# AdA: The First Electron-Positron Collider

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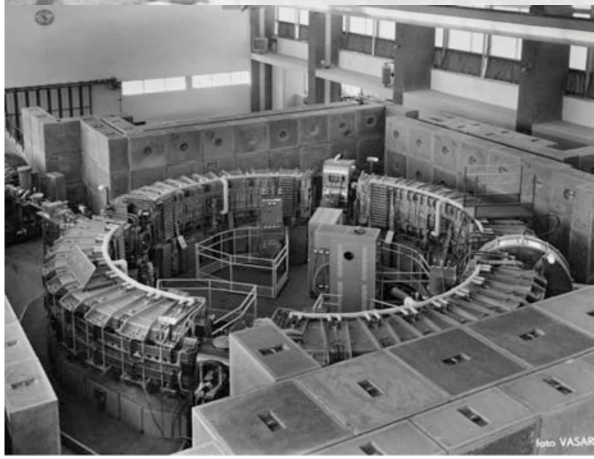
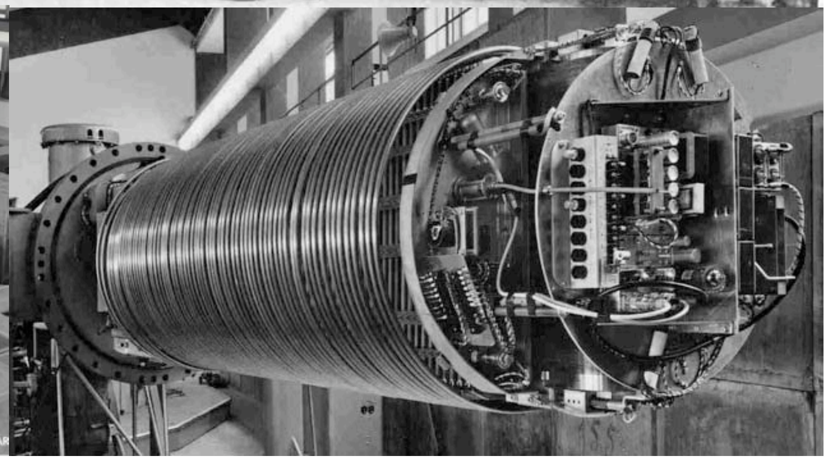
***“I dedicate this paper to some friends, now regrettably deceased, who carried out the most brilliant part of this work: Bruno Touschek, the leader of the group, Giorgio Ghigo, and Pierre Marin. Their versions of the events would have been more enlightening than mine”.***

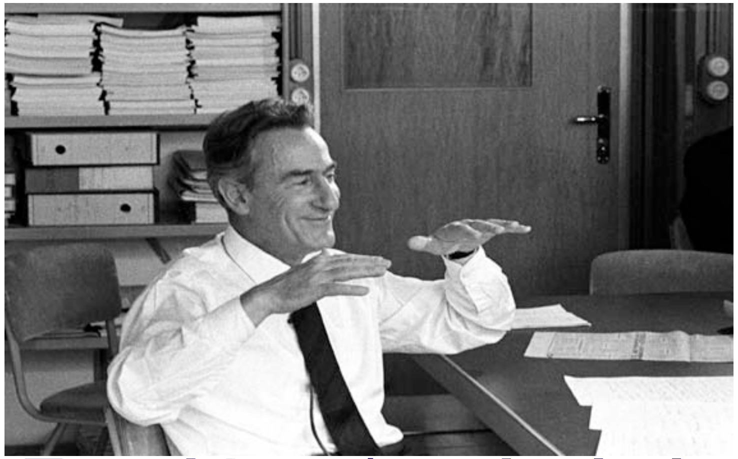
**(Physics in Perspective 6 - June 2004)**

# The electron synchrotron group with Giorgio Salvini

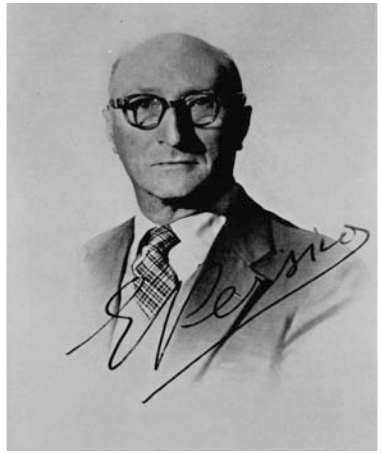
In 1958 the Italian National Institute for Nuclear Physics (INFN) was close to completing the construction of a large particle accelerator, a 1100-MeV (million-electron-volt) electron synchrotron, at the Frascati National Laboratories (Laboratori Nazionali di Frascati, LNF), about 25 kilometers South of Rome.







## Gilberto Bernardini (left) and Enrico Persico



**The idea (particularly by Gilberto Bernardini) was to build a national accelerator laboratory at a central site that would be staffed by physicists and engineers who were dedicated to the machine. The staff was greatly assisted – in some cases trained – by outstanding physicists from Italy and abroad, especially by Enrico Persico (1900–1969), a friend of the young Enrico Fermi, who was in charge of accelerator theory; Mario Ageno (1915–1992), Fermi's last student in Rome, who was in charge of the design of the injector; Italo Federico Quercia (1921–1987), who was in charge of organizing the many services required, particularly the electronics, Matthew Sands (b. 1919) and Robert L.Walker (b. 1919) from the California Institute of Technology, and later by Boyce McDaniel (1917–2002), Albert Silverman (b. 1919), and Robert Wilson (1914–2000) from Cornell University.**


Edoardo Amaldi and Gilberto Bernardini (circa 1960)

The planning, building, and exploitation of the Frascati National Laboratories was under the Direction of Giorgio Salvini (b. 1920).

Giorgio Salvini with Grace Kelly and Prince Rainier of Monaco during a visit at Frascati Laboratories

There were some theorists at Frascati, since Salvini recognized the importance of having theorists working at the same place where experiments were being performed. At first, Giacomo Morpurgo worked there but did not communicate very much with the problems with the experimentalists and distributing calculations to his students.

Edoardo Amaldi was president of INFN at that time; his great skills were reminiscent of those of Orso Mario Corbino, Fermi's sponsor in Rome.

Enrico Fermi

O. M. Corbino (1876–1937)

Giuseppe Fidecaro, Edoardo Amaldi and Werner Heisenberg in Geneva.

**Bruno Touschek and Edoardo Amaldi**

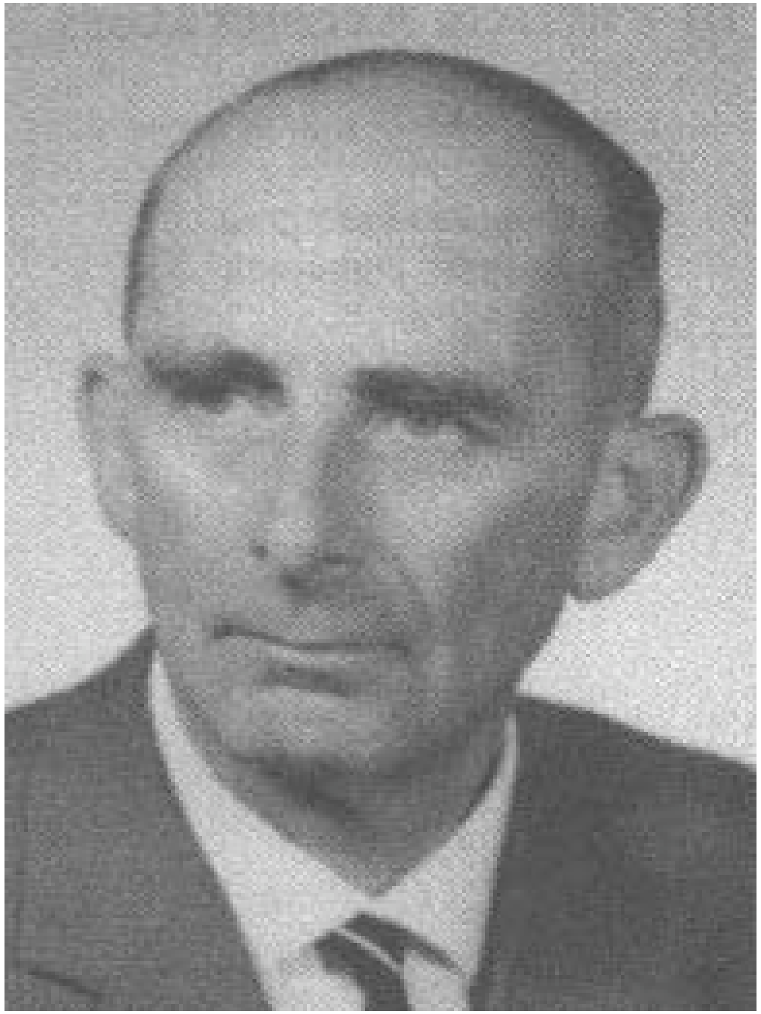
Meanwhile, Edoardo Amaldi, a true “talent scout,” had remembered someone who had visited Rome in 1938: Bruno Touschek (1920–1978), a brilliant Austrian theoretician who had survived a difficult time under the Nazis. Amaldi offered him a position in Rome, which Touschek accepted. At first, Bruno collaborated with Luigi Radicati and Giacomo Morpurgo on fundamental problems, particularly on time reversal and weak interactions, then with Marcello Cini on weak interactions.

**Bruno Touschek did not like much of the theoretical machinery of that time (dispersion relations, Regge poles, evasion and conspiration and so on), but he regarded as quite important the problem of analyticity of form factors and their analytical continuation to time-like values of squared-momentum transfer.**

**Theory was greatly influenced by the development of quantum electrodynamics**
**(QED), a highly successful theory (exploiting second quantization and Feynman diagrams) that had served as a prototype for Fermi's theory of weak interactions and worked in the lowest-order perturbative approximation because of the smallness of the relevant coupling constant, the fine-structure constant.**

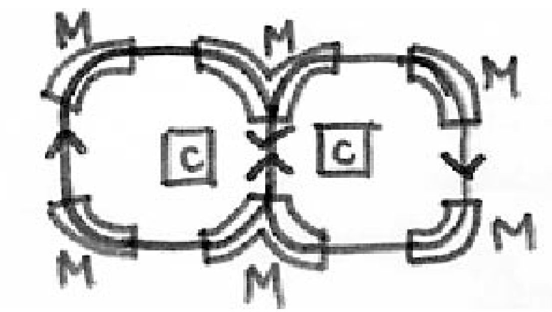
**Some people speculated on the possible breakdown of QED and looked for it in high-precision measurements, such as those of the gyromagnetic ratio g-2, and in electron-collision experiments. In the latter case, physicists generally believed that the breakdown might occur at some very high energy (or better, momentum-squared transfer) characterized by a length (or mass) cutoff occurring in the modified electron-photon vertex or in the electron or photon propagators.**

**The most naïve proposal was that of the so called "heavy-electron," e*, which was supposed to decay into an electron and gamma ray, a decay mode that already had been shown by Giuseppe Fidecaro and his collaborators to be forbidden for the mu meson.**



Rolf Wideröe
(1902–1992)

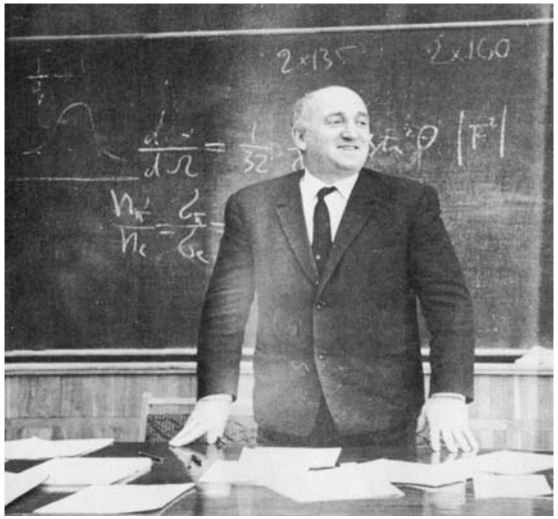
The idea of exploring collisions in the center-of-mass system to fully exploit the energy of the accelerated particles had been given serious consideration by the Norwegian engineer and inventor Rolf Wideröe, who had constructed a 15-MeV betatron in Oslo and had patented the idea in 1943 after considering the kinematic advantage of keeping the center of mass at rest to produce larger momentum transfers.



O’Neill’s rings drawn by Bruno Touschek

This idea was also taken seriously by a Princeton-Stanford group that included William C. Barber, Bernard Gittelman, Gerry O’Neill, and Burton Richter, who in 1959, following a suggestion of Gerry O’Neill in 1956, proposed to build a couple of tangent rings to study Møller scattering.

Andrei Mihailovich Budker (1918–1977) initiated a somewhat similar project at Novosibirsk, where the VEP-1 electron-electron collider was under construction in 1961.



A. M.Budker

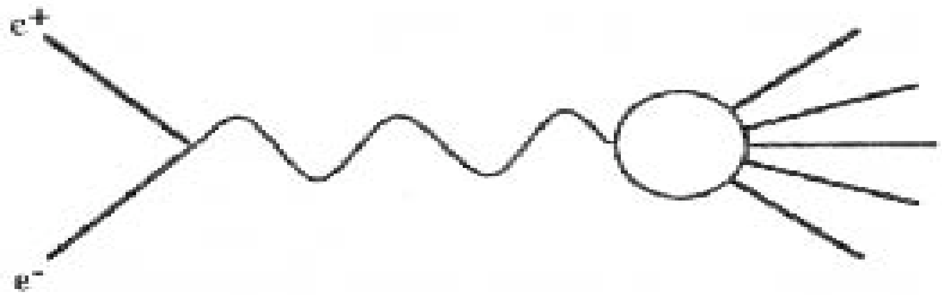
Donald W. Kerst (1911–1993), who had constructed the first successful betatron at the University of Illinois in 1940, also was considering colliders, particularly for protons, in 1959 using the Fixed-Field Alternating-Gradient (FFAG) concept; his contributions to accelerator physics and technology as technical director of the Midwest Universities Research Association (MURA) while at the University of Wisconsin in Madison during this period were of much interest to the accelerator community.

The attention of these people was apparently focused more on the kinematic advantage of colliding beams than on the new physics to be learned from them. To achieve head-on collisions between accelerated particles in flight required storing them in magnetic devices (storage rings) to allow them to collide repeatedly as they crossed at various points in their circular orbits.

That was precisely Bruno Touschek's starting point at Frascati. He considered the kinematics as rather obvious; to him the possible physics to be learned from colliding particles was far more significant. He had a very strong picture of the microscopic world in his mind. He conceived the vacuum as a reactive dielectric resonating at frequencies $\nu = mc^2/h$, where $c$ is the speed of light, $h$ is Planck's constant, and $m$ in this case is the mass of a boson homologous to the photon, that is, a neutral vector meson.

Some people at this time were speculating on the existence of such mesons. I was corresponding, for instance, with Yoichiro Nambu in Chicago, who had suggested searching for such particles as plausible intermediaries of the strong interactions; the concept of "vector dominance" was close at hand.

Bruno’s view, as he put it, was that a physical system can be characterized appropriately by investigating its “geometry” and its “dynamics.” Its geometry, its size and shape, is observable by employing space-like photons as in electron-proton scattering experiments (“diffraction of electron waves”); this was precisely what Robert Hofstadter was doing at Stanford using the Mark III Linac to measure form factors of nuclear particles.

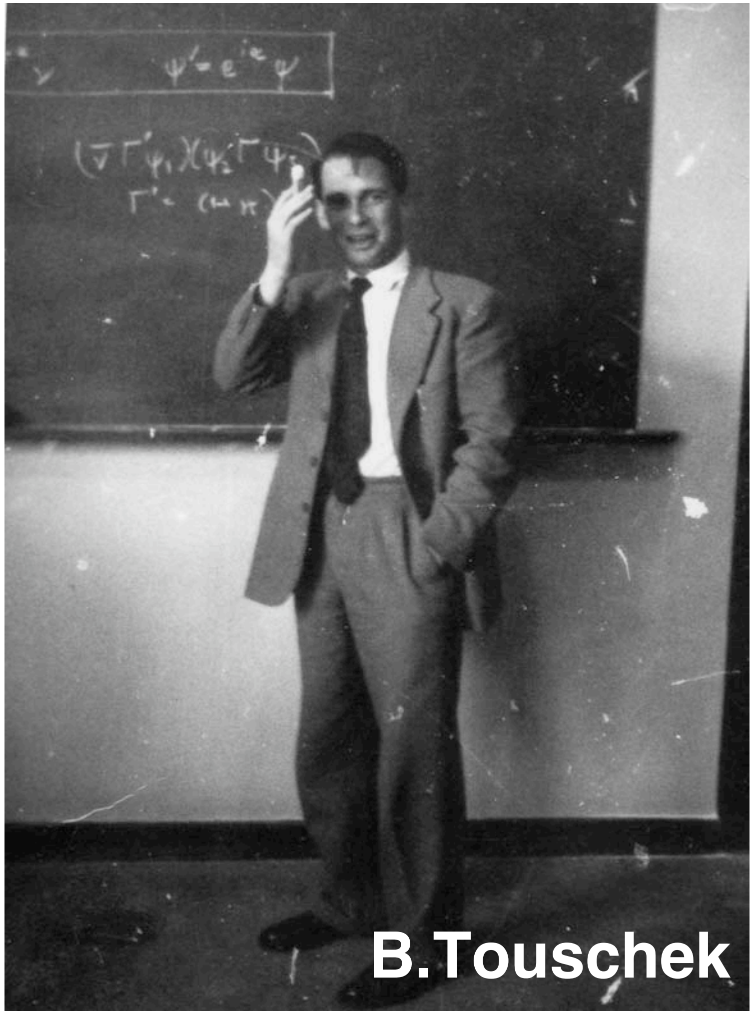



No one, however, had as yet observed the dynamics; for this one needed to produce time-like photons of sufficiently large energy to excite resonant modes of the vacuum corresponding to the masses of the vector mesons. Thus, Touschek concluded, we should make electrons and positrons collide and annihilate in the center-of-mass system to produce time-like photons (in the dominant one-photon channel where the small value of the fine-structure constant helps).

**Bruno Touschek gave a seminar on March 7, 1960, at Frascati in which he guaranteed that an electron and a positron necessarily meet in a single orbit because QED is CP (charge-parity) invariant. His skeptical colleagues did not have the courage to doubt him. His seminar was attended by many people, among them Salvini, Fernando Amman (who a couple of years later would be in charge of the Adone collider), and Raul Gatto, who with Nicola Cabibbo**

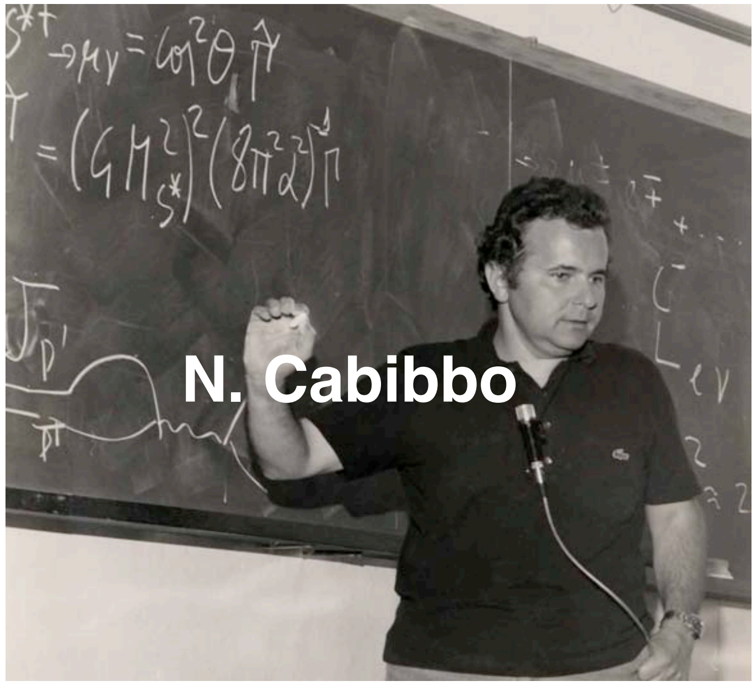
**immediately began to investigate all possible electron-positron reaction cross sections and derived formulas describing the relevant parameters, particularly in hadronic physics. The central question was asked: Will**

**many or few hadrons be produced?**



B.Touschek

R.Gatto



N. Cabibbo

(11)

N. Cabibbo and R. Gatto
1° Aprile 1961
*Il Nuovo Cimento*
Serie X, Vol. 20, pag. 185-193

# Theoretical Discussion of Possible Experiments with Electron-Positron Colliding Beams.

N. Cabibbo and R. Gatto

*Istituti di Fisica delle Università - Roma e Cagliari*
*Laboratori Nazionali di Frascati del CNEN - Frascati (Roma)*

(ricevuto il 2 Febbraio 1961)

**1.** – We discussed recently the possible determination of the pion form factors from the reactions $e^+ + e^- \to n\pi$ (1). There is at present a definite interest, particularly in Frascati, in the realization of electron-positron colliding beams. In this note we shall briefly present some further theoretical considerations on high energy electron-positron experiments.

**2.** – High energy $e^+$-$e^-$ experiments can test the validity of quantum electrodynamics at small distances. There are two other aspects of such experiments that we want to stress:

i) The possibility of exploring form factors of strong interacting particles. These form factors are explored for timelike momentum transfers. Electron scattering experiments — whenever possible — can only explore spacelike momentum tranfers.

ii) The possibility of carrying out consistently a « Panofsky program », *i.e.* the exploration of the spectrum of masses of elementary particles through their interaction with photons. This program can be extended to include the exploration of particular classes of unstable states.

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(1) N. Cabibbo and R. Gatto: *Phys. Rev. Lett.*, **4**, 313 (1960). The same results have also been derived by Yung Su Tsai: *Phys. Rev.*, **120**, 269 (1960).





## 4. – Production of strong-interacting particles.

We consider the lowest order graph in the electromagnetic interaction but including all strong interaction effects.

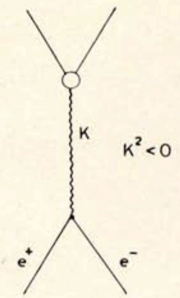



Fig. 4.

The form of the $PP\gamma$ vertex is only limited by Lorentz- and gauge-invariance.

*a*) for $e^+ + e^- \to f + \bar{f}$ where f is a charged or neutral fermion of spin $\frac{1}{2}$

$$\frac{d\sigma}{d(\cos\theta)} = \frac{\pi}{8}\alpha^2 \lambda\!\!\!^{-2} \beta_f F(\cos\theta)\,,$$

where

$$F(\cos\theta) = |F_1^{(f)}(-4E^2) + \mu_f F_2^{(f)}(-4E^2)|^2(1+\cos^2\theta) + \\ + \sin^2\theta \left| \frac{m_f}{E} F_1^{(f)}(-4E^2)|^2 + \frac{E}{m_f}\mu_f |F_2^{(f)}(-4E^2) \right|^2 .$$

Here $\mu_f$ is the static anomalous magnetic moment of f, and $F_1^{(f)}(k^2)$, $F_2^{(f)}(k^2)$ are the analytical continuation of the electric and magnetic form factors of f for negative values of $k^2$. The situation is illustrated in the following graph for the special case of the isotopic vector part of the nucleon electromagnetic vertex.

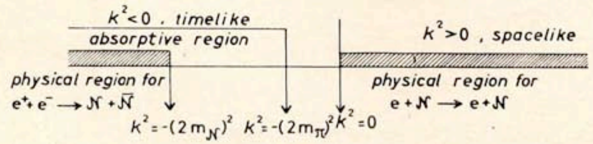
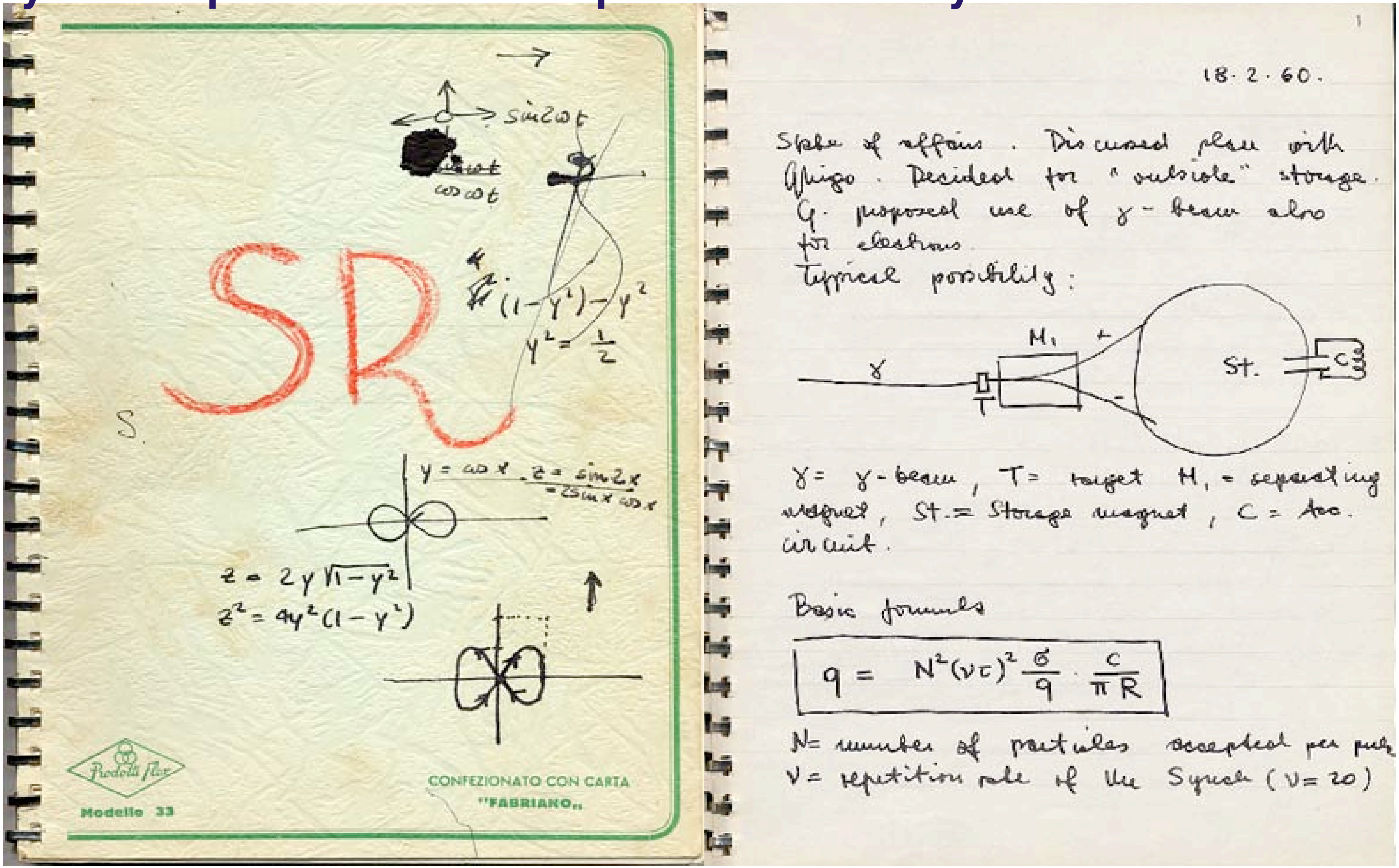
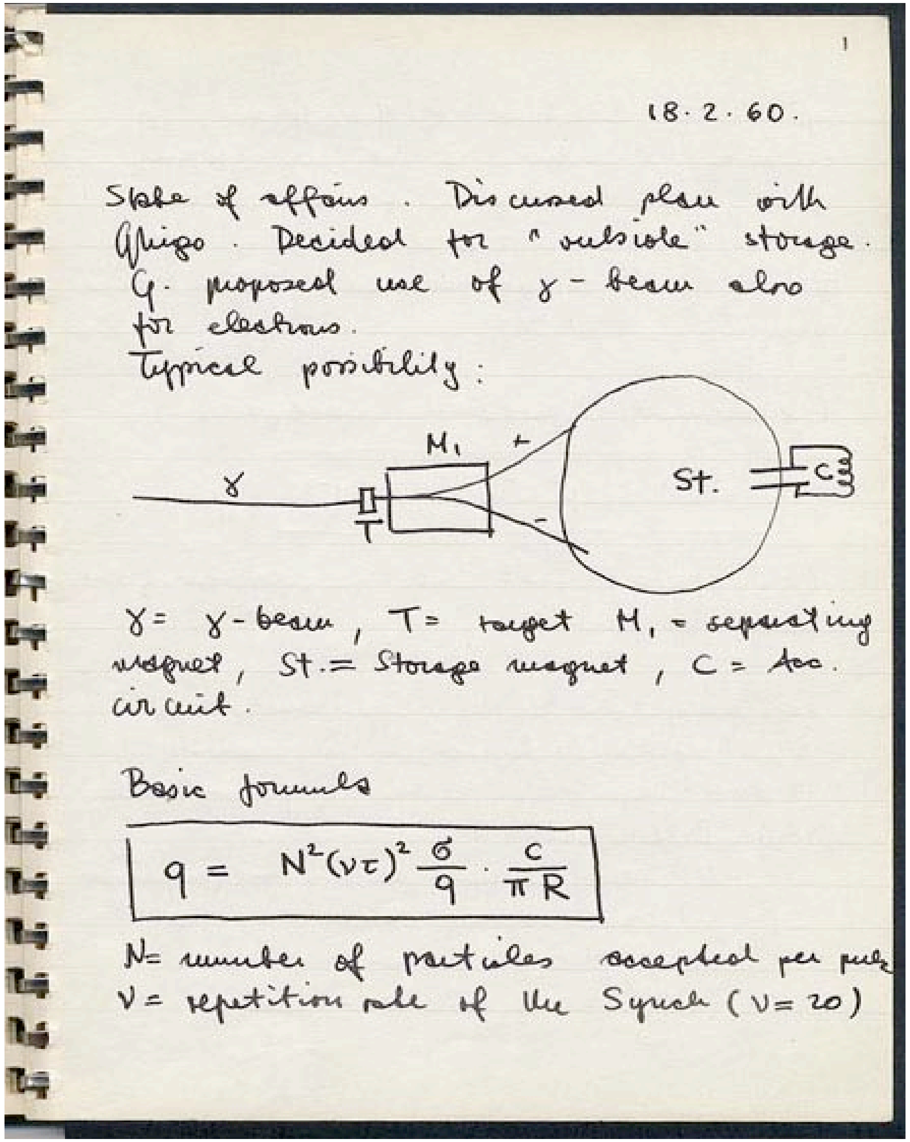



Fig. 5.

In the graph we have reported the physical regions and the absorptive region on the $k^2$ real axis.

**Touschek's seminar appears to have been thoroughly prepared during the whole period going from February 18 to March 7, as can be inferred from his notebook preserved in the archives of the Physics Department of La Sapienza University in Rome.**





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18.2.60.

State of affairs. Discussed plan with Ghigo. Decided for "outside" storage. G. proposed use of γ-beam also for electrons.
Typical possibility:



γ = γ-beam, T = target M1 = separating magnet, St. = Storage magnet, C = Acc. circuit.

Basic formula

$$\boxed{q = N^2(\nu\tau)^2 \frac{\sigma}{q} \cdot \frac{c}{\pi R}}$$

N = number of particles accepted per puls

ν = repetition rate of the Synch (ν = 20)

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ν = repetition rate of the Synch (ν = 20)

τ = lifetime of the beam,

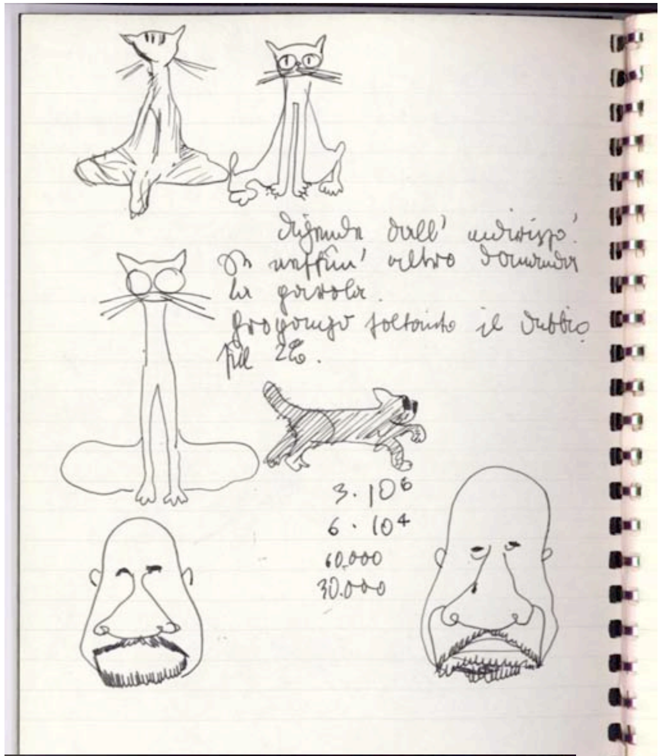
q = effective x-section of the circulating beam

σ = x-section for the process to be observed

c = velocity of light

πR = half circumference of the storage magnet

# Touschek's first note-book (February 18, 1960)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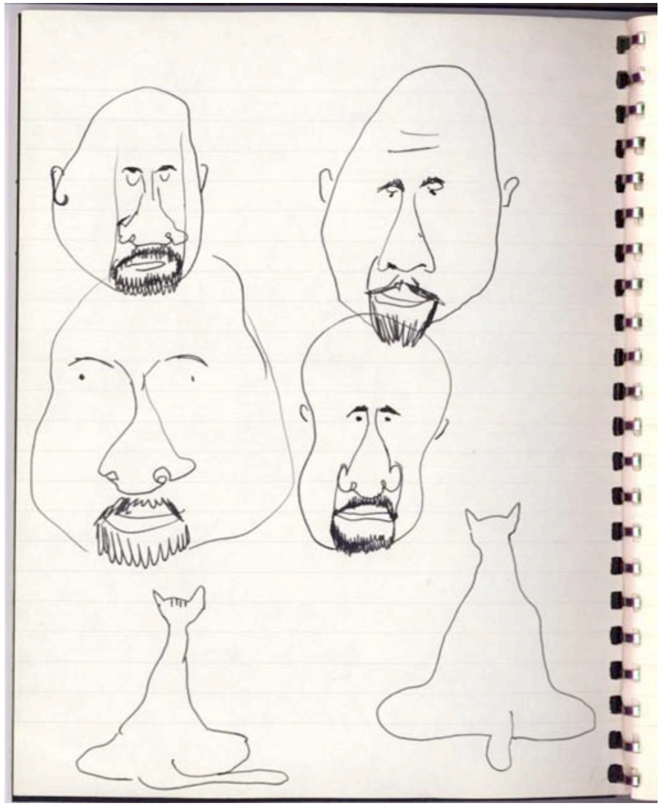

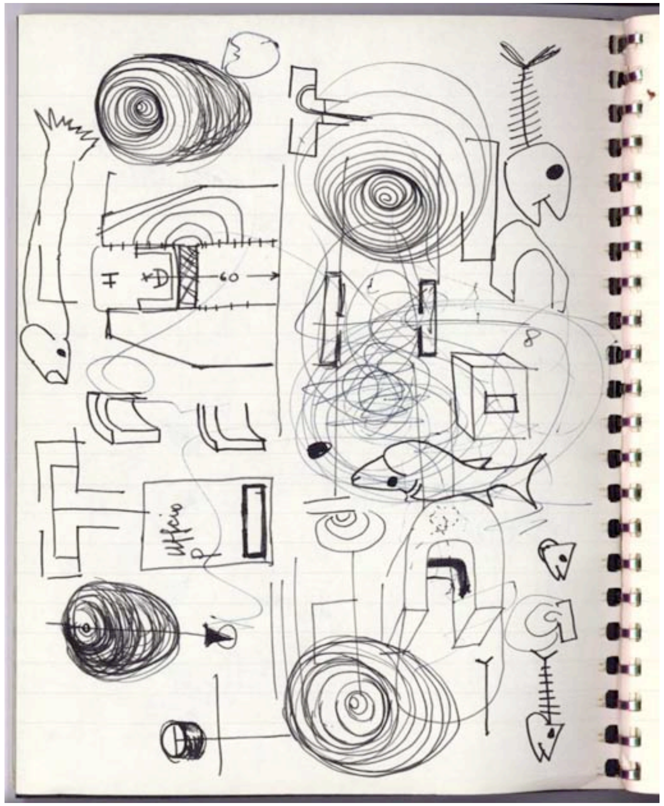
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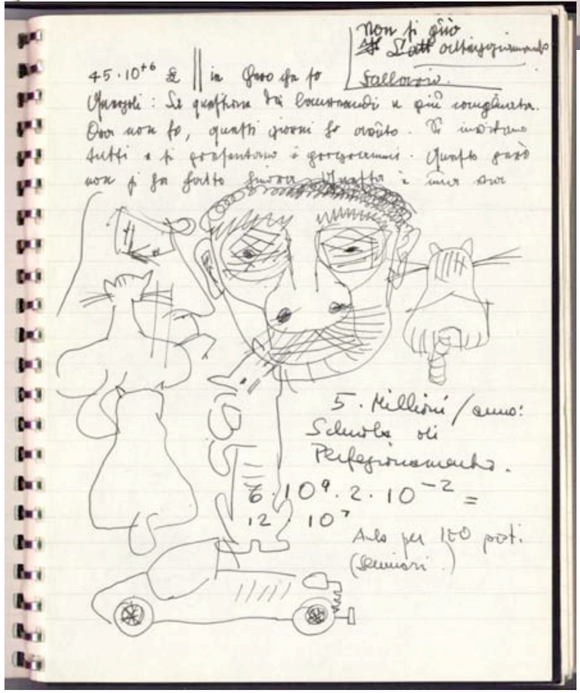
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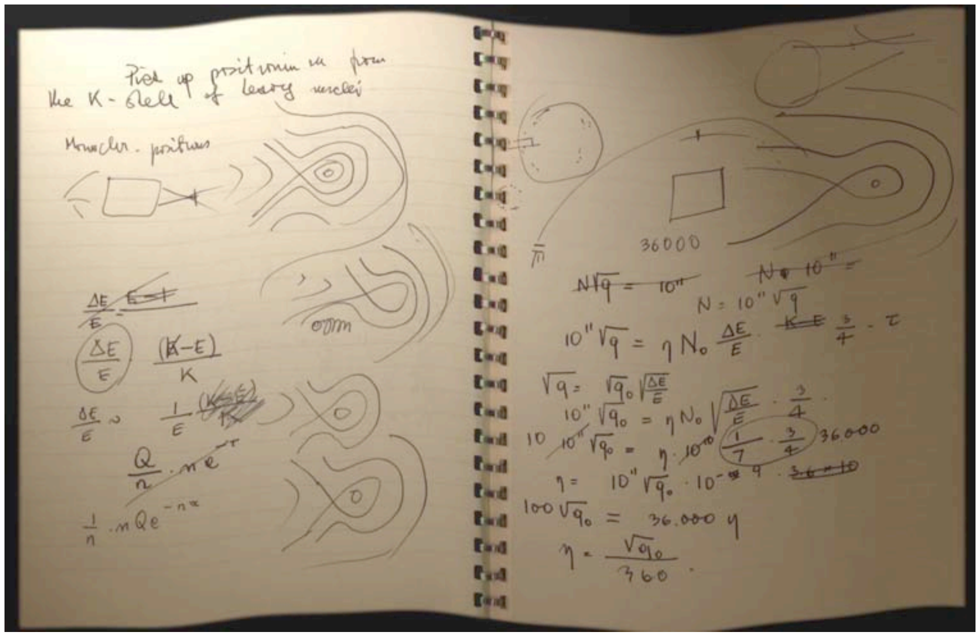
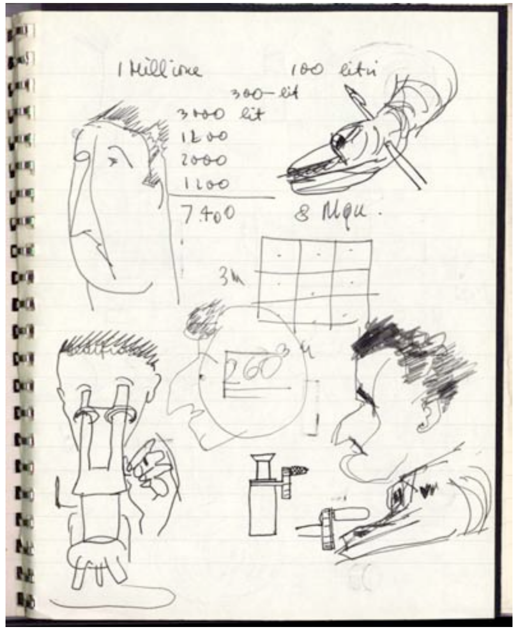

Pick up positronium from
the K-shell of heavy nuclei
36000
N = 10'' √q
10'' √q = η N₀ ΔE/E · 3/4 · τ
√q = √q₀ √(ΔE/E)
η = 10'' √q₀ · 10⁻⁹
100 √q₀ = 36.000 η
η = √q₀ / 360


1 Millione
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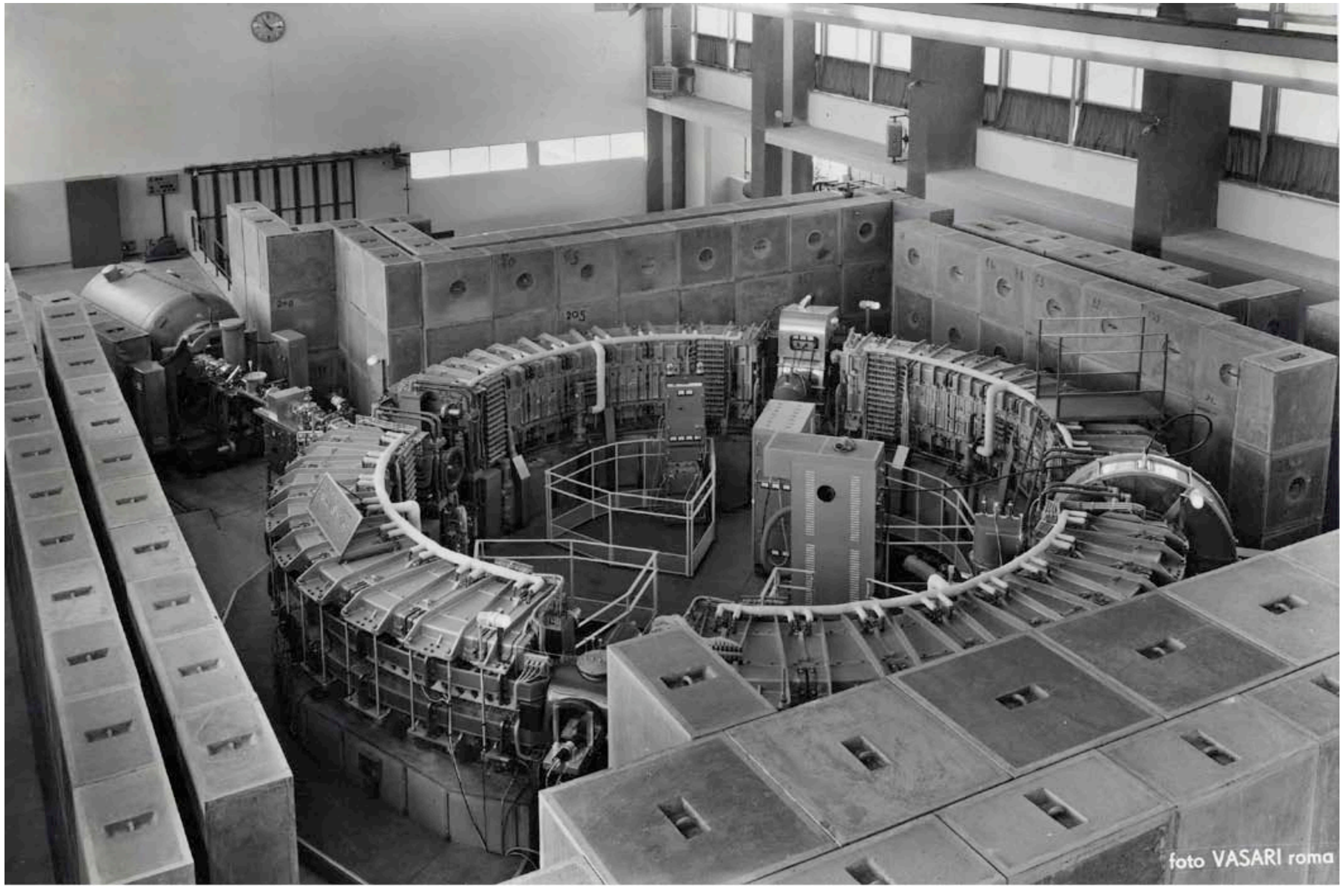
1200
2000
1100
7400
8 Mqu.
3m
260

Touschek, in his peculiar style, tried to convince Salvini to immediately convert the Frascati electron synchrotron into a collider ring (as actually was done ten years later for the Cambridge Electron Synchrotron). Salvini wisely refused : The Frascati electron synchrotron was unfit for this purpose, and many experiments had already been performed or scheduled for it.

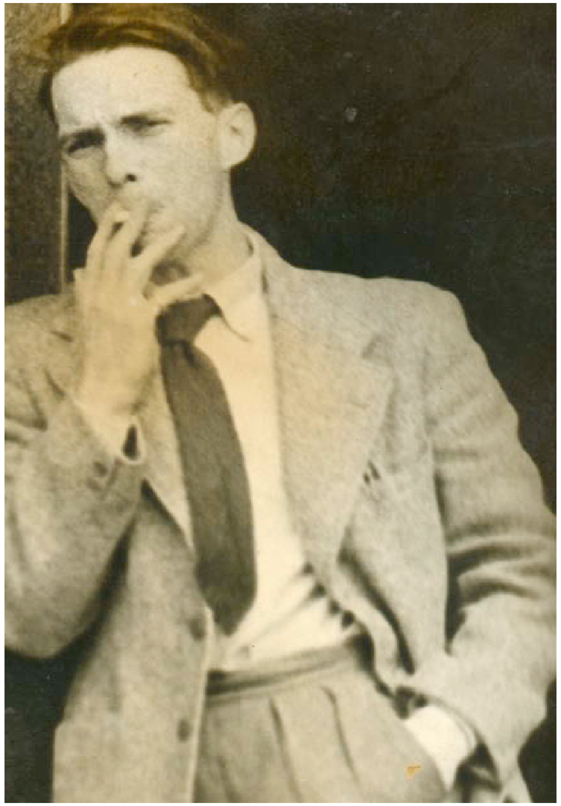



Salvini however warmly agreed with the proposal to prepare a new machine. We therefore immediately constituted a small group of people to investigate the most pressing problems that would have to be addressed to build an electron-positron collider ring *ex novo*.

Gianfranco Corazza working on the electron synchrotron donut

Carlo Bernardini

Giorgio Ghigo



Bruno Touschek

The original group consisted of Gianfranco Corazza (b. 1924), Giorgio Ghigo (1929–1968), Bruno Touschek,  and myself.
We agreed that the energy of the electron and positron beam should be 250 MeV, which was a reasonable amount higher than the threshold for producing a positive and negative pion pair.

## On The Storage Ring.

The following is a very sketchy proposal for the construction of a storage ring in Frascati. No literature has been consulted in its preparation, since this invariably slows down progress in the first stage, necessary though it may be in the consecutive stages of the development. I shall present you here all I have thought about it and much, which others have suggested to me and to anticipate the question: No, I have not properly read O'Neil, but I hope that somebody will.

Let me first explain why a storage ring is an important instrument, particularly when fed with electrons and positrons. The first suggestions to use crossed beams I have heard during the war from Widerøe, the obvious reason for thinking about them being, that one ~~wasted~~ a considerable amount of energy by using 'sitting' targets – most of the energy being wasted to pay for the motion of the centre of mass. If one wants to study electrodynamics one should try to use particles, which interact weakly except electromagnetically. This automatically cuts one down to electrons (and positrons) since $\mu$-mesons are hard to come by in large numbers. To use a crossed beam consisting of electrons a n d positrons has the further advantage that in all interesting processes the particles of the initial state (i.e. the electrons and the positrons) disappear: Experiments made in this way can only depend on two parameters (the energy and the angle, the first being given by the machine). This means that much more information can be gained by much fewer events.

At this stage it appears necessary to define the project a little better: I prefer to think of it as an experiment rather than as a machine – a fact which may change considerably our attitude to the project. As I think I will be able to demonstrate the project is closer to an experiment than to a machine in two important respects: in cost and in the limited range of applicability of the ironware. Talking of it as an experiment I propose to study the reactions

(1) $$e^+ + e^- \rightarrow \begin{cases} 2\gamma & \text{(A)} \\ \mu^+ + \mu^- & \text{(B)} \\ \pi^+\pi^-\ (2\pi^0) & \text{(C)} \end{cases}$$

and I admit that I think that there is nothing else of importance, which can be studied with the same set up.

The first of the processes listed is two quantum annihilation. The process is predominantly backward-forward in the C.M. system and in these preferred directions no 'radiative corrections' are to be expected. The cross section for this process is

(2) $$\sigma(A) = 6.3.10^{-30}\ \mathrm{cm}^2$$

at 250 Mev and it diminishes a little less than quadratically with rising energy.

I propose to use (1A) as a monitoring process. This is a

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$$\sigma(A) = 6.3.10^{-30}\mathrm{cm}^2$$

At 250 MeV[…]I propose to use (1A) as a monitoring process[…]

$$L = N_1 N_2 \left(\frac{\sigma}{q}\right) \frac{c}{u} \cdot \frac{s}{u} \cdot \eta$$

Problems:

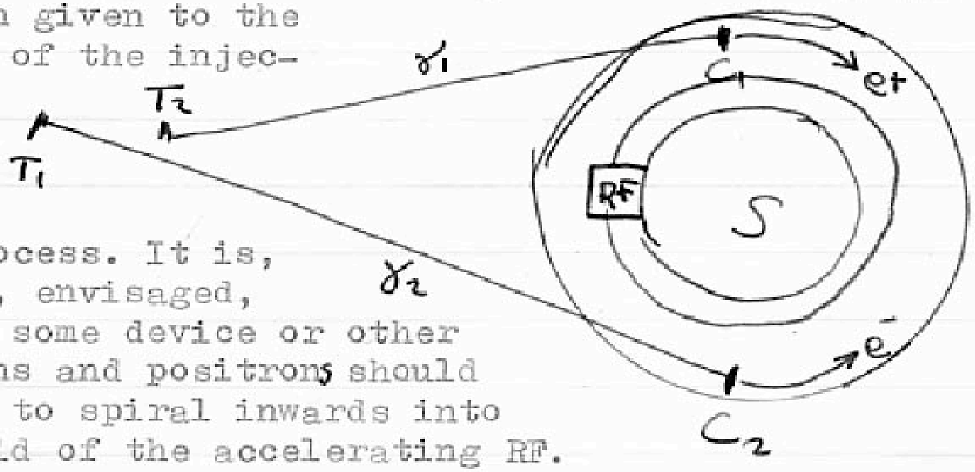
1 The evaluation of the "source factor," which from then on was called the "luminosity."

2 Analysis of the beam lifetime and of the processes that might influence it.

3 Injection of electrons and positrons.

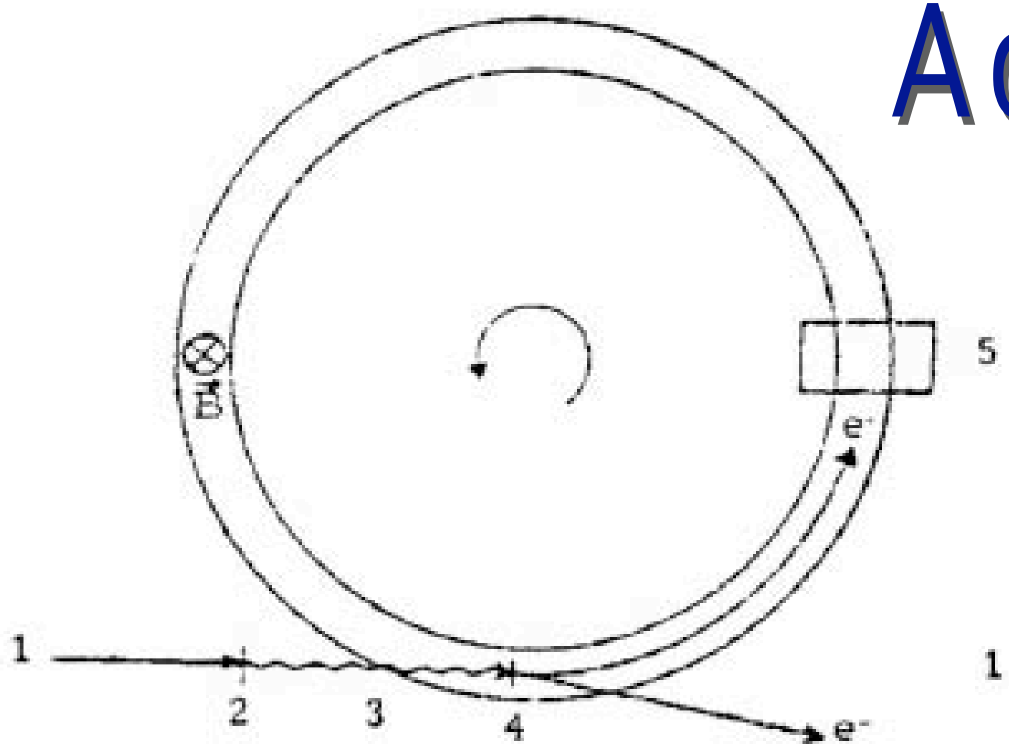
4 Design of the magnet to achieve compactness and to leave enough room to allow access to the electron and positron beams, and design of the RF cavity to compensate for the synchrotron-radiation losses.

All this indicates a design of maximum symmetry, minimum size and maximum field, as ~~indicated~~ in the drawing. Here S is the storage ring, $T_1$ and $T_2$ are two targets mounted in the doughnut of the synchrotron and $\gamma_1 \gamma_2$ two $\gamma$-ray beams. $C_1$ and $C_2$ are 'converter targets', $C_1$ producing positrons and $C_2$ electrons. So far no thought has been given to the details of the injec-

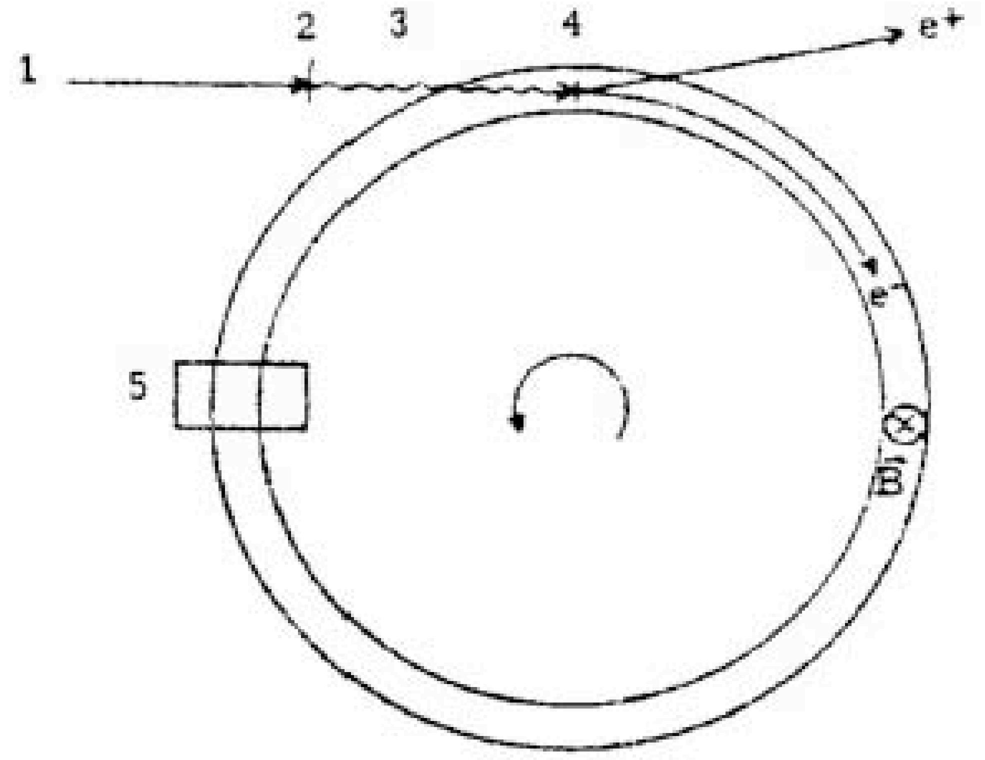



tion process. It is, however, envisaged, that by some device or other electrons and positrons should be made to spiral inwards into the field of the accelerating RF.

# AdA Collider Ring




(1) Electron beam from the electron syncrotron
(2) External target: production of bremsstrahlung gamma-rays
(3) Donut walls
(4) Internal target: tantalum converter
(5) RF Cavity




With the magnetic field (B) directed downward, electrons are injected into the ring when it is in the position shown at the right.
The ring is then translated and rotated 180° as shown above.
Positrons are then produced and orbit clockwise.

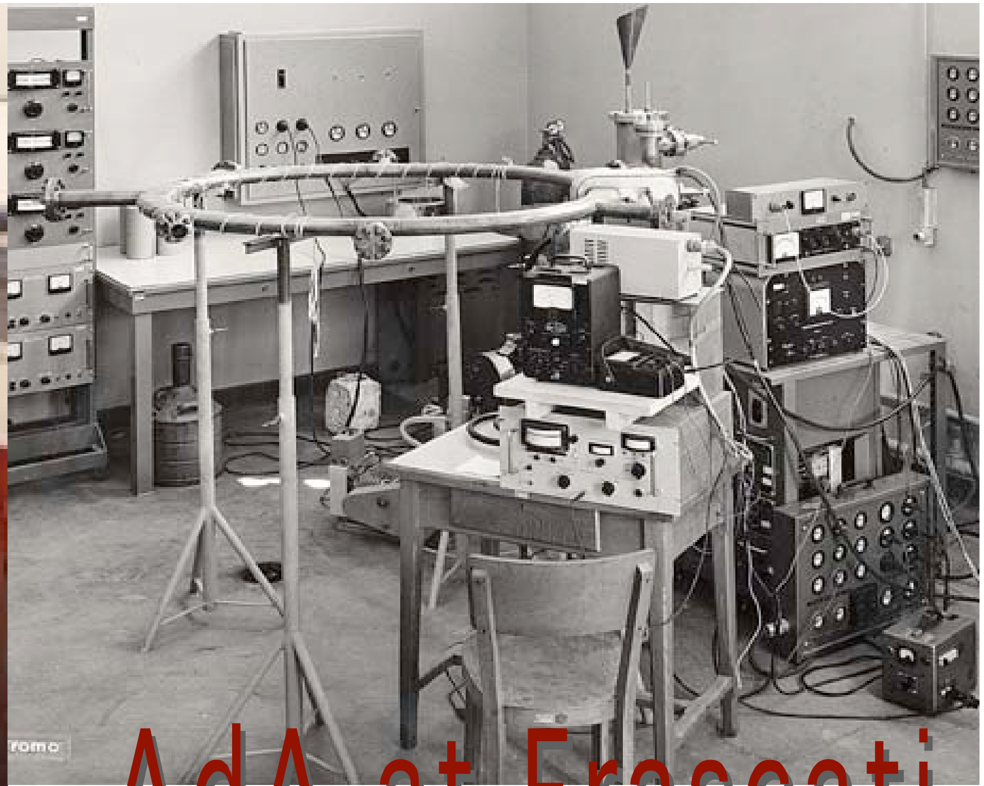
We did a lot of calculations trying to estimate the injection efficiency; most of them, however, were quite unreliable because of their sensitivity to imperfectly-known magnetic parameters.

Touschek kept himself fully informed on all details of these technical aspects of our work-in-progress with AdA, but his main concern, as always, was the physics.

To get physical results, the oppositely orbiting electron and positron beams had to meet and overlap completely. Touschek thus was fascinated with the luminosity formula, which actually followed from a classical calculation of the "quality" of the operating ring, something like the duty cycle of an engine.

To the question: "How can you be sure that electrons and positrons will meet?" he answered: "Obviously, TCP [time-charge-parity] theorem! Actually, CP is enough!" Another question sometimes was: "Will electromagnetic interactions with the walls of the donut separate the beams?" Bruno's answer: "Scheisse!" And so on.

# AdA at Frascati



It was also possible to photograph the light emitted by a few stored electrons. Such a photograph is shown in Fig. 3. The radial width (1.5 mm) corresponds to the theoretical prediction for electrons of 220 MeV, and the height

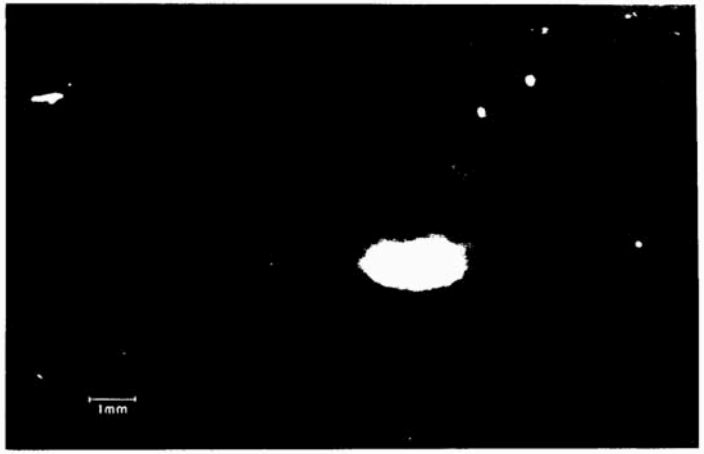



Fig. 3. – Cross-section of the circulating beam.

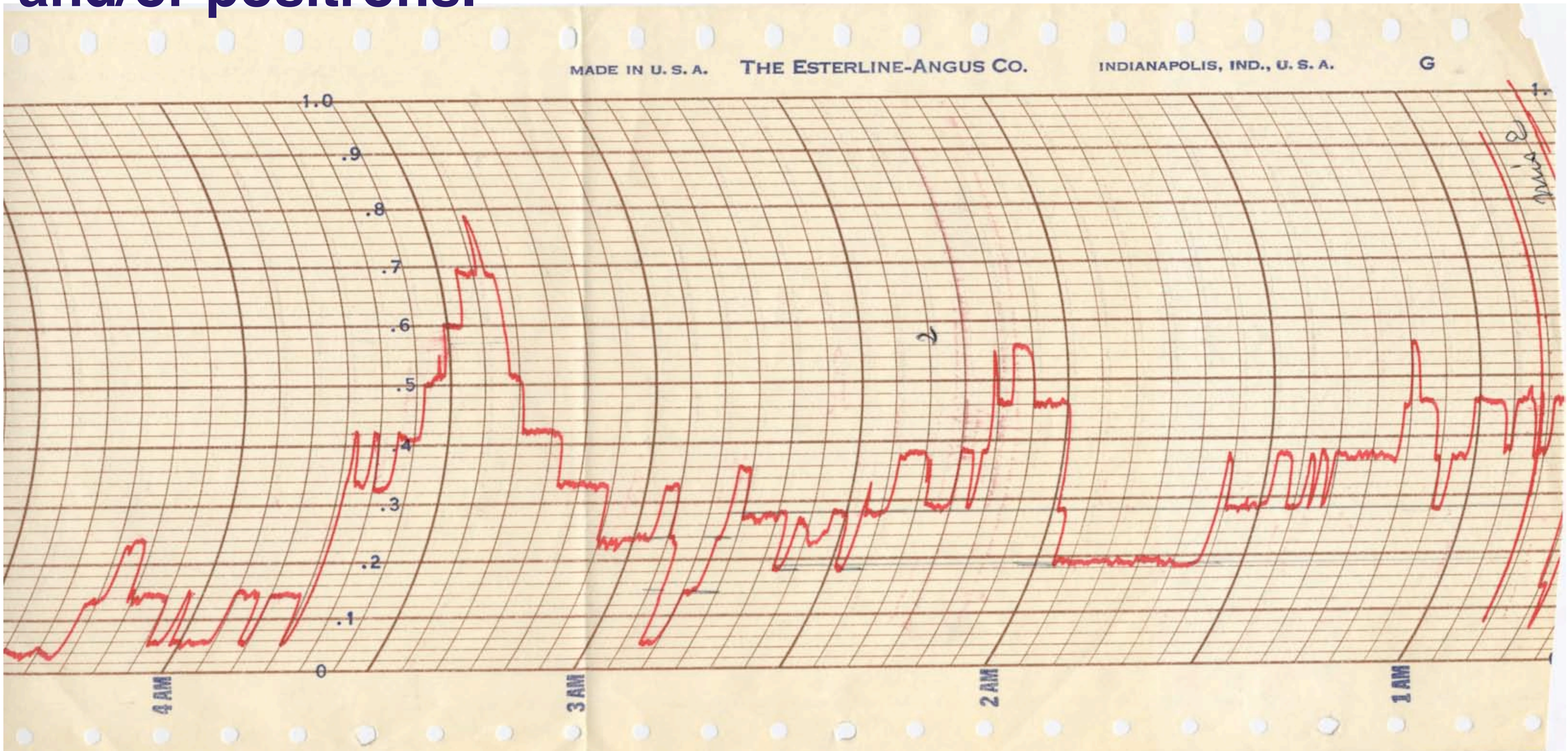
which is determined by the pressure of the residual gas corresponds well to the pressure at the time of the experiment.

In the period June-December 1961 work proceeded along two main lines: the development of a high vacuum doughnut and the search for a method of improving the capture efficiency. The latter problem reduced essentially to that of finding a way of speeding up the process by which the electrons are carried away from the target. In the previous tests the only mechanism available was the damping of the betatron and synchrotron oscillations, by which the electrons are carried away from the target at a rate of about $3 \cdot 10^{-6}$ cm/revolution. We tried to improve on this mechanism by finding other means of moving the equilibrium orbit during the time of the synchrotron pulse. We hoped to achieve displacements of the orbit of the order of millimetres in times of the order of about 0.1 μs and it was thought that this should increase the intensity by a factor of order 2, which could then be further improved by shortening the synchrotron pulse from 15 μs to about 0.1 μs, so that the



**To our surprise even a single electron was visible to the naked eye through one of the portholes. A common joke was to store a few electrons and astonish distinguished visitors, among whom were Edoardo Amaldi, Philip Ivor Dee from Glasgow (a former student of Ernest Rutherford and a good friend of Bruno),Wolfgang Paul from Bonn, Guy von Dardel from Lund, Boyce McDaniel and Albert Silverman from Cornell, and Matthew Sands and Robert Walker from Caltech.**

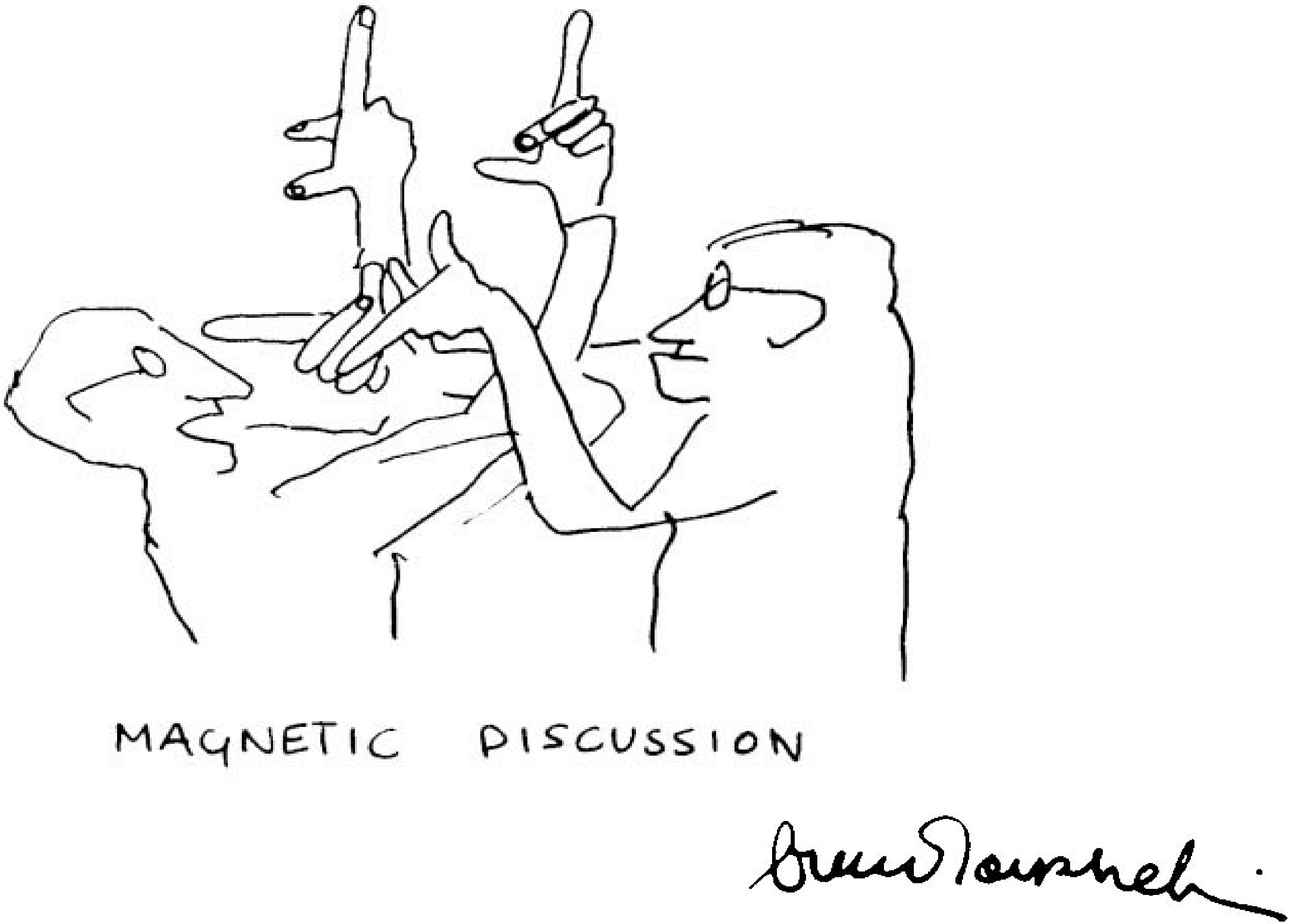
On February 27, 1961, just less than a year after Touschek's seminar, we got the first stored electrons and/or positrons.




The phototube record showing steps that correspond to single electrons entering or leaving AdA.

# The "Roasting Spit"

**The injection trials were carried out first by irradiating the internal converter target when the ring was installed far away from the electron syncrotron on a tower (tripod).**
**Then we moved the ring near the syncrotron mounting the magnet on a support that rotated around a horizontal axis. This made possible to invert the magnetic field to switch from electron to positrons, and *vice versa*.**

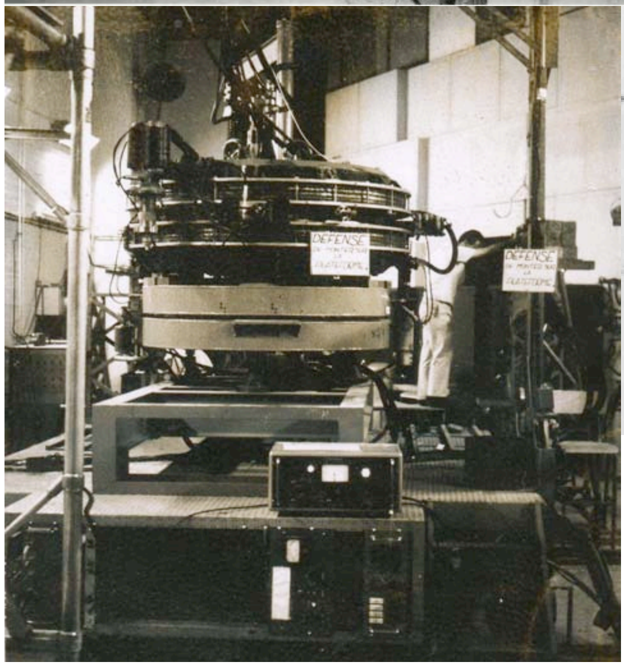


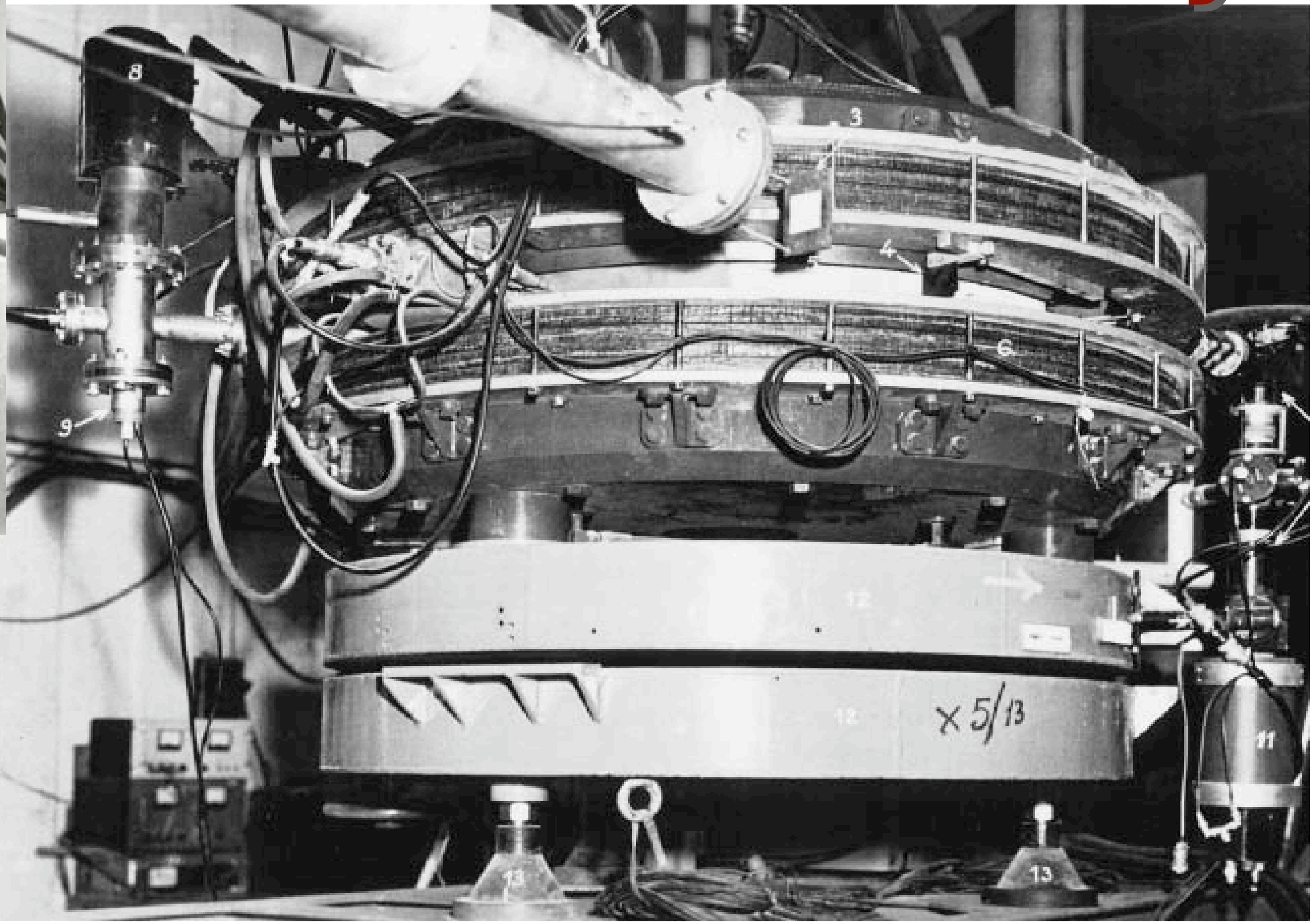

Many discussions occurred as to which were the electrons and which were the positrons; they ended when Bruno drew a famous cartoon underlining the inconclusive debate.

**The difficulties in using a well-collimated bremsstrahlung gamma-ray beam in Frascati to produce electrons and positrons in AdA was the subject of widespread bad humor, but they favored the rapid acceptance of Pierre Marin's proposal, on behalf of André Blanc Lapierre, the Director of the Orsay Laboratory, to move Ada to Orsay, where their electron linac beam could be positioned very close to AdA's evacuated donut and internal converter. Bruno and I agreed with Marin's proposal, and we easily convinced Salvini and Amaldi to accept it. We therefore immediately organized the transportation of AdA to Orsay on a truck in the first half of June 1962.**

**Jacques Haïssinski and Pierre Marin**

# AdA at Orsay




**AdA on the rotating and translating platform at Orsay. The injector beam channel is visible on the left.**

We eventually were able to inject a non-negligible electron/positron current, which was extremely satisfactory to us.

I already had reconsidered the calculation of the transverse size of the beam – its horizontal and vertical dimensions – and I realized that its vertical dimension was much smaller than we had believed.

We calculated that at an energy of 200 MeV and a pressure of $10^{-9}$ torr the root-meansquare dimensions of the electron and positron bunches were 1.8 millimeters in the horizontal direction, 1.5 microns in the vertical direction, and 255 millimeters in the longitudinal direction, where only the transverse (horizontal and vertical) dimensions matter for the beam's luminosity. Our enthusiasm, however, was short-lived.
That night in March of 1963 we were steadily filling the collider ring as usual; the vacuum was excellent, as was the electron-positron injection current. Everything gave the impression that we were reaching higher stored currents than ever before. Then, at a certain point, we noticed that the injection rate was decreasing, and sometime later the stored current increased no further – it had reached saturation.

The vacuum pressure gauge showed no change; a single beam was in. Touschek went crazy. It was about 2 or 3 o’clock in the morning – a time when we usually were at work at Orsay. Touschek left the laboratory and went to the Café de la Gare, which was open to serve passengers leaving and boarding the night trains.We continued to try to inject.

Suddenly, Bruno reappeared (I cannot claim that he was exactly sober at the moment) announcing: “I got it! It is Møller scattering in the bunch!” He then exhibited a formula, explaining that he had calculated that saturation should occur at the beam intensities we had reached because electron-electron scattering in the beam’s bunches was transferring energy from the betatron oscillations in the traverse directions into the longitudinal stability zone, which was limited in the amount of energy it could accept.

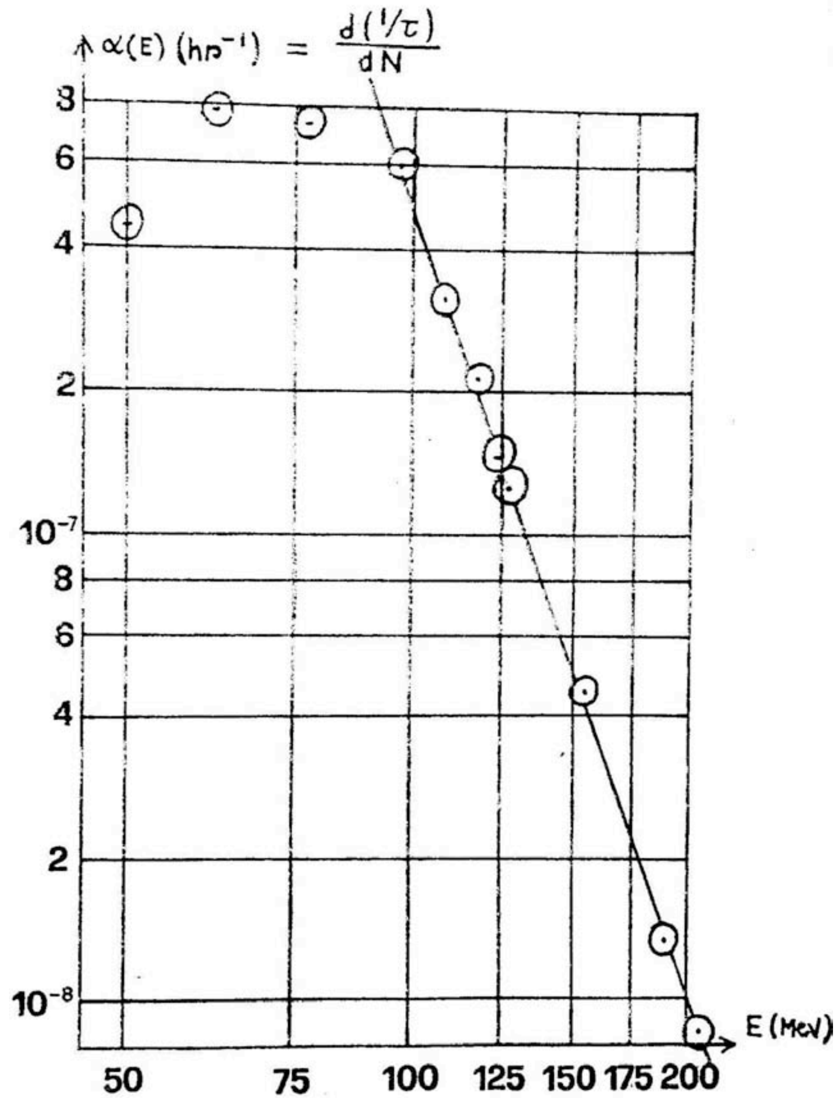
Bruno, however, was desperate. In thinking about the complete calculation, we understood that this disadvantage applied especially to small colliders. AdA thus looked like a flop. I began to reconsider the situation, trying to be optimistic. For some unknown reason, I pictured the beam in my mind as a strap because of the “different” mechanisms that resulted in forming its horizontal and vertical sizes. “Different” means “uncoupled.”

# "Touschek Effect"

Suppose, then, that you introduce a coupling. I telephoned Frascati:

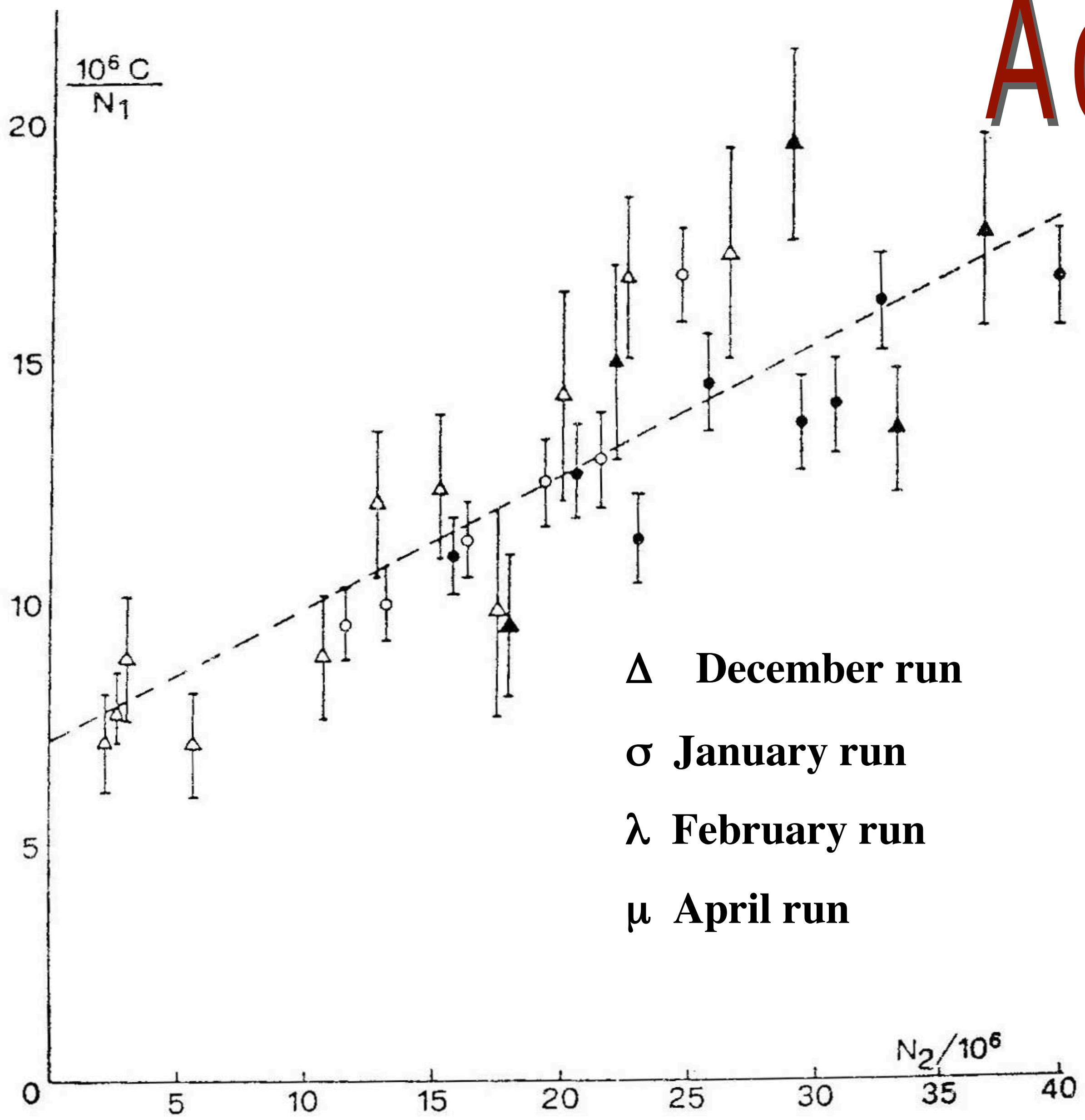
"Please prepare a small quadrupole magnet, of such and such dimensions, to be inserted into the quasi-straight section of AdA. I will fly tonight, come to the lab tomorrow morning, and bring the machined magnet back to Orsay in 48 hours. Thank you, guys."

But we had won the battle and not the war. When the coupling was turned off, the beam lifetime decreased drastically for the first hour, so that the number of annihilation events recorded by our Cerenkov counter was low. Bruno was disappointed, but not entirely: At higher energies, which for instance we later had with the Adone collider, we knew that this saturation effect, known as the "Touschek effect," was not a disaster.




Coefficient of the term linear in the stored particle number of inverse lifetime as a function of energy (original drawing by Bruno Touschek)

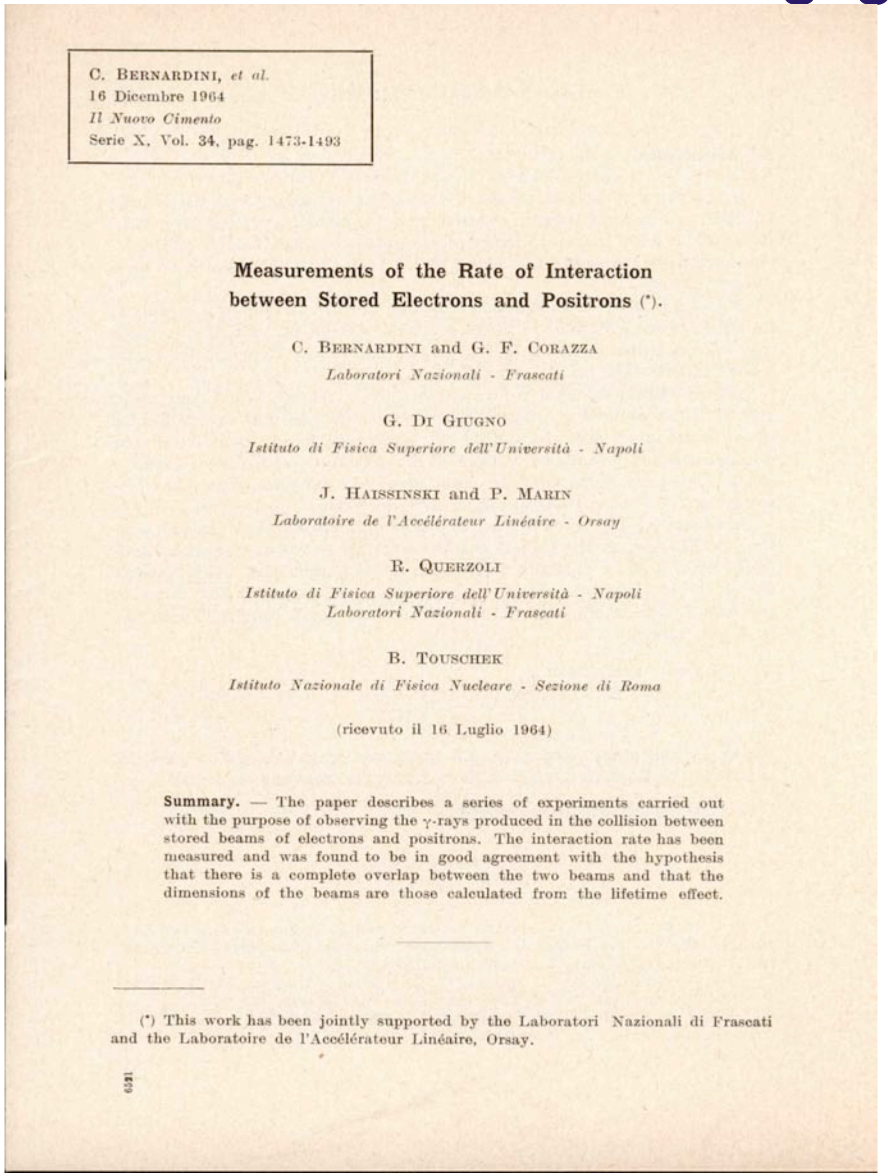
# Ada Luminosity




Counting rate per particle in beam n° 1 as a function of particle number in beam n° 2

**Bruno noticed that the rate of gamma rays observed in the direction of beam 1 is proportional to the number of particles $N_1$ in it, while for beam-beam events the rate is proportional to the number of particles $N_1N_2$ in both beams 1 and 2. Thus, the observed gamma-ray rate divided by $N_1$ depends linearly on $N_2$, and the slope of the line is a measure of the rate recorded by the detector monitoring the reaction, that is, of the luminosity of the beam.**

**Bruno and I took charge of the data analysis. We used his formula to predict the beam size and calculate its luminosity, finding a luminosity of $10^{25}$ particles per square centimeter per second – small but not negligible.**



C. Bernardini, *et al.*
16 Dicembre 1964
*Il Nuovo Cimento*
Serie X, Vol. 34, pag. 1473-1493

**Measurements of the Rate of Interaction between Stored Electrons and Positrons (*).**

C. Bernardini and G. F. Corazza
*Laboratori Nazionali - Frascati*

G. Di Giugno
*Istituto di Fisica Superiore dell'Università - Napoli*

J. Haissinski and P. Marin
*Laboratoire de l'Accélérateur Linéaire - Orsay*

R. Querzoli
*Istituto di Fisica Superiore dell'Università - Napoli*
*Laboratori Nazionali - Frascati*

B. Touschek
*Istituto Nazionale di Fisica Nucleare - Sezione di Roma*

(ricevuto il 16 Luglio 1964)

**Summary.** — The paper describes a series of experiments carried out with the purpose of observing the $\gamma$-rays produced in the collision between stored beams of electrons and positrons. The interaction rate has been measured and was found to be in good agreement with the hypothesis that there is a complete overlap between the two beams and that the dimensions of the beams are those calculated from the lifetime effect.

(*) This work has been jointly supported by the Laboratori Nazionali di Frascati and the Laboratoire de l'Accélérateur Linéaire, Orsay.

**"The paper describes a series of experiments carried out with the purpose of observing the $\gamma$-rays produced in the collision between stored beams of electrons and positrons. The interaction rate … was found to be in good agreement with the hypothesis that there is a complete overlap between the two beams…"**

**C. Bernardini et al., "Measurements of the Rate of Interaction between Stored Electrons and Positrons",**

***Il Nuovo Cimento 34*, December 16, 1964 - Received July 16**

# Frascati

**1960**

**Bruno Touschek**
**Carlo Bernardini**
**Gianfranco Corazza**
**Giorgio Ghigo**
**(Giancarlo Sacerdoti: magnet;**
**Antonio Massarotti and**
**Mario Puglisi: RF Cavity)**

**1961**

**(*joined in*:)**
**(Ubaldo Bizzarri)**
**Giuseppe Di Giugno**
**Ruggero Querzoli**

# Orsay

**1962**

**(*joined in*:)**
**(François Lacoste)**
**Pierre Marin**
**Jacques Haïssinski**

**1963**

**(*final group*:)**
**Carlo Bernardini**
**Gianfranco Corazza**
**Giuseppe Di Giugno**
**(Giorgio Ghigo)**
**Jacques Haïssinski**
**Pierre Marin**
**Ruggero Querzoli**
**Bruno Touschek**

**The adventure that was AdA thus came to its happy end. I particularly want to emphasize not only our scientific achievements with it, but also the exceptional – I would say unique – atmosphere of collaboration and friendship that we experienced during those four years, 1960 to 1964.**

A D O N E - a Draft Proposal for a Colliding Beam Experiment.

B.Touschek,
Rome, 9.Nov.60.

It is proposed to construct a synchrotron like machine capable of accelerating simultaneously electrons and positrons in identical orbits. The sugges-ted maximum energy is 1.5 Gev for the electrons as well as the positrons. This energy allows one to produce pairs of all the so called 'elementary particles' so far known, with the exception of the neutrino, which only becomes accessible via a weak interaction channel.

It is assumed that experiments in which there are only two particles in the final state are most easy to interpret. There are 16 such reactions, namely:

(1) $2\gamma$ . This is the only reaction in which the ~~xxxx~~ intermediate state is 'quasi real' and in which therefore there should be no 'radiative corrections'. This reaction should serve as a 'monitor'. The cross-section is $2.6\ 10^{-31}\ cm^2$.

(2) $e^+, e^-$ . This reaction will show strong angular variations and may require 'good geometry'. It would give information on the brakdown of electrodynamics at distances corresponding to about 1/3 the Comptonwave-length of the proton.

(3) $\mu^+, \mu^-$ . Test of electrodynamics in 'bad geometry'. May also serve as an indication of the funda-mental difference between electrons and muons.

(4) $\pi^+\pi^-$ reveals the interaction between pions in odd parity states.

(5) $2\pi^0$: charge exchange interaction for pion-pion scattering.

(6) $K^+K^-$ : interaction of K-mesons in odd parity states.

(7) $\bar{K}^0, K^0$ : Charge exchange interaction between K-mesons.

(8) $p, \bar{p}$ : interaction of proton and antiproton in even parity odd charge parity states.

(9) $n, \bar{n}$ : same as (8) but for the charge exchange reaction.

(10) through (15). Interactions simple or with charge exchange of hyperons.

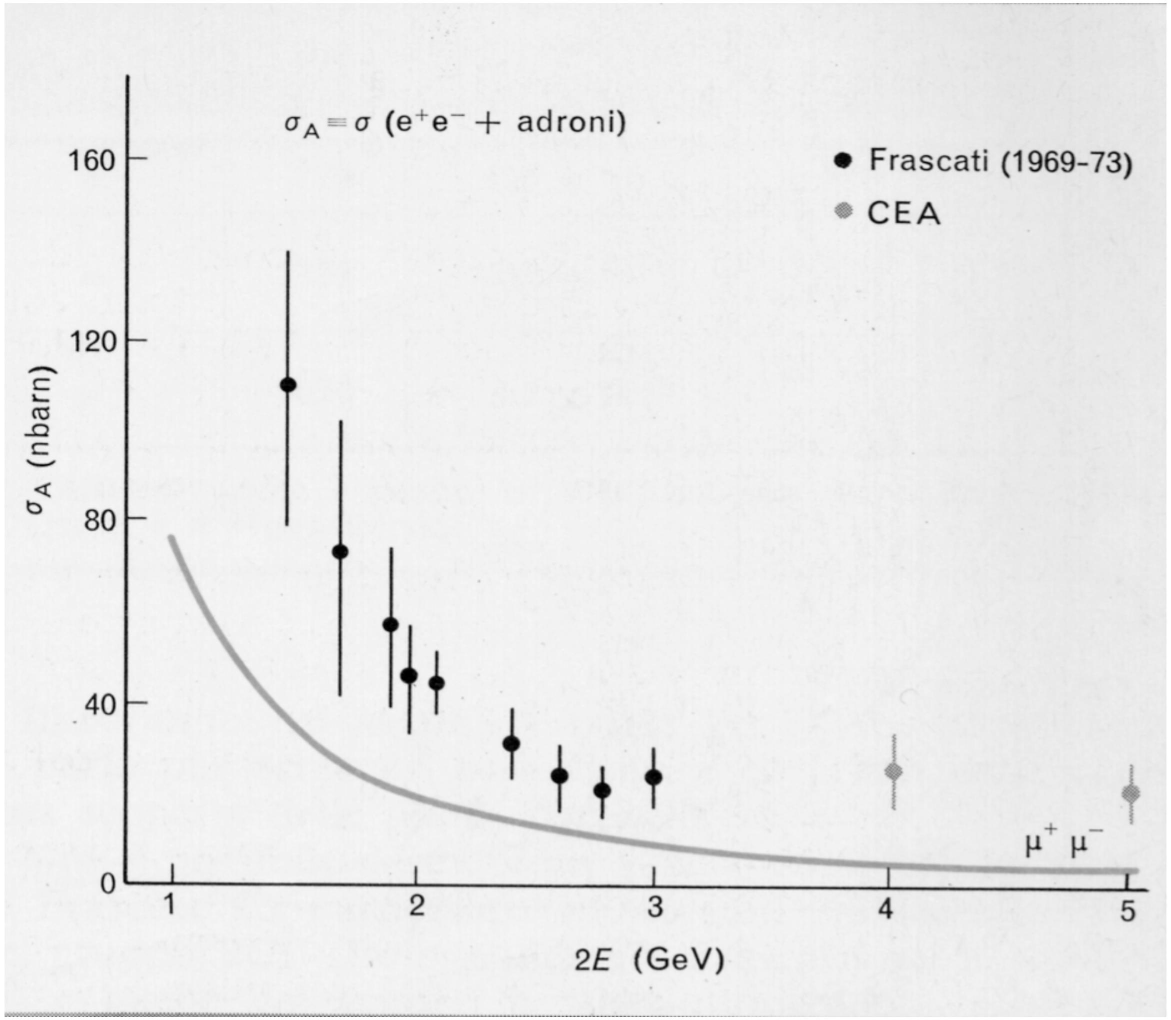
# ADONE - A Draft Proposal for a Colliding Beam Experiment

## Bruno Touschek, Rome, November 9, 1960

***"It is assumed that experiments in which there are only two particles in the final state are most easy to interpret. There are 16 such reactions…"***

**Touschek hesitated to get involved with Adone: there were too many problems of a "nonphysical" nature (placing orders, carrying out other duties, drawing up plans, lack of improvisation, and the like).**


Adone, a 3000-MeV electron-positron collider at Frascati (each beam had an energy of 1500 MeV), was Fernando Amman's masterpiece. Amman conceived its ring in 1961–1963 using the most advanced concepts, a powerful electron linac to use with the electron-positron converter, and a hall suited for experiments.




**Summary of the hadronic total production at various energies compared to μ-pairs**

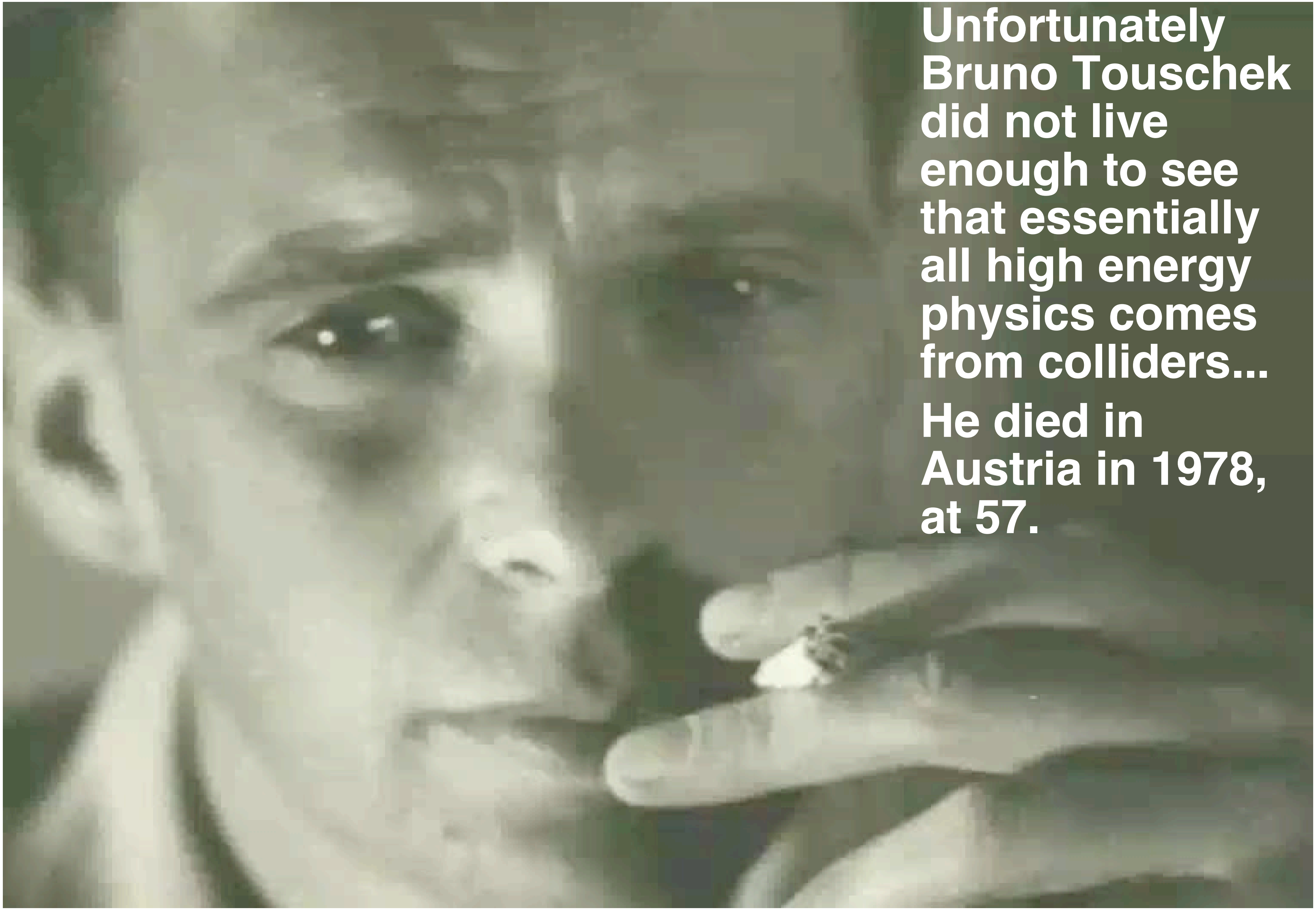
Adone was a unique new tool, and prominent Italian physicists wanted to measure something with it. My personal feeling (which I still maintain was right, after so many years) was that one should first explore, with unsophisticated multi-purpose experimental devices (counters and spark chambers covering a wide solid angle), if and how hadrons are produced at significant energies, particularly in the form of narrow resonances, to profit from the very precise energy definition of the colliding beams. We missed discovering the *J*/Ψ particle only because it was found at 50 MeV above Adone's maximum beam energy!

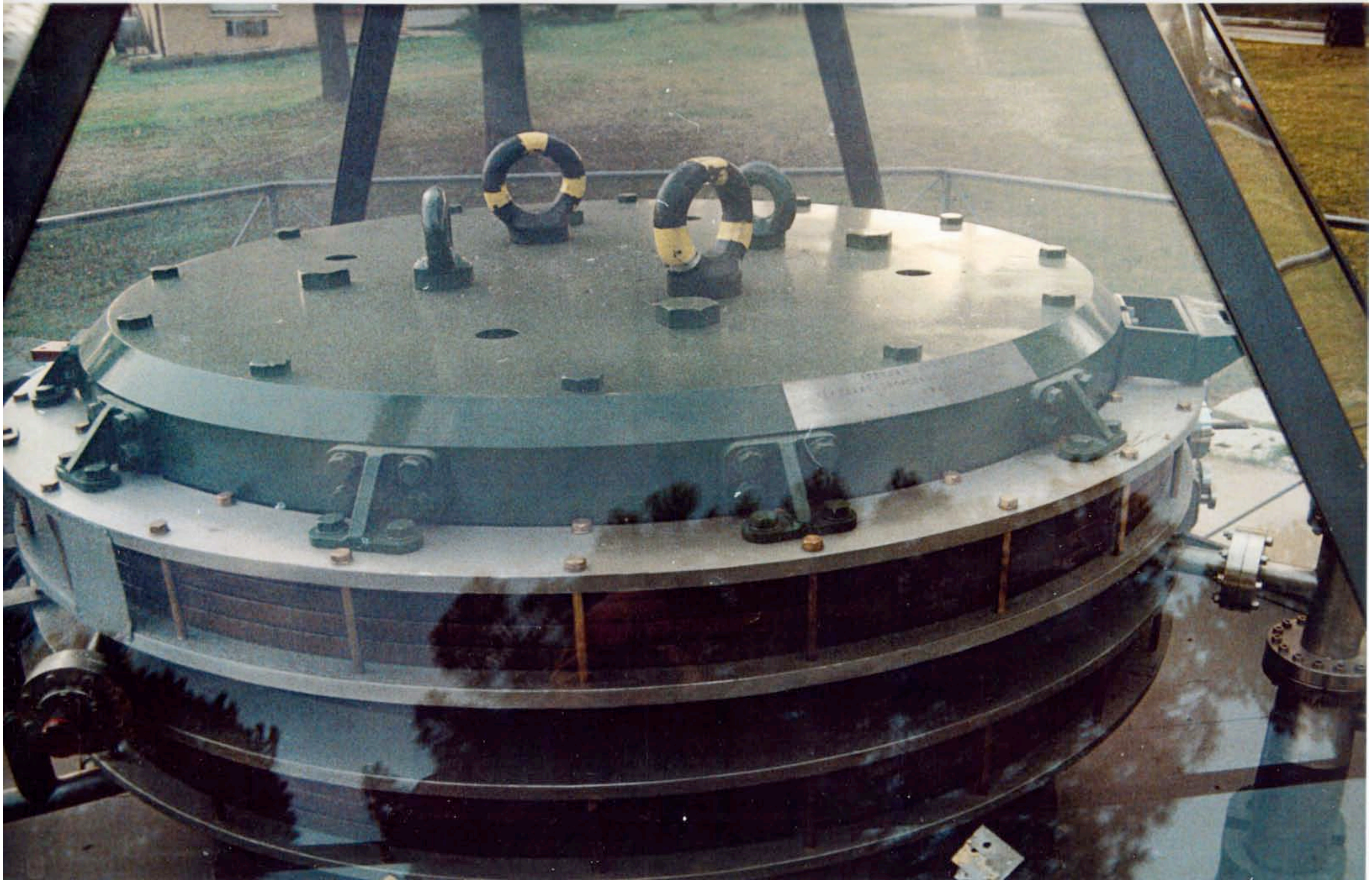
**Bruno Touschek**

**and**

**his dog Lola**

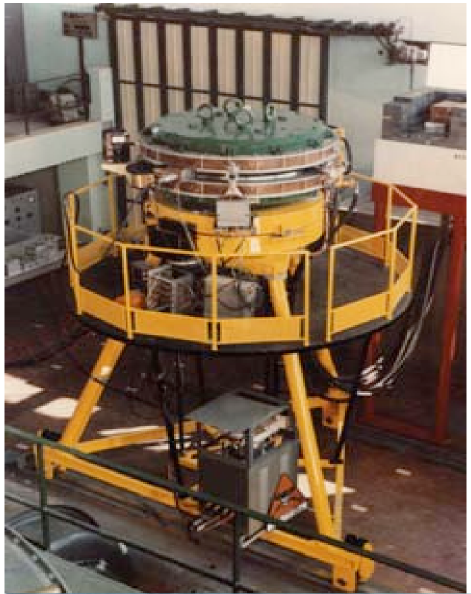
**(1965)**


Unfortunately Bruno Touschek did not live enough to see that essentially all high energy physics comes from colliders...
He died in Austria in 1978, at 57.



AdA under its glass showcase - Frascati, Open Air Museum.

# From AdA to LHC.



## Rings in the world

1961 AdA, Frascati
1964 VEPP 2, Novosibirsk, URSS
1965 ACO, Orsay, France
1969 ADONE, Frascati, Italy
1971 CEA, Cambridge, USA
1972 SPEAR, Stanford, USA
1974 DORIS, Hamburg, Germany
1975 VEPP-2M, Novosibirsk, URSS
1977 VEPP-3, Novosibirsk, URSS
1978 VEPP-4, Novosibirsk, URSS
1978 PETRA, Hamburg, Germany
1979 CESR, Cornell, USA
1980 PEP, Stanford, USA
1981 Sp-pbarS, CERN, Switzerland
1982 Fermilab p-pbar, USA
1987 TEVATRON, Fermilab, USA
1989 SLC, Stanford, USA
1989 BEPC, Peking, China
1989 LEP, CERN, Switzerland
1992 HERA, Hamburg, Germany
1994 VEPP-4M, Novosibirsk, Russia
1999 DAΦNE, Frascati, Italy
1999 KEKB, Tsukuba, Japan
1999 PEP-II, Stanford, USA
2003 VEPP-2000, Novosibirsk, Russia
? LHC, CERN, Switzerland