bmb+f - Förderschwerpunkt

Astroteilchenphysik

Großgeräte der physikalischen Grundlagenforschung

DPG

GERDA

Background by Neutron Activation in GERDA

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IKP, Universität zu Köln

Kepler Center for Astro and Particle Physics

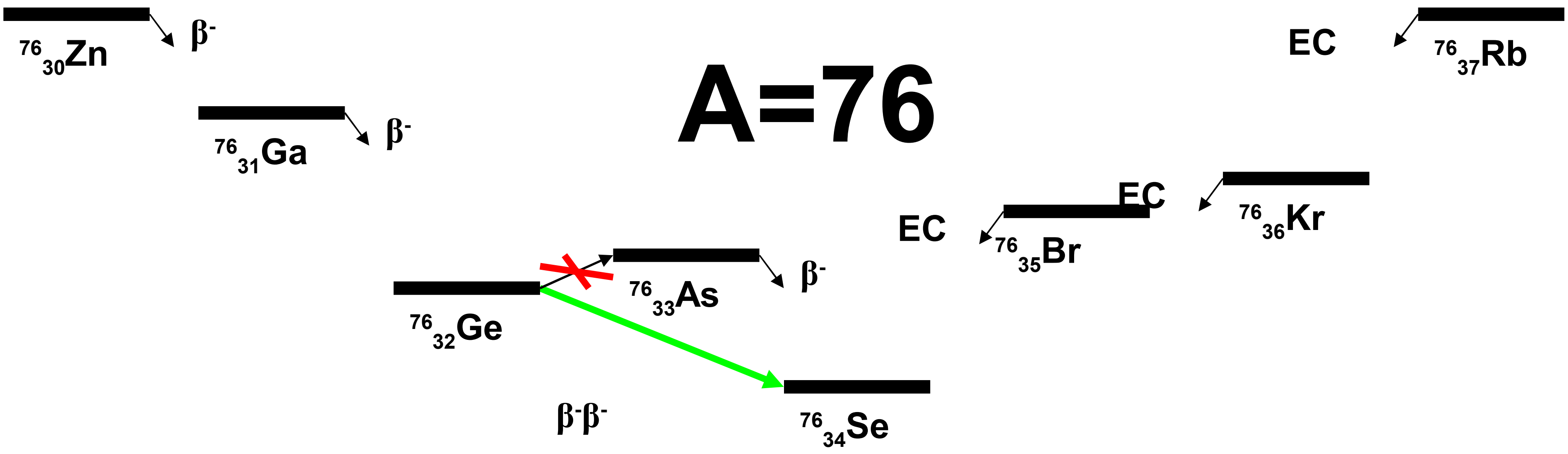
Eberhard Karls Universität Tübingen

Outline

- Motivated by Neutrinoless double beta decay experiments GERDA)
-
- Neutron capture and decay processes on ^{76}Ge
-
- Background by neutron capture on ^{76}Ge
-
- Measurements with cold neutrons @ FRM II
  - 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

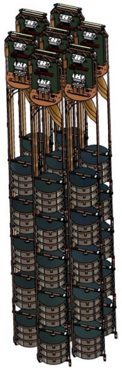
Double beta decay (2νββ)

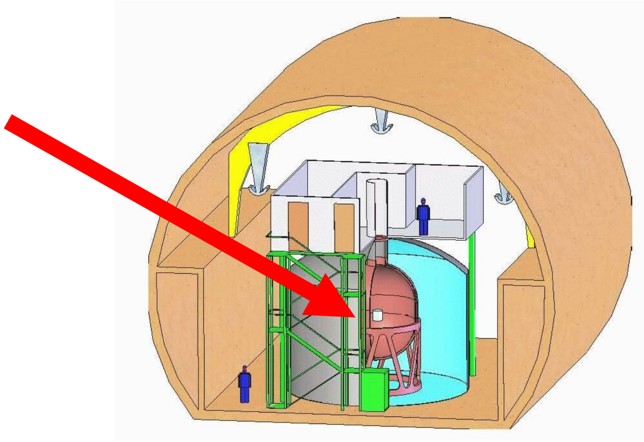
- Double beta decay (2νββ) can be observed if single beta decay is energetically forbidden, but the transition of two neutrons into two protons (or pp -> nn) is allowed. The nucleus emits two electrons (positrons) and two anti-neutrinos (neutrinos).
-
- 2νββ was observed in 11 isotopes: ^{48}Ca, ^{76}Ge, ^{82}Se, ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{128}Te, ^{130}Te,
- ^{150}Nd, ^{238}U, ^{130}Ba ($\beta^+\beta^+$)



GERDA: The GERmanium Detector Array

- Isotope: ^{76}Ge ($Q_{\beta\beta}$ = 2039 keV)
  - Phase I: ~18 kg of ^{76}Ge
  - Phase II: ~40 kg of ^{76}Ge
- Location: LNGS, Gran Sasso, Italy
- Design: Bare HPGe detectors (~86% ^{76}Ge) submerged into LAr. LAr acts as cooling liquid and γ-ray shield. Cerenkov muon veto (water tank with Ø=10 m) no high Z-materials used, 3400 m.w.e. of rock to shield cosmic radiation





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

- **Background level on ROI**
- $< 10^{-2}$ cts/(kev kg y) (Phase I)
- $< 10^{-3}$ cts/(kev kg y) (Phase II)

Background in GERDA

Radiopurity of:
Germanium detector (cosmogenic ^{68}Ge)
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Germanium detector (surface)
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Copper holder
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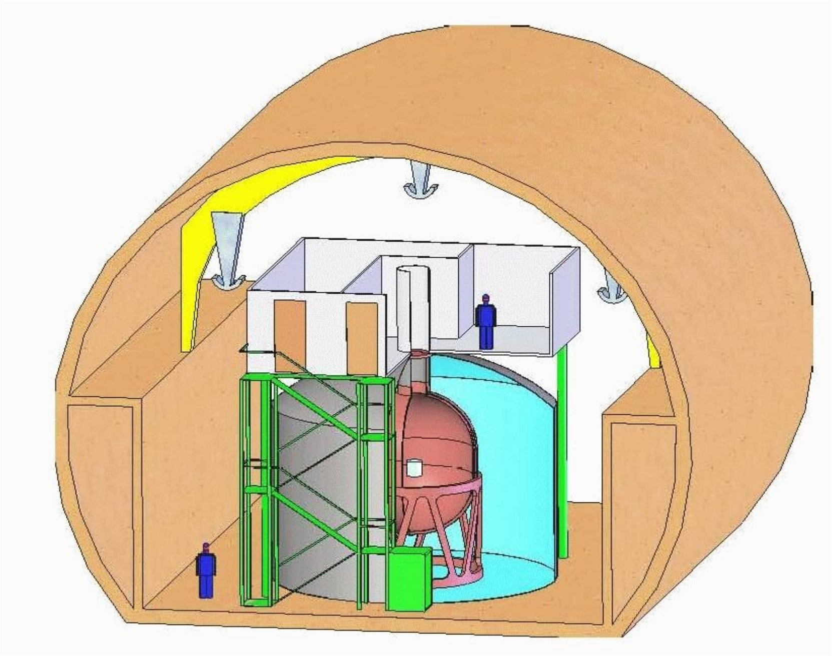
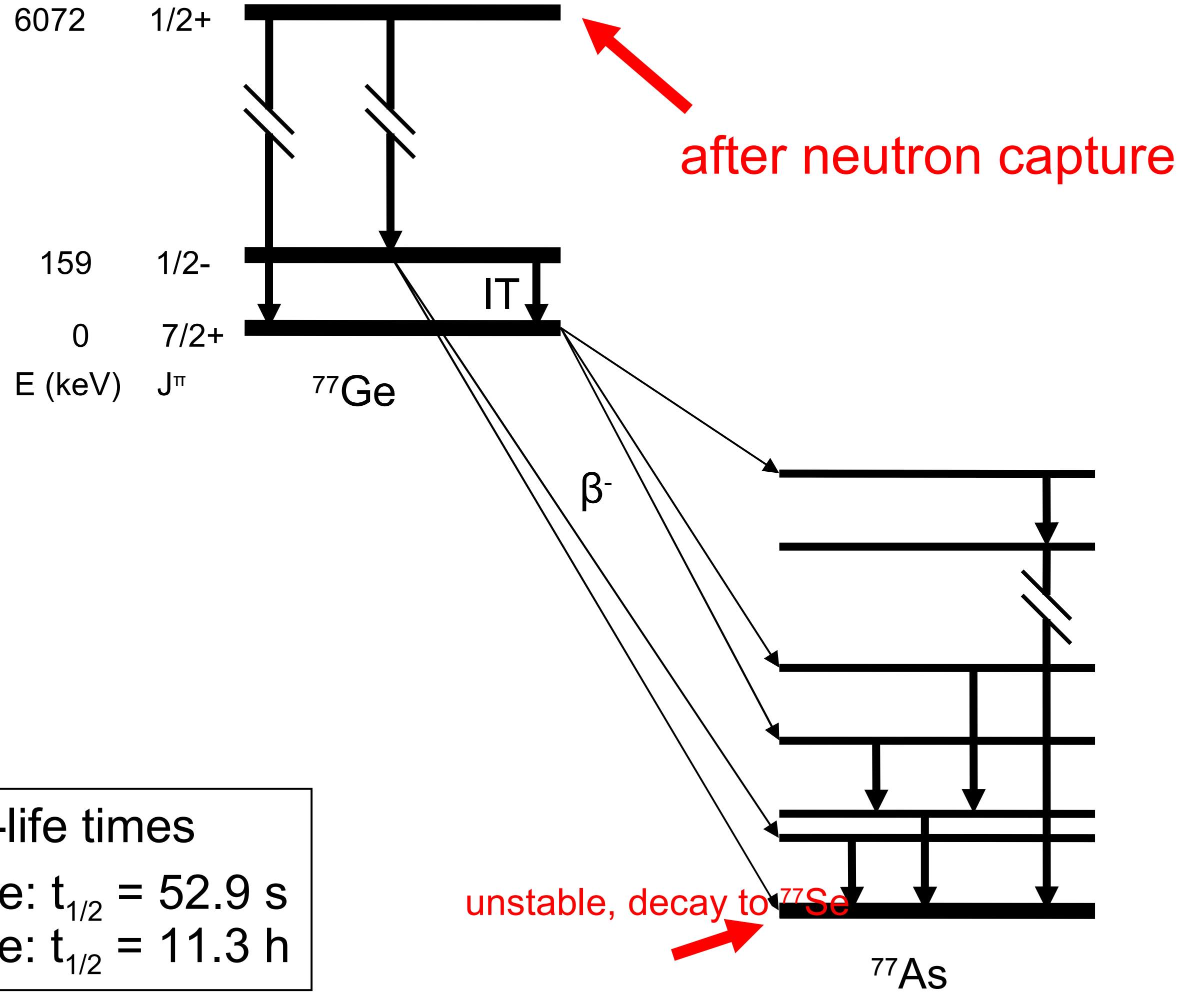


Sources:
Natural activity of rock
Muons and **neutrons**

neutrons produced by cosmic muons can propagate through the water tank and LAr to the Ge-diodes.

Neutron Capture by ^{76}Ge



- Muonflux @ LNGS: 1 muon/(m^2 h)
- MC-simulations:
- ~1 n-capture/(kg y)
-
- Limit from previous experiments:
- max. 6 $0\nu\beta\beta$-counts in phase I

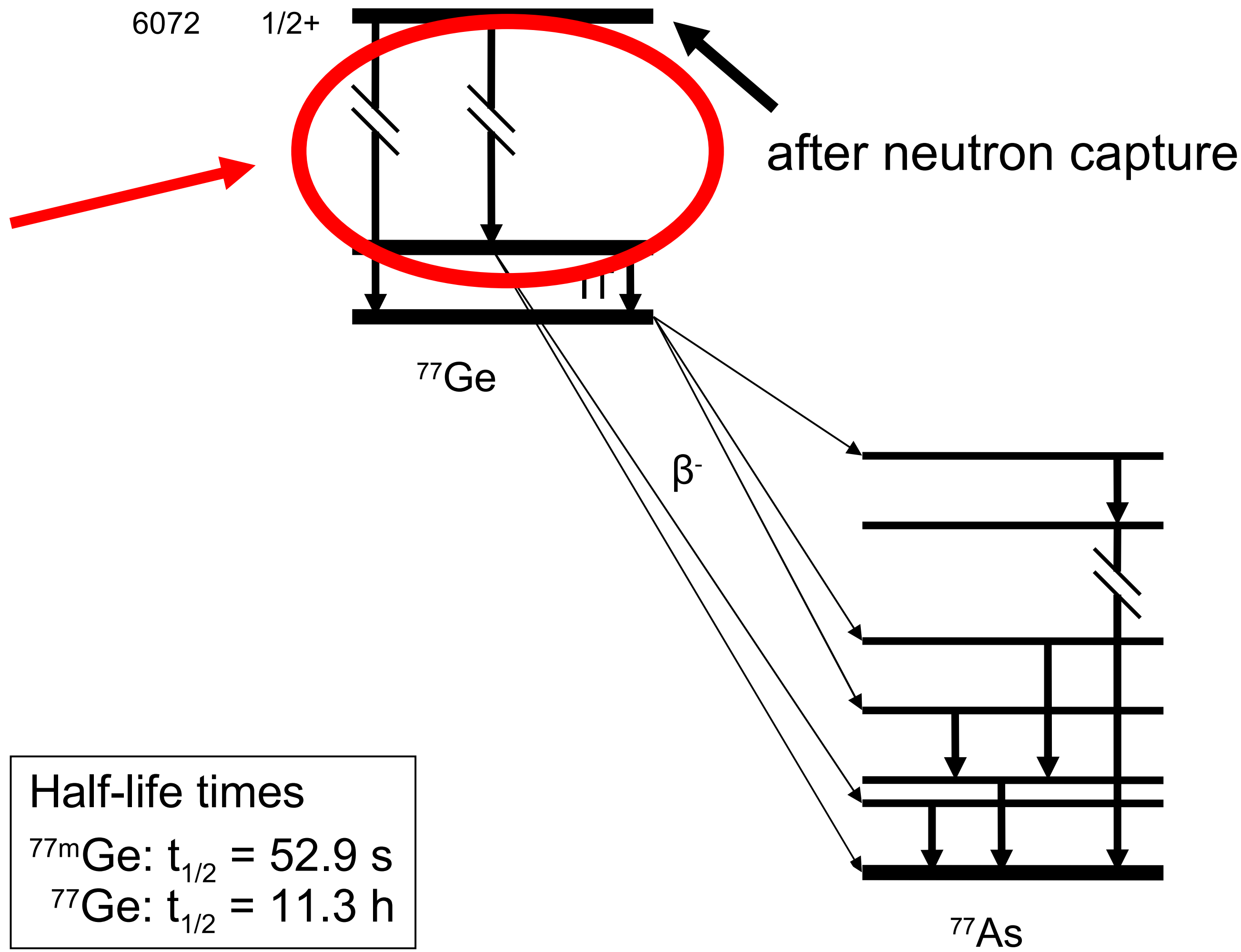
Half-life times

^{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



Half-life times

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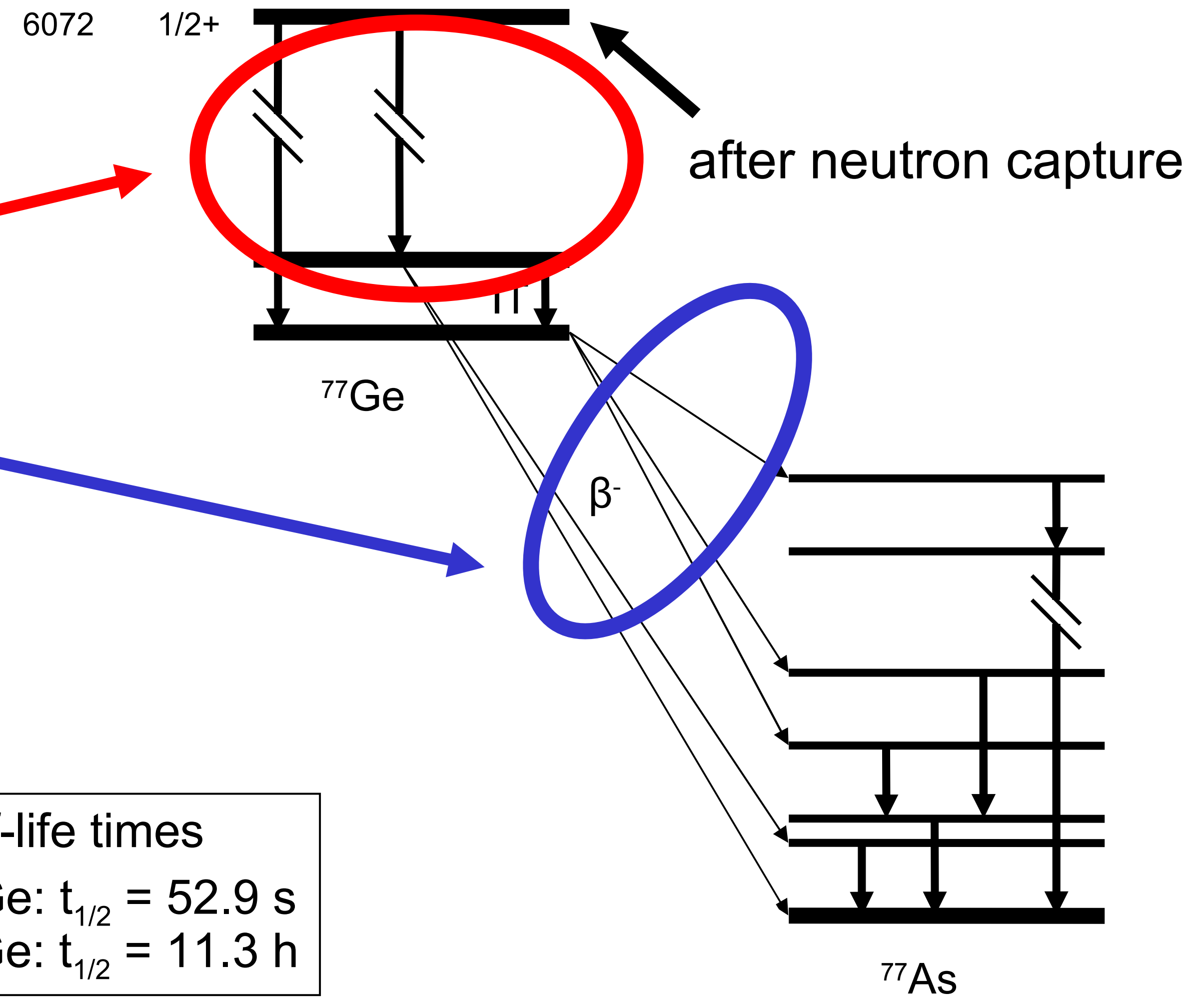
Neutron Capture by ^{76}Ge

prompt γ-cascade

E_{max} = 5911 keV

delayed β-spectrum

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



Half-life times

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

Neutron Capture by ^{76}Ge

prompt γ-cascade

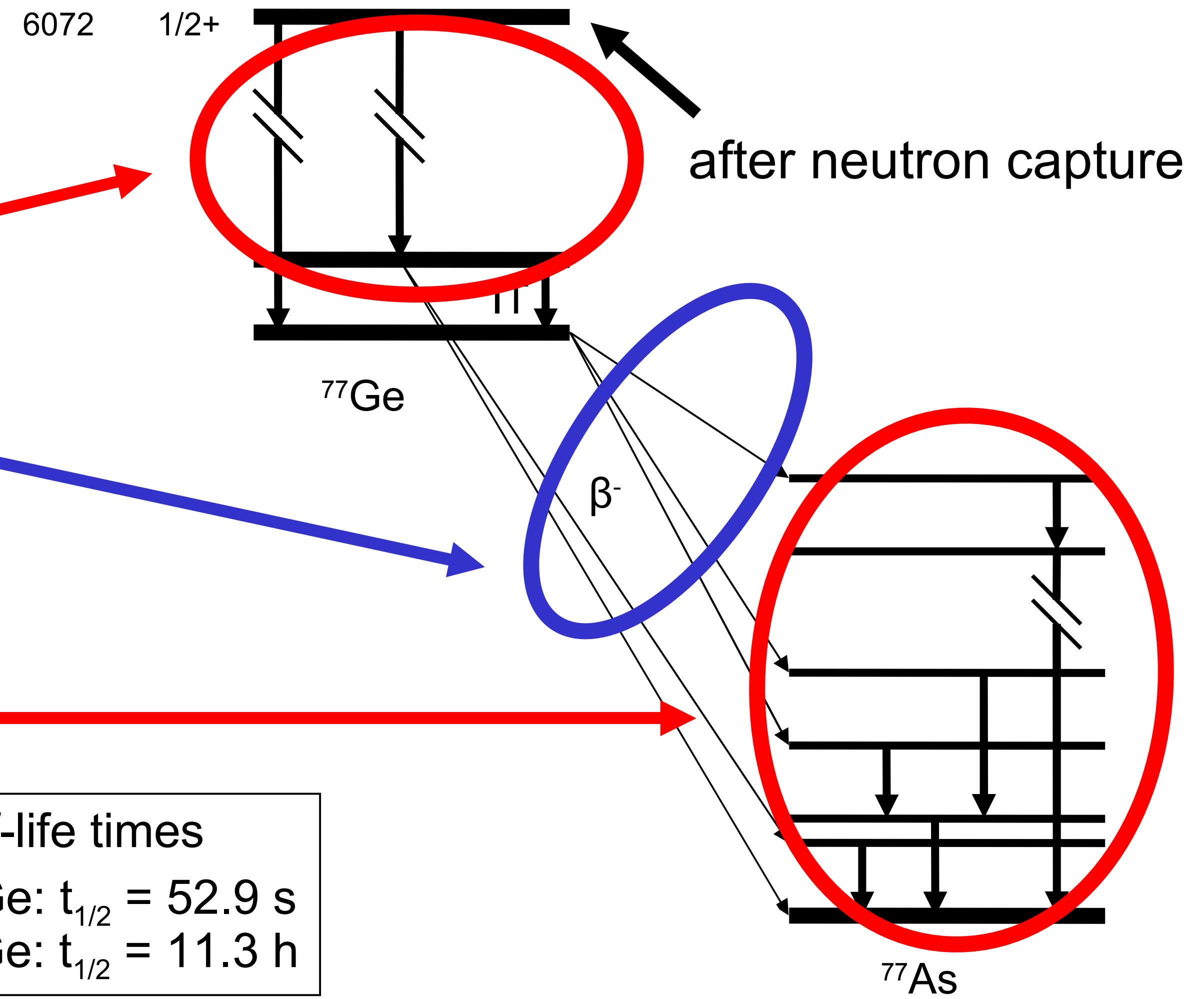
E_{max} = 5911 keV

delayed β-spectrum

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

delayed γ-rays

E_{max} = 2353 keV



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

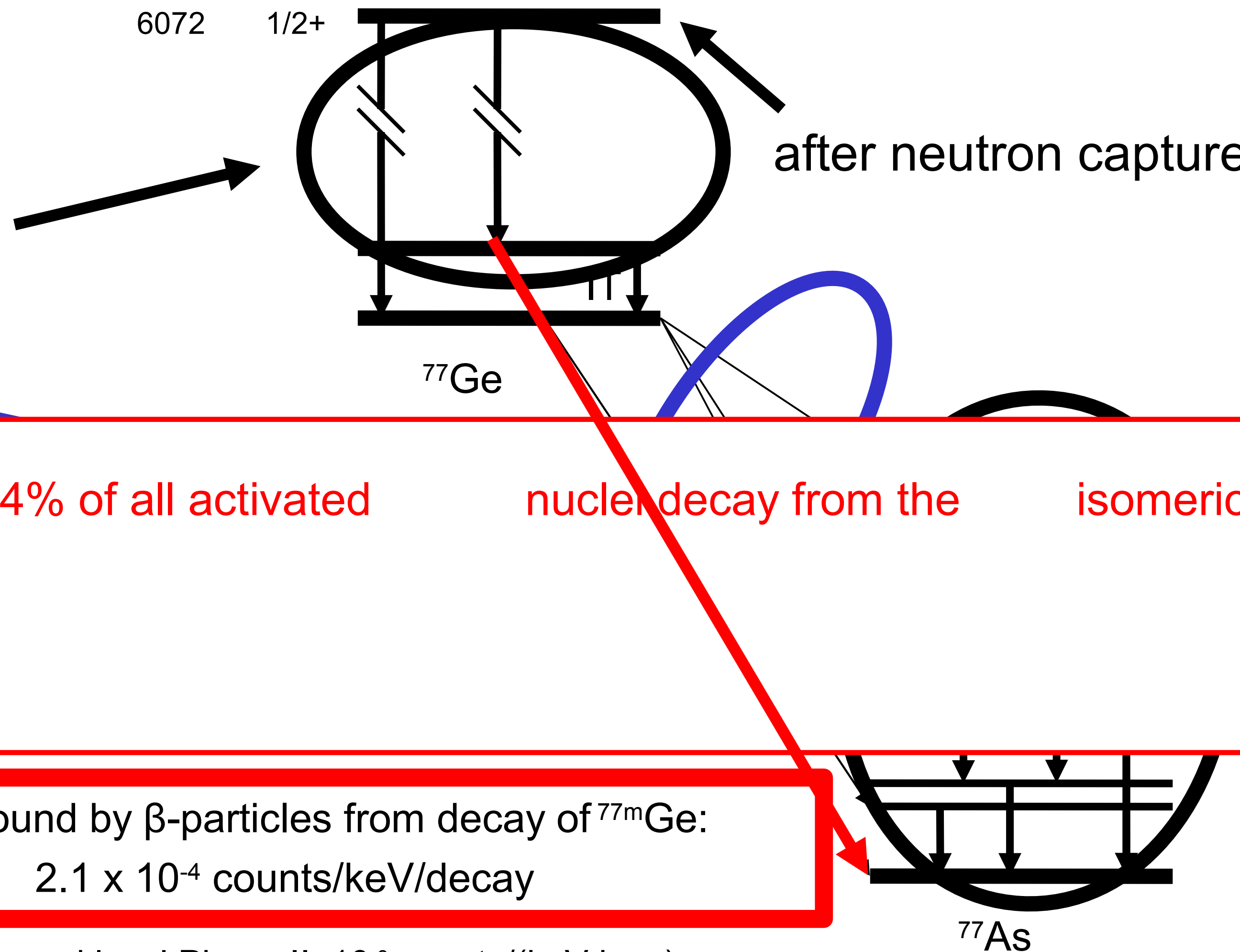
E_{max} = 5911 keV

delayed β-spectrum

E_{max} = 2862 keV
continouos, mim
signal

delayed γ-rays

E_{max} = 23

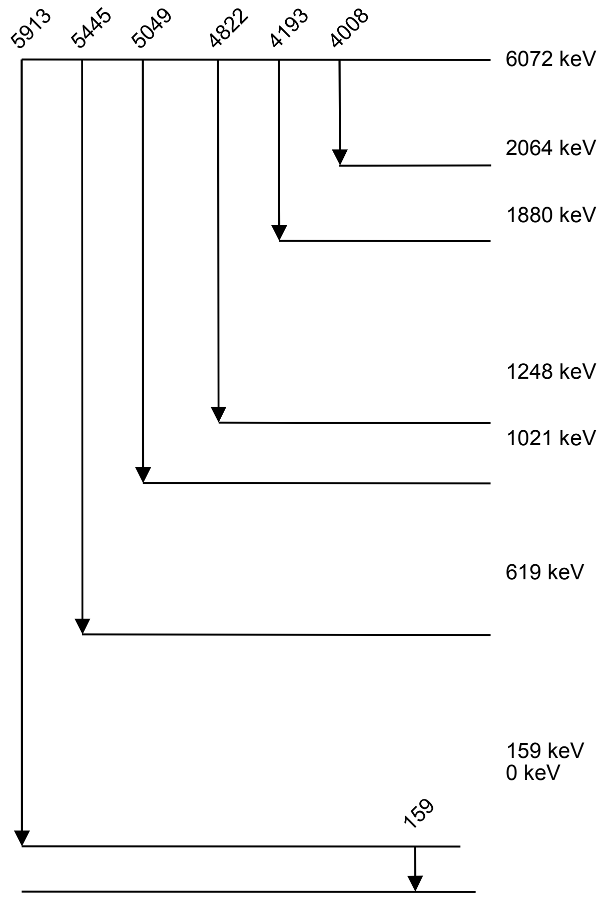


34% of all activated nucle decay from the isomeric s

Background by β-particles from decay of ^{77m}Ge:
2.1×10^{-4} counts/keV/decay

Required background level Phase II: 10^{-3} counts/(keV kg y)

Prompt transitions in ^{77}Ge



Nuclear Data Sheets 81

not in decay scheme E [keV]	IAEA Nuclear Data Services 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 $n_{th}/(cm^2\,s^1)$

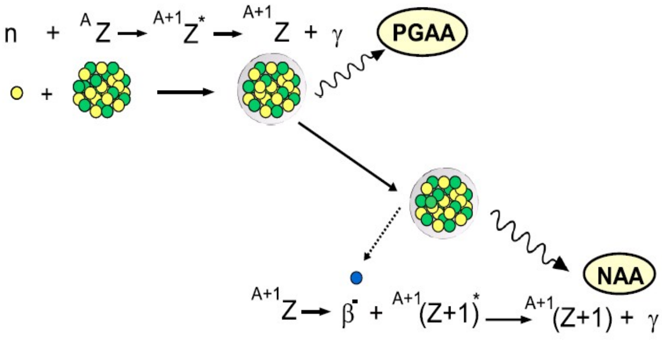
$<\lambda_n>$ = 6.7 Å (cold)

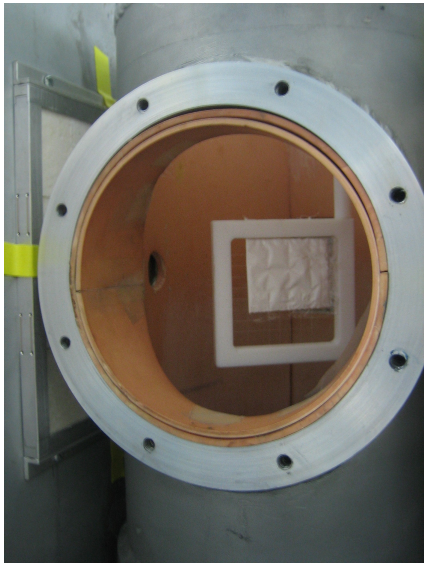
$<E_n>$ = 1.83 meV

Detectors

2 HPGe with Compton suppresion

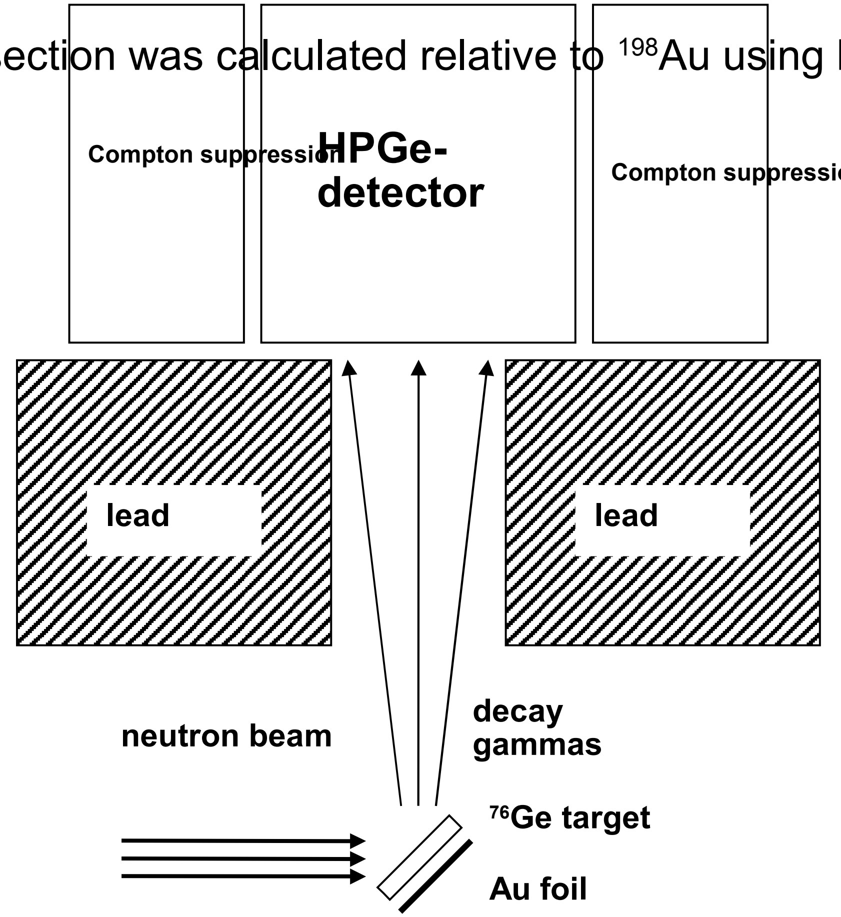
Li/Cd/Pb shielding

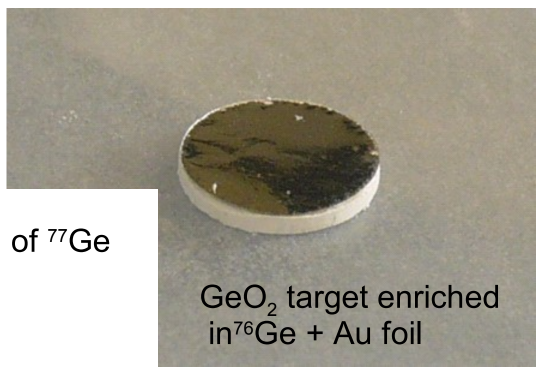


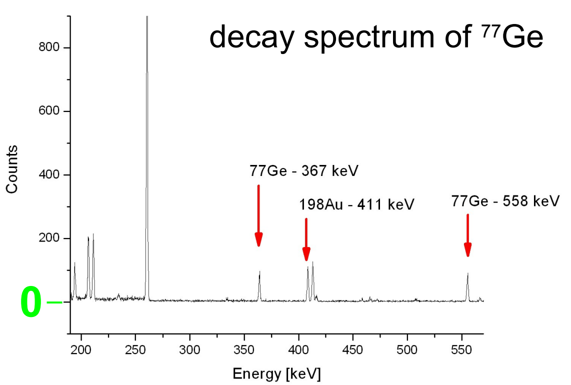


Thermal n-capture cross section

β-decay were measured by HPGe detectors. The cross-section was calculated relative to ^{198}Au using







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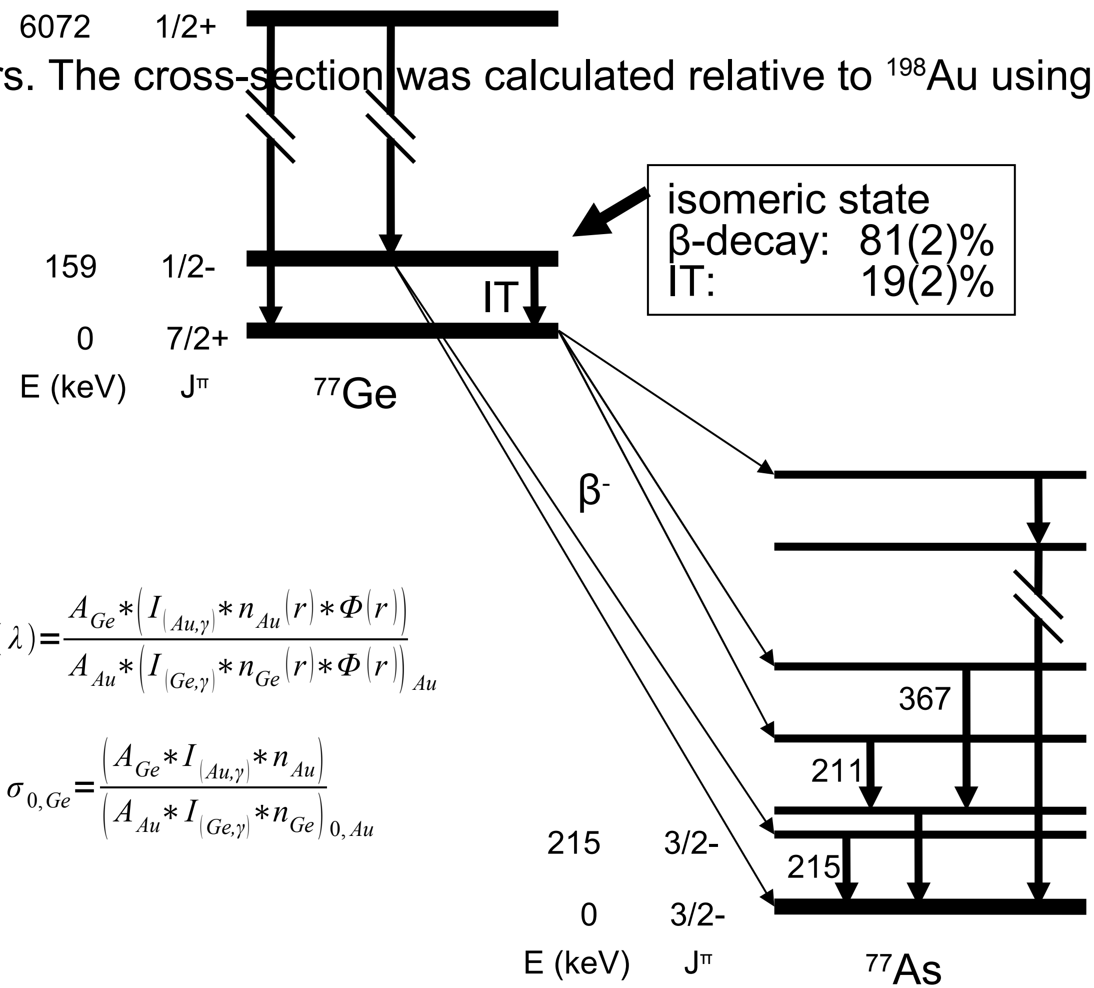
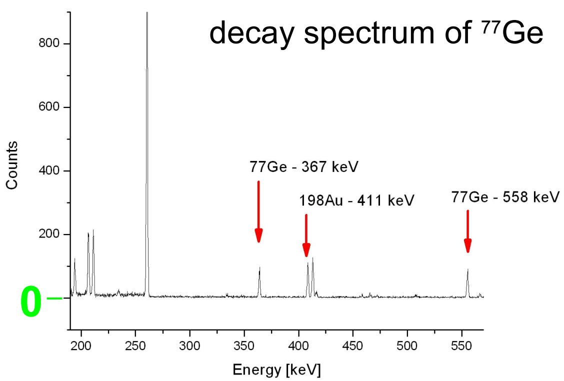




$$\sigma_{Ge}(\lambda)=\frac{A_{Ge}*\left(I_{(Au,\gamma)}*n_{Au}(r)*\Phi(r)\right)}{A_{Au}*\left(I_{(Ge,\gamma)}*n_{Ge}(r)*\Phi(r)\right)_{Au}}$$

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

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

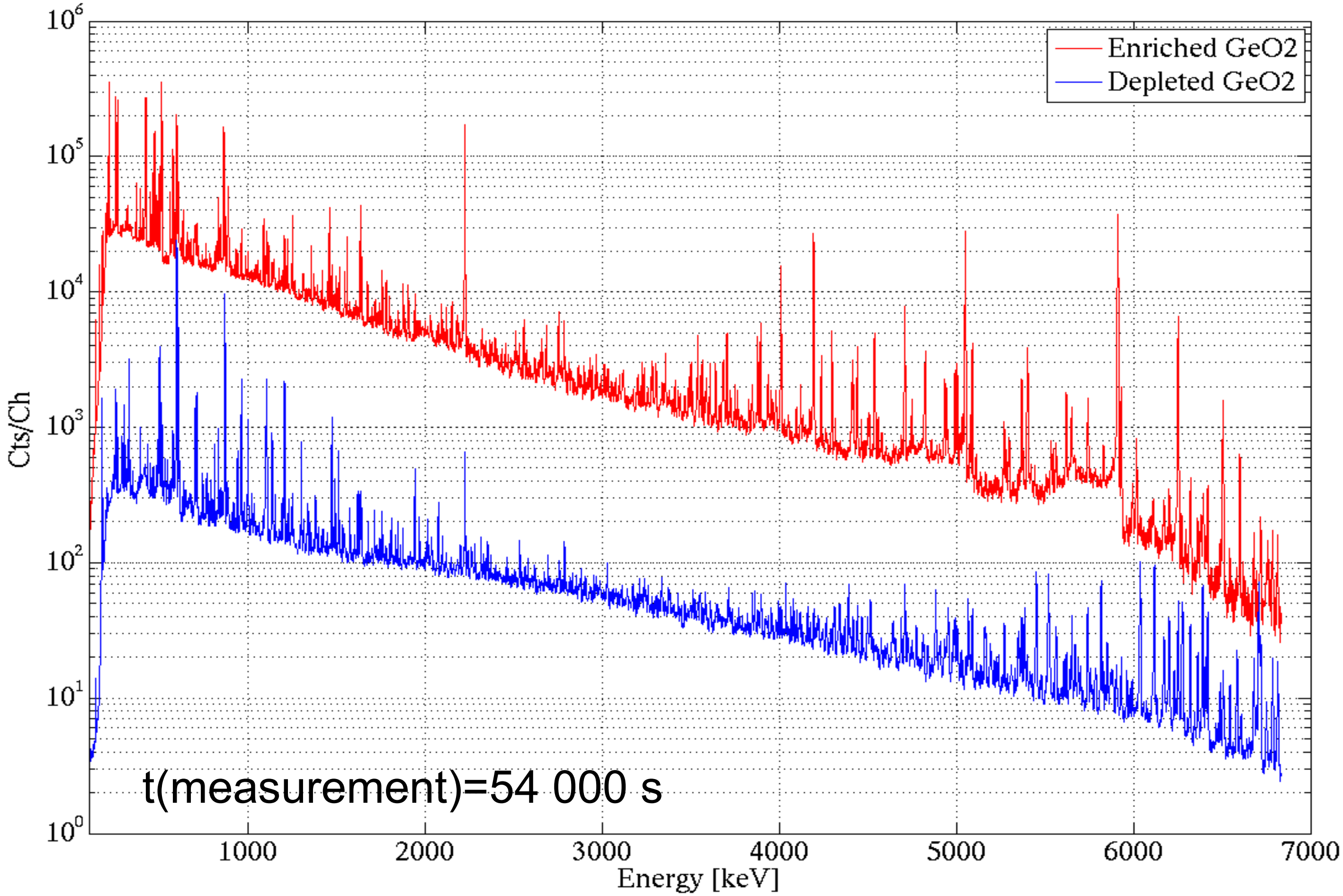
relativly large uncertainties due to branching ratio

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)

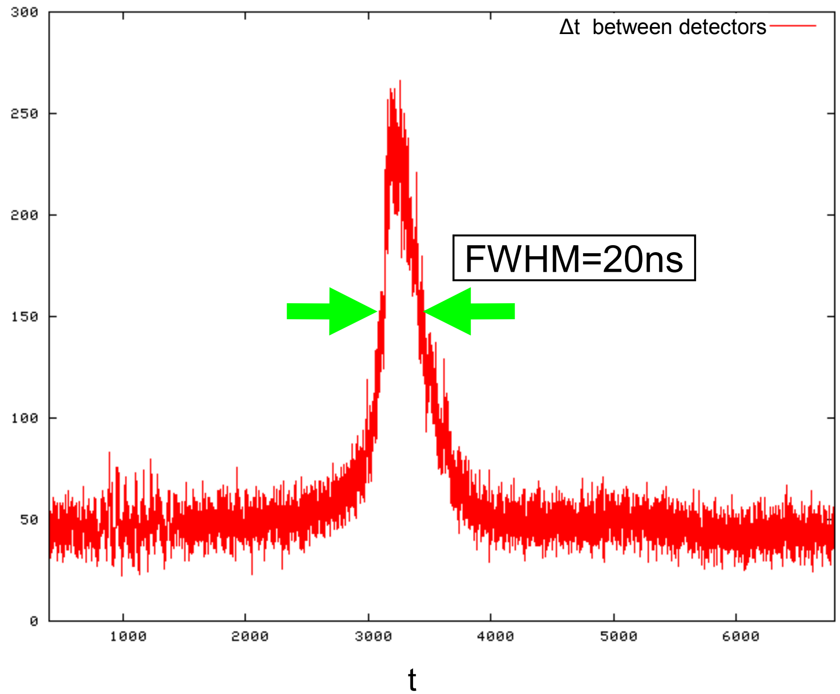
Depleted:
^{74}Ge
^{73}Ge
^{72}Ge
^{70}Ge
^{75}Ge (decay)

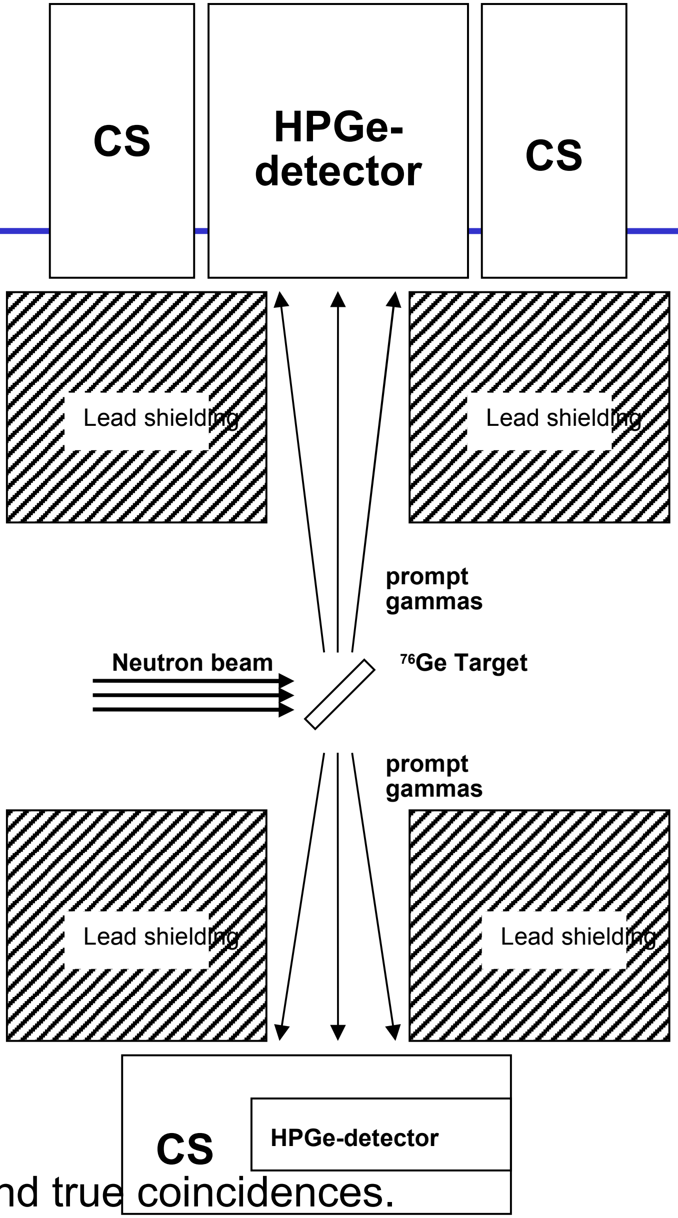
Background:
F, H, N, Na,
C,Cd, Al, Pb

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

Coincidence

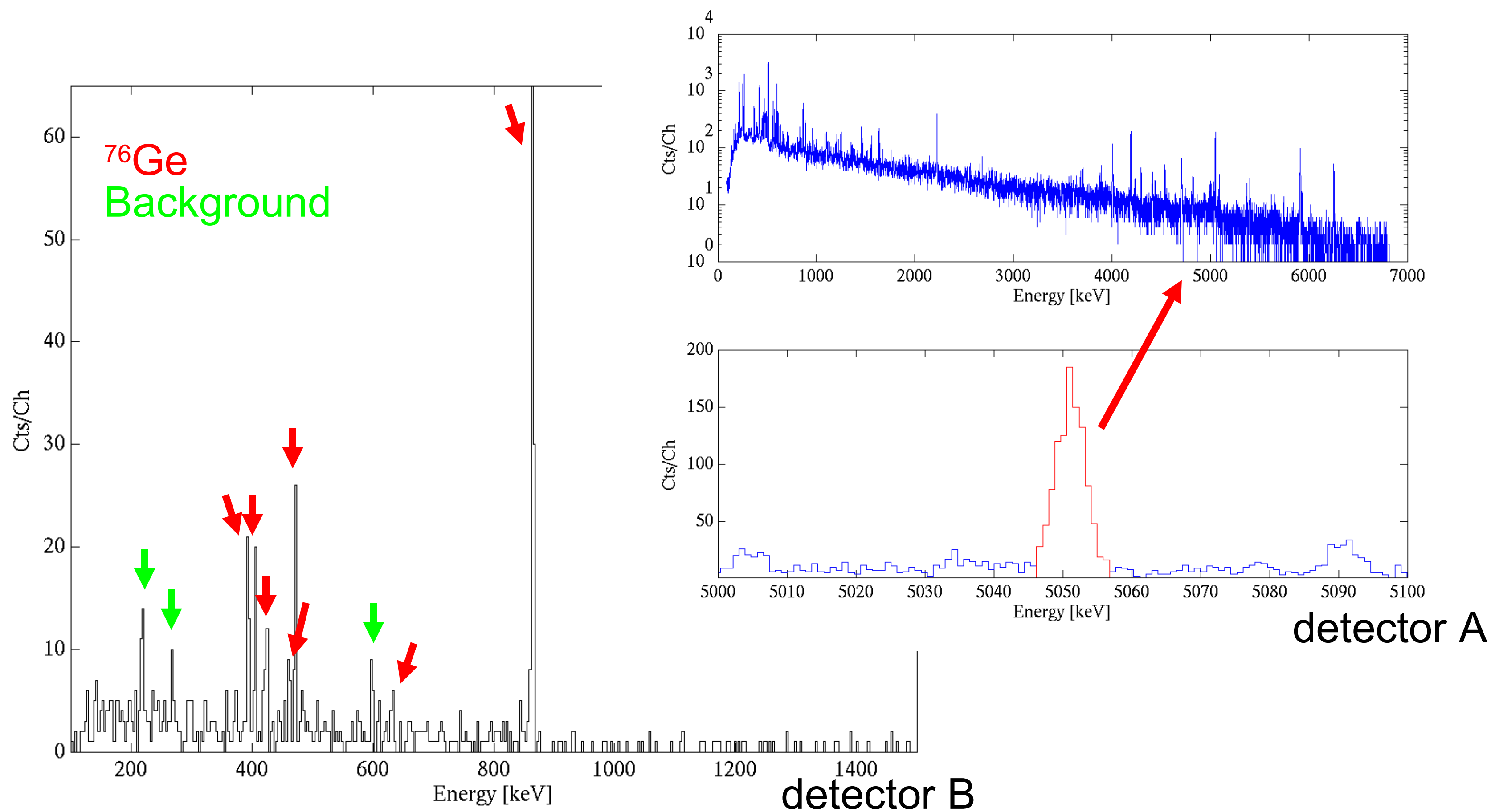
m ~ 300 mg of enriched $^{76}GeO_2$
Irradiation time 8 d





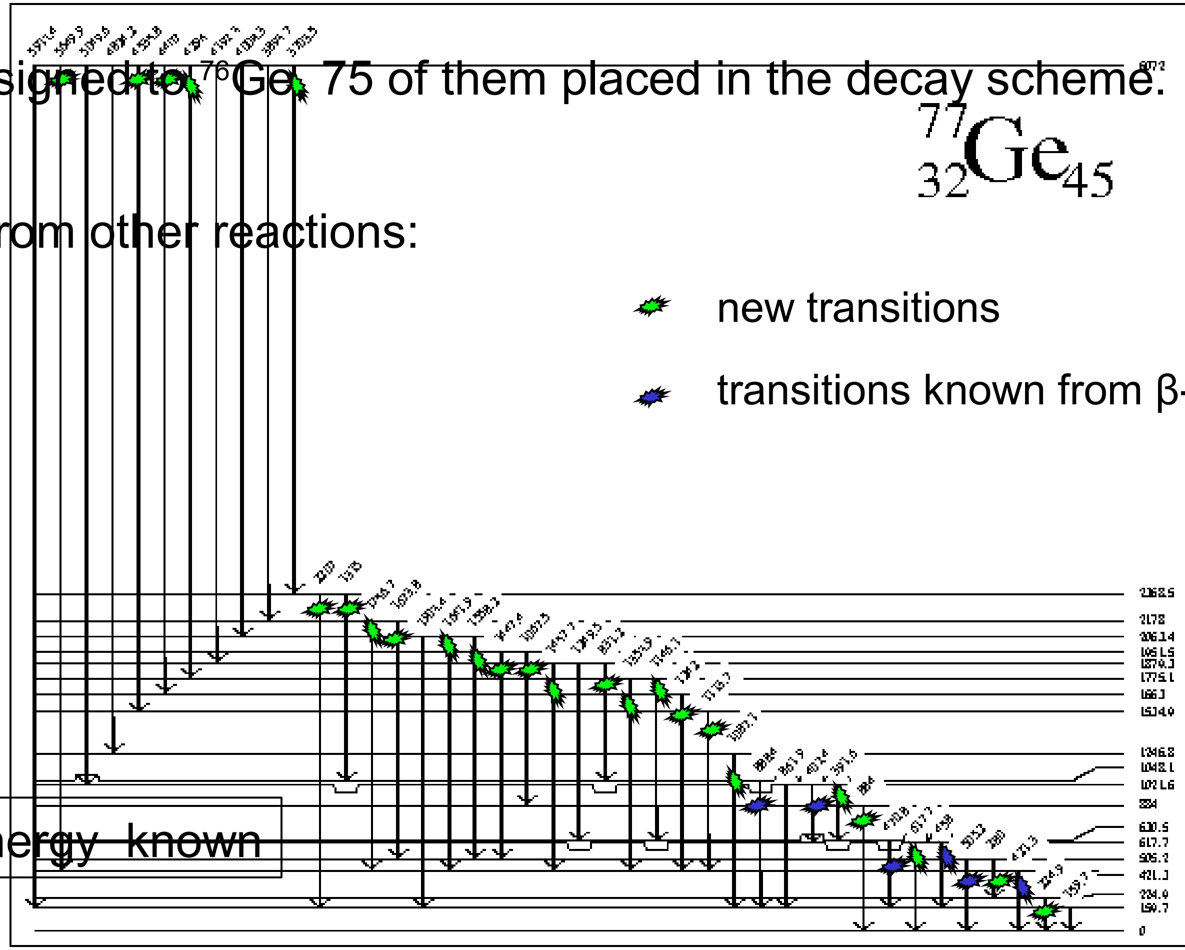
Time difference is used to distinguish between random and true coincidences.

Example 5049 keV



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

Summary

- Neutron capture on ^{76}Ge will produce background in GERDA (prompt cascade and delayed decay of ^{77}Ge). The prompt cascade has to be well known to veto the delayed decay of ^{77}Ge.
-
- The cross sections of the $^{76}Ge(n,\gamma)$ and $^{74}Ge(n,\gamma)$ reactions were measured by the activation method.
  - Values of higher reliability obtained
  -
- The prompt gamma-ray spectrum in ^{77}Ge and ^{75}Ge were measured and the level schemes reconstructed.
  - about 60% of emitted energy found

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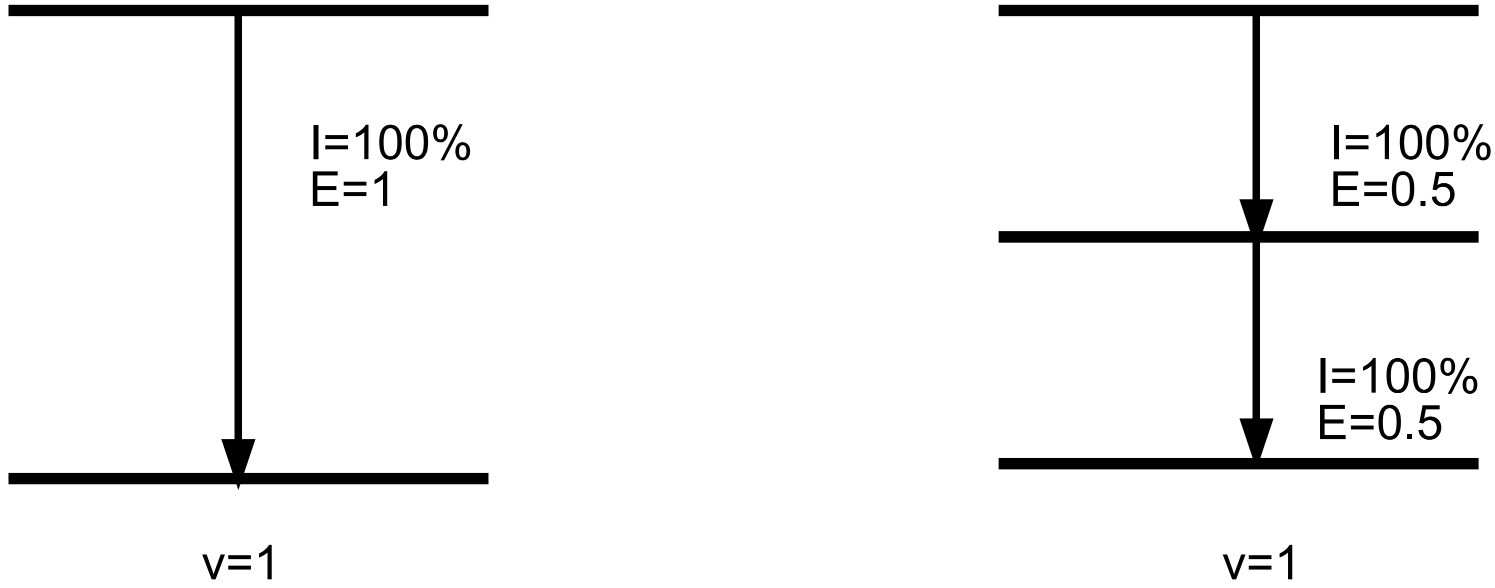
- Data will be used for further MC-simulations

Energy weighted intensities

$$v = \frac{I_\gamma * E_\gamma}{I_{total} * E_{total}}$$



Neutron Capture by ^{76}Ge

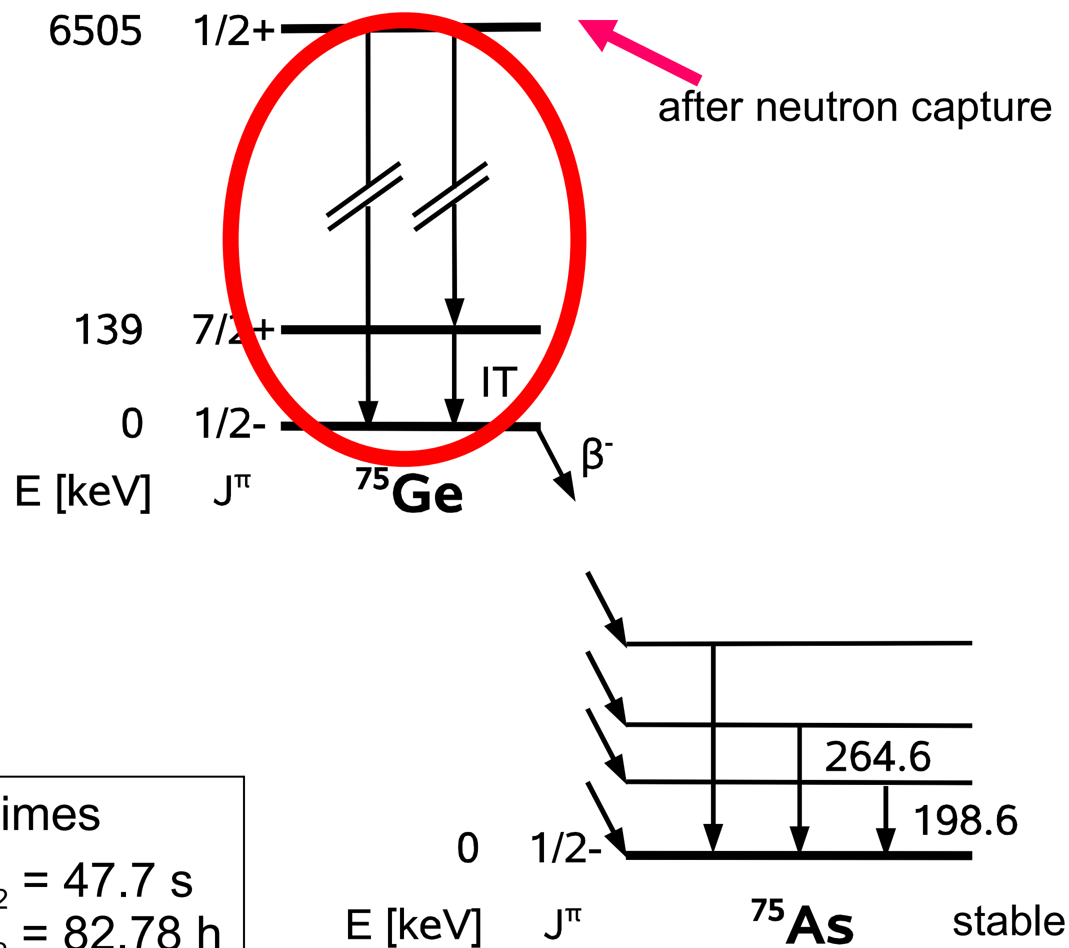
- In GSTR-06-012 Luciano discussed this problem:
-
- **Production rate: 0.5 – 1 nuclei/kg/y** (LAr)
- Counts in ROI due to β-particles
- **^{77}Ge: 8 x 10^{-5} counts/keV/decay** (can be reduced by factor of 3 by anti-coincidence).
- **^{77m}Ge: 2.1 x 10^{-4} counts/keV/decay** (small reduction due to 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.).
2. not feasible
3.
4. 2. Trigger on muon veto & prompt gamma-rays (after neutron capture) in HPGe (9 events/day).
5. $\varepsilon = \varepsilon_{mv} \times \varepsilon_{Ge} \times \varepsilon_{dec}$ — favoured
6. ε = 0.95 x 0.56 x 0.96 = 0.51

Neutron Capture by ^{74}Ge

S_n = 6505 keV

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



Half-life times

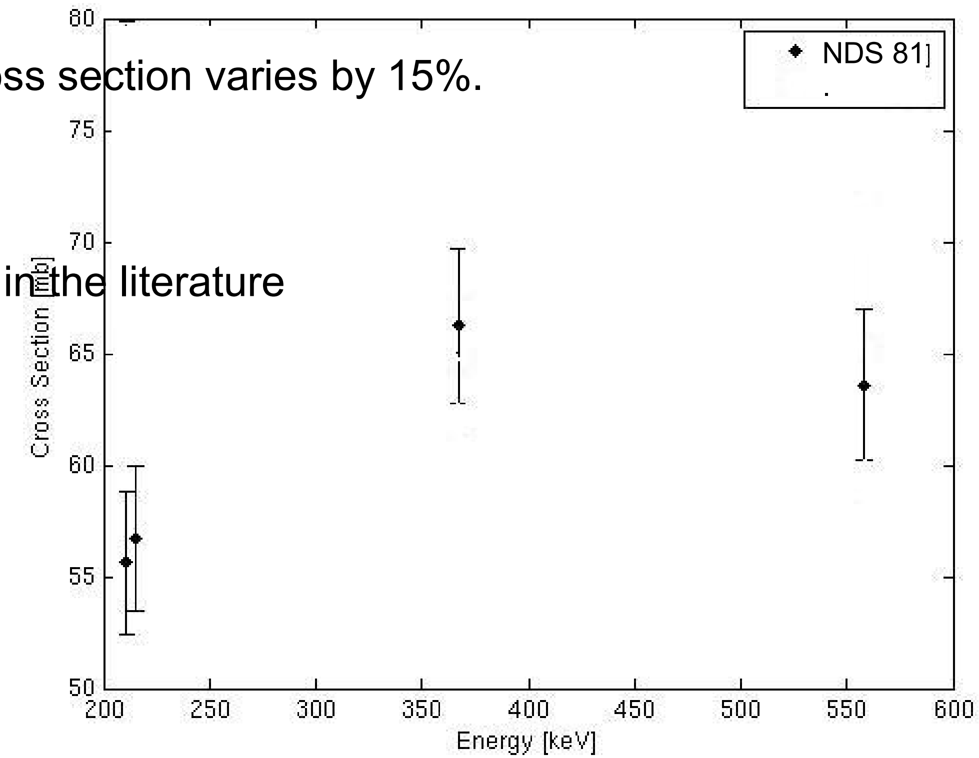
^{75m}Ge: $t_{1/2}$ = 47.7 s
^{75}Ge: $t_{1/2}$ = 82.78 h

Emission probabilities

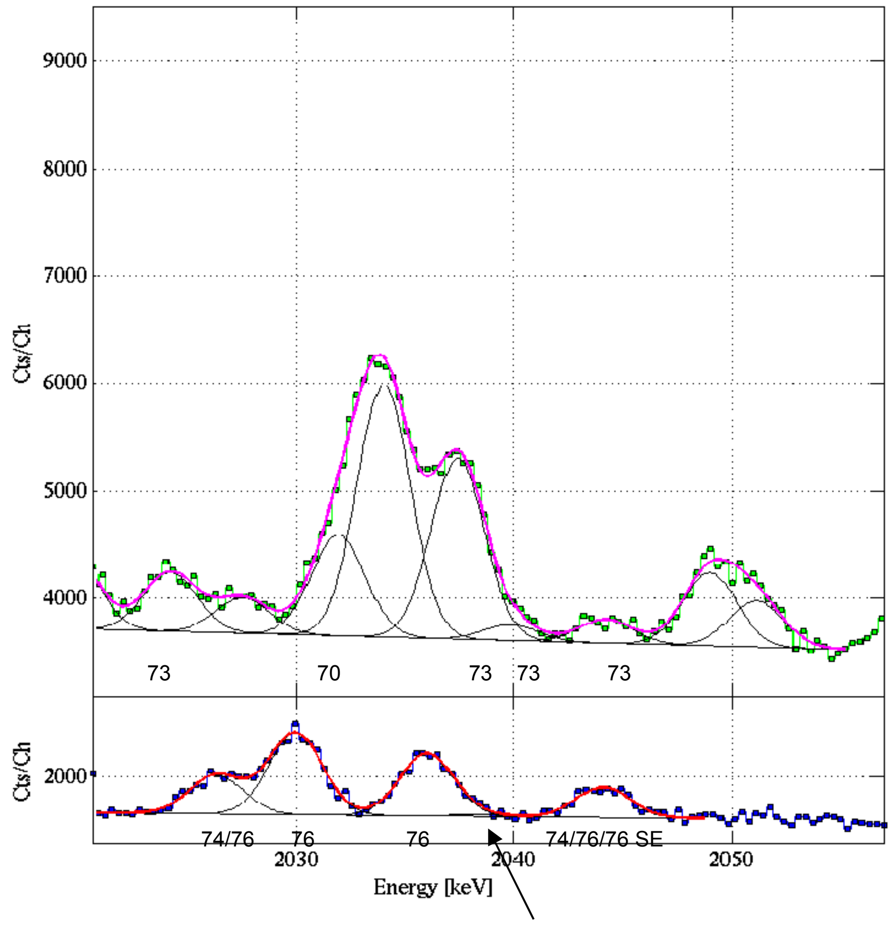
Depending on the transition used, the cross section varies by 15%.

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

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



ROI @ 2039 keV

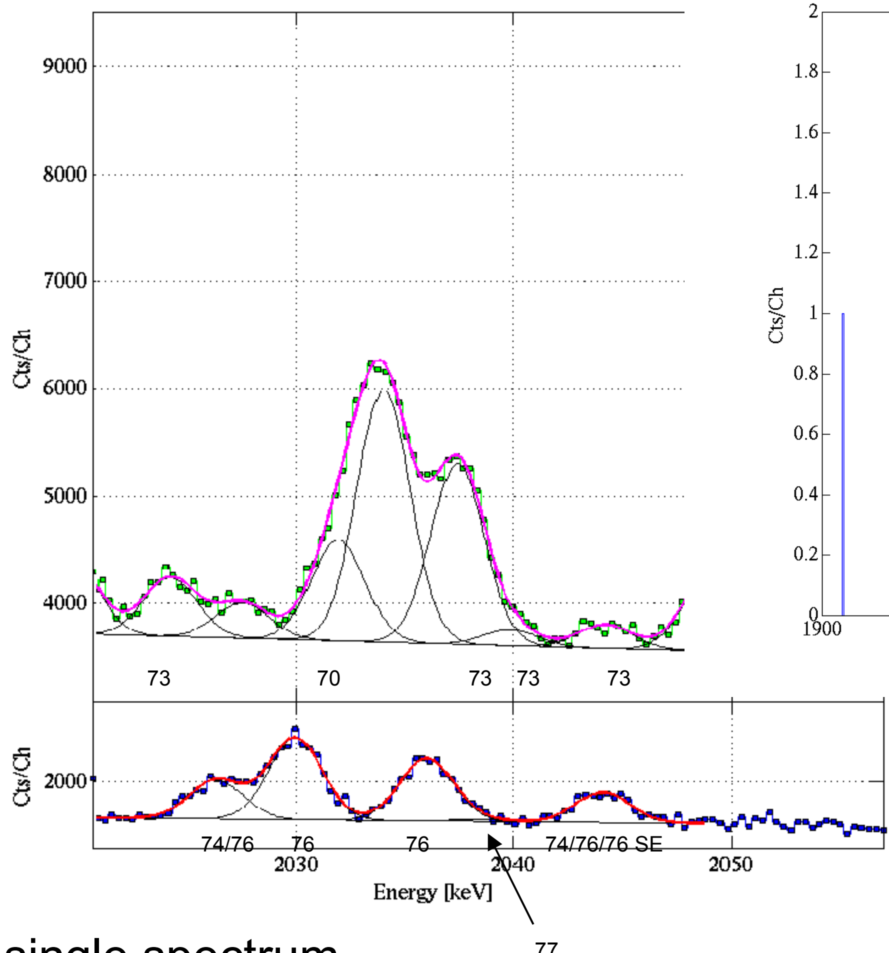


single spectrum

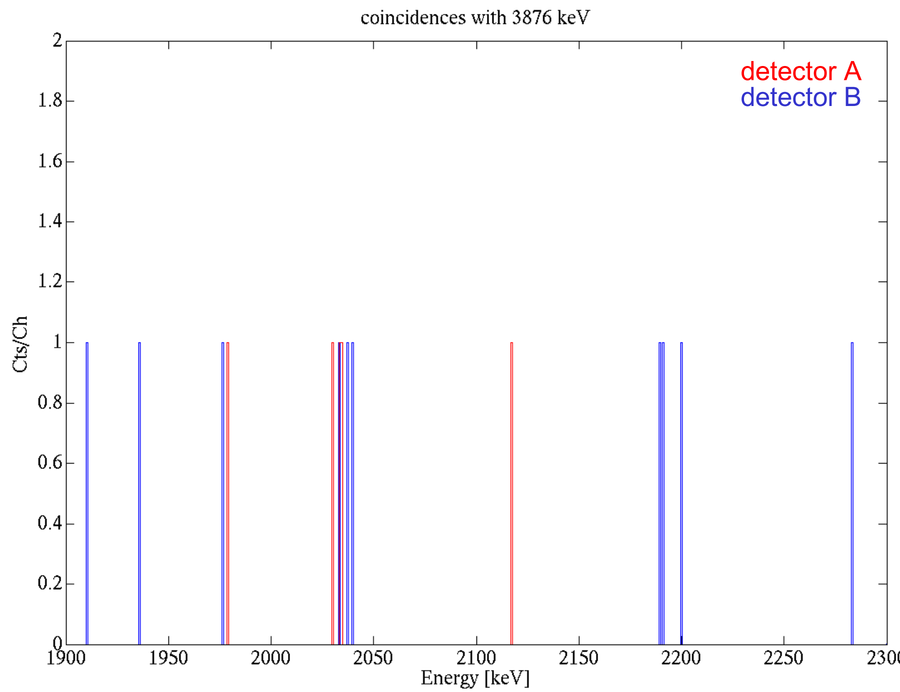
Depleted GeO_2
^{70}Ge: 22.078%
^{72}Ge: 30.04%
^{73}Ge: 8.40 %
^{74}Ge: 38.90 %
^{76}Ge: 0.59 %

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



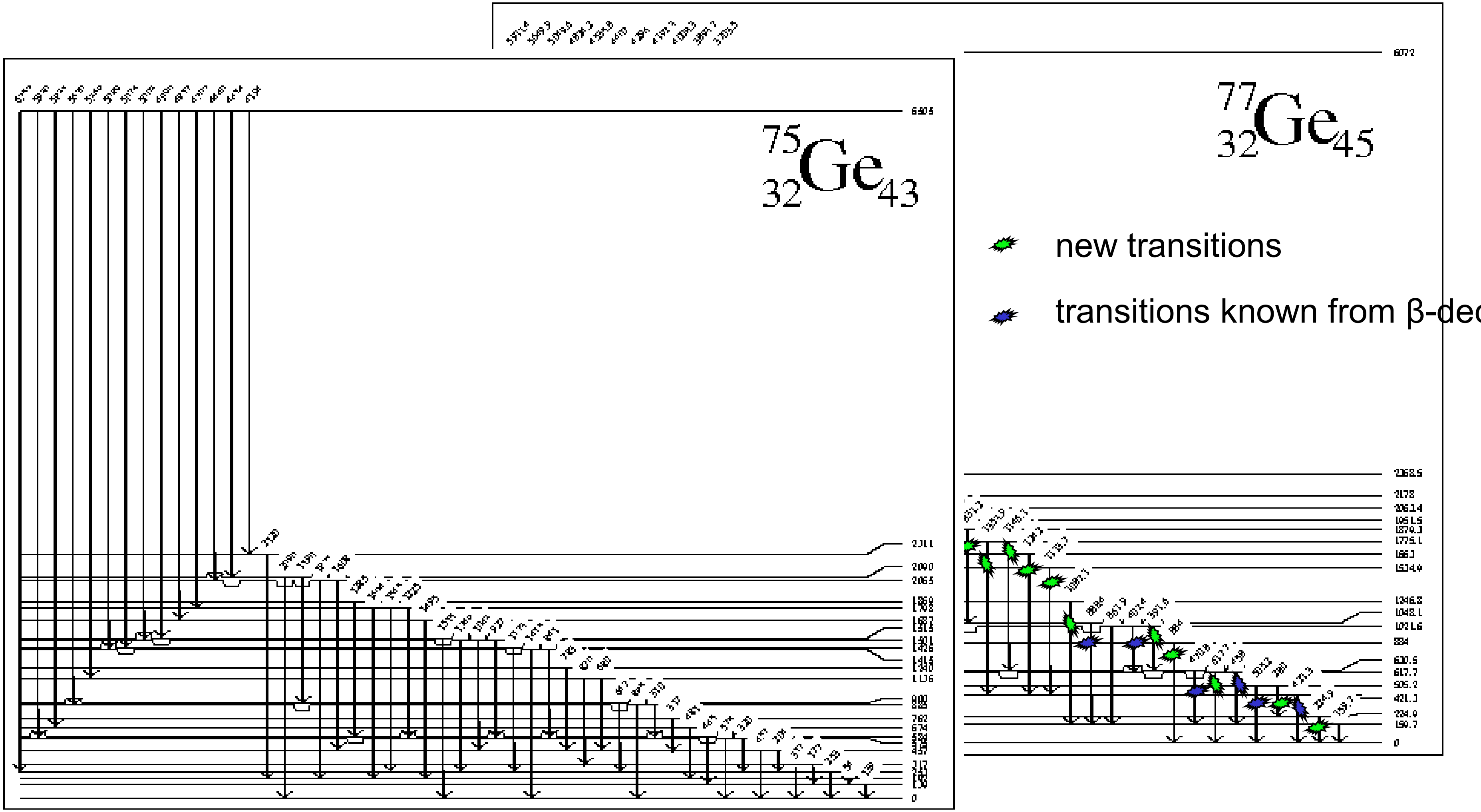
single spectrum



Coincident with transition 3876 keV

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

Decay scheme in ^{75}Ge (preliminary)



PGAA @ FRM II

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

Beam

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

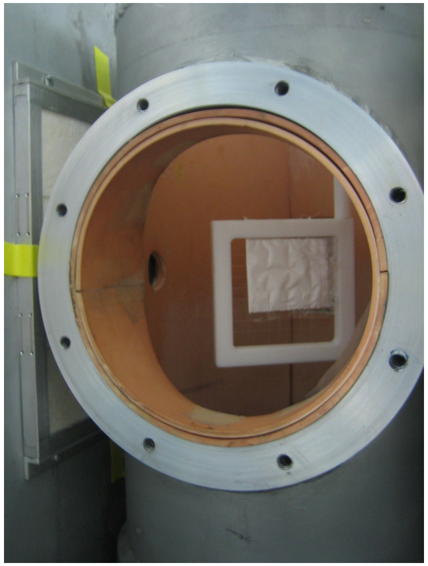
$<\lambda_n> = 6.7$ Å (cold)

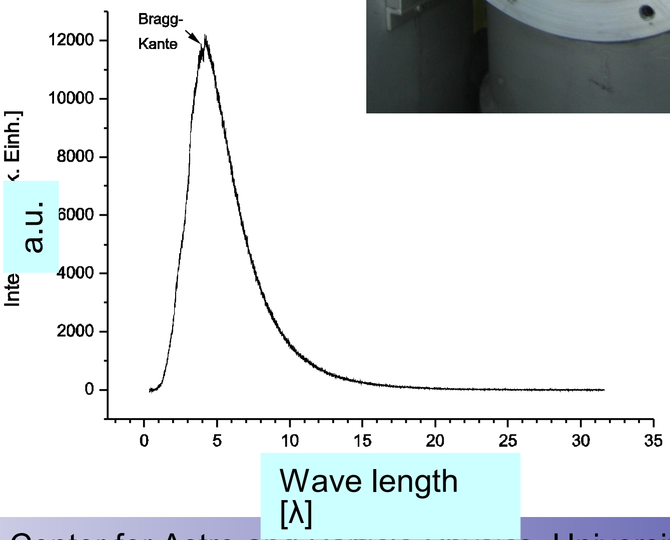
$<E_n> = 1.83$ meV

Detectors

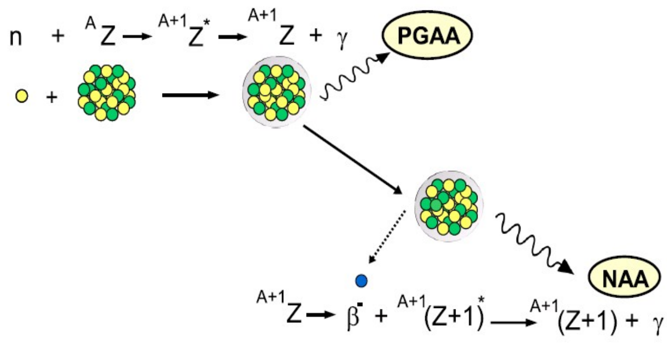
2 HPGe with Compton suppresion

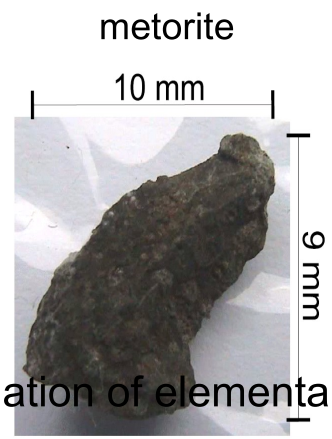
Li/Cd/Pb shielding

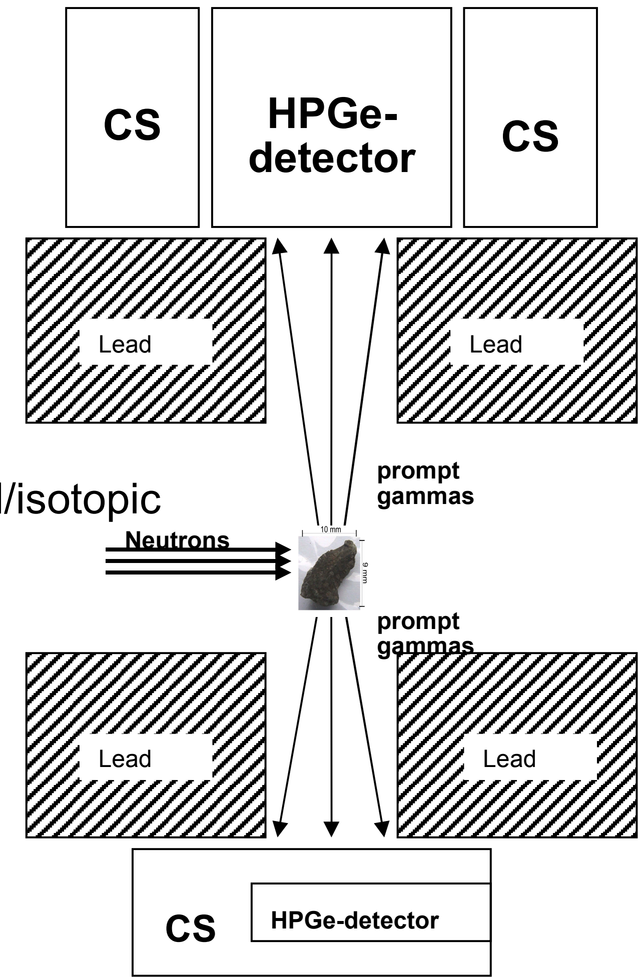




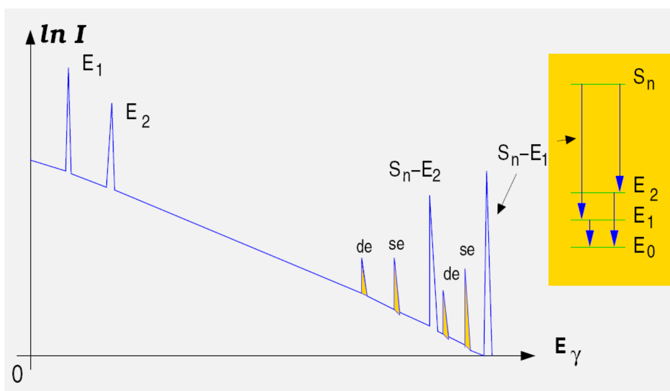
Prompt Gamma-ray Activation Analysis





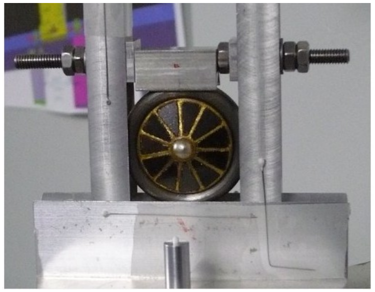
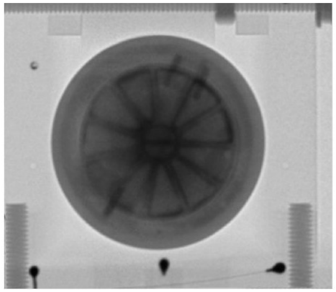
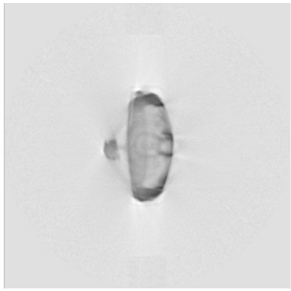
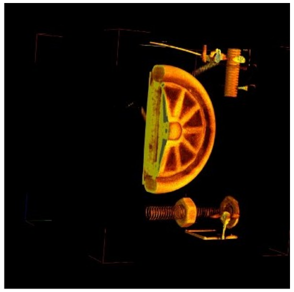


PGAA used for non-destructive determination of elemental/isotopic composition. Less sensitive than NAA, but in principle all (also non-radioactive) isotopes (except ^4He) can be detected.



PGAA/PGAI/NT

Other techniques: Prompt Gamma-ray Activation Imaging, Neutron Tomography

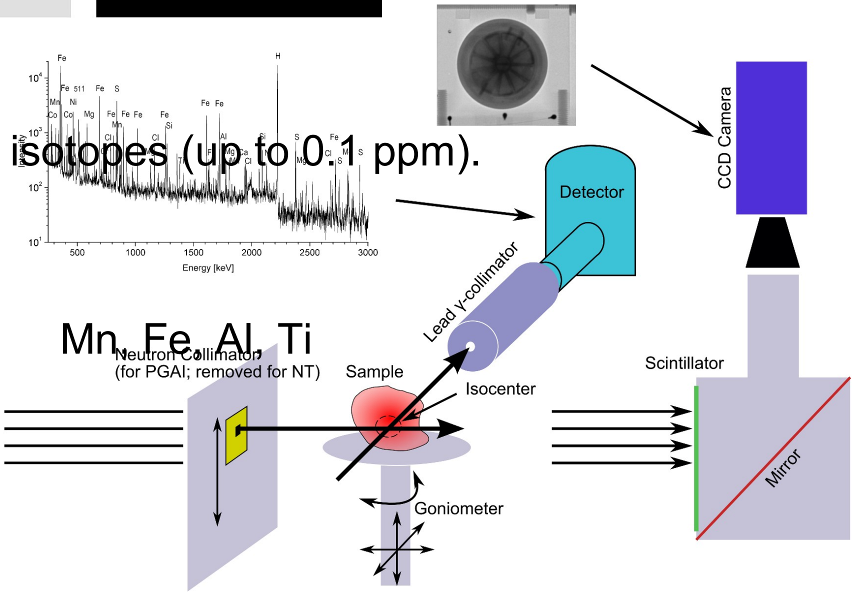
fibula 6 th(century (replica

Sensitivity depends on the cross sections of the isotopes (up to 0.1 ppm).

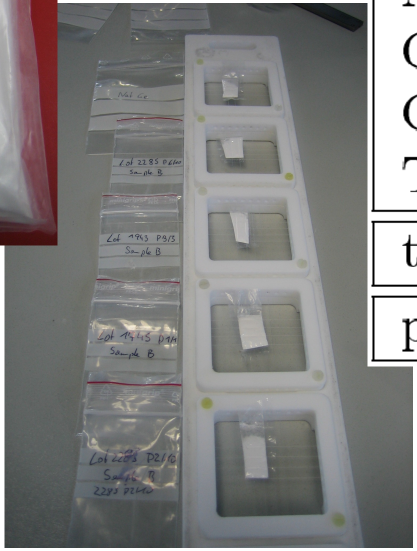
Sensitivity

high: B, Cd, Sm, Gd
medium: H, Cu, Ag, Au, Na, K,
low: C, N, O, Mg, Si, Sn, Pb

Mn, Fe, Al, Ti



Abundances in depleted GeO_2

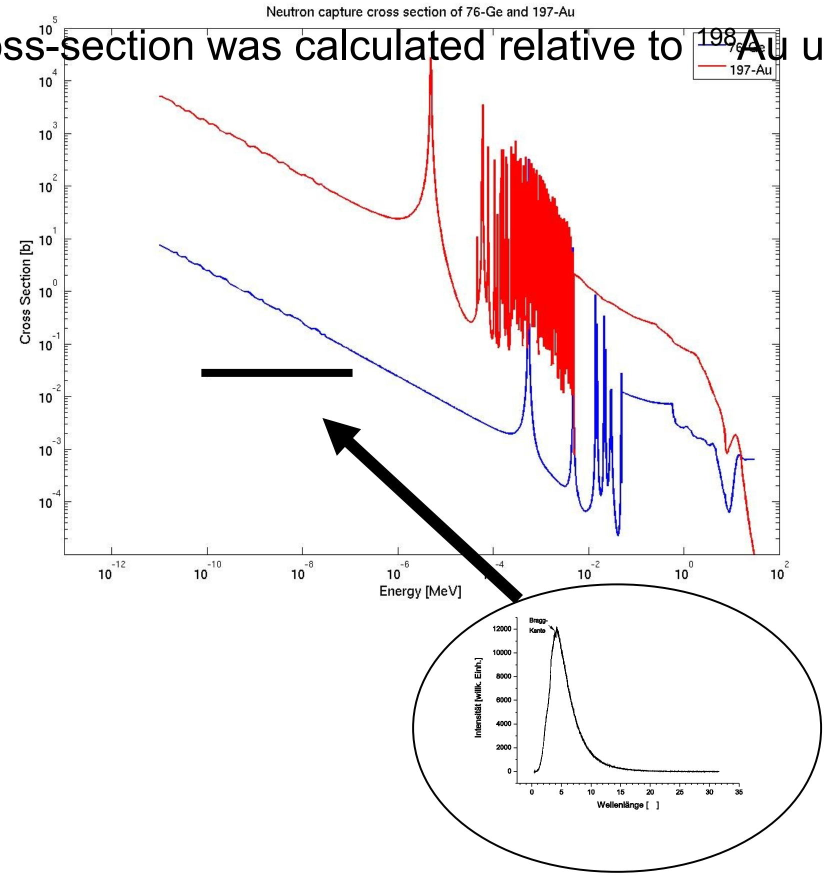


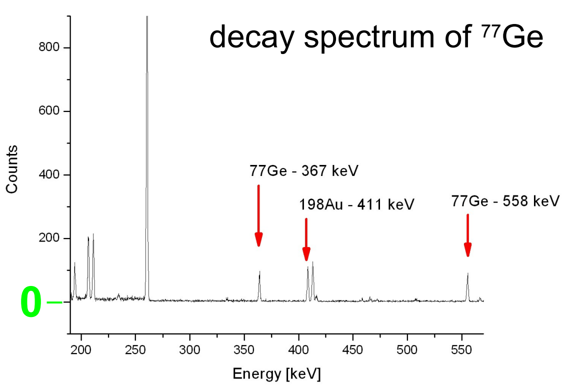
Ge-isotope	70	72	73	74	76
	averaged over all samples				
Certificate	21.50	29.90	8.45	38.92	0.57
LNGS 2	20.40	30.39	8.80	39.77	0.64
Moscow	22.74	30.05	8.30	38.42	0.60
Geel INAA	22.44	29.65	8.32	39.05	0.54
Geel k0-NAA	22.44	29.65	8.32	39.06	0.53
Tübingen	22.66	29.56	8.35	38.85	0.–
total avera	22.03	29.87	8.42	39.02	0.58
previous	22.8	30.1	8.31	38.3	0.60

For detection of ^{76}Ge PGAA is not competitive becaus

Thermal n-capture cross section

β-decay were measured by HPGe detectors. The cross-section was calculated relative to ^{198}Au using l





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)

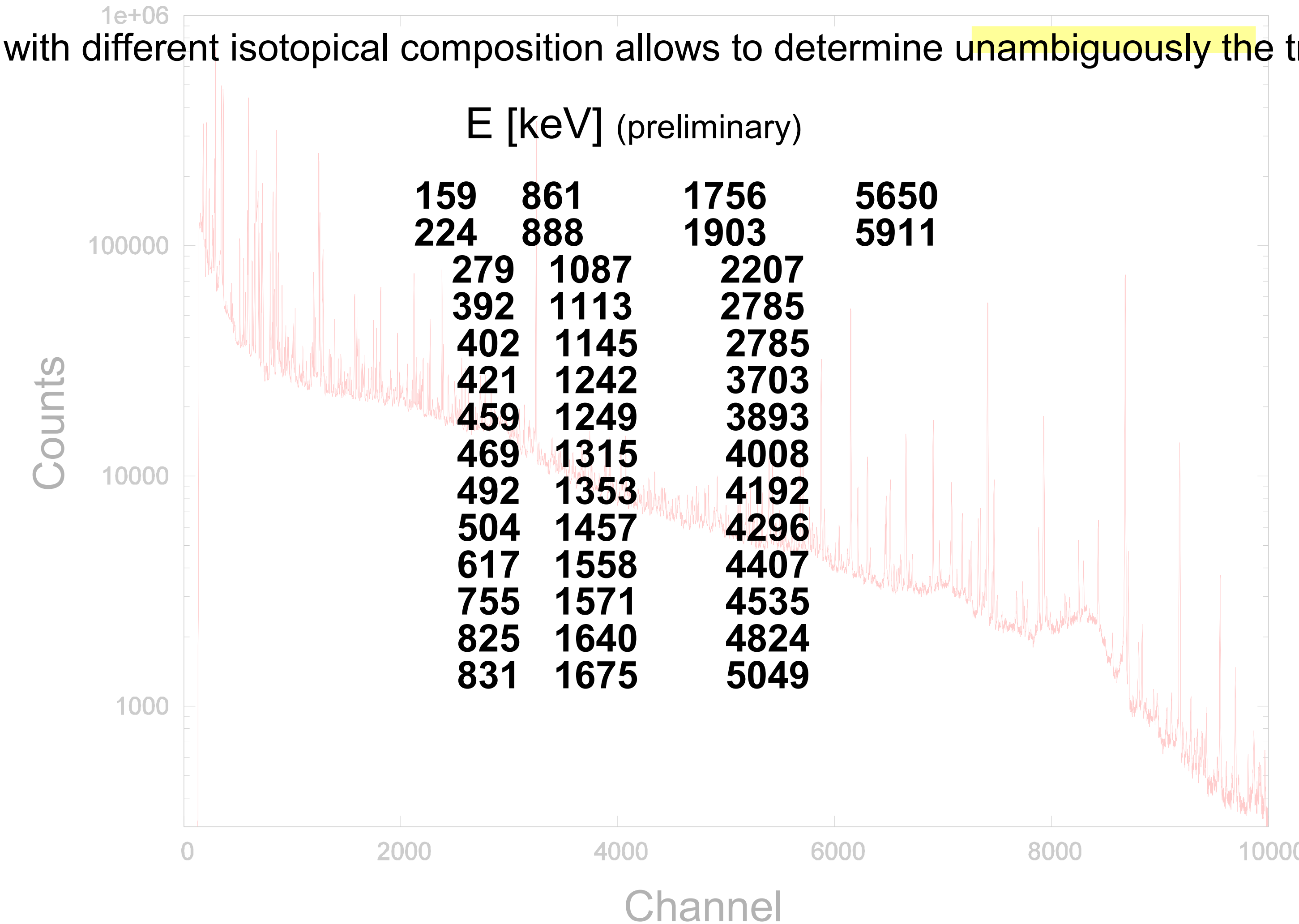
.

-
- 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.).
2. not feasible
3.
4. 2. Trigger on muon veto & prompt gamma-rays (after neutron capture) in HPGe (9 events/day). favoured
5. $\varepsilon = \varepsilon_{mv} \times \varepsilon_{Ge} \times \varepsilon_{dec}$
6. ε = 0.95 x 0.56 x 0.96 = 0.51
7.
8. Trigger on energy deposition of >4 MeV (above natural radioactivity) in HPGe.
9. lower efficiency than strategy 2.

Prompt γ-spectrum in ^{77}Ge

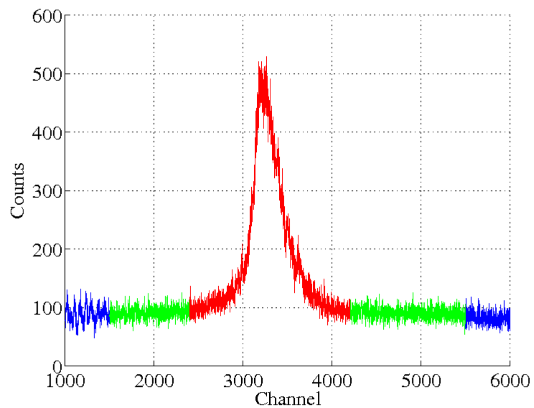
ring spectra with different isotopical composition allows to determine unambiguously the transitions in

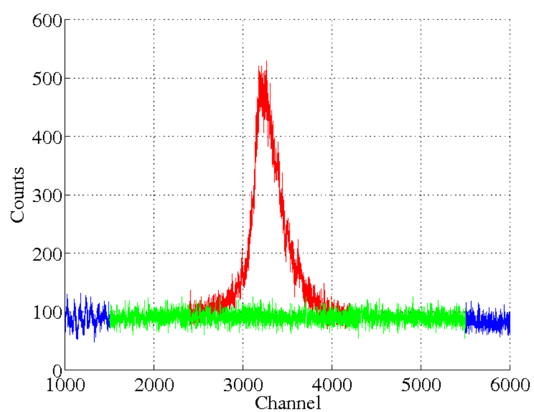


E [keV] (preliminary)

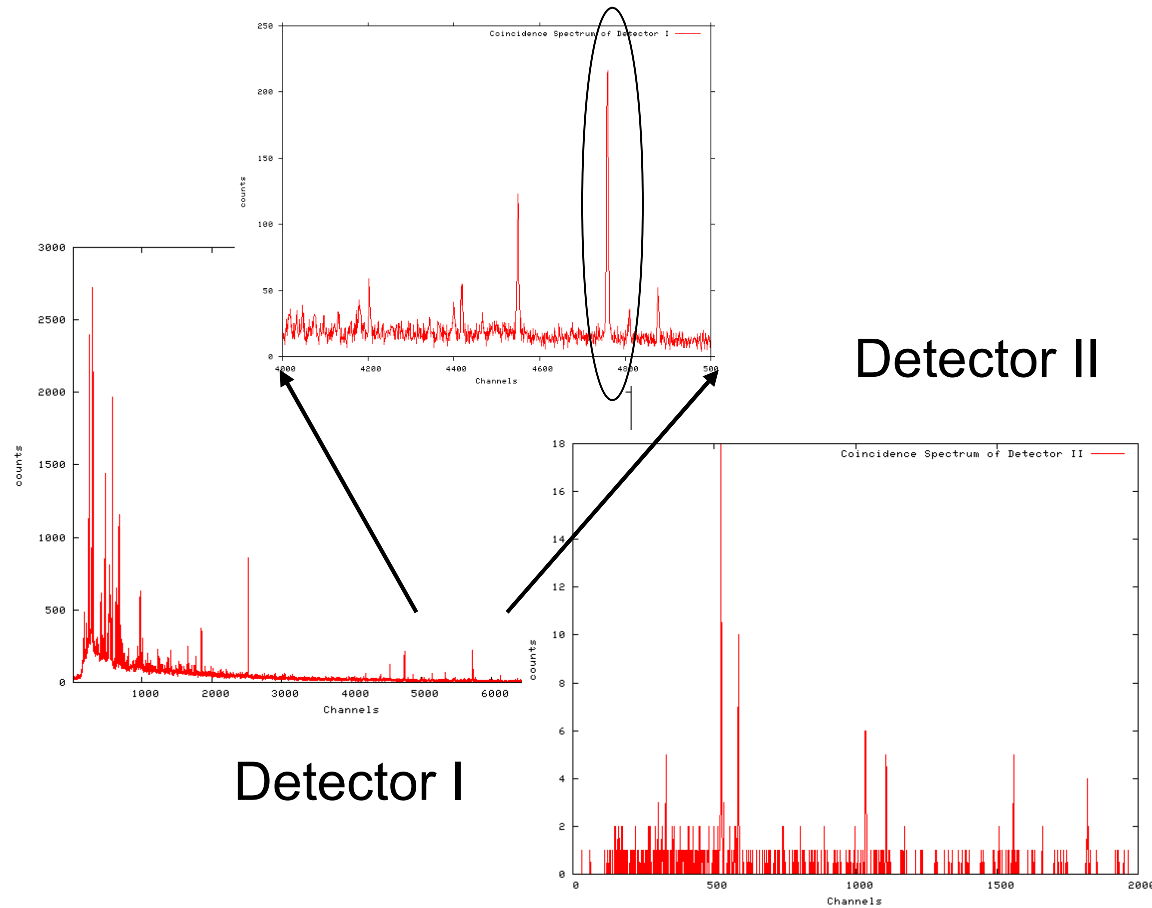
159	861	1756	5650
224	888	1903	5911
279	1087	2207	
392	1113	2785	
402	1145	2785	
421	1242	3703	
459	1249	3893	
469	1315	4008	
492	1353	4192	
504	1457	4296	
617	1558	4407	
755	1571	4535	
825	1640	4824	
831	1675	5049	

Analysis





Time information



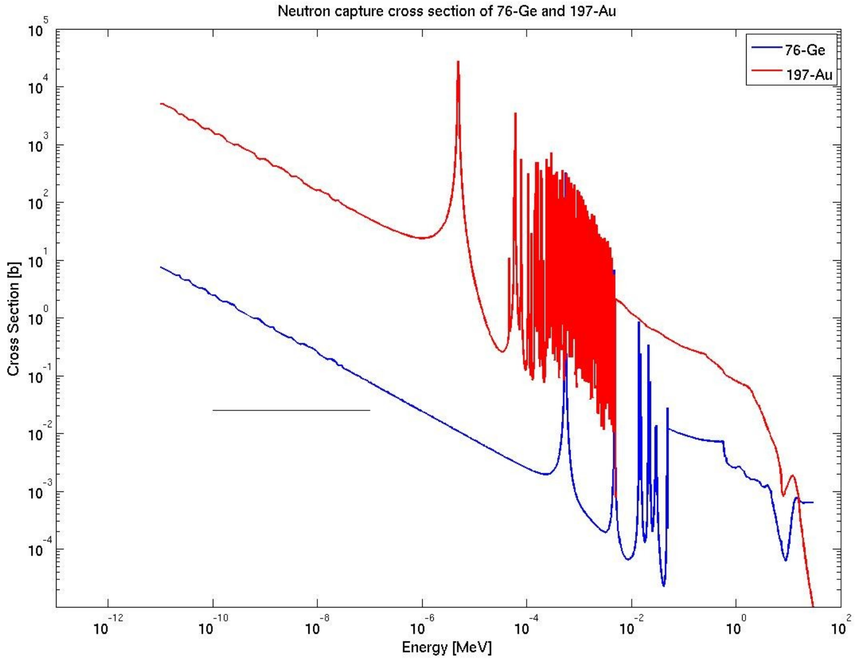
Detector II

Detector I

Cross Section

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

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



Coincidence