ENRICO FERMI
AND THE BEGINNING OF NUCLEAR PHYSICS


LUISA CIFARELLI — Centro Fermi, Rome (IT)
Società Italiana di Fisica
Università & INFN, Bologna (IT)
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
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.
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.
Roma, 25/10/1926

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

Dear Sir!


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. 26, 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

  o About 50 eminent Italian and foreign scientists were invited
  o Enrico Fermi was Secretary General of the Congress, Bruno Rossi, Gleb Watagin and Antonio Carrelli were Secretaries
  o Guglielmo Marconi (Nobel Prize, Senator and CNR President) was Honorary President
  o 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 and 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
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
Franco Rasetti (1901-2001)

Emilio Segrè (1905-1989)

Ettore Majorana (1906-1938 (?))

Edoardo Amaldi (1908-1989)

Enrico Fermi (1901-1954)

Bruno Pontecorvo (1913-1993)

Oscar D’Agostino (1901-1975)
• March 1934
Discovery of the neutron-induced beta radioactivity of Aluminium, then of Fluorine (Calcium fluoride CaF$_2$)

Documented in a logbook recently discovered in Avellino in 2002
The discovery of neutron-induced radioactivity
The discovery of neutron-induced radioactivity

Discovery:
- Al radioactive
- life time ≈ 10 mn

Counts/5 mn with BKG ≈ 50

Time  Progressive counts (→ clock)
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 Joliot.

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,

[Signature]

Ernest Rutherford

“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!”
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

1\textsuperscript{st} 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

<table>
<thead>
<tr>
<th>N. E. Edelmann</th>
<th>Soluzione</th>
<th>H₂BO₃</th>
<th>1/2 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 novembre</td>
<td>10,2</td>
<td>11,5</td>
<td>52,5</td>
</tr>
<tr>
<td></td>
<td>11,8</td>
<td>11,5</td>
<td>60,5</td>
</tr>
<tr>
<td></td>
<td>9,7</td>
<td>14</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>12,0</td>
<td>11,6</td>
<td>61,6</td>
</tr>
</tbody>
</table>

| 7 novebre      | 10,2      | 11,5  | 52,5  |
|                | 11,8      | 11,5  | 60,5  |
|                | 9,7       | 14    | 64    |
|                | 12,0      | 11,6  | 61,6  |

<table>
<thead>
<tr>
<th>Tempratura t₁</th>
<th>t₂ - t₁</th>
<th>t₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>17,5</td>
<td>29</td>
<td>4,7</td>
</tr>
<tr>
<td>19,3</td>
<td>39</td>
<td>6,0</td>
</tr>
<tr>
<td>17</td>
<td>35</td>
<td>4,5</td>
</tr>
<tr>
<td>19,8</td>
<td>65</td>
<td>9,0</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soluzione H₂BO₃</th>
<th>4,7 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,4</td>
<td>42</td>
</tr>
<tr>
<td>5,3</td>
<td>49</td>
</tr>
<tr>
<td>3,7</td>
<td>38</td>
</tr>
<tr>
<td>5,3</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Concentrazione %</th>
<th>Intensità</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>17,8</td>
</tr>
<tr>
<td>0,5</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>8,0</td>
</tr>
<tr>
<td>2</td>
<td>6,1</td>
</tr>
<tr>
<td>3,2</td>
<td>5,3</td>
</tr>
<tr>
<td>4,7</td>
<td>4,4</td>
</tr>
</tbody>
</table>
Aqua fontis
The 2\textsuperscript{nd} half of Fermi’s Nobel Prize in 1938 consisted in the slowing down of neutrons

\begin{itemize}
\item Strange results and discrepancies in the results obtained during the summer of 1934
  \rightarrow Fermi had the idea to insert different layers of different substances between the source and the sample to irradiate

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

\rightarrow 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 in 1938.
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, medicine 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 $\Delta^{++}$ 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*

(by Valentine Telegdi)

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

<table>
<thead>
<tr>
<th>Name</th>
<th>Ph.D. awarded</th>
</tr>
</thead>
<tbody>
<tr>
<td>George Farwell</td>
<td>Spring ’48</td>
</tr>
<tr>
<td>Geoffrey Chew</td>
<td>Summer ’48</td>
</tr>
<tr>
<td>Marvin Goldberger</td>
<td>Summer ’48</td>
</tr>
<tr>
<td>Lincoln Wolfenstein**</td>
<td>Winter ’49</td>
</tr>
<tr>
<td>Jack Steinberger*</td>
<td>Spring ’49</td>
</tr>
<tr>
<td>Owen Chamberlain*</td>
<td>Autumn ’49</td>
</tr>
<tr>
<td>Richard Garwin</td>
<td>Autumn ’49</td>
</tr>
<tr>
<td>Tsung Dao Lee*</td>
<td>Spring ’50</td>
</tr>
<tr>
<td>Uri Haber-Schaim</td>
<td>Summer ’51</td>
</tr>
<tr>
<td>Jay Orear</td>
<td>Summer ’53</td>
</tr>
<tr>
<td>John Rayne</td>
<td>Spring ’54</td>
</tr>
<tr>
<td>Robert Schluter</td>
<td>Spring ’54</td>
</tr>
<tr>
<td>Arthur Rosenfeld</td>
<td>Autumn ’54</td>
</tr>
<tr>
<td>Horace Taft†</td>
<td>Autumn ’55</td>
</tr>
<tr>
<td>Jerome Friedman*</td>
<td>Spring ’56</td>
</tr>
</tbody>
</table>

* 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.

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 …
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.
A celebrated group photo 1954

Salvini
Castagnoli
Steinberger
Puppi
Conversi
Leprince-Ringuet

Borsellino
Rossi
Fermi
G.Bernardini
Polvani
Occhialini

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
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.

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
Memories ...

https://www.youtube.com/watch?v=uBcDU2uEjro
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
Fermi Fountain
1st Historic Site of the European Physical Society
April 2012
Enrico Fermi’s Exhibition in 2015-2016
with over 30 000 visitors in 6 months → future MUSEO FERMI

http://www.mostrafermi.it/

Why the Exhibition | Perché la mostra
The exhibition highlights the extraordinary figure of Enrico Fermi, the great Italian physicist who, paradoxically, is better known abroad than in Italy.

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 traditional panels with video and audio.

A stop in Bologna | Uno stop a Bologna
After the success of its debut at the “Festival delle Scienze di Genova” of 2015 (about 15,000 visits), the exhibition arrives in the Emilian city, thanks to the support of the Ministry of Education, University and Research, the University of Bologna, the Province of Bologna, the City of Bologna, and the Emilia-Romagna Region.
… All this according to Enrico Fermi’s legacy

Thank you for your attention