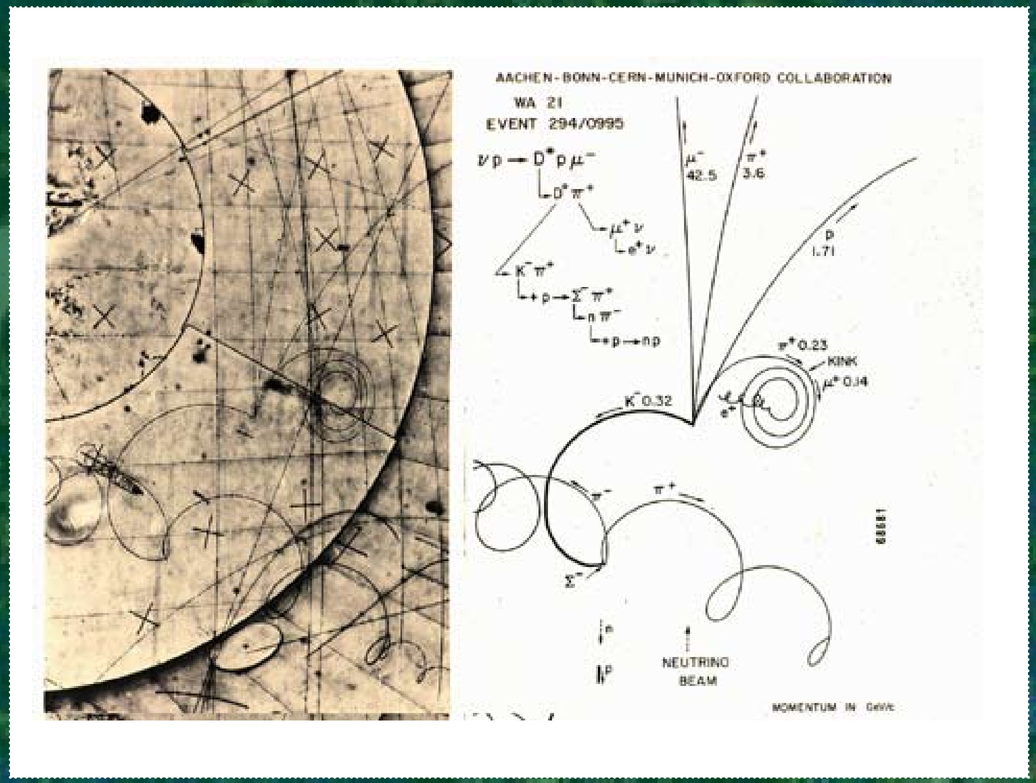
Neutrinos *at CERN*

Neutrinos are elusive particles. They are neutral, nearly weightless, travel almost at the speed of light, and hardly interact with ordinary matter. In neutrino experiments the rarity of the reactions has to be compensated for by an intense neutrino beam and very massive targets.

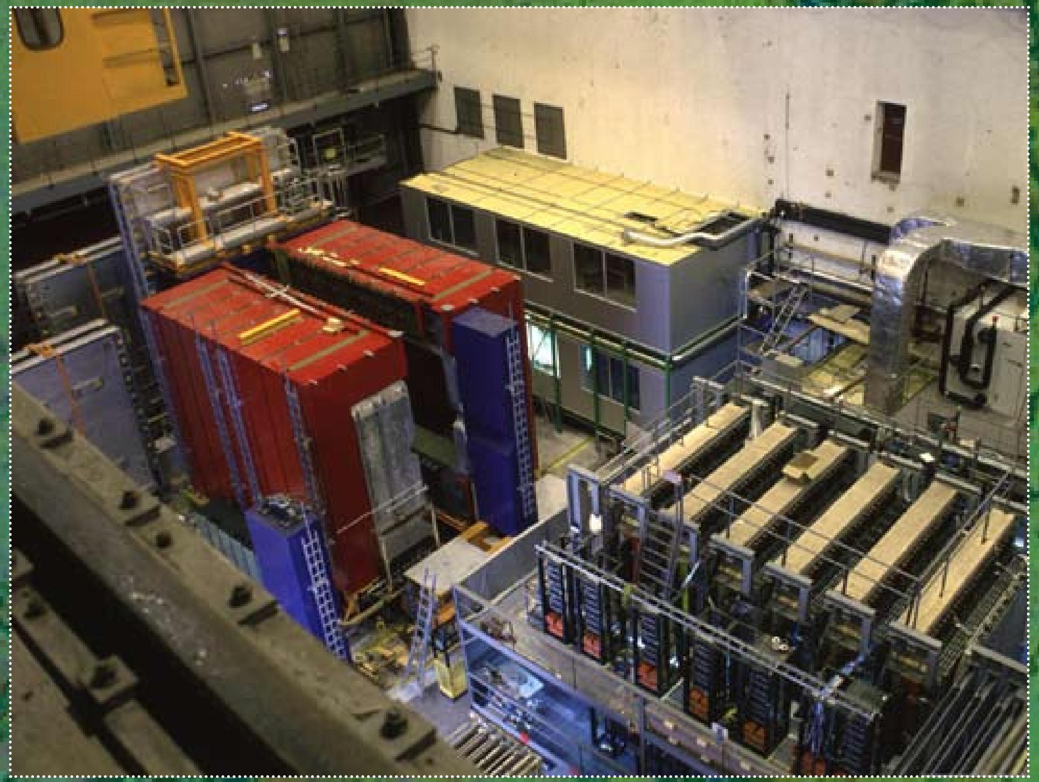
Research using neutrinos began at CERN in 1959 with particles from the PS. Its first major breakthrough was the discovery of the so-called 'neutral currents' in the Gargamelle bubble chamber in 1973.
In 1977 beams from the SPS took over, delivering 10 times higher energies. New, extremely massive detectors were built and set up, such as the 100 tonne CHARM and the 1250 tonne CDHS experiments. These were installed in the SPS neutrino beam together with the BEBC and Gargamelle bubble chambers.
First experiments focused on more detailed studies of neutral currents, on the inner structure of protons and neutrons, and on the theory of strong interactions. Gargamelle showed that the neutrino-nucleon cross-section rises linearly with energy, a direct demonstration of point-like constituents (quarks) inside the nucleon. By comparing the structure functions of the nucleon derived from neutrino scattering at Gargamelle and from muon scattering in other experiments, it could be shown that quarks have indeed a fractional electric charge as predicted by theory.
Neutrinos themselves were also examined, to find out if they have mass.



An example of charm production and decay by a neutrino beam in BEBC.

During its lifetime the Big European Bubble Chamber (BEBC) recorded many thousands of neutrino interactions. The enormous amount of detail available in bubble chamber pictures allowed the study of particular final state particles, notably charmed particles, and the measurement of production cross-sections, masses and decay modes.

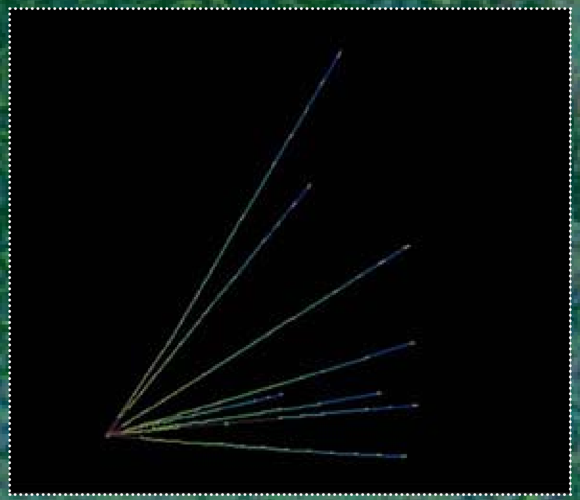
"The CDHS detector was used at CERN from 1977 to 1983 and with the help of neutrinos a good deal could be learned about the Standard Model as well as about the structure of the nucleon. Probably the most important result of the SPS neutrino experiments was the observation of so-called 'scaling violations', providing a first quantitative confirmation of the new theory of the strong interaction. Although the theory was very attractive, there had been no quantitative prediction of the theory that had been confirmed. The theoretical predictions were measured by the CDHS experiment for the first time, and thus gave experimental support to the new theory, a milestone in the establishment of the Standard Model. "
Jack Steinberger, Infinitely CERN, 2004



CHORUS and NOMAD.

Throughout the lifetime of CERN's West Area facility, neutrino oscillations were the object of continued conjecture and study. Expertise in neutrino beams and also the variety of detectors available meant very stringent limits were placed on the oscillations, and thus on neutrino mass. CHORUS and NOMAD began operation in 1993 exploring muon neutrino -> tau neutrino oscillations at a time when tau neutrinos were believed to have a mass of the order of 1 eV and would, therefore, have made up an important component of dark matter in the Universe. Over the years, the experiments pushed the limit for the probability of muon neutrino -> tau neutrino oscillations to ~ 0.015%.

Neutrino oscillations have since been seen with the help of neutrinos from the Sun and from high-energy cosmic rays, but such measurements depend on an unknown parameter - the neutrino flux from the Sun or from space. In fact, nature has chosen neutrino masses such that oscillations occur over baselines of several hundreds of kilometres. Today, the CERN Neutrinos to Gran Sasso project studies oscillations over a 730 km baseline. Since 2006, a neutrino beam produced at the SPS passes through the Earth to the Gran Sasso National Laboratory in Italy, where the OPERA detector looks for the rare tau-neutrinos created by oscillation of muon-neutrinos on the way.



The first neutrino event seen by OPERA in October 2007.