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# COMMENTS ON "LOW ENERGY NEUTRINO ASTROPHYSICS" AND ICARUS†

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## INTRODUCTION

Studies of Neutrino Astrophysics still are still at the beginning. While Solar Neutrinos have been detected and the anti-neutrinos from one SuperNova have been detected, there have not been any major discoveries in this field comparable to those in the study of low energy Photons from the Universe and the Galaxy. In Table 1 we illustrate the major discoveries in the latter case $[A_\gamma - D_\gamma]$. Note that nearly all have been made by *accident.*

We can compare the hypothetical discoveries in Neutrino Astrophysics in Table 2. Of the four conceivable types of discovery only two are even remotely practical $[C_\nu,\ D_\nu]$. We now know that the observation of relic neutrinos $[A_\nu]$ is virtually impossible at the current state of the art in low energy detector science. We can not conceive of a neutrino detector that can detect a low flux Burst of KeV $[B_\nu]$ neutrinos either.

## THE LOW ENERGY NEUTRINO "WINDOW"

We now discuss the prospects for observation of a diffuse neutrino flux in the "Window" of energy between $\sim 20 - 40\,\mathrm{MeV}$ $[C_\nu]$, Figure 1. The key new detectors to study this range will likely be ICARUS and Super Kamiokande. Thus, we describe some of the recent progress on the ICARUS detector[1] .

Figure 2 shows the 5000 Ton ICARUS detector as it would appear in Hall C at the Gran Sasso Laboratory[1]. There has been good progress in understanding this Liquid Argon electron drift imaging technique through the 3 Ton prototype detector at CERN[1]. In Figure 3 we show some events from that detector and in Figure 4 some simulated events that shows the wide range of physics potential from (simulations)

(i) $p \to K^+ \bar{\nu}_\mu$

† Contribution to the Round Table Discussion at the 5th International Conference on Neutrino Telescopes, Venice, Italy, March 1993.

(ii) A low energy (10 MeV) electron

(iii) A few GeV $\nu_e$ interaction from a long baseline neutrino and from CERN to the Gran Sasso

We have been unable to identify any source of significant background for the proton decay process. To search for $\nu_e$ in the window $(20 - 40)$ MeV events like (ii) would be used to search for

$$\nu_e + \mathrm{Ar} \rightarrow e^- + x \quad \text{or} \quad \bar{\nu}_e + \mathrm{Ar} \rightarrow e^+ + x$$

where $E_e > 10$ MeV.

The ICARUS detector is nearly ideal for such a detection. We estimate it would allow a search for a neutrino or anti-neutrino flux down to about the level of $10\,\mathrm{cm}^{-2}\,\mathrm{sec}^{-1}$.

## THE DEVELOPMENT OF A DEDICATED BURST DETECTOR (SNBO)

We have been warned at this meeting to hope for the discovery of sources of neutrino bursts with luminosity in the range of $(10^{34} - 10^{44})$ ergs/sec. No known source of such a burst is known but we also don't fully understand the origin of Gamma Ray bursts. Of course, it is essential to continue the search for the Neutrino burst from the next Galactic SuperNova and to use this information to extract the most information concerning both the SuperNova explosion process and the neutrino mass[2].

For several years a small group has been studying the possibility of designing and constructing a supernova neutrino detector to observe extra galactic supernova explosions. The members of this group are M. Balbas and R. Boyd of Ohio State University, D. Cline, D. Chrisman, W. Hong, J. Park, S. Ramachandran and T. Smart of University of California Los Angeles, S. Colgate of Los Alamos National Laboratory, E. Fenyves and T. McCarthy of University of Texas at Dallas, G. Fuller of University of California San Diego, P. Glassley and S. Labov of Lawrence Livermore National Laboratory, B. Meyer and J. Wilson of Lawrence Berkeley Laboratory for Experimental Astrophysics, and H. Wollenberg of the Lawrence Berkeley Laboratory Earth Sciences Division. We call this detector a SuperNova Burst Observatory. This group is also studying the possibility of detecting a finite neutrino mass in the range of $5 - 50$ eV from the detection of a galactic supernova.

The basic detection concept of the SNBO detector is to use neutrino inelastic scattering on nuclei together with subsequent neutron emission from the excited nucleus as the basis of an astrophysical neutrino detector. The process would be

$$\nu_x + A(Z,N) \rightarrow A(Z,N-1) + n + \nu'_x$$

where $\nu_x$ is either a $\nu_e$, $\nu_\mu$ or a $\nu_\tau$. Since we use the neutral current channel, $A(N,Z)$ is a nucleus of mass number $A$ with $Z$ protons and $N$ neutrons. $n$ is the final state free neutrons, and $\nu'_x$ is the scattered final state neutrino.

The initial SNBO detector would have the active mass of about $10^4$ tons of NaC$\ell$ and would be instrumented with a large number of neutron detectors. The detailed detector concept has been described in Reference 2. This detector is mainly sensitive to $\nu_\mu$ and $\nu_\tau$ neutrinos and anti-neutrinos due to the dynamics of the neutral current process which strongly discriminates against lower energy $\nu_e$ and $\bar{\nu}_e$ events. Thus, it is a $\nu_\mu$, $\nu_\tau$ detector.

The advantage of such a detector rests on three points:

(1) The enhancement of neutrino scattering cross sections due to nuclear collective effects
(2) Ease of maintaining the detector over a long period of time
(3) Inexpensively up-scalable due to the economical $BF_3$ neutron detectors as compared to Ĉerenkov counters.

A conceptual outline of the detection of a supernova by SNBO and data analysis is given in Fig. 5[2]. A SuperNova Watch is also a key part of this proposal[3].

One of the goals of the SNBO detector is the measurement of the $\tau$ or $\mu$ neutrino mass from a Galactic SuperNova. The key to SNBO is the detection of neutrinos produced in the inelastic neutral current reaction

$$\nu_x + \text{Nucleus} \rightarrow \nu_x + \text{Excited Nucleus}$$
$$\hookrightarrow \text{Neutron}$$

This process has a high energy threshold and helps discriminate between $\nu_{\mu,\tau}$ and the other neutrinos due to the higher mean energy of the $\nu_\mu$ and $\nu_\tau$ from the supernova. The neutron detector method provides an inexpensive detector concept.

Careful modeling of this reaction has been carried out by G. Fuller, B. Meyer and W. Hong. However, once a site for SNBO has been chosen these calculations must be carried out in greater detail to adapt to the target material at the site and the detector configuration.

Figure 6 shows the important properties of the neutrino emission from a SuperNova[4]. Note during the first 500 ms the process is <u>not thermal</u> and this sharp pulse provides a

method to detect the SN above on ambient background. Figure 7 shows the time dispersion of the neutrino pulse for various $\nu_\tau$ masses[2]. Note SNBO is sensitive only to $\mu$ and $\tau$ neutrinos due to the high threshold in the target.

For sometime the SNBO group has been searching for an appropriate site for the tests of the detector concept[2]. We have found a potentially very low radioactive background site at the WIPP project in New Mexico. For our own purposes, the proposed tests are crucial to design, and evaluate the feasibility of this detection scheme.

The number of neutrino induced events produced by a supernova in our galaxy can be estimated with good accuracy. Therefore, an accurate estimate can be made of the signal to noise obtainable with our detection scheme if the background detection levels are known. Some trade-off between the number, i.e. the size, of the detectors and the detection rates in each, can be made to optimize the signal to noise ratio. However, this requires good knowledge of the background rates. Thus, for a variety of reason, we must know the information which the proposed tests would provide in order to design our detection scheme. We anticipate that such tests might be useful from the the perspective of the WIPP as well.

Figure 8 shows a schematic of the WIPP Site.

## CONCLUSIONS

Many of the major discoveries in Astronomy have been by accident (see Table 1). However, by contrast to neutrino Astrophysics, these effects have been relatively easy to detect (see Table 2).

In this comment we have noted two new detectors that could make an accidental discovery

(1) ICARUS could observe a new source of neutrinos in nature in the $20 - 40\,\mathrm{MeV}$ range

(2) SNBO could discover new sources of neutrino bursts (other than SN)

However, we should be so lucky?

## REFERENCES

1. See, for example, and a list of references, A. Bettini, A. Graggiotti, F. Casagrande, P. Casoli, F. Cavanna, P. Cennini, S. Centro, M. Cheng, A. Ciocio, S. Cittolin, D. Cline, B. Dainese, G. Gasparini, L. Mazzone, G. Muratori, A. Pepato, G. Piano Mortari, P. Picchi, F. Pietropaolo, P. Rossi, C. Rubbia, S. Suzuki, S. Ventura, H. Wang, Z.H. Wang and M. Zhou, The ICARUS liquid argon TPC: a complete imaging device for particle physics, NIM, A315 223 (1992).

2. D.B. Cline, et al., Proposal for a SuperNova Burst Observatory, UCLA Report (unpublished), 1990.
3. D.B. Cline, F. Keyvan, W. Hong and J. Wilson, Progress on a Real Time SuperNova Watch Network, preprint UCLA-APH0054-4/92.
4. R. Mayle, et al., World Scientific, eds Blair and Buckingham, 1989.

**TABLE 1**

**Discoveries in Cosmic (Astrophysics) Photon Physics (nearly all by accident)**

| | OBSERVATION | SOURCE |
|---|---|---|
| $A_\gamma$ | Discovery of Relic Microwave Background Radiation (Perzias/Wilson) $\rightleftharpoons$ COBE | Early Universe (300,000 years) |
| $B_\gamma$ | Discovery of X-ray Bursters | AGN, etc. Blasers/? |
| $C_\gamma$ | Discovery of Diffuse $\gamma$ Background (1 − 100 MeV) | " " " |
| $D_\gamma$ | Discovery of $\gamma$ Bursters (30 KeV $\rightarrow$ 100 MeV) | Extra Galactic or Galactic |

**TABLE 2**

**The Comparable Discoveries in Neutrino Astrophysics that Could Be**

| | | |
|---|---|---|
| $A_\nu$ | Relic Neutrino Flux ($\sim$eV) ? | Early Universe ($\sim$ 10 sec) |
| $B_\nu$ | ? ? ? (Bursts of $\sim$KeV neutrinos ??) | ? ? |
| $C_\nu$ | Relic SN $\bar{\nu}$ Flux (> 10 MeV) + New Sources ($\nu_e$ from GRB) | Integrate over Galaxy SN's |
| $D_\nu$ | Real Time $\nu$ Burst Detection (> 10 MeV) | SN/PBH (Now) |

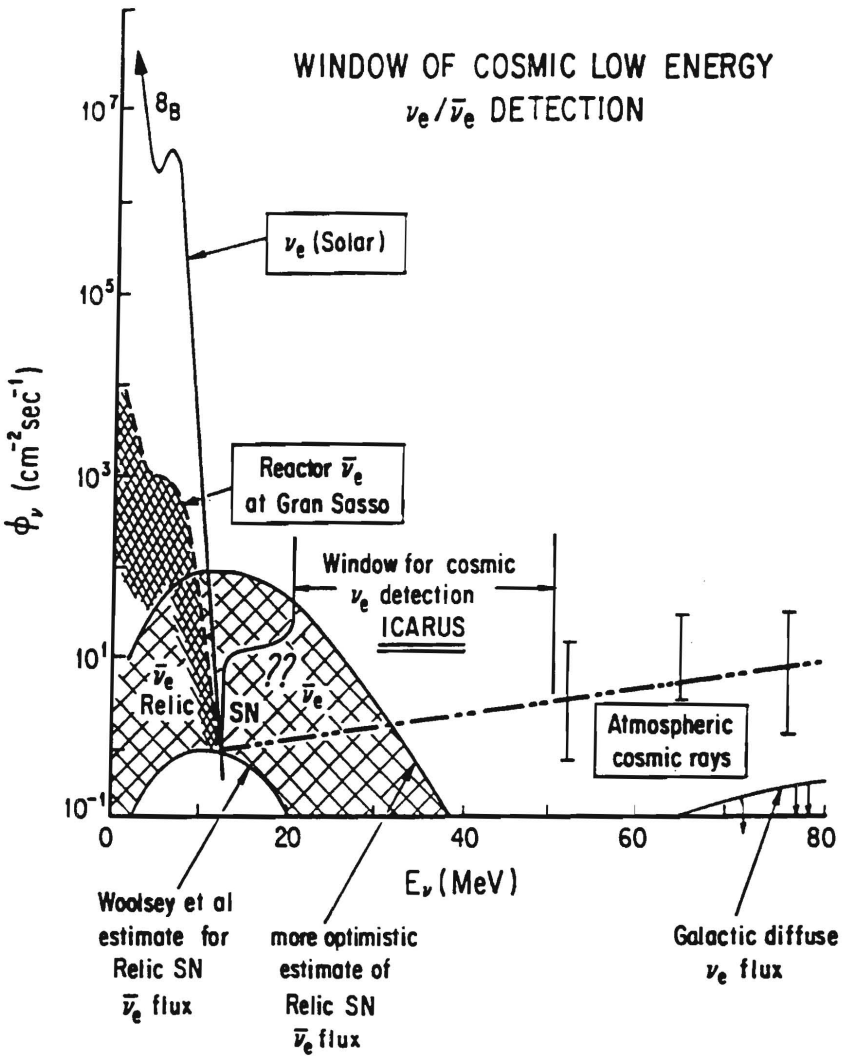



**Fig. 1:** Window of cosmic low energy $\nu_e/\bar{\nu}_e$ detection.

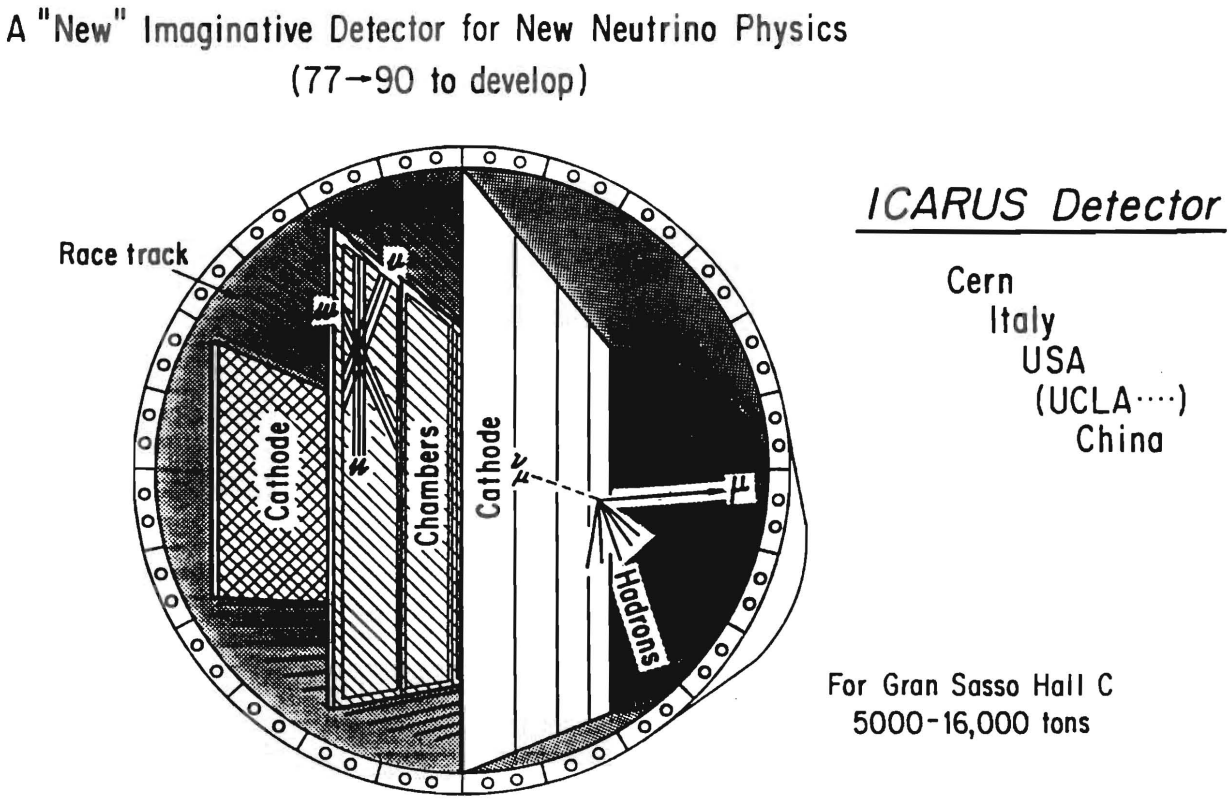



**Fig. 2:** A "new" imaginative detector for new neutrino physics.

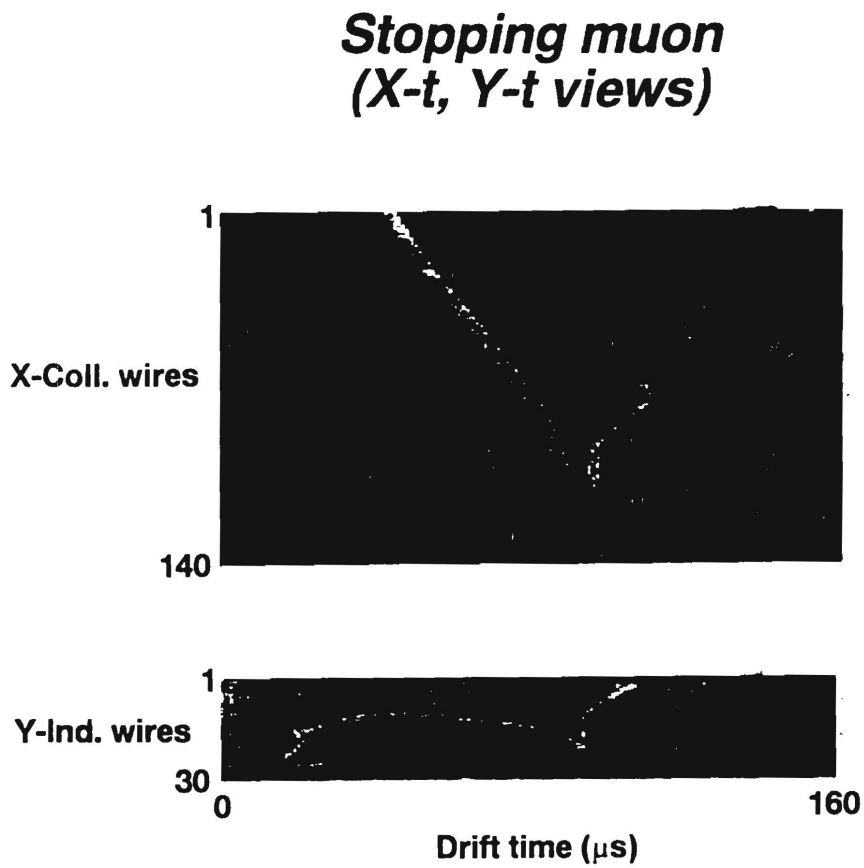



Fig. 3a: Stopping muon event.

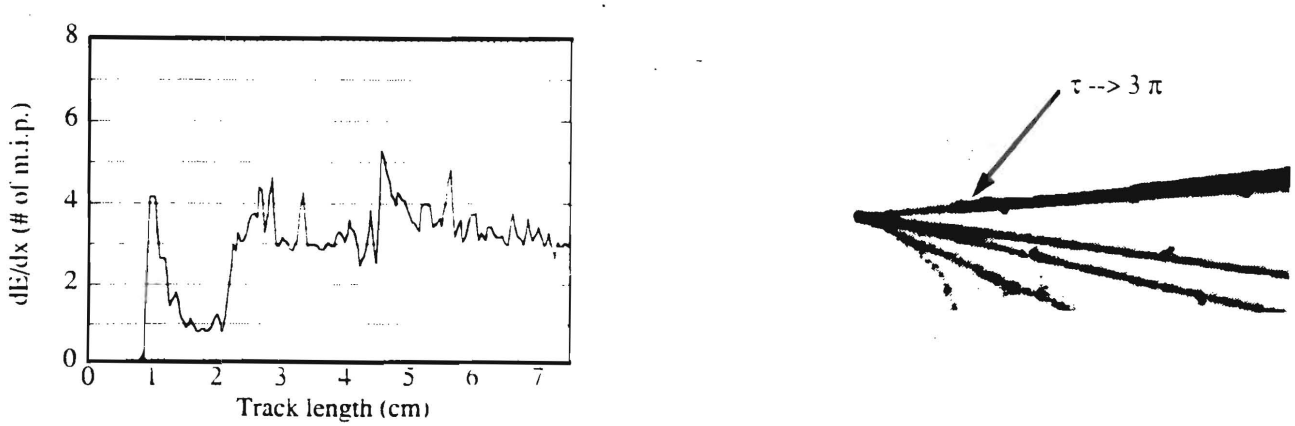



**Fig. 3b:** Simulation of a $\nu_-$ CC interaction followed by $\tau$ decaying into $3\pi$(left). The detection technique consists of identifying the secondary vertex by the sudden increase in the $dE/dx$ (+2 minimum ionizion particles) exiting the main vertex(right). The charmed particle background could be suppressed by requiring no single muon/electron from the main vertex. The background due to pair production along the track can be reduced exploiting the different hadron/electron energy loss development in the first 15 cm of the event (before the shower takes place).

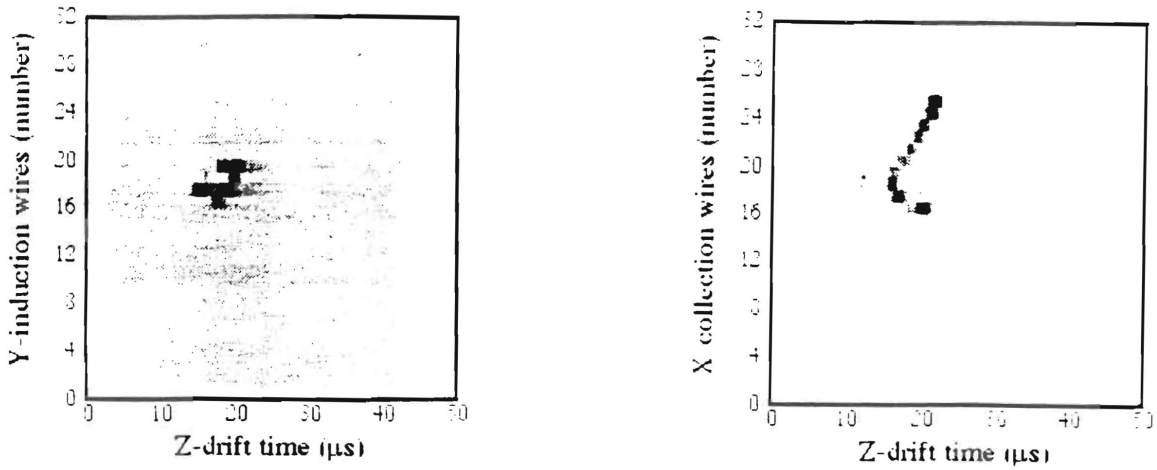



**Fig. 3c:** Two orthogonal views of an isolated pair produced inside the detector by a 6 MeV gamma.

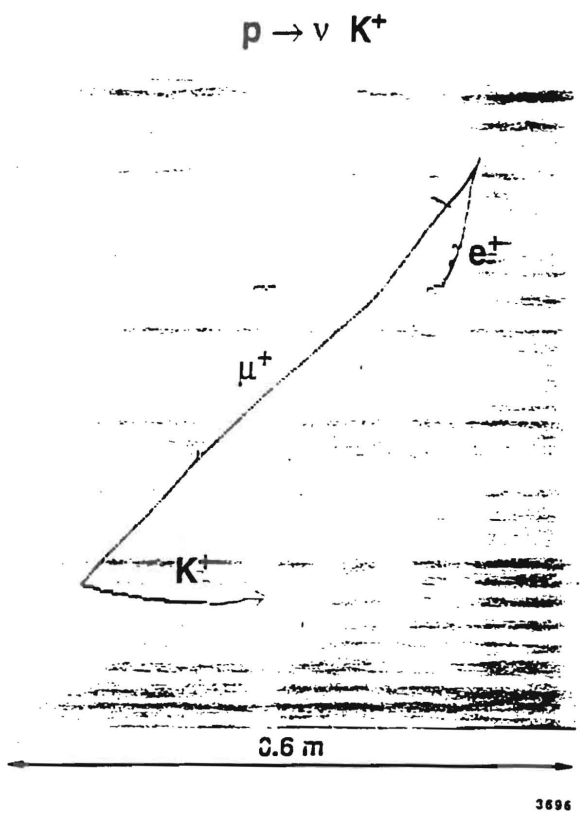



**Fig. 4a:**

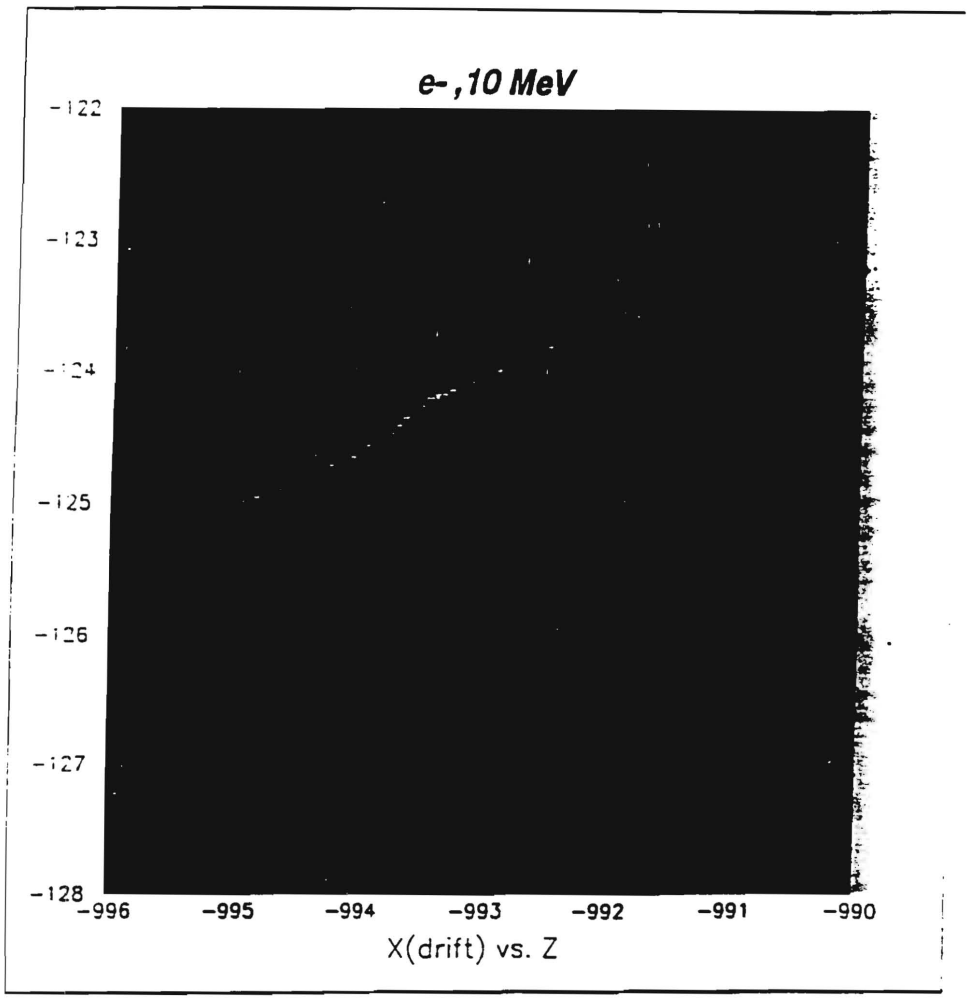

e-,10 MeV
-122
-123
-124
-125
-126
-127
-128
-996
-995
-994
-993
-992
-991
-990
X(drift) vs. Z

**Fig. 4b:**

## $\nu_e$ *Charged current*

| | | |
|---|---|---|
| | $\pi^0$ | 3.59 GeV |
| final state (clockwise) | $e^-$ | 1.79 GeV |
| | $\pi^+$ | 0.611 GeV |
| | p | 1.270 GeV |

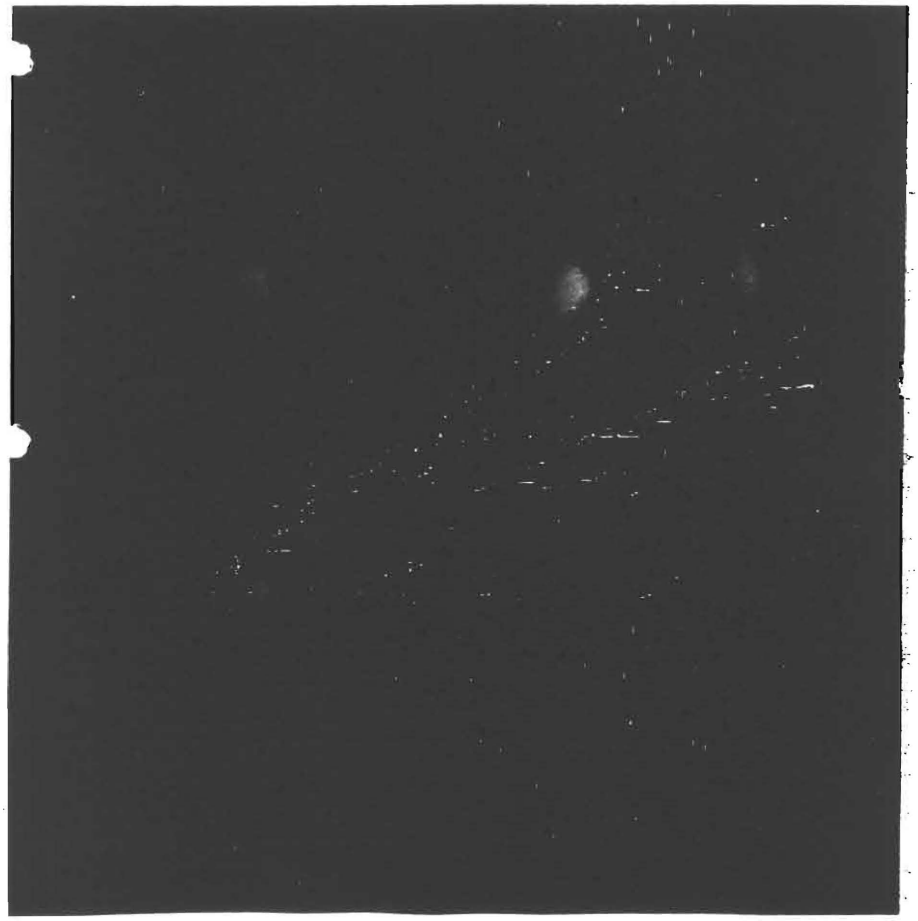
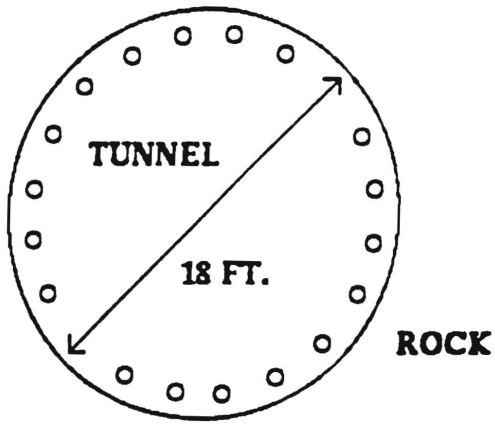


Fig. 4c:

## The Super Neutrino Burst Observatory Concept

1) GOAL: To measure $\tau$ neutrino mass
   – direct unambiguous measurement –
2) METHOD: Use time of flight from Galactic SN
3) DETECTOR: Rock ($\nu + A \rightarrow \nu' + A' + n$)
   (threshold exists since $n$ is initially bound)
4) ENERGY: Average $\nu_\tau$ energy is about 3/2 average ($\nu_e, \bar{\nu}_e$) energy




5) COUNTS: More than $10^4$ counts expected from Galactic SN
   Use "inexpensive" neutron detectors – and
   detectors requiring little direct maintenance
6) FROM CALCULATIONS:
   $\langle E_{\nu_e} \rangle = 12\text{MeV} \quad \langle E_{\bar{\nu}_e} \rangle = 15\text{MeV} \quad \langle E_{\nu_{\mu,\tau}} \rangle = 25\text{MeV}$
7) RISE TIME: $L_{\bar{\nu}_e}$ and $L_{\nu_{\mu,\tau}}$ rise rapidly at
   almost the same time (about 0.1sec)
8) FIRST PREDICTION: Take model output for spectra and $L_{\bar{\nu}_e}$
   and $L_{\nu_{\mu,\tau}}$ and feed into detector response
   to predict first 0.35 seconds of detection
9) MEASUREMENT DATA: Use Kamiokande II data for supernova
   in Milky Way to measure $L_{\bar{\nu}_e}$ rise time
10) LIMITS: Compare $\nu_\mu$ and/or $\nu_\tau$ signal to find limits on $m_{\nu_\mu}$ and/or $m_{\nu_\tau}$

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LLNL Cal. for SNBO Detector:

No. of Counts $= 2 \times 10^4 \frac{V}{R^2}$ with V in meters$^3$, R in Mpc;
For Milky Way R = 0.01 Mpc; Let V = $10^4$ meters$^3$
Then No. of Counts $= 2 \times 10^4$

Fig. 5:

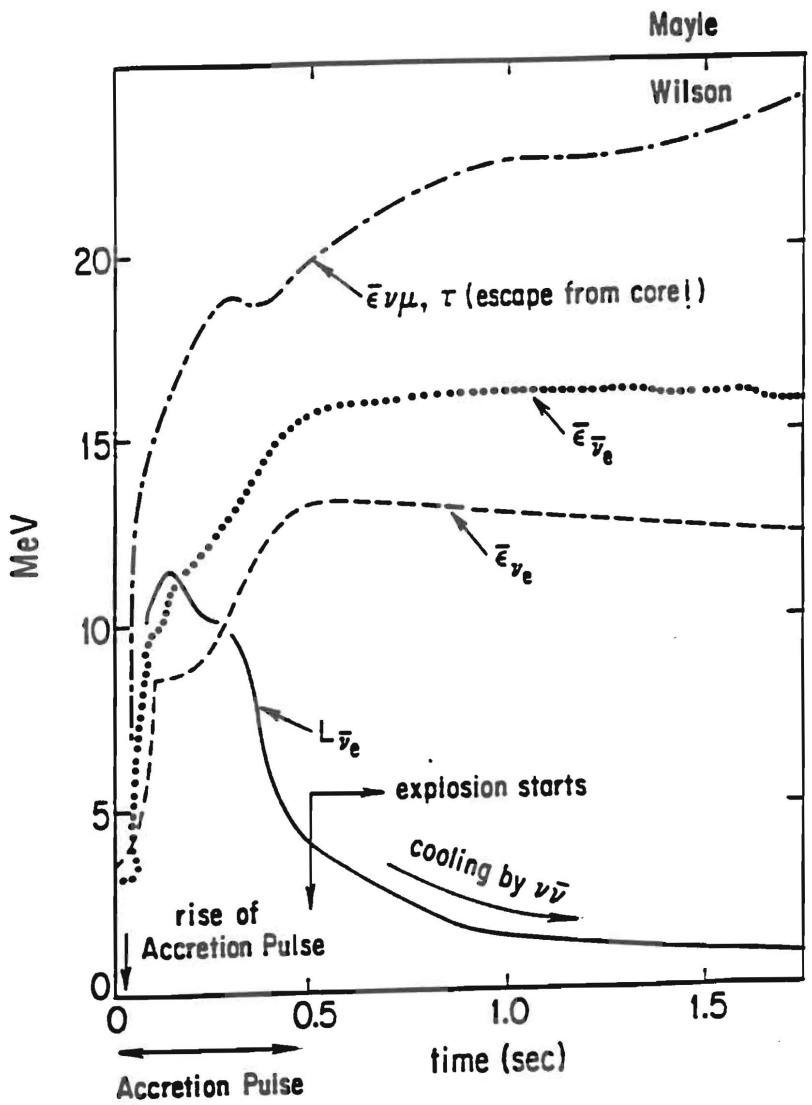
Mayle
Wilson
20
15
10
5
0
MeV
$\bar{\epsilon}\,\nu\mu,\ \tau$ (escape from core!)
$\bar{\epsilon}_{\bar{\nu}_e}$
$\bar{\epsilon}_{\nu_e}$
$L_{\bar{\nu}_e}$
explosion starts
cooling by $\nu\bar{\nu}$
rise of
Accretion Pulse
0
0.5
1.0
1.5
time (sec)
Accretion Pulse

Fig. 6:

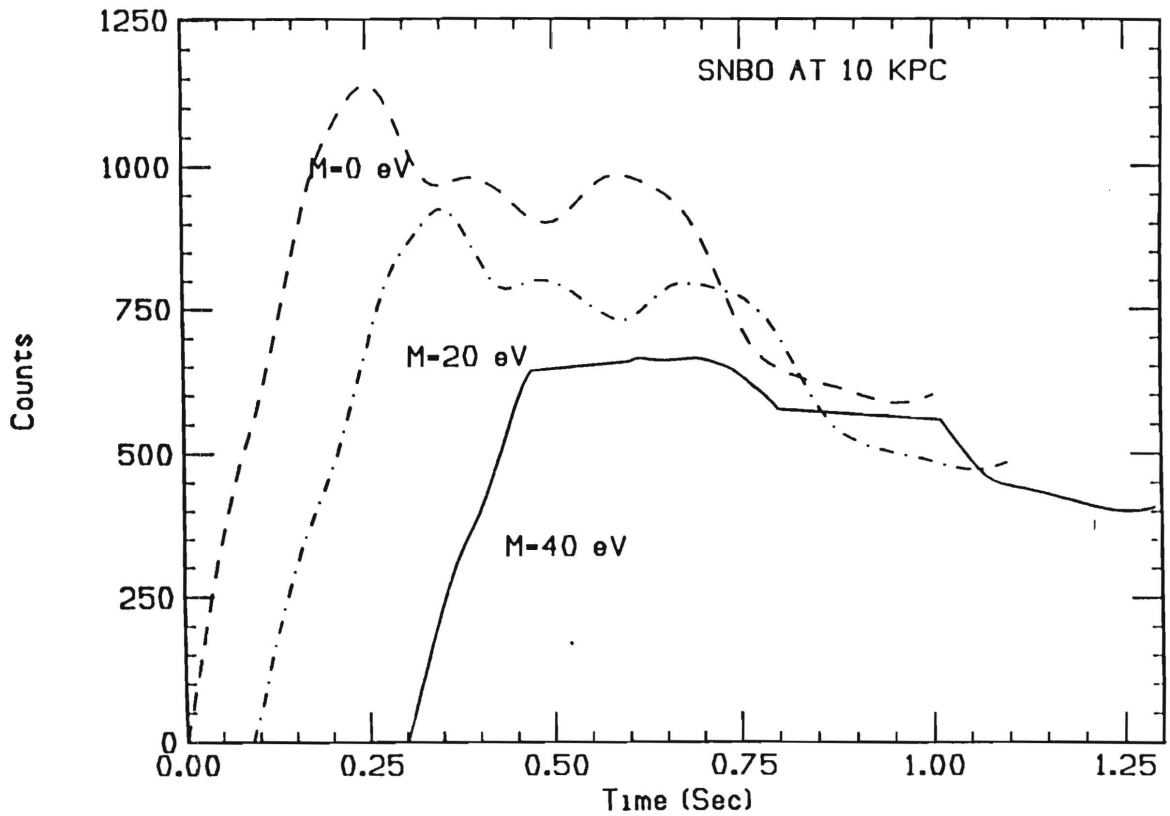
SNBO AT 10 KPC
M-0 eV
M-20 eV
M-40 eV
Counts
Time (Sec)
1250
1000
750
500
250
0
0.00
0.25
0.50
0.75
1.00
1.25

**Fig. 7:**

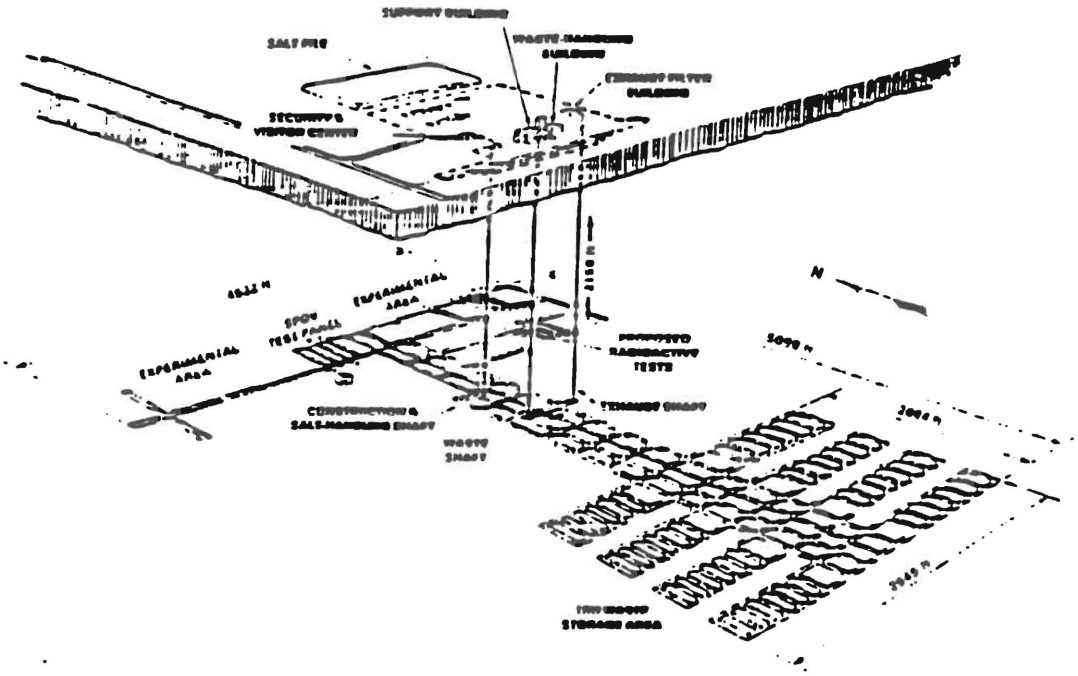
SUPPORT BUILDING
SALT PILE
WASTE-HANDLING BUILDING
EXHAUST FILTER BUILDING
SECURITY & VISITOR CENTER
EXPERIMENTAL AREA
SPOV TEST PANEL
EXPERIMENTAL AREA
PROPOSED RADIOACTIVE TESTS
EXHAUST SHAFT
CONSTRUCTION & SALT-HANDLING SHAFT
WASTE SHAFT
N
TRU WASTE STORAGE AREA

Fig. 8: