The History of Atmospheric Neutrino Oscillations

And Its Own History

John M. LoSecco

Physics Department University of Notre Dame du Lac

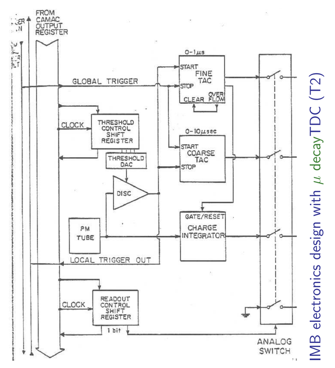
Contact Information:
Physics Department
University of Notre Dame du Lac
Notre Dame, Indiana 46556-5670, USA
Phone: +1 (574) 631 6044
Email: losecco@nd.edu

Abstract

From the start (1983-85) IMB found too few ν_μ. We looked for hardware or simulation deficiencies. Stopping cosmic ray muons were as expected. Searches for physics causes included oscillations tests in 1985. We published evidence of the deficit in 1986 and sought confirmation. Our evidence was confirmed in 1988.

Problems – IMB has too few muon signals

Author	When	Expected	Observed
Cortez & Foster PhD's	9/83	33±2%	22±4%
Schumard PhD	84	35±1%	26±4%
Blewitt PhD	10/85	34±1%	26±2%
LoSecco (LL) $\frac{\nu_e}{\nu_\mu}$	2/86	0.64	1.3
Phys. Rev. Let.	6/86	34±1%	26±3%
Haines PhD & SWOGU/ICOBAN Toyama, Japan	86	34±1%	26±3%



IMB electronics design with μ decayTDC (T2)

Extensive studies of stopping cosmic ray muons confirmed the correct response of the detector to muons. Multiple neutrino interaction sources and models were studied.

Kamiokande does not ... too many

Source	Date	Exposure kt-yrs	Events	M type Obs/MC	Event Rate per kt-yr	Expected Event Rate
5'th WGU	1984	0.485	80	Agreed	165	Agreed
Arisaka Thesis	1985	0.661	84	1.03	127	129
6'th WGU	1985	0.840	99	1.13	118	111
Kajita Thesis	1986	1.11	133	1.19	120	108

IMB explored ν oscillations via Up/Down comparisons and L/E in Phys. Rev. Lett. **54**, 2299 (1985) and ICRC 1985.

Management – of IMB *Information Tightly Controlled*

- Information tightly controlled ... Why? recognition? 12/11/80

```
in the results we will be getting.  We would like to avoid
things like the Alternating Current effect and the High Why
Anomaly.

(3)  Any preprints, talks, or other material intended for
publications or distribution, which contains discussion of,
or substantial reference to, our detector or its techniques
should be checked with all collaboration members before being
distributed.
```

- Senior members had very strong control. Careers could be ruined.
  - I had been fired from my first post doc job (E310) since I was skeptical of the high Y anomaly.
- Senior members had been involved in recent, very public mistakes.
- Reines *et al.* had discovered neutrino oscillations in 1980. $\bar{\nu}_e D$ NC/CC at SRP – Phys. Rev. Lett. 45, 1307 (1980)

```
                    ROUGH DRAFT                    4/21/80

To:  DOE
FROM:  IMB COLLABORATION
SUBJECT:  INCREASED FUNDING RATE FOR PROTON DECAY-NEUTRINO
          OSCILLATION EXPERIMENT.

     The recent discovery of neutrino oscillations(1) has
vast implications for particle physics and cosmology.  It is
```

- Proton decay was the highest priority.
- If it were known that we did not understand our detector response it would jeopardize our discovery of proton decay.
- Neutrino oscillations limits were OK. No hints of a ν_μ problem could be approved or shown.
- Secrecy had one good consequence; one maintained good records to keep *history* right.

Other Indications

August 27, 1985, while at the Aspen *Underground Physics* meeting with Y. Suzuki I realized Kamiokande also had a *"T2 problem"*. They had not noticed it.

Kamioka also has a T2 problem
Compatible with our own.

I could not discuss IMB's results at the time due to secrecy rules.
I reported this observation at the IMB collaboration meeting, November 14-16 1985.

February 1986 – Lake Louise IMB has $\nu_e/\nu_\mu \approx 1.3$ expect 0.64

Most proton decay detectors have reported a neutrino flux as measured in their detectors[4),6),8),12)]. In general the agreement with expected fluxes is good. Both the Kamioka detector[18)] and the Nusex detector[4)] can distinguish ν_e from ν_μ by shower development. They quote a ν_e/ν_μ flux ratio of 0.36 ± 0.08 and 0.28 ± 0.11 respectively. These are lower than the expected value[6)] of 0.64. The IMB group has studied the fraction of their contained events resulting in a muon decay[8)]. The 26% observed can be converted to a ν_e/ν_μ ratio with a number of assumptions about muon capture in water. If 40% of the ν_μ interactions do *not* result in a muon decay signal the observed value corresponds to $\nu_e/\nu_\mu \approx 1.3$.

This talk was a review based on public information such as Geof Blewitt's Caltech PhD thesis.

June 1986 – IMB Phys Rev Lett

```
simulation predicts that 34%+/-1% of the events should have
an identified muon decay while our data has 26%+/-2%.  This
discrepancy could be a statistical fluctuation or a          8 ± 2.2
systematic  error due to (i) an incorrect ratio of muon ν's
to electron ν's in the atmospheric fluxes, or (ii) an
incorrect estimate of the efficiency for our observing a
muon decay, or (iii) some other physics.
```

Draft of Apr 10, 86 and May 15, 86: *note Binomial errors* More details in Haines UC Irvine PhD thesis

This publication created the opportunity for discussion of the ν_μ rate outside the collaboration since once the paper was released secrecy was lifted.

Seek Confirmation from Kamiokande

After the ν'86 meeting in Sendai I stopped in Tokyo to emphasize our anomaly and to point out problems in the Kamiokande data. At the time Kamiokande was reporting a 1.6σ excess of M(uon) type events (with M/S analysis), but their data also showed a 2.4σ deficiency of muon decays which they failed to note. I suspected this would confirm our 3.5σ muon deficit. No confirmation was provided at that time.

January 1988 Confirmation by Kamiokande–Thanks

tectors. The IMB experiment has not reported data in which electron-like and muon-like events are distinguished, but it has reported [10] that the fraction of observed events manifesting muon decays is $26 \pm 3\%$, while their Monte Carlo simulations predict that $34 \pm 1\%$ of all events should exhibit muon decays. The preliminary result on the ν_e/ν_μ ratio from

Also: M. Takita, ICRR Tokyo, PhD Thesis 1989

2005 Referee Report misleading citation

```
In citing previous work near the end of the introduction the authors have
overlooked the 1986 IMB-1 paper on this subject.  The IMB-1 paper was very
similar to the current work in that it compared detailed atmospheric neutrino
event rate estimates with observations and "observed significantly smaller
nu-mu to nu-e flux ratios of atmospheric neutrinos" and was the first to do
so.

*** RESPONSE: We felt it was beyond the scope of this paper to provide
a full historical documentation. We chose recent publications that most
clearly addressed the same measurements. The diligent reader can trace back
to earlier work if interested. We also note that we have many IMB
collaborators as authors of this paper, and they have checked off on this
approach.
```

In 2010 – The discovery date is given as 1986

neutrino interactions. However, the IMB[21)] and Kamiokande[22)] observed in 1986 that the fraction of events accompanied with a muon decay signal was less than expected. One of the possibilities for these data was a deficit of ν_μ events. However, these data

*Kamiokande[22)] makes no mention of muon rate

T. Kajita Proc.Jpn.Acad. Ser.B **86**, 303 (2010).

In 2015 – The discovery date is given as 1988?

Research accomplishments:

I have been working in Kamiokande and Super-Kamiokande experiments. In particular, I have been studying atmospheric neutrinos and neutrino oscillations. In 1988, we discovered the atmospheric muon-neutrino deficit (this was called atmospheric neutrino anomaly), which was confirmed to be due to neutrino oscillations 10 years later. In this study we showed that the nm / ne ratio observed in Kamiokande was only about 60% of the predicted ratio. Subsequently, in 1994,