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Bruno Touschek (1921-1978). The Path toward Electron-Positron Collisions. Sources and Bibliography

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Abstract: The 100th anniversary of Bruno Touschek's birth also marks 60 years since the first beams of electrons and positrons circulated in AdA, the first matter-antimatter collider built in Frascati National Laboratories following Touschek's visionary proposal of February 1960. A brief biography, an extensive bibliography, and a description of archives containing documents related to the life and science of the father of electron-positron colliders are presented.

Keywords: Colliders, High-energy physics, Antimatter.

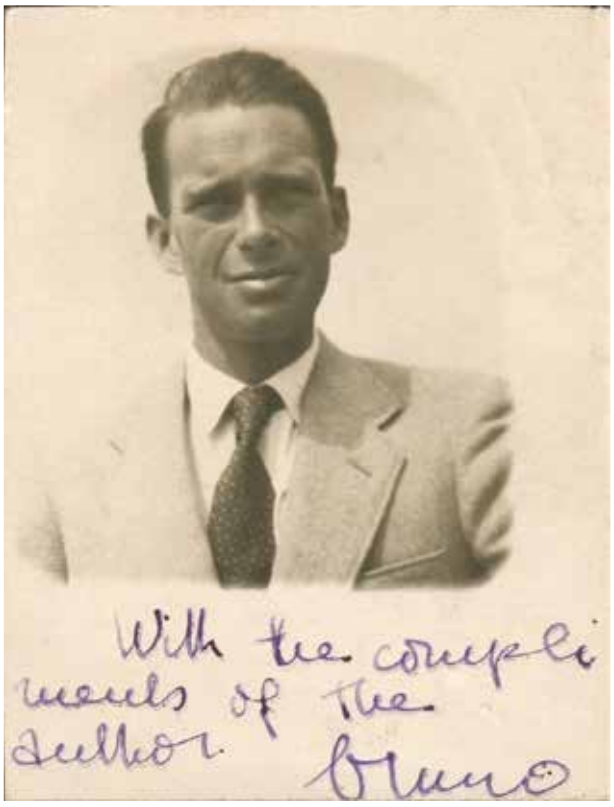

Fig. 1. Bruno Touschek at the end of the 1940s. Courtesy of Francis Touschek.

1. Introduction

Bruno Touschek's life unfolds across Europe in space and time, going through a terribly dramatic period of the last century. He was born on February 3rd, 1921, in Vienna, where he spent his childhood and early youth.

Between the end of the 19th century and the beginning of the First World War, the Austrian capital was a center of creation for modernity, the cradle for a number of ideas which shaped the whole 20th century and flourished in art, architecture, literature, science, philosophy and music. Touschek's own family was actively involved in this scenario. His mother Camilla Weltmann and his aunt Ella – and Ella's own husband, the architect Josef Margold – were active in the circle of the Wiener Werkstätte, the association evolving from the Vienna Secession as an alliance of artists, architects, designers and artisans which pioneered modern design and eventually influenced the Bauhaus movement and the Art Deco style. Touschek grew up in such amazing cauldron of great cultural movements. At the epicenter of this multifaceted world was the writer and essayist Karl Kraus. His caustic satirical spirit and his cultural engagement in the fundamental ideological issues of his time, had a profound influence on Touschek's intellectual formation, in parallel with the early imprinting he derived by the innovative expressionism of Egon Schiele and the famous psychological portraits of Oskar Kokoschka, which in turn influenced his precocious talent for drawing. The style of his own drawings – well-known among friends and colleagues – testifies the persistence during his whole life of such strong and lively bonds with the rich cultural and intellectual world of his home town, that subtly blended in his personal and very original style.

However, due to his Jewish origin on the maternal side, the annexation of Austria into Nazi Germany in 1938 completely turned his life upside down and dramatically affected his future. He was no longer able to attend classes as a regular student either at school or at the University of Vienna, which he had to leave, even ending up abandoning his home country.

He experienced firsthand, part of the horror that millions of people experienced across war-ravaged Europe, as preys of Germany's delirium, but he courageously pursued his passion for physics also during the war years, when he continued his studies in Germany (despite still being unable to attend classes as a regular student) protected by Arnold Sommerfeld's colleagues and friends in Hamburg and Berlin, and at the same time worked to support himself. During those difficult times, he had the chance to come in contact with some of the most influential European physicists, and found himself involved in the construction of a 15-MeV *betatron*, a pioneering accelerator designed by the Norwegian scientist Rolf Widerøe. He also went through extremely distressing experiences, such as being imprisoned by the Gestapo and being shot during a march towards the Kiel concentration camp.

He miraculously survived such dreadful events and, after the war, finally obtained his Diploma in Physics at the University of Göttingen with a dissertation on the theory of the *betatron* and for some time was Werner Heisenberg's assistant at the Max Planck Institute for Physics, continuing his formation under the influence of the great German theoretical school. Despite having lost several years of his youth, he re-emerged from

the war and early-post war years as one of the first physicists in Europe endowed with a unique expertise about the theory and functioning of accelerators. Such difficult period in his life proved to be a major step along his path to the conception of the first ever matter-antimatter collider which he eventually proposed and built in Frascati National Laboratories in 1960.

In early 1947 Touschek moved to Glasgow University and in 1949 was awarded a PhD in Physics with a dissertation on *Collisions between electrons and nuclei*, while being involved in theoretical studies and in the building of a 300-MeV electron *synchrotron*, also consulted as a *betatron* expert by other research centers in UK. In Glasgow, he became a full-fledged theoretical physicist. At that time, he came in contact with Max Born, one of the fathers of the new quantum mechanics, who had emigrated to UK after having been suspended from his position at the University of Göttingen being of Jewish origin. Touschek collaborated with him writing an appendix for a new edition of Born's book *Atomic Physics*.

In the very early 1950s, he met the well-known Italian theoretical physicist Bruno Ferretti, with whom he shared lively discussions on quantum field theory and from whom he also heard about the great plans and expectations for the reconstruction and revival of Italian physics, after the disaster of World War II. Edoardo Amaldi and Gilberto Bernardini, both heirs of the scientific tradition established by Enrico Fermi and Bruno Rossi in the 1930s, were in complete harmony in their efforts to restore the prewar excellence of Italian and European physics. Amaldi, in particular, was one of the promoters and founding fathers of CERN, where Bernardini soon became Director of Research. On the other hand, as we know from letters to his father and especially to Arnold Sommerfeld, since some time Touschek felt that in Glasgow he was rather far from the mainstream of theoretical physics and was considering other possible positions in Europe. Full of enthusiasm about the idea of Italy, a country he knew since his childhood, when he visited his maternal aunt Ada married with an Italian, he decided to obtain a leave of absence and move to Rome. Amaldi, deeply aware of Touschek's potential, invited him officially with an INFN contract.

When Touschek arrived in Italy at the end of 1952, the Istituto Nazionale di Fisica Nucleare had just been founded and Italian physicists were deciding to establish a national laboratory in order to host an electron synchrotron, a new-generation machine they had planned to build as a powerful tool for high-energy physics. After having been for many years at the frontier of nuclear and cosmic-ray research, Italy hoped to regain a prominent position in the sub-nuclear realm and indeed Touschek's unique expertise was destined to have a profound influence on the future of this field in Italy, both theoretically and experimentally.

He continued to play a role in the process of reconstruction and revival of physical sciences in Europe, and further evolved as a theoretician, giving relevant contributions to the study of discrete symmetries in particle physics and to neutrino physics. During the 1950s, while being actively involved in the life of the Italian scientific community, Touschek closely experienced the birth and development of Frascati National Laboratories. But between the end of 1959-early 1960, when the 1100 MeV electron synchrotron had just gone on line, Touschek surprised everybody proposing to go far beyond exper-

iments with gamma beams obtained by hitting electrons against a fixed target inside the *synchrotron*, or even experiments such as those US physicists were scheduling at Stanford with two colliding beams of electrons stored in two tangent rings. According to Touschek, what would really be worth exploring, instead, was the physics of electron-positron annihilations, which would allow to open a channel to the hadronic world through the quantum numbers of e^+e^-. The colliding beam technique, which other physicists were planning to exploit both in USA and USSR – basically to obtain a larger center-of-mass energy or to perform high-precision experiments to test the predictions of QED – was definitely moving towards a conceptually novel stage. Moreover, because of the CPT symmetry, an e^+e^- machine could be realized with a single magnetic ring, ensuring that electrons and positron could circulate in the same orbit. Following his challenging ideas – based on his firm belief in CPT and QED – the first matter antimatter collider AdA (for *Anello di Accumulazione*, *Storage Ring*) was built, inaugurating a brand-new research line at Frascati National Laboratories and heralding a new era in high-energy physics. The team led by Touschek, including Carlo Bernardini, Giorgio Ghigo, Gianfranco Corazza, Ruggero Querzoli and Giuseppe Di Giugno, was able already on February 1961 to observe the light signal from a single circulating electron after its capture in the ring as a pulse in the phototube output, or even as a white-bluish spot that could be seen with the naked eye through a small porthole. In Orsay, at the Laboratoire de l'Accélérateur Linéaire, where AdA was moved in 1962 to optimize the injection process into the storage ring, Touschek and his team, now including Pierre Marin and Jacques Haïssinski, were able to demonstrate that the two beams had actually collided, thus proving the feasibility of such machines. They also discovered an unexpected effect, a loss of particles from the stored beams reducing their lifetime, whose origin was immediately explained by Touschek. The so-called *Touschek effect* luckily becomes less pronounced with increase of energy.

After Touschek's new proposal for a larger and more powerful electron-positron collider presented at the end of 1960, ADONE (1.5 GeV per beam, 105 m in circumference) was built in Frascati and became operational in 1969. ADONE eventually discovered the multi hadron production making electron-positron physics a field of major interest, further encouraging the construction of a large family of high-energy colliders all over the world, where new states of matter were detected. In 1974, ADONE confirmed the existence of the J/Psi, a bound state of a charm quark and a charm anti-quark, discovered at the Brookhaven National Laboratory and at the Stanford Linear Accelerator Center, for which Samuel Ting and Burton Richter were awarded the 1976 Nobel Prize in Physics.

In the following years, Touschek made a fundamental contribution to the formation of a theoretical school in Rome and Frascati. In particular, he was Nicola Cabibbo's thesis advisor in 1958. While AdA was being built, Cabibbo and Raoul Gatto's investigations on the physics of electron-positron annihilations resulted in a seminal paper universally known as the "Bible". Touschek was particularly valued also as very brilliant teacher and in the early 1970s was elected as Foreign Member of the "Accademia Nazionale dei Lincei".

Between 1977-1978, Touschek spent the last months of his life as visiting scientist at CERN, at a time when early plans for a giant electron-positron collider were being discussed. However, when LEP, with an energy of 50 GeV per beam and a circumference of about 27 km, eventually came into operation in 1989, Touschek was no more there. He had prematurely passed away, on May 25th 1978, while he was participating in the planning of the proton-antiproton collider proposed by Carlo Rubbia. Unfortunately, he did not live enough to witness the discovery of the W and Z bosons and the related 1984 Nobel Prize in Physics to Rubbia and Simon van der Meer.

Bruno Touschek's small AdA (about 1.3 meters in diameter, storing beams of 250 MeV) has opened the way to new bigger matter-antimatter colliders and precision measurements which have been instrumental in confirming our understanding of the basic building blocks of matter in the Universe and the fundamental forces that operate between them. The detection of the long-sought Higgs boson at the Large Hadron Collider at CERN in 2012, has eventually completed the Standard Theory of particle physics.

2. Documents and Sources

Immediately after his death, the first to write on Bruno Touschek and AdA was his colleague and friend Carlo Bernardini (Bernardini 1978).[1] Soon after, Edoardo Amaldi published a long biography (Amaldi 1981), which includes a list of Touschek's papers as well as examples of his famous drawings.

A fundamental source is the publication *Le carte di Bruno Touschek,* a catalogue describing in detail his personal papers preserved at the "Edoardo Amaldi Archives", Physics Department of Sapienza University in Rome (Battimelli *et al*. 1989). Information on this collection, which can be consulted at the Library of the Physics Department, is also available online.[2]

Other archives containing documents related to Bruno Touschek are CERN Archives (correspondence with Wolfgang Pauli and Léon Van Hove), the Max Planck Society Archives in Berlin (correspondence with Werner Heisenberg), the Deutsches Museum Archives in Munich (correspondence with Arnold Sommerfeld and his son Ernst Sommerfeld), the University of Glasgow Archives & Special Collections (documents related to his years in Glasgow), Churchill Archives Centre in Churchill College, Cambridge (correspondence with Max Born). Copies of reports on the theory of the betatron written by Touschek during and immediately after the war are preserved in Rolf Widerøe's papers at the Eidgenössische Technischen Hochschule (ETH) in Zurich. The bulk of this material became part of his dissertation in Göttingen. Widerøe's autobiography edited by Pedro Waloschek contains several pages mentioning Touschek and their relationship (Widerøe 1994). Waloschek's *Death-Rays as Life-Savers in the Third Reich* is

[1] The references mentioned in this Section are included in the general bibliography listed in Section 3.
[2] See: https://archivisapienzasmfn.archiui.com/oggetti/5-bruno-touschek.

also a valuable source on Bruno Touschek's life and the context he lived during the war (Waloschek 2012).

The establishment of the "Bruno Touschek Memorial Lectures" at INFN National Laboratories in Frascati – promoted in 1987 by Giulia Pancheri, a former collaborator of Bruno Touschek – was marked by a conference whose proceedings include valuable contributions which can be consulted online (Greco, Pancheri 2004).

Several recollections by Touschek's colleagues are contained in a volume edited by V. Valente (*Adone, a milestone on the particle way*, Frascati Physics Series Vol. VIII, 1997), but especially in a dedicated volume edited by G. Isidori (*Bruno Touschek and the birth of e^+e^- physics*, Frascati Physics Series Vol. XIII, 1998).

More systematic historical studies began in the early 2000s, during the realization of the docu-film *Bruno Touschek and the Art of Physics* (Agapito, Bonolis 2004) also thanks to Touschek's widow, the late Elspeth Yonge, who kindly gave access to extremely relevant papers, correspondence and photos still preserved by the family.

Since 2009, an in-depth historical analysis has been conducted by Bonolis and Pancheri resulting in several contributions reconstructing different phases of Bruno Touschek's life, especially emphasizing his formation both as a theoretical physicist and an expert in accelerator science and showing how the merging of such articulated competences became the origin of his visionary proposal to build the first electron-positron collider and investigate the matter-antimatter physics (see articles in the Bibliography). Further relevant documents, such as the collection of Touschek's letters to his father put at disposal by Elspeth Touschek, have been instrumental for such research work, in particular because they have thrown light upon his crucial war and early post-war years, which had remained rather unknown apart from the very few episodes he had told Amaldi during the last days of his life. Part of the results of these studies were used during the realization of a second docu-film: *Bruno Touschek with AdA in Orsay* (Agapito *et al*. 2013).

A comprehensive biography of Bruno Touschek by Giulia Pancheri is under publication with the title *Bruno Touschek's Extraordinary Adventure – from death-rays to anti-matter* (Springer).

3. Bibliography on Bruno Touschek and AdA

The following fairly complete bibliography in chronological order is meant as a hopefully useful tool to learn about the life and science of this extraordinary protagonist of 20th century physics.

Whenever possible, a link to each reference has been provided, including the two docu-films, which are both accessible and visible online (access date for all links: 30/10/2021).

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4. Conclusion

The Memorial Symposium held in Rome in December 2021 to celebrate the centennial of Bruno Touschek's birth, inaugurated a new phase in the historical studies on one of the most original figures of 20th century physics. As historians, we are still left with the task of in-depth investigations related to the evolution of Touschek's theoretical thought during the twenty years or so between the war years – and his work on the *betatron* theory – to the late 1950s, when such a long process finally materialized into his daring and drastic proposal, that he considered "the future goal" of Frascati Laboratories: transform the electron *synchrotron*, that had just begun to function, into an electron-positron collider and explore the physics of matter-antimatter annihilations. His bold idea was wisely and enthusiastically converted into the decision to build a dedicated small prototype, AdA, the first ever matter-antimatter machine, which in the early 1960s set the stage for a new era in particle physics. The period from Touschek's arrival in Italy at the end of 1952, to the end of the 1950s, during which he fully developed into a mature theoretical physicist dialoguing with prominent theoreticians of his time, has not yet been thoroughly studied. In particular, his scientific production as well as his scientific correspondence with Heisenberg, which dates back to the early post-war period, and continued during the 1950s, has yet to be analyzed, as well as his exchange of letters with Wolfgang Pauli, himself born in Vienna from a prominent Jewish family. Touschek had always been an attentive follower of Pauli's work since his early youth. They had an intense scientific correspondence during 1957-1958, at a time when much of Pauli's research activity was centered on quantum field theory – and had already resulted in two fundamental pillars of the theory: the spin-statistics theorem and the CPT theorem – but in particular when the shocking discovery of Parity violation in weak interactions was increasing interest in the discrete symmetry operations, the charge conjugation *C* and time reversal *T*. Such interaction is also testified by the joint paper "Report and comment on F. Gürsey's group structure of elementary particles" published in 1959 as a contribution to the *International School of Physics "Enrico Fermi"* (8th Course: "Mathematical problems of the quantum theory of particles and fields") when Pauli had already passed away. The analysis of how Touschek's interaction with Pauli and other theorists (such as Walter Thirring, Charles Enz, Gerhart Lüders, Markus Fierz, Kurt Symanzik, Luigi Radicati) became instrumental for the development of his ideas on symmetry and in triggering his own reflections on the CPT theorem – the solid conceptual base for AdA – is to be pursued as one of the main keys to a deeper understanding of all the implications of his unique path towards what became a standard practice: using matter-antimatter annihilations to probe the ultimate nature of the basic building blocks of the Universe and their interactions.