On the observation of the neutrino recoil effect in beta-decay of ^{6}He 50 years ago

JULIUS CSIKAI

Institute of Experimental Physics, Debrecen University, Debrecen, Hungary
and
Institute of Nuclear Research of HAS (ATOMKI), Debrecen, Hungary


4 20 '02

- Pauli suggested the neutrino idea in 1930 and presented at the June 1931 meeting of the APS in Pasadena. “There must be a third, invisible neutral particle of small mass in beta decay responsible for the missing energy, momentum and angular momentum”.

- In 1932 Chadwick discovered the neutron and Anderson observed the positron (anti-electron) predicted by Dirac’s relativistic quantum theory. In both cases cloud-chamber photographs were evaluated.

- Fermi published his theory of beta-decay in 1934 based on the existence and postulated properties of the neutrino.

- In accordance with Dirac’s theory, an antineutrino (ν^*) was postulated too, and the beta decay could be written

$$n \rightarrow p + e^- + \nu^*.$$

Inside a nucleus a neutron splits into p, e^- and ν^* and the latter two are ejected.

- **Direct proof requires observation of the inverse beta reactions:**

  $$\nu + n \rightarrow p + e^- \; ; \quad \nu* + p \rightarrow n + e^-$$

  Reines and Cowan detected ν∗ in 1953 using 150kg H_2O + 10^{13} ν∗/cm^2s→

  0.41±0.20)cpm.

  $$\sigma(h\nu + \text{atom})/\sigma(\nu* + p) \geq 10^{28}.$$

- **Indirect investigations on the observation of neutrino based on its recoil effect were started in 1936. (Leipunski ^{11}C, β^+ decay, Allen ^{37}Ar K-capture, Sherwin ^{32}P, ^{90}Y, (β^- - A_R)(θ), Allen and Jentschke PR. 1953, et al.) Rustad and Ruby PR. 1955 have used GM-PM coincidence method for $^6He \rightarrow P(\beta^- - A_R) \rightarrow P(e-\nu*)$. The poor statistics prevented the deduction of a reliable interaction type (S, V, T, A, P) from the e-ν∗ angular correlation measurements presence in the β^- -decay.**

Investigations in Debrecen

- **Prof. A. Szalay suggested studying the principles and techniques of the expansions cloud chambers to me in 1951. Using a low-pressure cloud chamber the recoil effect of neutrino was expected to be observed in the β^- decay of ^6He by the detection of ^6Li tracks**

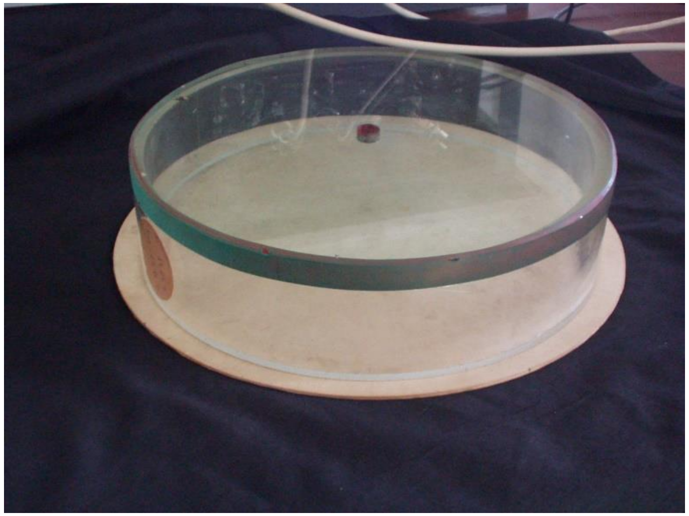
  $$^6He \rightarrow {}^6Li + \beta^- + \nu* + 3.6 \text{ MeV.}$$

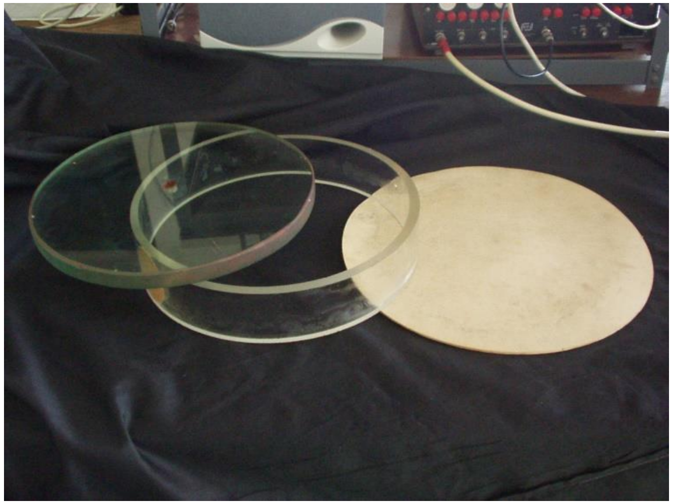
- **The recoil energy of ^6Li has the highest value ($E_R^{max.}$ = 1410 eV) of all β^- decay processes**

  $$E_R(eV) = 536/A\,(E_\beta^2 + 1.022E_\beta),\ \ E_\beta \text{ in MeV.}$$

  We hoped in 1953 to detect the ^6Li in a cloud chamber filled with H_2 under low pressure (200 mmHg and H_2O + C_2H_5OH vapor using 50-50% mixture of the liquids).

- A Wilson-chamber of expansion-type was designed, constructed and tested between 1953 and 1955. The sensitive volume has been determined by a 28 cm diam. and 5 cm high glass ring covered with a 2 cm thick glass window and at the bottom a rubber membrane with an Al disk of 3 mm thick inside to assure a well defined expansion.



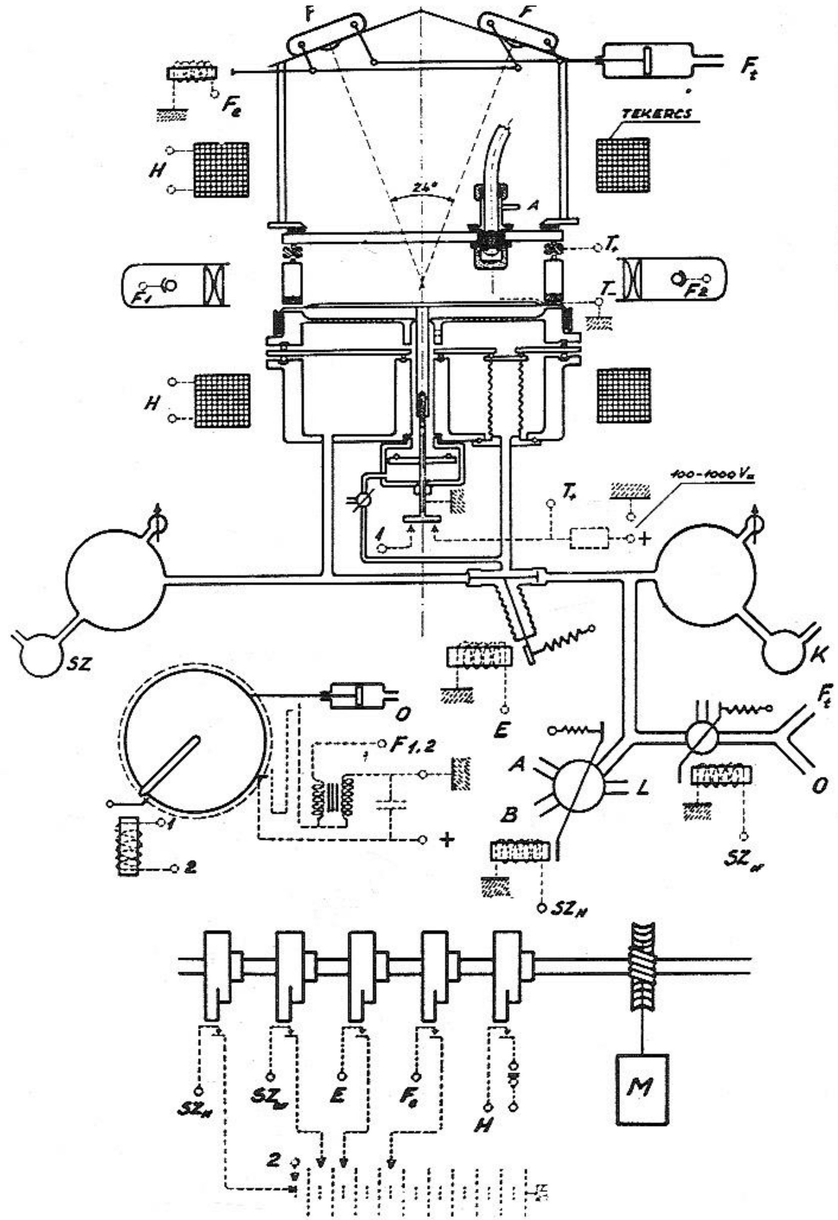


- **The expansion rate of 1.25 - 1.30 within 2 ms was produced by the rubber membrane covered with a black gelatin layer.**

- **Electrostatic field produced by 10^2-10^3 V difference between thin wires and the gelatin layer could eliminate the ions before the expansions.**

- **The sensitive time of the cloud-chamber was 0.15s, therefore, pictures were taken with ~ 0.1s after the expansions.**

- **The cyclic operation of the cloud chamber with 45s repetition rate was based on electro-mechanical and pneumatic remote control systems in the lack of μP and associated electronics at that time.**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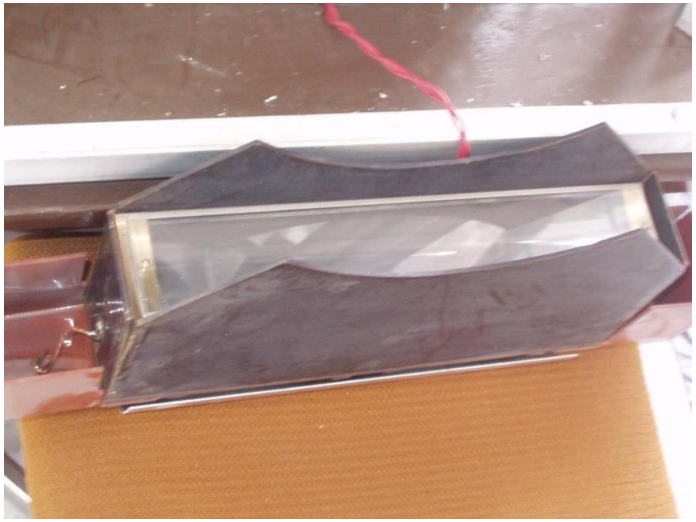
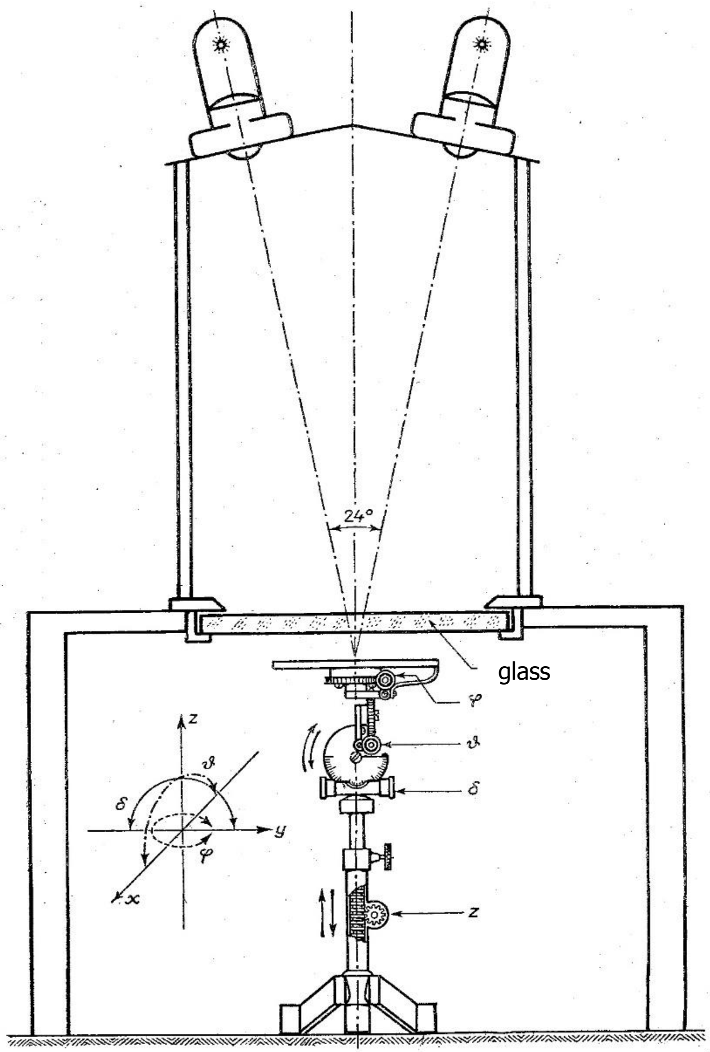
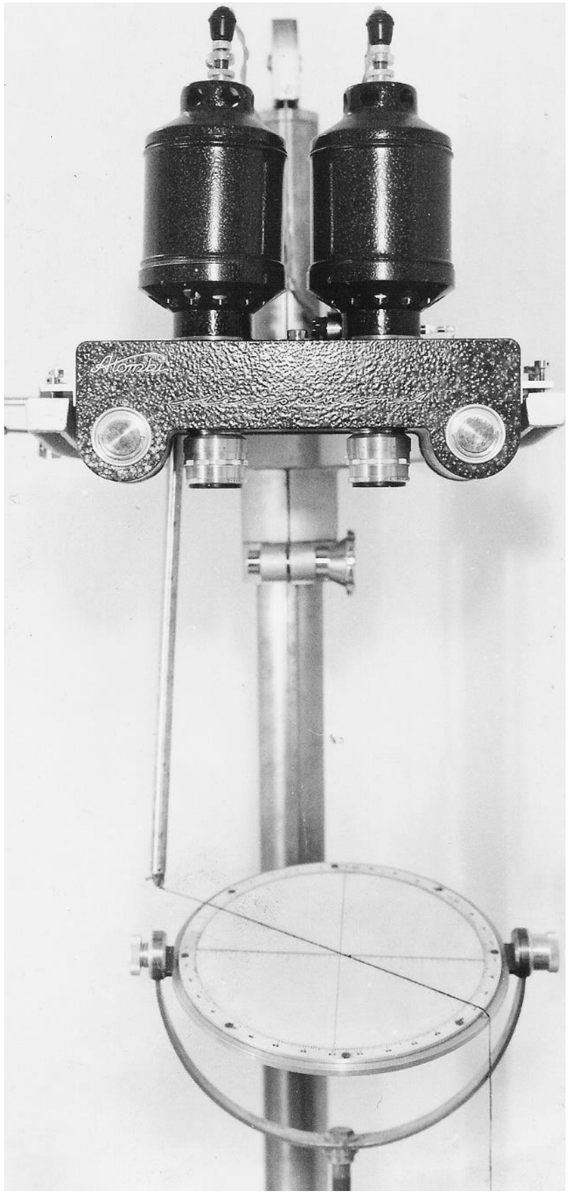
- The chamber was illuminated from 4 sides with parallel light beams using home-made pencil-shaped flash tubes of 0.5 cm diam. and 30 cm length placed in the focus of condenser lenses prepared from plexi-glass. The discharge time of these special flash tubes of high luminosity was ~ 10^{-4}s. The life-time of the tubes using W+Al electrodes in C-9 glass filled with 150 mmHg Xe gas was about 10^3 discharges at 100 J energy.

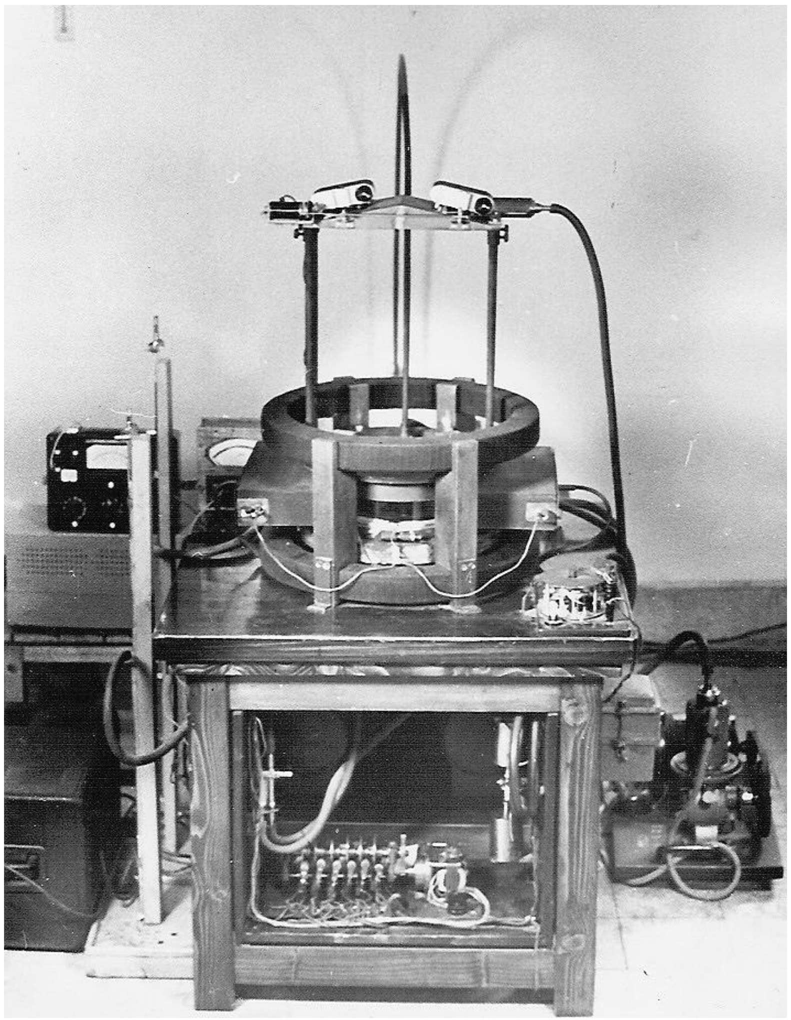


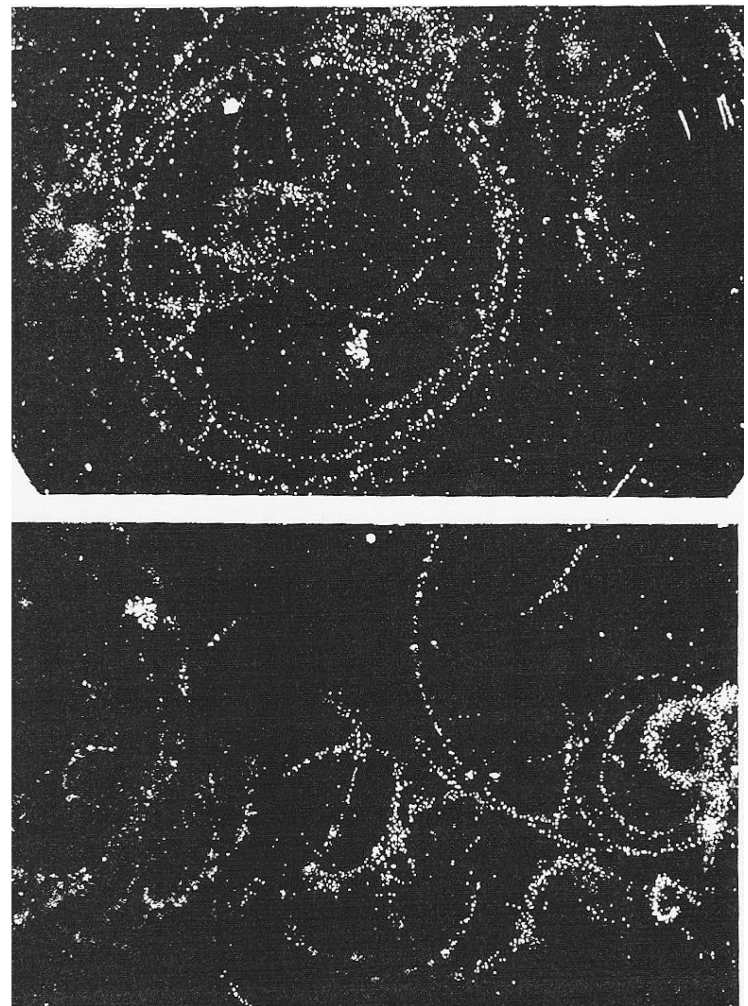
- **Photos were taken by two cameras with 24º stereo angles assuring the re-projection through the same optical system. The reaction plane could be reproduced by a scanning table.**



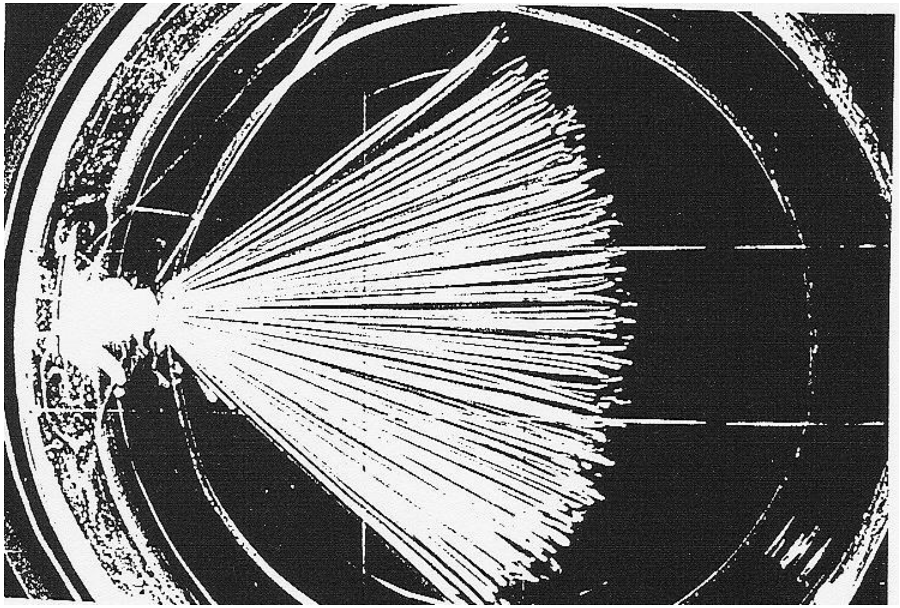


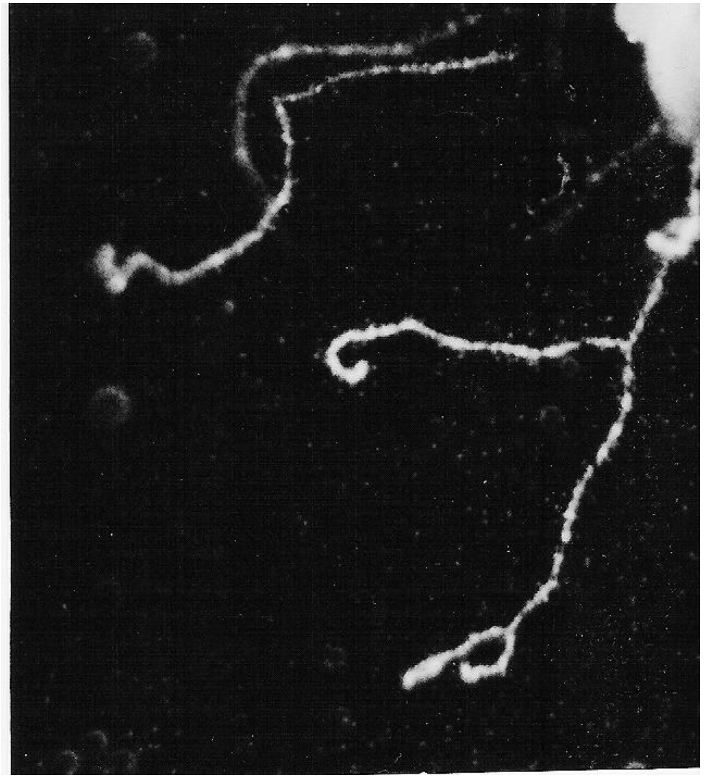
- **Energy of β^{-} particles, E_{β} was determined from their curvature in magnetic field produced by a Helmholtz coil during the expansion. The field strength of ~10^{3} Oe [$H(Oe) = 15.1 \times I(A)$, $I_{max} \approx 70A$] rendered to measure $E_{\beta} = 4\text{-}5$ MeV possible.**





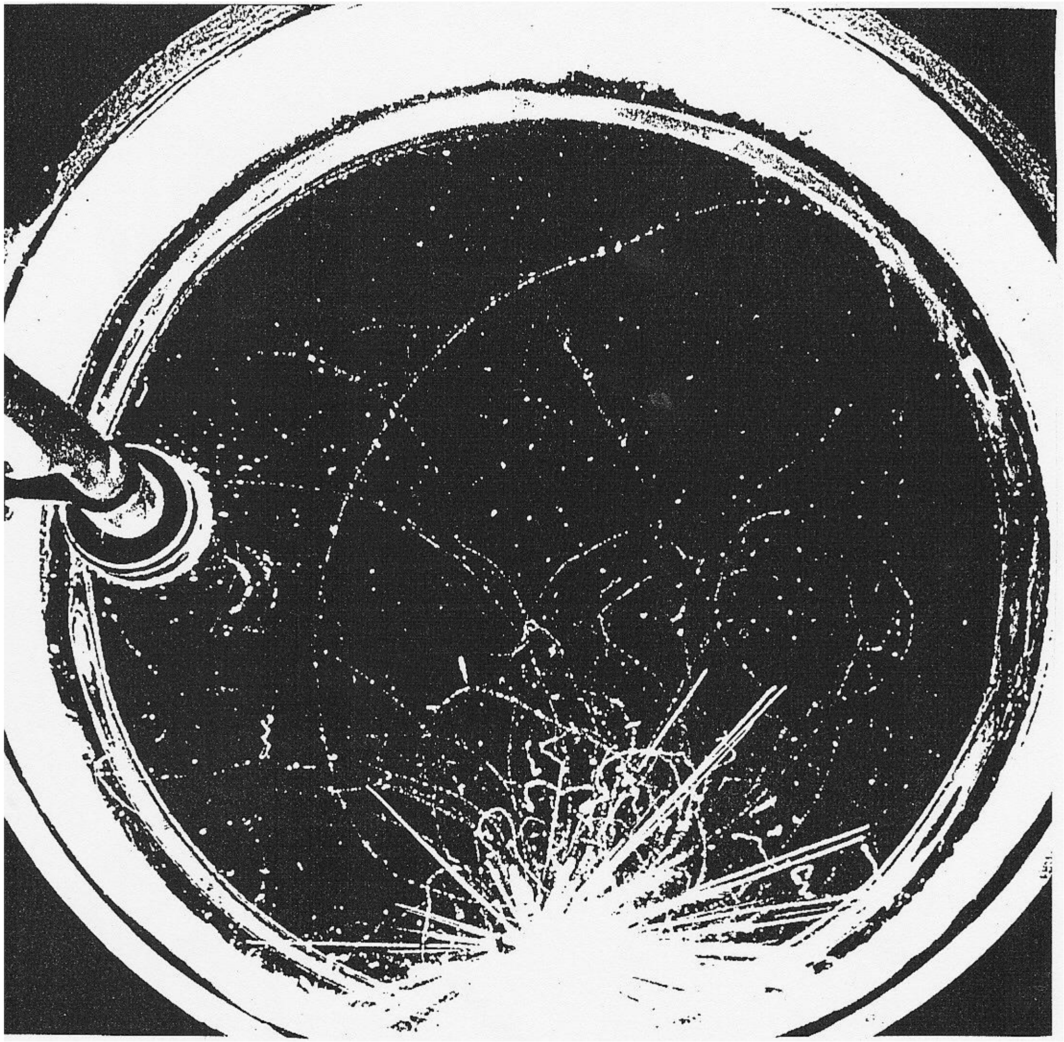
• **Working conditions of the chamber was tested by α, β and γ radiations. The energy of photo-electrons produced by ^{60}Co γ - rays coincided with the maximum of β-spectrum in the decay of ^{6}He.**





$^{210}_{84}Po \rightarrow {}^{206}_{82}Pb + {}^{4}_{2}He$

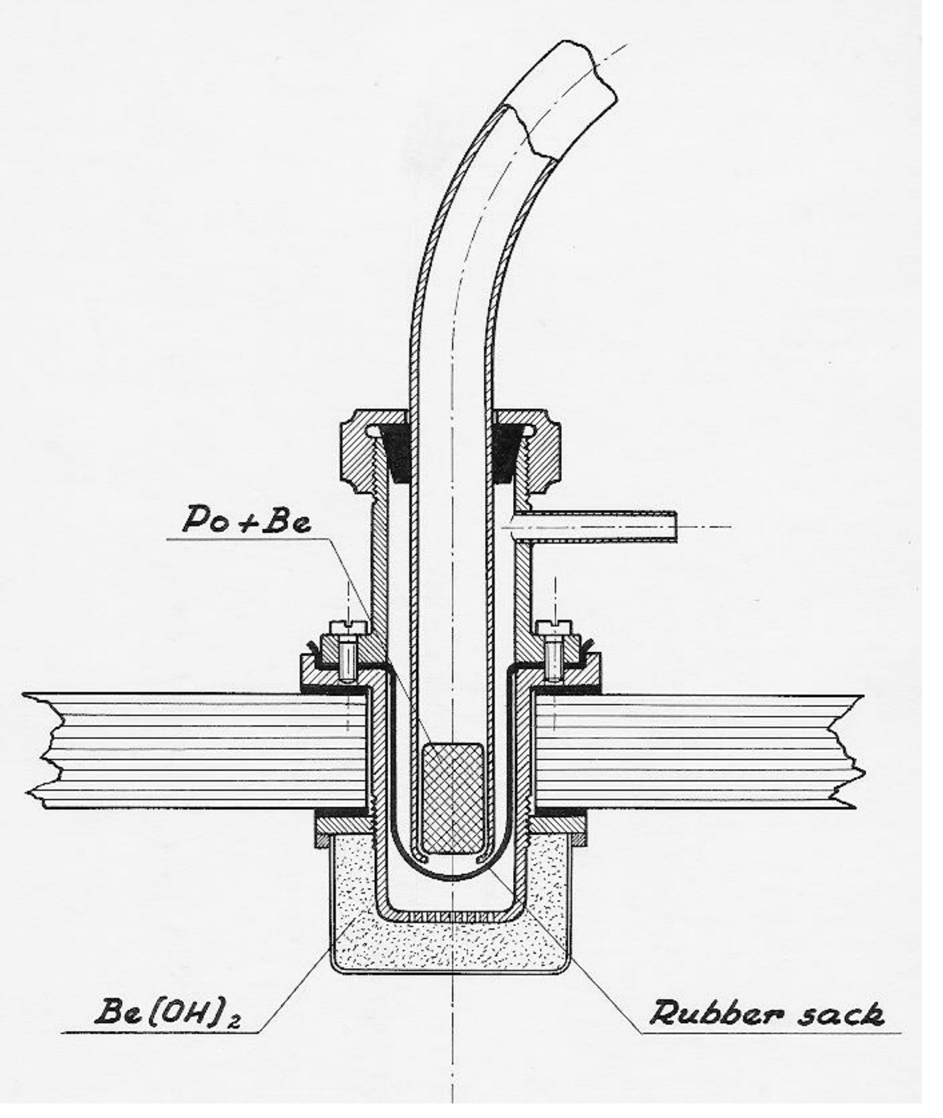
β^{-}-tracks from ^{131}I isotope

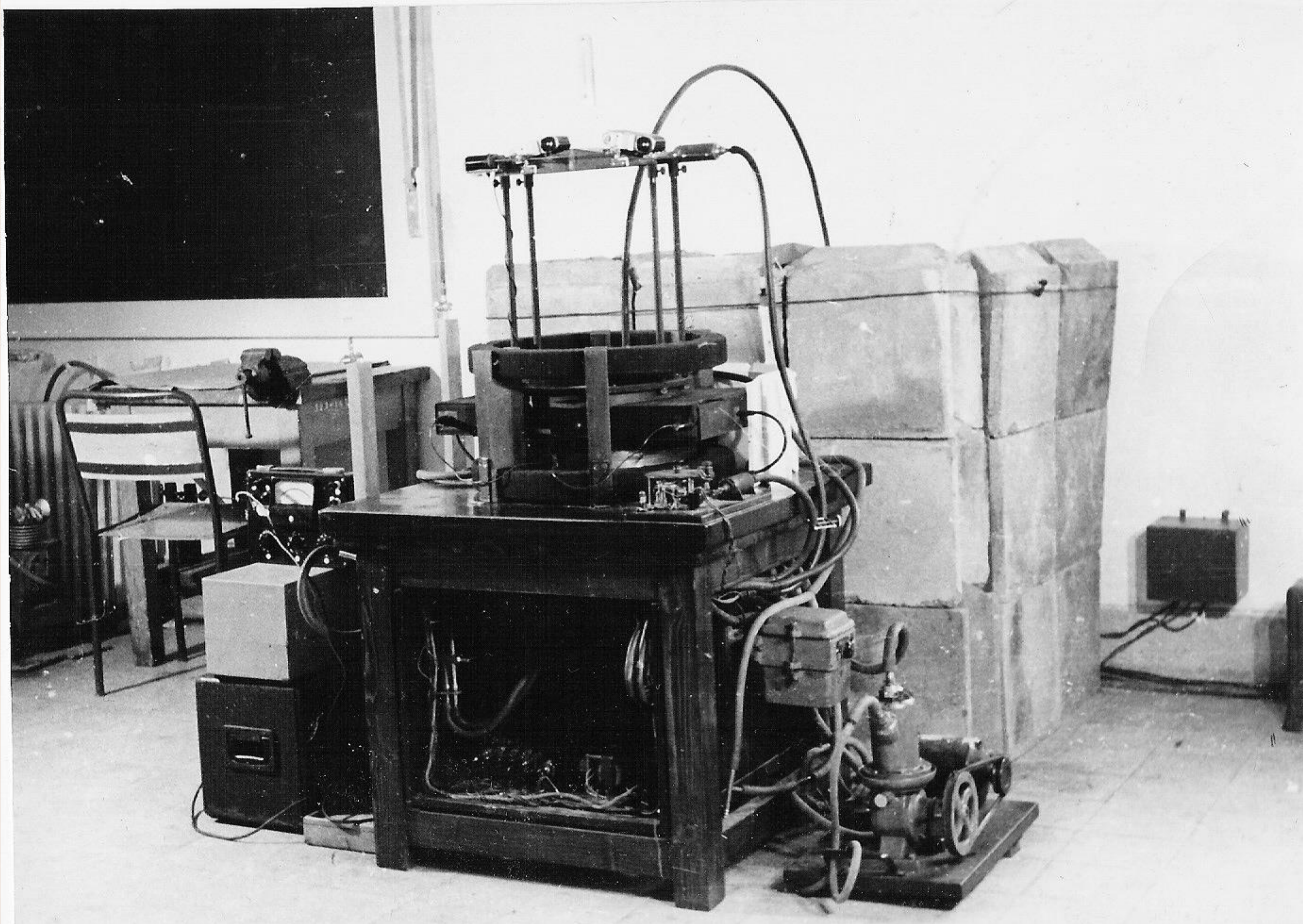


Two alpha groups (E_α~6MeV and ~9MeV) and beta-particles from Th(B+C) source.

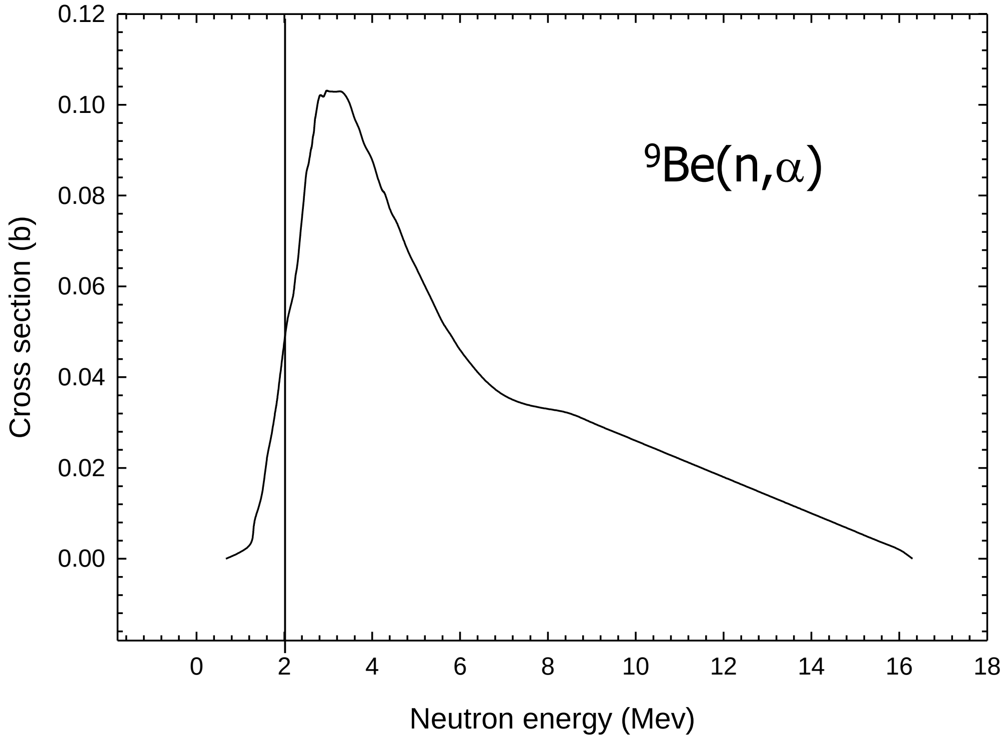
- Producing and introducing the short-lived ($T_{1/2}$ = 807 ms) ^{6}He into the chamber have been successfully solved. Some seconds before expansion, a ^{210}PoBe neutron source of 150GBq ($T_{1/2}$=138 days) was driven pneumatically to 5g $Be(OH)_2$ powder of highly emanating form, which had been placed in a porous filter-paper box within the chamber.

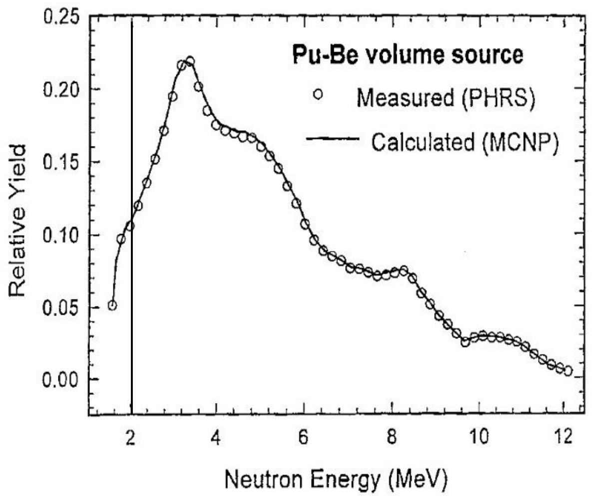
  The source was shot pneumatically behind a radiation shield with ~ 0.3s before the expansion. The same air-shock then expanded the rubber sack forcing the ^{6}He liberated from the $Be(OH)_2$ powder through the porous wall into the chamber.



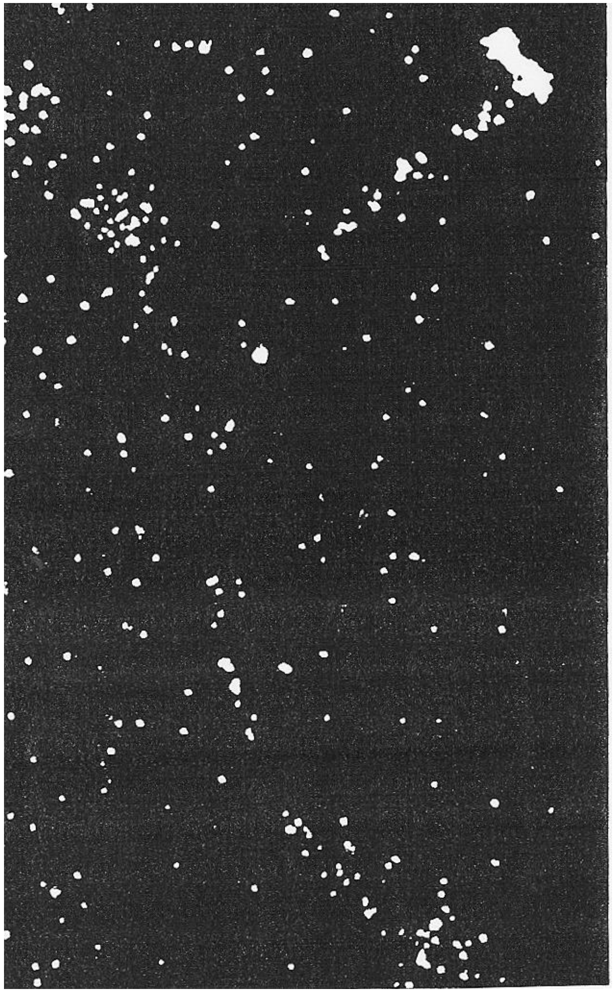


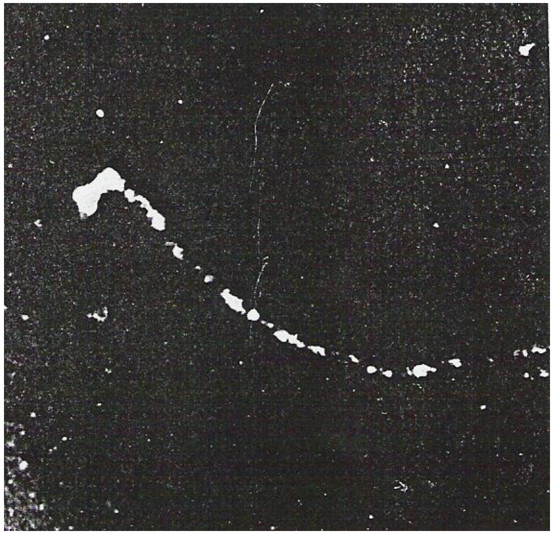
The saturation activity of ^{6}He produced in $^{9}Be(n,\alpha)$ reaction was estimated to be ~1170dps using the relations $A=n\langle\phi\rangle\langle\sigma\rangle$, where $\langle\phi\rangle=Y/4\pi\langle r^2\rangle$, $Y_n \sim 10^7$ n/s and $\langle\sigma\rangle = 50$mb was taken as the spectrum averaged cross section. No data were available for $\sigma_{n,\alpha}$ at that time. The threshold energy is 0.67 MeV. Cross section curve indicated in the figure was taken from ENDF/B-VI library (2000).

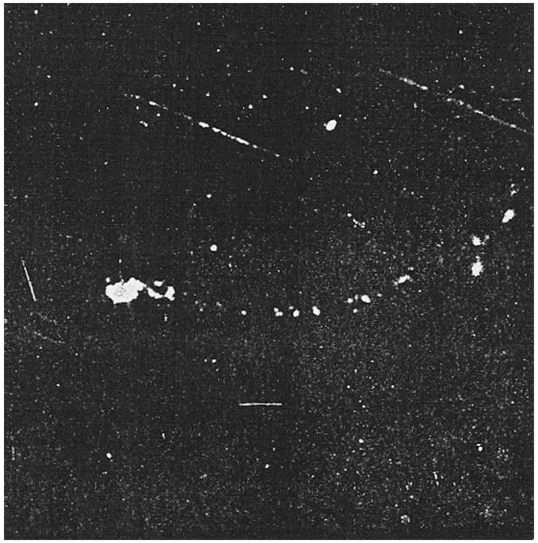


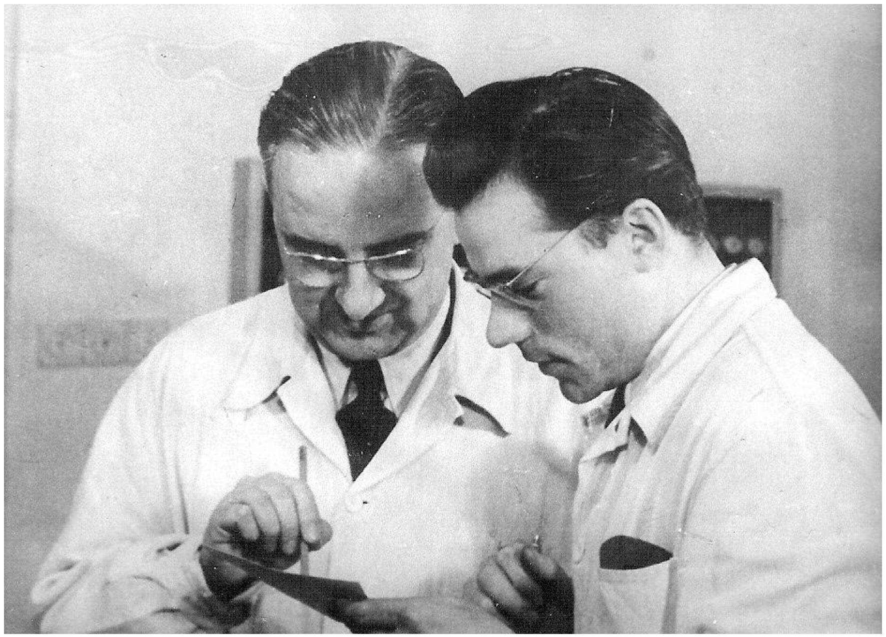


- Some typical photos can justify our expectation on the observation of the recoil effect of neutrino. The first successful pictures were taken in December 1956.









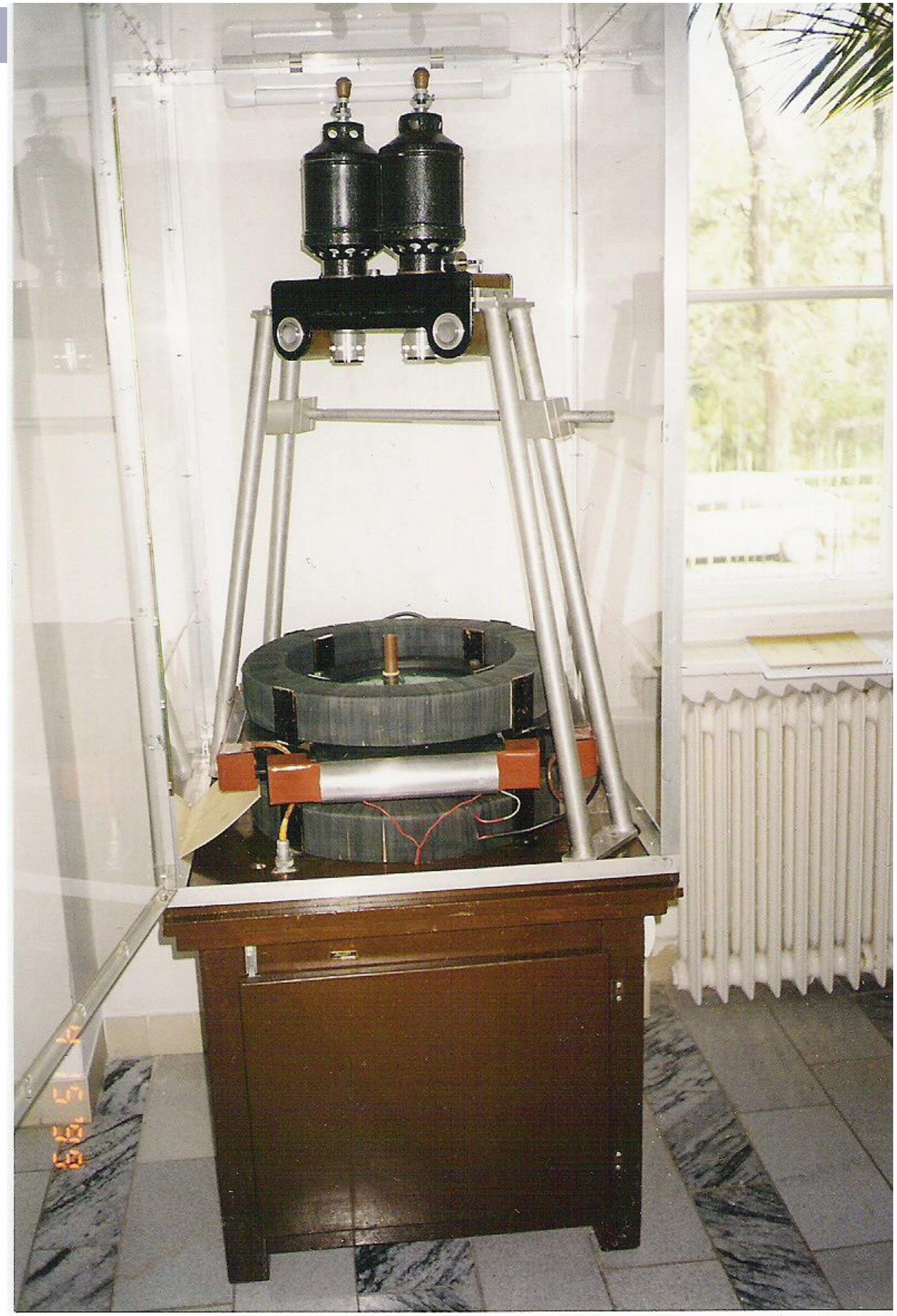
Discussion with Prof. Szalay on the neutrino experiments in 1956

Meeting with Pauli at Padua-Venice Conference (22-28. Sept. 1957.)

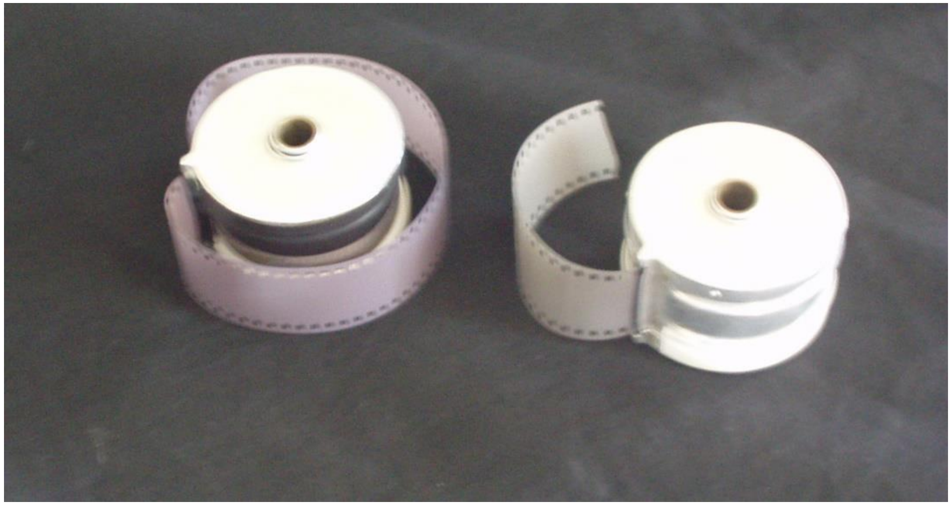
- **In the first series of measurements $\geq$ 2000 stereo photos were made, of which 120 tracks (~ 5% of dps) were sufficiently well defined for being numerically evaluated. By measuring the curvature of the β^- particle and the angle between the β^- and the recoil nucleus the momentum of the ν^* could be determined. We could not distinguish between the interactions present in the beta-decay by the β^-–ν^* angular correlation measurements due to the poor statistics.**

A matrix arrangement for identifying of the films containing the stereo photos has been used.

- Measurements were continued after ~1 year in average with an improved camera system and ~ 10^4 stereo-photos have been made. However, the statistics could not be improved because of the decay ($T_c \approx 3T_{1/2}$) of the PoBe neutron source. The total number of the numerically evaluated photos obtained in the two sets of measurements was 197.

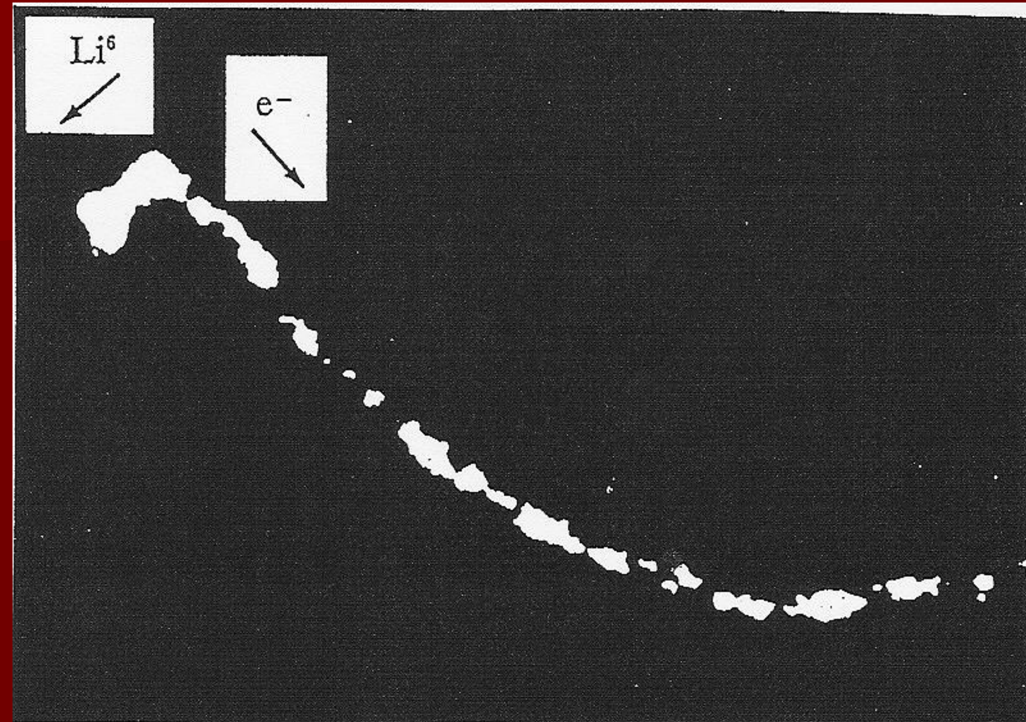


The new home-made stereo camera holds 17 m films.



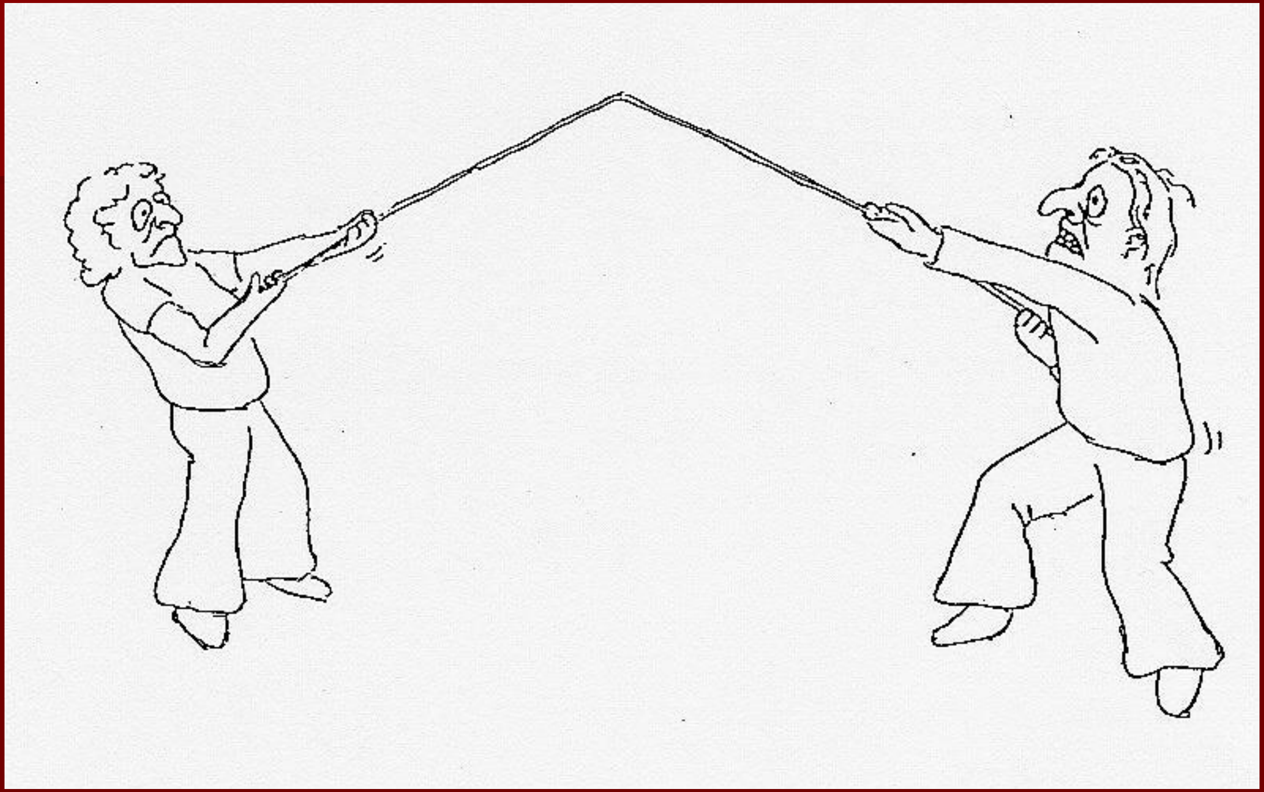
Some citations:

1) Joe S. Tenn, Griffith Observer, August, 1976.



Here is a dramatic display of apparent nonconservation of momentum in the beta decay of helium-6 (at rest!) into lithium-6 and an electron (from J. Csikai and A. Szalay, Proceedings of the International congress on Nuclear Physics in Paris, 1958, Publications Dunod, Paris, 1959).

$$^{6}He \rightarrow {}^{6}Li + e + \overline{\nu} \qquad \text{(Debrecen 1956)}$$

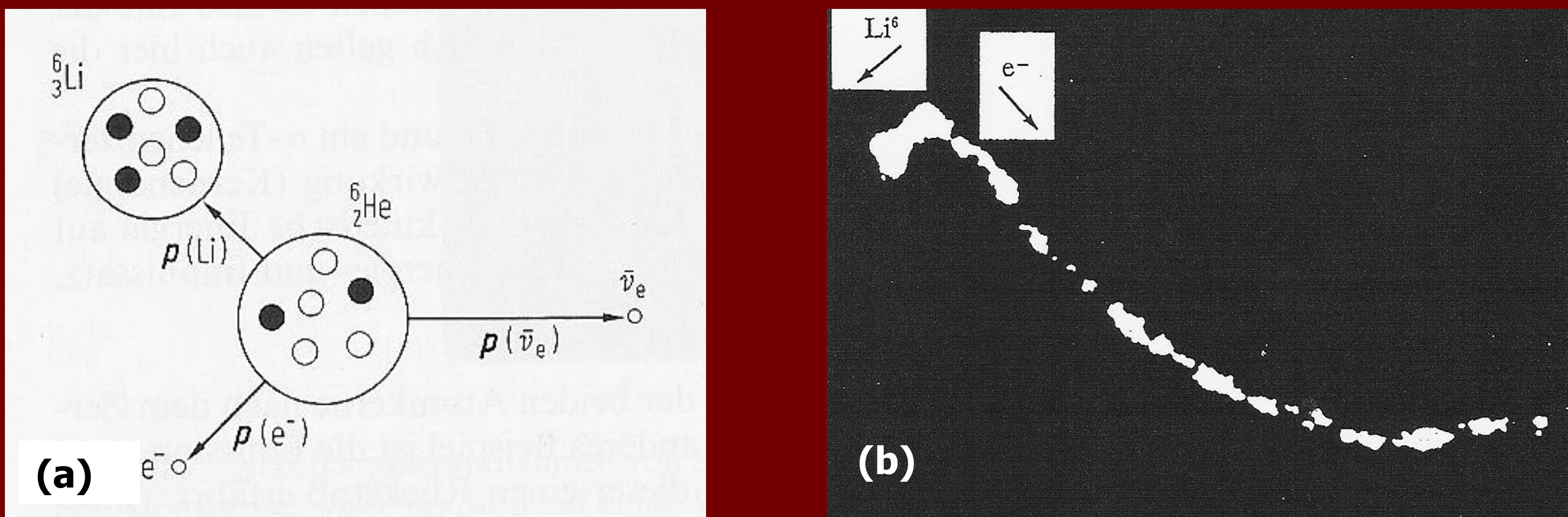


There must be an invisible person pulling on the rope!

2) Christine Sutton, New Scientist, 14. January, 1988.

"This picture taken in 1957, was the first to show the invisible presence of a neutrino, from the radioactive decay of helium-6 which has two more neutrons than ordinary helium. The short, thick track at the top left is the recoiling nucleus: the lighter, curving track is the electron. The two tracks are not back-to-back, indicating that a third particle –the neutrino- participated in the decay."

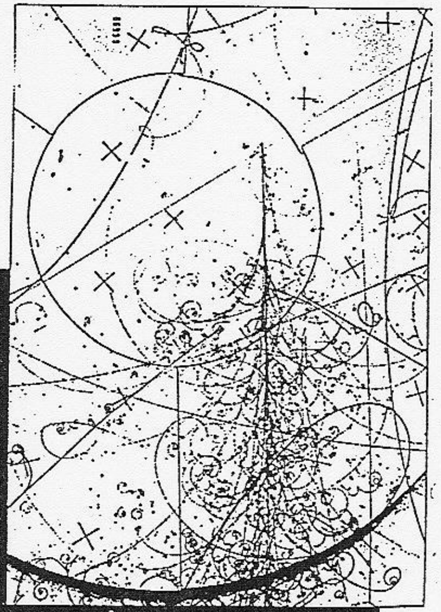
3) Bergman Schaefer, Lehrbuch der Experimentalphysik, Walter de Gruyter, Berlin, New York, 1998.

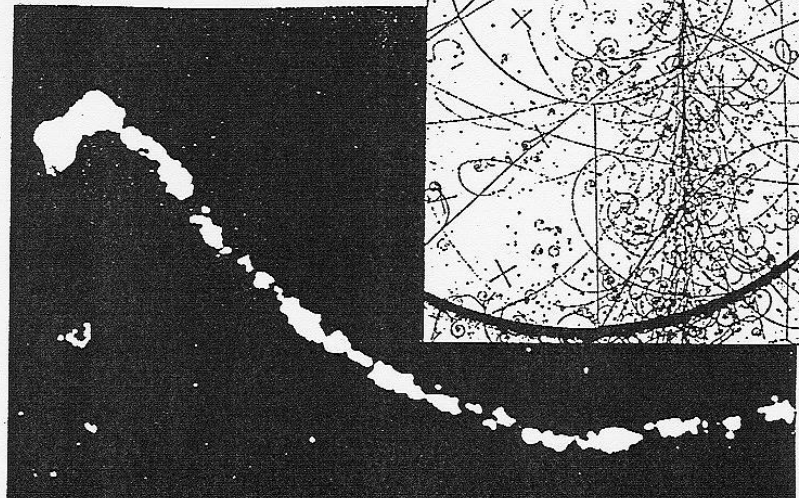


Beta-decay of 6-helium nucleus (a) principle (● neutrons, ● protons); (b) Cloud-chamber picture. (Photo: J. Csikai, Debrecen; JETP 35 (1958)1072.)

Death of a neutrino. A 200 GeV muon-type neutrino enters the buuble chamber at 12 o'clock and interacts with a nucleon, creating several neutral and charged muon (μ^-) with about 100 GeV energy (the rather straight track at 5 o'clock). Almost one billion neutrinos traversed the chamber at the time this single interaction took place.

Birth of a neutrino. A historic picture of the decay of a radioactive nucleus, ^{6}He, in a cloud chamber. The long track is due to the electron, and the short stub to the recoiling ^{6}Li nucleus. Obviously momentum is missing and is accounted for by a neutrino, roughly at 12 o'clock.

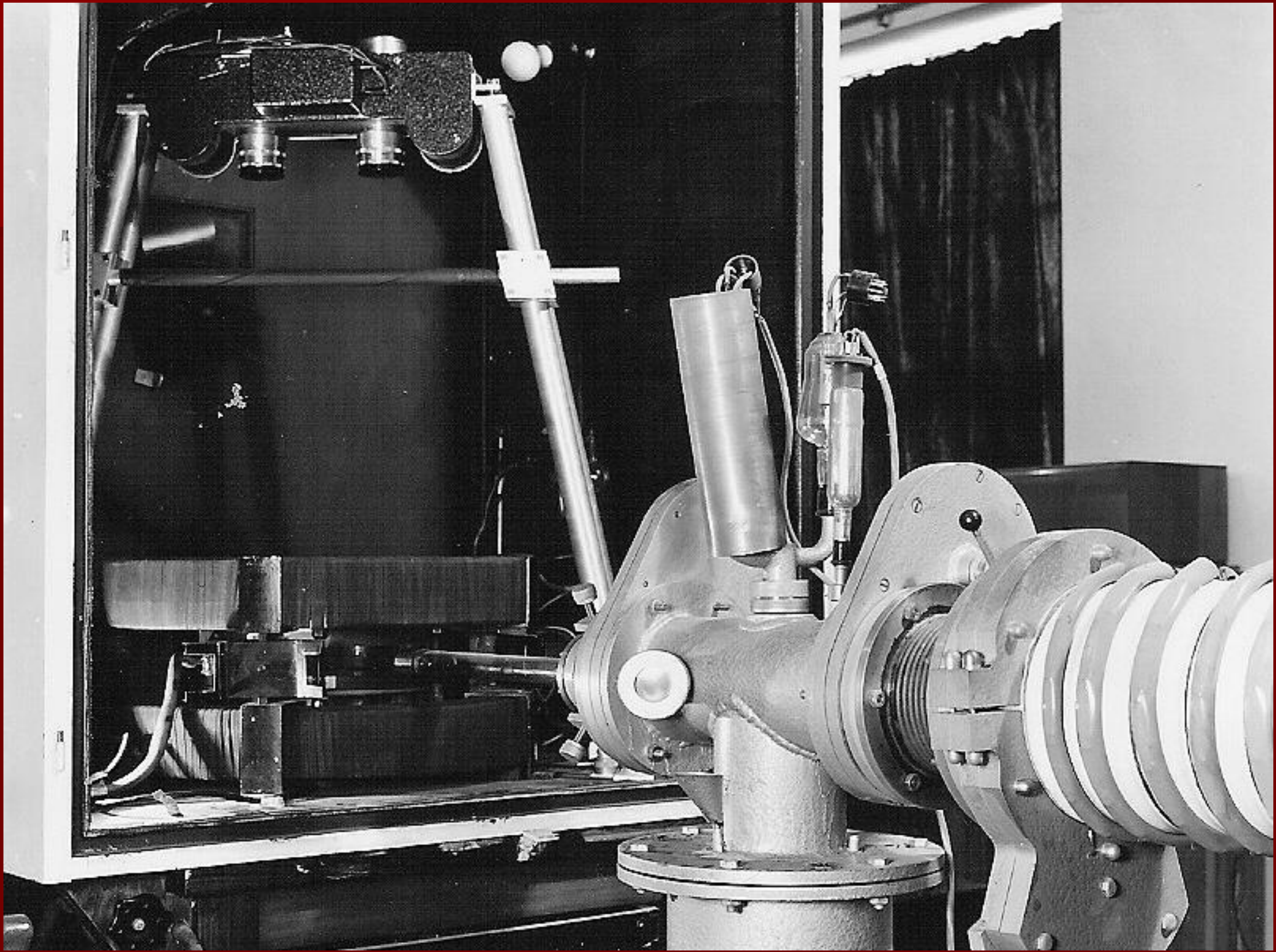




References:

1. J. Csikai, Small flash tube, Hungarian Physical Review 3(1955)417 (in Hungarian)
2. J. Csikai, Photograpic evidence for the existence of the neutrino, Il Nuovo Cimento 5 (1957) 1011.
3. J. Csikai, G. Hrehuss, A. Szalay, Precise automatic expansion cloud-chamber, Publication of the Mathematics and Physics Section of the Hungarian Academy of Sciences, 7(1957)137 (in Hungarian).
4. A. Szalay, J. Csikai, The recoil effect of the neutrino in the beta-decay of He-6, International Conference on Mesons and Recently Discovered Particles, Padua-Venice 22-28 September, 1957, p.IV.8.
5. J. Csikai, A. Szalay, The recoil effect of the neutrino in the b-decay of He^6, Journal of Experimental and Theoretical Physics, (JETP) 35 (1958) 5(11).
6. J. Csikai, Investigations on the recoil effect of neutrino and the electron-neutrino angular correlation in the decay of ^6He using a Wilson-chamber, Publication of the Mathematics and Physics Section of the Hungarian Academy of Sciences, 8(1958)245 (in Hungarian).
7. J. Csikai, A. Szalay, The electron-neutrino angular correlation in the decay of ^6He, International Congress on Nuclear Physics in Paris, 1958. Publicatons Dunod, Paris, 1959. p. 840.

A combination of the cloud-chamber with the neutron generator



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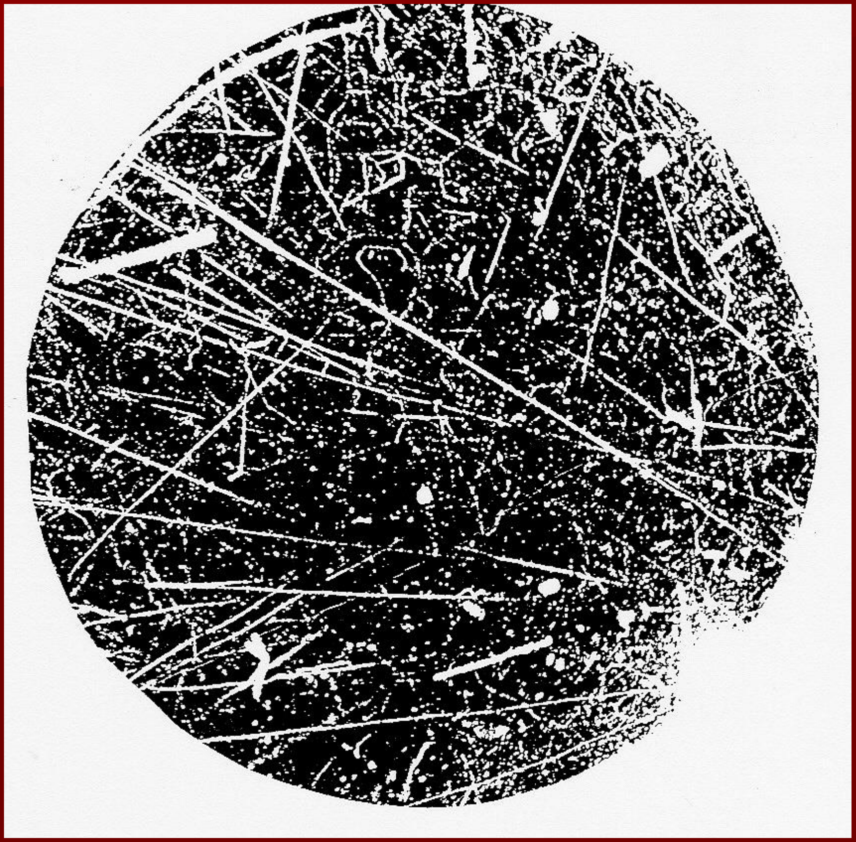
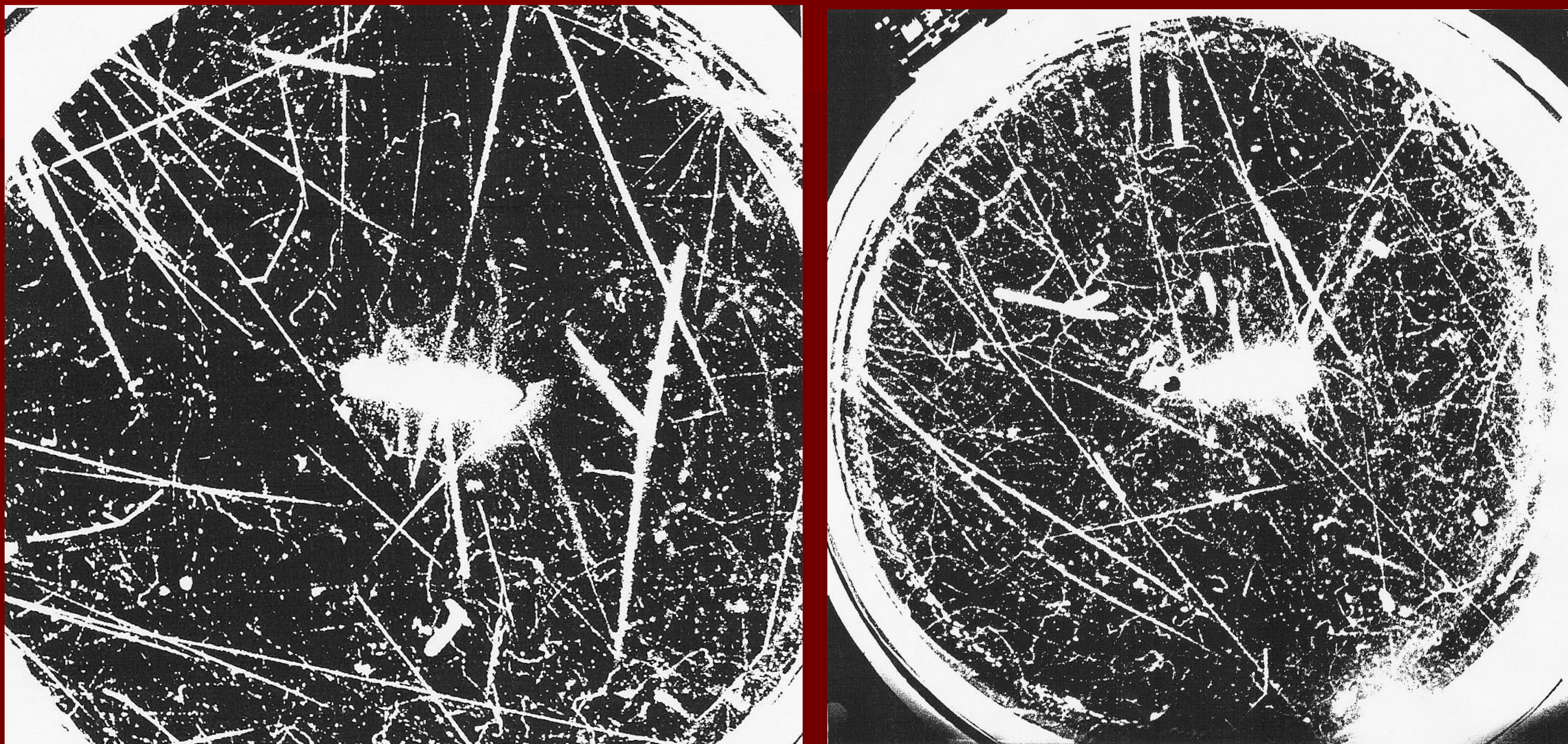
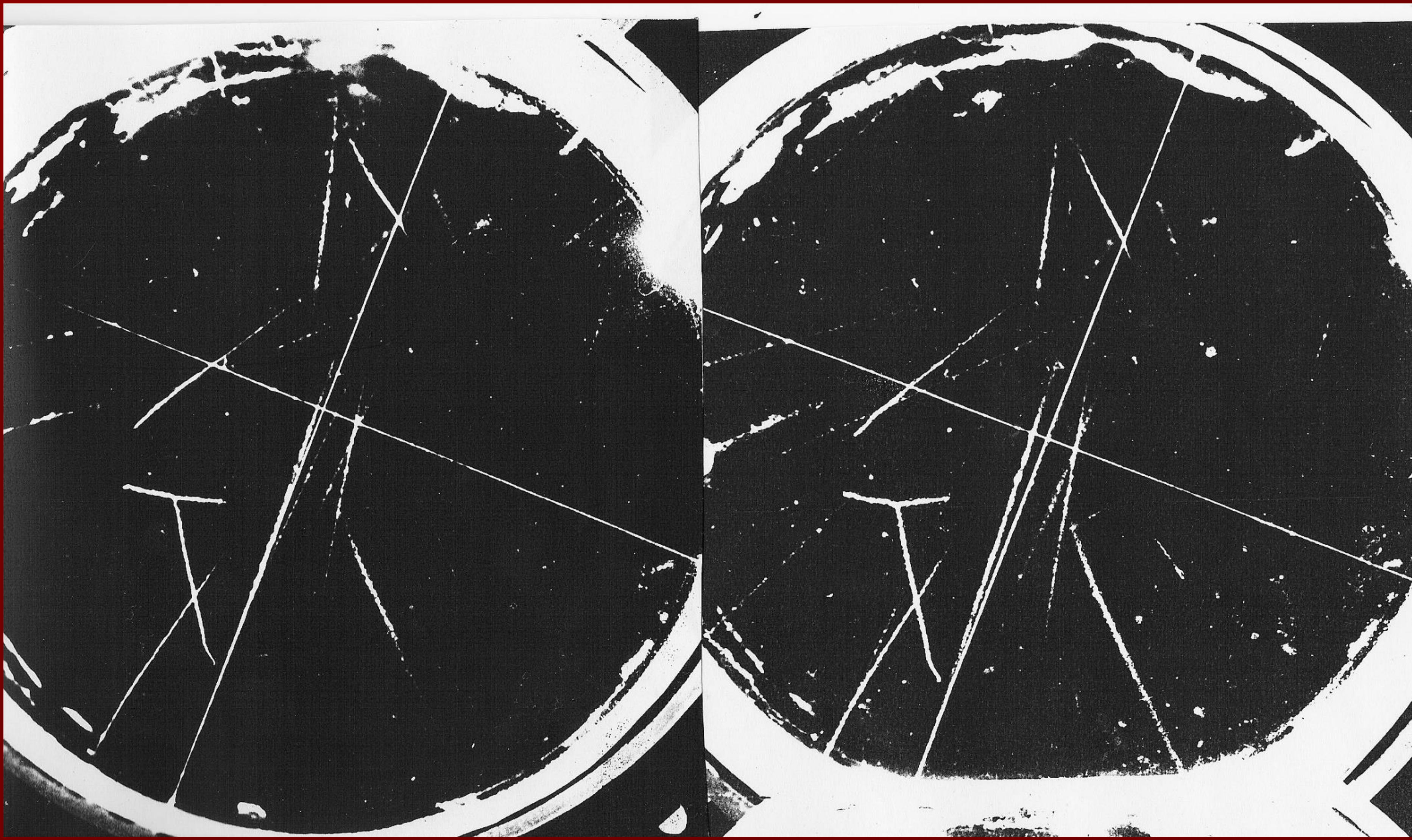


Fast neutron interactions using a $N_2+C_2H_5OH$ target

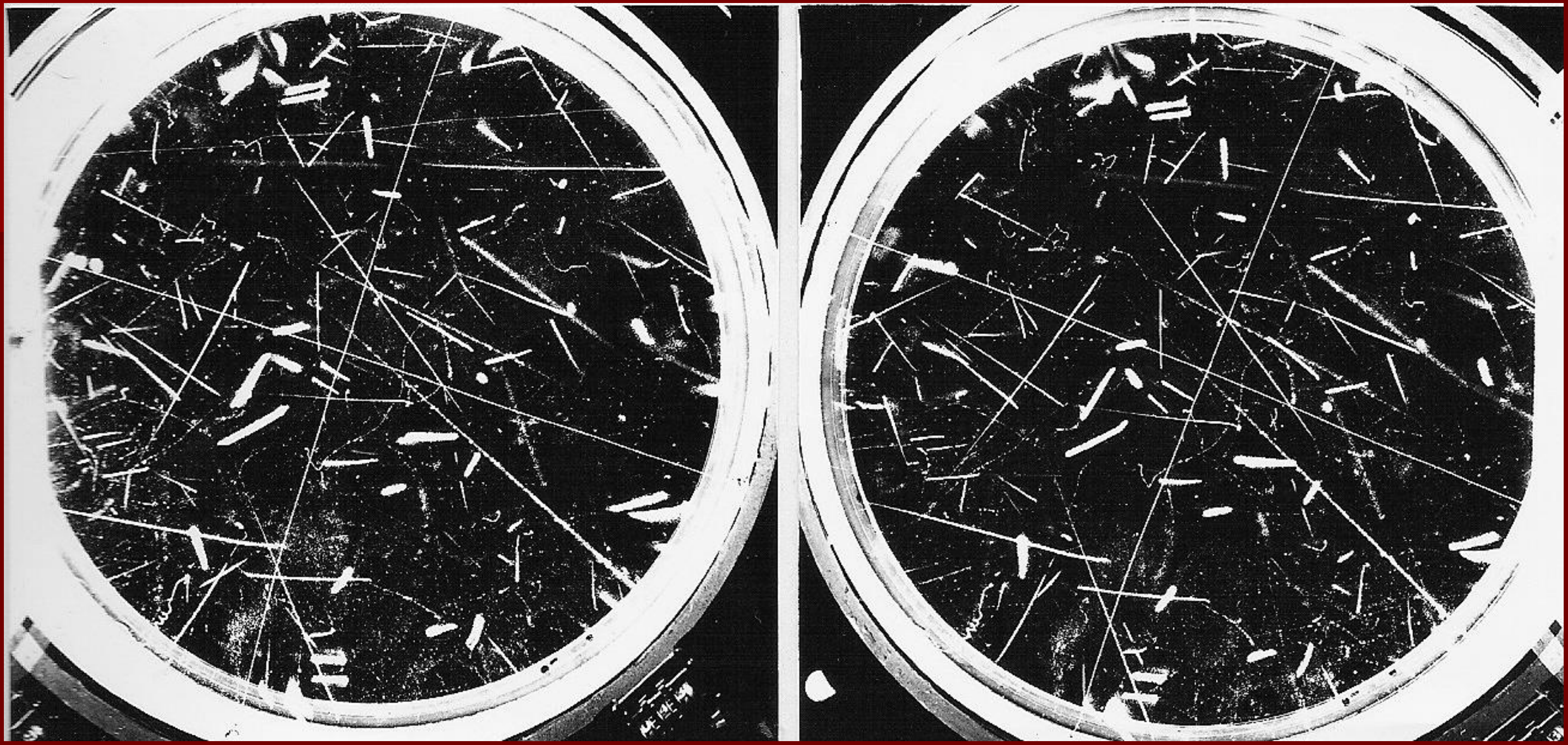
$^{7}Li(n,n`t)^{4}He$, ^{4}H?



$^{9}Be(n,2n)^{8}Be^{*} \rightarrow 2\alpha \quad \tau \sim 10^{-17} s$



Stereo-photo on $^{12}C(n,n')3\alpha$ reaction



Studies on polarization of $^{2}H(d,n)^{3}He$ neutrons by their elastic scattering on He gas