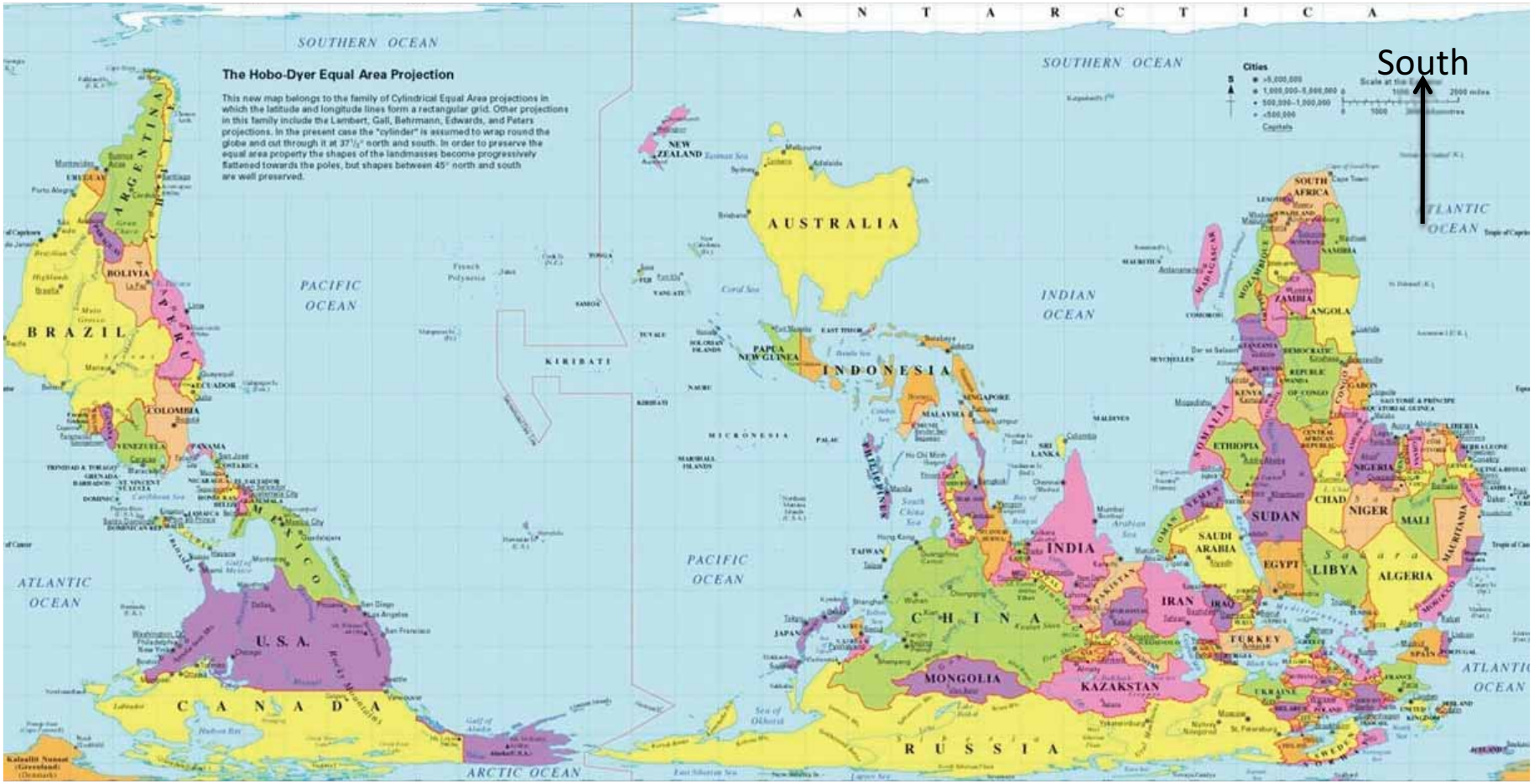
U.S. DEPARTMENT OF ENERGY

Where?

THE AUSTRALIAN NATIONAL UNIVERSITY

Where?

THE AUSTRALIAN NATIONAL UNIVERSITY

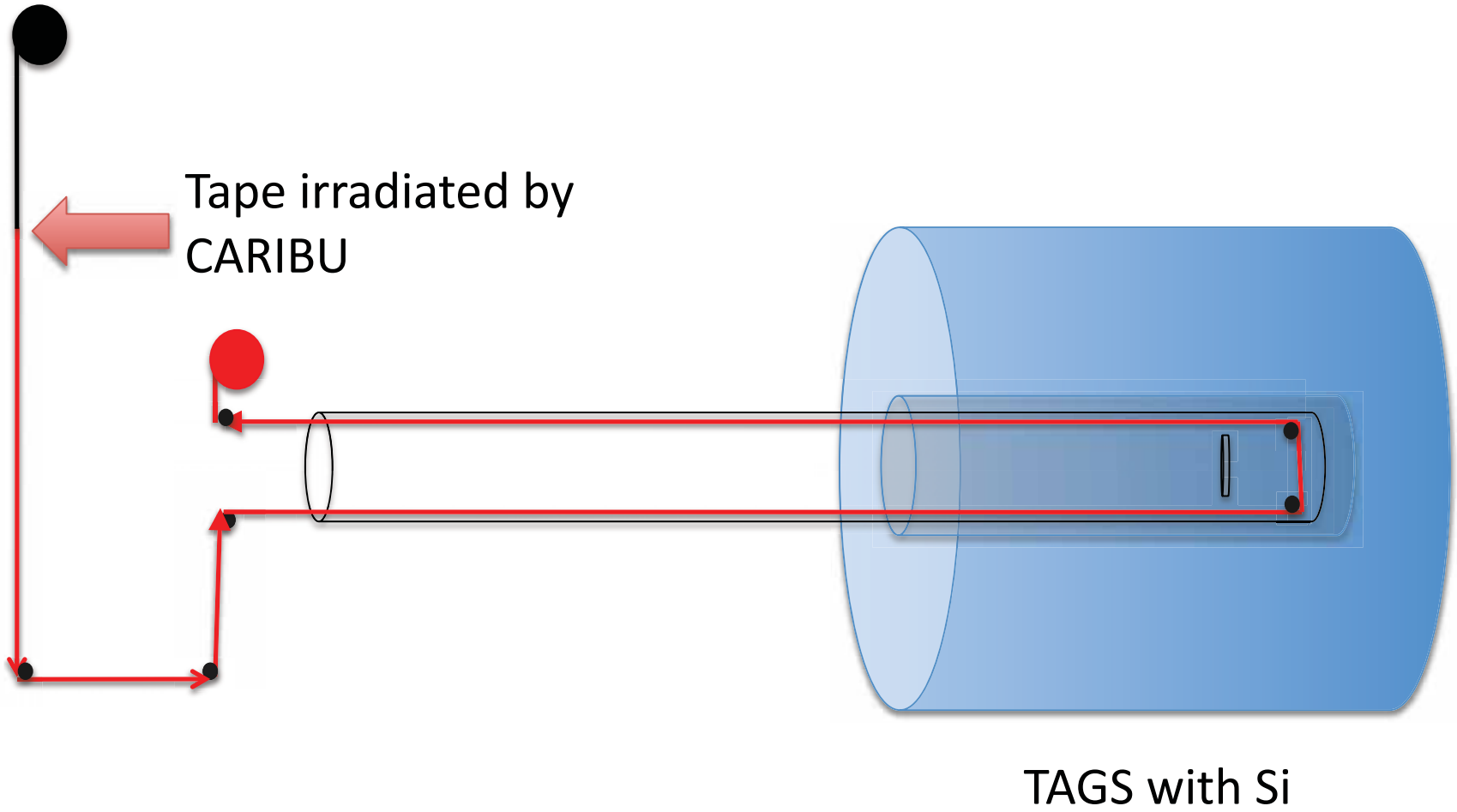


Where?

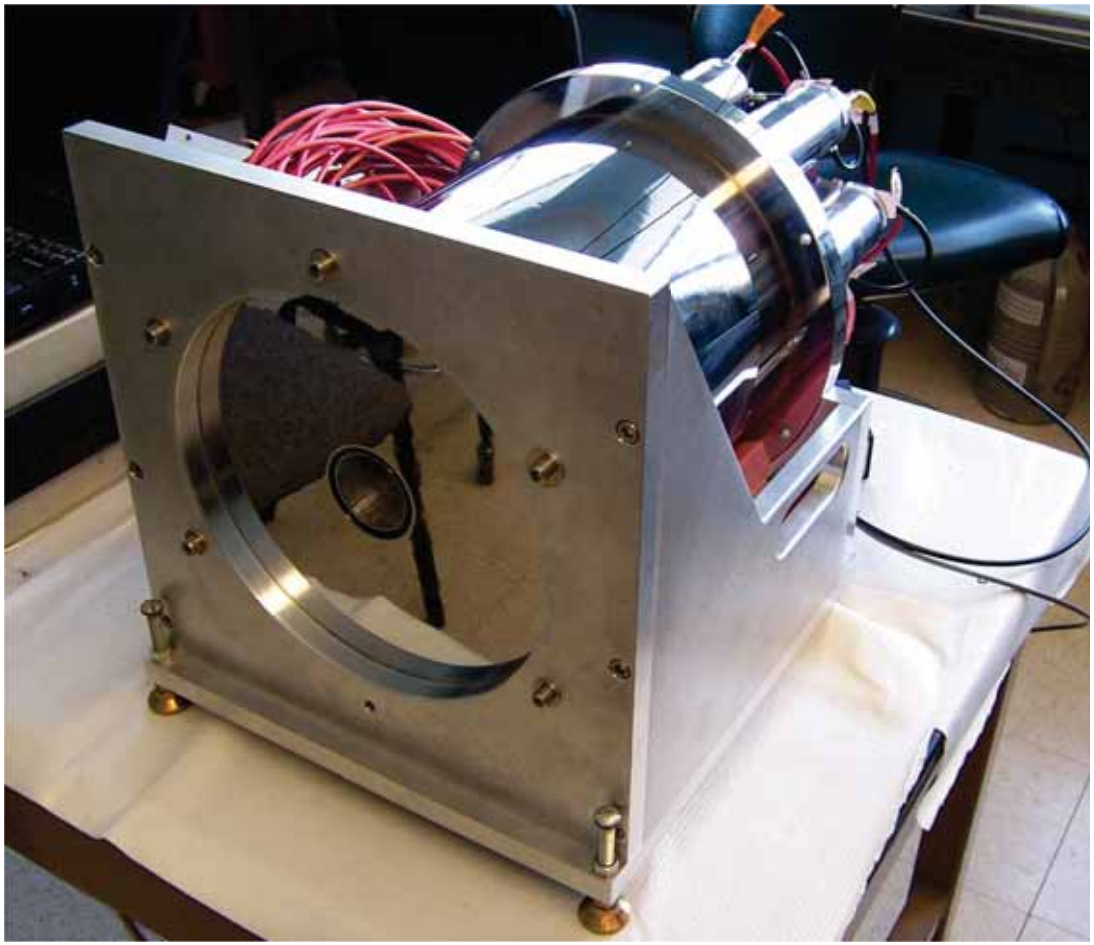
THE AUSTRALIAN NATIONAL UNIVERSITY

Canberra, Australian Capital Territory

Population:
345,000


Tape irradiated by
CARIBU
TAGS with Si

The TAGS detector



NaI(Tl) TAGS detector at Argonne

Original detector used by Greenwood et al @ Idaho.

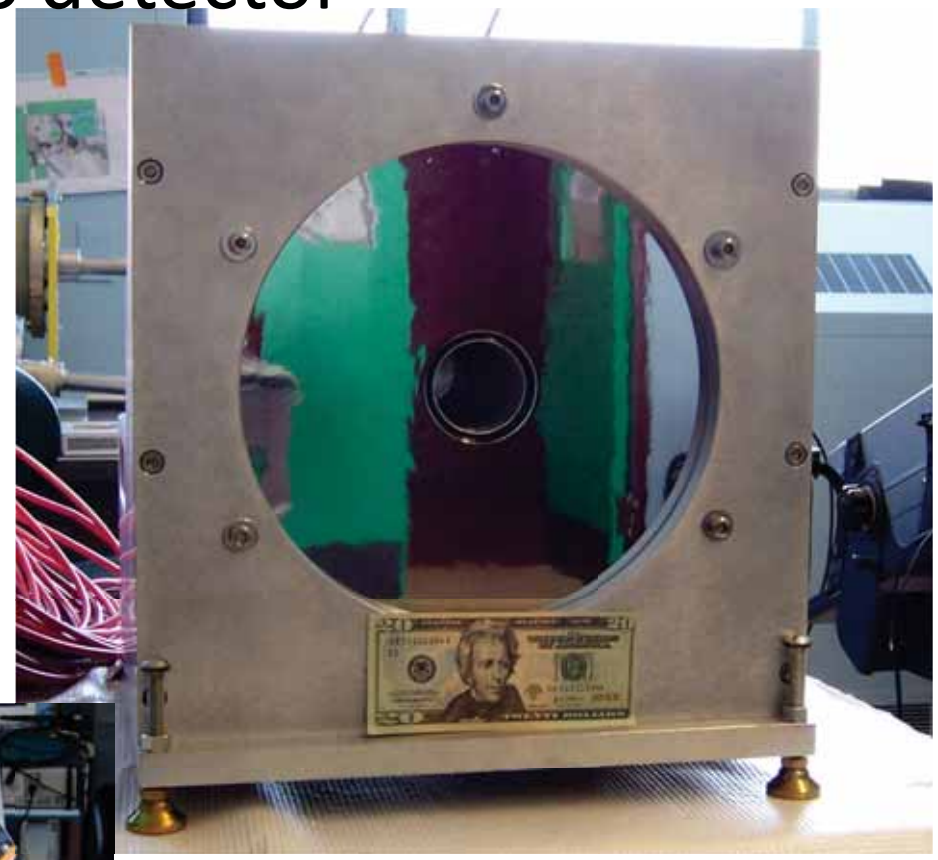
Greenwood et al. 1992 NIMA 314 pg514-540

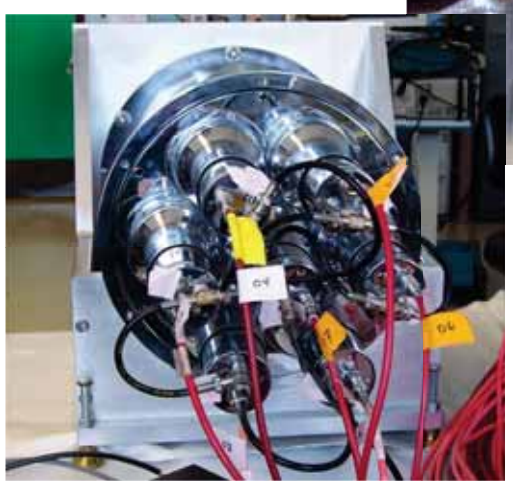
The TAGS detector

NaI(Tl) detector dimensions:
25.4 cm diameter x 30.5 cm length

Well Dimensions:
5.1 cm diameter x 20.3 cm length

7 x PMTs





GEANT4: Geometry ANd Tracking 4

International collaboration of programmers organized through CERN, started in 1999

Based on C++, update to Fortran based GEANT3

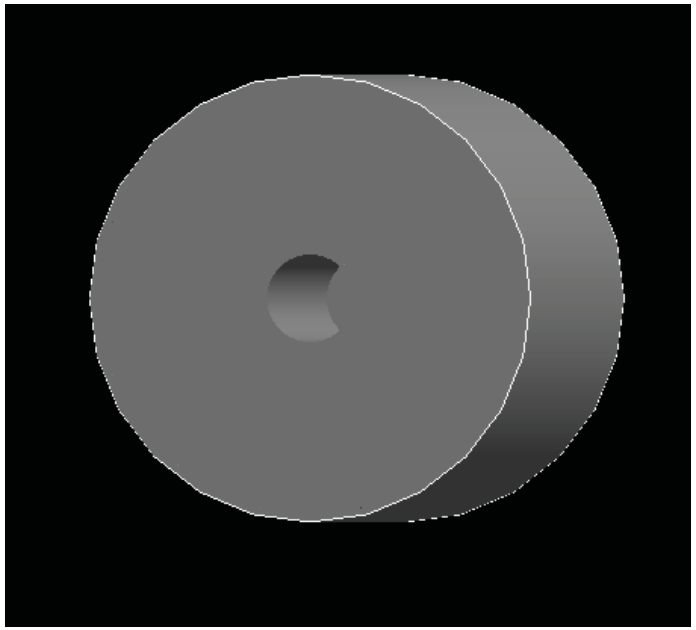
Originally intended for High Energy Physics simulations

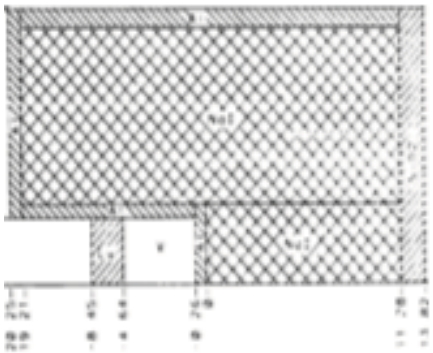
High modularity allowed greater use by the physics community

GEANT4 - NIMA 506 (2007) 250-303

TAGS model

NaI detector constructed in simulation using dimensions both measured and indicated in Greenwood

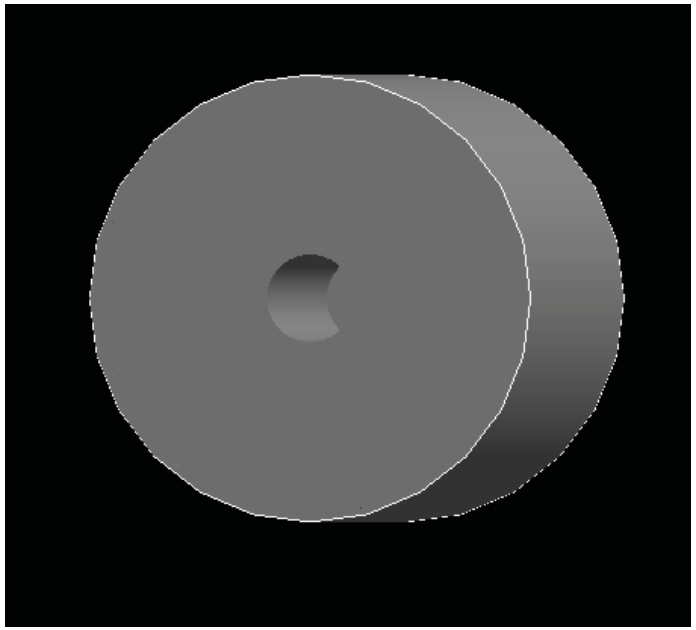




Dimensions given by Greenwood et al.

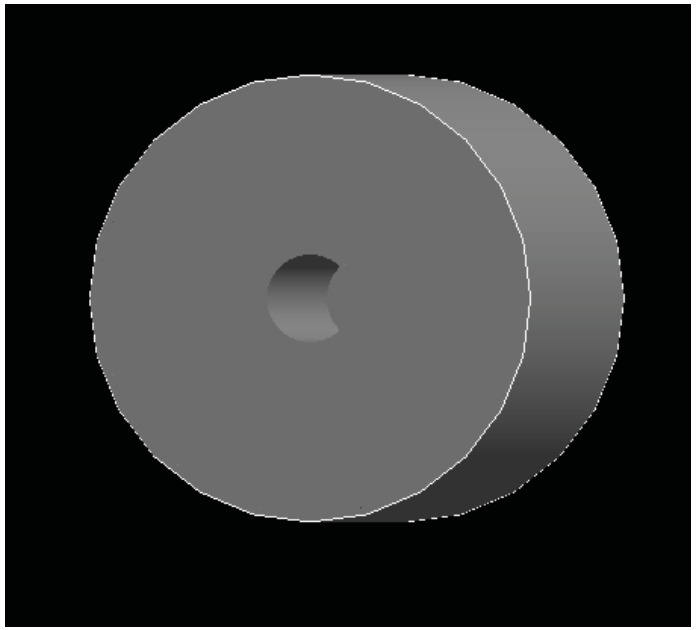
TAGS model

- Under the hood (bonnet)
- Simulation resolution
- Light non-proportionality correction
- Pile-up
- Model input
- Model output

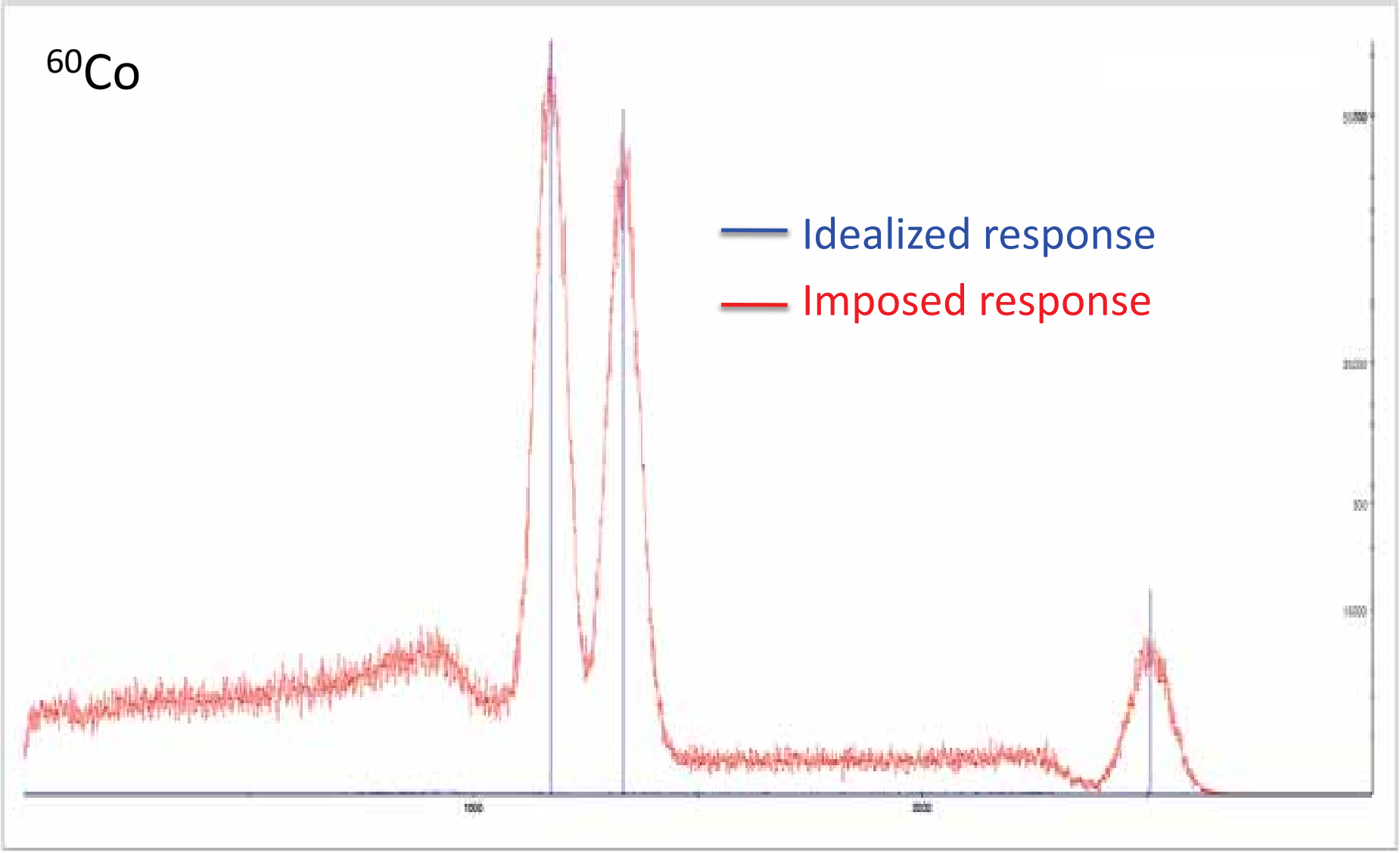


TAGS model

- Under the hood (bonnet)
- **Simulation resolution**
- Light non-proportionality correction
- Pile-up
- Model input
- Model output

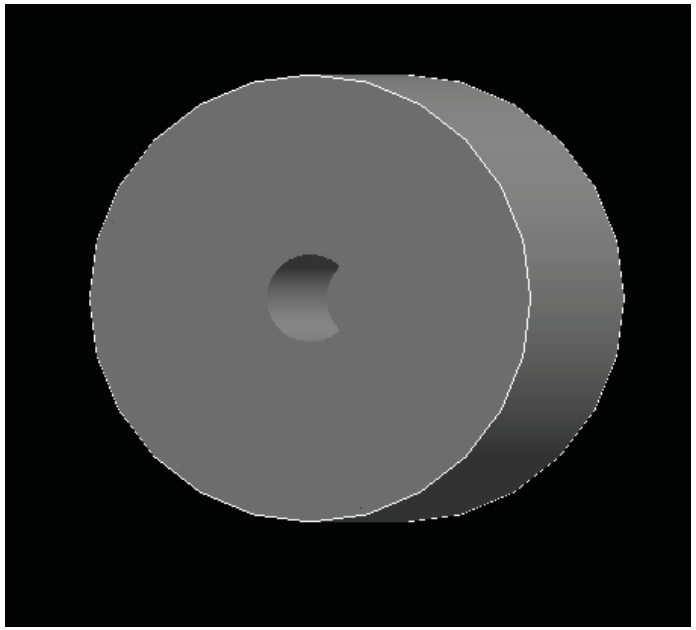


Simulation resolution



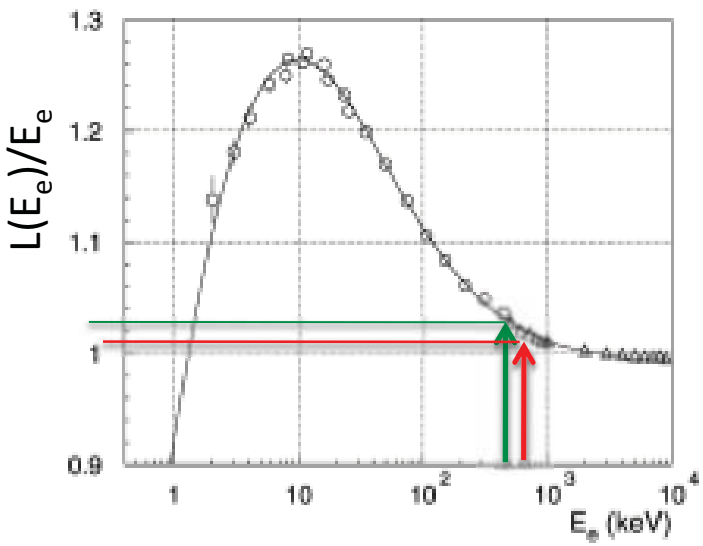
TAGS model

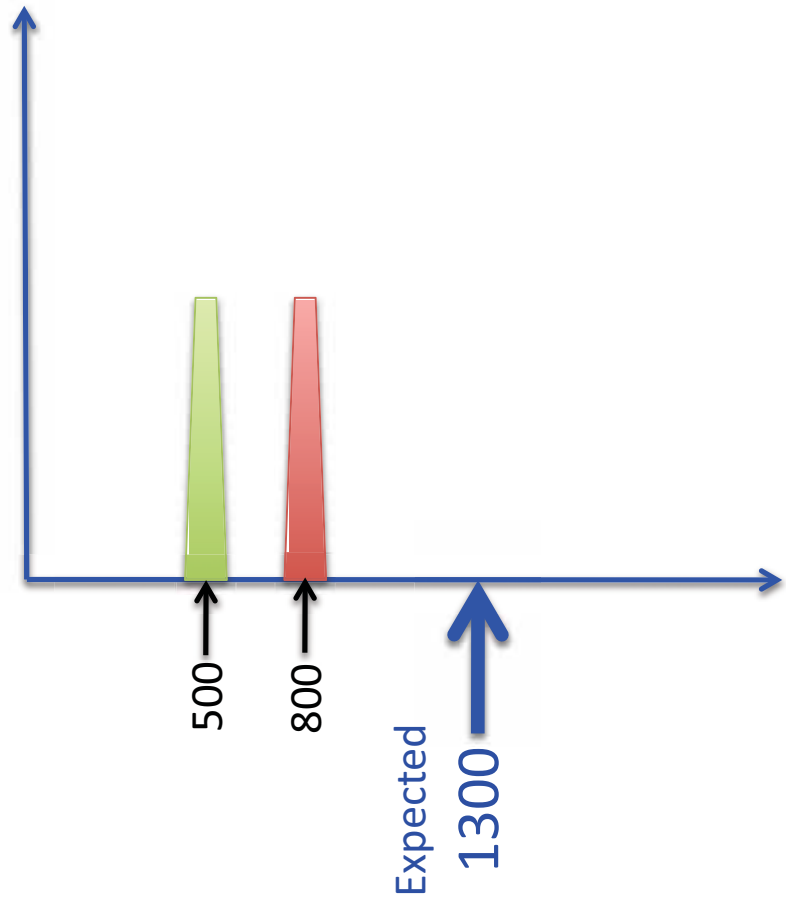
- Under the hood (bonnet)
- Simulation resolution
- Light non-proportionality correction
- Pile-up
- Model input
- Model output



Light non-proportionality correction

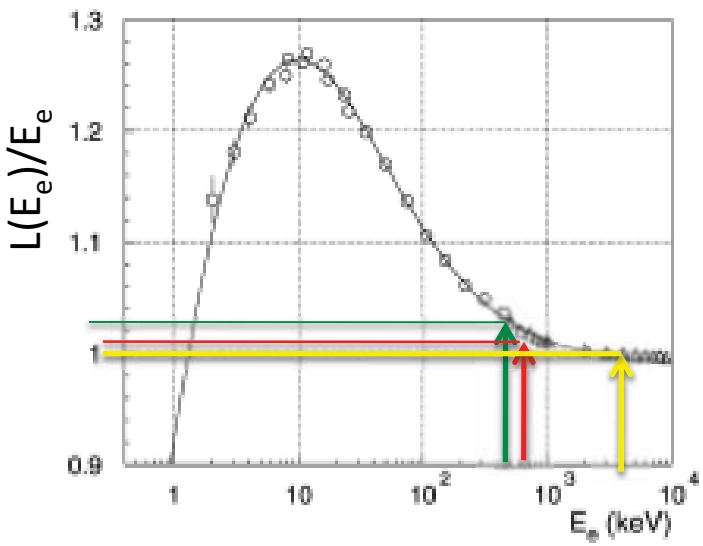
Method from Cano-Ott et al NIMA 430 (1999) pg 333 - 347

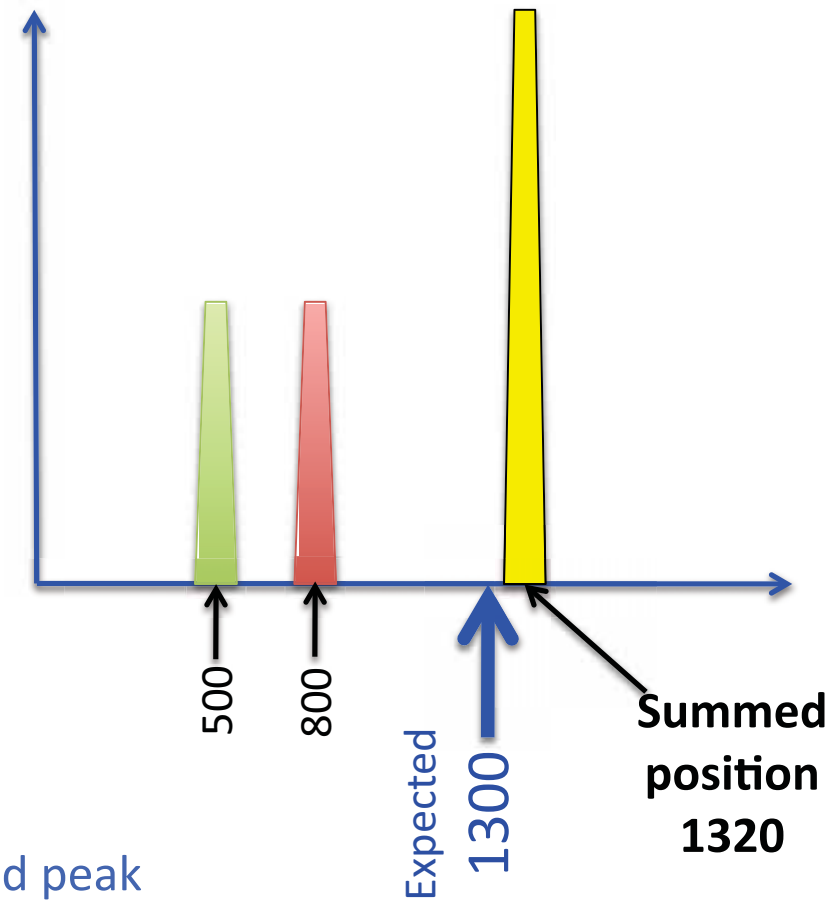




Light non-proportionality correction

Method from Cano-Ott et al NIMA 430 (1999) pg 333 - 347



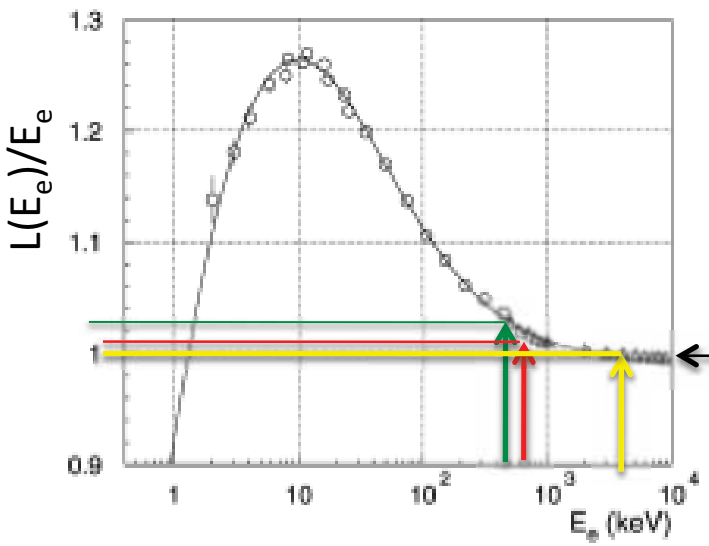


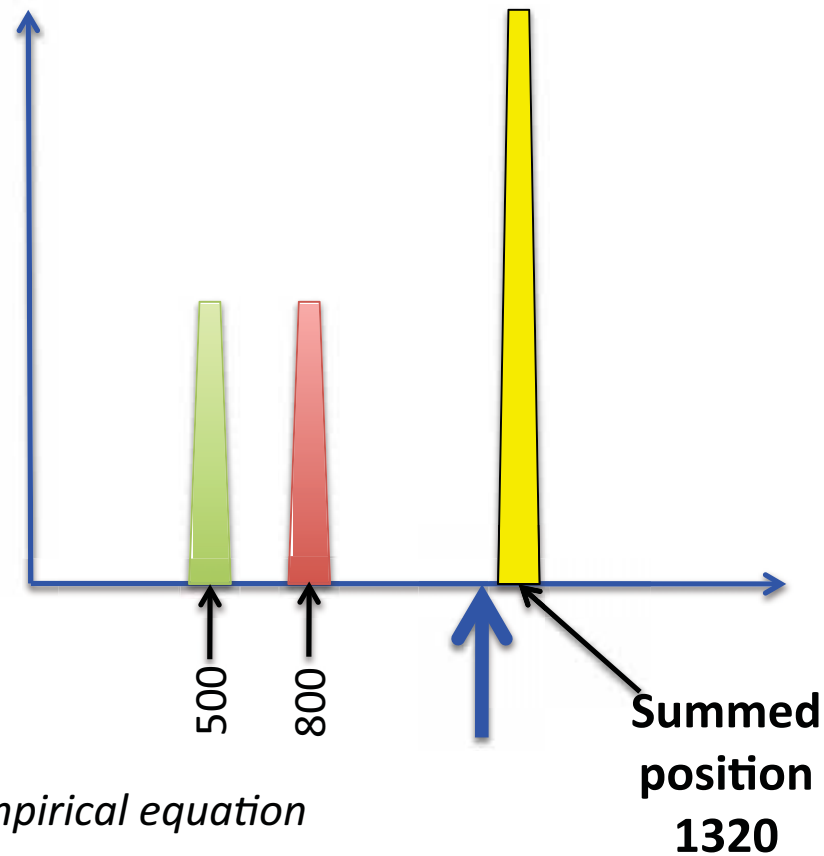
Shift in position of summed peak

More light generated for summed individual events than for a single event of the same energy

Light non-proportionality correction

Method from Cano-Ott et al NIMA 430 (1999) pg 333 - 347



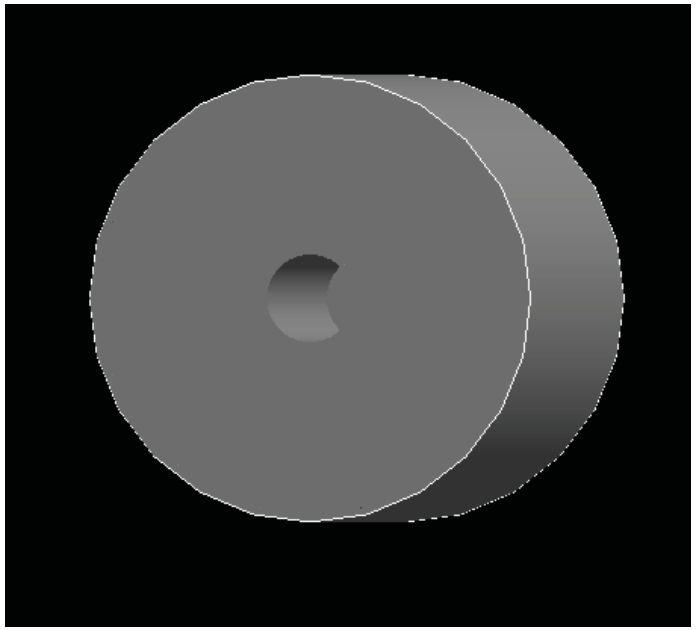


Empirical equation

$$\frac{L}{E_e} = \frac{a_1(1 - e^{-a_2 E_e}) + a_3 E_e + a_4 E_e^2}{a_5 + a_6 E_e + a_7 E_e^2}$$

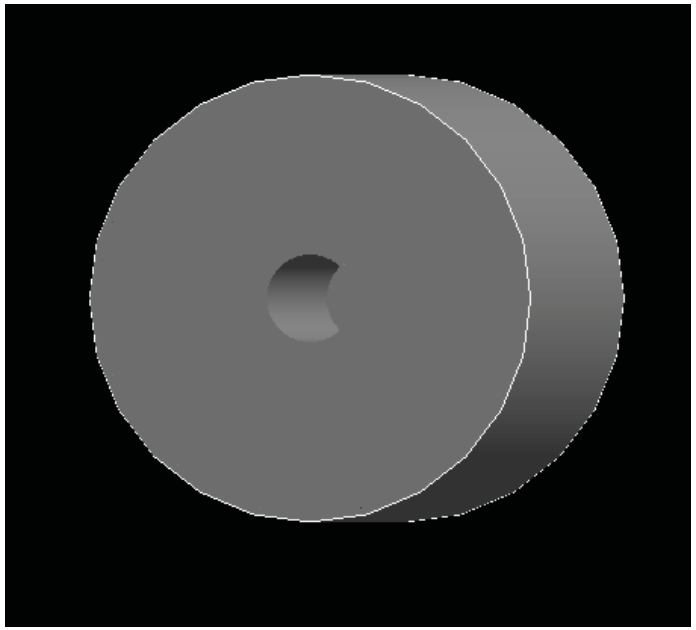
TAGS model

- Under the hood (bonnet)
- Simulation resolution
- Light non-proportionality correction
- Pile-up
- Model input
- Model output



TAGS model

- Under the hood (bonnet)
- Simulation resolution
- Light non-proportionality correction
- Pile-up
- **Model input**
- Model output



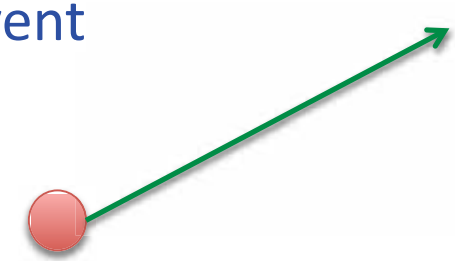
Model input

Standard particle gun:

Shoots particles

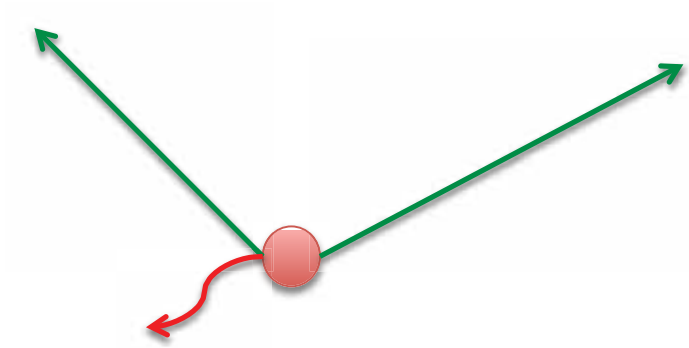
you define - Particle type
- Direction
- Energy

One particle per event

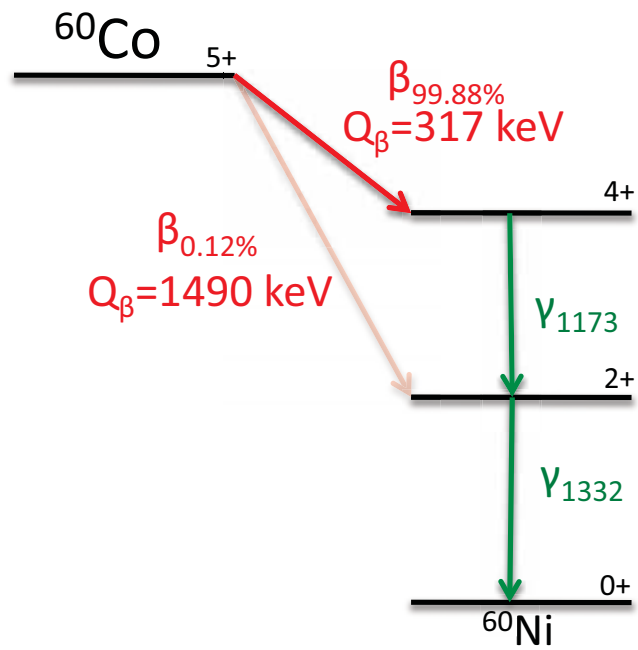


Radioactive Decay Module:

Define Co-60 and run.



single event



Decay information controlled by input files, default data from ENSDF

Transition type

$t_{1/2}$

E

$I_{\beta-}$

Q

Ground state

Excited state

```
#  60CO (5.2714 y)
#  Excitation   Halflife Mode       Daughter Ex  Intensity          Q
#  60CO (10.467 m)
#  Excitation   Halflife Mode       Daughter Ex  Intensity          Q
#
# File sanitized by Vanderbilt Decay-o-matic
# $Id: repair_decay_files.py,v 1.20 2006/04/24 14:53:36 marcus Exp $
# Fri Oct  6 15:26:19 2006
#
P       0.0000   1.6640e+08
                        BetaMinus       0.0000   1.0000e+00
                        BetaMinus    1332.5080   1.2000e-01    1491.3920
                        BetaMinus    2505.7480   9.9880e+01     318.1520
P      58.5900   6.2800e+02
                        BetaMinus       0.0000   2.4000e-03
                               IT       0.0000   9.9760e-01
                        BetaMinus    1332.5170   2.2990e-01    1549.7260
                        BetaMinus    2158.8100   8.4000e-03     723.4330
```

Decay input file for z27.a60

Starting level keV

Transition probability %

Angular momentum

Partial Conversion probabilities

						K	L1	L2	L3	M1	M2	M3	M4	M5	N+
1.332518e+03	1.332501e+03	1.000e+02	-2	7.13e-13	2.00	1.260e-04	8.968e-01	8.492e-02	6.714e-04	8.175e-04	1.262e-02	9.603e-05	1.159e-04	1.913e-08	3.881e-08	4.262e-03
2.158640e+03	8.260600e+02	1.000e+02	-2	5.90e-13	2.00	3.890e-04	8.946e-01	8.483e-02	1.167e-03	1.272e-03	1.252e-02	1.668e-04	1.817e-04	4.499e-08	6.812e-08	4.293e-03
2.158640e+03	2.158570e+03	1.760e+01	-2	5.90e-13	2.00	4.940e-05	8.968e-01	8.502e-02	3.887e-04	5.810e-04	1.259e-02	5.567e-05	8.300e-05	8.057e-09	2.591e-08	4.251e-03
2.284870e+03	9.524000e+02	1.000e+02	1	1.50e-12	0.00	1.150e-04	8.957e-01	8.478e-02	4.452e-04	1.026e-03	1.252e-02	6.391e-05	1.461e-04	2.748e-08	7.000e-08	4.243e-03
2.284870e+03	2.284870e+03	0.000e+00	0	1.50e-12	0.00	2.520e-04	8.968e-01	8.651e-02	1.190e-03	4.762e-04	1.282e-02	1.706e-04	6.825e-05	2.940e-08	1.214e-08	4.365e-03
2.505766e+03	3.469300e+02	7.600e-03	1	1.10e-12	4.00	1.270e-03	8.976e-01	8.504e-02	1.000e-03	1.803e-03	1.244e-02	1.425e-04	2.567e-04	1.362e-07	2.252e-07	4.276e-03
2.505766e+03	1.173237e+03	1.000e+02	-2	1.10e-12	4.00	1.660e-04	8.976e-01	8.554e-02	7.771e-04	9.096e-04	1.259e-02	1.120e-04	1.301e-04	2.416e-08	4.446e-08	4.283e-03
2.505766e+03	2.505000e+03	2.000e-06	-4	1.10e-12	4.00	8.630e-05	8.969e-01	8.552e-02	8.285e-04	4.751e-04	1.275e-02	1.182e-04	6.802e-05	1.010e-08	1.727e-08	4.287e-03
2.626080e+03	1.205000e+02	5.500e+00	1	6.00e-13	3.00	2.880e-02	8.958e-01	8.125e-02	2.076e-03	3.576e-03	1.198e-02	2.951e-04	5.104e-04	7.222e-07	1.049e-06	4.271e-03
2.626080e+03	4.673000e+02	1.000e+02	-2	6.00e-13	3.00	2.060e-03	8.932e-01	8.398e-02	2.097e-03	2.311e-03	1.238e-02	3.000e-04	3.301e-04	1.180e-07	1.510e-07	4.340e-03
2.626080e+03	1.293700e+03	5.300e+01	1	6.00e-13	3.00	6.550e-05	8.962e-01	8.473e-02	3.359e-04	8.687e-04	1.252e-02	4.809e-05	1.244e-04	1.649e-08	5.252e-08	4.229e-03
3.119700e+03	4.939000e+02	8.700e+00	1	2.40e-13	4.00	5.020e-04	8.964e-01	8.446e-02	7.689e-04	1.466e-03	1.247e-02	1.102e-04	2.092e-04	7.888e-08	1.444e-07	4.263e-03
3.119700e+03	1.787200e+03	1.000e+02	-2	2.40e-13	4.00	7.000e-05	8.971e-01	8.514e-02	4.771e-04	6.500e-04	1.257e-02	6.857e-05	9.300e-05	1.123e-08	2.971e-08	4.243e-03
3.124020e+03	4.979000e+02	3.680e+00	1	6.00e-13	2.00	4.920e-04	8.963e-01	8.435e-02	7.642e-04	1.459e-03	1.246e-02	1.093e-04	2.073e-04	7.805e-08	1.431e-07	4.268e-03

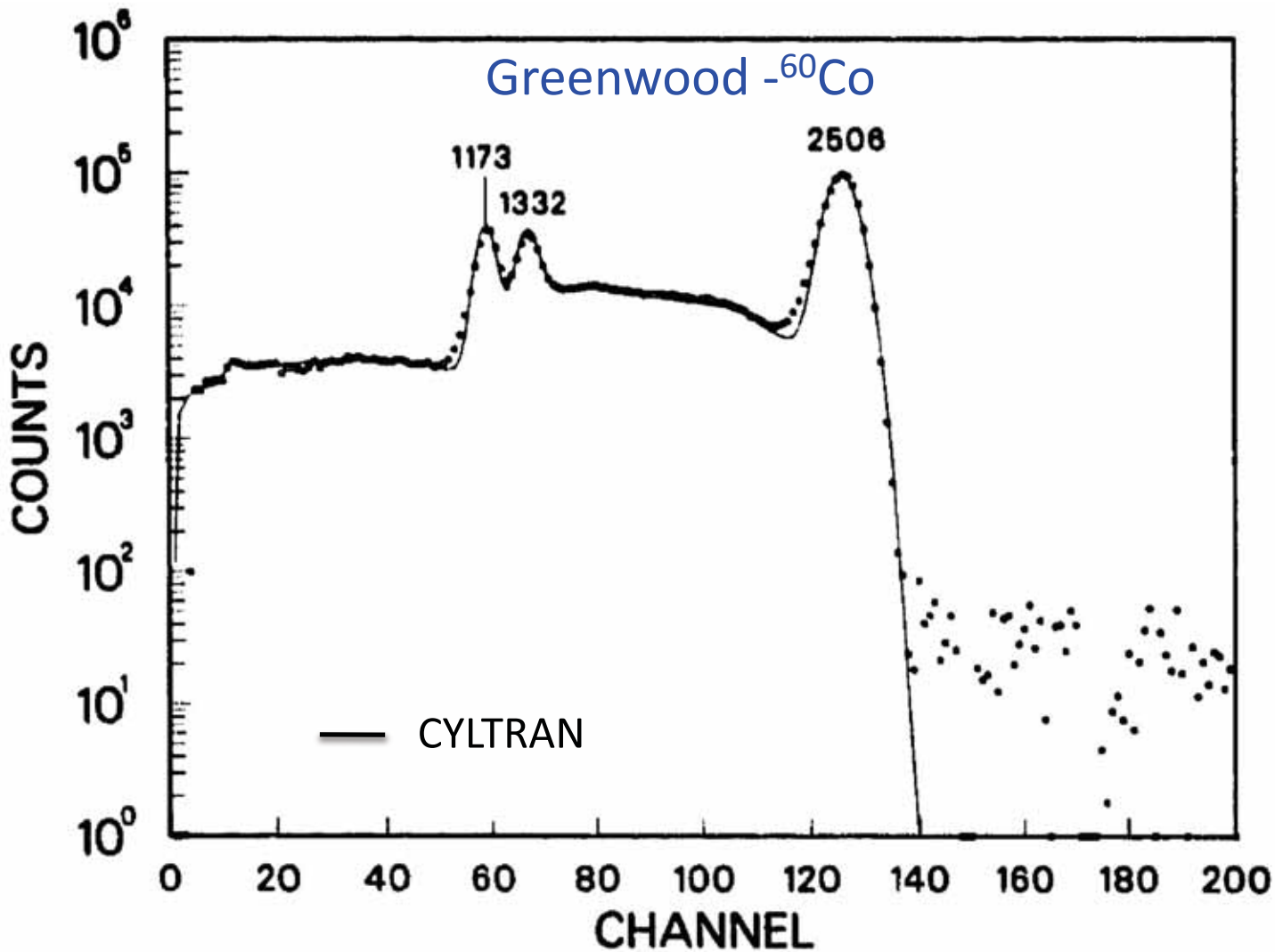
Transition energy keV

Spin parity variation

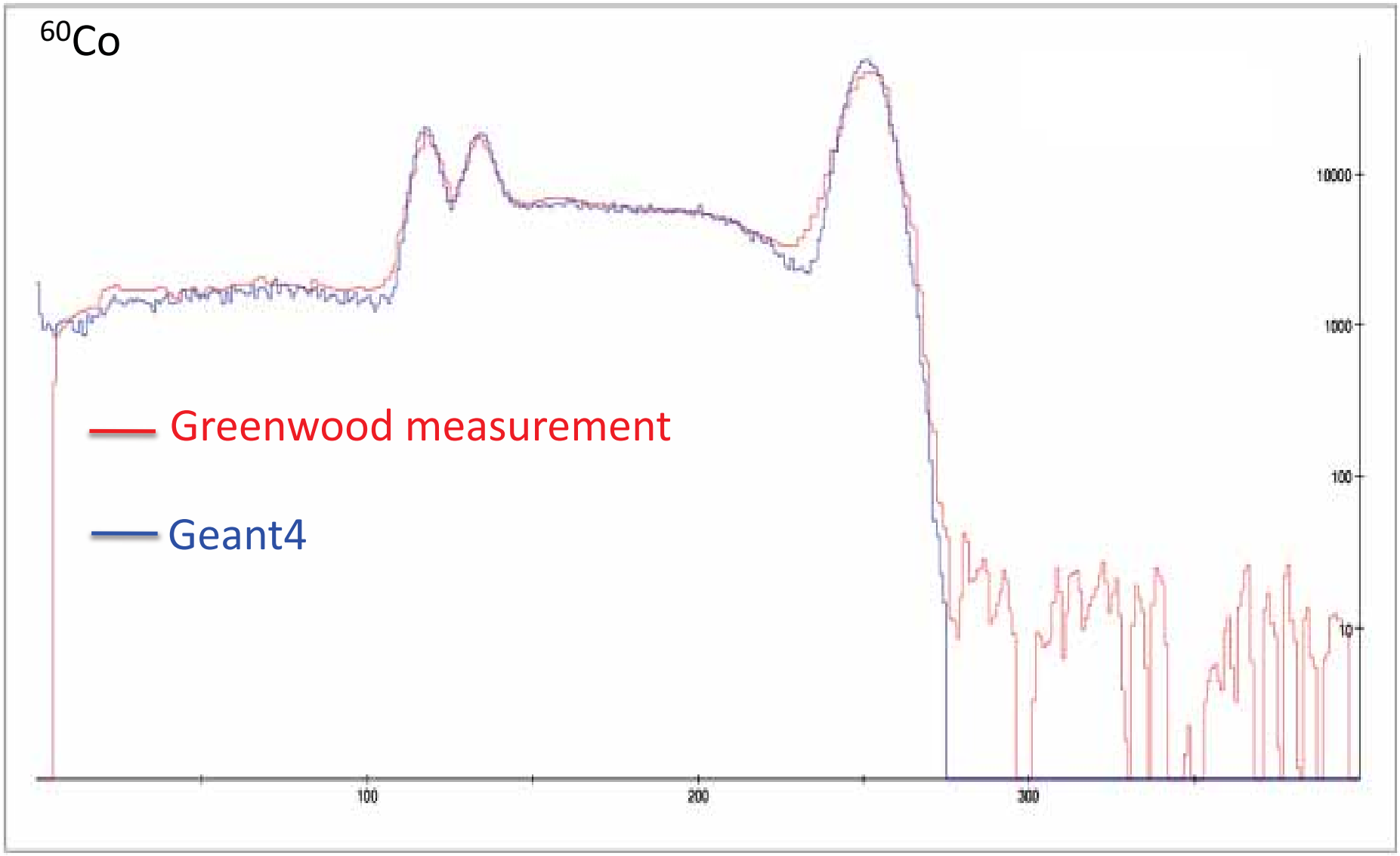
Level $t_{1/2}$

α-Total

Photo evaporation file for z28.a60

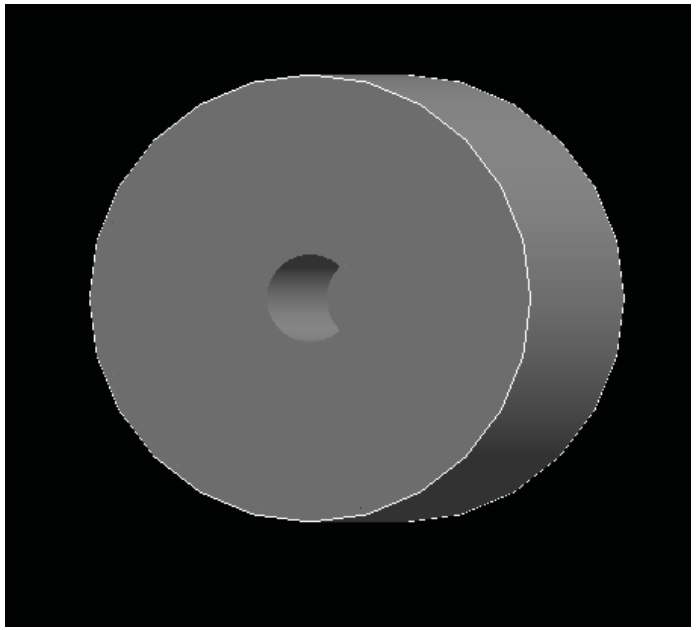


Greenwood et al. 1992 NIMA 314 pg514-540


60Co
Greenwood measurement
Geant4
10000
1000
100
10
100
200
300

TAGS model

- Under the hood (bonnet)
- Simulation resolution
- Light non-proportionality correction
- Pile-up
- Model input
- Model output



Model output

For each event:

RDM event information

Index1
Feed1
⋮
Index6
Feed6
Energy TAGS total
Energy TAGS (Feed1)
⋮
Energy TAGS (Feed6)
Energy TAGS LE correction
Energy Si Total
Energy Si-β
Energy Si- γ
PMT1
⋮
PMT6

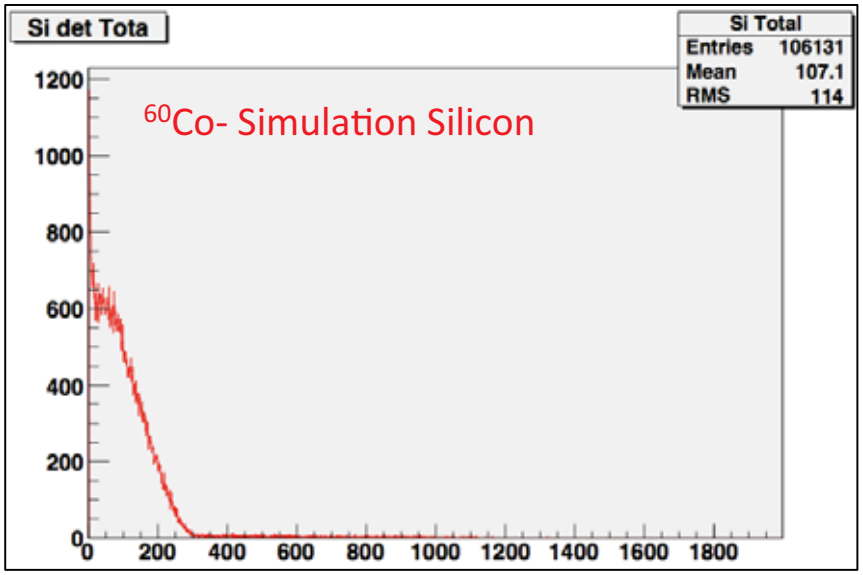
Interaction information

Where Index:

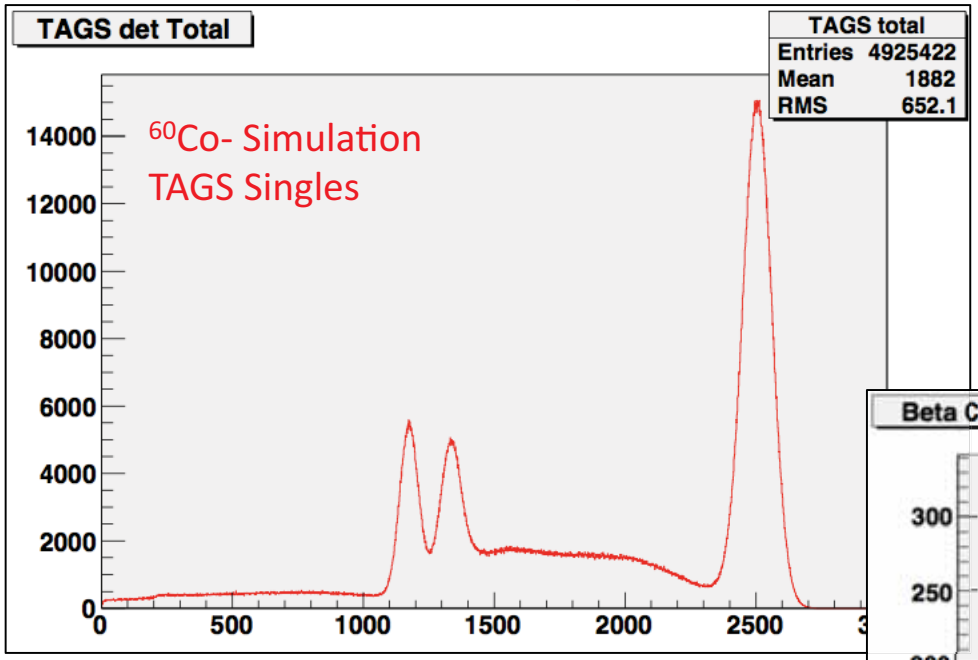
- 0- error
- 1 – e^-
- 2 – e^+
- 3 – e capture
- 4 – α
- 5 – γ

Addition of Silicon detector in the simulation

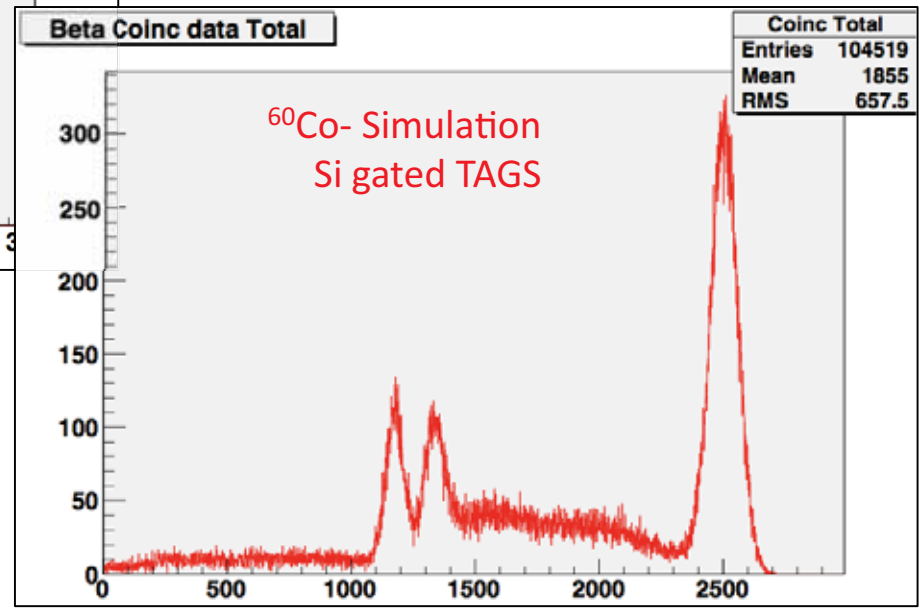
Ability to use in coincidence with TAGS



5 x 10^6 events generated

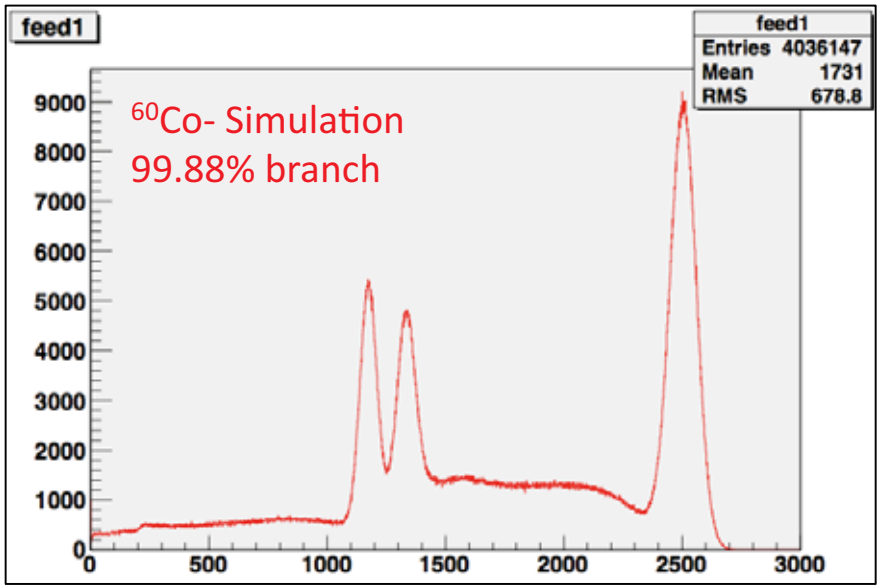


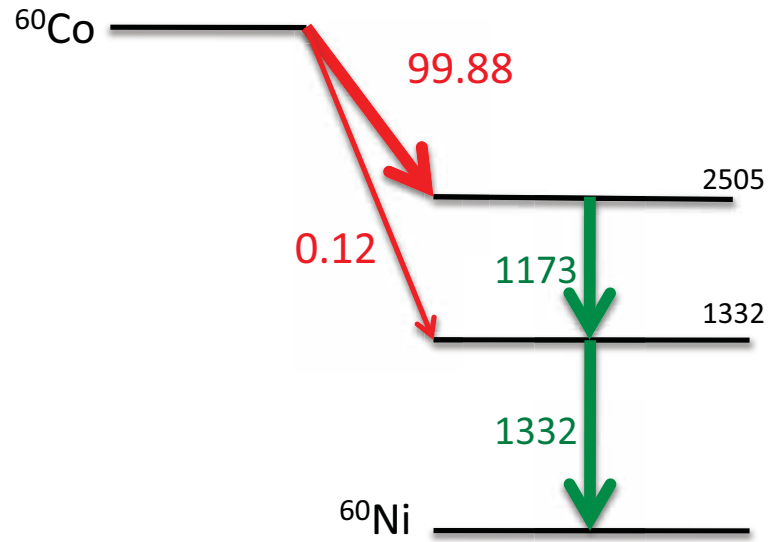
1.04 x 10^5 Si gated hits



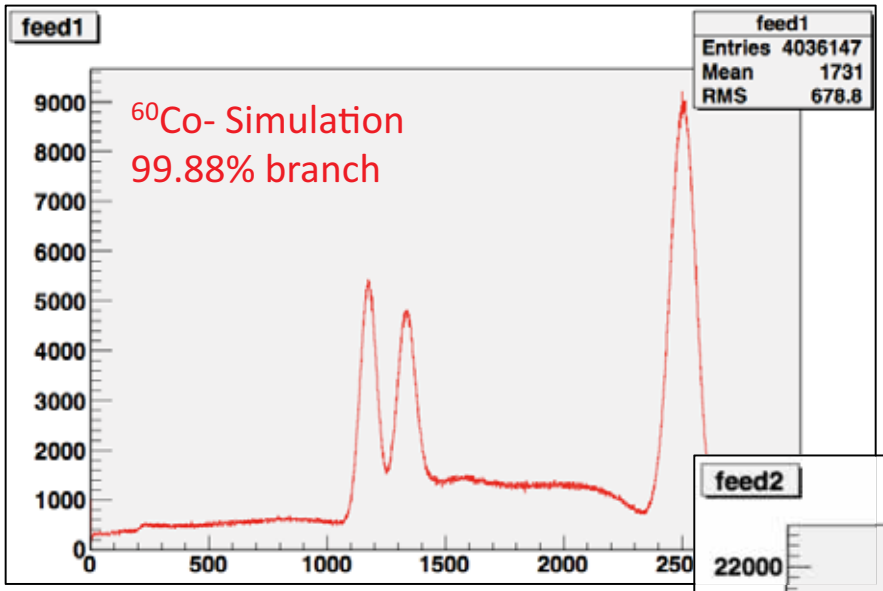
4.93 x 10^6 hit singles

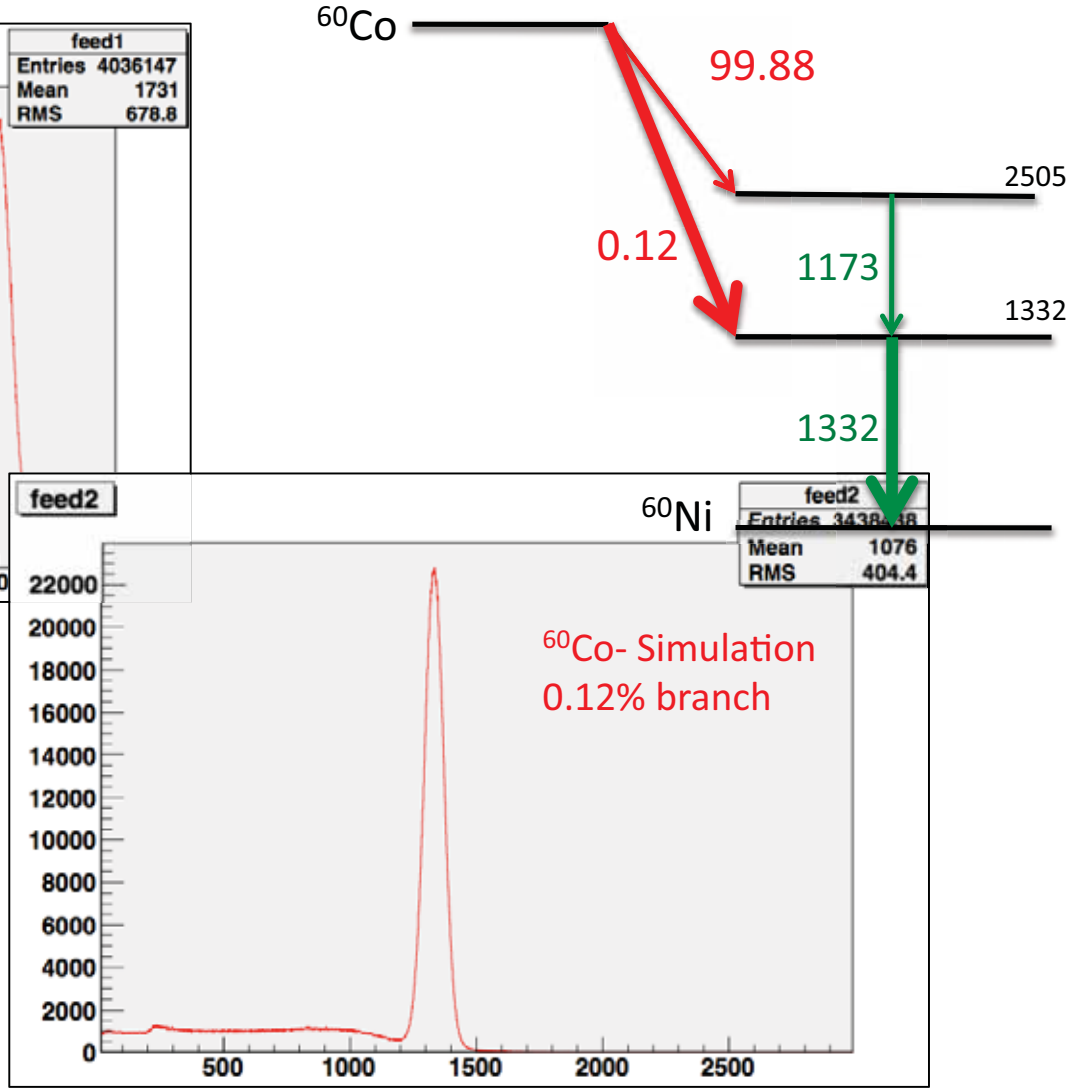
Gating with RDM information

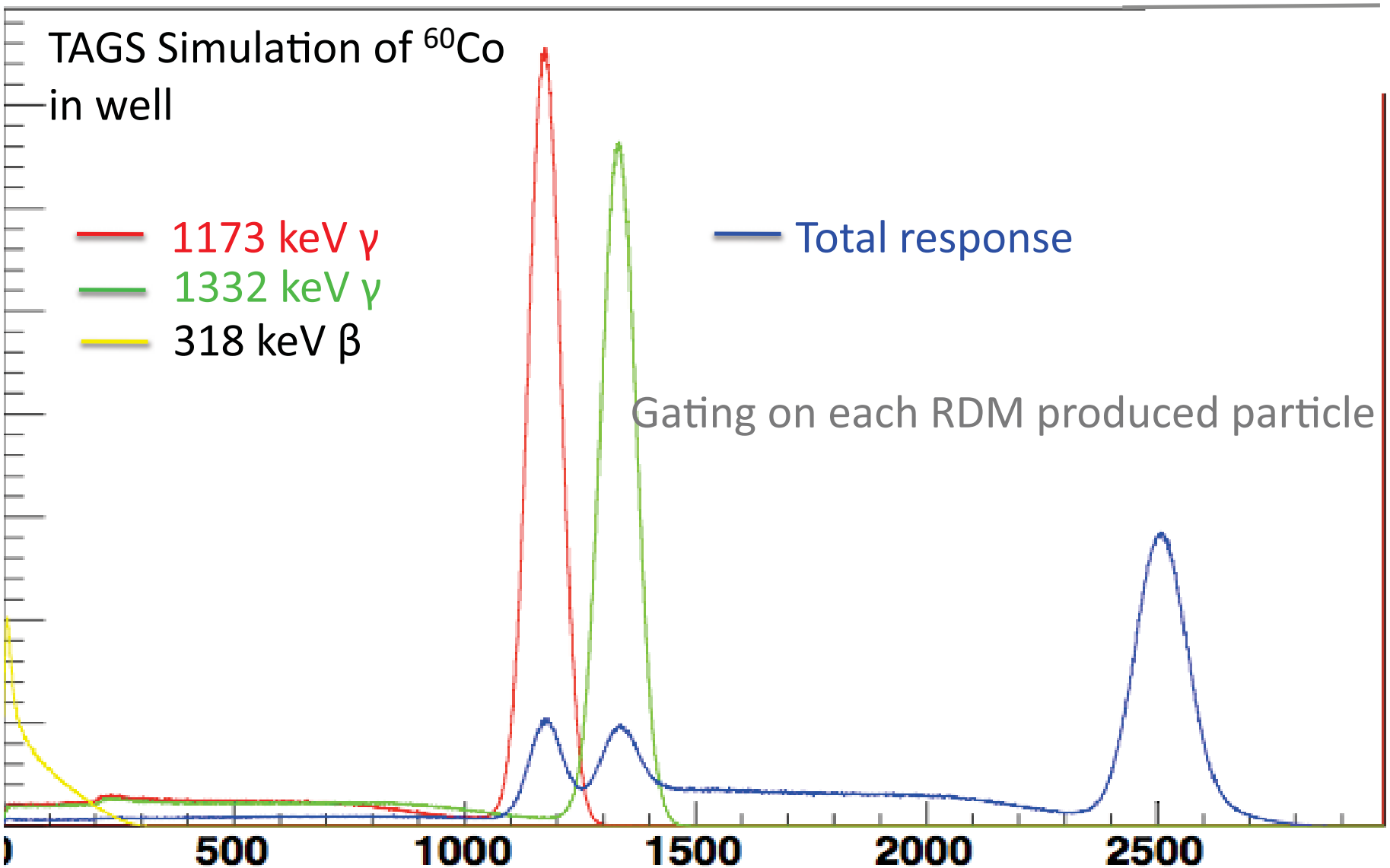




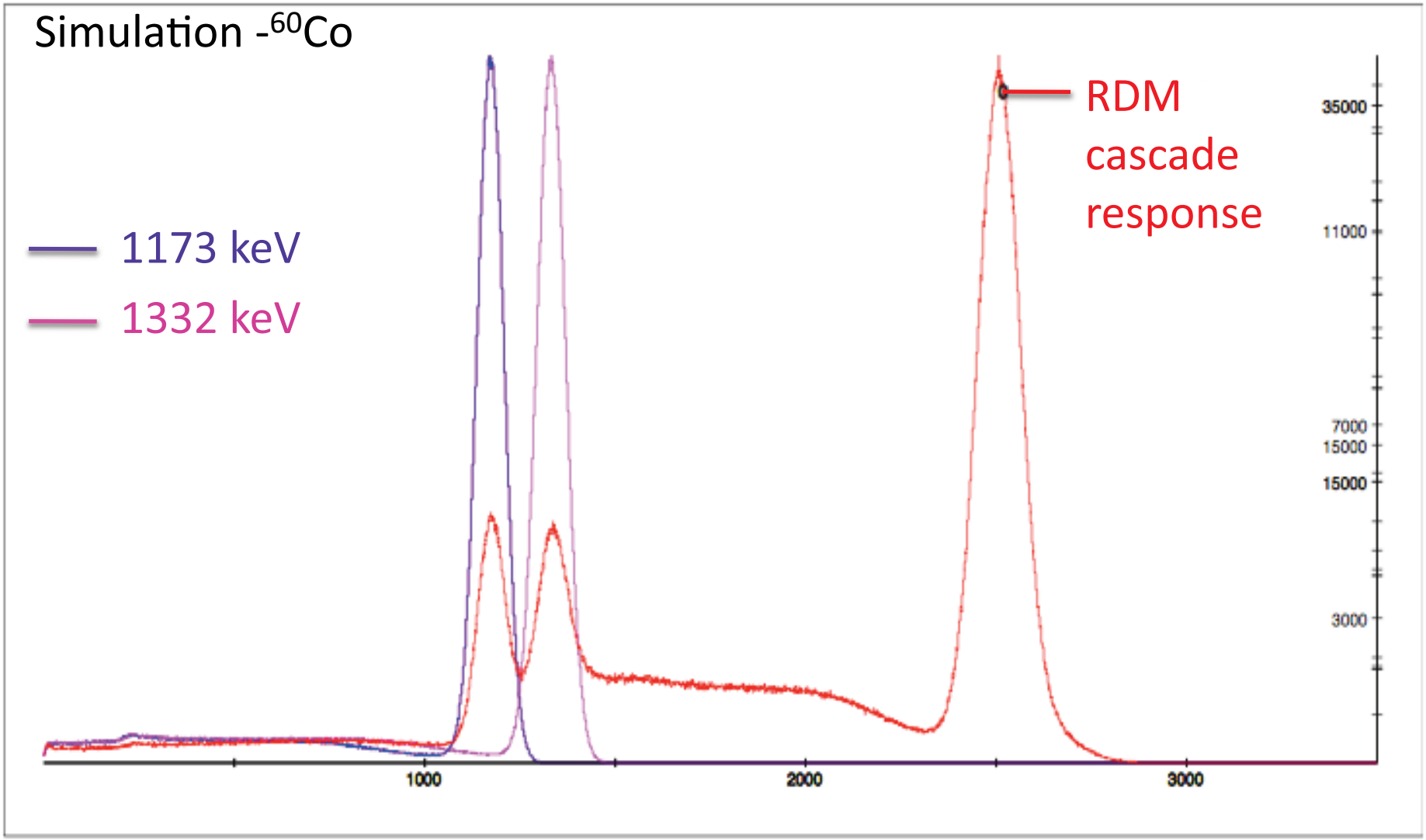
Gating with RDM information

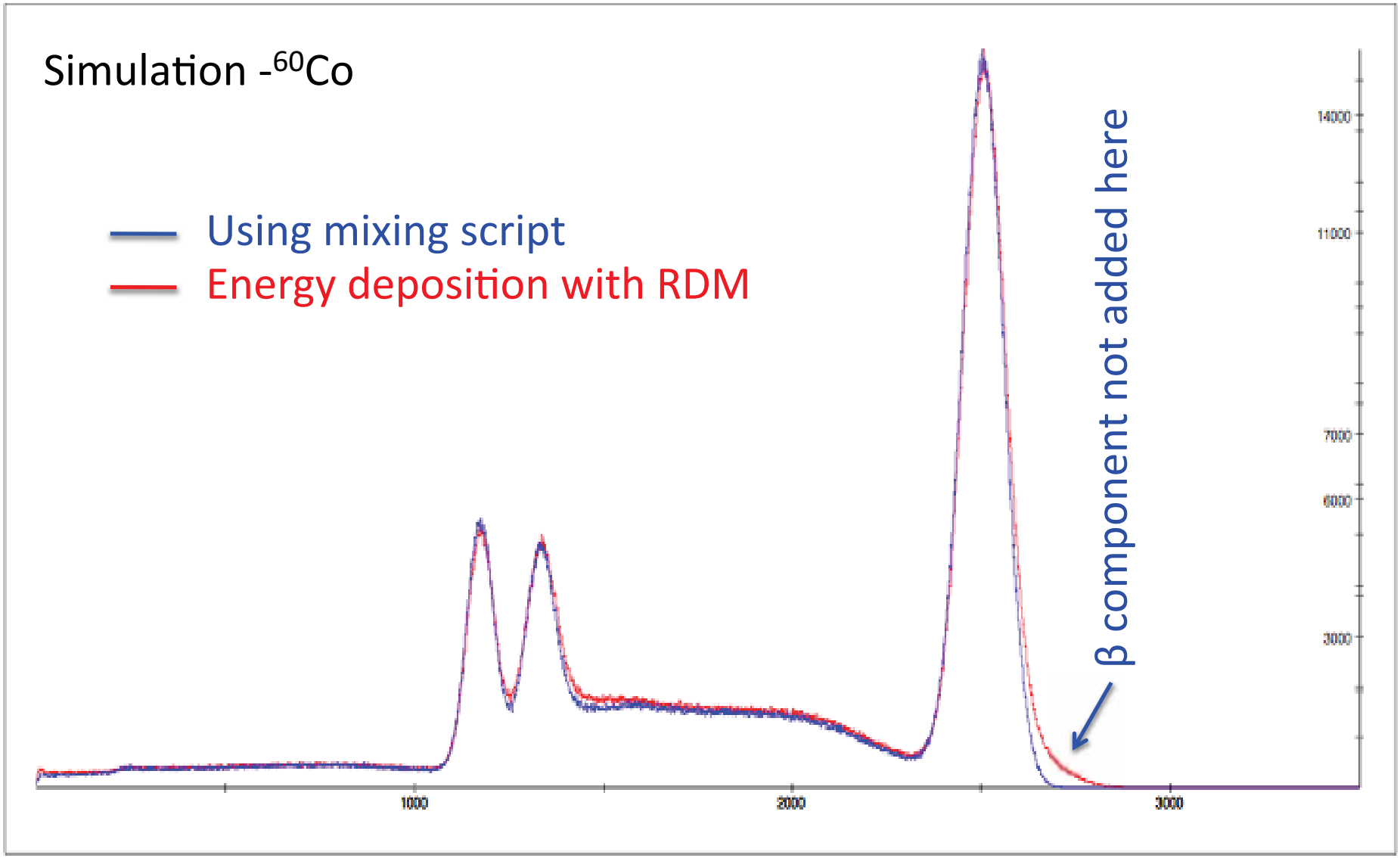




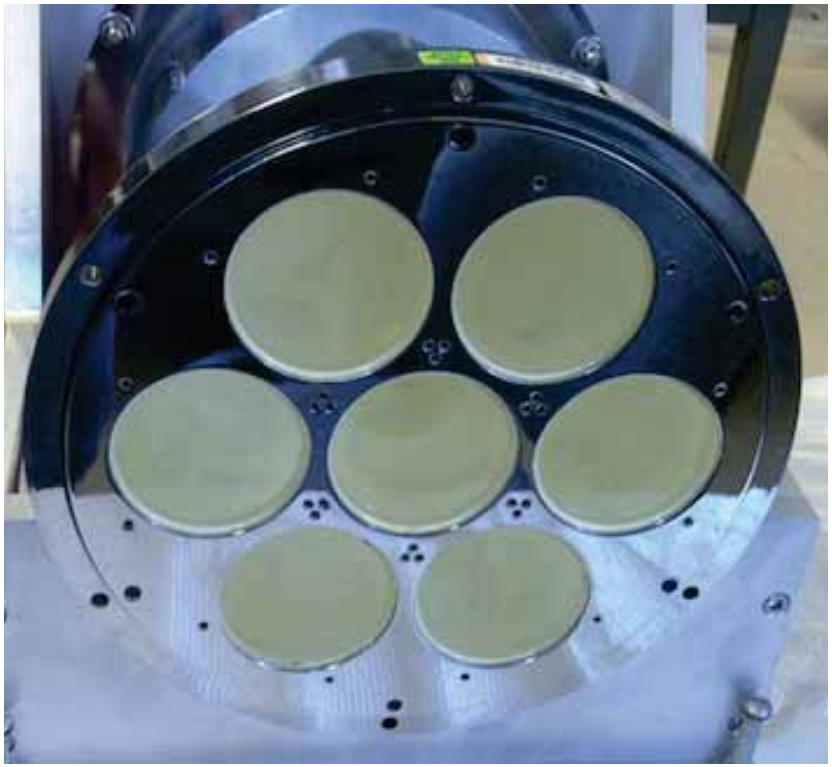

TAGS Simulation of ^{60}Co in well
1173 keV γ
1332 keV γ
318 keV β
Total response
Gating on each RDM produced particle
500
1000
1500
2000
2500

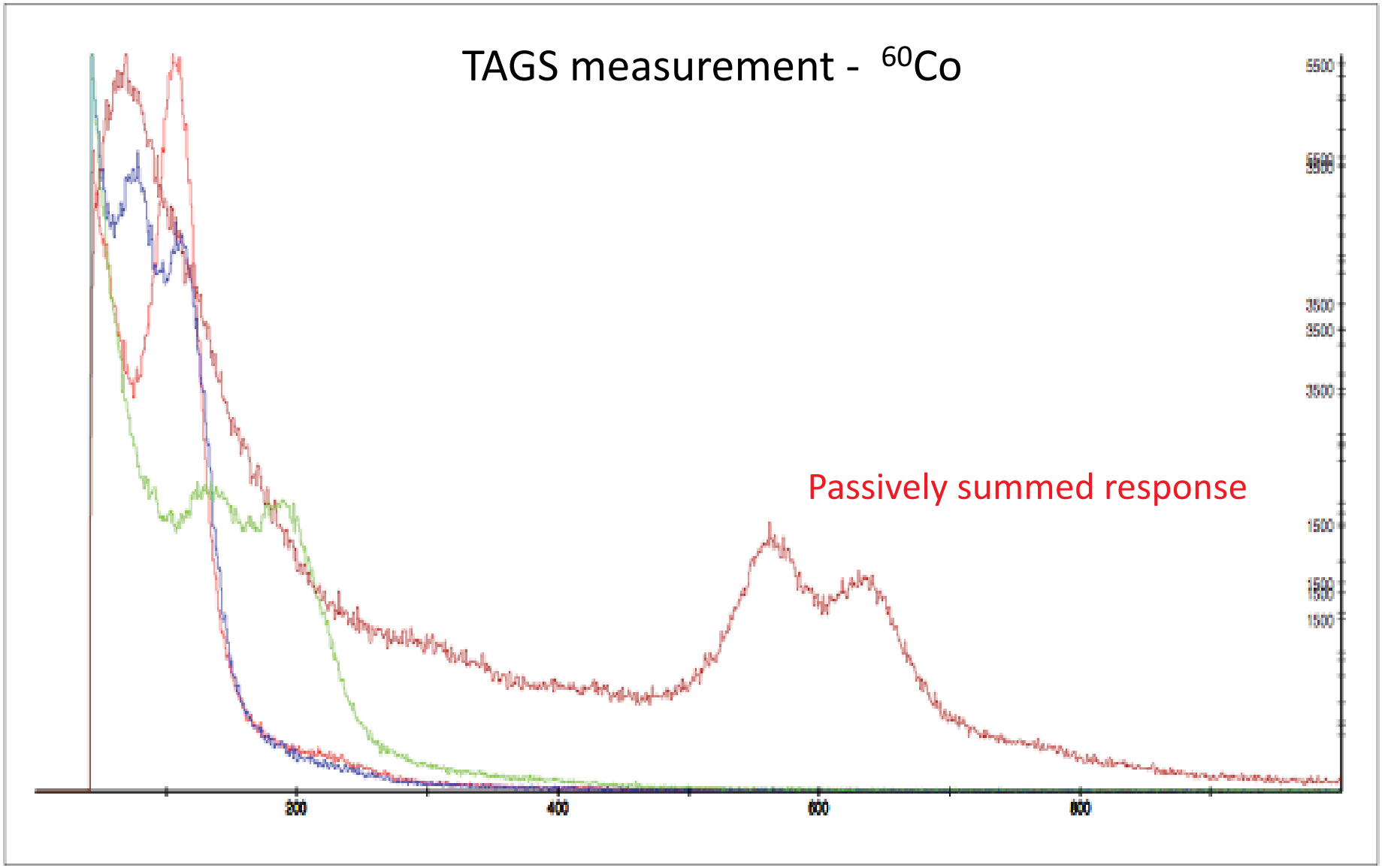
Alternative method

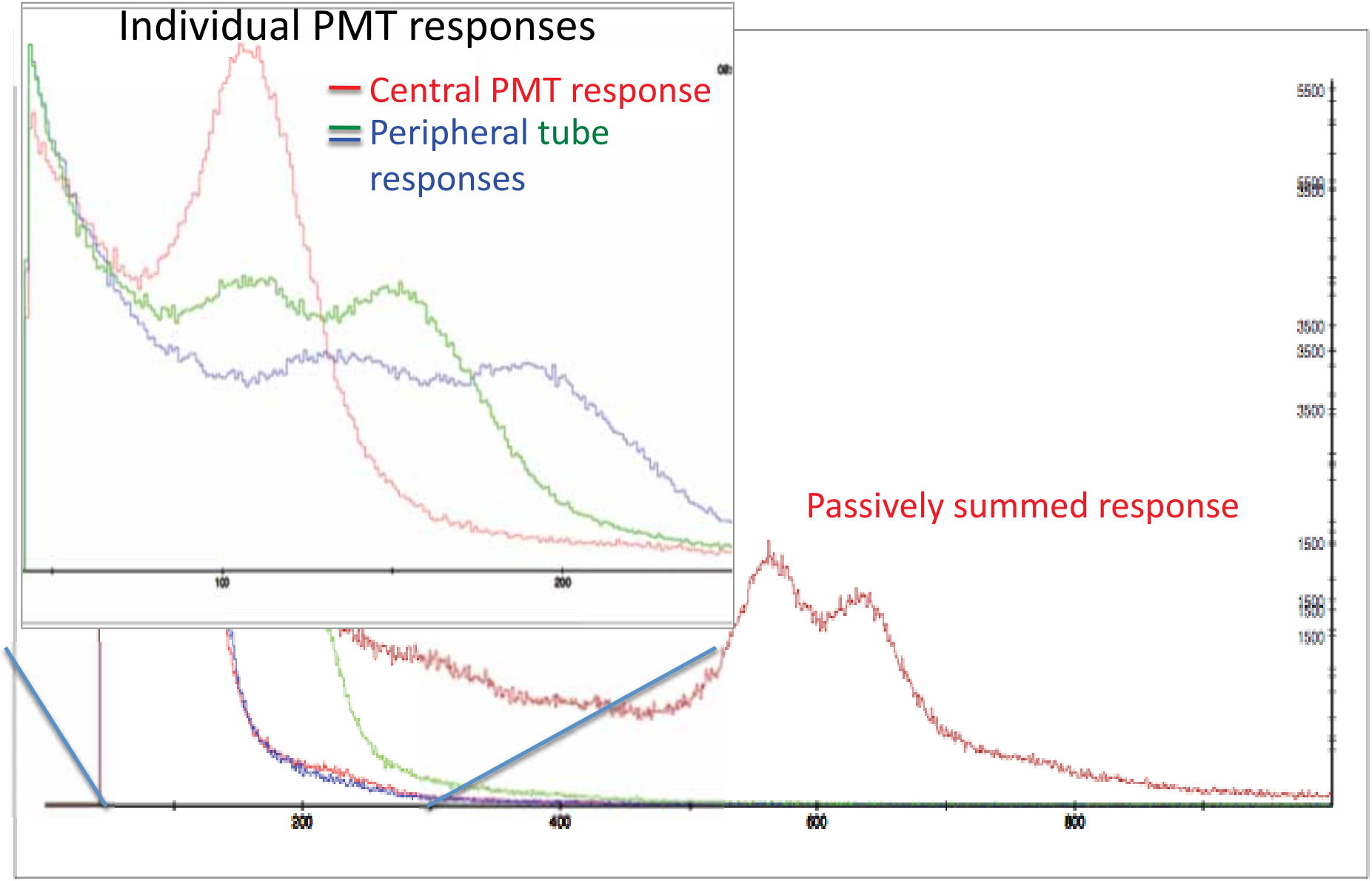



Simulation -60Co
Using mixing script
Energy deposition with RDM
β component not added here
14000
11000
7000
6000
3000
1000
2000
3000

Meanwhile in the lab……..

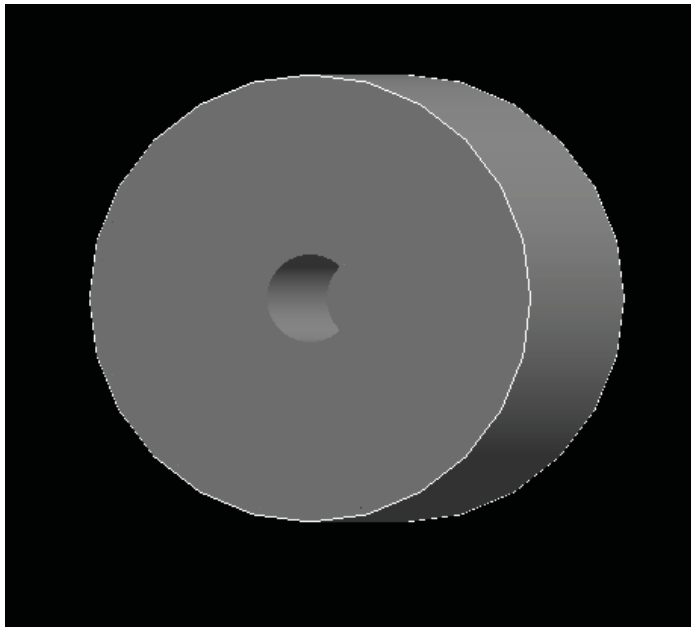



TAGS measurement - ^{60}Co
Passively summed response
200
400
600
800
5500
3500
3500
3500
1500
1500


Individual PMT responses
Central PMT response
Peripheral tube responses
Passively summed response
100
200
200
400
600
800
5500
3500
3500
3500
1500
1500

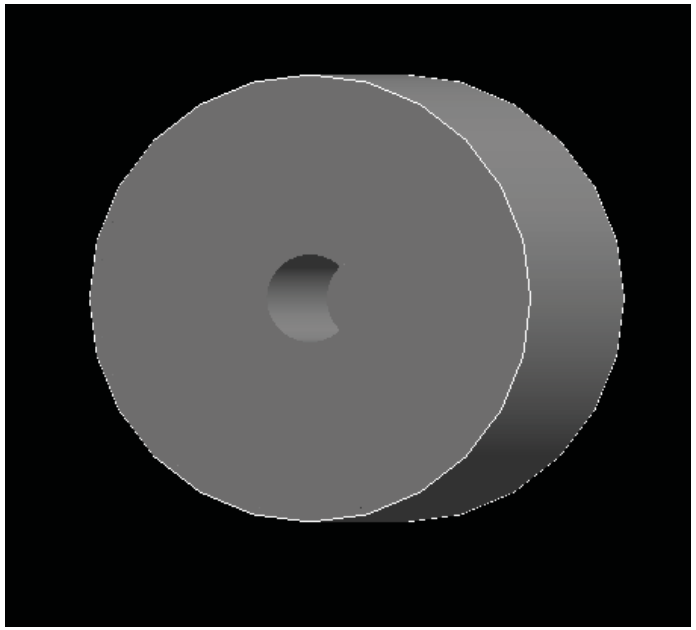
TAGS model

- Under the hood (bonnet)
- Simulation resolution
- Light non-proportionality correction
- Pile-up
- Model input
- Model output

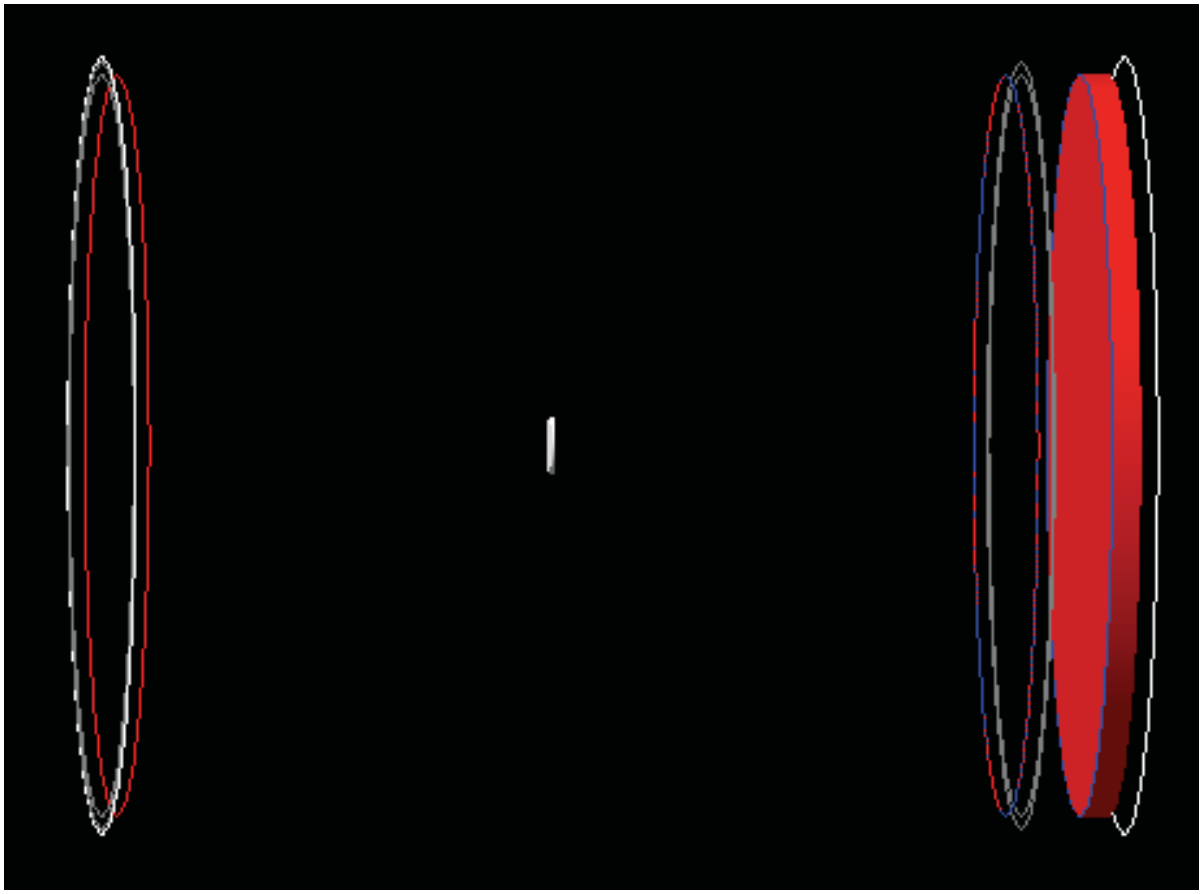


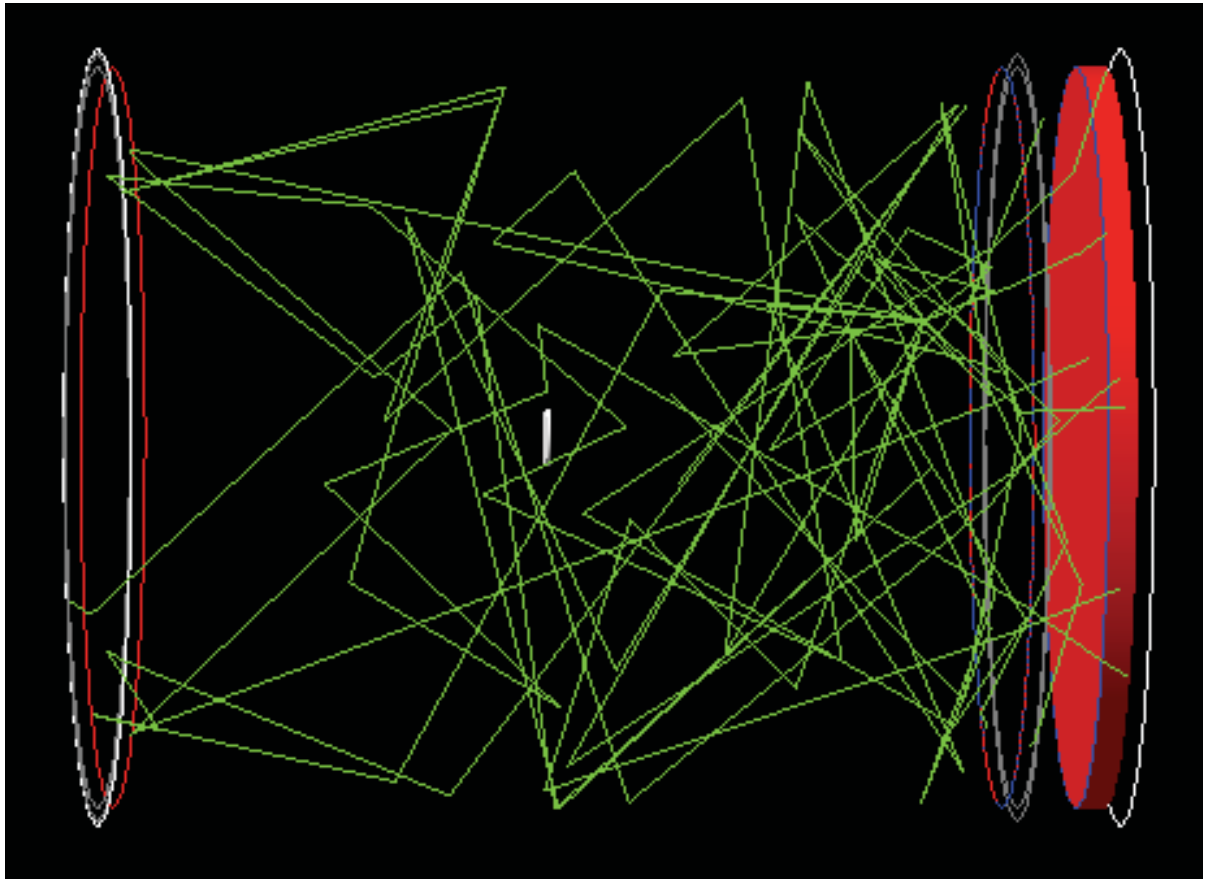
TAGS model

- Under the hood (bonnet)
- Simulation resolution
- Light non-proportionality correction
- Pile-up
- Model input
- Model output
- Optical Photons

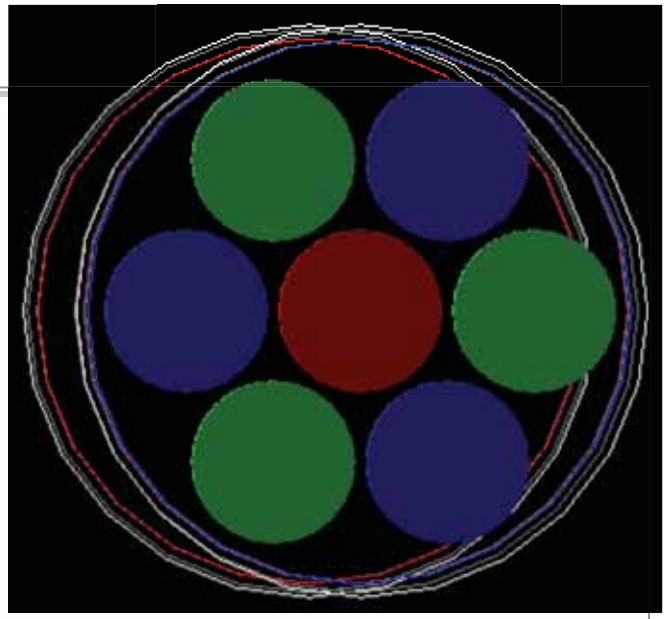


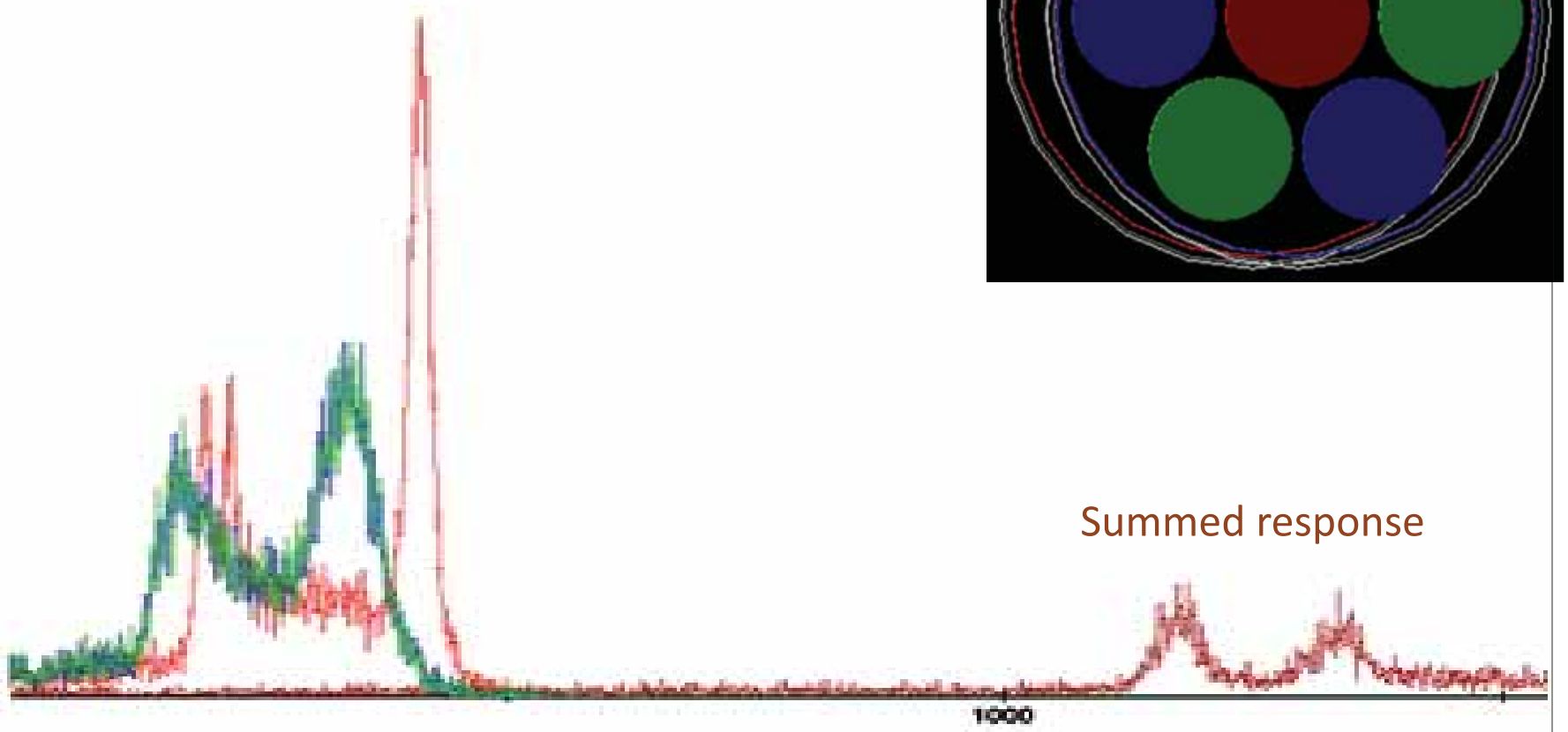
Using optical photons

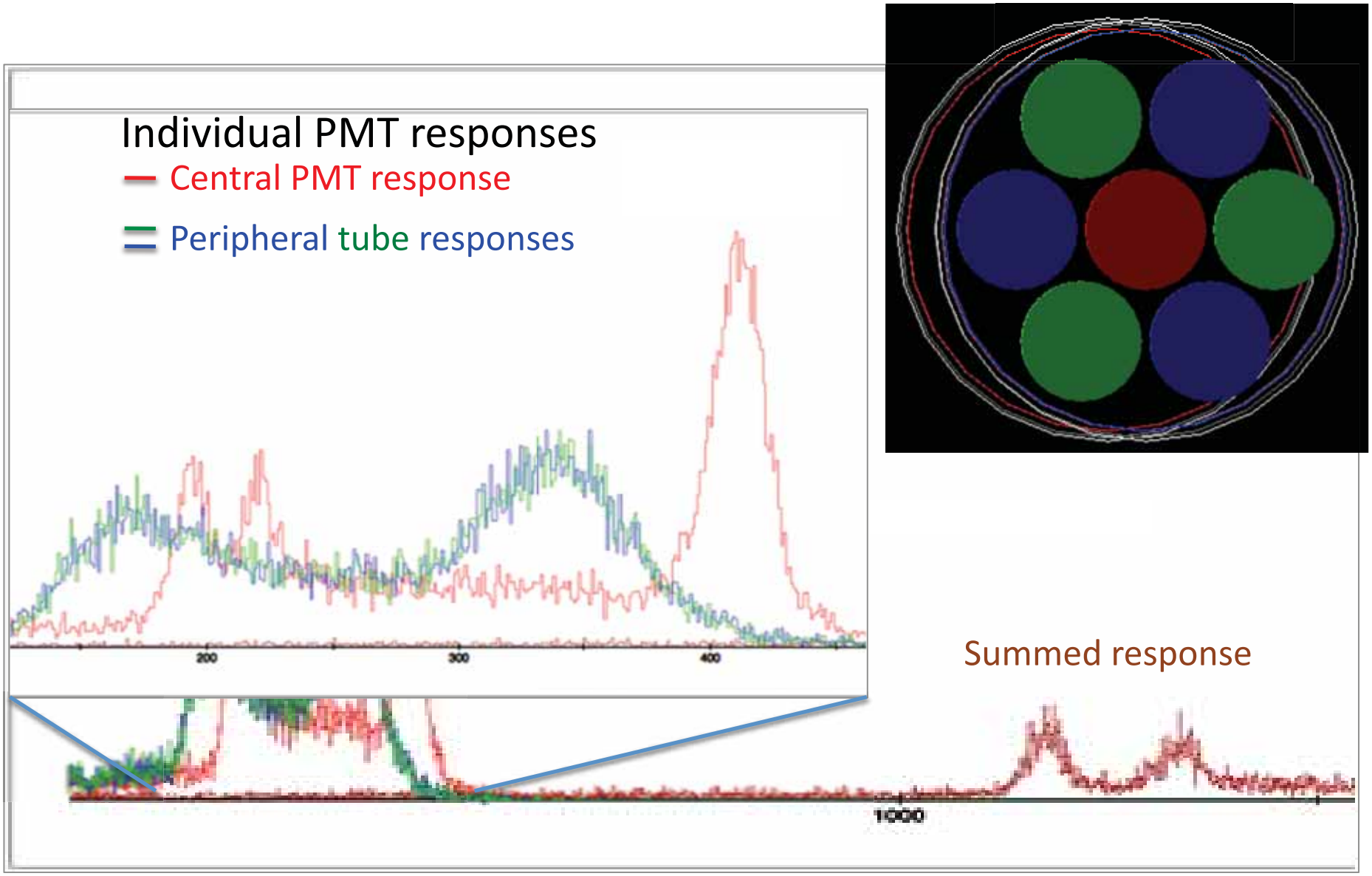




Simulation -^{60}Co






Individual PMT responses
Central PMT response
Peripheral tube responses
200
300
400
Summed response
1000

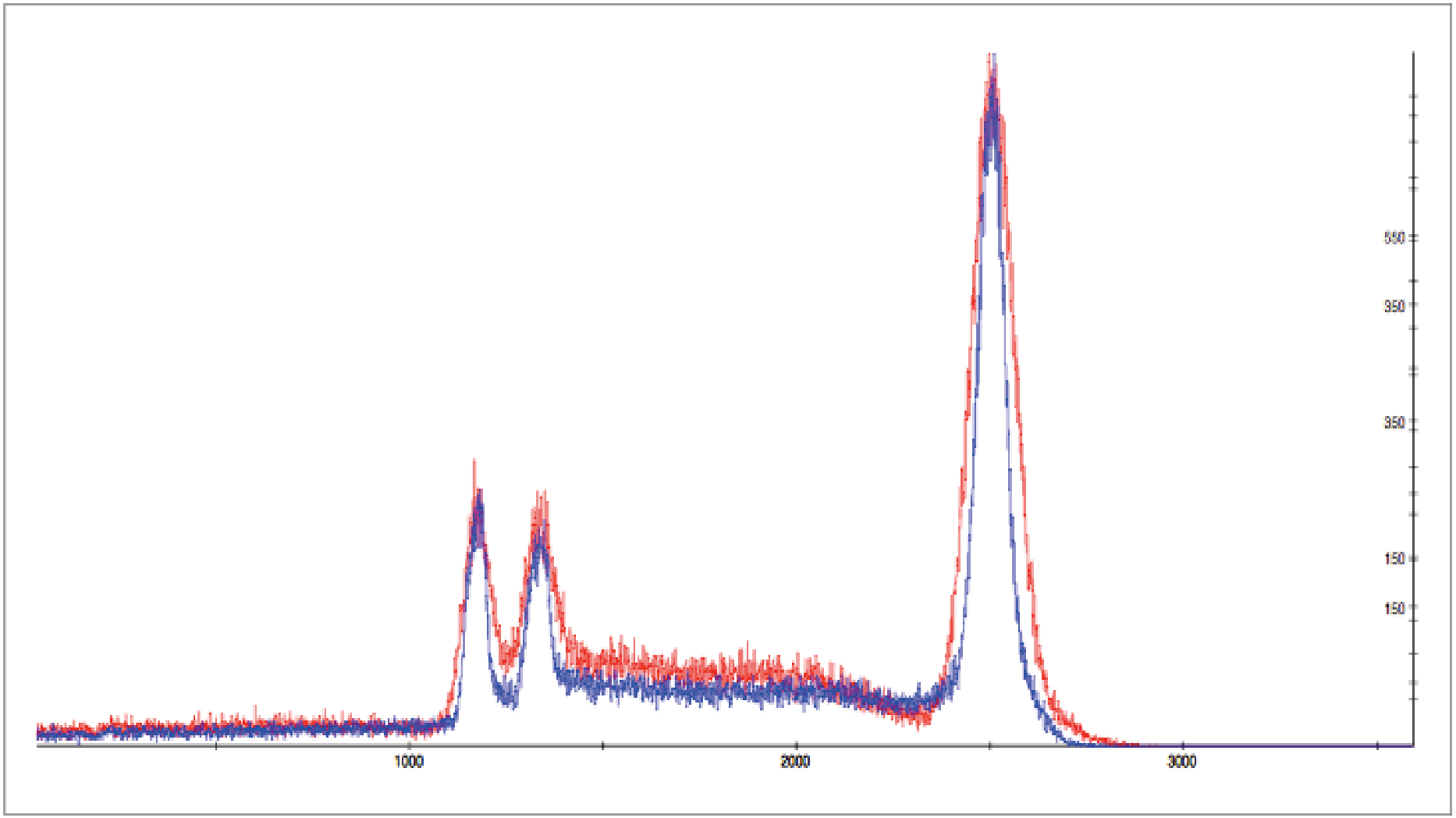
Disadvantage !!

Simulation time ~1000 x standard simulation time

Many weeks later

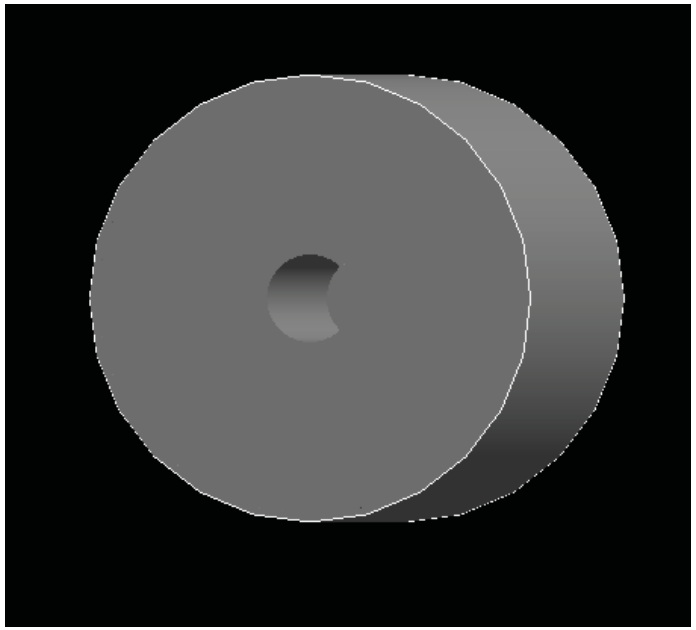
This can be overcome by running multiple threads in parallel

Advantage



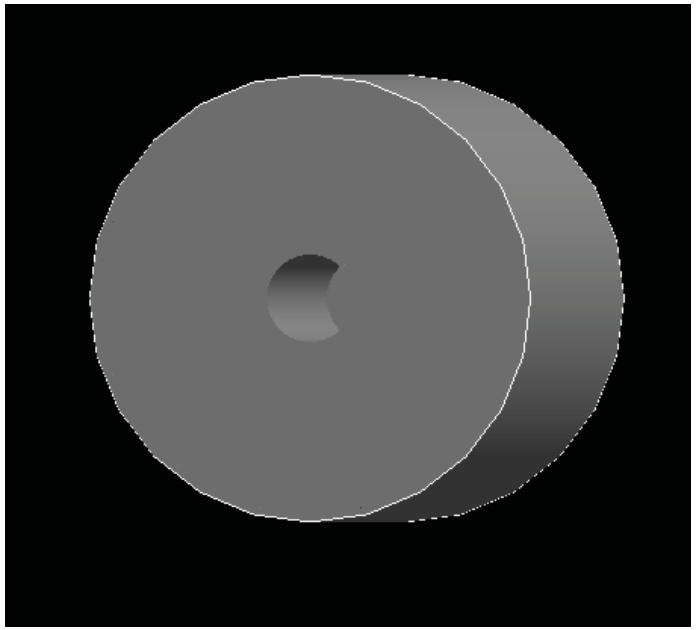
TAGS model

- Under the hood (bonnet)
- Simulation resolution
- Light non-proportionality correction
- Pile-up
- Model input
- Model output
- Optical Photons



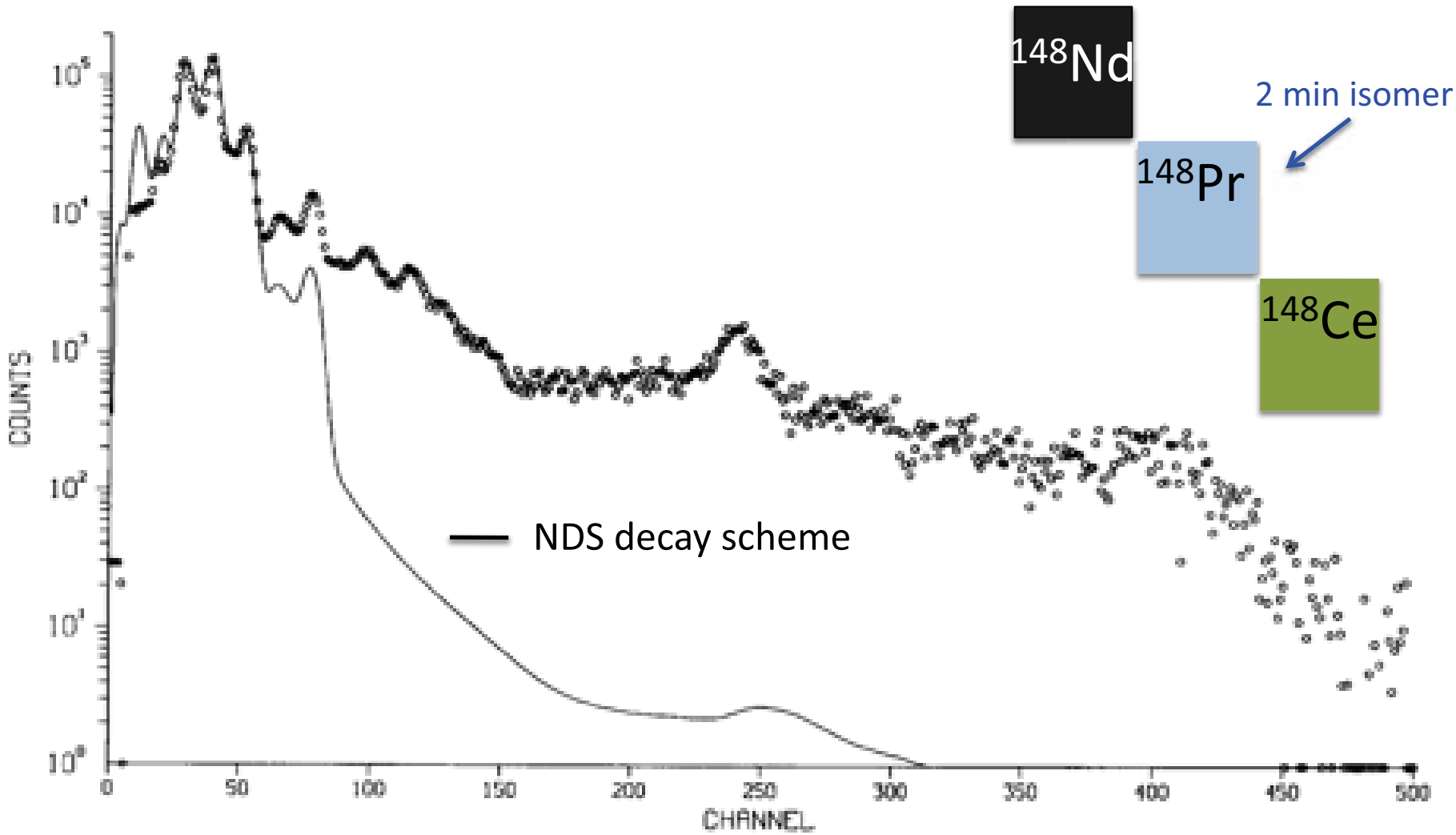
TAGS model

- Under the hood (bonnet)
- Simulation resolution
- Light non-proportionality correction
- Pile-up
- Model input
- Model output

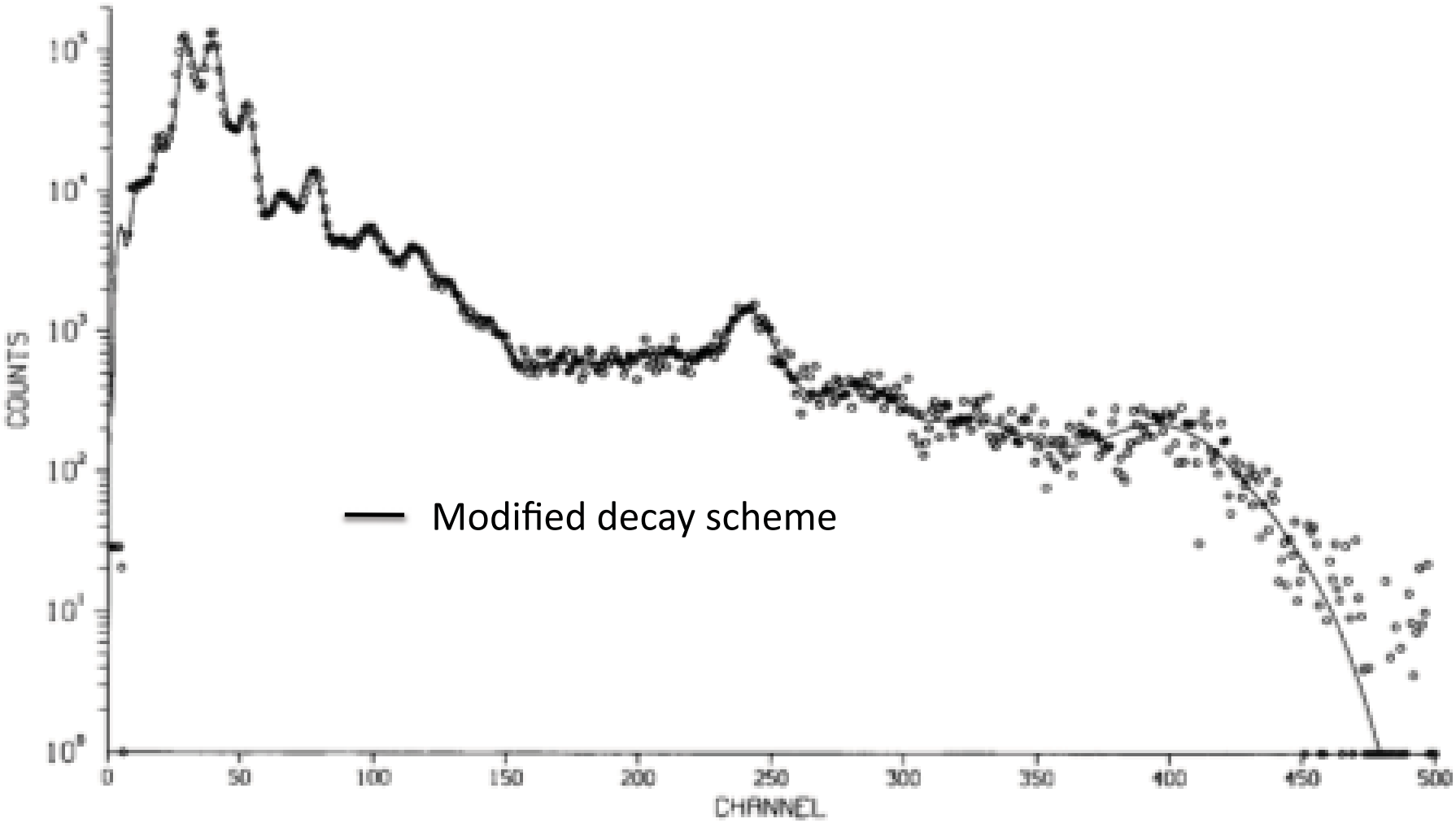


- Optical Photons

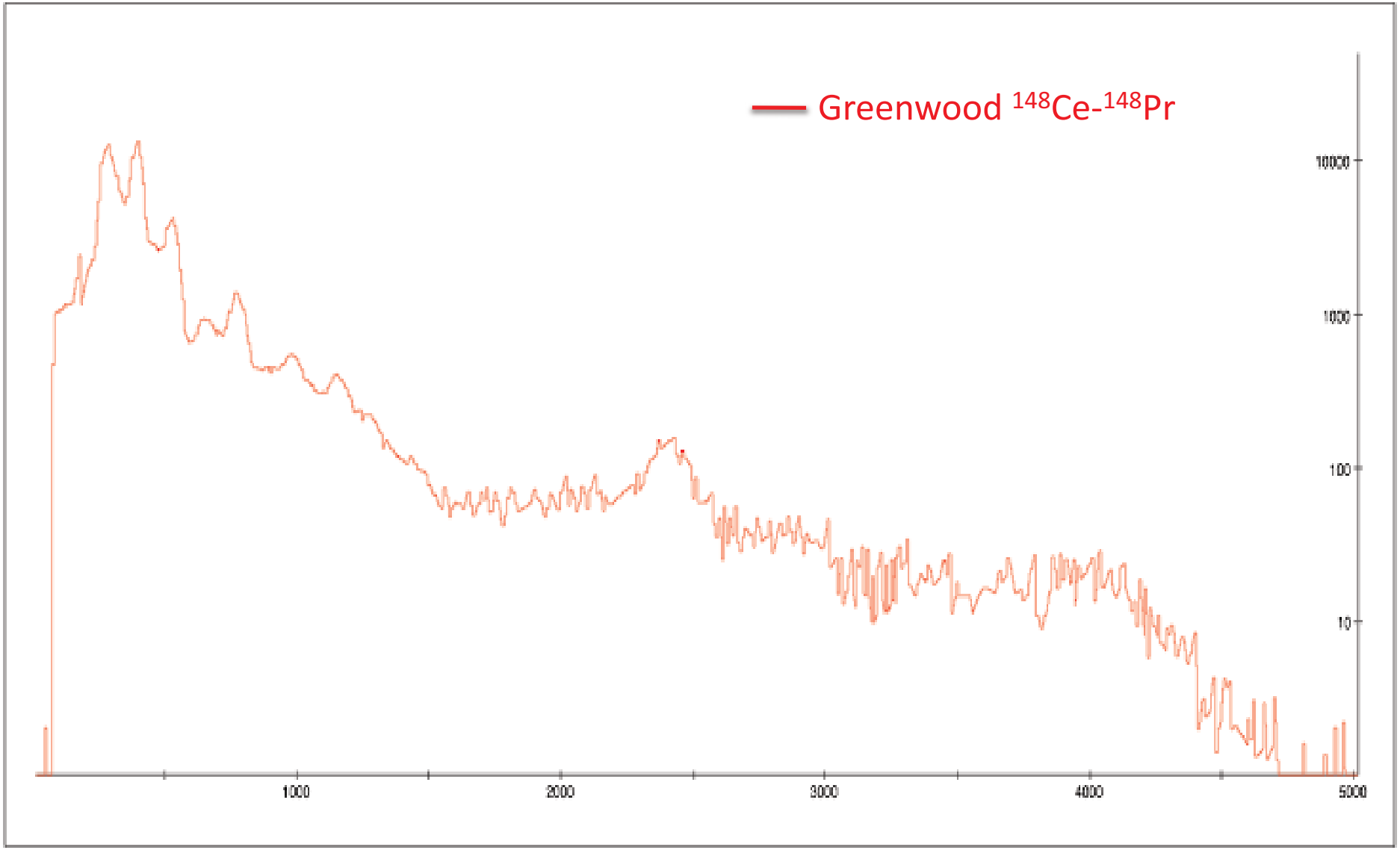
Greenwood ^{148}Ce – ^{148}Pr

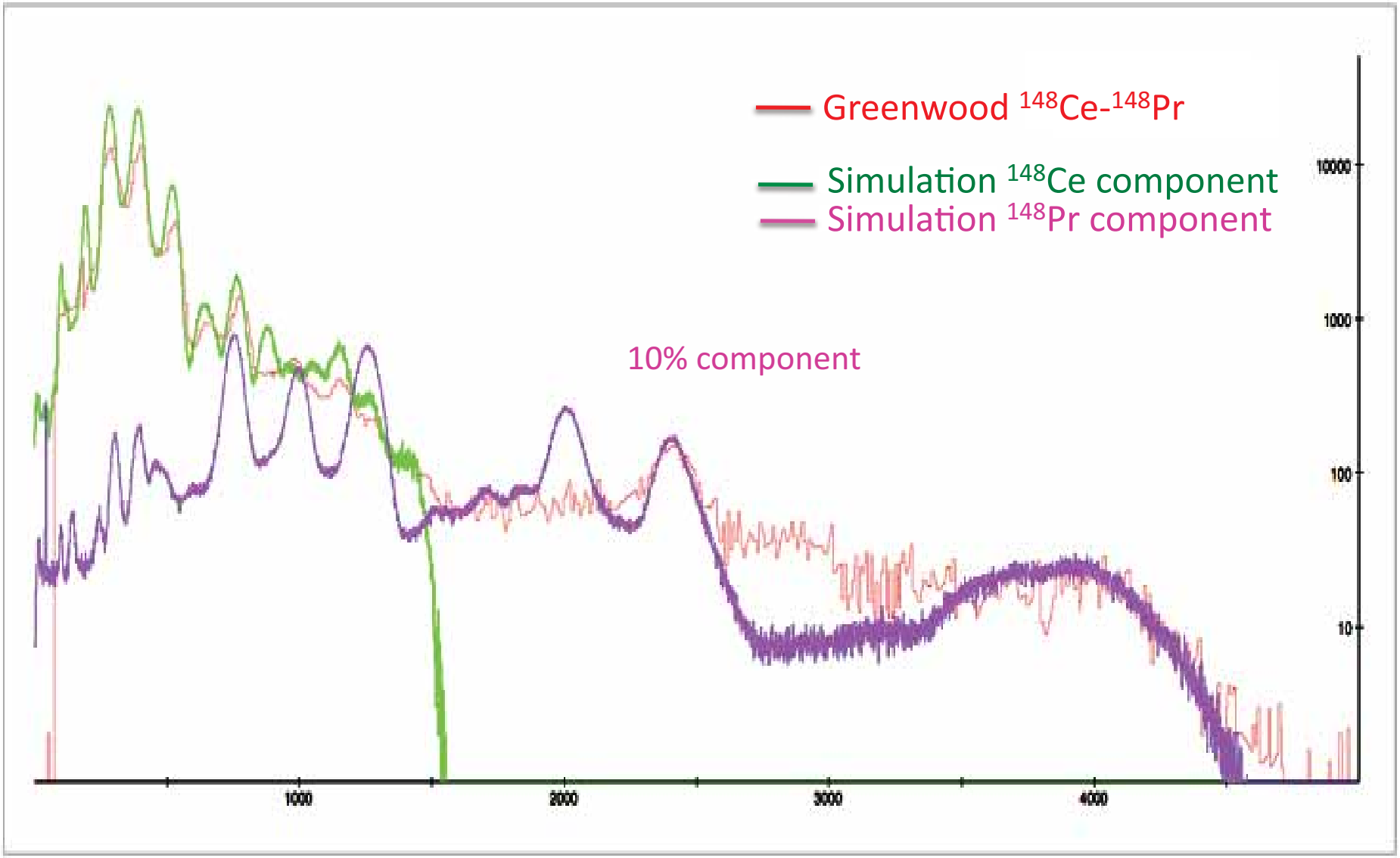


Greenwood et al. 1997 NIMA 390 pg 95-154

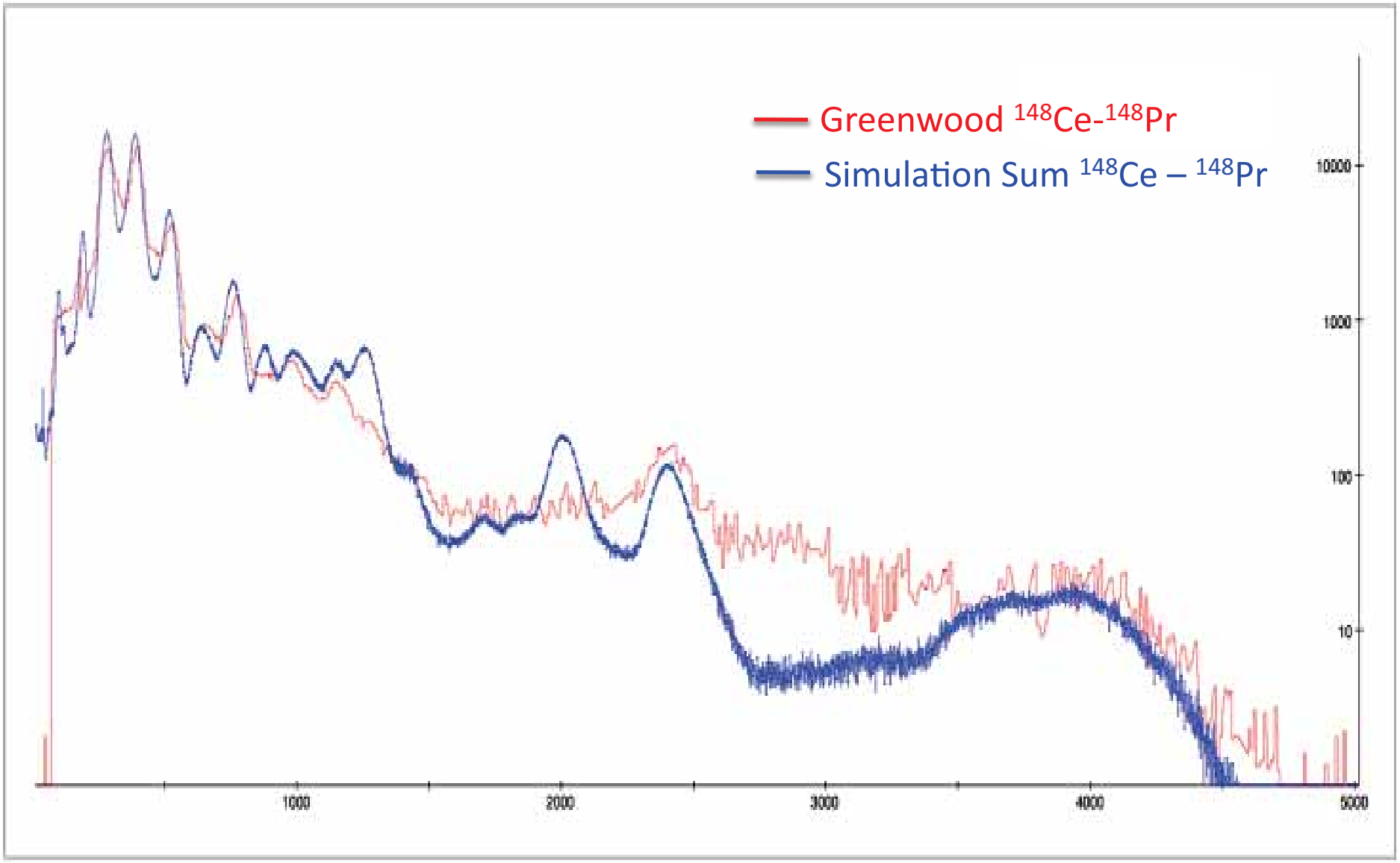


Greenwood et al. 1997 NIMA 390 pg 95-154

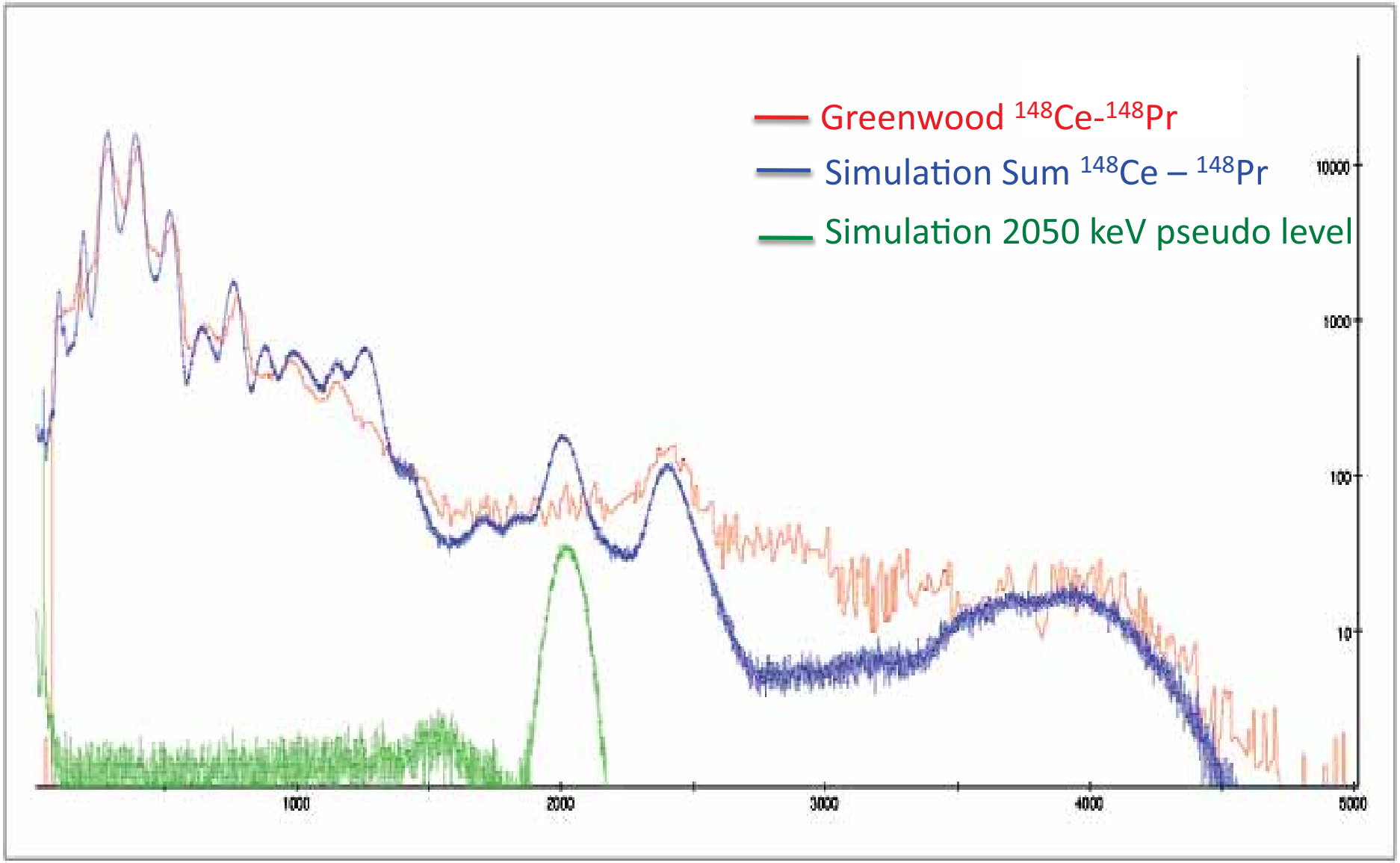

Greenwood ^{148}Ce-^{148}Pr
10000
1000
100
10
1000
2000
3000
4000
5000


Greenwood ^{148}Ce-^{148}Pr
Simulation ^{148}Ce component
Simulation ^{148}Pr component
10% component
10000
1000
100
10
1000
2000
3000
4000

Not there yet!



Not there yet!



Summary

- GEANT4 model exists
- ENSDF data as input
- Investigated microscopic behavior - optical photons

To be continued….