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MESONS IN 1946

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1. INTRODUCTION

The discovery made by Marcello Conversi, Oreste Pancini, and Ettore Piccioni is a well recognized milestone in the history of high-energy physics.[1] A less known aspect of this famous episode is that there were two Conversi-Pancini-Piccioni experiments, one completed in 1945 and the other in 1946.[2] They were the last phases of a series of experimental observations begun by Conversi and Piccioni a few years earlier.[3] Nevertheless, the 1945 work was reported separately by the authors in a letter to *Physical Review* and attracted significant attention, even though for us its importance has been overshadowed by the fame of the 1946 discovery. The 1945 experiment was received as a notable result in the local scene as well as in the international context. Its significance, however, rested on different reasons, and the difference was related to the changes that physical research was undergoing in the immediate aftermath of World War II. The birth of particle physics was characterized by the transition from an artisan-like form of experimentation, based on cosmic rays as a free source of high-energy phenomena, to the industrial-scale organization, engineering, and financing of accelerator physics. The Conversi-Pancini-Piccioni experiments were not just coincident with the restructuring of instrumentation and institutions, but played an active role in it.

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[1] This communication is based on Monaldi, Daniela (2005). "Life of μ: The Observation of the Spontaneous Decay of Mesotrons and Its Consequences, 1938-1947", *Annals of Science*, 2005, *62*:419-455.

[2] Conversi, Marcello; Pancini, Ettore; Piccioni, Oreste (1945). "On the Decay Process of Positive and Negative Mesons", *Physical Review*, 1945, 68:232. Conversi, Marcello; Pancini, Ettore; Piccioni, Oreste (1947). "On the Decay Process of Positive and Negative Mesons", *Physical Review*, 1947, *68*: 209-10. Conversi, Marcello; Pancini, Ettore; Piccioni, Oreste (1946). "Sull'assorbimento e sulla disintegrazione dei mesoni alla fine del loro percorso", *Nuovo Cimento*, 1946, *3*: 372-390.

[3] See, for example, Piccioni, Oreste (1983). *The observation of the leptonic nature of the "mesotron" by Conversi, Pancini, and Piccioni*, and Conversi, Marcello (1983). *The period that led to the 1946 discovery of the leptonic nature of the "mesotron"*, in: Brown, Laurie M.; Hoddeson, Lillian (eds.) (1983). *The Birth of Particle Physics* (Cambridge: Cambridge University Press, 1983): 222-241 and 242-250.

2. THE NUCLEAR CONNECTION AND THE DECAY OF MESOTRONS

In their 1945 letter, Conversi, Pancini, and Piccioni reported having confirmed the "Tomonaga effect" with the use of magnetic lenses. This finding was the outcome of an independent line of research that Piccioni and Conversi had undertaken during the war, within the activities of the group of "survivors" gathered in Rome after what Amaldi has called the "disaster of physics in Italy".[4] Since 1939, under the guidance of Gilberto Bernardini, Conversi, Piccioni, and other cosmic-ray experimenters, together with the theoreticians Bruno Ferretti and Gian Carlo Wick, had investigated the spontaneous decay of the particles then called mesotrons, or mesons, which had been found to constitute the most penetrating components of cosmic radiation.[5] Cosmic-ray specialists had adopted as a working hypothesis the identification of the new particles with the quanta of intermediate mass postulated by Hideki Yukawa. Yukawa had conceived of a new nuclear field expressly to reduce two phenomena of intractably different intensities, the strong nuclear binding and the weak β-decay, to the same theoretical framework. With the discovery of mesotrons, his theory also promised to encompass those aspects of cosmic radiation that were not accounted for by quantum electrodynamics. Nuclear and cosmic-ray physicists welcomed the theory for its unifying potential. For simplicity, I shall call the hypothetical identification of cosmic-ray mesotrons with Yukawa's heavy quanta "the nuclear connection." Yukawa's explanation of β-decay implied that the nuclear quanta would spontaneously disintegrate into electron-antineutrino pairs. The nuclear connection was thus able to explain the absence of mesotrons in ordinary matter, as it interpreted their vanishing as the most elementary form of β-radioactivity. Homi Bhabha followed this idea and extended the concept of mean lifetime from radioactivity to the fast-moving cosmic rays by applying the relativistic principle of time dilation. So articulated, the decay hypothesis immediately appeared as the most promising side of this web of conjectures to be tested experimentally. Cosmic-ray specialists responded enthusiastically, especially because relativistic spontaneous decay enabled them to clarify a number of hitherto unexplained observations related to the rate of absorption of mesotrons in air and in solid matter. Therefore, the application of the decay hypothesis to absorption data constituted the basis for a program of research: to observe for the first time the decay of a particle, and to measure its mean lifetime.[6]

The agreement between theoretical and experimental values of the mean lifetime, although buoyantly declared satisfactory after the first rough estimates, was actually poor and soon became worse. By 1941, the decay of mesotrons was firmly established experimentally, but it was clear that Yukawa's theory could not reproduce accurately the measured lifetime. The experimenters, however, did not pause to acknowledge a conflict between observation and theory. They were preoccupied with stabilizing the techniques for producing the new phenomenon and measuring a time parameter of the order of a microsecond. Their primary concern was to obtain agreement among different experiments, a goal not easy to reach. Still, they found sufficient consistence to be confident that the decay hypothesis was verified, and the verification reinforced the nuclear connection, lifetime discrepancy notwithstanding. Until 1945, the function of the

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[4] Amaldi, Edoardo (1979). "Gli anni della Ricostruzione", *Scientia*, 1979, *114*:29-50.

[5] The term "mesotron" and its variant "meson" were used interchangeably to indicate the particles that are now known as muons. I shall follow the historical usage, even though today "mesons" refers to a family of particles that does not include muons.

[6] For more detailed reconstructions of the history of mesotron decay, see Monaldi (2005) (note 1) and references therein, in particular, Brown, Laurie M; Rechenberg, Helmut (1996). *The Origin of the Concept of Nuclear Force* (Bristol: Institute of Physics Publishing, 1996).

nuclear connection for cosmic-ray experimenters was not to exhibit quantitative adequacy but to provide a unifying conceptual model and a research program.

3. FROM DECAY TO NUCLEAR CAPTURE

The nuclear connection was especially helpful in the so-called "direct" observations of decay, which aimed at detecting the electrons emitted by the disintegrations of mesotrons at rest. As decay became increasingly established as an experimental fact, it came to be used as a tool to observe another new phenomenon, the capture of mesotrons by nuclei. Failing to observe decay electrons from mesotrons that had come to rest inside an absorber was interpreted as a demonstration that the mesotrons were "captured" in reactions with the nuclei of the medium. Yukawa's theory, in fact, predicted that for nuclear quanta at rest the probability of capture was much higher than that of β-decay. When cloud chamber pictures did display decay electrons at the end of mesotron tracks, the evidence was interpreted as showing that nuclear capture was selective. Extending Yukawa's calculations of capture probabilities, Tomonaga and Araki reasoned that the positive electrical charge of the nucleus would keep positive mesotrons out of range of the nuclear force, while it would increase the rate of capture of negative mesotrons. Hence, it was expected that in a direct experiment only the fraction of stopped mesotrons corresponding to the positive ones would be seen to decay. This charge-selective character of nuclear capture was called the "Tomonaga effect."

Conversi and Piccioni focused on the Tomonaga effect as the second step of their direct observations of decay, following the lines of a pioneering effort carried out by Franco Rasetti at Laval University. Like Rasetti, they were happy to report that the decay fraction registered by their apparatus agreed with Tomonaga's prediction. As a further refinement of their investigation, they decided to try discriminating the mesons according to their charge by means of magnetized iron blocks. While their fast-electronics recording setup was a brilliant innovation of their own, the magnetized blocks were a resources of the experimental tradition in which they belonged. Called "magnetic lenses", the blocks were, to use Piccioni's words, "a household item" in the Rome Istituto di Fisica.[7] Using magnetic lenses to verify the charge dependence of nuclear capture was a natural step. Pancini, who had discussed the idea in general terms, joined Conversi and Piccioni in this third phase of the experimental series, at the end of the war.

4. NOVEMBER 1945: CONGRESSO DEI FISICI ED ELETTROTECNICI IN COMO

In November 1945, Edoardo Amaldi presented a report to the first post-war gathering of Italian physicists.[8] He announced the long-awaited *Centro per lo Studio della Fisica Nucleare*, stressing that this new institution was created by the CNR to further the research carried out during the war at the Rome university and the *Istituto Superiore della Sanità*. In Amaldi's account, the studies of neutron scattering, which his team had conducted by means of the ISS Cockroft-Walton accelerator, and the studies of cosmic radiation conducted by Bernardini's team, which had consisted of various investigations

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[7] Piccioni (1983): 239 (note 3).

[8] Amaldi, Edoardo (1946). "Sulle ricerche di fisica nucleare eseguite a Roma nel quadriennio di guerra", *La Ricerca Scientifica. Ricerca Scientifica e Ricostruzione*, 1946, *16*: 61-65.

of "mesons, as elementary particle", were naturally connected by the conceptual scheme of Yukawa's theory. Amaldi talked about the recent results obtained by Conversi, Pancini, and Piccioni as the final touch in a picture of great coherence. Until then, the neutron experiments had been financed by the CNR under the rubric of nuclear studies, while Bernardini had been able to secure funds for cosmic-ray studies through the *Istituto Nazionale di Geofisica*, from the *Comitato per la Geofisica e la Meteorologia* of the CNR. Piccioni and Conversi's experiments fell in between, and were funded partly as nuclear studies and partly as geophysics. Luckily, they were not expensive experiments. Amaldi's appeal to the unifying power of Yukawa's theory was an integral part of his advocacy for the creation of an institutional space to study mesotrons as elementary particles, rather than as atmospheric phenomena. Concerns about mesotrons, however, were different in America.

5. NOVEMBER 1945: SYMPOSIUM ON ATOMIC ENERGY AND ITS CONSEQUENCES, PHILADELPHIA

The Symposium on Atomic Energy held by the American Philosophical Society in November 1945 was one of many functions in which physicists in America pondered their recent involvement in the war and traced their new professional identity. Nuclear physicists were eager to recover a degree of separation between their science and the demands of public service, but without forgoing the political leverage that they had gained. The part that mesotrons were to have in this negotiation was articulated by John A. Wheeler in a lecture on the prospects of particle physics.[9] Wheeler presented an argument for government and military funding of expensive high-energy accelerators. He made his case by means of the exploration metaphor: the "Italian navigator" had reached the new world of atomic energy, but had only touched the "island of nucleonics", where energy could be tapped from nuclear processes like fission, conserving the total number of nucleons. Beyond nucleonics, the "continent of ultranucleonics" awaited discovery. There, even larger amounts of energy would be made available by processes involving the destruction of nucleons. Gaining control of ultranucleonic transformations required knowledge of the mechanisms of destruction and creation of mesotrons, for it was understood that these particles were the agents of the nuclear force. Such knowledge, however, could only be obtained by means of extensive experimental investigations because no reliable theory of the nuclear force was available yet. Far from regarding observations of mesotron decay and capture as evidence of the validity of Yukawa's theory, Wheeler considered both decay and capture as empirical facts in urgent need of an adequate theory. He quoted the Conversi-Pancini-Piccioni experiment, which had just been published in *Physical Review*, not as a finishing touch but as the first step of an open-ended experimental exploration.

6. 1946: A BAD YEAR FOR YUKAWA'S THEORY

The climate of skepticism toward Yukawa's theory was heightened at the beginning of 1946 by the announcement that mesons had been produced "artificially" at the 100 MeV betatron of the General Electric Research Laboratory. The news caused a sensation at the January meeting of the American Physical Society, which was attended by an

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[9] Wheeler, John A. (1946). "Problems and Prospects in Elementary Particle Research", *Proceedings of the American Philosophical Society*, 1946, *90*:36-47.

unprecedented number of physicists. The G.E. mesons were said to display a variety of masses. Cosmic-ray evidence was inconclusive on the question of whether all mesons had the same mass or there existed a spectrum of masses. Since the core of Yukawa's theory was the relationship between the mass of the nuclear quantum and the range of the nuclear force, the assumption of a single mass had become prevalent not on observational grounds but on the strength of the nuclear connection. The effect of the betatron excitement, therefore, was to weaken the nuclear connection and reinforce the agenda of ultranucleonics. The first project of the newly created Institute of Nuclear Physics at the University of Chicago, where Fermi and Teller went to work after they left Los Alamos, was a 100 MeV betatron.[10] The *Centro per la Fisica Nucleare* in Rome also planned to construct a 20 MeV betatron. Bernardo Nestore Cacciapuoti traveled to the U.S. to collect technical information on this kind of machines, and wrote to his colleagues in Rome about the G.E. exploits.[11] The echo of "homemade" mesons resonates in the letter in which Bernardini confided to Enrico Persico his worry that Italian physics was "losing ground at kilometers per second[.]"[12] The Italians, alas, could only long for the level of resources available to their colleagues in America. Even their 20 MeV project was too optimistic and would soon have to be abandoned for lack of funding.

The betatron-made mesons turned out to be an instrumental effect. Nonetheless, the rush to engineer machines for manufacturing mesons continued. Physicists turned to other kinds of accelerators, but the spotlight remained on the nuclear interactions of mesons. Against this pragmatic backdrop, the explanatory power of Yukawa's theory dissolved and its computational shortcomings became paramount. The scientists involved in accelerator projects needed information about the technical conditions for producing mesons. They focused on nuclear capture as the reverse process of nuclear production. The Conversi-Pancini-Piccioni experiment, with its vivid demonstration of charge-selective nuclear capture, was a key ingredient in this ferment. Rather than completing a coherent picture, it catalyzed the realization that too little was known about the involvement of mesons in nuclear reactions.

One of a list of experimental queries formulated by Wheeler concerned the extension of Conversi, Pancini, and Piccioni's work into a systematic investigation of how the rates of capture depended on the atomic number of the absorber. During the following year, the three Italians changed the material of the absorber in their apparatus from iron to carbon, and made the discovery for which they are famous. There is no historical evidence that they knew about Wheeler's query, and Piccioni emphatically denied, in his recollections, that testing the dependence of capture on atomic number had been in their intentions. Nevertheless, the 1946 Rome experiment provided the beginning of an answer to Wheeler's question: in a medium of low atomic number, reactions of mesotrons with nuclei were even less probable than their β-decay.

The events I have highlighted help explain the readiness with which theorists and experimenters in America responded to the Rome finding. The experiment was immediately replicated and extended to other materials by two researchers working in Princeton in close contact with Wheeler, who was ready to interpret the data according

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[10] Fermi to Amaldi and Wick, 24 January 1946, in Amaldi, Edoardo; Battimelli, Giovanni; De Maria, Michelangelo (1997). *Da Via Panisperna All'America:iI fisici italiani e la seconda guerra mondiale* (Roma: Editori Riuniti, 1997): 166.

[11] Cacciapuoti to Amaldi and Bernardini, 8 December 1945 and 1 January 1946, Archivio Amaldi, Sezione Archivi del Dipartimento di Fisica dell'Università di Roma 1, "La Sapienza", box 136, file 3.

[12] Bernardini to Persico, 4 February 1946, in Amaldi; Battimelli; De Maria (1997): 168-9 (note 10).

to his own model for the dependence of nuclear capture on atomic number. Fermi and Teller, in collaboration with Victor Weisskopf, provided the renowned theoretical analysis according to which the capture of a mesotron by a nucleus was 10^{12} times less probable than predicted by Yukawa. As the closing statements of their papers reveal, such alertness derived from the implications that the Conversi-Pancini-Piccioni experiments had for the production of mesons in accelerators.[13]

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[13] Wheeler, John A. (1947). "Mechanism of Capture of Slow Mesons", *Physical Review*, 1947, *71*: 320-1. Fermi, E.; Teller, E.; Weisskopf, V. (1947). "The Decay of Negative Mesotrons in Matter", *Physical Review*, 1947, *71*:314-5.