Inside Story: Pontecorvo and neutrino physics

The "father" of neutrino oscillations, born a century ago, had many ground-breaking ideas.

Pontecorvo

Bruno Pontecorvo was born in Pisa on 22 August 1913 to the family of a prosperous manufacturer. As a student in Rome from 1931 to 1936, he was a member of the famous group of "Via Panisperna boys" under Enrico Fermi. By 1943 he had moved to Canada and took part in the design and commissioning of the powerful heavy-water nuclear reactor in Chalk River but also investigated muon decays in experiments with Ted Hincks. These proved that the charged particle produced when a muon decays is an electron, that the muon decays into three particles and that it never decays into an electron and a photon – leading to the notion of "lepton charge". Pontecorvo went on to suggest the existence of a universal μ–e weak interaction in 1947.

At Chalk River he was the first to propose that it should be possible to detect neutrinos. In 1934, Hans Bethe and Rudolf Peierls had calculated that the cross-section for the interaction of a neutrino with matter should be less than 10^{-44} cm^2 and had concluded that it would be impossible to detect neutrinos. Pontecorvo doubted this and realizing that a nuclear reactor would be an intense source of neutrinos (in fact, antineutrinos), in 1946 he suggested detecting them through the extraction of the argon isotope produced in the reaction $\nu + {}^{37}Cl \rightarrow {}^{37}Ar + e$. This is the technique that became famous in Raymond Davis's detection of neutrinos from the Sun. Pontecorvo also designed a small proportional counter with high resolution, which he used to detect the nuclear capture of L-electrons in argon for the first time. This allowed him to make the first measurement of the tritium β-spectrum and to obtain a limit on the mass of the electron neutrino of less than 500 eV.

In August 1950, Pontecorvo, his wife and three sons moved to the USSR and he joined JINR, in Dubna. He arrived soon after the start-up of what was then the world's most powerful synchrocyclotron, and joined in research on strong interactions. However, his interest turned again to weak interactions and neutrino physics. In a paper published in 1959, he showed that neutrinos produced in the decays of particles from an accelerator could be observed with big detectors and proposed an experiment to find out if electron and muon neutrinos differ from each other. The successful implementation of such an experiment at Brookhaven in 1962 – independently proposed – was to mark the beginning of high-energy neutrino physics at accelerators. A year earlier, on Pontecorvo's initiative an attempt was made at the JINR synchrophasotron to detect weak neutral currents via the reaction $\nu_\mu + N \rightarrow \nu_\mu + N$. Neutral currents were discovered at CERN a decade later in 1973, with a much more intense neutrino beam.

It was a little earlier, in 1957, that Pontecorvo first suggested the possibility of transitions between muonium (μ^+e^-) and antimuonium (μ^-e^+). (These would be forbidden in the Standard Model because the lepton numbers of the particles both change by two). In discussing these transitions, he proposed that oscillations can occur not only in bosons – neutral kaons and muonia – but also in electrically neutral fermions, i.e. neutrinos. As in the neutral kaon system, this would be possible only if neutrinos possess small, nonzero masses. At a time when the muon neutrino was still unknown, he introduced the notion of the sterile neutrino and considered neutrino oscillations into sterile antineutrinos.

This marked the birth of the hypothesis of neutrino oscillations, which Pontecorvo founded on a close analogy between the weak interactions of leptons and hadrons, long before the idea of quark–lepton symmetry in today's Standard Model. The importance of neutrino oscillations – both for the detection of nonzero neutrino masses and the possible non-conservation of lepton charge – was clear to him. It was to take years of effort by many people for the tiny neutrino masses to become reality. The eventual discovery of neutrino oscillations was a triumph for Pontecorvo's idea. Sadly, it came nearly a decade after his death in 1993 but his name is now enshrined in the title of the neutrino mixing matrix – the Pontecorvo-Maki-Nakagawa-Sakata matrix.

His important ideas on neutrinos did not end with the oscillation hypothesis. In 1959 he was the first to indicate the significance of weak neutral currents between electron neutrinos and electrons for stellar evolution. Then in 1961 – four years before the discovery of the cosmic microwave background radiation – he and Yakov Smorodinsky proposed the possible existence of a "neutrino sea" that must result from the Big Bang. This was in effect the first discussion of dark matter in the form of relic neutrinos. Pontecorvo also stressed in other work the importance of neutrinoless double β-decay in non-accelerator physics, as the process is possible only if the neutrino is a Majorana particle – i.e. identical to its antiparticle. This decay is therefore a unique probe of new physics beyond the Standard Model.

In recognition of Pontecorvo's outstanding service to science, a memorial plaque of the European Physical Society was inaugurated on the doors of his study at JINR in

February this year. As a top-rank scientist, he had combined the gift of deep insight into the essence of physical phenomena with the extraordinary talent of an experimenter. His passion for science, his clear and critical mind that was open to new decisions, his talent to see a problem in a new light, his rich knowledge – all left an indelible impression on everyone who knew him. He was also incredibly amiable and his personality brightened the lives of those who were happy to be his friends.

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