bmb+f - Förderschwerpunkt

Astroteilchenphysik

Großgeräte der physikalischen Grundlagenforschung

GERDA

Neutron Activation of ^{76}Ge

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Outline

- Introduction
  - Neutron capture and decay processes
- Background by neutron capture on ^{76}Ge
- Measurements with cold neutrons
  - Cross section of the $^{74}Ge(n,\gamma)$ and $^{76}Ge(n,\gamma)$ reactions
  - Prompt γ-ray spectrum in ^{75}Ge and ^{77}Ge
- Summary

Background in GERDA

Radiopurity of:
Germanium detector (cosmogenic ^{68}Ge)
Germanium detector (cosmogenic ^{60}Co)
Germanium detector (bulk)
Germanium detector (surface)
Cabling
Copper holder
Electronics
Cryogenic liquid
Infrastructure

Sources:
Natural activity of rock
Muons and neutrons

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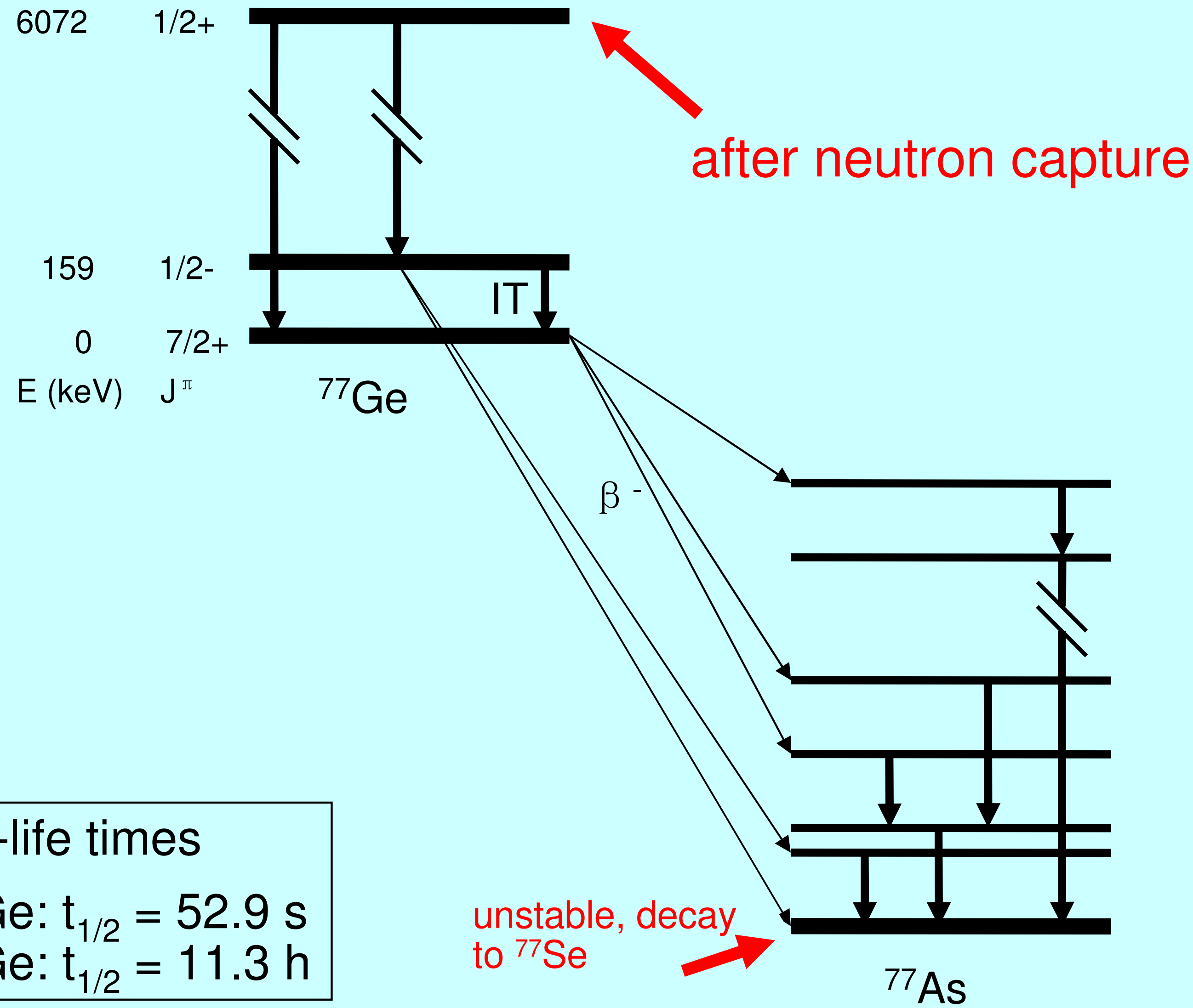
Sources:
Natural activity of rock
Muons and **neutrons**

Fast neutrons produced by cosmic muons can propagate through the water tank and LAr to the Ge-diodes. There they can be captured by a ^{74}Ge or ^{76}Ge nucleus.

Neutron Capture by ^{76}Ge



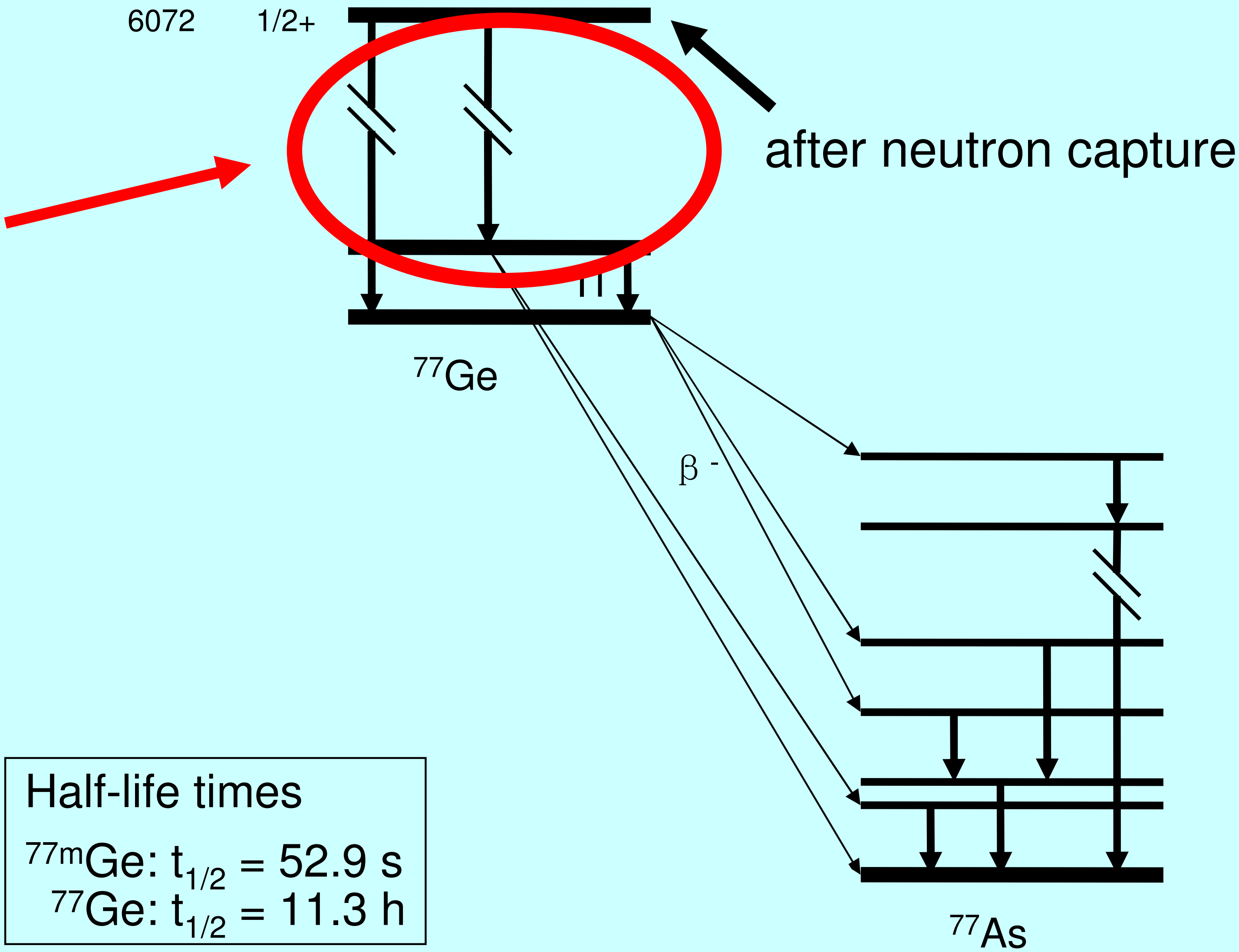
Half-life times

^{77m}Ge: $t_{1/2}$ = 52.9 s
^{77}Ge: $t_{1/2}$ = 11.3 h

Neutron Capture by ^{76}Ge

prompt γ-cascade

E_{max} = 5911 keV



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Neutron Capture by ^{76}Ge

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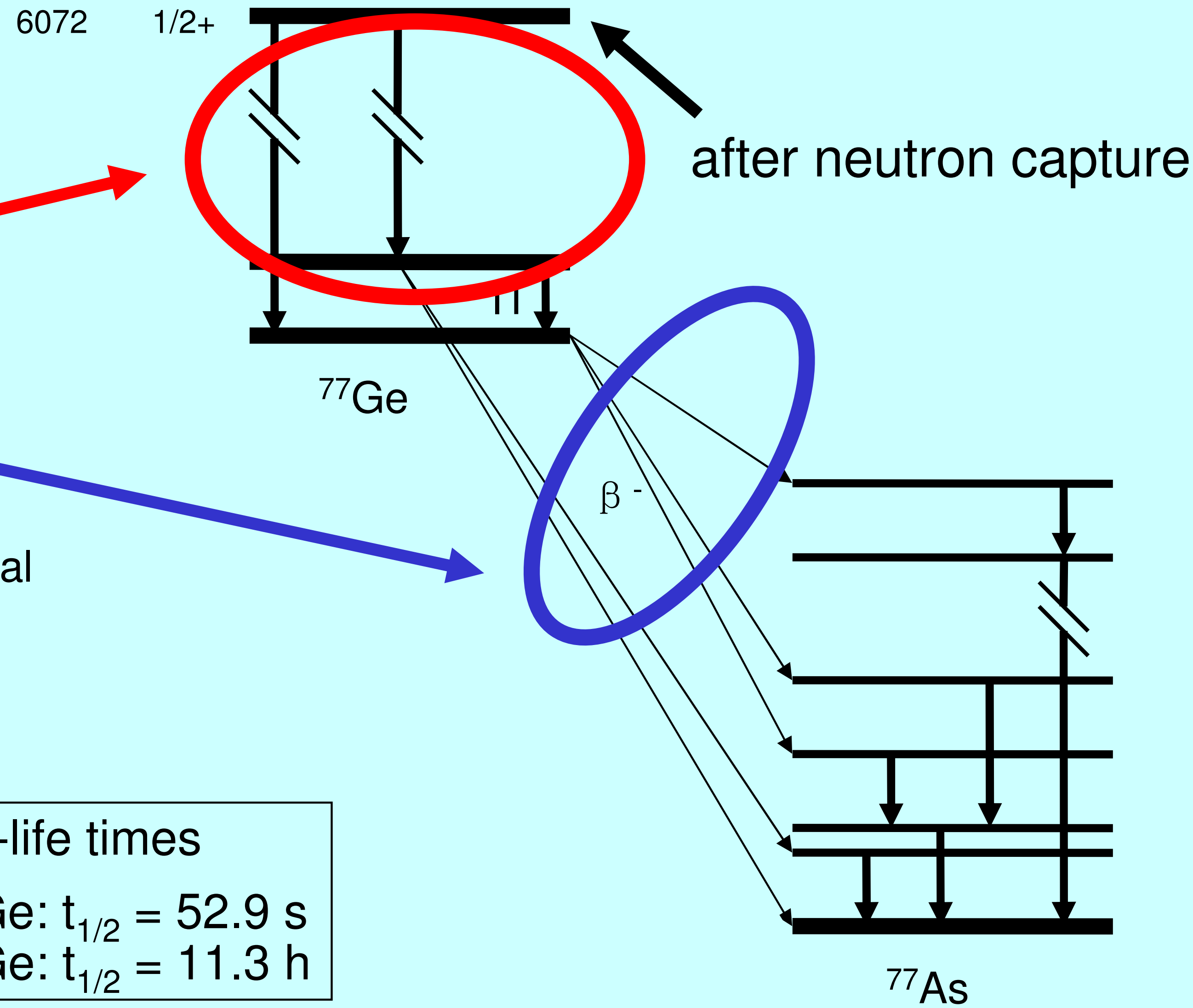
E_{max} = 5911 keV

delayed β-spectrum

E_{max} = 2862 keV
continouos, mimics 0νββ signal



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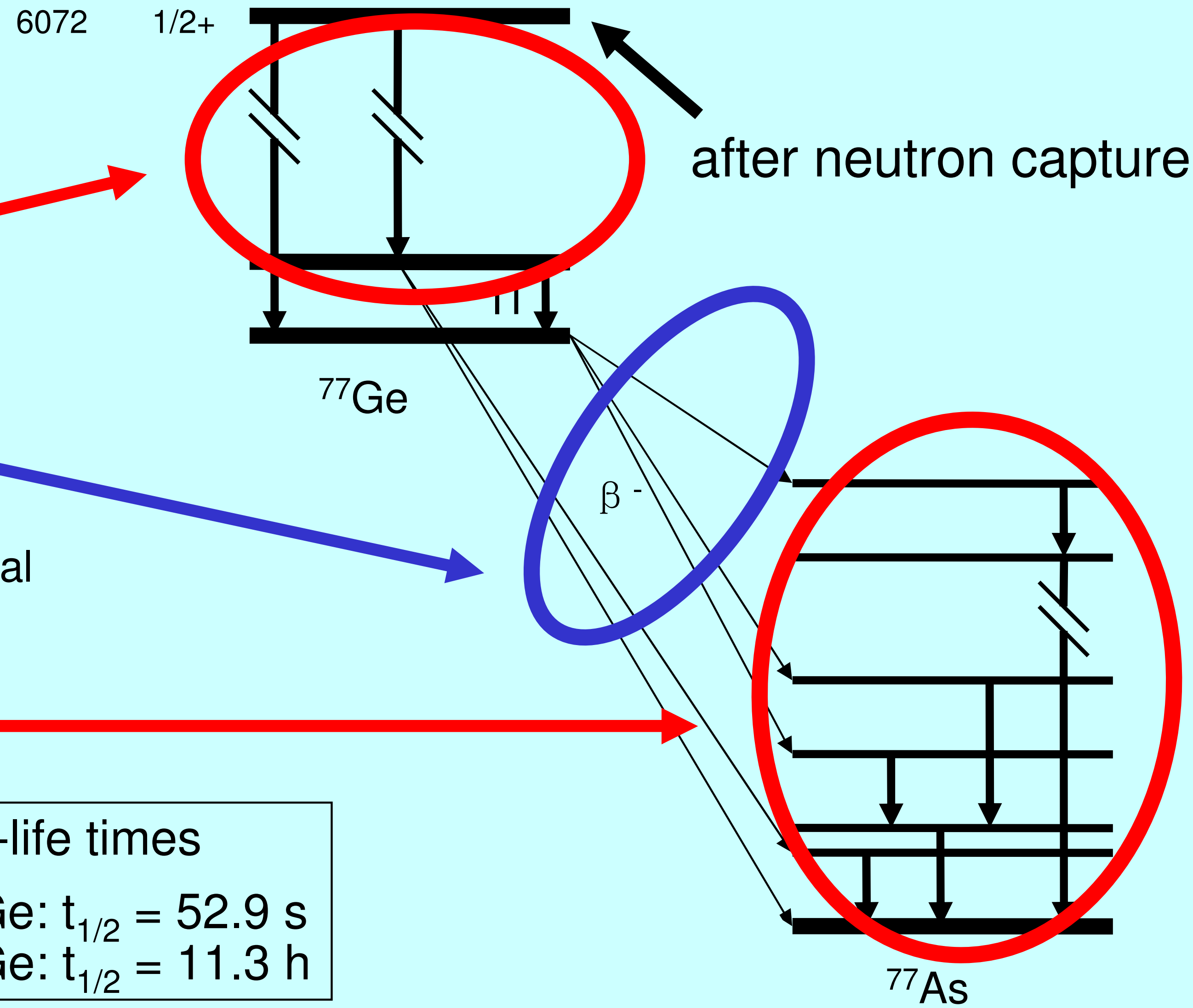
E_{max} = 2353 keV



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Neutron Capture by ^{76}Ge

prompt γ-cascade

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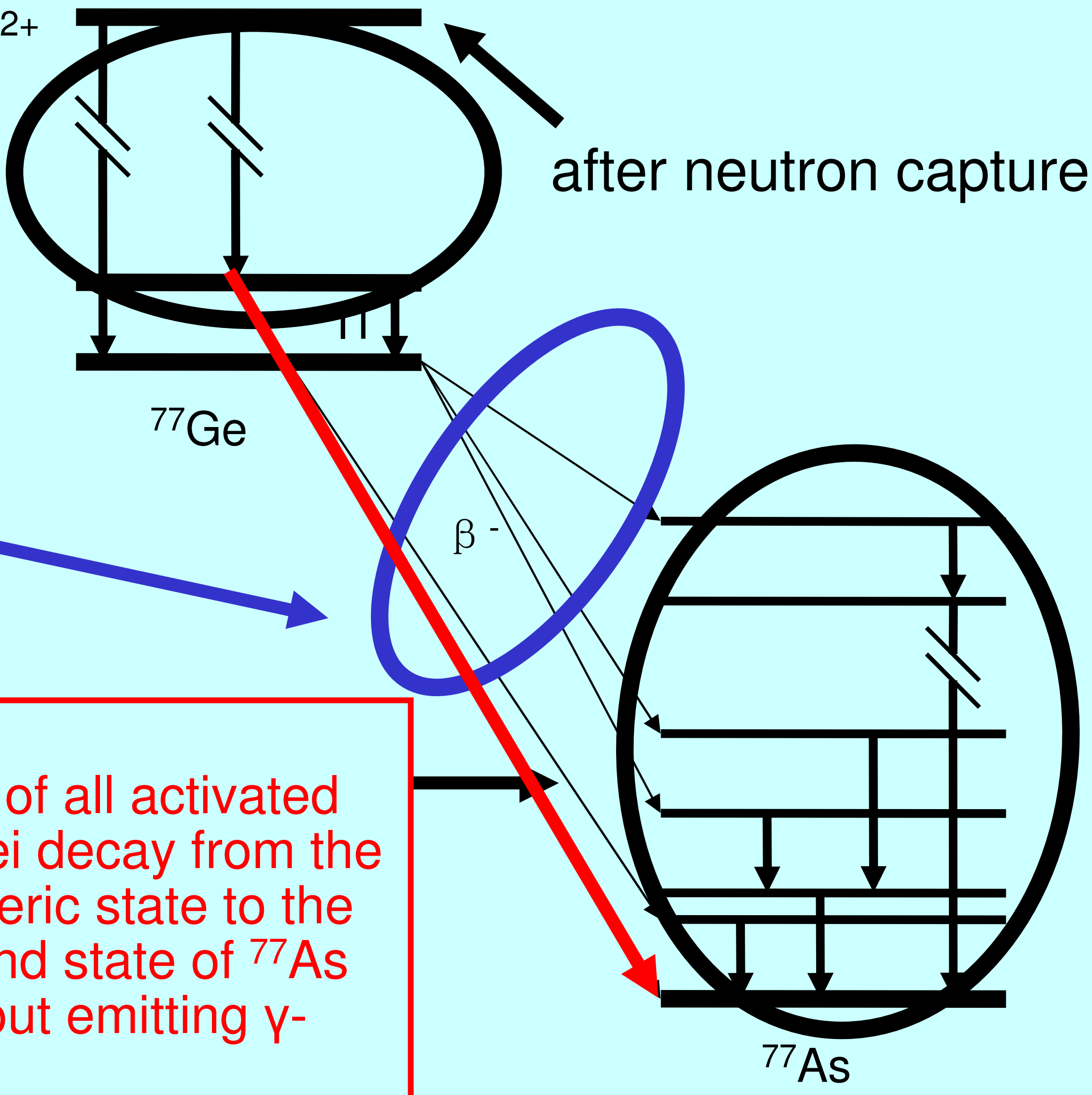
delayed γ-rays

E_{max} = 2353 keV

34% of all activated nuclei decay from the isomeric state to the ground state of ^{77}As without emitting γ-rays.



Neutron Capture by ^{76}Ge

In GSTR-06-012 Luciano discussed this problem:

Production rate: 0.5 – 1 nuclei/kg/y (LAr)

Counts in ROI due to β-particles

^{77}**Ge: 8 x 10^{-5} counts/keV/decay** (can be reduced by factor of 3 by anti-coincidence).

^{77m}**Ge: 2.1 x 10^{-4} counts/keV/decay** (small reduction due to direct transition to ground state).

Rejection strategy for β-particles from ^{77m}Ge: $t_{1/2}(^{77m}Ge)$=52.9s → **dead time 4min** (ε_{dec} = 0.96)

1. Trigger on muon veto (rate: 2.5 per min.).

not feasible

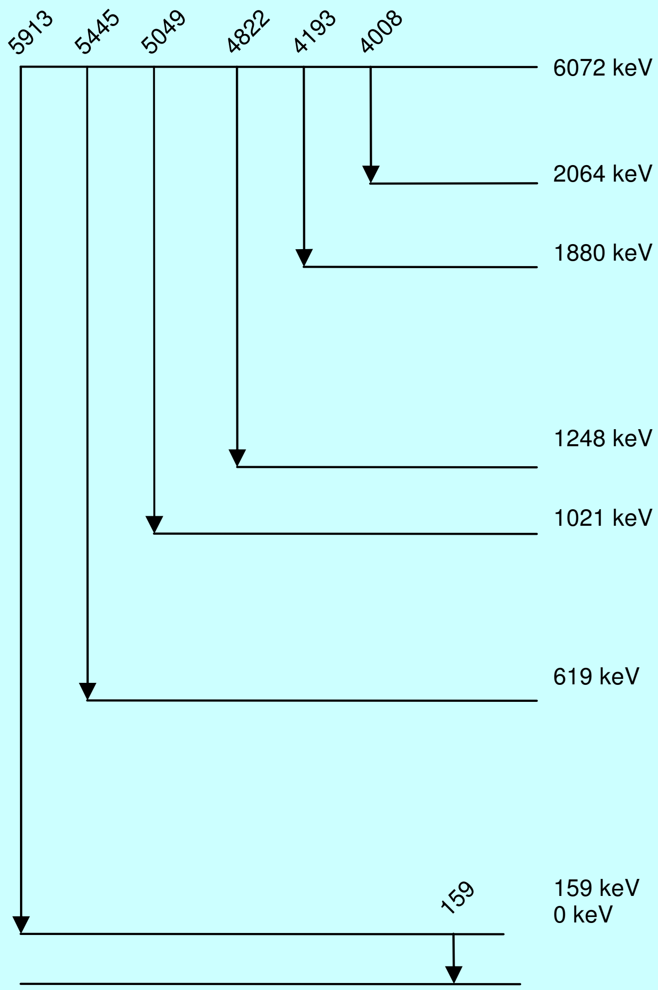
2. Trigger on muon veto & prompt gamma-rays (after neutron capture) in HPGe (9 events/day).

$$\varepsilon = \varepsilon_{mv} \times \varepsilon_{Ge} \times \varepsilon_{dec}$$

$$\varepsilon = 0.95 \times 0.56 \times 0.96 = 0.51$$

favoured

Prompt transitions in ^{77}Ge



Nuclear Data Sheets 81

not in decay scheme	IAEA Nuclear Data Services
E [keV]	E [keV]
196	862
431	1251
808	1903
851	
3895	
4514	
5420	

Only 15% of the emitted energy known

PGAA @ FRM II

(**P**rompt **G**amma-ray **A**ctivation **A**nalysis)

Beam

~3 x 10^9 $n_{th}/(cm^2\,s^1)$

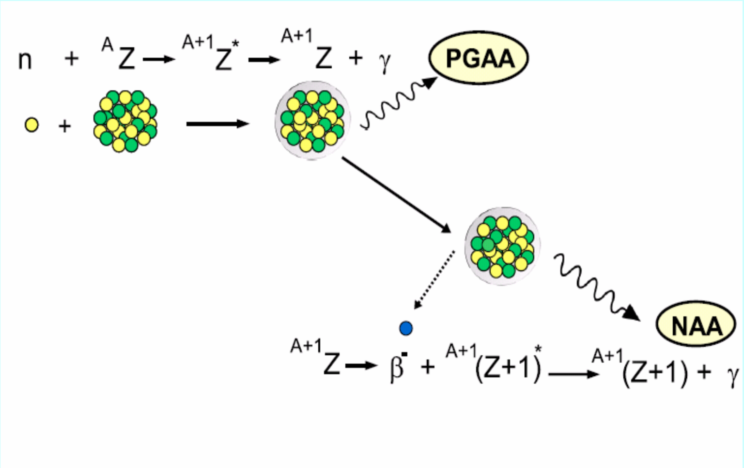
$\langle\lambda_n\rangle$ = 6.7 Å (cold)

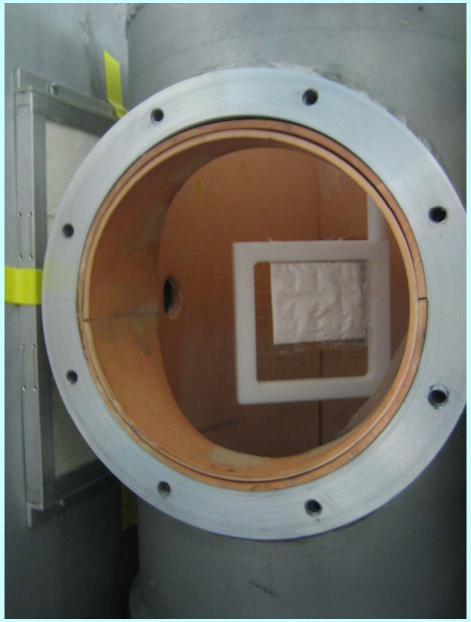
$\langle E_n\rangle$ = 1.83 meV

Detectors

2 HPGe with Compton suppresion

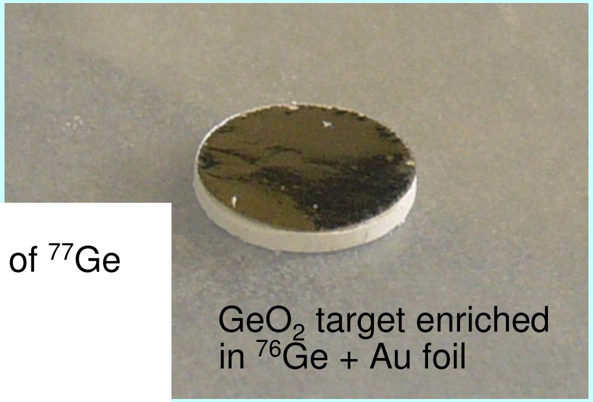
Li/Cd/Pb shielding

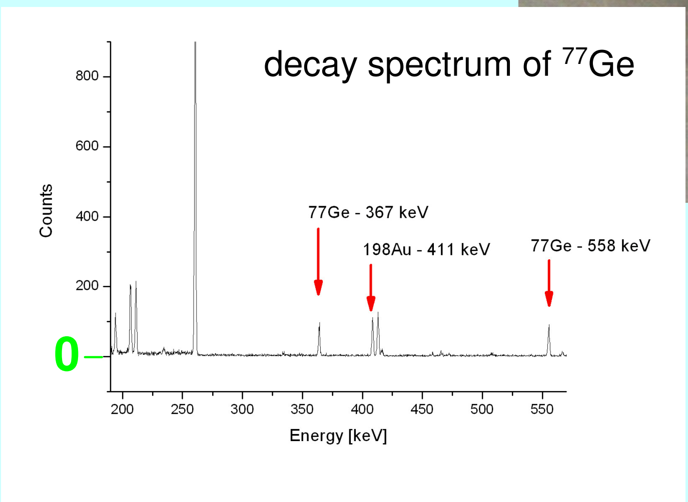


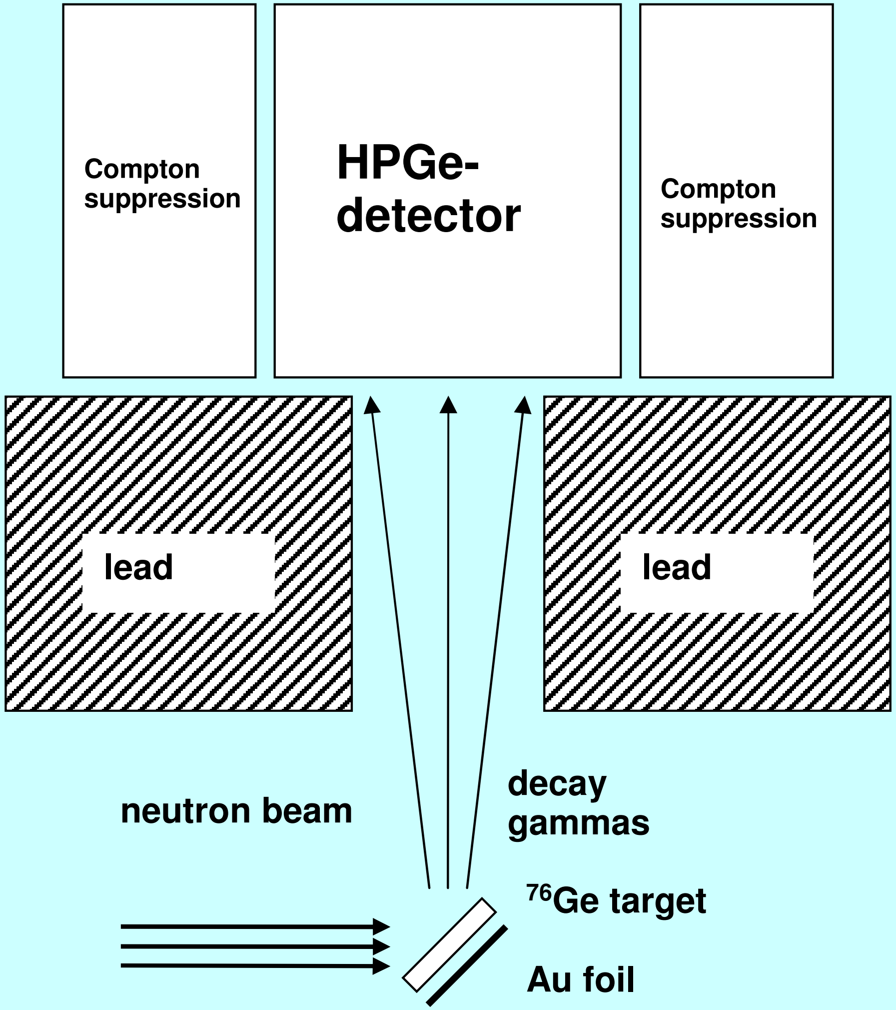


Thermal n-capture cross section

^{76}Ge target was activated together with a gold foil and after irradiation the γ-rays after β-decay were measured by HPGe detectors. The cross-section was calculated relative to ^{198}Au using known emission probabilities.







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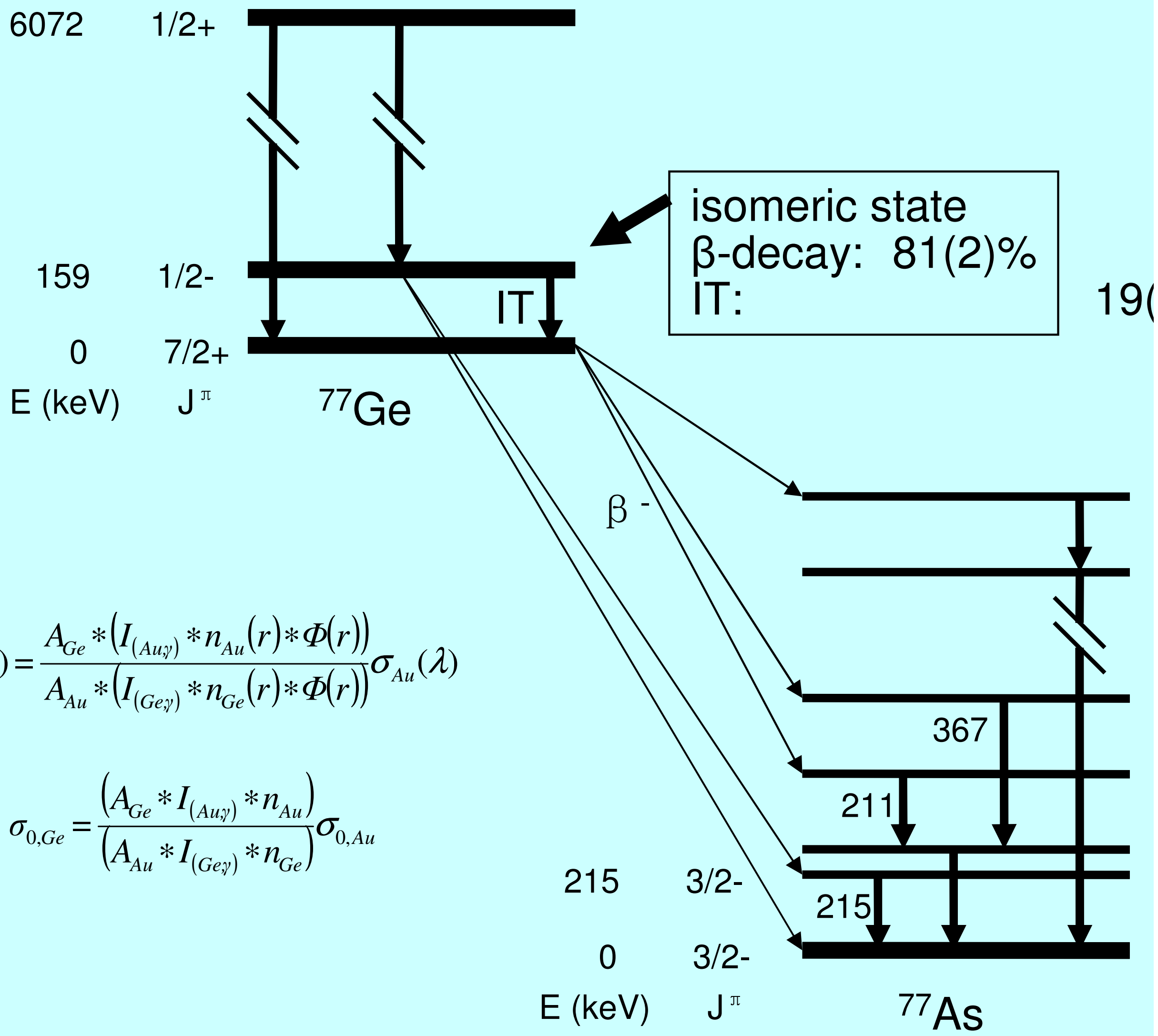
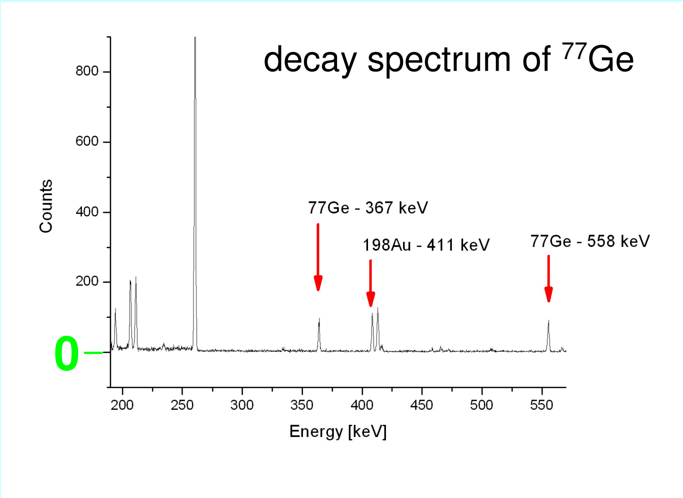




$$\sigma_{Ge}(\lambda) = \frac{A_{Ge} * \left(I_{(Au\gamma)} * n_{Au}(r) * \Phi(r)\right)}{A_{Au} * \left(I_{(Ge\gamma)} * n_{Ge}(r) * \Phi(r)\right)} \sigma_{Au}(\lambda)$$

$$\sigma_{0,Ge} = \frac{\left(A_{Ge} * I_{(Au\gamma)} * n_{Au}\right)}{\left(A_{Au} * I_{(Ge\gamma)} * n_{Ge}\right)} \sigma_{0,Au}$$

Results $^{76}Ge(n,\gamma)$

cross section [mbarn]		
$\sigma(^{77}Ge$ total)	$\sigma(^{77}Ge$ direct)	$\sigma(^{77m}Ge)$
Seren (1947): 85 ±17 Pomerance (1952): 350 ± 70 Brooksbank (1955): 300 ± 60 Metosian (1957): 76 ± 15 Lyon (1957): 43 ± 2	Lyon (1957): 6 ± 5	Metosian (1957): 87 ± 15 Lyon (1957): 137 ± 15 Wigmann (1962): 120 ± 20 Mannhart (1968): 86 ± 9
New value (2009): 68.8 ± 3.4 G. Meierhofer et al., EPJA 40, 61 (2009)	46.9 ± 4.7	115 ± 16

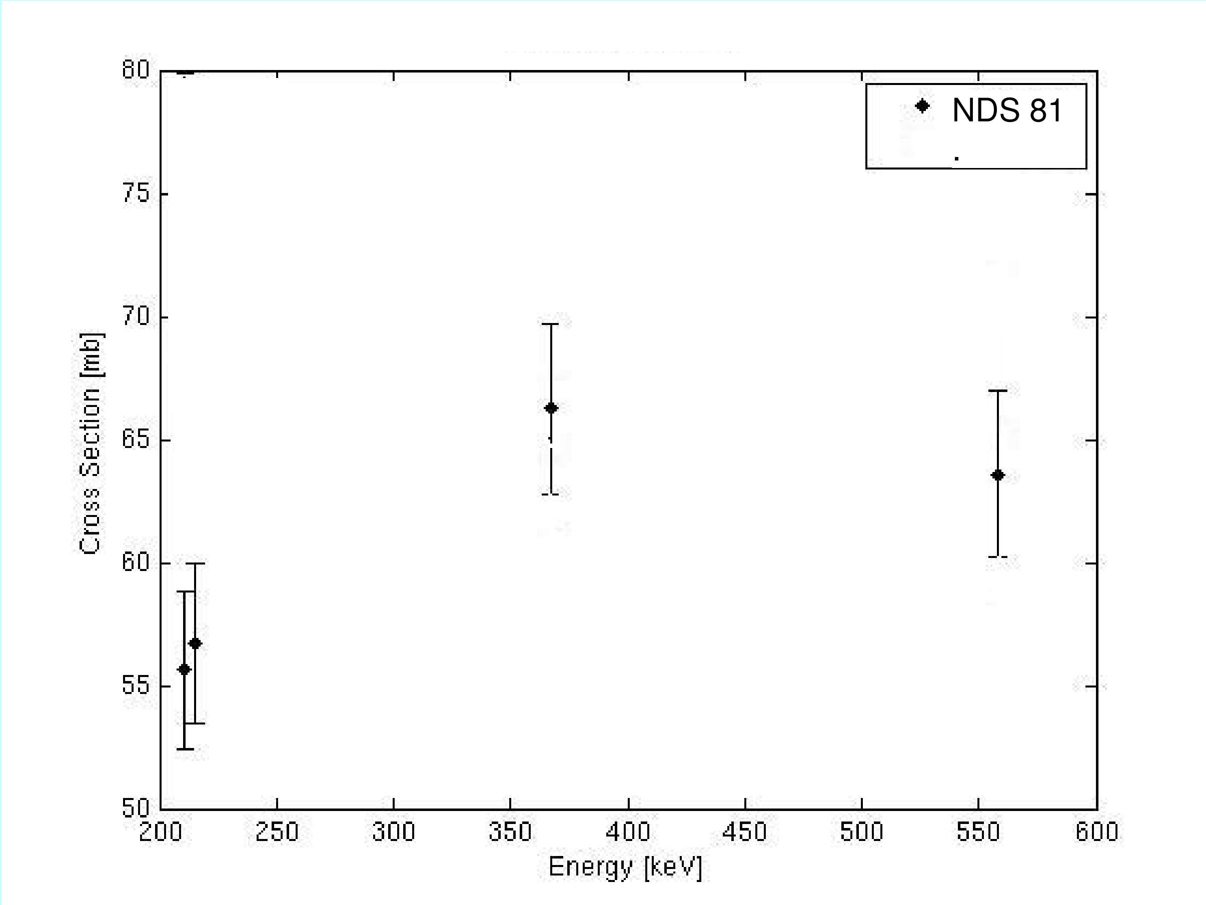
relativly large uncertainties due to branching ratio

Emission probabilities

Depending on the transition used, the cross section varies by 15%.

The same effect was observed by J. Marganiec, PRC79, 065802 (2009).

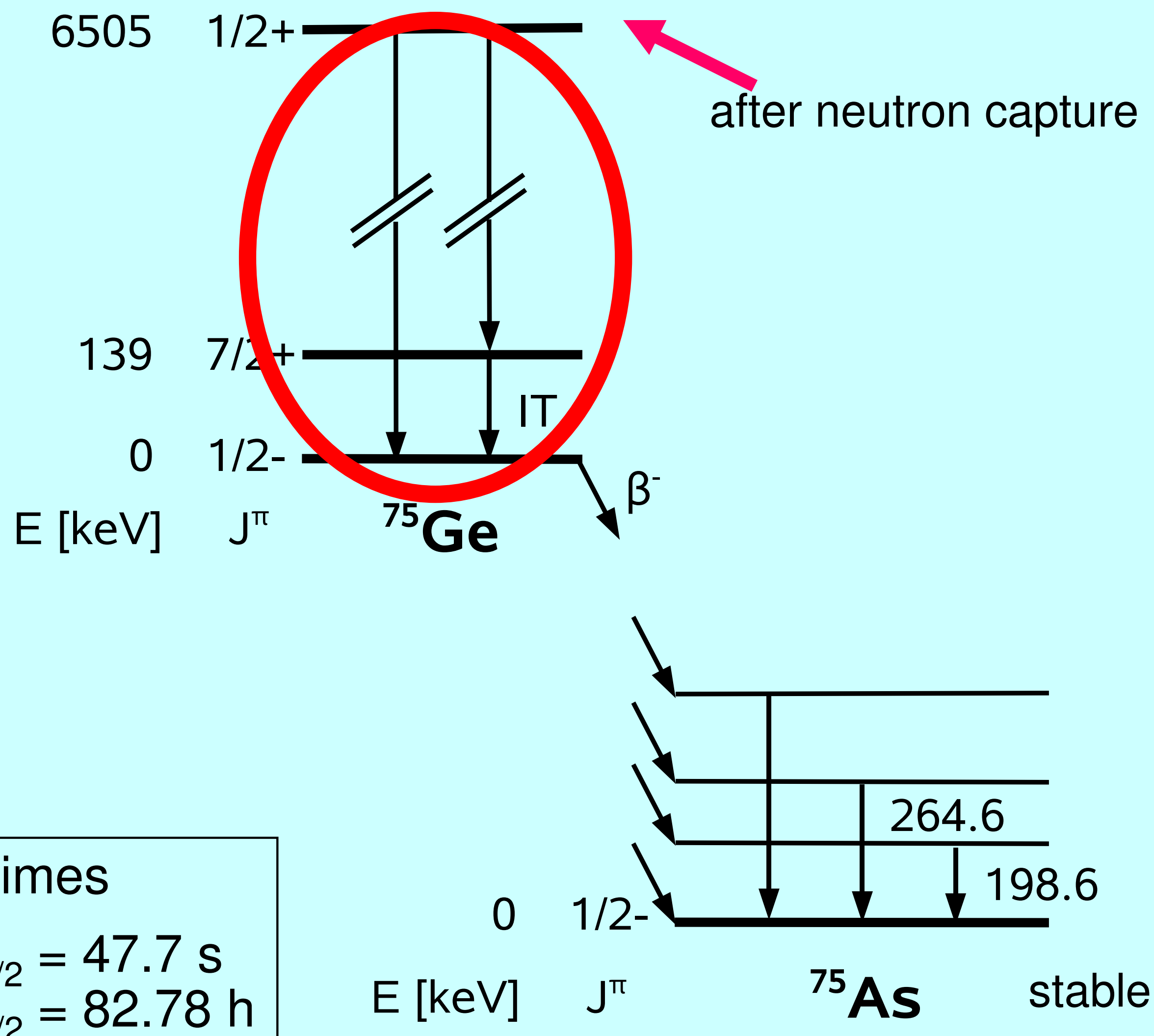
Very likely that the emission probabilities in the literature are not correct.



Neutron Capture by ^{74}Ge

S_n = 6505 keV

E_{max}(β delayed) = 1177 keV
E_{max}(γ delayed) = 618 keV



Half-life times

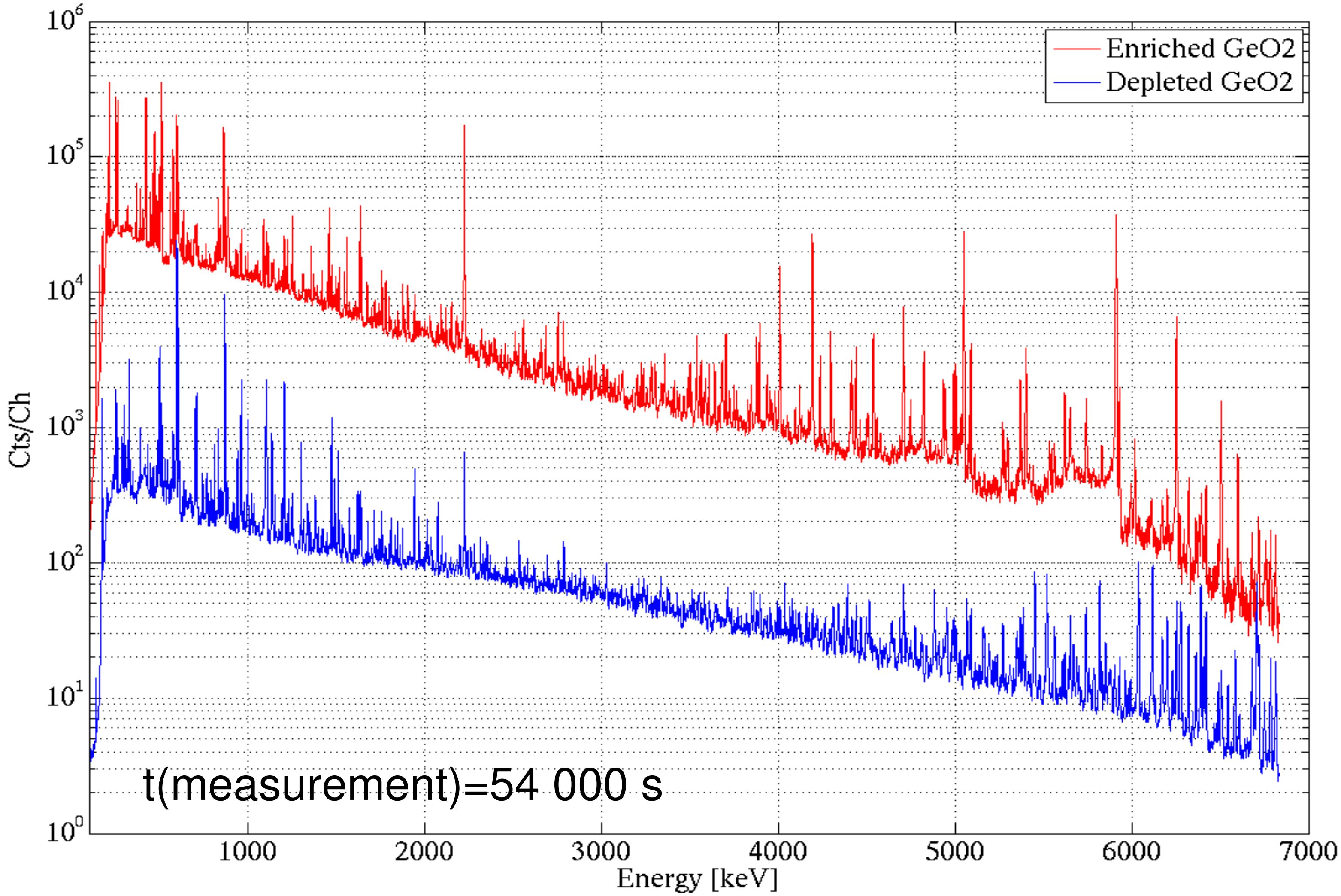
^{75m}Ge: $t_{1/2}$ = 47.7 s
^{75}Ge: $t_{1/2}$ = 82.78 h

Results $^{74}Ge(n,\gamma)$

cross section [mbarn]		
$\sigma(^{75}Ge$ total)	$\sigma(^{75}Ge$ direct)	$\sigma(^{75m}Ge)$
Seren (1947): 380 ±76 Pomerance (1952): 600 ± 60 Lyon (1960): 550 ± 55 Koester (1987): 400 ± 200	Metosian (1957): 180 ± 40	Metosian (1957): 40 ± 8 Wigmann (1962): 200 ± 20 Mannhart (1968): 143 ± 16
New value (2010): 497 ± 52 G. Meierhofer et al., PRC 81, 027603 (2010)	365 ± 51	130.5 ± 5.6

relativly large uncertainties
due to emission probabilities

Prompt γ-spectra (preliminary)



Enriched:
^{76}Ge
^{74}Ge
^{73}Ge
^{77}Ge (decay)
^{75}Ge (decay)

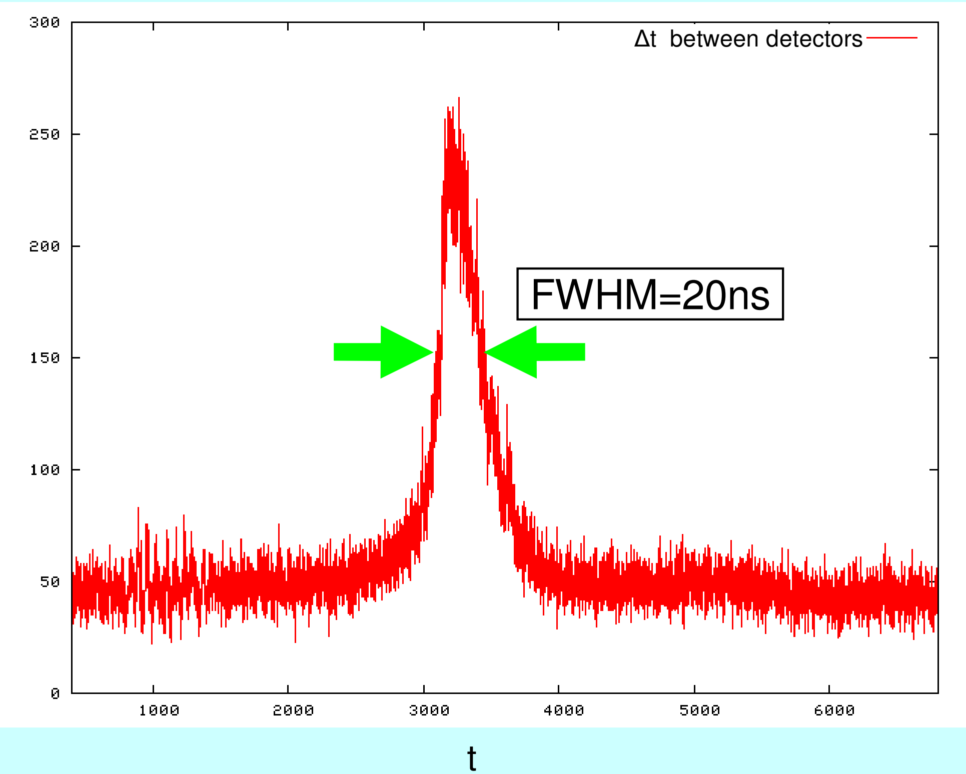
Depleted:
^{74}Ge
^{73}Ge
^{72}Ge
^{70}Ge
^{75}Ge (decay)

Background:
F, H, N, Na, C,Cd, Al, Pb

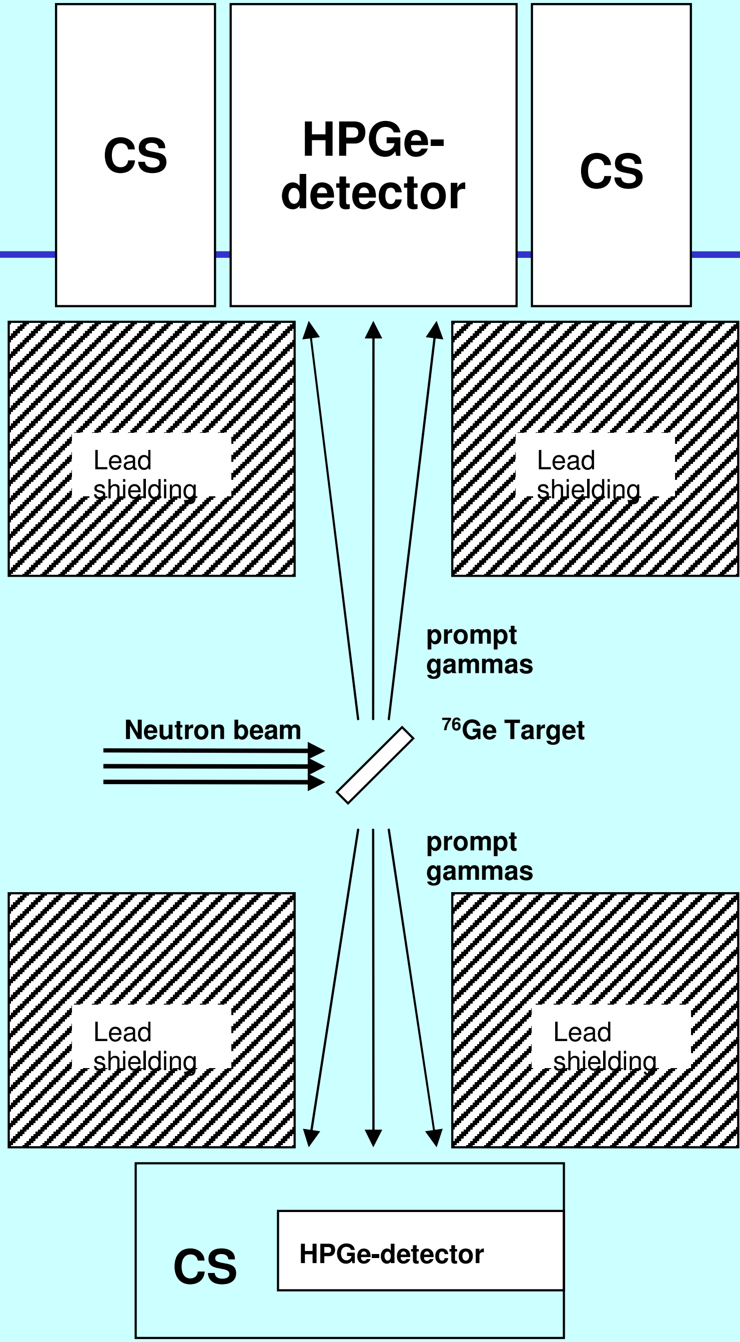
Further spectra:
Empty target (C_2F_4)
Decay (enriched)
Decay (depleted)

Coincidence

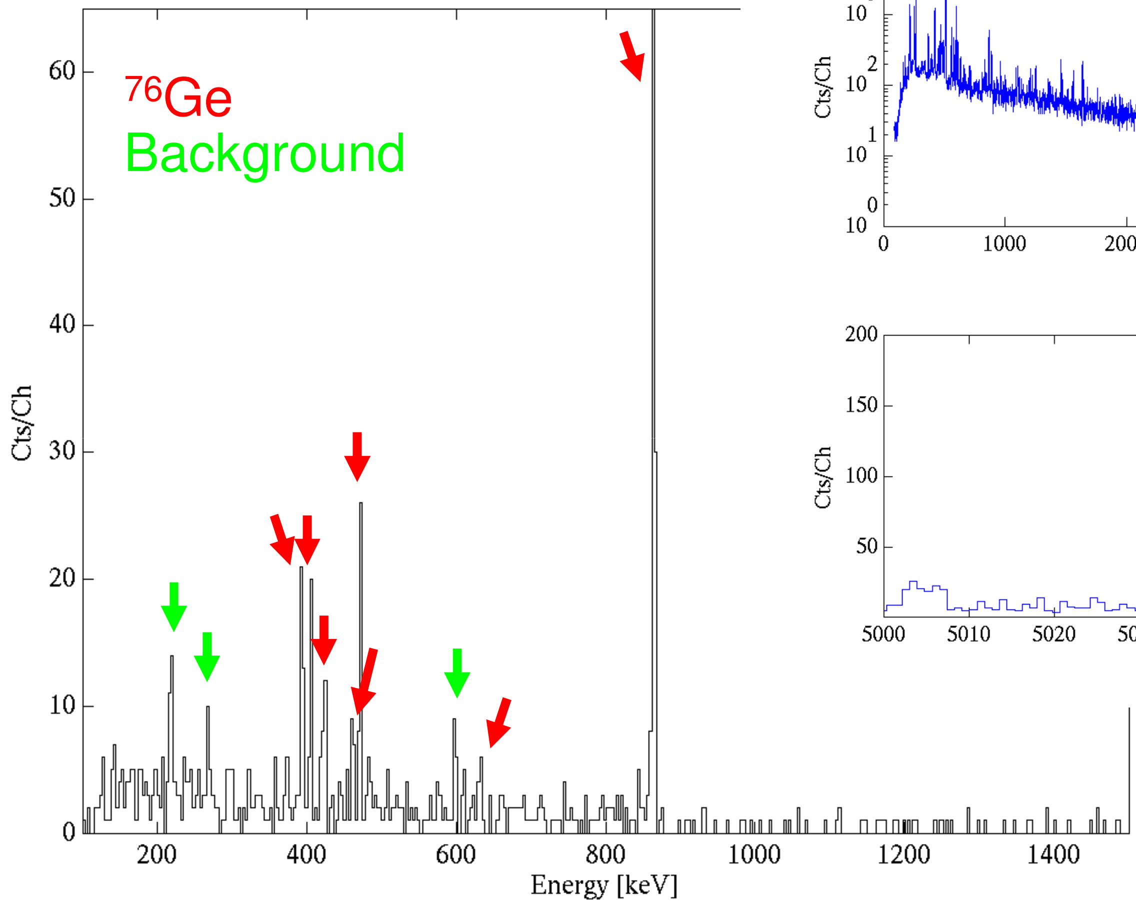
m ~ 300 mg of enriched $^{76}GeO_2$
Irradiation time 8 d

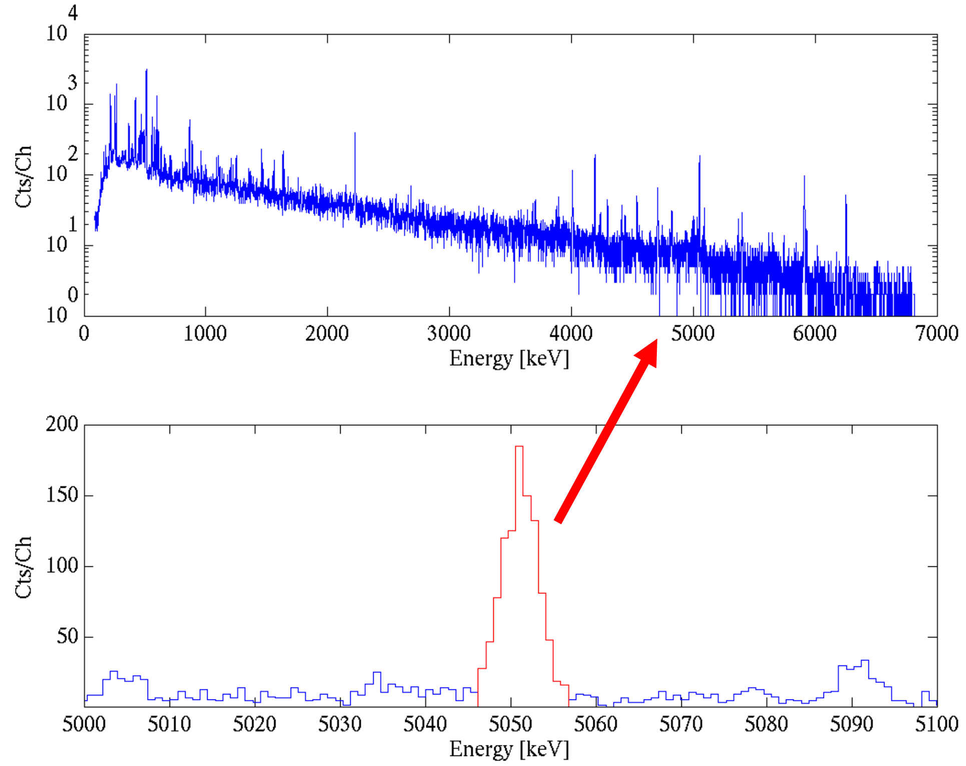


Time difference is used to distinguish between random and true coincidences.



Example 5049 keV

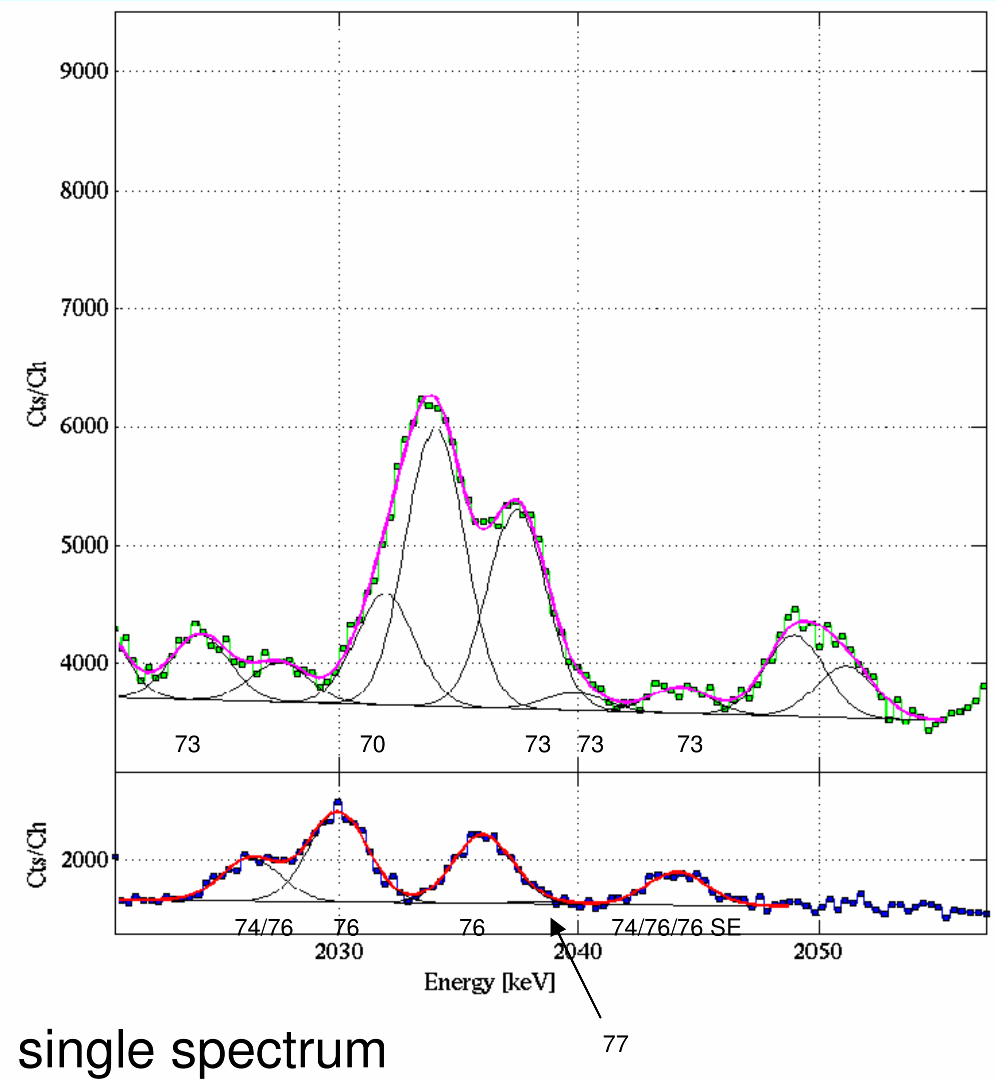




detector A

detector B

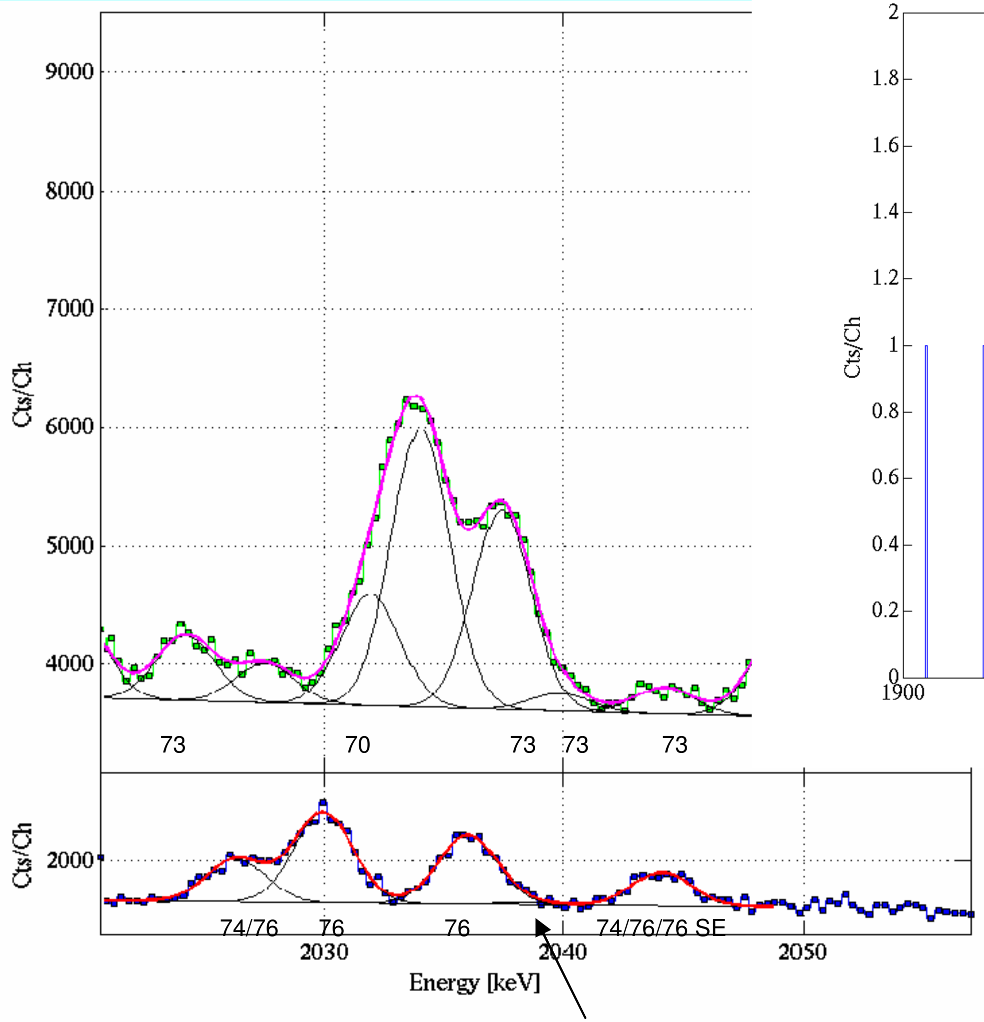
ROI @ 2039 keV



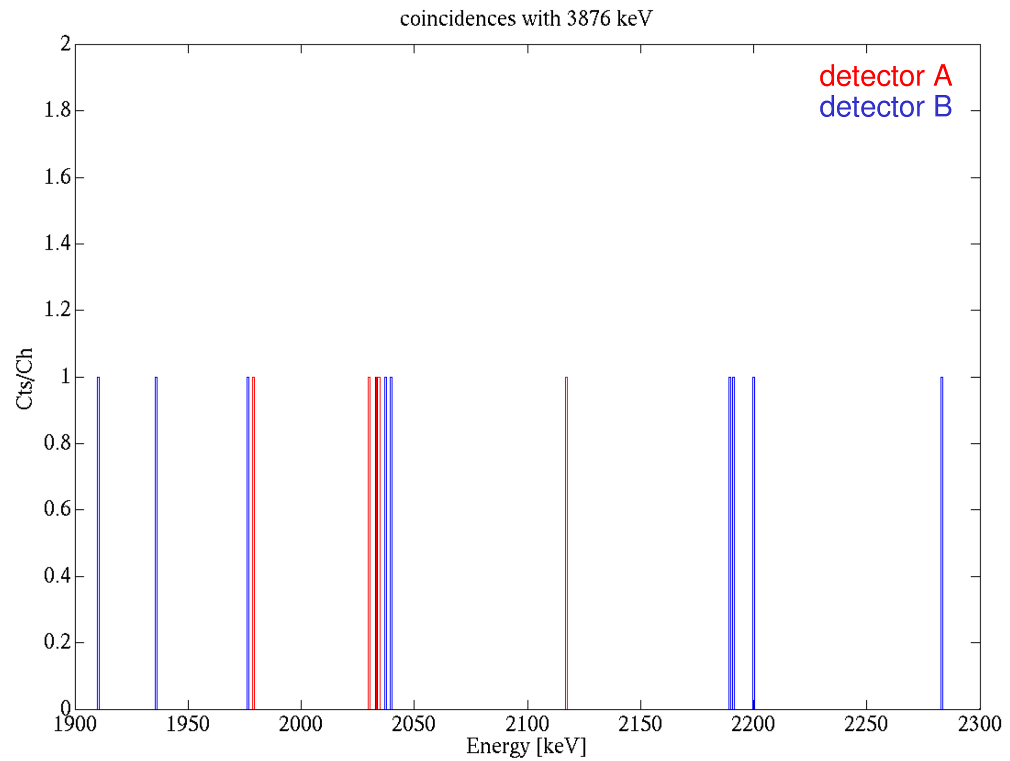
Depleted GeO_2
^{70}Ge: 22.078%
^{72}Ge: 30.04%
^{73}Ge: 8.40 %
^{74}Ge: 38.90 %
^{76}Ge: 0.59 %

Enriched GeO_2
^{70}Ge: 0.0 %
^{72}Ge: 0.03 %
^{73}Ge: 0.13 %
^{74}Ge: 12.1 %
^{76}Ge: 86.9 %

ROI @ 2039 keV



single spectrum



Coincident with transition 3876 keV

Background:
2029: < 10^{-3} cts/(kg keV y)
2035: < 10^{-3} cts/(kg keV y)

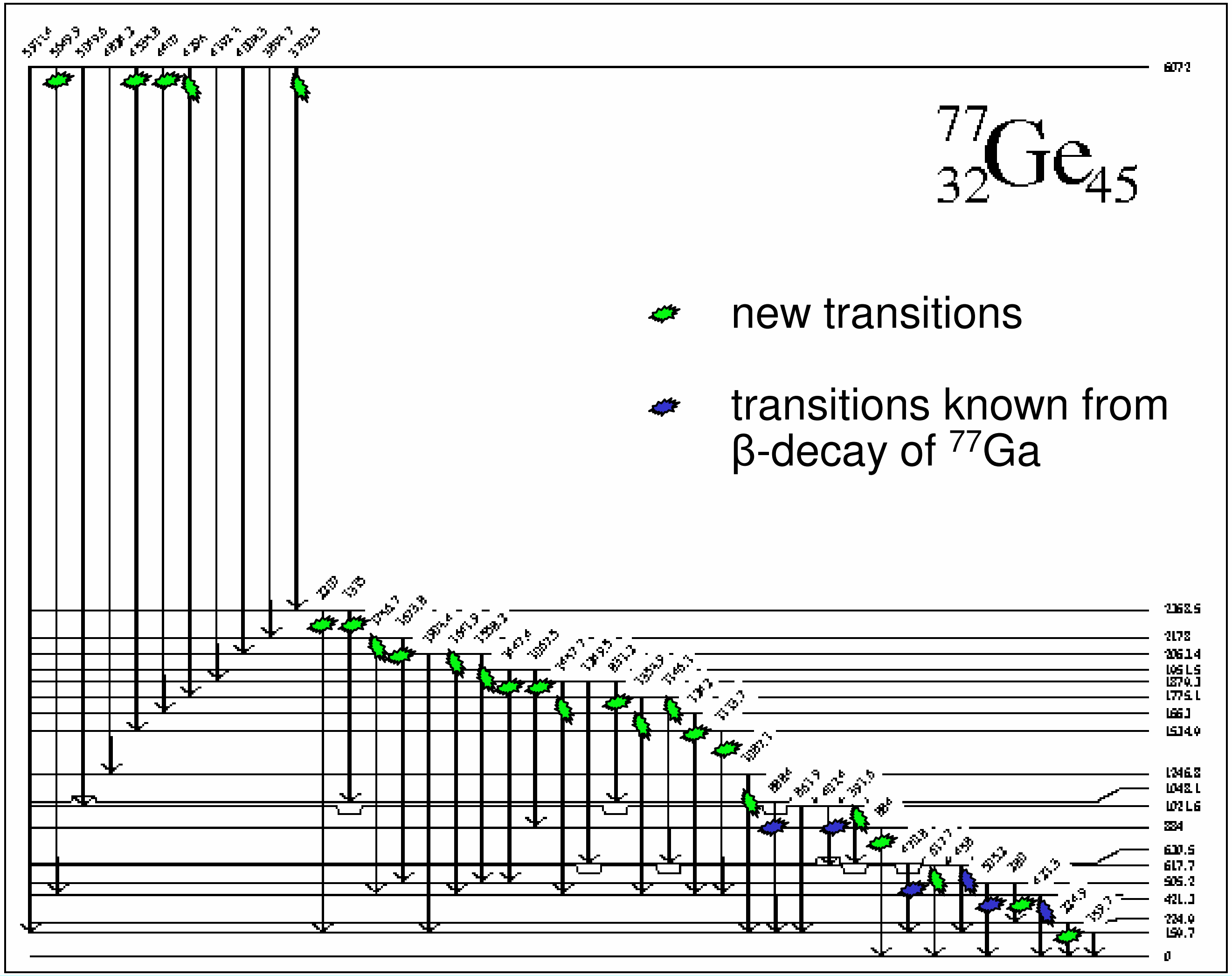
Decay scheme in ^{77}Ge (preliminary)

In total 122 transitions assigned to ^{76}Ge, 75 of them placed in the decay scheme.

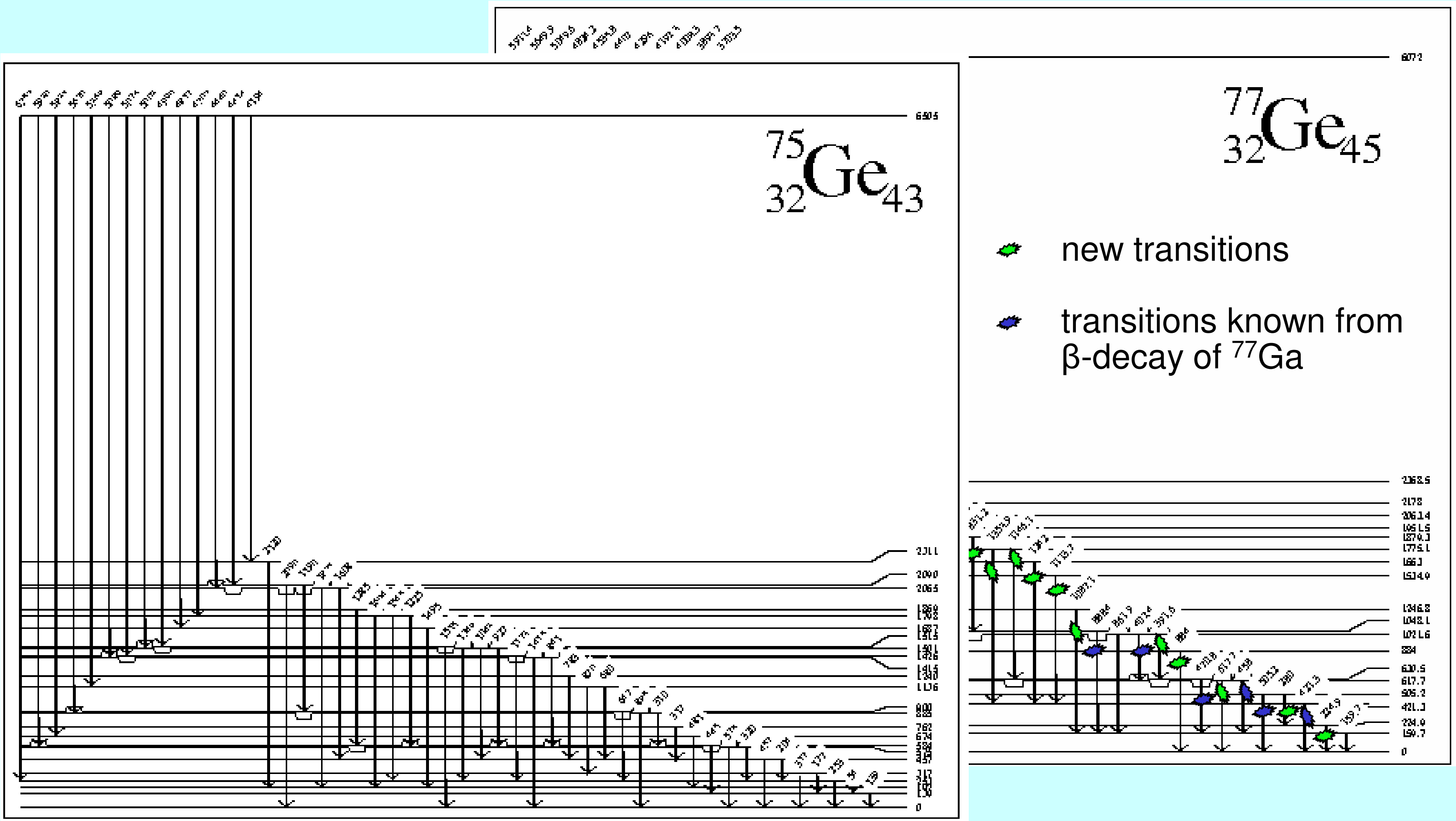
Some transitions known from other reactions:

- β-decay of ^{77}Ga
- ^{76}Ge(^{13}C,^{12}C)^{77}Ge

Now 60% of the emitted energy known



Decay scheme in ^{75}Ge (preliminary)



Summary

Neutron capture on ^{76}Ge will produce background in GERDA (prompt cascade and delayed decay of ^{77}Ge).

The prompt cascade is needed to veto the delayed decay of ^{77}Ge.

- Measurements
  - The cross sections of the ^{76}Ge(n,γ) and ^{74}Ge(n,γ) reactions were measured by the activation method.
  - The prompt gamma-ray spectrum in ^{77}Ge and ^{75}Ge were measured and the decay schemes reconstructed.
- Conclusions for GERDA
  - Cross sections: ^{77m}Ge slightly lower, ^{77}Ge significantly higher
  - There are peaks around 2039 keV
- Future measurements
  - Decay scheme of ^{77}Ge, determination of correct emission probabilities
  - Branching of the isomeric state in ^{77}Ge