Reactions A(ν,e⁻)B

12/11/83

% abundance	Groundstate A(J^P)	Groundstate B(J^P)	Decay B	$\tau_{1/2}$ Lifetime	(MeV) Q_{EC}	Other Transitions (A→B)
99.985	$^{1}_{1}H(\frac{1}{2}+)$	No	—	—	—	—
.0148	$^{2}_{1}H(\ )$	$^{2}_{2}He$(No)	—	—	—	—
1.38×10^{-4}	$^{3}_{2}He(\frac{1}{2}+)$	$^{3}_{3}Li$ (No)	—	—	—	—
99.99986	$^{4}_{2}He(0+)$	$^{4}_{3}Li(2-)$	EC?	?	≈ 27.0	?
7.5%	$^{6}_{3}Li$	$^{6}_{4}Be$(No)	—	—	—	—
92.5%	$^{7}_{3}Li(\frac{3}{2}-)$	$^{7}_{4}Be(\frac{3}{2}-)$	EC	53.3 days	.82	— ←
100%	$^{9}_{4}Be(\frac{3}{2}-)$	$^{9}_{5}B(\frac{3}{2}-)$	pαα	$.85\times10^{-18}$ sec	1.068	—
19.8%	$^{10}_{5}B(3+)$	$^{10}_{6}C(0+)$	β+	19.2 sec	3.651	(2+) state 3.35 Mev higher decays by γ to groundstate in 0.11 ps.
80.2%	$^{11}_{5}B(\frac{3}{2}-)$	$^{11}_{6}C(\frac{3}{2}-)$	β+ (99.76%) EC (.24%)	20.38 min	1.982	(½-) " 2.00 mev " " " " " " " " ?
98.89%	$^{12}_{6}C(0+)$	$^{12}_{7}N(1+)$	β+	11.0 ms	17.338	(2+) " .96 Mev, γ in ? time.
1.11	$^{13}_{6}C(\frac{1}{2}-)$	$^{13}_{7}N(\frac{1}{2}-)$	β+	9.96 min	2.221	?
99.63	$^{14}_{7}N(1+)$	$^{14}_{8}O(0+)$	β+	70.6 sec	5.145	(1-) state 5.17 Mev higher, γ in ? time
.366	$^{15}_{7}N(\frac{1}{2}-)$	$^{15}_{8}O(\frac{1}{2}-)$	β+	122 sec	2.754	(½+) state 5.183 Mev " , γ in ? time
99.76	$^{16}_{8}O(0+)$	$^{16}_{9}F$(No)	—	—	—	—
.038	$^{17}_{8}O(\frac{5}{2}+)$	$^{17}_{9}F(\frac{5}{2}+)$	β+	64.5 sec	2.762	—
.204	$^{18}_{8}O(0+)$	$^{18}_{9}F(1+)$	β+ 96.9% EC 3.1%	109.8 min	1.656	(0+) state 1.04 mev higher, γ in 3 fsec.
100%	$^{19}_{9}F(\frac{1}{2}+)$	$^{19}_{10}Ne(\frac{1}{2}+)$	β+ 99.9+% EC .102%	17.3 sec	3.238	(5/2+), .238 Mev γ, 18 ns
90.51	$^{20}_{10}Ne(0+)$	$^{20}_{11}Na(2+)$	β+	.446 sec	13.887	? , .59 mev γ, ? time
.27	$^{21}_{10}Ne(\frac{3}{2}+)$	$^{21}_{11}Na(\frac{3}{2}+)$	β+	22.47 sec	3.547	(5/2+), .35 mev γ, 9 ps
9.22	$^{22}_{10}Ne(0+)$	$^{22}_{11}Na(3+)$	β+ (90.5%) EC (9.5%)	2.602 yrs	2.842	(1+), (0+) at .583, .657 mev; 243 ns, 14 ps
100	$^{23}_{11}Na(\frac{3}{2}+)$	$^{23}_{12}Mg(\frac{3}{2}+)$	β+	11.3 sec	4.059	(5/2+), .451 mev γ, 1.3 ps
78.99	$^{24}_{12}Mg(0+)$	$^{24}_{13}Al(4+)$	β+	2.07 sec	13.878	(1+), .439 mev γ, 130 ms
10.00	$^{25}_{12}Mg(\frac{5}{2}+)$	$^{25}_{13}Al(\frac{5}{2}+)$	β+	7.18 sec	4.278	
11.01	$^{26}_{12}Mg(0+)$	$^{26}_{13}Al(5+)$	β+ (82%) EC (18%)	7.2×10^{5} yrs	4.005	(0+), .228 Mev higher - decays β+ in 6.36 sec
100	$^{27}_{13}Al(\frac{5}{2}+)$	$^{27}_{14}Si(\frac{5}{2}+)$	β+	4.17 sec	4.809	(½+), .780 γ in 35 ps
92.23	$^{28}_{14}Si(0+)$	$^{28}_{15}P(3+)$	β+	270 ms	14.332	(??), .106 γ in ? time
4.67	$^{29}_{14}Si(\frac{1}{2}+)$	$^{29}_{15}P(\frac{1}{2}+)$	β+	4.1 sec	4.944	(3/2+) at 1.384 Mev γ in .14 ps
3.10	$^{30}_{14}Si(0+)$	$^{30}_{15}P(1+)$	β+, EC	2.5 mins	4.227	(0+), .677 Mev γ in .11 ps
100	$^{31}_{15}P(\frac{1}{2}+)$	$^{31}_{16}S(\frac{1}{2}+)$	β+	2.6 sec	5.395	(3/2+), 1.249 mev γ in .5 ps
95.02	$^{32}_{16}S(0+)$	$^{32}_{17}Cl(1+)$	β+	298 ms	12.687	(??), .067 Mev γ in ? time
.75	$^{33}_{16}S(\frac{3}{2}+)$	$^{33}_{17}Cl(\frac{3}{2}+)$	β+	2.51 sec	5.583	(½+), .811 Mev γ in 1.2 ps
4.21	$^{34}_{16}S(0+)$	$^{34}_{17}Cl(0+)$	β+	1.526 sec	5.493	(3+), .146 Mev γ in 32 min (47%) a β+ (53%)
75.77	$^{35}_{17}Cl(\frac{3}{2}+)$	$^{35}_{18}Ar(\frac{3}{2}+)$	β+	1.78 sec	5.965	(½+), 1.184 Mev γ in ? time.
24.23	$^{37}_{17}Cl(\frac{3}{2}+)$	$^{37}_{18}Ar(\frac{3}{2}+)$	EC	35 days	.814	(½+), 1.410 Mev γ in .7 ps. ←
.337	$^{36}_{18}Ar(0+)$	$^{36}_{19}K(2+)$	β+	340 msec	12.805	(??), .80 above in ? time
.063	$^{38}_{18}Ar(0+)$	$^{38}_{19}K(3+)$	β+	7.61 min	5.913	(0+), .130 Mev above decays β+ in .93 sec
99.60	$^{40}_{18}Ar(0+)$	$^{40}_{19}K(4-)$	EC (10.7%) β- (89.3%)	1.28×10^{9} yrs	1.505	(3-), .030 Mev γ in 4.3 ns
93.26	$^{39}_{19}K(\frac{3}{2}+)$	$^{39}_{20}Ca(\frac{3}{2}+)$	β+	.86 sec	6.524	
1.28×10^{9} yrs EC (10.7%) β- (89.3%) .0117	$^{40}_{19}K(4-)$	$^{40}_{20}Ca(0+)$	STABLE	STABLE	-1.312	(3-), 3.736 γ in 42 ps
6.73	$^{41}_{19}K(\frac{3}{2}+)$	$^{41}_{20}Ca(\frac{7}{2}-)$	EC	1.0×10^{5} yrs	.421	(??) ←
96.94	$^{40}_{20}Ca(0+)$	$^{40}_{21}Sc(4-)$	β+	182 ms	14.320	(??), .034 above in ? time
.647	$^{42}_{20}Ca(0+)$	$^{42}_{21}Sc(0+)$	β+	682 ms	6.423	(7+), .617 Mev above decays by β+ in 62 sec
.135	$^{43}_{20}Ca(\frac{7}{2}-)$	$^{43}_{21}Sc(\frac{7}{2}-)$	β+, EC	3.89 hrs	2.220	(3/2+), .152 Mev γ in .44 ms, (3/2-), .473 mev γ above (3/2+) in .16 ns
2.09	$^{44}_{20}Ca(0+)$	$^{44}_{21}Sc(2+)$	β+ (95%) EC (5%)	3.92 hrs	3.655	(6+), .271 Mev γ (98.6%) + EC (1.4%) in 2.44 days
.0035	$^{46}_{20}Ca(0+)$	$^{46}_{21}Sc(4+)$	β-	83.8 days	1.383	(1-), .143 Mev γ in 18.7 secs.

^{39}Ar radioactive
260 yr = $\tau_{1/2}$ ← from bombs and cosmic rays
β⁻ 570 Kev endpt

1) Neutrino - Electron Elastic Cross Section

T. Hooft Phys Lett B37 (1971) 195
John N. Bahcall Rev. Mod. Phys. 59 (1987) 50.

T. Hooft Form

This is electron K.E. see E. Commins & P.H. Bucksbaum Weak Interactions of Leptons & Quarks

Error in T' Hooft paper left out ②.

$$\frac{d\sigma}{dE_e} = \frac{G_F^2 m_e}{2\pi}\left[(g_V+g_A)^2 + \left(1-\frac{E_e}{E_\nu}\right)^2 (g_V-g_A)^2 + \frac{m_e E_e}{E_\nu^2}\left(g_A^{\textcircled{2}} - g_V^2\right)\right]$$

$$g_V = \tfrac{1}{2} + 2\sin^2\theta_W \qquad \frac{g_V+g_A}{2} = \frac{1+2\sin^2\theta_W}{2} = \frac{1}{2}+\sin^2\theta_W$$

$$g_A = \tfrac{1}{2} \qquad \frac{g_V-g_A}{2} = \sin^2\theta_W$$

$$\frac{g_A^2-g_V^2}{4} = \frac{\frac{1}{4} - \left(\frac{1}{4} + 2\sin^2\theta_W + 4\sin^4\theta_W\right)}{4} = -\left(\tfrac{1}{2}\sin^2\theta_W + \sin^4\theta_W\right) = -\sin^2\theta_W\left(\tfrac{1}{2}+\sin^2\theta_W\right)$$

Taking (+ for ν_e, − for ν_μ)

$$g_L = \pm\tfrac{1}{2} + \sin^2\theta_W = \frac{g_V+g_A}{2}$$
$$g_R = \sin^2\theta_W = \frac{g_V-g_A}{2}$$
$$g_L g_R = \sin^2\theta_W\left(\tfrac{1}{2}+\sin^2\theta_W\right) = -\frac{g_A^2-g_V^2}{4}$$

} Bahcall Notation

$$\frac{d\sigma}{dE_e} = \frac{4G_F^2 m_e}{2\pi}\left[\left(\frac{g_V+g_A}{2}\right)^2 + \left(\frac{g_V-g_A}{2}\right)^2\left(1-\frac{E_e}{E_\nu}\right)^2 + \frac{m_e E_e}{E_\nu^2}\left(\frac{g_A^2-g_V^2}{4}\right)\right]$$

$$\frac{d\sigma}{dE_e} = \frac{2m_e G_F^2}{\pi}\left[g_L^2 + g_R^2\left(1-\frac{E_e}{E_\nu}\right)^2 - \frac{m_e E_e}{E_\nu^2} g_L g_R\right]$$

Let $E_e = m_e T \qquad E_\nu = m_e q$

$$\frac{d\sigma}{dT} = \left(\frac{2m_e^2 G_F^2}{\pi}\right)\left[g_L^2 + g_R^2\left(1-\frac{T}{q}\right)^2 + \frac{T}{q^2} g_L g_R\right] \leftarrow \text{Bahcall form}$$

(the prefactor $= \sigma_0$)

For Dimensional reasons ↓

$$\sigma_0 = \frac{2m_e^2 G_F^2}{\pi}\times(\hbar c)^2 \qquad G_F = 1.166\times10^{-5}\,\text{GeV}^{-2} = \text{Fermi } \beta \text{ decay constant.}$$

$$= \left(\frac{2}{\pi}\right)(.511\times10^{-3}\,\text{GeV})^2(1.166\times10^{-5}\,\text{GeV}^{-2})^2\times(1.97\times10^{-14}\,\text{GeV-cm})^2 = 8.77\times10^{-45}\,\text{cm}^2$$

Integrating over energy transfers $T_{max} = \frac{2q^2}{1+2q}$ to T_{min}

$$\sigma_{tot,q}(T_{min}) = \sigma_0\left[(g_L^2+g_R^2)(T_{MAX}-T_{min}) - \left[\frac{g_R^2}{q} + \frac{g_L g_R}{2q^2}\right](T_{max}^2 - T_{min}^2) + \frac{g_R^2}{3q^2}(T_{max}^3 - T_{min}^3)\right]$$

Example $E_\nu = 860\,\text{KeV}$ $\quad q = 1.683 = ①$ $\quad g_L = .72$ $\quad g_R = .22$

$g_L^2 + g_R^2 = .5668 = ③$

$\frac{g_R^2}{q} + \frac{g_L g_R}{2q^2} = .0567 = ④$

$\frac{g_R^2}{3q^2} = .0057 = ⑤$

$T_{max} = 1.2895 = ⑥$

$T_{min} = 0$

$$\sigma_{tot,q}(25\,\text{KeV}) = 8.77\times10^{-45}\,\text{cm}^2\left[.7077 - .0953 + .0125\right] = 8.77\times10^{-45}\,\text{cm}^2\times .6249 = 5.48\times10^{-45}\,\text{cm}^2$$

$$\sigma_{tot,q}(0) = 8.77\times10^{-45}\,\text{cm}^2\left[.7354 - .0955 + .0125\right] = 8.77\times10^{-45}\,\text{cm}^2\times .6524 = 5.72\times10^{-45}\,\text{cm}^2$$

$$\sigma_{tot,q}(100\,\text{KeV}) = 8.77\times10^{-45}\,\text{cm}^2\left[.6245 - .0937 + .0124\right] = 8.77\times10^{-45}\,\text{cm}^2\times .5436 = 4.77\times10^{-45}\,\text{cm}^2$$

$$\frac{T}{m_e} = \frac{2E_\nu^2/m_e^2}{1+2E_\nu/m_e}\; T_{max} = \frac{2E_\nu^2}{m_e^2+2m_eE_\nu}$$
$$T = \frac{2E_\nu^2}{m_e+2E_\nu}$$

Collège de France
LPC 92-31
12 / 8 / 92

A HIGH RATE SOLAR NEUTRINO DETECTOR WITH ENERGY DETERMINATION*

J. Séguinot [a, b], T. Ypsilantis [a, b] and A. Zichichi [c,d]

a) Collège de France, Paris, France
b) World Laboratory, Geneva, Switzerland
c) CERN, Geneva, Switzerland
d) INFN- Gran Sasso National Laboratory, Italy

Abstract:

A real time (non radiochemical) experiment is proposed which can detect the low energy solar neutrinos from the reactions pp---e^++d+ν_e and e^-+^{7}Be---^{7}Li+ν_e, identify the individual spectral components, is sensitive to ν_μ, ν_τ and ν_e with an event rate of 20,000 per year.

Neutrino-electron (νe) elastic scattering, like Compton scattering, results in transfer of kinetic energy (T) to the electron with a characteristic Compton edge. The proposed detector is a time projection chamber (TPC) filled with 20 tons of He gas as the electron target with 6.3 ktons of liquid nitrogen as the shield. The TPC method allows determination of the direction of the initial recoil track and its energy from the total track length. From these, and knowledge of the sun's position, the energy of the initiating neutrino can be calculated thus allowing monoenergetic line sources to be identified. A parallel method to determine the spectral composition of the sources is by observation of Compton edges. The energy resolution of this detector from range ($\sigma_T/T \leq 5\%$) is sufficiently good to keep these edges sharp. An event rate of $2 \cdot 10^4$/year can be attained, mainly from the pp and ^{7}Be channels, with 20 tons of He gas target. To keep the TPC size reasonable, the helium gas and the liquid nitrogen shield are pressurized to 25 bar at 77^0 K. The advantages of a He target and N_2 shield are: i) they have no long lived radioactive isotopes, ii) they freeze out potential radioactive impurities iii) they are cheap, easily available and safe iv) no muon induced radiogenesis in helium.

Detector calibration can be made with the pure EC radioactive source e.g. e^-+^{37}Ar---^{37}Cl+ν_e (E_ν=814 keV, $t_{1/2}$=35 days) placed just outside the shield. An activity of 1 MCi will produce ≈70 ν_ee elastic scatters/day, slightly more than the Standard Solar Model rate of ≈55/day. Apart from calibration, events from the low T region of the electron recoil spectrum can determine an upper limit for the ν_e magnetic moment. This scattering, due to a purely electromagnetic interaction between the neutrino magnetic moment and the electron charge, does not require the sun's magnetic field to produce transversely polarized neutrinos.

* Presented by T. Ypsilantis at the Neutrino Telescopes Conference, Venice, Italy, 10-13/ 3/ 92.

Résumé:

Une expérience (non radio-chimique) en temps réel est proposée pour détecter les neutrinos solaires de basses énergies des réactions pp---e^++d+ν_e et e^-+^{7}Be---^{7}Li+ν_e, et identifier les composantes du spectre. L'expérience est sensible aux neutrinos ν_μ, ν_τ et ν_e avec un taux de $2 \cdot 10^4$ événements détectés par année.

Le diffusion élastique neutrino-électron (νe) résulte, comme pour la diffusion Compton, au transfert d'une énergie cinétique T à l'électron avec une coupure caractéristique de l'effet Compton.

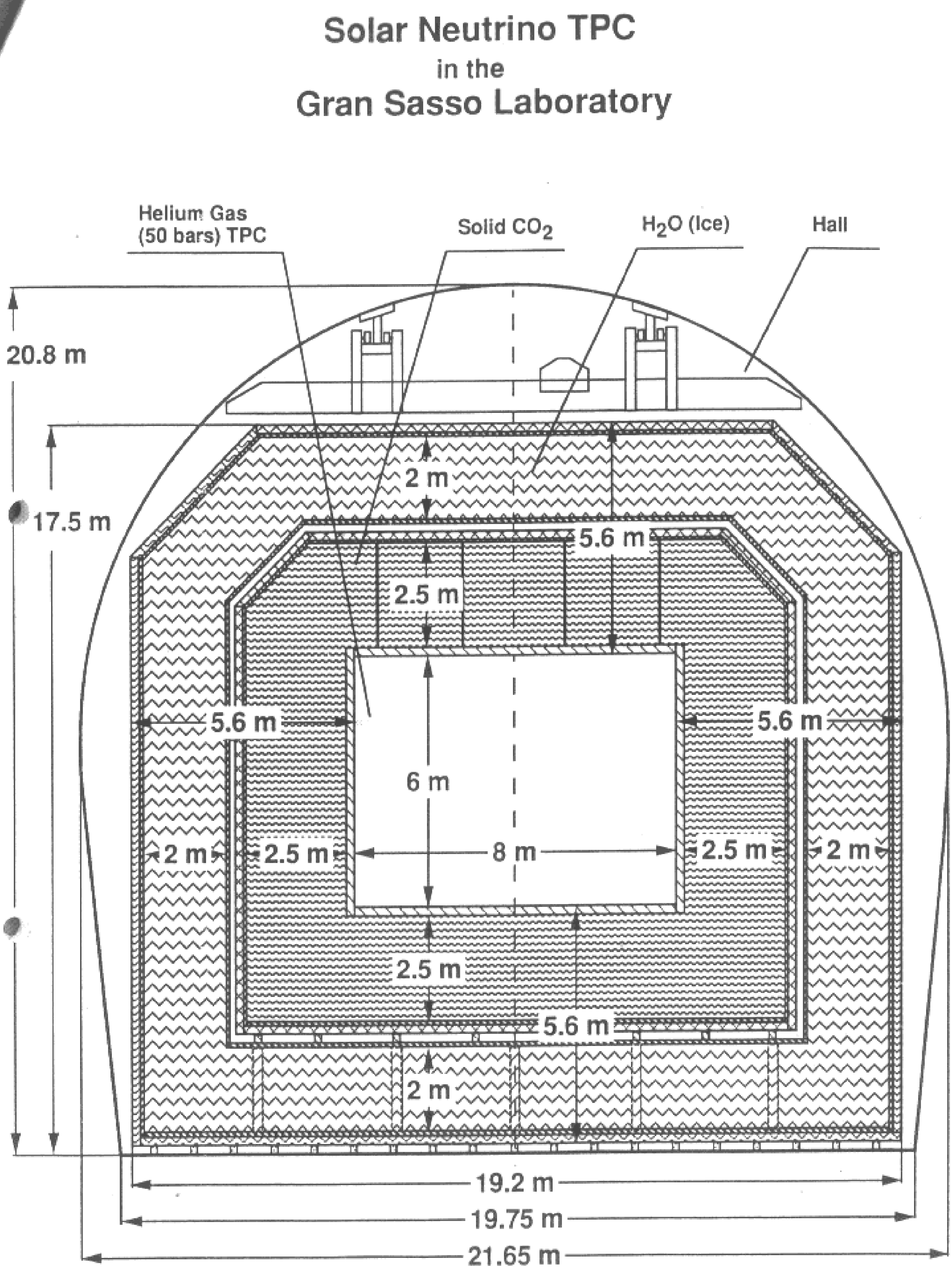
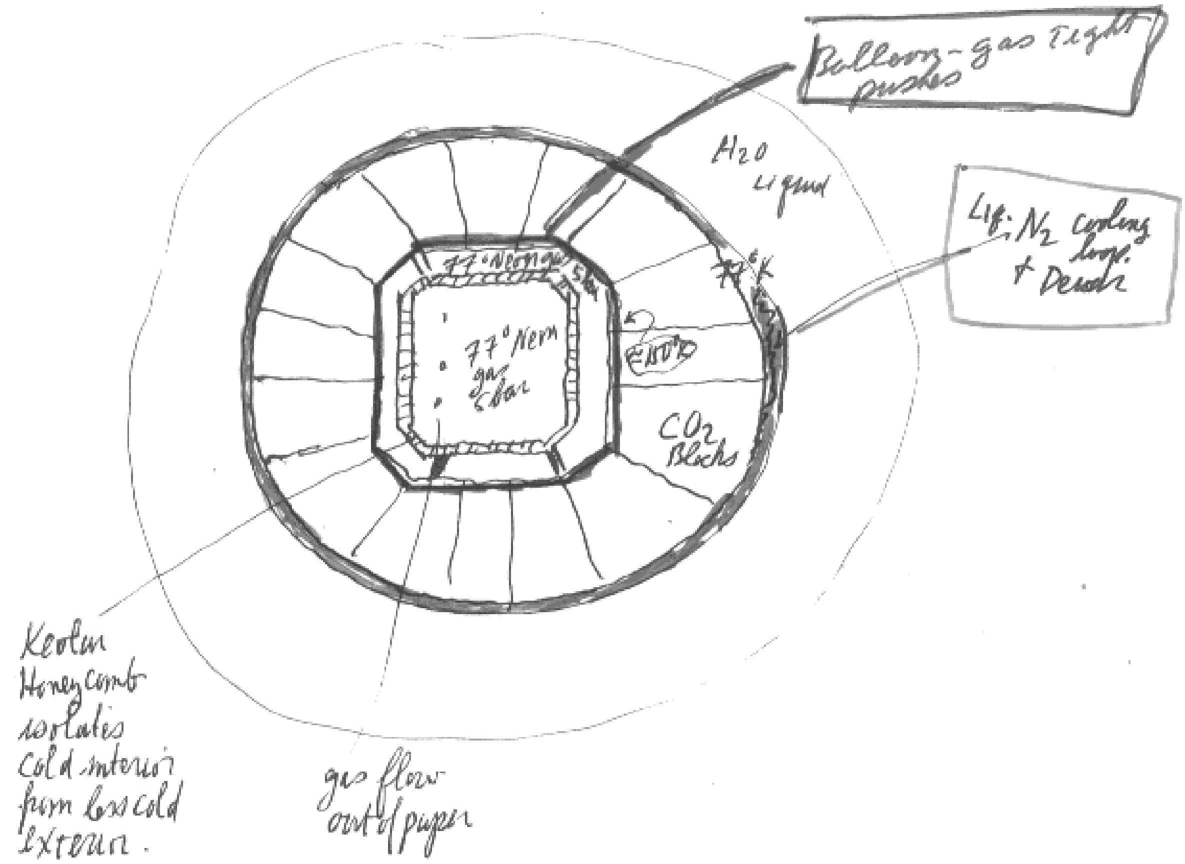


Fig. 14. A transverse view the TPC and shield assembly placed in a Gran Sasso underground experimental hall.

Meeting 9/9/92 with Laurenti, Bonoccini, Seguinot + Ypsilantis on SND at Bldg 54-R012.

• Decided that best strategy for SND proposal is



Advantages:
- 77° K Neon gas entered
- CO_2 blocks take their eventual temp. but because of low thermal conductivity it changes with time
- Temperature gradient is assured by Honeycomb + gas layer between honeycomb + balloon (CO_2 wall)
- Balloon pushes CO_2 wall outward + assure they stay in place even if wall contracts with temperature.

Neutron Induced Radioactivities

6-12/8/92 (1)

	^{1}H (99.985%)	^{2}H (0.015%)	^{3}He	^{4}He (1-1.38·10^{-6})	^{6}Li (7.5%)	^{7}Li (92.5%)	^{9}Be (100%)	^{10}B (20.0%)	^{11}B (80.0%)	^{12}C (98.9%)	^{13}C (1.1%)
					Good	Good	(Hughes, 3?) threshold Good?	Good	Good	Good	Good
n,γ	^{2}H(st)	^{3}H(12.3y, β^-, γ)	^{4}He(st)	—	^{7}Li(st)	^{8}Li(.845, β2α)	^{10}Be(1.6My, β^-, Noγ)	^{11}B(st)	^{12}B(20ms, β^-, γ)	^{13}C(st)	^{14}C(5730yrs, β^-, Noγ)
n,p	n(10.6m, β^-, 800)	n,n	^{3}H(12.3yrs, β^-, 18)	nnnp	^{6}Li(.85, β^-2α)	n+^{6}He(β^-)	^{9}Li(.185, β^-, n)	^{10}Be(1.6My, β^-, Noγ)	^{11}Be(14s, β^-, γ)	^{12}B(β^-, γ, α)	^{13}B(17ms, β^-, γ, βn)
n,d	γ(2.2MeV)	n	n,p	^{3}H(12.3y, β^-, 18)	n+α	^{6}He(.85, β^-)	^{8}Li(β^-2α)	^{9}Be(st)	^{10}Be(1.6My, β^-, Noγ)	^{11}B(st)	^{12}B(20ms, β^-, γ, βα)
n,t	—	γ( )	p(st)	^{2}H(st)	α	n+α	~~^{7}Li(st)~~	2α	^{9}Be(st)	^{10}B(st)	^{11}B(st)
n,α	—	—	γ( )	—	t	nnnp	^{6}He(.85, β^-)	^{7}Li(st)	^{8}Li(.845, β2α)	^{9}Be(st)	^{10}Be(1.6Myrs, β^-, Noγ)
n,2n	—	p(st)	p,p	^{3}HenPP	p+α	^{6}Li(st)	2α	p2α	^{10}B(st)	^{11}C(20m, β^+, Noγ)	^{12}C(st)
n,3n	—	—	—	p,p	p+p+d	p+^{4}He(st)	^{7}Be(53d, EC, γ478)	^{8}B(.77s, β^+2α)	p2α	^{10}C(19s, β^+, γ)	^{11}C(20m, β^+, Noγ)

Good for doping silicon

	^{14}N (99.63%)	^{15}N (0.37%)	^{16}O (99.762%)	^{17}O (0.038%)	^{18}O (0.2%)	^{19}F (100%)	^{20}Ne (90.51%)	^{21}Ne (0.27%)	^{22}Ne (9.22%)	^{23}Na (100%)	^{24}Mg (78.99%)
	Good	Good	Good	Good	Good	Good	Good	Good	Good	BAD	~~BAD~~ OK WITH CS
n,γ	^{15}N(st)	^{16}N(7s, β^-, γ, βα)	^{17}O(st)	^{18}O(st)	^{19}O(27s, β^-, γ)	^{20}F(11s, β^-, γ)	^{21}Ne(st)	^{22}Ne(st)	^{23}Ne(37s, β^-, γ)	^{24}Na(15h, β^-, γ)	^{25}Mg(st)
n,p	^{14}C(5730yrs, β^-, Noγ)	^{15}C(2.5s, β^-, γ)	^{16}N(7s, β^-, γ, βα)	^{17}N(4.2s, β^-, γ, βn)	^{18}N(.63s, β^-, γ)	^{19}O(27s, β^-, γ)	^{20}F(11s, β^-, γ)	^{21}F(4.2s, β^-, γ)	^{22}F(4.2s, β^-, γ)	^{23}Ne(37s, β^-, γ)	^{24}Na(15h, β^-, γ)
n,d	^{13}C(st)	^{14}C(5730yrs, β^-, Noγ)	^{15}N(st)	^{16}N(7s, β^-, γ, βα)	^{17}N(4.2s, β^-, γ, βn)	^{18}O(st)	^{19}F(st)	^{20}F(11s, β^-, γ)	^{21}F(4.2s, β^-, γ)	^{22}Ne(st)	^{23}Na(st) CS
n,t	^{12}C(st)	^{13}C(st)	^{14}N(st)	^{15}N(st)	^{16}N(7s, β^-, γ, βα)	^{17}O(st)	^{18}F(110m, β^+, Noγ)	^{19}F(st)	^{20}F(11s, β^-, γ)	^{21}Ne(st)	^{22}Na(2.6yrs, β^+, γ)
n,α	^{11}B(st)	^{12}B(20ms, β^-, γ, βα)	^{13}C(st)	^{14}C(5730yrs, β^-, Noγ)	^{15}C(2.5s, β^-, γ)	^{16}N(7s, β^-, γ, βα)	^{17}O(st)	^{18}O(st)	^{19}O(27s, β^-, γ)	^{20}F(11s, β^-, γ)	^{21}Ne(st)
n,2n	^{13}N(10m, β^+, Noγ)	^{14}N(st)	^{15}O(2m, β^+, Noγ)	^{16}O(st)	^{17}O(st)	^{18}F(110m, β^+, Noγ)	^{19}Ne(17s, β^+, γ)	^{20}Ne(st)	^{21}Ne(st)	^{22}Na(2.6yrs, β^+, γ)	^{23}Mg(11s, β^+, γ)
n,3n	^{12}N(11ms, β^+, γ, βα)	^{13}N(10m, β^+, Noγ)	^{14}O(71s, β^+, γ)	^{15}O(2m, β^+, Noγ)	^{16}O(st)	^{17}F(65s, β^+, Noγ)	^{18}Ne(1.7s, β^+, γ)	^{19}Ne(17s, β^+, γ)	^{20}Ne(st)	^{21}Na(22s, β^+, γ)	^{22}Mg(3.9s, β^+, γ)

	^{25}Mg (10.0%)	^{26}Mg (11.0%)	^{27}Al (100%)	^{28}Si (92.2%)	^{29}Si (4.7%)	^{30}Si (3.1%)	^{31}P (100%)	^{32}S (95.02%)	^{33}S (0.75%)	^{34}S (0.84%)	^{36}S (0.02%)
			BAD	Good? OK WITH C.S.	Good? OK WITH C.S.	Good? OK WITH C.S.	Good (for doping)	Good	Good	Good	Good
n,γ	^{26}Mg(st)	^{27}Mg(9.5m, β^-, γ)	^{28}Al(2.2m, β^-, γ)	^{29}Si(st)	^{30}Si(st)	^{31}Si(2.6h, β^-, γ)	^{32}P(14.3d, β^-, Noγ)	^{33}S(st)	^{34}S(st)	^{35}S(87.5d, β 0.2, Noγ)	^{37}S(5m, β 1.6, 4.9, γ3102)
n,p	^{25}Na(60s, β^-, γ)	^{26}Na(1.1s, β^-, γ)	^{27}Mg(9.5m, β^-, γ)	^{28}Al(2.2m, β^-, γ)	^{29}Al(6.6m, β^-, γ)	^{30}Al(3.6s, β^-, γ)	^{31}Si(2.62h, β^-, γ)	^{32}P(14.3d, β 1.7, Noγ)	^{33}P(25.3d, β 0.2, Noγ)	^{34}P(12.4s, β 5.4, γ2127)	^{36}P(?s, β^-, γ3290)
n,d	^{24}Na(15h, β^-, γ)	^{25}Na(60s, β^-, γ)	^{26}Mg(st)	^{27}Al(st)	^{28}Al(2.2m, β^-, γ)	^{29}Al(6.6m, β^-, γ)	^{30}Si(st)	^{31}P(st)	^{32}P(14.3d, β 1.7, Noγ)	^{33}P(25.3d, β 0.2, Noγ)	^{35}P(47.4s, β 2.3, γ1572) → ^{35}S
n,t	^{23}Na(st)	^{24}Na(15h, β^-, γ)	^{25}Mg(st)	^{26}Al(0^+, 6.4s, β^+, β^+)	^{27}Al(st)	^{28}Al(2.2m, β^-, γ)	^{29}Si(st)	^{30}P(2.5m, β+3.2, γ2230)	^{31}P(st)	^{32}P(14.3d, β 1.7, Noγ)	^{34}P(12.4s, β 5.4, γ2127)
n,α	^{22}Ne(st)	^{23}Ne(37s, β^-, γ)	^{24}Na(15h, β^-, γ)	^{25}Mg(st)	^{26}Mg(st)	^{27}Mg(9.5m, β^-, γ)	^{28}Al(2.25m, β^-, γ)	^{29}Si(st)	^{30}Si(st)	^{31}Si(2.62h, β 1.5, γ1266)	^{33}Si(6.18s, β 3.9, 5.5, γ1848)
n,2n	^{24}Mg(st)	^{25}Mg(st)	^{26}Al(0^+, 6.45, β^+, Noγ)	^{27}Si(4.2s, β^+, γ)	^{28}Si(st)	^{29}Si(st)	^{30}P(2.5m, β^+, γ)	^{33}S(st)	^{34}S(st)	^{35}S(87.5d, β 0.2, Noγ)	^{37}S(5m, β 1.6, 4.9, γ3103)
n,3n	^{23}Mg(11s, β^+, γ)	^{24}Mg(st)	Al(5^+, 7.4My, EC); Al(7.2s, β^+)	^{26}Si(2.2s, β^+, γ)	^{27}Si(4.2s, β^+, γ)	^{28}Si(st)	^{29}P(4.1s, β^+, γ)	^{34}S(st)	^{35}S(87.5d, β 0.2, Noγ)	^{36}S(st)	^{38}S(2.8h, β 1.1, 2.9, γ1942) → ^{38}Cl

GOOD FOR DOPING SILICON — 1.28Myrs, EC, β^-, β^+, γ1461 - 10.7%

	^{35}Cl (75.77%)	^{37}Cl (24.23%)	^{36}Ar	^{38}Ar	^{40}Ar	^{39}K (93.3%)	^{40}K (1.17·10^{-4})	^{41}K (6.73%)	^{40}Ca (96.9)	^{42}Ca (6.47·10^{-3})	^{43}Ca (1.35·10^{-3})
	Good	Good									
n,γ	^{36}Cl(3·10^{5}yrs, EC, β^-, Noγ)	^{38}Cl(37m, β^-, γ)				^{40}K(1.28Myrs, EC, β^-, β^+, γ1461)	^{41}K(st)	^{42}K(12.4h, β^-, γ)	^{41}Ca(.1Myrs, EC, Noγ)	^{43}Ca(st)	^{44}Ca(st)
n,p	^{35}S(87.5d, β^-, Noγ)	^{37}S(5m, β^-, γ)							^{40}K(1.28Myrs, EC, β^+, γ1461) CS		
n,d	^{34}S(st)	^{36}S(st)							^{39}K(st)		
n,t	^{33}S(st)	^{35}S(82.5d, β^-, Noγ)							^{38}K(7.6m, β^+, γ)		
n,α	^{32}P(14.3d, β^-, Noγ)	^{34}P(12.4s, β^-, γ)							^{37}Ar(35d, EC, Noγ)		
n,2n	^{34}Cl(32m, β^+, γ)	^{36}Cl(3·10^{5}yrs, EC, β^+, Noγ)				^{38}K(7.6m, β^+, γ2168)	^{39}K(st)	^{40}K(1.28Myrs, EC, β^+, γ1461)	^{39}Ca(.86s, β^+, Noγ)	^{41}Ca(.1Myrs, EC, Noγ)	^{42}Ca(st)
n,3n	^{33}Cl(2.5s, β^+, γ)	^{35}Cl(st)				^{37}K(1.22s, β^+, γ2796)	^{38}K(7.6m, β^+, γ2168)	^{40}K(st)	^{38}Ca(.439s, β^+, γ1568)	^{40}Ca(st)	^{41}Ca(.1Myrs, EC, Noγ, IB)

	^{44}Ca (2.085%)	^{46}Ca (4·10^{-5})	^{48}Ca (1.87·10^{-3})	^{45}Sc (100%)	^{46}Ti (8.2%)	^{47}Ti (7.4%)	^{48}Ti (73.8%)	^{49}Ti (5.4%)	^{50}Ti (5.2%)	^{50}V (.25%)	^{51}V (99.75%)
					GOOD WITH C.S — MUST BE MEASURED	GOOD WITH C.S — MUST BE MEASURED	GOOD WITH C.S — MUST BE MEASURED	GOOD WITH C.S — MUST BE MEASURED	GOOD WITH C.S — MUST BE MEASURED	GOOD ?	GOOD ?
n,γ	^{45}Ca(163d, β^-, γ12)	^{47}Ca(4.5d, β^-, γ)	^{49}Ca(8.7m, β^-, γ)	^{46}Sc(83.8d, β^-, γ889, 1121)	^{47}Ti(st)	^{48}Ti(st)	^{49}Ti(st)	^{50}Ti(st)	^{51}Ti(5.8m, β^-, γ)	^{51}V(st)	^{52}V(3.8m, β^-, γ)
n,p					^{46}Sc(84d, T½, β^-, γ889, 1121)	^{47}Sc(3.4d, β^-, γ)	^{48}Sc(44h, β^-, γ)	^{49}Sc(57m, β^-, γ)	^{50}Sc(1.7m, β^-, γ)	^{50}Ti(st)	^{51}Ti(5.8m, β^-, γ)
n,d					^{45}Sc(st)	^{46}Sc(84d, T½, β^-, γ889, 1121)	^{47}Sc(3.4d, β^-, γ)	^{48}Sc(44h, β^-, γ)	^{49}Sc(57m, β^-, γ)	^{49}Ti(st)	^{50}Ti(st)
n,t					^{44}Sc(2.4d, EC, γ)	^{45}Sc(st)	^{46}Sc(84d, T½, β^-, γ889, 1121)	^{47}Sc(3.4d, β^-, γ)	^{48}Sc(44h, β^-, γ)	^{48}Ti(st)	^{49}Ti(st)
n,α					^{43}Ca(st)	^{44}Ca(st)	^{45}Ca(163d, β^-, γ12)	^{46}Ca(st)	^{47}Ca(4.5d, β^-, γ)	^{47}Sc(3.4d, β^-, γ)	^{48}Sc(44h, β^-, γ)
n,2n	^{43}Ca(st)	^{45}Ca(163d, β^-, γ12)	^{47}Ca(4.5d, β^-, γ)	^{44}Sc(2.44d, IT, β^+, γ)	^{45}Ti(3.1h, β^+, γ)	^{46}Ti(st)	^{47}Ti(st)	^{48}Ti(st)	^{49}Ti(st)	^{49}V(330d, EC, Noγ, IB)	^{50}V(st)
n,3n	^{42}Ca(st)	^{44}Ca(st)	^{46}Ca(st)	^{43}Sc(3.9h, β^+, γ)	^{44}Ti(47yrs, EC, γ)	^{45}Ti(3.1h, β^+, γ)	^{46}Ti(st)	^{47}Ti(st)	^{48}Ti(st)	^{48}V(16d, EC, β^+, γ)	^{49}V(330d, EC, Noγ, IB)

C.S ≡ CHEMICALLY SEPERABLE

Looks Good if C.S (Cr) — BAD (Mn) — Good if Recent Chemical separation, certainly OK for containment. (Fe) — BAD (Co)

	^{50}Cr (4.3%)	^{52}Cr (83.8%)	^{53}Cr (9.5%)	^{54}Cr (2.4%)	^{55}Mn (100%)	^{54}Fe (5.8%) CS	^{56}Fe (91.7%)	^{57}Fe (2.2%)	^{58}Fe (0.3%)	^{59}Co (100%)	^{58}Ni (68.3%)
n,γ	^{51}Cr (28d; EC, γ320)	^{53}Cr (St)	^{54}Cr (St)	^{55}Cr (3.5m; β⁻, γ)	^{56}Mn (2.6h; β⁻, γ)	^{55}Fe (2.7y; EC)	^{57}Fe (St)	^{58}Fe (St)	^{59}Fe (45d; β⁻, γ)	^{60}Co (5.3y; β⁻, γ)	^{59}Ni (7.5·10⁴y; EC)
n,p	^{50}V (St)	^{52}V (3.8m; β⁻, γ)	^{53}V (1.6m; β⁻, γ)	^{54}V (50m; β⁻, γ)	^{55}Cr (3.5m; β⁻, γ)	^{54}Mn (312d; EC, γ835)	^{56}Mn (2.6h; β⁻, γ)	^{57}Mn (1.5m; β⁻, γ)	^{58}Mn	^{59}Fe (45d; β⁻, γ)	^{58}Co (71d; EC, β⁺, γ)
n,d	^{49}V (330d; EC)	^{51}V (St)	^{52}V (3.8m; β⁻, γ)	^{53}V (1.6m; β⁻, γ)	^{54}Cr (St)	^{53}Mn (3.7·10⁶y; EC)	^{55}Mn (St) CS	^{56}Mn (2.6h; β⁻, γ)	^{57}Mn (1.5m; β⁻, γ)	^{58}Fe (St)	^{57}Co (271d; EC, γ122, 136)
n,t	^{48}V (16d; EC, β⁺, γ)	^{50}V (St)	^{51}V (St)	^{52}V (3.8m; β⁻, γ)	^{53}Cr (St)	^{52}Mn (5.6d; EC, β⁺, γ)	^{54}Mn (312d; EC, γ835)	^{55}Mn (St)	^{56}Mn (2.6h; β⁻, γ)	^{57}Fe (St)	^{56}Co (79d; EC, β⁺, γ)
n,α	^{47}Ti (St)	^{49}Ti (St)	^{50}Ti (St)	^{51}Ti (5.8m; β⁻, γ)	^{52}V (3.8m; β⁻, γ)	^{51}Cr (28d; EC, γ320)	^{53}Cr (St)	^{54}Cr (St)	^{55}Cr (3.5m; β⁻, γ)	^{56}Mn (2.6h; β⁻, γ)	^{55}Fe (2.7y; EC)
n,2n	^{49}Cr (42m; β⁺, γ)	^{51}Cr (27.7d; EC, γ320)	^{52}Cr (St)	^{53}Cr (St)	^{54}Mn (312d; EC, γ835)	^{53}Fe (8.5m; β⁺, γ)	^{55}Fe (2.7y; EC)	^{56}Fe (St)	^{57}Fe (St)	^{58}Co (71d; EC, β⁺, γ)	^{57}Ni (36h; EC, β⁺, γ) → ^{57}Co
n,3n	^{48}Cr (22h; EC, γ)	^{50}Cr (St)	^{51}Cr (28d; EC, γ320)	^{52}Cr (St)	^{53}Mn (3.7·10⁶y; EC, No γ)	^{52}Fe (8.3h; β⁺, γ)	^{54}Fe (St)	^{55}Fe (2.7y; EC)	^{56}Fe (St)	^{57}Co (271d; EC, γ)	^{56}Ni (6d; EC, γ) → ^{56}Co

CS → (arrow to ^{48}V)

Nickel OK if C.S. (Ni) — Good IF C.S. (Cu) — BAD even with C.S. (Zn)

	^{60}Ni (26.1%)	^{61}Ni (1.13%)	^{62}Ni (3.6%)	^{64}Ni (0.9%)	^{63}Cu (69.2%)	^{65}Cu (30.8%)	^{64}Zn (48.6%)	^{66}Zn (27.9%)	^{67}Zn (4.1%)	^{68}Zn (18.8%)	^{70}Zn (0.6%)
n,γ	^{61}Ni (St)	^{62}Ni (St)	^{63}Ni (100y; β⁻, No γ)	^{65}Ni (2.5h; β⁻, γ)	^{64}Cu (13h; EC, β⁺, β⁻)	^{66}Cu (5m; β⁻, γ)	^{65}Zn (244d; EC, β⁺, γ1115)	^{67}Zn (St)	^{68}Zn (St)	^{69}Zn (14h; β⁻, γ)	^{71}Zn (4h; β⁻, γ)
n,p	^{60}Co (5.27y; β⁻, γ)	^{61}Co (1.7h; β⁻, γ)	^{62}Co (14m; β⁻, γ)	^{64}Co (0.3s; β⁻, γ)	^{63}Ni (100y; β⁻, No γ)	^{65}Ni (2.5h; β⁻, γ)	^{64}Cu (13h; EC, β⁺, β⁻)	^{66}Cu (5m; β⁻, γ)	^{67}Cu (62h; β⁻, γ)	^{68}Cu (3.8m; β⁻, γ)	^{70}Cu (42s; β⁻, γ)
n,d	^{59}Co (St)	^{60}Co (5.27y; β⁻, γ)	^{61}Co (1.7h; β⁻, γ)	^{63}Co (27.5s; β⁻, γ)	^{62}Ni (St)	^{64}Ni (St)	^{63}Cu (St)	^{65}Cu (St)	^{66}Cu (5m; β⁻, γ)	^{67}Cu (62h; β⁻, γ)	^{69}Cu (3m; β⁻, γ) → ^{69}Zn
n,t	^{58}Co (71d; EC, γ)	^{59}Co (St)	^{60}Co (5.27y; β⁻, γ)	^{62}Co (14m; β⁻, γ)	^{61}Ni (St)	^{63}Ni (100y; β⁻, No γ)	^{62}Cu (10m; β⁺, γ)	^{64}Cu (13h; EC, β⁺, β⁻, γ)	^{65}Cu (St)	^{66}Cu (5m; β⁻, γ)	^{68}Cu (3.8m; β⁻, γ)
n,α	^{57}Fe (St)	^{58}Fe (St)	^{59}Fe (41d; β⁻, γ)	^{61}Fe (6m; β⁻, γ) → ^{61}Co	^{60}Co (5.3y; β⁻, γ) CS	^{62}Co (14m; β⁻, γ)	^{61}Ni (St)	^{63}Ni (100y; β⁻, No γ)	^{64}Ni (St)	^{65}Ni (2.5h; β⁻, γ)	^{67}Ni (18s; β⁻, γ) → ^{67}Cu (62h; β⁻, γ)
n,2n	^{59}Ni (7.5·10⁴y; EC)	^{60}Ni (St)	^{61}Ni (St)	^{63}Ni (100y; β⁻, No γ)	^{62}Cu (9.7m; β⁺, γ)	^{64}Cu (13h; EC, β⁺, β⁻)	^{63}Zn (38m; β⁺, γ)	^{65}Zn (244d; EC, β⁺, γ1115)	^{66}Zn (St)	^{67}Zn (St)	^{69}Zn (13h; β⁻, γ)
n,3n	^{58}Ni (St)	^{59}Ni (7.5·10⁴y; EC)	^{60}Ni (St)	^{62}Ni (St)	^{61}Cu (3.4h; β⁺, γ)	^{63}Cu (St)	^{62}Zn (9h; EC, β⁺, γ)	^{64}Zn (St)	^{65}Zn (244d; EC, β⁺, γ1115)	^{66}Zn (St)	^{68}Zn (St)

EXCELLENT BUT MP≈30°C (Ga) — BAD (Ge) — SEMI-GOOD (As)

	^{69}Ga (60.1%)	^{71}Ga (39.9%)	^{70}Ge (20.5%)	^{72}Ge (27.4%)	^{73}Ge (7.8%)	^{74}Ge (36.5%)	^{76}Ge (7.8%)	^{75}As (100%)	^{74}Se (0.9%)	^{76}Se (9%)	^{77}Se (7.6%)
n,γ	^{70}Ga (21m; β⁻, γ)	^{72}Ga (14h; β⁻, γ)	^{71}Ge (11d; EC, No γ)	^{73}Ge (St)	^{74}Ge (St)	^{75}Ge (83m; β⁻, γ)	^{77}Ge (11h; β⁻, γ)	^{76}As (26h; β⁻, γ)	^{75}Se (120d; EC, γ)	^{77}Se (St)	^{78}Se (St)
n,p	^{69}Zn (14h; β⁻, γ)	^{71}Zn (3.9h; β⁻, γ)	^{70}Ga (21m; β⁻, γ)	^{72}Ga (14h; β⁻, γ)	^{73}Ga (4.9h; β⁻, γ)	^{74}Ga (8m; β⁻, γ)	^{76}Ga (32s; β⁻, γ)	^{75}Ge (83m; β⁻, γ)	^{74}As (17.8d; EC, β⁺, β⁻)	^{76}As (26h; β⁻, γ)	^{77}As (39h; β⁻, γ)
n,d	^{68}Zn (St)	^{70}Zn (St)	^{69}Ga (St)	^{71}Ga (St)	^{72}Ga (14h; β⁻, γ)	^{73}Ga (4.9h; β⁻, γ)	^{75}Ga (2m; β⁻, γ)	^{74}Ge (St)	^{73}As (80d; EC, γ53)	^{75}As (St)	^{76}As (26h; β⁻, γ)
n,t	^{67}Zn (St)	^{69}Zn (14h; β⁻, γ)	^{68}Ga (68m; β⁺, γ)	^{70}Ga (21m; β⁻, γ)	^{71}Ga (St)	^{72}Ga (14h; β⁻, γ)	^{74}Ga (8m; β⁻, γ)	^{73}Ge (St)	^{72}As (26h; β⁺, γ)	^{74}As (18d; EC, β⁺, β⁻)	^{75}As (St)
n,α	^{66}Cu (5m; β⁻, γ)	^{68}Cu (3.8m; β⁻, γ)	^{67}Zn (St)	^{69}Zn (13.8h; β⁻, γ)	^{70}Zn (St)	^{71}Zn (3.9h; β⁻, γ)	^{73}Zn (24s; β⁻, γ) → Ga	^{72}Ga (14h; β⁻, γ)	^{71}Ge (11d; EC, No γ)	^{73}Ge (St)	^{74}Ge (St)
n,2n	^{68}Ga (68m; β⁺, γ)	^{70}Ga (21m; β⁻, γ)	^{69}Ge (39h; β⁺, γ)	^{71}Ge (11d; EC, No γ)	^{72}Ge (St)	^{73}Ge (St)	^{75}Ge (83m; β⁻, γ)	^{74}As (18d; EC, β⁺, β⁻)	^{73}Se → As (80d; EC, γ)	^{75}Se (120d; EC, γ)	^{76}Se (St)
n,3n	^{67}Ga (78h; EC, γ)	^{69}Ga (Stable)	^{68}Ge (280d; EC) → Ga (β⁺)	^{70}Ge (St)	^{71}Ge (11d; EC, No γ)	^{72}Ge (St)	^{74}Ge (St)	^{73}As (80d; EC, γ53)	^{72}Se → As (26h; β⁺)	^{74}Se (St)	^{75}Se (120d; EC, γ 265, 136, 280, 121, 401)

GOOD (Br)

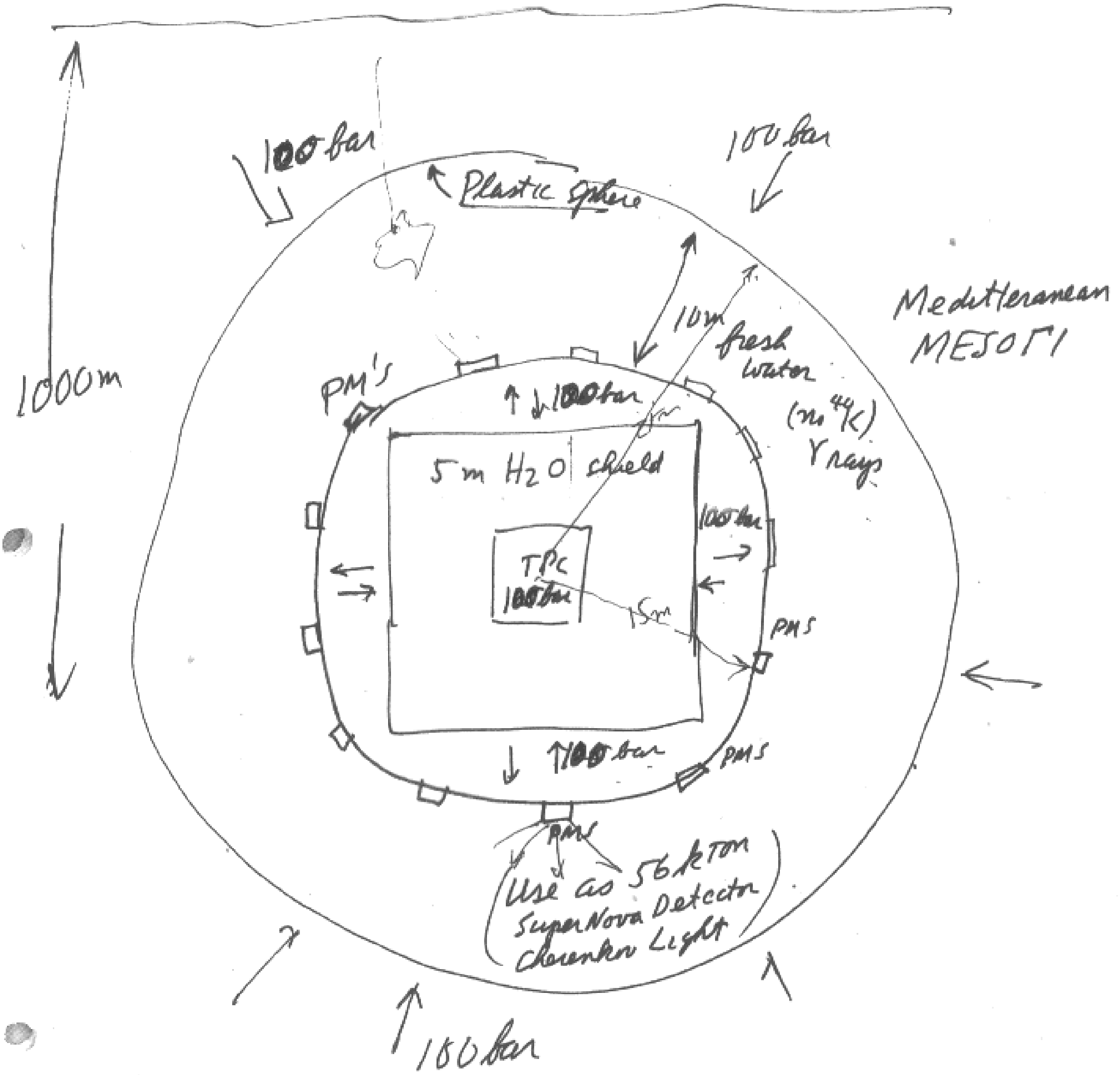
	^{78}Se (23.5%)	^{80}Se (49.6%)	^{82}Se (9.4%)	^{79}Br (50.7%)	^{81}Br (49.3%)	^{78}Kr (0.35%)	^{80}Kr (2.25%)	^{82}Kr (11.6%)	^{83}Kr (11.5%)	^{84}Kr (57%)	^{86}Kr (17.3%)
n,γ	^{79}Se (6.5·10⁴y; β⁻, No γ)	^{81}Se (57m; β⁻, IT, γ)	^{83}Se (22m; β⁻, γ)	^{80}Br (4.4h; β⁻, β⁺, γ)	^{82}Br (35h; β⁻, γ)	^{79}Kr (35h; EC, β⁺, γ)	^{81}Kr (2.1·10⁵y; EC, γ276)	^{83}Kr (St)	^{84}Kr (St)	^{85}Kr (10.8y; β⁻, γ514)	^{87}Kr (76m; β⁻, γ)
n,p	^{78}As (1.5h; β⁻, γ)	^{80}As (15s; β⁻, γ)	^{82}As (19s; β⁻, γ)	^{79}Se (6.5·10⁴y; β⁻, No γ)	^{81}Se (57m, 18m; β⁻, γ)	^{78}Br (6.5m; β⁺, γ)	^{80}Br (4.4h, 18m; β⁺, β⁻, γ)	^{82}Br (35h; β⁻, γ)	^{83}Br (2.4h; β⁻, γ)	^{84}Br (31.8m; β⁻, γ)	^{86}Br (54s; β⁻, γ)
n,d	^{77}As (39h; β⁻, γ)	^{79}As (9m; β⁻, γ) → Se	^{81}As (33s; β⁻, γ) → Se	^{78}Se (St)	^{80}Se (St)	^{77}Br (57h; EC, β⁺, γ)	^{79}Br (St)	^{81}Br (St)	^{82}Br (35.7h; β⁻, γ)	^{83}Br (2.4h; β⁻, γ)	^{85}Br (2.9m; β⁻, γ) → Kr
n,t	^{76}As (26h; β⁻, γ)	^{78}As (1.5h; β⁻, γ)	^{80}As (15s; β⁻, γ)	^{77}Se (St)	^{79}Se (6.5·10⁴y; β⁻, No γ)	^{76}Br (16h; β⁺, γ)	^{78}Br (6.5m; β⁺, γ)	^{80}Br (17.6m; EC, β⁺, β⁻)	^{81}Br (St)	^{82}Br (35h; β⁻, γ)	^{84}Br (32m; β⁻, γ)
n,α	^{75}Ge (83m; β⁻, γ)	^{77}Ge → As (39h; β⁻, γ)	^{79}Ge → As → Se	^{76}As (26h; β⁻, γ)	^{78}As (1.5h; β⁻, γ)	^{75}Se (120d; EC, γ)	^{77}Se (St)	^{79}Se (6.5·10⁴y; β⁻, No γ)	^{80}Se (St)	^{81}Se (57m, 18m; β⁻, γ)	^{83}Se (22m; β⁻, γ) → Br
n,2n	^{77}Se (St)	^{79}Se (6.5·10⁴y; β⁻, No γ)	^{81}Se (57m; β⁻, γ)	^{78}Br (6.5m; β⁺, γ)	^{80}Br (4.4h; β⁻, β⁺, γ)	^{77}Kr (1.2h; β⁺, γ)	^{79}Kr (35h; EC, β⁺, γ)	^{81}Kr (2.1·10⁵y; EC, γ276)	^{82}Kr (St)	^{83}Kr (St)	^{85}Kr (10.8y; β⁻, γ514)
n,3n	^{76}Se (St)	^{78}Se (St)	^{80}Se (St) [1.4·10⁶y no]	^{77}Br (57h; EC, β⁺, γ)	^{79}Br (St)	^{76}Kr (14.8h; EC, γ)	^{78}Kr (St)	^{80}Kr (St)	^{81}Kr (2.1·10⁵y; EC, γ276)	^{82}Kr (St)	^{84}Kr (St)

Radioactive (No γ) β⁻, 0.3 MeV

BAD (Y) — BAD (Zr)

	^{85}Rb (72.2%)	^{87}Rb (27.8%)	^{84}Sr (0.56%)	^{86}Sr (9.86%)	^{87}Sr (7.0%)	^{88}Sr (82.6%)	^{89}Y (100%)	^{90}Zr (51.5%)	^{91}Zr (11.2%)	^{92}Zr (17.1%)	^{94}Zr (17.3%)
n,γ	^{86}Rb (19d; β⁻, γ)	^{88}Rb (18m; β⁻, γ)	[illegible]	^{87}Sr (St)	^{88}Sr (St)	^{89}Sr (50d; β⁻, γ909)	^{90}Y (64h; β⁻, γ)	^{91}Zr (St)	^{92}Zr (St)	^{93}Zr (1.5My; β⁻ 60)	^{95}Zr (64d; β⁻, γ757, 724)
n,p	^{85}Kr (10.8y; β⁻, γ514)	^{87}Kr (76m; β⁻, γ)	^{85}Sr (65d; EC, γ514)				^{89}Sr (50d; β⁻, γ909)	^{90}Y (64h; β⁻, γ)	^{91}Y (59d; β⁻, γ)	^{92}Y (3.5h; β⁻, γ)	^{94}Y (19m; β⁻, γ)
n,d	^{84}Kr (St)	^{86}Kr (St)					^{88}Sr (St)	^{89}Y (St)	^{90}Y (64h; β⁻, γ)	^{91}Y (59d; β⁻, γ1205)	^{93}Y (10h; β⁻, γ) → ^{93}Zr
n,t	^{83}Kr (St)	^{85}Kr (10.8y; β⁻, γ514)					^{87}Sr (St)	^{88}Y (107d; EC, β⁺, γ)	^{89}Y (St)	^{90}Y (64h; β⁻, γ)	^{92}Y (3.5h; β⁻, γ)
n,α	^{82}Br (35h; β⁻, γ)	^{84}Br (32m; β⁻, γ)					^{86}Rb (19d; β⁻, γ)	^{87}Sr (St)	^{88}Sr (St)	^{89}Sr (50d; β⁻, γ909)	^{91}Sr (9.5h; β⁻, γ) → ^{91}Y (59d; β⁻, γ)
n,2n	^{84}Rb (33d; β⁺, γ882)	^{86}Rb (19d; β⁻, γ)	^{83}Sr → ^{83}Rb (86d; EC, γ)	^{85}Sr (65d; EC, γ514)	^{86}Sr (St)	^{87}Sr (St)	^{88}Y (107d; EC, β⁺, γ1836, 898)	^{89}Zr (78.4h; EC, β⁺, γ)	^{90}Zr (St)	^{91}Zr (St)	^{93}Zr (1.5My; β⁻ 60)
n,3n	^{83}Rb (86d; EC, γ520, 530, 553)	^{85}Rb (St)	^{82}Sr (25.5d; EC, No γ)	^{84}Sr (St)	^{85}Sr (65d; EC, γ514)	^{86}Sr (St)	^{87}Y (80h; EC, β⁺, γ)	^{88}Zr (85d; EC, β⁺, γ)	^{89}Zr (78.4h; EC, β⁺, γ)	^{90}Zr (St)	^{92}Zr (St)

HELLAZ AT PYLOS WITH NESTOR?



All in Pressure Equilibrium

Problems in Deployment of <u>Plastic Sphere</u>

$$V = \frac{4\pi}{3}\left(r_2^3 - r_1^3\right)$$

$$\approx 4\left(30^3 - 15^3\right)$$

$$\approx 15^3 \cdot 4(8-1) = 28(3375) \approx 30(3000) = 90000 \approx 100\,\text{kTon}$$

$$\begin{array}{r} 225 \\ 15 \\ \hline 1125 \\ 225 \\ \hline 3375 \end{array}$$

$$4\left(40^3 - 15^3\right)$$

$$\begin{array}{r} 64000 \\ 3375 \\ \hline \end{array}$$

$4 \times 60000 = $ … in ktons

Europhysics news 27-3 May-June 1996

The Hellaz Neutrino Detector

T. Ypsilantis
Collège de France, Paris

Simulations show that unlike other existing and proposed detectors, a track projection chamber based on 2000 cubic metres of a cold helium – methane gas mixture can help solve the solar neutrino problem by determining the direction and energy of solar neutrinos.

The most interesting solar neutrinos are pp neutrinos, with a continuum extending up to an energy of 420 keV, and the monoenergetic 862 keV ^{7}Be neutrinos formed in the $p+p \rightarrow e+d+\nu_e$ and $e^- + {}^7Be \rightarrow {}^7Li+\nu_e$ reactions. All neutrinos have a known flavour (electron-neutrino ν_e) at the sun and energy production in the sun mostly transits through the first reaction, so the pp neutrino flux is essentially determined by the solar luminosity. Since the neutrino-electron (νe) elastic scattering cross-section is given by the well tested electroweak theory, any observed differences in flux, flavour or spectral shape with respect to theoretical predictions will require either new physics (such as flavour oscillations whereby one type of neutrino mixes into another type) or a major revamping of the Standard Solar Model that describes the Sun's nuclear physics and hydrodynamics. This is the so-called the solar neutrino problem (see insert for a discussion of the latest situation).

A new solar neutrino experiment called Hellaz (Helium at liquid *azote* – nitrogen – temperature) is being proposed to help resolve the problem using pp solar neutrino data. It consists of 6 tonnes of cold helium gas as a target for neutrino-electron elastic scatters. A recoil electron from a νe event leaves a trail of ionization electrons which define a track. Each ionization electron drifts in an applied axial electric field until it reaches a two-dimensional x,y-detector located at each end of a cylindrical target volume (Fig. 1). Following the track projection chamber (TPC) method, the z-coordinate is obtained from the electron arrival time. The x,y,z data determine the recoil electron energy and direction and, given the sun's position, the neutrino energy E_ν.

Hellaz will measure recoil electrons with a kinetic energy T as low as 100 keV corresponding to a range of about 50 mm because it is filled with gases of low atomic number and low density. Simulations demonstrate that T is measured to within 3 % and the electron direction to within 35 mrad so the energy of incoming 300 keV neutrinos can be determined to within 2 to 4 % – an advantage of Hellaz in contrast to existing and proposed νe detectors (see insert). The proposed Borexino can detect recoil electrons with energies above 260 keV, but cannot determine the electron direction, and hence the neutrino energy.

Moreover, the cross-sections σ and differential cross-sections $d\sigma/dT$ for $\nu_e e$ electron-neutrino and $\nu_\mu e$ gamma-neutrino elastic scattering on electrons are sufficiently different to allow a sensitive determination of the flavour and flux of incoming neutrinos independently of solar models or mixing scenarios. Indeed, Hellaz will be able to determine the amount of flavour mixing for pp and pep neutrinos to permit resolution of all the current neutrino mixing scenarios.

Hellaz is also competitive when compared to other much heavier detectors. The calculated rate of νe elastic events from the pp and ^{7}Be solar neutrino fluxes is about 16 events/day for 6 tonnes of helium gas if all recoil electrons ($T \geq 0$ keV) are detected. With the more realistic limit of $T \geq 100$ keV there will still be 11 events/day. By comparison, the Gran Sasso Underground Laboratory's $GaCl_3$-based GALLEX detector with the same threshold and twice the mass only detects 0.2 events/day, since although the cross-section of ^{71}Ga is 4.5 times the average νe cross-section, its nuclear density is only 1/88 of the helium electron density.

Several prototypes of the Hellaz detector have been constructed and are now under test. A 40 m^3 device will soon be placed in a tunnel at Gran Sasso with full carbon dioxide (or B_2O_3) shielding to confirm estimates of the radiopurity of materials by neutron activation analysis and to measure the νe signal and the gamma-electron (γe) background. It will also serve an ideal tool for searching for dark matter, an aspect that will not be discussed.

Direction and Energy Resolution

The precision with which the direction and energy of the incident neutrinos can be determined in Hellaz has been estimated using accurate simulations of

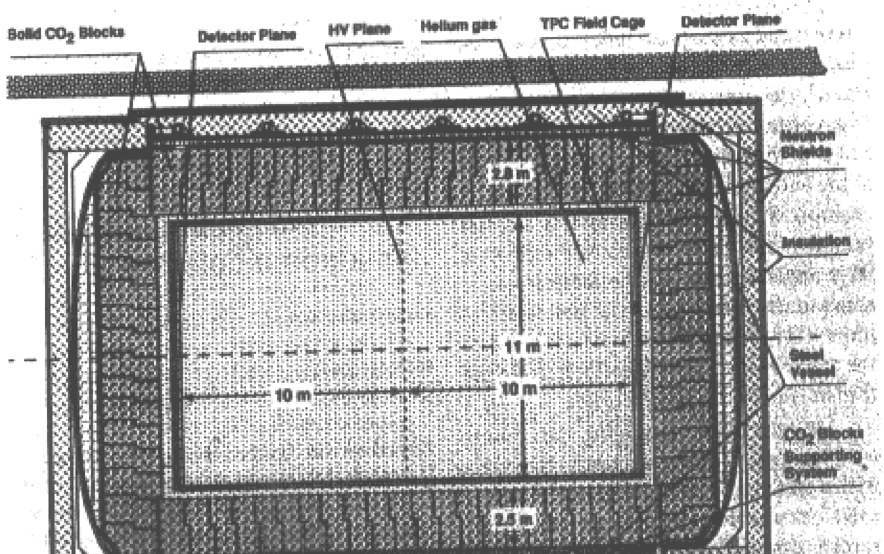


Fig. 1. A longitudinal view of the heavily shielded, cylindrical Hellaz time proportional counter solar-neutrino detector. Ionization tracks drift in an axial field generated by a field cage to modular multiwire detectors located at the endcaps which use the same low-temperature helium–methane gas mixture as the target volume.

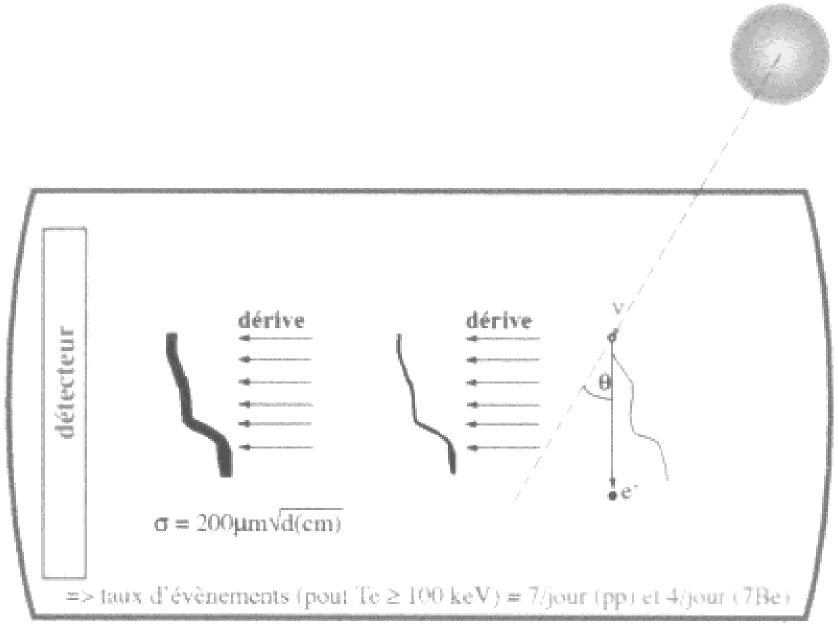
Tom Ypsilantis, a research physicist in high-energy particle physics based at the Collège de France in Paris, is currently working on neutrino experiments (Hellaz and Long Baseline RICH) and on applications of the RICH technique to B-physics at CERN's future LHC collider. He has worked at the Ecole Polytechique, Paris, the CE Saclay, CERN, and the University of Southern California, Berkeley.

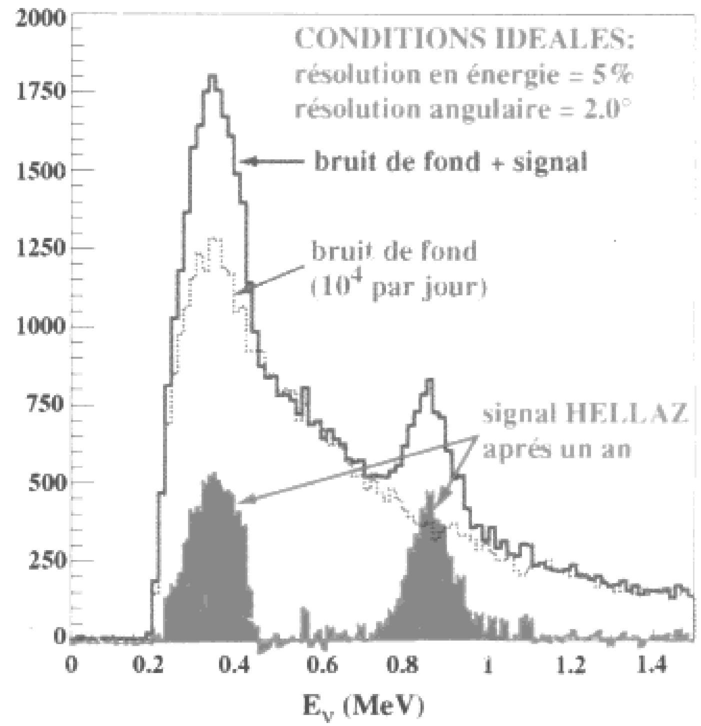
Principe de HELLAZ:

diffusion elastique neutrino - électron dans He - TPC

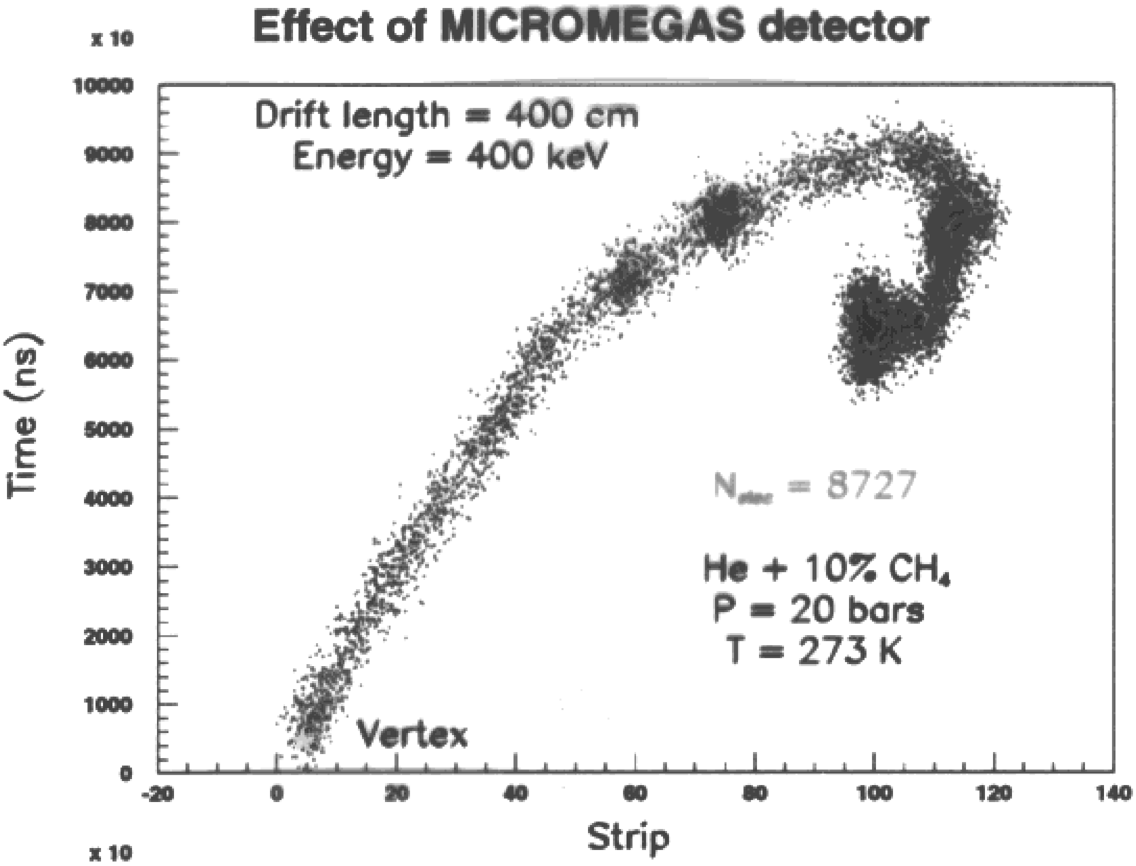
ρ_{He} **= 3.124 x 10^{-3} g/cm^3, 6 tonnes He =>N_e = 2 10^{30}**

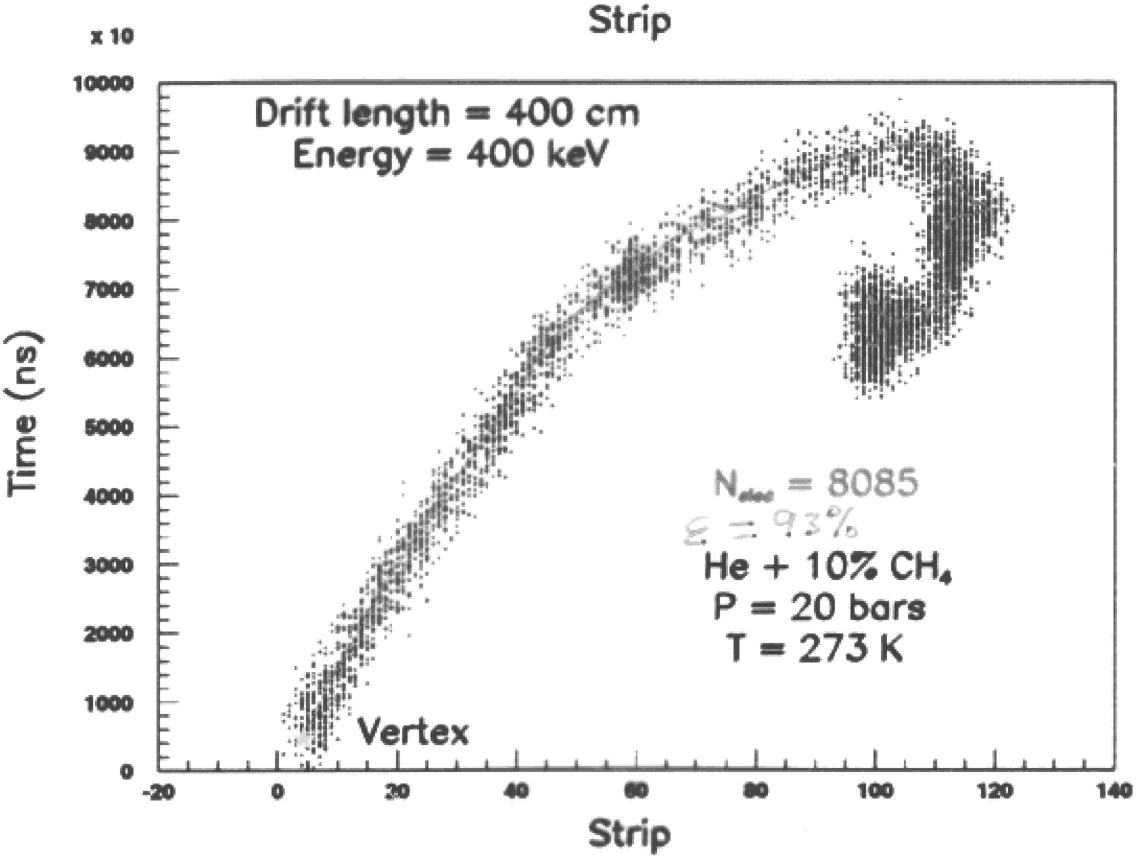
- mesure de T_e ($\sigma_T/T \approx 3\%$) et θ ($\sigma_\theta \approx 35$ mrad)
- Energie du neutrino $E_\nu = \frac{m_e}{\sqrt{1 + \frac{2m_e}{T_e}} \cos\theta_e - 1}$

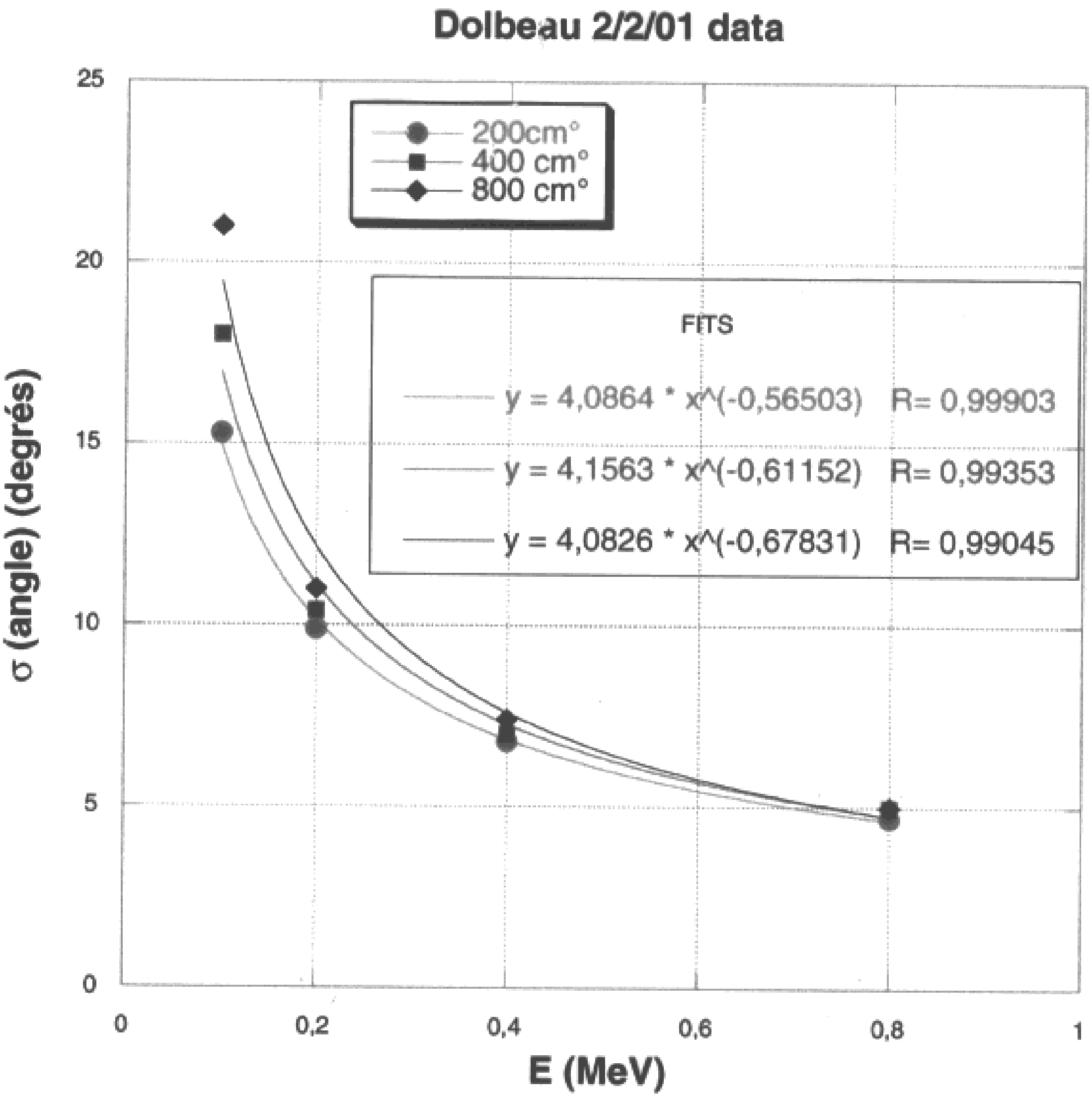




Effect of MICROMEGAS detector

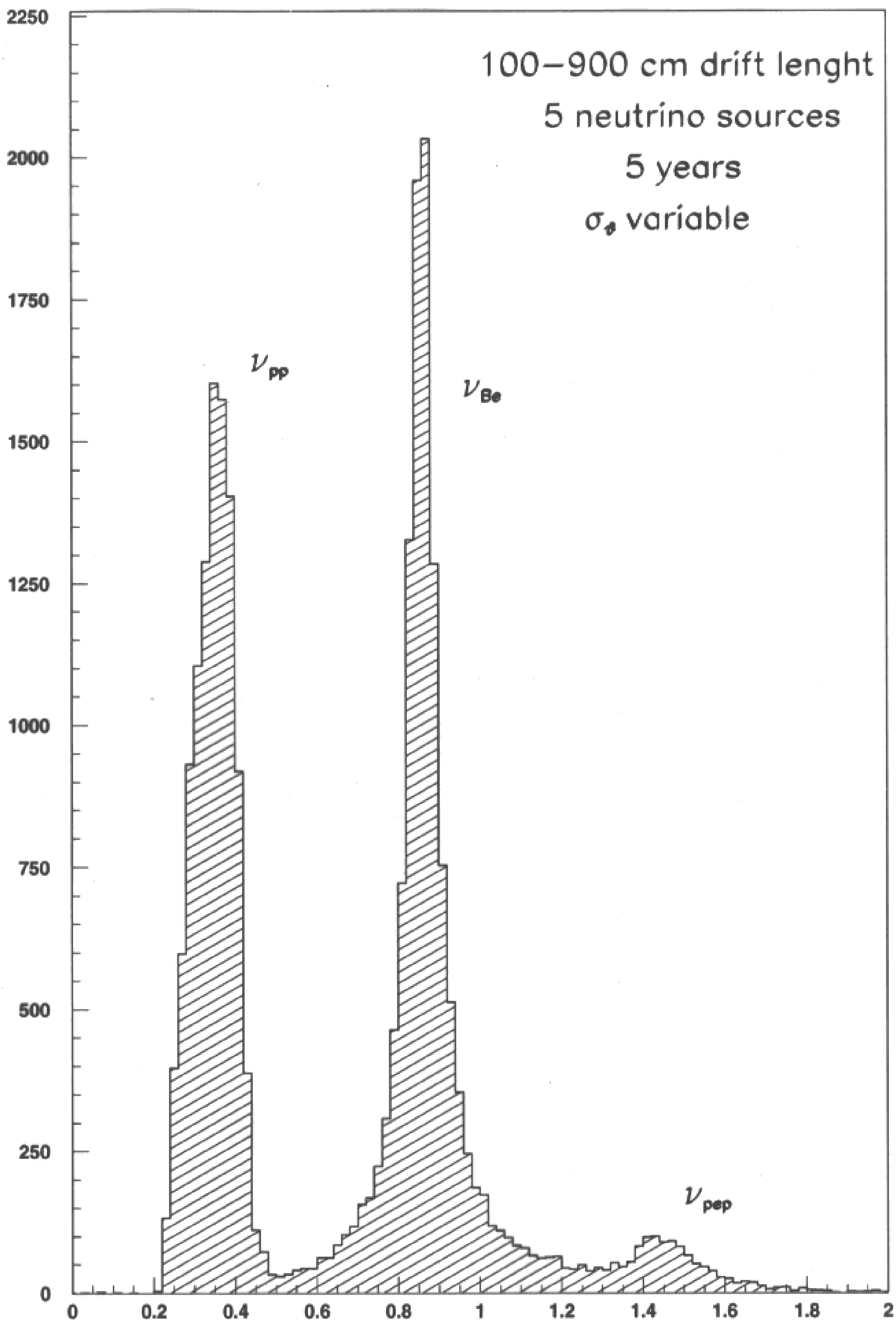






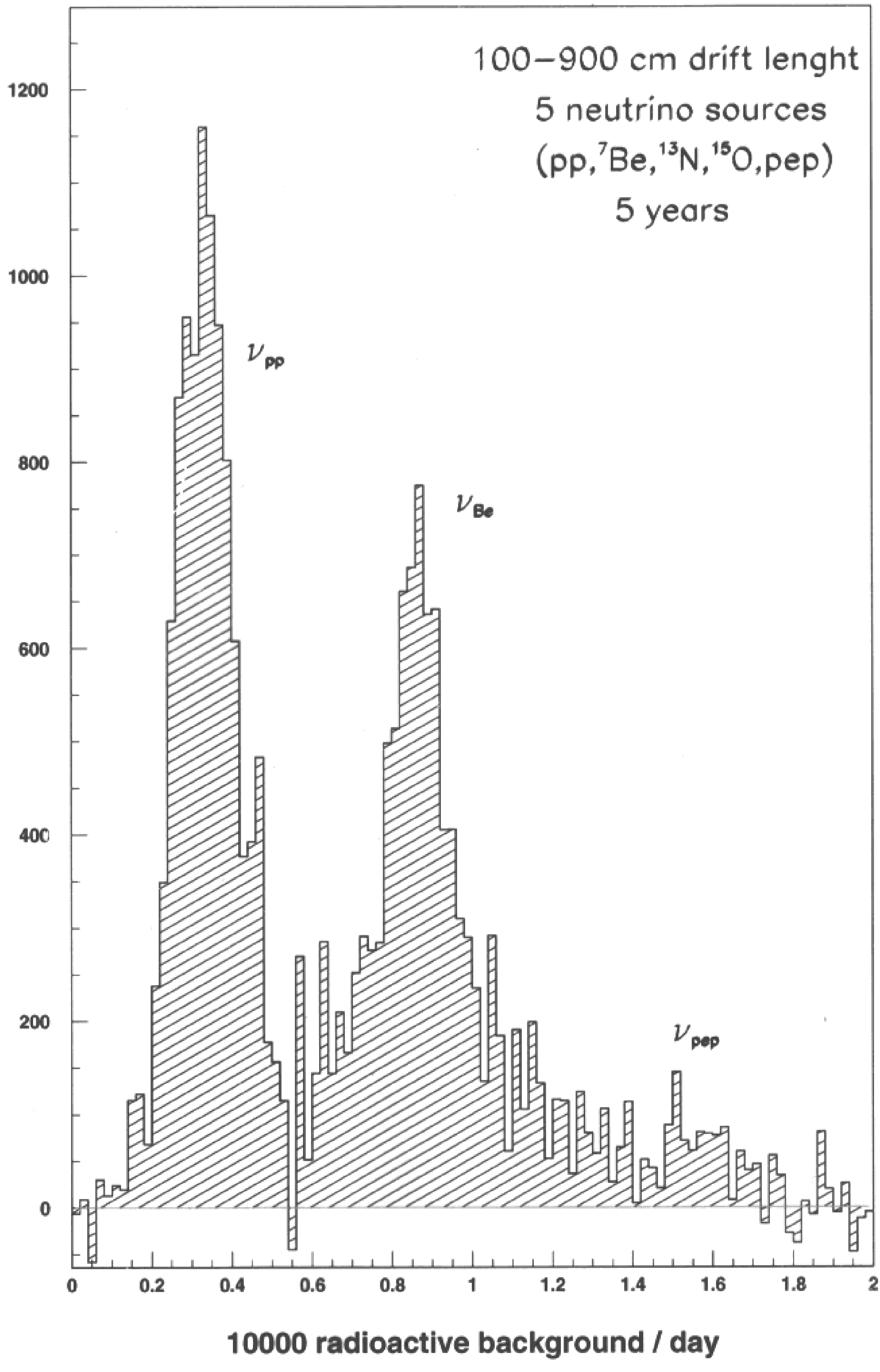
Dolbeau 2/2/01 data
200cm°
400 cm°
800 cm°
FITS
y = 4,0864 * x^(-0,56503) R= 0,99903
y = 4,1563 * x^(-0,61152) R= 0,99353
y = 4,0826 * x^(-0,67831) R= 0,99045
σ (angle) (degrés)
E (MeV)
0
5
10
15
20
25
0,2
0,4
0,6
0,8
1

Reconstruct neutrino spectrum

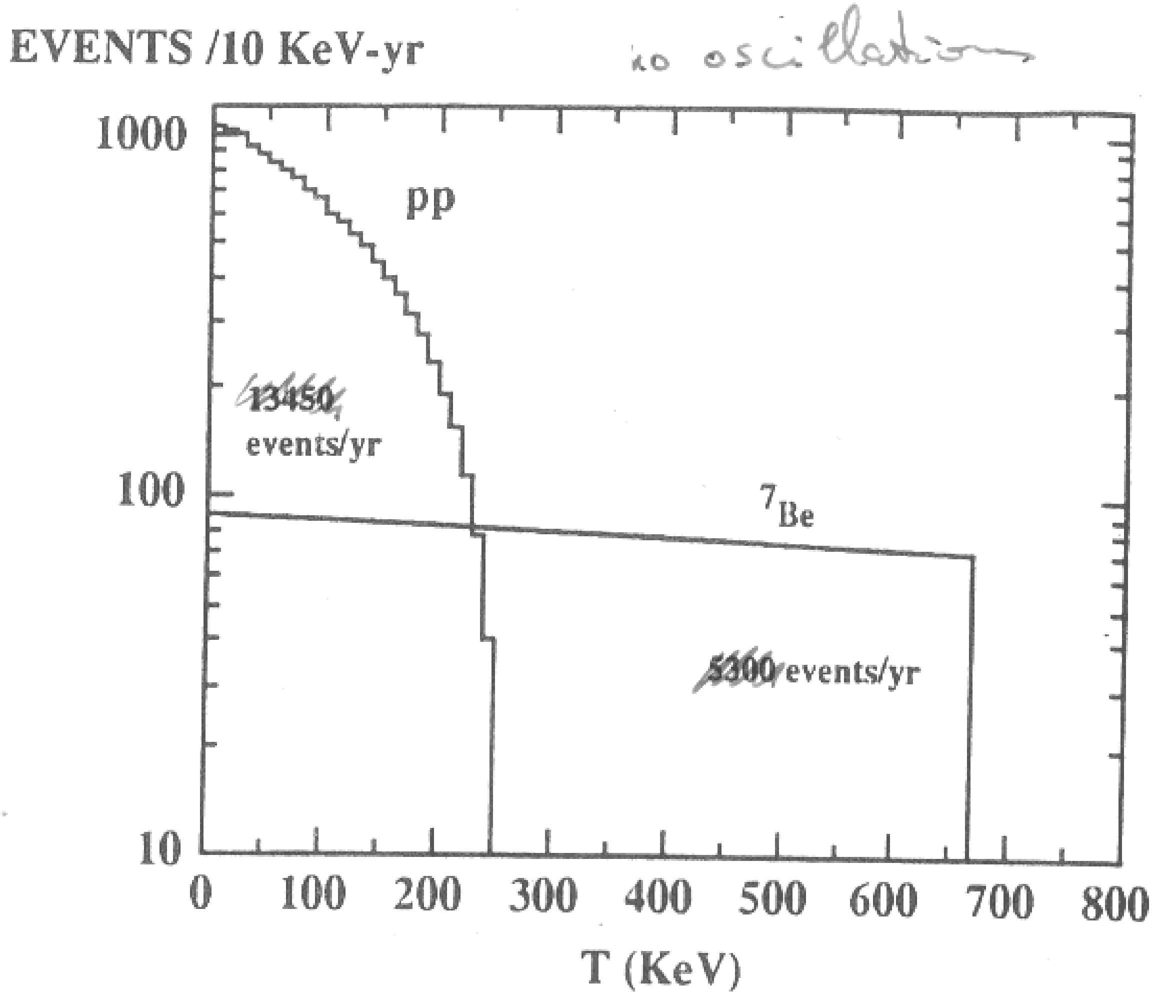


No radiactive background

Reconstruct neutrino spectrum



no oscillations



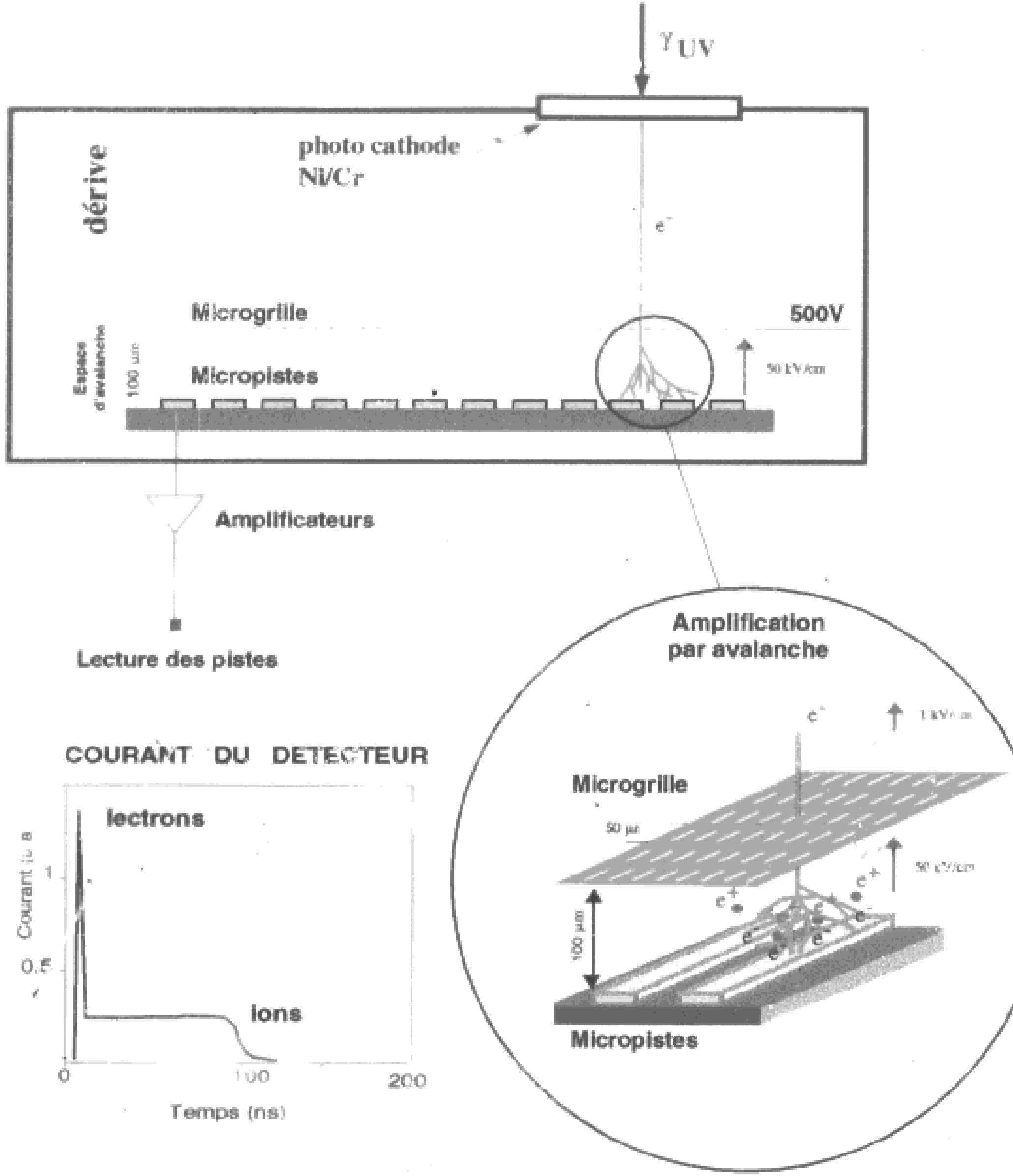
Comparison between E_ν and T_e spectra:

- Lines (^{7}Be) : obvious (ratio of surfaces)
- β spectra (pp, ^{8}B) : not so different in shape

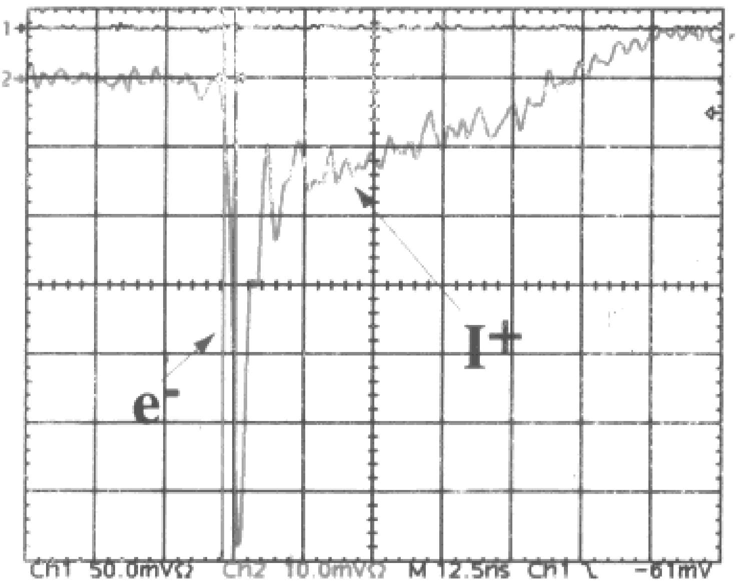
HOWEVER : if oscillations : cannot be seen in T_e.

MICROMEGAS

(Y. Giomataris et al., NIM A376 (1996), 2 9-35.)



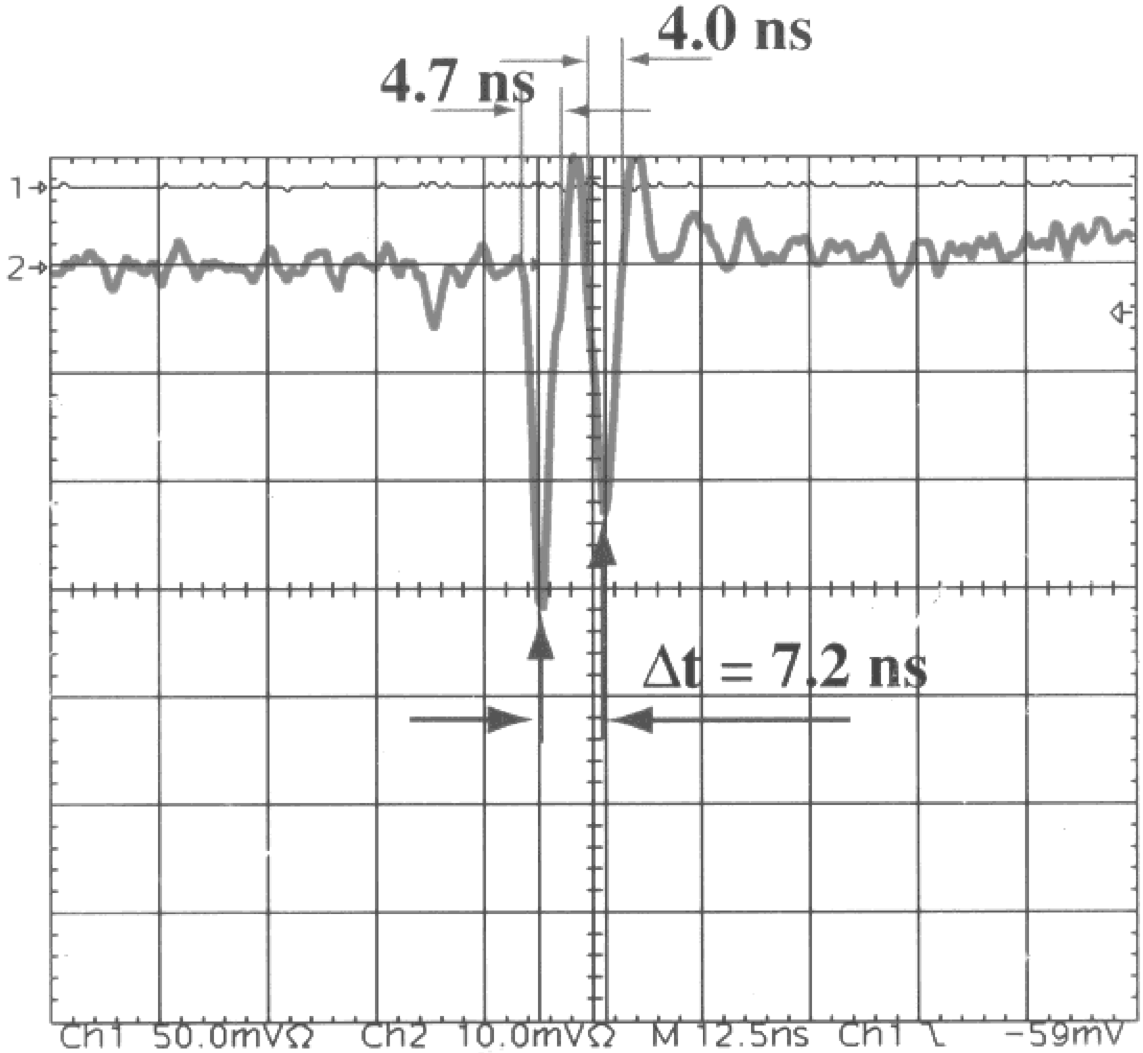
measure au PCC:



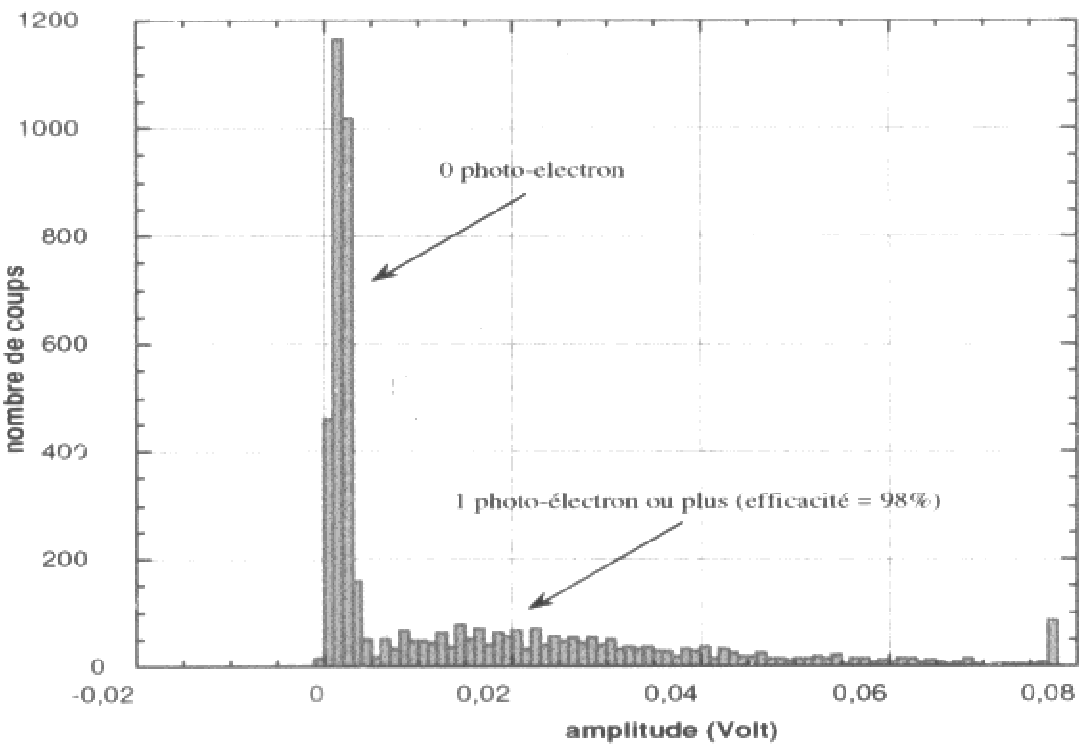
- 100 % He + 6 % Isobutan (P_{abs} = 1 bar, T = 310 K)
- distance photo cathode - mesh = 8.5 mm
- distance mesh - cathode = 100 µm
- ampli = ORTEC 120
- source = laser + 1 quartz fibre
- HT(pc) = -1900 V
- HT(mesh) = -570 V

- signal of a single electron
- fall time = 1.80 ns
- ≈ 6.9 ns on the base of the signal

H. de Kerret

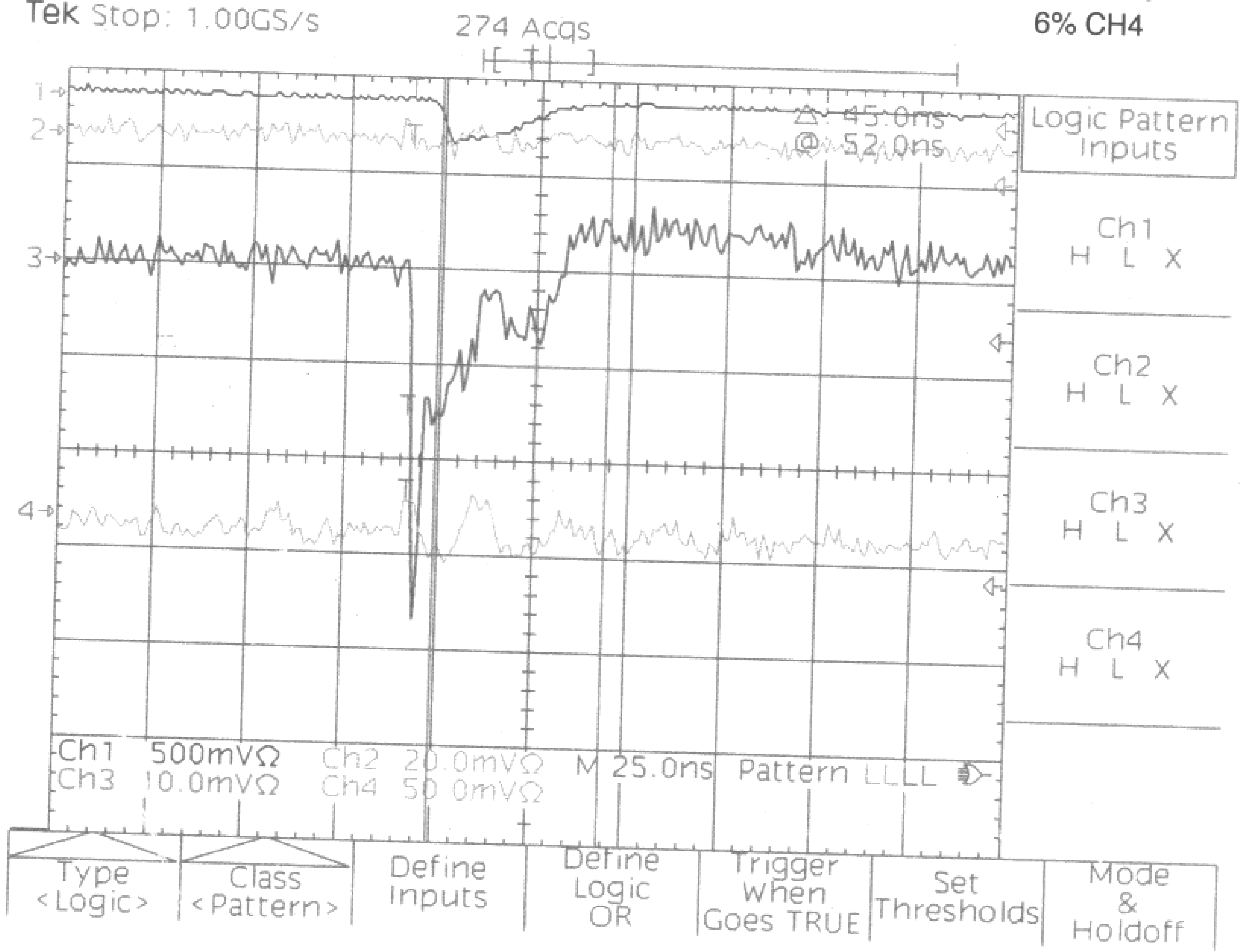


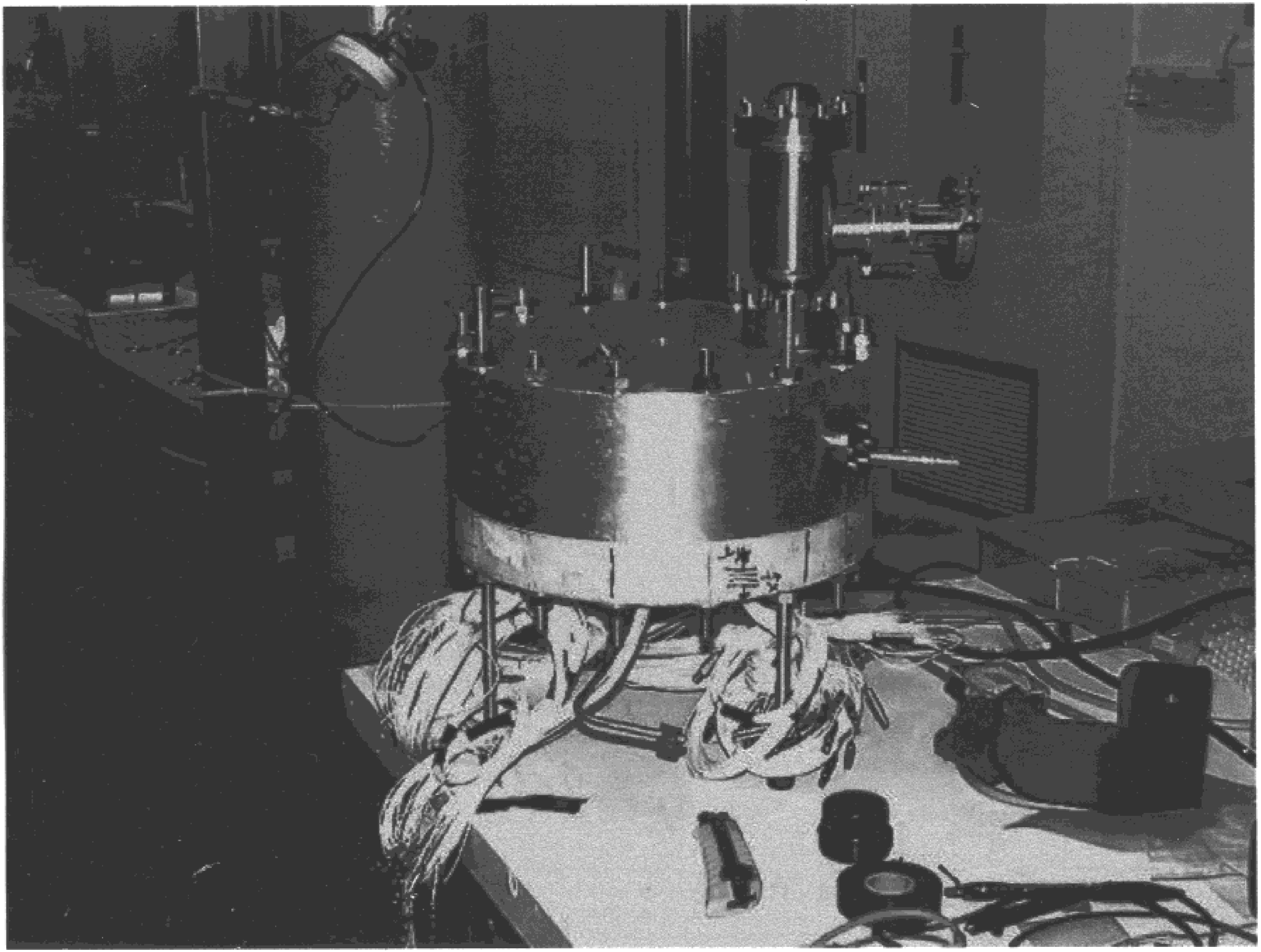
What about Racker limit? Gain ≳ 10^6 Ratio ~ 10^8 !



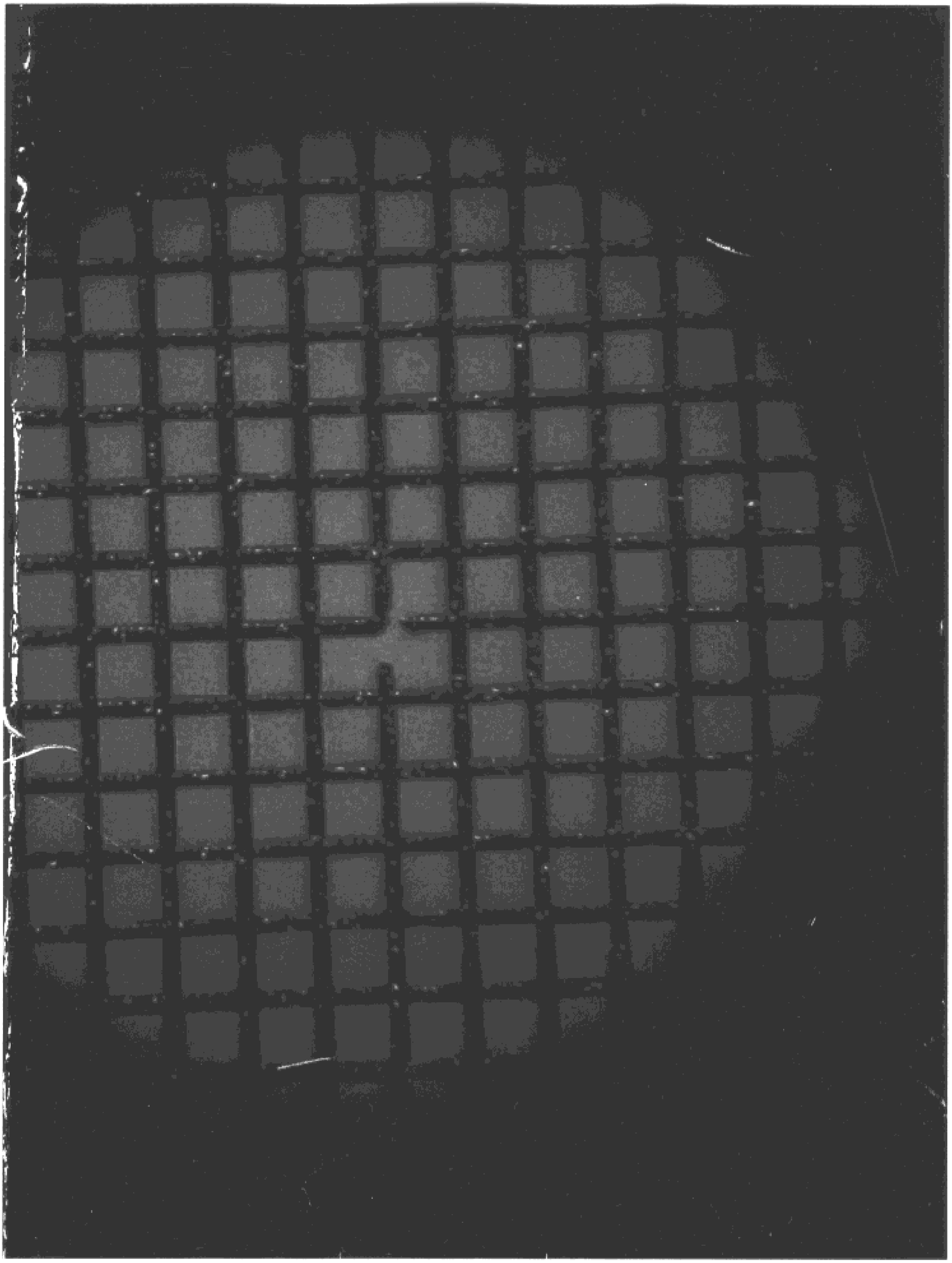
8 octobre 1999

19.94 bar
800 V
100% He
6% CH4



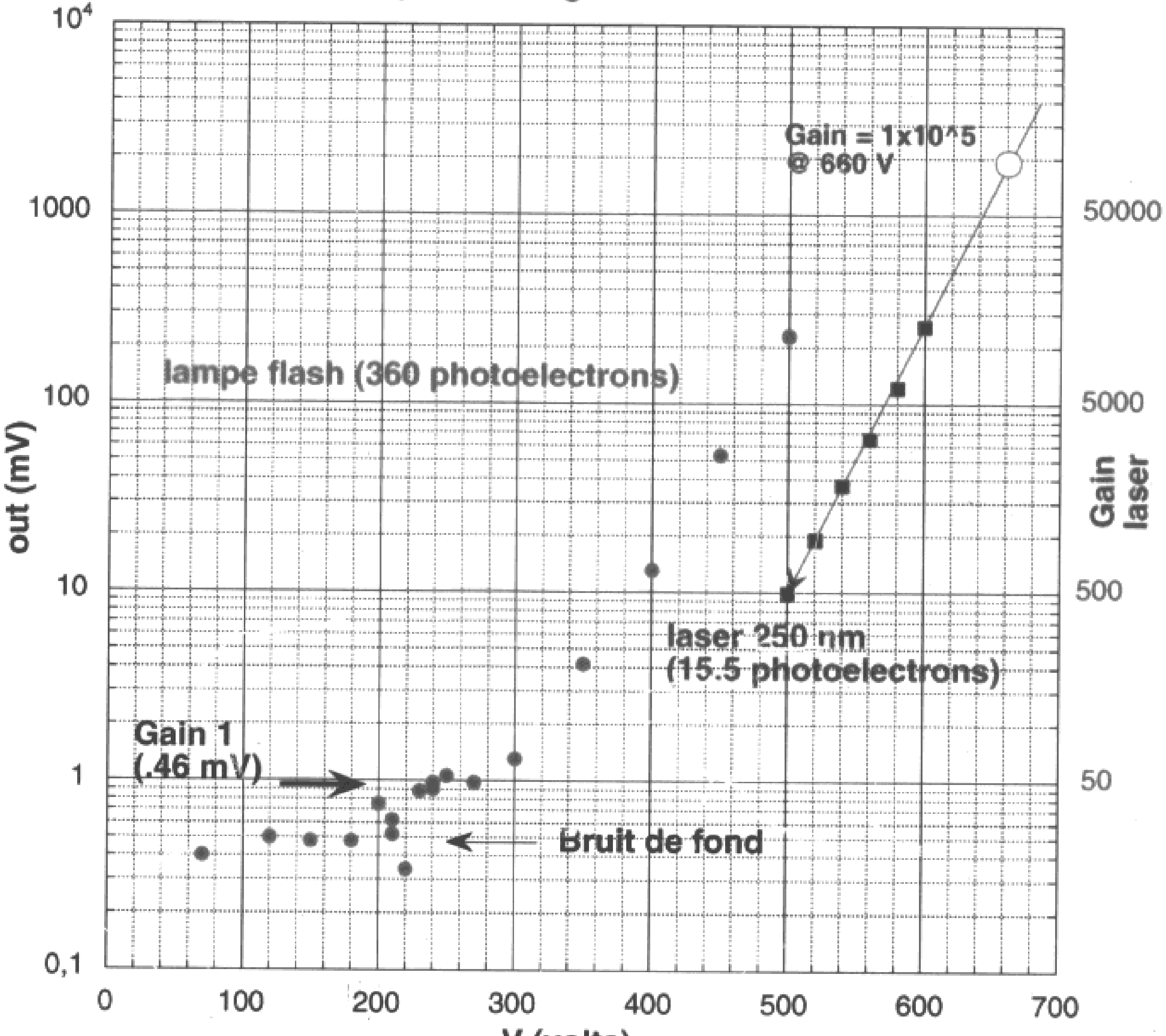


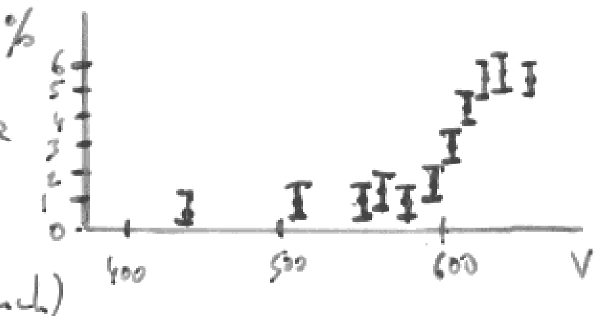
100 kF



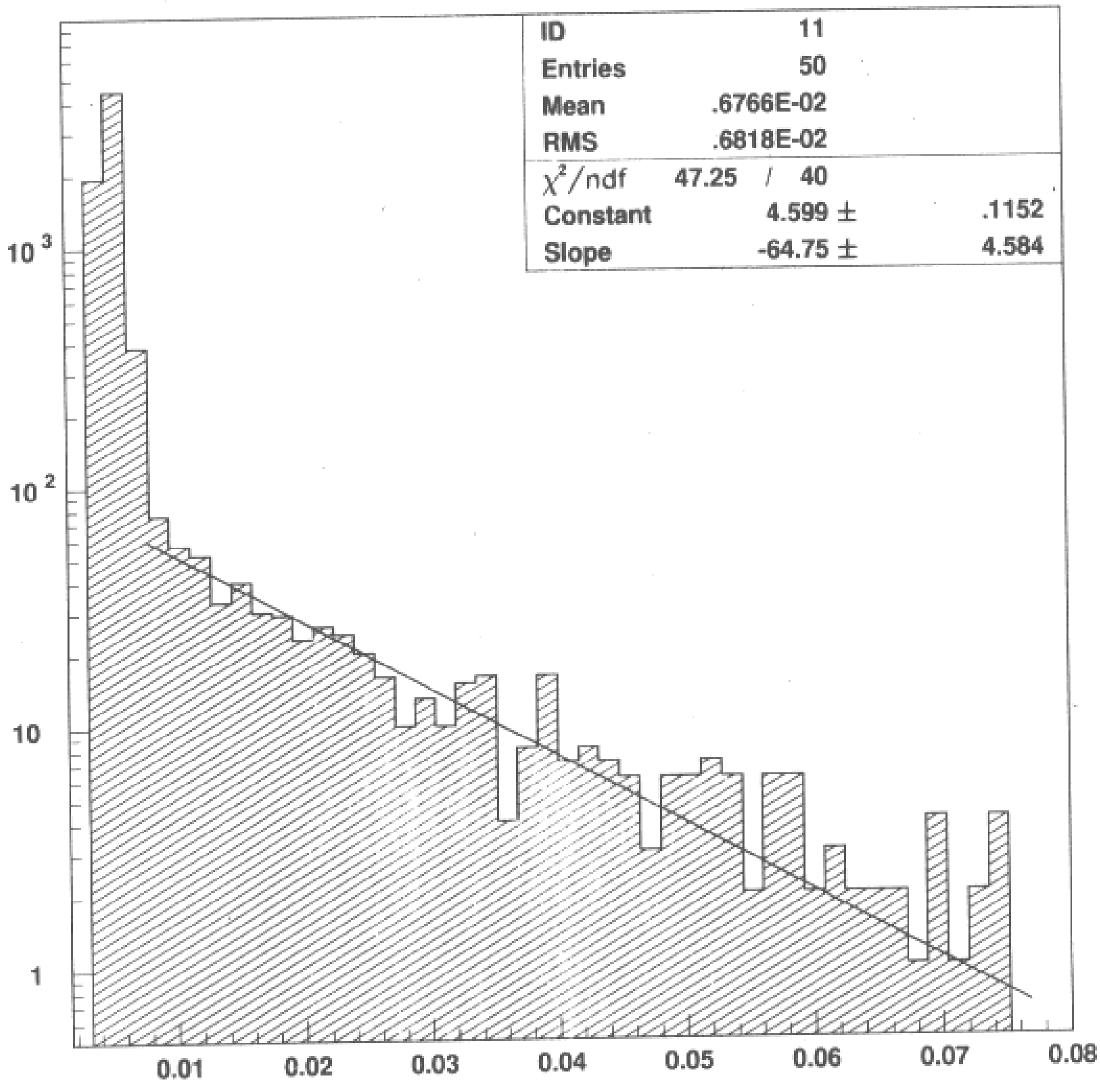
Micromegas 50µm
97.5% He, 2% CH4, 0.5% isobutane 20 bar

Ampli de charge sur cathode





Probabilité d'avoir un pulse de hauteur > 30 000 e⁻ (Rapport entre échelle discri et échelle déclench)


ID 11
Entries 50
Mean .6766E-02
RMS .6818E-02
χ²/ndf 47.25 / 40
Constant 4.599 ± .1152
Slope -64.75 ± 4.584
10 3
10 2
10
1
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08

Have signed the LOI

Wayne State (7 people)

Arizona (2 people)

FSU Tallahassee (5 people)

BNL (2 people)

College de France (4 people)

Have declared an interest:

LBL Berkeley

Chicago

Indiana Cyclotron

New Mexico

Pittsburgh

Alberta (Pinfold)

CEA: S. Turck-Chieze

Discussions with:

Japan

Bologna

Neuchatel