INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
34100 TRIESTE (ITALY) - P.O.B. 586 - MIRAMARE - STRADA COSTIERA 11 - TELEPHONE: 2240-1
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H4.SMR 346/35

SCHOOL ON
NON-ACCELERATOR PHYSICS
25 April - 6 May 1988

G A L L E X
GALLIUM EUROPEAN COLLABORATION

by

E. Bellotti
Universita degli Studi di Milano
Italy

GALLEX - - -

Gallium european collaboration

Heidelberg MPI, KfK (Karlsruhe)

Milan, Münich T.U., Nice, Rome II

Saclay, W.I.S. (Rehovot), BNL

$$^{71}Ga(\nu_e, e^-)^{71}Ge$$

low energy (p-p) $\nu_\odot$

at

Gran Sasso

Experiments

R. Davis jr. and coll.

$$^{37}Cl(\nu_e, e^-)\,^{37}Ar$$

$E_{th} = 814$ KeV $\Rightarrow$ ^8B $\nu_\odot$

$\phi_{exp} = 2$ SNU's vs. $\phi_{SSM} \sim 6 \div 8$ SNU's

[J.K. Rowley, B.T. Cleveland and R. Davis in Solar Neutrinos and Neutrino Astronomy, Homestake (1984) AIP Conf. Proc. N° 126, p. 1]

KAMIOKANDE II Collaboration

$$\nu_x e^- \rightarrow \nu_x e^-$$

Water Čerenkov detector

$E_{th} \geq 9.5$ MeV $\Rightarrow$ ^8B $\nu_\odot$

real time and directionality

$\phi_{meas} \leq 3.2\ 10^6\ \nu_e/(cm^2 s)$ 90% C.L.

$\phi_{SSM} \sim 6\ 10^6\ \nu_e/(cm^2 s)$

Experiments proposed or in progress

- geochemical

$^{97}Mo(\nu_e, e^-)\,^{97}Tc$ $E_{th} = 0.54$ MeV $\tau_{1/2} = 2.6\ 10^6$ y

$^{98}Mo(\nu_e, e^-)\,^{98}Tc$ $E_{th} = 1.7$ MeV $\tau_{1/2} = 4.2\ 10^6$ y

$^{205}Tl(\nu_e, e^-)\,^{205}Pb$ $E_{th} = 40$ KeV $\tau_{1/2} = 1.4\ 10^7$ y

(first excited state +2.3 KeV)

- radiochemical

$^{71}Ga(\nu_e, e^-)\,^{71}Ge$ $E_{th} = 235$ KeV

$^{81}Br(\nu_e, e^-)\,^{81}Kr$ $E_{th} = 470$ KeV

$\tau_{1/2} = 2.1\ 10^5$ y

- direct

Indium $E_{th} = 128$ KeV

tunnel junction, superconducting grains

Boron $^{11}B(\nu_e, e^-)\,^{11}C$ $E_{th} = 1.98$

$^{11}B(\nu_x, \nu_x)\,^{11}B^*$

Heavy Water (SNO) $\nu_e\, d \to p\, p\, e^-$

$\nu_x\, d \to p\, n$

Liquid Argon (ICARUS) $\nu_x\, e^- \to \nu_x\, e^-$

$^{40}Ar(\nu_e, e^-)\,^{40}K^*$

Gallium

(suggested by V. Kuzmin. Sov. Phys. JETP 22 (1966), 1051)

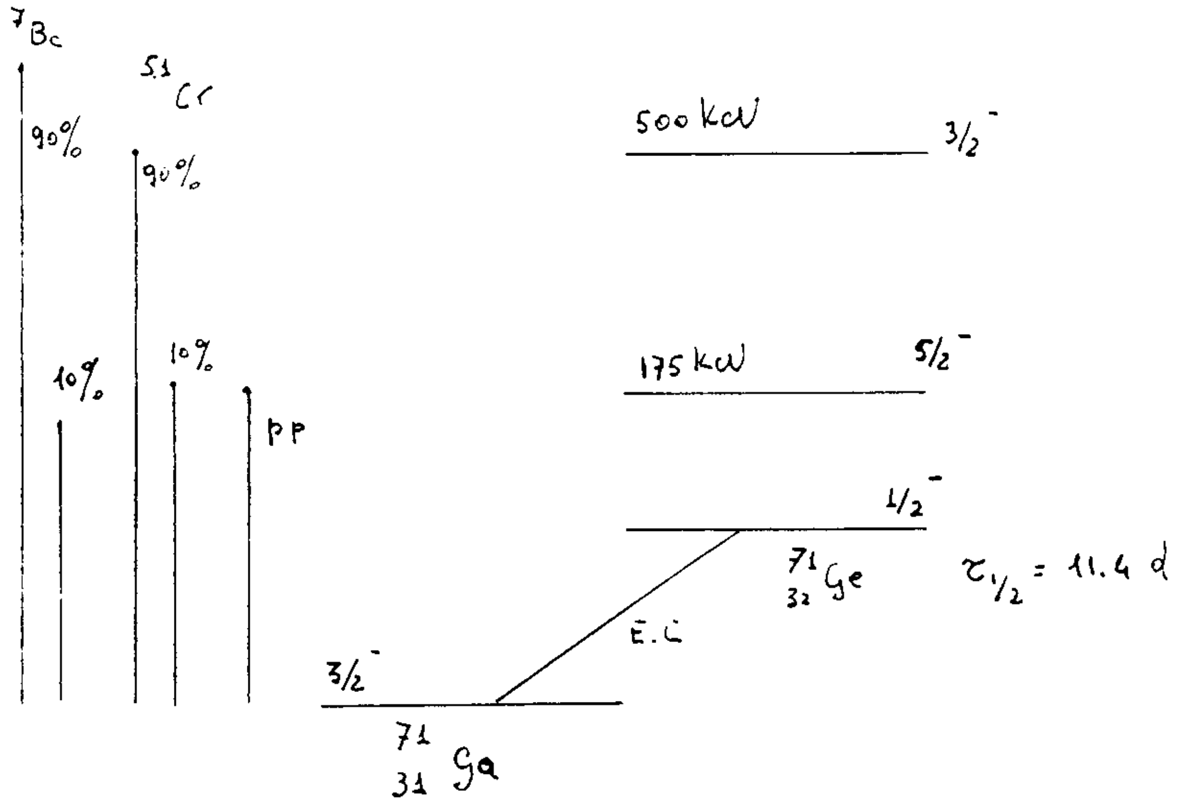
Properties of Gallium

M = 69.72 melting point 29.8 °C

$^{69}_{31}Ga$ i.a. 60.1 %

$^{71}_{31}Ga$ i.a. 39.9 %

($^{67}_{31}Ga \xrightarrow[78.3\,h]{E.C.} {}^{67}_{30}Zn$ (stable) + γ's)



Expected rates

$$n_{SNU's} = \phi \cdot \sigma \cdot 10^{36}$$

	ϕ ($cm^{-2}s^{-1}$)	σ	
pp	$6.05 \; 10^{10}$	$11.7 \; 10^{-46}$	} 73.5 SNU's
pep	$0.015 \; 10^{10}$	$167 \; 10^{-46}$	}
^{7}Be	$0.457 \; 10^{10}$	$68.2 \; 10^{-46}$	31
$^{8}B + ^{13}N + ^{15}O$			~ 20 *

* production of first excited state

Target mass = compromise cost – rate

1 ton $^{nat}Ga \approx 3.4 \; 10^{27}$ ^{71}Ga at

120 SNU's $\Rightarrow$ 0.035 ^{71}Ge at/day

30 tons $\simeq$ 1 atom/day

• Big tank 30 t of Gallium

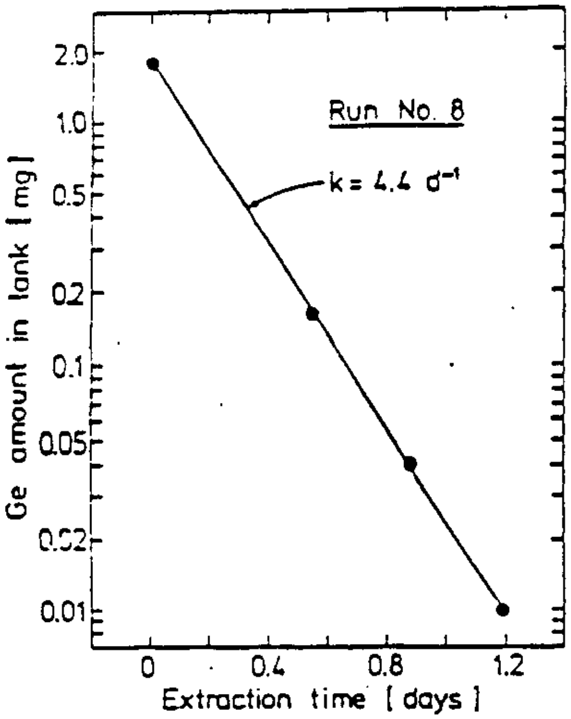
$GaCl_3 + HCl + H_2O$

Extraction

$Ge \rightarrow GeCl_4$

extraction by air purge

Efficency : pilot experiment at BNL (1.26 t)



Example of Ge extraction from the pilot tank.

Chemistry

$$GeCl_4 + \underbrace{KBH_4}_{} + \underbrace{3H_2O}_{} \rightarrow GeH_4 + H_3BO_3 + 3HCl + KCl$$

tritium free

GeH_4 purified and separated by gascromatography

GeH_4 + Ar / Xe = filling gas for miniaturized proportional counters

Properties of Ge

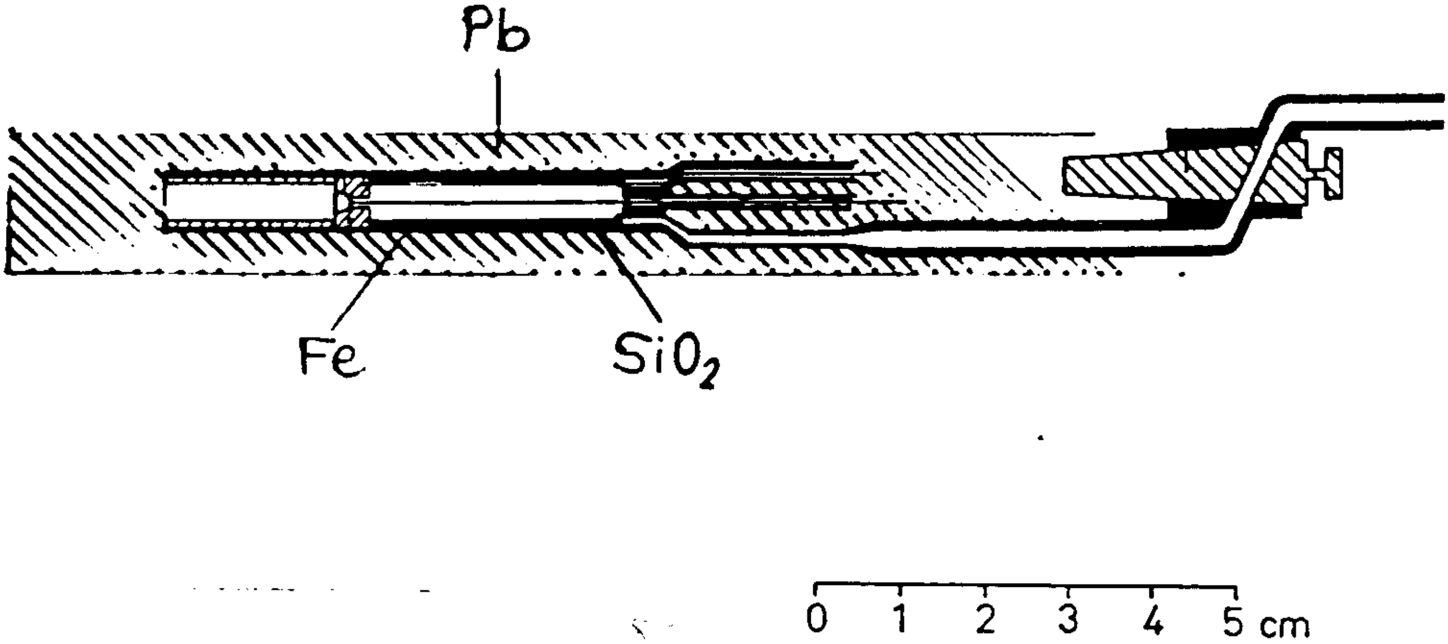
Stable isotopes		Unstable		
70	20.5 %	68	$\tau_{1/2} = 288$ d	E.C.
72	27.4 %	71	$\tau_{1/2} = 11.4$ d	E.C.
73	7.8 %			
74	36.5 %			
76	7.8 %			

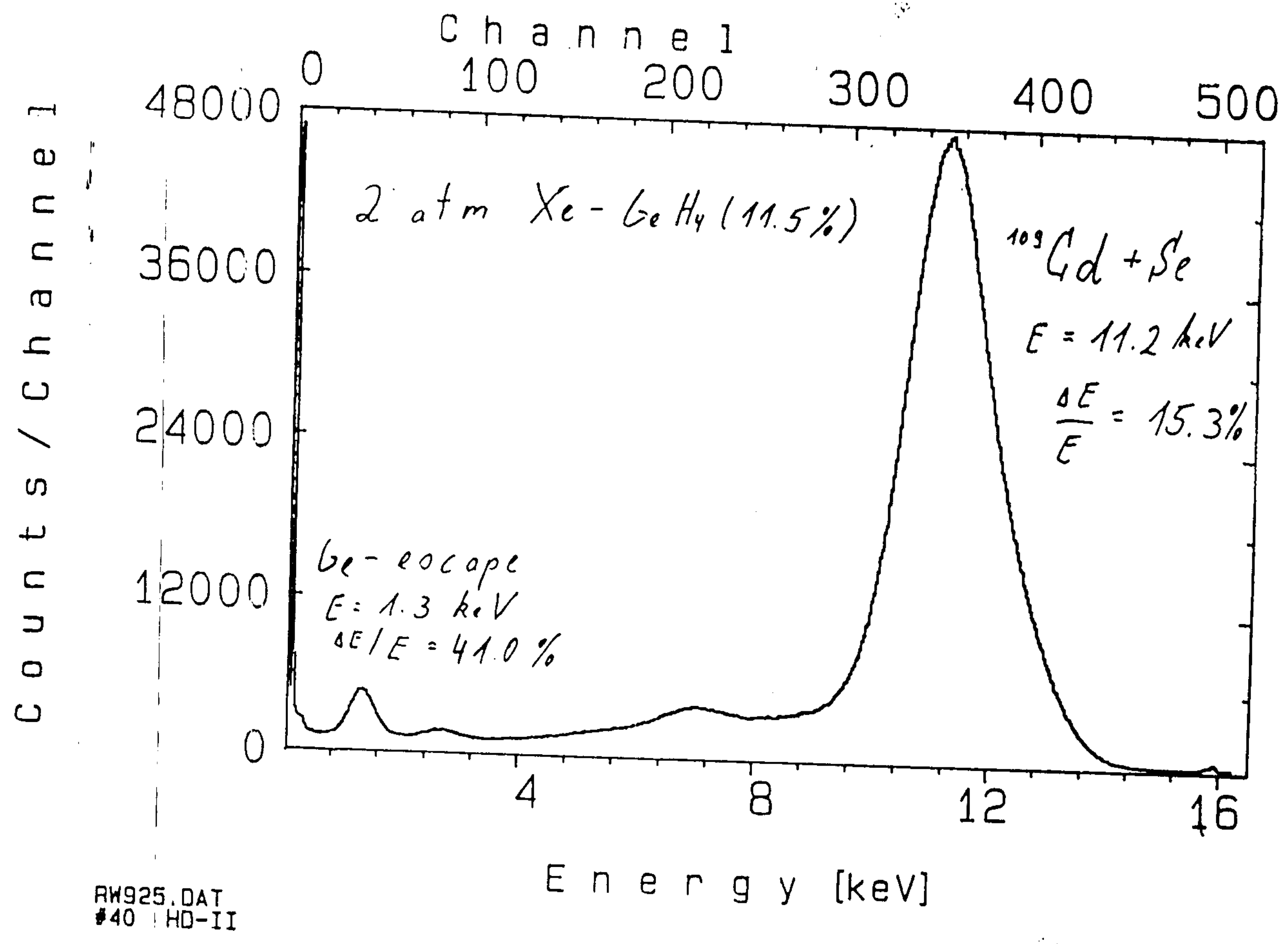
^{71}Ge decay

Capture	%	Auger (KeV)	X ray (KeV)
K	41.5	10.37	—
K	5.3	0.11	10.3
K	27.2	1.12	9.3
K	14.0	1.15	9.2
L	10.3	1.3	-
M	1.7	0.16	-

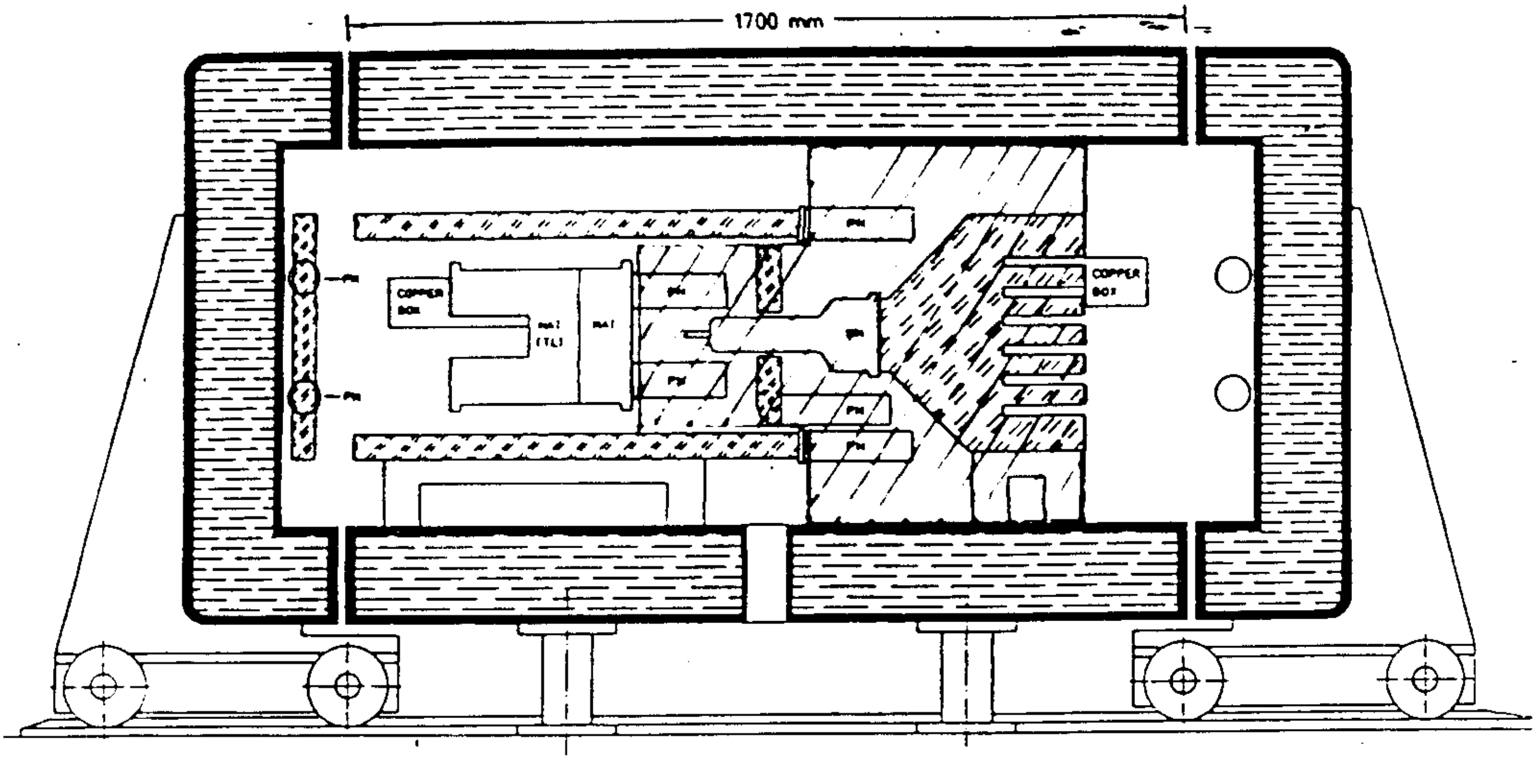
Many counters developed at Heidelberg.

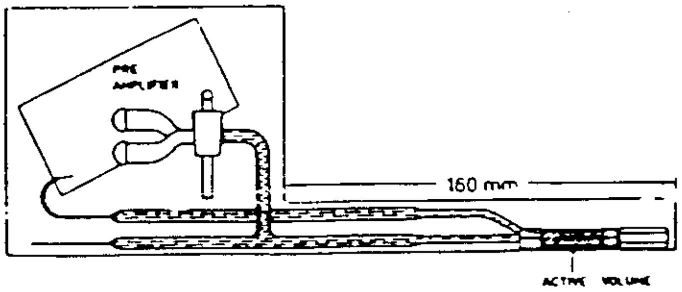
- $\frac{\text{active volume}}{\text{total volume}} = 90 \div 93\ \%$
- background : shielding of iron, lead et
- different mixtures
- efficency ; at present $\approx$ 70 %




Channel
0
100
200
300
400
500
Counts / Channel
48000
36000
24000
12000
0
2 atm Xe - GeH4 (11.5%)
109Cd + Se
E = 11.2 keV
ΔE/E = 15.3%
Ge - escape
E = 1.3 keV
ΔE/E = 41.0 %
4
8
12
16
Energy [keV]
RW925.DAT
#40 HD-II

GA-NEUTRINO DETECTOR ARRANGEMENT





COPPER BOX WITH PROPORTIONAL COUNTER

LOW ACTIVITY LEAD

PLASTIC SCINTILLATOR

PM = PHOTO MULTIPLIER

Background

$$^{71}Ga(p,n)^{71}Ge \equiv {}^{71}Ga(\nu_e,e^-)^{71}Ge$$

$E_{th} \sim 1.03$ MeV

p's are produced by

(n,p), (α,p) ..., μ's

neutrons are produced by:

U, (α,n) in rocks = shielding

impurities in solution

requirements < 2 ppb ^{232}Th

< 25 ppb ^{238}U bkg $< 2\%$

< 0.5 pCi/Kg ^{228}Ra

muons $\phi = 1\mu/(m^2 \times h)$ bkg $\sim 1\%$

monitor

$$^{69}_{31}Ga(p,n)^{69}_{32}Ge \quad \tau = 2.34\ d$$

$$\xrightarrow{\beta^+,\ E.C.} {}^{69}_{31}Ga + \gamma's$$

Test with muon beam at CERN

~ 80 ℓ of $GaCl_3$

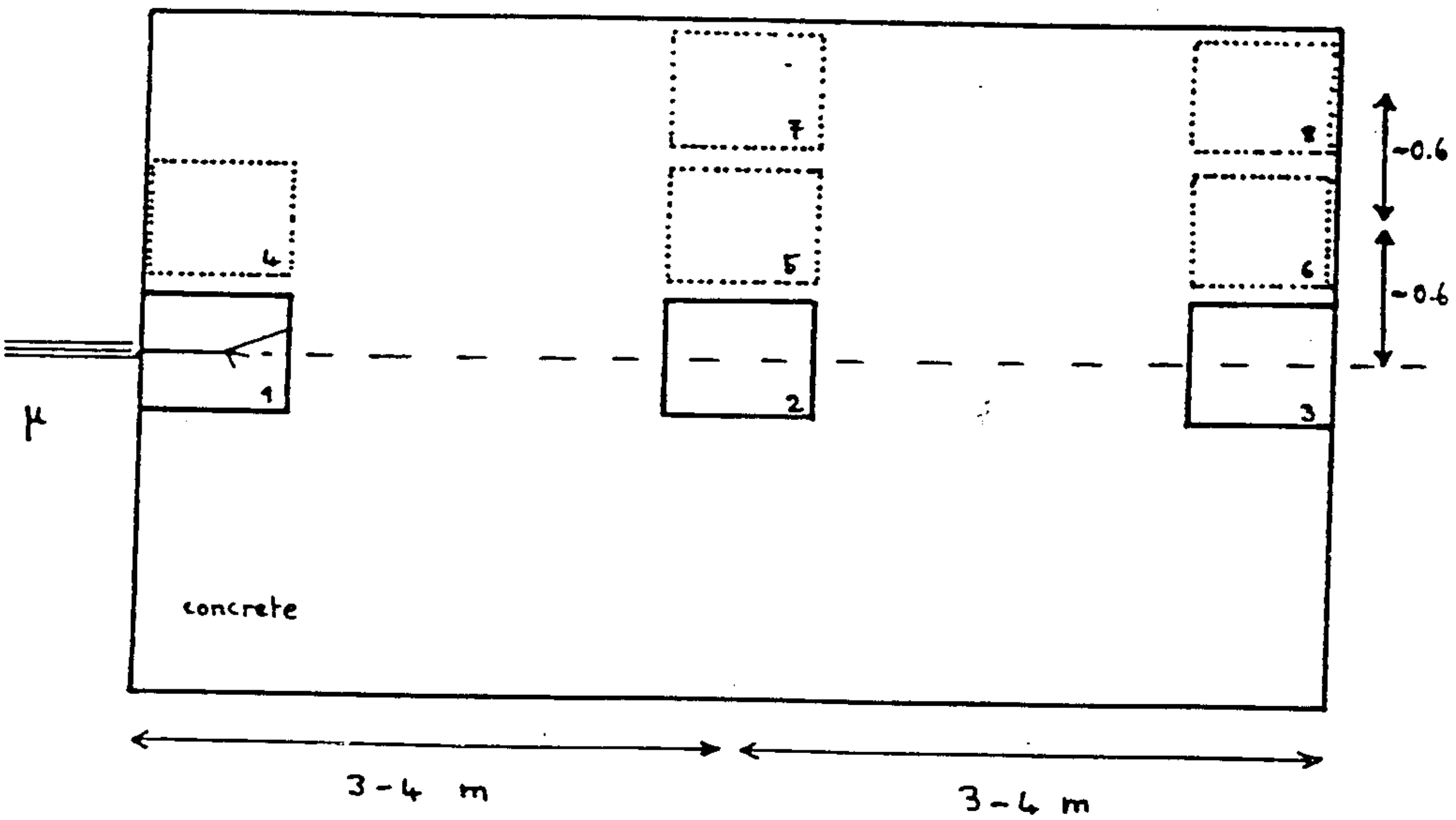
NA 37 area at CERN

μ beam: energy $90 \div 280$ GeV

intensity $2\,10^7 \div 5\,10^7$ GeV

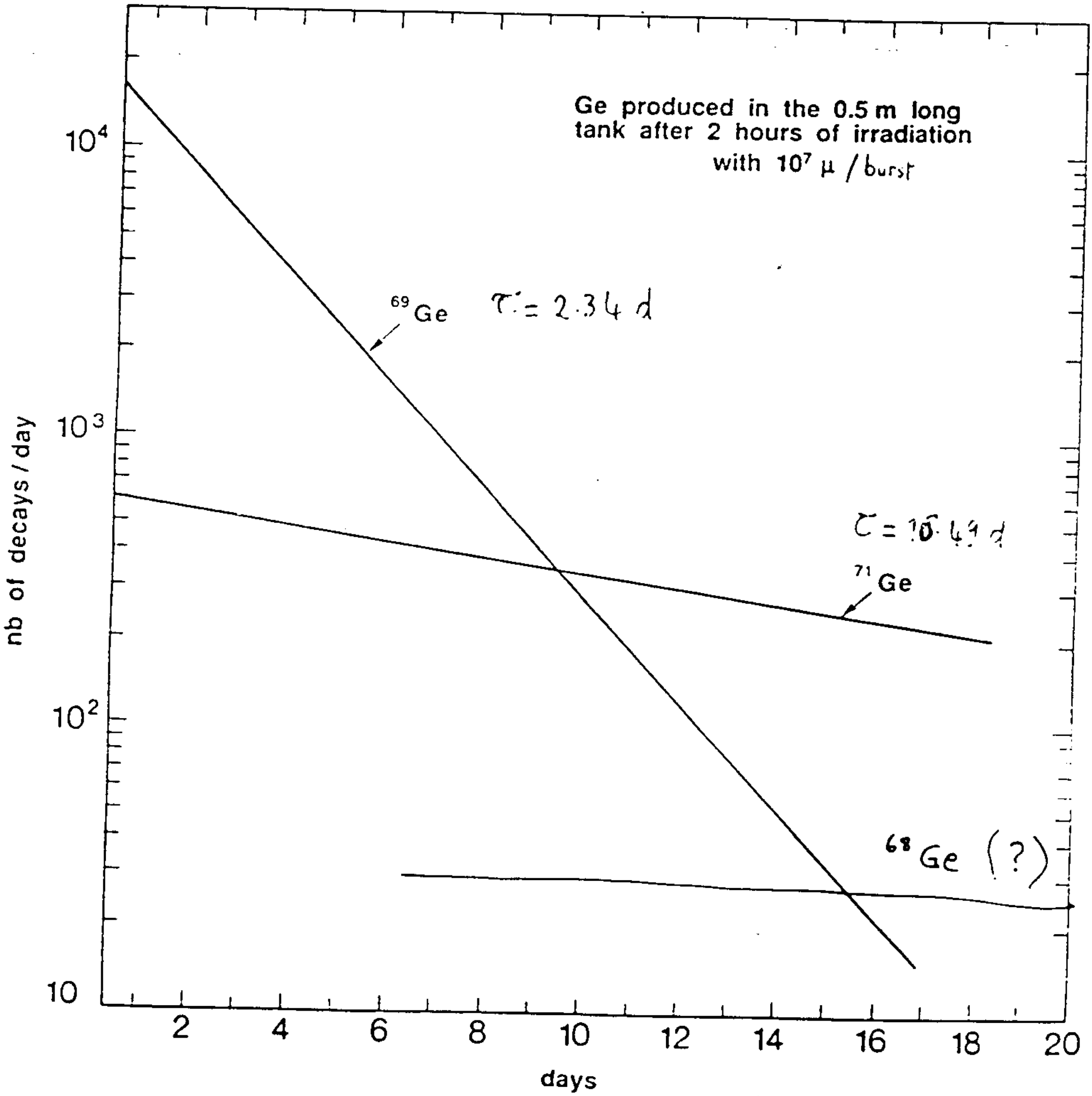
geometry $\phi = 10$ cm ; halo < 10%

different positions in the muon beam



- 3 weeks of counting → 2% precision

- 5 counters now available in Heidelberg (A. Lenzing) – small background

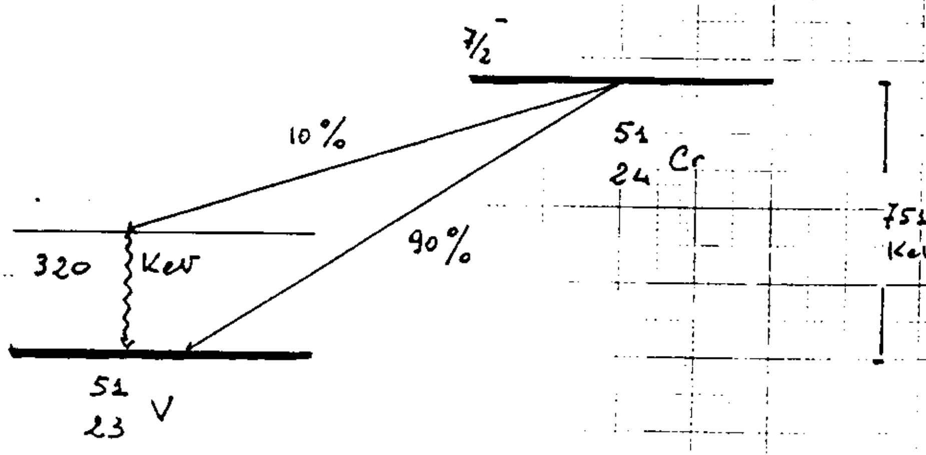


CALIBRATION WITH A ν SOURCE

R.S. Raghavan proposed to use a ^{51}Cr source to calibrate $\nu_\odot$ experiments with low threshold (Ga, Br, In ...)

^{51}Cr can be obtained by irradiation of ^{50}Cr;

^{51}Cr has a half life of 27.7 days and ~~decays~~ transforms ~~to~~ by E.C. in $^{51}_{23}V$ by emission of a 751 KeV (90%) or 431 KeV (10%) ν; ~~the~~ in the second case a 320 KeV γ ray is also emitted; decay scheme is shown in fig.



A source of ~ 1 MCi is needed

e.g. a source $\phi = 20$ cm, $h = 1$ m

shielded by 10 cm lead

with an activity of .6 MCi ($22\ 10^{15}$ Bq)

installed 5 days after the end of irradiation

would give

	10 d's	..					
^{51}Cr	14.5	11.3	8.8	6.8	5.3	4.1	= 51 at ^{71}Ge
$\nu_\odot$	5	5	5	5	5	5	: 30 " "

$50 \pm 10 \equiv 20\%$

* therefore, to achieve 10% accuracy:

4 times $22\ 10^{15}$ Bq

2 " $37\ 10^{15}$ Bq

Irradiation test

[M. Cribier et al - DPh PE 87-14 ; Sept. 1987]
(Saclay note)

Cromium was in form of grains ($\phi \sim 1-2$ mm)
✓ to allow ~~cods~~ for calibration of the irradiated sample

12.445 Kg of nat. Cr

irradiation 24th Oct - 14th Nov 1985 = 21 days

at SILOE (35 MW reactor in Grenoble)

Initial activity $0.94 \pm 0.05\ 10^{15}$ Bq

<u>Impurities</u>

main contribution ~~fess~~ to γ activity was from

^{124}Sb and ^{110m}Ag :

	activity	deduced impurity ppm
^{124}Sb	$3.4 \pm 0.5\ 10^{-6}$	$7.4 \pm$ ~~10^{-6}~~ 1.1 ppm
^{110m}Ag	$2.0 \pm 0.3\ 10^{-6}$	18.0 ± 2.7

Shielding thickness ~~is defin~~ has to reduce the radiation
to < 0.25 mrem/h at 2 m distance
< 6 " " ~~at~~ in contact

Thickness determined by impurities !

Table 3

Characteristics of the radioactive impurities found ~~in~~ the chromium after the irradiation test.

a) ^{110m}Ag : $T_{1/2}$ = 249.8 days $\sigma(^{109}Ag + n \rightarrow {}^{110m}Ag)$ = 4.2 barns

^{109}Ag = 48.6% (Ag)

Main photon energy (MeV)	Branching ratio	Interaction length in Pb (cm)	in W (cm)	in Cr grains (cm)
.657	100%	.7	.5	3.4
.884	74%	1.2	.7	4.0
.937	33%	1.3	.8	4.1
.763	24%	1.	.6	3.7
1.380	22%	1.8	1.1	5.1
1.505	11%	1.9	1.1	5.3

b) ^{124}Sb : $T_{1/2}$ = 60.2 days $\sigma(^{123}Sb + n \rightarrow {}^{124}Sb)$ = 3.4 barns

^{123}Sb = 42.7% (Sb)

Main photon energy (MeV)	Branching ratio	Interaction length in Pb (cm)	in W (cm)	in Cr grains (cm)
.602	100%	.65	.45	3.3
1.690	51%	2.0	1.2	5.5
2.090	7%	2.3	1.4	6.3

Natural chromium ; two possibilities

two reactors irradiation : cycle 21 – 7 – 21 days
irr. irr.

one reactor (modified)

Enriched sample

Isotope	σ(b)	nat. %	σ x i.a.	enriched (CrO_2F_2) % (1)	% (2)	% (3)	σ x i.a. (3)
50	15.9	4.35	0.69 (22%)	10.5	15.51	21.4	3.4 (73)
52	0.76	83.8	0.64	82	79.8	74.4	0.56
53	18.2	9.5	1.73 (56)	6	4.1	3.7	0.67
54	0.36	2.35	0.008	1	0.5	0.47	~

1 Gas centrifuges separation (Oak-Ridge)

(1) one pass not optimized
(2) " " optimized
(3) two " "

Remark : the enriched sample can be used many times

Time schedule

- first delivery of Gallium ~ summer 1988

  last " " . end 1989

possible schedule

1990 $\nu_\odot$ accuracy ~15% SSM ÷ 30% Max. mixing

1... ^{51}Cr calibration

199.. $\nu_\odot$

⋮