Chapter 23
Remembering Bruno Touschek

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Abstract Participants' recollections about their relations with Bruno Touschek.

23.1 Remembering the Founders: Bruno Touschek's Papers, *Giovanni Battimelli*

I cannot say that I ever came to really know Bruno Touschek, when he was still active at the Physics Institute in Rome. Back then, around 1970, I was a student there, and almost all I knew of him was that he was in charge of the course of

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"Metodi matematici della fisica", and, in his official role of professor, one of the "counterparts" of the frequent and confused agitations shaking in that turbulent period our students' life. We had some hints about his being a brilliant theorist that had been involved with the creation in Frascati of a new kind of clever experimental tool, but what made him famous to us were rather the humorous and seemingly incongruous puns that he scattered liberally across his course notes, which left us at the same time dumbfounded and pondering how close he was to the stereotype of the crazy scientist.

It was about ten years later when I had the first real interaction with Touschek's legacy. It must have been someday early in 1982. I was chatting with my friend and colleague Michelangelo De Maria in the office we shared at the first floor of the Institute, when the door opened and the head of Amilcare Bietti poked in. Amilcare had been Bruno's assistant for quite some time, in my student years. "Hey guys, they are cleaning Bruno's office upstairs. You'd rather have a look on what's going on".

(Which shows two things: one, that back then there must have been no pressing demand for space in the Institute, given that Touschek's papers still were in his old office, almost four years after his death and over seven years after his actually no longer coming to the university; and, two, that back then it still was a current practice, in order to make room in an office previously occupied by a retired, or deceased professor, to get rid of old books and papers just throwing everything away, thus paying tribute, probably unknowingly, to Alfred Whitehead's famous sentence "a science that hesitates to forget its founders is lost").

Well, we were, or pretended to be, historians of physics, and did not hesitate to act in the opposite direction to the one suggested by a strict interpretation of Whitehead's prescription. Urged by Amilcare's intervention, upstairs we went and we found out that the current practice referred above was being duly performed, and already a good portion of the papers left in the office had been discharged in the large garbage can on the back of the building. We ran down and started searching through the box like hungry homeless desperate for leftover food, extracting from the overall mess quite a bit of correspondence, including letters to and from Werner Heisenberg, Max von Laue and the like, lab logbooks, drawings, original sketches and notes related to the early days of the AdA project, and so on. Luckily, we could stop the "current practice" just in time to prevent that valuable documentation from getting lost.

And so was born the first block of what was going to become, in the course of the following years, the richest collection of physicists' personal papers in Italy, now duly preserved in the basement of the department's library. A few days after our first intervention, we went to see Francis Touschek at the family house in via Pola, and he lent us more papers and documents that his father had kept at home, thus allowing the building up of a substantial archive that has proved to be, in the course of time, a unique and most valuable source for those who have researched, documented, and written about, Touschek's scientific life and his impact on the course of twentieth century physics.

Sometimes I ask myself the seemingly silly question "what if". What if Bietti had not knocked on our door that day? What if he went to see us and we had not been there? What if we had dismissed his warnings? Silly questions maybe, that leave us pondering on the fortuitous contingencies impending upon so many of our endeavours. Be it as it may, it gives us pleasure to know that, among the several possibilities open at that moment for the course of events to be, the one that actually materialized gave us the chance to keep the door open for our science to not forget (one of) its founders.

23.2 Touschek: A Great Master of Quantum Electrodynamics and Statistical Mechanics, *Franco Buccella*

In the summer of 1963 Guido Altarelli and I were trying to compute the differential cross-section for the emission of a photon in electron–positron scattering, the issue proposed for our thesis by our tutor Raffaele Gatto. The numerical evaluation gave conflicting results, negative (!) or very large values. To account for this last case, we told Prof. Touschek that the amplitude with all the final particles in the same direction had a very small denominator. Immediately he replied with his nice Austrian accent: "Denominatore piccolo, numeratore zero." In fact, the transverse polarization vector of the photon is orthogonal to all the longitudinal momenta of the particles. This led us to perform the ultrarelativistic approximation for the final fermions, which allowed us to complete the analytical evaluation. The comparison of the formula with the experimental measurements at AdA proved that the machine worked. Our paper (1) was quoted on the book of quantum field theory by Landau and his collaborators.

Few months before I followed the course taught by Prof. Touschek on Statistical Mechanics and I was impressed by the mathematical elegance of the derivation of the Maxwell–Boltzmann, Fermi–Dirac and Bose–Einstein formulas. This allowed me to propose Fermi–Dirac and Planck formulas, respectively, for the valence partons and gluons distributions, as boundary conditions to the DGLAP equations.

These formulae are in agreement with the shapes of the distributions and with the isospin and spin asymmetries of the proton sea (2). More recently, the gluon distribution measured by ATLAS has been well described with a value equal to the adimensional variable, which plays the role of the temperature and fixes the behaviour of valence partons (3).

(1) G. Altarelli and F. Buccella, Nuovo Cimento 34 (1964) 1337
(2) F. Buccella, F. Tramontano and Sozha Sohaily, J. Stst. Mech. (2019) (7) 073,302
(3) L. Bellantuono, R. Bellotti and F. Buccella, arxiv::2201.07640v2 [hep-ph].

23.3 AdA as Historic Site of the European Physical Society to Pay a Tribute to Bruno Touschek, *Luisa Cifarelli*

The European Physical Society (EPS) was founded in Geneva, Switzerland in 1968 through the visionary leadership of Gilberto Bernardini (then CERN Research Director) "as a further demonstration of the determination of scientists to collaborate as close as possible in order to make their positive contribution to the strength of European cultural unity".

In line with this "cultural unity", the Historic Sites initiative of the European Physical Society was launched at the end of 2011, when I had the honour of being president of the EPS. The initiative was inspired by an analogous initiative on the other side of the Atlantic by the American Physical Society. A dedicated EPS Historic Sites Committee was created, which has been actively operating since then.

The EPS Historic Site awards commemorate places in Europe, sometimes outside geographical Europe, with national or international significance for the development and the history of physics. Examples of sites to be considered are laboratories, buildings, institutions, universities, towns, etc., each associated with an event, a discovery, a research or body of work, by one or more individuals, that made long lasting contributions to physics.

Until now, more than 100 proposals of Historic Sites were received, either spontaneous or channelled through national member societies of the EPS. The Historic Sites Committee examines the proposals typically three times per year. Almost 70 EPS Historic Sites have been inaugurated up to 2022 in 25 different countries (even outside geographical Europe): Austria, Belgium, Bulgaria, Czech Republic, Denmark, France, Germany, Hungary, India, Israel, Ireland, Italy, Lithuania, The Netherlands, Norway, Poland, Portugal, Romania, Russia, Serbia, Spain, Sweden, Switzerland, United Kingdom, United States.

On December 5, 2013, the Frascati National Laboratories (LNF) of the Italian National Institute of Nuclear Physics (INFN) hosted the naming ceremony of AdA (*Anello di Accumulazione*/Storage Ring) as a Historic Site of the European Physical Society (EPS).

AdA was built in 1961 by a small group of Italian physicists under the brilliant leadership of Austrian physicist Bruno Touschek. It was the world's first prototype electron–positron storage ring. AdA was later moved to Orsay, to the *Laboratoire de l'Accélérateur Linéaire* (LAL), in order to operate with higher intensity beams. AdA was by far the forerunner of several generations of e^+e^- colliders of gradually increasing energy and luminosity, in Italy and around the world. In Frascati, in particular, its successors were ADONE and DAPHNE.

As for each Historic Site inauguration "fest", a plaque was unveiled in the presence of the local representatives and authorities. The ceremony was chaired by Umberto Dosselli, then LNF Director, and the speakers included, in particular: Stefano Di Tommaso, then Mayor of Frascati; Giorgio Salvini, Director of LNF

in 1961; Fernando Ferroni, then President of INFN. The many distinguished participants included Samuel C. C. Ting, who was also invited for a special seminar the same day on the AMS (Anti Matter in Space) experiment as part of the traditional "Bruno Touschek Memorial Lectures". The establishment of the AdA Historic Site was not only meant as a recognition of a glorious past but also as a wish for a brilliant future of the LNF.

So far, the Historic Site initiative of the EPS has been a series of success stories implying the improvement of mutual relations between the EPS, its national member societies, and local institutions and official bodies. Therefore, while stamping important and meaningful places for the history and the progress of physics, the EPS Historic Sites provide visibility to physics and to the physics community and, at the same time, enhance a sense of belonging to the EPS.

This initiative has also the (maybe) ambitious objective to create the awareness that not only artistic cultural heritage and natural heritage should be preserved for humankind, but also scientific cultural heritage. AdA is indeed part of it.

23.4 Touschek's Approach to Students, *Carlo Di Castro*

I entered the university as a freshman in 1956. All people at the Physics Institute in that period are in debt in a way or another to Bruno Touschek, in Rome since 1952. I was not an exception. In my personal studies I became interested in thermodynamics, statistical mechanics and in the theoretical physics of condensed matter—largely ignored in Rome, at a time when everyone was engaged in the study of elementary particle physics. The course in statistical mechanics was given by Bruno Touschek. Even though statistical mechanics was not his field, his course was brilliant and stimulating. For him physics was a unifying vision, the basic notions were given following E. Schrödinger's *Statistical Thermodynamics*, but he would also extemporize on specific topics, not teaching, strictly speaking professional statistical mechanics, but rather how a theoretical physicist should approach problems with technique, imagination and enthusiasm. When time came to select the argument for my Laurea thesis, I had to use this imagination to find my way. The Institute in Rome had little to offer in terms of my interests in condensed matter physics and statistical mechanics. Obviously, there was also a problem of cultural legacy. Under the Fascist dictatorship (the Racial Laws of '38, the war, etc.), Italian physics was destroyed, and after the war, Edoardo Amaldi had the difficult task of rebuilding the field. Obviously, capable young physicists, at least in the theory group, wanted to pursue the physics of the moment, i.e. elementary particles. Giorgio Careri however, at that time in Padua, had obtained brilliant results with his experiments on Superfluid Helium four and was supposed to come back to Roma. So, I started to study superfluidity. According to the newly proposed BCS theory (1957) of superconductivity, below a certain temperature, electrons may couple in Cooper pairs and then condense, like

bosons. I therefore decided, for my thesis, to introduce the pairing approximation in superfluidity. Marcello Cini was my advisor, and my outside examiner was of course my Statistical Mechanics teacher, who returned the thesis with a comment written in his typical misspelled Germano-Italian style: "Con complimenti del avvocato del diavolo" ("With best wishes from the devil's advocate").

In the same period, we all were in a classroom waiting for a seminar on the Landau quasiparticle spectrum of superfluid helium and the speaker didn't arrive. Touschek, the theoretician present, was asked to extemporize a short talk. He drew the quasiparticle spectrum energy versus momentum which starts linearly (the so-called phonon part), goes through a maximum and then has a minimum (the so-called roton part) at a wave vector inversely proportional to the average distance between the Helium particles. Touschek then paradoxically presented superfluid helium as a missed solid. According to him the rotonic minimum was the sign of the missed periodicity of the solid Helium when the average distance between the helium particles is substituted with the lattice constant. Actually, I realized that after all Touschek was not far from the famous Feynman explanation of those few excited states compatible with superfluidity of a system of bosonic interacting particles. In short, the ground state function is a real positive totally symmetric function of the positions of the well separated and evenly spaced atoms. Phonons are the only low-lying excited states compatible with the Bose statistics because variation in the density cannot be accomplished by just permuting atoms starting from a homogeneous configuration. All other states either are equivalent to the ground state by permutations or involve movements of atoms on distances less than the average atomic distance, i.e., are rotons separated from the ground state by parabolic excitation energies with an effective mass and wavevector proportional to the inverse average distance between Helium particles. Bruno, with his approach to physics, was a continuous unintentional teacher for all of us.

23.5 Memories of Bruno Touschek, *Giovanni Gallavotti*

In 1963 I asked Professor Touschek to accept to follow my work towards my "Laurea". He assigned me a problem on quantum electrodynamics and soon he realized that I was not ready to work on such a subject. I still feel gratitude that he simply did not insist to deal with the problem and changed it into a more technical study on the lifetime of electrons in the storage rings at the time under construction (ADONE) or already operative (AdA).

The electrons of one packet collide with the light emitted from the positrons of another packet and as a consequence are expelled from the orbit. The question is to estimate how long a packet can stay on the ring in which it circulates, i.e. which is the half-life of a packet. The problem is relevant for the storage rings and was checked independently, while being useful to a student to learn not to hesitate over very long calculations.

This was for me a very difficult task although it did not require particular originality, but it trained me to consider computations as a minor problem. So, I kept asking regularly suggestions by daring to go to his office: the explanations were given on a blackboard (still there in the office that has become a room for visiting scholars) which was densely covered by ever changing formulae: during the several months of my work I vividly recall that there, essentially in the center, was written with white chalk, immutable, "*amice diem perdidi*".

The work for the graduation was over around November: I cannot think that he was happy with it and I thank him for letting me, nevertheless, go through the final exam. I regard that a sign of his confidence that my future work might be of better quality.

I then left Roma for about 10 years without further interaction with him: until in 1971 he chaired an Italian Physical Society meeting where I was a speaker. He listened to my work and, returning to Roma, he mentioned it enthusiastically to some of the senior professors (so I was told). I warmly thank him for this as, from that moment, I was accepted as a "physicist". Although my work was not on a subject of his typical interests, still he was open minded to publicly appreciate it: his open mindedness remains for me as a permanent example of the attitude that senior researchers have to take in dealing with the new generations. I remember it with deep gratitude.

Eventually, in the eighties, I obtained a position at "La Sapienza" in the Physics Institute (now department): but it was too late to interact regularly with Touschek and I can only regret that his departure had happened too early.

23.6 Memories of an Extraordinary Person: Bruno Touschek, *Luciano Pietronero*

It was 1970 when I attended the course of Mathematical Methods for Physics by Bruno Touschek and Amilcare Bietti as assistant. The cour*se* was very original, all based on his personal and mostly handwritten notes and, even the response of a harmonic oscillator, already studied in other courses, became a fascinating scientific adventure: "at high frequency the oscillator trembles but it does not oscillate". So, after this course, I went to him asking for some possible subject for a Laurea thesis. I was 20 and pretty ignorant and he was the great scientist. He started discussing with me almost on any subject in physics and beyond and manifested a certain scepticism about the situation of high energy physics which he considered a bit stuck at the time. In that period, he was intrigued by a chapter of Pauli's book on General Relativity which he found unclear. In his words: "It is always difficult to nail down Pauli". The question was about Mach's principle, the equivalence principle and the meaning of the inertial mass. The gravitational mass is a local property of particles like the electric charge, while the inertial mass is the resistance to acceleration, quite a different property. Mach's principle states that inertial forces should be due to the interaction of a body with all the other masses in the universe. It was never stated in a mathematically

rigorous form, but it was very influential to Einstein. In General Relativity this principle is not fully present and is replaced by the equivalence principle, according to which inertial and gravitational masses are linked by the gravitational constant, which is a fixed number. However, according to a strict interpretation of Mach's principle, the inertial mass should be non local and depend on all the other masses of the universe and their positions. In this perspective the gravitational constant cannot be just a fixed number. All this may appear almost philosophical but it took a very concrete perspective in 1918 with two papers. In one Lens and Thirring computed the so-called frame dragging of the earth that induces an inertial dragging and precession to the orbit of satellites. This has been accurately measured in the past years with the LARES satellites. This effect does not touch directly the problem of the inertial mass but it begins to show that the motion of masses induces inertia like effects. The second paper by Thirring was more intriguing. It studied the metric inside a rotating cylindrical mass shell and it was clearly inspired by the conceptual problem of Mach's principle. This study revealed the appearance of a force with the structure of Coriolis force. No centrifugal like force was present but there was also a curious vertical force. This was the paper discussed by Pauli that intrigued Touschek. He immediately realized that the vertical force was spurious and due to the spherical shell that should be substituted by a cylindrical one to have the correct rotational symmetry. Also Thirring had resorted to the linearization of the GR equations and clearly this cannot lead to quadratic effects that are necessary for the centrifugal force. So the problem was clear, use a cylindrical geometry and solve the GR equations to second order in the gravitational constant. This implied the construction of a novel mathematical scheme to go to second order and then consider the cylinder as the source of the field. Well, after quite some calculations, we found that a rotating cylinder leads to a metric which gives exactly the Coriolis term and the centrifugal one with the correct relations. Touschek was extremely excited because this result paved the way for a more concrete implementation of Mach's principle and possibly a generalization of GR. However, he did not want to sign the paper because, in his opinion, I had done all the calculations, but he had given me all the ideas. The paper was published in *Annals of Physics* in 1973. After this enthusiastic period things became problematic with his health and I realized that this beautiful and exciting experience was not going to have a continuation. So I moved to the field of condensed matter and went first to US and then to Switzerland. I never missed to visit him when I could, up to the last days in 1978. I was so influenced by his sparkling originality that, on many occasions, in front of a difficult problem, I asked myself what would Touschek do with this problem? Grazie Bruno, una luce brillante nella mia vita.