NICOLA CABIBBO AND HIS ROLE IN ELEMENTARY-PARTICLE THEORY

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Nicola Cabibbo has played an historical role in elementary-particle theory. In this writing I shall mostly concentrate on the times which I had spent in scientific discussion and collaboration with Nicola, as those times are more vivid in my memory. Those were the times were Nicola was working essentially in Rome and Frascati, as a young bright theoretician.

Nicola's work in weak interactions was an essential contribution to the interpretation of the experiments and to the basis of the theory. The developments leading to such work have been recently described in various articles by contemporary authors, who were not yet active in physics at the time of those debates, and so they could not know the problematic of that time. Fortunately Cabibbo himself has given the most authoritative account of such developments in a paper published for the Congress of the 1997 Centennial of Italian Physics in Il Nuovo Saggiatore in the section dedicated to the Evolution of Modern Physics (IL NUOVO SAGGIATORE, vol.14, no. 3-5, 1998 pag.125). In this paper Cabibbo explains, with his usual clarity and conciseness, the essential experimental and theoretical facts that led to the introduction of the Cabibbo angle.

When I first met Nicola in 1958 he was finishing his laurea with Bruno Touschek. I was just coming back from Berkeley, after a period which had been dense to weak interaction theory and experiments. Talking with Nicola, it was easy to understand that he was of an exceptional intelligence and that he had the qualities to become a good theoretician.

A little later while discussing with Castagnoli, who was working on radiative pion decays, it appeared to me that a modern calculation of the process would offer Nicola a vast opportunity for learning various theoretical techniques. Nicola did the calculation rather rapidly and published his paper in Il Nuovo Cimento, 11 (1959) 837. This was his first paper and showed his ability to rapidly learn advanced techniques.

At the beginning of the sixties Giorgio Salvini with his far-reaching vision considered that Frascati needed a theoretical group to support the experimental work and to influence the cultural environment of the laboratory. Cabibbo was the first member of the Frascati theory group. He contributed with an intense theoretical activity and a continuous interest in the experimental activities.

At that time, his works on the weak decays of K-mesons and hyperons, on the proton time-like structure (with Zichichi), and on the physics of photons in crystals (Il Nuovo Cimento , 27 (1963) 979) were much appreciated. Very important was indeed the first calculation for that time (Il Nuovo Cimento, 15 (1960) 304) of possible cross-sections from neutrino beams, which had just been imagined as feasible in accelerators. However the main activity was on electron-positron collisions and on $SU(3)$ in weak interactions. On both we shall now discuss in more detail.

The work on $SU(3)$ in electroweak interactions (Il Nuovo Cimento , 21 (1961) 872) showed the limits of an elementary application of $SU(3)$ to weak decays. The decay rates of the strangeness-violating decays of hyperons were experimentally much smaller by factors of tenths than one would have expected from universality. A similar effect was present in K-decays, confirming the presence of a general problem that was hard to understand at that time. Renormalization effects due to strong interactions could always be invoked and they were difficult to calculate. But their required experimental magnitude seemed too large to be reproduced by theory. Some, quantitatively much smaller, difficulty was present with β decay as compared to μ-decay. It was numerically less relevant than in the case of hyperon decays, but still suggesting some perplexity, and Feyman in particular was taken by that problem, to which he worked with Berman.

The problem was at the time complicated by an apparent evidence, which was later not confirmed, of possible transitions for which the jump in strangeness, S, was opposite in sign to the jump in electric charge, Q, that is $\Delta S = -\Delta Q$. This fact, if confirmed, would have killed, already at a qualitative level, a basic theoretical notion strongly suggested by the comparison with electromagnetism of the strangeness conserving weak vector current. This unpleasant situation was clarified shortly after by an experiment by Paolo Franzini. In a recent mail Franzini tells me: "At least once each day I was saying Nicola: I have not yet seen any event with $\Delta S = -\Delta Q$".

The suspicion of the existence of transitions with $\Delta S = -\Delta Q$ played a non-negligible negative role in the situation and probably produced a delay in the solution of the problem, leading to thinking of new groups, such as exceptional groups to find a suitable

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framework. More important, Murray Gell-Mann, who had already foreseen a solution in his work with Levy, was most probably discouraged to continue on that line. In the words of Nicola (in the aforementioned papers in il Nuovo Saggiatore):" In October 1963 I met Murray Gell-Mann at Brookhaven. The first thing he asked was: How did you know about $\Delta S = -\Delta Q$? This answered a question of my own: why hadn`t Murray found the correct solution? Then I knew: he probably had, but had put it aside because of the evidence for $\Delta S = -\Delta Q$."

On a deeper speculative side Cabibbo, with a conceptual experiment on the abstract exact *SU*(3), considered the real significance of the notion of strangeness, thus coming to the notion of mixing of currents (Cabibbo mixing). With the coming of the notion of quarks the mixing appeared as a quark mixing. A further general clarification came in 1969 with the important work of Glashow-Iliopoulos-Maiani. Their work showed the necessity of a quark with charm, allowing for a more symmetric formulation.

The parameter for the mixing is the Cabibbo angle. Determining its experimental value required some careful work, examining numerically the available data on weak decays. A non-renormalization theorem helped with this analysis. At present the value of the Cabibbo angle is a best known number in electroweak theory. We refer to a recent comprehensive study of Cabibbo and collaborators for a modern analysis of the subject (N. Cabibbo, E. Swallow, R. Winston, Ann. Rev. Nucl. Part. Sci 53 (2003) 39).

The mixing within two quark families would not allow for phases, such as to possibly give rise to *CP* violation. The extension of the mixing when three quark families are present would instead allow for one such phase, and this was pointed out in '73 by Kobayashi and Maskava, in their work which was at the origin of their Nobel Prize. Also we mention that after discovering neutrino masses an entirely new field, that of neutrino mixings, opened up and is a center of great experimental and theoretical work at this moment.

At a more speculative level the problem rapidly arose whether the value of the Cabibbo angle could be theoretically calculated. Intense efforts in this sense were made at the end of the 60's. But the final conclusion is still lacking. In the words of Cabibbo : "...quark mixing is alive and well, but still shrouded by mystery... As in Henry James "The Figure in the Carpet", nature is trying to tell us something, what exactly we still do not understand".

The other important field to which Cabibbo contributed was that of electron-positron collisions. A very complete work for that time contained the calculation of the conceivable electron-positron processes. It was referred to as "the Bible" by the experimentalists, and even today it still serves as a reference. The courageous vision and dedicated activity of Bruno Touschek, together with the work of the physicists and engineers in Frascati, originated this line of research of electron-positron accelerators, which has played since then an important role in the development of physics. Particle-antiparticle collisions are a fundamental instrument for the understanding of the physics of elementary particles. These developments have been described in historical papers by Giorgio Salvini, by Carlo Bernardini, by Mario Greco and Giulia Pancheri (Analysis, no. 2, 3, 2008), as well as in the complete work by Luisa Bonolis (Rivista del Nuovo Cimento, 28, no. 11 (2005) 1), to which we refer.

The Bibbia went much beyond the expected experimental possibilities for that time, and, with courageous anticipation, calculated effects for a not impending future such as the production from electron-positron of W pairs and of Z. These processes were seen much later at CERN. Other effects like for instance the hadronic contribution to the *g*-2 of the muon from electron-positron cross-sections were also calculated, in view of their future relevance when such cross-sections would be experimentally known.

Even before the Bibbia, after a historical seminar by Panofsky in Rome in 1959, Nicola worked at the possible production of two and of three pions (Phys. Rev. Lett., 4 (1960) 313) from, at the time only desired, electron-positron beams. That work was mainly caused by the intense interest at that time on the unknown electromagnetic form-factors in the time-like region, which was an essential ingredient for writing down the relevant dispersion relations. Without the courage and the initiative of Bruno Touschek all that work would have remained at the level of purely theoretical speculation.

I have here especially expanded on the years in Rome and Frascati, or related to them, when I was in close contact with Nicola. However Nicola, after those years and those scientific activities, had always intensively worked, producing high quality physics. He was full professor in L'Aquila, at Rome Tor Vergata , and mostly at "Sapienza" Rome. He had been working at CERN, in Berkeley, in Princeton, in Paris, in New York, in Syracuse. He was the founder of the APE project to calculate quantum chromodynamics, beyond any perturbation scheme. He formed a number of high-quality students, among whom I cannot avoid mentioning Giorgio Parisi.

Nicola took most important responsibilities for Italian physics as President of INFN and as President of ENEA. He was President of the Pontifical Academy of Science from 1993.

In the delicate and important role of President of the Pontifical Academy of Science he had no hesitations on the debate around the creationistic theories, with an attitude marked by absolute scientific objectivity. This contribution to the debate was especially important due to his prestigious position in the scientific catholic community.

Cabibbo received many prizes and honors, which I can only enumerate here very briefly. He obtained the Sakurai Prize from the American Physical Society in 1989, the National Prize of the President of the Italian Republic, the Prize of the European Physical Society in 1991, the Fermi Prize of the Italian Physical Society in 2003, and lastly in the current year the Dirac Prize from the International Institute of Theoretical Physics. He received the Matteucci Medal, and the Culture Prize from the Italian President of the Ministers twice. He was elected Cavaliere di Gran Croce of the Italian Republic, and decorated by a golden medal attributed to the leading personalities in Science and Culture.

One cannot close this writing without mentioning the human qualities of Nicola. He had a great humanity and personal kindness. Besides his scientific sense of objectivity, he was very rational, thoughtful, open to new original ideas. And beyond that he also had a great sense of humor and of conviviality.

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Prize of the President of the Italian Republic in 1975. Weak Interactions in Bologna in 1984. Prize of the SIF Centenary in 1997. Fermi Prize of the Italian Physical Society in 2003 (together with Cabibbo and Maiani).