Bruno Pontecorvo: Mister Neutrino

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In 1933-34 after famous Pauli idea of neutrino E. Fermi proposed first theory of $\beta - decay$

$$n \to p + e^- + \nu_e$$

Fermi Hamiltonian

$$\mathcal{H}_\beta = G_F \bar{p}\gamma_\alpha n \; \bar{e}\gamma^\alpha \nu_e + \text{h.c.}$$

In 1934 Bethe and Peierls calculated the cross section of the interaction of neutrinos with nuclei

They showed that the cross section is extremely small , $\simeq 10^{-43}\,\text{cm}^2$ at a few MeV energy

During many years neutrinos were considered as undetectable particles

The first ideas of neutrino detection belong to B. Pontecorvo

"Inverse β process" (1946 Chalk River, Canada)

"It has been currently stated in the literature that inverse β-processes produced by neutrinos can not be observed, due to the low yield"

"The object of this note is to show that experimental observation of neutrinos is not out of question and to suggest a method which might make an experimental observation feasible"

B.P. considered the process

$$\nu_e + (A, Z) \to e^- + (A, Z + 1)$$

Main idea; "radioctivity of the produced nucleus may be looked for as a proof of the inverse β process"

An experiment based on the reaction

$$\nu_e + {}^{37}\mathrm{Cl} \rightarrow \mathrm{e}^- + {}^{37}\mathrm{Ar}$$

B.P. considered as a promising one (cheap target, convinient life-time of ^{37}Ar, rare gas, etc)

However, this was an example In 1946 B.P. proposed general radichemical method of the detection of neutrinos which is very important for the detection of solar neutrinos.

In the 1946 paper B.P. considered the following sources of neutrinos

1. Sun
2. Reactor during operation (the most promising)
3. Radiactive materials extracted from reactor

In 1948 B.Pontecorvo invented low-background proportional counter with high amplification. The Pontecorvo counter was crucial for detection of neutrinos in Homestake, GALLEX and SAGE experiments.

Universal weak interaction

In 1947-49 in Canada B. Pontecorvo and E. Hincks made a series of brilliant, pioneer experiments on the investigation of muon decay

They proved that

1. The charged particle emitted in μ-decay is electron;

2. Muon decays into three particles

3. Decay $\mu \to e + \gamma$ is forbidden

After famous Conversi, Pancini, Piccioni experiment B.P. came to an idea that muon is a particle with spin 1/2 and in muon capture neutrino is emitted

He noticed that probababilities of μ-capture and electron K-capture are of the same order (if kinematics and initial wave function effects are taken into account).

He concluded that exist " fundamental analogy between β- processes and processes of emition and absorption of charged mesons" (muons)

B.P. was the first (1947) who came to an idea that weak interaction include not only $e - \nu$ pair but also $\mu - \nu$ pair and that this general weak interaction is $\mu - e$ universal

Accelerator neutrinos, $\nu_\mu \neq \nu_e$

In 1958-59 in Dubna B. Pontecorvo came to an idea of the feasability of experiments with accelerator neutrinos

There was some model dependent indication at that time, coming from the limit on $\mu \to e\gamma$, that ν_μ and ν_e could be different

In 1959 B.P. was the first who understood that decisive answer on question whether exist second type of neutrino can be obtained in an experiment with accelerator neutrinos

His proposal was realized in the famous Brookhaven experiment in 1962

J. Steinberger and L.Lederman before going to Stockholm send Pontecorvo postcards in which they wrote it is a pity that you are not with us

In 1957 Pontecorvo came to idea of neutrino oscillations

After two-component neutrino theory, based on hypothesis of massless neutrino, and Goldhaber et al experiment this was a courageous idea

Motivation for B.P. was similarity of the weak interaction of hadrons and leptons and existence of $K^0 \leftrightarrows \bar{K}^0$ oscillations

"If the two-component neutrino theory turn out to be incorrect and if the conservation law of neutrino charge would not apply, then in principle neutrino $\rightleftharpoons$ antineutrino transitions could take place in vacuum."

he wrote in the paper in which transitions $\mu^+ e^- \to \mu^- e^+$ were considered

First paper dedicated to neutrino oscillations was published by Bruno Pontecorvo in 1957

Another motivation for B. Pontecorvo was successful F. Reines and C. Cowan neutrino experiment and R.Davis experiment in which he searched for the process

$$\bar{\nu}_e + {}^{37}\mathrm{Cl} \to \mathrm{e}^- + {}^{37}\mathrm{Ar}$$

A rumor reached B.Pontecorvo that Davis observed such events

In 1957 only one type of neutrinos was known.

Bruno Pontecorvo assumed

1. neutrino and antineutrino emitted in β-processes are different particles
2. exists some interaction which do not conserve lepton number

'neutrinos in vacuum can transform themself into antineutrinos and vice versa. This means that neutrino and antineutrino are particle mixtures , i.e., a symmetric and antisymmetric combination of two truly neutral Majorana particles ν_1 and ν_2. "

"a beam of neutral leptons from a reactor which at first consists mainly of antineutrinos will change its composition and at certain distance R from the reactor will be composed of neutrino and antineutrino in equal quantities."

"the cross section of the production of neutrons and positrons in the process of the absorption of antineutrinos from a reactor by protons would be smaller than the expected cross section.

Pontecorvo strongly believed in neutrino oscillations. From 1957 (at that time majority of physicists considered neutrino is massless particle) he became great enthusiast of neutrino oscillations. For the rest of his life neutrino oscillations was his beloved subject

From 1957 paper

"effects of transformation of neutrinos into antineutrinos and vice versa may be unobservable in the laboratory because of large values of R but will certainly occur, at least on an astronomical scale"

In the sixties Pontecorvo discussed the problem of neutrino mass with L. Landau. After V-A theory Landau, the author of two-component neutrino theory, changed his opinion about neutrino mass. He supported Pontecorvo idea of small neutrino masses

In 1967 after discovery of ν_μ it was natural (and not difficult) for B.Pontecorvo to generalize his idea of neutrino oscillations for the case of two types of neutrinos

He considered transitions $\nu_\mu \leftrightarrows \nu_e$ and transitions into sterile neutrinos $\nu_\mu \leftrightarrows \bar{\nu}_{\mu L}$ etc. The notion of "sterile neutrinos" so popular nowadays was invented by B.P. in 1967

About one year before R. Davis published his first result B. Pontecorvo wrote

"From observational point of view the ideal object is sun. If the oscillation length is smaller than the radius of the sun region effectively producing neutrinos direct oscillations will be smeared out and unobservable. The only effect on the earth's suffice would be that the flux of observable solar neutrinos must be two times smaller than the total neutrino flux".

B. Pontecorvo envisaged the solar neutrino problem The conclusion of the 1967 paper

the question of lepton conservation has a bearing on the interpretation of the first experiments which will be soon performed with sun neutrinos

In 1969 B.Pontecorvo and V. Gribov considered neutrino oscillations in a scheme with two Majorana neutrinos (without sterile). They applied the developed formalism to solar neutrinos

B.P. like very much underwater fishing in small and clean rivers not far Dubna. Very often he invited my wife and me for such trips. While he was in a river we made fire and collected mushrooms. Usually B.P. went out from the river without fish, ...fire and mushrooms were there. Only once during very dry summer, when fires were forbidden, he captured a lot of fish.

We started our collaboration on neutrino oscillations in 1975 in a car during such trips

We published about 25 papers and first review on neutrino oscillations Our last review (for Italian Encyclopedia) was written in 1987

It required many years and heroic efforts of many experimental groups to reveal effects of tiny neutrino masses

The discovery of neutrino oscillations was real triumph of Bruno Pontecorvo who proposed neutrino oscillations and pursued the idea of oscillations for many years, when the general opinion favored massless neutrinos and no neutrino oscillations

The years of work and friendship with Bruno Pontecorvo were the happiest and unforgettable years in my life

His wide and profound knowledge of physics, his love of physics, his ingenious intuition and his ability to understand complicated problems in a clear and simple way were gifts of God.

Bruno Pontecorvo was a true scientist in the best, classical sense of the word.

When he thought about some problem he thought about it continuously from early morning till late evening

He devoted all his resources and great intellect to science, and though he was not indifferent to the recognition of his contribution to physics, his main stimulus was search for the truth

More than ten last years were for Bruno Pontecorvo years of courages struggle against Parkinson illness. His love to physics and to neutrino helped him to overcome difficult problems of the illness. He never stoped to work, to think about neutrinos and to continue active life.

Two days before death he was in his office at the second floor of the Laboratory of Nuclear Problem in Dubna, where he spend 43 years. When he was leaving the Laboratory for the last time he looked into window and said to his secretary Irina Pokrovskaja: "Look how beautiful these colours...." It was nice Russion September 1993

Bruno Pontecorvo was born in Pisa in 1913

"A scuola ero bravo ma la cosa piu' impotrante nella mia vita era il tennis" (Una nota autobiografica)

The family was big. Five brothers and three sisters. One of his brother Guido was famous biologist; Gillo Pontecorvo is famous film producer. Opinion of parents....

"Guido era il piu intelegente dei fratelli, Paolo era il piu' serio, Giuliana la piu' colta, Bruno il piu' buono ma il piu' limitato, come era demonstrato dai suoi occhi buoni ma non intelligenti....

(una nota autobiografica)

1933 - 1936 Bruno Pontecorvo worked in Rome in E. Fermi group. 1936- 1940 he worked in Paris in F. Joliot-Curtie laboratory. 1940-42 he worked in USA. 1943-48 worked in Canada. 1948-50 he worked in Harwell. From September 1950 he worked in Dubna.