IMB…. The Early Years

J. C. van der Velde
University of Michigan

August, 1978
XIXth International Conference on High Energy Physics

The Tokyo conference was all a-buzz with Grand Unification Theories

- "Minimal" SU_5 was predicting a proton lifetime of 10^{29} years for the mode

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

Planes leaving Tokyo were filled with strange characters holding little books and making weird scratches on paper napkins, like….

6.02×10^{26} protons/Kg

This is not a small number compared to 10^{29} years

Make that 6.02×10^{29} protons/tonne

……gives 6 decays per tonne per year!

Hmmm….that's only a cubic meter of water

Pre-History

- 1929, Hermann Weyl:

  " Why doesn't P+e $\longrightarrow$ photons ?"

- 1939, E.C.G.Stueckelberg:

  "Heavy Charge" (N & P) is conserved"

- 1949, E.P. Wigner :

  Why doesn't P decay into positron?

  "That's easy, there's something called Baryon Number which is conserved !"

Or as Maurice (Dr. Conservationlaw) preferred:

"Its non-conservation has not been established"

Our universe, clearly, does not have zero baryon number, but the Big Bang undoubtedly did…. so something is fishy.

It needs to be measured !

If the proton lifetime is < 10^{16} years we would die of our own radiation.

Existing apparatus can do better than that

1954, Reines, Cowan, and Goldhaber:

$t > 10^{22}$ years (Phys Rev 96, 1157)

1960 Backenstoss et al. (Nuovo Cimento 16 749)

$t > 10^{26}$ years

1967 Gurr, Kropp, Reines, Meyer (Phys Rev 158 1321)

$t > 10^{28} – 10^{30}$ years (depending on mode)

1974, Reines and Crouch: (Phys Rev Lett 32 493)

$t > 10^{30}$ years (for modes with muon)

1978 Fall Flurry of Activity

- M.G. gives an inspiring seminar at Michigan
- Brookhaven, Irvine, Harvard, Imperial College, Michigan, Oxford, Purdue, Wisconsin…. Lots of head-scratching.
- For IMB the dust settled in January ’79.

A meeting at Irvine signed up:

W. Kropp, J. Learned, R. March, F. Reines, J. Schultz,

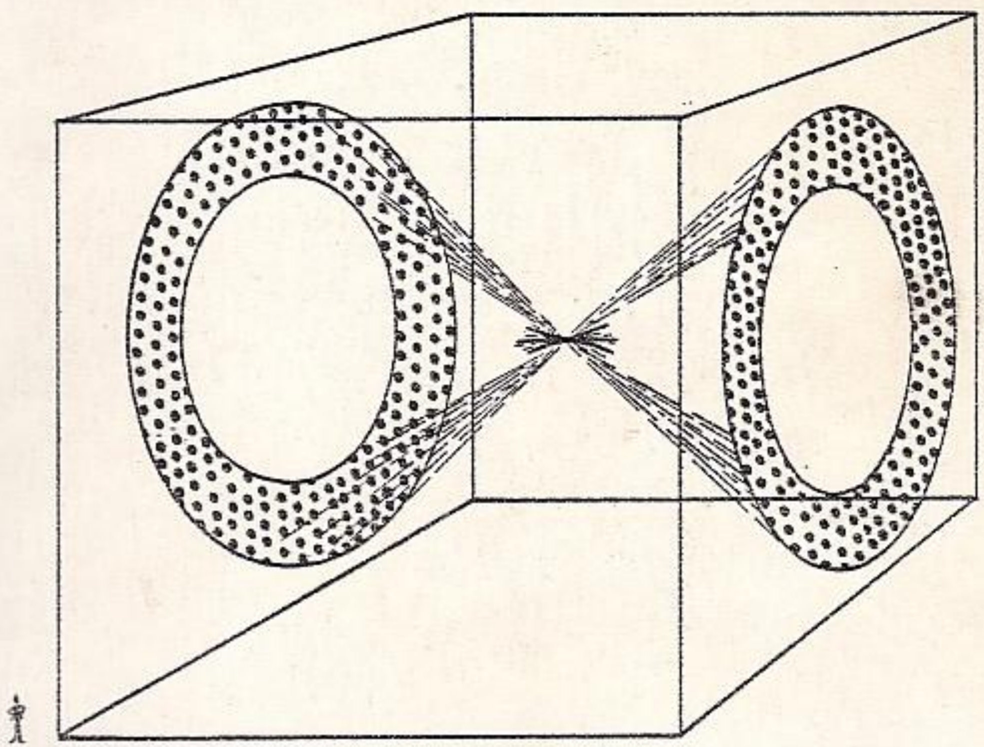
D. Sinclair, H. Sobel, L. Sulak, J. van der Velde.

M. Goldhaber was soon added and letters of support were solicited from Glashow, Gell-Mann, Salam and Weinberg.

3 Months Later….

PROPOSAL FOR A
NUCLEON DECAY DETECTOR

IRVINE/MICHIGAN/BROOKHAVEN



A PROPOSAL

TO TEST FOR BARYON STABILITY

TO A LIFETIME OF 10^{33} YEARS

Abstract

We have studied the properties of, and the expected backgrounds in, a totally active, 10,000 ton water Cerenkov detector located deep underground and sensitive to many of the conjectured decay modes of the nucleons in it. Sensitivity to π, μ and γ secondaries, good energy resolution, and good angular resolution provide sufficient background rejection in the proposed device and will permit us to obtain significant information about several decay channels, should they be observed. If no events should be recorded in the device in one year, a lower limit of $\sim 10^{33}$ years will thus be placed on the partial lifetime for the most distinct nucleon decay modes. Depending upon the decay channel, this is ~ 3 orders of magnitude longer than previous measurements, and is at or beyond the level suggested by many unifying theories. The sensitivity predicted for this instrument is within an order of magnitude of that achievable in an arbitrarily large detector of this general type, since known background from atmospheric neutrinos imposes an inherent limit.

Relegated to the appendix, a paragraph about possible supernova detection:

"While insensitive to neutrinos below about 50 MeV, [the detector] would give excellent data on the spectrum above this energy and perhaps (uniquely) indicate [the supernova] source direction."

(But that's another story)

Proposal Presentation,Washington, May 31, 1979

Einstein LoSecco

Smith Wuest Sinclair Learned Cortez

Bratton Sobel Van der Velde Goldhaber Reines Sulak

“That was a motley crew….

I wonder if they’ll ever amount to anything ?”

28 November '79… Big Day!

- Official approval from D.O.E.
- Dosco machine starts digging

28 November '79… Big Day!

- Official approval from D.O.E.
- Dosco machine starts digging
- 2400 five-inch PMT's ordered from EMI

…. One year of salt dust, construction, plumbing, and other grub work…plus testing, electronics, software….

- September 1980….
  Digging finished!
- Schlegel Co. is engaged to install plastic liner

Another year (and $200K) later…

September

1981

Things are rolling.

We have time to think about solar neutrinos.

9/8/’81 confidential memo to IMB group:

“FEASIBILTY STUDY OF A DIRECTIONAL DETECTOR FOR SOLAR NEUTRINOS”

The proposal would cover one wall of IMB with the new 20-inch Hamamatsu phototubes. Expect 40 events/year at the “Davis” flux.

At IMB group meeting Maurice brings up the question of cosmic ray muon spallation of oxygen nuclei producung lighter elements which beta decay and simulate solar neutrino interactions.

Hmmm……..

Two months later, another IMB memo

"BACKGROUND TO SOLAR NEURINO ELASTIC SCATTERING EVENTS"

- Main culprits are ^{8}B and ^{8}Li with 12 MeV betas and 1 sec lifetimes.
- Raw noise/signal is about 1/ 1 …. Uncertain by a factor of 3. Can be cut off-line by a factor of 10 or more but we would need to install more buffering.

Hmmm…….

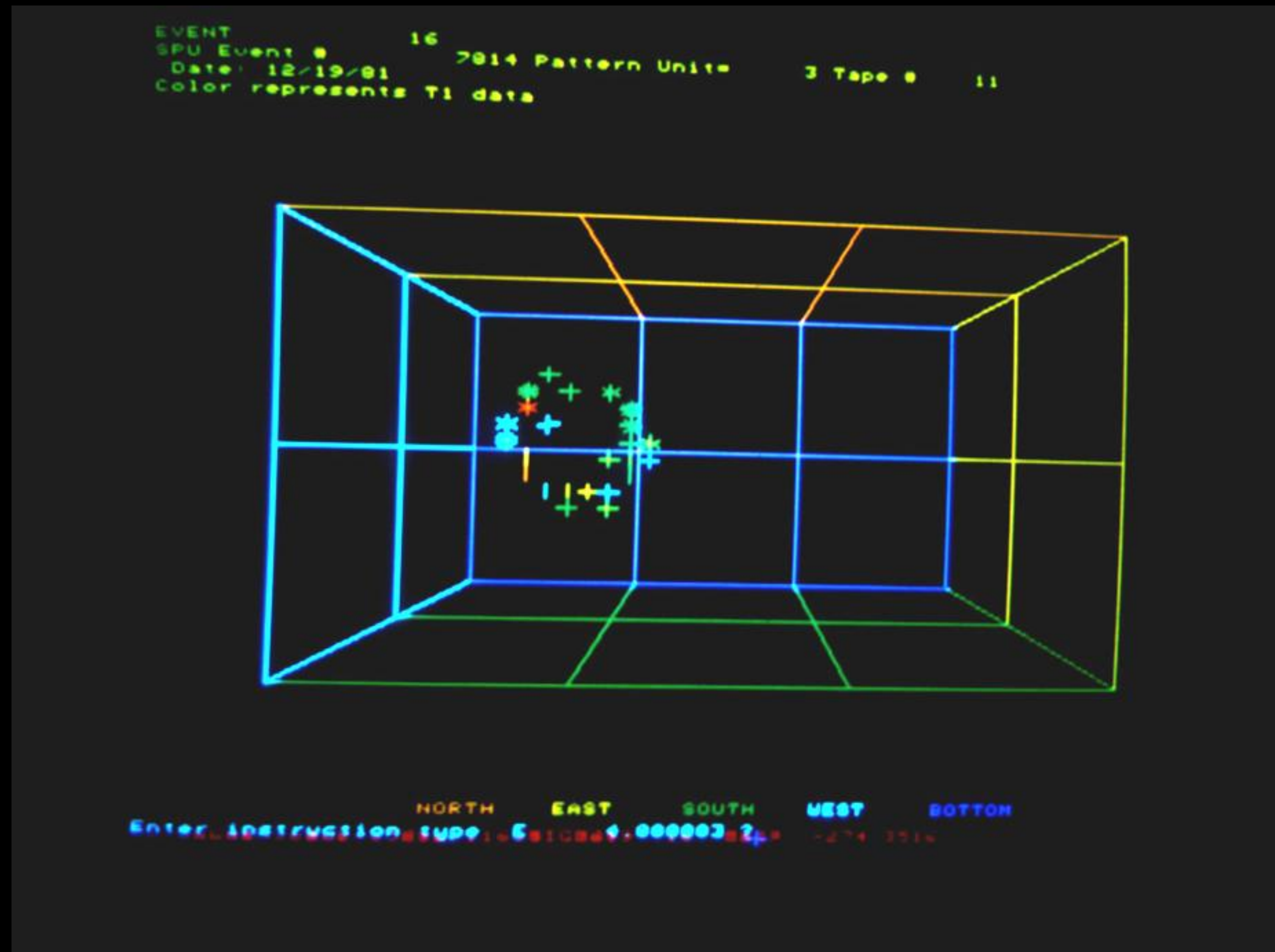
Back to proton decay…

Turn on the watah Hank !

- 30 November: 10 ft of water, small leaks develop
- Divers called in to patch them

December '81

Cosmic ray muon signals look good in 10 ft of water



Yes, it really works…. Nice and clean

20 January 1982

Water depth = 13 ft.

Larger leaks develop

The pool is MT'd

We need a better plan

Something smooth to support the liner against the water pressure

Something that doesn't dissolve salt !

The Answer

Use low density ($\rho = 1$) concrete

Pour it in while filling with water

Do it in stages to let it harden

May, ’82

Dan Sinclair gives schedule:

“Full by August”

May 1982

We have some time to think…

Idea: (revival)

by J. Losecco & E. Shumard

How about installing some hardware which would possibly enable us to see a supernova explosion in our galaxy?

Hmmmm…

- Bethe estimates ≤ one SN /30 years
- Essentially all of the signal would be below our threshold

Let’s put it on the Back Burner

July 31, 1982

The pool is full: 70 ft, no leaks

Reports from Paris ICRC meeting:
Soudan-1, NUSEX, KGF are finding
"Candidates"

We start taking data (slowly)
Then…

A Basic Particle Of the Universe May Be Decaying

By WALTER SULLIVAN

DEEP in the heart of Mont Blanc, in a 134-ton iron detector mounted inside a chamber alongside the highway tunnel that links France and Italy through Western Europe's highest mountain, an event has been recorded by nuclear physicists who regard it as the strongest candidate so far for the decay of a proton.

Such proton decay, predicted recently in a variety of so-called Grand Unification theories of the universe, is a phenomenon scientists around the world have been competing to detect.

If protons do decay, as a number of physicists say they must, then all matter is eventually destined to vanish as the nuclei of all atoms, formed of protons and their sister particles, neutrons, simply cease to be.

The Grand Unification theories, which seek to bring into a single theoretical framework all the basic forces of nature except gravity, call for protons to be very, very durable; the time in which half of any given number of protons will decay must exceed, other tests have shown, 1,000 billion billion billion years.

Still, that is less than forever, and there are enough protons around that one of them, according to the theories, ought to decay, on the average, in every human body during a lifetime.

The event in Mont Blanc was observed by physicists from Frascati, Milan and Turin in Italy and from the European nuclear research center near Geneva, called CERN. Three weeks after the detector began operation early in the summer, Dr. Donald Cundy, the experimenter from CERN, said it might be a year or more before a proton decay event was recorded in the detector, but in fact the event was seen within a few weeks. The detector itself took two years in preparation and consists of 134 half-inch iron plates, each weighing one ton. Sandwiched between them are 48,000 detection tubes to record the tracks of particles ejected if a proton inside one of the plates decays.

The Mont Blanc detector is not, however, the largest. Bigness counts because the frequency of observed proton decay events depends on the mass of the detector, and the biggest of all now in operation is a tank containing almost 10,000 tons of water in a

October 7, 1982

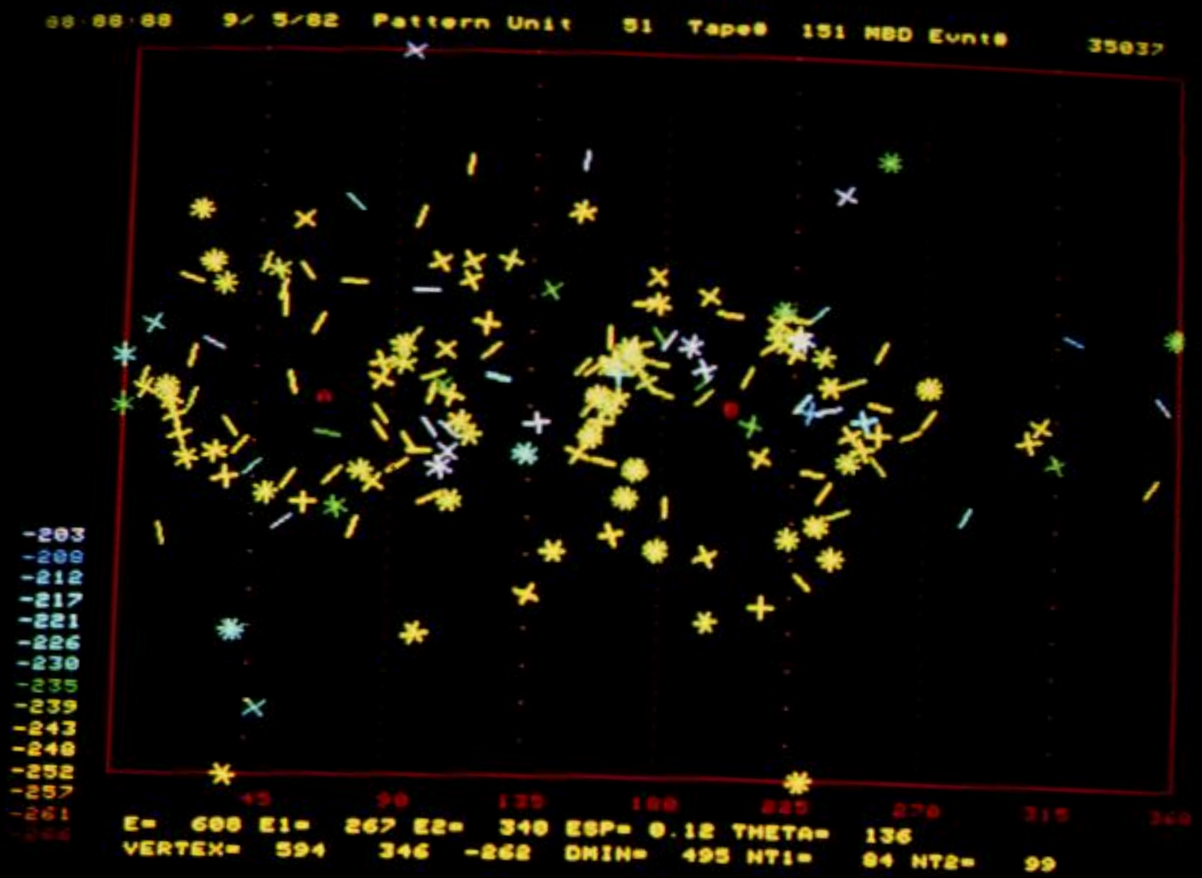
10 million triggers

20 contained events

Any candidates for PDK ?

This one looks interesting…
Check it on the “sphere plot”.

- Check opening angle on the cylinder plot



Opening angle = 135 deg
(Should be 150-180)

Hmmm….

- Total energy ?

1230 MeV

(Should be ≤ 1100)

Muon decay ?

Slow time scale window

Clear evidence for muon decay

Cancel that call to the NY Times

January '83

First public report:

80 days of live time

No candidates for $P \rightarrow e^{+} \pi^{0}$

$t/b \geq 5 \times 10^{31}$ yr

The New York Times

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NEW YORK, SUNDAY, JANUARY 23, 1983

Y

STUDY CHALLENGES PROTON THEORIES

Hypotheses That the Particles Eventually Decay Are Not Confirmed in New Test

By WALTER SULLIVAN

The most ambitious effort to test the hypothesis that protons are all destined to decay has so far failed to confirm the process.

Evidence reported by physicists last fall suggested that the particles, the basic building blocks of matter, had long, but finite, lifetimes. But a recent report by researchers who participated in an Ohio study says that proton lifetimes may be even longer than the billions of years previously estimated. They also say this could mean theories predicting such decay are invalid.

Such theories, which have gained wide popularity in the past couple of years, are called "grand unification theories," because they attempt to define relationships among all the major forces in nature except gravity. Scientists subscribing to this theory predict that protons and neutrons, from which all atomic nuclei are formed, will eventually decay, leading to the ultimate disintegration of all matter.

However, the predicted decay rate is so slow that of the billions upon billions of protons in a human body only one or two should disintegrate in the span of a lifetime.

Experiments Under Way

The theory, which also holds that such decay would occur more often in a larger volume, has been tested in a chamber filled with 10,000 tons of water. The chamber, part of a salt mine 2,000 feet under the floor of Lake Erie near Cleveland, has been monitored since late July, but instruments have failed to record a single proton decay, according to findings presented last week.

The instruments search for flashes of light produced by particles ejected by a decaying proton.

Last fall researchers monitoring an area about 7,000 feet underground in the Kolar gold field in India said they found at last three likely examples of proton decay. A tentative instance was also reportedly observed in a pile of metal plates inside Mont Blanc on the French-Italian border.

The experiments are conducted underground to minimize the interference from cosmic rays and other sources of radiation.

No telltale flashes have yet been detected in the Lake Erie project, and scientists have inferred that the half-life of the proton, the time in which half of the particles would decay, must be at least 500,000 billion billion billion years.

However, supporters of the unification theories say that such slow decay would not invalidate their findings.

The Lake Erie project, in which 29 physicists are participating, is a collaboration among the University of California at Irvine, the University of Michigan at Ann Arbor and the Brookhaven National Laboratory at Brookhaven, L.I.

The results were reported to scientific gatherings last week by Dr. Frederick Reines of the Irvine group and Dr. John van der Velde of the University of Michigan.

25 January 1983
APS Annual Meeting, NYC

Maurice gives an address* as the retiring president of the APS and describes the new IMB results on the proton decay lifetime limits.

(*Reported in "Physics Today" ,April 1983).

He signs off with a quote from the Buddha:

"All composite things decay…

Strive diligently".

Spring of '83
the theorists regroup…

"How about $\mu^+ k^0$ …… etc ?"

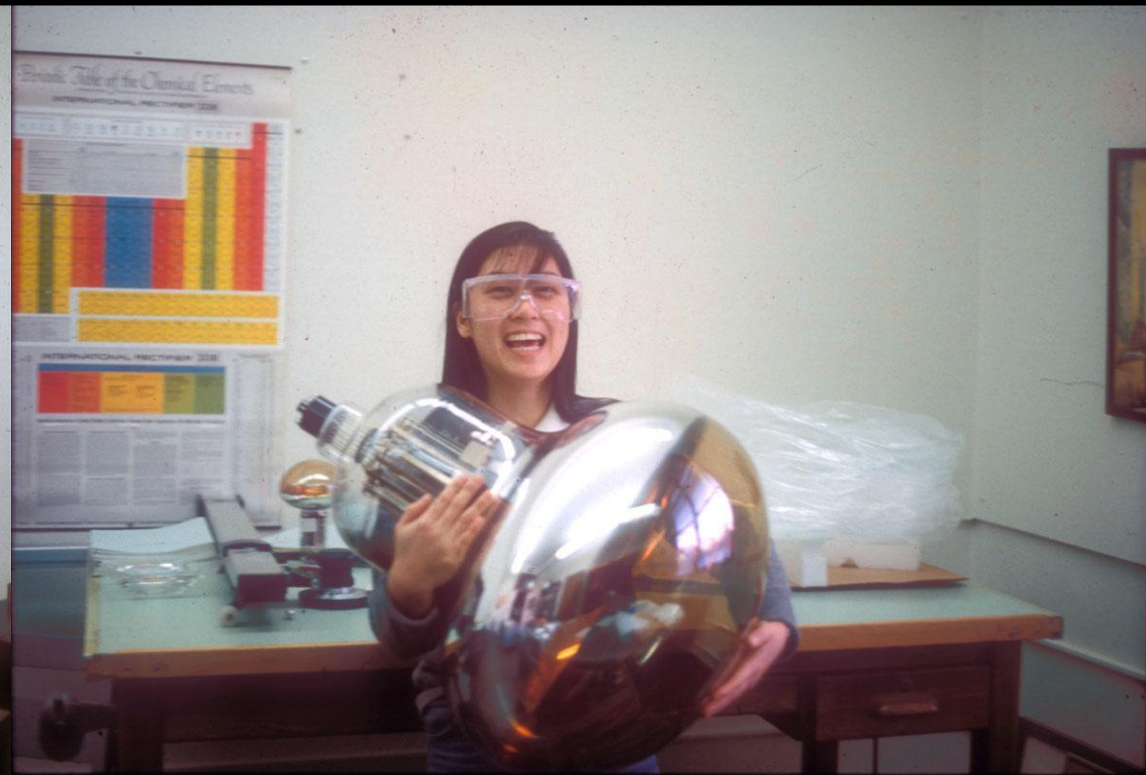
May '83…. Kamiokande taking data

with their 20-inch phototubes!

We need more light collection !

Pictures for Upgrade Proposal to D.O.E.

Us



Them !

Summer of ‘83

- Set limit on PDK to ($\mu^+ k^0$)… ≥ 10^{31} yr
- Set limits on Monopole Catalysis of PDK
- We find an apparent anomaly in our cosmic ray neutrino data. The proportion of muon decays is only about 60% of what it ought to be, but the theoretical uncertainties are about 50%. We argue a lot about this “too-few-mu”effect, (is it related to Ray Davis?) but don’t publish anything about it until 1986, (Haines et al., PRL 57 1986 (1986)). Again, in 1991, (Casper et al., PRL 66 2561) we confirm a two sigma deficit of non-showering (i.e. muon) cosmic rays.
- Kamiokande sees something similar. Super-Kamiokande finally nails it down in the 1990s as being due to atmospheric neutrino oscillations.

September ‘83

- Upgrade proposal presented to D.O.E.

  8-inch Hamamatsu PMT’s imbedded in wave shifter plates ⇨ 4X light collection ($1.7 M)

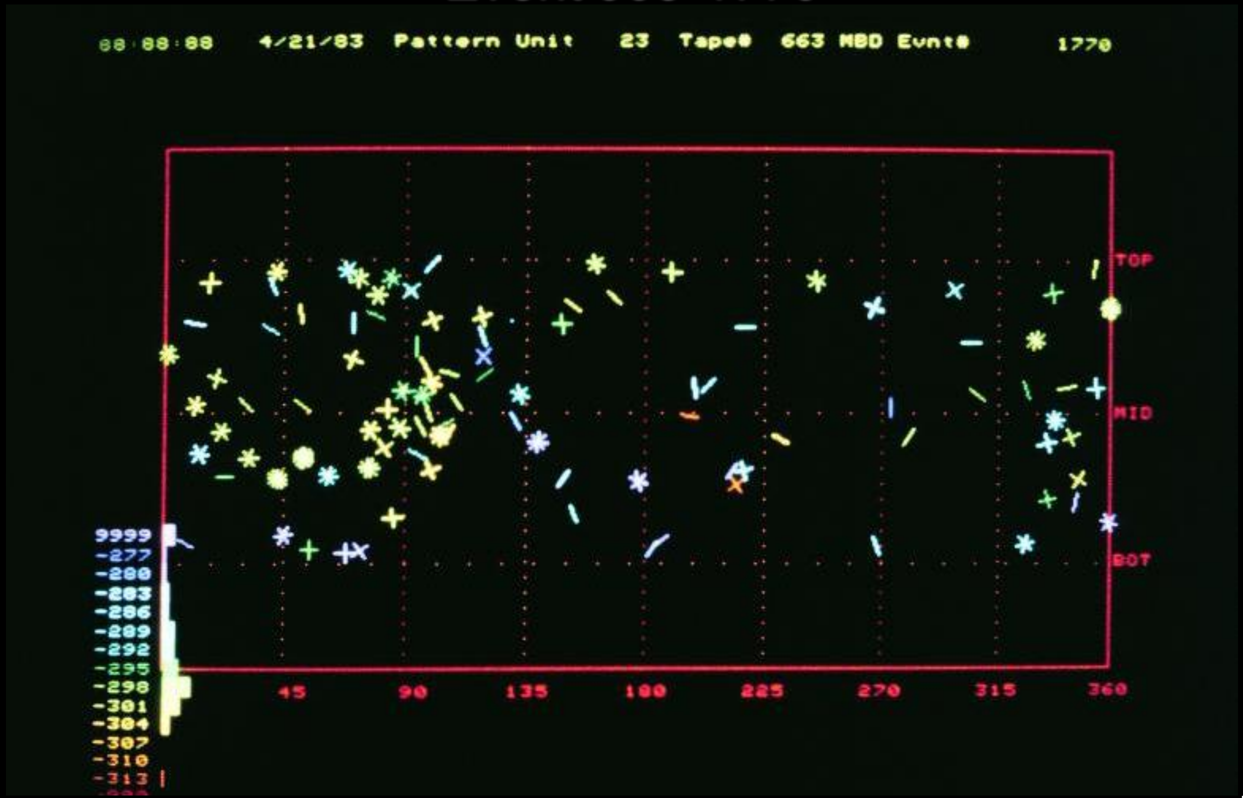
- April ’84: D.O.E. agrees to $1.5 M, spread out over 3 years. We order 8-inch tubes from Hamamatsu.
- Meanwhile we are installing wave shifters on our 5-inch tubes… = “IMB-2”

Fall 1984

- “Big List” of limits on 34 decay modes of nucleons sent to PRL.

Nine “candidates” could be various off-beat modes, but all are consistent with neutrino background, e.g.…..

Event 663-1770



This is a candidate for neutron decay into $e^+ \pi^-$

But it could also be a cosmic ray neutrino interaction.

We see 4 similar events, and expect 4 from CR backgound

“The value of a candidate depends on his background”
……Maurice (1984…also an election year)

to combine limits for modes with more than one requirement region.

1	2	3	4	5	6	7	8	9	10
Mode	Requirements				Effic. with Nuclear Corr.	Effic. without Nuclear Corr.	Candi- dates Observed	No. of Bkgnd. Est. -50%, +100%	Limit on τ/B ($\times 10^{31}$ yr) 90% C.L.
	E_c (Mev)	A	#μ	Back to Back					
$p \to e^+\gamma$	750-1100	< 0.3	0	0	0.66	0.66	0	0.1	18.
$p \to e^+\pi^\circ$	750-1100	< 0.3	0	0	0.46	0.75	0	0.1	12.
†$p \to e^+K^\circ$	300-500	< 0.5	1		0.12	0.12	i	2	
	750-1100	< 0.3	0		0.14	0.14	0	0.2	4.9
$p \to e^+\eta^\circ$	750-1100	< 0.3	0		0.37	0.54	0	0.2	
	400-650	< 0.5	1		0.07	0.15	0	2	12.
$p \to e^+\rho^\circ$	200-600	0.1-0.5	1		0.16	0.30	i	4	2.5
$p \to e^+\omega^\circ$	300-600	0.1-0.5	1		0.19	0.39	i	3	
	750-1100	< 0.3	0		0.05	0.06	0	0.2	4.0
$p \to \mu^+\gamma$	550-900	< 0.5	1	2	0.52	0.52	0	0.4	14.
$p \to \mu^+\pi^\circ$	550-900	< 0.4	1	1	0.32	0.44	b	0.2	5.1
†$p \to \mu^+K^\circ$	150-400	0.1-0.5	1,2		0.19	0.20	f,i	2	
	550-900	<0.5	1		0.14	0.14	a,b	2	2.9
$p \to \mu^+\eta^\circ$	550-900	< 0.5	1		0.23	0.44	a,b	2	
	200-400	< 0.5	1,2		0.12	0.22	f,i	2	3.1
$p \to \mu^+\rho^\circ$	150-400	0.1-0.5	1,2		0.10	0.16	f,i	2	1.2
$p \to \mu^+\omega^\circ$	200-450	0.1-0.5	1,2		0.18	0.32	f,i	2	
	650-900	< 0.5	1		0.03	0.05	a,b	0.8	2.1
$p \to \nu K^+$	150-375	0.3-0.6	1		0.08	0.08	3	4	0.7
$p \to \nu \rho^+$	300-600	0.2-0.5	1		0.07	0.19	1	3	1.1
$p \to \nu K^{*+}$	250-500	0.3-0.6	1		0.09	0.19	4	4	0.7
$p \to e^+e^+e^-$	750-1100	< 0.3	0		0.93	0.93	0	0.2	25.
$p \to u^+u^+u^-$	200-425	< 0.5	2,3		0.58	0.58	f	0.2	9.
$n \to e^+\pi^-$	450-950	< 0.5	0		0.40	0.55	c,e,g,h	4	2.5
$n \to e^-\pi^+$	400-700	< 0.5	1		0.10	0.24	0	2	
	700-950	< 0.5	0		0.10	0.07	c,e	2	2.5
$n \to e^+\rho^-$	400-800	< 0.4	0		0.20	0.42	c,d,e,g	2	1.2
$n \to e^-\rho^+$	400-800	< 0.4	0,1		0.22	0.57	a,c,d,e,g	3	1.2
$n \to \mu^+\pi^-$	200-700	< 0.5	1		0.30	0.43	i	4	3.8
$n \to \mu^-\pi^+$	200-500	< 0.5	1,2		0.29	0.45	f,i	3	2.7
$n \to \mu^+\rho^-$	300-550	< 0.5	1		0.07	0.29	i	2	0.9
$n \to \mu^-\rho^+$	300-550	< 0.5	1,2		0.10	0.41	f,i	2	0.9
$n \to \nu\gamma$	350-600	0.5 <	0		0.77	0.77	28	19	1.1
$n \to \nu\pi^\circ$	350-600	0.5 <	0		0.51	0.82	28	19	0.7
$n \to \nu K^\circ$	450-700	0.2-0.5	0		0.10	0.11	2	2	1.0
$n \to \nu\eta^\circ$	450-800	0.1-0.5	0		0.29	0.56	4	3	1.8
$n \to \nu\rho^\circ$	150-500	0.1-0.4	0,1		0.05	0.11	7	3	0.2
$n \to \nu\omega^\circ$	200-450	0.2-0.5	1		0.08	0.24	1	2	
	650-950	< 0.3	0		0.03	0.06	0	0.3	1.6
$n \to \nu K^{*\circ}$	200-700	.15-0.5	1		0.06	0.11	1	4	0.7
$n \to e^+e^-\nu$	500-850	< 0.5	0		0.41	0.41	4	3	2.6
$n \to \mu^+\mu^-\nu$	150-375	0.2-.65	1,2		0.31	0.31	4	7	1.9

PRL 54 22
(7 Jan 1985)

A tough time for theorists…

"You just can't stand being wrong, can you, Harold?"

136 • AMERICAN WAY, JULY 1983

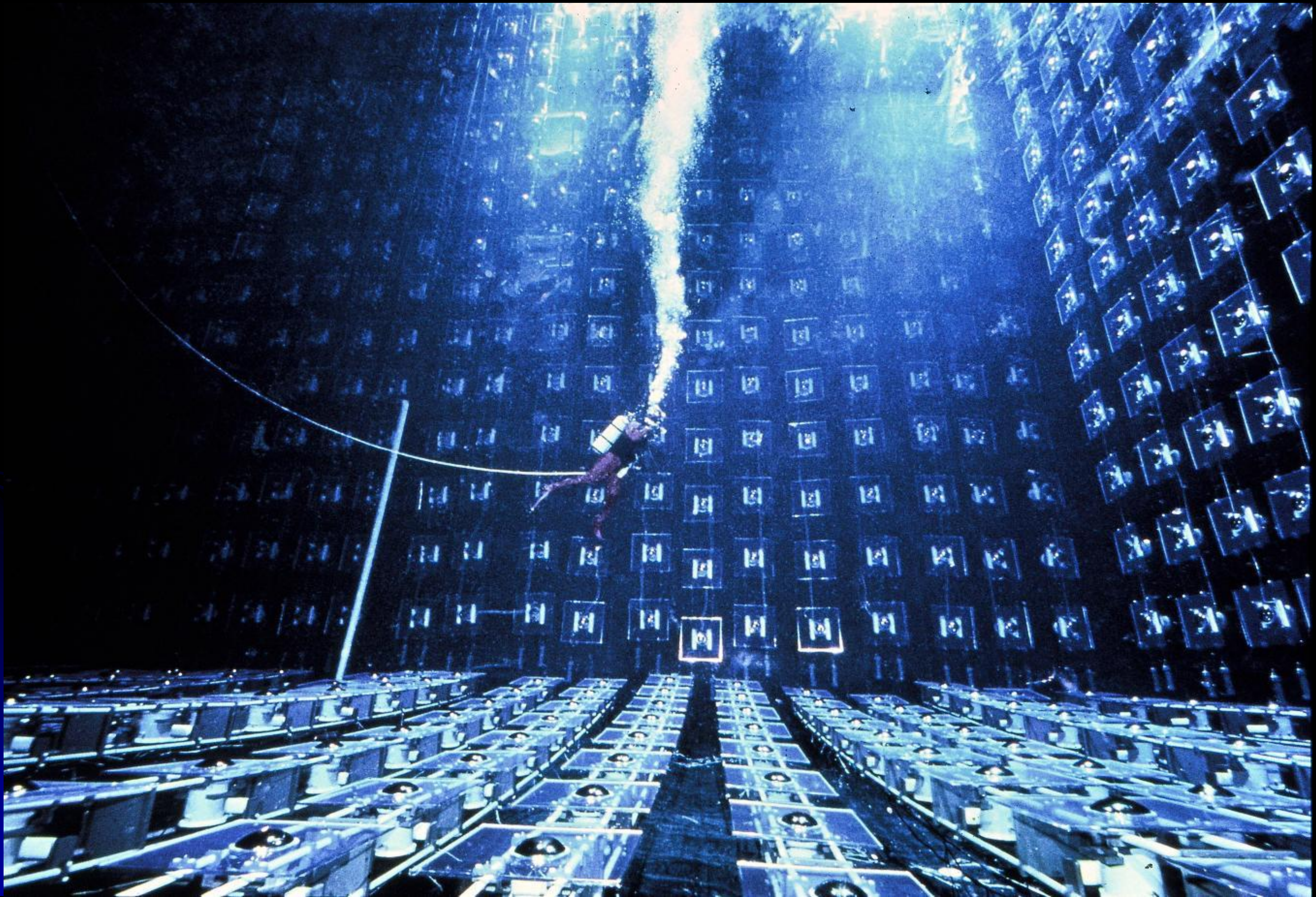
American Way, July, 1983

1985

While waiting for the proton to decay, the community of underground experiments experiences a self-induced frenzy of rumors and reports of extra-terrestrial sources of neutrinos etc. from Cygnus X-3 etc. which show up as underground muons etc. We analyze all of our muon data but never find anything convincing.

(A review of the subject can be found in Physics Reports 170 #6 (1988) by Bonet-Bidau and Chardin)

Sept. 1986….IMB-3 is ready!



October '86

We now have four times the

Light collection of IMB-1

At a collaboration meeting Eric Shumard revives (again) the idea to upgrade our data acquisition system to facilitate automatic supernova detection.

Decision: No $$$, No time, No urgency

Rule #One: Listen to your graduate students !

A Few Months Later….

February 23, 1987
UT 02:30

Neutrinos just passed Pluto

UT 05:00

the neutrino pulse is just passing Saturn.

Detector on auto…Nobody there
no supernova alert system in place.

UT 05:00:00.001

One of four HV power supplies shuts down at IMB.

On-line data analysis system shuts down.

Detector limps ahead with ¾ tubes and raw data tapes only

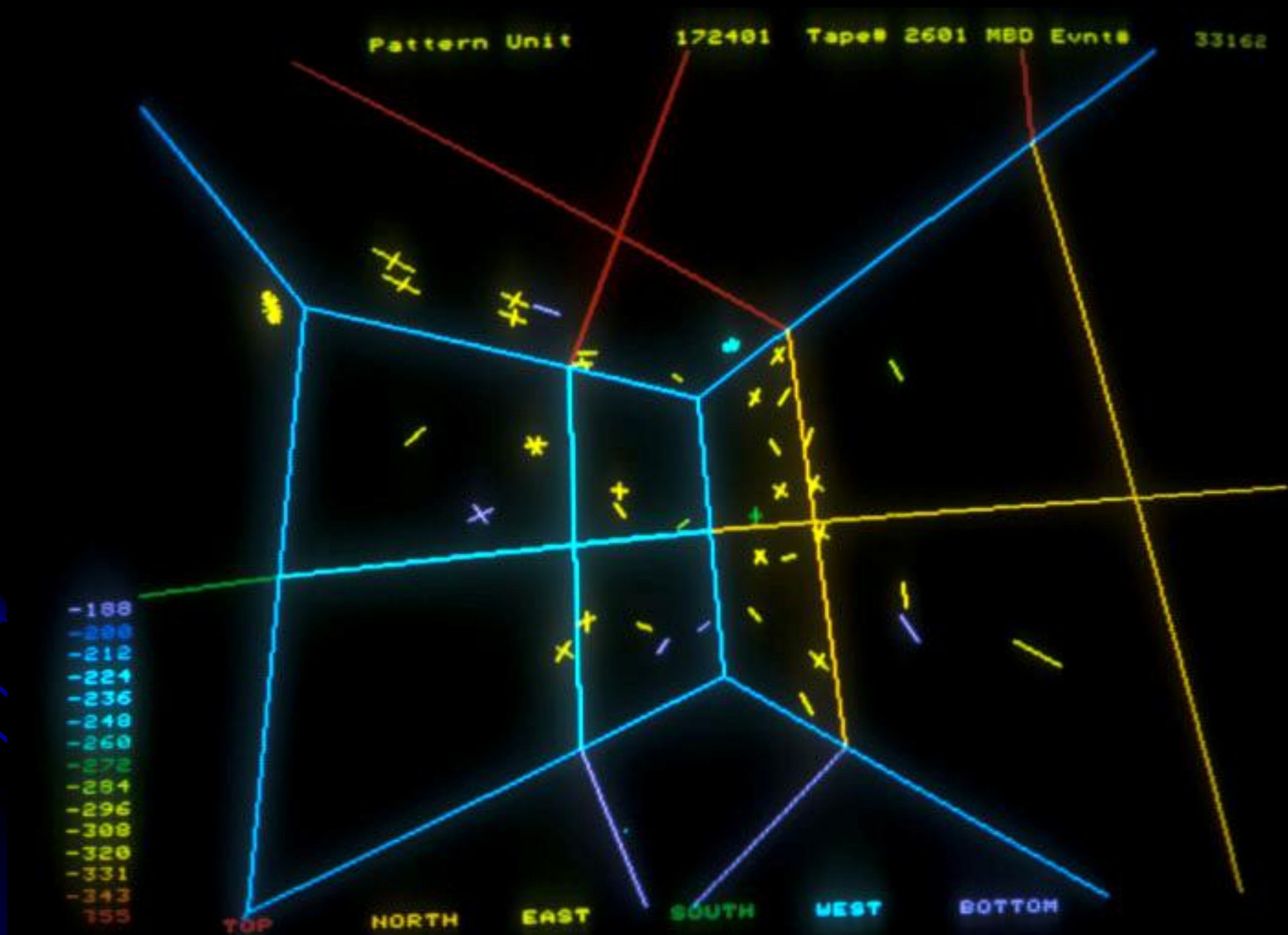
Two hours later…….

UT 07:35:41

Thirty thousand trillion neutrinos pass through the IMB detector

Only 8 are left behind

UT 7:35:41.4



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-224
-236
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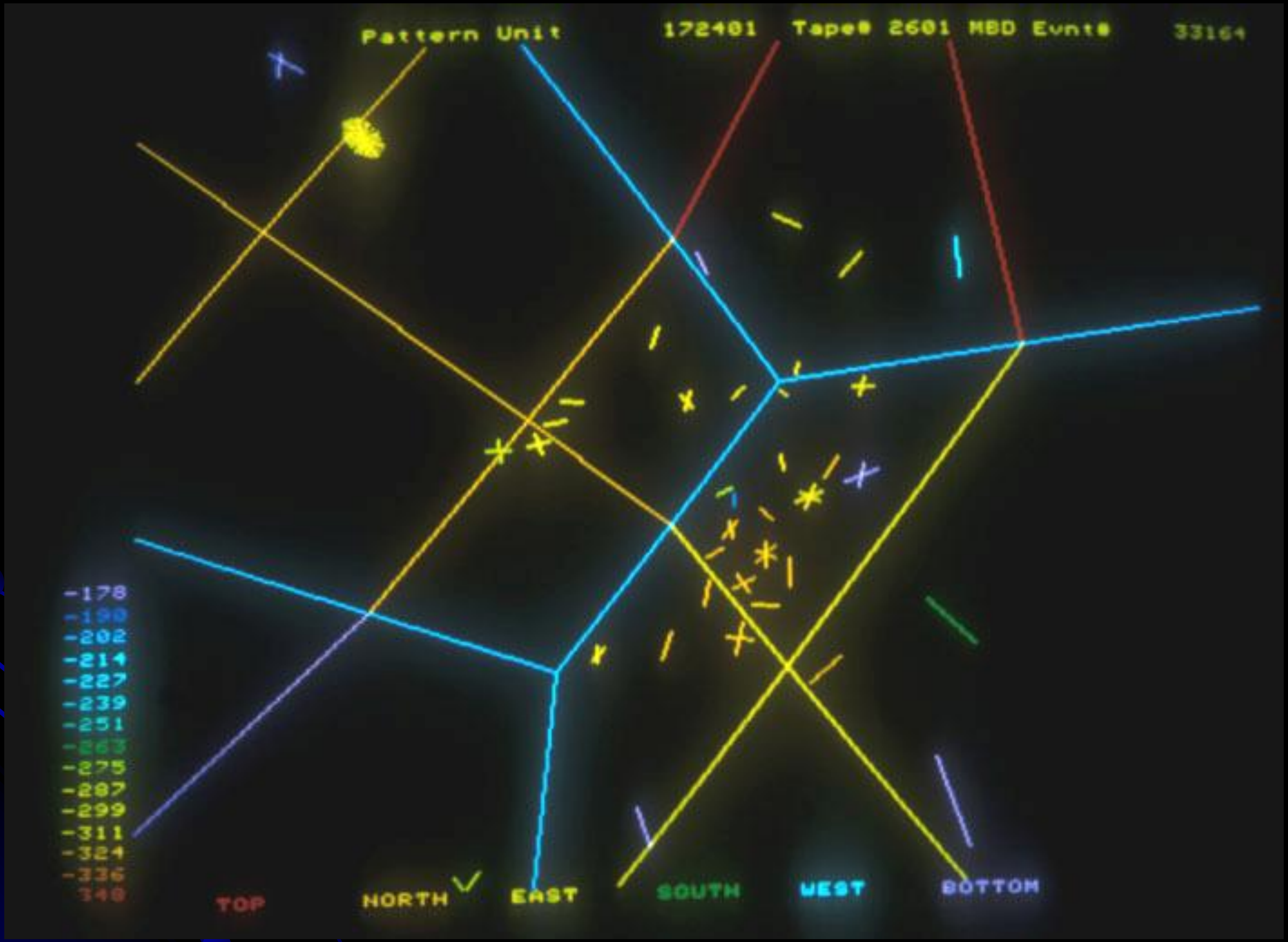
SOUTH
WEST
BOTTOM

UT 7:35:41.8



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NORTH
EAST
SOUTH
WEST
BOTTOM

UT 7:35:42.0

Pattern Unit
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-244
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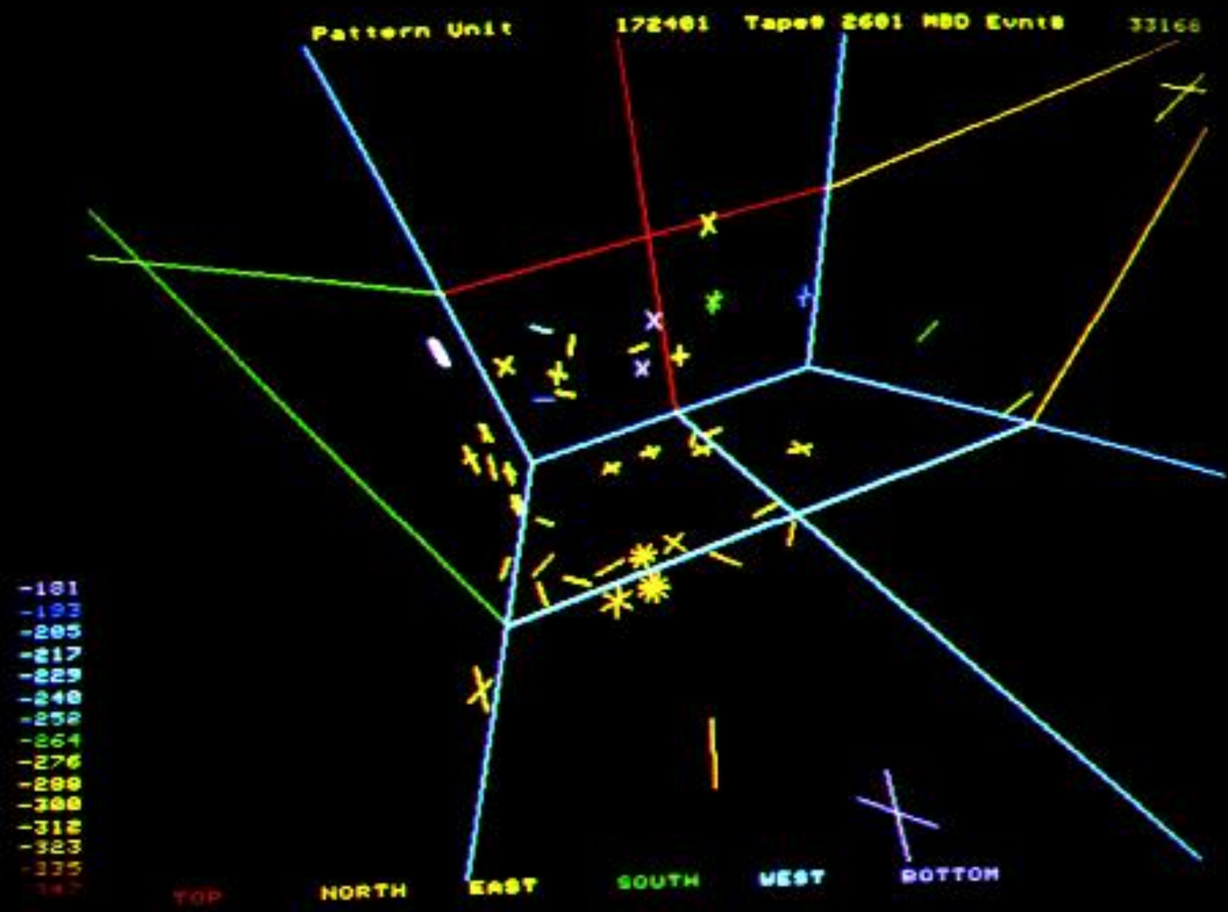
WEST
BOTTOM

UT 7:35:42.5



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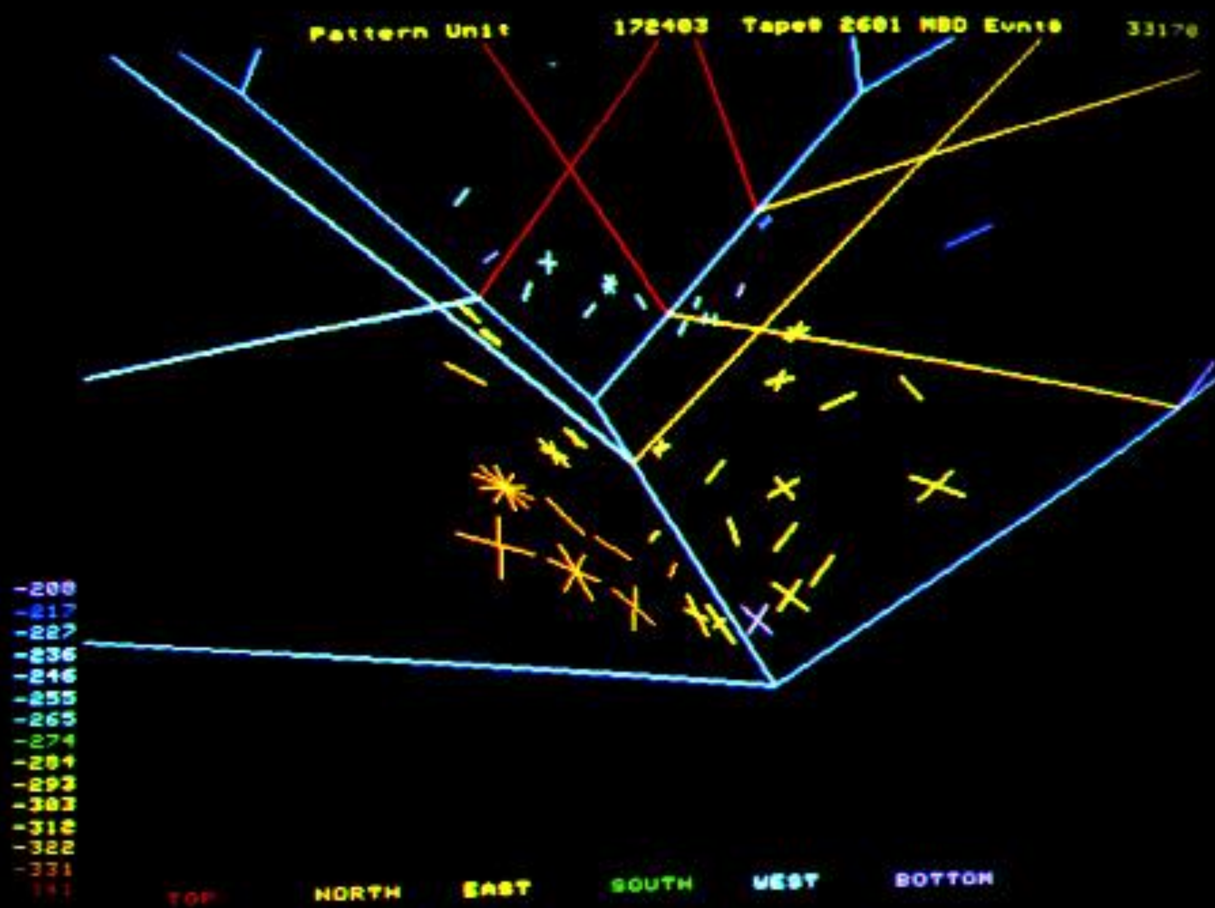
SOUTH
WEST
BOTTOM

UT 7:35:42.9



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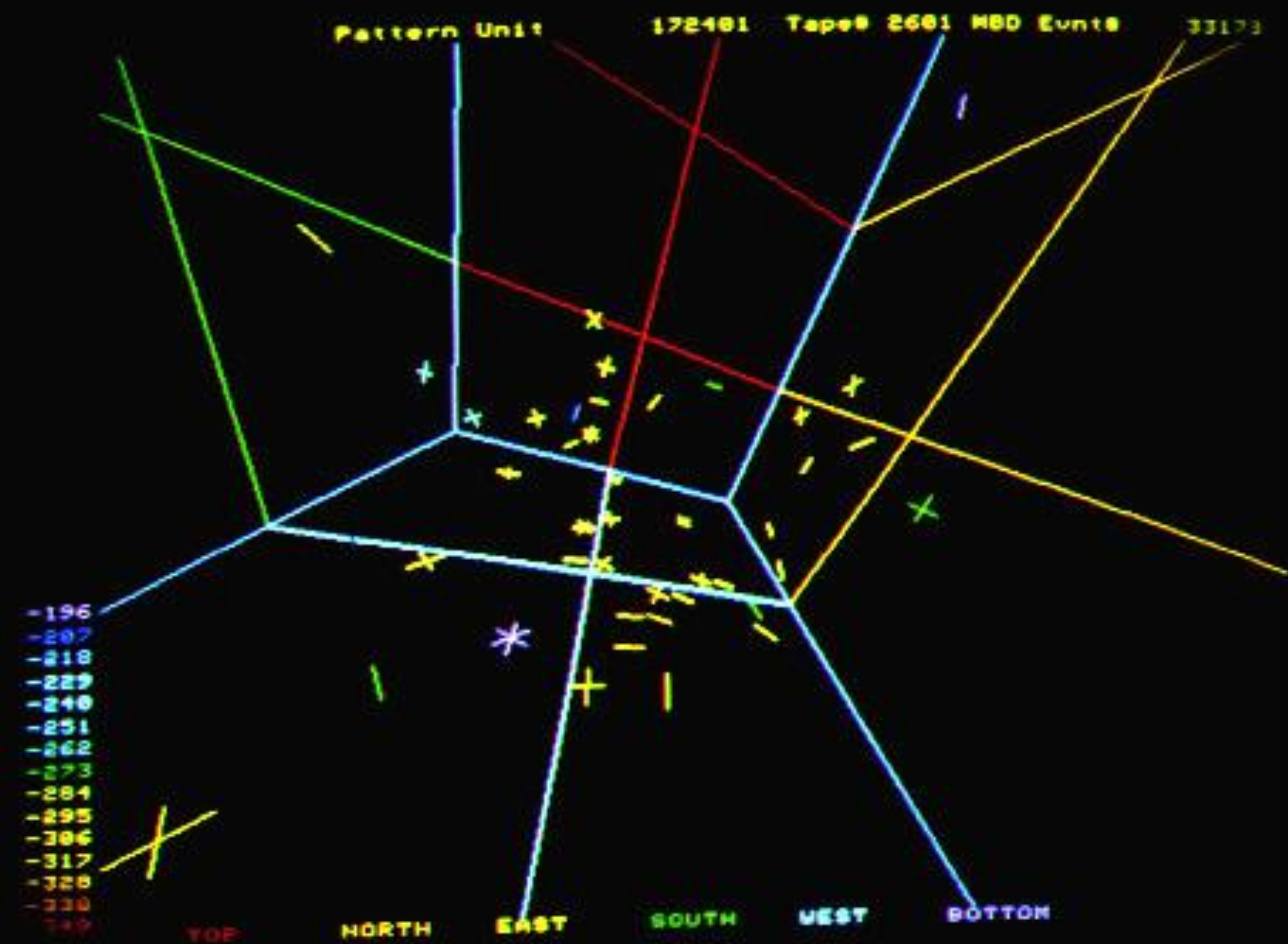
UT 7:35:44.1



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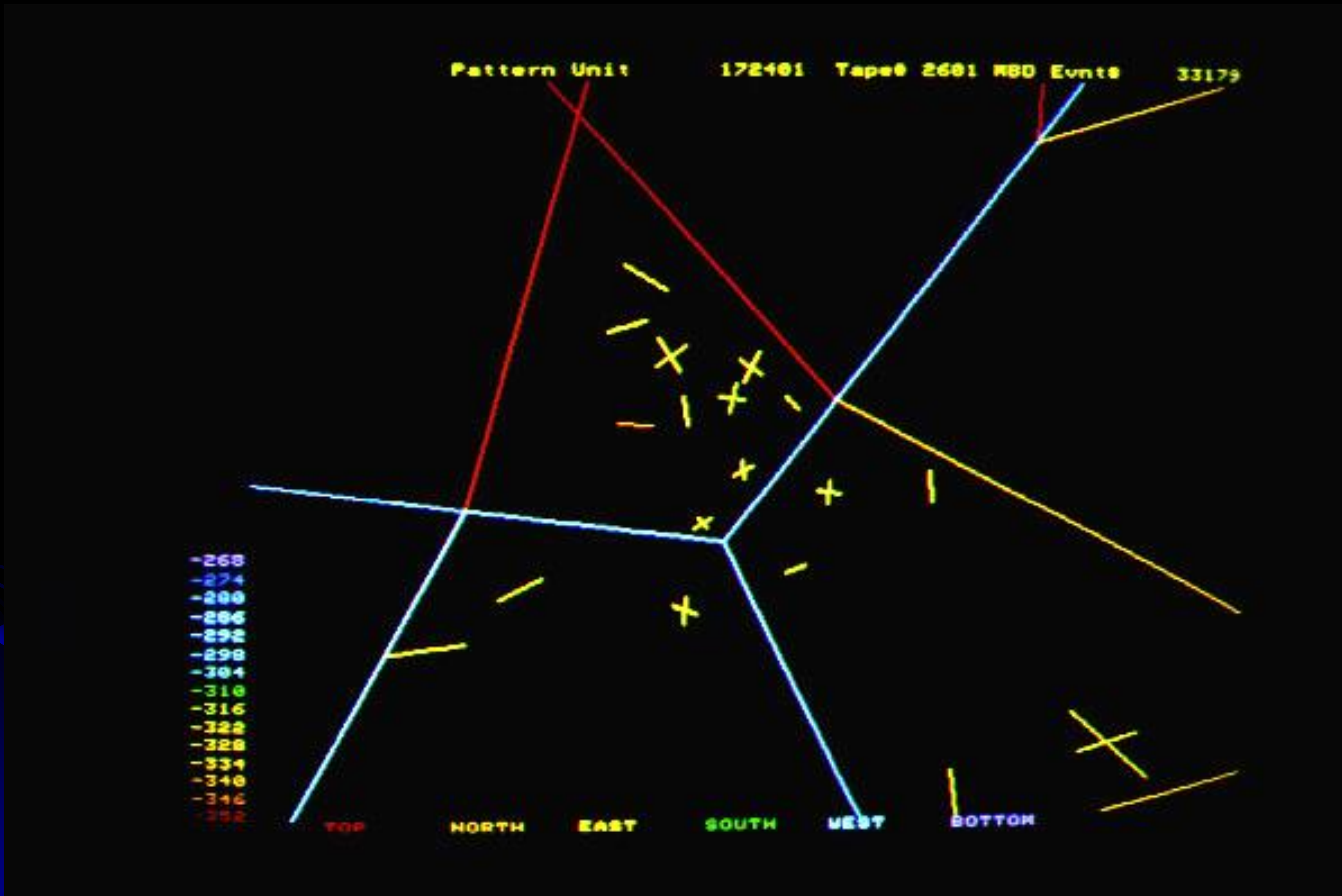
UT 7:35:46.4



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-298
-304
-310
-316
-322
-328
-334
-340
-346
-352
TOP
NORTH
EAST
SOUTH
WEST
BOTTOM

UT 7:35:46.9

Pattern Unit
172403
2601 MBD
-270
-274
-279
-283
-288
-292
-296
-301
-305
-310
-314
-318
-323
TOP
NORTH
EAST
SOUTH
WEST
BOTTOM

The rest is history….

It took us a while to dig out these events from the raw data tape, but once we did the signal was dramatic.

- The normal rate of similar events is one every 5 days.
- From random probability, 8 such events in 6 sec will occur:

Once every $2X10^{34}$ years !

The Cast

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Observation of a Neutrino Burst in Coincidence with Supernova 1987A in the Large Magellanic Cloud

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A burst of eight neutrino events preceding the optical detection of the supernova in the Large Magellanic Cloud has been observed in a large underground water Cherenkov detector. The events span an interval of 6 s and have visible energies in the range 20–40 MeV.

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The Diaspora, 1987

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IMB continued to operate until 1991 when a rupture of the water container caused its demise.

But we had a lot of fun….

It was a good ride

I'm sure Maurice will agree !