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THE BRUNO TOUSCHEK LEGACY

(Vienna 1921 – Innsbruck 1978)

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ERRATUM TO CERN 81-19

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On p. 12, line 32, please read Schwinger (instead of Schrödinger).

On p. 14, line 7, please read Glasgow (instead of Edinburgh).

On p. 32, line 12, please read $(m_e c^2/2E)^{1/2}$ [instead of $(m_e c^2/E)^{1/2}$].

On page 43, for the sixth entry (ISR), the column *Type* should read Intersecting rings (and not Single ring);
for the eleventh entry (DCI), the column *Particles accelerated* should read e^+e^- , e^-e^- , e^+e^+ (instead of e^+e^-);
for the last entry (UNK), the column *Type* should read Intersecting beams (instead of Intersecting rings).

On p. 79, the page number in Ref. 120 should read 620 (and not 20).

On p. 80, line 3 of Ref. 131, please read Ref. 128 (instead of Ref. 131).

ABSTRACT

A biographical portrait of Bruno Touschek, an Austrian physicist who, before and during the Second World War, went through the dramatic adventures of a non-pure arian young person. Later he worked in Germany, Great Britain and Italy.

Touschek was the first to propose chiral symmetry. He was the initiator and main driving force in the early developments of e^+e^- colliding machines. His wide scientific culture, his ingenuity and enthusiasm for any new challenging problem and the search of its solution were essential elements in determining the extraordinary influence Bruno had on the work of his younger colleagues. "He led an intense and vigorous life and by his example and friendliness helped many colleagues and friends to achieve greater happiness and awareness in their own lives".

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1. THE DEPARTURE OF BRUNO TOUSCHEK

On 25 May 1978, Bruno Touschek died in the Medical Ward of the University Hospital, Innsbruck, as a result of the last of a series of hepatic comas. He had been suffering from this illness for several years. He had had it in a serious form since February 1977, when he was taken to the Medical Ward II of the Policlinico of the University of Rome. This “dramatic collapse” as he wrote to me on 29 March 1977, a few days after he had returned home, “is somewhat providential as it has convinced me more than any preaching to put an end to this childish alcoholism, which has led me to my climacteric, and has made me realize that my Bursche¹⁾ days are over”. The doctors had already explained, however, that not only his liver but also his kidneys were in a bad condition, so that it was not possible to carry out any major clinical or surgical treatment.

After a fresh collapse which had caused an ever greater irritability towards his family—an irritability characteristic of his illness—he was taken at the beginning of July 1977 to the Medical Ward I of the Policlinico, where he remained for practically the whole summer. In the meanwhile, he had been appointed “Senior Visiting Scientist” at CERN for a year from the autumn of 1977. As soon as he was fit to face the journey, he moved to Geneva at the beginning of October.

Another attack in the middle of November forced him to enter the Cantonal Hospital of Geneva. A little later he was transferred to the Hospital of La Tour, near the CERN Laboratories in Meyrin. During his whole period in Geneva, Touschek’s various friends and colleagues took an interest in his health, in particular Giorgio Salvini, who had gone to Geneva at the end of August 1977 on a year’s sabbatical leave from the University of Rome. CERN’s Director-General for Research, Leon Van Hove, himself took an interest in Touschek’s problems and asked the CERN doctors to check on his state of health.

The nearness of the Meyrin laboratories made it easier for him to receive visits from many physicists, his friends, of different nationalities—above all Italians, Germans and Austrians—so that every day he saw different people with whom he discussed his state of health, his family problems and—above all—physics.

He always put forward, in an original and unexpected way, a point of view of substantial value on matters not yet sufficiently clarified. As he had always done, he read a great deal of literature and, in particular, history, and he had a great interest in figurative arts.

Nevertheless, Bruno was not happy in the La Tour Hospital, chiefly because the staff spoke French, and he felt that he did not know it well enough. It is true that he did not speak French so well as English and Italian, which he spoke fluently, using precise expressions—even if they were sometimes unusual or betrayed in their origin a Viennese mentality. But he understood everything and could express any thought in this language too. He probably succeeded in doing this by a much greater effort of concentration than he needed in order to express the same needs or thoughts in German.

One day, during his stay at the La Tour Hospital, he picked up the phone next to his bed, with which he communicated regularly with his wife and younger son in Rome or the elder one in London, and managed to book a room in the Sport Hotel in Igls, 5–6 km from Innsbruck.

When I went to see him in the La Tour Hospital on 27 and 28 February, he spoke to me with a certain amount of enthusiasm about this plan of his and of his success in arranging to be transferred on 8 March 1978 from Geneva to Innsbruck by a car, put at his disposal by CERN.

In a letter to me dated 2 May 1978 he spoke of the “very comfortable journey” and said that the hotel was without doubt the best that one could find, “with the staff always smiling, excellent food, and a 20-metre indoor swimming pool at 28°, with also a doctor in attendance.” In the same letter he also wrote of “the Alps in Springtime” and of having “enjoyed the balcony, from which one can see the Patscherkofel.”²⁾

In a note written the day before, he gave me news of his “state of health”, saying that between 25 February and 1 May he had been in the Nursing Home five times (the first time with a stomach haemorrhage) and had had six attacks of hepatic coma. He discussed in a detached way—I would say almost humorous, had his situation not been so tragic—the possible causes of “hepatic coma” and its “immediate effects”. He had been transferred from the Sport Hotel to the Psychiatric Hospital in Innsbruck, and then to the Medical Ward of the University more than once until the final crisis in which he died. Because of a railway strike in Italy his wife Elspeth did not arrive from Rome until the day after his death.

In his letter of 1 May, Bruno wrote to me: “I can write—still badly—and can read; I am still a little weak even for short walks in the village.... I do everything at a snail’s pace. So far, the only unwise action has been

to hold a seminar in Innsbruck... Cap and Rothleitner, (dean)³⁾ took care of me with Ernst⁴⁾, Valentino⁵⁾, etc., while I was in hospital. Everything went well, except that after 30 minutes I had to sit down”.

As Rothleitner wrote to me, when together with Cap he visited Bruno for the first time in the clinic in Innsbruck:

“...he was very weak but still had a strong will to live. He told us: ‘I have been in coma and I have forgotten everything. I should start again from the beginning: I should again learn to speak, I should learn everything again’. He kept on his table a heft, in which he noted the important thoughts as soon as he found them again. On top of the first page I read: ‘Cogito ergo sum’.

“In spite of his weakness, he expressed the desire to give a seminar and offered a number of themes....”

The news of his death was a very severe blow to all of his friends, especially the physicists at the University of Rome and the Frascati Laboratories (Laboratori Nazionali di Frascati del CNEN). The announcement was made by his friends on 31 May 1978 in Information Bulletin No. 4, which, in just over a page, attempts to portray the personality and achievements of Bruno Touschek⁶⁾:

“He was one of the few physicists able to speak authoritatively in an extremely wide range of physics fields, from elementary particles to statistical mechanics and accelerators. His intelligence was that of a genius, and was inexhaustible....

“His reflections were to cross the destiny of our laboratories in 1960, when Touschek started to give thought to the possibility of building storage rings for electrons and positrons....

“Bruno Touschek was not only extremely intelligent, but was also endowed with enormous drive and enthusiasm. It so happened that the young scientific environment at the (Frascati) Laboratories was wisely receptive to this proposal, and in the space of a year AdA was constructed. The prime contributor to the designing and construction of this project was our much regretted colleague Giorgio Ghigo.

.....
“It is precisely for this reason that his memory will remain alive throughout the future existence of the Laboratories.”

Various articles which appeared during the following days in the daily press stressed his gift as a designer⁷⁾ and his middle-European culture, which incorporated a certain Anglo-Saxon empiricism⁸⁾.

At 3.30 p.m. on 7 July 1978 an official tribute was paid to Bruno Touschek in the main hall of the National Laboratories of the CNEN at Frascati, by Carlo Bernardini and Giorgio Salvini, who gave an address after a short introduction by Renato Scrimaglio, Director of the Laboratories.

The ceremony, which took place in a hall packed with physicists of all ages from many Italian universities, was concluded with the unveiling of a memorial erected in the centre of the area where ADONE is situated: the AdA magnet, bearing the inscription “Bruno Touschek 1921–1978”.

An account of this ceremony, published in the *Corriere della Sera* of 22 July 1978 and entitled “Who was the man of No. 137” recalled Bruno Touschek’s great interest in the scientific investigation of fundamental problems. One such example is the value of the electric charge of electrons and protons, the square of which, expressed in adimensional form, is the reciprocal of 137. “Because the real problem is the number of this room”, Bruno suddenly remarked to a young friend during a visit he received at the La Tour Hospital, where he occupied room No. 137. “This is the problem around which I have hovered throughout my life, without success.”⁹⁾

2. HIS YOUTH¹⁰⁾

Bruno Touschek was born in Vienna on 3 February 1921, and was the son of Franz Xaver Touschek, a Staff Officer in the Austrian Army, who had fought on the Italian front in the First World War, and of Camilla Weltmann.

Owing to a very serious form of Spanish flu, contracted during the epidemic that struck all Europe in 1918, his mother remained in very poor health, so that Bruno always saw her in bed or, at best, lying on a sofa.

Bruno's father had left the Army and entered the reserve at the age of 31, with the rank of Major, when in 1932 the power in Austria was taken over by Dollfuss' Christian-Socialists, in reality Clerico-Fascists, who tried to gain support from Mussolini's Italy and Horthy's Hungary against the threat of Germany's annexation of Austria. Franz Touschek found a job in an employment agency and in this way established contacts with many building and industrial firms.

When Hitler took over control of Germany on 30 January 1933¹¹⁾, the German pressure on Austria was strongly increased. On 19 June 1933, Dollfuss had succeeded in declaring the Austrian National-Socialist Party illegal, but, on 25 July 1934, a group of 154 members of this party, wearing uniforms, burst into the Federal Chancellor's Office in Vienna, and murdered Dollfuss.

The international reaction, in particular that of Mussolini's Government, which immediately sent four Divisions to the Brenner Pass, prevented the immediate annexation of Austria by Germany. Dollfuss' successor was his party-companion Kurt Schuschnigg, who tried to save Austria's independence by following a policy of detente with Hitler's Germany. But the Austro-German agreement, signed on 11 July 1936, contained concessions that spelt disaster for Schuschnigg and his country. The Austrian National-Socialist Party was reconstituted, with a strong renewal of antisemitism, the roots of which in Austria dated back to the years 1880–1890¹²⁾.

Bruno had attended school in Vienna and, at the beginning of the summer of 1937, he had completed the 8th class of the Piaristen Gymnasium, that is a year before the Abitur (state examination), when he was told that he could no longer attend school because he was of mixed blood, as his mother was Jewish.

He stayed away from school but he had many friends that he met in cafés, and this kept him in touch with what was happening. With the beginning of war in sight, the Austrian High Command was already making preparations. In particular, the Abitur examination of 1938 was brought forward to February, so that a large number of young men would be immediately available as junior officers. A friend who attended another school suggested that he sat the exam at a different school as an external student without making any mention of his real position. Bruno took his advice and sent in his application to the Director of Education for the Schottengymnasium. He was allowed to take the exam and passed it very well in all subjects except Greek, in which he was declared, at first, "nicht genügend" (insufficient), but the decision was later changed to "genügend", as an order had arrived to pass large numbers of young men who would soon be needed as reserve officers.

Thus he passed his state examination and in February 1938 he went to Rome for the "school-leaving holiday" according to the tradition of the bourgeoisie of that period.

Around the end of that same month, Vienna entered a period when the Schuschnigg government was engaged in a death-struggle, which ended on 13 March 1938 with the proclamation of the "Anschluss" of Austria by Hitler's Germany. This occurred without Great Britain and France taking any measure, and with the consent of Mussolini who, first with the Abyssinian war (1935–36) and later through participation in the Spanish civil war (1936–39), had once and for all espoused Hitler's cause.

Bruno had thought of studying engineering in Rome and so he began to attend the first two-year course in engineering in the spring of 1938. He attended, in particular, Francesco Severi's course on "Mathematical analysis". In the meanwhile, however, he had applied for a visa to enter Great Britain in order to study Chemistry in Manchester. He was told that this could be obtained through an organization established in Vienna and run by the Quakers, who were very active in that period, as in other dramatic circumstances, trying to save people persecuted for political or racial reasons. Towards the summer of that year he returned to Vienna and not long after went on holiday with his family, namely his father and his second wife, Rosa Reichel; Bruno's mother had died in 1931.

Following the Hitler-Stalin Pact, at the beginning of September 1939 the Second World War broke out, when the Russian and German armies entered Poland from opposing fronts.

Franz Xaver Touschek was invited to re-enter active service, in order to collaborate with the German authorities in maintaining good relations with the groups he had worked with during the previous few years. He declined the invitation, however, and Bruno, even years later, was clearly pleased at his father's refusal. I realized, however, from conversations I had with him many years later, that at the height of the racial persecutions, Bruno suffered at the thought that he was a burden on his father, and that he was unintentionally damaging his career as well as his private life, as a living testimony of his first marriage to a Jewish girl.

With the war raging in Europe, every possibility of going to study in Great Britain had vanished. As a result Bruno remained in Vienna and started to attend the University courses in physics and mathematics, trying to avoid attracting attention. By the third term he was clearly the best in his course, so much so that he gave a talk at the preseminar (or seminar for students) on the Markov double sum series, prepared in verse. But in June 1940 he received a notice that he could no longer attend the University for racial reasons.

Luckily, some time earlier he had, with the help of Paul Urban¹³⁾, studied the first volume of the famous treatise *Atombau und Spektrallinien* written by Arnold Sommerfeld¹⁴⁾, then Professor at Munich University. Touschek had spotted a few minor errors and, encouraged by Edmund Hlawka¹⁵⁾, wrote to Sommerfeld. Sommerfeld replied asking Touschek to read also the second volume of the same treatise which, at that time, was one of the best of its kind for both clarity and mathematical rigour. In the preface of the second edition of this second volume, Sommerfeld thanked Bruno Touschek for his critical review of the text.

When Bruno was expelled from the University of Vienna, Urban endeavoured, as I will tell later, to obtain the support of Sommerfeld. Sommerfeld wrote a letter of introduction to Paul Harteck¹⁶⁾, who was teaching in Hamburg, and Bruno moved to that town, where nobody knew of the "racial imperfection" of the young Austrian. That of course, was not true for Sommerfeld nor for Harteck or a few other professors who were perfectly well aware of it.

Harteck was a chemical physicist well known for his work on the production of heavy water (1934), on the chemistry of deuterium compounds (1937–38), and on artificial radioactivity and neutron physics (since 1938). He welcomed Touschek and advised him on how to behave when approaching the other professors, particularly one of them, Professor P.P. Koch¹⁷⁾, who had developed a high-sensitivity method for the photometric analysis of X-ray plates. Following Harteck's advice, Bruno studied this method in great detail. When, therefore, Koch questioned him during his admission examination, Touschek was in a position to answer in a very competent way, to the great satisfaction of his examiner.

In order to keep himself Bruno was forced to work; in fact, he had to do several jobs simultaneously. There were periods when he had to do four or five jobs at the same time. In addition, he did not have a fixed residence, but frequently moved so that he could not be easily found. In Hamburg he worked for a long time for the Studiengesellschaft für Elektronengeräte, an industry affiliated to the Dutch firm Philips, where "drift tubes", forerunners of the klystron (tubes in which the transit time is the same for all electrons), were being developed. This was a very important problem at that time for high-frequency communications.

At the University, Bruno attended various courses, without being registered, in particular the courses on theoretical physics, at the invitation of W. Lenz¹⁸⁾, who gave a course on relativity, and H.J.D. Jensen¹⁹⁾ who, about twenty years later, in 1963, won the Nobel Prize for Physics with Maria Goeppert-Mayer for the nuclear shell model.

During this period he was also in frequent contact with H. Suess²⁰⁾, who is well known for his study of the abundance of chemical elements in the Universe. His uncle Eduard Suess²¹⁾ had been a famous geologist, who had collaborated with the Curies and with Rutherford, and owned the largest collection of meteorites in the world. This had stimulated Suess to study and closely examine the problem of abundance.

For long periods "Touschek lived in the flat of Professor Lenz in Hamburg ... and he had considerable difficulty bringing the old and often sick man to the cellar when the bombers came."²²⁾

Once in a train in Berlin he met a girl, M. Hatschek—she too was half Jewish—who worked in a factory that had changed its name from *Lowenradio*, typically Jewish, to that of *Opta*. Miss Hatschek introduced Touschek to the management, who employed him in a section directed by Dr. Egerer, working on the

development of Brown's small tubes (i.e. cathodic oscillographs) for television. At that time Egerer was also Chief Editor of the scientific magazine *Archiv für Elektrotechnik*. Bruno worked at Opta for a long time, even after Dr. Egerer had left it to work only for the *Archiv für Elektrotechnik*. Egerer had Bruno's help in this work too, and it was thus that, at the beginning of 1943, Touschek heard of a proposal presented by Rolf Wideröe²³⁾ to construct a 15 MeV betatron. The proposal was kept secret because of its possible applications. Such secrecy, to tell the truth, appears today and certainly would have seemed to me (and to many others) rather curious even at that time²⁴⁾. The *Physical Review* of 1940–1 contained the papers by D.W. Kerst²⁵⁾ in which he described, with an abundance of detail, the 2.3 MeV betatron that they had conceived, designed, constructed, and put into operation at the University of Illinois, together with the theory, practically complete, of the orbits of the electrons, which had been developed by Kerst and R. Serber²⁶⁾. Furthermore, it was already clear that the betatron could be employed only as a source of X-rays used mainly for medical purposes. Reading Wideröe's proposals Touschek had the impression that the relativistic treatment of the stability of the orbits contained some mistakes. He wrote to Wideröe, who replied and invited him to go and work with him when, towards the end of 1943, he was ordered to build a machine of this type. So Touschek began working with Wideröe, R. Kollath²⁷⁾, and G. Schumann¹⁶⁴⁾, to develop a betatron. His principal contribution at that period was the use of the Hamiltonian formalism to study the orbits of circular machines. As Wideröe wrote to me: "He was of great help to us in understanding and explaining the complications of electron kinetics, especially the problems associated with the injection of the electrons from the outside to the stable orbit where they are being accelerated. Touschek showed that the process could be described by a Painlevé differential equation."²²⁾

The machine was constructed in the Röntgenröhrenwerk (X-ray tubes workshop) of C.H.F. Müller, at Pfuhsbüttel near Hamburg. In the autumn of 1944, the betatron began to function at 15 MeV.

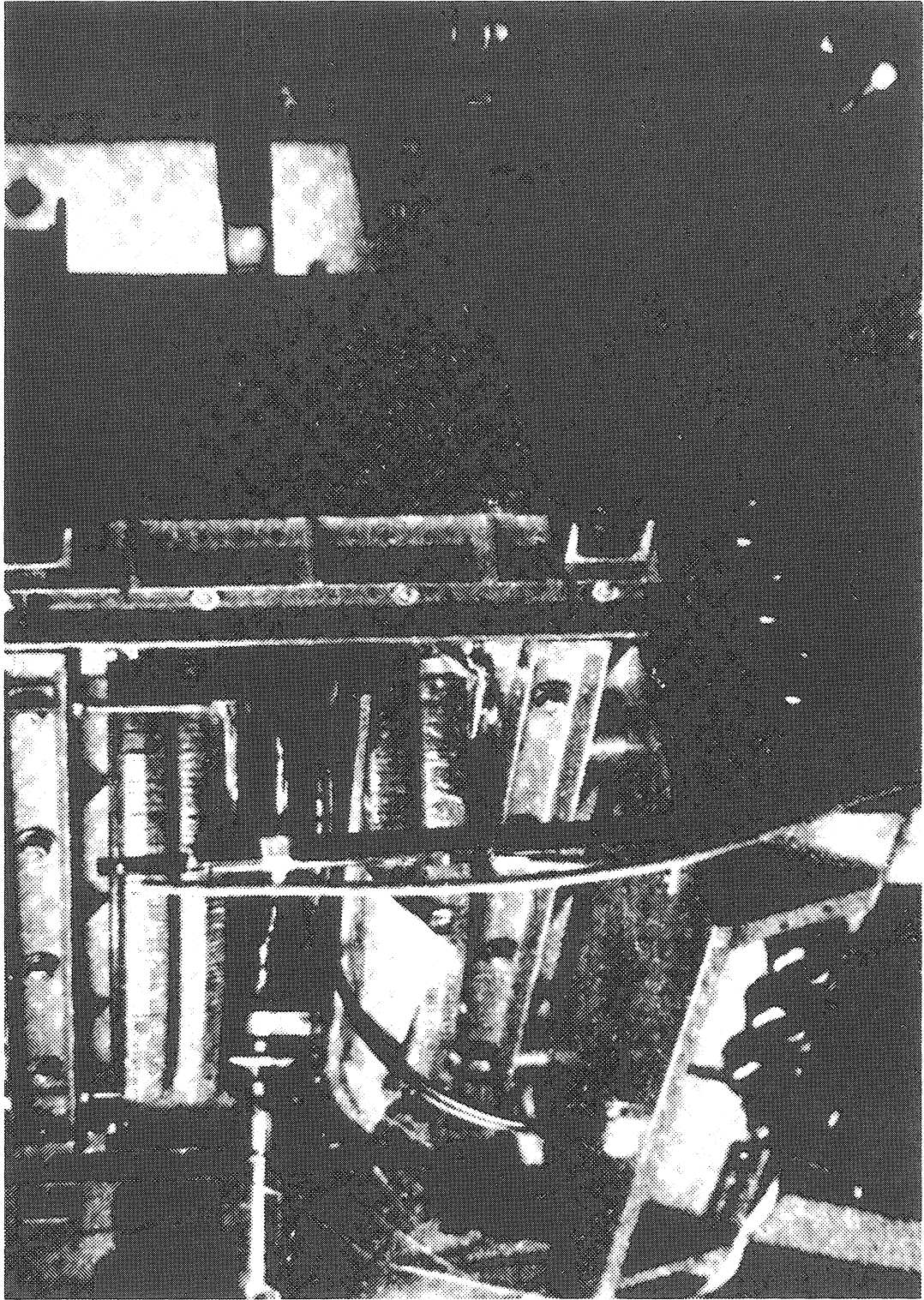
At the same time Touschek devoted a great deal of time to the development of fluorescent screens for radar tubes in which, in addition to the instantaneous blue fluorescence, a delayed reddish flash was produced. This work was done for the Strategic Command of Berlin in a building of a control tower which—being situated in the Tiergarten (Zoological Gardens) of Berlin—was practically unattackable. At this period he was also following a course in theoretical physics on superconductivity held by M. von Laue at the University of Berlin.

Once "in the evening Berlin had been attacked by bombers and heavily hit. In his neighbourhood many of the houses were burning and confusion was great. When he came out in the street with his heavy bookparks he had no way of getting to the railway station. But he was lucky. In the confusion someone had left a small electric goods stacker (Elektrostapler) in the street. He placed his books on the machine and drove off. He had never ridden on such a device before but everything went well; he got to the station and then caught a train to Hamburg."²²⁾

More or less at the same time he had got into the habit of going to the Chamber of Commerce in Hamburg, where there was a room in which one could read all the foreign newspapers. These repeated visits of his caused people to notice him, with the result that at the beginning of 1945 he was arrested by the Gestapo on racial grounds. At first, Wideröe went to see him in prison and brought him "some food, his dear books and, even more important, cigarettes."²²⁾ During these visits, Rolf and Bruno continued to talk of the betatron.

It was in prison that Touschek conceived the idea and developed the theory of "radiation damping" for electrons circulating in a betatron, which he wrote in invisible ink in the pages of Heitler's book *The quantum theory of radiation*²⁸⁾.

Around the end of February, or the beginning of March 1945, an order arrived to transfer the prisoners from Hamburg prison to a concentration camp in Kiel. Touschek had a very high temperature but was nevertheless ordered to leave the prison. He carried with him a heavy package of books and while he was marching, escorted by the SS, in the outskirts of Hamburg, he felt ill and collapsed into the gutter at the side of the street²⁹⁾. An SS officer took out his pistol and, pointing at his head, shot at him, wounding him behind the left ear. It was not a serious wound but he lost a lot of blood. As they thought he was dead, the column with the SS guards went on. A short time after, a group of civilians gathered on the edge of the road, discussing whether the prisoner abandoned in the gutter was dead or not. Really Touschek was still conscious and could



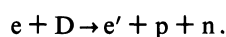
Photograph of the 15 MeV betatron constructed near Hamburg in 1943–1944 by Wideröe, Kollath, Schumann and Touschek (from the book by Kollath, see Ref. 27)

hear their conversation, but, as they went on for a long time, at a certain point he got up and to the general surprise asked where the nearest telephone was. They pointed to a building not far away and he went there. It proved to be a hospital, and he was treated there, but the Greek director told the police, who arrested him again and transferred him to the prison of Altona.

As Bruno said, this was a “prison of bats”³⁰⁾ where everything was extremely old. In particular, the guards and staff were all very old and kind to the prisoners. On Sundays a number of Czech prisoners of war were brought in and they did various odd jobs such as cutting wood for the stoves.

In the meanwhile the betatron group, in particular Kollath and the machine itself, were transferred to Wrist (in Holstein, near the Danish border), where some time later (probably in June 1945) the English arrived. Touschek was freed and went to Wrist, where the English asked him if he was willing to go with the troops as an interpreter. Having thought over the proposal, Touschek refused, also because at that moment both the occupying troops and the Germans—in particular the peasants in the country—were all extremely violent and killed each other practically without reason or purpose.

At the beginning of 1946, Bruno succeeded in going to Göttingen, where he had been attracted by the presence of a large number of physicists and the existence of a 6 MeV betatron. This machine had been constructed by K. Gund³¹⁾ in the Siemens Reiniger Laboratories at Erlangen, and had been transferred to the Institute of Physics of the University of Göttingen as a place that, presumably, would be left more or less alone by the Allied Authorities in Germany. W. Paul³²⁾, who at the time was “Privat Dozent”, had succeeded in extracting the electron beam from the machine, and started to use it for a few experiments, in particular for the study of the disintegration of deuterium³³⁾



Bruno arrived in Göttingen just at that time and came into contact with R. Becker³⁴⁾, O. Haxel³⁵⁾, H.C. Kopfermann³⁶⁾, W. Heisenberg³⁷⁾, F.G. Houtermans³⁸⁾, L. Prandtl³⁹⁾ and C.F. von Weizsäcker⁴⁰⁾.

During the summer, Bruno obtained the title of Diplomphysiker with a thesis on the theory of the betatron, made under the supervision of Becker and Kopfermann. A short time later, he was appointed a “wissenschaftliche Hilfskraft” (research worker) at the Max Planck Institute of Göttingen⁴¹⁾, where he began to work under the direction of Heisenberg. During this period he did two pieces of work, one on the double beta decay [6] and the other on the branching points of the solutions of Schrödinger equations [7].

Before passing on to the period spent by Touschek in Glasgow, it seems in order to add two historical notes, one concerning the manner in which Paul Urban managed to help Bruno to go to Hamburg, the other on the origin and development of betatrons, which are circular machines in which electrons are accelerated by the electric field generated by the time variation of the magnetic flux linked with the electron orbit.

For the first point, I reproduce a few parts of a long letter sent to me by Paul Urban in June 1980⁴²⁾. From 1931 to 1939 Urban had been employed in the Technical Division of the Austrian Railroads and had been at the same time in charge of a course at the Institute of Physics of the University of Vienna. Urban writes:

“This had been before the chair held by Professor Hans Thirring which had remained vacant, when the latter had been removed from his teaching because of his political ideas⁴³⁾. The chair had been entrusted to a temporary substitute, Professor Ludwig Flamm (son-in-law of Boltzmann) of the Technische Hochschule. Later E. Fues was called to Vienna from Wroclaw as one of the three taken into consideration, Weizsäcker, Sauter and Fues. Fues occupied this post until the final collapse of [Nazism]....

“I took Bruno with me to give him the possibility, together with a few other similar cases, such as Koch, Fränkl, etc., to work with me and use the library undisturbed. He immediately appeared to me to be a talented person but rather difficult because he was self-opiniated.

“Having been dismissed from my State employment (State Railroads) on 13 March 1938 because of my ‘hostile’ behaviour towards the NSDAP (National-Sozialist Deutsche-Arbeiter Partei) under the existing regime (§ 4 of the Law on the New Regulation concerning State Employment) also my position at the University had become very uncertain. My political convictions were so well known that I could not become a ‘Dozent’ but I had to content myself with the title of ‘Dr. habil.’ in order to prevent me from coming into contact with the students through teaching. At that time I was working on the theory of the experimental work

of my friend R. Haefer: Experimental research aiming at verifying the quantum mechanical theory of electron-emission (tunnel effect) published in the *Zeit. f. Phys.* 116, 604 (1940). I wanted to give a lecture on this subject at the seminar led by Sommerfeld. As is well known, Sommerfeld had been sent away from his institute and had been replaced by Professor J. Müller (hydrodynamics). Professor Clusius allowed the old Sommerfeld to hold a small seminar at the Institute of Chemical Physics at the University of Munich at Amalienstrasse, where his friends and admirers could meet and discuss with him. Taking advantage of my seminar, fixed for 24 November 1942, I wanted to introduce Touschek to those important people and provide a job for him in Germany, since his presence in Vienna had already become difficult. My principal, Professor Theodor Sexl, was always called on the telephone from the Second Institute for Experimental Physics (Professor Dr. Stetter) and requested to take measures concerning me, should I still be gathering with students who were not of pure race. At the end, I was forced to lend the books privately to my protégés and had to meet them frequently at my home at 28, St. Veitg (Vienna 13), where my mother also provided us with food.

“Thus we went to Munich together and I gave my lecture in the presence of Sommerfeld and other famous physicists (Touschek took care of the projection of the slides).

“In this way, I obtained a job for Touschek at Hamburg, so that he could leave Vienna. I do not know how he fared after this, since I had lost all contact with him. When we separated I gave him, however, a research subject that I recommended to him very warmly: the double beta decay. Later, he was able to obtain his diploma on the basis of a paper on this theme.

“I should not wish to keep you in the dark about another interesting fact which we lived. All the papers of Einstein, Laue, etc., were cut away with a razor blade from our scientific journals and books in order to prepare an auto-da-fê and thus cancel the ‘Judaic spirit’. The evening before this event, Sexl and I saved some of these publications, so that we could complete our library after the final collapse [of Nazism]. A person who shared my opinion, Hofrat (Councillor) R. Chorherr (at that time retired) helped us with extraordinary ability in these sad circumstances.”

I pass now to the origin and development of the betatrons. The first suggestion of constructing accelerators based on this principle was proposed by J. Slepian⁴⁴⁾ in order to produce X-rays. In the short text of this patent, however, the electrons moved in a region where the magnetic field remained constant with the passing of time. Consequently, the electrons could undergo only a very small acceleration. Shortly after (autumn 1922) and independently from Slepian, Rolf Wideröe proposed a scheme not essentially different from that of the present betatrons and started, at Aachen, some experimental research⁴⁵⁾, whose negative result was due in part to the lack of a theory of the stability of the orbits, in part to the absence of a thin conducting layer on the internal surface of the acceleration chamber. Wideröe noticed that the electric charges deposited on the glass wall of the chamber destroyed the equilibrium orbit of the electrons.

A series of experimental as well as theoretical papers followed these first steps⁴⁶⁾, which led in 1939 to the construction by Kerst et al., of the University of Illinois, of a small betatron of 2.3 MeV^{25,26)}. At that time Kerst did not know about the work done previously by Slepian, Wideröe and a few others.

The search carried out during the war by Wideröe and others near Hamburg, and by K. Gund and others⁴⁷⁾, first at Erlangen and later at Göttingen, certainly has an important place in the story of the development of accelerators⁴⁸⁾.

In a short note entitled “Das erste europäische Betatron für 15 MeV” (The first 15 MeV European Betatron) prepared by Wideröe for the Röntgen Museum in Lennep, the construction and end of the machine constructed near Hamburg is described as follows:

“...The construction of the Betatron was made possible in 1943 by the Air Force (Colonel Geist). Wideröe prepared the design and computations; C.H.F. Müller constructed the machine in the Röntgenröhrenwerk, at Pfuhsbüttel near Hamburg; tests of the betatron were made by R. Kollath, G. Schumann and R. Wideröe, with a remarkable support by R. Seifert. B. Touschek developed the various theoretical investigations. Towards the end of the war, the machine was transferred to Wrist, in Mittelholstein, and at the end of 1945 was brought to England as booty of war and deposited in the Woolwich arsenal (near London), where it was used for the non-destructive examination by means of X-rays of thick steel plates. Here the betatron disappeared.”

3. THE GLASGOW PERIOD

In February 1947 Touschek moved to Glasgow on being awarded a fellowship of the Department of Scientific and Industrial Research (DSIR) and started to be interested in the construction of the 350 MeV Synchrotron, initiated more or less at that time under the direction of P.I. Dee⁴⁹⁾, who has kindly sent me the following recollection:

“My association with Bruno Touschek began in April 1947 when he was brought to my office (under guard!) for an interview. This had been arranged by Dr. Ronald Fraser⁵⁰⁾ (a friend of mine), who had met Bruno when serving on a post-war Allied commission which was visiting laboratories in Germany and elsewhere. Touschek had expressed a wish to work in a British laboratory, and Fraser knew that I had recently come to Glasgow to try to construct a nuclear physics centre in the university here.

“I was quickly impressed by Touschek’s obvious ability, his extensive knowledge of Physics and his enthusiasm, and I arranged forthwith for him to have a research appointment in the department, which at that time had only one staff member on the theoretical side.

“In the following five years Touschek took an active part in the expansion of the department and worked closely with Professor Gunn⁵¹⁾ who, after his appointment in 1949, formed a strong theoretical team in parallel with the expansion of experimental work. Over this period Bruno became a close collaborator and personal friend. He was a person with immense vitality and enthusiasm. He was very clever and very original. He was also untiringly energetic and extrovert. Bruno led his life to the full extent in all situations and at all times. His enthusiasms were many and, although often brief, were exploited in a manner which most people would have found utterly exhausting.

“Naturally over this early period he gave me many problems! The first was his housing. A room in a small lodging house seemed satisfactory for a while but after a short ‘holiday’, which he spent potato picking in the north of Scotland, under spartan conditions, but fortified by the prospect of an early return to his comfortable room in Glasgow, this arrangement came to an abrupt end. On his return he found that the landlady had changed his curtains without prior consultation and, enraged by this destruction of his anticipated homecoming, he immediately returned the curtains to the manageress with a demand for instant restoration of the original ones. After a few further abortive attempts to find agreeable lodgings we seemed finally to reach a solution by installing him as a paying guest with a local resident. This however came to an end on a Sunday morning when, during my lunch, I answered the door to find Bruno on the doorstep, very dishevelled and agitated and exhibiting a severely bruised eye. It transpired that during lunch his host had spoken very rudely to his wife and Bruno’s attempts to teach him marital civility had ended in a violent physical encounter. After this event my wife and I decided that the only solution was to give Bruno the top room in our house in the university and for him to eat with us, this hopefully not only to put an end to my searches for accommodation, but also perhaps to provide a present restraint on my own behaviour. Our house in the university was an old one on five floors, with rather steep communicating stairways. During the year or two which followed I never met Bruno on these stairs. His transit times from top to bottom and in reverse were always so short that there was negligible probability of an encounter. Touschek’s varied and intense enthusiasms added much to the lives of the members of my family. On a neighbouring court my wife taught him to play tennis but never succeeded in providing sufficiently long periods of play to satisfy him, despite the fact that she has an abnormally low heart rate and is normally never tired under any other known circumstances. Frequently, near midnight, he would raid my study for a quick game of chess or some similar activity. At chess he was very quick and enterprising but often too original, or too obsessed with some new plan, to be regularly successful. At five minute games however, he was invincible, often perhaps because he would keep one finger firmly pressed upon his timing button so that my clock would be registering almost throughout and his rarely, if at all, until my time limit had elapsed.

“Bruno’s passion for novelty and independence knew no bounds. When he decided to have a desk made by a local carpenter he produced detailed drawings which the carpenter was forced to follow despite his strong reluctance. The end product was a desk having drawers with no backs and sides (to avoid dusty corners and edges) and which were to serve as withdrawable trays. This scheme might have been successful for a person of less ebullient character, but with Bruno’s rapidity of movement the result, in use, was a progressive and systematic transfer of the contents of all the drawers to the bottom level.



Bruno Tuschek in Glasgow (1949)

“On many occasions Bruno joined us in climbs on Scottish mountains. On these he would gradually discard and hide items of clothing, the final stage being completed in almost complete nudity. This also had the advantage that he could immerse himself in any small pools or burns which we came across on the way. He was an excellent swimmer with a dolphin like action, but here again he was rash and adventurous, once swimming to an island on Loch Lomond which even he felt to be too remote to risk the return swim. Fortunately he managed to hail a passing boat which returned him, blue with cold, to our picnic site.

“Bruno’s impatience with the slowness of behaviour of normal people often had very amusing consequences. Once having been allocated a new room in the laboratory and being unable to wait for a proposed redecoration, he embarked personally and without warning on this activity, during a weekend when the department was otherwise unoccupied. Apparently he soon found that proceeding systematically was very dull and boring, so he covered various areas at random as the spirit moved him. By Monday morning the room had a nightmarish patchwork appearance, whilst the fine teak block floor (left uncovered during the operation) was now coated with thousands of spots and streaks, so numerous as to give the impression that perhaps this had been intended. The situation was seemingly irrevocable and further exacerbated by a local contractor working in the department at the time, who took his friends and visitors to see the workmanship of what he claimed to be the university’s own works department. This led to official protests and the placing of an embargo on any work on that room by university staff. My only course was to lock the room up for a period to allow passions to subside.

“I hope I have not given the impression that Bruno did not normally produce tidy and systematic work. In fact his written work was always very tidy and ordered, set out in stylish calligraphy and overall with a presentation which had quite an artistic flavour. Indeed, he had quite marked artistic talent and could make sketches showing a fine sensitivity and economy of line. My daughters still have some beautiful bookmarkers which he put into their birthday presents. I once even tried to persuade him to develop and exploit this ability but his reaction was that to do so would spoil the pleasure he derived from such an occasional pastime.

“I have perhaps not written enough about Bruno’s work because I think others can do better than I can, but I must refer to the delight he always experienced in the solution of a problem or the presentation of a piece of scientific argument. Requiring the proof of a theorem he would only rarely bother to consult the literature. In this there was a degree of arrogance. He seemed to assume that his own proof would probably be shorter and neater. Despite his excitement when reaching the desired result there was no lasting pride or boast. For a brief instant he would beam with satisfaction, perhaps self satisfaction, but moments later all would be forgotten and he would be away with something new.

“In Bruno’s personal relationships he was normally very polite, friendly and loyal. He could certainly be hot-tempered, angry and emotional but in the end he was basically kind and reasonable. When I met him in Rome in 1962 he was much more stable and much quieter in demeanour but still very considerate and kind. He took great pains to ensure that my wife and I had a happy and interesting stay in that beautiful city. I think he knew that we were rather raw and inexperienced travellers and did much to make us feel welcome and at home there.

“I am deeply sad to realise that he has gone from us all. He was a person who led an intense and vigorous life and one who, by his example and friendliness, helped me and I expect many others to achieve greater happiness and awareness in their own lives.”

P.I. Dee
25.5.1979

4. HIS SCIENTIFIC WORK AT GLASGOW (1947–1952)

Touschek's friendship and collaboration with Dee enabled him to study in depth the problems related to the working of the synchrotron, and he published an article on its characteristics some years later [10]. That same year, he was awarded his Ph.D. with a thesis on nuclear excitation and the production of mesons by electrons, of which Gunn was the internal rapporteur and Rudolf Peierls⁵²⁾ the external one. Immediately after this he was appointed "Official Lecturer in Natural Philosophy" at the University of Glasgow, a position he held until he left for Rome.

The subject of his thesis already reveals the nature of his scientific interests at the time. In a series of papers [some of which were written with I.N. Sneddon⁵³⁾] he dealt with the problem of nuclear excitation by electrons [1, 5], nuclear models [3], the density of the energy levels of the nuclei [4], the evaluation of the position of the lowest level excited by electric dipole transitions, and the quadrupole moments of the nuclei in the shell model [11, 12]. Other papers concerned the problem of meson production: by electrons (with Sneddon [8, 9] and in proton-proton collisions (with J.C. Gunn and E.A. Power [13, 14]). Other papers study the divergence in quantum field theory [2] and the perturbative treatment of the bound (closed) states in quantum field theory [16].

In September-October 1950, Walter Thirring⁵⁴⁾ came up to Glasgow as Nuffield Fellow, and met Touschek. In those months they worked together [15] on the covariant formulation of the Bloch-Nordsieck method to solve the general electrodynamic problem in the presence of an external current. They saw that in this case perturbation theory cannot be used, since the perturbed state is orthogonal to the unperturbed state.

In a paper written with Roy Chisholm [19] Touschek discussed the spin orbit coupling in nuclei as essentially due to the exchange of pions in an S state between the nucleon and the rest of the nucleus. The spin orbit interaction thus calculated, however, has the wrong sign. After Touschek had left Glasgow, Ernest Laing, a student of Chisholm⁵⁵⁾ showed that the sign of the spin orbit interaction becomes the correct one because of an enhancing factor originating from a nucleon self-energy term due to the simultaneous emission and reabsorption of a pion in a P state⁵⁶⁾. However, an extremely high density of nucleons in the nucleus was necessary to obtain the right order of magnitude of the interaction. Many years later, in his paper with A. Bietti ("Scalar mesons and the nuclear spin-orbit coupling" [55]) Touschek showed that introducing an interaction between the two pions in an S state so as to create a resonance (with $mc^2 \simeq 380$ MeV, as suggested by some experiments) one obtains a scalar spin orbit potential, which is basically correct for reasonable densities of the rest of the nucleus.

In other papers written with W.K. Burton, Touschek examined the commutation relationship [18] and Schrödinger's dynamic principle [20].

As Chisholm relates, in Glasgow Bruno had bought a motor cycle "which had a special feature, independent suspension of the front forks. During the first fortnight with this vehicle, he fell off it twice. He was convinced that he was not to blame for these accidents, and the evening after the second he settled down to make a complete study of the dynamics of the motor cycle. This took him about nine or ten hours, ending in the early hours of the next morning. His study showed that the new degree of freedom which had been introduced by the makers was unstable. He sent his full analysis to the manufacturers together with a letter beginning 'Dear Assassins,' The model was withdrawn from the market shortly afterwards. Some of those who suffered as a result of this accident were members of the first year Physics class, who had a lecture on Mechanics from Bruno the next day. Since he had prepared no other material they were treated to a lecture on Mechanics of the motor cycle and the bicycle; you can imagine that they would find this fairly difficult."

5. BRUNO ARRIVES AND SETTLES IN ROME (1952)

In December 1952 Bruno Touschek moved to Rome, to which he had always been attracted owing to cultural and family ties. It was in Rome that his aunt Ada resided, having come there many years before. She was his mother's sister, and had married an Italian, Gaetano Vannini. Aunt Ada was the owner and joint manager with her husband of an agency in Rome representing an Austrian firm (Garvens s.r.l.), which specialized in the manufacture of water pumps and irrigation systems. His aunt and uncle also owned a house in the neighbourhood of Albano and, as they had no children, were always happy when their nephew visited them, although Bruno sometimes could not conceal a certain intolerance for the care and advice which his aunt Ada lavished on him. Their relationships, which could be glimpsed from the incidental remarks made by Bruno, were often reminiscent of those which existed between Bertie Wooster and Aunt Agatha in the books by P.G. Woodhouse, devoted to the butler Jeeves, although the background, typically Viennese, was quite different from that which prevailed in Britain.

His mother's mother, Joseffa, had come to Rome to live in 1938, but at the beginning of the war her daughter Ada persuaded her to return to Vienna, thinking that it would be safer there. During 1941, however, on a date which I have not been able to determine, she was arrested by the Nazis and sent to the Theresienstadt extermination camp, where she died shortly after.

Rather more than for family reasons, however, Bruno Touschek was attracted to Rome as a result of his acquaintance with Bruno Ferretti, owing to their papers which appeared in the scientific press.

In 1948, Ferretti⁵⁷⁾ was invited to be Professor of Theoretical Physics at the University of Rome, a post previously held by G.C. Wick, who had accepted an offer from the University of Notre Dame at South Bend (Indiana).

Ferretti, in fact, had been in Rome until he was appointed Professor of Theoretical Physics at the University of Milan in 1947, and on his return had succeeded in strengthening the group of young theoretical physicists from Rome and instilling considerable life into it. I should mention that among the members of the groups were the following, in order of age and training: E. Corinaldesi, M. Verde, B. Zumino, G. Morpurgo, R. Gatto, F. Fabri and C. Bernardini.

In September 1952, Bruno Touschek went to visit Ferretti at the Guglielmo Marconi Physics Institute. A few hours after their first meeting, spent discussing mutual scientific questions, they established such a marked professional respect and personal attachment for each other that Touschek decided to remain permanently in Rome. This became possible because he was appointed to the post of researcher (grade R2, equivalent to that of an Extraordinary Professor) in the Rome Section of the Istituto Nazionale di Fisica Nucleare, of which I was Director at that time⁵⁸⁾.

Bruno Touschek and Bruno Ferretti never published a joint paper, perhaps because both were too individualistic in their manner of thinking, and because they had complementary qualities. This was so much the case that they were always ready to engage in a detailed discussion but had difficulty in following a systematic approach in solving a specific problem. Their daily discussions of the very diverse and most difficult problems of theoretical physics provided, however, for many years, an extremely strong incentive to a deep understanding of these very problems, not only by themselves, the two main protagonists, but also by other young theoreticians, who had studied or were studying in those years at the Institute of Physics.

This form of discussion came to an end in 1954, when Bruno Ferretti moved to Bologna and was replaced by Marcello Cini. But Touschek's influence on the group of theorists continued to have an effect for many years, and began to diminish only from 1960 onward, when his interests shifted towards the possibility of constructing accelerator machines in order to study the processes produced by electron-positron collisions, of which we shall speak later.

When Touschek moved to Rome, the main interest which he shared with Ferretti was the construction of a quantum field theory which would also include bound states, i.e. a theory which would go beyond perturbation methods.

Ferretti pointed out to me that Touschek was among the first to maintain that it was possible to construct a unified theory of electromagnetic and weak interactions, the first example of which was actually constructed by S. Weinberg and A. Salam shortly after⁵⁹⁾. A passing reference to this idea had already been given in a work by Touschek on the neutrino theory [43] but was dealt with in a more detailed manner in a

subsequent paper prepared with the collaboration of I.M. Barbour and A. Bietti [51], and we shall come back to this later (see Section 13). Ferretti had some correspondence on this subject with Tousek.

In those early years of his life in Rome, Bruno Tousek owned a motor cycle which he called Josephine; he claimed that when he had been out late drinking in a pub or at a friend's Josephine knew how to bring him home safely.

In 1955, Bruno returned to Glasgow to marry Elspeth Yonge, the daughter of a well-known professor of Zoology at the University of Edinburgh, Sir (Charles) Maurice Yonge⁶⁰. Elspeth gave Bruno two sons, Francis in 1958 and Stefan in 1961. The Touseks first lived in a flat in Via Mancinelli (Piazza Vescovio), then in Via Saliceto, in a flat which had a terrace overlooking a most beautiful garden with trees. They then moved to Viale Regina Margherita, at the corner with Via Morgagni, and finally to No. 23 Via Pola.

Each time he looked for accommodation and found a vacant flat in a district which he liked he went to the doorkeeper and asked "Do any officers live here?" The reason for this question, he explained to those that accompanied him or to his friends at the Institute next day, was that "it is impossible to cohabit in the same building as officers". This profound antimilitarism also emerged on other occasions. For example, as Careri recalls, when in 1957 "Sputnik II" was launched carrying a living being for the first time (the she-dog Laika), Bruno went around the Institute and, rubbing his hands out of satisfaction, said "it is rather a costly method but you will see that gradually we will get rid of all the military by sending them out into space."

On another occasion one night on his motor cycle he ran into the rear of a large car at a cross-roads, flew right over the top of it and injured his skull during the fall. He was immediately taken to the Neurological Clinic, which at that time was directed by Professor Ugo Cerletti.

The injured person was in a state of great agitation and even if what he said was not understandable, he appeared to be of German tongue. The next morning, the doctor of the Psychiatric Section asked Dr. Valentino Braitenberg, of the Bolzano province, to go from the laboratory where he was working to fill in the hospital sheet for the newly admitted person. As Braitenberg relates "... a first superficial examination (that would not have lasted more than a few minutes) allowed my colleagues to determine that he was not Italian and to suspect psychosis. The injured man had declared he was a theoretical physicist, Vice-Director of the Scuola di Perfezionamento di Fisica Nucleare and a specialist in time reversal (see Section 6). I found Bruno sitting on his bed in the ward, still rather angry but already occupied in observing with interest the spectrum of mental alienations displayed by the surrounding patients. He wore a turban applied by the first-aid doctors when they treated the wound that he had received during the fall. The slight concussion which he suffered in combination with the high alcohol content in his blood had caused a state of agitation, as frequently happens, as a result of which the police decided to apply the rules of psychiatry rather than those of the Penal Code. We immediately became friends. His story was convincing and not at all psychotic, his German was delicious, rich and precise, his humour was uncontrollable even in such embarrassing circumstances. I wrote his clinical story with his help. The only slightly abnormal detail was the daily quantity of wine, but Bruno gave good reasons: tennis, the scarcity of water in aqueducts, etc. I thought it appropriate to give him the "routine" sermon. Bruno answered that his liver was his and that if I wanted to associate myself with his habits, he would be very glad to bring me to Nemi the following Sunday. I accepted and after that for many months we spent almost all week-ends together, Bruno, my future wife, whom I had just met at that time, and myself. We started to talk of cybernetics, there was a seminar on the computer machines in which I participated as a guest, and finally the avalanche of cybernetic activities that carried me with it and transformed my life".

On arriving in Rome Tousek spoke a peculiar form of Italian which was a combination of Latin and English.

Bruno Ferretti's wife, Maria, who at that time worked at the Institute as a "Nostromo" (a combination of a secretary, purchasing employee and store-keeper of materials and instruments), recalls the following expressions which were typical of Bruno: "... il giusto tecnico del tornare", instead of "la tecnica giusta per voltare (l'automobile)"; "... c'era tant'acqua che si nagiava e la padrona diceva che ero io che avevo pizzicato le pipe..." (pinched the pipes); "... mia zia è tanto affezionata ai suoi cannelli lunghi lunghi (bassotti)..." and so on. But as years went by, his Italian became excellent, although he continued to use his own characteristic turns of phrase.

At home, he had two cats, a black one, which he called Planck, and a striped cat which he called Pauli. After making Pauli undergo a series of intelligence tests, Bruno decided that he was extremely intelligent. He made him undergo another test but Pauli failed to pass this one: after very careful preparation, Bruno gave him a tin of sardines and a key to open it, but Pauli did not open the tin and so did not eat the sardines.

Shortly after his arrival, we acquired the habit of playing tennis together two or three times a week. Sometimes we were joined by Francesco Calogero. We always played very seriously and enjoyed ourselves very much. On one occasion, a few years later, we were both taken with an irresistible desire to wear out our opponent. We played for a long time, putting everything into it, each trying to make the other run as much as possible. We played much longer than usual and finally we gave up, exhausted but satisfied. During the night I felt ill; by all appearances, I had taxed my heart unduly. I was seen by a doctor whose harsh words were combined with those which I inevitably received from my wife who, on this as on every other occasion, pointed out how foolish I was, although I had almost reached my fifties.

For many years I kept quiet about this incident, but one day, much later, Bruno by chance told me that on that particular night he had not felt well either.