Supernova and Neutrino Detector And Neutrino Oscillation Parameters

David B. Cline

Astrophysics Division

UCLA

1. General Properties of the Neutrino Burst Signal and Relic SN Neutrinos

2. General Detector Needs for the Neutrino Burst Observation and Neutrino Oscillation Study

3. Some Existing and Near Term Detectors
   - a. Super K
   - b. SNO
   - c. Kam Land/Borixino
   - d. LVD
   - e. ICARUS
   - Moon; AMANDA

4. Very Brief Comments on Some Possible New Detectors

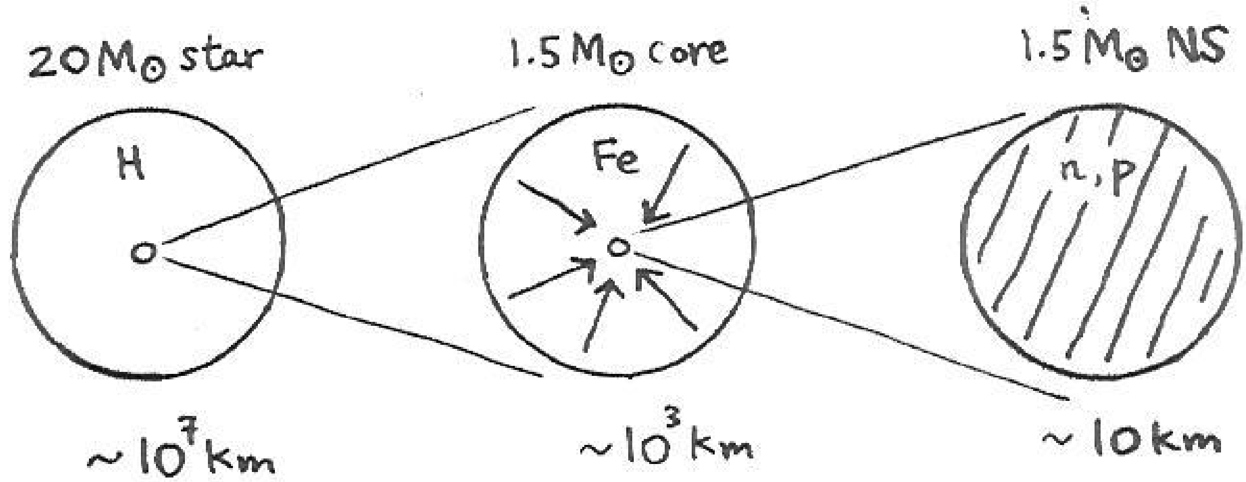
5. Detection of the Relic Neutrinos from Past SN: H_2O vs. Liquid Argon Detection

\- Summary –

NNN Conference
CERN - Jan. 16, 2002

A Burrows

Supernova: Core-Collapse



type-II SN : core collapse of an $M > 8M_\odot$ star

$$\Delta E_B \simeq \frac{GM_\odot^2}{R_{NS}} - \frac{GM_\odot^2}{R_{core}} \simeq \boxed{3\times10^{53}\text{ ergs}}$$

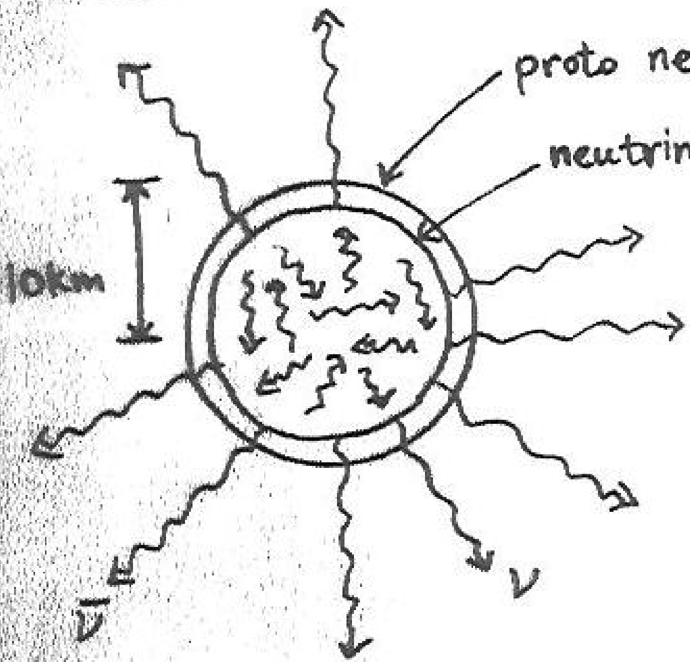
$$\simeq 2\times10^{59}\text{ MeV}$$

observations :

kinetic energy of explosion $\simeq 10^{-2}\cdot\Delta E_B$

electromagnetic radiation $\simeq 10^{-4}\cdot\Delta E_B$

Supernova: Energy Release



"cooling" by neutrino emission:

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

$$e^+ + e^- \longrightarrow \nu_e + \bar{\nu}_e,\ \nu_\mu + \bar{\nu}_\mu,\ \nu_\tau + \bar{\nu}_\tau$$

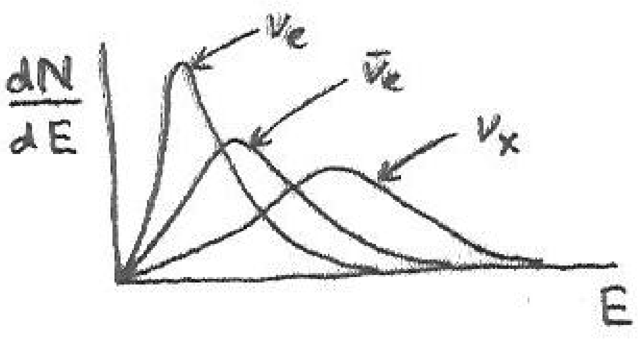
etc.

diffusion until $\lambda = 1/\rho\sigma$ from surface, then escape

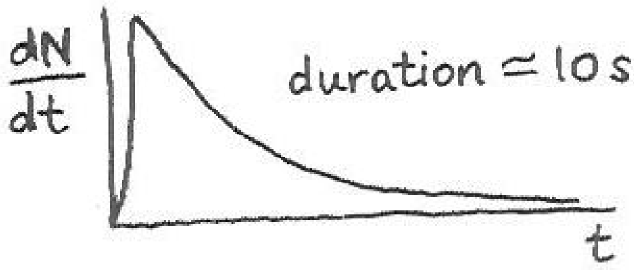
$$\langle E_{\nu_e} \rangle \simeq 11\ \text{MeV}$$

$$\langle E_{\bar{\nu}_e} \rangle \simeq 16\ \text{MeV}$$

$$\langle E_{\nu_x} \rangle \simeq 25\ \text{MeV}$$

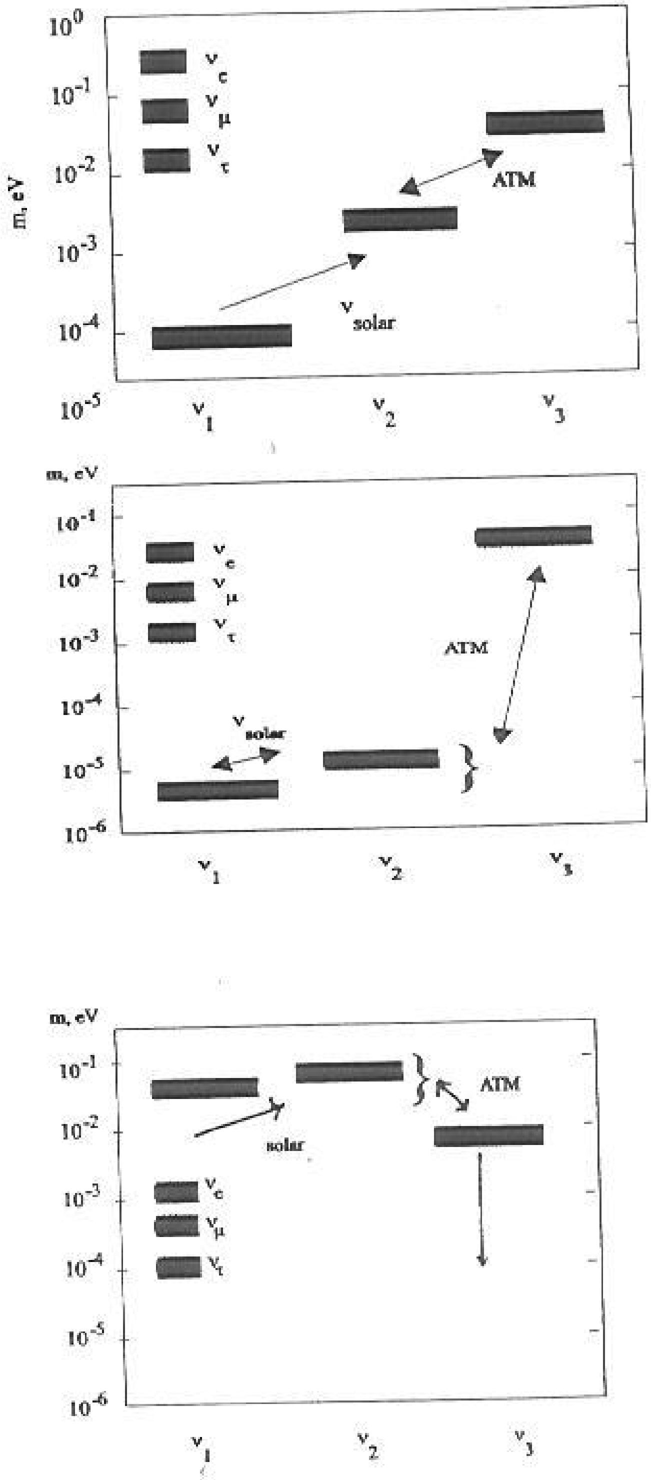


$$L_{\nu_e}(t) \simeq L_{\bar{\nu}_e}(t) \simeq L_{\nu_x}(t)$$



MSW effect in SN II

Mass has important effect inside SN
Spectrum



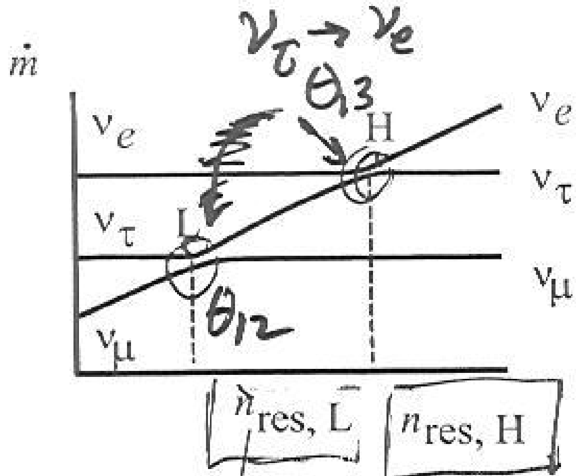
Dighe & Smirnov PRD, 62, 033007

Fuller Haxton

CAN SEPARATE THESE POSSIBILITIES IN NEXT SN II DETECTION

Inverted

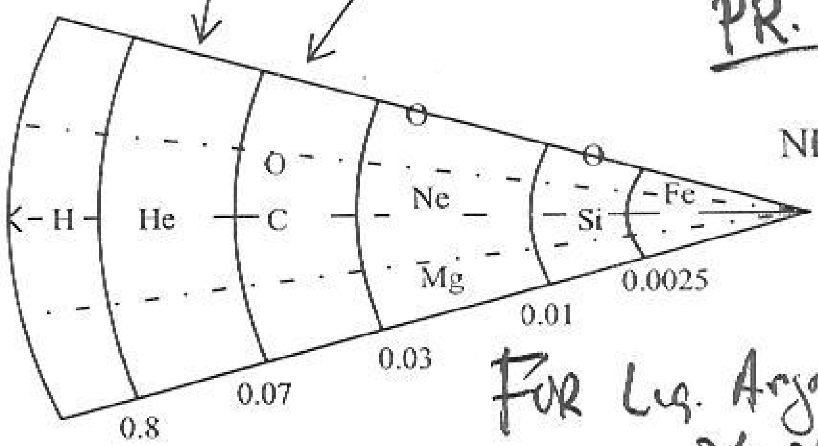
Fig. 2a, 2b, 2c. Different schemes for the Neutrino Mass spectrum adopted from Ref. 3



H Saito (U Tokyo)
UCLA
Meeting

Now Published
PR. 2001

(WOOSLEY & WECKER, 1995)



FOR Liq. Argon
$\nu_\mu, \nu_\tau \to \nu_e$

RESONANCE CONDTITION: $n_e = n_{res} = \frac{1}{2\sqrt{2}G_F} \frac{\Delta m^2}{E} \cos 2\theta$ θ_{12} θ_{13}

TWO RESONANCES (H at C+O shell, L at He shell)

Make Harder ν_e Spectrum

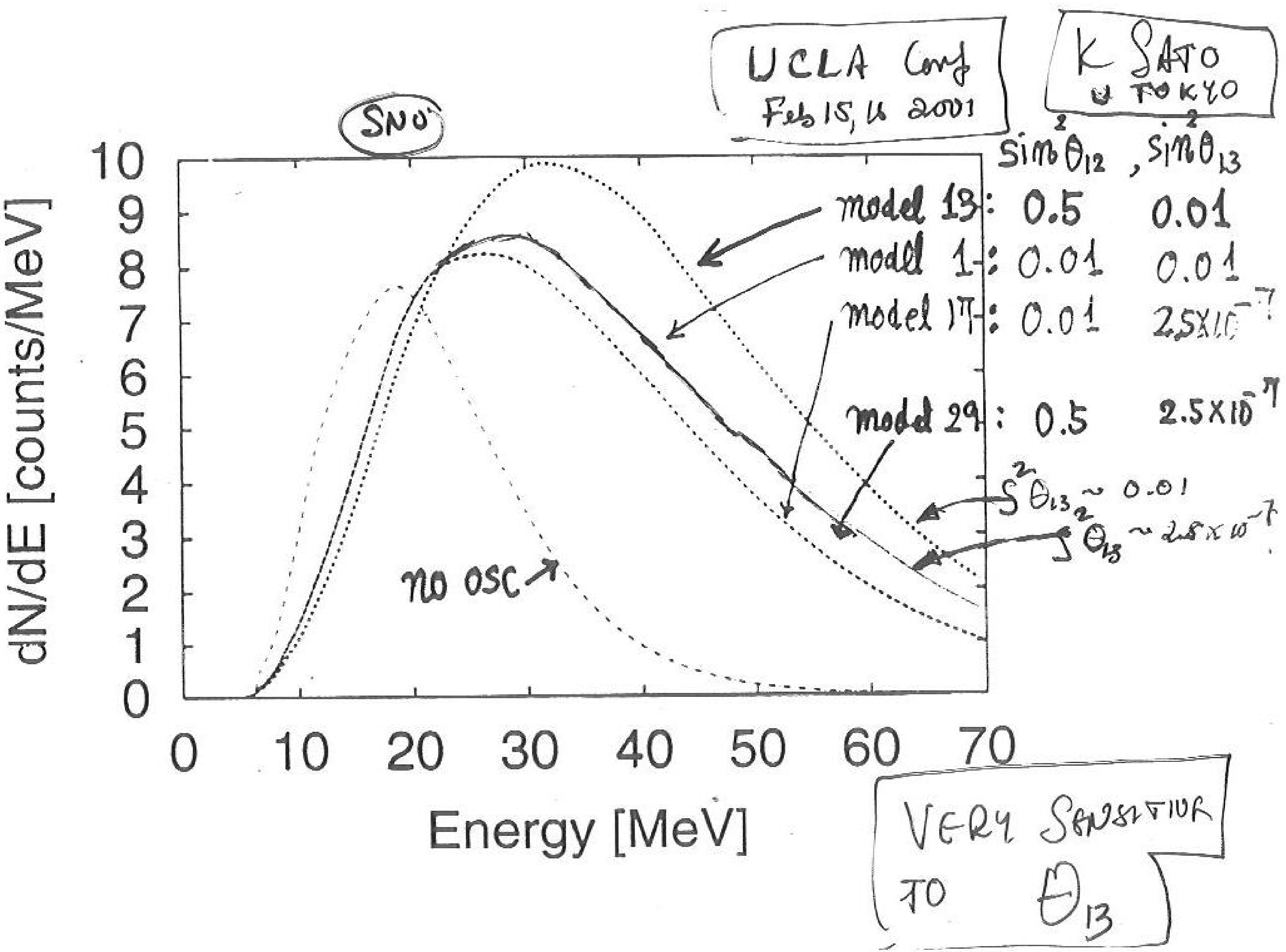
THEN

HOW ARE ν_e , ν_μ, ν_τ COVERTED EACH OTHER?
HOW ARE THE ENERGY SPECTRA DEFORMED?

PRECEDING WORKS:

DIGHE, SMIRNOV hep-pk/9907423

Measure Density Change in Side Exploding SNs in Real Time using Neutrino Osc.


UCLA Conf
Feb 15, 16 2001
K Sato
U Tokyo
SNO
$\sin^2\theta_{12}$, $\sin^2\theta_{13}$
model 13: 0.5 0.01
model 1: 0.01 0.01
model 17: 0.01 2.5×10^{-7}
model 29: 0.5 2.5×10^{-7}
$s^2\theta_{13} \sim 0.01$
$s^2\theta_{13} \sim 2.5\times10^{-7}$
no osc
dN/dE [counts/MeV]
Energy [MeV]
0
1
2
3
4
5
6
7
8
9
10
0
10
20
30
40
50
60
70
VERY SENSITIVE
TO θ_{13}

Relic SN Neutrinos

PBC Venice Talk

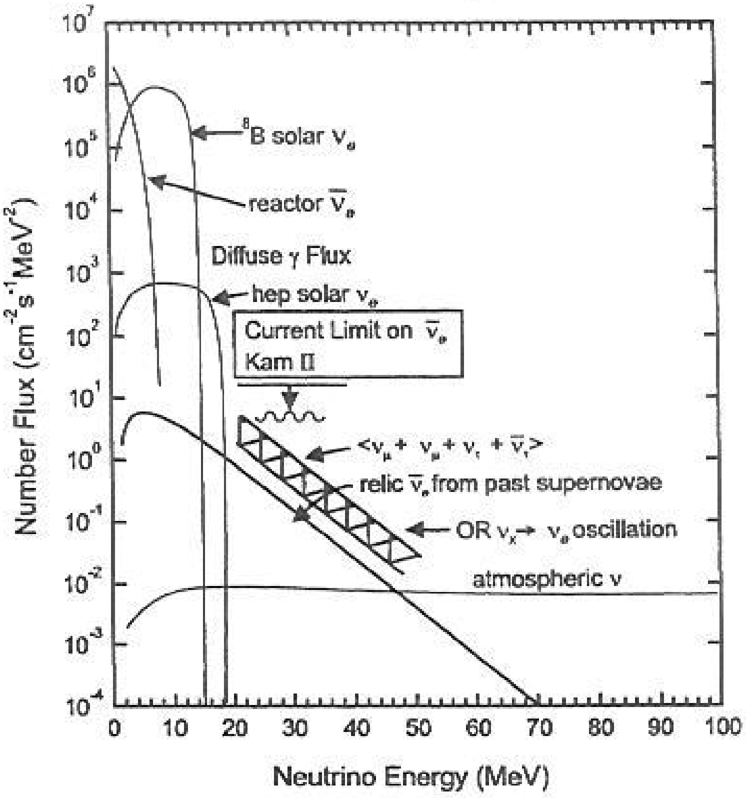


FIGURE 8. Relic neutrinos from past supernova. Note: $\nu_x \rightarrow \nu_e$ in the supernova can boost the energy of the ν_e if we find $<E\nu_e> > <E\bar{\nu}_e>$. This will be a signal for neutrino oscillation in supernovae! and measure $\sin^2 \theta x_e$. [1]

Table 3. Detection of $\nu/\bar{\nu}_e$ relic neutrino flux from time integrated SNII.

1. Relic $\nu/\bar{\nu}_e$ from all SNII back to Z ~ 5: $<E_\nu> \sim 1/(1+Z)<E_\nu>$
2. Detection would give integrated SNII rate from Universe
   - Window of detetion [D. Cline, ICARUS proposal, 1984]
3. Neutrino oscillations in SNII would give $\nu_x \rightarrow \nu_e$ with higher energy than $\bar{\nu}_e$
4. Detect $\bar{\nu}_e$ with SK or ICARUS. Attempt to detect ν_x/ν_e detection.

5. THE OMNIS DETECTOR CONCEPT AND OTHER SUPER NOVA NEUTRINO DETECTORS

Recently there has been real progress in supernova simulations giving an explosion. These calculations give

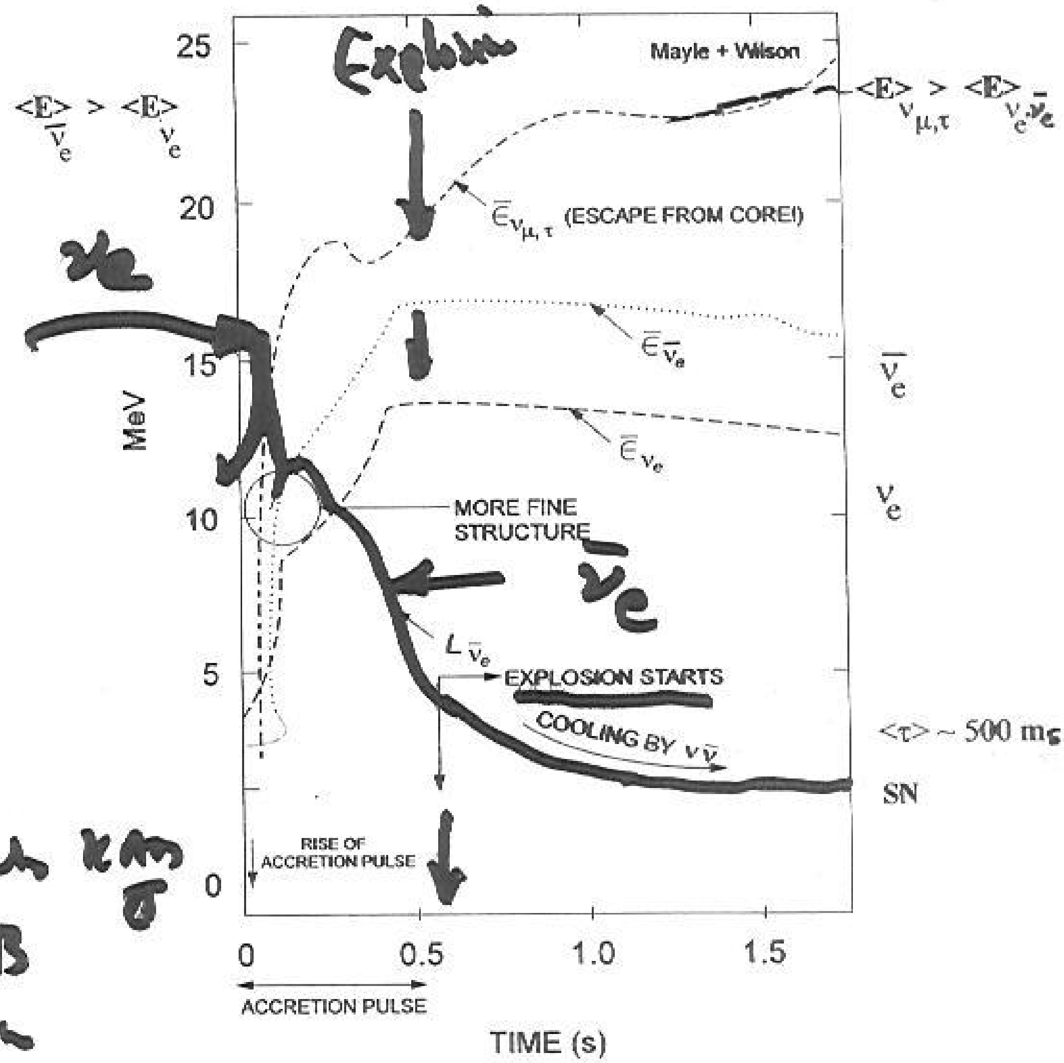
A Burrows

Features in Supernova Neutrino Signal

- "ν_μ" emission dominates (oscillation?) OMNIS !
- break-out flash of ν_e's (and sudden spectral change) (SNO ICARUS)
- slow (~20 ms) rise of $\bar{\nu}_e$'s (and ν_μ's)
- pulsations in L_ν Super K OMNIS LVD
- Drop in L's after "long-tem" explosion due to reversal of accretion: Mechanism!
- Post break-out rise in average neutrino energy
- Long-term decay of L_ν and ε_ν (in 10's of seconds)
- Black hole formation (abrupt turn-off)
- Signatures of hydrodynamic instabilities ("convection") + ROTATION!! → Soft $\nu_{\mu,\tau}$ Spectra
- CAN DISCRIMINATE DELAYED EXPLOSION FROM PROMPT !

General Features and SN 1987 A

Mayle + Wilson



SN 1987 A DATA

11 (12) Events Kam

8 IMB

5 Baksan

24 – 25 Events → ~ 1/2 of Events in First Sec

sharp rise in ν luminosity function $\lesssim 50$ ms

$\bar{E}_{\nu_\mu, \nu_\tau} > \bar{E}_{\nu_e}, \bar{E}_{\bar{\nu}_e}$

60 People

Physics Potential of Supernova II Neutrino Detection

Marina Beach Marriott
Marina del Rey, California
February 15 and 16, 2001

Thursday February 15: Registration (Sierra Ballroom)	**8:00 – 9:00am**
Session I: Supernova Dynamics; Chair: David Cline (Sierra Room)	**9:00am – 12:10pm**
R-Process Nucleosynthesis in Protoneutron Star Winds – Adam Burrows (Univ. of Arizona)	9:00
Structure of the SN1987A Ejecta – Lifan Wang (LBL)	9:25
LLNL SN explosion calculations – Comments from the Floor	9:50
Break	10:15-10:30
Chair: George Fuller	
Mass Ejection by Supernovae II: The Expected Role of 2-D and 3-D Simulations of Convection – Stirling Colgate (LANL)	10:30
Newton Plus: Approximate Relativity for Supernova Simulations – Christian Cardall (ORNL)	10:55
Neutrino Transport in Supernovae: Determining the Important Ingredients – Bronson Messer (Univ. of Tennessee)	11:20
Extracting Neutrino Properties and Explosion Mechanism Diagnostics from Realistic SN Neutrino Signals – Stephen W. Bruenn (Florida Atlantic Univ.)	11:45
Collective Neutrino Interactions with the Plasma Sphere in Type II Supernovae – Hans-Thomas Elze (Instituto de Fisica, Univ. Federal do Rio de Janeiro	12:10
Lunch (Palisades Room)	12:35– 1:35
Session II: Neutrino, Supernova and Nuclei Synthesis; Chair: Petr Vogel (Sierra Room)	**1:35 – 6:25pm**
Neutrino Masses and Mixings, Nucleosynthesis, and Dark Matter – G. Fuller (UC San Diego)	1:35
Spectra ~~Formation – G. Raffelt (Munich MPI)~~	2:00
Rocks, Stars, and Neutrinos– Yong-Zhong Qian (Univ. of Minnesota)	2:25
Effects of Neutrino Oscillation on the Supernova Neutrino Spectrum – K. Sato (Univ. of Tokyo)	2:50
Supernova Neutrino Oscillations: Nucleosynthesis and Detection – Gail McLaughlin (Stony Brook)	3:15
Break	3:40-3:55
Chair: A. Burrows	
Supernova Neutrinos – A Probe of Matter at Extreme Density – Sanjay Reddy (Univ. of Washington)	3:55
Sterile Neutrinos and Core-collapse Supernovae – A. Balantekin (Univ. of Wisconsin)	4:20
Doublet-Singlet Neutrino Transformation in Core-Collapse Supernovae – Mitesh Patel (UC San Diego)	4:45
Neutrinos and Heavy-Element Synthesis – Bradley S. Meyer (Clemson Univ.)	5:10
Value of the Cosmological Constant: Theory Versus Experiment – Moshe Carmeli and Tanya Kuzmenko (Ben Gurion Univ.)	5:35
Nonlinear and Collective Effects in Neutrino Transport in Supernovae II plasmas – Luis O. Silva (IST/UCLA)	6:00
Reception and Conference Dinner (Promenade Room)	**6:30pm**
Special Discussion of a possible So. Cal. Underground Laboratory – H. Sobel (UCI)	8:00-9:00pm

SN II Explosion

Heavy Element Synthesis

Friday February 16: Coffee (Venice Room)	7:00 – 8:00am
Session III: Neutrino Signal ; Chair: Georg Raffelt (Venice Room)	**8:00-10:00**
Earth Matter Effects on Supernova Neutrinos – Cecilia Lunardini (Trieste)	8:00
Is the 1987A Kam. Data Consistent with the LMA Solar Neutrino Solution? – David B. Cline (UCLA)	8:20
Supernova Neutrino Physics – J. Beacom (FNAL)	8:40
Neutrino Oscillation and Supernova Signal – R. Schirato (UC San Diego/LANL)	9:00
Sterile Neutrino Dark Matter – Kev Abazajian (UC San Diego)	9:20
Using Extra Dimensions to Fit Solar Data and Implications for Supernovae – David Caldwell (SLAC)	9:40
Break	10:00-10:20
Session IVa: Experiments, Detectors, Underground Facilities; Chair: N. Smith (Venice)	**10:20-12:00**
Physics Opportunities at ORLaND Relevant to Supernova Detectors – F. Avignone (Univ. of South Carolina/ORNL)	10:20
MiniBooNE - A Definitive Test of the LSND Oscillation Results – W. Louis (LANL)	10:40
Work on OMNIS in the UK – Peter Smith (RAL)	11:00
OMNIS U.S. Program – R. Boyd (OSU)	11:20
OMNIS R & D – Kevin Lee (UCLA)	11:40
Lunch (Peninsula Room)	12:00– 1:00
Session IVb: Experiments, Detectors, Underground Facilities; Chair: Tim Sumner (Venice)	**1:00-4:35**
Solar Neutrinos with ICARUS Detector – InesGil Botella (ETH/CERN)	1:00
Super K – M. Vagins (UC Irvine)	1:20
Supernova Detection with KamLAND – Petr Vogel (Caltech)	1:40
Supernova Trigger and Analysis with SNO – Réda Tafirout (Laurentian Univ.)	2:00
The LVD Experiment in Italy – F. Fulgione (INFN)	2:20
MOON (Molybdenum Observatory of Neutrinos) for Supernova Neutrino Detection – Hiroyasu Ejiri (RCNP, Osaka Univ.)	2:40
Break	3:00-3:20
Chair: K. Arisaka	
Neutrino Detection Using Lead Perchlorate – S. R. Elliott et al (Univ. of Washington)	3:20
Design of a Modular Multipurpose Neutrino Detector for the Homestake Laboratory – Alfred Mann (Univ. of Pennsylvania)	3:40
Facilities and Experiments at the UK Boulby Mine – N. Smith (RAL)	4:00
Comments on the Carlsbad Underground Site – David B. Cline (UCLA)	4:20
Session V: Worldwide SN Watch; Chair: A.K. Mann (Venice)	**4:35-5:35**
SN Watch – M. Vagins (UC Irvine)	4:35
SNEWS Status – Kate Scholberg (MIT)	4:55
LIGO – B. Barish (Caltech)	5:15

Neutrino Mass Effects

Supernova Type II ν Detectors

World Wide SN Watch

To ~~be~~ published on the Web

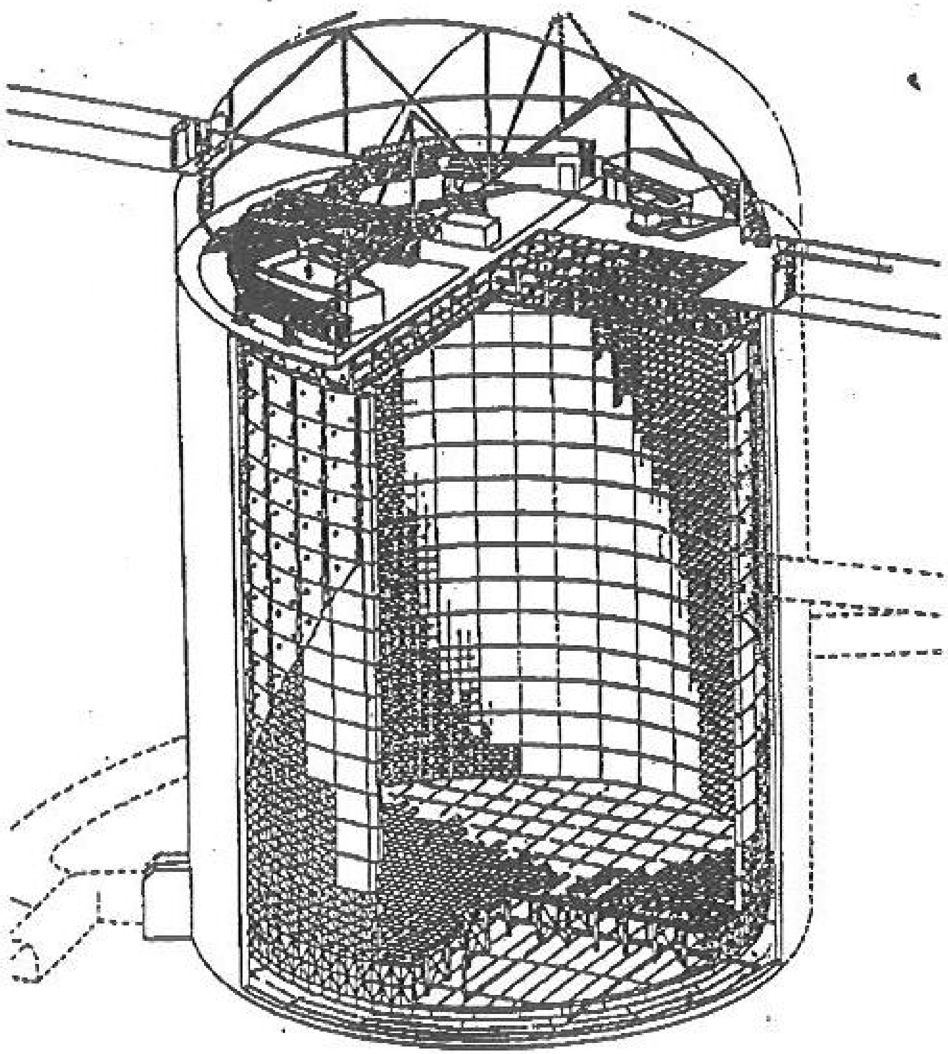


FIG. 17. The Super-Kamiokande detector. The inner water Cherenkov detector of 32,000 ton is surrounded by a 4π water Cherenkov outer-detector (anti-counter). The total weight of the detector is 50,000 tons, the height is 42 meters and the diameter is 39 meters.

Super K (MDK my)

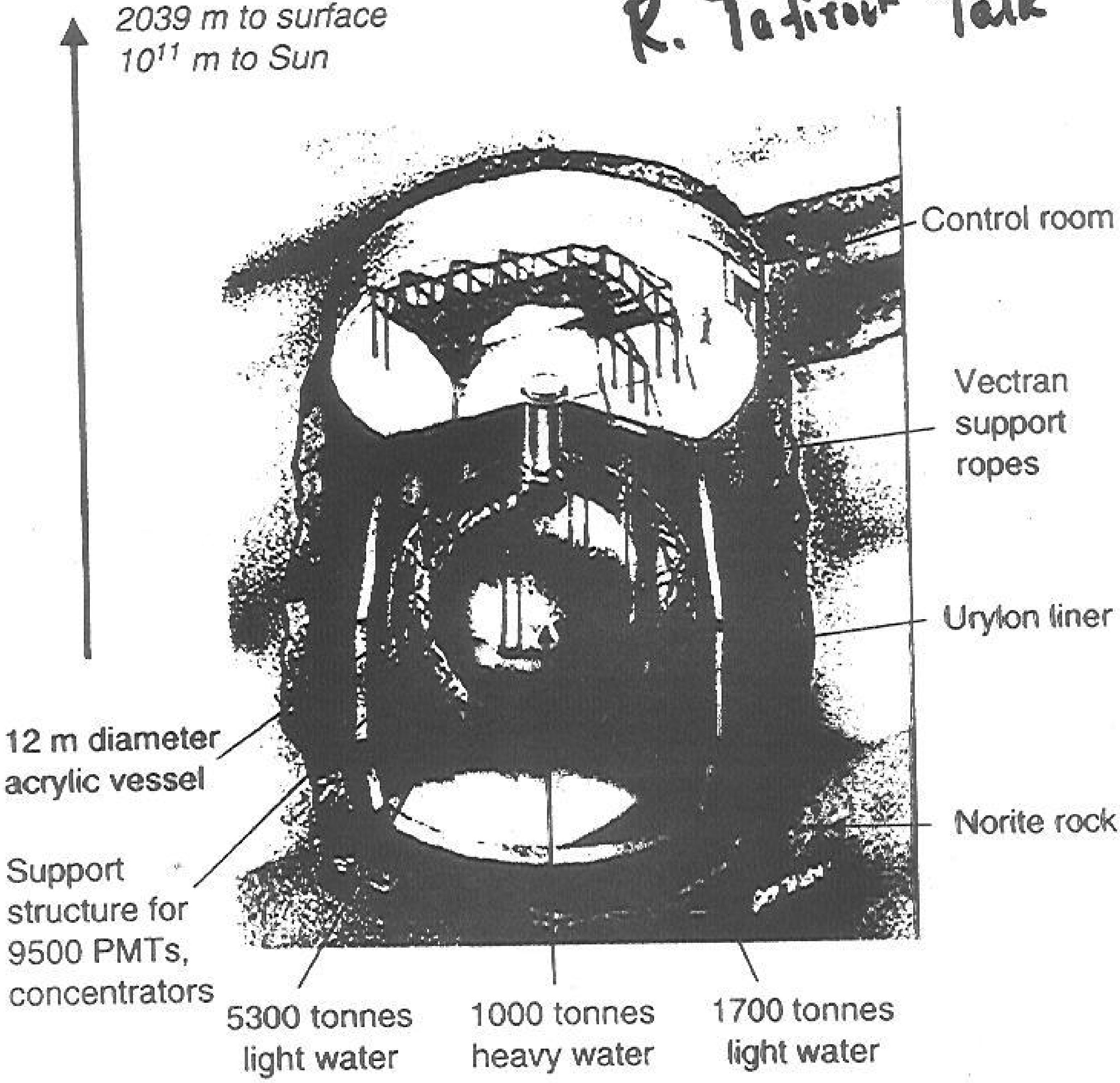
TABLE I. Calculated numbers of events expected in SK with a 5 MeV threshold and a supernova at 10 kpc. The other parameters (e.g., neutrino spectrum temperatures) are given in the text. In rows with two reactions listed, the number of events is the total for both. The second row is a subset of the first row that is an irreducible background to the reactions in the third and fourth rows.

Reaction			No. of events
$\bar{\nu}_e + p \rightarrow e^+ + n$	detected particle:	e^+	8300
$\bar{\nu}_e + p \rightarrow e^+ + n$ ($E_{e^+} \leq 10$ MeV)		e^+	530
$\nu_\mu + {}^{16}O \rightarrow \nu_\mu + \gamma + X$ $\bar{\nu}_\mu + {}^{16}O \rightarrow \bar{\nu}_\mu + \gamma + X$	Neutral Current Modes	γ	355
$\nu_\tau + {}^{16}O \rightarrow \nu_\tau + \gamma + X$ $\bar{\nu}_\tau + {}^{16}O \rightarrow \bar{\nu}_\tau + \gamma + X$		γ	355
$\nu_e + e^- \rightarrow \nu_e + e^-$ $\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$		e^-	200
$\nu_\mu + e^- \rightarrow \nu_\mu + e^-$ $\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-$		e^-	60
$\nu_\tau + e^- \rightarrow \nu_\tau + e^-$ $\bar{\nu}_\tau + e^- \rightarrow \bar{\nu}_\tau + e^-$		e^-	60

However - when Super K is Rebuilt it is not clear that the sensitivity directionality to all of these modes will be the same

The SNO Detector

R. Tafirout Talk

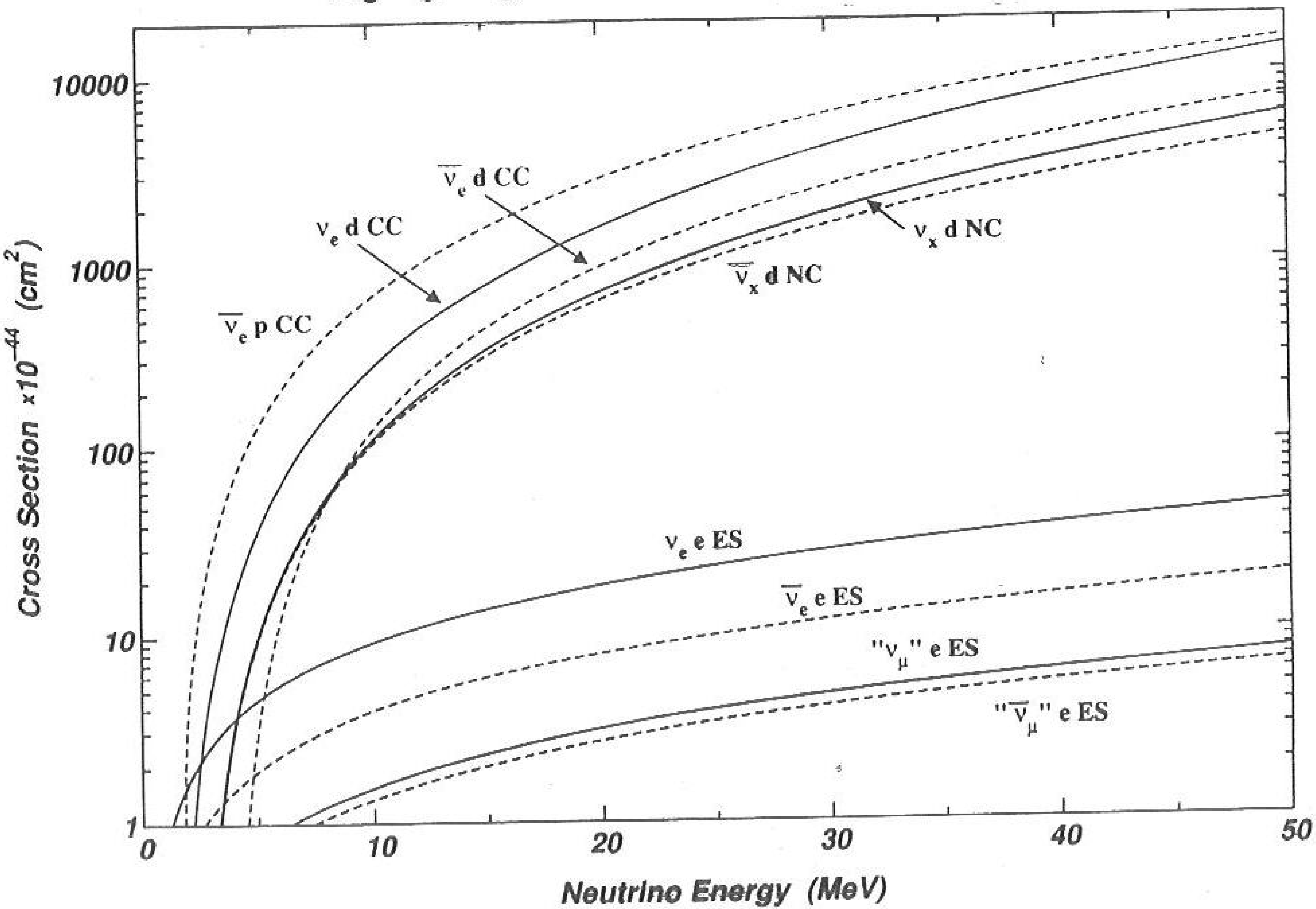


- **Location:** 6800 ft. level of INCO's Creighton mine near Sudbury, ON, Canada (~70 muons / day)
- **SNO Detector:** $9438_{inward} + 91_{outward}$ Hamamatsu 8" PMTs + concentrators = 64% coverage

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

Supernova Neutrino Cross Sections

Highlighting the dominant supernova interactions



Supernova Detection Simulation

Simulation Ingredients:

(Very Detailed Calculations)

1. SNO energy threshold set to ~2 MeV
2. Use detected particle counts from 100 supernova bursts (in the case of the NCDs, expect ε = 45% [NCD] + 12% [D_2O])

Number of Particles From 10 kpc Supernova:

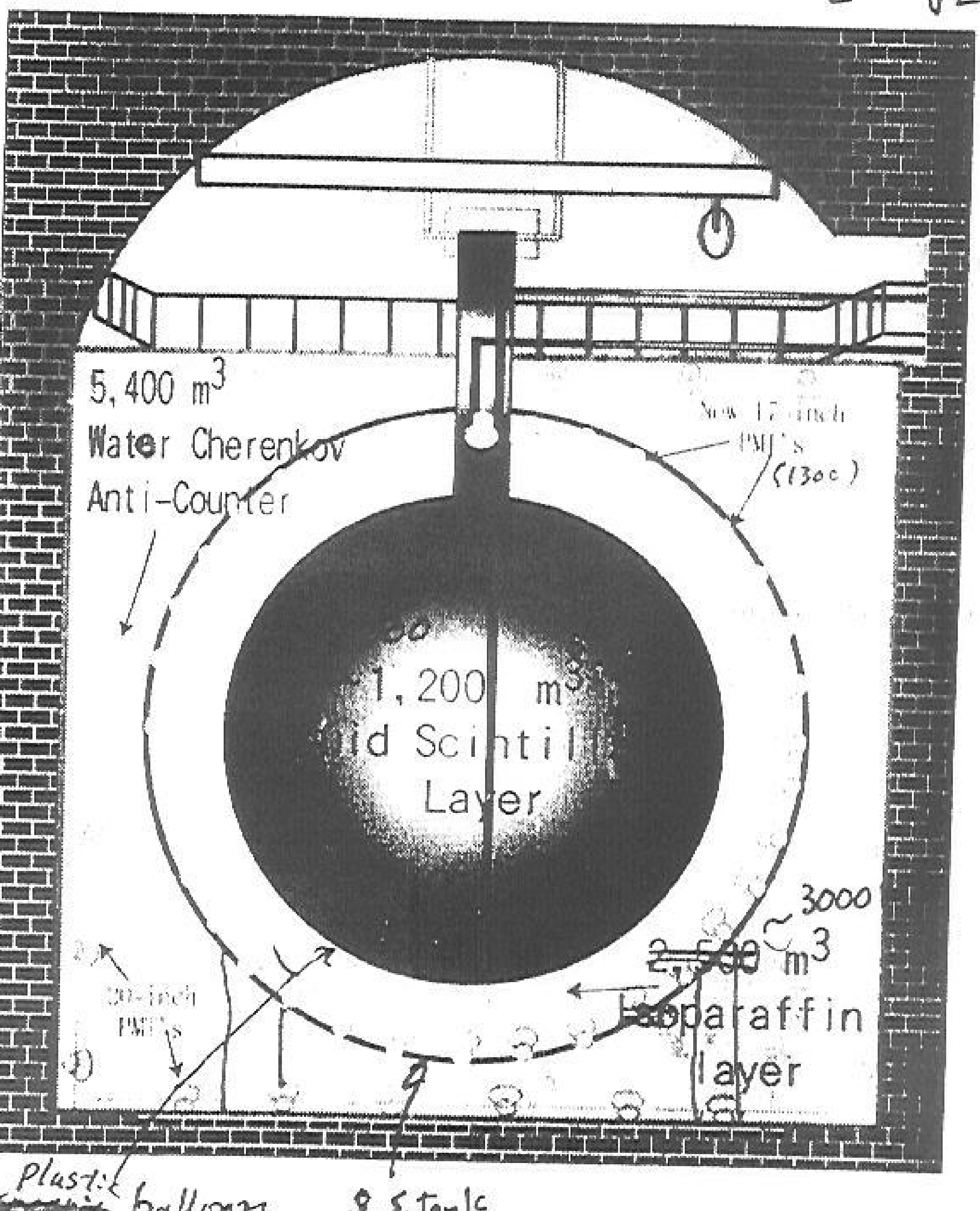
Neutrino Reaction	Type	SNO Counts [ε = 100%]	SNO Counts [monte carlo]
$\bar{\nu}_e + p_{H_2O} \rightarrow n + e^+$	CC	356	331
$\bar{\nu}_e + p_{D_2O} \rightarrow n + e^+$	CC	0.2	
$\bar{\nu}_e + p_{AV} \rightarrow n + e^+$	CC	5	
$\nu_e + d \rightarrow p + p + e^-$	CC	83	72
$\bar{\nu}_e + d \rightarrow n + n + e^+$	CC	53 (× 3)*	82 [D_2O] 138 [salt] 90 [NCD]*
$\nu_e + {}^{16}O \rightarrow {}^{16}F + e^-$	CC	1	
$\bar{\nu}_e + {}^{16}O \rightarrow {}^{16}N + e^+$	CC	3	
$\nu_e + d \rightarrow \nu_e + p + n$	NC	36	12 [D_2O] 30 [salt] 20 [NCD]*
$\bar{\nu}_e + d \rightarrow \bar{\nu}_e + p + n$	NC	36	12 [D_2O] 32 [salt] 21 [NCD]*
"ν_μ" + d → "ν_μ" + p + n	NC	192	60 [D_2O] 164 [salt] 110 [NCD]*
"ν_μ" + ^{16}O → (n, γ, n + γ)	NC	7	
$\nu_e + e^- \rightarrow \nu_e + e^-$	ES	26	20
$\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$	ES	9	8
"ν_μ" + e^- → "ν_μ" + e^-	ES	12	9
TOTAL SNO SN COUNTS:		917	606 [D_2O] 804 [salt] 681 [NCD]

Petr Vogel

KamLAND Detector

Kamioka
Liquid scintillator
Anti - Neutrino
Detector

$\frac{\Delta E}{E} \leq \frac{0.1}{\sqrt{E(M}}$



Supernova neutrino signals at Kamland

1) Electron antineutrinos $\bar{\nu}_e$ detected by
$\bar{\nu}_e + p \rightarrow e^+ + n$

2) All neutrinos detected by the charged and neutral current reactions on ^{12}C, leading to the $T, I^\pi = 1, 1^+$ triad. In particular the neutral current excitation of the 15.1 MeV state in ^{12}C, dominated by the ν_x flux. (Possible only with liquid scintillator)

3) All neutrinos detected through the elastic scattering on protons,
$\nu + p \rightarrow \nu + p$ and $\bar{\nu} + p \rightarrow \bar{\nu} + p$;
with detection of the spectrum of recoil protons. (Possible only due to the very low threshold).

Event rates

1) $\bar{\nu}_e + p \rightarrow e^+ + n$: 330 events, (300 ev. > 10 MeV)

2) ν^{12}C: ~ 10 events (CC), ~ 60 events (NC). However, with oscillations ~ 20 - 40 CC events.

~730 events

3) $\nu + p \rightarrow \nu + p$: 300 events above 150 keV

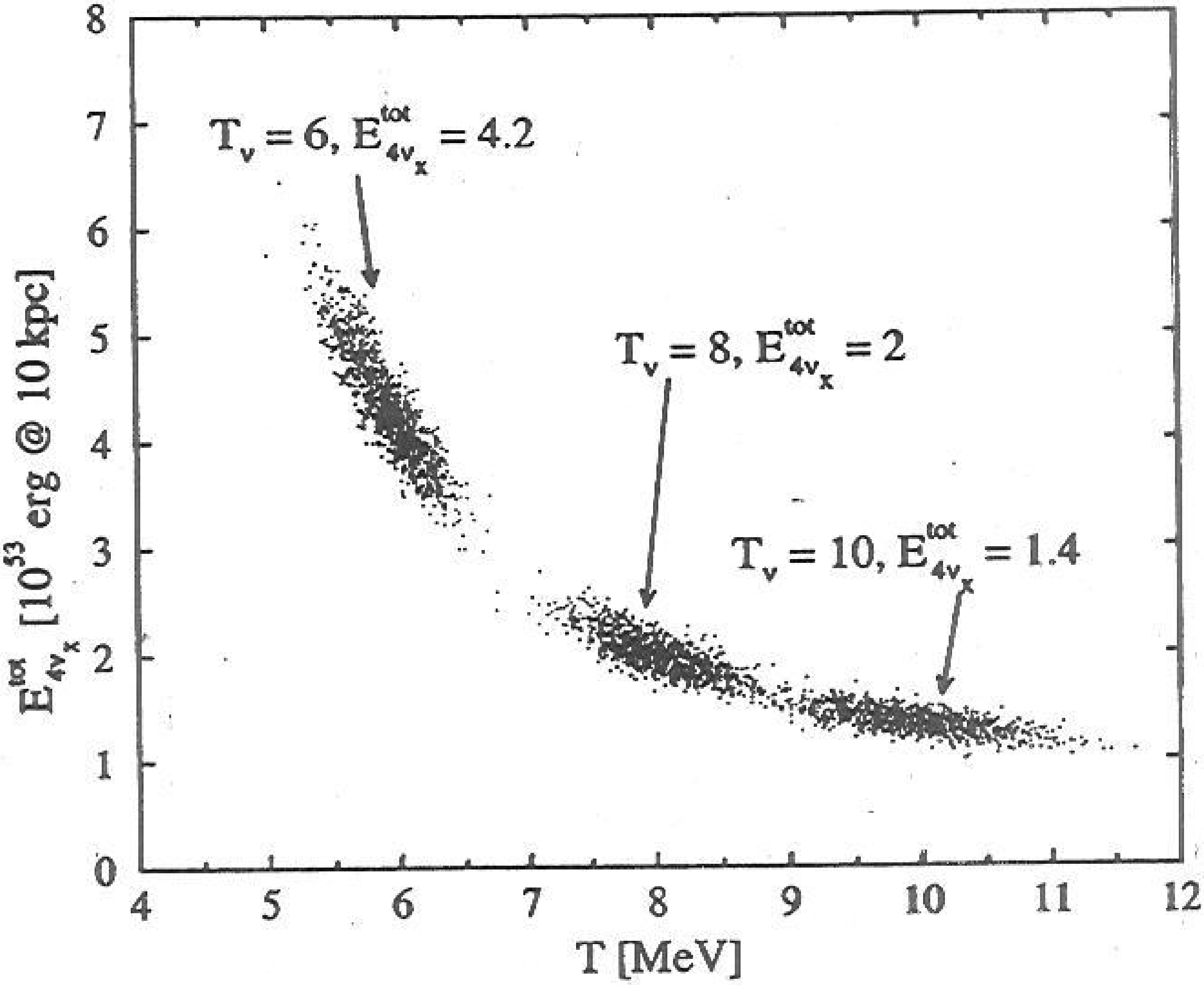
BoREXINO ASTRO. PART. PHYSICS 16, 361 (2002)

Total Events ~ 110 for Galactic SN

Elastic Scatter

$\nu + p \rightarrow \nu + p$

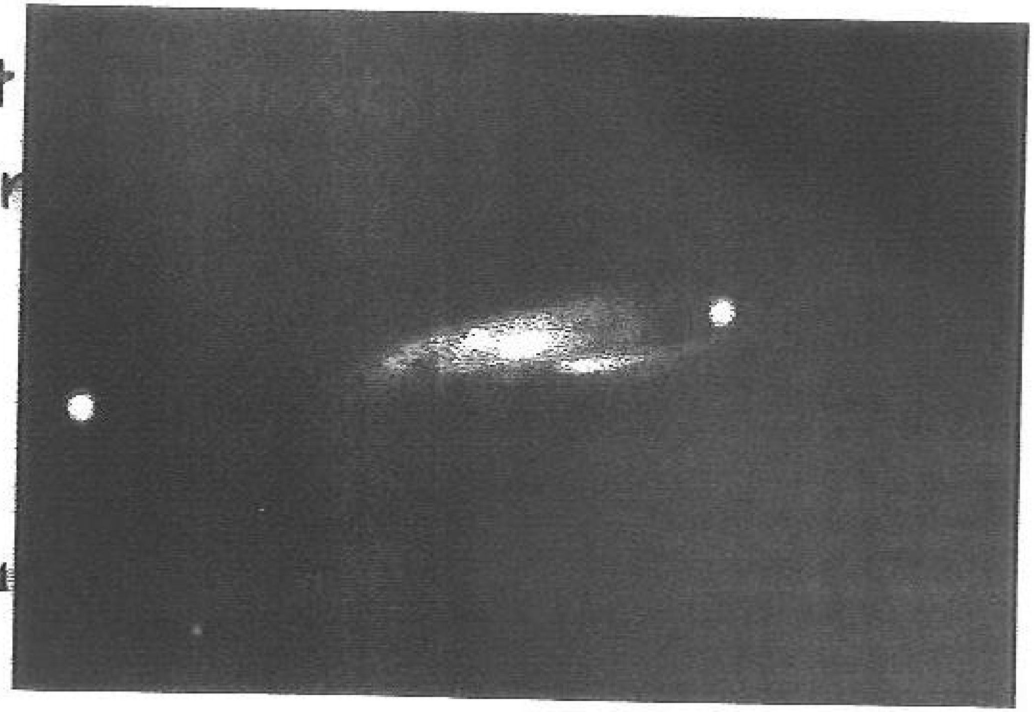
Recoil P energy



Large Volume Detector

LVD

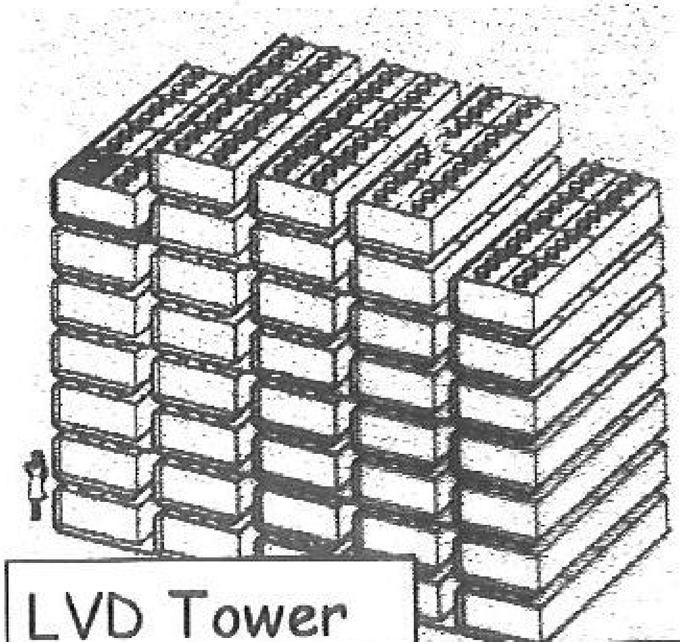
To detect neutrino burst
galactic Super



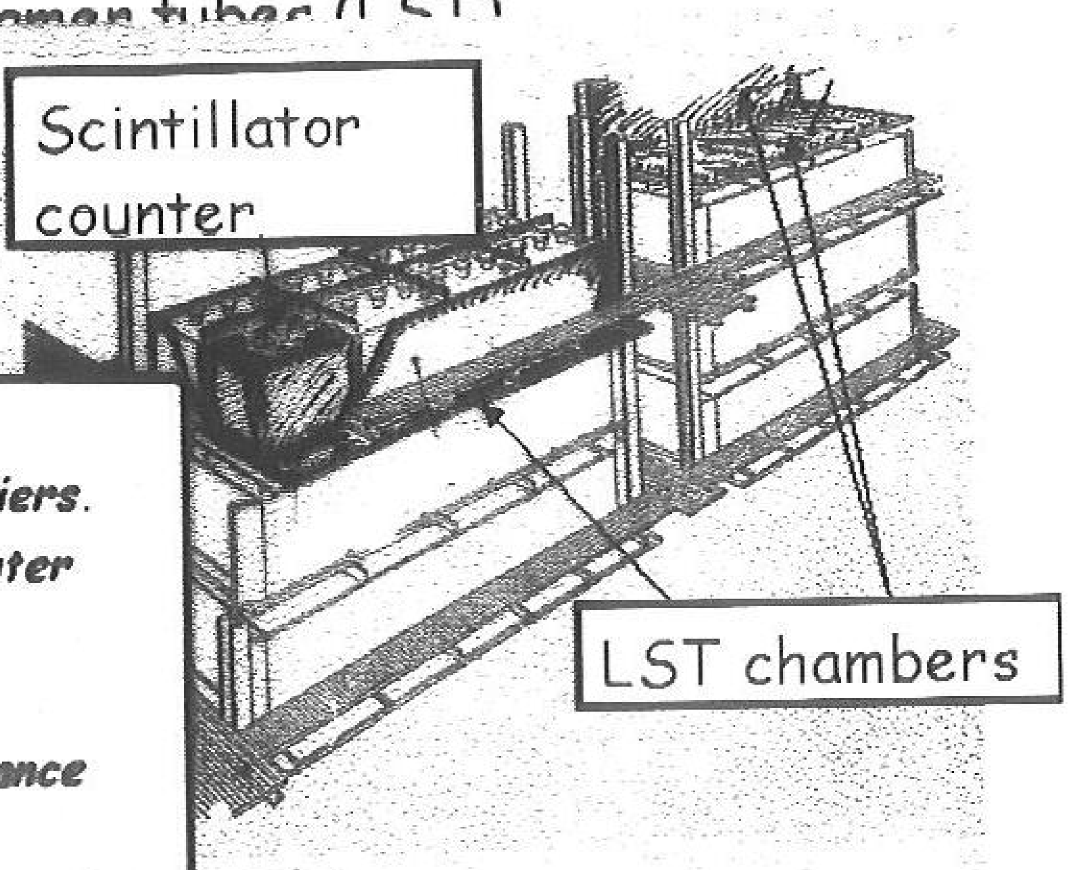
University of Bologna and INFN-Bologna, Italy
Brown University, Providence, USA
University of Campinas, Campinas, Brazil
INFN-LNF, Frascati, Italy
INFN-LNGS, Assergi, Italy
University of Houston, Houston, USA
Indiana University, Bloomington, USA
Massachusetts Institute of Technology, Cambridge, USA
Institute for Nuclear Research, Russian Academy of Sciences, Moscow, Russia
Okayama University, Okayama, Japan
Okayama University of Science, Okayama, Japan
Hirosaki University, Hirosaki, Japan
Ashikaga Institute of Technology, Ashikaga, Japan
Institute of Cosmo-Geophysics, CNR, Torino, University of Torino and INFN-Torino, Italy

Spokesperson: A. Zichichi

The detector



Three towers of liquid scintillator counters interleaved with limited streamer tubes (LST)



Total active mass 1 kton

840 scint. Counters, 2520 photomultipliers.

E threshold: 4 MeV (core) - 7 MeV (outer counters)

15% energy resolution @ 10 MeV

L-shaped module for LST (high acceptance for nearly horizontal tracks)

Bi-dimensional read-out made by 4 cm strips

Angular resolution ≤ 4 mrad

LVD

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

$$n + p \rightarrow d + \gamma$$

$E\gamma = 2.2\ MeV; \quad \tau = 185\ \mu s$

- during a 1 ms period after a high energy threshold trigger, a low energy threshold is enabled allowing n-capture tagging
- the average counting rate per counter for E > 1 MeV is 140 Hz

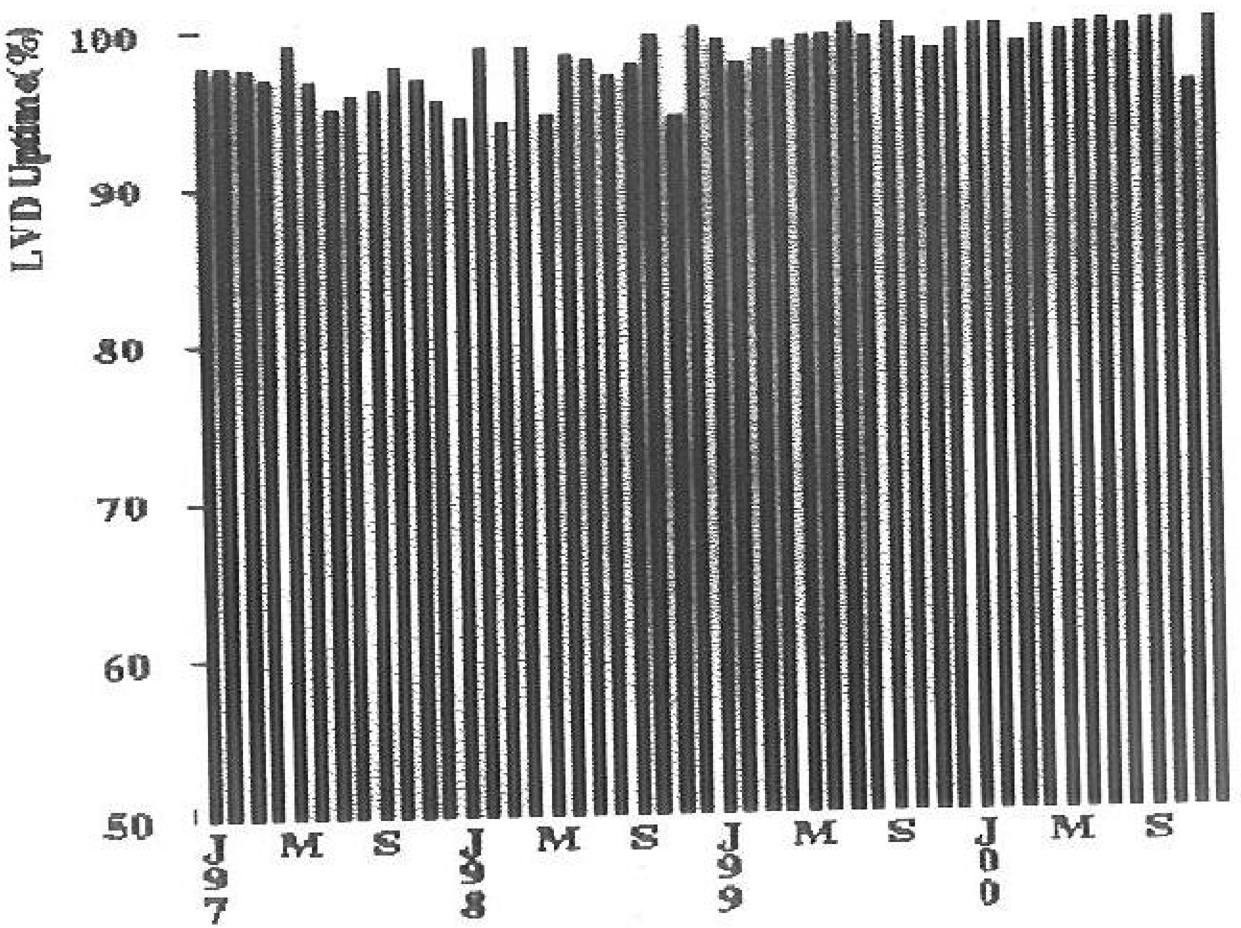
Counters	Internal [570 ton]	External [430 ton]
High E threshold	4 MeV	7 MeV
Low E threshold	0.6 MeV	1.2 MeV
n-detection efficiency	60%	40%
Low th. bk counting rate	60 Hz	250 Hz
$\bar{\nu}_e$ (p,n) e^+ s/n ratio	>15	>2.5

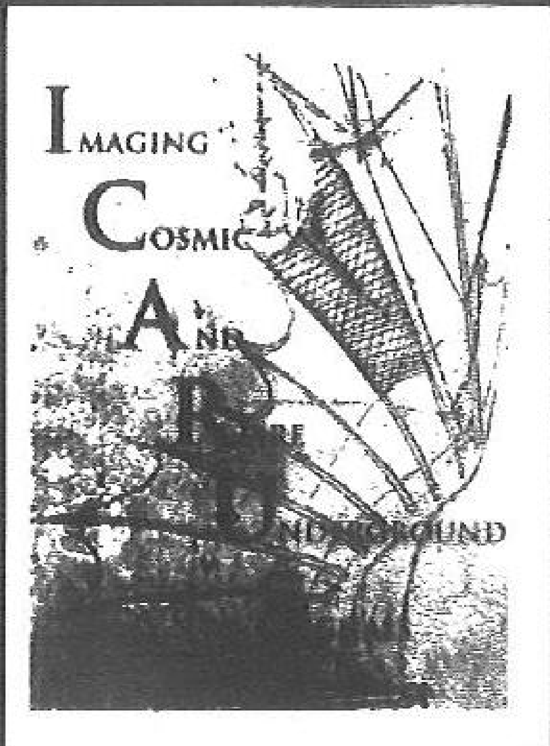
Expected Rate for Galactic SN: 540

Similar to KAMLAND

Search for SN burst

High duty cycle > 99% since 1999





The ICARUS Project

CERN

China
IHEP

Italy
Aquila, LNGS, Milano, Padova, Pavia, Pisa, Torino

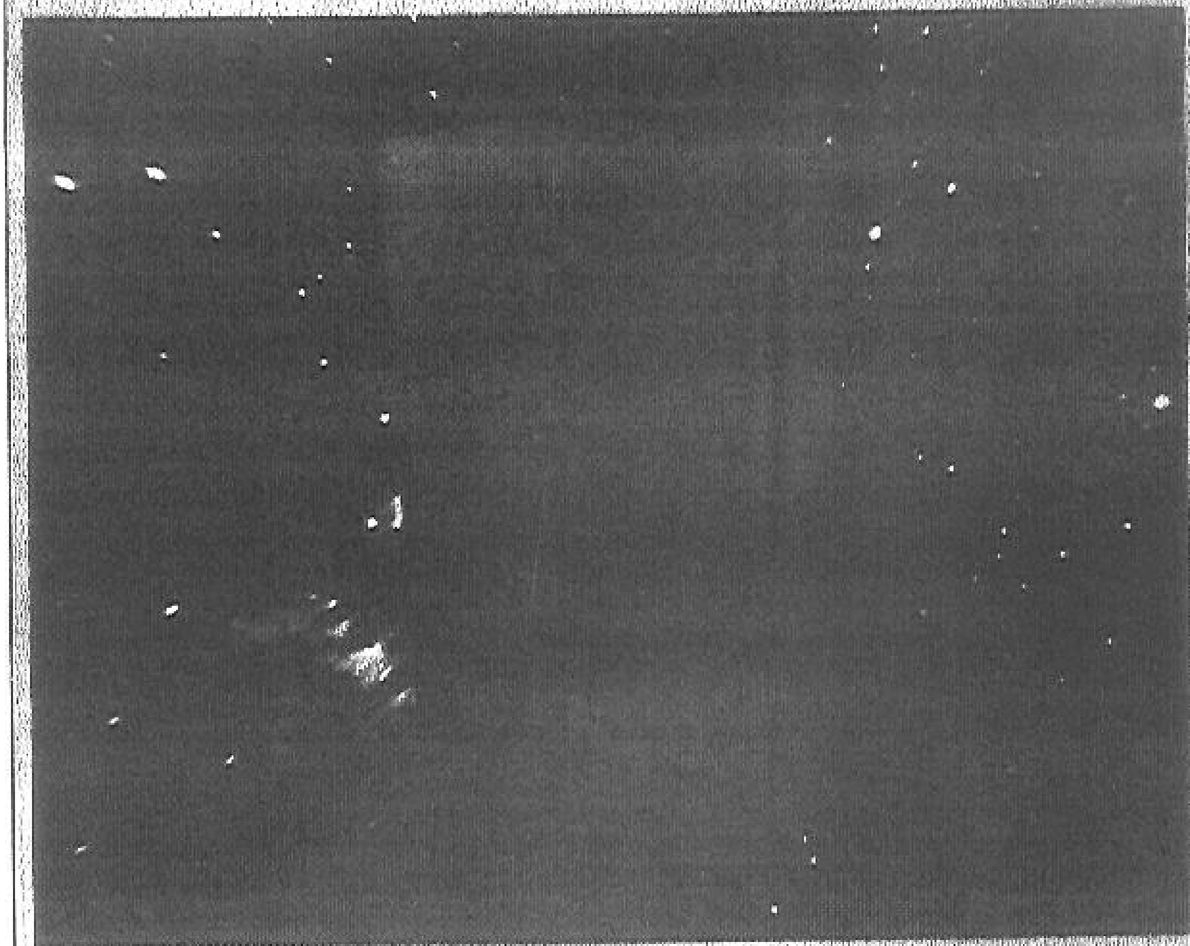
Switzerland
ETH/Zurich

Poland
Katowice, Krakow, Warszawa, Wroclaw

USA
UCLA

LNGS Laboratori Nazionali del Gran Sasso
CERN European Laboratory for Particle Physics

LNGS-EXP 13/89 add. 2/01
ICARUS-TM/2001-09
November 26, 2001



A Second-Generation Proton Decay Experiment and Neutrino Observatory at the Gran Sasso Laboratory

By the ICARUS Collaboration

ICARUS T600 module

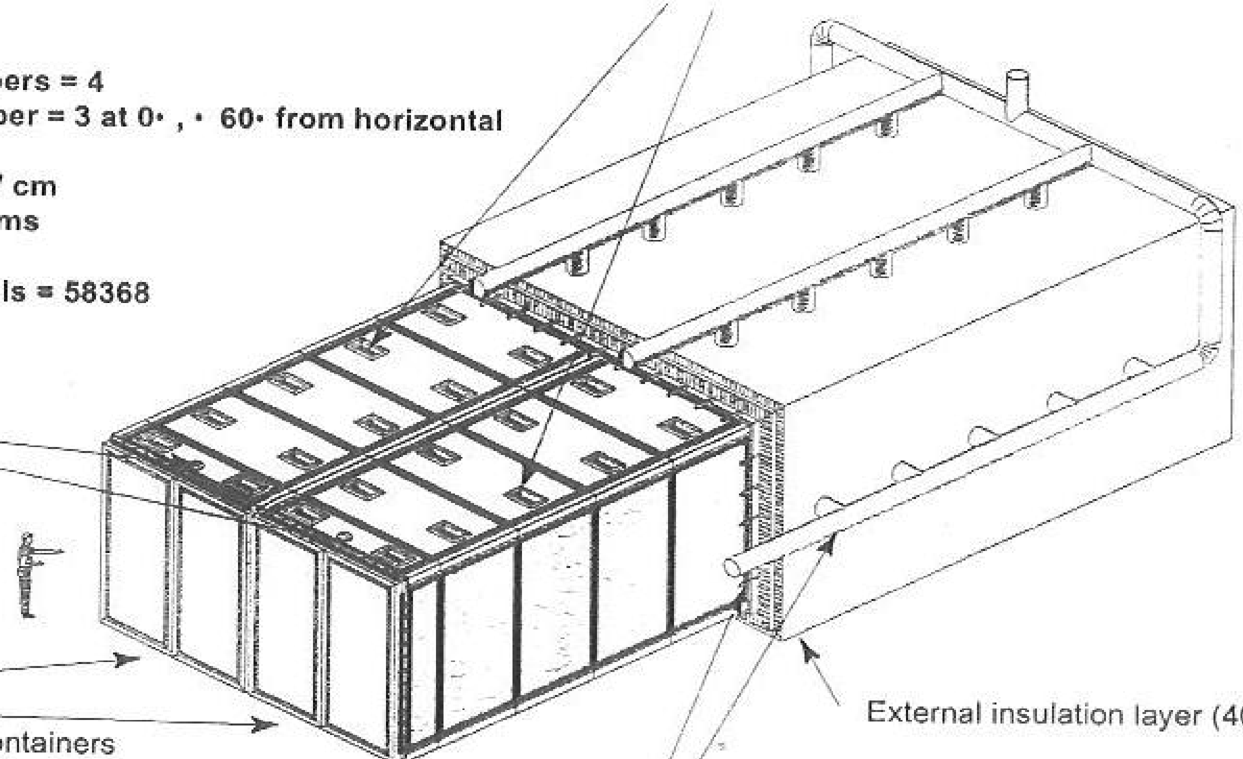
Under construction ← operation At PAVIA

Number of independent containers = 2
Single container Internal Dimensions: Length = 19.6 m , Width = 3.9 m , Height = 4.2 m
Total (cold) Internal Volume = 534 m^3
Sensitive LAr mass = 476 ton

Number of wires chambers = 4
Readout planes / chamber = 3 at 0° , ± 60° from horizontal
Maximum drift = 1.5 m
Operating field = 500 V / cm
Maximum drift time ≈ 1 ms
Wires pitch = 3 mm
Total number of channels = 58368

Signal feedthroughs

HV feedthroughs

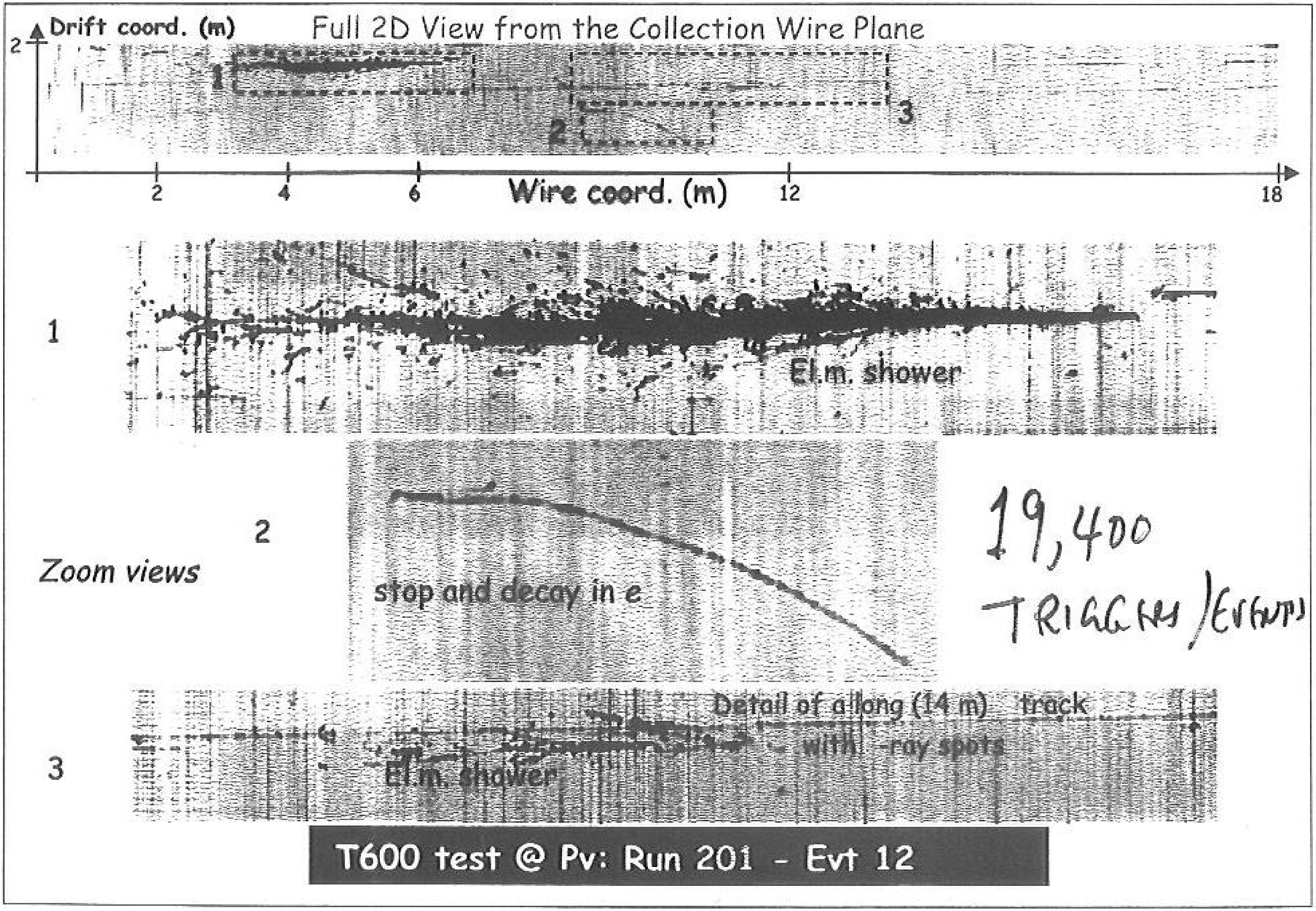


External insulation layer (400 mm)

2 independent aluminum containers each one transportable inside the GS Laboratory

LN2 cooling circuit

DATA TAKING ON 300T
IN PAVIA – JUNE/JULY 2001



19,400
TRIGGERS / EVENTS

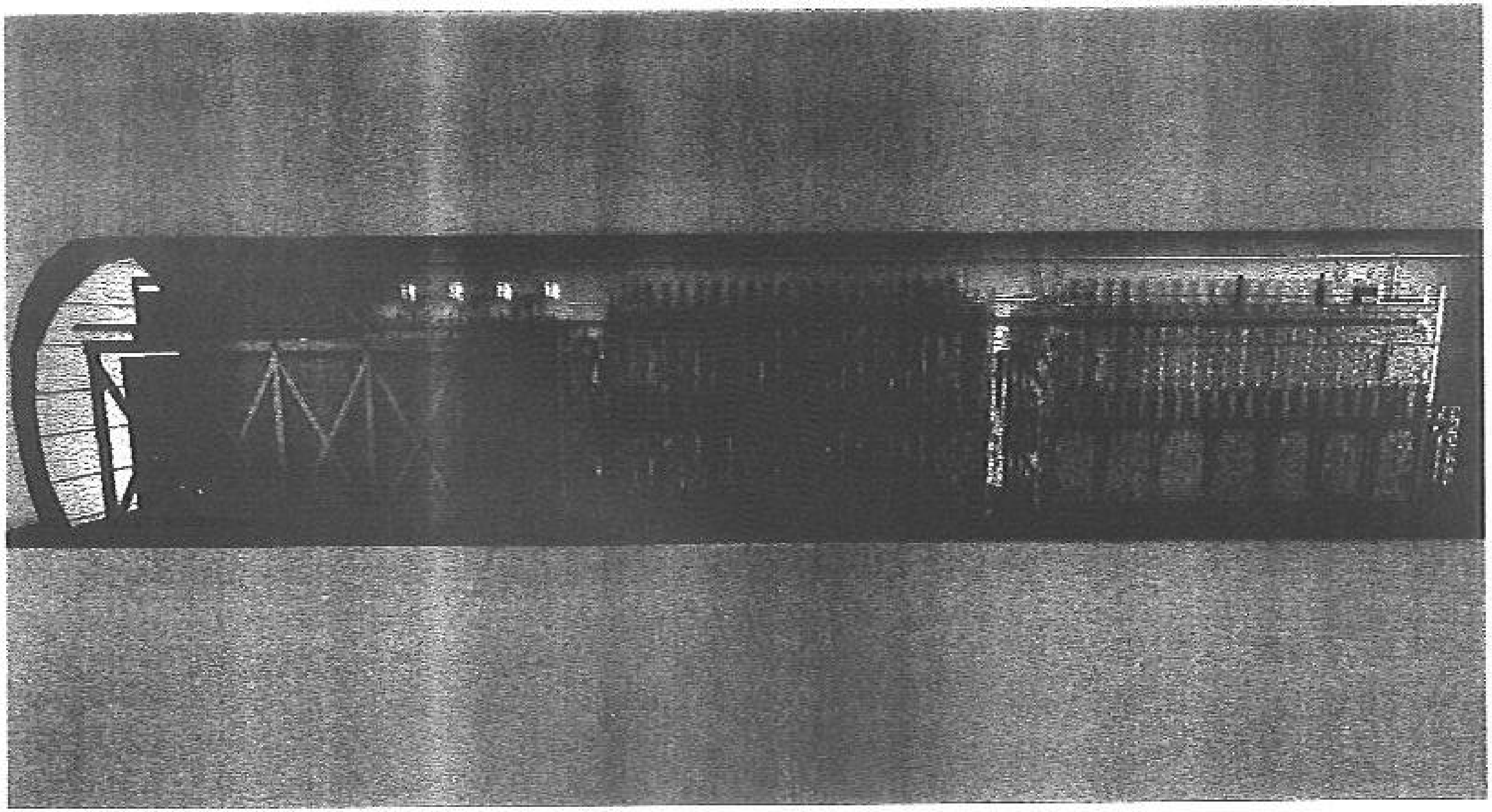


Figure 4.2: Side view of the ICARUS T600 (left) plus two T1200 detectors.

OR Super-Nova

Solar neutrinos detection in ICARUS

- Two reactions can be measured independently:

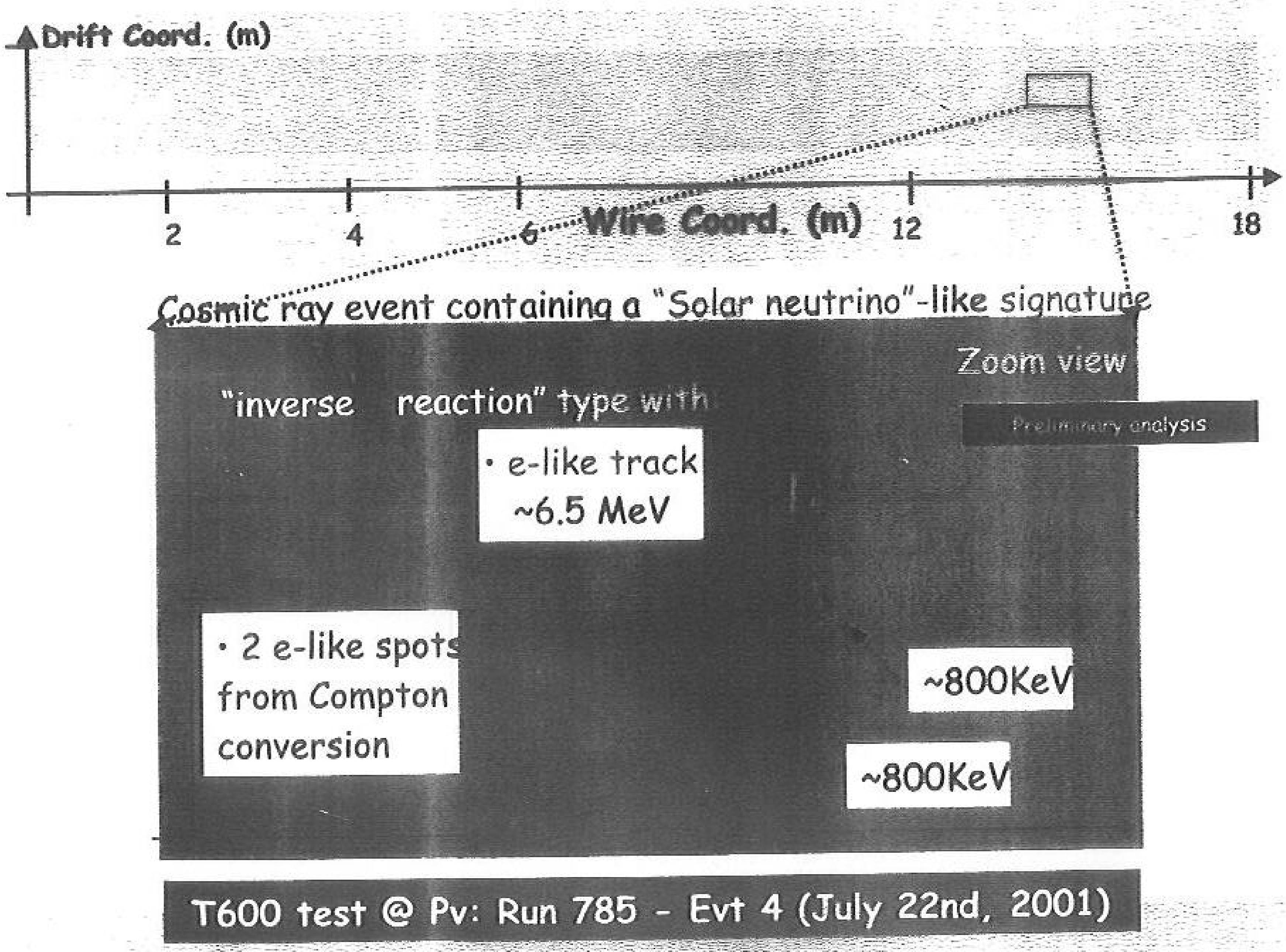
Elastic scattering on atomic electron

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

ν absorption on Argon nuclei

$$\nu_e + {}^{40}Ar \rightarrow {}^{40}K^* + e^-$$

- **Signature:** primary electron track eventually surrounded by low energy secondary tracks (${}^{40}K^*$ de-excitation).
- Electron track threshold = 5 MeV (needed to reduce background contribution and to establish the e^- direction in elastic scattering).
- Sensitive to ${}^{8}B$ component of the solar spectrum.


Drift Coord. (m)
2
4
6
Wire Coord. (m)
12
18
Cosmic ray event containing a "Solar neutrino"-like signature
Zoom view
"inverse reaction" type with
Preliminary analysis
• e-like track
~6.5 MeV
• 2 e-like spots
from Compton
conversion
~800KeV
~800KeV
T600 test @ Pv: Run 785 - Evt 4 (July 22nd, 2001)

Estimated Rates for Galactic SNII Neutrino Events in ICARUS 2.4kT

David B. Cline

UCLA

(I) $\nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K^* +$

(II) $\overset{(-)}{\nu}_{x} + e \rightarrow \overset{(-)}{\nu}_{x} + e$

Assumption	(I)	(II)
No Mixing	180	32
Full Mixing ($\nu_x \rightarrow \nu_e$) Sensitive to θ_{12} and θ_{13}	450	56

- **ICARUS is the only detector in construction that is sensitive to clean inelastic interaction.** of ν_e

MOON

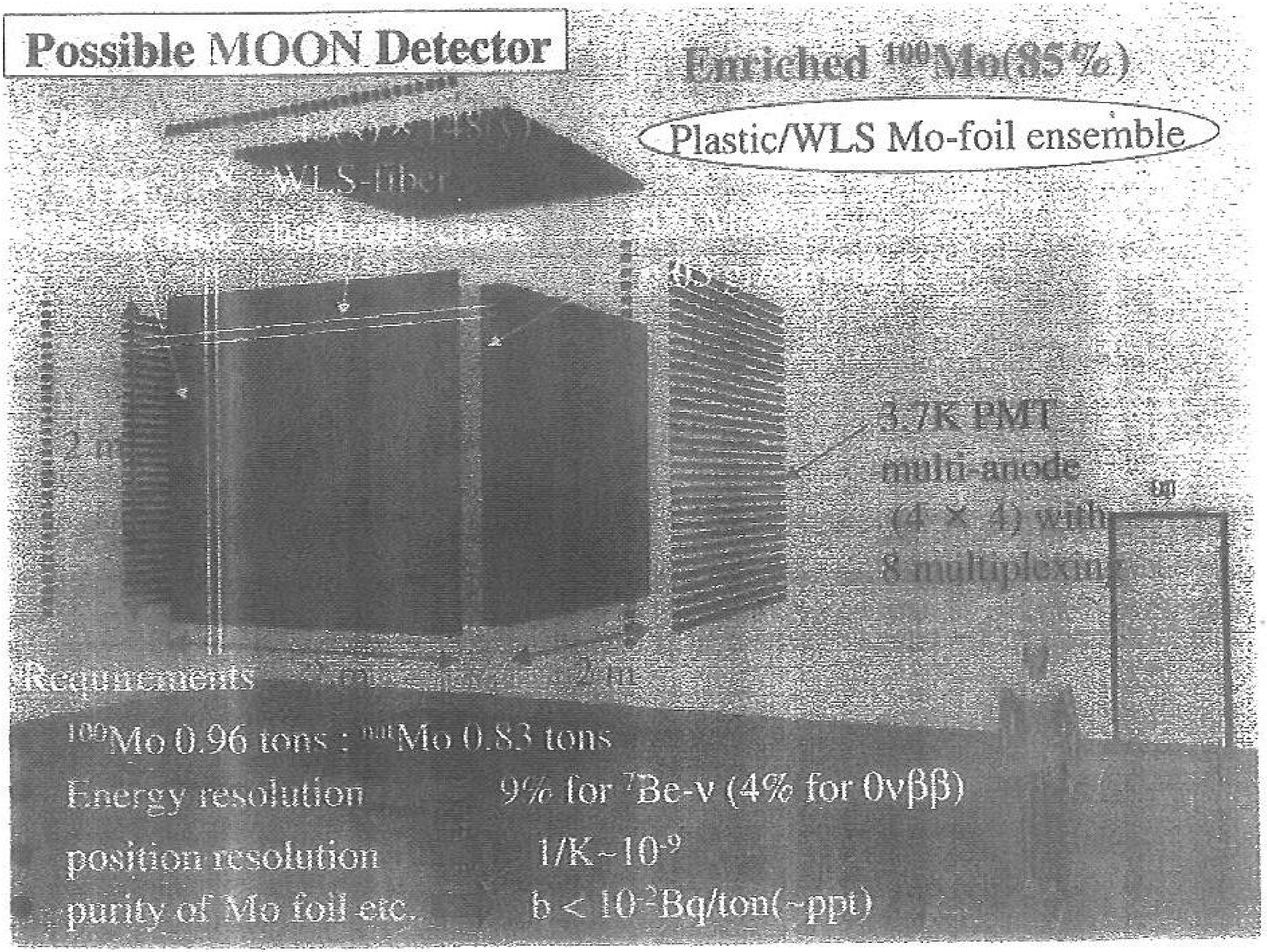
(Molybdenum Observatory Of Neutrinos)

for

Double β decays and solar ν

Hiro Ejiri

RCNP Osaka, JASRI.Spring-8


Possible MOON Detector
Enriched 100Mo(85%)
Plastic/WLS Mo-foil ensemble
WLS-fiber
3.7K PMT
multi-anode
(4 × 4) with
8 multiplexing
2 m
2 m
Requirements
100Mo 0.96 tons : 100Mo 0.83 tons
Energy resolution 9% for 7Be-ν (4% for 0νββ)
position resolution 1/K~10-9
purity of Mo foil etc. b < 10-2Bq/ton(~ppt)

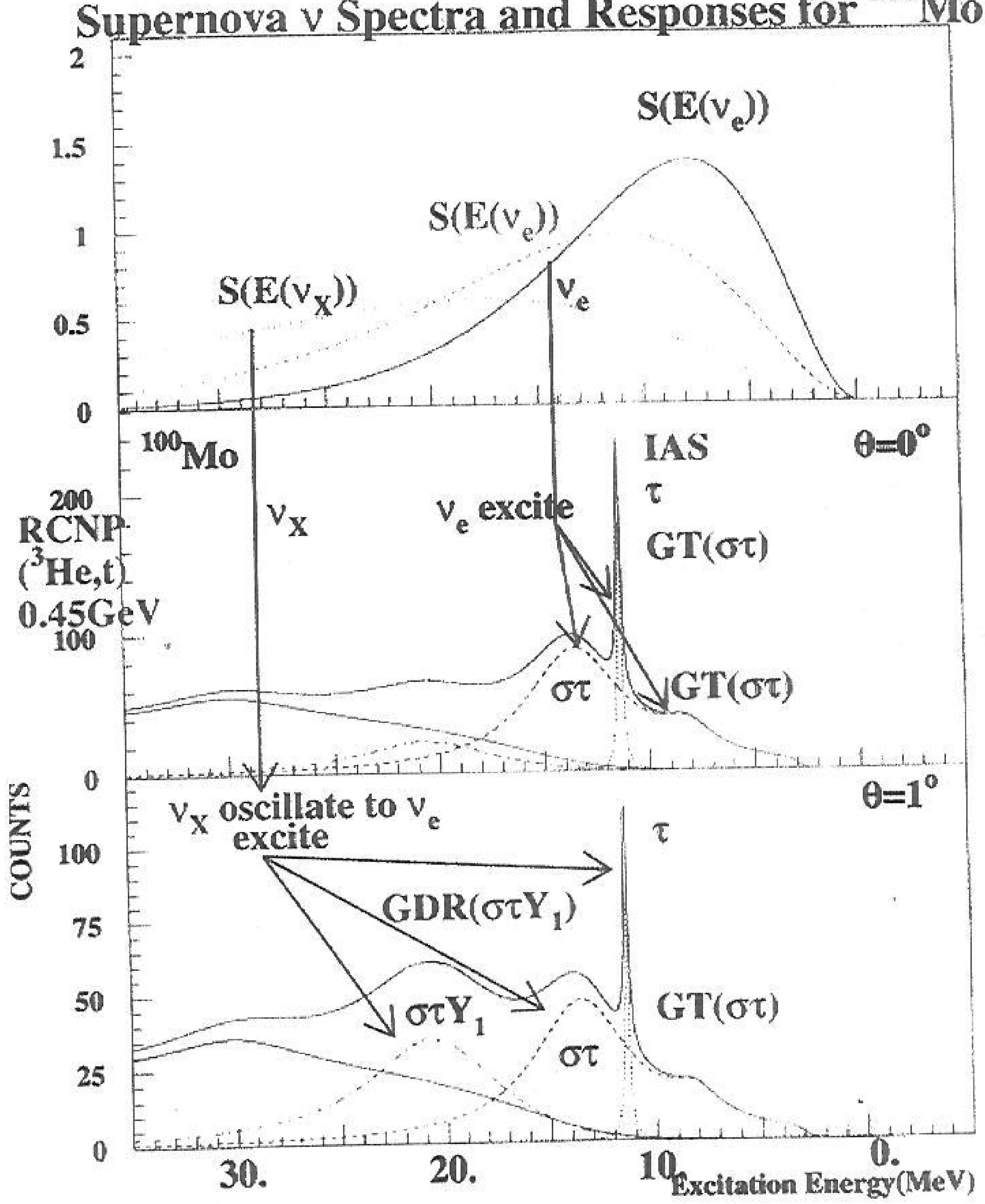
Nuclear Responses of ^{100}Mo for supernova ν

$\sigma(\nu, e)$ cm^2 J. Engel Preliminary

	ν_e	< 7 MeV	ν_x-ν_e	< 7MeV
0+	3.9 (-42)		8.6 (-41)	
0-	--		5.3 (-42)	
1+	4.7 (-41)		4.1 (-40)	1.3 (-40)
1-	--		8.7 (-41)	1.0 (-42)
2+	--		2.4 (-41)	5.3 (-42)
2-	1.8 (-42)		1.2 (-40)	1.5 (-41)
3+	--		2.1 (-41)	3.7(-42)
Σ	5.3 (-41)	3.1 (-41)	7.5 (-40)	1.5 (-40)

ν_e T=2.75 α-3, ν_x T=6.4, α=3.

Neutron threshold 7 MeV.


Supernova ν Spectra and Responses for ^{100}Mo
S(E(ν$_e$))
S(E(ν$_e$))
S(E(ν$_X$))
ν$_e$
^{100}Mo
θ=0°
IAS
τ
GT(στ)
ν$_X$
ν$_e$ excite
RCNP
(^{3}He,t)
0.45GeV
στ
GT(στ)
COUNTS
θ=1°
ν$_X$ oscillate to ν$_e$
excite
τ
GDR(στY$_1$)
στY$_1$
GT(στ)
στ
Excitation Energy(MeV)
2
1.5
1
0.5
0
200
100
0
100
75
50
25
0
30.
20.
10.
0.

Other Detectors

AMANDA J Ahrens et al
Astro part Phys. 16, 345 (2002)

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

215 days of live time

Upper limit of 90% C.L. for 4.3 events/year

Not clear what the rate of clean events would be for a SN II detector from this paper.

Homestake R Davis Detector / K Lande

Considering an upgrade by Inserting PMT's to "trigger" on the light from a ν Interaction — this could give real time information on a SN II

+ Increase the mass to Multi Kilotons

Detection of ν_μ and ν_τ, [redacted] From SuperNova Neutrinos In REAL TIME

DAVID CLINE
UCLA

Two Possibilities:

a) $\nu_x + e^- \rightarrow \nu_x + e^-$

- **Rate Low because $\sigma_{\nu_x e}$ Small**
- **Background from $\nu_e e \rightarrow \nu_e e$**

b) $\nu_x + N \rightarrow \nu_x + N'$

N = D, C, O, NaCl, Pb, Fe...

$N' \rightarrow n + X$ — SNO / SNBO/OMNIS

$N' \rightarrow \gamma + X$ — Super K / LVD / ICARUS

SIGNAL DEPENDS ON ν_μ, ν_τ ENERGY SPECTRUM

- OMNIS -

Neutrino Signal Detection

Charge Current Interaction

$$\nu_e + X(A,Z) \longrightarrow X^*(A,Z\pm1) + e^-$$

$$\hookrightarrow X(A-1,Z\pm1) + n$$

$$\rightarrow 2n$$

Neutral Current Interaction

$$\nu_{\mu,\tau} + X(A,Z) \longrightarrow X^*(A,Z) + \nu_{\mu,\tau}$$

$$\hookrightarrow X(A-1,Z) + n$$

Being Designed for WIPP Site
at Carlsbad

and

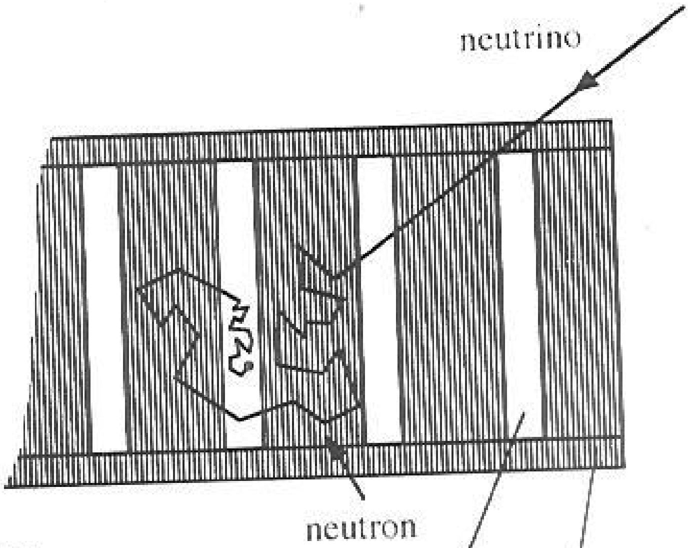
Homestake

Combination of Pb Slab Detectors
and
Pb Perchlorate

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

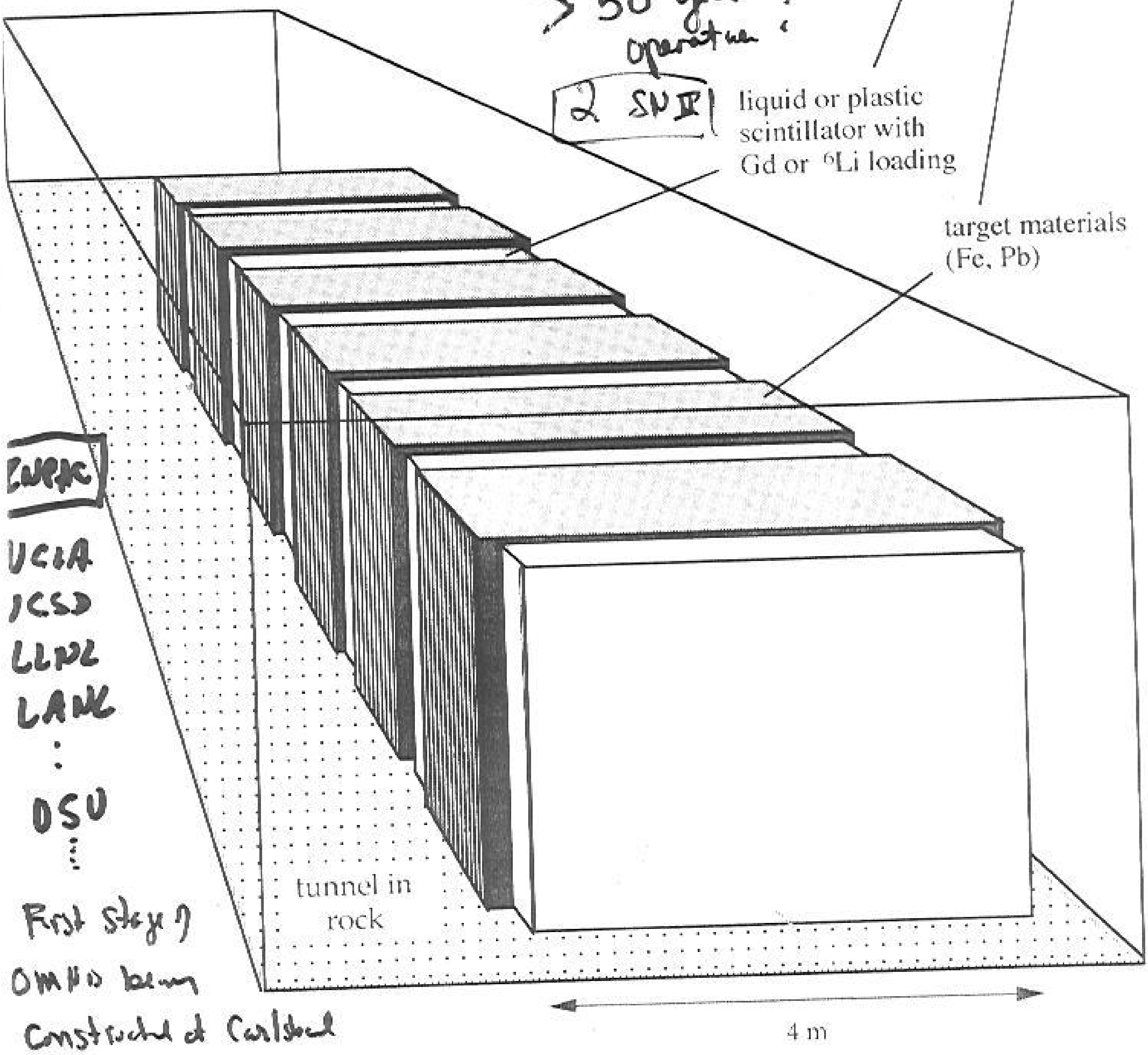
DBC/G Fuller 1990

P.F.Smith Astroparticle physics 8 (1997) 27
Astroparticle physics (2001) t.b.p



> 50 year operation!

2 SNII



OMNIS

UCLA
UCSD
LLNL
LANL
:
OSU
:

First stage?
OMNIS being constructed at Carlsbad

COMPARISON WITH NEW DETECTORS WITH ν_e SENSITIVITY

OMNIS — **Per 500 Ton Module +**

	NO MIXING	FULL MIXING (θ_{12}, θ_{13})
1 neutron Event	330 events	750 events
2 neutron Events (ν_x -> ν_e)	8 events	150 events

+ **Fully optimized Neutron Detector**

900 events per 500 Ton → 2KT ~ 4000 events

LANNDD — 70KT Liquid Argon Detector

	NO MIXING	FULL MIXING (θ_{12}, θ_{13})
$\nu_x \rightarrow \nu_e$ ($\nu_x \rightarrow \nu_x$) elastic	730	1300
$\nu_e \rightarrow e$ inelastic	4100	10,350

LANNDD
70 kTon Liquid Argon Concept

obtained in a horizontal plane and appears in the imaging as an arc in each of the planes (x, t) and (y, t).

The detector is foreseen as located underground at a depth of 655m (2150 ft) in a housing equipped with an emergency liquid argon pool and with argon vapor exhaust ducts. Forced fresh air inlet, liquid/vapor nitrogen in/out ducts, assembling hall with crane and elevator complete the basic organization of the underground cave.

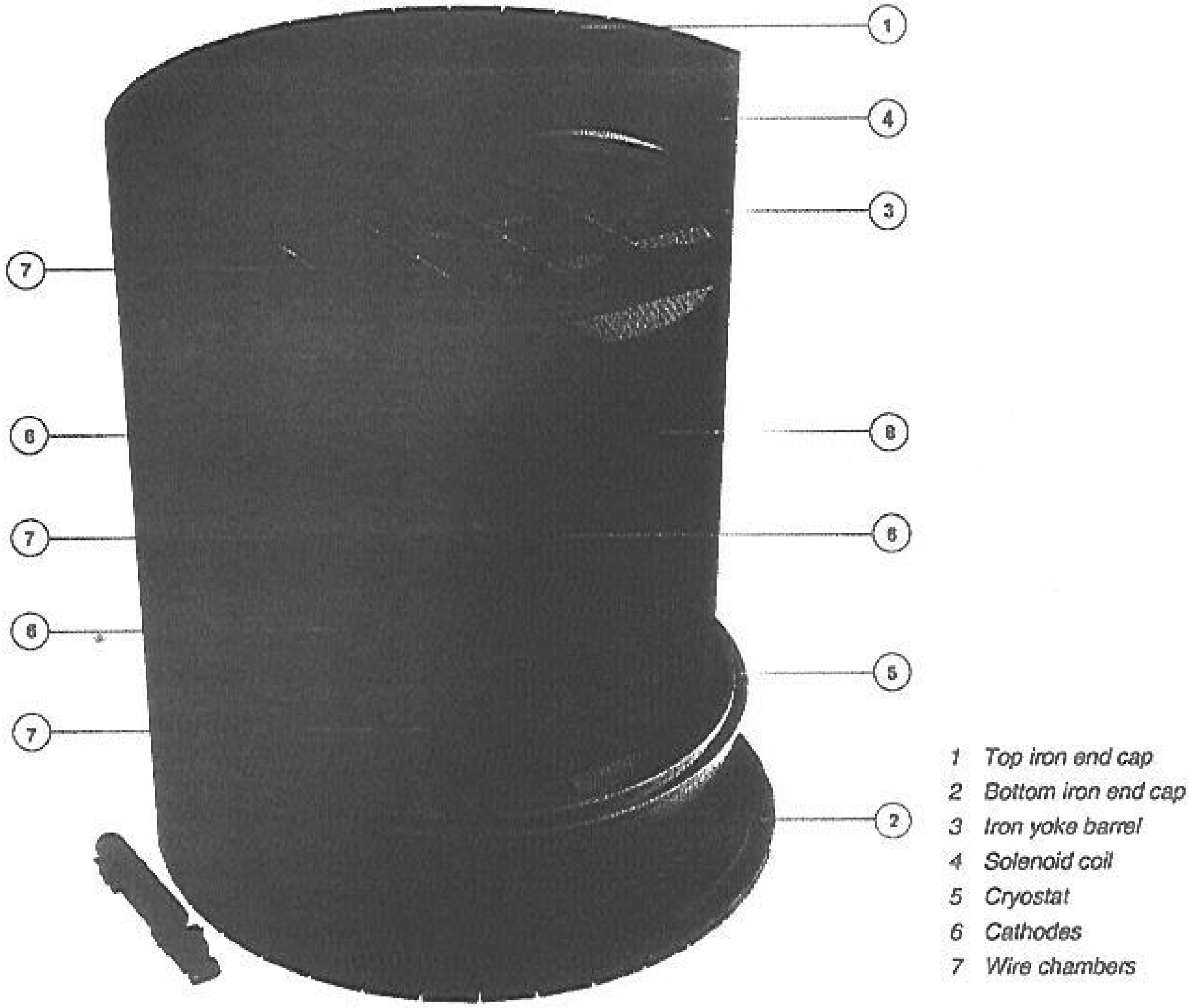


Figure 16 Cutaway view of the LANNDD detector.

Possible location?
LANNDD – CARLSBAD NM

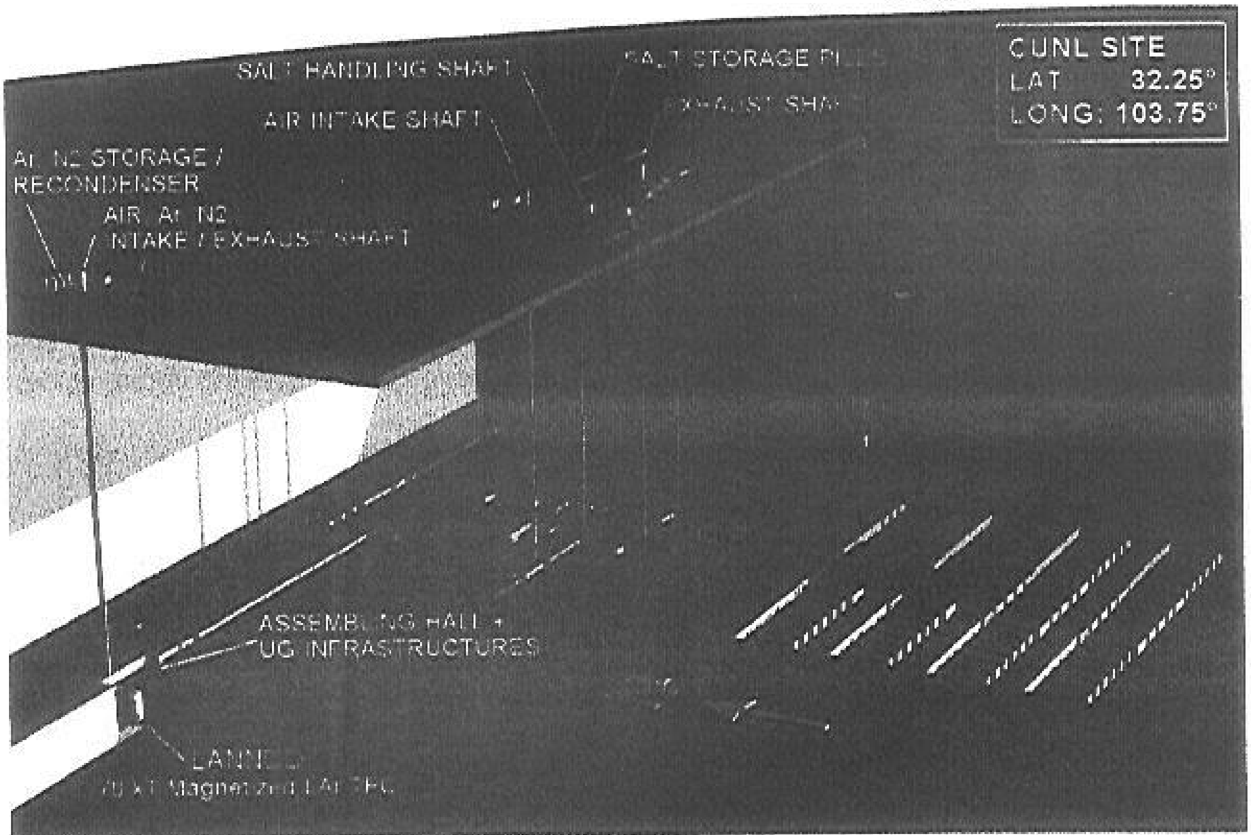


Figure 14 LANNDD at the CUNL site.

In Figure 15 we show the schemata of neutrino factory beams to the CUNL site for detection by LANNDD – we consider this a universal neutrino factory detector.

Scientific goals – Much of the scientific studies that are being done with LANNDD follow the success of the ICARUS detector program. The main exception is for the use of the detector at a neutrino factory where it will be essential to measure the energy and charge of the $\mu^{\pm}$ products of the neutrino interaction. We will soon propose an R&D program to study the effects of the magnetic field possibilities for LANNDD.

a) Search for proton decay to 10^{35} years

The detection of $p \rightarrow K^{+} + \overline{\nu}_{\mu}$ would seem to be the key channel for any SUSY-LUT model. This channel is very clear in liquid argon due to the measurement of the range and detection of the decay products. We expect very small background events at 10^{35} nucleon years for this mode (refer to ICARUS studies).

For Completeness

[03]

Supernova Neutrino Requirements of UNO

Vagins, M

UNO

As I hope you will recall from the last few meetings, in the event of a supernova 10 kpc distant, for the proposed UNO baseline design (10%/40%/10%) we would expect:

→ About 130,000 inverse beta decay events

(these events would allow UNO to resolve the absolute arrival time of the burst to within ±4 milliseconds)

→ About 4,500 elastic scattering events

(these events would allow UNO to resolve the absolute direction to the burst to within ±0.4°)

→ About 4,500 ^{16}O events

→ Resolving power down to 1.0 eV for the mass of the ν_e in the case of black hole formation

Return

SN Relic Neutrino Search: Data and Fit

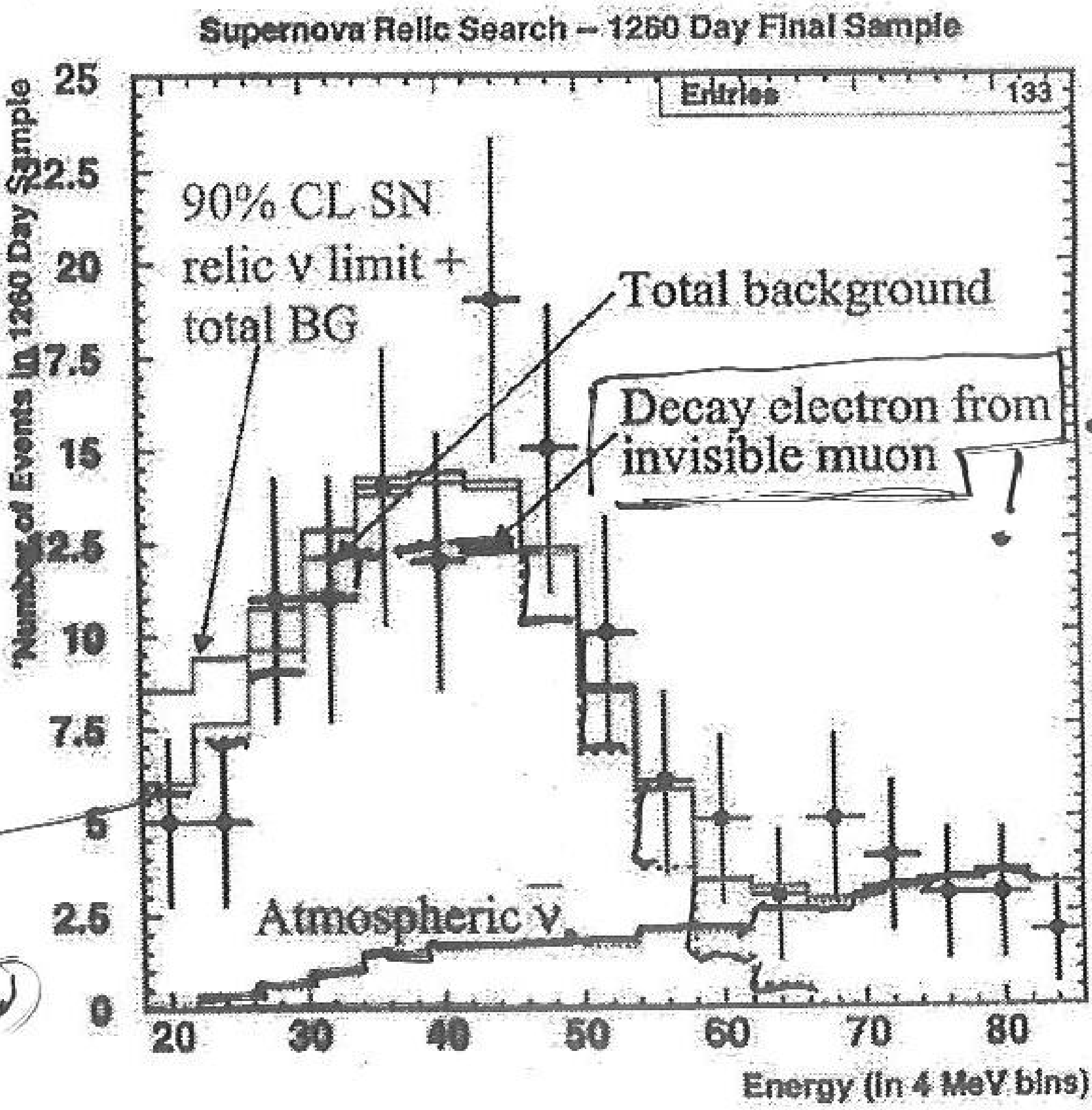
- 18 MeV ≤ E ≤ 86 MeV
- Stringent spallation cut
- Reject events with $\cos\theta_{\odot} > 0.866$

From K. Nakamura Talk

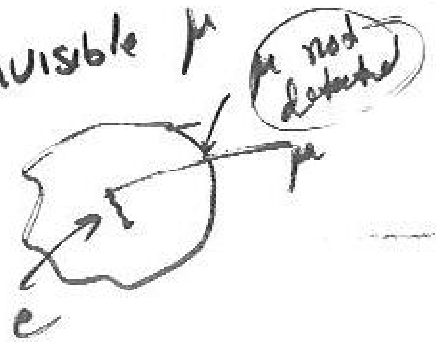
COSMO mtg

Sept Finlnd

SK DATA



Invisible μ



SN Relic Neutrino Limits

	Kaplinghat et al.	Totani et al.	Constant
Number of relic Neutrinos (90% CL)	< 6.5	< 7.0	< 7.5
Flux limit ($cm^{-2}\ s^{-1}$) (full spectrum)	< 39	< 180	< 27
Flux prediction ($cm^{-2}\ s^{-1}$) (full spectrum)	< 54	● 44	● 52
Flux limit ($cm^{-2}\ s^{-1}$) ($18 \le E_\nu \le 86$ MeV)	< 1.6	< 1.6	< 1.7

Model-independent upper limit from the directly observed results

Relic Neutrinos from PAST SN II in the Universe   DBC paper

New Search for Relic $\bar{\nu}_e$ from Super K

COSMO 01

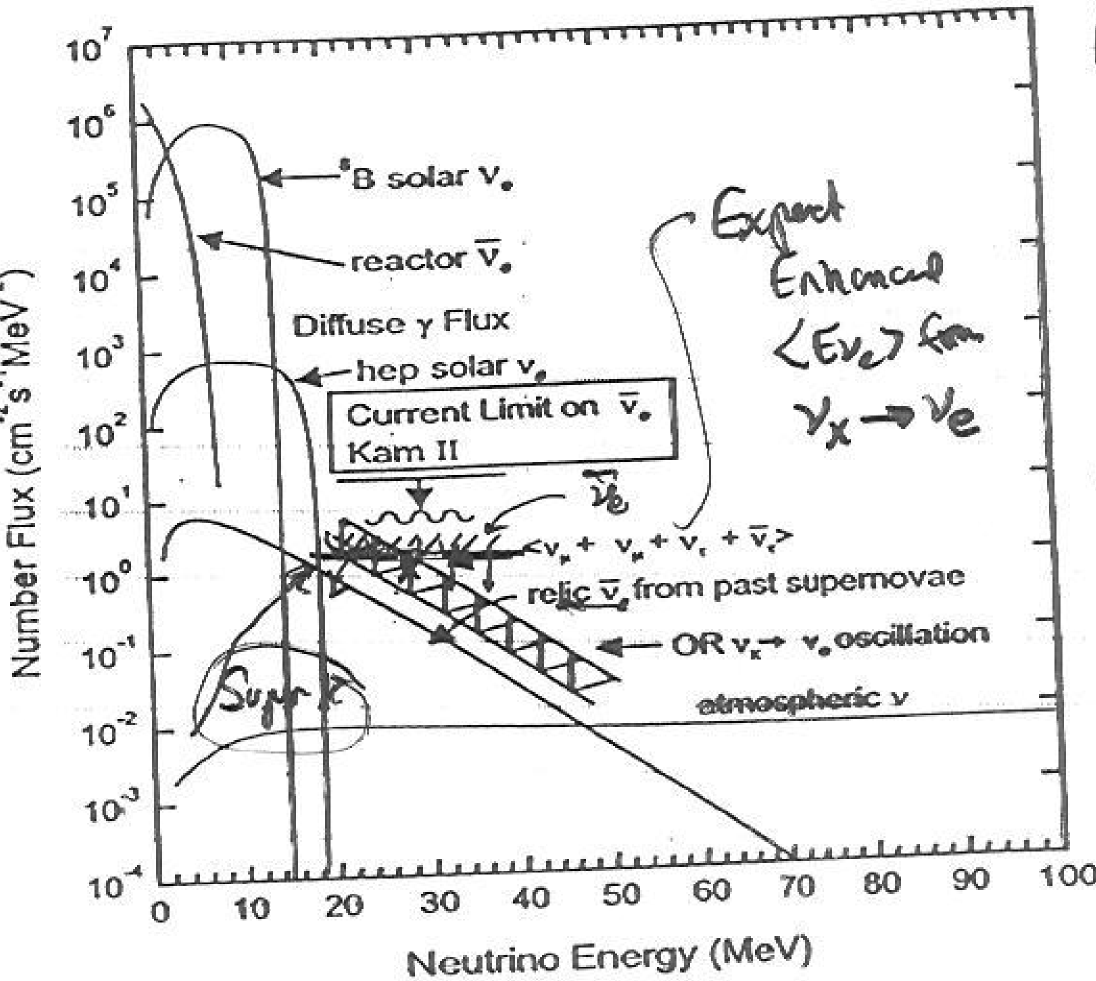


FIGURE 8. Relic neutrinos from past supernova. Note: $\nu_x \to \nu_e$ in the supernova can boost the energy of the ν_e if we find $<E\nu_e> > <E\bar{\nu}_e>$. This will be a signal for neutrino oscillation in supernovae! and measure $\sin^2 \theta x_e$. [1]

ICARUS [illegible] KT can
Search for the ν_e Flux
(Being Const. at Gran Sasso)

TABLE 6: YIELDS OF SUPERNOVA NEUTRINO DETECTORS

Detect\or	Target Material	Fiducial Mass (Ton)	Target Element	Yield (υ_e)	Yield ($\overline{\upsilon_e}$)	Yield (υ_μ υ_τ $\overline{\upsilon_\mu}$ $\overline{\upsilon_\tau}$)
Super K	H_2O	32000	p, e, O	180	8300	50700
LVD	CH_2	1200	p, e, C	14	540	30
SNO	H_2O	1600	p, e, O	16	520	6
SNO	D_2O	1000	d, e, O	190	180	300[illegible]
ICARUS	Argon	600T -> 4800T	^{40}Ar	400 to ~1600 full mixing		
OMNIS	*Fe*	8000	*Fe*	20*	20*	1200*
OMNIS	*Pb*	2000	*Pb*			
no osc.				110**	40**	860**
υ_μ υ_e osc.				4420**†	40**	640**
LANNDD				10,350		

* Assumes same efficiency as in Smith 1997

** Assumes a single neutron detection efficiency of 0.6

† Mostly 2n events

Number of Events from a Galactic SN

8,300 + 540 + 900 + 1600 + 4420 => 16,000

A New paper by Sato et al shows that this array of SN II detectors could measure $\Theta^2_{13} \sim 7\times10^{-7}$ by the MSW effect in the SN II

if $\theta_{12} = \theta_{23} = 45°$

Summary

1) Detection of SN II ν Burst of great importance for

   a) Astrophysics → Model of Stellar Collapse

   Neutrino Physics → Neutrino Oscillations θ_{12} and θ_{13}

   Black Hole formation observation in Real Time

2) When SK gets rebuilt and with a modest OMNIS detector there will be > 10^4 events detected with all channels CC and NC included

3) It is a challenge to detect the Relic SN Neutrinos - SK has problems with "invisible" muons

   Perhaps the ICARUS 3KT and LANNDD 70KT detectors can observe the ν_e Relic ν for the first time —