

Institute of Nuclear and Particle Physics (IKTP)  
TU Dresden

HK 22.6

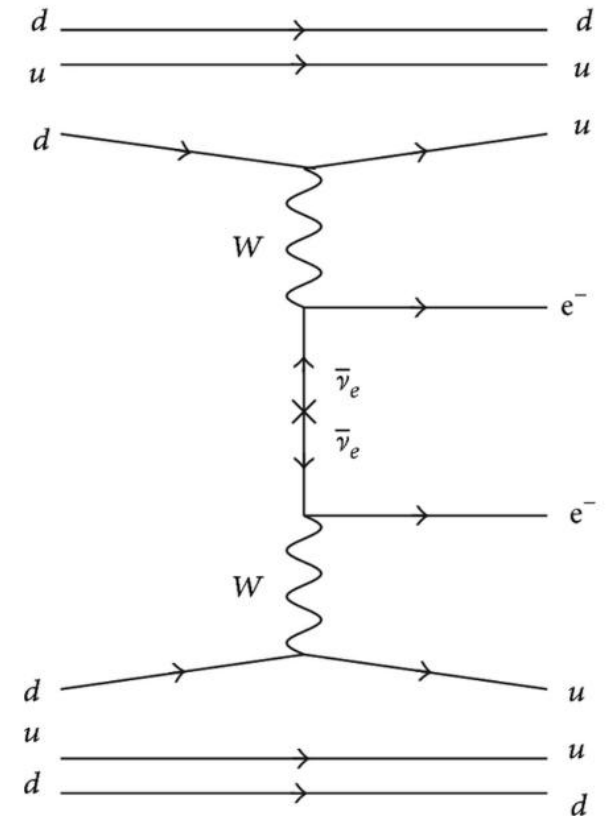
# Studies of the $^{76}\text{Ge}$ Level Scheme via Neutron Activation and $\gamma$ - $\gamma$ Coincidence Spectroscopy for Germanium-Based $0\nu\beta\beta$ decay Experiments

• Marie Pichotta, Toralf Döring, Björn Lehnert, Max Osswald,  
Ronald Schwengner, Christoph Seibt, Steffen Turkat, and Kai Zuber

18.03.2026

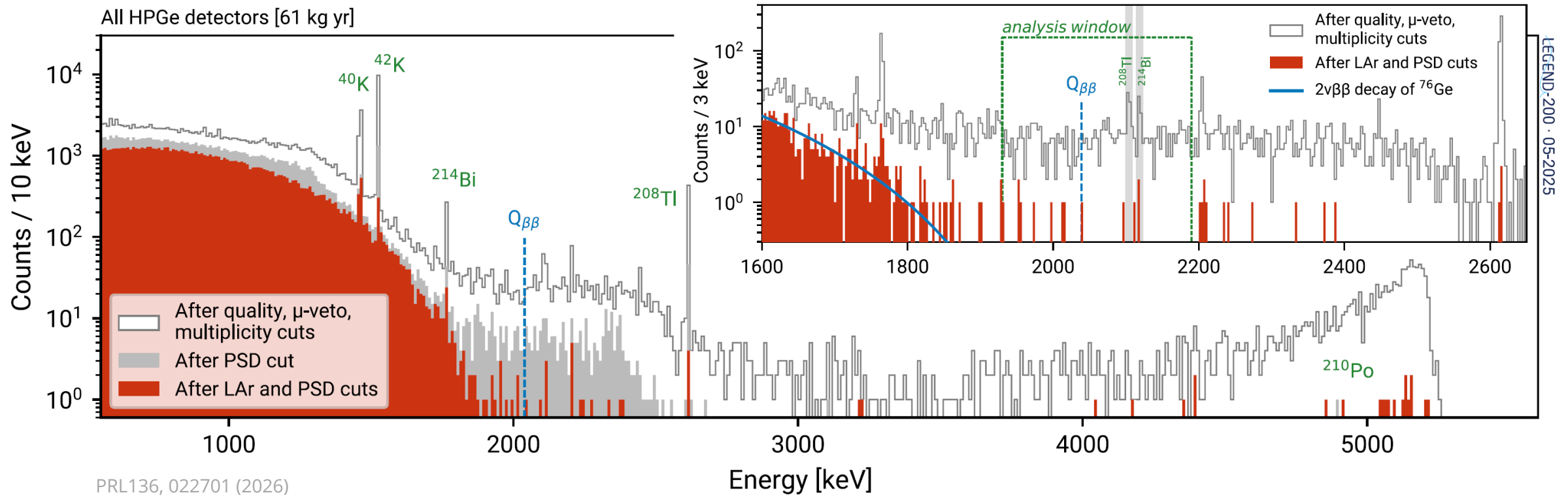
# Search for Neutrinoless Double-Beta Decay $0\nu\beta\beta$ of $^{76}\text{Ge}$

- Neutrinoless double-beta decay could provide insights into physics beyond the Standard Model



# Search for Neutrinoless Double-Beta Decay $0\nu\beta\beta$ of $^{76}\text{Ge}$

- Neutrinoless double-beta decay could provide insights into physics beyond the Standard Model
- Searching for  $0\nu\beta\beta$  decay of  $^{76}\text{Ge}$  ( $Q_{\beta\beta} = 2039 \text{ keV}$ ) in LEGEND

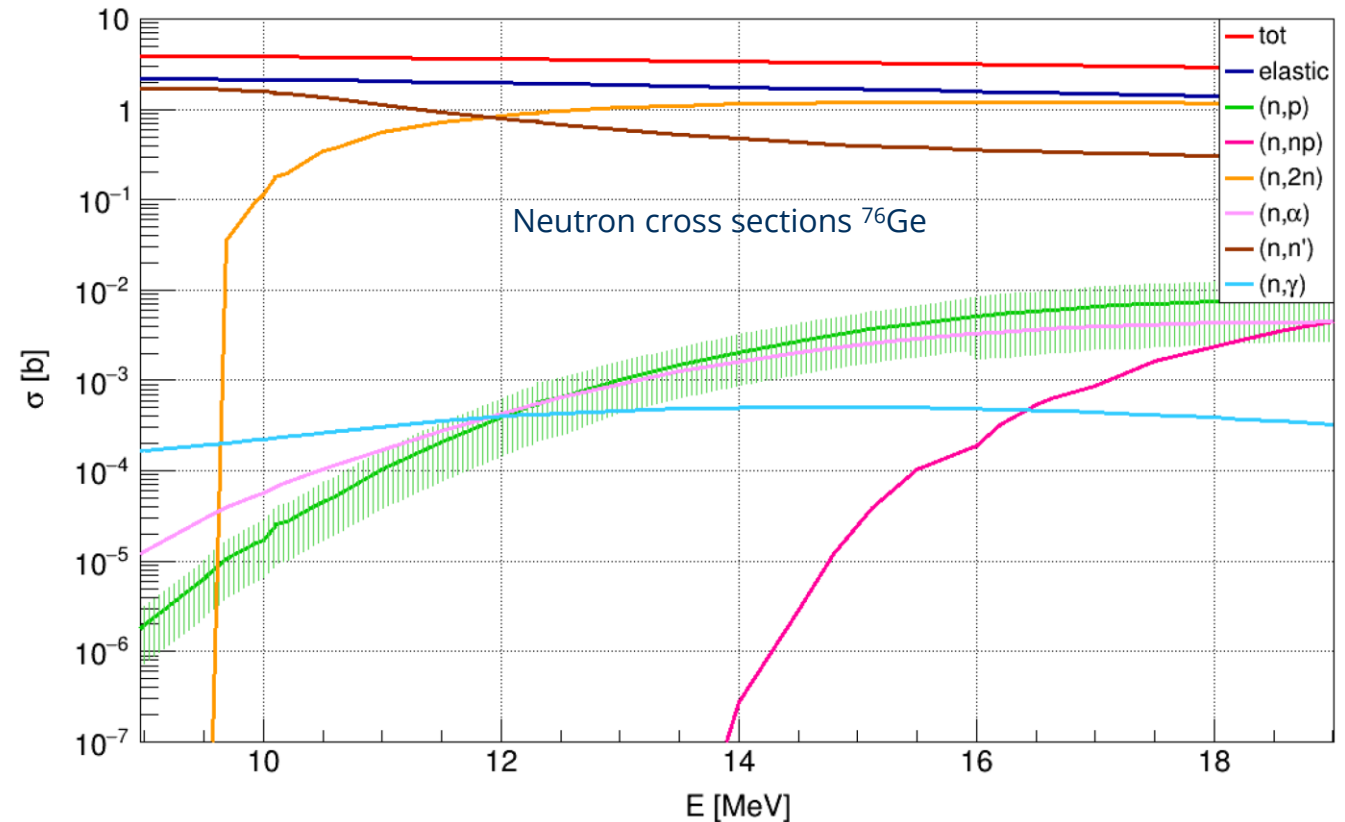


# Neutron-Induced $\gamma$ Rays in the $^{76}\text{Ge}$ $0\nu\beta\beta$ Signal Region?

- Background contribution from enriched Ge due to neutron activation of  $^{76}\text{Ge}$  and  $^{74}\text{Ge}$

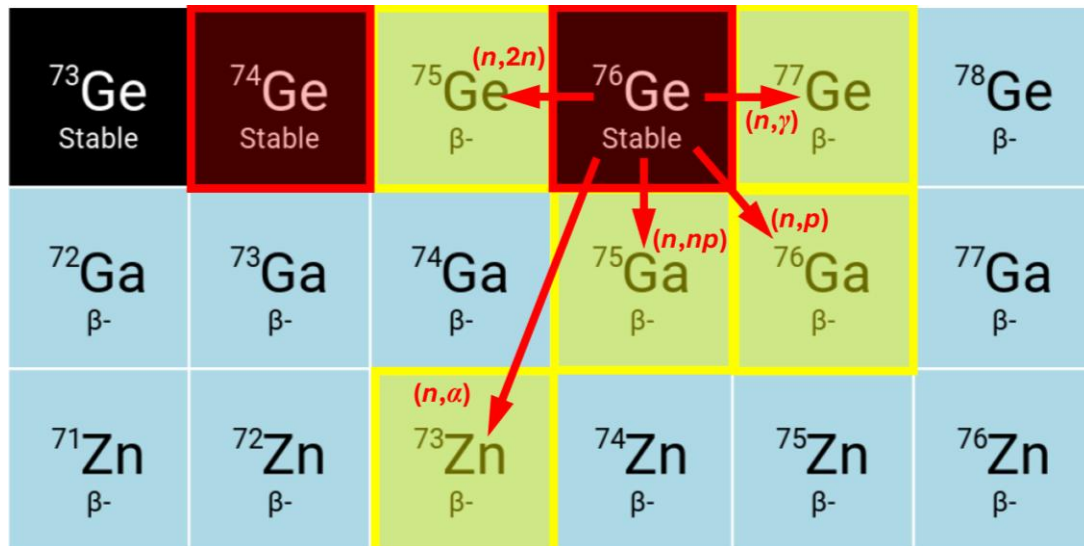
$^{73}\text{Ge}$ Stable	$^{74}\text{Ge}$ Stable	$^{75}\text{Ge}$ $\beta^-$	$^{76}\text{Ge}$ Stable	$^{77}\text{Ge}$ $\beta^-$	$^{78}\text{Ge}$ $\beta^-$
$^{72}\text{Ga}$ $\beta^-$	$^{73}\text{Ga}$ $\beta^-$	$^{74}\text{Ga}$ $\beta^-$	$^{75}\text{Ga}$ $\beta^-$	$^{76}\text{Ga}$ $\beta^-$	$^{77}\text{Ga}$ $\beta^-$
$^{71}\text{Zn}$ $\beta^-$	$^{72}\text{Zn}$ $\beta^-$	$^{73}\text{Zn}$ $\beta^-$	$^{74}\text{Zn}$ $\beta^-$	$^{75}\text{Zn}$ $\beta^-$	$^{76}\text{Zn}$ $\beta^-$

Isotopic abundance	Isotopically enriched in $^{76}\text{Ge}$	Natural abundance
$^{76}\text{Ge}$	87 - 91%	7.4%
$^{74}\text{Ge}$	9 - 12%	36.5%
$^{73}\text{Ge}$	$\geq 0.16\%$	7.8%
$^{72}\text{Ge}$	$\geq 0.07\%$	27.4%
$^{70}\text{Ge}$	$\geq 0.02\%$	20.5%

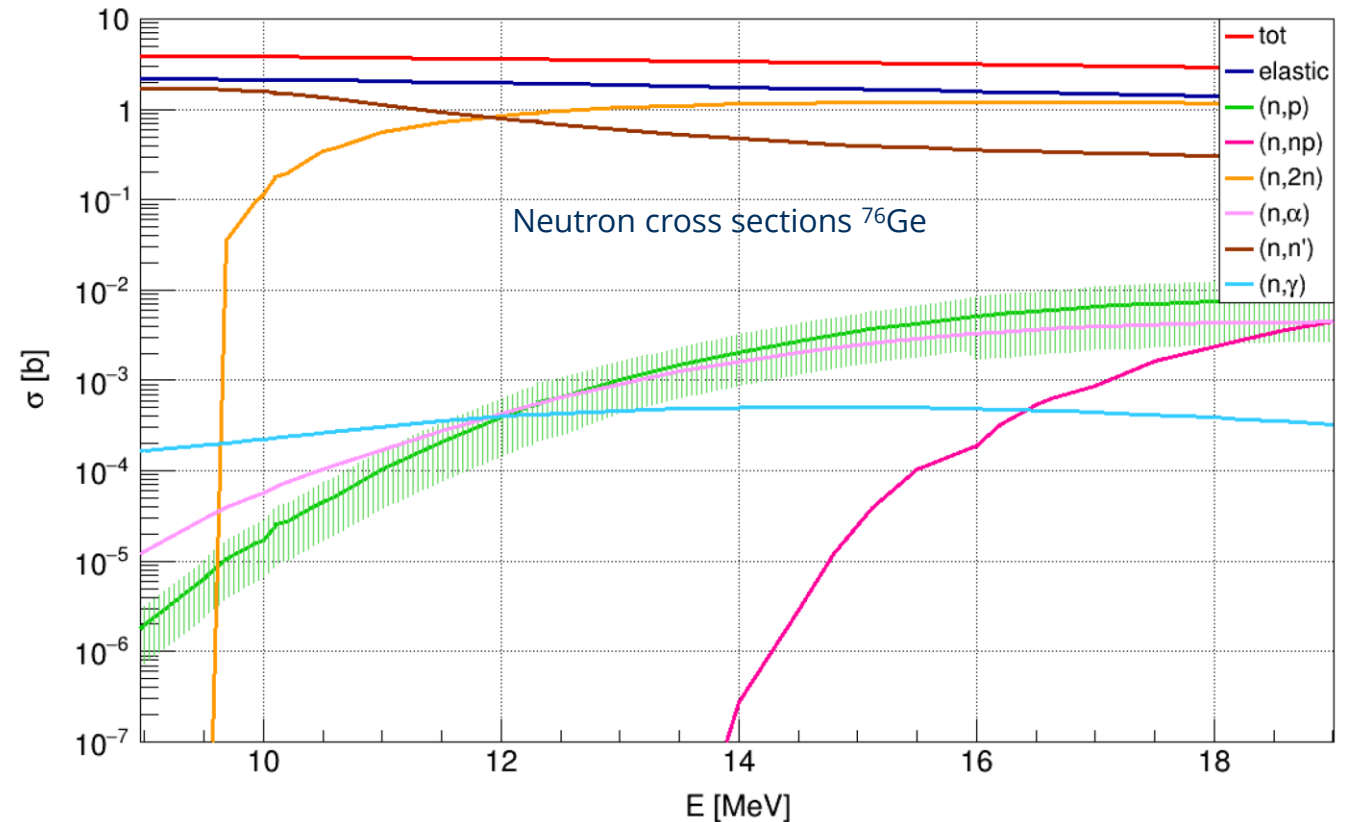


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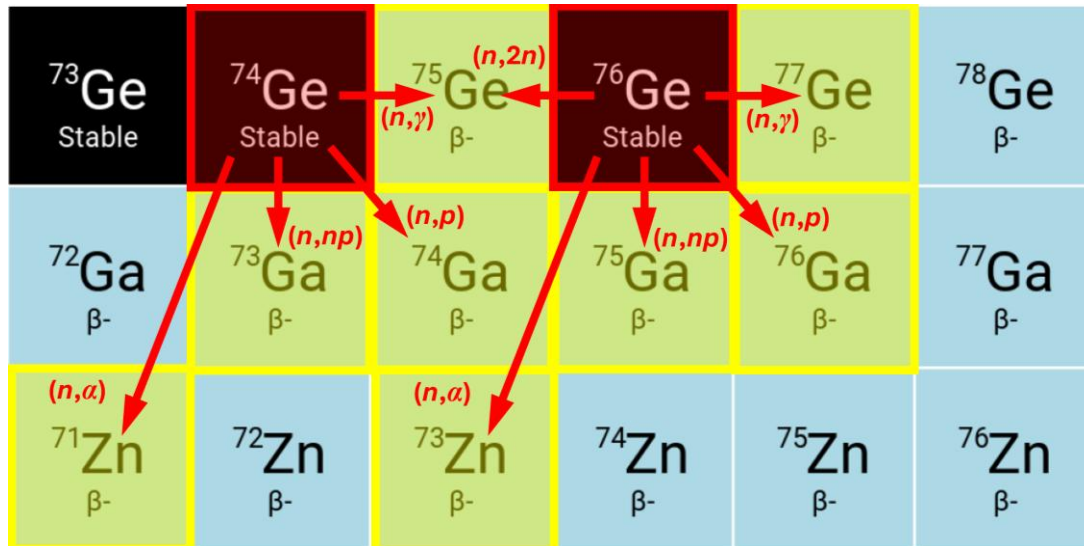


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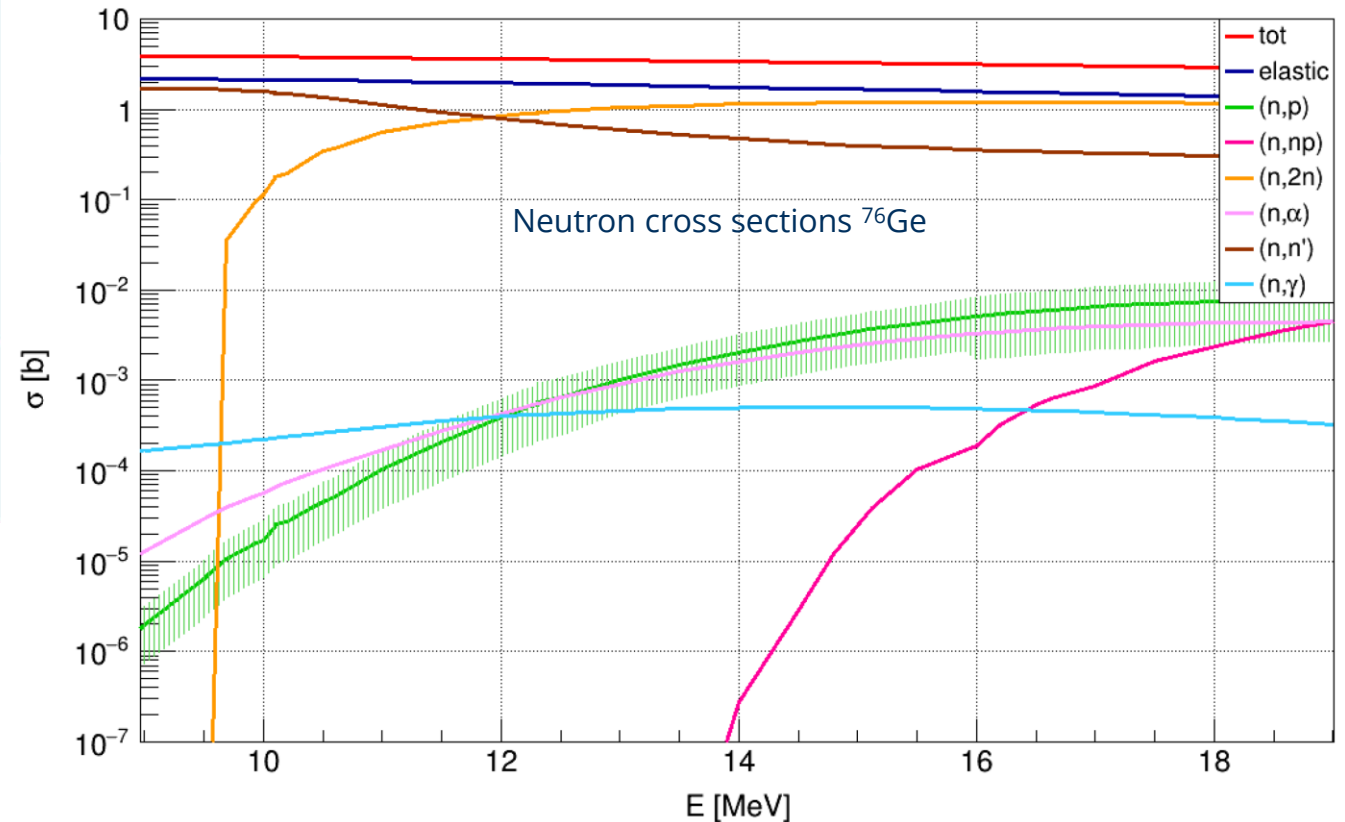
Marie Pichotta

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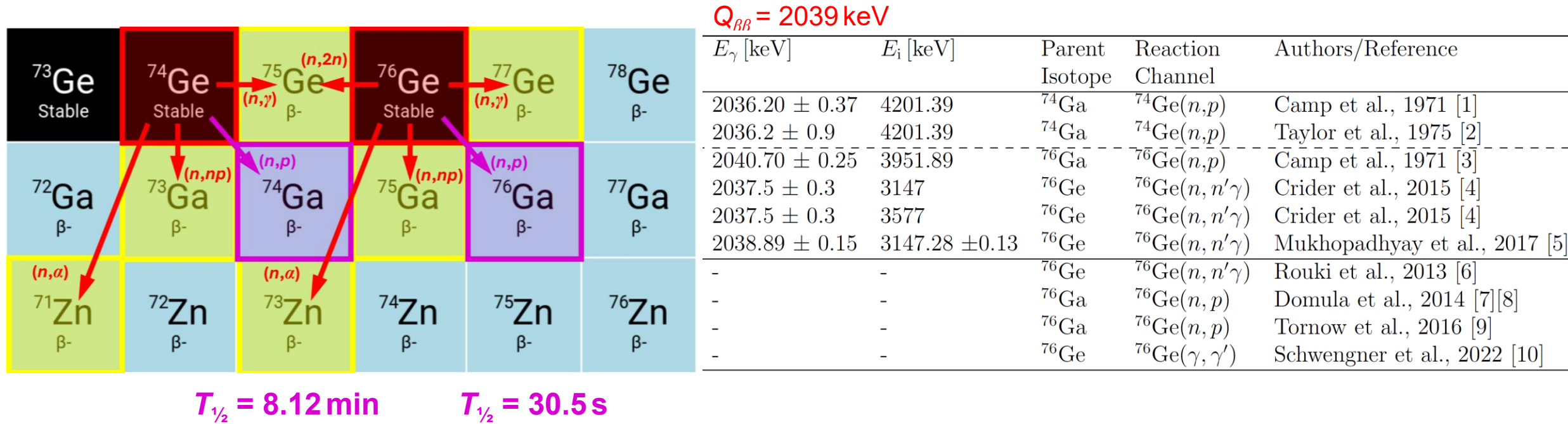


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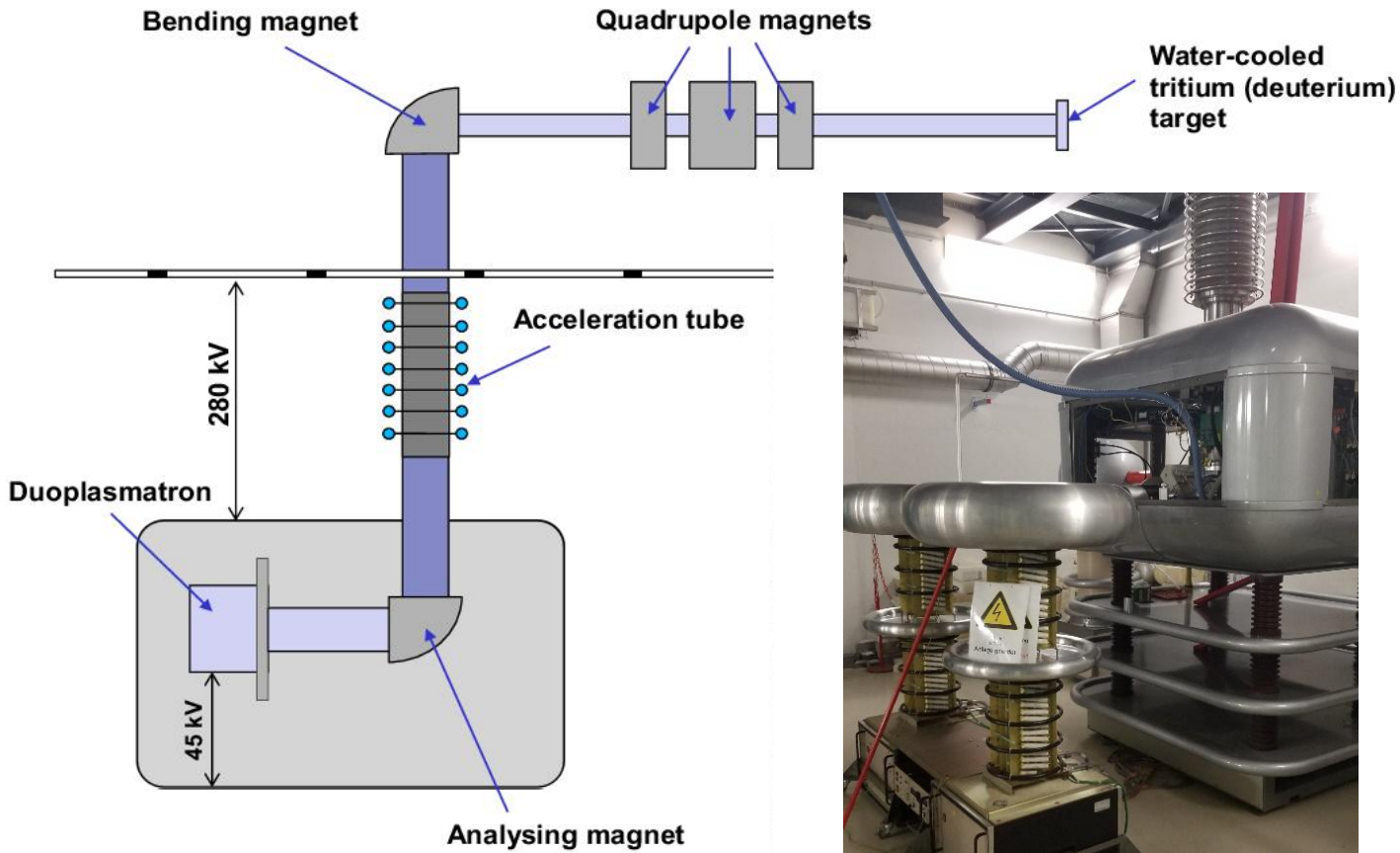
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**Aim of this work:** investigate potential  $\gamma$ -ray background near 2039 keV in isotopically enriched Ge

# Experimental Setup

DT neutron generator

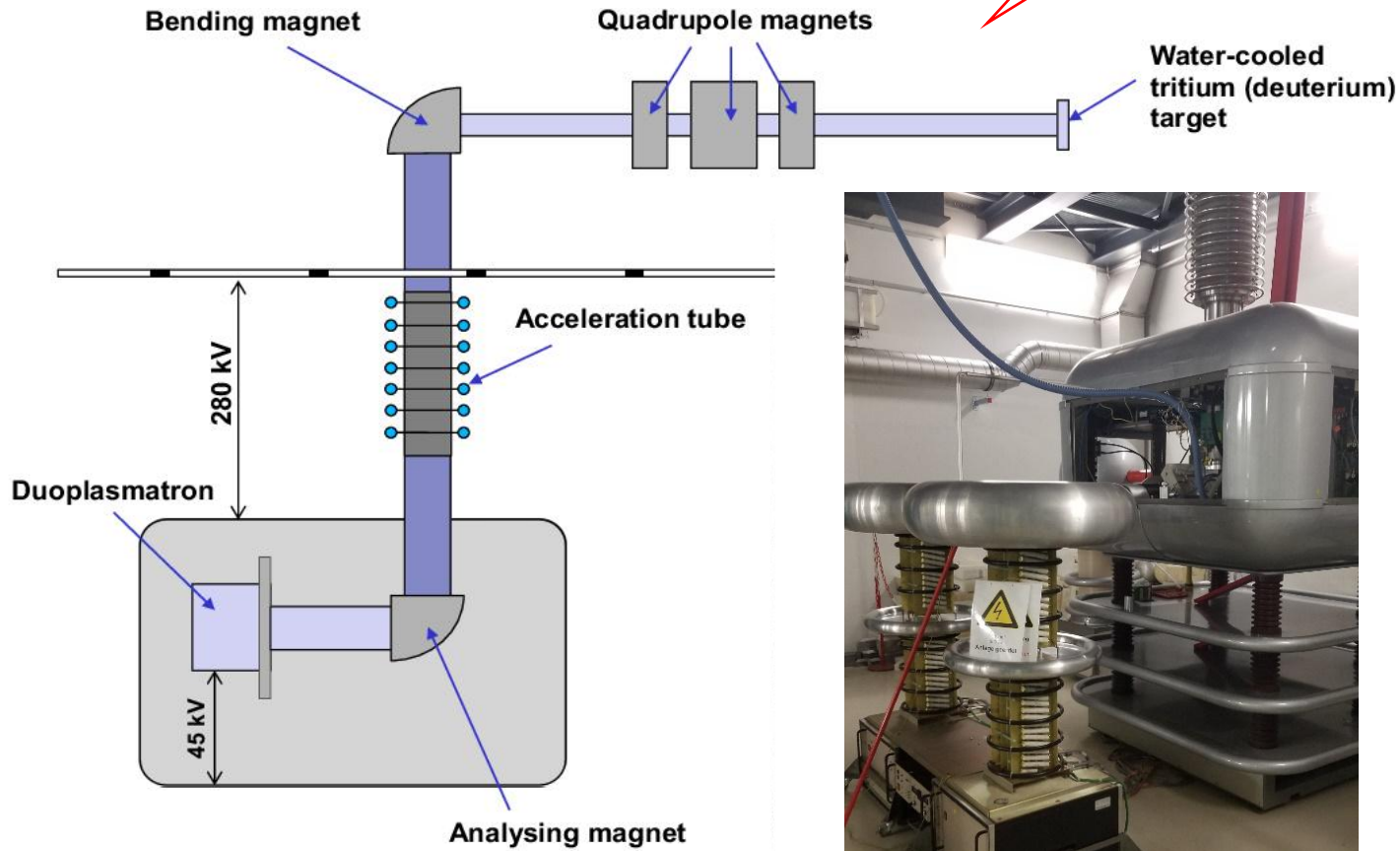


- Sample irradiation at DT neutron generator of TU Dresden
- Produces 14.1 MeV quasi-monoenergetic neutrons

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DT neutron generator

HK 33.7

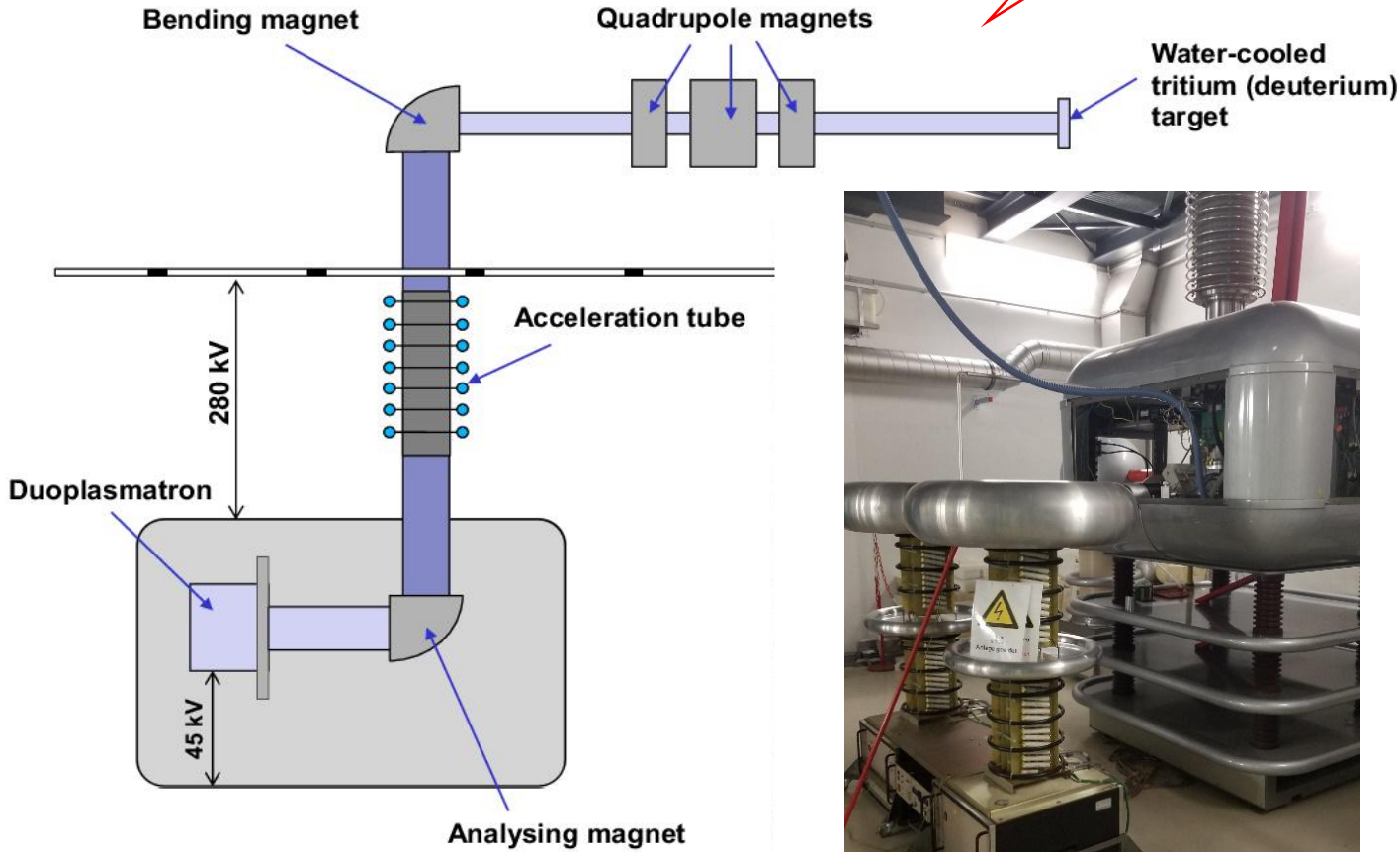


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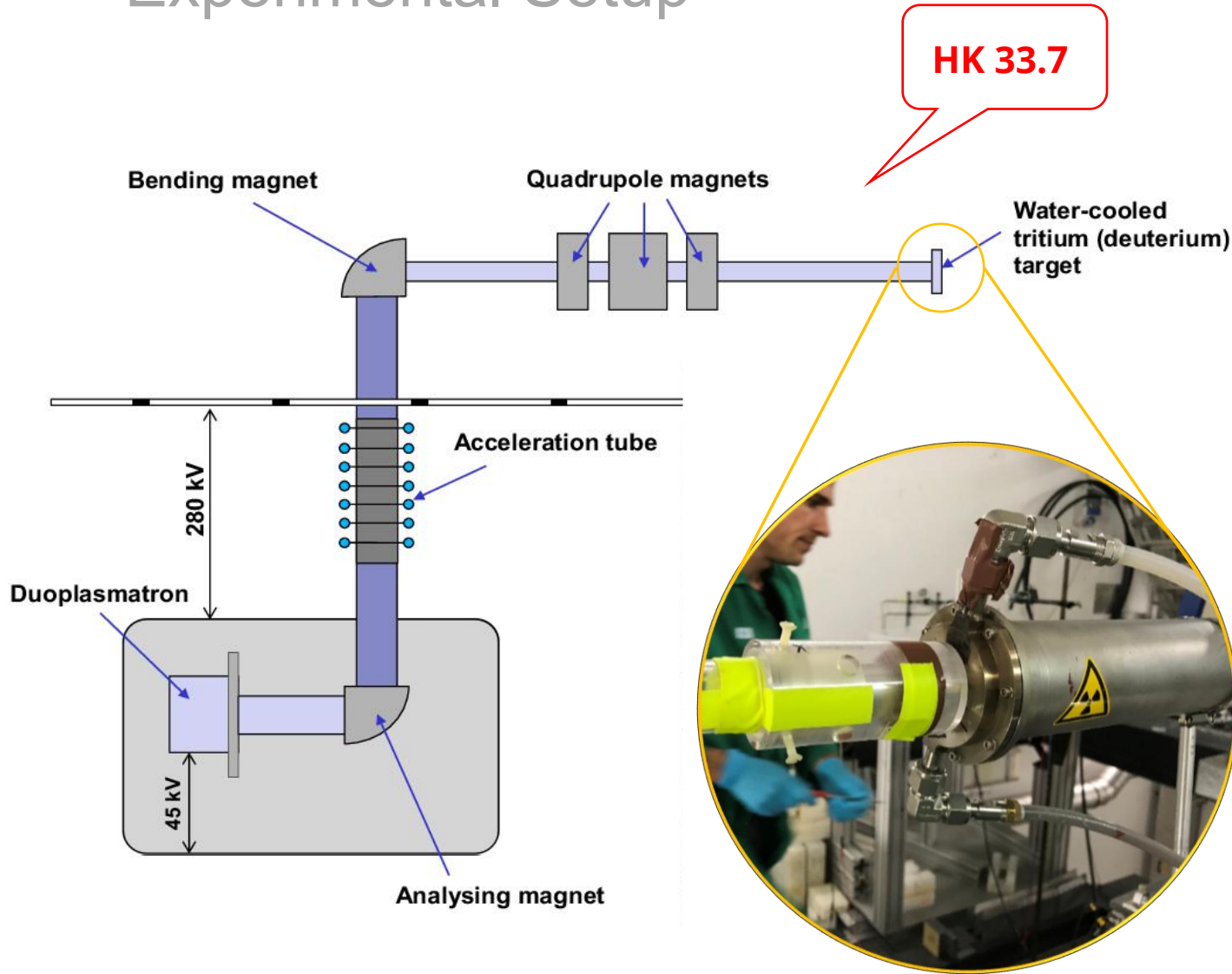


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- Within borated PE transportation shuttles



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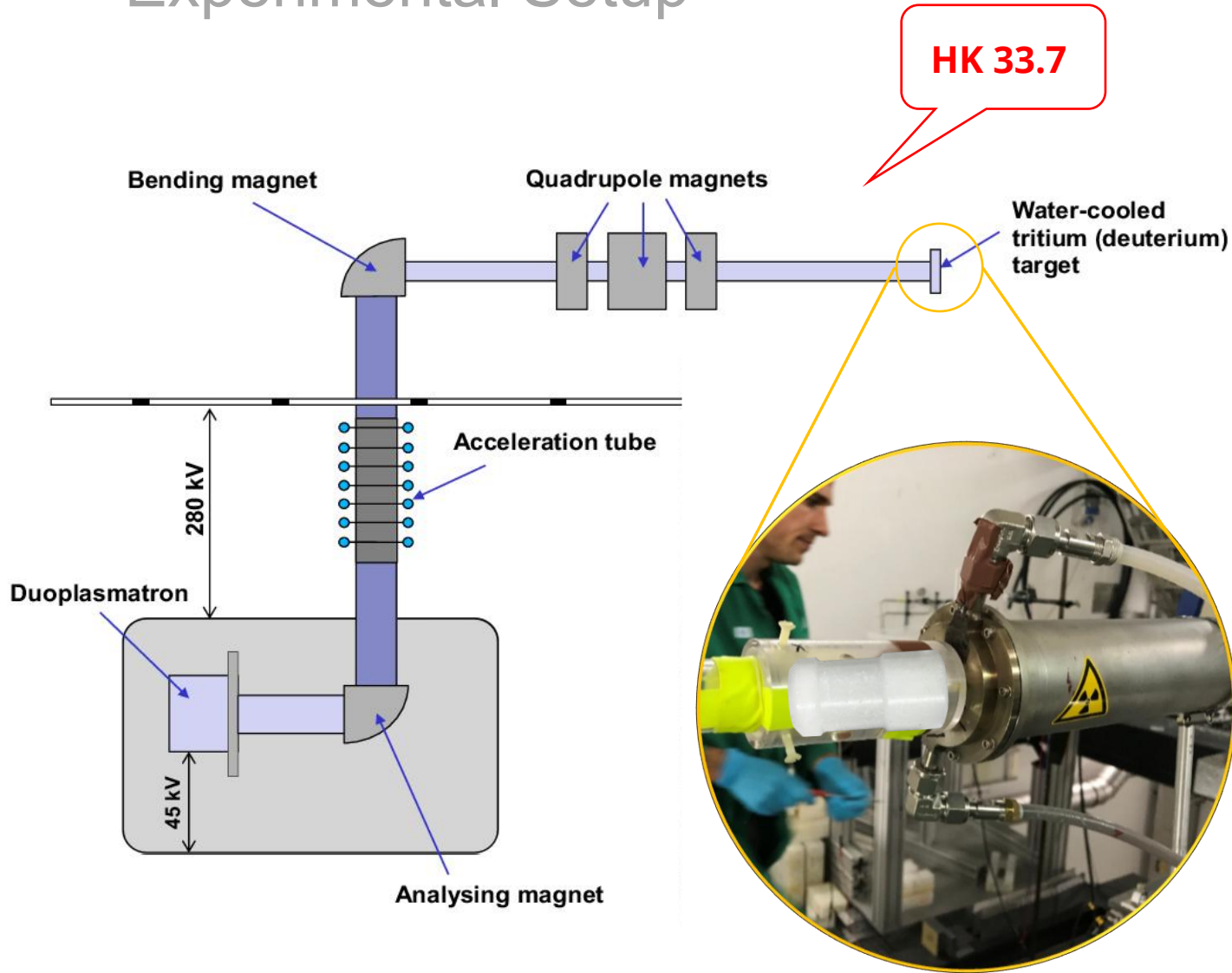


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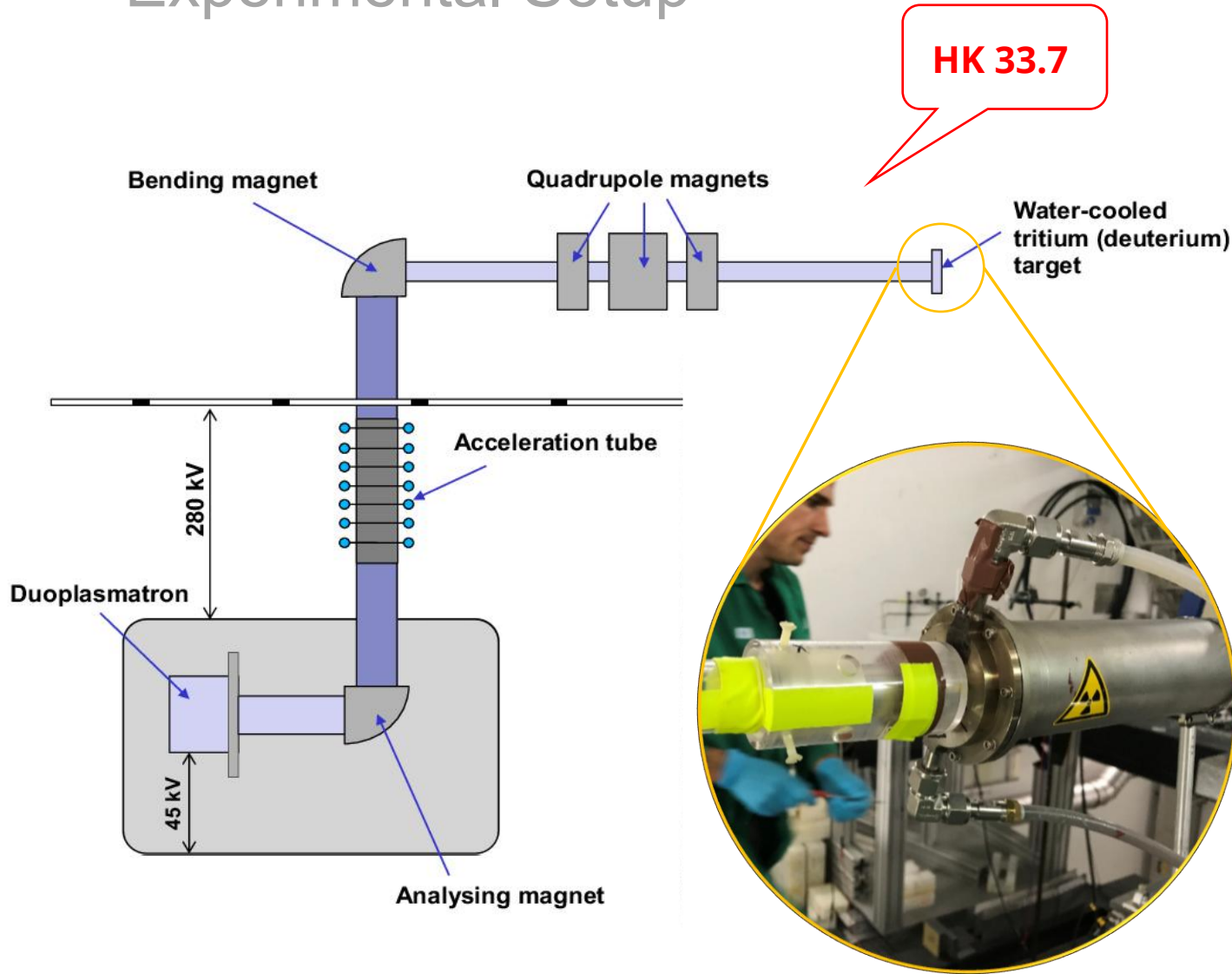
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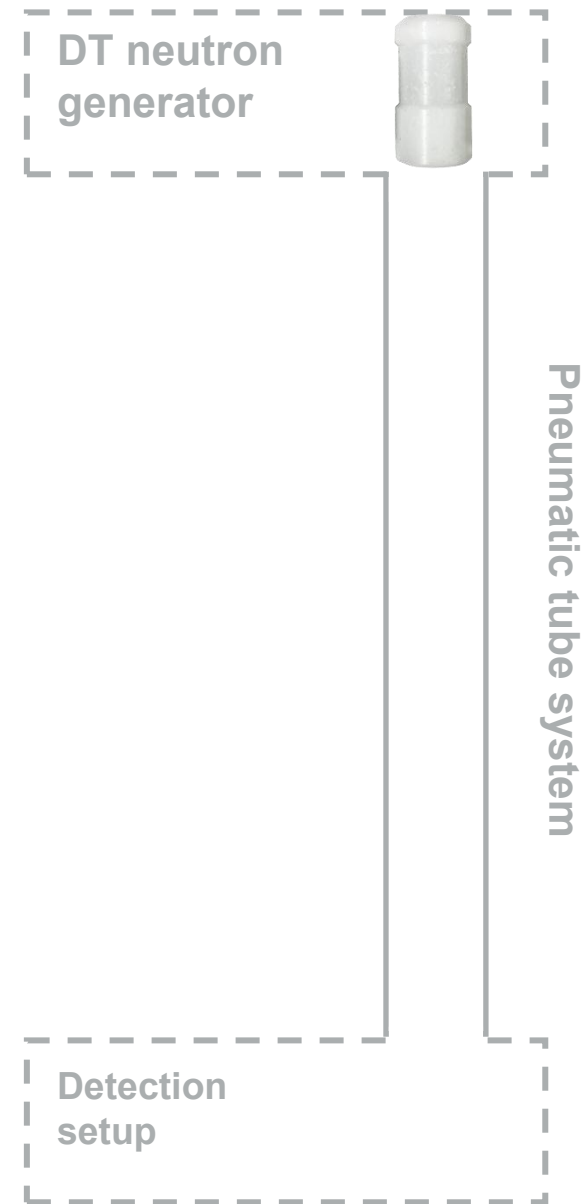
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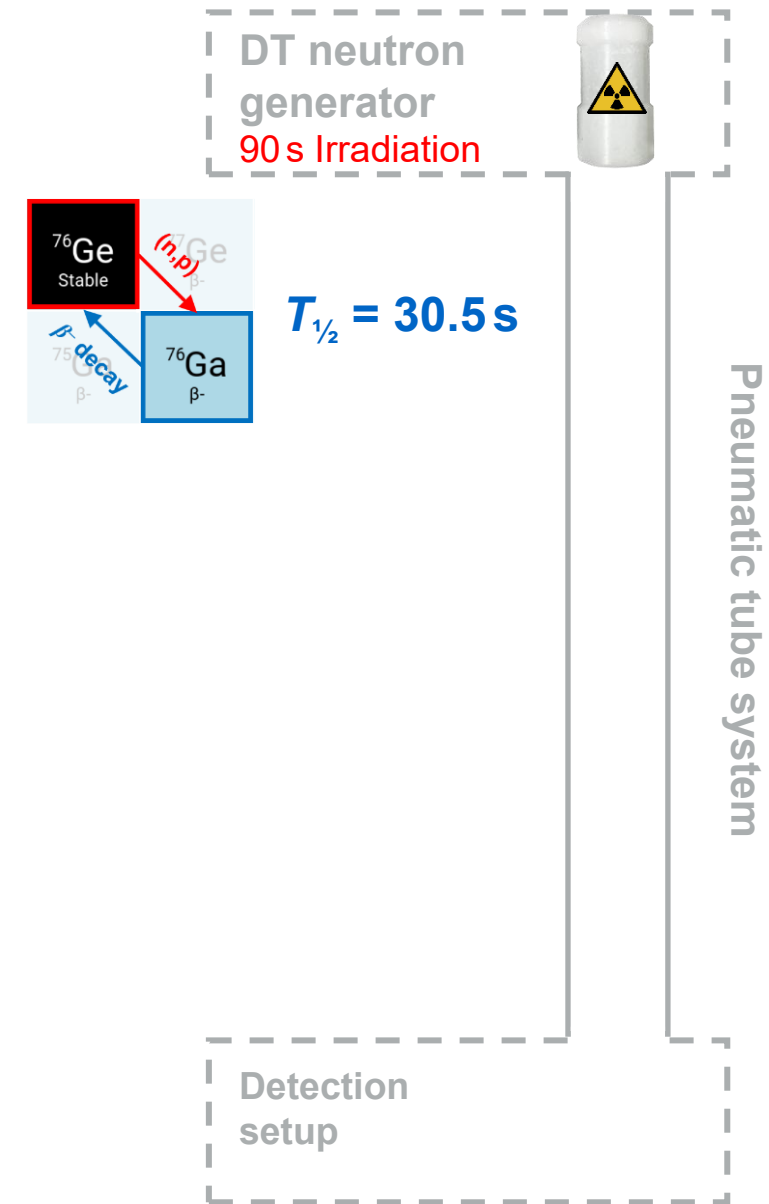
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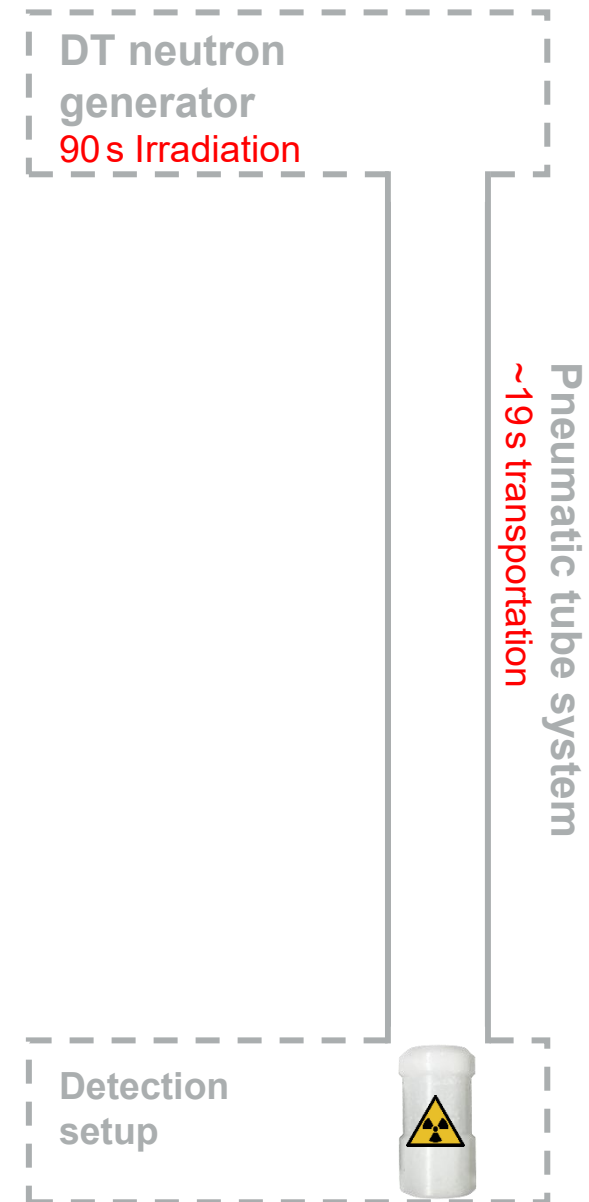
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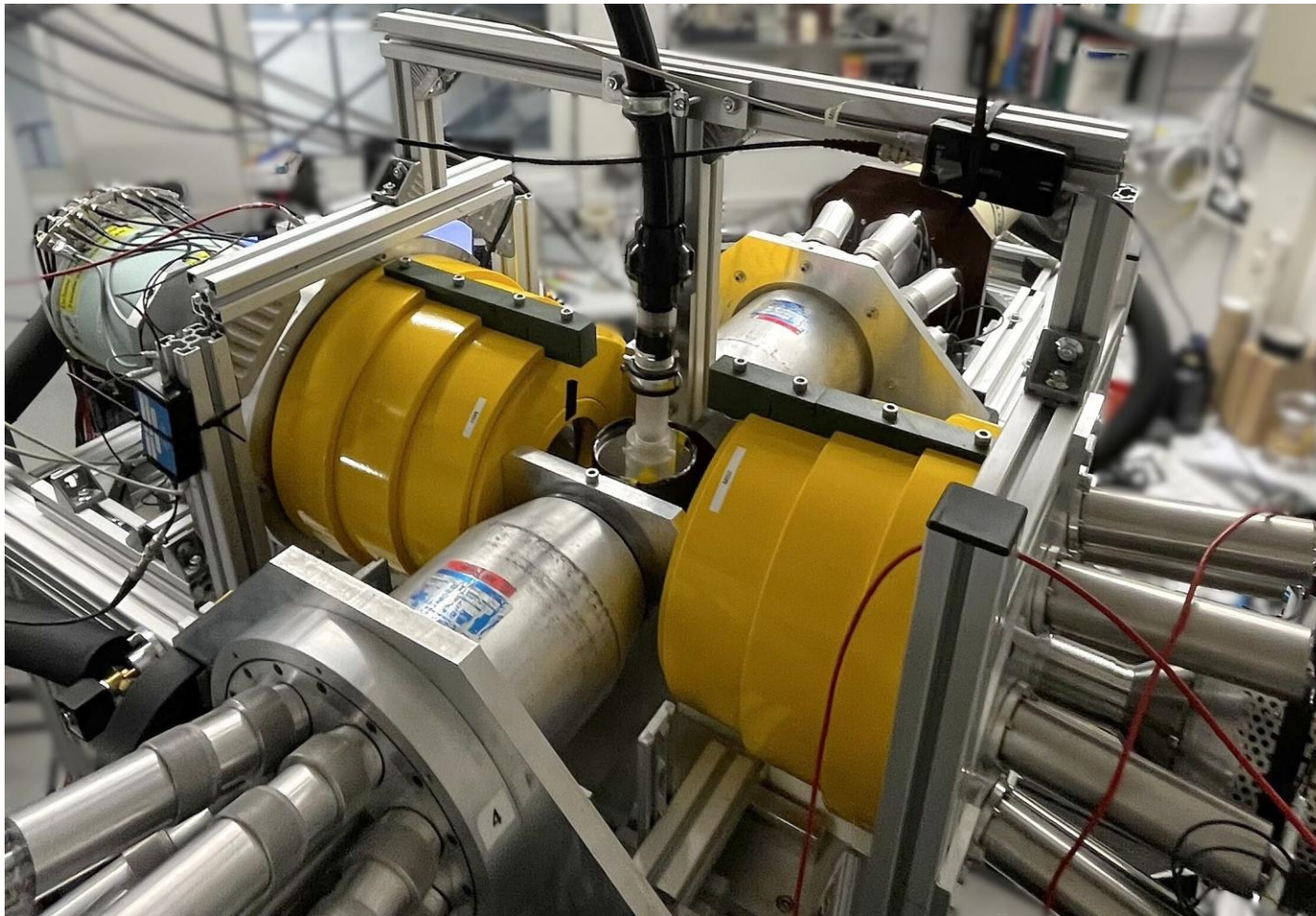
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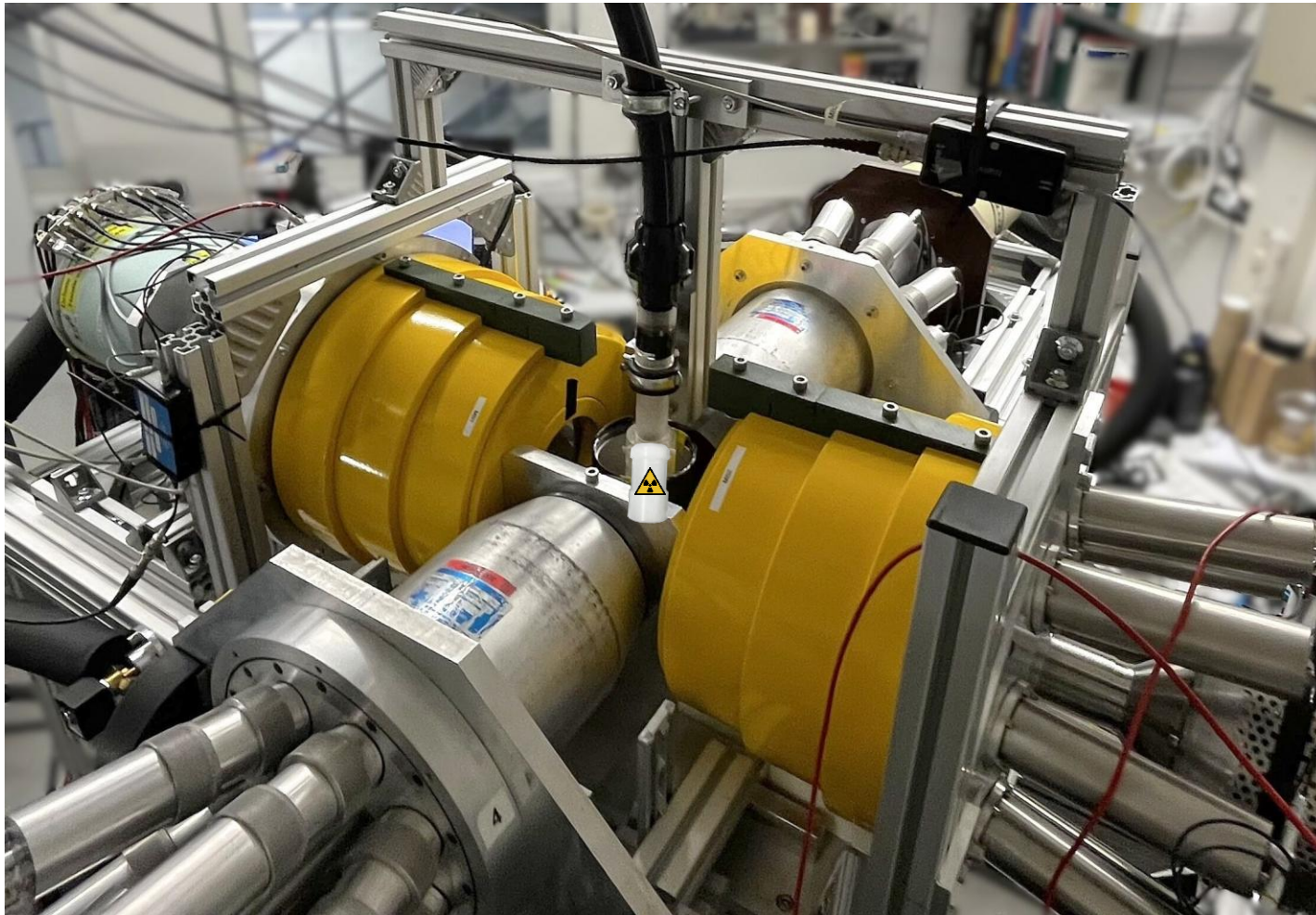
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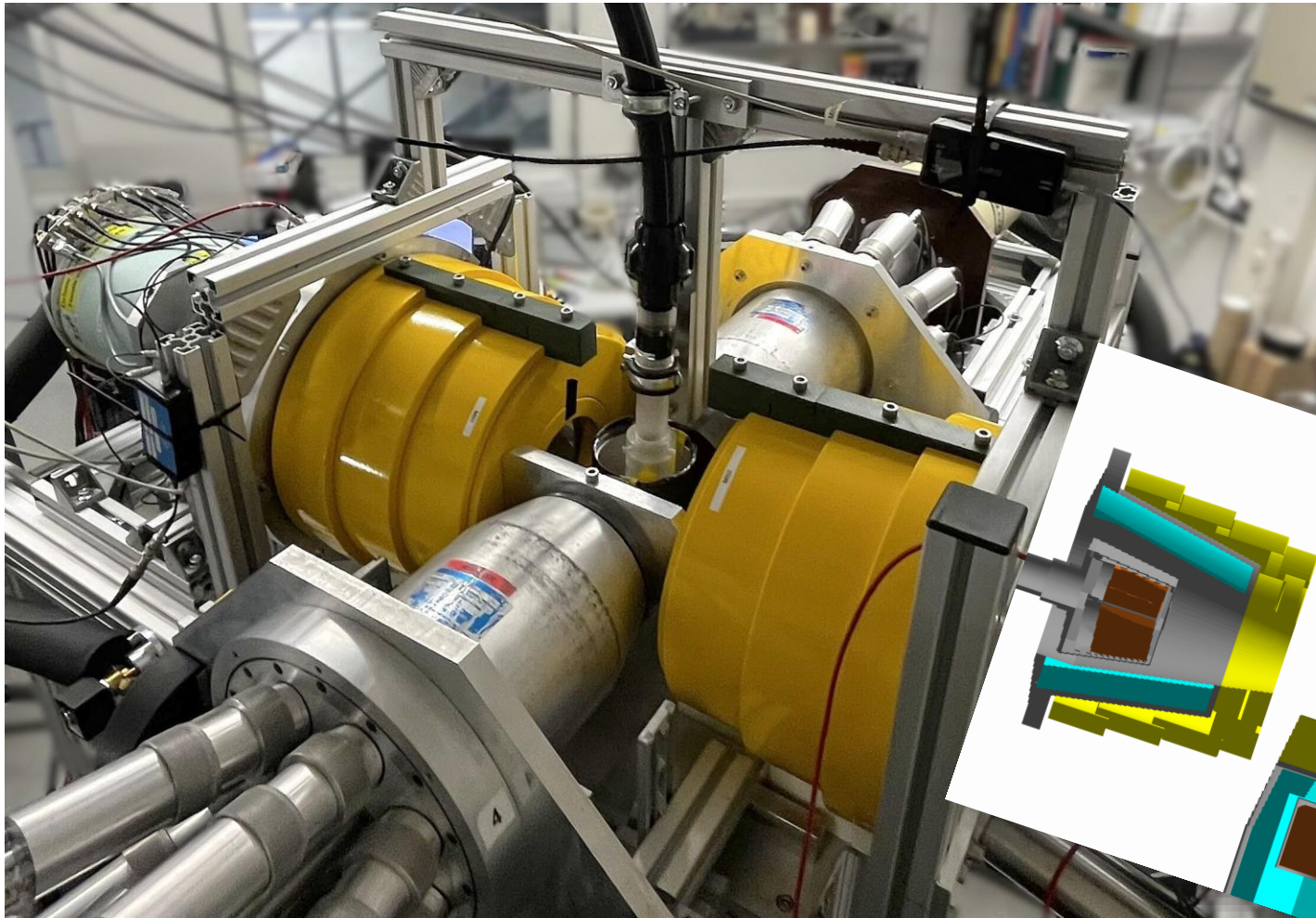


DT neutron  
generator  
90 s Irradiation

Pneumatic tube system  
~19 s transportation

Detection  
setup  
60 s measurement

# Experimental Setup



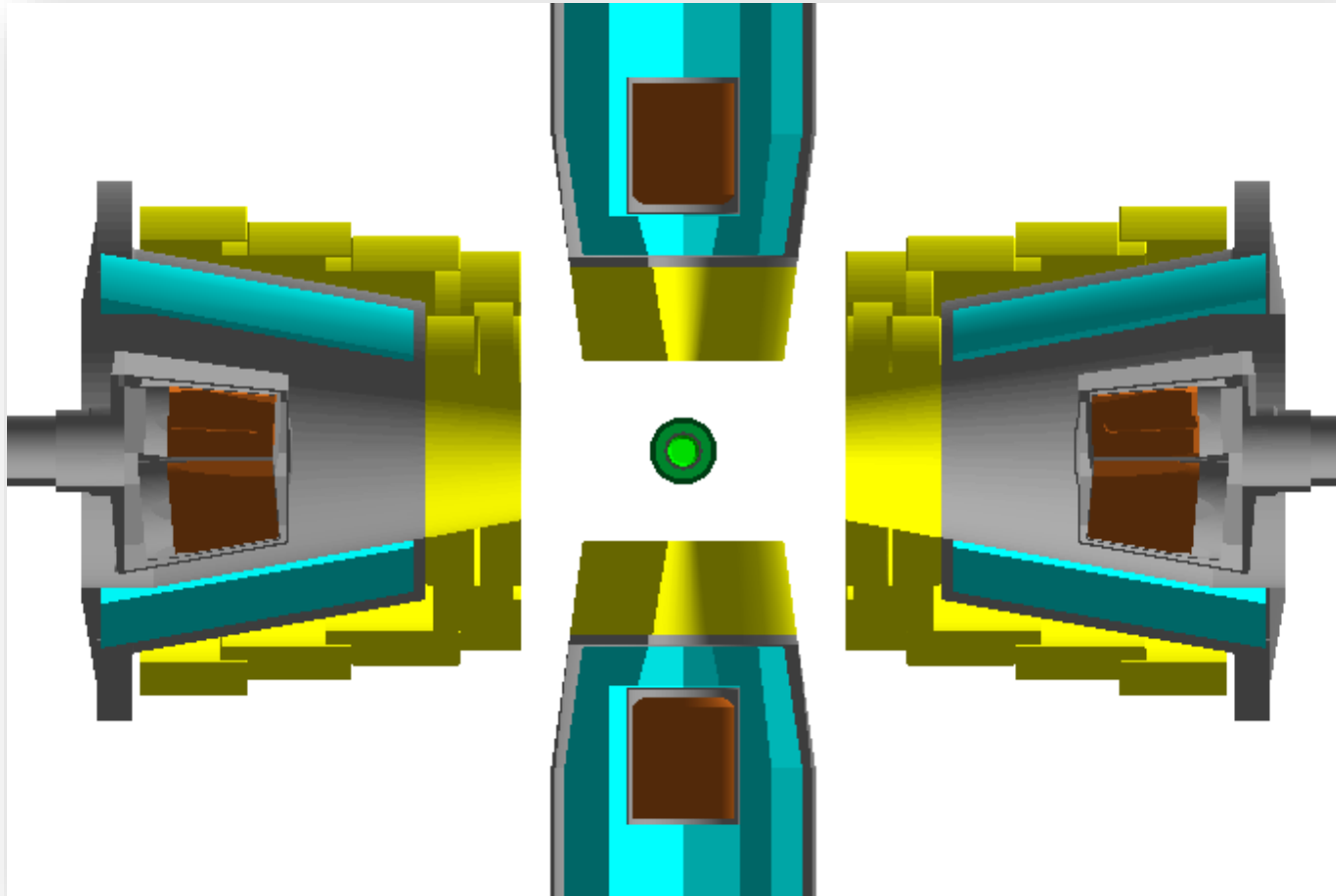
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- 8 HPGe detectors (2 triple-cluster, 2 single-crystal)
- Active Compton suppression with 4 BGO detectors + lead collimators
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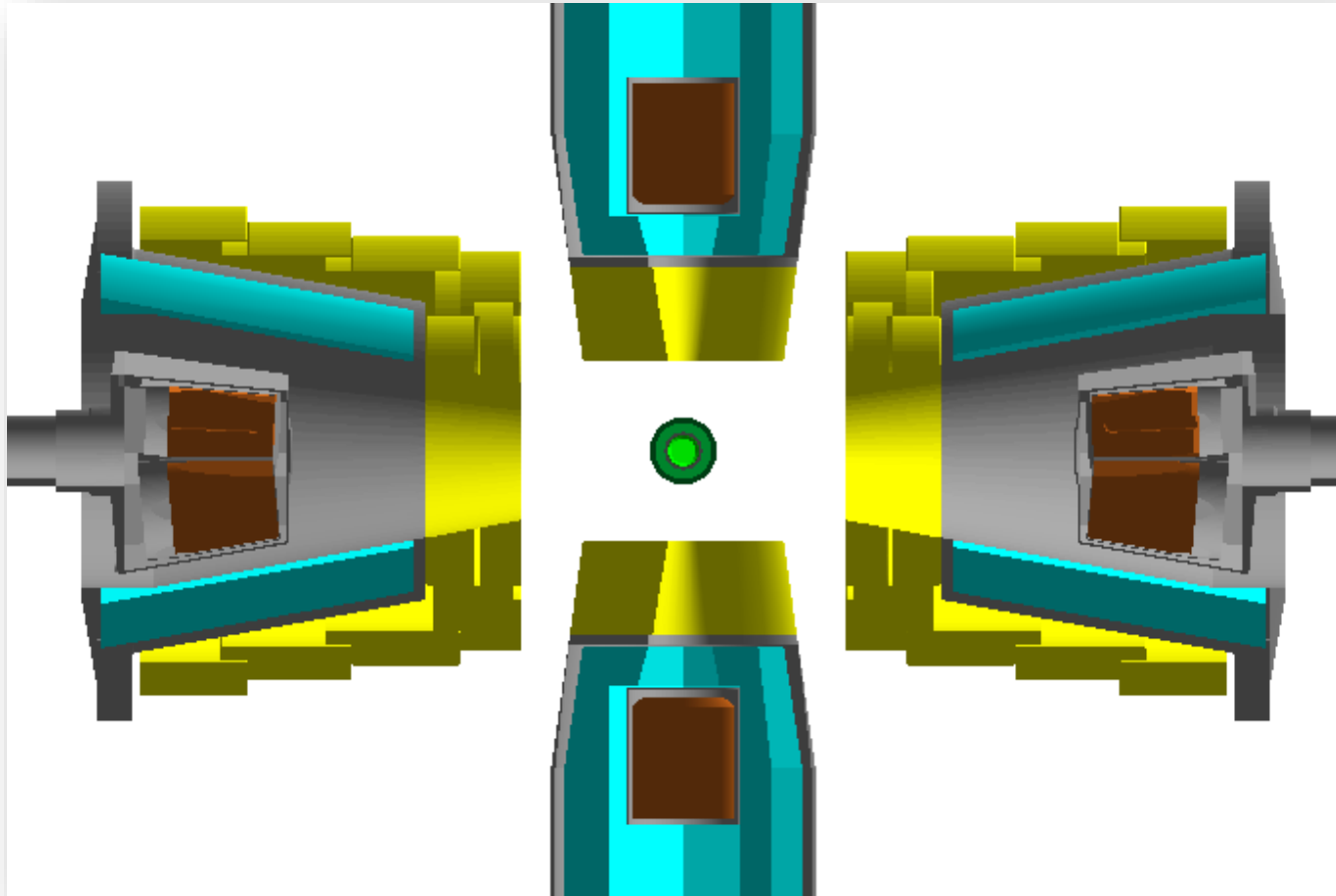
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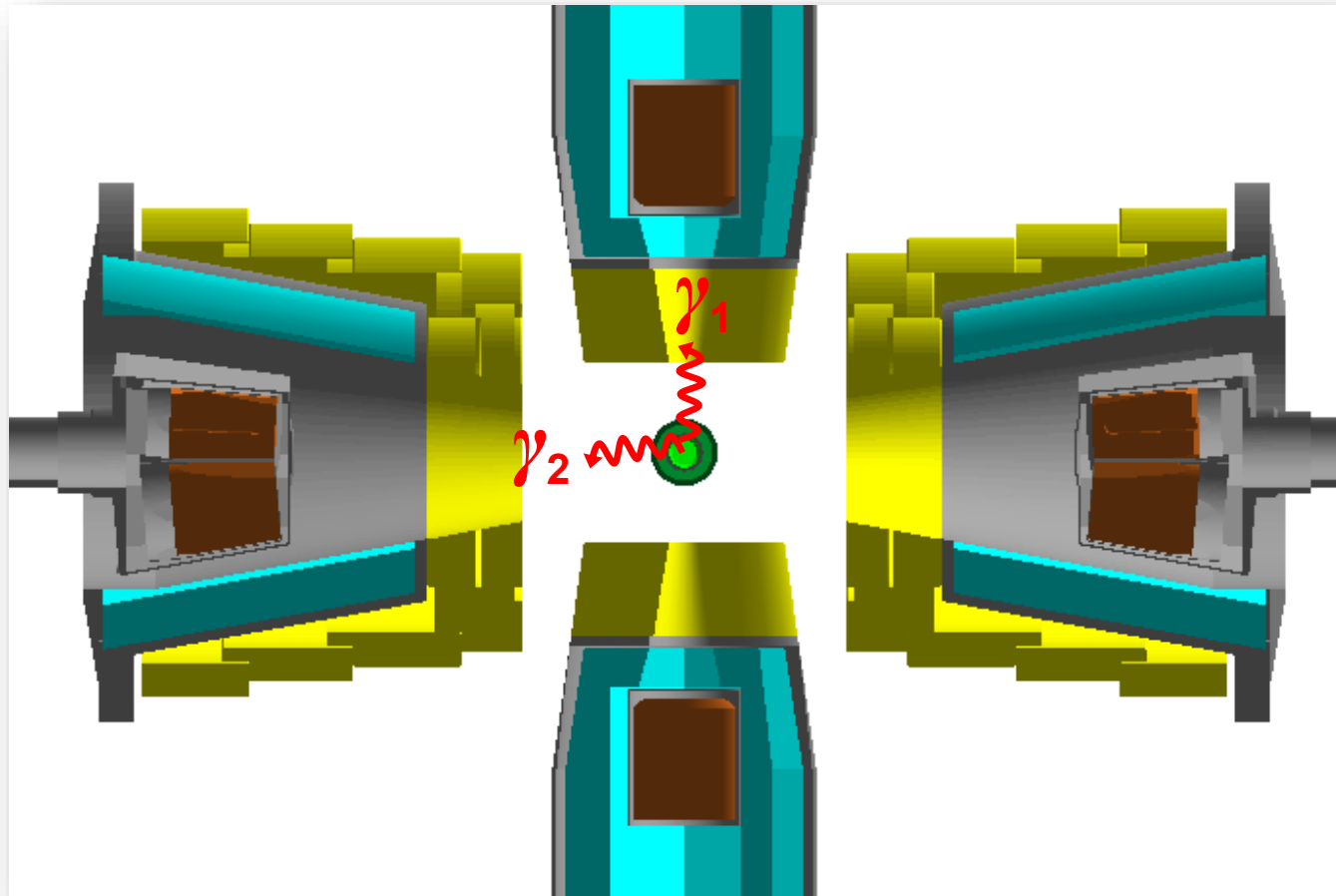
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Detection of  $\gamma$  rays emitted in coincidence

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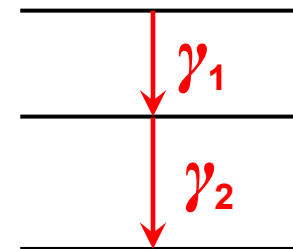
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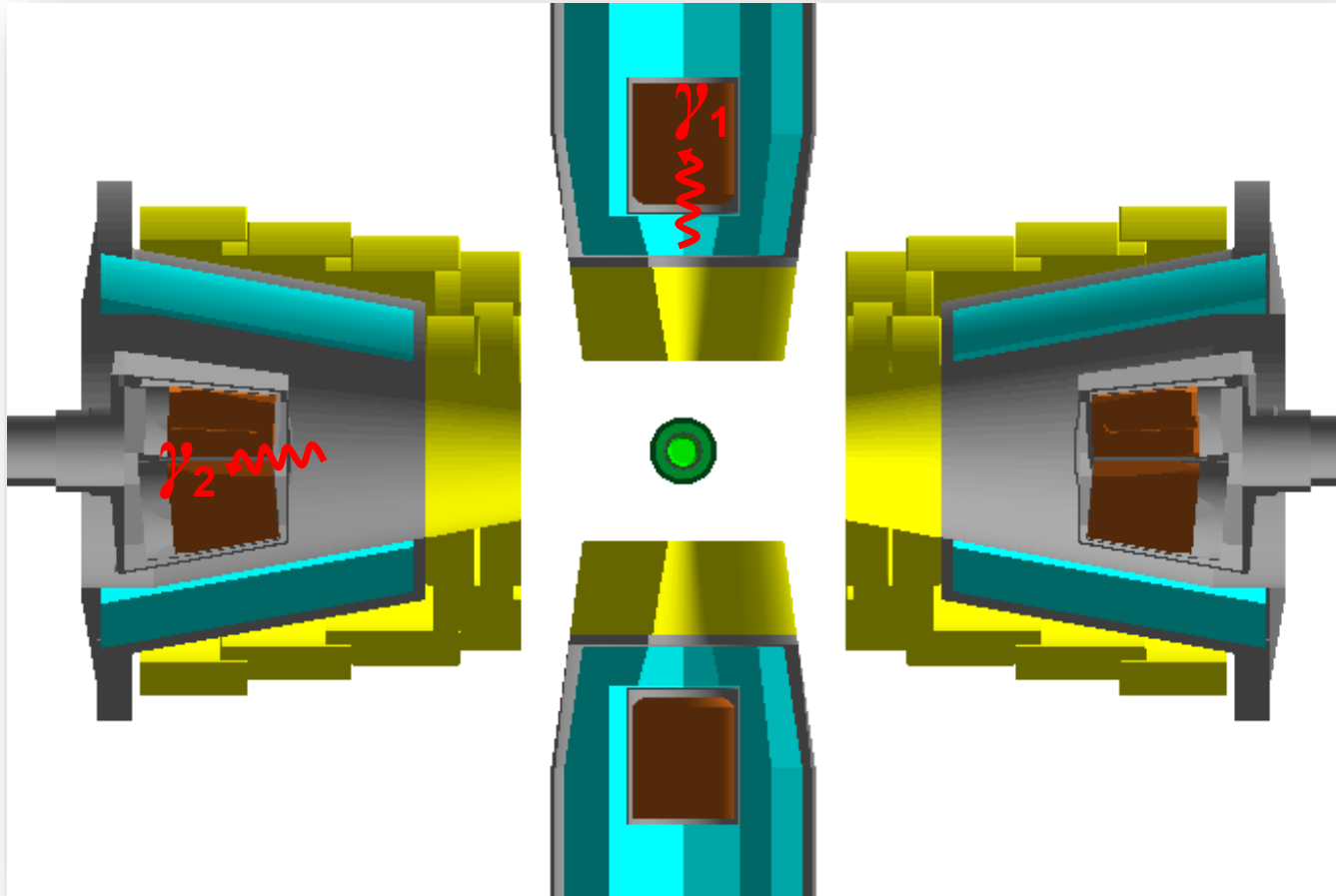
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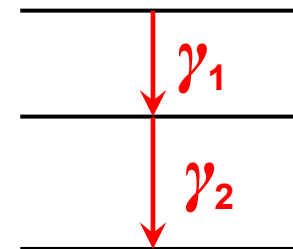
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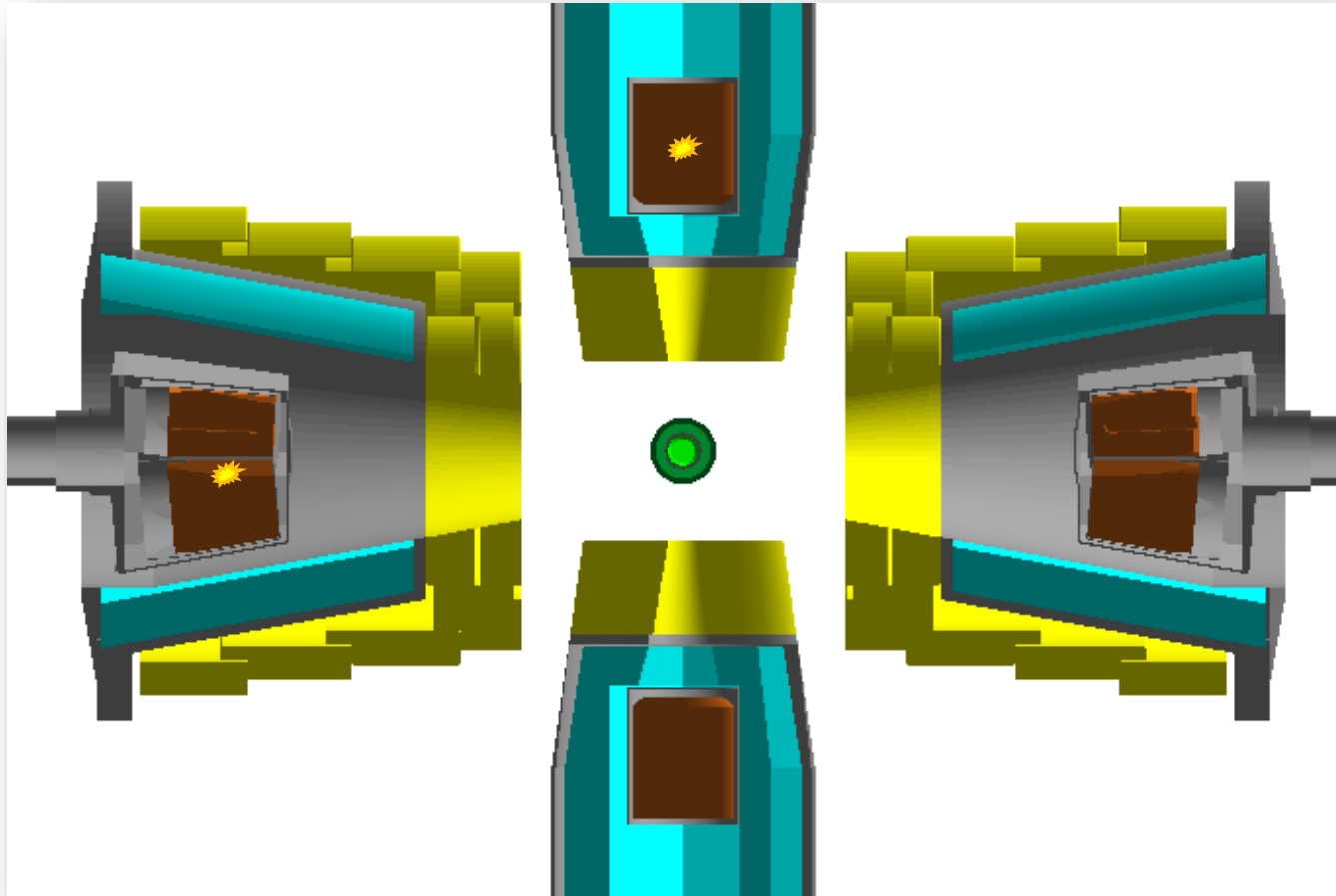
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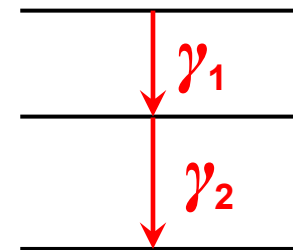
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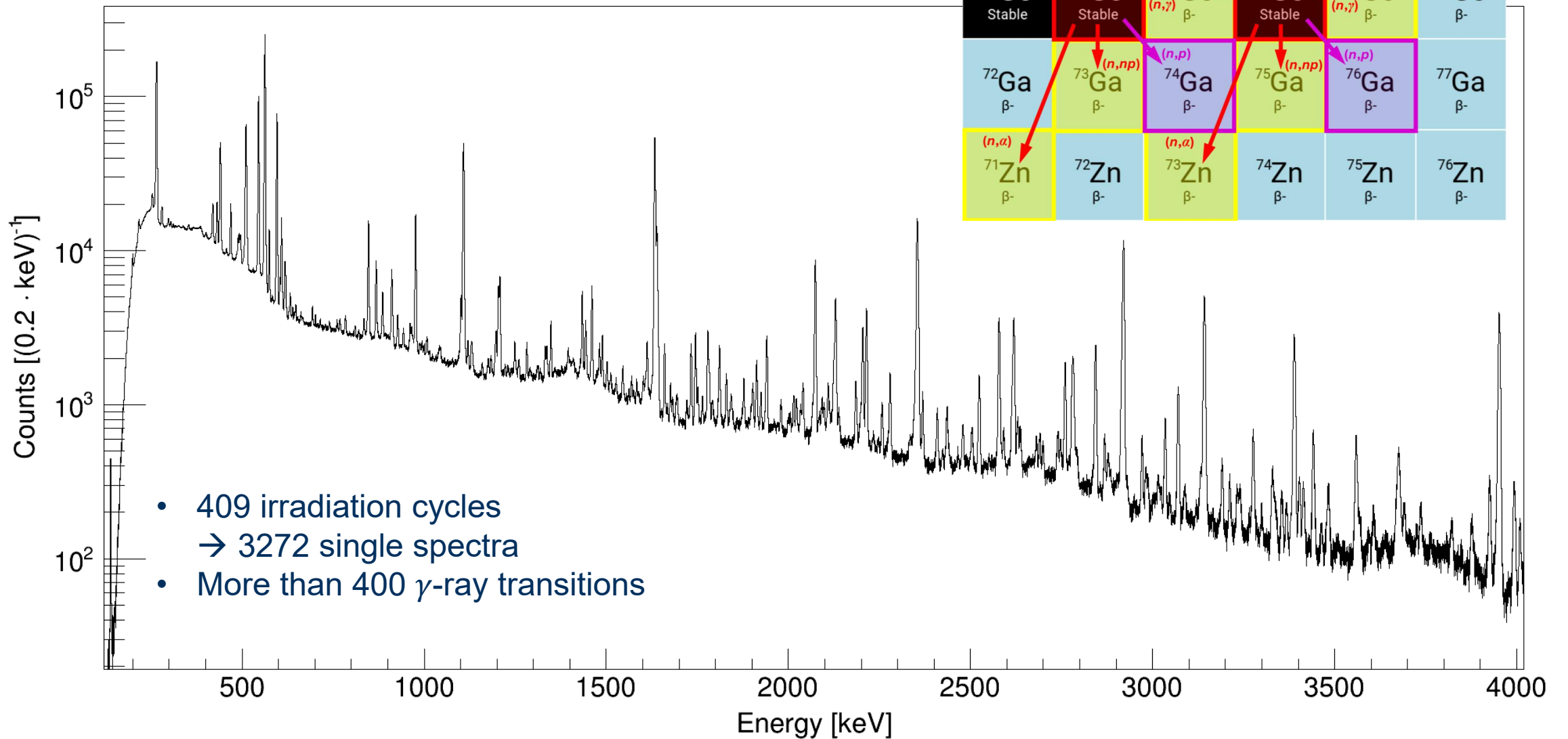
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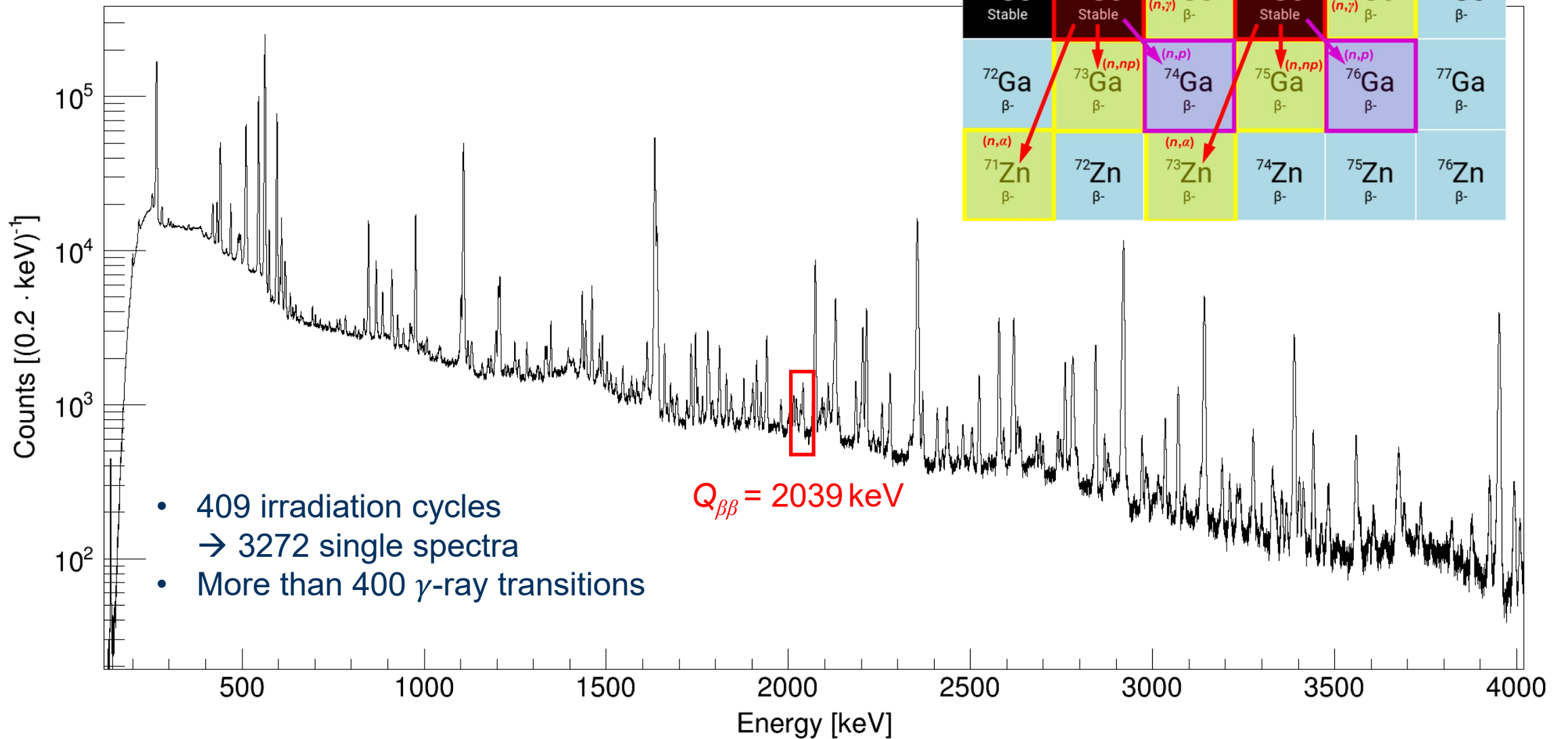
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# Summed Spectra Enriched Ge Sample

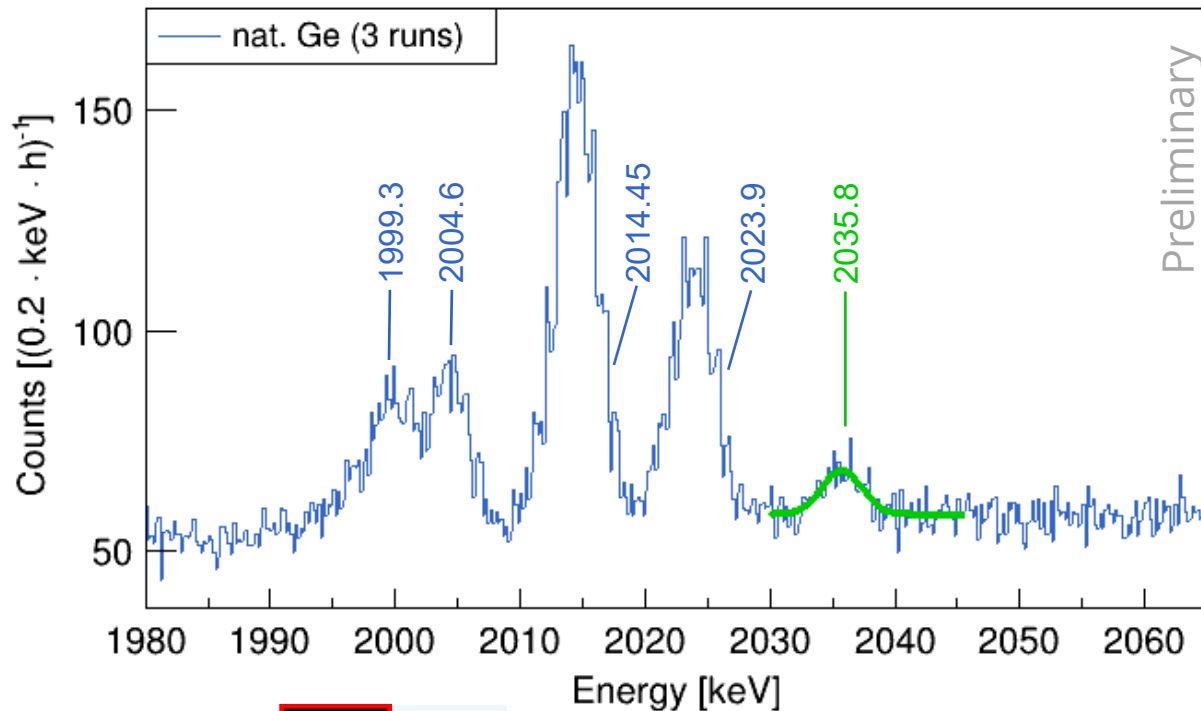


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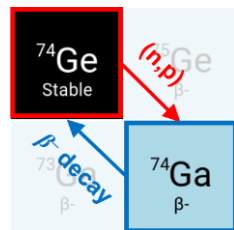


# Summed Spectra near $^{76}\text{Ge}$ $0\nu\beta\beta$ Signal Region

Activation time: 10 min  
Timing window: 5 - 60 min



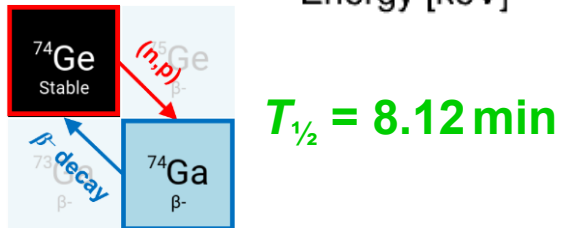
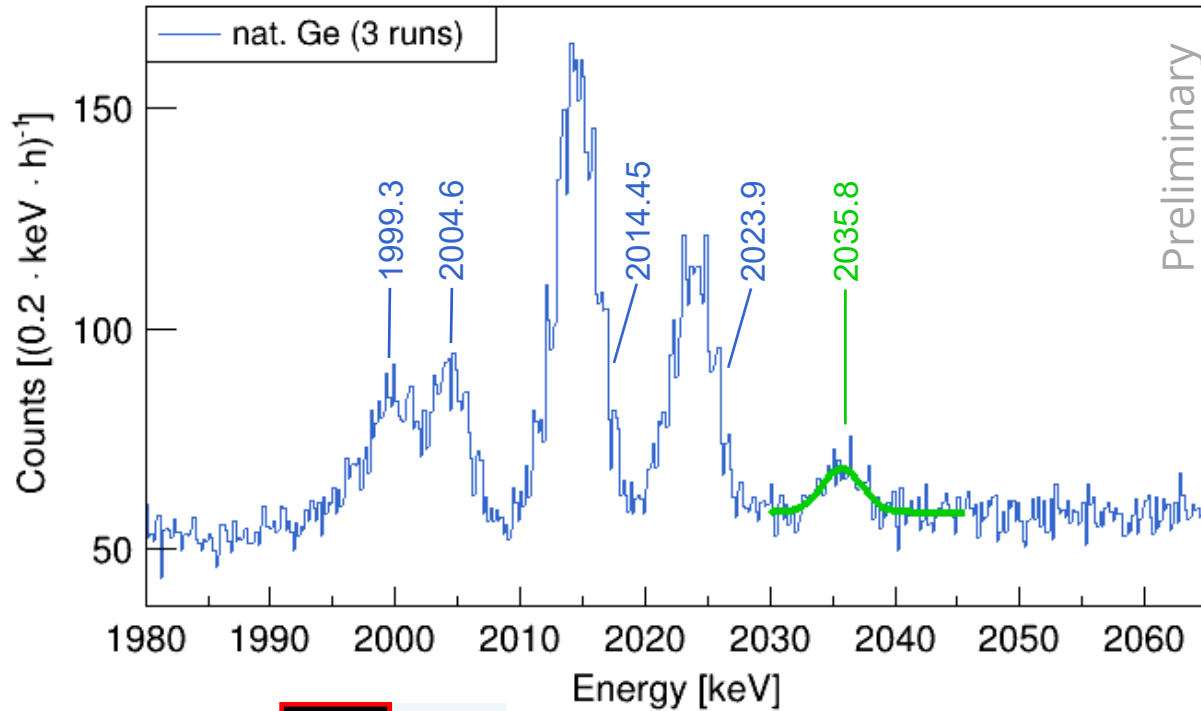
$E_\gamma$ [keV]	$E_i$ [keV]	Parent Isotope	Reaction Channel	Authors/Reference
$2036.20 \pm 0.37$	4201.39	$^{74}\text{Ga}$	$^{74}\text{Ge}(n,p)$	Camp et al., 1971 [1]
$2036.2 \pm 0.9$	4201.39	$^{74}\text{Ga}$	$^{74}\text{Ge}(n,p)$	Taylor et al., 1975 [2]
$2040.70 \pm 0.25$	3951.89	$^{76}\text{Ga}$	$^{76}\text{Ge}(n,p)$	Camp et al., 1971 [3]
$2037.5 \pm 0.3$	3147	$^{76}\text{Ge}$	$^{76}\text{Ge}(n, n'\gamma)$	Crider et al., 2015 [4]
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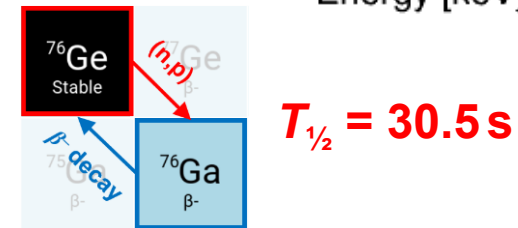
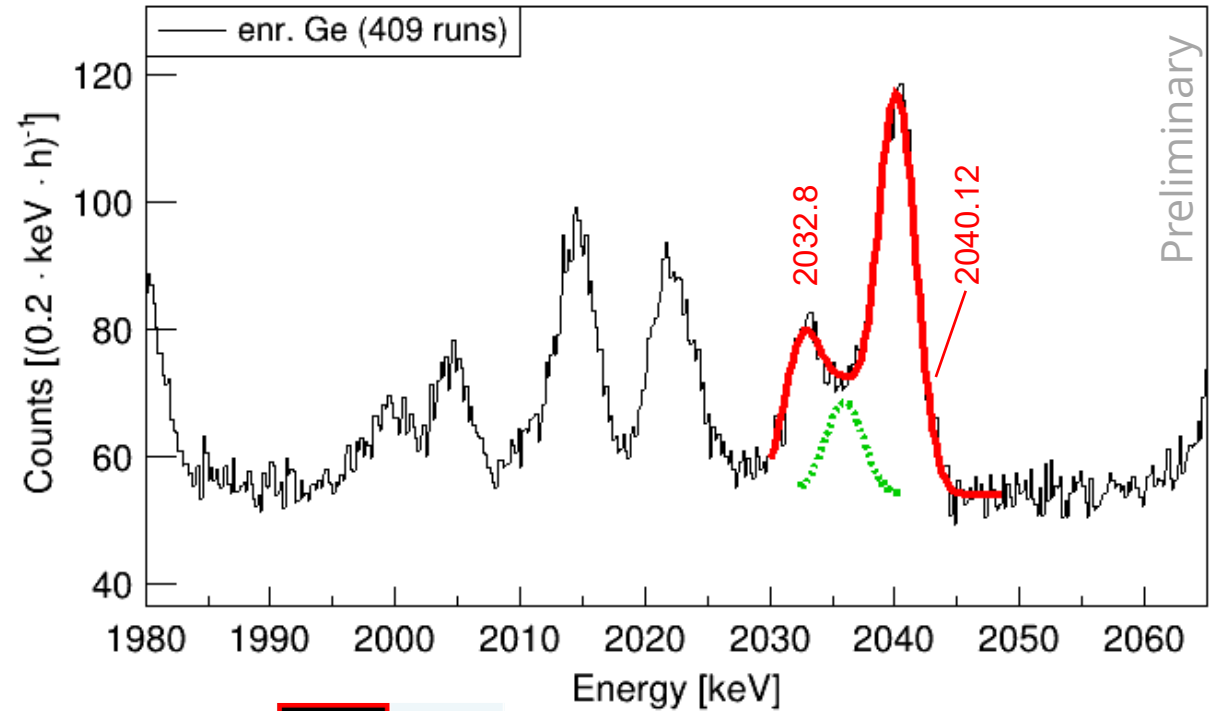
$T_{1/2} = 8.12 \text{ min}$

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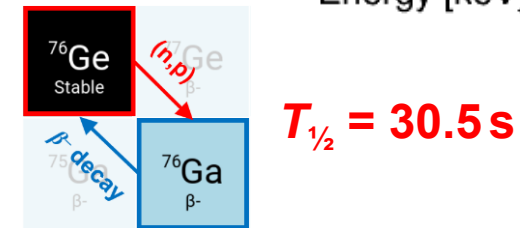
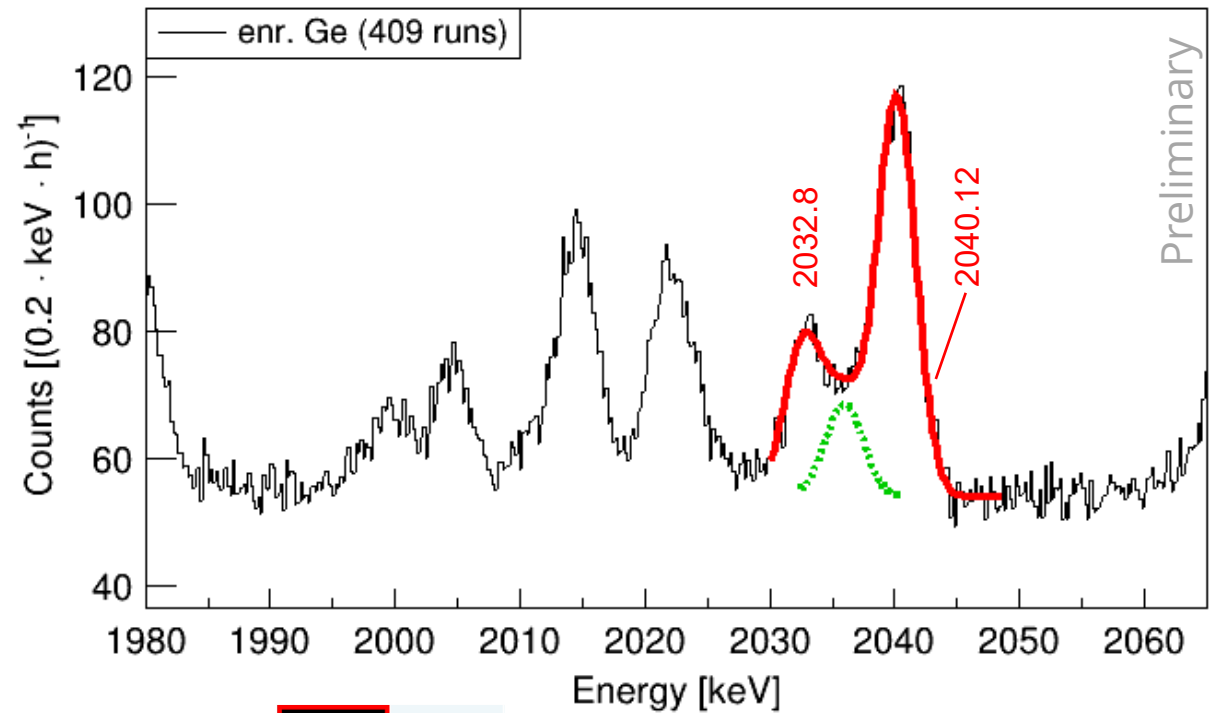
Activation time: 90 s  
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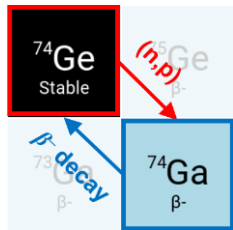
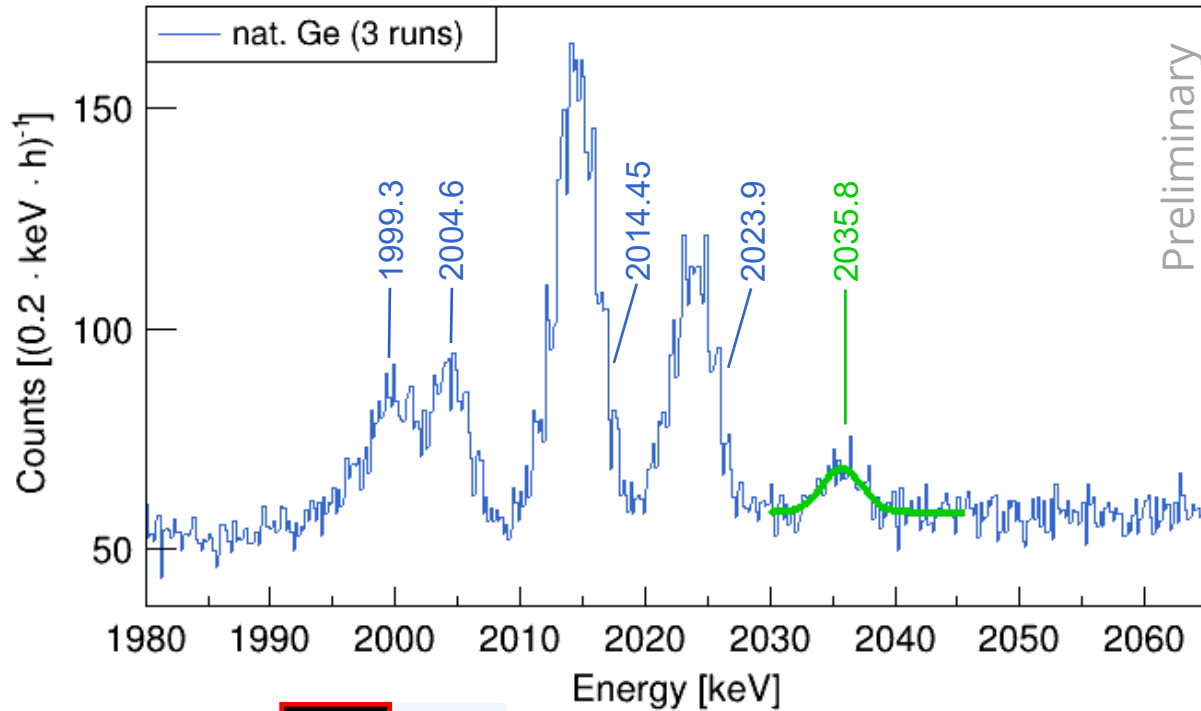
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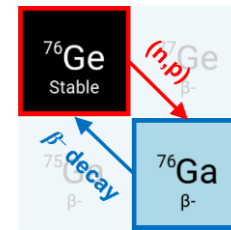
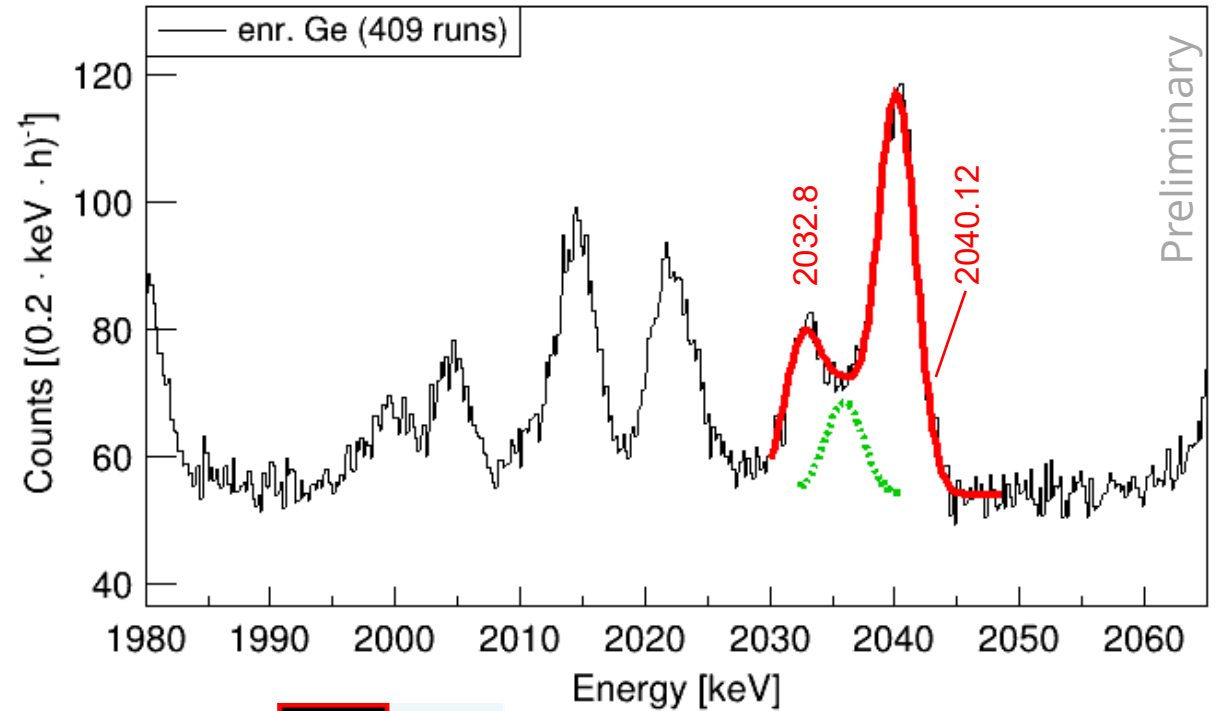
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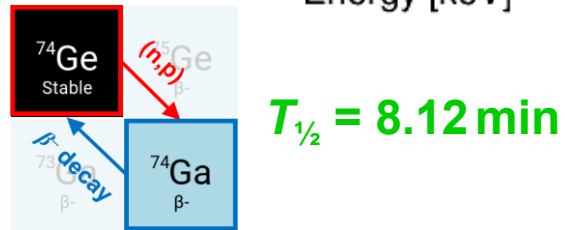
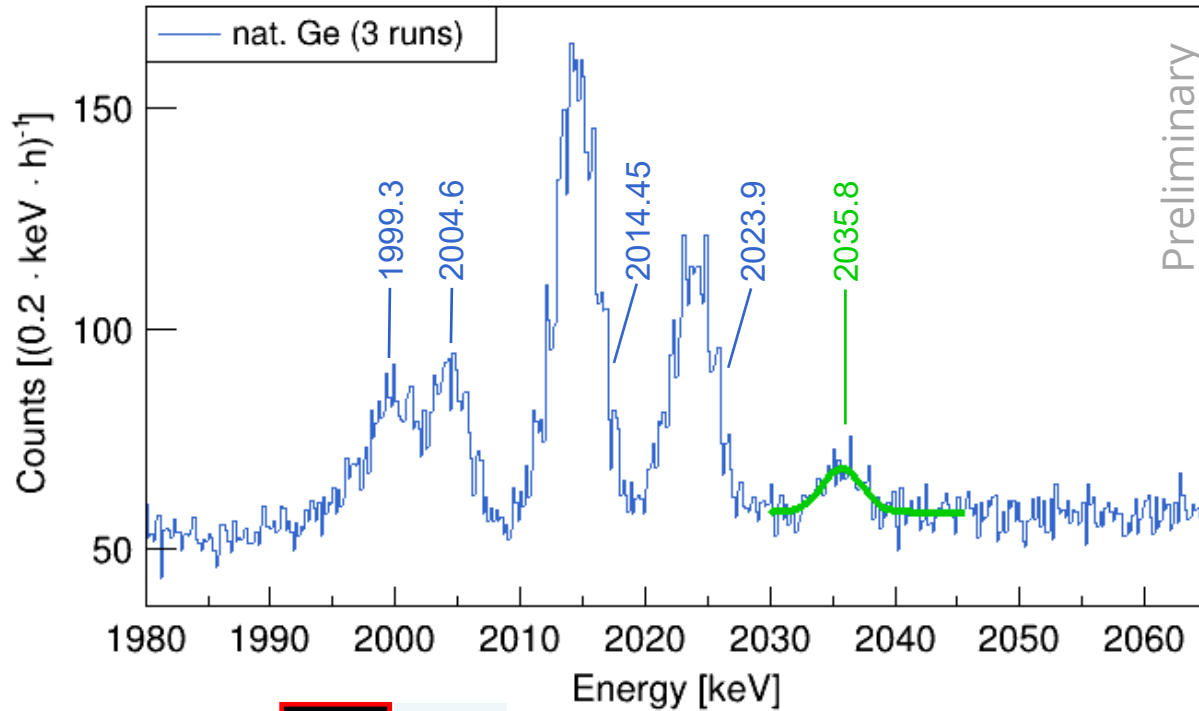


$T_{1/2} = 30.5 \text{ s}$

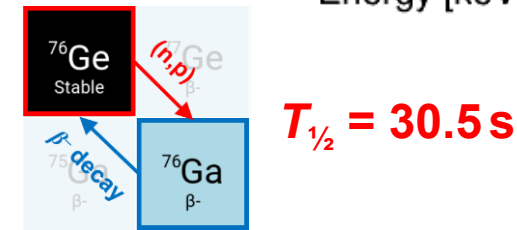
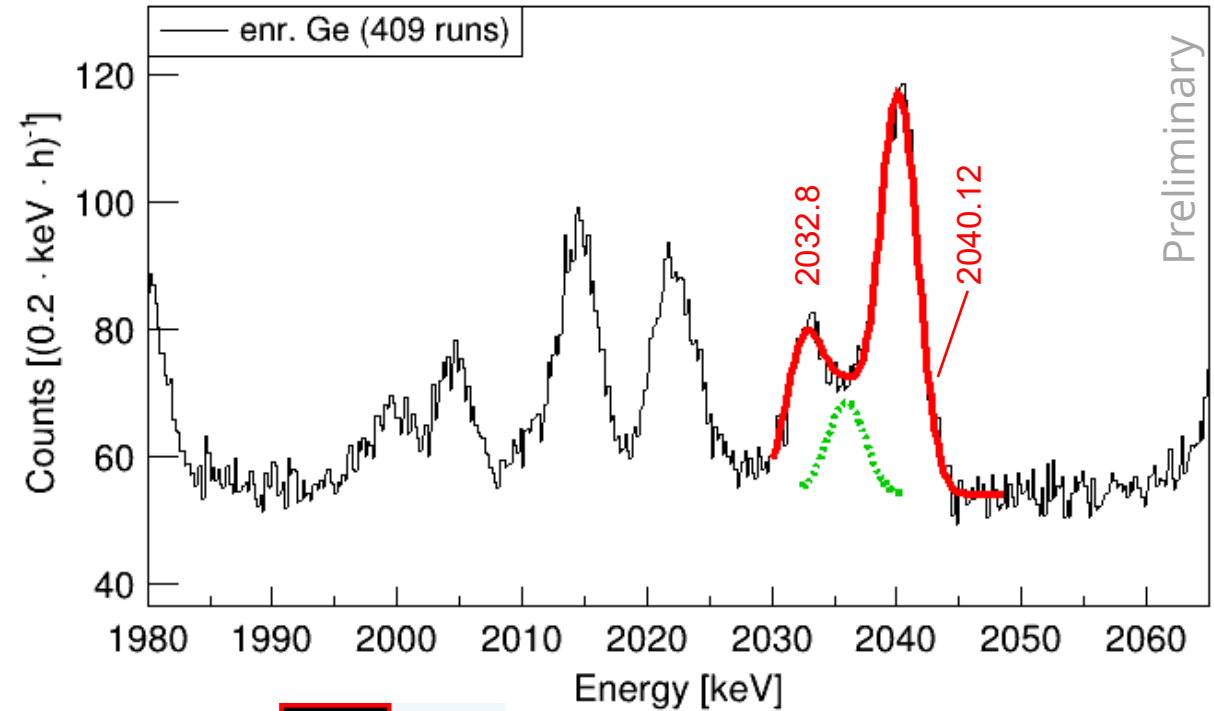
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Pichotta et al.,  
Phys. Rev. C **112**, 014325 (2025)

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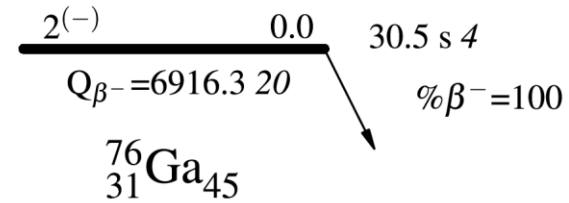
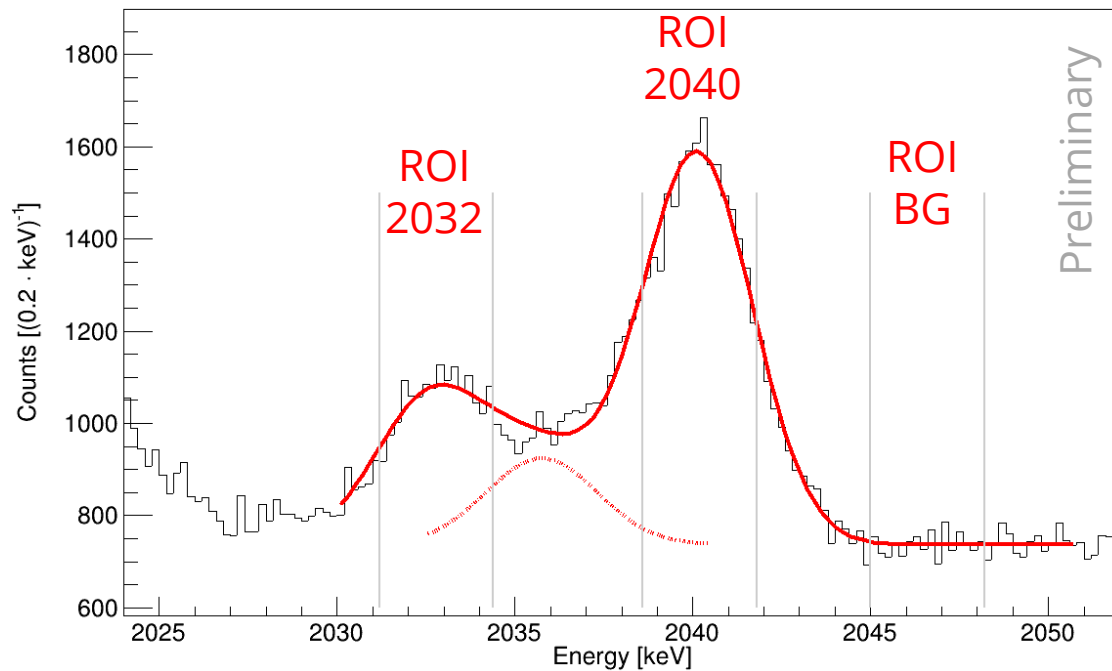


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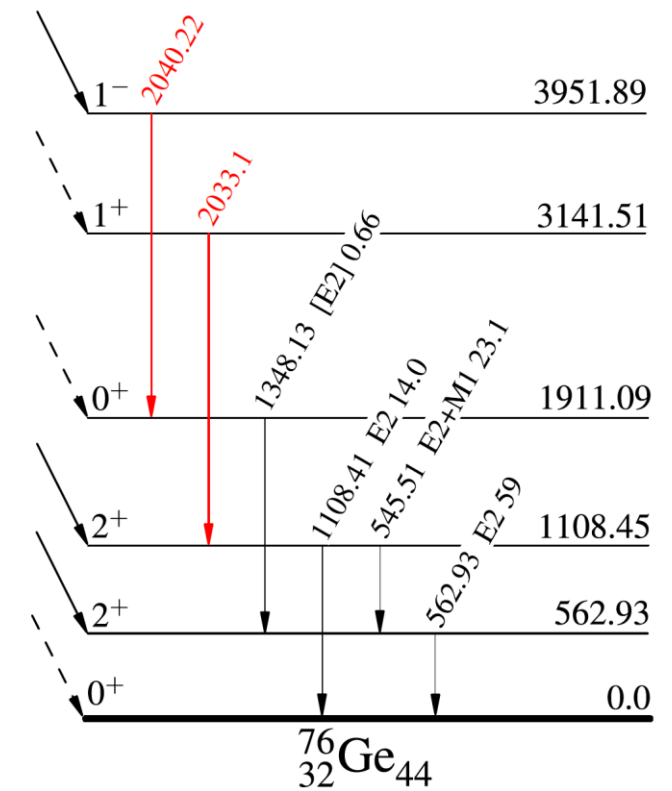


# $\gamma$ - $\gamma$ Coincidence Analysis

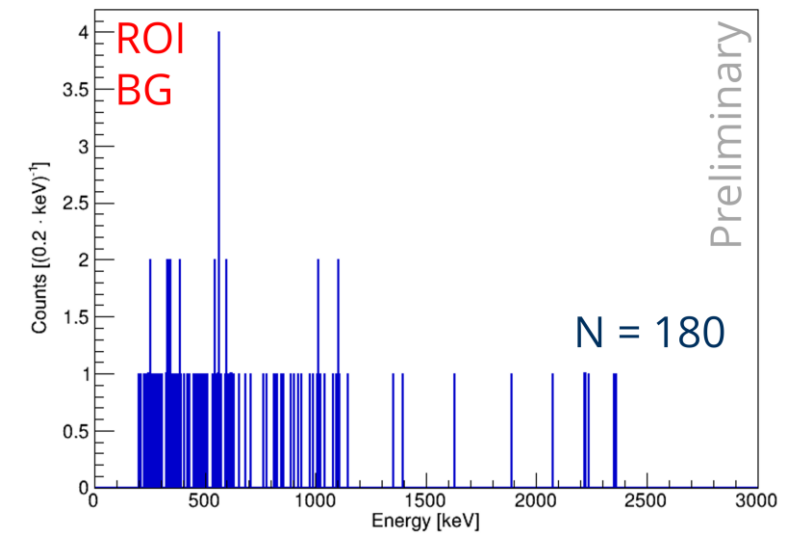
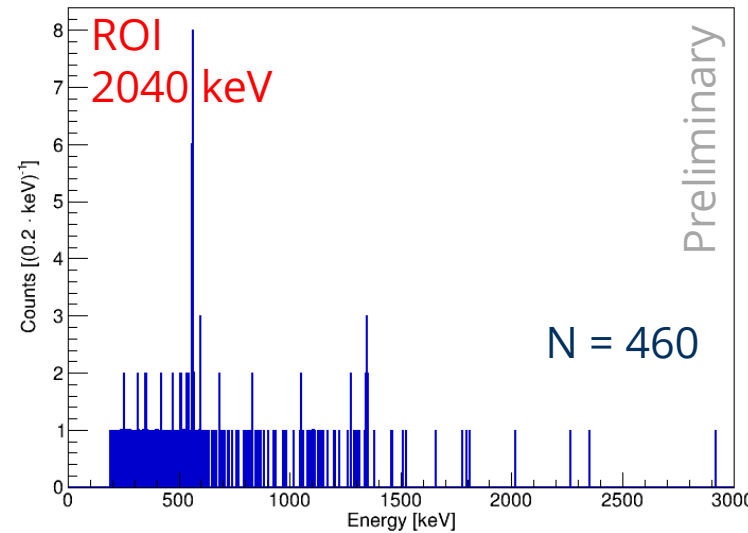
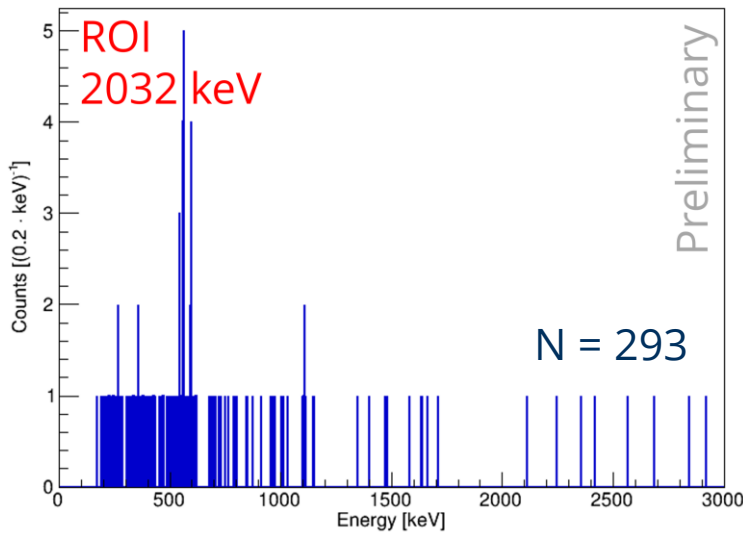
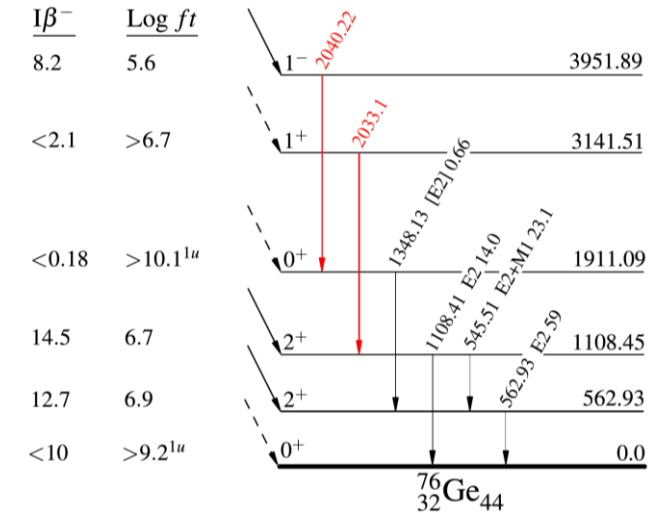
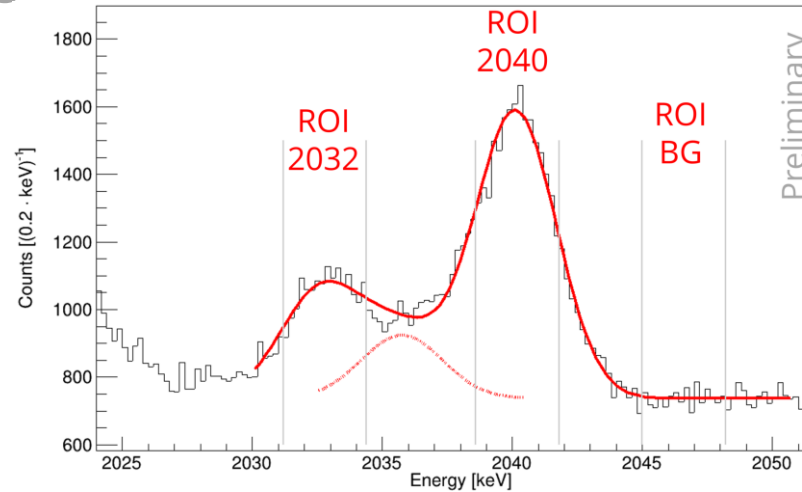
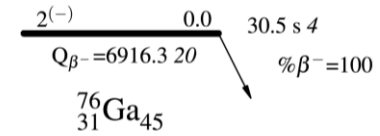
- Cut conditions:**  
 What do the other detectors measure when one detector records an event in the ROI?  
 + BGO veto  
 + ...



$I\beta^-$	$\text{Log } ft$
8.2	5.6
<2.1	>6.7
<0.18	>10.1 <sup>1u</sup>
14.5	6.7
12.7	6.9
<10	>9.2 <sup>1u</sup>



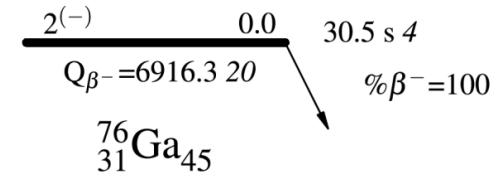
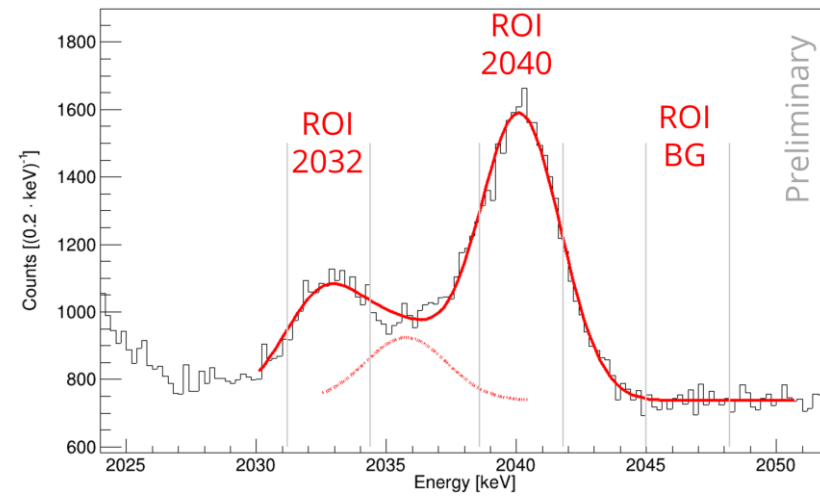
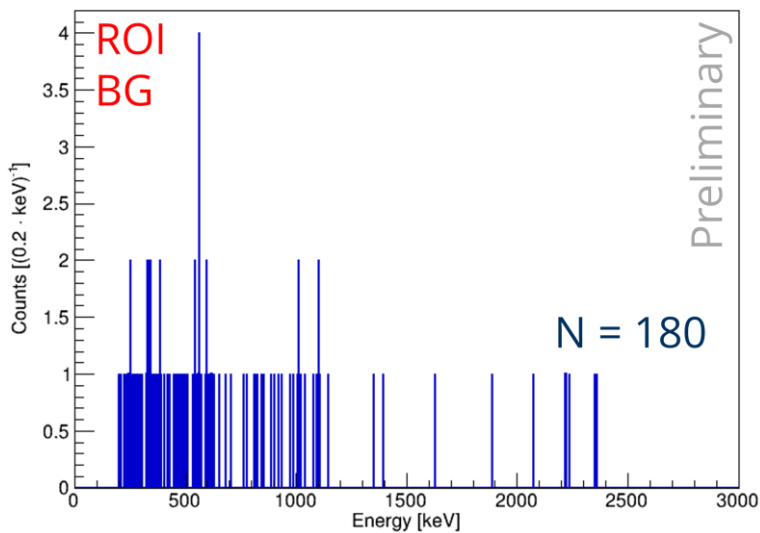
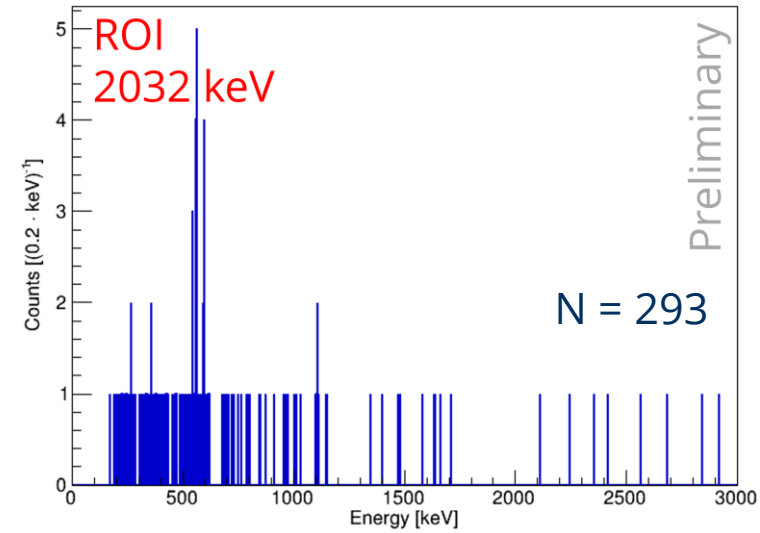
# $\gamma$ - $\gamma$ Coincidence Analysis



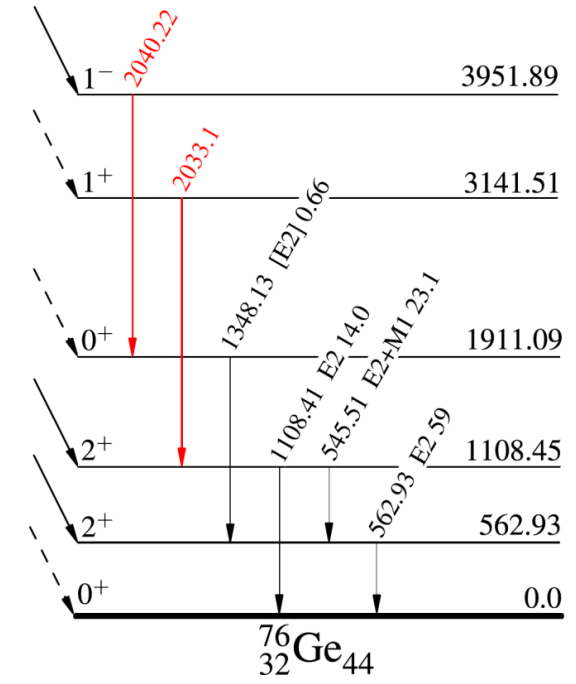
Studies of the  $^{76}\text{Ge}$  Level Scheme via Neutron Activation and  $\gamma$ - $\gamma$  Coincidence Spectroscopy for Germanium-Based  $0\nu\beta\beta$  decay Experiments

Marie Pichotta

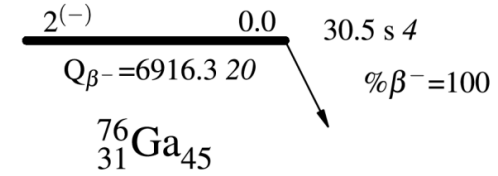
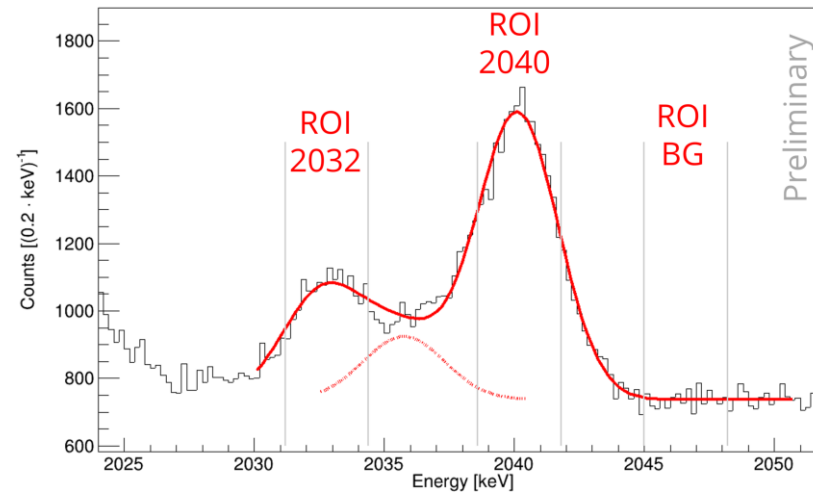
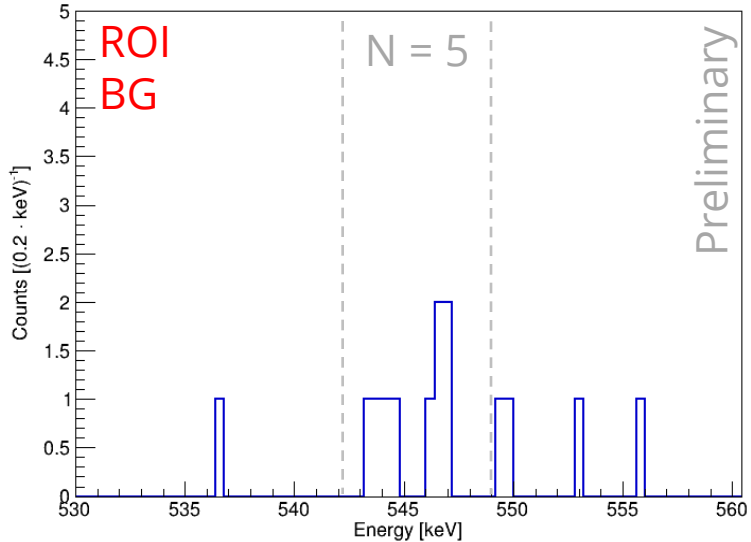
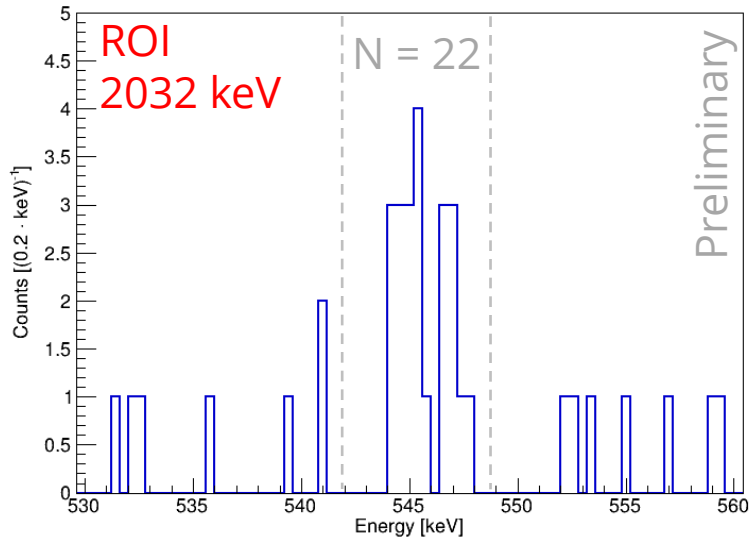
# $\gamma$ - $\gamma$ Coincidence Analysis



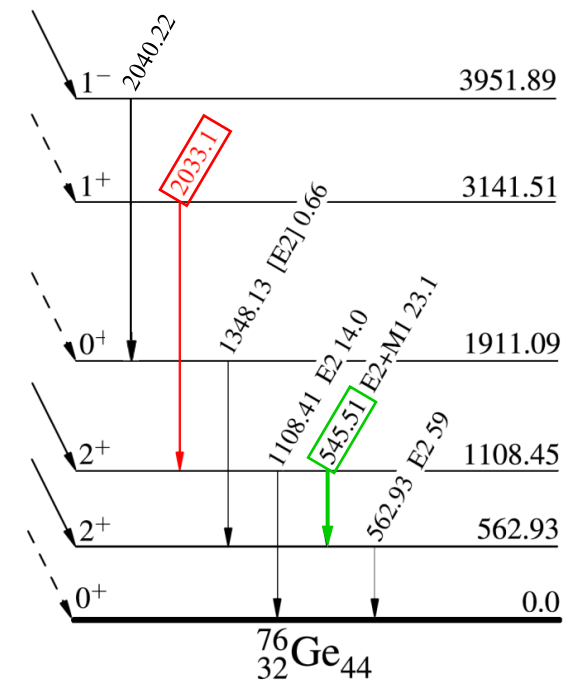
$I\beta^-$	$\text{Log } ft$
8.2	5.6
<2.1	>6.7
<0.18	>10.1 <sup>1u</sup>
14.5	6.7
12.7	6.9
<10	>9.2 <sup>1u</sup>



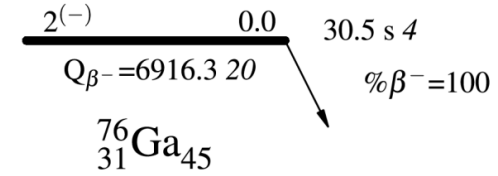
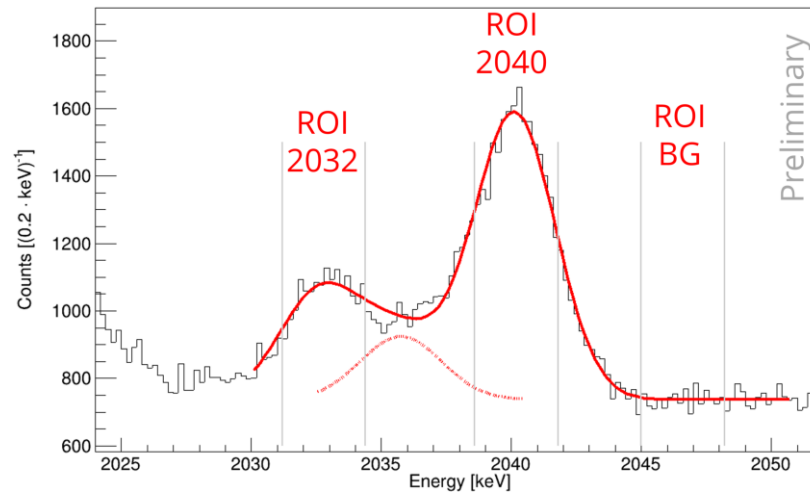
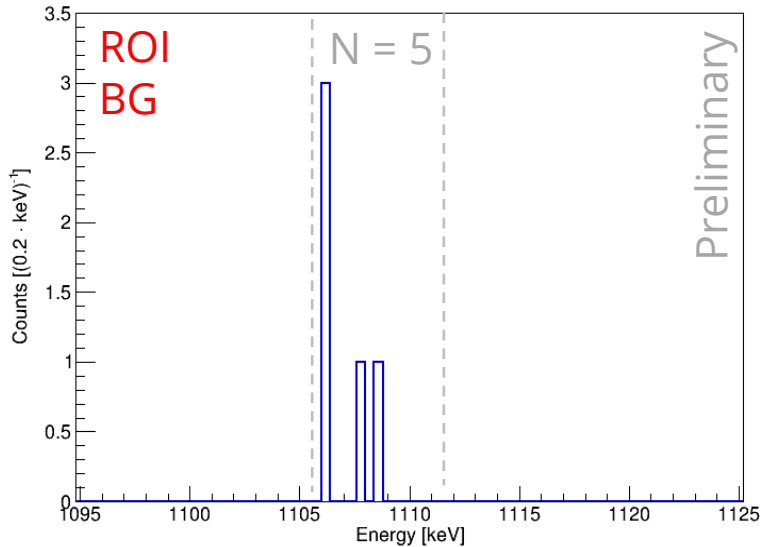
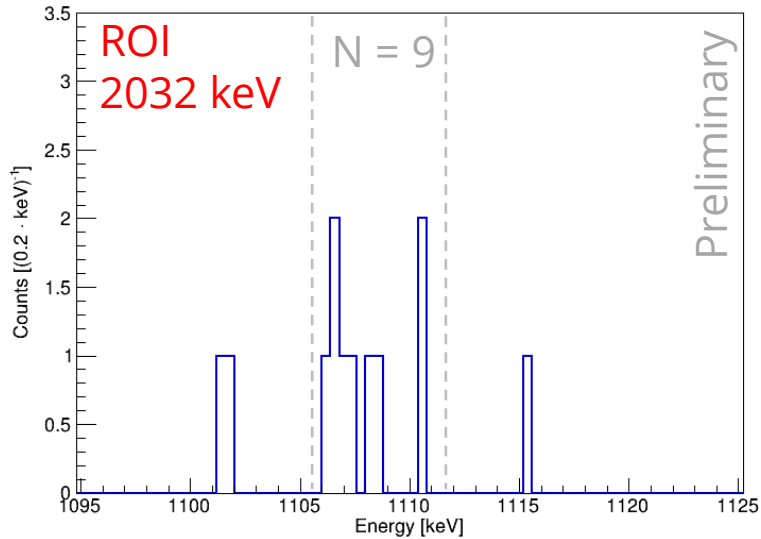
# $\gamma$ - $\gamma$ Coincidence Analysis



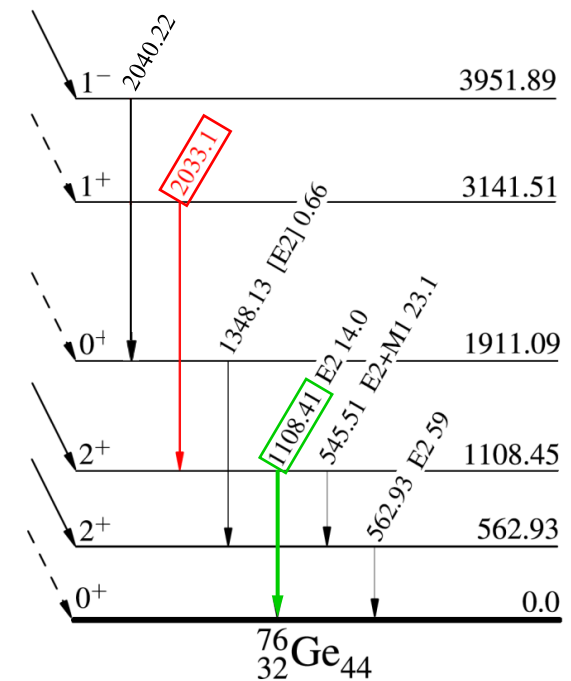
$I\beta^-$	$\text{Log } ft$
8.2	5.6
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<0.18	>10.1 <sup>1u</sup>
14.5	6.7
12.7	6.9
<10	>9.2 <sup>1u</sup>



# $\gamma$ - $\gamma$ Coincidence Analysis



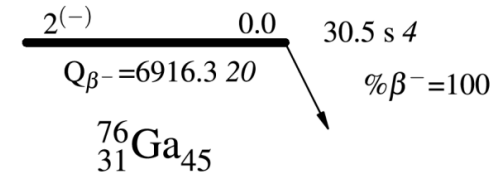
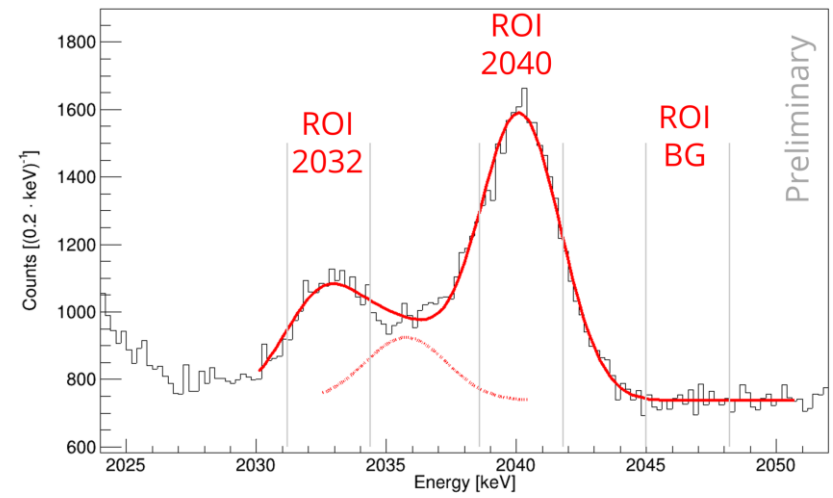
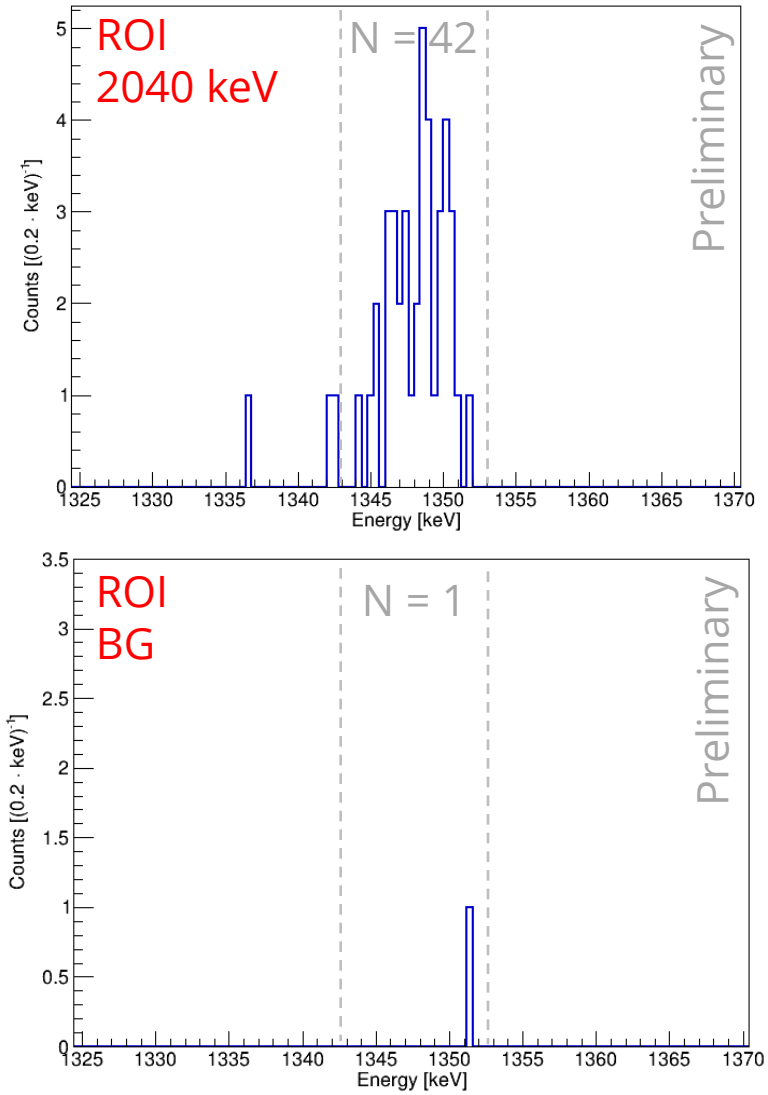
$I_{\beta^-}$	$\text{Log } ft$
8.2	5.6
<2.1	>6.7
<0.18	>10.1 <sup>1u</sup>
14.5	6.7
12.7	6.9
<10	>9.2 <sup>1u</sup>



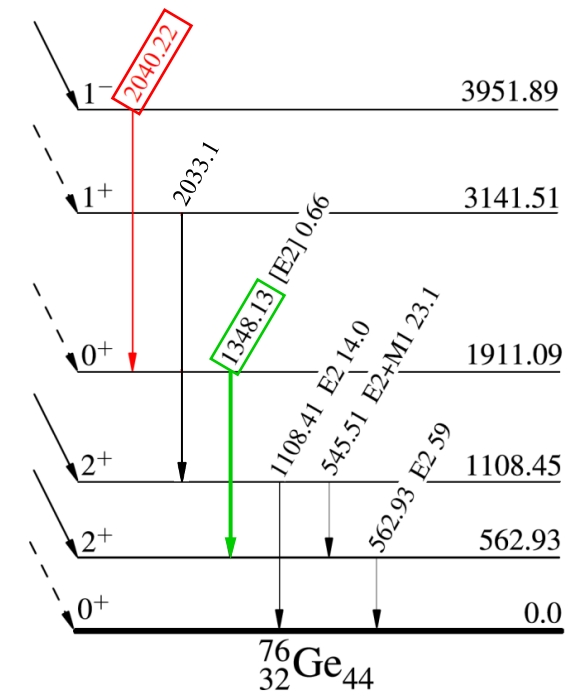
Studies of the  ${}^{76}\text{Ge}$  Level Scheme via Neutron Activation and  $\gamma$ - $\gamma$  Coincidence Spectroscopy for Germanium-Based  $0\nu\beta\beta$  decay Experiments

Marie Pichotta

# $\gamma$ - $\gamma$ Coincidence Analysis



$I_{\beta^-}$	$\text{Log } ft$
8.2	5.6
<2.1	>6.7
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14.5	6.7
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<10	>9.2 <sup>1u</sup>



# $\gamma$ - $\gamma$ Coincidence Analysis & Outlook

- Multiple unknown  $^{76}\text{Ge}$   $\gamma$ -ray transitions investigated via  $\gamma$ - $\gamma$  coincidence analysis  
 → Filling the gaps in the  $^{76}\text{Ge}$  decay scheme

	$E_\gamma$ [keV]	Peak Area	BG area	$E_i$ [keV]	$E_f$ [keV]	Coincident $\gamma$
Very preliminary	$^{76}\text{Ge}$					
	1751	1749.5-1752.5	1757-1760	4443.5?	2692.40	2129.46
	1783	1782-1785	1799-1802	3322.85	1539.46	431.0
						976.50
	1791	1789-1793	1798-1802	3200.01	1410.08	847.15
	1878	1876-1880	1883-1887	2986.08	1108.45	545.51
						1108.41
	2021	2020-2022	2027-2029	3129.85	1108.45	545.51
						1108.41
	2085.7	2084-2087	2058-2061	4778?	2692.40	2129.46
	2335	2331-2338	2318-2325	6661.7	4326.5	1634.0
	2423	2421.5-2425	2415-2418.5	3833?	1410.08	847.15
2637	2635-2639	2644-2648	3200.01	562.93	562.93	
3015	3014-3017	3025.5-3028.5	4555	1539.46	431.0	

To be continued...

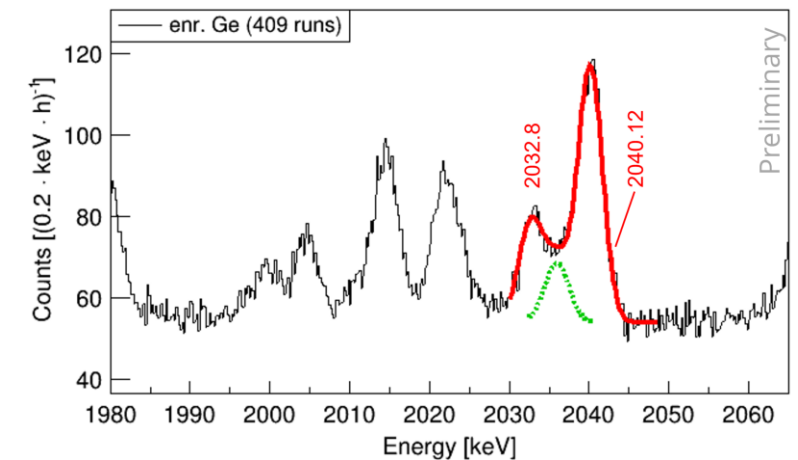
# Summary

- Multiple  $\gamma$ -ray transitions near  $Q_{\beta\beta} = 2039$  keV detected
  - $E_{\gamma} = 2032.8$  keV from  $^{76}\text{Ga}$
  - $E_{\gamma} = 2035.8$  keV from  $^{74}\text{Ga}$
  - $E_{\gamma} = 2040.12$  keV from  $^{76}\text{Ga}$
- Isotopically enriched Ge itself can contribute to potential background for  $^{76}\text{Ge}$   $0\nu\beta\beta$  decay experiments
- Identification of the origin of these  $\gamma$  rays in the decay scheme using  $\gamma$ - $\gamma$  coincidence analysis currently ongoing

# Outlook

- Applying  $\gamma$ - $\gamma$  coincidence analysis to newly observed peaks and  $\gamma$ -ray transitions of previously unknown origin

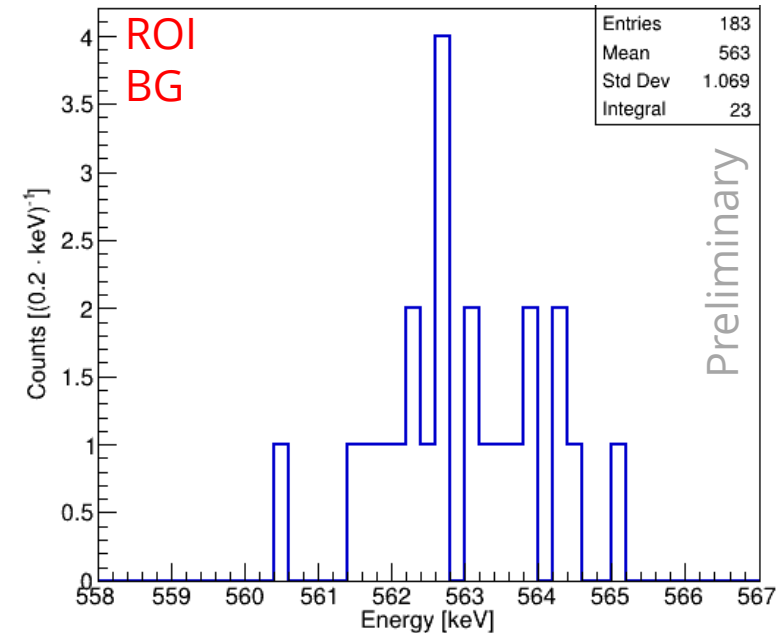
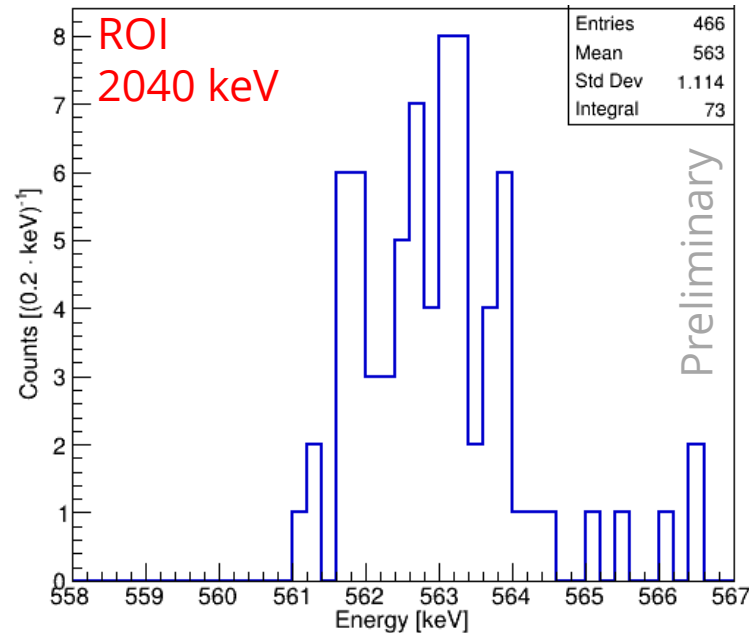
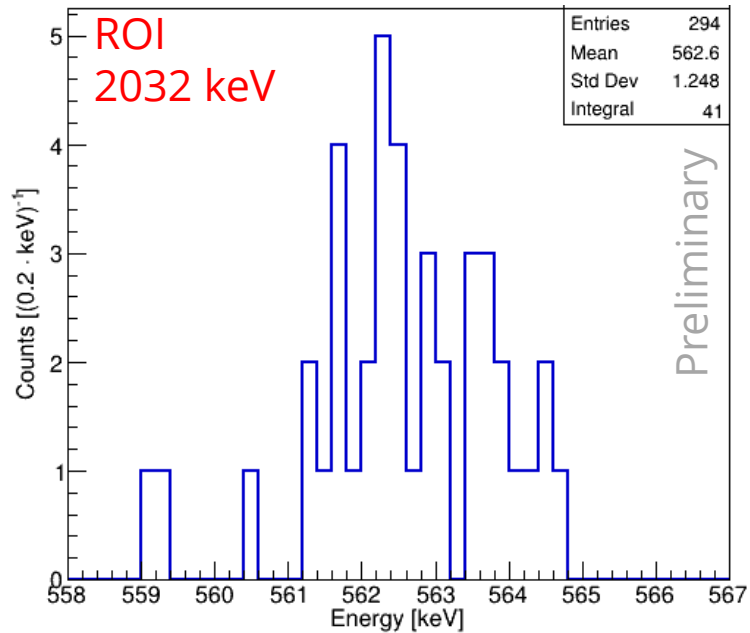
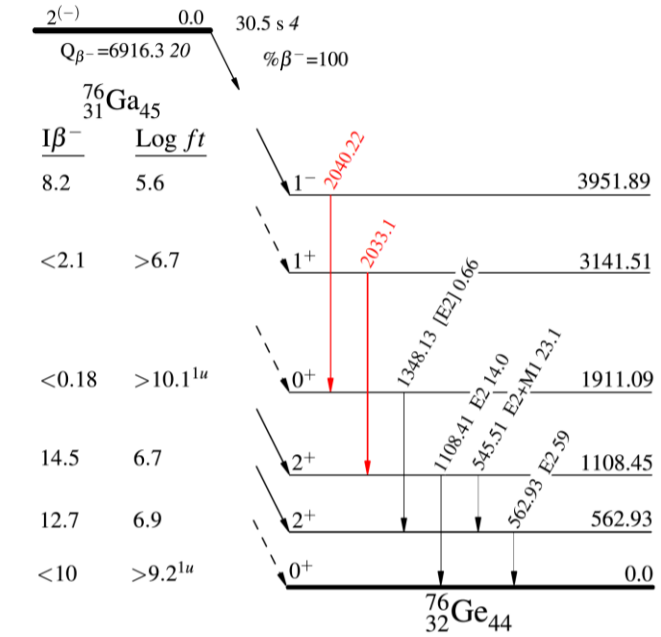
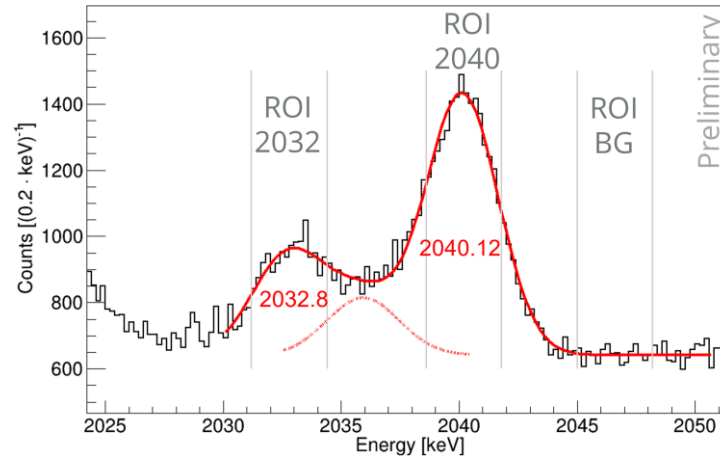
Pichotta et al.,  
Phys. Rev. C **112**, 014325 (2025)



# Literature

- [1] D. C. Camp, D. R. Fielder, and B. P. Foster, “*Energy levels in  $^{74}\text{Ge}$  from the decay of  $^{74}\text{Ga}$* ”, Nucl. Phys. A, 163(1):145 – 160, 1971
- [2] H. W. Taylor et al., “*The decay of 8.0 min  $^{74}\text{Ge}$* ”, Can. J. Phys., 53:107, 1975
- [3] D. C. Camp and B. P. Foster, “*Energy levels in  $^{76}\text{Ge}$  from the decay of  $^{76}\text{Ga}$* ”, Nucl. Phys. A, 177:401–417, 1971
- [4] B. P. Crider, “*Inelastic neutron scattering cross sections for  $^{76}\text{Ge}$  relevant to background in neutrinoless double- $\beta$  decay experiments*”, Phys. Rev. C 92, 034310, 2015
- [5] S. Mukhopadhyay et al., “*Nuclear structure of  $^{76}\text{Ge}$  from inelastic neutron scattering measurements and shell model calculations*”, Phys. Rev. C 95, 014327, 2017
- [6] C. Rouki et al., “ *$\gamma$  production and neutron inelastic scattering cross sections for  $^{76}\text{Ge}$* ”, Phys. Rev. C 88, 054613, 2013
- [7] A. Domula et al., “*New Nuclear Structure and Decay Results in the  $^{76}\text{Ge} - ^{76}\text{As}$  System*”, Nucl. Data Sheets 120 4447, 2014
- [8] A. Domula, “*Neutronenphysikalische Studien an Germanium für Experimente zum neutrinolosen Doppelbetazerfall von  $^{76}\text{Ge}$* ”, PhD thesis, 2013
- [9] W. Tornow et al., “*Fast-neutron-induced potential background near the Q value of neutrinoless double- $\beta$  decay of  $^{76}\text{Ge}$* ”, Phys. Rev. C 93, 014614, 2016
- [10] R. Schwengner et al., “*Photoexcitation of  $^{76}\text{Ge}$* ”, Phys. Rev. C 105, 024303, 2022

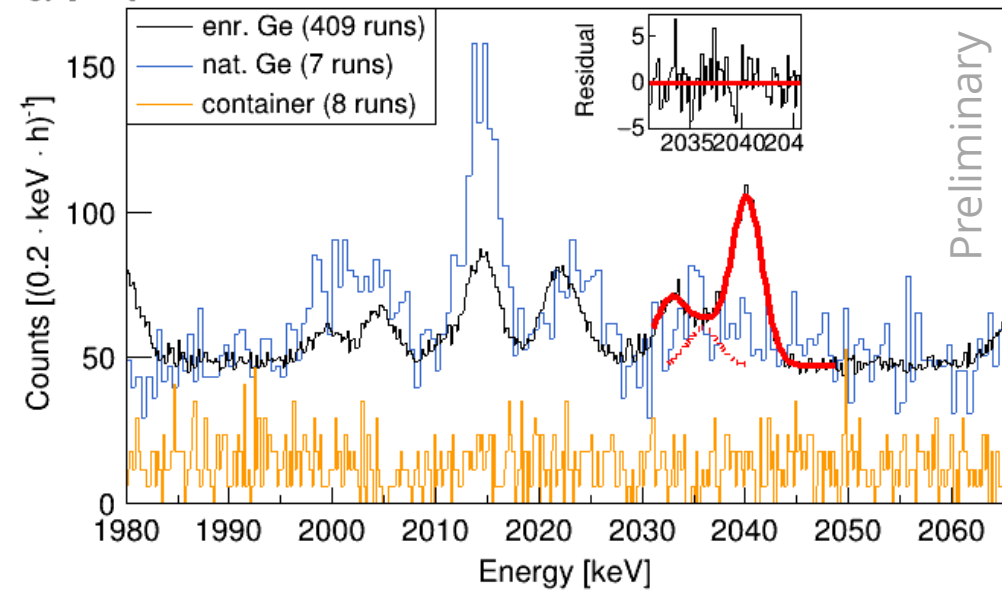
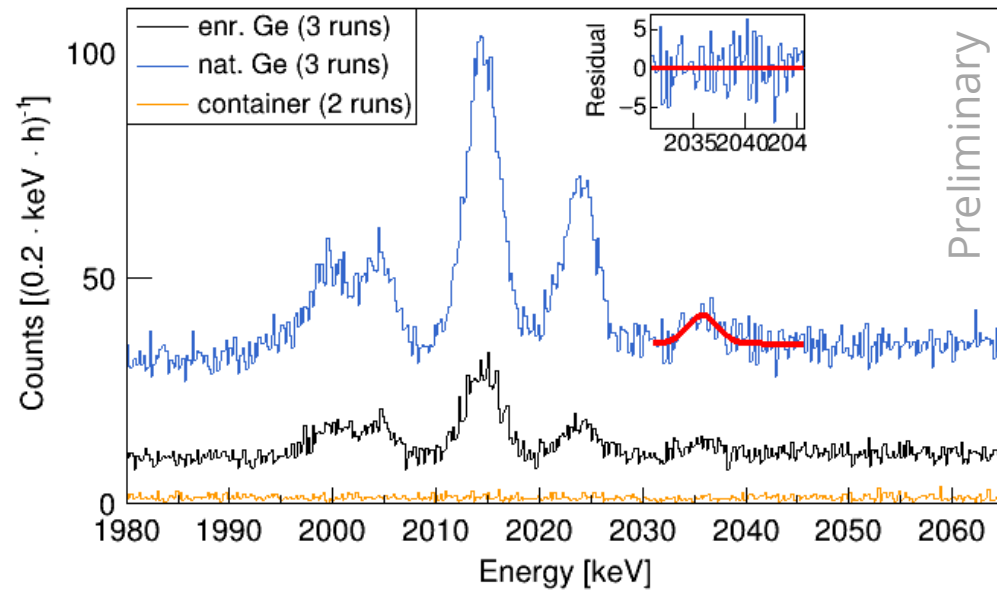
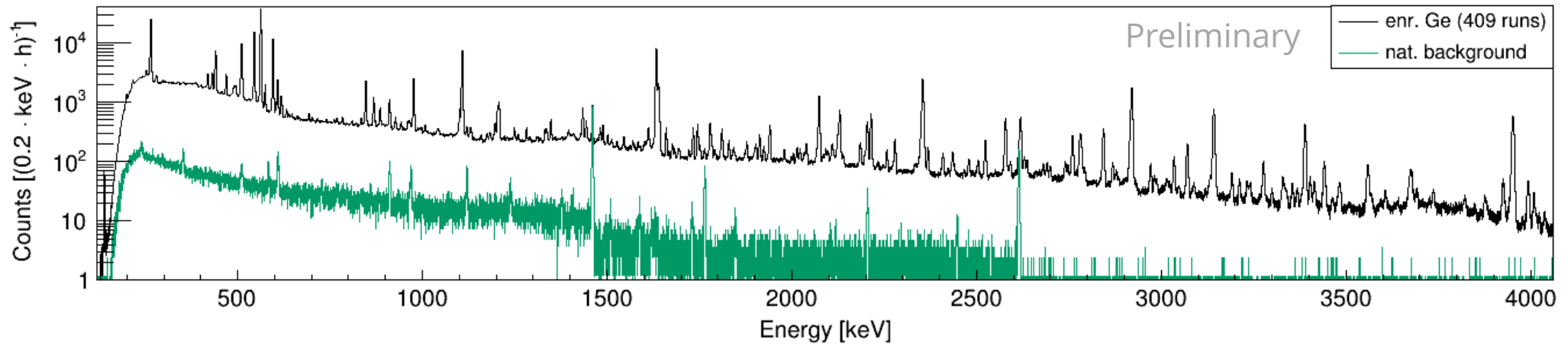
# $\gamma$ - $\gamma$ Coincidence Analysis



Studies of the  $^{76}\text{Ge}$  Level Scheme via Neutron Activation and  $\gamma$ - $\gamma$  Coincidence Spectroscopy for Germanium-Based  $0\nu\beta\beta$  decay Experiments

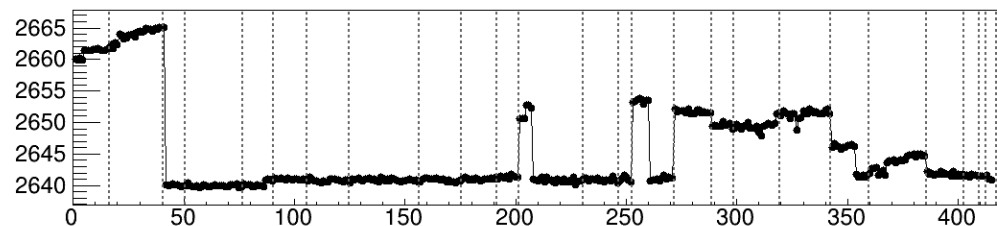
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# Results

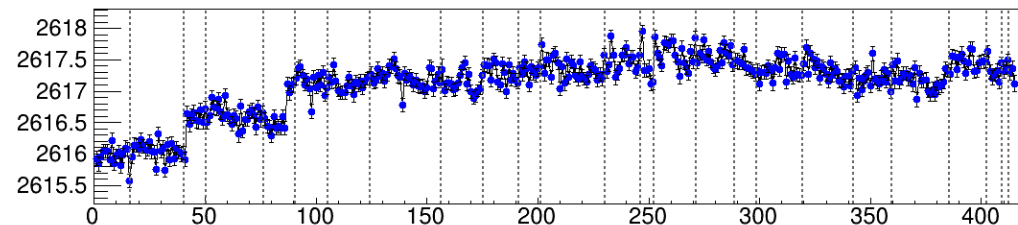


# Channel Stability HPGe Detectors

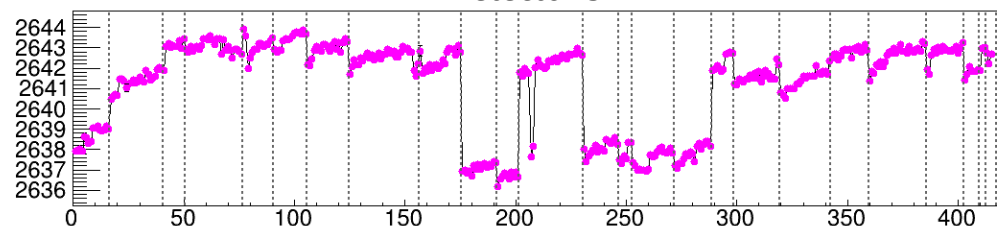
Detector 1



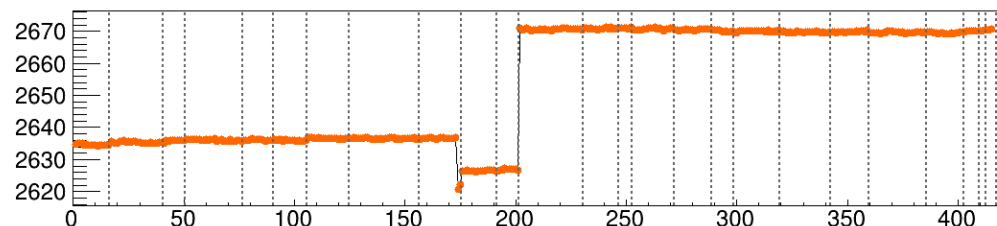
Detector 3



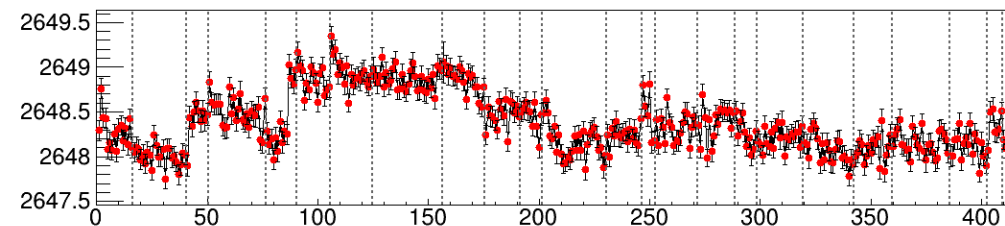
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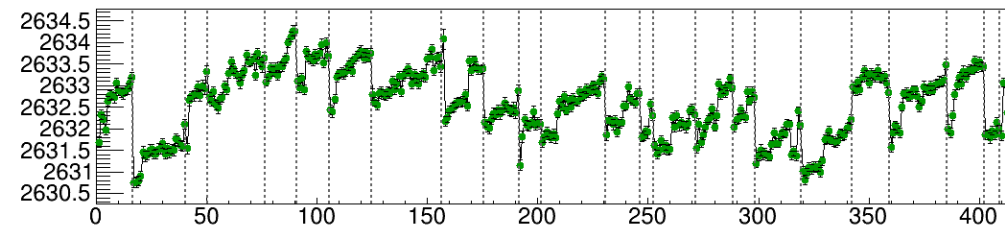
Detector 7



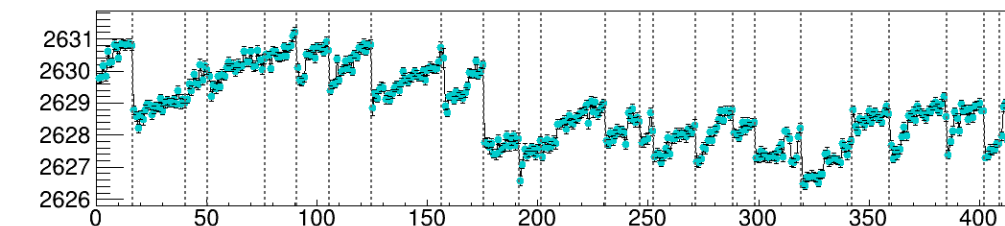
Detector 2



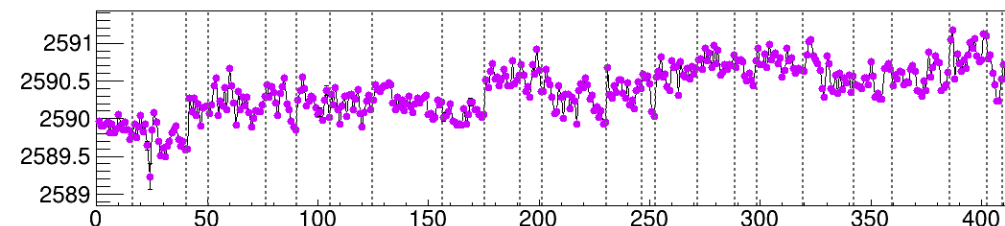
Detector 4



Detector 6

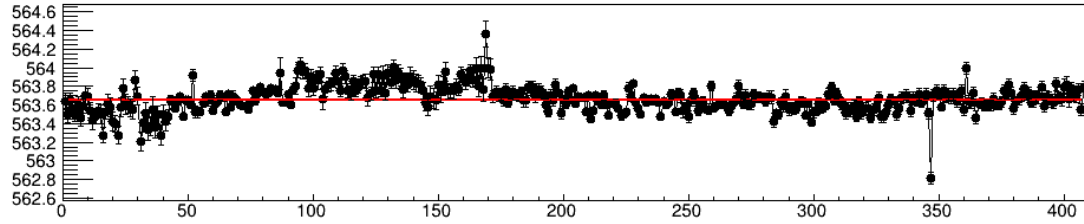


Detector 8

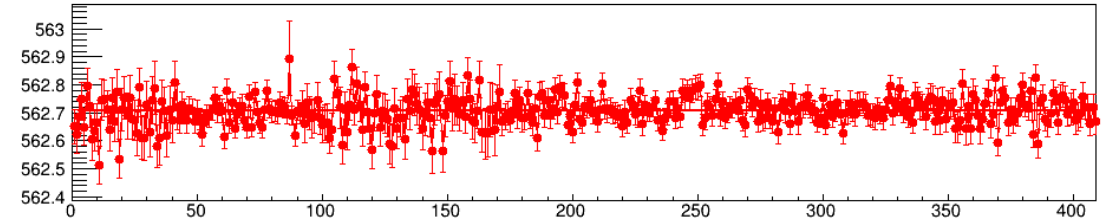


# Energy Calibration Stability HPGe Detectors

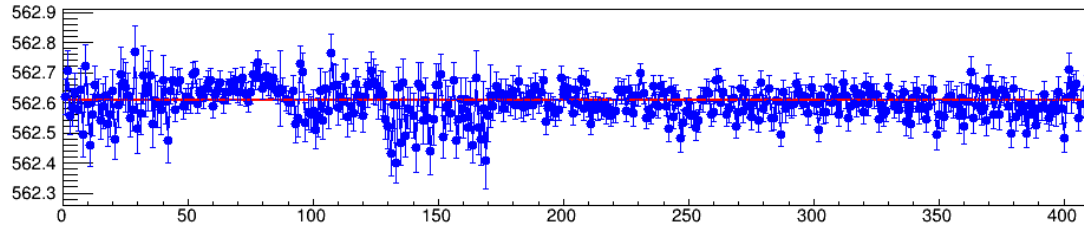
Detector 1



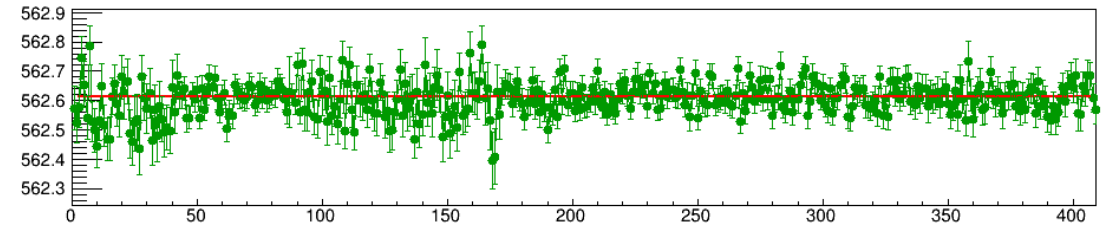
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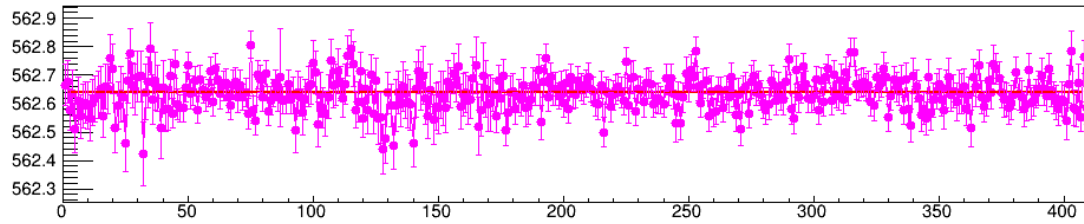
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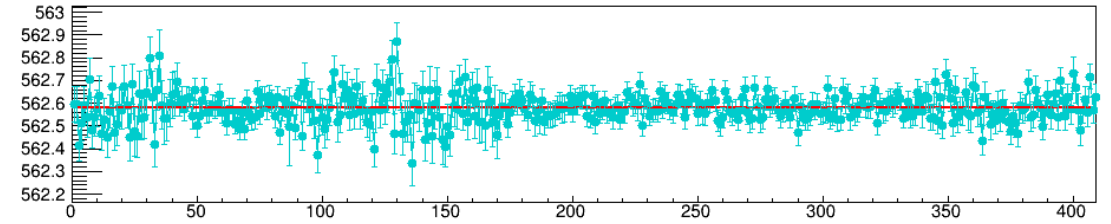
Detector 4



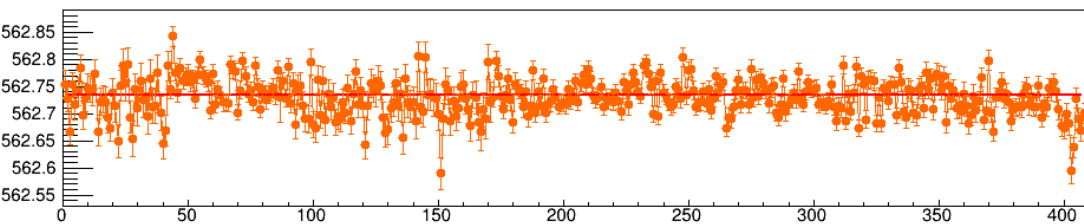
Detector 5



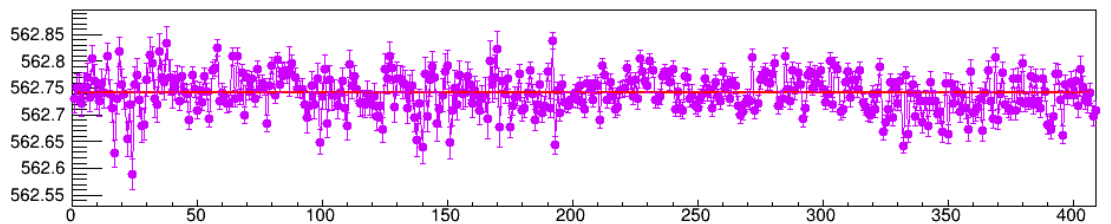
Detector 6



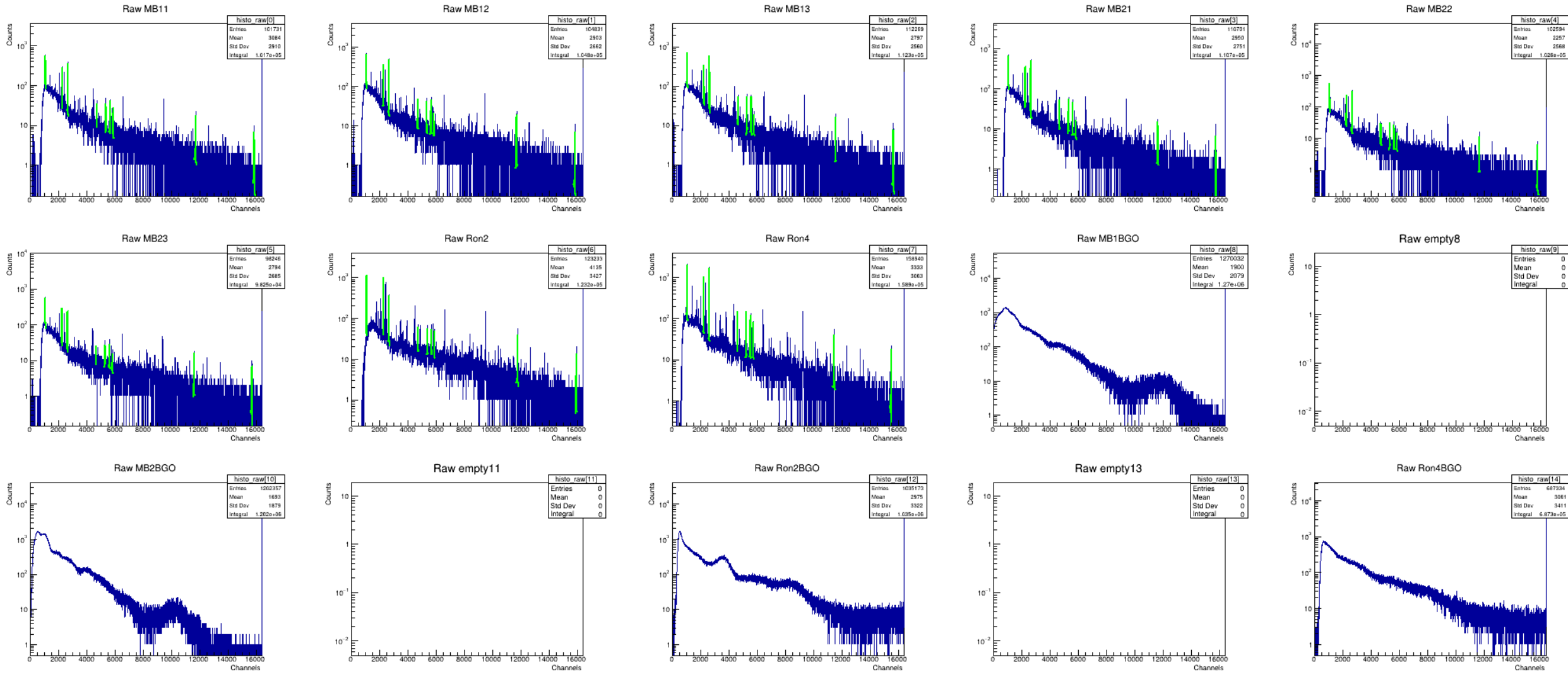
Detector 7



Detector 8



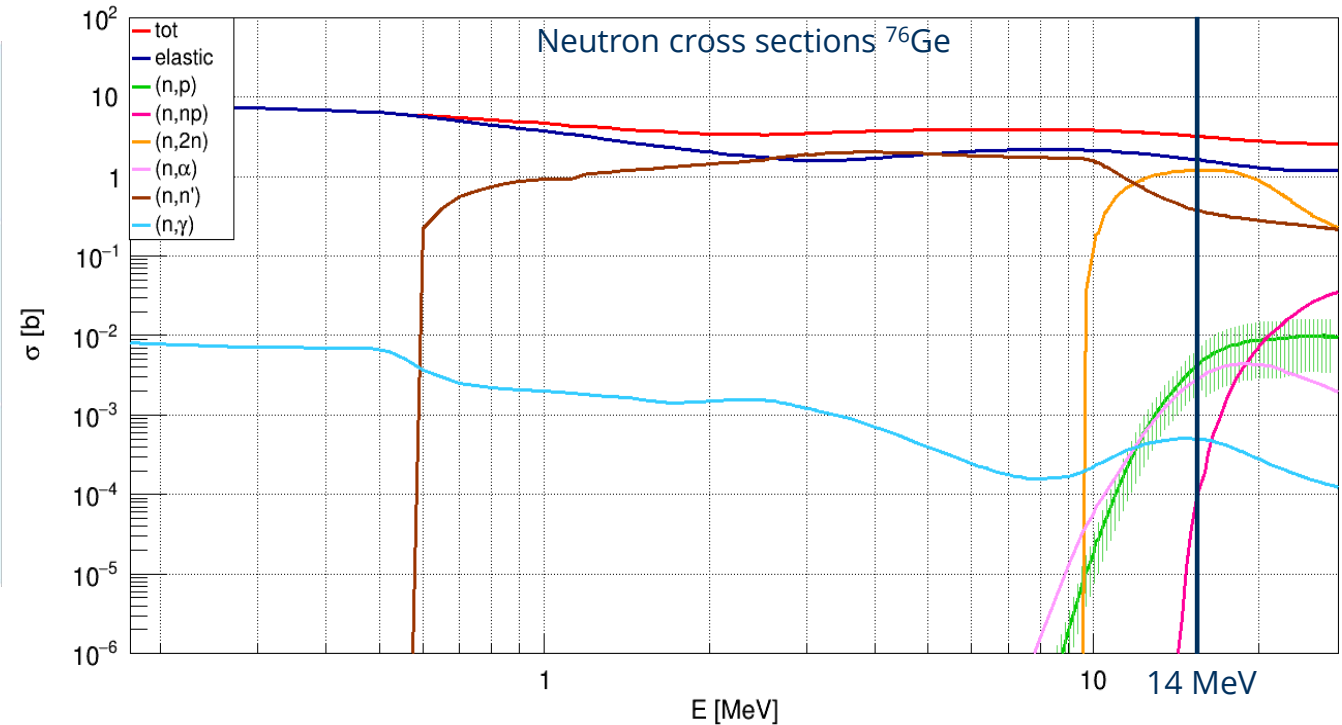
# Energy Calibration



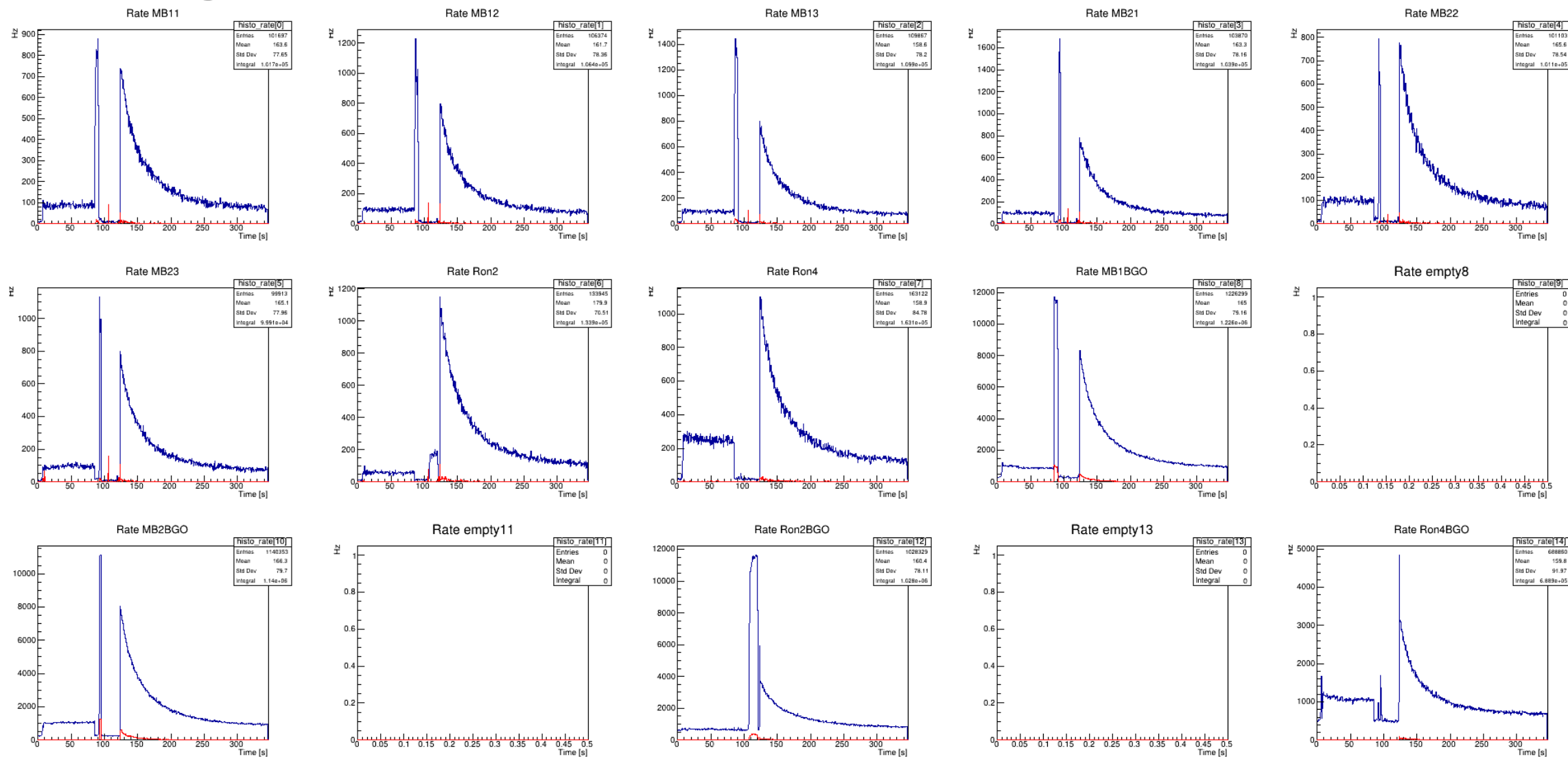
# Neutron-Induced $\gamma$ Rays in the $^{76}\text{Ge}$ $0\nu\beta\beta$ Signal Region?

- Background contribution from enriched Ge due to neutron activation of  $^{76}\text{Ge}$  and  $^{74}\text{Ge}$

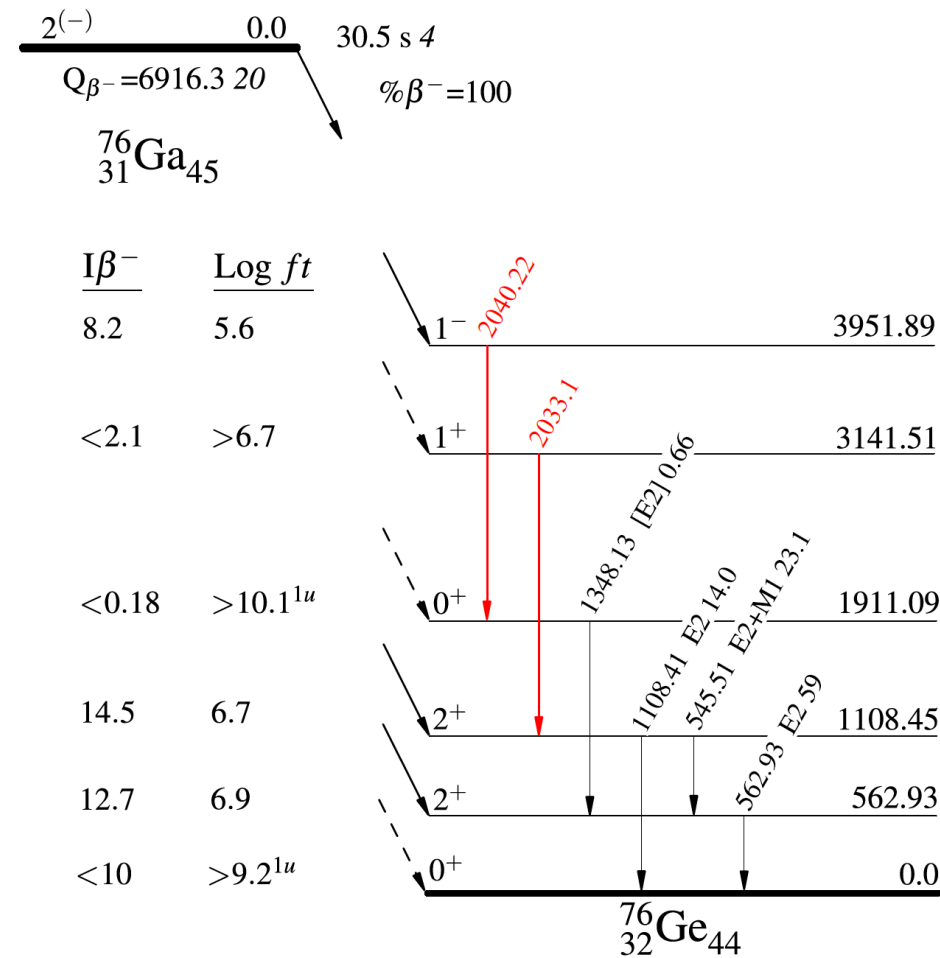
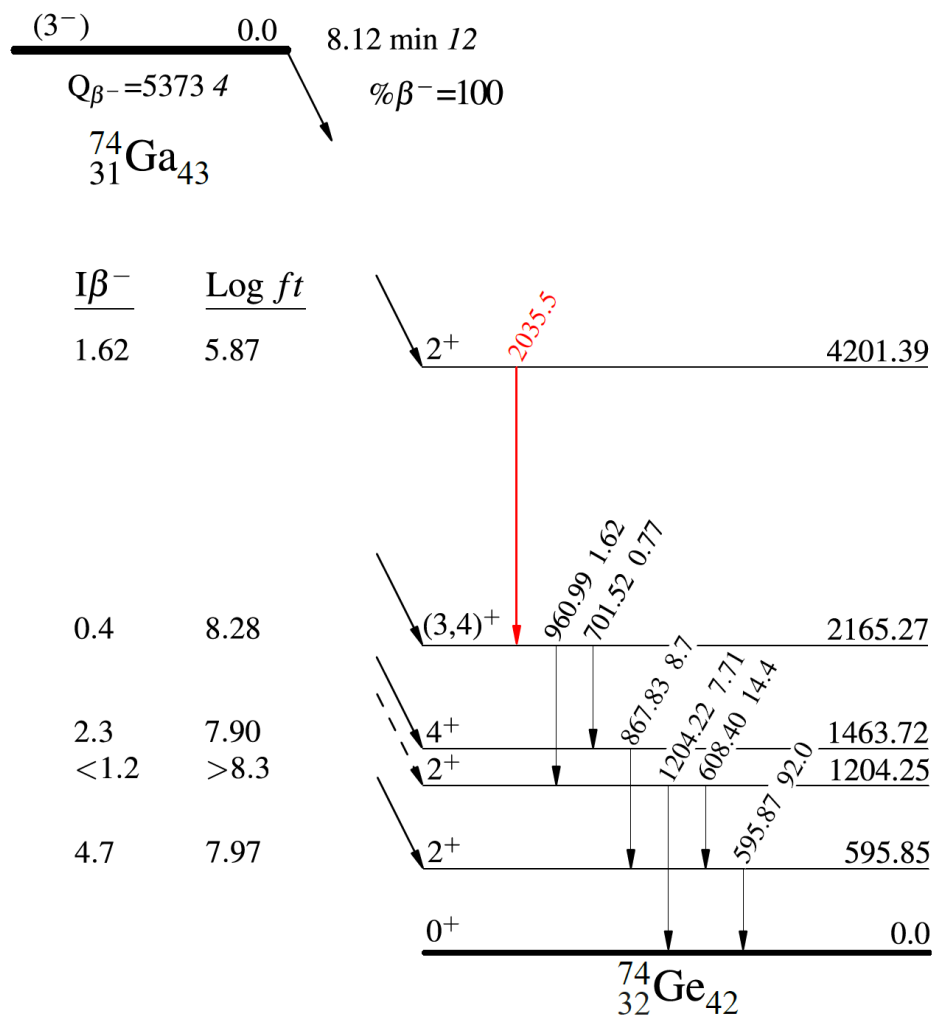
$^{73}\text{Ge}$ Stable	$^{74}\text{Ge}$ Stable	$^{75}\text{Ge}$ $\beta^-$ $(n,2n)$	$^{76}\text{Ge}$ Stable	$^{77}\text{Ge}$ $\beta^-$ $(n,\gamma)$	$^{78}\text{Ge}$ $\beta^-$
$^{72}\text{Ga}$ $\beta^-$	$^{73}\text{Ga}$ $\beta^-$	$^{74}\text{Ga}$ $\beta^-$	$^{75}\text{Ga}$ $\beta^-$ $(n,np)$	$^{76}\text{Ga}$ $\beta^-$ $(n,p)$	$^{77}\text{Ga}$ $\beta^-$
$^{71}\text{Zn}$ $\beta^-$	$^{72}\text{Zn}$ $\beta^-$	$^{73}\text{Zn}$ $\beta^-$ $(n,\alpha)$	$^{74}\text{Zn}$ $\beta^-$	$^{75}\text{Zn}$ $\beta^-$	$^{76}\text{Zn}$ $\beta^-$



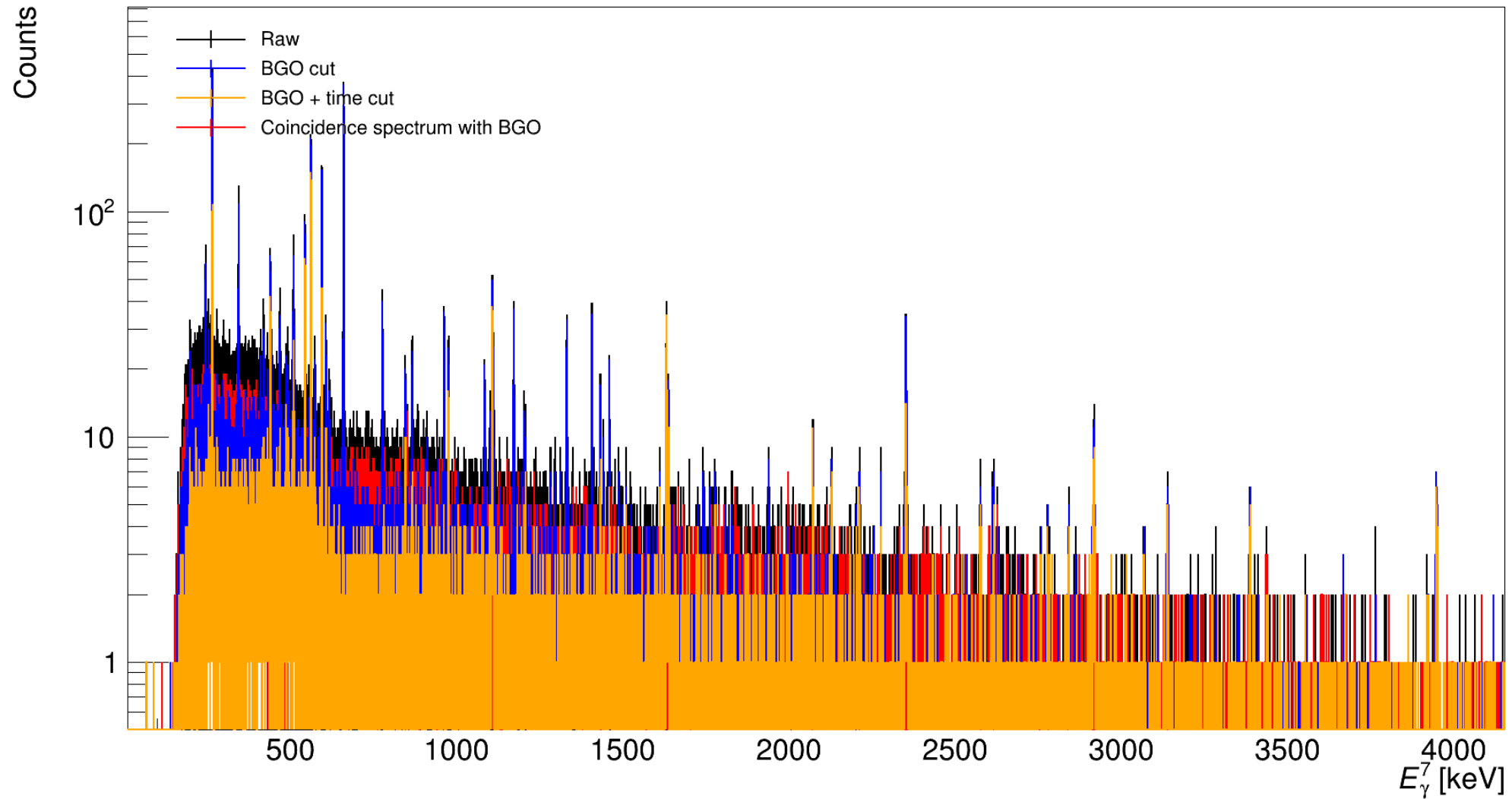
# Counting rate



# Decay schemes



# Data Cuts



Studies of the  $^{76}\text{Ge}$  Level Scheme via Neutron Activation and  $\gamma$ - $\gamma$  Coincidence Spectroscopy for Germanium-Based  $0\nu\beta\beta$  decay Experiments

Marie Pichotta