John’s early career: Physics at Two Lakes

Lake Chelan, WA
Echo Lake, CO

Jeffrey Wilkes

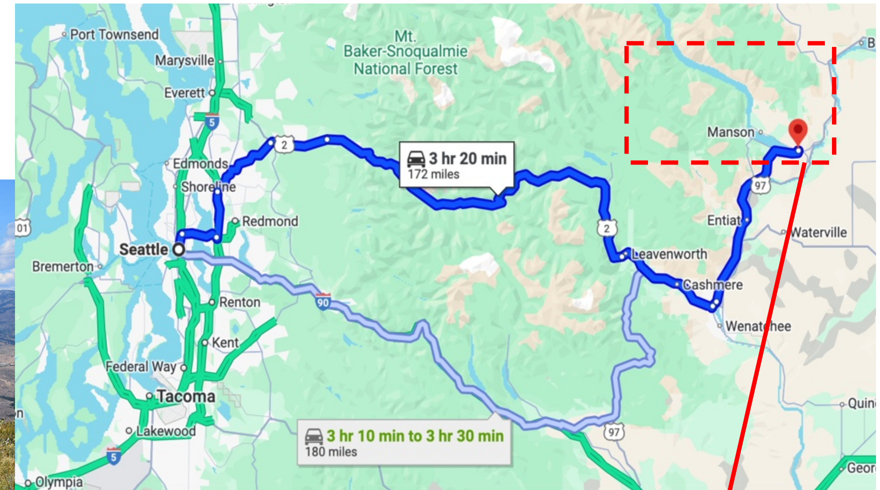
Dept of Physics (emeritus)

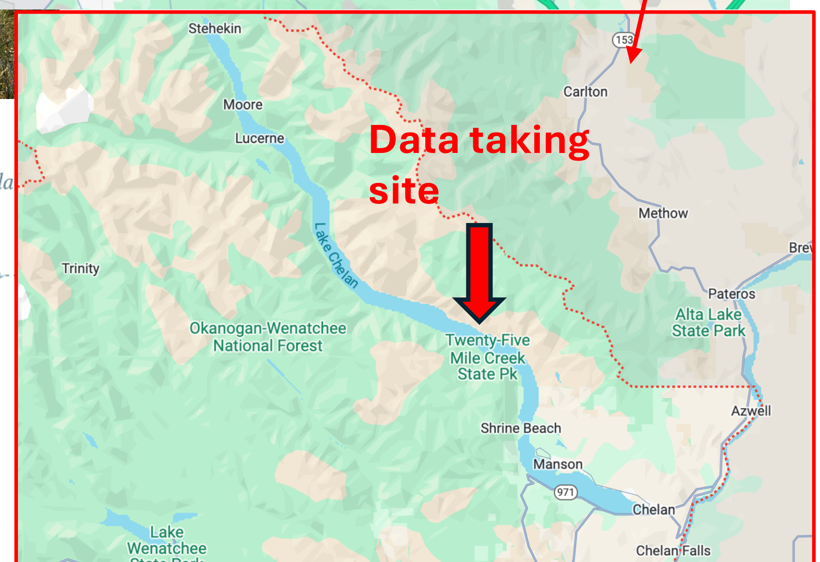
University of Washington, Seattle

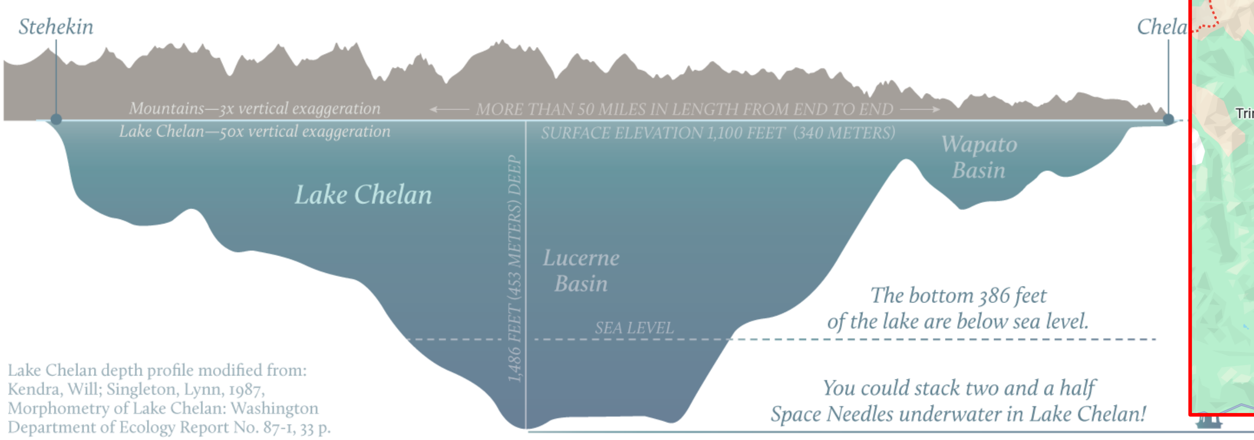
1. Lake Chelan experiment, 1966-67

JGL's thesis project: underwater muons in Lake Chelan, WA

450m deep glacial lake east of
Cascade range, 170 miles E of Seattle

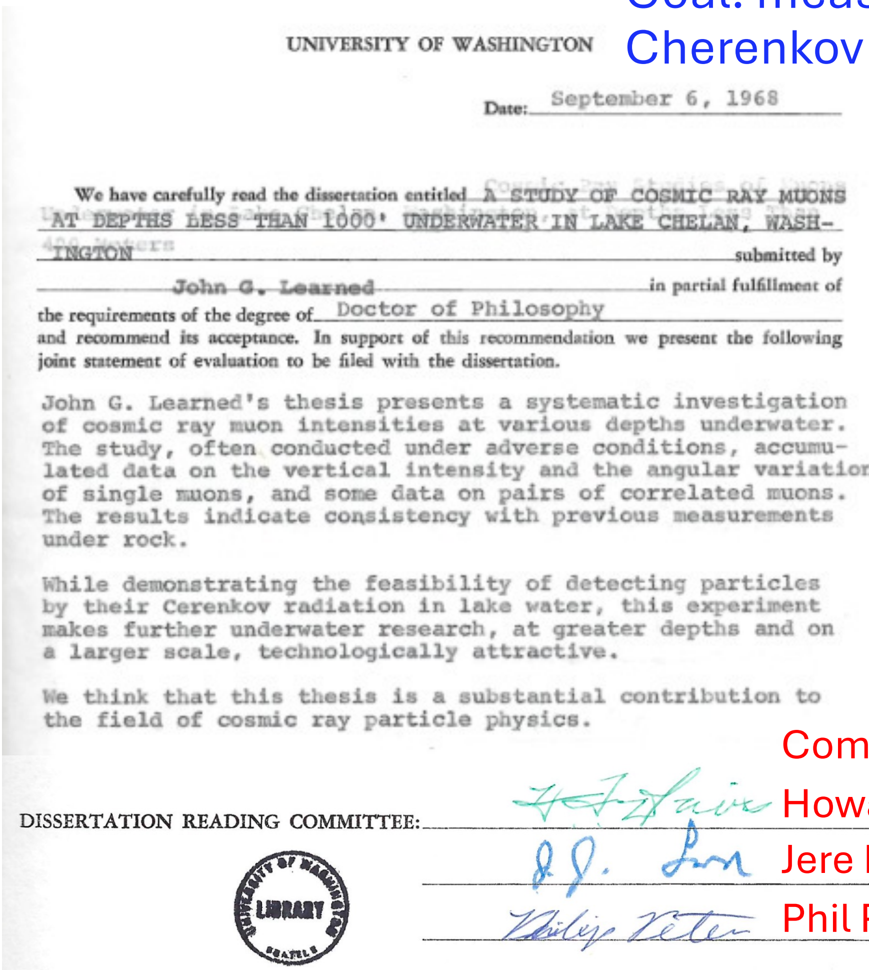






Lake Chelan depth profile modified from:
Kendra, Will; Singleton, Lynn, 1987,
Morphometry of Lake Chelan: Washington
Department of Ecology Report No. 87-1, 33 p.

Goal: measure muon depth-intensity curve with a water Cherenkov detector -- Paleo-DUMAND !



UNIVERSITY OF WASHINGTON

Date: September 6, 1968

We have carefully read the dissertation entitled A STUDY OF COSMIC RAY MUONS AT DEPTHS LESS THAN 1000' UNDERWATER IN LAKE CHELAN, WASHINGTON submitted by John G. Learned in partial fulfillment of the requirements of the degree of Doctor of Philosophy and recommend its acceptance. In support of this recommendation we present the following joint statement of evaluation to be filed with the dissertation.

John G. Learned's thesis presents a systematic investigation of cosmic ray muon intensities at various depths underwater. The study, often conducted under adverse conditions, accumulated data on the vertical intensity and the angular variation of single muons, and some data on pairs of correlated muons. The results indicate consistency with previous measurements under rock.

While demonstrating the feasibility of detecting particles by their Cerenkov radiation in lake water, this experiment makes further underwater research, at greater depths and on a larger scale, technologically attractive.

We think that this thesis is a substantial contribution to the field of cosmic ray particle physics.

DISSERTATION READING COMMITTEE:

"For many decades, measurements of muons have been conducted underwater and underground to study the energy spectrum and composition of primary cosmic rays..."

Committee:
Howard Davis
Jere Lord
Phil Peters

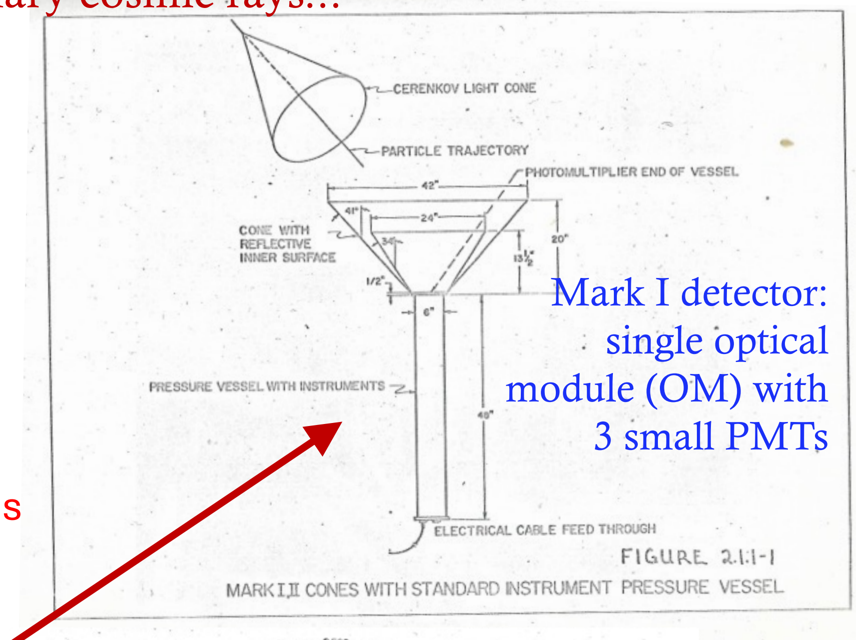
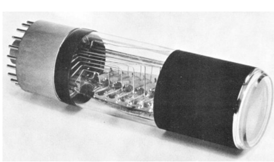
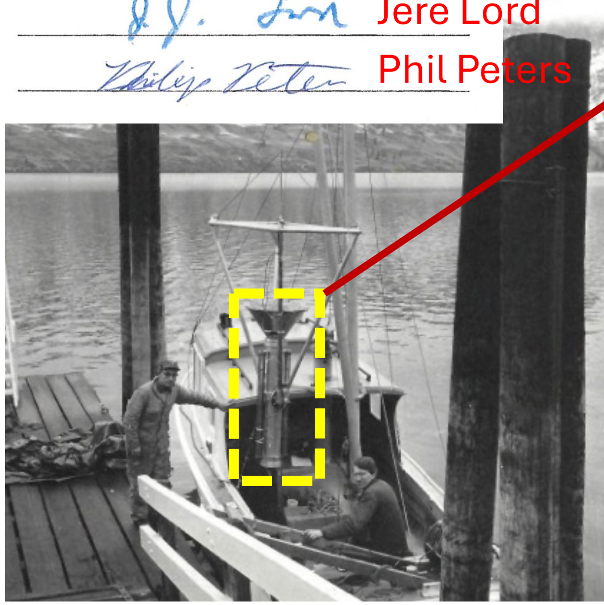


FIGURE 2.1.1-1
MARK I,II CONES WITH STANDARD INSTRUMENT PRESSURE VESSEL

Mark I detector: single optical module (OM) with 3 small PMTs



56AVP
42mm
PMTs



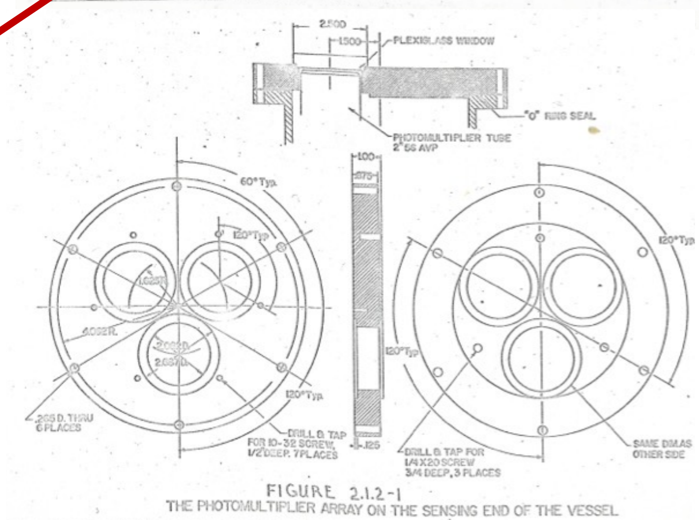
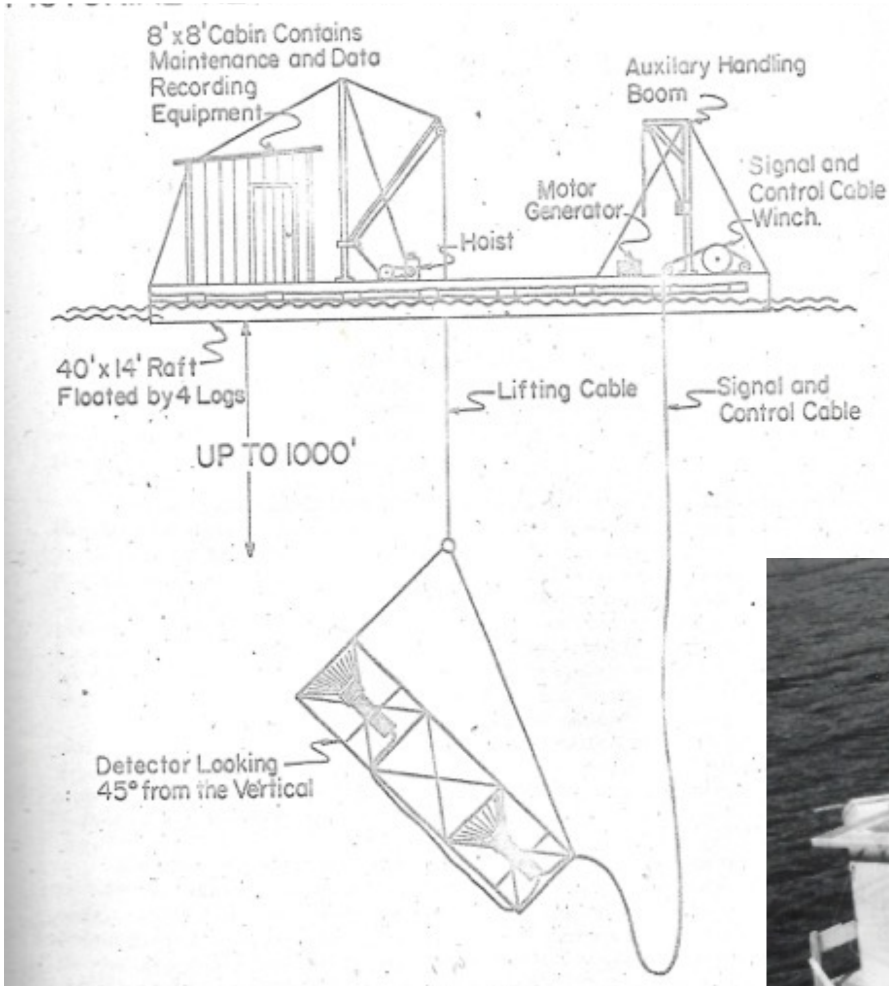


FIGURE 2.1.2-1
THE PHOTOMULTIPLIER ARRAY ON THE SENSING END OF THE VESSEL

Mark II: improved instrument (1967)



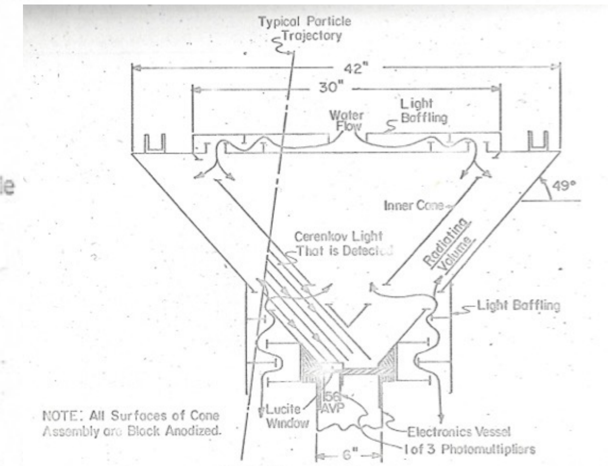
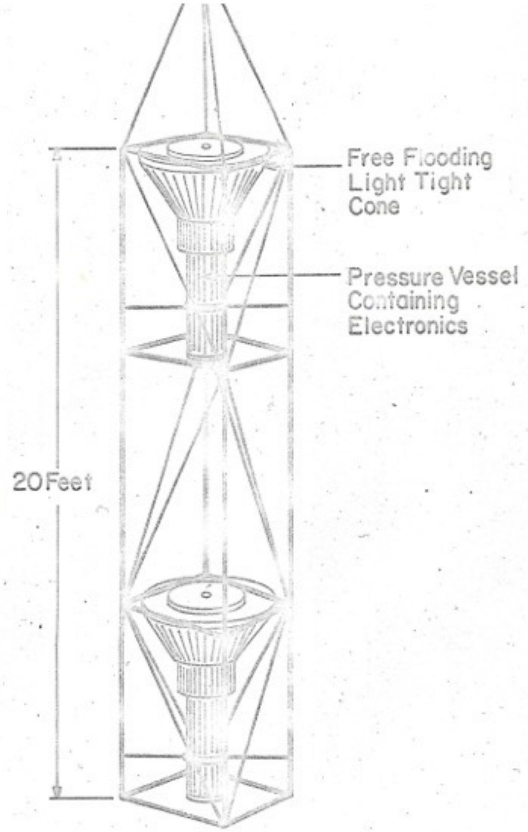
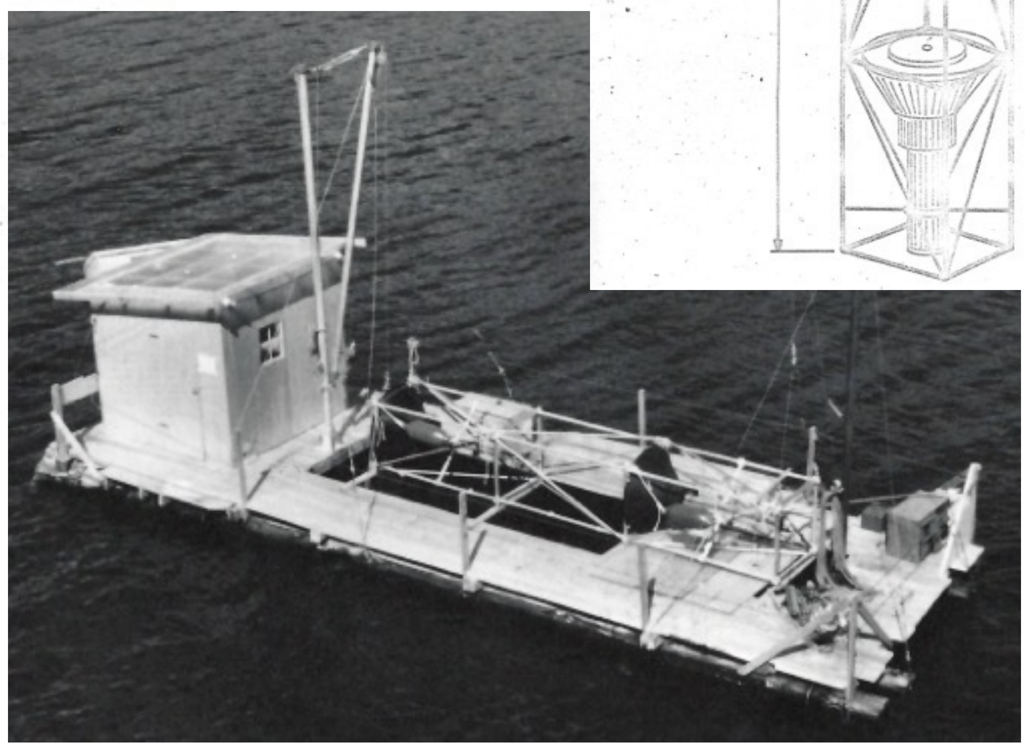


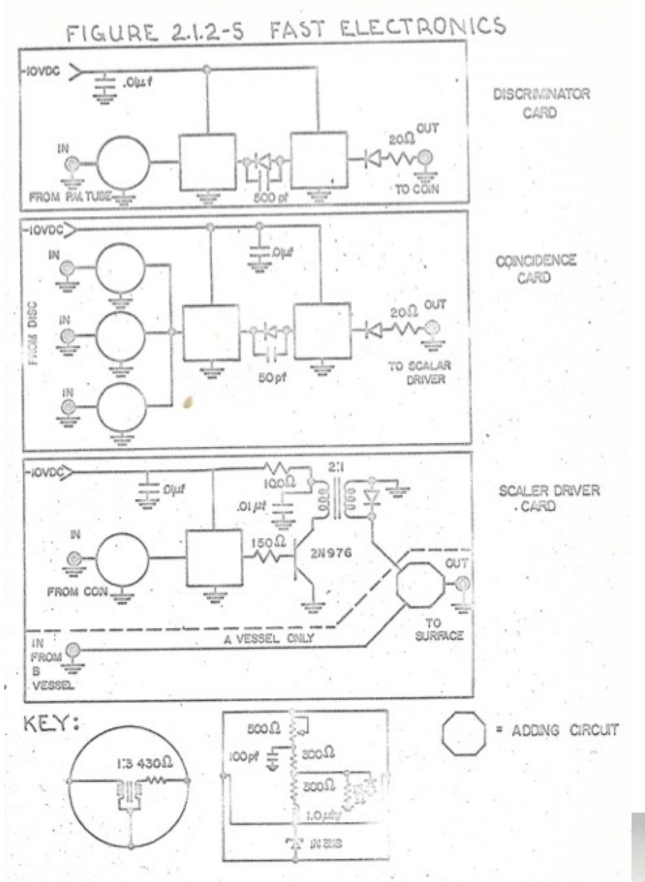
FIGURE 2.2.1 - 4
CROSS SECTIONAL VIEW OF MARK III DETECTOR OPTICS

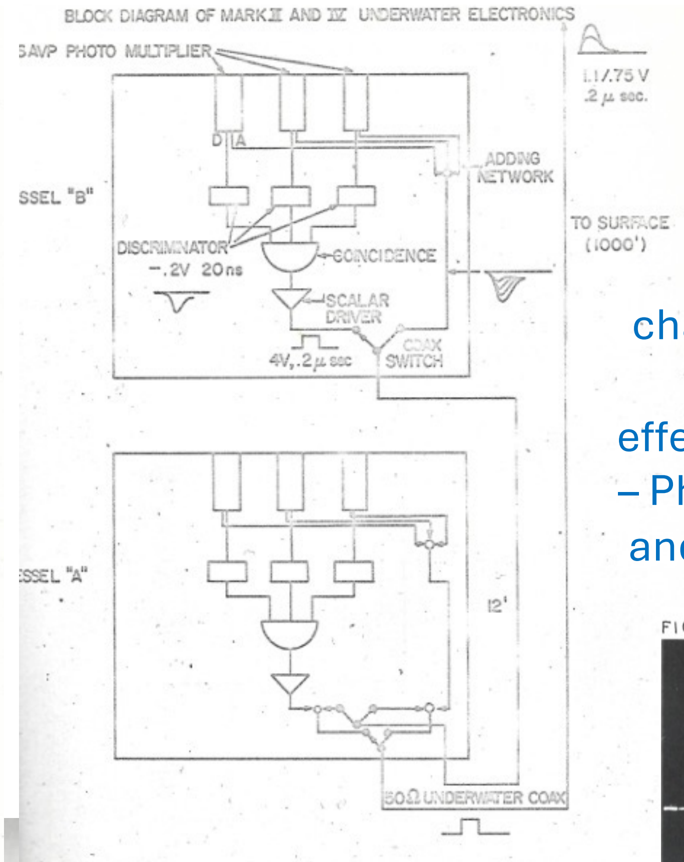




Now 2 OMs in improved reflectors, lowered from raft towed by the boat

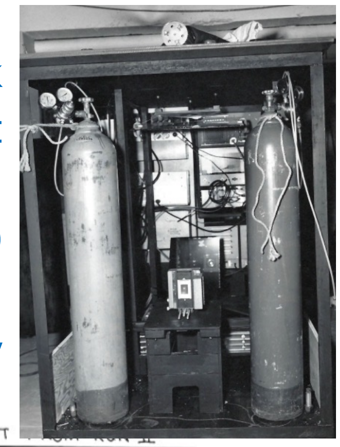
Look Ma, no chips! Hand-made DAQ with diodes





Remember “microseconds”?

Used spark chambers on raft to check OM effective area vs θ – Photos scanned and measured by hand



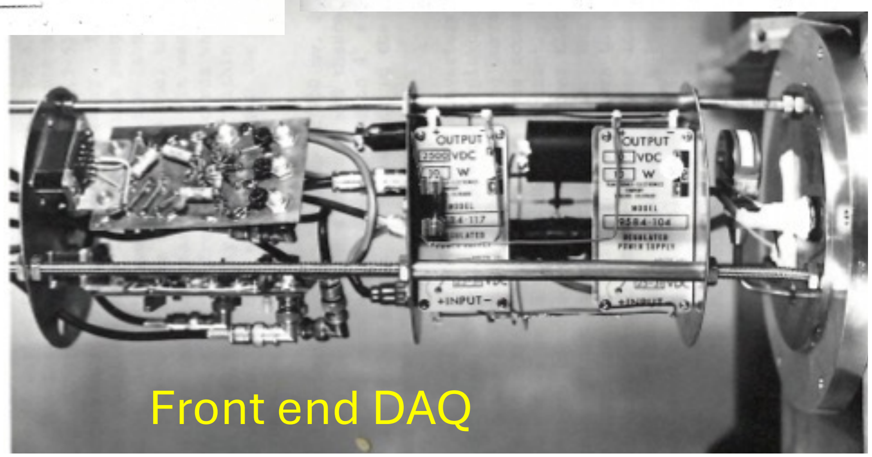
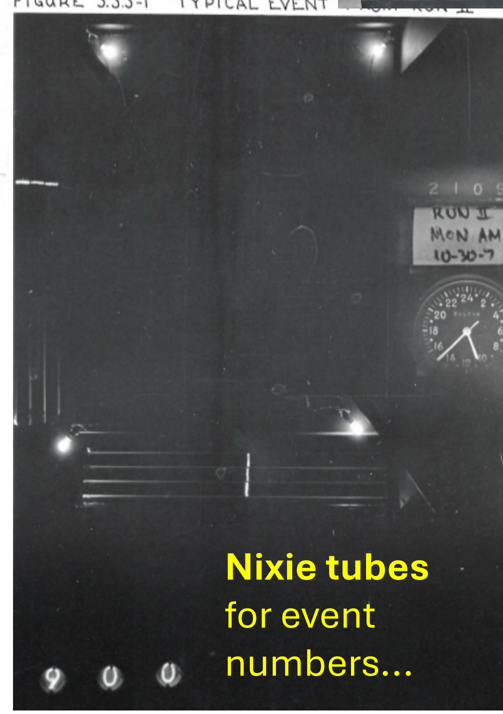
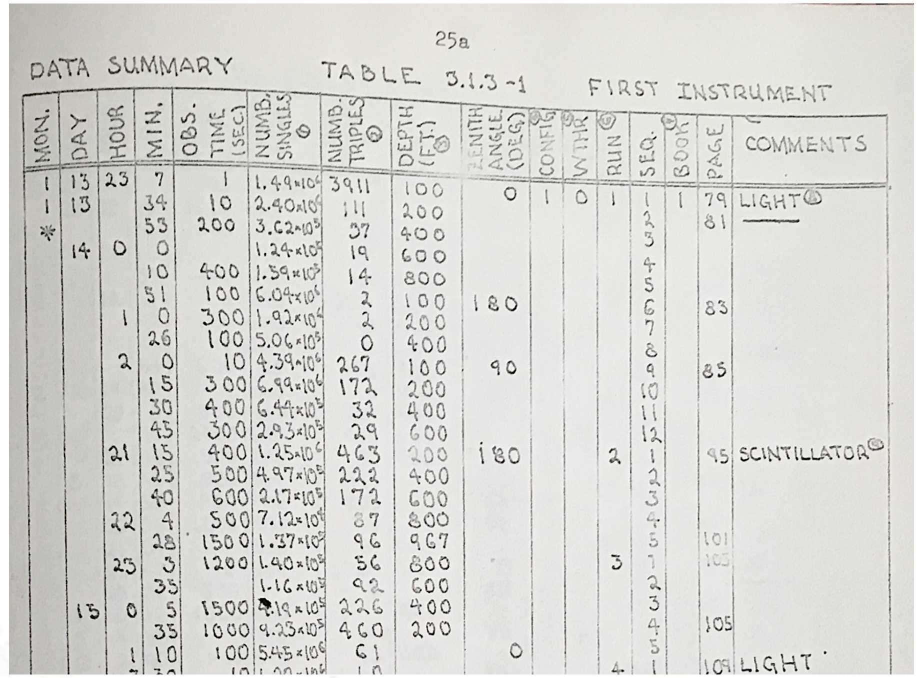


FIGURE 3.3.3-1 TYPICAL EVENT



Example of data file:
counts from scalers,
hand-written in logbook:

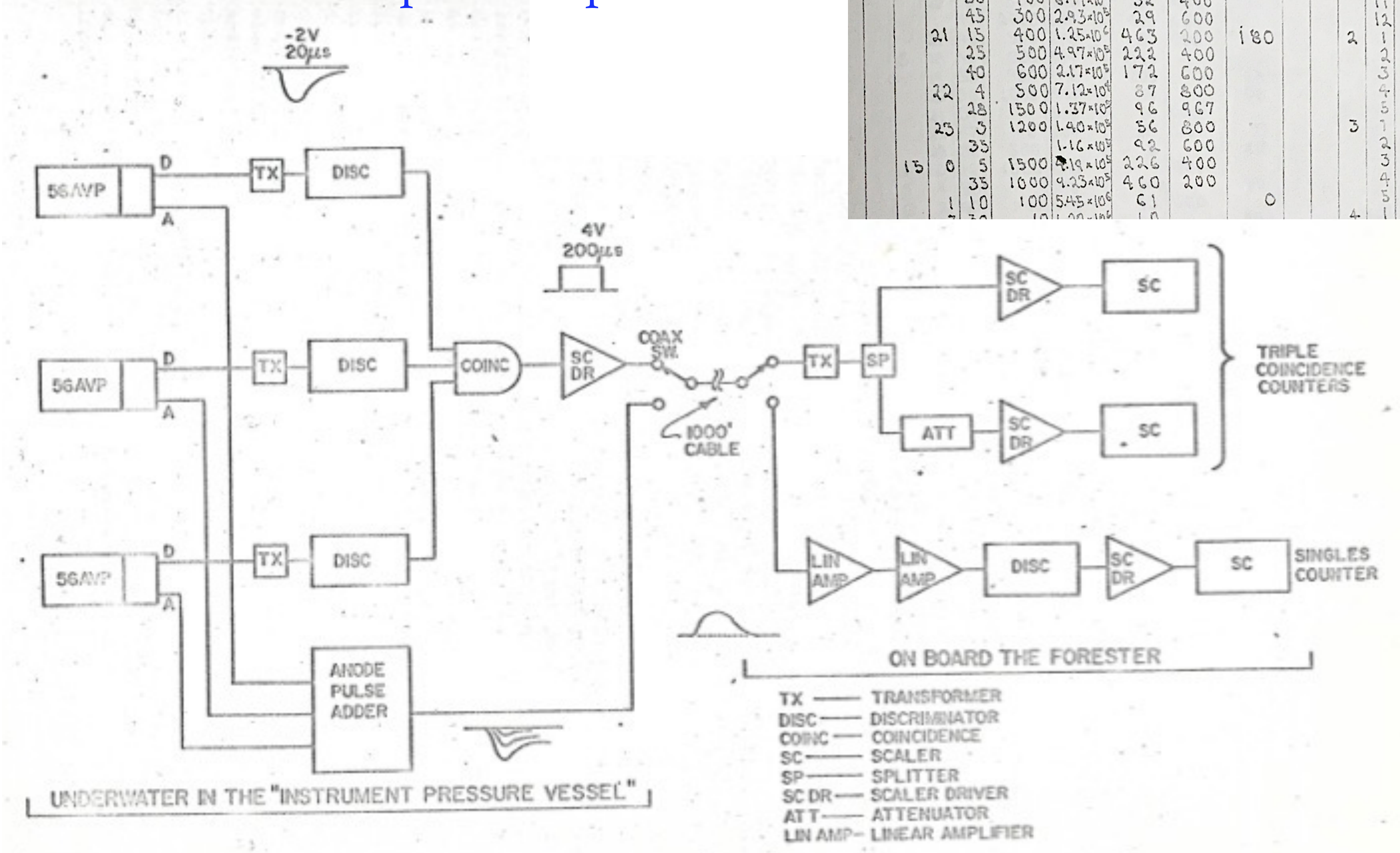


25a

DATA SUMMARY TABLE 3.1.3-1 FIRST INSTRUMENT

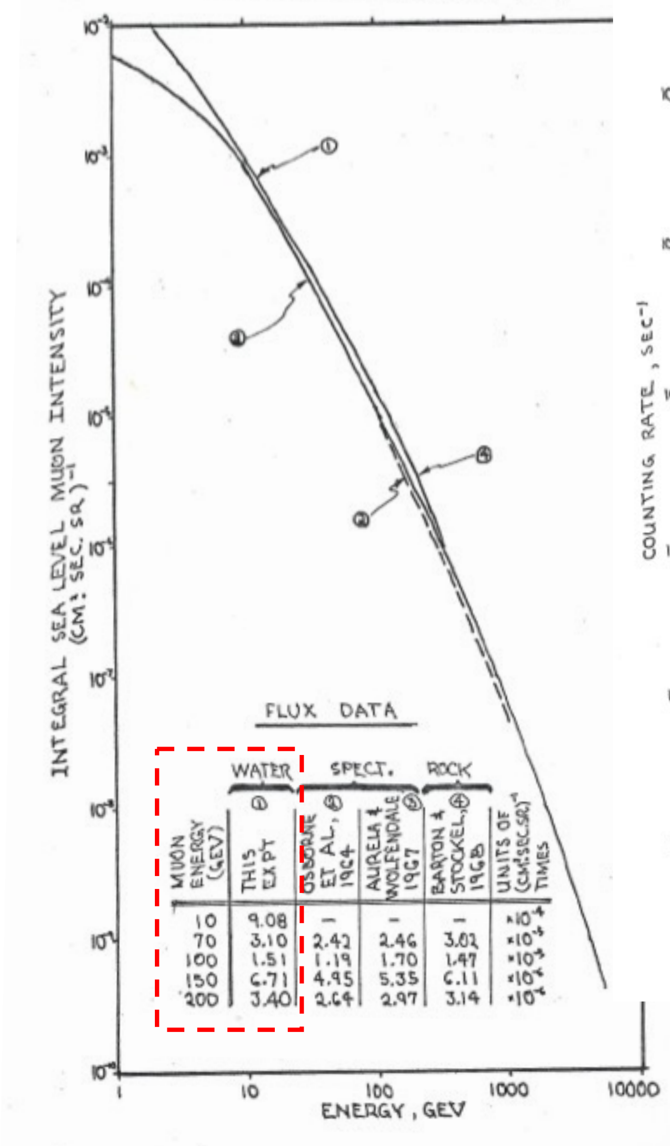
MON.	DAY	HOUR	MIN.	OBS. TIME (SEC)	NUMB. SINGLES ①	NUMB. TRIPLES ②	DEPTH (FT.) ③	ZENITH ANGLE (DEG)	CONFIG ④	WTHR ⑤	RUN ⑥	SEQ.	BOOK ⑦	PAGE	COMMENTS
1	13	23	7	1	1.49×10^6	3911	100	0	1	0	1	1	1	79	LIGHT ⑧
1	13		34	10	2.40×10^6	111	200					2		81	
*			53	200	3.62×10^5	37	400					3			
	14	0	0		1.24×10^5	19	600					4			
			10	400	1.59×10^5	14	800					5			
			51	100	6.04×10^6	2	100	180				6			
		1	0	300	1.92×10^4	2	200					7		83	
			26	100	5.06×10^5	0	400					8			
		2	0	10	4.39×10^6	267	100	90				9		85	
			15	300	6.99×10^6	172	200					10			
			30	400	6.44×10^5	32	400					11			
			45	300	2.93×10^5	29	600					12			
		21	15	400	1.25×10^6	463	200	180			2	1		95	SCINTILLATOR ⑨
			25	500	4.97×10^5	222	400					2			
			40	600	2.17×10^5	172	600					3			
		22	4	500	7.12×10^4	87	800					4			
			28	1500	1.37×10^5	96	967					5		101	
		23	3	1200	1.40×10^5	56	800				3	1		103	
			35		1.16×10^5	92	600					2			
	15	0	5	1500	4.19×10^5	226	400					3			
			35	1000	9.23×10^5	460	200					4		105	
		1	10	100	5.45×10^6	61		0				5			
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					4	1		109	LIGHT

Choose: count 3-PMT coincidences, or
summed pulse heights above a threshold
1000 ft cable softens pulse shapes…



Results: comparable to other underground muon measurements

FIGURE 5.4-1
INTEGRAL MUON SURFACE INTENSITY, VERTICA



MUON ENERGY (GEV)	WATER ① THIS EXPT	SPECT. OSBORNE ET AL, ② 1964	SPECT. AURELA & WOLFENDALE ③ 1967	ROCK BARTON & STOCKEL, ④ 1968	UNITS OF (CM².SEC.SR)⁻¹ TIMES
10	9.08	—	—	—	×10⁻⁴
70	3.10	2.42	2.46	3.02	×10⁻⁵
100	1.51	1.19	1.70	1.47	×10⁻⁵
150	6.71	4.95	5.35	6.11	×10⁻⁶
200	3.40	2.64	2.97	3.14	×10⁻⁶

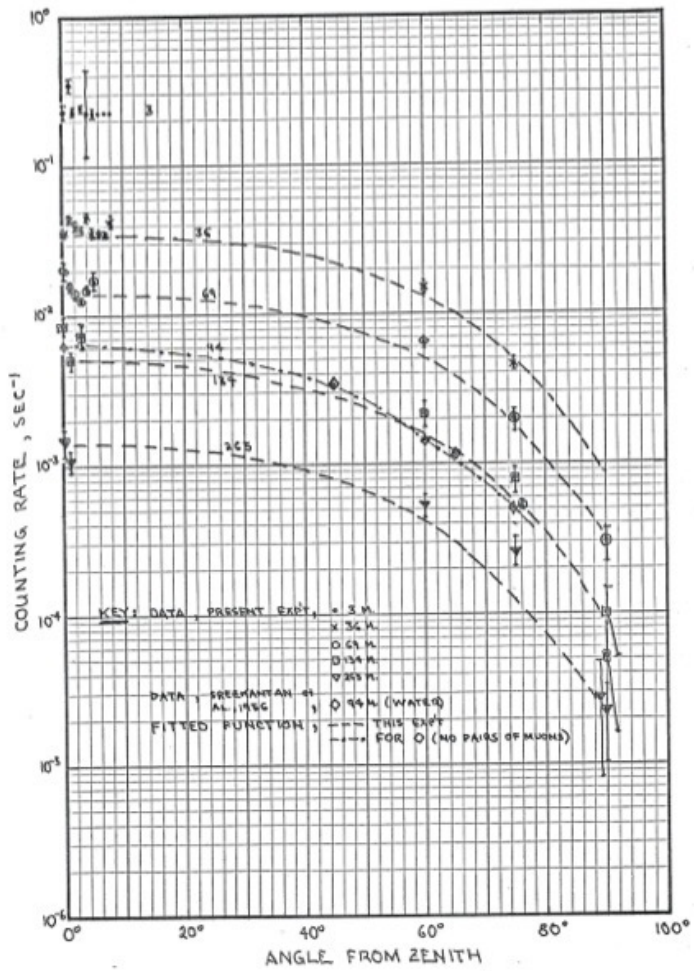


FIGURE 5.4-3
UNDERGROUND ANGULAR DIST.

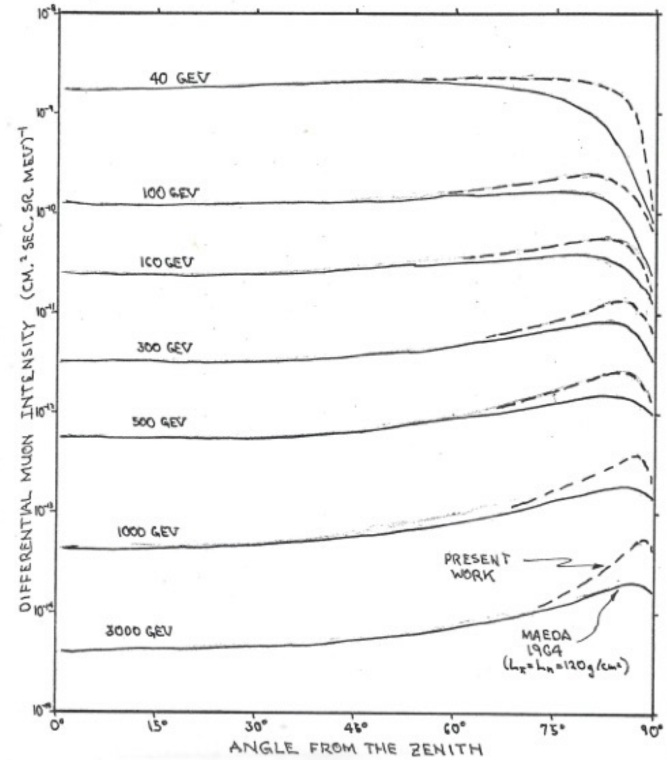
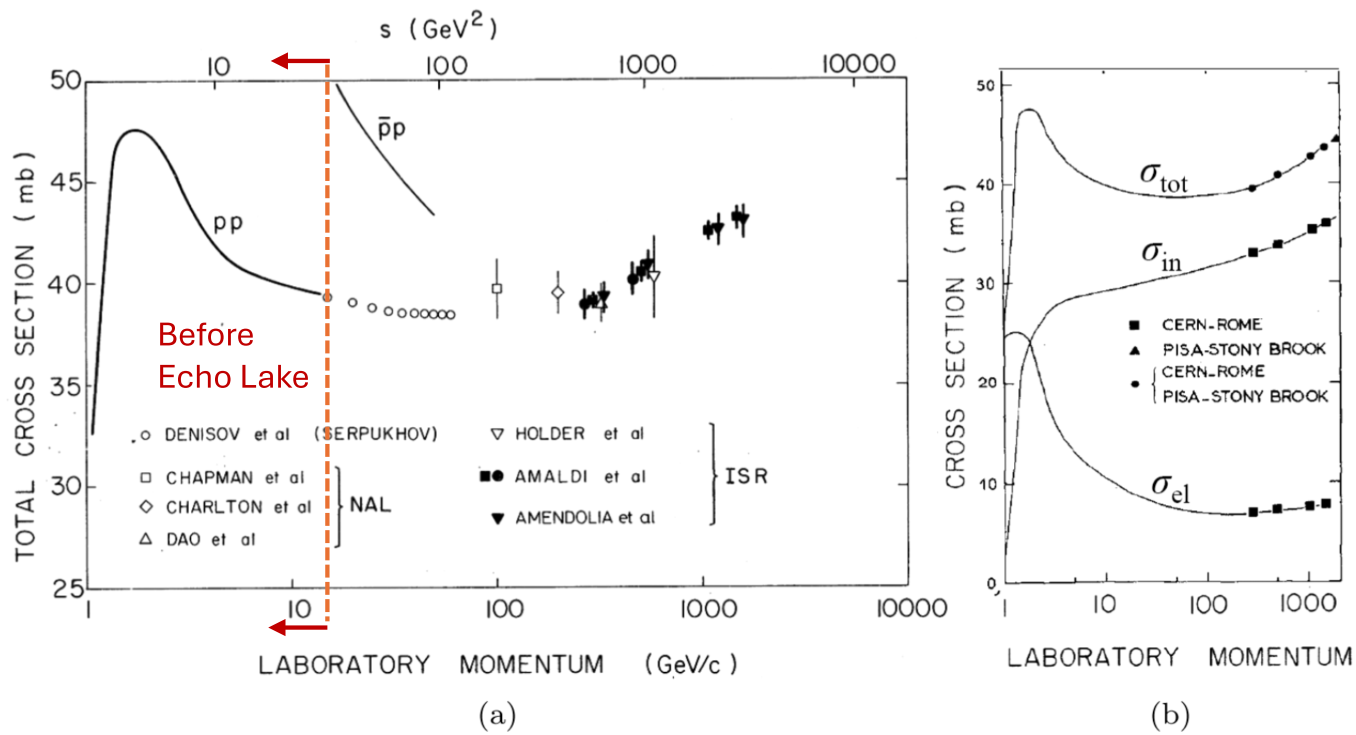


FIGURE 5.4-2
ANGULAR VARIATION OF SURFACE INTENSITY

2. Echo Lake experiment, 1968-72

Key question in mid-60s: does the p-p cross section in the 100-1000 GeV range rise, stay flat, or fall?

- Important theory implications
- Well-measured at lower energies at CERN, BNL, Serpukhov
- Fermilab under construction – not expected until 70s



Larry Jones et al: use cosmic rays to get an early view

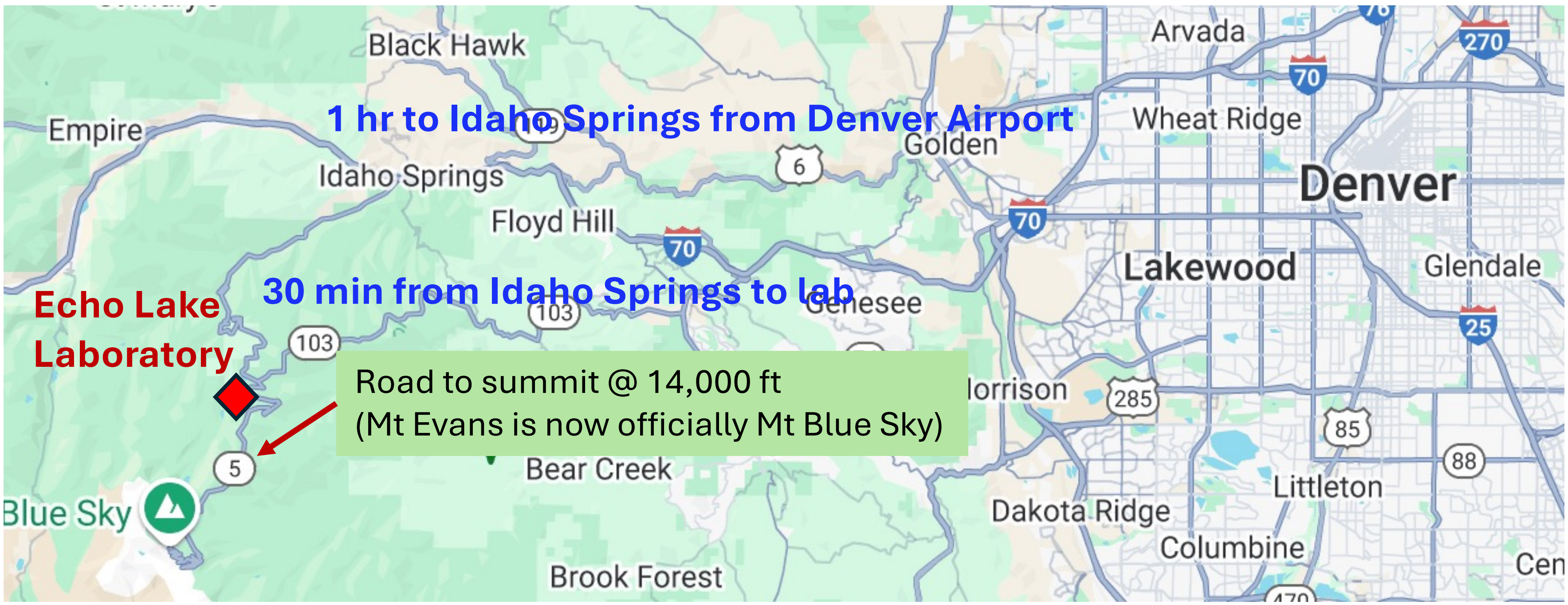
- At mountain altitudes a (very) few primary protons survive
- Accessible mountain lab exists in Colorado: Echo Lake on Mt. Evans

Fig. 18. (a) The proton–proton total cross-section increases for laboratory momenta larger than 300 GeV/c ($s > 500$ GeV^2). (b) The inelastic cross-section was computed by subtraction: $\sigma_{\rm in} = \sigma_{\rm tot} - \sigma_{\rm el}$.

U. Amaldi, 60 Years of CERN Experiments and Discoveries (2015) in worldscientific.com/worldscibooks/10.1142/9441

Echo Lake experiment, 1968-72

- Echo Lake Laboratory
  - 11,000 ft (3230 m) altitude, atmospheric depth 715 g/cm2
  - Used for cosmic ray research since 1930s
  - Year-round accessible by plowed highway
    - Mt Evans summit (14,000 ft) is impractical



- Idaho Springs, CO — nearby small town with basic amenities (supported by gold and molybdenum mines nearby!)
  - 40 miles W of Denver, 1 hour by freeway from (Stapleton) airport
  - 13 miles (30 min) to Echo Lake lab by state highway kept open year-round (but 4WD vehicle useful in winter)

Life on the mountain: Ranch and dorm, natural beauty…

Family housing at “the Ranch”, 10 min drive below lab

Jeff & Roberta Wilkes at Summit Lake

JGL and JW napping on the trail, with Alison Learned

Bachelor housing: dormitory at lab

Collaboration members:

L.W. JONES, A.E. BUSSIAN, G.D. DEMEESTER **, B.W. LOO, D.E. LYON, Jr., P.V. RAMANA MURTHY ***, R.F. ROTH‡ and P.R. VISHWANATH
The University of Michigan, Ann Arbor, Michigan 48104,

J.G. LEARNED, D.D. REEDER and R.J. WILKES
University of Wisconsin, Madison, Wisconsin 53706,

K.N. ERICKSON ‡‡
Colorado State University, Fort Collins, Colorado 80521,

F.E. MILLS
Brookhaven National Laboratory, Upton, New York 11973,

B. CORK
Argonne National Laboratory, Argonne, Illinois 60439

Lab is now an official APS historic site:

Echo Lake, Mount Evans Laboratory Dedicated as Historic Physics Site

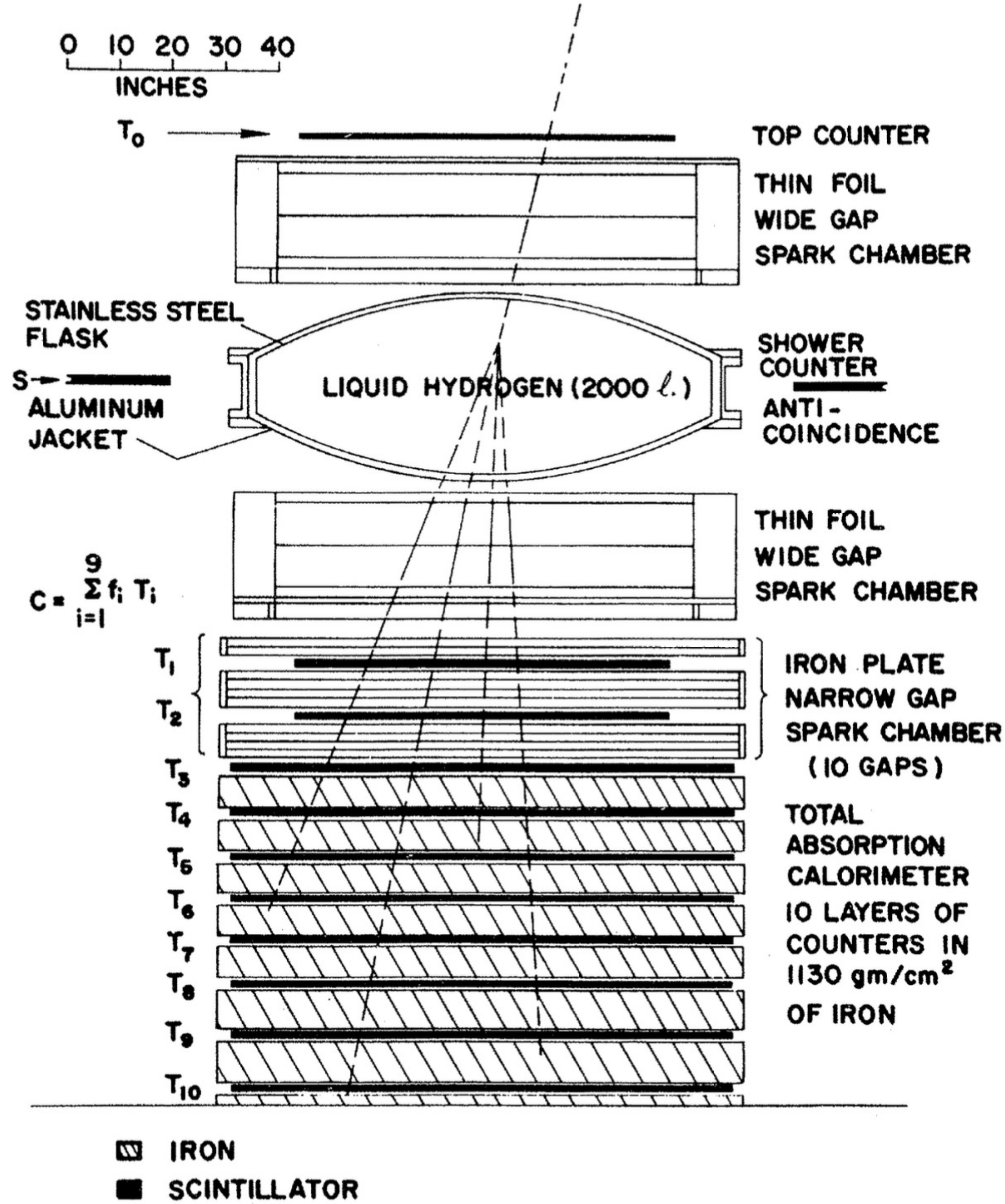
DU physics department has long history of contributing to cosmic ray research at site

· October 25, 2017

Echo Lake experiment, 1968-72

Hydrogen target: 10/68 - 5/69

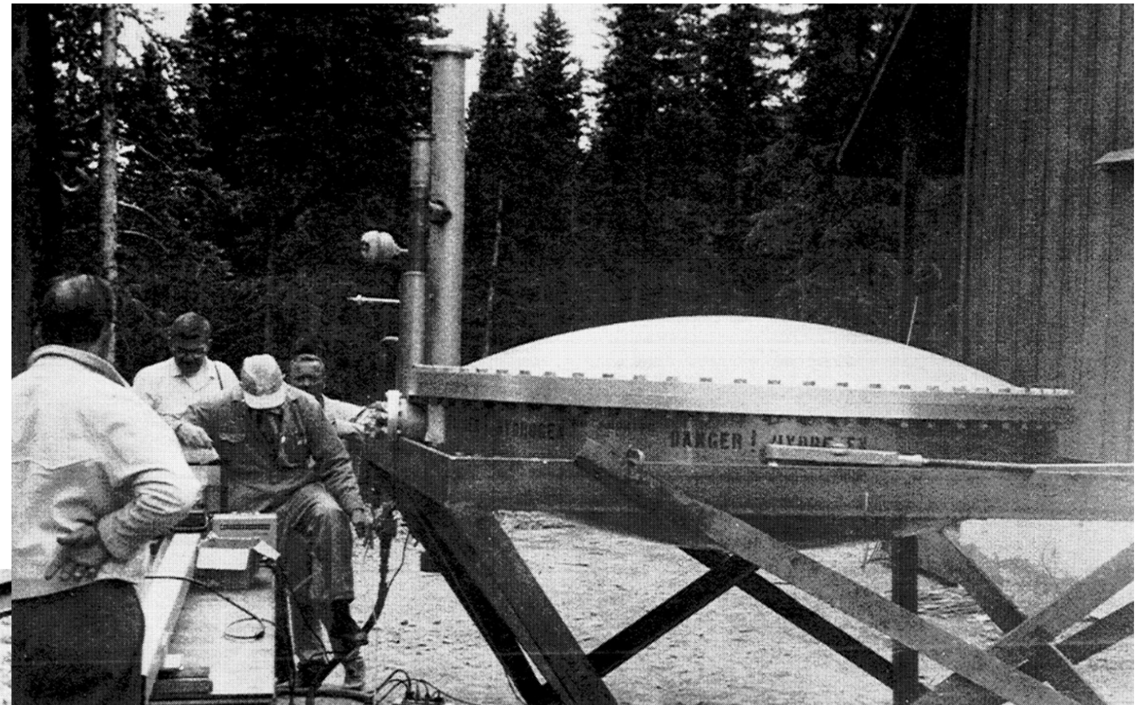
- LH2 topped off every 7~10 days (by Nitro drivers from Boulder)
- Wide-gap chambers: 2.0 m × 2.0 m, with two 20 cm gaps
  - Beautiful chambers made by Billy Loo at U. Michigan — excellent multi-track efficiency
- Narrow-gap chambers (E-M calorimeter): ten-layer spark chamber with 20 g-cm^2 Fe between gaps.
- Hadronic calorimeter: 10 layers of iron with graduated thickness from 40 ~ 160 g-cm^2, total 1130 g-cm^2, scintillators with 8 PMTs per layer
- Trigger = Top counter + sum of nine calorimeter layers (dynodes) + side counters in anticoincidence
  - Hadron trigger rate ~ 20/hr, with 90 GeV (nominal) threshold.
- Recorded summed anode signals for each of the 10 layers with 7 bit (127 channel!) logarithmic ADCs



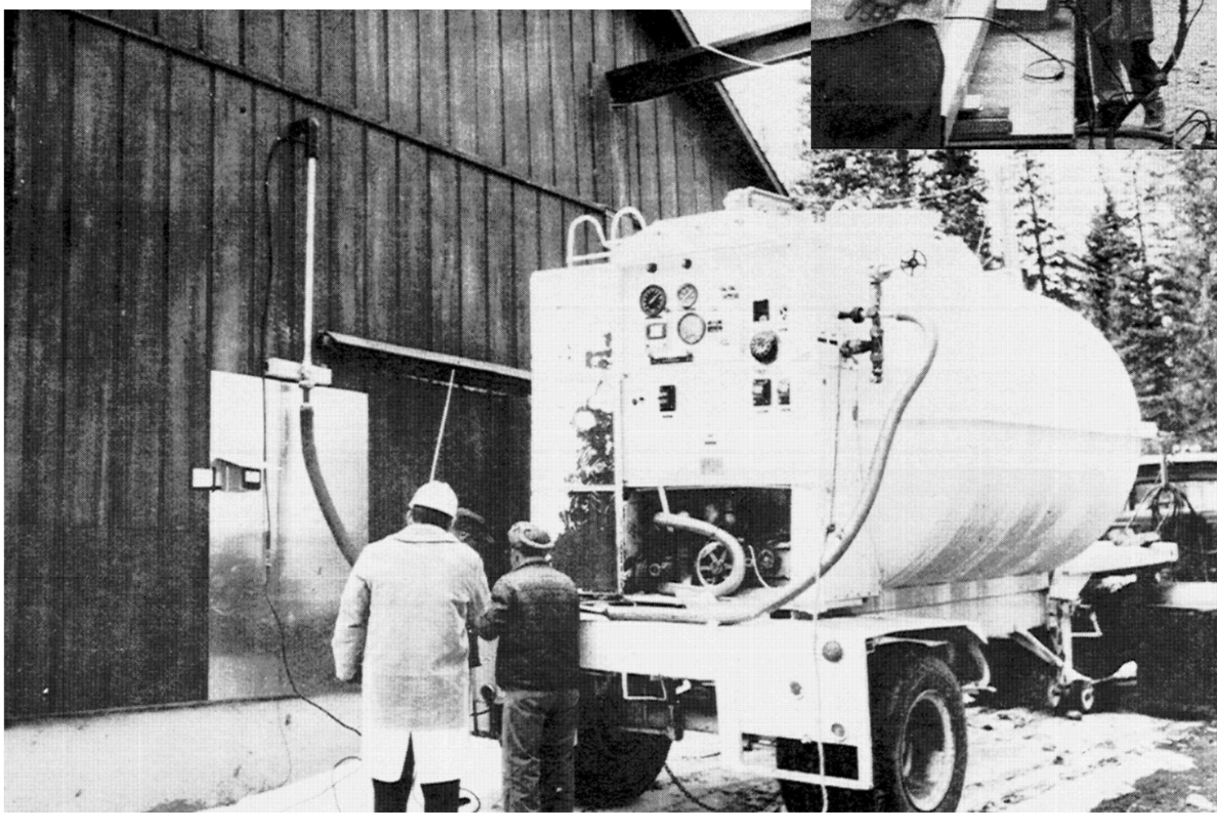
Hydrogen target

Fred Mills supervising...

Installation



LH2 truck filling target



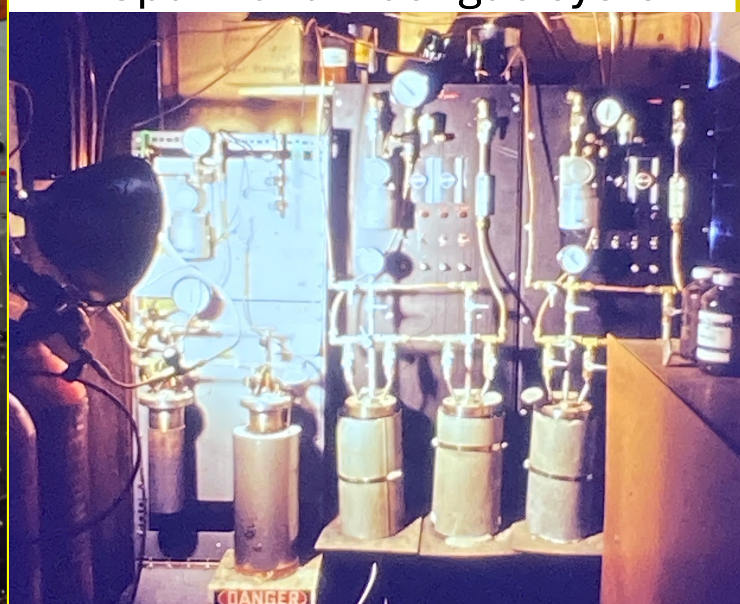
BW Photos from Larry Jones history of ELL

Lab building with electronics trailer in front

Wide-gap spark chambers

Electronics trailer interior

Spark chamber gas system



EM and hadronic calorimeters

Wide-gap spark chambers

"Typical" multiparticle production interaction in H target, seen in 90^{o} stereo

Narrow-gap iron plate spark chambers (E-M calorimeter)

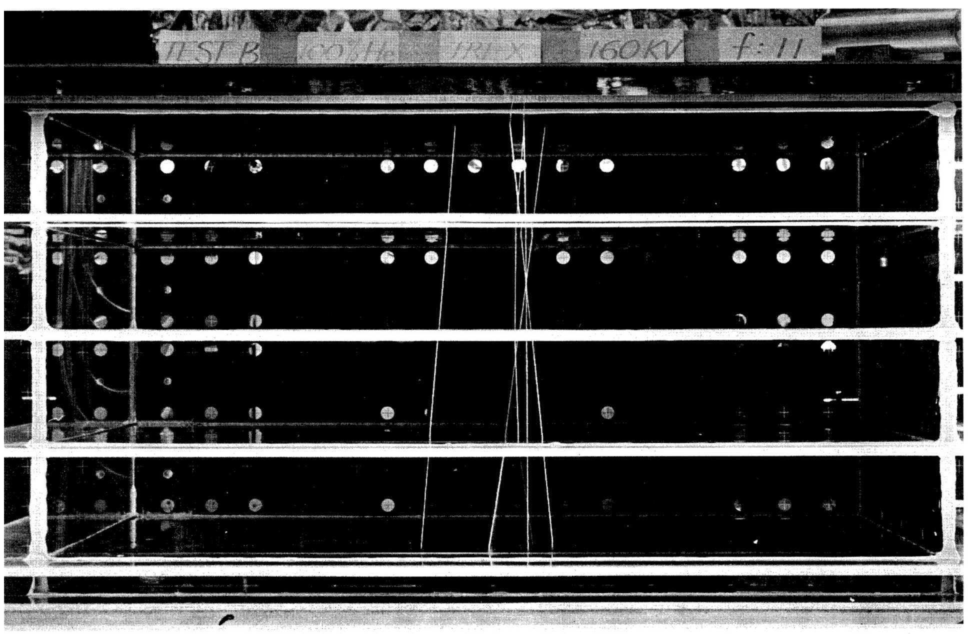
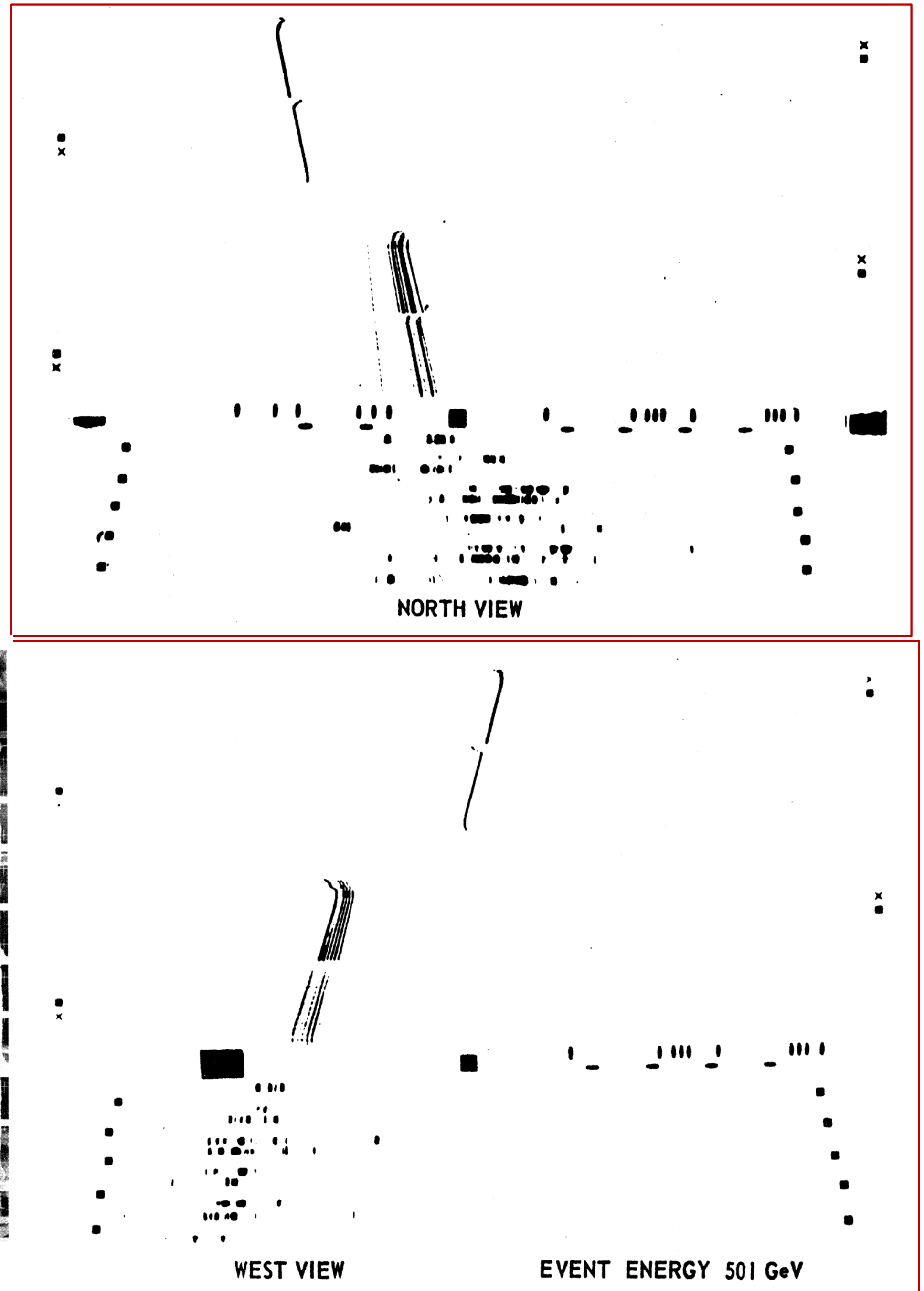


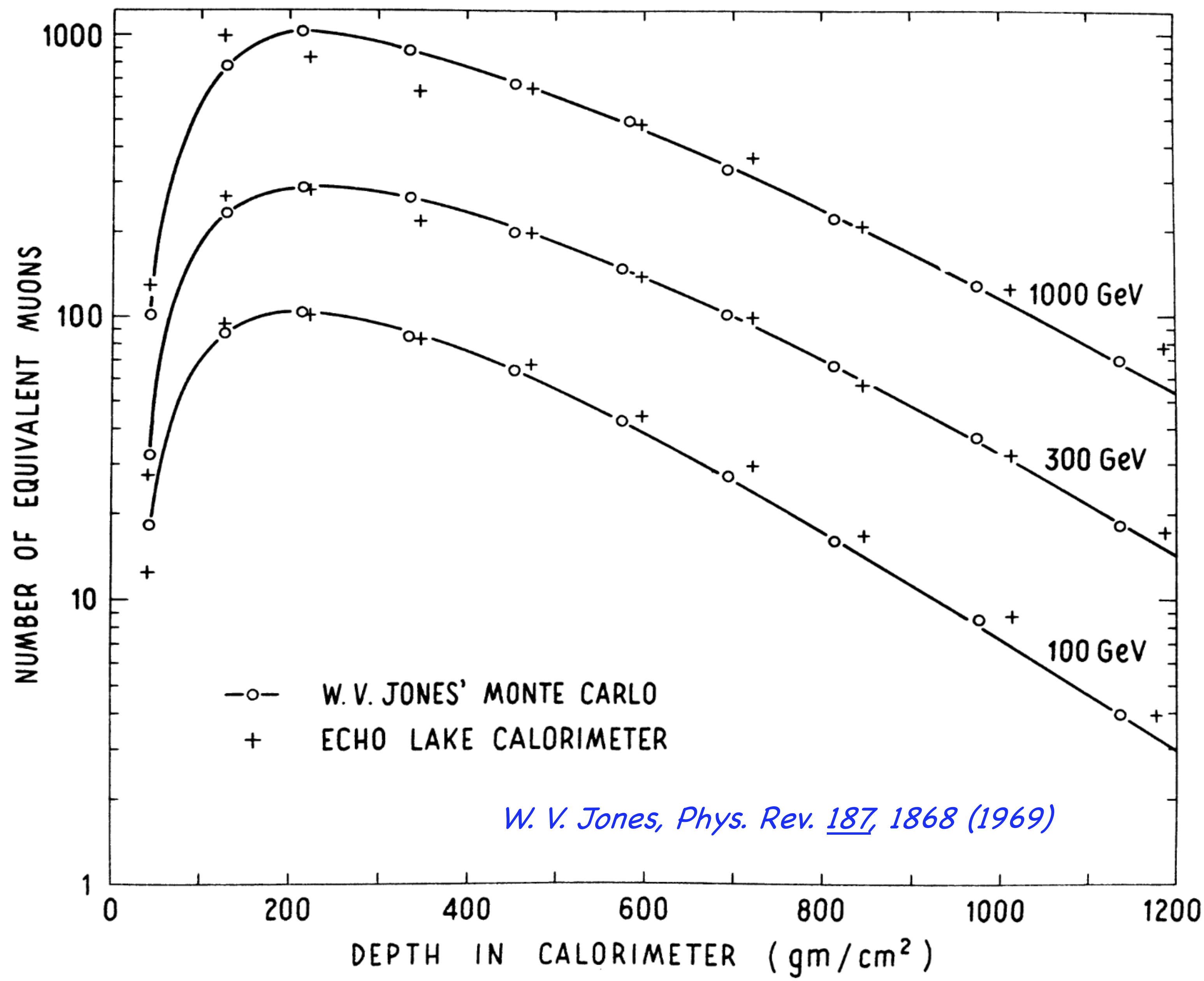
Fig.56 Spark Characteristics at 160 kV

from Billy Loo U.M. PhD thesis



from Gordon DeMeester U.M. PhD thesis

Calorimeter data for energy estimation



from Gordon DeMeester U.M. PhD thesis

Additional equipment needed (or just wanted)

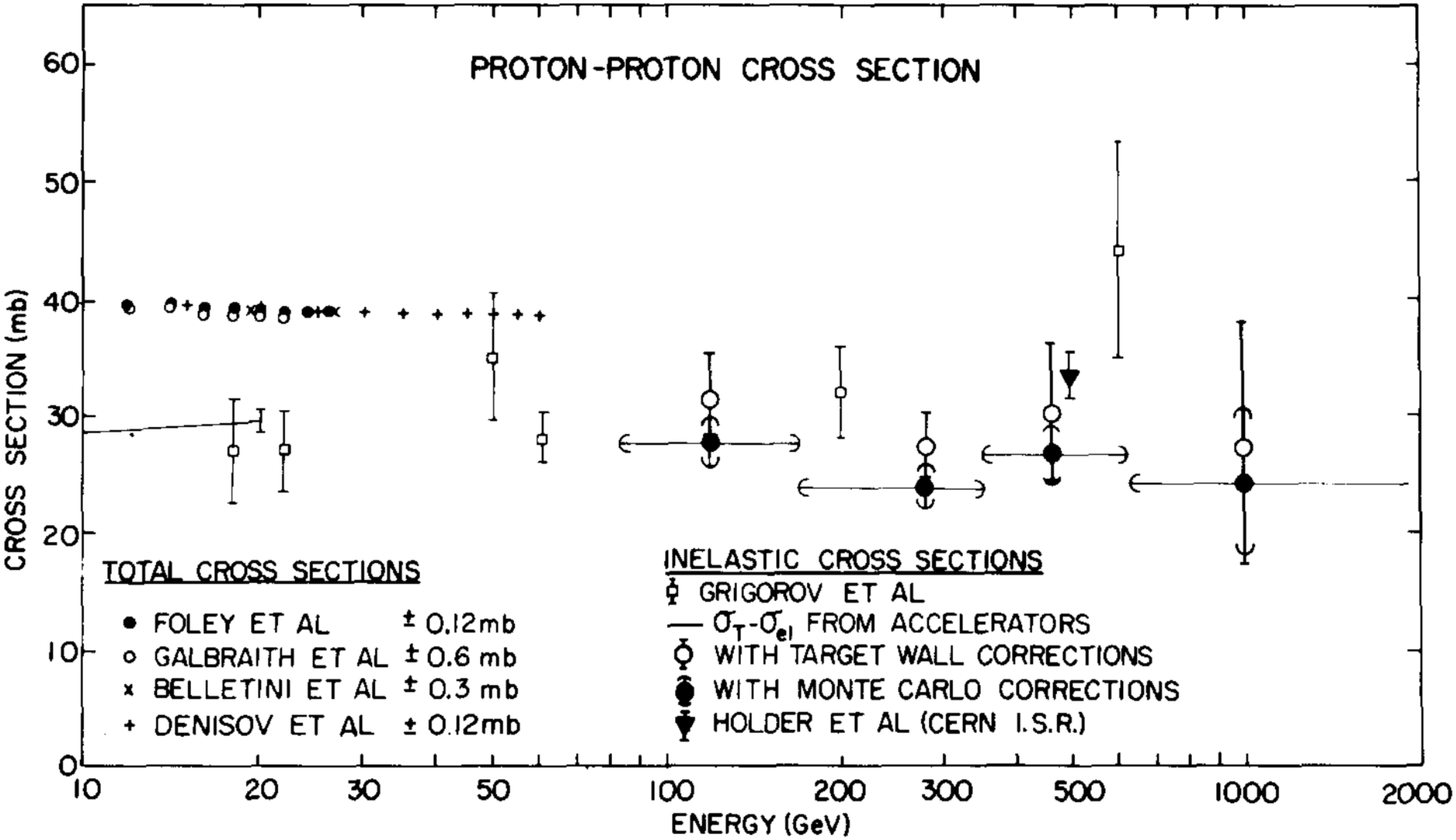
Backup generator – allowed 95% up-time, even when heavy snowfall brought down utility lines

Step 1: dig out of dorm and put on snowshoes to go start it

- JGL's hobby: scanning US government surplus lists for free goodies
- Project supported by AEC (remember that?), so we qualified for federal surplus...
- One great find: ex-Army "6x6" truck
  - Could go anywhere!
- After this photo, painted Michigan Maize & Blue by UM Motor Pool

Echo Lake: Results from hydrogen target runs

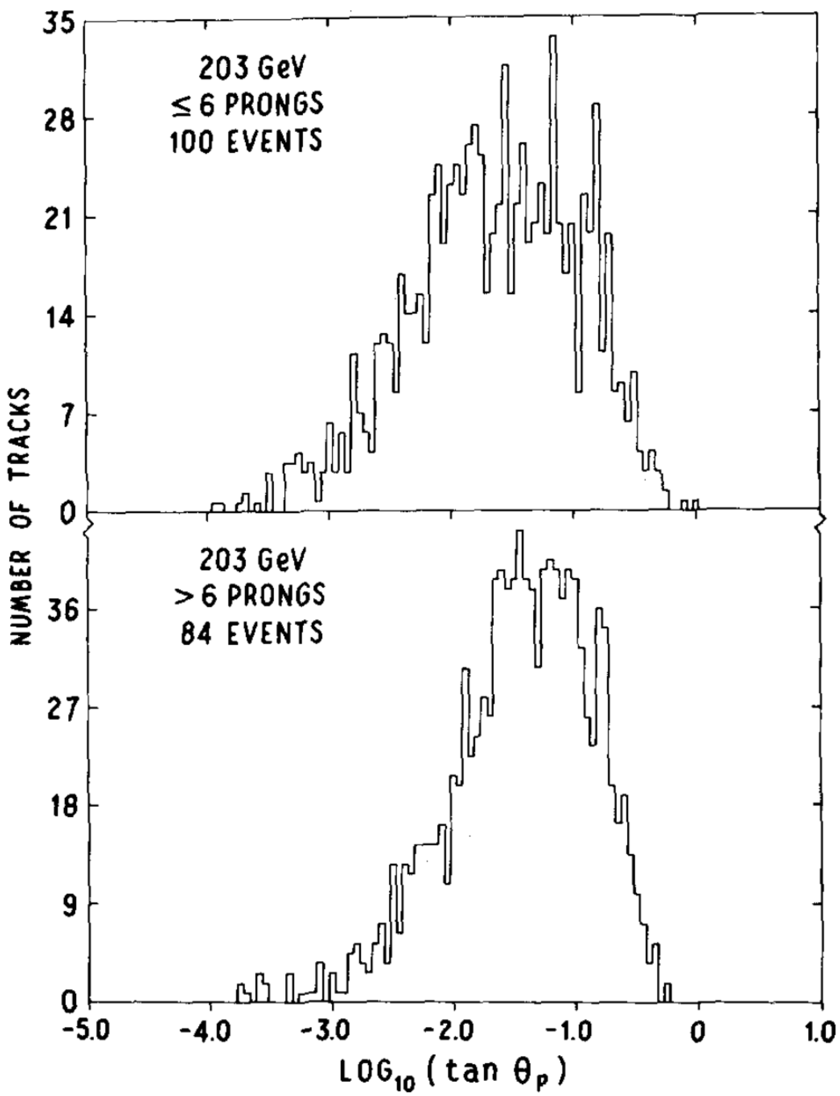
- p-p inelastic cross section 100 – 1000 GeV
  - Corrections from Vern Jones monte carlo *W. V. Jones, Phys. Rev. 187, 1868*



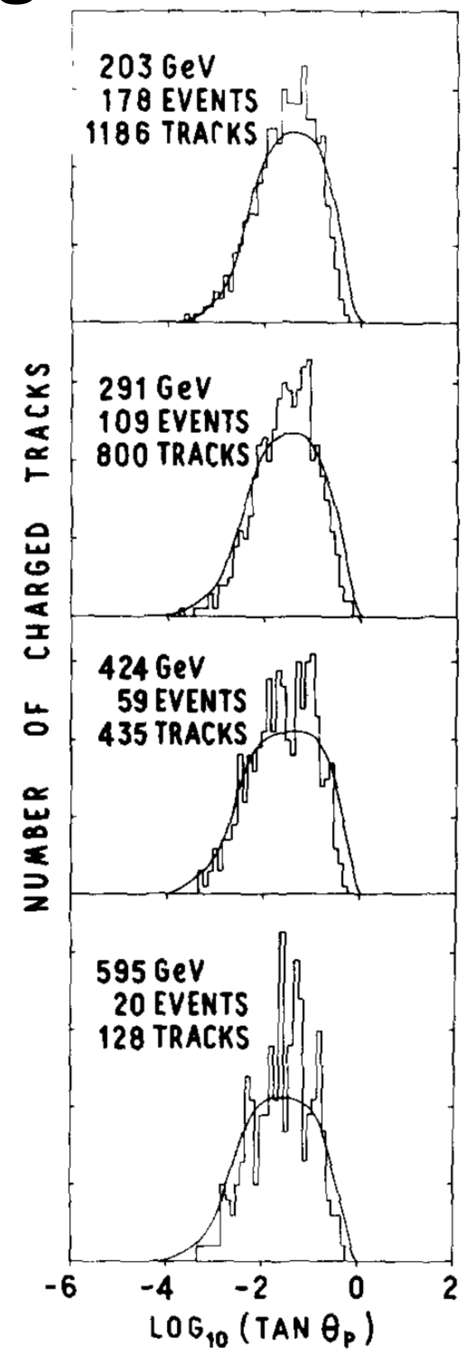
Echo Lake: Results from hydrogen target runs

- p-p angular distributions ($\log_{10} \tan \theta$)

For low and high multiplicity events @ 200 GeV

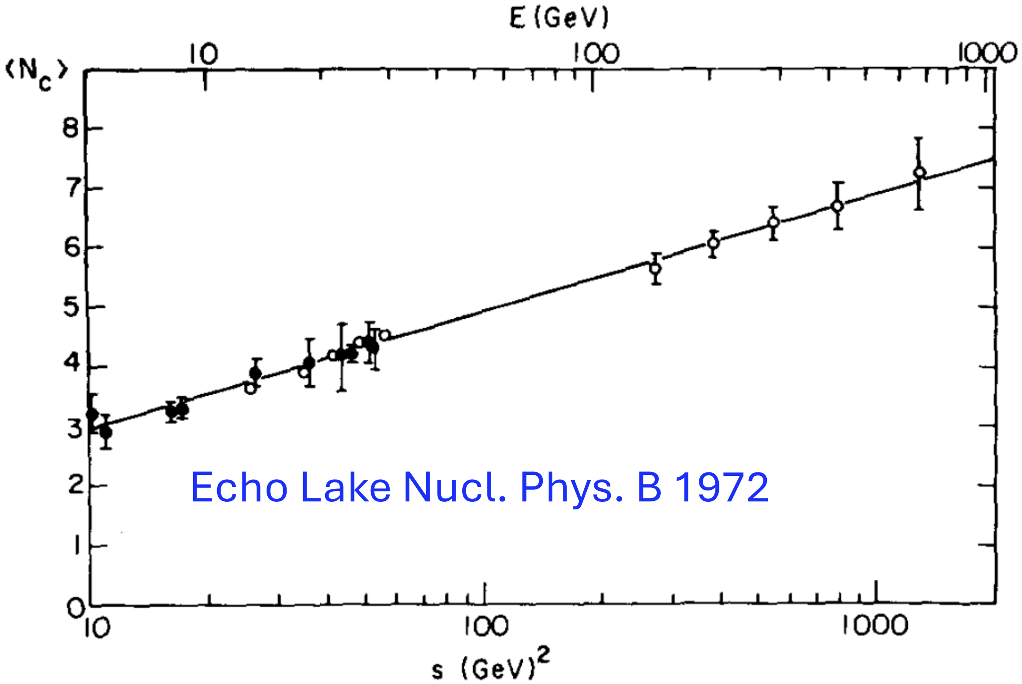


For all n >3 events vs energy



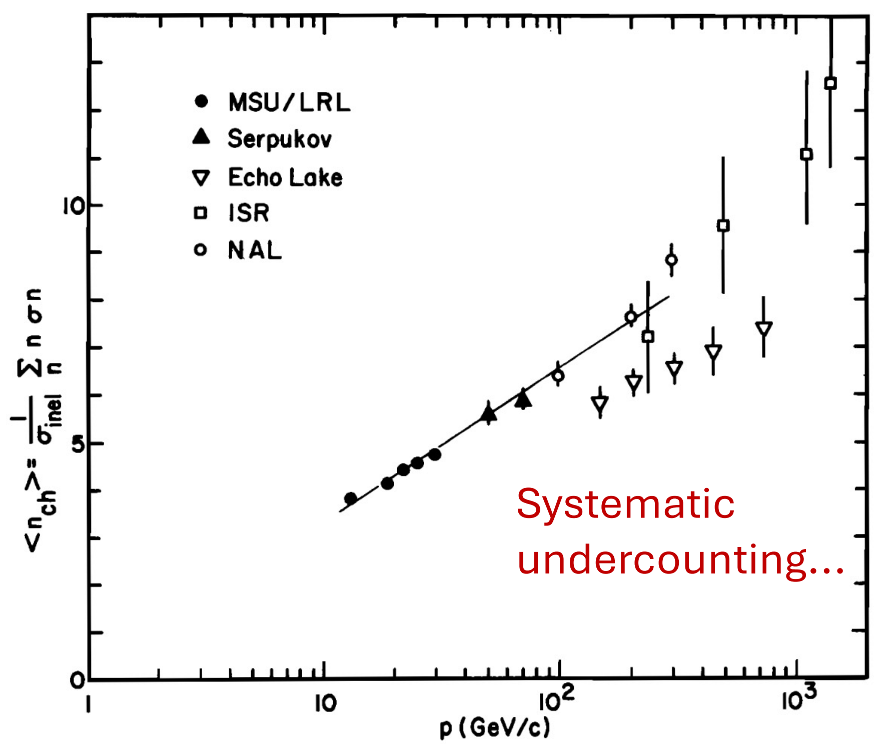
Echo Lake: Results from hydrogen target runs

- p-p inelastic average charged multiplicity $<n_{CH}>$



Echo Lake Nucl. Phys. B 1972

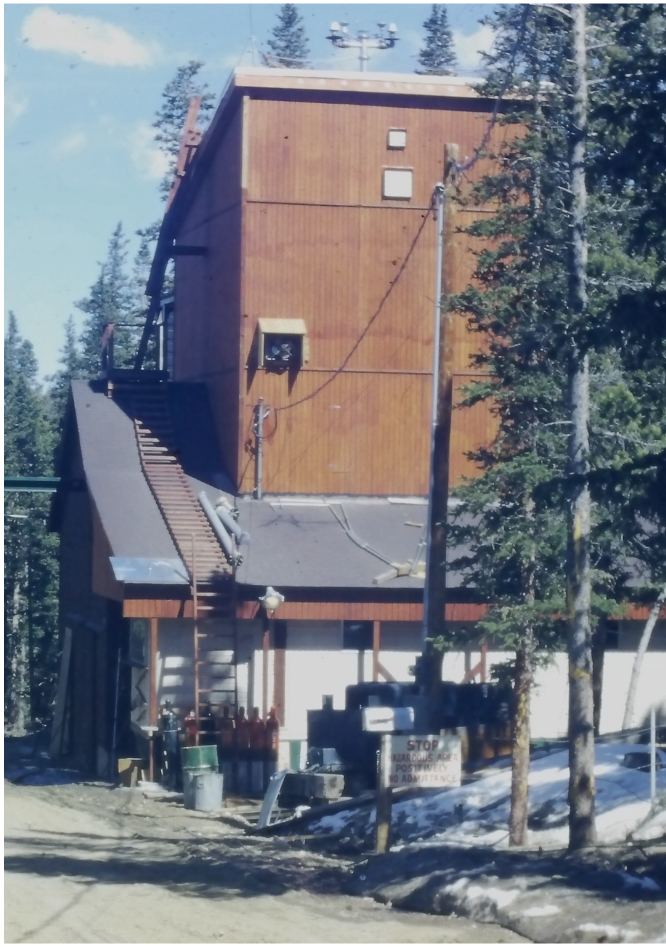
M. Jacob review, ICHEP 1972



Systematic undercounting...

The Alvarez Magnet adventure

- UCB Alvarez group built large-gap superconducting magnet, for emulsion balloon flights
  - High Altitude Particle Physics Experiment (**HAPPE**), 1 m bore,2m long, 1 T field
  - Crashed in attempted flight, abandoned for experiment with smaller SC magnet
- Available as surplus… put it above our target and we have a magnetic spectrometer! **But**
  - Nobody had made a helium liquefier work at such high altitude before
  - Magnet design focused on light weight…
  - Superconductor was 1960s alloy, none too stable

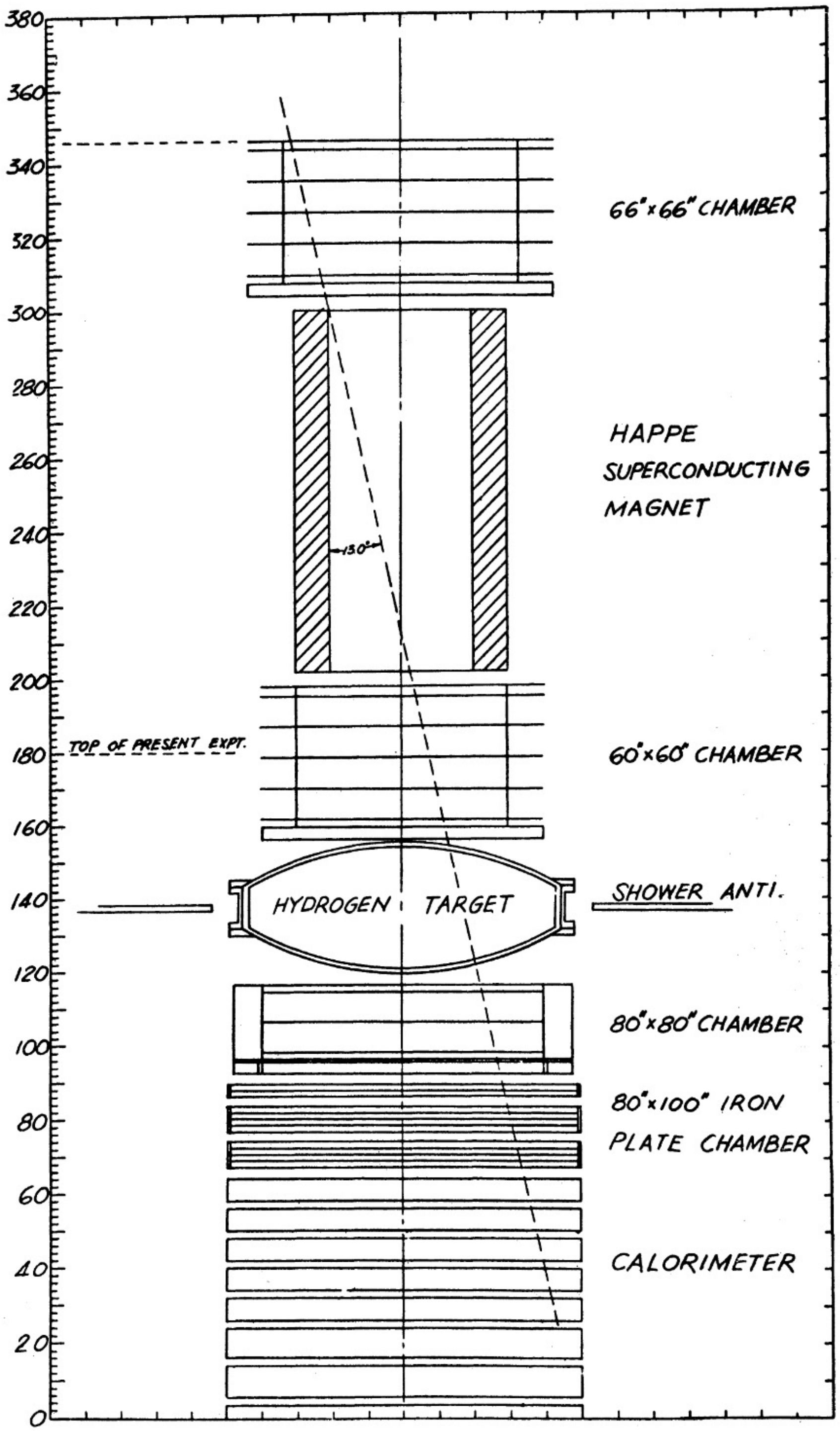


Lab building roof was raised

Magnet arrived

He liquefier shed

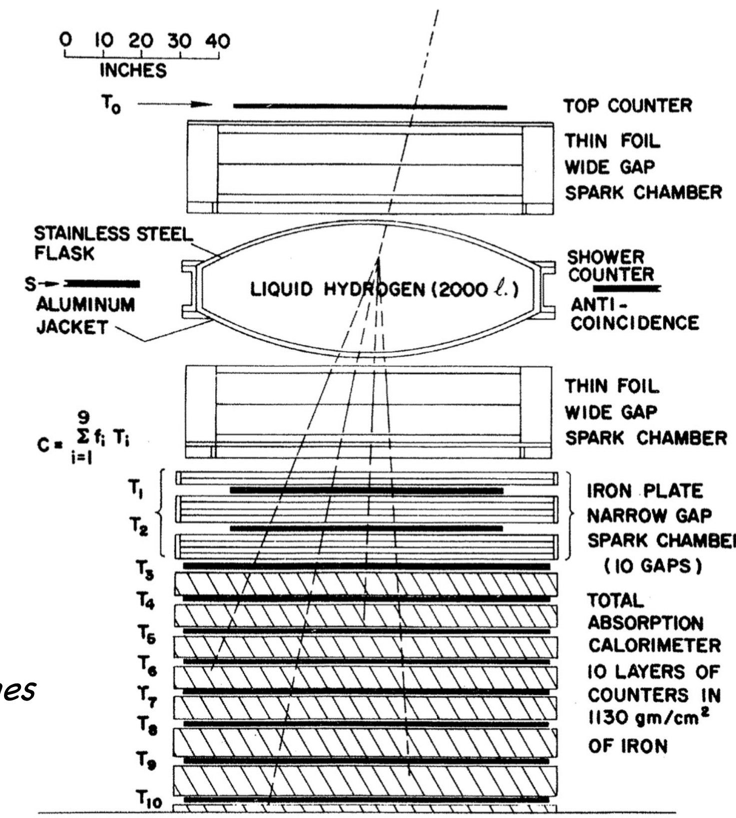
He gas tank looming in the background



Echo Lake: Superconducting magnetic spectrometer layout

- New, larger wide-gap spark chambers for tracking
- Air-core magnet! Significant B field outside magnet shell

from Larry Jones history of ELL



The first time I blew up an experiment with JGL

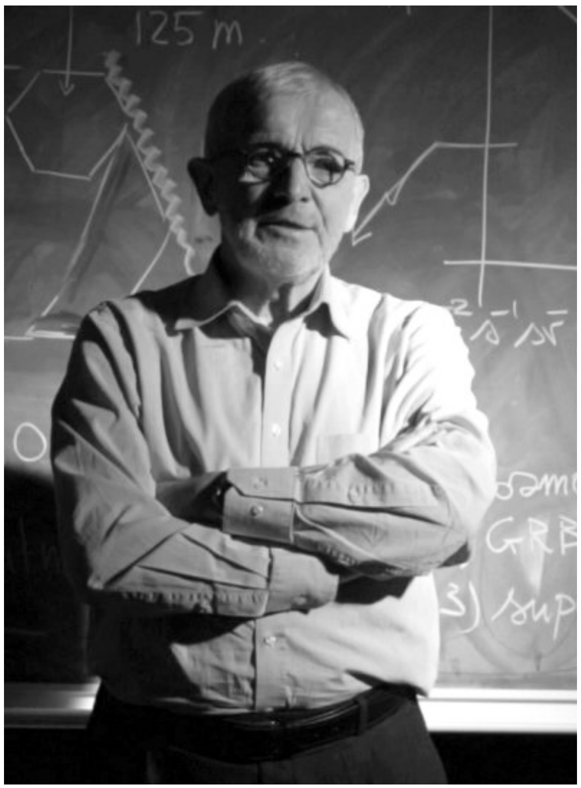
- Brilliant technician from CTI (refrigerator company) made his machine produce LHe, albeit slowly
- Intense effort recommissioned detector, put magnet system in place, and filled it with Lhe
  - Successfully charged magnet, mapped field, ran for a week
  - Magnet went normal, relief valve worked, no damage
- One snowy night on Mt Evans, we charged the magnet for data-taking successfully, then…
  - I dropped a large (non-ferrous) wrench, and a moment later the magnet went normal

    (John bugs me to this day…)
  - Relief valve failed, rupture disk failed, magnet's end cap blew off from sudden gas pressure
  - Lab filled with cold He vapor, superinsulation shreds, and fog
  - Team bailed from 2nd story – a technician followed me to the ladder but beat me to ground
  - JGL heroically kept his thumb on the "recover gas" button until his voice went Donald Duck, slid out roof door onto a snowbank

CTI 1400 helium refrigerator
(Not ours! Buy it on ebay for $3500)

After the Happe-ness

- Results from magnet installation
  - CON: Two extra years to get data for my thesis…
  - PRO: **Francis Halzen** joins UWis faculty – and my committee!



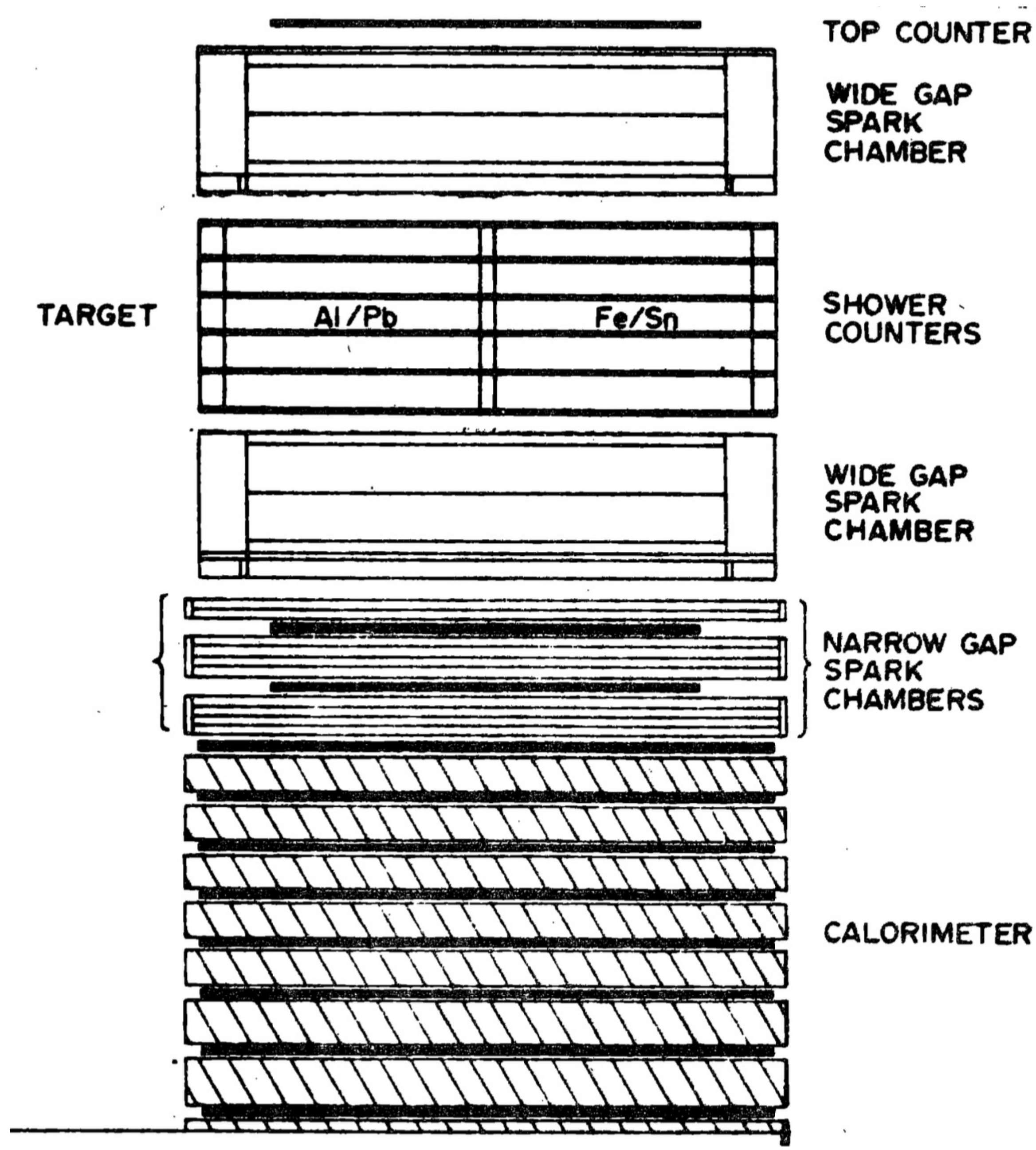
*The first paper I wrote on the subject was with **John Learned**, because he knew all the detection techniques, so in fact if you look at the ICE CUBE optical module it looks very much like one of DUMAND… Luckily I was quite naive and had not read all the books that I had to read before making the proposal. For example, should I have read the standard textbook of the time, called "The optics of water and ice", I would have never started the experiment… In fact, ever since I always advise, specially to High Schools and undergraduates, "don't read too many books, do things!"*

from
www.jotdown.es/2014/05/francis-halzen-i-always-advise-to-my-students-dont-read-too-many-books-do-things/

Echo Lake experiment, 1968-72

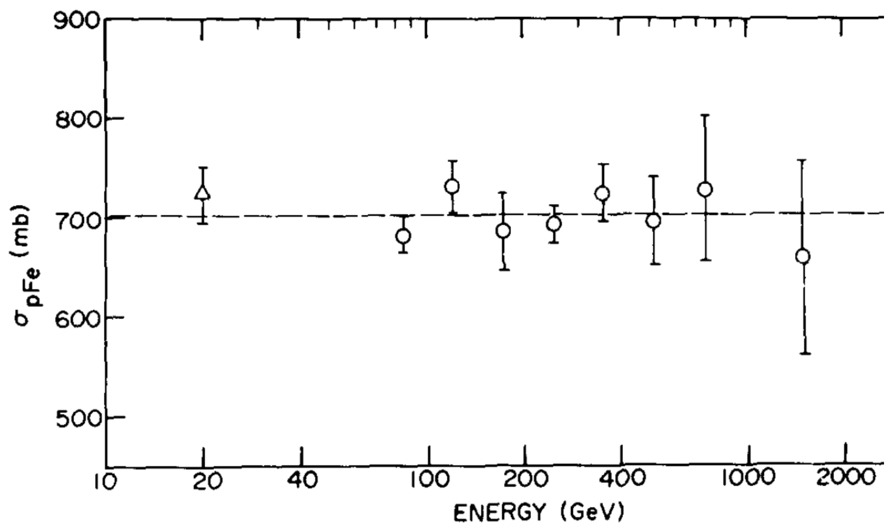
Metal plate targets: 1969 – 1970

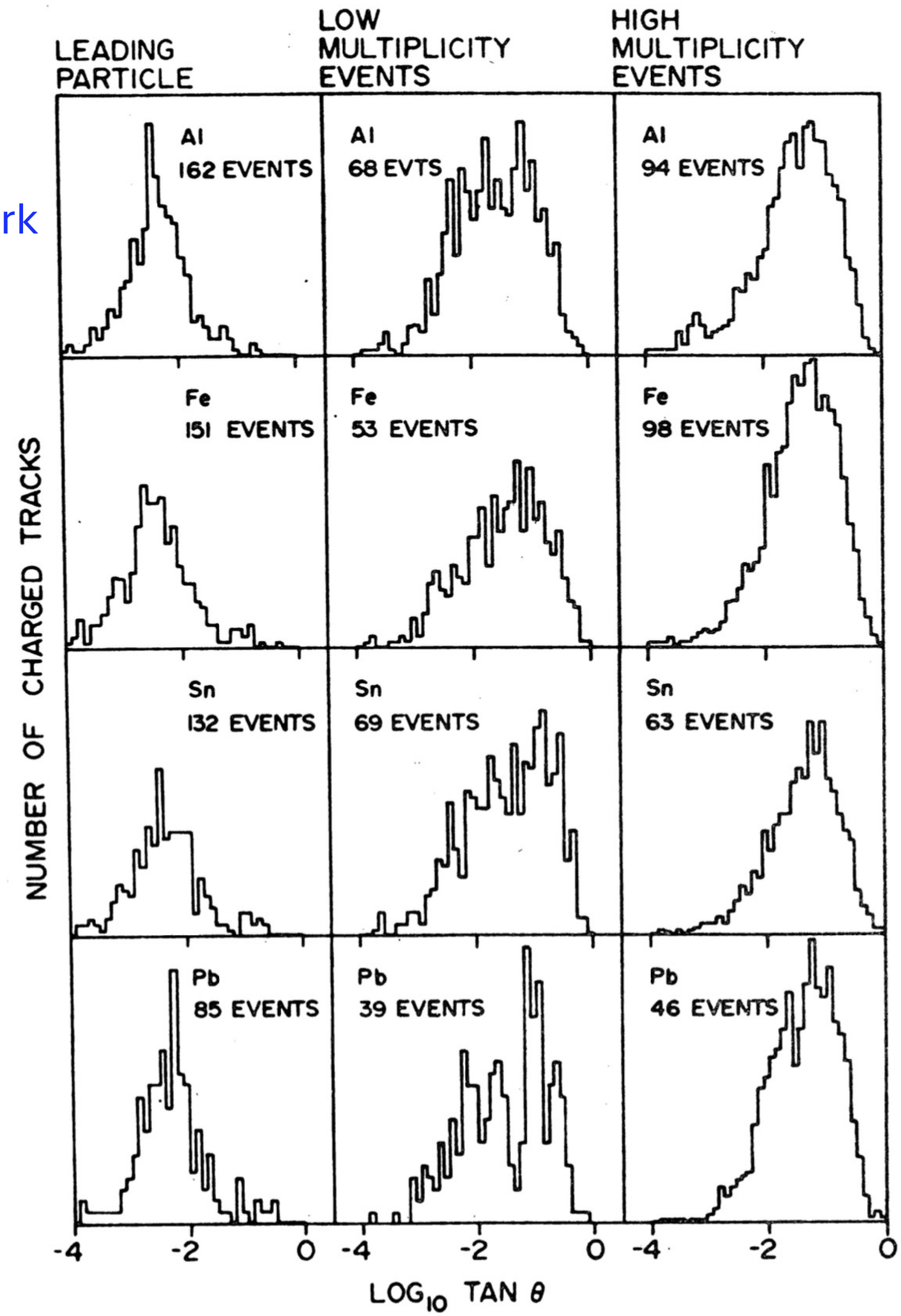
- Same basic configuration, with LH2 target replaced by sheets of various metals side-by-side, spaced 15 cm
    - Preliminary run with carbon slab
    - Run 1: Al and Fe
    - Run 2: Pb and SN
- Total target thickness ~0.2 λ_{mfp}
- Wide-gap chambers allowed reconstruction of event vertex accurate enough to identify which metal plate was target
- Provided thesis data for P.R. Vishwanath and J. Wilkes



Echo Lake: p-A data

p-Fe inelastic cross section vs E from interactions in Fe plate narrow-gap spark chambers, H target runs





$\eta' = \log_{10} \tan(\theta)$ plots for p-A data:

$\langle E \rangle$ = 200 GeV

"Leading particle" = most negative η' in each event

Low multiplicity = $n_{CH} \leq 6$

High multiplicity = $n_{CH} > 6$

Value of our metal-target results was recently cited

(Thanks to P.R. Vishwanath for pointing me to this recent paper)

"… It was in this context that pseudorapidity ***** , now ubiquitous in the field, was introduced as a variable of necessity.…A major advance in these studies was made by Jones and collaborators in a cosmic ray experiment at Echo Lake which solved one of the problems, resolving for each collision the nature of the target **[16]**…"

From The Early History of the Quark-Gluon Plasma, W. Busza and W.A. Zajc, *Contribution to "Quark Gluon Plasma at Fifty - A Commemorative Journey", Springer Nature Switzerland AG, Eds: Tapan Nayak, et al,* arXiv:2504.08720 [nucl-th]

[16] *P. R. Vishwanath, A. E. Bussian, L. W. Jones, D. E. Lyon, Jr., J. G. Learned, D. D. Reeder, and R. J. Wilkes, Cosmic Ray Results on the A-Dependence of Multiplicity and Angular Distributions in Proton Nuclear Interactions Above 100-GeV, Phys. Lett. B 53 (1975) 479–483.*

* Initially we used $\eta' = \log_{10} \tan(\theta)$, familiar from emulsion experiments; later $\eta = \ln \tan(\theta/2)$

…and then we did DUMAND

Loyal UWa tribe delivering traditional Spam® tribute to our Chief

UWa team led by our late dear friend and colleague Ken Young (joined UW HEP faculty and met JGL in 1966)

Thanks for the ride, John!

- JGL taught me every practical thing I know about doing physics
- Taught me to choose what's interesting, potentially very important, and **fun** – instead of what's safe
- All the best for this year, and let's do this again when your odometer rolls over in 5 years…

- And thanks to Jelena and friends for organizing this wonderful event and letting me babble !