ENRICO FERMI
AND THE BEGINNING OF NUCLEAR PHYSICS

Joint EPS-SIF International School on Energy – Varenna – 26 July 2017



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Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi

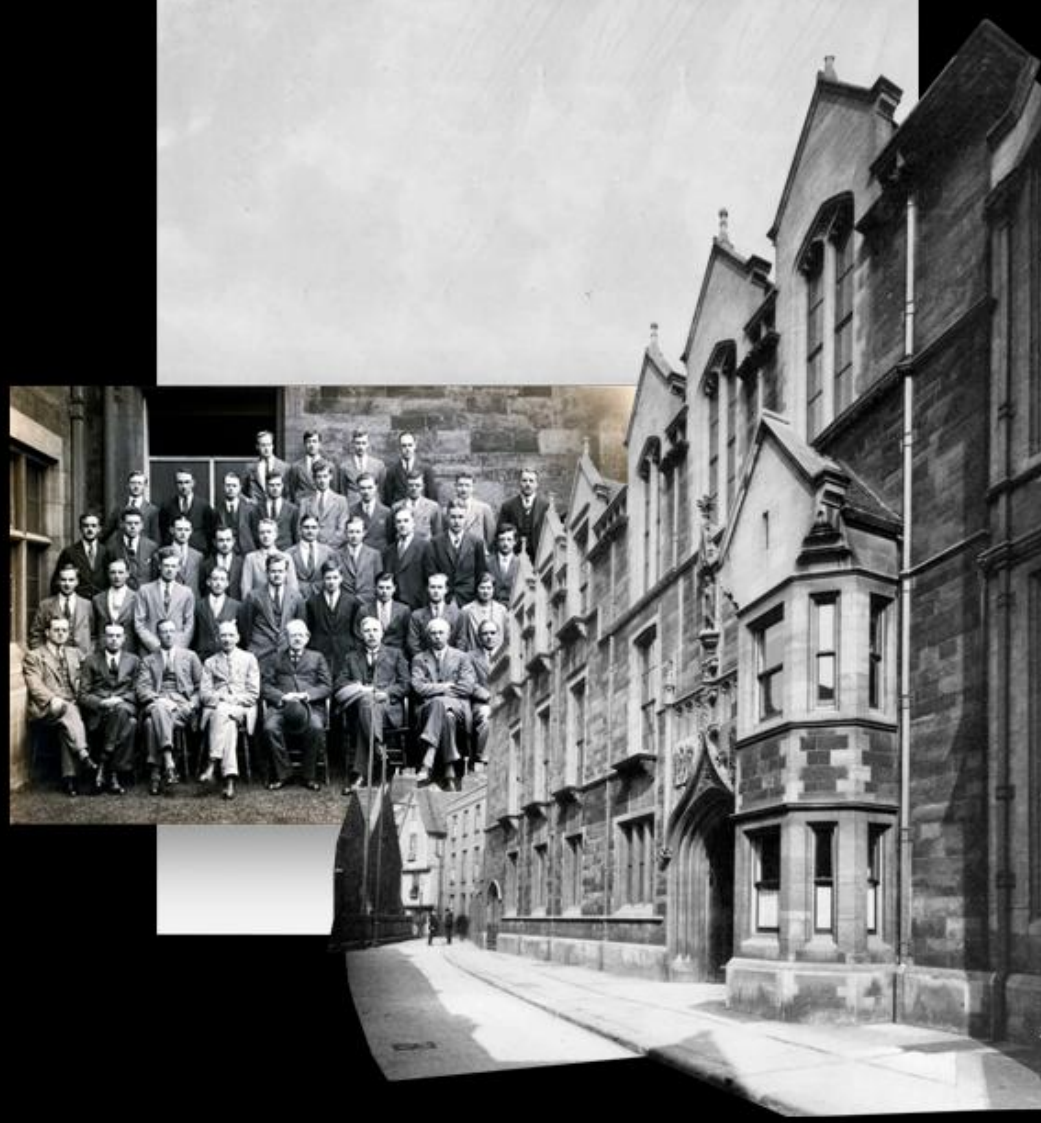
GALILEI

NEWTON

MAXWELL

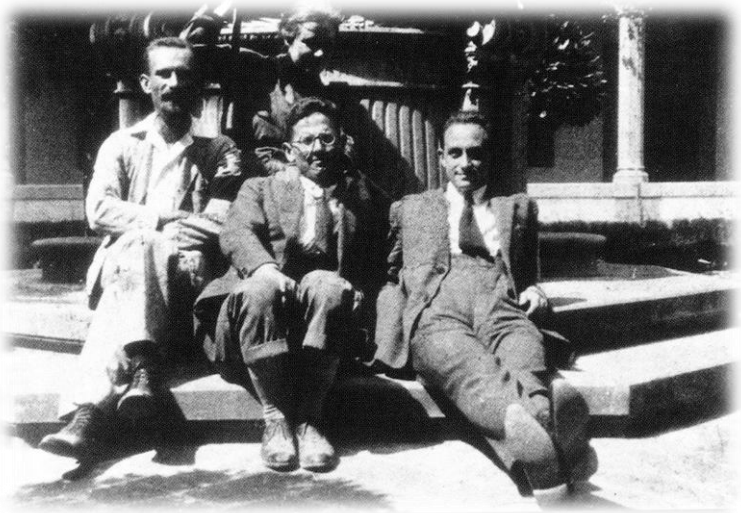
FERMI

How and where it all began …
at the Physics Institute of Via Panisperna in Rome

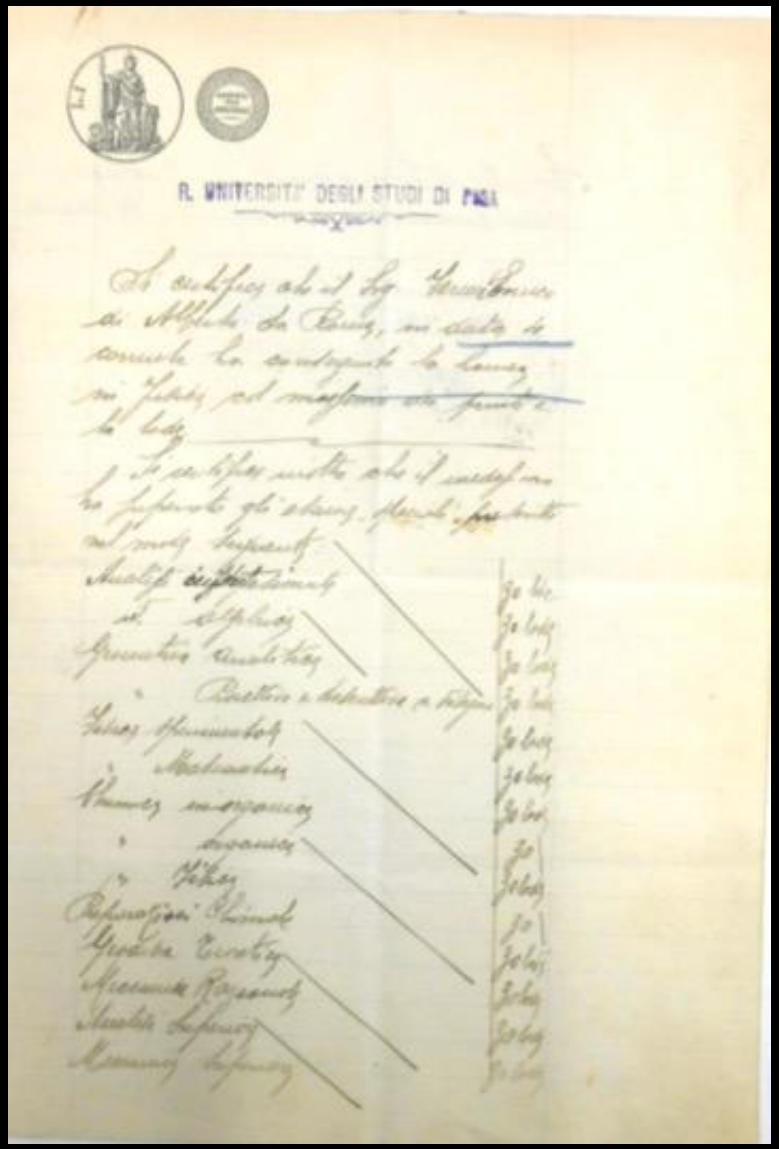


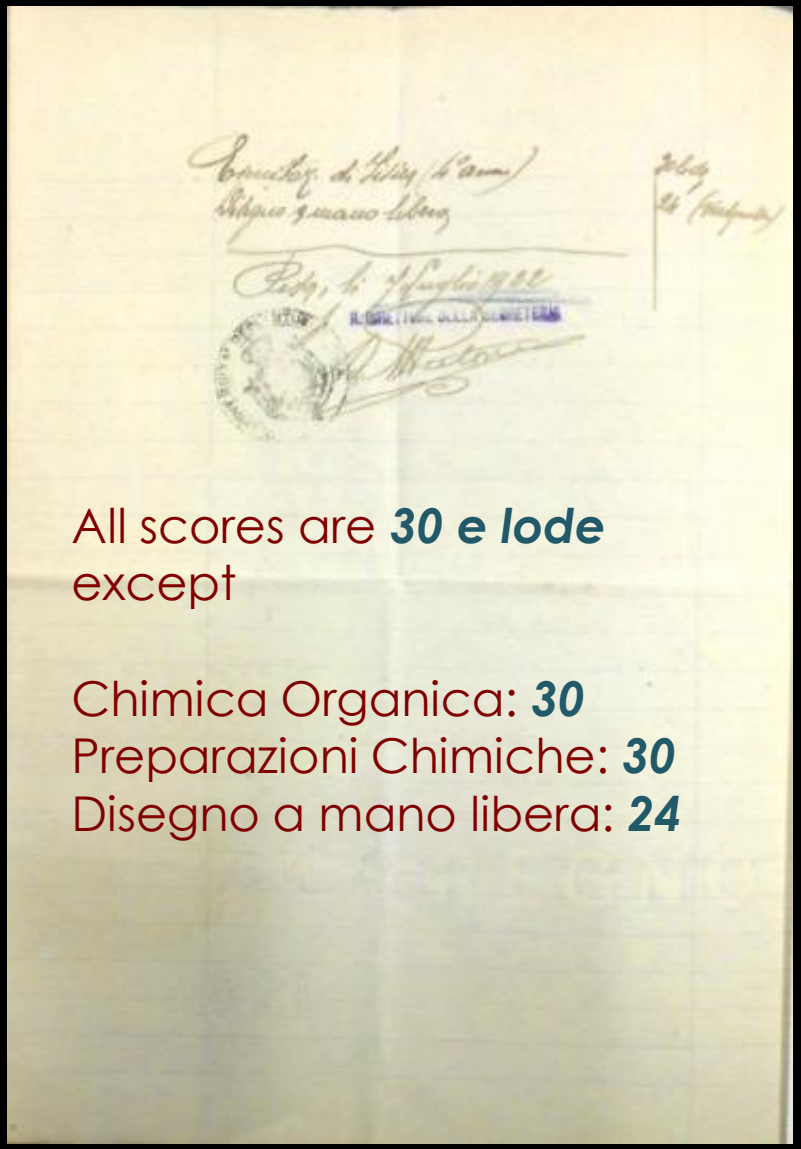
The Physics Institute
of Via Panisperna
in Rome
was built in 1877-1880
by Pietro Blaserna
inspired by foreign scientific institutes
such as the Cavendish Laboratory in Cambridge

- Enrico Fermi was born in Rome in 1901
- He obtained in 1922 his diploma from the *Scuola Normale Superiore* of Pisa
- He was immediately attracted to quantum physics which at the time was not well known in Italy: he spent periods abroad in Göttingen (Max Born) and Leiden (Paul Ehrenfest) in 1923-1924
- In 1924-1926 Fermi was visiting professor of Mathematical Physics at the University of Florence



- In 1926 he obtained the first chair of Theoretical Physics in Italy, specially created for him at the University of Rome by Orso Mario Corbino





All scores are ***30 e lode*** except

Chimica Organica: ***30***
Preparazioni Chimiche: ***30***
Disegno a mano libera: ***24***

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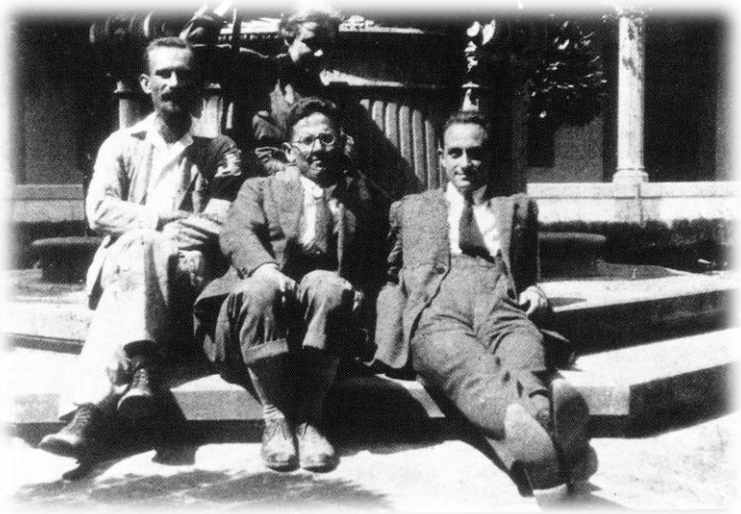
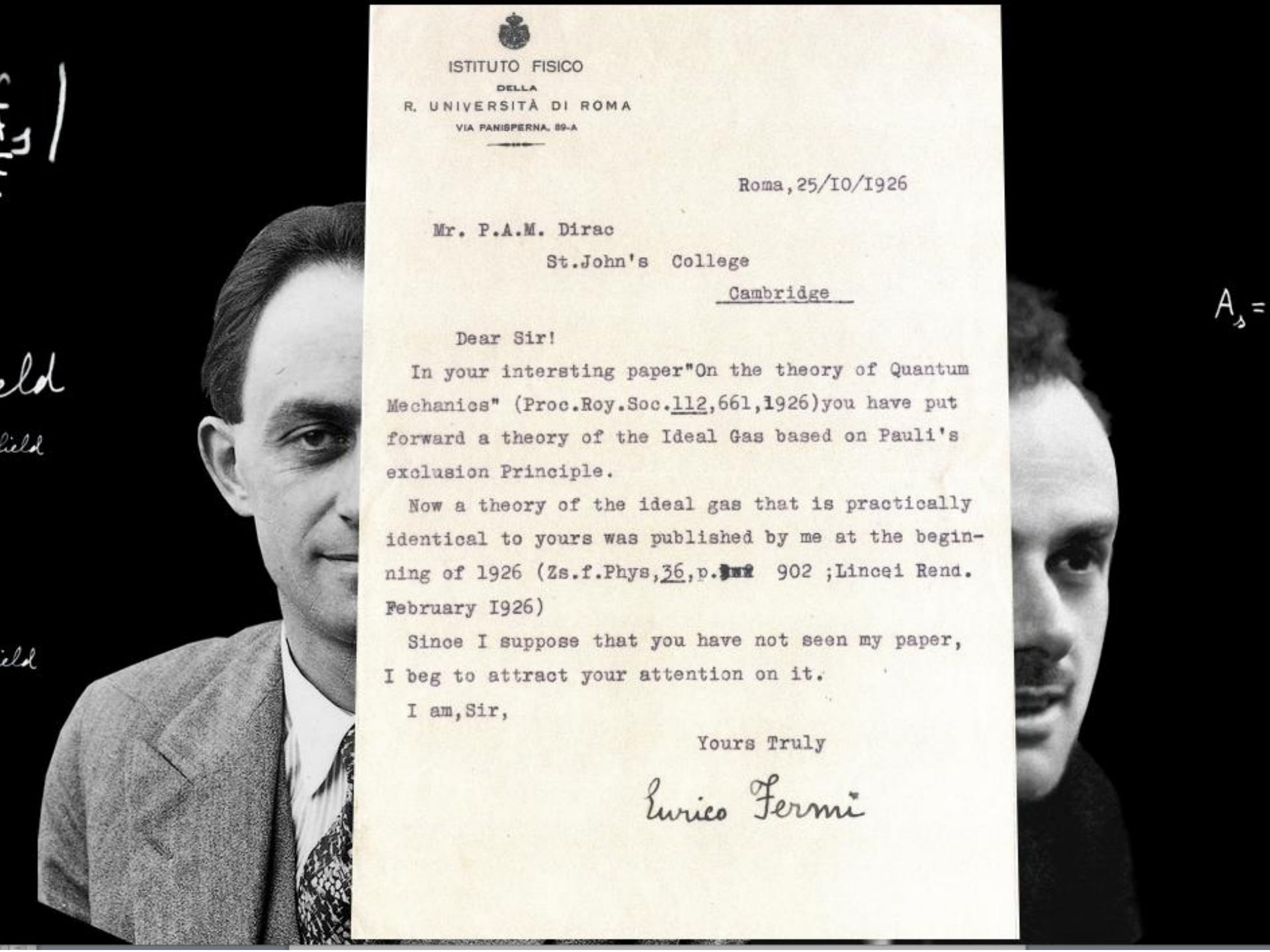


- In 1926 he obtained the first chair of Theoretical Physics in Italy, specially created for him at the University of Rome by Orso Mario Corbino

- In 1926, while still very young, Fermi formulated a new statistical theory to describe the collective behaviour of particles on the quantum scale, known today as Fermi-Dirac statistics

  → The exclusion principle introduced by Pauli in 1925 to explain the electronic structure of atoms was transformed into a universal principle

  → It is the first great theoretical success of Fermi



ISTITUTO FISICO
DELLA
R. UNIVERSITÀ DI ROMA
VIA PANISPERNA, 89-A

Roma, 25/IO/1926

Mr. P.A.M. Dirac
St.John's College
Cambridge

Dear Sir!

In your intersting paper"On the theory of Quantum Mechanics" (Proc.Roy.Soc.112,661,1926)you have put forward a theory of the Ideal Gas based on Pauli's exclusion Principle.

Now a theory of the ideal gas that is practically identical to yours was published by me at the beginning of 1926 (Zs.f.Phys,36,p. 902 ;Lincei Rend. February 1926)

Since I suppose that you have not seen my paper, I beg to attract your attention on it.

I am,Sir,

Yours Truly

Enrico Fermi

- In 1926, while still very young, Fermi formulated a new statistical theory to describe the collective behaviour of particles on the quantum scale, known today as Fermi-Dirac statistics

  → The exclusion principle introduced by Pauli in 1925 to explain the electronic structure of atoms was transformed into a universal principle

  → It is the first great theoretical success of Fermi

- In 1927 formulation of the Thomas-Fermi statistical atomic model

- In 1928-1932 several contributions of Fermi in Quantum Electrodynamics

- In 1929 first interest of Fermi in nuclear physics as supervisor of Ettore Majorana's thesis on "The Mechanics of Radioactive Nuclei" (alpha decays)

- In 1931 the first International Congress of Nuclear Physics took place in Rome, in the Via Panisperna building

  - About 50 eminent Italian and foreign scientists were invited
  - Enrico Fermi was Secretary General of the Congress, Bruno Rossi, Gleb Watagin and Antonio Carrelli were Secretaries
  - Guglielmo Marconi (Nobel Prize, Senator and CNR President) was Honorary President
  - Orso Mario Corbino (Director of the Physics Institute and Senator; former Minister for Education and Economy) was President

PHOTOGRAPH OF THE FIRST INTERNATIONAL CONGRESS OF NUCLEAR PHYSICS PHYSICS INSTITUTE, ROME, 1931

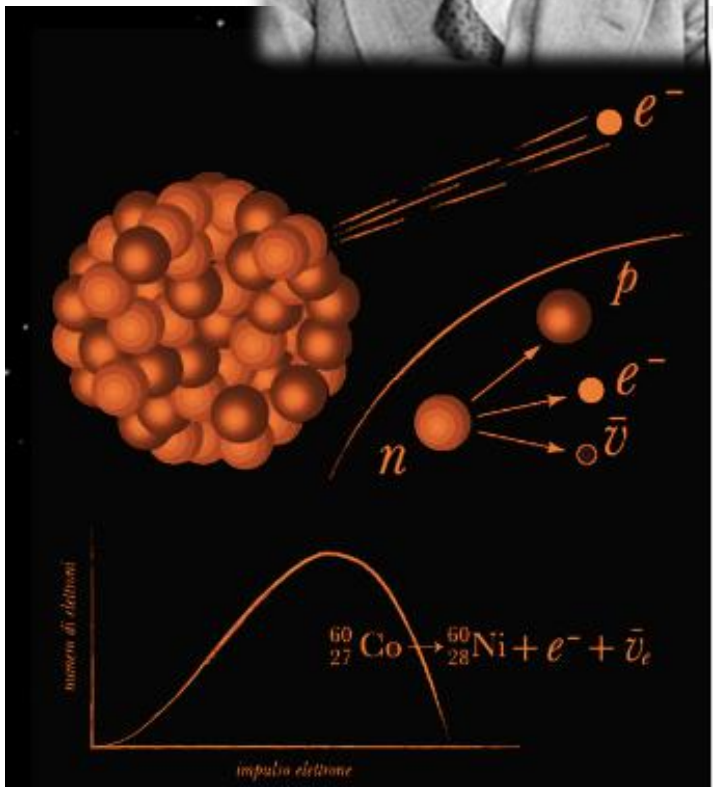
In 1932:

- Alpha, beta, gamma natural radioactivity known
- Neutron (Chadwick, 1932) discovered
- Positron (Anderson, 1932) discovered
- Nuclear model with protons & neutrons attempted (Heisenberg and Majorana)

… but mystery of beta decay

- Electrons confined in the nucleus then emitted?
- Energy non conservation?

Hypothesis of Pauli of an "invisible" and light neutral particle that would explain the energy & momentum conservation violation



In 1933 *coup de génie* of Fermi

→ beta radiation theory

with electron and (anti)neutrino non existing in the nucleus but simultaneously created in the decay

→ New type of interaction: nuclear weak interaction

(Name of "*neutrino*" by Fermi)

- In the 30s Fermi "*superstar*" in theoretical physics
  → but strongly and more&more attracted by nuclear physics

- In 1934 Joliot-Curie discovered artificial radioactivity
  induced by alpha particles

  → The dual genius of Fermi showed up:
  after theories … experiments
  and Fermi's *début*
  in experimental research

- Fermi's idea: use neutrons instead, smaller and more penetrating than alpha particles

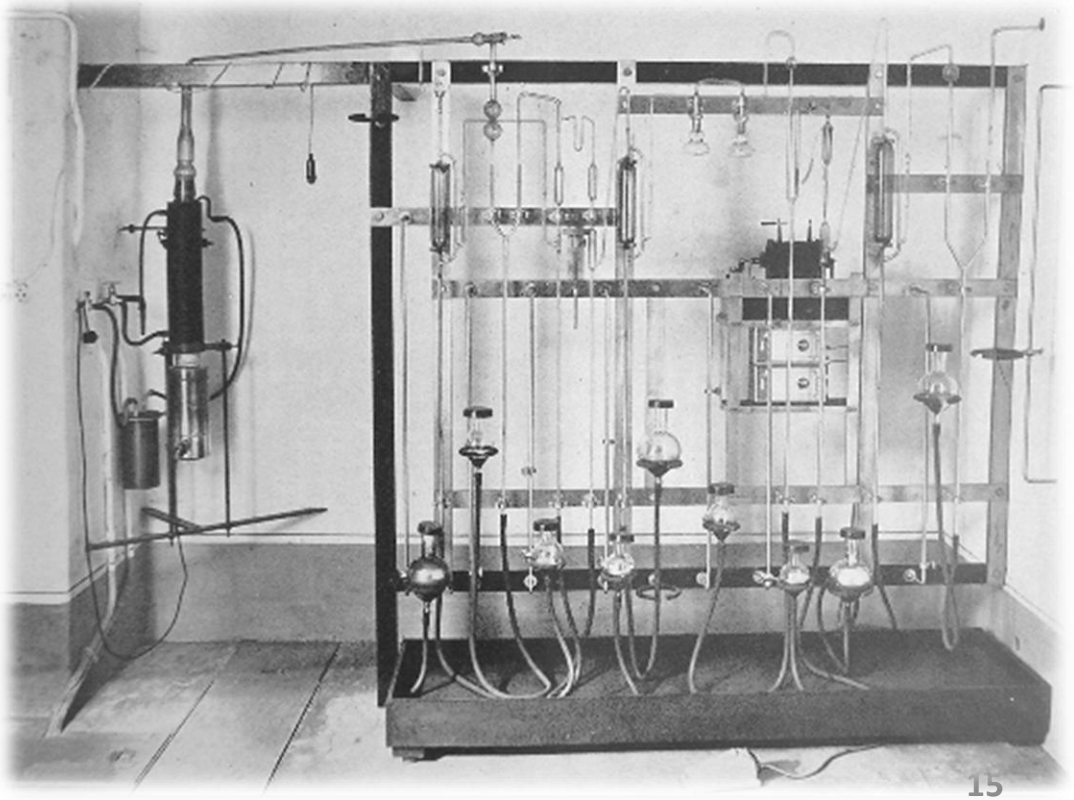
- How to get neutron sources?

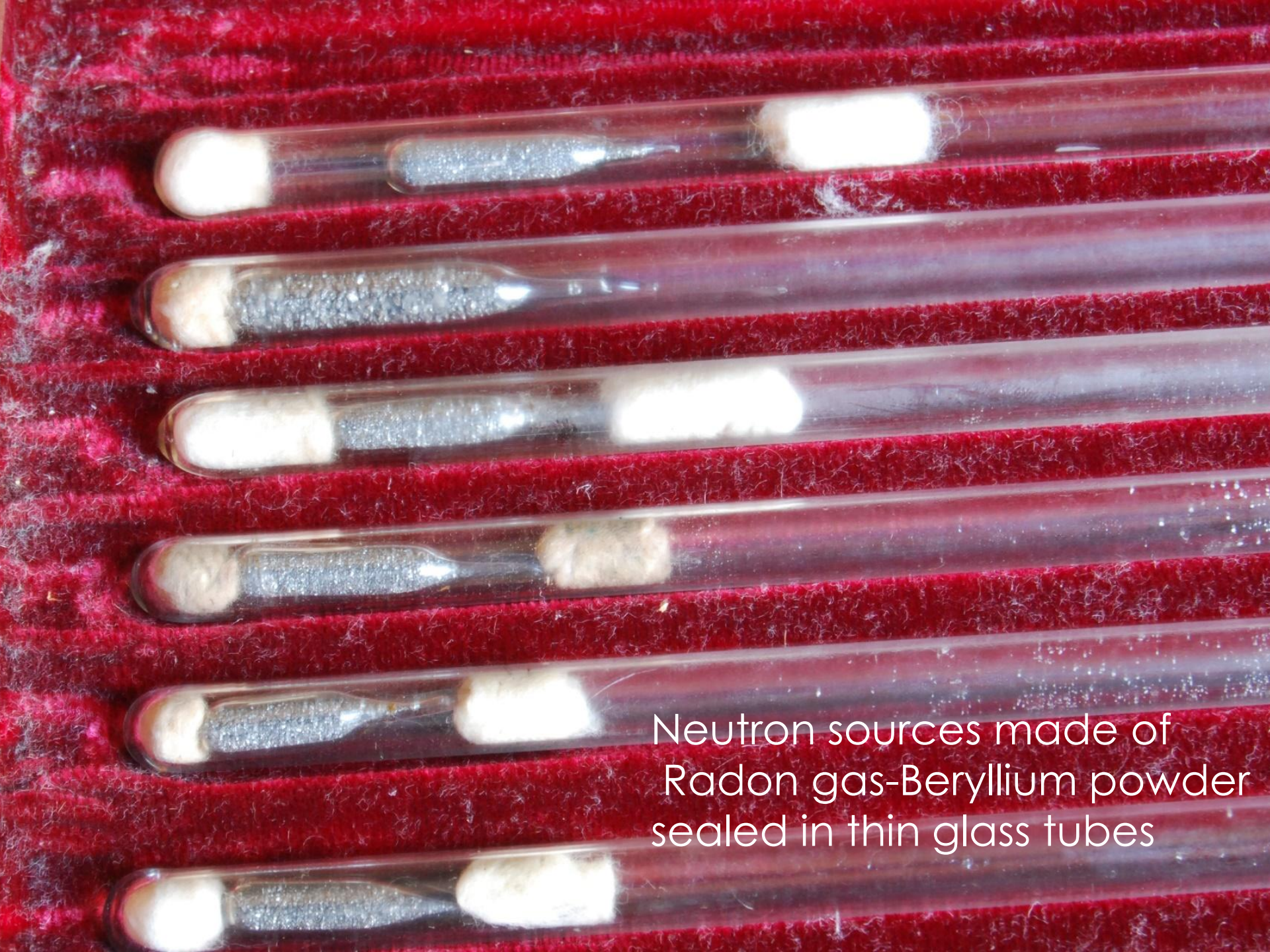
- Neutron sources made of Radon gas-Beryllium powder sealed in thin glass tubes

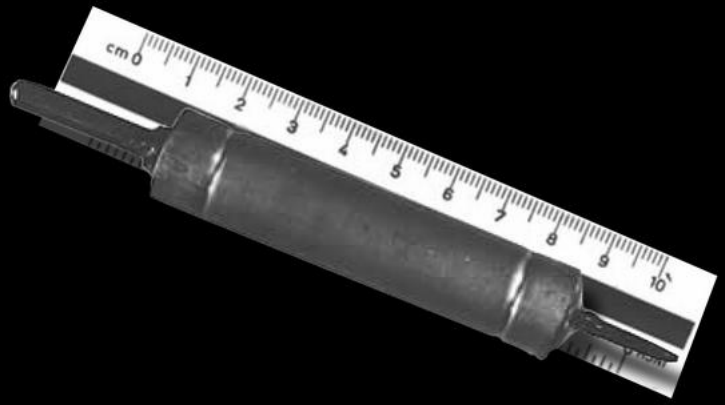
- Radon produced using Radium from the Institute of Public Health ISP in Rome (G.C. Trabacchi)

- Low intensity & short lifetime of neutron sources

→ Simple but ingenious experimental procedures & equipment




Neutron sources made of
Radon gas-Beryllium powder
sealed in thin glass tubes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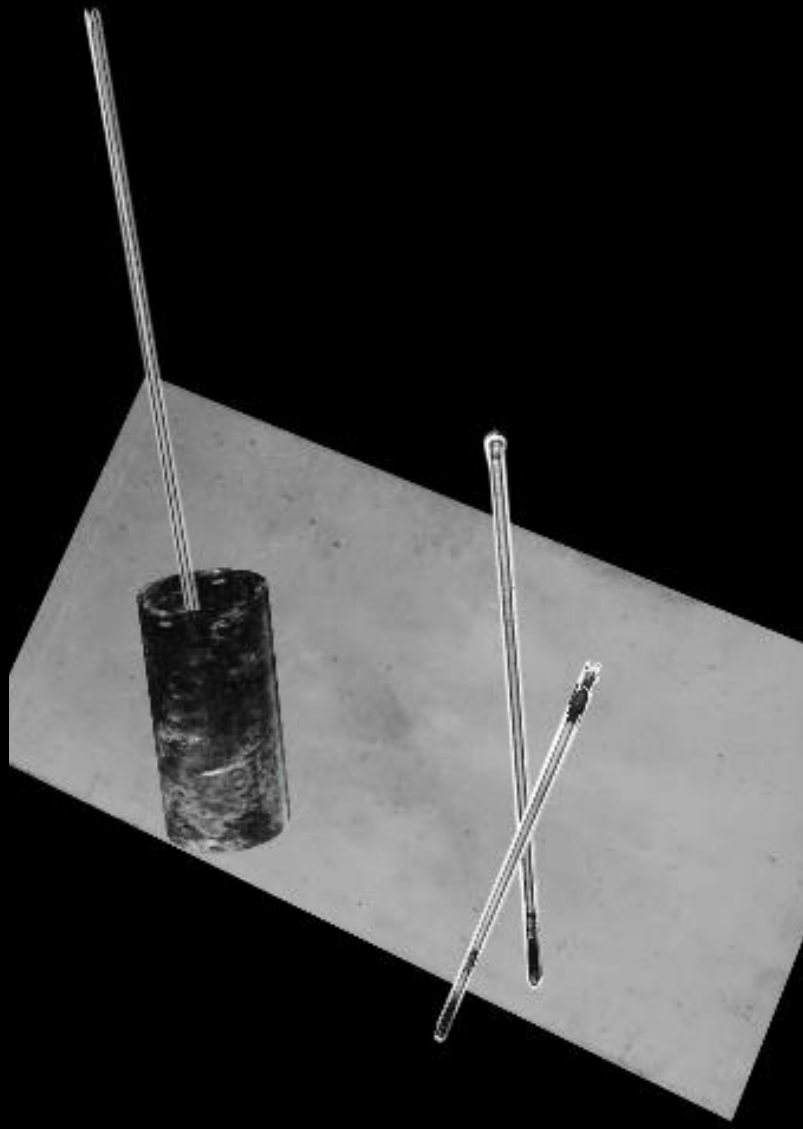


O. D'Agostino, E. Segrè, E. Amaldi, F. Rasetti, E. Fermi
plus B. Pontecorvo (the photographer)
and E. Majorana

"*I ragazzi di Via Panisperna*"
according to O.M. Corbino

Oscar D'Agostino
(1901-1975)

Franco Rasetti
(1901-2001)

Emilio Segrè
(1905-1989)

Ettore Majorana
(1906-1938 (?))

Edoardo Amaldi
(1908-1989)

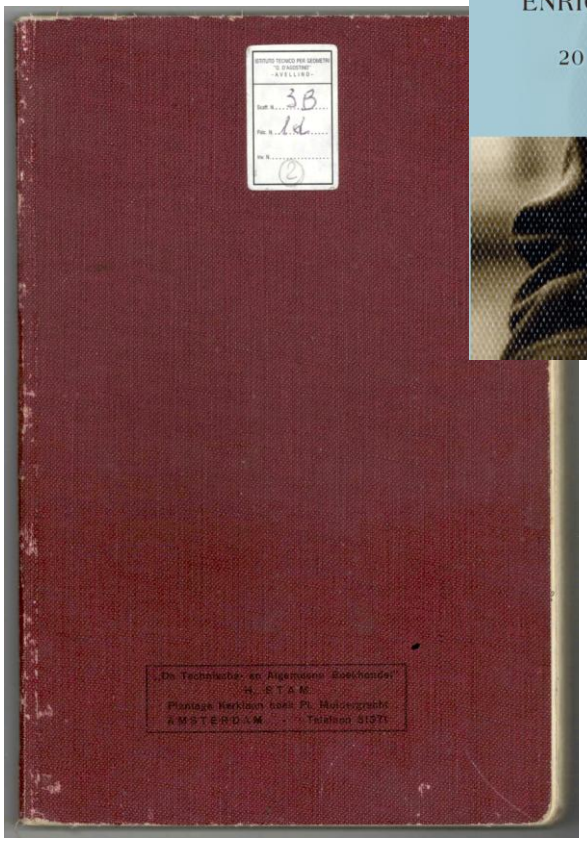
Enrico Fermi
(1901-1954)

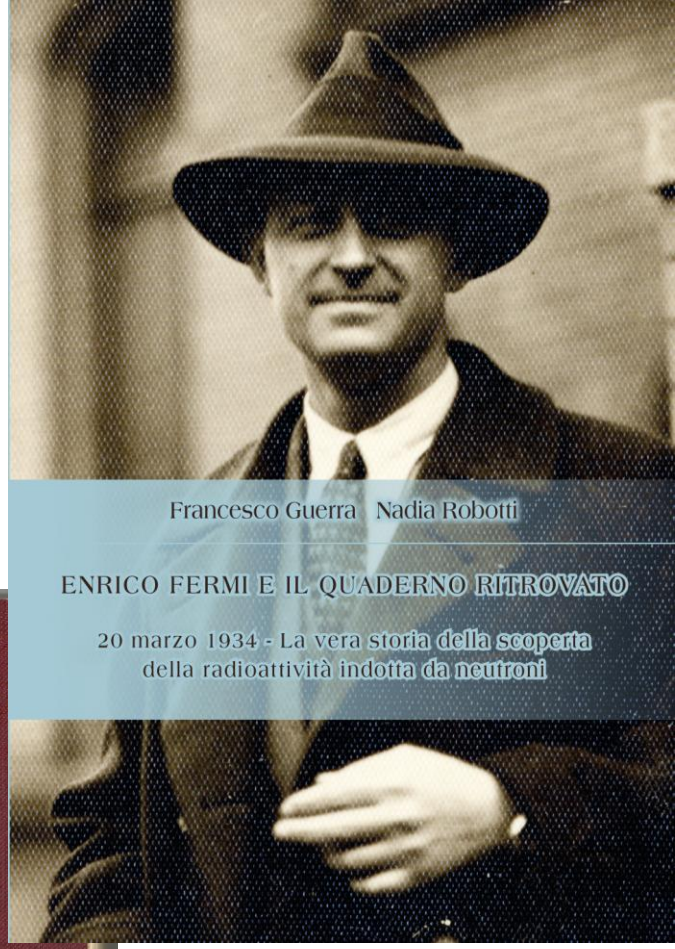
Bruno Pontecorvo
(1913-1993)

- March 1934

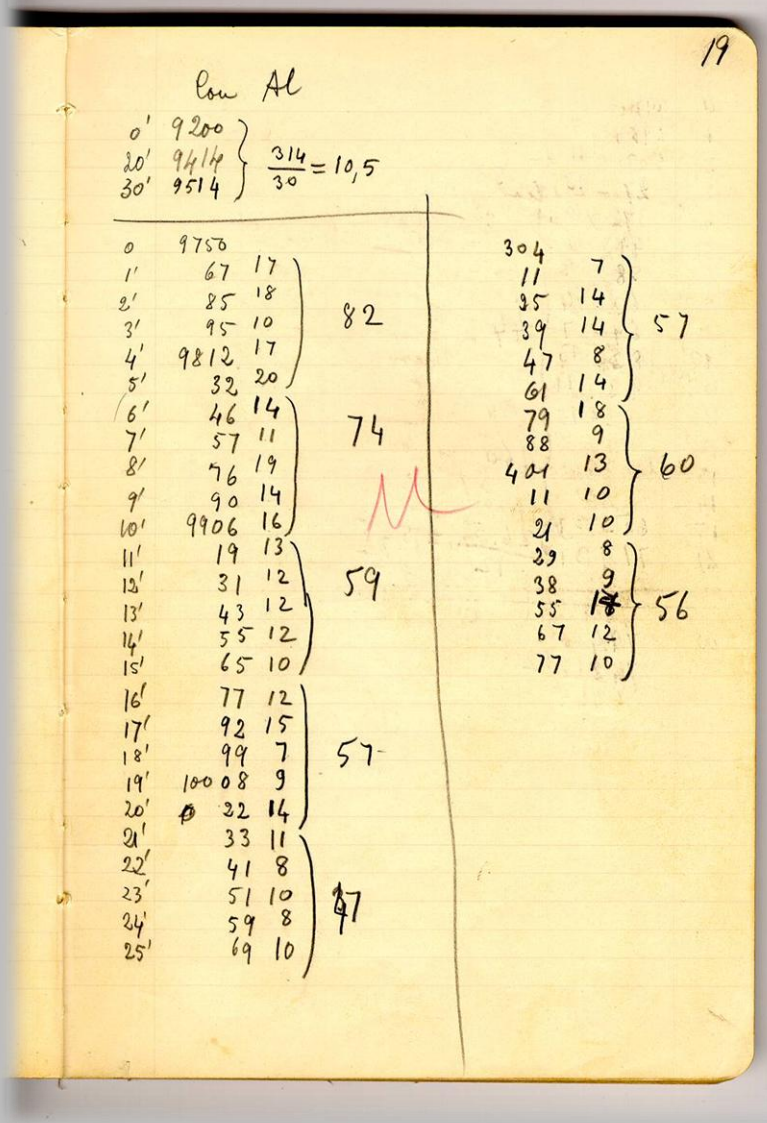
Discovery of the neutron-induced beta radioactivity of Alluminium, then of Fluorine (Calcium fluoride CaF_2)

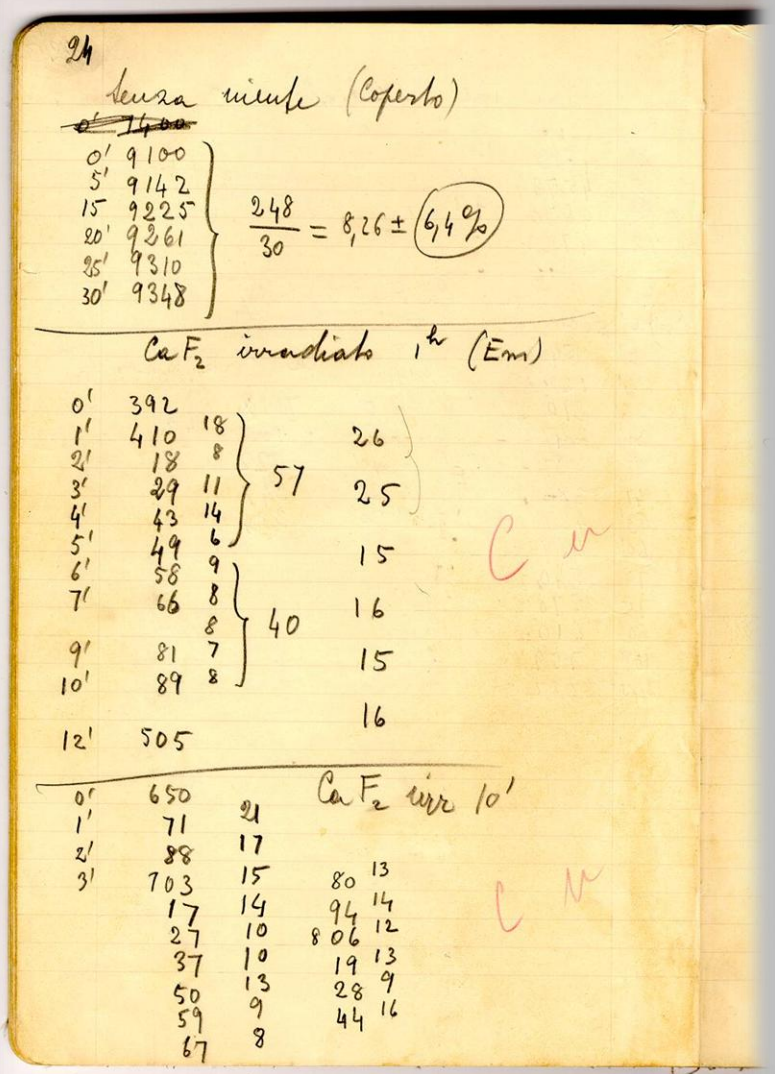
Documented in a logbook recently discovered in Avellino in 2002





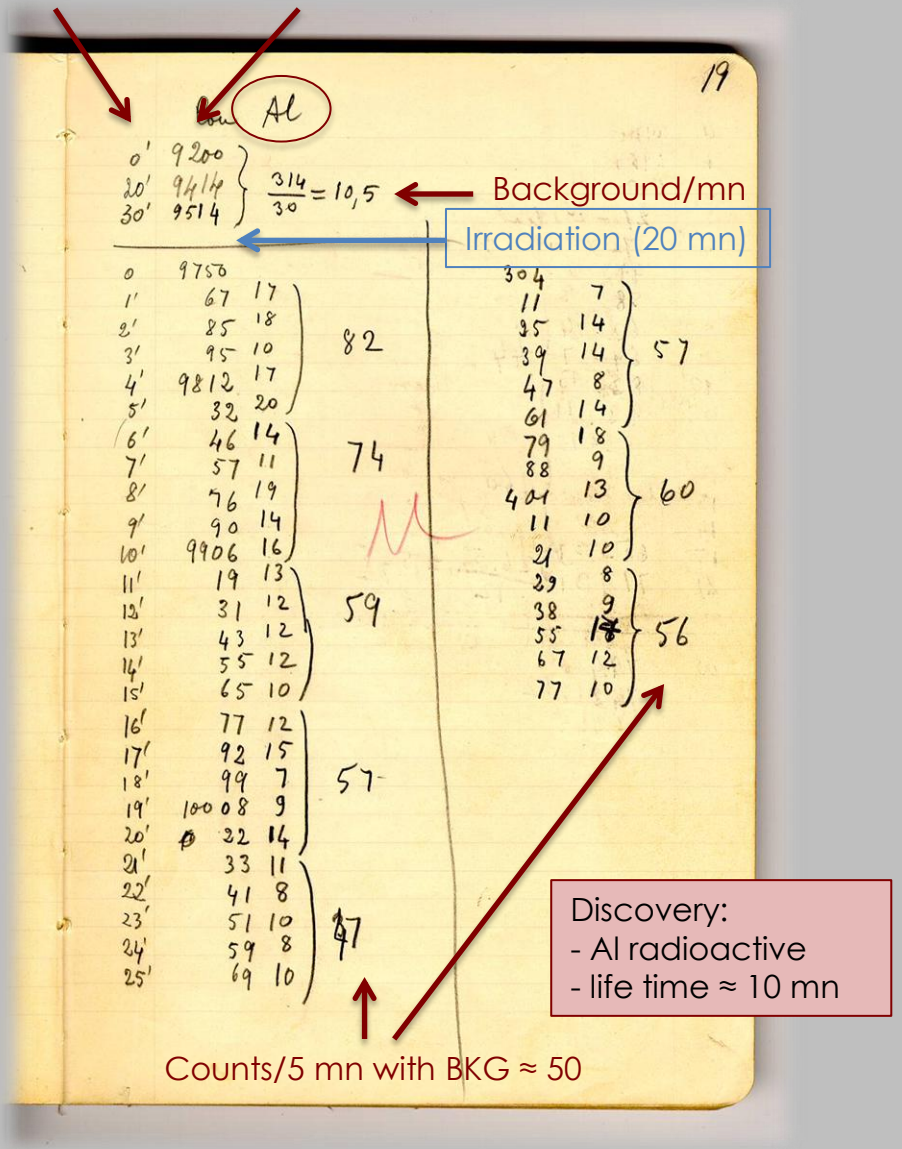
The discovery of neutron-induced radioactivity

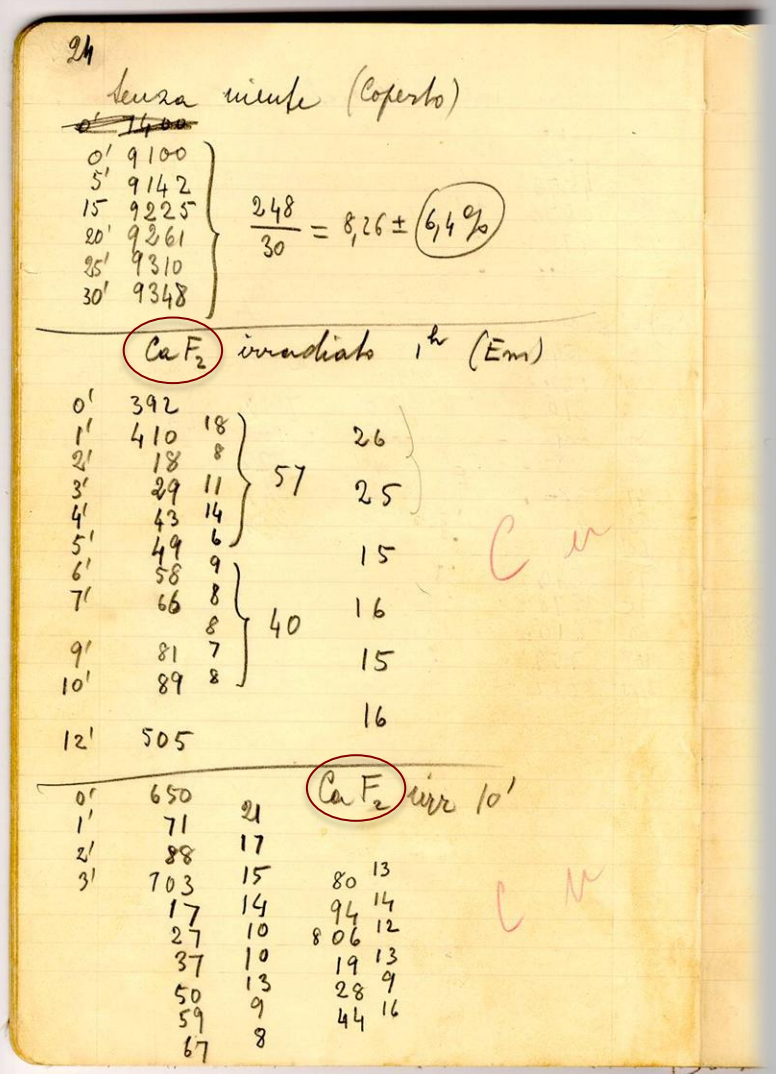




La Ricerca Scientifica, 5, (1), 283, 25 March 1934

The discovery of neutron-induced radioactivity





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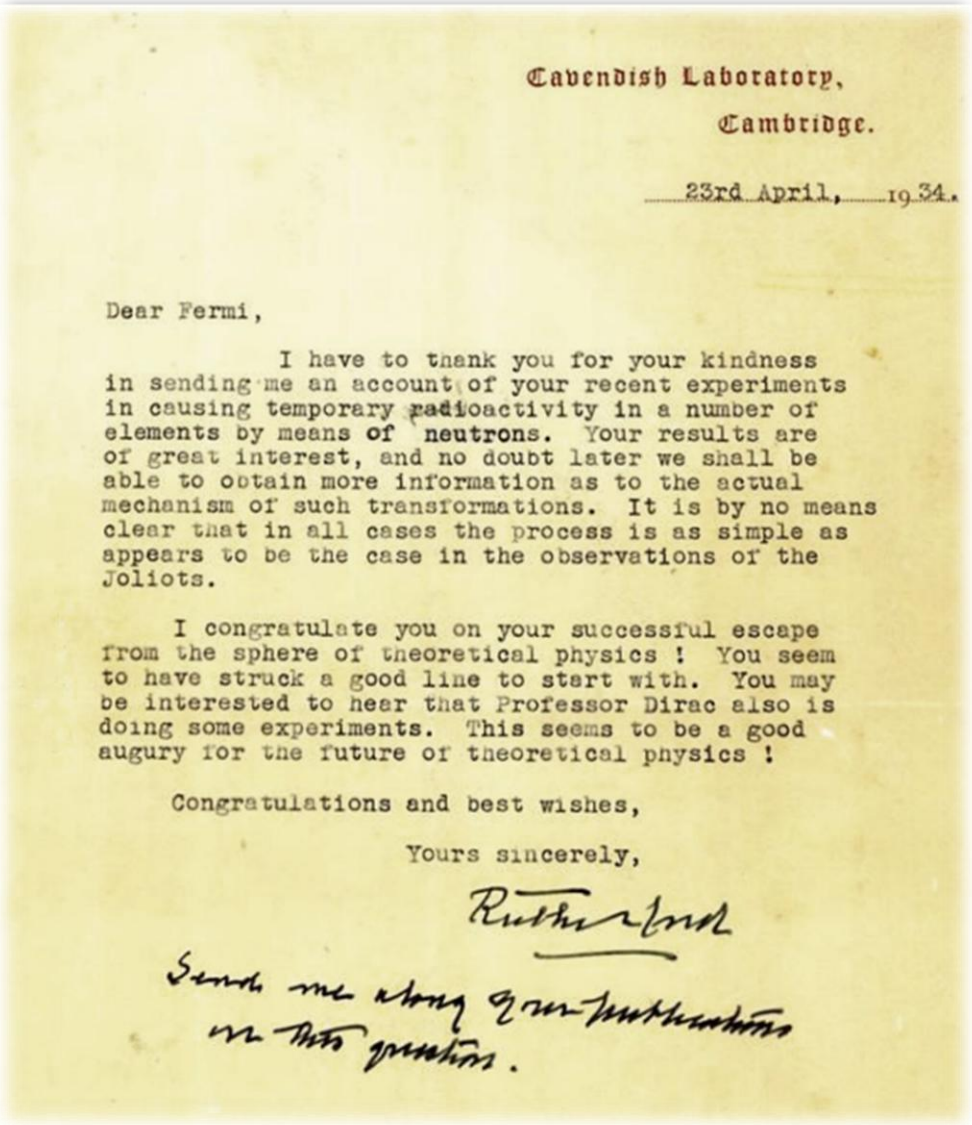


Cavendish Laboratory,
Cambridge.

23rd April, 1934.

Dear Fermi,

I have to thank you for your kindness in sending me an account of your recent experiments in causing temporary radioactivity in a number of elements by means of neutrons. Your results are of great interest, and no doubt later we shall be able to obtain more information as to the actual mechanism of such transformations. It is by no means clear that in all cases the process is as simple as appears to be the case in the observations of the Joliots.

I congratulate you on your successful escape from the sphere of theoretical physics ! You seem to have struck a good line to start with. You may be interested to hear that Professor Dirac also is doing some experiments. This seems to be a good augury for the future of theoretical physics !

Congratulations and best wishes,

Yours sincerely,

Rutherford

Send me along your publications on this question.

"I congratulate you on your successful escape from theoretical physics !

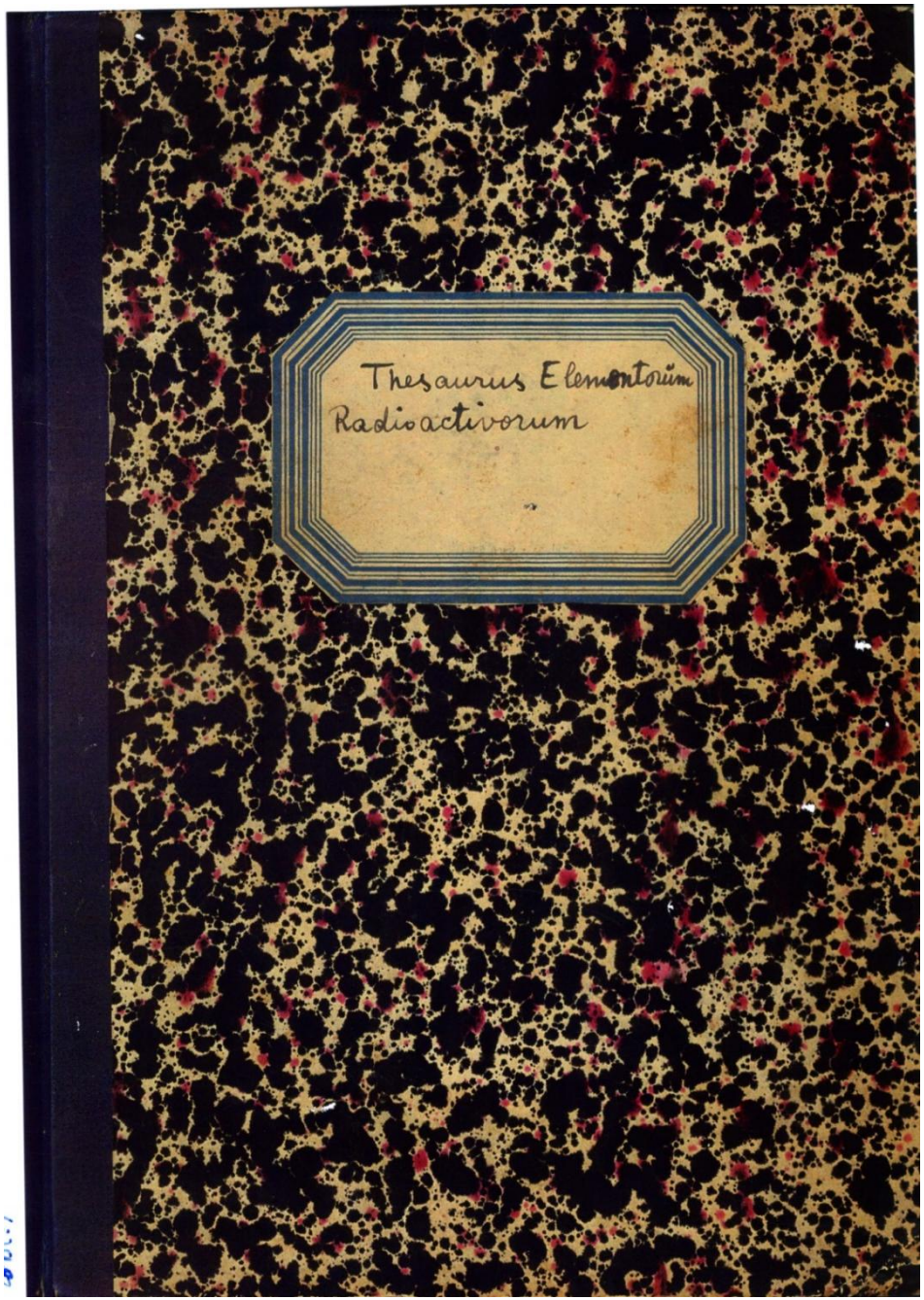
…

Dirac also is doing some experiments. This seems to be a good augury for theoretical physics !"

Ernest Rutherford

Dirac in the lab of Blackett and Occhialini in the Cavendish Laboratory, playing with the stereoscopic system of the apparatus

(Confirmation of e^+ and e^+e^- pair production with cloud chamber in cosmic rays)



- Then Fermi carried out a systematic study of the activation of all the elements up to Uranium

  1st half of Fermi's Nobel Prize in 1938

- "Discovery" of transuranic elements (Ausonium & Esperium)
  → These were in reality the first fission reactions ever observed that however could not yet be identified as such in 1934

The 2nd half of Fermi's Nobel Prize in 1938 consisted in the slowing down of neutrons

- Strange results and discrepancies in the results obtained during the summer of 1934
  → Fermi had the idea to insert different layers of different substances between the source and the sample to irradiate

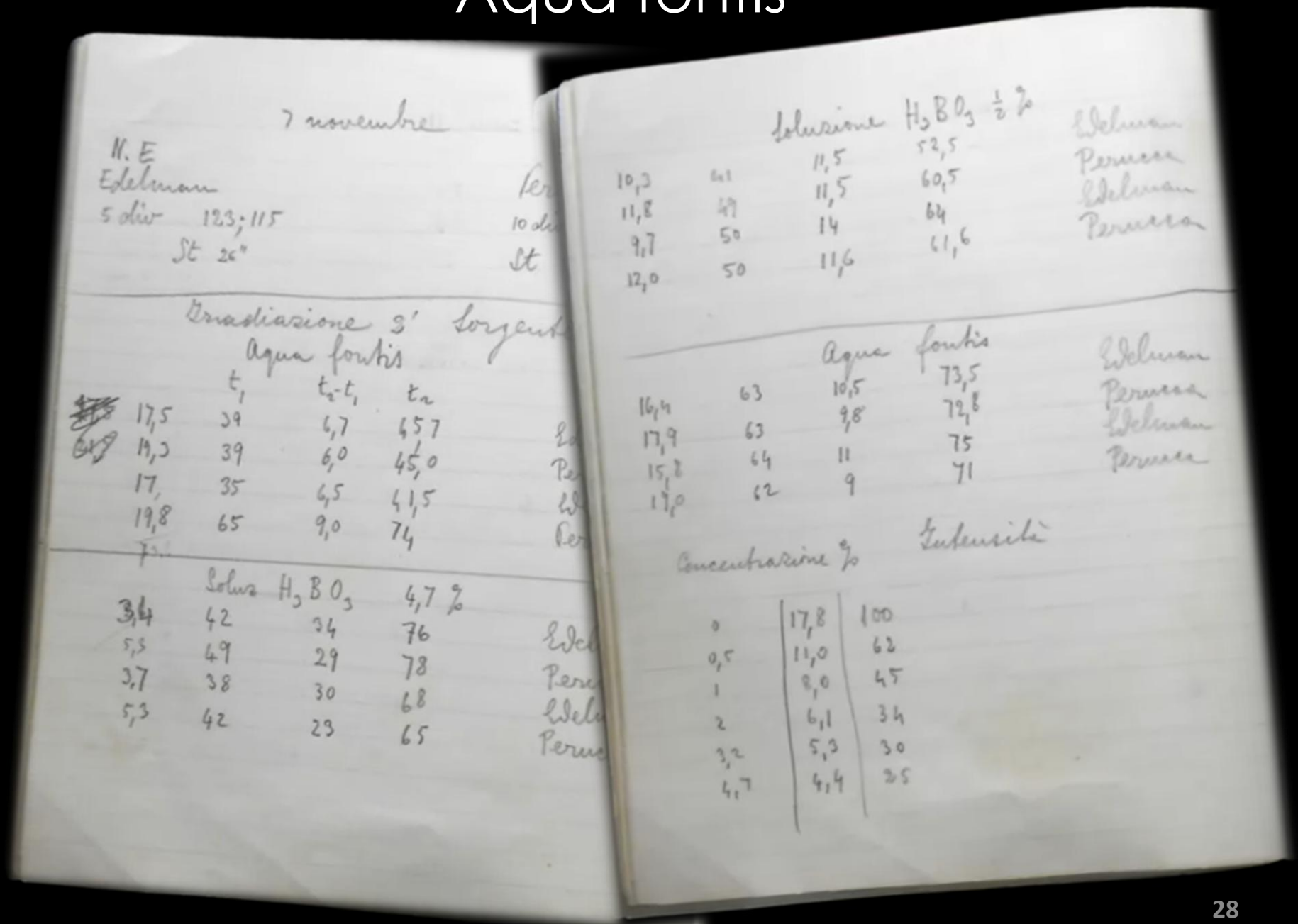
- October 1934
  Discovery that neutrons that have been slowed down when passing through paraffin wax or water, substances rich in Hydrogen, are much more efficient in producing induced radioactivity in samples of Silver and of other heavy elements

In particular water from the goldfish fountain
in the garden of Via Panisperna

"AQUA FONTIS" (as found several times in one of Fermi's logbooks)

was used to demonstrate the efficiency of slow neutrons

Aqua fontis



7 novembre

N. E
Edelman
5 div 123; 115
St 26°

Irradiazione 3' Sorgente
Aqua fontis

	t_1	$t_2 - t_1$	t_2	
17,5	39	6,7	45,7	Ed
19,3	39	6,0	45,0	Pe
17,	35	6,5	41,5	Ed
19,8	65	9,0	74	Pe

Soluz H_3BO_3 4,7 %

3,4	42	34	76	Edel
5,5	49	29	78	Peru
3,7	38	30	68	Edel
5,3	42	23	65	Peru

Soluzione H_3BO_3 $\frac{1}{2}$ %

		11,5	52,5	Edelman
10,3	61	11,5	60,5	Perucca
11,8	49	14	64	Edelman
9,7	50		61,6	Perucca
12,0	50	11,6		

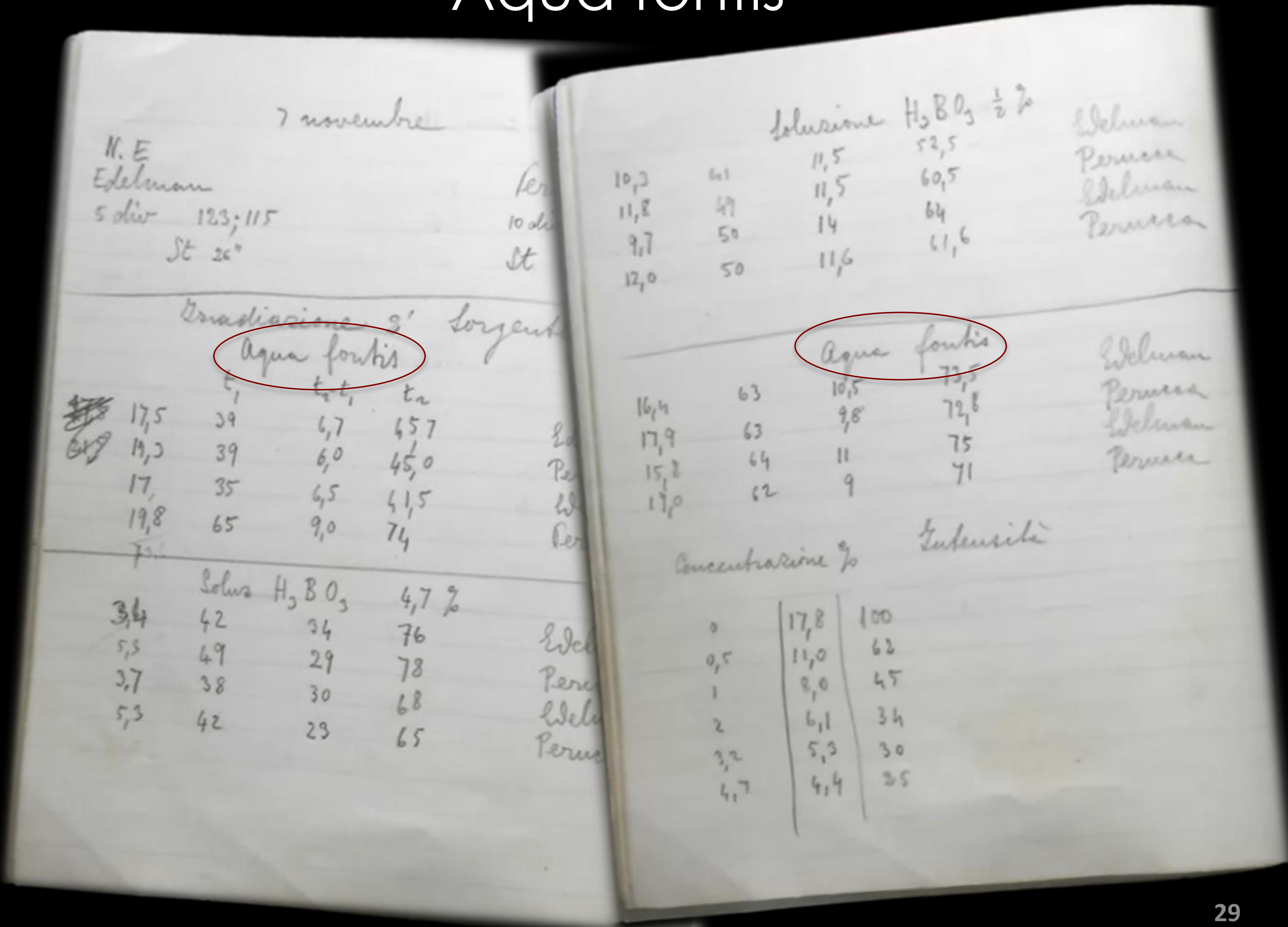
Aqua fontis

		10,5	73,5	Edelman
16,4	63	9,8	72,8	Perucca
17,9	63	11	75	Edelman
15,8	64	9	71	Perucca
17,0	62			

Concentrazione %

	Intensità	
0	17,8	100
0,5	11,0	62
1	8,0	45
2	6,1	34
3,2	5,3	30
4,7	4,4	25

Aqua fontis


7 novembre
N. E
Edelman
5 div 123; 115
St 26"
Gradiazione d' sorgente
Aqua fontis
t_1 $t_2 t_1$ t_n
17,5 39 6,7 45,7
19,3 39 6,0 45,0
17, 35 6,5 41,5
19,8 65 9,0 74
Solus H_3BO_3 4,7 %
3,4 42 34 76
5,5 49 29 78
3,7 38 30 68
5,3 42 23 65
Soluzione H_3BO_3 ½ %
10,3 41 11,5 52,5 Edelman
11,8 49 11,5 60,5 Perucca
9,7 50 14 64 Edelman
12,0 50 11,6 61,6 Perucca
Aqua fontis
16,4 63 10,5 73,5 Edelman
17,9 63 9,8 72,8 Perucca
15,8 64 11 75 Edelman
17,0 62 9 71 Perucca
Concentrazione % Intensità
0 17,8 100
0,5 11,0 62
1 8,0 45
2 6,1 34
3,2 5,3 30
4,7 4,4 25

The 2nd half of Fermi's Nobel Prize in 1938 consisted in the slowing down of neutrons

- Strange results and discrepancies in the results obtained during the summer of 1934
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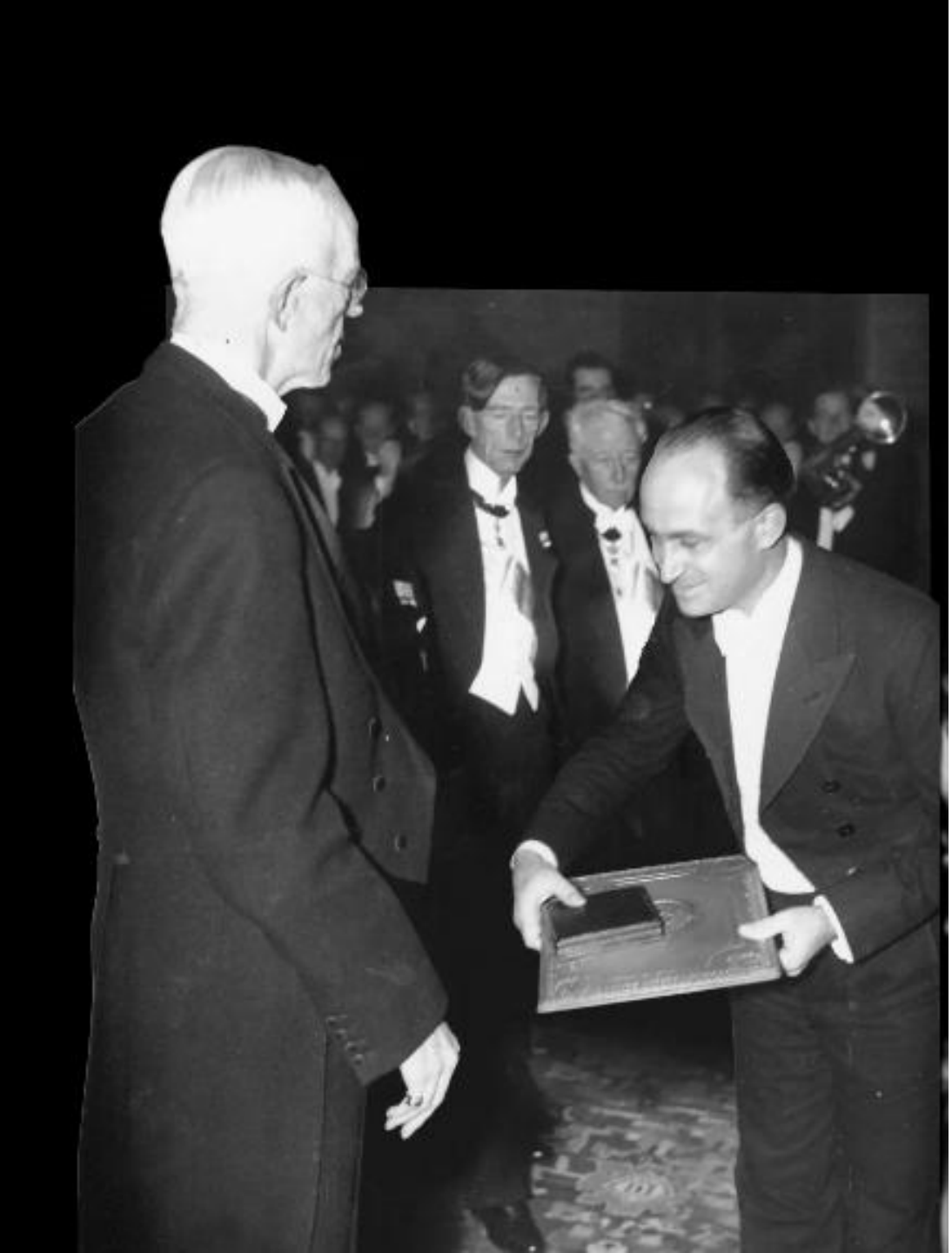
→ **This discovery would have an exceptional scientific and technological impact**

PATENT
for
the discovery
of the
slow neutrons
method
to enhance
artificial
radioactivity

First in Italy
then in other European
countries, USA and Canada



The significance of Fermi's discoveries, also at an applied level, earned him the Nobel Prize for Physics in1938

Guglielmo
Marconi
(1874 – 1937)

Orso Mario
Corbino
(1876 – 1937)

Meanwhile
Fermi's "patron saints"
have passed away …

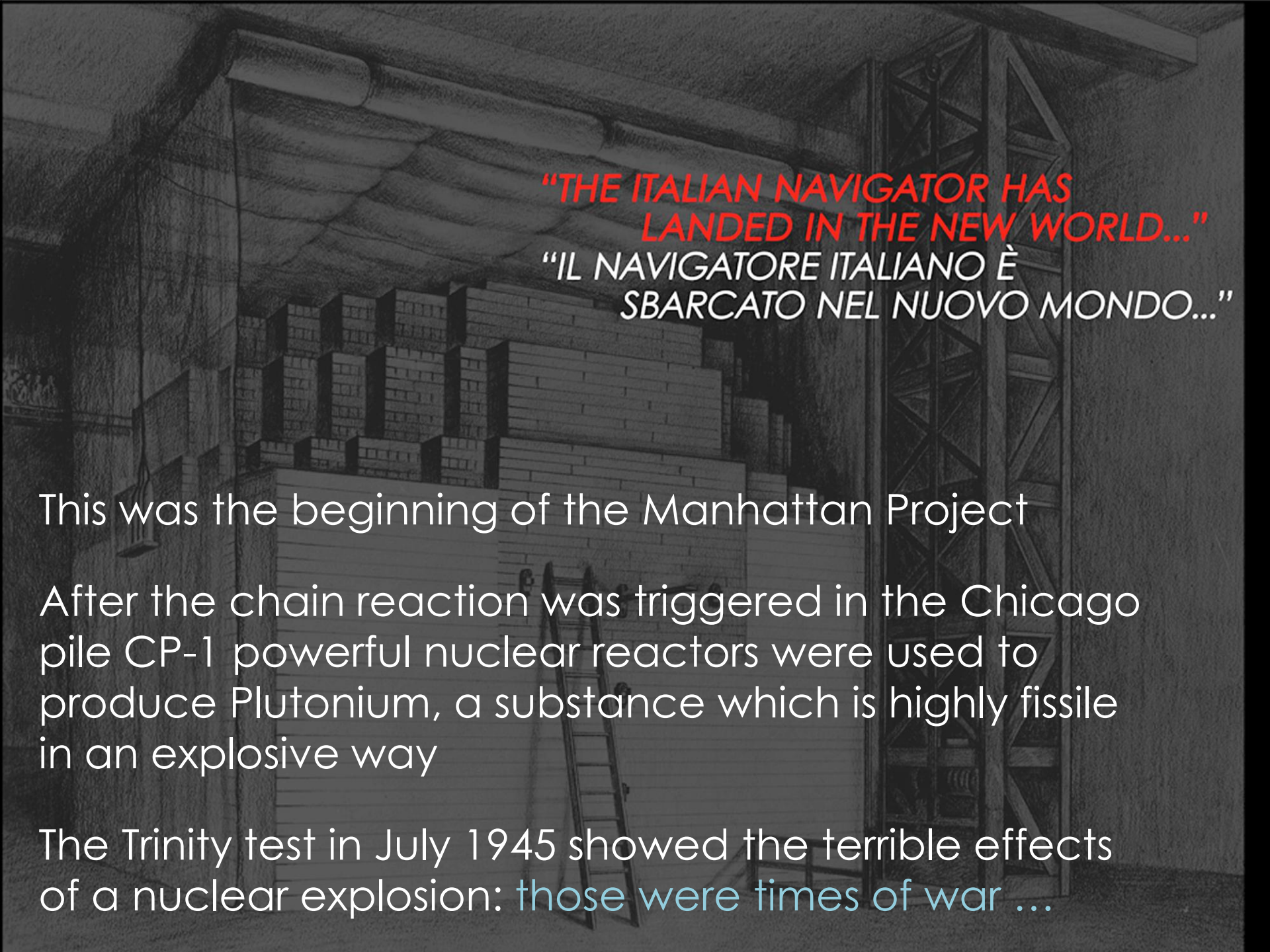
After the ceremony in Stockholm on 10 December 1938, Fermi carried out his decision to move with his family to the United States, where his research could develop much further, also because of the progressive involution of the Italian regime, going so far as the passing of the racial laws

In the USA

On arriving in New York in early January 1939 Fermi learned that in Berlin Otto Hahn had discovered nuclear fission and he immediately threw himself into the challenge of finding a way to exploit the enormous energy produced in this kind of process

On 2 December 1942, in Chicago, Fermi created the first nuclear pile (CP-I): with this device he succeeded in producing a controlled nuclear fission chain reaction using natural Uranium as the fuel and extremely pure graphite as the moderator to slow down the neutrons

It was a decisive step towards the exploitation of nuclear energy



This was the beginning of the Manhattan Project

After the chain reaction was triggered in the Chicago pile CP-1 powerful nuclear reactors were used to produce Plutonium, a substance which is highly fissile in an explosive way

The Trinity test in July 1945 showed the terrible effects of a nuclear explosion: those were times of war …

After the War

Fermi campaigned for new peaceful applications of nuclear technology

(motors, energy, medecine etc.)

USS Nautilus

Underneath the North Pole in 1958

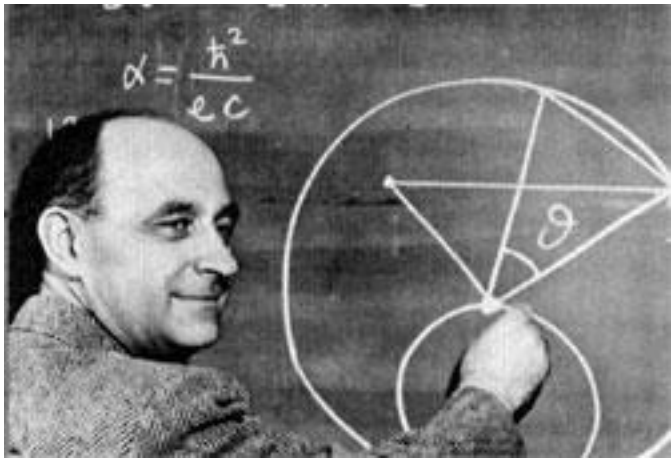
Fermi worked intensely on the new cyclotron accelerator in Chicago and discovered in 1952 the first example of a new class of particles, extremely short lived, called "resonances":

the Δ^{++} particle that would take on a crucial role in the understanding of the quark structure of the particles and of the strong interaction between quarks

→ Fermi produced a far-sighted vision for the development of accelerators

In the 1950s Fermi was universally considered one of the giants of physics of all times

He was 50 years old and, as well as his genius, he still had the enthusiasm and vivacity of a boy

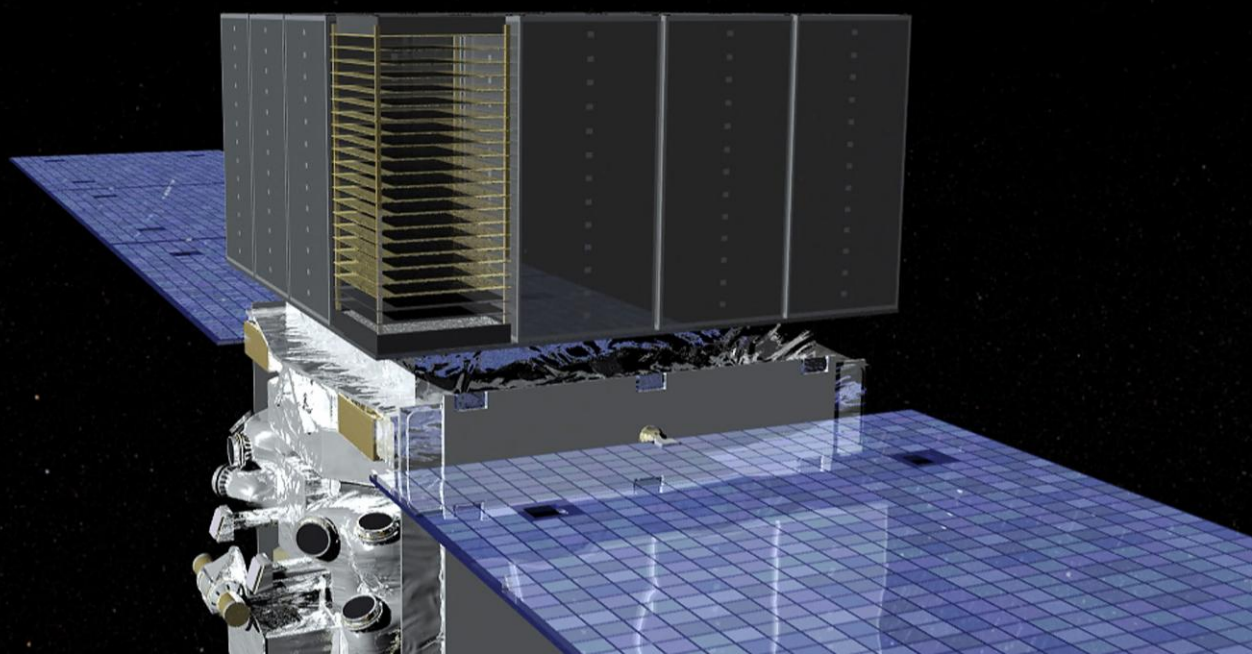


Fermi formulated a theory on the acceleration of cosmic rays, particles that come from the Cosmos and that constantly bombard the Earth with energies that can be greater than those of the LHC at CERN

What accelerators are this powerful?

Fermi answered in 1949: the cosmic accelerators use gravitational energy

→ His theory has been confirmed today by FERMI LAT satellite (NASA mission)



… All his life a dual genius between theories and experiments

Premature death in 1954 after memorable lessons on the interactions of pions and nucleons at the International School of Physics of the Italian Physical Society in Varenna, Lake Como

"Today, one would need another Fermi"

Luciano Maiani

Fermi as a unique master

In addition to the brilliant people who had studied under or worked with Fermi in Italy (Florence and Rome), in particular:

Ettore Majorana
Bruno Pontecorvo
Emilio Segrè*

Here is the list of Fermi's graduate students at Chicago:

Name	*Ph.D. awarded*
George Farwell	Spring '48
Geoffrey Chew	Summer '48
Marvin Goldberger	Summer '48
Lincoln Wolfenstein**	Winter '49
Jack Steinberger*	Spring '49
Owen Chamberlain*	Autumn '49
Richard Garwin	Autumn '49
Tsung Dao Lee*	Spring '50
Uri Haber-Schaim	Summer '51
Jay Orear	Summer '53
John Rayne	Spring '54
Robert Schluter	Spring '54
Arthur Rosenfeld	Autumn '54
Horace Taft†	Autumn '55
Jerome Friedman*	Spring '56 (awarded after Fermi's death)

*Nobel Laureate
**To the writer's knowledge, Wolfenstein was a student of Teller's. The above table, provided by the Department of Physics at the University of Chicago, lists him under Fermi.

(by Valentine Telegdi)

James Cronin*
Chen Ning Yang*

1953

The then President
of the Italian Physical Society
Giovanni Polvani
Inaugurated the 1st course of the
Varenna School which was titled:

"Issues related to elementary-particle detection, with special attention to cosmic radiation"

The course was directed by
Giampietro Puppi and the lecturers
were outstanding scientists like
Cecil Powell, Patrick Blackett,
Hannes Alfvén,
Giuseppe (Beppo) Occhialini,
to name but a few

1954

The 1st course was a real success, to the extent that Puppi was asked to direct another one in the Summer of 1954

The 2nd course was again devoted to elementary particles, this time placing emphasis on accelerators:
"The contribution from existing and planned accelerators to elementary particles physics"

In his opening address Puppi talked about *"the fantastic world of high-energy phenomena"*

To illustrate them, eminent physicists were invited to lecture, like Enrico Fermi, Werner Heisenberg, Gilberto Bernardini, Bruno Rossi …

INTRODUZIONE

1954

Enrico Fermi and Werner Heinsenberg gave the first two lectures of a series on the physics of pions and nucleons

Gilberto Bernardini, Bernard T. Feld and others took care of a second group of lectures on photoproduction

Bruno Rossi lectured on fundamental particles and on the origin of cosmic rays

Various **particle accelerator facilities and projects** in different laboratories in Europe were illustrated by a number of world experts

Salvini

Castagnoli

Steinberger

Puppi

Conversi

Leprince-Ringuet

Borsellino

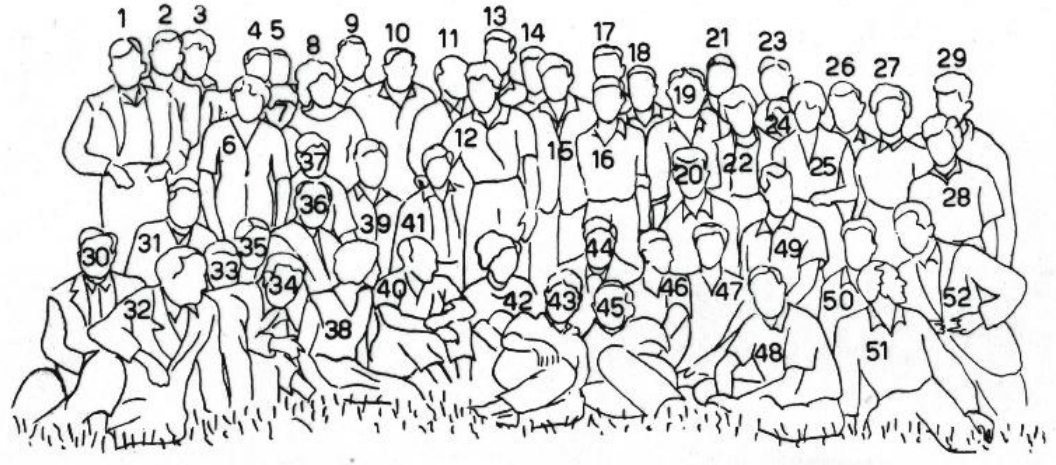
Rossi

Fermi

G.Bernardini

Polvani

Occhialini



1. M. Cresti. - 2. M. Deutschmann - 3. B. Puppi - 4. J. Steinberger - 5. N. Dallaporta - 6. I. Polvani - 7. S. C. Nassar - 8. A. Orkin-Lecourtois - 9. G. Salvini - 10. C. Castagnoli - 11. G. Poiani - 12. A. Rogozinsky - 13. J. Brizot - 14. J. Tremblay - 15. M. Ceccarelli - 16. M. Porter - 17. P. Giacometti - 18. K. Kandiah - 19. G. Wataghin - 20. U. Haber-Schaim - 21. J. G. Röderer - 22. B. Locatelli - 23. K. Gottstein - 24. C. M. Garelli - 25. C. Dilworth-Occhialini - 26. Y. Fujimoto - 27. L. Tallone - 8. G. Tomasini - 29. R. Levi-Setti - 30. A. Rostagni - 31. B. Brunelli - 32. A. Borsellino - 33. G. Fidecaro - 34. P. Caldirola - 35. B. Rossi - 36. G. Polvani - 37. D. Keefe - 38. G. Cini - 39. M. G. K. Menon - 40. E. Fermi - 41. Y. Goldschmidt-Clermont - 42. M. Bruin - 43. G. Bernardini - 44. G. Puppi - 45. G. Occhialini - 46. L. Scarsi - 47. B. Vitale - 48. M. Conversi - 49. G. Quareni - A. Bonetti - 51. L. Leprince-Ringuet - 52. B. T. Feld

A celebrated group photo 1954

Fermi gave 16 lectures in Varenna on
“PIONS and NUCLEONS”
from 16th of July to 6th of August 1954

His last gift to Italy

He passed away a few months later

Exactly one year later on the 6th of August 1955
an official commemorative ceremony was organised
by President Polvani in Varenna and Como
in the presence of Fermi’s wife, Laura Fermi Capon,
and Fermi’s sister, Maria Sacchetti Fermi

President Polvani announced that
the School would be named after Enrico Fermi

In the Aula of Villa Monastero in Varenna
a bronze medallion with his low-relief effigy
was unveiled in memory and in honour of
Enrico Fermi in 1955

work of the sculptor
Giannino Castiglioni

Also a porphyry plaque was placed bearing a Latin epigraph:

ENRICO FERMI
— 1954 - 53rd of his life —

”Here with quiet spirit among so many natural
beauties, I revealed for the last time,
to a rank of men of science, the ultimate and
most remote elements in motion inside the atoms,
with which I had already made my name immortal ”

A very recent gift to SIF by Jack Steinberger

PASSION FOR PHYSICS

International School of Physics Enrico Fermi

60th Anniversary

15 June 2013
Villa Monastero
Varenna (Lake Como)

Memories …

https://www.youtube.com/watch?v=uBcDU2uEjro

ARCHIVIO STORICO LUCE

La Scuola Internazionale di Fisica e le lezioni di Enrico Fermi e di altri noti professori di fisica.

LA SETTIMANA INCOM 01126
del 28/07/1954

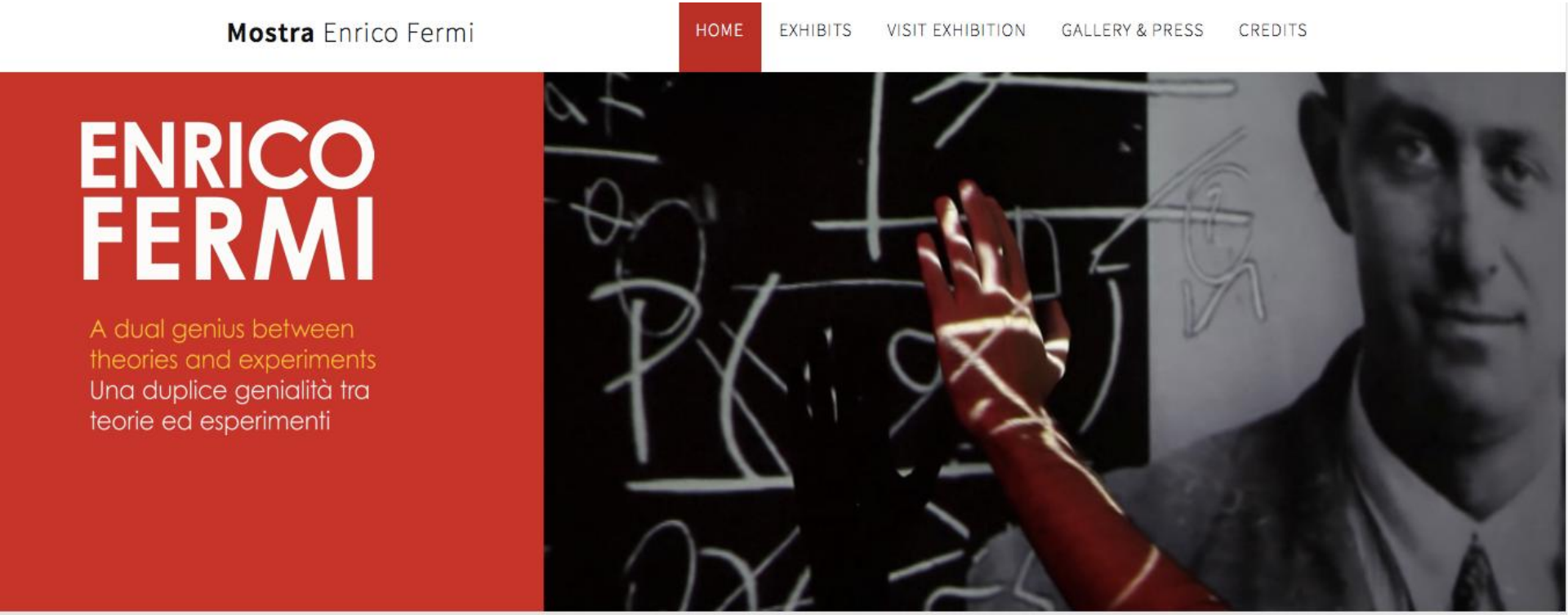
Status of CENTRO FERMI

NOW

Fermi Fountain
1st Historic Site of the European Physical Society
April 2012

http://www.mostrafermi.it/

Enrico Fermi's Exhibition in 2015-2016
with over 30 000 visitors in 6 months → future MUSEO FERMI



Why the Exhibition| **Perchè la mostra**

The exhibition highlights the extaordinary figure of Enrico Fermi, the great Italian physicist who, paradoxically, is better known abroad than in

Who is it for | **A chi si rivolge**

The scientific achievements, integrated into the various stages of the scientist's life, are presented in a new light suitable for the general public, including the very young, combining objects and

A stop in Bologna | **Uno stop a Bologna**

After the success of its debut at the "Festival delle Scienza di Genova" of 2015 (about 15.000 visits), the exhibition arrives in the Emilian city, thanks to

… All this according to

Enrico Fermi's legacy

Thank you for your attention