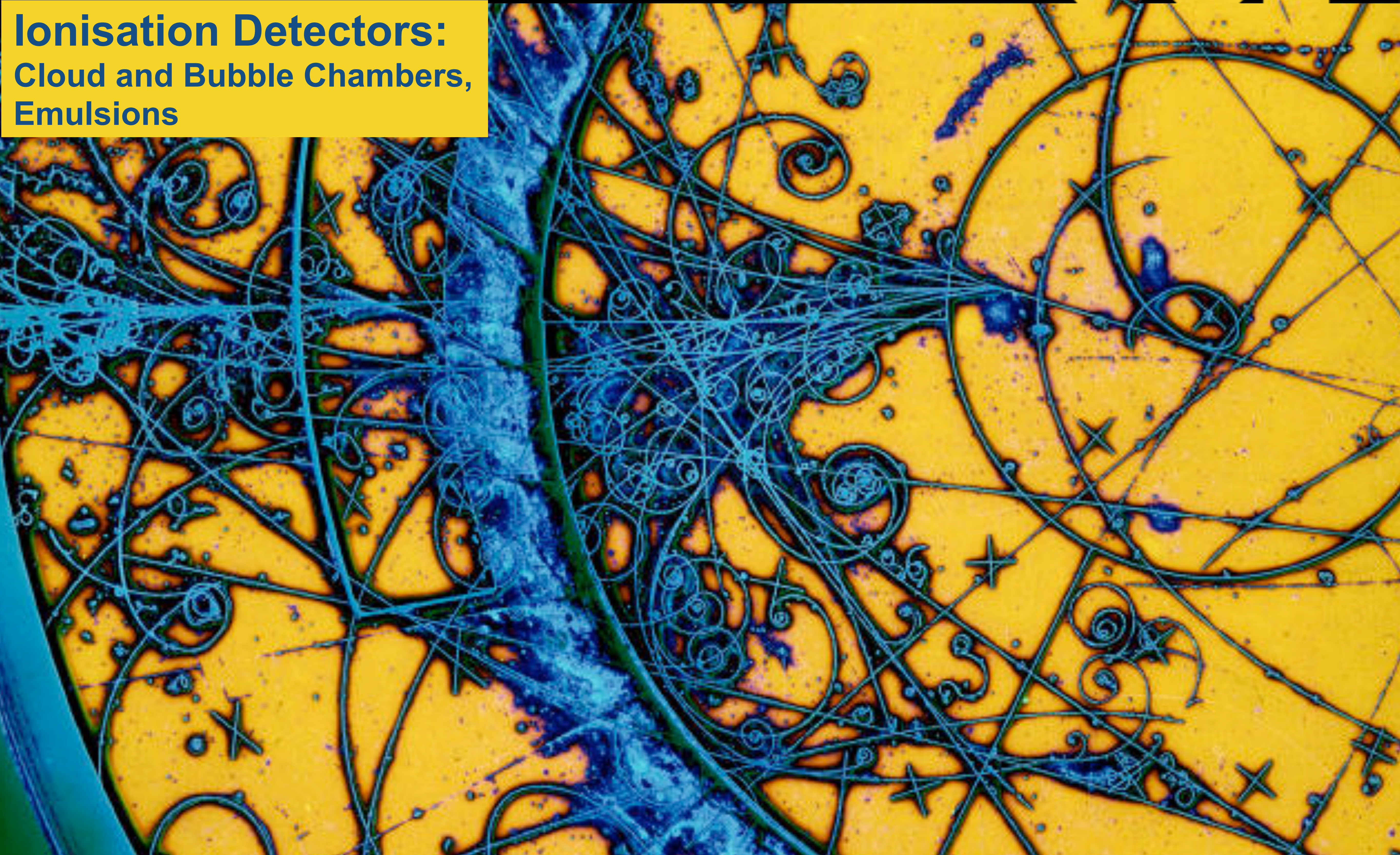
Experimental Particle Physics
Detectors and Experiments

Ionisation Detectors:
Cloud and Bubble Chambers, Emulsions



- In 1912 C. T. R. Wilson published a paper describing his development of an “Expansion Apparatus”

On an Expansion Apparatus for making Visible the Tracks of Ionising Particles in Gases and some Results obtained by its Use.

By C. T. R. Wilson, M.A., F.R.S.

(Received June 7,—Read June 13, 1912.)

- For the first time this allowed scientists to actually ‘see’ fundamental particles

No one will deny the extraordinary interest and importance of this method which showed for the first time and in such minute detail the effects of the passage of ionizing radiations through a gas… I am personally of the opinion that the researches of Mr Wilson in this field represent one of the most striking and important of the advances in atomic physics made in the last twenty years… It may be argued that this new method of Mr Wilson’s has in the main only confirmed the deductions of the properties of the radiations made by other more indirect methods. While this is of course in some respects true, I would emphasize the importance to science of the gain in confidence of the accuracy of these deductions that followed from the publication of his beautiful photographs.

Ernest Rutherford, 1927[1]

The working principle

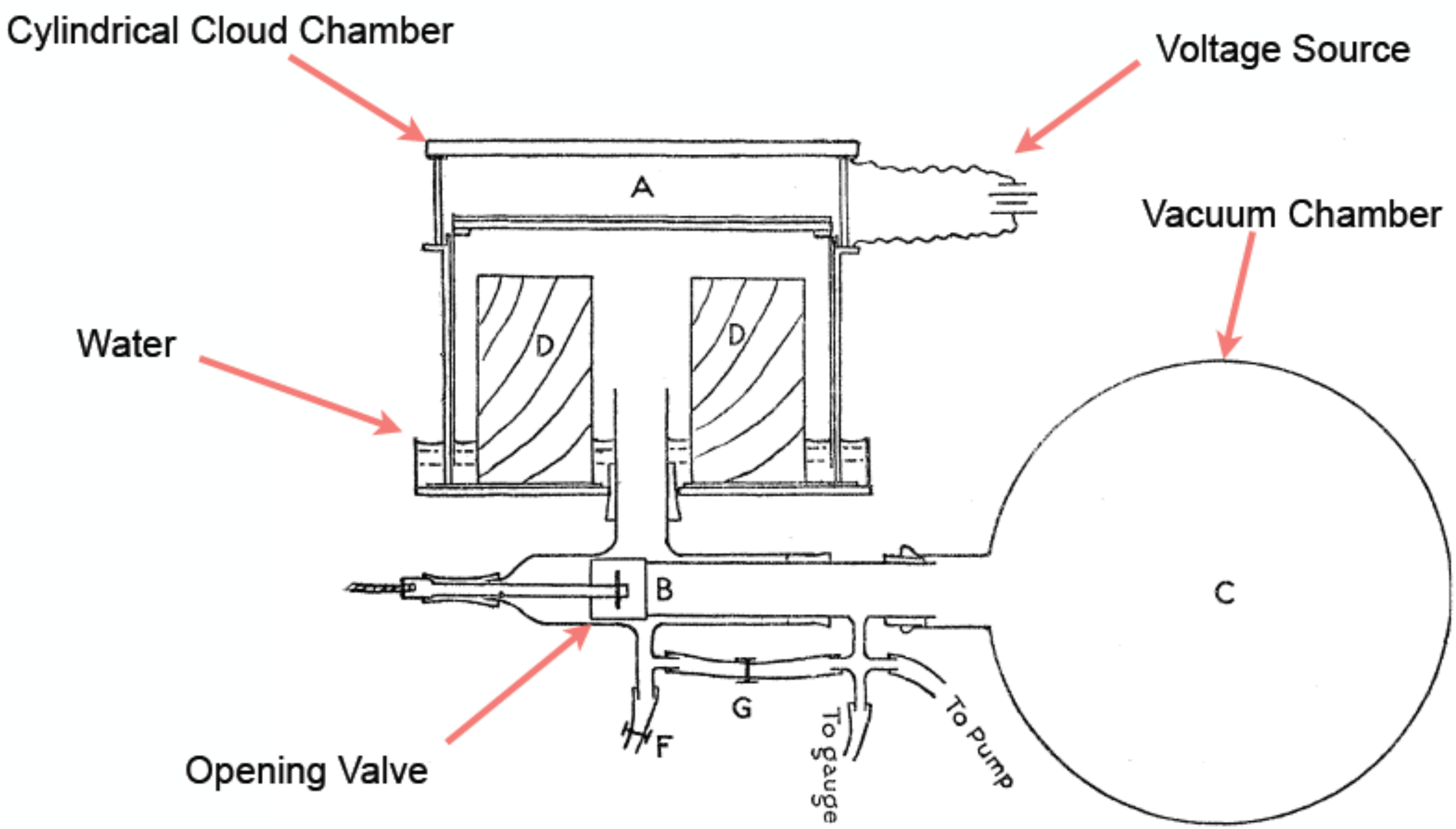
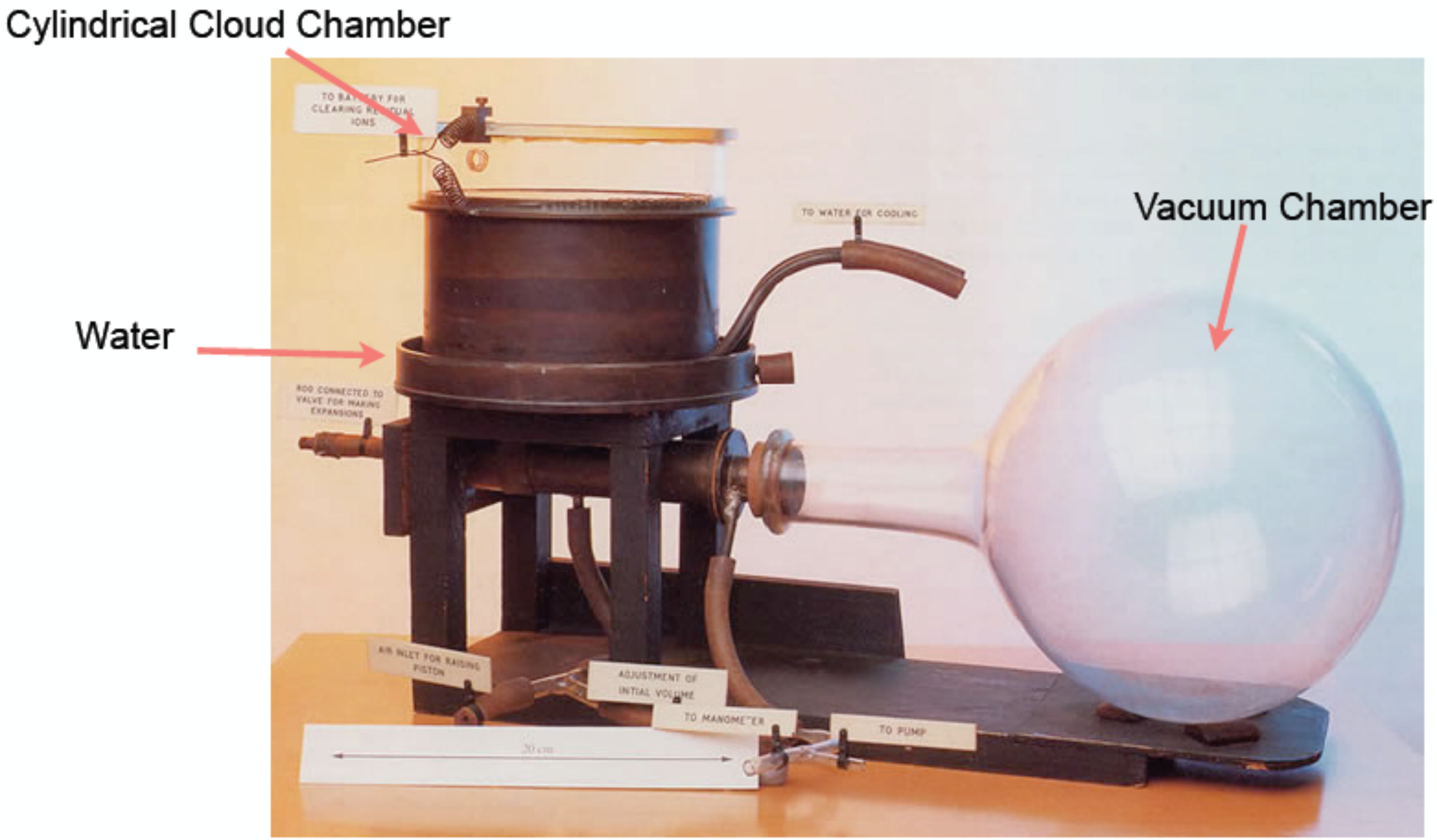
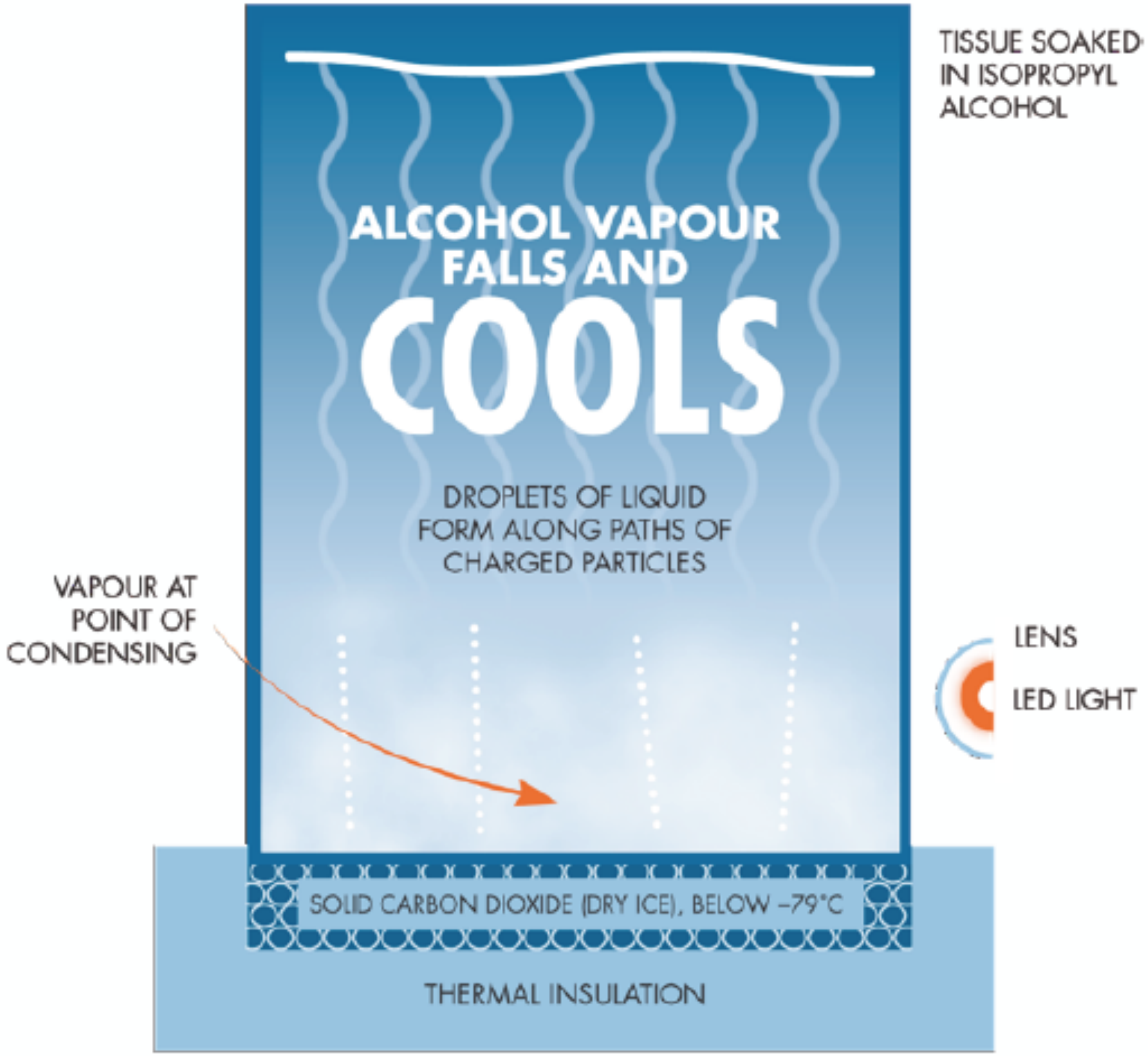


FIG. 1.



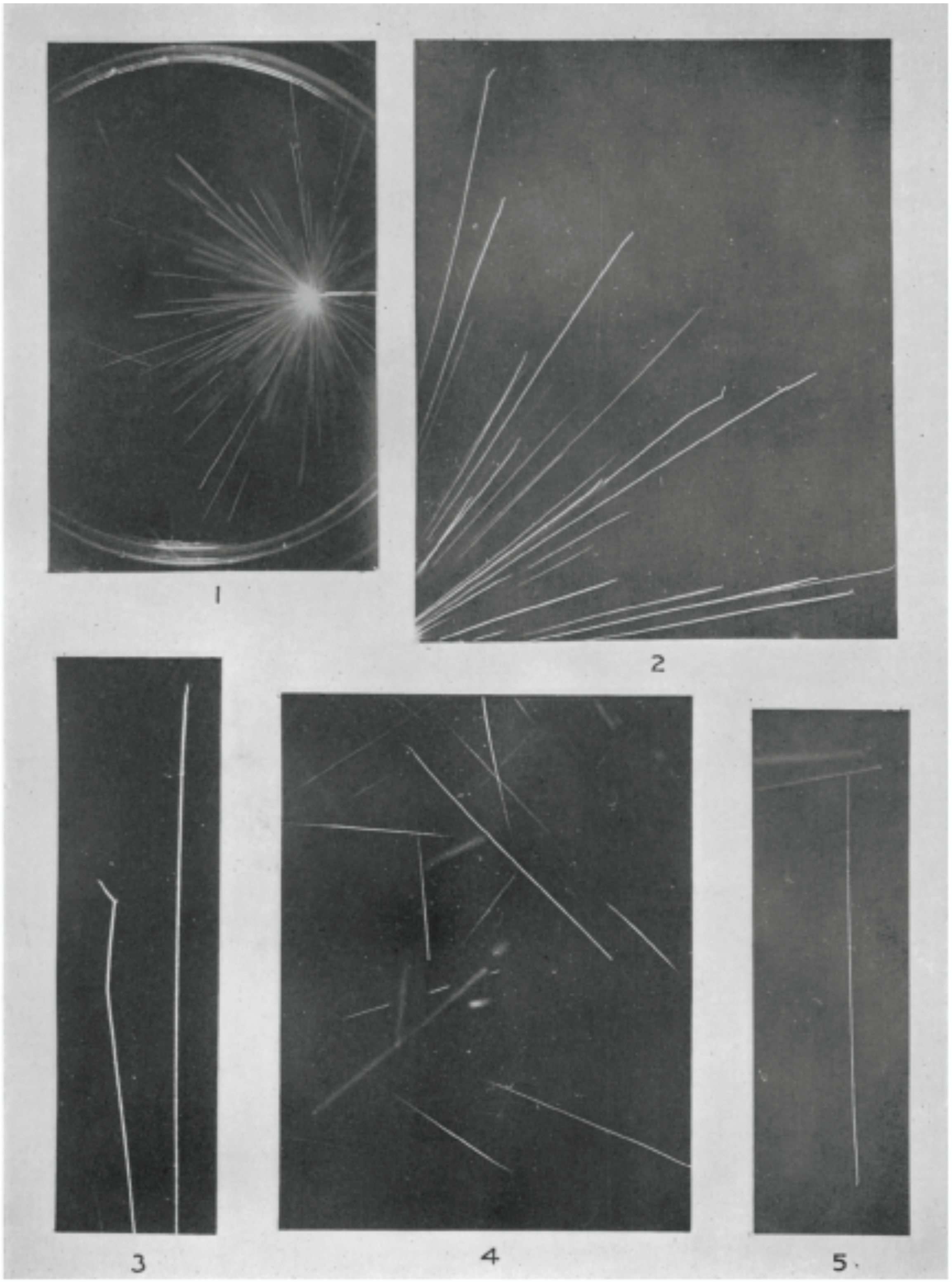
http://www-outreach.phy.cam.ac.uk/camphy/cloudchamber/cloudchamber10_2.htm

- These days it is easy to build your own cloud chamber using dry ice and alcohol



Alpha particles

Bragg's 1911 prediction



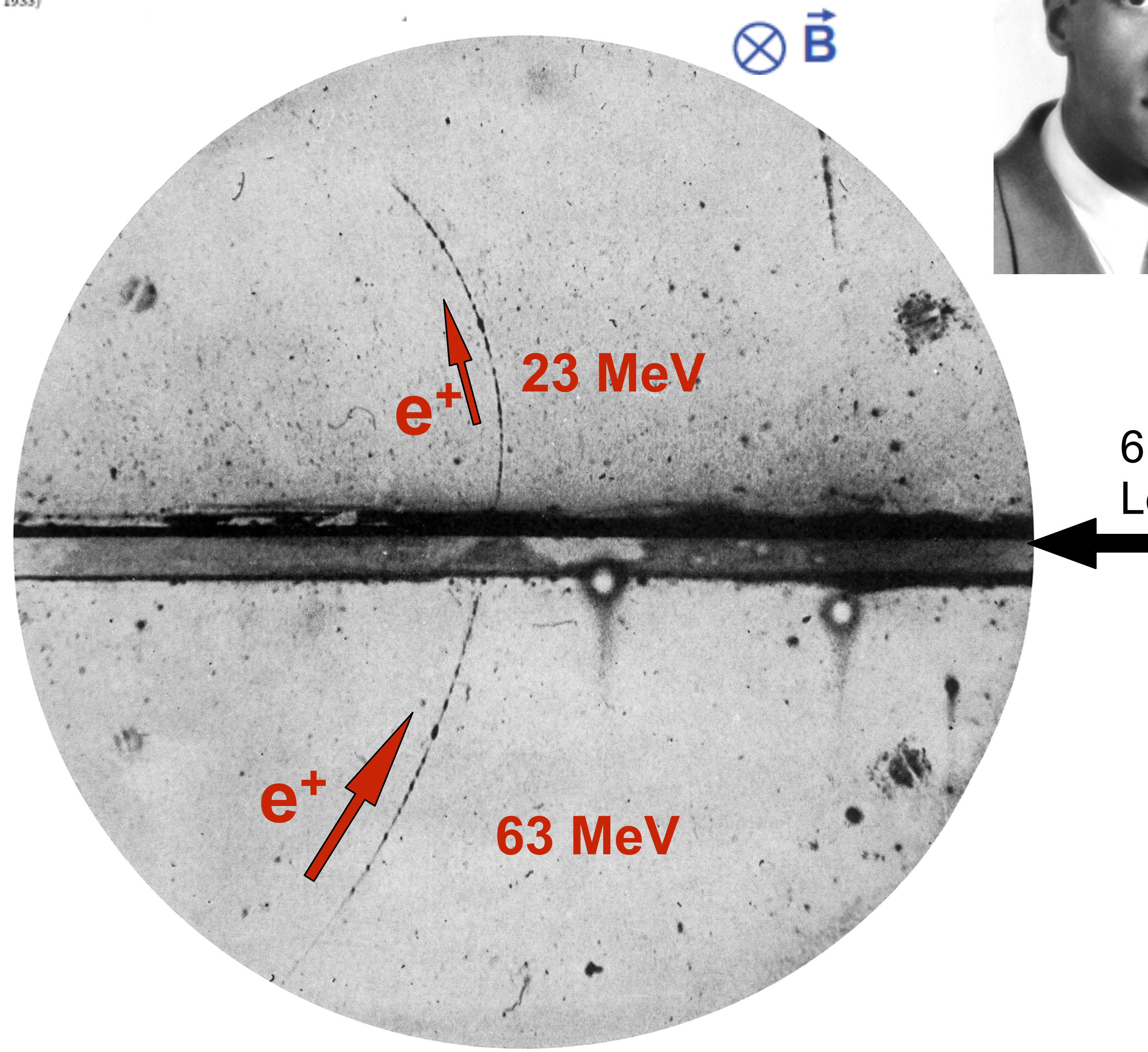
The Positron

MARCH 15, 1933 PHYSICAL REVIEW VOLUME 43

The Positive Electron

CARL D. ANDERSON, *California Institute of Technology, Pasadena, California*
(Received February 28, 1933)

CARL D. ANDERSON



- In 1929 Dirac identified negative energy solutions to his equation — could be interpreted as positive energy positively charged particles (predicting **antiparticles**) — more on that later in the course.
- In 1933 Anderson measured one of these particles using a cloud chamber

Q1.: How do we know it is not an electron?
Q2. How do we know it is not a proton?

The Discovery of the Muon

NOVEMBER 1, 1937 PHYSICAL REVIEW VOLUME 52

New Evidence for the Existence of a Particle of Mass Intermediate Between the Proton and Electron

J. C. Street
E. C. Stevenson

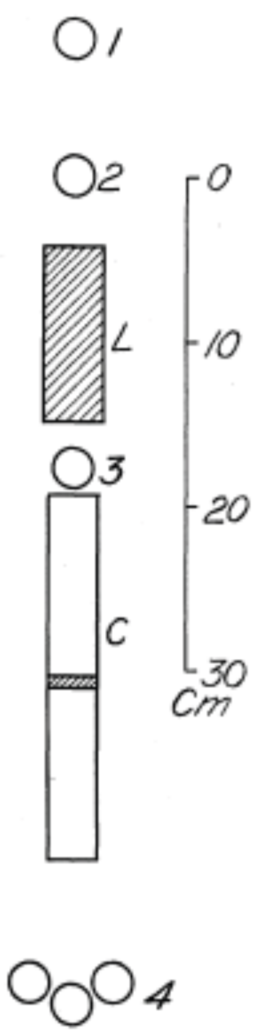


FIG. 1. Geometrical arrangement of apparatus.

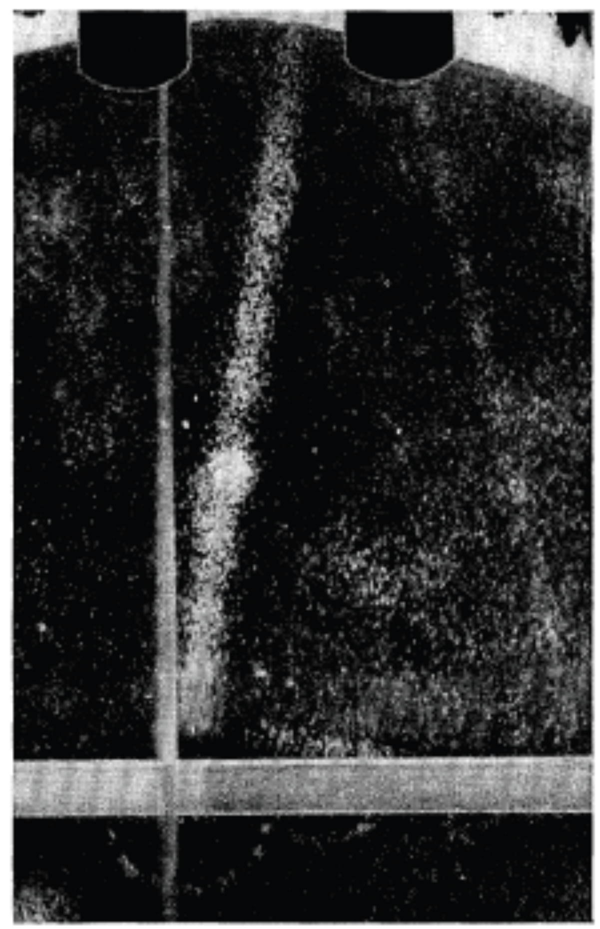


FIG. 2. Track *A*.

Proton

FIG. 3. Track *B*.

Muon

CLOUD — Cosmics Leaving OUtdoor Droplets

- CLOUD is an active experiment at CERN which is investigating the link between galactic cosmic rays and cloud formation
- Utilises a gigantic cloud chamber in a beam of particles from the CERN PS (proton synchrotron)

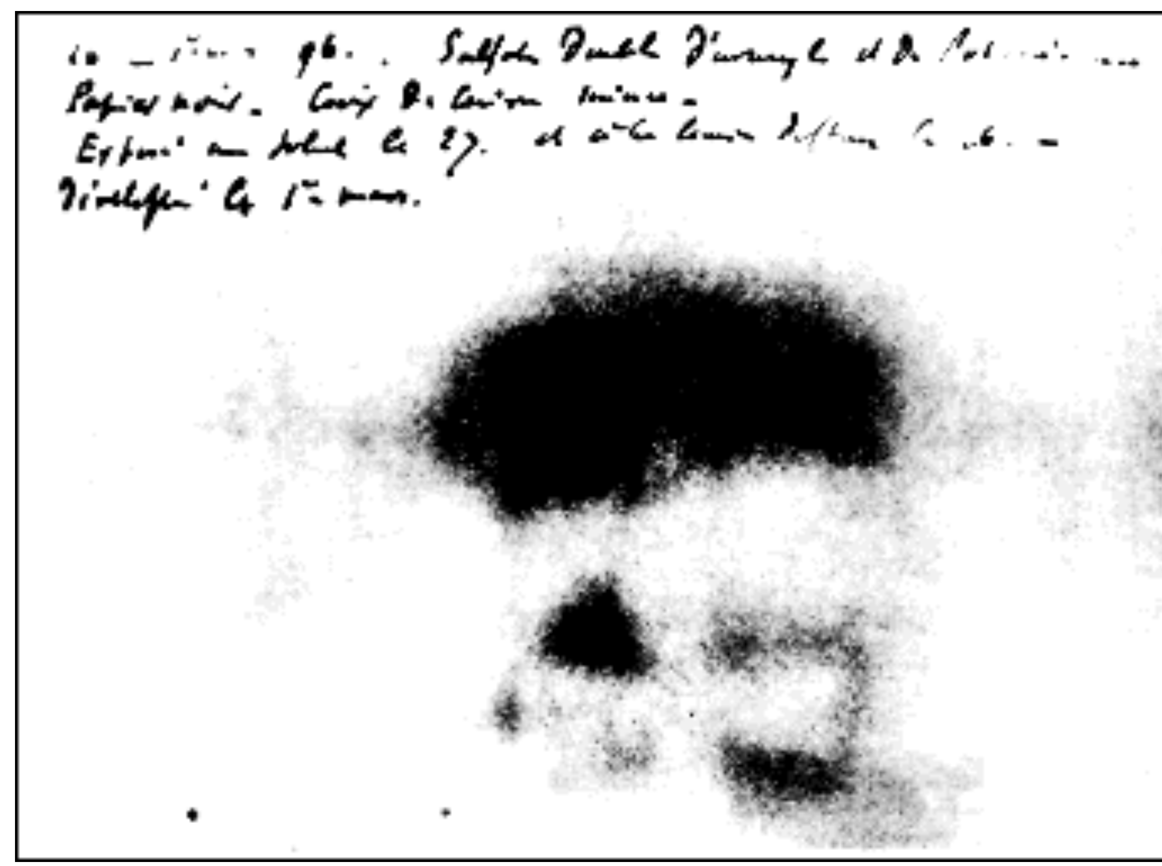
References

- C. T. R. Wilson, “On an Expansion Apparatus for Making Visible the Tracks of Ionising Particles in Gases and Some Results Obtained by Its Use”, Proc. R. Soc. Lond. A, 87, 595, 277-292 (1912),
- P. A. M. Dirac, “A theory of electrons and protons”, Proc. R. Soc. Lond. A, 126, 360-365 (1930)
- Carl. D. Anderson, “The Positive Electron”, Phys. Rev. 43, 491–494 (1933)
- J. C. Street and E. C. Stevenson, “New Evidence for the Existence of a Particle of Mass Intermediate Between the Proton and Electron”, Phys. Rev. 52, 1003–1004 (1937)

Really old history

- Radioactivity was discovered by Henri Becquerel in 1896 using photographic plates
- It wasn't until 50 years later and the development of high resolution nuclear emulsions that the technique had its heyday

Henri Becquerel



Bubble Chambers

- Invented by Donald Glaser in 1952 to provide “a cloud-chamber-like detector whose sensitive volume is filled with a hydrogen-rich medium whose density is of the order of 1 g/cc”
- John Wood was the first to photograph individual particle tracks in bubble chambers
- In 1960 Donald Glaser was awarded the Nobel Prize in Physics for his invention

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

DONALD A. GLASER
University of Michigan, Ann Arbor, Michigan
(Received June 12, 1952)

Bubble Tracks in a Hydrogen-Filled Glaser Chamber*

JOHN G. WOOD
Radiation Laboratory, Department of Physics, University of California, Berkeley, California
(Received March 3, 1954)

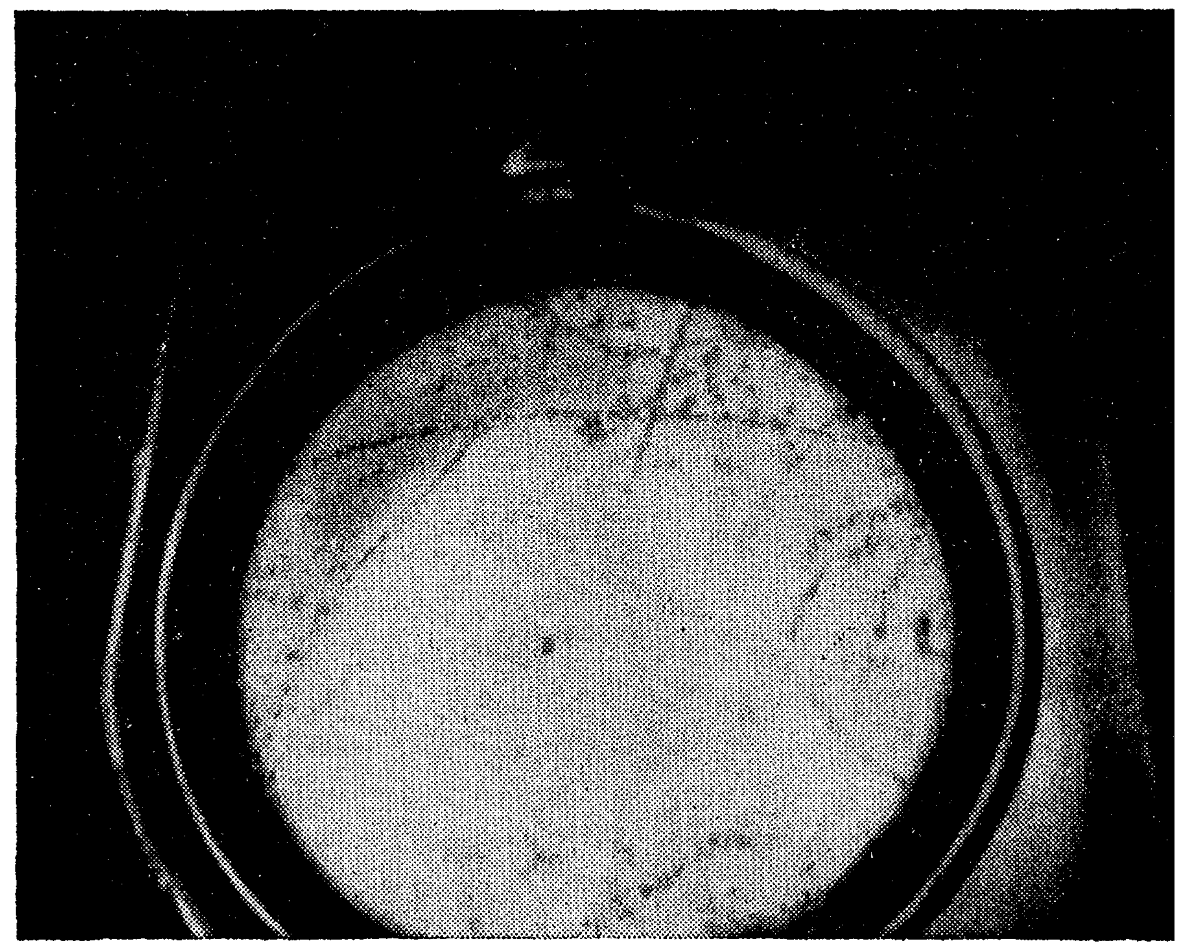


FIG. 1. $1\frac{1}{2}$-inch chamber irradiated with a Po-Be source.

Bubble Chambers

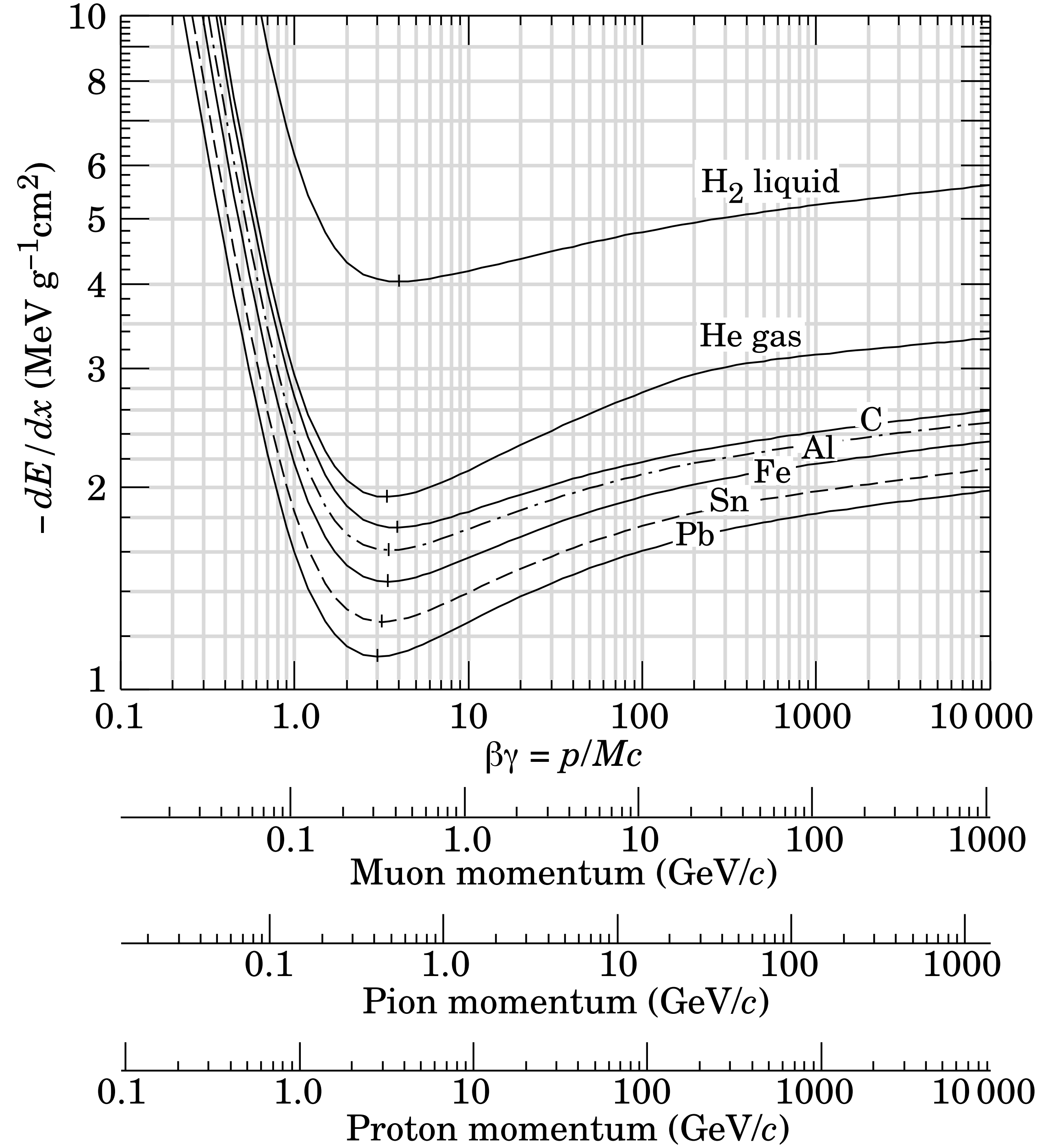
- Bubble chambers work by creating a super-heated volume of liquid (normally hydrogen or freon)
- When an ionising particle passes through little bubbles are formed along the ionisation tracks
- The tracks were then photographed using multiple camera angles

Energy Loss

- Bubble chambers, emulsion detectors and cloud chambers all detect particles through ionisation energy losses

$$-\left\langle \frac{dE}{dx} \right\rangle = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

- Particles with the same momentum can be distinguished by differing amounts of energy loss along the track



The Pion

- Before the muon and pion were discovered Yukawa predicted a ~100MeV particle which was the nuclear force carrier
- How do we know that the muon cloud chamber pictures were not these Yukawa particles?
- In modern language how do you distinguish a pion from a muon?
  - What happens when a π^- is captured on a nucleus?

Nuclear Disintegration by Meson Capture

D. H. PERKINS

No. 4030 January 25, 1947 NATURE

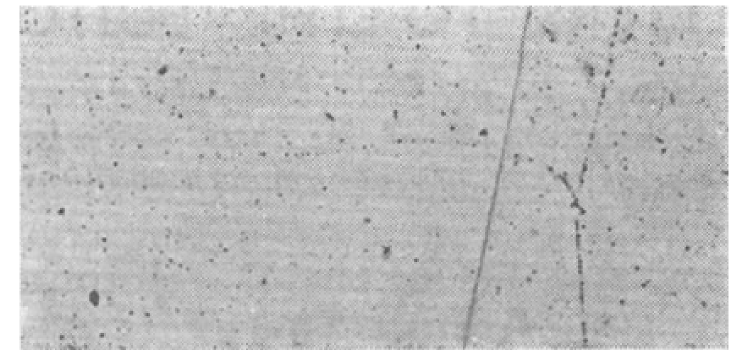


Fig. 1 *a*. PHOTOMICROGRAPH OF CENTRE OF STAR, SHOWING TRACK OF MESON PRODUCING DISINTEGRATION. (LEITZ 2 MM. OIL-IMMERSION OBJECTIVE. × 500)

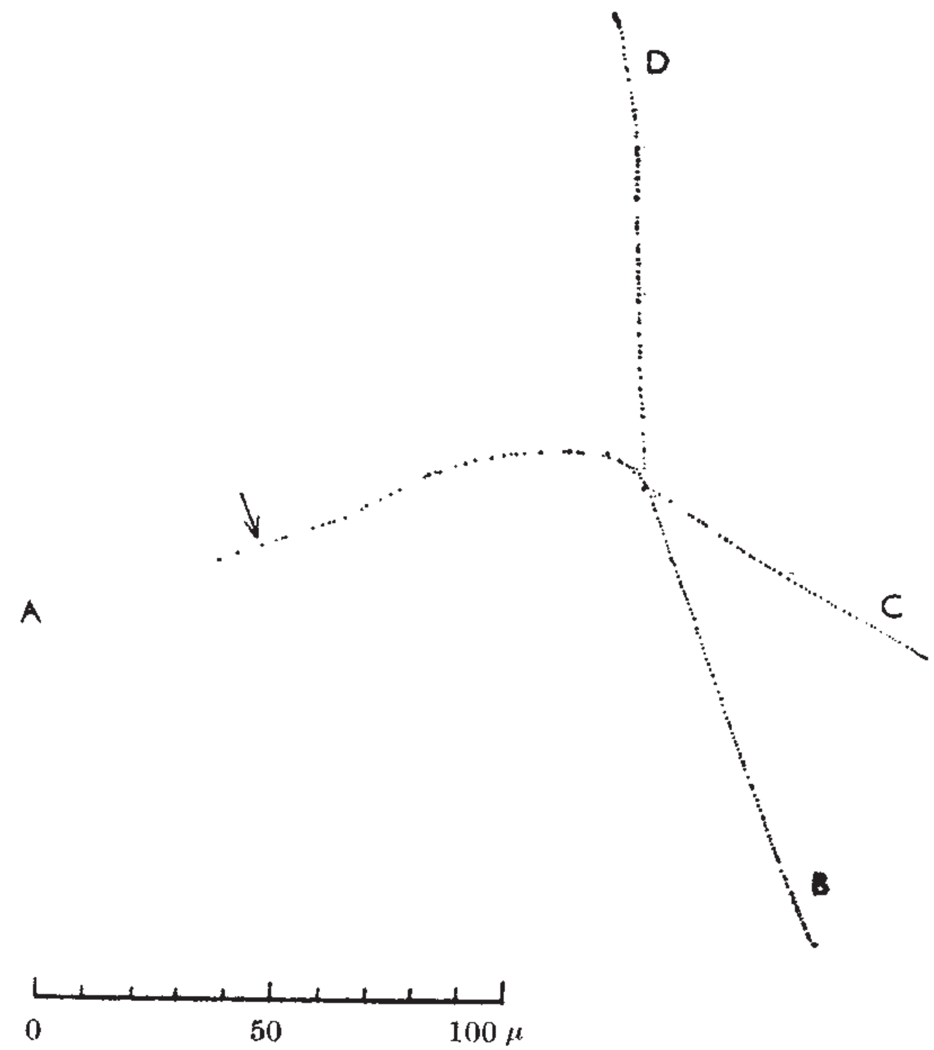


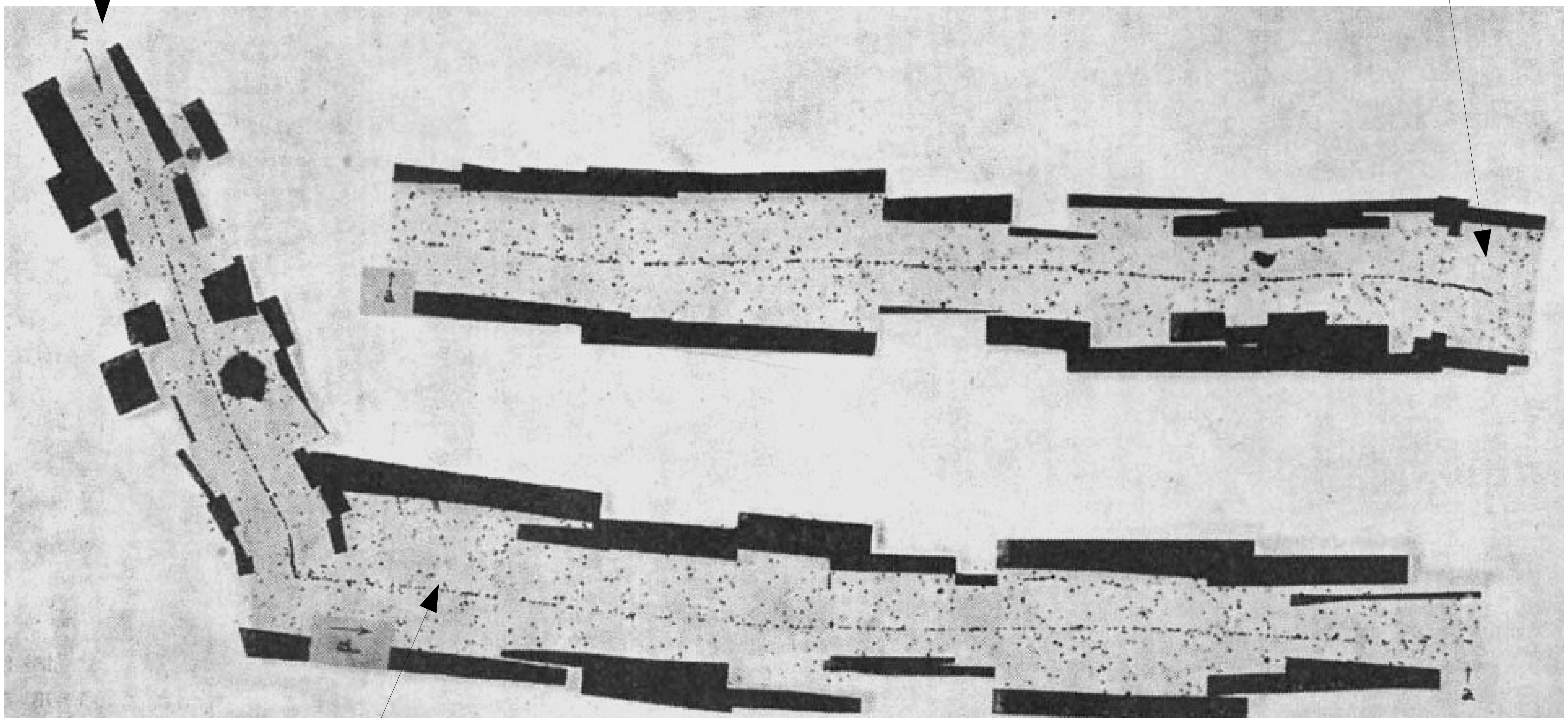
Fig. 1 *b*. TRACE OF COMPLETE STAR ON SCREEN OF PROJECTION MICROSCOPE, SHOWING PROJECTION OF THE TRACKS IN THE PLANE OF THE EMULSION. TRACK *A* CANNOT BE TRACED WITH CERTAINTY BEYOND THE ARROW

Pion --> Muon

π→μ event

π

μ stops in emulsion



μ (estimated mass = 100-300m_e)

15

(Oct 1947, observed by Powell, Occhialini, Lattes)

Antiproton Annihilation

- The key feature of antiprotons is that they should annihilate with protons in matter
- This annihilation was first observed using an emulsion detector at the Bevatron
- This is the star produced when this annihilation happens

O. Chamberlain, W. W. Chupp, G. Goldhaber, E. Segrè and C. Wiegand - *Berkeley*
E. Amaldi, G. Baroni, C. Castagnoli, C. Franzinetti and A. Manfredini - *Rome*

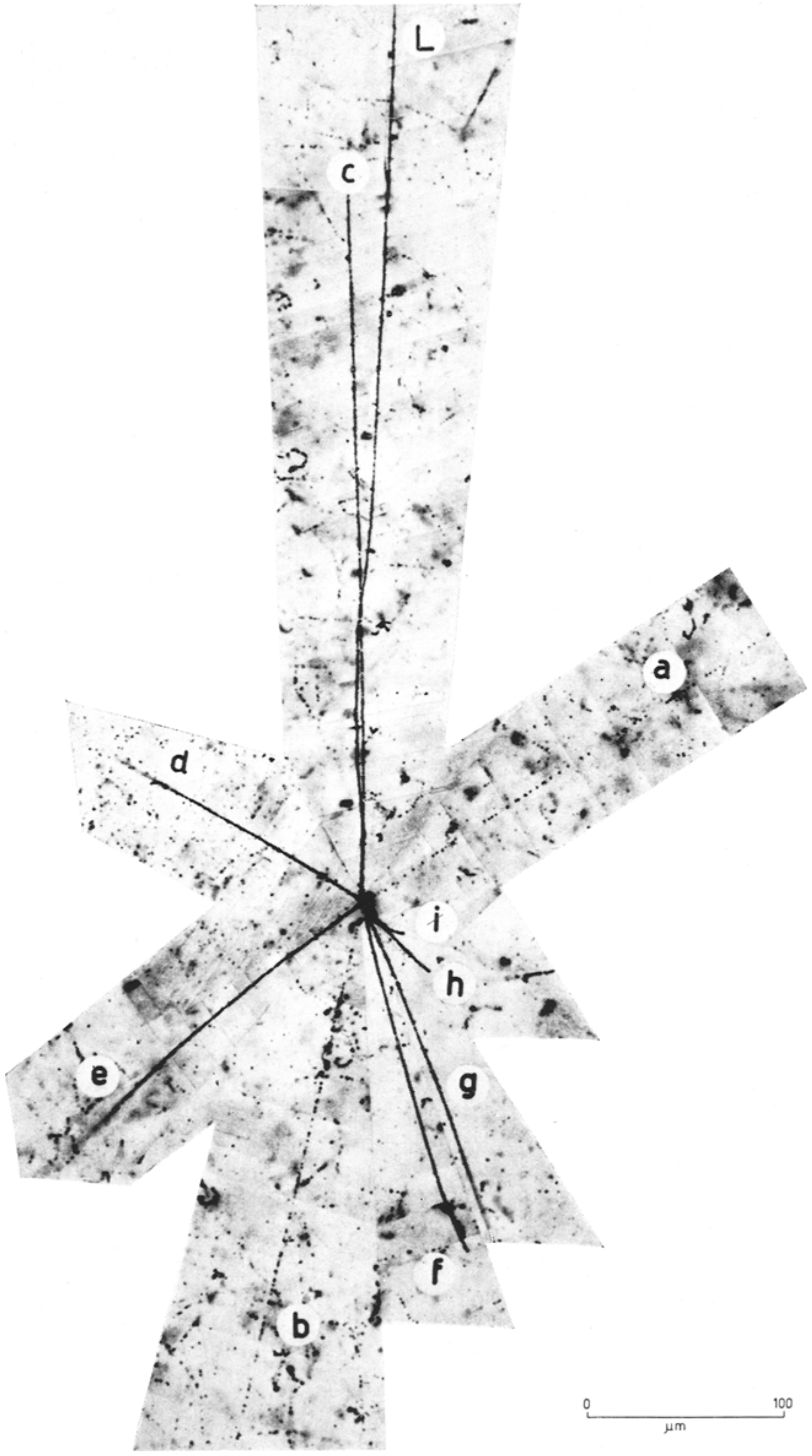


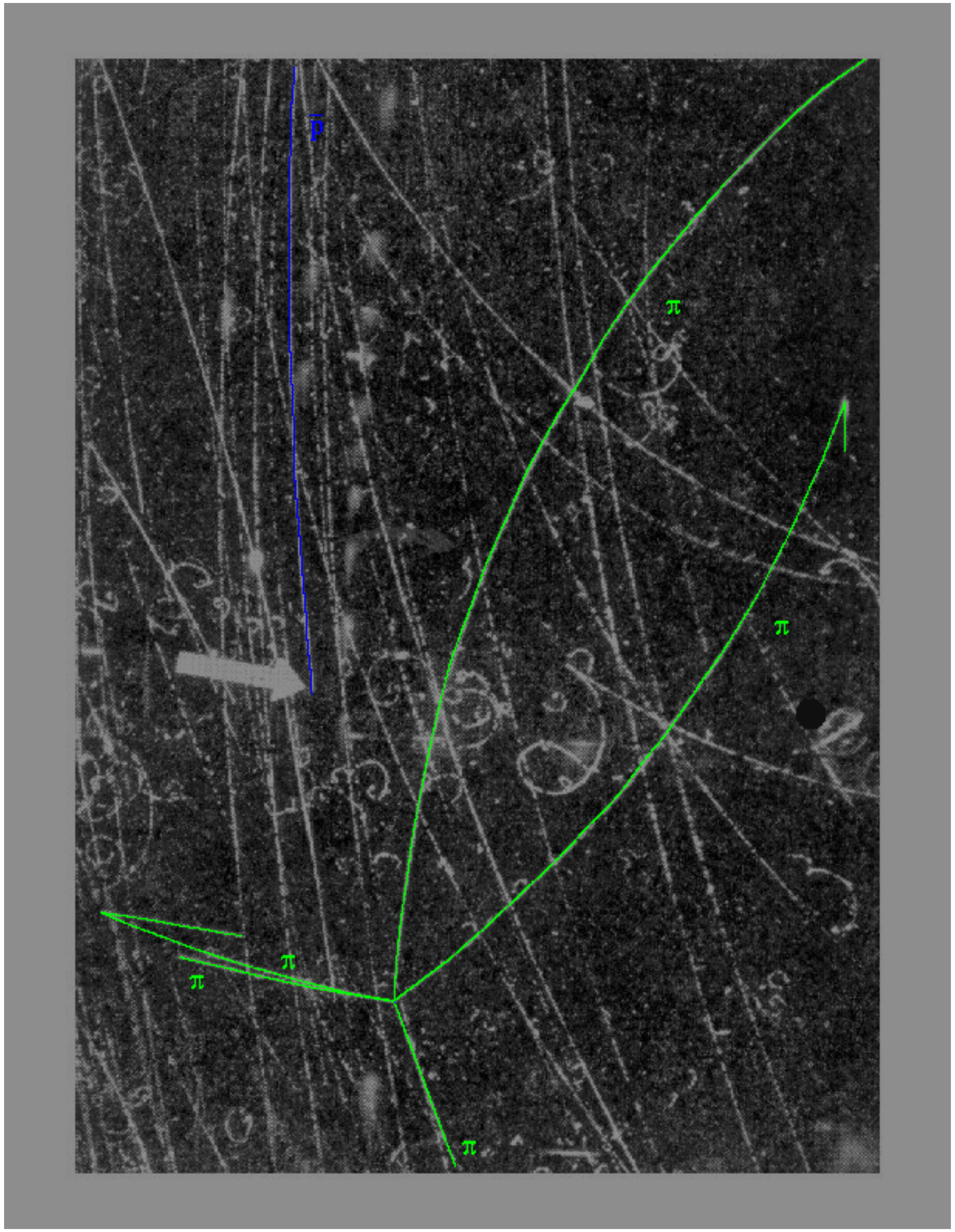
Fig. 6. – The star. *L* indicates the incoming antiproton track. Tracks *a* and *b* are pions, and *c* is a proton. The remaining tracks could be protons or α-particles.

Antiparticles

- The bubble chamber contributed significantly to the discovery of antibaryons
- In 1958 the antineutron was observed through the charge exchange process

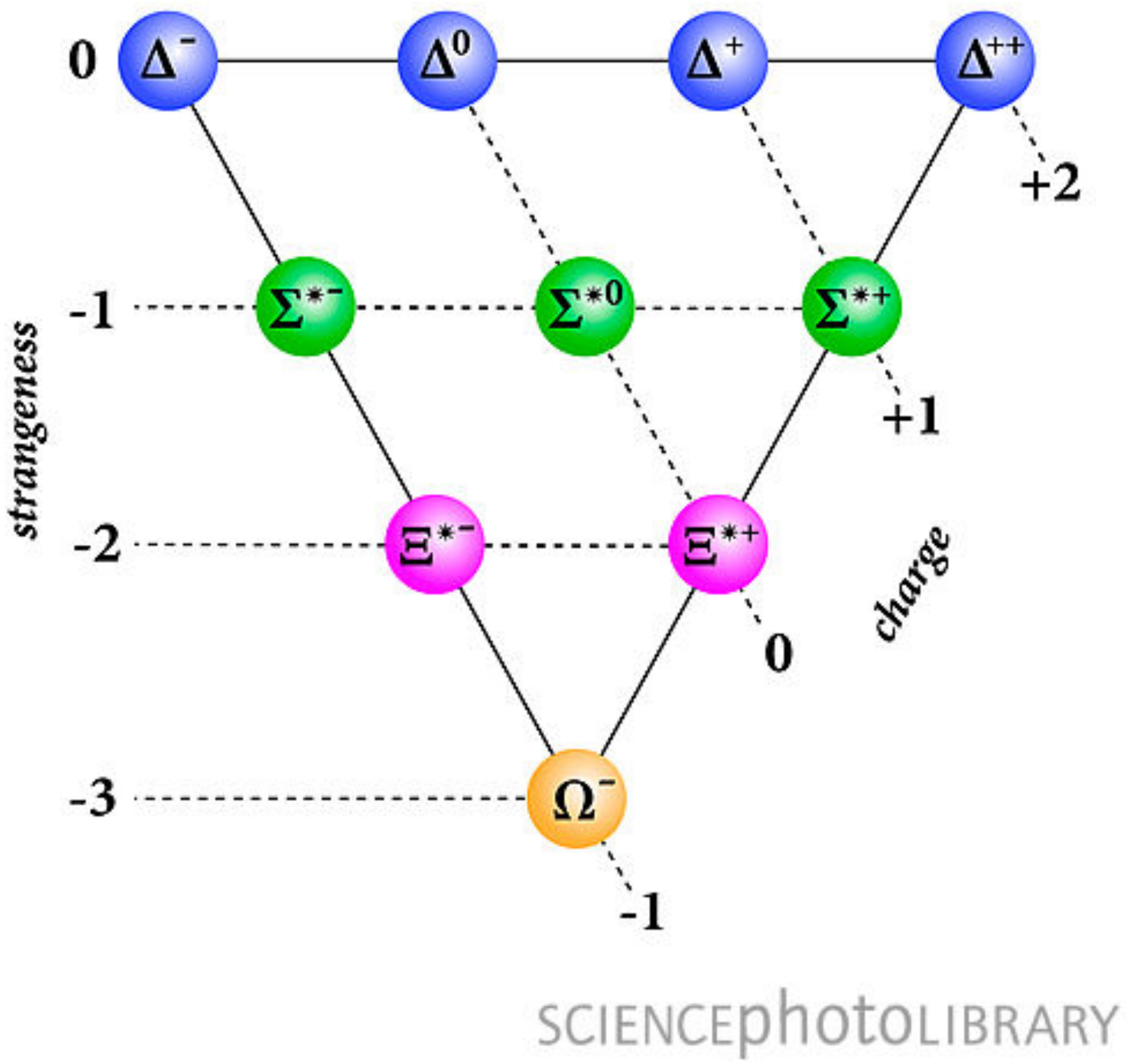
$$p + \overline{p} \to n + \overline{n}$$

- In the years that followed all of the stable baryons were found to have antiparticle partners



"Eight-fold way"

- Murray Gell-Mann (and Yuval Ne'eman) proposed a classification scheme for the seeming endless area of hadrons
- This included predicting the existence of the negatively charged Ω^- baryon
- This classification scheme formed the basis of the quark model, featuring initially u, d and s quarks
- Gell-Mann won the Nobel prize in 1969



Discovery of Omega$^-$

- In 1964 the missing Ω^- was discovered using a bubble chamber at Brookhaven
- It had a similar mass to Gell-Mann's prediction
- This completed the set of u, d, s quark derived baryons (almost before the quarks were invented).

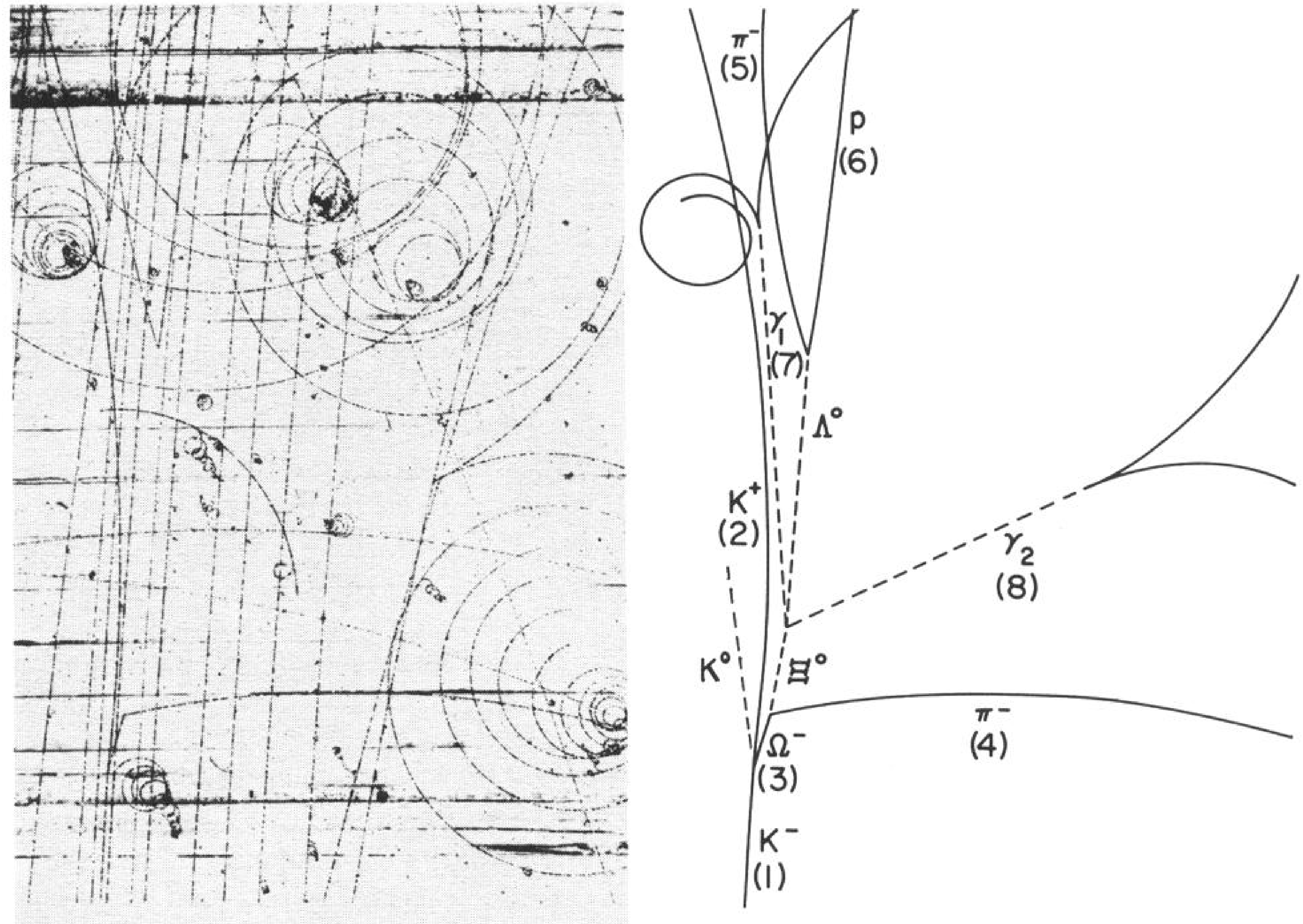


FIG. 2. Photograph and line diagram of event showing decay of Ω^-.

$$K^- + p \to \Omega^- + K^+ + K^0$$
$$\Omega^- \to \Xi^0 + \pi^-$$
$$\Xi^0 \to \Lambda^0 + \pi^0$$
$$\pi^0 \to \gamma_1 + \gamma_2$$
$$\gamma_2 \to e^+ + e^-$$
$$\gamma_1 \to e^+ + e^-$$
$$\Lambda^0 \to \pi^- + p.$$

Nucleon Structure

- Bubble chambers were also used in the study of nucleon structure
- The differences between neutrino and antineutrino nucleon cross-sections is a measure of the quark content of protons and neutrons... more on this later in the course.

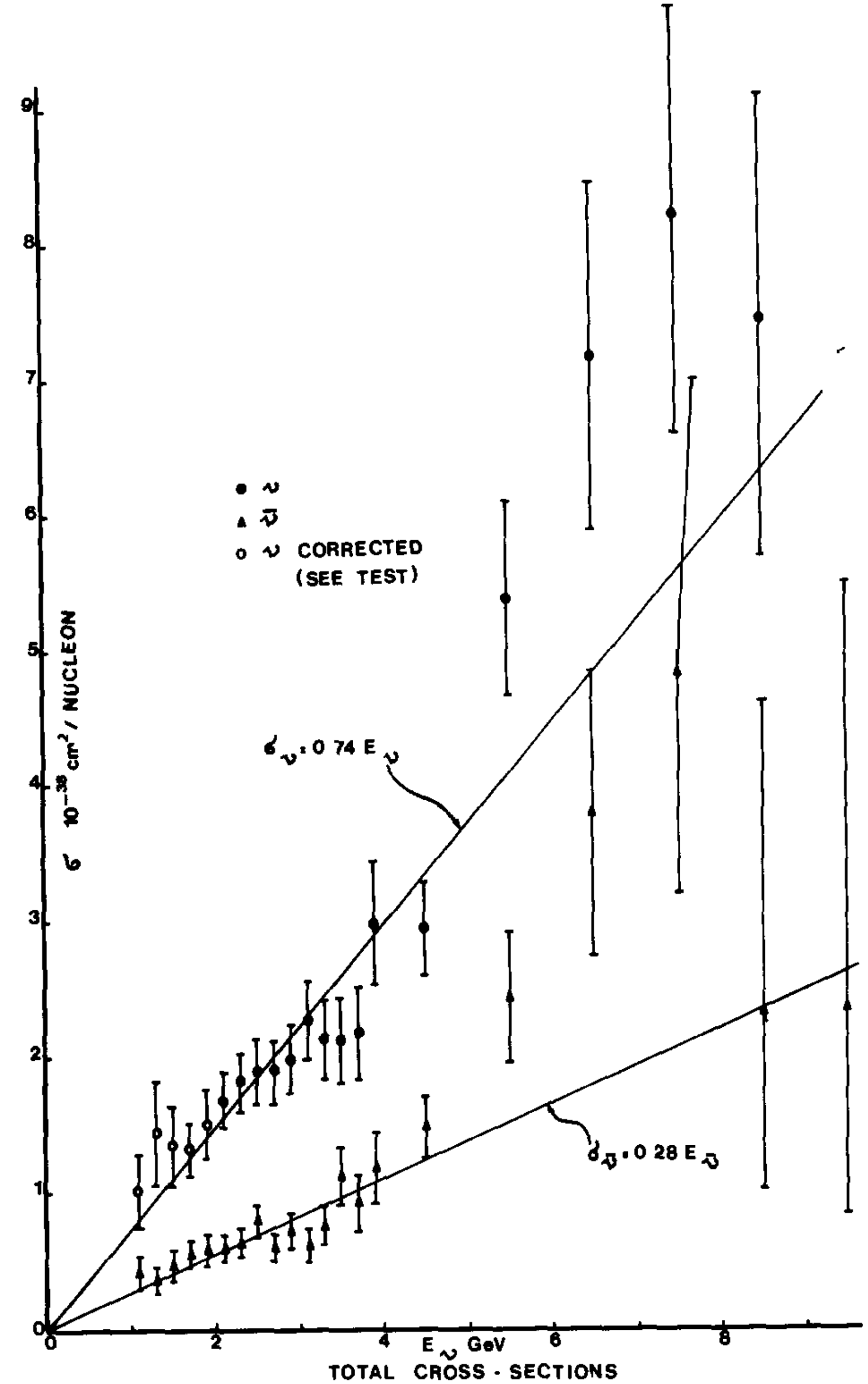
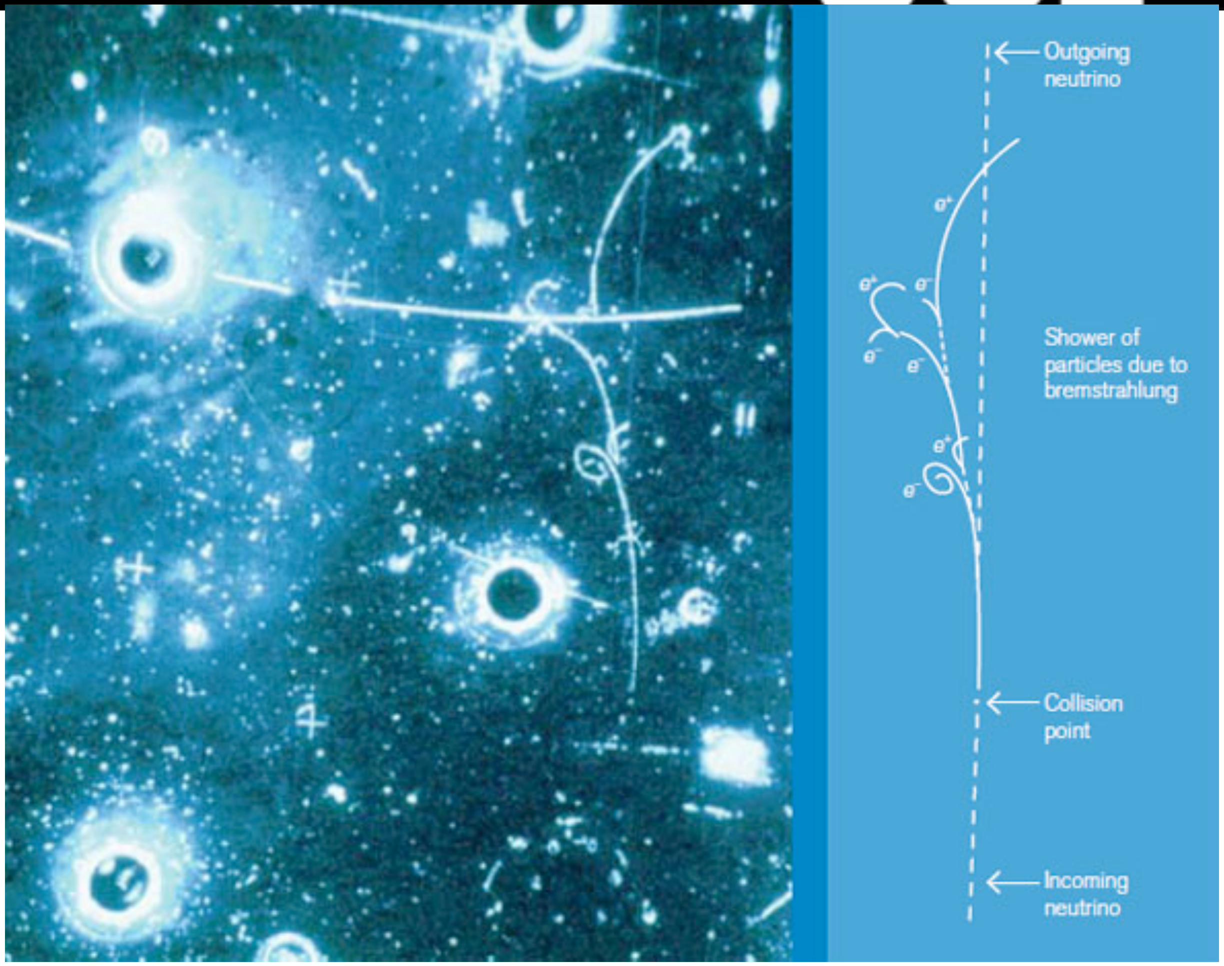
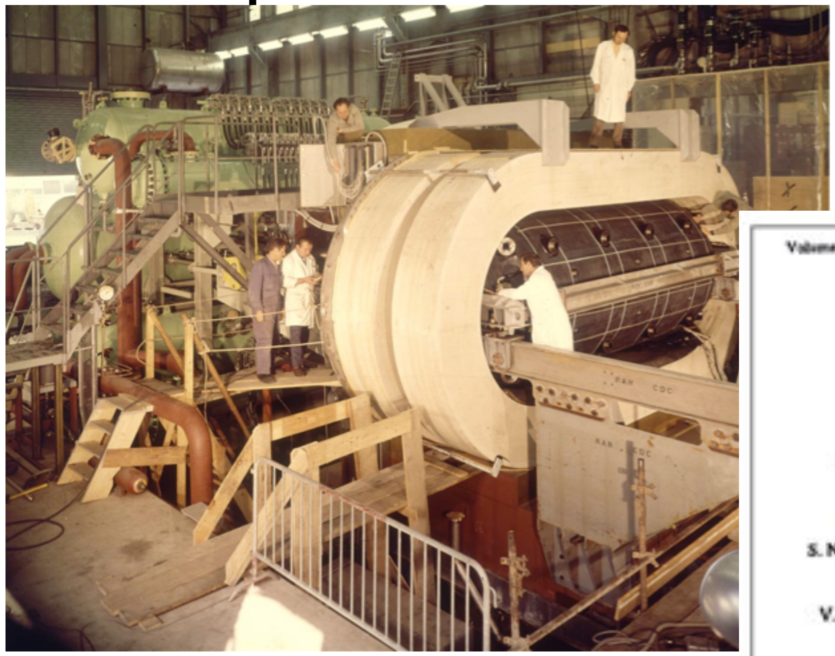


Fig. 1. Total neutrino and antineutrino cross-sections as a function of energy.

Weak Neutral Currents

- Electroweak unification brought with it the prediction of weak neutral currents
- In 1974 they were discovered at the Gargamelle bubble chamber
  - Glashow, Salam & Weinberg won the 1979 Nobel Prize for the prediction





Volume 46B, number 1 PHYSICS LETTERS 3 September 1973

SEARCH FOR ELASTIC MUON-NEUTRINO ELECTRON SCATTERING

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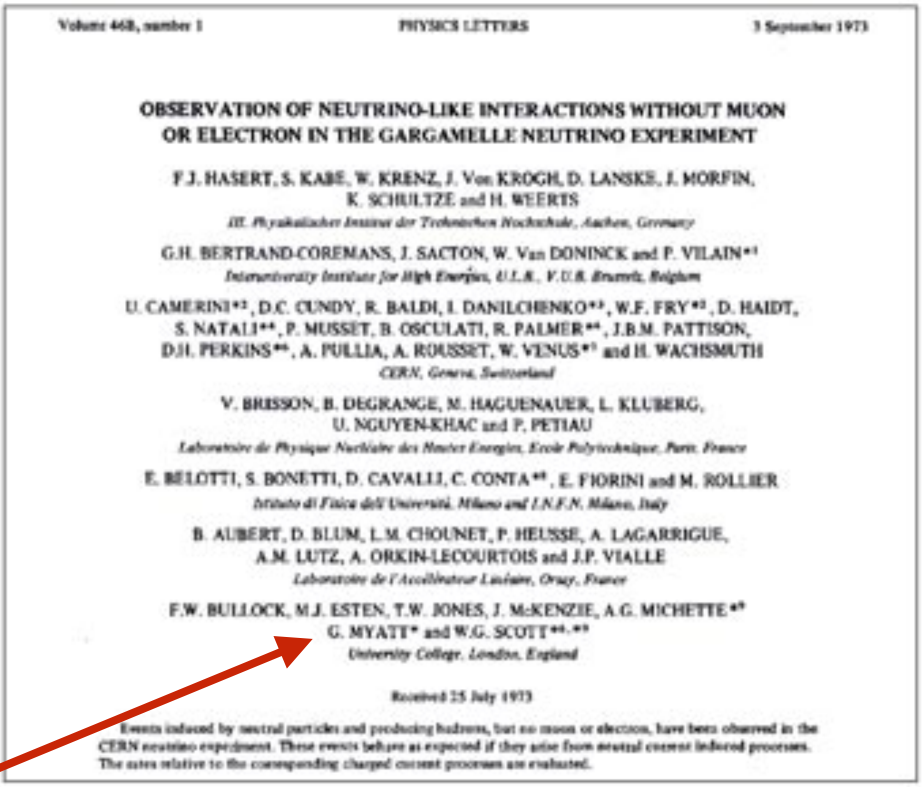
Received 2 July 1973

One possible event of the process $\bar{\nu}_\mu + e^- \to \bar{\nu}_\mu + e^-$ has been observed. The various background processes are discussed and the event interpreted in terms of the Weinberg theory. The 90% confidence limits on the Weinberg parameter are $0.1 < \sin^2\theta_W < 0.6$.



Volume 46B, number 1 PHYSICS LETTERS 3 September 1973

OBSERVATION OF NEUTRINO-LIKE INTERACTIONS WITHOUT MUON OR ELECTRON IN THE GARGAMELLE NEUTRINO EXPERIMENT

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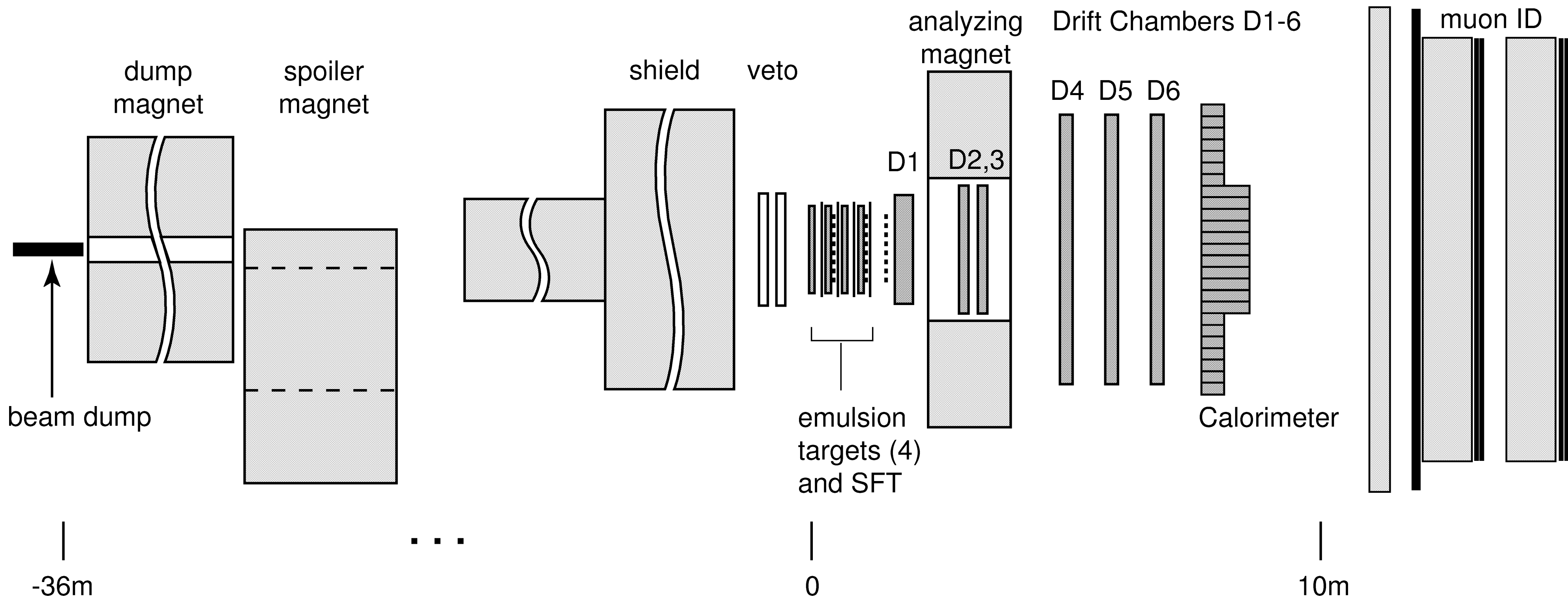
Received 25 July 1973

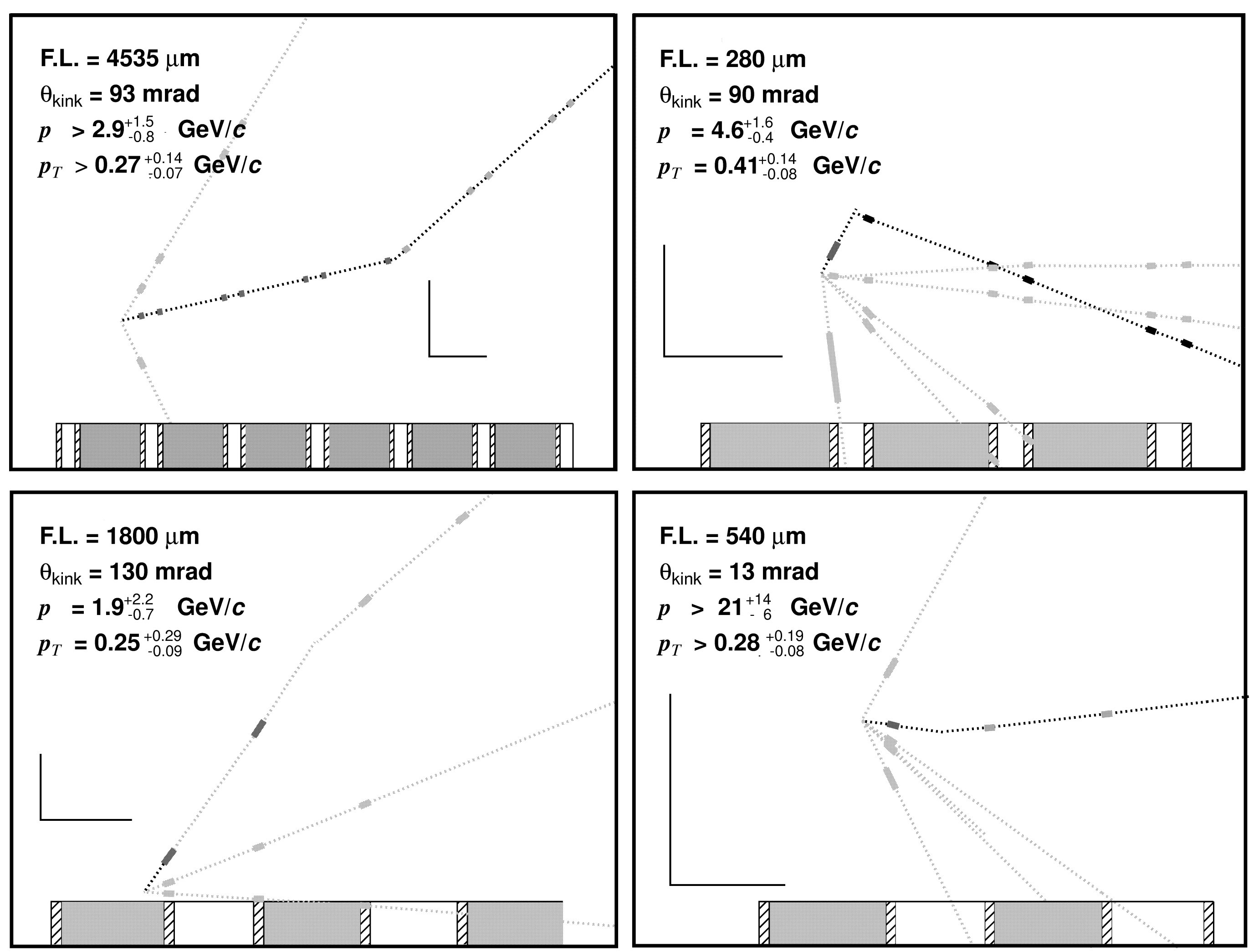
Events induced by neutral particles and producing hadrons, but no muon or electron, have been observed in the CERN neutrino experiment. These events behave as expected if they arise from neutral current induced processes. The rates relative to the corresponding charged current processes are evaluated.

UCL involvement

Discovery of Tau Neutrino (2001)



The Fermilab DONUT experiment looked for kinks in tracks due to the short lifetime of the tau lepton



References

- D. H. Perkins, “Nuclear Disintegration by Meson Capture”, Nature, 159, 4030, 126-127 (1947)
- C. M. G. Lattes, G. P. S. Occhialini and C. F. Powell, “Observations on the Tracks of Slow Mesons in Photographic Emulsions”, 160, 4067, 486-492 (1947)
- D. Glaser, “Some Effects of Ionizing Radiation on the Formation of Bubbles in Liquids”, Phys. Rev. 87, 665-665 (1952)
- O. Chamberlain et al., “On the observation of an antiproton star in emulsion exposed at the bevatron”, Il Nuovo Cimento, 3, 2, 447-467 (1955)
- L. Alvarez *et al.*, “Neutral Cascade Hyperon Event”, Phys. Rev. Lett. 2, 215 (1959)
- F. Hasert *et al.*, “Observation of neutrino-like interactions without muon or electron in the Gargamelle neutrino experiment”, Phys. Lett. B 46, 138-140 (1973)
- H. Sun and D. Zhang, “Nuclear emulsion and high-energy physics”, Radiation Measurements, 43, S139-S143 (2008)
- K. Kodama et al., “Observation of tau neutrino interactions”, Phys. Lett. B., 504, 218-224 (2008)
- J. Beringer *et al.* (PDG), PRD 86, 010001 (2012) http://pdg.lbl.gov