E1A's muonless events…

Its massive, totally-active calorimetry leads to
MACRO monopole search,
IMB & K supernova neutrinos,
Oscillating atmospheric neutrinos.

"The discoveries of weak neutral currents in the US"

Dedicated to the contributing physicists now in the heavens:
Norman Ramsey, Sam Treiman; Tim Toohig, Bob Wilson;
Alberto Benvenuti, Dave Cline, Al Mann;
George Charpak; Chuck Hurlbut; Hans Weedon

By L. Sulak, with recent input from E1A collaborators W. Ford, R. Imlay, J. Pilcher, D. Reeder, P. Wanderer
"*50^{th} Anniversary of Neutral Currents*", Orsay, December 6, 2023

Bon après-midi, mes amis de Paris, et de plus loin.

Merci à Guy et à Michel pour l’invitation de vous parler ici à Orsay.

Cet après-midi,

je vous propose une visite à mes archives personnelles,

de l’année ‘70 jusque l’arrêt de l’Accelerator NAL de Noël '73,

quelques 126 documents, pour la plupart des notes internes.

Tous est en anglais.

Donc…

Vas-y !

C'était l'année '70…A Paris, le tube de l'été, « La chasse au boson intermédiaire »

Aux USA, Leon: 2 types de neutrinos,

l'un qui se transforme en muon,

l'autre en électron.

⇒ 1) un courant neutre,

⇒ 2) un boson intermédiaire.

⇒ un accélérateur à l'énergie beaucoup plus haute.

« Chaque PI droit écrire une proposition.
C'est obligatoire ! »

…Alors, en anglais…

'70 Archives LRS

Let's scan through some of the 126 documents, touching upon:

Conceiving experiment E1A

Measuring the ν fluxes

Determining required characteristics for each detector element

Inventing technologies for massive scintillation calorimetry

Calibrating timing, energy, angle

Recording data

Analyzing & simulating events

…using many figures from my seminars at Harvard & MIT in October '73.

Legacy of E1A: it spawned several detectors…discovering neutral currents & more.

June 1970,

First proposal to National Accelerator Lab
(NAL…now known as Fermilab):

Dave Cline & Al Mann's "E1": Magnet

Enter Carlo Rubbia.

His genius #1: Hadron target/calorimeter:

… "E1" morphs into "E1A".

HARVARD-PENNSYLVANIA-WISCONSIN NEUTRINO DETECTOR (SCHEMATIC)

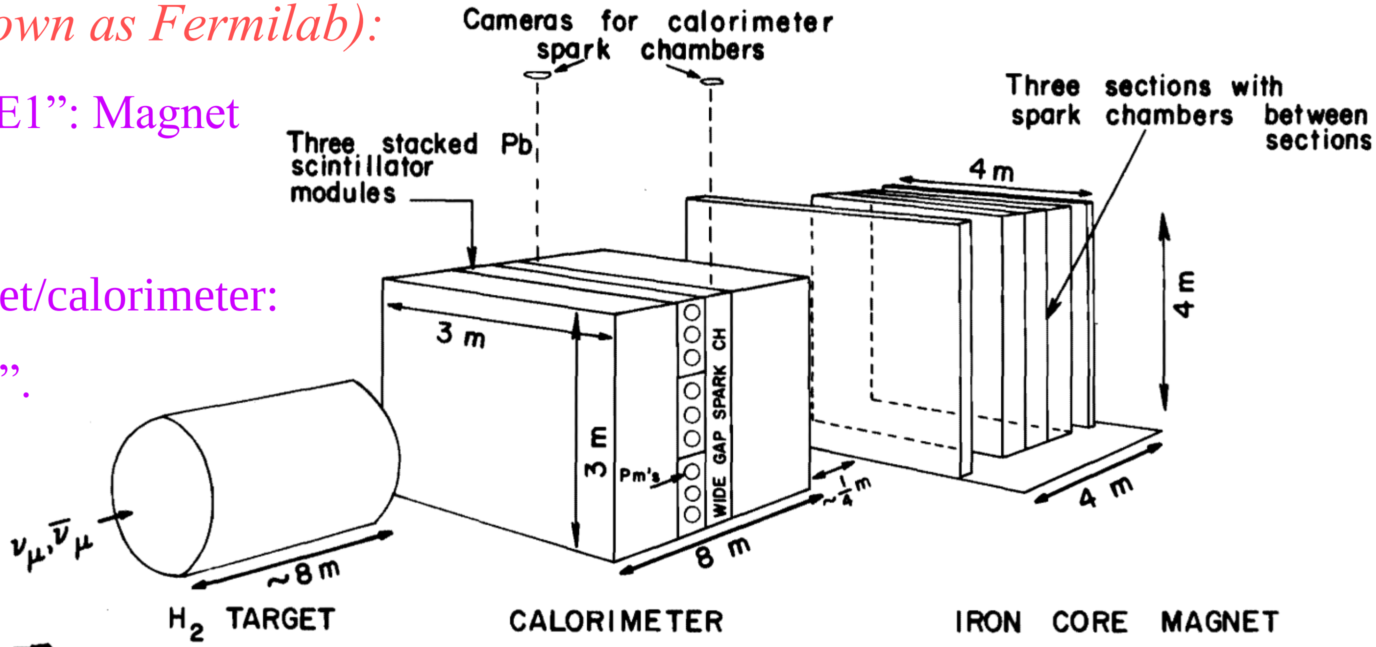


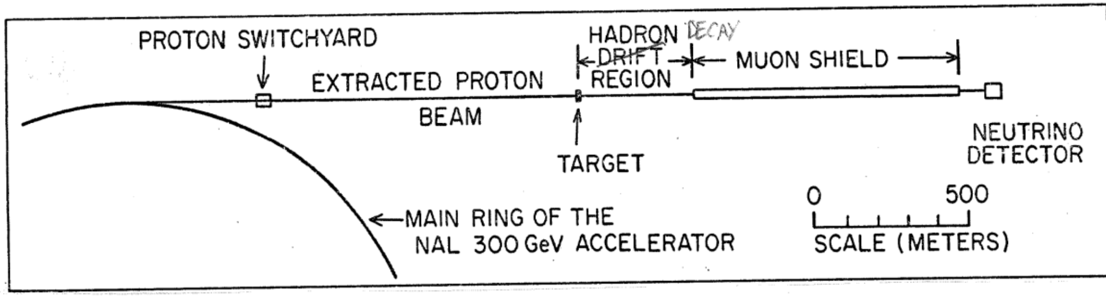
FIG 1

$$\nu + p \rightarrow X + \mu^+$$

FIG 1

What about the accelerator?

Bob Wilson, DG of NAL, promising?

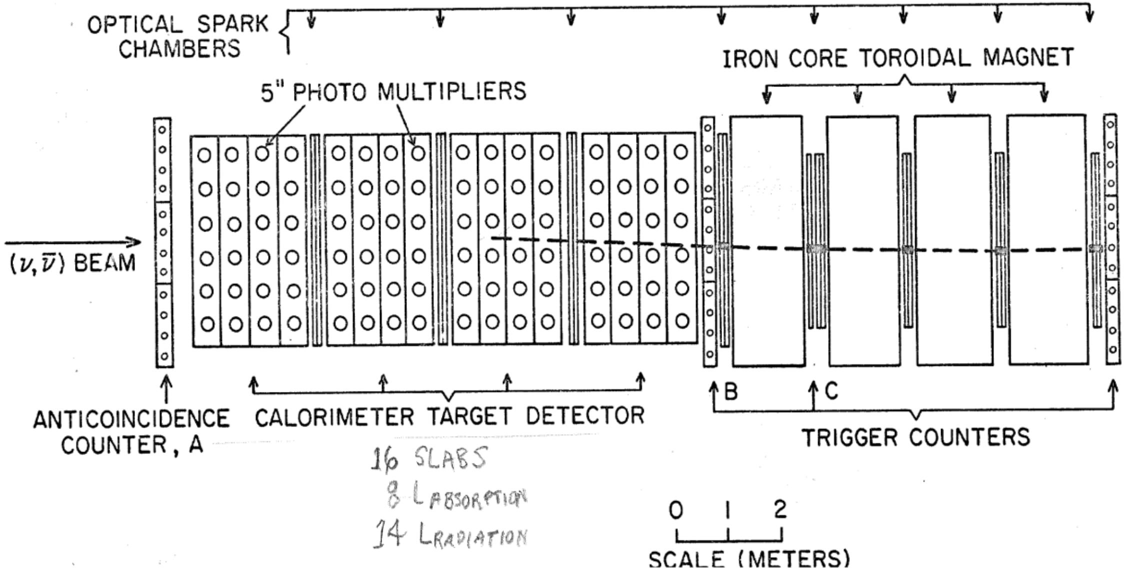


We at E1A commit to designing & building in 2 years.

Let me describe the detector.

1) A totally-active Hcal tracking target:

2) A magnetized iron toroidal tracker:



Jim Pilcher + LRS

wooed by ν's & Carlo to Harvard as Ass't Profs.

Jim to commute from CERN to Harvard,

bringing back to Carlo E1A memos & news.

LRS to focus on E1A in Boston,

& to teach Carlo's classes when not there.

July 26, 1971

Carlo & I go to NAL to confer with Bob Wilson.

Result of meeting, this Agreement:

The main ring soon to be turned on.

Must design, prototype & build E1A.

Agreement

This is an agreement between the National Accelerator Laboratory and Professors D. Cline of the University of Wisconsin, A. Mann of the University of Pennsylvania and C. Rubbia of Harvard University to accomplish a Neutrino Experiment. It is understood that the scientific responsibility for this experiment rests with all the senior members of the collaboration. It contains an enumeration of the major items needed for the proper execution of Phases 0, I and II of Experiment 1A, as expressed in the proposal for the experiment, the draft agreement and subsequent communications. Appendix I defines the physics objectives of Phases 0, I, II and III of this experiment as expressed by the experimenters. Phase III is not covered by this agreement.

A. Manpower

1. The Ph.D. experimenters committed to this experiment are: D. Cline, R. Imlay, D. Reeder, Wisconsin; J. Pilcher, C. Rubbia, L. Sulak, Harvard; A. Mann, Pennsylvania. Graduate students from Harvard, Penn and Wisconsin will also participate in the experiment.

2. D. Cline is the scientific manager.

3. The presently assigned liaison physicist for NAL is F. Nezrick.

B. Beam and Equipment

1. The experiment will initially use a monoenergetic neutrino beam in the Neutrino Laboratory. It will be designed and equipped with appropriate collimators, quadrupoles, bending magnets, etc., by NAL. Later it is expected that an un-focussed wide band system will be available.

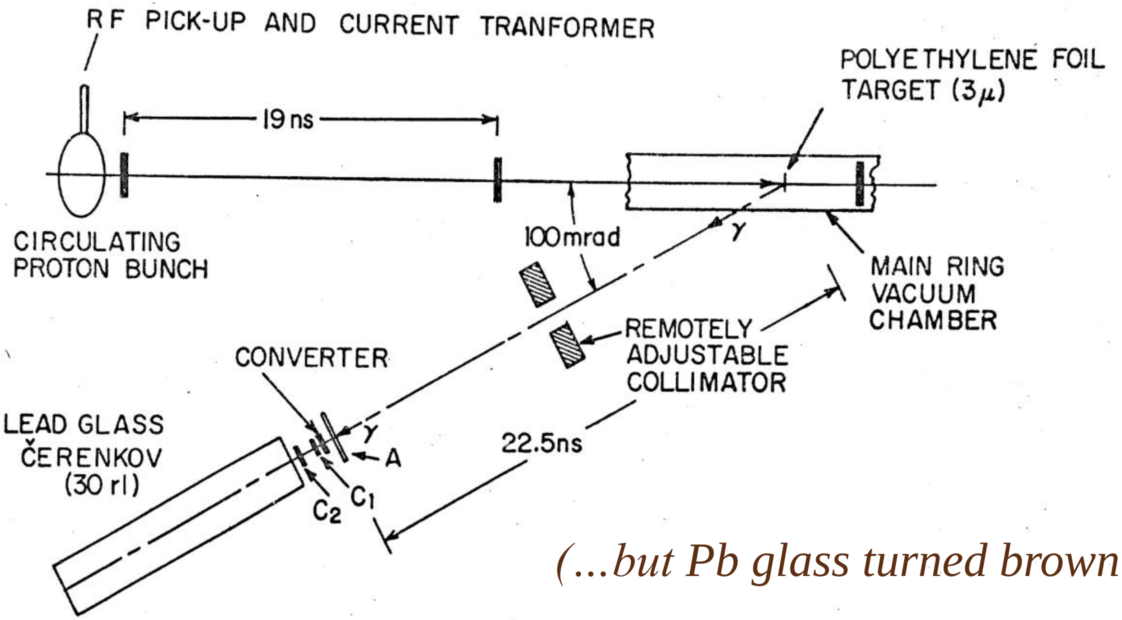
Criteria for detector design: width, depth, granularity, resolution?

Big jump from 28 GeV protons of Brookhaven to 350 GeV of NAL!

⇒ Must measure pion production!

Carlo's brainchild #2:

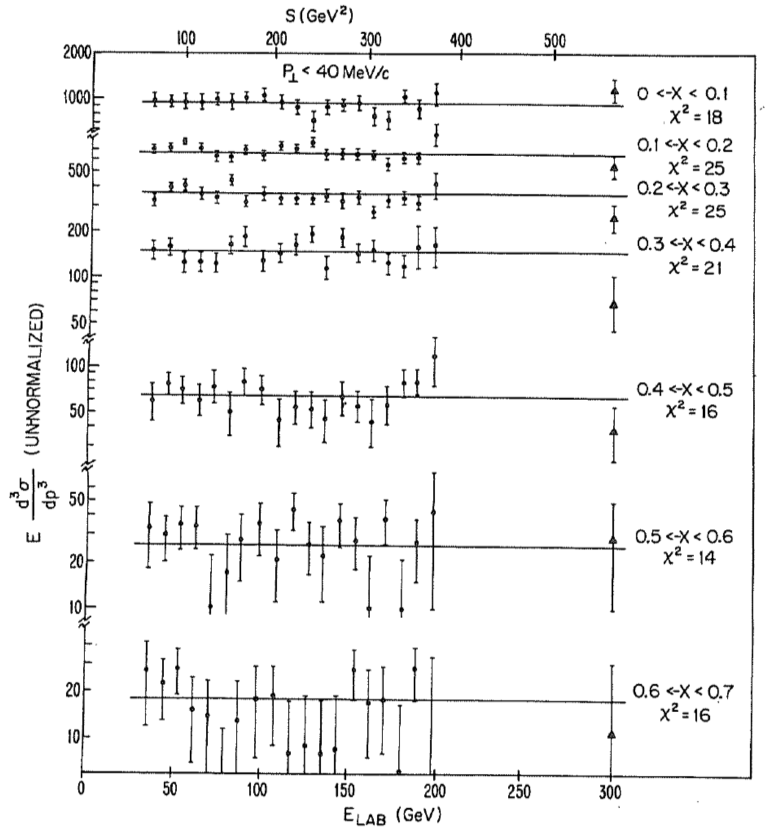
Collide proton beam with an internal target: Measure π^o production via of γs, scale to $\pi^\pm$

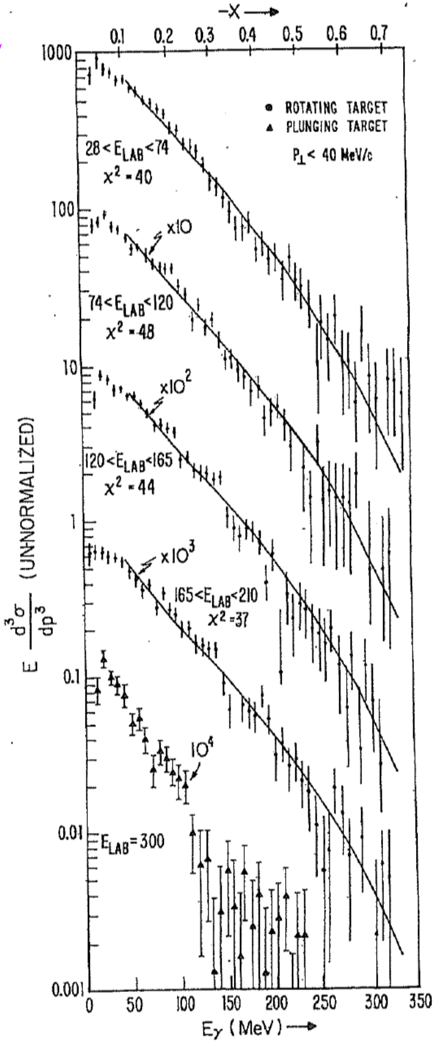


(…but Pb glass turned brown!)

…nevertheless, already enough data for the very first physics from NAL

Detailed π^o flux cross-sections (x, s, E_{Lab}, E_γ):





(…Fast forward…then back)

Proceedings of the
XVI International Conference on High Energy Physics

Parallel Sessions:
Strong Interactions

Volume 1

Very first, & only physics results from NAL:

"Photon production at Hi Energies & scaling"

Scientific Editors
J. D. Jackson
A. Roberts

Technical Editor
Rene Donaldson

Reported (LRS) at Chicago ICHEP, July1972:

PHOTON PRODUCTION AT HIGH ENERGIES AND SCALING (#177)

Presented by L. R. Sulak
Harvard University
Cambridge, Massachusetts

We present results from an NAL experiment[1] in which photon production in nucleon-nucleon collisions has been explored over the energy range 28-300 GeV. This experiment has two useful features:

1. The polyethylene foil target interacts with the internal NAL proton beam during the whole acceleration so that data over the entire s range are taken at every machine cycle.
2. We exploit the Lorentz transformation from cm to laboratory in order to transform the variable x into the longitudinal laboratory momentum $p_{\parallel}$:

$$|x| = 2P_{\parallel}^{*}/\sqrt{s} = E_{\gamma}(\beta_{cm} - \cos\theta_L)/M_p \approx \frac{2E_{\gamma}}{M_p}\sin^2(\theta_L/2).$$

The scaling hypothesis predicts complete independence of the photon energy spectrum from the energy of the incident protons.

We have performed measurements at a fixed laboratory angle $\theta_L = 175°$, corresponding to $P_{\perp}$ from 0 to 40 MeV/c and fractional longitudinal momenta from 0 to 1, and our data therefore reflect directly the x dependence at $P_{\perp} \approx 0$.

Our results are in excellent agreement with the scaling assumption, as shown in Fig. 1 where the gamma yield for fixed x is plotted as a function of the incident energy. Figure 2 shows the photon energy spectra for various bombarding energies. Our lower energy results are in excellent agreement with the extrapolated values of the experiment by Fidecaro et al.[2] who have measured the gamma yield for 24-GeV incident protons. Results at all energies are well described by the thermodynamical model of Hagedorn and Ranft.[3] However, they are in apparent disagreement with the fit of Neuhofer et al.[4] of the gamma yield at the ISR, who find an x dependence roughly twice as fast as ours. The discrepancy could be due either to experimental errors or to the fact that the assumption made in Ref. 4 about independence of the variables $p_{\perp}$ and x is not valid (recall that the present experiment covers a range of $p_{\perp}$ not previously explored at high energies). Relevant to the reliability of our data are the facts that 1) a CH_2 - C subtraction yields the same spectra as the CH_2 alone, with 35% of the events coming from the hydrogen in the polyethylene, and 2) energy calibration in the lead glass blocks has been made (in the forward direction geometry) using the known muon line.

With fluxes, begin designing the detector:

Transverse size of the ν beam? ~4m

∴ the detector transverse size

Neutrino energies (~40 GeV)? Fluxes?

∴ the mass of the Hcal (~100T) to yield sufficient statistics

∴ dynamic ranges of electronics.

But how to hold & seal in 100 T of scinti oil, with walls of minimal mass?

Aluminum honeycomb walls between Al sheets …aircraft wing technology.

Oct 1 '71

HARVARD UNIVERSITY

DEPARTMENT OF PHYSICS

LYMAN LABORATORY OF PHYSICS
CAMBRIDGE, MASSACHUSETTS 02138

October 1, 1971

Technical Memorandum

Subject: Liquid Scintillator Seals in the Calorimeter

From: J. Pilcher, C. Rubbia, L. Sulak

Introduction

In the present liquid scintillator calorimeter there are seals between modules, between cover plates and modules, and between the plexiglas windows and modules. They must satisfy five requirements:

1) light tightness (seal must be opaque)
2) chemical inertness in both mineral oil and 1,2,4 trimethyl benzene; i.e., mechanical properties must not deteriorate with time and, most importantly, the seal must not contaminate the scintillator
3) liquid tightness
4) elasticity to survive transport between installation at Harvard and arrival at NAL
5) reasonable cost

An exhaustive search for one material that satisfies all five requirements has been unsuccessful, principally because the chemical activity of 1,2,4 trimethyl benzene is

What will the data rates be at 350 GeV?

Using the internal target data,

LRS's new student John Osuch re-simulates.

Nov 12 '71:

…meanwhile, Wisconsin is machining magnet cores…

Preliminary Draft

HARVARD UNIVERSITY

DEPARTMENT OF PHYSICS

LYMAN LABORATORY OF PHYSICS
CAMBRIDGE, MASSACHUSETTS 02138

November 12, 1971

Technical Memorandum

Subject: Rate Calculations for the NAL 350 GeV Beam

From: John Osuch

<u>Introduction</u>

The rates for the four-fermion interaction, W^+ production and total interactions have been calculated for the 350 GeV proton beam, updating the estimates in the original proposal made for a beam with 200 GeV protons. The following assumptions are applicable to all of the calculations:

1) E_p = 350 GeV
2) 10^4 machine pulses/day
3) 2×10^{13} protons/pulse
4) Hagedorn-Ranft Particle Production Model
5) 50 ton fiducial volume of liquid (of 96 tons total) and 250 ton fiducial volume of lead (of 560 tons total)

<u>Determination of the Flux and Flux Factors</u>

Two sets of calculations have been made in each case, one assuming the NAL two horn focusing system, and a second assuming no focusing, which will be the case during the first few months of operation. Because of the limited amount of

Early 1972:

Knowing width & depth from fluxes,

magnet first to arrive at NAL.

4 soft-iron magnet cores:

Positioned inside E1A “tent frame,”

before installing plastic walls.

Reeder

We did get diverted? ...once...

Should we insert lead sheets to see electrons?

Oct 4 '71

L. R. Sulak

HARVARD UNIVERSITY

DEPARTMENT OF PHYSICS

LYMAN LABORATORY OF PHYSICS
CAMBRIDGE, MASSACHUSETTS 02138

October 4, 1971

Technical Memorandum

Subject: Lead Plate Calorimeter Scheme

From: J. Pilcher, C. Rubbia, L. Sulak

We present the design philosophy and a parameter list for the lead plate calorimeter. Also included are some of the mechanical drawings for a 10 ton prototype.

Design Philosophy

The basic problem is to support a 12 ft. x 12 ft. x ¼ in. lead surface (1.06 tons) so that an inter-plate spacing of ¼ inches is accurately maintained. We have considered a number of possibilities:

1. Use smaller plates 12 ft. by 4 ft. which are easier to handle. A frame around the reduced periphery would maintain the spacing. Place the 12 foot dimension horizontal since there must be photo-tubes on either end. Stack three modules, one on top of the other to obtain a surface 12 ft. x 12 ft.

   The drawback of this method is the support of the modules. The lead plates of the lower module cannot directly hold the weight of the above modules. Reinforcement of the lead with thin sheets of aluminum cladding is ruled out because of cost, so a heavy superstructure must be built.

Electronics? What's the required performance?

Nervous, more event rate studies…

Jan 3 '72…working thru the holidays

HARVARD UNIVERSITY

DEPARTMENT OF PHYSICS

LYMAN LABORATORY OF PHYSICS
CAMBRIDGE, MASSACHUSETTS 02138

January 3, 1972

Technical Memorandum

Subject: Neutrino Event Rates for Early Operation of NAL

From: J.E. Pilcher, C. Rubbia, L.R. Sulak

A. Scope

A number of important factors have changed since the first approval of neutrino experiments for NAL. Firstly, the neutrino beam line and detectors have taken tangible form. Secondly, the projected machine intensity and energy, for the first months of operation, will be significantly lower than anticipated. In light of these facts we have undertaken to review the possibility of doing neutrino physics during the early months of machine operation.

B. The Broad-Band Detector

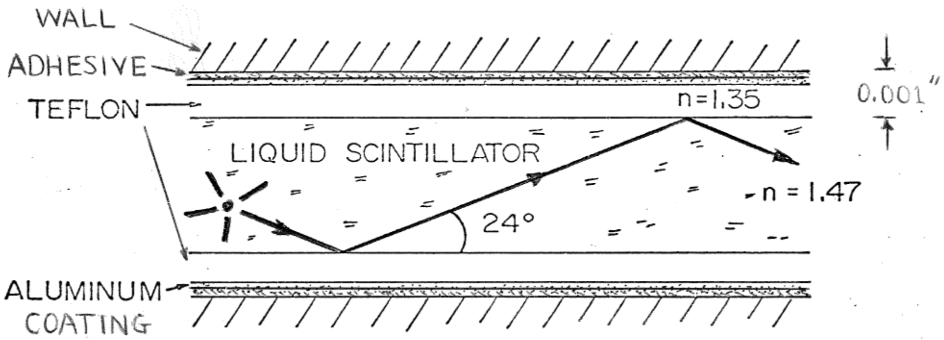
Since our detector must operate in a neutrino beam with a broad and an initially poorly known energy spectrum it has been designed to give maximal energy resolution. The first version consists of a calorimeter of 70 tons of pure liquid scintillator followed by a 4-section iron core magnet. The calorimeter can be roughly considered as a tank of liquid 12 ft. x 10 ft. x 24 ft. long with wide-gap spark chambers following each quarter

Confirmed, a ~100 Ton Hcal, totally-active target/detector: How to make it?

My wife's good cooking to rescue:

Teflon's all the rage, nothing sticks to it, but Teflon sticks to the aluminum of pans!

Shock #1: n = 1.35 ⇒ total internal reflection *vs* n = 1.47 mineral oil scintillator!



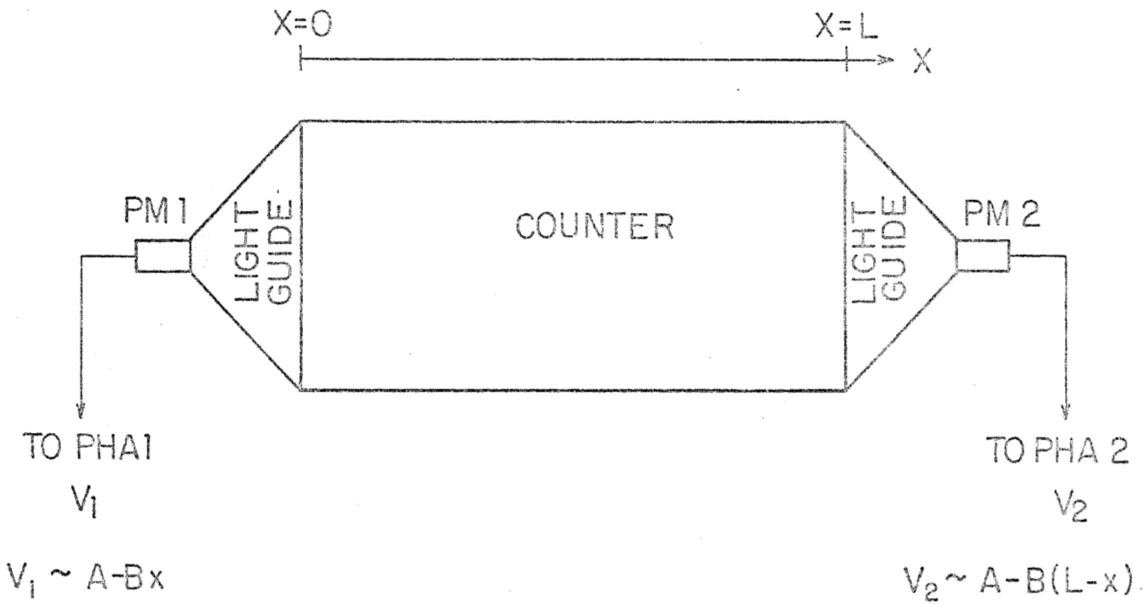
Shock #2: Teflon comes in sheets, can be flashed with aluminum, then adhesive on the back!

Figure 6

Attaching to aluminum walls? wet Al, strip off the backing, squeegee water out thru Teflon pours!

A "prototype", a section of the anti-counter…

Try Teflon technology on counters:



…and compare pulse height from 2 ends to get track position.

Figure 19

Finished, stack of 3 trigger counters,

red, from the side:

Just after 4 magnet cores (brown):

Magnet energizing conductors (white):

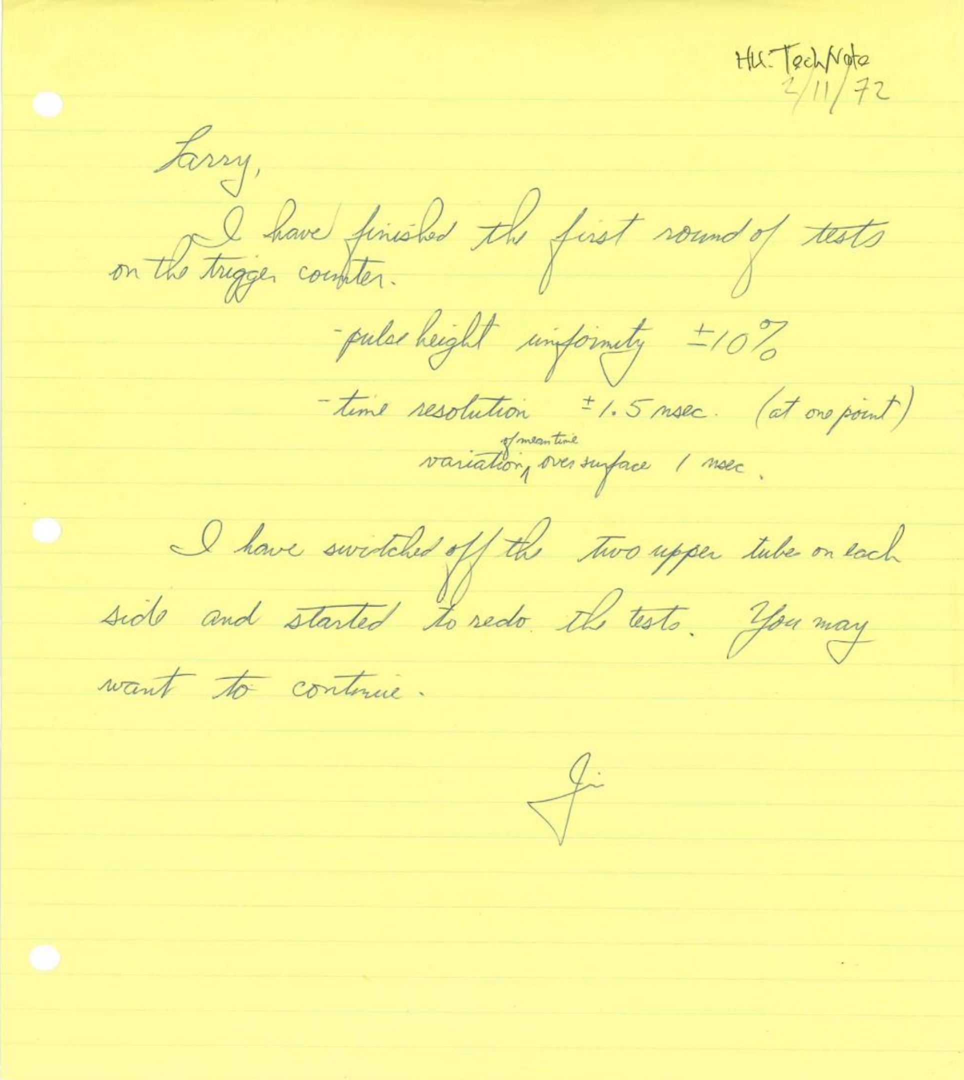
.

Magnet design & implementation by Reeder.
Fred Messing in pix.

Does that prototype counter work?

Equalize PM tubes with ^{60}Co source.

2/11/72 Pilcher on shift:


HU: TechNote 2/11/72

Larry,

I have finished the first round of tests on the trigger counter.

- pulse height uniformity ±10%
- time resolution ±1.5 nsec. (at one point)

variation of mean time over surface 1 nsec.

I have switched off the two upper tube on each side and started to redo the tests. You may want to continue.

J

Put external cosmic ray counters at 45°.

pulse height uniformity 10%

time resolution ± 1.5 ns

More detailed test of Teflon performance?

1.0 ns timing…

vs 19 ns between *ν* bunches, rf structure of ring.

Yes, will cut 19-fold any background slower than "c"

e.g. the anticipated neutrons.

Note very little tails:

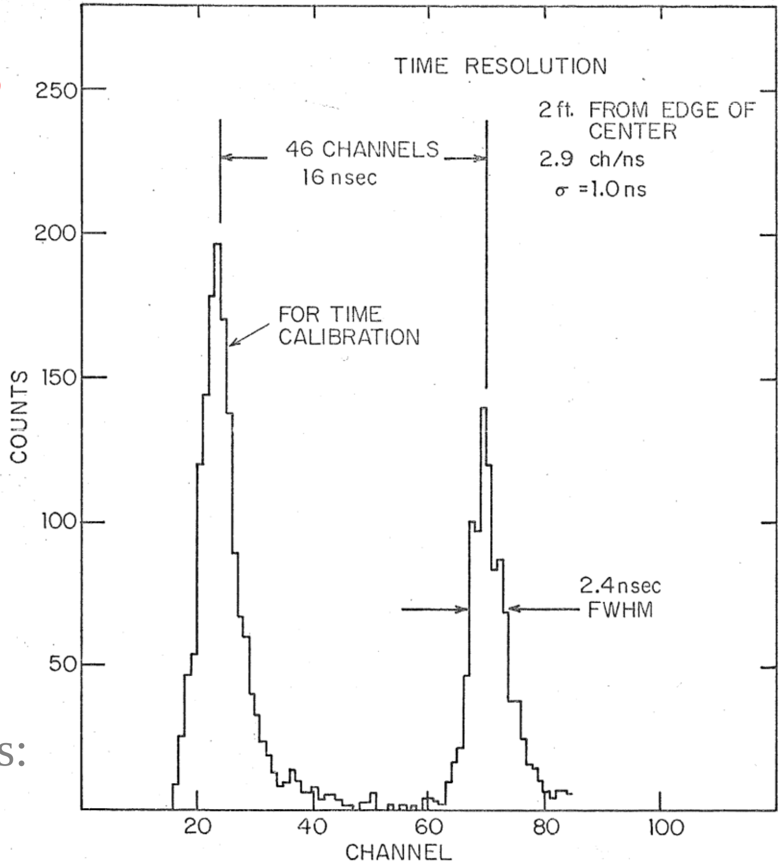


Figure 5

How to design/build the electronics?…

Bubble chamber & beamline rf noise:

How making pms & insensitive?

Carlo's brilliance #3:

Twinax…twisted pair inside a shield.

Getting those signals to coax? LRS job.

A ferrite coil to couple Twinax to coax.

How delay signals to enable processing?

Acoustically, 0.3 μsec. LRS job

.

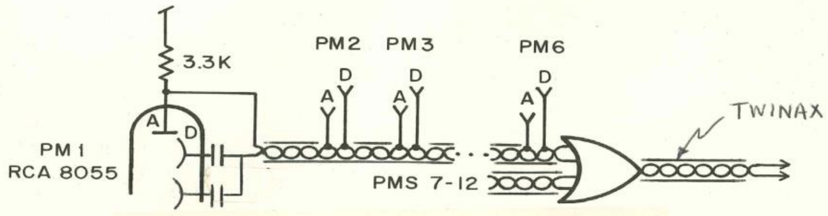


Figure 9

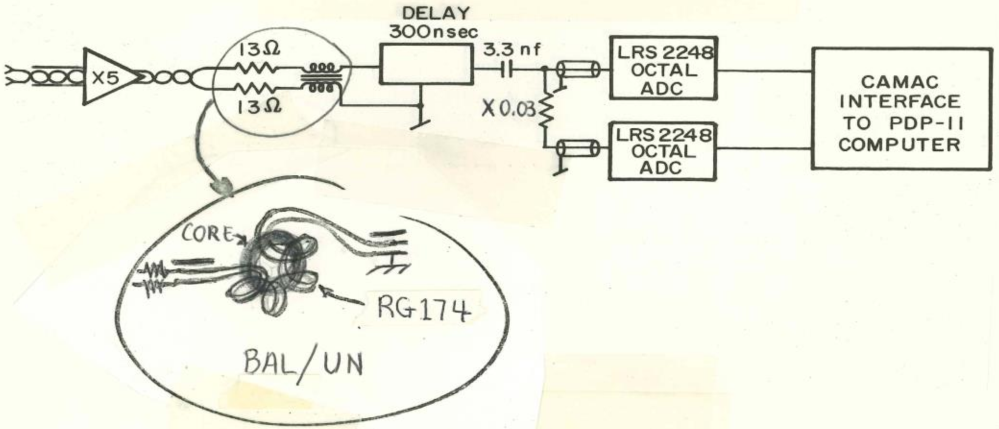


Figure 10

Functionality required of Hcal electronics?

Timing to 20 ns, the proton spill period.

0.5 nsec least count for *x*-localization.

2 ADCs, hi & lo for full dynamic range,
10s of GeV shower, to min ionizing μ.

LRS

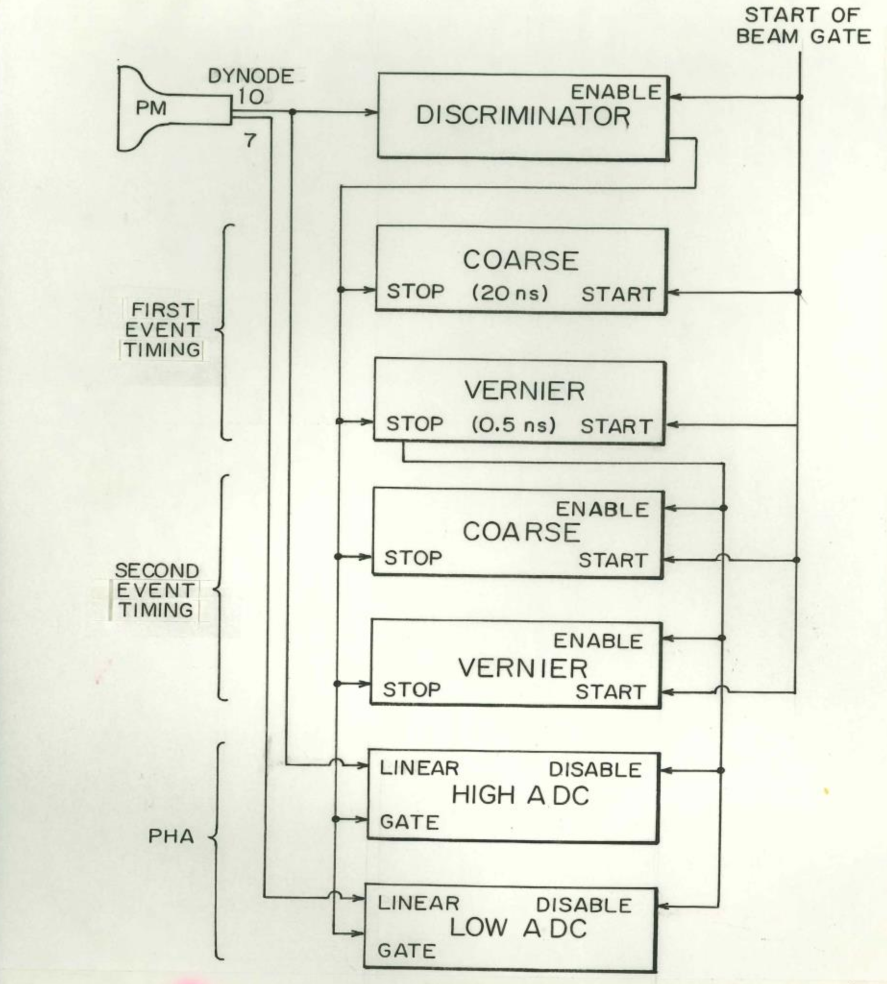
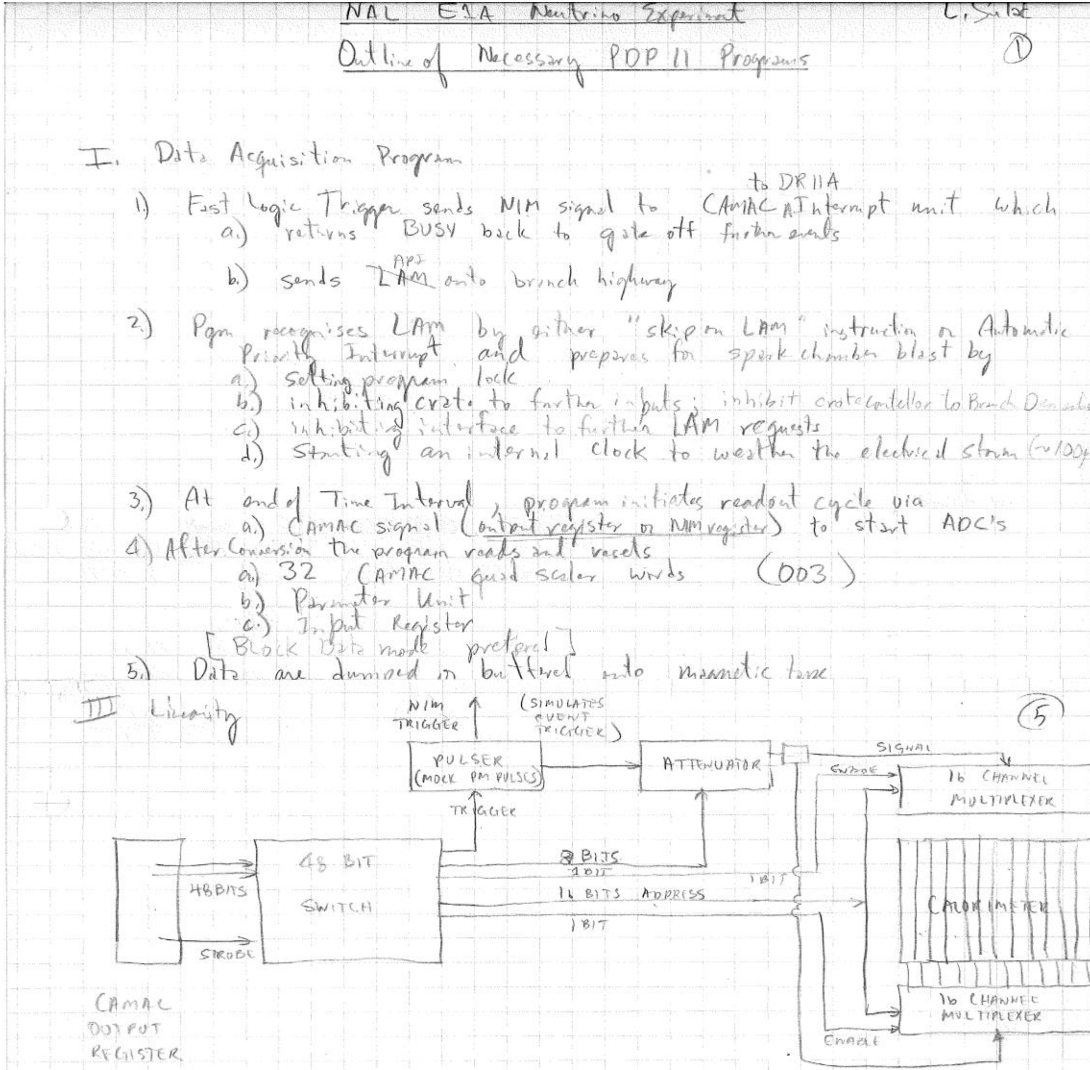


Figure 3

Draft of electronics, DAQ, PDP11:



NAL E1A Neutrino Experiment — L. Sulak

(1)

Outline of Necessary PDP 11 Programs

I. Data Acquisition Program

1) Fast Logic Trigger sends NIM signal to CAMAC Interrupt unit (to DR11A) which
   a.) returns BUSY back to gate off further events
   b.) sends LAM (APJ) onto branch highway

2) Pgm recognises LAM by either "skip on LAM" instruction or Automatic Priority Interrupt and prepares for spark chamber blast by
   a.) setting program lock
   b.) inhibiting crate to further inputs; inhibit crate controller to Branch Demand
   c.) inhibiting interface to further LAM requests
   d.) Starting an internal clock to weather the electrical storm (~100μ

3.) At end of Time Interval, program initiates readout cycle via
   a.) CAMAC signal (output register or NIM register) to start ADC's

4) After Conversion the program reads and resets
   a.) 32 CAMAC quad scaler words (003)
   b.) Parameter Unit
   c.) Input Register

[Block Data mode preferred]

5.) Data are dumped in buffered into magnetic tape

III Linearity

(5)

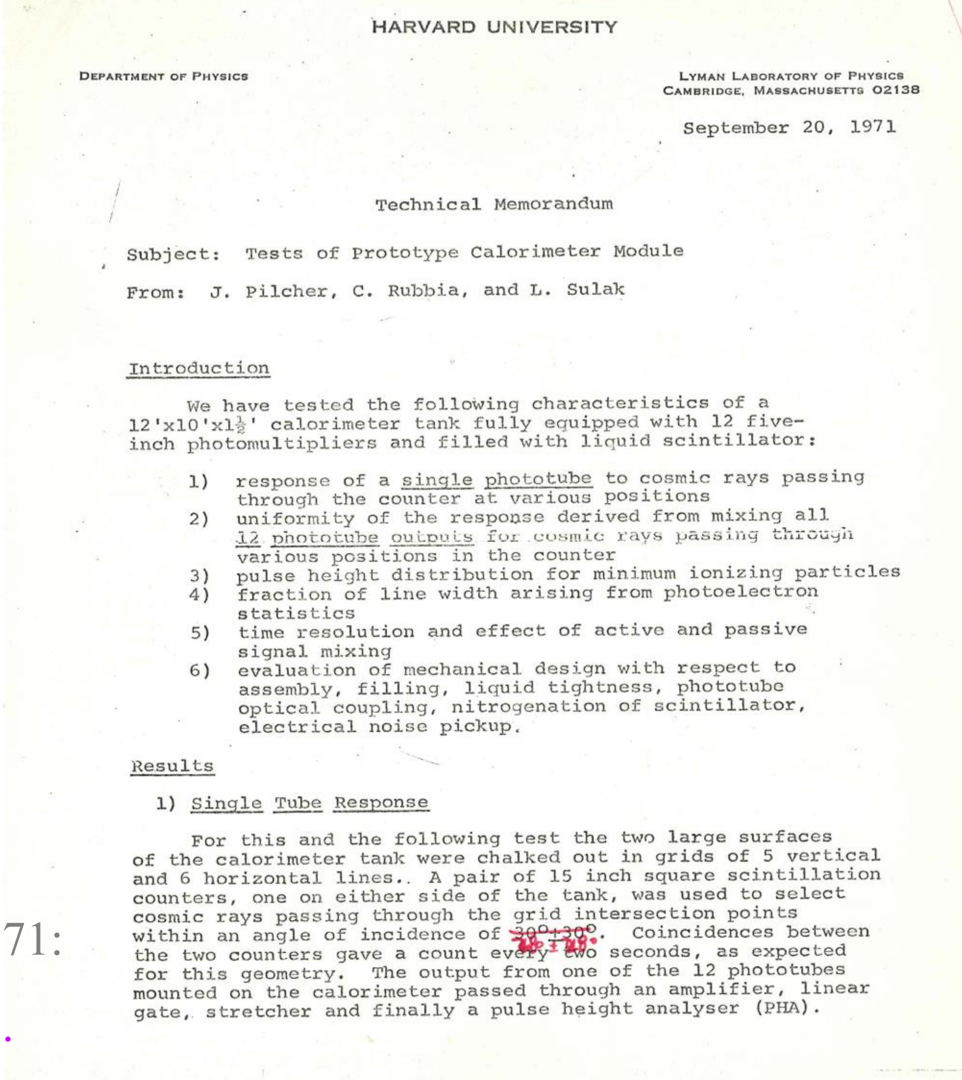
Original, LRS

What about first segment of Hcal?

Excellent performance:

Sept 20 ’71:

Let’s see the results of the tests…



HARVARD UNIVERSITY

DEPARTMENT OF PHYSICS

LYMAN LABORATORY OF PHYSICS
CAMBRIDGE, MASSACHUSETTS 02138

September 20, 1971

Technical Memorandum

Subject: Tests of Prototype Calorimeter Module

From: J. Pilcher, C. Rubbia, and L. Sulak

__Introduction__

We have tested the following characteristics of a 12'x10'x1½' calorimeter tank fully equipped with 12 five-inch photomultipliers and filled with liquid scintillator:

1) response of a __single phototube__ to cosmic rays passing through the counter at various positions
2) uniformity of the response derived from mixing all __12 phototube outputs__ for cosmic rays passing through various positions in the counter
3) pulse height distribution for minimum ionizing particles
4) fraction of line width arising from photoelectron statistics
5) time resolution and effect of active and passive signal mixing
6) evaluation of mechanical design with respect to assembly, filling, liquid tightness, phototube optical coupling, nitrogenation of scintillator, electrical noise pickup.

__Results__

1) __Single Tube Response__

For this and the following test the two large surfaces of the calorimeter tank were chalked out in grids of 5 vertical and 6 horizontal lines. A pair of 15 inch square scintillation counters, one on either side of the tank, was used to select cosmic rays passing through the grid intersection points within an angle of incidence of ~~$30^\circ \pm 30^\circ$~~. Coincidences between the two counters gave a count every two seconds, as expected for this geometry. The output from one of the 12 phototubes mounted on the calorimeter passed through an amplifier, linear gate, stretcher and finally a pulse height analyser (PHA).

Is the pulse height resolution of the Hcal sufficient?

Test with constant height fast blue LEDs: just fine.

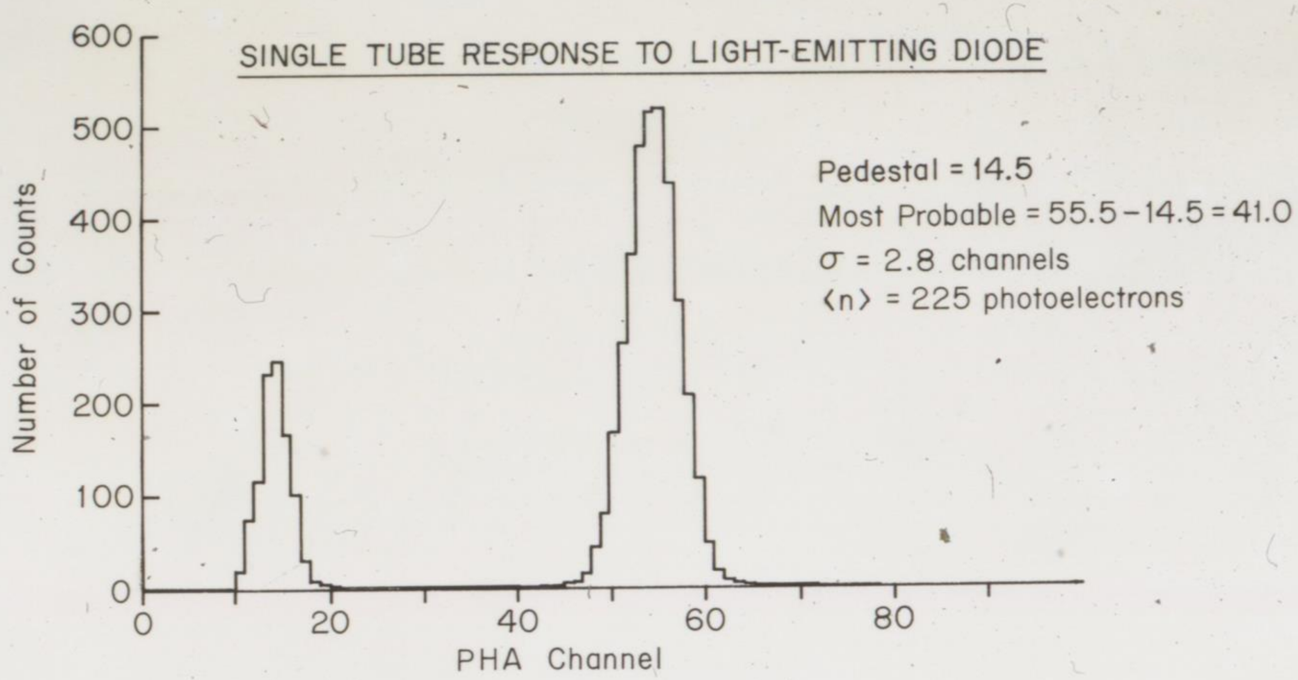


FIGURE 6

Tests with vertical cosmic rays…

Is Landau distribution good?

Lovely:

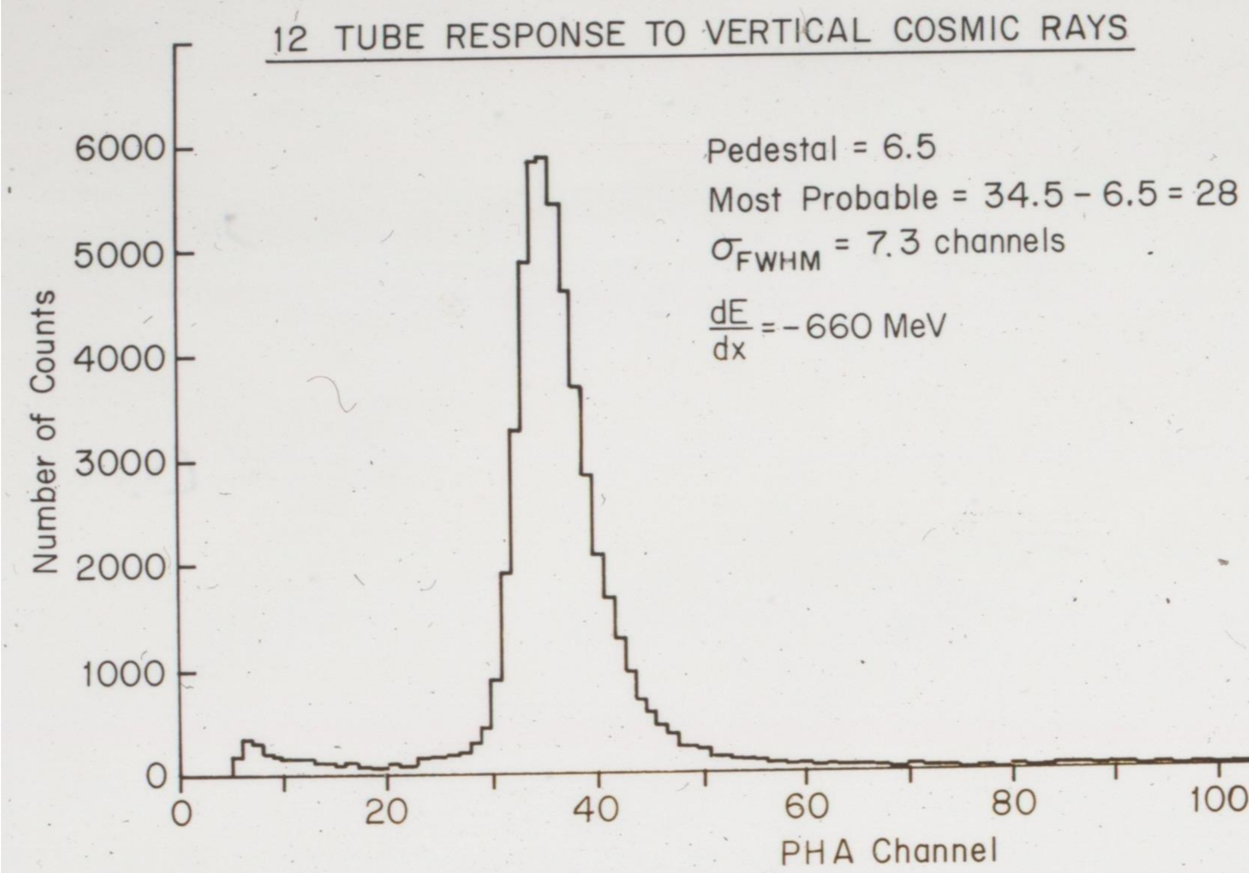
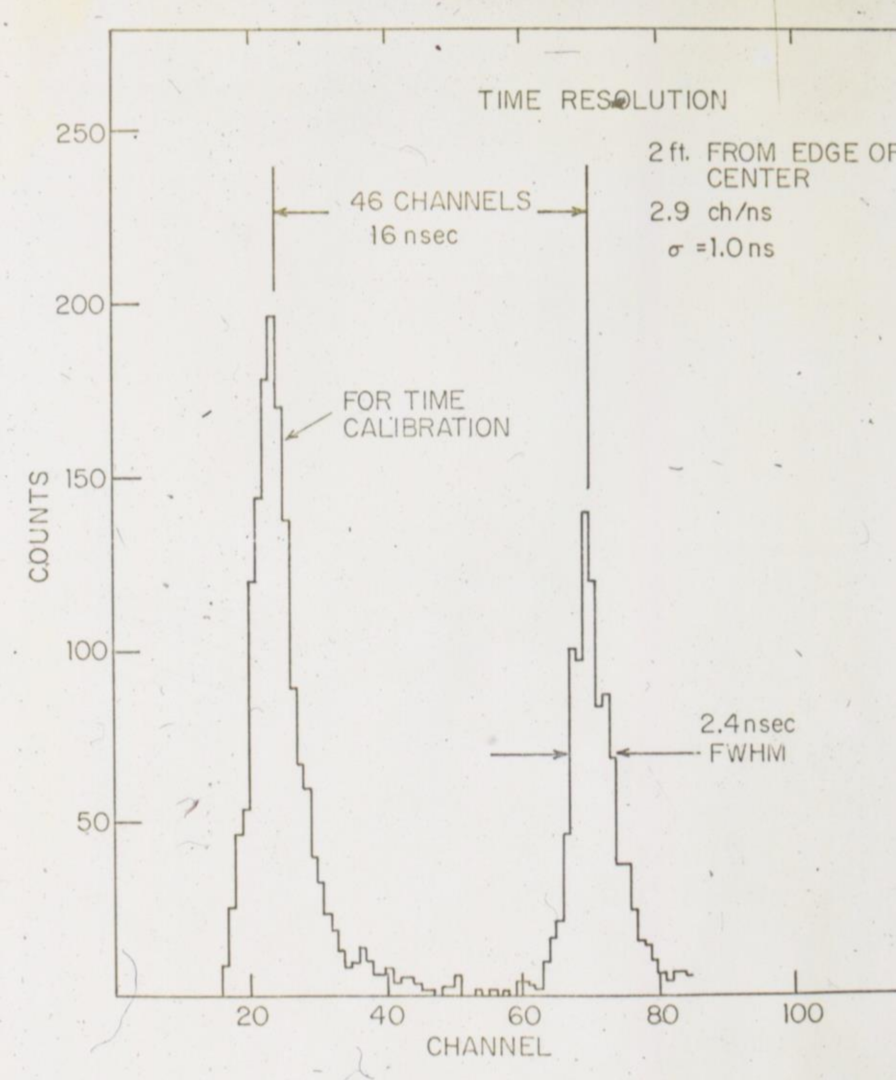


FIGURE 5

Is timing sufficient from a 4m long scintillator?

It is! $\sigma = 1.0$ ns



Pulse height uniformity over full width?

Only 6%, minimal correction

Calibrate pulse height for all 16 Hcal segments with blue LED.

Move everything to NAL…

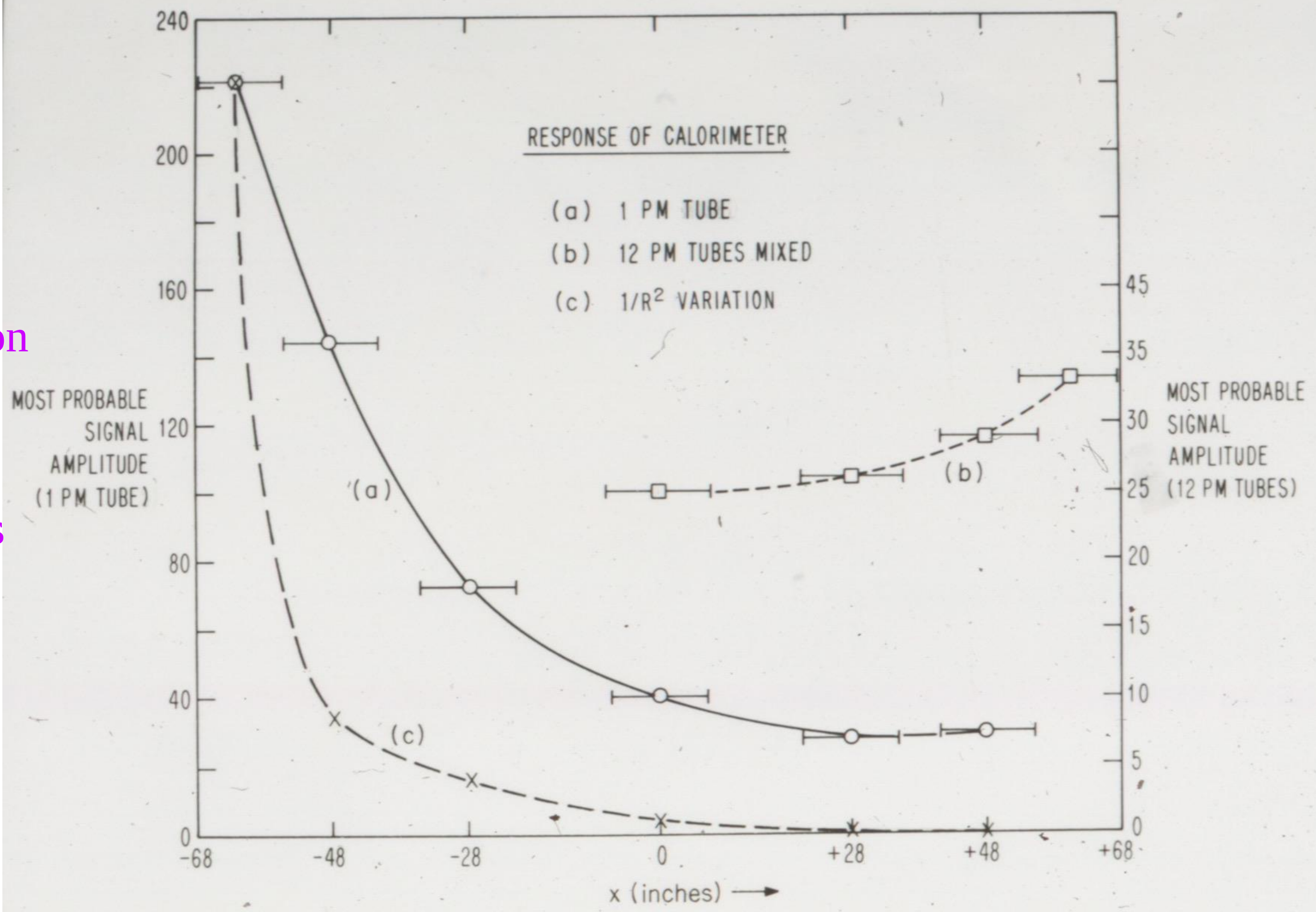


FIGURE 3

Sept 20 ’71:

All in place, end 1972.

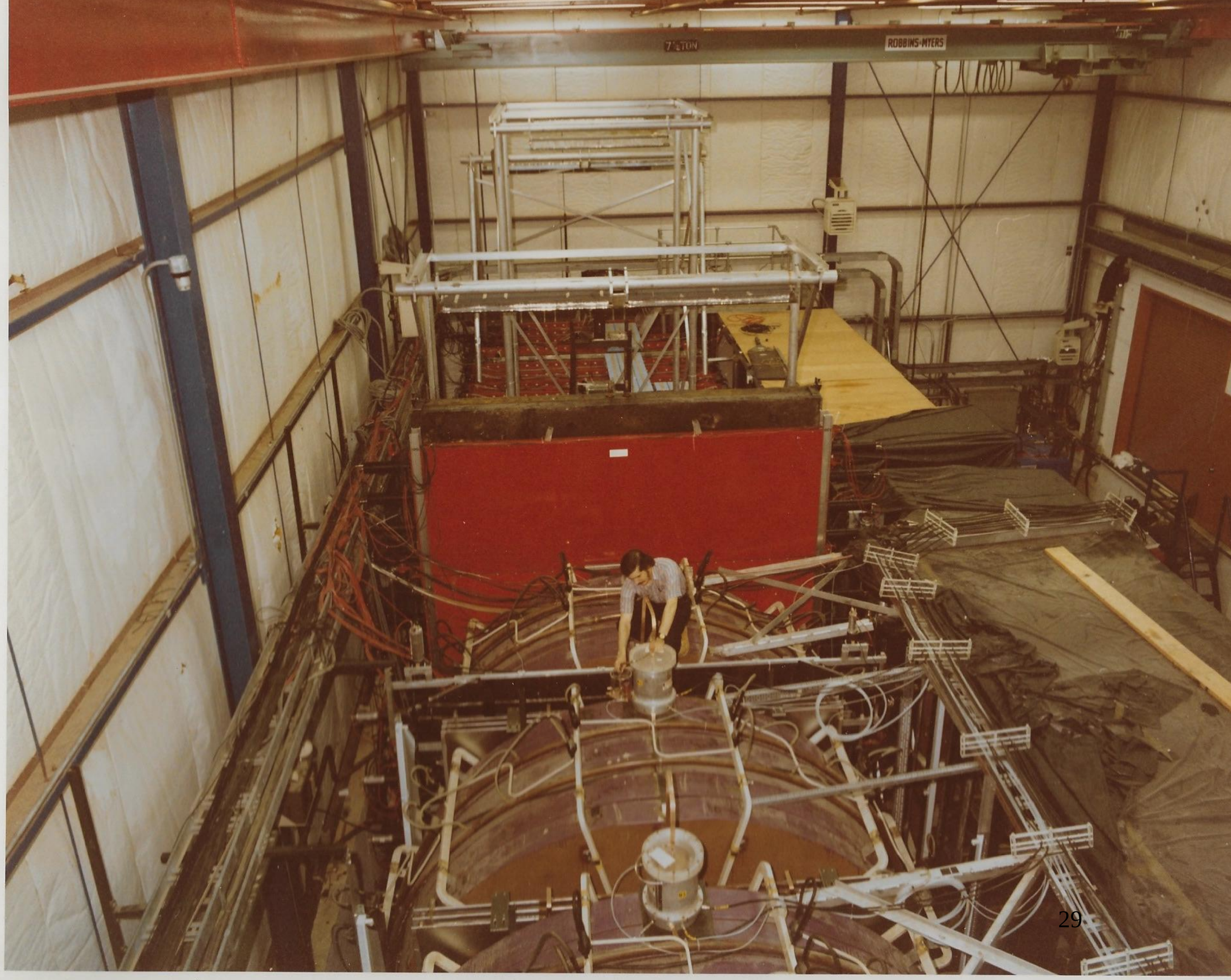
Awaiting black light shrouds, looking upstream:

Hcal (obscured crimson) →

Trigger counter (crimson)→

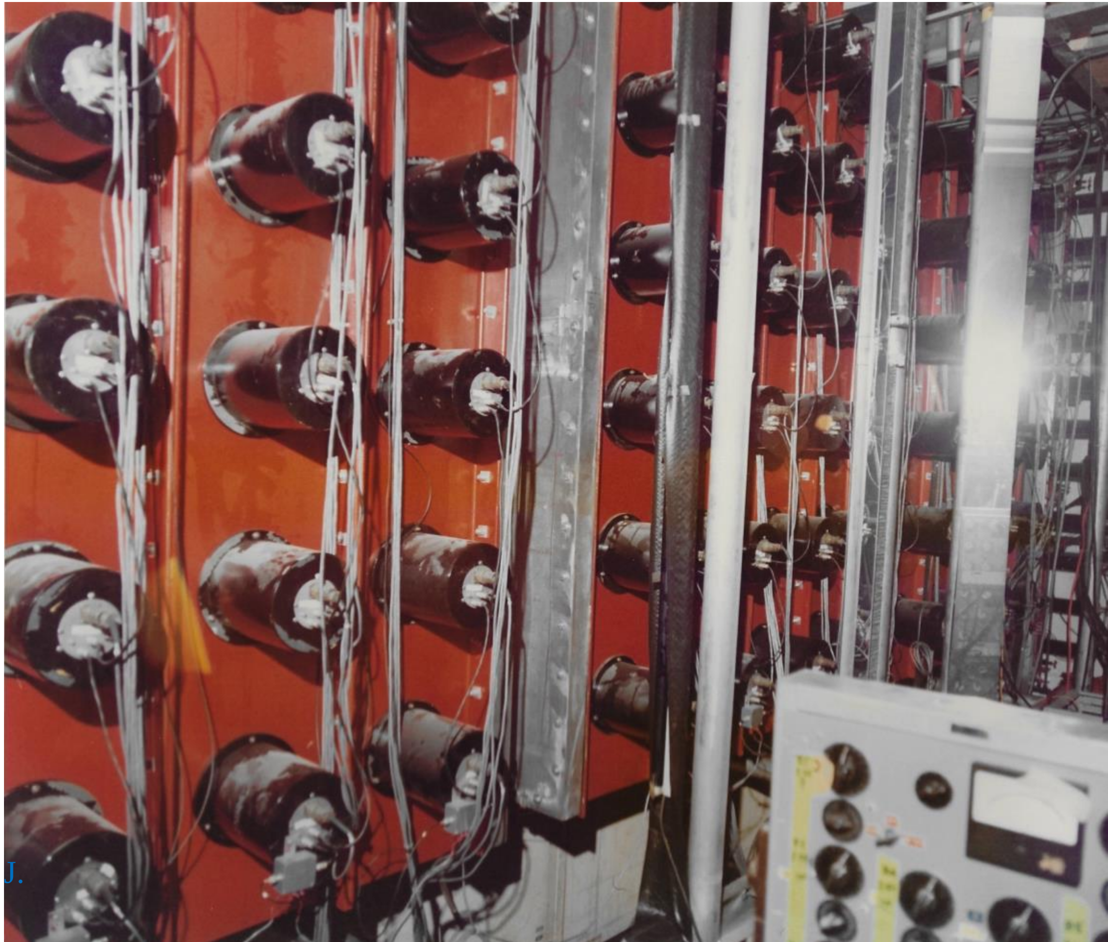
Toroidal magnets (brown)→

Spark chambers (silver) →



Looking from side:

liquid scintillator target-detector:



In red, Aluminum Hcal segments →

Black phototube covers →

Low mass honeycomb wall (silver) →

Spark chamber (hidden)

Designed & built with help from D. Hanna, P. Meyers, J. Osuch, W. Smith

Jan 1973: Couldn't thread beam through all the ring magnets!

1) Something blocked beam when magnets energized.

A trained ferret scampered around the vacuum chamber to find a razor blade accidentally left behind stood up upon magnetization! Bob Wilson

2) Helen Edwards, Savior, personally aligned each quad…Voila!

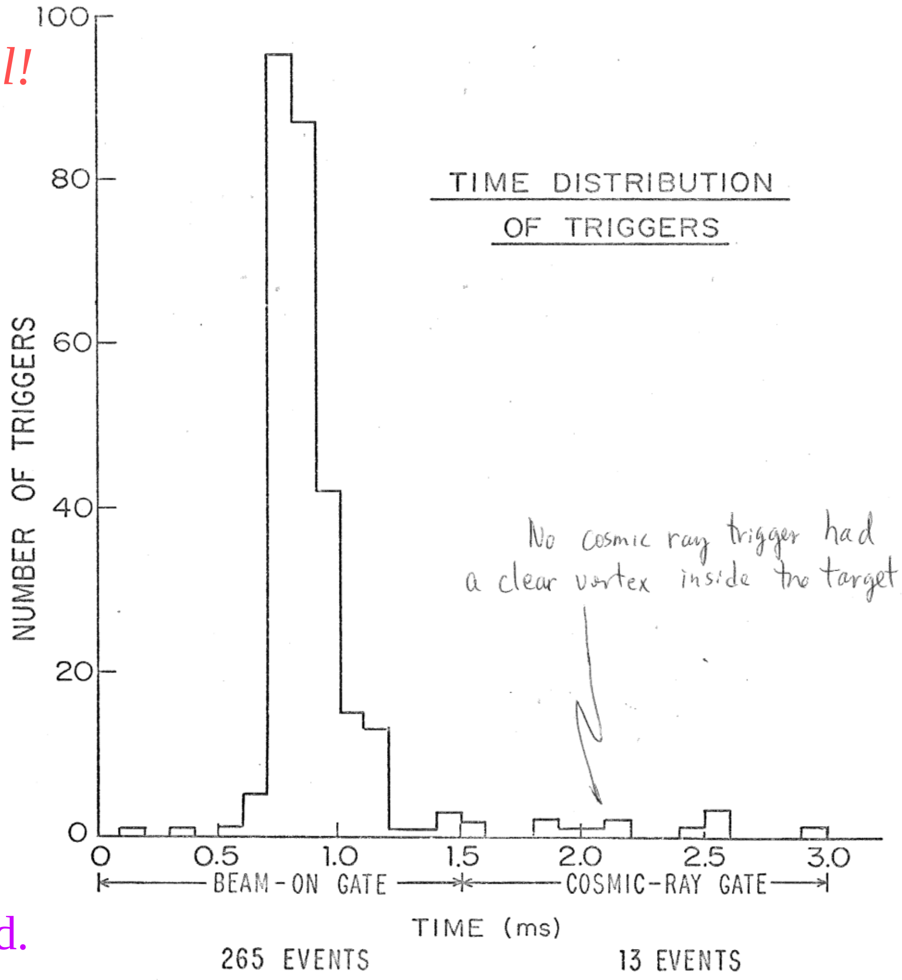
Tim Toohig & I survey parallel beam lines, to E1A & bubble chamber.

Jan '73 Beam on! ~No cosmic vertices in Hcal!

2 timing gates to evaluate cosmic background:

1) beam-on,

2) cosmic rays, e.g. out of time



Fast timing essentially eliminates all background.

Scanning spark chamber pix?

3 independent scanning tables at

Harvard

NAL

Wisconsin

measured particle tracks, consistently reproducing all events.

Archive retains both scanning & run time logs (next)

MAGNET FOCUS +

90° STEREO	Z	X	SHOWER QUALITY	SPARK CHAMBERS			
				2	3	4	5
	5	−60	B	—	9	9	0

15° STEREO	Z	Y	SHOWER QUALITY	SPARK CHAMBERS								SIGN OF MUON
				2	3	4	5	6	7	8	9	
	5	−10 −30	A	—	3/14	13	0	0	0	0	0	0

PDP-11 OUTPUT	Z	PATERN UNIT					EVENT TIME	E_{VIS}	CONT.
		A	B	μ	C	E			
	4	141	476	519	519	✓	41	683	0.9

EVENT QUALITY B CLASS N?

COMMENT Wide angle tk in 3 + 4 going out top + missing B

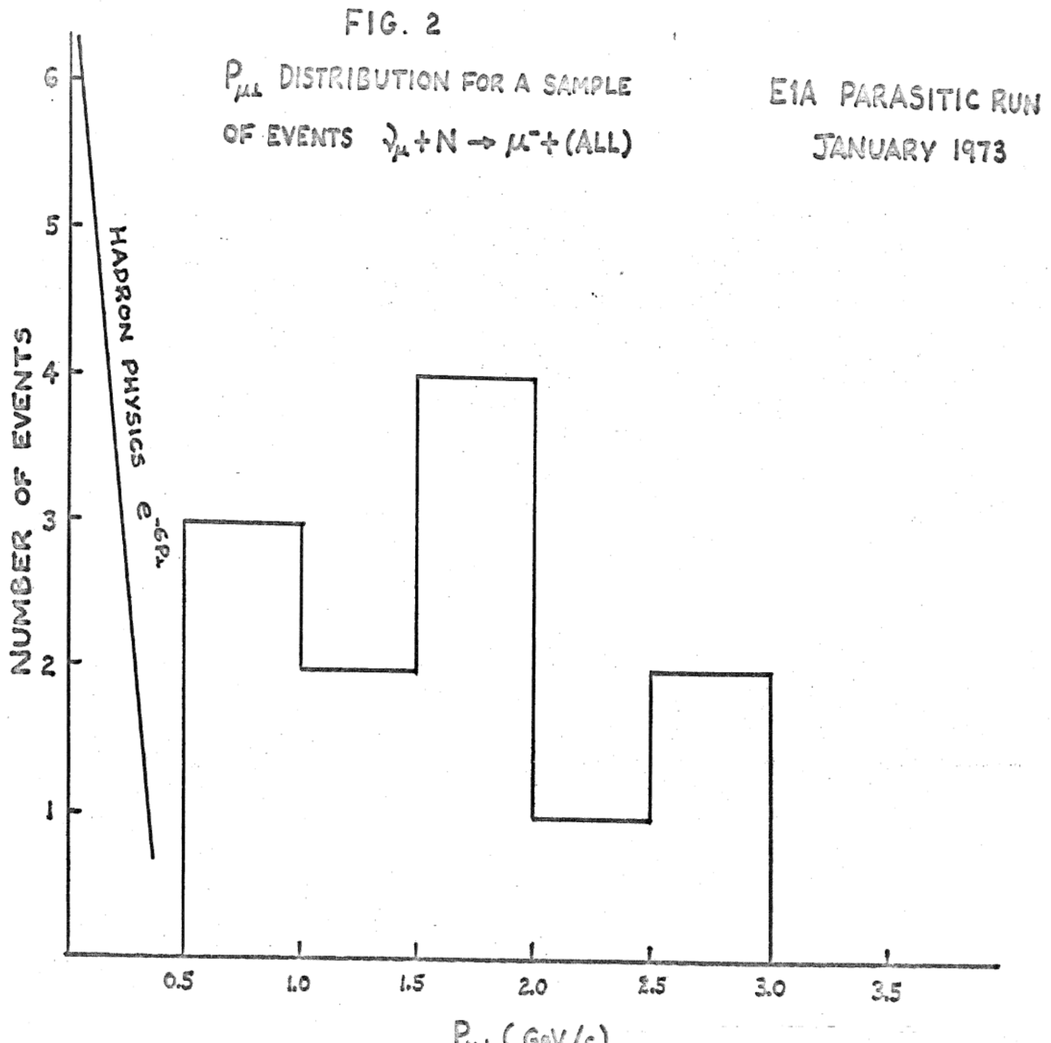
2x Min. ion. in MOD 4 ⇒ WHY NO TK IN 2?? IMPT

DATE	RUN	START	END	AMPS	FOCUS	BEAM	SPILL GATE		TRIGGER	SEM	OVFL	COMMENTS	2.5 TRIGS
10/29/73	315	–	–	–	-	– –	— —	-	ABμC			TEST ADC (W.G.S.C ON)	
	316	-	–	800	+	—	—		"			" (OFF)	
10/30/73	318	201377	201674	"	+	300	49292, 49322	4	μC + E	91461		HORN OFF	274
	319	201676	201738	"	+	"	49292, 49312	4	μC + E (1+2.5)	139960		HORN ON FOCUS –	65
	320	201739	202005	"	+	"	49292, "		"	685124		" " "	232
10/31/73	321	202006	202513	"	+	"	49302, "	4	"	1521261		" " (HORN OFF 202049 ON 202109 OFF 202452 ON 202472; SPILL CHANGED AFTER 40 FRAMES	485
11/2/73	322	—	—	—		OFF	—	-	ABμC	—		S.C. ON CALIBRATION RUN	
	323	211687	211830	"	+	300	49297, 49317	4	μC, E (E=1, Δ=2.5)	259288		HORN FOCUS –	134
11/3/73	324	217741	218010	"	+	"	49102, 49112	4	$\bar{A}$(BμC, E) E=1.3 Δ=2.2	2776550			205
	325	218011	218209	"	+	"	"		$\bar{A}$(μC, E) "	1085362		" " "	186
	326	218210	218733	"	+	"	"		$\bar{A}$(μC, E) "	2082107		" " " FRAME 218363 H. OFF 218378 H. ON 218657 H. OFF 218733 H ON	347
11/3/73	327	218734	219863	"	+	"	"		A(μC, E) "	7106567		" " – CHANGE DELAY E TRIGGER AT 219757	1110
11/4/73	328	219866	220080	"	+	"	"		BμC	1853004		" " – BUBBLE C. BEAM OFF NO E TRIG.	213
11/4/73	329	220081	220103	"	+	"	"		$\bar{A}$(μC, E) E=2.3 Δ=1.2	280115		" " – BUBBLE C. OFF. 220094 HORN OFF	22
	330	220105	220569	"	+	"	"		"	2885553			455
	331	220569	221155	"	+	"	"		" "	"		" " – BUBBLE ON	579
	332	221155	221594	"	+	"	"			2665251			
	333	221595	223075	"	+	"	"			16777216		– B.C. BEAM ON	1461
11/5/73	334	223094	223184	"	+	"	"		$\bar{A}$ E E=2.3 Δ=1.2	1187148			89
	335											LINEARITY TEST	
	336	–	–	"	+	OFF	—	-	ABμC		- -	CALIBRATION S.C. ON	
	337				+	OFF			"			"	
	338	–	–		+	OFF			"			"	
11/6/73	339	223458	223493	"	+	300	49102, 49112	4	$\bar{A}$ E E=2.3 Δ=1.2	803337		HORN OFF.	36
	340	223494	223772	"	+	"			" "	5670468		HORN ON ⊖ B.C. TUNING	275
	341	223773	224091	"	+	"	"		$\bar{A}$(BM, μC, E) "	1208357		" "	313
	342	224092	224189	"	+	"	" "		$\bar{A}$(μC, E)	625133		" "	96
	343					OFF						TEST	
	344	224191	224366	"	+	300	" "		" "	1642803			175

First physics plot from ν data:

What's $p_\perp$ distribution of muons?

from Jan '73 data:



Writing the first E1A PRL:

"Early Observation of ν and anti-ν events at High Energies"

L. R. Sulak

7105

April 16, 1973

EARLY OBSERVATION OF NEUTRINO AND ANTINEUTRINO EVENTS

AT HIGH ENERGIES

A. Benvenuti[+], D. Cheng[++], D. Cline[+], W. T. Ford[+++],
R. Imlay[+], T. Y. Ling[+++], A. K. Mann[+++], F. Messing[+++], J. Pilcher[++x], (moved to U/Chicago)
D. D. Reeder[+], C. Rubbia[++] and L. Sulak[++]

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ABSTRACT

Presented here are preliminary results of two short runs with a broad band neutrino-antineutrino beam at NAL incident on about 120 tons of target which is part of a detector consisting of an ionization calorimeter and a muon magnetic spectrometer. These results include (i) the observed distribution in transverse muon momentum, $dN/dp_\perp$, (ii) the average neutrino cross section at a mean neutrino energy of roughly 30 GeV, and (iii) the ratio of the antineutrino to the neutrino total cross section at a mean neutrino energy of 40 GeV.

*Supported in part by the U. S. Atomic Energy Commission

Bjorken, Chiamvitz, Applequist

Sadly, Pilcher, my only partner, left for Jim Cronin's U. Chicago. I had to take sole lead on the ground.

Apr 16 '73

Within a week PRL publishes our paper!

Apr 23 ’73

nate radius.

Hartle and Thorne[1] found, for rigidly rotating neutron stars, a maximum mass enhancement of 1.31. Their rotation was limited by equatorial shedding, rather than instability. Hence, the differential-rotation mass enhancement of 1.5 to 1.7 is only a slight increase over the rigid rotator. It may be noted, however, that the rotational enhancement found by Hartle and Thorne is strongly dependent on the equation of state and central density, while with the differential rotation the mass enhancement is a weak function of density and equation of state.

I would like to thank R. V. Wagoner, J. LeBlanc, M. Alme, and R. Ruffini for helpful discussions.

*Work performed under the auspices of the U. S. Atomic Energy Commission.

[1]J. B. Hartle and K. S. Thorne, Astrophys. J. 153, 807 (1968).

[2]J. P. Ostriker and J. L. Tassoul, Astrophys. J. 155, 987 (1969).

[3]J. M. Bardeen and R. V. Wagoner, Astrophys. J. 167, 359 (1971).

[4]J. R. Wilson, Astrophys. J. 176, 195 (1972).

[5]J. R. Wilson, Astrophys. J. 163, 209 (1971).

Early Observation of Neutrino and Antineutrino Events at High Energies*

A. Benvenuti, D. Cheng, D. Cline, W. T. Ford, R. Imlay, T. Y. Ling, A. K. Mann, F. Messing, J. Pilcher,† D. D. Reeder, C. Rubbia, and L. Sulak

Department of Physics, Harvard University,‡ Cambridge, Massachusetts 02138, and Department of Physics, University of Pennsylvania,‡ Philadelphia, Pennsylvania 19104, and Department of Physics, University of Wisconsin,‡ Madison, Wisconsin 53706

(Received 23 April 1973)

Presented here are preliminary results of two short runs with a broad-band neutrino-antineutrino beam at National Accelerator Laboratory incident on about 120 tons of target which is part of a detector consisting of an ionization calorimeter and a muon magnetic spectrometer. These results include (i) the observed distribution in transverse muon momentum, dN/dp_μ, (ii) the average neutrino cross section at a mean neutrino energy of roughly 30 GeV, and (iii) the ratio of the antineutrino to the neutrino total cross section at a mean neutrino energy of 40 GeV.

The energy (300 GeV) and intensity ($\sim 10^{12}$ protons per pulse) of the external proton beam now available at the National Accelerator Laboratory (NAL) are sufficiently large to permit the observation of a substantial number of high-energy neutrino interactions, even without any focusing of the secondary pions and kaons which, through their decays, produce the neutrino beam. In order to provide an early description, albeit crude, of neutrino interactions in this new energy region, we report here the preliminary results of two short runs (approximately 10^{15} interacting protons on target) with such a broad-band neutrino-antineutrino beam incident on about 120 tons of target-detector.

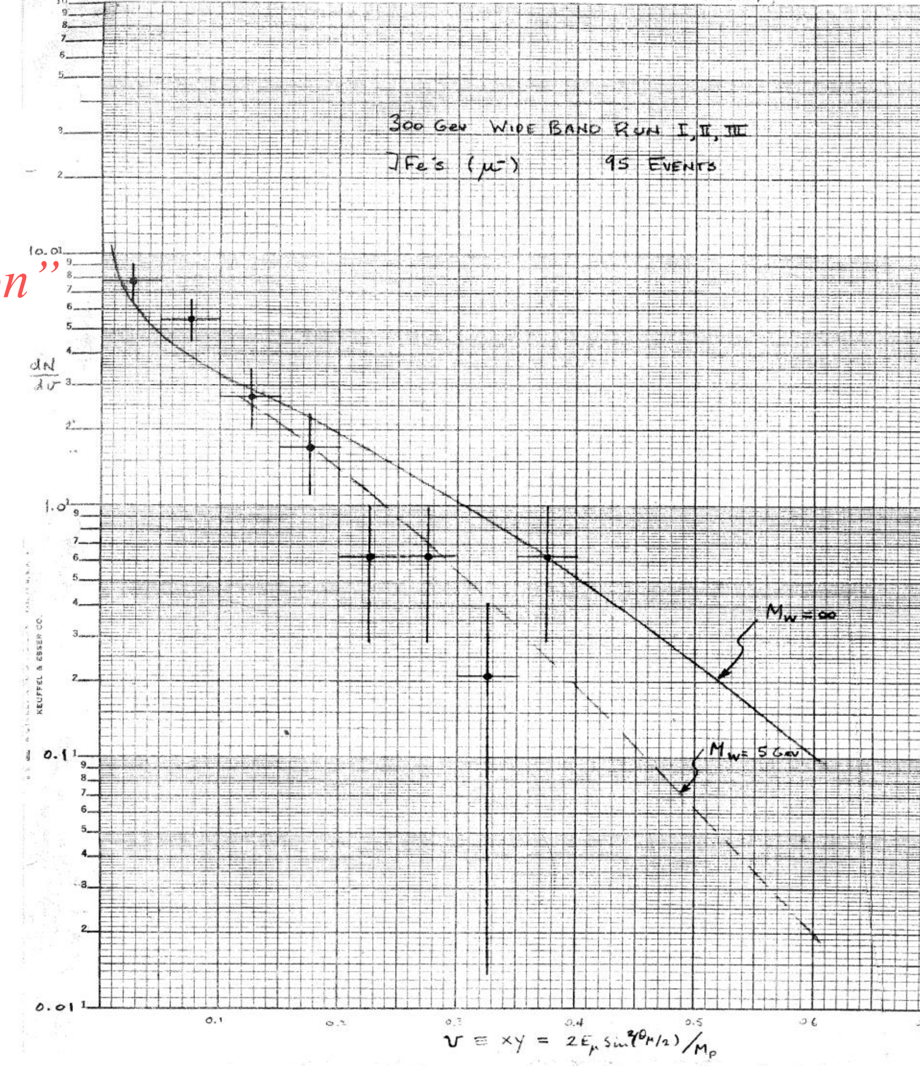
The experimental arrangement is shown schematically in Fig. 1(a). The hadron-producing target (a collision length of iron) on which the extracted proton beam impinges is about 1400 m from the accelerator. The secondary hadrons travel unvexed through a drift region 350 m in length and 1 m in diameter. The drift region is in turn followed by a muon shield, primarily of earth, about 1000 m long, at the end of which our neutrino detection apparatus is located.

The main outlines of the target-detector are sketched in Fig. 1(b). The neutrinos are incident on an ionization calorimeter (IC) consisting of four main sections in series along the beam axis, each main section of cross-sectional area 3×3 m^2 and length along the beam of 1.8 m, and containing about 15 metric tons of mineral-oil–based liquid scintillator. Each main section is divided into four optically separated subsections viewed from two sides, as indicated in Fig. 1(b), by twelve photomultipliers (5-in. diam). There are wide-gap optical spark chambers of area 3×3 m^2 after each main section of the ionization calorimeter as shown in Fig. 1(b). Immediately downstream of the IC is a magnetic spectrometer made up of four units of toroidal iron magnets, one behind the other along the beam line, with narrow-gap optical spark chambers following each magnet unit. The toroids have an inside diameter of 0.3 m, an outside diameter of 3.6 m, and are 1.2 m long; they are driven into satura-

Plotting for our first search for new physics…

“E1A search for the Intermediate Vector Boson”

dN/dv *vs.* $v=xy=2E_\mu \sin(2\theta_\mu/2)/M_p$:



May 11’73

Spark chamber photos: How look during this first run?

Most images are as expected:

2 stereo pix of ~40 GeV shower in Hcal:

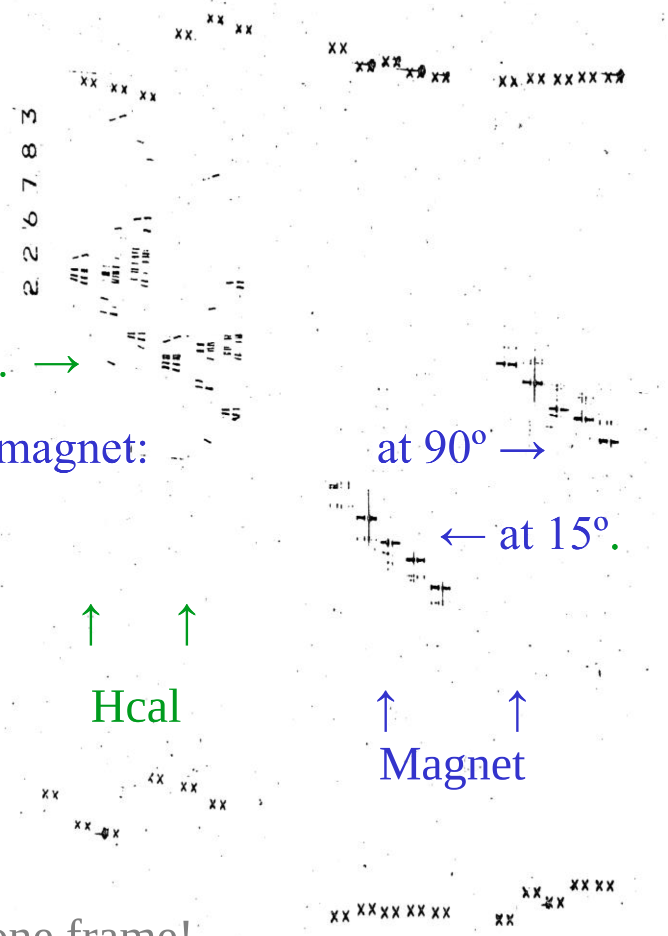
at 90º →

at 15º. →

2 stereo pix of a muon in the magnet:

at 90º →

← at 15º.



↑ ↑

Hcal

↑ ↑

Magnet

Richard Imlay aligned mirrors to get all sparks into one frame!

…but something terribly wrong…

1 of 3 of events have no muon!!!

How could our chambers be

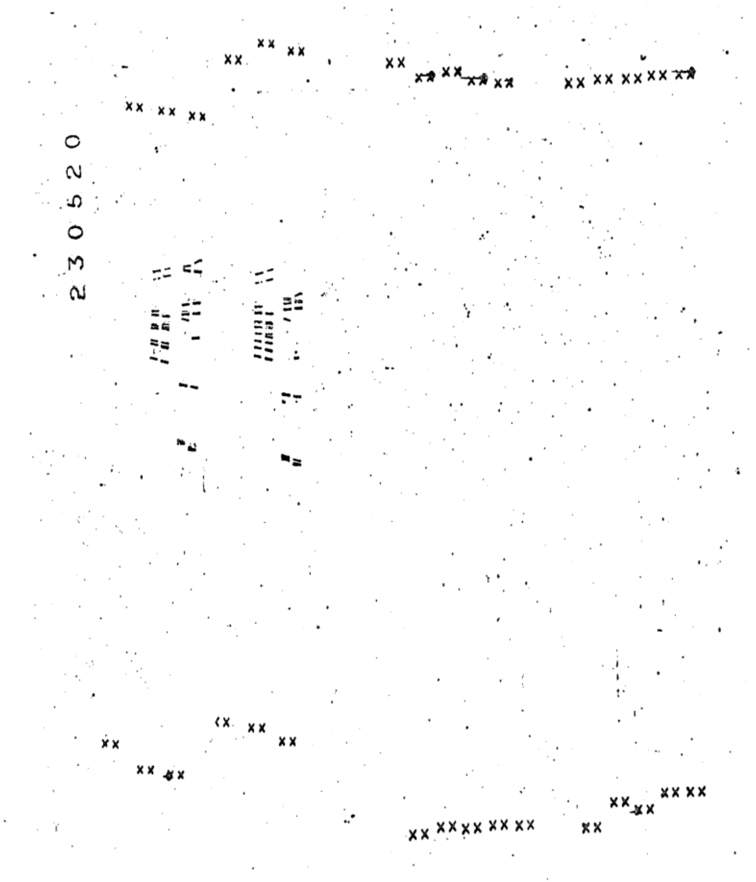
missing all those muons???

Leon's well-known chambers;

Triple scanned.

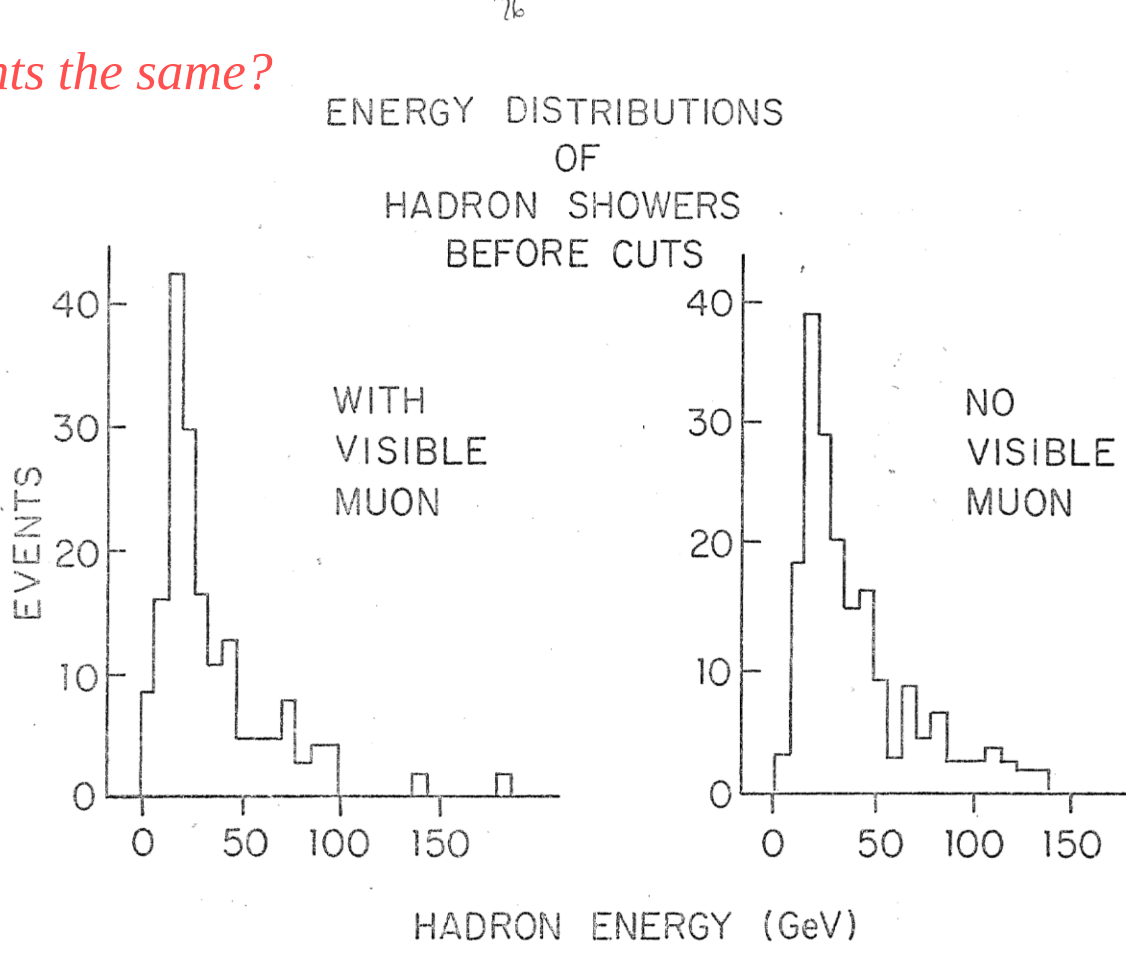
Evaluate muon detection efficiency using data itself.

We go back & check absolutely everything…



Are showers from both types of events the same?

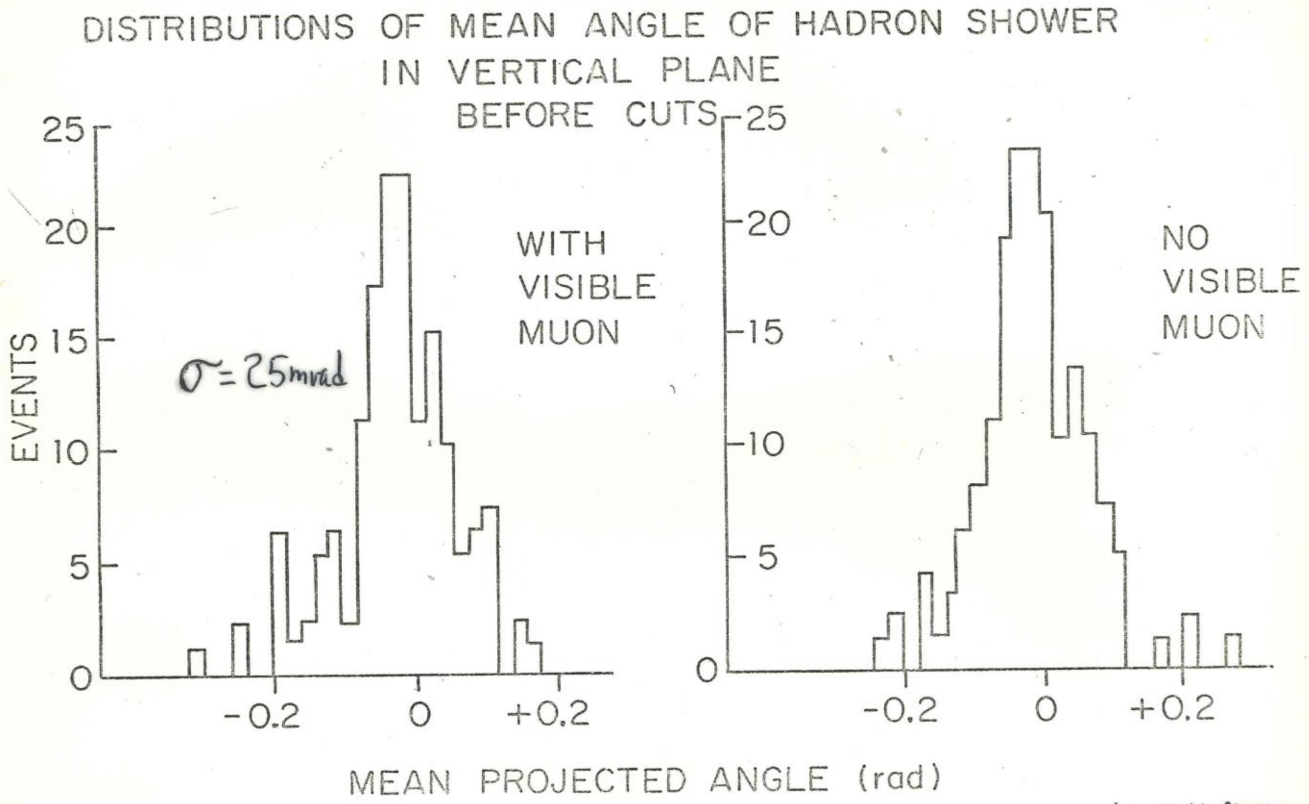
Vs energies? No differences:



Are shower angles the same?

No difference, with a μ or not:

No showers entering from outside.



IF HADRONS ENTERING SIDE, EFFECTIVE TRANSVERSE ATTENUATION LENGTH ~ ℓ_{coll} / sin θ

LACK OF ENHANCEMENT NEAR EDGES ⇒ NO HADRONS FROM SIDES

Chicago (JP)
Harvard & MIT (LRS)
Oct ‘73

Are events flat in depth: without & with muon?

Events would appear muonless

if muon escapes

out the edge of Hcal or the magnet, no mu

would have losses with depth.

Neutrinos from both 300 & 400 GeV protons,

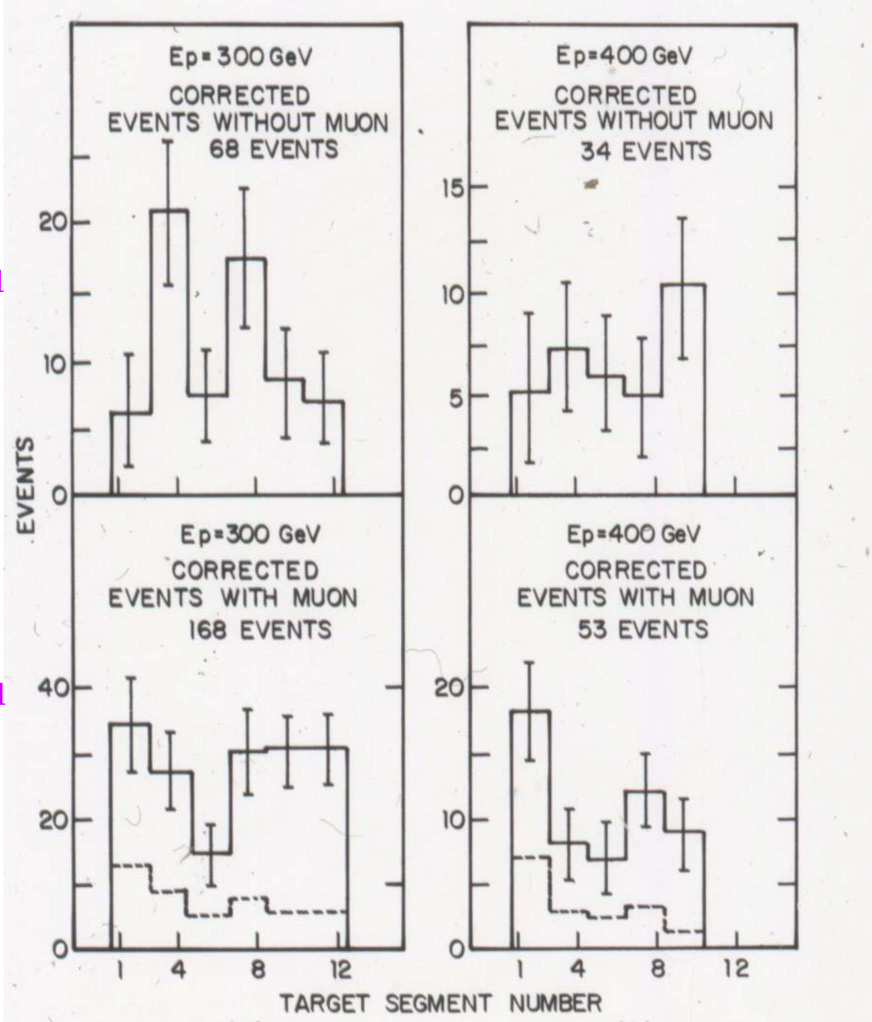
have flat Z distributions!

End of the year 1973 runs: with mu

300 GeV 236 total ν events

400 GeV 87 total ν events

300 GeV 400 GeV



Anti-neutrinos:

Visible energy: Are anti-ν events similar to ν events?

Neutrinos:

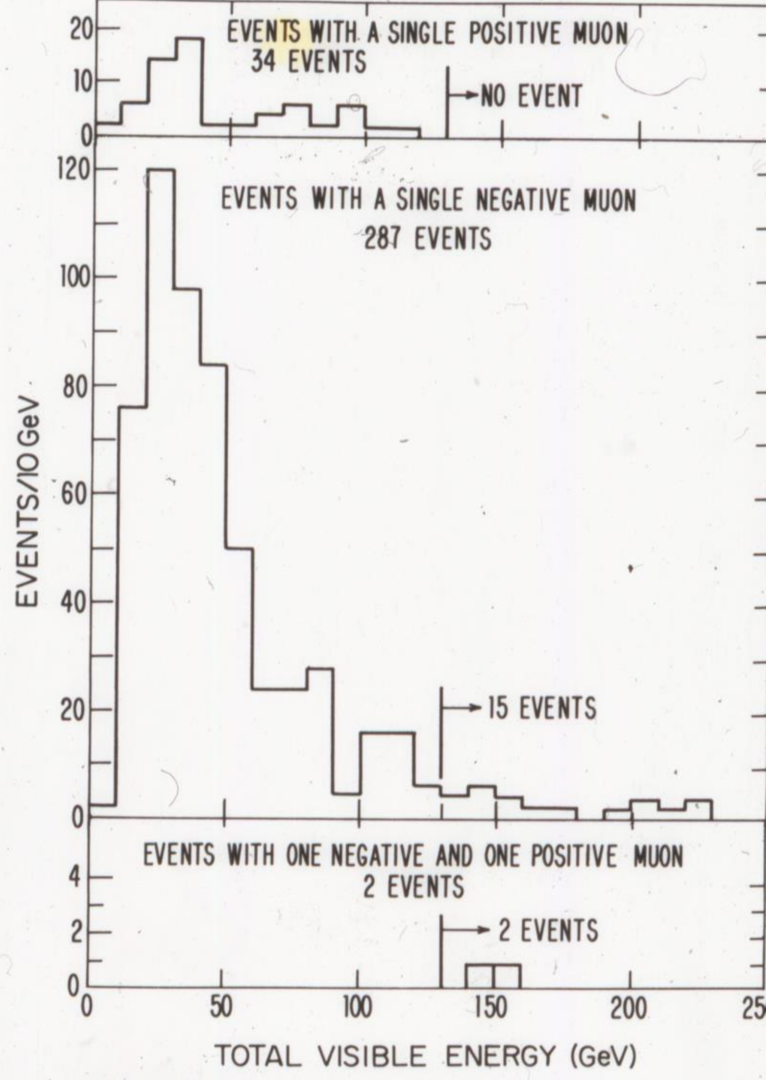
Fake mu's from pion punch-through of deep showers.

i.e. a pion could mimic a muon? No…

< 1% of events have di-muons.

Di-muon events:

(Detailed punch through evaluation, Imlay, Aug 3 PRL)



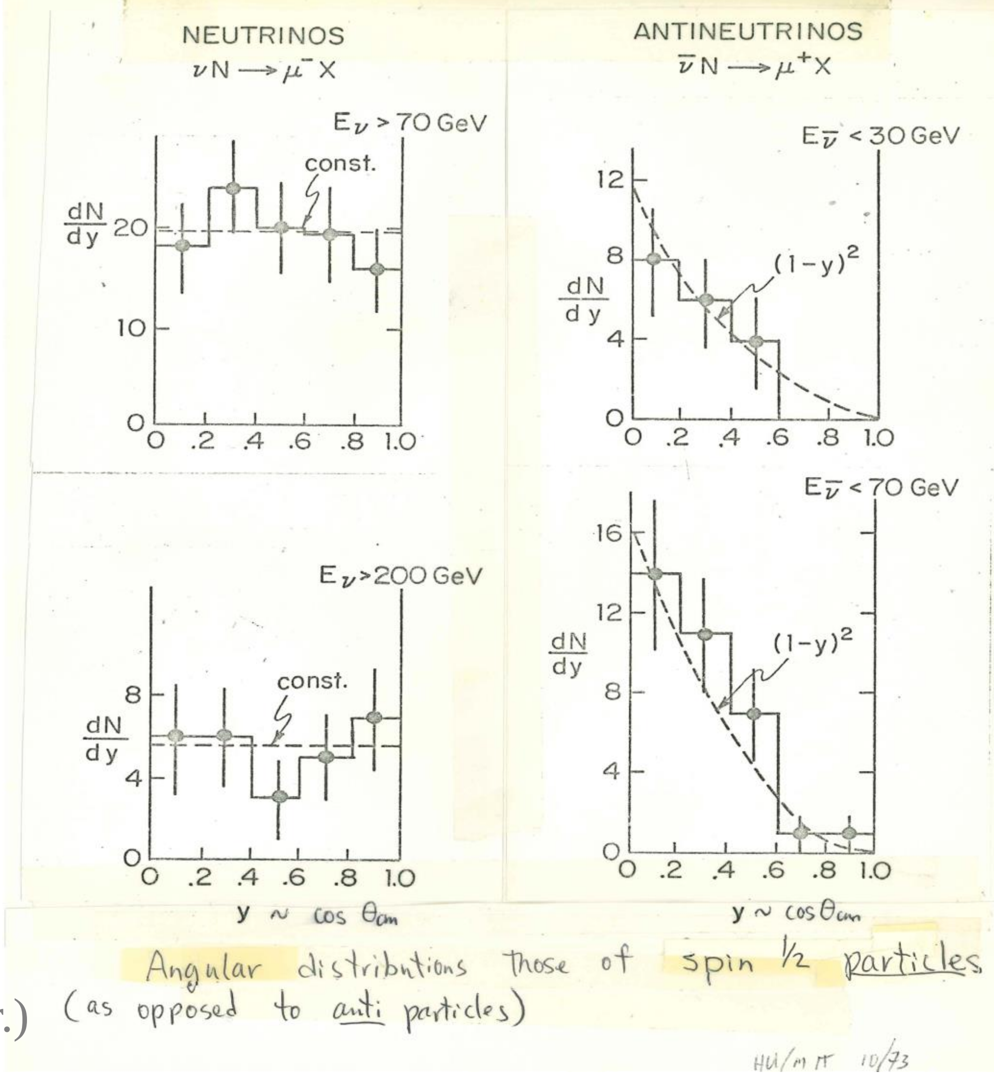
Are Y distributions as expected,
e.g. scattering from spin ½ particles?

1) flat for neutrinos:

2) $(1\text{-}y)^2$ for anti-neutrinos:

Both at low & at hi energies?

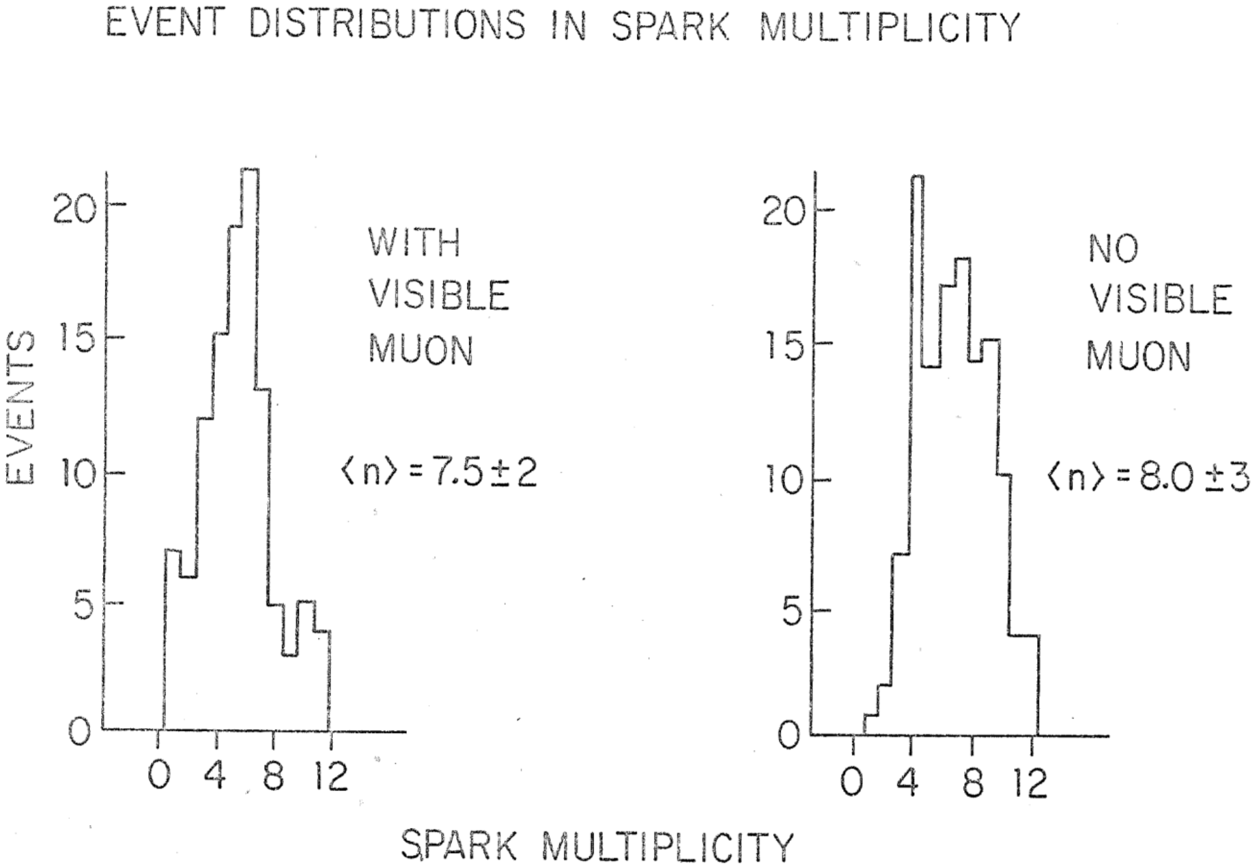
Yes & yes.



Oct '73 seminars: Harvard & MIT (LRS)
Chicago (Pilcher) (though Jim left HPW in Apr.)

Hcal spark chamber signatures: any different between the 2 types of events?

No:



Lack of muons also at higher energy ν's?

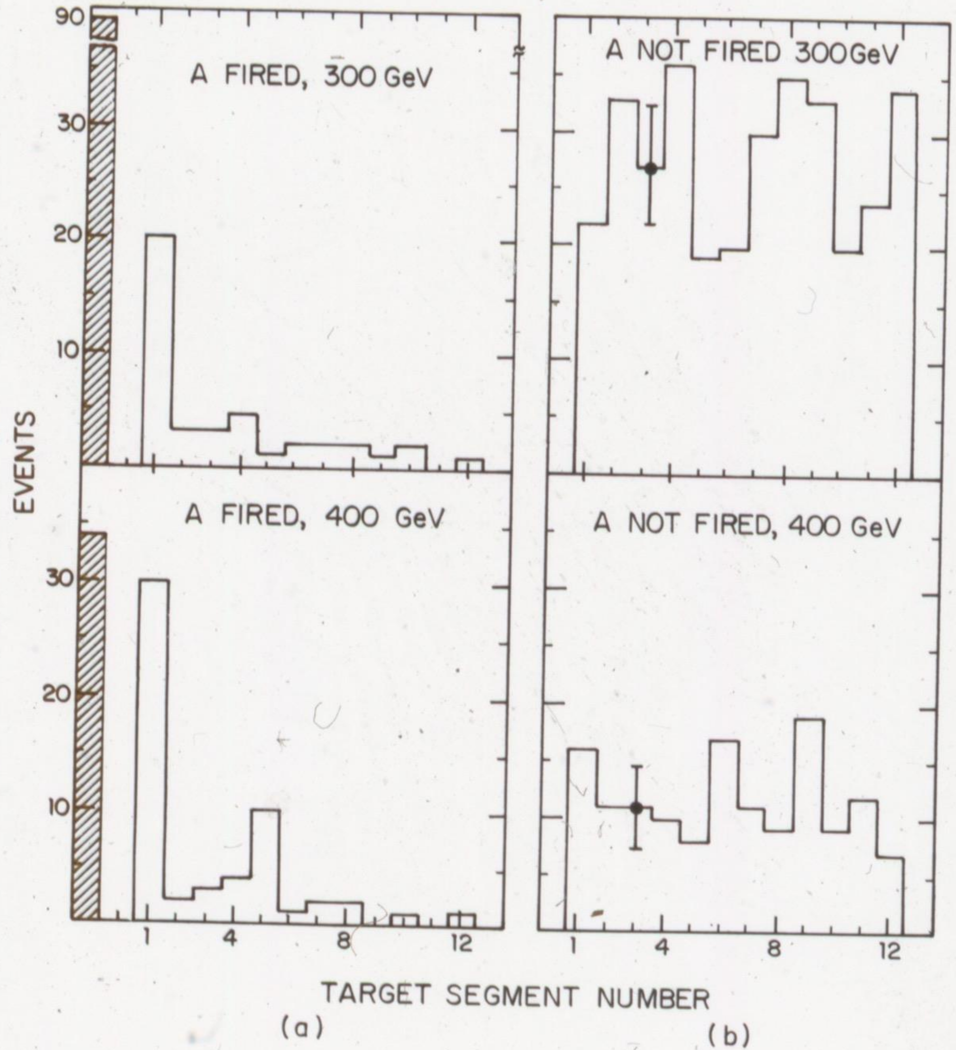
NAL ups proton E, from 300 to 400 GeV,
more, & higher E neutrinos…

Anticounter "A" does its job….
Rejects incoming charged particles
in time with beam.

All background gone after hcal segment #1,
1 absorption length.

Events flat in z, as neutrinos should be.

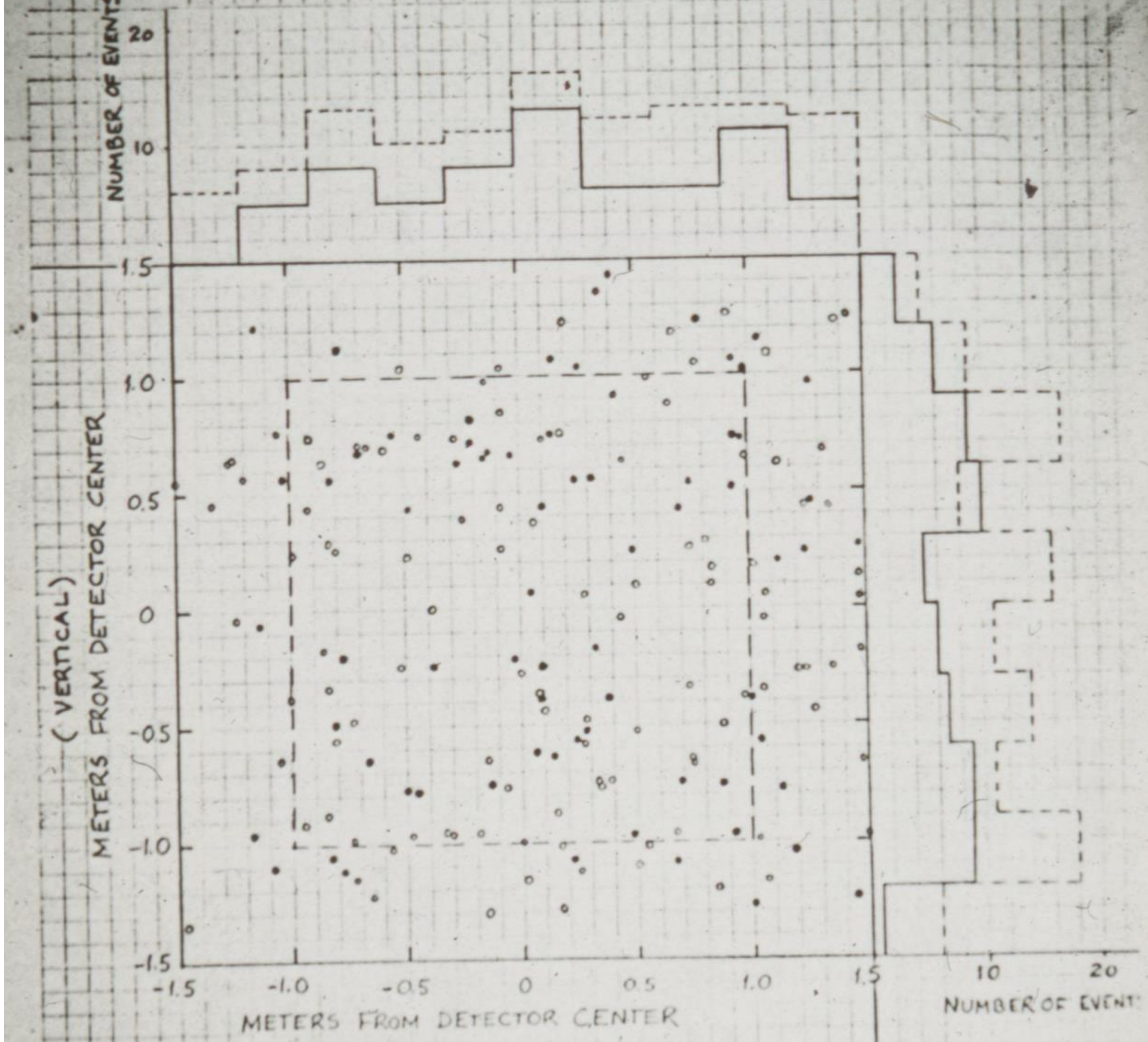
Aug '73 PRL:



Losing muons near the edges?

No.

Transverse distribution of vertices:



LRS plot for Aug 3 PRL,
with fiducial cuts.

Are vertex distributions flat transversely?

for both muon & muonless events?

Yes.

To fully contain showers, we make fiducial cuts:

Vertex must be within

first 12 of 16 Hcal segments,

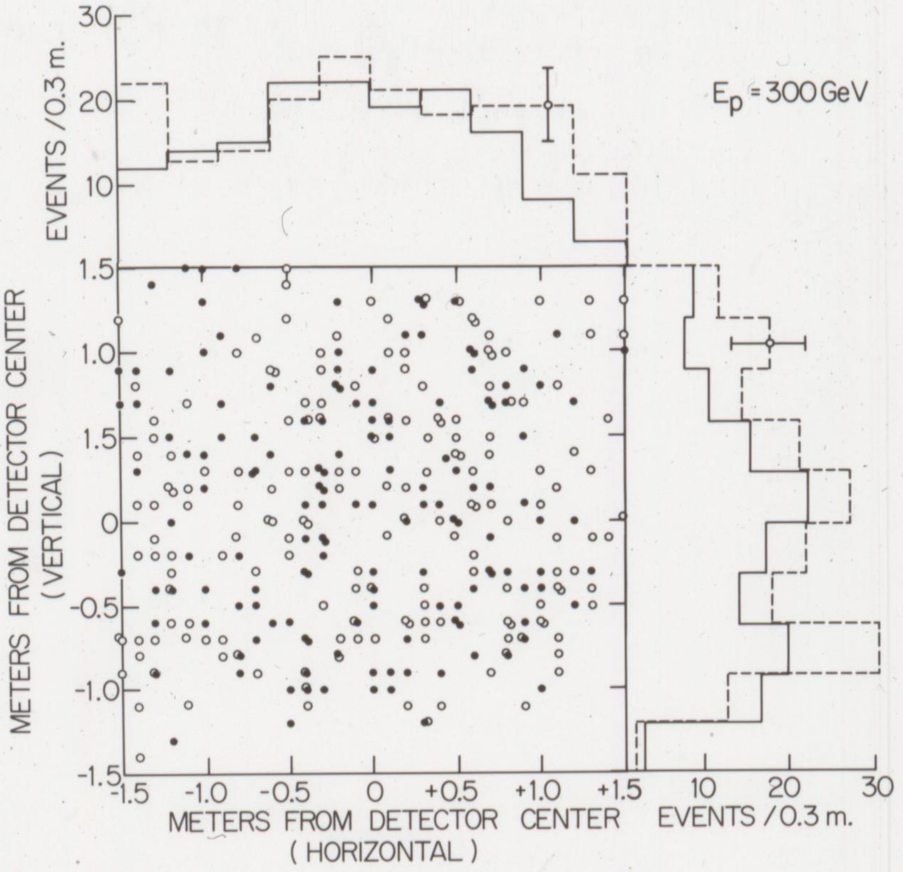
0.5 m from 4x4m^2 Hcal edges.

We record

1116 triggers & 236 events at 300 GeV,

368 triggers & 96 events at 400 GeV.

Aug ‘73 PRL:



VERTEX DISTRIBUTION PERPENDICULAR TO BEAM

Are muon angular distributions as expected?

Yes.

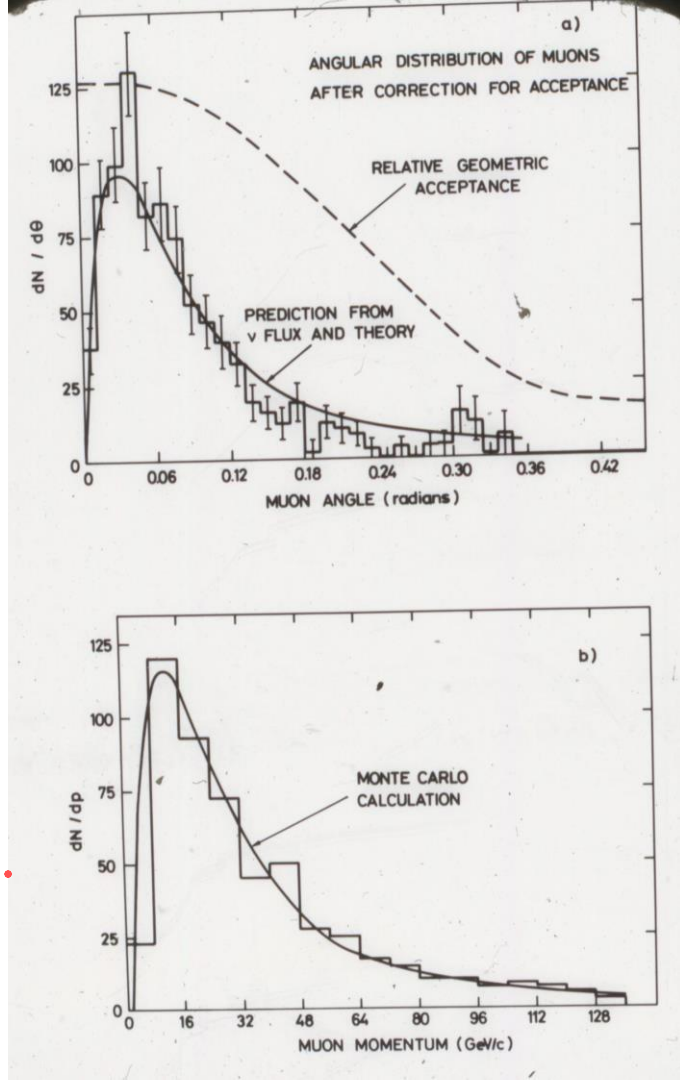
Data & expectations of muon agree:

What about muon momenta?

Fits.

Inescapable: ~1/3 of events are missing a muon.

Aug 3 '73 PRL:



3 independent analyses, 2 different beam energies:

All yield muonless/total ν events consistent with 0.29 at 5.2 standard deviations.

TABLE I. Summary of analyses. (I) Analysis of totality of events (II) Analysis with angular requirements in one plane (III) Analysis with angular requirements in both planes

Target segments	Proton energy (GeV)	Visible muon events	No visible muon (1)	UME	Excess muonless events (2)	Purity of sample (2)/(1)	Statistical significance of effect s.dev.	Ratio of cross-sections R
I 1-6	300	52	59	41	18	25%	2.1	0.20 ± 0.12
	400	27	23	20	3		0.5	0.06 ± 0.14
7-12	300	72	53	28	25	50%	4.0	0.25 ± 0.10
	400	21	23	10	13		3.3	0.42 ± 0.23
7-12	300 + 400 combined	93	76	38	38	50%	5.2	0.29 ± 0.09
II 1-12	300	56	54	24	30	56%	5.1	0.29 ± 0.10
III 1-12	300	13	11	1.9	9.1	83%	6.7	0.39 ± 0.19

No choice: must publish!

Table from Aug 3 '73 PRL

After exhausting all alternatives…

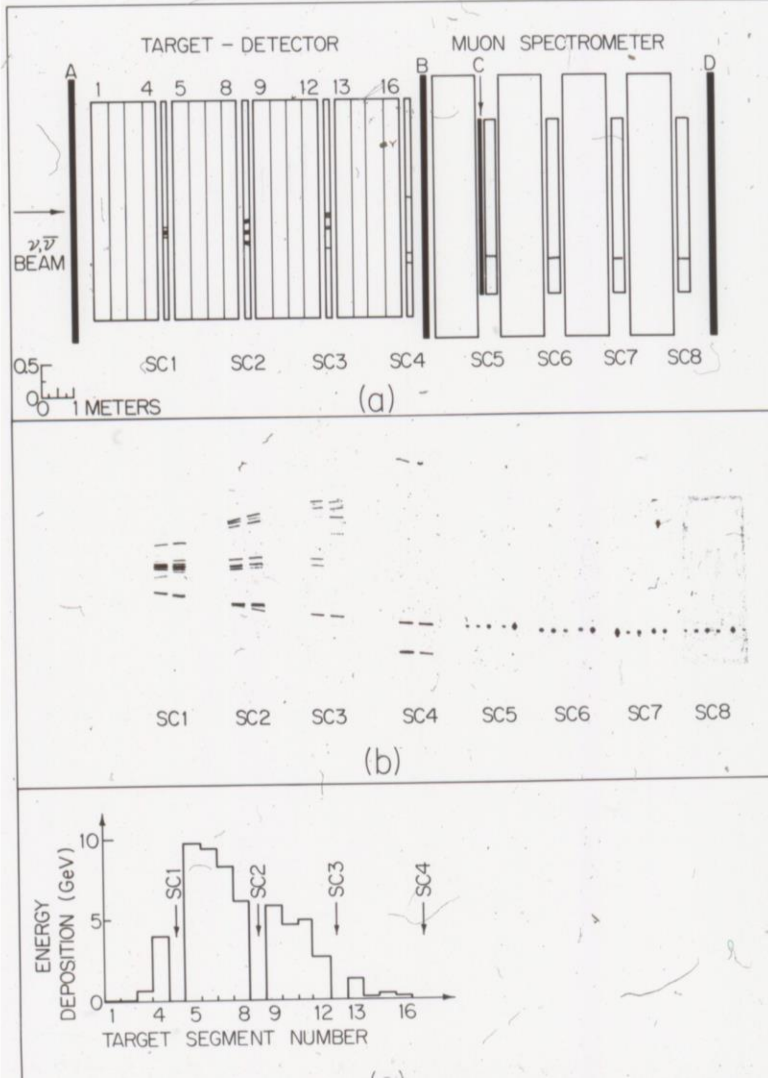
Bill Ford & Richard Imlay come to Harvard.
Extensive re-checks, re-scans & re-simulations.

Find nothing wrong, nothing disturbing.

Telephone PIs, they concur by phone:
Cline in middle of moving from Wisconsin to Hawaii.
Carlo exiled from US for insulting Border Control
Agent working exclusively at CERN
Mann at Penn.

…PIs agree to submit our research to PRL.

LRS original for PRL:



Original manuscript muonless paper:

Hand delivered Aug 3 '73 by LRS:

the printed submission date of publication.

Denouement:

Carlo calls Mann from CERN.
Mann goes to PRL; they agree to hold printing.

With no physics justification whatever!!!
Another hue & cry from all the worker bees.

Neutral currents oscillate?...NO, CR oscillates?

PRL printed, unchanged, Feb '74

OBSERVATION OF MUONLESS NEUTRINO-INDUCED INELASTIC INTERACTIONS

A. Benvenuti, D.C. Cheng, D. Cline, W.T. Ford, R. Imlay, T.Y. Ling, A.K. Mann, F. Messing, R.L. Piccioni, J. Pilcher*), D.D. Reeder, C. Rubbia, R. Stefanski and L. Sulak

Department of Physics, Harvard University**)
Cambridge, Massachusetts

Department of Physics, University of Pennsylvania**)
Philadelphia, Pennsylvania

Department of Physics, University of Wisconsin**)
Madison, Wisconsin

National Accelerator Laboratory,
Batavia, Illinois

ABSTRACT

We report here the observation of inelastic interactions induced by high-energy neutrinos and antineutrinos in which no muon is observed in the final state. A possible, but by no means unique, interpretation of this effect is the existence of a neutral weak current.

(Submitted to Physical Review Letters)
8/3/73

Life goes on…

Original run plan for first data (LRS)?

Trigger apparatus on events with large energy deposit in calorimeter — look then for μ in final state

Look at distributions

1.) vertex along beam — uniform

2.) vertex transverse to beam

no up-down, left-right asymmetries

3.) angular distributions — no events from side

But large angle muons lost ~40%.

…conclusion from first 2 runs:

1.) Preliminary measurement:

$R = 0.29 \pm 0.07$ (statistical error only)

$\langle E_\nu \rangle \sim 40$ GeV, predominantly ν beam

…our response to first results:

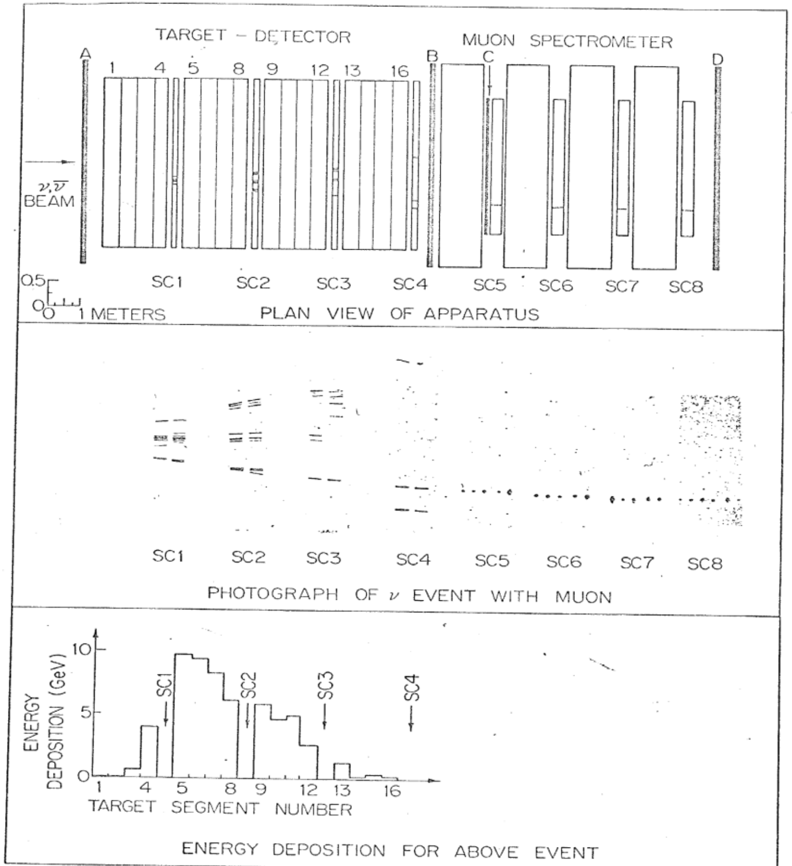
2.) Rebuilt apparatus: efficiency for detecting μ ~85% by increasing solid angle of spark chambers

$\langle E_{\bar\nu} \rangle \sim 10$ GeV, predominantly $\bar\nu$ beam

Oct '73 Harvard & MIT seminars, LRS:

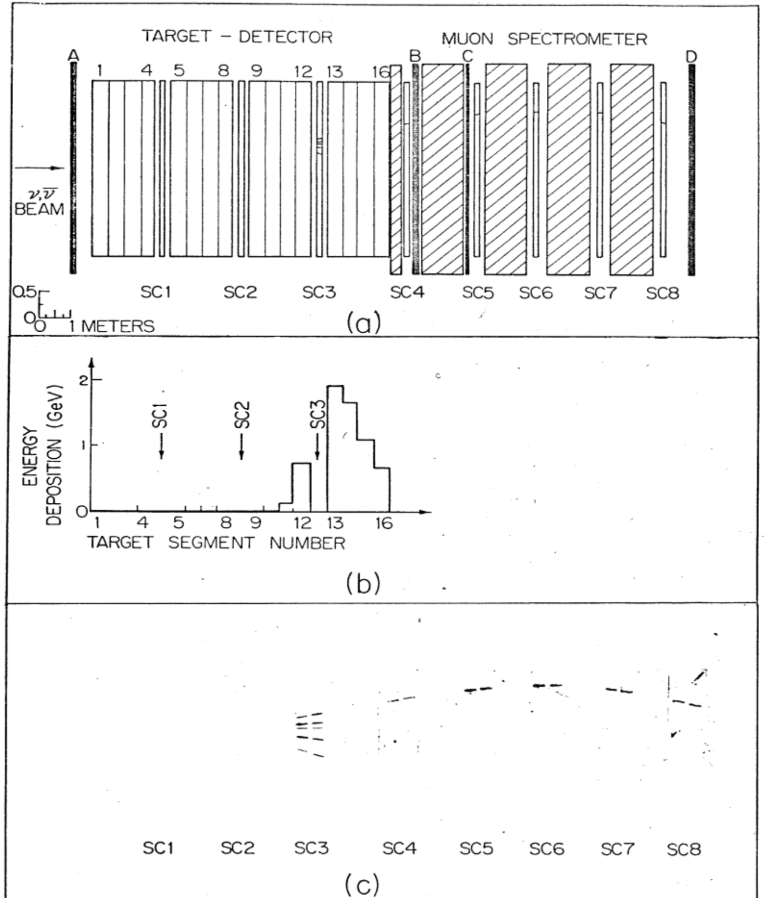
Leon's spark chambers too small transversely?

Before, < Oct '73:



Penn replaces them covering full area.

After, > Oct '73:



After submitting our Aug 3 PRL,
we again challenge everything…

Electron-neutrinos mimicking muonless?

Could our event rates be off?

Are our neutrino spectra incorrect?

No.

Aug 18 '73:

HARVARD UNIVERSITY

DEPARTMENT OF PHYSICS

CYCLOTRON LABORATORY
CAMBRIDGE, MASS. 02138

August 18, 1973

J. Pilcher, C. Rubbia,
L. Sulak

Technical Memorandum

UNFOCUSED NEUTRINO SPECTRA FROM SCALING

We have evaluated the neutrino yield for $E_p = 300$ GeV and $E_p = 400$ GeV protons incident on a 1 collision length thick aluminum target. The calculation divides naturally into three separate phases:

i) Determination of K^+, π^+ yields

ii) corrections for thickness of the target

iii) calculation of the ν-flux from the K^+, π^+ yields

The basic idea behind this determination is that the overwhelming majority of neutrinos come from kinematical regions for which the validity of the hadronic scaling has been firmly established by ISR and NAL results.[1] The very simple geometry of the unfocused beam (unvexed, as Prof. Mann would most certainly say) makes the connection between the hadron and neutrino yields very direct and related only to very elementary, geometrical transformations.

The dependence of the calculated flux on the scaling variable $P_\perp$ of the parent hadrons is shown in Fig. 1. Particles with $P_\perp > 0.3$ GeV do not contribute to the neutrino flux. The dependence of the ν-flux on the scaling variable x is shown in Fig. 2. Values $x < 0.1$ and > 0.75 do not contribute to the neutrino flux.

We continue rechecking everything:

Neutrino & anti-neutrino fluxes right.

Got to make sure muonless events not electron-neutrino induced.

Aug 18 ’73:

HARVARD UNIVERSITY

DEPARTMENT OF PHYSICS

CYCLOTRON LABORATORY
CAMBRIDGE, MASS. 02138

August 18, 1973

J. Pilcher, C. Rubbia, L. Sulak

Technical Memorandum

TESTING THE NEUTRINO FLUX CALCULATIONS WITH THE GAMMA RAY YIELDS OF EXPERIMENT 120

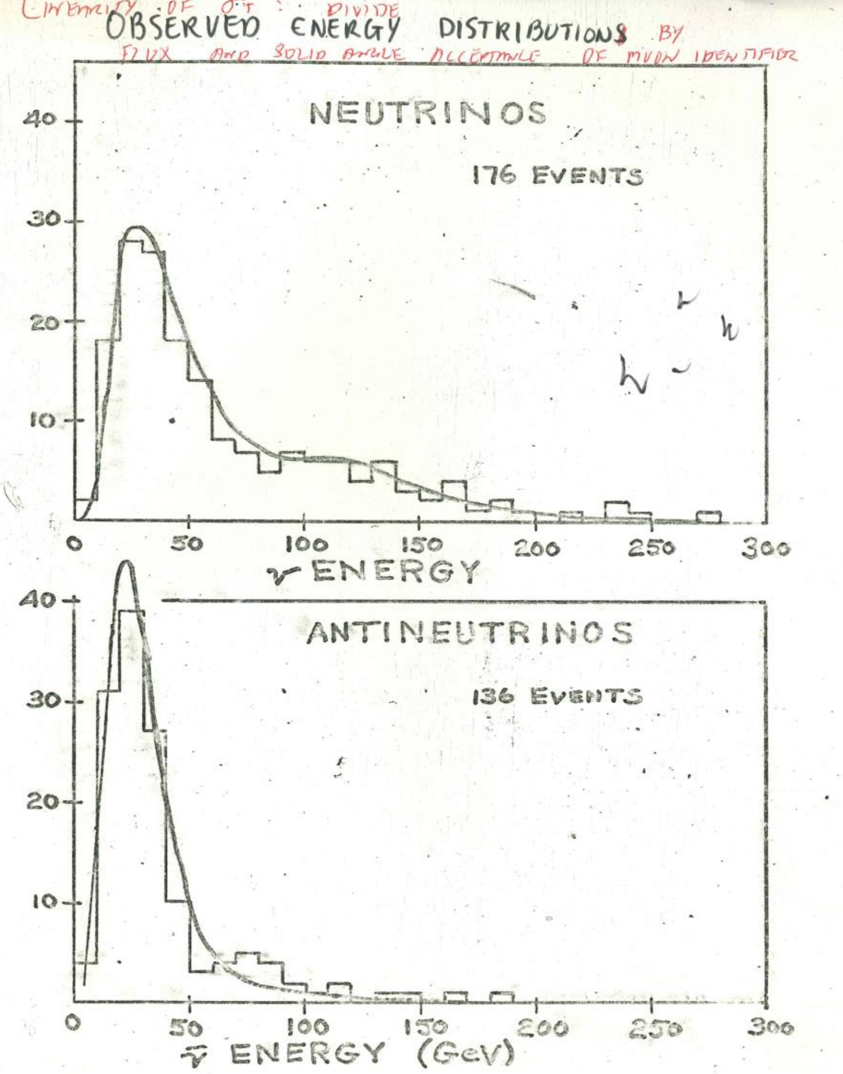
A crucial step in the determination of the neutrino spectrum is an experimental test of the overall validity of the assumptions used in the calculations. The traditional method used at CERN consists in comparing the muon distribution inside the shielding with the predictions of a calculation using identical production spectra, beam geometry and particle degradation throughout the shield.

In the case of the high energy unfocused beam at NAL, the beam geometry is considerably simpler, since we now have a naked target and no focusing element. On the other hand due to the higher energies and to the actual geometry of the shield, the analog study of muon diffusion is extremely difficult and probably not very useful since masked almost entirely by multiple Coulomb scattering effects.

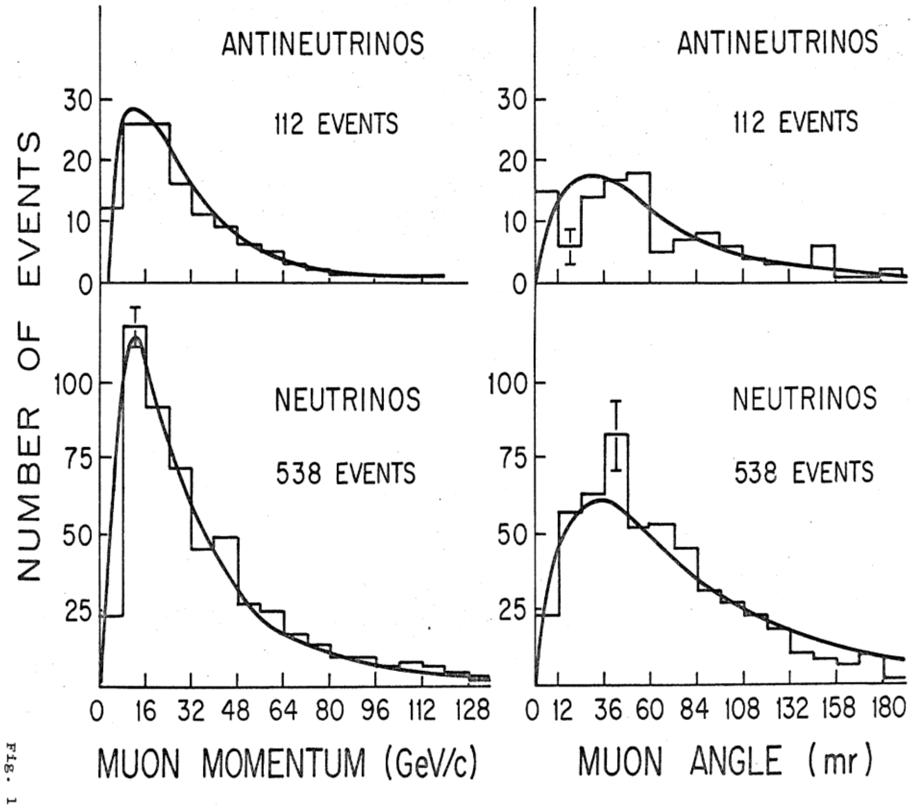
In the present application almost all uncertainties come from the production spectra since parent particles travel "unvexed" and the beam geometry is relatively simple and exactly known. Under these circumstances a very valid test of the ν-flux calculation can be provided by comparing the experimentally observed yield of γ-rays from π^0 decays with the prediction of a parallel calculation starting from the same initial production spectra.

Obviously the experiment tests almost exclusively the π-produced neutrinos, with the additional assumption that the π^0 spectrum coincides with the sum of the

Data confirms calculation of fluxes.



Are we losing muons out the sides? No. *Do muon angles agree with expectation?* Yes.



VOLUME 32, NUMBER 3 PHYSICAL REVIEW LETTERS 21 JANUARY 1974

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[10] E. L. Berger, M. Jacob, and R. Slansky, Phys. Rev. D 6, 2580 (1972).
[11] R. C. Hwa and C. S. Lam, Phys. Rev. D 5, 766 (1972).
[12] R. N. Diamond, A. R. Erwin, R. Loveless, and M. A. Thompson, Nucl. Phys. B62, 128 (1973).

Measurements of Neutrino and Antineutrino Cross Sections at High Energies

A. Benvenuti, D. Cline, W. T. Ford, R. Imlay, T. Y. Ling, A. K. Mann, F. Messing, R. L. Piccioni, J. Pilcher,* D. D. Reeder, C. Rubbia, R. Stefanski, and L. Sulak
Department of Physics, Harvard University,† Cambridge, Massachusetts 02138, and Department of Physics, University of Pennsylvania,† Philadelphia, Pennsylvania 19104, and Department of Physics, University of Wisconsin,† Madison, Wisconsin 53706, and National Accelerator Laboratory, Batavia, Illinois 60510
(Received 23 October 1973)

The dependence of the neutrino total cross section σ_ν on neutrino energy has been measured up to 160 GeV. The data are consistent with a linear dependence with slope $(0.58 \pm 0.25) \times 10^{-38}$ cm^2/GeV. The ratio of the antineutrino to the neutrino total cross section $\sigma_{\bar{\nu}}/\sigma_\nu$ has been found to be approximately constant up to 70 GeV at a value which is consistent with the numerical value of $\frac{1}{3}$ expected for the scattering of neutrinos and antineutrinos by relativistic pointlike spin-$\frac{1}{2}$ fermions.

We discuss here the observation of events of the types $\nu_\mu(\bar{\nu}_\mu) + N \to \mu^-(\mu^+) +$ hadrons, from which are obtained (i) a measurement of the dependence of the neutrino total cross section σ_ν on neutrino energy E_ν up to 160 GeV, and (ii) measurements of the ratio of antineutrino to neutrino total cross sections $\sigma_{\bar{\nu}}/\sigma_\nu$ up to 70 GeV.

Details of the experimental arrangement were described previously.[1] Briefly, useful neutrino interactions occurred either in a liquid-scintillator ionization calorimeter, or in the first section of an iron magnetic spectrometer located immediately downstream of the calorimeter. For all events the vector momentum and sign of charge of the secondary muon were measured in the magnetic spectrometer. In the temporary absence of other information we assume that negative and positive muons are produced in neutrino and antineutrino interactions, respectively. For interactions occuring in the ionization calorimeter the energy of the hadron cascade, E_h, was also measured. The detector was activated by either of two coincidence modes: (i) a muon traversing the entire length of the magnetic spectrometer, or (ii) a muon traversing at least the first section of the spectrometer in conjunction with various preset minimum depositions of energy in the calorimeter. Data were taken with primary proton energies E_p of 300 and 400 GeV.

We plot in Fig. 1 the observed distributions in momentum p_μ and angle θ_μ for muons of negative and positive charge, combining data it ...

1 are Monte Carlo distributions calculated by assuming scale invariance and form factors obtained from electroproduction[2] and low-energy neutrino data.[3] The calculation includes the geometric and magnetic-focusing properties (detection efficiency) of the detector, and an incident neutrino or antineutrino spectrum.[4] The good agreement between the observed and predicted distributions in p_μ and θ_μ indicates the approximate validity of the combined input to the Monte Carlo calculation.

In Figs. 2(a) and 2(b) are shown the observed and Monte Carlo calculated distributions in hadron energy E_h for interactions that occur in the ionization calorimeter. The agreement on aver-

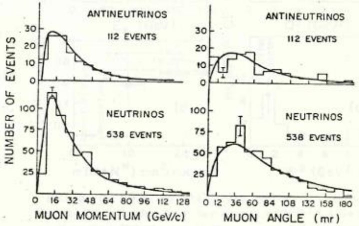


FIG. 1. Observed distributions (histograms) in muon momentum p_μ and angle θ_μ for antineutrinos and neutri-

Dave Cline presents a seminar at NAL, Dec 7 '73

Events Analyzed So far

All (x,y), $5 < z < 12$

$N_c = 673$; $N_{\mu less} = 195$

$R^m = 0.29$

Cline reiterates Aug 3 submission to PRL:

All (x,y) $1 < z < 12$

$N_c = 237$, $N_{\mu less} = 103$

$|x,y| < 100$ cm $5 < z < 12$

$N_c = 446$, $N_{\mu less} = 114$

Then reaffirms it with different fiducial cuts:

$R^m = 0.25 \pm 0.02$

1. All events scanned and measured by physicists
2. Punch Through being measured in several ways
3. μ's being measured and reconstructed to get (P_μ, θ_μ) distributions

2 slides later Cline concludes his NAL seminar slides with:

Then, with absolutely no justification,
Cline negates our work,
blotting it out on his slide:

Carlo had called from CERN…

…oscillating his collaborators results by fiat !!!

"But Carlo, nothing in the data or analysis has changed!!!" shouted all of us in the US.

ENTATIVE

Conclusions

1. R′ Very likely too small to be consistent with Weinberg model and lower bounds deduced by Paschos and Wolfenstein for this model – also CERN data, if due to Weinberg model – Energy dependence is still a loop hole

   (R′ > 0.28 CERN at $E_\nu \sim 2$-3 GeV)

2. R′ = 0.29 ± 0.09 Suggested by first E1A experiment is [redacted] [redacted] not confirmed in the present experiment – uncertainty in the (x, y) vertex reconstruction in that experiment was perhaps the trouble – there are still loop holes however!
3. There are events in the present experiment that don't appear to have a visible μ track – could be due to spark chamber ineff. – but seems unlikely – needs further study
4. Some μ-less events appear to have showers that are suggestive of predominate electromagnetic effects – perhaps due to ν_e's

…then, one week later,
Cline circulates the slides from his talk:

CLINE RETRACTS
HIS ERRONEOUS OSCILLATION:

His E1A collaborators,
who did all the work,
were again furious.

THE UNIVERSITY OF WISCONSIN
MADISON 53706

DEPARTMENT OF PHYSICS
475 NORTH CHARTER STREET

December 13, 1973

SUBJECT: Data Reported at NAL Talk, December 6, 1973

FROM: D. Cline

To minimize confusion concerning the data presented at my talk of December 6 at NAL, I have reproduced some of the figures and include them here. The only experimental number reported was the raw ratio of μless to μ events in the appropriate fiducial region of 0.25 ± .02.

Improvements accomplished:

A pion focusing horn is installed.
An additional iron filter after Hcal for muon ID.

We verify muon detection efficiency:

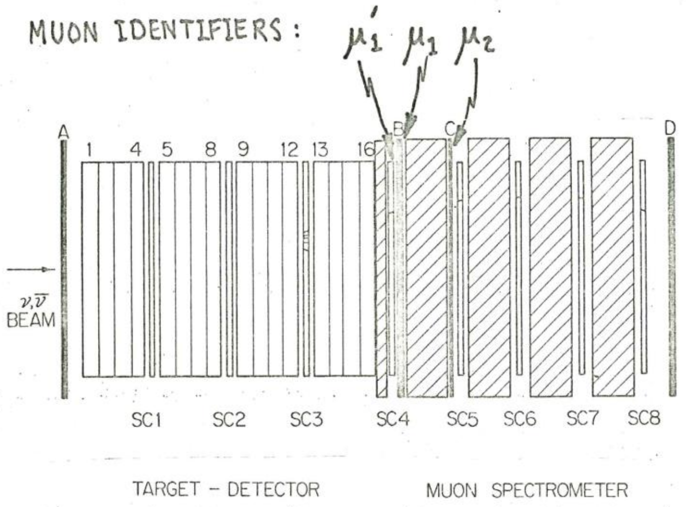
Summary of data for the four neutrino beam configurations.

Data Sample		Number of events	Muon Detection Efficiency* μ_1	μ_1'	μ_2	α	R
Mixed Beam	Horn Off	255	.86	.77	.74	0.74 ± 0.06	0.18 ± 0.05
	Horn On	283	.89	.81	.80	0.45 ± 0.06	0.22 ± 0.05
Sign-selected $(\pi,K)^-$		100	.93	.87	.83	0.12 ± 0.05	0.34 ± 0.12
Sign-Selected $(\pi,K)^+$		188	.93	.87	.83	0.98 ± 0.01	0.13 ± 0.06

Universal agreement:

4 different ways of ν beam focusing, &

3 different muon identifiers:



All consistent with, muonless/with muon ~0.29

POSTLOGUE I: > 1 year later

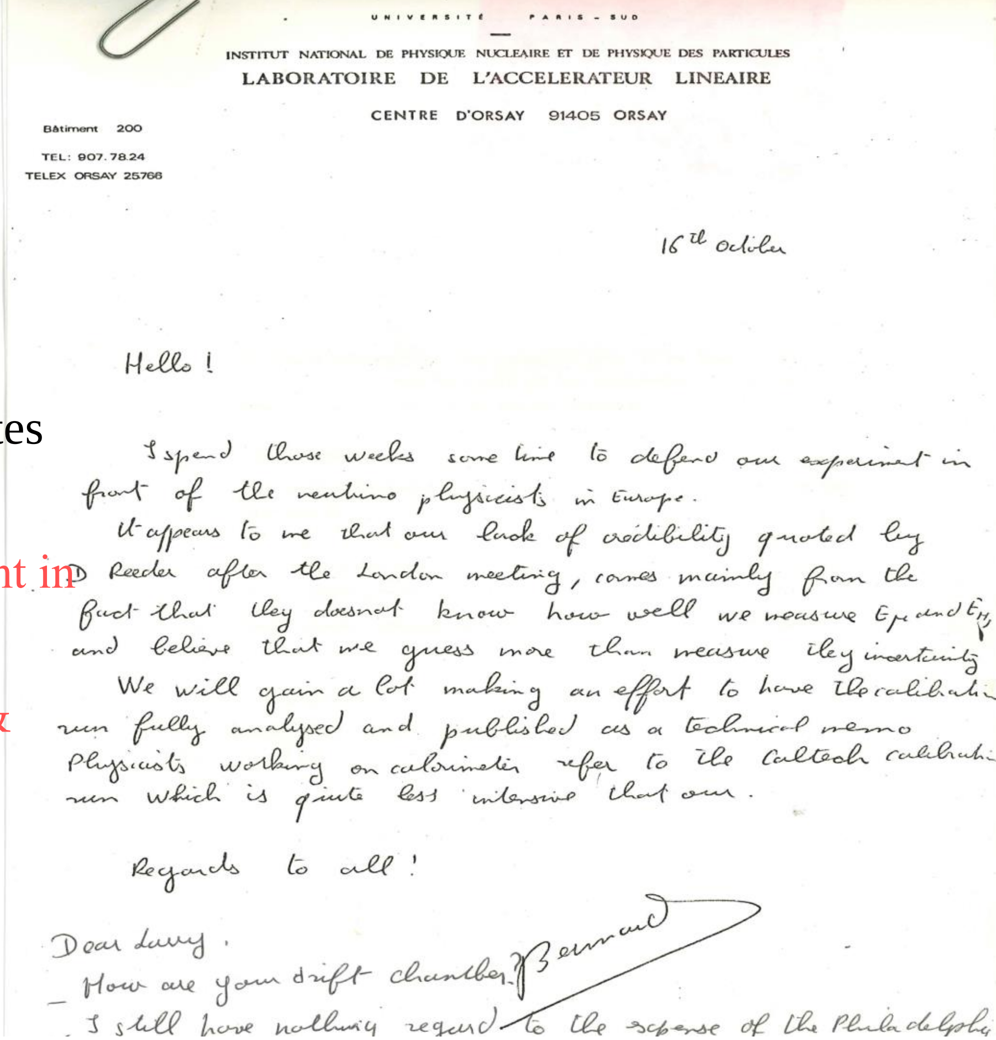
Feedback from Bernard Auber back in Europe:

Bernard, E1A collaborator back at LAL, writes in frustration:

"I spent…weeks to defend our [E1A] experiment in front of the neutrino physicists in Europe.

…they [don't] know how well we measure E_μ & E_H"

Oct 16 '74:


UNIVERSITÉ PARIS - SUD

INSTITUT NATIONAL DE PHYSIQUE NUCLEAIRE ET DE PHYSIQUE DES PARTICULES

LABORATOIRE DE L'ACCELERATEUR LINEAIRE

CENTRE D'ORSAY 91405 ORSAY

Bâtiment 200

TEL: 907.78.24

TELEX ORSAY 25766

16th October

Hello!

I spend those weeks some time to defend our experiment in front of the neutrino physicists in Europe.

It appears to me that our lack of credibility quoted by Reeder after the London meeting, comes mainly from the fact that they doesn't know how well we measure E_μ and E_H, and believe that we guess more than measure they incertainty.

We will gain a lot making an effort to have the calibration run fully analysed and published as a technical memo. Physicists working on calorimeter refer to the Caltech calibration run which is quite less intensive that our.

Regards to all!

Bernard

Dear Larry.

– How are your drift chamber?

– I still have nothing regard to the expense of the Philadelphia

’73-’74: Harvard shops keep humming,
simultaneously with E1A data & analysis,

adapting E1A technology to

$\nu p \rightarrow \nu p$ elastic scattering…
with ν and anti-neutrinos.

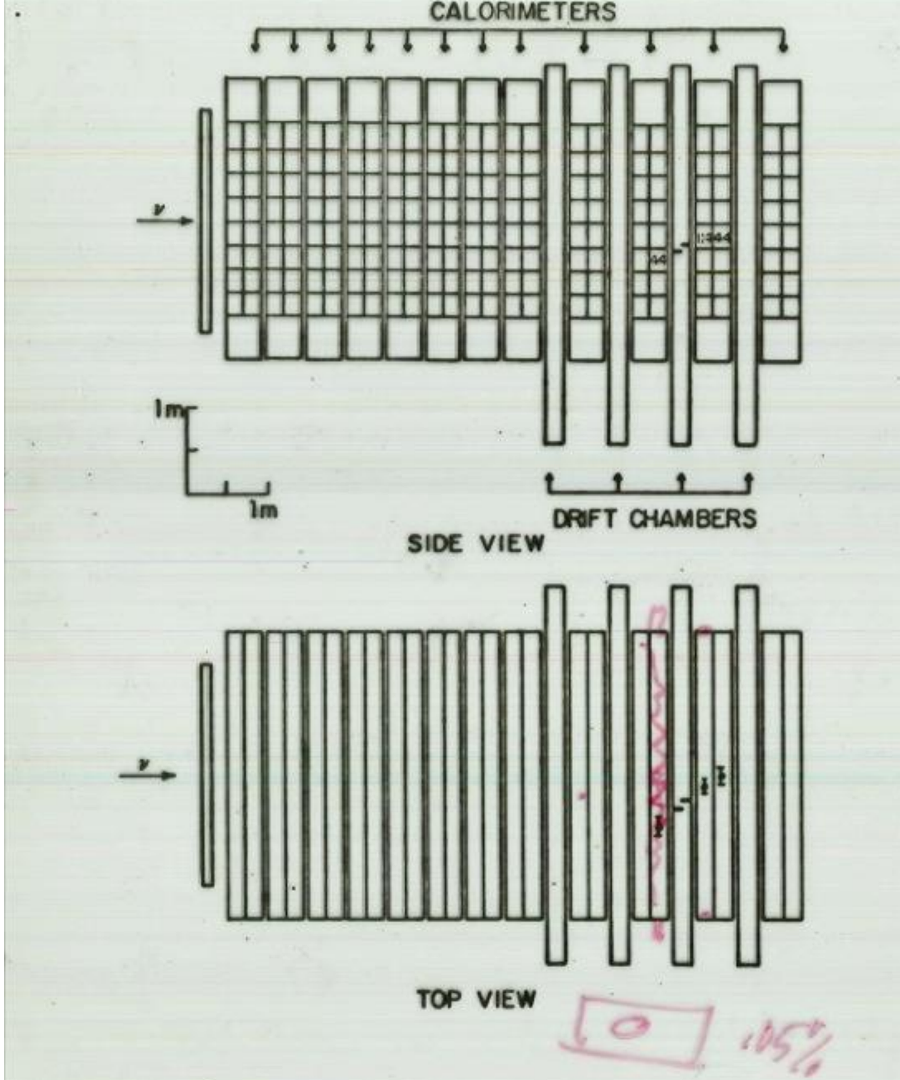
For ~1.5 GeV low energy neutrinos

With a target-calorimeter of

high granularity along, and ⊥ to, the beam line.
adhesive Teflon & oil again

Large area drift chamber trackers… the first ever

Scaled Charpak’s 5x10 cm^2 up 100x to 4x4 m^2.
87% ethylene, 13% Ar
3 cm/μsec drift speed with 300 v/cm



At Brookhaven in ’74, using refined E1A technology:

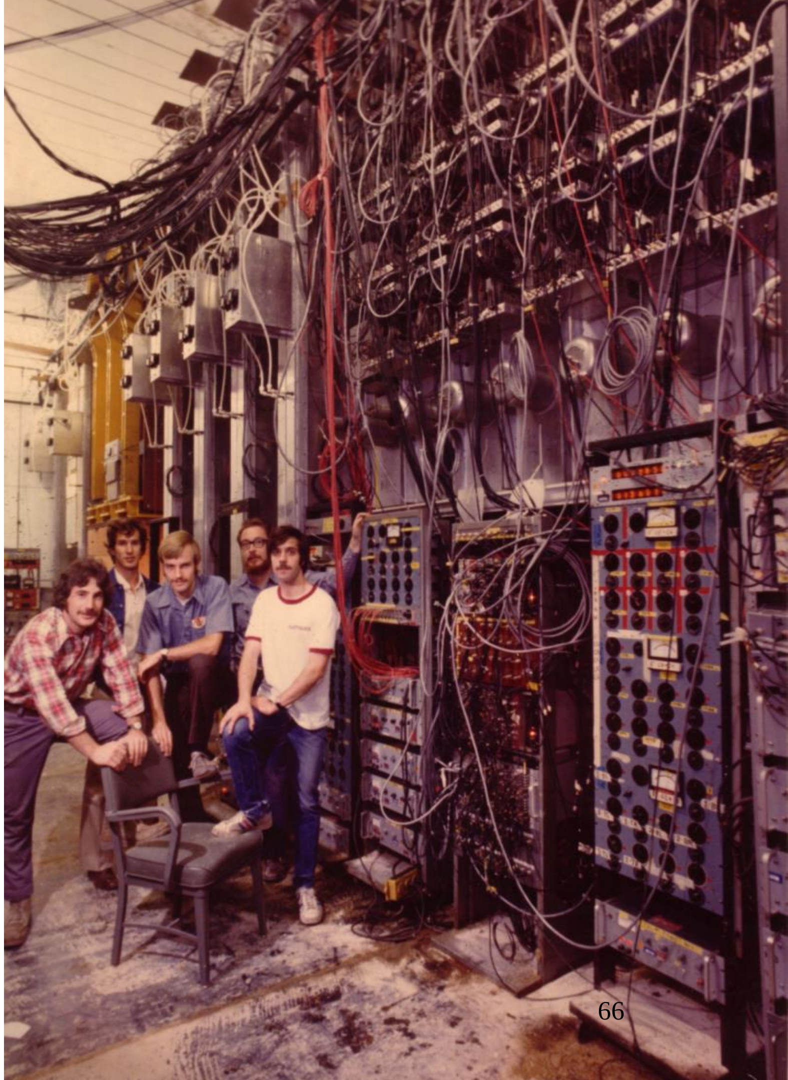
Discoveries of more neutral currents:

$\nu_\mu\, p \rightarrow \nu_\mu\, p$ *elastic scattering*

…just like. γ p $\rightarrow$ γ p…electro-weak unification!

Also discover the anti-neutrino counterpart,

anti-$\nu_\mu\, p \rightarrow$ anti-$\nu_\mu\, p$



Egelman, LRS, J. Strait, W. Kozanecki & Yudis.

Not shown: G. Gollin, D. Hanna, M. Levi, J. LoSecco, P. Meyers,

L. Rivkin, W. Smith; Al Mann, Brig Williams, A Enterberg,

POSTLOGUE II 32 years later,

Sam Ting sends unsolicited letter for public display at my festschrift, stating:

"Your work with a calorimeter at Fermilab in the 1970s has led to the discovery of neutral weak currents with neutrino beams."

Oct 15, 2005:

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Laboratory for Nuclear Science
CAMBRIDGE, MASSACHUSETTS 02139

October 14, 2005

Professor Lawrence R. Sulak
Chairman
Physics Department
Boston University
Metcalf Science Center
590 Commonwealth Avenue
Boston, MA 02215
Fax: 617 353 9393

Dear Larry:

Please accept my sincere congratulations on this great occasion. I have treasured your indomitable spirit, your dedication to physics and your true friendship for over thirty years.

Some time ago I booked a flight to Boston specifically to attend this important occasion. However, because of the great uncertainty prevailing with NASA shuttle flights to transfer AMS to the Space Station, I must attend a meeting with the Head of the Italian Space Agency this weekend and therefore may not be able to congratulate you in person. I have the following comments:

Your work has fundamentally changed our knowledge of modern physics.

Your work with a calorimeter at Fermilab, in the 1970s, has led to the discovery of neutral weak currents with neutrino beams.

Your work with a massive ring-imaging Cherenkov detector to search for proton decay has recorded an inexplicable absence of atmospheric neutrinos.

You and Masatoshi Koshiba deserve major recognition for extending your original work at the Kamioka mine, which led to the verification of the initial observation of a deficit of neutrinos.

Your work at MACRO, in the *g-2* experiment and in CMS is a testimony of your ingenuity in instrumentation and your insight in physics.

I am confident that with your foresight and intelligence, you will continue to do excellent physics, inspire many more students and provide many stimulating discussions with your colleagues. Susan and I send our congratulations and warmest wishes to you and Beth.

Sincerely yours,

Sam

Samuel C.C. Ting

Samuel C.C. Ting, Thomas D. Cabot Professor, AMS Principal Investigator
MIT - Building 44-114, 51 Vassar Street, Cambridge MA 02139-4308 - Tel: 617 253 5065 Fax: 617 253 4100

Summary: daunting challenges facing E1A builders…

Spectra of neutrinos at hi E? Only 28 GeV protons known, not the anticipated 350 GeV:

Measure $\pi^{\pm}$…via $\pi^{o} \rightarrow \gamma\gamma \Rightarrow$ lateral size of trigger counters, Hcal, spark chambers, magnet

Need Hcal with good σ_E

Mass of target-detector for sufficient rate?

Scintillator? How capture light at 4m distance?

How withstand 4m hydrostatic pressure with little mass?

How track the muon, with lateral spread of 4 m?

How get inexpensive nanosec timing on Hcal re: rf beam structure?

to kill neutrons slower that neutrinos from target, and cosmic rays

How to delay signal from hadronic showers until after fast trigger decision?

How get enough BL^2 for sagitta resolution?

How to identify muons, and measure their angular distribution?

…yield discoveries in the US of "muonless" events, i.e. neutral currents.