Venice, Feb 23, 1999

"Neutrino Telescopes"

Maurice Goldhaber

Introduction.

Emission Experiments

- **1914** Chadwick: evidence for continuous β spectrum;
- **1927** Ellis and Wooster: calorimetric proof of missing energy in β-decay;
- **1929** Bohr: hypothesis that energy is not conserved in β-decay;
- **1930** Pauli: proposal of neutrino.

Natural Sources of Neutrinos

(1) Solar Neutrinos

(2) Atmospheric Neutrinos

(3) Supernova Neutrinos

Man-made Sources of Neutrinos

(1) Reactors

(2) Accelerators

Neutrino

Neutretto

Neutralino

Calculation of Atmospheric Neutrino-Induced Backgrounds in a Nucleon-Decay Search

T. J. Haines, R. M. Bionta, G. Blewitt, C. B. Bratton, D. Casper, R. Claus, B. G. Cortez, S. Errede, G. W. Foster, W. Gajewski, K. S. Ganezer, M. Goldhaber, T. W. Jones, D. Kielczewska, W. R. Kropp, J. G. Learned, E. Lehmann, J. M. LoSecco, J. Matthews, H. S. Park, L. R. Price, F. Reines, J. Schultz, S. Seidel, E. Shumard, D. Sinclair, H. W. Sobel, J. L. Stone, L. Sulak, R. Svoboda, J. C. van der Velde, and C. Wuest

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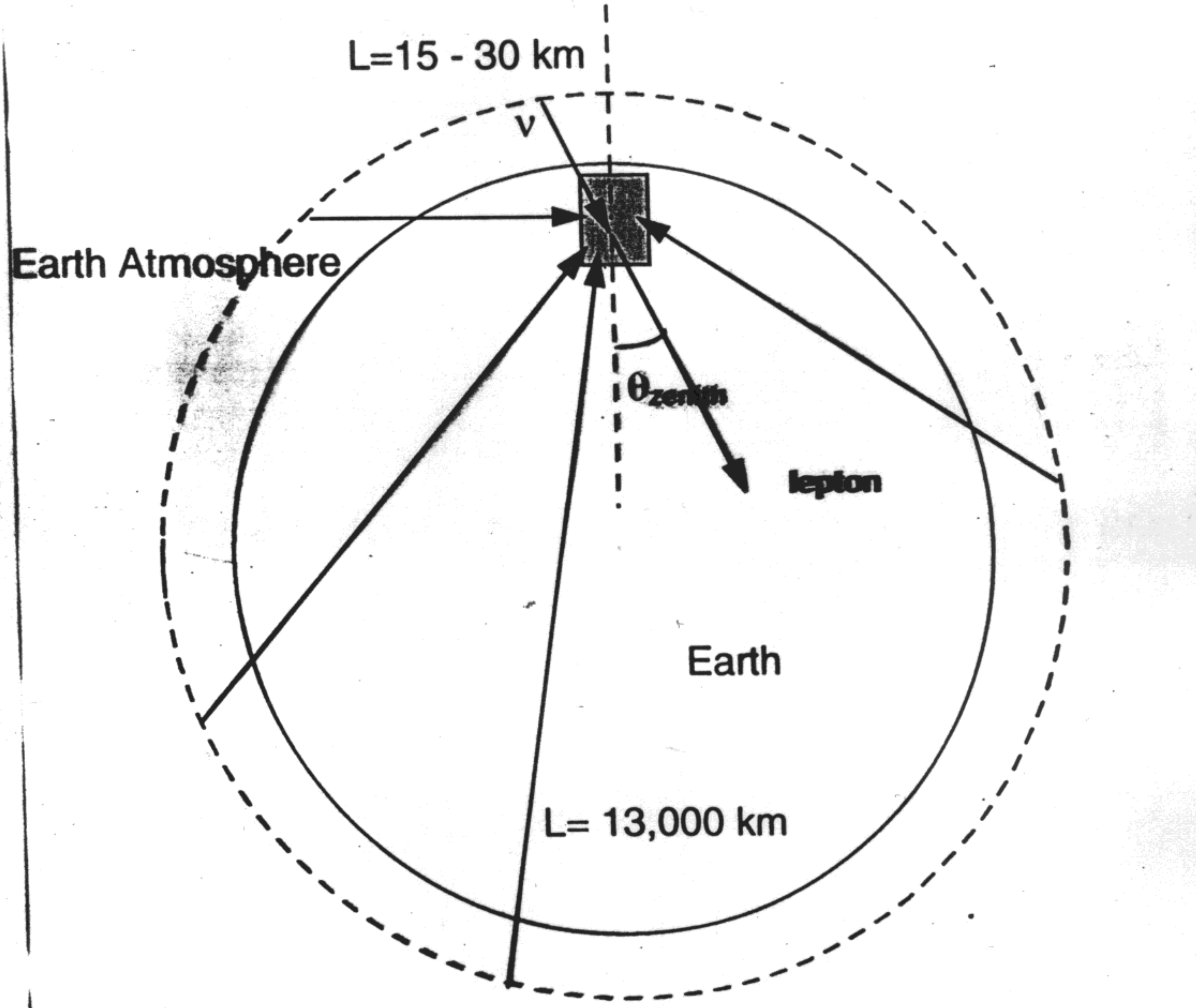
(Received 6 June 1986)

The simulation predicts that 34% ± 1% of the events should have an identified muon decay while our data has 26% ± 3%. This discrepancy could be a statistical fluctuation or a systematic error due to (i) an incorrect assumption as to the ratio of muon ν's to electron ν's in the atmospheric fluxes, (ii) an incorrect estimate of the efficiency for our observing a muon decay, or (iii) some other as-yet-unaccounted-for physics.

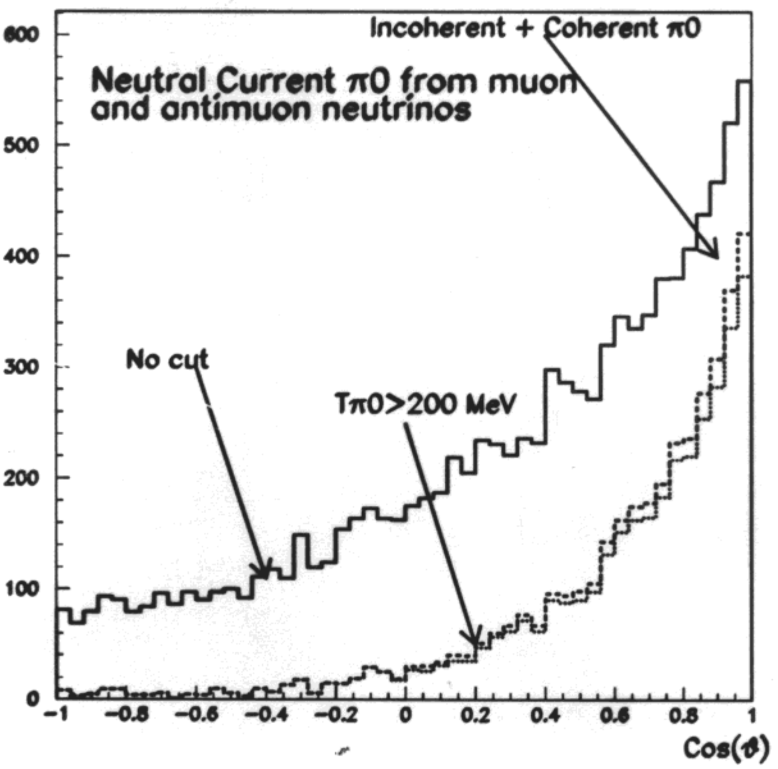
Neutrino flux dependence on the zenith angle due to neutrino oscillation

$$P_{\nu \rightarrow \nu'} = \sin^2 2\theta \, \sin^2 (1.27 \, \Delta m^2 \, L/E)$$

$$L = f(\theta_{zenith})$$



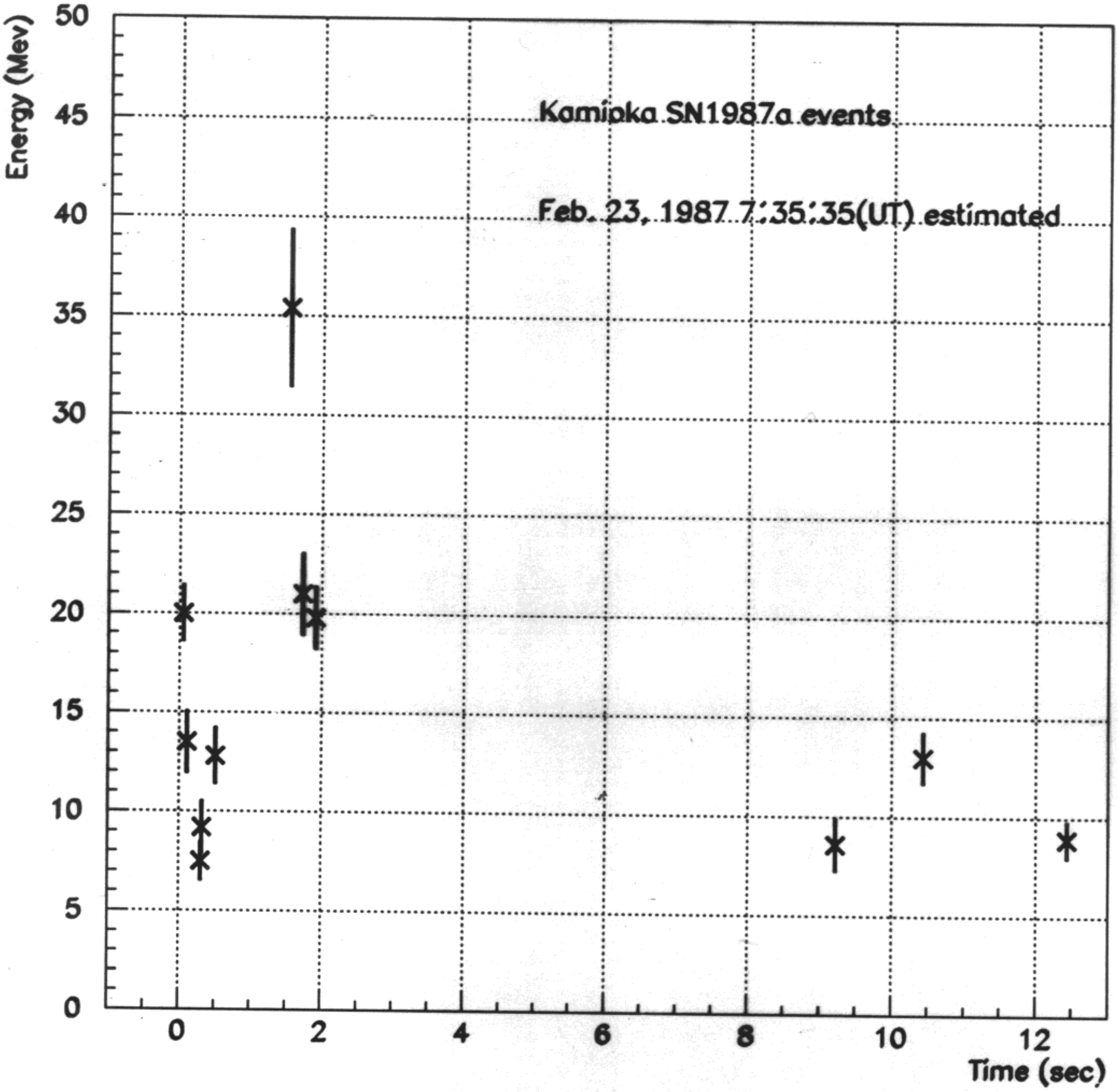
NC π^0 Production off water from atmospheric muon neutrinos



- Check atmospheric muon neutrino up/down asymmetry using neutral current π^0.
- $\sigma(\nu_\mu\ (p/n/O) \Rightarrow \nu_\mu\ (p/n/O)\pi^0) \approx 0.18\sigma(\nu_\mu n \Rightarrow \mu^- p)$
- A modest cut on the π^0 kinetic energy enhances the π^0 direction and should reduce backgrounds.

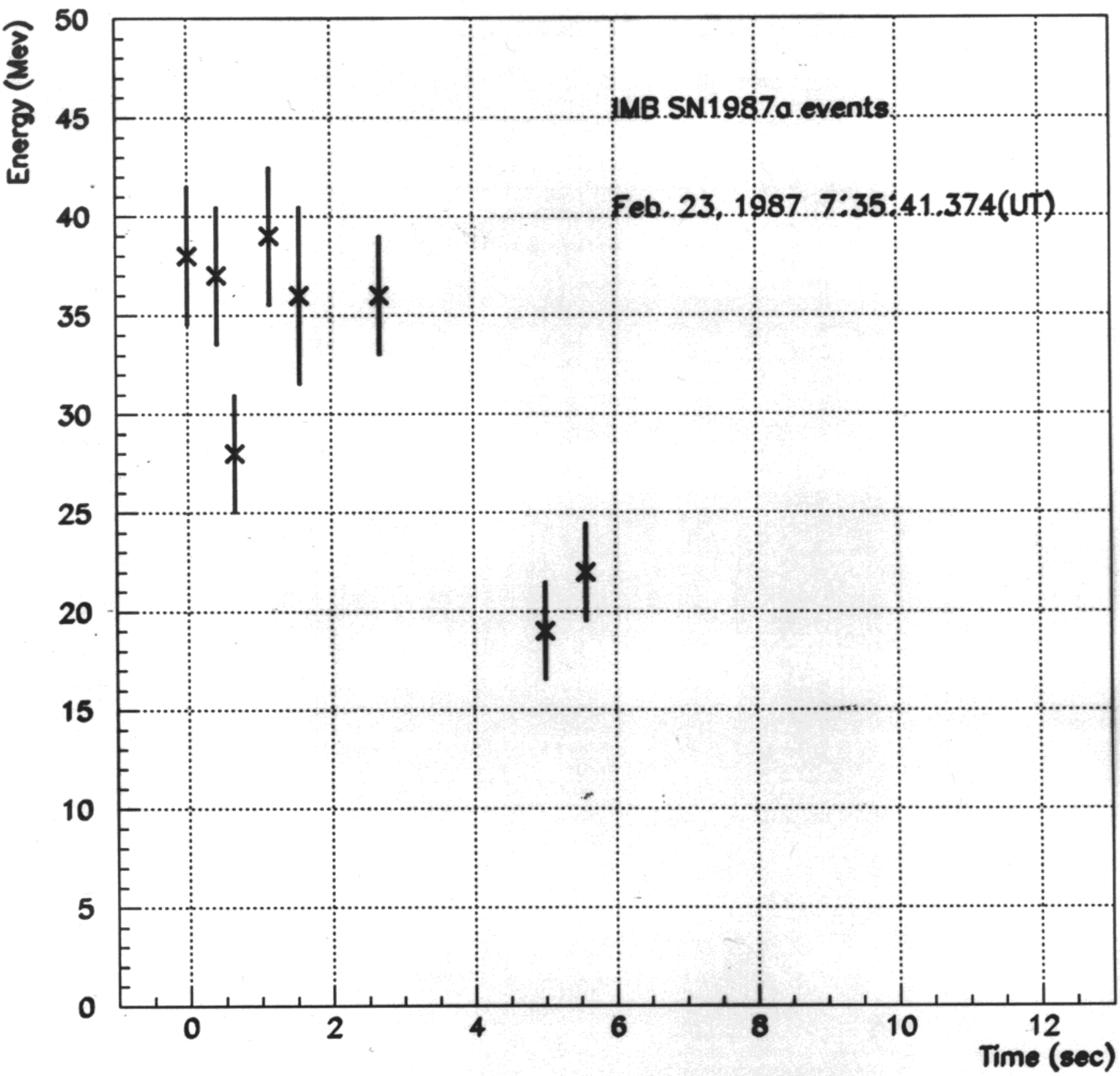
3/11/98 diwan

99/02/18 14.35



Kamioka SN1987a events
Feb. 23, 1987 7:35:35(UT) estimated
Energy (Mev)
Time (sec)
0
5
10
15
20
25
30
35
40
45
50
0
2
4
6
8
10
12

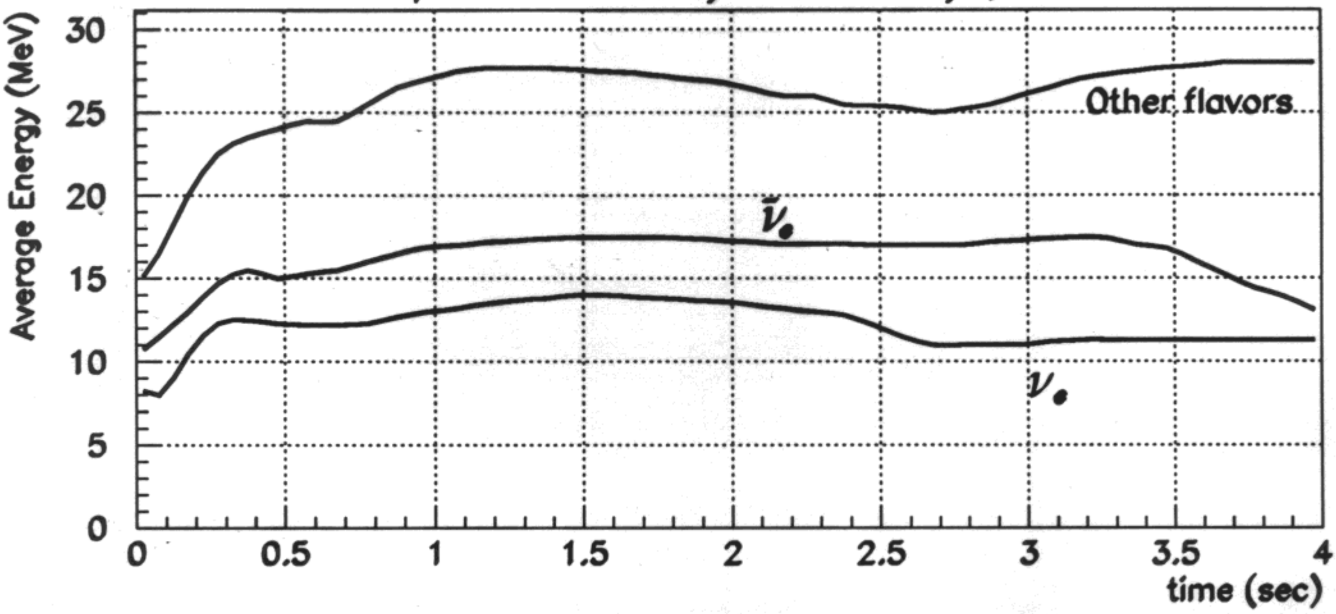
99/02/18 14.35

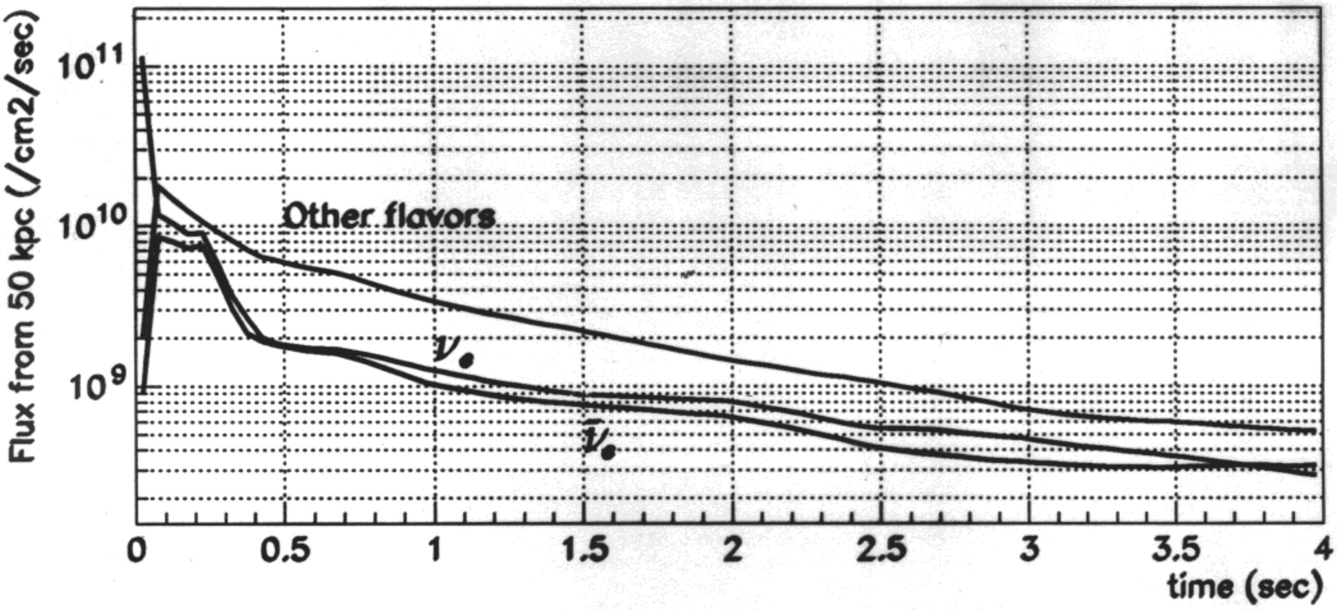


IMB SN1987a events
Feb. 23, 1987 7:35:41.374(UT)
Energy (Mev)
50
45
40
35
30
25
20
15
10
5
0
0
2
4
6
8
10
12
Time (sec)

99/02/18 21.15

Supernova-II model by Wilson and Mayle, 1989





M. Diwan

If maximally mixed, the neutrino flavor changes are after phase averaging:

Short distance (large Δm^2) (order of Earth radius)	Long distance (small Δm^2) (order of Sun-Earth or Super Nova distance)
$\nu_e \to \nu_e$	$\nu_e \to \frac{1}{2}\nu_e + \frac{1}{4}\nu_\mu + \frac{1}{4}\nu_\tau$
$\nu_\mu \to \nu_\tau$	$\nu_\mu \to \frac{1}{4}\nu_e + \frac{3}{8}\nu_\mu + \frac{3}{8}\nu_\tau$
$\nu_\tau \to \nu_\mu$	$\nu_\tau \to \frac{1}{4}\nu_e + \frac{3}{8}\nu_\mu + \frac{3}{8}\nu_\tau$

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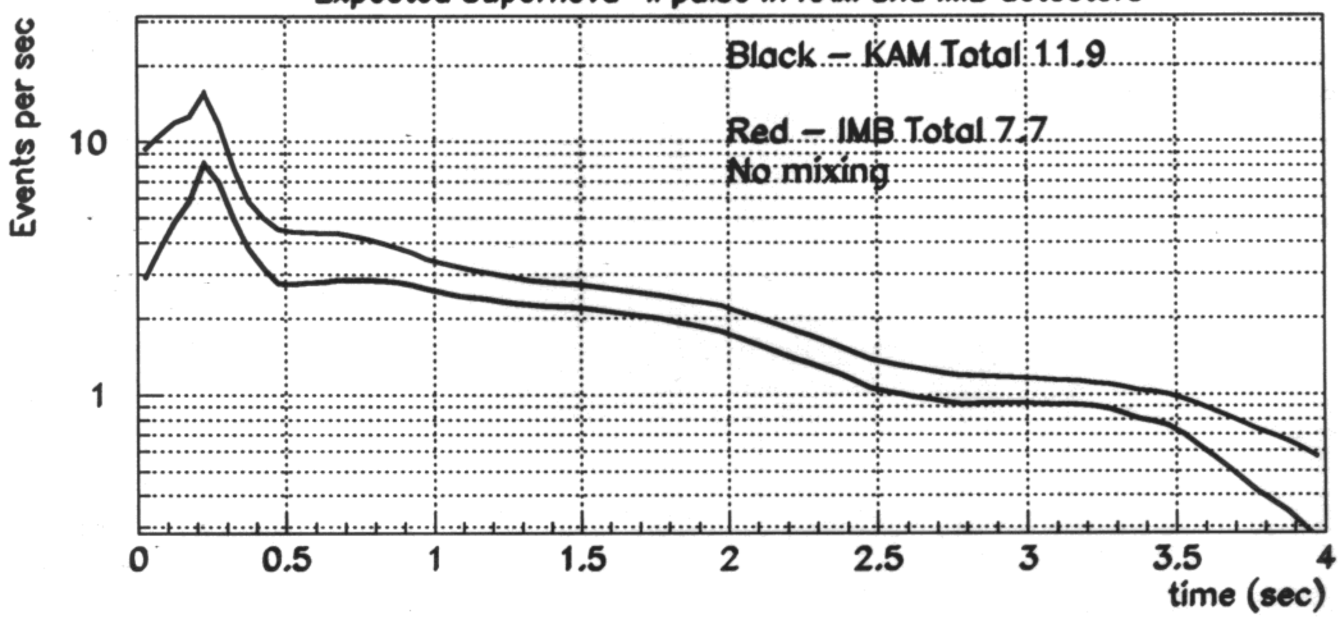
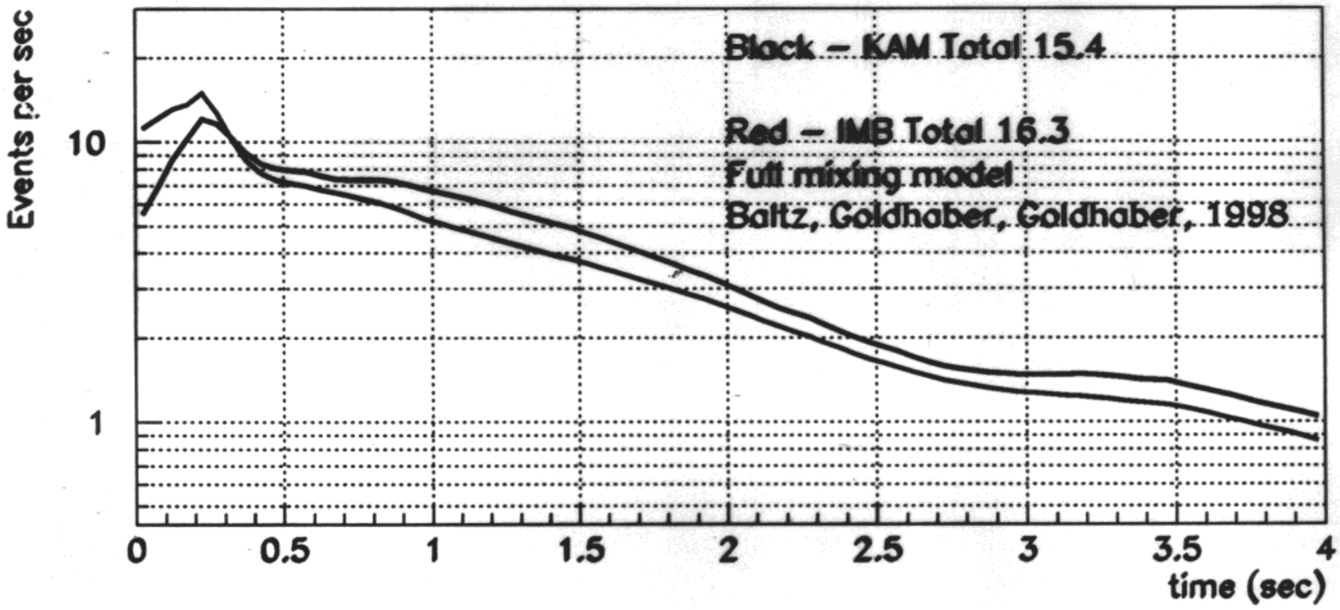
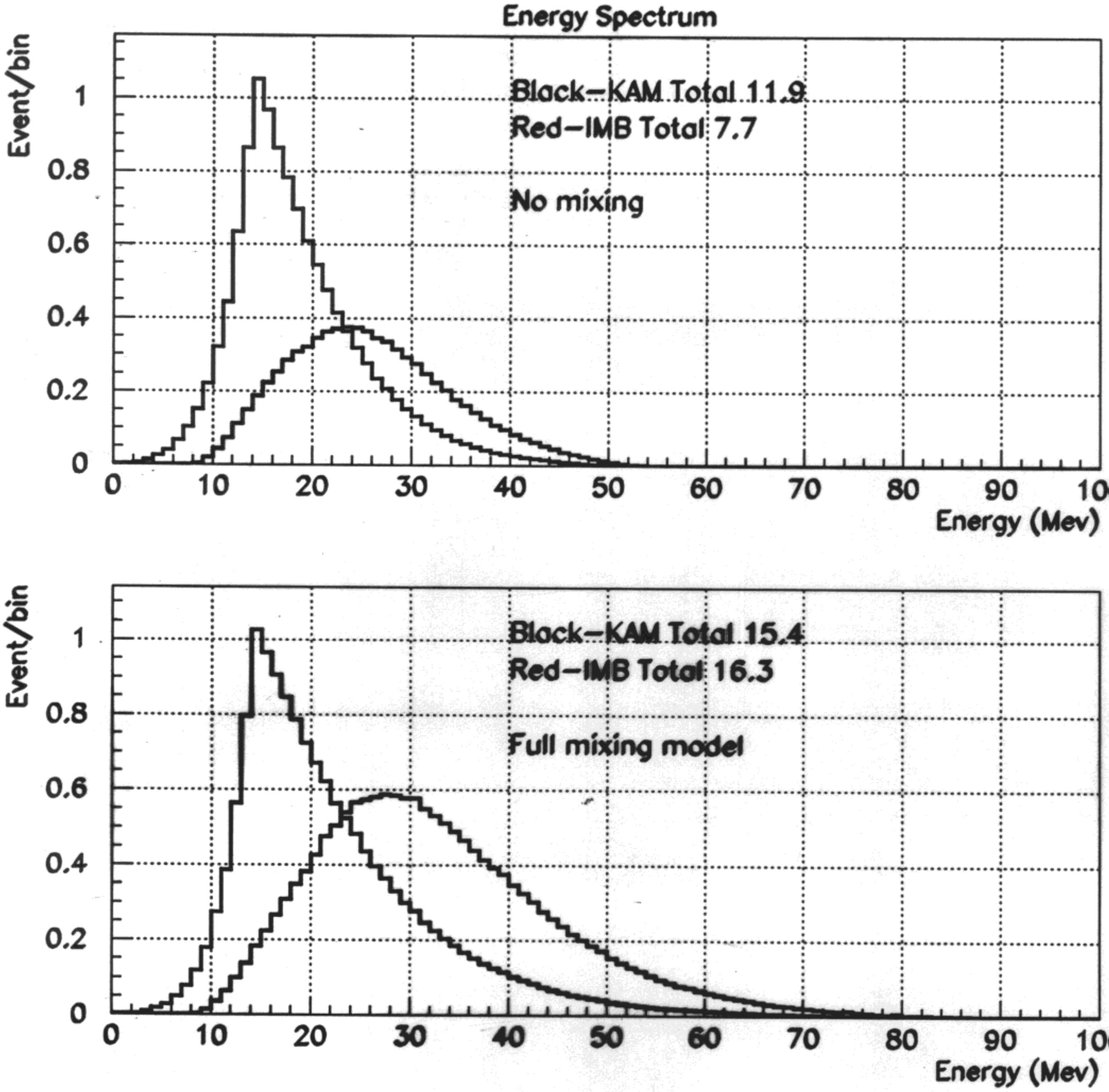
Expected Supernova-II pulse in KAM and IMB detectors





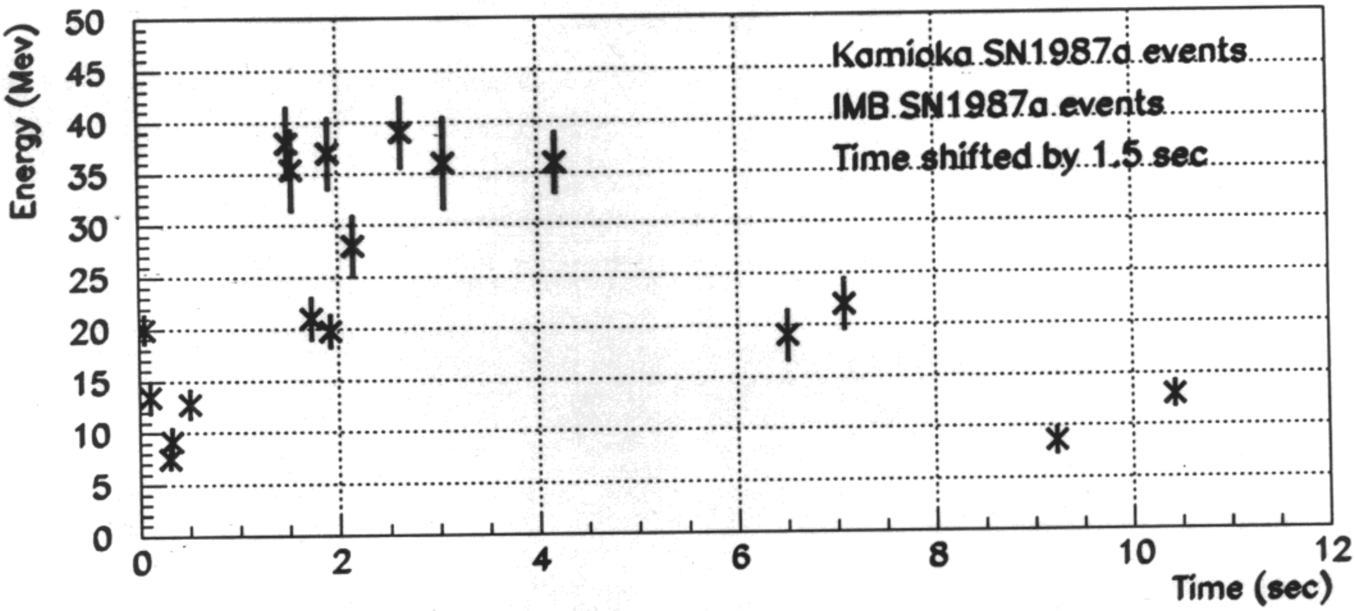
M. D.

99/02/18 21.45



M.D.

98/11/04 11.54



Kamioka SN1987a events
IMB SN1987a events
Time shifted by 1.5 sec
Energy (Mev)
Time (sec)
50
45
40
35
30
25
20
15
10
5
0
0
2
4
6
8
10
12

A cautionary tale on a "new degree of freedom":

K, L, M,.... were originally called

A, B, C,....

C.G. Barkla (~ 1910) **thought that if an X-ray edge more energetic than A were** found, we would not know what to call it. **He therefore suggested the switch to K, L, M,....**

<u>and</u>

promptly **found J radiation!**

Neutrino Oscillations & Lepton Flavor Violating Decays

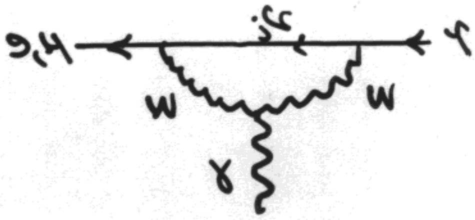
SuperK → Maximal $\nu_\mu - \nu_\tau$ osc.

$$\Delta m^2_{32} = m_3^2 - m_2^2 \simeq 3\times10^{-3}\,eV^2$$

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix}\cos\theta_{12} & \sin\theta_{12} & 0\\ -\sin\theta_{12}/\sqrt{2} & \cos\theta_{12}/\sqrt{2} & 1/\sqrt{2}\\ \sin\theta_{12}/\sqrt{2} & -\cos\theta_{12}/\sqrt{2} & 1/\sqrt{2}\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

All FCNC Decays Suppressed By $m_3^4/m_W^4 \sim 1.5\times10^{-49}$!!

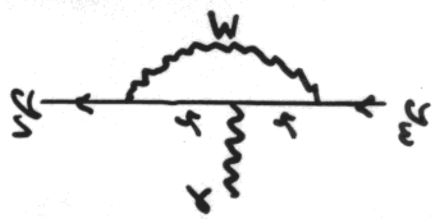
eg. $\tau\to\mu\gamma$ or $e\gamma$



$$\Gamma(\tau\to\ell\gamma) \sim \frac{G_F^2 m_\tau^5}{192\pi^3}\underbrace{\left(\frac{3}{8}\frac{\alpha}{\pi}\frac{m_3^4}{m_W^4}\right)}_{2\times10^{-52}\,!}$$

$$\tau(\tau\to\ell\gamma) \simeq 10^{33}\,yr\ !!$$

Neutrino Decays: $\nu_3 \to \nu_2\gamma$ or $\nu_1\gamma$



Further Suppressed by Phase Space

$$\tau(\nu_3\to\nu\gamma) \sim 10^{40}\,yr \gtrsim 10^{30}\,\tau_{universe}\ !$$

All other leptonic FCNC Induced Decays Suppressed

Only ν-osc phenomena observable

W. Marciano

Workshop for the

Next Generation Nucleon Decay and Neutrino Detector (NNN99)

September 23-25, 1999
SUNY at Stonybrook, NY, USA

Working groups

- Nucleon decay
- Neutrino Oscillations
- Neutrino Astrophysics

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