Padova, March 2009

Neutron induced reaction measurements at Dresden

K. Zuber, TU Dresden

Contents

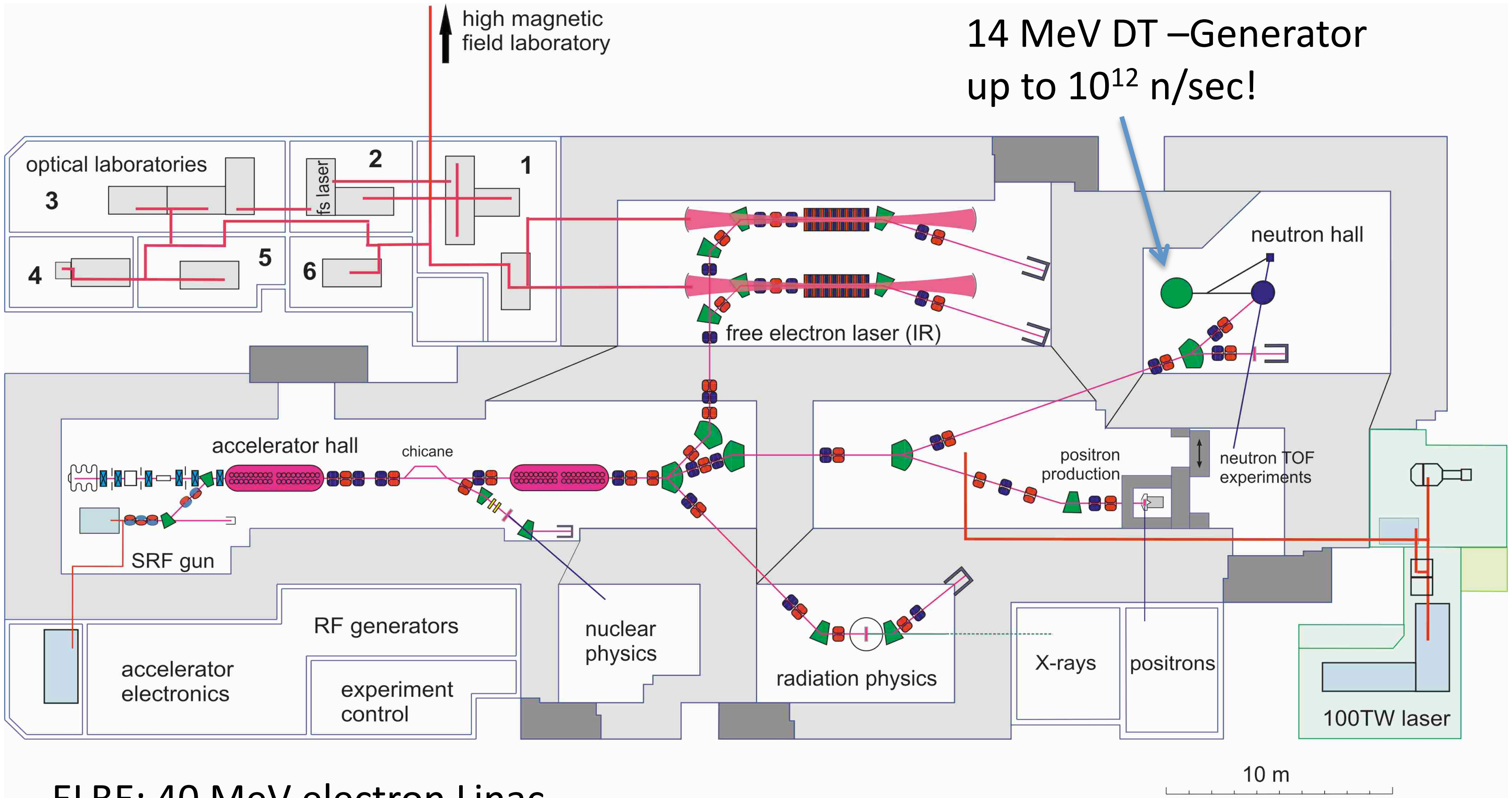
- Why neutron reactions, neutron sources
- Activation of materials relevant for GERDA
  - Ge
  - Cu (talks by G. Heusser, Nov 08 meeting and A. Domula)
  - Steel (talks by G. Heusser, Nov 08 meeting and A. Domula)
  - Ar (?)

Other Dresden activities:

I won‘t talk about phase II crystal characterisation ➔ J. Janicsko

I won‘t talk about > 150% ultralow BG Ge-detector to be installed in Felsenkeller Lab (125 mwe)

Neutron sources (at FZD Rossendorf)

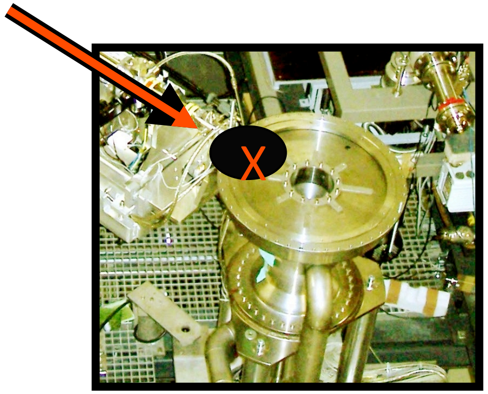


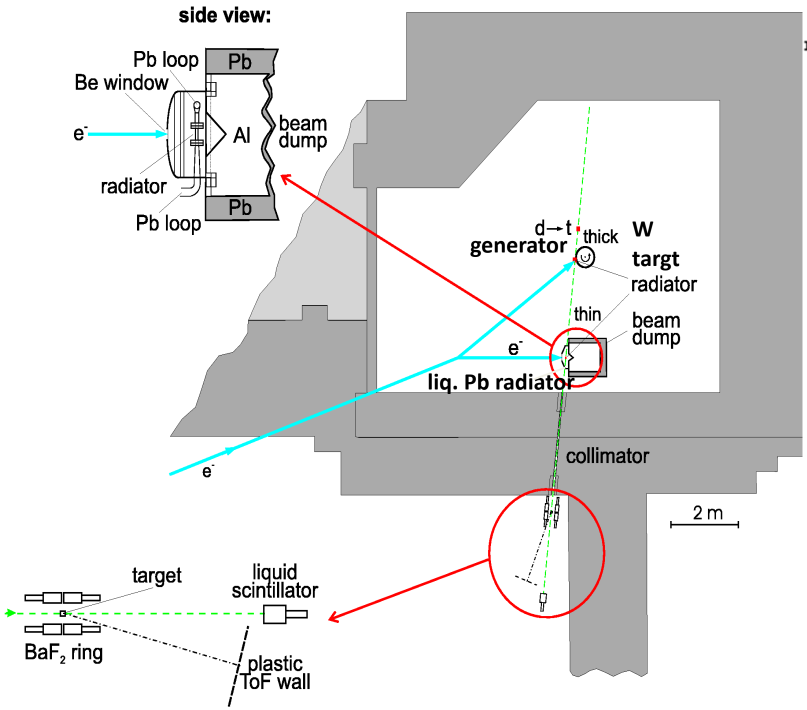
ELBE: 40 MeV electron Linac

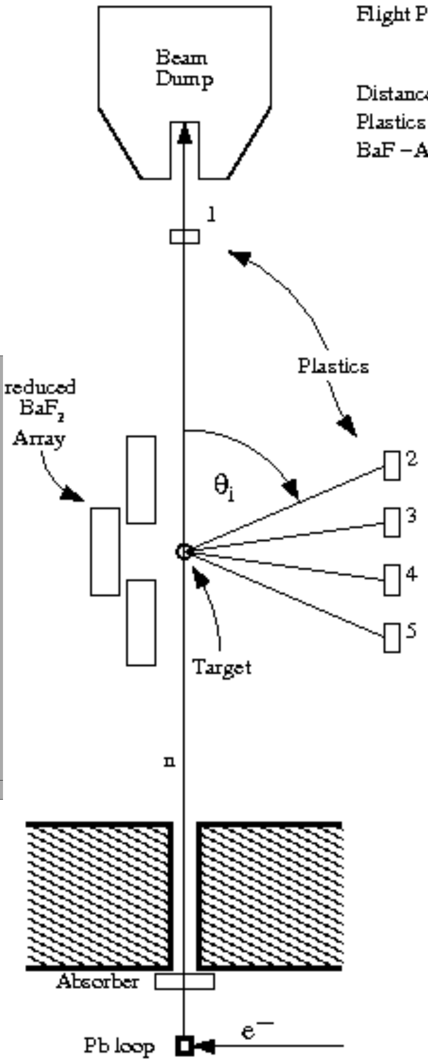
1: Diagnostic station, IR-imaging and biological IR experiment
2: Femtosecond laser, THz-spectroscopy, IR pump-probe experiment
3: Time-resolved semiconductor spectroscopy, THz-spectroscopy

4: FTIR, biological IR experiment
5: Near-field and pump-probe IR experiment
6: Radiochemistry and sum frequency generation experiment, photothermal deflection spectroscopy

Photoneutron sources





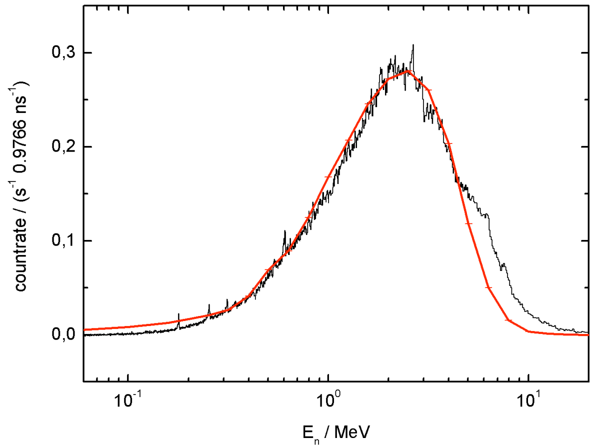


Flight Path to Target: 612.04 cm
Plastic 1: 726.24 cm

Distance to Neutron Beam:
Plastics 2..5 69.3–70.7 cm
BaF –Array: 14.6–34.8 cm

Angle to neutron beam:	
Plastic 1	0°
Plastic 2	77.8°
Plastic 3	85.9°
Plastic 4	94.1°
Plastic 5	102.2°

Measured neutron spectrum + MCNP sim.

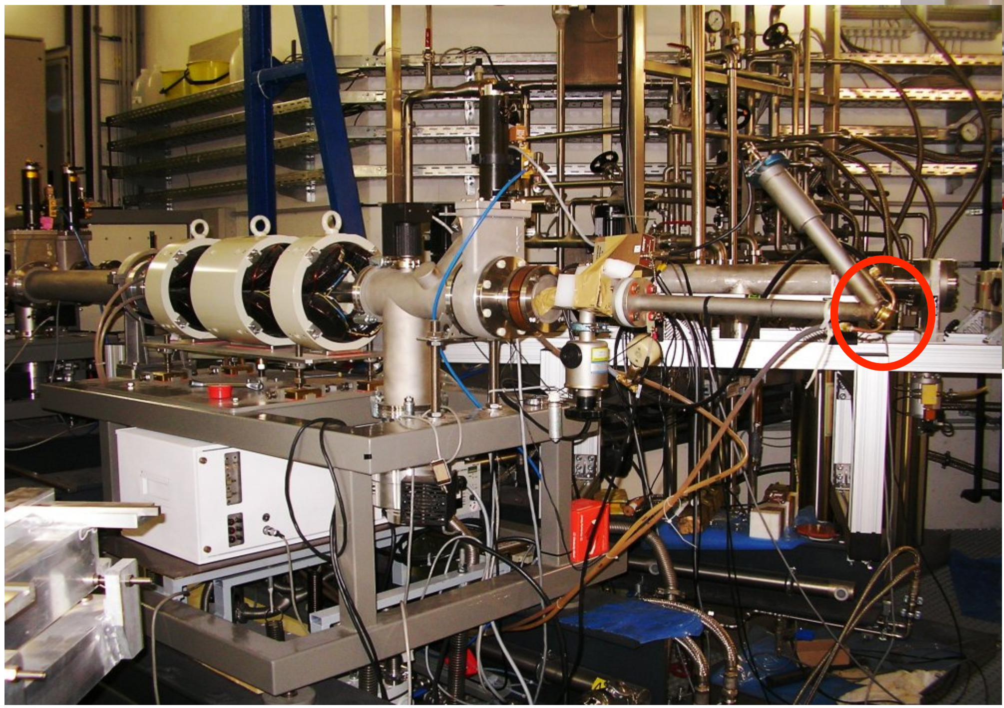


DT Neutron Source

Accelerator: 300 kV, 10 mA

Operation modes:

- cw
- pulsed: 30 ns and 10-100 us

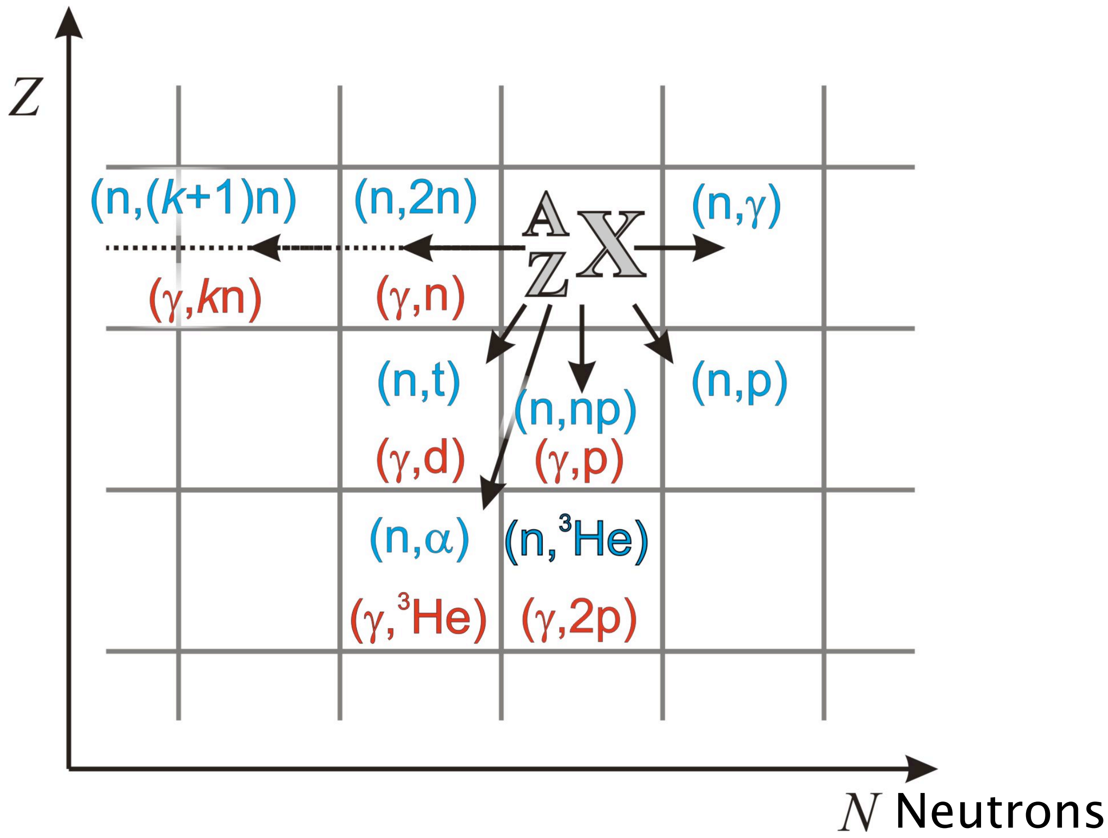


Targets:

Tritium 3, 30, 250 Ci
Deuterium

Neutron activation

Reactions possible with 14 MeV neutrons

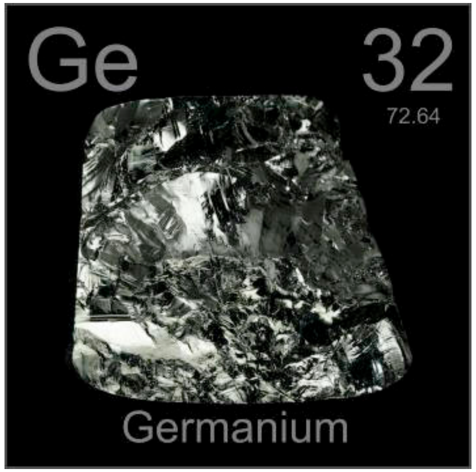


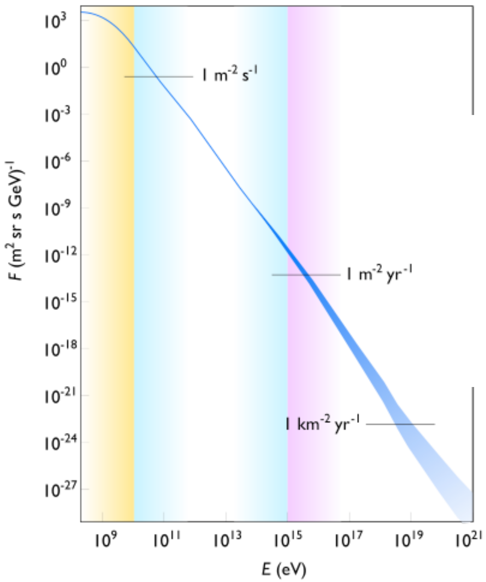
Cosmogenic activation

Minor: In situ production, but as background gets lower and lower ...

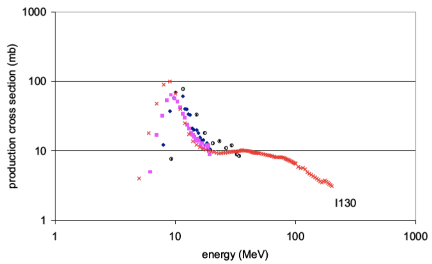
Radioisotope production due to cosmic rays

$$R(day) = N_{atom} \times \Phi(E) \times \sigma(E) \times t$$





?

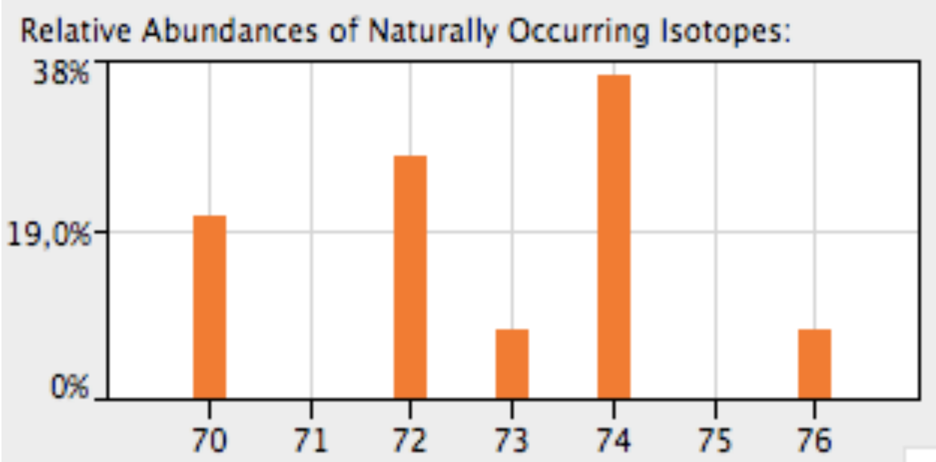


10^{26} atoms — $1\ cm^{-2}s^{-1}$ — $10^{-23}\ cm^{-2}s^{-1}$ — $10^{5} s\,day^{-1}$

Production rates of roughly 10^{8} atoms/day are feasible

Radioisotopes in Ge

Abundances of 5 natural isotopes:
Ge-70: 20,5%
Ge-72: 27,4%
Ge-73: 7,8%
Ge-74: 36,5%
Ge-76: 7,8%



	$T_{1/2}$	progenitors	decay of progenitors	$T_{1/2}$ of progenitors
^{68}Ge	270.8 d	^{68}As	EC,β^+	151.6 s
^{65}Zn	244.3 d	^{65}As, ^{65}Ge, ^{65}Ga	EC,β^+	0.19 s, 30.9 s, 15.2 m
^{63}Ni	100.1 y	^{63}Cr, ^{63}Mn, ^{63}Fe, ^{63}Co	β^-	110 ms, 0.25 s, 6.1 s, 27.4 s
^{57}Co	271.8 d	^{57}Zn, ^{57}Cu, ^{57}Ni	EC,β^+	40 ms, 199.4 ms, 35.6 h
^{56}Co	77.3 d	^{56}Ni	EC	6.1 d
^{55}Fe	2.73 y	^{55}Co	EC+β^+	17.5 h

Not all can be explored at TU Dresden, needs higher energy beams

^{68}Ge background

Collection of statements from GERDA-Proposals:

According to calculations in reference [Avi 92], the production rate of ^{68}Ge in ^{76}Ge is about 1 atom/(kg d). Within an exposure time of 180 days and $T_{1/2} \simeq 270$ days about 40% of the saturation activity is reached.

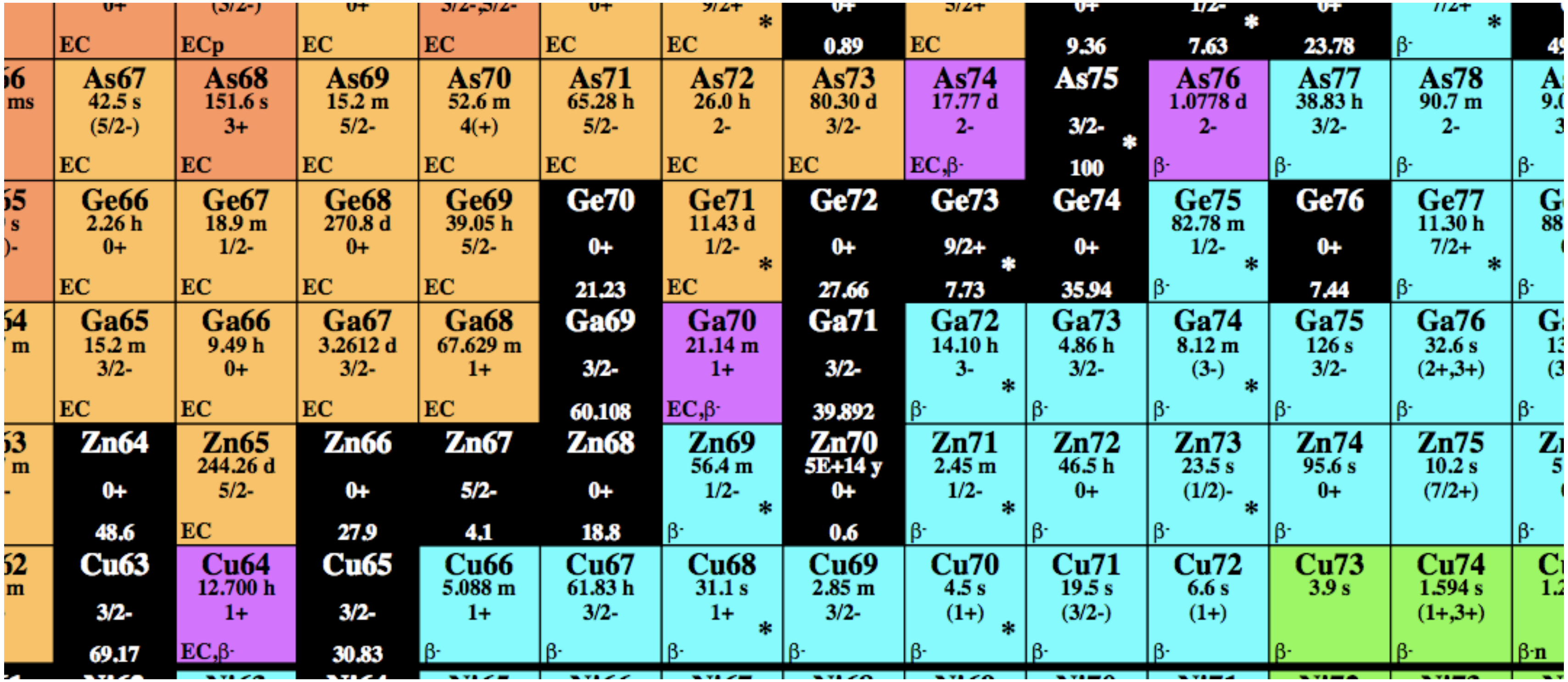
The saturation activity is 1 decay/(kg d) at the time the detector is brought underground which corresponds to 400 ^{68}Ge atoms/kg. After 180 days of storage and for 40%

source	B $\frac{10^{-3}\text{cts}}{\text{keV}\cdot\text{kg}\cdot\text{y}}$	B after bkg. rej. $\frac{10^{-3}\text{cts}}{\text{keV}\cdot\text{kg}\cdot\text{y}}$	B after add. det. segm. $\frac{10^{-3}\text{cts}}{\text{keV}\cdot\text{kg}\cdot\text{y}}$
ext. γ from ^{208}Tl, ^{228}U	1	0.4	0.2
ext. neutrons	≤ 0.05	≤ 0.03	≤ 0.02
ext. muons	≤ 0.1	≤ 0.05	≤ 0.03
internal ^{68}Ge	12	1.1	0.3
internal ^{60}Co	2.5	0.8	0.2
^{222}Rn in LN/LAr	0.2	≤ 0.1	≤ 0.1
^{208}Tl, ^{228}U in holder mat.	≤ 1	≤ 0.1	≤ 0.1
surface contamination	≤ 0.6	≤ 0.1	≤ 0.1

Phase II: A summary of the estimated background contributions is given in Table 4.

Ex.: ^{68}Ge production

Real danger is ^{68}Ga decay (betas up to 2.9 MeV)



Production: 70Ge(n,3n)68Ge
70Ge(p,3n)68As➔68Ge
70Ge(γ,2n)68Ge

Direct Production: 70Ge(n,nd)68Ga
70Ge(γ,np)68Ga

Ga68

GERDA Proposal

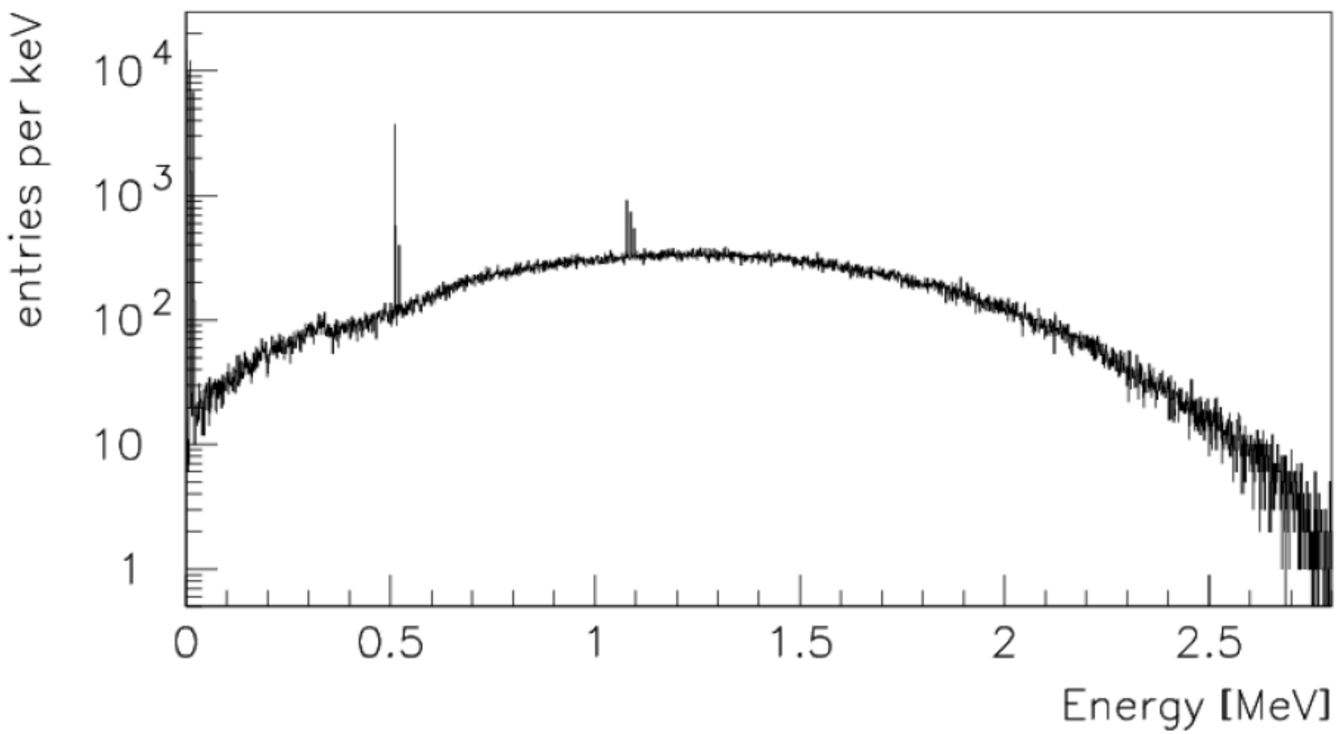
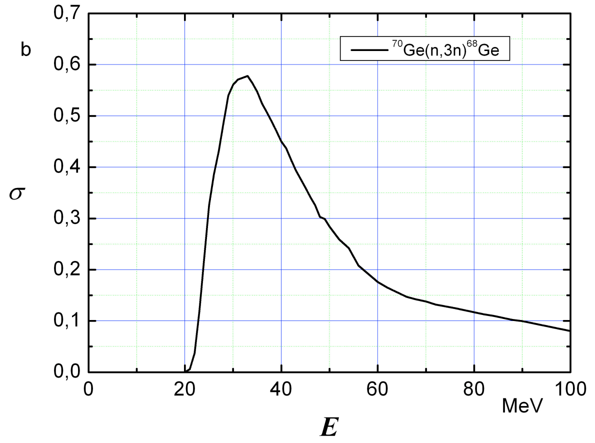
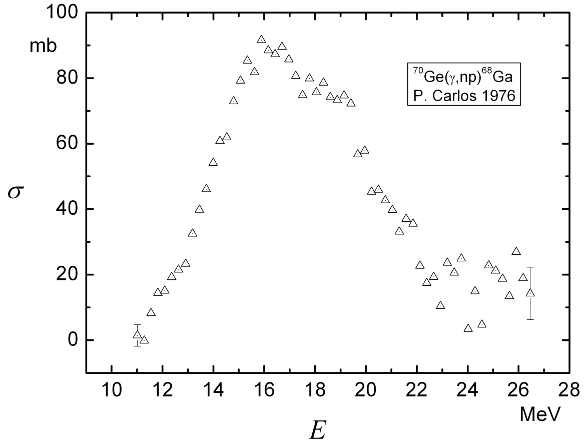


Figure 5: Energy deposition in a germanium detector from ^{68}Ga decays inside the crystal.

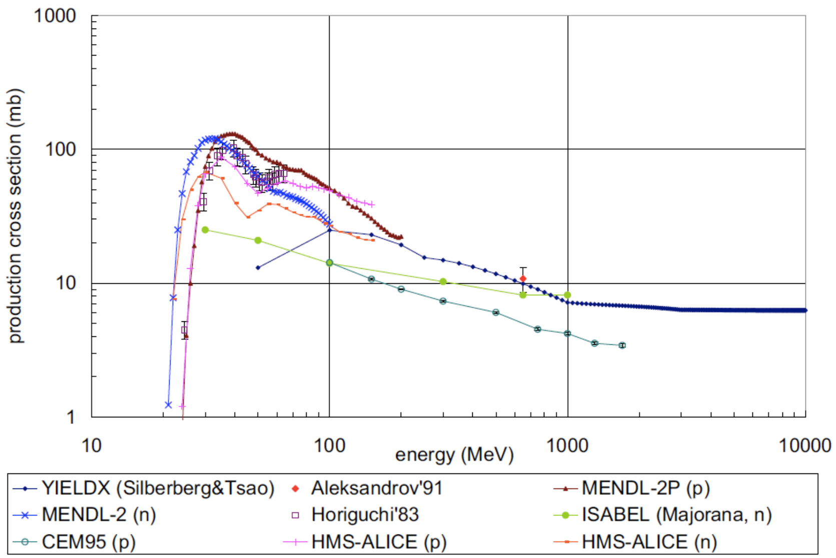
^{68}Ge production

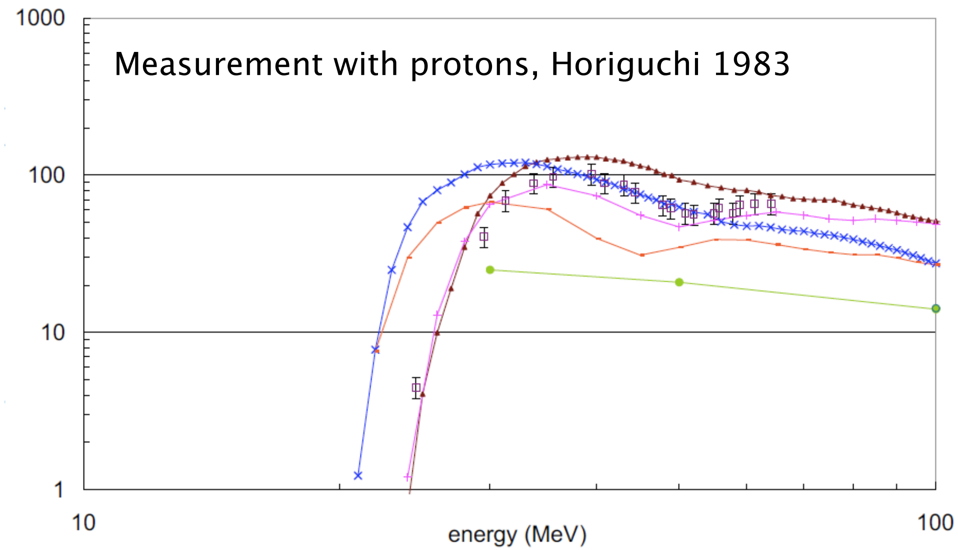
Examples:





Problem with neutrons: Precise knowledge of neutron flux

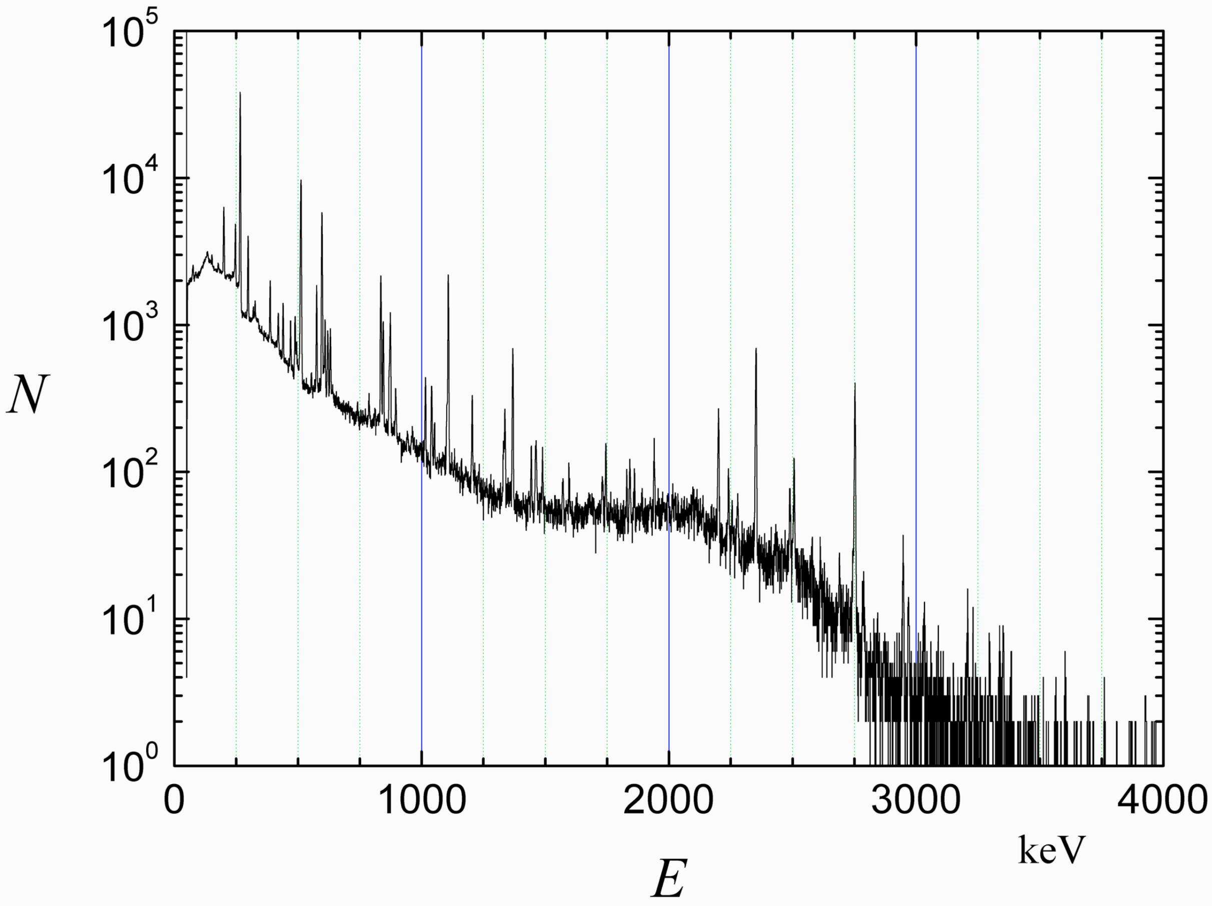




Plots by S. Cebrian, ILIAS

Ge activation

Activation for 8 min, 500 μA current, measuring time: 5511 s



Ge-activation

E [keV]	FWHM [keV]	Isotop
73,91	4,07	Cu/Pb Xray
150,63	3,26	?
176,51	4,13	70Ga
198,68	3,21	75Ge
245,34	3,13	?
264,81	3,24	75Ge
297,52	3,18	73Ga
318,03	0,83	69Ge
326,37	0,08	73Ga
386,59	3,24	?
419,44	3,04	75Ge
438,92	3,13	?
469,34	3,08	75Ge
487,67	3,3	73Ga
493,66	3,31	74Ga
511,12	3,93	Annihilation
553,63	3,53	69Ge
574,61	3,4	69Ge
596,18	3,26	74Ga
608,81	3,06	74Ga
619,78	4,46	75Ge
630,34	3,39	72Ge
739,9	2,25	73Ga
785,73	2,52	72Ga
834,32	3,45	72Ga

E [keV]	FWHM [keV]	Isotop
843,99	3,34	?
872,19	3,9	69Ge
894,71	3,95	72Ga
942,15	3,48	74Ga
961,97	3,95	74Ga
1014,64	3,16	?
1039,56	3,59	70Ga
1051,26	3,47	69Ge
1107,5	3,42	69Ge
1204,42	3,7	74Ga
1332,5	3,7	74Ga
1336,29	3,7	69Ge
1368,65	3,63	24-Na??
1443,58	3,48	74Ga
1462,23	5,92	72Ga
1489,12	2,57	74Ga
1571,04	5,36	72/74Ga; 69Ge
1597,08	1,82	72Ga
1731,53	5,75	DE-24Na
1745,18	3,85	74Ga
1830	3,76	74Ga
1842,46	4,73	Se_74Ga
1861,41	3,44	72Ga
1940,73	4,92	74Ga
2201,82	4,11	72Ga

E [keV]	FWHM [keV]	Isotop
2242,94	3,92	SE_24-Na??
2257,38	2,46	74Ga
2280,45	5,13	74Ga
2353,85	4,15	74Ga
2491,02	3,91	72Ga
2508,14	3,72	72Ga
2580,95	1,8	74Ga
2613,2	1,11	74Ga
2692,67	4,86	74Ga
2753,21	4,24	24-Na??
2789,61	1,76	74Ga
2949,94	4,23	
2970,99	4,07	74Ga
3036,76	1,49	72Ga

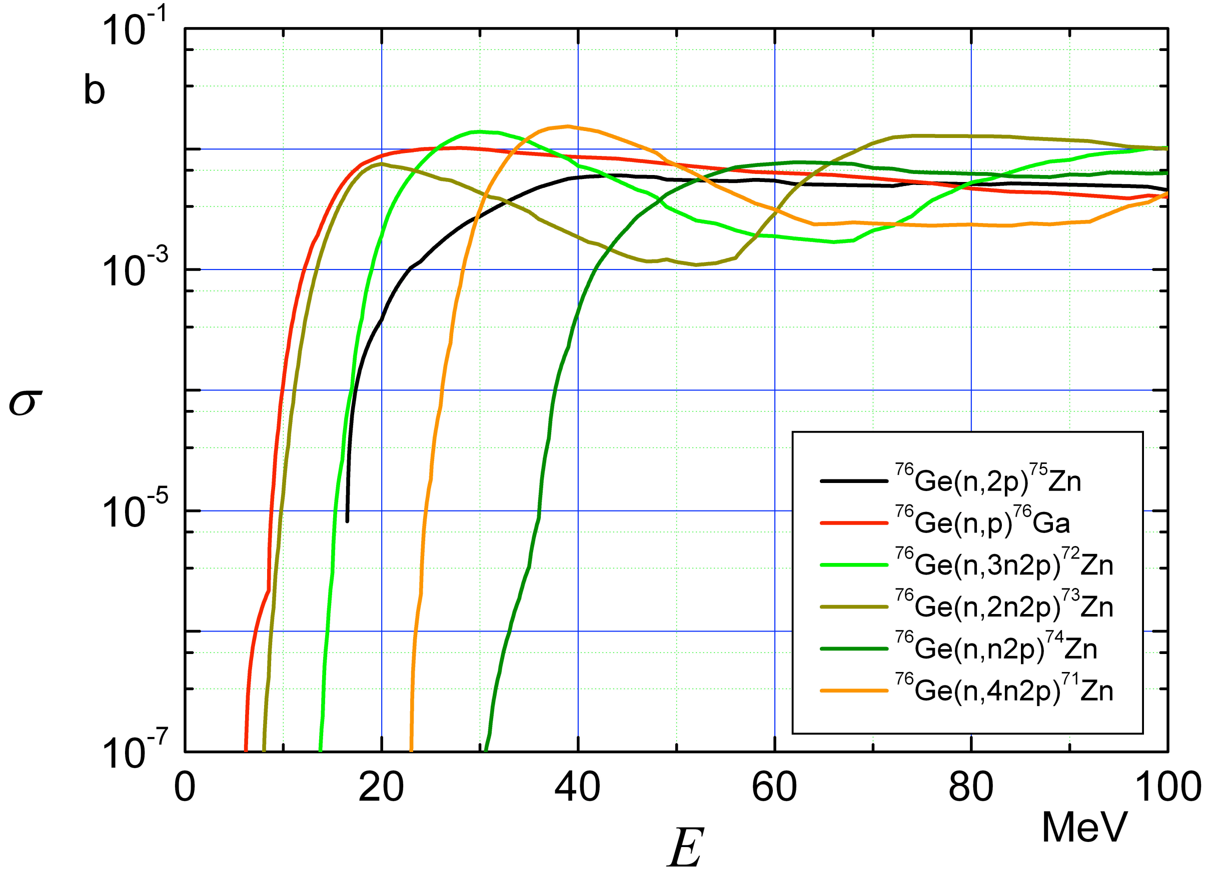
Gallium

Germanium

Arsen

Analysis ongoing

Some cross sections on ^{76}Ge

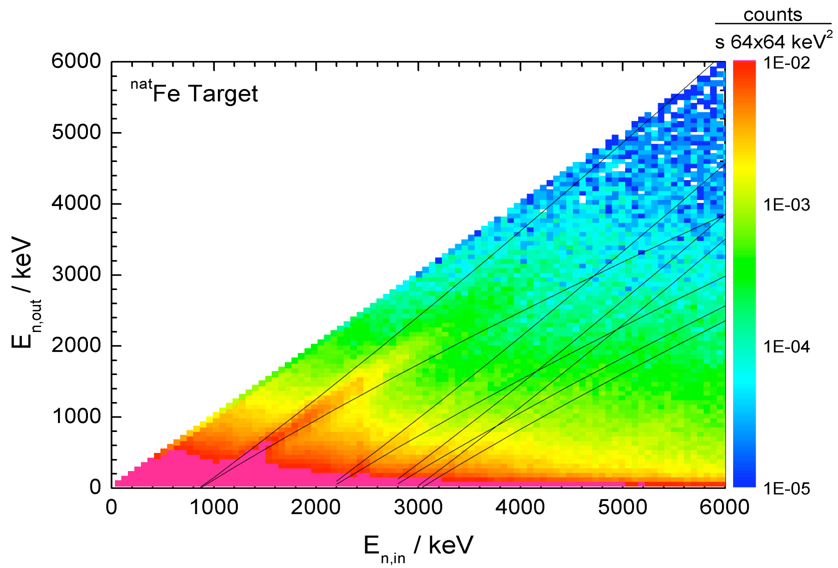


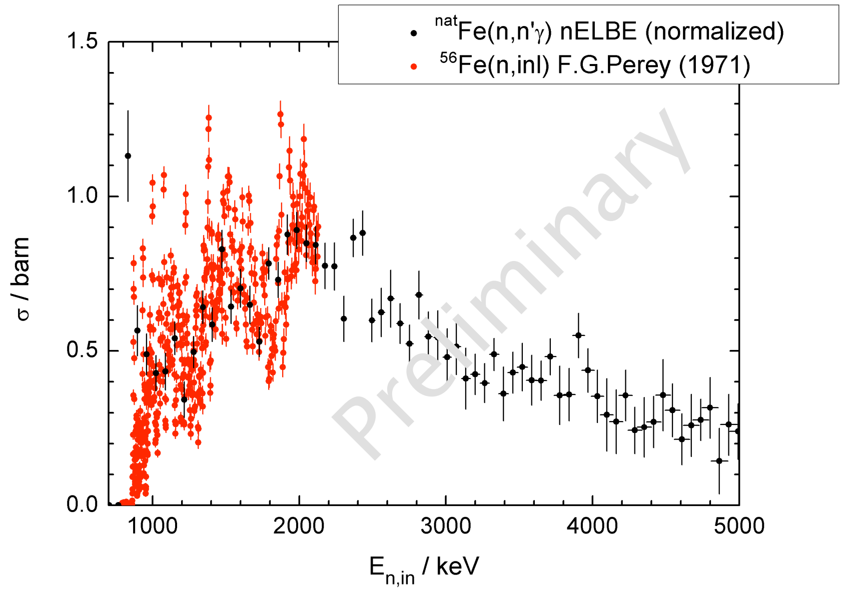
Ar activation?

K35 190 ms 3/2+ ECp	K36 342 ms 2+ ECp,ECα,...	K37 1.226 s 3/2+ EC	K38 7.636 m 3+ * EC	K39 3/2+ 93.2581	K40 1.277E+9 y 4- EC,β- 0.0117	K41 3/2+ 6.7302	K42 12.360 h 2- β-	K43 22.3 h 3/2+ β-
Ar34 844.5 ms 0+ EC	Ar35 1.775 s 3/2+ EC	Ar36 0+ 0.337	Ar37 35.04 d 3/2+ EC	Ar38 0+ 0.063	Ar39 269 y 7/2- β-	Ar40 0+ 99.600	Ar41 109.34 m 7/2- β-	Ar42 32.9 y 0+ β-
Cl33 2.511 s 3/2+ EC	Cl34 1.5264 s 0+ * EC	Cl35 3/2+ 75.77	Cl36 3.01E+5 y 2+ EC,β-	Cl37 3/2+ 24.23	Cl38 37.24 m 2- * β-	Cl39 55.6 m 3/2+ β-	Cl40 1.35 m 2- β-	Cl41 38.4 s (1/2,3/2)+ β-
S32 0+ 95.02	S33 3/2+ 0.75	S34 0+ 4.21	S35 87.51 d 3/2+ β-	S36 0+ 0.02	S37 5.05 m 7/2- β-	S38 170.3 m 0+ β-	S39 11.5 s (3/2,5/2,7/2)- β-	S40 8.8 s 0+ β-

Inelastic x-sections

Example: Inelastic scattering on Fe
(Courtesy A. Junghans, FZD Rossendorf)





Summary

Various intense neutron sources are at hand to measure radioisotope production in materials

In combination with Felsenkeller Underground Laboratory a rather unique facility

Radioisotope production by cosmic rays lack reliable cross section measurements, essential input to estimate background contribution

Higher energy beams necessary (talk L. Bezrukov)

Systematic study of Ge-system ongoing

First activation on various samples done -> see talk by A. Domula

General option for NAA of GERDA samples/materials