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Raoul Gatto and Bruno Touschek: the Rise of e^+e^- Physics

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Abstract

The story of the collaboration between Raoul Gatto and Bruno Touschek, before during and after the construction of AdA, the first electron-positron collider built at the Frascati National Laboratories in 1960, is only partially known. A brief outline is presented here to show how electronpositron physics was influenced by Gatto and Touschek's common early interest in the CPT theorem. Their legacy is also illustrated with examples of their lasting impact as mentors to their students and collaborators. Starting with the early days after Fermi's departure, we describe the various physics scenarios behind the beginning of a deep relationship between Touschek and Gatto in Rome in 1953, the years of AdA between Rome, Frascati and Orsay, up to the construction of ADONE, the more beautiful and powerful collider, where multihadron production was first discovered in 1968/69 and the existence of the charm quark was confirmed in 1974.

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PACS numbers: history of physics, elementary particles, electron-positron colliders

I. INTRODUCTION

AdA, the first electron-positron collider, was born in Frascati on February 17th, 1960. On that day, the scientists of the Frascati Laboratory met to decide on the creation of a theoretical physics group in Frascati, where an electron synchrotron had been operating since the spring of the previous year. The discussion was initiated by Bruno Touschek. Having rejected both the proposal for a dedicated theory group and for a theoretical physics school, the former being insufficiently motivated and the latter unnecessary, he put forward a completely orthogonal idea: to do a new experiment, something that could attract theorists, not only from the University of Rome, but also from other Italian universities and beyond. His vision was to do something new that had never been done before: to study e^+e^- collisions with two counter-rotating beams in the same vacuum chamber. Bruno was no newcomer to the novel science of particle accelerators, an expertise stemming from wartime and early postwar experience, first in Germany and later in the United Kingdom. However, to better understand the articulated motivations and scientific background behind Touschek's bold proposal, it is essential to place it within the broader and dynamic Italian scenario of the 1950s. The developments that followed, the construction and operation of AdA, the first electron-positron collider, and its main achievements have been largely reconstructed[1,2]. A recent paper[3] has highlighted how the synergy between Touschek and Raul Gatto was instrumental in the rise of electron-positron physics and its impact on the construction and early operation of the larger ADONE collider.[a]

This paper aims to shed light on previously unexplored aspects of the collaboration between the two physicists. It will explore the differences and convergences of the collaboration, as well as sketch out the backstage on which they appeared in the physics community and how their legacies were created and continued.

II. FERMI'S LEGACY AND THE ROLE OF BRUNO FERRETTI

Bruno Touschek and Raoul Gatto owed their contemporary presence in Rome in the early 1950s to Bruno Ferretti, who had been Fermi's assistant in the last days of the "Via Panisperna group". Ferretti somehow represented the continuity with modern theoretical physics that had been initiated in Rome in the 1930s by Fermi and other younger theorists such as Giovanni Gentile Jr, Ettore Majorana, Ugo Fano and Gian Carlo Wick, who had rotated around Fermi at different times.

A graduate of the University of Bologna, Ferretti joined the cosmic ray group founded by Fermi in 1937, shortly before Fermi left Italy for the United States. Ferretti was influenced by Gian Carlo Wick, Fermi's successor in the chair of theoretical physics, and Gilberto

[a] For full bibliographic references to the narrated events, see Bonolis *et al.* in *Raoul Gatto and Bruno Touschek's joint legacy in the rise of electron positron physics*, EPJH 2004[3].

FIG. 1: Bruno Ferretti in the last row behind Rudolf Peierls and Homi Bhabha, at the 8th Solvay Conference on Elementary Particles, 1948. Wikimedia

Bernardini, with whom he worked on theoretical problems related to subnuclear physics with cosmic rays. These were attracting general attention after the discovery in 1936 of the "mesotron", a new - and unstable - particle whose nature and identity would remain unknown until its rebirth as the "muon" in 1947[4]. During the war and in the early post-war years, the study of cosmic rays ensured the survival of the physics community in Rome and other centers in Italy.

Beginning in 1948, Ferretti began teaching theoretical physics at University of Rome in the chair left by Fermi and his successor Wick, who had left taking a position in the United States. Ferretti, seen in Fig. 1 together with other eminent theoretical physicists whose work played an important role in Touschek's scientific development, assisted Edoardo Amaldi in carrying on Fermi's legacy in Rome. They were joined by Gilberto Bernardini, an expert in nuclear physics and cosmic rays, whose post-war experience in particle physics at accelerators in the United States would later be instrumental in future plans to revive Fermi's prewar dreams of a modern competitive laboratory equipped with a high-energy accelerator[5]. As Amaldi recalled, Ferretti helped to strengthen the group of young theoretical physicists that included Bruno Zumino, Giacomo Morpurgo, Raul Gatto, Elio Fabri, Benedetto De Tollis and Carlo Bernardini[1] (p. 13), in addition to the young experimentalist Marcello Conversi, Fig. 2. In various ways, the new generation and its students ensured the continuity of the new era inaugurated by the fathers of modern physics in Italy, and would in turn ensure the full revival of Italian physics in the post-war period.

Towards 1947, during a stay in the UK, Ferretti collaborated with Rudolf Peierls (Radiation Damping Theory and the Propagation of Light[6]), who was later to be external examiner for Bruno Touschek's doctoral thesis in Glasgow[7]. Ferretti was also Edoardo Amaldi's closest collaborator on the international scene, particularly in promoting the birth of CERN.

After receiving his Doctorate from the University of Glasgow in November 1949, Bruno Touschek became Nuffield Lecturer, giving a contribution on weak interactions to Max Born's *Atomic Physics* book, and collaborating with Walter Thirring[8] on a problem related to Ferretti's radiation damping paper with Peierls. The mutual interest in the emerging field of Quantum Field Theory, which tied Touschek with Ferretti, gave probably rise to a plan for Touschek's sabbatical year in Italy. In September 1952 Touschek visited Ferretti in Rome. After a few hours spent discussing scientific issues of mutual interest, "they established such a marked professional respect and personal attachment for each other that Touschek decided to remain permanently in Rome"[1] (p. 13). Touschek, seen with Edoardo Amaldi in Fig. 2, moved to Rome at the end of 1952, and this was made possible because he was given a contract as a researcher thanks to Amaldi, who was director of the Rome Section of the newly established National Institute of Nuclear Physics, INFN.

When Touschek arrived in Rome in December 1952, Raul Gatto, Fig. 2, had just become Ferretti's assistant after graduating from the University of Pisa under the supervision of Marcello Conversi, then a professor of Experimental Physics in Pisa, and with Ferretti as external advisor in theoretical physics. The intellectual interaction established between Touschek and Gatto is evidenced by his later writings about Touschek[3], by the letter reproduced at the end of this paper and by the fact that Gatto acknowledged discussions with Touschek in his early articles on nuclear and subnuclear physics based on the cosmic ray research of Amaldi's group in Rome. In this sense he was following Ferretti's example, but at the same time, he was moving towards current problems in theoretical particle physics. He found a mentor in Bruno Touschek, who was ten years older and added a unique experience in subnuclear physics with accelerators to a deep mathematical and theoretical physics knowledge, developed during his years in Germany and the United Kingdom. This unique expertise, gained from such mentors as Arnold Sommerfeld, Werner Heisenberg, Max Von Laue, Max Born, and Rolf Widerøe[1,9], was highly valued in Italy, where INFN was being established, including ambitious plans to build a powerful accelerator and a national laboratory to house it[10]. While waiting for this facility to be-

FIG. 2: From left: Marcello Conversi in 1961, Bruno Touschek with Edoardo Amaldi in 1953, soon after his arrival in Rome, and young Raoul Gatto, family photos

come operational, the traditional work with cosmic rays continued in all the Italian centers, with the support of theoreticians[11–13].

III. NEW CHALLENGES FOR THEORETICAL PHYSICS

In the early 1950s, when Touschek and Gatto began their new scientific life in the exciting context of the reconstruction of Italian physics and its revival on a completely new basis, they became involved in the new, enigmatic physics of strange particles and the emergence of the $\theta - \tau$ puzzle, where data were still being derived from both cosmic ray and accelerator physics. But inexorably, the accelerators took over and particle physics moved beyond free beams of high-energy particles from the sky, while the theorists began to face new, unprecedented challenges. Touschek found a very congenial atmosphere in the Physics Institute at Sapienza University of Rome. He immediately started collaborating with visiting scientists, such as Matthew Sands, or Giacomo Morpurgo and Luigi Radicati di Brozolo. The latter, considered Touschek one of the persons who had the greatest influence on his scientific life[14] (p. 67).

Radicati, who had graduated in 1943, with Enrico Persico in Turin, had discussed the time reversal problem with Peierls in UK, but they did not continue to work on that until, once in Italy, he resumed these topics with Touschek and Morpurgo[15–17]. Morpurgo had met Touschek at the end of August 1953, in the almost empty physics Institute, and, in less than one hour[14] (p. 80), a collaboration had started on a topic of common interest, concerning strong interactions through non-perturbative methods. By January 1954, their interests had shifted to the study of space-time symmetry properties, in particular time reversal. According to Morpurgo, the interest in time reversal had been sparked by Touschek, who had read a paper by Lüders[18] and may also have discussed the subject with Radicati, who was in Rome at the time. Meanwhile Touschek was also involved in work on K mesons with several experimentalists. In April 1954 he attended the Padua Conference on *Unstable Heavy Particles and High-Energy Events in Cosmic Rays* [Particelle Instabili Pesanti e Sugli Eventi di Alta Energia nei Raggi Cosmici], Fig. 3, where he contributed two papers[19,20].

Both out of genuine interest in a puzzling problem, and his commitment to give advice to the experimentalists, he followed ongoing experimental work on cosmic ray searches for anti-protons and strange particle decays, and his commitment culminated in August 1958 when he organized and directed the Fermi International Summer School on Pion Physics, held in Varenna.

During these early years, Gatto was also involved in particle physics problems, of current interest worldwide and in Rome in particular[12,22]. In 1956 Gatto won a Fulbright fellowship and went to the United States, first to Columbia and then for a longer period to Berkeley, where the powerful Bevatron was operating. During this time, Gatto wrote several articles discussing the decays of K mesons and hyperons[23–25] within the strangeness scheme proposed independently by Gell-Mann and Nishijima[26,27]. Related experiments at Berkeley were followed by the first observation of the antiproton[28] and later of the antineutron[29], which consolidated the question of antimatter and strengthened the proof of its existence, almost twenty years after the discovery of the positron. In fact, an event interpreted as a proton-antiproton annihilation had been observed by the cosmic ray group in Rome[30], and it was the subject of an article written by Gatto before he left for Berkeley[31].

In the same 1956, Touschek travelled with Amaldi to

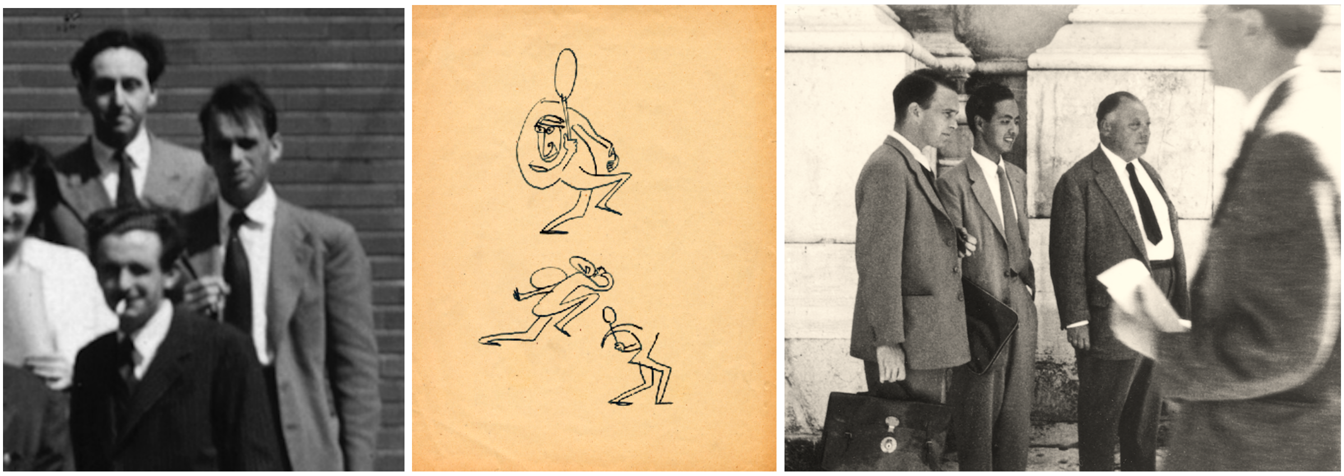


FIG. 3: Bruno Touschek in Padua: at left in April 1954 at the *Conference on Unstable Heavy Particles and High-Energy Events in Cosmic Rays* in[21], and, at right, in September 1957 with T.D. Lee, Wolfgang and Robert Marshak at the *Padua-Venice Conference on Mesons and Recently Discovered Particles* organized by the Italian Physical Society, courtesy of M. Baldo Ceolin. At the center, a contemporary drawing by Bruno Touschek[1] (p.15), © Touschek's family

New York and attended the Rochester Conference, where anti-nucleons were discussed and the idea of parity non-conservation in weak processes was aired by Richard Feynman during the theoretical physics session chaired by C.N. Yang. Soon after, Lee and Yang reviewed the experimental evidence in detail and suggested experiments that could settle the problem[32].

As high-energy nuclear physics evolved into particle physics, and accelerators – together with new kind of detectors – gradually replaced cosmic rays as the main source of high-energy particles, both Touschek and Gatto continued to work on the new puzzling phenomenology derived by experiments and on the classification of the new particles, which also raised the need to know more about symmetries and conservation laws.

Topics such as the annihilation process, time reversal, charge conjugation invariance, the $\theta - \tau$ puzzle and parity non conservation, and more generally the weak hyperon decay interactions under P, C, and T were studied by Gatto in articles between 1956-1958[33,34], and a close look at Touschek's articles from the same period reveals a remarkable similarity between the two in terms of the underlying fundamental themes and issues addressed.

IV. SETTING THE STAGE FOR THE ADA PROPOSAL: THE INSPIRING ROLE OF THE CPT THEOREM

As mentioned above, Touschek's attention had long been drawn to various aspects related to fundamental symmetries, also stimulated by German theorists such as Pauli and Gerhardt Lüders. Beginning in 1953, Touschek discussed with Pauli questions related to time reversal, whose correct formulation in relativistic Quantum Field Theory was actually related to the roots of the CPT theorem (Blum et al. 2022). He wrote more than one paper on this subject[15,35] and discussed with Morpurgo the extension of the procedure to Parity and Charge Conjugation[16]. In 1957/1958, as evidenced by his personal papers, Touschek exchanged several letters with Lüders, Pauli and Zumino discussing topics related to symmetry properties of physical theories.[b]

For his part, Gatto mentions how he became aware of the CPT theorem[36–39] through Bruno Zumino and Gerhard Lüders. Zumino had also graduated with Ferretti, but soon left for the United States, occasionally returning to Rome.

In a later paper by Zumino with Gerhart Lüders entitled "Some Consequences of TCP-Invariance", a direct reference is made to Zumino's having suggested in early 1953 the original formulation[40].

The CPT theorem, deeply connected with the physics of the weak interactions, acquired a central importance after the experimental discovery of parity violation in 1957[41–43]. Here we would only like to emphasize how the theorem and its implications formed the backbone of Touschek's thought from which the idea of studying particle-antiparticle annihilations as a channel to new physics emerged. A clue to how things intermingled in his mind is provided by a letter that he wrote to Pauli on January 31, 1957. In the last lines, after discussing Lee and Yang's work, Abdus Salam's recent article on the neutrino, and the problem of K-decay, Touschek wrote: "I have been trying for about a week to figure out whether invariance under CP (and not under P) means that one

[b] See the correspondence folders in Box 1 of Bruno Touschek Archives in Sapienza University of Rome, Archives of the Physics Department.

can distinguish between particles and antiparticles [. . .]".

After the actual detection of the neutrino as a particle in 1956 and the explosion of interest surrounding the problem of parity violation, he focused on such relevant discoveries in the framework of the weak interactions. Alongside with a renewed interest in the symmetry properties of Fermi-Dirac fields[44,45], Touschek wrote several articles discussing a massless two-component neutrino. He was the first to introduce the concept of chiral symmetry as a consequence of parity violation[46] and in 1958 had begun a work with Pauli which was published only after Pauli's death[47]. Interestingly, in that same period, Gatto wrote an article with Lüders on "Invariants in Muon Decay" based on the assumption of a vanishing neutrino mass[48], which again shows how strong was their intellectual and scientific interaction during the 1950s. On the wave of parity violation, Touschek assigned three joint dissertations on weak interactions to Paolo Guidoni, Nicola Cabibbo, and Francesco Calogero.

At the end of the 1950s, after wandering between the puzzles in new elementary particles, and working in the "most abstract field of theoretical research [. . .] the discussion of symmetries", Touschek wanted to get his feet "out of the clouds and onto the ground again" and get back to what he thought "[he] really understood: elementary physics".[c] Bruno Touschek was also coming to terms with Pauli's death in December 1958, an event which prompted him to write that "Without him [Pauli], physics is really only half as interesting for me".[d]

In Touschek's mind CPT represented the central argument in his proposal of electron-positron annihilations as an alternative to the electron-electron collisions planned in the Princeton-Stanford project, presented by Pief Panofski at ICHEP 1959, in Kiev, and during a seminar in Frascati in October of that year[2] (p.310). Gatto recalled how, after the seminar, "Bruno kept insisting on CPT invariance, which would grant the same orbit for electrons and positrons inside the ring". Nicola Cabibbo, who had recently graduated with Touschek with a thesis on "Pauli invariants in the decay of the μ meson" also testified: "Bruno Touschek came up with the remark that an e^+e^- machine could be realized in a single ring, because of the CTP theorem"[49].

These and similar remarks by Gatto and Rubbia in 1987[14] – after so many years – highlight Touschek's firm belief in CPT as the tool that guaranteed the soundness of his proposal for a collider in which electron and positron beams would meet and annihilate. *Something that was not taken for granted at the time* as Carlo Bernardini always pointed out.[e]

V. EXPERIMENTAL AND THEORETICAL CHALLENGES: ADA IN FRASCATI AND ORSAY, 1960-1964

The making of AdA unfolded[2] (Ch. 10) between October 26th, 1959 – date of Panofsky's seminar in Frascati – and March 7th, 1960, when the Frascati Laboratory Council approved Touschek's detailed proposal for a electron-positron storage ring[50,51]. In between, there is the crucial meeting of February 1960, when Touschek – pressed to form a theoretical physics group in Frascati – proposed to make an experiment on electron positron collisions, in parallel with the submission of two articles by Rome theoretical physicists about the interest such experiments would entail[52,53].

After the Frascati scientists gave the green light to Touschek's "experiment", Gatto and Touschek still had an uphill road ahead of them: AdA had to be built, but the project's feasibility was far to have been established, both in the sense of making AdA as "proof of principle" for future colliders, and in making sure that physics could be extracted and be of interest for fundamental research. Touschek and Gatto's collaboration was the building stone. Establishing the dignity and richness of the physics came from the talks and papers they gave at international conferences, the thesis work they assigned to their students and their complementary insight in the processes to study. Crucial were the talks given by Gatto and Touschek at the Geneva International Conference in June 1961[54], and the talk given by Gatto in September 1961 at the Aix-on-Provence Conference[55], when plans for moving the Frascati collider to the Laboratoire de l'Accélérateur Linéaire d'Orsay were laid out.

In the minutes of the Meeting of the Frascati Scientific Council held on February 17th, 1960[2] (ch. 10, p. 319), Touschek is recorded as having put forward the proposal for an experiment "that would be truly first order and that would be capable of attracting theorists to Frascati (not only him [Touschek] but also Gatto and certainly others) ... [and] would be an experiment intended for the study of electron positron collisions." On February 18, 1960, the very day after the meeting, Touschek started a new notebook, and wrote SR for "Storage Ring" on the cover. On the first page, after stating the experimental reactions to be studied, he wrote: "Ask Gatto...", as shown in Fig. 4. Together with the drawings on the last page, these two words indicate that Touschek considered Gatto his *alter ego* in the task of studying the physics governing the electron-positron "experiment".

And indeed, after Panofsky's seminar, discussions among theorists about electron-positron physics had taken place in Rome, and, a few days before the Frascati

[c] B. Touschek , "Ada and Adone are storage rings", Bruno Touschek Papers, Box 11, Folder 3.92.4, p. 7.

[d] *Ohne ihn ist die Physik für mich wirklich nur halb so interessant,* letter to Bruno's father on December 24th, 1958, relating Wolfgang Pauli's recent passing on December 15th.

[e] Bernardini was a member of Enrico Persico's Theory group, which had contributed to the design of the Frascati electron synchrotron, and was in the AdA team led by Touschek from the beginning.

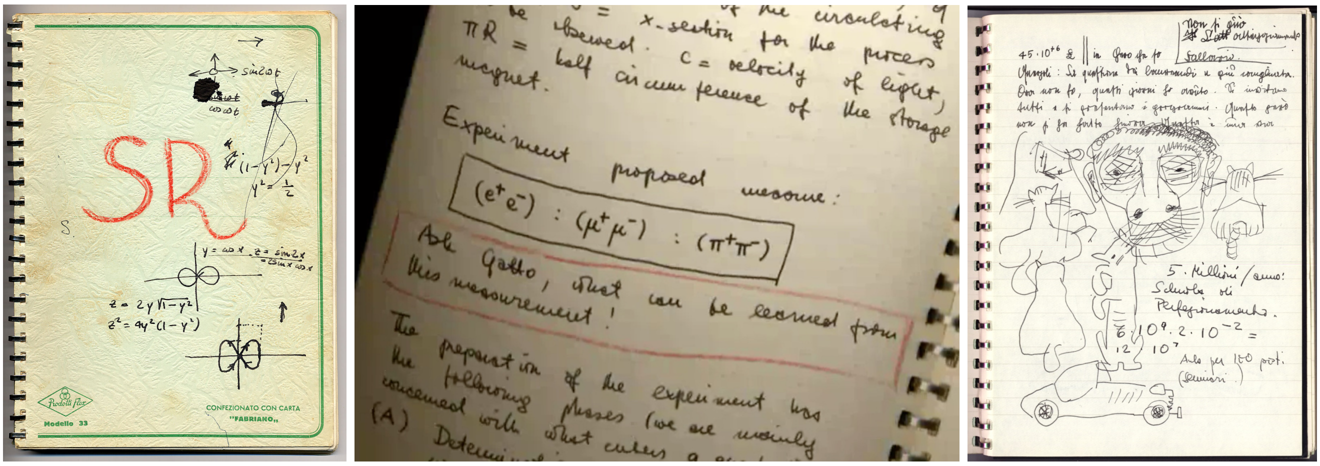


FIG. 4: Cover and two pages from AdA's *Storage Ring* Notebook, started by Bruno Touschek on February 18th, 1960. © Touschek Family, and Touschek Papers, Sapienza University of Rome, Archives of the Physics Department, all rights reserved

meeting, Gatto and Cabibbo had sent an article to the *Physical Review Letters*. They were the first to address the phenomenology of e^+e^- physics[53], and in the famous paper that became known as "The Bible" they discussed all possible experiments with high-energy colliding beams of electrons and positrons[56]. Their exploratory work not only confirmed Touschek's intuitions, but clarified that e^+e^- machines would open up a whole world of physics to be explored.

Such was the enthusiasm and determination at Frascati Laboratory that by the end of 1960, while AdA's magnet was on its way from Terni and AdA was still to be assembled, Touschek had already prepared a preliminary report for a larger collider, ADONE, and plans for its design and construction began in early 1961. Two months later the memo had become an actual proposal which included both Gatto and Touschek's name[57].

A. Moving to Orsay

One of the reasons behind the final success of the AdA experiment is that Frascati was not alone in developing Italy's pathways to high energy accelerators, as crucial roles were played through CERN, at European level, and at the Laboratoire de l'Accélérateur Linéaire d'Orsay, in France.

CERN had been officially approved in 1954, after a rather long gestation period of at least five years[58]. Its planning during this period was complemented by various national initiatives, which the result that at the end of 1959 three high energy modern type accelerators in continental Europe were ready to take data, in as many large laboratories: the Proton Synchrotron (PS) at CERN in Geneva[59] (p. 139–269), the electron LINAC in Orsay[54] and the Frascati electron synchrotron[10,60]. This almost contemporary appearance offered an international stage to European scientists, who could exchange ideas and communicate their results to a wide audience.

This is precisely what happened with AdA. After the initial excitement of observing electrons (or positrons) circulate in AdA in February 1961, gloom descended on the Frascati group which had constructed AdA, because of the feeble luminosity obtained by using the synchrotron as an injector. Prospects changed after Touschek and Gatto attended a Conference in Geneva and both gave a talk in the session about Electrodynamics experiments[61] (p. 67,75). Following Burton Richter from SLAC, who described the Stanford electron electron project, Bruno's talk on electron positron storage rings in Frascati (AdA and ADONE), and the one by Gatto, on their physics prospects, fascinated two French physicists and started spreading some enthusiasm among others, planning experiments with proton beams. Thus, while at CERN a group of enthusiasts began gathering around Kjell Johnsen, Pierre Marin from the Laboratoire de l'Accélérateur Linéaire and Georges Charpak, now at CERN, decided to go to Frascati and see with their eyes the little jewel, *un petit bijoux*, as Marin later called AdA[54]. The photon beam from the Orsay linear accelerator (the LINAC) was soon recognized as the way forward to improve AdA's luminosity and, thus, the probability to observe collisions. One year later, in July 1962, AdA was moved to the Laboratoire de l'Accélérateur Linéaire, with all its dowry and endowments, namely vacuum pumps, oscillographs, etc. The final leg of the journey towards high energy physics with electron positron colliders had began.

The move to Orsay proved to be a winner, but, once more, the final success did not come without Gatto's playing a part, namely a dissertation at the University of Rome under Gatto's supervision on the cross-section for "Single photon emission in high-energy e^+e^- collisions".

The French team in Orsay consisted of the two physicists Pierre Marin and François Lacoste, who had been enthused to join von Halban's linear collider team, and welcomed AdA in July 1962. They were supported by highly skilled technicians, some of them having come from working in the UK during the war and who had built the linear collider. When Lacoste left to pursue other interests, Jacques Haïssinski joined in. His doctoral thesis would become the main document describing in detail AdA's operation in Orsay and its success in proving the observation of electron positron collisions[62].

The Italian team consisted of Bruno Touschek, Giorgio Ghigo, Gianfranco Corazza, Carlo Bernardini, Ruggero Querzoli, his student Giuseppe Di Giugno and the technicians Giorgio Cocco, Bruno Ilio, Mario Fascetti and Angelino Vitale. At first they felt to have done the right move, but at the turn of the year, during the January 1963 run, the unexpected struck. They found that the high intensity photon beam from the Orsay LINAC would not provide the hoped for evidence for annihilation into pion pairs or even two photons. When the team was ready for reaching the high current in the doughnut which could break the threshold of sufficient luminosity, the beam life-time started to decrease. Another run confirmed the presence of a collective effect, since then known as the *Touschek effect*, namely a decrease in the beam life-time even while increasing the current in the doughnut. The effect seemed to shatter the team's hopes, although it did not affect future colliders, since it was lessening as the beam energy increased. They could have stopped there and waited for the construction of higher energy colliders. But Bruno did not give up. Once more, what he knew and had thought came to his mind, and he understood that proof of feasibility of collision did not only come from annihilation into new particles. There was a process, which had not been listed in his note book – Fig. 4 – and with a higher cross-section, for which experimental evidence could be gathered by the existing set up, namely single photon emission in elastic positron scattering. Emission of a photon in coincidence with the final e^+e^- pair is in fact proof that the initial particles have disappeared and have been recreated with emission of one or more photons. The hitch was that while an approximate calculation showed the process could be measured with the LINAC photon beam, a precise calculation had never been done. What to do? Ask Gatto once more.

There were at the time many promising physics students at the University of Rome, looking for a thesis, among them Guido Altarelli and Franco Buccella. After some initial contacts with Gatto and Bruno Touschek[2] (Ch.12, p. 377), they joined forces under Gatto's supervision and Touschek occasional crucial advice[63] and calculated the cross-section for the process, needed to confirm the experimental proof of collisions in AdA[64,65], through an ultra relativistic approximation for the final leptons, which made possible the computation of the differential cross-section in the energy and angle of the emitted photon. They graduated in November 1963 with a thesis on "Single photon emission in high-energy e^+e^- collisions".

The approximation neglecting the annihilation diagrams has the consequence of predicting an equal cross section for electron-electron and electron-positron beams: indeed, the work is cited in the book by Landau and his collaborators for the emission of photons with electron-electron beams.

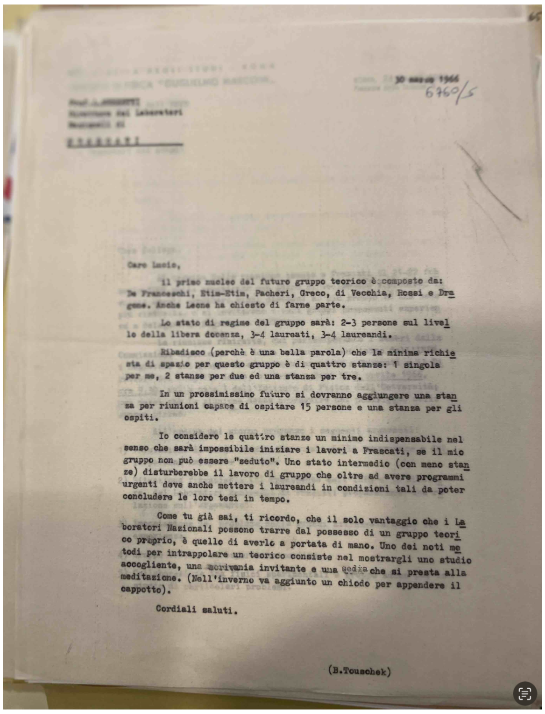
FIG. 5: Exterior of the ADONE building in 1966, © INFN-LNF, all rights reserved

VI. FORMATION OF YOUNG THEORISTS

Gatto and Touschek's influence on theoretical physics is heralded by the quality and number of the young people who graduated with them, their collaborators and the lectures in statistical mechanics, which Touschek started teaching at the University of Rome in November 1959[66–68], while his former student Nicola Cabibbo was starting work with Raoul Gatto on the physics relevance of electron positron collisions.

After an initial period at the chair of theoretical physics in Cagliari, in the academic year 1962-63 Gatto moved to the University of Florence, where young graduates and new students came together in a group which came to be know as those of the "Gattini", the kittens in English. In Florence Gatto gathered some of the most brilliant graduates from Rome, Cagliari and Florence, leaving a lasting legacy to theoretical physics. Memories of this period[69–73] highlight Gatto's legacy.

As for Touschek, after AdA's confirmation of collisions in 1964, he turned his full attention to ADONE, the new collider, whose construction had been approved by INFN in 1963. Not wanting to change his citizenship status (he was Austrian by birth) he could not become professor in Italy until 1968, when the law changed[1]. This made him turn his full attention to develop the tools needed to explore the higher energy landscape where ADONE would operate. His contributions include participation to meetings to plan for future experiments, theoretical insight about the working of the new machine[74], and mostly formation of students and young graduates from the University of Rome. Thus, in 1966, while ADONE was being



30 maggio 1966
6760/5

Direttore dei Laboratori

Caro Lucio,

il primo nucleo del futuro gruppo teorico è composto da: De Franceschi, Etim-Etim, Pacheri, Greco, di Vecchia, Rossi e Dragone. Anche Leone ha chiesto di farne parte.

Lo stato di regime del gruppo sarà: 2-3 persone sul livello della libera docenza, 3-4 laureati, 3-4 laureandi.

Ribadisco (perchè è una bella parola) che la minima richiesta di spazio per questo gruppo è di quattro stanze: 1 singola per me, 2 stanze per due ed una stanza per tre.

In un prossimissimo futuro si dovranno aggiungere una stanza per riunioni capace di ospitare 15 persone e una stanza per gli ospiti.

Io considero le quattro stanze un minimo indispensabile nel senso che sarà impossibile iniziare i lavori a Frascati, se il mio gruppo non può essere "seduto". Uno stato intermedio (con meno stanze) disturberebbe il lavoro di gruppo che oltre ad avere programmi urgenti deve anche mettere i laureandi in condizioni tali da poter concludere le loro tesi in tempo.

Come tu già sai, ti ricordo, che il solo vantaggio che i Laboratori Nazionali possono trarre dal possesso di un gruppo teorico proprio, è quello di averlo a portata di mano. Uno dei noti metodi per intrappolare un teorico consiste nel mostrargli uno studio accogliente, una scrivania invitante e una sedia che si presta alla meditazione. (Nell'inverno va aggiunto un chiodo per appendere il cappotto).

Cordiali saluti.

(B.Touschek)

FIG. 6: May 1966 letter by Touschek to Lucio Mezzetti, Frascati Laboratories director, Sapienza University of Rome, Archives of the Physics Department, all rights reserved

built across the street from the synchrotron, Fig. 5, he started a theoretical physics group in Frascati, for which he asked for positions and physical space, as in the letter seen in Fig. 6.

At this time Touschek's planning included Gian De Franceschi, who had graduated with Marcello Cini and was already in Frascati, Mario Greco, who had been supervised by Benedetto De Tollis for his 1964 thesis on new vector mesons photo production and had then been hired by Frascati in the accelerator division, Paolo Di Vecchia, Giancarlo Rossi, Francesco Drago, Etim Gabriel Etim and G.P.[75–78]. Memories and personal recollections about working with Bruno Touschek describe these years as particularly important for their formation and future work[79]. Shortly after, and for a brief period, the group also included Maria Grazia (Pucci) De Stefano, who had graduated with a thesis on the problem of scattering on singular potentials[80] under the supervision of Francesco Calogero - who had written one of the first articles about electron positron physics[52].

Among the young cohort he assembled, a remarkable expertise in QED calculation was present and with him or with his input a series of seminal papers on the problem of radiative processes emerged. Once more, Gatto's help came from the papers he kept writing to highlight the new field of electron positron physics, such as the one he presented at a meeting in Hamburg in 1964[81] on "Theoretical aspects of colliding beam experiments". In 1966, when Touschek started to prepare his treatment of soft

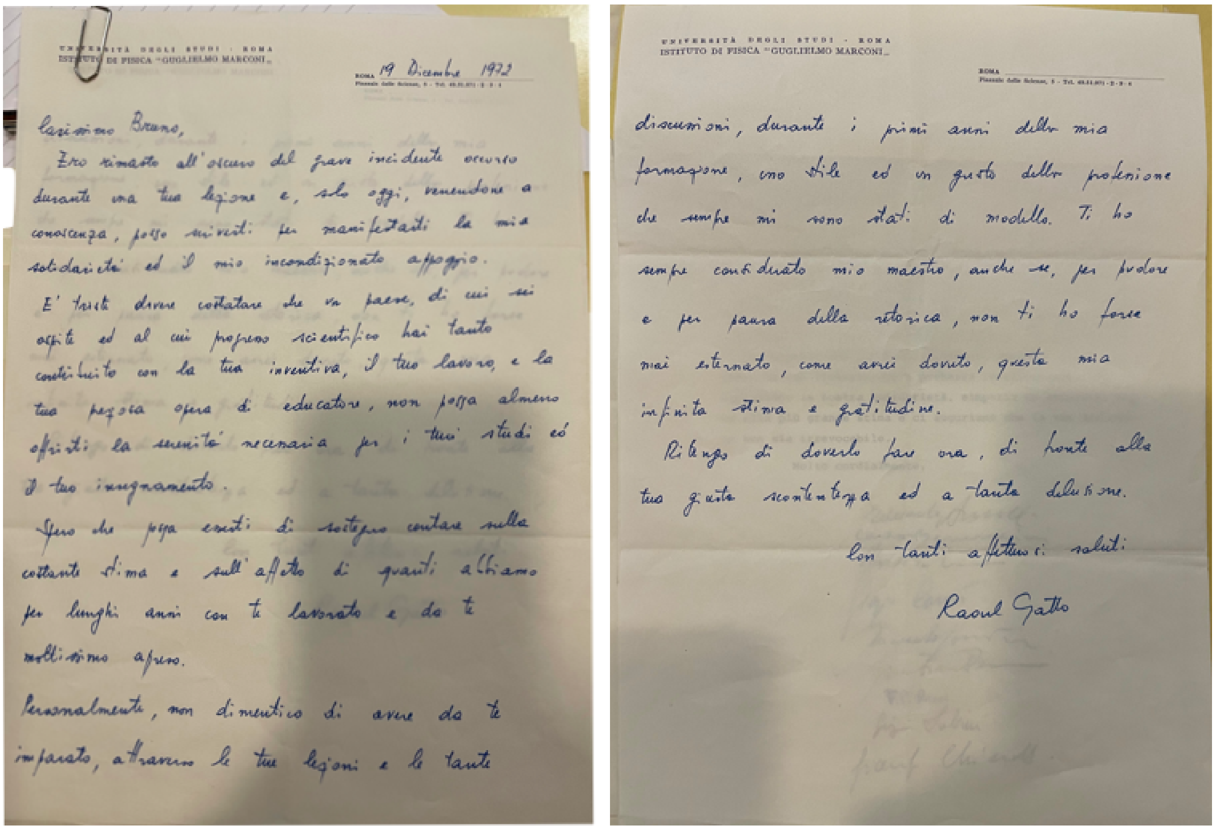
FIG. 7: Raoul Gatto, receiving blessings from Pope John Paul II, INFN-LNF images

photon resummation, Gatto's paper was among those he suggested to his two young collaborators in the work on the infrared radiative corrections to electron and positron experiments[77]. As also discussed in these Proceeding by M. Greco, Touschek's input and insistence for the need to go beyond perturbative calculations for higher and higher energy collisions led the way to further developments of resummation techniques in Quantum ElectroDynamics and later inspired analogous applications to Quantum Chromodynamics.

In the fall of 1968, two beams, of electrons and positrons, circulated in ADONE. The long road Italian physicists had started in 1953, with the approval of the construction of the Frascati National Laboratories to host an electron synchrotron, opened the world stage to the Frascati Laboratories. At the time, and for few years to come, ADONE was the electron positron collider operating at the highest energy in the world. It would soon show that a new physics threshold had been reached, sparking the interest of theorists. ADONE set the experimental stage for further discoveries culminating in the detection of the J/Ψ[82–84], which confirmed the existence of a fourth quark[85] and Touschek's vision that the quantum vacuum should be explored beyond the nucleon anti-nucleon threshold, as Heisenberg's had urged in his summary contribution to the 1953 Conference in Geneva[86].

Gatto's friendship and admiration for Bruno Touschek never wavered and he was deeply moved by Touschek's death in 1978[3]. A few year later, Gatto moved to University of Geneva, where he continued his mentoring in theoretical physics as Editor of Physics Letters B, receiving wide recognisance for his scientific life, Fig. 7.

ADONE gave green light to new physics arising from e^+e^- collisions with the unexpected discovery of the multi hadron production which immediately sparked the interest of the new generation of theorists such as Giorgio Parisi and Massimo Testa, who had graduated with


UNIVERSITÀ DEGLI STUDI - ROMA
ISTITUTO DI FISICA "GUGLIELMO MARCONI"

ROMA 19 Dicembre 1972

Carissimo Bruno,

Ero rimasto all'oscuro del grave incidente occorso durante una tua lezione e, solo oggi, venendone a conoscenza, posso scriverti per manifestarti la mia solidarietà ed il mio incondizionato appoggio.

E' triste dover constatare che un paese, di cui sei ospite ed al cui progresso scientifico hai tanto contribuito con la tua inventiva, il tuo lavoro, e la tua preziosa opera di educatore, non possa almeno offrirti la serenità necessaria per i tuoi studi ed il tuo insegnamento.

Spero che possa esserti di sostegno contare sulla costante stima e sull'affetto di quanti abbiamo per lunghi anni con te lavorato e da te moltissimo appreso.

Personalmente, non dimentico di avere da te imparato, attraverso le tue lezioni e le tante

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ROMA

discussioni, durante i primi anni della mia formazione, uno stile ed un gusto della professione che sempre mi sono stati di modello. Ti ho sempre considerato mio maestro, anche se, per pudore e per paura della retorica, non ti ho forse mai esternato, come avrei dovuto, questa mia infinita stima e gratitudine.

Ritengo di doverlo fare ora, di fronte alla tua giusta scontentezza ed a tanta delusione.

Con tanti affettuosi saluti

Raoul Gatto

FIG. 8: Raoul Gatto's letter to Bruno Touschek on 19th December 1972, *. . . I hope it can be helpful for you to know that you can count on the affection and consideration of those who worked with you and much gained . . . . . . Personally, I do not forget to have learnt from you, during the early years of my formation as a physicist, through your lectures and many conversations, a style and a sense of the our profession which have been my model to follow. I have always considered you my mentor and teacher, although my natural reserve and shyness have prevented me, in the past, to express my infinite admiration and gratefulness. I think it's right to do it now, facing your justly felt discontent and disillusionment . . .*; Sapienza University of Rome, Archives of the Physics Department, all rights reserved.

Nicola Cabibbbo[87]. In 1971 Gatto was called back to Rome and gathered a new group including Aurelio Grillo, Sergio Ferrara and Giorgio Parisi[88]. He also started to look for correlations between deep-inelastic scattering and (what he called) "deep-inelastic electron–positron annihilation", together with Giuliano Preparata[89].

A moving testimony of Gatto's feelings about Bruno Touschek appears in a December 1972 letter from Gatto to Touschek, written on the occasion of an incident occurring during the student unrest which took place in Italian universities, starting from 1968, lasting a few years. When a crude accusation of being a 'Nazi baron' was directed at Touschek by some students motivated by wanting to pass the exam for his course despite their ignorance, Touschek's decided to resign from his position at University of Rome (he was by that time "Professore aggregato"). In solidarity, and to deter him from leaving, Gatto wrote to him the letter shown in Fig. 8.

VII. CONCLUSIONS

We have presented a short overview of how Raul Gatto and Bruno Touschek together contributed to the rise of electron positron physics in the 1960s. Although they never wrote a paper together, their collaboration and mutual understanding were deep and highly productive, resulting in a lasting legacy to particle physics. Bruno Touschek passed away on May 25th, 1978, without seeing many great discoveries which gave rise to the Standard Model of Particle Physics, whose experimental confirmation came through accelerators of which AdA was prototype. Raoul Gatto passed away 39 years later in September 2017. Together, Touschek and Gatto shaped XXth century particle physics, its discoveries and theoretical formulation, in different but lasting ways, their collaboration being the building stone of a physics which they forged and explored, through their work, their students and collaborators.

Acknowledgements

We thank Yogendra Srivastava for contributions on Benedetto De Tollis. We are indebted to Alessandro Bettini for a clarification about Fig. 3 and to Adele La Rana for bringing the photo to our attention. We are grateful to Raoul Gatto and Bruno Touschek's families, and to the Archives of the Sapienza University of Rome and INFN Frascati National Laboratories for permission to reproduce photographs and documents.

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Raoul Gatto and Bruno Touschek: the Rise of e^+e^- Physics

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The story of the collaboration between Raoul Gatto and Bruno Touschek, before during and after the construction of AdA, the first electron-positron collider built at the Frascati National Laboratories in 1960, is only partially known. A brief outline is presented here to show how electron-positron physics was influenced by Gatto and Touschek's common early interest in the CPT theorem. Their legacy is also illustrated with examples of their lasting impact as mentors to their students and collaborators. Starting with the early days after Fermi's departure, we describe the various physics scenarios behind the beginning of a deep relationship between Touschek and Gatto in Rome in 1953, the years of AdA between Rome, Frascati and Orsay, up to the construction of ADONE, the more beautiful and powerful collider, where multihadron production was first discovered in 1968/69 and the existence of the charm quark was confirmed in 1974.

PACS numbers: history of physics, elementary particles, electron-positron colliders

I. INTRODUCTION

AdA, the first electron-positron collider, was born in Frascati on February 17th, 1960. On that day, the scientists of the Frascati Laboratory met to decide on the creation of a theoretical physics group in Frascati, where an electron synchrotron had been operating since the spring of the previous year. The discussion was initiated by Bruno Touschek. Having rejected both the proposal for a dedicated theory group and for a theoretical physics school, the former being insufficiently motivated and the latter unnecessary, he put forward a completely orthogonal idea: to do a new experiment, something that could attract theorists, not only from the University of Rome, but also from other Italian universities and beyond. His vision was to do something new that had never been done before: to study e^+e^- collisions with two counter-rotating beams in the same vacuum chamber. Bruno was no newcomer to the novel science of particle accelerators, an expertise stemming from wartime and early postwar experience, first in Germany and later in the United Kingdom. However, to better understand the articulated motivations and scientific background behind Touschek's bold proposal, it is essential to place it within the broader and dynamic Italian scenario of the 1950s. The developments that followed, the construction and operation of AdA, the first electron-positron collider, and its main achievements have been largely reconstructed[1,2]. A recent paper[3] has highlighted how the synergy between Touschek and Raul Gatto was instrumental in the rise of electron-positron physics and its impact on the construction and early operation of the larger ADONE collider.[a]

This paper aims to shed light on previously unexplored aspects of the collaboration between the two physicists. It will explore the differences and convergences of the collaboration, as well as sketch out the backstage on which they appeared in the physics community and how their legacies were created and continued.

II. FERMI'S LEGACY AND THE ROLE OF BRUNO FERRETTI

Bruno Touschek and Raoul Gatto owed their contemporary presence in Rome in the early 1950s to Bruno Ferretti, who had been Fermi's assistant in the last days of the "Via Panisperna group". Ferretti somehow represented the continuity with modern theoretical physics that had been initiated in Rome in the 1930s by Fermi and other younger theorists such as Giovanni Gentile Jr, Ettore Majorana, Ugo Fano and Gian Carlo Wick, who had rotated around Fermi at different times.

A graduate of the University of Bologna, Ferretti joined the cosmic ray group founded by Fermi in 1937, shortly before Fermi left Italy for the United States. Ferretti was influenced by Gian Carlo Wick, Fermi's successor in the chair of theoretical physics, and Gilberto

[a] For full bibliographic references to the narrated events, see L. Bonolis, F. Buccella and G. Pancheri in EPJH 2004[3].

FIG. 1: Bruno Ferretti in the last row behind Rudolf Peierls and Homi Bhabha, at the 8th Solvay Conference on Elementary Particles, 1948. Wikimedia

Bernardini, with whom he worked on theoretical problems related to subnuclear physics with cosmic rays. These were attracting general attention after the discovery in 1936 of the "mesotron", a new - and unstable - particle whose nature and identity would remain unknown until its rebirth as the "muon" in 1947[4]. During the war and in the early post-war years, the study of cosmic rays ensured the survival of the physics community in Rome and other centers in Italy.

Beginning in 1948, Ferretti began teaching theoretical physics at University of Rome in the chair left by Fermi and his successor Wick, who had left taking a position in the United States. Ferretti, seen in Fig. 1 together with other eminent theoretical physicists whose work played an important role in Touschek's scientific development, assisted Edoardo Amaldi in carrying on Fermi's legacy in Rome. They were joined by Gilberto Bernardini, an expert in nuclear physics and cosmic rays, whose post-war experience in particle physics at accelerators in the United States would later be instrumental in future plans to revive Fermi's prewar dreams of a modern competitive laboratory equipped with a high-energy accelerator[5]. As Amaldi recalled, Ferretti helped to strengthen the group of young theoretical physicists that included Bruno Zumino, Giacomo Morpurgo, Raul Gatto, Elio Fabri, Benedetto De Tollis and Carlo Bernardini[1] (p. 13), in addition to the young experimentalist Marcello Conversi, Fig. 2. In various ways, the new generation and its students ensured the continuity of the new era inaugurated by the fathers of modern physics in Italy, and would in turn ensure the full revival of Italian physics in the post-war period.

Towards 1947, during a stay in the UK, Ferretti collaborated with Rudolf Peierls (Radiation Damping Theory and the Propagation of Light[6]), who was later to be external examiner for Bruno Touschek's doctoral thesis in Glasgow[7]. Ferretti was also Edoardo Amaldi's closest collaborator on the international scene, particularly in promoting the birth of CERN.

After receiving his Doctorate from the University of Glasgow in November 1949, Bruno Touschek became Nuffield Lecturer, giving a contribution on weak interactions to Max Born's *Atomic Physics* book, and collaborating with Walter Thirring[8] on a problem related to Ferretti's radiation damping paper with Peierls. The mutual interest in the emerging field of Quantum Field Theory, which tied Touschek with Ferretti, gave probably rise to a plan for Touschek's sabbatical year in Italy. In September 1952 Touschek visited Ferretti in Rome. After a few hours spent discussing scientific issues of mutual interest, "they established such a marked professional respect and personal attachment for each other that Touschek decided to remain permanently in Rome"[1] (p. 13). Touschek, seen with Edoardo Amaldi in Fig. 2, moved to Rome at the end of 1952, and this was made possible because he was given a contract as a researcher thanks to Amaldi, who was director of the Rome Section of the newly established National Institute of Nuclear Physics, INFN.

When Touschek arrived in Rome in December 1952, Raul Gatto, Fig. 2, had just become Ferretti's assistant after graduating from the University of Pisa under the supervision of Marcello Conversi, then a professor of Experimental Physics in Pisa, and with Ferretti as external advisor in theoretical physics. The intellectual interaction established between Touschek and Gatto is evidenced by his later writings about Touschek[3], by the letter reproduced at the end of this paper and by the fact that Gatto acknowledged discussions with Touschek in his early articles on nuclear and subnuclear physics based on the cosmic ray research of Amaldi's group in Rome. In this sense he was following Ferretti's example, but at the same time, he was moving towards current problems in theoretical particle physics. He found a mentor in Bruno Touschek, who was ten years older and added a unique experience in subnuclear physics with accelerators to a deep mathematical and theoretical physics knowledge, developed during his years in Germany and the United Kingdom. This unique expertise, gained from such mentors as Arnold Sommerfeld, Werner Heisenberg, Max Von Laue, Max Born, and Rolf Widerøe[1,9], was highly valued in Italy, where INFN was being established, including ambitious plans to build a powerful accelerator and a national laboratory to house it[10]. While waiting for this facility to be-

FIG. 2: From left: Marcello Conversi in 1961, Edoardo Amaldi with Bruno Touschek in 1953, soon after Bruno's arrival in Rome, and young Raoul Gatto, family photos

come operational, the traditional work with cosmic rays continued in all the Italian centers, with the support of theoreticians[11–13].

III. NEW CHALLENGES FOR THEORETICAL PHYSICS

In the early 1950s, when Touschek and Gatto began their new scientific life in the exciting context of the reconstruction of Italian physics and its revival on a completely new basis, they became involved in the new, enigmatic physics of strange particles and the emergence of the $\theta - \tau$ puzzle, where data were still being derived from both cosmic ray and accelerator physics. But inexorably, the accelerators took over and particle physics moved beyond free beams of high-energy particles from the sky, while the theorists began to face new, unprecedented challenges. Touschek found a very congenial atmosphere in the Physics Institute at Sapienza University of Rome. He immediately started collaborating with visiting scientists, such as Matthew Sands, or Giacomo Morpurgo and Luigi Radicati di Brozolo. The latter, considered Touschek one of the persons who had the greatest influence on his scientific life[14] (p. 67).

Radicati, who had graduated in 1943, with Enrico Persico in Turin, had discussed the time reversal problem with Peierls in UK, but they did not continue to work on that until, once in Italy, he resumed these topics with Touschek and Morpurgo[15–17]. Morpurgo had met Touschek at the end of August 1953, in the almost empty physics Institute, and, in less than one hour[14] (p. 80), a collaboration had started on a topic of common interest, concerning strong interactions through non-perturbative methods. By January 1954, their interests had shifted to the study of space-time symmetry properties, in particular time reversal. According to Morpurgo, the interest in time reversal had been sparked by Touschek, who had read a paper by Lüders[18] and may also have discussed the subject with Radicati, who was in Rome at the time. Meanwhile Touschek was also involved in work on K mesons with several experimentalists. In April 1954 he attended the Padua Conference on *Unstable Heavy Particles and High-Energy Events in Cosmic Rays* [Particelle Instabili Pesanti e Sugli Eventi di Alta Energia nei Raggi Cosmici], Fig. 3, where he contributed two papers[19,20].

Both out of genuine interest in a puzzling problem, and his commitment to give advice to the experimentalists, he followed ongoing experimental work on cosmic ray searches for anti-protons and strange particle decays, and his commitment culminated in August 1958 when he organized and directed the Fermi International Summer School on Pion Physics, held in Varenna.

During these early years, Gatto was also involved in particle physics problems, of current interest worldwide and in Rome in particular[12,22]. In 1956 Gatto won a Fulbright fellowship and went to the United States, first to Columbia and then for a longer period to Berkeley, where the powerful Bevatron was operating. During this time, Gatto wrote several articles discussing the decays of K mesons and hyperons[23–25] within the strangeness scheme proposed independently by Gell-Mann and Nishijima[26,27]. Related experiments at Berkeley were followed by the first observation of the antiproton[28] and later of the antineutron[29], which consolidated the question of antimatter and strengthened the proof of its existence, almost twenty years after the discovery of the positron. In fact, an event interpreted as a proton-antiproton annihilation had been observed by the cosmic ray group in Rome[30], and it was the subject of an article written by Gatto before he left for Berkeley[31].

In the same 1956, Touschek travelled with Amaldi to

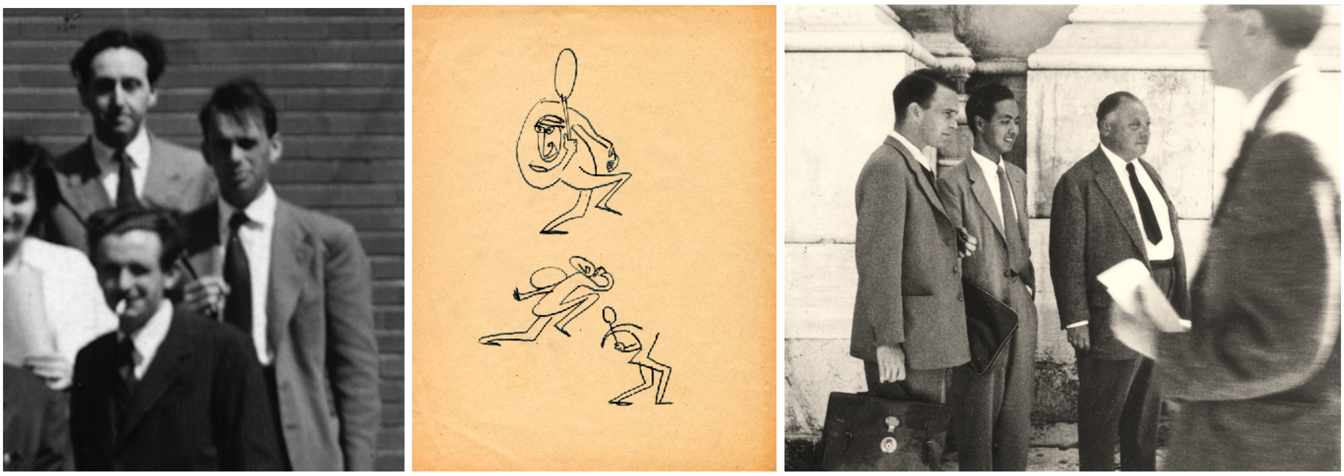

FIG. 3: Bruno Touschek in Padua: at left in April 1954 at the *Conference on Unstable Heavy Particles and High-Energy Events in Cosmic Rays*[21], and, at right, in September 1957 with T.D. Lee, Wolfgang Pauli and Robert Marshak at the *Padua-Venice Conference on Mesons and Recently Discovered Particles* organized by the Italian Physical Society, courtesy of M. Baldo Ceolin. At the center, a contemporary drawing by Bruno Touschek[1] (p.15), © Touschek's family

New York and attended the Rochester Conference, where anti-nucleons were discussed and the idea of parity non-conservation in weak processes was aired by Richard Feynman during the theoretical physics session chaired by C.N. Yang. Soon after, Lee and Yang reviewed the experimental evidence in detail and suggested experiments that could settle the problem[32].

As high-energy nuclear physics evolved into particle physics, and accelerators – together with new kind of detectors – gradually replaced cosmic rays as the main source of high-energy particles, both Touschek and Gatto continued to work on the new puzzling phenomenology derived by experiments and on the classification of the new particles, which also raised the need to know more about symmetries and conservation laws.

Topics such as the annihilation process, time reversal, charge conjugation invariance, the $\theta - \tau$ puzzle and parity non conservation, and more generally the weak hyperon decay interactions under P, C, and T were studied by Gatto in articles between 1956-1958[33,34], and a close look at Touschek's articles from the same period reveals a remarkable similarity between the two in terms of the underlying fundamental themes and issues addressed.

IV. SETTING THE STAGE FOR THE ADA PROPOSAL: THE INSPIRING ROLE OF THE CPT THEOREM

As mentioned above, Touschek's attention had long been drawn to various aspects related to fundamental symmetries, also stimulated by German theorists such as Pauli and Gerhardt Lüders. Beginning in 1953, Touschek discussed with Pauli questions related to time reversal, whose correct formulation in relativistic Quantum Field Theory was actually related to the roots of the CPT theorem (Blum et al. 2022). He wrote more than one paper on this subject[15,35] and discussed with Morpurgo the extension of the procedure to Parity and Charge Conjugation[16]. In 1957/1958, as evidenced by his personal papers, Touschek exchanged several letters with Lüders, Pauli and Zumino discussing topics related to symmetry properties of physical theories.[b]

For his part, Gatto mentions how he became aware of the CPT theorem[36–39] through Bruno Zumino and Gerhard Lüders. Zumino had also graduated with Ferretti, but soon left for the United States, occasionally returning to Rome.

In a later paper by Zumino with Gerhart Lüders entitled "Some Consequences of TCP-Invariance", a direct reference is made to Zumino's having suggested in early 1953 the original formulation[40].

The CPT theorem, deeply connected with the physics of the weak interactions, acquired a central importance after the experimental discovery of parity violation in 1957[41–43]. Here we would only like to emphasize how the theorem and its implications formed the backbone of Touschek's thought from which the idea of studying particle-antiparticle annihilations as a channel to new physics emerged. A clue to how things intermingled in his mind is provided by a letter that he wrote to Pauli on January 31, 1957. In the last lines, after discussing Lee and Yang's work, Abdus Salam's recent article on the neutrino, and the problem of K-decay, Touschek wrote: "I have been trying for about a week to figure out whether invariance under CP (and not under P) means that one

[b] See the correspondence folders in Box 1 of Bruno Touschek Archives in Sapienza University of Rome, Archives of the Physics Department.

can distinguish between particles and antiparticles [...]".

After the actual detection of the neutrino as a particle in 1956 and the explosion of interest surrounding the problem of parity violation, he focused on such relevant discoveries in the framework of the weak interactions. Alongside with a renewed interest in the symmetry properties of Fermi-Dirac fields[44,45], Touschek wrote several articles discussing a massless two-component neutrino. He was the first to introduce the concept of chiral symmetry as a consequence of parity violation[46] and in 1958 had begun a work with Pauli which was published only after Pauli's death[47]. Interestingly, in that same period, Gatto wrote an article with Lüders on "Invariants in Muon Decay" based on the assumption of a vanishing neutrino mass[48], which again shows how strong was their intellectual and scientific interaction during the 1950s. On the wave of parity violation, Touschek assigned three joint dissertations on weak interactions to Paolo Guidoni, Nicola Cabibbo, and Francesco Calogero.

At the end of the 1950s, after wandering between the puzzles in new elementary particles, and working in the "most abstract field of theoretical research [...] the discussion of symmetries", Touschek wanted to get his feet "out of the clouds and onto the ground again" and get back to what he thought "[he] really understood: elementary physics".[c] Bruno Touschek was also coming to terms with Pauli's death in December 1958, an event which prompted him to write that "Without him [Pauli], physics is really only half as interesting for me".[d]

In Touschek's mind CPT represented the central argument in his proposal of electron-positron annihilations as an alternative to the electron-electron collisions planned in the Princeton-Stanford project, presented by Pief Panofski at ICHEP 1959, in Kiev, and during a seminar in Frascati in October of that year[2] (p.310). Gatto recalled how, after the seminar, "Bruno kept insisting on CPT invariance, which would grant the same orbit for electrons and positrons inside the ring". Nicola Cabibbo, who had recently graduated with Touschek with a thesis on "Pauli invariants in the decay of the μ meson" also testified: "Bruno Touschek came up with the remark that an e^+e^- machine could be realized in a single ring, because of the CTP theorem"[49].

These and similar remarks by Gatto and Rubbia in 1987[14] – after so many years – highlight Touschek's firm belief in CPT as the tool that guaranteed the soundness of his proposal for a collider in which electron and positron beams would meet and annihilate. *Something that was not taken for granted at the time* as Carlo Bernardini always pointed out.[e]

V. EXPERIMENTAL AND THEORETICAL CHALLENGES: ADA IN FRASCATI AND ORSAY, 1960-1964

The making of AdA unfolded[2] (Ch. 10) between October 26th, 1959 – date of Panofsky's seminar in Frascati – and March 7th, 1960, when the Frascati Laboratory Council approved Touschek's detailed proposal for a electron-positron storage ring[50,51]. In between, there is the crucial meeting of February 1960, when Touschek – pressed to form a theoretical physics group in Frascati – proposed to make an experiment on electron positron collisions, in parallel with the submission of two articles by Rome theoretical physicists about the interest such experiments would entail[52,53].

After the Frascati scientists gave the green light to Touschek's "experiment", Gatto and Touschek still had an uphill road ahead of them: AdA had to be built, but the project's feasibility was far to have been established, both in the sense of making AdA as "proof of principle" for future colliders, and in making sure that physics could be extracted and be of interest for fundamental research. Touschek and Gatto's collaboration was the building stone. Establishing the dignity and richness of the physics came from the talks and papers they gave at international conferences, the thesis work they assigned to their students and their complementary insight in the processes to study. Crucial were the talks given by Gatto and Touschek at the Geneva International Conference in June 1961[54], and the talk given by Gatto in September 1961 at the Aix-on-Provence Conference[55], when plans for moving the Frascati collider to the Laboratoire de l'Accélérateur Linéaire d'Orsay were laid out.

In the minutes of the Meeting of the Frascati Scientific Council held on February 17th, 1960[2] (ch. 10, p. 319), Touschek is recorded as having put forward the proposal for an experiment "that would be truly first order and that would be capable of attracting theorists to Frascati (not only him [Touschek] but also Gatto and certainly others) ... [and] would be an experiment intended for the study of electron positron collisions." On February 18, 1960, the very day after the meeting, Touschek started a new notebook, and wrote SR for "Storage Ring" on the cover. On the first page, after stating the experimental reactions to be studied, he wrote: "Ask Gatto...", as shown in Fig. 4. Together with the drawings on the last page, these two words indicate that Touschek considered Gatto his *alter ego* in the task of studying the physics governing the electron-positron "experiment".

And indeed, after Panofsky's seminar, discussions among theorists about electron-positron physics had taken place in Rome, and, a few days before the Frascati

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[c] B. Touschek , "Ada and Adone are storage rings", Bruno Touschek Papers, Box 11, Folder 3.92.4, p. 7.

[d] *Ohne ihn ist die Physik für mich wirklich nur halb so interessant,* letter to Bruno's father on December 24th, 1958, relating Wolfgang Pauli's recent passing on December 15th.

[e] Bernardini was a member of Enrico Persico's Theory group, which had contributed to the design of the Frascati electron synchrotron, and was in the AdA team led by Touschek from the beginning.

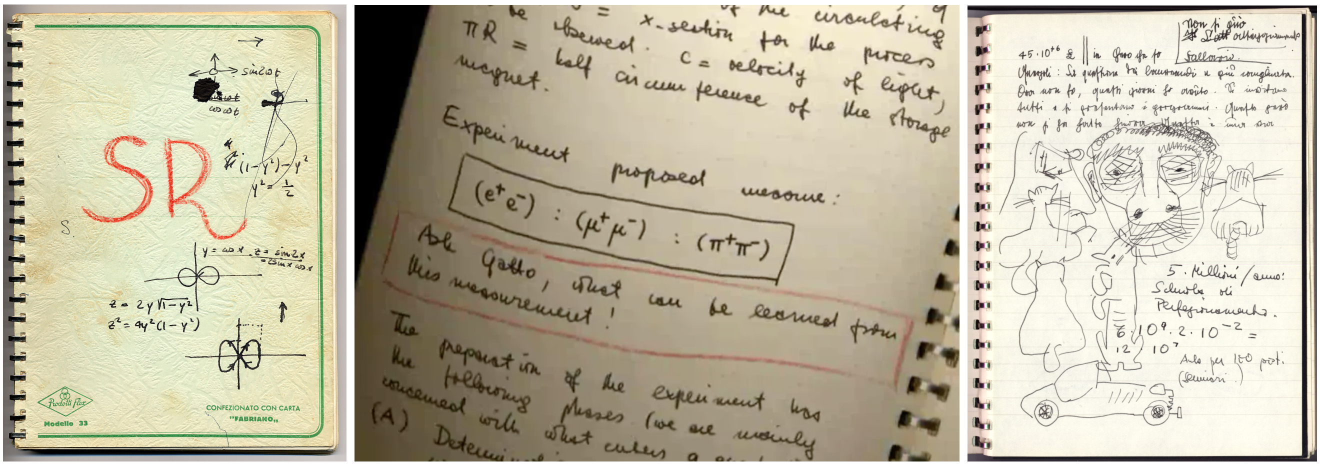


FIG. 4: Cover and two pages from AdA's *Storage Ring* Notebook, started by Bruno Touschek on February 18th, 1960. © Touschek Family, and Touschek Papers, Sapienza University of Rome, Archives of the Physics Department, all rights reserved

meeting, Gatto and Cabibbo had sent an article to the *Physical Review Letters*. They were the first to address the phenomenology of e^+e^- physics[53], and in the famous paper that became known as "The Bible" they discussed all possible experiments with high-energy colliding beams of electrons and positrons[56]. Their exploratory work not only confirmed Touschek's intuitions, but clarified that e^+e^- machines would open up a whole world of physics to be explored.

Such was the enthusiasm and determination at Frascati Laboratory that by the end of 1960, while AdA's magnet was on its way from Terni and AdA was still to be assembled, Touschek had already prepared a preliminary report for a larger collider, ADONE, and plans for its design and construction began in early 1961. Two months later the memo had become an actual proposal which included both Gatto and Touschek's name[57].

A. Moving to Orsay

One of the reasons behind the final success of the AdA experiment is that Frascati was not alone in developing Italy's pathways to high energy accelerators, as crucial roles were played through CERN, at European level, and at the Laboratoire de l'Accélérateur Linéaire d'Orsay, in France.

CERN had been officially approved in 1954, after a rather long gestation period of at least five years[58]. Its planning during this period was complemented by various national initiatives, which the result that at the end of 1959 three high energy modern type accelerators in continental Europe were ready to take data, in as many large laboratories: the Proton Synchrotron (PS) at CERN in Geneva[59] (p. 139–269), the electron LINAC in Orsay[54] and the Frascati electron synchrotron[10,60]. This almost contemporary appearance offered an international stage to European scientists, who could exchange ideas and communicate their results to a wide audience.

This is precisely what happened with AdA. After the initial excitement of observing electrons (or positrons) circulate in AdA in February 1961, gloom descended on the Frascati group which had constructed AdA, because of the feeble luminosity obtained by using the synchrotron as an injector. Prospects changed after Touschek and Gatto attended a Conference in Geneva and both gave a talk in the session about Electrodynamics experiments[61] (p. 67,75). Following Burton Richter from SLAC, who described the Stanford electron electron project, Bruno's talk on electron positron storage rings in Frascati (AdA and ADONE), and the one by Gatto, on their physics prospects, fascinated two French physicists and started spreading some enthusiasm among others, planning experiments with proton beams. Thus, while at CERN a group of enthusiasts began gathering around Kjell Johnsen, Pierre Marin from the Laboratoire de l'Accélérateur Linéaire and Georges Charpak, now at CERN, decided to go to Frascati and see with their eyes the little jewel, *un petit bijoux*, as Marin later called AdA[54]. The photon beam from the Orsay linear accelerator (the LINAC) was soon recognized as the way forward to improve AdA's luminosity and, thus, the probability to observe collisions. One year later, in July 1962, AdA was moved to the Laboratoire de l'Accélérateur Linéaire, with all its dowry and endowments, namely vacuum pumps, oscillographs, etc. The final leg of the journey towards high energy physics with electron positron colliders had began.

The move to Orsay proved to be a winner, but, once more, the final success did not come without Gatto's playing a part, namely a dissertation at the University of Rome under Gatto's supervision on the cross-section for "Single photon emission in high-energy e^+e^- collisions".

The French team in Orsay consisted of the two physicists Pierre Marin and François Lacoste, who had been enthused to join von Halban's linear collider team, and welcomed AdA in July 1962. They were supported by highly skilled technicians, some of them having come from working in the UK during the war and who had built the linear collider. When Lacoste left to pursue other interests, Jacques Haïssinski joined in. His doctoral thesis would become the main document describing in detail AdA's operation in Orsay and its success in proving the observation of electron positron collisions[62].

The Italian team consisted of Bruno Touschek, Giorgio Ghigo, Gianfranco Corazza, Carlo Bernardini, Ruggero Querzoli, his student Giuseppe Di Giugno and the technicians Giorgio Cocco, Bruno Ilio, Mario Fascetti and Angelino Vitale. At first they felt to have done the right move, but at the turn of the year, during the January 1963 run, the unexpected struck. They found that the high intensity photon beam from the Orsay LINAC would not provide the hoped for evidence for annihilation into pion pairs or even two photons. When the team was ready for reaching the high current in the doughnut which could break the threshold of sufficient luminosity, the beam life-time started to decrease. Another run confirmed the presence of a collective effect, since then known as the *Touschek effect*, namely a decrease in the beam life-time even while increasing the current in the doughnut. The effect seemed to shatter the team's hopes, although it did not affect future colliders, since it was lessening as the beam energy increased. They could have stopped there and waited for the construction of higher energy colliders. But Bruno did not give up. Once more, what he knew and had thought came to his mind, and he understood that proof of feasibility of collision did not only come from annihilation into new particles. There was a process, which had not been listed in his note book – Fig. 4 – and with a higher cross-section, for which experimental evidence could be gathered by the existing set up, namely single photon emission in elastic electron positron scattering. Emission of a photon in coincidence with the final e^+e^- pair is in fact proof that the initial particles have disappeared and have been recreated with emission of one or more photons. The hitch was that while an approximate calculation showed the process could be measured with the LINAC photon beam, a precise calculation had never been done. What to do? Ask Gatto once more.

There were at the time many promising physics students at the University of Rome, looking for a thesis, among them Guido Altarelli and Franco Buccella. After some initial contacts with Gatto and Bruno Touschek[2] (Ch.12, p. 377), they joined forces under Gatto's supervision and Touschek occasional crucial advice[63] and calculated the cross-section for the process, needed to confirm the experimental proof of collisions in AdA[64,65], through an ultra relativistic approximation for the final leptons, which made possible the computation of the differential cross-section in the energy and angle of the emitted photon. They graduated in November 1963 with a thesis on "Single photon emission in high-energy e^+e^- collisions".

The approximation neglecting the annihilation diagrams has the consequence of predicting an equal cross section for electron-electron and electron-positron beams: indeed, the work is cited in the book by Landau and his collaborators for the emission of photons with electron-electron beams.

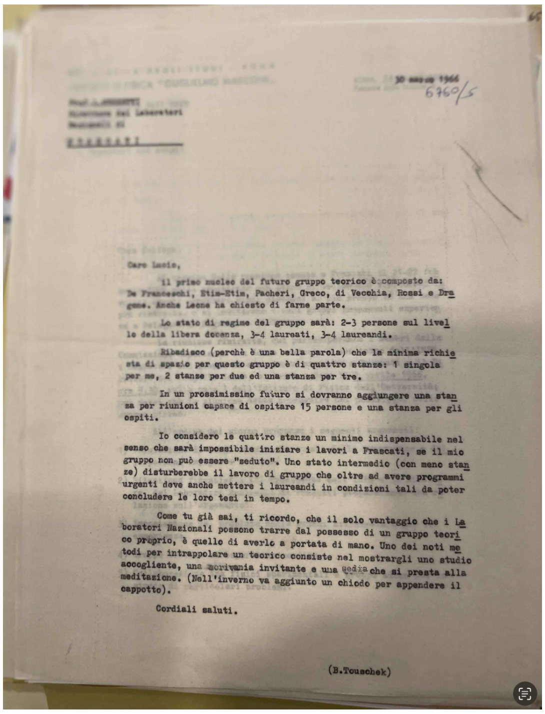
FIG. 5: Exterior of the ADONE building in 1966, © INFN-LNF, all rights reserved

VI. FORMATION OF YOUNG THEORISTS

Gatto and Touschek's influence on theoretical physics is heralded by the quality and number of the young people who graduated with them, their collaborators and the lectures in statistical mechanics, which Touschek started teaching at the University of Rome in November 1959[66–68], while his former student Nicola Cabibbo was starting work with Raoul Gatto on the physics relevance of electron positron collisions.

After an initial period at the chair of theoretical physics in Cagliari, in the academic year 1962-63 Gatto moved to the University of Florence, where young graduates and new students came together in a group which came to be know as those of the "Gattini", the kittens in English. In Florence Gatto gathered some of the most brilliant graduates from Rome, Cagliari and Florence, leaving a lasting legacy to theoretical physics. Memories of this period[69–73] highlight Gatto's legacy.

As for Touschek, after AdA's confirmation of collisions in 1964, he turned his full attention to ADONE, the new collider, whose construction had been approved by INFN in 1963. Not wanting to change his citizenship status (he was Austrian by birth) he could not become professor in Italy until 1968, when the law changed[1]. This made him turn his full attention to develop the tools needed to explore the higher energy landscape where ADONE would operate. His contributions include participation to meetings to plan for future experiments, theoretical insight about the working of the new machine[74], and mostly formation of students and young graduates from the University of Rome. Thus, in 1966, while ADONE was being



30 maggio 1966
6760/5

Direttore dei Laboratori

Caro Lucio,

il primo nucleo del futuro gruppo teorico è composto da: De Franceschi, Etim-Etim, Pacheri, Greco, di Vecchia, Rossi e Dragone. Anche Leone ha chiesto di farne parte.

Lo stato di regime del gruppo sarà: 2-3 persone sul livello della libera docenza, 3-4 laureati, 3-4 laureandi.

Ribadisco (perchè è una bella parola) che la minima richiesta di spazio per questo gruppo è di quattro stanze: 1 singola per me, 2 stanze per due ed una stanza per tre.

In un prossimissimo futuro si dovranno aggiungere una stanza per riunioni capace di ospitare 15 persone e una stanza per gli ospiti.

Io considero le quattro stanze un minimo indispensabile nel senso che sarà impossibile iniziare i lavori a Frascati, se il mio gruppo non può essere "seduto". Uno stato intermedio (con meno stanze) disturberebbe il lavoro di gruppo che oltre ad avere programmi urgenti deve anche mettere i laureandi in condizioni tali da poter concludere le loro tesi in tempo.

Come tu già sai, ti ricordo, che il solo vantaggio che i Laboratori Nazionali possono trarre dal possesso di un gruppo teorico proprio, è quello di averlo a portata di mano. Uno dei noti metodi per intrappolare un teorico consiste nel mostrargli uno studio accogliente, una scrivania invitante e una sedia che si presta alla meditazione. (Nell'inverno va aggiunto un chiodo per appendere il cappotto).

Cordiali saluti.

(B.Touschek)

FIG. 6: May 1966 letter by Touschek to Lucio Mezzetti, Frascati Laboratories director, Sapienza University of Rome, Archives of the Physics Department, all rights reserved

built across the street from the synchrotron, Fig. 5, he started a theoretical physics group in Frascati, for which he asked for positions and physical space, as in the letter seen in Fig. 6.

At this time Touschek's planning included Giovanni, nicknamed *Gian*, De Franceschi, who had graduated with Marcello Cini and was already in Frascati, Mario Greco, who had been supervised by Benedetto De Tollis for his 1964 thesis on new vector mesons photo production and had then been hired by Frascati in the accelerator division, Paolo Di Vecchia, Giancarlo Rossi, Francesco Drago, Etim Gabriel Etim and G.P.[75–78]. Memories and personal recollections about working with Bruno Touschek describe these years as particularly important for their formation and future work[79]. Shortly after, and for a brief period, the group also included Maria Grazia (Pucci) De Stefano, who had graduated with a thesis on the problem of scattering on singular potentials[80] under the supervision of Francesco Calogero - who had written one of the first articles about electron positron physics[52].

Among the young cohort he assembled, a remarkable expertise in QED calculation was present and with him or with his input a series of seminal papers on the problem of radiative processes emerged. Once more, Gatto's help came from the papers he kept writing to highlight the new field of electron positron physics, such as the one he presented at a meeting in Hamburg in 1964[81] on "Theoretical aspects of colliding beam experiments". In 1966, when Touschek started to prepare his treatment of soft

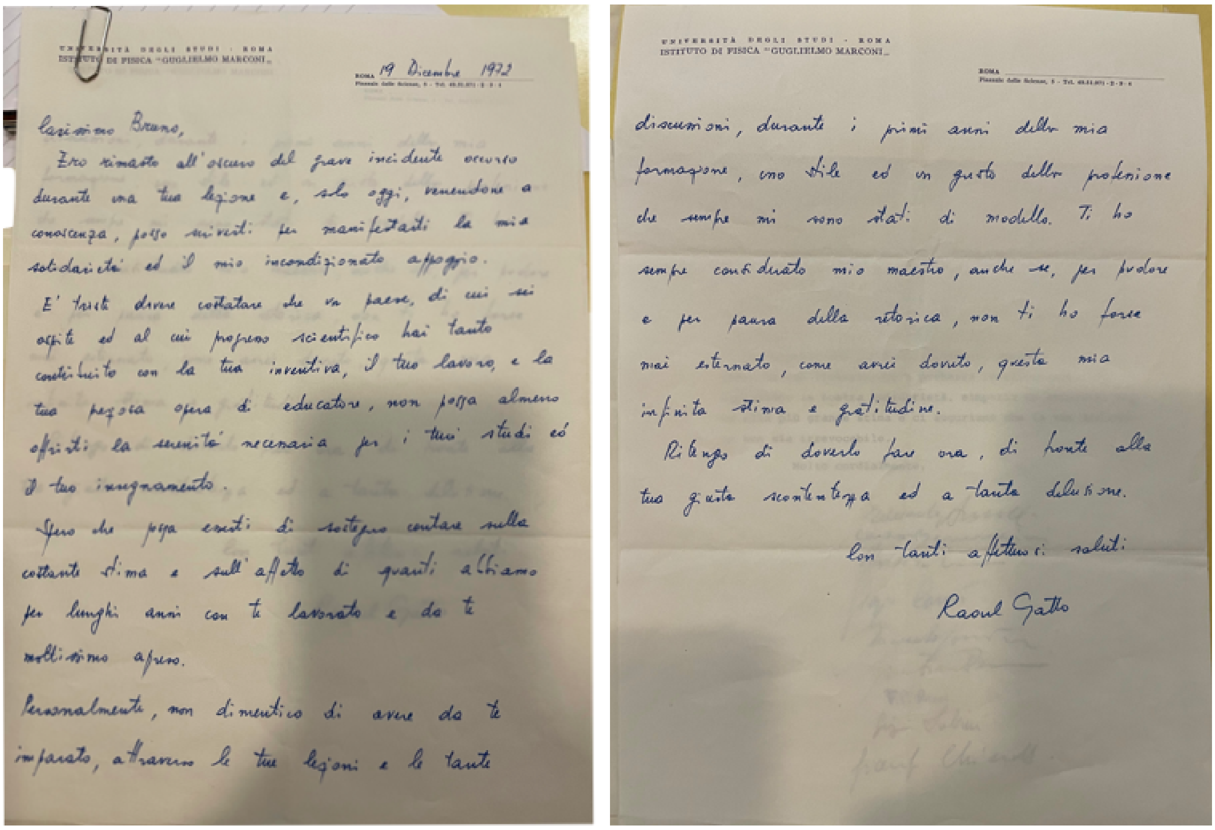
FIG. 7: Raoul Gatto, receiving blessings from Pope John Paul II, INFN-LNF images

photon resummation, Gatto's paper was among those he suggested to his two young collaborators in the work on the infrared radiative corrections to electron and positron experiments[77]. As also discussed in these Proceeding by M. Greco, Touschek's input and insistence for the need to go beyond perturbative calculations for higher and higher energy collisions led the way to further developments of resummation techniques in Quantum ElectroDynamics and later inspired analogous applications to Quantum Chromodynamics.

In the fall of 1968, two beams, of electrons and positrons, circulated in ADONE. The long road Italian physicists had started in 1953, with the approval of the construction of the Frascati National Laboratories to host an electron synchrotron, opened the world stage to the Frascati Laboratories. At the time, and for few years to come, ADONE was the electron positron collider operating at the highest energy in the world. It would soon show that a new physics threshold had been reached, sparking the interest of theorists. ADONE set the experimental stage for further discoveries[82] culminating in the detection of the J/Ψ[83–85], which confirmed the existence of a fourth quark[86–88] and Touschek's vision that the quantum vacuum should be explored beyond the nucleon anti-nucleon threshold, as Heisenberg's had urged in his summary contribution to the 1953 Conference in Geneva[89].

Gatto's friendship and admiration for Bruno Touschek never wavered and he was deeply moved by Touschek's death in 1978[3]. A few year later, Gatto moved to University of Geneva, where he continued his mentoring in theoretical physics as Editor of Physics Letters B, receiving wide recognisance for his scientific life, Fig. 7.

ADONE gave green light to new physics arising from e^+e^- collisions with the unexpected discovery of the multi hadron production which immediately sparked the interest of the new generation of theorists such as Giorgio Parisi and Massimo Testa, who had graduated with


UNIVERSITÀ DEGLI STUDI - ROMA
ISTITUTO DI FISICA "GUGLIELMO MARCONI"

ROMA 19 Dicembre 1972

Carissimo Bruno,

Ero rimasto all'oscuro del grave incidente occorso durante una tua lezione e, solo oggi, venendone a conoscenza, posso scriverti per manifestarti la mia solidarietà ed il mio incondizionato appoggio.

E' triste dover constatare che un paese, di cui sei ospite ed al cui progresso scientifico hai tanto contribuito con la tua inventiva, il tuo lavoro, e la tua preziosa opera di educatore, non possa almeno offrirti la serenità necessaria per i tuoi studi ed il tuo insegnamento.

Spero che possa esserti di sostegno contare sulla costante stima e sull'affetto di quanti abbiamo per lunghi anni con te lavorato e da te moltissimo appreso.

Personalmente, non dimentico di avere da te imparato, attraverso le tue lezioni e le tante

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discussioni, durante i primi anni della mia formazione, uno stile ed un gusto della professione che sempre mi sono stati di modello. Ti ho sempre considerato mio maestro, anche se, per pudore e per paura della retorica, non ti ho forse mai esternato, come avrei dovuto, questa mia infinita stima e gratitudine.

Ritengo di doverlo fare ora, di fronte alla tua giusta scontentezza ed a tanta delusione.

Con tanti affettuosi saluti

Raoul Gatto

FIG. 8: Raoul Gatto's letter to Bruno Touschek on 19th December 1972, *. . . I hope it can be helpful for you to know that you can count on the affection and consideration of those who worked with you and much gained . . . . . . Personally, I do not forget to have learnt from you, during the early years of my formation as a physicist, through your lectures and many conversations, a style and a sense of our profession which have been my model to follow. I have always considered you my mentor and teacher, although my natural reserve and shyness have prevented me, in the past, to express my infinite admiration and gratefulness. I think it's right to do it now, facing your justly felt discontent and disillusionment . . .*; Sapienza University of Rome, Archives of the Physics Department,

Nicola Cabibbbo[90]. In 1971 Gatto was called back to Rome and gathered a new group including Aurelio Grillo, Sergio Ferrara and Giorgio Parisi[91]. He also started to look for correlations between deep-inelastic scattering and (what he called) "deep-inelastic electron–positron annihilation", together with Giuliano Preparata[92].

A moving testimony of Gatto's feelings about Bruno Touschek appears in a December 1972 letter from Gatto to Touschek, written on the occasion of an incident occurring during the student unrest which took place in Italian universities, starting from 1968, lasting a few years. When a crude accusation of being a 'Nazi baron' was directed at Touschek by some students motivated by wanting to pass the exam for his course despite their ignorance, Touschek's decided to resign from his position at University of Rome (he was by that time "Professore aggregato"). In solidarity, and to deter him from leaving, Gatto wrote to him the letter shown in Fig. 8.

VII. CONCLUSIONS

We have presented a short overview of how Raul Gatto and Bruno Touschek together contributed to the rise of electron positron physics in the 1960s. Although they never wrote a paper together, their collaboration and mutual understanding were deep and highly productive, resulting in a lasting legacy to particle physics. Bruno Touschek passed away on May 25th, 1978, without seeing many great discoveries which gave rise to the Standard Model of Particle Physics, whose experimental confirmation came through accelerators of which AdA was prototype. Raoul Gatto passed away 39 years later in September 2017. Together, Touschek and Gatto shaped XXth century particle physics, its discoveries and theoretical formulation, in different but lasting ways, their collaboration being the building stone of a physics which they forged and explored, through their work, their students and collaborators.

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