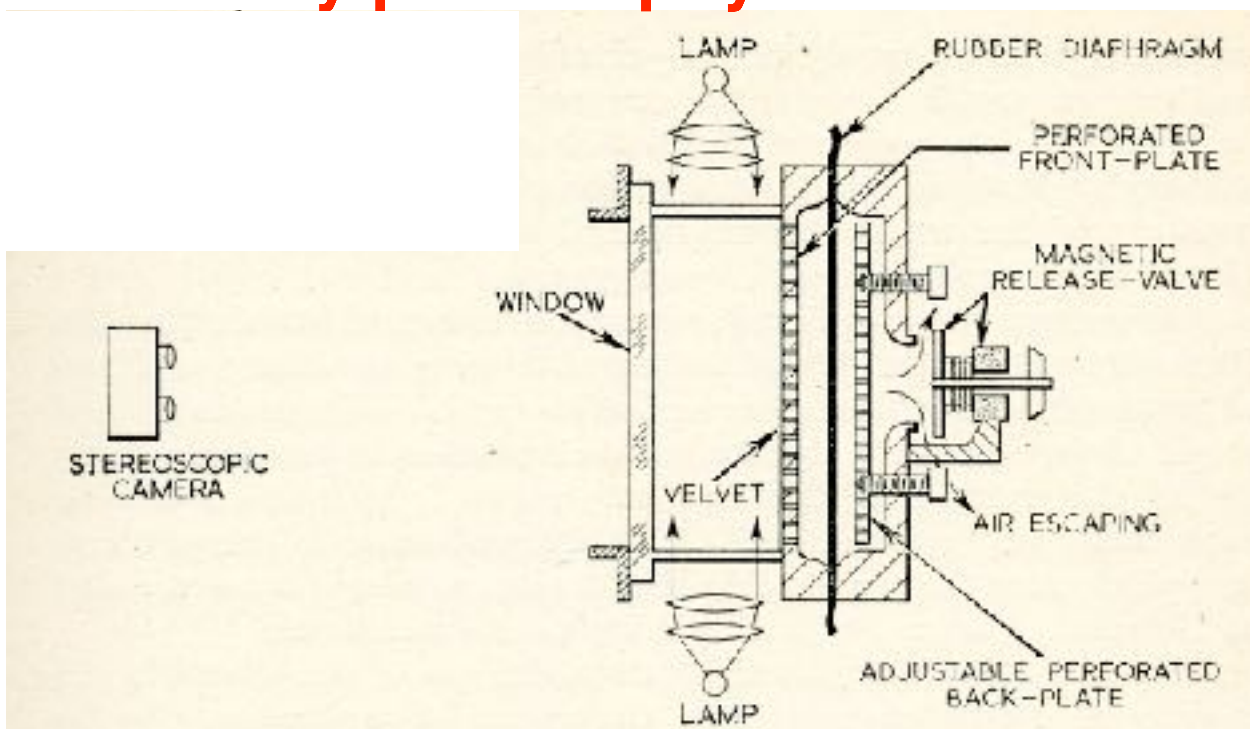
~1930 „elementary particles“:

		charged	neutral		
Rutherford	(1919)	p	n	(1932)	Chadwick
Thomson	(1897)	e^-	γ	(1905/26)	Einstein

Discovery of new particles in cosmic rays
~1930 – 1950
birth of elementary particle physics

cloud chamber
C.T.R. Wilson
Nobel Prize 1927



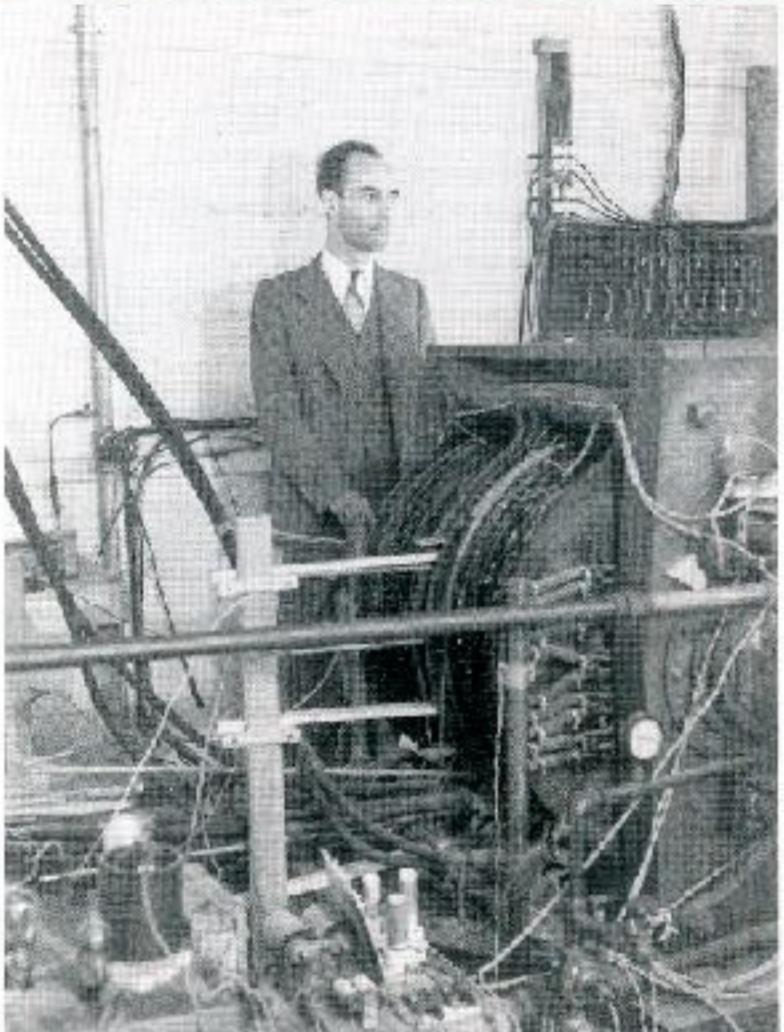
MARCH 15, 1933 PHYSICAL REVIEW VOLUME 43

Nobel Prize 1936

The Positive Electron e^+

CARL D. ANDERSON, *California Institute of Technology, Pasadena, California*

(Received February 28, 1933)



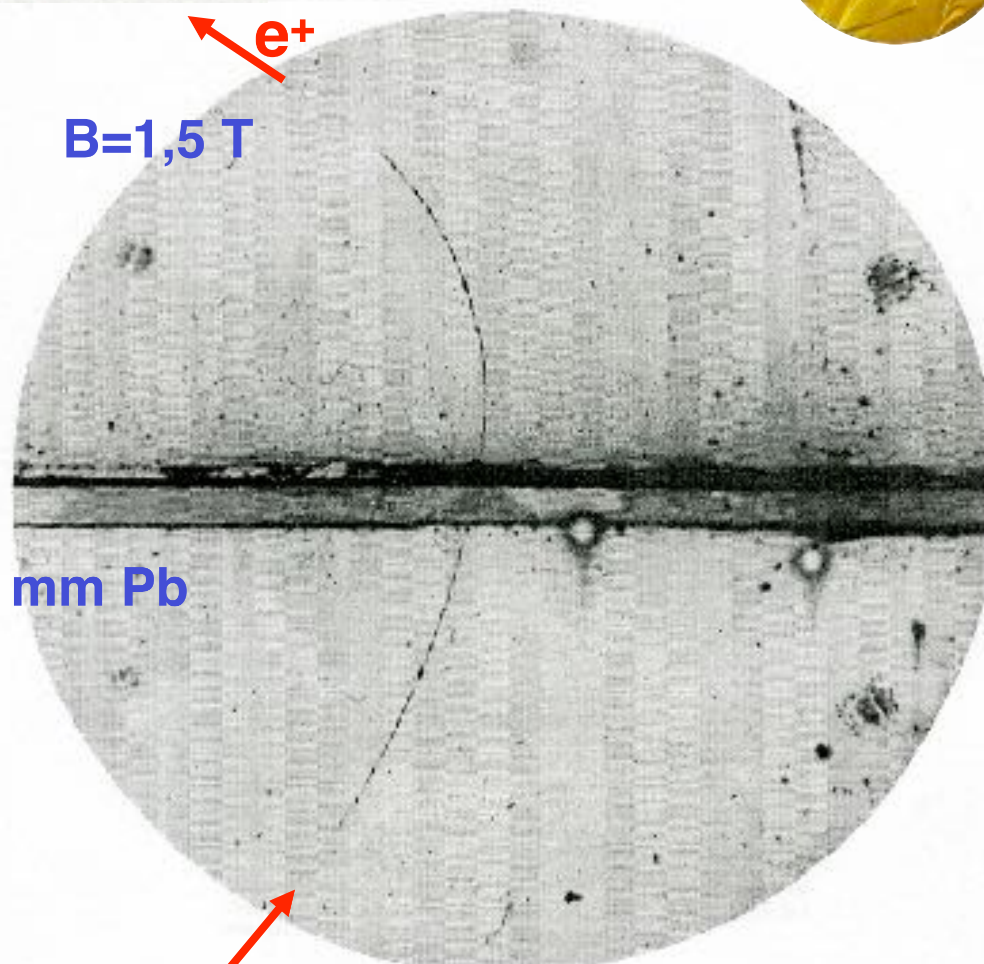
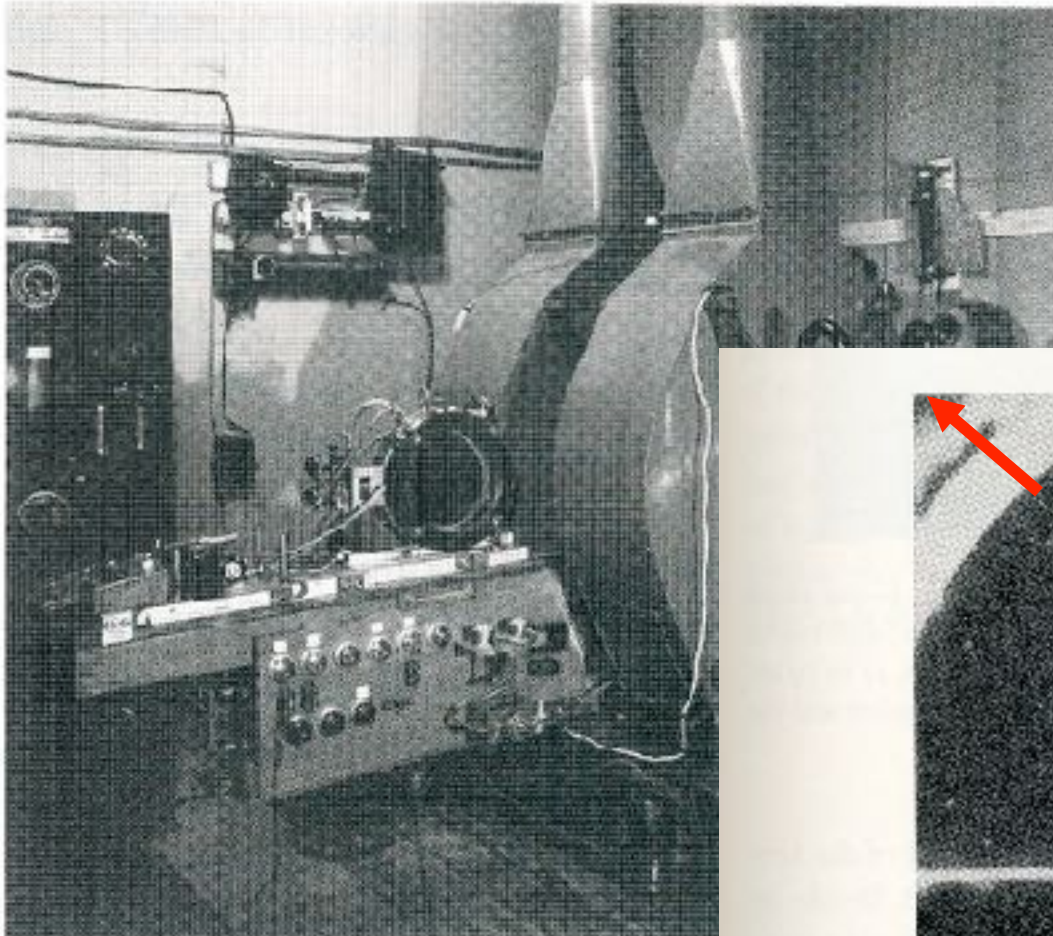


FIG. 1. A 63 million volt positron ($H\rho = 2.1 \times 10^5$ gauss-cm) passing through a 6 mm lead plate and emerging as a 23 million volt positron ($H\rho = 7.5 \times 10^4$ gauss-cm). The length of this latter path is at least ten times greater than the possible length of a proton path of this curvature.

P.M.S. Blackett
Nobel Prize 1948



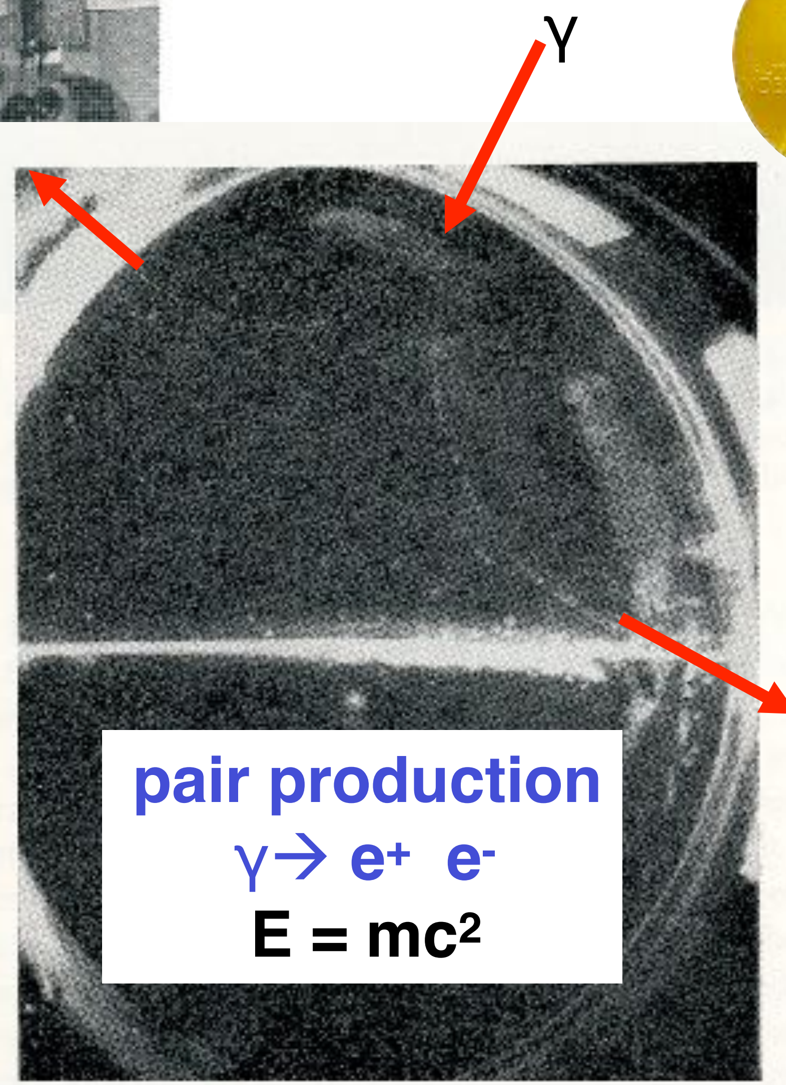


Fig. 9. Pair of positive and negative electrons produced by gamma rays. (Chadwick, Blackett, and Occhialini, 1934)

1933 Blackett & Occhialini

10 t electromagnet
30 cm cloud chamber

Electromagnetic Cascades B. Rossi 1933

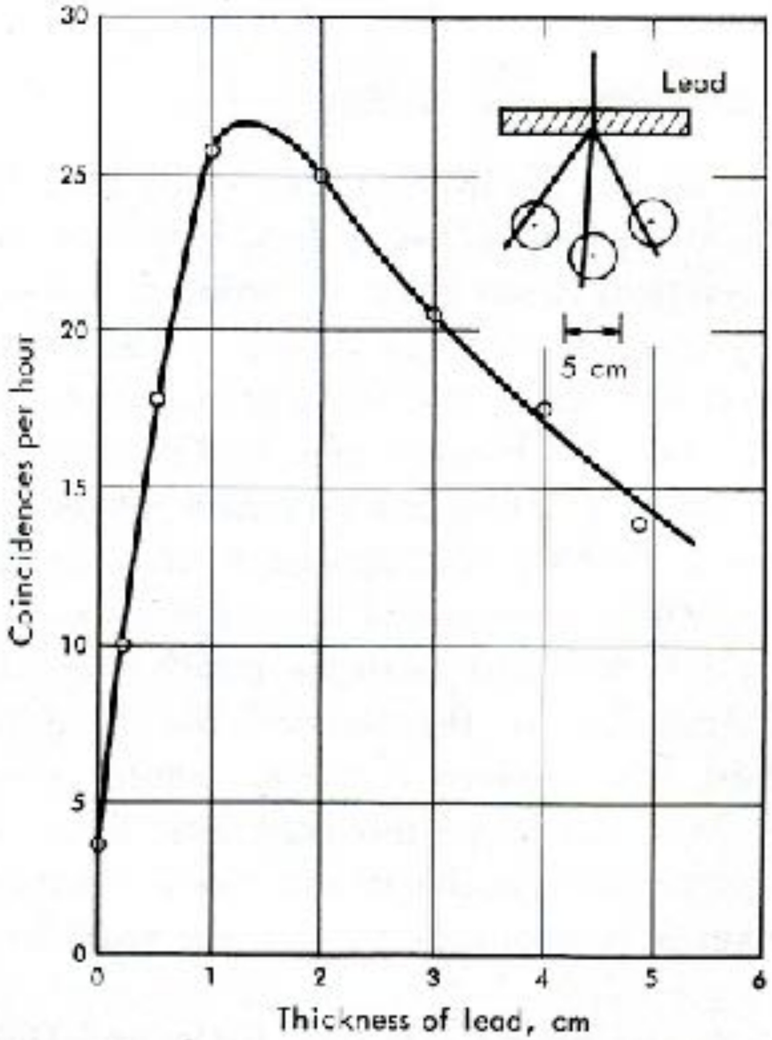


Fig. 7-1 Shower curve. The number of coincidences per hour is plotted as a function of the thickness of lead above the counters. The experimental arrangement is shown schematically in the inset. The circles are experimental points. (This figure is based on one appearing in a paper by the author in *Zeitschrift für Physik*, vol. 82, p. 151, 1933.)

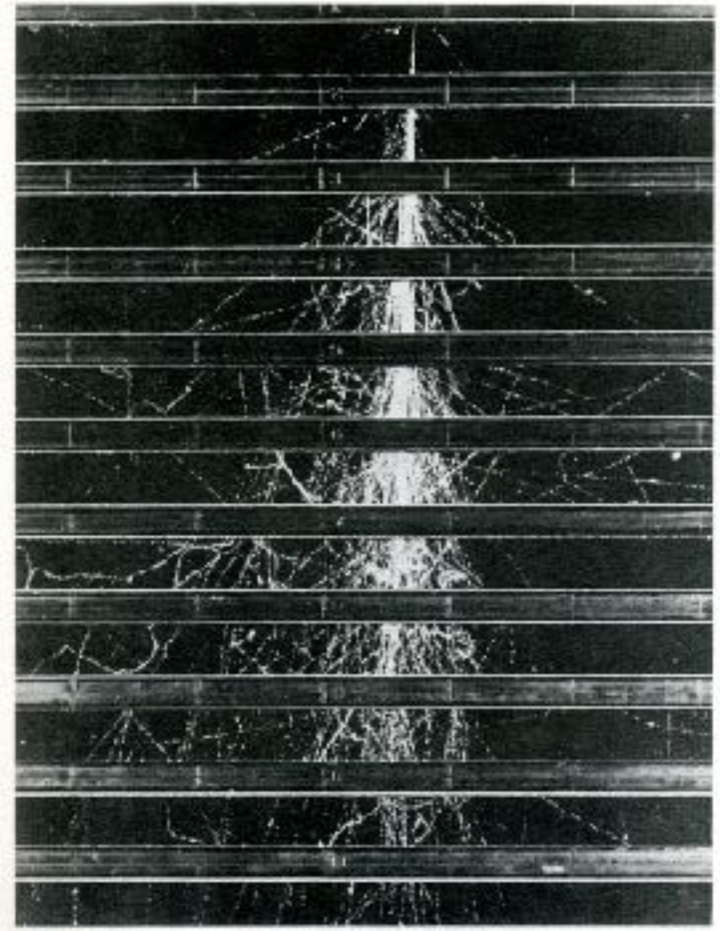


Fig. 7-5 A shower developing through a number of brass plates 1.25 cm thick placed across a cloud chamber. The shower was initiated in the top plate by an incident high-energy electron or photon. The photograph was taken by the MIT cosmic-ray group.

$\gamma \rightarrow e^+ e^-$

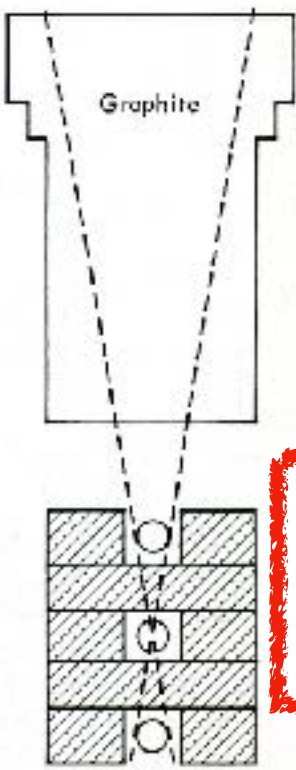
$e^{+/-} \rightarrow \gamma$

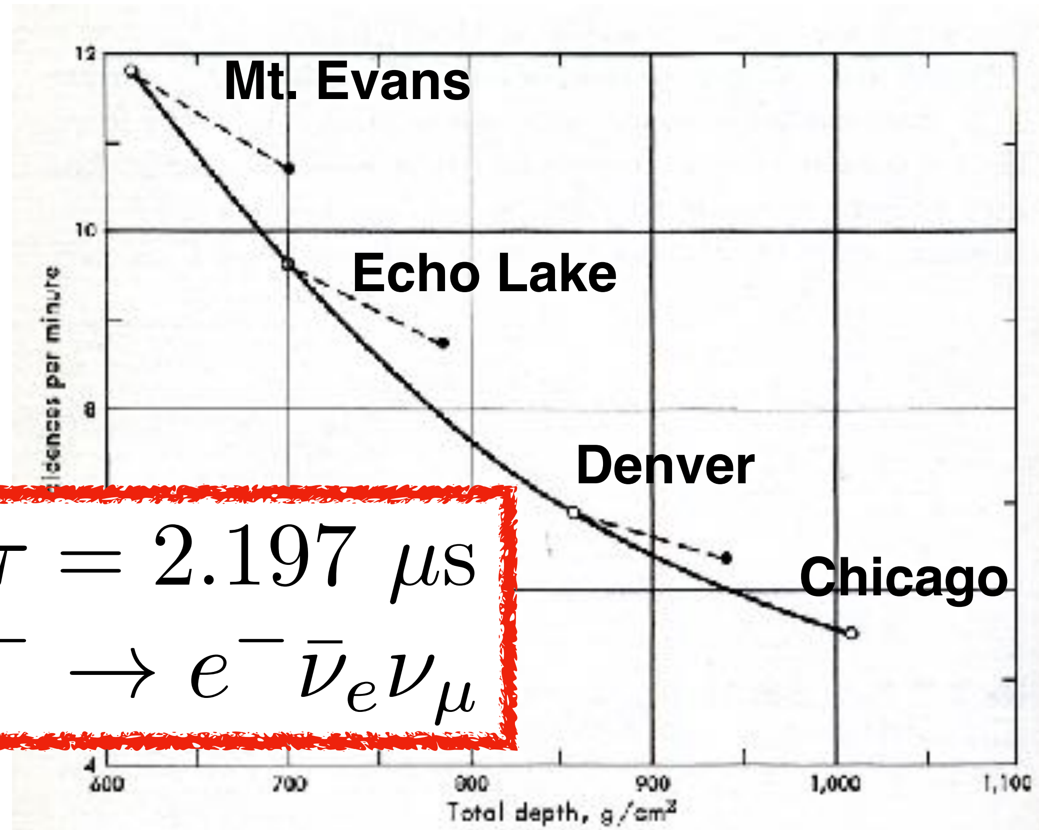
Discovery of the Muon

1937 Anderson & Neddermeyer: μ in cloud chamber

$m_\mu \sim 200\, m_e$

1939 B. Rossi: life time





PDG: $\tau = 2.197\ \mu s$

$$\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$$

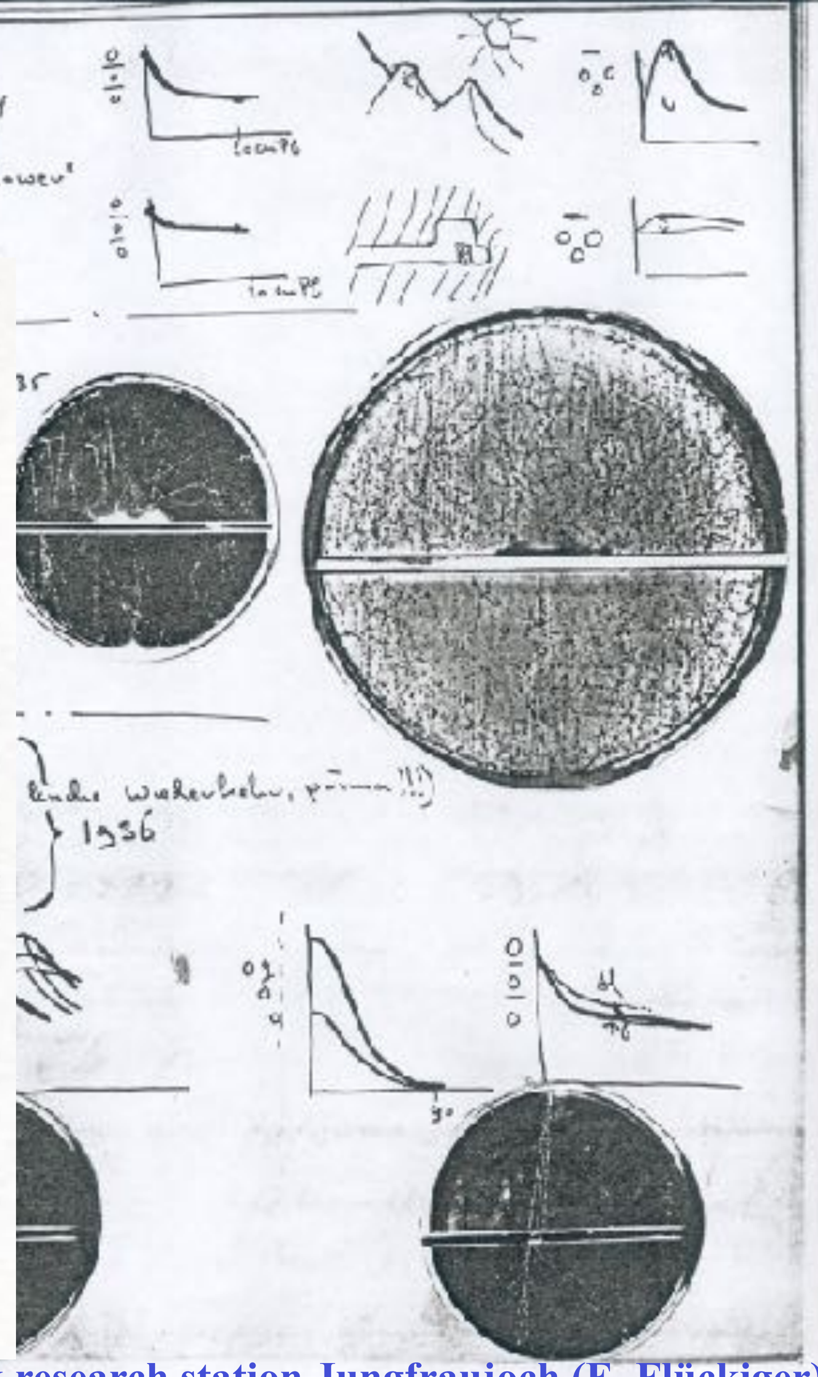
➡ life time $\tau \sim 2\ \mu s$ $\qquad$ $\mu \rightarrow e + \ldots$

P. Auger Jungfraujoch

Measuring Cosmic Rays in the Swiss Alps

The author (*left*) and his collaborator, P. Ehrenfest, set up their apparatus in the Jungfraujoch.

P. Auger et al., Comptes renduz 206 (1938) 1721



Guest book research station Jungfraujoch (E. Flückiger)

Kurze Originalmitteilungen.

Für die kurzen Originalmitteilungen ist ausschließlich der Verfasser verantwortlich.

Gekoppelte Höhenstrahlen.

coupled „high-altidute rays“

Bei Bestimmungen der Zufallskoinzidenzen hoch auflö- der Zählrohrverstärkeranordnungen (bis $5 \cdot 10^{-7}$ sec) ergab sich eine wesentlich größere Anzahl, als nach den elektrischen Konstanten der Anordnung zu erwarten war, ferner ihre Anzahl abhängig vom gegenseitigen Abstand der Zählrohre, wie z. B. für Zählrohre von 430 qcm wirksamer Oberfläche (90 · 4,8) und $\tau = 5 \cdot 10^{-6}$ sec Tabelle 1 zeigt.

Tabelle 1. Anzahl der zusätzlichen Koinzidenzen je Stunde in Abhängigkeit vom gegenseitigen Abstand der ungepanzerten Zählrohre.

Rohrabstand in m:	1,25	3,75	5,00	7,50	10,00	20,00	75,00
Im Experimentierraum	13,3 ± 2,1	13,3 ± 1,3	13,1 ± 1,3	9,3 ± 1,2	0,4 ± 0,8	—	—
Im Freien	37,5 ± 4,4	—	21,5 ± 2,1	—	10,0 ± 2,2	2,5 ± 1,5	0,7 ± 1,3

Mit zunehmendem Abstand der Zählrohre voneinander nimmt die Anzahl der Zufallskoinzidenzen zunächst dauernd ab, bis sich bei über 10,0 m Abstand (Beobachtungen im Experimentierraum) konstante Werte einstellen und überschüssige Koinzidenzen nicht mehr nachweisbar sind. Wurde ein Bleipanzer (10 · 10 · 40 cm³) so zwischen die Zählrohre gebracht, daß er den Durchgang ein und desselben Strahles durch die beiden horizontal liegenden Rohre hinderte, so änderte sich wesentlich nichts, wie ja nach der Richtungsverteilung der Höhenstrahlen zu erwarten ist. Wohl aber machten sich die zusätzlichen Koinzidenzen nicht mehr bemerkbar, wenn die Rohre allseitig durch 10 cm Blei geschirmt wurden. Dann erhielt man auch bei nahe aneinanderliegenden Rohren dieselben konstanten Werte für τ wie bei über 10 m Abstand ungepanzert. Die zusätzlichen Koinzidenzen mußten demnach von Strahlen herrühren, die durch 10 cm Blei weitgehend absorbiert werden. Bei starker Erhöhung der Stoßzahlen durch radioaktive Bestrahlung wird der Einfluß der Höhenstrahlen unwirksam. Dann ergab sich ebenfalls bei kleinerem Zählrohrabstande (5 m) der Wert des Auflösungsvermögens, der 1. nach den elektrischen Daten, 2. nach den Bestimmungen mit allseitigem Panzer und 3. nach den Messungen über 10 m Abstand ungepanzert das wahre Auflösungsvermögen der Anordnung darstellt.

Nur bei statistisch verteilten und voneinander unabhängigen Einzelstößen N_1 und N_2 der beiden Zählrohre gilt die Beziehung $K_z = 2 N_1 N_2 \tau$ zur Bestimmung des Auflösungsvermögens τ. Es müssen also bei ungeschirmten und zu nahe ...

Strahlen im Schauer. Unter der Decke des Experimentierraumes sind diese Sekundärstrahlen über eine Fläche von mindestens 60 qm sicher nachweisbar.

Sollten sie bevorzugt in ... würden nach der Geometri... bis zu 80° aus ihrer urs... worden sein. Indessen ist ... von nur 1 cm Blei und d... Strahlen von $\mu_{Pb} = 0{,}12$ cm ... überwiegend in der Atmos... Boden erzeugt werden. D... bierende als strahlenauslös... Freien eine größere Anzahl ... dingungen zu erwarten ist. ... mit der 2-fach-Koinzidenz... die zusätzlichen Koinziden... 20 m sicher beobachtet we... strahlen im Freien sogar b... (Tabelle 1). Selbst bei 75 m ... Überschuß vorhanden, der ... reihen sichergestellt werde...

Aus dem niedrigen Abso... daß selbst Schauerstrahlen ... dem Boden entstehen, dies... würden dann über eine ... Da für solche Schauer tro... die räumliche Dichte der S... ordentlich gering sein kan... wenn sie als zusätzliche Ko...

Kolhörster discovery of air showers

... wird sich also um Sekundärstrahlen der ... um Schauer, handeln. Das zeigen auch folgende Versuche mit einer 3fachen Koinzidenzapparatur, deren Auflösungsvermögen mit einer besonderen Anordnung zu $5 \cdot 10^{-6}$ sec bestimmt worden war. Bei Aufstellung der Zählrohre horizontal und radial auf einem Kreise ist dann überhaupt keine meßbare Anzahl von Zufallskoinzidenzen zu erwarten (höchstens 10^{-4} Koi/Std.). Es ergaben sich aber bei Zählrohren von 216 qcm wirksamer Fläche

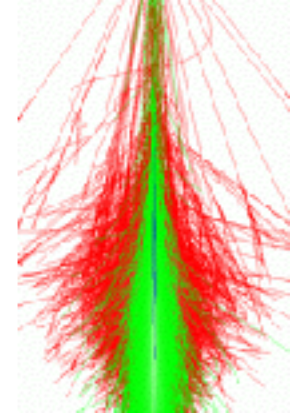
Ungepanzert . . . . . 2,7 ± 0,4 Koi/Std.
1 Rohr gepanzert . . . . 0,7 ± 0,1 Koi/Std.
3 Rohre gepanzert . . . . 0,08 ± 0,02 Koi/Std.

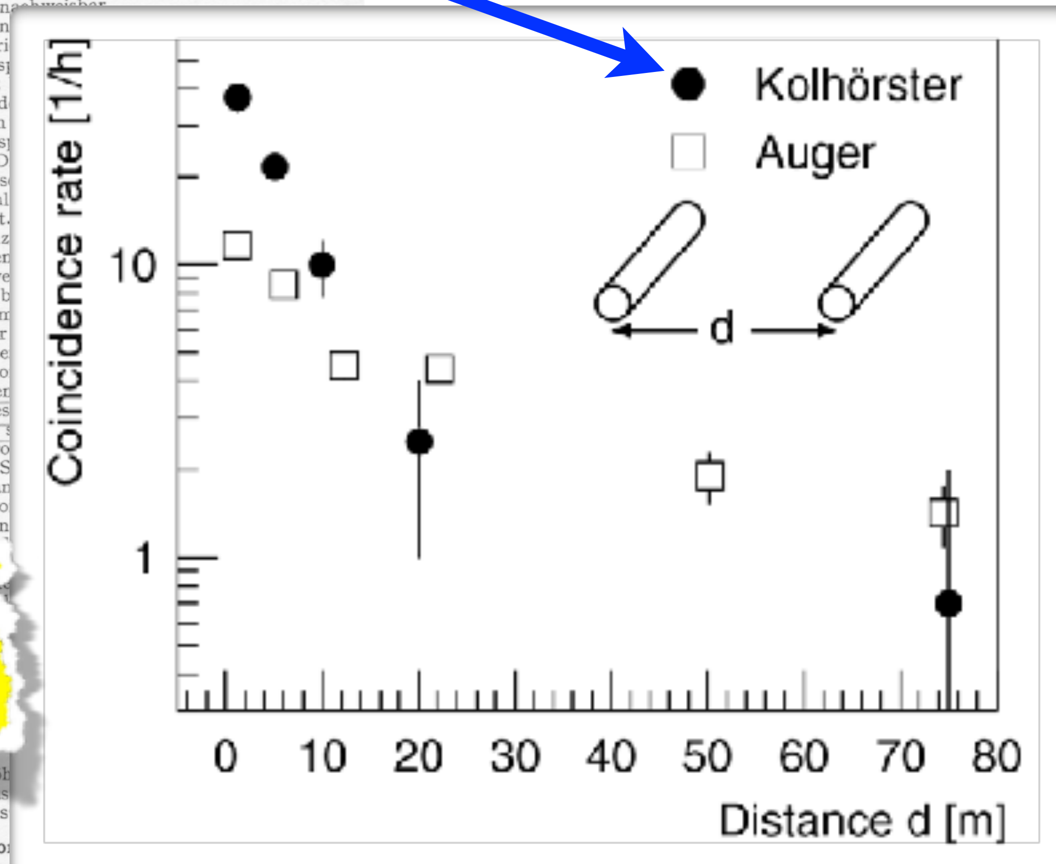
Dresden kurz berichte...
Berlin, Institut für Höh...
tät Berlin, den 25. August ...
W. Kolhörs...

Neue Messungen der Fluo... grüne...

Ein günstiges Versuchsobjekt für quantitative Messungen ist die Meeresalge Ulva lactuca[1]. Sie besteht aus blattartigen, ...

[1] Das Versuchsmaterial verdanken wir dem Entgegenkommen der Staatlichen Biologischen Anstalt auf Helgoland.



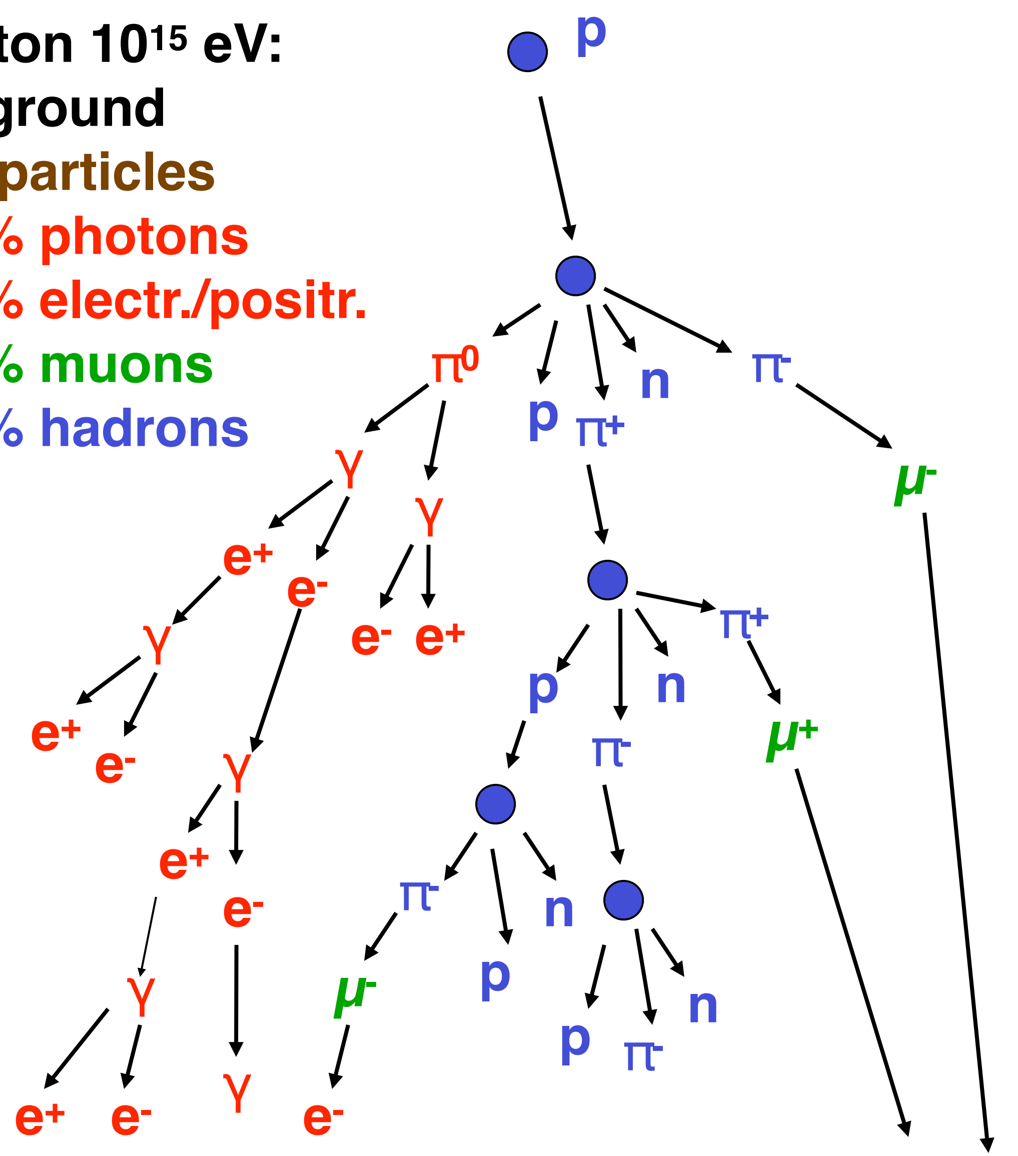


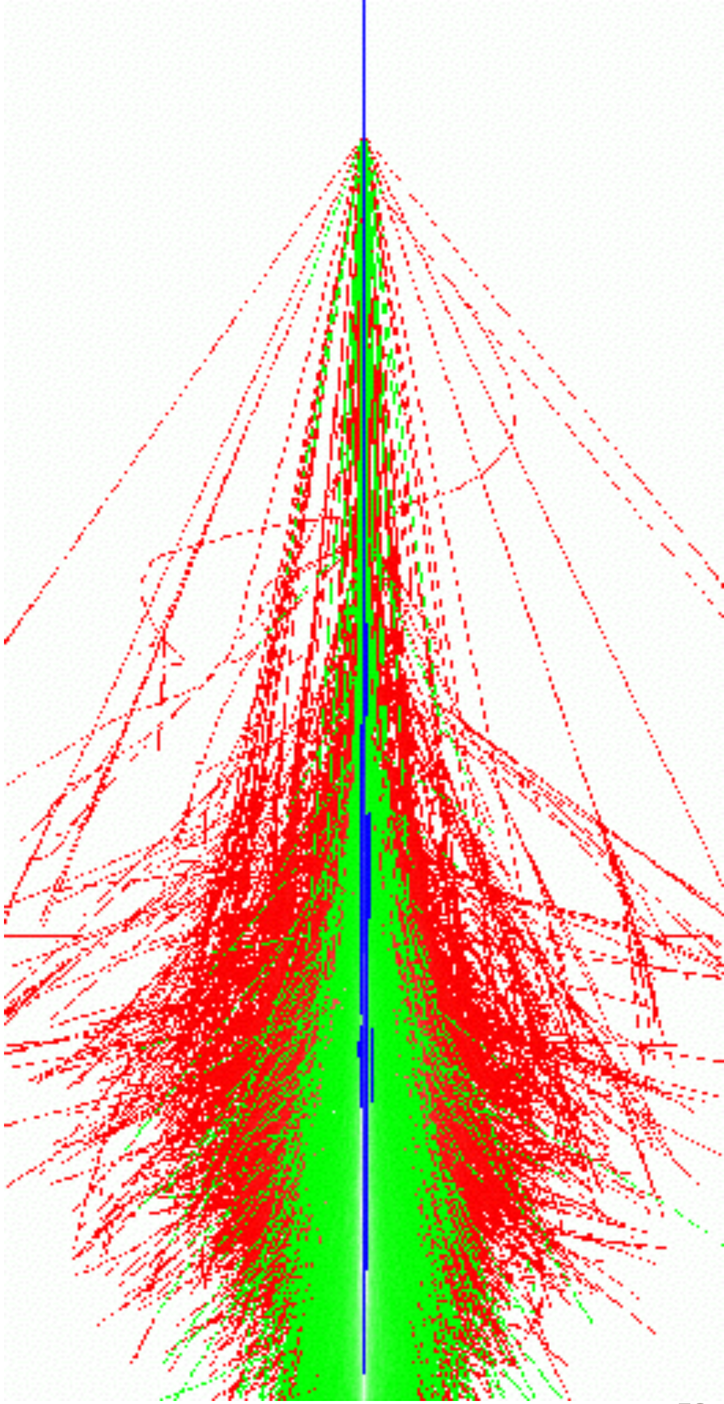
P. Auger et al., Comptes renduz 206 (1938) 1721

W. Kolhörster et al., Naturwiss. 26 (1938) 576

Extensive Air Shower

Proton 10^{15} eV:
on ground
10^{6} particles
80% photons
18% electr./positr.
1.7% muons
0.3% hadrons





electromagnetic **hadronic** **muonic**
shower component

~ 1950 large detector arrays to measure extensive air showers

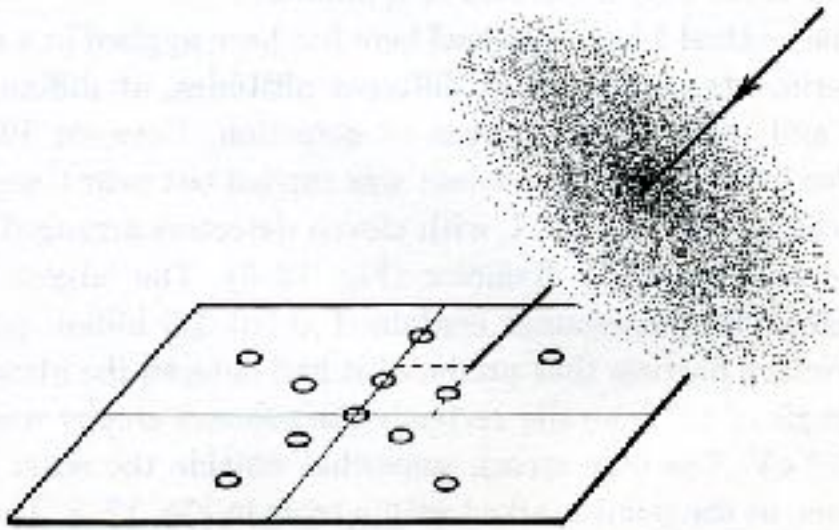


Fig. 12-4 Shower disk approaching detectors (represented by circles on a horizontal plane).

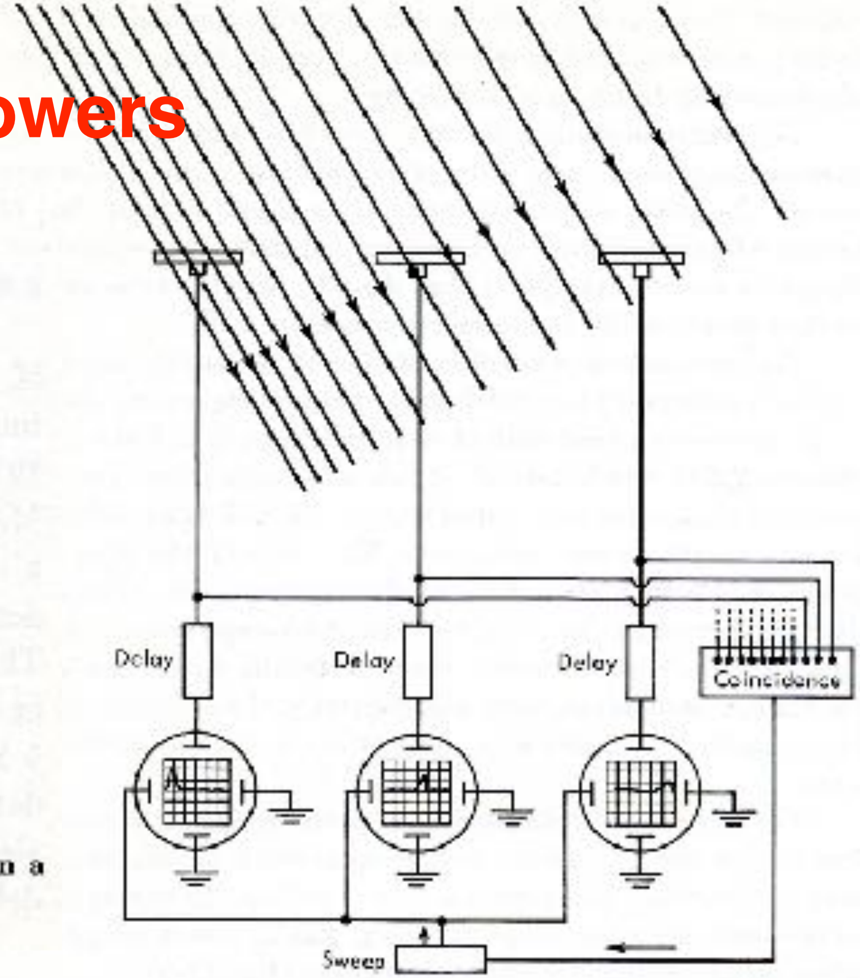


Fig. 12-3 Experimental arrangement used by the MIT cosmic-ray group to study air showers. Fluorescent plastic disks (thin rectangles at top) emit flashes of light when struck by charged particles. At the center of each disk is a photomultiplier tube that converts the light into an electrical pulse; the amplitude of the pulse is proportional to the brightness of the flash. Pulses travel to cathode-ray oscilloscopes (circles) through transmission lines containing delay circuits, which equalize the lengths of the electrical paths. Horizontal sweeps of all oscilloscope screens (grids) are triggered at the same time whenever three or more pulses pass through the coincidence circuit simultaneously. The amplitudes of the "spikes" (that is, the heights of the vertical deflections in the oscilloscope traces) indicate the numbers of particles striking the corresponding detectors. The positions of the spikes in the horizontal traces show the relative arrival times of the particles.

B. Rossi

EVIDENCE FOR A PRIMARY COSMIC-RAY PARTICLE WITH ENERGY 10^{20} eV†

John Linsley
Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received 10 January 1963)

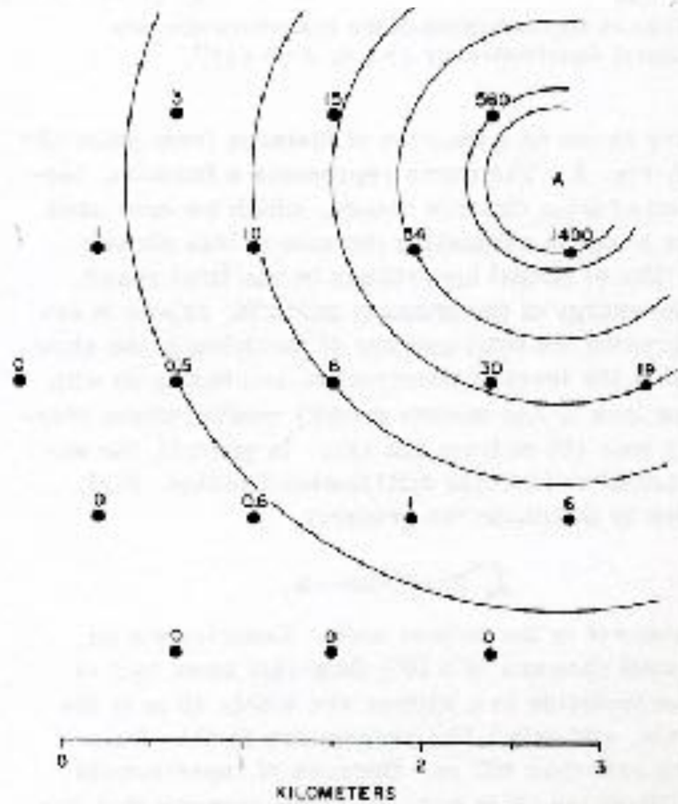
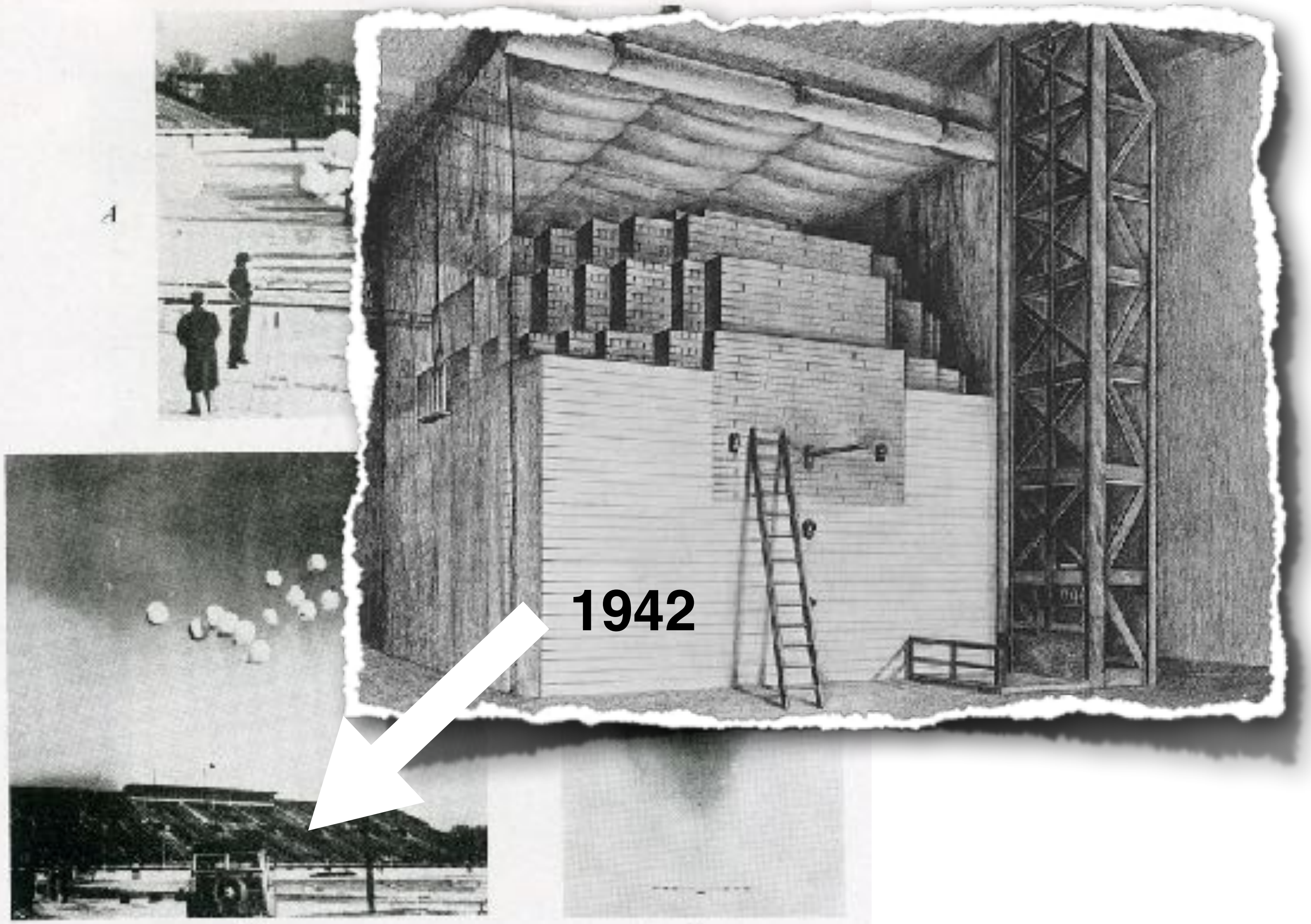


FIG. 1. Plan of the Volcano Ranch array in February 1962. The circles represent 3.3-m^2 scintillation detectors. The numbers near the circles are the shower densities (particles/m^2) registered in this event, No. 2-4834. Point "A" is the estimated location of the shower core. The circular contours about that point aid in verifying the core location by inspection.

1943

The University of Chicago



P. Auger

BALLOON FLIGHT OF JANUARY, 1943, CONDUCTED BY THE AUTHOR, SCHEIN, AND ROGOZINSKI FOR THE MEASUREMENT OF EXTENSIVE (OR AUGER-) SHOWERS IN THE STRATOSPHERE

A. The balloons are assembled on Stagg Field at the University of Chicago, Chicago, Illinois. In the foreground can be seen the long frame which was required for the wide separation of the cosmic-ray counters.

B. The large cluster of balloons as it is about to be released.

C. The balloon train sails into the sky after its release. Suspended below the balloons is the frame supporting the counters and recording apparatus.

Fig. 1. Participants at the Cosmic Ray Conference (Symposium on Cosmic Rays, 1939) convened at the University of Chicago in the summer of 1939. The identification of participants is given by numbers in the over lay of this photograph as follows:

1. H. Bethe
2. D. Froman
3. R. Brode
4. A.H. Compton
5. E. Teller
6. A. Baños, Jr.
7. G. Groetzinger
8. S. Goudsmit
9. M.S. Vallarta
10. L. Nordheim
11. J.R. Oppenheimer
12. C.D. Anderson
13. S. Forbush
14. Nielsen (of Duke U.)
15. V. Hess
16. V.C. Wilson
17. B. Rossi
18. W. Bothe
19. W. Heisenberg
20. P. Auger
21. R. Serber
22. T. Johnson
23. J. Clay (Holland)
24. W.F.G. Swann
25. J.C. Street (Harvard)
26. J. Wheeler
27. S. Neddermeyer
28. E. Herzog (?)
29. M. Pomerantz
30. W. Harkins (U. of C.)
31. H. Beutler
32. M.M. Shapiro+
33. M. Schein*
34. C. Montgomery (Yale)
35. W. Bostick+
36. C. Eckart
37. A. Code+
38. J. Stearns (Denver?)
39. J. Hopfield
40. E.O. Wollan*
41. D. Hughes+
42. W. Jesse*
43. B. Hoag
44. N. Hillberry+
45. F. Shonka+
46. P.S. Gill+
47. A.H. Snell
48. J. Schremp
49. A. Haas? (Vienna)
50. E. Dershem*
51. H. Jones+

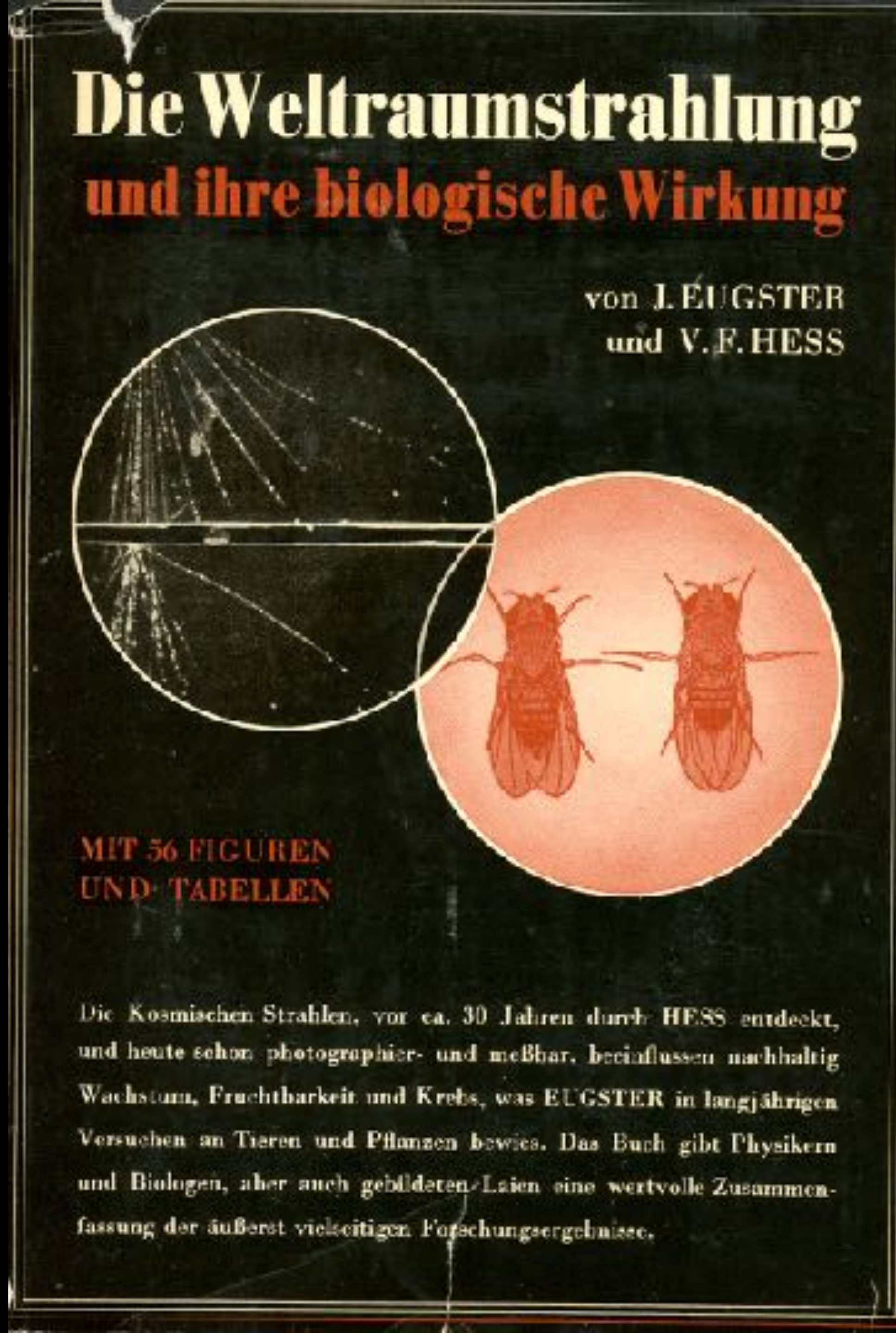
*Then research associate of Compton.

+Then graduate student of Compton.

ICS

C RAYS

AGO


Die Weltraumstrahlung
und ihre biologische Wirkung
von J. EUGSTER
und V. F. HESS
MIT 56 FIGUREN
UND TABELLEN
Die Kosmischen Strahlen, vor ca. 30 Jahren durch HESS entdeckt,
und heute schon photographier- und meßbar, beeinflussen nachhaltig
Wachstum, Fruchtbarkeit und Krebs, was EUGSTER in langjährigen
Versuchen an Tieren und Pflanzen bewies. Das Buch gibt Physikern
und Biologen, aber auch gebildeten Laien eine wertvolle Zusammen-
fassung der äußerst vielseitigen Forschungsergebnisse.

1939

emulsion chambers at high-altitude lab above Innsbruck (Austria)

about it is the simultaneous emission of so many heavy particles with such long ranges, which excludes any confusion with 'stars' due to radioactive contamination. A similar configuration of tracks by chance is equally out of question. Brode and others[1]

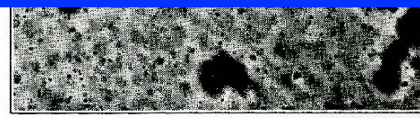


Fig. 1.

observed a single case of a disintegration with three heavy particles in a Wilson cloud chamber. The phenomenon which Wilkins believes was a shower of protons is perhaps a similar process, but he did not observe a centre[2].

TRACK. AN INTERRUPTED LINE MEANS THAT THE TRACK IS TOO LONG TO BE REPRODUCED ON THE SAME SCALE. THE ARROWS INDICATE THE DIRECTION FRO THE SURFACE OF THE EMULSION TO THE GLAS

Disintegration Processes by Cosmic Rays with the Simultaneous Emission of Several Heavy Particles

On photographic plates which had been exposed to cosmic radiation on the Hafelekar (2,300 m. above sea-level) near Innsbruck for five months, we found, apart from the very long tracks (up to 1,200 cm. in length) which have been reported recently in a note in the Wiener Akademie-Berichte, evidence of seve processes described below.

From a single point within the emulsion seve tracks, some of them having a considerable leng take their departure. We observed four cases w three particles, four with four and 'stars' with s seven, eight and nine particles, one of each kind.

The longest track corresponded to a range in (15°, 760 mm. Hg) of 176 cm. The ionization p duced by the particles is different in the differ cases. Most of the tracks show much larger me grain-distances than α-particles and slow protons.

In Fig. 1 a 'star' with eight tracks is reproduc On account of the rather steep angles at which so of the particles cross the emulsion-layer (appro mately 70 μ thick) it is not possible to have all t tracks of a 'star' in focus simultaneously. Fig. shows a sketch of the same 'star'. Measurement the tracks gives the results in the accompanyi table.

Track	Length in cm. of air (15°, 760 mm.)	Number of grains	Position of the end of the track
A	30·0 cm.	113	Within the emulsion
B	11·0 ,,	15	,, ,, ,,
C	44·6 ,,	71	Glass
D	6·2 ,,	11	,,
E	7·0 ,,	22	,,
F	1·2 ,,	5	Within the emulsion
G	13·6 ,,	67	Surface of the emulsion
H	23·9 ,,	58	Glass

Centre of the 'star' 25 μ under the surface of the emulsion.

We believe that the process in question is a disintegration of an atom in the emulsion (probably Ag or Br) by a cosmic ray. The striking feature

The total energy involved in the process cannot as yet be calculated as most of the particles do not end in the emulsion.

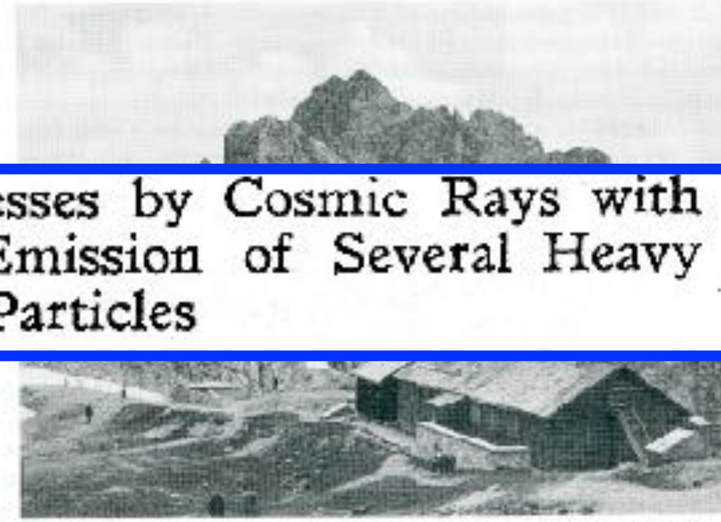
We hope to give further details before long in the Wiener Akademie-Berichte.

M. Blau.
H. Wambacher.

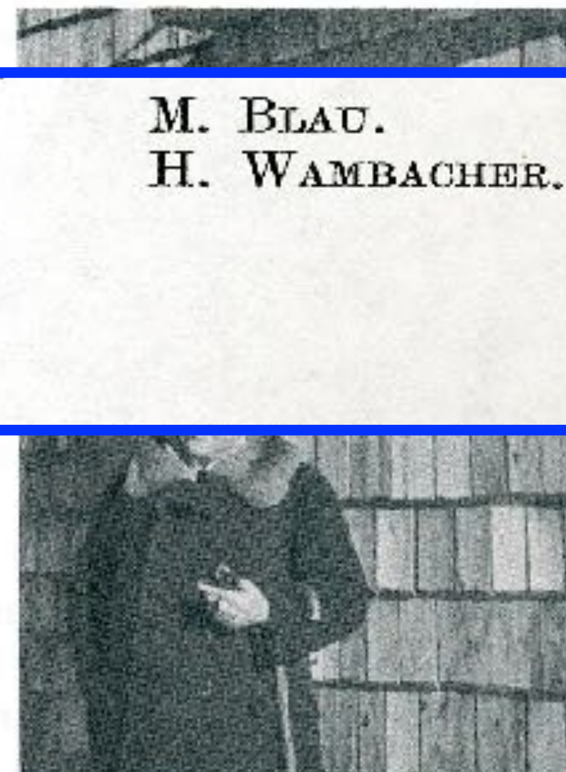
Radium Institut
u. 2 Physik. Institut,
Wien.
Aug. 25.

[1] Brode, R. L., and others, *Phys. Rev.*, 50, 581 (October, 1936).
[2] Wilkins, *Nat. Geog. Soc.*, Stratosphere Series, No. 2, 37 (1936).

Disintegration Processes by Cosmic Rays with the Simultaneous Emission of Several Heavy Particles



Die "Station für Ultrastrahlenforschung" auf dem Hafelekar bei Innsbruck (2300 m), 1950, vor dem späteren Ausbau.



M. Blau.
H. Wambacher.
Radium Institut
u. 2 Physik. Institut,
Wien.
Aug. 25.

JANUARY, 1941 REVIEWS OF MODERN PHYSICS VOLUME 13

Tracks of Nuclear Particles in Photographic Emulsions

MAURICE M. SHAPIRO
Ryerson Laboratory, University of Chicago, Chicago, Illinois

CONTENTS

1947 Discovery of the Pion

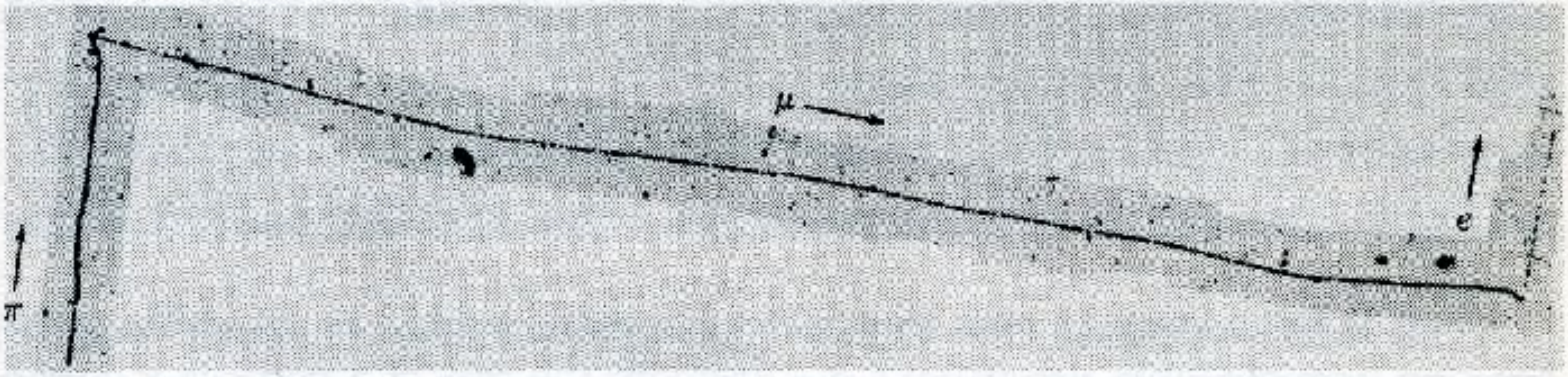


Fig. 9-4 Photomicrograph of tracks in a nuclear emulsion, showing a π meson (π) that comes to rest and decays into a μ meson (μ). The μ meson in turn comes to rest and decays into an electron (e). (From R. H. Brown, U. Camerini, P. Fowler, H. Muirhead, C. F. Powell, and D. M. Ritson, *Nature*, vol. 163, p. 47, 1949.)

C.F. Powell
Nobel Prize 1950

$m_\pi \sim 280\ m_e$

Pion: nuclear interaction

decay $\pi^{+/-} \rightarrow \mu^{+/-} \rightarrow e^{+/-}$

$\pi^0 \rightarrow \gamma\gamma$

End 1940s plastic balloons

Fig. 1. Inflation of balloon of polyethylene just after dawn. The balloon has a total length of about 120 ft and most of the fabric is on the ground. Such a balloon can in favourable conditions give level flight at about 90,000 ft. for many hours with a load of 40 kg.

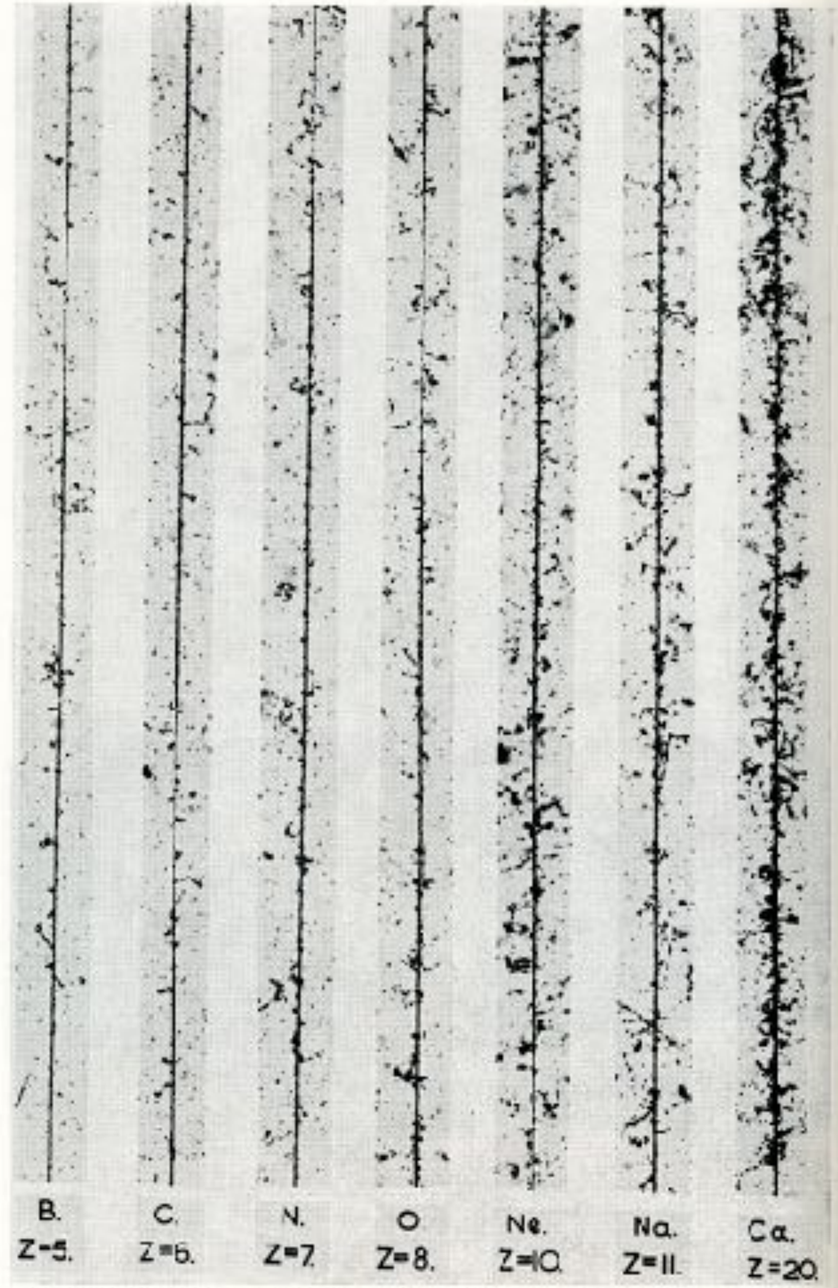


Fig. 2. Examples of the tracks in photographic emulsions of primary nuclei of the cosmic radiation moving at relativistic velocities.

1941 protons (M. Schein)

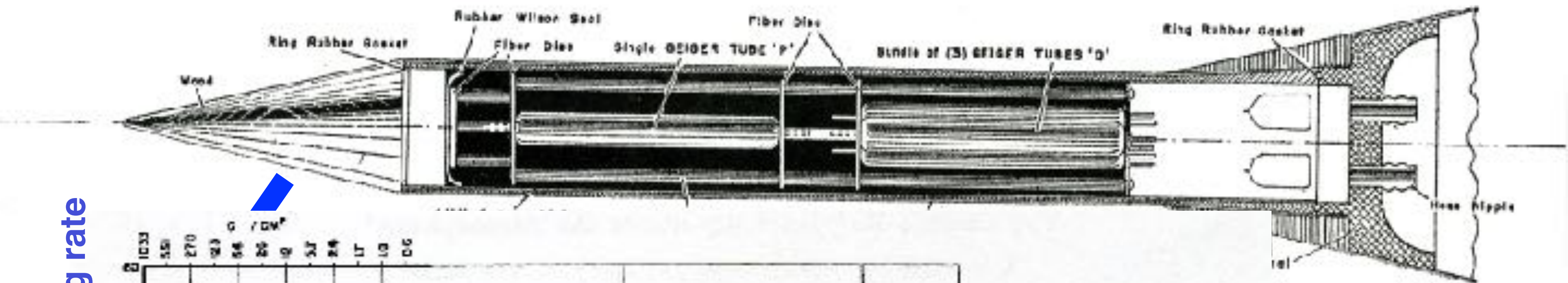
1948 heavy nuclei (Brandt & Peters)

PHYSICAL REVIEW VOLUME 73, NUMBER 3 FEBRUARY 1, 1948

The Cosmic-Ray Counting Rate of a Single Geiger Counter from Ground Level to 161 Kilometers Altitude

J. A. VAN ALLEN AND H. E. TATEL*
Applied Physics Laboratory, Johns Hopkins University, Silver Spring, Maryland

(Received October 16, 1947)



counting rate

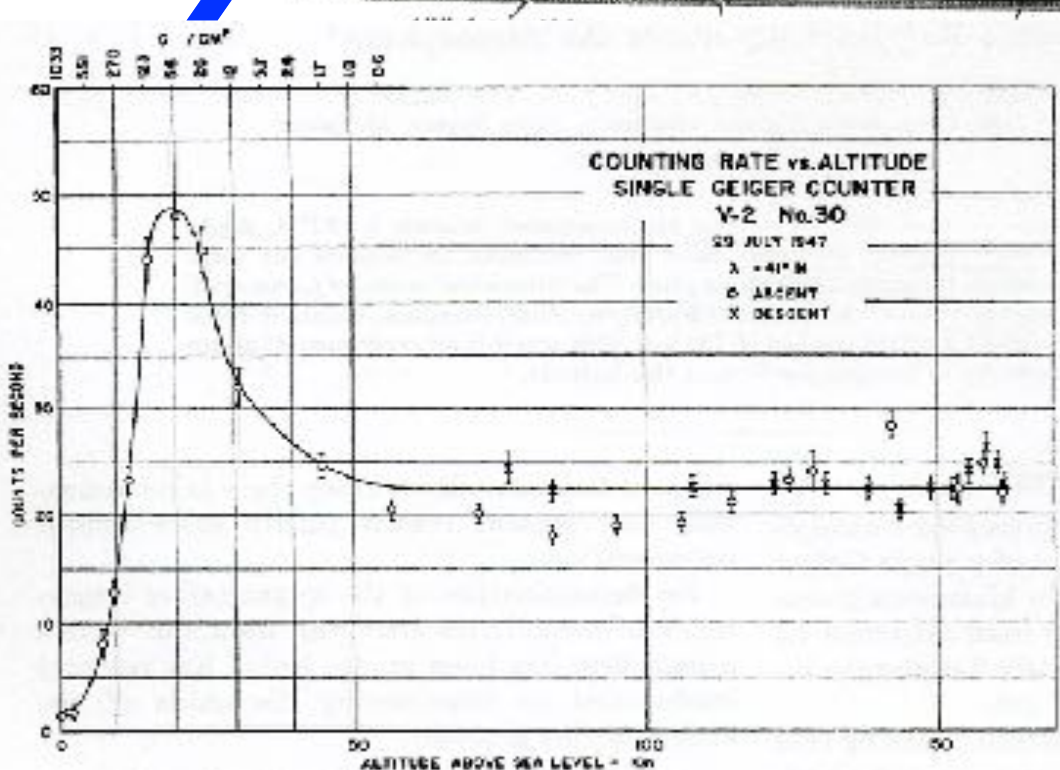
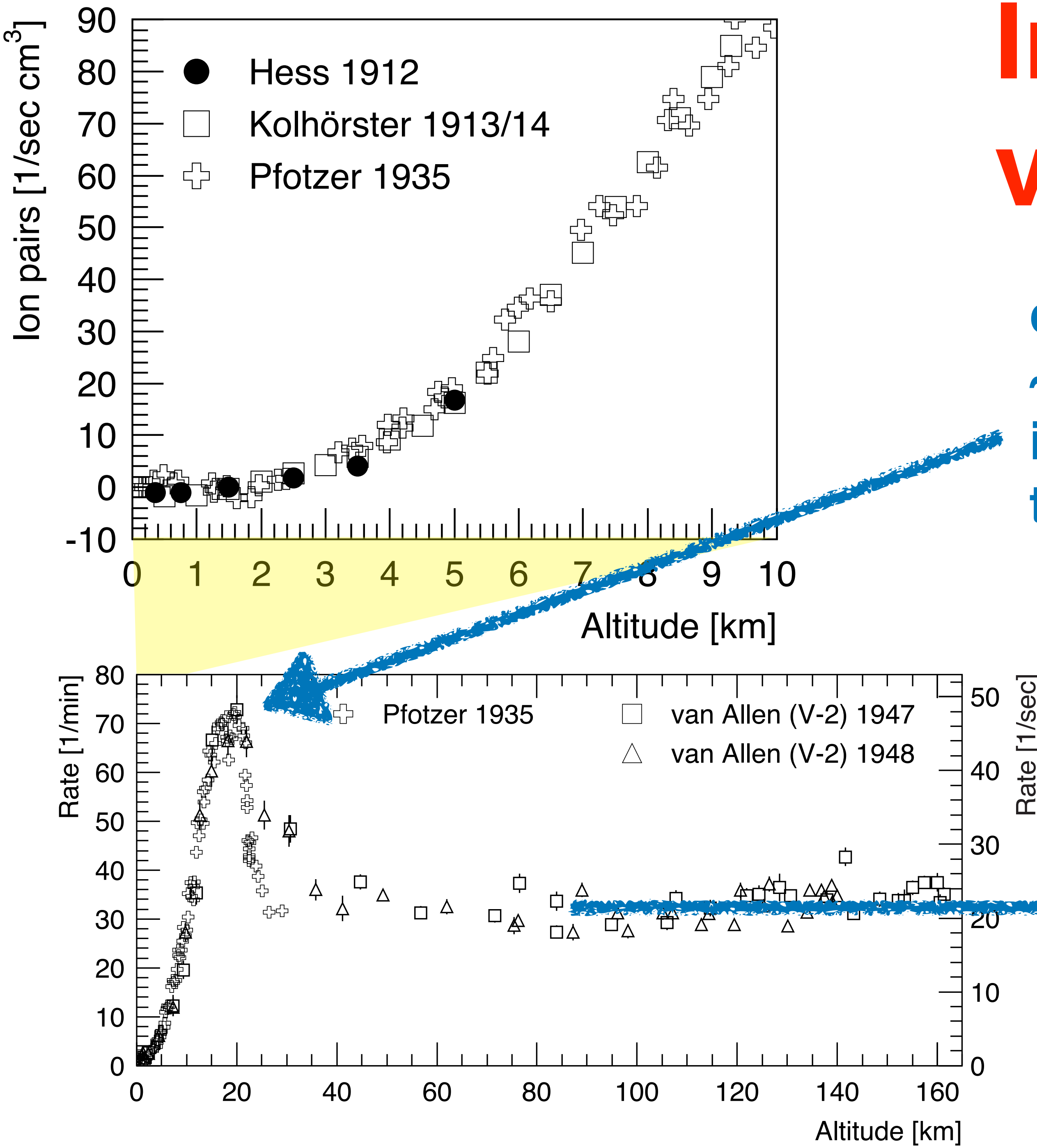


FIG. 1. Counting rate of a single Geiger counter as a function of altitude.

50 km 150 km

Intensity vs. height



cosmic rays with ~GeV energies initiate cascades in the atmosphere

(galactic) cosmic rays

PHYSICAL REVIEW VOLUME 78, NUMBER 6 JUNE 15, 1950

Stars and Heavy Primaries Recorded during a V-2 Rocket Flight

HERMAN YAGODA, HERVASIO G. DE CARVALHO,* AND NATHAN KAPLAN
Laboratory of Physical Biology, Experimental Biology and Medicine Institute,
National Institutes of Health, Bethesda, Maryland

(Received February 23, 1950)

Plates flown to an altitude of 150.7 km in a V-2 rocket exhibit a differential star population of 5000±800 per cc per day and a flux of heavy primaries of about 0.03 per cm² per min. above the stratosphere. The star intensity is about 3.6 times greater than that recorded by plates exposed in the stratosphere, the increment being attributable to secondary star forming radiations created by interaction of cosmic-ray primaries with the massive projectile. The flux of heavy primaries is essentially of the same order of magnitude as reported for elevations of 28 km.

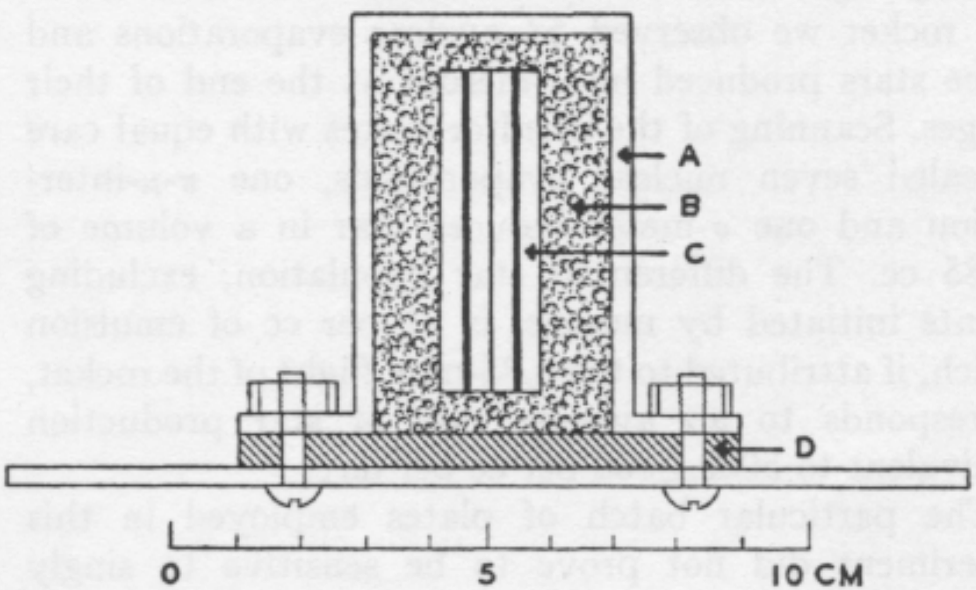


FIG. 1. Cross section of plate holder. A. Aluminum jacket 3 mm thick. B. Sponge rubber packing. C. Plates assembled with emulsion layers adjacent to each other. D. Rubber gasket.

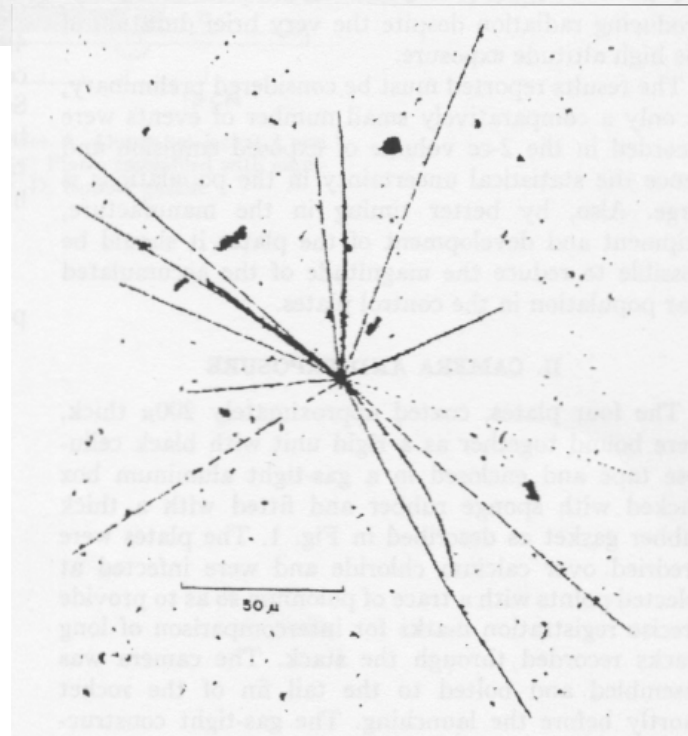
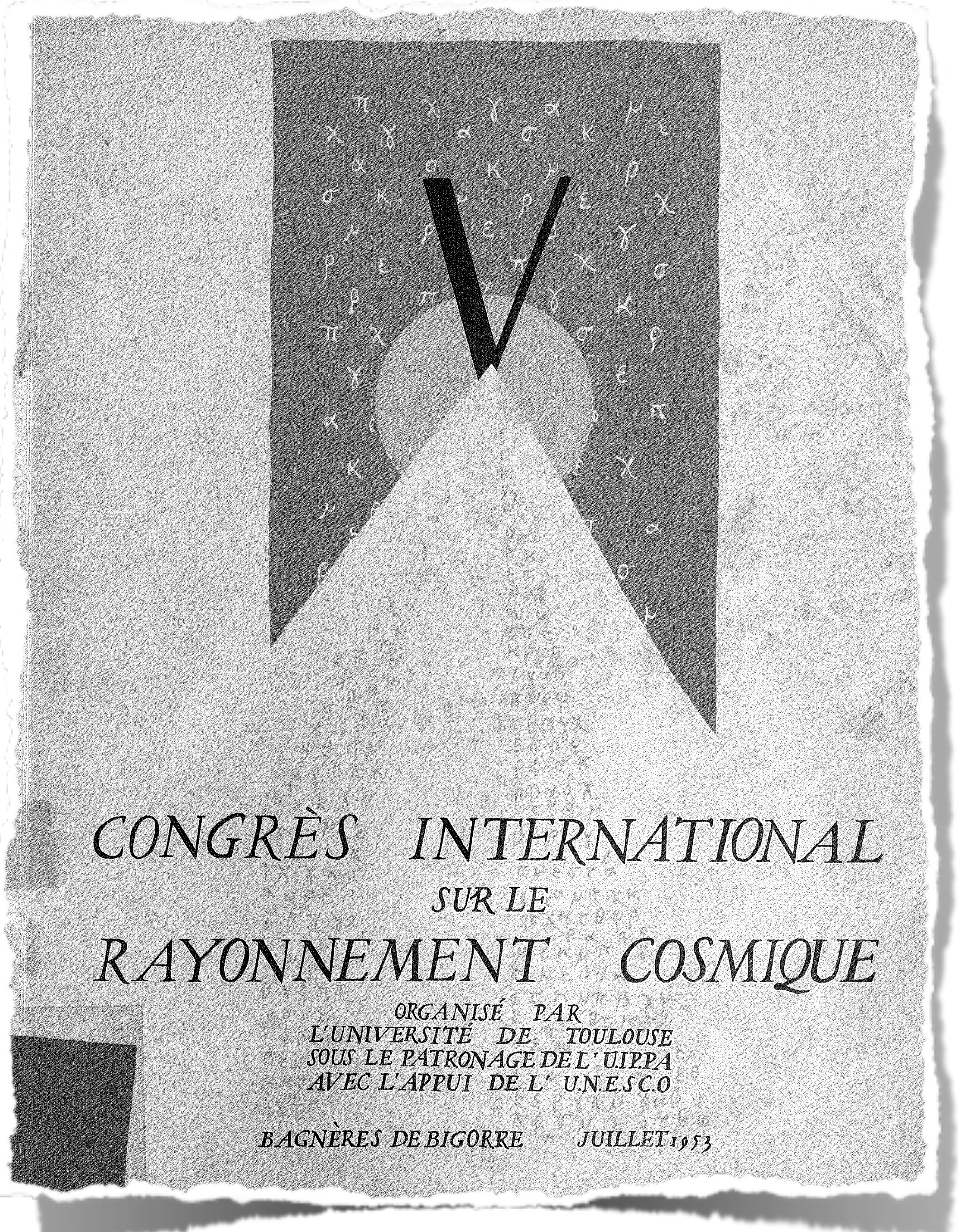


FIG. 3. Nuclear evaporation recorded in one of the rocket plates.



1953 Cosmic-Ray Conference

birth of particle physics

particles discovered in cosmic rays:

- **1932 e^+ Anderson**
- **1937 μ Anderson/ Neddermeyer**
- **1947 π Lattes, Occhialini, Powell**
- **1947 K Rochester, Butcher, Powell**
- **1951-53 hyperons**

$\Lambda \quad \Xi \quad \Sigma$

PHYSICAL REVIEW VOLUME 88, NUMBER 2 OCTOBER 15, 1952

Rocket Determination of the Ionization Spectrum of Charged Cosmic Rays at $\lambda = 41°$N

G. J. PERLOW,* L. R. DAVIS, C. W. KISSINGER, AND J. D. SHIPMAN, JR.
U. S. Naval Research Laboratory, Washington, D. C.

(Received June 30, 1952)

In a V-2 rocket measurement at $\lambda = 41°$N an analysis has been made of the various components of the charged particle radiation on the basis of ionization and absorption in lead. The ionization was determined by two proportional counters, the particle paths through which were defined by Geiger counters. With increasing zenith angle toward the north, the intensity is found to be substantially constant until the earth ceases to cover the under side of the telescope. The intensity of all particles with range ≥ 7 g/cm² is 0.079 ± 0.005 (cm² sec steradian)$^{-1}$. Of this an intensity 0.012 ± 0.002 is absorbed in the next 14 g/cm². The ionization measurement is consistent with $\frac{3}{4}$ of these soft particles being electrons of $<\sim 60$ Mev, the remainder being slow protons and alpha-particles. For the particles with greater range an ionization histogram is plotted, the smaller of the two ionization measurements for a single event being used to improve the resolution. The particles divide into protons, alpha-particles, and one carbon nucleus, with $N_p/N_\alpha = 5.3 \pm 1.0$. Their absorption is exponential with mean free path 440 ± 70 g/cm² Pb. Extrapolating to zero thickness, the total primary intensity is 0.070 ± 0.005 (cm² sec steradian)$^{-1}$ with 0.058 ± 0.005 as protons, 0.011 ± 0.002 as alpha-particles, and 0.001 ± 0.001 as $Z > 2$.

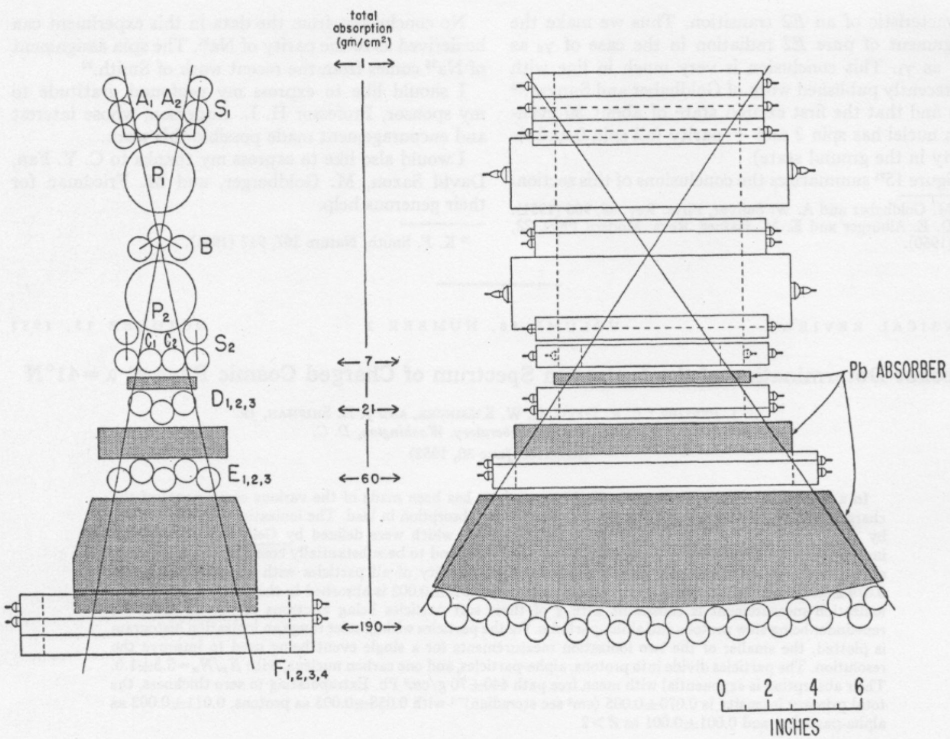


FIG. 1. Diagram of telescope.

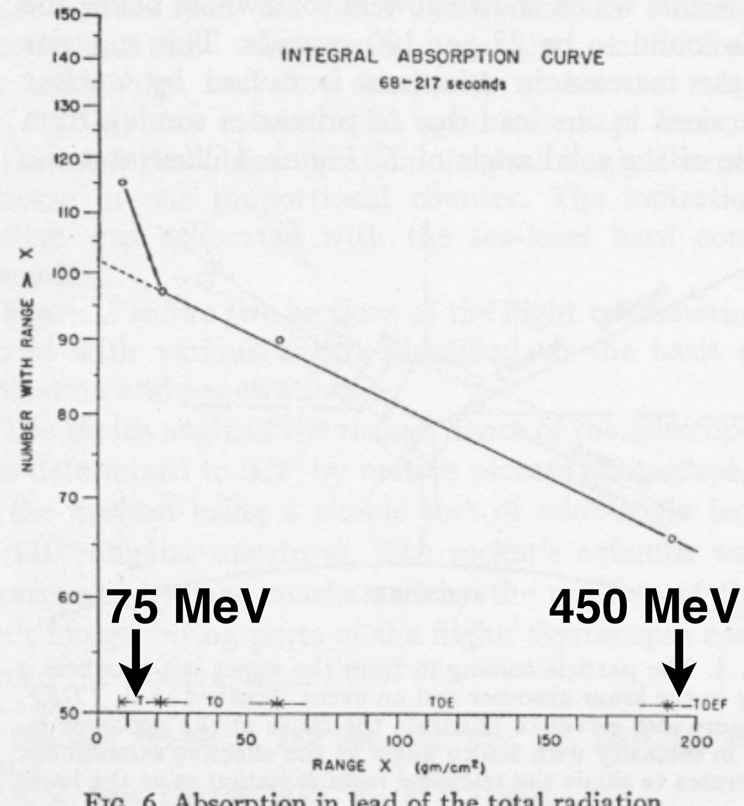


FIG. 6. Absorption in lead of the total radiation.

Van Allen Belts

KEY

1. Cosmic ray burst detector.
2. Vertical telescope.
3. and 4. Dynamotor power supply and flight batteries.
5. Magnetic orientor for determining direction of rocket axis with respect to earth's magnetic field.
6, 7, 8 and 10. Geiger counter coincidence circuits, telemetering circuits and radio telemetering transmitter.
9. Horizontal telescope.
11. 45° telescopes.
12. Photocell orientor to determine angle of rocket axis with the solar vector.
13. Coaxial cable to telemetering antenna 14.

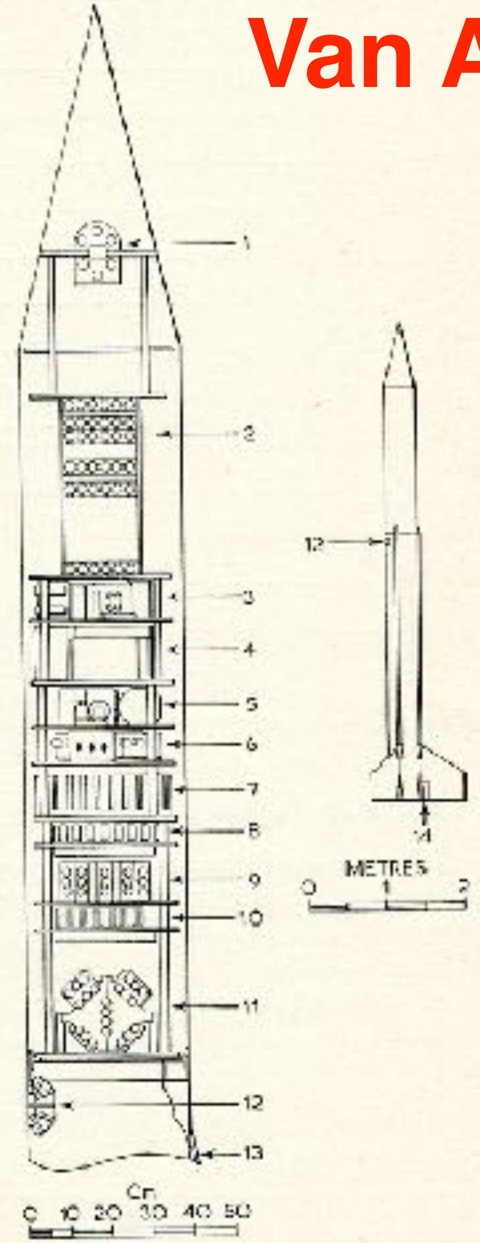


FIG. 32. EXPERIMENTAL ARRANGEMENT FOR AEROBEE ROCKET COSMIC RAY EXPERIMENTS OF VAN ALLEN AND SINGER.

(Reproduced from S. F. Singer, "Progress in Elementary Particle and Cosmic Ray Physics" Vol. IV., Ed. J. G. Wilson and S. A. Wouthuysen, North-Holland Publishing Co., 1958, by permission of the author and publisher).

Nature **183**, 430 - 434 (14 February 1959); doi:10.1038/183430a0

Van Allen Belts

Radiation Around the Earth to a Radial Distance of 107,400 km.

JAMES A. VAN ALLEN & LOUIS A. FRANK

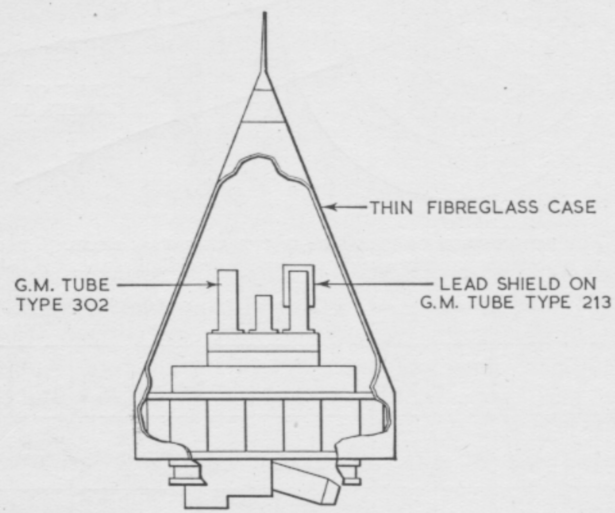


FIG. 71. THE ARRANGEMENT OF RADIATION DETECTORS IN PIONEER IV.
(*After van Allen*).

THE RADIATION BELTS 173

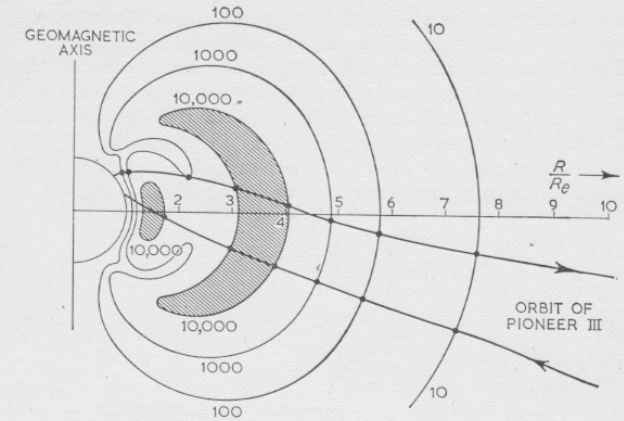


FIG. 69. THE DISTRIBUTION OF INTENSITY IN THE RADIATION BELTS. (6 DEC. 1958).
The diagram represents a cross section through a meridian plane. R_e(∼6400 km) is the radius of the earth.
(*After van Allen and Frank, Nature*, **183**, 430 (1959)).

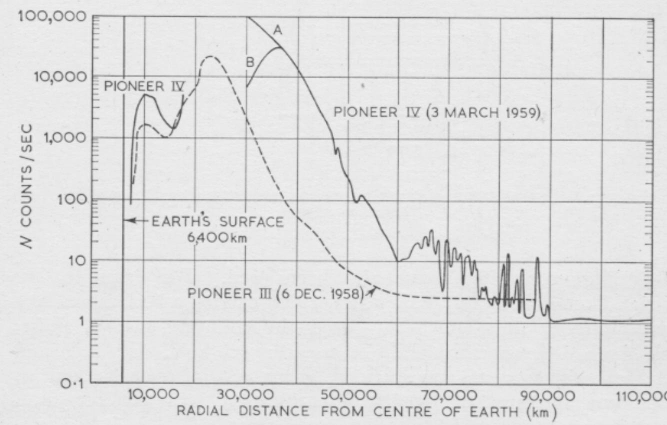


FIG. 70. A COMPARISON OF THE INTENSITIES OF RADIATION FOUND WITH NEARLY IDENTICAL COUNTERS IN PIONEER III AND PIONEER IV.
The trajectories of the two probes were almost, but not quite, the same. At the peak of the second belt the readings of the intensity from Pioneer IV were ambiguous and followed either curve A or curve B. Curve A is more probable.
(*After van Allen and Frank, Nature* **184**, 219 (1960)).

John Si

Preciss
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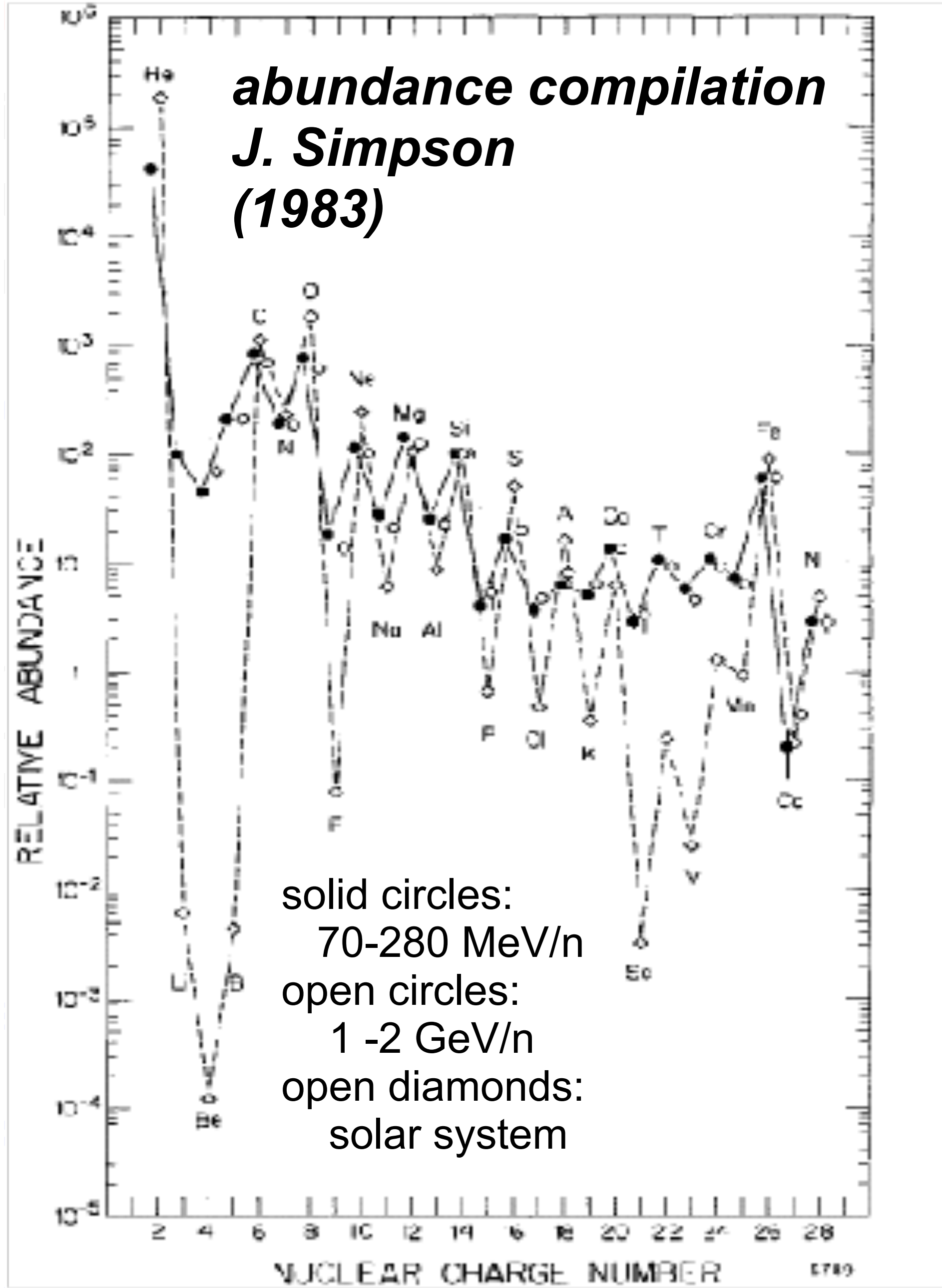
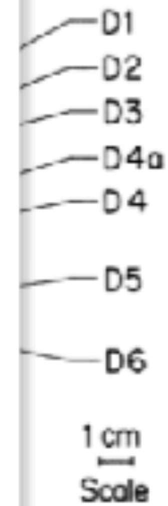


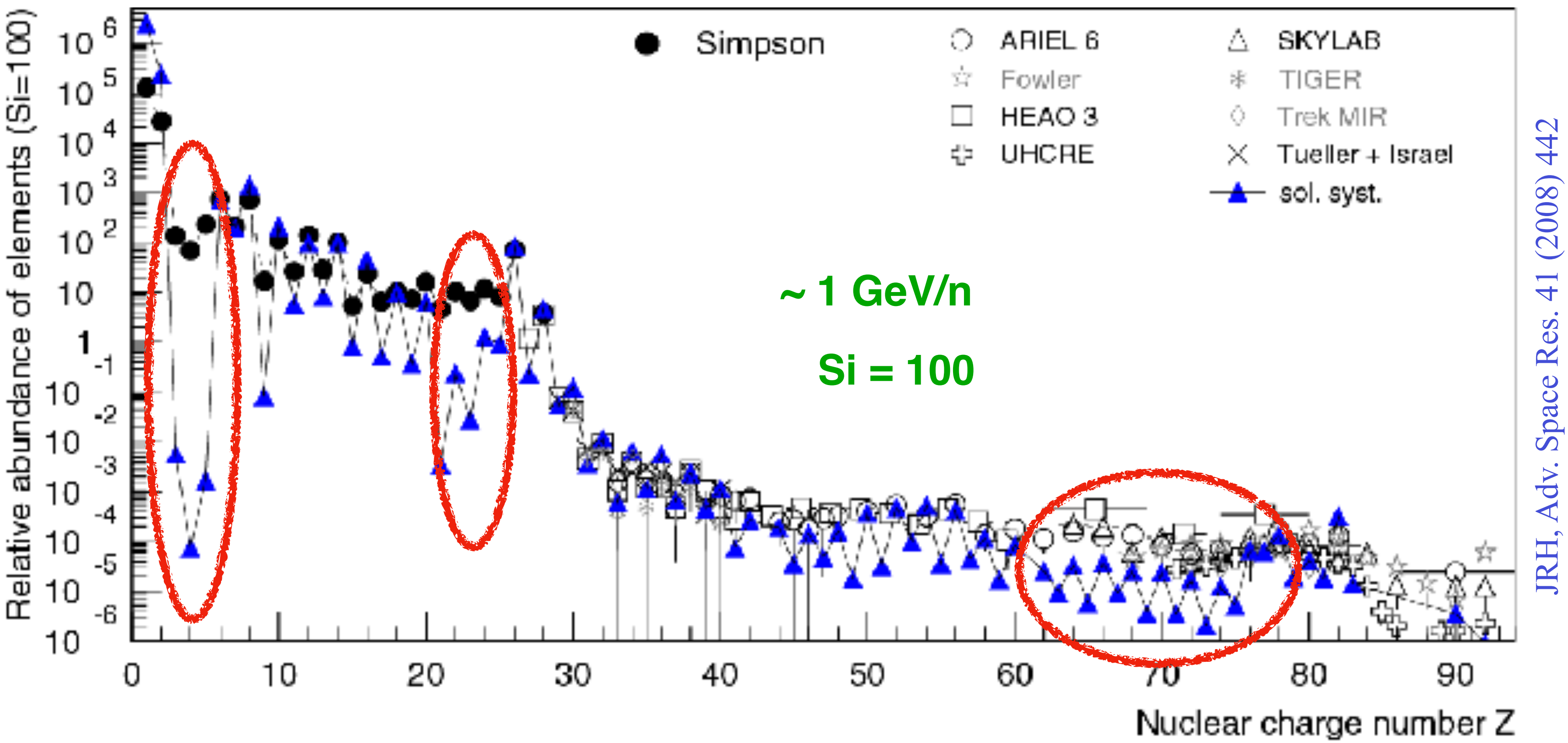


1958 PIONEER 2
1959 EXPLORER 6
subsequently, more than 20 o
including: ***IMP1-8; OGO 1,3,5***
PIONEER 5,6,7 **- S**
PIONEER 10,11 **- o**
ULYSSES **- out of**

- **Elemental composition of c**
- **Isotopic composition**
- **Measurement of anomalous**
- **Particles and fields in the He**
- **Planetary magnetospheres**
- **Solar modulation to outer H**

Formation of the chemical composition

Relative abundance of elements at Earth



abundance of elements in CRs and solar system mostly similar

but few differences, e.g. Li, Be, B —> important to understand propagation of cosmic rays in Galaxy —> column density of traversed matter

primary cosmic rays generated at source e.g. p, He, Fe
spallation products —> secondary cosmic rays, e.g. Li, Be, B

Age of cosmic rays

THE ASTROPHYSICAL JOURNAL, 217:859–877, 1977 November 1

THE AGE OF THE GALACTIC COSMIC RAYS DERIVED FROM THE ABUNDANCE OF ^{10}Be*

M. GARCIA-MUNOZ, G. M. MASON, AND J. A. SIMPSON†
Enrico Fermi Institute, University of Chicago
Received 1977 March 14; accepted 1977 April 21

$\tau = 17*10^6$ a

$^{10}Be \rightarrow {}^{10}B + e^-$ (τ=2.4 10^6 a)

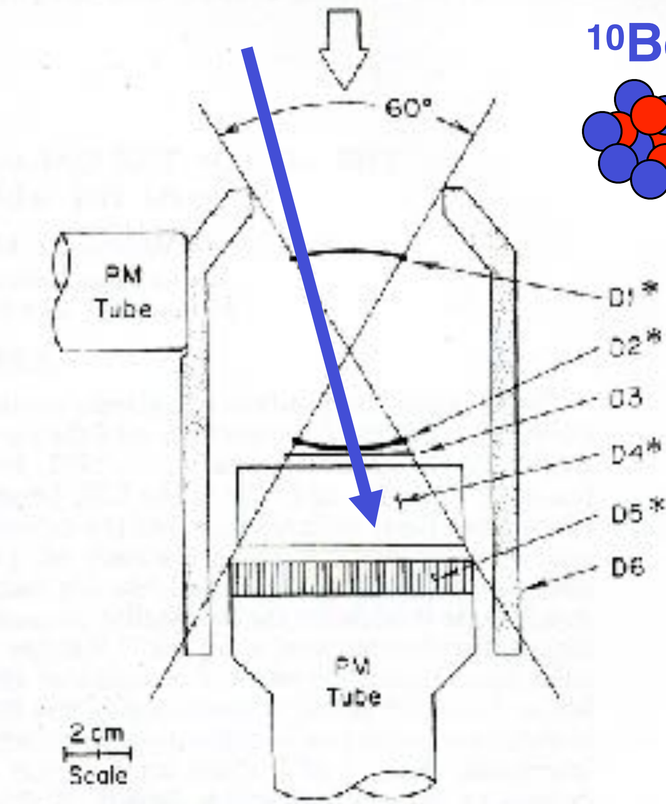
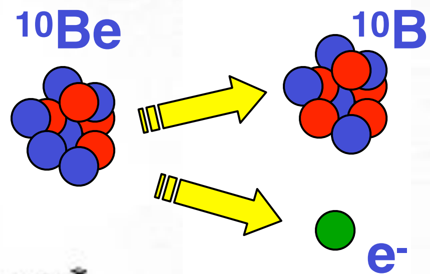
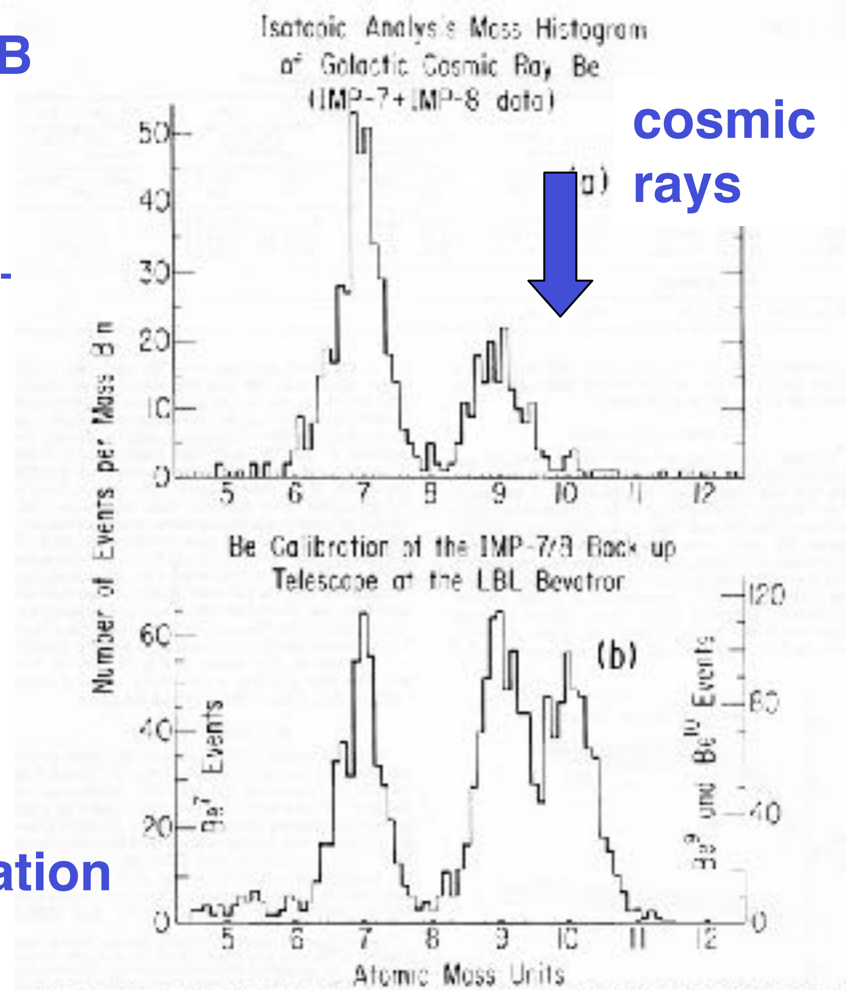


FIG. 1.—Cross section of the IMP-7 and IMP-8 telescopes. D1, D2, and D3 are lithium-drifted silicon detectors of thickness 750, 1450, and 800 μm, respectively. D4 is an 11.5 g cm^{-2} thick CsI (Tl) scintillator viewed by four photodiodes. D5 is a sapphire scintillator/Cerenkov radiator of thickness 3.98 g cm^{-2}, and D6 is a plastic scintillation guard counter viewed by a photomultiplier tube. Asterisks denote detectors whose output is pulse-height analyzed.





Path length of cosmic rays

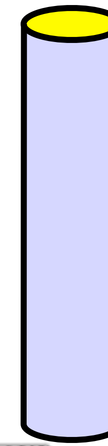
VOLUME 29, NUMBER 7 PHYSICAL REVIEW LETTERS 14 AUGUST 1972

Composition of Cosmic-Ray Nuclei at High Energies*

Einar Juliusson, Peter Meyer, and Dietrich Müller
Enrico Fermi Institute and Department of Physics, University of Chicago, Chicago, Illinois 60637
(Received 26 May 1972)

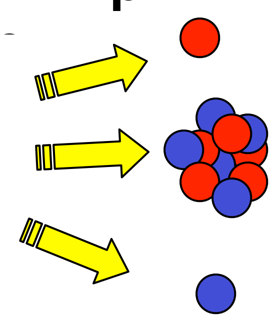
We have measured the charge composition of cosmic-ray nuclei from Li to Fe with energies up to about 100 GeV/nucleon. A balloon-borne counter telescope with gas Cherenkov counters for energy determination was used for this experiment. Our first results show that, in contrast to low-energy observations, the relative abundances change as a function of energy. We find that the ratio of the galactic secondary nuclei to primary-source nuclei decreases at energies above about 30 GeV/nucleon.

g/cm²

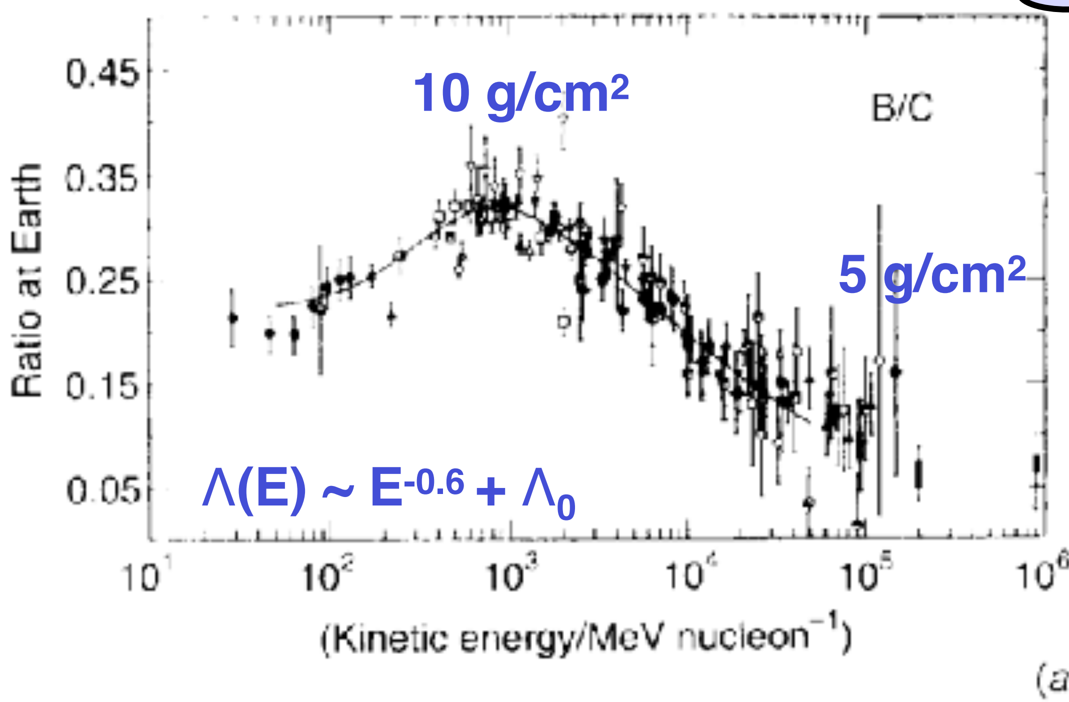


spallation

C → B + n + p

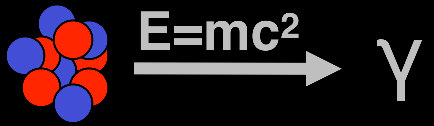


B/C-ratio



Origin of Cosmic Rays?

1927 R.A. Millikan: „death cries of atoms“

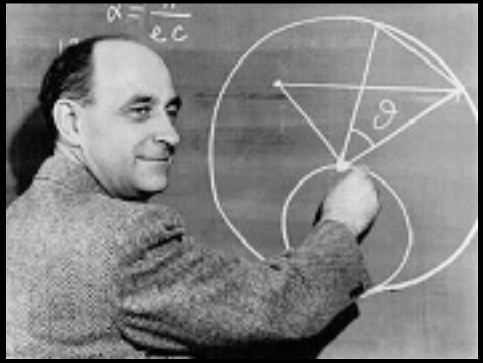


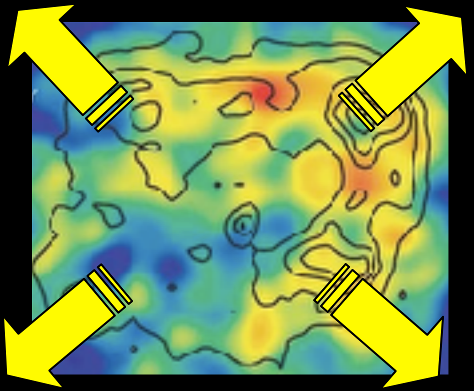
1933 Regener: E density in CRs ~ E density of B field in Galaxy

1934 Supernovae

Walter Baade Fritz Zwicky

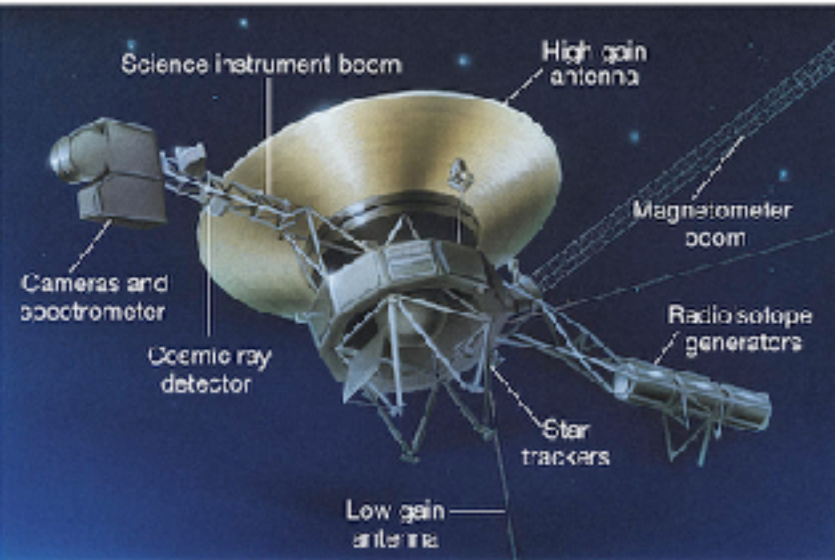
1949 E. Fermi: acceleration at magnetic clouds

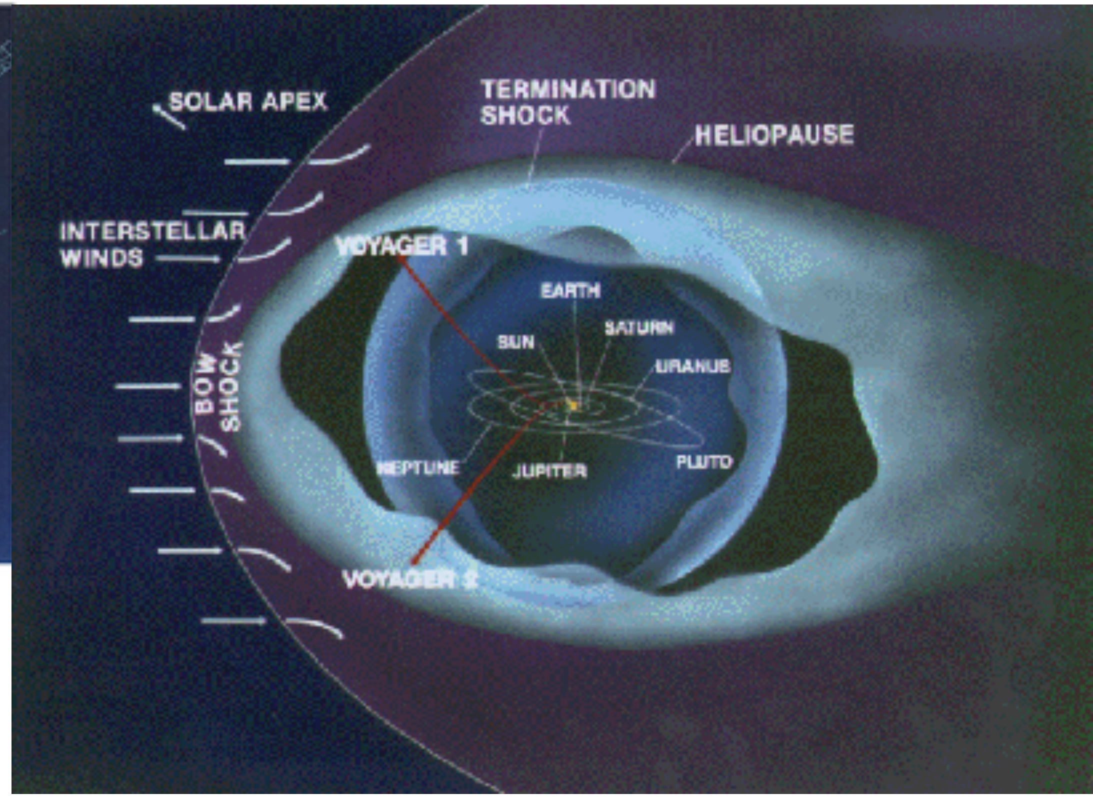




1978 R.D. Blanford, J.P. Ostriker: acceleration at strong shock front
(1st order Fermi acceleration)

Beyond the boundaries of our Solar System





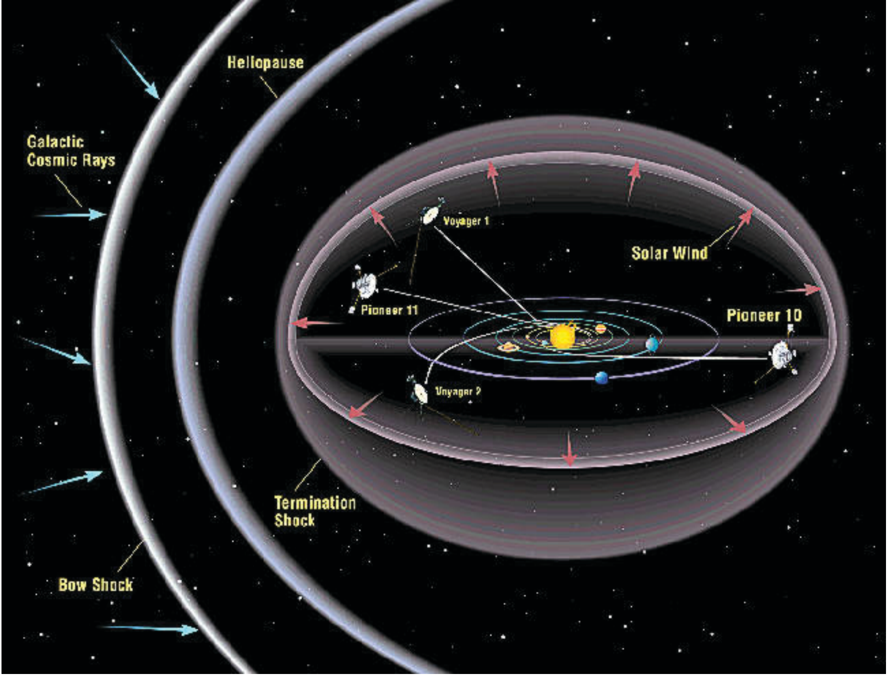
passage through termination shock ended
Voyager 1: 94 AU, December 2004
Voyager 2: 84 AU, August 2007

February 2012: Voyager 1: 119.7 AU from Sun
Voyager 2: 97.7 AU from Sun

$$\Delta T = c\, d \approx 17\ \mathrm{h}$$

Voyager 2: 20 August 1977
Voyager 1: 5 September 1977
Kenedy Space Center

Galactic Cosmic Rays and the Heliosphere



August 25th, 2012
Interstellar Space