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Raoul Gatto and Bruno Touschek's collaboration in the birth of electron-positron physics

Luisa Bonolis[1], Franco Buccella[2], Giulia Pancheri [3]

[1]Max Planck Institut f¨ur Wissenschaftsgeschichte, Boltzmannstrasse 22, Berlin, 14195, Germany lbonolis@mpiwg-berlin.mpg.de
[2]INFN Sezione di Roma1, c/o Dipartimento di Fisica, Sapienza Università di Roma, Piazzale Aldo Moro 5, Rome, 100184, Italy –franco.buccella@roma1.infn.it
[3]INFN Frascati Laboratories, Via Enrico Fermi 56, Frascati, 100044, Italy – giulia.pancheri@lnf.infn.it

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Keywords: history of physics, elementary particles, electron-positron colliders

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Introduction

The rise of particle physics during the last century and the contribution given by Italian physicists, is a story still to be completed. Historians agree that in the 1930's in Europe, the major physics centers in what was known as "nuclear physics" were in Cambridge, Paris, Berlin and Rome with Fermi's group. Likewise, it can be said that in the 1970s, great progress in the field of particle physics, was taking place in Italy, and, in particular at University of Rome and the nearby INFN Frascati National Laboratories. Such flourishing of important theoretical work and just as extraordinary advances in experimental and accelerator physics can be traced back to the 1950's, when the country was recovering from twenty years of political isolation and the tragic disruptions brought by the Second World War to both society and scientific progress. Among the many protagonists of the reconstruction of Italian science during this period, there were in Rome two scientists who left important legacies, Raoul Gatto and Bruno Touschek [1]. Recently new articles and books have appeared about them [2–9], but publications about Gatto and the work with Cabibbo about electron-positron physics [10, 11], do not fully address his crucial collaboration with Touschek in bringing to success the construction of AdA, the first ever electron-positron collider, and his contribution to the ADONE proposal. The present article is meant to fill this gap.

In this article we shall see the extent of Gatto's scientific contribution to the enterprise Touschek is famous for, based on existing documents and the reconstruction

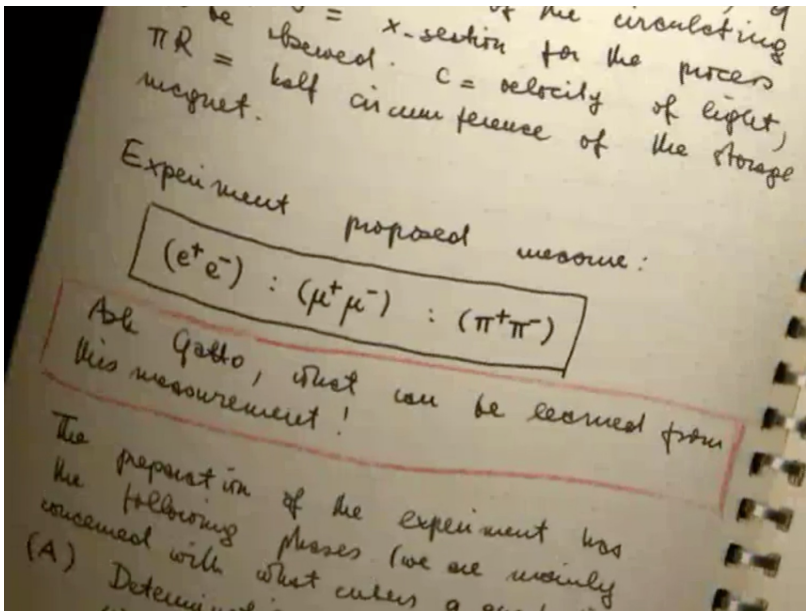


Fig. 1 A page from AdA's *Storage Ring* Notebook, started by Bruno Touschek on February 18th, 1960, the day after the discussion at the Frascati Scientific Council meeting, where he had proposed an "experiment worth doing", namely electron-positron collisions and annihilation into new particles.

of the making of AdA in [9]. We shall also include Gatto's personal remembrances of Bruno Touschek, from [12] and some private communications from Gatto to one of the authors [13].

Interestingly, while we have Gatto's memories of Bruno [12], very little was written by Touschek about his friend. There is however one sentence, which Touschek jotted down in the first hand-written draft of AdA'a proposal. On February 18th, 1960, in the famous *Storage Ring* Notebook, SR for short,[1] Touschek writes : "Ask Gatto...", as shown in Fig. 1. These two words testify to the closeness between these two scientists, as they opened the road to electron-positron colliders. They discussed together the processes to study and were needed to prove the feasibility of collider rings as tool for probing the world of elementary particles. Together they assigned these calculations to the students who were asking for a *Tesi di laurea in fisica* at University of Rome, among them Guido Altarelli, Franco Buccella, Etim G. Etim, Giovanni Gallavotti, G. Putzolu, Paolo di Vecchia, Giancarlo Rossi. They went to conferences and showed the world what could be gained by the new type of accelerator. And, together with Fernando Amman, Carlo Bernardini, Gianfranco Corazza, and Giorgio Ghigo, they put forward the proposal for the construction of the storage ring ADONE [14], an electron-positron collider much larger and more powerful than AdA, meant to explore the creation and properties of all known elementary particles [15].[2]

After the discovery of the Touschek effect in 1963 [16], and the proof of the feasibility of electron-positron colliders [17], Gatto and Touschek's roads moved apart, physics-wise and geographically. Touschek remained to work in Rome, except for the time he was commuting weekly to Orsay,[3] and the time he spent at CERN during the

[1] The Notebook is kept among Bruno Touschek papers in Rome Sapienza University, Physics Department Archives.

[2] Amman, Bernardini, Corazza and Ghigo had all participated in the construction of the Frascati electron synchrotron, which came into operation in April 1959, and had all encouraged Touschek in his proposal to build an electron-positron collider. Fernando Amman would later be in charge of the construction of ADONE.

[3] See Carlo Bernardini's interview in the docu-film *Touschek with AdA in Orsay* by E. Agapito, L. Bonolis and G.P., 2013.

Fig. 2 Raoul Gatto in 1983, from Phototèque UNIGE, © University of Geneva.

last year of his short life [1, 18]. Gatto went to Florence to create an extraordinary school in theoretical physics [4],[4] then to Padova and Rome, before moving finally to University of Geneva, Fig. 2, from where he retired in 1997.

He was for many years Chief Editor of Physics Letters, which, under his tenure, became one of the most influential journals in particle physics. But Gatto and Touschek's legacy to physics continued through their students and beyond their separation. Gatto and Touschek's theoretical physics legacy appears jointly in a 1984 article [19], where the calculation of the $W - boson$ transverse momentum proceeds via the Altarelli-Parisi equations proposed by Guido Altarelli and Giorgio Parisi [20].[5] While the $W - p_t$ paper does not refer to Touschek's work, some of its authors directly come from Gatto and Touschek's school of theoretical physics: Altarelli had graduated with Gatto, Keith Ellis was Altarelli's student, while Mario Greco, a member of the Frascati theory group since 1965 [21], inspired by Touschek, had formulated a coherent state approach to Touschek's resummation ideas together with Giancarlo Rossi [22]. Rossi had graduated under Touschek's supervision, and would later write with him a book on Statistical Mechanics [23] and participate to the development of Lattice Gauge Theories studies at University of Rome, together with Guido Martinelli [24, 25]. Touschek's legacy is particularly explicit in an earlier work by Giorgio Parisi and Roberto Petronzio, both graduates under Nicola Cabibbo's supervision. Their well known [26]

[4] Gatto's name, *cat* in English, led to his students to be known as the " gattini", the *kittens* in English.
[5] Giorgio Parisi was awarded the 2021 Nobel Prize in Physics "for the discovery of the interplay of disorder and fluctuations in physical systems from atomic to planetary scales", sharing one half of the prize with Syukuro Manabe and Klaus Hasselmann, who jointly received it "for the physical modelling of Earth's climate, quantifying variability and reliably predicting global warming".

paper about transverse momentum in strong interaction processes extends Touschek Resummation technique [27, 28] to transverse momentum distributions in ChromoDynamics. Such extensions [29, 30] had been, and would be for many years, subject of intense study in the Frascati theory group, which Touschek had created in the mid-'60s to exploit ADONE's physics [14].

We shall start with what Gatto said of Touschek in 1987, Sect. 1, followed by an overview of the discoveries in particle physics in the '50s, Sect. 2, and then discuss the extent of Gatto's contribution to AdA and the collaboration with Touschek, in Sect. 3.

1 About Gatto and Touschek: an overview

In this paper we reproduce three documents about Gatto's participation in the work on electron-positron collisions: the first one is courtesy of the Laboratori Nazionali di Frascati, and was contributed by Gatto on the occasion of the Bruno Touschek Memorial Lectures (BTML) held in Frascati in 1987 [12], one is presented in the next section in English translation from the original Italian version, and is a private communication to L.B., via e-mail in 2003, during the preparation of the docu-film *Bruno Touschek and the art of Physics*, the third one is a letter from Gatto, sent to G.P. , around 2010 during the preparation of Ref. [2].

The Lectures were held in Frascati in May 1987 to remember Bruno Touschek, who had passed away 9 years before. Touschek's friends and colleagues were asked to come to Frascati and contribute their recollections before time erased them, including Burton Richter, Carlo Rubbia and Simon van der Meer.[6] Due to unforeseen and unfortunate circumstances, the written contributions to this event appeared only 17 years later, transcribed from the audio-record, and published in Ref. [31], after the authors' own checks. This gives a unique flavour to the memories presented in this little volume, that resonate with an immediacy and warmth not always to be found in conference proceedings. Gatto participated in the event which centered on a series of lectures by John Bell on Quantum Mechanics. Fig. (3) shows Gatto with John and Mary Bell, and in the ADONE Conference Hall of Frascati Laboratories.

In Gatto's words, Bruno comes alive, as a friend and a physicist who played an important role during Gatto's first years in Rome and with whom he shared a strong interest in the physics of the CTP theorem [32]. His testimony constitutes one of the most moving and clear descriptions of their friendship and the beginnings of the electron positron rings story. Gatto is somewhat dismissive of his role in the creation and construction of AdA, the first electron positron storage ring in the world, but we shall argue that the close collaboration between Bruno and Raoul was the key to AdA's success, much more than what is usually said.

1.1 What Gatto said of Touschek in 1987

Memories of Bruno Touschek by
Raoul Gatto
Department de Physique Théorique, Université de Genève

When Mario Greco called some month[s] ago, he asked for a general talk on the present status of electroweak theory. I accepted with pleasure and I felt honored to be able to present such a talk within this commemoration of Bruno Touschek, one of the most intelligent physicist I have ever known, and a dear friend. Later on, Greco informed me that the program had to be modified and that he rather expected a talk

[6] Burton Richter shared with Samuel Ting the 1976 Nobel Prize in Physics for the discovery of the particle J/Ψ, as described in later section. Carlo Rubbia and Simon van der Meer were awarded the 1984 Nobel Prize in Physics, "for their decisive contributions to the large project, which led to the discovery of the field particles W and Z, communicators of weak interaction", from https://www.nobelprize.org/prizes/physics/1984/summary/.

Fig. 3 The top photograph shows Raoul Gatto in conversation with Mary and John Bell, during the Bruno Touschek Memorial Lectures; below, from the left on first row, Simon van de Meer, Burton Richter, Mary Bell, John Bell, Raoul Gatto and Mario Greco, second from right LNF Director Sergio Tazzari. Carlo Rubbia can be seen in third row, just above Gatto in the photograph. Frascati 1987. © LNF-INFN.

within the present open session. It is much harder for me to talk on things that go beyond present day physics, essentially because of the limitations of my personality. But, I consider a compelling duty to dedicate my thoughts to Bruno Touschek and to some of the physics to which he contributed. We are here to commemorate Bruno, who was a friend of most of us, a most original and profound physicist, who disappeared so prematurely, leaving all of us in great sadness. I think that for what he did, he deserved much more than the difficult times and the circumstances his life offered him [1]. Particularly to me, the memory of Bruno is so dear, as he was, together with Ferretti and Amaldi, one of my first teachers in physics. I learned a lot from him, discussing entire afternoons at my early times in physics during the years 1953-1956.

I never had unfortunately the chance of directly collaborating with Bruno. I must say that the only paper where our two names appear jointly was the internal Frascati report [15] containing the Adone proposal, written together with Giorgio Ghigo, Fernando Amman, and Carlo Bernardini. But I had only been asked to join a few pages on the theory to this proposal, which was essentially the work of Bruno and his collaborators. The reason for this lack of direct collaboration were mostly logistic. I was too inexpert in the period in Rome before I went to the United States, and, afterwards, I

had to travel so frequently between Universities[7] that I could'nt enjoy that constant precious contact with Bruno that I had had before. So my most intense memories go mainly back to the years from 1953 to 1956 when I met Bruno almost every day and I talked with him and learned so much from him. Looking back at the work of that time, I see how often I felt I had to acknowledge his generous help and encouragement. Most important was his friendliness and his consideration. At that time, especially at the beginning, I felt rather lost and unsecure, in a career which seemed to be very competitive and where some people occasionally exhibited an intense pride of hierarchies. Bruno, on the opposite, was friendly, cordial, encouraging. I remember, I was 22, at a Conference in Cagliari. He was sitting at a cafè with Pauli,[8] who partecipated in the meeting, and I was passing [by] the side walk, rather trying to get unnoticed. He called me and wanted me to sit down with him and Pauli and partecipate in the discussion. Similar things happened many times. When a foreign visitor arrived, we often went with the visitor to Albano or Nemi, two small towns here in the neighbourhoods, for a walk and a glass of wine. He had bought at that time a strange sports car, I think it was a Triumph, an extremely uncomfortable convertible. He used to drive in full winter with the windshield lowered so that all the air would blow directly into our faces. Before returning to Rome, in the not very dense but totally disordered traffic of the roman fifties, he would not separate from the colleagues before pronouncing the historical sentence that the fighters in the Coliseum would tell Cesar in the old Rome: "morituri te salutant", in his wonderful precise Latin. He was referring to the uncertain conditions of his car. I think we lived in that period a rather adventurous life, but the friendliness and generosity of Bruno were an uncomparable and unforgettable compensation.

I have been instructed to try to give a view on what were the theoretical problems of the late fifties, which related to the yet inexisting electron-positron physics. As always happens when one tries to compare with older times, one cannot avoid to remark how different it was from nowadays, how much more limited were our problems and purposes. Of course, it would not be correct, historically, to judge on such a perspective. At the same time, comparing with all that was later done, illustrates, I think, the courage and vision of Bruno, with his unique combination of competences in so many different fields of physics.

As the older people in this audience will remember, one of the dominant problems of theory in the late fifties, was that of the nucleon's electromagnetic from factors. Measurements had been done at Stanford, a laboratory which was at that time, and still is, at the advancing frontiers of physics. Already since 1955, Hofstadter and McAllister [33, 34] first observed structure effects in the proton, and in the subsequent years an impressive amount of data was collected. In a very short note of remarkable originality, in 1957, Nambu [35] pointed out two main features: (i) the relevance of using a spectral representation, and, (ii), the possible role of mesonic resonances. Specifically he drew attention on the role of a possible isoscalar resonance of the type later called ω (but he called it ρ). The isoscalar property would guarantee same sign for proton and neutron. On the other hand, what Nambu called the pion cloud, the isovector part, would change sign. The electric form factor would thus add in the proton and approximately cancel in the neutron. The dispersion theory approach for the nucleon form factors was soon later developed by Chew, Karplus, Gasiorowicz, and Zachariasen [36], and by Federbush, Goldberger, and Treiman [37]. Basic to the dispersion analysis is the knowledge of the absorptive contribution, like in optics for the Kramers- Kroning relations. For the nucleon form factors the absorptive part starts with contributions which correspond to a virtual time-like photon going into two pions for the isovector

[7] In 1959 Gatto won the national competition for a Chair in Theoretical Physics, together with Bruno Zumino and Sergio Fubini. His first assignement was at the University of Cagliari, which he joined in 1960. After moving to Florence, Padova and Rome, his final academic destination was University of Geneva.

[8] Wolfgang Pauli had been awarded the 1945 Nobel Prize in Physics "for the discovery of the Exclusion Principle, also called the Pauli Principle".

part, and into three pions for the isoscalar part. Having an electron- positron machine would have rapidly settled most of the problems. Nobody however dared to start such a project. When e^+e^- machine became operational, and it was essentially the merit of Bruno and of a few other courageous physicists, part of this particular history had already been unveiled. Frazer and Fulco [38] had already proposed a resonant isovector pion-pion interaction. The experimental evidence came from pion- proton inelastic collisions, preliminarly by Derado [39] and through extrapolation method by Anderson at al. [40], by Erwin et al. [41], by Stonehill at al. [42]. As for the isoscalar resonance, that Nambu had conjectured, it was Maglic, Alvarez, Rosenfeld, and Stevenson [43], who discovered it in proton-antiproton. But the precision work still came from the electron-positron machines.

This is one particular aspect of the theoretical situation and problematics of that time. Another aspect had to do with the efforts to test the validity of quantum electrodynamics. Again at Stanford, especially Sidney Drell [44] had pushed in this direction. In Europe, we had the successful g-2 experiment [45].

Electron-electron collisions would allow to test the photon propagator. I remember a conference by Professor Panofsky, at the end of 1959, reporting on the pioneering work of Barber, Gittelman, O'Neil, Panofsky, and Richter [46], on electron rings. Answering to a question, Panofsky mentioned that, to test the electron (rather than the photon) propagator, electron-positron collisions would have been suitable, through observation of 2-photon annihilation, but that such a development could present additional technical difficulties and that for the moment had been postponed. This also, I think, shows that a strong courage and optimism was required to embark in the direction of e^+e^-collisions and, beyond any doubt, without the vision, the optimism, the courage of Touschek, e^+e^- physics would, at least, have suffered a delay.

The Frascati laboratory produced at that time first class physics, in a quiet and almost unperceptible way. The Frascati atmosphere was a typical country atmosphere. From the windows of our offices one could admire a large extension of vineyards and sometimes hear people singing what in America would be called country songs. It was a relaxed and perhaps provincial atmosphere. But it gave all of us the possibility of working hard and of imagining the future not only the immediate future but also what was, for that time, the far-away future. To imagine, for instance, the e^+e^- production of neutral weak vector bosons, coupled to neutral currents, or the e^+e^- production of pairs of weak charged vector bosons, and the weak asymmetries which are now being measured. That relaxed Frascati atmosphere may have been provincial, but certainly it gave all of us a feeling of doing something together, and that something was worthwhile. All this we owe to Bruno, to his scientific and human qualities. The contribution of Touschek's direct collaborators, Giorgio Ghigo, Carlo Bernardini, Gianfranco Corazza, who were the initial collaborators for AdA [47], of Querzoli, Sacerdoti, Puglisi, Massarotti, Bizzarri, Di Giugno, of Marin and Lacoste at Orsay at those early times, was undoubtedly of the highest quality [48]. Fernando Amman took [on] the responsibility directing of the Adone project [49]. As far as theory is concerned, let me mention the contribution of Nicola Cabibbo and the contribution of Francesco Calogero. Much physics was done with Adone. Much more, we all know, could and should have been done, were it not situations and circumstances which were essentially external to us physicists.

I shall not go back to those results, to which so many Italian physicist contributed [...] Although mainly concentrated on proton machines, CERN was not insensitive to progress on electron-electron and electron-positron physics. Already in June 1961, a conference on very high energy phenomena was organized at CERN and it was remarkable that all the three invited talks on electromagnetic interactions were on electron-electron and electron-positron colliding beams. One of the three talks was given by Bruno, who gave an exact presentation of Ada and of the Adone project. The report [50], is in the Proceedings, which were edited by John Bell et al.

We know that Touschek had a deep respect for Pauli. His relations with Pauli were steady but they become more intense when Pauli got interested in what were later called the Pauli-Pursey transformations, a general class of rigid, that is global as opposite to local, transformations [51, 52]. This was towards the end of Pauli's life [53, 54].[9]But, even before, Touschek always found very attractive Pauli's ideas on non-abelian gauge theories (Professors Enz and Jost have recently helped me in clarifying this part of Pauli's history). Bruno often told me of these, for that time, quite new ideas [55].[10] Touschek and, I must say, also Ferretti, during so many discussions, always showed a special attention to the role of gauge invariance. In a sense I am grateful for this to both Touschek and Ferretti, as they transmitted this interest also to their students.

What I learned from Bruno was also a sort of style. He never liked extremely long calculations and uninspiring formulae. He put ideas and invention before the hard mechanical effort. When he wrote a formula he seemed to carefully draw it, designing, more than just writing it down. He never would waste his time in checking hundredth of papers in the literature, but he would rather try to go directly to the heart of the problem. He first wanted everything to be simplified and reduced to the essential. His loved books, in physics, were few and of classical authors, Sommerfeld, Pauli, Heitler. Once, he was going on vacation to the mountains, and he told me he wanted to work on beta-decay. The only thing he was taking with him was a very small note-book, still empty. No books, no articles, no preprints. The notebook was extremely tiny. Like any good theoretician he always thought that right things have to be simple and not require a cumbersome apparatus.

Touschek had a deep classical culture, which certainly allowed him to assimilate the Italian culture and to adapt himself so easily to our country and our people. A deep side of his personality was however his relation to the Viennese culture. I always found remarkable how Austrian culture, Anglo-saxon culture, and Latin culture could so well coexist in him. He had deeply thought and elaborated on the aspects of these apparently so disjoined cultures. The Jewish culture was undoubtly also part of his personality. I think it became manifest in his particular intelligent, sometimes critical, sense of humor, which reminds me of modern Yiddish theater.

In autumn 1977, already seriously ill, Bruno was at CERN. In spite of his evident unhealthy conditions he always was willing to discuss. He often developed typical particular interests, even outside physics. He liked to speculate on that explosion of cultural life that characterized the Vienna of Franz Joseph. For that he proposed a socio-economical explanation, which included elements of politics and also of urbanism. Unfortunately I have not been able to entirely reconstruct his arguments, which perhaps I never could follow completely because of my incompetence.

I had written, in the first version of these notes, additional recollections of my last encounters with Bruno at CERN. I think they are not really so relevant here, although they will remain vivid in my memory. When I learned of his death in Innsbruck I was so shocked that for a few days I could not do any useful physics. All those, among us, who had the privilege of knowing Bruno, will never forget him, and we have an immense debt of gratitude to his intelligence, generosity, and friendliness.

[9]Ref. [53] is a posthumous work, introduced by a note (by Touschek) which reads: "The contribution by W. Pauli to this report was not intended for publication. However, it was decided to publish it, in the form the talk was given, as a document of His last activities."

[10]Gatto refers here to a book by P. Gulmanelli, "Su una teoria delle spin isotopico", edited by Pleion, Milan, Italy, 1954, after the author's work under Pauli. See a recent comment to this book, where Pauli's invention of the non-Abelian Kaluza-Klein theories is discussed [55].

Fig. 4 A young Raoul Gatto from a photograph kindly received by L. B., through Carlo Bernardini, courtesy of Gatto's family, all rights reserved; a drawing by Bruno Touschek, where he plays on Gatto's name to make a doodle, © Touschek family, all rights reserved.

We shall now briefly illustrate where Gatto and Touschek came from when they met in Rome in 1953.

1.2 From Catania to Rome

[Raffaele] Raoul Gatto was born in Catania on December 8, 1930 and enrolled in physics at the University of Pisa, in 1947, having been awarded a scholarship to the Scuola Normale Superiore (SNS), a very prestigious institution that accepts students through an extremely selective process.[11] He obtained his degree in 1951, and his Diploma from the Scuola Normale soon after. He had received a special dispensation to do his thesis in theoretical physics under the guidance of Bruno Ferretti, from University of Rome. In Pisa, among his close friends there was Benedetto De Tollis, with whom he shared a vocation for theoretical physics, and who would later become Professor in Perugia.[12] But in Pisa, at the time, the chair of theoretical physics was empty, and there was no way to obtain a thesis on the subject. In order to fullfil their dream, a thesis supervisor outside University of Pisa had to accept them, and the Scuola Normale had to give special dispensation. The solution may have come from Marcello Conversi, Professor of Experimental Physics in Pisa, who had graduated in Rome with Bruno Ferretti, former assistant to Enrico Fermi, before the latter's departure for the United States in 1938. Ferretti, a close collaborator with Edoardo Amaldi in the post-war reconstruction of European science, was well known both in Italy and Europe. At the time, he held the Chair of Theoretical Physics in Rome and it was with trepidation that the two friends approached him to ask for his supervision in their thesis work. They were accepted, the special dispensation was granted,[13] and

[11] A student accepted by the SNS would have to both graduate from University of Pisa (or Florence) and receive a diploma from the SNS whose courses he had to attend in parallel with the regular university studies.

[12] Recently, a Symposium was held at the University of Perugia to commemorate De Tollis' death in 2018, http://fisgeo.unipg.it/pacetti/nino.

[13] In a conversation with Y.N. Srivastava, his colleague at University of Perugia, De Tollis used to remember the epic trip when, together with Gatto, they went to Rome to ask Ferretti to be their thesis supervisor: Gatto already confident in his capacities swept easily by the doorman in charge of letting only deserving students into the Institute, while De Tollis, affected by a stammering disability, was just as brilliant, but,

Gatto graduated with first class honours with a thesis on the shell models of nuclei, under Ferretti's guidance, with Conversi as supervisor, and obtaining his diploma from the SNS, with Prof. Derenzini [7].

After graduation, he was offered a position as assistant professor to Ferretti's Chair [4, 7], and was in Rome when Touschek arrived at the end of 1952.

1.3 Touschek came from Vienna

Bruno Xaver Touschek was born in Vienna on February 3rd 1921. When Touschek arrived in Rome in late December 1952, he was coming to a city he knew well from his pre-war visits to a maternal aunt, Adele Weltmann, married to an Italian industrialist, Gaetano Vannini. Bruno had lost his mother in 1930, when only nine years old. Possible visits to Rome with her can be gathered from a passport photo where he is in his mother's arms, and in another photo which shows him as a young boy, 12 or 13 year old, in his aunt's garden in Via di Villa Sacchetti, in Rome.

Then, in March 1938, the annexation of Austria to Germany, the *Anschluss*, was declared and everything changed for the Vienna Jews. From his letters home [9] and from [1], we know that in March 1939 he was visiting aunt Ada (nicknamed from Adele), having passed his high school exams in Vienna.[14] At this time he was in Rome trying to obtain a Visa to emigrate to England, where he had applied to study chemistry in Manchester [1]. Having suffered from discrimination in Vienna because of his Jewish origin from the maternal side, and fearing for worst to come, he had decided to leave Austria, and study abroad. It did not happen and he spent the next eight years between Austria and Germany, suffering further discrimination and losses, imprisonment and a brush with death. Not until 1950, he was able to visit Italy again, but the memory of his pre-war days in a city he loved, remained and when the opportunity arose to have a position in Rome, he was eager to accept it. This opportunity had come through Bruno Ferretti, the same physicist who supervised Gatto's graduation thesis in Rome.[15] In 1947, Ferretti had visited Manchester and Birmingham, where he worked with Rudolph Peierls on radiation damping [56], a subject of life-long interest to Touschek. Peierls had been the external examiner for Touschek's Ph.D. thesis in Glasgow, and, later, Touschek's interest in working with Ferretti on the radiation problems was a reason for him to accept Amaldi's offer of a research position at the INFN in Rome [1].[16]

2 The particle physics scenario before 1959

Gatto's contribution to the Memorial Lectures brings interesting details about the birth of AdA and how he started developing an active interest in electron-positron physics. The memories reproduced in the previous section show that Raoul and Bruno became close to each other shortly after they had met in Rome. The episode mentioned about meeting Wolfgang Pauli through Bruno in Cagliari confirms it. In September 1953, the annual congress of the Italian Physical Society, was held in Cagliari, Sardinia. Bruno had arrived in Rome at the end of December 1952, from the University of Glasgow, where he had held a position as Nuffield Lecturer, after his PhD in 1949. Behind him, he held a story of discrimination and losses, but also a unique formation in theoretical physics, from his peers, such Hans Thirring, Arnold Sommerfeld, Werner Heisenberg and Max Born, among others. He was also an expert in electron accelerators, thanks to his work on Widerøe's betatron during the war years [57, 58], and

much unsure of himself, hesitated for a whole week before picking up enough courage to come through the intimidating doors, personal communication to G.P.

[14] He may have also been in Rome in 1938, since in a 1939 letter, he writes: *Rome without the Fürer is wonderful* . . . , a possible reference to Hitler's visit to Rome in 1938.

[15] For more details about Touschek's prewar visits to Rome and the post-war years in Glasgow, where he obtained his PhD, and came to know of Ferretti's work, see Chapts. 5 and 6 in [9].

[16] This fact was mentioned by Luigi Radicati in an interview recorded by L. B. in Pisa on June 16, 1997.

having participated in the UK post-war effort to build novel types of particle accelerators such as synchrotrons [2, 9]. As such, he had been hired by Edoardo Amaldi as INFN researcher to do theoretical physics, and "assist experimenters in [...] accelerator physics", a field which was rapidly taking over the traditional cosmic rays experimentation as a major investigation tool in particle physics.

The physics institute in Rome was in those days a cross-road of ideas and projects, which included the creation of a National Institute for Nuclear Physics (INFN) [59], and setting plans for the construction a national laboratory, where an accelerator should be built. Many distinguished visitors from abroad enriched the atmosphere, such as Wolfgang Pauli from Zurich, and Matthew Sands from Caltech, while a new generation of students was graduating, ready to be the protagonists of the reconstruction. Touschek immediately entered into the spirit of the place and within three months of his arrival to Rome joined Matthew Sands writing an article about *Alignment errors in the strong-focusing synchrotron* [60], which received immediate attention among the physicists working on a proposal to build a proton synchrotron (PS) at CERN. [17]

At the time, Gatto, nine years junior to Touschek, was already in Rome, a young assistant to Bruno Ferretti, after having done his *Tesi di Laurea* under his guidance. Older to Gatto, Touschek owed his formation in theoretical physics to some of the greatest theorists of his time, whom he had personally known. Thus, when he arrived in Rome, Touschek could easily discuss physics on the same level with a Nobel prize winner, such as Wolfgang Pauli. Gatto remembers to have been at a Conference in Cagliari, in 1953, and of being invited by Touschek to join a coffee talk with Pauli, something perfectly natural for Bruno, much less so to the shy Raoul.

2.1 On the CERN PS, CPT, and violation of parity

In 1953, the reconstruction of European science entered in its operational phase. With the expected approval of the establishment of CERN by the national governments, plans to build powerful particle accelerators in Europe moved forward. These plans would lead to the construction of the Proton Synchrotron (PS) at CERN [61], the electron synchrotron in the Frascati National Laboratories (LNF) [62], and the Linear Accelerator in Orsay [63]. Alongside, in theoretical physics, the role of symmetry to study space-time properties of elementary particles started to take central place, leading to the formulation of what is now known as the CPT theorem, which would play a crucial role in the development of electron-positron colliders. The genesis of the theorem is complex, with roots in the work by Julian Schwinger, Wolfgang Pauli, and Gerhart Lüders as detailed in a recent reconstruction [64].

The considerations which led to the construction of the CERN PS were the subject of a 26-27-28 October1953 conference on the Alternating-Gradient Proton Synchrotron, held at the Institute of Physics of the University of Geneva to summarize the work done by a study group established one year earlier. The Conference Proceedings [61] give a fascinating description of the work of the group, and the development of the project, from the beginning in Bergen (Oslo) [65] to the final comments by Werner Heisenberg, who wrote: "For research in elementary particles, the decisive quantity is not the energy in the laboratory system but the energy available for particle creation in the center of mass system of the two colliding nucleons". Having stated this basic physics objective, Heisenberg goes on recommending a proton beam to be accelerated to a final energy of 30 GeV, as it will allow creation of nucleon-antinucleon pairs, a process which could not be adequately studied with a 20 GeV machine. These words resonate years later in Touschek's November 6th 1960 note for the construction of

[17] In a letter to his parents on February 24 1953, Bruno mentions " ... in connection with a new project (strong focussing synchrotron) I covered myself with fame, at least in small circles, and I believe that even if I got stuck in Rome I wouldn't have too much worry." Sands, in a later interview with the American Physical Society, is more explicit about the interest of their work to people at CERN working on the proposed PS, see https://www.aip.org/history-programs/niels-bohr-library/oral-histories/5052, M. Sands, interviewed by F. Aaserud, 4-5 May 1987, Niels Bohr Library & Archives, AIP.

ADONE with center of mass (c.m.) energy of 3 GeV, the value definitely included in the subsequent proposal with Gatto, Amman, Ghigo and Bernardini [15]. Had Bruno read these Proceedings when deciding ADONE's energy goal? Or heard the argument directly from Heisenberg, whom he knew very well? He always acknowledged having heard of the kinematic advantage from Widerøe, but the interest in Heisenberg's words is the stated objective of creating matter-antimatter pairs, in particular nucleons, at a time, 1953, when the antiproton had not yet been discovered. Touschek's suggestion of 3 GeV was very courageous for the time, but was bitterly regretted in 1974 for not having been bolder, when ADONE lost to the Americans the race to discover new particles. Its maximum energy was in fact a few percent lower than the one needed to discover the J/Ψ [66–68], a bound state of a new type of quark, called *charm*, whose existence and properties had been anticipated a few years earlier in [69].[18] Studies of nucleon-antinucleon threshold properties, as auspicated by Heisenberg, were later performed in 1995, at ADONE's 3 GeV c.m. energy with the detector FENICE [14].

This observation by Heisenberg brings in the strong interest in anti-matter with respect to matter, and the use of symmetry properties in Quantum Field Theory in the early and mid 1950s. Confronted with the discoveries of more and more elementary particles and their anti-matter counterparts, symmetry properties became a central theoretical issue, and the formulation of a theorem of invariance of particles processes under Charge, Parity and Time transformation was proposed and developed. How these developments were perceived by Gatto can be seen in a 2004 letter to one of the authors, L.B., translated and reproduced in the box to follow. Gatto mentions how he had been aware of the CPT [32, 71–73] theorem through Bruno Zumino's occasional visits to Rome. Zumino also had graduated with Ferretti, and soon left Rome for the United States.[19] In a later paper with Gerhart Lüders entitled *Some Consequences of TCP-Invariance*, a direct reference is given of Zumino's early attention to particle symmetries [74]: " ... One of us (G.L.) wants to emphasize here again the importance of the role of the other (B.Z.) during all stages of the work that led to the theorem both through personal discussions and through correspondence. In particular the original formulation of the theorem [TCP-invariance], for parity conserving interactions, was suggested by B.Z early 1953."

As Gatto describes, during the first period he spent in Rome Touschek was his mentor. Then, in 1956 Ferretti moved from Rome to the University of Bologna, his *alma mater*, where he held the Chair of Theoretical Physics until his retirement in 1988, and Gatto left Rome for a stay at Berkeley, following the traditional pattern of a formation trip abroad, a *Bildungsreise...*, to gain a broader international research experience, and, we can add, acquiring the knowledge and the track record needed to become a university professor. The place where novel discoveries were taking place was the United States. Gatto had been awarded a Fulbright fellowship for studies abroad and, perhaps inspired by Edoardo Amaldi, went to Berkeley, where the Lawrence Berkeley National Laboratory, hosted a new powerful particle accelerator, operating since 1954. It was called the Bevatron, a weak-focusing proton synchrotron that accelerated protons to energies of billions of electronVolts, BeV. Such high energies could be used to discover hitherto unknown particles and, or, to confirm the existence of predicted antiparticles. Among them there was the antiproton, whose production and observation at the Bevatron was announced by Emilio Segrè and collaborators in the fall of 1955 [75]. In 1953, Amaldi's cosmic ray group had also detected an annihilation

[18] This discovery was announced jointly by Samuel Ting and Burton Richter on November 12th, 1974 and became known among physicists as the *November revolution*. As soon as the news spread to Frascati, by way of phone calls from both the East and the West coast of the USA, searches started with ADONE, where the new particle was soon observed after forcing the machine energy beyond its design limits. Two years later, Ting and Richter were awarded the 1976 Nobel prize in Physics "for their pioneering work in the discovery of a heavy elementary particle of a new kind". In [70], the Frascati side of the story is commented in an interview with Giorgio Bellettini, LNF director at the time.

[19] Before moving definitely to Berkeley, Zumino also spent many years at CERN, where in the 1970's he proposed Supersymmetry as an important property of the elementary particle world.

event — a star which they named *Faustina* — in emulsion stacks exposed at high altitudes, which they interpreted as associated with an antiproton [76]. For this reason, Amaldi and Segrè decided to expose photographic emulsion stacks at the Bevatron, in order to observe the annihilation process undergone by an antiproton inside the emulsion, and to compare it with the cosmic-ray event possibly due to such an antiparticle. The emulsions were analyzed by both groups and what they found corroborated the interpretation given in [75] that the particles observed in the Bevatron were antiprotons and also supported the hypothesis that the *Faustina* event was indeed due to an antiproton [77]. A second paper was published by the Berkeley/Rome groups [78] in the *Nuovo Cimento* in parallel with Raul Gatto's theoretical paper discussing the capture and annihilation of antiprotons, as well as processes involving positive and negative kaons [79]. The discovery of the antiproton was presented by Emilio Segrè, at the April 1956 Rochester Conference in New York, where Amaldi also presented their contribution from the cosmic rays observation and the emulsions exposed at the Bevatron.[20]

Therefore, when Gatto left Italy for Berkeley, he had been fully immersed in the whole process, further consolidating the concept of antiparticles at the level of the fundamental constituents of matter. On his part, Touschek had travelled with Amaldi to the Rochester Conference, and was profoundly impressed by the discussion about possible non-conservation of parity in weak interaction, which had come up in the theoretical session, following a question by Feynman [81, 82]. The interest in the existence of anti-matter was heightened by the discovery of the antineutron [83], which brought in also in the question of searches of anti-atoms.

The 1956 Rochester Conference represents a *water-shed* for particle physics. This is where for the first time, parity conservation in weak interactions was put in doubt, the discovery of the antiproton made its public appearance, and a whole *zoo* of new particles took center stage. Then, a few months later, at the CERN Symposium on High Energy Accelerators, the idea of building new accelerators where center-of-mass collisions would allow to reach higher and higher energies, was presented [84, 85]. By the time Gatto was back in Rome in 1958, the scenario had changed: within two years center-of-mass collisions would be conceived, where the symmetry properties of particles vs. antiparticles could be exploited, in particular through electron-positron collisions.

In the box, we reproduce a letter by Gatto, in which he describes the period he spent in Rome before leaving for the United States, and his relation to Touschek.

[20] Segrè and Chamberlain received the 1959 Nobel Prize in Physics for their discovery. For Edoardo Amaldi's contribution, see [80].

Geneva, January 15, 2004
Dear Mrs. Bonolis,
I am sorry for the delay of this reply, due to a family accident (not serious).
During the last years of my stay in Rome before leaving for the United States (I am talking about the years '54, '55, '56) Touschek was the expert person from whom I most learned and referred to for discussions, doubts, ideas. Much of my work done in Rome in those early years carries explicit thanks to Bruno Touschek who was my main reference for theory. In fact, my teacher had been Ferretti, who had been thinking for some time about returning to Bologna (which he did in '56). Ferretti's various health problems and overwork did not always allow me to bother him with discussions related to my calculations, which I felt I could do with less scruples with Bruno Touschek instead. Ferretti had brilliant and important ideas, and I will remember, for example, the role he already at that time saw in gauge theories, something that remained engrained in my education in Rome.
The discussions I remember as most decisive from the point of view of my work in the following years took place with our group of theorists, with Bruno Touschek at the forefront.
I must also mention Zumino's visits to Rome. Bruno Zumino in those years would drop by Rome from time to time. Zumino had also been a student of Ferretti but had continued his career abroad in Germany and the United States. Zumino informed us about the work of Pauli and especially Gerhart Lüders on the TCP theorem. Zumino had discussed with Lüders, who as early as 1952 had been working on the problem, which he then correctly formulated during 1953. These things were close to Touschek's interests and there were extensive discussions. This shows how in a sense in Rome at that time one was at the center of the most important progress, and this was because of Bruno's vision and his contacts abroad.
Touschek was also aware of Pauli's thoughts on various topics such as gauge theories. It must be said that all things at that time were at a very preliminary and pioneering stage.
I think Schwinger was already convinced of the TCP theorem perhaps even before 1953 because he somehow followed it up with the spin-statistics theorem. I don't recall him giving an explicit statement of it, though. These issues, fundamental to field theory, were still not well defined in the crucial years 1953, 54 and 55, i.e., somewhat ahead of the discovery of non-conservation of parity, which then made apparent their fundamental importance to particle physics.
The discussions in Rome, which unfortunately did not lead to anything published, but were in the sole intention of understanding Lüders' and Pauli's ideas, concerned the role of the Lorentz group and the spin-statistical connection for local theories with at most spin 1/2 (Pauli was the one who removed this last restriction). For me these discussions were very important because (1) I realized the crucial role of symmetries, and I realized (2) that general questions of field theory could characterize the phenomenology of elementary particles.
Of course for Bruno Touschek these things had perhaps been clear all along and he had been interested especially in time reversal publishing at that time various papers with Morpurgo and Radicati.
I was already in the U.S., or about to leave, when Touschek became interested in the role of parity in the theory of zero-mass spinors. Touschek was one of the rare physicists at that time who was familiar with Majorana's work, and he was clear about the distinction between Dirac and Majorana neutrinos. Touschek kept a little notebook on the neutrino that he showed me from time to time, and the discussions were about how to characterize the various representations of the Dirac algebra in terms of space-time invariance properties. Not only that: but also about the massive or non-massive character of the fermion. Had Bruno's premature death not deprived us of his intelligence, there would probably have been, by now, his important contributions to the theory of neutrinos and their mixing.
As soon as I arrived in the United States, I was naturally imbued with the Roman discussions and especially the style of problematics mainly originated by Bruno's fervent intelligence and curiosity. With what I had learned about TCP and with the knowledge I had of K phenomenology (and here I must mention my long collaboration with the Rome emulsion group, in particular with Carlo Castagnoli) I quickly realized that it made sense to make the hypothesis that CP was a good quantum number and to search for its consequences (a few years later it turned out that CP also was only an approximate symmetry). On February 4, 1957 I sent the work you mention to *The Physical Review*, where I used the name L for the new quantum number, as a tribute to Lüders, whom I had in the meantime met personally. In the same days a paper by Landau was sent to *Nuclear Physics*, with the same proposal and a general paper by Lee,Oehme and Yang (the one that is usually cited) was sent to Physical Review, in which however the proposal of CP as the conserved quantum number was not made. This shows the simultaneous interest in these problems held by different groups at that time.
Simultaneous in various places was also the interest in the still not well defined concept of chiral symmetry, which for Touschek arose from his mastery of neutrino theory. Chiral symmetry is not only the basis of the electroweak theory, but has long played a crucial role in QCD, the theory of strong interactions, where it is spontaneously broken in the hadronic normal phase, only to be restored at very high temperatures. Touschek, living, would certainly have contributed a great deal to these theoretical developments in QCD, partly because of his continuing interest in thermodynamics. Touschek quickly realized that the extension of discrete symmetry to continuous symmetry was to play a role that was not yet well defined at that time. This extension was the basis for the formulation of electroweak theory in terms of continuous groups, as required for a gauge theory (both in the electroweak case and for QCD).
Bruno should also be credited with preparing excellent graduates. On my return from the U.S. I met at the Institute Nicola Cabibbo who had just finished his dissertation under Bruno's guidance on beta transitions between nuclei. He was planning to continue working on weak interactions. I at that time was working with Malvin Rudermann on the decay of the pion into neutrino electron, which was a difficulty (fortunately only apparent) for V-A theory. I gave Nicola a problem on Kaons, which he brilliantly solved. Afterwards I had the pleasure of collaborating with Nicola for many years. Besides Nicola, Bruno had welcomed other good undergraduates. These included [Giovanni] Gallavotti who came with me to Florence, [Aurelio] Grillo, who collaborated with me and Sergio Ferrara for a long time, G. Putzolu who interacted with me and Cabibbo at Frascati, and many others with whom I had less close scientific relations.
With best wishes for your work and cordial greetings,
Raoul Gatto

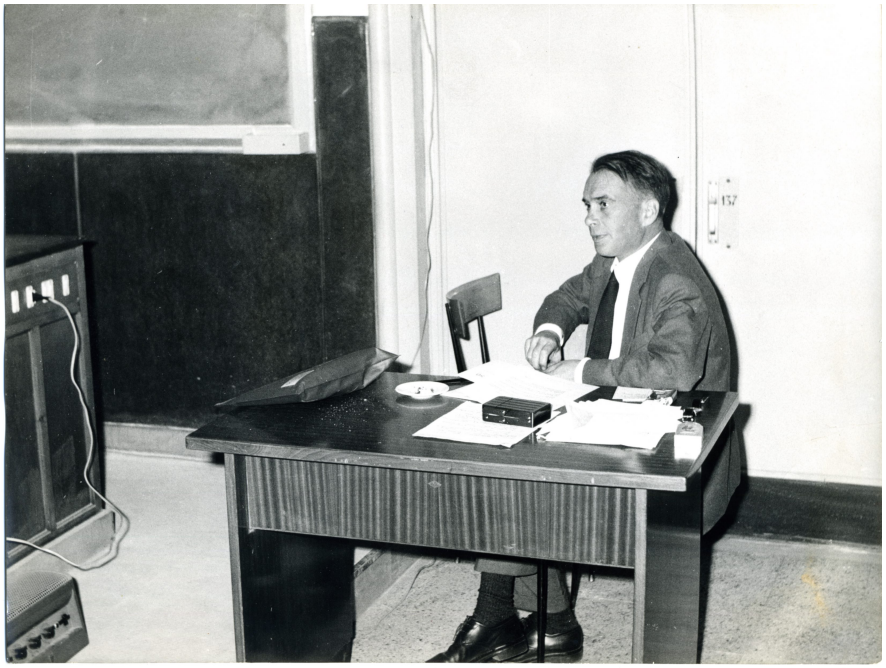


Fig. 5 Bruno Touschek, at the 1964 Congress of the Italian Physical Society, in Catania, © Touschek family, all rights reserved.

3 AdA

In this section, we shall describe how the making of AdA developed between Rome and Frascati.

3.1 The birth of AdA between October 1959 and March 1960

As shall be seen, Gatto's recollections join those from Cabibbo in [86, 87] to confirm how the idea of AdA developed [9], namely that the road which led to electron positron colliders started on or around October 26, 1959, after a seminar by Wolfgang Panofsky in Rome [86][21] or, more likely, in the Frascati National Laboratories. A confirmation of the impression from such seminar is found in [10], where the authors wrote : "We are indebted to Professor Panofsky for a stimulating seminar on the possibility of colliding beam experiments." Or perhaps, it started a few months before, when both Touschek, Gatto and Marcello Cini participated in the 1959 Rochester Conference in Kiev (now Kyiv), at the end of July [88]. This was the International High Energy Physics Conference, also known as the *Rochester Conference*, from the place in New York where it had been first held in 1953.[22]

We shall indicate here the sequence of events, as can be gathered from personal documents, Touschek's letters to his father, conference proceedings, bibliographic references.

- Kiev, July 1959: among the rather large number of Italian scientists participating in the conference, there were three theoretical physicists from University of Rome: Marcello Cini, Raoul Gatto and Bruno Touschek, who listened to Hofstadter's talk

[21] Nicola Cabibbo in 1997 mentions a seminar in Rome, but his testimony about the content of Panofsky's seminar has some inconsistencies - such as "the Princeton-Stanford e^+e^- ring then under construction", not supported by known sources - and some typos, such as R. Panofsky instead of W. Panofsky. The location of the seminar, Rome instead of Frascati, could have been a memory lapse.

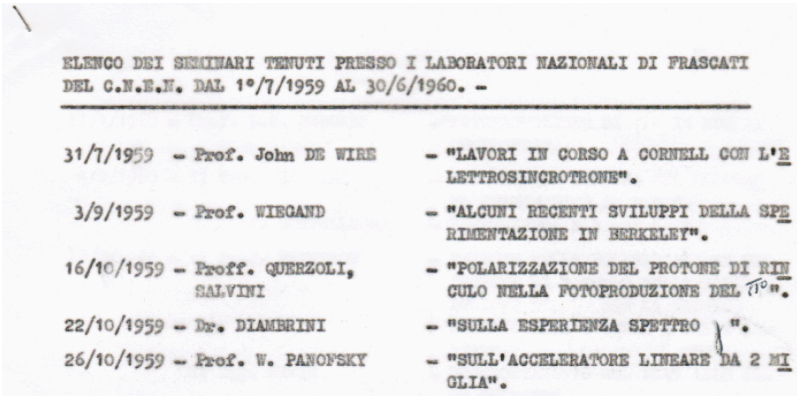
[22] The 1959 Conference had originally been meant to take place in Moscow, 15-25th of July. but the location was later changed to Kiev, perhaps because of the contemporary International Cosmic Ray Conference, ICRC 1959, held in Moscow in those same days (15-26 July). Cold war scientific competition was at its peak with the US organizing an extraordinary exhibition https://www.rferl.org/a/Fifty_Years_Ago_American_Exhibition_Stunned_Soviets_in_Cold_War/1783913.html.

on his measurements of the proton electromagnetic form factor, as well as to Panofsky's talk on the tangential electron-electron collision project at Stanford, and on results from an experiment to measure in flight electron positron-collisions at the linear accelerator [89].

- In September, Panofsky was in Geneva attending the 2nd Accelerator conference [90, 91] and then came to Rome, visiting Frascati and giving a seminar, which is known to have taken place in the laboratories on October 26th, Fig. 6 [9].
- Gatto, Cabibbo and Touschek all attended Panofsky's seminar, at the end of which Touschek pointed out the advantage of using electron-positron collisions for both practical reasons – one ring instead ot two - and physics discovery potential.
- From November 1959 until February 1960, four theorists in Rome started looking at physics processes to be possibly observed in electron-positron collisions: Gatto, two of Touschek's former students, Nicola Cabibbo and Francesco Calogero, and Laurie Brown, a distinguished American physicist visiting from Northwestern University in the US, started and finished work on two separate aspects of the possibility to study strong interaction contributions in electron-positron collisions. The first article to be finished and be received by *The Physical Review Letters* (PRL) office on February 8th, 1960, is the one about the contribution to the time-like photon propagator by pion-pion interactions, by Brown and Calogero [92]. The second one was by Cabibbo and Gatto about the time-like observation of the pion form factor in electron-positron collisions [10], and was submitted on February 17th, the same day Touschek in Frascati aired the idea of making an experiment to transform the newly built electron synchrotron into an electron-positron collider. This proposal was not approved by the Scientific Council of the Laboratories, but Touschek and Giorgio Ghigo were encouraged to prepare plans to build a small machine, where Touschek's idea could be tested, in view of future accelerators, where it would be realized and become a new discovery tool. A meeting to prepare a detailed proposal took place on the same afternoon. Touschek and Ghigo were joined by Carlo Bernardini, at the time a theorist on the LNF staff, and Gianfranco Corazza, expert on how to produce extreme vacuum in an accelerator chamber. On March 7th, about two weeks later, a proposal was submitted to the Scientific Council of the Laboratories, which approved that it be forwarded for INFN funding.
- The two theoretical physics papers from Rome were published on March 15th, 1960, and, shortly after, AdA's construction was approved by INFN with an 8 Million Lire initial budget.

Neither of the two theoretical papers mentions Bruno Touschek, nor Frascati, which is obvious since Bruno's proposal came up only on February 17th, the day both papers were already laying at the PRL editorial office. Only Marcello Cini is mentioned in Brown and Calogero's paper, where he is thanked for his encouragement. Marcello Cini (1923-2012), seen with Touschek in the bottom panel of Fig.(6), was a theoretical physicist who joined the Physics Institute in Rome becoming Professor of Institutions of Theoretical Physics in 1957, and is also acknowledged in one of De Tollis' works about the influence of pion-pion interactions in photoproduction of charged pions [93].[23] This points to the frequent exchanges and discussions about pion-pion interactions taking place in Rome in 1960 and to the possibility that discussions about electron-positron collisions and/or Hofstadter type experiments were started in Rome among the senior theorists, such as Cini, Gatto and Touschek, soon after returning from Kiev, and continuing after Panofsky's seminar in Frascati on October 26th, 1959. The interest in the precise date arises because it has been said in [94] that the birth of electron-positron physics started in Novosibirsk on October 29th, 1959, after a visit by Isaac Pomeranchuk, who had criticized Budker's plan to build an electron-electron

[23] See De Tollis Symposium, and contribution by Giorgio Parisi.



ELENCO DEI SEMINARI TENUTI PRESSO I LABORATORI NAZIONALI DI FRASCATI DEL C.N.E.N. DAL 1°/1/1959 AL 30/6/1960. -

31/1/1959	- Prof. John DE WIRE	- "LAVORI IN CORSO A CORNELL CON L'ELETTROSINCROTRONE".
3/9/1959	- Prof. WIEGAND	- "ALCUNI RECENTI SVILUPPI DELLA SPERIMENTAZIONE IN BERKELEY".
16/10/1959	- Proff. QUERZOLI, SALVINI	- "POLARIZZAZIONE DEL PROTONE DI RINCULO NELLA FOTOPRODUZIONE DEL π^0".
22/10/1959	- Dr. DIAMBRINI	- "SULLA ESPERIENZA SPETTRO ".
26/10/1959	- Prof. W. PANOFSKY	- "SULL'ACCELERATORE LINEARE DA 2 MIGLIA".

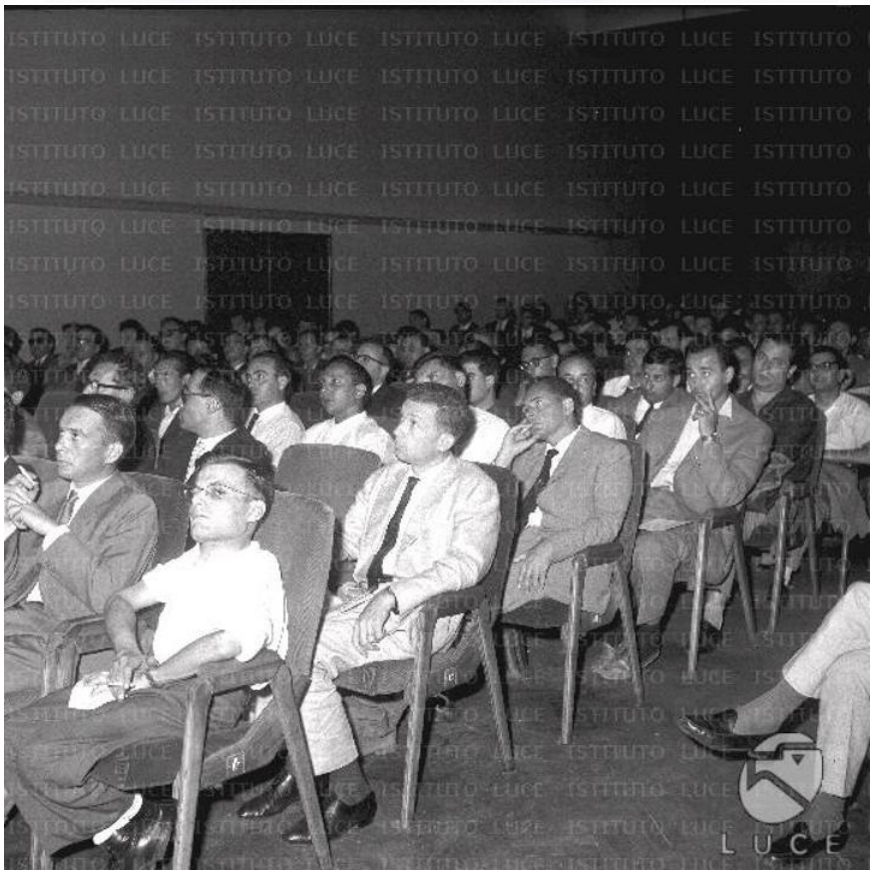


Fig. 6 On top, an excerpt from the list of seminars held in Frascati during the year 1959-60, courtesy Vincenzo Valente to G.P., all rights reserved. Below, Bruno Touschek, extreme left, and Marcello Cini, first in second row, attending a 1960 meeting at the Eliseo Theatre in Rome, during a strike by nuclear scientists, in favour of more adequate salaries and better prospects for younger scientists, Archivio fotografico Istituto Luce, Fondo DIAL/D128-24.

tangential collider, envisioned since 1958 [95].[24] As the precise date of Panofsky's seminar in Frascati is established by a contemporary document from Frascati National Laboratories, such as the list of seminars held through 1959-60, the question of AdA's priority, USSR or Italy?, is in our opinion fully settled.

But a question could still be asked: which came first, the theoretical ideas or the experimental proposal? And what was Touschek doing while Cabibbo, Calogero, Gatto

[24]The project was similar to the one set in motion by the Princeton-Stanfords group, except that the two tangential rings were laying on a horizontal plane, while the Russian project VEPP-I placed the two rings on a vertical plane.

and Brown did and checked the calculations, wrote the papers, had them typed and sent to PRL? Cabibbo, in an interview with Luisa Bonolis, remembers that feverish period, saying " ... calcolavamo e calcolavamo ... ". Nothing much transpires from Touschek's letters in relation to that period, except that Bruno, in a letter to his father, dated January 16th, 1960, acknowledges a proposal to create a theoretical physics group to support the newly operating electron synchrotron in Frascati. Of notice is the fact that on October 29th, 1959, he had already received official permission to regularly enter the Frascati Laboratories [14]. He had also started teaching a new course on *Statistical Mechanics* at the University of Rome, still remembered by many of the students who attended it [96], and which can be considered the initiator of the intense and successful line of research later developed in the Rome Physics Institute. Was this all he was doing? From the fact that, on March 7th he came up with a detailed proposal for the building of AdA, with many details specified in the Storage Ring notebook, which he had started on February 18, one can argue that while his former students, Cabibbo and Calogero, and his friend Gatto were doing calculations about the physics, he was absorbed by the task of devising if the idea would be feasible, and developing the ways to make it work. For this, as he says, "all he knew and had thought about" had to be put together. This is how the extraordinary exploit of AdA arose during those few months, from October 1959 to March 1960, between the Physics Institute in Rome University and the Frascati National Laboratories.

AdA's first Act was over, and Act II began, with the funding of AdA's construction definitely approved by INFN Board of Directors at the end of March, making Touschek in charge of the project. While Touschek followed the day-by-day work in Frascati, in the machine shop, and through weekly trips from Frascati to the town of Terni, in central Italy, where AdA's magnet was being manufactured under the specifications from the Laboratories, namely Giancarlo Sacerdoti and Giorgio Ghigo's, Gatto started a long paper with Cabibbo about all the processes which they could think worth to be measured in electron positron collisions. This article was completed in one year and was published in *The Physical Review*, becoming known among the Frascati physicists as *la Bibbia, (the Bible*, in English), since it contained all and more of the physics which could be done with electron positron rings [11]. Less than 8 months later, AdA's magnet was delivered and on February 27, 1961, electrons started circulating in the ring: AdA's first Act was over, and Act II could begin.

There was great enthusiasm in Frascati as AdA started working, and the proposal to build a much higher energy collider, ADONE, was prepared [15] and presented to INFN [97]. This proposal had been partly anticipated in a hand-written note by Touschek dated November 6th, 1960, and became a LNF internal report, completed by Gatto's theoretical introduction and practical details about ADONE technical specification and projected costs (1.5 Billion Italian Lire).

The final part of AdA's story developed between Rome, Frascati and the Laboratoire de l'Accélérateur Linéaire, in Orsay, where AdA was brought in July 1961 [98–100], to improve its luminosity performance by way of the powerful linear accelerator built in Orsay, by Pierre Marin [63] and his collaborators. The final success [17] was reached through the observation of the process $e^+e^- \to e^+e^- + \gamma$, whose theoretical calculation [101] brought in a new generation of physicists, the class which had entered university in the fall 1959 and started to graduate in November 1963.

3.2 Making AdA work

Here we shall outline the contribution from Gatto and his students to the theoretical physics background needed to prove that AdA had observed collisions between electrons and positrons, although its luminosity was and remained too low to observe annihilation with creation of new particles.

After the bout of enthusiasm for AdA's first electrons or positrons circulating in the ring and emitting visibly observable radiation, there had come the task of proving that collisions and subsequent annihilation into new particles had actually taken place. This turned out to be rather difficult. Ada was fed electrons and positrons from the conversion in the doughnut of a photon produced by the synchrotron, next to which AdA was positioned, as shown in Fig, 7. But new particles were not seen to be produced and it soon became clear from Gatto and Cabibbo's calculations that the cross-section for producing new particles required a much larger *luminosity* that what AdA could attain. Still the machine had been built and electrons or positrons were circulating in it, and this result was important even if the electron synchrotron could not feed a sufficiently large number of photons for physics to be observed. The solution came from abroad, after Bruno and Raoul had presented their work at the CERN conference in Geneva in June 1961 [50]. At the conference three talks on colliding

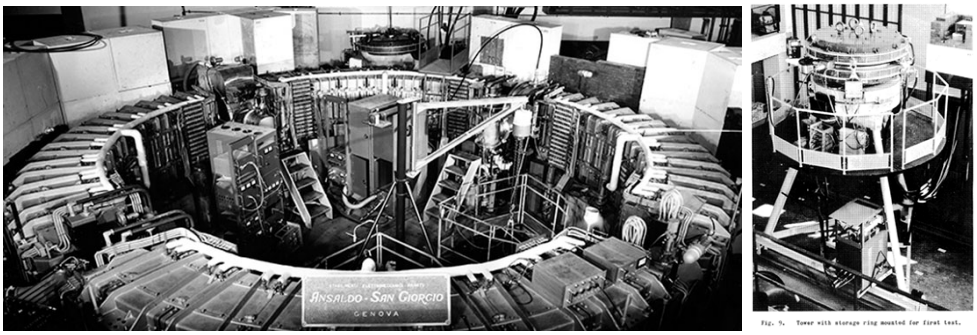


Fig. 7 At left, AdA positioned next to the Frascati synchrotron, which acted as injector, © INFN-LNF; at right photograph of AdA presented by Touschek at the CERN conference, June 1961 from [50].

beams were held in sequence, from Richter, Touschek and Gatto. Richter presented the ongoing electron-electron collider project, Touschek presented AdA and ADONE, whose proposal Gatto had also signed and which was going to be soon approved by the Italian government agencies, and Gatto presented his extensive work with Cabibbo on electron-positron colliding beam experiments, *la Bibbia*. More than anything else, this sequence of the three speakers and the content of their talks show the rising of the idea of electron-positron colliders and the collaboration between Gatto and Touschek in bringing electron-positron physics to become a mainstream subject both for experimenters and theorists.

3.2.1 AdA and the Laboratoire de l'Accélérateur Linéaire in Orsay

A crucial consequence of Touschek and Gatto's talks at CERN, was the interest it arose in the French physicists who had attended the conference, and mentioned to their colleagues in Orsay that in Frascati *... ils se passaient des choses qui intriguaient les esprits* [63], namely very intriguing things were happening. This interest materialized one year later in bringing AdA to the Laboratoire de l'Accélérateur Linéaire, where it remained for the next three years and where the feasibility of electron positron colliders was proved through a Franco-Italian collaboration.[25]

AdA's move to the Laboratoire de l'Accélérateur Linéaire in Orsay had started with a visit by Pierre Marin and George Charpak in July 1961, and negotiations began in September during a Conference in Aix-on-Provence [102]. Gatto contributed to the success of this first step by giving a talk on the experimental possibilities with colliding beams of electrons and positrons [103].

[25] For interviews to the protagonists of the Franco-Italian collaboration, see the 2013 docu-film *Touschek with AdA in Orsay*.

After AdA was brought to Orsay, in July 1962, it was placed next to the linear accelerator, the LINAC. In the fall, the actual experimentation started, with Jacques Haïssinski joining the French team, after François Lacoste left to work in a different field.[26] Thus there started three months of intense work, which culminated in February with the discovery of a crucial phenomenon, first named the *Frascati effect*, later to be known as the *Touschek effect*. The effect established the existence of inter beam Møeller scattering between electrons in a single beam (or positrons in the positron beam), an effect which *de facto* limited the lifetime of the beams, but could be calculated and the energy dependence clarified [16]. The effect was lessening with increasing energy, but at AdA's energies, Gatto and Cabibbo's calculations [11] showed that AdA could not observe annihilation into new particles, as Touschek had hoped to see, and indicated in the Storage Ring notebook, as seen in Fig. 1. Thus, a different process had to be envisioned, which could prove that collisions had taken place. Touschek made some fast thinking, and order of magnitude calculations, figuring out that single *bremsstrahlung*, photon emission, could be the one to work, as indicated in some of his notes. In the month following the *Touschek effect* publication, he presented this idea to a Brookhaven conference [104]. But an order-of-magnitude calculation was not sufficient for actual proof of collision. To proceed further, Gatto's help was needed.

In spring 1963, Gatto had started spending his time between Rome, Florence, where he had been called to the Chair of Theoretical Physics [7], and the Frascati Laboratories, where he had an office. An affectionate and vivid description during this period is given by Giuliano Preparata, one of Gatto's students and collaborators, who would graduate with him in November 1964. Giuliano writes [6]:
On a clear day in May 1963, I went up, from the University of Rome towards the hills of the Castelli Romani, to Frascati and to the Laboratories, where Professor Gatto worked, and with whom I had an appointment. Although quite young – he must have been just over thirty years old – Gatto was considered one of the leading theoretical physicists in the world. The meeting took place in a very informal way. Gatto was a big boy a little overweight, with an open and friendly face, perhaps a little shy; I immediately liked him very much. [. . .] Once our conversation was over, he offered to take me back to Rome, where he had to go for the evening.[27]

3.2.2 The thesis calculation which opened the way to electron positron colliders

The Touschek effect had been observed in Orsay during AdA runs in January and February 1963. During the following months, Touschek mulled about the possibility of using the bremsstrahlung process as proof-of-principle that electron positron-collision were feasible, and, when in Rome, he discussed with Gatto about the need to do the exact calculation, which nobody had yet done. The process of photon emission in electron positron annihilation is a radiative effect, belonging to the general topic of radiative corrections to a given process, extensively discussed in a text book, by Jauch and Rohrlich [105]. When Franco Buccella approached Gatto to graduate under his supervision, and asked for a thesis subject, Gatto told him to read the book by Jauch and Rohrlich in preparation for a thesis, and then come back to him. Some time later, another of the year's brilliant students, Guido Altarelli, went to see Bruno Touschek for possible supervision and a thesis subject. The interview between Guido and Touschek did not work out [9, 106], and Altarelli approached Gatto, as his possible tutor. Thus Guido and Franco joined their forces under Gatto's supervision and Touschek's encouragement, and through summer 1963 calculated the cross-section for

[26] François Lacoste had participated to the preparation for AdA's transfer and to the initial installment in Orsay.
[27] Translated from the original Italian version.

"Single photon emission in high-energy e^+e^- collisions", i.e, the process

$$e^+e^- \to e^+e^-\gamma \tag{1}$$

This calculation has both numerical and theoretical complexity, and their work encountered some difficulties. After an initial phase in Rome, the two students decided to use the Frascati computer for the required numerical integration. At the Laboratories, they would oscillate beween the computer room and the young researchers' office, discussing their work with Gatto and his assistant Mosco, or with Touschek and Carlo Bernardini.

In his contribution to the BTML, Gatto describes the special atmosphere pervading Frascati in those days. In the ten years during which the synchroton and AdA were built, from 1957 to 1964 and while ADONE was under construction, until 1967, a spirit of collaboration and companionship pervaded the place. Short satirical poems about the director were circulated to everybody's merriment, letting off the pressure the intense work entailed. Elaborate pranks were prepared and realized by both the researchers and the technicians. In particular, Gatto and Touschek's voice were easy to imitate and their students could also occasionally be the targets.

Physically, Touschek and Gatto were very different, one lean and nervous, the other quiet and soft. They also had extremely unique and recognisable ways of speaking. In Touschek's case, his very good spoken Italian was accompanied by a strong Austrian accent characterised by a rounded pronounciation of the letter "r", which made his talking easily recognizable and often copied when mentioning him. Unforgettable for one of this article's authors is his sentence "Signorrina, dobbiamo guadagnarrci il pane e il burrro", *Miss, we must earn our bread and butter*, all pronounced with many "r's". This is how he meant that work for the paper on the infrared radiative corrections to electron-positron experiments with ADONE had to be started.

Touschek is also remembered for his loud voice, as Carlo Rubbia writes in [107]: "I have met for the first time Bruno when I was a student at the Scuola Normale di Pisa [where he was teaching.] ... Then I spent a few years in the United States. On my return to Italy, I moved to the University of Rome, where in the meanwhile Marcello Conversi had become professor. I met then often again Bruno in the wide and relatively dark corridors of the Physics Department. ... I still remember him saying with a very loud voice resonating in the corridors 'the positron and the electron *must* collide because of the CPT theorem' ".

Touschek's Austrian accent and loud voice, made a strong contrast to Gatto's Sicilian accent and soft carrying. Gatto's demeanour was cat-like, true to his name. His voice was also easy to recognize and imitate. This characteristic way of speaking was at the heart of a memorable prank, which took place in Frascati in summer of 1963, and was still remembered many years later [106].

That was the summer, during which Guido Altarelli and Franco were struggling to calculate the cross-section for single *bremsstrahlung* in e^+e^- scattering. The calculation was lagging behind, due to its computational difficulties. The calculation of the bremsstrahlung in electron-positron can not be analytically completely performed and the computer gave contradictory answers, very large values or even negative values for the cross-section: the reason is that the subtraction of very large numbers to give a very small result was beyond the precision of the computer. Their difficulties and resulting frustration were shared with the young members of the Frascati theory group, Giovanni, nicknamned *Gian*, De Franceschi, who had graduated with Marcello Cini and was able to imitate Gatto, and Giuseppe, *Beppe*, Da Prato, who had graduated in Rome with Ezio Ferrari. As the two students struggled with their calculational difficulties, De Franceschi, called Altarell on the phone, feigning to be Gatto and warned him to check what Buccella did. Guido, loyally defending his colleague, anyway told him about the call: luckily, shortly after, Da Prato disclosed the prank's author, telling them that Gatto had nothing to do with the call.

As it is said in [9] and [108]. after the very inspiring discussion with Touschek, the two students found the relativistic approximation, which allowed them to complete in Rome the analytical computation, which gave rise to the formula of the cross-section for the emission of a photon. Their work [101] is quoted in the Landau book on relativistic field theory for electron-electron scattering, since the approximation, which neglects the annihilation diagrams, gives the same result for electron-positron and electron-electron scattering. The electron-electron scattering calculation was of particular interest for the Budker's group in the Novosibirsk laboratory where in 1963 an electron-electron collider, VEPP-1, had been built and an electron-positron ring, VEPP-2, was in advanced stage of construction. As Baier writes [94] when the results from Frascati had started appearing in print, the Novosibirsk group had felt encouraged to continue in their efforts, which remained basically unknown to their Western colleagues until the International Conference on High Energy Accelerators, which was

held in Dubna in August 1963 [109], and the post-conference trip to the Novosibirsk laboratory [63].

Altarelli and Buccella graduated in November 1963. Their work showed compatibility between AdA's output and the theoretical predictions, once other issues, such as volume of interaction in the collision, had been clarified. The article they wrote reporting the result of their calculations was prepared and sent for publication to the Nuovo Cimento, where it was received on 17 June 1964, and published in the December issue of the same year [101]. In AdA's final paper [17] this work is cited as "G. Altarelli and F. Buccella: *Thesis* (unpublished)", notwithstanding it having been received at the Nuovo Cimento's office one month ahead of AdA's submission of its final results,[28] with publication in the same Vol. 34 of the journal. This article is a landmark and *per se* widely known, but the timing and importance of this work in connection with AdA's success is not always appearing in the story of the first electron-positron colliders and Gatto's role in the last step towards establishing proof of principle of the feasibility of electron-positron storage rings is blurred.

3.3 How Gatto and Touschek shaped the Frascati theory group

In this subsection, we shall take a step back in the time-line of events, as we wish to outline in particular the beginnings of the Frascati theoretical physics group, and the interplay between Gatto and Touschek in shaping it. Some events, already mentioned in the previous parts of this article, will be revisited, and presented in this perspective.

Altarelli and Buccella belonged to a group of students who had enrolled in the academic year 1959-60, a year which saw the number of physics students almost doubling with respect to the previous one. This class had seen the launch of the Sputnik satellite, but also, in Italy, had listened to Giorgio Salvini's lectures in physics broadcast by the public television company, RAI-TV. This class and the ones which followed as Gatto and Touschek's students or collaborators, was to play an important role in the post-war renaissance of theoretical physics in Italy. The impact of the Florence school created by Gatto is well known [5, 7], his role for Frascati less so.

There is a golden thread linking the Laboratori Nazionali di Frascati to Enrico Fermi, and the theory group in particular, which passes through Fermi's colleague and high school friend Enrico Persico.[29] Persico had left Italy in 1947 for Quebèc in Canada, returning to Italy in 1951, and was at University of Rome when in 1953, plans started for building a national laboratory to host a modern type particle accelerator, such as a weak-focusing electron synchrotron, as it then became. The designated laboratory director was Giorgio Salvini [110], who forged a first class team with both senior and junior scientists. For the latter, he scouted through all the Italian universities and technical institutes, hiring the best Italian graduates, including theorists in the laboratory staff, Fig. 8.

Salvini was aware of the need for advanced mathematical calculations and advice, and referred to Enrico Persico to be the senior scientist overlooking the synchrotron construction. Among the younger staff, he hired Carlo Bernardini, who had just graduated with Bruno Ferretti and would then play an important part both in AdA and in the ADONE project [111, 112]. Persico, who has just returned from Canada, accepted and, starting with 1953, was author of many Laboratory Notes, some of which with Carlo Bernardini as co-author.[30]

[28] The submission date of AdA's fourth and final article is July 16th, 1964, with publication date December 16th 1964.

[29] The other important tie between the Frascati theory group and Fermi is of course Bruno Ferretti, who had been Fermi's youngest assistant and taught Fermi's theoretical physics course after Fermi left Europe for the US in December 1938. Ferretti was never directly involved with Frascati, only indirectly through Touschek, who came to Rome attracted by their common theoretical physics interests, and through the students who graduated with him, among them Gatto and Carlo Bernardini.

[30] Persico authored the first Laboratory Note. His last two appear in 1959 and in 1962.

Fig. 8 At left, listing of the perspective Synchrotron staff assembled by Salvini in 1954 [62], when the laboratories had not yet been built, with age between brackets, in a cartoon from a talk by G. Mencuccini, experimenter at both the Frascati synchtrotron and ADONE; at right a photograph of LNF personnel in 1957, during the construction of the synchrotron. One distinguishes Giorgio Salvini, seated, in the middle, Carlo Bernardini and Giorgio Ghigo second and third from right in first row, Gianfranco Sacerdoti, third row, first at right. © INFN-LNF, all rights reserved.

In 1959, as soon as the synchrotron started operations, Persico asked to be relieved from his Frascati obligations to go back to teaching. Up to that time, efforts in the Laboratories and at the Rome Physics Institute had focused on commissioning the accelerator and start the planned experiments. At the same time, it was necessary to look forward to future projects, which would keep Italian physics in the front runners line-up. This is when the INFN management began looking for a scientist who could give advice and vision to the Laboratories. As we have seen in the previous sections, there were two obvious choices, Raoul Gatto and Bruno Touschek. In 1959, Gatto and Touschek were both on the brink of a change in their lives. Gatto had become a Professor at University of Cagliari, in Sardinia, and was going to start teaching in the academic year 1960-61, commuting between Cagliari and Rome. Touschek had lost his mentor in theoretical physics, Wolfgang Pauli, in December 1958, and in May 1959, his maternal aunt Ada, the closest connection to his life before the war and to the mother he had lost as a 9 years old. Both Raoul and Bruno were ready for new directions. The search for a head theorist in Frascati began with the latter.

In the already mentioned January 16th, 1960 letter to his father, Touschek mentions the possibility to take up a larger responsibility in the laboratory future, and in this letter he even envisages finding a villa to live in Frascati, noting that, in such case, Elspeth would have to learn driving, moving out of the city at least until their son Francis (born in 1958) would begin school. But Bruno was suspicious of becoming a "house theorist", from his past experience during the war with Widerøe and his betatron, or from the times in the UK, after the war, when he was participating in the construction of the Glasgow synchrotron

The situation came to a crisis point in February 1960, when a meeting was called by the Scientific Council of the Laboratories to discuss the creation of a theoretical physics group or school in Frascati. During the meeting Touschek dismissed such need beyond what the University of Rome could already provide, and instead suggested to make what he called an electron-positron *experiment*, as the best way to attract people and generate new ideas. The proposal caught the imagination of Salvini and the scientists who were present, and the project went ahead, with Touschek appointed

to be in charge. Such engagement was clearly to take up most of Touschek's energies and time, but theoretical guidance for the Laboratories was still needed, especially since it was evident that more calculations had and could be done to show the road to electron positron physics. Gatto stepped lightly in. Having won his Professorship in Cagliari he could be expected to commute between Cagliari and Rome and follow students who could work on Frascati related physics problems.

Having been decided that a dedicated theoretical physicist was needed, Raoul Gatto began his official affiliation with Frascati some time in spring 1960.[31] In this new capacity he also followed the developments of AdA's construction and, in February 1961, co-authored the ADONE proposal with Touschek, as they could literally see the first electrons (or positrons) circulating in AdA, and understood that the road was open for building a larger and more powerful collider. Gatto then embarked in the longer paper about e^+e^- collisions with Cabibbo, presenting the work at many international conferences, including the one in Aix-en-Provence in September 1961, where the possible transfer of AdA to France was first realistically discussed [98].

In 1962, Gatto's commuting between Rome and Cagliari came to an end. Problems with research funding in Sardinia and relative isolation, made him leave and move to the University of Florence. Touschek, after the discovery of the *Touschek effect* in February 1963, decided to prove AdA's feasibility through the process in Eq. (1), while Raoul assigned the calculation as thesis to Altarelli and Buccella. At the same time he started also spending more and more time in Florence, and in the summer one finds him installed in Arcetri, as his student Giuliano Preparata remembers him, when he went to see Gatto with the results for the thesis which had been assigned to him [6]:[32]

It was around eleven o'clock on a summer Saturday morning, when on the platform at the Santa Maria Novella station [in Florence] I saw my teacher again, who welcomed me with a broad smile. We got into the car towards the Arcetri hill, where the Physics Institute of the University of Florence is located. Once we reached our destination, Gatto led me into his large study, with a marvellous view of the Florentine hills, he pointed to the blackboard and sat down comfortably at the desk [to listen to my presentation].

As Gatto's involvement in Florence grew, his presence in Frascati necessarily diminished, and his role was taken up by Touschek, who had returned from Orsay after AdA's successful runs. It was now time for Touschek to start his active engagement in ADONE, worrying about the extraction of significant physics from possible experiments. ADONE's enterprise was a much larger one than AdA's, from both the scientific and financial point of view, and Touschek could now see the need for the creation of a Frascati based theoretical physics group. Once more, we see how, together, these two exceptional scientists shaped physics between Rome and Frascati from 1960 to 1964, and, in Touschek's case until 1969, when he was finally nominated University Professor[33] and turned his full attention to teaching and science communication to high school students, their teachers and the academic public at large [1], Fig. (9).

Even after his affiliation to Frascati ended, Gatto's interest in e^+e^- physics [113–117], and his involvement with the Frascati theory group, continued through the ADONE years and with new collaborators, as one can see from the box to follow,

[31] Gatto's affiliation with Frascati first appears in July 1960 [10]. Since in Gatto's February paper with Cabibbo [10], there is no Frascati affiliation, one can easily date Gatto's appointment in Frascati to have occurred sometime in spring 1960.

[32] Ref. [6] is a revised and expanded edition of the 2002 volume, posthumosly published by Boringhieri.

[33] Touschek never relinquished his Austrian citizenship. Due to the 1928 laws about Italian universities concerning foreign nationals, he could not hold a Professor Chair, until 1969, when the law changed and he became a *Professore aggregato*. A subsequent change of the law in 1973 allowed him to become *Professore Staordinario*, a position which would have allowed him to become *Professore ordinario*, the top position in the university career - with more prestige and better pay - in three years' time. As Amaldi writes, this final step took place only in 1978, the year Touschek died, thanks to his close friends and colleagues, who collated and presented all the neeeded paper work, as he was refusing to do it, considering it an "unbearable obligation".

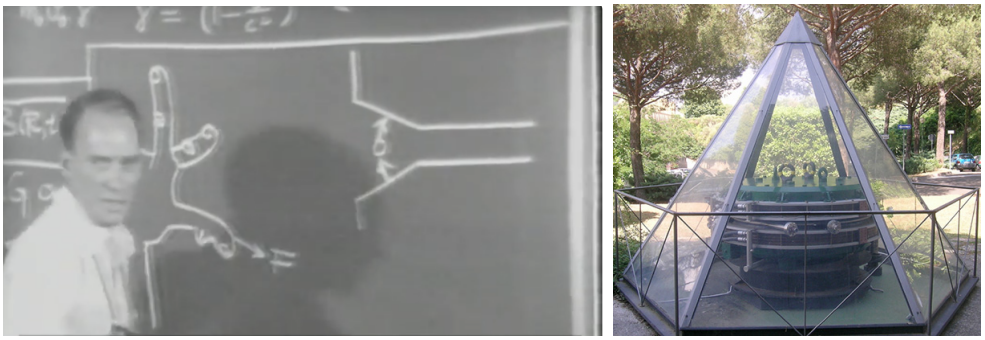


Fig. 9 At left, Bruno Touschek during a 1975 lecture at Accademia dei Lincei, in a video-registration by Francis Touschek, © Accademia dei Lincei, all rights reserved. At right, AdA is on the grounds of Laboratori Nazionali di Frascati, in 2015, photo by A. Srivastava, all rights reserved.

where we present a letter by Raoul Gatto to G.P., translated from the original Italian version.[34]

Dear Lia,
it is with with great shock that, looking back at old emails, I discovered that I probably never responded to your email about the history of Frascati. If so, I apologize and will try to give you all the help I can by answering your questions.
My graduation was in 1951 and it's a little complicated. As a student at the Scuola Normale I should have done my thesis in Pisa. But the chair of theoretical physics in Pisa was vacant. From the School I was able to work on my thesis in Rome, except for the final discussion which was to take place in Pisa. My thesis, with Ferretti, was on a non-perturbative model of inelastic diffusion (with a view to application to diffusions on systems with excited states). Marcello Conversi, who had been the chair of experimental physics in Pisa, acted as relator of my work with great awareness and competence.
After graduation I stayed in Rome, where I was when Bruno Touschek came. Bruno's arrival was a great fortune for the theoretical group in Rome. Ferretti moved to Bologna shortly afterwards and in fact Bruno Touschek was the person with whom I mainly discussed in those years and who generously offered me a lot of his time. For this I cannot help but be grateful to him.
From the end of 1956 my scientific base became Berkeley where I initially stayed for just over a year and then returned regularly for shorter periods.
I became Extraordinary Professor in 1960 in Cagliari. Almost at the same time I was offered, by Giorgio Salvini, always full of scientific initiatives, and by the then director Italo Federico Quercia, the possibility of creating a theoretical group in Frascati through a consultancy contract. (To answer your question, there was no discussion or info regarding how much time this would go through once enacted, etc.). I cannot say if a similar offer had previously been made to Bruno, which would have seemed completely right and natural to me. Bruno had never told me about it and it is only now from your email that I learned of this possibility, which would have seemed completely correct and scientifically excellent to me.
After my move to Florence I continued to deal with Frascati on a regular basis, within the limits of my increased university commitments until 1965. These last years, however, were years of serious economic difficulties for Frascati and for all of Italian physics and the discussions we had in the Senate of the laboratory were largely centered on financial and administrative issues.
The theoretical group of the laboratory, in addition to myself and Nicola Cabibbo, had as members and collaborators (I hope I remember everybody), Bassetti, De Franceschi, Putzolo, Mosco, Altarelli, Buccella, and regular visitors from the French CNRS and various foreign universities. I don't have precise records but everyone was very active. I particularly remember Nicola's work with De Franceschi and Da Prato on photons in crystals.
In 1973 I resumed contact with the Frascati group (the collaboration with Ferrara - Grillo - Parisi) and worked on the commission for SuperAdone and the preparation of the related project, which unfortunately did not come to fruition. I say "unfortunately "because" [with such machine] we could have done the physics of heavy mesons in Frascati.
I'm not very tidy. However, I have found, among my works containing the Frascati affiliation, some , which I give the list of below. There were no electronic databases at that time so it is not easy to find them or realize the impact of these works: No medium, no message. It's a miracle that they are still sometimes mentioned. Worse goes, of course, for the articles published in the Nuovo Cimento, a journal which that cannot be found in most libraries. I think that Nicola [Cabibbo], who contributed substantially to the first important works, can provide any comments (I am sending him a copy of this email).
Works with Frascati affiliation : [in refs.] [118],[119],[120],[121],[122],[123].
I'm sorry for the unexpected delay. I remember that I had put your email in a separate file telling myself that I had to give you all my help. I hope to be useful to you anyway.
With warm greetings,
Raoul Gatto

[34]The letter can be dated around 2010, in response to inquiries about Gatto and Touschek's role in the development of the theory group in Frascati. Notice that in addition to what Gatto writes in this letter, there are other papers cited in *inspirehep.net* with affiliation to Frascati (or CNEN) and a number of LNF reports as well.

Gatto's presence in Frascati reappeared thirty years later. When in 1995, the scientific personnel of the Frascati National Laboratories moved from one side of Via Enrico Fermi to a new building across the street, a box full of books showed up in the first floor corridor where the theory group had been relocated.[35] The books were mostly paperbacks, in English, and of literary nature. Some of them bore the name of their owner, Raoul Gatto, having survived in some corner of the library in the old CNEN building, from the time Gatto had an office in the Laboratories, when he was head of the theory group, before passing the *baton* to his friend and colleague, Bruno.

4 Conclusion

The parallel but also converging accomplishments of Raoul Gatto and Bruno Touschek in developing both accelerator and theoretical physics in the 1960's in Italy have been described.

We have recounted here the little known story of how Gatto collaborated with Bruno Touschek in contributing to the theoretical grounds for the construction of the first electron positron collider, AdA, and to ADONE proposal.

Gatto and Touschek also shaped the further development of theoretical and particle physics through their students, who were part of an exceptional roster of pupils and collaborators whose work contributed to the renaissance of Italian theoretical physics after the Second World War, and to the establishment of the Standard Model of particle physics. Outstanding among them in shaping theoretical physics in Rome and elsewhere, there is Nicola Cabibbo, Gatto's collaborator and one of Touschek's first students.[36] In Nicola's subsequent scientific and public life, we can see the profound interconnection between Gatto and Touschek: after Cabibbo became INFN president in 1983, he was instrumental in envisioning a new electron-positron accelerator project in Frascati, meant to study CP violation effects, the ϕ-factory DAFNE, whose construction was approved and fully funded by the INFN Board of Directors in June 1990.

In the present note, the extent of Gatto and Touschek's contribution to particle physics has only considered in detail the period during which AdA was built and ADONE conceived. Work is in progress towards a more complete discussion of the overall impact of Gatto and Touschek's theoretical physics legacy.

Acknowledgements. We thank Francis Touschek for allowing to reproduce some family documents, which had been photographed courtesy of the late Mrs. Elspeth Yonge Touschek in 2009-2010. Among them, we acknowledge a cache of unpublished drawings and letters written by Bruno Touschek to his father, from 1939 until 1960, and then from 1969 until 1971. We also thank Gatto's family for permission to reproduce his photographs. We thank Gianni Battimelli, Mario Greco and Yogendra Srivastava for exchanges and useful discussions. G.P. thanks the LNF library staff for assistance. We gratefully acknowledge permission from the Laboratori Nazionali di Frascati to reproduce documents and photographs.

[35] The Frascati National Laboratories had started as a joint enterprise between the Comitato Nazionale dell'Energia Nucleare CNEN, INFN – both government agencies – and a number of Italian Universities, in particular Rome. Funding for construction and infrastructures, including experimental equipment, were responsibility of CNEN, which also employed technicians and technical staff, in addition to offer a few fellowships to new graduates, most of whom would later move to university positions. The arrangement was that the academic institutions and INFN would have full and sole responsibility for scientific planning and exploitation. In time this partnership changed, as the scientific goals of CNEN and INFN evolved and diverged. In 1975 the two components of the laboratories separated: CNEN kept the old grounds on one side of Via Enrico Fermi, INFN moved equipments across the street, where ADONE had been built and the accelerator division created. Researchers and other staff split as well, some of the remaining with CNEN, others becoming INFN employees.

[36] The other two students who graduated with Touschek in 1958 were Guido Calogero and Paolo Guidoni.

References

[1] Amaldi, E.: The Bruno Touschek Legacy (Vienna 1921 - Innsbruck 1978). CERN Yellow Reports: Monographs, vol. 81-19. CERN, Geneva (1981). https://doi.org/10.5170/CERN-1981-019 . https://cds.cern.ch/record/135949/files/CERN-81-19.pdf

[2] Bonolis, L., Pancheri, G.: Bruno Touschek: Particle Physicist and Father of the e^+e^- Collider. European Physical Journal H **36**(1), 1–61 (2011) https://doi.org/10.1140/epjh/e2011-10044-1 1103.2727 [physics.hist-ph]

[3] Maiani, L., Bonolis, L.: The Charm of Theoretical Physics (1958-1993). Eur. Phys. J. **H42**(4-5), 611–661 (2017) https://doi.org/10.1140/epjh/e2017-80040-9 arXiv:1707.01833 [physics.hist-ph]

[4] Casalbuoni, R., Dominici, D.: The teacher of the gattini (kittens) (2018). https://arxiv.org/abs/1810.06413

[5] Battimelli, G., Buccella, F., Napolitano, P.: Raoul Gatto, a great Italian scientist and teacher in theoretical elementary particle physics. Quaderni di Storia della Fisica **22**, 145–169 (2019) https://doi.org/10.1393/qsf/i2019-10065-7

[6] Preparata, G.: Dai Quark Ai Cristalli. Breve Storia di Un Lungo Viaggio Dentro la Materia. Ediz. Ampliata. Bibliopolis, Naples (2020)

[7] Casalbuoni, R., Domini, D., Mazzoni, M.: Lo Spirito di Arcetri. A Cento Anni Dalla Nascita dell'Istituto di Fisica dell'Università di Firenze. Firenze University Press, Firenze (2021)

[8] Casalbuoni, R., Dominici, D., Mazzoni, M.: A brief history of Florentine physics from the 1920s to the end of the 1960s. Eur. Phys. J. H **47**(1), 15 (2022) https://doi.org/10.1140/epjh/s13129-022-00048-7 arXiv:2207.05441 [physics.hist-ph]

[9] Pancheri, G.: Bruno Touschek's Extraordinary Journey. Springer, Cham (2022). https://doi.org/10.1007/978-3-031-03826-6

[10] Cabibbo, N., Gatto, R.: Pion Form Factors from Possible High-Energy Electron-Positron Experiments. Physical Review Letters **4**, 313–314 (1960) https://doi.org/10.1103/PhysRevLett.4.313

[11] Cabibbo, N., Gatto, R.: Electron Positron Colliding Beam Experiments. Physical Review **124**, 1577–1595 (1961) https://doi.org/10.1103/PhysRev.124.1577

[12] Gatto, R.: Memories of Bruno Touschek. In: Greco, M., Pancheri, G. (eds.) Bruno Touschek Memorial Lectures. Frascati Physics Series, vol. 33, pp. 69–75 (2004). INFN-Laboratori Nazionali di Frascati. http://www.lnf.infn.it/sis/frascatiseries/Volume33/volume33.pdf

[13] Bonolis, L.: Maestri e Allievi nella Fisica Italiana del Novecento. Compositori, Pavia (2008)

[14] Valente, V.: Strada del Sincrotrone Km 12. Istituto Nazionale di Fisica Nucleare, Frascati (2007)

[15] Amman, F., Bernardini, C., Gatto, R., Ghigo, G., Touschek, B.: Anello di accumulazione per elettroni. ADONE. Technical Report LNF-61/5, LNF (1961).

http://www.lnf.infn.it/sis/preprint/search.php

[16] Bernardini, C., Corazza, G.F., Di Giugno, G., Ghigo, G., Querzoli, R., Haissinski, J., Marin, P., Touschek, B.: Lifetime and beam size in a storage ring. Physical Review Letters **10**(9), 407–409 (1963)

[17] Bernardini, C., Corazza, G.F., Di Giugno, G., Haissinski, J., Marin, P., Querzoli, R., Touschek, B.: Measurements of the rate of interaction between stored electrons and positrons. Il Nuovo Cimento **34**(6), 1473–1493 (1964) https://doi.org/10.1007/BF02750550

[18] Rubbia, C.: Role of Bruno Touschek in the realization of Particle-Antiparticle Colliders. In: Bruno Touschek 100 Years Memorial Symposium 2021, pp. 59–62. Springer, Cham (2023). https://doi.org/10.1007/978-3-031-23042-4

[19] Altarelli, G., Ellis, R.K., Greco, M., Martinelli, G.: Vector Boson Production at Colliders: A Theoretical Reappraisal. Nucl. Phys. B **246**, 12–44 (1984) https://doi.org/10.1016/0550-3213(84)90112-3

[20] Altarelli, G., Parisi, G.: Asymptotic Freedom in Parton Language. Nucl. Phys. B **126**, 298–318 (1977) https://doi.org/10.1016/0550-3213(77)90384-4

[21] Greco, M.: Fisica e Avventure. Exorma, Avellino (2018). http://www.exormaedizioni.com

[22] Greco, M., Rossi, G.: A Note on the Infrared Divergence. Nuovo Cim. **50**, 168 (1967) https://doi.org/10.1007/BF02820731

[23] Touschek, B., Rossi, G.: Meccanica Statistica. Boringhieri, Torino (1970)

[24] Rossi, G.: Bruno Touschek and Statistical Mechanics. In: Bruno Touschek 100 Years Memorial Symposium 2021, pp. 45–57. Springer, Cham (2023). https://doi.org/10.1007/978-3-031-23042-4

[25] Martinelli, G.: QCD and Supercomputers. In: Bruno Touschek 100 Years Memorial Symposium 2021, pp. 125–143. Springer, Cham (2023). https://doi.org/10.1007/978-3-031-23042-4

[26] Parisi, G., Petronzio, R.: Small Transverse Momentum Distributions in Hard Processes. Nucl. Phys. **B154**, 427–440 (1979) https://doi.org/10.1016/0550-3213(79)90040-3

[27] Etim, G.E., Touschek, B.: A Proposal for the Administration of Radiative Corrections. http://www.lnf.infn.it/sis/preprint/detail-new.php?id=2655

[28] Etim, G.E., Pancheri, G., Touschek, B.: The infra-red radiative corrections for colliding beam (electrons and positrons) experiments. Il Nuovo Cimento B **51**(2), 276–302 (1967)

[29] Pancheri-Srivastava, G., Srivastava, Y.: Transverse-Momentum Distribution from Bloch-Nordsieck Method. Phys. Rev. **D15**, 2915 (1977) https://doi.org/10.1103/PhysRevD.15.2915

[30] Greco, M. (ed.): Coherent States in Gauge Theories and Applications in Collider Physics. World Scientific, Singapore (2019). https://doi.org/10.1142/9789811213908_fmatter

[31] Greco, M., Pancheri, G. (eds.): 1987 Bruno Touschek Memorial Lectures. Frascati Physics Series, vol. XXXIII. INFN Frascati National Laboratories, Frascati (2004). http://www.lnf.infn.it/sis/frascatiseries/Volume33/volume33.pdf

[32] Lüders, G.: On the Equivalence of Invariance under Time Reversal and under Particle-Antiparticle Conjugation for Relativistic Field Theories. Kong. Dan. Vid. Sel. Mat. Fys. Med. **28N5**(5), 1–17 (1954)

[33] Hofstadter, R., McAllister, R.W.: Electron Scattering From the Proton. Phys. Rev. **98**, 217–218 (1955) https://doi.org/10.1103/PhysRev.98.217

[34] McAllister, R.W., Hofstadter, R.: Elastic Scattering of 188-MeV Electrons From the Proton and the α Particle. Phys. Rev. **102**, 851–856 (1956) https://doi.org/10.1103/PhysRev.102.851

[35] Nambu, Y.: Possible existence of a heavy neutral meson. Phys. Rev. **106**, 1366–1367 (1957) https://doi.org/10.1103/PhysRev.106.1366

[36] Chew, G.F., Karplus, R., Gasiorowicz, S., Zachariasen, F.: Electromagnetic Structure of the Nucleon in Local-Field Theory. Phys. Rev. **110**(1), 265 (1958) https://doi.org/10.1103/PhysRev.110.265

[37] Federbush, P., Goldberger, M.L., Treiman, S.B.: Electromagnetic Structure of the Nucleon. Phys. Rev. **112**, 642–665 (1958) https://doi.org/10.1103/PhysRev.112.642

[38] Frazer, W.R., Fulco, J.R.: Effect of a pion pion scattering resonance on nucleon structure. Phys. Rev. Lett. **2**, 365 (1959) https://doi.org/10.1103/PhysRevLett.2.365

[39] Derado, I.: Experimental evidence for the pion-pion interaction at 1 GeV. Nuovo Cimento **15**, 853–855 (1960)

[40] Anderson, J.A., Bang, V.X., Burke, P.G., Carmony, D.D., Schmitz, N.: Experimental Results on the pi pi Cross Section. Phys. Rev. Lett. **6**, 365 (1961) https://doi.org/10.1103/PhysRevLett.6.365

[41] Erwin, A.R., March, R., Walker, W.D., West, E.: Evidence for a $\pi\pi$ Resonance in the I = 1, $J = 1$ State. Phys. Rev. Lett. **6**, 628–630 (1961) https://doi.org/10.1103/PhysRevLett.6.628

[42] Stonehill, D., Baltay, C., Courant, H., Fickinger, W., Fowler, E.C., Kraybill, H., Sandweiss, J., Sanford, J., Taft, H.: Pion-Pion Interaction in Pion Production by pi+-p Collisions. Phys. Rev. Lett. **6**, 624–625 (1961) https://doi.org/10.1103/PhysRevLett.6.624

[43] Maglich, B., Alvarez, L.W., Rosenfeld, A.H., Stevenson, M.L.: Evidence for a $T = 0$ Three Pion Resonance. Phys. Rev. Lett. **7**, 178–182 (1961) https://doi.org/10.1103/PhysRevLett.7.178

[44] Drell, S.D.: Quantum electrodynamics at small distances. Annals Phys. **4**, 75–80 (1958) https://doi.org/10.1016/0003-4916(58)90038-1

[45] Charpak, G., Farley, F.J.M., Garwin, R.L., Muller, T., Sens, J.C., Telegdi, V.L., Zichichi, A.: Measurement of the anomalous magnetic moment of the muon. Phys. Rev. Lett. **6**, 128–132 (1961) https://doi.org/10.1103/PhysRevLett.6.128

[46] Barber, W.C., Richter, B., Panofsky, W.K.H., O'Neill, G.K., Gittelman, B.: An Experiment on the Limits of Quantum Electrodynamics. Technical Report HEPL-170, Stanford University (June 1959). https://www.osti.gov/servlets/purl/4081479

[47] Bernardini, C., Corazza, G.F., Ghigo, G., Touschek, B.: The Frascati storage ring. Il Nuovo Cimento **18**(6), 1293–1295 (1960) https://doi.org/10.1007/BF02733192

[48] Bernardini, C., Corazza, G.F., Ghigo, G., Querzoli, R., Touschek, B.: Progress Report on AdA (Frascati Storage Ring). Il Nuovo Cimento **23**(1), 202–207 (1962)

[49] F. Amman, F., Bassetti, M., Bernardini, M., Corazza, G.F., Mango, L., Massarotti, A., Pellegrini, C., Placidi, M., Puglisi, M., Tazzioli, A. Ricerca Scientifica **32**, 1–197 (1962)

[50] Bell, J.S., Cerulus, F., Ericson, T., Nilsson, J., Rollnik, H. (eds.): Proceedings, International Conference on Theoretical Aspects of Very High-Energy Phenomena. 5 - 9 Jun 1961, CERN, Geneva, Switzerland. CERN, Geneva (1961). https://doi.org/10.5170/CERN-1961-022 . http://www.slac.stanford.edu/spires/find/books/www?cl=QCD161:I55:1961

[51] Pursey, D.L.: Invariance properties of fermi interactions. Nuovo Cimento **6**, 266–277 (1957)

[52] Pauli, W.: On the conservation of the Lepton charge. Nuovo Cim. **6**(1), 204–215 (1957) https://doi.org/10.1007/bf02827771

[53] Pauli, W., Touschek, B.: Report and comment on F. Gürsey's "Group Structure of Elementary Particles". Nuovo Cim. **14**(1suppl), 205–211 (1959) https://doi.org/10.1007/BF02724849

[54] Touschek, B.: The symmetry Properties of Fermi Dirac Fields. Il Nuovo Cimento **8**(1), 181–182 (1958)

[55] Straumann, N.: On Pauli's invention of non-Abelian Kaluza-Klein theory in 1953. In: 9th Marcel Grossmann Meeting on Recent Developments in Theoretical and Experimental General Relativity, Gravitation and Relativistic Field Theories (MG 9), pp. 1063–1066 (2000)

[56] Ferretti, B., Peierls, R.: Radiation Damping Theory and the Propagation of Light. Nature **160**, 531–532 (1947)

[57] Waloschek, P.: The Infancy of Particle Accelerators. Life and Work of Rolf Widerøe (edited by P. Waloschek). Friedr. Vieweg & Sons Verlagsgesellschaft (Braunschweig and Wiesbaden), Braunschweig, Germany (1994). https://doi.org/10.1007/978-3-663-05244-9_7

[58] Sørheim, A.: Obsessed by a Dream. The Physicist Rolf Widerøe – a Giant in the History of Accelerators. Springer, ??? (2020). https://doi.org/10.1007/978-3-030-26338-6 . https://doi.org/10.1007/978-3-030-26338-6

[59] Battimelli, G., De Maria, M., Paoloni, G.: L'Istituto Nazionale di Fisica Nucleare Storia di Una Comunità di Ricerca. Laterza, ??? (2001)

[60] Sands, M., Touschek, B.: Alignment errors in the strong-focusing synchrotron. Il Nuovo Cimento **10**(5), 604–613 (1953)

[61] Blewett, M.H. (ed.): Proceedings, Lectures on the Theory and Design of an Alternating-Gradient Proton Synchroton: Geneva, Switzerland, 26-28 Oct 1953, (1953)

[62] Salvini, G.: L'elettrosincrotrone e i Laboratori di Frascati. Nicola Zanichelli, Bologna (1962)

[63] Marin, P.: Un Demi-siècle D'accélérateurs de Particules. Éditions du Dauphin, Paris (2009)

[64] Blum, A.S., Velasco, A.: The genesis of the CPT theorem. Eur. Phys. J. H **47**(1), 5 (2022) https://doi.org/10.1140/epjh/s13129-022-00037-w

[65] Dahl, O.: Review of the CERN-PS project. In: Conference on the Theory and Design of an Alternating-Gradient Proton Synchroton, pp. 7–17 (1953)

[66] Aubert, J.J., *et al.*: Experimental Observation of a Heavy Particle J. Phys. Rev. Lett. **33**, 1404–1406 (1974) https://doi.org/10.1103/PhysRevLett.33.1404

[67] Augustin, J.E., *et al.*: Discovery of a Narrow Resonance in e^+e^- Annihilation. Phys. Rev. Lett. **33**, 1406–1408 (1974) https://doi.org/10.1103/PhysRevLett.33.1406 . [Adv. Exp. Phys.5,141(1976)]

[68] Bacci, C., *et al.*: Preliminary Result of Frascati (ADONE) on the Nature of a New 3.1-GeV Particle Produced in e+ e- Annihilation. Phys. Rev. Lett. **33**, 1408 (1974) https://doi.org/10.1103/PhysRevLett.33.1408,10.1103/PhysRevLett.33.1649 . [Erratum: Phys. Rev. Lett.33,1649(1974)]

[69] Glashow, S.L., Iliopoulos, J., Maiani, L.: Weak Interactions with Lepton-Hadron Symmetry. Phys. Rev. **D2**, 1285–1292 (1970) https://doi.org/10.1103/PhysRevD.2.1285

[70] Bemporad, C., Bonolis, L.: Storie di Uomini e Quarks. Società Italiana di Fisica, Bologna (2012)

[71] Schwinger, J.S.: The Theory of quantized fields. 1. Phys. Rev. **82**, 914–927 (1951) https://doi.org/10.1103/PhysRev.82.914

[72] Lüders, G.: On some symmetry operations in quantum theory (1955) https://doi.org/10.5170/CERN-1955-025

[73] Pauli, W.: Exclusion principle, Lorentz group and reflection of space-time and charge. In: Niels Bohr and the Development of Physics, pp. 30–51 (1955)

[74] Lüders, G., Zumino, B.: Some Consequences of TCP-Invariance. Phys. Rev. **106**, 385–386 (1957) https://doi.org/10.1103/PhysRev.106.385

[75] Chamberlain, O., Segre, E., Wiegand, C., Ypsilantis, T.: Observation of Antiprotons. Phys. Rev. **100**, 947–950 (1955) https://doi.org/10.1103/PhysRev.100.947

[76] Amaldi, E., Castagnoli, C., Cortini, G., Franzinetti, C., Manfredini, A.: Unusual event produced by cosmic rays. Il Nuovo Cimento **1**, 492–500 (1955)

[77] Chamberlain, O., Chupp, W.W., Goldhaber, G., Segrè, E., Wiegand, C., Amaldi, E., Baroni, G., Castagnoli, C., Franzinetti, C., Manfredini, A.: Antiproton star observed in emulsion. Phys. Rev. **101**, 909–910 (1956) https://doi.org/10.1103/PhysRev.101.909

[78] Chamberlain, O., Chupp, W., Goldhaber, G., Segrè, E., Wiegand, A.E.B.G. C., Castagnoli, C., Franzinetti, C., Manfredini, A.: On the observation of an antiproton star in emulsion exposed at the bevatron'. Il Nuovo Cimento **3**, 447–6 (1956) https://doi.org/10.1007/BF02745430

[79] Gatto, R.: About the capture and annihilation of antiprotons. Il Nuovo Cimento **3**, 468–472 (1956) https://doi.org/10.1007/BF02745431

[80] Battimelli, G., Falciai, D.: Dai raggi cosmici agli acceleratori: il caso dell'antiprotone. In: Rossi, A. (ed.) Atti del XIV e XV Congresso Nazionale di Storia della Fisica,(Udine 1993 - Lecce 1994, pp. 375–386. Conte, Lecce (1995)

[81] Oppenheimer, J.R., Yang, C.N., Wentzel, C., Marshak, R.E., Dalitz, R.H., Gell-Mann, M., Markov, M.A., D'Espagnat, B.: Theoretical interpretation of new particles. In: 6th Annual Rochester Conference on High Energy Nuclear Physics, pp. 1–36 (1956)

[82] Ceolin, M.B.: The discreet Charm of the nuclear Emulsion Era. Annual Review of Nuclear and Particle Science **52**(1), 1–21 (2002) https://doi.org/10.1146/annurev.nucl.52.050102.090730 https://doi.org/10.1146/annurev.nucl.52.050102.090730

[83] Cork, B., Lambertson, G.R., Piccioni, O., Wenzel, W.A.: Antineutrons produced from antiprotons in charge-exchange collisions. Phys. Rev. **104**, 1193–1197 (1956) https://doi.org/10.1103/PhysRev.104.1193

[84] Kerst, D.W.: Properties Of An Intersecting-Beam Accelerating System. In: CERN Symposium on High-Energy Accelerators and Pion Physics, pp. 36–39 (1956). https://cds.cern.ch/record/1241555?ln=it

[85] O'Neill, G.K.: The Storage-Ring Synchrotron. In: CERN Symposium on High-Energy Accelerators and Pion Physics, pp. 64–67 (1956)

[86] Cabibbo, N.: In: Valente, V. (ed.) Adone a Milestone on the Particle Way. Frascati Physics Series, p. 219. INFN Frascati National Laboratories, Frascati

[87] Cabibbo, N.: In: Bonolis, L., Melchionni, M.G. (eds.) Fisici Italiani del tempo presente. Storie di vita e di pensiero. Interview with Nicola Cabibbo, pp. 45–66. Marsilio, Venezia (2003)

[88] Academy of Science USSR and IUPAP (ed.): Proceedings, 9th International Conference on High Energy Physics, V. 1-2 (ICHEP59), Kiev, USSR, Jul 15-25, 1959. Academy of Science USSR / International Union of Pure and Applied Physics, Moscow (1960). http://inspirehep.net/record/1280969

[89] Panofsky, W.K.H.: Electromagnetic Interaction and Nucleon Structure. In: Science USSR, A., Pure, I.U., Physics, A. (eds.) Proceedings, 9th International Conference on High Energy Physics, V.1-2 (ICHEP59): Kiev, USSR, Jul 15-25, 1959, vol. 1. Moscow, pp. 378–409 (1960). http://inspirehep.net/record/44195/files/c59-07-15-p378.pdf

[90] Panofsky, W.K.H.: Beams From High Energy Linear Accelerators. In: 2nd International Conference on High-Energy Accelerators, pp. 427–427 (1959)

[91] Kowarski, L. (ed.): Proceedings, 2nd International Conference on High-Energy Accelerators and Instrumentation, HEACC 1959: CERN, Geneva, Switzerland, September 14-19, 1959. CERN, Geneva (1959)

[92] Brown, L.M., Calogero, F.: The effect of pion-pion interaction in electromagnetic processes. Physical Review Letters **4**, 315–317 (1960) https://doi.org/10.1103/PhysRevLett.4.315

[93] De Tollis, B., Ferrari, E., Munczek, H.: The influence of a possible pion-pion interaction on the photoproduction of charged pions. Nuovo Cimento **18**, 198–202 (1960)

[94] Baier, V.N.: Forty years of acting electron-positron colliders (2006) arXiv:hep-ph/0611201

[95] Budker, G.I., Naumov, A.A.: Studies Of Colliding Electron-Electron, Positron-Electron And Proton-Proton Beams. In: Kolomenskij, A.A., Kuznetsov, A.B. (eds.) Proceedings, 4th International Conference on High-Energy Accelerators, HEACC 1963, V. 1-3: Dubna, USSR, August 21 - August 27 1963, pp. 334–363. NTIS, Oak Ridge, TN (1965). http://inspirehep.net/record/918675

[96] Margaritondo, G.: A lezione da Bruno Touschek. Quaderni di Storia della Fisica **29** (2021)

[97] Amman, F.: Proposta per la realizzazione di un anello di accumulazione per elettroni e positroni da 1.5 GeV . Technical Report LNF-61/65, LNF (1961). http://www.lnf.infn.it/sis/preprint/getfilepdf.php?filename=LNF-61-065.pdf

[98] Bonolis, L., Pancheri, G.: Bruno Touschek and AdA: from Frascati to Orsay. arXiv e-prints **arXiv: 1805.09434** (2018) [physics.hist-ph]. Accessed 23.05.2018

[99] Pancheri, G., Bonolis, L.: Touschek with AdA in Orsay and the first direct observation of electron-positron collisions. arXiv e-prints **arXiv:1910.09075** (2018) [physics.hist-ph]

[100] Haïssinski, J.: AdA at Orsay. Springer Proc. Phys. **287**, 33–44 (2023) https://doi.org/10.1007/978-3-031-23042-4_3

[101] Altarelli, G., Buccella, F.: Single photon emission in high-energy $e^+ - e^-$ collisions. Il Nuovo Cimento **34**(5), 1337–1346 (1964) https://doi.org/10.1007/BF02748859

[102] Crémieu-Alcan, E., Falk-Vairant, P., Lebey, O. (eds.): Proceedings, Conférence Internationale d'Aix-en-Provence sur les Particules Elémentaires: Aix-en-Provence, France, Sep 14-20, 1961. CEN, Gif-sur-Yvette, France (1962)

[103] Gatto, R.: On the experimental possibilities with colliding beams of electrons and positrons. In: 1st Aix en Provence International Conference on Elementary Particles, vol. Vol.1, pp. 487–502 (1962)

[104] Touschek, B.: The Italian Storage Rings. In: Bittner, J.W. (ed.) Proceedings, 1963 Summer Study on Storage Rings, Accelerators and Experimentation at

Super-High Energies. 10 June - 19 July, 1963, Brookhaven National Laboratory, Upton, NY, vol. C63-06-10, pp. 171–208 (1963). http://lss.fnal.gov/conf/C630610/p171.pdf

[105] Jauch, J.M., Rohrlich, F.: The Theory of Photons and Electrons. Addison-Wesley Educational Publishers Inc, Cambridge, Ma (1955)

[106] Greco, M., Pancheri, G.: Frascati e la fisica teorica da AdA a DAϕNE. In: Baroncelli, T., Pancheri, G. (eds.) 50 Anni dei Laboratori Nazionali di Frascati, pp. 93–106 (2008). http://www.analysis-online.net/wp-content/uploads/2013/03/greco.pdf

[107] Rubbia, C.: The role of Bruno Touschek in the realization of the proton antiproton collider. In: Greco, M., Pancheri, G. (eds.) Bruno Touschek Memorial Lectures. Frascati Physics Series, vol. 33, pp. 57–60 (2004). INFN-Laboratori Nazionali di Frascati. http://www.lnf.infn.it/sis/frascatiseries/Volume33/volume33.pdf

[108] Buccella, F.: Touschek: A Great Master of Quantum Electrodynamics and Statistical Mechanics. In: Bruno Touschek 100 Years Memorial Symposium 2021, p. 301. Springer, Cham (2023). https://doi.org/10.1007/978-3-031-23042-4

[109] Kolomenskij, A.A., B., K.A., Lebedev, A.N. (eds.): Proceedings, 4th International Conference on High-Energy Accelerators, HEACC 1963, V.1-3 : Dubna, USSR, August 21 - August 27 1963. NTIS, Oak Ridge, TN (1965). NTIS. http://inspirehep.net/record/19356

[110] Salvini, G.: L'uomo Un Insieme Aperto. La Mia Vita da Fisico. Mondadori Education, Mondadori Universitá, Milano (2010)

[111] Bernardini, C.: AdA: the first electron-positron collider. Physics in Perspective **6**(2), 156–183 (2004)

[112] Bernardini, C.: Fisica Vissuta. Codice edizioni, Torino (2006). https://books.google.com/books?id=hYhpAAAACAAJ

[113] Gatto, R., Preparata, G.: The problem of continuation from deep-inelastic electron scattering to deep electron-positron annihilation. Nucl. Phys. B **47**, 313–332 (1972) https://doi.org/10.1016/0550-3213(72)90119-8 . [Erratum: Nucl.Phys.B 73, 548–548 (1974)]

[114] Gatto, R., Preparata, G.: One-particle and two-particle inclusive deep-inelastic electron-positron annihilation in a massive quark model. Nucl. Phys. B **67**, 362–380 (1973) https://doi.org/10.1016/0550-3213(73)90202-2

[115] Gatto, R., Preparata, G.: Role of two-photon inclusive hadron production in high-energy e+ e- collisions. Lett. Nuovo Cim. **7S2**, 507–517 (1973) https://doi.org/10.1007/BF02727865

[116] Gatto, R., Preparata, G.: Two-photon and possible weak interferences in e+ e- annihilation. Lett. Nuovo Cim. **7S2**, 89–97 (1973) https://doi.org/10.1007/BF02727607

[117] Gatto, R., Preparata, G.: Senile Scaling in electron-Positron Annihilation. Phys. Lett. B **50**, 479–481 (1974) https://doi.org/10.1016/0370-2693(74)90265-2

[118] Cabibbo, N., Gatto, R.: Theoretical discussion of possible experiments with electron-positron colliding beams. Nuovo Cimento **20**, 185–193 (1961) https://doi.org/10.1007/BF02781712

[119] Cabibbo, N., Gatto, R.: Consequences of unitary symmetry for weak and electromagnetic transitions. Nuovo Cimento **21**, 872–877 (1961) https://doi.org/10.1007/BF02785616

[120] Gatto, R.: Classification of lepton currents. Nuovo Cimento **28**, 567–589 (1963) https://doi.org/10.1007/BF02828873

[121] Ademollo, M., Gatto, R.: Complete Spin Tests for fermions. Phys. Rev. **133**, 531–541 (1964) https://doi.org/10.1103/physrev.133.b531

[122] Ademollo, M., Gatto, R.: Non-renormalization Theorem for the Strangeness Violating Vector Currents. Phys. Rev. Lett. **13**, 264–265 (1964) https://doi.org/10.1103/PhysRevLett.13.264

[123] Borchi, E., Gatto, R.: Assignment of higher Boson resonances to a P-wave multiplet of SU(6). Phys. Lett. **14**(4), 352–354 (1965) https://doi.org/10.1016/0031-9163(65)90236-2