SN1987A in the IMB Detector

R.Svoboda

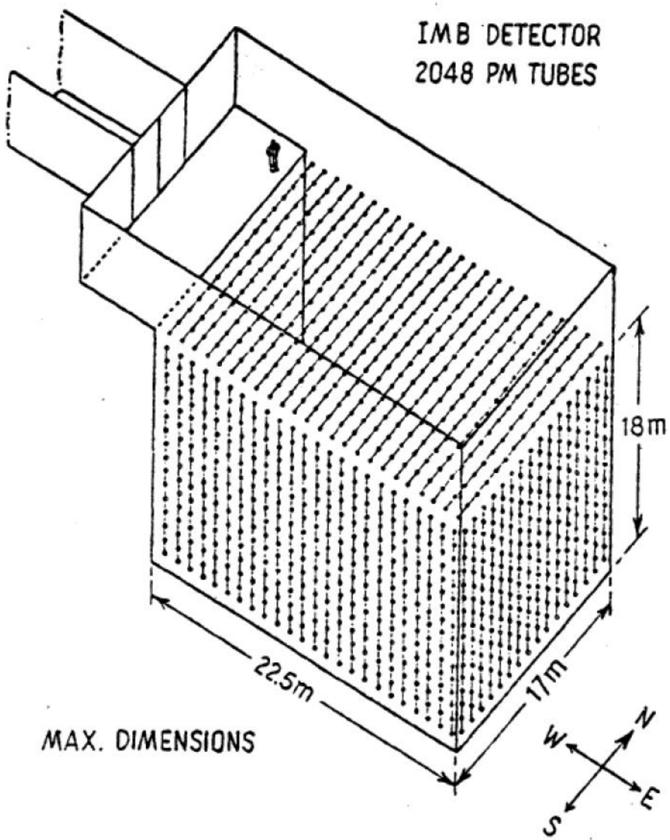
29 April, 2025

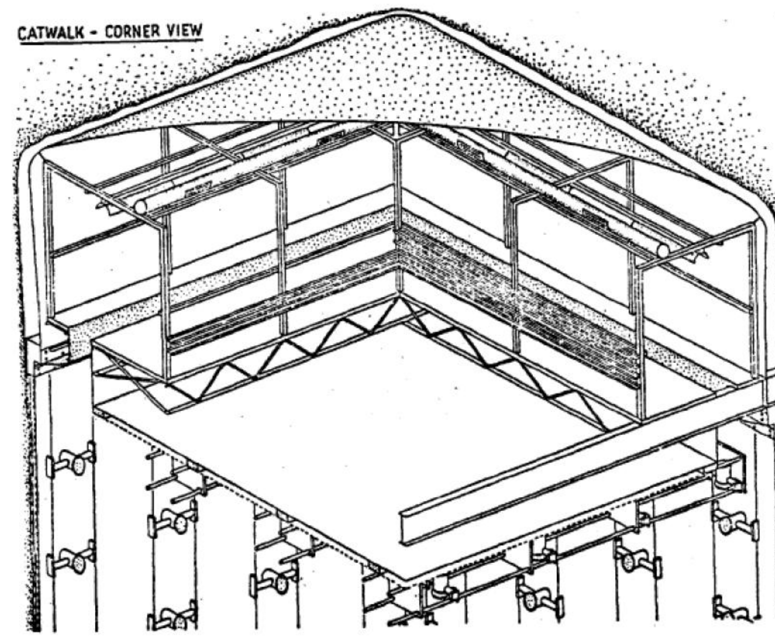
Einstein LoSecco

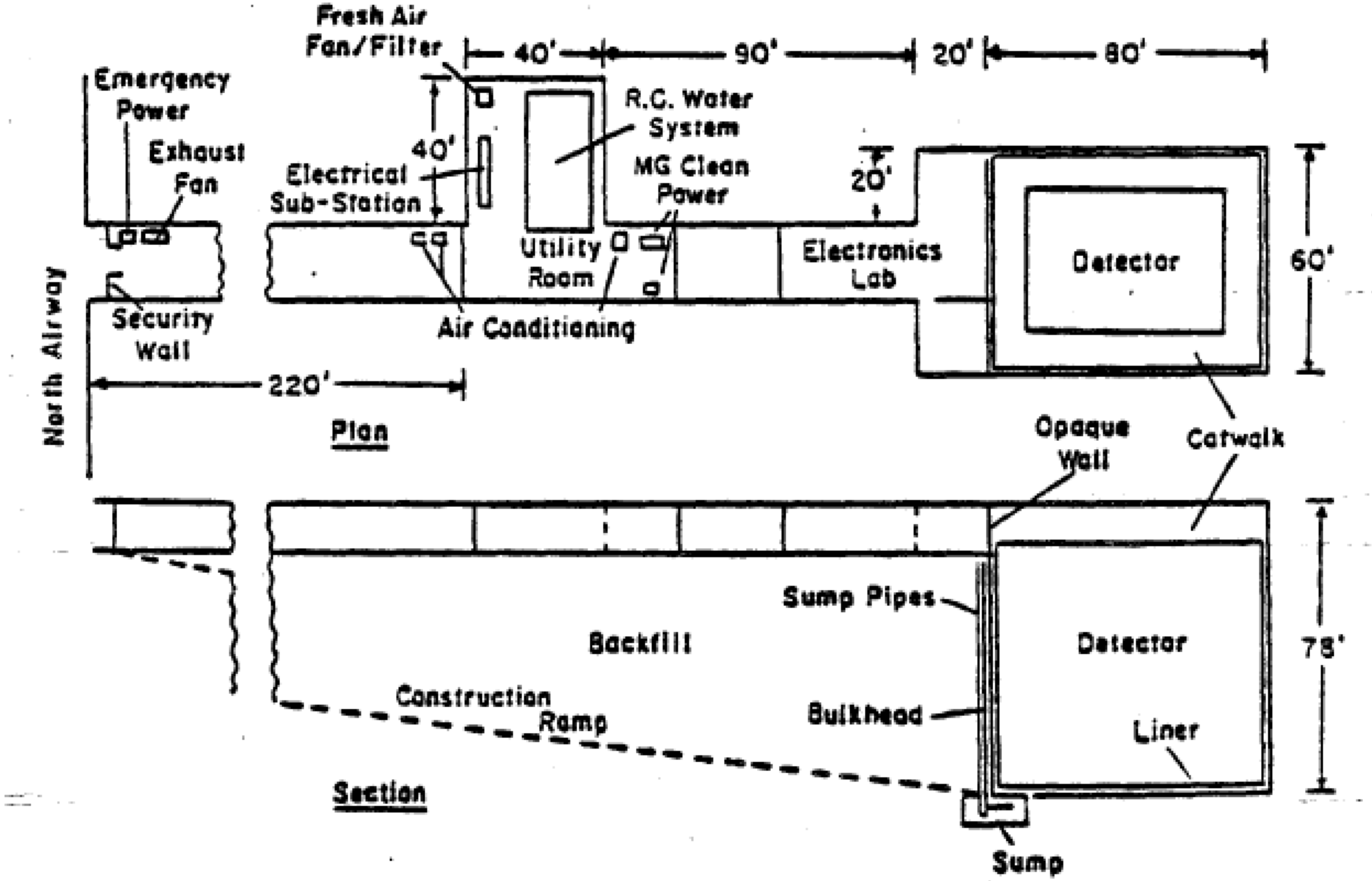
Smith Wuest Sinclair Learned Cortez

Bratton Sobel Vander Velde Goldhaber Reines Sulak

An Idea for a Large Imaging Water Cherenkov Detector



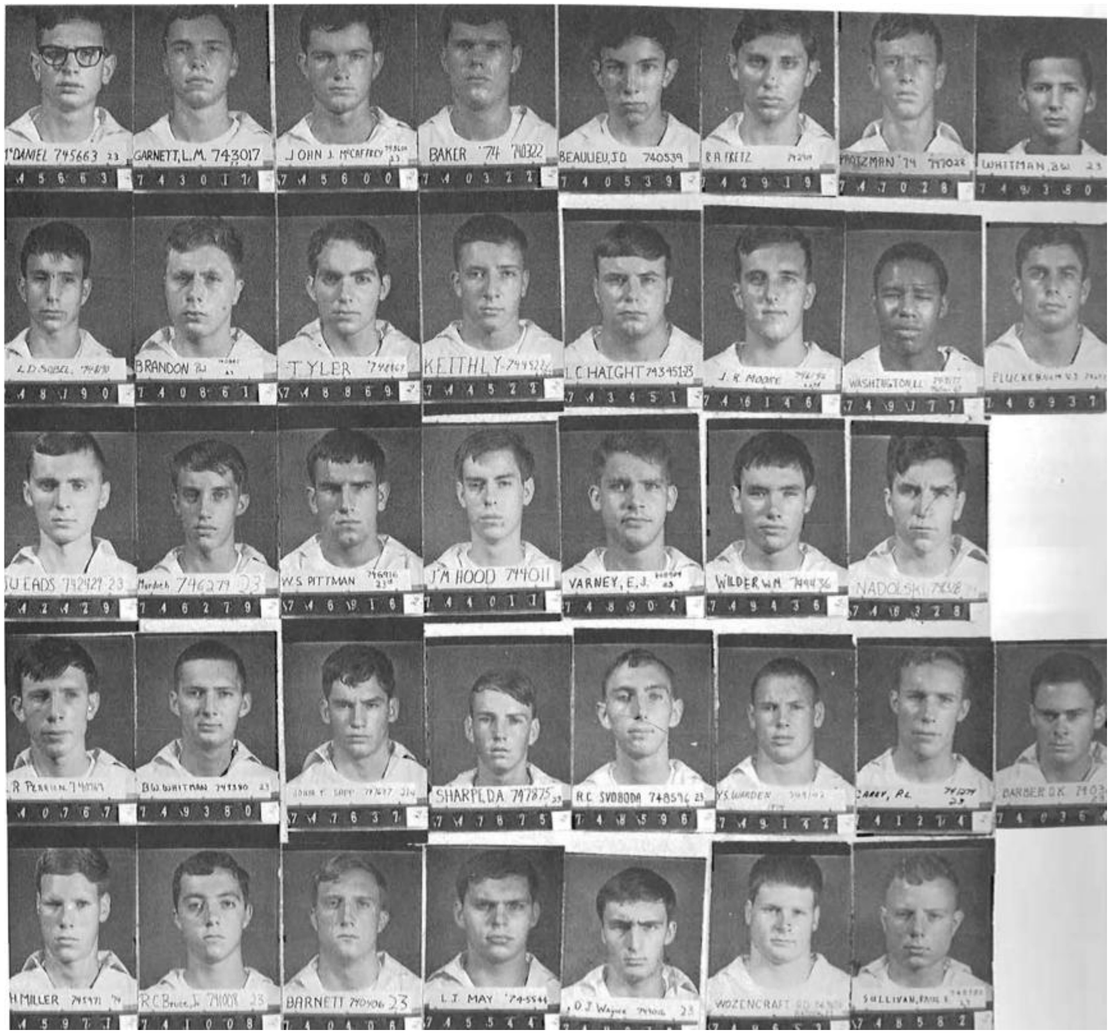




PROTON DECAY LABORATORY

I met John right after I got out of the Navy and entered graduate school

I went into the Navy since they offered FREE COLLEGE instead of Vietnam



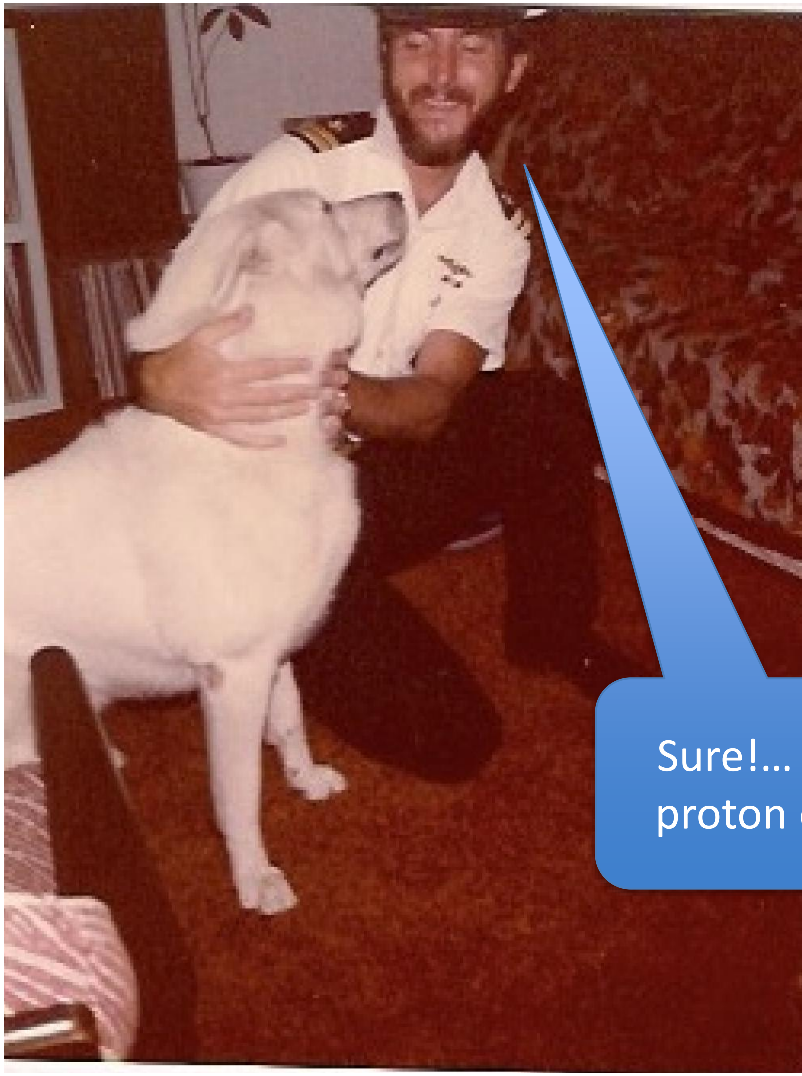
…but I knew my real love was science and engineering!

Which one is me?

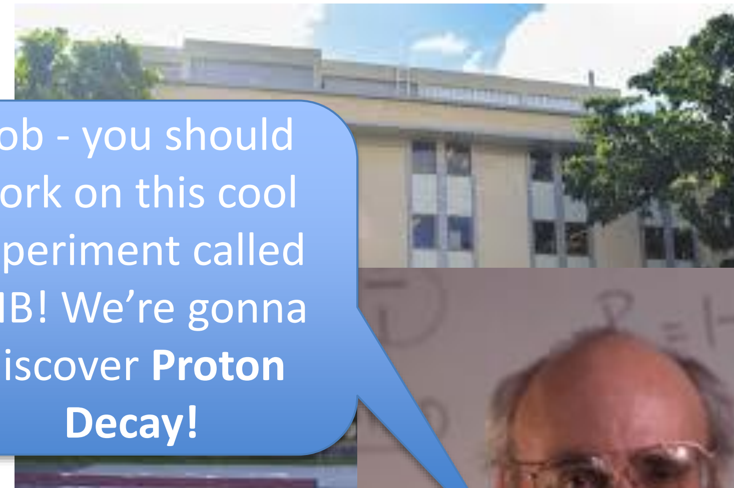
I went into the Navy since they offered FREE COLLEGE instead of Vietnam

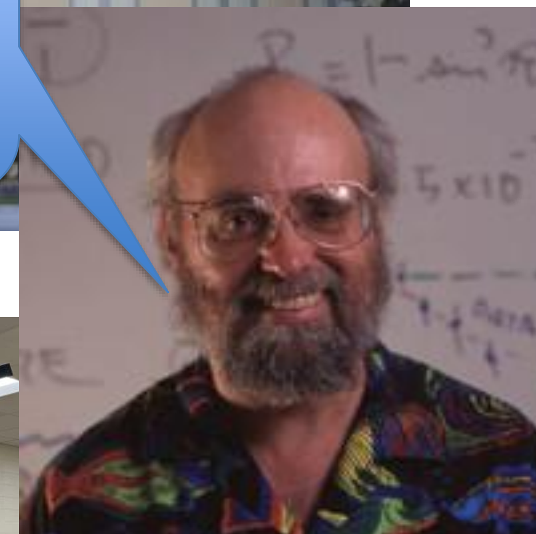
…but I knew my real love was science and engineering!

Which one is me?

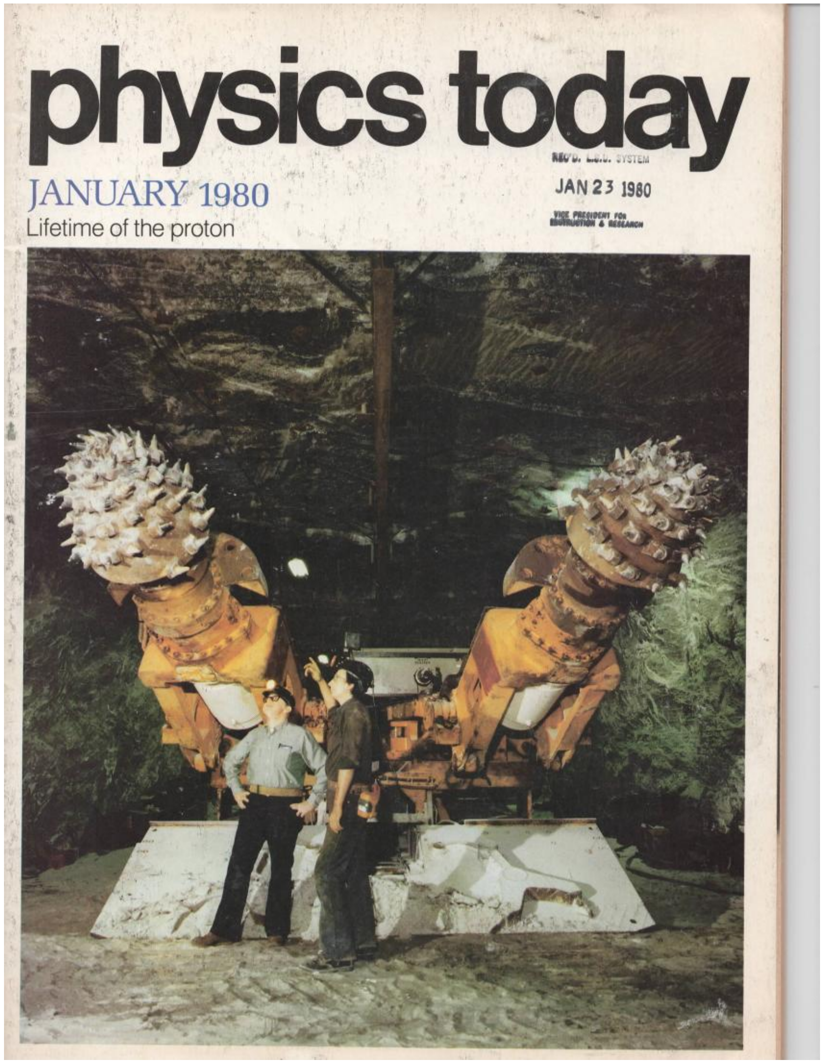


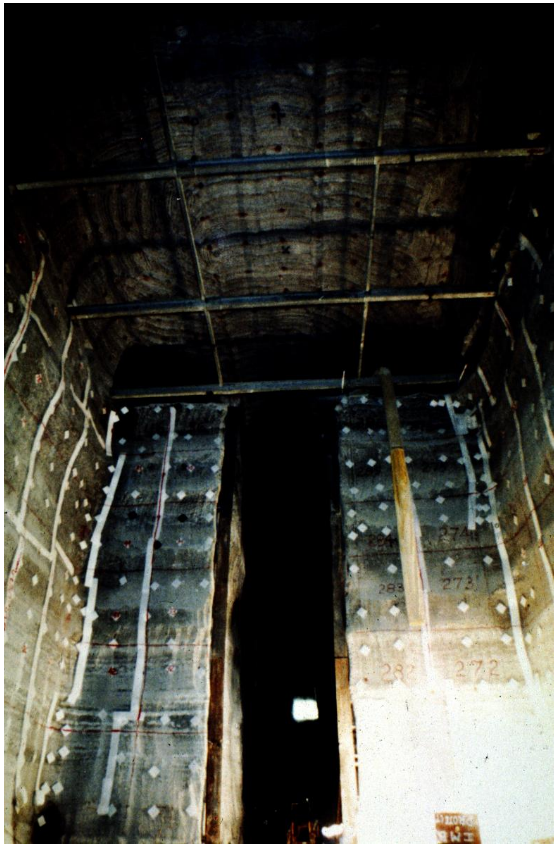
Last month in the Navy 1980





Morton Fairport Salt Mine



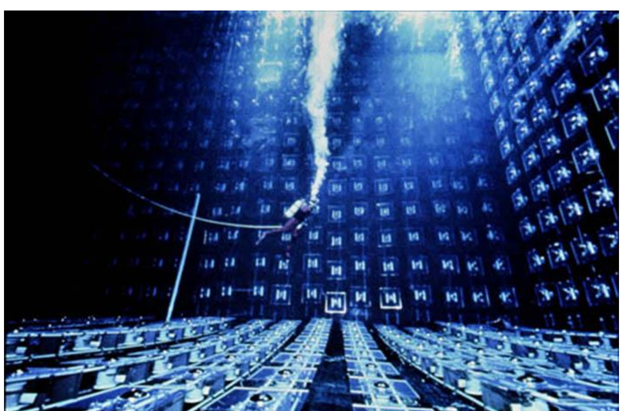


Ground broken for detector Hall at the mine in 1979

Cavern and hall excavation completed in 1981

Some leak problems, but
By end of summer 1982
IMB was running at full
size and data rate

First results on proton decay released in 1982



IMB control room

IMB DETECTOR - THE FIRST 30 DAYS*

R. M. Bionta[2], G. Blewitt[4], C. B. Bratton[5], B. G. Cortez[2,a], S. Errede[2], G. W. Foster[2], W. Gajewski[1], M. Goldhaber[3], J. Greenberg[2], T. J. Haines[1], T. W. Jones[2,7], D. Kielczewski[1], W. R. Kropp[1], J. G. Learned[6], E. Lehmann[4], J. M. LoSecco[4], P. V. Ramana Murthy[1,2,b], H. Park[2], F. Reines[1], J. Schultz[1], E. Shumard[2], D. Sinclair[2], D. W. Smith[1,c], H. Sobel[1], J. L. Stone[2], L. R. Sulak[2], R. Svoboda[6], J. C. van der Velde[2], and C. Wuest[1].

(1) The University of California at Irvine
Irvine, California 92717

(2) The University of Michigan
Ann Arbor, Michigan 48109

(3) Brookhaven National Laboratory
Upton, New York 11973

(4) California Institute of Technology
Pasadena, California 91125

(5) Cleveland State University
Cleveland, Ohio 44115

(6) The University of Hawaii
Honolulu, Hawaii 96822

(7) University College
London, U.K.

(a) Also at Harvard University

(b) Permanent address: Tata Institute of Fundamental Research, Bombay, India

(c) Permanent address: University of California, Riverside, California

* Talk presented by D. Sinclair

Sept. 1982

TABLE 1. PROPERTIES OF THE IMB DETECTOR

SIZE:

Between PM-tube planes: 4×10^{33} nucleons
Estimated fiducial volume: 2×10^{33} nucleons

ENERGY RESOLUTION:

500 MeV shower: $\sigma = 11\%$
500 MeV $\pi\pm$, $\mu\pm$: $\sigma = 15\%$
1 GeV shower: $\sigma = 8\%$

VERTEX LOCALIZATION:

Two tracks, wide opening angle: $\sigma \sim .5$ m
Single track: $\sigma \sim 2$ m

ANGULAR RESOLUTION:

Showers ($e\pm$, π°): $\sigma = 10^\circ$-20°
Charged tracks: $\sigma = 5^\circ$

TRIGGERING:

Noise triggers: $\lesssim 1\%$
Cosmic rays: 2.7 ev./sec.
Energy threshold: ~ 30 MeV

OPERATION OF THE DETECTOR

The detector was filled with water in July '82 and the PM tubes were installed immediately thereafter. Serious data taking had started by the end of August. At the time of this talk (Sept. 28, '82) the detector has taken 30 days of data suitable for the study of nucleon decay. This corresponds to a duty cycle of ~ 70%. All but 1% of the PM tubes are working. The quality of the data is excellent, corresponding closely with our Monte Carlo simulations.

…by early 1983 it was clear that the SU(5) model was in trouble – no proton decays seen.

AN EXPERIMENTAL LIMIT ON PROTON DECAY:

$p \to e^+ + \pi^0$

A Thesis Presented

by

George William Foster

to

The Department of Physics

in partial fulfillment of the requirements

for the degree of

Doctor of Philosophy

in the subject of

Physics.

Harvard University

Cambridge, Massachusetts

September 1983

A search for the decay $p \to e^+ \pi^0$ was performed in the 8000 metric ton Irvine-Michigan-Brookhaven water Cherenkov detector which was constructed underground at a depth of 1570 meters of water equivalent. In a 130 live day exposure (3.9×10^{32} proton years in the 3300 ton fiducial volume of the detector) no events consistent with the above decay were found. With calculated detection efficiencies of 0.92 and 0.54 for $p \to e^+ \pi^0$ events occurring in hydrogen and oxygen respectively, this thesis establishes at the 90% confidence level that the partial lifetime for this decay mode exceeds 1.1×10^{32} years. This result is incompatible with predictions from minimal SU(5), the simplest of the Grand Unified Theories and with previously reported experimental

Congressman Bill Foster

Disappointing, but at least some people got Ph.D.'s…

Interactive 3D scanning is a new concept in 1982 and was used in IMB data analysis.

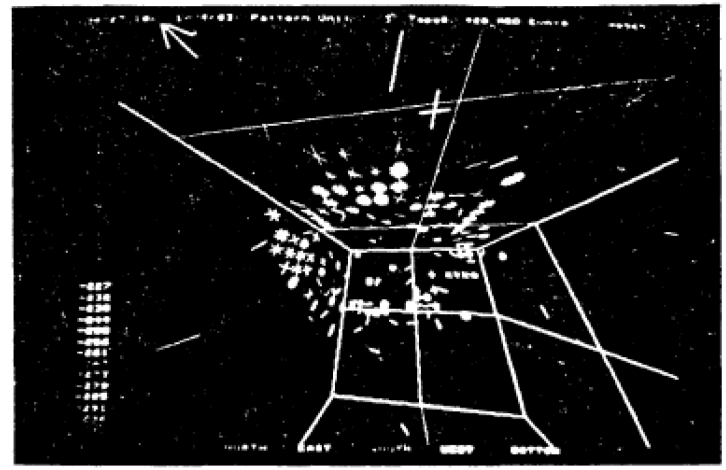


Fig. 3.V.2. Color graphics display perspective view looking down the reconstructed track of a single track event in the fiducial volume. The ring due to the Cherenkov geometry is clearly visible. Tubes displayed in red fired earlier due to the shorter times of flight to these tubes.

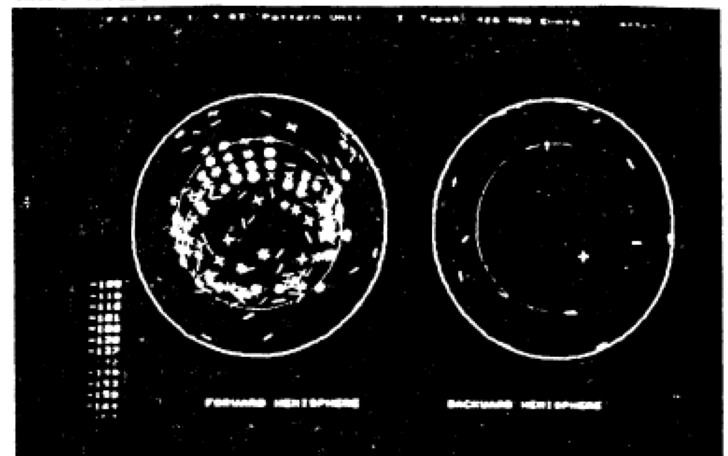
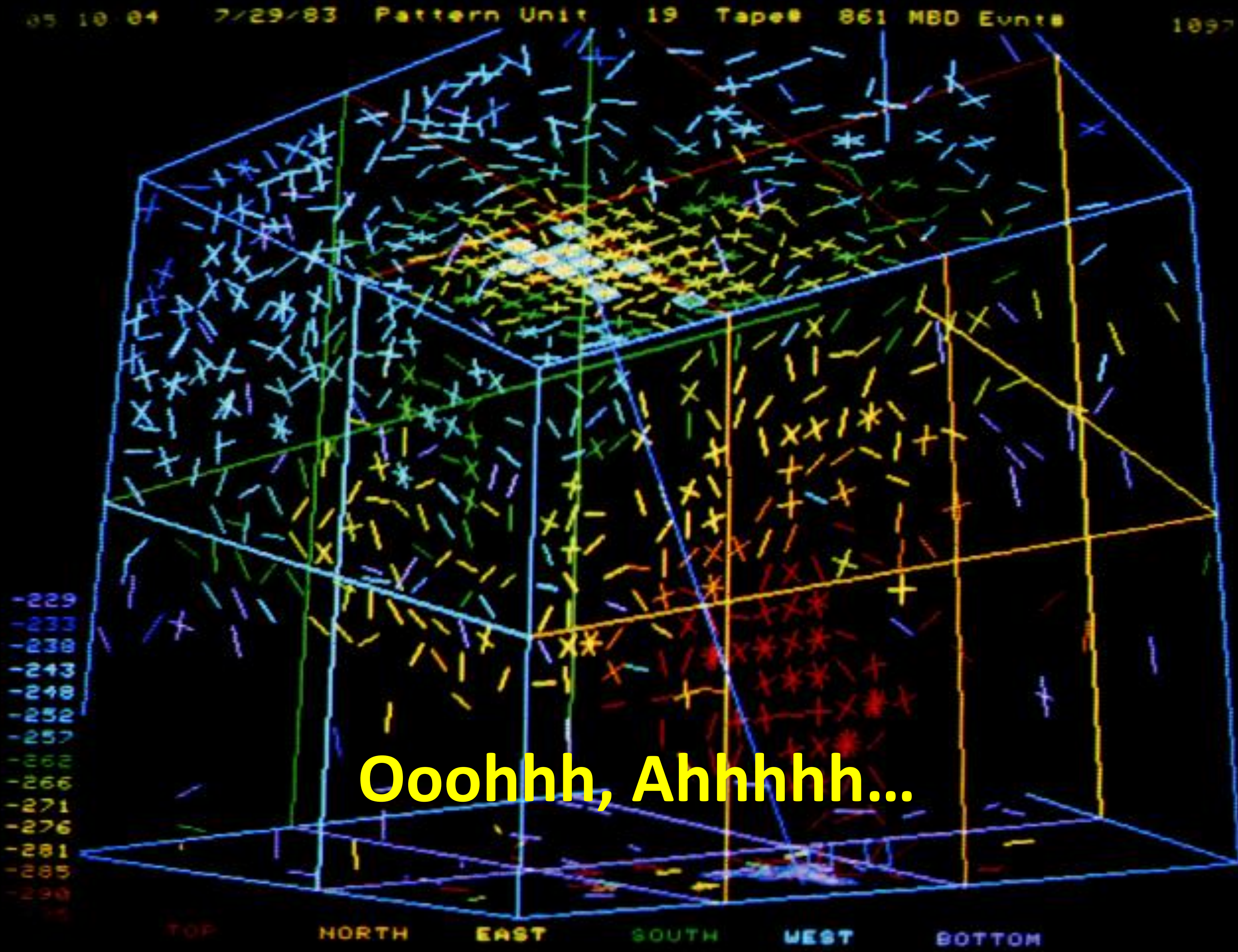
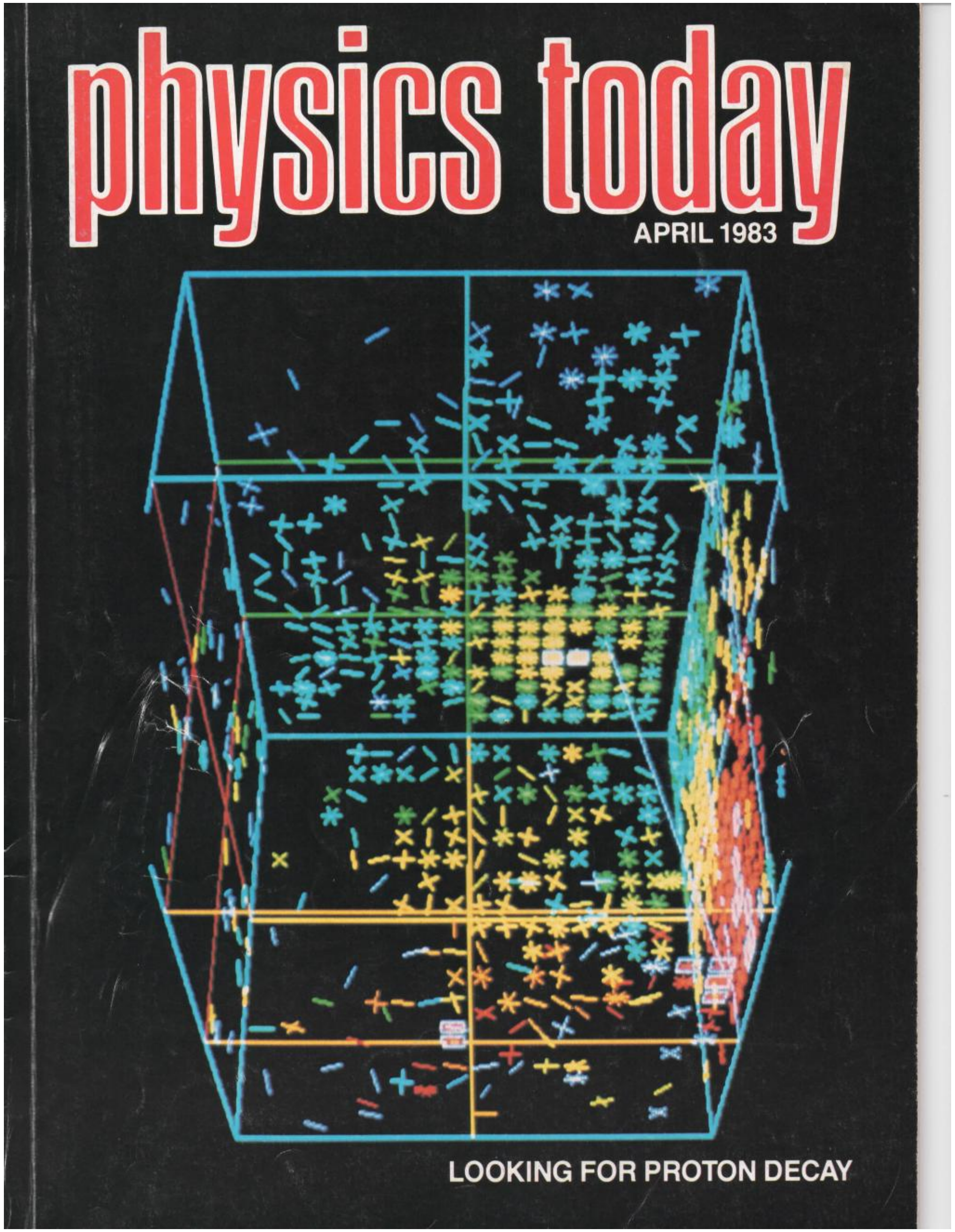


Fig. 3.V.3. Color graphics projection of the PMT firings in the solid angle surrounding the reconstructed vertex of the previous event. The PMT colors (firing times) have been corrected for the time-of-flight from the fit vertex to each tube. The absence of any systematic color shifts indicates that the event has been properly fit. Note the absence of any energy deposition in the backward hemisphere of solid angle. The interior ring in each hemisphere indicates the Cherenkov angle of 41°.



Ooohhh, Ahhhhh…

Non-discovery of Proton Decay beats out other inconsequential stories for the cover of Physics Today



Same issue…

news search & discovery

$p\bar{p}$ collisions yield intermediate boson at 80 GeV, as predicted

In January the UA1 collaboration working at the new CERN proton–antiproton collider announced the discovery of the charged intermediate vector boson, or W. The electroweak theory unifying the weak and electromagnetic interactions, for which Sheldon Glashow, Abdus Salam and Steven Weinberg received the 1979 Nobel prize in physics, requires the existence of three massive intermediate bosons, or weakons, with spin 1—the Z^0, the W^+ and W^-, to mediate the electroweak interaction.

By the end of the 30-day run, ending in December, the 270-GeV on 270-GeV collider achieved a luminosity of 5×10^{28} $cm^{-2}sec^{-1}$, obtained from beams of 3×10^{11} protons and 4.8×10^{10} antiprotons. The UA1 detector in one interaction region and the UA2 detector in the other interaction region each examined 10^9 $p\bar{p}$ collisions during the run, out of which they recorded about 10^6.

Both groups looked for a charged intermediate vector boson decaying into a charged lepton and a neutrino. During the month of January in a series of appearances—on 13 January at the 3rd Topical Workshop on Proton–Antiproton Collider Physics in Rome, at a CERN colloquium on 20 January, and the finale at the APS meeting in New York on 26 January—the UA1 collaboration announced they had found five W events: four in which a W^- decayed into an electron and a neutrino and one in which a W^+ decayed into a positron and a neutrino. The mass is reported[1] (in *Physics Letters B* in February) as (81 ± 5) GeV/c^2, in excellent agreement with predictions from the electroweak theory.

Meanwhile the UA2 group, also at the Rome meeting, at a separate CERN colloquium the day after that of UA1, and then at the New York APS meeting, reported seeing four events that were consistent with a W signature; at that time they did not report a mass. Since then, in mid-February, the group submitted a paper[2] to *Physics Letters B*, in which they say their four events, all involving $W^\pm \rightarrow e^\pm + \nu$, allow a mass estimate for the W of 80 $(+10, -6)$ GeV/c^2.

UA1 detector at the CERN $p\bar{p}$ collider. The hard-hatted man stands on the so-called Cs, which are layers of iron interleaved with scintillator to form the hadron calorimeter. Across from the hard hat is the other half of the Cs. When closed, the Cs form the iron return yoke for the magnetic field of the central detector (a large-volume drift chamber) inside, but not visible in this photo. The shiny black section inside the Cs is the front face of the electromagnetic calorimeter.

Theory predicts weakon. In the 1930s, motivated by analogy to the photon in electromagnetism, both Hideki Yukawa and Enrico Fermi proposed a massive particle, a meson, that would mediate either the strong or the weak interactions. The meson that mediates the strong force—the pion—was in fact found in 1947. In 1954 C. N. Yang and Robert L. Mills developed a non-Abelian gauge theory, a vector-meson theory that would eventually be used for the electroweak theory. Three years later Julian Schwinger suggested a vector-meson theory that might lead to a unification of the weak and electromagnetic interactions; it involved the exchange of a vector meson, the W. Then his student Sheldon Glashow in 1961 developed a weak-interaction theory using an $SU(2)\times U(1)$ group with four generators—the photon, W^+, W^- and a neutral-current vector boson now known as Z^0. In 1967 Steven Weinberg and independently in 1968 Abdus Salam developed an electroweak theory based on the same four generators. In their theory the symmetry is exact but spontaneously broken by the Higgs mechanism, named after Peter Higgs (University of Edinburgh). When the symmetry is broken by this mechanism, one can obtain a relation between the masses of the weakons:

$$m_W = (37.4\ \mathrm{GeV})/\sin\theta_W$$

$$m_Z = m_W/\cos\theta_W$$

The angle θ_W can be experimentally determined from neutrino experiments or from the scattering of polarized electrons from protons, for example. Using the most recently estimated values for θ_W, the predicted mass of the charged W is (82 ± 2.4) GeV/c^2.

Search for weakons. Throughout the 1950s and 1960s, each time higher-energy accelerators started up, an attempt would be made to find the intermediate vector boson. But through much of this period the theo-

0031-9228 / 83 / 0400 17-06 / $01.00

History of IMB

- SVOBODA joined in 1981 (grad. student)
- Begin Operation 1982 (5" EMI PMT's)
- IMB-1 1982-85 (added waveshifters
- IMB-2 1985-86 (added 8" PMT's)
- IMB-3 1986-91 (major water leak) in March 1991

  SVOBODA @ LSU in 1989
- Detector Shut down April 1991

Physics Goals

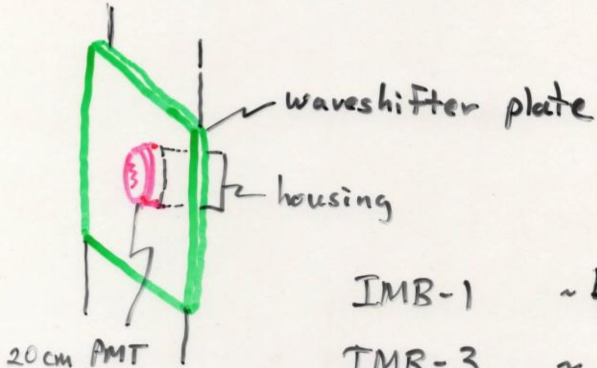
- Proton Decay
- Neutrino Oscillations
- High Energy Cosmic Ray Neutrinos
- Supernova Neutrinos (added after February 1987 !)

Upgrades

- IMB-1: 5 inc PMT coverage (1.3%)
- IMB-2: added WLS plates for a factor of ~1.5 increase
- IMB-3: In 1986 shut down to add 8-inch PMTs to bring coverage to effectively about 5%

IMB-3

12.7 cm PMT's replaced by
20 cm PMT's and waveshifter plates.



IMB-1 ~ 4 MeV/p.e.
IMB-3 ~ 1 MeV/p.e.

neutrino-induced interactions above 20 MeV now identified and reconstructed individually.

2.5×10^5 events/day $\xrightarrow{\text{on-line filter (computer)}}$ 2×10^4 day^{-1}

$\xrightarrow{\text{off-line computer}}$ 60 day^{-1} $\xrightarrow{\text{scan}}$ 2 day^{-1}

"CONTAINED" EVENTS
20 - 3000 MeV

This is in agreement with the rate expected from atmospheric neutrinos.

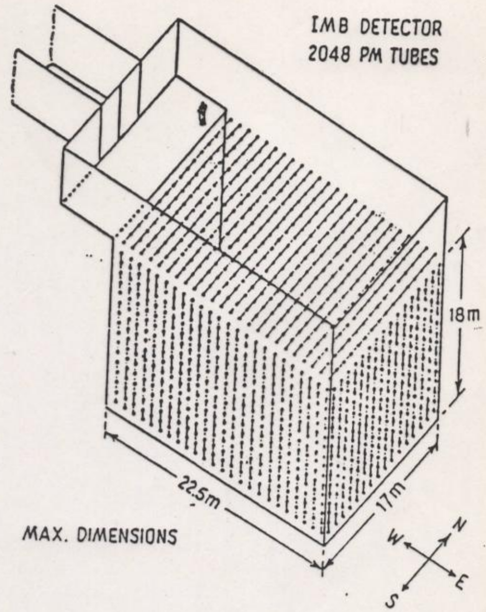
- The enhanced light collection was a big improvement over IMB-1
- Not only better resolution, but could now reconstruct much lower energy events…

Irvine - Michigan - Brookhaven (IMB)

Location: Cleveland, Ohio, USA
41.72°N 81.27°W

Depth: 1570 mwe

Period of Operation (ν):
10 Sep 82 – present



- Threshold for upward-going muons ⇒ 2 GeV
- Effective Area ⇒ 390 m^2
- Acceptance ⇒ Roughly Isotropic
- Angular Resolution (Including Scattering in rock and $\theta_{\mu\nu}$) ⇒ 7° to include 90° of events from $\gamma = 2.3$ source ⇒ 4.6° for 1σ (68%)
- Timing Resolution ⇒ 5 minutes (old data ≲ 1984)
  1-50 ms (new data)

- IMB-3 upgrade also added better online computing, with an online fitter that reduced the recorded data rate by a factor of ten (written to a separate tape system)
- **Also added a WWVB clock to get absolute time to better than 50 milliseconds**
- Just in case a supernova might go off…

It did…

HE 5.2-10

A Search for Stellar Collapse and a Search for time Correlated Signals From SN1987A.

IMB Collaboration

R. Becker-Szendy, C.B. Bratton, D. Casper, S. Dye, W. Gajewski, M. Goldhaber, T. Haines, T. Jones, D. Kielczewska, W. Kropp, J. Learned, J. LoSecco, S. Matsuno, J. Matthews, C. McGrew, M. Mudan, L. Price, D. Sinclair, F. Reines, J. Schultz, H. Sobel, L. Sulak, R. Svoboda, J. Van der Velde, F. Wittel

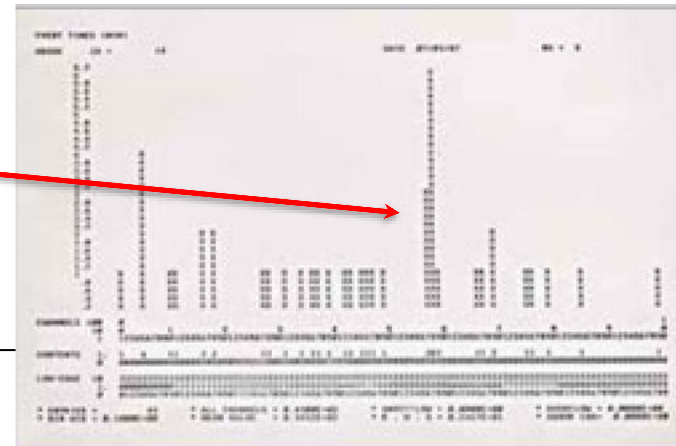
- Detection of SN1987a by The IMB, Kamiokande, and Baksan detectors prove That SN can be detected out To a range of 50 kpc.
- Are other bursts present in our data set? i.e., do low energy neutrino events arrive randomly in time? Galactic SN ~ several 100s events

- IMB detector description and construction
- Detection of neutrinos from SN1987A
- Analysis of the neutrino events
- A search for other bursts in IMB-I,II,III

ABSTRACT

A six-second burst of eight neutrino events was recorded by the IMB proton decay detector roughly five hours before the SN1987A Type II supernova in the Large Magellanic Cloud. The events have energies in the range 20-40 MeV and are consistent with being inverse beta decay interactions of anti-electron neutrinos generated in a stellar core collapse preceding the supernova.

R.Svoboda, 1987ESOC 26 2298



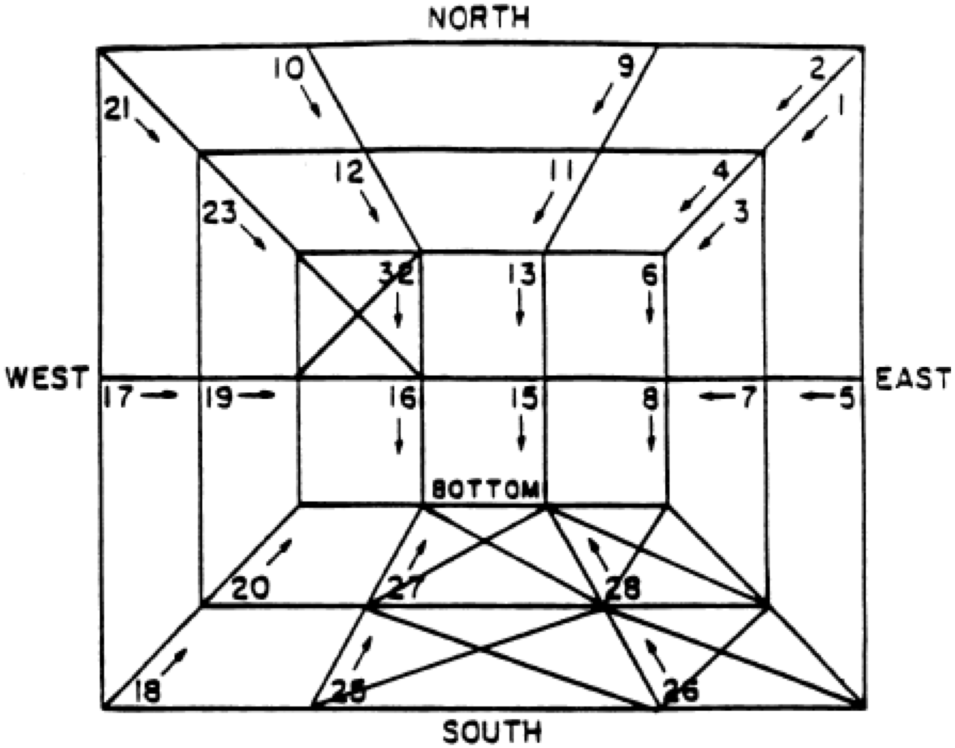
UT 23 February $7^h\ 35^m\ 41.37^s$

Tape#	D	M	YR	H:M											
2591	17	2	87	18:52	0	0	0	9:35	-2	-2	28	-2	-2	RCS	
2592	18	2	87	6:14	0	0	0	9:19	-2	-2	59	-2	-2	RCS	
2593	18	2	87	17:19	0	0	0	9:04	-2	-2	96	-2	-2	RCS	
2594	19	2	87	4:19	0	0	0	2:58	-2	-2	33	-2	-2	RCS	
2595	19	2	87	16:49	0	0	0	7:05	-2	-2	88	-2	-2	RCS	
2596	20	2	87	3:00	0	0	0	7:05	-2	-2	78	-2	-2	RCS	
2597	20	2	87	13:22	0	0	0	9:36	-2	-2	34	-2	-2	RCS	
2598	21	2	87	0:31	0	0	0	9:35	-2	-2	69	-2	-2	RCS	
2599	21	2	87	21:52	0	0	0	9:25	-2	-2	48	-2	-2	RCS	
2600	22	2	87	9:01	0	0	0	9:25	-2	-2	-2	-2	-2	RCS	
2601	22	2	87	20:11	0	0	4	3:30	-2	-2	-2	-2	-2	RCS	<Supernova SN1987A>BAD HOWIE
2602	0	0	00	0 00	0	0	0	0:00	-2	-2	-2	-2	-2	---	NO SUCH TAPE
2603	23	2	87	11:32	0	0	0	9:19	-2	-2	66	-2	-2	RCS	
2604	23	2	87	22:40	0	0	0	3:42	-2	-2	52	-2	-2	RCS	POWER FAILURE
2605	24	2	87	8:10	0	2	2	0:00	-2	-2	-2	-2	-2	---	CALFXD

THE BURST SIGNAL

The signal from a stellar collapse is expected to be a burst of low energy neutrino events lasting a few seconds. To search for such a burst, the data from a 60-hour period around the sighting of the optical supernova was analyzed for such a sequence of low energy contained events. The details of this search have been published.[4] Eight such events were found in a six-second interval commencing at UT 23 February $7^h\ 35^m\ 41.37^s$. Since the background rate of contained interactions in the range of this search (<100 firing PMT's, or about 75 MeV) is only about one event every three days, the probability of a chance occurrence is calculated to be $<10^{-30}$, or a reasonably good approximation to "never". Experimentally, even two neutrino events have not been recorded in such close time proximity to each other over the entire energy range of the detector (up to 2000 MeV) since going into operation in 1982.

From my ESO sponsored talk at MPI Garching very shortly after the SN1987A neutrino detection announcement.



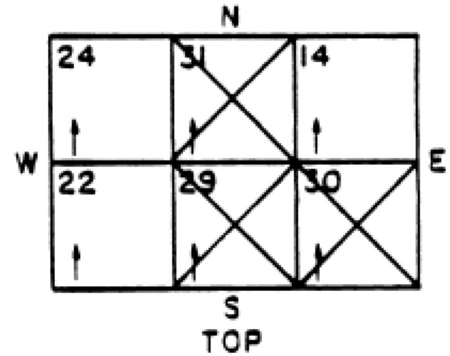


Figure 1 - Position of the inoperative sections of the IMB detector (marked by an "X") during the SN1987a neutrino burst. The LMC was in the southwest at this time and below the horizon.

About 2 hours prior to the burst one of four power supplies failed and was dead for 7 hours. This had the impact of making the efficiency smaller
And also required special corrections to the energy-estimation software. Laser calibrations for timing and gain. CR muons for tuning an MC for energy.

TABLE I. The estimated trigger efficiency for the detector with the loss of one high-voltage power supply as a function of visible energy.

Visible energy (MeV)	Trigger efficiency
20	0.14
30	0.56
40	0.76
50	0.89
60	0.92

(note: these are superseded by the later PRD paper)

Energy of the individual events
Both CR muon tuned MC and also an empirical method based on CR muon decay data

Table 1

IMB Neutrino Burst Signal

Time[1] (s)	Vertex (m)[2] X	Y	Z	Direction Cosines[3] X	Y	Z	Energy[4] (MeV)	#PMT	Angle[5]	Fid.[6] Dist (m)
0.00	-1.7	-0.4	0.9	-.711	.697	.086	33/43/38	47	74	7.9
0.42	7.2	5.3	0.7	-.128	.992	.008	30/44/37	61	52	3.2
0.65	6.8	4.9	1.1	.055	.292	.060	40/40/40	49	56	3.5
1.15	-7.4	-4.4	-2.4	-.480	.037	.876	35/35/35	60	63	4.1
1.57	-10.2	3.0	-8.7	-.300	.482	.823	32/26/29	52	40	1.3
2.69	-6.7	2.1	-2.9	-.420	.260	.869	34/40/37	61	52	4.8
5.01	-5.3	0.8	2.8	-.327	.632	.702	17/23/20	44	39	5.9
5.59	6.5	3.2	-0.9	.384	.349	-.855	18/30/24	45	102	5.0

1. Relative time in seconds from the first event.
2. The origin of the detector is at its geometrical center.
3. East is in the +X, North the +Y, and straight up the +Z.
4. Energy by: muon decay method/Monte Carlo method/Average. Overall error is taken as ±25%.
5. Angle in degrees of the reconstructed track direction to the vector pointing directly away from SN1987a. Individual track reconstruction uncertainty is ±15 degrees.
6. Distance in meters to the nearest plane of PMT´s. The mass of the detector excluding the outer 1 meter is 5 kilotonnes.

Gain calibrations done
Feb 10, Mar 1
Timing calibration
Feb 11, Feb 24

(note: the energy numbers are superseded by the later PRD paper)

THIRD SERIES, VOLUME 37, NUMBER 12 15 JUNE 1988

Angular distribution of events from SN1987A

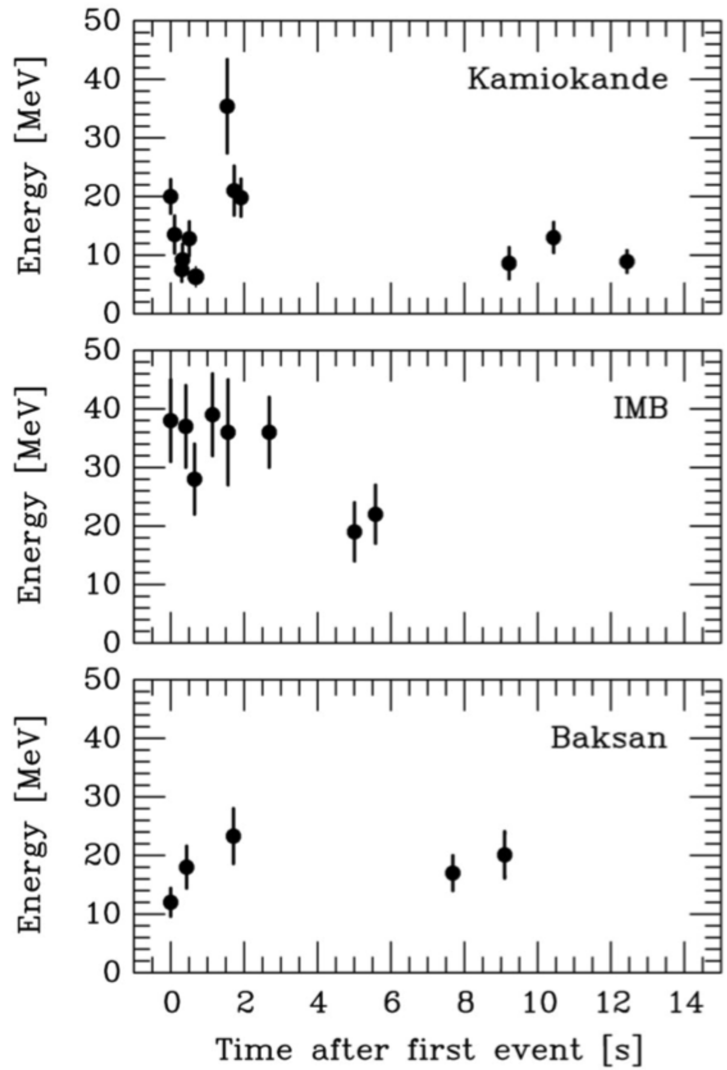
C. B. Bratton,[d] D. Casper,[b,k] A. Ciocio,[k] R. Claus,[k] M. Crouch,[h] S. T. Dye,[e] S. Errede,[i] W. Gajewski,[a] M. Goldhaber,[c] T. J. Haines,[l] T. W. Jones,[f] D. Kielczewska,[a,g] W. R. Kropp,[a] J. G. Learned,[e] J. M. LoSecco,[j] J. Matthews,[b] R. Miller,[a] M. Mudan,[f] L. R. Price,[a] F. Reines,[a] J. Schultz,[a] S. Seidel,[b,k] D. Sinclair,[b] H. W. Sobel,[a] J. L. Stone,[k] L. Sulak,[k] R. Svoboda,[a] G. Thornton,[b] and J. C. van der Velde[b]

[a]*The University of California, Irvine, California 92717*
[b]*The University of Michigan, Ann Arbor, Michigan 48109*
[c]*Brookhaven National Laboratory, Upton, New York 11973*
[d]*Cleveland State University, Cleveland, Ohio 44115*
[e]*The University of Hawaii, Honolulu, Hawaii 96822*
[f]*University College, London WC1E 6BT, United Kingdom*
[g]*Warsaw University, Warsaw, Poland*
[h]*Case Western Reserve University, Cleveland, Ohio 44106*
[i]*The University of Illinois, Urbana, Illinois 61801*
[j]*The University of Notre Dame, Notre Dame, Indiana 46556*
[k]*Boston University, Boston, Massachusetts 02215*
[l]*University of Maryland, College Park, Maryland 20742*
(The IMB Collaboration)
(Received 21 December 1987)

Later, laser driven "cone generator" runs and a more detailed analysis of the energy was done with the same PMTs turned off in software

TABLE I. Energies and angles of the eight events from supernova SN1987A. (a) Absolute UT is accurate to ±50 ms. Relative times are accurate to the nearest millisecond. (b) Additional systematic error in energy scale estimated to be ±10%. (c) Angle with respect to direction away from SN1987A. Angle errors include multiple scattering and event reconstruction. (d) assumes events are due to $\bar{\nu}+p \rightarrow e^{+}+n$ on free protons.

Event	(a) Time (UT) 23 Feb. 1987	(b) Measured energy (MeV)	(c) Polar angle (deg)	(d) Antineutrino energy (MeV)
1	7:35:41.374	38±7	80±10	41±7
2	7:35:41.786	37±7	44±15	39±7
3	7:35:42.024	28±6	56±20	30±6
4	7:35:42.515	39±7	65±20	42±7
5	7:35:42.936	36±9	33±15	38±9
6	7:35:44.058	36±6	52±10	38±6
7	7:35:46.384	19±5	42±20	21±5
8	7:35:46.956	22±5	104±20	24±5



Baksan time shifted
By ~30 seconds

In The period 1:45 - 2:45 UT Feb. 87 both the Baksan and LSD (Large Scintillation Detector) have reported Time correlation between recorded events

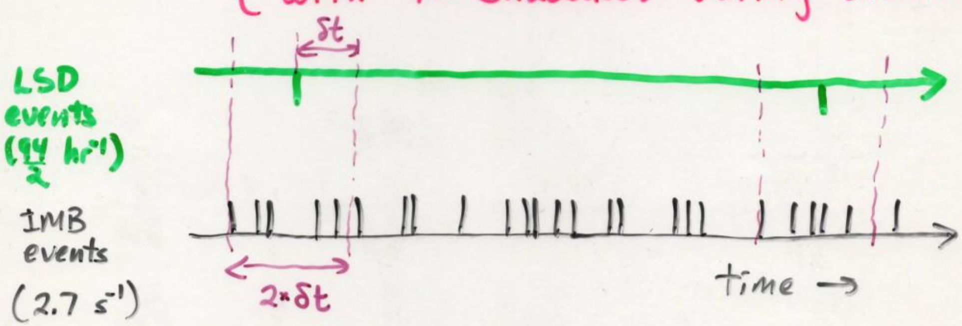
(Aglietta, et al. 1989 Il Nuovo Cim.)

(Alexeyev, et al. 1989 preprint)

LSD has also reported correlations with Gravity Wave detectors at Rome and Maryland.

Are such correlations present in IMB data?

(with A. Chudakov during U.S.A. visit)



From 1:45 - 3:45 UT There are 94 LSD events and 16,237 IMB events

muons!

$$\#\text{ IMB events expected in window (ignore overlap)} = \left(\frac{\overset{16,237}{N}}{\underset{2\text{ hours}}{T}}\right)(\overset{94}{m}\cdot \underbrace{2\delta t}_{\text{seconds/window}})$$

- The Large Scintillation Detector claimed to see an earlier burst
- A search was done for such a burst at this earlier time using raw IMB data

IMB data No CUTS

(also note both LSD and IMB had radio clocks → Time difference not a Free parameter)

Using reported parameters of $T = 1$ hour, $\delta t = 1$ second

got 214 events in window

expected 198 ~ $+1\sigma$, no effect

Low energy deposition events (<100 PMTs)

got 4

expected 4.6

(this makes more sense to me)

High Energy deposition events (>1850 PMTs)

got 2

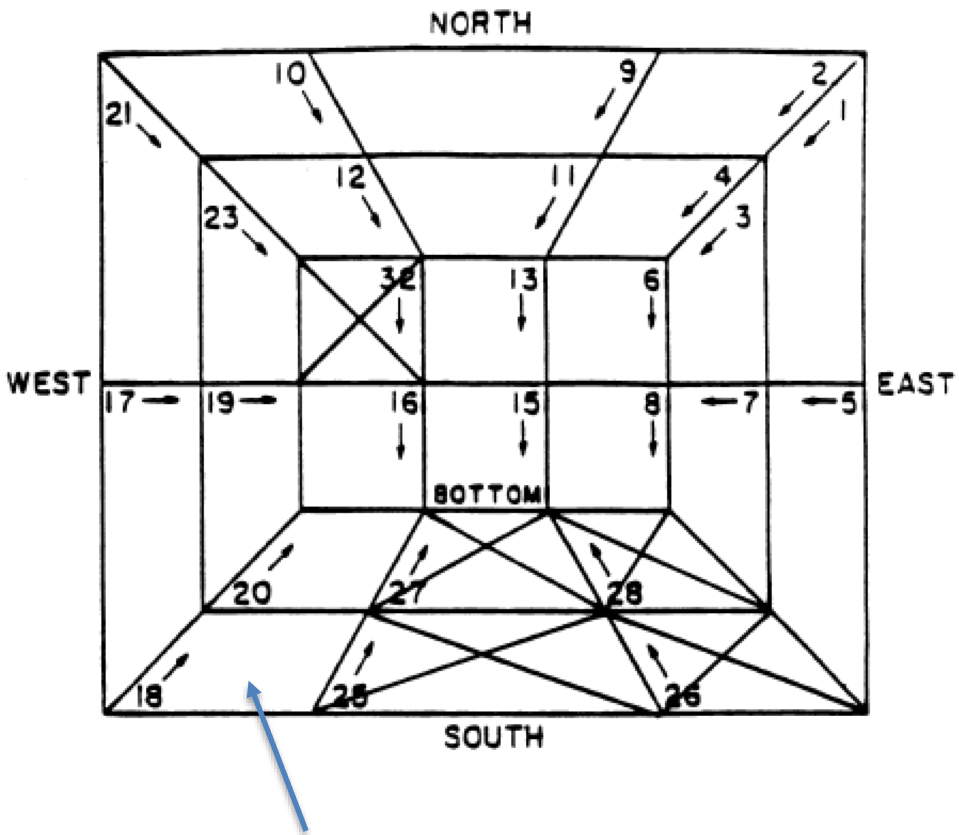
expected 3.8

We have also used Baksan data, but with time shifted by 29.5 seconds To align 07:35 Baksan burst with IMB.

No bursts seen at the LSD time

(even a search of **below threshold trigger scalers** showed nothing)

Below threshold trigger scalers



a “patch” of
64 PMTs

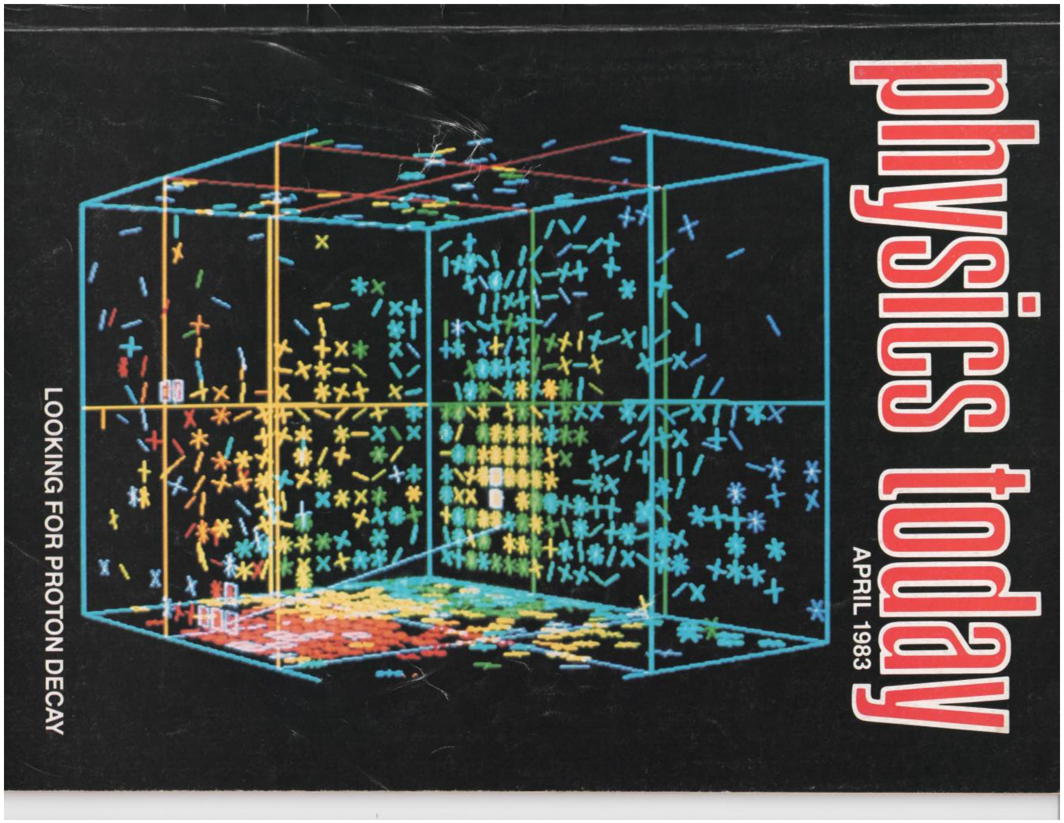
Majority Logic Trigger:

- just add up the total number of PMT hits in a fixed window
- when this exceeded a fixed threshold (about 2-25 PMTs in 50 ns) a detector readout was initiated

Segmented Trigger:

- each 64 PMT “patch” also had an individual majority logic sub-trigger generated called a “patch” trigger
- when two patch triggers were in coincidence a detector readout was generated
- Patch sub-triggers were fed into scalers to monitor below threshold detector activity

Were there events in the "regular" IMB atmospheric neutrino data?



This is actually an upward-going muon.

Physics Today rotated it for to fit on the cover better…

Let's look at these first…

date	time	RA (h)	RA(rad.)	Dec (deg.)	Dec(rad.)	angle to SN
1/4/87	23:49:29	11.08	2.90073722	0.05	1.56992366	87
1/5/87	6:39:51	10.02	2.62322987	-50.58	2.45358386	36
1/14/87	0:50:32	9.18	2.40331838	-44.86	2.35375103	36
1/16/87	7:53:56	2.05	0.53668874	-35.72	2.19422794	44
1/24/87	2:37:33	17.1	4.47676953	1.26	1.54880518	112
1/29/87	1:36:45	17.13	4.48462351	-20.87	1.93504654	90
2/1/87	5:26:38	17.77	4.65217512	37.7	0.9128072	148
2/1/87	8:21:44	22.59	5.91404817	-0.93	1.58702789	94
2/1/87	17:16:14	4.09	1.0707595	-30.92	2.11045213	40
2/3/87	9:57:56	7.23	1.89280957	-8.31	1.71583319	63
2/5/87	9:35:41	4.83	1.26449104	-25.46	2.01515715	44
2/6/87	17:53:13	13.93	3.64686547	-32.26	2.13383954	71
2/8/87	22:42:09	18.02	4.71762497	-27.34	2.04796934	83
2/11/87	0:59:34	10.72	2.80648944	-14.45	1.8229964	72
2/14/87	14:43:09	9.95	2.60490391	16.13	1.28927472	97
2/24/87	5:27:54	1.58	0.41364303	11.22	1.37497038	91
2/27/87	15:14:27	21.27	5.56847298	-66.04	2.72341176	39
3/4/87	22:26:38	20.41	5.3433255	-33.15	2.14937297	73
3/11/87	16:51:42	18.77	4.91397451	-33.44	2.15443443	76
3/13/87	7:04:10	12.8	3.35103216	-58.88	2.59844619	42
3/15/87	1:57:46	21.76	5.69675468	-55.5	2.53945406	47
3/18/87	15:10:19	6.42	1.68075207	27.92	1.0835004	98
3/19/87	17:51:44	6.35	1.66242611	-38.48	2.24239902	31
3/20/87	8:31:10	23.58	6.17322956	-36.76	2.21237936	56
3/20/87	9:49:57	3.59	0.9398598	-31.91	2.12773089	41
3/27/87	8:36:49	3.37	0.88226394	40.93	0.85643306	113
3/28/87	1:52:49	23.82	6.23606142	-54.84	2.52793489	39
3/31/87	2:24:58	23.51	6.15490361	36.41	0.93532195	124

Upward-going muon data was also searched for any angular correlation with the SN direction

…none found

(unpublished)

HE 5.2-10

A Search for Stellar Collapse and a Search for time Correlated Signals From SN1987A.

IMB Collaboration

R. Becker-Szendy, C.B. Bratton, D. Casper, S. Dye, W. Gajewski, M. Goldhaber, T. Haines, T. Jones, D. Kielczewska, W. Kropp, J. Learned, J. LoSecco, S. Matsuno, J. Matthews, C. McGrew, M. Mudan, L. Price, D. Sinclair, F. Reines, J. Schultz, H. Sobel, L. Sulak, R. Svoboda, J. Van der Velde, F. Wittel

- Detection of SN1987a by The IMB, Kamiokande, and Baksan detectors prove That SN can be detected out To a range of 50 kpc.

- Are other bursts present in our data set? i.e., do low energy neutrino events arrive randomly in time? Galactic SN ~ several 100s events

- A search was also done through all previous data for any other bursts
- None were found

The relatively high threshold energy of IMB (~40 MeV for IMB-1, ~20 MeV for IMB-3) means that the most likely reaction to observe from a SN neutrino burst is inverse beta decay on free protons.

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

$$E_{e^+} = E_\nu - 1.8 \text{ MeV}$$

IMB-1 (Dye et al., 1989, P.R.L. 62)

- even with high threshold, trigger efficiency is [redacted] high for nearby SN ($\frac{1}{N_{tot.}}\int_{galaxy} \epsilon(D)\, \rho_{stars}\, dV \approx 50\%$)

in period

10 September 1982 to 2 July 1984

No Bursts Detected

427 live days

IMB-1 427 live days
no burst
IMB-2 also no burst

IMB III'

(1) AUTOMATED BURST SEARCHING (DONE)

DET → VAX → μVAX
- BURST
- PDK
- ↑ μ's

1 TAPE / 4 DAYS
(possibly reduce to ~1/week)

(2) NEW EQUIPMENT TO INCREASE ON-TIME

(DONE) * NEW POWER SUPPLY INSTALLED
* NEW DATA COLLECTION ELEC.
  - DEAD TIME REDUCTION
  - BUFFERING TO 512 EVENTS
* BACKUP TIMING STANDARD FOR WWVB

(3) INCREASE SPEED OF DATA ANALYSIS

- The online processing system was very soon after programmed to also look for bursts and then dial out on phone lines (no underground internet)
- Ran for the next few years until the “big leak”

- In 524 days of IMB-3 data no bursts found (except SN1987a).

rate galactic SN = 0.5 (−0.15, +1.7) / year (include SN1987a)

rate from SNR, nucleosynthesis, other galaxies → 0.2 to 0.01 yr^{-1}

note: The rate of galactic SN is expected to be ~ 10x historical rate of observed optical SN.

If ignore SN1987a and combine with previous IMB-1 result

90% cl rate < 1.2 yr^{-1}

SN search is done "automatically" with proton decay search. We intend to run for several more years.

IMB-3, no bursts

In 1991 a serious leak forced the detector to be shut down.

A proposal to repair IMB and add a veto by excavating more cavern was **not approved**.

A proposal to build a long baseline neutrino experiment to IMB in 1990 was also **not approved**.

A Proposal
for a Long Baseline Oscillation Experiment
Using A High Intensity Neutrino Beam from
the Fermilab Main Injector to the IMB Water
Čerenkov Detector.
FNAL P805

W. Gajewski, P.G. Halverson, W.R. Kropp,
S. Matsuno, C. McGrew, L.R. Price, F. Reines,
J. Schultz, H.W. Sobel
University of California, Irvine

D. Casper, S.T. Dye, L.R. Sulak, F. Witt
Boston University

M. Goldhaber
Brookhaven National Laboratory

C.B. Bratton
Cleveland State University

R. Becker-Szendy, J.G. Learned
The University of Hawaii, Manoa

T.W. Jones
University College, London

R. Miller, R. Svoboda
Louisiana State University

T.J. Haines
The University of Maryland

R. Cady, J.M. LoSecco
The University of Notre Dame

D. Kielczewska
Warsaw University, Warsaw

October 1990

six years before
start of Super-K

Abstract

We propose to study muon neutrino oscillations by detecting in the IMB detector neutrinos produced by a proton beam from the Main Injector at Fermilab. The distance between the beam source and the detector is 570 km. The interactions span the energy range up to about 60 GeV with a mean of about 13 GeV.

We are able to detect the muon neutrino disappearance of more than 2%, which together with the L/E ratio of 43.8km/GeV makes the experiment sensitive to the range of mass squared difference $\delta m^2 \approx$ few $\times 10^{-3}(\mathrm{eV})^2$. This range is a two order of magnitude improvement over the existing limits from the CHARM experiment.

Figure 1: Schematic of neutrino beam traveling from FNAL to the IMB detector.

Disappointing!

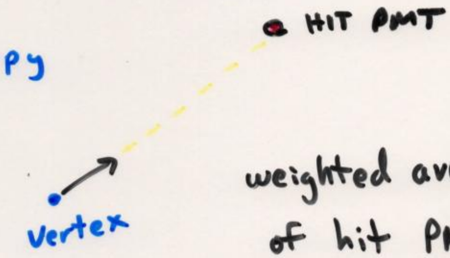
- IMB-3 data analysis
  - 7.6 kton-years
  - 935 contained events > 70 NT1
  - 223 contained events ≤ 70 NT1

  (Done at LSU over last year)

- Energy-Anisotropy

  Energy from total collected p.e.'s
  - corrections for vertex position, dead pmt's, water absorption, muon decay, track direction

  Anisotropy



weighted average of hit PMT's

- Invariat Mass
  - Track Resolution
  - Particle ID (μ, π, e)

DPF 1992

Unfortunately, the contained atmospheric neutrino data I only have on magnetic tape which I cannot read

...but would be fun to look at this in more detail again.

FERMILAB-PUB-23-087-PPD, UCI-HEP-TR-2023-02, LA-UR-23-22079

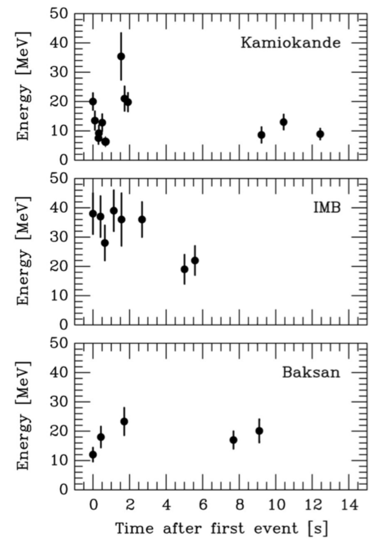
Old Data, New Forensics: The First Second of SN 1987A Neutrino Emission

Shirley Weishi Li [1,2,*] John F. Beacom [3,4,5,†] Luke F. Roberts [6,‡] and Francesco Capozzi [7,8,§]

[1] *Theoretical Physics Department, Fermi National Accelerator Laboratory, Batavia, IL 60510*
[2] *Department of Physics and Astronomy, University of California, Irvine, CA 92697*
[3] *Center for Cosmology and AstroParticle Physics (CCAPP), Ohio State University, Columbus, OH 43210*
[4] *Department of Physics, Ohio State University, Columbus, OH 43210*
[5] *Department of Astronomy, Ohio State University, Columbus, OH 43210*
[6] *Computer, Computational, and Statistical Sciences Division, Los Alamos National Laboratory, Los Alamos, NM 87545*
[7] *Dipartimento di Scienze Fisiche e Chimiche, Università degli Studi dell'Aquila, 67100 L'Aquila, Italy*
[8] *Istituto Nazionale di Fisica Nucleare (INFN), Laboratori Nazionali del Gran Sasso, 67100 Assergi (AQ), Italy*

(Dated: June 13, 2023)

The next Milky Way supernova will be an epochal event in multi-messenger astronomy, critical to tests of supernovae, neutrinos, and new physics. Realizing this potential depends on having realistic simulations of core collapse. We investigate the neutrino predictions of nearly all modern models (1-, 2-, and 3-d) over the first ≃1 s, making the first detailed comparisons of these models to each other and to the SN 1987A neutrino data. Even with different methods and inputs, *the models generally agree with each other.* However, even considering the low neutrino counts, *the models generally disagree with data.* What can cause this? We show that neither neutrino oscillations nor different progenitor masses appear to be a sufficient solution. We outline urgently needed work.



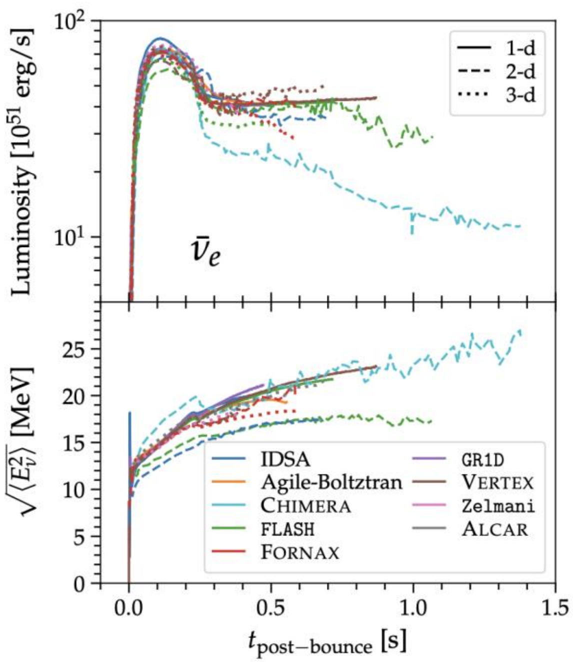
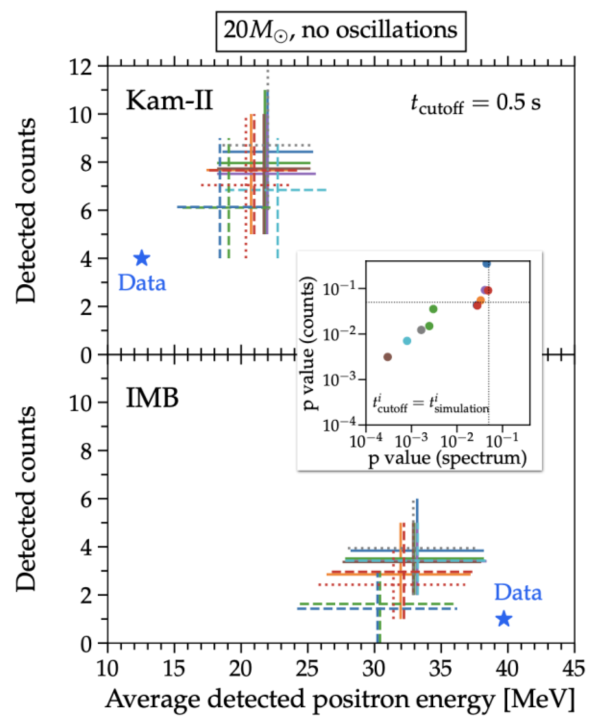


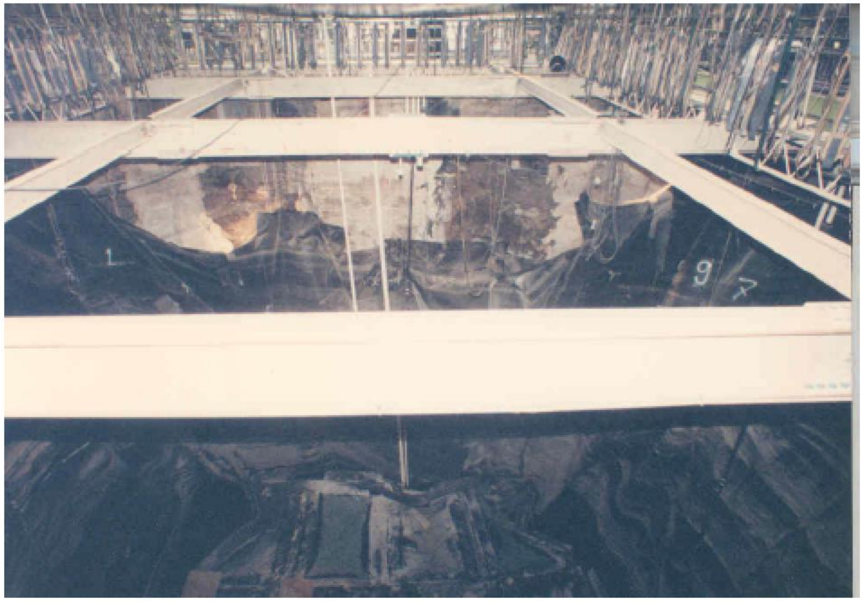
FIG. 1. Neutrino ($\bar{\nu}_e$; others shown in S.M.) luminosity and RMS energy profiles from supernova simulations [18–28].



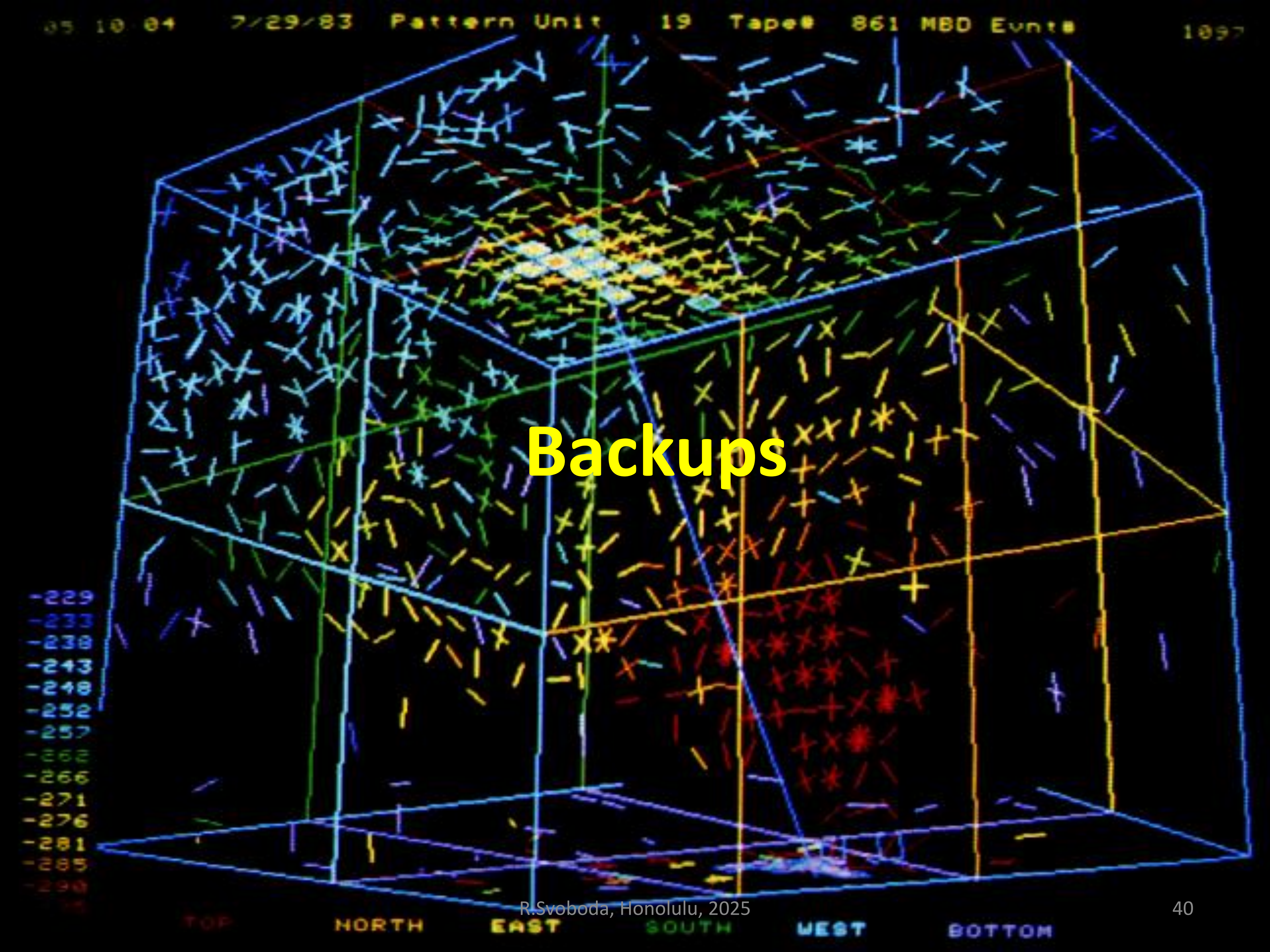
Conclusions

- The single burst detected in the IMB detector was unique in the entire 9 year data set
- Even with the relatively high threshold of 20 MeV, events were reconstructed in direction to about 15 degrees and energy to about 25%
- Timing was accurate to better than 50 milliseconds as it came from an oscillator locked to a timing radio signal (WWVB)
- Could the analysis be improved? How to do this techinically?

Thanks!



Backups


05 10 04 7/29/83 Pattern Unit 19 Tape# 861 MBD Evnt#
-229
-233
-238
-243
-248
-252
-257
-262
-266
-271
-276
-281
-285
-290
TOP
NORTH
EAST
SOUTH
WEST
BOTTOM

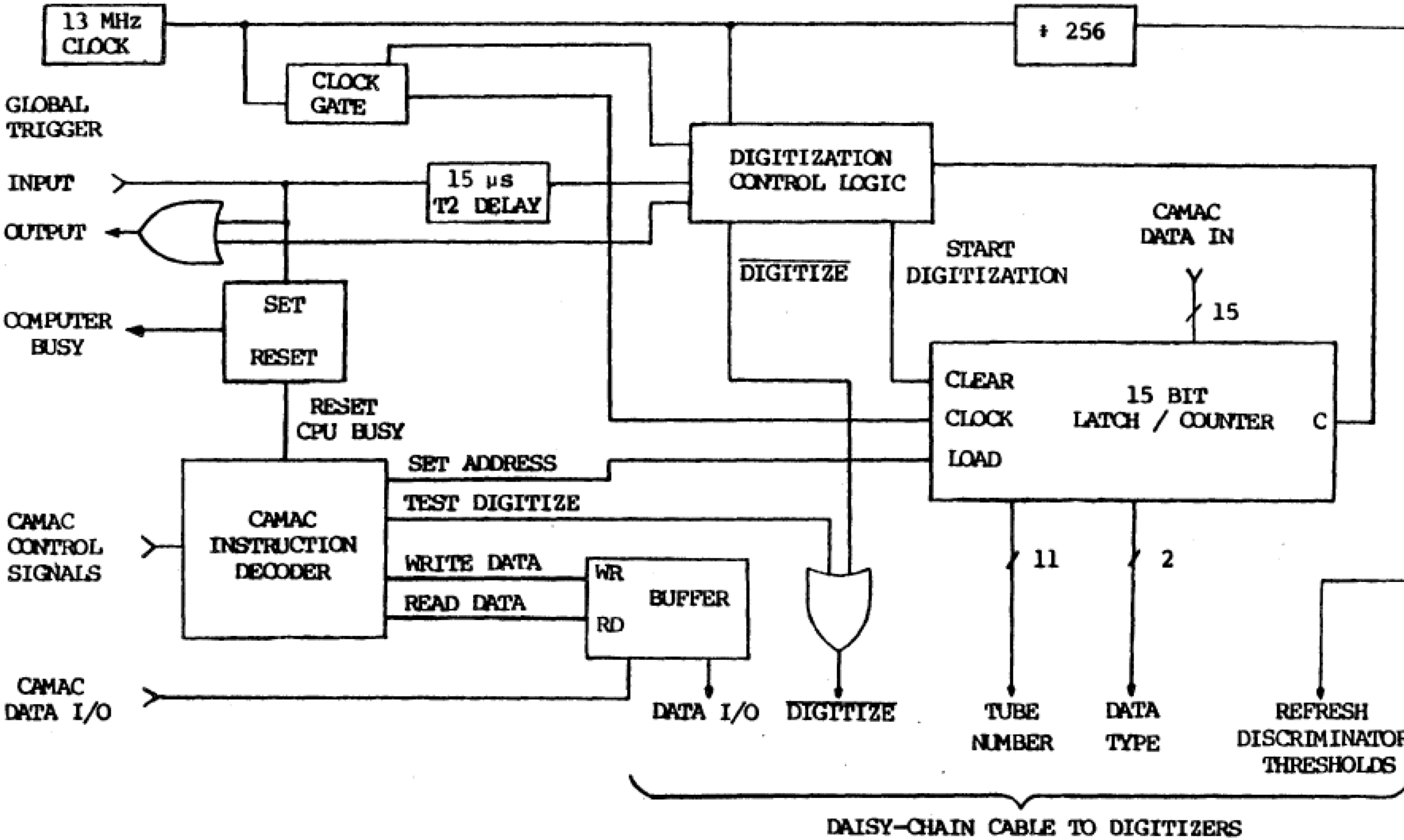


Fig. A.4. Simplified block diagram of custom electronics supervisor/CAMAC interface module.

Fig.2.I.6. Summary of IMB Detector Properties

Detector Size:

Total mass: 8000 metric tons
Fiducial Mass: 3300 metric tons
$= 2.0 \times 10^{33}$ nucleons

Energy Resolution:

500 MeV shower: $\sigma = 13\%$
300-500 MeV/c $\mu^{\pm}$: $\sigma = 15\%$
$p \to e^{+}\pi^{0}$: $\sigma = 10\%$
Systematic error in
absolute energy calibration: $< 15\%$

Trigger Threshold:

Hardware: ~ 30 MeV
Software: ~ 160 MeV

Vertex Localization:

Nucleon decay $\sigma = 65$ cm
~ 500 MeV ν_{μ} $\sigma = 75$ cm
Cosmic Ray ν $\sigma = 135$ cm

Angular Resolution:

Showering tracks: $\sigma = 6^{\circ}$
300-500 MeV/c $\mu^{\pm}$: $\sigma = 4^{\circ}$
Straight-through muons: $\sigma < 4^{\circ}$

Track Direction:

No sign ambiguity

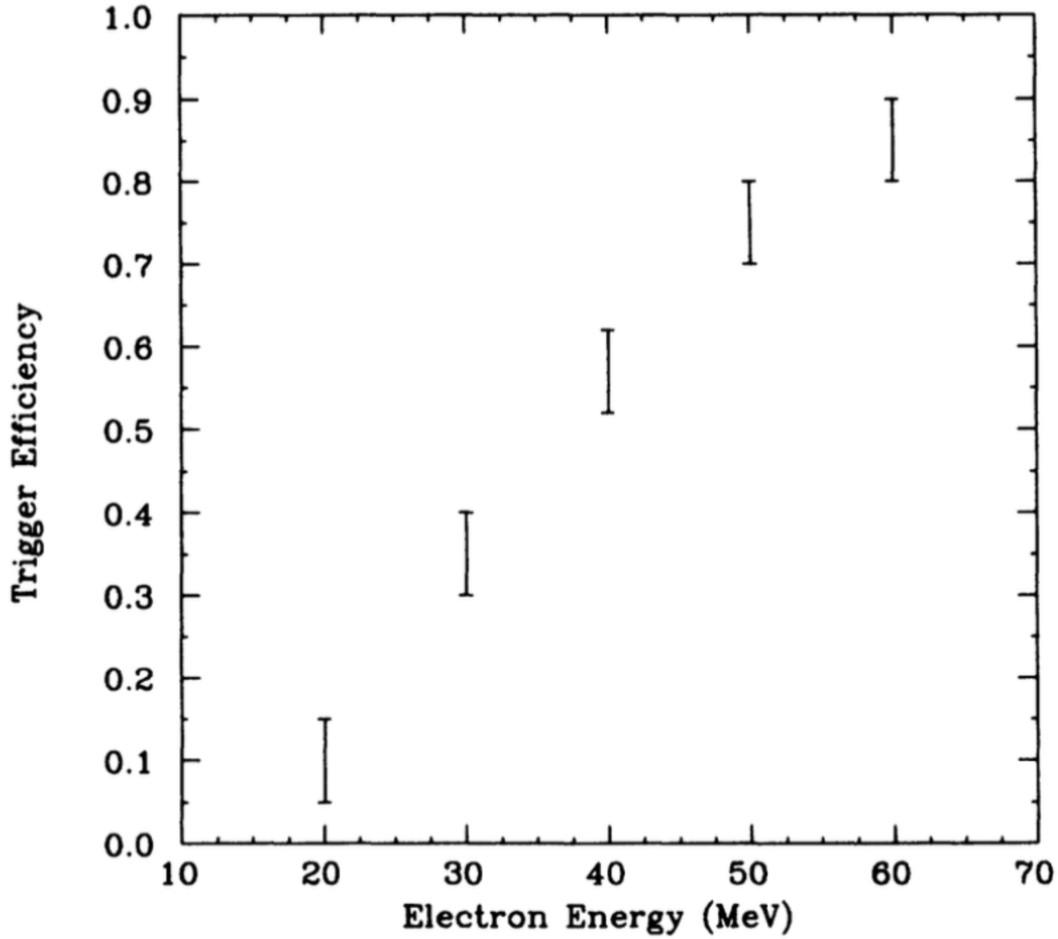


FIG. 1. Trigger efficiency vs electron (or positron) energy averaged over an isotropic distribution in the full 6800-m^3 volume of the detector. Error bars represent systematic uncertainty in efficiency (see text).