Prospects for neutrino astrophysics at the UK Boulby Mine

P F Smith (RAL)

Four opportunities for new experiments

Two immediate:

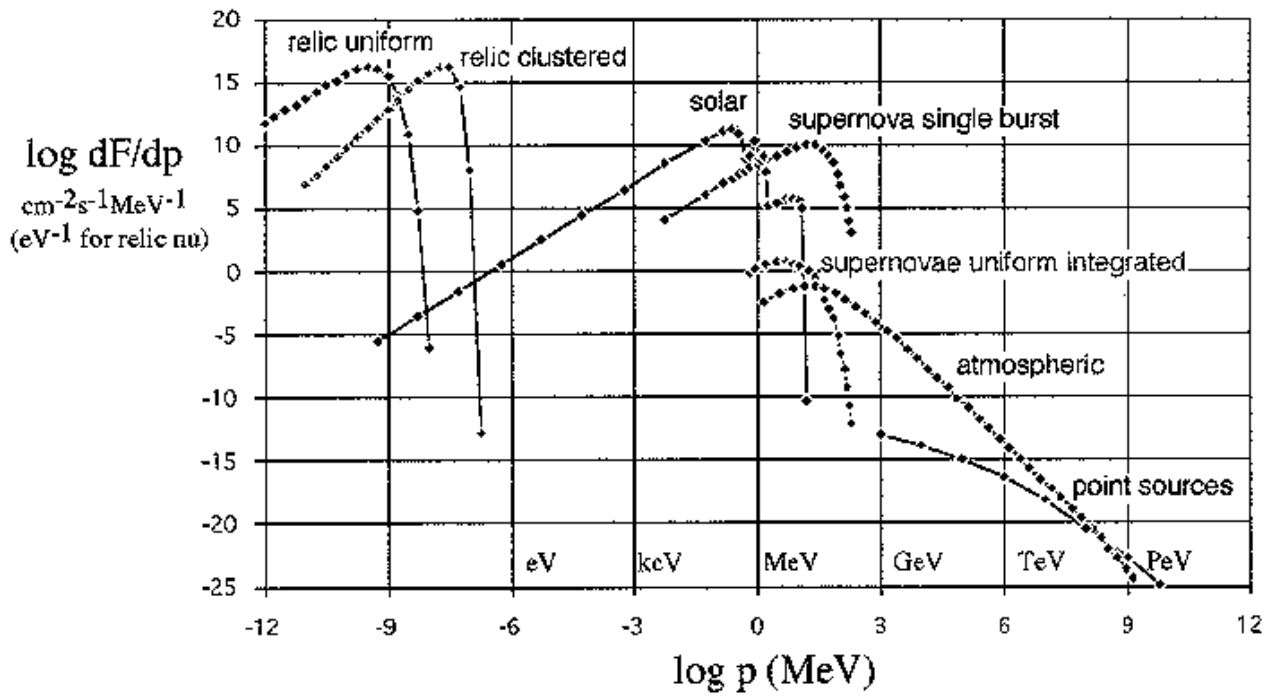
- OMNIS detector for supernova mu and tau neutrinos
  - new mixing signal, wide MSW coverage.
- SIREN real time solar neutrino detector
  - distinguishes models for deficit
  - can be combined with OMNIS

New collaboration:
Manchester, RAL, Sheffield, ICSTM, QMW

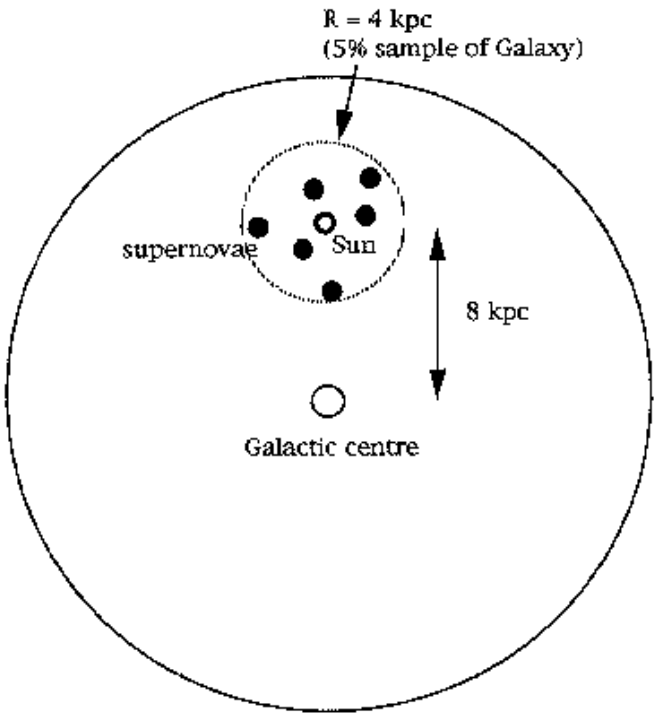
Two future:

- Measurement of integrated cosmic supernova antineutrino flux.
- Measurement of of relic neutrino density and any $N(\nu) - N(\overline{\nu})$ difference

Astrophysical Neutrino Spectra

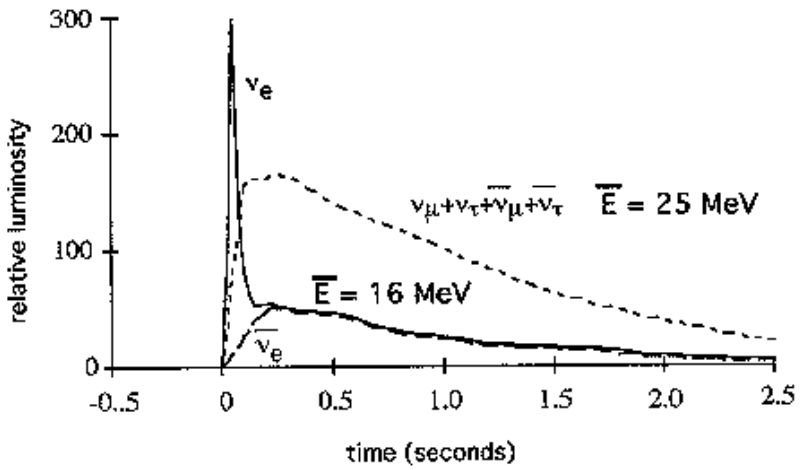


Supernova frequency in Galaxy

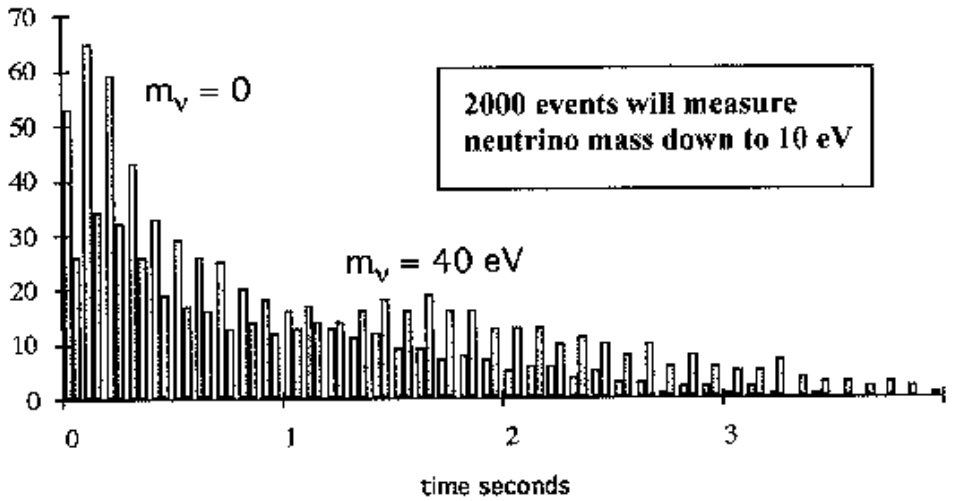


- various recent estimates give 3-10 /century
- 1000 year record in local 4 kpc gives 6-8 /century
- possibility of additional 'ultra-dim' supernovae

neutrino emission time profile



arrival time profile and tau neutrino mass

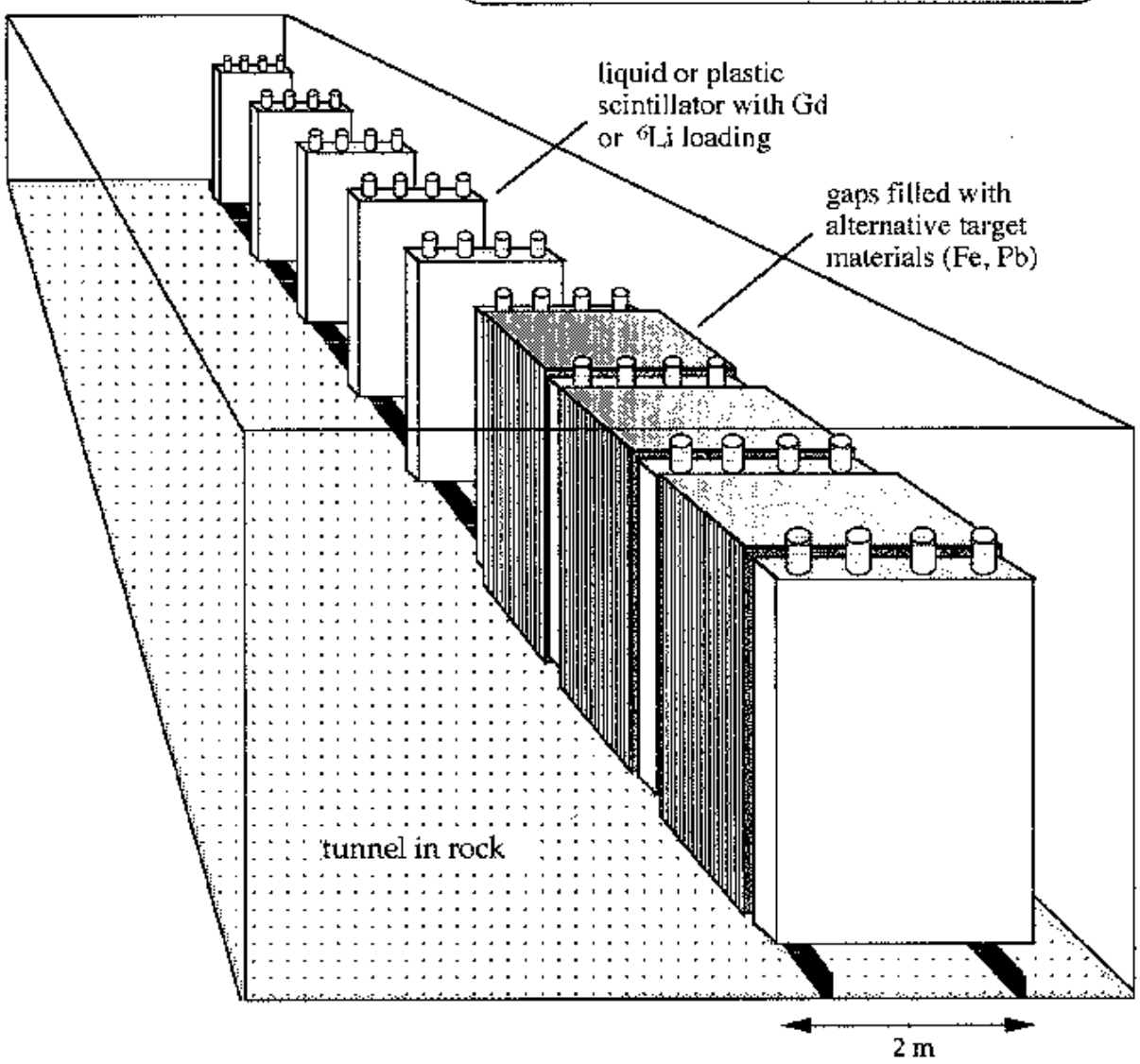


Observatory for **M**ultiflavour **N**eutrino **I**nteractions from **S**upernovae

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

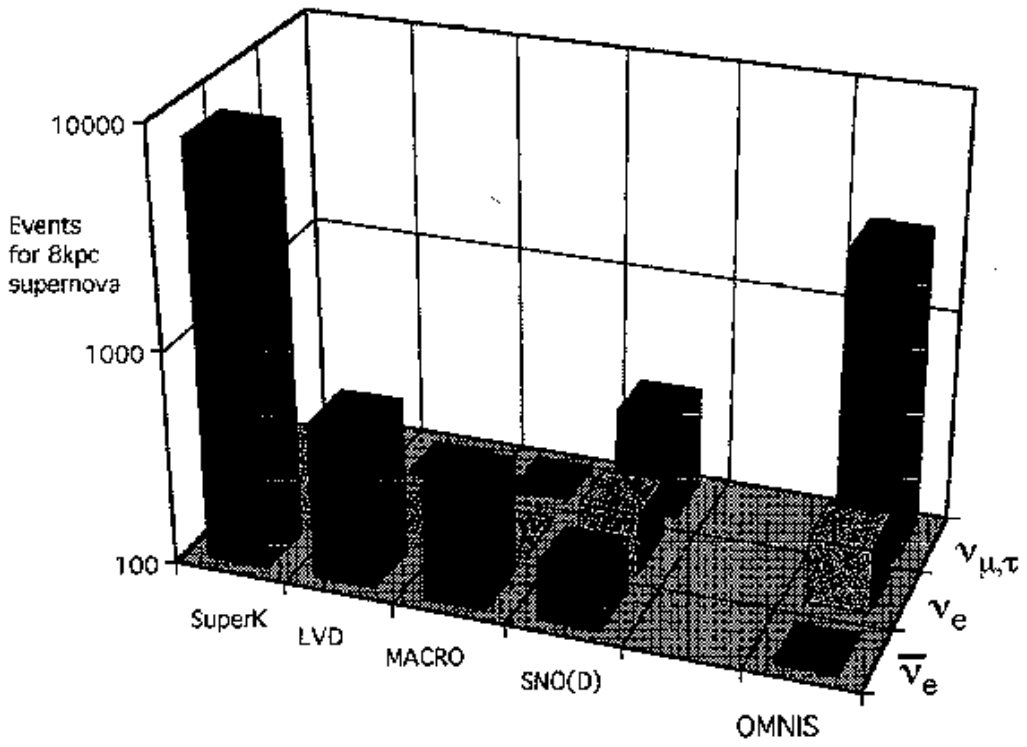
$$\nu_{\mu,\tau} + A(Z,N) \longrightarrow A^*(Z,N) + \nu \longrightarrow A(Z,N-1) + n$$

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

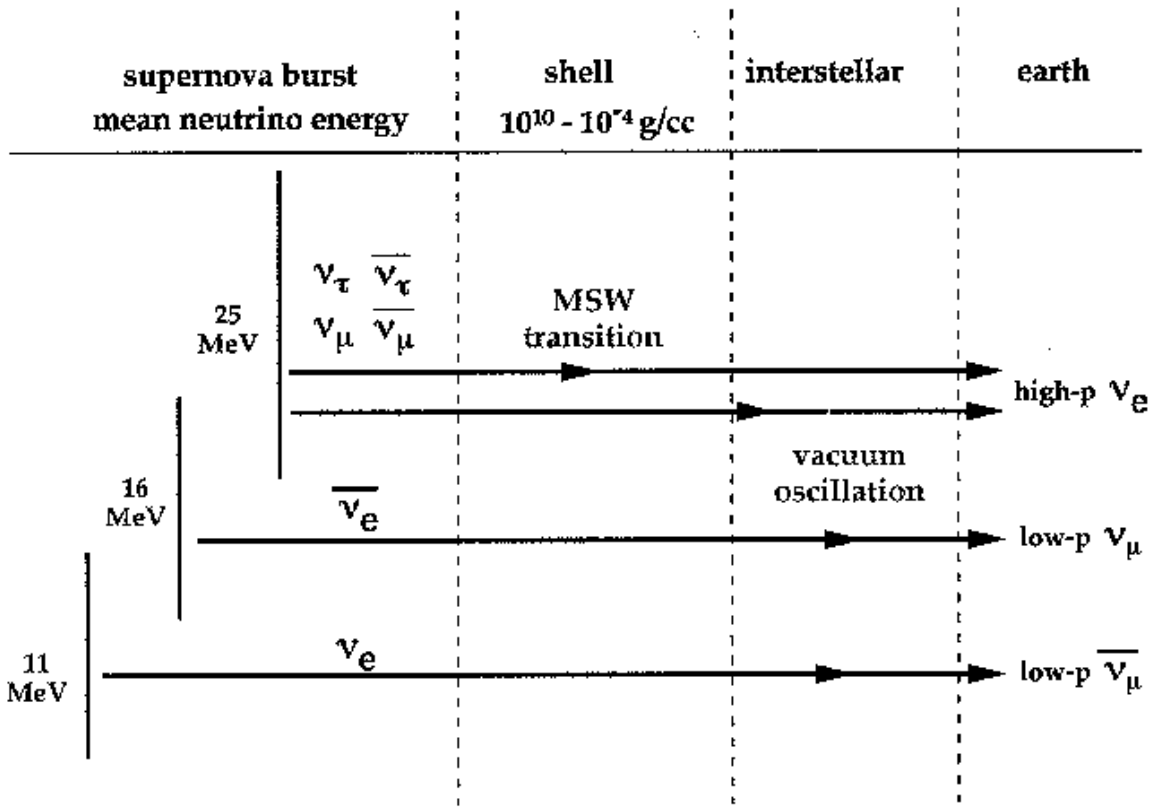


Comparison of world detectors - event numbers for supernova at 8 kpc

OMNIS complementary to existing detectors - provides large signal and accurate time profile for $\nu_{\mu,\tau}$

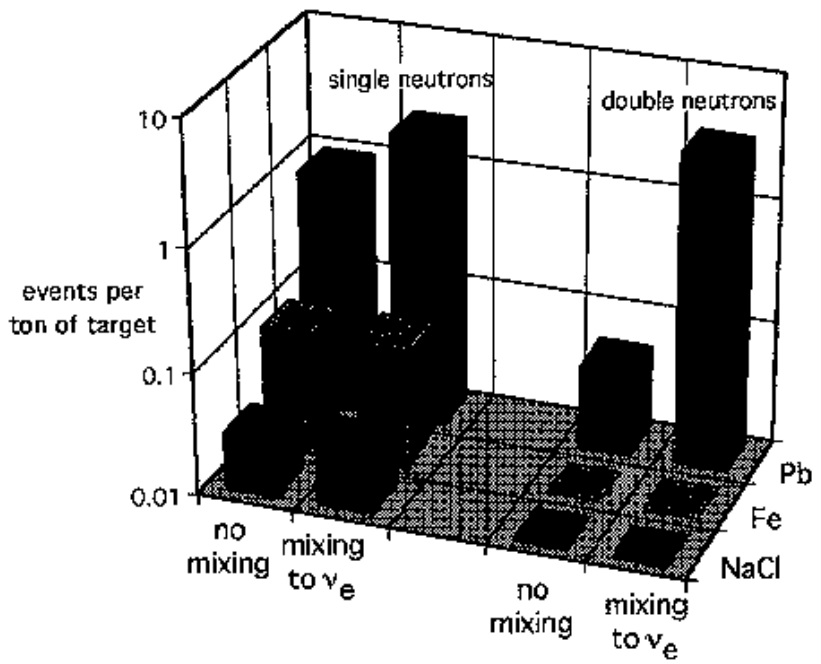


Mixing possibilities from supernova

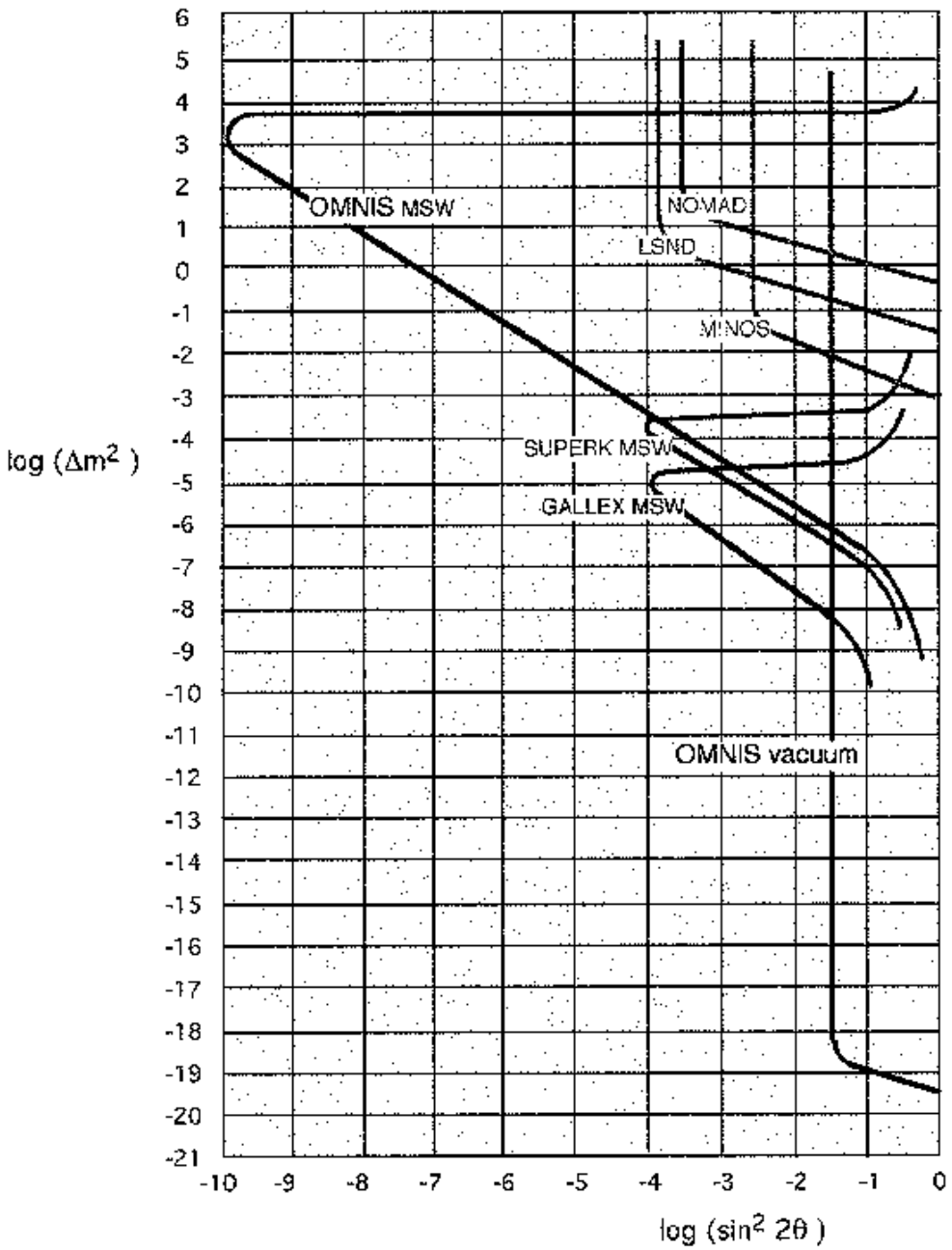


single and two-neutron production by mu and tau neutrinos in different target materials

(with and without mixing to electron neutrinos)



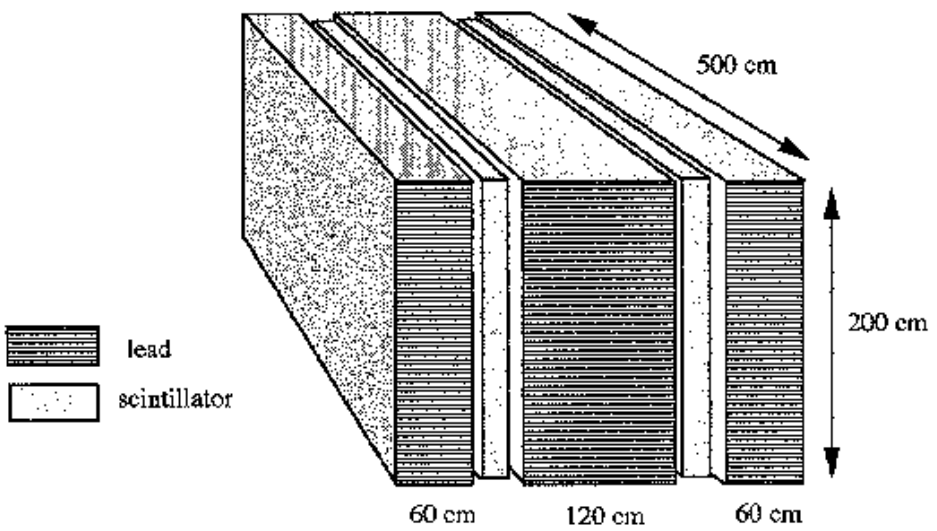
mixing sensitivity of OMNIS
(a) MSW in supernova
(b) vacuum oscillations through 8 kpc



Proposed OMNIS/SIREN prototype

(Manchester, RAL, Sheffield, Imperial College, QMW)

- Optimised geometry for lead+scintillator module to detect 100 events from 8 kpc supernova.
- Contains 250 tons lead, 3 tons scintillator
- Mixing from mu/tau to e neutrinos produces additional 140 two-neutron events
- Plastic/Gd layers provide 5% Gd for SIREN target and study of backgrounds



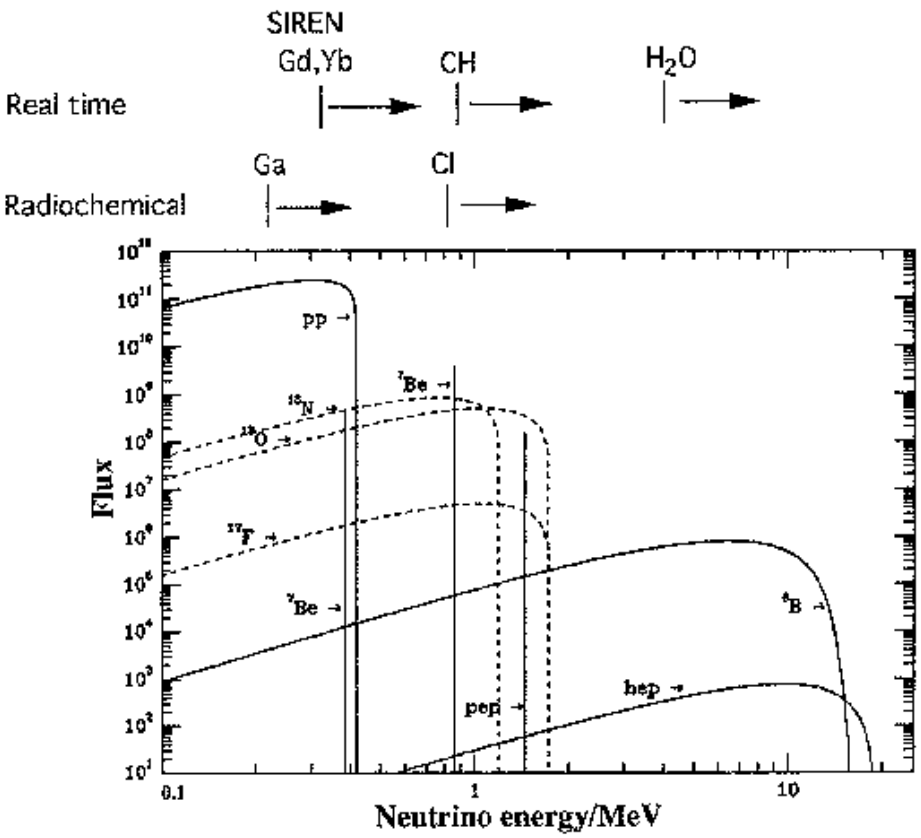
event numbers for supernova at 8 kpc

lead mass	scintillator area	no mixing		full mixing	
		1n	2n	1n	2n
250 t	16 m^2	100	2	600	140

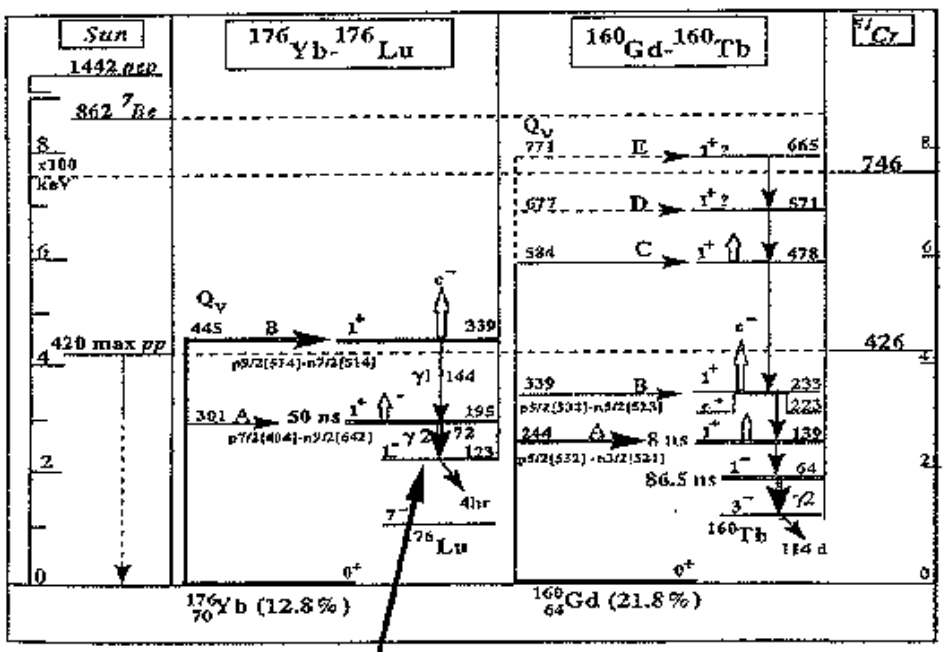
Solar neutrinos

Need for real time, sub-MeV, solar neutrino spectroscopy, to understand deficit in terms of oscillations

New SIREN experiment can provide this



Ragahavan (PRL 78,1997, 3618)
real time signature from nuclear excitatior
in rare earth targets



TYPICAL SIGNATURE

Prompt electron, measuring neutrino energy

↓

50 ns time delay

↓

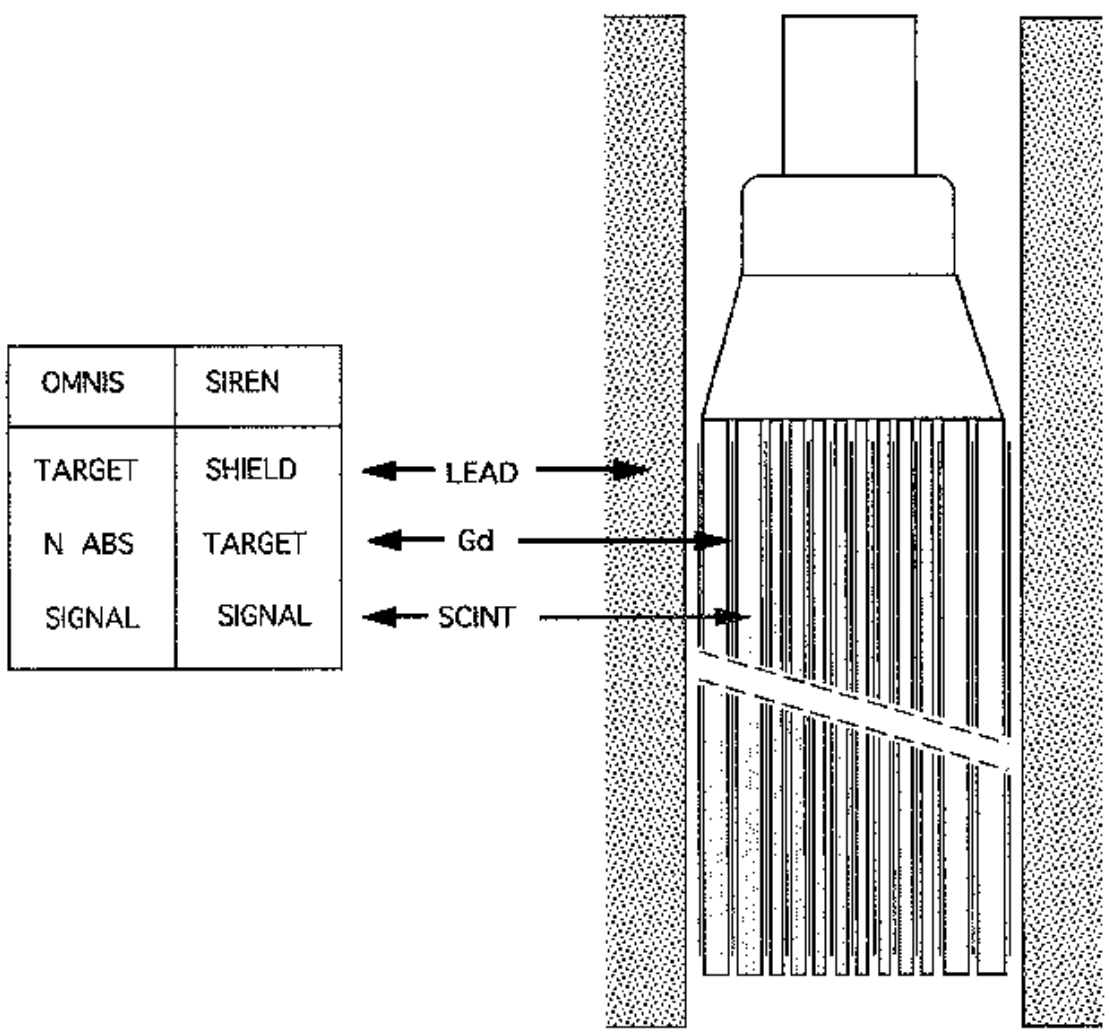
70 keV gamma

Combining SIREN with OMNIS

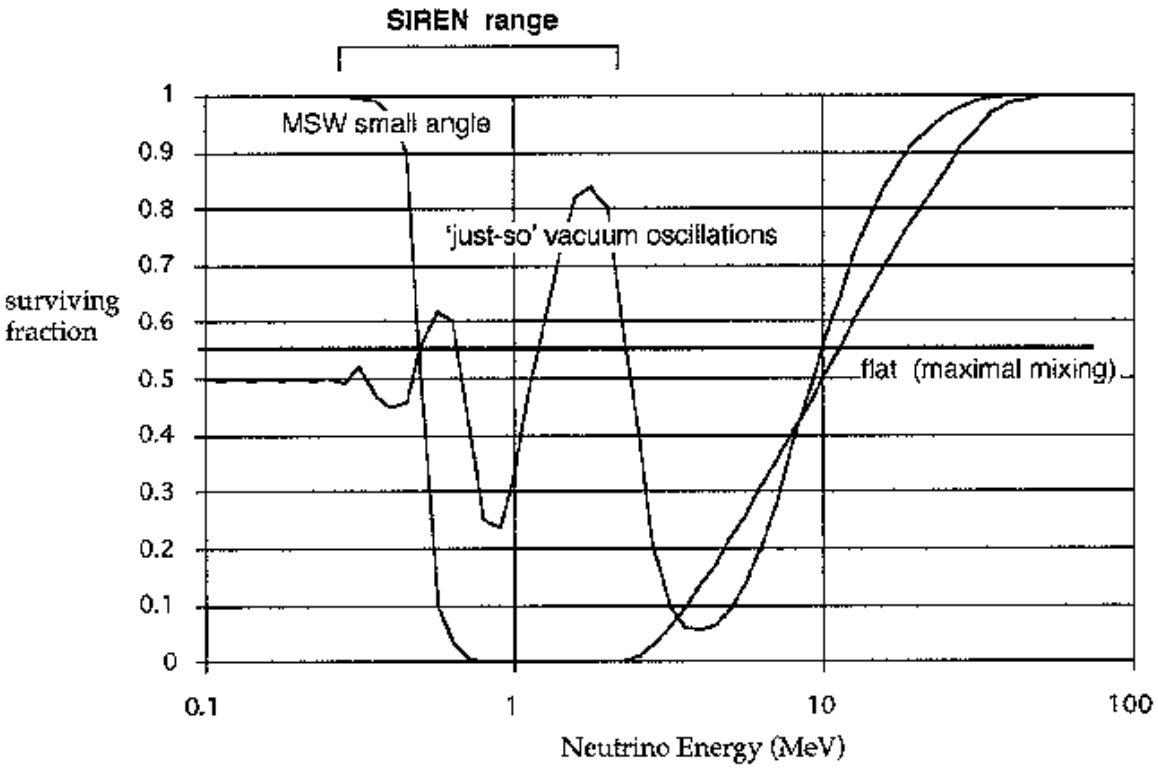
Advantages of combined project:

- New solar neutrino studies while running as OMNIS
- Most major components in common

OMNIS	SIREN
TARGET	SHIELD
N ABS	TARGET
SIGNAL	SIGNAL

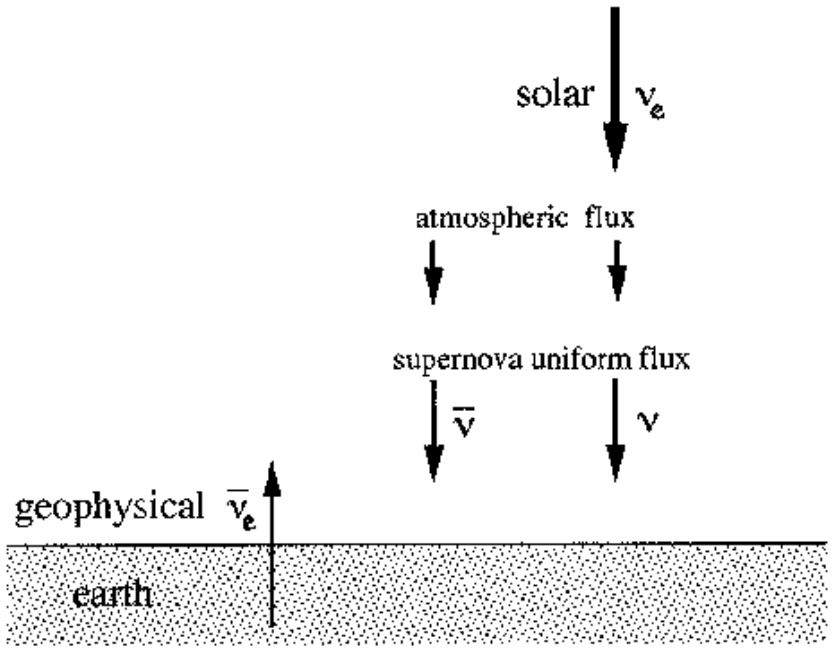


solar neutrino oscillation models



Integrated cosmic supernova flux

Total ~ 100/cm^2/s



① downward antineutrinos are above background in range 5-30 MeV } $\bar{\nu}_e$

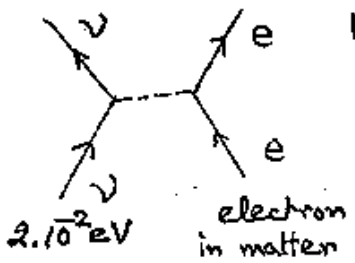
② Larger window for $\nu_\mu, \bar{\nu}_\mu, \nu_\tau, \bar{\nu}_\tau$.

RELIC NEUTRINOS

- decoupled at 1 MeV (t =1s), p now redshifted to 10^{-4} eV
- 300/cc expected for 3 flavours and antiparticles
- If m > 10eV and clustered in Galaxy, could be 10^7 /cc
- If $N(\nu) = N(\bar{\nu})$, effects $\sim G^2$ exist, but not $\sim G$
- active-sterile mixing could create $N(\nu) \neq N(\bar{\nu})$ giving effects $\sim G$

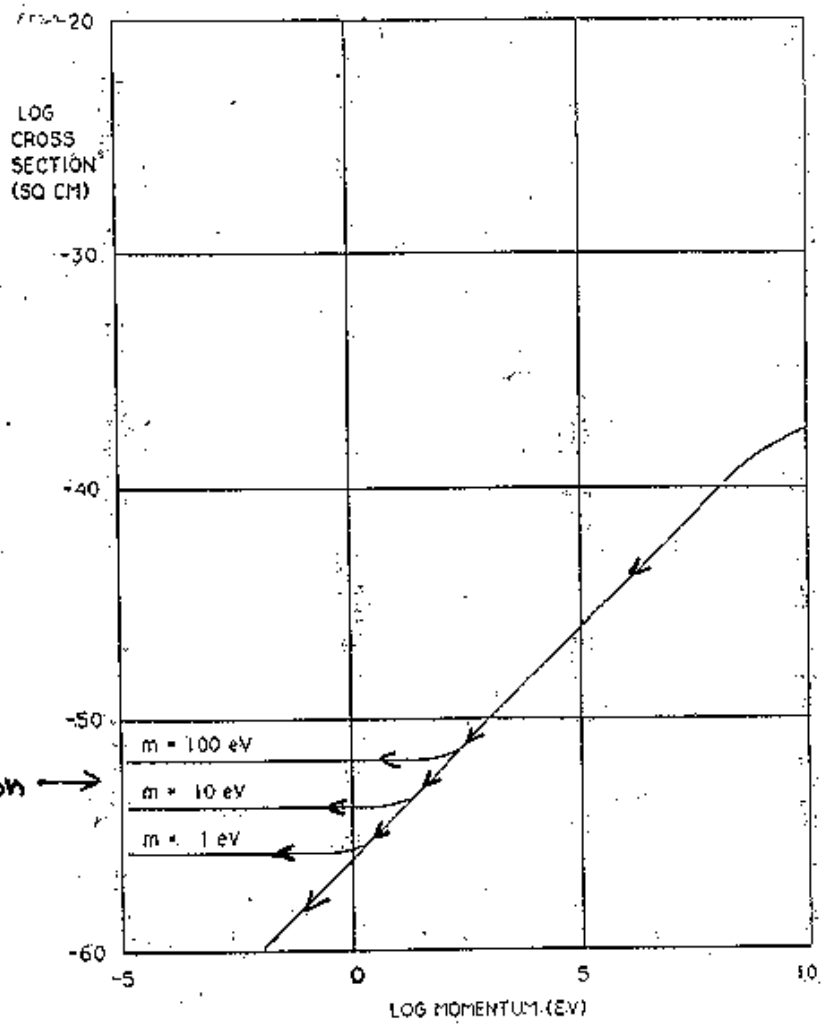
absolute numbers and particle-antiparticle differences are fundamental cosmological parameters, needing eventually to be measured. Can this be done ?

NEUTRINO ELASTIC SCATTERING

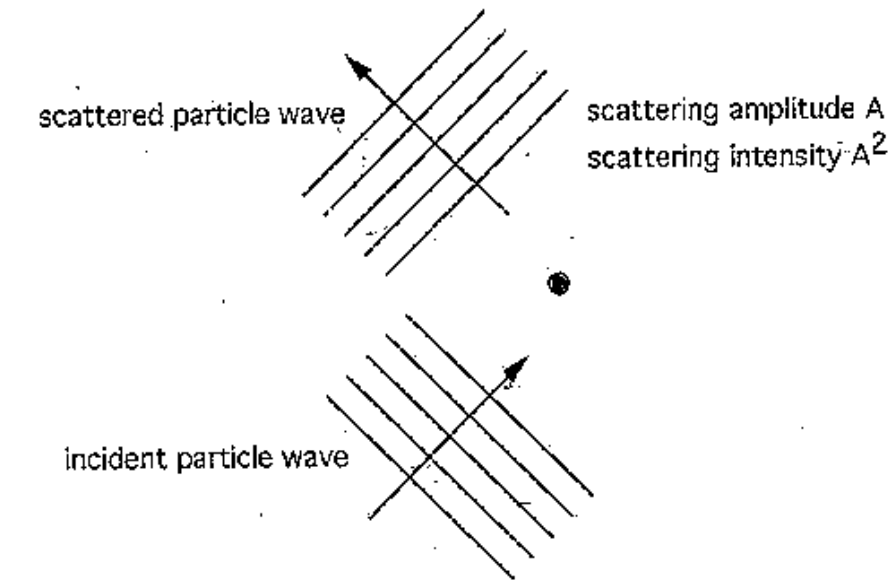


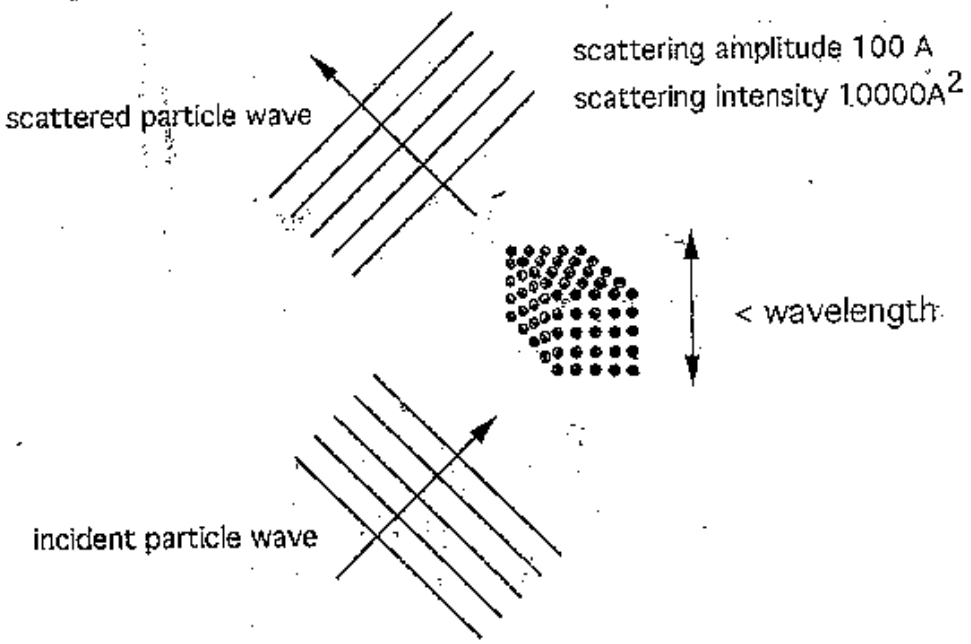
typical recoil energy 10^{-9}eV

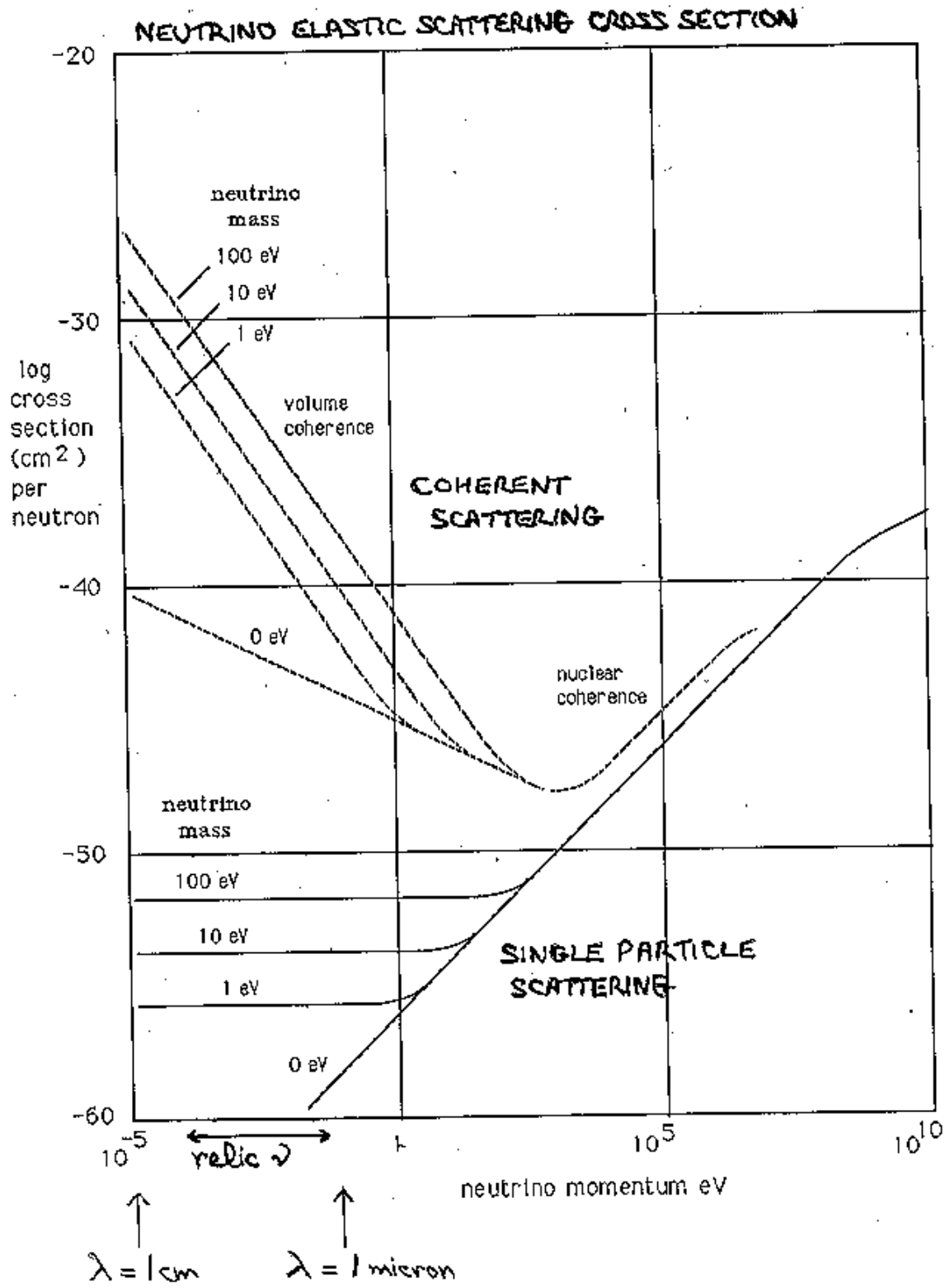
Rate 1/day/kton →



increased cross section through coherent scattering

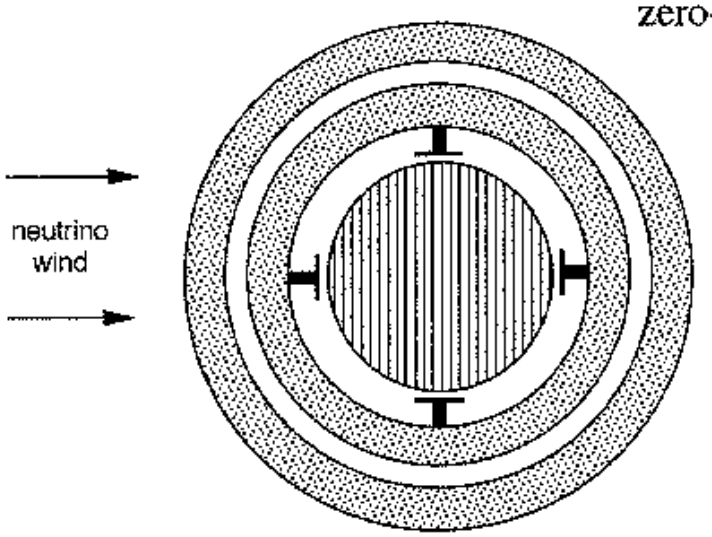





NEUTRINO ELASTIC SCATTERING CROSS SECTION
-20
-30
-40
-50
-60
log cross section (cm 2) per neutron
neutrino mass
100 eV
10 eV
1 eV
volume coherence
COHERENT SCATTERING
0 eV
nuclear coherence
neutrino mass
100 eV
10 eV
1 eV
0 eV
SINGLE PARTICLE SCATTERING
10^{-5}
relic ν
1
10^{5}
10^{10}
neutrino momentum eV
λ = 1 cm
λ = 1 micron

Coherent relic neutrino detectors

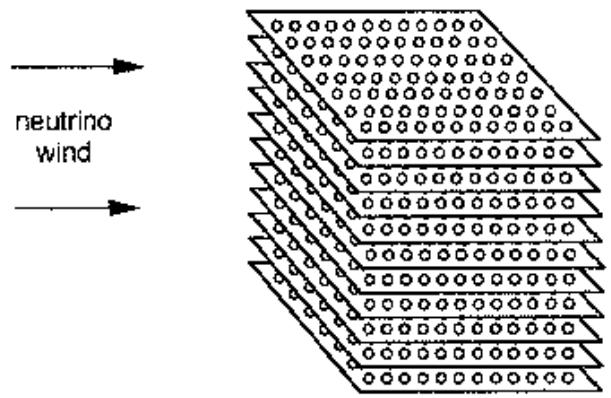
zero-gravity experiment



based on integrated coherent force

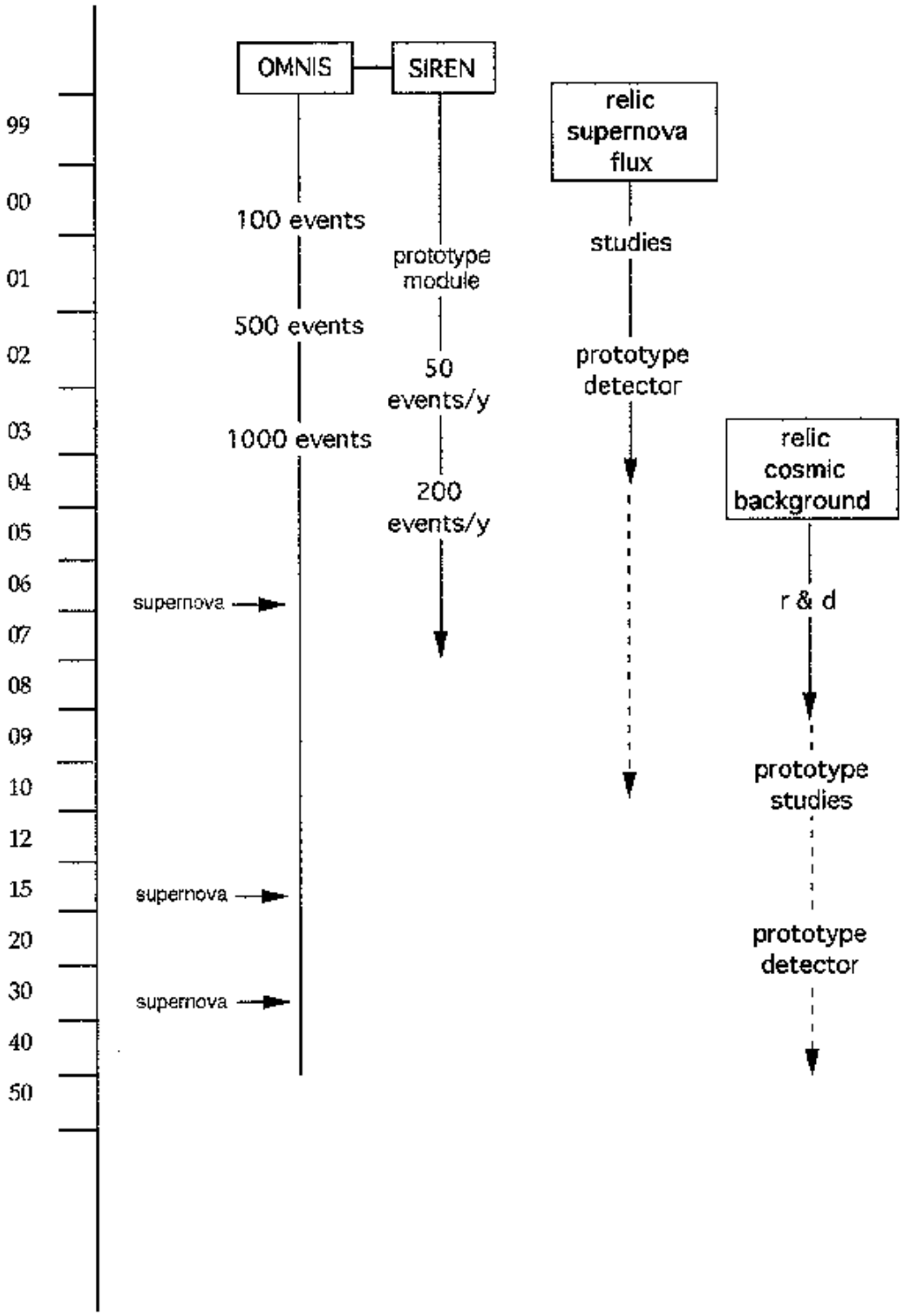
measures relative displacement of 1.0 ton laminated metal target over 4 hour periods

nano-target experiment



based on individual coherent collisions with sub-micron granules

detects discontinuous speed changes of single granules in levitated array

Both techniques can satisfy quantum measurement limit with appropriate choice of target size and mass

TIMESCALE FOR NEUTRINO ASTROPHYSICS AT BOULBY