YUKAWA AND THE DISCOVERY OF THE PION

Estifa'a Zaid

HIDEKI OGAWA

- Hideki Ogawa was born in Tokyo and was one of 5.

- “not as outstanding a student as his older brothers” - Takuji Ogawa

- His maths teacher put him off being a mathematician and wasn’t very good at experiments.

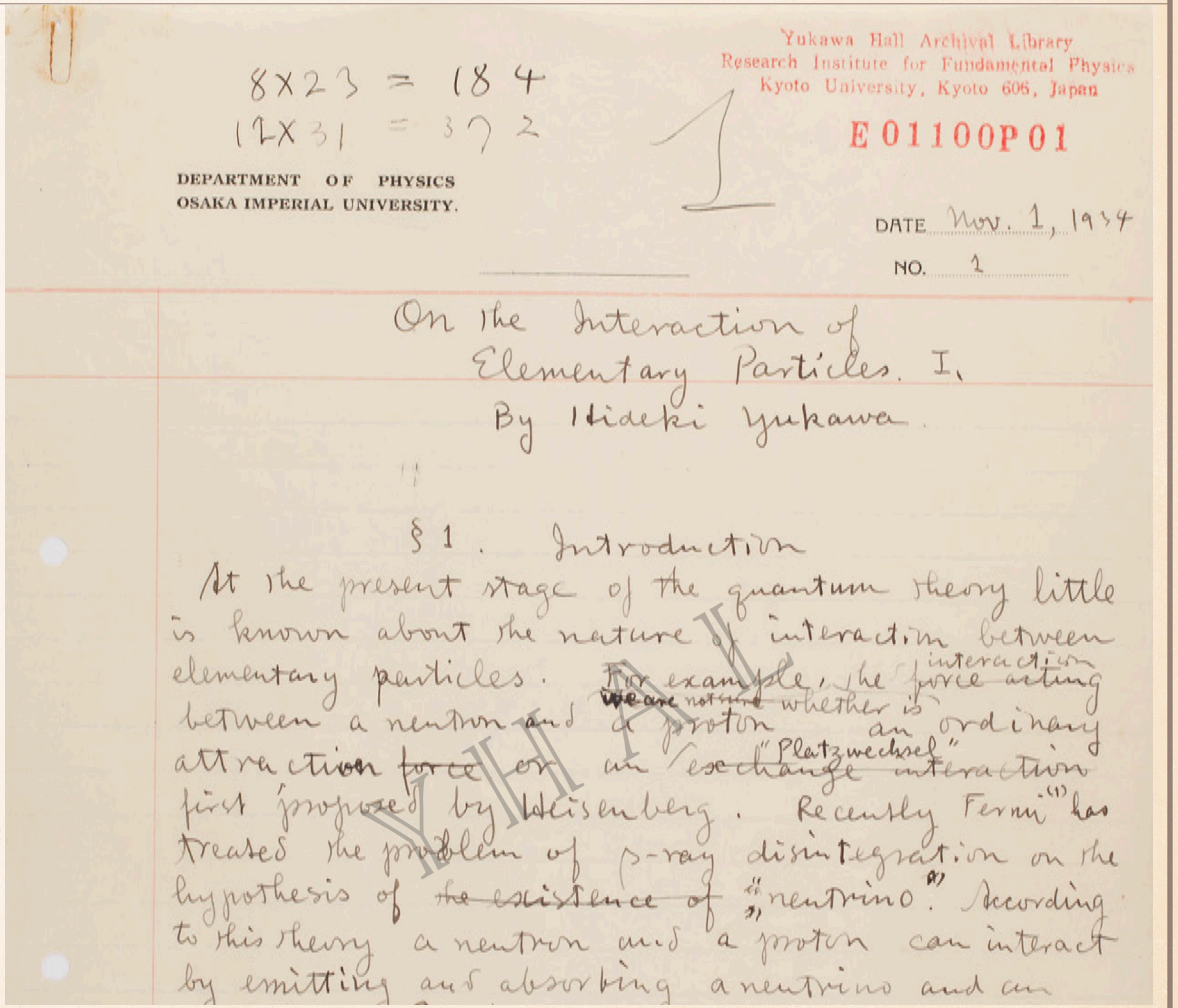
- In 1929 he graduated from Kyoto University

HIDEKI YUKAWA

- Hideki Ogawa married Sumi Yukawa
- In accordance to Japanese customs he changed his name to Hideki Yukawa
- In 1933 at 26 years old he became a lecturer and published his theory of mesons in 1935.
- Received a Nobel prize in 1949 after the discovery of the pion.

HIDEKI YUKAWA

- 1932 atomic model to include the neutron - Chadwick
- 1932 "platzwechsel" theory of migration - Heisenberg
- 1934 Beta decay $n \rightarrow p + e^{-} + \bar{\nu}$ - Fermi
- Yukawa modified theory of short range interaction using protons and neutrons and exchange of light particles for neutron-proton interaction.
- He proposed a heavier exchange particle to mediate the strong force. 1/6th of proton mass.



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DEPARTMENT OF PHYSICS
OSAKA IMPERIAL UNIVERSITY.

DATE Nov. 1, 1934
NO. 1

On the Interaction of
Elementary Particles. I.
By Hideki Yukawa.

§1. Introduction

At the present stage of the quantum theory little is known about the nature of interaction between elementary particles. For example, the interaction between a neutron and a proton whether is an ordinary attraction or an "Platzwechsel" interaction first proposed by Heisenberg. Recently Fermi(1) has treated the problem of β-ray disintegration on the hypothesis of "neutrino". According to this theory a neutron and a proton can interact by emitting and absorbing a neutrino and an

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Now such interaction between the elementary particles can be described by means of a field of force, just as the interaction between the charged particles is described by the electromagnetic field. The above considerations show that the interaction of heavy particles with this field is much larger than that of light particles with it.

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(2) E. Fermi, ibid. **88**, 161 (1394).
(3) Ig. Tamm, Nature **133**, 981 (1934); D. Iwanenko, ibid. 981 (1934).

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No such particle exists :(

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    - Wrong lifetime
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- A possible explanation of these difficulties had been put forward in Japan in 1942 and 1943 by Yasutaka Tanikawa and by Shoichi Sakata and Takeshi Inoue,
- They suggested a two-meson hypothesis with a Yukawa-type meson decaying to a weakly interacting mesotron.
- Because of the war their ideas were not published in English until 1946 and 1947, the journals in question not reaching the USA until the end of 1947.

NUCLEAR EMULSION

- Photographic emulsions were key to the discovery of the pion. Previously the tools available were Geiger Counters and Cloud Chambers

First ever observation of proton tracks in photographic emulsion using alpha rays in paraffin wax - Marietta Blau

Discovery of radioactivity and alpha rays using photographic emulsion

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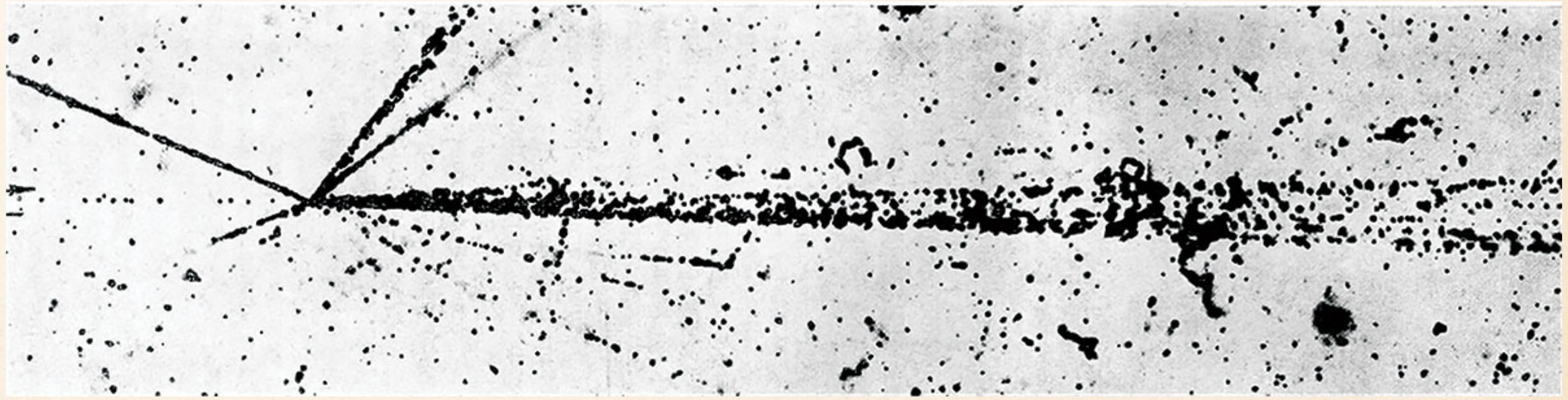

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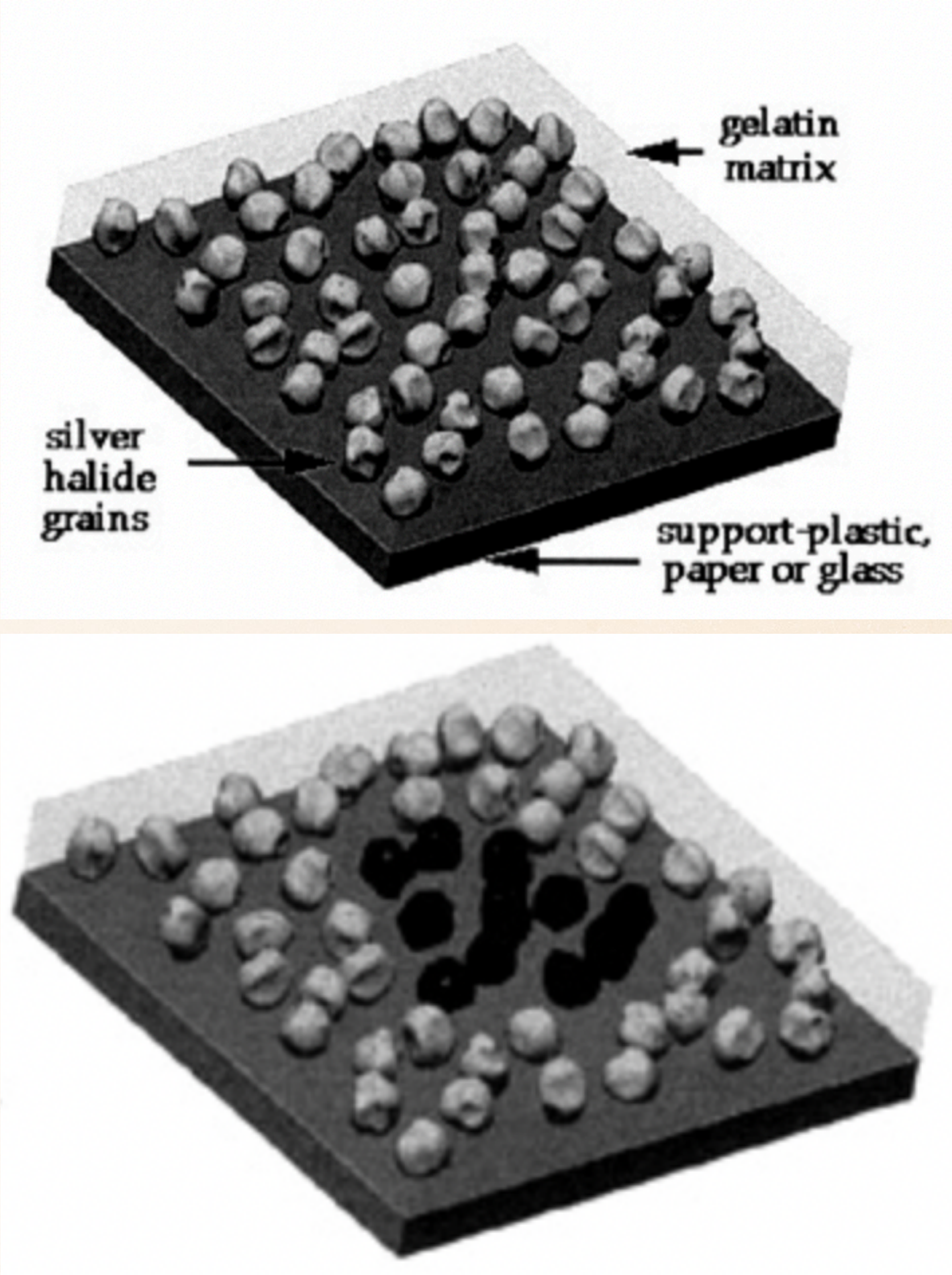
Observation of kaon using emulsion plates exposed to cosmic rays on Jungfraujoch- Rosmary Brown

PHOTOGRAPHIC EMULSIONS

- In photographic emulsion a thin layer of radiation-sensitive silver halide (silver bromide or chloride) crystals suspended in a gelatin matrix which is supported by a glass plate.

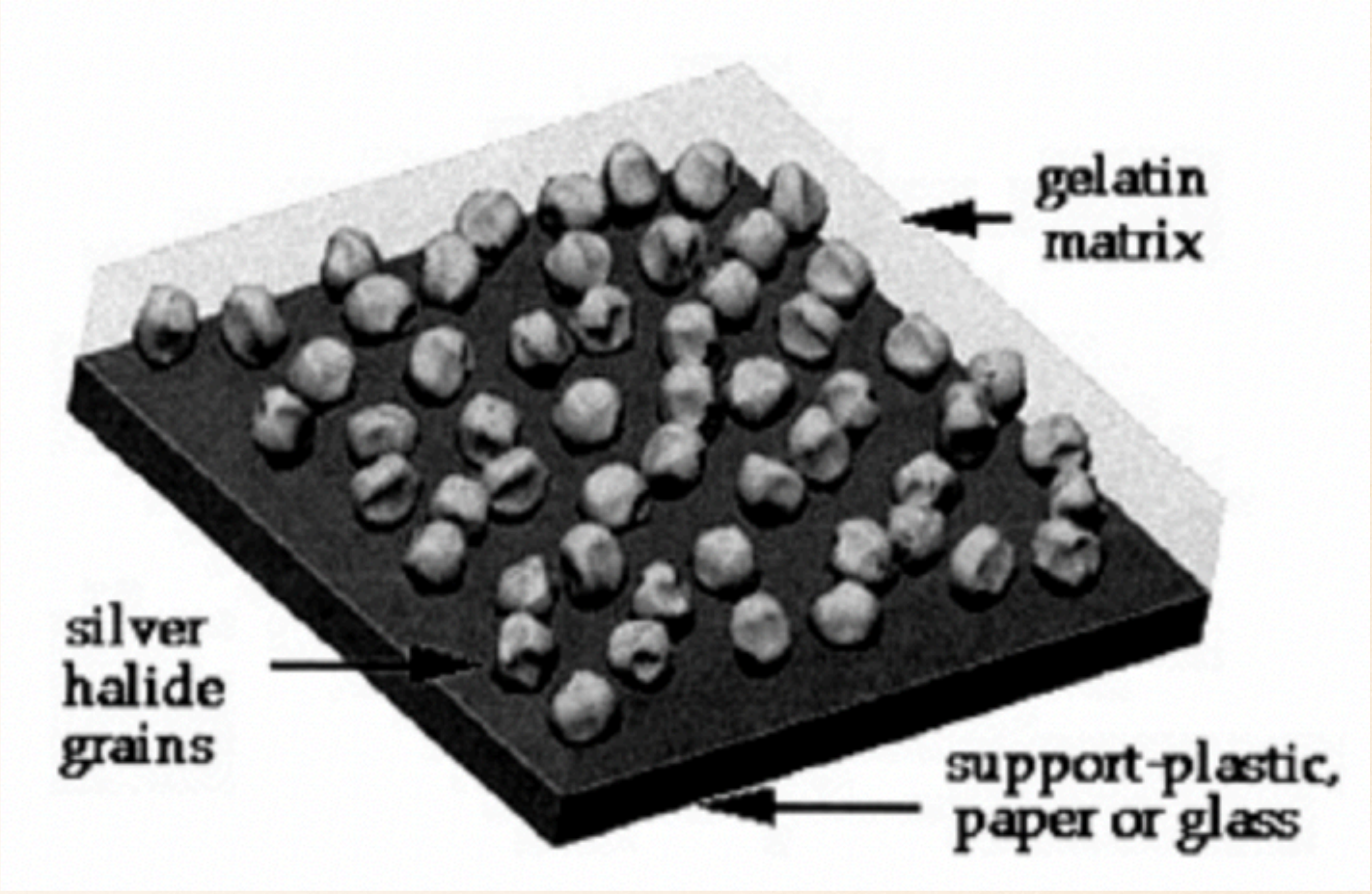
- Radiation particles ionise the silver halide grains and reduces them to metallic silver during developing.

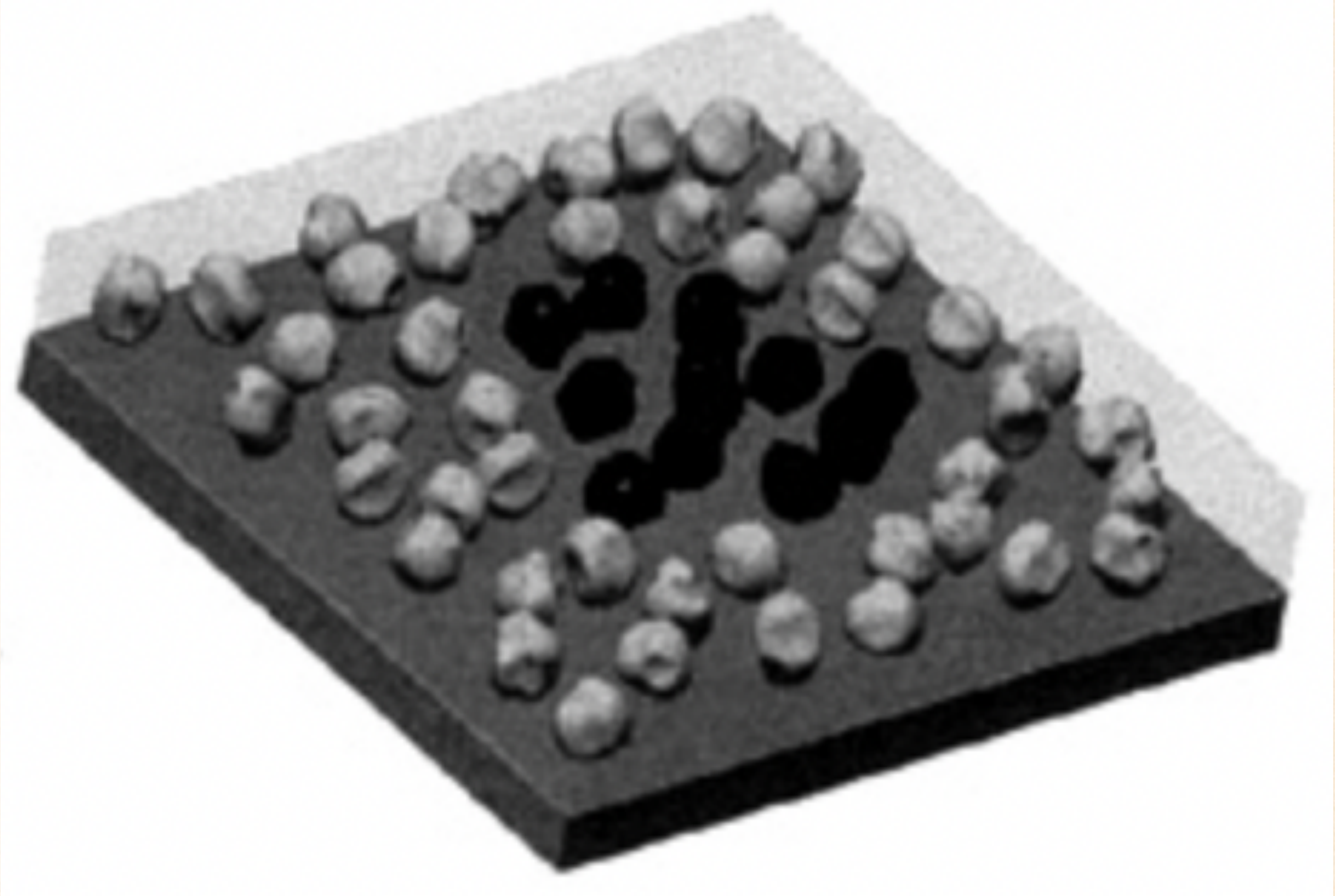
- This causes blackening of the image and leaves unexposed grains unaffected.



PHOTOGRAPHIC EMULSIONS

- Problems:
  - Low sensitivity to ionisation
  - Fades over time
  - Hard to observe tracks after development
  - Active material is non-uniform

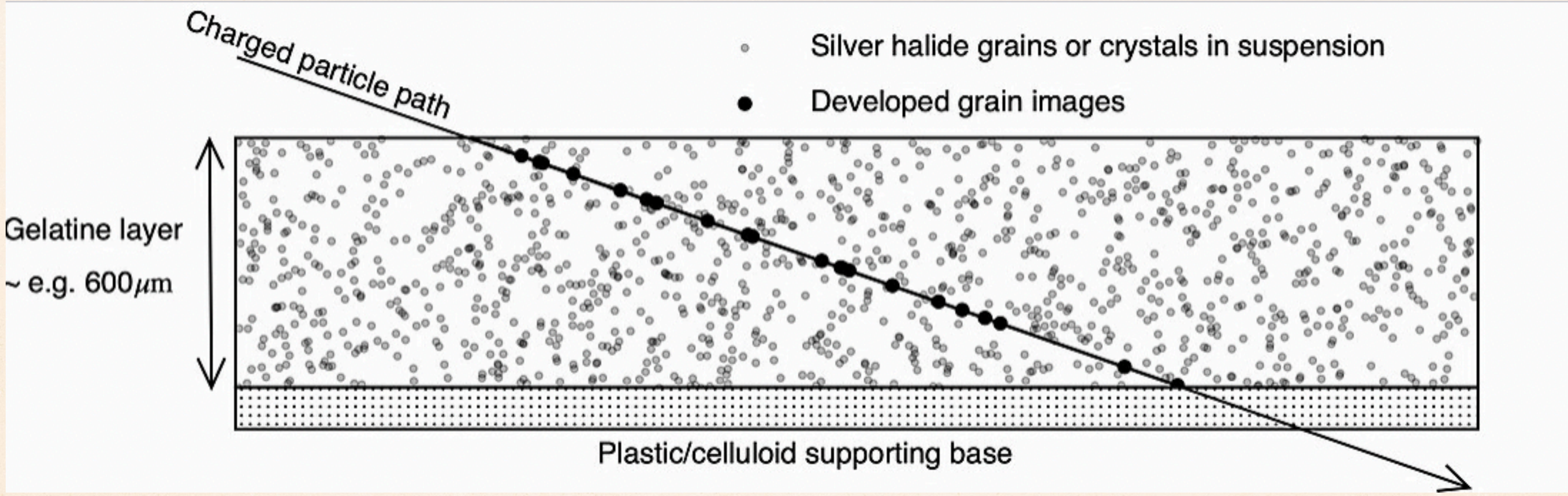




NUCLEAR EMULSIONS

- Kodak and Ilford produced photographic emulsions specifically for recording tracks of charged particles.

- Emulsions now had four times the normal silver halide to gelatin ratio.



FIRST SIGHTING

- Photographic Reconnaissance Unit was the first dedicated photo and aerial recon unit of the Royal Air Force of the Second World War.
- Thousands of photo Interpreters (PI) worked analyse the data and sent it to commanders strategic and tactical use.
- Perkins' supervisor persuaded the RAF to carry 6 3" x 1" 50 micron thick nuclear emulsions.

FIRST SIGHTING

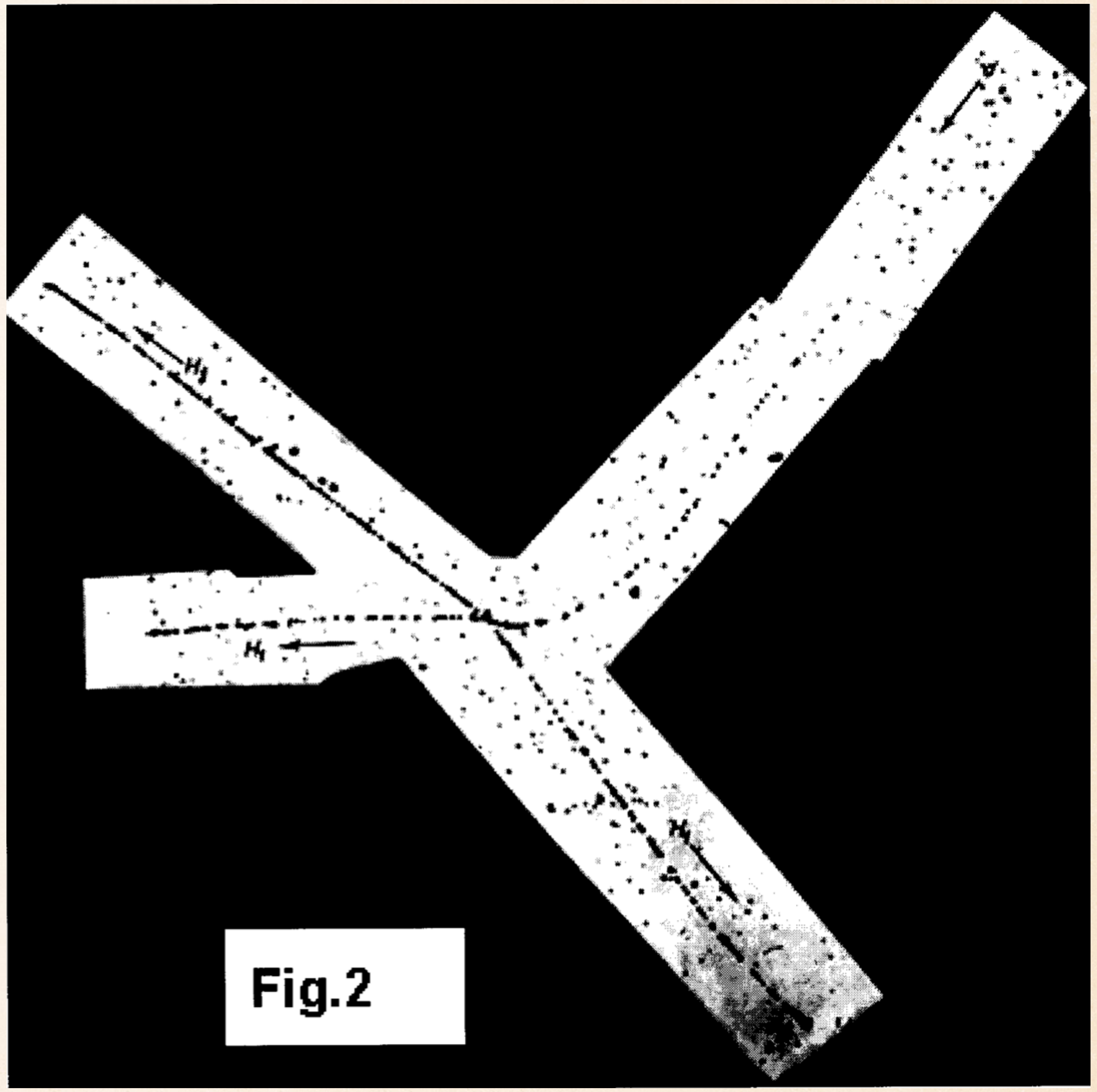
- **Tomonga and Araki's hypothesis** on the nature of positive and negative Yukawa particles states that negative particles should be absorbed into the nuclei and positive particles would not interact and instead have time to decay

- Perkins found **20 nuclear disintegrations** one was produced by an incoming charged particle.

- The negatively charged particle was **absorbed in the nucleus** and blasted it apart leaving 3 fragments

- He calculated the mass to be **100-300 x mass of the electron**.

- This was different from the negative mesotrons seen by CPP which always decayed



FIRST SIGHTING

- Perkins inferred:
  - Particle was travelling towards the disintegration point:
    - Assuming the particle is singly charged, both ionisation and scattering increase towards the centre of the disintegration star.
  - It is not an electron :
    - The ionisation is too high and scattering too small to be an electron (electrons could probably not be detected at this range)
  - It's not a proton :
    - Scattering is too high to be a proton.
- **Mass is therefore intermediate**

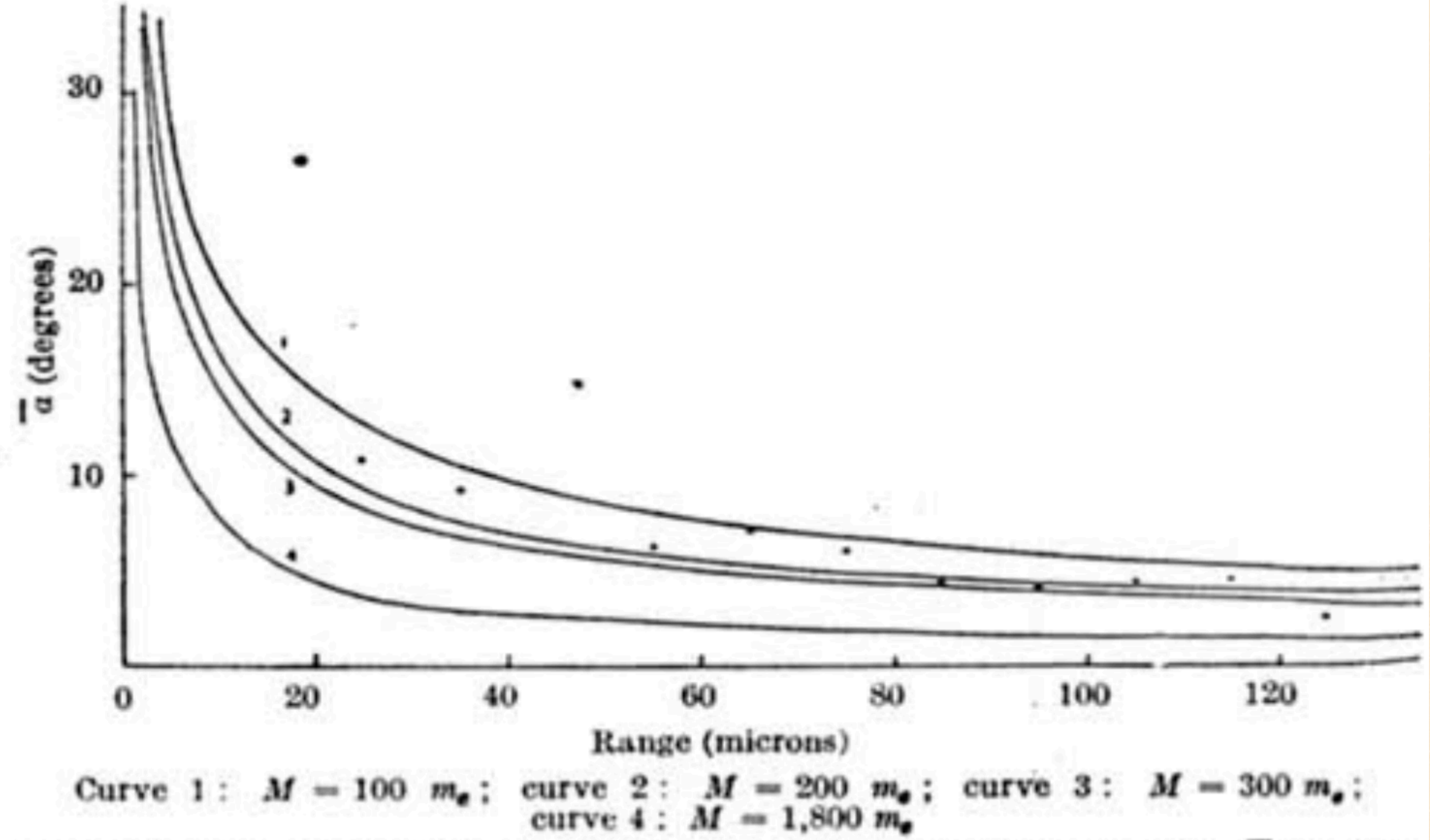


Fig. 2. MULTIPLE SCATTERING OF MESONS AND PROTON IN THE EMULSION. $\bar{\alpha}$ DENOTES THE MEAN ANGLE OF SCATTERING FOR A 10 μ LAYER OF THE EMULSION. CURVES CALCULATED FOR PARTICLES OF MASS 100 m_e, 200 m_e, 300 m_e AND 1,800 m_e (PROTON). m_e BEING THE ELECTRON MASS. EXPERIMENTAL POINTS, FROM MEASUREMENTS ON TRACK A, INDICATED BY DOTS

BREAKTHROUGH

- A few months later Cecil Powell, Lattes, Occhialini and Muirhead exposed plates in the Andes at 5,500 meters and also at 2,800 m in the Pyrenees

- In total they observed 644 meson tracks. They found **40 examples of one meson decaying into another.**

- In 11 cases the secondary meson can be observed traveling through the emulsion.

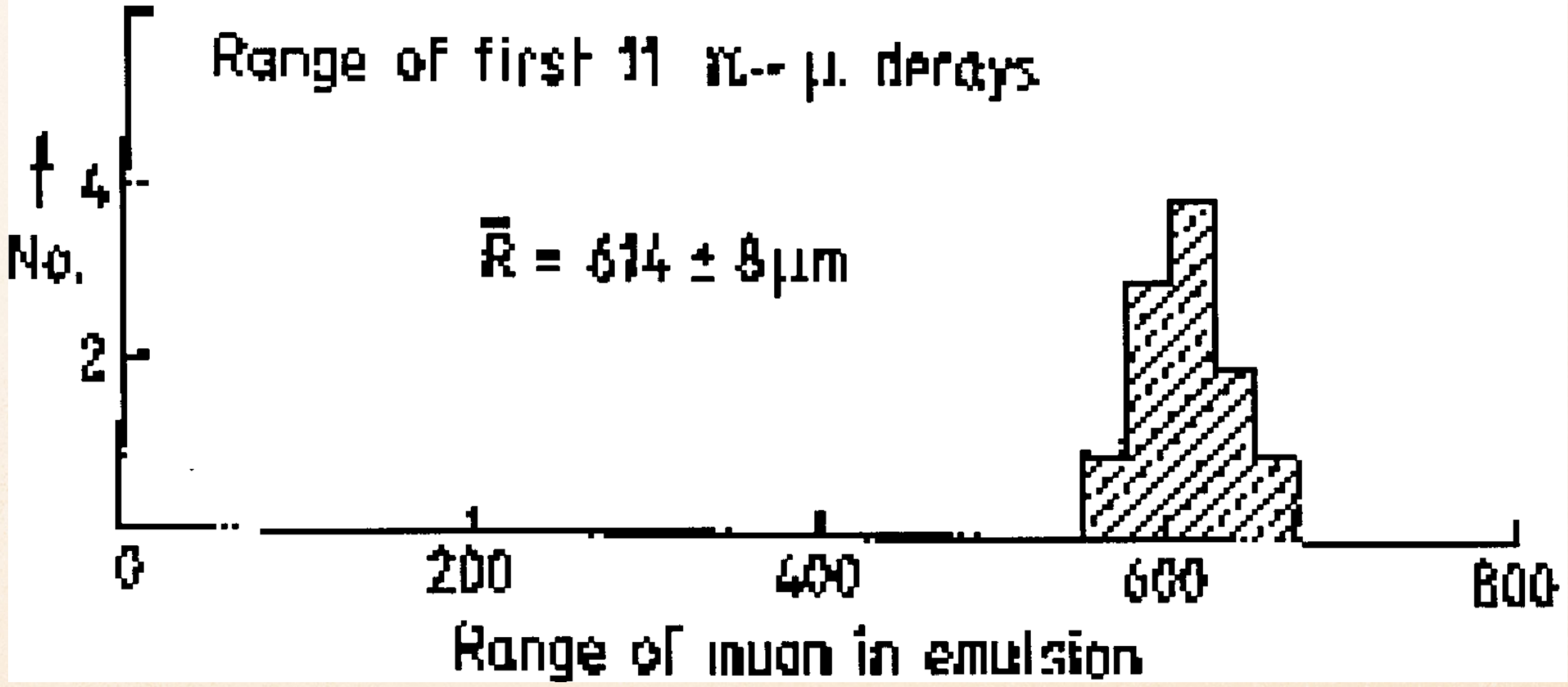
- The **range of the second particles are consistent** (variations due to Bohr straggling), secondary particles are of the **same mass and kinetic energy.**

- They postulated a **two body decay with one neutral particle**

TABLE 1

Event No.	Range in emulsion in microns of: Primary meson	Secondary meson
I	133	613
II	84	565
III	1040	621
IV	133	591
V	117	638
VI	49	595
VII	460	616
VIII	900	610
IX	239	666
X	256	637
XI	81	590

Mean range 614 ± 8 μ. Straggling coefficient $\sqrt{\Sigma\Delta_i^2/n} = 4{\cdot}3$ per cent, where $\Delta_i = R_i - \bar{R}$, R_i being the range of a secondary meson, and $\bar{R}$ the mean value for n particles of this type.



BREAKTHROUGH

454 NATURE October 4, 1947 Vol. 160

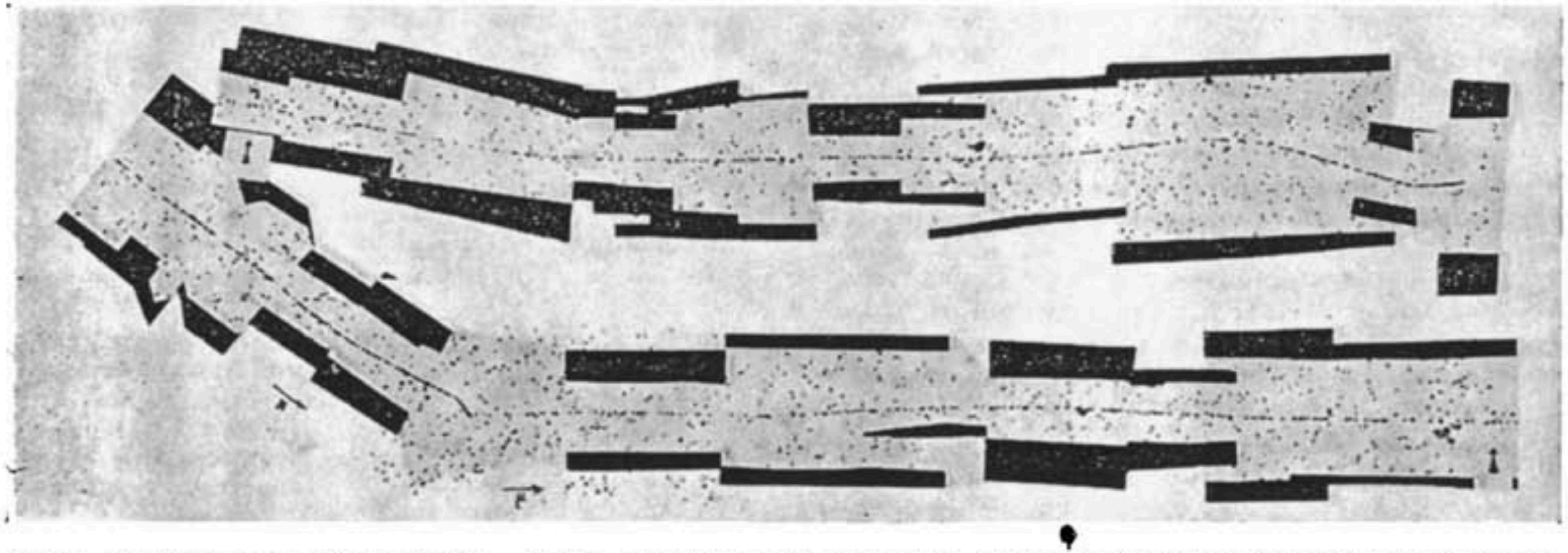


Fig. 1. OBSERVATION BY MRS. I. POWELL. COOKE × 95 ACHROMATIC OBJECTIVE; C2 ILFORD NUCLEAR RESEARCH EMULSION LOADED WITH BORON. THE TRACK OF THE μ-MESON IS GIVEN IN TWO PARTS, THE POINT OF JUNCTION BEING INDICATED BY *a* AND AN ARROW

- The first observation of $\pi \rightarrow \mu\nu$, the names of the primary and secondary particles given by authors
- $\pi^{\pm}$ depends on whether the pion produced in nuclear disintegration underwent nuclear capture (negative) or decay (positive)

THE CHARGED PION

- Powell et al tried to calculate the **mass of the pion from the range-energy relations** of existing particles.
- This was done using the grain count in the track and the range. They determined that the **ratio of the pion to the muon is ~ 2**
- If assuming the emission of a **massless particle** ejected in the opposite direction to the **muon the ratio is ~1.4.** They thus deduce:
    - "Our preliminary measurements appear to indicate, therefore, that the emission of the secondary meson cannot be regarded as due to a spontaneous decay of the primary particle, in which the momentum balance is provided by a photon, or by a particle of small rest-mass. On the other hand, the results are consistent with the view that a neutral particle of approximately the same rest-mass as the μ-meson is emitted."

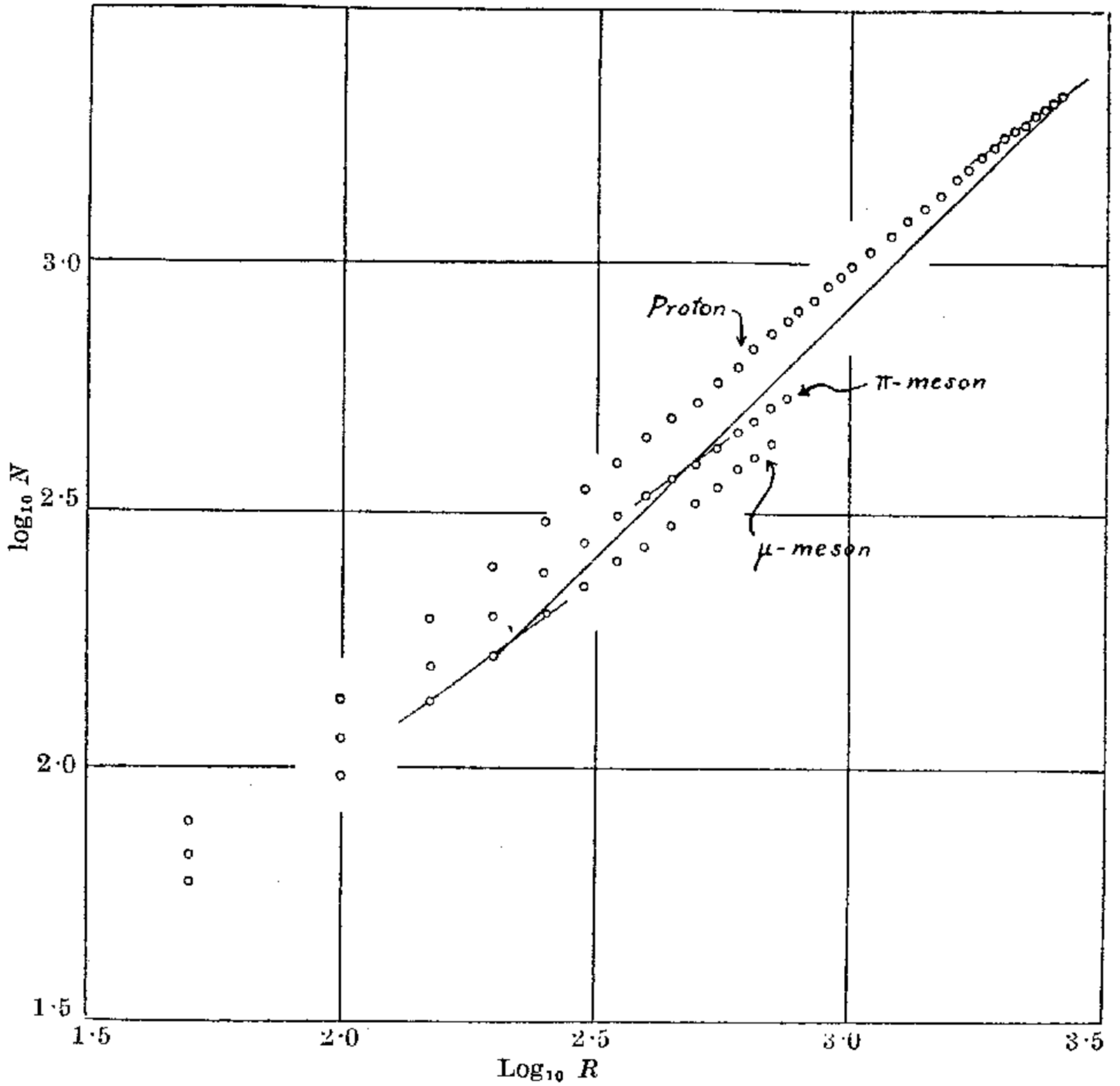


Fig. 5. N IS TOTAL NUMBER OF GRAINS IN TRACK OF RESIDUAL RANGE R (SCALE-DIVISIONS). 1 SCALE-DIVISION = 0·85 MICRONS
THE 45°-LINE CUTS THE CURVES OF THE MESONS AND PROTON IN THE REGION OF THE SAME GRAIN DENSITY

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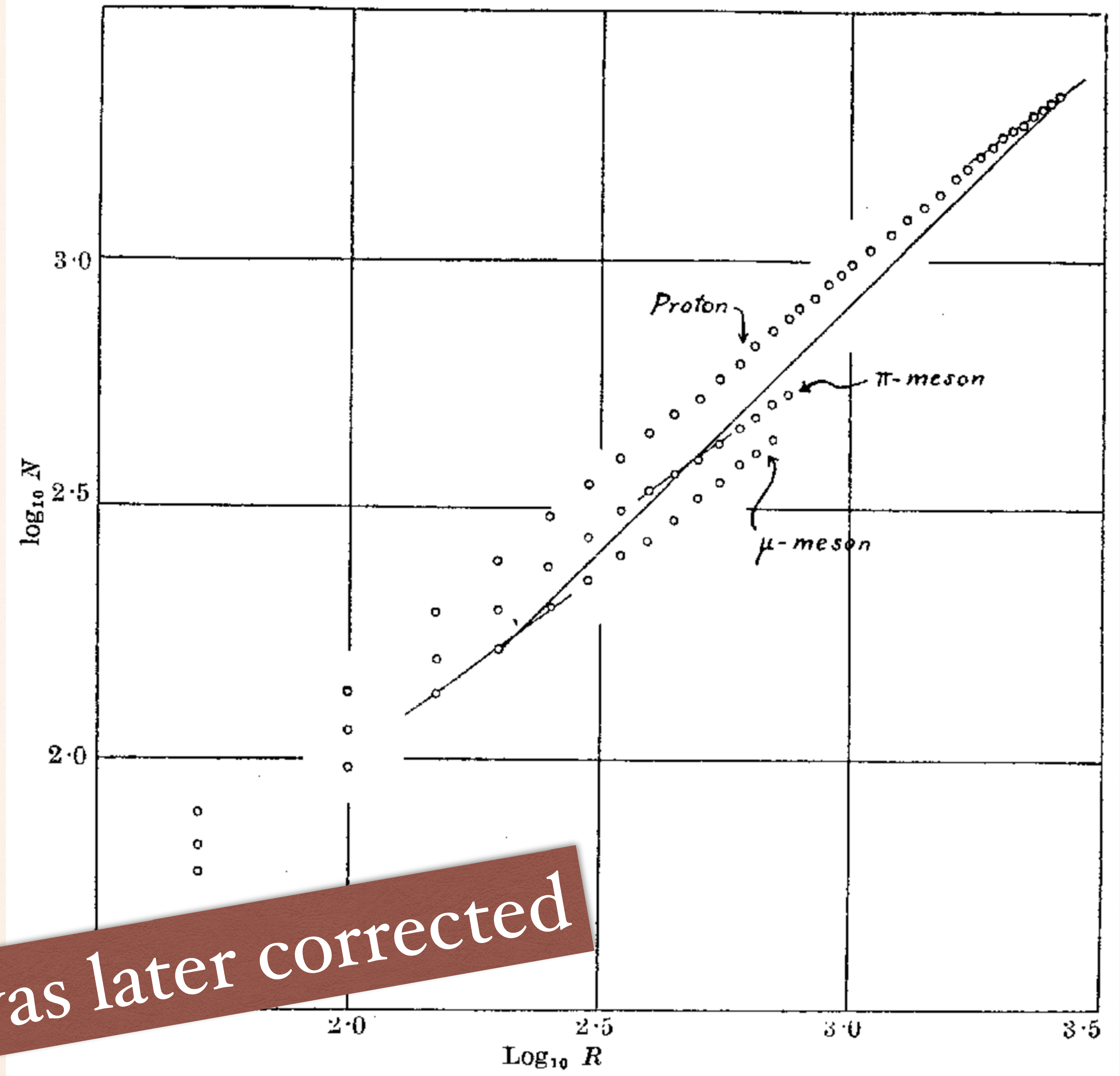

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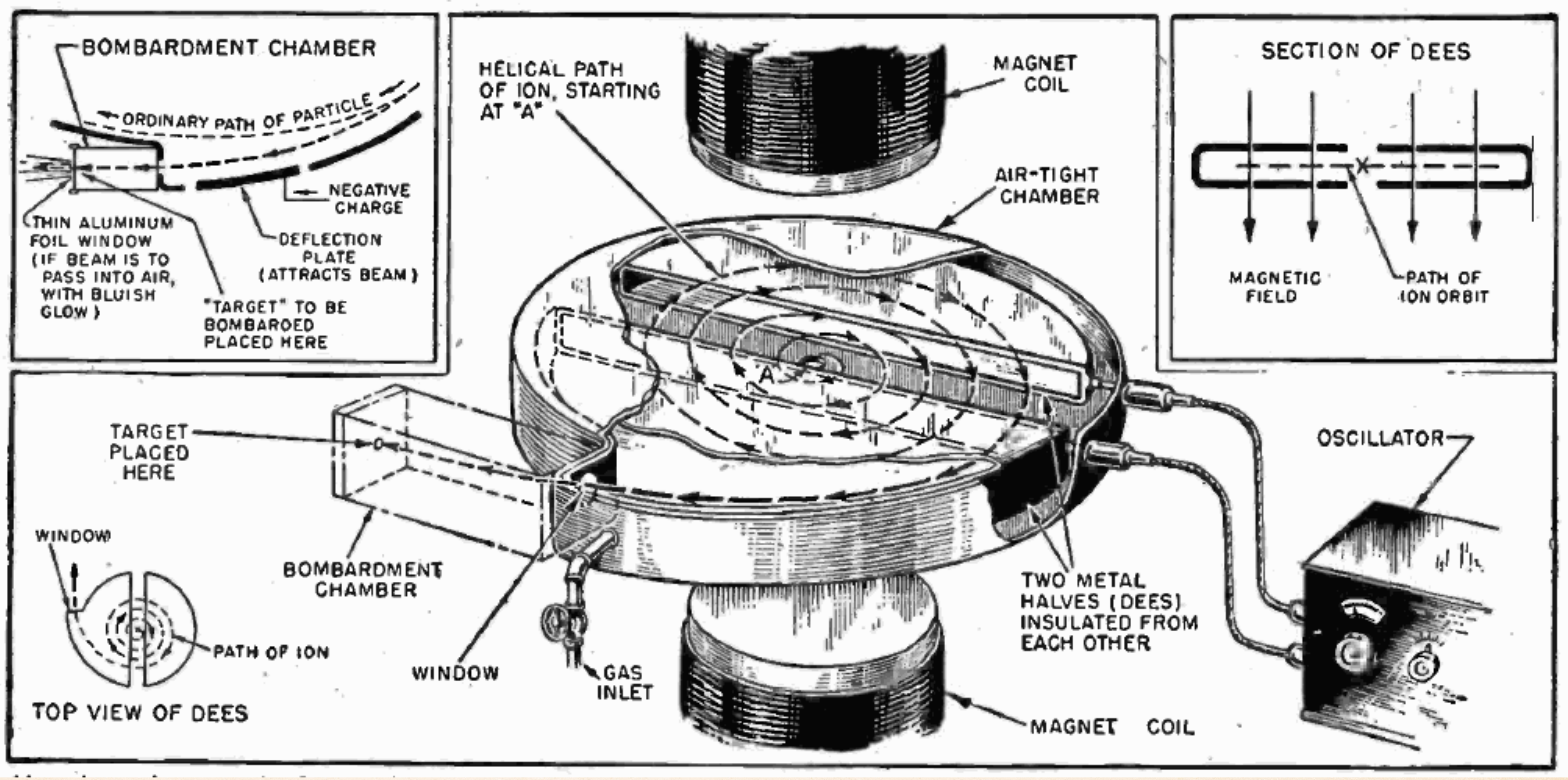
This was later corrected

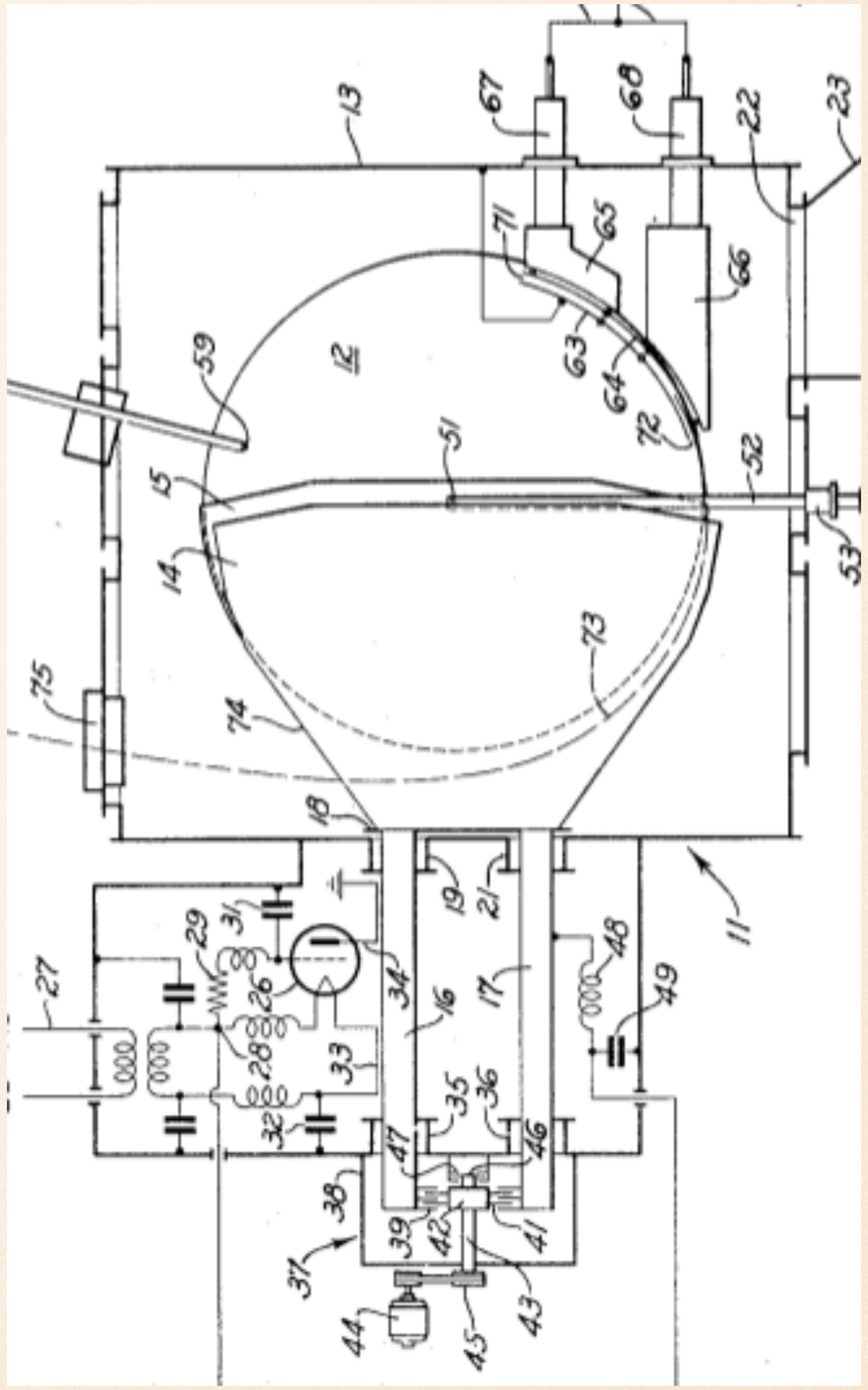
CYCLOTRON

- 1930 - Cyclotron invented by Ernest Lawrence at Berkeley. First cyclical accelerator
- The accelerating **electric field reverses** just at the time the electrons finish their half circle, so that it accelerates them across the gap. **With a higher speed, they move in a larger semicircle.**
- Lawrence kept increasing their size to get to higher energies, **but was limited by relativistic effects**
- Enter synchrocyclotron !



SYNCHROCYCLOTRON

- Frequency of oscillating electric field in a synchrocyclotron is **decreasing continuously instead of kept constant** so as to maintain cyclotron resonance for relativistic velocities
- This became operational at Berkley in 1948.
- Lattes then used it to **observed charged pions in photographic emulsions.**



THE NEUTRAL PION

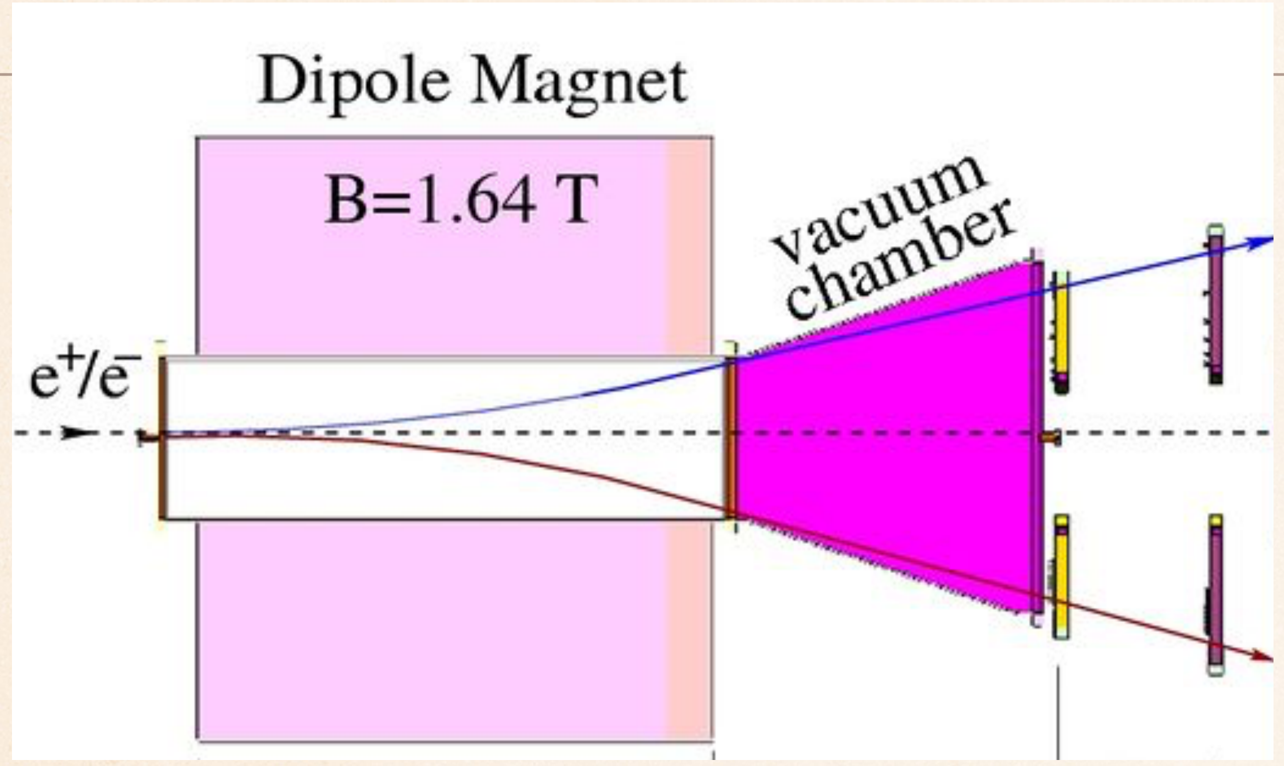
- 1938 - Neutral mesons, suggested as partners of charged pions - Nicholas Kemmer
- He proposed that the nuclear force between protons and protons or between neutrons and neutrons is the same as the one between protons and neutrons. This **symmetry required the existence of a neutral intermediary.**
- **Neutral mesons that decayed into pairs of photons** - Lewis, Oppenheimer, and Wouthuysen and independently Tanikawa

PHYSICAL REVIEW VOLUME 73, NUMBER 2 JANUARY 15, 1948

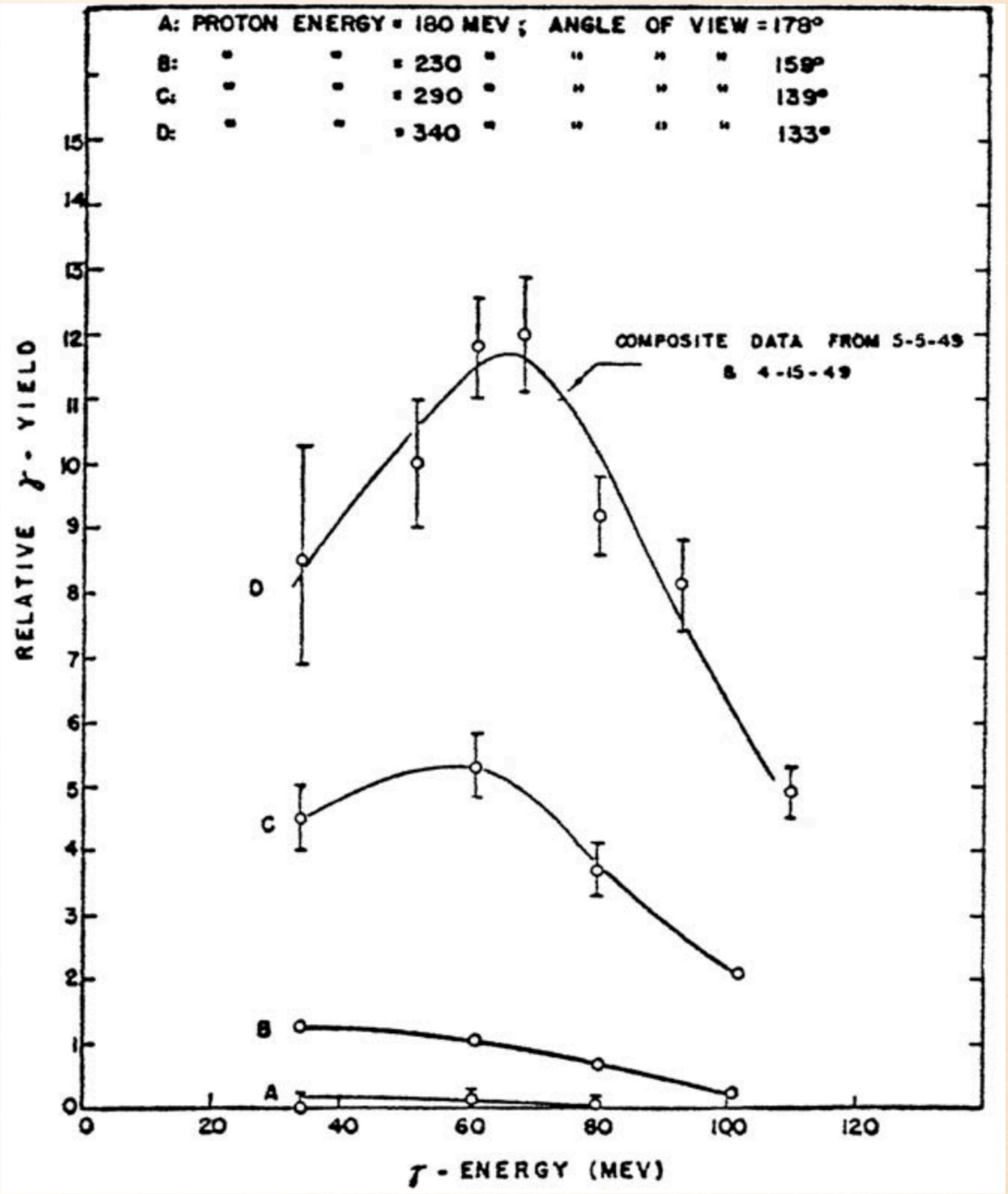
The Multiple Production of Mesons

H. W. LEWIS, J. R. OPPENHEIMER, AND S. A. WOUTHUYSEN
*Department of Physics, University of California, Berkeley, California**
(Received October 2, 1947)

FIRST CLUES



- **Evidence for a neutral meson with a mass like the charged pion** was found by Bjorklund, Crandall, Moyer, and York using 184 inch synchrotron.
- They used a **pair spectrometer** with protons colliding on carbon and beryllium targets.
- Photon yields observed at proton energies below 175 MeV aligned with expectations from proton bremsstrahlung. **Above 230 MeV, more photons were observed, with an energy spectrum unlike bremsstrahlung,** suggesting the production of a neutral meson decaying into two photons.



DIRECT OBSERVATION

- Steinberger, Panofsky, and Steller confirmed the two-photon decay using the **electron synchrotron at Berkeley**.
- Electron synchrotron confined the beam to a **small tube** and **varied the magnetic field** strength during acceleration.
- They generated a gamma ray beam up to **330 MeV** using the electron beam and directed it towards a **beryllium target.**

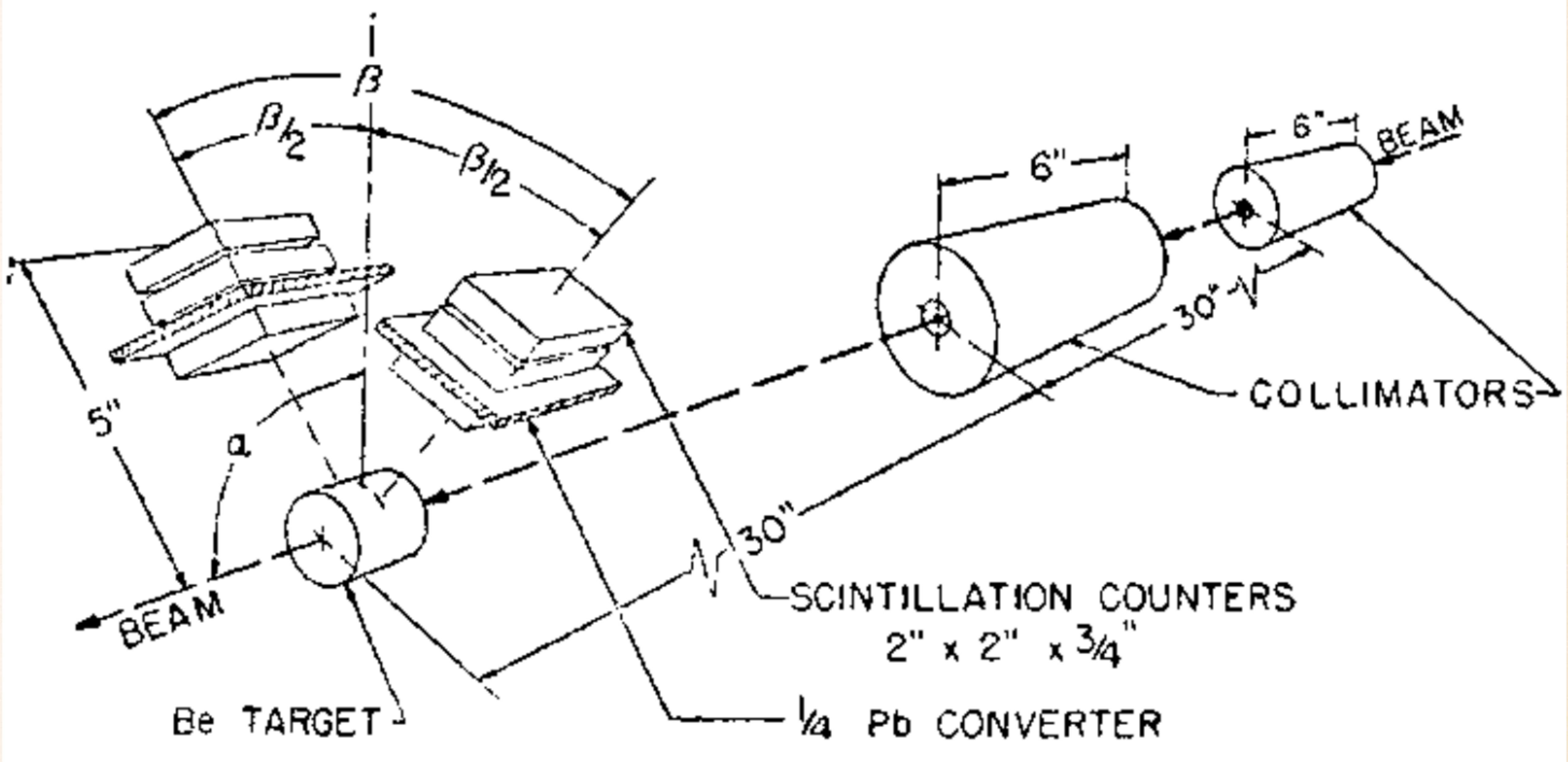
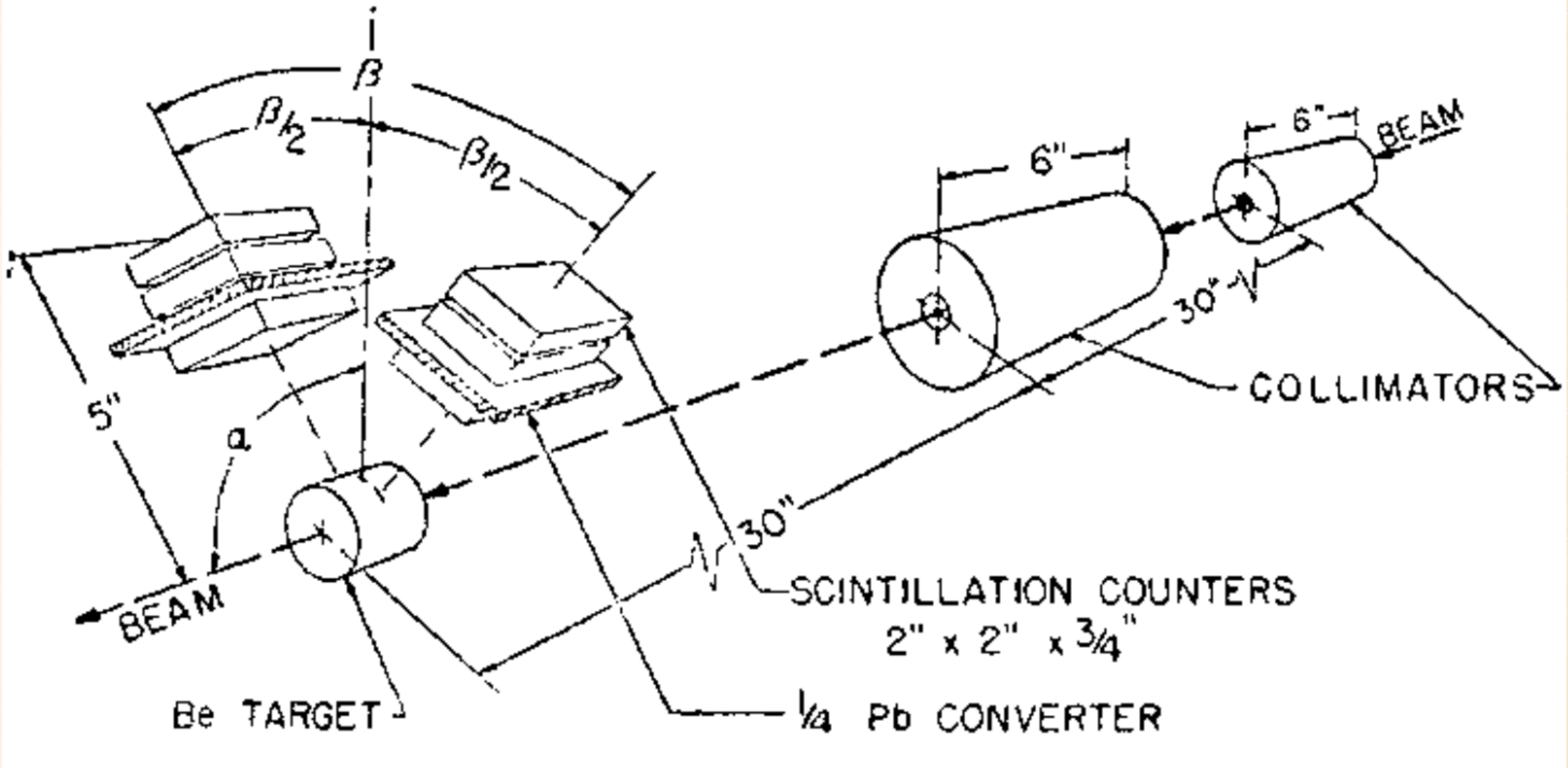


FIG. 1. Experimental arrangement.

DIRECT OBSERVATION

- **Two photon detectors** made of three scintillation counters were positioned near the target.
- There was a **1/4 of an inch** lead converter between the first and second counters. Events are accepted only if **two photons are detected simultaneously** in the outer 4 crystals. Time resolution is 10^{-7} seconds.
- The coincidence rate was measured as a function of α and β. At fixed α the event count increases with decreasing β with **maximum** 90^0**.**
- A measurement of the distribution in β corresponds to energy distribution
- Data supported the **decay of a neutral meson into two photons,** with a production cross-section similar to that of charged mesons.



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HIDEKI YUKAWA

- Yukawa retired from Kyoto University in 1970 as a Professor Emeritus.
- His final years he appeared in public in a wheelchair.
- He died at his home in Sakyo-ku, Kyoto, on 8 September 1981 from pneumonia and heart failure, aged 74.
- His tomb is in Higashiyama-ku, Kyoto.