The hunt for the muon neutrino

In order to understand how the **weak force** works and to explore the possible existence of **two neutrinos**, it was necessary to study neutrino interactions at high energies. **Leon Lederman**, **Melvin Schwartz** and **Jack Steinberger** were working to achieve a sufficiently intense neutrino beam for several years. This neutrino beam was produced in several steps:

- Protons were accelerated to an energy of 15 GeV (1 GeV = 10^9 eV) in the Brookhaven accelerator AGS (Alternating Gradient Synchrotron) on Long Island, USA.

- The intense proton beam was directed onto a target of beryllium. In each collision a handful of particles were produced, mainly pi-mesons.

- The many pi-meson decays
$(\pi \rightarrow \mu + \nu_\mu)$
resulted in a collimated beam of muons and neutrinos.

- The neutrinos, the muons and the surviving pi-mesons crashed into a 13 m thick steel shield, which stopped all particles except the neutrinos.

The steel shield, which was made of armour plates from scrapped warships, was essential for the experiment. All particles, except the neutrinos, had to be prevented from reaching the detector, as they could give rise to a large number of particle reactions and completely swamp the incredibly few neutrino reactions. The pi-mesons, which interact through the strong force, were stopped after less than half a metre of armour plates, while the muons, which interact mainly through the electromagnetic force, penetrated much further. The steel shield, which had a weight of about 2000 tons, was dimensioned to stop the penetrating muons.

For the neutrinos to have a fair chance to interact, i.e. collide, **the detector had to be massive**. Furthermore, the charged particles produced in the collision had to be detected. **Leon Lederman**, **Melvin Schwartz** and **Jack Steinberger** studied different types of detectors before they decided, in 1960, to construct a 10 ton spark chamber. The detector was divided into 90 plates of aluminium, each an inch thick. The spaces between the plates were filled with neon gas.

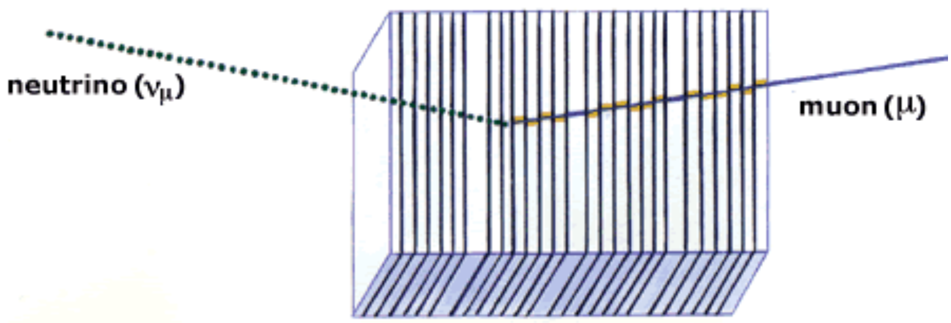
As neutrino interactions are very rare, the background from other processes was disturbing, particularly the background caused by the penetrating muons from the cosmic radiation. The background was reduced by keeping the experiment active only during the short pulses, 3 microseconds, when the accelerator delivered particles. During the 8 month experiment period they accumulated data for 25 days, but because of the short pulses, the efficient time for the detector was only 6 seconds.

Each neutrino pulse contained 10^7 neutrinos. During the experiment a total of 10^{14} neutrinos went through the detector during the six seconds it was active. When a reaction took place, a high voltage was applied to the spark chamber and a discharge occurred where the produced charged particles had passed. The sparks were photographed and gave a picture of the particles' path through the detector. A total of 51 neutrino interactions were registered with a muon observed in the spark chamber. These results showed that the neutrinos, produced together with muons, give rise to muons, not electrons.

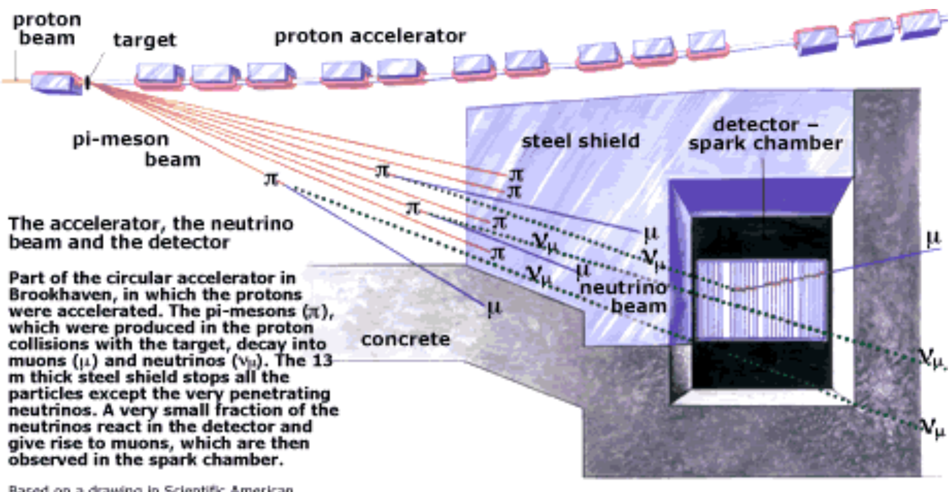
The muon neutrino was discovered!

The experiment of the Nobel Prize winners not only showed that the muon and the muon neutrino form a pair, it also showed that the other two leptons, the electron and the electron neutrino, form a pair. The grouping in pairs of elementary particles is fundamental in particle physics and became even more significant after the establishment of the so called standard model.

Several experiments have since been carried out both in the USA and Europe in order to study **the innermost structure of matter** and to further explore the weak force.



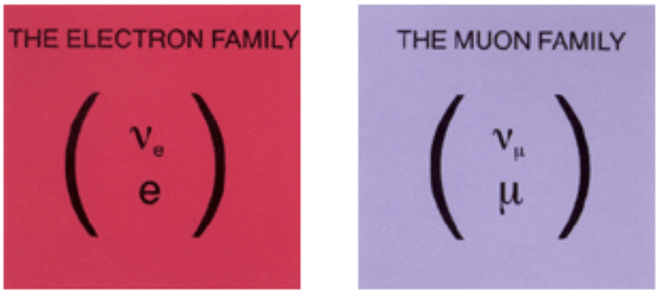
A muon produced in a neutrino reaction gives rise to discharges observed in the spark chamber.



The accelerator, the neutrino beam and the detector

Part of the circular accelerator in Brookhaven, in which the protons were accelerated. The pi-mesons (π), which were produced in the proton collisions with the target, decay into muons (μ) and neutrinos (ν_μ). The 13 m thick steel shield stops all the particles except the very penetrating neutrinos. A very small fraction of the neutrinos react in the detector and give rise to muons, which are then observed in the spark chamber.

Based on a drawing in Scientific American, March 1963.



The known lepton families after the neutrino experiment; the electron (e) and the electron neutrino (ν_e), the muon (μ) and the muon neutrino (ν_μ).

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