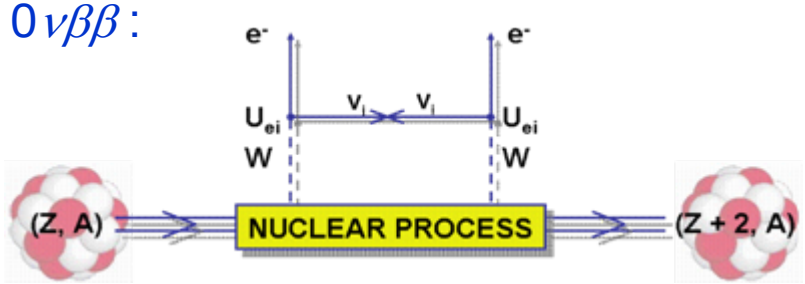
Neutron Interactions

as Seen by a Segmented Germanium Detector

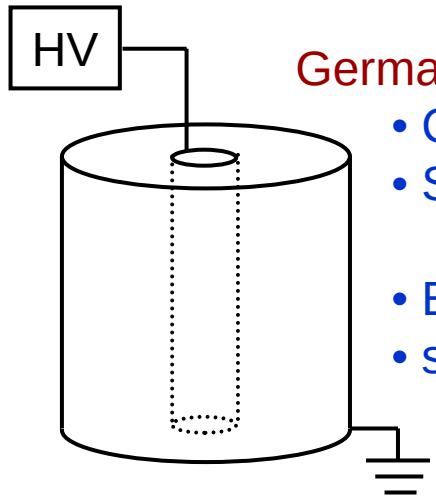
[arXiv: nucl-ex/0711.2255]

Iris Abt, Allen Caldwell, Kevin Kröninger, Jing Liu, Xiang Liu, Bela Majorovits*

$0\nu\beta\beta$:



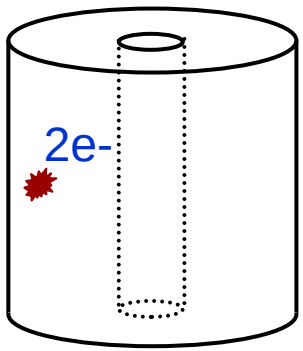
$^{76}Ge \rightarrow {}^{76}Se + 2e^-$



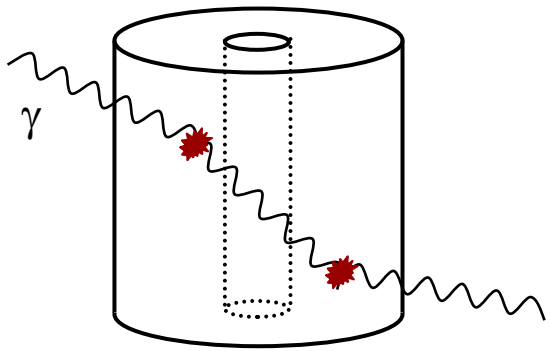
Germanium Crystal:

- Coaxial cylinder
- Semiconductor detector
- Enriched with 76Ge
- source

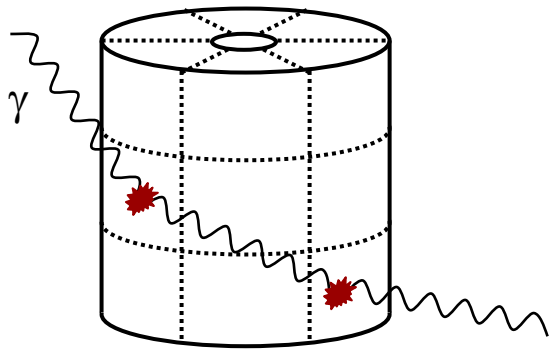
Signal, E=2.039 MeV



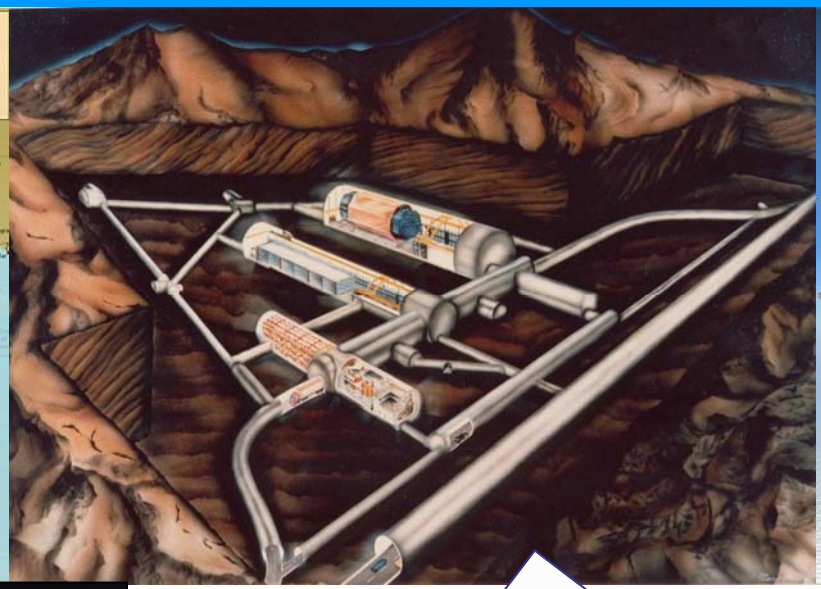
Typical background

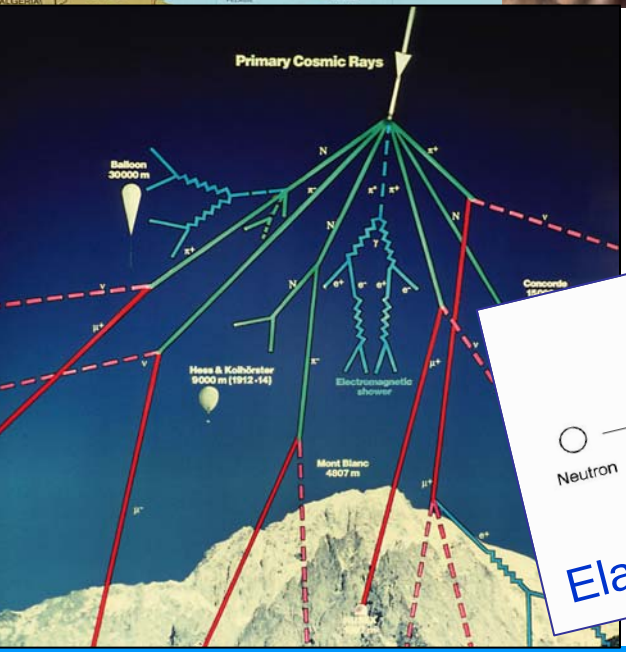


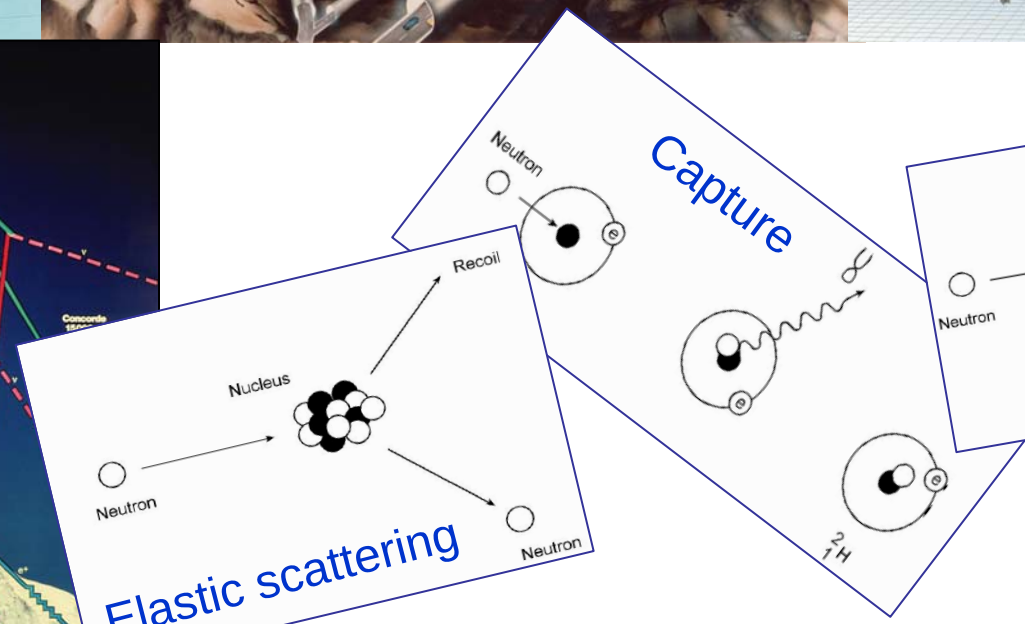
Segmented detector

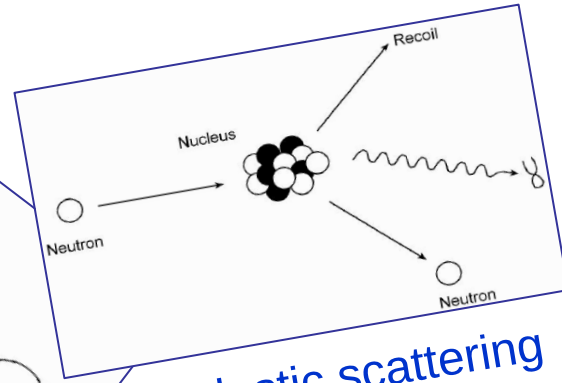


Introduction :: Neutron as background for GERDA

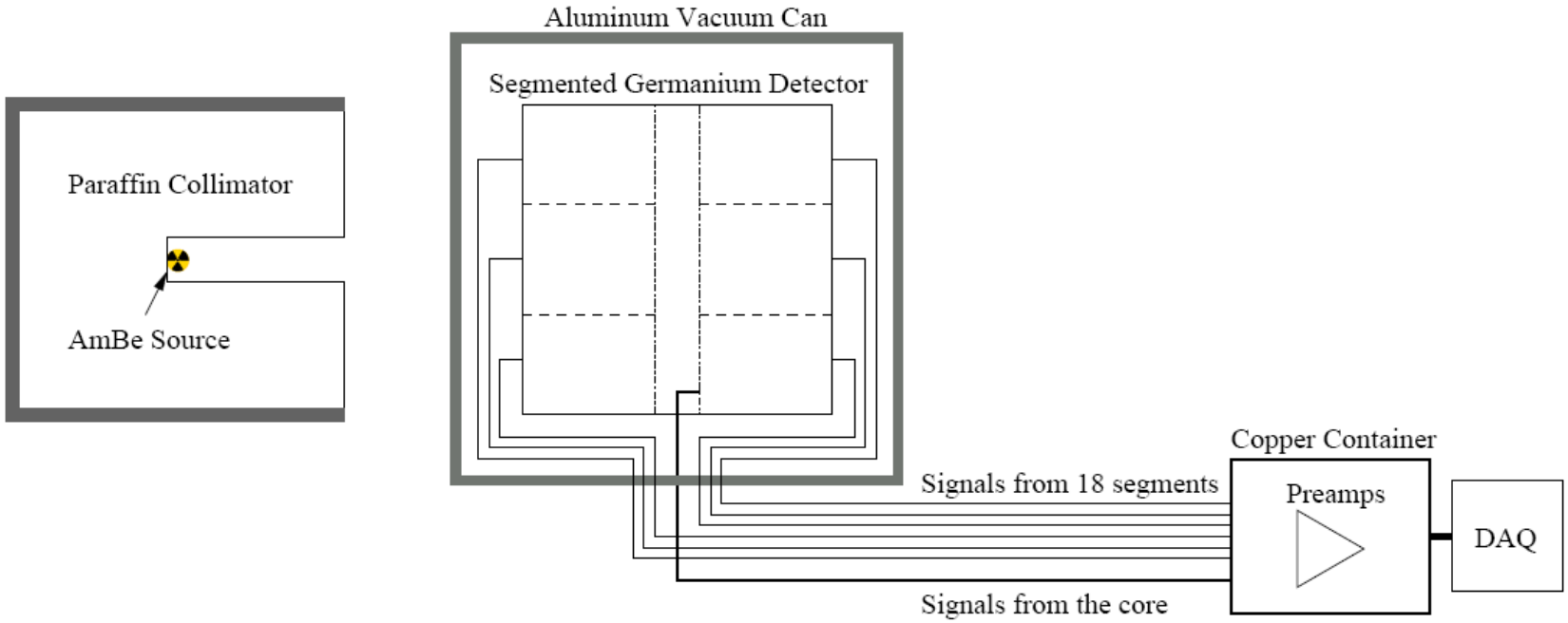






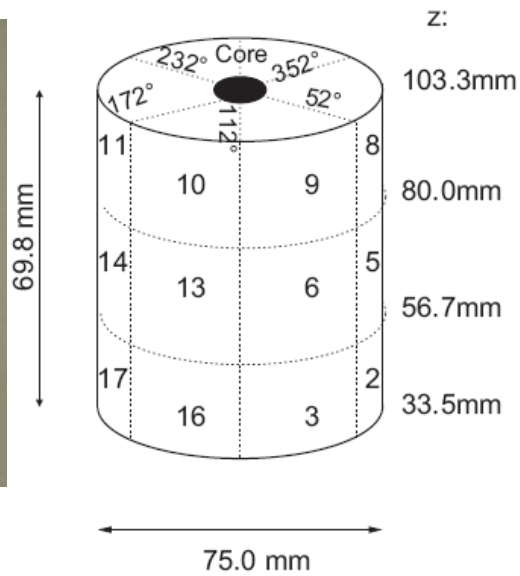


Experimental setup



Schematic experimental setup (not to scale).

GERDA Prototype Detector

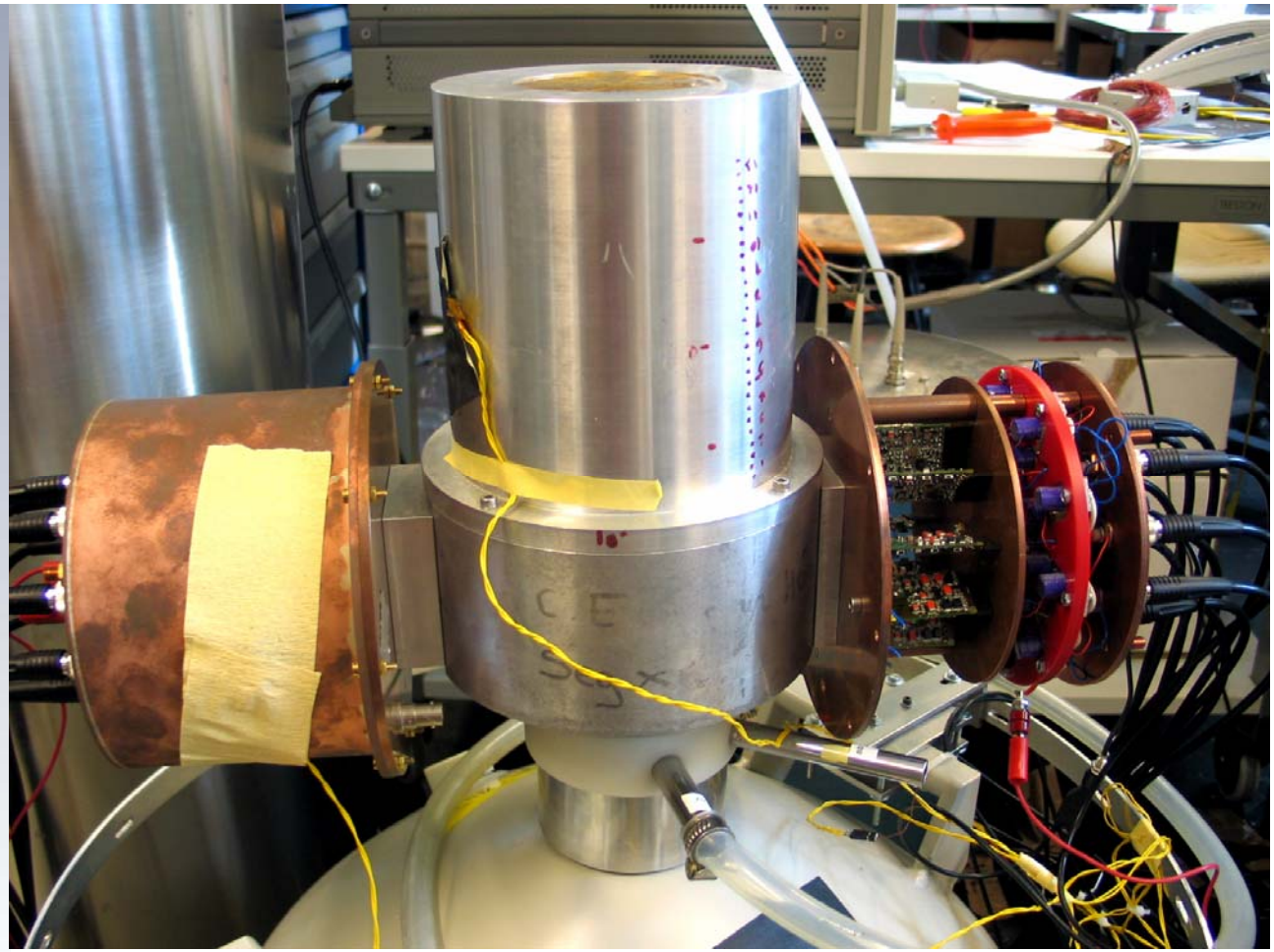


Detector:

- Natural germanium
- n-type
- True coaxial
- Segmented: 3(z) x 6(ϕ)
- Resolution ~3keV@1.3MeV

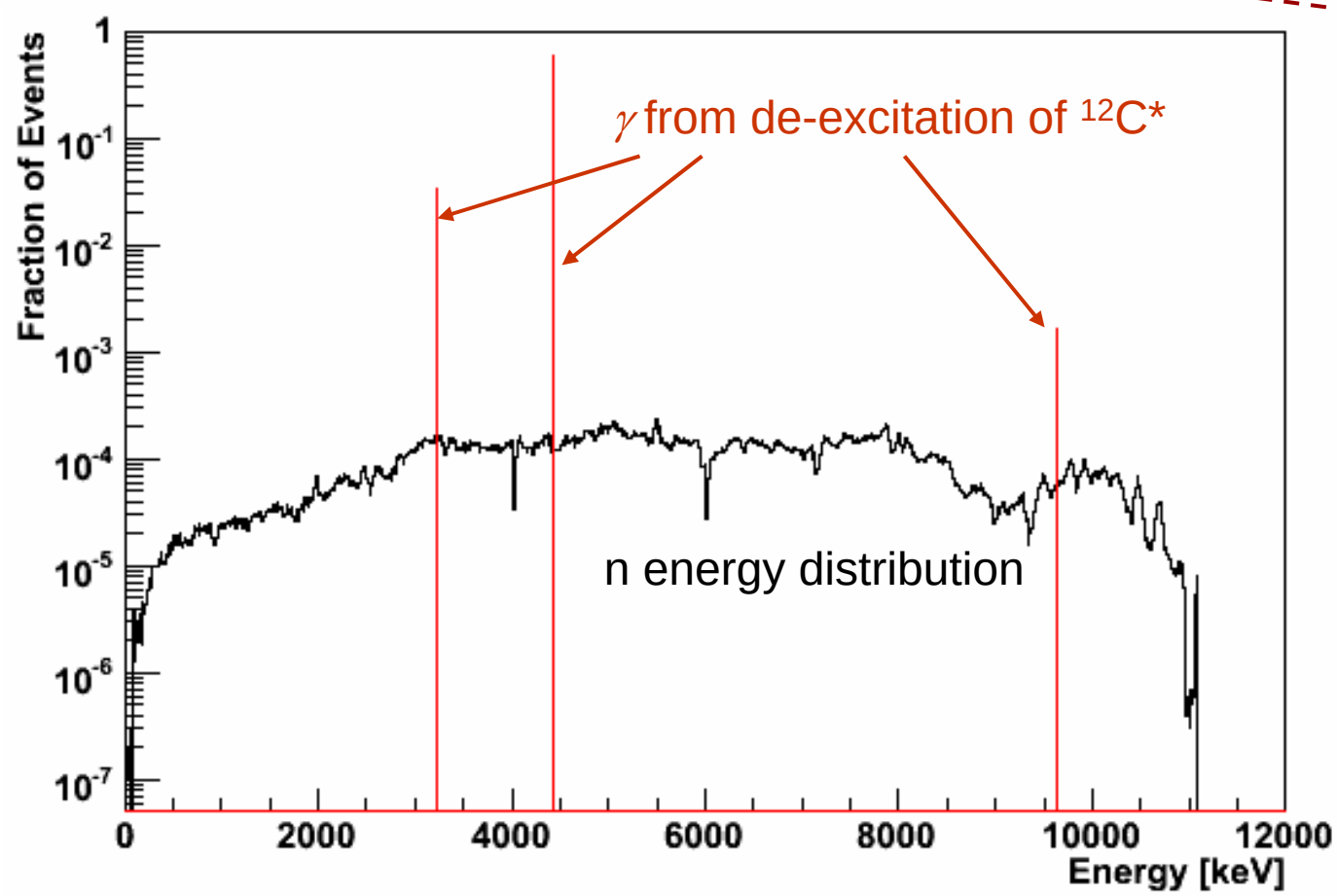
Cryostat and electronics

Nucl. Instrum. Meth. A **577** (2007) 574 [nucl-ex/0701004]



$^{9}\mathrm{Be}(\alpha, n)^{12}\mathrm{C}^{*}$

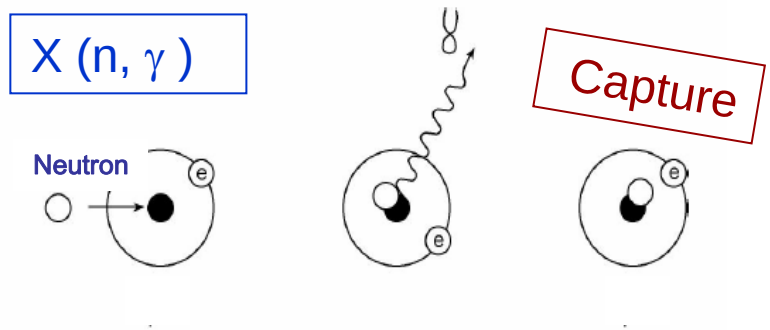
~ 500 neutrons / second

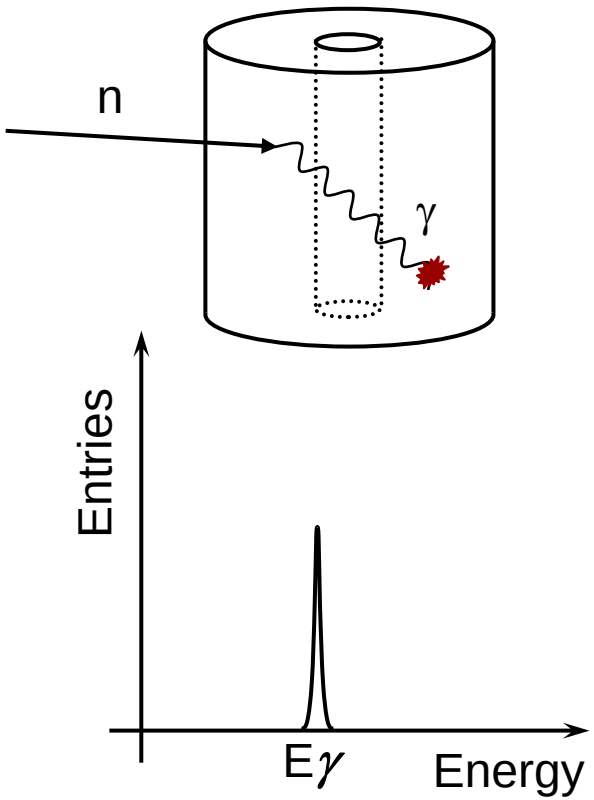


Neutron interactions that can be identified

X (n, γ)

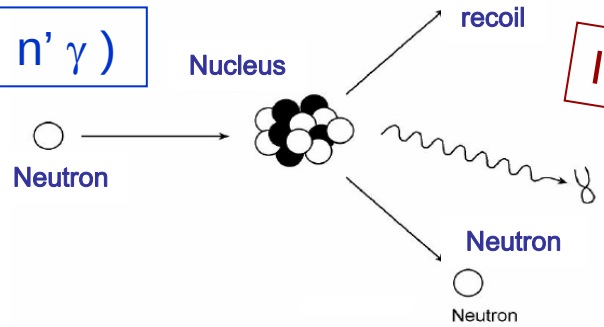
Capture

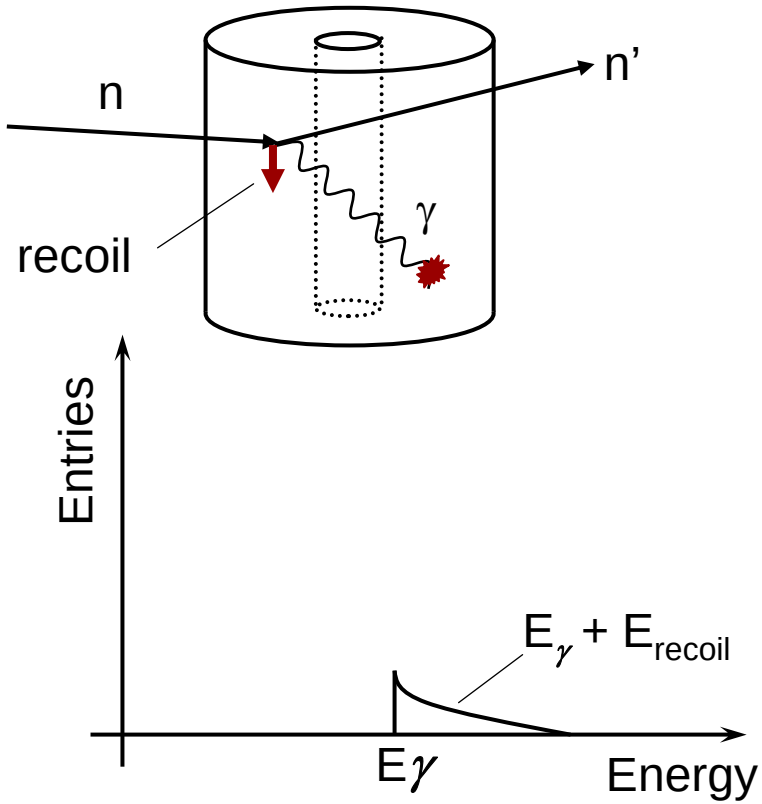




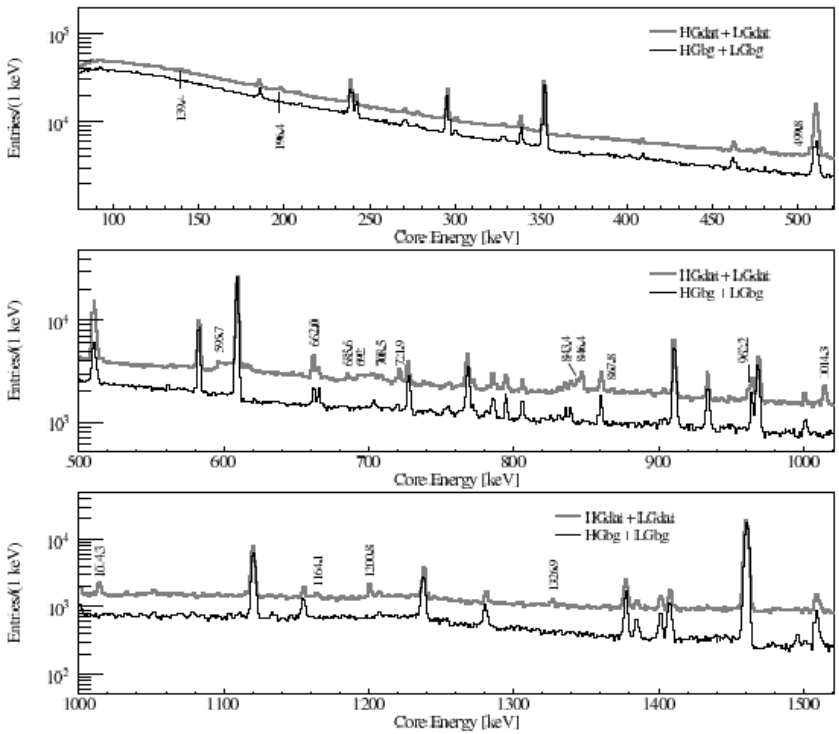
X (n, n' γ)

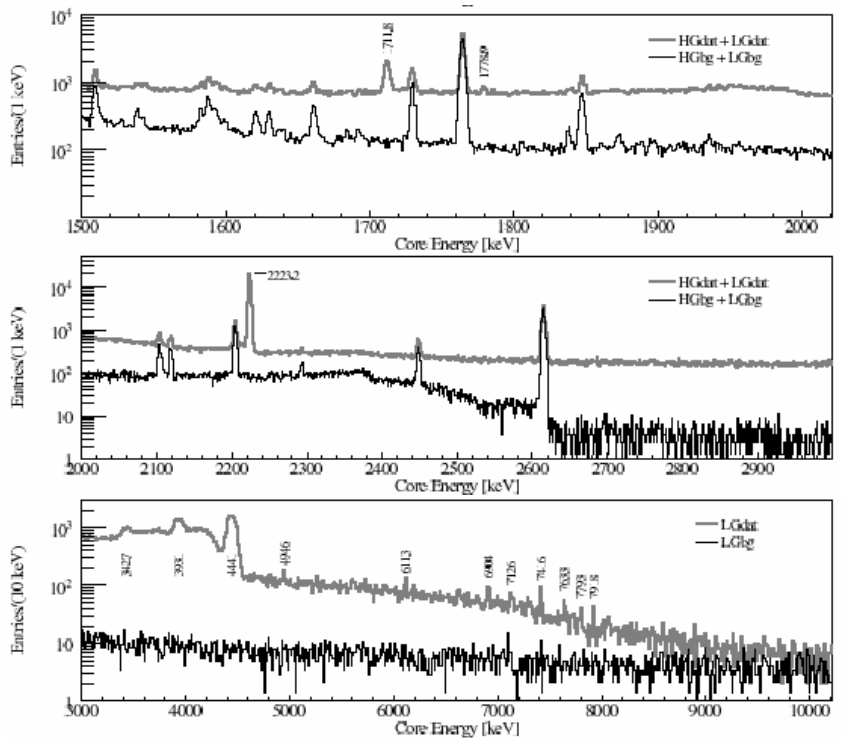
Inelastic





Core energy spectra



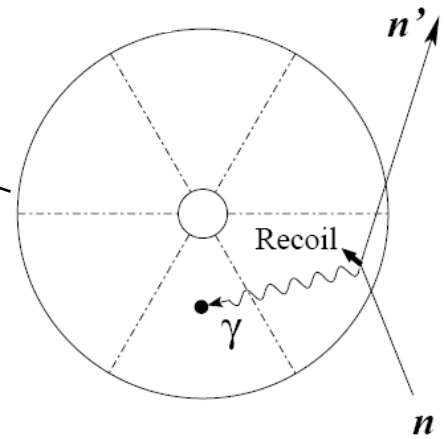


Peaks induced by AmBe neutron source

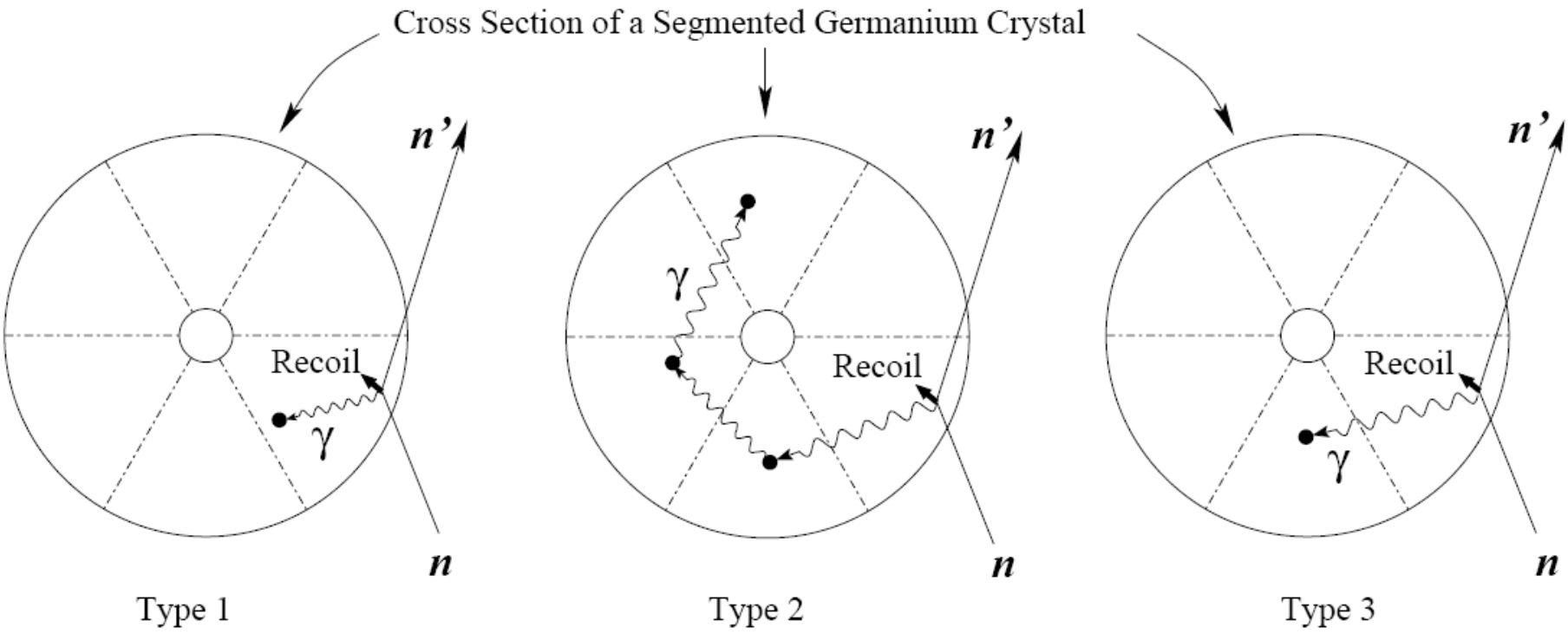
Fitted Energy [keV]	Fitted FWHM [keV]	Interaction Type	Number of Events
139.4	1.6 ± 0.2	$^{74}\mathrm{Ge}(n,\gamma^m)$	3377 ± 520
197.9	1.9 ± 0.2	$^{70}\mathrm{Ge}(n,\gamma^m)$	3306 ± 503
499.8	1.9 ± 0.7	$^{70}\mathrm{Ge}(n,\gamma)$	503 ± 186
595.7[a]	-	$^{74}\mathrm{Ge}(n,n'\gamma)$	$(18.4 \pm 2.5) \times 10^3$
662.0[b]	1.9 ± 0.1	$^{140}\mathrm{Ce}(n,\gamma)$	2802 ± 188
685.6	1.4 ± 0.2	?[c]	628 ± 111
692[d]	-	$^{72}\mathrm{Ge}(n,n'e)$	~ 7000[e]
708.5	2.4 ± 0.5	$^{35}\mathrm{Cl}(n,\gamma)$, $^{36}\mathrm{Cl}\rightarrow{}^{36}\mathrm{Ar}$	782 ± 197
721.9	1.9 ± 0.2	?[c]	3502 ± 148
843.4	2.4 ± 0.5	$^{27}\mathrm{Al}(n,n'\gamma)$	1558 ± 202
846.6	2.4 ± 0.2	$^{56}\mathrm{Fe}(n,n'\gamma)$	2802 ± 196
867.8	1.9 ± 0.5	$^{73}\mathrm{Ge}(n,\gamma)$	425 ± 129
962.2	2.4 ± 0.2	$^{63}\mathrm{Cu}(n,n'\gamma)$	1041 ± 129
1014.3	2.4 ± 0.2	$^{27}\mathrm{Al}(n,n'\gamma)$	1958 ± 123
1164.1	2.6 ± 0.5	$^{35}\mathrm{Cl}(n,\gamma)$	646 ± 140
1200.8	2.8 ± 0.2	DEP[f] of 2223	2318 ± 122
1326.9	2.4 ± 0.2	$^{63}\mathrm{Cu}(n,n'\gamma)$	711 ± 91
1711.8	3.8 ± 0.1	SEP[f] of 2223	5555 ± 133
1778.9	2.6 ± 0.2	$^{27}\mathrm{Al}(n,\gamma)$, $^{28}\mathrm{Al}\rightarrow{}^{28}\mathrm{Si}$	469 ± 73
2223.2	3.8 ± 0.1	$^{1}\mathrm{H}(n,\gamma)$	79349 ± 300

Fitted Energy [keV]	Fitted FWHM [keV]	Interaction Type	Number of Events
3427	85 ± 7	DEP[a] of 4441	2354 ± 263
3931	87 ± 5	SEP[a] of 4441	5873 ± 368
4441	92 ± 2	$^{9}\mathrm{Be}(\alpha,n)^{12}\mathrm{C}^*$	14672 ± 297
4946	4.9 ± 1.4	$^{12}\mathrm{C}(n,\gamma)$	68 ± 15
6113	7[b]	$^{35}\mathrm{Cl}(n,\gamma)$	75 ± 12
6904	7[b]	SEP[a] of 7416	60 ± 10
7126	7[b]	?[c]	38 ± 9
7416	7[b]	$^{35}\mathrm{Cl}(n,\gamma)$	70 ± 10
7633	7[b]	$^{56}\mathrm{Fe}(n,\gamma)$	18 ± 10
7793	7.1 ± 2.1	$^{35}\mathrm{Cl}(n,\gamma)$	21 ± 8
7918	6.8 ± 1.4	$^{63}\mathrm{Cu}(n,\gamma)$	29 ± 8

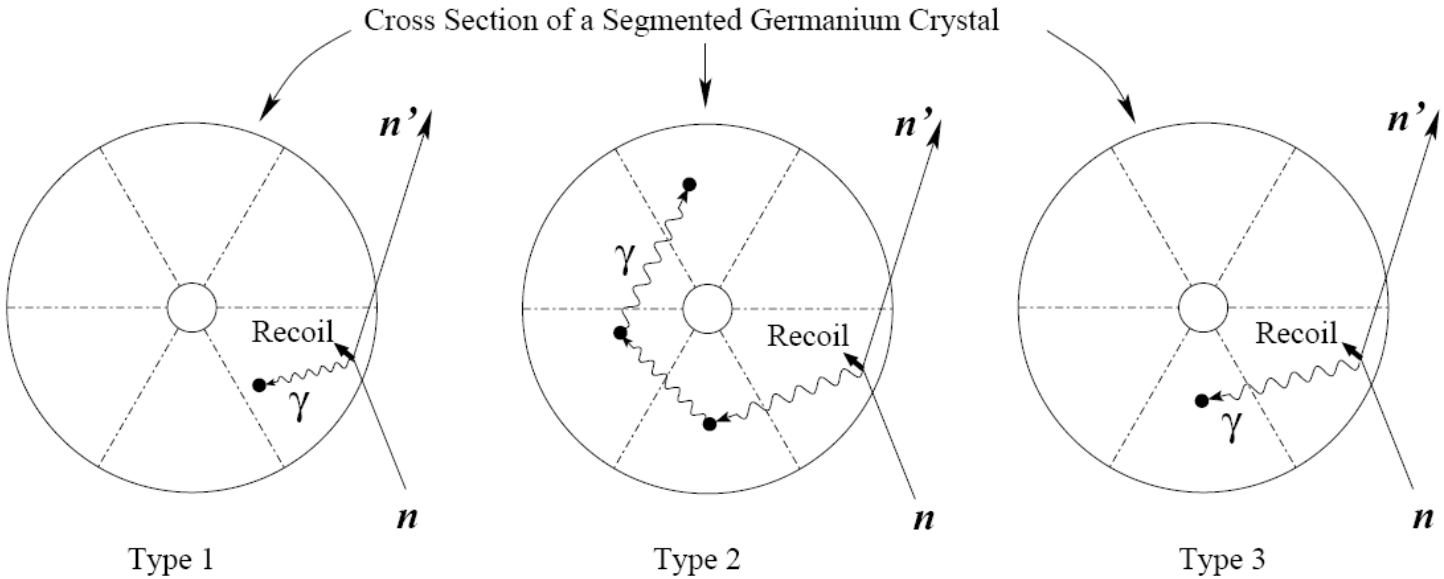
Cross section of the detector

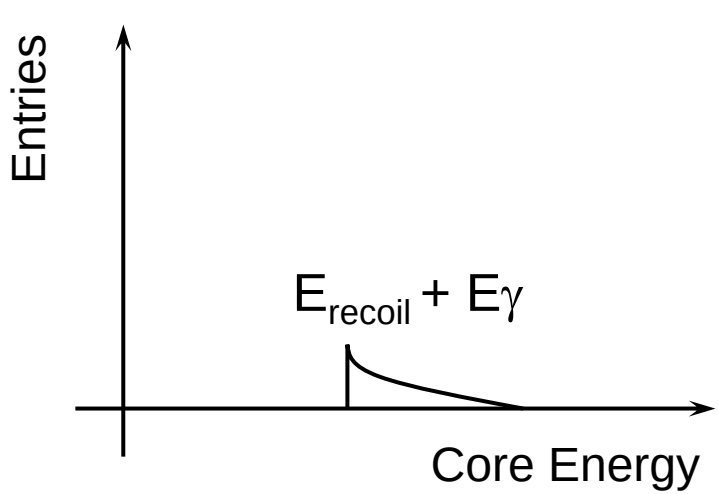


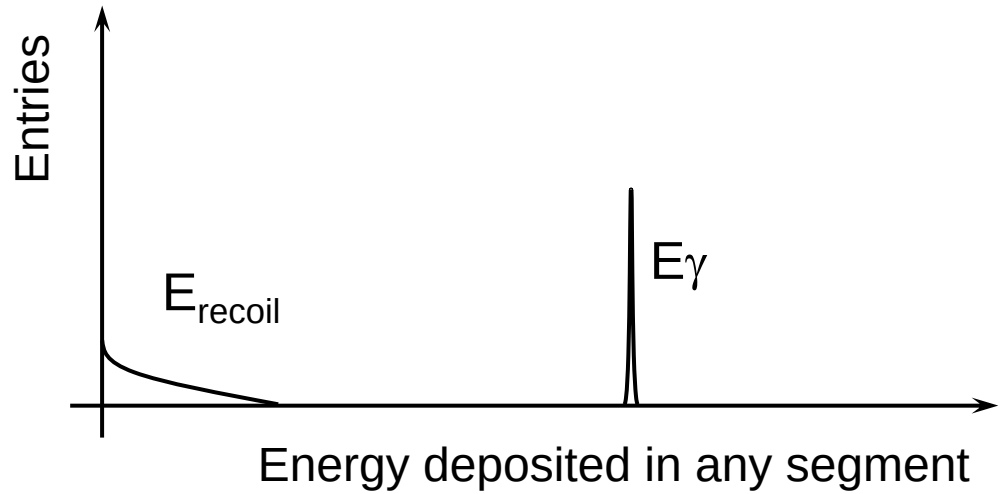
Interaction topologies of events in 595.7 keV peak from $^{74}Ge(n,n'\gamma)$



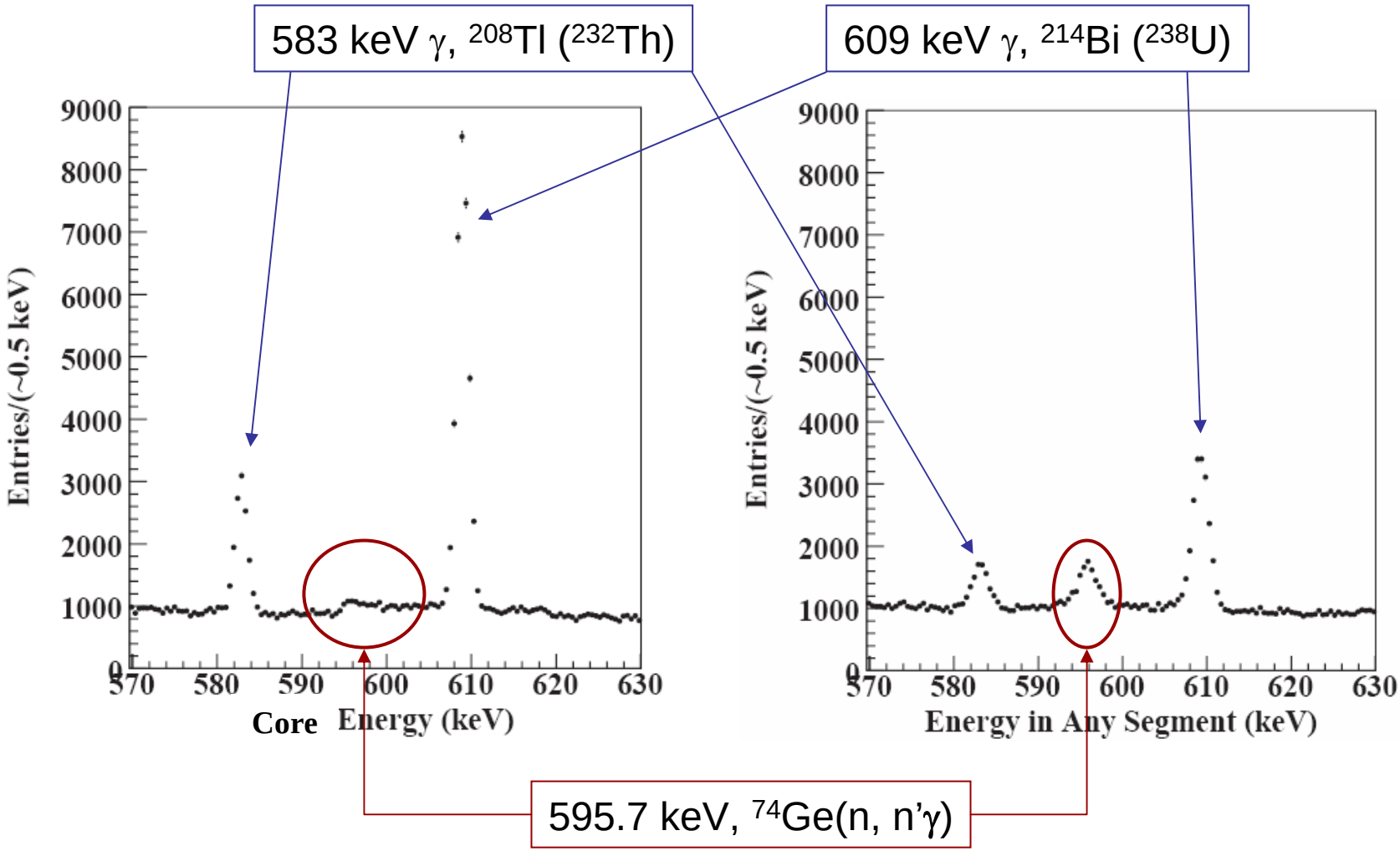
Interactions as seen by core & segments



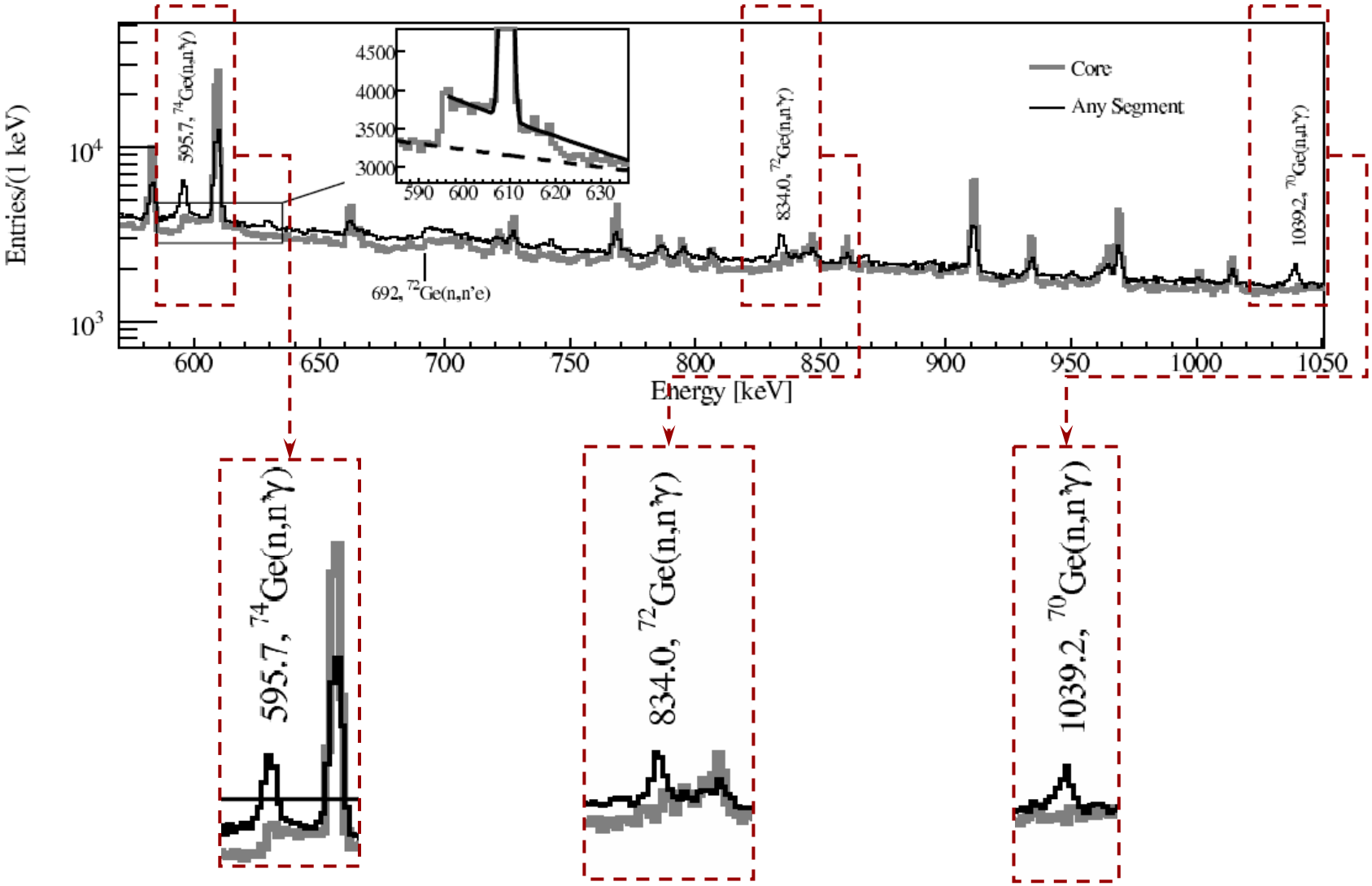




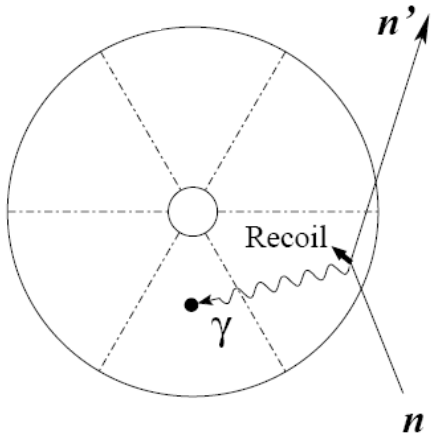
595.7 keV peak from $^{74}Ge(n, n'\gamma)$



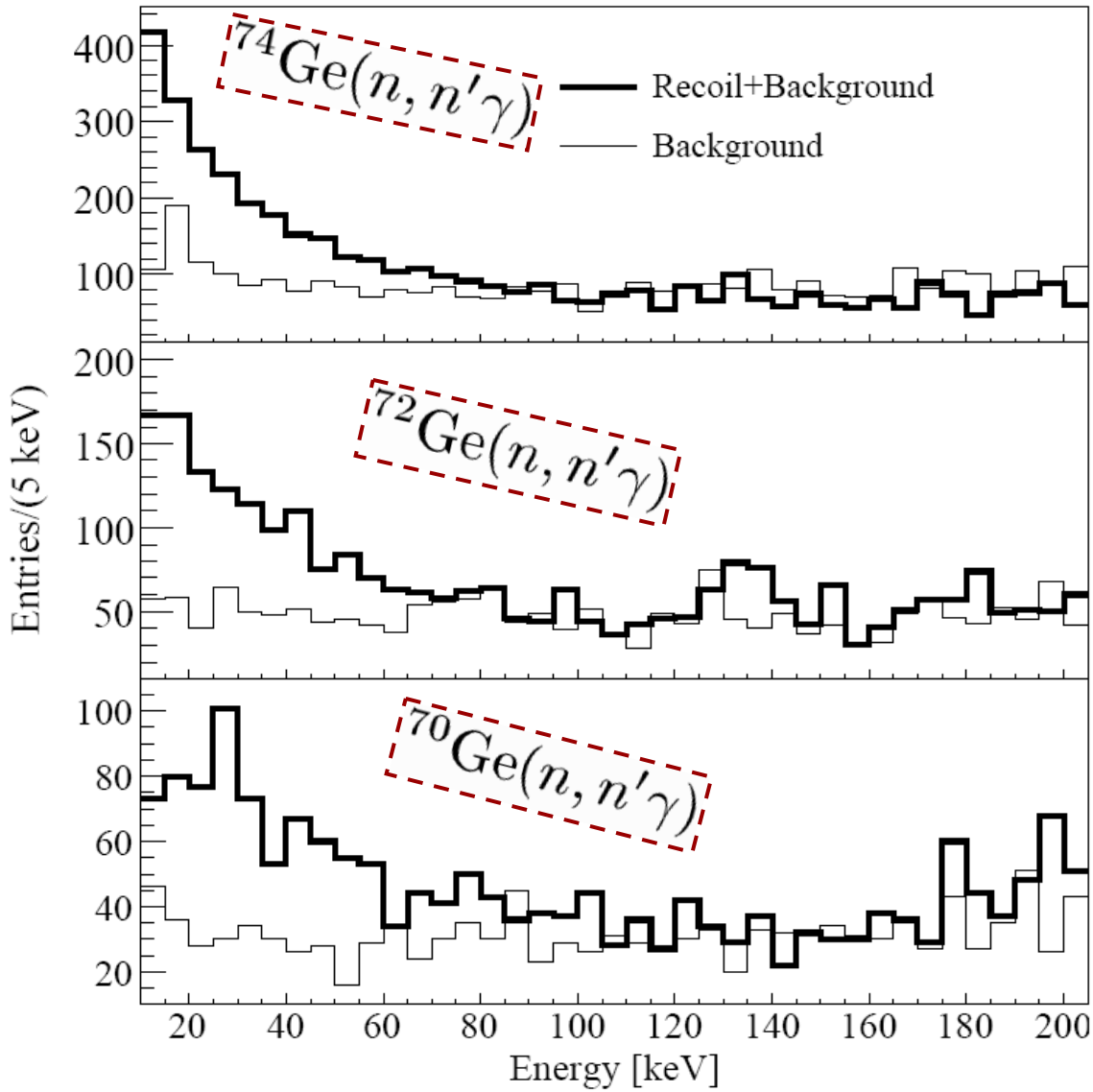
Two more peaks from neutron inelastic scattering



Recoil energy spectra

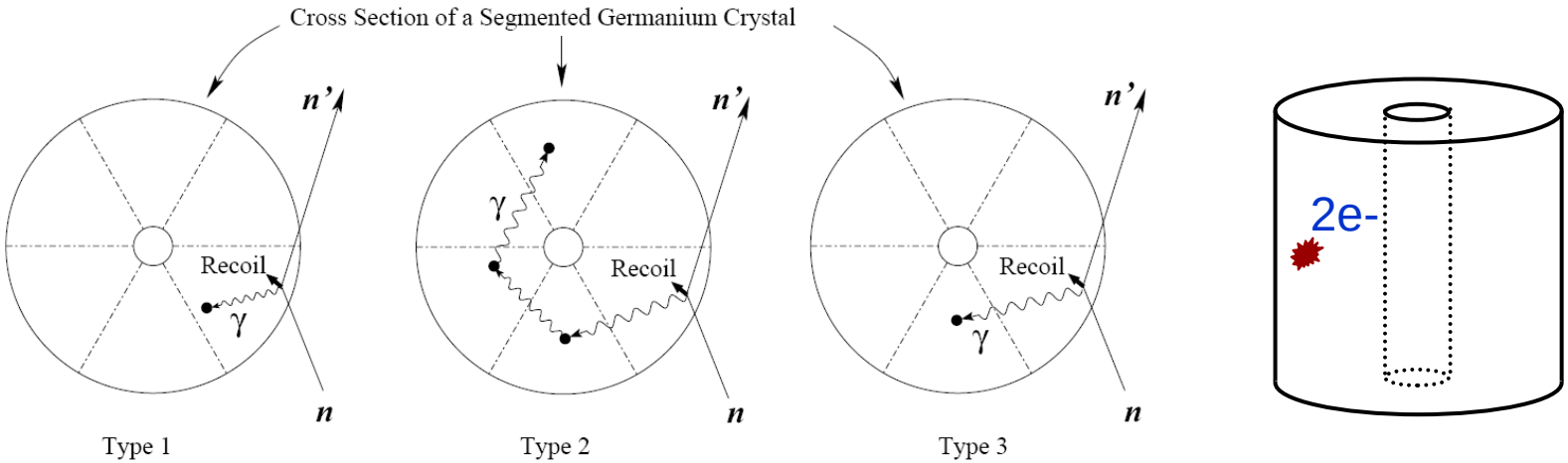


Type 3



Number of events belonging to different types

E [keV]	N_{type1}	N_{type2}	N_{type3}	N_{total}
595.8	$(1 \pm 1) \times 10^3$*	$(10 \pm 3) \times 10^3$	7285 ± 218	$(18.4 \pm 2.5) \times 10^3$
834.0	[0, 380]	[4100, 4700]	2592 ± 186	[6700, 7700]
1039.2	[0, 240]	[2700, 3100]	1429 ± 182	[4100, 4800]

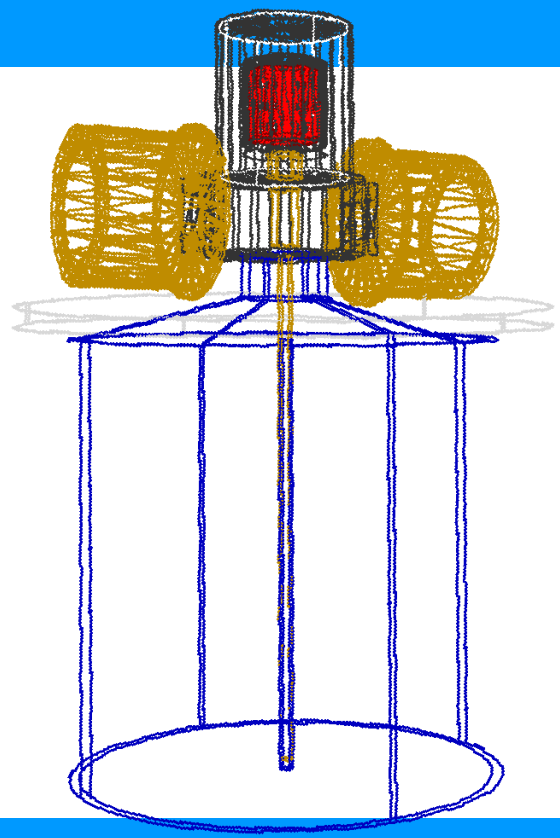


Simulation

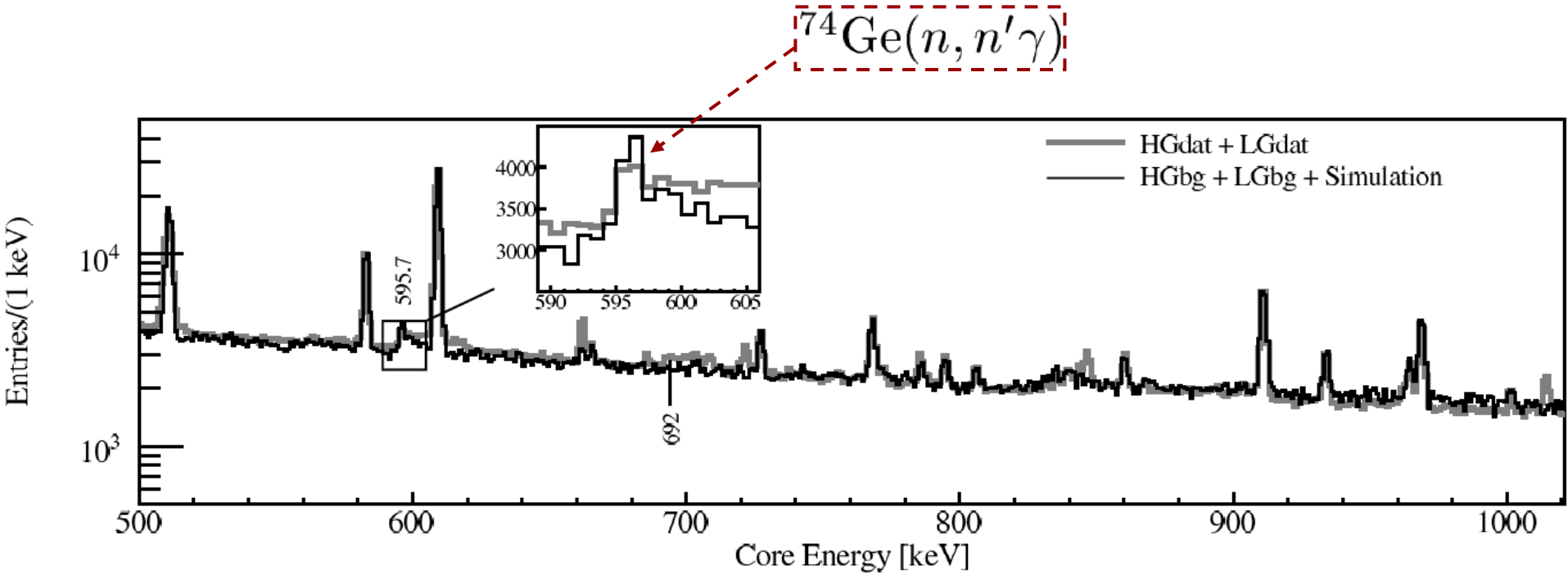
MaGe:

- a C++ simulation package developed by the MC groups of the Majorana and Gerda collaborations
- based on Geant4

Geant4.8.2-patch01
with G4NDL3.10



Nuclear recoil is not simulated by Geant4



Bugzilla/Geant4 – Problem 675: No boost from CM->Lab for G4NeutronHPInelastic

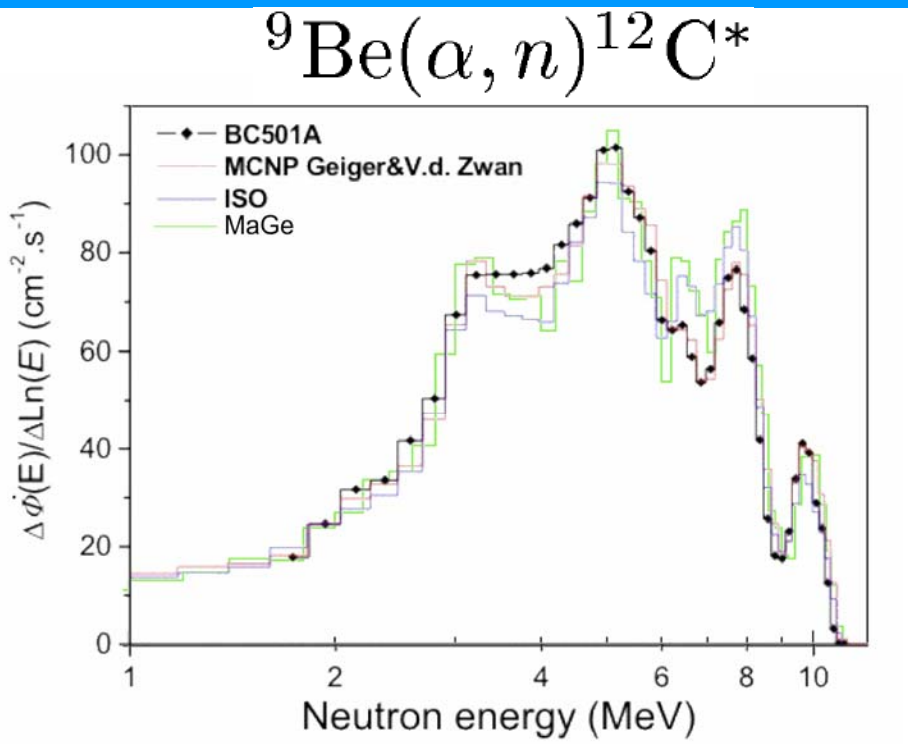
Other Geant4 bugs

- Meta stable states are missing [will be fixed]
- Internal conversion is missing [no evaluated data]
- Energy of a photon from H(n,γ) is wrong [fixed]

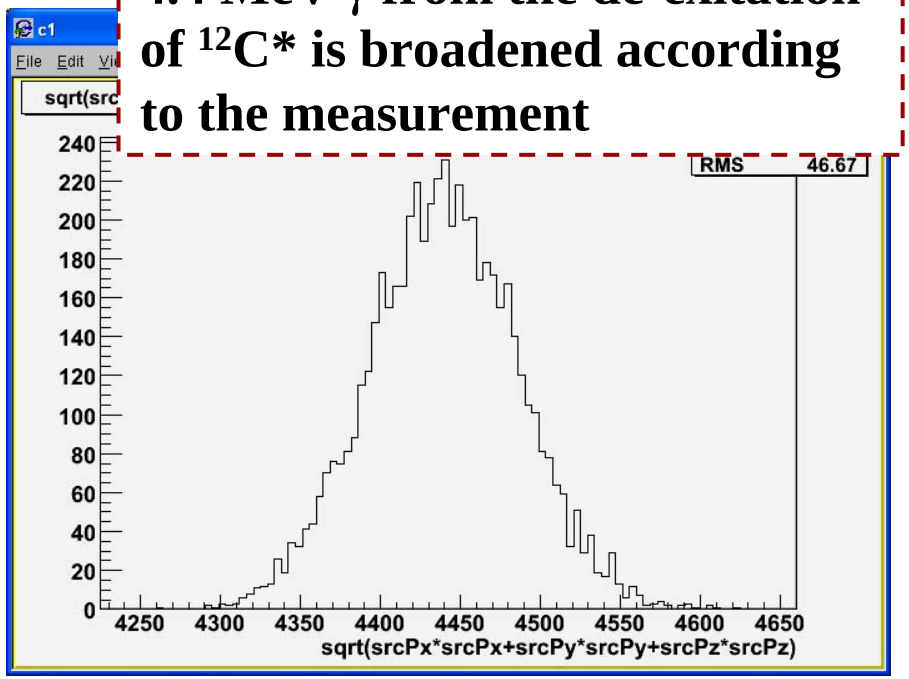
Summary

- Neutron interactions are a potential background for GERDA
- Neutron experiment using GERDA prototype detector carried out
- Peaks due to neutron interactions identified
- Different topologies of neutron inelastic scatterings with the segmented germanium detector studied in great detail
  - Segmented detector proved to be powerful to distinguish some neutron interactions from $0\nu\beta\beta$ signal.
  - Recoil and gamma energy of neutron inelastic scattering can be disentangled from each other using segmented detector
- MC simulation verified. Several crucial problems found. Some fixed, some not.

Simulation of Am-Be neutron source



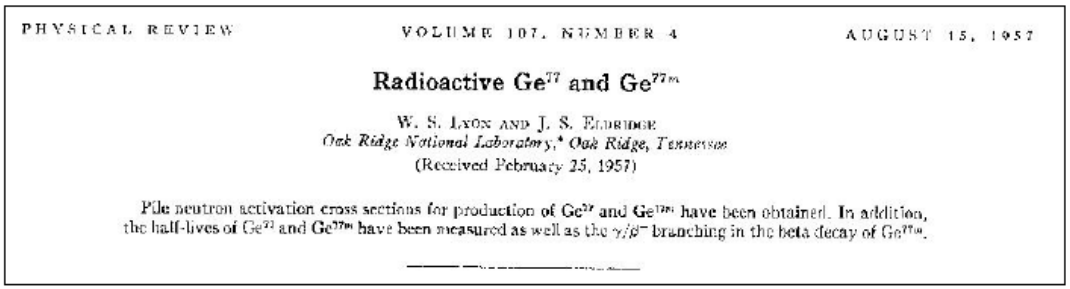
4.4 MeV γ from the de-exitation of ^{12}C* is broadened according to the measurement



Thermal neutron capture

Neutron capture in ^{76}Ge (0^+) can eventually populate (after IT) $^{77}Ge_{g.s.}$($7/2^+$) or ^{77m}Ge ($1/2^-$, 159 keV)

^{77}Ge β-decays to ^{77}As ($T_{1/2}$ = 11.3 h, Q =2.7 MeV). ^{77m}Ge ($T_{1/2}$ = 52.9 s) can IT to $^{77}Ge_{g.s.}$ (20%) or β-decay to ^{77}As (Q = 2.8 MeV)



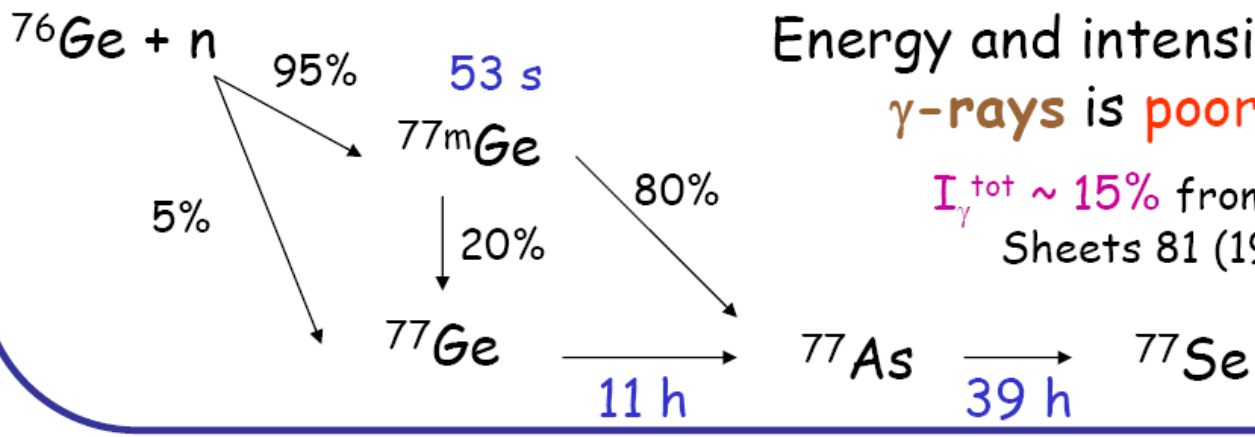
PHYSICAL REVIEW VOLUME 107, NUMBER 4 AUGUST 15, 1957

Radioactive Ge^{77} and Ge^{77m}

W. S. Lyon and J. S. Eldridge
Oak Ridge National Laboratory, Oak Ridge, Tennessee*
(Received February 25, 1957)

Pile neutron activation cross sections for production of Ge^{77} and Ge^{77m} have been obtained. In addition, the half-lives of Ge^{77} and Ge^{77m} have been measured as well as the γ/β^- branching in the beta decay of Ge^{77m}.

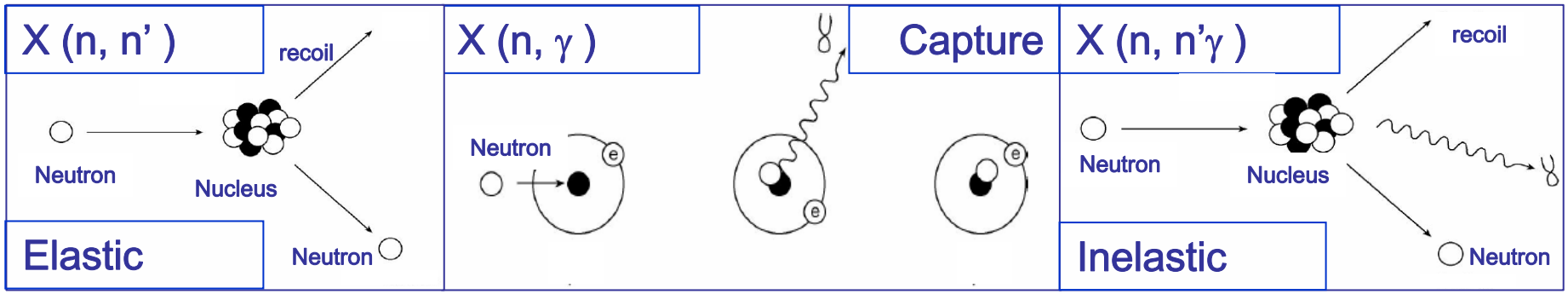
Direct production of $^{77}Ge_{g.s.}$: **5%**
Production through IT of ^{77m}Ge : **19%**



Energy and intensity of **prompt γ-rays** is **poorly known**

I_γ^{tot} ~ 15% from Nucl. Data Sheets 81 (1997) 417

Neutron Interactions with Nuclei



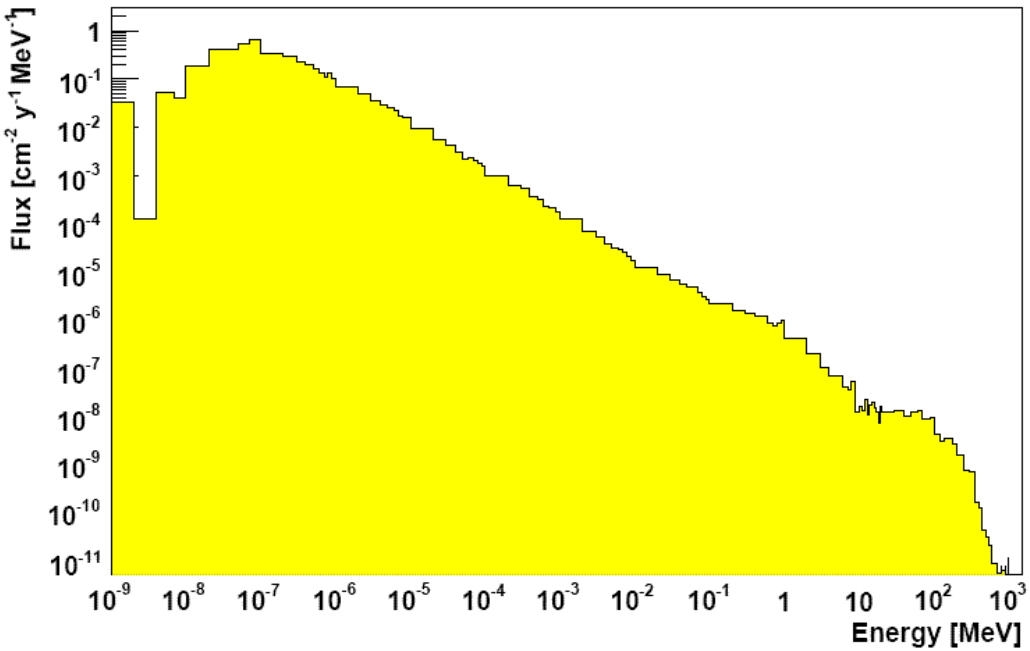
$$n + {}^{A}X \rightarrow {}^{A+1}X^{*}_{m}, \quad {}^{A+1}X^{*}_{m} \rightarrow {}^{A+1}X + \gamma$$

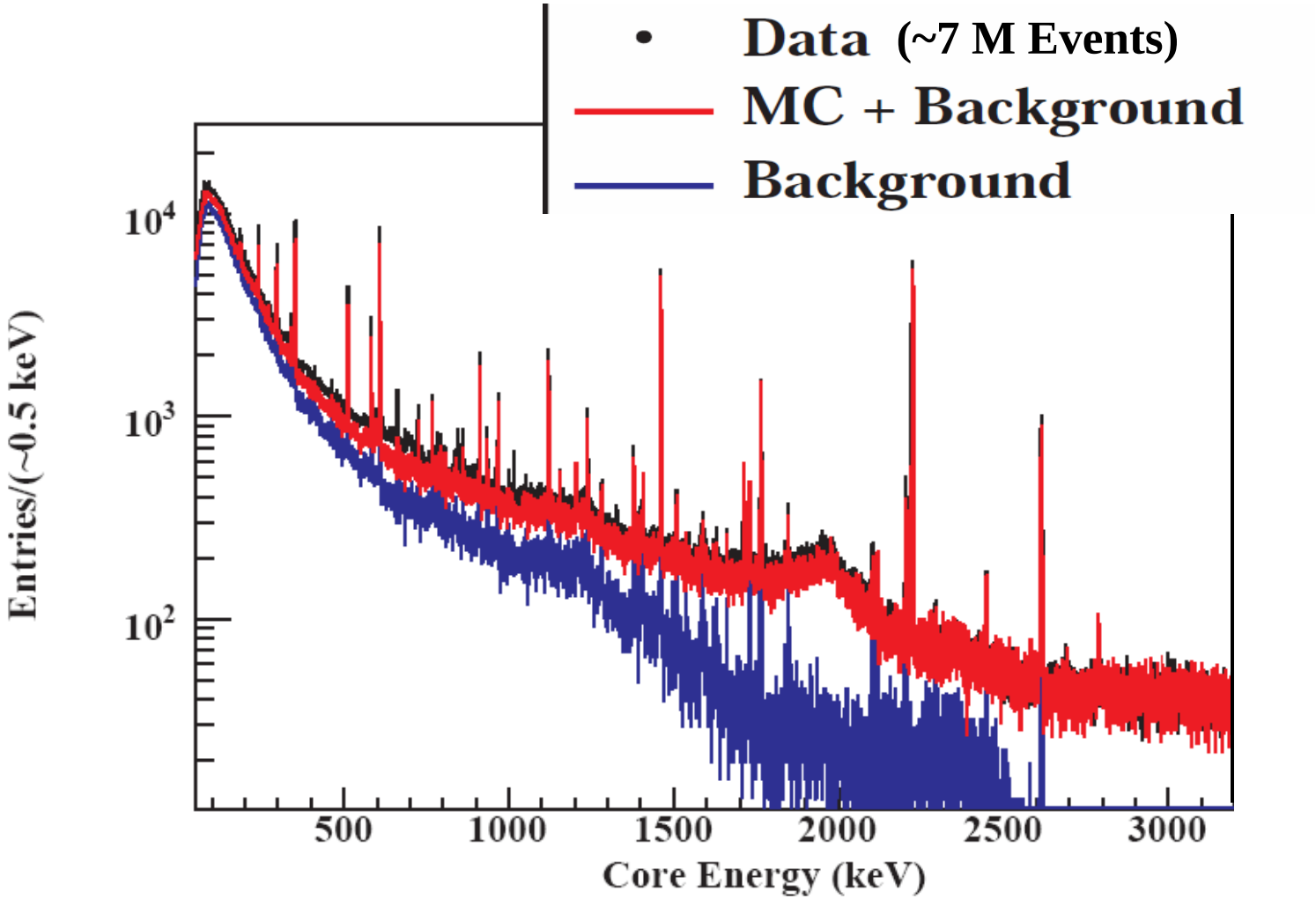
Meta-stable State

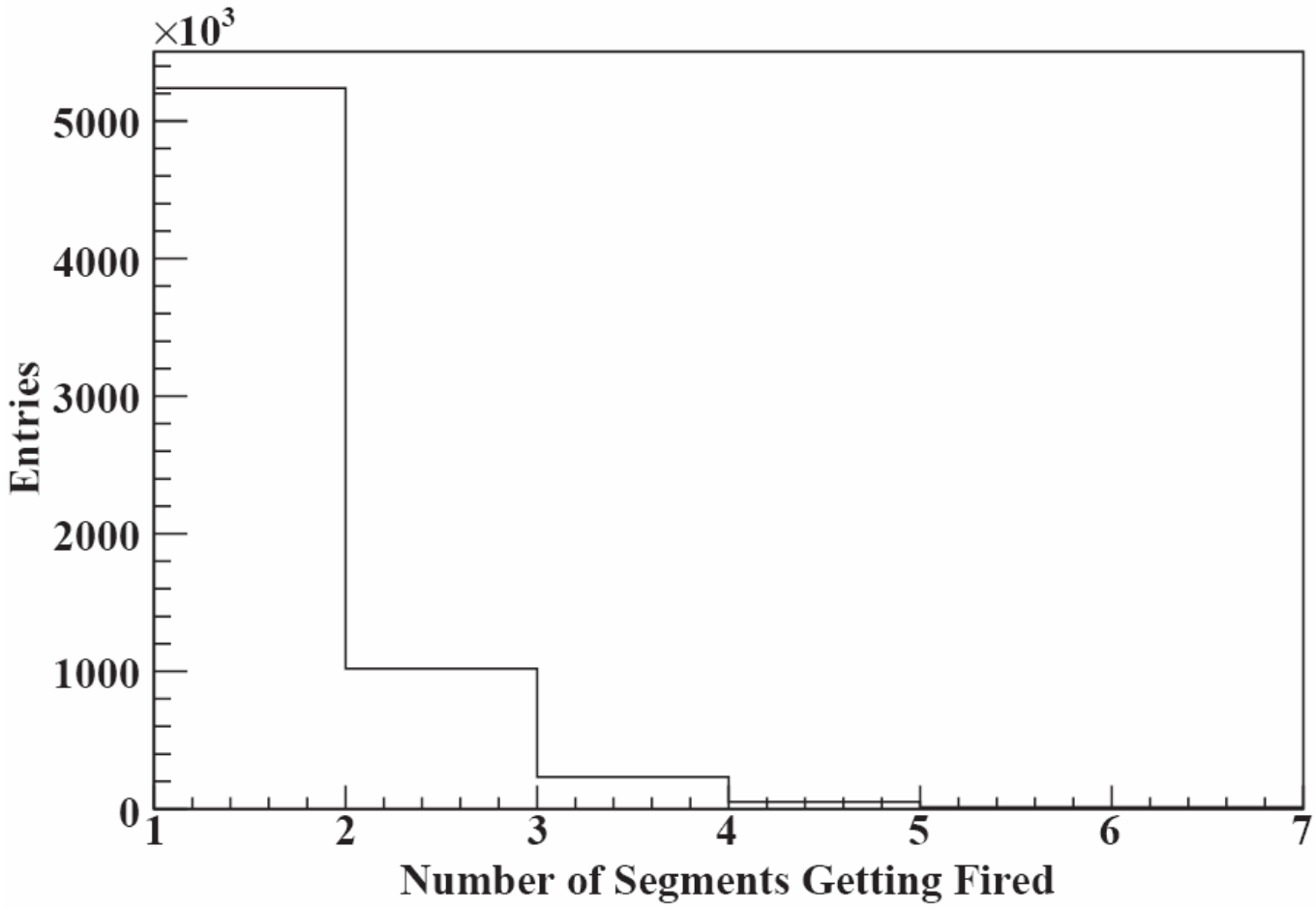
$$n + {}^{A}X \rightarrow {}^{A+1}X^{*}, \quad {}^{A+1}X^{*} \rightarrow {}^{A+1}X^{+} + e$$

Internal Conversion

Daniel Kollar, GSTR-05-018




Data (~7 M Events)
MC + Background
Background
Entries/(~0.5 keV)
10^4
10^3
10^2
500
1000
1500
2000
2500
3000
Core Energy (keV)


×10^3
5000
4000
3000
2000
1000
0
Entries
1
2
3
4
5
6
7
Number of Segments Getting Fired

type 1 events can be calculated as $N_{type1} = N_{total}/\mathcal{R}(E_{\gamma}^{inelastic}) - N_{type3}$.

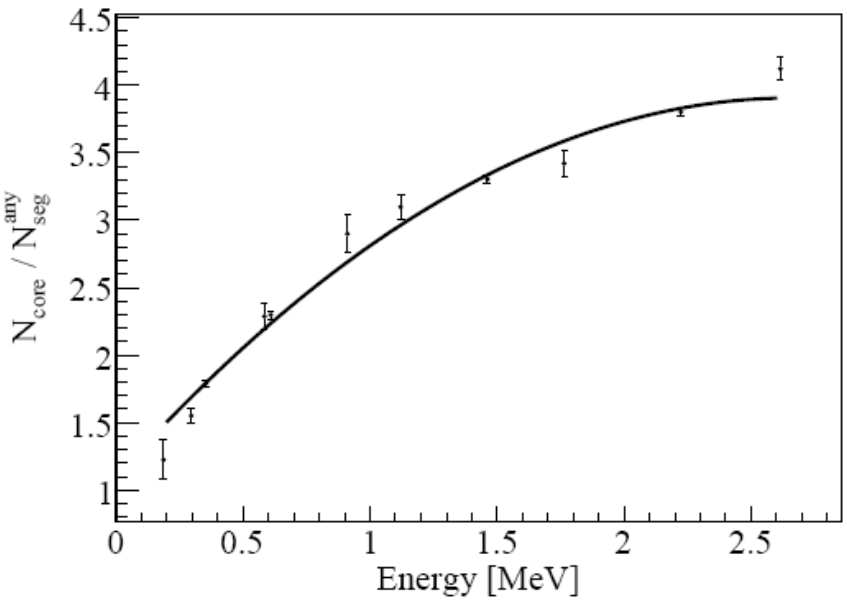
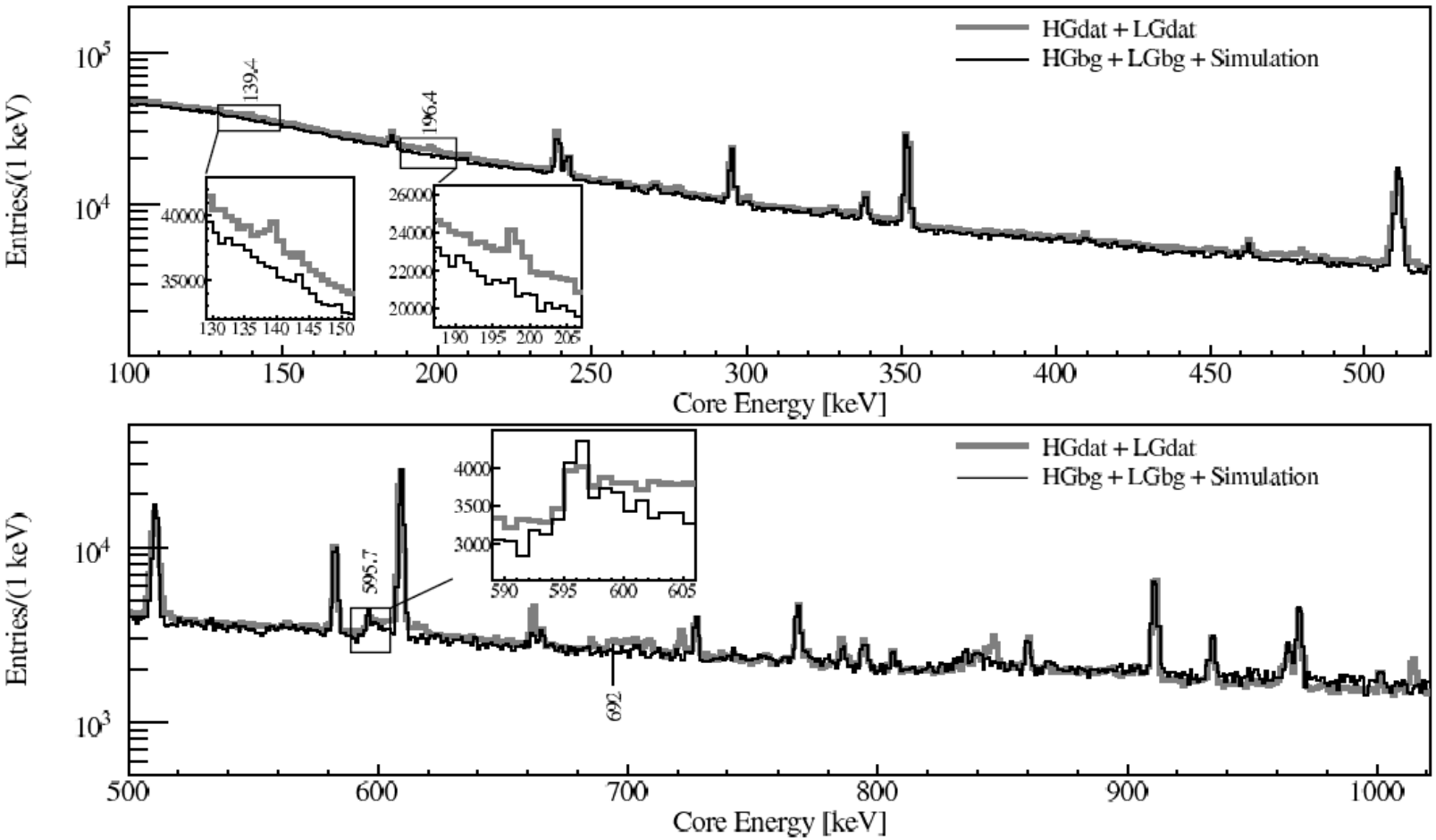
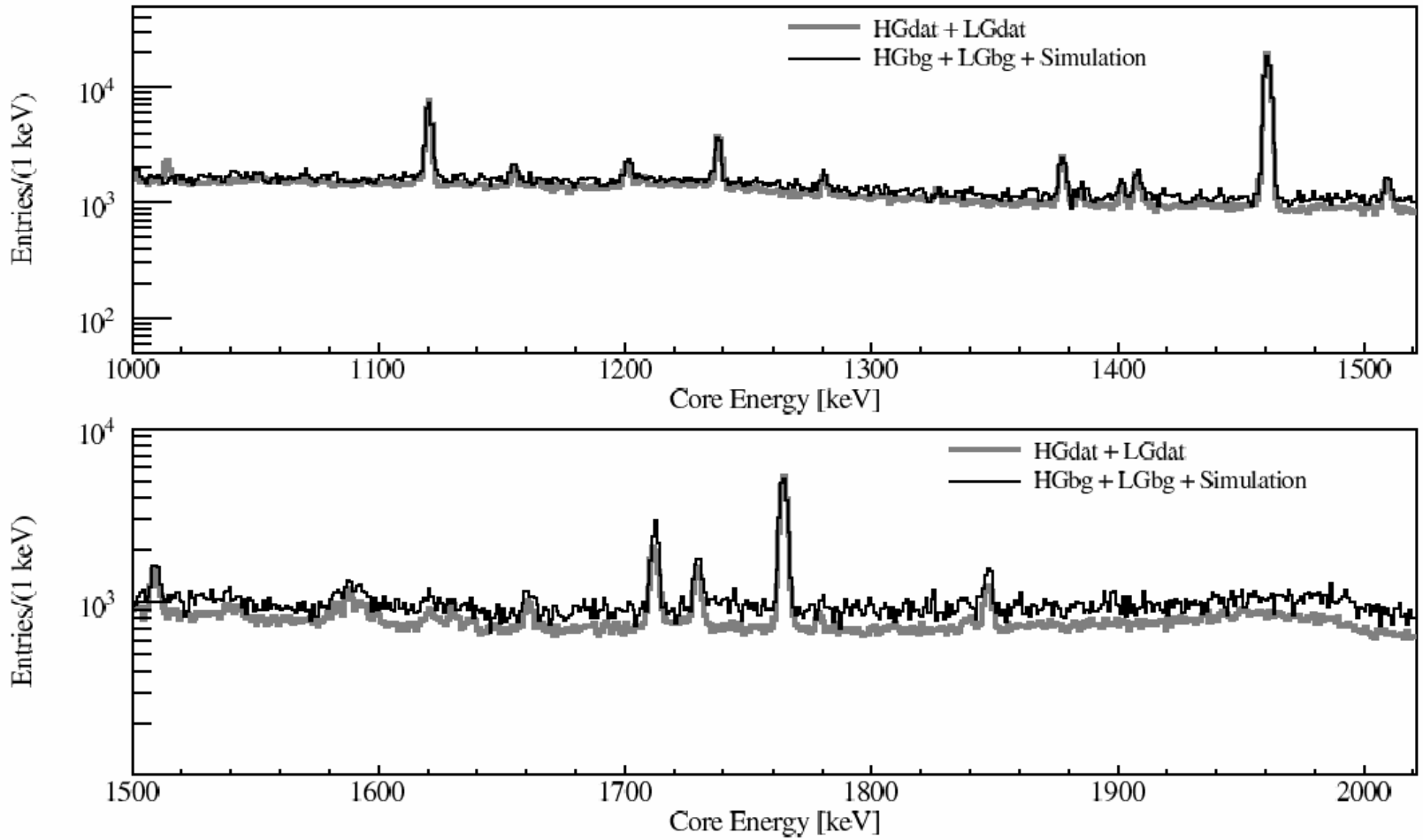
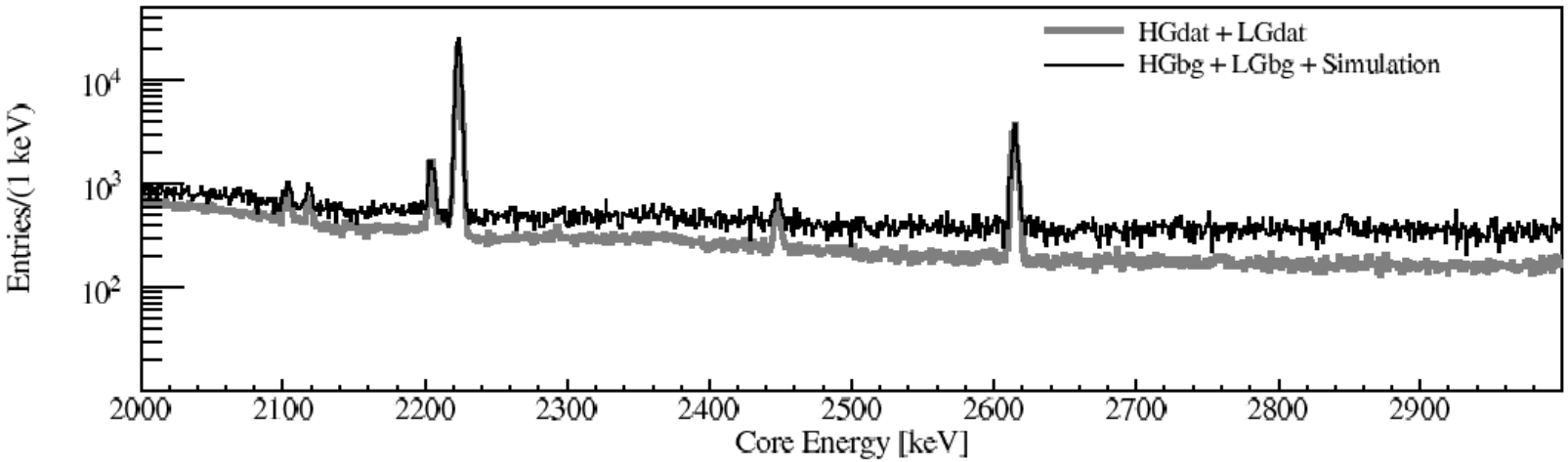
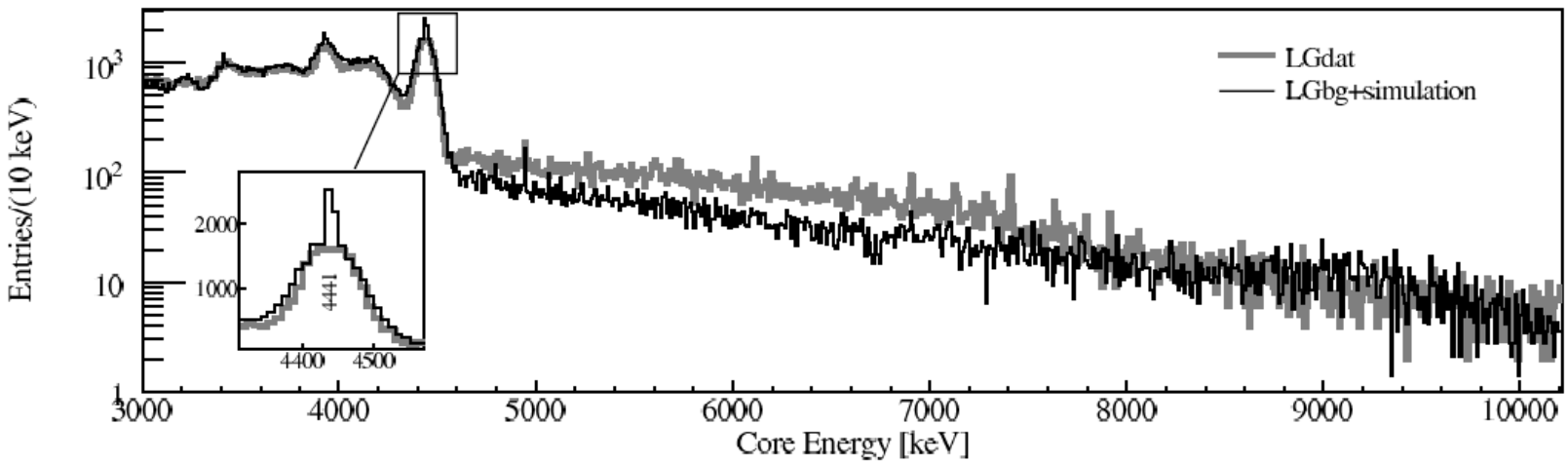


Fig. 7. The "core to any segment ratio" as a function of the energy.

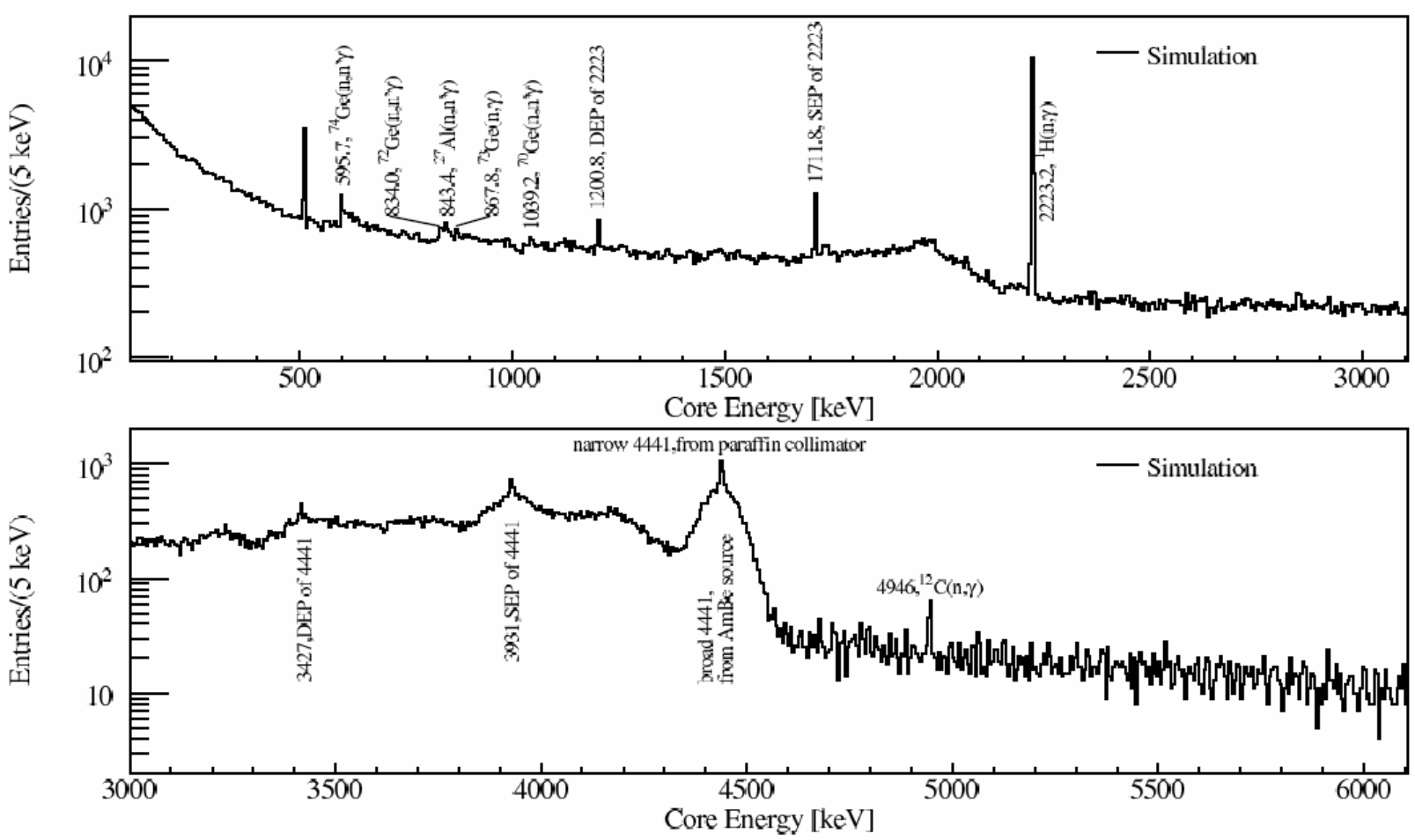

HGdat + LGdat
HGbg + LGbg + Simulation
Entries/(1 keV)
Core Energy [keV]
139.4
196.4
595.7
692


HGdat + LGdat
HGbg + LGbg + Simulation
Entries/(1 keV)
10^4
10^3
10^2
1000
1100
1200
1300
1400
1500
Core Energy [keV]
HGdat + LGdat
HGbg + LGbg + Simulation
Entries/(1 keV)
10^4
10^3
1500
1600
1700
1800
1900
2000
Core Energy [keV]

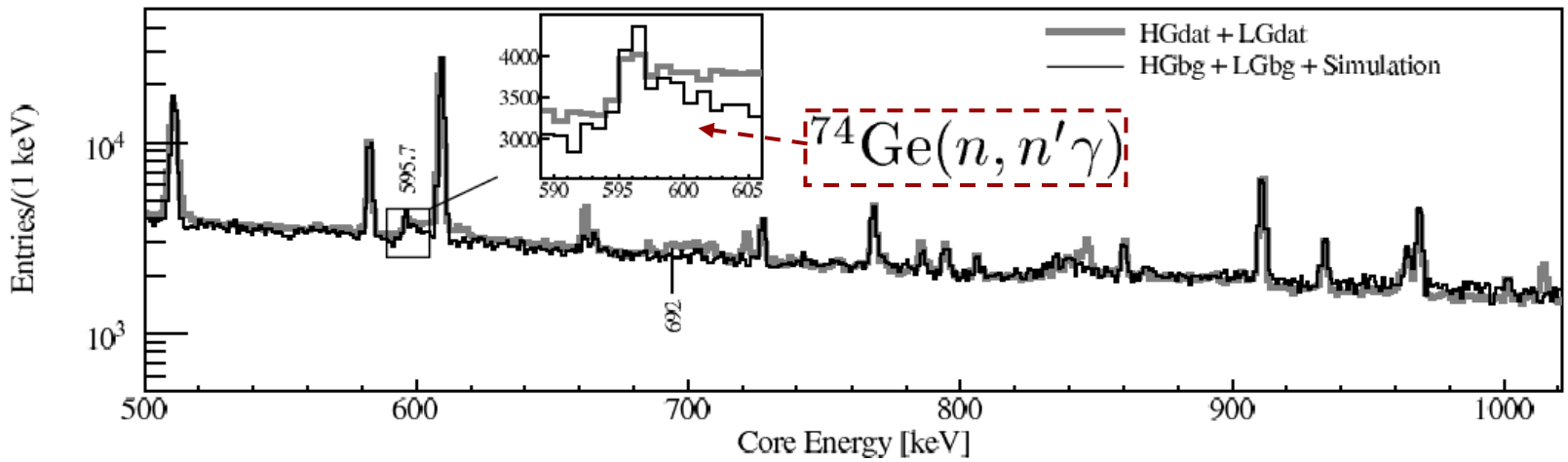

HGdat + LGdat
HGbg + LGbg + Simulation
Entries/(1 keV)
10^4
10^3
10^2
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
Core Energy [keV]

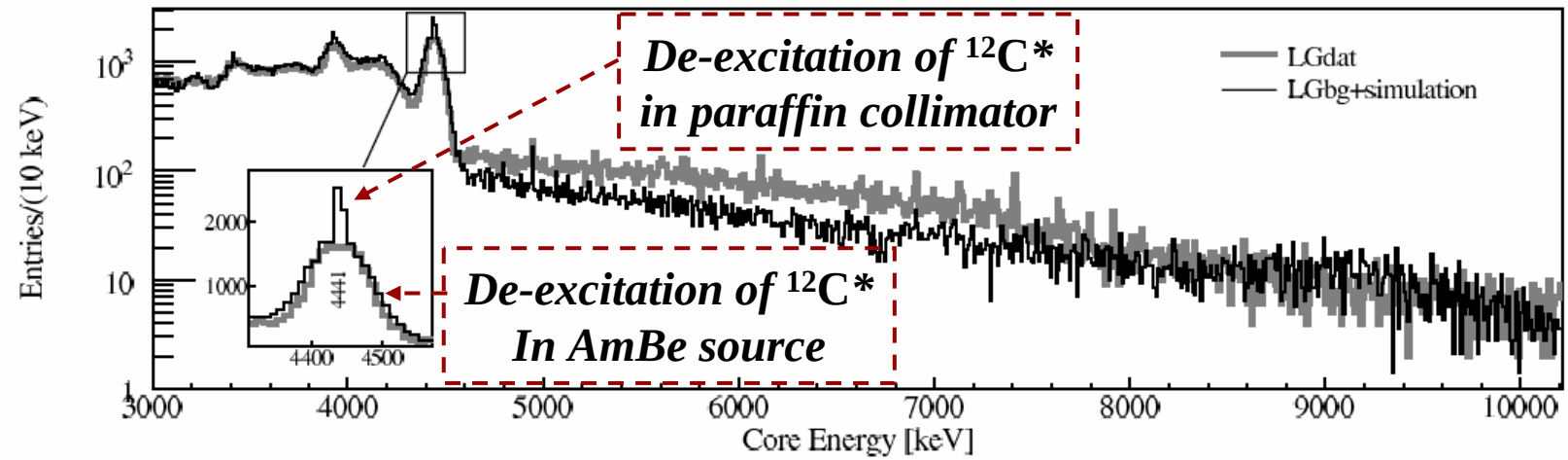

LGdat
LGbg+simulation
Entries/(10 keV)
10^3
10^2
10
1
2000
1000
4441
4400
4500
3000
4000
5000
6000
7000
8000
9000
10000
Core Energy [keV]

Simulated core energy spectrum

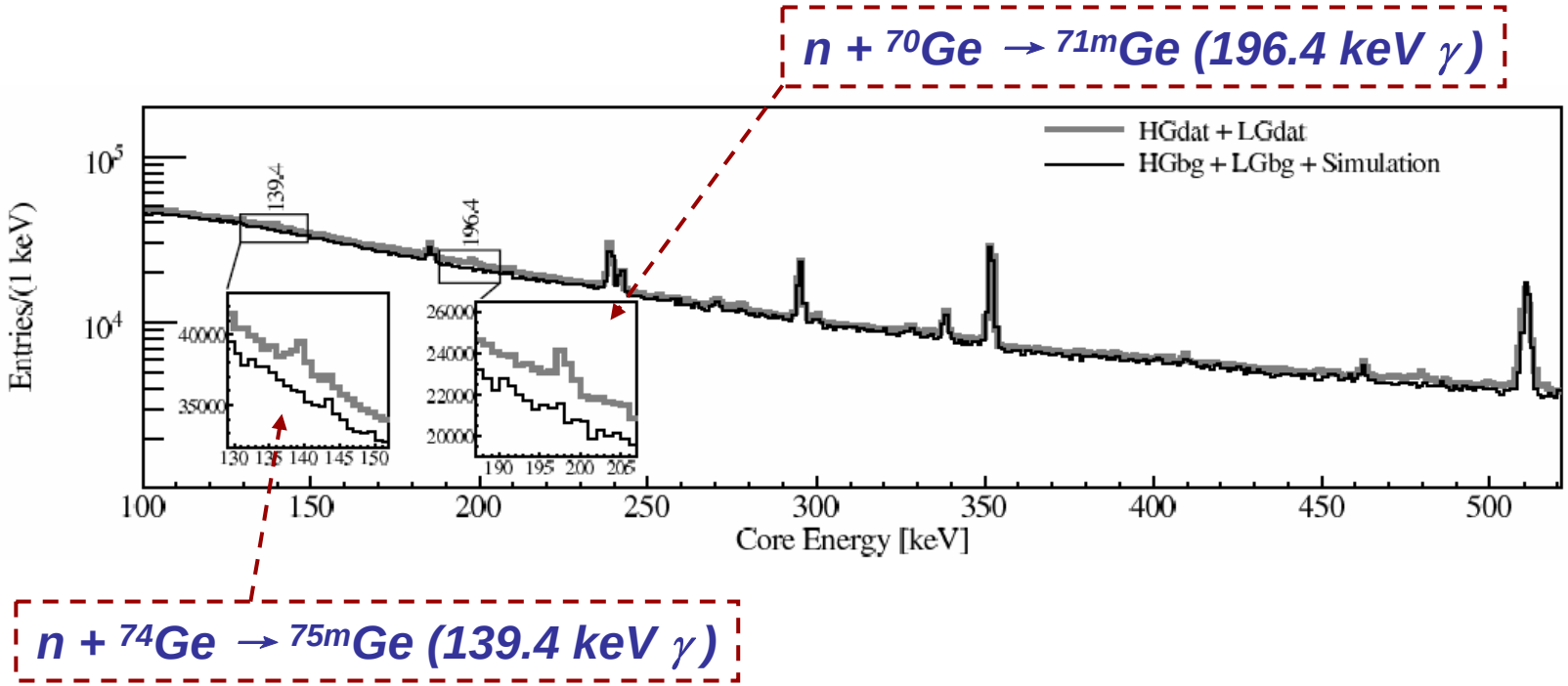


Lorenz boost from CM. to lab. is missing





Meta stable states are missing



Energy of γ is wrong

The 2223 keV photon peak from $H(n,\gamma)$