NEUTRINOS FROM THE UNIVERSE

David B. Cline
Physics and Astronomy
UCLA

1. Effects of Neutrino Mixing:
   Low Energy to UHE

2. Supernova Neutrino Physics and Determination
   Of: $\theta_{12}, \theta_{23}, \theta_{13}$

3. UHE Neutrino Detection: Water and Ice
   Detectors

4. UHE Neutrinos:
   a. Propagator of ν_τ in Dense Matter
   b. Upward τ Events: Possible Evidence in TGF, Airplanes, etc.
   c. Space Based Future Studies: OWL/EUSO

5. A Possible Universal Neutrino Factory Detector
   at CUNL

SUMMARY

Neutrino Oscillations

$$\nu_\alpha \rightarrow \nu_\beta$$

$$P(\nu_\alpha \rightarrow \nu_\beta) = \sin^2 2\theta \, \sin^2\left[\frac{1.27 \Delta m^2 L}{E_\nu}\right]$$

Δm^2 eV^2 $\quad$ E (GeV)

L km

Before 1988 the only evidence for ν osc was for Solar Neutrinos

In the late 80's the Kam II / IMB experiments found a deficit of ν_μ in Atmospheric Neutrinos

<u>More Recently Super K results</u>

SUPER K RESULTS

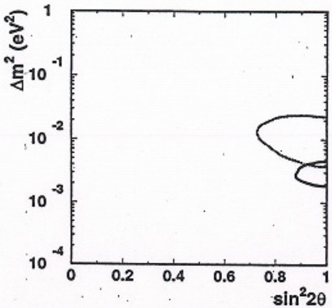


FIG. 44. 90% C.L. allowed region of the $\nu_\mu \rightarrow \nu_\tau$ neutrino oscillation parameters from a combined analysis of fully-contained, partially-contained, upward-stopping muon and upward through-going muon events from Super-Kamiokande (black line, Fukuda *et al.*, 2000a). The result from a combined analysis (without the upward-going stopping muon data) from Kamiokande (gray line, Hatakeyama *et al.*, 1998) is also shown.

Best Fit to Date

Strong Suggests

$\nu_\mu \rightarrow \nu_\tau$

$P(\mu\tau) \sim 1$

$\Delta^2 m \sim 3 \times 10^{-3}\, eV^2$

Oscillation length for UHE ν

Dec 2002
DF.

$$l_{\nu_\mu \to \nu_\tau} = 4 \times 10^{-3}\,\text{pc} \left[\frac{E_\nu}{10^{16}\,\text{eV}}\right] \Big/ \Delta m^2 / 10^{-2}\,\text{eV}^2$$

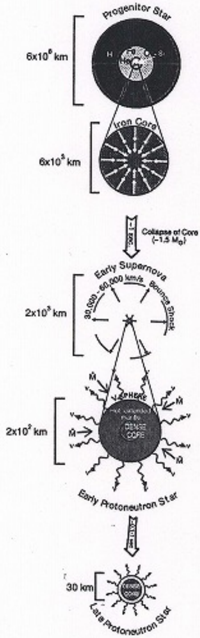
For $E_\nu = 10^{20}\,\text{eV}$, $\Delta m^2 \sim 3 \times 10^{-3}\,\text{eV}^2$

$$l_{\nu_\mu \to \nu_\tau} \sim 10^2\,\text{pc} \sim 320 \text{ light years}$$

If there were any local sources of ν_μ ($l < 10^2\,\text{pc}$) this could be a method to measure distance (the $\nu_\mu \to \nu_\tau$) oscillation magnitude

Supernova "Neutrino Factory"

Super Nova Type II, (Ib, Ic) (Not Ia)
Explosion



$10^6 - 10^8$ y

$\sim 10^{-2}$ sec

Size

6×10^8 km
↓
6×10^3 km
↓
2×10^3 km
↓
200 km
↓
30 km
↙ ↘
NS, BH

"A Neutrino Factory"

$\sim 10^{57}$ Neutrinos
All Flavors

If we can detect all Flavors

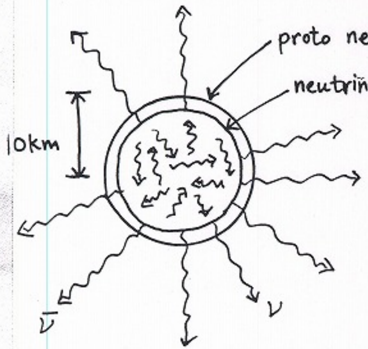
— Neutrinos Play a key Role in the Explosion Process —

MARINA DEL REY
MITP FEB 15th
2011

1

A Burrows

Supernova: Energy Release



"cooling" by neutrino emission:

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

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

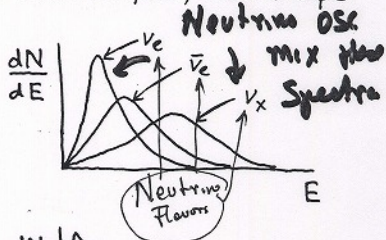
etc.

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

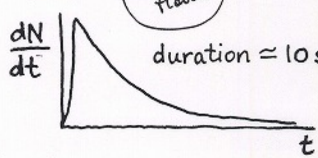
$\langle E_{\nu_e} \rangle \simeq 11$ MeV

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

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



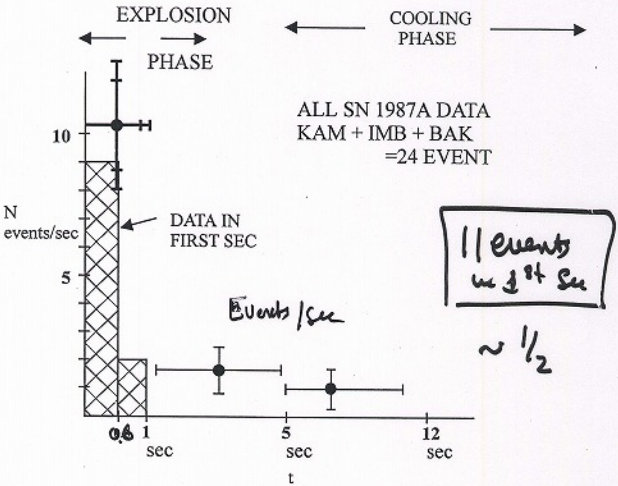
$$L_{\nu_e}(t) \simeq L_{\bar{\nu}_e}(t) \simeq L_{\nu_x}(t)$$



duration $\simeq 10$ s

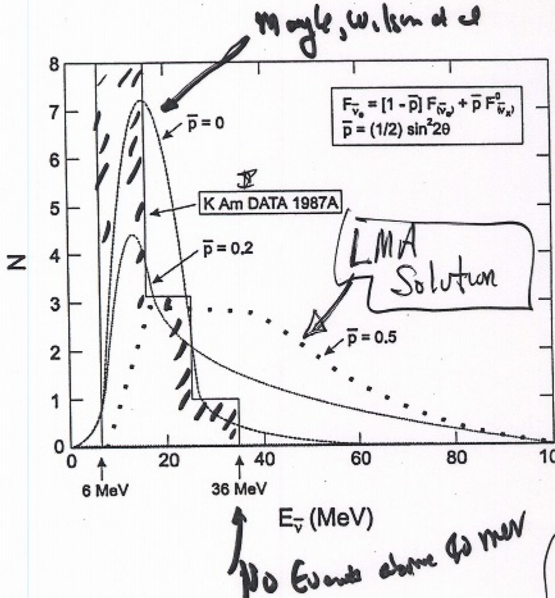
Neutrino Flavors $\nu_e,\ \nu_\mu,\ \nu_\tau$ / $\bar{\nu}_e\ \bar{\nu}_\mu\ \bar{\nu}_\tau$ [all diff Neutrinos]

DATA KAM II 11 (+1) 12
IMB 8 events
BAKSAN 5



1987A Data Time Distribution consistent with Mayle/Wilson

A New Analysis DBC
- Use KAm II DATA ONLY



$\bar{p} = \frac{1}{2} \sin^2 2\theta$

Figure 7. Comparison of the Kamiokande data with the neutrino oscillation models.

Seems to Rule out LMA if correct

DBC ASTRO PH 0010339

SITUATION IN THE SNII SIMULATION PROGRAM

MARINA DEL-REY MTG FEB 15/16 2001

1. Some 1D Calculations give explosions regularly. (LLNL - J. Wilson, et. al.) Some do not (ORNL...) The difference is not understood but could be due to the equation of State used. However, all agree that the most complete physics can be put into 1D calculation.

2. Some 2D Calculations give explosion (A. Burrows, etc.), but the 1D Modeler claims the physics in the codes is marginal!

Still A State Of Confusion As To What Causes The Explosion

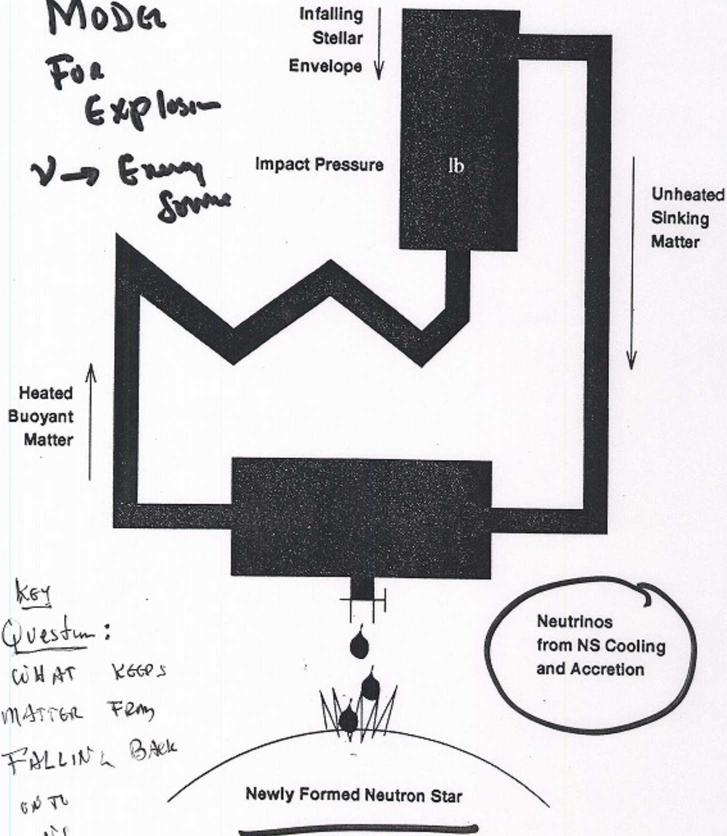
Perhaps detection of all Neutrino Flavor for a SNII will give the key information.

Most agree there should be some feature in the Neutrino spectrum at the time of Explosion! (ν_x from Core)

S. Colgate et al

MODEL FOR EXPLOSION

$\nu \rightarrow$ Energy Source



Key Question:

WHAT KEEPS MATTER FROM FALLING BACK ONTO NS

G. Raffelt Talk

Neutrino Spectra from a Supernova Core

Different flavors are trapped by different reactions

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

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

$\nu_{\mu,\tau}\ (\bar{\nu}_{\mu,\tau}) + N \rightarrow N + \nu_{\mu,\tau}\ (\bar{\nu}_{\mu,\tau})$

Opacity ↑ $\langle E_\nu \rangle$ ↓

Beta reactions are more efficient than neutral-current scattering, and there are more n than p. Typical SN simulations yield a hierarchy of spectral temperatures

$$\langle E_\nu \rangle = \begin{cases} 10 - 12\ \text{MeV} & \text{for } \nu_e \\ 14 - 17\ \text{MeV} & \text{for } \bar{\nu}_e \\ 24 - 27\ \text{MeV} & \text{for } \nu_\mu, \nu_\tau, \bar{\nu}_\mu, \bar{\nu}_\tau \end{cases}$$

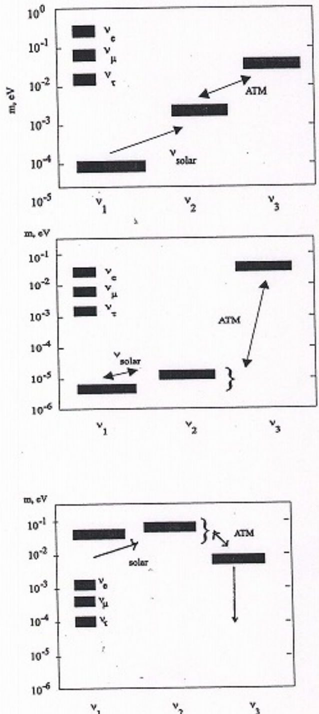
(Possibly a little softer ν_x spectra)

Approximate equipartition of energy among flavors

Neutrino oscillations can partially swap spectra

Mass has Important Effect Inside SN
Spectrum

MSW Effect in SN II



Can separate these possibilities in next SN II detection

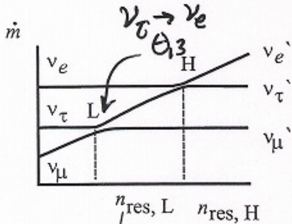
Dighe & Smirnov PRD, 62, 033007

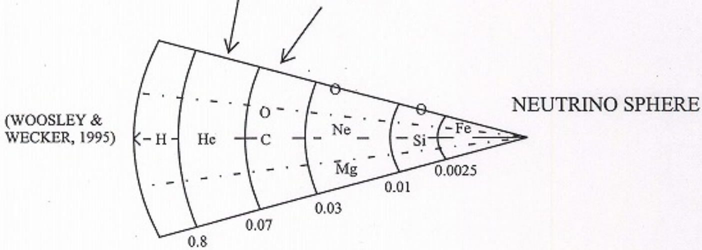
Fuller Haxton

Inverted

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

K Sato (U Tokyo)
UCLA
Meeting





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

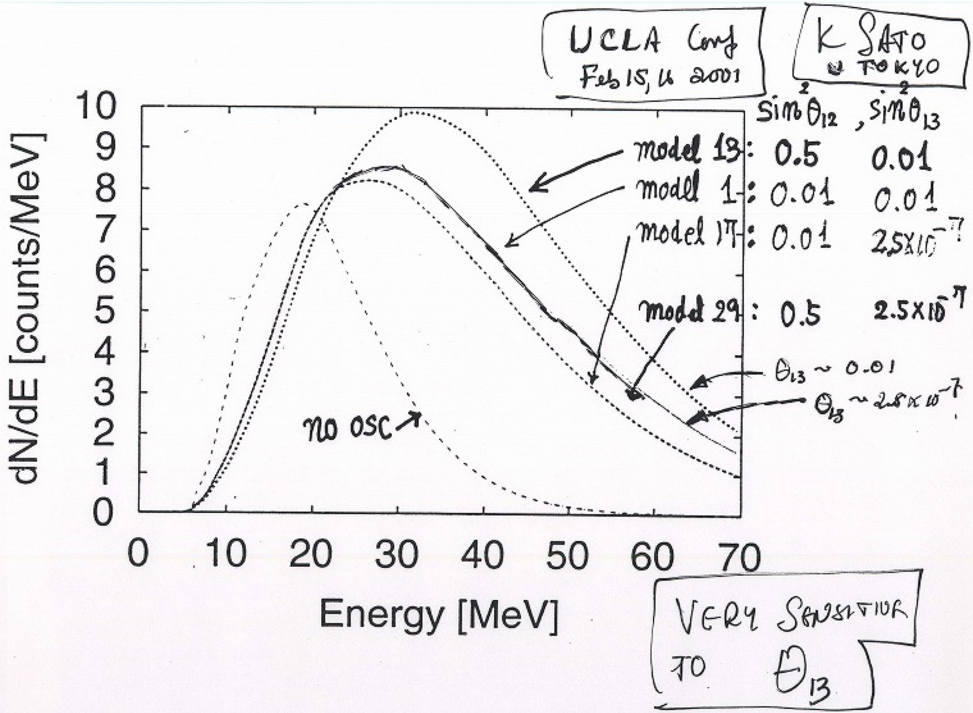
TWO RESONANCES (H at C+O shell, L at He shell)

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


UCLA Conf
Feb 15, 16 2001
K SATO
TOKYO
$\sin^2\theta_{12}$, $\sin^2\theta_{13}$
model 13: 0.5 0.01
model 1: 0.01 0.01
model 17: 0.01 2.5x10^-7
model 29: 0.5 2.5x10^-7
θ_{13} ~ 0.01
θ_{13} ~ 2.8x10^-7
no osc
dN/dE [counts/MeV]
Energy [MeV]
VERY SENSITIVE
TO θ_{13}

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

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...

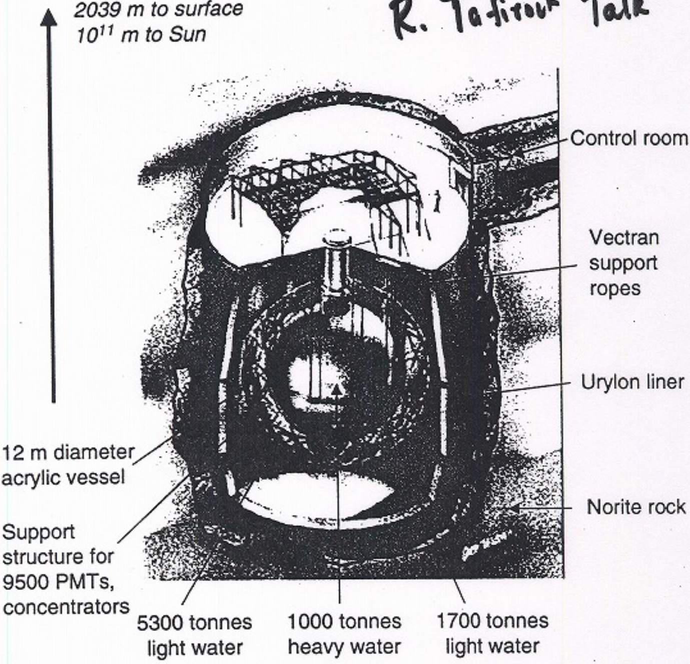
$N' \rightarrow n + X$ — SNO / SNBO/OMNIS

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

SIGNAL DEPENDS ON ν_μ, ν_τ ENERGY SPECTRUM

The SNO Detector

R. Tafirout Talk



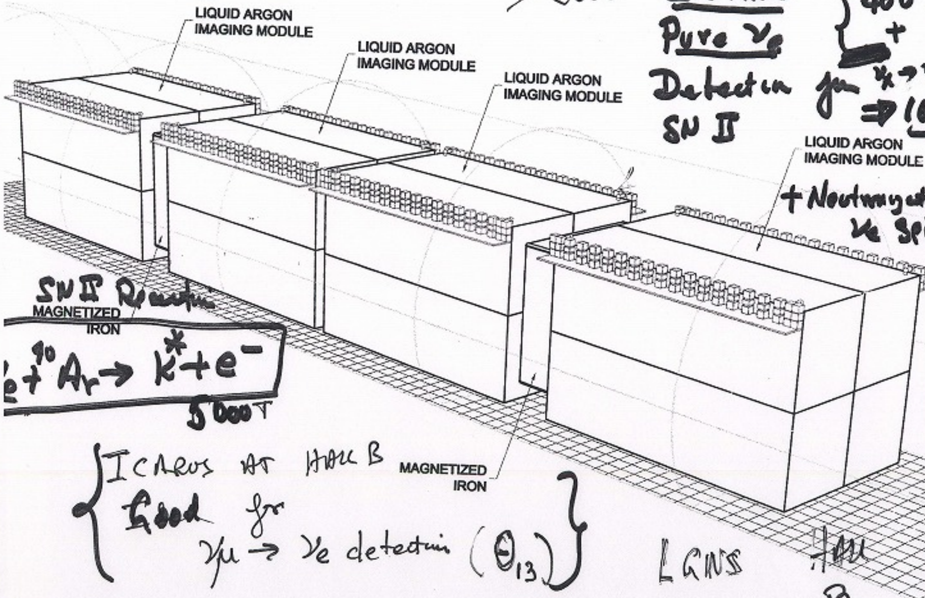
- **Location:** 6800 ft. level of INCO's Creighton mine near Sudbury, ON, Canada (~70 muons / day)

- **SNO Detector:** 9438_{inward} + $91_{outward}$ Hamamatsu 8" PMTs + concentrators = 64% coverage

I Botelle Talk > 2005

ICARUS
Pure ν_e
Detection
SN II

{400 ν_e
+
$\nu_x \to \nu_e$ ⇒ 1000



\+ Neutronization ν_e Spike

SN II Reaction

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

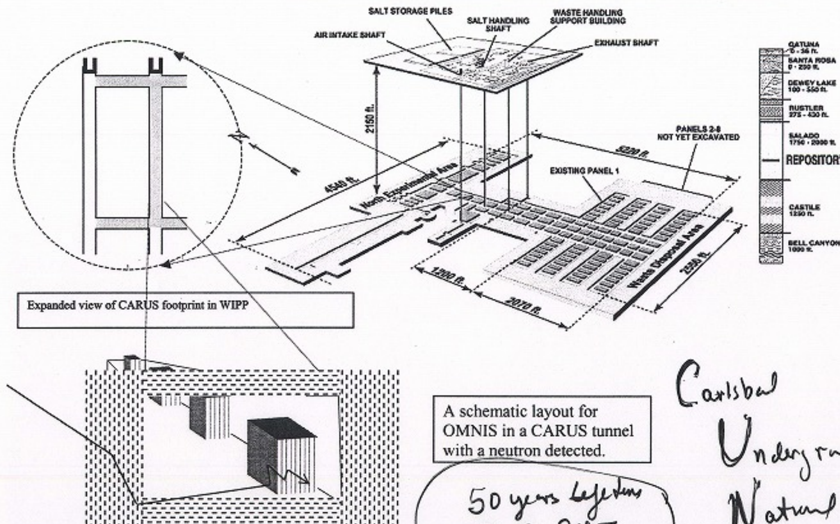
5000 T

{ICARUS AT HALL B
Good for
$\nu_\mu \to \nu_e$ detection (Θ_{13})}

LGNS Hall B

UCLA
04/26/01

WIPP Facility and Stratigraphic Sequence



Expanded view of CARUS footprint in WIPP

A schematic layout for OMNIS in a CARUS tunnel with a neutron detected.

50 years lifetime
⇒ 2 SN II
Detection

Carlsbad
Underground
National
Laboratory

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

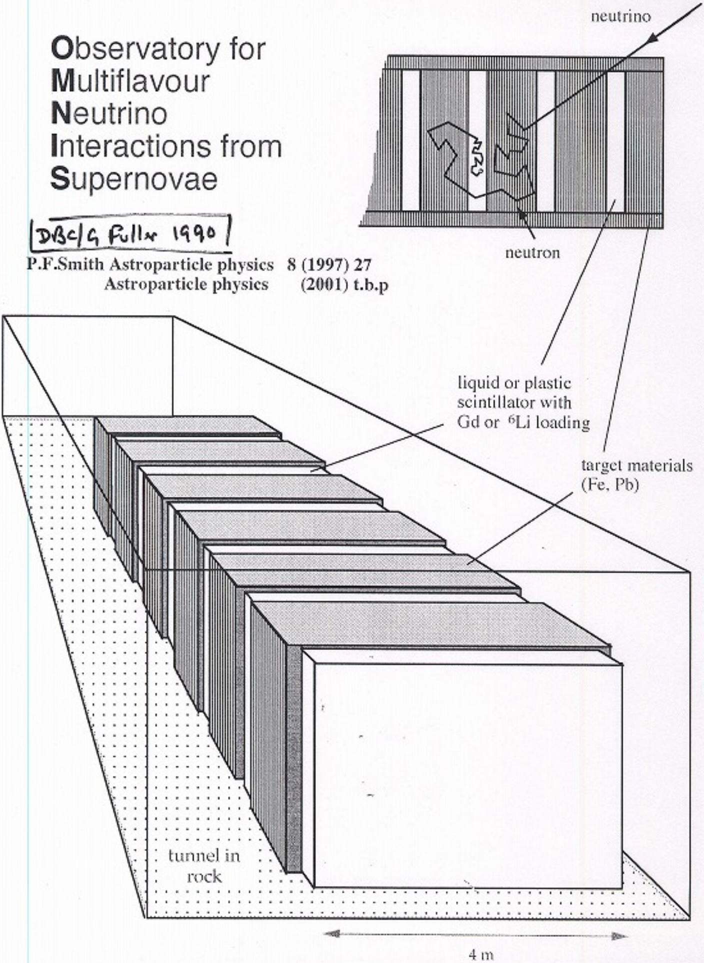


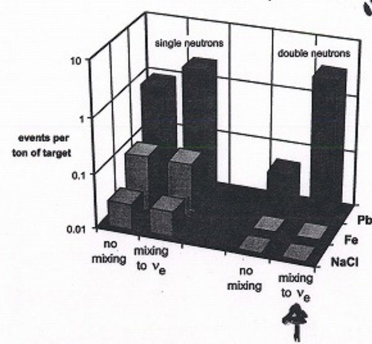
TABLE 6: YIELDS OF SUPERNOVA NEUTRINO DETECTORS

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**	**50**
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**	**360 counts:**
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****

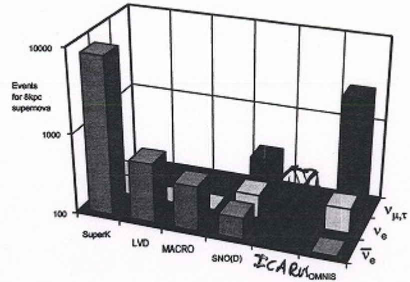
* Assumes same efficiency as in Smith 1997

** Assumes a single neutron detection efficiency of 0.6

2n/1n → Neutrino Oscillation in the SN II



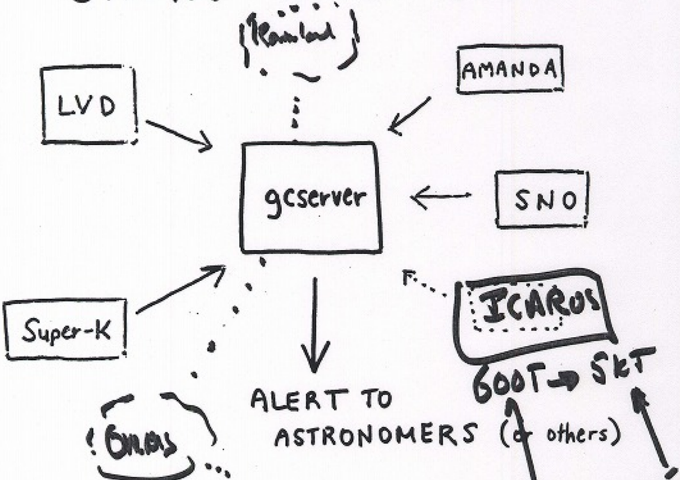
Comparison of events detected per ton of target for mixing versus no mixing and for 1n versus 2n events. The detection of large number of 2n events comparable to that of 1n events in the Pb target will be a clear indication of full MSW mixing. Alternatively, ratio of 1n events in the Pb and Fe target can be used to detect the presence of neutrino mixing by way of model calculations.



Comparison of neutrino event numbers from world underground detectors, for a supernova at 8 kpc, showing that OMNIS is complementary to other detectors.

K. Scholberg

SNEWS IMPLEMENTATION



Each experiment sends a datagram if it finds a burst with:

- experiment no.
- time of 1st event

Current configuration: kaboom server @ Kamioka

Alert if ≥ 2 different exp'ts within 10 seconds

Alert message does not yet go automatically

10^{16} – 10^{20} eV Neutrinos

OWL PROJECT

UCLA workshop
Nov 1999

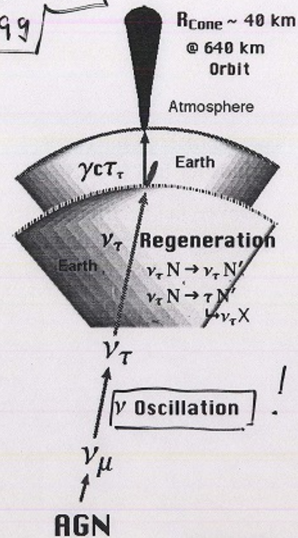
Tau Neutrino Regeneration

• The diameter of the Earth becomes opaque to neutrinos for E > 40 TeV

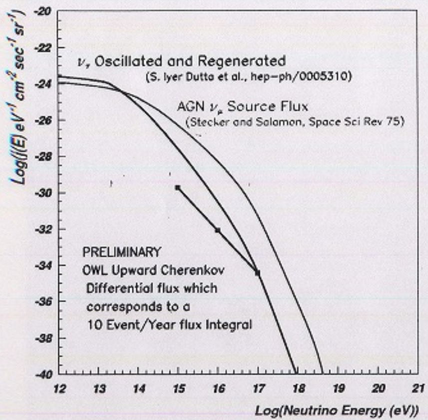
• However, tau neutrinos traverse the Earth albeit with degraded energy due to regeneration (Halzen & Saltzberg (1998), PRL 81)

• This effect opens the possibility to perform a cosmological long-baseline muon -> tau neutrino oscillation appearance experiment.

Directional Cherenkov radiation from upward airshowers → ~ 8 (E_ν /10^{15} eV) pe's for nominal OWL baseline.



Upward Airshower Flux Sensitivity

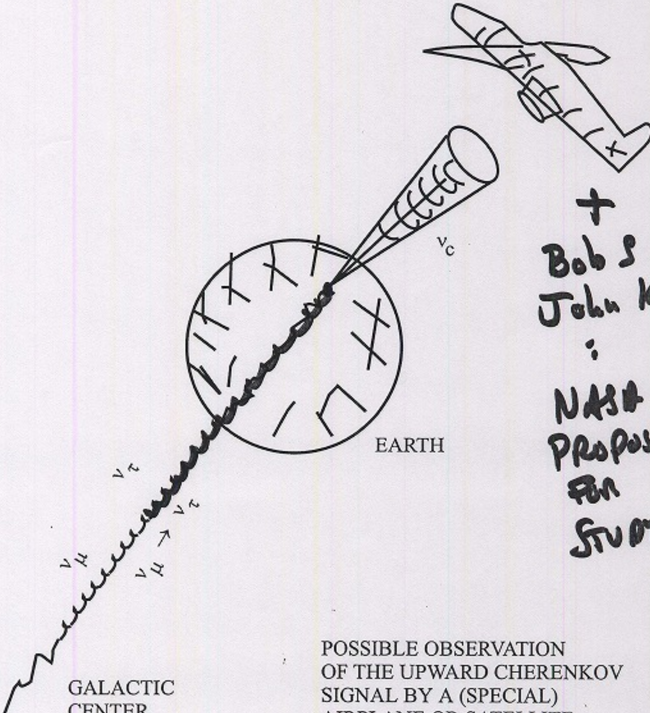


The Earth's crust is a huge neutrino target
(1 km^3 of ice ~ 10^{10} ton-ster ν Aperture)

Tau Energy	$\gamma c\tau_\tau$	***Effective*** **ν Aperture**
10^{14} eV	5 m	10^{11} ton-ster
10^{15} eV	50 m	10^{12} ton-ster
10^{16} eV	500 m	10^{13} ton-ster
10^{17} eV	5 km	~ 10^{14} ton-ster

Orbiting Wide-angle Light-collectors

DBC
D. Salzberg



\+ Bob S
John K
:
NASA
PROPOSAL
FOR
STUDY

POSSIBLE OBSERVATION
OF THE UPWARD CHERENKOV
SIGNAL BY A (SPECIAL)
AIRPLANE OR SATELLITE
POINTING BACK TO THE
GALACTIC CENTER

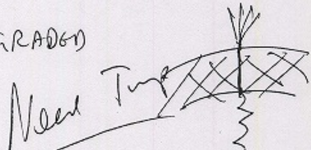
Mr SDI
Agents
:

Some New Ideas for Neutrino TARGETS

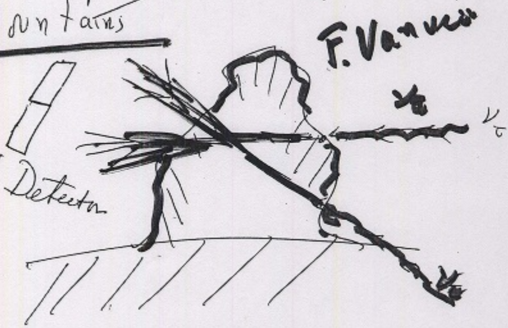
I Fargion
U Rome

F Vannucci Paris

1) CRUST of EARTH FOR UPWARD ν_τ's — ENERGY DEGRADED



2) Mountains



3) HORIZONTAL AIR SHOWERS
COULD BE ν_τ INDUCED

ONE INTERESTING POSSIBILITY

A mini GRB from a UHE τ decay

$\nu_e \to e$ in earth e is absorbed

$\nu_\mu \to \mu$ μ loses energy gently

$\nu_\tau \to \tau$ - τ penetrates the crust and τ decays

$$\tau \to \ldots \pi^0 \ldots$$
$$\hookrightarrow \gamma \gamma$$

Would appear upward 'mini GRBs' -

Such strange events have been seen by BATSE TGF's (~ 75)

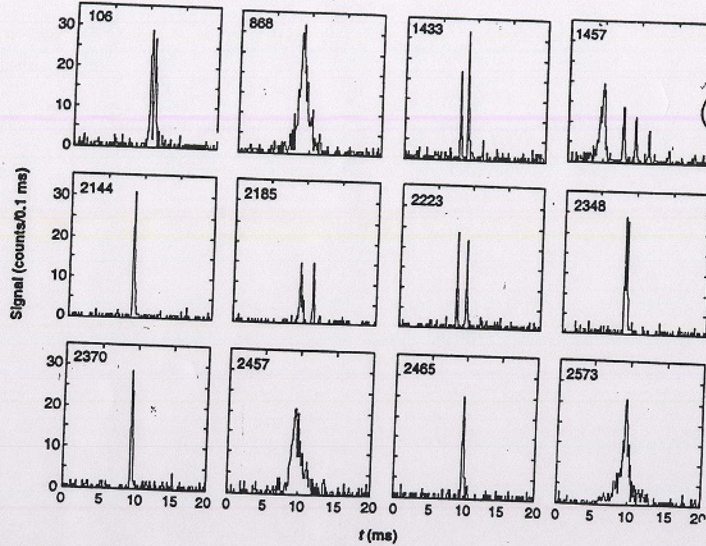


Fig. 4. Time profiles of the events listed in Table 1 (arbitrary start time). The time resolution of the plots is 0.1 ms per bin. Multiple peaks are evident in many of the events, with peak separations from 1 to 4 ms. Typical rise and fall times are ~0.1 to 2.0 ms.

Some TFG Events

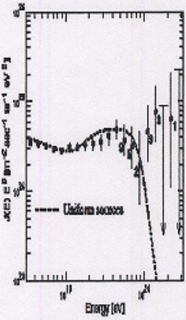
1) Some Correlation with Thunderstorms

2) Some Events too long $\Delta t > 2$ ms

But Some could be k_c Interaction

UHE NEUTRINOS > 10^{19} eV

The Mystery of the Highest Energy Cosmic Rays

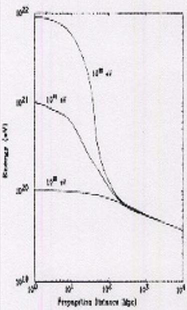


Takeda et al. (1998) PRL, **81**,1163

- Greisen-Zatsepin-Kuz'min (GZK) effect implies source must be close (< 50 Mpc) if UHECR are nuclei.
- 'Bottom-up' acceleration to 10^{20} eV is difficult, and no nearby sources are evident.
- Alternate hypothesis, UHECR are the result of a 'top-down' process, i.e. topological defects ($E_{TD} \sim 10^{25}$ eV) or Z-bursts.

OWL will identify source of UHECR by extending energy reach to > 10^{21} eV

Item	'Bottom-up'	'Top-down'
Proton Spectrum	Softer	Harder
Photon Spectrum	Softer (γ's are *secondaries*)	Harder (γ's are *primaries*)
Neutrino Flux	Softer (ν's are *secondaries*)	Harder (ν's are *primaries*)



Cronin (1992), Nucl Phys B (Proc Suppl) **28B**, 213

OWL

The OWL Collaboration

NASA GSFC Laboratory for High Energy Astrophysics
University of Utah
University of Alabama, Huntsville
NASA MSFC
UCLA
Washington University
Columbia University
Vanderbilt University
Rutgers University
Montana State University

IN NASA LONG RANGE PLAN FOR [illegible] -PROJECT

Outline:

- Science Motivation
- The OWL Concept
- Preliminary OWL Simulation Results

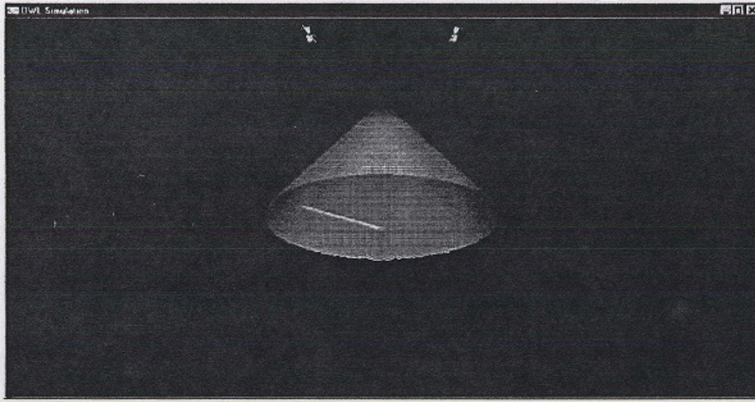
Orbiting Wide-angle Light-collectors

FUTURE SPACE BASED STUDY

The Orbiting Wide-angle Light-collectors Experiment

(10^{20}–10^{21} eV Neutrinos)

http://owl.gsfc.nasa.gov/



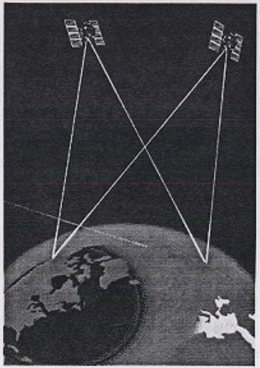
John Krizmanic

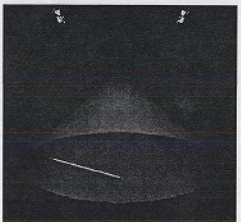
USRA/NASA/GSFC Code 661

for the OWL Collaboration

Orbiting Wide-angle Light-collectors

The OWL Concept





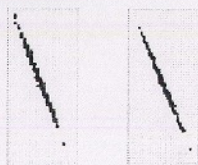
Use air fluorescence technique to image 300 → 400 nm photons in ~ 0.1^{O} pixels (with 10 ns → μs timing), from low Earth, equitorial orbit, airshowers induced by $E \gtrsim 10^{19}$ eV cosmic rays

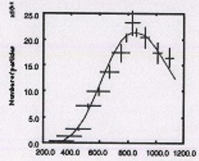
Wide angle (~ 60^{O} full, FOV) optics at a 600 - 1200 km orbit in a stereo configuration → an asymptotic, *instantaneous* aperture ~ 3 x 10^6 km^2-ster (640 km orbit, 60^{O} full, FOV)

10% duty cycle → *effective* aperture ~ 3 x 10^5 km^2-ster

Assuming Φ_{CR} (E) ~ $E^{-2.75}$, the asymptotic OWL stereo aperture leads to ~ 3000 events/year with $E \geqslant 10^{20}$ eV

OWL could be a stepping stone to viewing majority of night side atmosphere





Orbiting Wide-angle Light-collectors

OWL Preliminary Electron Neutrino Event Rates

640 km Orbits, 10% Duty Cycle, 2.5 m Optical Aperture

Interaction	2 Satellites Independently `Looking Down'	Stereo 500 km Sat. Sep.	Stereo 2000 km Sat. Sep.
$p\gamma_{2.7K}$ (1)	16 Events/Year	5 Events/Year	1 Events/Year
Topological Defects (2)	46 Events/Year	17 Events/Year	13 Events/Year
Z_{Burst} (3)	20 Events/Year	9 Events/Year	20 Events/Year
$E_{Threshold}$	10^{19} eV	2 x 10^{19} eV	10^{20} eV
No. of Satellites Viewing Event	1	2	2

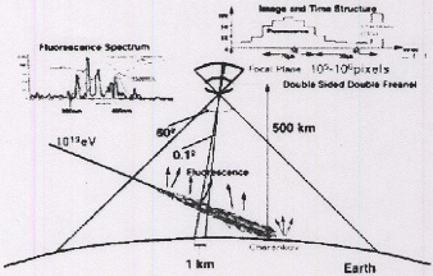
1 Stecker, Done, Salamon, &Sommers, PRL 66 (1991)
2 Sigl, Lee, Bhattacharjee, & Yoshida, Phys Rev D 59 (1998), $m_X = 10^{16}$ GeV, X -> q+ q, SuperSymmetric fragmention
3 Yoshida, Sigl, & Lee, PRL 81 (1998), $m_\nu = 1$ eV, Primary $\Phi_\nu \sim E^{-1}$

rbiting
ide-angle
ight-collectors

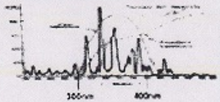
EUSO Concept

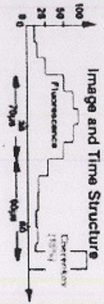
FOR Columbus Module on the Space Station

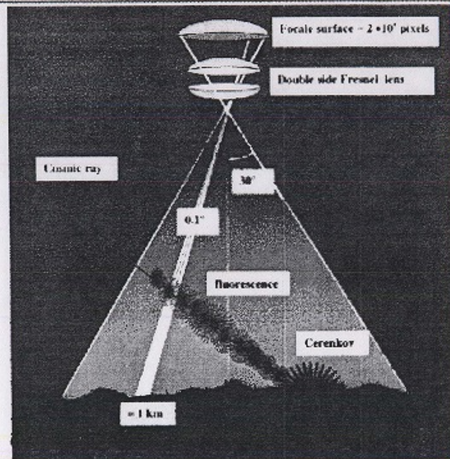
1st Stage Approved by ESA



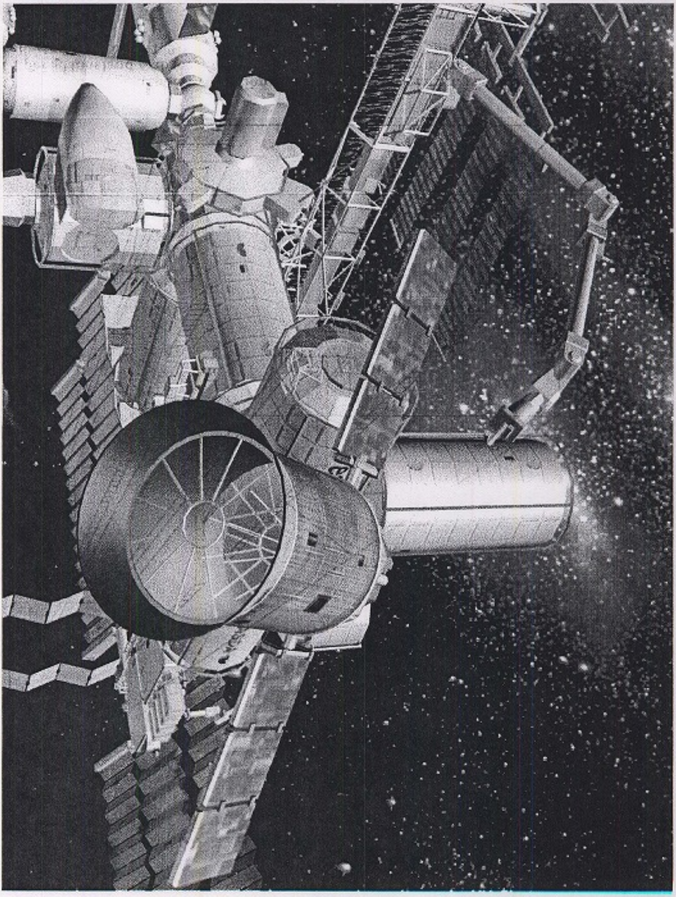
EUSO Approach







EUSO : Extreme Universe Space Observatory



UNIVERSAL NEUTRINO FACTORY DETECTOR AT CARLSBAD

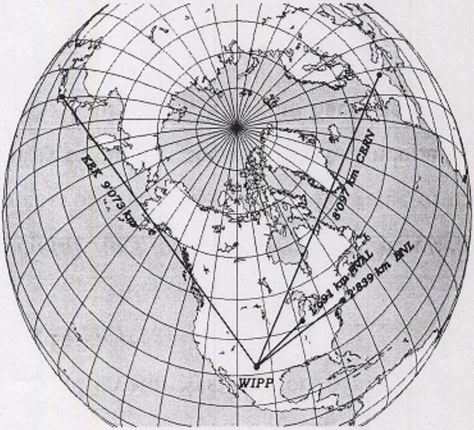


Figure 2. Schematic of the possible neutrino factory beams to the CUNL site.

This detector may also be used to study

- $p \rightarrow K^+ \bar{\nu}_\mu$ to $\tau = 10^{35}$ years
- Neutrinos from SN II Explosion
- Solar Neutrinos / Atmospheric Neutrinos

CUNL

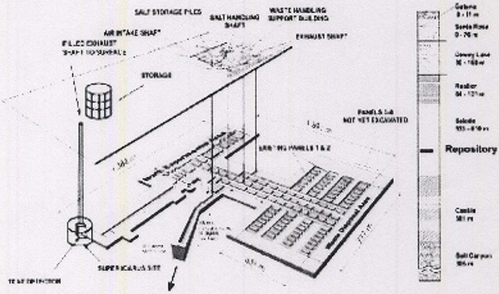


Figure 1. *Liquid Argon Neutrino and Nuclear Decay Detector at the CUNL site.*

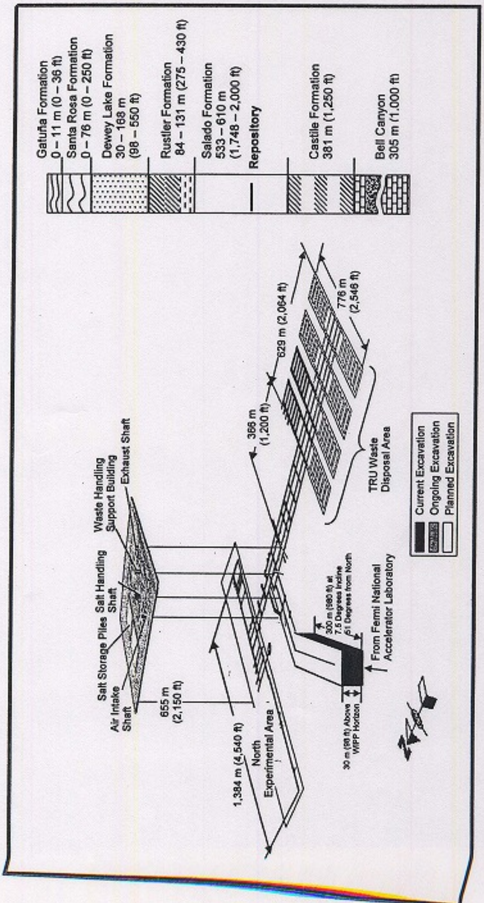
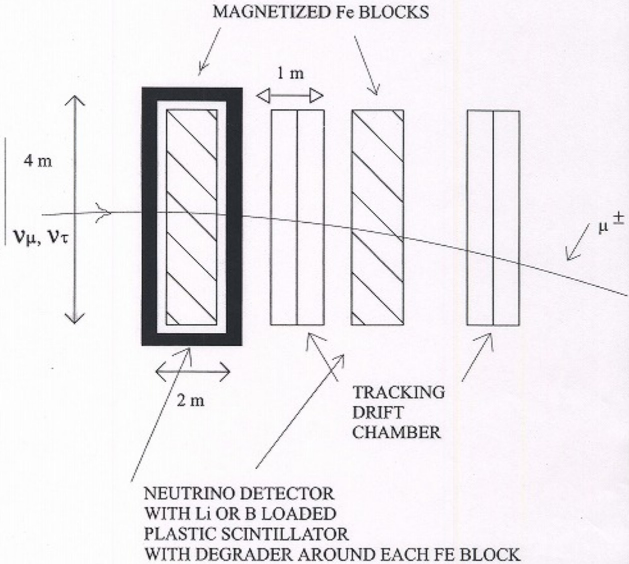


Figure 2-6. Proposed Neutrino Factory Detector at WIPP

A COMBINED NEUTRINO FACTORY TRACKING DETECTOR AND OMNIS/Fe SUPERNOVA DETECTOR



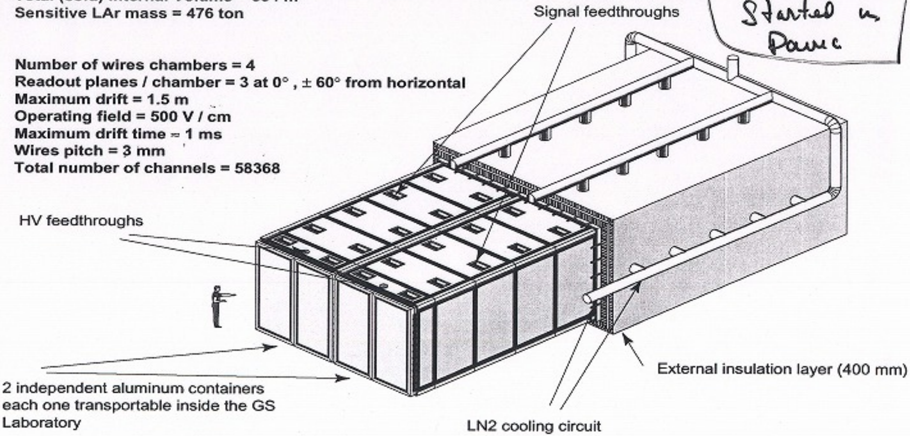
The ICARUS T600 module

Under construction

First Fill of 300 Ton Started in 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



Liquid Argon Neutrino and Nucleon Decay Detector
LANNDD

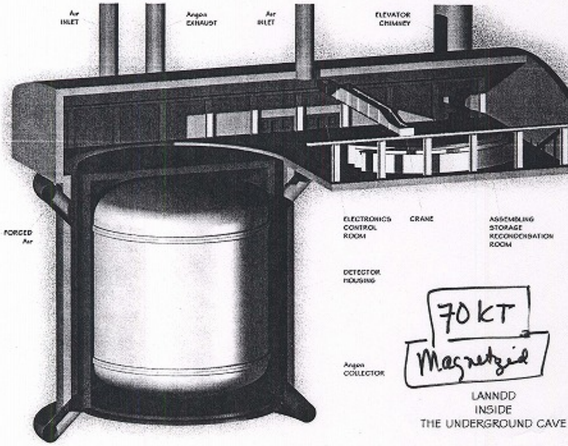


Figure 5. *The LANNDD inside the underground cave*

- $p \to K^+ + \bar{\nu}_\mu$ to 10^{35} years
- Universal Neutrino Factory Detector

(LANNDD)

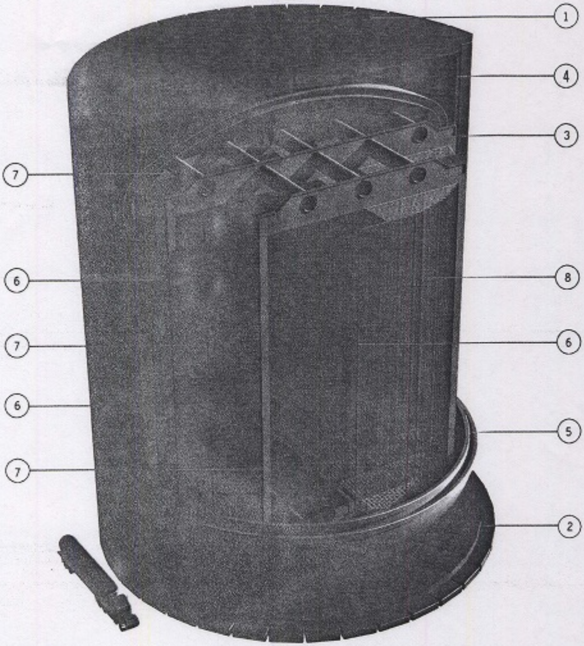


Figure 4. *Artistic view of the preliminary sketch for the LANNDD detector: 1) Top end cap iron yoke; 2) Bottom end cap iron yoke; 3) Barrel iron return yoke; 4) Coil; 5) Cryostat; 6) Cathodes; 7) Wire chamber frames; 8) Field shaping electrodes.*

SUMMARY

1) $\nu_\mu \to \nu_\tau$ Oscillation will have Important Effect on Neutrinos from the Universe

2) SuperNova Neutrino are a "Neutrino Factory"
   - With Correct Set of Detectors can even measure θ_{13} to very low Value
   [$10^6 - 10^8$ eV]

3) In the [$10^{12} - 10^{14}$ eV] Range New Water / Ice Detectors AMANDA / ICECUBE NESTOR / BAIKAL ..

4) UHE NEUTRINOS [$10^{15} - 10^{21}$ eV]
   → UPWARD ν_τ EVENTS COULD BE IMPORTANT – TFA ?
   → AUGER / HI RES / TELESCOPE ARRAY
   → OWL / EUSO FOR $10^{20} - 10^{21}$ eV
   COULD BE TOTALLY NEW PHYSICS [TOP DOWN]

5) A UNIVERSAL NEUTRINO FACTORY DETECTOR COULD ALSO STUDY PROTON DECAY ETC
(ICARUS) → CUNL / LANNDD / UNO / ..