Quo vadis Physics?: Nobel Prize 2015, Bruno Pontecorvo and the science lobbies

Diego Julio Cirilo-Lombardo

Instituto de Fisica del Plasma (INFIP), Consejo Nacional de Investigaciones Cientificas y Tecnicas CONICET, FCEN-Universidad de Buenos Aires, Buenos Aires, Argentina and

Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, Dubna, Moscow Region, 141980 Russian Federation

WHO IS Bruno Pontecorvo?

20/11/2015 from TACC-agency about the Nobel prize and Bruno Pontecorvo idea of the neutrino oscillation

Bruno was born in 1913 in a family of Italian textile magnate,
however, youth sympathized with leftist ideas.
The course of physics at the University of Rome he read how created the world's first nuclear reactor Enrico Fermi.

In 1936 Pontecorvo got a grant from the Ministry of Education sent to Italy for training in Paris in the hadron laboratory of Joliot Curie.
Next door in Spain: at this time of the civil war erupted and set Franco's fascist dictatorship.
And in 1938, Mussolini's government adopted laws restricting the rights of Jews and Pontecorvo (and by this time he got family) road to Italy was closed .
In 1950 Pontecorvo and his family fled to the Soviet Union passing by Italy, Sweden and Helsinski respectively. Consequently he worked at the International Nuclear Center, which soon grew up in Dubna. It was there that he created the first classic work on neutrinos.

He is an academician, director of the Department of Physics of
elementary particles of MSU. Since he arrived in Dubna, physicists and poets became Pontecorvo a very popular man. And not only through science: the Italian scientist was one of the first popularizers tennis and spearfishing in the USSR. But Pontecorvo's scientific ambitions were not fully satisfied. His theoretical discoveries in neutrino require experimental evidence.

Pontecorvo with his knowledge and skill could be the first to detect neutrinos. But to solve this problem in the USSR was impossible because of
lack of appropriate Accelerator, as was pointed out by the
Academician Semen Gerstein, Or to spend experiment abroad in cooperation with research centers in the US and Europe. About it then it was impossible even to think. The saddest thing is that some of Pontecorvo discovery of reactor neutrinos appeared closed to him. Eventually Bruno outlook began to change. Particularly strong influence on him were the events in Czechoslovakia in 1968.

Finally Pontecorvo died in 1993.

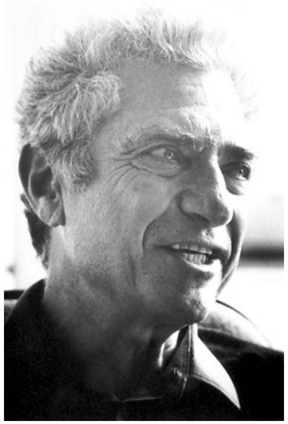
Neutrinos ALREADY GIVEN FOR 4 NOBEL!

Works of Pontecorvo did not get due recognition abroad. Although in the study of neutrinos (that Bruno was a pioneer here) Nobel Prizes awarded 4 times.

Premio Nobel 1988:

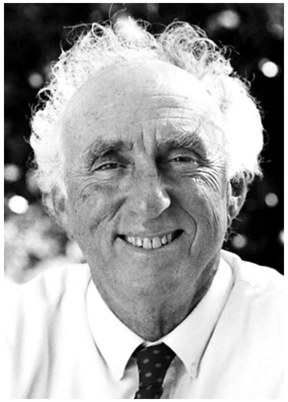
Leon M. Lederman

Mel Schwartz



Jack Steinberger

1995 for the detection of reactor neutrinos awarded the American Frederick Raines and Perl



Martin L. Perl
Premio Nobel 1995

2002 for the creation of neutrino astronomy "

Masatoshi Koshiba

Raymond Davis

In 2015 for the discovery of neutrino oscillations Prize was awarded to Japanese Takaaki Kajita and Canadian Arthur McDonald.

1957 (before the discovery of the second neutrino): Pontecorvo publishes an article (in Russian, translated version in English in 1958), which suggests the possible existence of oscillations neutrino - antineutrino, in analogy with the oscillations $K^o - K^o$ proposed in 1956 by Gell - Mann and Pais checked experimentally with K^o mesons produced by accelerators: a meson K^o product in the collisions of a proton with a nucleus it is revealed as K^o at a certain distance from the source.

1957: discovery of symmetry violation of "parity" in weak interactions:
neutrinos emitted in the decay of β^+ and decay $\pi^+ \rightarrow \mu^+ + \nu$
have the spin anti-parallel to the direction of motion (helicity -1);
antineutrinos emitted in the decay of β^- and decay $\pi^- \rightarrow \mu^- + \bar{\nu}$
they have spin parallel to the direction of motion (helicity +1).

This finding requires a revision of the theory of Fermi neutrino helicity +1 and antineutrinos with helicity -1 are excluded from the theory - if they exist, do not interact with matter (neutrinos "sterile").
Oscillations neutrino - antineutrino suggested by Pontecorvo are then swings between a neutrino active and sterile neutrino.
In 1967 (after the discovery of the second neutrino), a second Pontecorvo's article, which suggests the possible existence of oscillations $\nu_e - \nu_\mu$.
A 1969 article in collaboration with the theoretical physicist VN Gribov presents detail the mathematical formalism of the theory of oscillations between two neutrinos.

Neutrino oscillation

some QM

- **Dualism wave - particle**

a particle with definite momentum is described by a plane wave of complex amplitude

$$\psi(\vec{r},t) = e^{2\pi i(\vec{p}\cdot\vec{r}-Et)/h}$$

where $\vec{r}$ ≡ (*x*, *y*, *z*), *E* ≡ particle energy, *t* ≡ time, *h* ≡ Plank constant. | ψ |^2 represents the probability density that the particleis in $\vec{r}$ at time t.

- **States superposition**

<u>Hyp.</u> : the neutrinos(ν_e, ν_μ) do not have a mass defined but are described by combinations linear, orthogonal of two states of neutrino (ν_1 , ν_2) with definite mass (m_1, m_2) ("mass eigenstates"):

$$\nu_e = \cos(\theta)\nu_1 + \sin(\theta)\nu_2$$
$$\nu_\mu = -\sin(\theta)\nu_1 + \cos(\theta)\nu_2$$

θ : "mixing" angle

Example: time evolution of a neutrino ν_μ produced with momentum $\vec{p}$ at time *t* = 0

$$\nu(t) = e^{2\pi i\vec{p}\cdot\vec{r}/h}(-\sin(\theta)\nu_1 e^{-2\pi i E_1 t/h} + \cos(\theta)\nu_2 e^{-2\pi i E_2 t/h})$$

where $E_k = \sqrt{(pc)^2 + (m_k c^2)^2}$ (*k* = 1, 2) . Because $m_1 \neq m_2$, $E_1 \neq E_2$ → the mix of states ν_1 , ν_2 changes as a neutrino ν_e appears at *t* > 0.

Probability to reveal ν_e at time t if $\nu(0) = \nu_\mu$:

$$\mathcal{P}_{\mu e}(L) = \sin^2(2\theta)\sin^2(1.267\Delta m^2 \frac{L}{E})$$

$\Delta m^2 \equiv m_2^2 - m_1^2$

$L = ct$ distance between the neutrino source and detector

Unit : Δm^2 [eV^2]; L [km]; E [GeV] (or L [m]; E [MeV])

NOTE : $P_{\mu e}$ it depends on Δm^2 (not by m !).

Length of oscillation λ:

$$\lambda = 2.48 \frac{E}{\Delta m^2}$$

Unit: λ [km]; E [GeV]; Δm^2 [eV^2]
(or λ [m]; E [MeV])

$\Rightarrow$

$$\mathcal{P}_{\mu e}(L) = \sin^2(2\theta)\sin^2(\pi \frac{L}{\lambda})$$

Article by Bruno Pontecorvo that discusses the physical experiment of Conversi, Pancini and Piccioni.

Phys. Rev <u>72</u> (1947) 246

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.

Pontecorvo think that the nuclear capture of the meson and the capture of an electron by an atomic nucleus are due to the same interaction although the huge difference between the probabilities of the two reactions

In the same article :

.... We shall consider then the hypothesis that the meson has spin $\frac{1}{2}\hbar$ and that its instability is not a β-process, in the sense that it does not involve the emission of one neutrino. The meson decay must then be described in a different way: it might consist of the emission of an electron and a photon or of an electron and 2 neutrinos[5] or some other process.

Yukawa suggested that the meson has an integer spin decays into an electron and a neutrino

The article suggests that the Pontecorvo "meson" of cosmic rays It behaves as an electron 208 times heavier than that interacts with nucleons as described by the theory of Fermi

Experiments conducted in the 1950s show that this particle, today called "muon", decays into three particles: an electron and two Neutrinos, according to the scheme::

$$\mu^{\pm} \rightarrow e^{\pm} + \nu + \bar{\nu}$$

The first experimental proposal to verify if there exist two distinct types neutrinos (ν_e , ν_μ)

SOVIET PHYSICS JETP VOLUME 37 (10), NUMBER 6 JUNE, 1960

ELECTRON AND MUON NEUTRINOS

B. PONTECORVO

Joint Institute for Nuclear Research

Submitted to JETP editor July 9, 1959

J. Exptl. Theoret. Phys. (U.S.S.R.) **37**, 1751-1757 (December, 1959)

Some processes due to free neutrinos, not heretofore considered, are discussed. Particular attention is paid to those processes which, in principle, could help decide whether two neutral lepton pairs [electron pair (ν_e and $\bar{\nu}_e$) and muon pair (ν_μ and $\bar{\nu}_\mu$)] exist.

To answer the fundamental question about the identity of ν_μ and ν_e a method is proposed which in essence is analogous to the method used to distinguish neutrinos from antineutrinos or K^0 mesons from $\bar{K}^0$ mesons. In principle the problem is solved when an experiment is carried out showing whether a beam of $\bar{\nu}_\mu$ is capable of initiating transitions which can without any doubt be initiated by $\bar{\nu}_e$ (for example the reaction $\bar{\nu}_\mu + p \rightarrow e^+ + n$).

Conclusion Article Pontecorvo: the proton accelerators in operation in 1959 does not have sufficient intensity to allow the experiment:

To sum up one could say that an experiment to establish the identity of ν_e and ν_μ, although very difficult, should be seriously considered in the planning of new accelerators. In particular the problem of shielding of the $\bar{\nu}_\mu$ detector from radiation should be looked to in the very first stages of design.

In the historical review "The infancy and youth of Neutrino Physics: Some Recollections" presented at the International Symposium on Particle Physics (Paris, July 1982), Pontecorvo wrote:

At the Laboratory of Nuclear Problems of the JINR in 1958 a proton relativistic cyclotron was being designed with a beam energy 800 MeV and a beam current $\sim$500 μA. By the way, this accelerator eventually was not built. Anyway at the beginning of 1959 I started to think about the experimental research program for such an accelerator.

Experiments conceptually very similar to the experiment proposed by Pontecorvo in 1959 it was performed in the 1990s at the National Laboratory Los Alamos (New Mexico, USA) and at the Laboratory Rutherford - Appleton Britain, using new high intensity proton accelerators, with different physical reasons, more than 30 years after the discovery of the second neutrino.

A few months after the publication (in Russian) of Pontecorvo,
"The Physical Review Letters," published an article of Mel Schwartz:

FEASIBILITY OF USING HIGH-ENERGY NEUTRINOS TO STUDY THE WEAK INTERACTIONS

M. Schwartz*
Columbia University, New York, New York
(Received February 23, 1960)

For many years, the question to how to investigate the behavior of the weak interactions at high energies has been one of considerable interest. It is the purpose of this note to show that experiments pointed in this direction, though not quite feasible with presently existing equipment, are within the capabilities of present technology and should be possible within the next decade.

We propose the use of high-energy neutrinos as a probe to investigate the weak interactions.

A natural source of high-energy neutrinos are high-energy pions.

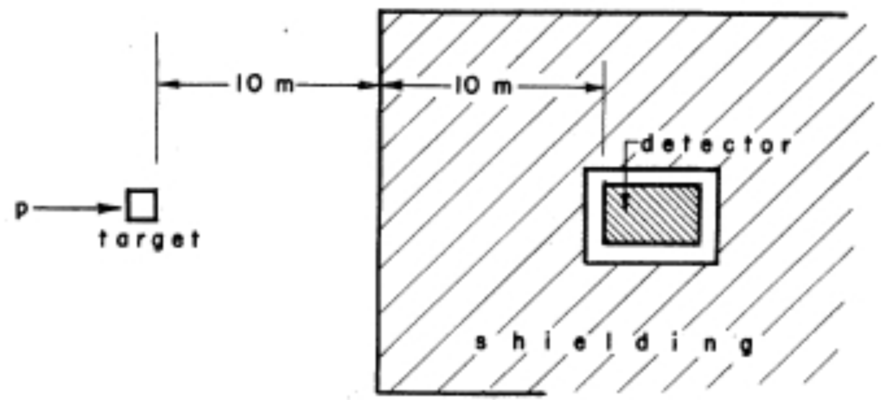


FIG. 1. Proposed experimental arrangement.

The main physics motivation for this proposal is the study of the interactions of high energy neutrinos with matter, in order to elucidate the behavior of weak interactions at high energy.
The problem of the two neutrinos($\nu_\mu \neq \nu_e$?) It is never mentioned in the article.

At the end of the article by Mel Schwartz we read :

Note added in proof. The author's attention has been called to a somewhat related paper which has just appeared: B. Pontecorvo, J. Exptl. Theoret. Phys. (U.S.S.R.) 37, 1751 (1959).