Neutron induced backgrounds and measurements neutron activation of ^{76}Ge

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the GERDA Collaboration

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Germany

previous ^{76}Ge experiments

previous experiments: HDM (5 det) and IGEX (3 det)

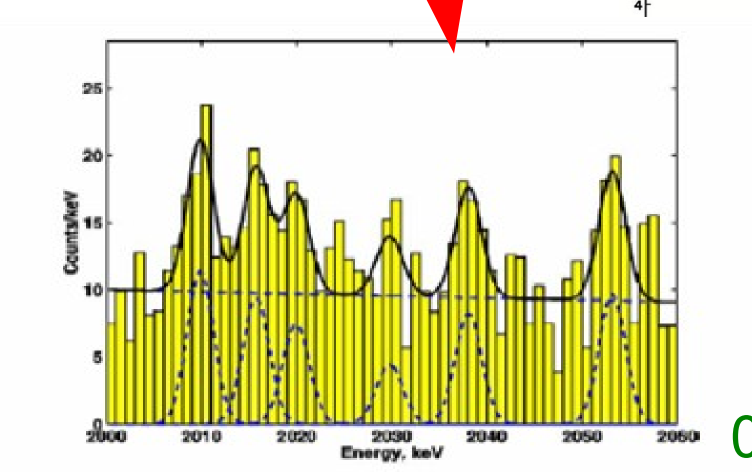
Klapdor-Kleingrothaus et al.

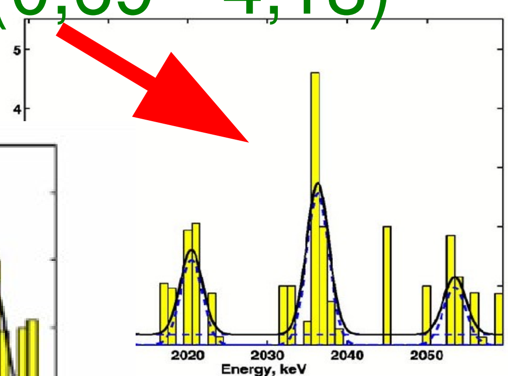
Phys Lett B586 (2004) 198

71,7 kg·y

$T_{1/2} > 1{,}9 \cdot 10^{25}$ y (90%CL)

(0,69 - 4,18)





MPLA21 (2006):

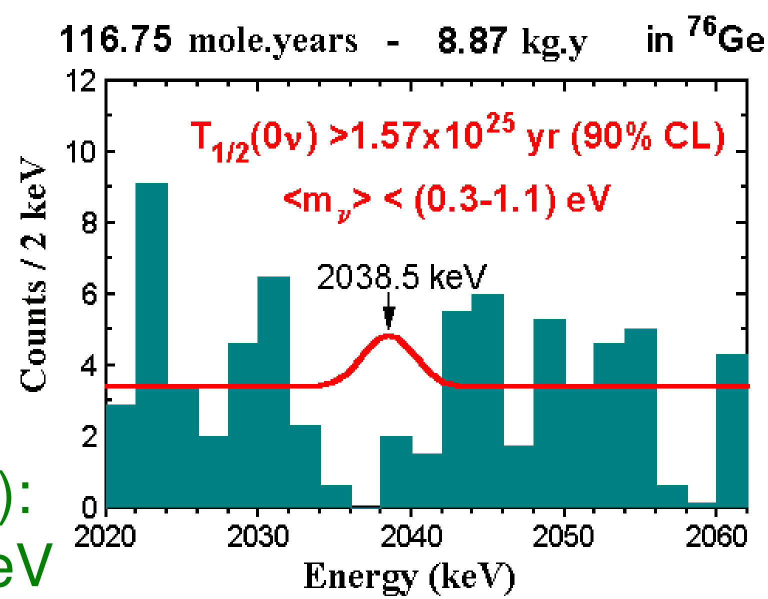
$0{,}27 < m_{\beta\beta} < 0{,}4$ eV

Aalseth et al.

Phys Rev D65 (2002) 092007

8,9 kg·y

$T_{1/2} > 1{,}6 \cdot 10^{25}$ y (90%CL)



need of support experiments

Higher sensitivity needs less background

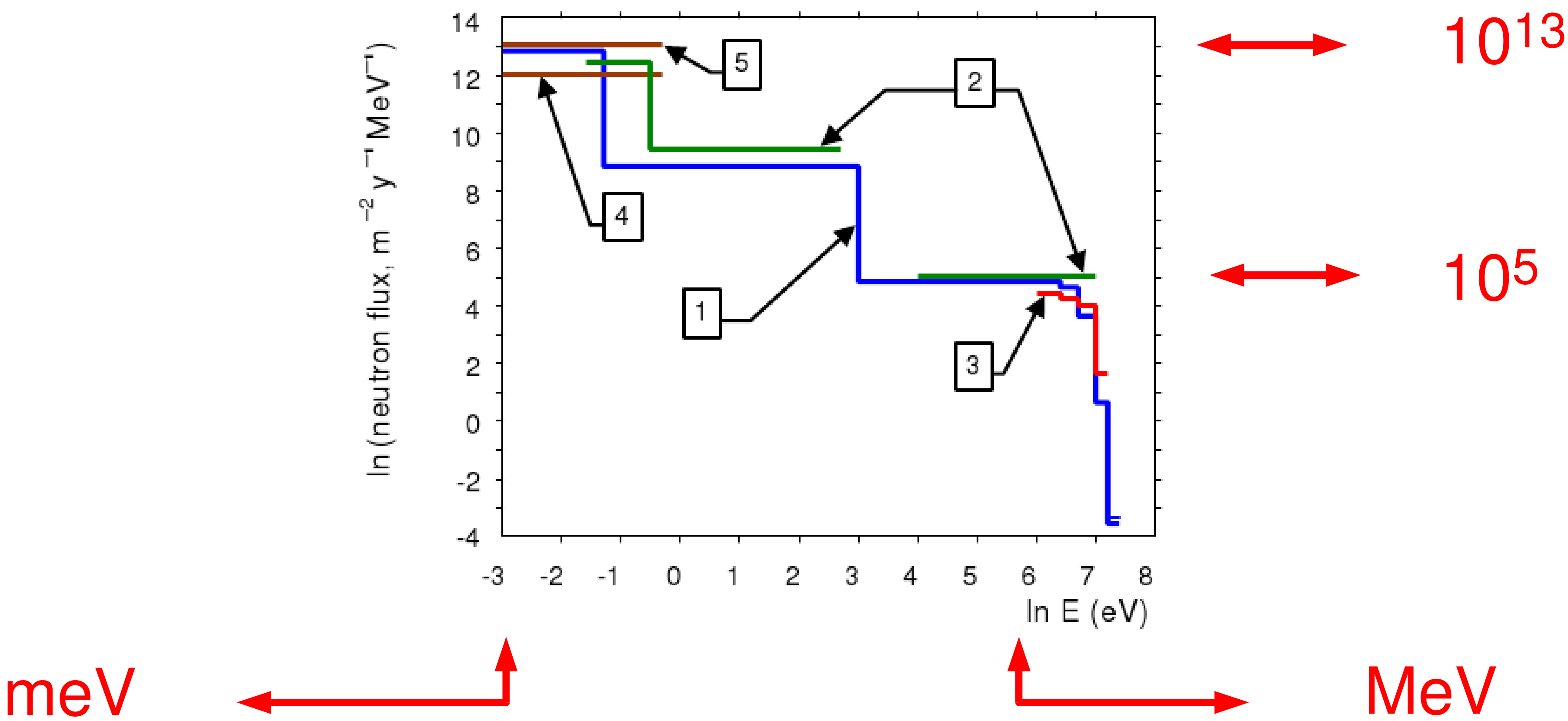
nature & structural components & calibration

- understand (reduce) background contributions
  in laboratory LNGS 3800 m.w.e.
- production of isotopes

- neutron capture (n,γ)
- elastic and inelastic neutron scattering (n,n), (n,n')
- neutron production reactions (n,p),..

neutron flux in underground labs

Measurements: difficult, selective, incomplete



Measured neutron flux in several underground laboratories.
1 LNGS, P. Belli et al. [5]; 2 LNGS, A. Rindi et al., [6] ;
3 LNGS, F. Arneodo et al., [7] ;4 Modane, V. Chazal et al., [11] ;
5 Broken Hill, S.R. Hashemi-Nezhad ad L.S: Pearl, [13]

calibrations

select source for

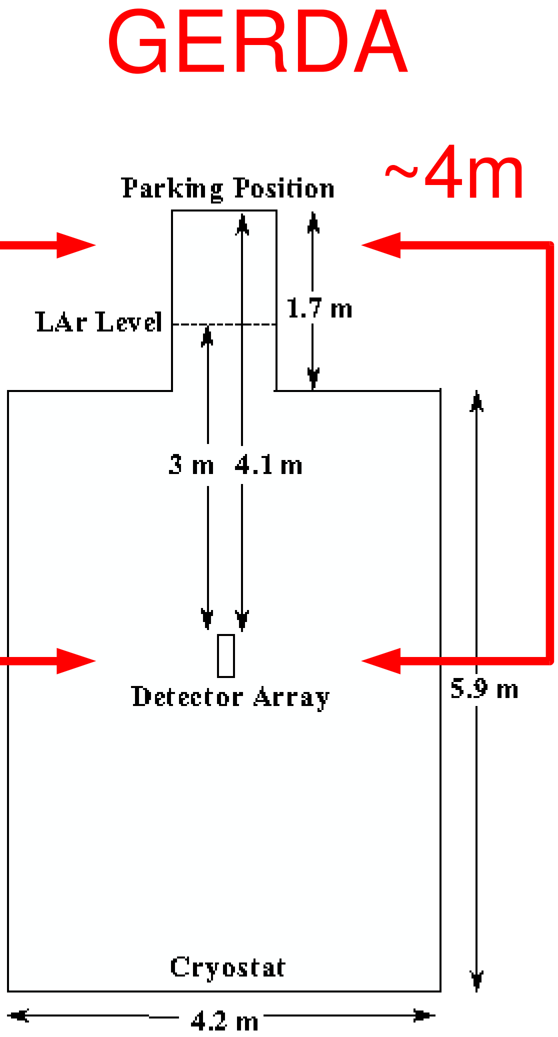
- lines (DEP,FEP) close to $Q_{\beta\beta}$
- reasonable $T_{1/2}$
- low α – energy

select holder for

- good shielding
- low emission prob.

select positions for optimal

- parking
- calibration



F.Froborg, NIMA/PhD thesis

calibrations

select source for

lines close to $Q_{\beta\beta}$ — ^{228}Th (^{56}Co, ^{238}U)

reasonable $T_{1/2}$ — 1,9 y

low α – energy — 7,7 MeV

select holder for

good shielding

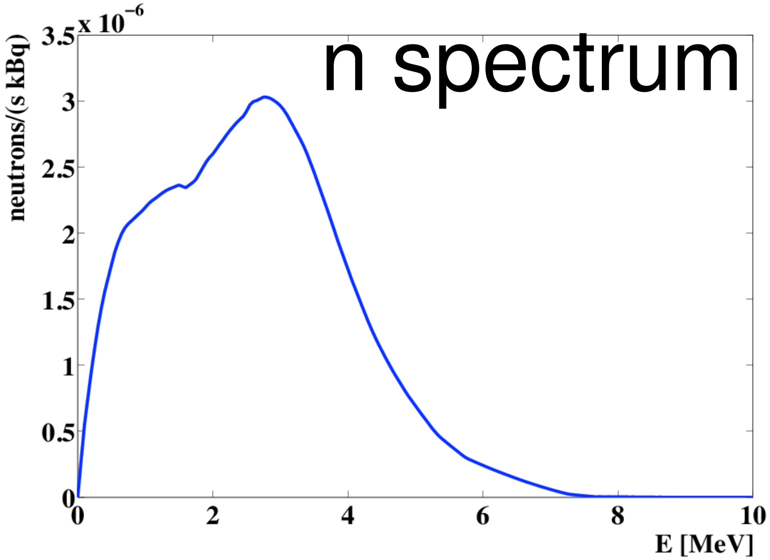
low emission prob.

select positions for optimal

parking

calibration

F.Froborg, NIMA/PhD thesis



calibrations

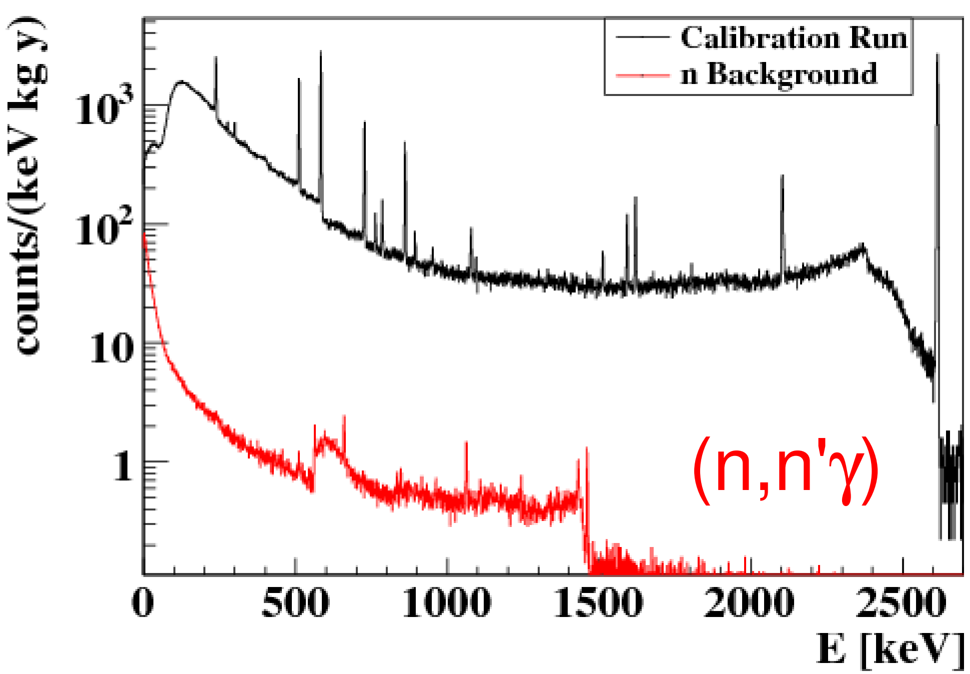
select source for
- lines close to $Q_{\beta\beta}$
- reasonable $T_{1/2}$
- low α – energy

select holder for
- good shielding
- low emission prob.

select positions for optimal
- parking
- calibration

^{228}Th (in Au)

A = 20 kBq

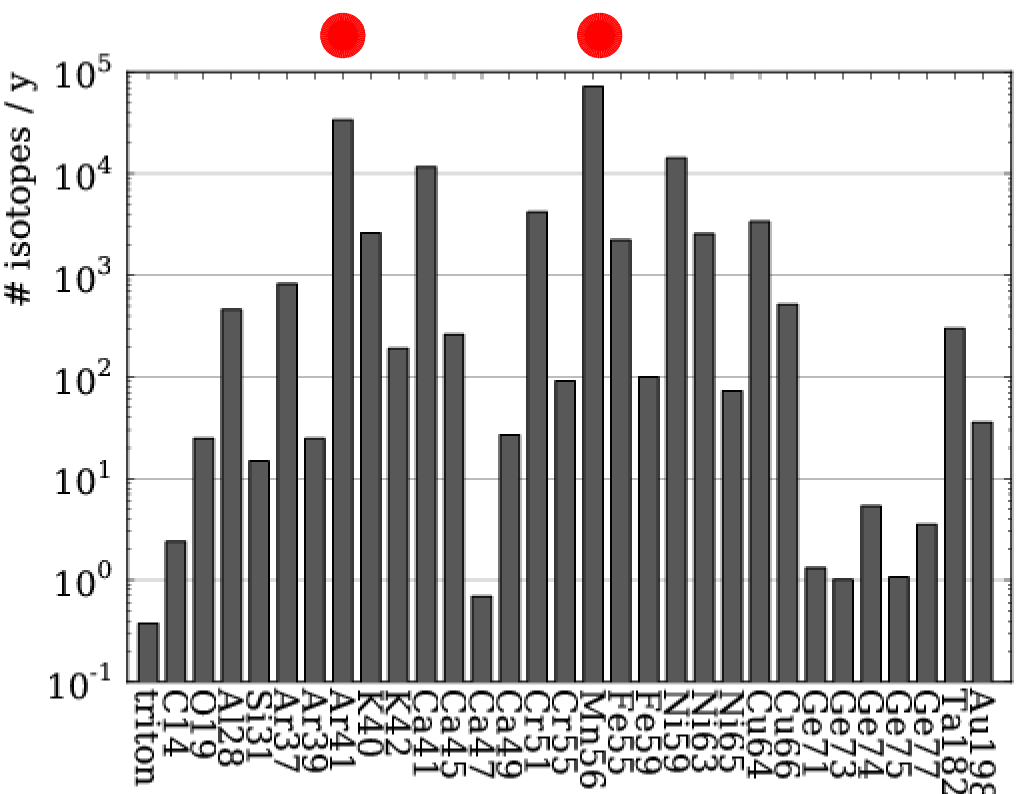


F.Froborg, NIMA/PhD thesis

calibrations

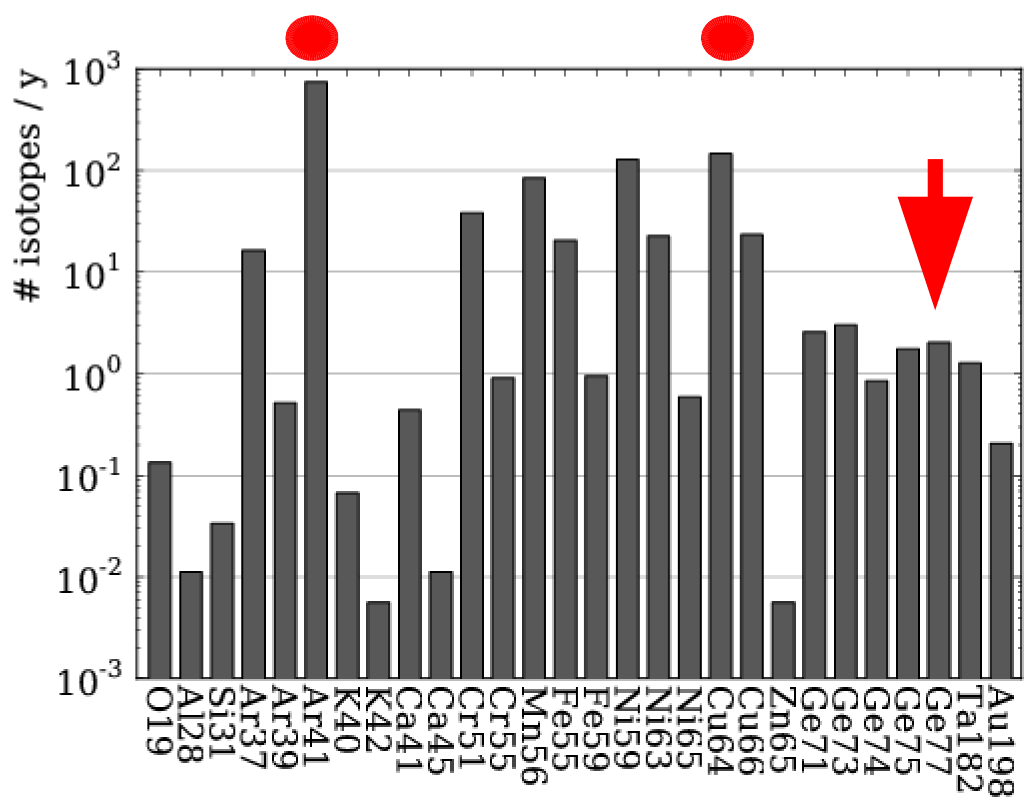
isotopes produced per year

parking



^{41}Ar ^{56}Mn ^{77}Ge

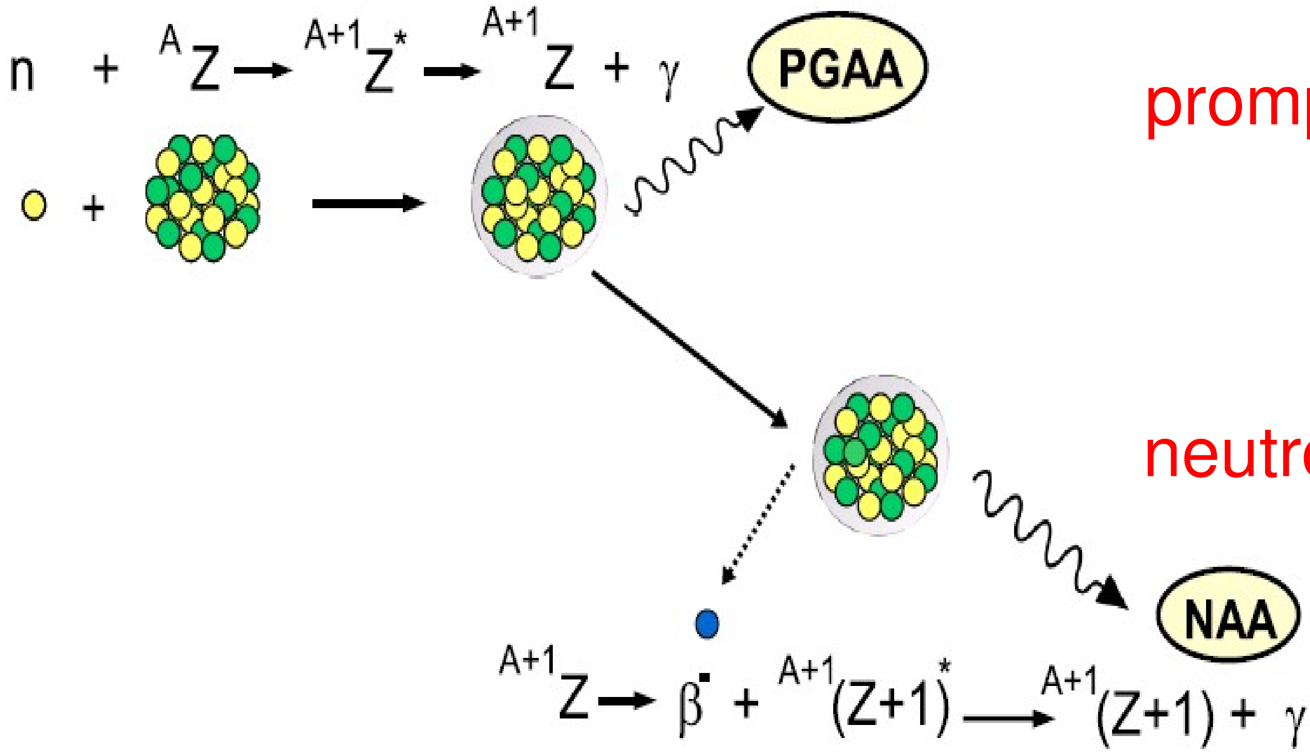
calibration



^{41}Ar ^{64}Cu $^{75,77}Ge$

F.Froborg, NIMA/PhD thesis

neutron capture

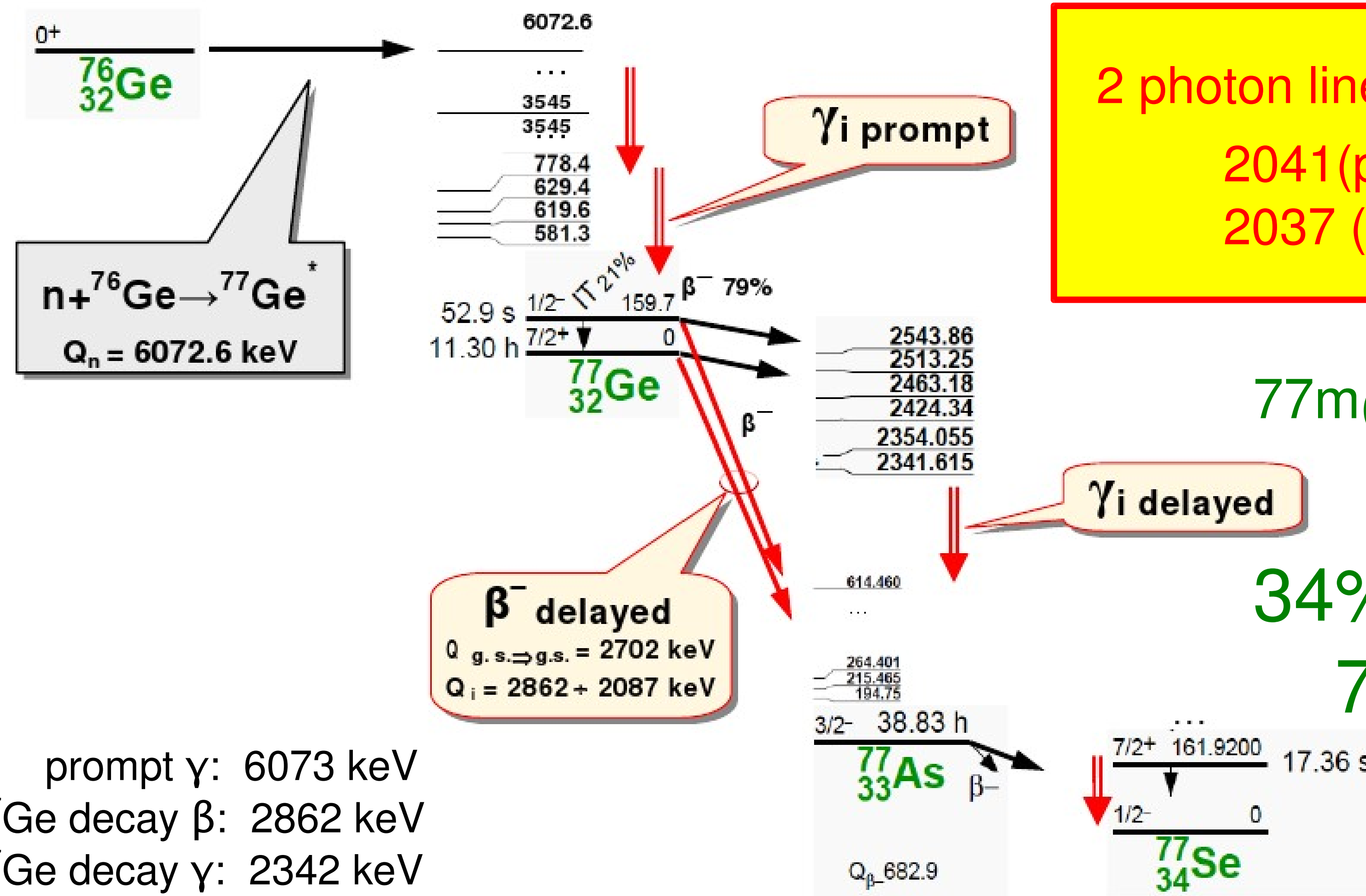


prompt gamma

neutron activation

slow neutrons: large cross section & large flux

^{76}Ge experiments



2 photon lines close to $Q_{\beta\beta}$:

2041 (prompt) keV

2037 (delayed) keV

^{77m}Ge β-decay:

34% directly to ^{77}As g.s.

prompt γ: 6073 keV

^{77}Ge decay β: 2862 keV

^{77}Ge decay γ: 2342 keV

^{77}As decay β: 683 keV

$$n + {}^{76}Ge \rightarrow {}^{77}Ge + \gamma \rightarrow {}^{77}As + \beta + \gamma \rightarrow {}^{77}Se + \beta + \gamma$$

production rates

production rate: 0.5 – 1 ^{77}Ge/(kg y)

(relate to HdM : ~0,5 0νββ-events/(kg y)

energy deposition around 2039 keV via β :

^{77}Ge: 8 x 10-5 counts/(keV decay)

(possible reduction via anti-coincidence / PSA)

^{77m}Ge: 2.1 x 10-4 counts/(keV decay)

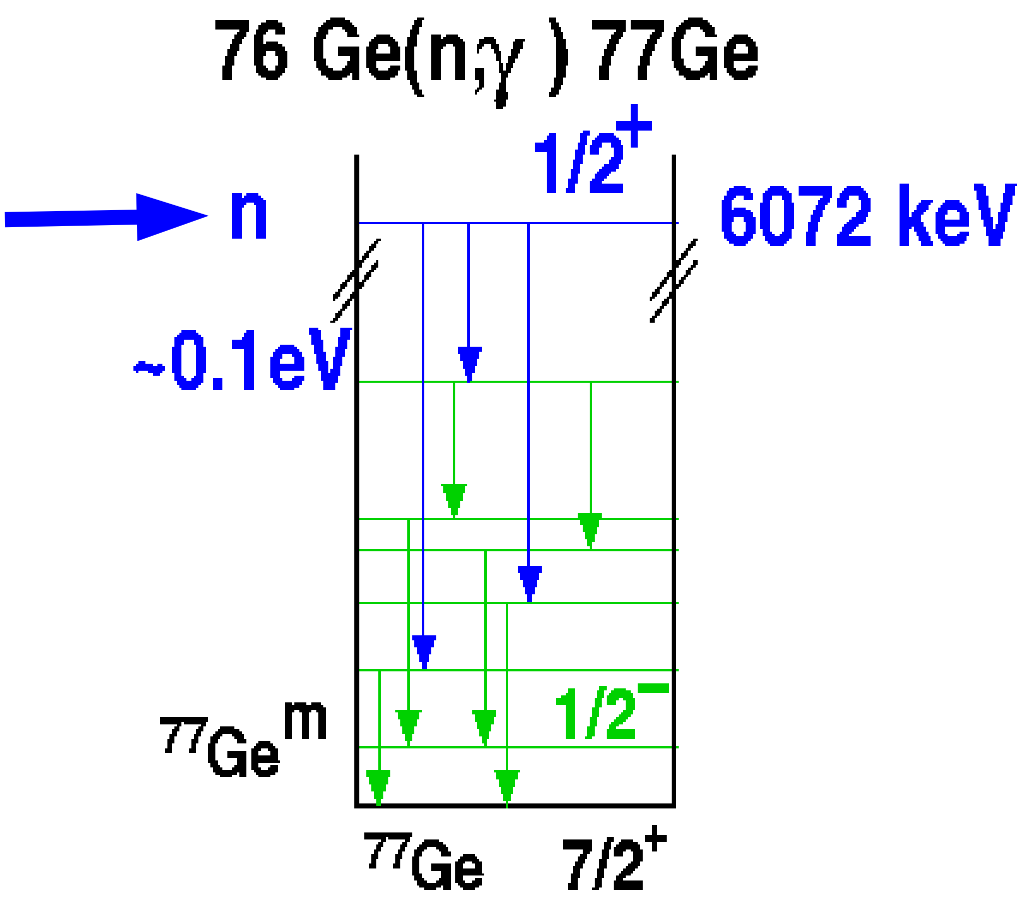
(less reduction due to direct β g.s. Transition)

at LNGS

neutron capture

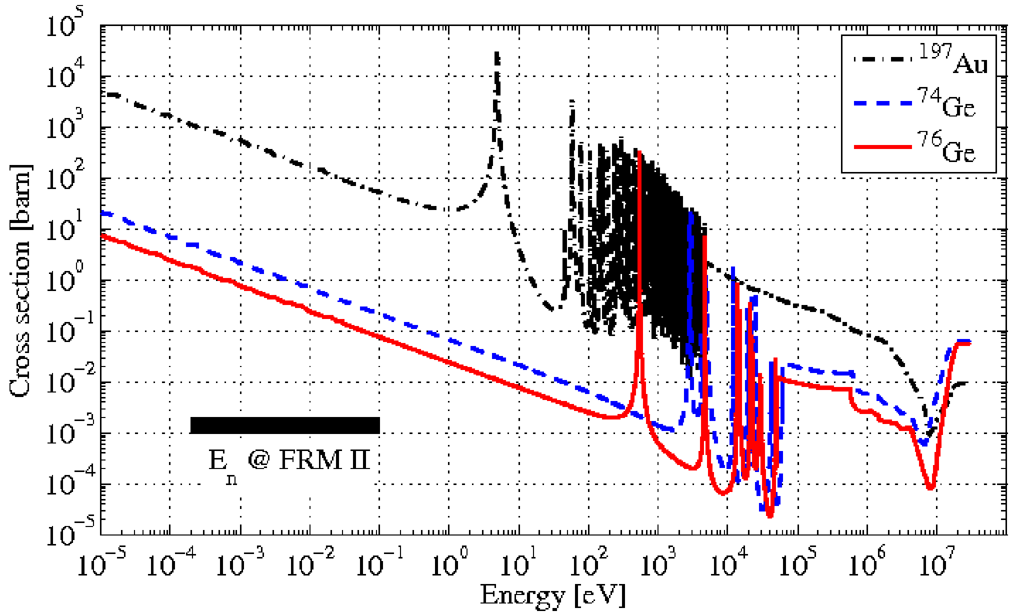
2 photon lines: 2041(prompt) & 2037 (delayed) keV close to $Q_{\beta\beta}$= 2039keV

2 experiments: thermal (< meV, FRM-II) & astro (25 keV, FZK)

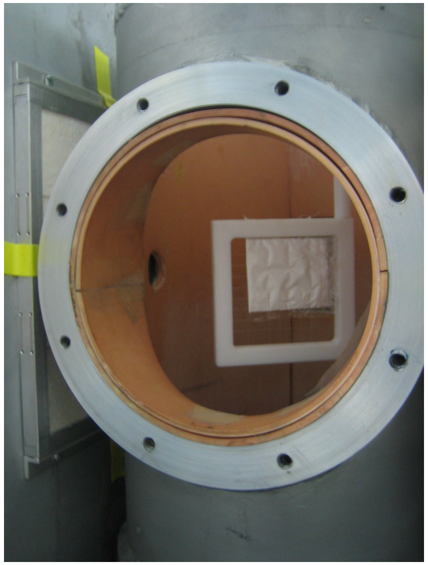


$$v=\frac{\sum E_i\sigma_i}{S_n\sigma_{tot}}=\frac{\sum E_i I_i}{S_n}$$

only 15% known



^{76}Ge experiments

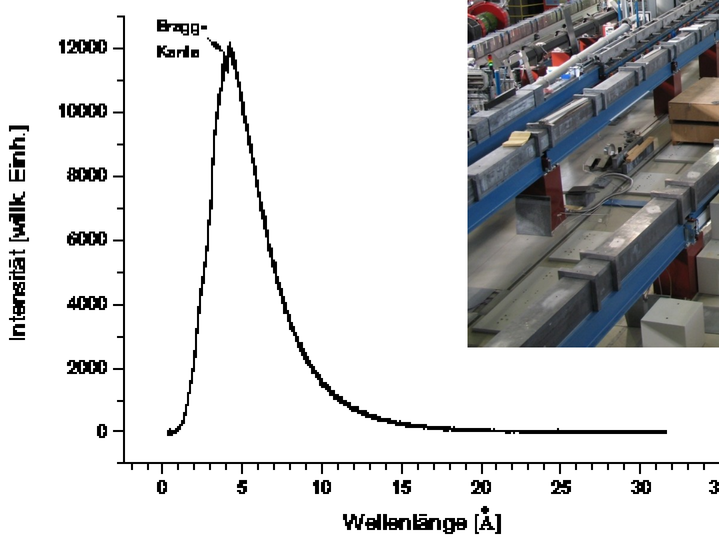


neutron beam

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

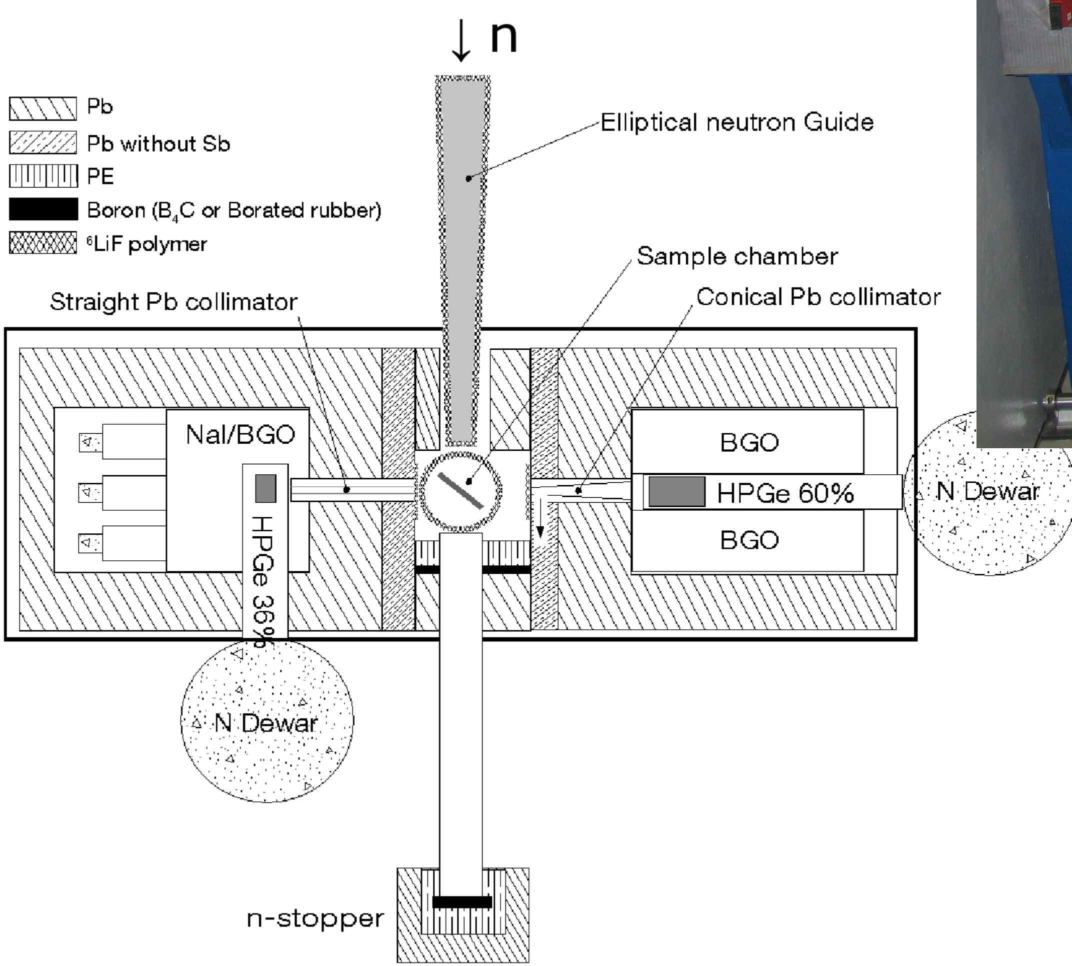
$<\lambda_n>$ = 6.7 Å (cold)

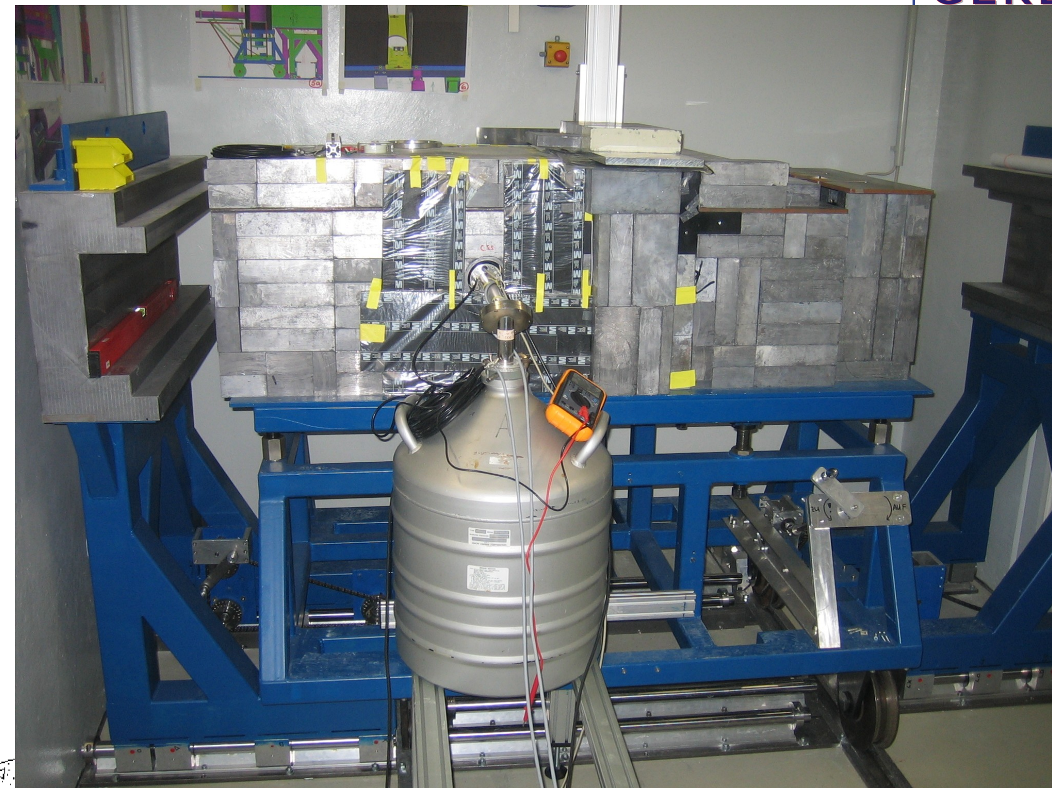
$<E_n>$ = 1.83 meV



the detectors

- m ~ 300 mg of enriched GeO_2
- irradiation time > 50 000 s
- 2 HPGe with Compton suppr.
- Li/Cd/Pb/PE absorbers





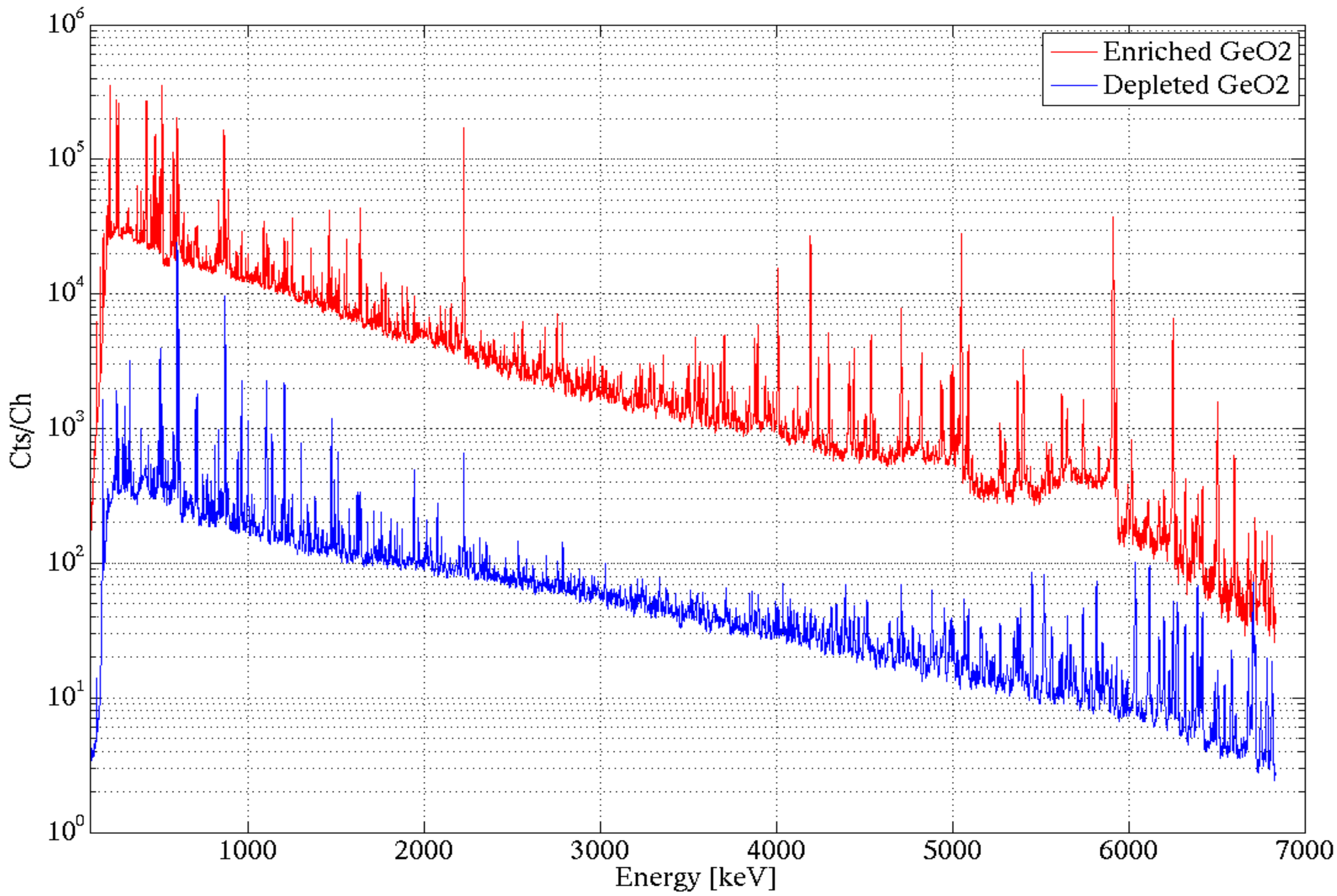
•7.83 x 10^9 n/(cm^2 s^1)

•<λ_n> = 6.7 Å

•<E> = 1.83 meV

the spectra

- m ~ 300 mg of enriched / depleted GeO_2 86 % vs. < 0.5%
- irradiation time > 50 000 s



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

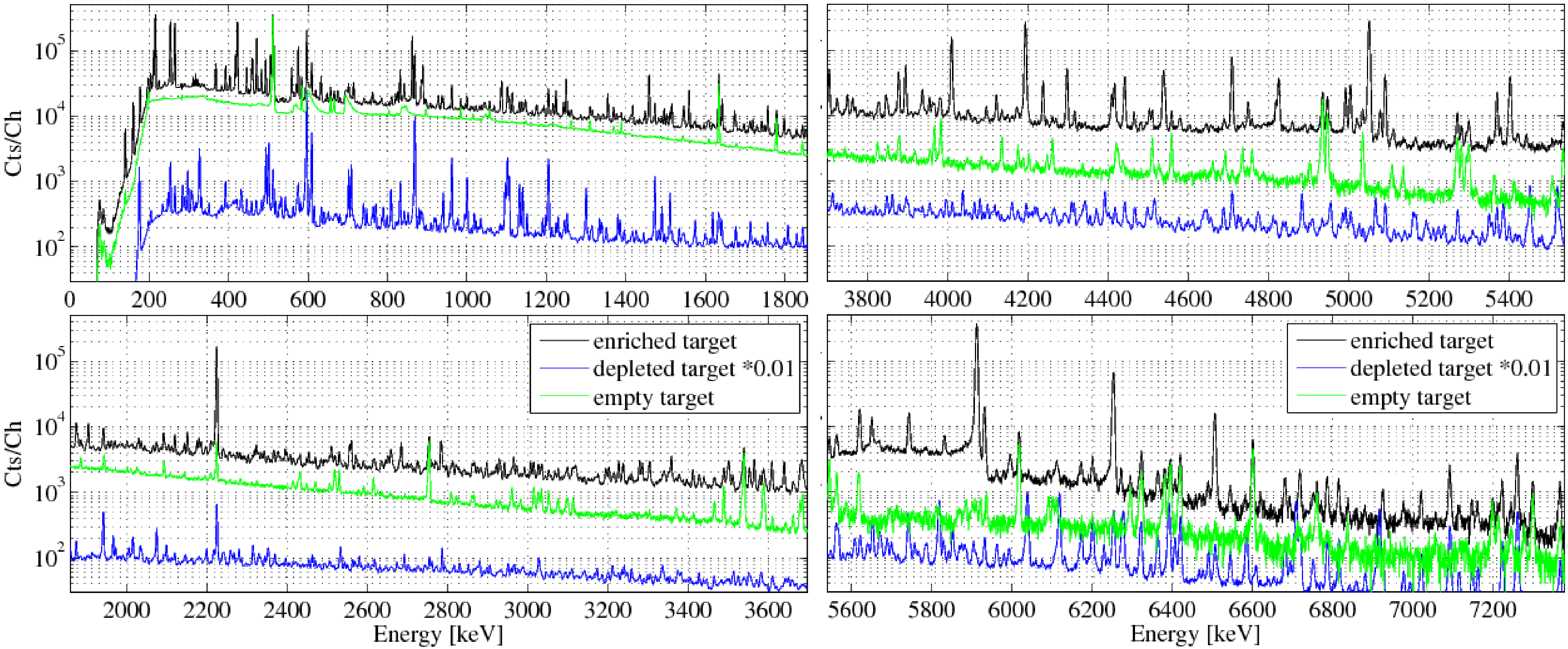
depleted:
^{74}Ge
^{73}Ge
^{72}Ge
^{70}Ge
^{75}Ge (decay)

more spectra:
background (FEP)
decay (enriched)
decay (depeted)

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

the spectra

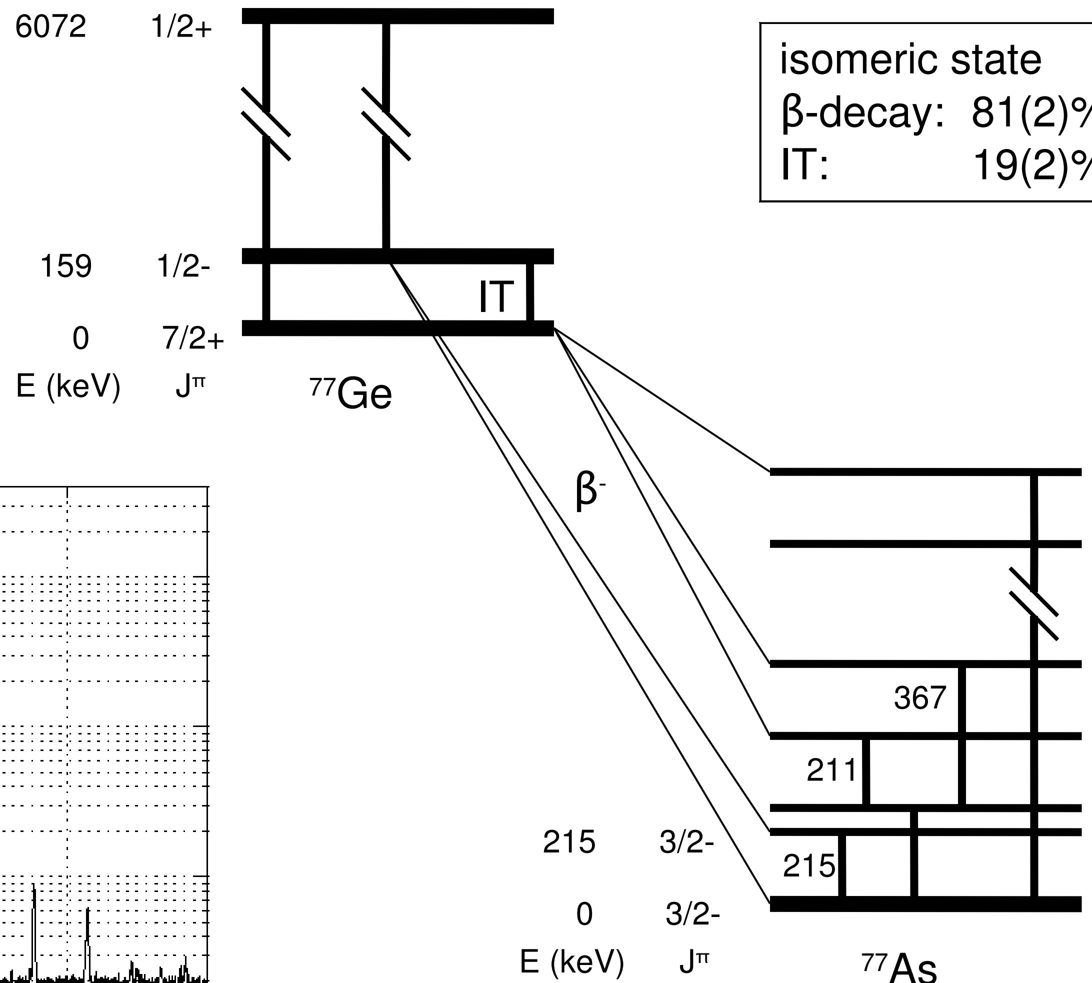
- m ~ 300 mg of enriched / depleted GeO_2 86 % vs. < 0.5%
- irradiation time > 50 000 s



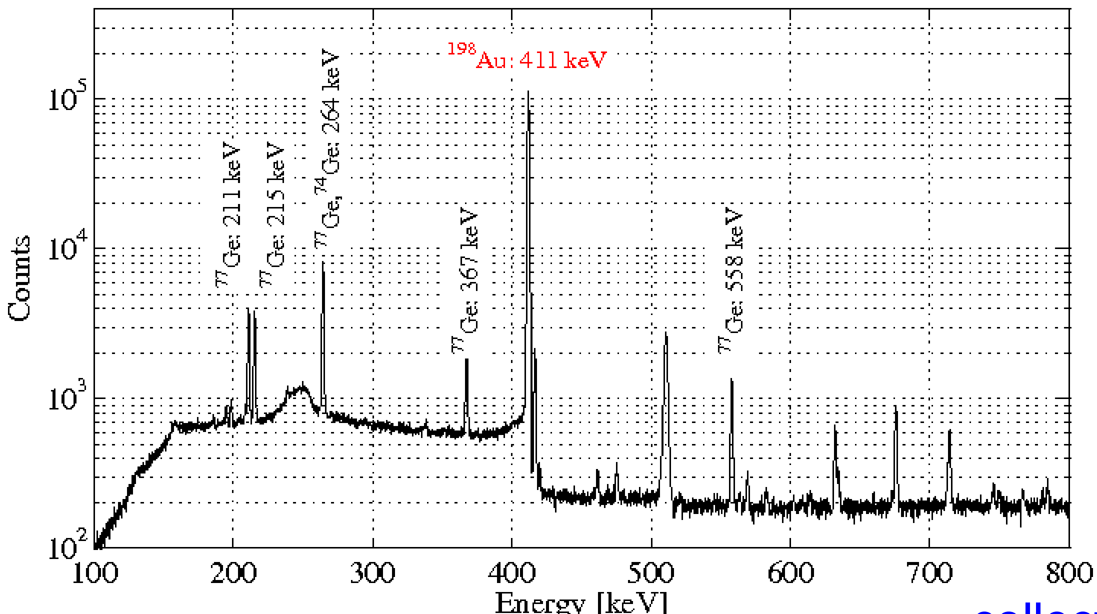
^{76}Ge capture cross section

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

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



isomeric state
β-decay: 81(2)%
IT: 19(2)%



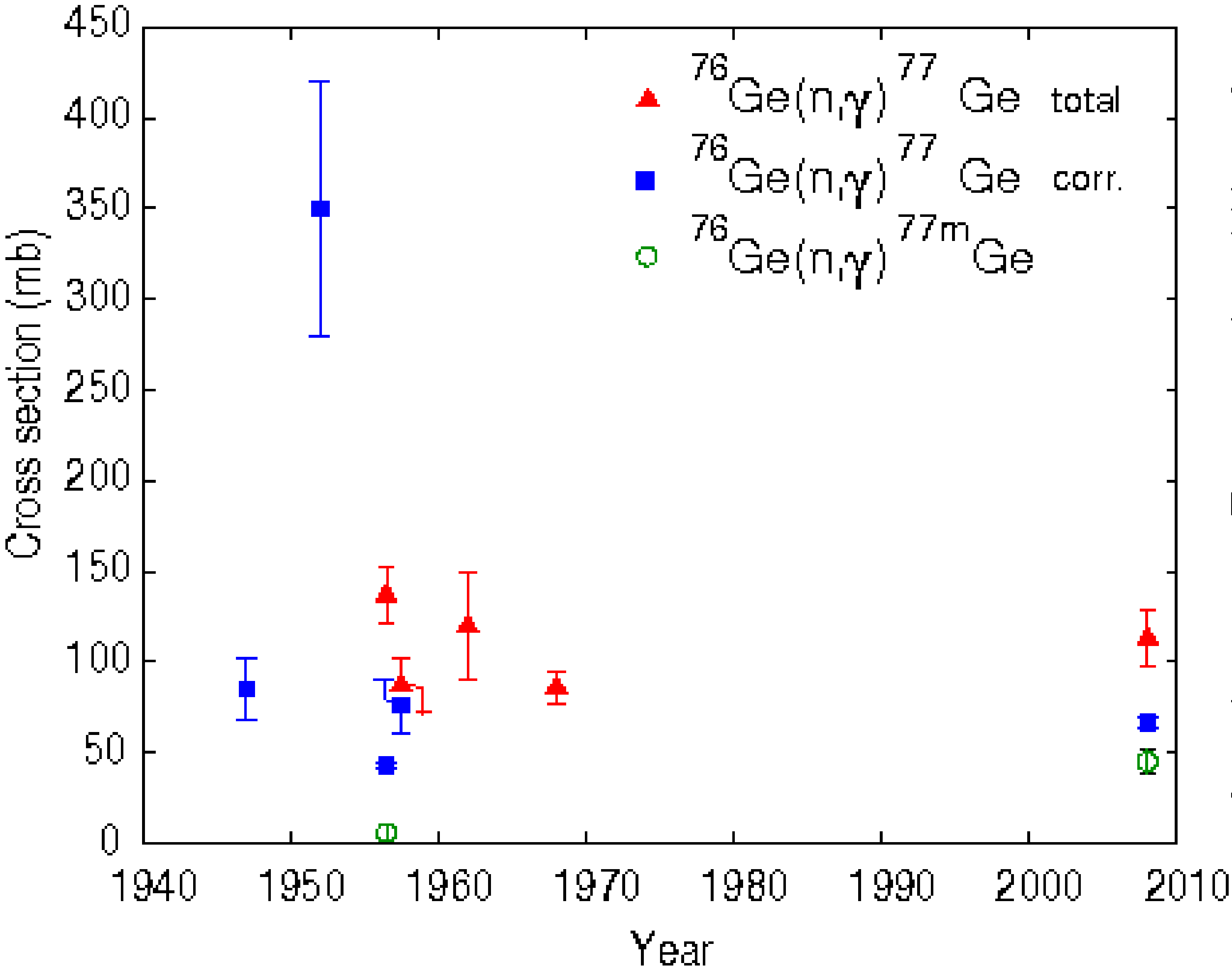
collect the prompts & check intensity of know lines

^{76}Ge experiments

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	46.9 ± 4.7	115 ± 16

G. Meierhofer et al., EPJA 40 (2009) 61

^{76}Ge experiments



(77mGe)

1957): 87 ± 15
1957): 137 ± 15
1962): 120 ± 20
1968): 86 ± 9

115 ± 16

G. Meierhofer et al., EPJA 40 (2009) 61

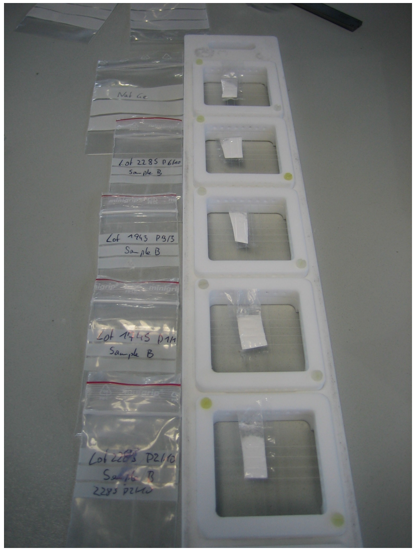
^{74}Ge experiments & results

cross section [mbarn]		
σ(^{75}Ge total)	σ(^{75}Ge direct)	σ(^{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

G. Meierhofer, P.G. etal PRC81 (2010) 027603

^{76}Ge isotopic composition



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

depleted material for
test of production chain

neutron capture

2 photon lines: 2041(prompt) & 2037 (delayed) keV close to $Q_{\beta\beta}$

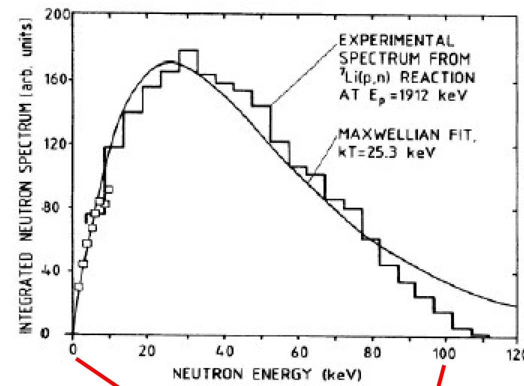
2 experiments: thermal (< meV, FRM-II) & astro (25 keV, FZK)

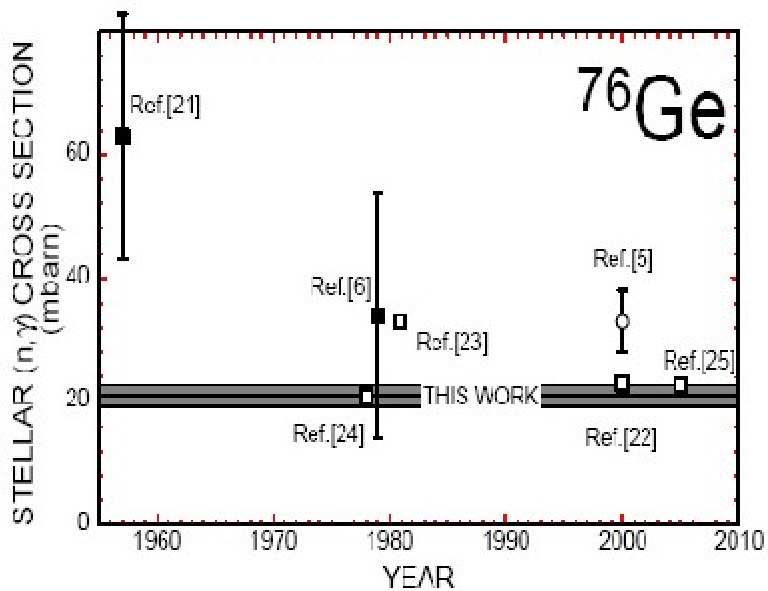
IOP PUBLISHING JOURNAL OF PHYSICS G: NUCLEAR AND PARTICLE PHYSICS

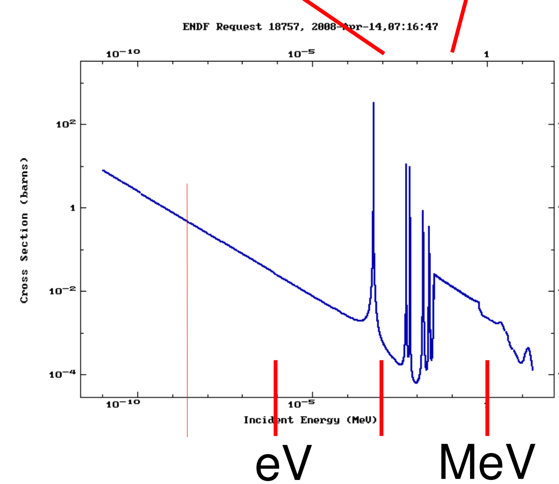
J. Phys. G: Nucl. Part. Phys. 35 (2008) 014022 (5pp) doi:10.1088/0954-3899/35/1/014022

Neutron capture cross section of ^{76}Ge

J Marganiec[1,2], I Dillmann[1], C Domingo Pardo[1], P Grabmayr[3] and F Käppeler[1]



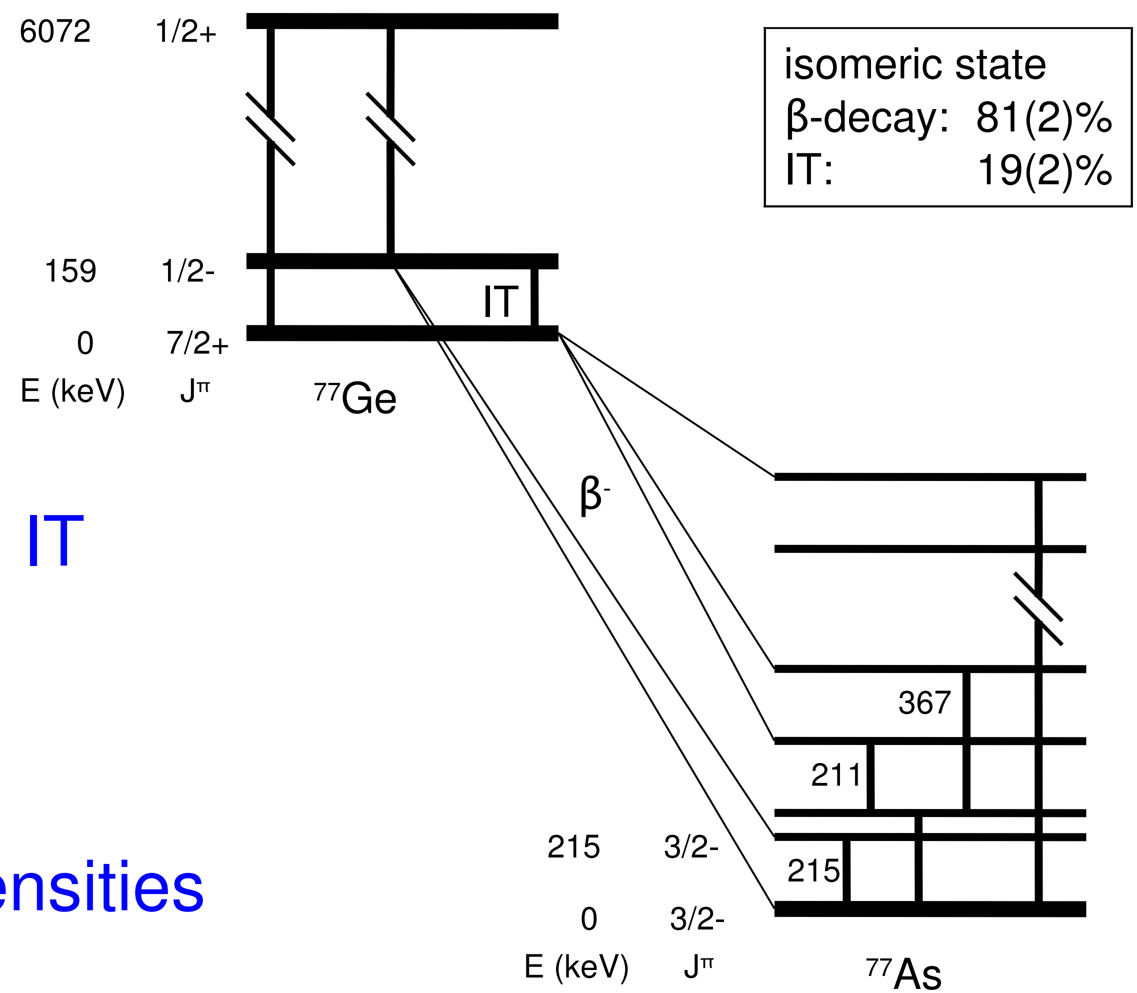




2nd publication in PRC

$\sigma^{gs} + \sigma^{m}$

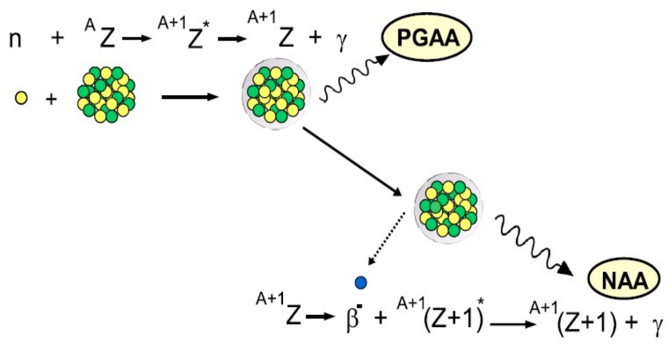
remaining problem

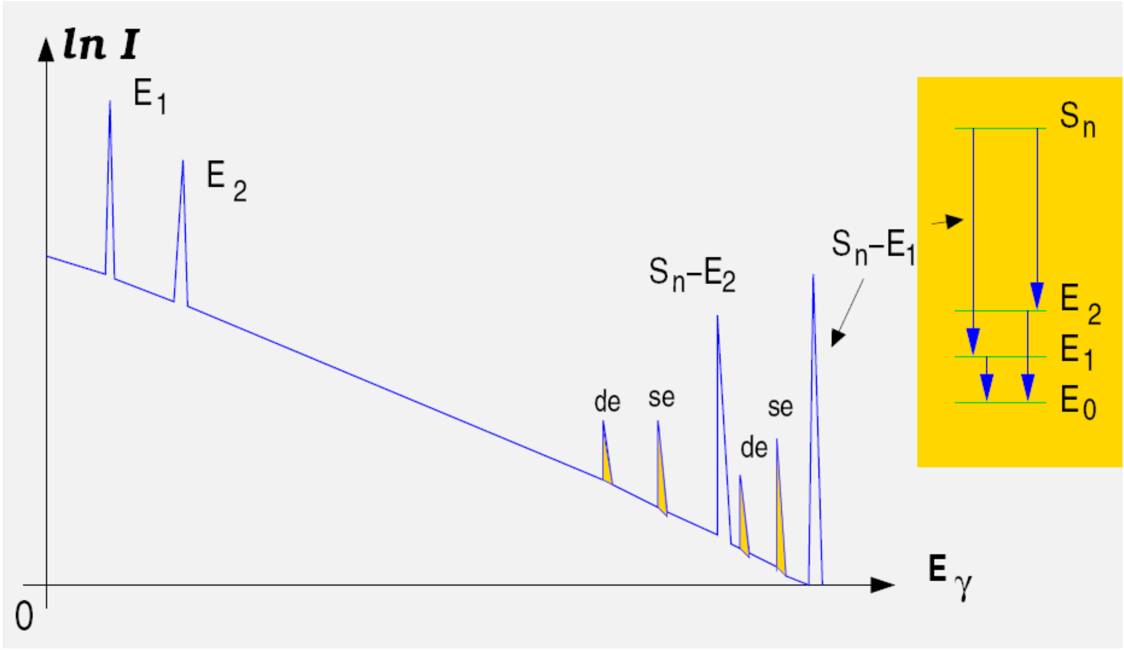


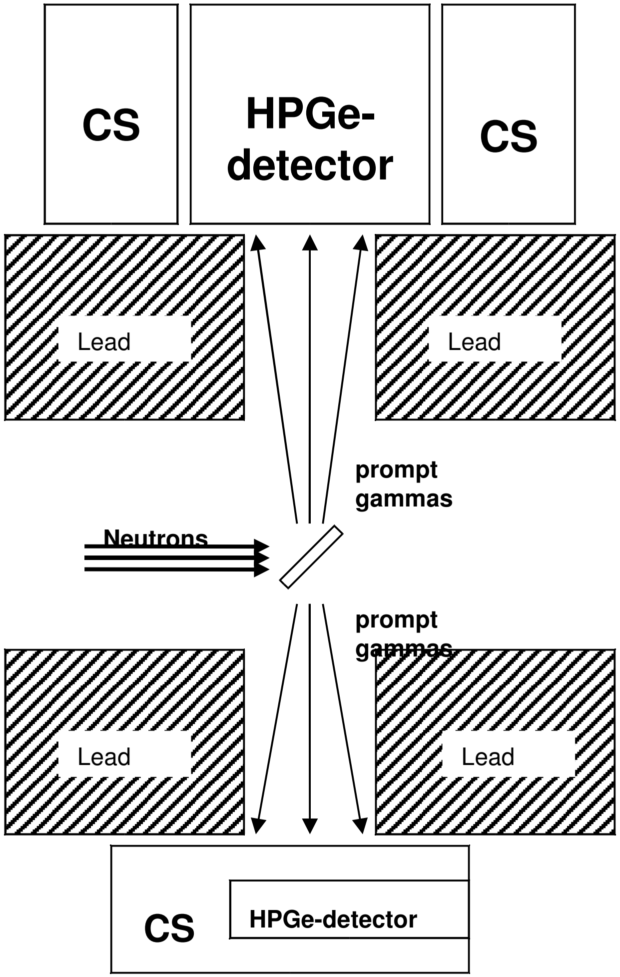
large error of rel. 20% on IT

relative and absolute intensities branching ratios

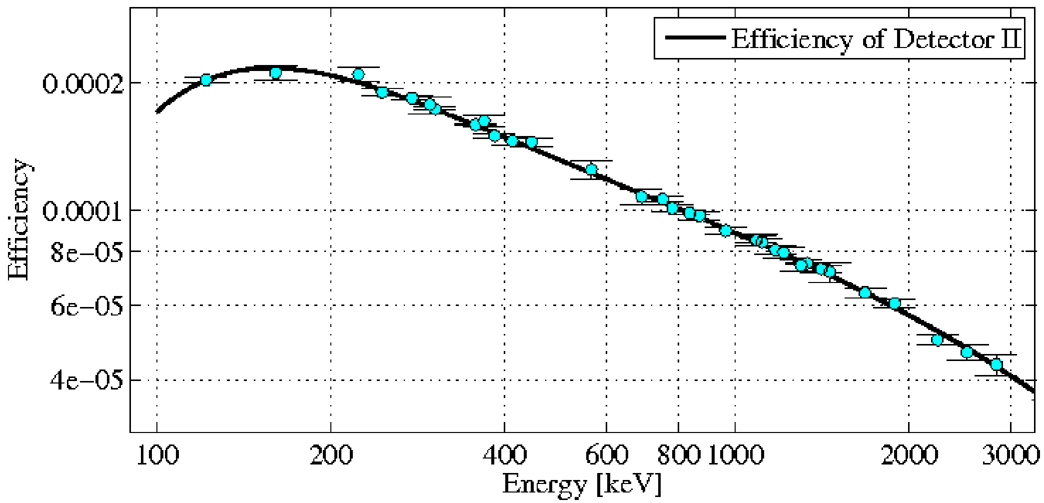
the coincidence principle

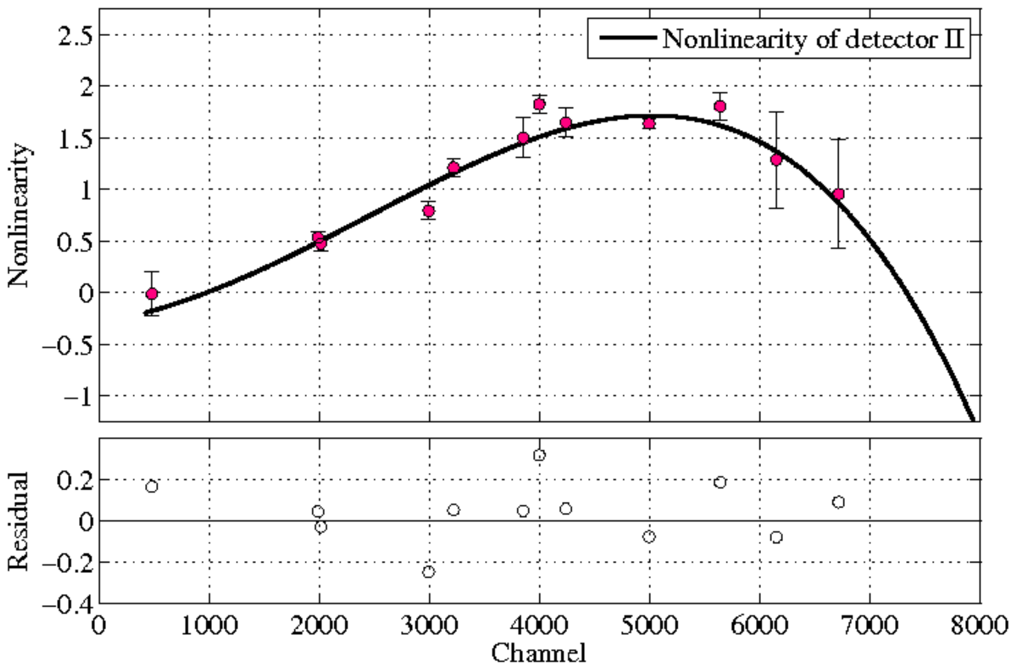


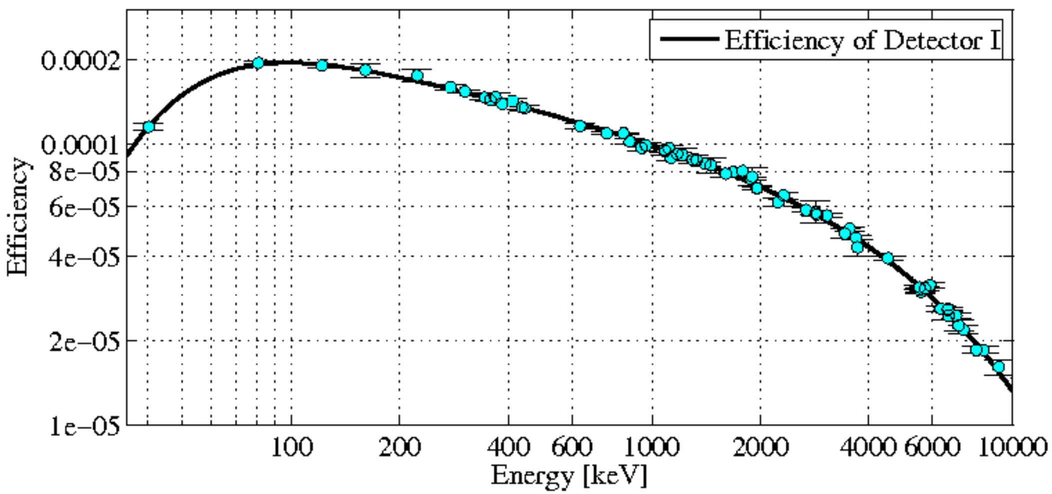




the technical details





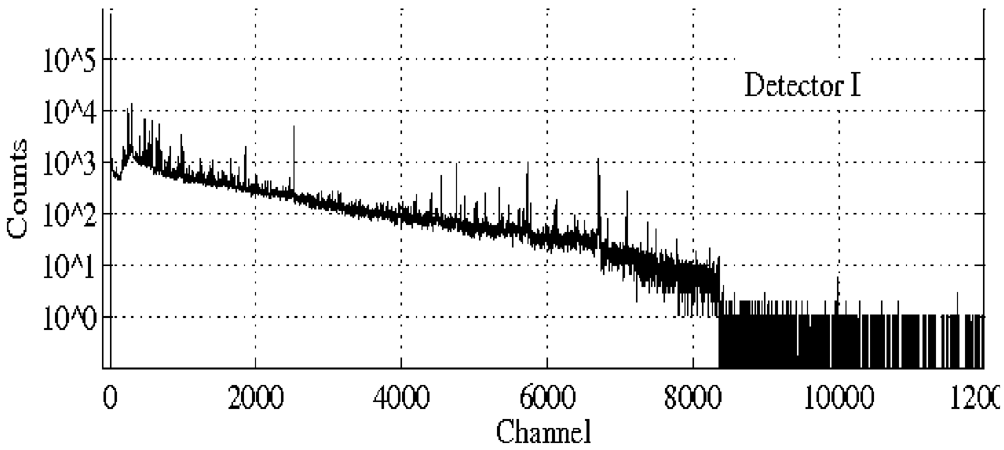


efficiency and non-linearity

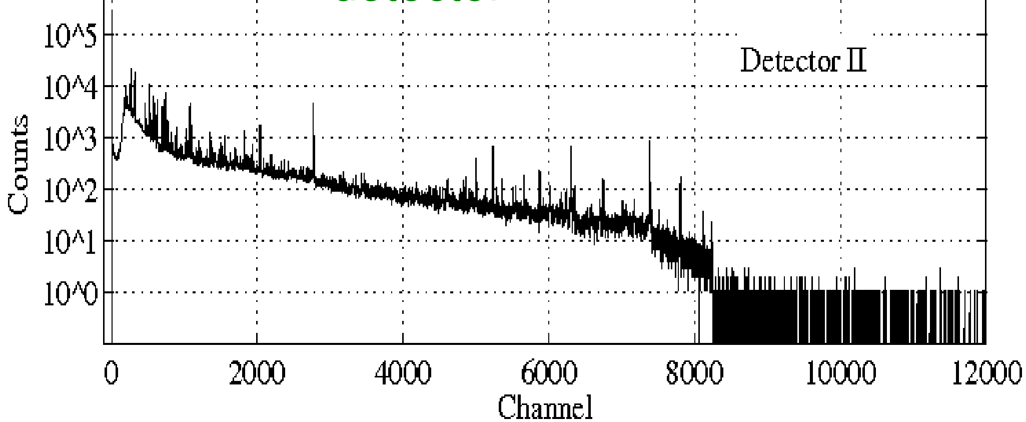
G. Meierhofer

the coincidences

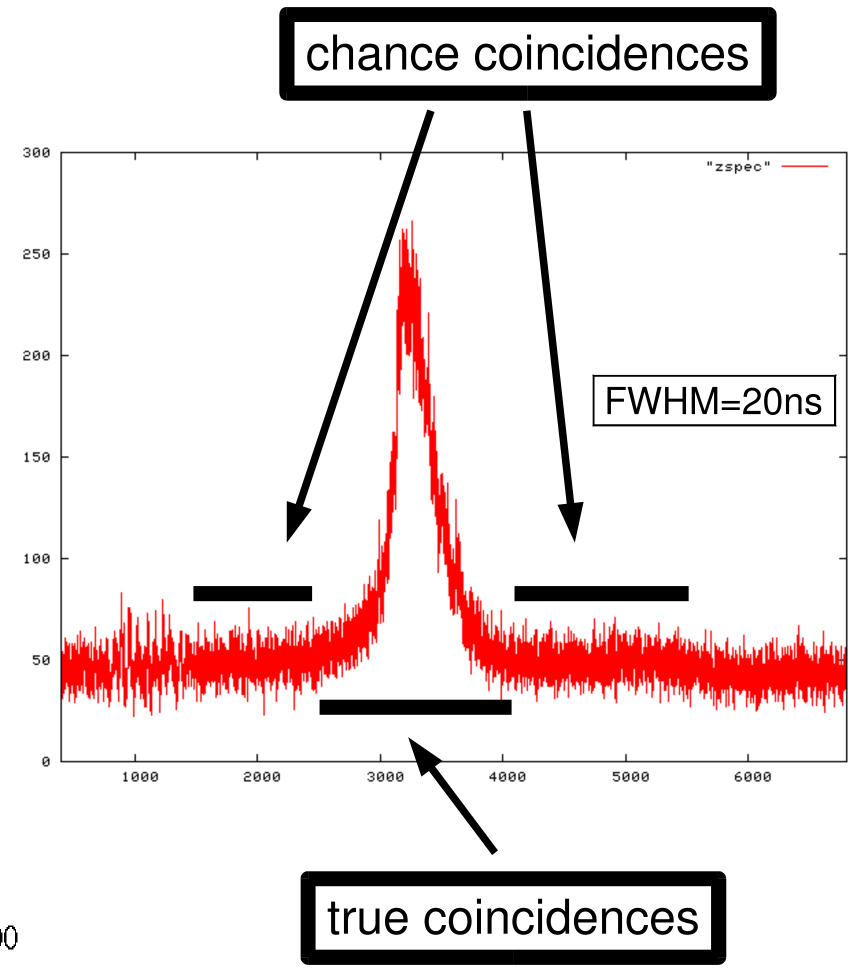
detector I



detector II



Δ t (I- II)



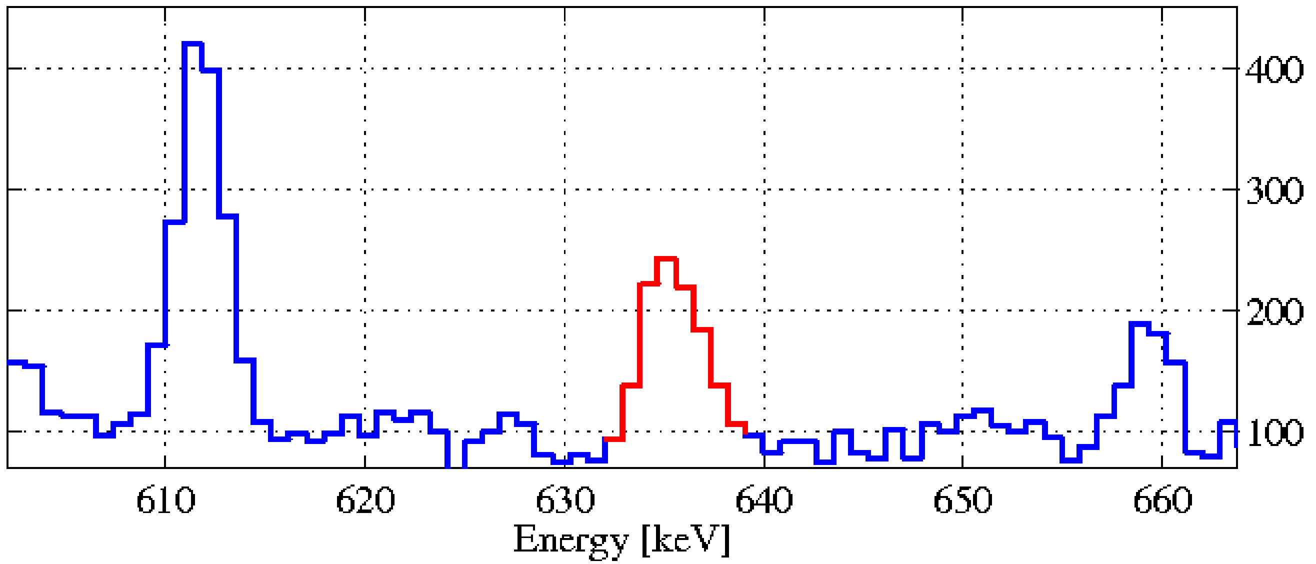
energy and time difference

G. Meierhofer

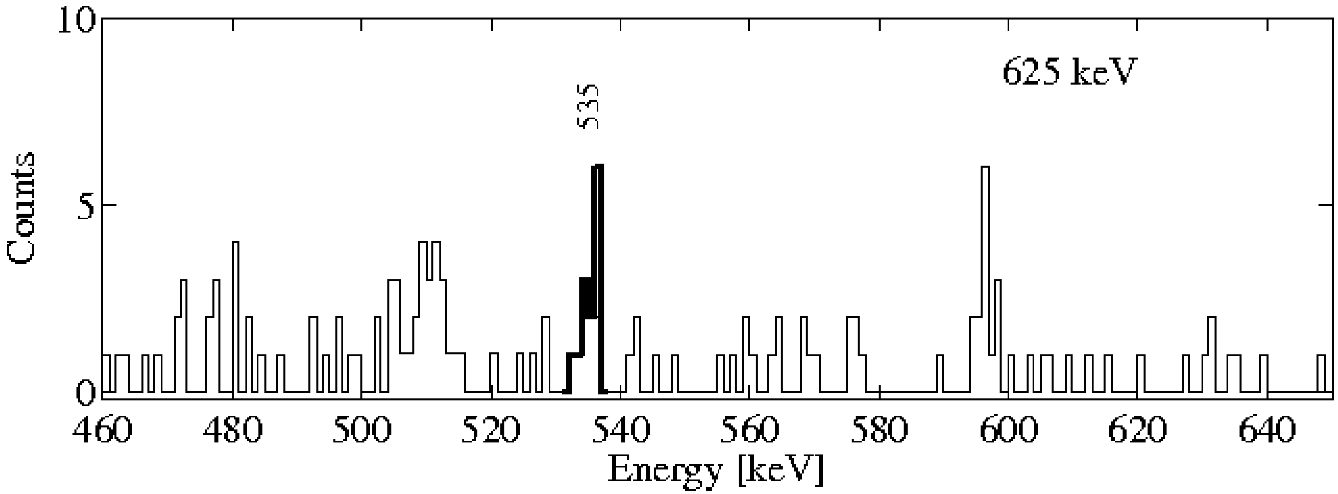
the coincidences

625 – 535

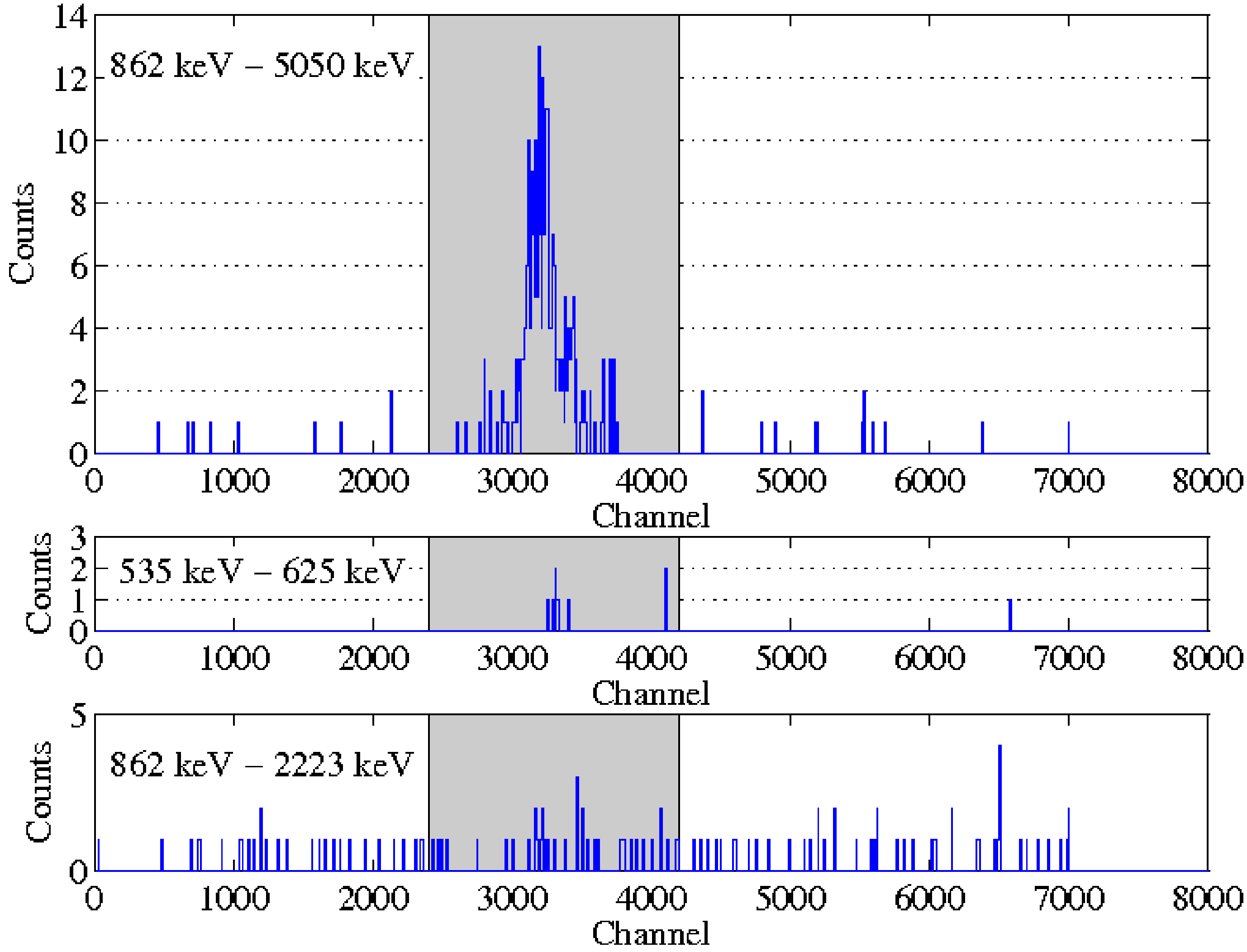
detector I



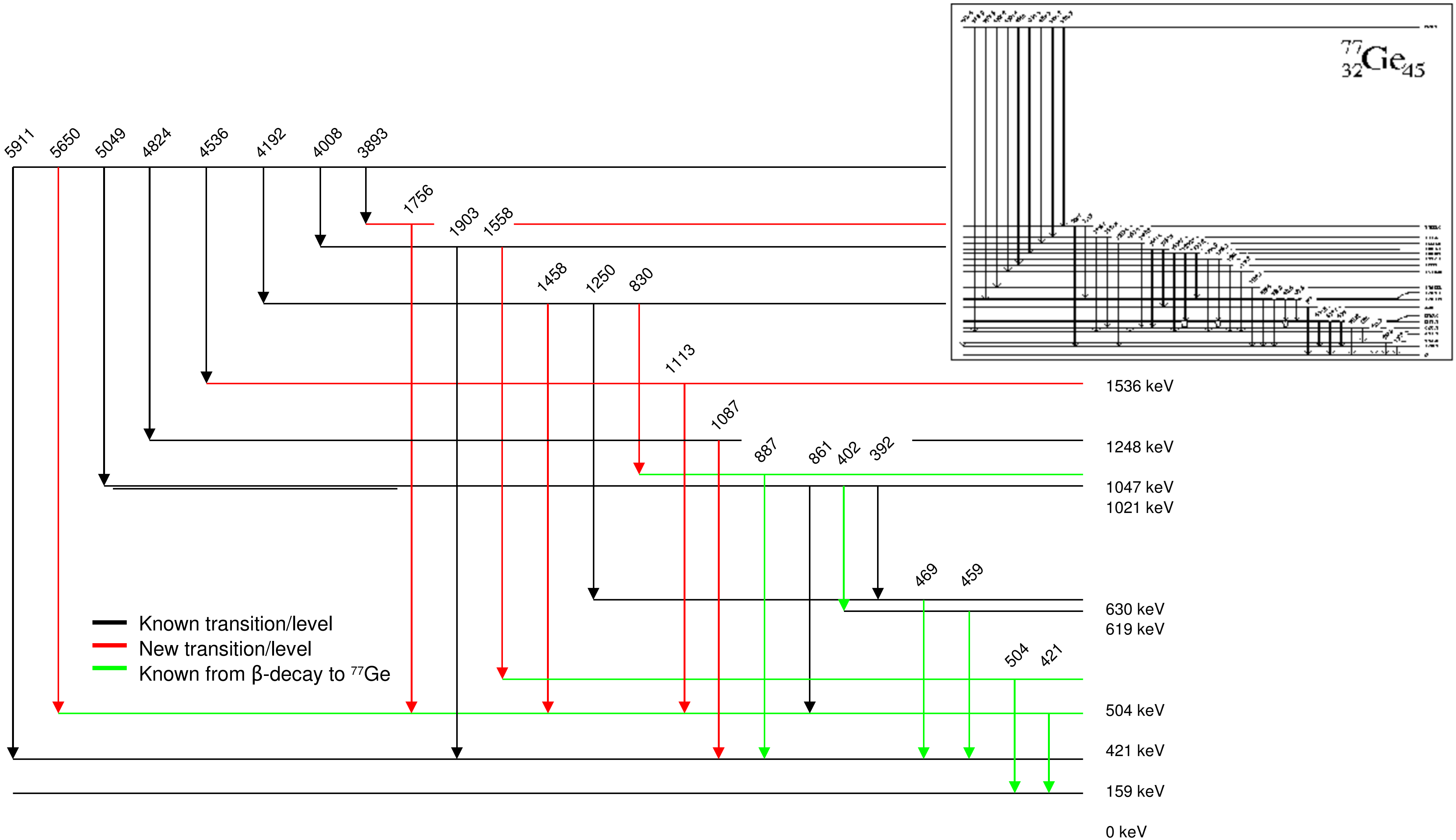
detector II



other coincidences



first look at coincidence data



coincidence results

^{76}Ge

119 lines found
(prior 17, 13 confirmed)

84 lines in decay schema

S_n = 6071,29 ± 0,05 keV

ν = 65.5 % (up to now 10.6 %)

^{74}Ge

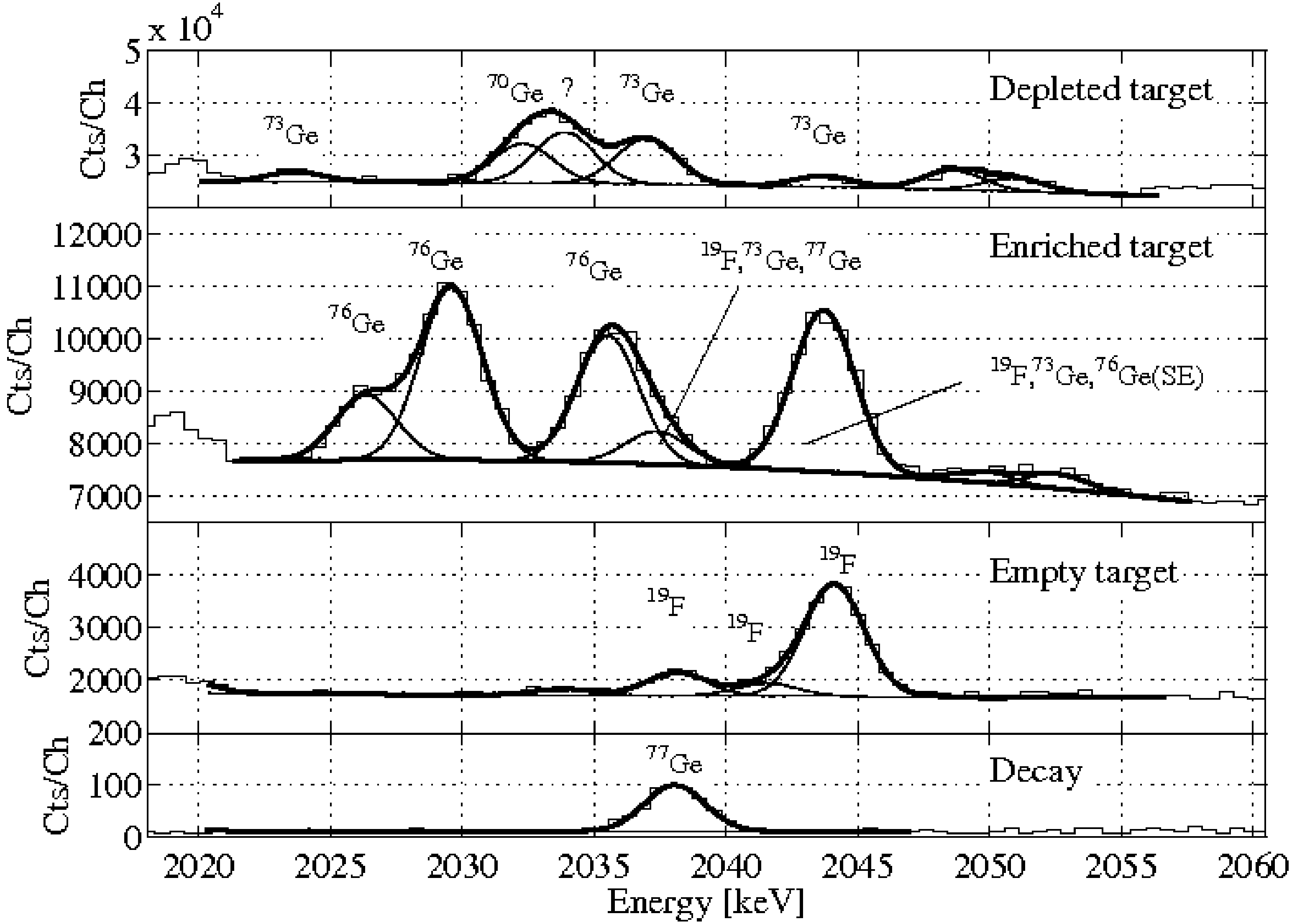
68 lines found
(32 of them new)

68 lines in decay schema

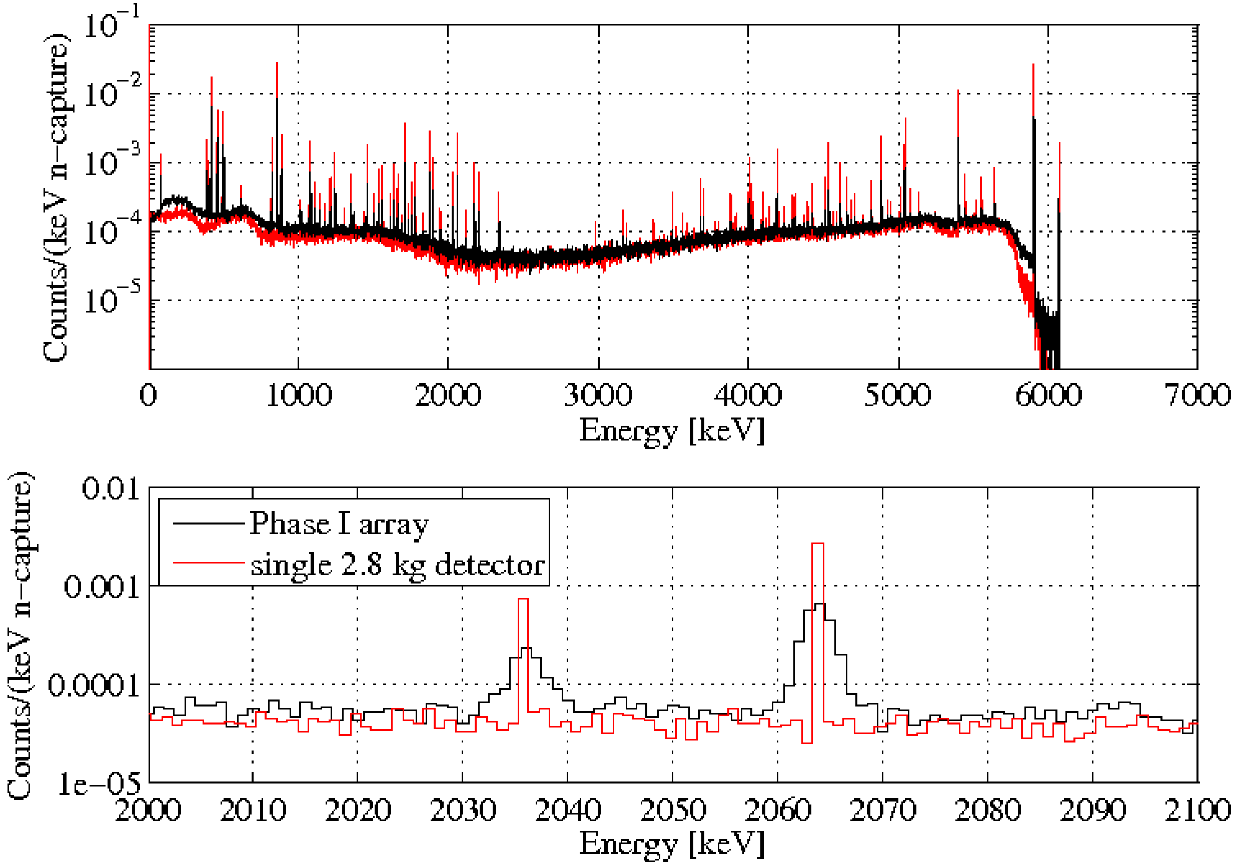
S_n = 6505,84 ± 0,05 keV

ν = 53 % (up to now 30 %)

the Qββ region



background contribution



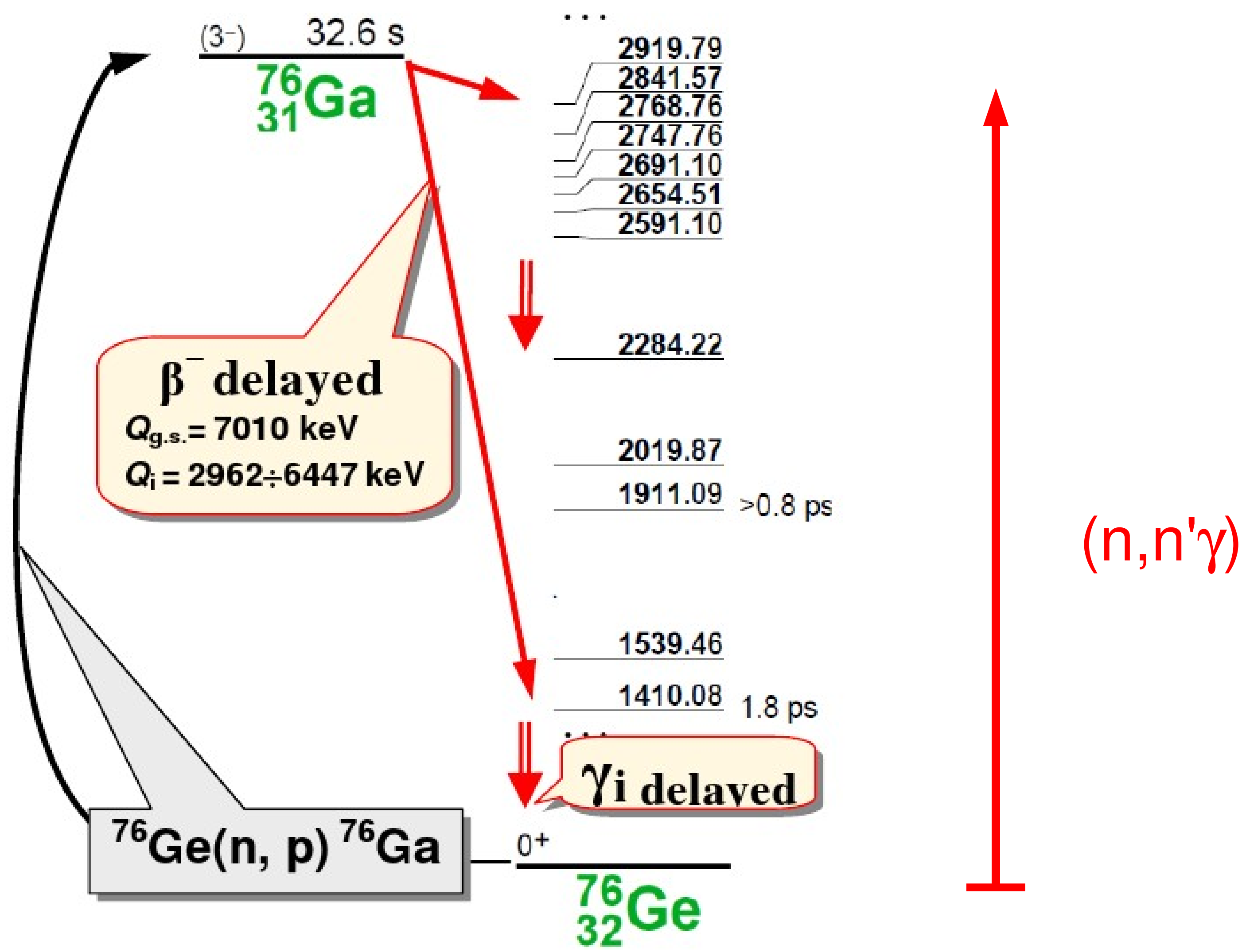
MaGe MC Simulation
by L. Pandola

line 2035 keV:
1,5 x 10^{-4} counts/(capture)
1,7 x 10^{-4} counts/(capture)

Compton:
0,55 x 10^{-4} counts/(keV capture)
0,44 x 10^{-4} counts/(keV capture)

the ^{76}Ge(n,p) reaction

Q_β = 7,01 MeV



(n,p) worse than the (n,n'γ) because of the additional β's

summary

finished setup by summer 2010

neutron background:

calibration sources:

$$B_\gamma = 3.2 \times 10^{-5} \text{ counts/(keV·kg·y)}$$

$$B_\text{n} = 3.7 \times 10^{-5} \text{ counts/(keV·kg·y)}$$

muon rejection:

97,9 [+1,2,-2,0] %

$B_\mu < 10^{-4}$ cts/(keV kg y)

summary

save for GERDA Phase I

manageable for Phase II

much of this background
scales with target mass

new ideas in case of
tonne-scale exp. ..... to see

summary

save for GERDA Phase I

manageable for Phase II

much of this background
scales with target mass

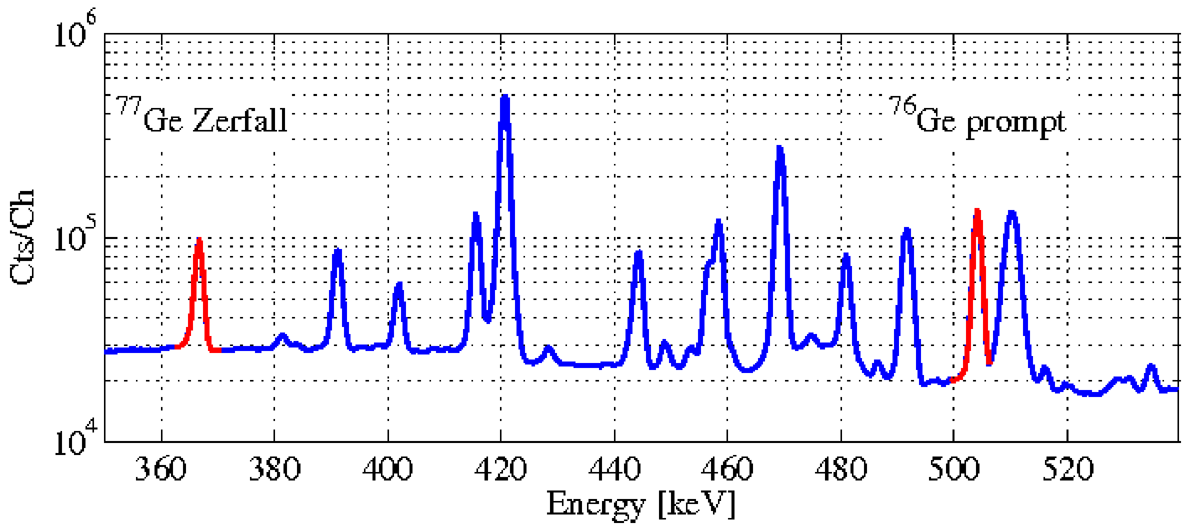
new ideas in case of
tonne-scale exp. ..... to see

.... if he is right

normalize

relate prompt and decay intensities

to get relative intensities, and finally absolute



S

Finish