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COULD NEUTRAL CURRENTS HAVE BEEN DISCOVERED IN THE 1960s? - THE ROLE OF FLAVOR-CHANGING NEUTRAL CURRENT (FCNC)[a]

UCLA-PPH-0077-6/97

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UCLA-PPH-0077-6-97

While it is well known that neutral currents were discovered in 1973, a lesser known fact is that the search for various forms of neutral current actually started a decade earlier. We review this search and provide some comments on the probable reasons for the failure to detect a 30% effect in the case of weak neutral current (WNC), and the significance of the role played by the null searches for FCNC in the rise of the standard model. Theoretical prejudices played an important role during this period.

1 The Early Concepts of the IVB and Neutral Currents

As is well known, the weak interaction was accidentally discovered by H. Beckerel in 1896 when he placed uranium and a photographic emulsion in the same drawer and then discovered that the emulsion had become exposed. This was the discovery of the charged-current weak interaction. It took 77 more years to discover the neutral current weak interactions in 1973. In the intervening years, there were repeated suggestions that there could be a neutral current interaction. The earliest explicit suggestion seems to have been made by Gamow and Teller in 1937.[1] In the 1950s and 1960s, there were many models of the weak force that included a neutral component.

After the formulation of the formulation of the point interaction theory of Fermi in 1932, the first attempt to unify the charged and neutral current interaction seems to have been carried out by Oscar Klein in 1938.[2] However, the real search for WNC started in the early 1960s in rare K decays.[3] There were many theoretical models that suggested that neutral currents might exist. Although there was no real lack of motive to search for WNC, nevertheless there was a strong, general, theoretical prejudice against such a search. In Fig. 1, I have attempted to give a history of the search and discovery of various forms of neutral currents, a process in which I personally was involved.

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2 The Search for WNCs in the 1960s

Table 1 shows the important milestones for the search for WNC in the 1960s. Because of the great difficulty of rejecting various backgrounds, there were many zigs and zags in the search. The role of theoretical prejudice was very confusing and important.

In 1963, a CERN neutrino group published a very low limit on WNC from their neutrino experiment of 0.03.[4] This incorrect result diminished the prospects for detecting WNC and discouraged some groups (including a Wisconsin heavy-liquid

[a]Presented at the UCLA International Symposium on Flavor-Changing Neutral Currents (Santa Monica, CA, February 1997) and to be published in the Proceedings by World Scientific, Singapore.

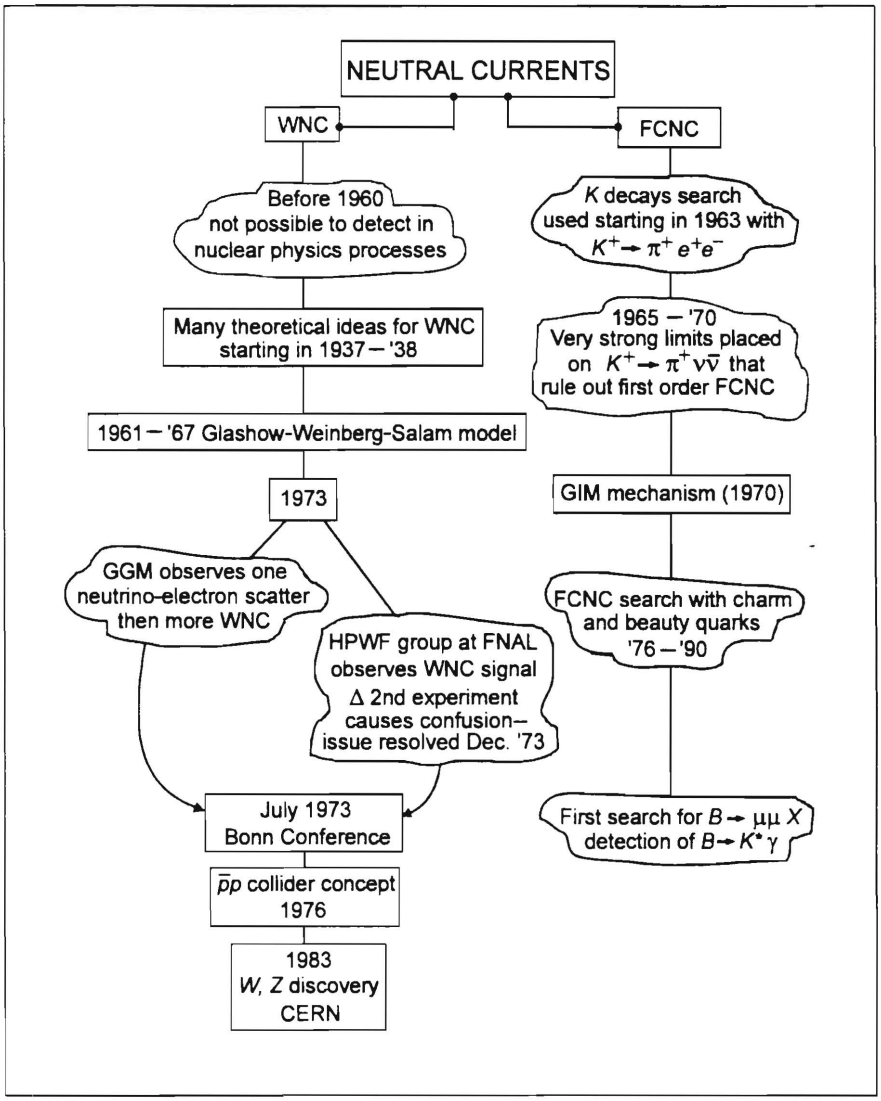

Figure 1: This figure gives a brief history of the efforts to discover the WNC and the search for FCNC. (See Ref. 5 for a full account of the discovery of WNC and Ref. 6, Ch. 3 for a discussion of the search for FCNC.)

Table 1: Some milestones in the search for WNC (1962 - 1973).[a]

	Milestones	Comments
1962	BNL neutrino experiment detects 2nd neutrino. Unusual events (Little Crappers) noted in PhD thesis.	Strange events are associated with neutrons from the shield.
1964	CERN bubble-chamber group reports a limit of 3% for WNC.	Reason for this incorrect limit given later in 1970 paper.
1967	E. C. Young thesis at Oxford notes that NC-like events exist in data.	
	Large, heavy-liquid bubble chamber studied by the MURA-Wisconsin-Berkeley Group to search for WNC ($\nu + p \rightarrow \nu + p$) at ANL. Later proposed for BNL then rejected.	GGM bubble chamber already approved. Incorrect CERN limits on WNC discourage further searches.
1969	HPW experiment proposed. Only mention of NCs is for leptonic processes.	1964 limit on WNC makes search for this process difficult, so leptonic processes considered.
1970	CERN group revises 1964 limit on WNC to ~ 12%.	
1972	Schwartz-Mann-SLAC black-hole experiment finds some NC-like events.	Too few events to make conclusive arguments.
	Perkins reports limits on WNC at FNAL meeting.	Limit still below currently observed values.
1973	GGM HPW	Struggle with large WNC signal.[5]

[a]From Ref. 6, Chap. 5.

bubble-chamber group) from searching for WNC in other proposed neutrino experiments. It might have been possible for the WNC to have been discovered in 1964, which would have altered the history in this field considerably.

The null results of the WNC search reinforced much of the theoretical prejudice of the time, once again showing that sometimes experimentalists rely too heavily on the guidance of theory. On the other hand, the search for WNC in the HPWF experiment benefited from S. Weinberg's advice, which resulted in an energy trigger being installed in that experiment in the middle of 1972.

However, even after the Weinberg–Salem model was gaining acceptance, the null results on WNC searches continued.

3 The Significance of the Search for FCNC in the 1960s

The concept of flavor was not well understood in the early and mid-1960s, and it appeared that studying rare K decays was as good a technique as any to search for the WNC. One of the earliest experiments[3,7] set a limit of $\sim 10^{-6}$ on $K^+ \to \pi^+ e^+e^-$. The limits on FCNC were summarized in a report I wrote in 1967, which included $K \to \mu\mu$ and the search for $K^+ \to \pi^+ \nu\bar{\nu}$ from my early work.[3]

In 1965 through 1970, a crucial search for $K^+ \to \pi^+ \nu\bar{\nu}$ was started.[8,9] This search was for a pure FCNC process, whereas all other searches had charged particles in the final state and may have been affected by electromagnetic interaction, as some claimed. The history of the search for this decay mode is given in Fig. 2, and it continues today.

By 1970, the correct CERN limit on WNC and the extremely strong limits on FCNC caused most people to believe that neutral currents did not exist in nature. The Glashow–Illiopoulos–Maiani (GIM) model was invented and showed that (1) FCNC could be suppressed in certain models and (2) a hadron–lepton symmetry existed.[10]

Today the GIM mechanism has only been well tested for light quarks. Charm and B quarks are a rich ground in which to continue the search for FCNC.[11] In 1966, FCNC played a very important role, and we expect it to be even more important in the next millenium.

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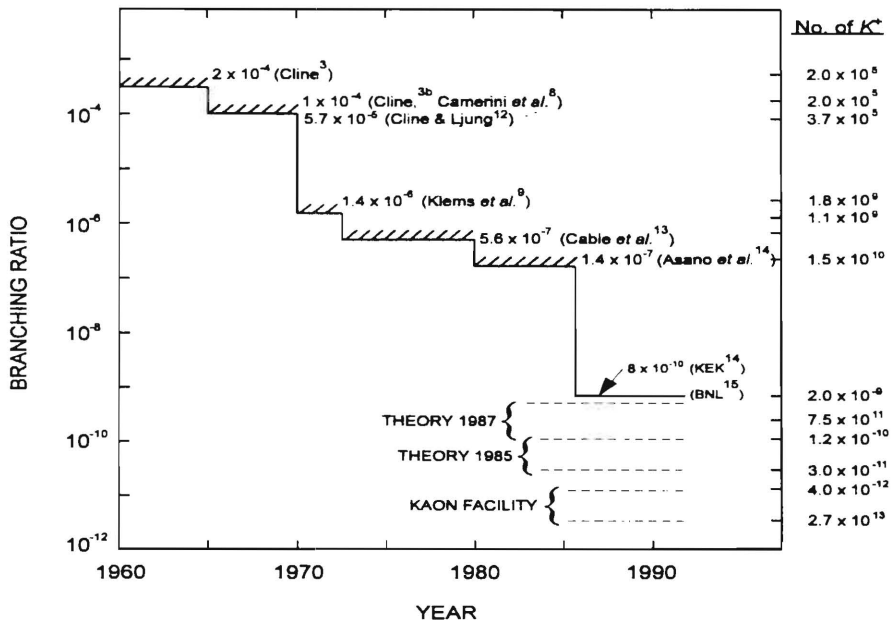

Figure 2: The history of the search for the decay mode $K^+ \to \pi^+ \nu\bar{\nu}$. This decay was crucial to indicate the absence of FCNC in the standard weak interaction.

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