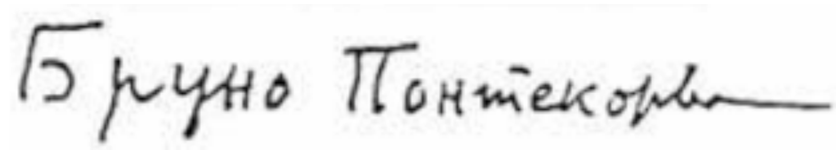
Bruno Maximovich Pontecorvo



From slow neutrons with Enrico Fermi in Rome
to
neutrino oscillations in Dubna

Luisa Bonolis
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Born at Marina di Pisa, August 22, 1913

- **Pisa**: Early education, Engineering at University of Pisa
- **Rome**, laurea, Artificial radioactivity induced by neutrons with Enrico Fermi and his group
- **Paris**, with Frédéric Joliot-Curie, Nuclear isomerism
- **Tulsa**, Oklahoma, Well Surveys Inc., Neutron well logging, First technical application of neutrons
- **Canada**: Montreal and Chalk River. Anglo-Canadian collaboration. Design and building of a nuclear reactor, nuclear physics, beginning of particle physics, free neutrino detection, proportional counters
- **Harwell**: nuclear and particle physics, neutrino
- **Russia**, Dubna and Moscow, particle physics, neutrino physics, teaching

Died in Dubna, September 24, 1993

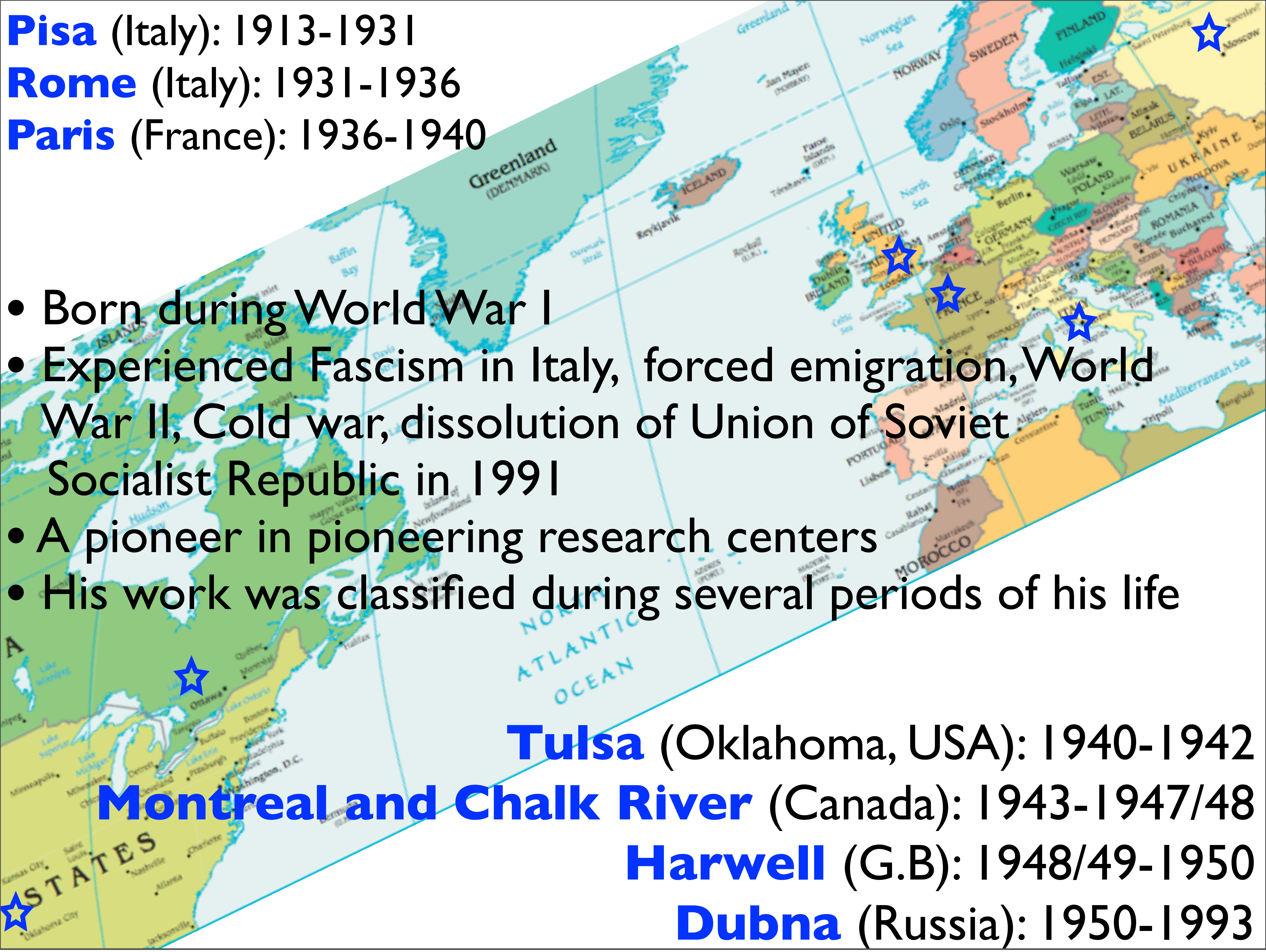
Archival material

Churchill Archives (Cambridge), Chicago University Library (Chicago), Joliot-Curie Archives (Paris), Collège de France (Paris), University Sapienza Archives (Rome), Amaldi Archive Physics Department University Sapienza, Domus Galilaeana Archives (Pisa), Gian Carlo Wick personal papers Archives Scuola Normale Superiore Pisa, The National Archives London, S. A. Scherbatskoy personal papers Smithsonian Institution Washington D.C., Pontecorvo personal papers in Dubna.

Pisa (Italy): 1913-1931
Rome (Italy): 1931-1936
Paris (France): 1936-1940

- Born during World War I
- Experienced Fascism in Italy, forced emigration, World War II, Cold war, dissolution of Union of Soviet Socialist Republic in 1991
- A pioneer in pioneering research centers
- His work was classified during several periods of his life

Tulsa (Oklahoma, USA): 1940-1942
Montreal and Chalk River (Canada): 1943-1947/48
Harwell (G.B): 1948/49-1950
Dubna (Russia): 1950-1993



1913, August 22. Born in Marina di Pisa,

Early education in Pisa
Enrolled in Engineering at Pisa University

The old factory of Bruno's father building hosts today the Departments of Physics and Mathematics, at Largo Pontecorvo in Pisa.

Orso Mario Corbino, Director of the Royal Institute of Physics at Via Panisperna, “God the Almighty”

Enrico Fermi, the “Pope”
Franco Rasetti, the “Cardinal Vicar” or “Venerable Master”

Bruno Pontecorvo is accepted at the third year of the Faculty of Physics and Mathematics of the Rome and becomes the “Cub”.

Edoardo Amaldi, the “kid” or “Adonis”

Ettore Majorana, the “Great Inquisitor”

Emilio Segrè, the “Basilisk” a fabulous beast believed to cause death with a single glance

Rome, Hans Bethe to Arnold Sommerfeld: "I visited the the Colosseum, but the most beautiful thing in rome is Fermi..."

Rome, October 1931
First International Conference of Nuclear Physics

H. Bethe to A. Sommerfeld, Rome, 9 April 1931: The stimulus I have here by Fermi, is larger by orders of magnitude [. . .] Dirac is well known for speaking only one word per light year, and the other people in Cambridge are far from having the general view of the quantum theory that Fermi has

1932 Chadwick demonstrates the existence of the Neutron.
It marks the end of "nuclear prehistory."

1932 Anderson discovers the positron in cosmic rays

January 1933. Adolf Hitler is appointed as chancellor

1933, November 10
Pontecorvo receives his laurea degree, with the maximum mark of 110/110 and the *summa cum laude* honor. He is only 20 years old. He is immediately involved in spectroscopic research, the main activity of Fermi group at the time and the specialty of Rasetti and Segrè.

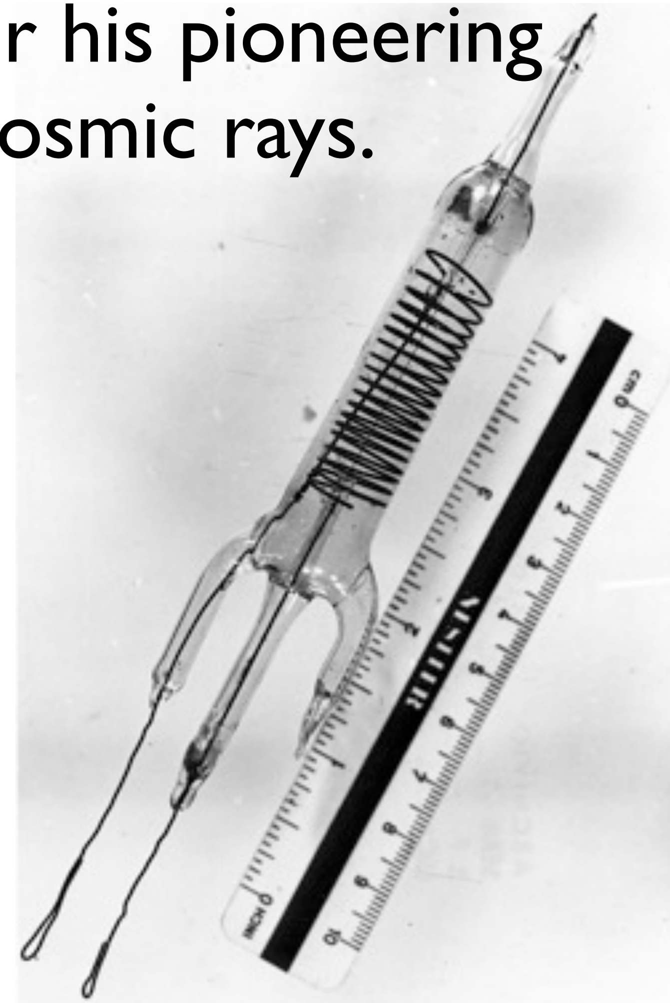
Fall 1933:
7th Solvay Conference, on structure and properties of nuclei

During the conference, for the first time, Pauli is “officially” talking of his idea about the neutrino, which is mentioned in the Proceedings

December 1933: Fermi publishes his first article on the theory of beta decay

Fall 1933: Irène Curie and Frédéric Joliot discover artificial radioactivity induced by alpha particles
First results published January 1934

Geiger-Müller counters in Rome are built after indications of Bruno Rossi who is using them for his pioneering researches on cosmic rays.

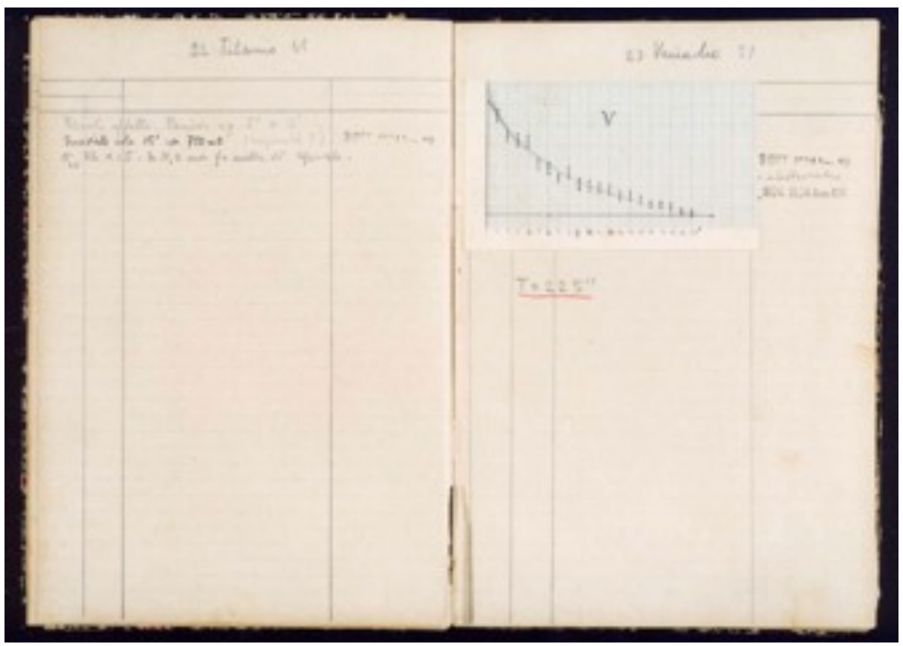


Neutrons from Radon-berillium sources

On March 20, 1934, Fermi discovers that neutrons can induce artificial radioactivity in some elements

Fermi's guess is that neutrons can easily penetrate also the nuclei of heavy elements. He thus decides to start a systematic exploration of the entire table of elements.
In this work Oscar D'Agostino, a young chemist, Edoardo Amaldi, Emilio Segrè and Franco Rasetti are collaborating with Fermi. By the Summer of 1934, the team has activated and studied more than 40 elements, out of the 60 tested.
They also think having obtained transuranic elements.

Sources and Register of elements *Domus Galilaeana, Pisa*



Pontecorvo is invited to participate at the end of the summer vacation, in September 1934.
He is asked with Amaldi to establish **a quantitative scale** of induced radioactivity.

However, since the beginning of their work, Amaldi and Pontecorvo realize that it is very difficult "to reproduce the results" In particular, Pontecorvo realizes that some wooden tables appeared to have miraculous properties: silver irradiated on those tables gains more activity than when it is irradiated on the usual marble table.

On October 20, 1934, Fermi takes the decision to study the effects of the irradiation on the induced radioactivity by **interposing a paraffin block** directly between the source and the silver sample. Incredibly, the activity, in the presence of the paraffin "absorber", does not diminish but it is much more intense. After a few hours Fermi is explaining to his collaborators that neutrons slowed down by elastic collisions with hydrogen atoms in paraffin (or other hydrogenated materials) are more easily interacting with the nuclei, and therefore much more effective in inducing radioactivity.

A Letter is immediately written to "La Ricerca Scientifica", signed by E. Fermi, E. Amaldi, B. Pontecorvo, F. Rasetti, E. Segrè.

REGNO D'ITALIA

MINISTERO DELLE CORPORAZIONI

UFFICIO DELLA PROPRIETÀ INTELLETTUALE

Attestato di Privativa Industriale

№ 324458

Nel Registro degli attestati di privativa industriale di questo Ufficio è stata regolarmente inscritta la domanda depositata, coi documenti voluti dalla legge, all'Ufficio stesso

nel giorno ventisei *del mese di* ottobre *1934 alle ore* 12,15

da Fermi Enrico,
Amaldi Edoardo,
D'Agostino Oscar,
Pontecorvo Bruno, a Roma
Rasetti Franco,
Segrè Emilio
e Trabacchi Giulio Cesare

per ottenere una privativa industriale per il trovato designato col titolo:

Metodo per accrescere il rendimento dei procedimenti per la produzione di radioattività artificiali mediante il bombardamento con neutroni.

Il presente attestato non garantisce che il trovato abbia i caratteri voluti dalla legge perchè la privativa sia valida ed efficace, e viene rilasciato senza esame preliminare del merito e della novità di esso

Roma, li -2 FEB. 1935 Anno XIII

Il Direttore

Nei riferimenti al presente *attestato* richiamare *soltanto* il suindicato numero, adottando la dizione

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B

After a suggestion of Orso Mario Corbino, only four days later, on October 26, a patent is submitted by Fermi, Amaldi, D'agostino, Pontecorvo, Rasetti, Segrè and Trabacchi (director of the Institute of Public Health, who had provided the radioactive sources.

Istituto Fisico della R. Università.
Roma, 22 ottobre 1934-XII.

E. FERMI
E. AMALDI
B. PONTECORVO
F. RASETTI
E. SEGRÈ

HERBERT GAWEHN

Azione di sostanze idrogenate sulla radioattività provocata da neutroni

Nel corso di esperienze sulla radioattività provocata nell'argento da bombardamento di neutroni si sono notate anomalie nella intensità della attivazione: uno spessore di alcuni centimetri di paraffina interposto fra la sorgente e l'argento invece di diminuire l'attivazione la aumenta. In seguito abbiamo potuto constatare che la presenza di grossi blocchi di paraffina circondanti la sorgente e l'oggetto irradiato esalta

From November 1, 1934, up to June 30, 1935, Pontecorvo is appointed "temporary assistant. On November 7, 1934, a second Letter on slow neutrons is sent to *La Ricerca Scientifica*. It is only signed by Fermi, Pontecorvo, Rasetti.

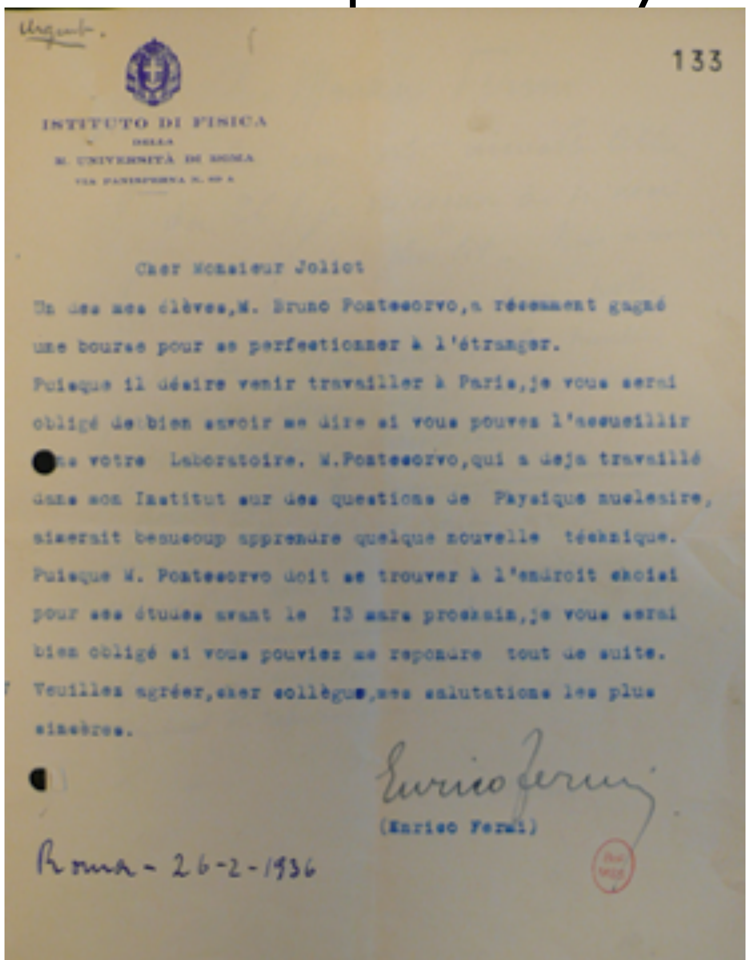
Pontecorvo in Rome continues all alone his research on slow neutrons, and publishes his results in a paper (“Research on the absorption of slow neutrons”) on “La Ricerca Scientifica” in the second half of September 1935.

The argument of this research is the recently discovered selective absorption of slow neutrons on various nuclei. His pioneering work, performed with a new experimental set up, is extended by Fermi and Amaldi in a systematic research on the selective absorption of slow neutrons, including their diffusion and slowing down, for which they use Pontecorvo’s set up.

Pontecorvo was not invited to work with Fermi and Amaldi, but in that same period he is carrying on an autonomous research on slow neutron diffusion in intermediate and heavy nuclei with Gian Carlo Wick, at the time a young theoretician and Fermi assistant. They established a deep friendship, which is testified by letter preserved ad Churchill Archives. The results of their work were published in two Letters, in spring 1936.

In the meantime, Pontecorvo receives a communication from the Minister of National Education: he is the first with mark 30/30 in two national competitions, both for fellowships abroad and in Italy. Pontecorvo decides to go to the Istitute of Radium in Paris, a choice which might have been suggested by the presence of his cousin Emilio Sereni, an opponent of the fascist regime, and a refugee in Paris like many other Italians.

His arrival is preceded by Fermi's letter to Joliot:



Urgent.

133

ISTITUTO DI FISICA
DELLA
R. UNIVERSITÀ DI ROMA

Cher Monsieur Joliot

Un des mes élèves, M. Bruno Pontecorvo, a récemment gagné une bourse pour se perfectionner à l'étranger.
Puisque il désire venir travailler à Paris, je vous serai obligé de bien savoir me dire si vous pouvez l'accueillir dans votre Laboratoire. M. Pontecorvo, qui a deja travaillé dans mon Institut sur des questions de Physique nucleaire, aimerait beaucoup apprendre quelque nouvelle téchnique.
Puisque M. Pontecorvo doit se trouver à l'endroit choisi pour ses études avant le 13 mars prochain, je vous serai bien obligé si vous pouviez me reponure tout de suite.
Veuillez agréer, cher collègue, mes salutations les plus sincères.

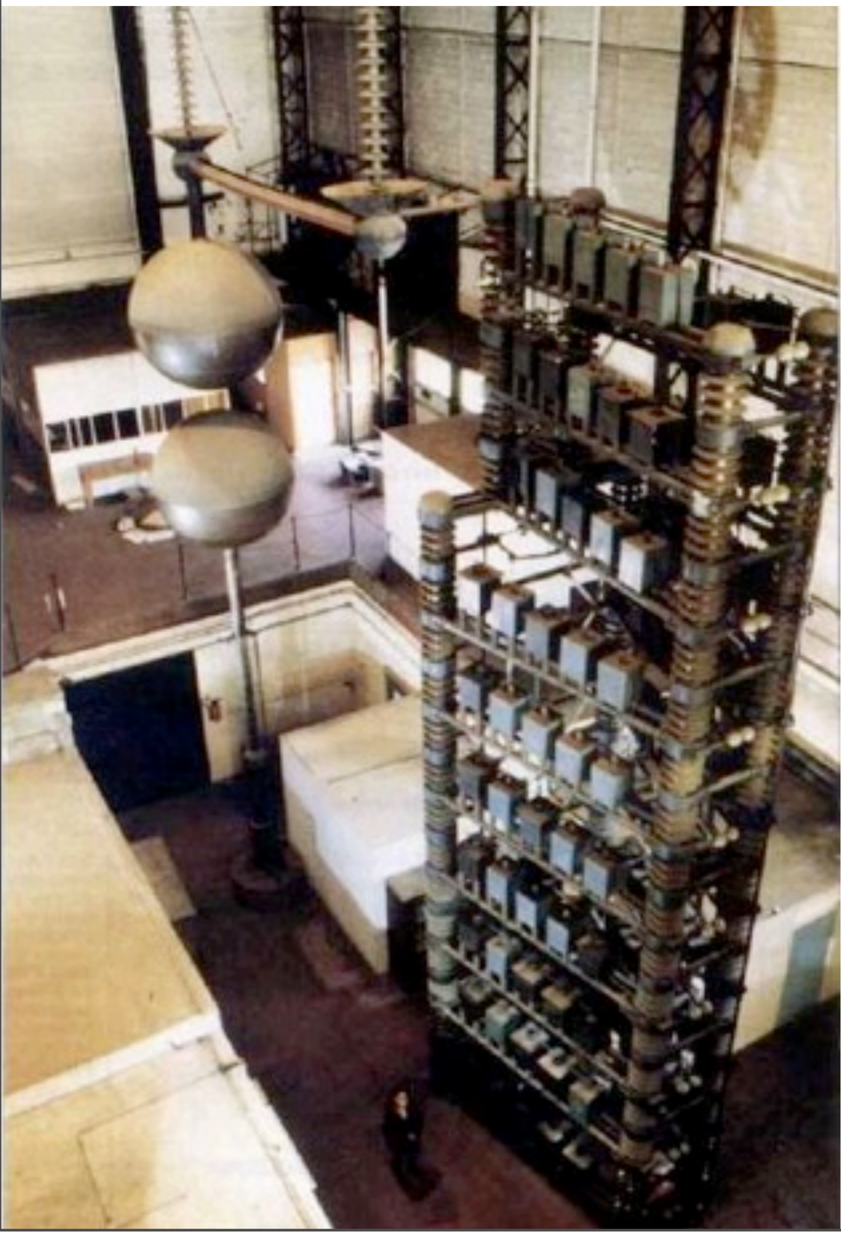
Enrico Fermi
(Enrico Fermi)

Roma - 26-2-1936

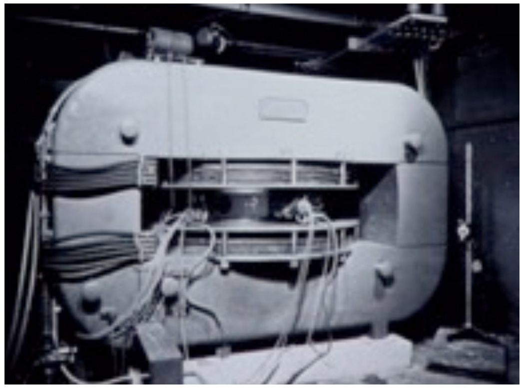
Joliot-Curie Archives

The Joliot-Curie have just been jointly awarded the 1935 Nobel Prize for Chemistry "in recognition of their synthesis of new radioactive elements."

From “string and wax” physics in Rome to “big science” in Paris



That same 1936, Joliot is appointed on the chair of nuclear chemistry at Collège de France.
At the same time he is organizing a new laboratory at Ivry for fundamental research and production of radioactive substances. A high voltage impulses generator of Marx type is installed there.



Joliot is also planning the construction of a cyclotron

Irène is the first woman appointed as Secretary to Scientific Research in the Blum Government

International Brigades Flags

Pablo Picasso, *Guernica*,
created in response to the bombing of Guernica, a Basque Country village in northern Spain, by German and Italian warplanes at the behest of the Spanish Nationalist forces on 26 April 1937 during the Spanish Civil War.

A new perspective is opening for Bruno (and Gillo) Pontecorvo in Paris, he discovers cultural and political commitment.
Up to that time tennis has been his main activity outside physics.


Spanish Civil War
1936-1939


JSU
Toda la juventud unida
POR ESPAÑA


¡No pasarán!


el generalisimo


¡ESTO ES EL
FASCISMO!
SOCORRO
ROJO
INTERNACIONAL


P.O.U.M.
¡UNION!
¡DISCIPLINA! POR EL
SOCIALISMO


F.A


la
CULTURA
ES UN ARMA MAS
PARA COMBATIR el
FASCISMO
JSU

Following some theoretical ideas of his own, and working mostly alone, though enjoying advice from Joliot-Curie whom he considered as his second *maestro* after Fermi, Pontecorvo did excellent pioneering work in the field of nuclear isomerism for which he got the Curie-Carnegie prize and financed his stay in Paris.

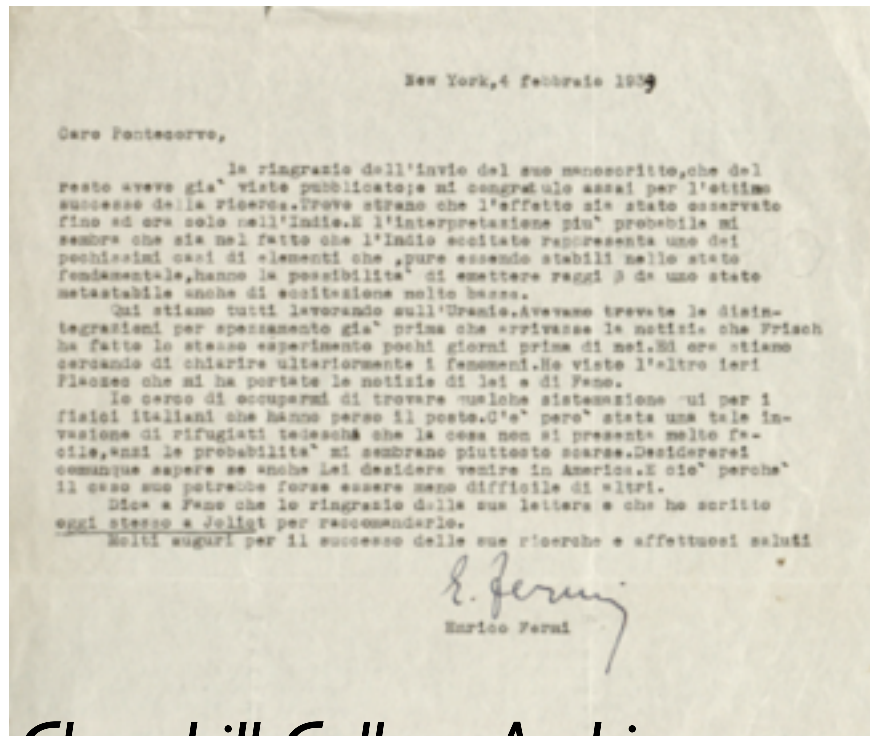
In 1937 he renounced to participate to a competition for a stable position of assistant in Rome, for which he certainly had excellent possibilities, but he did not send the necessary documents.
In doing this he clearly decided to remain in Paris.

Joliot always considered Pontecorvo his best pupil.

Pontecorvo's interests toward nuclear isomerism, intended as a new way to study the nuclear structure led him to the idea that nuclear β stable nuclear isomers might possibly exist. With M. Dodé he eventually discovered the first β stable isomer (fast neutron excitation on Cadmium) in 1939, and then, in the same year, working with A. Lazard he succeeded in producing β stable isomers (Indium and others), irradiating stable nuclei with high-energy X-rays. The new phenomenon was called *nuclear phosphorescence* by Joliot.

"I highly congratulate with you for the excellent result of the research."

Pontecorvo was very happy and proud Because he thought that Fermi, who called him "the great champion" had some respect for him only as a tennis expert.



New York, 4 febbraio 1939

Caro Pontecorvo,

La ringrazio dell'invio del suo manoscritto, che del resto avevo gia' visto pubblicato; e mi congratulo assai per l'ottimo successo della ricerca. Trovo strano che l'effetto sia stato osservato fino ad ora solo nell'Indio. E l'interpretazione piu' probabile mi sembra che sia nel fatto che l'Indio eccitato rappresenta uno dei pochissimi casi di elementi che, pure essendo stabili nello stato fondamentale, hanno la possibilita' di emettere raggi β da uno stato metastabile anche di eccitazione molto bassa.

Qui stiamo tutti lavorando sull'Uranio. Avevamo trovato le disintegrazioni per spezzamento gia' prima che arrivasse la notizia che Frisch ha fatto lo stesso esperimento pochi giorni prima di noi. Ed ora stiamo cercando di chiarire ulteriormente i fenomeni. Ho visto l'altro ieri Placzek che mi ha portato le notizie di lei e di Fano.

Io cerco di occuparmi di trovare qualche sistemazione qui per i fisici italiani che hanno perso il posto. C'e' pero' stata una tale invasione di rifugiati tedeschi che la cosa non si presenta molto facile, anzi le probabilita' mi sembrano piuttosto scarse. Desidererei comunque sapere se anche Lei desidera venire in America. E cio' perche' il caso suo potrebbe forse essere meno difficile di altri.

Dica a Fano che lo ringrazio della sua lettera e che ho scritto oggi stesso a Joliot per raccomandarlo.

Molti auguri per il successo delle sue ricerche e affettuosi saluti

E. Fermi

Enrico Fermi

Churchill College Archives

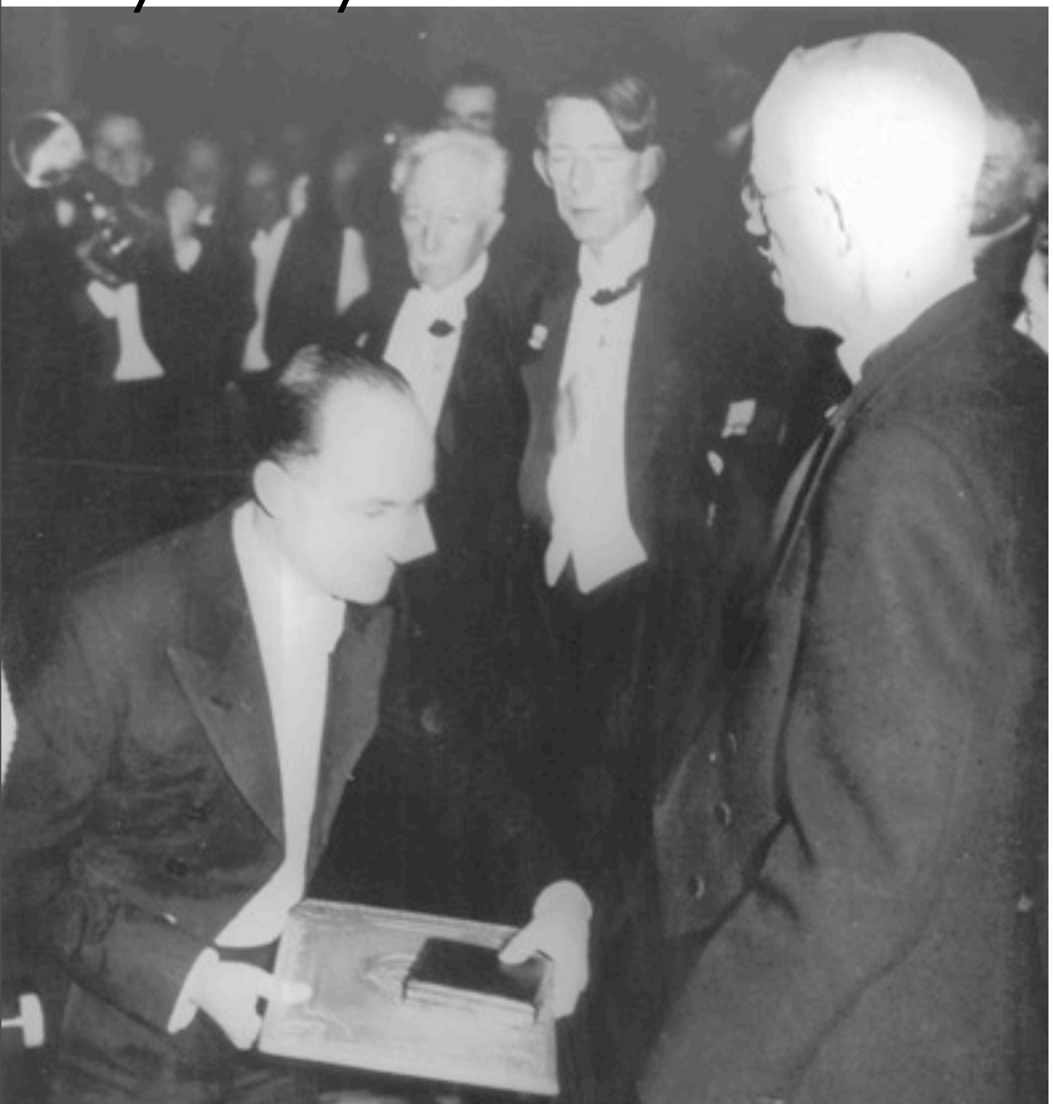
martedì 14 gennaio 2014

Fall 1938

Fermi leaves Italy.

Bruno Rossi is dismissed from his chair in Padua. Both will emigrate to US.

Many young physicists are obliged to go. The young Italian modern physics is nearly destroyed.



il Resto del Carlino

IL DUCE PRESIEDE IL CONSIGLIO DEI MINISTRI

Le leggi per la difesa della Razza

Proibizione dei matrimoni misti - Chi è considerato di razza ebraica - Servizi, uffici, proprietà, gestioni, impieghi vietati ai giudei - Limitazione nel possesso di terreni e di fabbricati - I casi previsti per il beneficio della discriminazione - 12 marzo: termine per le espulsioni - Esclusione totalitaria dalla Scuola

Intransigenza necessaria

Il testo dei provvedimenti

Scuola incontaminata

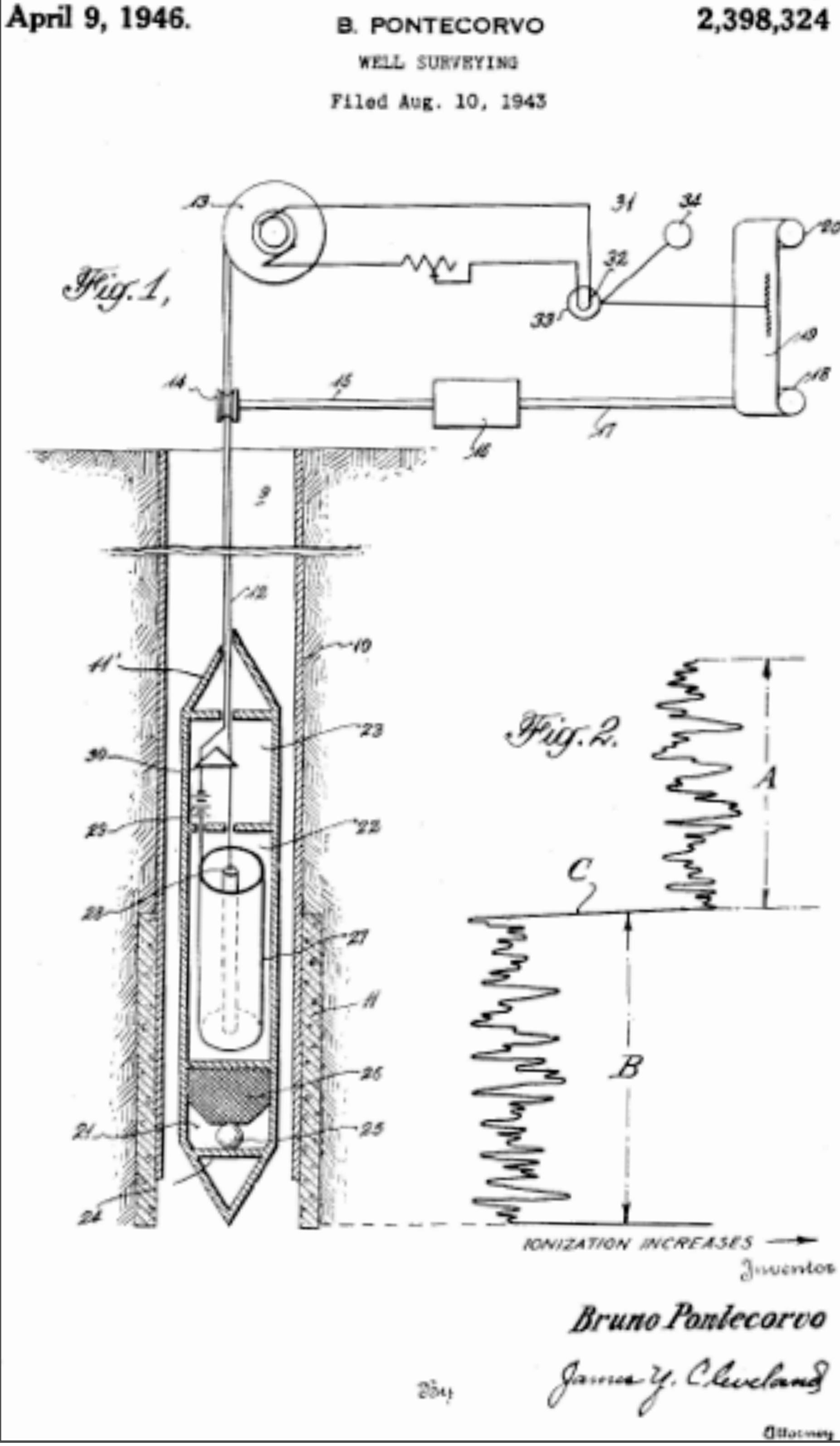
In January 1939 Hahn and Strassmann's article on the fission of uranium bombarded by neutrons appears, followed by Meitner and Frisch physical interpretation of the phenomenon.
News of the discovery spread through the scientific community. Physicists noticed the fission of one uranium atom gave off extra neutrons which could in turn split other uranium atoms, starting a chain reaction.

April 1 – The Spanish Civil War comes to an end when the last of the Republican forces surrender. Dictator Francisco Franco assumes power in Madrid
May 22 – Germany and Italy sign the Pact of Steel
August 2 – Albert Einstein writes to U.S. President Franklin D. Roosevelt about the possibility of developing a nuclear weapon using uranium. He mentions the risk that Germany might be already working at such a project. All this eventually led to the creation of the Manhattan Project.
August 23 – Molotov-Ribbentrop Pact signed between Germany and the Soviet Union, a neutrality treaty that also agreed to division of spheres of influence (Finland, Estonia, Latvia, eastern Poland and Bessarabia (today Moldova), north-east province of Romania to the Soviet Union; Lithuania and western Poland to Germany).
On this occasion, Bruno Pontecorvo decides to become member of the Italian Communist Party. A kind of "faith act", which inaugurates his long "religious attitude" toward what he hopes to become a world without classes and full of justice.
September 1 – Opening shots of World War II and Invasion of Poland
The United Kingdom, France, New Zealand and Australia declare war on Germany.

June 14, 1940. Paris is invaded by German troops

The day before Bruno and his brother Gillo, and other friends and colleagues have fled by bycicle. Marianne with Gil has taken a train, she is pregnant and will lose the baby. In Tolouse they take a train for Spain, to reach Portugal and embark for US.

Pontecorvo has a regular visa and a contract with the Well Survey, an oil company in Oklahoma.
They arrive in New York on August 20, 1940.



Pontecorvo invents a very brilliant technique for the survey of oil fields, "the neutron well-logging", based on the absorption of slow neutrons, still up to date.

B. Pontecorvo, Neutron well logging. A new geological method based on nuclear physics, *Oil and Gas Journal* 40, 1941, 32.

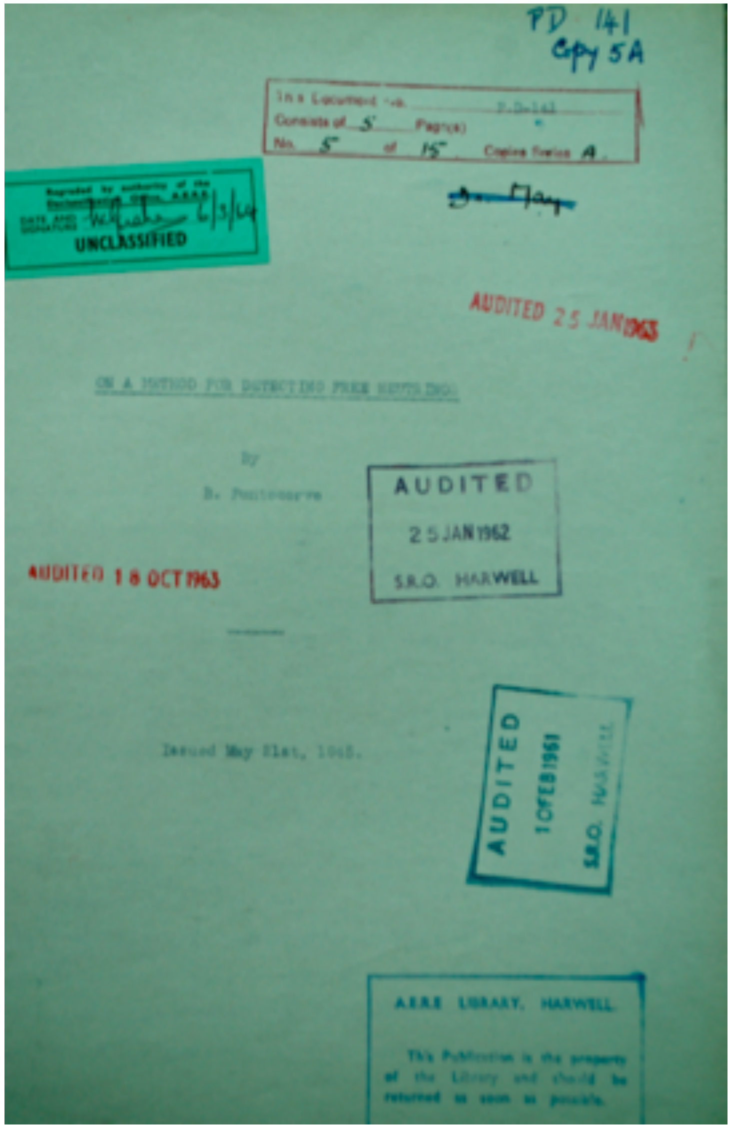
A probe consisting of a strong neutron source, an ionization chamber shielded from the rays coming directly from the source, with an amplifier, and a recording meter, is moved at constant speed (as large as possible) in a well. As a consequence of the interaction of neutrons with the surrounding formations, the signal in the ionization chamber varies with the properties of the strata, which strongly depends on the presence in the rocks of hydrogenated substances, like water and oil.

Montreal 1944. From left, Henri Seligman, Bruno Pontecorvo, Bertrand Goldschmidt, Jules Guèron, Hans von Halban, Pierre Auger

In September 1942 B. Pontecorvo was invited to take part in the Anglo-Canadian Uranium Project in Canada led by von Halban and including many of his former French colleagues. Bruno (30 years old) was scientific leader of the project of the research reactor which was built in 1945 and was the first nuclear reactor outside of USA. In December 1942 Fermi switched on the first controlled nuclear chain reaction in Chicago

In the period 1943-45 Pontecorvo worked essentially on design problems writing some 25 reactor related reports, including work with design engineers on the shielding from mid-1944.
After the decision, under John Cockcroft in middle 1944, to build a large heavy water and natural Uranium reactor NRX (National Research eXperimental), Pontecorvo was in charge of several physics aspects of the reactor.
The NRX reactor started operation on July 22, 1947. Designed as the most powerful research reactor it was opened to physicists, chemists, biologists, metallurgists.

Chalk River, September 1945. ZEEP (1 W) becomes operational, the first heavy water reactor outside USA.
NRX is being constructed (on the back). The NRX reactor started operation on July 22, 1947.



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May 1945. PD 141. **On a method for detecting free neutrinos**.

"So far as it is known to this author, the most significant experiments devised to detect the neutrinos which have been made, attempted to investigate the recoil of the nucleus produced in a beta process... We will now discuss processes produced by 'free neutrinos', i.e. processes produced by neutrinos <u>after</u> they have been emitted in a disintegration."

The National Archives, London

In 1934, Bethe and Peierls had estimated the cross section of the interaction of postulated by Pauli neutrino with a nucleus. The estimated cross section was extremely small. At ~ MeV energies $\sigma < 10^{-44}$cm^2. During many years neutrino was considered as an "undetectable particle."

May 1945: P.D.141: On a method for detecting free neutrinos: The experimental observation of an inverse β process is "not" out of question. Bruno Pontecorvo was the first physicist who challenged this opinion and proposed a method for neutrino detection.

1946: P.D.205: *Inverse Beta Process*. Deep analysis of neutrino interactions. To study such rare events he suggested the use of a radiochemical method: radioactive atoms produced have different chemical properties. Pontecorvo's method was based on the observation of decay of daughter nucleus produced in the reaction $\nu+(A, Z) \rightarrow e^{-}+(A, Z+1)$. He considered as the most promising the reaction $\nu+{}^{37}Cl \rightarrow e^{-} + {}^{37}Ar$ for many reasons: CCl_4, carbon thetrachloride, is a cheap, non-flammable liquid, ^{37}Ar is unstable nucleus with a convenient half-life (34.8 days), a few atoms of ^{37}Ar (rare gas), produced during an exposition time, can be extracted from a large detector, etc.

Sources: Neutrinos from the sun (not very energetic) and Neutrinos from reactor. Difference between neutrino and antineutrino is not at all clear ("Majorana neutrinos" ?).

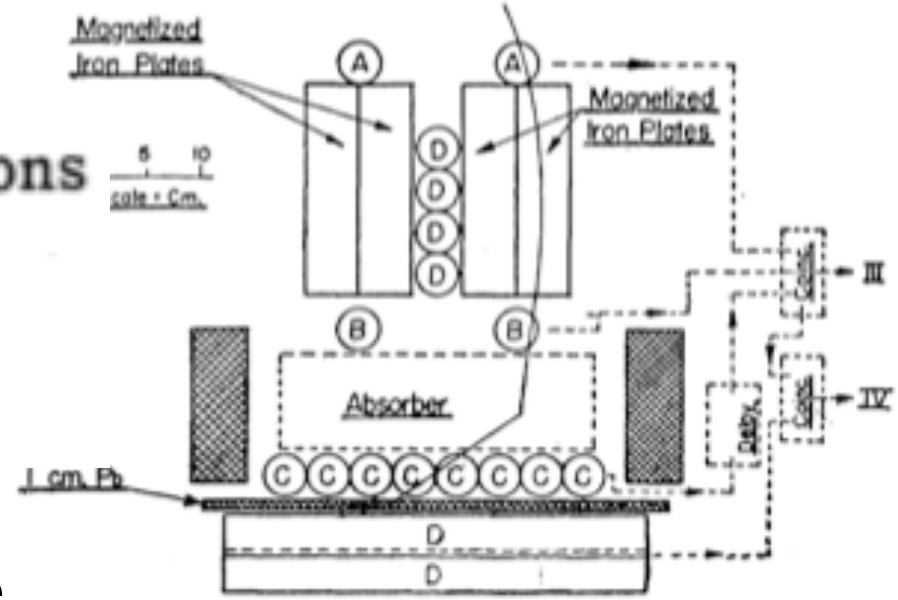
1947, the great revelation. Pontecorvo's reaction to the Conversi Pancini Piccioni experiment on the capture of cosmic-ray mesotrons

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



This remarkable experiment was mentioned by L. Alvarez in his Nobel Lecture

Pontecorvo-Wick correspondence 1946-1947

The mesotron of CR

Yukawa 1935: A new particle is responsible for the nuclear force. Hypothesis of its decay

1936-1937 Anderson&Neddermeyer, Street and Stevenson "confirm" the existence of Yukawa's meson, now becoming the *mesotron* of cosmic rays

Mesotron decay: lifetime measured starting from Rasetti and Rossi et al. end 1930s-beginning of 1940s (1942 Rossi & Nereson, better statistics, lifetime determined with an accuracy of less than 4%) about 2.2 10^{-6} s. From Williams and Robertson 1940, one cloud chamber event (meson stopping and electron track emerging) to thousands of decay events

Unaware of Rossi's experiments, Conversi & Piccioni obtained a value in substantial agreement with Rossi & Nereson.

Tomonaga & Araki, 1940:
"strong" capture
(Yukawa) 10^{-18} s

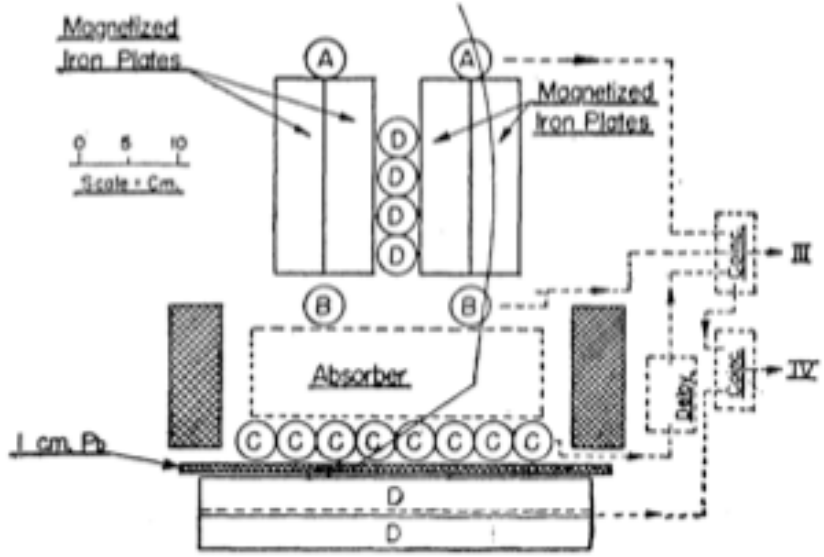
Sakata, Inoue, Tanikawa, 1940-1942: Two meson theory: conflicts between lifetime of the mesotron (10^{-6} s), interaction cross section

The mesotron of CR cannot be Yukawa particle

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



The Decay of Negative Mesotrons in Matter

E. Fermi, E. Teller,
University of Chicago, Chicago, Illinois
and
V. Weisskopf
Massachusetts Institute of Technology, Cambridge, Massachusetts

(Received February 7, 1947)

The experimental result[1] leads to the conclusion that the time of capture from the lowest orbit of carbon is not less than the time of natural decay, that is, about 10^{-6} second. This is in disagreement with the previous estimate by a factor of about 10^{12}. Changes in the spin of the

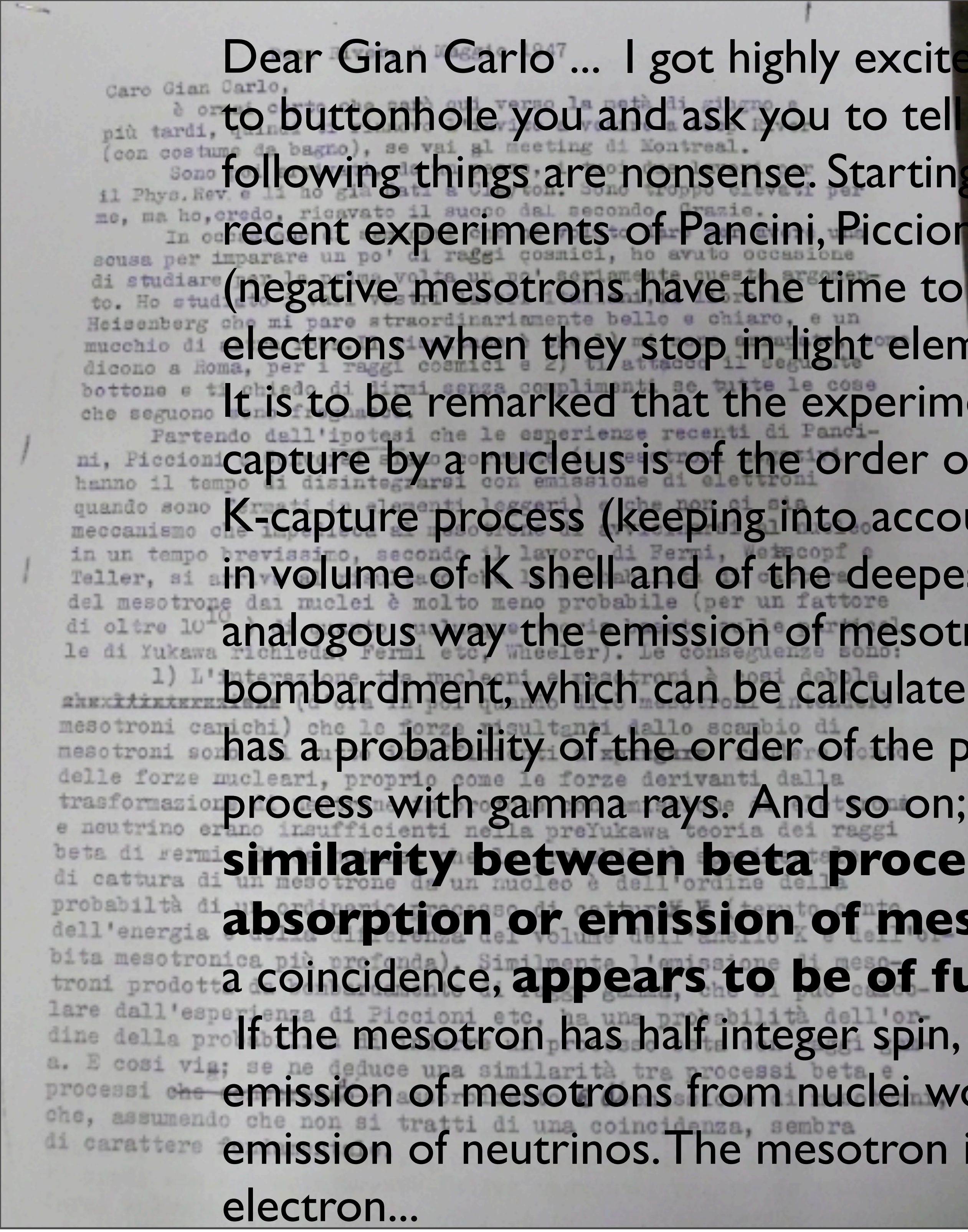
Jack Steinberger:
"My first contact with ongoing physics was a ***seminar*** *early in 1947, in which* ***Fermi discussed the result of a cosmic-ray experiment performed in Rome****... as Fermi put it, the mesotron would be "eaten up by the nucleus before it had time to die in bed." This was indeed the case for iron, but in carbon the negative mesotrons decayed quite happily."*

About this experiment I heard while working in Canada. Until 1947 cosmic ray physics for me was a quite remote field some knowledge of which I had acquired from my friends in Florence (Bernardini and Occhialini), in Paris (P. Ehrenfest Jr., a very promising experimentalist, working in the cosmic ray Auger team, who prematurely lost his life in a mountain accident), in Montreal (Rasetti, one of my teachers, who in Quebec first measured directly the mean life of the "mesotron", and Auger, who did the same measurement together with Maze, and under whom I was working in Canada during the war).

Why the spin of the muon should be integer ?
Who said that the muon must decay into an electron and a neutrino and not into an electron and two neutrinos, or into an electron and a photon ?
Is the charged particle emitted in the muon decay an electron ?
Are particles other than electrons and neutrinos emitted in the muon decay ?

Pontecorvo with Gilberto Bernardini

1) The muon capture must be a process practically identical to the beta process proceeding according to the reaction: ***negative mesotron + p = neutrino + n***
2) In the muon capture most of the released energy is "invisible", because it is carryed away in the form of neutrinos, a conjecture which was supported by experiments and agrees with 1);
3) *"I felt sure that the muon is a fermion. A fermion cannot be produced singly"*



Dear Gian Carlo ... I got highly excited for cosmic rays and I am going to buttonhole you and ask you to tell me frankly whether all the following things are nonsense. Starting from the hypothesis that the recent experiments of Pancini, Piccioni and Conversi are correct (negative mesotrons have the time to disintegrate with emission of electrons when they stop in light elements) ....

It is to be remarked that the experimental probability of mesotron capture by a nucleus is of the order of the probability of an ordinary K-capture process (keeping into account the energy and the difference in volume of K shell and of the deepest mesotronic orbit). In an analogous way the emission of mesotrons produced by gamma ray bombardment, which can be calculated from Piccioni etc. experiment, has a probability of the order of the probability to induce a beta process with gamma rays. And so on; **one can deduce a similarity between beta processes and processes of absorption or emission of mesons,** that, assuming that it is not a coincidence, **appears to be of fundamental character...**

If the mesotron has half integer spin, the processes of absorption and emission of mesotrons from nuclei would be accompanied by emission of neutrinos. The mesotron is then a sort of isomer of the electron...

Compared the probabilities of the processes

$\mu^- + (A,Z) \rightarrow \nu + (A,Z-1)$

$e^- + (A,Z) \rightarrow \nu + (A,Z-1)$

The constants which characterize these two processes are of the same order of magnitude

Nuclear Capture of Mesons and the Meson Decay

B. PONTECORVO
National Research Council, Chalk River Laboratory, Chalk River, Ontario, Canada

June 21, 1947

THE experiment of Conversi, Pancini, and Piccioni[1] indicates that the probability of capture of a meson by nuclei is much smaller than would be expected on the basis of the Yukawa theory.[2,3] Gamow[4] has suggested that the nuclear forces are due exclusively to the exchange of neutral mesons, the processes involving charged mesons and the β-processes having probabilities which are smaller by a factor of about 10^{12}.

We notice that the probability ($\sim 10^6$ sec.$^{-1}$) of capture of a bound negative meson is of the order of the probability of ordinary *K*-capture processes, when allowance is made for the difference in the disintegration energy and the difference in the volumes of the *K*-shell and of the meson orbit. We assume that this is significant and wish to discuss the possibility of a fundamental analogy between β-processes and processes of emission or absorption of charged mesons.

"Fundamental analogy between β-processes and processes of absorption of muons"

7

Concludo rinnovando l'invito a tutti voi di venire qui

Affett.

Bruno.

Deep River, 6 July 1947

P. S. 1) Includo una lettera che uscirà prossimamente sulla Phys. Rev. Ho scritto questa lettera su pressione di varia gente, poi ho pensato di ritirarla. E infine ho deciso di lasciarla uscire, se tu però hai l'impressione che non dovrei pubblicarla, perchè quanto è scritto lì è ~~[illegible]~~ ovvio, dimmelo francamente che ~~[illegible]~~ probabilmente la potrei ritirare.

2) Completamente a parte le considerazioni fatte fin qui, sembra interessante notare che i seguenti tre processi hanno probabilità comparabili:

1) Disintegrazione del mesotrone
2) Cattura del mesone dai nuclei
3) Processi β (cattura K)

Nuclear capture of the mesons and meson decay, August 1947

"... an experiment suggests itself... to decide definitely whether the meson decays into either an electron plus neutral particle(s) or electron plus photon."

What is the nature of the neutral decay particles?

Search for Gamma-Radiation in the 2.2-Microsecond Meson Decay Process

E. P. Hincks and B. Pontecorvo
National Research Council, Chalk River Laboratory, Chalk River, Ontario, Canada
December 9, 1947

THE meson decay process which is identified by a mean life of 2.2 microseconds[1] has been usually thought of as consisting of the emission of an electron and a single neutrino, as suggested by the well-known Yukawa explanation of the ordinary beta-process in nuclei. However, the Yukawa theory is at variance with the results of the experiment of Conversi, Pancini, and Piccioni,[2] and since there remains no strong justification for the electron-neutrino hypothesis,[3] a direct experiment to test an alternative hypothesis—*that the decay process consists of the emission of an electron and a photon, each of about 50 Mev*—has been performed.

Hincks and Pontecorvo, performed a direct experiment (electron-photon delayed coincidences) in order to decide definitely whether or not one of the neutral decay particles is a photon

ON THE ABSENCE OF PHOTONS AMONG THE DECAY PRODUCTS OF THE 2.2 MICROSECOND MESON[1]

By E. P. Hincks and B. Pontecorvo[2]

A meson of spin $\frac{1}{2}(h/2\pi)$ could, a priori, decay in a number of ways. One possibility would be the decay into one electron and two neutrinos.‡ Another possibility would be that the *2.2 μsec. decay process consists of the emission of one photon and one electron*, each of about 50 Mev. according to the laws of conservation of energy and momentum. Radiative decay of mesons has been

Can. J. Res.
Rec. Aug. 4, 1949

The principle of the experiment: "one may look to the delayed coincidence due to the simultaneous emission of photon and electron in opposite directions..."

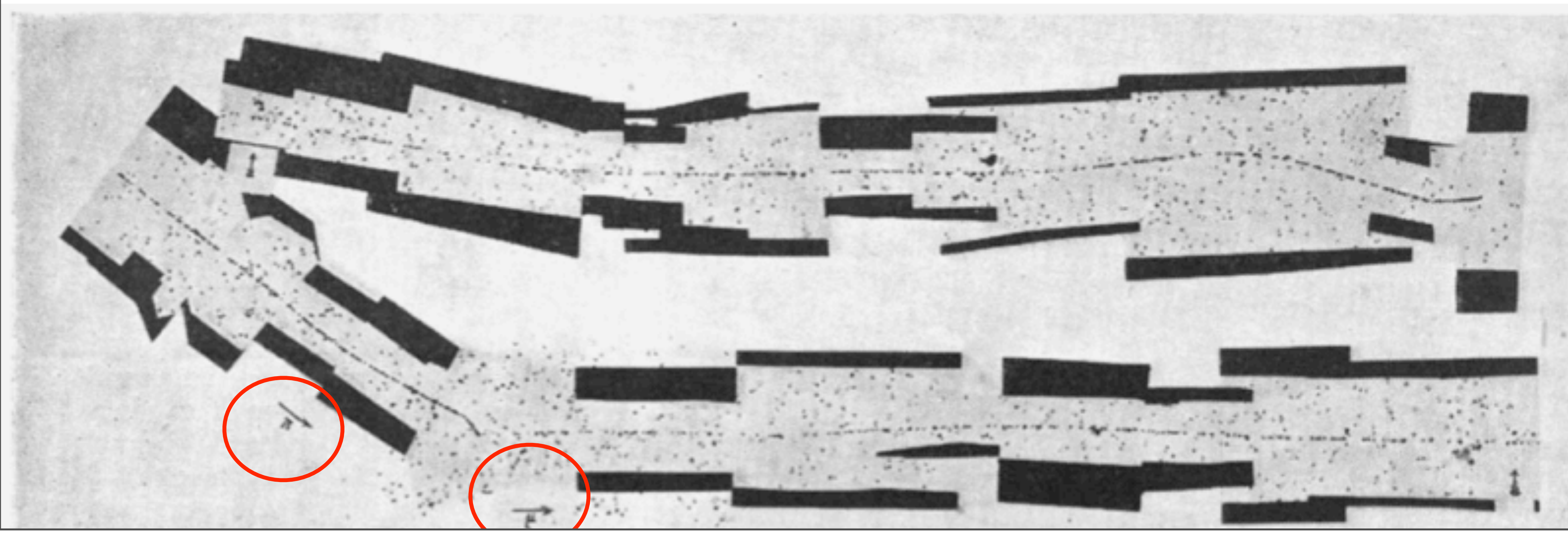
"The 2.2 μsec. meson decay process does not consist of the emission of an electron and a photon..."

Our result definitely eliminates one of the decay processes that could have been postulated for a meson of spin $\frac{1}{2}(h/2\pi)$. However, a half-integral meson spin still presents a considerable attraction as was pointed out in the introduction to this paper, and in more detail in reference (28). Another process involving such a value for the meson spin, and currently in favor, is disintegration into an electron and two neutrinos. Recent experimental evidence supporting this hypothesis includes (*a*) the establishment of the fact that the charged decay particles have electronic mass (16, 17, 18), and (*b*) the form of the energy spectrum of the decay electrons (21).

Shelter Island Conference June 1947: Marshak & Bethe: 2 mesons theory (Yukawa particle interacts strongly but decays quickly into another meson interacting weakly)

In Japan between 1940 and 1943 Sakata & Tanikawa and Sakata & Inoue, suggested a two-meson hypothesis with a Yukawa-type meson decaying into a weakly interacting mesotron.

October 1947
Lattes, Occhialini, Powell



On the Stability of the Neutral Meson

E. P. Hincks and B. Pontecorvo
*National Research Council, Chalk River Laboratory
Chalk River, Ontario, Canada*
March 17, 1948

THE discovery[1] of the disintegration of a heavy (π) meson into a light one (μ meson, most likely the particle constituting the penetrating component of the cosmic radiation) has provided strong evidence[2] in favor of the existence of neutral mesons of mass about 70 Mev.

In order to explain a photograph of a 24-Mev decay electron, observed by Anderson, Adams, Lloyd, and Rau,[3] these authors and later Marshak[4] have suggested that the μ-meson might decay into an electron and a neutral particle apparently identical with the neutral meson of Lattes, Occhialini, and Powell. Greisen[5] has recently indicated that several cosmic-ray phenomena "which have defied even qualitative explanation up to the present are made understandable in the light of the neutral meson hypothesis" provided the neutral meson decays immediately into two photons. This γ-instability has been predicted on theoretical grounds by several authors.[6]

We want to point out that we have secured experimental evidence proving an incompatibility between the hypothesis that the 2.2-μs meson decay sinto an electron and a neutral meson and the hypothesis that the neutral meson is unstable *versus* emission of two photons with a very short lifetime. The experimental arrangement has been described[7] in connection with a research—which gave a negative result—to find out whether the decay of the 2.2-μs meson consists of the emission in opposite directions of one electron and one photon, each of about 50 Mev. Clearly the same arrangement, for the details of which we refer to our previous note, is capable of deciding whether the decay of the 2.2-μs meson consists of the emission of an electron and a neutral meson unstable *versus* emission of two photons of about 35 Mev. The number of decay electrons from mesons stopped in graphite was recorded, and at the same time electron-photon coincidences were looked for. While the net number of measured delayed coincidences (observed rate minus casual rate) is $0.01\begin{cases}+0.06\\-0.01\end{cases}$ per hour, the rate to be expected according to the hypothesis of a neutral meson unstable *versus* emission of two photons of 35 Mev with a mean life $\lesssim 10^{-10}$ sec. is about one per hour.

We conclude that either the neutral meson is not emitted in the 2.2-μs decay process, or, if it is emitted, it does not decay into two photons with a mean life $\lesssim 10^{-10}$ sec.

It seems that a similar conclusion can be reached from the experiment of Sard and Althaus,[8] who, by using a method different from ours, failed to observe a γ-radiation in the 2.2-μs decay of mesons brought to rest in brass. It should be noticed that while our experiment refers to positive and negative mesons, their experiment refers only to positive ones.[9]

There remains, of course, the possibility that there are two distinct types of neutral mesons, one of which is stable and the other unstable *versus* emission of γ-radiation.

A more complete account of this work will be submitted for publication in the near future.

[1] C. M. Lattes, H. Muirhead, G. P. S. Occhialini, and C. F. Powell, Nature **159**, 694 (1947).
[2] C. M. G. Lattes, G. P. S. Occhialini, and C. F. Powell, Nature **160**, 453 (1947); **160**, 486 (1947).
[3] C. D. Anderson, R. V. Adams, P. E. Lloyd, and R. R. Rau, Phys. Rev. **72**, 724 (1947).
[4] R. E. Marshak, Bull. Am. Phys. Soc. **22**, No. 6, p. 14.
[5] K. I. Greisen, Phys. Rev. **73**, 521 (1948).
[6] J. R. Oppenheimer, New York Meeting of American Physical Society, January, 1947; R. J. Finkelstein, Phys. Rev. **72**, 415 (1947).
[7] E. P. Hincks and B. Pontecorvo, Phys. Rev. **73**, 257 (1948).
[8] R. D. Sard and E. J. Althaus, Bull. Am. Phys. Soc. **23**, No. 2, p. 20 (1948).
[9] M. Conversi, E. Pancini, and O. Piccioni, Phys. Rev. **71**, 209 (1947).

The Absorption of Charged Particles from the 2.2-μsec. Meson Decay

E. P. Hincks and B. Pontecorvo
National Research Council of Canada, Chalk River Laboratory, Chalk River, Ontario, Canada
July 26, 1948

THE energy spectrum of the charged particles (commonly assumed to be electrons) emitted in the 2.2-μsec. meson decay is still unknown. Conversi and

15 g/cm² of carbon. Therefore, we conclude that there are decay electrons having energies greater than 25 Mev and therefore that the 2-particle decay process (Eq. (1)), with a *unique* energy of about 25 Mev for the decay electron, is incompatible with our results.

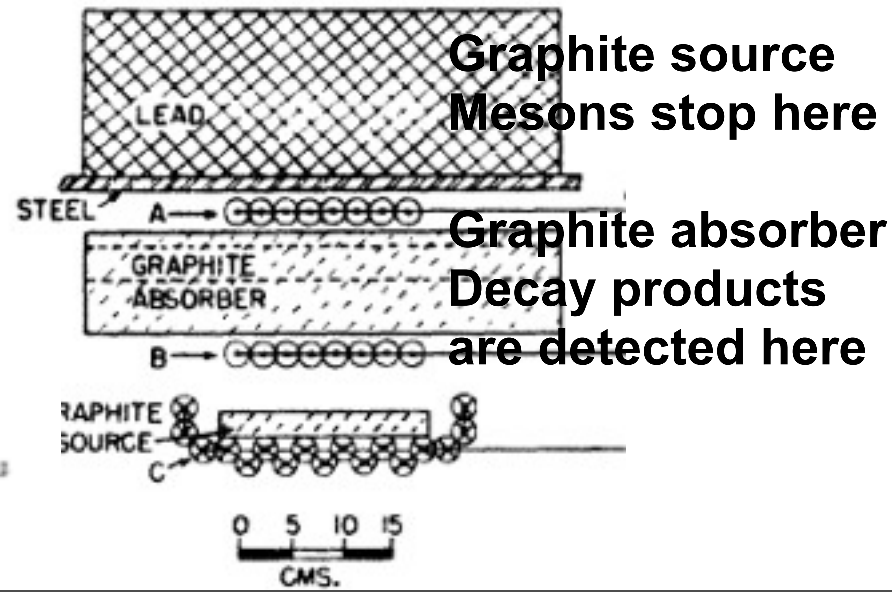
Charged products of the decay are electrons
(measuring the intensity of Bremsstrahlung)

The muon decay is not a two-body process, 3 particles are emitted
(measuring the electron spectrum by absorption)

The Penetration of μ-Meson Decay Electrons and Their Bremsstrahlung Radiation

E. P. Hincks and B. Pontecorvo
National Research Council of Canada, Chalk River Laboratory, Chalk River, Ontario, Canada
January 3, 1949

MEASUREMENTS of the penetration of the charged particles from the 2.2-μsec. meson decay using the arrangement of counters and delayed coincidence circuits previously described[1] have been extended with absorbers of lead and aluminum, in addition to carbon. The results confirm our previous conclusion that at least a substantial number of particles have an energy >25 Mev. Although



On the Disintegration Products of the 2.2-μSec. Meson

E. P. Hincks and B. Pontecorvo*
National Research Council of Canada, Chalk River Laboratory, Chalk River, Ontario, Canada

(Received September 19, 1949)

On the Disintegration Products of the 2.2-μSec. Meson

E. P. HINCKS AND B. PONTECORVO*
National Research Council of Canada, Chalk River Laboratory, Chalk River, Ontario, Canada

(Received September 19, 1949)

neutral products of μ decay

The observation of a meson disintegration in a cloud chamber, in which the energy of the decay particle is 24 Mev, led Anderson and co-workers[11] to suggest the process:

$$\text{meson} \rightarrow \text{electron} + \text{neutretto}, \qquad (3)$$

the mass of the neutretto, or neutral meson, being 25–30 Mev less than that of the original meson. While

As an example of a process with three decay products, the following has been suggested:[14]

$$\text{meson} \rightarrow \text{electron} + \text{neutretto} + \text{neutrino}. \qquad (4)$$

Another process which would result in a continuous distribution of electron energies was mentioned by Nordheim[16] in 1941:

$$\text{meson} \rightarrow \text{electron} + 2\ \text{neutrinos}. \qquad (5)$$

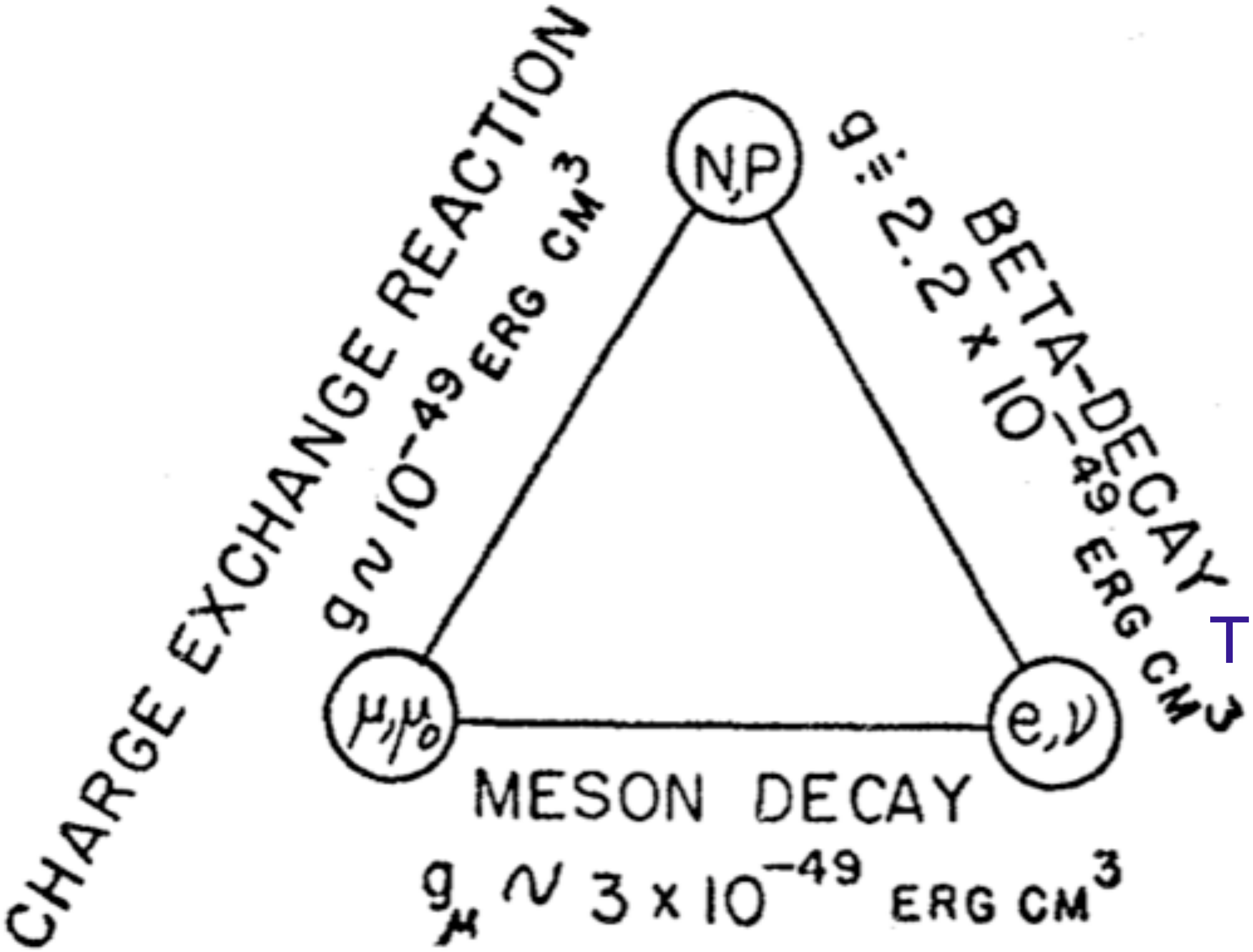
Good evidence for a continuous spectrum of the decay particles was published recently by Brown *et al.*[17] and by Leighton *et al.*,[18] after our work as well as Steinberger's was finished. The California authors measured in a cloud chamber the momenta of a great number of decay charged particles, contributing most of the present knowledge on the energy spectrum. Their results support the process (5).

These pioneering experiments proved that:
- Muon does not decay into electron and high energy photon.
- The charged particle emitted in μ-decay is an electron.
- Muon decays into three particles.

Our main conclusion referring to the mass of the charged decay particles excludes the possibility that a new type of meson (charged light meson or λ-meson) is emitted in the 2.2-μsec. decay, and adds to the body of evidence in support of the "electron+2 neutrinos" process (Eq. (5)), requiring a spin $\frac{1}{2}\hbar$ for the μ-meson.

UNIVERSALITY OF WEAK INTERACTION

Klein, June 1948 (citing BP)



Puppi, November 1948
and March 1949

Tiomno&Wheeler, Jan. 1949 (citing BP)

Lee, Rosenbluth & Yang, Jan. 1949

In the meantime, with the solar experiment still in his mind, Pontecorvo developed with Geoff C. Hanna and D. H. W. Kirkwood a low background high-gain proportional counter that allowed him to determine the energy of the Auger electrons (2.8 KeV) and see the K capture. This kind of counter was later used for detection of solar neutrinos by Davis, and at GALLEX and SAGE experiments.
By introducing tritium produced in the NRX reactor which had become operational, he found with Hanna that the **neutrino mass had to be smaller than 500 eV.**
In 1948, the Cl-A method acquired full shape with recording of the beta-spectrum of ^{37}A gas introduced in the high-gain proportional counter, and measurement of the energy of Auger electrons.
Pontecorvo never did the experiment with a tank wagon filled with carbon tetrachloride and taken in a tunnel.
At the beginning of 1949 Pontecorvo definitely moved to England and collaborated at the construction of a nuclear reactor at Harwell.

B. Pontecorvo, Recent Developments in proportional Counter Technique, Helv. Phys. Acta 23, Suppl. 3: 97-118 (1950)

1949 Back to Paris invited by Joliot

Abingdon le 26 Avril, 1949

Cher Monsieur Joliot,

Merci beaucoup de votre aimable lettre m'invitant à venir donner deux conférences à Paris.

J'accepte avec grand plaisir, et je suis heureux d'avoir ainsi l'occasion de vous revoir, avec tous les amis du Labo. Comme vous le suggerez, les sujets de mes causeries pourraient être:

1) Spectrographie beta dans la region des faibles énergies, à moyen du compteur proportionel

2)Quelques recherches sur la radioactivité du meson.

Je pensai arriver à Paris jeudi le 12 Mai, et je pourrai parler n'importe quand dans les jours suivants: j'ai prié Bertrand Goldschmidt de me faire savoir si cette d date vous convient.

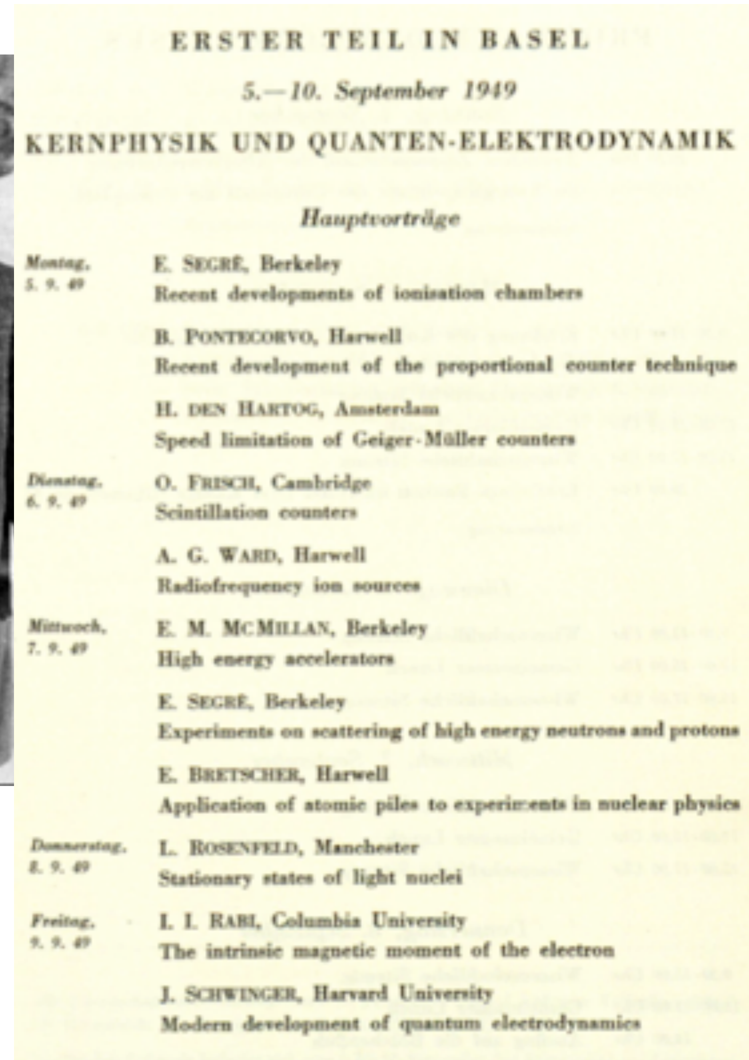
Je vous prie de croire, cher Monsieur Joliot, à mes sentiments amicaux

B. Pontecorvo

The National Archives, London

Como-Basel Conference
5-16 September 1949

The National Archives, London



ERSTER TEIL IN BASEL

5.—10. September 1949

KERNPHYSIK UND QUANTEN-ELEKTRODYNAMIK

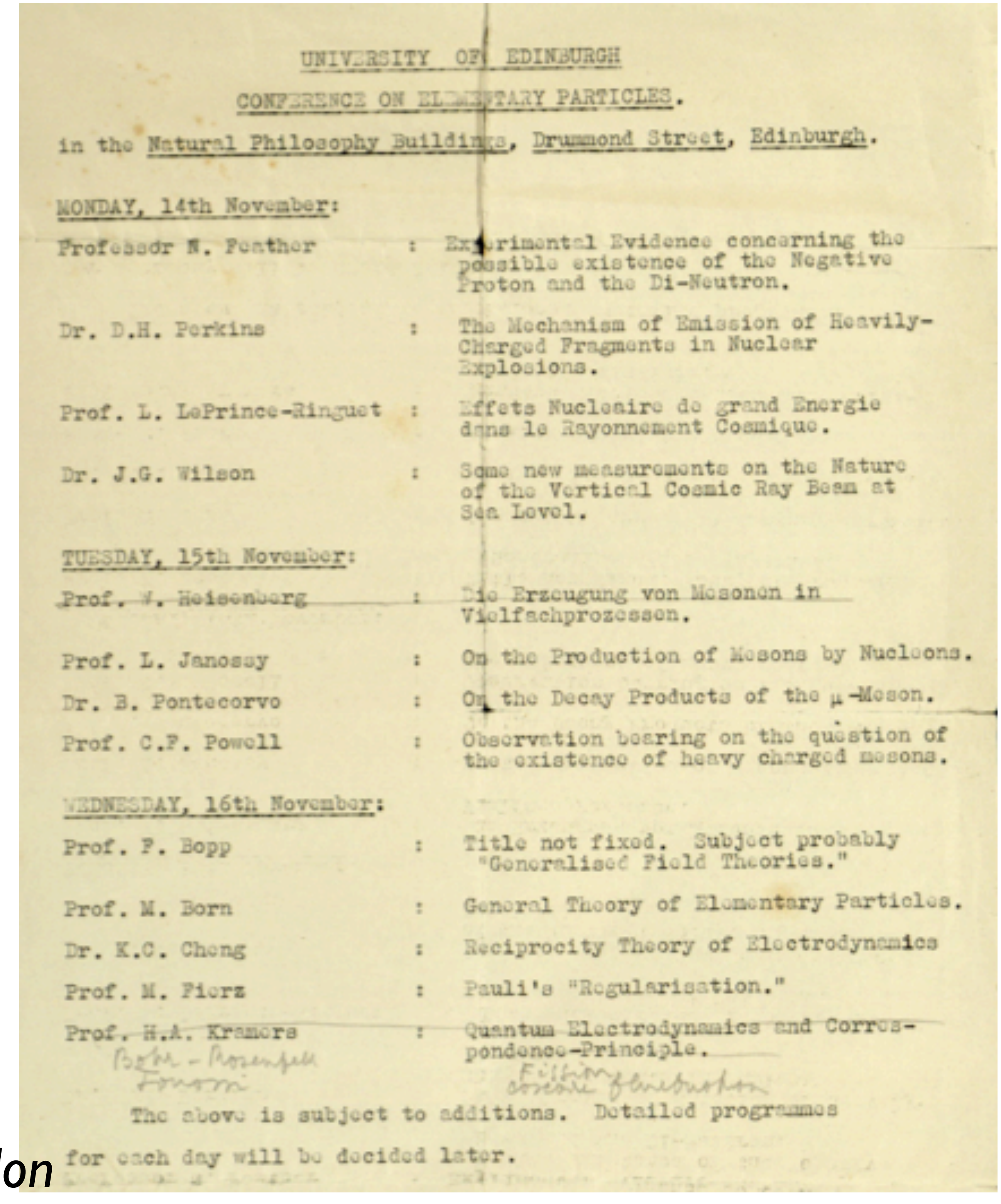
Hauptvorträge

Montag, 5. 9. 49	E. Segrè, Berkeley Recent developments of ionisation chambers
	B. Pontecorvo, Harwell Recent development of the proportional counter technique
	H. den Hartog, Amsterdam Speed limitation of Geiger-Müller counters
Dienstag, 6. 9. 49	O. Frisch, Cambridge Scintillation counters
	A. G. Ward, Harwell Radiofrequency ion sources
Mittwoch, 7. 9. 49	E. M. McMillan, Berkeley High energy accelerators
	E. Segrè, Berkeley Experiments on scattering of high energy neutrons and protons
	E. Bretscher, Harwell Application of atomic piles to experiments in nuclear physics
Donnerstag, 8. 9. 49	L. Rosenfeld, Manchester Stationary states of light nuclei
Freitag, 9. 9. 49	I. I. Rabi, Columbia University The intrinsic magnetic moment of the electron
	J. Schwinger, Harvard University Modern development of quantum electrodynamics

Several offers in US (in particular from Bethe, who hopes to have BP in Cornell)

Fall 1949 Edinburgh Conference on Elementary Particles

BP talk: “On the Decay products of the μ-meson



UNIVERSITY OF EDINBURGH

CONFERENCE ON ELEMENTARY PARTICLES.

in the Natural Philosophy Buildings, Drummond Street, Edinburgh.

MONDAY, 14th November:

Professor N. Feather	:	Experimental Evidence concerning the possible existence of the Negative Proton and the Di-Neutron.
Dr. D.H. Perkins	:	The Mechanism of Emission of Heavily-Charged Fragments in Nuclear Explosions.
Prof. L. LePrince-Ringuet	:	Effets Nucleaire de grand Energie dans le Rayonnement Cosmique.
Dr. J.G. Wilson	:	Some new measurements on the Nature of the Vertical Cosmic Ray Beam at Sea Level.

TUESDAY, 15th November:

~~Prof. W. Heisenberg~~	:	~~Die Erzeugung von Mesonen in~~ Vielfachprozessen.
Prof. L. Janossy	:	On the Production of Mesons by Nucleons.
Dr. B. Pontecorvo	:	On the Decay Products of the μ-Meson.
Prof. C.F. Powell	:	Observation bearing on the question of the existence of heavy charged mesons.

WEDNESDAY, 16th November:

Prof. F. Bopp	:	Title not fixed. Subject probably "Generalised Field Theories."
Prof. M. Born	:	General Theory of Elementary Particles.
Dr. K.C. Cheng	:	Reciprocity Theory of Electrodynamics
Prof. M. Fierz	:	Pauli's "Regularisation."
Prof. H.A. Kramers	:	Quantum Electrodynamics and Correspondence-Principle.

Bohr - Rosenfeld

The above is subject to additions. Detailed programmes for each day will be decided later.

The National Archives, London

1950:
moving to Russia
From cosmic rays to accelerators

1946 On the initiative of I. Kurchatov, the government of the Soviet Union took a decision to build, near the village of Novo-Ivankovo, a proton accelerator – the Synchrocyclotron – for an energy of 460 (later 680) MeV, launched by the end of 1949.
In the early 1950s, the Electrophysical Laboratory of the USSR Academy of Sciences (EFLAN) was established and work was started to construct a new accelerator with unique parameters at that time – the proton Synchrophasotron with an energy of 10 GeV. These activities were headed by V. Veksler.

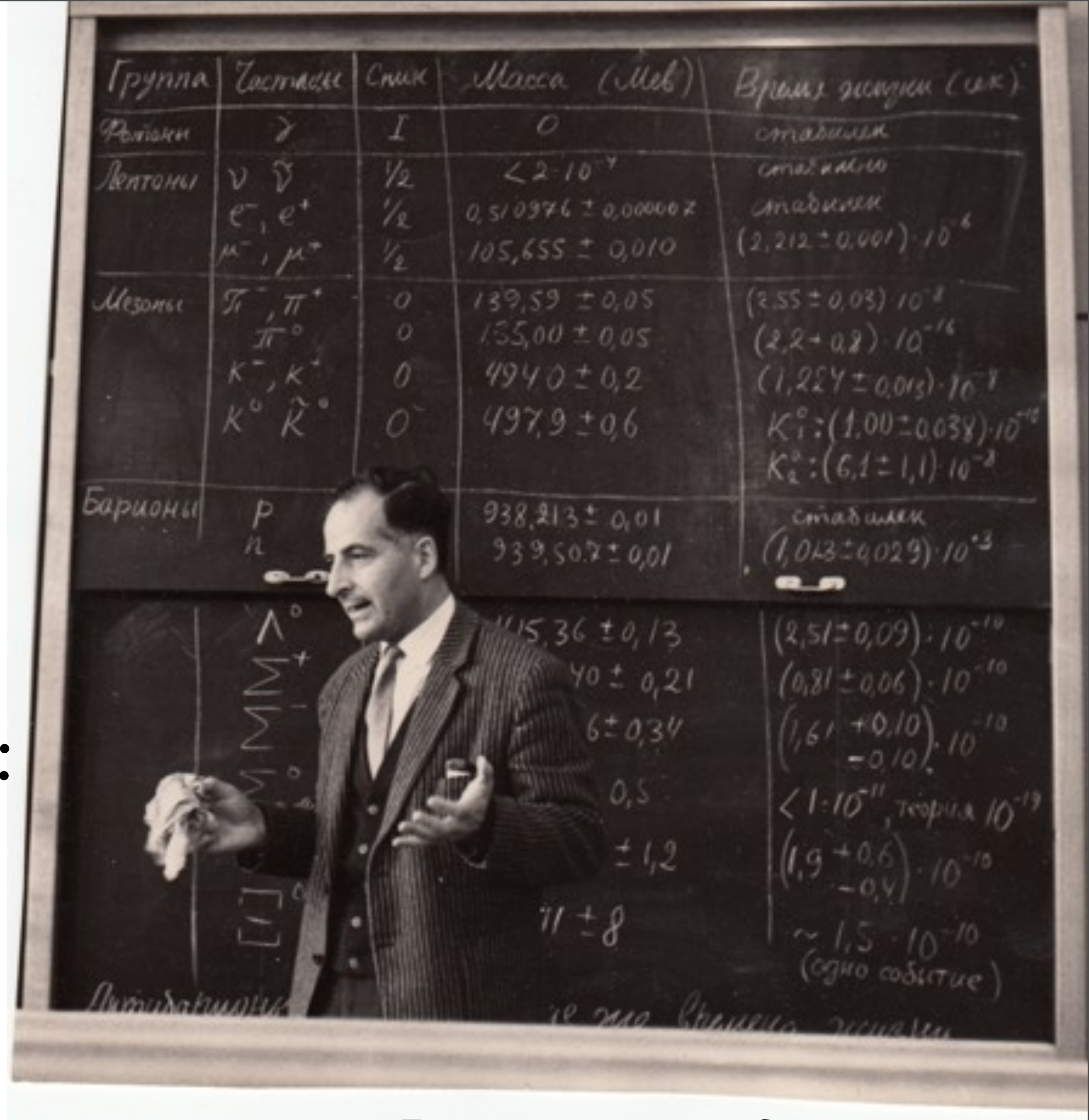
1954 CERN was established and a year and a half later, initiated by the government of the USSR, the East European block took a decision to establish the Joint Institute for Nuclear Research.
In 1956, the small scientific town of JINR together with the village of Bolshaya Volga was reorganized into a city which was christened as Dubna.

My political views are leftist. Originally, they were mainly due to my hate against the fascism and, I think now, the sense of justice instilled in me by my father. . ., political views dominated by a not logical category that now I call "religion", a kind of "fanatical belief...

According to his brother Gillo: "He believed that from the elimination of division in classes a new society would arise, funded on advanced laws and on human rights."
He had a real passion, a childish infatuation. At a certain time he listened to a radio where the Kremlin bells could be heard. he told to Luigi Radicati that if the 3rd world war would burst he did not want to be at west, he wanted to be in soviet union. Until 1956-57 he had believed in every word printed in Pravda. He had his first doubts after Kruschev's report..."

Letter from Fermi to senator McMahon in 1951: "Scientifically he is one of the brightest men with whom I have come in contact in my scientific career. I do not know of course what are the reasons that prompted his alleged escape to Russia. My personal impression of his research activities has been that he did not have much interest in the atomic developments except as a tool for scientific research.... he did not seem to have any special interest in atomic weapons. For these reasons my impression is that if he went to Russia he may not be able to contribute to their work by the things that he has learned during his connection with the Canadian and the English projects but rather through his general scientific competence"

Pontecorvo in Dubna during the 1950s



The saga of the strange particles

The associated production: Lambda+K

A new analogy:

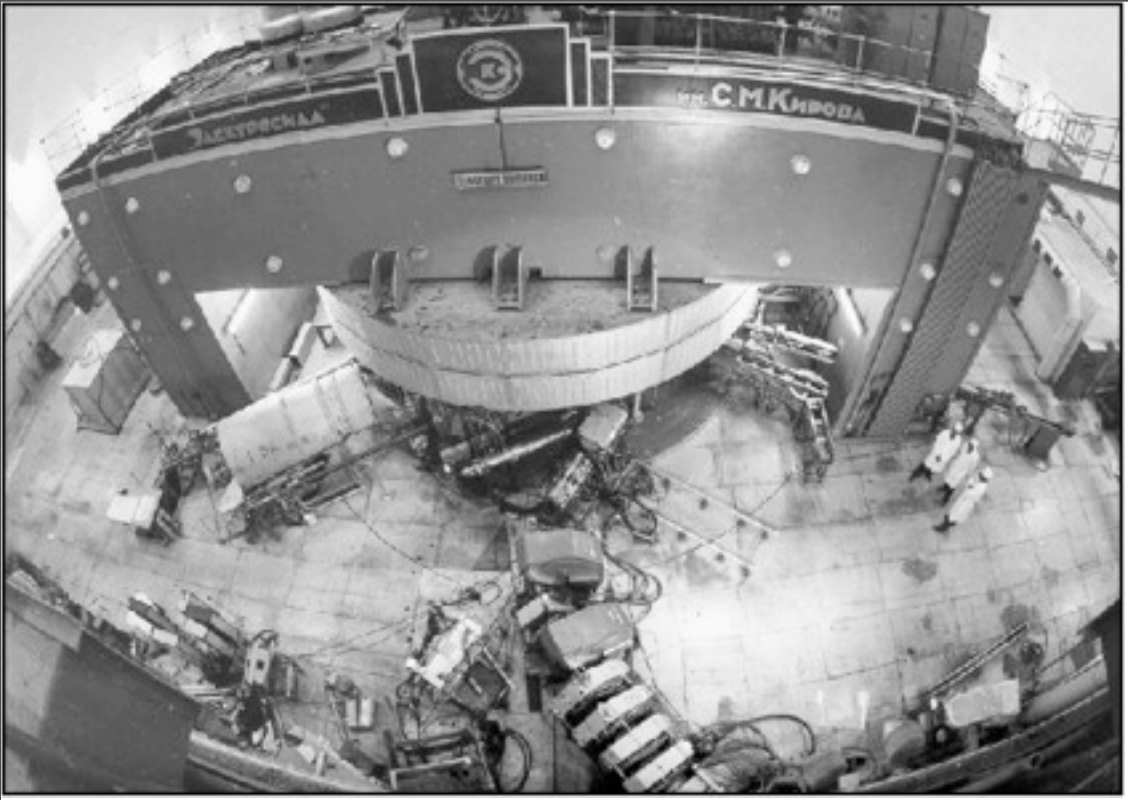
From *K^0 ↔ anti-K^0* oscillations

to

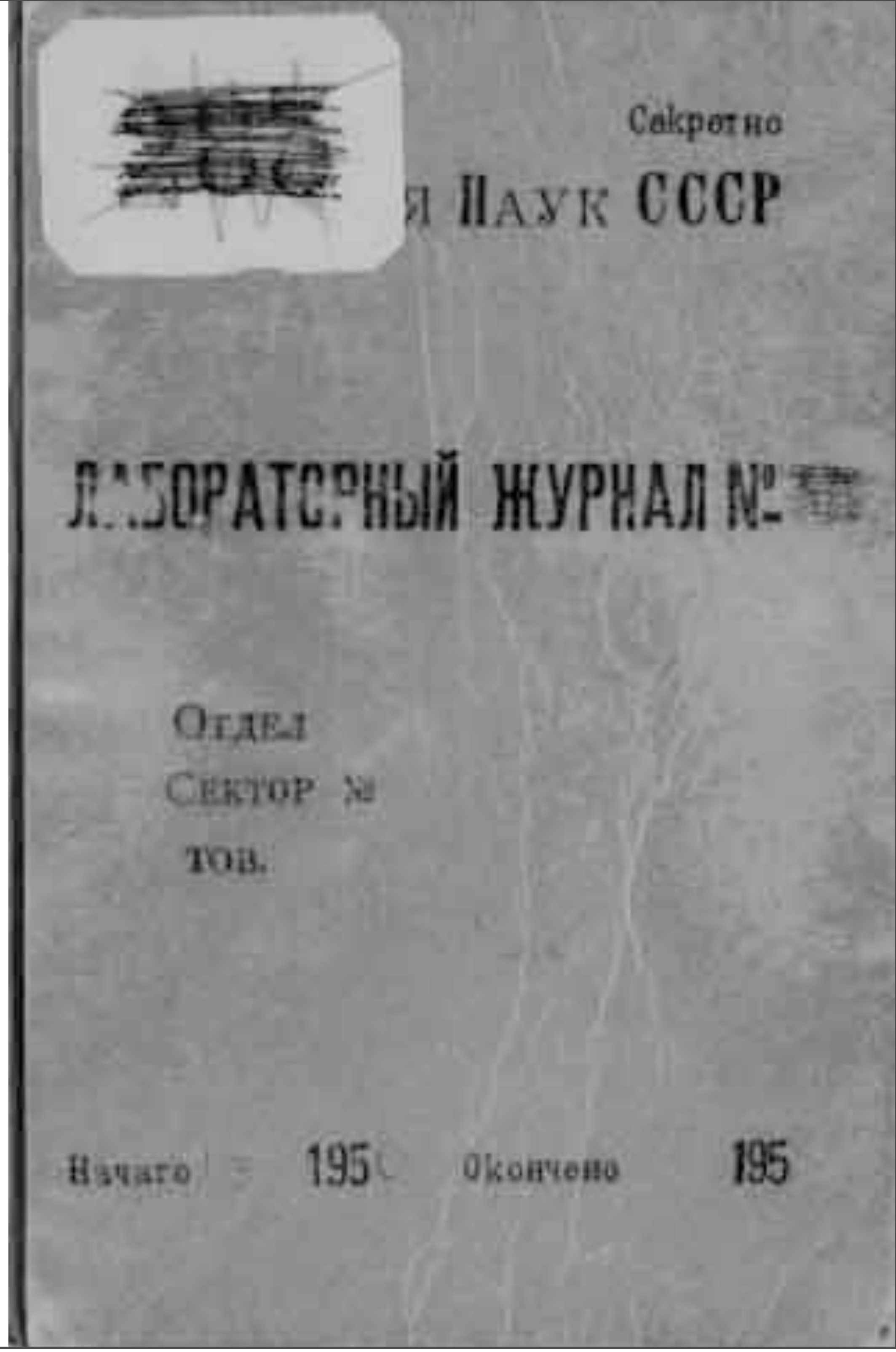
neutrino ↔ antineutrino oscillations

Prevision of solar neutrino deficit

ν_e different from ν_μ ?



Pontecorvo and his group performed experiments on the production of π^0 in neutron-proton and neutron-nuclei collisions, on pion-nucleon scattering.



Bruno Pontecorvo, Dubna
Notebook 1
Beginning November 1, 1950

Courtesy of Gil Pontecorvo

In September 1951, Pontecorvo is already the leader of a group of young researchers, and has a clear view of the research programs to be carried on.

In 1951 a 450 MeV synchrocyclotron came into operation in Chicago. Fermi's discovery of the (3/2, 3/2) resonance confirmed the conservation of isotopic spin in the strong interactions and was actually the first evidence of an excited state of the nucleon and the first indication of the sub-structure of the nucleon.

November 1950

The associated production of kaons and hyperons

There is a contradiction between the existence of a strong interacting particle and his long lifetime. This contradiction, of course , is resolved if the strongly interacting particle is produced in pair.

"Indipendentemente da altri autori, notai l'apparente contraddizione tra l'alta probabilità di generazione mella radiazione cosmica di certe particelle (oggi dette strane) e la bassa probabilità del loro decadimento.
Per risolvere la contraddizione, indipendentemente da PAIS, formulai la legge di produzione associata dei kaoni insieme con gli iperoni" B. P. in Mafai, *The long cold*

The results of all experiments carried on by Bruno Maximovich Pontecorvo with his group of young researchers in the period 1951-1954 at the five-meter synchrocyclotron were published as internal reports in Russian, some of those were also published later in 1955.

1955, in full cold war, the *Atoms for Peace Conference* is held in Geneva from August 8

Although the first research instrument was built at Dubna in 1947, it was not until the creation of CERN in 1954 that a countervailing group from the West was created, JINR.

The agreement on the establishment of JINR was signed on March 26, 1956 in Moscows.

In 1949 he wrote to Edoardo Amaldi about his work, talking of his hope of revealing the neutrino. End of 1951 Pontecorvo is still thinking and hoping about revealing the neutrino as one can deduce by his Dubna Notebook

1950s Cowans and Reines detect free neutrino through inverse beta decay at reactor.

The 1995 Nobel Prize in Physics was awarded to Reines

Howeer, as recalled by S.S.Gershtein, in the Recollections on B. Pontecorvo, Collected Works of BP: "...He was not granted access to any reactor".

Pontecorvo was impressed by a possibility of $K^0 \leftrightarrow$ *anti*-K^0 oscillations suggested by Gell-Mann and Pais.

The first proposal of an analogy with this process can be found in a paper of 1957 "Mesonium and antimesonium":

"We discuss here the problem as to whether there exist other mixed neutral particles (not necessarily elementary ones) (besides the K^0-mesons) which are not identical to the corresponding antiparticles and for which the particle-antiparticle transitions are not strictly forbidden... if the conservation law for neutrino charge took no place, neutrino-antineutrino transitions in vacuum would be in principle possible."

In 1958, in a new paper, he pointed out that in reactor experiments a deficit of antineutrino events would be observed "due to the fact that the neutral lepton beam which at the source is capable of inducing the reaction antineutrino+p$\rightarrow$e$^+$+n changes its composition on the way from the reactor to the detector."

In the meantime Ray Davis had picked up the idea of the radiochemical method and since 1954 began to try revealing neutrinos from a reactor. Between 1956-1957 rumours reached Pontecorvo that Davis had observed such event. He suggested that these events could be due to transitions of reactor antineutrinos into right-handed neutrinos on the way from the reactor to the detector and published a first paper dedicated to neutrino oscillations (1958).

Davis upgraded his experiment and his results published in 1958, together with Cowans and Reines' represented the first demonstration that antineutrinos (reactor neutrinos) are different particles from neutrinos.

From 1957 to 1967, in several papers Pontecorvo anticipated more than ten years in advance the phenomenon of the deficit of the solar neutrinos.

And only in 1967, 21 years after the original Pontecorvo proposal, R. Davis used the radiochemical method to detect the neutrinos emitted by the sun with a giant tank located in the Homestake mine in South Dakota, thus showing a **deficit** in the predicted solar neutrino flux.

Raymond Davis and Masatoshi Koshiba were awarded the Nobel Prize in Physics 2002 for having revealed neutrinos from cosmic sources opening the era of neutrino astronomy.

At the end of 1950s a meson factory was being planned in Dubna, which unfortunately was not realized. In connection with this project, Pontecorvo thought about the feasibility of neutrino experiments with neutrinos from decays of pions and kaons produced at high intensity accelerators.

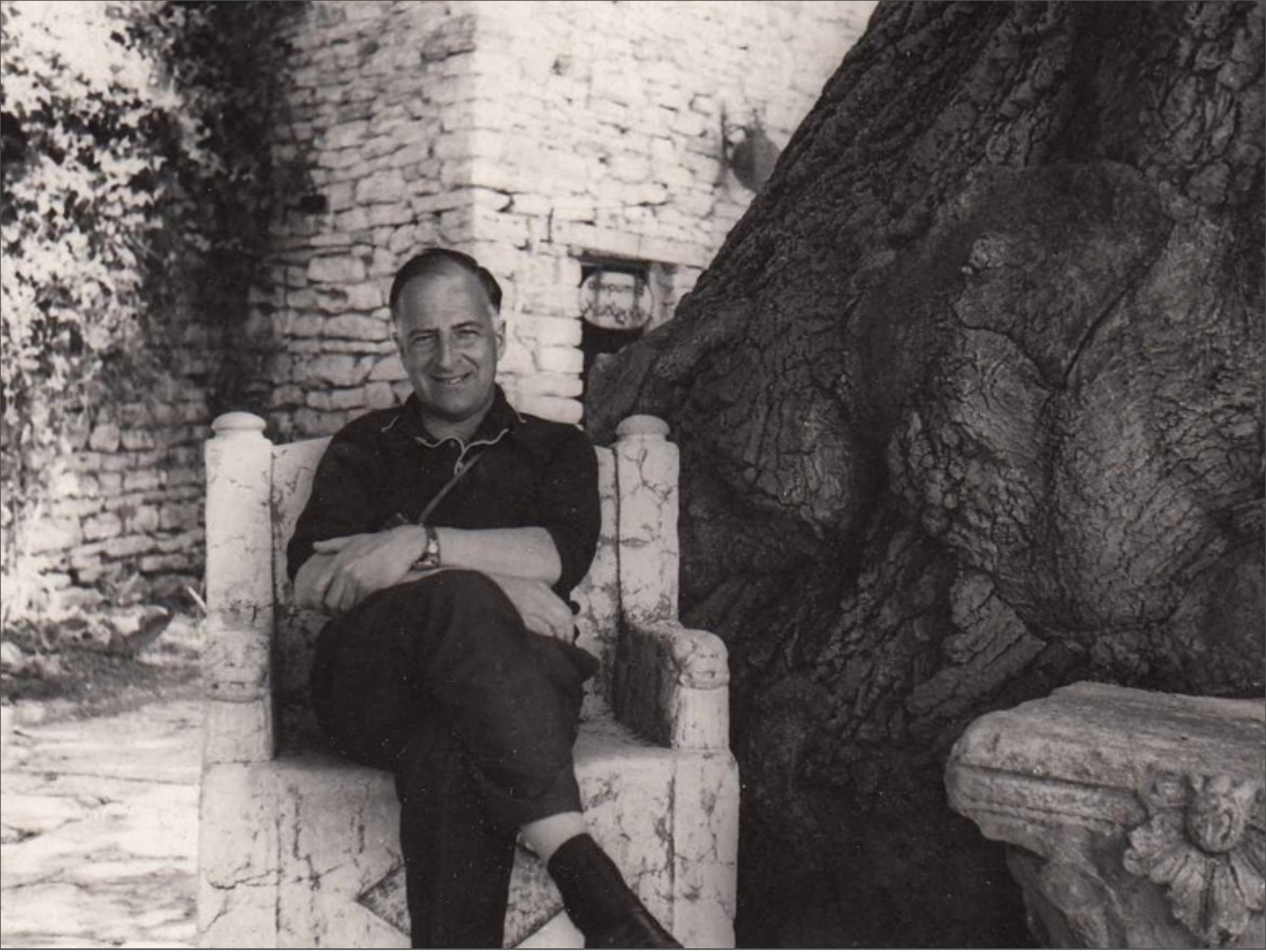
In 1959, at the Kiev Conference, he expressed the idea that such experiments with high energy accelerators could answer a fundamental question: Is ν_e different from ν_μ?

In 1969 Pontecorvo and V. Gribov write the equations of the oscillations $\nu_e \leftrightarrow \nu_\mu$

In 1962 the famous Brookhaven neutrino experiment proved that ν_e is different from ν_μ

In 1988 Lederman, Schwartz and Steinberger were awarded the Nobel Prize in Physics for the discovery of the muon neutrino, leading to classification of particles in families

martedì 14 gennaio 2014



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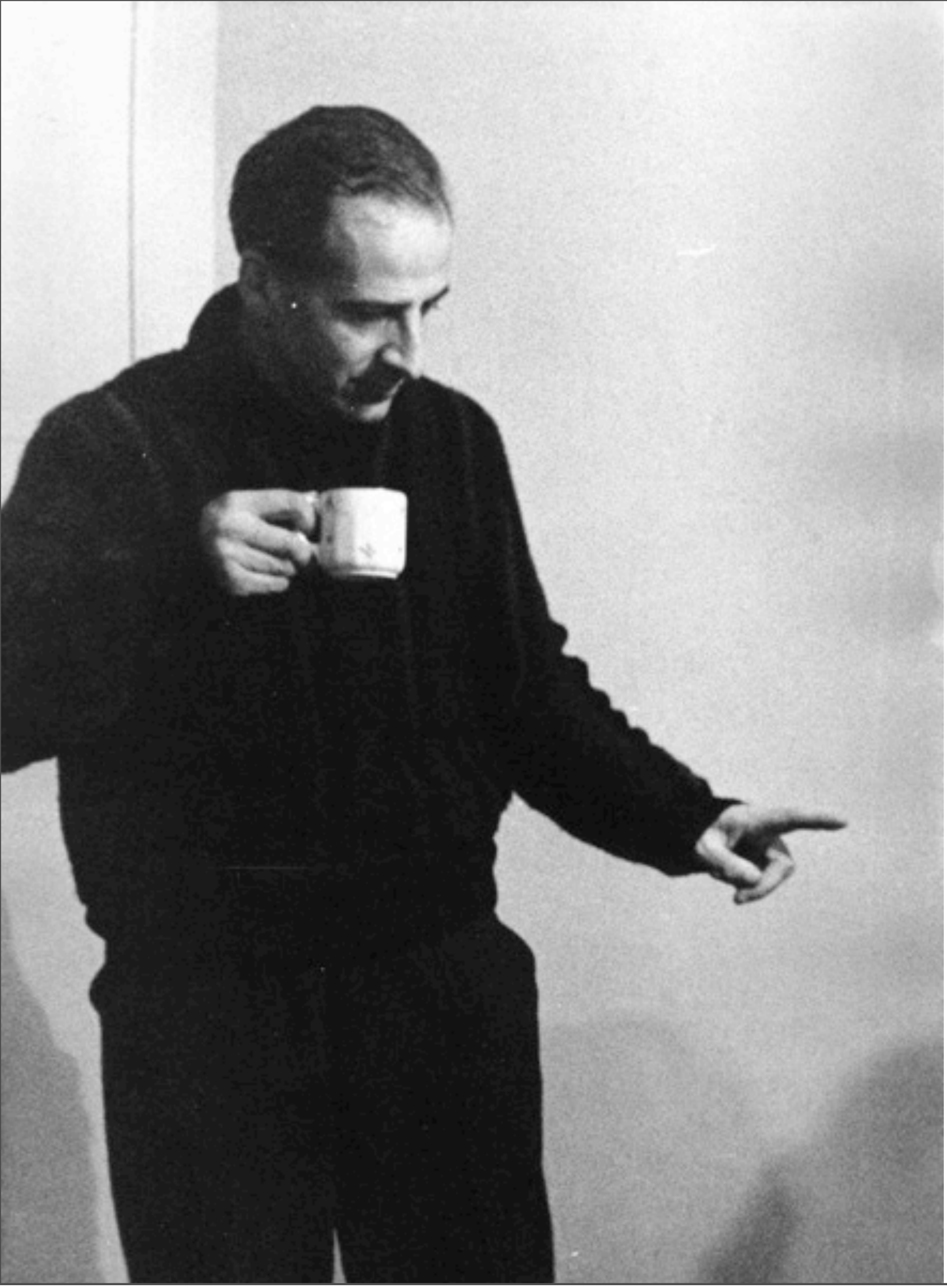

Pontecorvo considered Russia his second homeland.

Nevertheless, Italy was always in his dreams:

"In 1978, in connection with the 70th anniversary of Edoardo Amaldi, I returned to Italy for several days after 20 long years of absence. I have no words to express the emotion I experienced when I was in front of the Physics Institute of Fermi, Amaldi, Rasetti and Segrè. Subsequently I travelled Italy practically every year and for much longer time... to my great shame, for the first time, at the age of 65, I was astounded by the beauty of small Italian towns.

"*Because, according to my opinion, who wants to discover something, must use imagination, and play with inventiveness and guess...*"

Galileo Galilei (1590)

"*I want to express once and for all, my deep respect for the work of the experimenter and for his fight to wring significant facts from an inflexible Nature, who says so distinctly 'No' and so indistinctly 'Yes' to our theories.*"

Hermann Weyl (1932)