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BRUNO PONTECORVO AND HIS VISION*

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The first time I met Bruno Pontecorvo was in 1964 at Dubna where the International High Energy Physics Conference was held. Never before the USSR allowed physicists from USSR to go and visit their colleagues in the East and vice versa. It was a great event (see Fig. 1), Bruno Pontecorvo having played a vital role for its establishment.

He was eager to interact with the young fellows engaged in the physics frontiers of the time. During the conference, Cronin presented the discovery of CP violation in K-meson physics.[1] Ten years before the celebrated invariance Laws of Charge Conjugation, C, and Parity, P, were proved to be violated.[2–5]

A theoretical proposal in 1957 by Landau[6] on the conservation of CP invariance appeared to be the solution.

On the same year Lee, Oehme and Yang[7] proved that the existence of two neutral K^0-states K_1^0 and K_2^0 was not the proof of CP invariance. This paper was neglected by nearly all physicists but Bruno Pontecorvo. At CERN only John Bell and Victor Weisskopf knew this paper and were supporting the proposal to check CP invariance in K^0 decays. Had Bruno Pontecorvo been the then CERN Research Director, the experiment would have been performed at CERN. It should be noticed that the experiment of Christenson *et al.*[1] was not planned to search for the 2π

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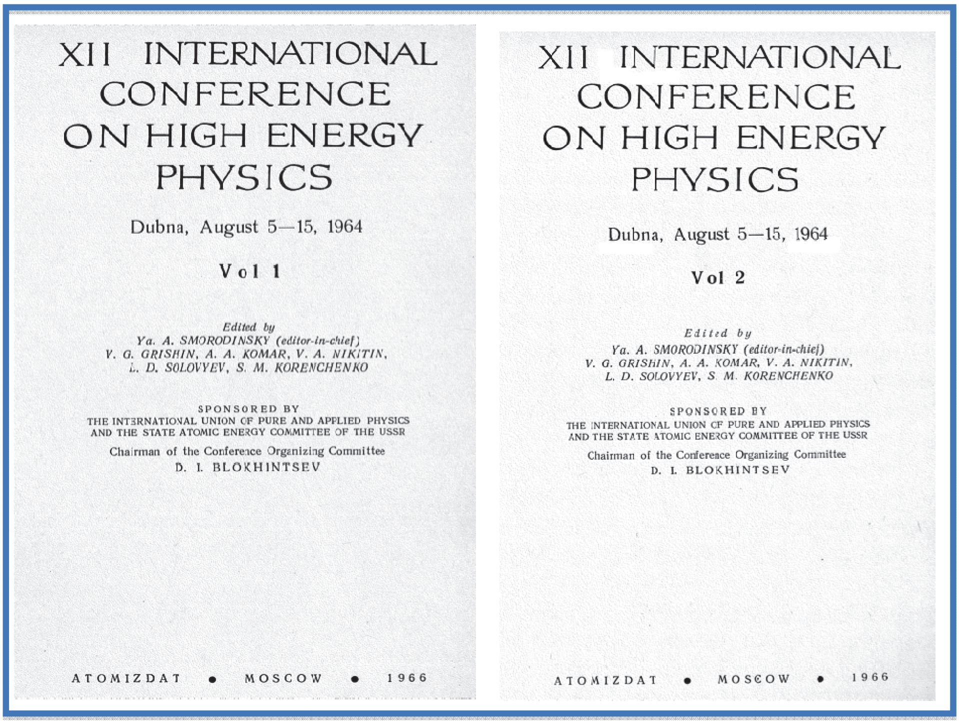
XII INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS

Dubna, August 5—15, 1964

Vol 1

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Chairman of the Conference Organizing Committee
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ATOMIZDAT • MOSCOW • 1966

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Vol 2

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Fig. 1. Covers of the proceedings — Volumes 1 and 2 – of the XII International Conference on High Energy Physics, Dubna.

decay mode of the K_2^0 meson. The aim of the experiment was to check the anomalous regeneration in hydrogen, previously reported by Robert Adair *et al.*[8] (and found to be more than an order of magnitude lower[1]). The search for the 2π decay mode of the long-lived K_2^0 was proposed at CERN, but rejected because the neutral beam in the PS experimental hall had already been allocated to another group's programme. On the other hand, my group was already engaged with the PAPLEP (**P**roton **A**nti**P**roton into **LE**pton **P**airs) experiment to search for the production of the third lepton through the $(e\mu)$ final state produced in $(\bar{p}p)$ annihilation,[9] using the CERN-PS beam which was next to the neutral beam we wanted for the $K_2^0 \to 2\pi$ search. I was told by G. Cocconi, the CERN Research Director of the time, "*give other people the chance*," when trying to convince him that the existence of the long-lived K_2^0 was not a proof of CP invariance as shown by the 1957 paper of Lee, Oehme and Yang,[7] therefore the search for the $K_2^0 \to 2\pi$ decay mode violating CP invariance was not in contradiction with the existence of the long-lived K_2^0 meson. It would have been too much to give two PS beams to the same group, he told me later. Moreover we were not proposing to check the anomalous regeneration in hydrogen (a proposal considered very interesting). Our aim was to check if CP was really valid in K-meson physics.

The flavor mixing problem and its CP invariance or noninvariance, is extremely topical today with many experiments being planned in order to understand the basic distinction between "flavor mixing" and CP invariance, for all flavors.

In addition to these novelties there was the problem of the Relativistic Quantum Field Theory (RQFT) versus the much simpler mathematical formalism of the S-matrix theory, which appeared to be the winning formalism.

In 1961, at the 12th Solvay Conference devoted to "The Quantum Theory of Fields," Marvin Goldberger said: "*From a philosophical point of view and certainly from a practical one the S-matrix approach at the moment seems to me by far the most attractive.*"[10]

Geoffrey Chew, in 1963, wrote: "*Let me say at once that I believe the conventional association of fields with strong interacting particles to be empty. It seems to me that no aspect of strong interactions has been clarified by the field concept. Whatever success theory has achieved in this area is based on the unitarity of the analytically continued S-matrix plus symmetry principles. I do not wish to assert (as does Landau) that conventional field theory is necessarily wrong, but only that it is sterile with respect to the strong interactions and that, like an old soldier, it is destined not to die but just to fade away.*"[11]

S-matrix was the negation of the Field concept. The general feeling was that there had to be compelling reasons for RQFT to be wrong.

Bruno Pontecorvo was convinced that RQFT was the correct way to go.

The reason to recall all these problems is to remind the young generation of physicists what were the "new frontiers" at the time of the Dubna Conference. On this occasion I realized that Bruno Pontecorvo had an impressive vision for new experiments and new facilities related to these physics frontiers.

Another topic attracting his attention was the neutrino mass and its consequences. Bruno Pontecorvo organized a dinner with few physicists interested to know more about problems that had been discussed at the Conference, including the possible existence of a small mass associated with the neutrinos. This was an inspiring dinner. The standard wisdom was that neutrinos had to be massless; this wisdom has been dominant during many decades to the point of being incorporated in the "Standard Model."[12] Nevertheless ideas to check possible small masses for neutrinos were investigated and Bruno Pontecorvo's paper on $(\nu, \bar{\nu})$ oscillations in 1957 was an interesting consequence. On this occasion Pontecorvo (the youngest member of the Fermi's group in Rome) also told the story about Enrico Fermi drawing up the Majorana neutrino paper.[13] If the neutrinos were nonzero-mass particles, the oscillations between neutrinos could take place, not only between neutrinos and antineutrinos of the same "flavor" but, also between neutrinos of different flavors. So it was that I talked about the mixing of neutrino flavors: if three kinds of charged leptons existed, as we were hoping to find with PAPLEP at CERN (see later), three neutrinos had to be there and, if their masses were nonzero, oscillations between neutrinos with different flavors could be experimentally detected. This was recently recollected by Pontecorvo's son, Gil, who was also the youngest translator of the

Conference where all lectures were directly translated into Russian. Here are his words: "*It was in* 1964, *at the Dubna Conference, that Zichichi presented the first results of his PAPLEP experiment at CERN to search for a 3rd heavy lepton with its own neutrino by detecting acoplanar electron-muon pairs. He discussed his experiment with Bruno who, I remember, already at that time was impressed by Zichichi's idea. This idea is at the origin of the CERN to Gran Sasso neutrino beam, included in the original Gran Sasso Project that Zichichi presented to the Italian Government in* 1979. *To study the oscillation of the* 3*rd-family neutrino into neutrinos from the other two families was first proposed by Nino Zichichi.*"[14]

It was not easy to find in 1964 physicists with whom to talk about neutrino oscillations and projects to detect them. At Dubna I found Bruno Pontecorvo; at CERN again only John Bell and Viki Weisskopf. These were times when the head of the Theory Division at CERN was saying:[a] "*Nature cannot be so stupid to have many neutrinos when only one neutrino is enough to do the job.*"

Let me add to my recollection of the Dubna Conference an amusing detail. The Conference was from 5 to 15 August and in Geneva it was a quite hot summer. I went to Dubna with very light dressing. On the second day of the Conference the warm Dubna dropped to zero degrees. I was in trouble. The organizers helped to find a solution. No shops in Dubna could provide me with a heavy sweater. So a trip was organized to Moscow. Few unknown fellows were in my car; probably they were KGB fellows. No shops in Moscow could sell me a sweater. Coming back to Dubna, it was Bruno Pontecorvo who gave me his own heavy sweater, thus avoiding that I could get a strong cold.

When Pontecorvo came in Rome, he recalled me of the Dubna events and was very happy to support my Gran Sasso Project. In fact many problems discussed during the Dubna Conference with Pontecorvo were very much linked with the Gran Sasso Project.

The so-called "Rome School" in Italy was divided into two conflicting sectors. One was strongly against the Gran Sasso Project, saying that it was an example of Zichichi's Napoleonic ventures. In fact, surprisingly enough, after my presentation, during a special Seminar organized in honour of Bruno Pontecorvo (Fig. 2, Ref. 15), a journalist asked the following question:[a] "*Professor Pontecorvo, what do you think about the Napoleonic Gran Sasso Project elaborated by Professor Zichichi?.*" The audience — with a large number of journalists and other media fellows — was quite interested to know what the "communist" Pontecorvo would have answered about something proposed by the "anticommunist" Zichichi. Professor Pontecorvo with his standard stile of slowly expressing his view said:[a] "*I am sorry not to be young enough to take an active part in this formidable project of Professor Zichichi.*" This answer destroyed all opposition from the "Rome School" against the Gran Sasso Project.

Another reason for my gratitude to Pontecorvo was his support to my projects going on at CERN. The already mentioned PAPLEP experiment at CERN was

[a]The words may have been different but their meaning is exact.

Fig. 2. Antonino Zichichi and Bruno Pontecorvo, Rome, September 1978. During the Cold War Pontecorvo was accused of having passed from the West to the East (USSR) some secrets of the first nuclear weapon ever built by mankind. After many years spent in the USSR, Bruno Pontecorvo was suddenly allowed to visit Italy. The Berlin Wall was up and this became a great occasion for the media. It was the time when we had proposed the Gran Sasso Project. The so-called "*Rome School*" tried to bring to a halt the "Gran Sasso Project" with arguments similar to those used at Frascati with ADONE ("*Zichichi is searching for butterflies*," to boycott the energy increase of the (e^+e^-) collider). Apparently, underground lobbying had produced effects. For instance the CERN-Director General (DG) Leon Van Hove, during a CERN Council meeting declared that Zichichi's Gran Sasso Project was invented to stop the new collaboration between Italy and France to realize a joint venture in underground physics using the Fréjus tunnel. After this unprecedented attack against a very important initiative in Italy, the other CERN-DG, John Adams, called the author into his office, to tell him "*not to worry.*" This ended all attacks from CERN against the project. During the visit and the various lectures centred on Pontecorvo, a journalist asked: "*Professor Pontecorvo, what do you think of the Gran Sasso Project proposed by Professor Zichichi? Many physicists consider it a useless Napoleonic venture with weak scientific content.*" After a few seconds of thinking, in the usual Pontecorvo style of soft and slow answering, he said: "*I regret not to be young enough to participate in this formidable project. The scientific content of the project appears to me extremely interesting.*" This declaration by Pontecorvo came as a surprise, since we were on opposite political sides and every journalist was expecting a strong negative statement from Pontecorvo on the Gran Sasso Project. But physics prevailed. And this put an end to all — open as well as underground — lobbying against the Gran Sasso Project.

planned to search for new particles including the existence of a third lepton (in addition to the electron and the muon). The PAPLEP setup was the first example of a powerful detector which is now a standard technology in our Labs.

At the Dubna Conference a totally unexpected support came from the most qualified Centre in USSR for the physics I was engaged in at CERN.

The majority of physicists were working with bubble chambers technology. My group was one of the very few engaged in other technologies whose purpose was the search for rare phenomena, having as initial state the highest energy antiproton–proton annihilation. This production process had been theoretically studied[16] in order to call attention on the vast range of new physics where the dominant technology of the time, the bubble chamber, was unable to operate.

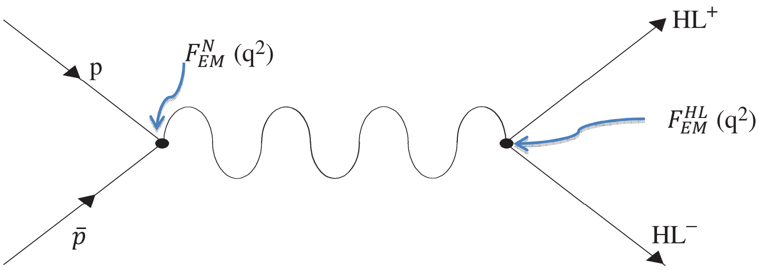
This work[16] had attracted the interest of Bruno Pontecorvo and other physicists at Dubna. With the PAPLEP setup — as already mentioned — it was possible to search for new physics, including a third lepton, much heavier than the muon, with a mass in the GeV range. The idea to search for a third lepton was fascinating. The starting point was to realize the reason why the second lepton (the muon) was so abundant in our Labs. This abundance was (and is) due to an incredible coincidence: the mass of the pion slightly higher than that of the muon. The π being (and is) produced in strong interactions but decaying thanks to weak interactions into the slightly lighter lepton, the muon.

My contribution to the Conference was divided in three parts: physics, technology and beams. We had constructed at CERN the most intense negative particle beam.[17,18] Nowadays high intensity seems obvious but at that time, as said, since the dominant technology was the bubble chamber, few particles per burst were enough. To have fifty thousands antiprotons per burst was considered to be totally useless. An intense beam of negative particles was instead needed in order to have the annihilation process ($\bar{p}p$) as source of high energy timelike photons producing all possible states,[16] including the vector bosons and eventually heavy leptons pairs.

The basic reaction at the tree level was described by the Feynman diagram with two timelike electromagnetic form factors $F_{\rm EM}$. If the production process was for

$$H^{\pm}H^{\mp}$$

pairs, the diagram was expected to be



(1)

There was a critical point about reaction:

$$\bar{p}p \to HL^+ + HL^- \,; \tag{2}$$

namely the presence of two timelike electromagnetic form factors: one for the nucleon and one for the heavy lepton. This last one was taken to be pointlike. The one for the nucleon $F^N_{\rm EM}(q^2)$ was unknown. According to some theoretical speculations, this could also have been pointlike,

$$F^N_{\rm EM}(q^2 \text{ timelike}) \simeq 1\,. \tag{3}$$

The results from the elastic scattering experiments by Hofstadter and collaborators gave for the electromagnetic form factor of the nucleon a non-pointlike result for spacelike q^2. For us it would have been great if in the timelike region the nucleon form factor was going to be pointlike, our aim being to produce as many $HL^{\pm}$ pairs as possible.

This is how, instead of discovering the third lepton, we discovered that in the timelike q^2 range the electromagnetic form factor of the nucleon

$$F^N_{\rm EM}(q^2 \text{ timelike})$$

was (and is) so large that the cross-section for reaction (2) was (and is) at least 500 times smaller than the one theoretically predicted for pointlike value (3). When I presented these results at the Dubna Conference,[17–21] Bruno Touschek was enthusiastically happy. In fact his project for a high energy (e^+e^-) collider ADONE (i.e. big ADA) would have lost the competition against the annihilation process $(\bar{p}p)$ where high energy timelike photons could have been produced at high rate[22] if $F^N_{\rm EM}$ (q^2 timelike) had been pointlike (3).

Going back to reaction (2)

$$\bar{p}p \to HL^+ + HL^-$$

the decays of the heavy lepton pairs, would have produced

$$HL^+ \begin{cases} e^+ + \nu_e + \bar{\nu}_{HL}\,, \\ \mu^+ + \nu_\mu + \bar{\nu}_{HL}\,, \end{cases} \tag{4}$$

$$HL^- \begin{cases} e^- + \bar{\nu}_e + \nu_{HL}\,, \\ \mu^- + \bar{\nu}_\mu + \nu_{HL} \end{cases} \tag{5}$$

in the final state an $(e^{\pm}\mu^{\mp})$ pair plus missing momenta,

$$\bar{p}p \to e^{\pm}\mu^{\mp} + \text{neutrinos}\,. \tag{6}$$

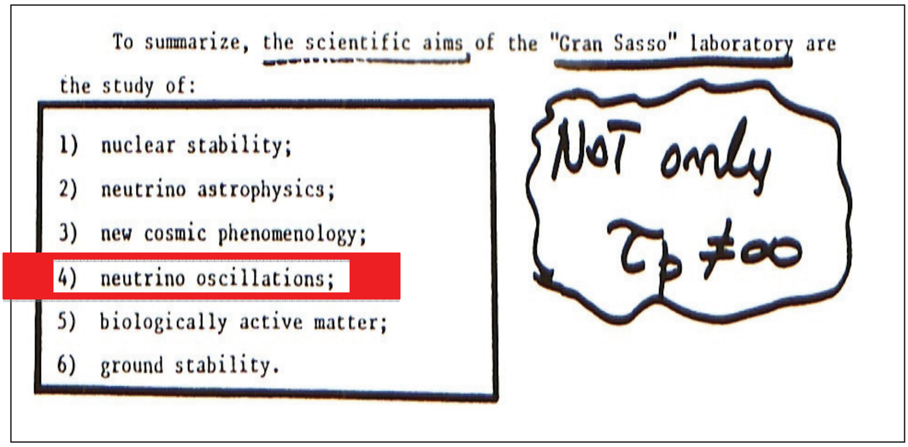
To select a final state with $(e^{\pm}\mu^{\mp})$ plus missing momenta, our enemy was the background from the standard annihilation channels

$$\bar{p} + p \to \pi^{\pm} + \pi^{\mp} + \pi^0 + \cdots\,. \tag{7}$$

A strong selection of $(e^{\pm})$ and $(\mu^{\pm})$ was needed at the level of 10^{-3}–10^{-4} against pions. This was achieved via the newly invented technology for electrons.[23,24] Bruno Pontecorvo became a strong supporter of this new venture in physics.

These are the reasons why in many occasions I have expressed my gratitude to Bruno Pontecorvo whose vision played an important role in my experimental programme at CERN and Frascati. In fact it was the discovery[19–21] of the large timelike electromagnetic form factor of the nucleon which prompted my group to go to Frascati where the highest energy (e^+e^-) collider of the time (ADONE) was planned to be built, in order to go on with the search for new particles such as new vector mesons and a third lepton with its own neutrino.

In order to appreciate the vision of Bruno Pontecorvo it is necessary to remember once more what the status of our physics was at the time of the Dubna Conference. The problem of the charged leptons with the muon neutrino not identical to the electron neutrino was (and still is) not understood. Were the neutrinos all massless



To summarize, the scientific aims of the "Gran Sasso" laboratory are the study of:

1) nuclear stability;
2) neutrino astrophysics;
3) new cosmic phenomenology;
4) neutrino oscillations;
5) biologically active matter;
6) ground stability.

NOT only $\tau_p \neq \infty$

Fig. 3. The scientific aims at the Gran Sasso Lab.

particles? As shown in Figs. 3, 4 and 5, the problem of neutrino mixing was still open in 1979 when the Gran Sasso Project was presented at the Special Committee of the Italian Senate. And this was fifteen years after Dubna. Another problem was the missing antideuteron production at the level of $10^{-7}(\bar{d}/\pi^-)$ and the CP breaking announced at the Dubna Conference. In this context it should be recalled that no one was (and still now is) able to formulate nuclear forces on a basic fundamental form like QED; moreover Relativistic Quantum Field Theory (RQFT) was — as

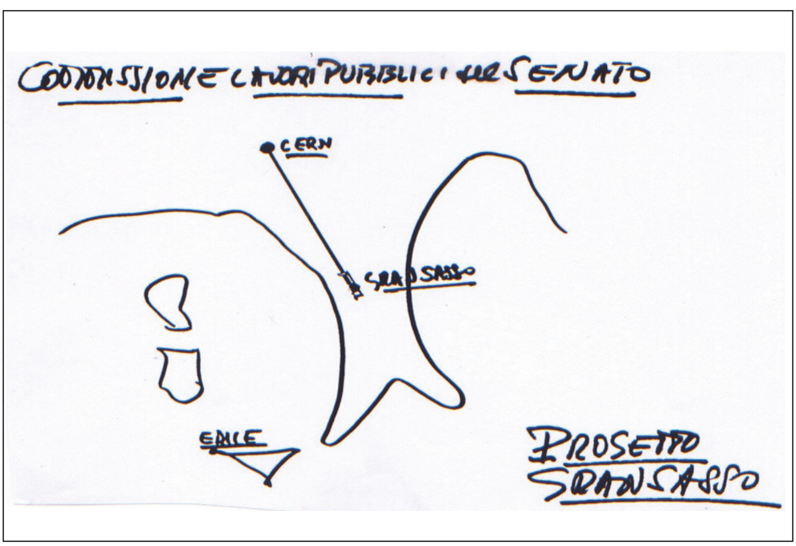


Fig. 4. Handwritten notes from the presentation by A. Zichichi to the Commission on Public Works of the Senate in a Session convened on short notice by the President of the Senate to discuss the proposal for the Gran Sasso Project (1979).

The range of scientific perspectives opened up by the Gran Sasso Laboratory goes far beyond the measurement of the proton lifetime, as shown in Fig. 1.1.

These *scientific perspectives* depend on the *basic features* of the Gran Sasso Laboratory, which are:

1) very low noise due to local radioactivity;
2) neither too deep, nor too shallow underground;
3) orientation towards the most powerful (artificial) source of neutrinos and other unknowns (Fig. 2.1);
4) link with a laboratory at the top of the Gran Sasso, which allows time coincidences to be made (Fig. 2.2);
5) instrumentation which uses the most advanced technologies.

The *low noise* level in terms of *natural radioactivity*, was proved before the excavation work started. The measurements of the cosmic ray flux and of the local rock radioactivity were first performed by one of my collaborators, – L. Federici [3] – whom I want to pay tribute to, in this solemn occasion. These measurements demonstrated that over the length of one Km the cosmic ray flux was constant. This nice feature is due to the shape and structure of the mountain. The Gran Sasso rock radioactivity was so low that the term «laboratory of cosmic silence» could be coined.

REFERENCES

[1a] *THE GRAN SASSO PROJECT.* A. Zichichi, Proceedings of the GUD-Workshop on "Physics and Astrophysics with a Multikiloton Modular Underground Track Detector", Rome, Italy, 29-31 October 1981 (INFN, Frascati, 1982), 141.

[1b] *THE GRAN SASSO PROJECT.* A. Zichichi, NFN/AE-82/l, 28 February 1982.

[1c] *THE GRAN SASSO PROJECT.* A. Zichichi, Proceedings of the Workshop on "Science Underground", Los Alamos, NM, USA, 27 September-1 October 1982 (AIP, New York, 1983), 52.

[2] *THE GRAN SASSO LABORATORY.* A. Zichichi, Proceedings of the International Colloquium on "Matter Non-Conservation" - ICOMAN '83, Frascati, Italy, 17-21 January 1983 (INFN, Frascati, 1983), 3.

[3] *THE GRAN SASSO LABORATORY AND THE ELOISATRON PROJECT.* A. Zichichi, "Old and New Forces of Nature" (Plenum Press, New York-London, 1988), 335.

[4] *PERSPECTIVES OF UNDERGROUND PHYSICS: THE GRAN SASSO PROJECT.* A. Zichichi, Invited Plenary Lecture at the Symposium on "Present Trends, Concepts and Instruments of Particle Physics", in honour of Marcello Conversi's 70th birthday, Rome, Italy, 3-4 November 1987, *Conference Proceedings* Eds. G. Baroni, L. Maiani and G. Salvini (SIF, Bologna, 1988), Vol. 15, 107.

Fig. 5. Basic characteristics of the Lab as presented to the Senate Commission in 1979 and related references.

already reported — loosing credibility against the much simpler mathematics of the S-matrix theory. The search for $\bar{d}$ at the level of $10^{-8}\bar{d}/\pi^-$ produced the first evidence for its existence. Thirty years later Luciano Maiani[25] wrote: "*The discovery* *of the antideuteron added another fundamental piece of information to the issue of matter–antimatter symmetry, opened by Dirac in the twenties, and gave more confidence to the search of a field theoretical basis for the strong interactions, that today seems so obvious to us.*"

At the time of Dubna Conference neither QCD nor neutrino oscillations had been discovered. The reason for my gratitude to Bruno Pontecorvo has very simple roots. Before going to the Dubna Conference I could not imagine that I would have found in my Dubna colleagues such a strong support to the physics I had in mind.

References

1. J. Christenson, J. W. Cronin, V. L. Fitch and R. Turlay, *Phys. Rev. Lett.* **13**, 138 (1964).
2. T. D. Lee and C. N. Yang, *Phys. Rev.* **104**, 254 (1956).
3. C. S. Wu, E. Ambler, R. W. Hayward and D. D. Hoppes, *Phys. Rev.* **105**, 1413 (1957).
4. R. Garwin, L. Lederman and M. Weinrich, *Phys. Rev.* **105**, 1415 (1957).
5. J. J. Friedman and V. L. Telegdi, *Phys. Rev.* **105**, 1681 (1957).
6. L. D. Landau, *Zh. Eksp. Teor. Fiz.* **32**, 405 (1957).
7. T. D. Lee, R. Oehme and C. N. Yang, *Phys. Rev.* **106**, 340 (1957).
8. R. Adair, W. Chinowsky, R. Crittenden, L. B. Leipuner, B. Musgrave and F. T. Shively, *Phys. Rev.* **132**, 2285 (1963).
9. C. S. Wu, T. D. Lee, N. Cabibbo, V. F. Weisskopf, S. C. C. Ting, C. Villi, M. Conversi, A. Petermann, B. H. Wiik and G. Wolf, *The Origin of the Third Family*, eds. O. Barnabei, L. Maiani, R. A. Ricci and F. Roversi Monaco (Rome, 1997, World Scientific, 1998).
10. M. Goldberger, *The Quantum Theory of Fields, Proceedings of the 12th Solvay Conference* (Interscience, New York, 1961).
11. G. Chew, *S-Matrix Theory* (W.A. Benjamin Inc., 1963).
12. A. Zichichi, A few words on the Standard Model, in Subnuclear Physics: The First 50 Years: Highlights from Erice to ELN, World Scientific Series in 20th Century Physics, Vol. 24, eds. O. Barnabei, P. Pupillo and F. Roversi Monaco (World Scientific, 2000), p. 168 [a joint publication by University and Academy of Sciences of Bologna, Italy, 1998].
13. A. Zichichi, Ettore Majorana — His genius and long-lasting legacy, in *The Majorana 'Neutrinos' — Recollections by Bruno Pontecorvo* (Italian Physical Society, 2007), Chapter 5, pp. 27–51.
14. G. Pontecorvo, *Il Nuovo Saggiatore* **27**, no. 3-4 (2011).
15. A. Zichichi, Subnuclear Physics: The First 50 Years: Highlights from Erice to ELN, World Scientific Series in 20th Century Physics, Vol. 24, eds. O. Barnabei, P. Pupillo and F. Roversi Monaco (World Scientific, 2000), p. 8 [a joint publication by University and Academy of Sciences of Bologna, Italy, 1998].
16. A. Zichichi, S. M. Berman, N. Cabibbo and R. Gatto, *Nuovo Cimento* **24**, 170 (1962).
17. G. Brautti, G. Fidecaro, T. Massam, M. Morpurgo, Th. Muller, G. Petrucci, E. Rocco, P. Schiavon, M. Schneegans and A. Zichichi, A high-intensity enriched beam of kaons and antiprotons, in *Proc. Int. Conf. on "High-Energy Physics"*, Vol. 2, Dubna, USSR, 5–15 August 1964 (Atomizdat, Moscow, 1966), p. 556.
18. G. Brautti, G. Fidecaro, T. Massam, M. Morpurgo, Th. Muller, G. Petrucci, E. Rocco, P. Schiavon, M. Schneegans and A. Zichichi, *Nuovo Cimento* **38**, 1861 (1965).

19. M. Conversi, T. Massam, Th. Muller, M. Schneegans and A. Zichichi, Proton antiproton annihilation into muon pair, in *Proc. Int. Conf. on "High-Energy Physics"*, Vol. 1, Dubna, USSR, 5–15 August 1964 (Atomizdat, Moscow, 1966), p. 857.
20. M. Conversi, T. Massam, Th. Muller and A. Zichichi, *Phys. Lett.* **5**, 195 (1963).
21. M. Conversi, T. Massam, Th. Muller and A. Zichichi, An experiment on the timelike electromagnetic structure of the proton, in *Proc. Int. Conf. on "Elementary Particles"*, Vol. 1, Siena, Italy, 30 September–5 October 1963 (Italian Physical Society, Bologna, 1964), p. 488.
22. M. Conversi, T. Massam, Th. Muller and A. Zichichi, The timelike form factor of the nucleon and its consequences on the experiments with colliding electron-positron beams, in *Proc. Int. Conf. on "High-Energy Accelerators"*, Frascati, Italy, 9–16 September 1965 (CNEN, Rome, 1966), p. 289.
23. T. Massam, Th. Muller and A. Zichichi, A telescope to identify electrons in the presence of pion background, CERN Report 63-25, 27 June 1963.
24. T. Massam, Th. Muller, M. Schneegans and A. Zichichi, *Nuovo Cimento* **39**, 464 (1965).
25. L. Maiani, *Symposium to Celebrate the 30th Anniversary of the Discovery of Nuclear Antimatter*, Conference Proceedings, Vol. 53, eds. L. Maiani and R. A. Ricci (Italian Physical Society, Bologna, Italy, 1996), p. XI.