charged π mesons have this electromagnetic interaction, and the μ meson and the electron. The latter two do not have the strong interaction. In addition there are little wiggles, shown with all the particles, that represent the weak interaction.

These embellishments to the idea of particles represent the couplings and in fact represent the only way we have of studying these particles, i.e., by means of their interactions. The neutrino is unique in that it has no strong interactions and no electromagnetic interaction but is susceptible only to weak interactions. There may be particles which have none of these interactions, but I can't list them because we don't know about them.

The strong interaction is the thing that holds the nucleus together. The difference between interaction as we talk about it and the normal kind of force that everyone knows about is that these interactions are not only capable of attraction and repulsion in the usual way but are also capable of generating transformations. For example, a π^+ meson can disassociate itself into a proton and an antineutron:

$$\pi^+ \rightarrow p^+ + \bar{n}^0 . \tag{1}$$

This is evidence of the strong interaction at work.

The electromagnetic interaction, from our point of view, is relevant only in that charged particles leave tracks in bubble chambers and spark chambers and uncharged particles do not. There is also a transformation which involves the electromagnetic interactions, for example, an electron can radiate, can give rise to another electron and a photon (which I did not list as a particle, but you can "see" that it is one):

$$e \rightarrow e + \gamma . \tag{2}$$

I might also state, for future use, that the probability of this reaction varies as $\sim 1/m^2$, where m is the mass of the particle involved; an electron, being a light particle, just loves to radiate.

Finally, there are the weak interactions, and so far the only types of weak interactions are transformations; we have not yet observed the other kind of effect. The transformations of the weak interactions are very well known in this Laboratory; they are manifest in the radioactivity of nuclei. The most important example is the decay of a proton or a neutron in the nucleus, i.e., neutron gives rise to proton plus electron plus, in this case, antineutrino:

$$n^0 \rightarrow p^+ + e^- + \bar{\nu}^0 . \tag{3}$$

This, then, occurring in the nucleus gives rise to the vast phenomena of beta radioactivity.

The story of this reaction tells the basic history of the neutrino, which I can review only very briefly.

In the early days only the charged particle was observed in the disintegration of the nucleus when, say, an electron was emitted. The energies of the electron in successive disintegrations were distributed over a wide region. Although the change in energy of the disintegrating nucleus was always the same, only *part* of this energy was carried away by the emitted electron. One school of physics was ready to give up the law of conservation of energy, but Pauli, with great insight and with an appreciation of other things involved, like angular momentum, held on to it and postulated an unseen particle in order to preserve conservation of angular momentum and energy. This was in 1930, and in the next 20 years or so a vast amount of data succeeded in confirming this hypothesis. Fermi was the first one to write down the detailed theory of this reaction.

All sorts of measurements, on the spectrum of electrons, on the angular correlation, on conservation of momentum, led to a confirmation of the hypothesis that a neutral particle of very small mass was needed. Finally, in 1956, Reines and Cowan succeeded in doing an experiment in which they actually took neutrinos from an intense source of radioactivity (a nuclear reactor) and produced a reaction of this kind,

$$\bar{\nu} + p^+ \rightarrow n^0 + e^+ , \tag{4}$$

which is essentially a rearrangement of the particles involved in beta radioactivity. It was the first time the reaction was generated on purpose rather than spontaneously, as in the decay

$$p^+ \rightarrow n^0 + e^+ + \nu^0 . \tag{5}$$

Therefore, this was the final confirmation that this particle had a real existence, although the reality of the neutrino had pretty much been accepted by about that time or even before. In the 1950's, and through the incident of the violation of parity conservation, a large number of people contributed to the subject of beta decay and the subsequent observation of other decays. After the war the mesons had taken the stage, and a large variety of these particles were observed. For example, the μ meson was observed to decay into an electron plus a neutrino plus an antineutrino, and the π meson was discovered to decay into a μ meson plus a neutrino: