The 20th Century, good for Particle Physics (and physics). Some key (approximate) dates:

1895 Discovery of electron. Thompson.
1904 Photon is also a particle. Einstein.
1905 Special Relativity. Einstein.
1906 Atomic Nucleus. Rutherford.
1914 General Relativity. Einstein.
1925--Quantum Theory. Heisenberg,Schrödinger,Dirak.
1930 Neutrino conjectured. Pauli.
1931 Neutron. Chadwick.
1932 Antiparticle (positron). Anderson (cloud chamber).
1937 Mesotron (Muon). Anderson (cloud chamber).
1947 Pion. Powell.
1947 "Strange" particles. Rochester, Butler (Blackett).
1949–'54 Properties of pion.
1953 Particle resonances. Fermi et al.
1954--64 Properties of strange particles.
1957 Parity violation. C.S. Wu et al.
1964 CP violation. Cronin, Fitch et al.
1969 Nucleons not elementary, composed of "partons".
1970 Unification of EM and weak interactions. Electro-weak gauge theory.
1973 "Charm" flavour.
1973 QCD gauge theory of Strong interaction. Quarks.
1973 Neutral current discovery (CERN, Gargamelle) establishes E-W theory.
1983 W and Z heavy intermed. Bosons, Rubbia, Van der Meer et al, CERN.
1989 Three "families" of fermions. CERN, LEP.

Cosmic Rays — Geiger Counters

On the Disintegration of Negative Mesons

M. Conversi, E. Pancini, and O. Piccioni*

Centro di Fisica Nucleare del C. N. R. Istituto di Fisica dell'Università di Roma, Italia

December 21, 1946

NUMBER 3 FEBRUARY 1, 1947

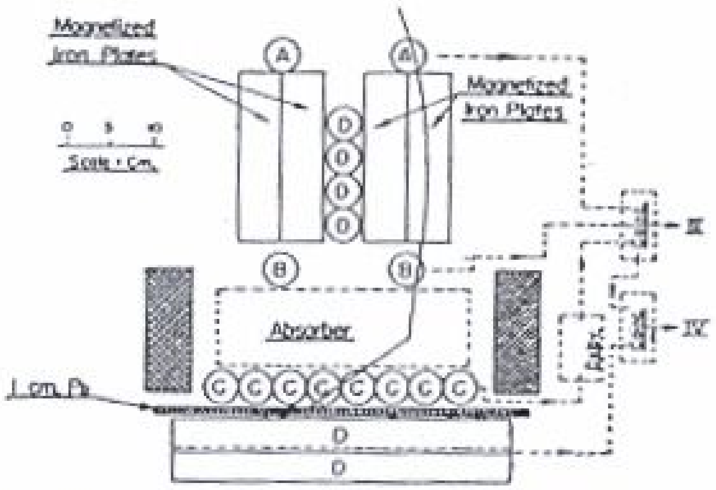


Fig. 1. Disposition of counters, absorber, and magnetized iron plates. All counters "D" are connected in parallel.

Table I. Results of measurements on β-decay rates for positive and negative mesons.

Sign	Absorber	III	IV	Hours	M/100 hours
(a) +	5 cm Fe	213	106	155.00′	67 ±6.5
(b) −	5 cm Fe	172	158	206.00′	3
(c) −	none	71	69	107.45′	−1
(d) +	4 cm C	170	101	179.20′	36 ±4.5
(e) −	4 cm C+5 cm Fe	218	146	243.00′	27 ±3.5
(f) −	6.2 cm Fe	128	120	240.00′	0

Conclusion: nuclear interaction of "mesotrons" is too weak to produce Yukawa forces

("meso-tron" now called muon)

E. Fermi (1948)

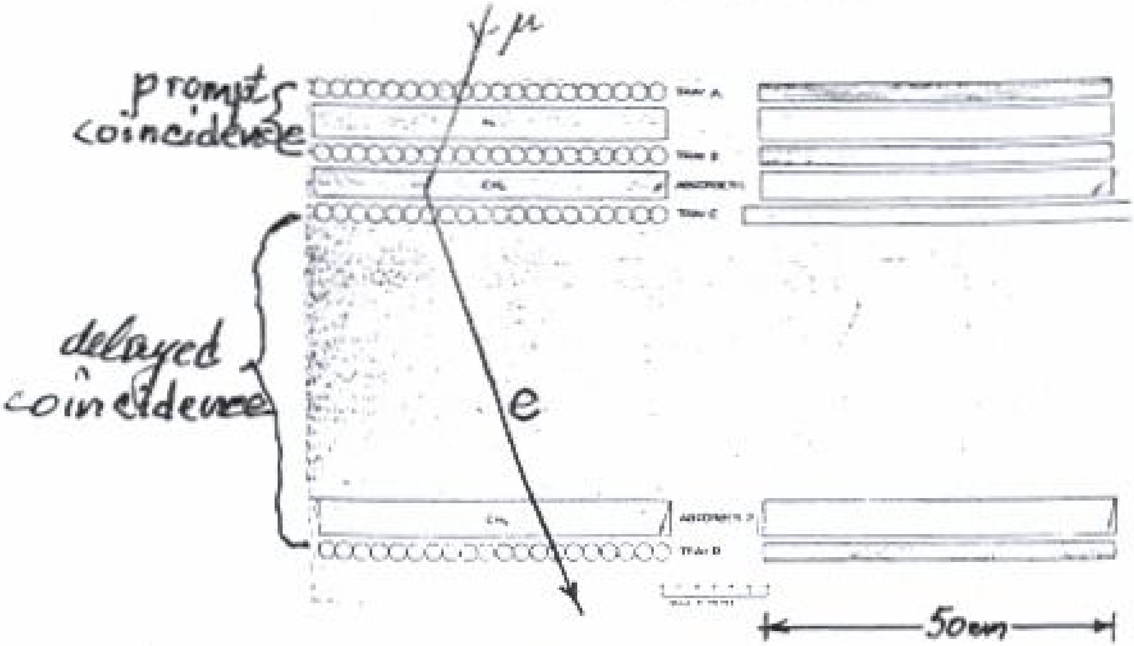
Varenna 1954

On the Range of the Electrons in Meson Decay

cosmic rays
my thesis

J. Steinberger*
The Institute for Nuclear Study, University of Chicago, Chicago, Illinois

(Received January 10, 1949)



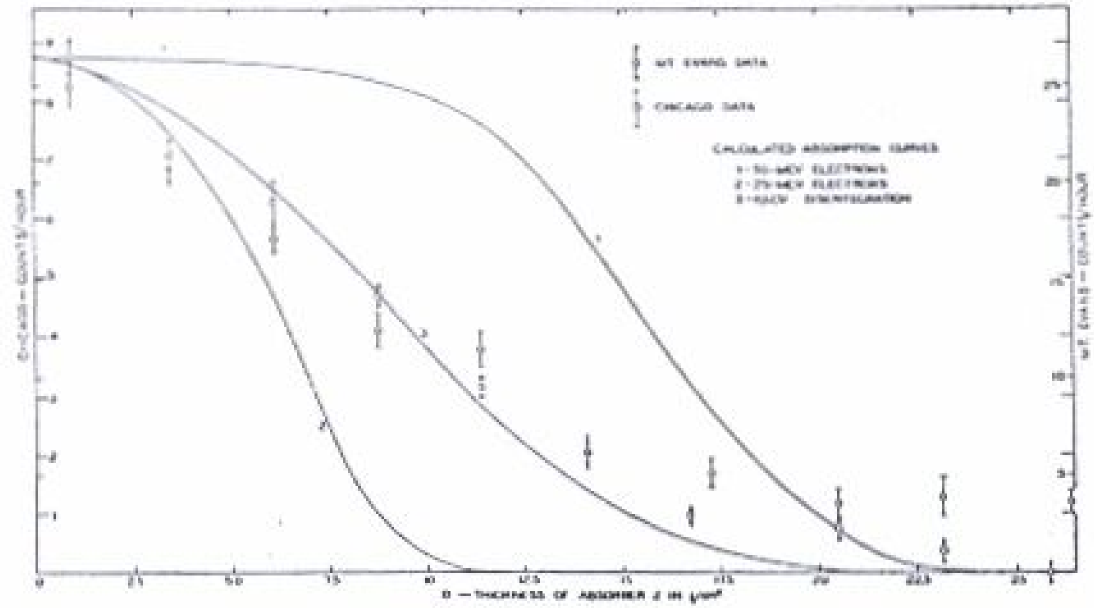


Fig. 8. The experimental points represent the data obtained in Chicago and on Mt. Evans. The indicated error is the standard deviation. The full curves 1 and 2 represent the calculated absorption curves for 50 and 25 Mev, respectively. Curve 3 is the absorption curve calculated for electrons emitted in a continuous spectrum. The spectrum is calculated from Eq. (2), taking $\mu c^2 = 100$ Mev.

Result:
μ decays into
3 particles
$\mu^+ \to e^+ + \nu + \bar{\nu}$

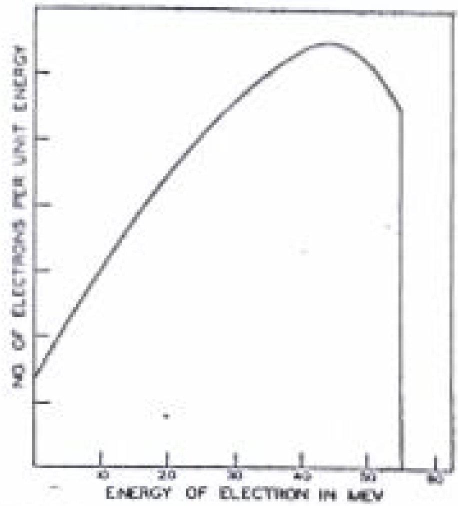
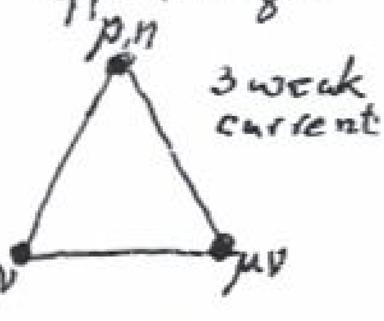


Fig. 9. The decay electron spectrum in this figure has be[en] calculated to give as good a fit as possible with the data, [at] the same time excluding energies greater than 55 Mev. T[he] limits of error of this spectrum are unknown, but large.

Puppi triangle



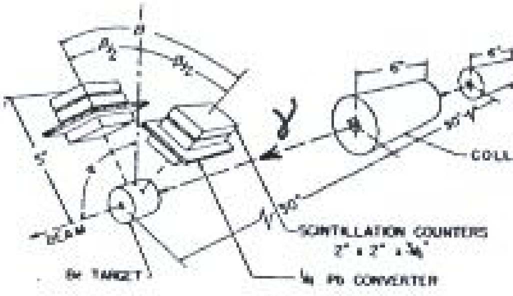
universality
of Fermi interaction

PHYSICAL REVIEW VOLUME 78, NUMBER 6 JUNE 15, 1950

Evidence for the Production of Neutral Mesons by Photons*

J. STEINBERGER, W. K. H. PANOFSKY, AND J. STELLER
Radiation Laboratory, Department of Physics, University of California, Berkeley, California

(Received April 28, 1950)



$\gamma\,(<.3\,\text{GeV}) + Be \rightarrow \pi^0 + \text{hadrons}$

$\pi^0 \xrightarrow[\sim 10^{-15}\,\text{sec}]{} \gamma + \gamma$

$m_{\pi^0} \simeq .14\,\text{GeV}; \quad E_\gamma \simeq .07\,\text{GeV}$

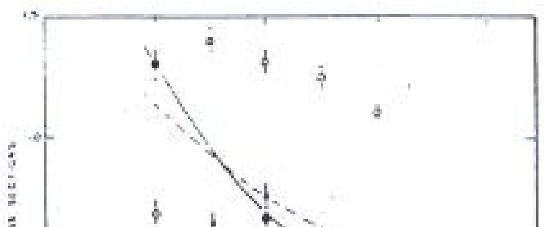
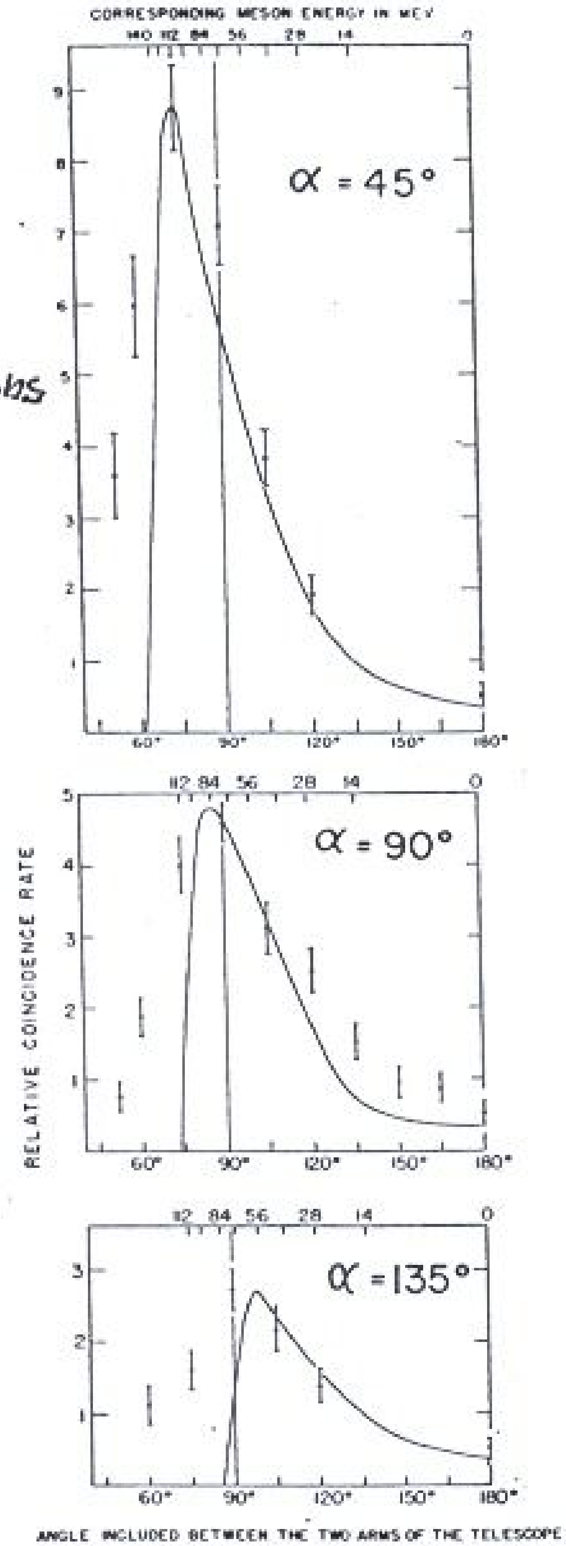
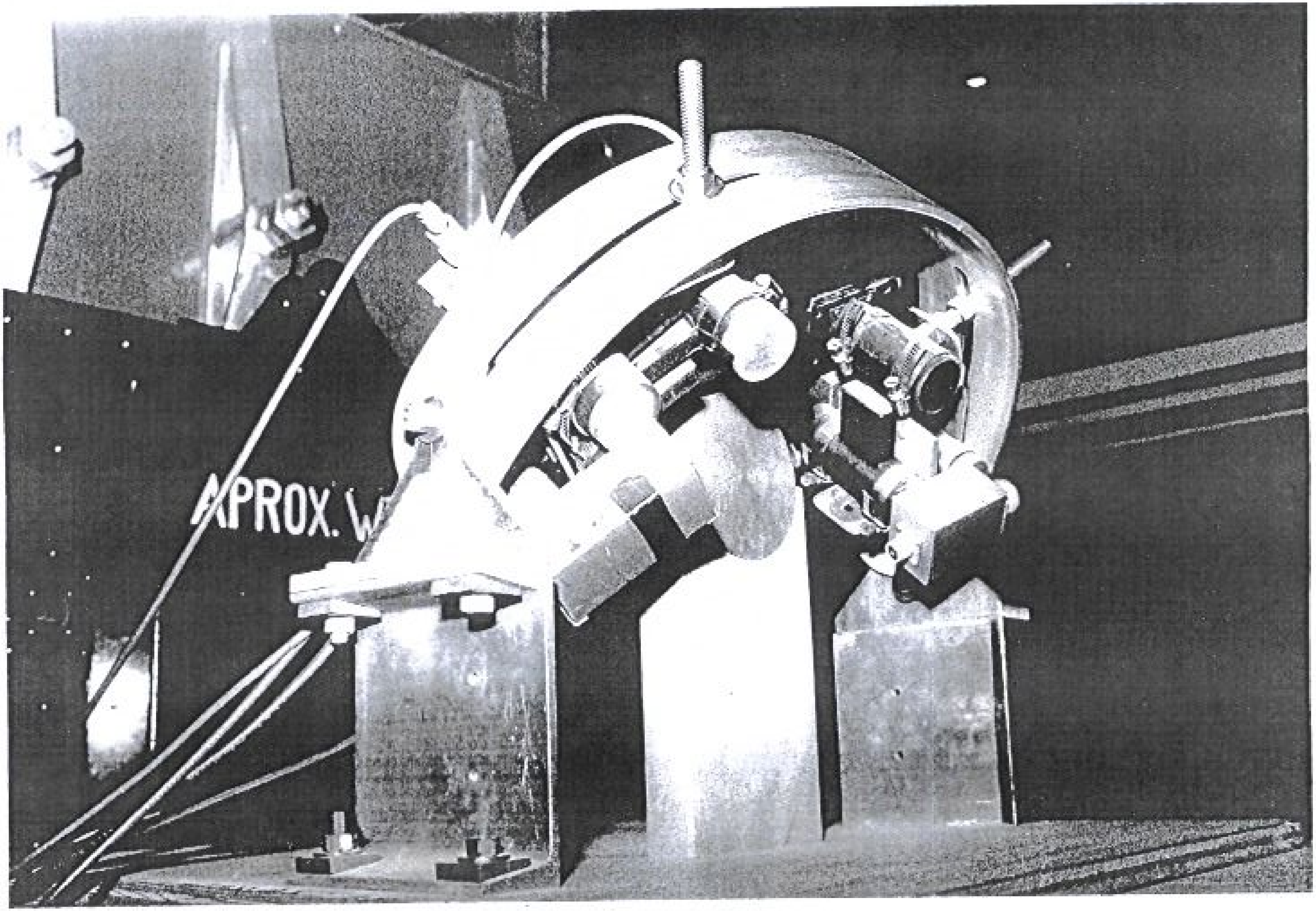
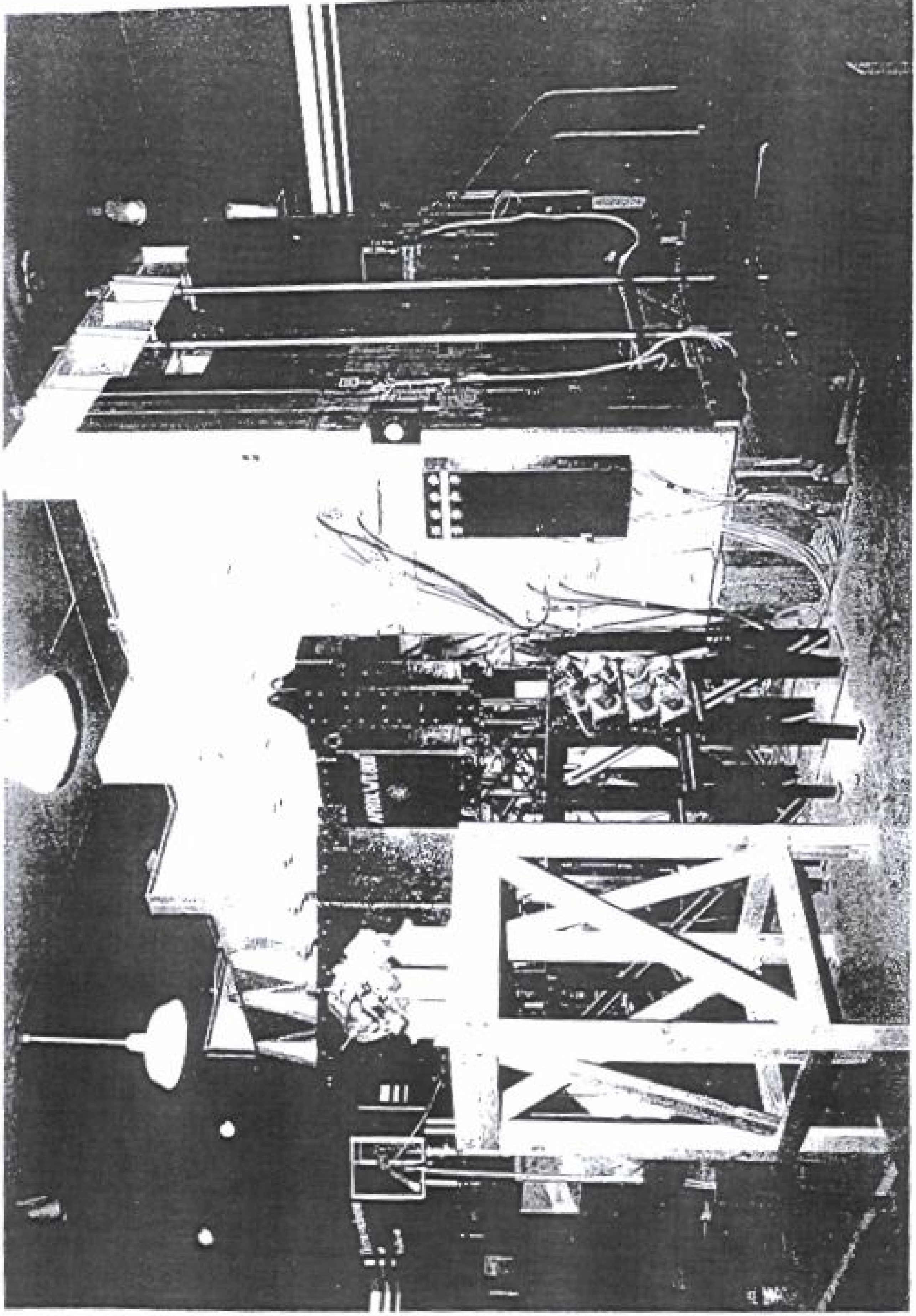


FIG. 4. Variation with the angle α between the plane of the telescope and the beam. Each point represents an integral over the angle β.



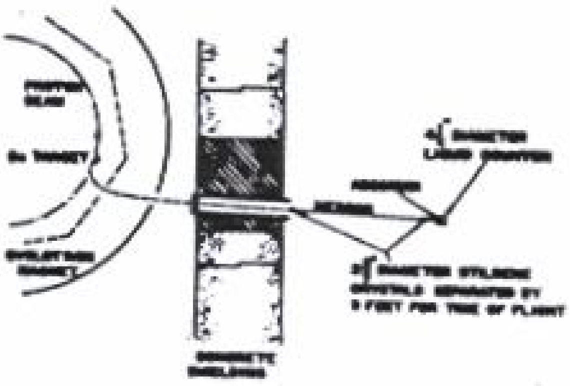

APPROX.



Columbia 1951. 380 MeV Cyclotron.
1st experiments on nuclear crossections of pions.

Total Cross Sections of π-Mesons on Protons and Several Other Nuclei*

C. Chedester, P. Isaacs, A. Sachs, and J. Steinberger
Columbia University, New York, New York
(Received April 30, 1951)



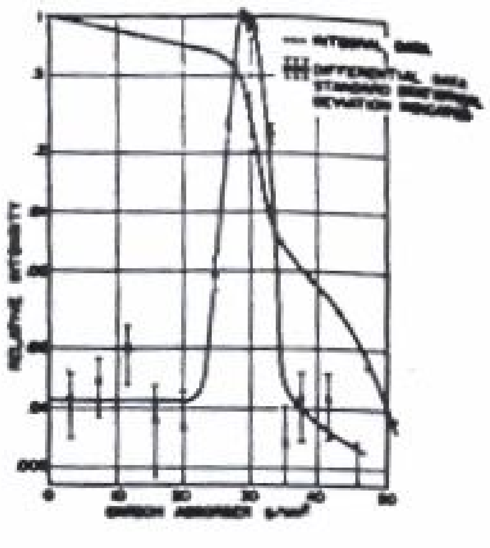


TABLE I. Total cross sections of various nuclei for 85-Mev π⁻ mesons.

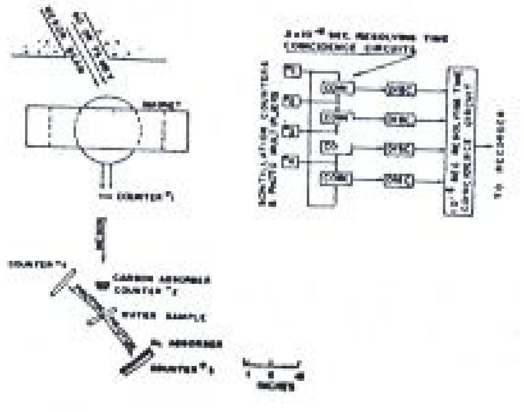
Nucleus	Mean free path g/cm²	Cross section in cm²	Nuclear area $\pi A^{2/3}(\frac{h}{\mu c})^2$ cm²
H	125 ± 10	1.33 ± 0.11 × 10⁻²⁶	6.1 × 10⁻²⁶
Li	60 ± 2	24.2 ± 1	22.6
Be	39 ± 4	25.5 ± 2	26.5
C	38 ± 2	34.6 ± 1.3	31.9
O	57 ± 2	46.6 ± 1.6	35.9
Al	72 ± 3	62.8 ± 2.5	38.1
Cu	106 ± 3	99 ± 3	90
Sn	117 ± 3	130 ± 7	142
Pb	142 ± 6	240 ± 11	216

PHYSICAL REVIEW VOLUME 83, NUMBER 3

The Spin of the Pion via the Reaction $\pi^+ + d \rightleftharpoons p + p$

R. Durbin, H. Loar, and J. Steinberger
*Columbia University, New York, New York**

(Received June 21, 1951)



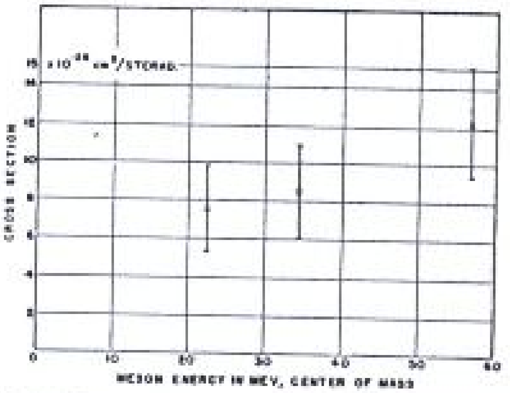


Fig. 3. Differential cross section for the emission of a proton at 45° (and one at 135°) to the meson beam in the c.m. system.

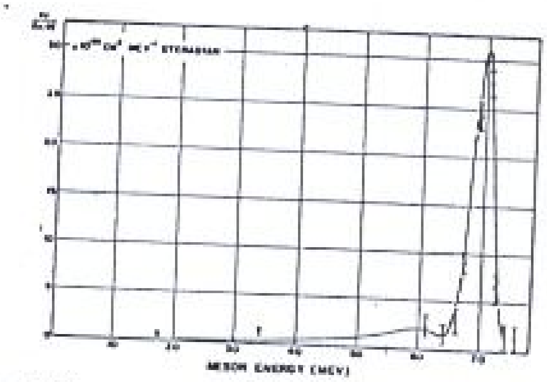


Fig. 5. The spectrum of mesons produced in the collision of 340 Mev protons in the forward direction. This experiment has been performed by Cartwright, Richman, Whitehead, and Wilcox (see reference 5).

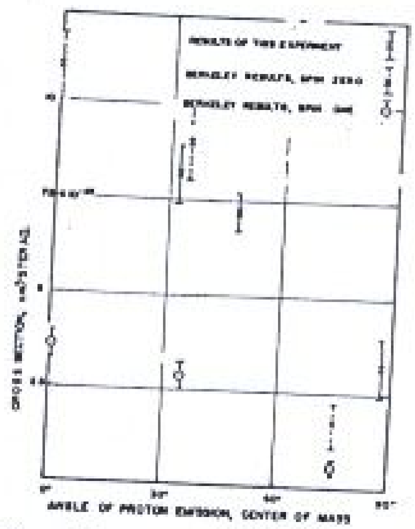
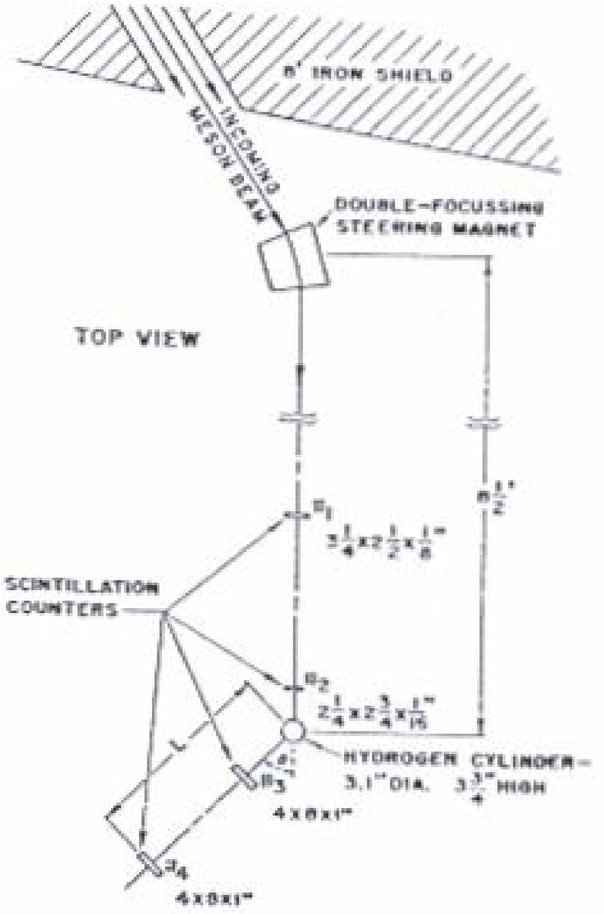


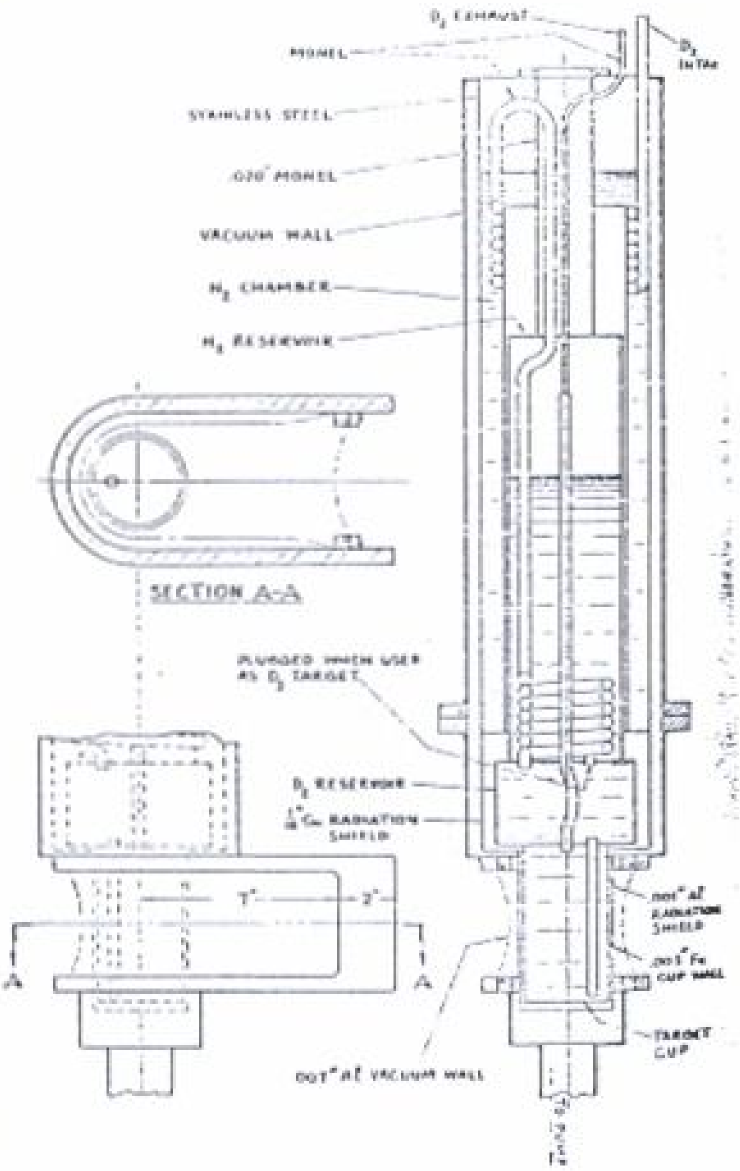
Fig. 4. Differential cross section of the reaction $\pi^+ + d \rightarrow p + p$ at three angles of emission of the proton in the c.m. system. The average meson energy is 28 Mev in the c.m. system. The dotted points show the cross sections expected for spin one and spin zero pions on the basis of the Berkeley results (see reference 5).

Phase-Shift Analysis of the Scattering of Positive Mesons at 58 Mev*

Columbia 390 Mev cyclotron

D. Bodansky, A. M. Sachs, and J. Steinberger
Columbia University, New York, New York
(Received March 26, 1953)





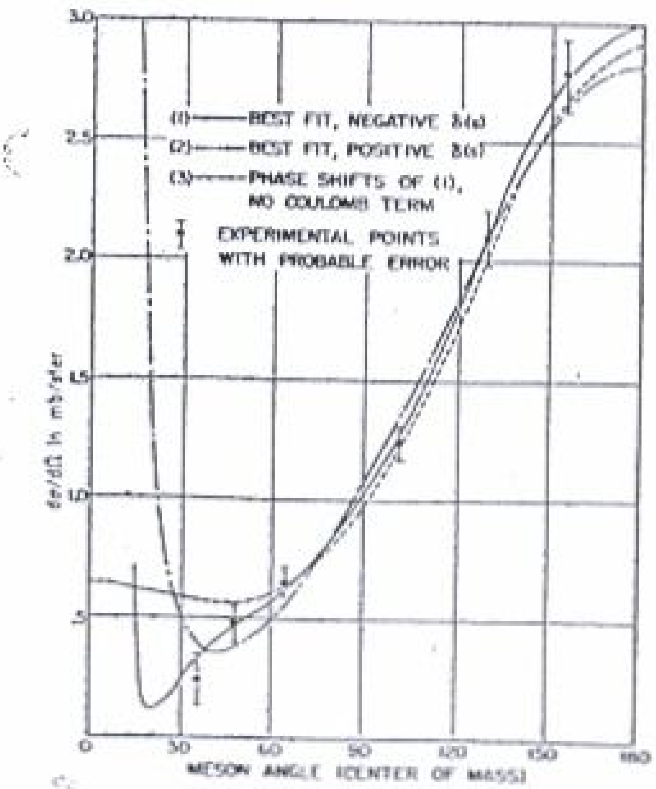


Fig. 1. Differential cross section for 58-Mev π^+-p scattering.

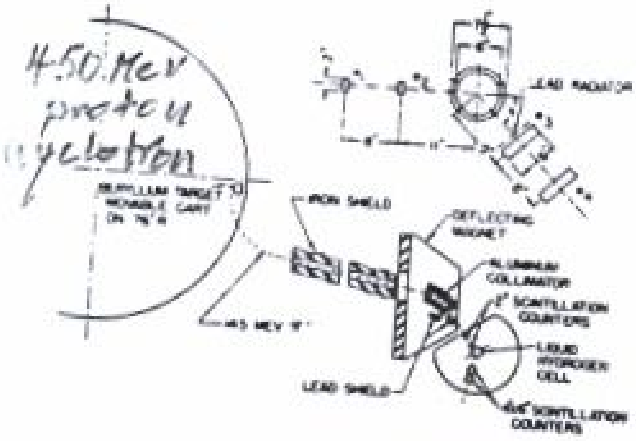
Chicago 440 MeV cyclotron

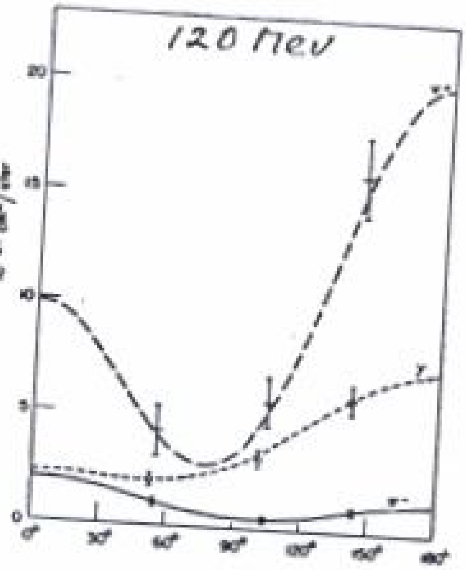
Angular Distribution of Pions Scattered by Hydrogen*

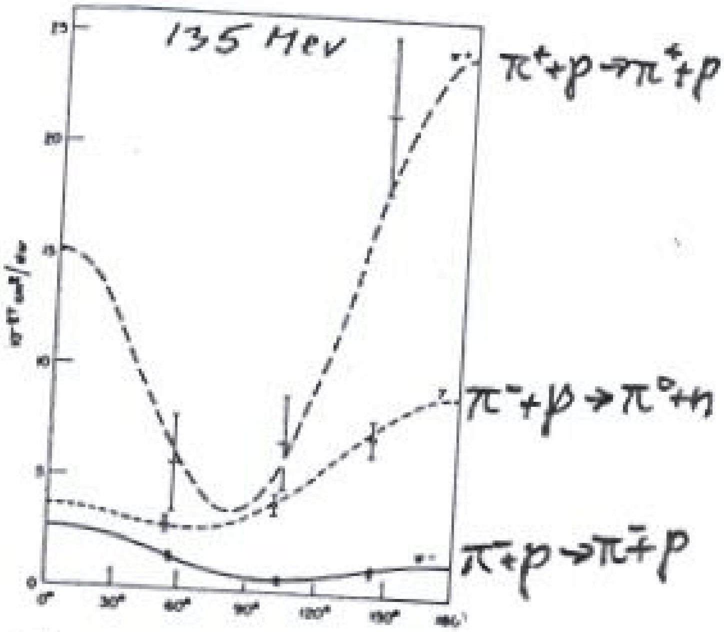
H. L. ANDERSON, E. FERMI, R. MARTIN, AND D. E. NAGLE
Institute for Nuclear Studies, University of Chicago, Chicago, Illinois

(Received March 6, 1953)

The beginnings of the Δ 3/2, 3/2 resonance







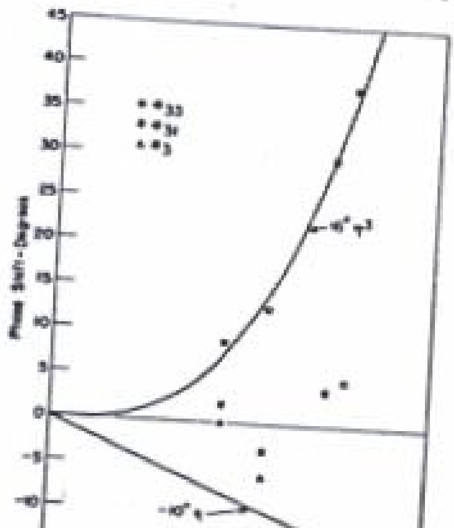
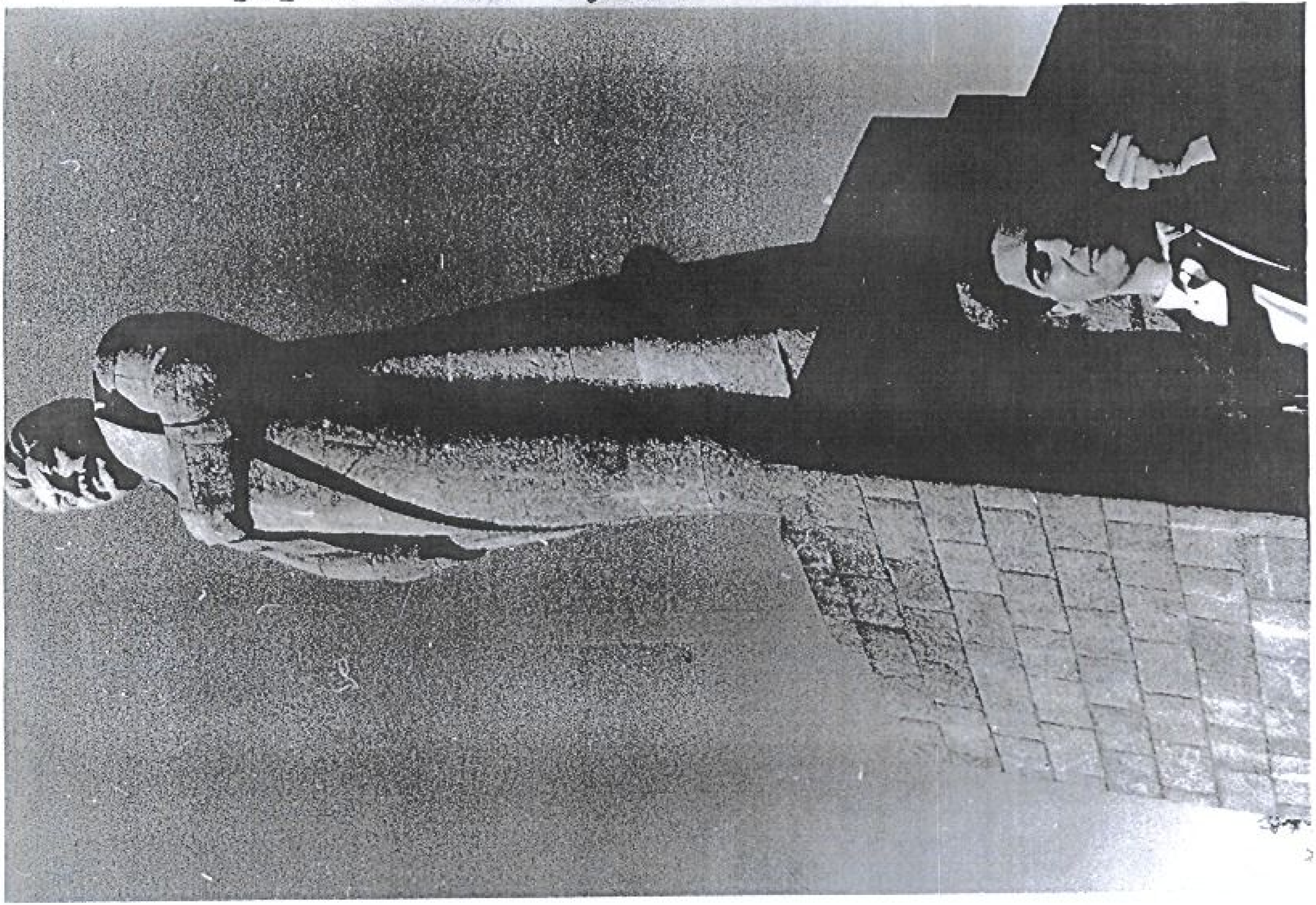


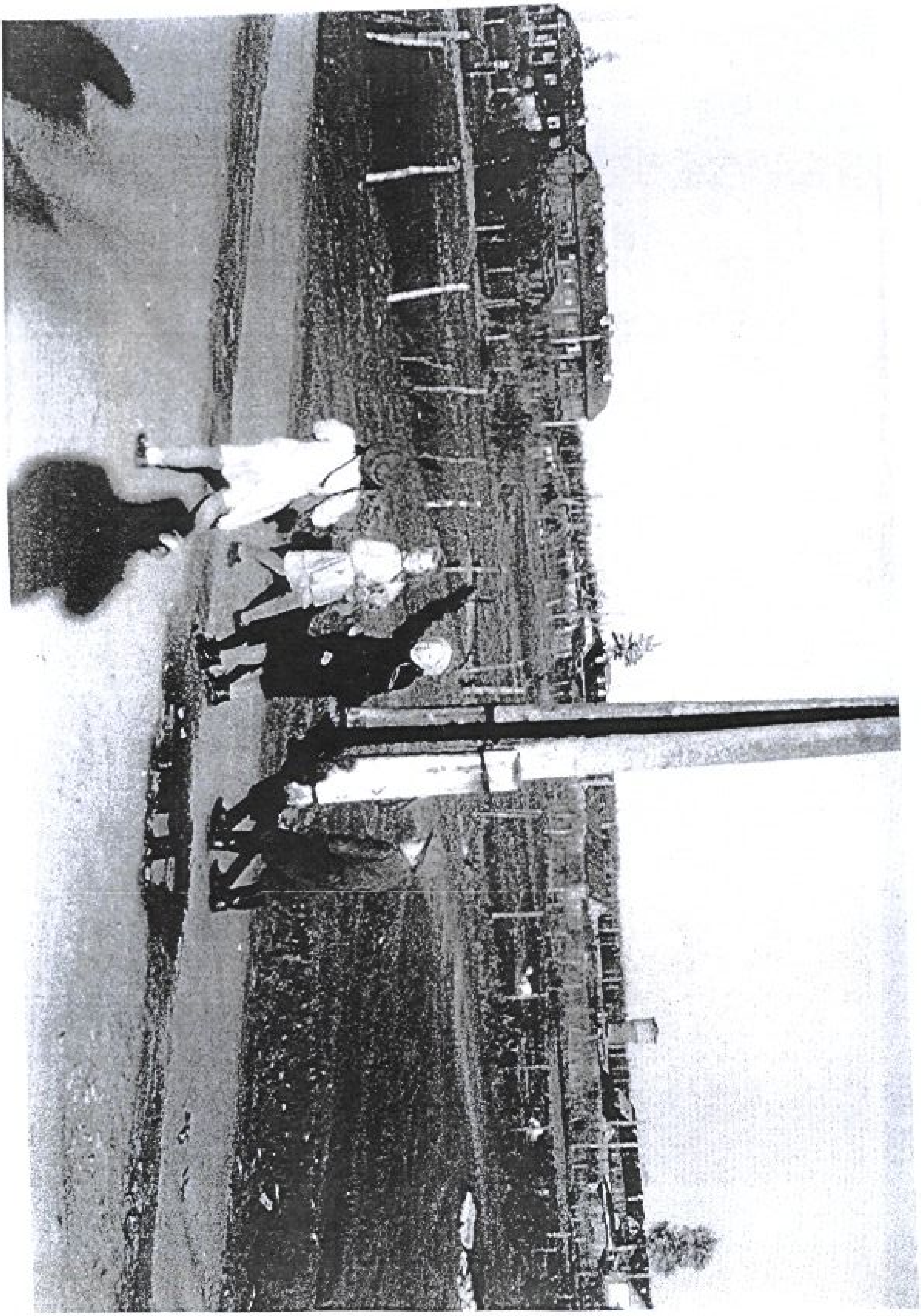
FIG. 11. Phase shifts plotted *versus* relative momentum.

1956 Moscow

Landau Pomeranchuk

1956 Soviet Union





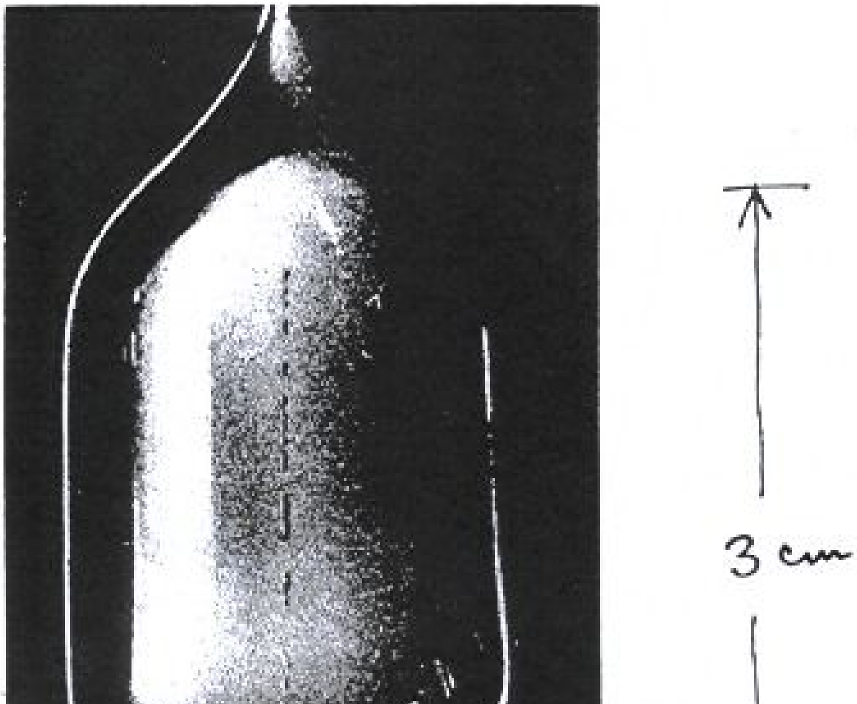
1956 CERN

Bubble chamber days

Phys. Rev. 87 665 (1952

Some Effects of Ionizing Radiation on the Formation of Bubbles in Liquids*

DONALD A. GLASER
University of Michigan, Ann Arbor, Michigan
(Received June 17, 1952)



Nevis Cyclotron Laboratories
Columbia University
Department of Physics
New York, New York

Joint ONR-AEC Program
Office of Naval Research Contract
Contract N6-ori-110-Task No.1

LIQUID PROPANE BUBBLE CHAMBER

J. Leitner, N. Samios, M. Schwartz, and J. Steinberger

(4)

May, 1955

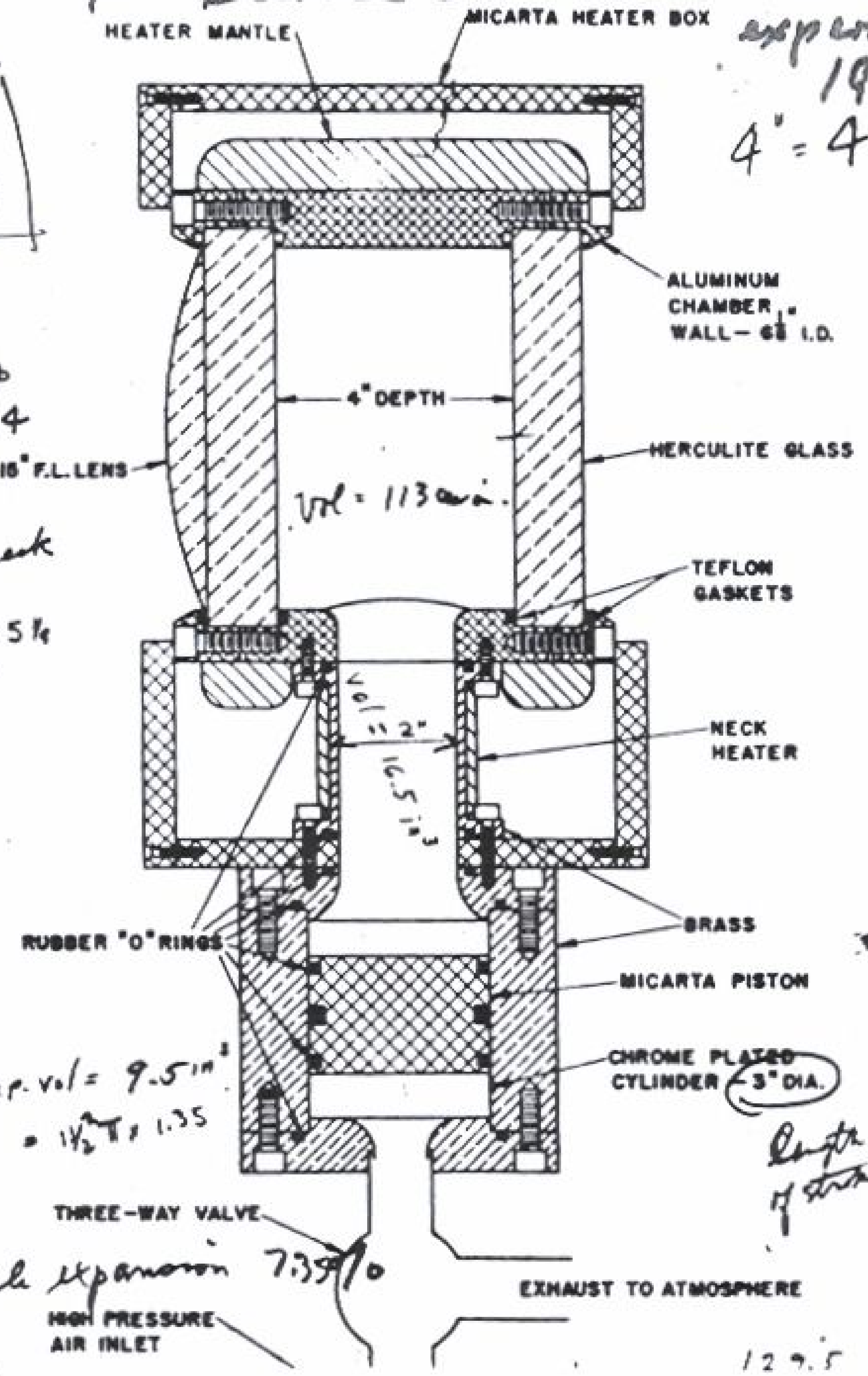
1st Bubble Chamber to do an experiment! 1955

4" = 4 cm.

Original courtesy E. Fowler

vol of Tp = 3² × π × 4 = 36π

vol of neck = 1² × π × 5¼ = 5¼π



exp. vol = 9.5 in³ = 1½² π × 1.35

length of stroke 1.35 in

allowable expansion 7.35%

12.9.5

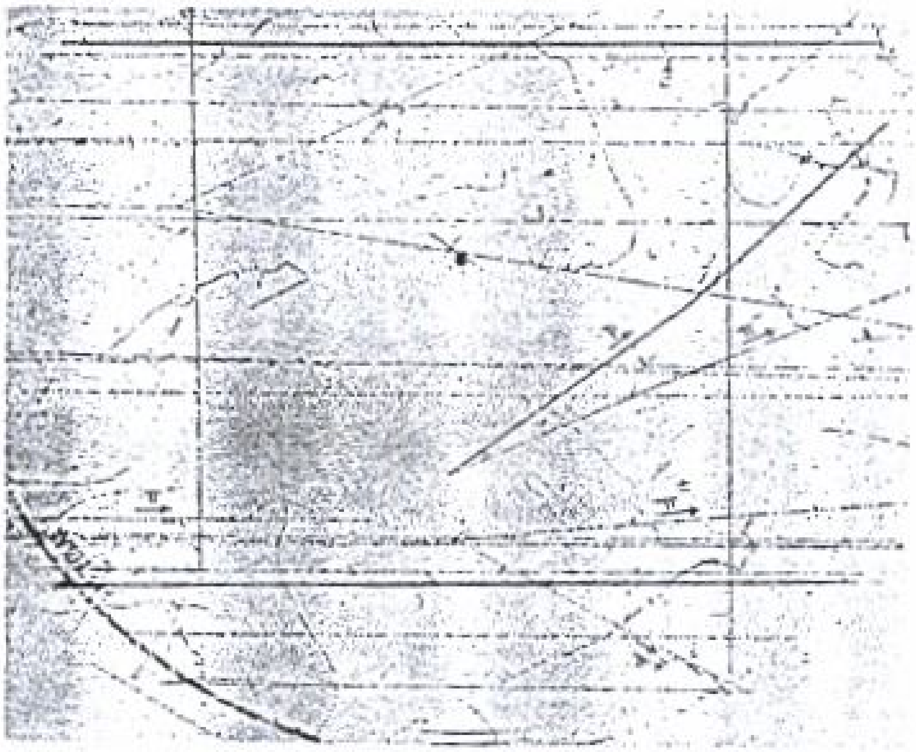


FIG. 5. A $\Lambda^0-\theta^0$ production in which both V's are seen. The Λ^0 shows, characteristically, a heavily ionizing proton and a minimum-ionizing π^-. The θ^0 shows two minimum-ionizing π's.

1956, 6" (15cm) diam. Bubble Chamber
propane, no magnetic field,
in 1.4 GeV pion beam, Cosmotron,
BNL

Example of interaction:

$$\pi^- + p \rightarrow \Lambda^0 + K^0$$

$$\Lambda^0 \rightarrow p + \pi^- \qquad K^0 \rightarrow \pi^+ + \pi^-$$

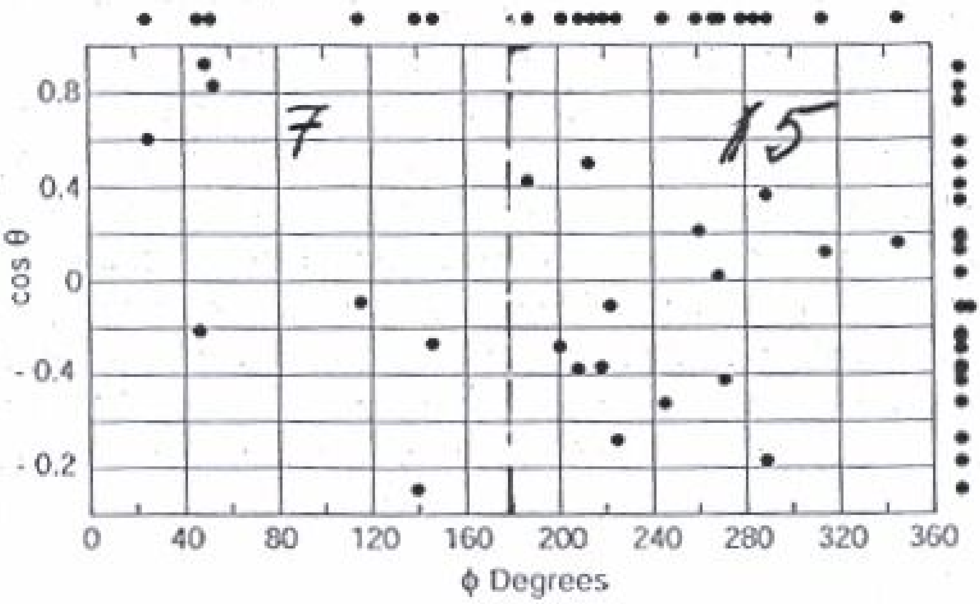


Figure 5.6: Premature parity violation, seen in the first bubble chamber experiment, at Brookhaven, in 1956 [48]. The asymmetry about $\phi = 180°$ is a manifestation of parity violation.

Demostration of the Existence of the Σ^0 Hyperon and a Measurement of its Mass (*).

12" (30 cm) chamber in magnetic field

R. Plano and N. Samios

Columbia University - New York, N.Y.

M. Schwartz and J. Steinberger (*)

Brookhaven National Laboratory - Upton, Long Island, N.Y.

$\pi^- + p \rightarrow \Sigma^0 + K^0$

$\Sigma^0 \rightarrow \Lambda + \gamma$

(ricevuto il 12 Novembre 1956)

$m_{\Sigma^0} = 2323 \pm 7 \; m_e$

Experimental Test of Parity Conservation in Beta Decay*

C. S. Wu, *Columbia University, New York, New York*

AND

E. Ambler, R. W. Hayward, D. D. Hoppes, and R. P. Hudson,
National Bureau of Standards, Washington, D. C.

(Received January 15, 1957)

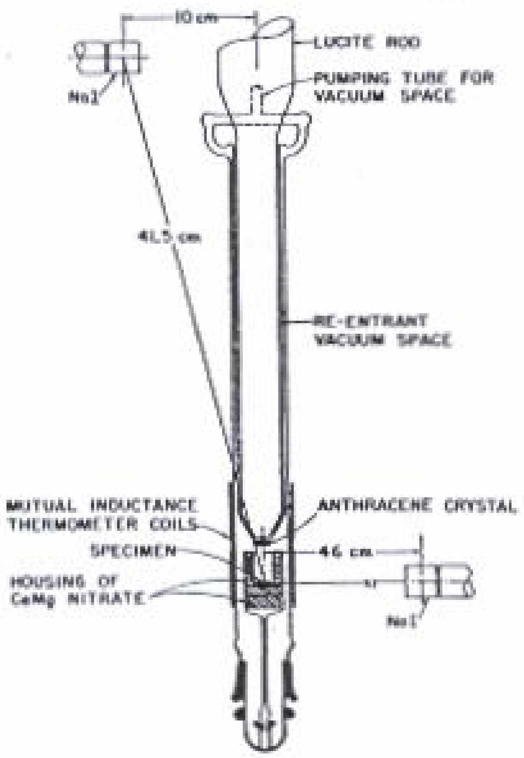


Fig. 1. Schematic drawing of the lower part of the cryostat.

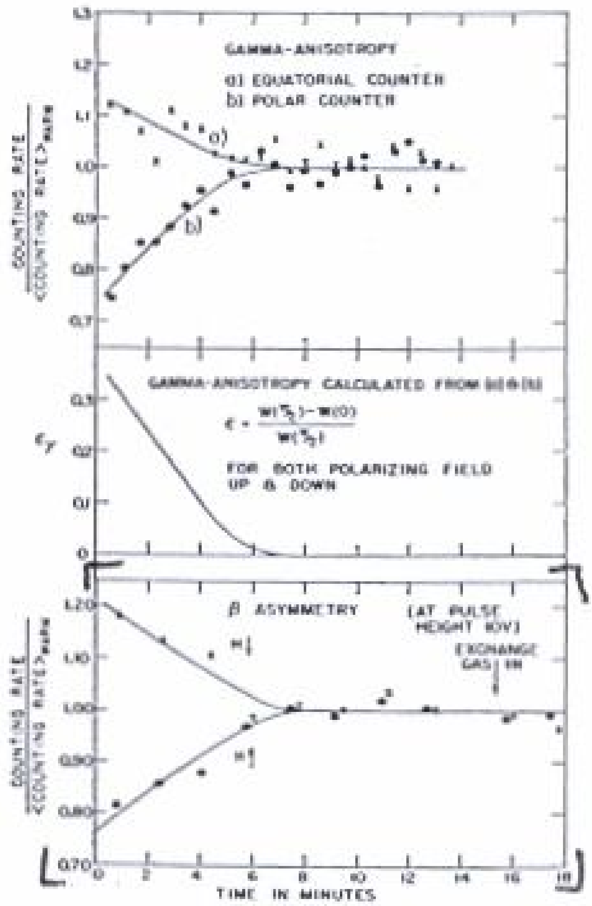


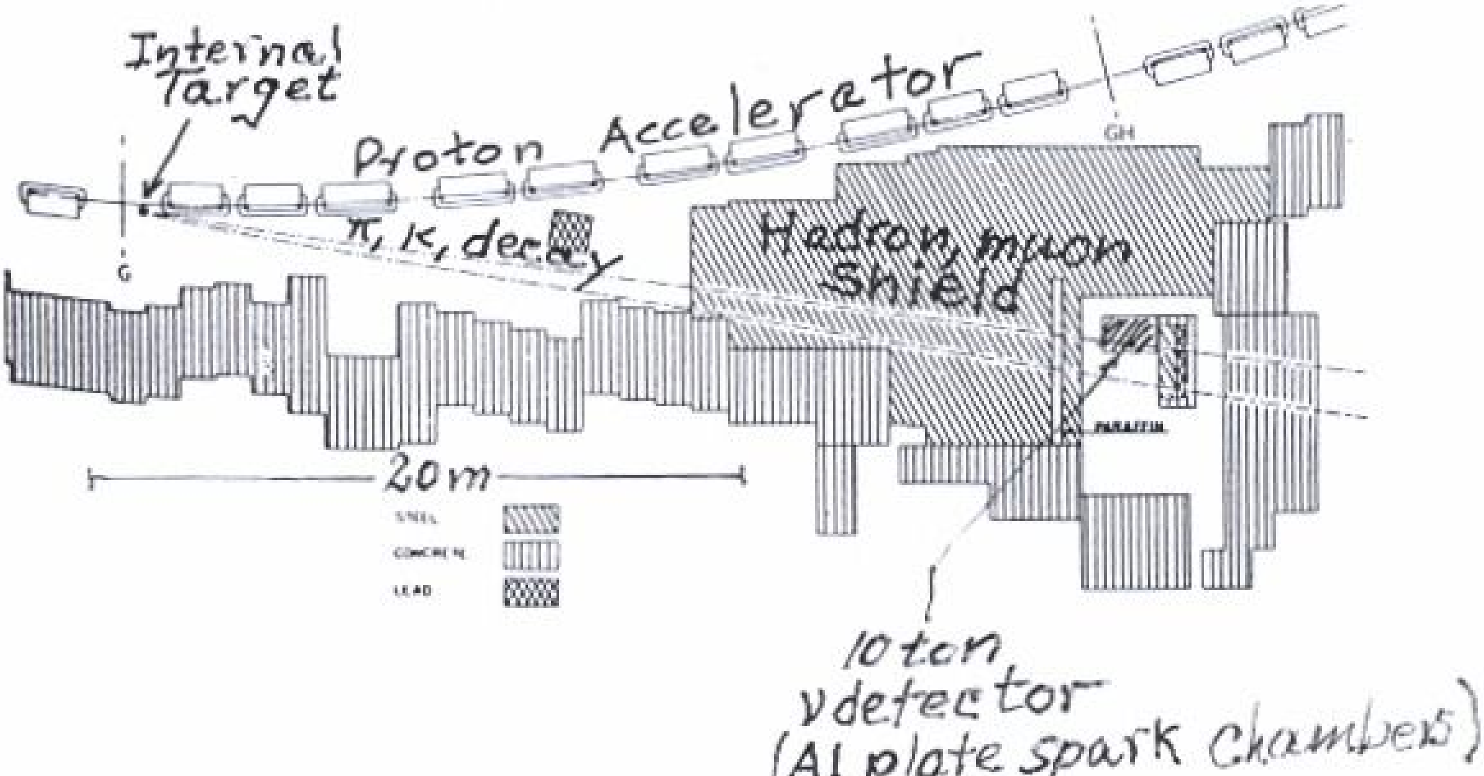
Fig. 2. Gamma anisotropy and beta asymmetry for polarizing field pointing up and pointing down.

OBSERVATION OF HIGH-ENERGY NEUTRINO REACTIONS AND THE EXISTENCE OF TWO KINDS OF NEUTRINOS*

G. Danby, J-M. Gaillard, K. Goulianos, L. M. Lederman, N. Mistry, M. Schwartz,† and J. Steinberger†

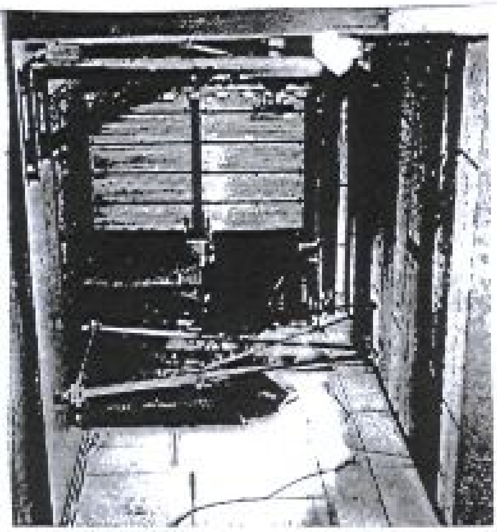
Columbia University, New York, New York and Brookhaven National Laboratory, Upton, New York

(Received June 15, 1962)



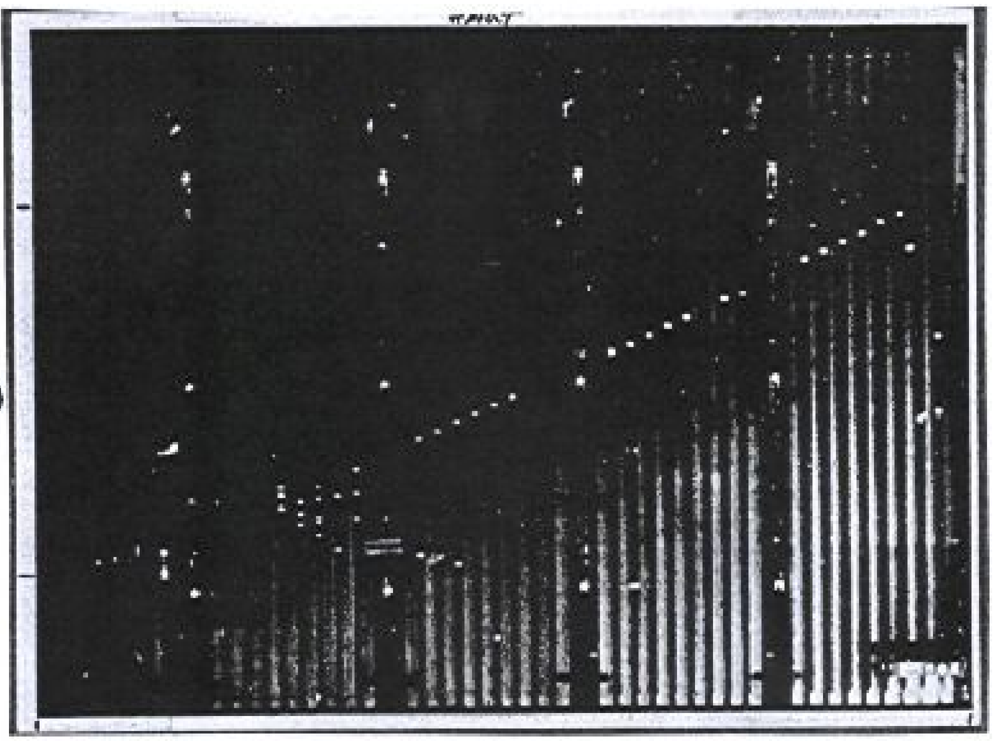
ν source: $\pi^+ \to \mu^+ + \nu$; $K^+ \to \mu^+ + \nu$

$\pi^- \to \mu^- + \bar{\nu}$; $K^- \to \mu^- + \bar{\nu}$



$$\frac{1 \text{ event}}{10^{13}\ \nu\text{'s}}$$

ν beam



$E_\nu \simeq 1\text{-}5$ GeV

$$\nu + n,p \rightarrow \mu + X(\text{hadrons})$$ ~2 doz events

$$\not\rightarrow e + X$$

so $\nu_\mu \neq \nu_e$

Spectrometers to detect recoil electron from $e^- + p \rightarrow e^- + X$

SLAC 1968 – '72

Discovery of "partons" -> quarks

in Inelastic electron – nucleon scattering

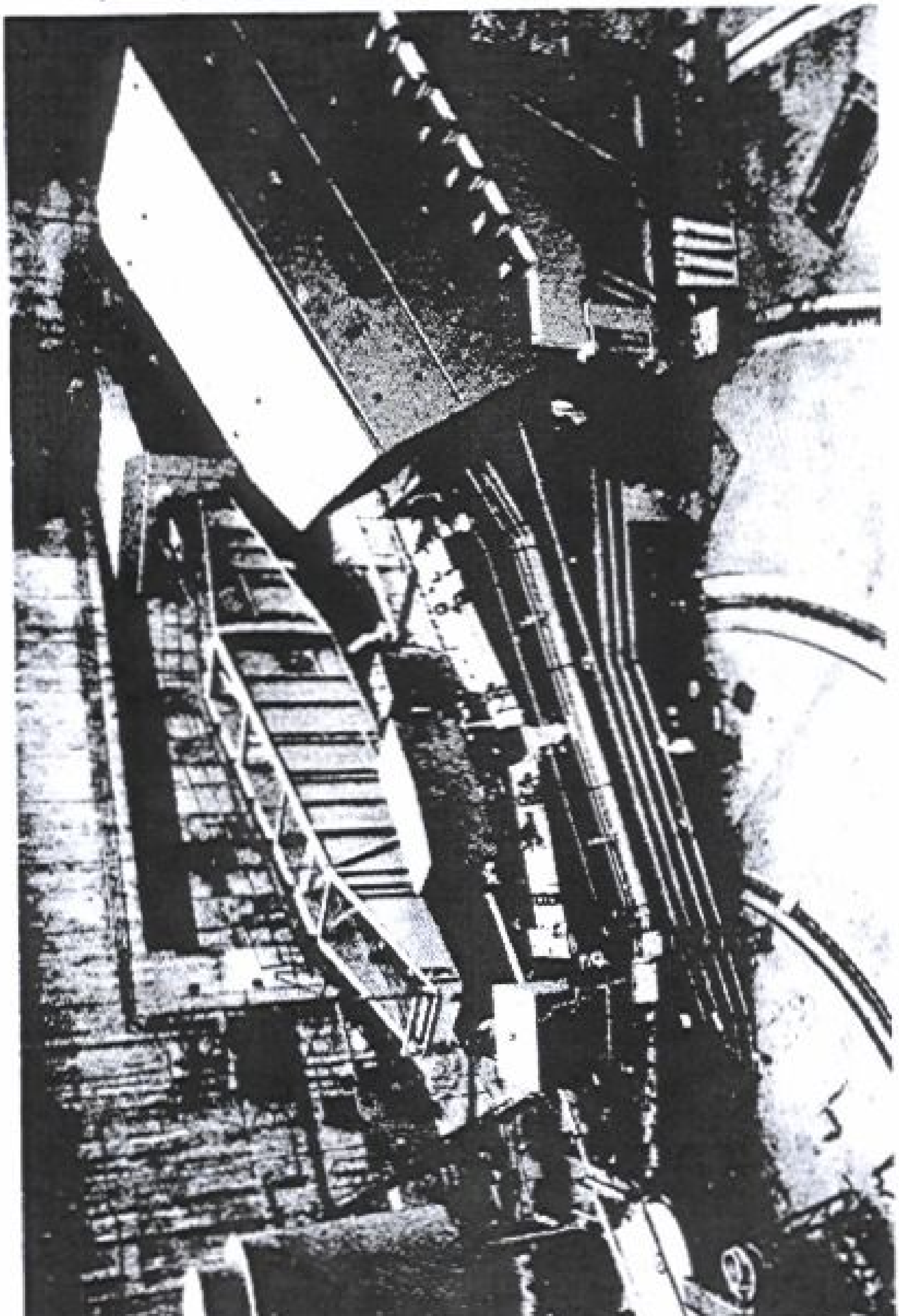
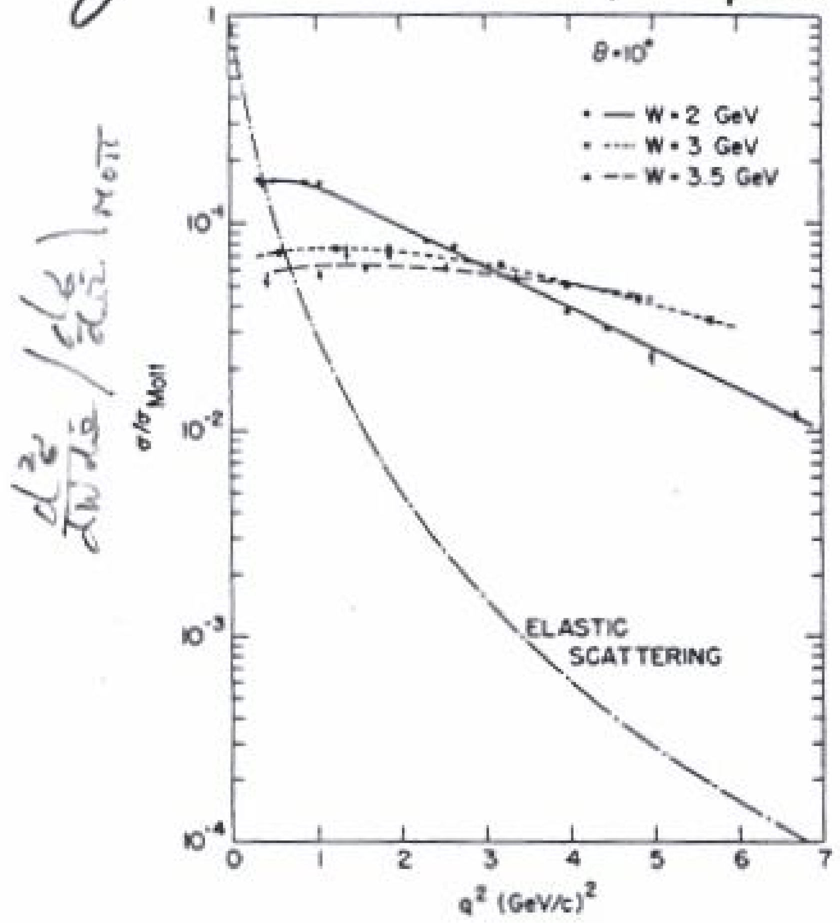


Fig. 7 View of the floor at SLAC with 20 GeV and 8 GeV spectrometers.

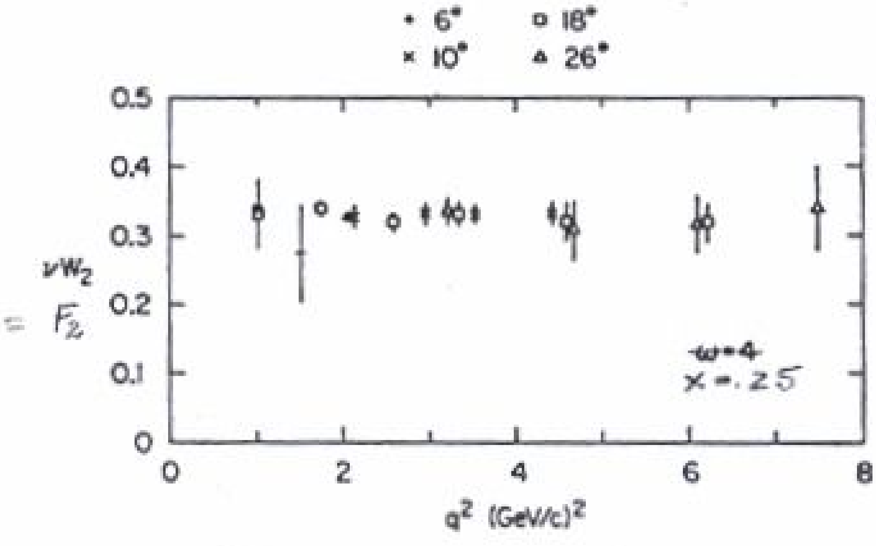
leads way to theory of strong Interaction of quarks and gluons

Protons are complex, not "elementary". They are made of "partons" (quarks/gluons)



MIT-SLAC
1969
Scaling

Fig. 9 $(d^2\sigma/d\Omega dE')/\sigma_{Mott}$ plotted as a function of Q^2 in W bins. 10° data. (Ref. 15.)



MIT SLAC
1970
Scaling

Fig. 10 νW_2 structure function at x = 0.25 as a function of Q^2, demonstrating scaling. Presented at the 15th Int. Conf. on High Energy Physics, Kiev, 1970. (Ref. 15.)

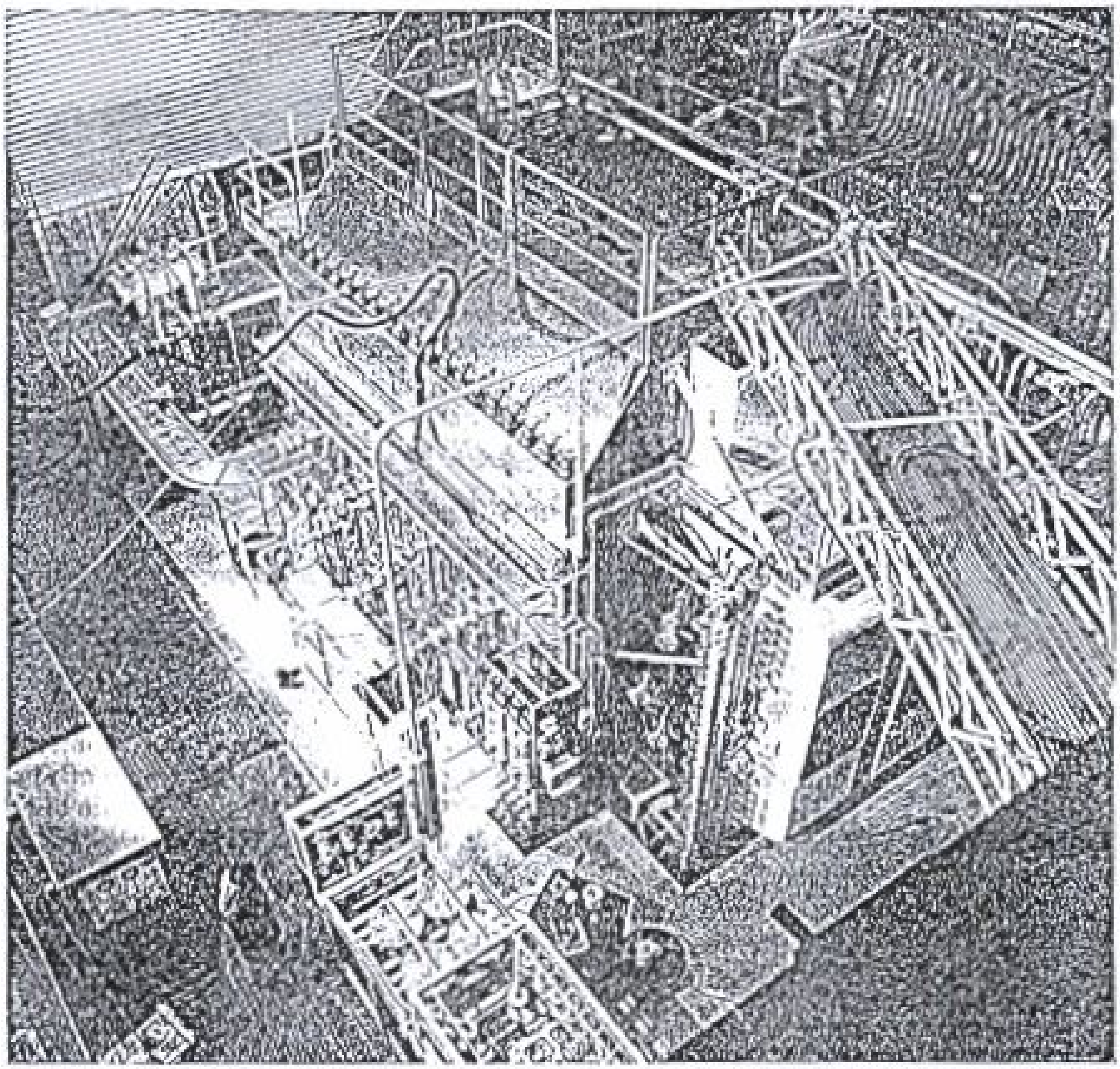
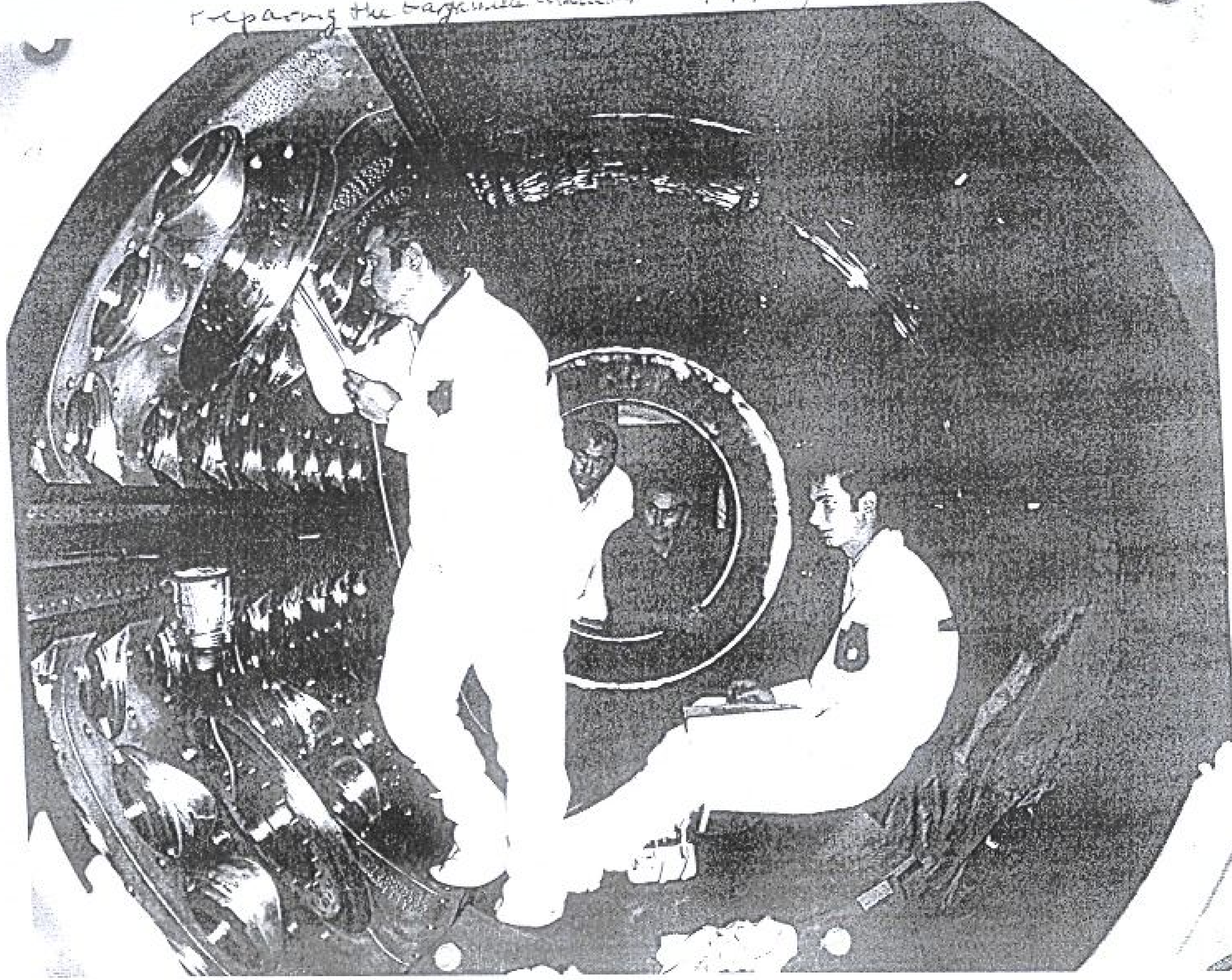
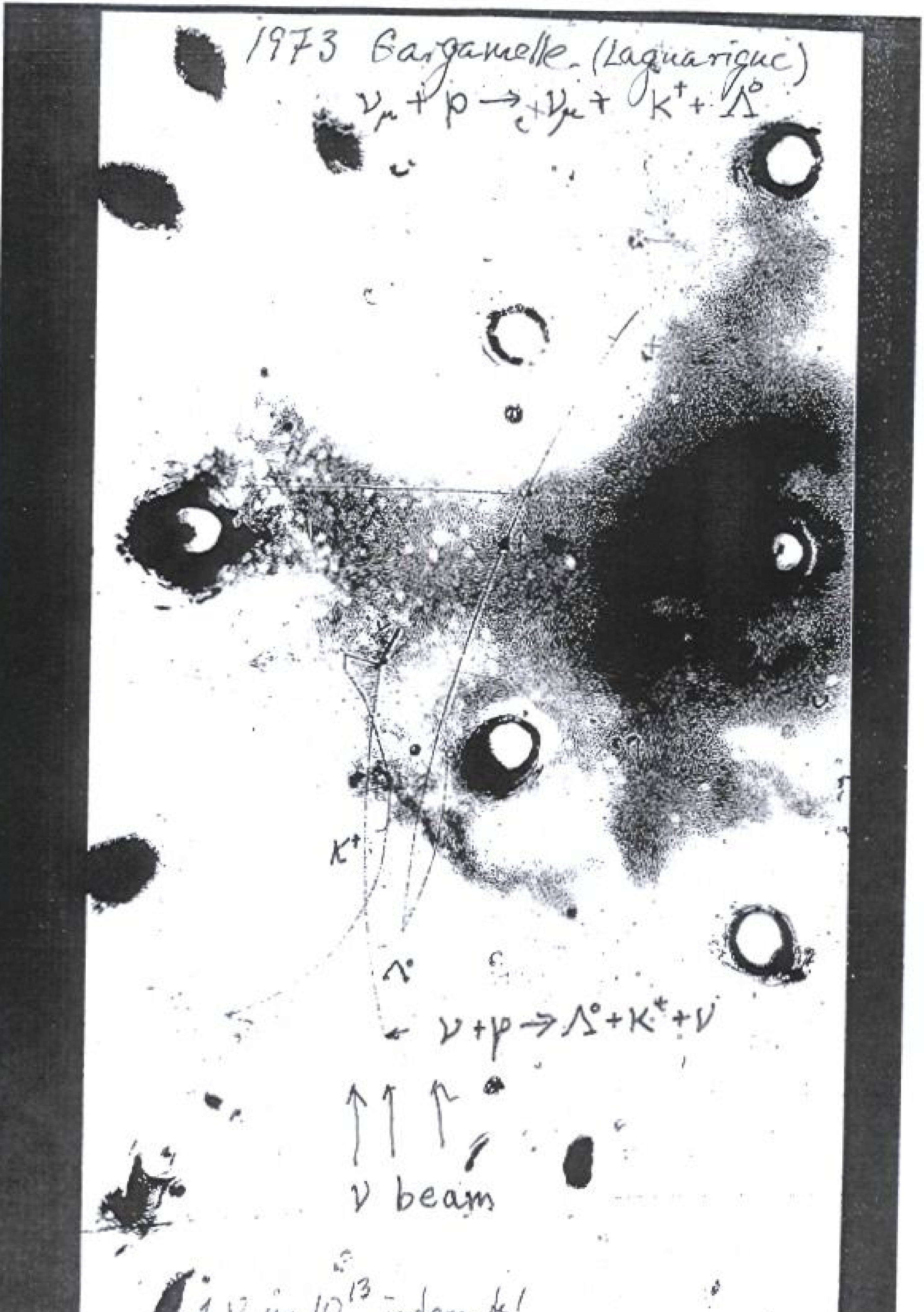


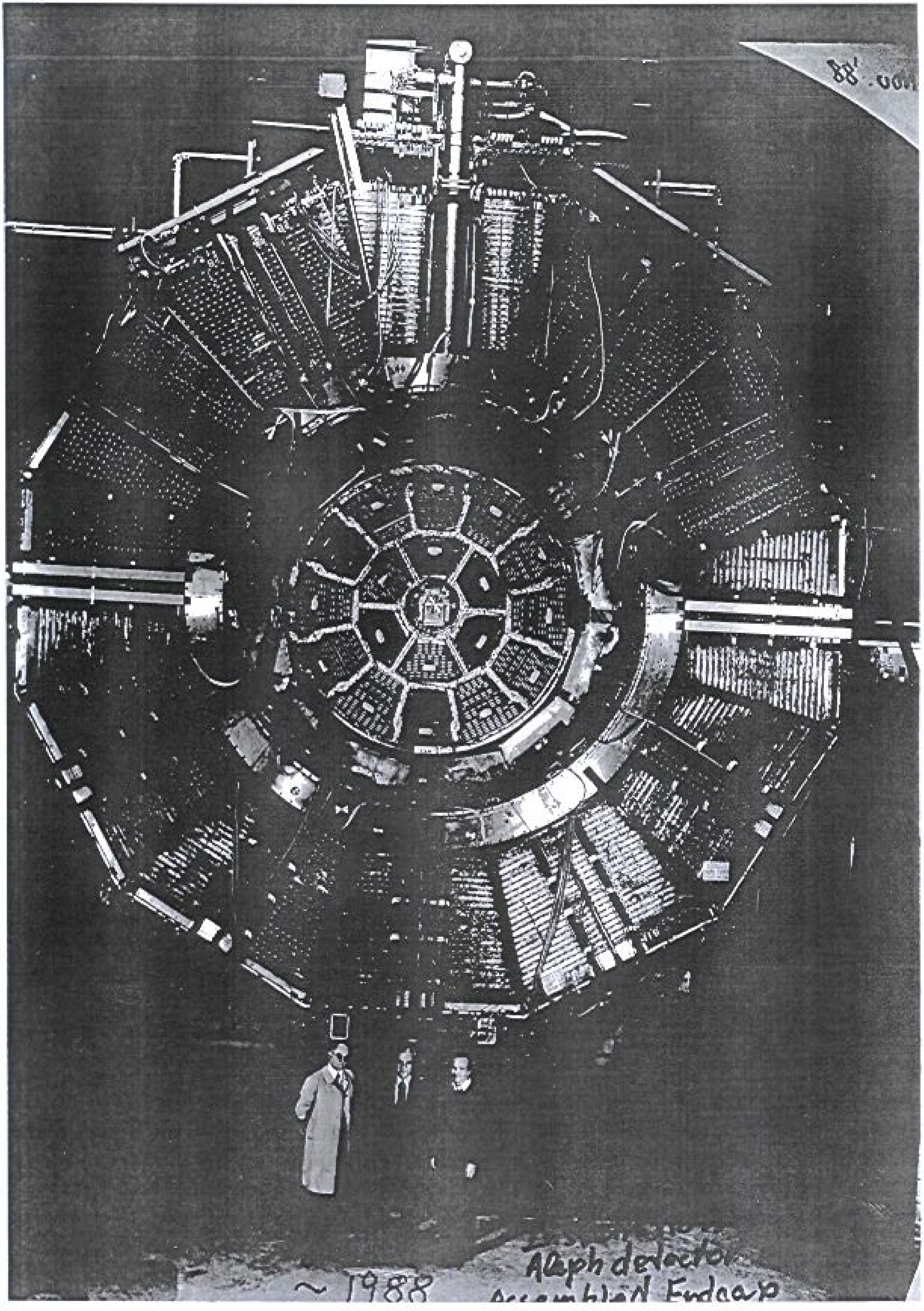
Fig. 4. Gargamelle and its environment.

Discovery of weak neutral current.
Establishes Electro-weak theory.

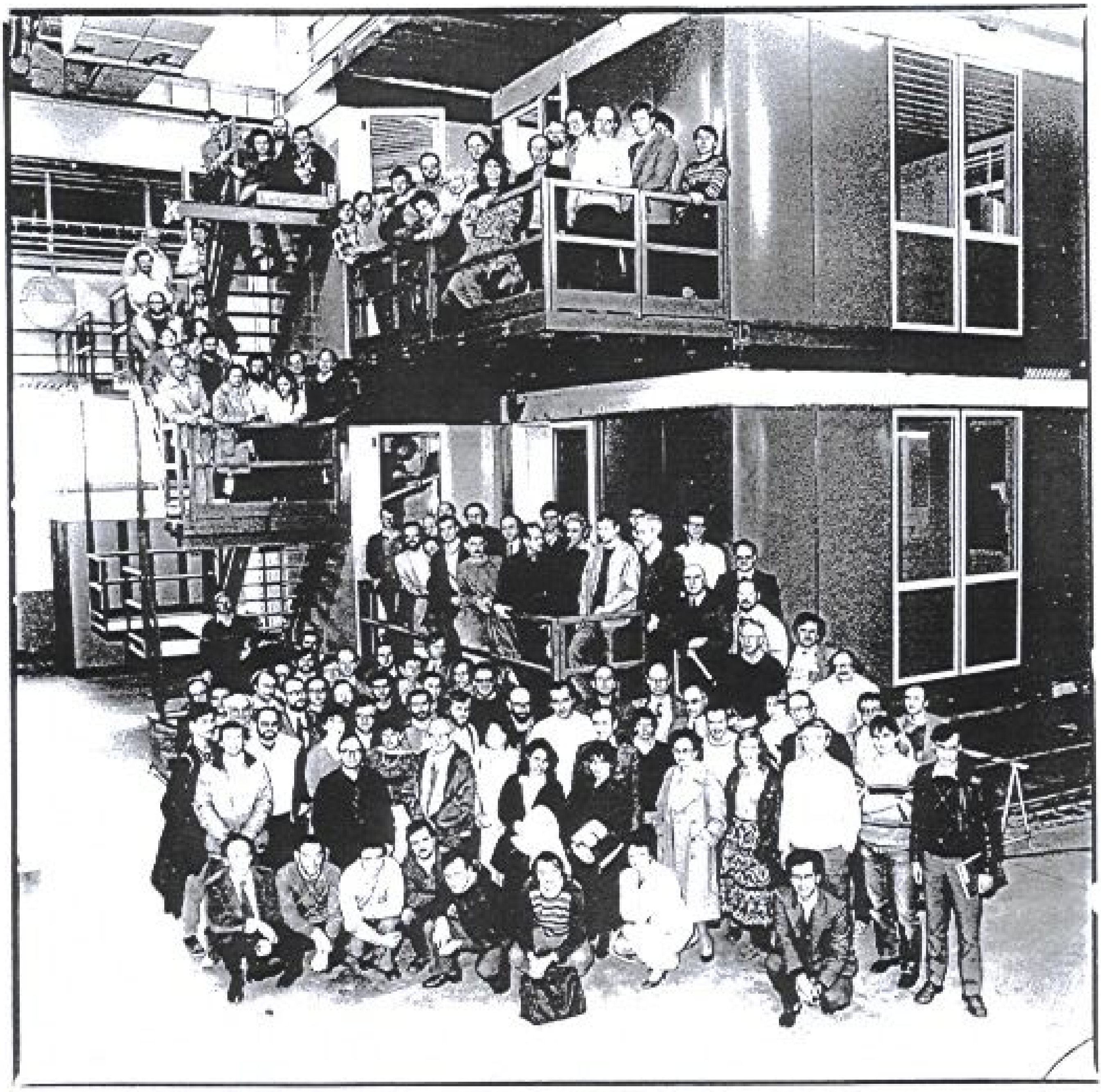
Preparing the Gargamelle chamber [illegible]




1973 Gargamelle (Lagarrigue)
$\nu_\mu + p \to \nu_\mu + K^+ + \Lambda^0$
K^+
Λ^0
$\nu + p \to \Lambda^0 + K^+ + \nu$
ν beam
1 ν in 10^{13} interacts!



Aleph detector
~1988



ALEPH Group meeting '87

Measurement of the absolute luminosity with the ALEPH detector

ALEPH Collaboration

D. Decamp, B. Deschizeaux, C. Goy, J.-P. Lees, M.-N. Minard
Laboratoire de Physique des Particules (LAPP), IN²P³-CNRS, F-74019 Annecy-le-Vieux Cedex, France

R. Alemany, J.M. Crespo, M. Delfino, E. Fernandez, V. Gaitan, Ll. Garrido, Ll.M. Mir, A. Pacheco
Laboratorio de Fisica de Altas Energias, Universidad Autonoma de Barcelona, E-08193 Bellaterra (Barcelona), Spain[9]

M.G. Catanesi, D. Creanza, M. de Palma, A. Farilla, G. Iaselli, G. Maggi, M. Maggi, S. Natali, S. Nuzzo, M. Quattromini, A. Ranieri, G. Raso, F. Romano, F. Ruggieri, G. Selvaggi, L. Silvestris, P. Tempesta, G. Zito
INFN Sezione di Bari e Dipartimento di Fisica dell' Università, I-70126 Bari, Italy

Y. Gao, H. Hu[21], D. Huang, X. Huang, J. Lin, J. Lou, C. Qiao[21], T. Ruan[21], T. Wang, Y. Xie, D. Xu, R. Xu, J. Zhang, W. Zhao
Institute of High-Energy Physics, Academia Sinica, Beijing, People's Republic of China[8]

W.B. Atwood[2], L.A.T. Bauerdick, F. Bird[4], E. Blucher, G. Bonvicini, F. Bossi, J. Boudreau, D. Brown, T.H. Burnett[3], H. Drevermann, R.W. Forty, C. Grab[23], R. Hagelberg, S. Haywood, J. Hilgart, B. Jost, M. Kasemann[18], J. Knobloch, A. Lacourt, E. Lançon, I. Lehraus, T. Lohse, A. Lusiani, A. Marchioro, M. Martinez, P. Mato, S. Menary, A. Minten, A. Miotto, R. Miquel, H.-G. Moser, J. Nash, P. Palazzi, F. Ranjard, G. Redlinger, A. Roth, J. Rothberg[3], H. Rotscheidt, M. Saich, D. Schlatter, M. Schmelling, M. Takashima, W. Tejessy, H. Wachsmuth, S. Wasserbaech, W. Wiedenmann, W. Witzeling, J. Wotschack
European Laboratory for Particle Physics (CERN), CH-1211 Geneva 23, Switzerland

Z. Ajaltouni, F. Badaud, M. Bardadin-Otwinowska, A.M. Bencheikh, R. El Fellous, A. Falvard, P. Gay, C. Guicheney, J. Harvey, P. Henrard, J. Jousset, B. Michel, J.-C. Montret, D. Pallin, P. Perret, J. Proriol, F. Prulhière, G. Stimpfl
Laboratoire de Physique Corpusculaire, Université Blaise Pascal, IN²P³-CNRS, Clermont-Ferrand, F-63177 Aubière, France

H. Bertelsen, F. Hansen, J.D. Hansen, J.R. Hansen, P.H. Hansen, A. Lindhal, R. Møllerud, B.S. Nilsson, G. Petersen
Niels Bohr Institute, DK-2100 Copenhagen, Denmark[19]

I. Efthymiopoulos, E. Simopoulou, A. Vayaki
Nuclear Research Center Demokritos (NRCD), GR-Athens, Greece

J. Badier, A. Blondel, G. Bonneaud, J. Bourotte, F. Braems, J.C. Brient, G. Fouque, A. Gamess, R. Guirlet, S. Orteu, A. Rosowsky, A. Rougé, M. Rumpf, R. Tanaka, H. Videau
Laboratoire de Physique Nucléaire et des Hautes Energies, Ecole Polytechnique, IN²P³-CNRS, F-91128 Palaiseau Cedex, France

D.J. Candlin, E. Veitch
Department of Physics, University of Edinburgh, Edinburgh EH9 3JZ, UK[11]

L. Moneta, G. Parrini
Dipartimento di Fisica, Università di Firenze, INFN Sezione di Firenze, I-50125 Firenze, Italy

M. Corden, C. Georgiopoulos, M. Ikeda, J. Lannutti, D. Levinthal[16], M. Mermikides, L. Sawyer
Supercomputer Computations Research Institute and Dept. of Physics, Florida State University, Tallahassee, FL 32306, USA[13,14,15]

A. Antonelli, R. Baldini, G. Bencivenni, G. Bologna[5], P. Campana, G. Capon, F. Cerutti, V. Chiarella, B. D'Ettorre-Piazzoli[6], G. Felici, P. Laurelli, G. Mannocchi[6], F. Murtas, G.P. Murtas, L. Passalacqua, M. Pepe-Altarelli, P. Picchi[5], P. Zografou
Laboratori Nazionali dell'INFN (LNF-INFN), I-00044 Frascati, Italy

B. Altoon, O. Boyle, A.W. Halley, I. ten Have, J.L. Hearns, J.G. Lynch, W.T. Morton, C. Raine, J.M. Scarr, K. Smith, A.S. Thompson, R.M. Turnbull
Department of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ, UK[11]

B. Brandl, O. Braun, R. Geiges, C. Geweniger, P. Hanke, V. Hepp, E.E. Kluge, Y. Maumary, A. Putzer, A. Stahl, K. Tittel, M. Wunsch
Institut für Hochenergiephysik, Universität Heidelberg, W-6900 Heidelberg, Federal Republic of Germany[17]

A.T. Belk, R. Beuselinck, D.M. Binnie, W. Cameron, M. Cattaneo, P. ...
J.F. Hassard, N.M. Lieske, S.J. Patton, D.G. Payne, M.J. Phillips, J.K. ...
A.G. Wright
Department of Physics, Imperial College, London SW7 2BZ, UK[11]

P. Girtler, D. Kuhn, G. Rudolph
Institut für Experimentalphysik, Universität Innsbruck, A-6020 Innsbruck, Austri...

C.K. Bowdery[1], T.J. Brodbeck, A.J. Finch, F. Foster, G. Hughes, N.R ...
B.S. Rowlingson, T. Sloan, S.W. Snow, E.P. Whelan
Department of Physics, University of Lancaster, Lancaster LA1 4YB, UK[11]

T. Barczewski, K. Kleinknecht, J. Raab, B. Renk, S. Roehn, H.-G. Sa...
B. Wolf
Institut für Physik, Universität Mainz, W-6500 Mainz, Federal Republic of Germ...

J.-J. Aubert, C. Benchouk, V. Bernard, A. Bonissent, J. Carr, P. Coyle, ...
P. Payre, B. Pietrzyk, Z. Qian, D. Rousseau, P. Schwemling, M. Talby
Centre de Physique des Particules, Faculté des Sciences de Luminy, IN²P³-CNRS

H. Becker, W. Blum, P. Cattaneo, G. Cowan, B. Dehning, H. Dietl, F. ...
T. Hansl-Kozanecka[2,11], A. Jahn, W. Kozanecki[3], E. Lange, J. Laube...
R. Richter, J. Schröder, A.S. Schwarz, R. Settles, U. Stierlin, R.St. Der...
Max-Planck-Institut für Physik und Astrophysik, Werner-Heisenberg-Institut für ...
Germany[17]

V. Bertin, J. Boucrot, O. Callot, X. Chen, A. Cordier, M. Davier, G. G...
D.W. Kim[20], F. Le Diberder, J. Lefrançois[1], A.-M. Lutz, J.-J. Veillet, ...
Laboratoire de l'Accélérateur Linéaire, Université de Paris-Sud, IN²P³-CNRS, F-...

D. Abbaneo, S.R. Amendolia, G. Bagliesi, G. Batignani, L. Bosisio, U. ...
M.A. Ciocci, R. Dell'Orso, I. Ferrante, F. Fidecaro, L. Foà, E. Focardi ...
F. Ligabue, E.B. Mannelli, P.S. Marrocchesi, A. Messineo, F. Palla, G. ...
G. Tonelli, G. Triggiani, C. Vannini, A. Venturi, P.G. Verdini, J. Walsh
Dipartimento di Fisica dell'Università, INFN Sezione di Pisa, e Scuola Normale S...

J.M. Carter, M.G. Green[1], P.V. March, T. Medcalf, I.S. Quazi, J.A. St...
Department of Physics, Royal Holloway & Bedford New College, University of L...

D.R. Botterill, R.W. Clifft, T.R. Edgecock, M. Edwards, S.M. Fisher, T...
J.C. Thompson
Particle Physics Department, Rutherford Appleton Laboratory, Chilton, Didcot, O...

B. Bloch-Devaux, P. Colas, C. Klopfenstein, E. Locci, S. Loucatos, E. ...
J. Rander, J.-F. Renardy, A. Roussarie, J.-P. Schuller, J. Schwindling, ...
Département de Physique des Particules Elémentaires, CEN-Saclay, F-91191 Gif-s...

J.G. Ashman, C.N. Booth, C. Buttar, R. Carney, S. Cartwright, F. Com...
J. Martin, D. Parker, P. Reeves, L.F. Thompson
Department of Physics, University of Sheffield, Sheffield S3 7RH, UK[11]

E. Bach, E. Barberio, S. Brandt, H. Burkhardt[1], G. Gillessen, C. Grup...
U. Schäfer, H. Seyweld, C. Stupperich, H. Trier, V. Zeuner
Fachbereich Physik, Universität Siegen, W-5900 Siegen, Federal Republic of Germ...

G. Giannini, B. Gobbo, F. Ragusa[22], L. Rolandi, U. Stiegler
Dipartimento di Fisica, Università di Trieste e INFN Sezione di Trieste, I-34127 T...

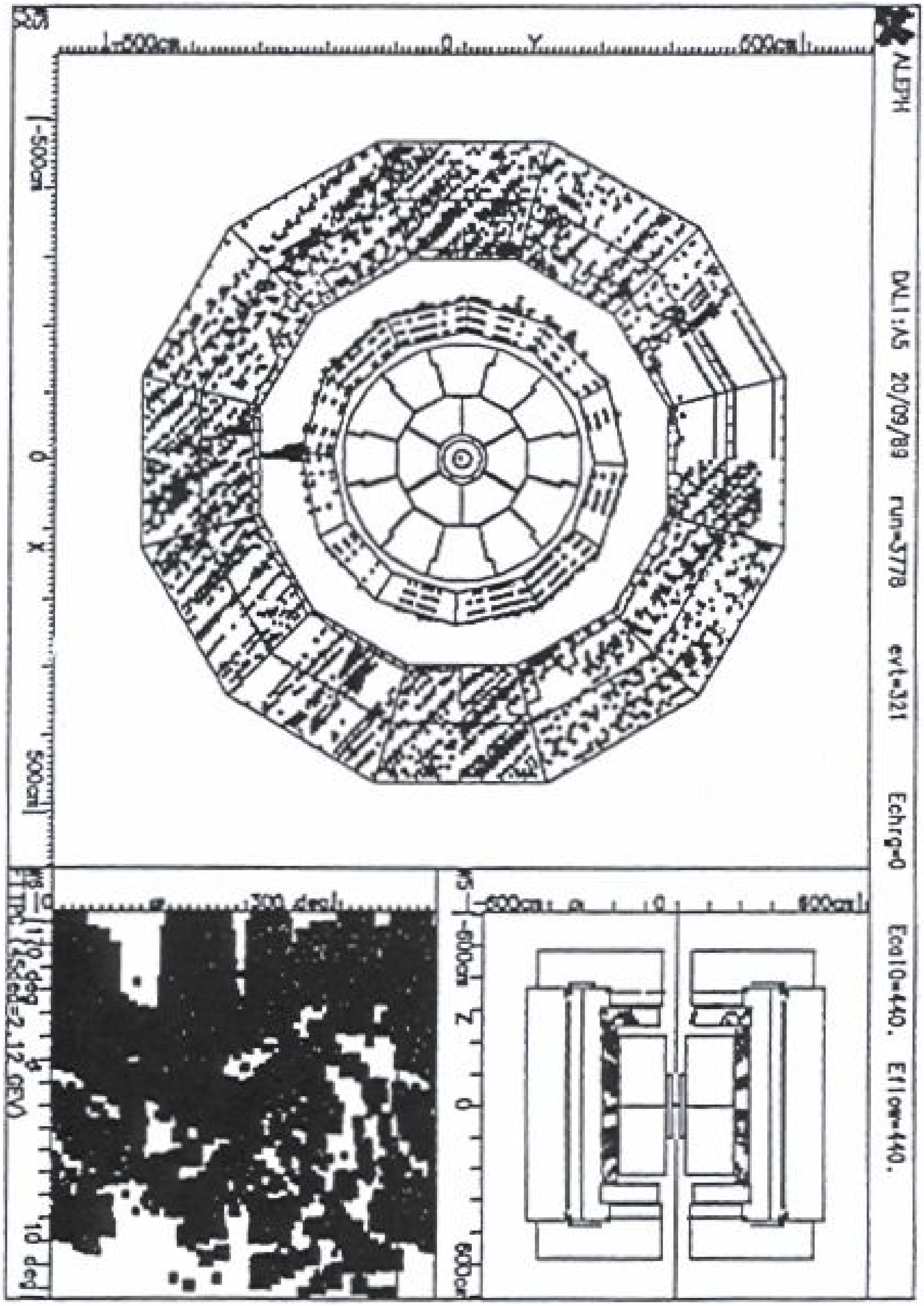
L. Bellantoni, X. Chen, D. Cinabro, J.S. Conway, D.F. Cowen[24], Z. Fe...
J.L. Harton, J.E. Jacobsen, R.C. Jared[7], R.P. Johnson, B.W. LeClaire, ...
Z.H. Shi, Y.H. Tang, A.M. Walsh, J.A. Wear[27], F.V. Weber, M.H. Whi...
Department of Physics, University of Wisconsin, ...

1990
375±50
authors
Two of the
experimental
teams prepari[ng]
for the 'LHC'
have more tha[n]
1000 members.

BUON GIORNO !!

Cosmic ray event

Energy of cosmic ray ~ 10^7 GeV? ($10^5 \times$ Lep energy)

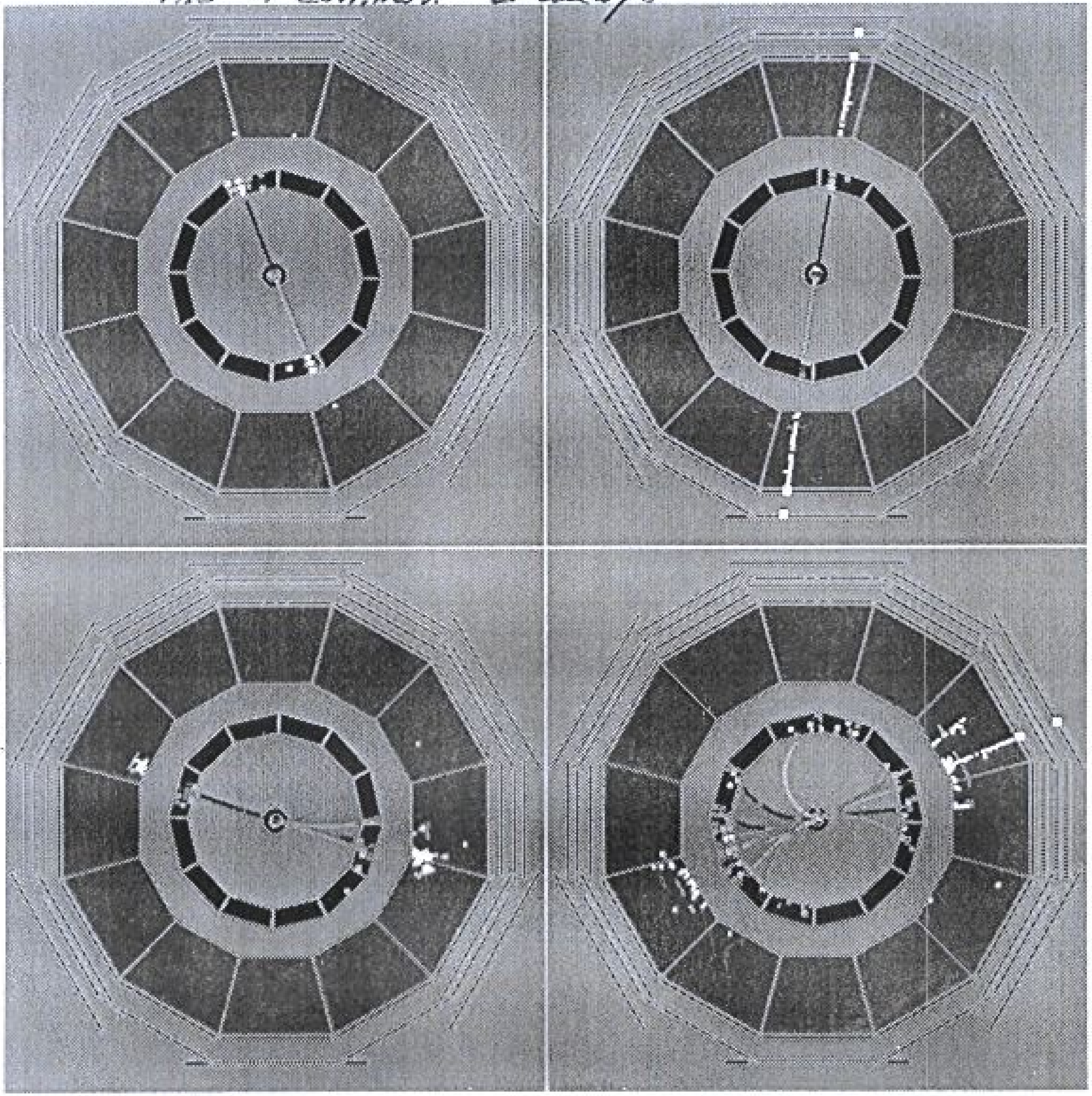


The 4 common Z decays

$Z \to e^+e^-$
B.R. = 3%

$Z \to \mu^+\mu^-$
B.R. = 3%

LEP 1989–20



B.R. ≈ 3%
$Z \to \tau^+\tau^-$
$\tau^+ \to \nu_\tau + \pi^+$
$\tau^- \to \nu_\tau + 3\pi$

$Z \to q\bar{q}$
B.R. = 70%

[$Z \to \nu\bar{\nu}$, invisible
B.R. ≈ 20%]

Neutrinos at LEP

The Three Families of Matter

$e^+ + e^- \rightarrow Z$; $Z \rightarrow f + \bar{f}$;

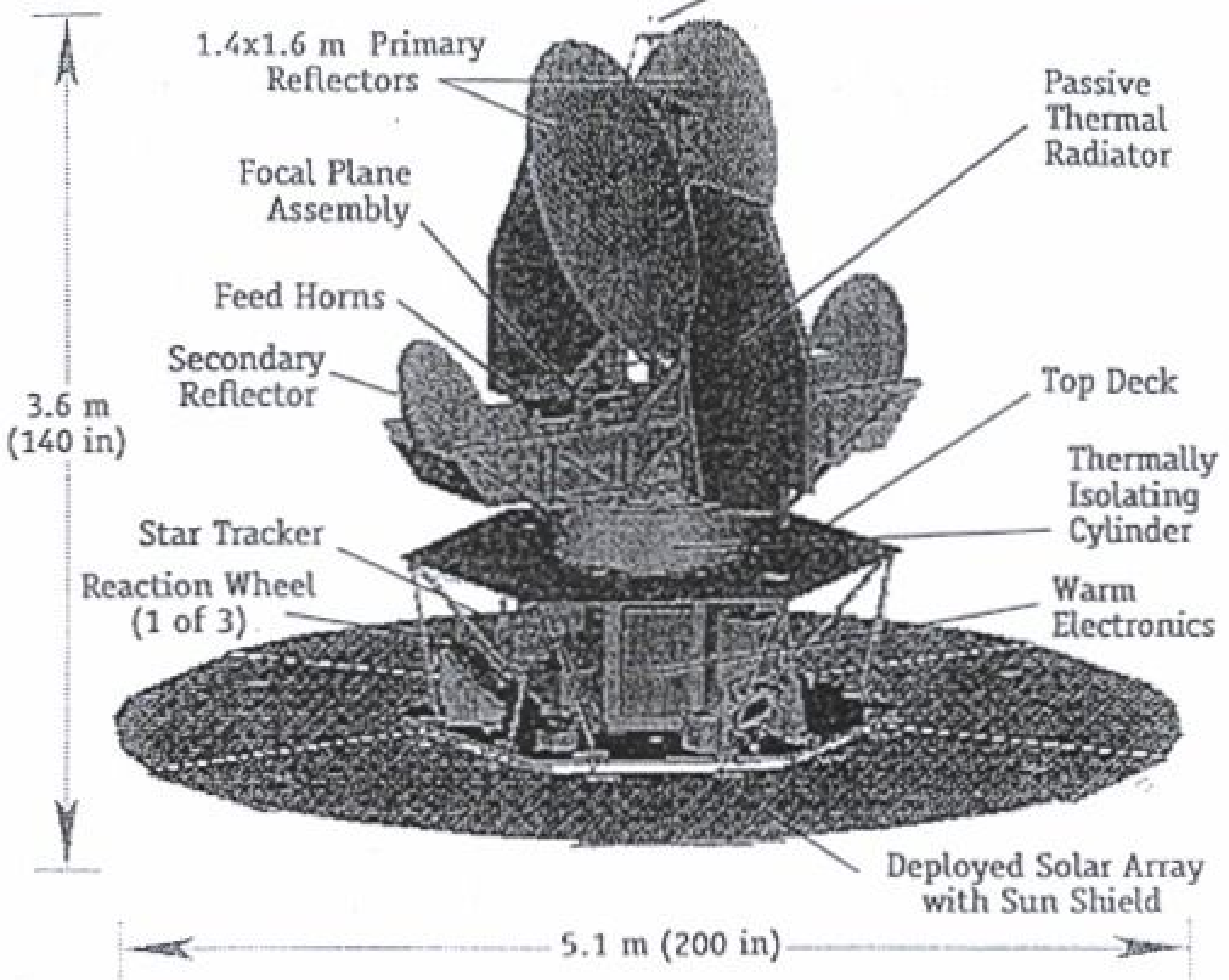
$$\Gamma_Z = \Sigma\, \Gamma(Z \rightarrow f+\bar{f})$$

f	$\Gamma(Z \rightarrow f+\bar{f})$ (MeV)	
e, μ, τ	85 (*3)	These channels are seen
d, s, b	377 (*3)	
u, c	298 (*2)	
each light neutrino family	170 (*?)	← This channel is not. But it contributes to Γ_Z
sum, with 3 neutrino families	2492±10 MeV	
LEP measurement	2487±10 MeV	→ 2492 ± 7

Number of neutrino families = number of families of matter = 3.00 0.05 → 3.04 ±.04


Helen Susskind '90
Glasgow

MAP Satellite (NASA) took launched 2001



Mission Overview

Launch: Fall 2001 on a Delta II 7425-10

Orbit: Halo orbit about L2 Sun-Earth Lagrange point, 1.5 million km (1 million miles) from Earth

Lifetime: 27 months (3 months transit to L2, 24 months observing)

Mass: 800 kg (approx)

Power: 400 W (approx)

Instrument Overview

Radiometer: Differential pseudo-correlation with polarization

Optics: Dual Gregorian, 1.4 x 1.6 m primary reflectors

Thermal: Passive radiative cooling to < 95 K

Frequencies (GHz):	22	30	40	60	90
Resolution (FWHM, deg):	.93	.68	.47	.35	.21
Number of Channels:	4	4	8	8	16

WMAB Bennet et al Astro-ph/0302207

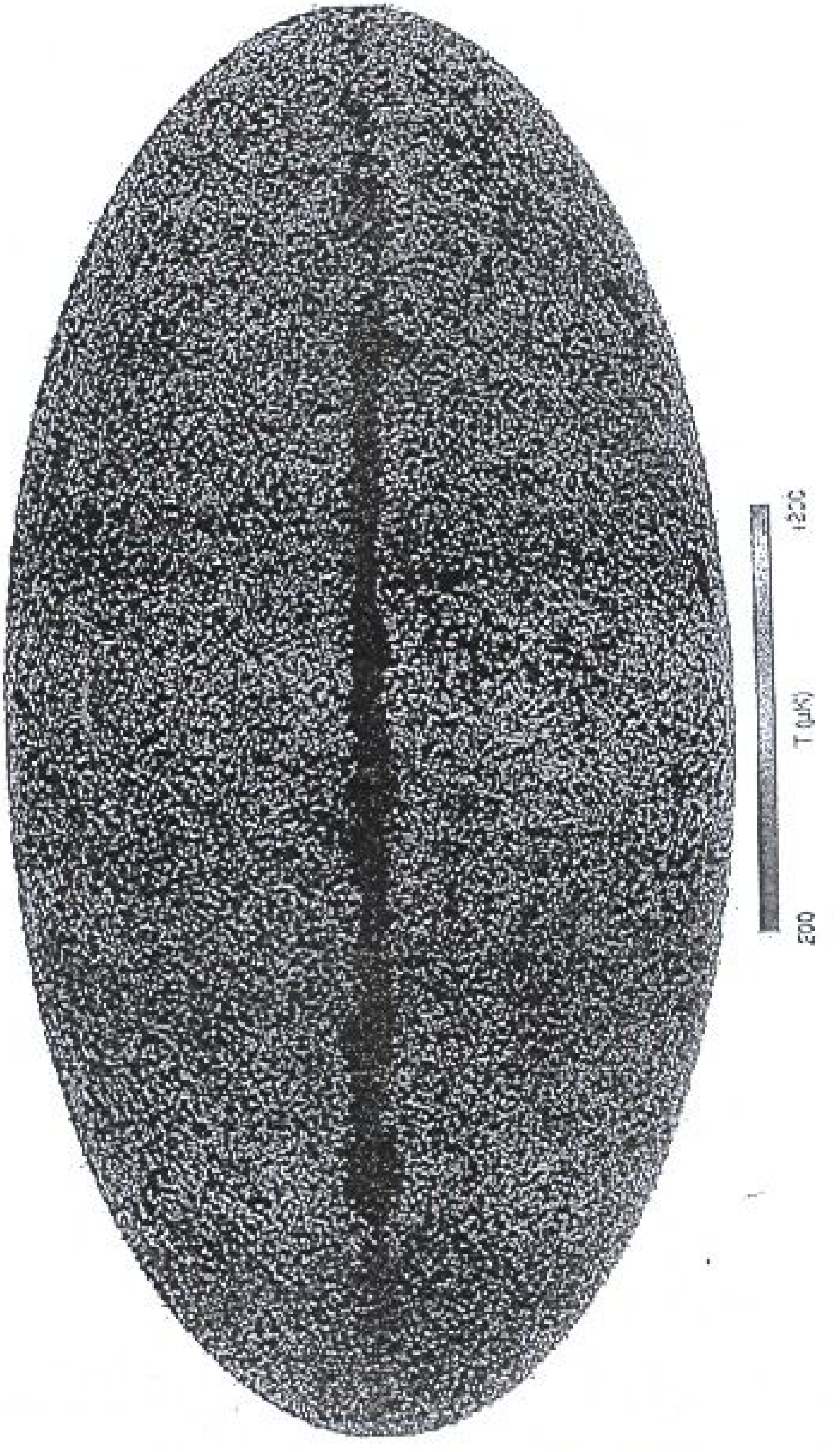


Fig. 2e.— W-band. *A higher quality rendering is available on the LAMBDA web site.*

arXiv:astro-ph/0302207 v2 11 Feb 2003

First Year Wilkinson Microwave Anisotropy Probe (*WMAP*) Observations: Determination of Cosmological Parameters

D. N. Spergel[2], L. Verde[2,3], H. V. Peiris[2], E. Komatsu[2], M. R. Nolta[4], C. L. Bennett[5], M. Halpern[6], G. Hinshaw[5], N. Jarosik[4], A. Kogut[5], M. Limon[5,7], S. S. Meyer[8], L. Page[4], G. S. Tucker[5,7,9], J. L. Weiland[10], E. Wollack[5], & E. L. Wright[11]

Table 7. Best Fit Parameters: Power Law ΛCDM

	WMAP	WMAPext[a]	WMAPext+2dFGRS	WMAPext+ 2dFGRS+ Lyman α
A	0.9 ± 0.1	0.8 ± 0.1	0.8 ± 0.1	$0.75^{+0.08}_{-0.07}$
n_s	0.99 ± 0.04	0.97 ± 0.03	0.97 ± 0.03	0.96 ± 0.02
τ	$0.166^{+0.076}_{-0.071}$	$0.143^{+0.071}_{-0.062}$	$0.148^{+0.073}_{-0.071}$	$0.117^{+0.057}_{-0.053}$
h	0.72 ± 0.05	0.73 ± 0.05	0.73 ± 0.03	0.72 ± 0.03
$\Omega_m h^2$	0.14 ± 0.02	0.13 ± 0.01	0.134 ± 0.006	0.133 ± 0.006
$\Omega_b h^2$	0.024 ± 0.001	0.023 ± 0.001	0.023 ± 0.001	0.0226 ± 0.0008
χ^2_{eff}/ν	1431/1342	1440/1352	1468/1381	...[b]

[a] WMAP +CBI+ACBAR

[b] Since the Lyman α data points are correlated, we do not quote an effective χ^2 for the combined likelihood including Lyman α data (see Verde et al. (2003)).

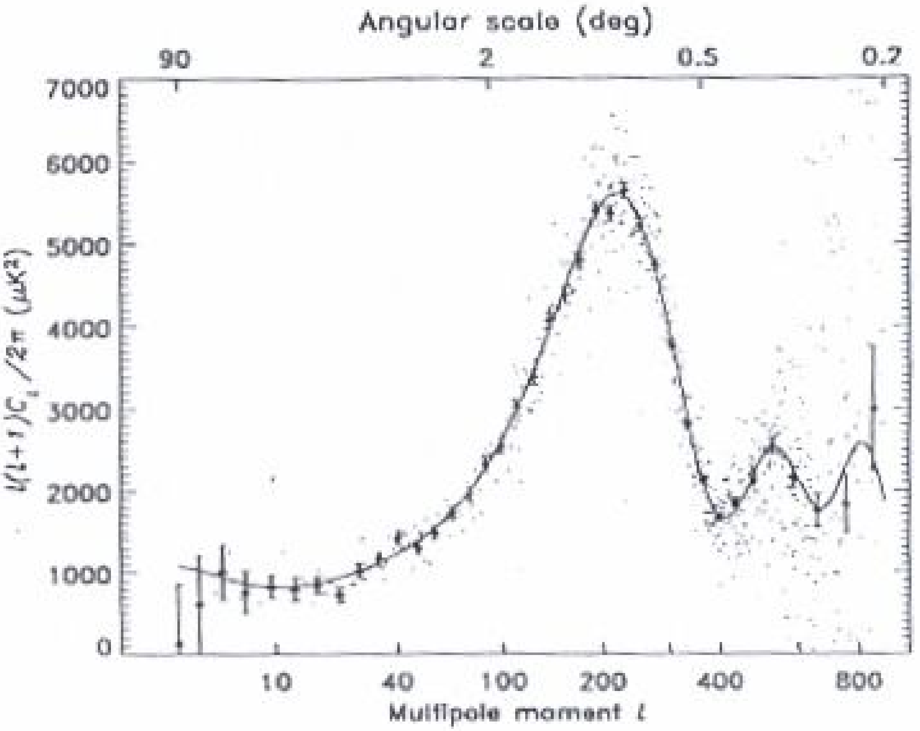


Fig. 1.— This figure compares the best fit power law ΛCDM model to the *WMAP* temperature angular power spectrum. The gray dots are the unbinned data.

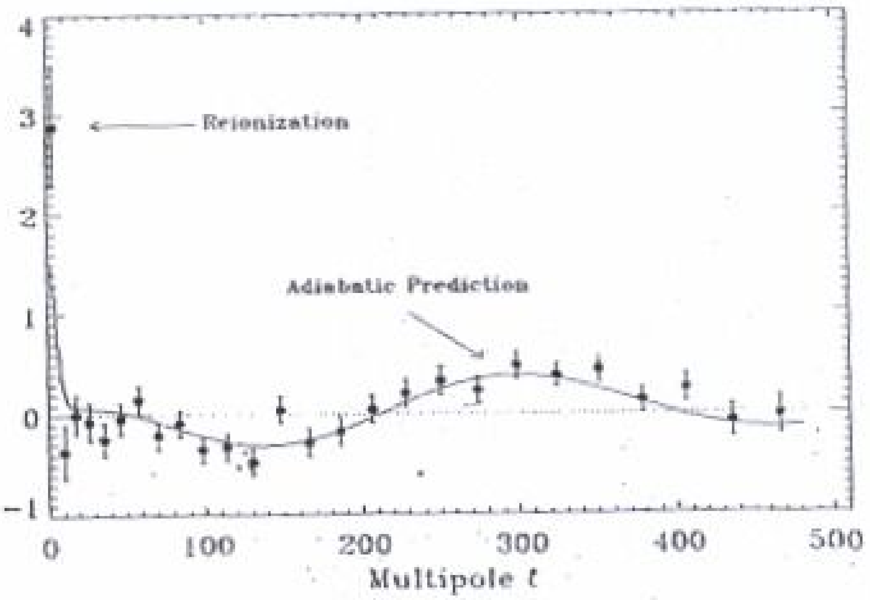


Fig. 2.— This figure compares the best fit power law ΛCDM model to the *WMAP* temperature angular power spectrum.