Bruno Pontecorvo; Mister Neutrino

S. Bilenky
JINR(Dubna)

December 16, 2009

12 fundamental fermions exist in nature

Six quarks: u, d, c, s, t, b

All hadrons are bound states of quarks: $p = (uud)$, $n = (udd)$, etc

Three leptons: e, μ, τ

Atoms are bound states of electrons and nuclei

$\mu(\tau)$ 200(3500) times heavier

Three neutrinos: electron neutrino ν_e, muon neutrino ν_μ and tau neutrino ν_τ

electron neutrino is produced together with electron $n \to p + e + \bar{\nu}_e$

Three interactions exist in the nature: strong, electromagnetic and weak

Quarks participate in all three interactions

Leptons in the electromagnetic and weak

Neutrinos have ONLY IN WEAK INTERACTION

It is very difficult to detect neutrinos (very large detectors, underground, ...)

If neutrinos are detected it is possible to obtain unique information (internal part of the sun where solar energy is produced, mechanism of the gravitational collaps (SN), quark structure of the nucleon etc)

Idea of the existence of neutrino was put forward by W.Pauli (1930)

On the basis of the hypothesis of neutrino E. Fermi built the first theory of the beta-decay

In 1934 Bethe and Pierls estimated the cross section of the interaction of neutrino with a nucleus

The estimated cross section was so small ($\sigma \simeq 10^{-43}\text{cm}^2$) that during many years the neutrino was considered as an "undetectable particle".

The first method of neutrino detection was proposed by Bruno Pontecorvo in 1946

"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. Pontecorvo proposed radiochemical method of neutrino detection based on the observation of the decay of the daughter nucleus produced in the reaction

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

An experiment based on the observation of the reaction

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

he considered as the most promising (cheap target (C_2Cl_4), convenient half-life of ^{37}Ar (34.8 days), possibility to extract a few atoms of ^{37}Ar from a large detector etc)

The $Cl - Ar$ method was used by R. Davis in the first experiment on the detection of the solar neutrinos. Radiochemical $Ga - Ge$ method of neutrino detection was used in the GALLEX-GNO and SAGE solar neutrino experiments.

In 2002 R. Davis was awarded the Nobel Prize for the detection of the solar neutrinos

BRUNO PONTECORVO (short biography)

Bruno Pontecorvo was born in Pisa in 1913

"A scuola ero bravo ma la cosa piu' impotrante nella mia vita era il tennis, di cui mi picco a tutt'oggi di essere un profondo conoscitore" (Una nota autobiografica)

At school I met expectations, yet the most important thing in my life was tennis, to this day I pride myself on my deep knowledge of it.

There were five brothers and three sisters in the family.

Three brothers became famous. Guido was very important biologist; Gillo was famous film director and Bruno was great physicist

Opinion of parents about children

"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)

Guido was the most intelligent among the siblings, Paolo the most serious, Giuliana the most knowledgeable, Bruno the most good-natured but also the least smart, as shown also by his eyes, which expressed kindness but not intelligence...

1932-36 Rome, E. Fermi group. Neutron physics. Effect of slow neutrons

1936-40 Paris, F. Joliot-Curtie laboratory. Nuclear isomerism

1940-42 USA, oil company. Neutron well logging, first practical application of neutrons

1943-48 Chalk River Laboratory, Canada. Muon physicks, neutrino, reactor physics

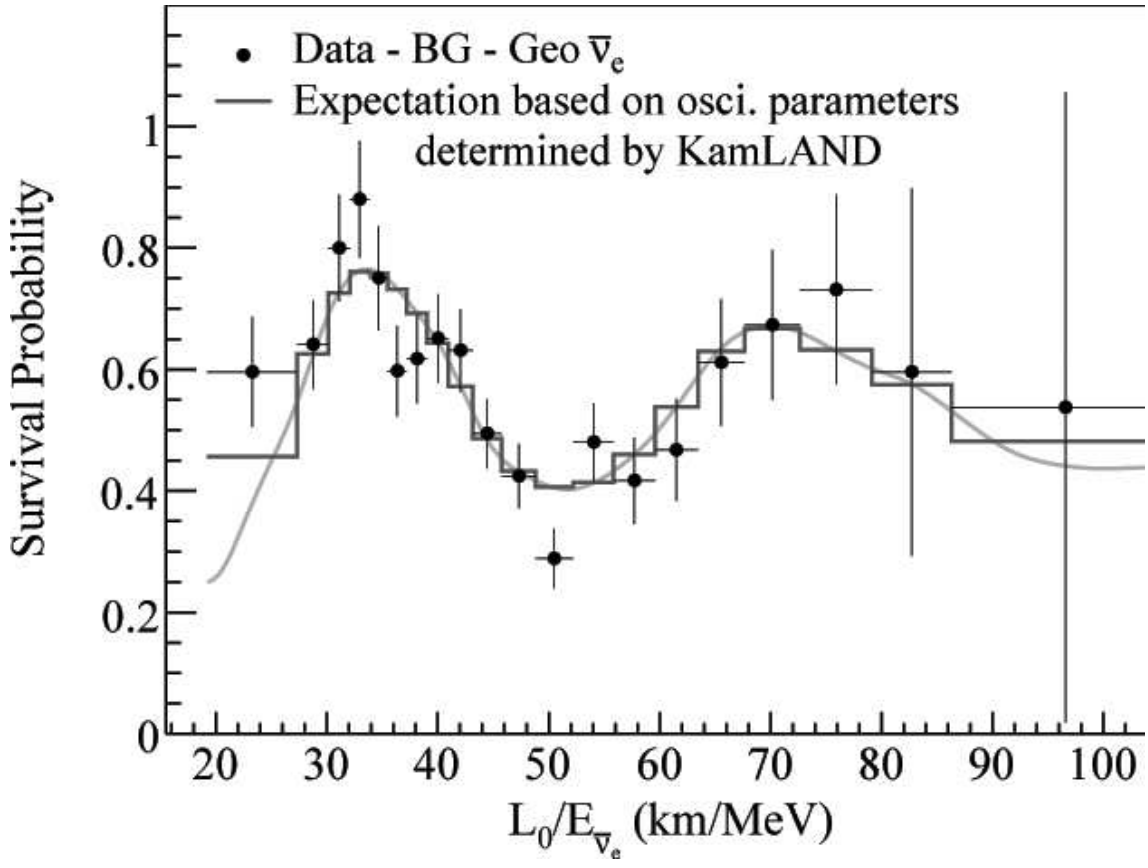
1948-50 Harwell Laboratory, England. Muon physics

1950-93 JINR, Dubna. Production and scattering of pions, weak interaction, neutrino physics

NEUTRINO OSCILLATIONS

The most important recent discovery in the particle physics was discovery of neutrino oscillations in the Super-Kamiokane atmospheric experiment, solar neutrino experiments, KamLAND reactor neutrino experiment, accelerator neutrino experiments

If you detect reactor $\bar{\nu}_e$ at a distance about 180 km from a reactor you will see that the average flux of $\bar{\nu}_e$ will be about 0.6 of the expected flux. If you detect flux as a function of $\frac{L}{E}$ you will observe a periodical dependence on this parameter



Neutrino oscillations are possible only if

- Neutrino masses are different from zero

- Produced (detected) neutrinos (ν_e, ν_μ, ν_τ) are "mixtures" (superpositions) of states of neutrinos with definite masses

It was discovered that neutrino masses are many order of magnitudes smaller than quark and lepton masses

This is an evidence that masses of neutrinos and quarks and leptons are of DIFFERENT ORIGIN

Masses of quarks and leptons are geneated by the standard Higgs mechanism (will be checked by LHC experiments)

Small neutrino masses are generated by a NEW MECHANISM

Small neutrino masses is a first signature of a new beyond the SM physics

First idea of neutrino oscillations was put forward by Bruno Pontecorvo in 1957-58 in Dubna

After the discovery of the violation of parity in the weak interaction Landau, Lee and Yang and Salam proposed the theory of the two-component neutrino

THIS THEORY WAS BASED ON THE ASSUMPTION THAT NEUTRINO IS MASSLESS PARTICLE

According to the two-component neutrino theory neutrino is a left-handed particle and antineutrino is a right-handed particle

Helicity of neutrino was measured in Goldhaber et al experiment (1958)

It was confirmed the neutrino is the left-handed particle

After the confirmation of the two-component neutrino theory it was a general belief that neutrinos are massless particles

B. Pontecorvo believed that exist a similarity of the weak interaction of hadrons and leptons

He searched in the lepton sector for a phenomenon, analogous to the famous Pais-Picconi effect ($K^0 \leftrightarrows \bar{K}^0$ 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."

In 1957 R.Davis with antineutrinos from a reactor searched for the process

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

which is forbidden due to the conservation of the lepton charge

A rumor reached B.Pontecorvo that Davis observed such events. He decided that the possible explanation could be transformation of the reactor antineutrinos into neutrinos and PUBLISHED FIRST PAPER ON NEUTRINO OSCILLATIONS (1958)

"Neutrinos in vacuum can transform themselves 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".

" 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"

The Pontecorvo idea of a reactor neutrino oscillation experiment was realized in the KamLAND experiment in 2002

In 1970 R. Davis published first results of the experiment on the detection of the solar neutrinos. Observed flux of the solar neutrinos was 2-3 times smaller than the predicted flux (solar neutrino problem).

In the second paper on neutrino oscillations (1967) Pontecorvo generalizes his idea of neutrino oscillations for the case of two types of neutrinos ν_μ and ν_e . In this paper he considered solar neutrinos. He envisaged the solar neutrino problem

"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".

We started to work on neutrino oscillations in 1975. It was in car in the September. B.P. liked underwater fishing. In autumn he usually went for that at the river Nerl, about 150 km from Dubna. Often he invited me and my wife for such trips. We usually prepared fire and collected mashrooms. In such an invirement we started our collaboration on neutrino oscillations.

We worked on neutrino oscillations for many years. We considered all possible schemes of neutrino mixing and different neutrino oscillation experiments. We published about 25 papers and first review on neutrino oscillations which attracted interest to the problem of many physicists. Our last neutrino review (for Italian Encyclopedia) was written in 1987.

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

I am very happy that after a lot of efforts contribution of Bruno Pontecorvo to neutrino oscillations is recognized by the community.

Neutrino mixing matrix is called Pontecorvo-Maki-Nakagawa-Sakata (PMNS) mixing matrix

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 great gifts

He devoted all his resources and 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 stopped to work, to think about neutrinos and to continue active life.

After perestroika it was natural for me to continue collaboration on neutrino physics and neutrino oscillations with many Italien physicists.

Together with C. Giunti, A, Bottino, W. Alberico, C. Majoron (Torino) A. Masiero and S. Petcov (SISSA, Trieste) we wrote many papers. We considered decoupling of neutrino oscillations in the three-neutrino case, neutrinoless double beta-decay, NC neutrino-nucleon scattering and many other problems.

Now a stage of high-precision neutrino oscillation experiments started. Together with W. Alberico and C. Giunti (Torino) we have a program of detailed investigation of uncertainties of the neutrino cross sections. Without detailed knowledge of cross sections it is impossible to answer such fundamental problems as the value of the crucial parameter $\sin\theta_{13}$ and the values of other parameters.