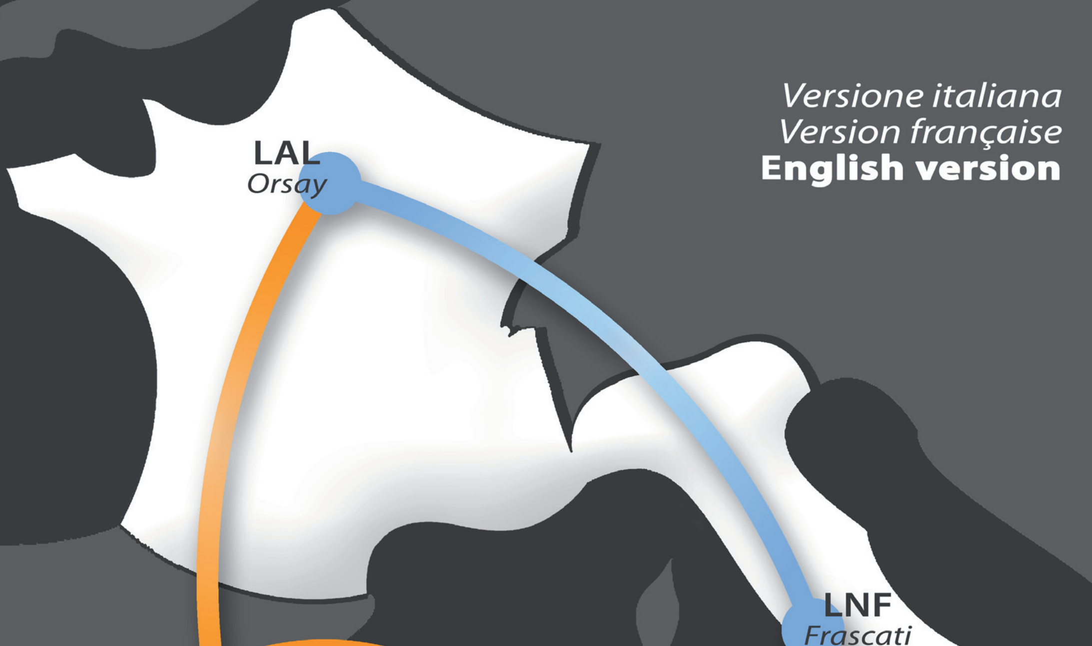
# Bruno Touschek Memorial Lectures

## 1961-2011 From **AdA** to **SuperB**

Anniversary Brochure

*Versione italiana*
*Version française*
**English version**




Bruno Mazoyer -LAL Orsay

Laboratoire de l'Accélérateur Linéaire

INFN Istituto Nazionale di Fisica Nucleare
Laboratoire National de Frascati

http://www.lnf.infn.it/conference/btml2011

# Bruno Touschek Memorial Lectures

## AdA the first electron-positron storage ring

INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati

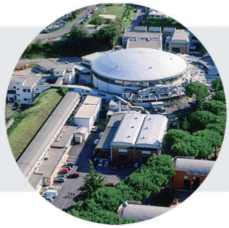
LAL Laboratoire de l'Accélérateur Linéaire

## 1961-2011 from AdA to SuperB

Comune di Frascati

Commune d'Orsay

Scientific twinning Frascati-Orsay



SuperB

**Thursday December 1st, 2011**
**10:00 a.m.**
**Bruno Touschek auditorium**

### Speakers

| | |
|---|---|
| C. Bernardini | Univ. Sapienza, Roma |
| J. Haïssinski | LAL, Orsay |
| G. Pancheri | LNF, Frascati |
| R. Petronzio | Univ. Tor Vergata, Roma |
| P. Raimondi | LNF, Frascati |
| G. Salvini | Univ. Sapienza, Roma |
| A. Skrinsky | BINP, Novosibirsk |
| A. Stocchi | LAL, Orsay |

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## PREFACE

Fifty years ago, the first electron-positron storage ring in the world, the Anello di Accumulazione (AdA), started operating in Frascati at INFN National Laboratories. AdA had been conceived by the Austrian born theorist Bruno Touschek, who, in February-March 1960, put forward a project, which had been rapidly approved. Built in less than one year by a team of engineers, technicians and physicists, some of whom had just completed the construction of a powerful electron synchrotron of 1100 MeV, AdA was brought to operation in February 1961.

To celebrate this historical milestone, in Frascati on December 1st, the INFN Frascati National Laboratories and the French IN2P3/CNRS Laboratoire de l'Accélérateur Linéaire d'Orsay, LAL, where AdA was successfully operated as a collider for the first time, jointly organize a workshop entitled "From AdA to SuperB" as a special event in the series "Bruno Touschek Memorial Lectures".

The workshop programme is divided in two parts: the first, targeted to the scientific community, is dedicated to the history of electron-positron collisions and to the new SuperB project; the second part, hosted in the beautiful setting of the Scuderie Aldobrandini in the town of Frascati, consists in a seminar on SuperB tuned for the general public. Thanks to the Mayors of Frascati and Orsay, a scientific twinning between the two cities will be established.

INFN Frascati Laboratory Director — Umberto Dosselli

Laboratoire de l'Accélérateur Linéaire Director — Achille Stocchi

## CHAPTER 1

## INFN – THE FRASCATI NATIONAL LABORATORY

INFN Istituto Nazionale di Fisica Nucleare
Laboratoire National de Frascati

The Frascati National Laboratory (LNF) has been the first institute created in Italy to study nuclear and subnuclear physics using particle accelerators. Today it is the biggest laboratory of the INFN (Istituto Nazionale di Fisica Nucleare), the national agency which promotes, manages and finances public research activities in the field of nuclear and subnuclear physics.

*Aerial view of the LNF.*

The LNF was built in 1955, a period of major breakthroughs in particle physics. During the previous decades, physicists had studied the structure and the transformations of the nuclei and they were just starting to discover the nature of their components. Moreover, cosmic ray experiments had shown the existence of new particles, absent in ordinary matter. INFN gave LNF the task to build particle accelerators able to probe the nucleus constituents and to produce these new forms of matter in laboratory experiments.

Since then, LNF has always been a major actor in all INFN research fields: accelerator physics, nuclear and subnuclear physics, cosmic ray physics and synchrotron light applications in physics. Today the laboratory manpower counts 348 perople in total: researchers, engineers, technicians and administrative staff. In addition, about 450 visitors from Italy and abroad contribute to the on-site activities.

The main asset of LNF is its capability to build state-of-the-art particle accelerators. This activity started in 1957 with the 1100 MeV synchrotron, the most powerful machine at that time; then it proceeded with AdA and ADONE, to lead today to the successful DAΦNE machine which holds the world record of instantaneous luminosity at low energy. Nowadays, the LNF is hosting as well SPARC, a free-electron laser built in collaboration with ENEA and CNR, and FLAME, an ultra-high power laser which is used to study innovating techniques to accelerate particles.

The technical and scientific skills of the LNF Accelerator Department are unique in Italy and rare in Europe; they are resources INFN provides to the society. Indeed, in addition to its fundamental research activities, the Accelerator Department (90 people in total) took part in the building of an accelerator of protons and carbon ions, used for medical therapies at CNAO (Centro Nazionale per la Adroterapia Oncologica) in Pavia, as well as the building of SPARX, a free-electron laser producing X rays, located in the Tor Vergata University and which will be used for studying the structure of the matter, in biology and in material science.

Alongside the Accelerator Division and supported by the Technical and Administrative Departments, stands the Research Division, which counts 180 people between staff and associates: researchers, engineers and technicians involved in research activities at Frascati and in international collaborations. Two experiments are currently running on the LNF site: KLOE, a particle physics detector which is studying the differences between matter and antimatter and the gravitational wave detector NAUTILUS. The LNF is also taking part in ongoing experiments at CERN near Geneva, at Fermilab near Chicago, at Stanford's SLAC (California), at JLAB (Virginia), at DESY in Germany and at the INFN laboratories of Legnaro, Gran Sasso and Catania. The close collaboration with all these research institutes allows LNF researchers and technicians to continuously seek a direct confrontation with their foreign counterparts; that confrontation is mandatory for initiating and maintaining high quality research in Italy.

On-site accelerators such as the international collaborations named above, have given a great contribution to the laboratory while motivating the best physicists, engineers and technicians to come and work at Frascati. Thanks to this cultural richness, complementary activities to the research in particle physics could be created. Examples of this include the use of the synchrotron light emitted by the DAΦNE electrons; the use of electron, positron and photon beams extracted from the DAΦNE injector; research in material science; medical and spatial applications; the development of new detectors; imaging techniques; the development of X-ray optics; radioprotection and environment control; the management of computing networks; finally the construction of advanced computing centers.

Moreover, the LNF has been active for years in science outreach thanks to educational programs targeting schools and the general audience: guided tours of experiments; training sessions for students; physics meetings ("Incontri di Fisica") for high school teachers in addition to regular courses; seminars; conferences with the authors of books dealing with science outreach. These activities are organized both at LNF and in many schools and science institutes nationwide.

*Overall view of the DAΦNE accelerator.*

## CHAPTER 2

## CNRS - LAL

### Laboratoire de l’Accélérateur Linéaire

The "Laboratoire de l’Accélérateur Linéaire" (in English the Linear Accelerator Laboratory, in short LAL) is a major laboratory in fundamental research whose main field is the physics of the two infinities. On the one hand, the study of the tiniest components of matter, the elementary particles; on the other hand, the cosmology which explores the history, the composition and the evolution of the Universe. As implied by its name, LAL has been tightly coupled to particle accelerators since its creation in 1956, both on the physics side and through the associated technological developments.


*Entry of the LAL.*

LAL is a joint research unit of the IN2P3 (the "National Institute of Nuclear Physics and Particle Physics", one of the ten institutes of the French "National Center for Scientific Research", in short the CNRS) and of the Paris-Sud University. Hence, the lab physicists are either CNRS or faculty staff. Indeed, LAL is deeply involved in teaching activities at all levels – bachelor and master degrees, "Grandes Écoles" – and a dozen students start their PhD thesis at LAL every year. In addition to fundamental research, LAL is sponsoring many outreach activities which target students, teachers and the general audience. Two examples: first, the "Élémentaire" journal ("Elementary", http://elementaire.web.lal.in2p3.fr) about particle physics which redaction was mainly made up of LAL staff members; secondly, a long-term parternship with the Sciences-ACO association (http://www.sciencesaco.fr), whose main goal is to make the general audience visit the "Anneau de Collisions d'Orsay" (ACO, in English "Orsay Colliding Ring"), a former LAL accelerator perfectly preserved and now a French historical landmark.

LAL includes about 120 researchers who work in a dozen projects. The largest teams are the ATLAS and LHCb groups who work in these big LHC experiments at CERN (Switzerland). As always, LAL contributions range from technical developments (design, building, commissioning and maintenance of large detectors) to state-of-the-art physics analysis. On the cosmology field, the main experiment is currently the Planck satellite, launched in Spring 2009, which has already surveyed a few times the whole sky to measure the characteristics of the Cosmic Microwave Background, emitted about 300,000 years after the Big Bang when the Universe became transparent to the electromagnetic radiation. After having contributed to the satellite main embedded computer and to the HFI detector, the lab team is now focusing on the extraction of the physics results which will be published within a few months. Beyond CERN and the space, LAL is involved in many international projects: the DØ and BaBar experiments in the USA, the Pierre Auger observatory in Argentina, the successive NEMO detectors in the Modane underground laboratory located inside the Frejus tunnel, the giant Virgo interferometer in Italy which aims at detecting directly gravitational waves, the search for dark matter and dark energy with the LSST and BAO-radio projects. In addition, LAL is also involved in many new programs to plan its future activities: the LHC detector upgrades, the next linear collider, the JEM-EUSO experiment on the International Space Station and finally the project of a new generation B-factory – SuperB – in Italy.

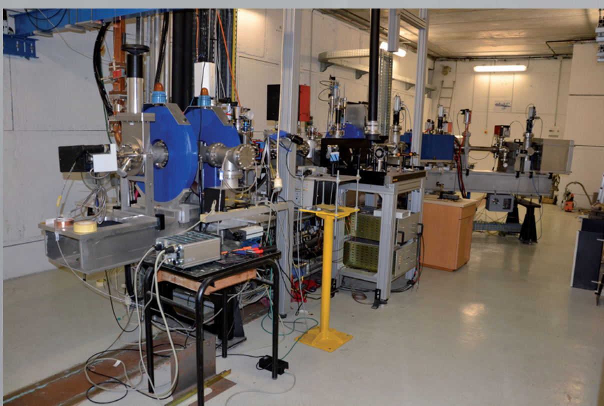
Although the large linear accelerator, which gave its name to LAL, was turned off at the end of 2004 and then disassembled, the lab involvement in the particle accelerator field has always been important. Today, LAL is completing the construction of a 10 MeV electron accelerator, built in the lab and whose R&D activities will allow the development of tomorrow's particle injectors. The PHIL facility will also be open to a large user community which will use its unique beam properties for dedicated experiments. Moreover, LAL is responsible for the building and the conditioning of the 640 couplers of the new free-electron laser XFEL which will be built at DESY in Germany. This multi-million contract requires a strong partnership between the lab and private companies like Thales. Moreover, LAL started the construction of an innovative X-ray source, ThomX, which will deliver its beams in a nearby building. This top-class equipment (which was awarded "Equipement d'Excellence" by the French National Research Agency in 2011) will have many applications, from medical research to non-invasive studies of art masterpieces. Thanks to its small size and its limited cost, ThomX is likely to interest many labs and private companies worldwide. More fundamental activities are also ongoing, like for instance the commissioning of beams with record emittance at the ATF2 beamline in Japan.

LAL successes are primarily due to its high-quality technical and administrative services which count in total more than 200 engineers and technicians. The electronics, mechanics, computing and accelerator services design, build, install and repair key components of the experiments of which LAL is part, both locally and in the largest laboratories in the world. The human resources, finance, travel and infrastructure & logistics departments, manage the lab manpower and allow them to realize the lab projects in the best possible conditions.

LAL history is very rich, as shown during the two-day celebrations of the lab 50th's anniversary in 2006. Built under the leadership of professor Yves Rocard (from the "École Normale Supérieure" physics laboratory) to provide physicists with a state-of-the-art large linear accelerator, LAL obtained its first successes in the early 1960's. In particular, the first electron-positron collisions in the world have been observed in 1963 in the AdA ring – designed and built at the INFN Frascati laboratory in 1961 and moved to Orsay the following year, in order to use LAL linac as injector – and the startup of the ACO ring in 1965. First, ACO allowed important measurements in particle physics. Then, ACO, followed later by SuperACO, was a leader in the use of synchrotron light for other physics fields (material science, chemistry, etc.). The "Laboratoire pour l'Utilisation du Rayonnement Électromagnétique" (LURE, in English the "Laboratory for the Use of Electromagnetic Radiation") was created in 1973 to develop this activity and it became independent from LAL in 1985. Today, the LURE has led to the SOLEIL synchrotron on the Saclay plateau, a first-class third generation light source.

Until the beginning of the 1970's, LAL was mainly involved in local experiments installed on colliding rings which were using the large linac (whose energy reached 2.3 GeV) as injector. This period ended with the DM-2 detector on the DCI ring ("Dispositif de Collisions dans l'Igloo", or "Colliding Experiment in the Igloo building"). In parallel, LAL joined experiments located in other laboratories, in particular at CERN. Indeed, in the early 1970's, LAL played a key role in the Gargamelle experiment, under the leadership of its director, André Lagarrigue. From more than a million pictures of bubble chamber events, a few special ones allowed the discovery of the "neutral currents", a key prediction of the electroweak Standard Model. The partnership with CERN got extended in the 1980's and 1990's, with the discovery of the W and Z bosons (LAL was part of the UA2 experiment on the proton-antiproton $Sp\bar{p}S$ collider) followed with precision measurement of their properties (in the ALEPH and DELPHI experiments on the electron-positron LEP collider). Today, LAL strong involvement with CERN is best illustrated by its participation in the LHC ATLAS and LHCb experiments.

To conclude, LAL history is a great adventure marked by many great scientific, technical and human achievements. The lab is not only contemplating its past; now and more than ever, it is deeply involved in the greatest scientific challenges of the 21 st century: the search for New Physics beyond the Standard Model, understanding of the laws which rule the Universe and studies of its characteristics, applications for society deriving from fundamental research, etc. The laboratory is building a promising future, rich of discoveries and progress in science, both fundamental and applied.



*The PHIL photoinjector.*

## CHAPTER 3

## THE CITY OF FRASCATI


**City of Frascati : province of Rome**

The city of Frascati is located in an area occupied in ancient times by Roman villas – among which Cicero’s – and in the region originally belonging to the suburbs of the ancient Latin city of Tusculum. Considered as the pearl of the Roman Castles (“Castelli Romani”), both for its marvelous geographical location and for its archeological, historical-artistic and environmental distinctive features, Frascati – whose name was mentioned for the first time in the Liber Pontificalis around the middle of the 16th century – grew in size after the destruction of Tuscolo, in 1191. After some ups and downs that had as principal characters people like Cola di Rienzo, Pope Pius II Piccolomini – who undertook to build the first city walls –, the Cardinal Guillaume d’Estouteville, Lucrezia Borgia, Lucrezia della Rovere and Marcantonio Colonna, Frascati became a property of the Farnese family and in 1538 Pope Paul III Farnese established it with the title of city ("civitas").

From the second half of the 16th century, some of the most important members of the Apostolic Chamber undertook to build their residences, all gorgeous houses erected to show their owner’s power, among which the villas Aldobrandini, Tuscolana (La Rufinella), Lancellotti and Falconieri. These places were beautified by the masterpieces of the best architects and artists of that period, like Bernini, Borromini, Della Porta, Maderno, Cavalier d’Arpino, Domenichino or Pier Leone Ghezzi. Because of its splendor, Frascati was one of the compulsory stops for the Grand Tour travelers during the 18th century and until the first half of the 19th century; the works of artists such as Gaspar van Wittel, Robert Hubert, Charles de Chatillon, Claude Lorrain still measure today the extent of the attraction the city of Frascati had for its famous visitors. The writings of Goethe, Scott, Stendhal, Charles De Brosses, Mark Twain, Erik Ibsen, George Sand, Emile Zola account for this strong feeling as well.

In 1856, during the pontificate of Pio IX, the Rome-Frascati railway line was inaugurated, the first in the Lazio region and one of the first in all of Italy;

consequently, trade and tourist circulation to the city got boosted. Unfortunately, World War II gave Frascati the mark of a deep wound: the city was heavily bombed by allied planes on September 8th, 1943, due to the presence on its territory of the German Center-South headquarters. Most of the city center was destroyed by this bombing. The Day of Remembrance ("Giorno della Memoria") anniversary is commemorated every year; that day, since 1999, the City Council invites other cities which have been victims of war as well to introduce a symbolic Peace twinning. In chronological order, the cities invited to take part to this memorial day are: Cassino, Marzabotto, Gernika, Hanoi, Mostar, Hiroshima, Sant’Anna di Stazzema, L’Aquila, Sant’Eusanio Forconese, Isernia, Lanciano.

*View of Frascati.*

During the postwar years, an important rebuilding program of the city has been carried out; and since the 1950's, one of the most important European centers of scientific research has developed. Indeed, this area has hosted a laboratory from the National Institute for Nuclear Physics (INFN); the Organization for New Technologies, Energy and Environment (ENEA) laboratories; the ESRIN, an ESA office in Italy; many CNR institutions, and also the National Astrophysics Institute (Istituto Nazionale di Astrofisica - OAR, IASF e IFSI) and computing centers of the Bank of Italy. Nowadays, Frascati is twinned with the cities of Saint-Cloud, Bad Godesberg, Kortrijk and Windsor & Maidenhead.

Since the end of the 1990's, many public projects have been completed; this policy reached its height with the Massimiliano Fuksas' renovation of the 15th century Aldobrandini stables ("Scuderie Aldobrandini"), which got transformed into a modern cultural and multifunctional pole. They have been unveiled on April 8th, 2000, and together with the fascinating archeological sites and the gorgeous Renaissance houses, they extol the beauty of a city with no equivalent thanks to its historical importance, its panoramic beauty, its architectural opulence and its gastronomy, obviously including the famous Frascati wine, known and appreciated all around the world.

*Villa Aldobrandini.*

## CHAPTER 4

## THE CITY OF ORSAY

### City of Orsay: province of "Île de France"

The history of Orsay started during the Merovingian dynasty in 754 A.D. but the existence of a village named Orsay is mentioned for the first time in 999 during the feudal wars. The building of the Romanesque church dedicated to Saint-Martin started in 1151. Around the beginning of the 15th Century, the Raguier family undertook to build a castle at Orsay, which was later destroyed. A descendant of this family named Charles Boucher was elected trade provost marshal in Paris and led to the cleaning up of the "quai de la Grenouillère" near the Seine river. In his honor, King Louis the XIVth called this bank "quai d'Orsay" which name now symbolizes the French diplomacy. The current "Bouvêche" building, an ancient castle used nowadays as cultural hall by the current town council, was built during the 17th century.

*The Bouvêche.*

The official birth of the Orsay district took place in 1790. From 1815, social progress was speeding up in the city (creation of a hospice and of a school for the poorest people) and was accompanied by technical progress: the train line got extended from Bourg-la-Reine to Orsay. In 1873, the current town hall got erected while the city was growing. In 1901, there were 1850 citizens in

Orsay. In the interwar years, town planning and urbanization continued with the creation of residential areas. Thus, over the centuries, Orsay succeeded in modifying its aspect, evolving from a modest town to a booming city.

Within sight distance of Paris and of the "Vallée de Chevreuse", Orsay is enjoying a very privileged geographical location in the Paris area. Served by two regional train stations, a wide road and motorway network and close to TGV stations and airports, it is fully inserted into the regional dynamism.

*Sight of the Orsay city from the roof of the town hall.*

Both a city and a village, Orsay counts about 17,000 citizens who live on a territory of about 1,900 acres, among which protected green (50 acres) and forested (120 acres) areas. The city is livened up by a rich community life of about 200 associations. It counts six child-care centers, six nursery schools, five primary schools, three secondary schools, two high schools and a hospital complex. The cultural policy is notably disseminated thanks to an auditorium and a cinema.

Orsay is a member of a community of cities – the "Communauté d'Agglomérations du Plateau de Saclay", CAPS for short – which groups 10 districts together representing a total of 100,000 citizens, 4,000 firms and 13 economical business parks. The CAPS main goal is to maximize the quality of the general public-service and to pool means to improve its quality at a lesser cost (pooling the network of libraries and multimedia libraries or public roads transfer).

The local economic life is very rich. More than 600 firms, shops, craftsmen and liberal professionals work in Orsay.

The science university occupies about 580 acres on the Orsay campus, which include an exceptional woodland area of 336 acres containing rare classified species and a botanical garden. It accommodates more than 9,500 students, 1,500 lecturers and researchers, 1,650 administrative people and technicians, such as 1,500 PhD students. Teaching and research include biology, chemistry, computing science, mathematics, physics and Earth & Universe sciences.

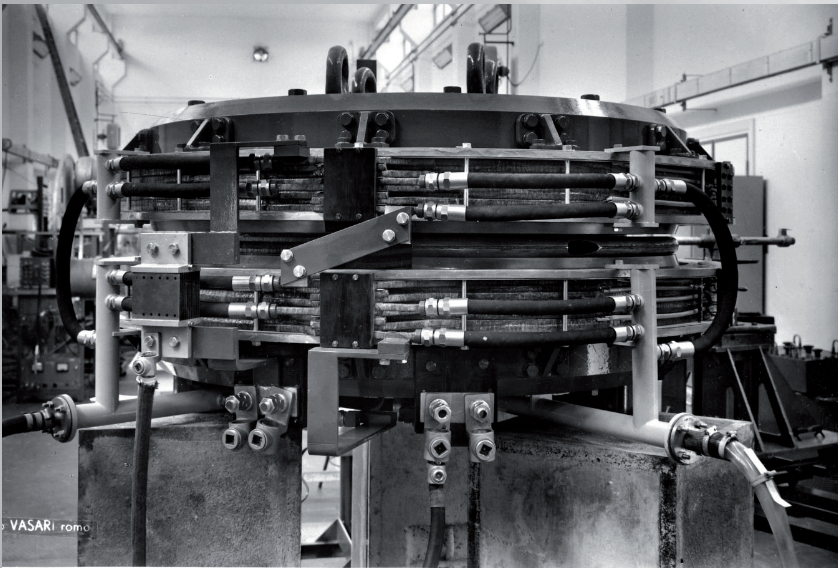
This adventure all started in 1954 when building plots were sought in the "Vallée de Chevreuse" to allow the Radium Institute, led by Prof. Irène Joliot-Curie, to get extended. The self-direction of the Orsay science university was acknowledged in 1965. Nowadays, more than 120 laboratories do research here, spanning the main fields of present research. The campus location on the Orsay territory, close to the Saclay site of the CEA and to CNRS laboratories, has attracted many organizations, institutes, laboratories and Grandes Écoles, which have strengthened the academic and scientific purpose of the Saclay plateau and of the Yvette river valley.

Between Paris and the "vallée de Chevreuse", right in the middle of a scientific cluster, Orsay is in essence an open city. Open to Europe and willing to expand its international relations, Orsay put preferred links with three cities in place: Kempen (Germany), Vila Nova de Paiva (Portugal) and Dogondoutchi (Niger). In short, two European twinnings and a decentralized program of aid to Africa to open up to other cultures, to interact, to share and to be enriched with all cultures.


*Orsay town hall.*

## CHAPTER 5

## AdA AND BRUNO TOUSCHEK




*AdA.*

In 1960, at LNF, the physicist Bruno Touschek proposed to realize the prototype of an accelerator based on a brand new concept: AdA, a storage ring where electrons and positrons would circulate in opposite directions in the same vacuum chamber and colliding hundreds of millions of times per second. Beside the new possibilities offered by the study of the physics of matter-antimatter annihilation, a collider has the advantage to make the total energy of the two beams available for the creation of new particles, through a conversion based on the mass-energy equivalence given by the Einstein equation $E=mc^2$. Touschek's proposal highlighted the "kinematical" advantage to make collisions in the center of mass, which follows an idea of Rolf Widerøe from 1943 – Widerøe talked Touschek about and also patented it later.

In the late fifties, collisions in the center of mass, at rest before and during the collision, were seeked by the Americans with the Princeton-Stanford project of tangent electron rings. This concept was an innovative feature compared to the conventional accelerators where a single beam is used to hit a fixed target, and in which a large fraction of the original energy is lost in the motion of the center of mass. Nevertheless, Touschek's idea of colliding particles and antiparticles in the center of mass appeared as a fundamental innovation compared to the American project, which only allowed to access a limited number of final states. This is due to the fact that the two electrons in the initial state correspond to a double negative charge which has to be there also after the collision (for the electric charge conservation). On the contrary, in the case of electron-positron collisions the total charge is zero and quantum mechanics allows more final states, balanced between matter and antimatter.

Under Bruno Touschek's leadership, a small team including Carlo Bernardini, Giorgio Ghigo and Gianfranco Corazza committed to the AdA project and its construction. The AdA structure consisted of a vacuum chamber of diameter 160 cm, shaped like a doughnut, and embedded in a 8.5 tons magnet that was able to keep beams with an energy up to 200 MeV circulate in the ring. Giancarlo Sacerdoti took care of the magnet and Mario Puglisi (assisted by Antonio Massarotti and Dino Fabiani) had the job to tune the radiofrequency cavity, needed to maintain the energy to the beam particles. Afterwards, Giuseppe Di Giugno and Ruggero Querzoli joined the original team.

On February 27th, 1961, the first electrons circulated in AdA. The immediate challenge was to guarantee the lifetime of the beam for periods long enough. For that reason, an extreme vacuum was necessary in the AdA chamber, well beyond the technological capabilities at that time. This challenge was successfully taken up by Gianfranco Corazza. Moreover, at that time nobody had produced and stored yet a positron beam; so it was not clear that collisions with electrons circulating on the same circular trajectory but in the opposite direction could happen. Preliminary studies, performed once AdA had been moved to Orsay, demonstrated new features of accelerators physics, in particular related to the interaction among particles of the same beam. Indeed, it was discovered that the lifetime of a beam decreases with the increase of the spatial density of particles: Touschek explained the phenomenon (known today as the Touschek effect) as due to the interactions among neighbour particles, which loose energy and are finally ejected from the beam trajectory. Appropriate techniques of beam steering were developed to limit this loss, through modulations of electromagnetic fields.

AdA confirmed the possibility to store electrons and positrons in a ring for hours, but it was not able to observe reactions of annihilation associated with the production of new particles. Nevertheless, the final evidence of the actual beam-beam collisions was given by the observation of photon production in electron-positron interactions; that result ended the AdA experiment in Spring 1964. At that time, the project to build a bigger ring, ADONE, a 1500 MeV accelerator, had already been approved. ADONE started running at LNF in 1967.

*Sight of AdA.*

AdA had a short scientific life, but it remains a milestone in the science history. Many other electron-positron colliders followed AdA. This configuration became one of the most powerful tools in modern high energy physics, culminating in the late eighties with LEP, the largest ever electron-positron collider, built at CERN in an underground tunnel of 27 km of perimeter, and which was a powerful scientific instrument that confirmed the existence of three families of quarks and leptons.

The matter-antimatter collision concept leads as well to the study of quark-antiquark collisions through proton-antiproton colliders and now, with the Large Hadron Collider (LHC) at CERN, to proton-proton collisions. With the LHC, a machine which beam energy will ultimately reach 7 TeV, physicists hope to tackle new goals, among which the search for the Higgs boson and for new physics beyond the Standard Model, like the supersymmetic particles.

## Who was Bruno Touschek?

Bruno Touschek has been one of the most important physicists of the second part of the XXth century. He used all his knowledge in theoretical physics and the experience acquired in Germany with Widerøe to conceive, suggest and build the first matter-antimatter accelerator and to improve the knowledge of the world we live in.

Born in Vienna in 1921, a brilliant student, Touschek had serious difficulties after the annexation of Austria by Germany in March 1938, because his mother was Jewish. Nevertheless, he passed his high school diploma and got into University. But again he had to quit prior to completing his studies because of racial reasons. Thanks to some friends, he could keep on studying in Hamburg where nobody knew about his origins, doing different jobs besides in order to make a living.

In 1943 he was invited by Rolf Widerøe to work with him on the construction of a betatron. From 1943 to 1945, Touschek developed and collaborated to many publications in particle accelerator physics, submitting different patents.

When Touschek was arrested by the Gestapo in March 1945, Widerøe visited him in prison, bringing him food, books and cigarettes. Having miraculously escaped death while being transfered to Kiel concentration camp, Touschek finally graduated in 1946 at the University of Göttingen and began to work at the Max Planck Institut.

In February 1947 he moved to Glasgow where he had obtained a fellowship in the Department of Scientific and Industrial Research, working with another great accelerator expert, Philip I. Dee. In 1949, after having successfully defended his PhD, he was appointed as Official Lecturer in Natural Philosophy at the University of Glasgow; he kept this position until 1952 when he moved to Rome where one of his maternal aunts, Adele, known also as Ada, lived. In this way he became part of the Roman scientific community, and decided to stay permanently in Italy after getting a researcher position from INFN. Three years later, he came back to Glasgow to marry Elspeth Yonge, the daughter of a well-known Professor of Zoology at the University of Glasgow, who gave him two children.

Since Fall 1959, Touschek had emphasized the importance of exploring the physics of electron-positron annihilation processes. Ongoing discussions in Rome and Frascati about concrete developments of $e^+e^-$ physics stimulated papers written by Laurie Brown and Francesco Calogero as well as by Raoul Gatto and Nicola Cabibbo. On March 7th, 1960, Touschek held a seminar at the National Laboratory of Frascati advocating for the first time the relevance of a systematic investigation of electron-positron collisions and the possibility to obtain them using a single magnetic ring in which bunches of electrons and positrons would circulate with the same energy but in opposite directions. In less than a year, Touschek and his collaborators completed the prototype of the matter-antimatter accelerator AdA (Anello di Accumulazione). It was a happy coincidence that the name of the accelerator was the same as Touschek's aunt, Adele, to whom he had always been close since his first visits to Italy, during the thirties.


*Bruno Touschek.*

## What was Touschek idea?

The genius of Bruno Touschek was to conceive AdA and understand how to make it, suggesting the idea at the right place and at the right time. The LNF synchrotron, an accelerator whose construction required great scientific, technological and organizational efforts, had just been completed in Frascati. The laboratories, the researchers, the technicians were already available. Moreover, at that time, people from all over the world were looking for new techniques to achieve higher collision energies than those allowed by conventional accelerators and the scientific community was ready to welcome Touschek's idea.

The story of subnuclear physics since the sixties clearly shows how the use of electron-positron collisions at high energy has been one of the main tools to investigate the intimate structure of matter, confirming Bruno Touschek's expectations on the richness of electron-positron processes in all new energy domains.

AdA represents a milestone in the history of science marking the origin of the most profitable tool for the exploration of the frontiers of the infinitely small. After its implementation in 1961, AdA was moved to Orsay, in France, where the Linear Accelerator proved to be the ideal electron-positron injector to improve its luminosity, allowing the discovery of many important results about the physics of storage rings, like the Touschek Effect.

Afterwards, Touschek followed with great interest the design and the construction phases of ADONE (1965-1967), in particular investigating beam physics.

As a great cartoonist, Touschek succeeded in representing the academic world with extreme irony: "Bruno had a natural skill in caricaturing; he could sketch with a pen on any piece of paper, during examinations sessions at the University, or during meetings or working groups, dealing with the activities of INFN of the Frascati Laboratory" (Edoardo Amaldi).

*Touschek drawing representig the physicist T. D. Lee, Nobel Prize in 1957 for the discovery of the parity violation in the weak interactions.*

# CHAPTER 6

# AdA AT ORSAY

*The injector beam channel in Orsay.*

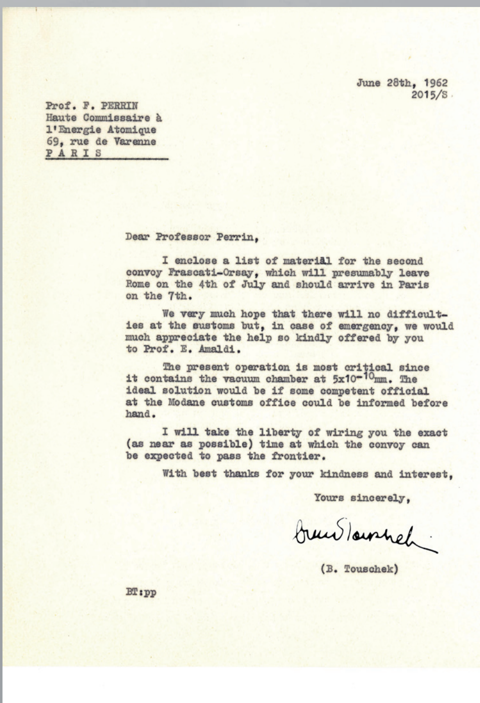
In early summer 1962, AdA was transferred to France, at LAL, the Laboratoire de l'Accélérateur Linéaire at Orsay, near Paris, where a high intensity linear accelerator (LINAC) was available. This transfer led to the first experimental evidence of electron-positron collisions in a storage ring, and thus opened the era of electron-positron physics.

It had all started with a visit to Frascati by Pierre Marin (1927-2002). After a period spent at CERN, Pierre Marin, who would later play a principal role in the French effort to accelerator building in post-war Europe, including research with ACO, was trying to find his own research direction and was told that in Frascati "[il] se passait des choses qui intriguaient les esprits". In summer 1961, Pierre Marin visited Frascati, finding AdA to be "un vrai bijou" and, on September 19, 1961, prepared a report of his visit, in which a collaboration between Frascati and Orsay is discussed.

Following Marin's visit, letters were exchanged between Frascati and Orsay. On December 22, 1961, André Blanc-Lapierre, LAL Director, wrote to Italo Federico Quercia, Director of Frascati Laboratories, that preliminary studies for a 1.3 GeV storage ring for electrons and positrons had started, and proposed a visit of French scientists from Orsay in the near future. François Fer, Pierre Marin and Boris Milman came thus to Frascati in early 1962. During their discussions with Carlo Bernardini and Bruno Touschek, the idea of bringing AdA to Orsay and obtain a higher luminosity thanks to the high intensity of the Orsay LINAC, took form. By early April a decision to move AdA to LAL had been taken, and the transfer of AdA to Orsay was prepared.

At the beginning of July 1962 AdA was packed on a big truck, which had to cross the Alps with a fully evacuated beam pipe and with batteries lasting about three days to power the vacuum pumps: at that time, one needed months to reach the required extreme vacuum and one could not waste precious time to obtain it anew.

When the truck arrived at the Italian-French border, the custom officers wanted to inspect the inside of the doughnout. What was inside it? "Vacuum, the best possible vacuum", was the answer. It would not suffice. It took high-level diplomatic interventions before AdA could cross the border between Italy to France, with its high vacuum still intact. According to Jacques Haïssinski, who would do his doctoral thesis on AdA in Orsay, "It took the intervention



June 28th, 1962
2015/S

Prof. F. PERRIN
Haute Commissaire à
l'Energie Atomique
69, rue de Varenne
PARIS

Dear Professor Perrin,

I enclose a list of material for the second convoy Frascati-Orsay, which will presumably leave Rome on the 4th of July and should arrive in Paris on the 7th.

We very much hope that there will no difficulties at the sustoms but, in case of emergency, we would much appreciate the help so kindly offered by you to Prof. E. Amaldi.

The present operation is most critical since it contains the vacuum chamber at $5\times10^{-10}$mm. The ideal solution would be if some competent official at the Modane customs office could be informed before hand.

I will take the liberty of wiring you the exact (as near as possible) time at which the convoy can be expected to pass the frontier.

With best thanks for your kindness and interest,

Yours sincerely,

(B. Touschek)

BT:pp

*Touschek's letter to Francis Perrin, announcing AdA's departure for Orsay in July 1962.*

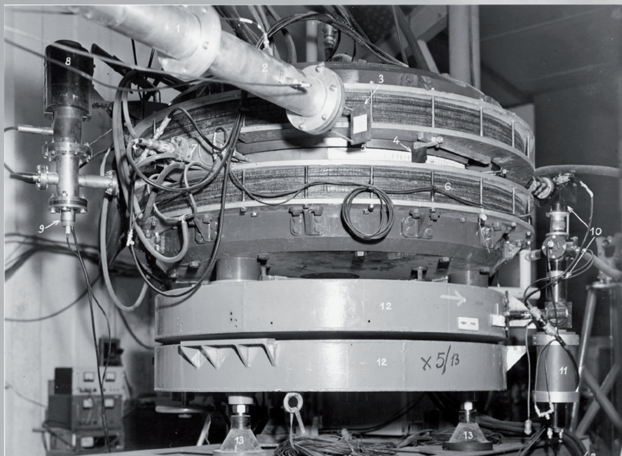
of Francis Perrin, then the Haut Commissaire à l'Énergie Atomique, to get over this hurdle". Carlo Bernardini remembers also the intervention from the Italian side, with Edoardo Amaldi, Director of the Physics Department in Rome, calling the Italian Ministry of Foreign Affairs, and, through this, the French authorities.

*Pierre Marin (at right) and Jacques Haïssinski.*

By August 1962 AdA was installed in Orsay. During the installation, while being hauled by a heavy crane in its place, AdA was almost smashed against a wall. It was Pierre Marin, alerted by yelling from the Italian group, who ran and pushed the buttons that averted the crash. Later on, one of the detectors, while being moved close to the AdA ring, tipped over and broke Pierre Marin's foot. None of this could however quench the enthusiasm and drive of the Franco-Italian group, which was joined in the fall 1962 by Jacques Haïssinski.

In Orsay, thanks to the linear accelerator, collisions were observed and important effects in beam dynamics appeared. One such is the Touschek effect, immediately explained by Touschek. This effect limits the machine luminosity, manifesting itself through a progressive decrease in the beam lifetime while the number of stored particles increases, and is still one of the effects that limit the beam lifetime in accelerators.

Thus AdA opened the way to the machines that would discover new fundamental particles and bring the experimental confirmation of the Standard Model.



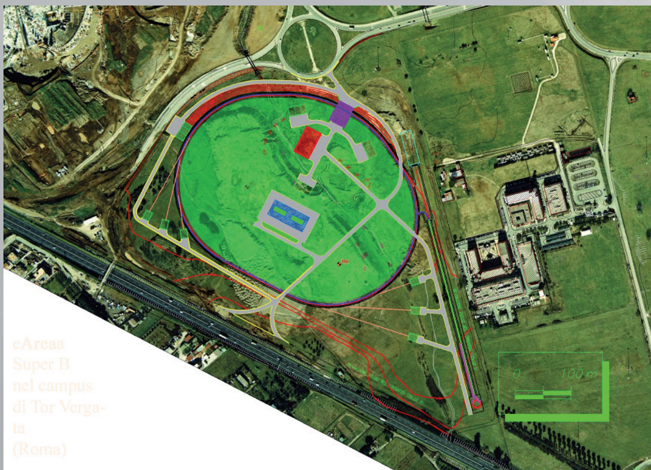

*AdA at LAL.*


*The "Café de la Gare" in front of the Orsay station in November 2011. Bruno Touschek spent a night there in March 1963, making computations to explain the observed decrease of the lifetime of the beams of the AdA collider which was then running at LAL. Nowadays this phenomenon, named "Touschek effect" after his discoverer, is known by all accelerator manufacturers.*

## CHAPTER 7

### SuperB

The SuperB Factory, a major international research centre for fundamental and applied physics will be built on the campus of the University of Rome Tor Vergata. The project proposed by the INFN is the first on the list of the 14 flagship projects of the National Research Plan of the Italian Ministry for Education, Universities and Research (MIUR).




*Composite image combining a drawing of the SuperB accelerator and an actual view of the Tor Vergata Campus.*

The project involves the construction of a large underground electron-positron collider which will occupy an area of approximately 30 hectares on the University of Rome Tor Vergata campus and be closely linked to the INFN Frascati National Laboratories, located nearby.

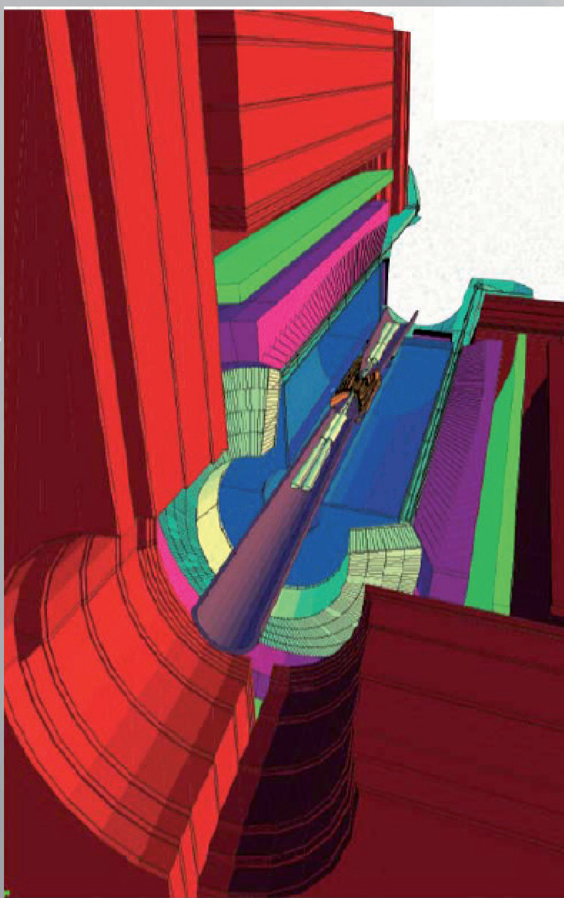
The physicists' objective is to cast light on some of the great questions of contemporary physics: on the mechanisms which led to the disappearance of antimatter shortly after the Big Bang at the dawn of the history of our Universe, for example, or on the forces which hold the fundamental components of matter together. The SuperB research programme can be seen as complementary to that of CERN's Large Hadron Collider (LHC), since the two accelerators deal with two different frontiers of experimental subnuclear physics: intensity and energy. SuperB will concentrate on increasing the rate of the particle beam collisions which produce extremely rare physical phenomena that have not yet been fully explored, while the LHC, which has enormously increased the energy at which collisions take place, investigates the new physics with this different method. The leap forward in the luminosity (the number of collisions produced) of SuperB is based on ideas developed in Italy and experimented at the INFN Frascati National Laboratories, using the DAΦNE collider.

However, the same infrastructure will also provide new technologies and advanced experimental instruments for research in the domains of solid state physics, biology, nanotechnologies and biomedicine. Once operational, SuperB will immediately offer to a broad interdisciplinary scientific community, both Italian and international, the opportunity to use the lines of light located along the collider's path. Several of these facilities will collect and focus the "synchrotron light" emitted by the electrons during their race around the accelerator. Beams of light with unique coherence and collimation characteristics will enable biological or inorganic structures to be visualized at a nanometer resolution and allow "micro-snapshots" to be taken of the biochemical processes underway. They can be used for the construction of nanostructures or electronic components and will be useful for the synthesis of new drugs or innovative materials. Not by chance the Italian Institute of Technology (IIT) was involved since the very beginning into the project and will be one of the users of the accelerator as a source of high brilliance light. Of course, the SuperB's location at Tor Vergata also opens up the possibility of collaboration with the entire Italian academic community and research organizations sited in the same area, as well as many international partners.

This is the first time an accelerator has been designed from the outset to satisfy the needs of both fundamental and applied physics. SuperB represents a historical opportunity for these two important international communities to meet. The project fits naturally into a context of international collaborations and will contribute to reinforcing Europe's leading position in high energy physics, which already has its guiding light in CERN in Geneva. Finally, to underline the importance of this initiative, it should be pointed out that once the SuperB is fully operational, an international scientific community of more than a thousand scientists and technicians will be involved.

SuperB, which will ultimately cost few hundred million euros, obtained funding approval for 250 million euros in the Italian government's CIPE Economic

Planning Document. The huge amount of data produced by experiments in fundamental physics, as well as the multidisciplinary research related to the machine, will also be stored, processed and analyzed by a network of computing resources and memory, distributed throughout the country. In particular, large new computer nodes and data sorting will be made in different regions of the South and will support the computing center of the CNAF - INFN Bologna, one of the 11 top-level nodes of the global network for GRID processing and analysis LHC data. The new computer centers then become a valuable resource for the computerization and computer networks linked to local services.



*Simulation of the interaction region of the SuperB collider.*

## Credits

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