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B.Pontecorvo

RECOLLECTIONS ON THE ESTABLISHMENT OF THE WEAK INTERACTION NOTION

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Introduction

In the spring of 1984 Leon Lederman kindly invited me to deliver a talk on neutrino physics at the 1985 Fermilab international symposium on particle physics in the 1950's. At the time I did not know whether I would be able to attend the symposium, and, besides, I did not feel like talking about neutrino physics, since I had covered such topic at recent meetings. Thus I replied to L.Lederman that I would report on some early Dubna work on strange particles, should such contribution be considered useful. Now on May 16, 1985 I have received a kind telex by Prof. Laurie Brown, the organiser of the Fermilab symposium, where I am asked to contribute for the Symposium proceedings a paper on a subject of my choice.

Well, I am very glad to have the opportunity of writing about some early, practically unknown, Dubna work on strange particles. True, in his delightful talk on strange particles at the Paris 1982 Colloquium on the history of particle physics M.Gell-Mann mentioned my work /1/. It is quite natural that I would like people to be informed about some of my work, significant in my opinion, performed a long time ago. Now, the only way of fulfilling such a desire in a decent way is to be invited to take part at a symposium... Thus I have explained how the present note came to be written and I am glad to thank once more L.Lederman and L.Brown.

I shall cover mainly some Dubna work on new particles, performed in 1951-1955 /2,3/, in the context of the notion of weak interaction, a notion which was certainly not taken as granted in the early 50's, but since 1947 had become one of my pet ideas /4/.

The β-decay of nuclei

The nuclear β-decay, the first known weak process, was discovered by Rutherford about 85 years ago. However not every physicist knows that the notion of weak interaction, a conception much wider than that of the single process of β-decay, came to be well established in the 50's only, that is about fifty years after the discovery of β-rays, and about forty years after the discovery by Chadwick of the continuous β-spectrum.

Below I shall present some personal recollections about the way the notion of weak interaction first was born and then became well established. Of course, my story is going to be neither objective nor full. I shall talk about some episodes which either I saw by my own eyes or in which I directly took part. Naturally I must keep in mind that I am writing the present note in June 1985. However I have been relying mostly on my memory and not on literature.

There is no need to recall here the most decisive ideas and experiments, I would say the "final" contributions to the creation of the universal electro-weak interaction theory. I shall limit myself to the evidence in favour of my 1947 idea, that the β-decay "is not alone". The processes, other than the β-decay, which pointed to some kind of universal behaviour concern first the muon and then strange particles. This story starts in 1947 and terminates in 1955.

The muon capture by nucleons and the muon decay

Conversi, Pancini and Piccioni /5/ in 1947 demonstrated that the (cosmic) 2.2 microsecond mesotrons, that is, the muons, have not the properties postulated for the Yukawa particles: the muon is interacting with nucleons much more weakly than the Yukawa particle should /6/.

Elsewhere I have already described in detail how the experiment of Conversi and others personally influenced all my way of thinking. Briefly, since the muon was not the particle of Yukawa, there were no compelling reasons to believe that the muon had properties which were being postulated for the Yukawa particle. Thus, in my opinion the following questions were entirely open:

1) Why the spin of the muon should be integer?

2) Who said that the muon must decay into an electron and a neutrino and not into an electron and two neutrinos or into an electron and a photon?

3) Is the charged particle emitted in the muon decay an electron?

4) Are particles other than electrons and neutrinos emitted in muon decay?

5) In what form the nuclear muon capture energy is released mainly?

Some of the questions were answered experimentally by Hincks and myself and by other groups. As far as question 5) is concerned, I wish to discuss it here in some detail.

The nuclear muon capture energy, I was thinking in 1947, must be released mainly in form of neutrinos. The relevant reaction is then $\mu^- + Z \rightarrow (Z-1) +$ neutrino, very similar to the process of nuclear K capture $e^- + Z \rightarrow (Z-1) +$ neutrino. I interpreted the similarity of these two processes as a very significant and deep effect, because, as a matter of fact, the rate of nuclear electron capture and that of muon capture are quite close /4/ (when proper account is taken of space phase effects and of the different electron and muon orbit volumes). I excluded the possibility of a chance coincidence and reached the following conclusions: i) the muon capture must be a process in some way identical to the β-process, proceeding according to the reaction * $\mu^- + p \rightarrow$ neutrino $+ n$, ii) in the muon capture most of the released energy is "invisible", because it is carried away in the form of neutrinos, a conjecture which is supported by experiments and agrees with i) and, iii), the muon spin must be 1/2.

Thus in 1947 I started to think in terms of weak interaction processes /4/, and understood first that both the muon capture by nuclei and the β-decay are processes due to a definite weak interaction existing in nature. It was clear to me that the muon is a sort of heavy electron and that the muon-electron symmetry is taking place under a type of interaction which is properly called weak, grace to the smallness of the corresponding constant G - the Fermi β-decay constant.

A similar point of view was adopted later /7/ to include among weak processes the muon decay by O.Klein; G.Puppi; T.D.Lee, M.Rosenbluth and C.N.Yang; J.Tiomno and J.A.Wheeler.

The original 1947 idea that there exists a muon-electron symmetry in nature was the first hint of an universal weak interaction (but how far away still from the 1957 form of such interaction, the V-A theory of Marshak-Sudarshan and Feynman-Gell-Mann, implemented later by the Cabibbo hadron mixing, the Glashow-Weinberg-Salam "final" electro-weak interaction with the Higgs mechanism, the discoveries of neutral currents and of W^+, W^-, Z^0).

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* It took 15 years before the two particle reactions $\mu^- + p \rightarrow n + \nu_\mu$, $\mu^- + {}^3He \rightarrow {}^3H + \nu_\mu$ were directly observed in the experiments of R. Hildebrand and in our own experiments (together with R.Sulyaev et al.).

The main physical content of my 1947 idea is still not understood today; it does concern the existence of families of leptons (and families of quarks). Why there exist in nature such families? I must say that the existence of several (weak) processes, in addition to the β-decay process, seemed clear to me in 1947 (much more clear than today). Anyway my credo in 1947 led to my expectation that there must exist a number of weak interaction processes in addition to the β-decay. Below I shall be concerned only with processes of the "charged current" type, although neutral current processes later turned out to be quite relevant.

Because the weak interaction conception was formulated first for the capture of muons and electrons, for some time I believed that every weak process must imply the participation in it of neutrinos. This wrong idea maybe slowed down the development of the notion of weak interaction, but the discovery of new unstable particles unmistakably widened the weak interaction conception to include hadrons.

Strange particles and the weak interaction

I shall not give details about the very important investigations and discoveries of new particles /8/. I am limiting myself to few particle discoveries (which I remember very well), sufficient to illustrate the question about the weak interaction being responsible for the particle decay. In a short period starting from 1947 there were discovered a number of unstable new particles, some electrically neutral and some electrically charged. Among the neutral particles, one could definitely recognise in a cloud chamber those having baryon charge, later called Λ^0, and decaying slowly according to the scheme $\Lambda^0 \rightarrow p+\pi^-$ /8/. Besides, in a very clean way it was shown /8/ that some charged mesons, called now K-mesons, decay, into pions: $K^+ \rightarrow \pi^+\pi^+\pi^-$. Here too the decay was slow as indicated by the very fact that the meson has time enough to stop in a thick photoplate before its decay. The properties of Λ^0 and K^+ were in my opinion an indication that the decays $\Lambda^0 \rightarrow p+\pi^-$, and $K^+ \rightarrow \pi^+\pi^+\pi^-$ are due to a weak interaction and probably to the same weak interaction which is responsible for the β-decay and muon processes. A similar point of view was expressed independently by N.Dallaporta (Nuovo Cimento 1 (1955) 962.

At the time physicists usually reasoned in terms of the Yukawa process and only strong processes at high energy were considered. However such a picture would fail to explain the generation and the decay of such (strange) particles like Λ^0 and K . These particles are copiously produced in cosmic rays, but have a quite long lifetime: they have a strange behaviour, if one assumes that the process of particle generation is fundamentally the same as the decay process. However, if we assume that the strange particles are generated in strong processes, but decay in weak interaction processes, then there are no more difficulties. If we assume that Λ^0 and K are generated (together), the difficulties connected with the long mean life of both baryons such as Λ^0 and of mesons such as K are resolved together /2/. At this moment I would like to tell about an episode. In the early 50's once a week from Moscow to Dubna came several theoreticians with the function to conduct seminars at high level. Among them often appeared I.Pomeranchuk. Well, I briefly told my arguments to Pomeranchuk, who liked them very much and right away organized the seminar just to illustrate the (curious) properties of hyperons and kaons along the lines I had suggested, that is: the (weak) decays of hyperons and kaons are not due to the (strong) interaction which together generates them. Since 1947 I had been expecting new weak processes, so that I was very happy about all this. I felt that the notion of weak interaction became wider once again, but in new processes. Thus at the time the weak interaction appeared to me as an universal interaction, acting between any group of four fermions. This was not very far from today point of view: W decays into elementary particles, leptons and quarks (and only that way) there being some choice of flavour (masses) for the decay products.

On the basis of the simple arguments expressed above I introduced /2/, independently of Pais /9/, the idea of pair production of the new particles, more exactly the pair production of hyperons and kaons.

The reactions $N+N \rightarrow N+\Lambda^0$ and $n+n \rightarrow \Lambda^0+\Lambda^0$

The question of strange particle generation can be investigated effectively in experiments performed near the production threshold. We investigated experimentally the question of a possible generation of Λ^0-particles in nucleon-nucleon collisions /3/. The method we used was due to a brilliant suggestion of R.Garwin /10/, who also was investigating the production of Λ^0 particles. The idea of Garwin was that in some experiments it is convenient to register Λ^0-particles, by detecting photons from π^0s emitted in the channel $\Lambda^0 \rightarrow n+\pi^0$. Our experiment at the time was interesting, because Shein et al. /11/ had claimed to have detected the production of Λ^0-particles, and the question as to whether Λ^0 are produced is one of principle /1,2,3/.

In our experiment, in which 670 MeV protons from the Dubna synchrocyclotron impinging on the accelerator internal carbon target were used, we reached the conclusions that Λ^0 are not produced either in the reaction $N+N \rightarrow N+\Lambda^0$ or in the reaction $n+n \rightarrow \Lambda^0+\Lambda^0$.

The absence of the reaction $N+N \rightarrow N+\Lambda^0$ agreed well with the idea /2,9/ of generation of two new particles together.

As for the vanishing value of the cross section for the reaction $n+n \rightarrow \Lambda^0 + \Lambda^0$, this was just the expectation of M.Gell-Mann (and of K.Nishijima), for reasons which today are obvious to everybody. Two words about our interpretation of such vanishing value, which we were able to give correctly, even without possessing the notion of strangeness.

I had figured out a scheme based on the assumption that there is a strong interaction responsible for the generation of new particles (two at the same time) and conserving the isotopic spin and the weak interaction, responsible for the decays of particles and non-conserving the isotopic spin. The isotopic spin has a meaning only in strong interactions and cannot be determined by weak decays. There arises the possibility of existence of fermions with integer isotopic spin (example Λ^0) and of bosons with half integer isotopic spin (example kaons). The scheme allowed to interpret the failure to observe the reaction $n+n \rightarrow \Lambda^0 + \Lambda^0$, through the assumption that the isotopic spin of the kaon is 1/2 (that is $K^0 \neq \tilde{K}^0$) and to make a number of predictions. Of course the conservation of strangeness is identical with the conservation of the third component of the isotopic spin. However the notion of strangeness was a very powerful tool without which physics could not have made the great steps ahead it did. As we know now the physical content of strangeness is that charge multiplets of hadrons are classified by the number (0,1,2,...) of something material - the number of s-quarks they contain.

In conclusion I would say that at the Pisa conference of 1955, mainly as a result of the wonderful talk of M.Gell-Mann, the notion of weak interaction, which was introduced in 1947 /4/ became finally established.

I am very grateful to S.M.Bilenky for discussions.

References

1. M.Gell-Mann. "International Colloquium on the History of Particle Physics", Paris,France,July 1982, p. C8-395.
2. B.Pontecorvo. JETP 29 (1955) 140, with quotations on previous papers.
3. M.P.Balandin, B.D.Balashov, V.A.Zhukov, B.Pontecorvo, G.I.Selivanov, JETP 29 (1955) 265, with quotations on previous papers.
4. B.Pontecorvo. Phys.Rev. 72 (1947) 246.
5. M.Conversi, E.Pancini, O.Piccioni. Phys.Rev. 71 (1947) 209.
6. E.Fermi, E.Teller, V.Weiskopf. Phys.Rev. 71 (1947) 314.
7. O.Klein. Nature, 161 (1948) 897; G.Puppi.Nuovo Cimento 5 (1948) 587; T.D.Lee, M.Rosenbluth, C.N.Yang. Phys.Rev. 75 (1949) 905; J.Tiomno, J.A.Wheeler. Rev.Mod.Phys. 21 (1949) 144.
8. See for example in "International Colloquium on the History of Particle Physics", Paris, July 1982, the articles of C.C.Butler. p. C8-177; R.H.Dalitz, p. C8-195; W.S.Fretter p. C8-191; L.Leptince-Rinquet p. C8-165; O'Cellaigh, p. C8-185; Ch.Peyrou p.C8-185; Ch.Peyrou p. C8-7; G.D.Rochester, p.C8-169; J.Rosch, p. C8-215; J.Six and X.Artru, p. C8-465.
9. A.Pais. Phys.Rev. 86 (1952) 655.
10. R.L.Garwin. Phys.Rev. 90 (1953) 274.
11. M.Schein, D.Haskin, R.Glasse, F.Fainberg, K.Brown. Congress International sur le rayonement cosmique, Bagnere de Bigorre,1953.

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