P. Smith

Possible international project:

Observatory for Multiflavour Neutrino Interactions from Supernovae

Uses neutrino burst from next supernova to answer key questions in neutrino physics

- Is one of the neutrino masses in the 'cosmologically significant' range 5-50 eV ?
- Is there mixing over Galactic distances ?
- Could neutrino mass account for the Galactic dark matter ?

- Simple detectors, relatively low cost
- Gives large signal from mu/tau neutrinos
- Three targets to differentiate neutrino response

- Complements other world detectors
- Proposed as two-site US/UK collaboration

Cosmological neutrino density

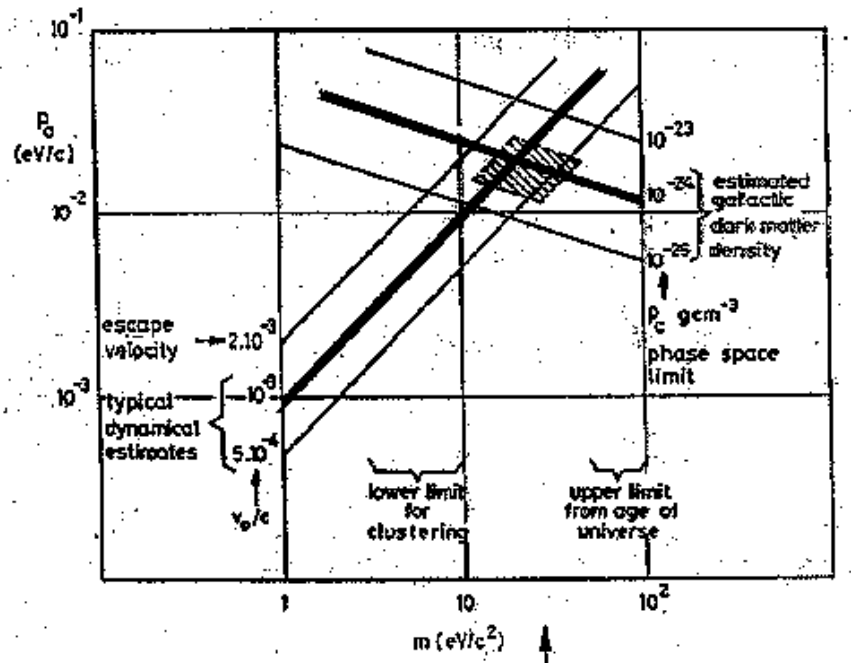
from number density after decoupling

$$\sum_{1,2,3} m_\nu = 50 \left[\frac{H}{70}\right]^2 \Omega_\nu$$

eg
H = 70 km/s/Mpc
Ω_ν = 0.5 -1
m_ν = 25-50 eV

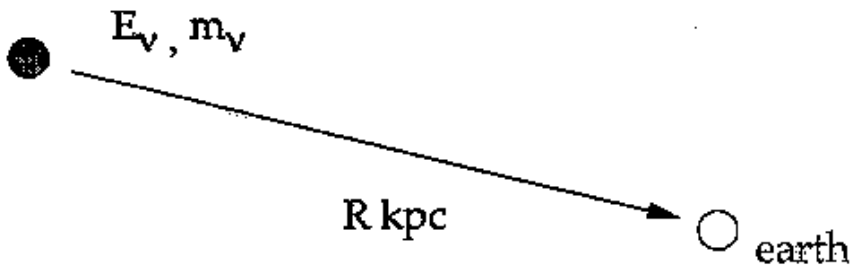
Neutrinos as Galactic dark matter

Estimate from phase space at decoupling (at T=1 sec, 1 MeV) and Galactic velocity



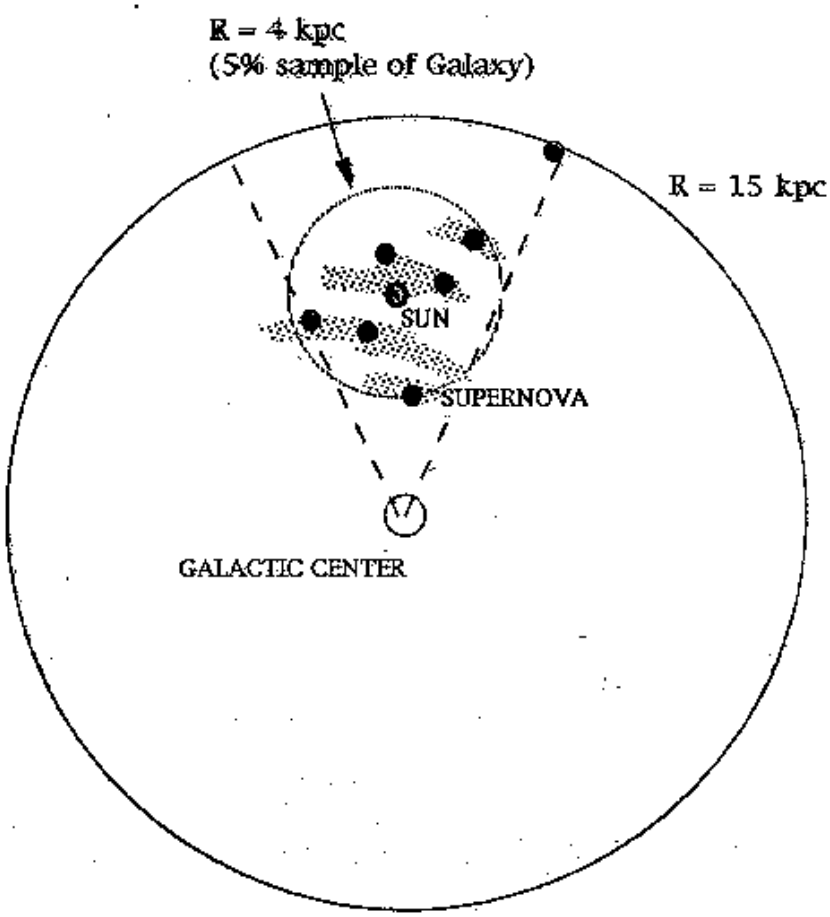
m_ν = 20-40 eV for Galactic halo

Time delay due to non-zero mass

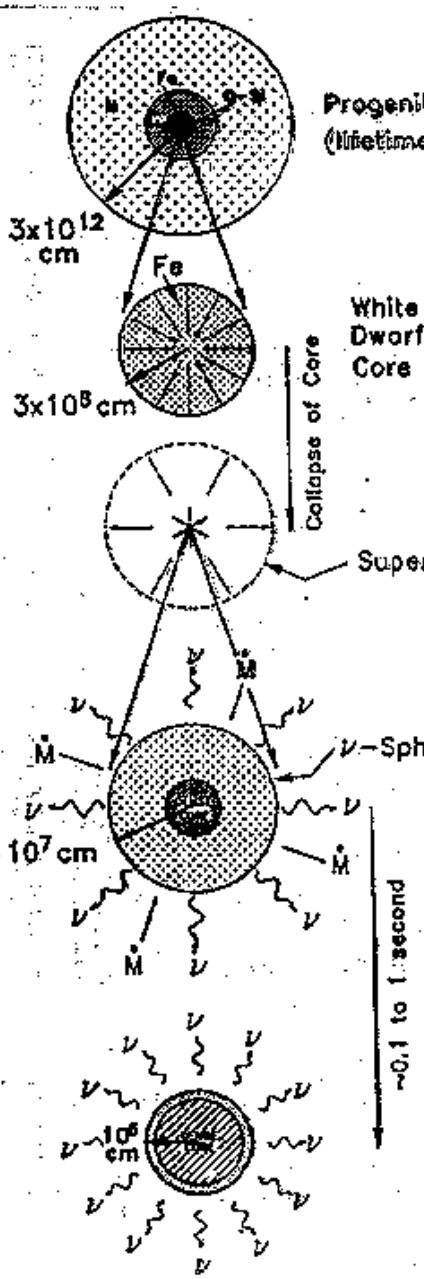


$$\Delta t\,(s) = 1.6 \left[\frac{R}{8\ \text{kpc}}\right] \left[\frac{m_\nu}{50\ \text{eV}}\right]^2 \left[\frac{25\ \text{MeV}}{E_\nu}\right]^2$$

Galactic supernova rates



- 5 type II/Ib observed in 1000 years within 4 kpc of sun
- 4 kpc is 5% sample of Galaxy
- Hence possible 100 ± 40 in whole Galaxy = 10 -15 year interval
- All would be seen by neutrino detector



neutrino emission

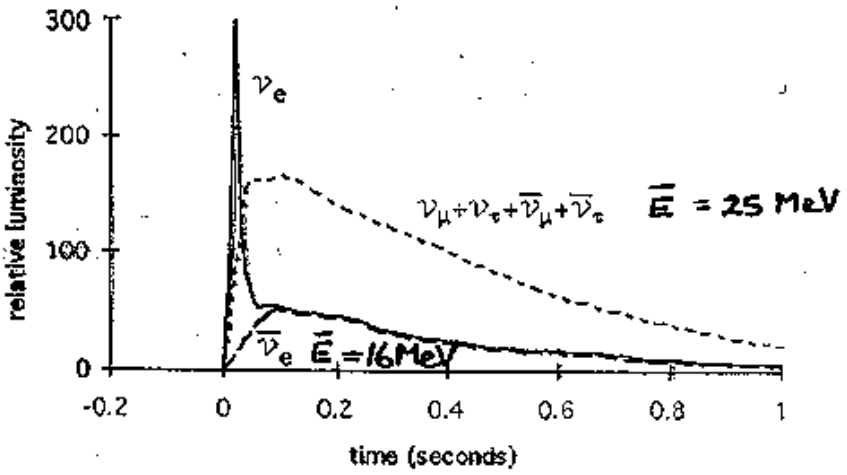
$$e^- + p \rightarrow n + \nu_e$$

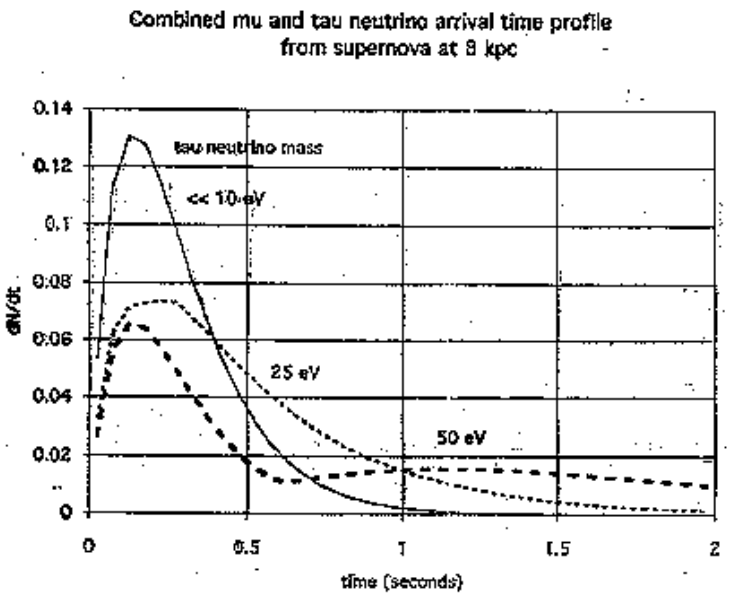
$$e^- + e^+ \rightarrow \begin{cases} \nu_e + \bar{\nu}_e \\ \nu_\mu + \bar{\nu}_\mu \\ \nu_\tau + \bar{\nu}_\tau \end{cases}$$

inverse processes

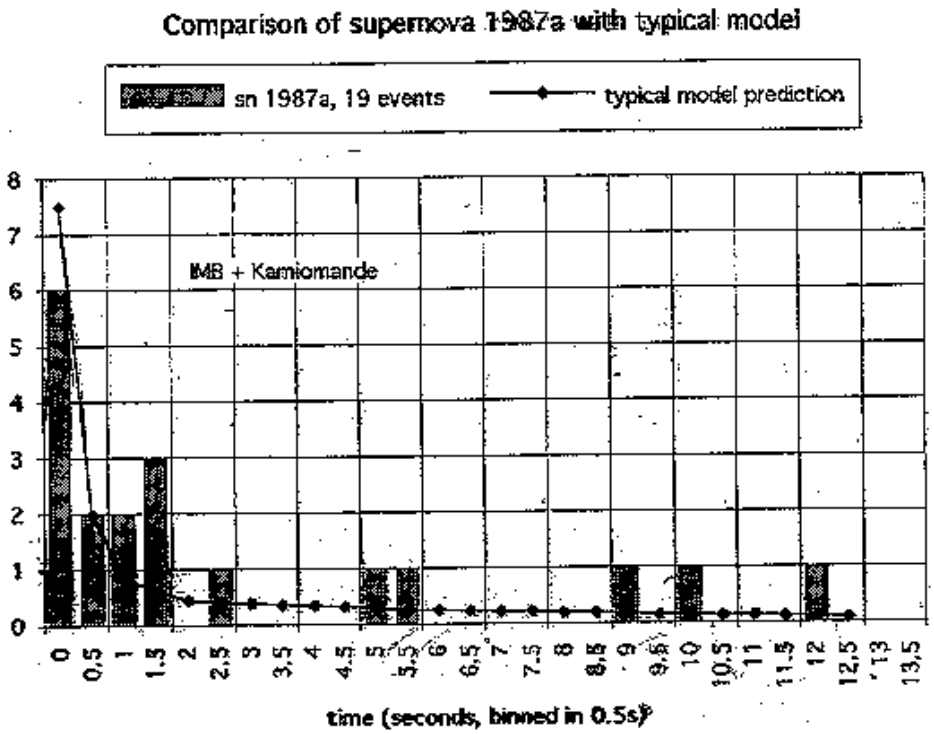
$$\bar{\nu}_e + p \rightarrow n + e^+$$
$$\nu_e + n \rightarrow p + e^-$$
$$\nu_e + e^+ \rightarrow \nu_e + e^+$$

} delays $\nu_e, \bar{\nu}_e$ & lower temp.





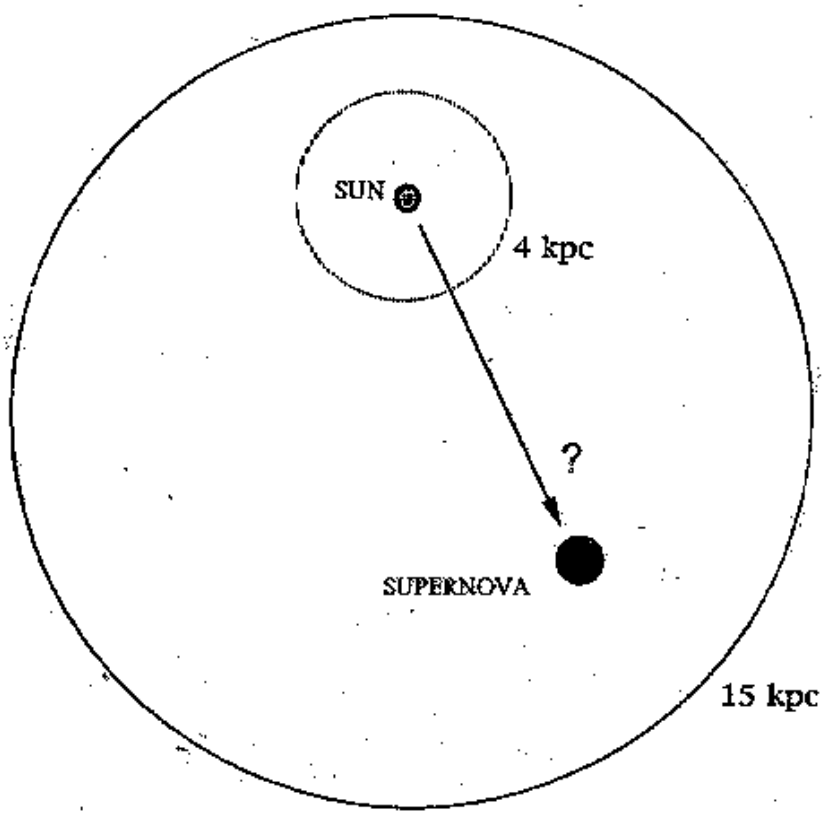
Needs 2000 neutral current events to measure neutrino mass in 10-100èV range



Consistent with models:

60% events in first 2 seconds

Distance estimates for 'invisible' supernova



- **Stage 1 estimate:**
  If not visible but in Galaxy then distance known within factor 4.
  Hence neutrino mass known within factor 2 - ie 1.5±0.5, or 30%

- **Stage 2 estimate:**
  If flux known from SuperKamiokande, then distance known to factor √2 and neutrino mass to √√2, ie ±10%

- **Stage 2 estimate:**
  Approximate direction allows searches in infra-red and radio, giving more accurate distance if found.

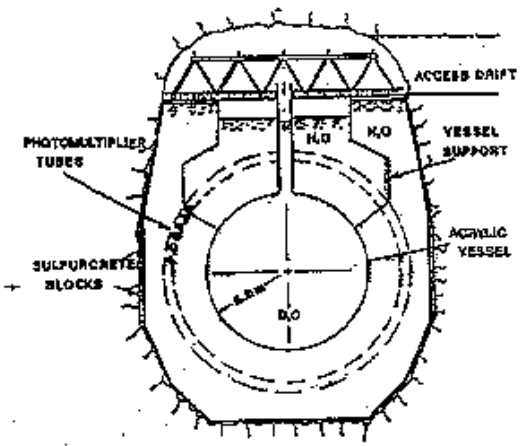


FIGURE 4. Outline of the SNO detector.

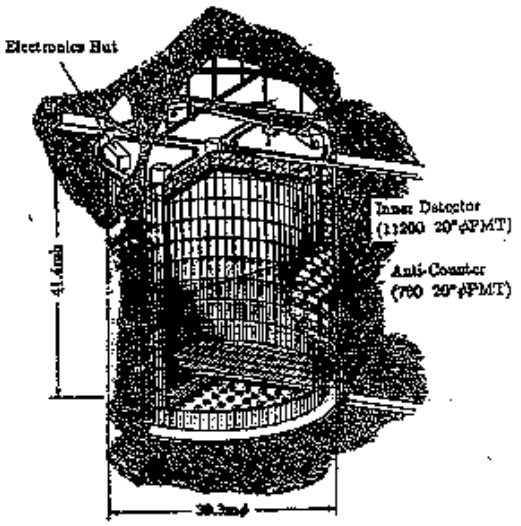


FIGURE 3. Outline of the Super-Kamiokande detector.

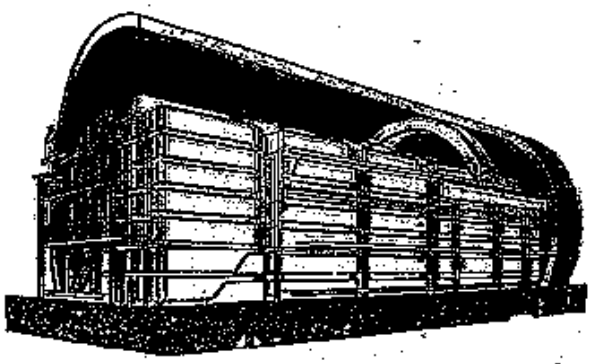


Fig. 5. Schematic view of the LVD detector.

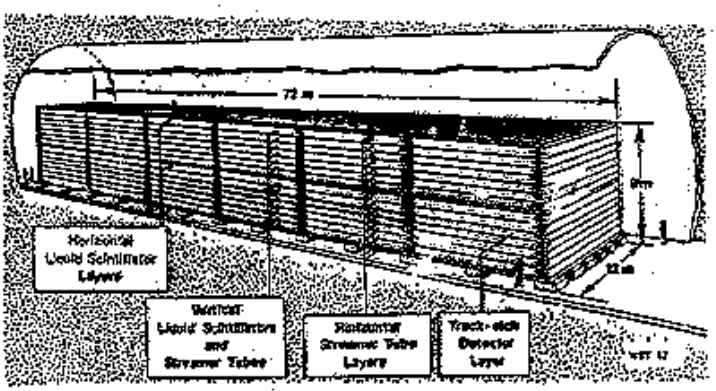


Fig. 6 - Schematic diagram of the MACRO detector. (4)

Neutrino events in world detectors from supernova at 8 kpc

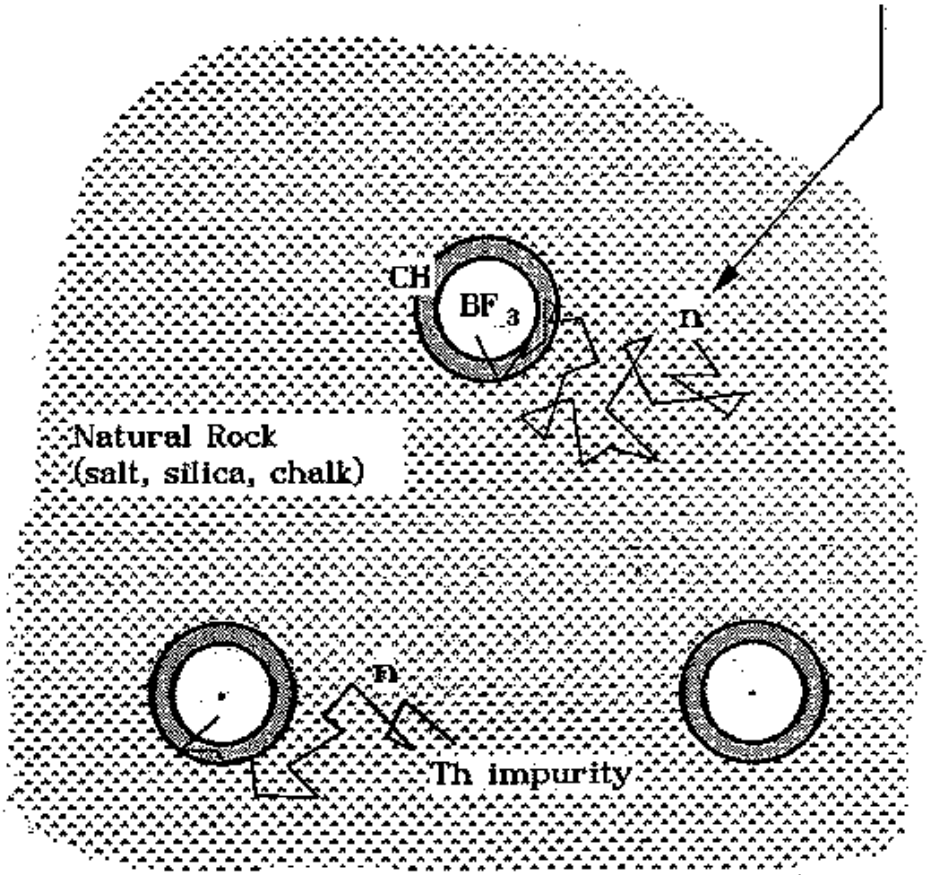
	target material	fiducial mass (ton)	target elements	νe	$\bar{\nu} e$	$\nu_{\mu,\tau} + \bar{\nu}_{\mu,\tau}$
Combined target/detector:						
Super-Kamiokande	H_2O	32000t	p, e, O	180	8300	50
LVD	'CH_2'	1200t	p, e, C	14	540	30
MACRO	'CH_2'	1000t	p, e, C	8	350	25
SNO	H_2O	1600t	p, e, O	16	520	6
SNO	D_2O	1000t*	d, e, O	190	180	300*

*D_2O target not available indefinitely

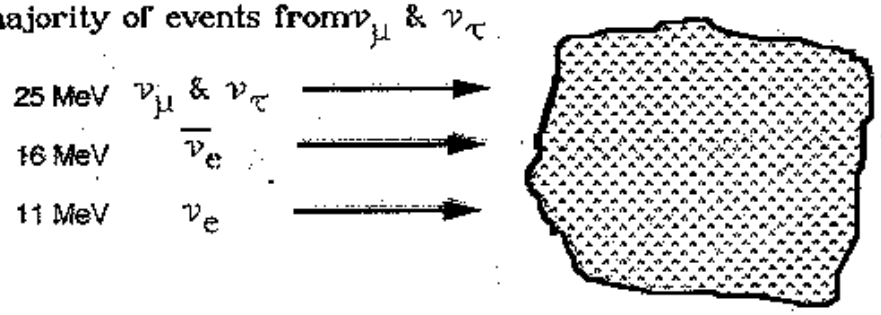
Supernova Neutrino Burst Observatory (Cline & Fuller 1990)

Neutral current excitation

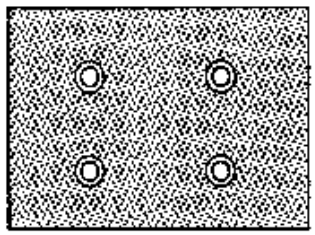
$$\nu + A(Z,N) \longrightarrow A^*(Z,N) \longrightarrow A(Z,N-1) + \nu + n$$



Energy dependence $(E - E_o)^2$ gives majority of events from ν_μ & ν_τ

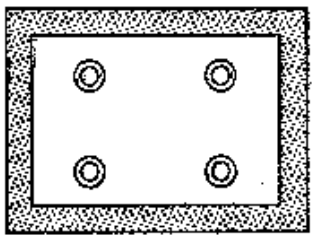


Neutron production at 8kpc: 0.1 per ton rock



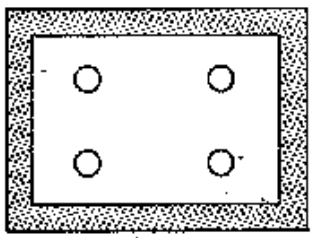
BF_3 / polythene embedded in rock

0.2 - 0.3 c/m^3



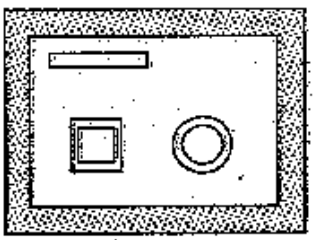
BF_3 / polythene in open cavern

0.6 - 0.9 c/m^3



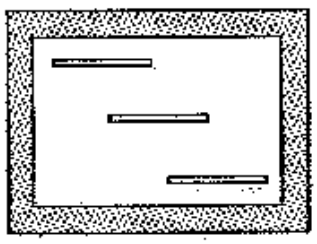
Loaded scintillator in open cavern

1 - 2 c/m^3



Loaded scintillator 10 -20 cm shells or slabs

2 - 3 c/m^3



Loaded scintillator 2 - 10 cm slabs

4 - 6 c/m^3

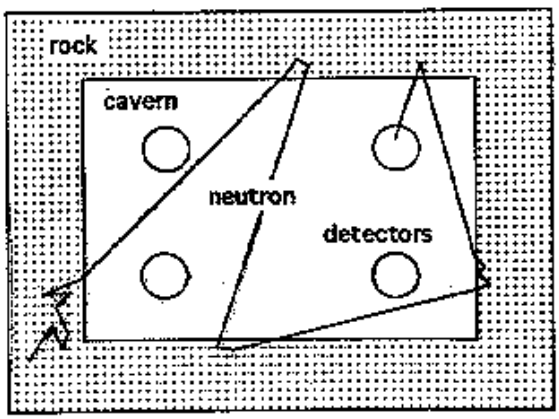


Fig 5
Detection enhancement by multiple scattering in open cavern. Typical neutron path from emission in rock to thermalisation and capture in detector

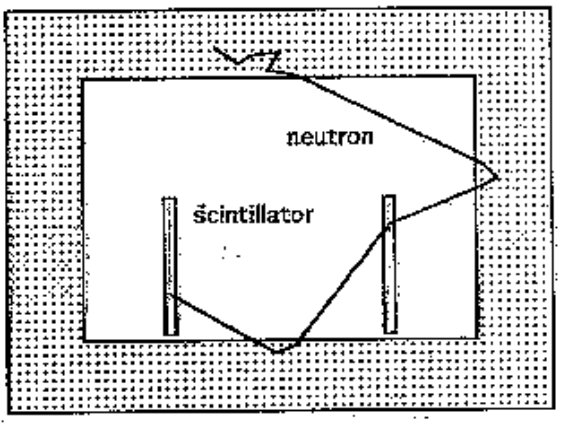


Fig 6
Optimum neutron cature geometry - thin (~5 cm) scintillator slabs allowing multiple traversal and progressive thermalisation.

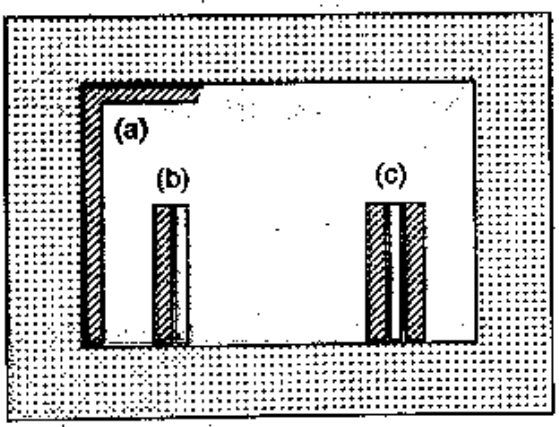
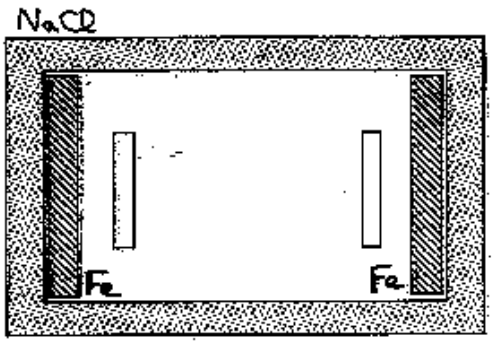
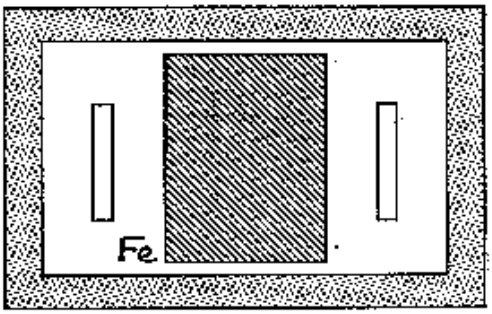


Fig 7
Alternative positions for supplementary iron and lead:
(a) lining cavern walls
(b) backing detector
(c) enclosing detector

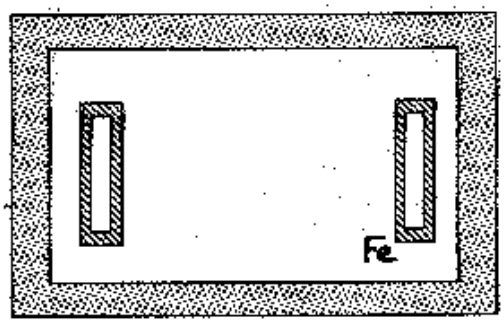
Supplementary materials - variations



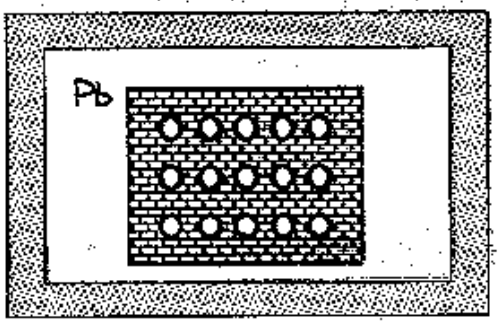
Walls partly covered with Fe (as reflector)



Larger quantity of Fe (as target)

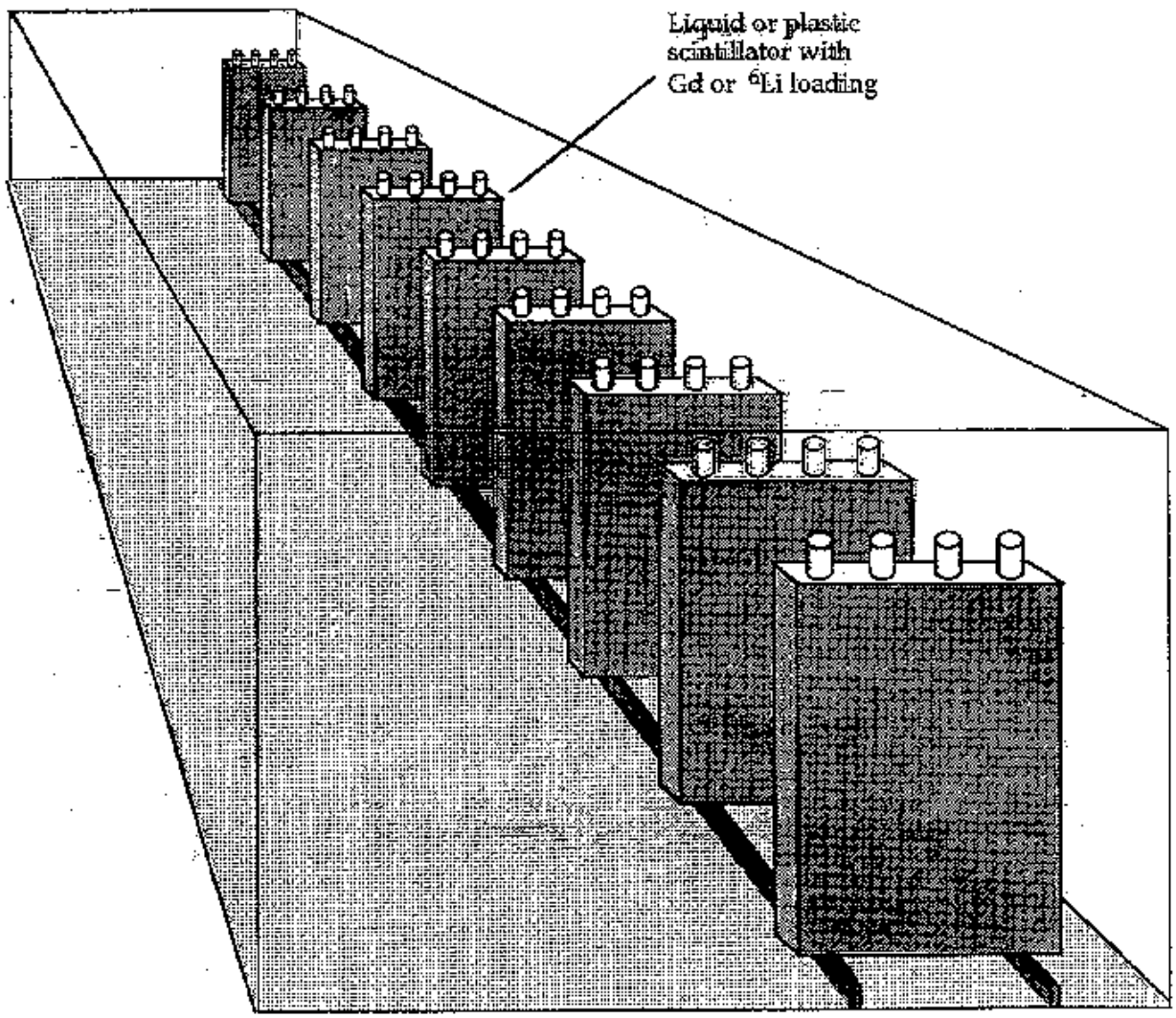


Fe around detectors (trap n, shield γ)



Pb block with embedded counters

C. Hargrove "LAND"

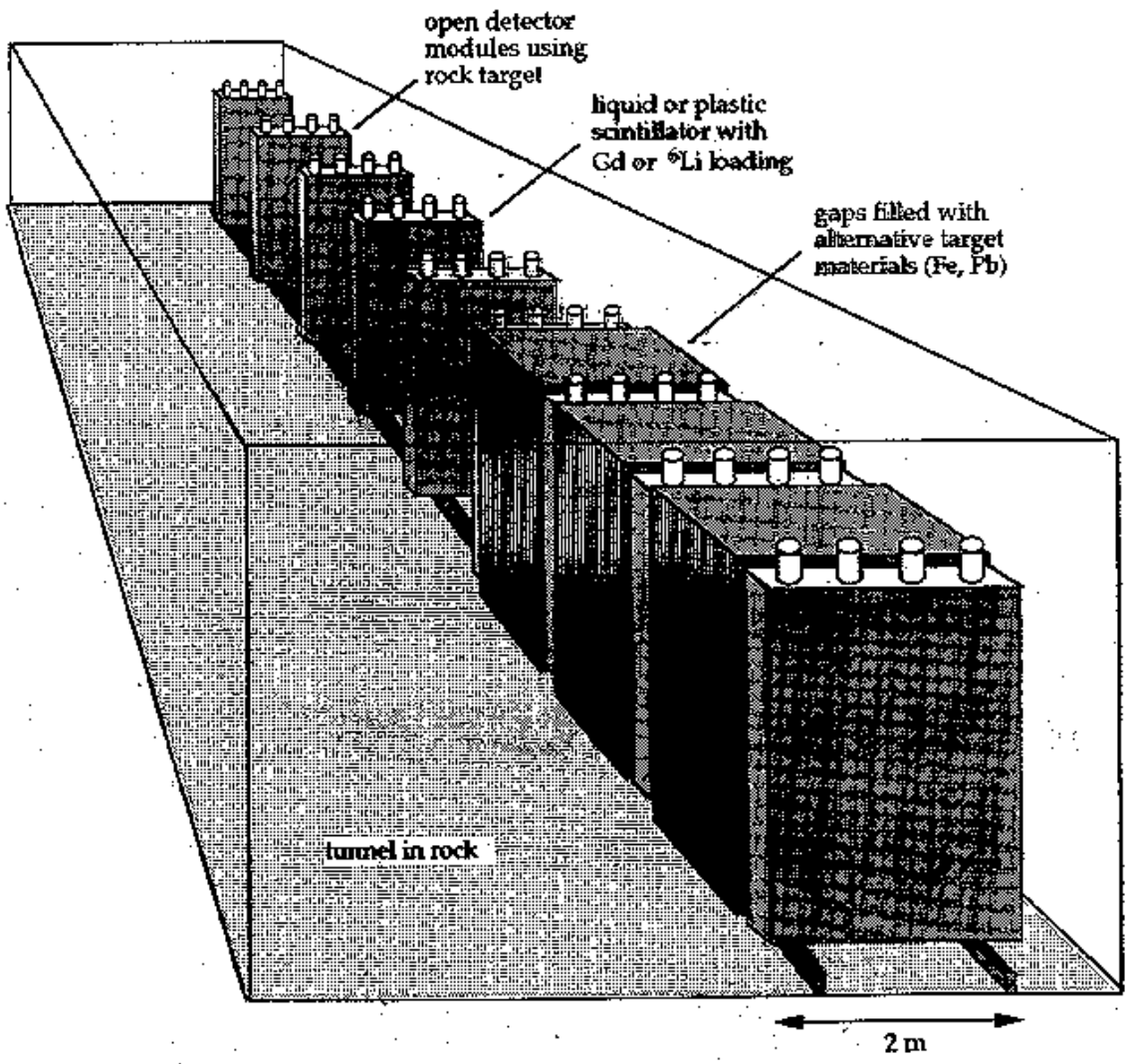

Liquid or plastic
scintillator with
Gd or ^{6}Li loading

Observatory for
Multiflavour
Neutrino
Interactions from
Supernovae

Includes both neutral and charged current excitation in Pb, with neutral current only in Fe & rock)

$$\nu_{\mu,\tau} + A(Z,N) \longrightarrow A^*(Z,N) + \nu$$
$$\longrightarrow A(Z,N-1) + n$$

$$\nu_e + A(Z,N) \longrightarrow A^*(Z,N) + e$$
$$\longrightarrow A(Z,N-1) + n$$



250 modules between 2-3 sites to give ~ 2000 events

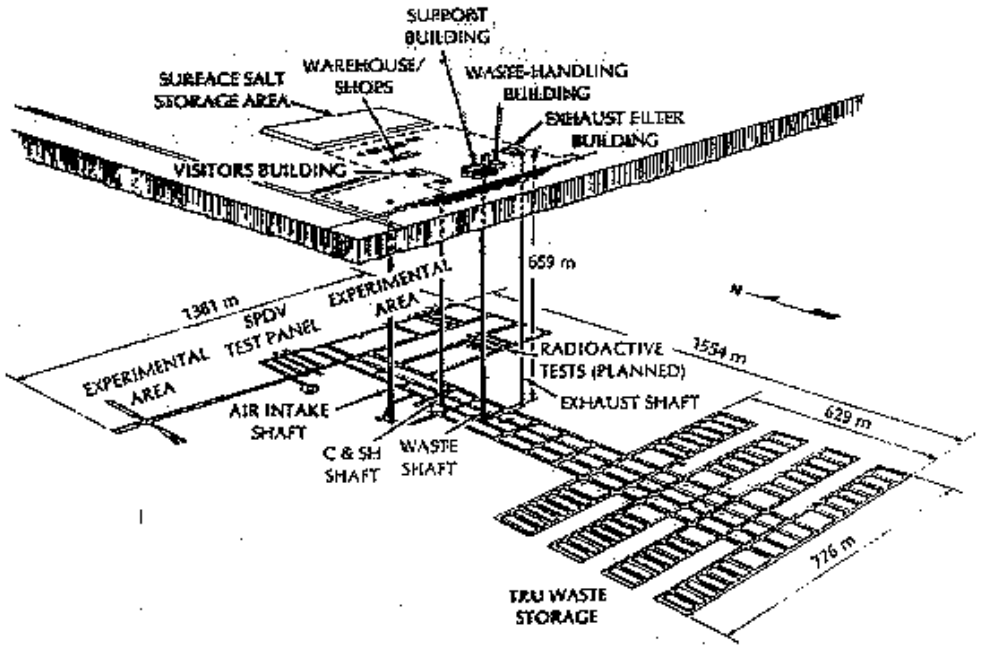
Table 2 Comparison of proposed OMNIS multi-target observatory with world detectors based on direct detection with water and scintillator targets. Approximate event numbers for each neutrino type shown for a supernova at 8 kpc.

	target material	fiducial mass (tons)	target elements	ν_e	$\bar{\nu}_e$	$\nu_{\mu,\tau} + \bar{\nu}_{\mu,\tau}$
Combined target/detector:						
Super-Kamiokande	H_2O	32000t	p, e, O	180	8300	50
LVD	'CH_2'	1200t	p, e, C	14	540	30
MACRO	'CH_2'	1000t	p, e, C	8	350	25
SNO	H_2O	1600t	p, e, O	16	520	6
SNO	D_2O	1000t [a]	d, e, O	190	180	300 [a]
Separated target & detector:						
OMNIS						
200 t scintillator +	NaCl(rock)	'8000t'	Na,Cl	10	10	400
natural rock +	Fe	4000t	Fe	10	10	600
installed targets	Pb	4000t	Pb	280	30	1000
			totals	**300**	**50**	**2000**
Direct interaction with scintillator	'CH_2'	200 t	p,e,C	2	70	5

[a] D_2O target not available indefinitely

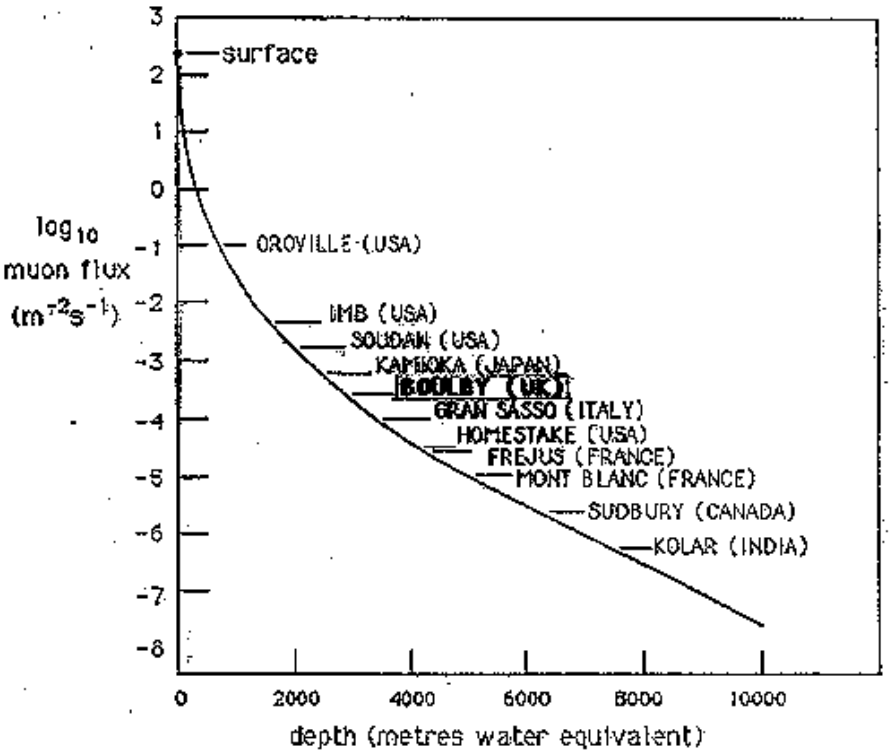
D.O.E. Waste Isolation Pilot Plant

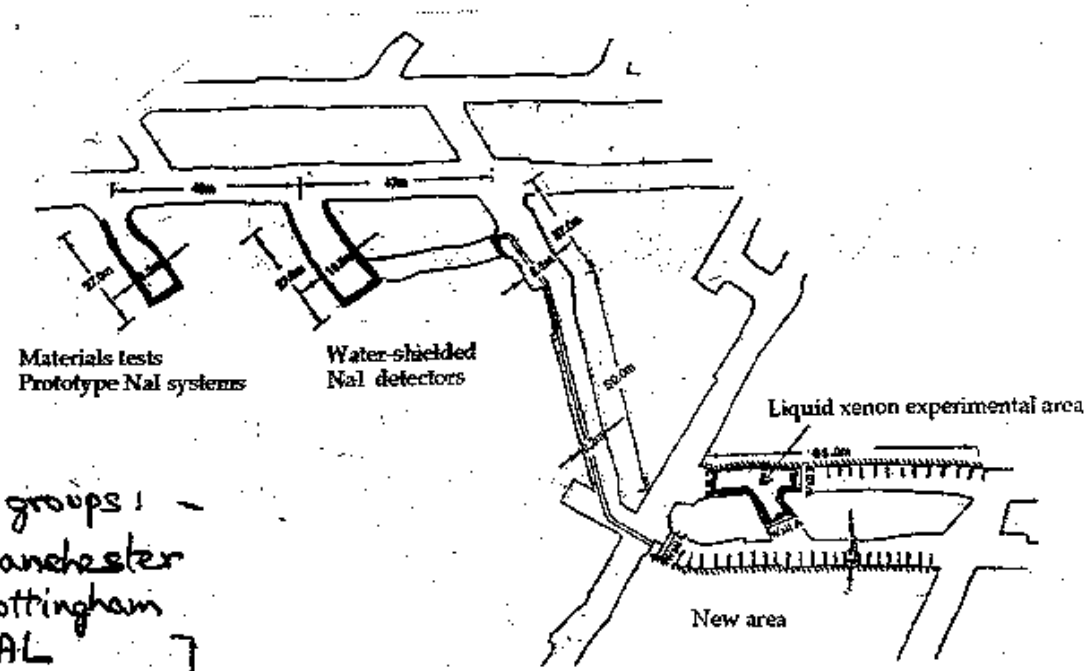
Carlsbad, New Mexico



Experimental tunnels available
away from proposed active material storage

US Groups: Ohio
UCSD
UCLA
LANL
LLNL
UT-Dallas



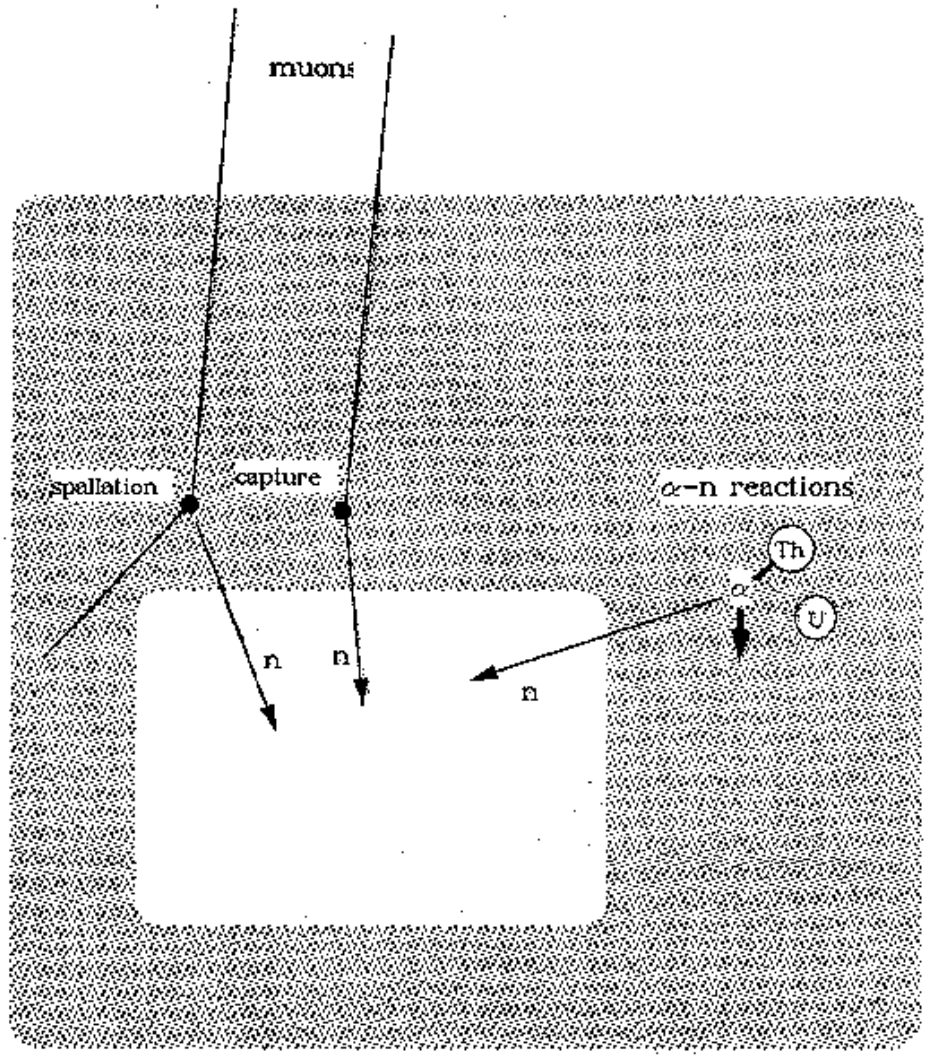


UK groups:
- Manchester
- Nottingham
- RAL
- Sheffield
- IC (HEP)
- IC (Astro)

] DM groups

Neutron Background

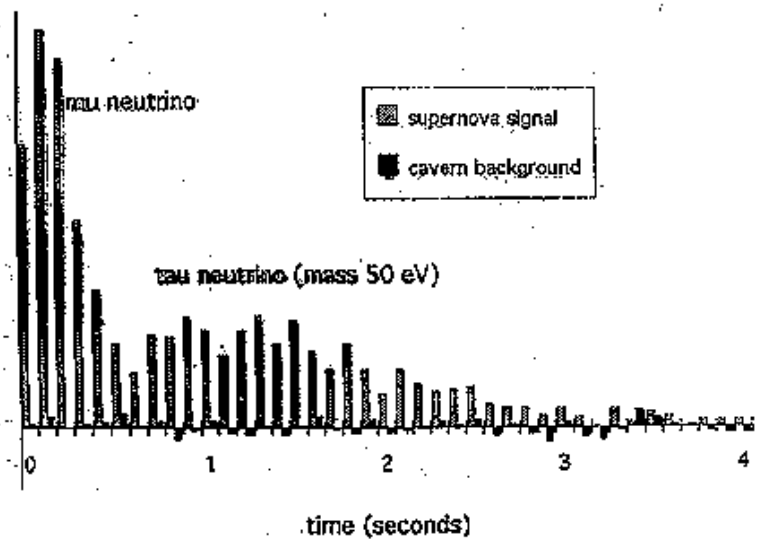
(principal processes)



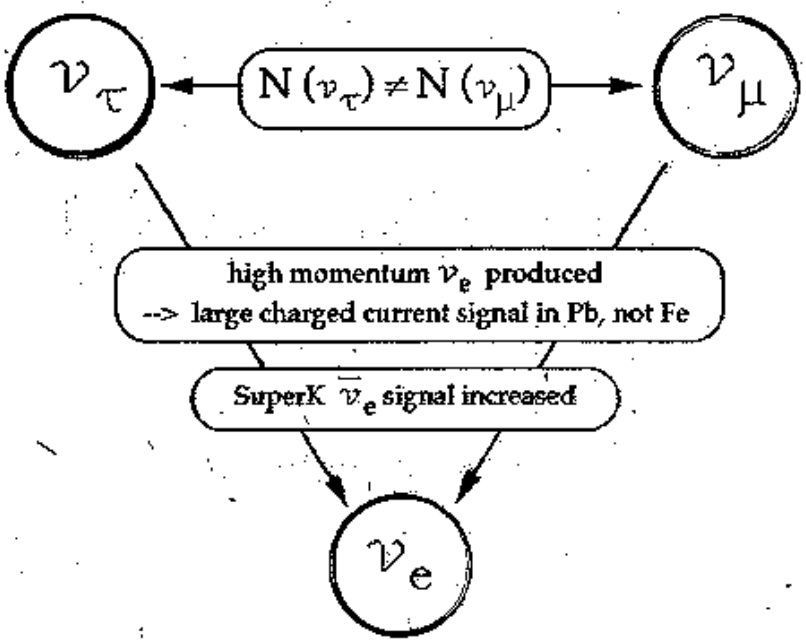
From muons	From U/Th
10^{-5} /g/s at surface 10^{-9} /g/s at Carlsbad (670m) 10^{-10}/g/s at Boulby (1100m)	10^{-8} /g/s

Average Galactic supernova : 10^{-7}/g

Signal/Noise



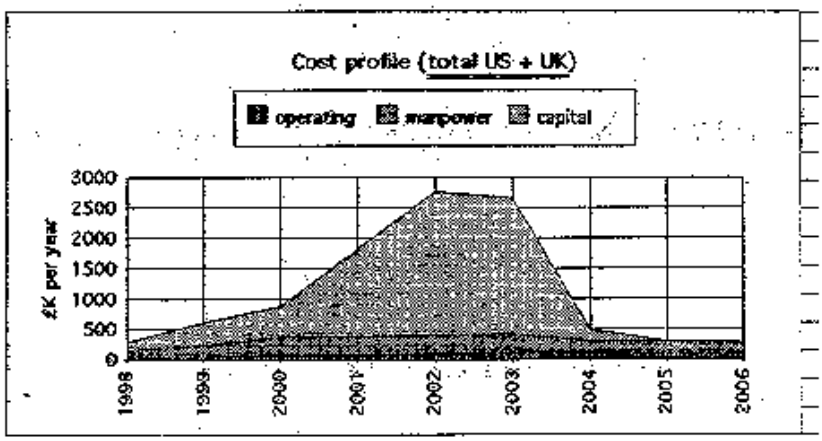
Mixing



Construction schedule and Cost Profile

Table 2a

OMNIS construction schedule	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Stage 1: single module development										
Underground background studies										
Monte Carlo design studies										
Lab performance tests										
Underground tests										
Stage 2: underground test section										
Manufacture & installation										
Performance tests										
Continuous running										
Stage 3: test section with Fe/Pb targets										
Manufacture & installation										
Performance tests										
Continuous running										
Stage 4: Full array installation & running										
arrays 20% operational										
arrays 50% operational										
arrays 100% operational										



Conclusions and Prospects

- Neutrino observatory based on neutral current nuclear excitation would give accurate measurement of $\nu_\tau + \nu_\mu$ time profile from next Galactic supernova (0–20 years).

- Use of Pb, Fe, rock target materials would allow
  (a) direct measurement of a cosmologically significant mass
  (b) estimate mixing effects on the Galactic distance scale,
  (c) settle viability of neutrino as dark matter candidate.

- Nuclear excitation technique provides highly efficient supernova detector – 2000 events possible with 200 tons scintillator (in 0.5–1 ton modules) + supplementary iron and lead.

- Technique simple and modular – can be built up progressively in existing sites. Needs 2–3 separated sites for coincidence and supernova direction.
  Possibilities with adequate background and infra-structure are Carlsbad, Boulby, Soudan.

- Total (shared) construction cost (for 2000 events at 8 kpc) £8M over 5 years.
  Running cost 60K/y in maintained sites.

- Feasible with known technology.
  Practical US/UK studies in progress on lab scale.
  First full-size underground prototypes could now be constructed