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Neutral kaon decays-weak process

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In the history of bubble chamber experiments, the study of weak interactions has been one of the most brilliant chapters, specially with the particular tool which is the decay of the neutral Kaons.

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11

The study of weak interactions with the bubble chamber came to a very unique historical coincidence in the early sixties. The high energy accelerators were able to produce intense Kaon beams and the bubble chamber became a mature experimental technology. At the same time, the Universal Fermi Interaction took shape and the solution of the τ - θ puzzle helped to build a comprehensible system K^0 - $\bar{K}^0$.

We will first provide a brief overview of the situation in the early sixties and then choose few of the topics where the contributions of our technology have been the most valuable.

The sixties.

Following R.K.ADAIR at the 1961 Aix en Provence Physics conference : "A basic postulate, or better, faith, in our concern with the weak interactions, is our belief in the Universal FERMI Interaction". This theory was able to represent β decay, μ decay and the decays of strange particles. All interactions were adequately described by one phenomenological current x current lagrangian. This description was completed with many assumptions, which were not in contradiction with experiment, such as :

1. The two component neutrino theory, ν_μ ν_e have the helicity +1
2. Lepton conservation
3. Absence of neutral current
4. μe universality
5. $|\Delta I| = 1/2$, $\Delta S = \Delta Q$, $\Delta S = \pm 1$
6. Charge symmetry of $\Delta Y = 0$
7. CVC
8. PCAC
9. CPT invariance

The experimental program was largely based on tests of such rules.

The discovery of the Parity violation in 1957 solved what was called the τ - θ puzzle and so the representation of Gell-Mann and Pais for the K^0 - $\bar{K}^0$ were commonly accepted. But W.K.H. Panofsky at CERN in 1959 admitted that "The K^0 - $\bar{K}^0$ versus θ_2 - θ_1 complex (including the mass differences) remains unexplored in details. Further exploration is limited by lack of intensity".

At the same time the particle physics community was stopping the cosmic ray experimental program to turn toward accelerator based experiments. The Bevatron, Cosmotron, Saturne, Synchrotron were followed by the CERN PS and the AGS. Intense extracted beams allow for a large production of neutral Kaons. K^0 's were produced in pp collisions or in associated production ΛK . H.Ticho designed charged K beams which were used to produce K^0 by the reaction $K^+ + n \rightarrow K^0 + p$ or $K^- + p \rightarrow K^0 + n + \pi^-$. Intense flux of K^0 with known momenta became available.

And finally, the needed tool showed up. After the discovery of Glaser a few years were necessary to extrapolate the cubic centimeter device to a real bubble chamber of several hundreds liters with magnetic field. A large quantity of liquid hydrogen, deuterium, propane, freon, helium, xenon... provided a variety of choices to pursue the purpose of the particular experiment : production or decays with identification and measurement of neutral and charged particles.

The coincidence of all those events allowed the bubble chamber technology to play a unique role in the building of the present theory of weak interactions.

Selected topics

Now it is worth spending some time on a few of the experiments which have played a key role in the building of the weak interaction theory.

The $\Delta I = 1/2$ Rule

The most interesting news of the year 1960 was the spectacular success of the verification of this rule. This predicted a ratio for the K^0 short decay rate into two pions of $1/3$. The study of the K^+ decay rate into 2 pions had already shown a small violation, of the order of $4.5 \pm 0.5\%$, but the available technologies enabled the hydrogen bubble chamber team to count the ratio of the number of $\pi^+\pi^-$ decays by the number of K^0 product and the heavy liquid bubble chamber team to count the number of $\pi^0\pi^0$ decays. The global fit gave a world average of 0.316 ± 0.014 to be compared to 0.33 , compatible with the violation observed in K^+ decays.

The $\Delta S < 2$ Rule

When a K_L^0 beam crosses a heavy nucleus target inside a bubble chamber, it can regenerate a K_S^0 meson by three different processes : the interaction with a single nucleon, with the whole nucleus and the different absorption between the K^0 and the $\bar{K}^0$ amplitudes. In the latter case the produced K_S^0 emerges in exactly the same direction as the incoming K_L^0 .

The angular distribution as well as the intensity as a function of the target thickness will allow us to measure the mass difference. If the mass difference is of the order of G , the coupling constant, this indicates a $\Delta S = 2$ transition from K^0 to $\bar{K}^0$, however, if the mass difference is of the order of G^2 , then this proves that the direct transition is forbidden and must go through two distinct vertices.

The theoretical idea had been put forward by L.Okun and B.Pontecorvo and the experimental tricks by R.L.Good, F.Muller and O.Piccioni. In order to take away the nuclear effect, the next idea was to use two plates with an air gap method. The result of $\Delta m = 0.84 \pm 0.29 - 0.22 \hbar/\tau_1$ ruled out the presence of $\Delta S = 2$ transition.

The $\Delta S/\Delta Q = 1$ rule

The test of this rule has been one of the longest stories of weak interaction and K^0 particles. It started as a by-product of the $K^0\bar{K}^0$ mass difference analysis. J.Fry and U.Camerini remarked that following this rule the K^0 should produce only $\pi^-e^+\nu$ decay and the $\bar{K}^0$ only $\pi^+e^-\nu$. If at the point of K^0 production you have a pure K^0 state the analysis of the sign of the decay electron could be a good test of the rule. Obviously as soon as the K^0 propagates in the liquid, the mixing of eigenstates occurs and the complete time distribution of the sign asymmetry must be used.

An ill-fated event found in a very low statistics experiment created a lot of excitement in the physics community and an almost 10 years search for $\Delta S/\Delta Q$ violation...

The difficulty in the selection of the event came from the electron identification and the track measurability for the sign determination. The standard two pion decays were used for background evaluation. If x is the ratio of forbidden to allowed transitions, the present result is $\text{Re } x = 0.03 \pm 0.06 - 0.07$

$$\text{Im } x = 0.07 \pm 0.06 - 0.07,$$

compatible with no violation and at the limit of what bubble chamber technology could provide.

CP violating $K_L^0 \rightarrow 2\pi^0$ decay

One of the nicest and fun experiments, had been proposed by A.Lagarigue after the

A good example of the versatility of bubble chamber technology. The $K_L^0 \rightarrow 2\pi^0$ decay in the CERN 1.1. m heavy liquid bubble chamber with a vacuum pipe and a mirror. Photo CERN.

discovery of the CP violation in 1964. This discovery was the presence of a two charged- pion decay in a K_L^0 beam. The physics question was, at this time : "is it an anomalous decay specific to this channel, or an indication of a general weak interaction characteristic?". To answer, the evidence of a CP violating transition in another channel was mandatory. Lagarrigue proposed sending a K_L^0 beam into a vacuum pipe running inside the 1.1m heavy liquid CERN bubble chamber.

The presence of such a body makes difficult the pressure equilibrium of the chamber. Also the pipe was hiding a part of the volume needed for gamma rays identification. The expertise of the CERN engineers solved the first problem and a mirror glued on the expansion plate eased the second one.

A sample of 26560 pictures had been used where all neutral decay with N gamma's rays were recorded. The 6 γ events were used to generate fake $2\pi^0$ events. Finally a significant number of 24 ± 6.3 events showed the presence of this CP violating mode. After flux normalisation the ratio of η_{00}/η_{+-} was equal to $1.16 \pm .20$, which showed that the process involved is of the same nature and confirmed the presence of a CP violation in weak interaction.

V-A Theory of weak interaction

For a long time the study of the kinematics of K decay has been 'bread and butter' for the experimentalist. The spectrum, angular distribution and Dalitz Plot allow for the evaluation of form factor which indicates the nature Scalar, Vector, Tensor, Axial or Pseudo vector of the weak interaction. The best place for this study is the K^+ decay as presented in this conference by G.Kalmus, but a good contribution came also from an experiment of K^0 decay in the ZGS hydrogen bubble chamber.

A sample of 45000, 3 body K^0 decays showed that the values obtained for the form factor in a V-A hypothesis provides a good consistent picture for all known decay modes. This was, in 1980, the last significant test of the V-A nature of the weak interaction, and also marked the end of an era of the bubble chamber and K^0 physics.

Conclusion

The contribution of bubble chamber experiments in particle physics is especially important in the development of the weak interaction theory, and in our present knowledge of the standard model, with particular insight from studies of the neutral Kaon system. Even today in the Particle Data booklet more than 80 references come from our community. The golden age for the bubble chamber history has been the sixties, but some groups remained active until the mid eighties. Today, the branching ratios of the order of 10^{-8} and Dalitz plot with millions of events are several orders of magnitude away from a realistic bubble chamber experiment.

One of the most valuable aspects of this contribution was the very active life of friendship, communication, sharing of clever ideas inside a large international community using a great variety of bubble chambers.