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Cabibbo mixing and the experiments that proved it.

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Abstract

The "leaning structure" of weak interactions that now encompasses flavor mixing of three quark families and even CP violation started with Nicola Cabibbo's proposal in the context of hyperon decays that the d and s quarks are "rotated" by an angle (Cabibbo angle). I will recall the origins of this radical idea and recount the key experiments that established its validity. In addition I will suggest possible new hyperon experiments.

Keywords: Cabibbo angle, Hyperon, Hyperon beam, Faraday rotation, Form factor

1. Introduction

I have been asked by the organizers to place Nicola Cabibbo's contributions to hyperon physics in perspective and also to substitute for Leon Lederman. I have some hope to fulfil the first assignment, but little hope for the second.

All I can do is recall my first encounter with Leon. I was a Chicago grad student attending a conference at Argonne Lab. Chicago and Columbia were famously rivals, each having their own cyclotron. Val Telegdi (my thesis sponsor) was first speaker, Leon second, and Yoichiro Nambu third. When it was Leon's turn he began: "I feel like a piece of ham – sandwiched as I am between two such well-bred speakers". The audience roared with laughter—the ice was broken.

2. Nicola's work

In 1999 I made a visit to Nicola in Rome, arranged by a mutual friend Cesare Silvi, then President of ISES (Nicola had been director of ENEA). This began a friendship that lasted over a decade. Every trip to Rome would start with a cultural experience and a "lesson". This one was a visit to his office in the Vatican.

It has been two years since the we lost Nicola Cabibbo; A long time in the life of a physicist, but a short time to form a perspective on a scientist's contributions. It takes more like 50 years to assess contributions to science (S. Chandrasekhar, private communication). In what follows I will use Nicola's words whenever possible, *even though he was writing in the third person.*

2.1. Intimations of Cabibbo universality

A key clue can be found in the thesis of Feynman's student Sam Berman.

The issue was the comparison between the experimental value of the Fermi coupling constant as deduced from neutron and muon beta decay: Could the slight discrepancy be accounted for by radiative corrections? Berman and Feynman discovered that radiative corrections for beta decay had the opposite sign from that needed to close the gap between beta decay and muon decay. The conclusion of the thesis was, "The disagreement between experiment and theory appears to be outside the limit of experimental error and might be regarded as an indication of the lack of universality even by the strangeness conserving part of the vector interaction."

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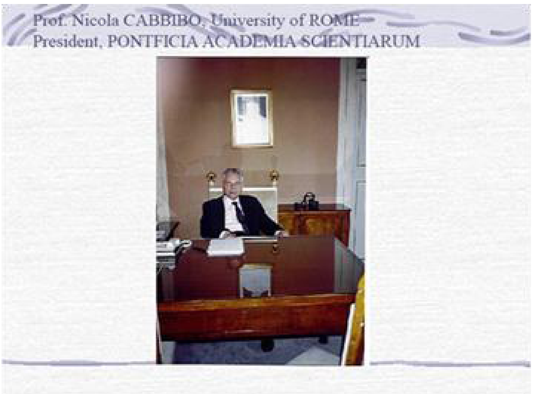

Fig. 1. Nicola Cabibbo's Vatican Office.

In 1963 Cabibbo proposed a theory of the weak current, parameterized by a single mixing angle θ_c, in the context of the octet model of SU(3) symmetry.

The central assumption was that the week current J_α is a member of an octet of currents $J_\alpha^i = V_\alpha^i + A_\alpha^i$, where V_α^i and A_α^i are octets of vector and axial currents [1],

$$J_\alpha = \cos\theta_C (J_\alpha^1 + i\, J_\alpha^2) + \sin\theta_C (J_\alpha^4 + i\, J_\alpha^5).$$

By assuming that the vector and axial parts of the weak current are "parallel," i.e. the same element of the respective octets, the theory included the $V - A$ hypothesis, and it also included the conserved vector current (CVC) hypothesis by assuming that the vector part of the weak current belongs to the same octet as the electromagnetic current.

In September 2008, during a visit to UC Merced, Nicola told me this was the highest cited PRL [1]:

When expressed in terms of quarks, which were only proposed in 1964, Cabibbo's weak current takes the simple form

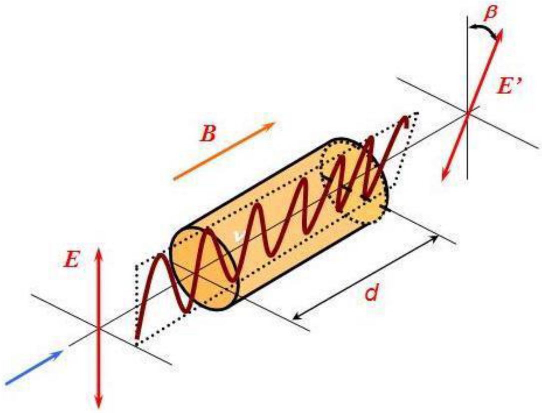

Fig. 2. Faraday rotation of the electric field.

$$J_\alpha = \cos\theta_C \bar{u}\gamma_\alpha(1+\gamma_5)d + \sin\theta_C \bar{u}\gamma_\alpha(1+\gamma_5)s.$$

Also in 1964 Bjorken & Glashow proposed the existence of a fourth charge 2/3 quark, the charmed quark, coupled to the $(\cos\theta_C\, s - \sin\theta_C d)$ combination. The mixing between d and s quarks would then be described by a 2×2 matrix.

2.2. Intimation of CP violation

Soon after Cabibbo proposed the mixing hypothesis, S. Glashow suggested to him that the same picture could naturally accommodate CP violation by allowing the mixing angle to be complex (adding a phase). However, it was obvious that a 2×2 unitary matrix (in the case of four quarks) can always be reduced to a form with real elements and thus necessarily preserves CP.

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In 1973, Kobayashi & Maskawa noted that the mixing of three quark families entails a single complex phase that cannot be eliminated by field redefinitions. They thus proposed that the four-quark model should be extended to a six-quark model in which mixing offers a natural explanation for the existence of CP violation.