Chapter 3
AdA at Orsay

Jacques Haïssinski

Abstract AdA, acronym for *Anello di Accumulazione* in Italian, was the first electron−positron storage ring ever built and operated. During a meeting held in the Frascati National Laboratories in February 1960, Bruno Touschek had proposed to equip these Laboratories with an accelerator of a new kind that would allow the investigation of matter−antimatter annihilation. Soon after, Touschek designed AdA, an e^+e^- storage ring prototype. Quickly built, AdA was first commissioned in Frascati where the behavior of the counter rotating beams was investigated in the low stored particle number regime. Then, in 1962, AdA was brought on a truck to the Orsay *Laboratoire de l'Accélérateur Linéaire* to benefit from the high intensity electron linear accelerator available there. The commissioning was then continued by a small Italo-French collaboration which pursued the study of the machine performances, collective effects included. Exploring this entirely new accelerator physics domain was a unique and exciting period for the team. It lasted close to two years during which the beam lifetime limitations, the size of the stored bunches and the particle-antiparticle collision rate were measured. By the end of that period, the basic underlying concept of e^+e^- colliders was established, showing that the road to future powerful colliders was open.

3.1 Introduction

The making of AdA can be set in a time sequence which illustrates the major steps which led to the proof-of-principle of electron−positron storage rings to be a major discovery tool for particle physics in the second half of last century:

> February 1960: Touschek proposes to turn the Frascati synchrotron into an electron-positron ring.

J. Haïssinski (✉)
Laboratoire IJCLab Orsay, Paris, France
e-mail: jhaiss@lal.in2p3.fr

Fig. 3.1 Bruno Touschek in Catania in 1963. Credit: Rome Sapienza University Physics Department Archives

March 1960: Decision to engage the Frascati Laboratory in an e^+e^- colliding beam experiment.

May 1961: First electrons/positrons stored in AdA [1, 2].

July 1962: AdA is brought to the Laboratoire de l'Accélérateur Linéaire (LAL) in Orsay.

1963: Discovery of the *Touschek effect* [3] and first evidence ever of collisions between counter-rotating stored particles [4].

Summer 1964: AdA goes back to Frascati.

In what follows, I shall outline why the AdA storage ring was brought to Orsay after having been commissioned in Frascati, the first commissioning period in France, AdA's operations at LAL, AdA beam lifetime and the Touschek effect, bunch size and luminosity measurements, to conclude with a summary of the main physics results obtained with AdA at Orsay [5].

I would start by showing a picture of Bruno Touschek, (Fig. 3.1), which I like particularly since it captures very nicely Bruno's personality which was characterized by a quick and imaginative mind and also by a permanent sense of humour.

To put the birth of AdA in perspective, I would like to recall what was the status of the conventional accelerators at the time in Europe. By conventional I mean accelerators which accelerate particles (projectiles) which are sent and hit some target at rest in the laboratory. Towards the end of the 1950s, several machines had been commissioned, as shown in Fig. 3.2.

There were three proton machines and two electron machines, in particular the Frascati electron synchrotron, which at the time offered the perspective for a fruitful experimental high-energy physics program.

Following the successful commissioning of the Frascati synchrotron, and Touschek's proposal, a decision by the Frascati Laboratories was taken in March 1960 to build AdA, Anello di Accumulazione, *Storage Ring* in English (Fig. 3.3), a small accelerator for an experiment to study electron−positron collisions, as suggested by Bruno Touschek [1].[1]

---

[1] See L. Bonolis and G. Pancheri's contributions to this conference.

Name	Country Laboratory	Particles	Energy	First beam
Synchrophasotron	USSR Dubna	protons & ions	10 GeV	1957
SATURNE	France Saclay	protons & ions	3 GeV	1958
Proton Synchrotron (PS)	CERN	protons	20 GeV	1959
Linac	France Orsay	electrons	1 GeV	1959
Electron Synchrotrone	Italty Frascati	electrons	1.1 GeV	1959

Fig. 3.2 Conventional accelerators commissioned in Europe between 1957–1959

Fig. 3.3 AdA in Frascati in 1961, before being moved to LAL. Credit: INFN-LNF

Less than one year later, in February 1961, the first electrons circulated in AdA. However, it happened that the capture rate of electrons and positrons in the ring was much lower than anticipated.

In July 1961, following Italy's success in constructing AdA and planning for a more powerful and bigger e^+e^- machine (ADONE), AdA was presented at CERN and discussions taking place during the conference inspired a visit to Frascati by Pierre Marin and Georges Charpak [6].

During this visit, Marin, a researcher from the *Laboratoire de l'Accélérateur Linéaire*, suggested to Carlo Bernardini and Bruno Touschek to move AdA to Orsay and use the newly built Linear Accelerator (LINAC) (Fig. 3.4, left panel) as injector and thus increase the e^+ or e^- capture rate achieved in Frascati from a few 10^2 particles per beam to a few 10^7 per beam. The LINAC provided a 500 MeV beam and this

meant multiplying the number of stored particles in AdA by a factor of the order of 10^5.

After his visit to Frascati, Pierre Marin (Fig. 3.4, right panel) wrote a report where he already envisaged that AdA could be transported to Orsay (Fig. 3.5).

Official negotiations between André Blanc-Lapierre, LAL's director, on the one side and Edoardo Amaldi, INFN director in Rome, Giorgio Salvini and Italo Federico Quercia, first and second director of the Frascati Laboratories (Fig. 3.6) on the other,

Fig. 3.4 The Orsay linear accelerator wave guide, credits *Laboratoire de l'Accélérateur Linéaire d'Orsay*, and Pierre Marin (1927–2002) in a 1966 photograph. Credit: Yvette Haïssinski
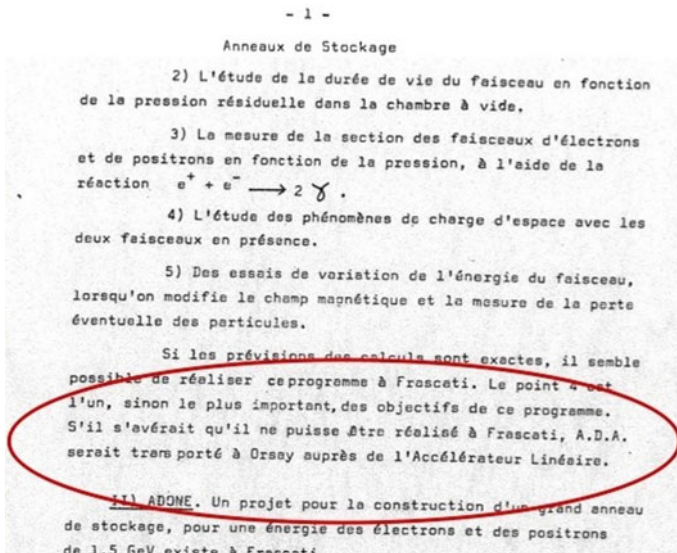

Fig. 3.5 The report presented in September 1961 by Pierre Marin to LAL's director André Blanc-Lapierre after meeting with Ruggero Querzoli, at a conference in Aix-en-Provence. Credit: *Laboratoire de l'Accélérateur Linéaire d'Orsay*

led to AdA arriving in Orsay in July 1962 [7] and be installed at the experimental hall of the *Laboratoire de l'Accélérateur Linéaire* (Fig. 3.7).

The end part of the LINAC vacuum pipe—which was used to inject particles in AdA—is visible in the upper part of Fig. 3.7. The 500 MeV particles were going through the small scintillating screen on the right used to focus the beam, then the same beam was hitting the tantalum foil where they were producing high-energy bremsstrahlung photons which were entering the vacuum chamber of AdA. Within the vacuum chamber there was another tantalum plate where the high-energy photons were creating electrons and positrons, some of which were stored. AdA could in fact be rotated and translated and thus, depending on the geometric configuration of AdA with respect to the LINAC vacuum tube, one could move from electrons to positrons storing process.

A view of AdA's control room in Orsay is shown in Fig. 3.8, with Giuseppe Di Giugno. There was no computer at the time to control the injection process, nor the
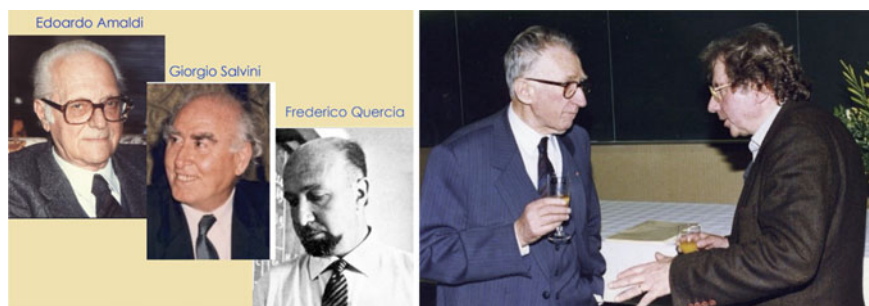

Fig. 3.6 Left panel: Edoardo Amaldi, Giorgio Salvini (Frascati Director during approval of AdA's construction), Italo Federico Quercia (Frascati Director during AdA's construction). Credit: Rome Sapienza University Physics Department Archives, and INFN-LNF. Right panel: André Blanc-Lapierre with Pierre Marin in a later photograph. Credit: *Laboratoire de l'Accélérateur Linéaire*

Fig. 3.7 Ada in Salle 500 in Orsay. Credit: *Laboratoire de l'Accélérateur Linéaire*
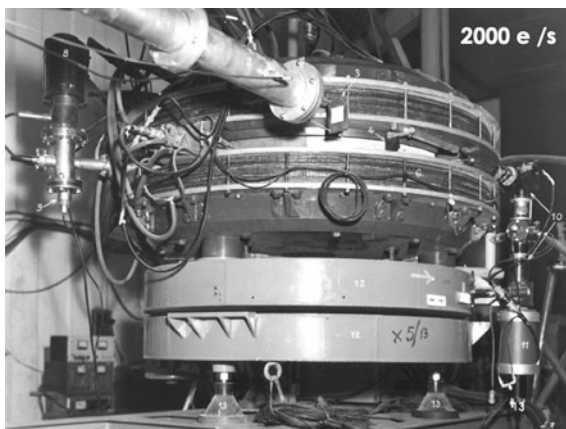
Fig. 3.8 The youngest member of the collaboration, Giuseppe (Peppino) Di Giugno, in AdA's control room, in Orsay. Credit: Giuseppe Di Giugno

ring parameters, but a number of meters and screens and a number of knobs for the operator to turn.

In Fig. 3.9 I show the synchrotron radiation emitted by electrons and positrons circulating in AdA, which was in the visible region. The first picture shows that when the beam was unperturbed, the transverse profile of the bunch was flat and looked like the transverse view of an optical focussing lens. Its larger dimension was about 3 mm (FWHM). When some magnetic coupling is applied between the horizontal and the vertical betatron oscillations, the beam becomes slanted and rounder, and then a little wider.

In Fig. 3.10 I show a few AdA parameters. The overall size of AdA was about 1.2 m, the orbit length was 4.1 m long and we used to work at an energy of around 225 MeV. The value of the beam current in each beam was about 1/2 mA and the vacuum which was maintained in the ring was about 1 nTorr. At that time, it was a real challenge to maintain it at such a low level.

The AdA collaboration at Orsay was comprised of five physicists from Italy: Bruno Touschek, Carlo Bernardini, Gian Franco Corazza—who took care of much of the machine hardware—Ruggero Querzoli, see Fig. 3.11, and Giuseppe Di Giugno [8]. Together with Pierre Marin, François Lacoste was one of the two first French physicists who greeted AdA at Orsay, then I replaced him. I was a graduate student at the time and AdA became the subject of my Ph.D thesis [9]. Eventually, Bernardini and Touschek were members of the examination board.

3.2 The Orsay Scientific Program

The program envisioned for AdA in Orsay was based on measuring:

1. The beam life-time
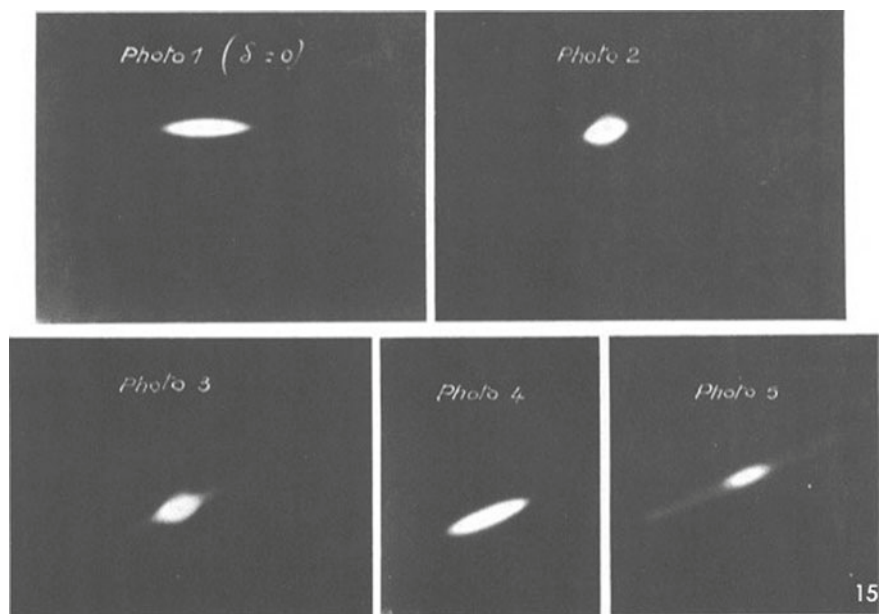2. The e^+ and e^- bunch size in the ring

Fig. 3.9 AdA transverse bunch shape without and with an applied magnetic coupling [9]

Parameter	Value or typical operation value	Units
Orbit length	4.1	m
Energy per beam	225	MeV
Luminosity	~10^{25}	cm^{-2} s^{-1}
Beam current, per beam	0.5	mA
Vacuum pressure	1	nTorr

Fig. 3.10 AdA parameters [9]

3. The collision rate (ring luminosity)

After checking the beam life-time and measuring the bunch size in the ring, the last step was the most important point of our program: measuring the ring luminosity.

In Fig. 3.12 the plot shows the current in nA *vs* time driven by a photomultiplier which could detect the synchrotron light produced by the stored particles. On the left of the graph one can see that at a certain point there were five electrons stored in the

Fig. 3.11 Members of AdA collaboration in Orsay, from left: Carlo Bernardini, Gianfranco Corazza working at the vacuum chamber of the Frascati synchrotron and Ruggero Querzoli. Credit: INFN-LNF

machine. Then, by playing with the radiofrequency (RF) power, one could shorten the lifetime of these particles. Each subsequent step in the graph corresponds to the loss of a single stored particle, until what remained is just the photomultiplier dark current. And so, one could observe even a few particles stored in the macroscopic AdA setup. I think this graph—which had been already obtained in Frascati—is quite remarkable and that it would have deserved much more advertisement.

Coming to the lifetime of the stored beams, one of the first measurements which were carried out was to check how this lifetime was affected when varying the power fed in the RF cavity which kept the electrons and positrons rotating despite the fact that they were continuously losing their energy in the form of the synchrotron radiation. If one increases the high voltage in the RF cavity, the lifetime of the bunch gets longer, as shown in the logarithmic graph at left in Fig. 3.13. What happens is the following: electrons and positrons stored in the beams were trapped in the potential well provided by the RF cavity and when such potential well was progressively increased by putting more power in the cavity, the lifetime increased very rapidly.

Fig. 3.12 The plot showing counting electrons one-by-one in AdA, from J. Haïssinski's dissertation (1965)
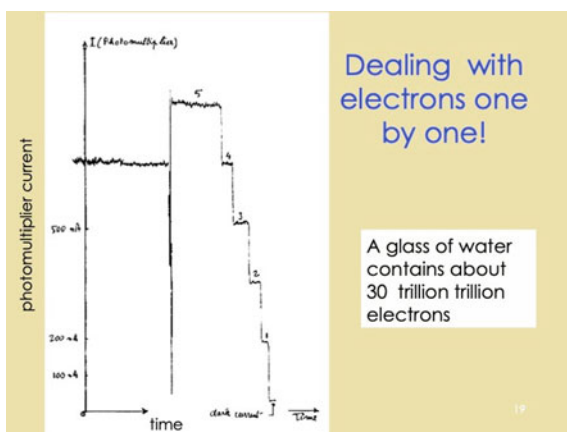
From this measurement one could infer the length of the stored bunch which, at the time of this observation, was about 10 cm.

To increase AdA's luminosity and take advantage of the superior electron current from the LINAC, various attempts were made with different injection techniques for the positrons, as well as looking for different final state processes.
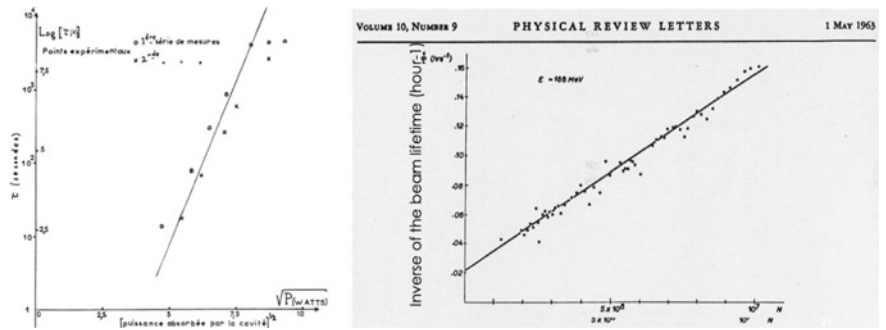

Fig. 3.13 At left, particle losses due to quantum fluctuations in AdA *versus* RF power [9], at right the plot showing the life-time decrease due to the Touschek effect. Figure reprinted with permission from [3], ©American Physical Society

Fig. 3.14 Synthesis of all experimental points with two beams, showing correlation between number of particles in beam 1 versus number of particles in beam 2, observed in coincidence with a bremsstrahlung photon. The point at $N_2 = 0$ is normalized to $p = 10^{-9}$ torr [4]
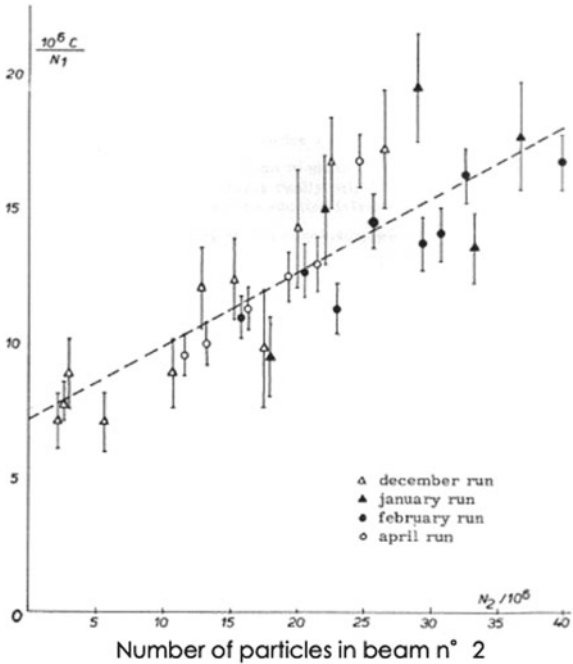
A breakthrough occurred when, one night, early in 1963, efforts to increase the beam current resulted in a decrease of the beam life-time. This was a totally unexpected effect which was right away interpreted by Bruno Touschek, and this is how it was later called the *Touschek effect*. This effect could not have been measured in Frascati, because of insufficient number of stored particles in a bunch. The observation of such effect was a major step towards understanding stored beam dynamics.

It was understood by Touschek to be a collective effect inside a single beam (intra-bunch effect) due to Møller scattering: his interpretation and calculation of the beam life-time τ from $1/\tau \approx N/V$ (particle number density within the bunch) led to infer the measurement of the bunch volume and its energy dependence. The effect was devastating for AdA's hope to see particle production through annihilation, but, decreasing with increasing beam energy, Touschek's calculation gave hopes for storage rings to work at higher energies: ADONE (at 3 GeV c.m. energy) [10] and ACO (at 1300 GeV) [11], respectively approved by INFN and CNRS, were safe.

The results were submitted to *The Physical Review Letters* [3] and gave confidence to the accelerator physics community that electron−positron storage rings could open the road to high energy physics.

The bunch size was crucial for measuring the collision rate. Its calculation depends on:

σ_{radial} was measured optically, giving $\sigma_{radial} = 0.5$ mm, taking a picture of the transverse dimensions of the bunches,

$\sigma_{longitudinal}$ was inferred from the measured lifetime due to quantum fluctuations $\sigma_l \approx 7$ cm (at $E_{beam} = 195$ MeV and $V_{RF} = 5.5$ kV),

$\sigma_{vertical}$ was the only big unknown.

From the Touschek effect $\sigma_{vertical} \approx 20\mu$, while $\sigma_{vertical}$ expected from synchrotron radiation recoil effects was only 2μ. When all this was understood, the team had a realistic estimate of which process could prove that collisions had taken place, namely $e^+e^- \rightarrow e^+e^- + \gamma$, whose theoretical calculation was being done in Rome by two students of Raoul Gatto, Guido Altarelli and Franco Buccella [8]. During fall 1963 and spring 1964 the team focused on gathering data and submitted an article about the first observation ever of electron−positron collisions in a storage ring [4].

3.3   Conclusion

The main storage ring physics results obtained with AdA were [5]:

- Check of the calculation of the beam scattering effects by the residual gas
- Confirmation of the theory of the RF lifetime due to synchrotron radiation quantum fluctuations
- Discovery and theory of the Touschek effect
- Evidence for the mechanism that determines the stored bunch height
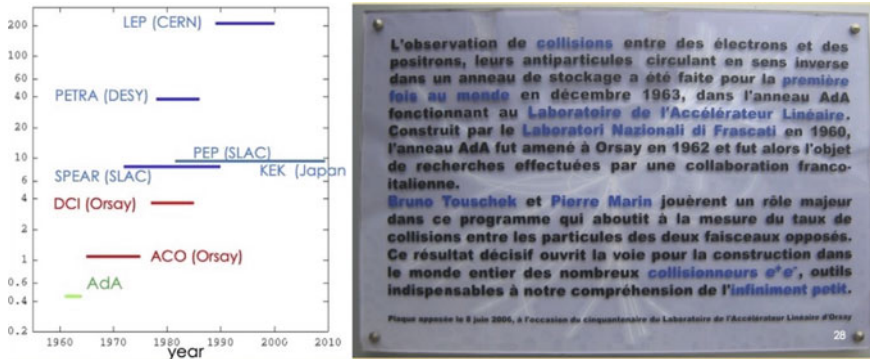- First evidence ever of collisions between opposite stored beams.

Fig. 3.15 The scientific impact of AdA (besides the ADONE ring in Frascati), eventually resulting in the building of LEP at CERN. Right: plaque placed at the entrance of the *Laboratoire de l'Accélérateur Linéaire* in Orsay, to commemorate AdA's pioneering contribution to the development of matter–antimatter storage rings

Thus, the basic underlying concept of e^+e^- colliders was established.

The scientific impact of the coming of AdA to Orsay resulted in the building of three storage rings, ACO, DCI and Super-ACO, and the opportunity for Ph.D students trained at LAL to pursue their research at other colliders (Fig. 3.15 left panel).

In 2006, when 50 years of the *Laboratoire* were celebrated, a commemorative plaque was placed at its entrance (Fig. 3.15 right panel).

References

1. C. Bernardini, G.F. Corazza, G. Ghigo, B. Touschek, The Frascati Storage Ring. Il Nuovo Cimento **18**(6), 1293–1295 (1960). https://doi.org/10.1007/BF02733192
2. C. Bernardini, U. Bizzarri, G. F. Corazza, G. Ghigo, R. Querzoli, B. Touschek, A 250-Mev Electron-Positron Storage Ring: The A. D. A. Contribution to HEACC, (Geneva, 1961), pp. 256–261
3. C. Bernardini, G.F. Corazza, G. Di Giugno, G. Ghigo, R. Querzoli, J. Haissinski, P. Marin, B. Touschek, Lifetime and Beam Size in a Storage Ring. Phys. Rev. Lett. **10**(9), 407–409 (1963). https://doi.org/10.1103/PhysRevLett.10.407
4. C. Bernardini, G. Corazza, G. Di Giugno, J. Haissinski, P. Marin, R. Querzoli, B. Touschek, Measurements of the Rate of Interaction between Stored Electrons and Positrons. Il Nuovo Cimento **34**(6), 1473–1493 (1964). https://doi.org/10.1007/BF02750550
5. J. Haïssinski, in *Bruno Touschek and the birth of* e^+e^- *physics*, ed. by G. Isidori. Frascati Physics Series Vol. 13 (1998) pp. 17–31
6. P. Marin, *Un demi-siècle d'accélérateurs de particules* (Editions du Dauphin, Paris, 2009)

7. L. Bonolis, G. Pancheri, Bruno Touschek and AdA: from Frascati to Orsay. In memory of Bruno Touschek, who passed away 40 years ago, on May 25th, 1978, arXiv:1805.09434 [physics.hist-ph](2018) doi: https://doi.org/10.48550/arXiv.1805.09434

8. G. Pancheri, L. Bonolis, Touschek with AdA in Orsay and the first direct observation of electron-positron collisions, arXiv:1812.11847 [physics.hist-ph] (2018) doi: https://doi.org/10.48550/arXiv.1812.11847

9. J. Haïssinski, Thèse d'État, 1965

10. F. Amman, C. Bernardini, R. Gatto, G. Ghigo and B. Touschek, *Storage Ring for Electrons and Positrons, ADONE*. Internal Report No. 68 (the Laboratori Nazionali di Frascati, 1961)

11. A. Blanc-Lapierre et al., The Orsay Project of a Storage Ring for Electrons and Positrons of 450 MeV Maximum Energy, in *Proceedings of 4th International Conference on High-Energy Accelerators*, (Dubna, 1963)