Institute of Nuclear and Particle Physics (IKTP)
TU Dresden

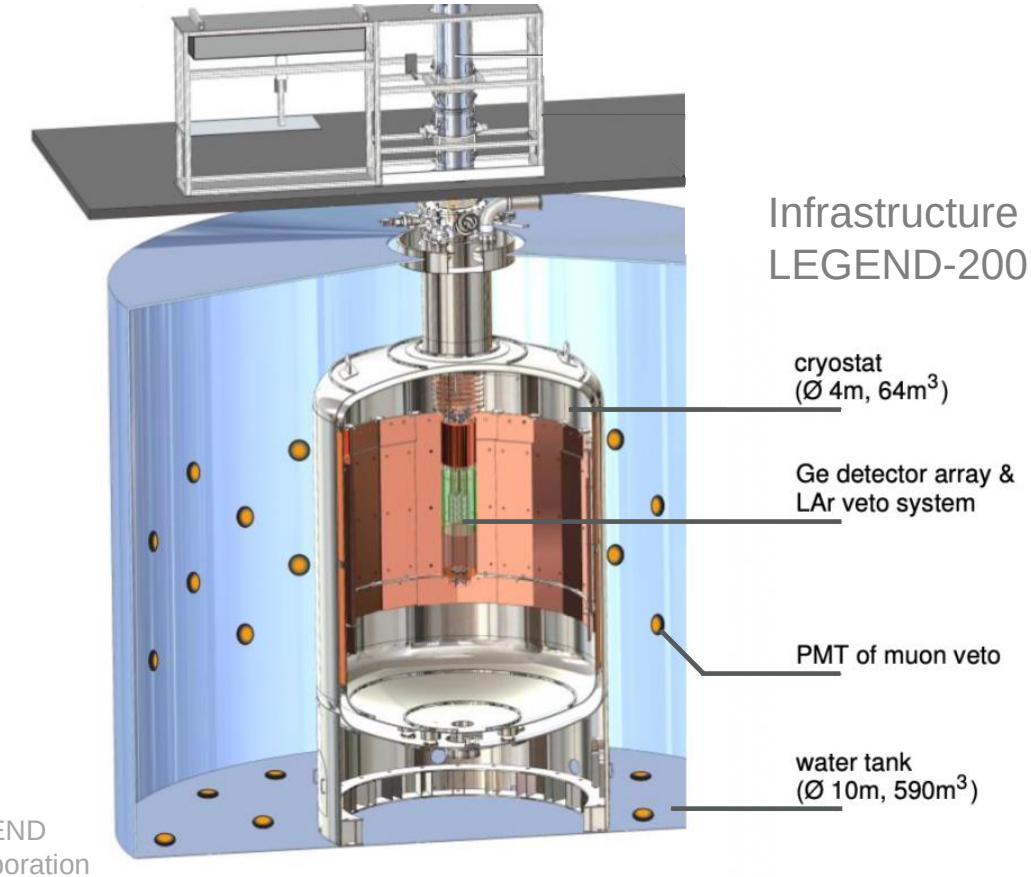
Investigation of neutron-induced γ rays from Ge-nuclides in the region of interest of GERDA/LEGEND

• Marie Pichotta, Toralf Döring, Hans Hoffmann, Konrad Schmidt, Ronald Schwengner, Steffen Turkat, Birgit Zatschler, and Kai Zuber

23.03.2023

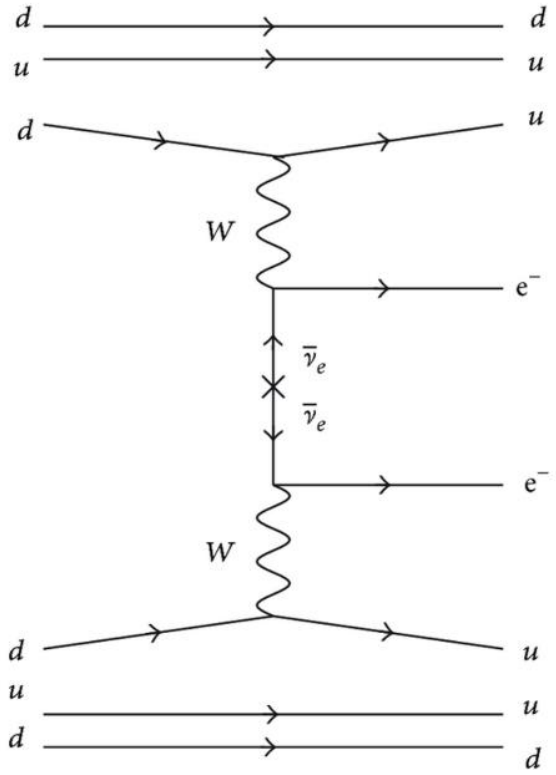
GERDA & LEGEND

- searching for $0\nu\beta\beta$ decay of ^{76}Ge (Q = 2039 keV)
- located at LNGS (Laboratori Nazionali del Gran Sasso), 1400 m underground



Infrastructure of LEGEND-200

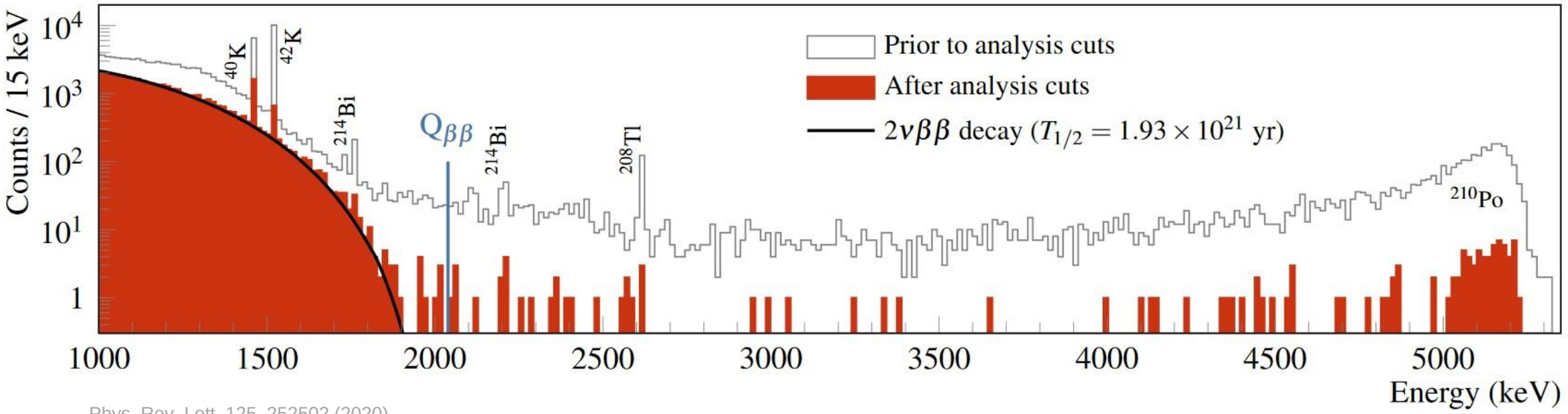
LEGEND collaboration



GERDA & LEGEND

- searching for $0\nu\beta\beta$ decay of ^{76}Ge (Q = 2039 keV)
- quasi background-free experiments

GERDA Phase II (exposure of 103.7 kg yr)



Phys. Rev. Lett. 125, 252502 (2020)

→ precise understanding of background is crucial

Neutron induced γ-ray lines in the ROI?

- searching for $0\nu\beta\beta$ decay of ^{76}Ge (Q = 2039 keV)
- previous work (Camp & Foster, 1971) indicates γ-ray line at E_γ = 2040.7 keV from decay of ^{76}Ga into excited ^{76}Ge states [1]

^{72}Ge Stable	^{73}Ge Stable	^{74}Ge Stable	^{75}Ge β-	^{76}Ge Stable	^{77}Ge β-	^{78}Ge β-
^{71}Ga Stable	^{72}Ga β-	^{73}Ga β-	^{74}Ga β-	^{75}Ga β-	^{76}Ga β-	^{77}Ga β-
^{70}Zn Stable	^{71}Zn β-	^{72}Zn β-	^{73}Zn β-	^{74}Zn β-	^{75}Zn β-	^{76}Zn β-

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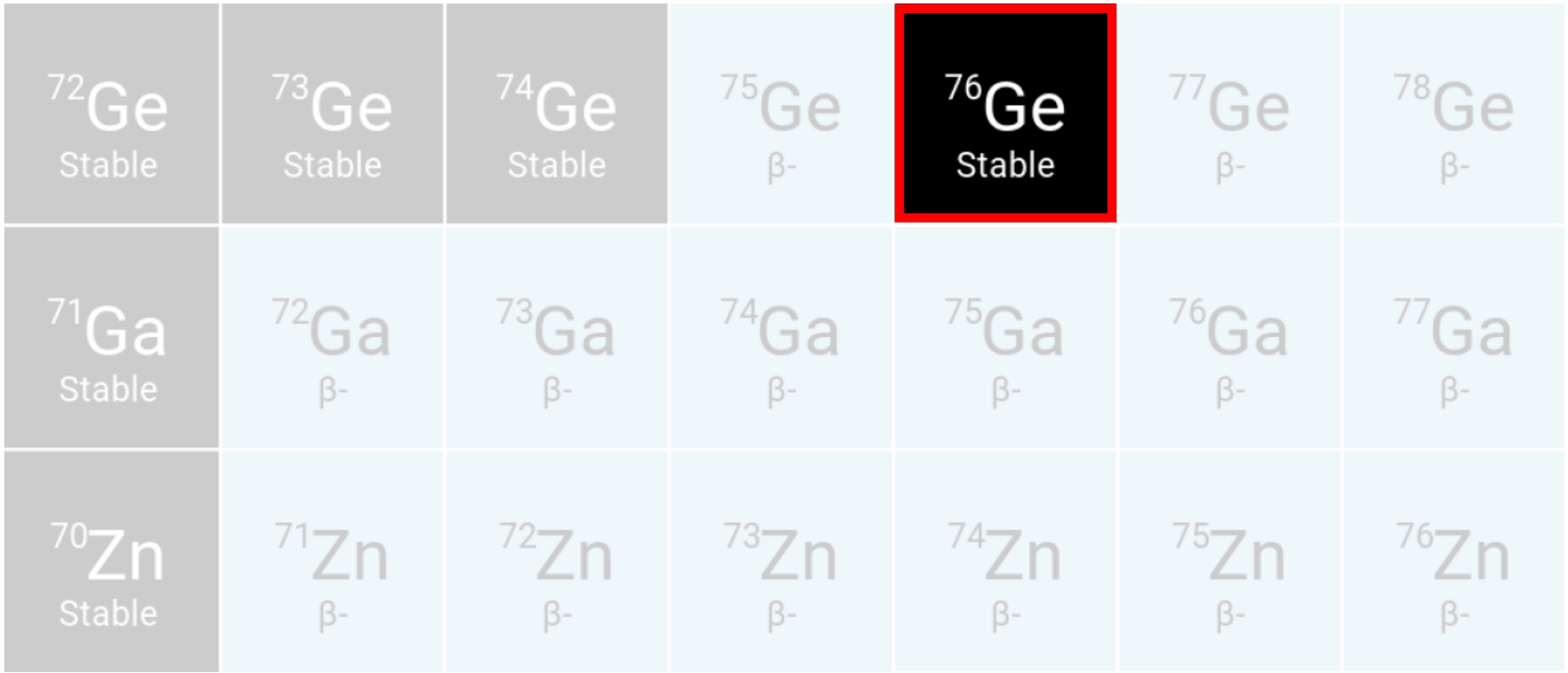

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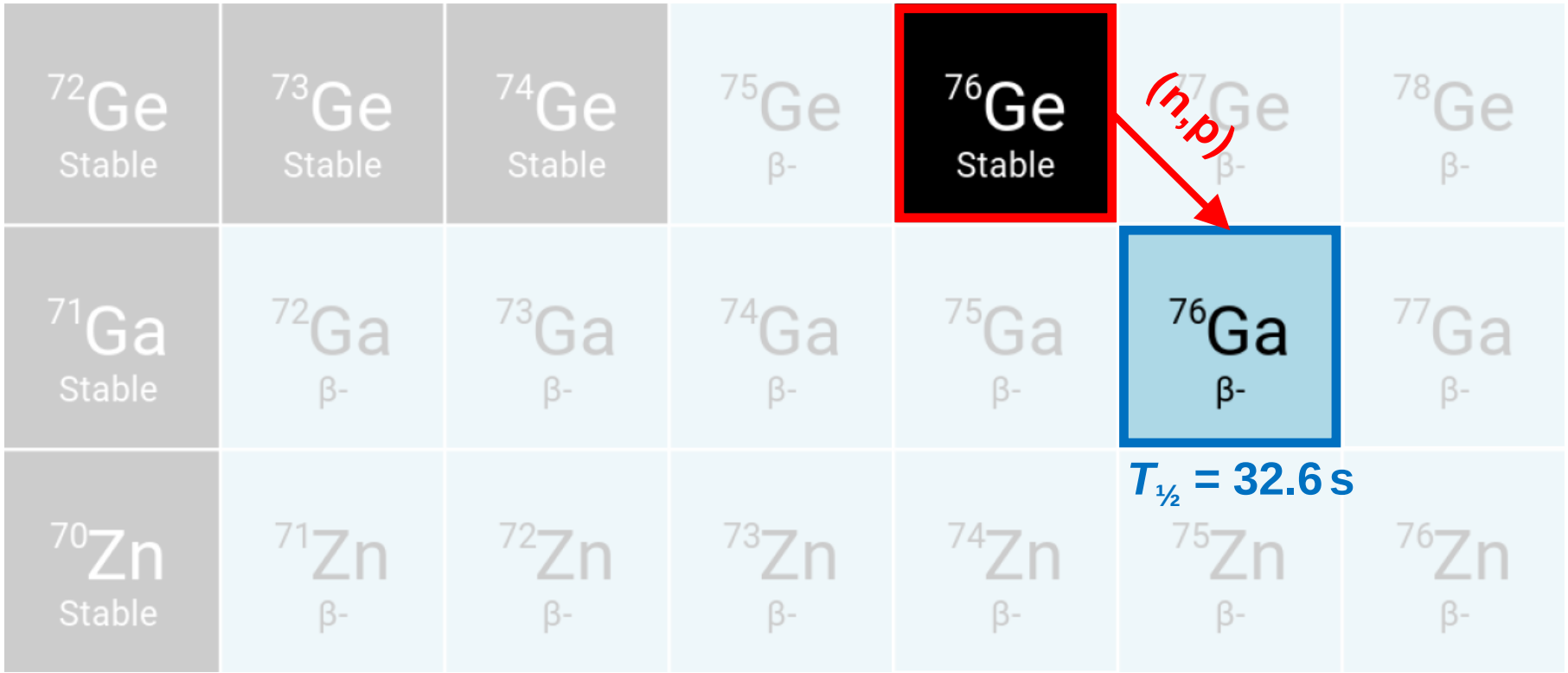

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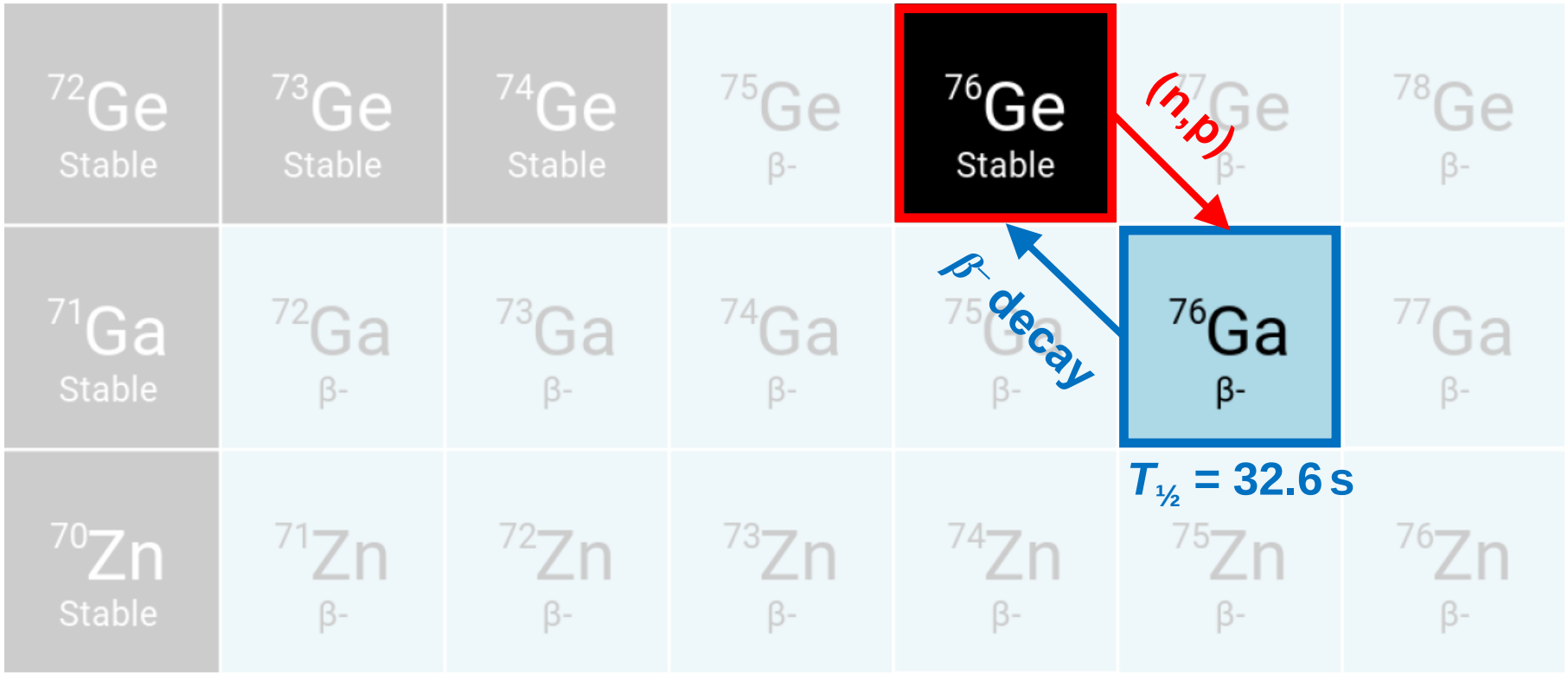

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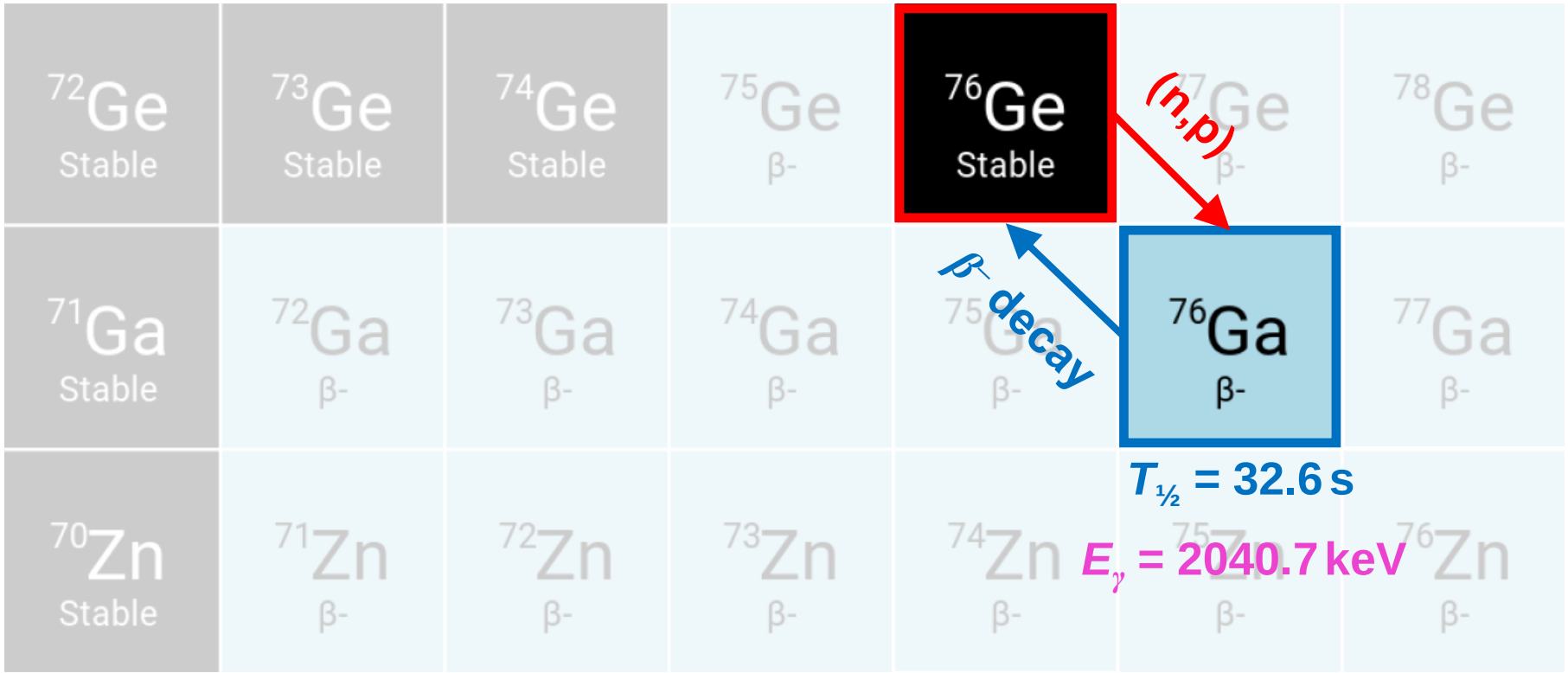

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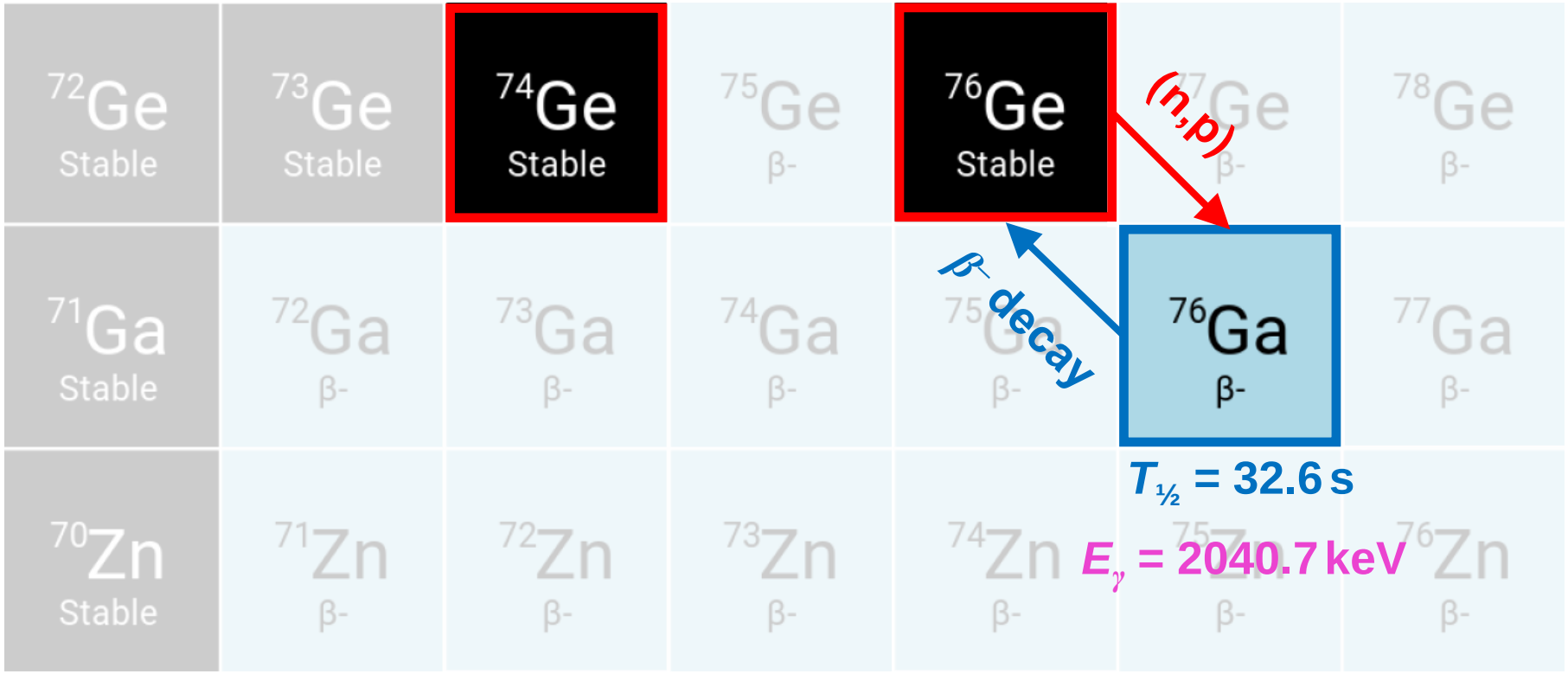

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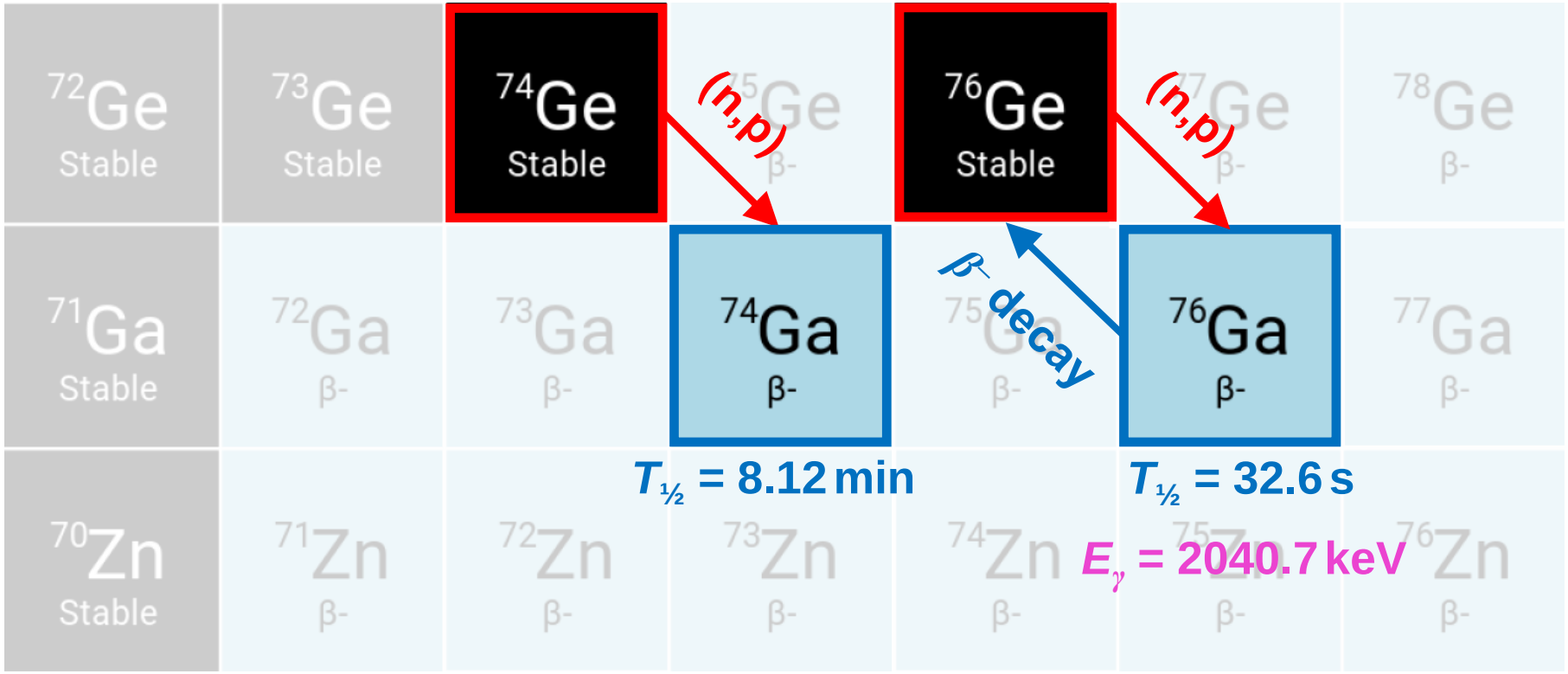

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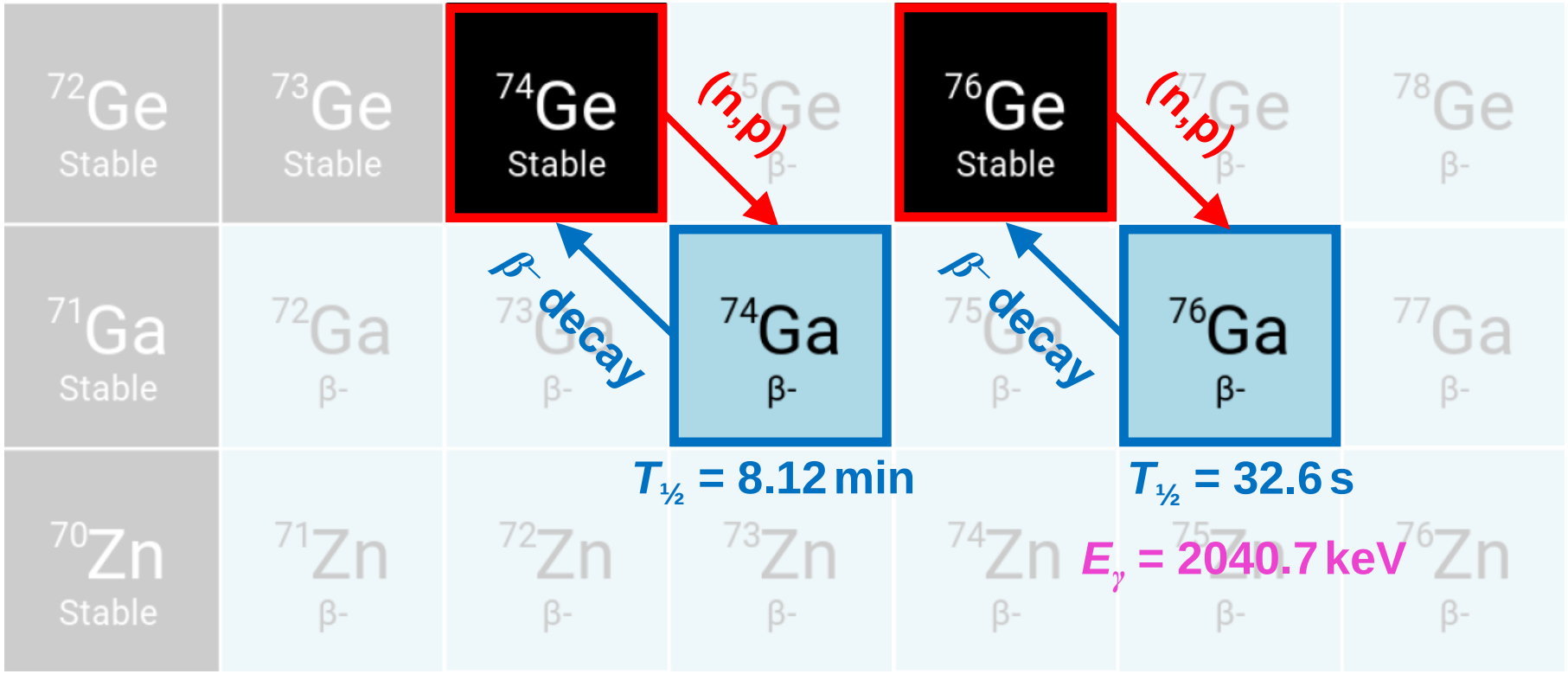

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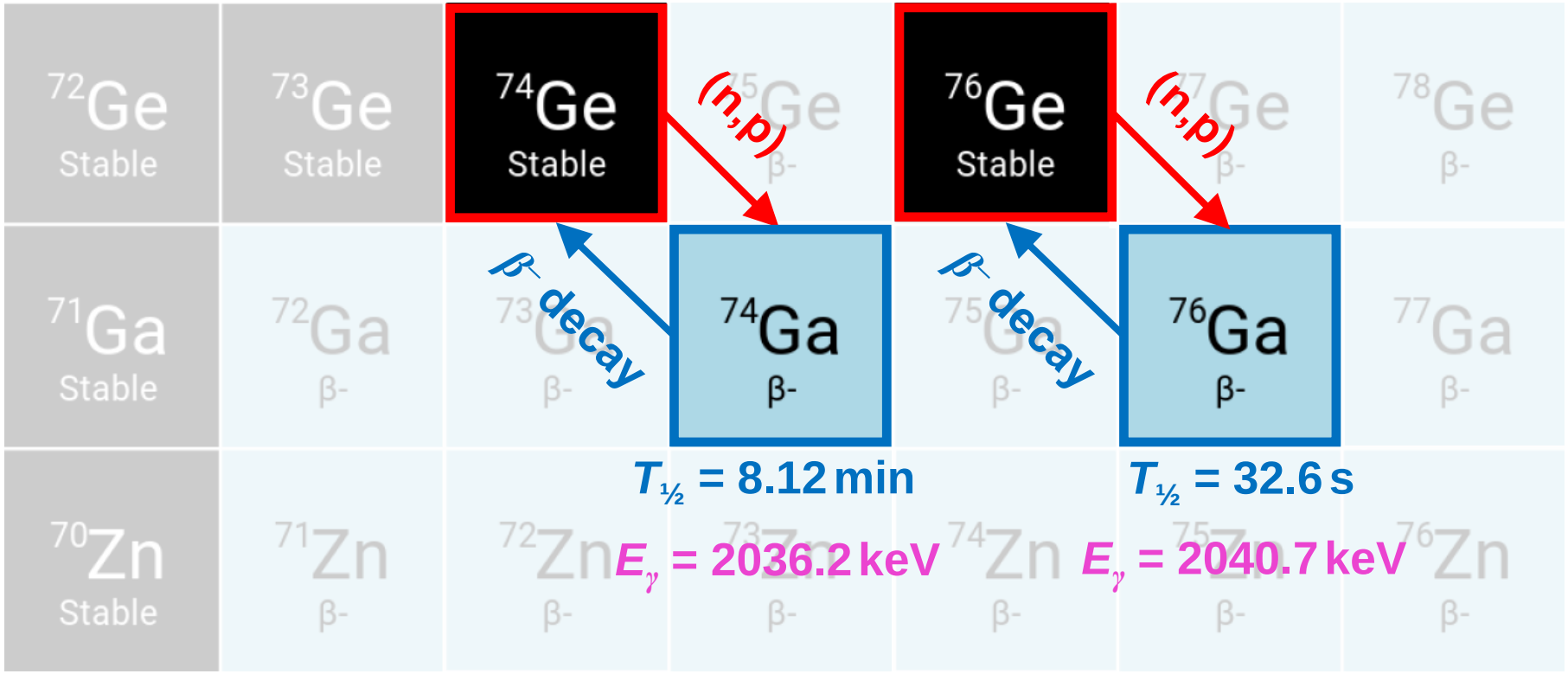

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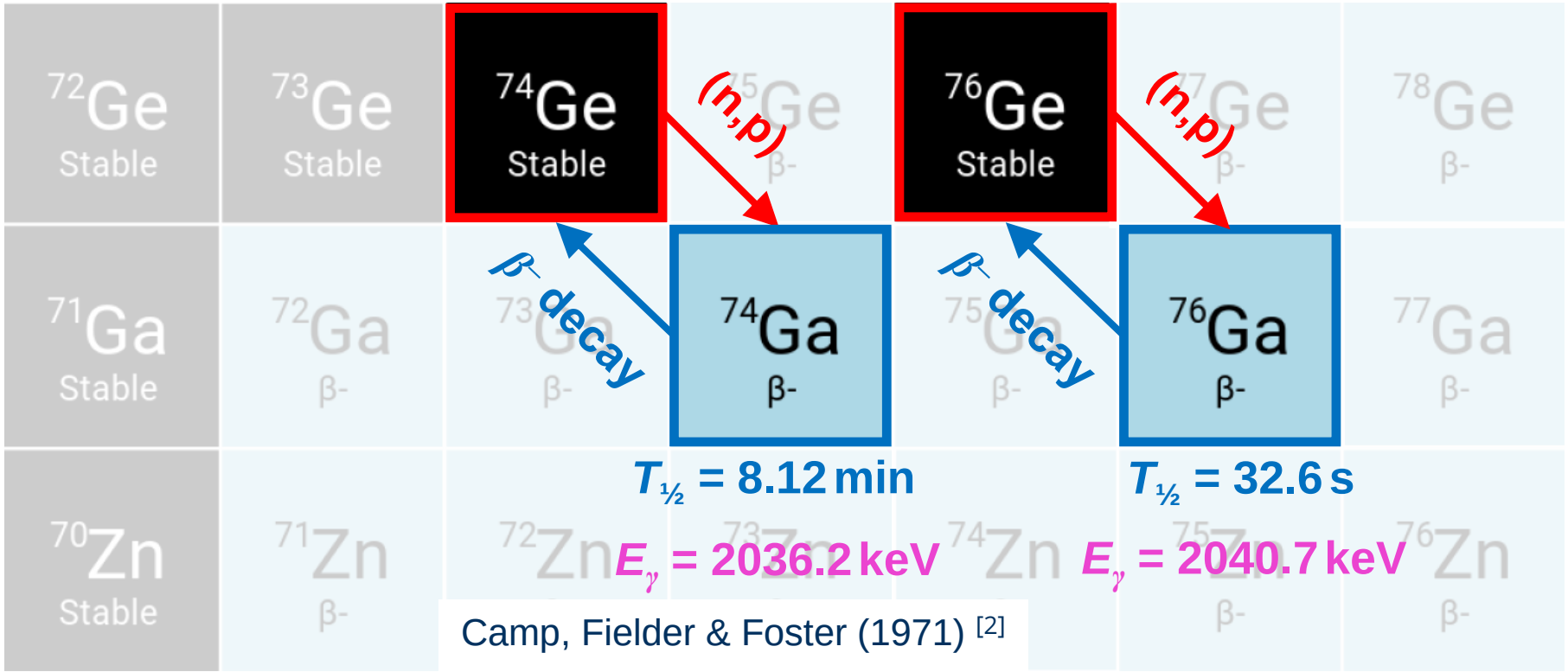

Camp, Fielder & Foster (1971) [2]

Taylor et al. (1975) [3]

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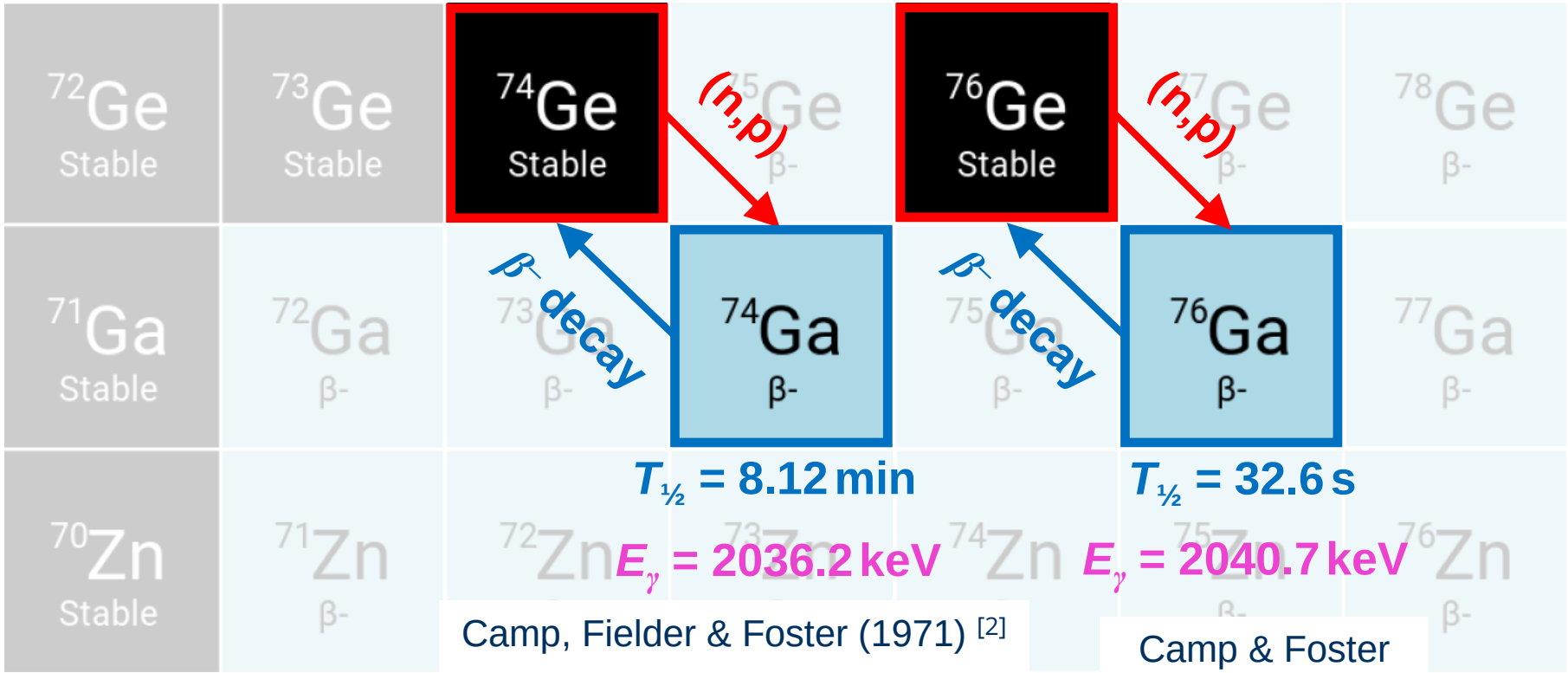
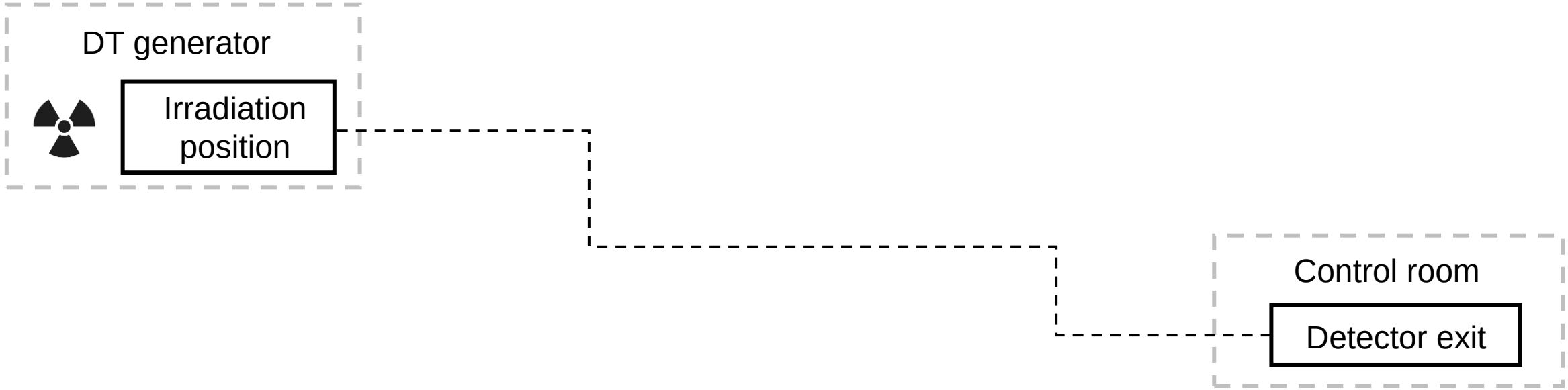


Experimental setup

- transportation of samples by pneumatic tube system



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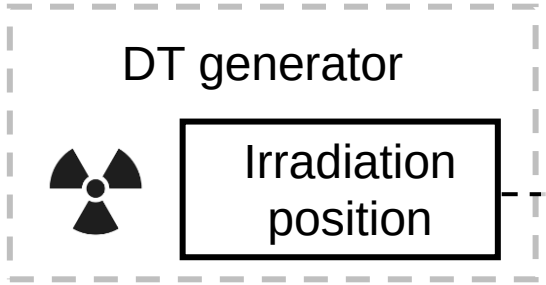


- DT generator produces 14.1 MeV quasi-monoenergetic neutrons

Experimental setup

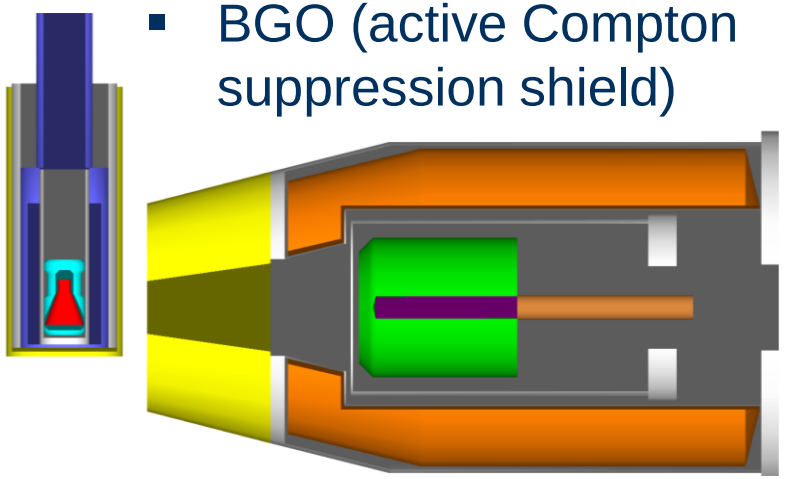
- transportation of samples by pneumatic tube system

DT generator

Irradiation position

- DT generator produces 14.1 MeV quasi-monoenergetic neutrons

- HPGe detector (relative efficiency 110%)
- BGO (active Compton suppression shield)



Control room

Detector exit

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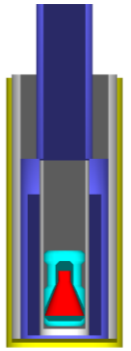

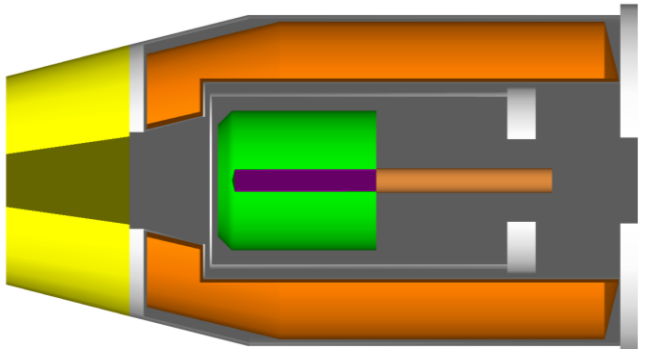

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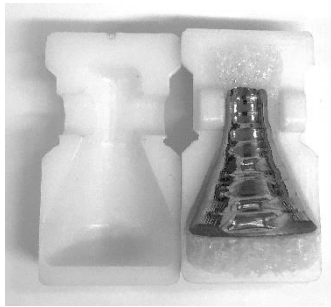
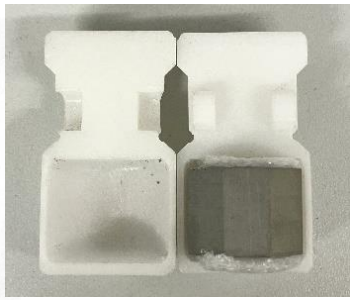
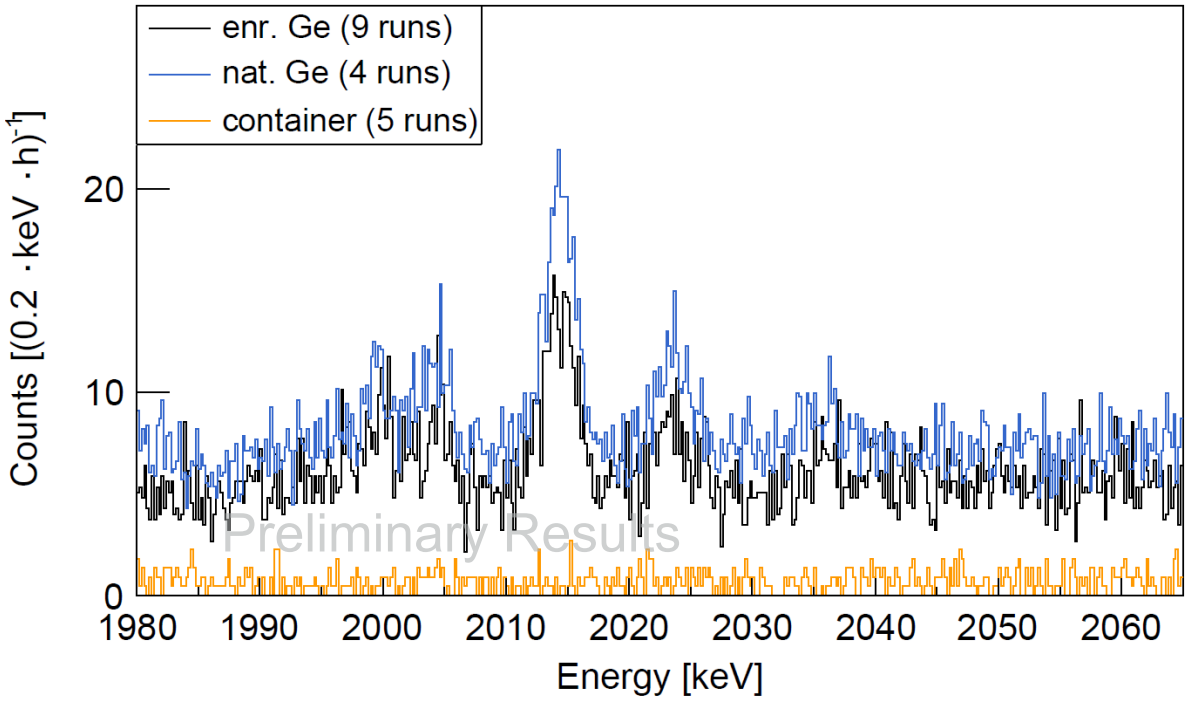




- enriched Ge-sample (≈ 89.5% of ^{76}Ge)
- natural Ge-sample (7.4% of ^{76}Ge)

Summed spectra around Q = 2039 keV

Timing window: 5 - 30 min



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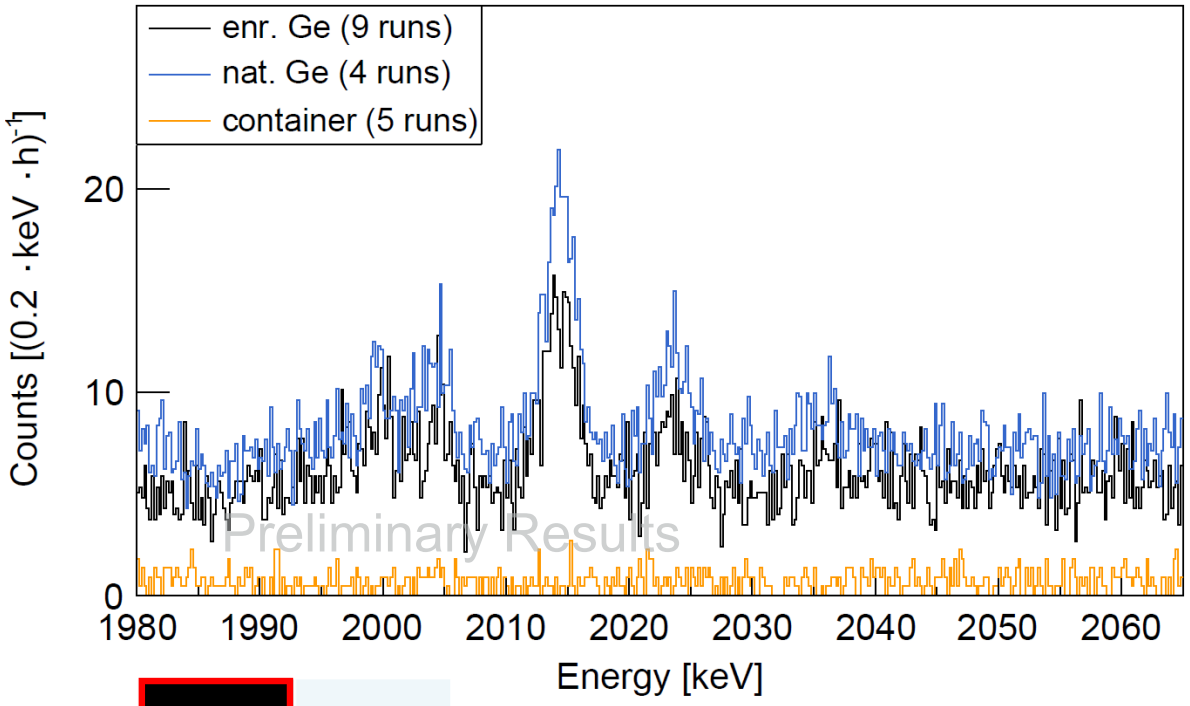
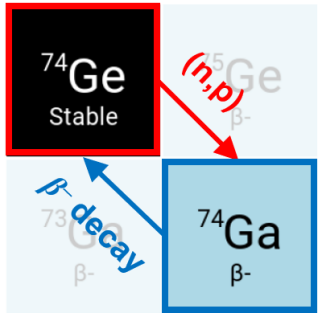
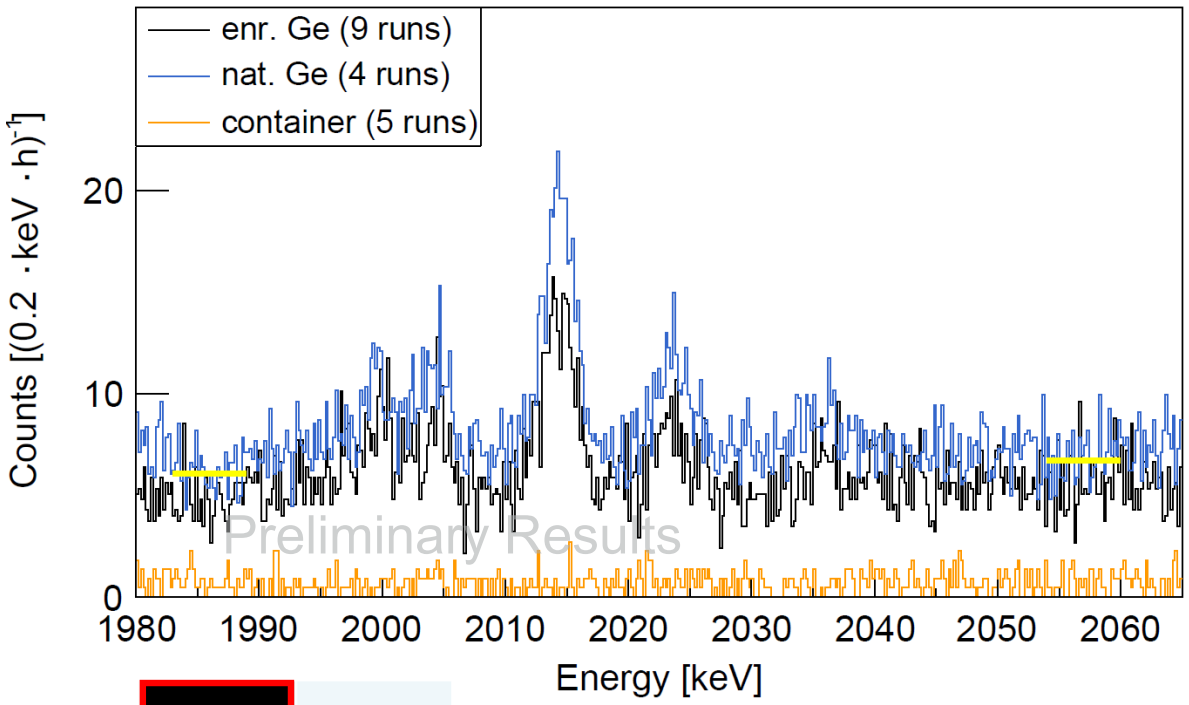


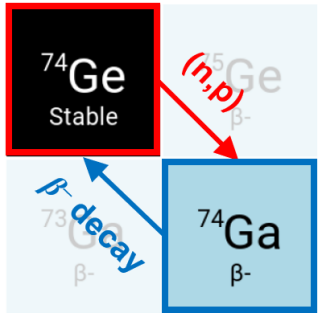


$T_{1/2}$ = 8.12 min

Summed spectra around Q = 2039 keV

Timing window: 5 - 30 min





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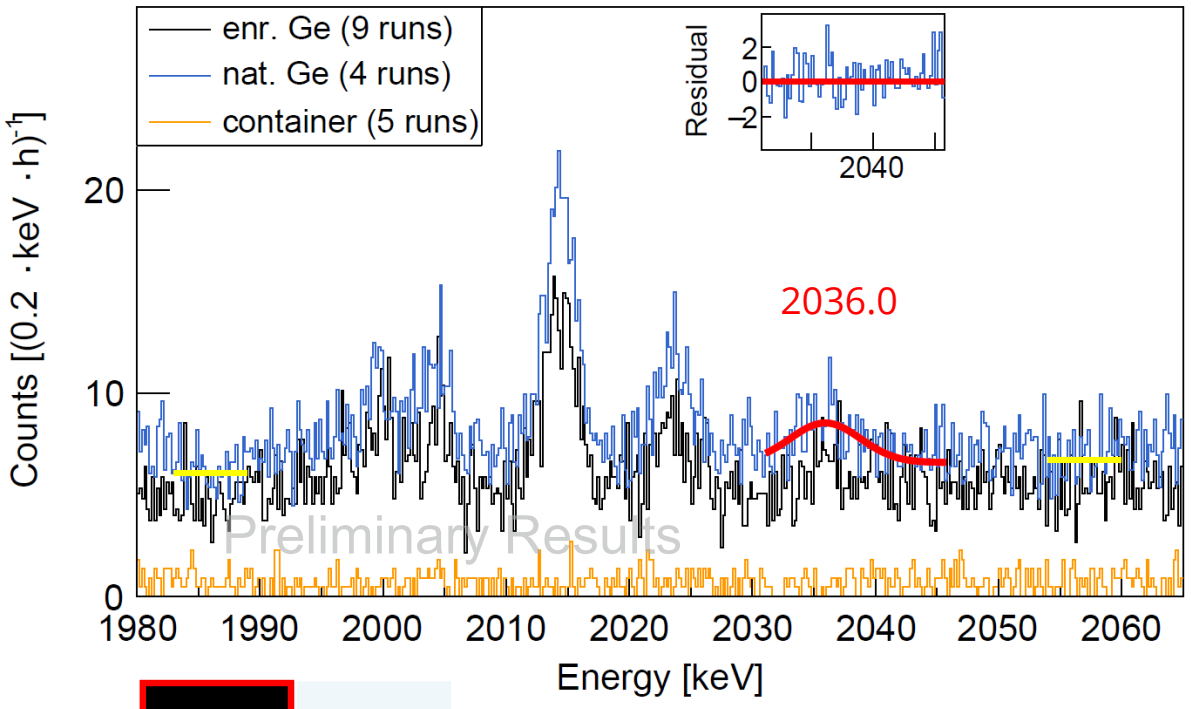

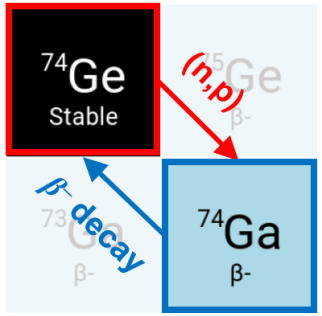

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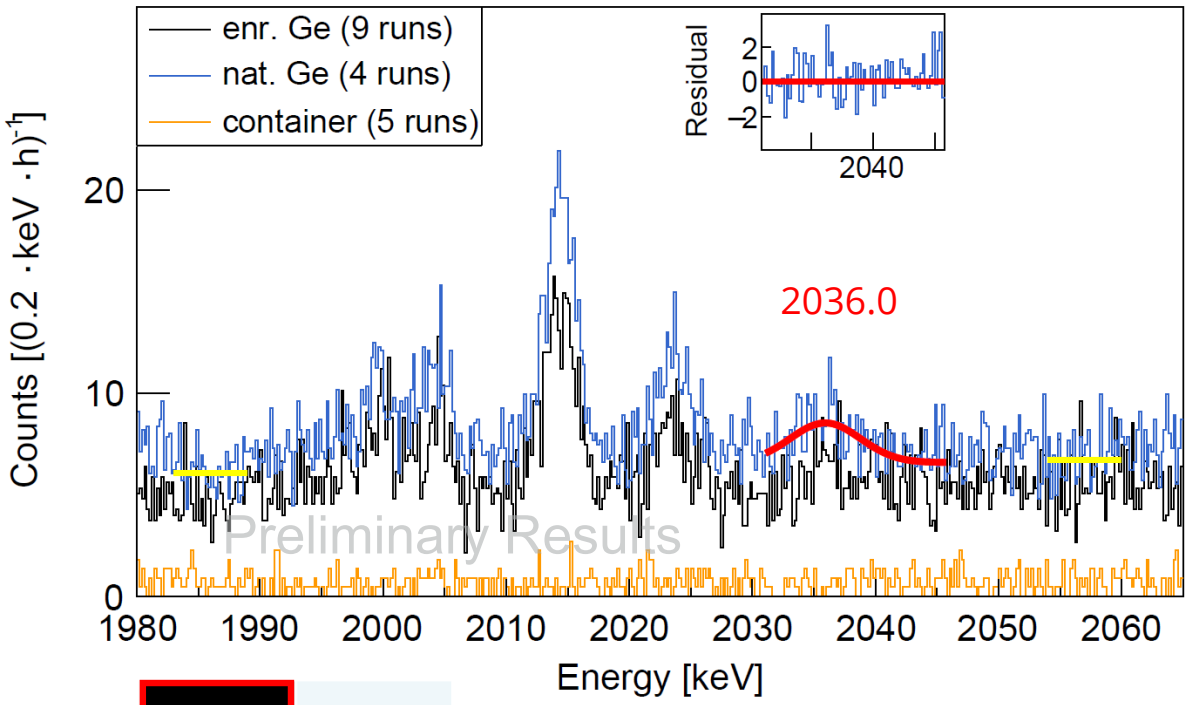
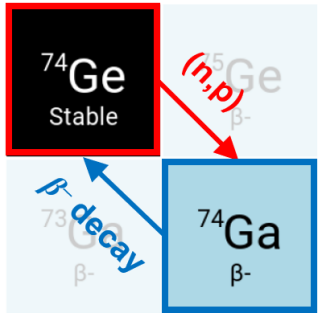




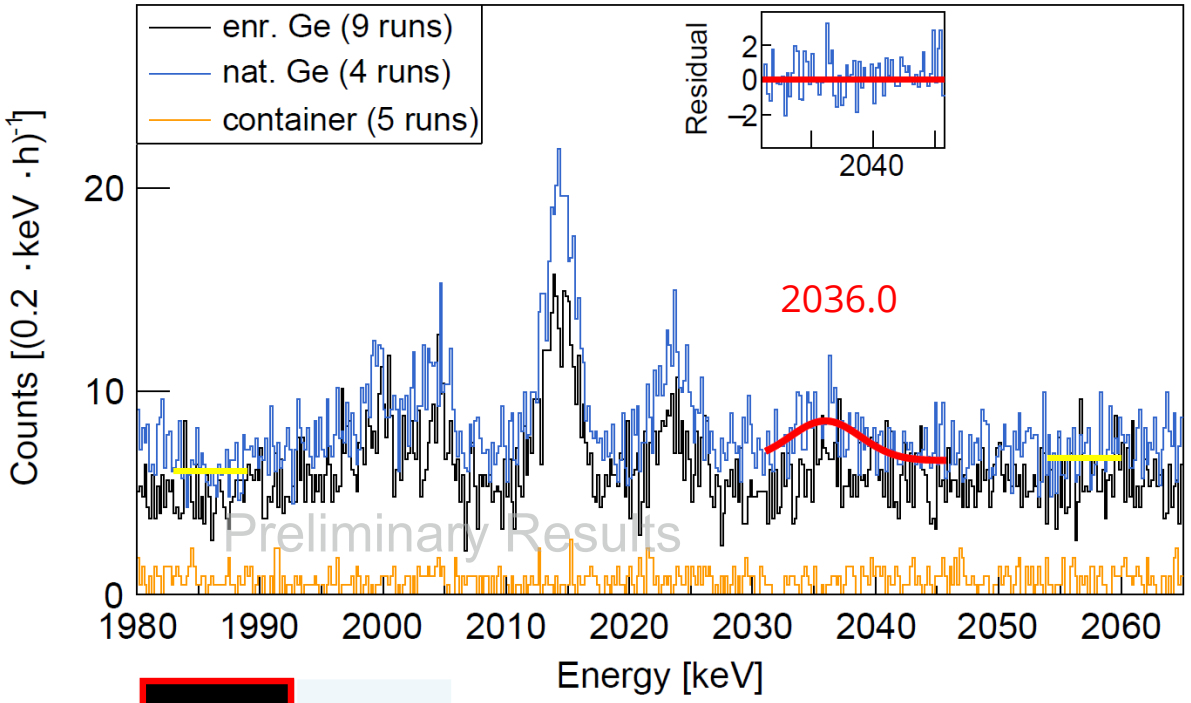
$T_{½}$ = 8.12 min

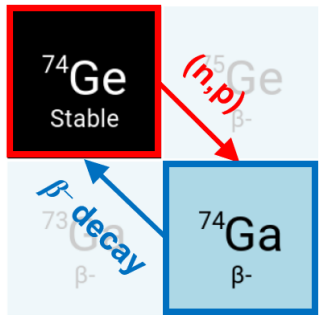
Literature [2] [3]

E_γ = 2036.2 keV

Summed spectra around Q = 2039 keV

Timing window: 5 - 30 min





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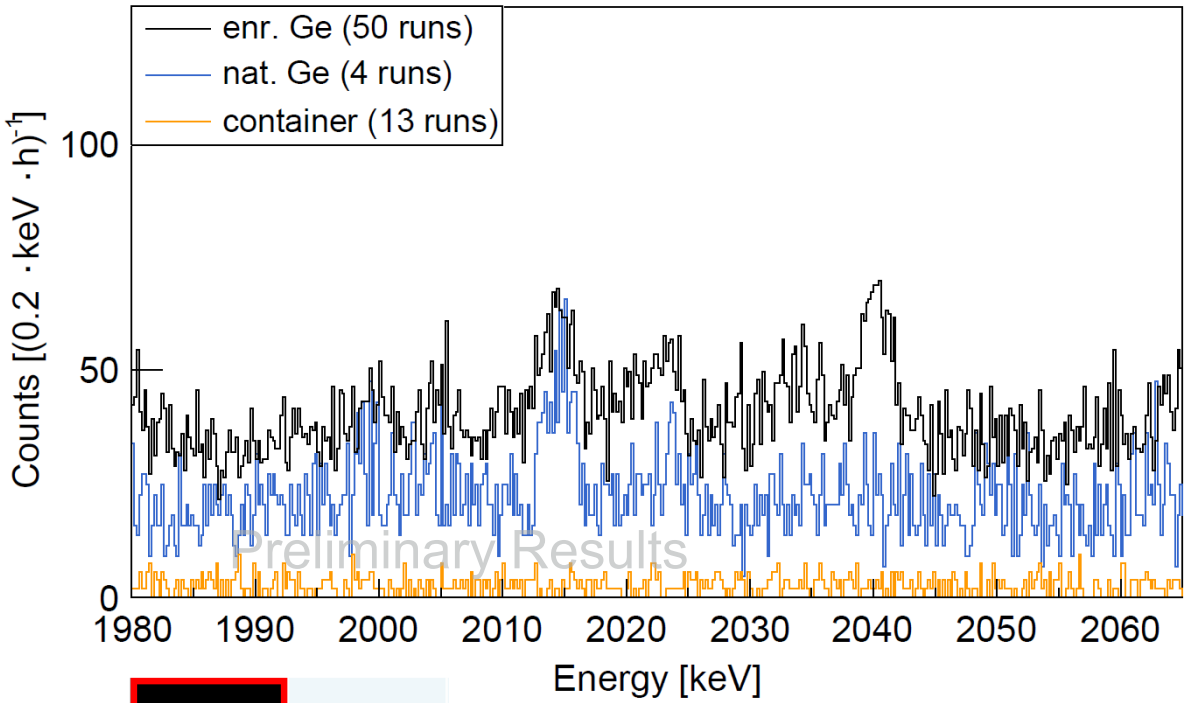

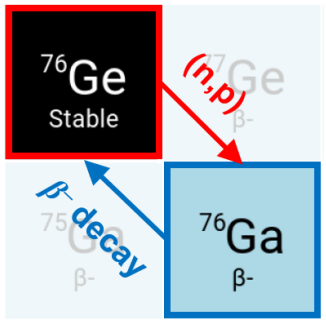

$T_{½}$ = 32.6 s

Summed spectra around Q = 2039 keV

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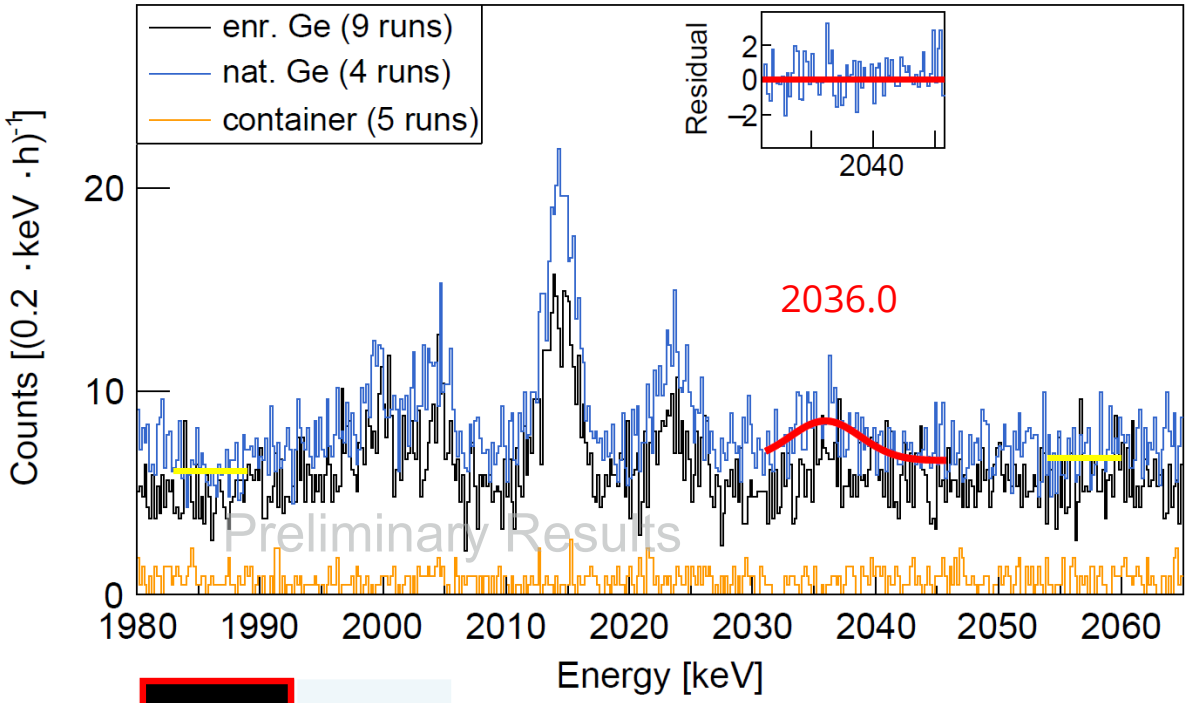

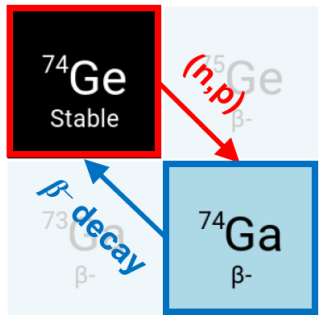

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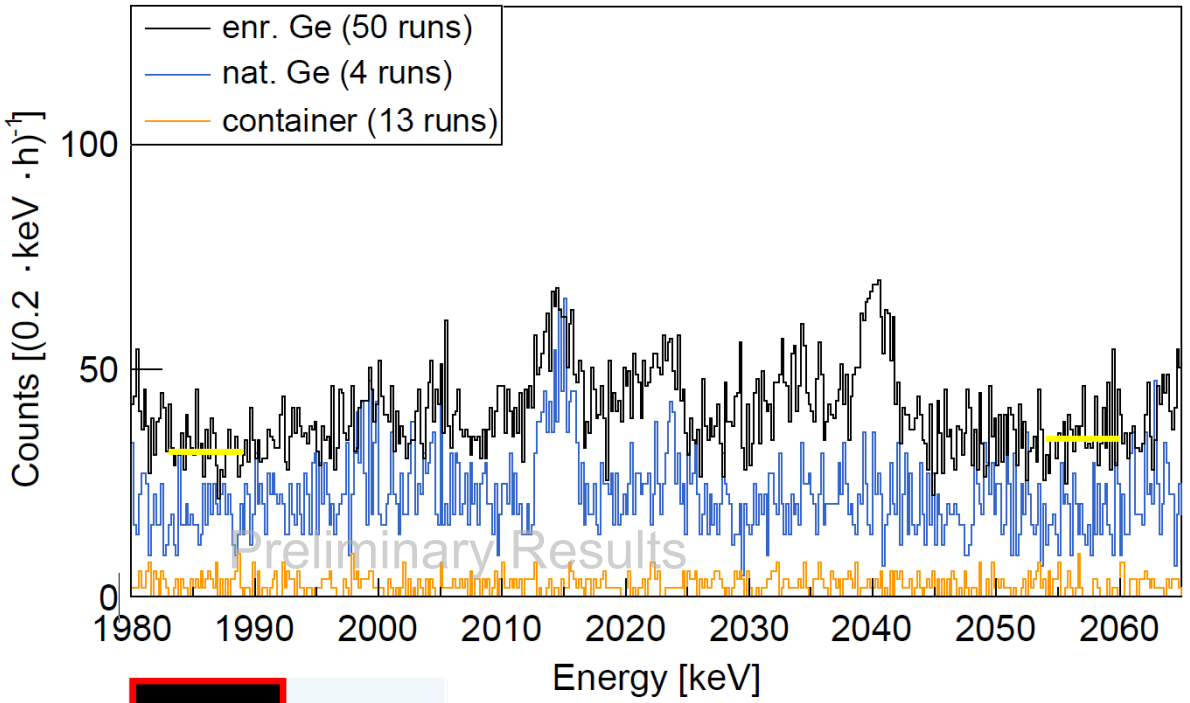

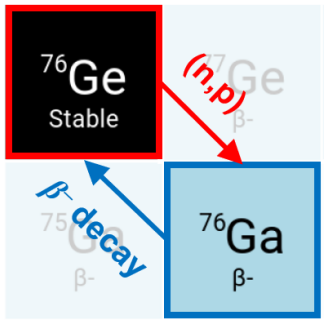

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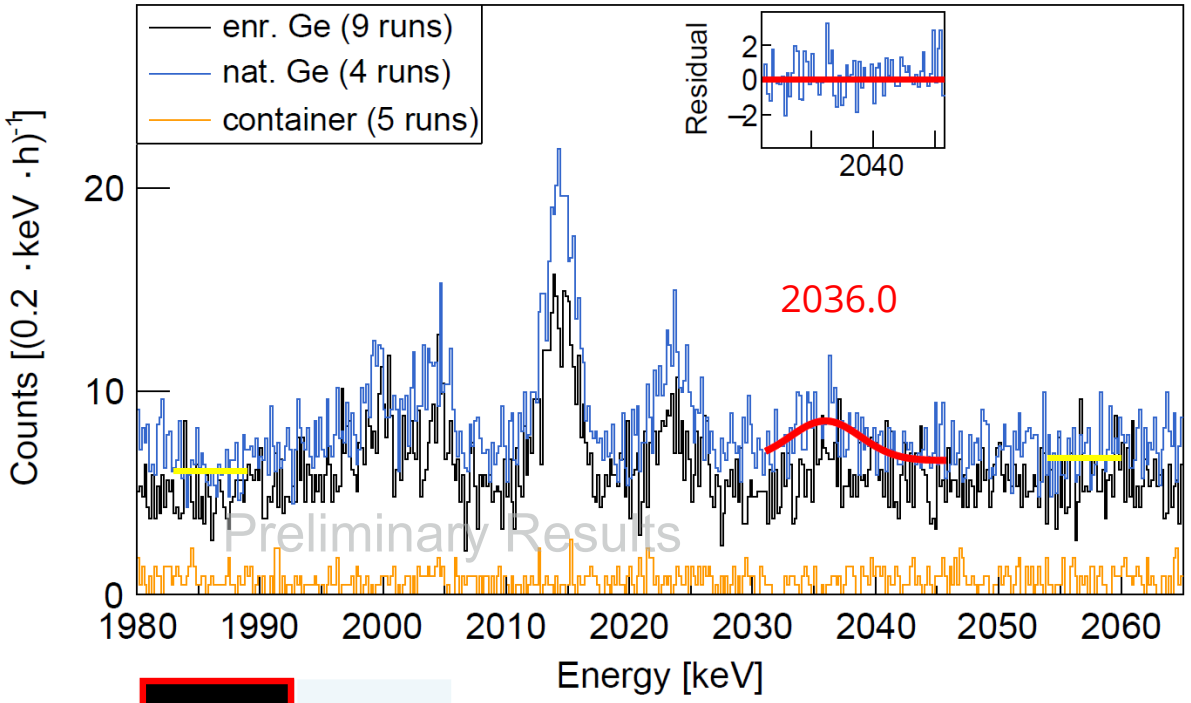

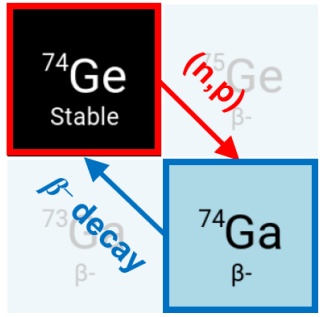

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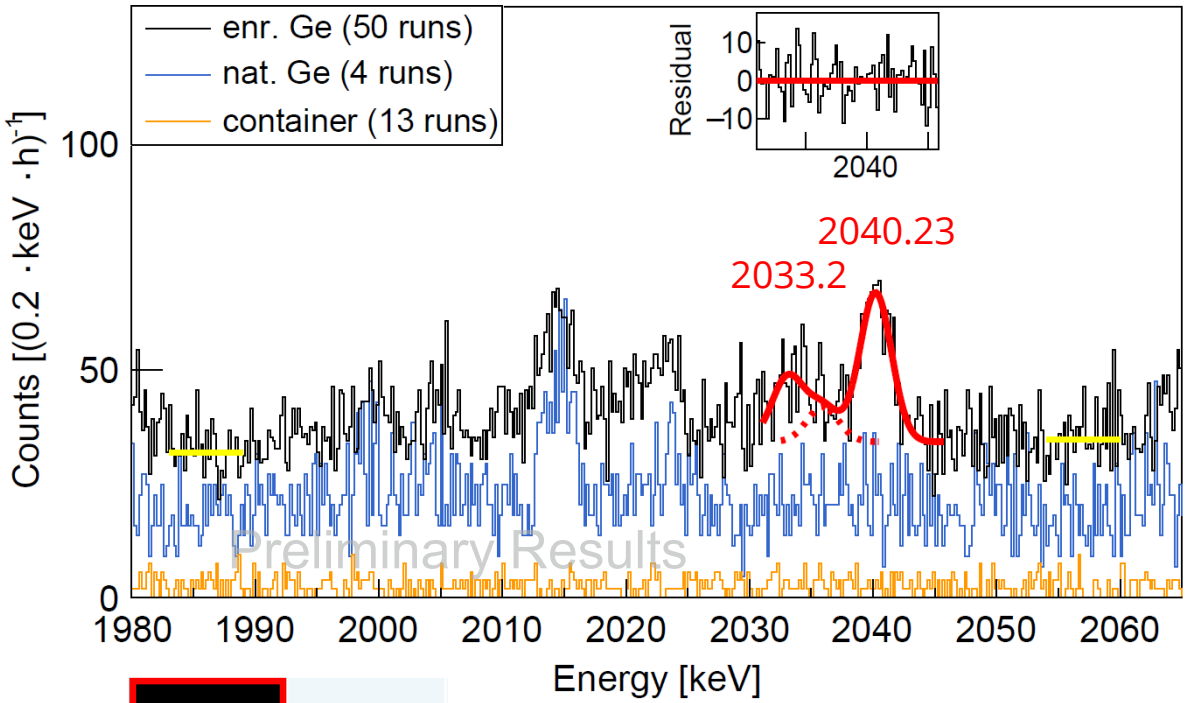

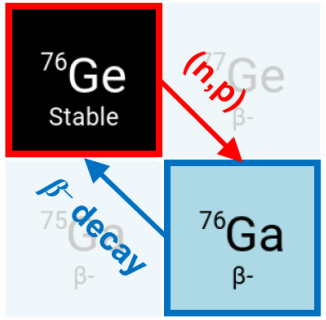

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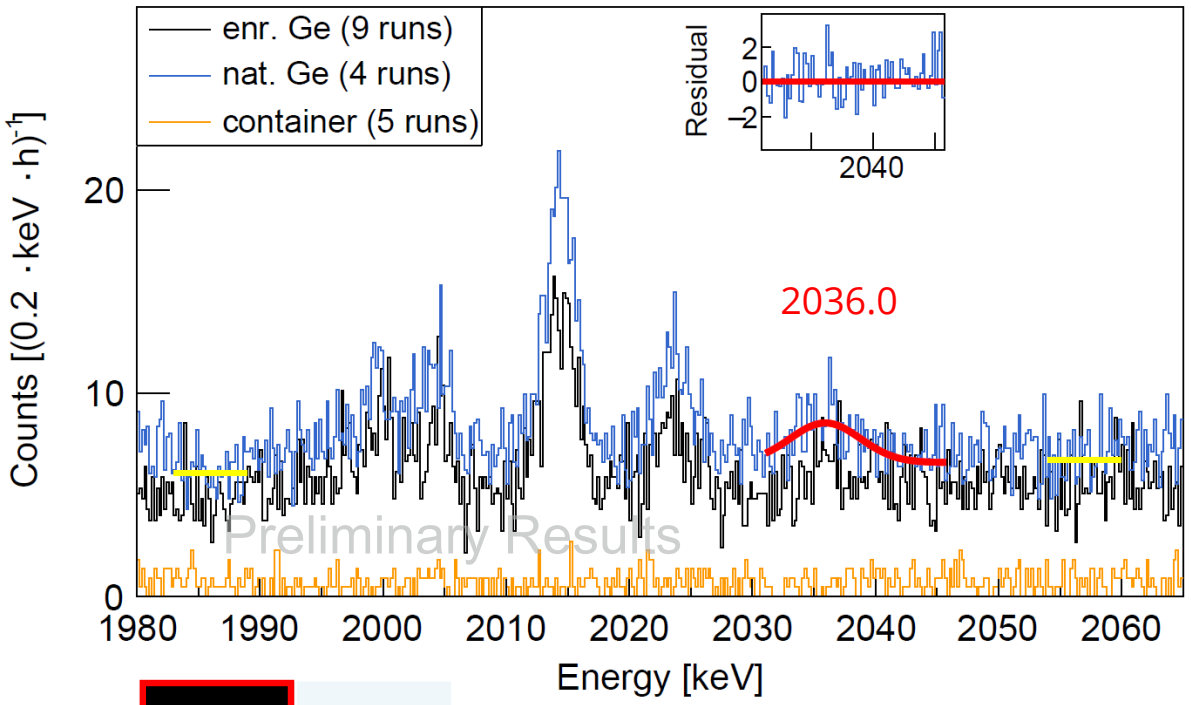

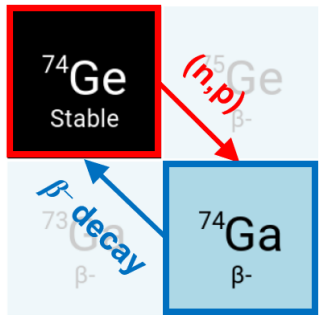

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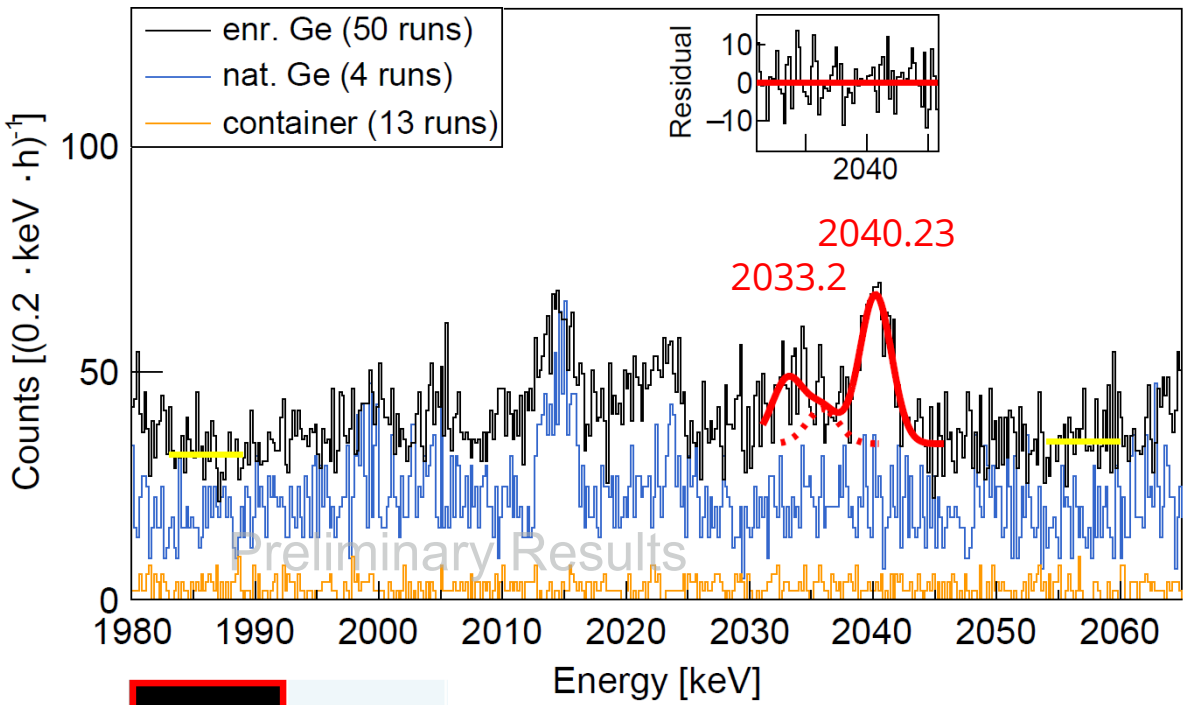
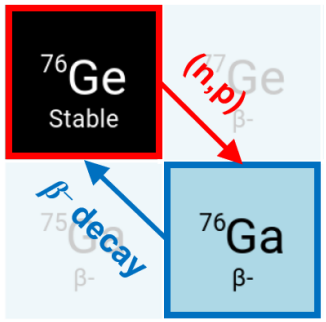


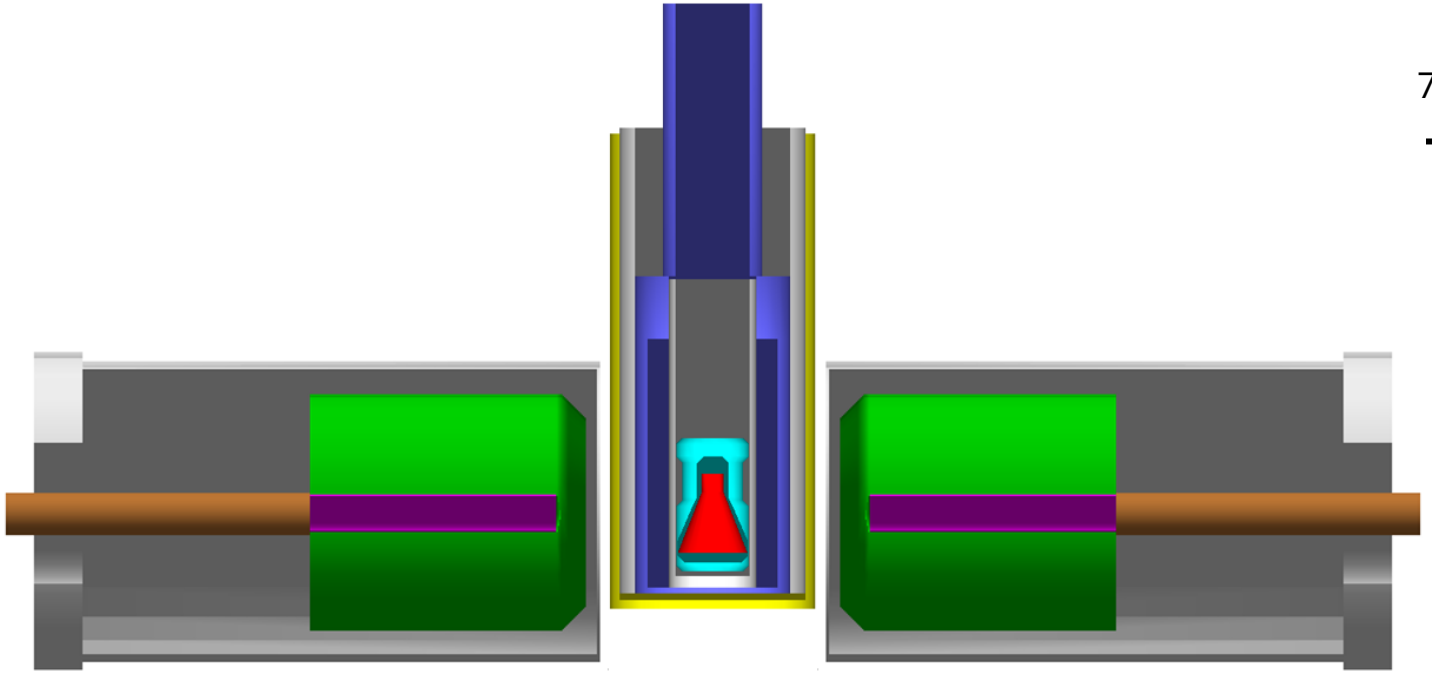


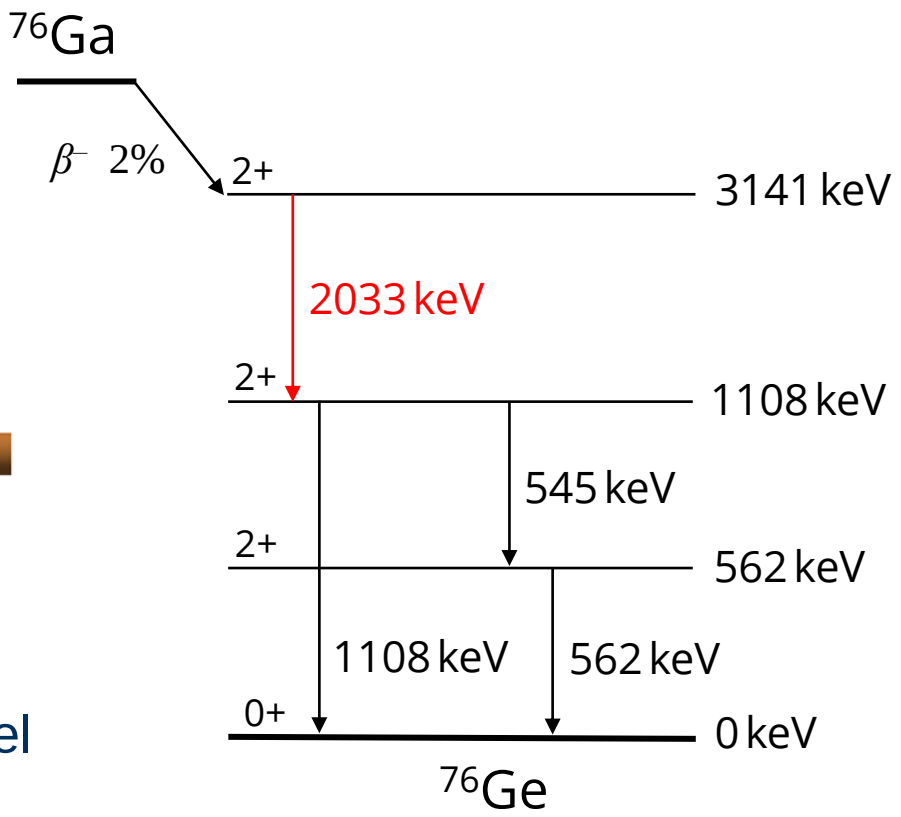
$T_{½}$ = 32.6 s

Literature [1]
E_γ = 2040.7 keV

Extended detection setup

- implementation of second HPGe for coincidence measurement





- investigation of the origin of 2033 keV γ-ray line in the level schema of ^{76}Ge

Summary

- existence of γ-ray line at E_γ = (2040.23 ± 0.16) keV from ^{76}Ga confirmed

  → ^{76}Ge itself can contribute to potential background for ^{76}Ge $\beta\beta$ decay experiments

- found new γ-ray line at E_γ = (2033.2 ± 0.3) keV from ^{76}Ga

Outlook

- publication in progress
- determination of emission probabilities of ^{76}Ga and ^{74}Ga γ-ray lines
- coincidence measurement to investigate origin of 2033 keV line in the level schema of ^{76}Ge

Literature

[1] D. C. Camp and B. P. Foster, “Energy levels in ^{76}Ge from the decay of ^{76}Ga”, Nucl. Phys. A, 177:401–417, 1971

[2] D. C. Camp, D. R. Fielder, and B. P. Foster, “Energy levels in ^{74}Ge from the decay of ^{74}Ga”, Nuclear Physics A, 163(1):145 – 160, 1971

[3] H. W. Taylor, R. L. Schulte, P. J. Tivin, and H. Ing, “The decay of 8.0 min ^{74}Ge”, Can. J. Phys., 53:107, 1975

Thanks for your attention!

How dangerous is the 2040 keV γ-ray line?

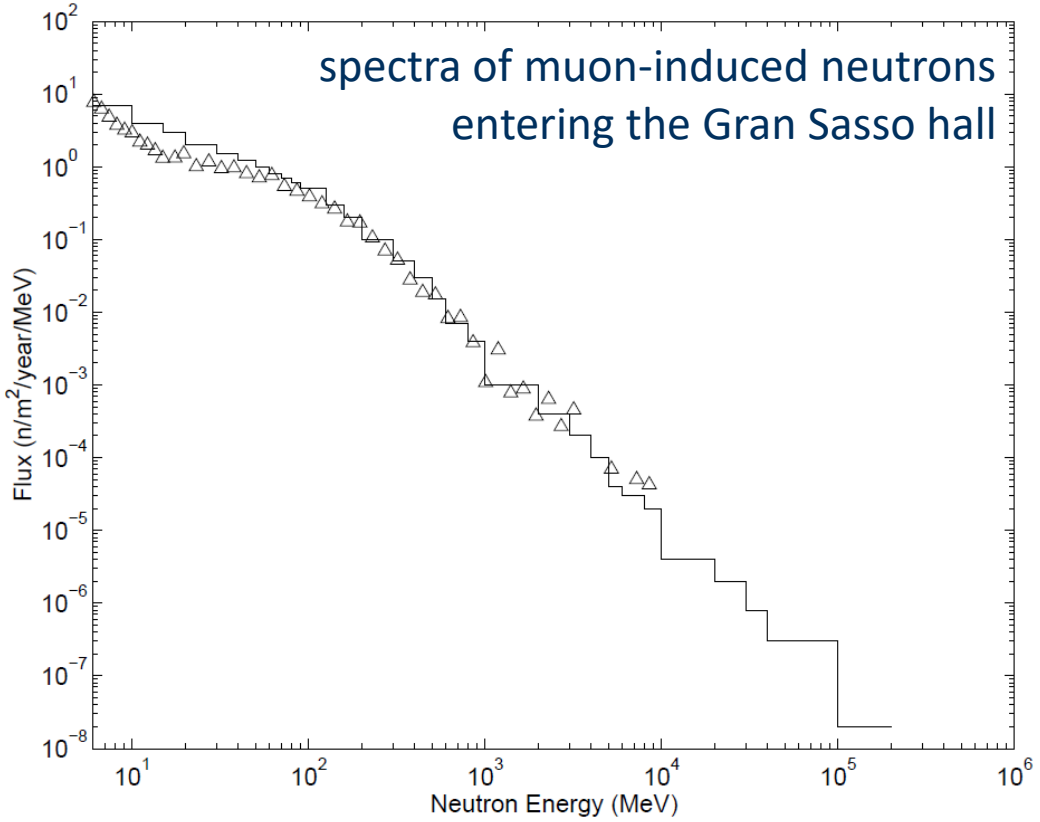
- cosmic muons induce several processes of neutron production

  → high energetic neutrons can enter setup

- Cherenkov detector and LAr cryostat reduces prompt muon-induced background with "only" 99.2 % efficiency [4]

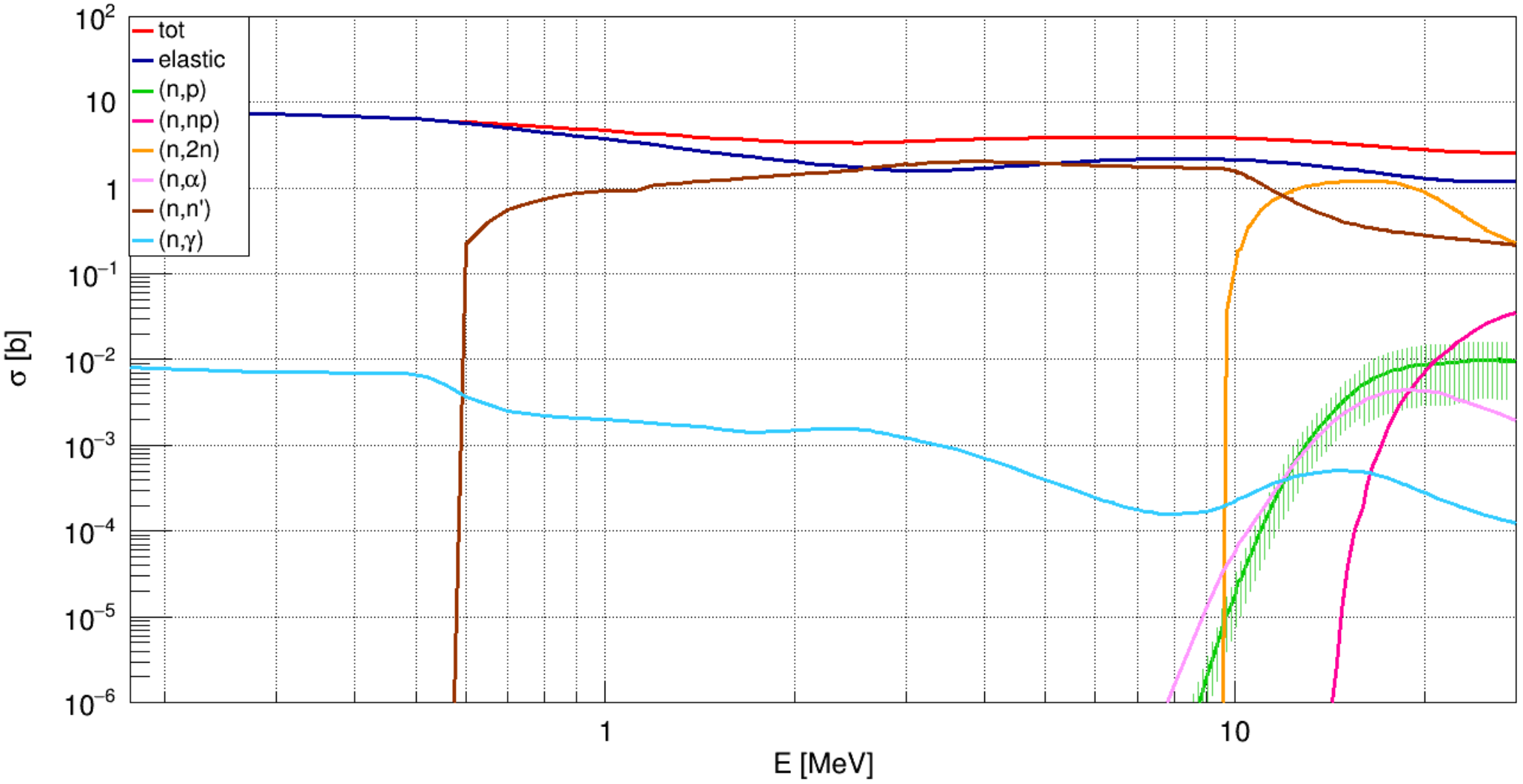
- production of 2040 keV γ-ray due to (n,p) and (n,n') reactions on ^{76}Ge

  → probability strongly depends on σ, ν_γ and neutron flux

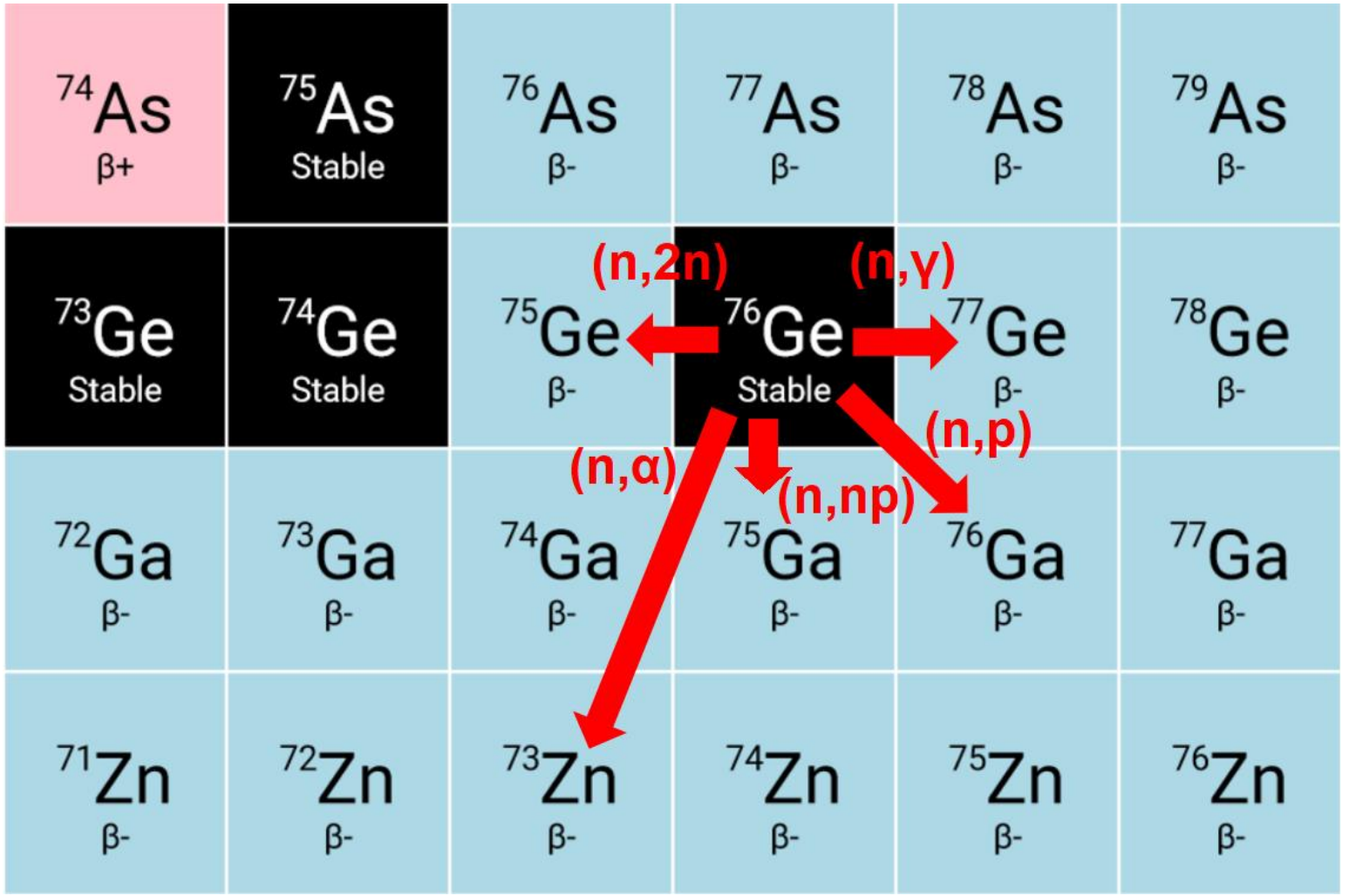


Neutron Background Studies for the CRESST Dark Matter Experiment, H. Wulandari , J. Jochum, W. Rau, F. von Feilitzsch, 2004

Neutron cross-sections of ^{76}Ge



Possible reactions with 14 MeV neutrons

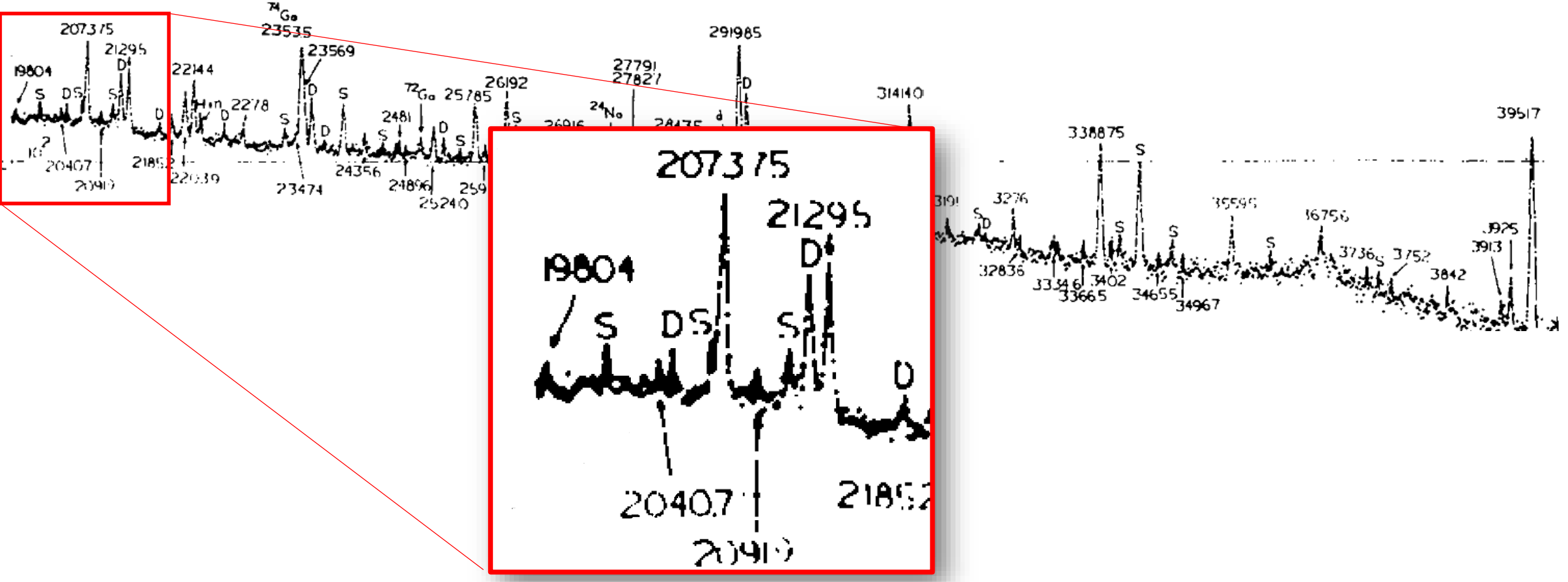


Possible γ-ray structures within the fit range of 1980-2070 keV

Channel	E [keV]	ν_γ [%]	$T_{1/2}$
^{76}Ge$(n,\alpha)^{73}$Zn	1979.7	0.41	24.5 s
^{76}Ge$(n,p)^{76}$Ga	1980.4	0.22	32.6 s
^{72}Ge$(n,p)^{72}$Ga	1991.16	0.101	14.10 h
^{74}Ge$(n,p)^{74}$Ga	1999.3	0.4	8.12 min
^{74}Ge$(n,p)^{74}$Ga	2004.6	<0.4957	8.12 min
^{74}Ge$(n,p)^{74}$Ga	2014.45	1.29	8.12 min
^{74}Ge$(n,p)^{74}$Ga	2023.9	0.45	8.12 min
^{76}Ge$(n,\alpha)^{73}$Zn	2028.3	0.026	24.5 s
^{72}Ge$(n,p)^{72}$Ga	2028.94	0.115	14.10 h
^{74}Ge$(n,\alpha)^{71}$Zn	2064.6	0.045	2.45 min
Compton edges			
^{72}Ge$(n,p)^{72}$Ga	1984.96	0.218	14.10 h
^{76}Ge$(n,p)^{76}$Ga	1985.29	2.24	32.6 s
^{74}Ge$(n,p)^{74}$Ga	2002.64	0.1	8.12 min
^{74}Ge$(n,p)^{74}$Ga	2027.54	1.75	8.12 min
^{76}Ge$(n,p)^{76}$Ga	2049.06	0.44	32.6 s
^{74}Ge$(n,p)^{74}$Ga	2049.31	2.34	8.12 min
^{74}Ge$(n,\alpha)^{71}$Zn	2064.90	0.026	2.45 min

SE peaks $E = E_\gamma$ - 511 keV			
^{72}Ge$(n,p)^{72}$Ga	1980.026	7.73	14.10 h
^{74}Ge$(n,p)^{74}$Ga	1993.2	0.65	8.12 min
^{72}Ge$(n,p)^{72}$Ga	1996.718	13.33	14.10 h
^{72}Ge$(n,p)^{72}$Ga	2004.857	0.258	14.10 h
^{76}Ge$(n,p)^{76}$Ga	2013.0	0.80	32.6 s
^{74}Ge$(n,p)^{74}$Ga	2069.07	1.28	8.12 min
^{76}Ge$(n,p)^{76}$Ga	2067.55	2.24	32.6 s
DE peaks $E = E_\gamma$ - 1022 keV			
^{74}Ge$(n,p)^{74}$Ga	1996.8	0.064	8.12 min
^{74}Ge$(n,p)^{74}$Ga	2008.3	<0.1652	8.12 min
^{74}Ge$(n,p)^{74}$Ga	2009.7	0.19	8.12 min
^{76}Ge$(n,p)^{76}$Ga	2012.6	0.52	32.6 s
^{74}Ge$(n,p)^{74}$Ga	2014.1	0.046	8.12 min
^{74}Ge$(n,p)^{74}$Ga	2021.6	0.046	8.12 min
^{76}Ge$(n,p)^{76}$Ga	2047.9	0.92	32.6 s

Previous experiment by Camp & Foster (1971)



Experimental setup

1.+ 2. End piece of the tube system

3. Lead shielding (3 mm)

4. Aluminium shielding (5 mm)

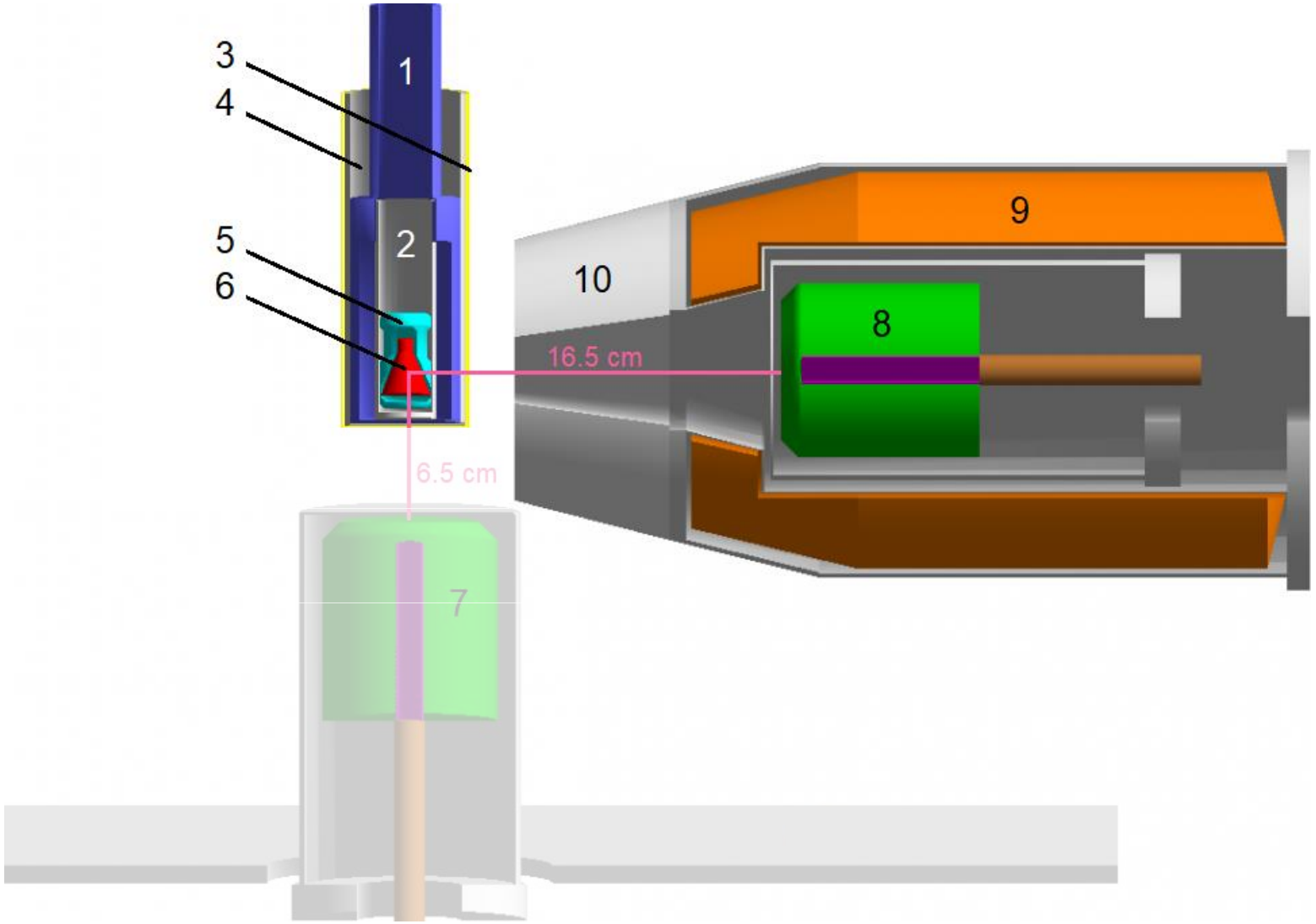
5. Sample container

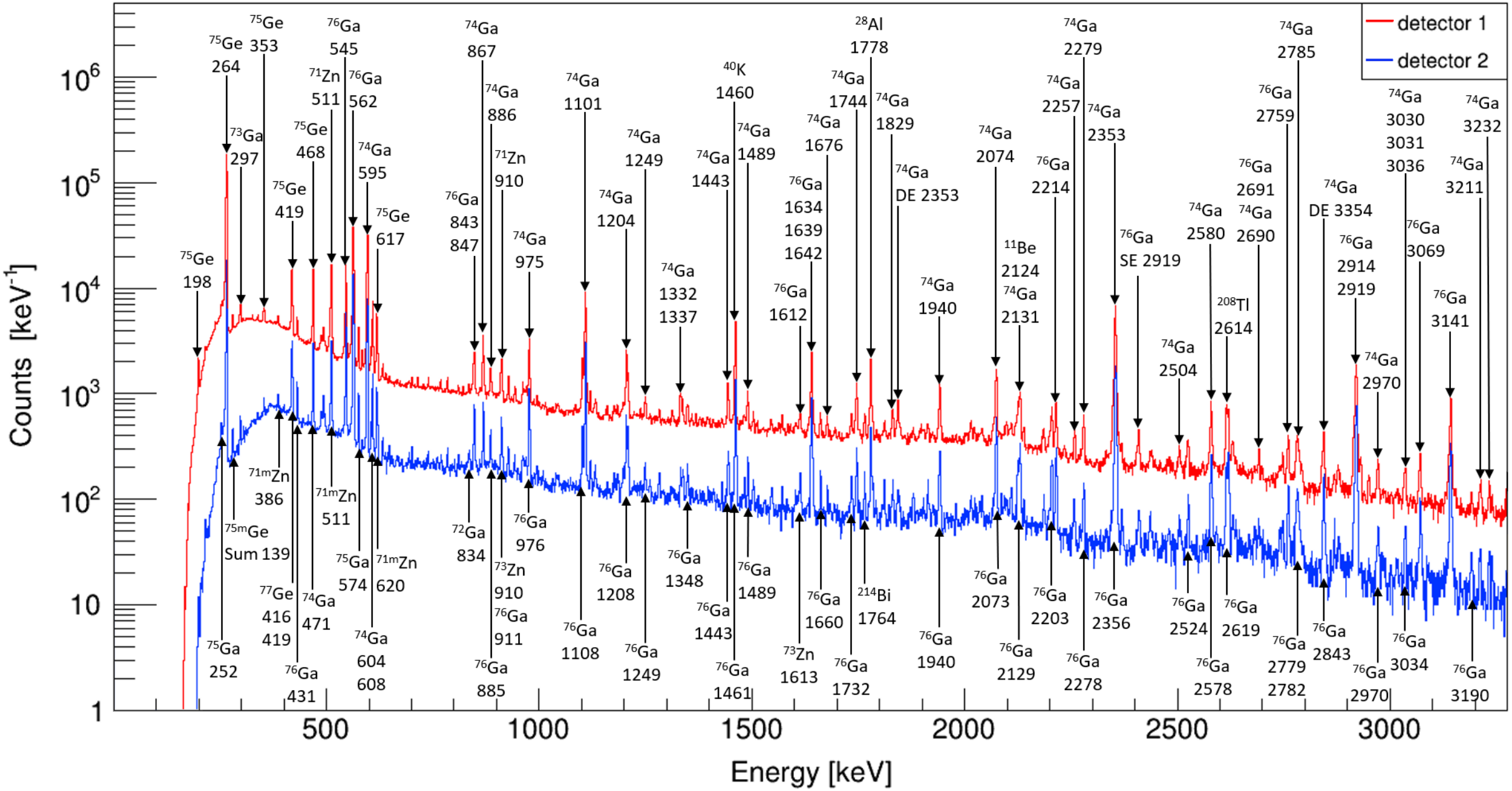
6. Sample

7.+ **8.** HPGe detectors

9. BGO

10. Lead collimator




detector 1
detector 2
Counts [keV^{-1}]
Energy [keV]
^{75}Ge 198
^{75}Ge 264
^{75}Ge 353
^{73}Ga 297
^{75}Ge 419
^{71}Zn 511
^{76}Ga 545
^{76}Ga 562
^{75}Ge 468
^{74}Ga 595
^{75}Ge 617
^{76}Ga 843
^{74}Ga 867
^{74}Ga 886
^{71}Zn 910
^{74}Ga 975
^{74}Ga 1101
^{74}Ga 1204
^{74}Ga 1249
^{74}Ga 1332
^{74}Ga 1337
^{74}Ga 1443
^{40}K 1460
^{74}Ga 1489
^{76}Ga 1612
^{76}Ga 1634
^{76}Ga 1639
^{76}Ga 1642
^{74}Ga 1676
^{74}Ga 1744
^{28}Al 1778
^{74}Ga 1829
^{74}Ga DE 2353
^{74}Ga 1940
^{74}Ga 2074
^{11}Be 2124
^{74}Ga 2131
^{74}Ga 2257
^{74}Ga 2279
^{74}Ga 2353
^{76}Ga 2214
^{76}Ga SE 2919
^{74}Ga 2504
^{74}Ga 2580
^{208}Tl 2614
^{74}Ga 2690
^{76}Ga 2691
^{74}Ga 2785
^{76}Ga 2759
^{74}Ga DE 3354
^{76}Ga 2914
^{76}Ga 2919
^{74}Ga 2970
^{74}Ga 3030
^{74}Ga 3031
^{74}Ga 3036
^{76}Ga 3069
^{74}Ga 3211
^{74}Ga 3232
^{76}Ga 3141
^{75}Ga 252
^{75m}Ge Sum 139
^{71m}Zn 386
^{77}Ge 416
^{77}Ge 419
^{74}Ga 471
^{76}Ga 431
^{71m}Zn 511
^{75}Ga 574
^{71m}Zn 620
^{74}Ga 604
^{74}Ga 608
^{72}Ga 834
^{76}Ga 885
^{73}Zn 910
^{76}Ga 911
^{76}Ga 976
^{76}Ga 1108
^{76}Ga 1208
^{76}Ga 1249
^{76}Ga 1348
^{76}Ga 1443
^{76}Ga 1461
^{76}Ga 1489
^{73}Zn 1613
^{76}Ga 1660
^{76}Ga 1732
^{214}Bi 1764
^{76}Ga 1940
^{76}Ga 2073
^{76}Ga 2129
^{76}Ga 2203
^{76}Ga 2278
^{76}Ga 2356
^{76}Ga 2524
^{76}Ga 2578
^{76}Ga 2619
^{76}Ga 2779
^{76}Ga 2782
^{76}Ga 2843
^{76}Ga 2970
^{76}Ga 3034
^{76}Ga 3190