

Birth of colliding beams in Europe, two photon studies at Adone

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LNF-INFN

Novosibirsk, Photon 2015, June 16 2015

Hallo to everybody!

Thanks to the Photon 2015 Organizers and

Apologies for missing the party...

Outline

- The birth of e^+e^- colliders in Italy:
 - Bruno Touschek and the AdA proposal
 - What Touschek wanted

$$e^+e^- \rightarrow \gamma\gamma$$

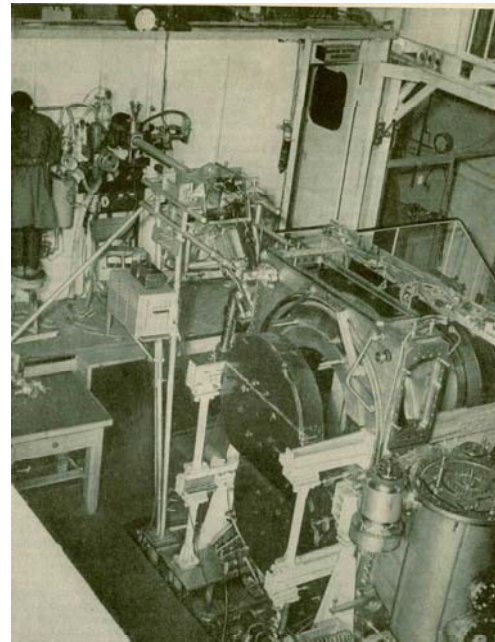
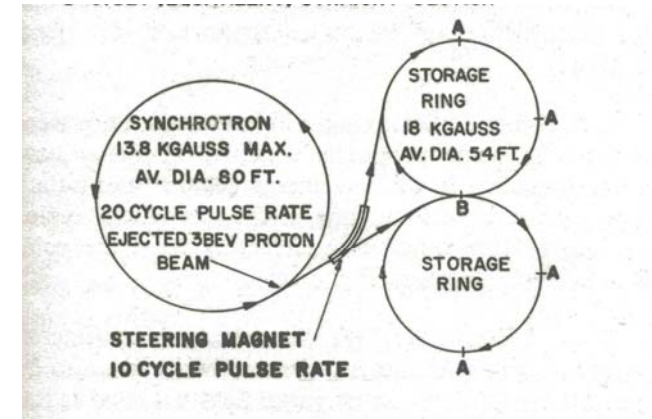
A monitor for the interaction

- Touschek's life
 - 1943-44 Learning about betatrons in Germany
 - 1952-59 Rome and Frascati synchrotron
 - 1960-64 AdA from Frascati to Orsay
 - 1960 → Proposal and construction of ADONE
- Gamma gamma experimentation in ADONE
 - 1971-72 $e^+e^- \rightarrow e^+e^- \gamma\gamma \rightarrow e^+e^- e^+e^-$
 - 1972-73 $e^+e^- \rightarrow e^+e^- \gamma\gamma \rightarrow e^+e^- \mu^+\mu^-$

Mid 1950's

- The idea of colliding particles had been in the air already at the 1956 CERN symposium
- Colliders for electrons against electrons were planned
- Electrons against positrons was more difficult and a design for proper set-up was not put forward
- The difficulty, wrote TouscheK later, was to produce and store enough antimatter in a laboratory.

Gerard O'Neill,
Phys. Rev. 1956



VEPP1

1959: accelerators starting in Europe

- The Frascati Synchrotron
- The Linear Accelerator in Orsay
- The CERN protosynchrotron


Bruno Touschek and the AdA proposal 1959-60

October 1959:

-Pief Panosksy comes to Italy, and gives seminars in Rome and Frascati on the Stanford linear collider and on the e- e- project

-After the seminar, a discussion starts about physics: Cabibbo, Gatto, Touschek, among others are present

-Cabibbo remembered that Touschek started the discussion with the question: "Why not do electrons against positrons?"



ELENCO DEI SEMINARI TENUTI PRESSO I LABORATORI NAZIONALI DI FRASCATI DEL C.N.E.N. DAL 1°/7/1959 AL 30/6/1960. -		
31/7/1959	- Prof. John DE WIRE	- "LAVORI IN CORSO A CORNELL CON L'E LETTROSINCROTRONE".
3/9/1959	- Prof. WIEGAND	- "ALCUNI RECENTI SVILUPPI DELLA SPE RIMENTAZIONE IN BERKELEY".
16/10/1959	- Proff. QUERZOLI, SALVINI	- "POLARIZZAZIONE DEL PROTONE DI RIN GULO NELLA FOTOPRODUZIONE DEL π^0 ".
22/10/1959	- Dr. DIAMBRINI	- "SULLA ESPERIENZA SPETTRO".
26/10/1959	- Prof. W. PANOFKY	- "SULL'ACCELERATORE LINEARE DA 2 MI GLIA".

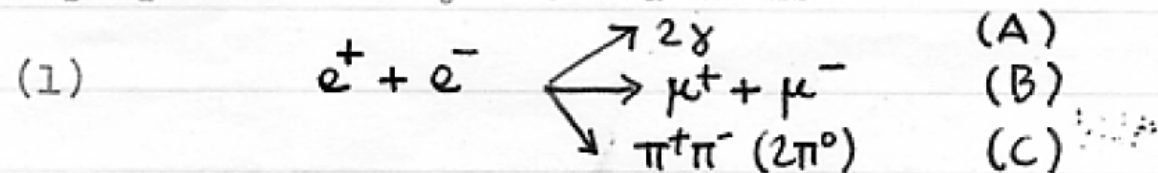
November 1959-January 1960

-Between Rome and Frascati discussions and exchanges took place

26/10/1959 : On the two miles linear accelerator

Touschek's notes : february-March 1960

average 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



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

$$(2) \quad \sigma(A) = 6.3 \cdot 10^{-30} \text{ cm}^2$$

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

Rome-Frascati : february –march 1960

- **February** 1960:
 - -17th: A paper by Gatto and Cabibbo is submitted to Physical Review Letters on measuring the pion form factor at electron-positron collisions
 - -17th: In a meeting about the future of the Laboratory, **Bruno Touschek** launches the proposal to use the synchrotron to make electrons collide against positrons: no way! But the idea of a prototype is put forward
 - -18th : Touschek starts preparing detailed plans for constructing a small ring in which to store electrons and positrons together
- **March** 1960:
 - -7th : Touschek presents to the Laboratory the actual AdA proposal, which is accepted
 - -Funding for 8 million lire is asked and approved
 - -Construction of the AdA magnet starts

June 28th, 1962
2015/S

Prof. F. PERRIN
Haute Commissaire à
l'Energie Atomique
69, rue de Varenne
P A R I S

Ada 1961-62: from Frascati to Orsay

February 1961

-Ada is working, electrons circulate, synchrotron light emitted by the electrons is observed

-Summer : the injection process is not very good, it is hard to prove that collisions are taking place

-July-August Pierre Marin (from LAL) arrives to Frascati together with George Charpak to see the “intriguing little machine” scientists are talking about

-Fall-december 1961

French and Italian scientists exchange letters to bring AdA to Orsay

- July 4th 1962

AdA leaves Frascati for Orsay

June 28th, 1962: Touschek to F. Perrin

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 be no difficulties at the customs 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 5×10^{-10} mm. The ideal solution would be if some competent official at the Modane customs office could be informed beforehand.

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.

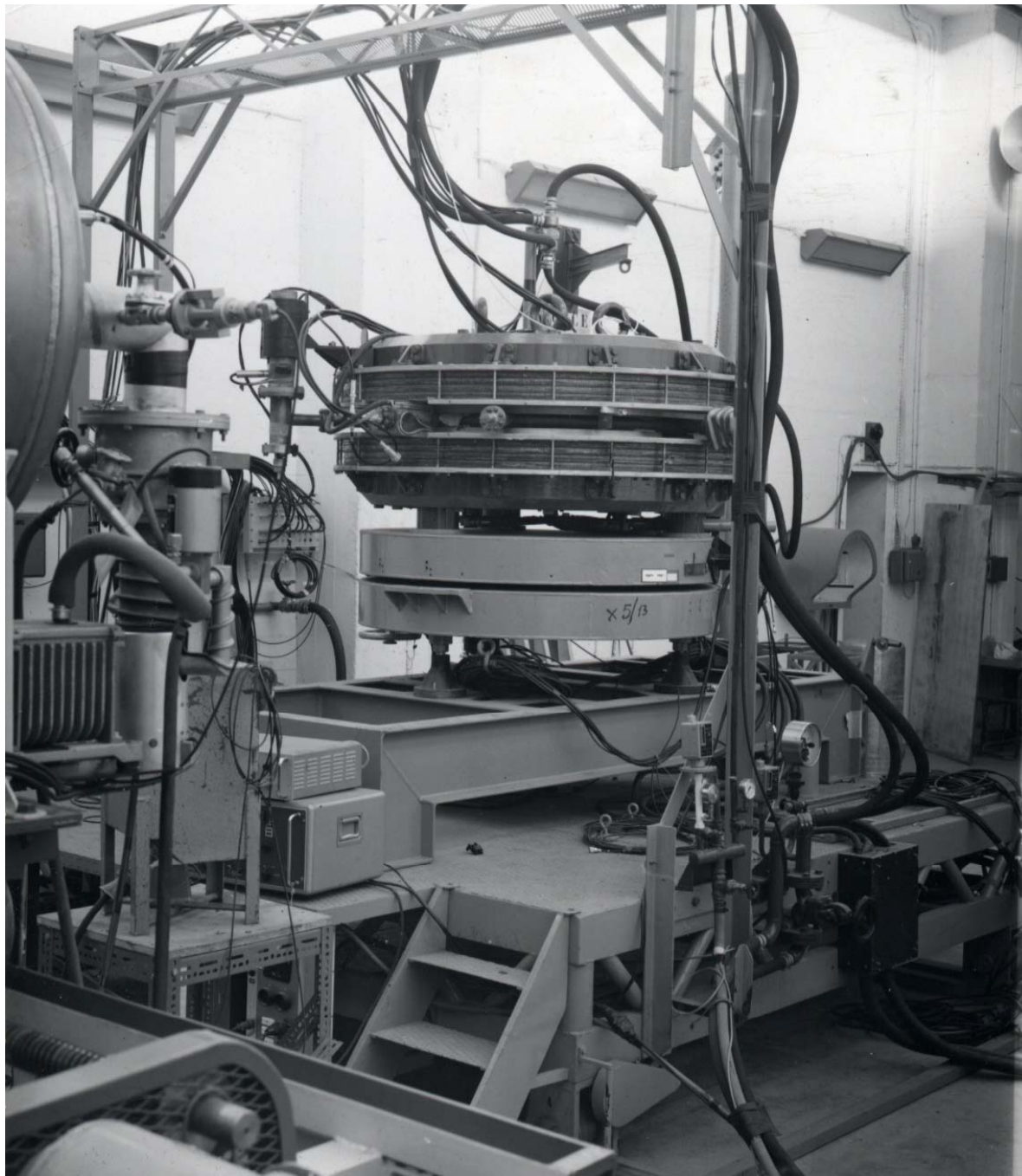
With best thanks for your kindness and interest,

Yours sincerely,

(B. Touschek)

BT:pp

AdA in Orsay



AdA in Orsay: 1962-64

March 1963:

-Touschek effect is discovered
and published in PRL

1963-64

-Measurements are taken of

$$e^+ e^- \rightarrow e^+ e^- \gamma$$

-Data are compared with theoretical
calculations by Altarelli and Buccella
(thesis work with Raul Gatto)

-The rate is in agreement with the
theoretical calculations and Touschek's
effect: collisions are proved.

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

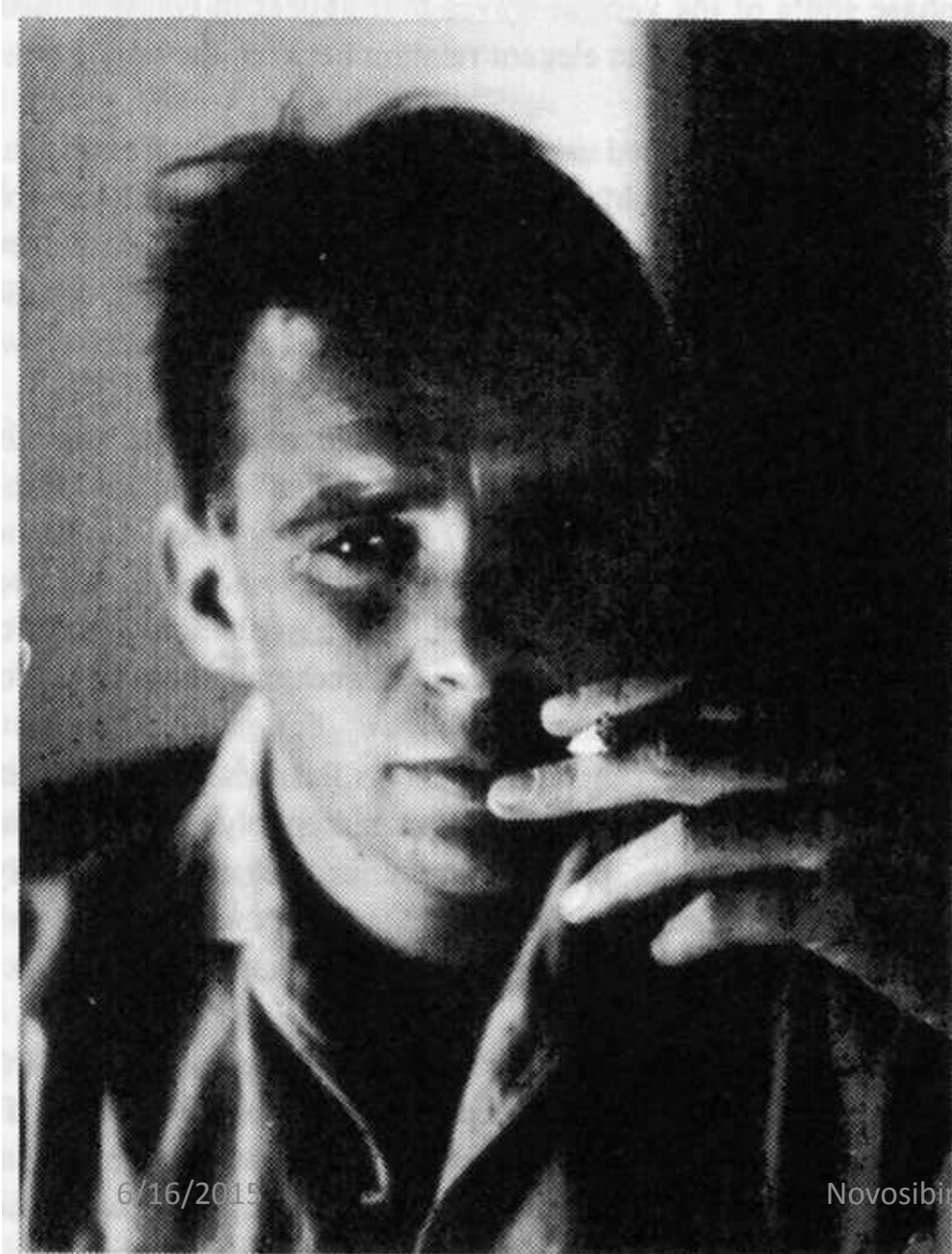
B. TOUSCHEK

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 γ -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.

Who was Bruno Touschek?



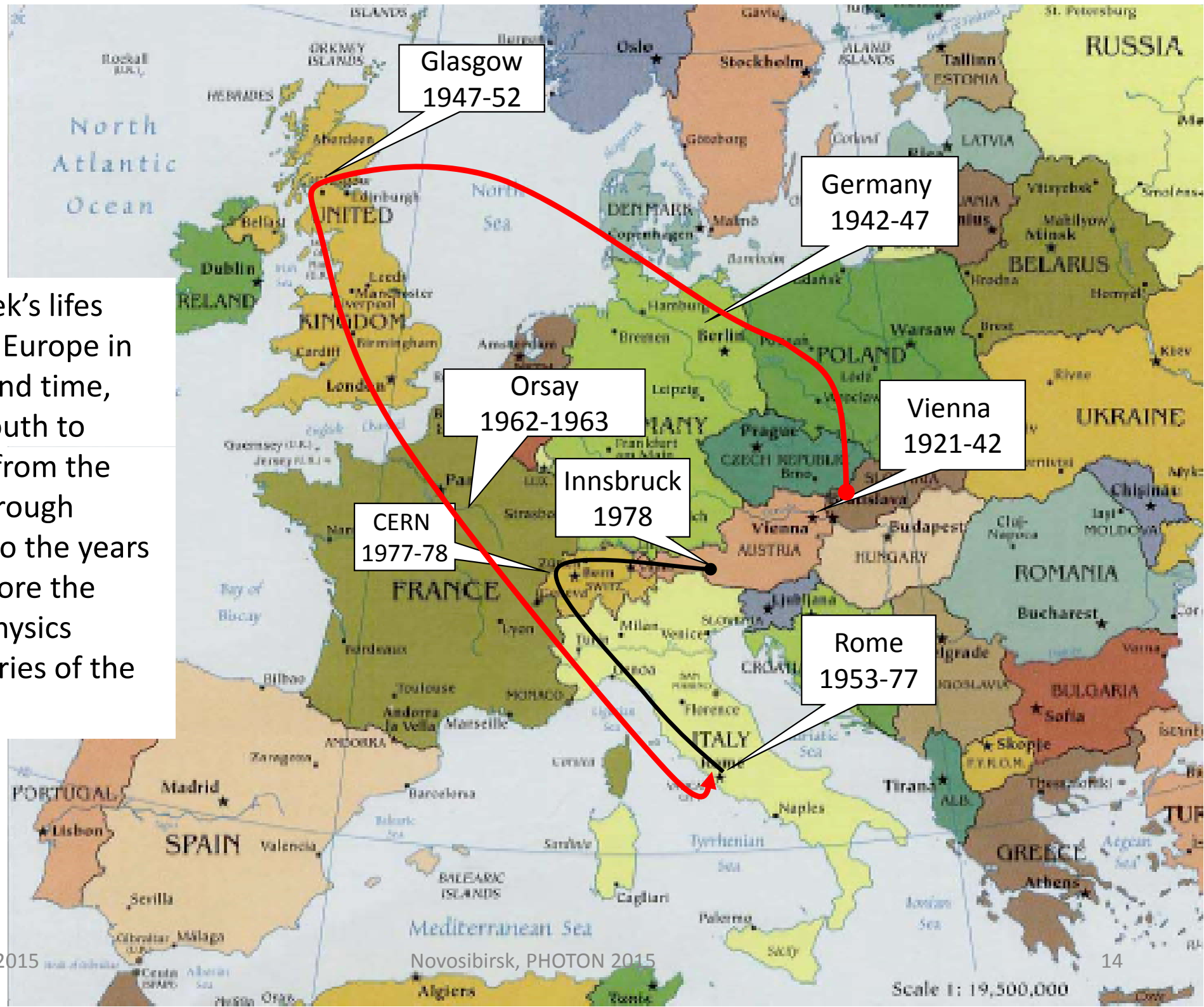
- Where did he come from ?

How

- had he learnt to build particle accelerators?

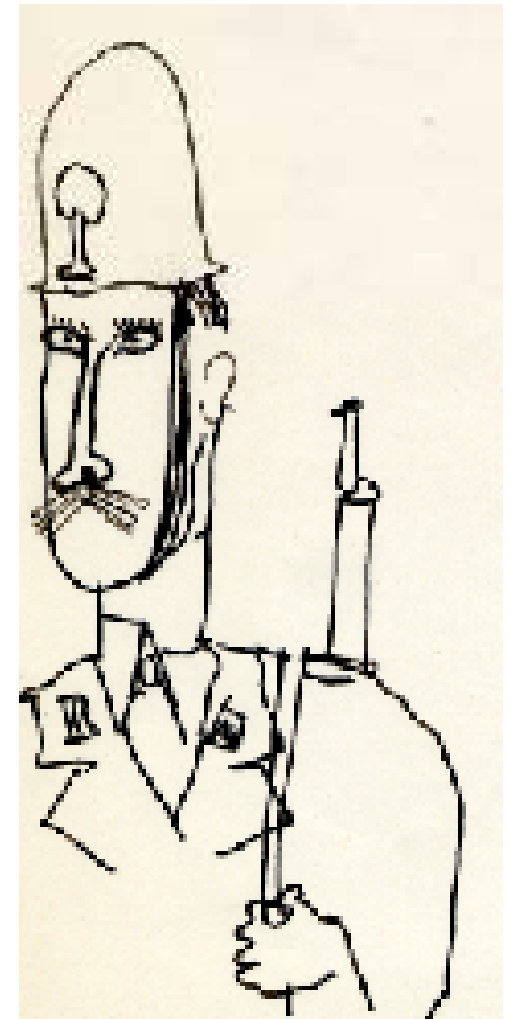
Bruno Touschek's life told through some of his drawings

Touschek's life crosses Europe in space and time, from South to North, from the 30's, through WWII, to the years just before the great physics discoveries of the 1980's.



A short summary of events in Touschek's life : from Vienna to Germany: 1939-1942

- In Spring 1939, having finished his high school years, BT visits Rome, where his **maternal aunt Adele, nicknamed Ada**, lived
- He attends some engineering course at the University of Rome
- BT tries, **without success, to get a visa** to go to Manchester and study physics
- In the summer he returns to Vienna
- In Septembre 1939: WWII starts
- In autumn 1939 : BT enrolls in University of Vienna
- At end of the academic year he is told that he cannot continue his studies, because of his Jewish origin from the maternal side.
- **1941-42** : Arnold Sommerfeld admires and likes this young brilliant student and helps him go to Germany to complete his studies, and **BT moves to Germany**, first via Monaco, then to Hamburg and Berlin



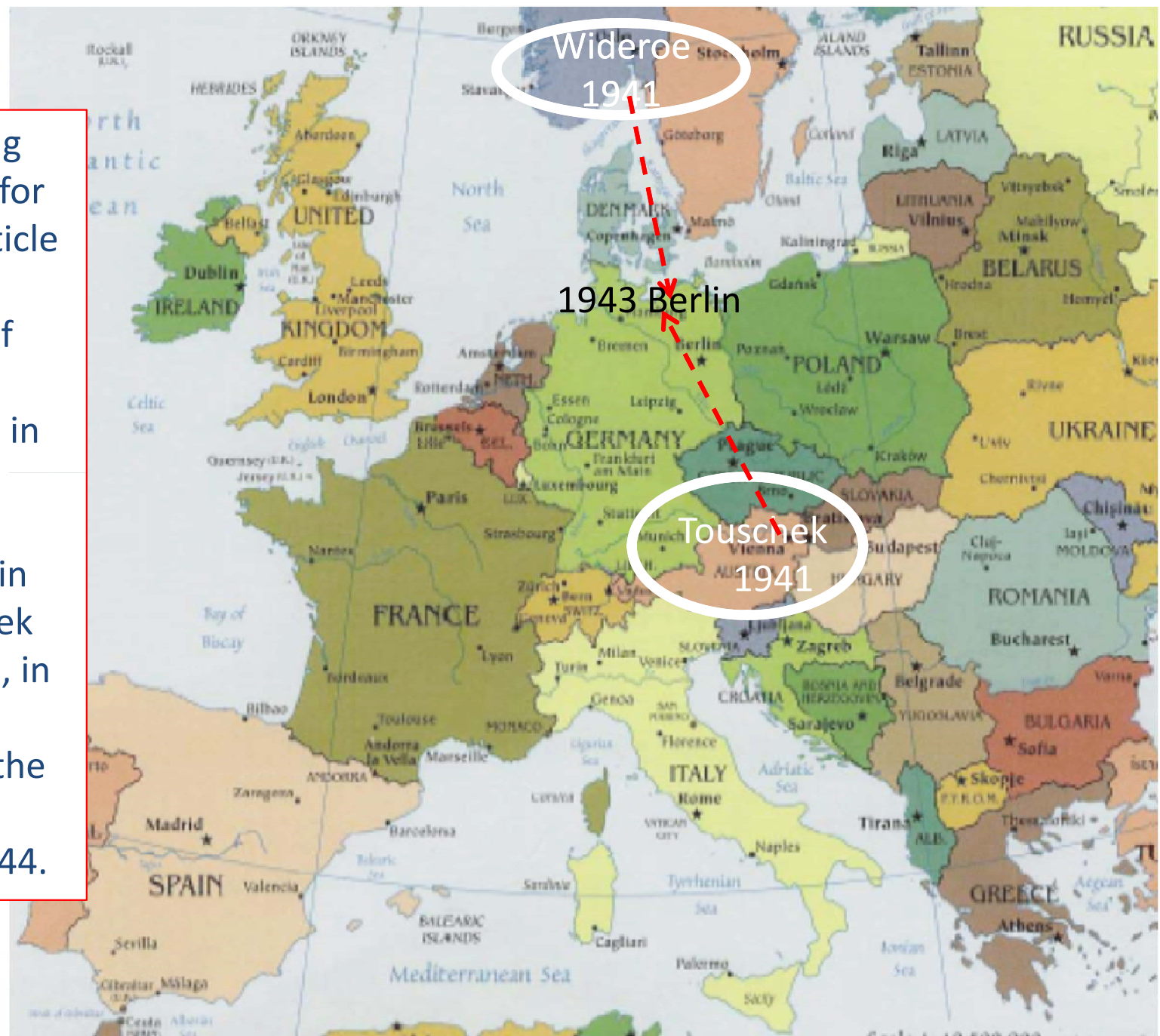
Drawing by Bruno Touschek from (unpublished) letters to his father, from Hamburg and Berlin: 1942-1944



- Hamburg 3rd April, 1942

...Bruno and his desires
...desiderabilia sua..

In 1943, something crucial happened for the history of particle accelerators in Europe. A series of unrelated events, which had started in 1941 in different parts of Europe, brought together in Germany, Touschek and Rolf Widerøe, in Berlin and then Hamburg, where the Widerøe betatron was built in 1943-44.



- In Germany **Touschek** attended classes at Universities of Hamburg and Berlin, and in november 1942 found a job at the journal **Archiv fur Elektrotechnik**.
- **Touschek** thus came in contact with **Widerøe**, a Norwegian engineer, who was Europe's most prominent expert on betatrons, having written the betatron equation in 1928, in his PhD thesis, and had attempted to build a betatron himself.
- In September 1942, after Kerst's article on the betatron, **Widerøe** had submitted to the **Archiv** a paper suggesting the construction of a 15 MeV betatron.
- **Touschek** saw the paper and spoke of the project to his boss, k. Egerer, who knew people at the Aviation Ministry

During the war, in Germany there had been a number of projects for building betatrons, to be placed on airplanes and used to emit powerful X-rays to destroy enemy's engines, the so called *death rays*

In **1943**, after Widerøe had submitted his paper to the Archiv, alerted by Egerer, the Aviation Ministry of the Third Reich asked **Widerøe** to come Germany and build his betatron. Widerøe accepted, since his brother was imprisoned in Germany, and he wanted to help him.
[Pedro Waloshek in RW's biography]



June 1943, Touschek and Widerøe meet in Berlin

Widerøe's project for a betatron was approved and became a secret project.

Widerøe's article was classified and was never published (as L. Bonolis and G.P. discovered).

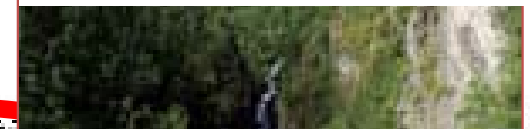
Touschek, who had been corresponding with Widerøe about his article and some relativistic corrections to the electron's orbits, met him in person in Berlin, and joined the collaboration for construction of a betatron.

During a holiday, in late summer 1943, RW watches clouds colliding in the sky and imagines what could happen if

particles would collide one against the other:

Back in Hamburg, he mentions his idea to Touschek

From Touschek's notes on the birth of AdA and Adone

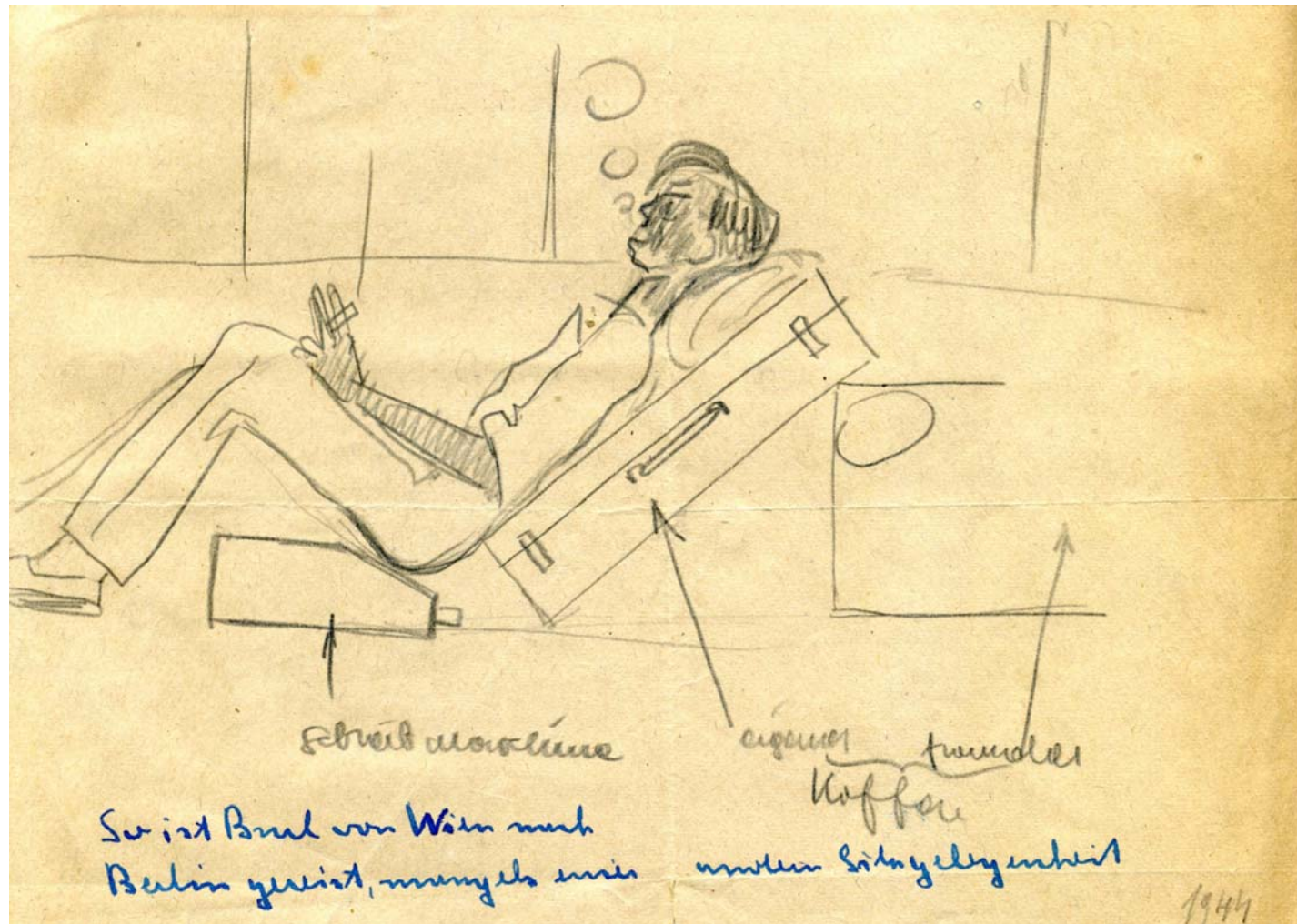


Let me first explain why a storage ring is a convenient instrument, particularly when fed with electrons and positrons. The first suggestions to use crossed beams I have heard during the war from Widerøe, the obvious reason for thinking about them being, that one ~~wasted~~ a considerable amount of energy 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 electromagnetic interactions one should try to use particles, which interact weakly except electromagnetically. This automatically cuts one down to electrons (and positrons) since μ -mesons are hard to come by in large numbers. To use a crossed beam consisting of electrons and 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.

18 january 1944 : Tuschek sends a “virtual gift” to his father: a drawing of food and wine... but his pockets are empty



Traveling between Vienna and Berlin: 11 september 1944



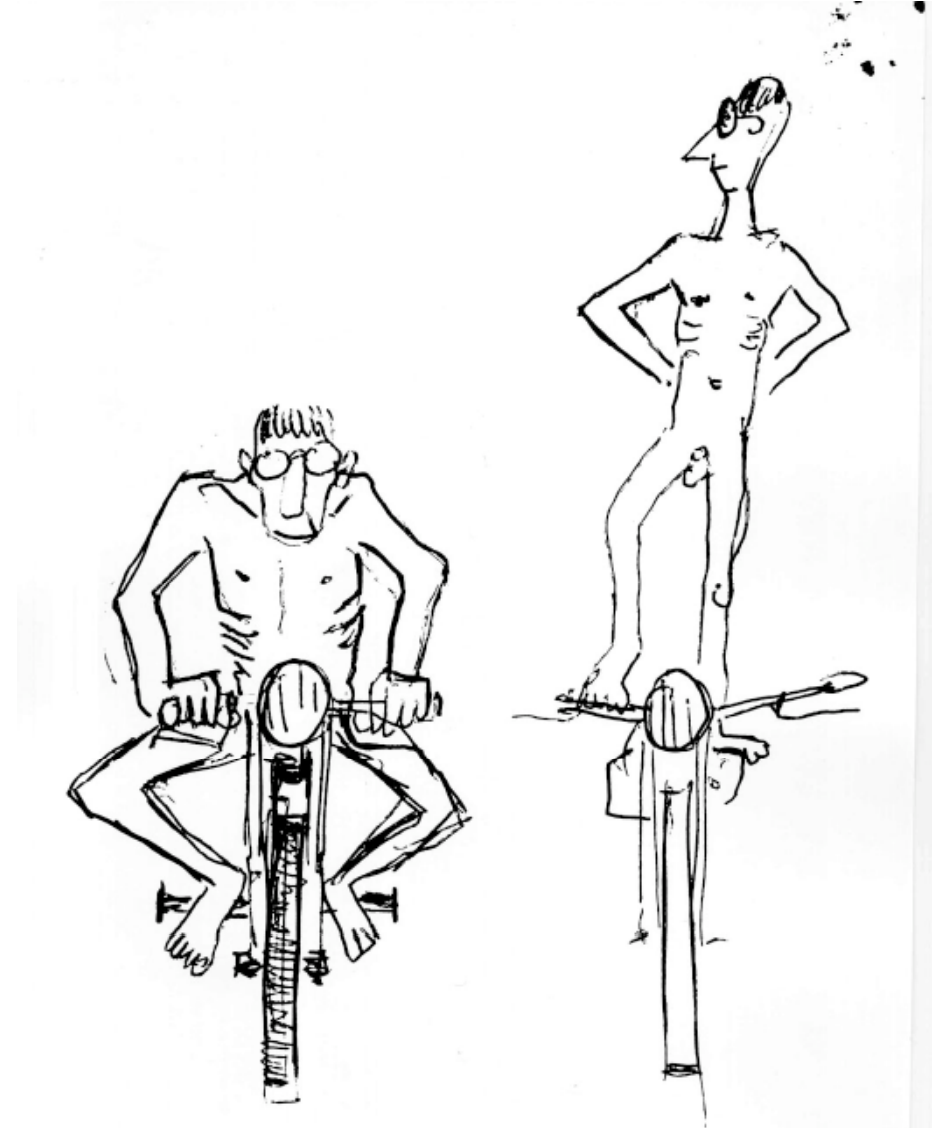
“I did not write from Berlin, mail was not working anyway. The trip was ok, with my typing machine, the small suitcase and the big trunk, I built for myself a decent arrangement...”

1945

- In March 1945, the Allied troops were approaching Hamburg, where Widerøe's group had finished building the betatron, and the German military command ordered to take it to safety. Tuschek and Widerøe bring it to a Kellinghuse, 30 km from Amburgo in a deserted farm building.
- Back to Hamburg on March 14 night, **Tuschek is arrested** by the Gestapo who arrives at his home at 7 in the morning and takes him to jail. From there, three weeks later, he is made to march towards the Kiel concentration camp, while the Allied troops enter Hamburg.
- During the march, he is sick and falls to the ground, a soldier shoots at him and he is left for dead. He is saved, as the wound is superficial. He wanders from prisons to hospital, but the war is winding down and he joins the occupation command as an interpreter.
- Finally in 1946 he can go back to his studies, in **Göttingen**, where he receives his diploma.
- After this, he goes to **Glasgow** where he will obtain his doctorate.

Traveling South

- In 1952 Edoardo Amaldi offered Touschek a position as an INFN researcher at Istituto di Fisica dell'Universita' di Roma Guglielmo Marconi
- He buys himself a motorcycle, a PUK model, and goes to Rome
- In december he writes to his family full of enthusiasm for the Institute, the colleagues, the weather, the food , the wine...

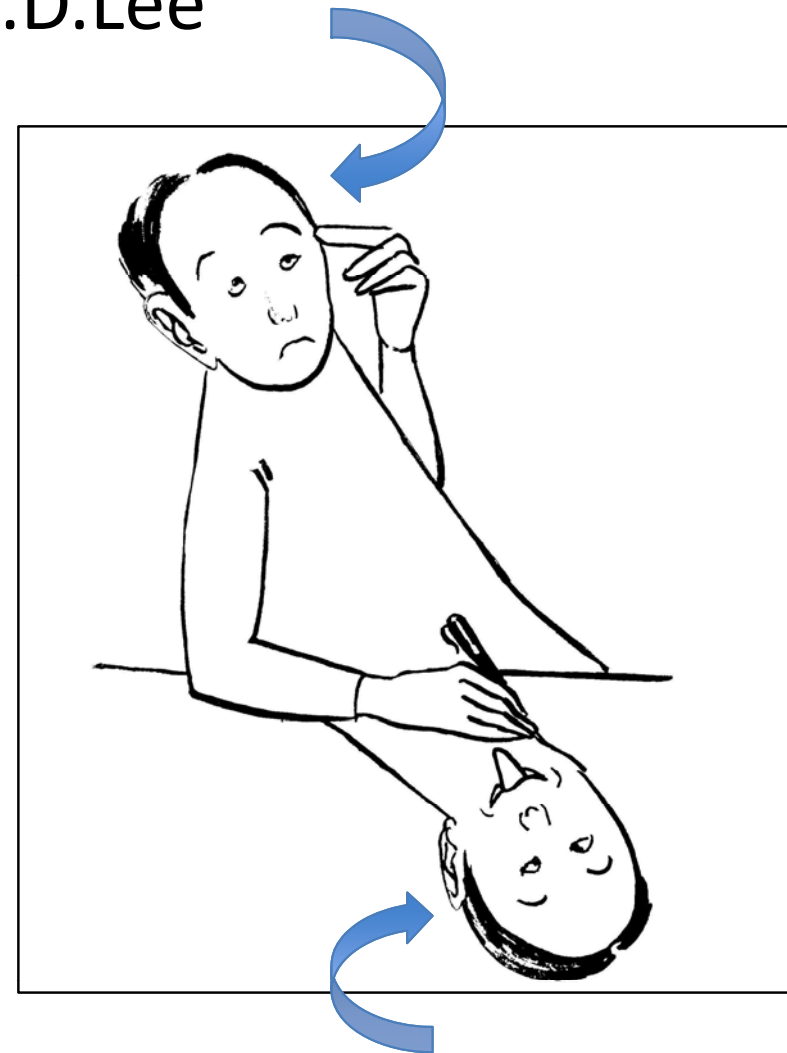


1952-1960 During these years in Rome, Tauschek mostly works on theoretical papers, neutrino physics, chiral transformations, has some exceptional student, Nicola Cabibbo was his first laurea student, and follows the latest physics developments such as parity non conservation, discovered by T.D.Lee e C.N Yang in 1956

Tauschek with T.D. Lee
SIF - Catania 1957



T.D.Lee



**When AdA started working in
february 1961**

**ADONE had already been
envisioned**

Touschek proposed to build
ADONE as soon as he saw that his
idea of how to **store positrons and
electrons** in a single ring was
working

NOVEMBER 1960



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

**E. Touschek,
Rome, 9. Nov. 60.**

ADONE - a Draft Proposal for a Colliding Beam Experiment.

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

- The choice of **maximum cm energy of 3 GeV** followed Touschek's 1960 proposal
- We now know that this would be too low to observe the J/Psi, I.e, charm, 14 year later.
- At the time, 1960, it was difficult to imagine that anything more interesting would be present above the nucleon-antinucleon threshold
- But although ADONE missed the discovery of the J/psi, it saw multihadronic production and **gamma gamma** interactions

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) 2γ . This is the only reaction in which the ~~xxx~~ 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 $2.6 \cdot 10^{-31} \text{ cm}^2$.

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

(3) μ^+, μ^- . Test of electrodynamics in 'bad geometry'. May also serve as an indication of the fundamental 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.

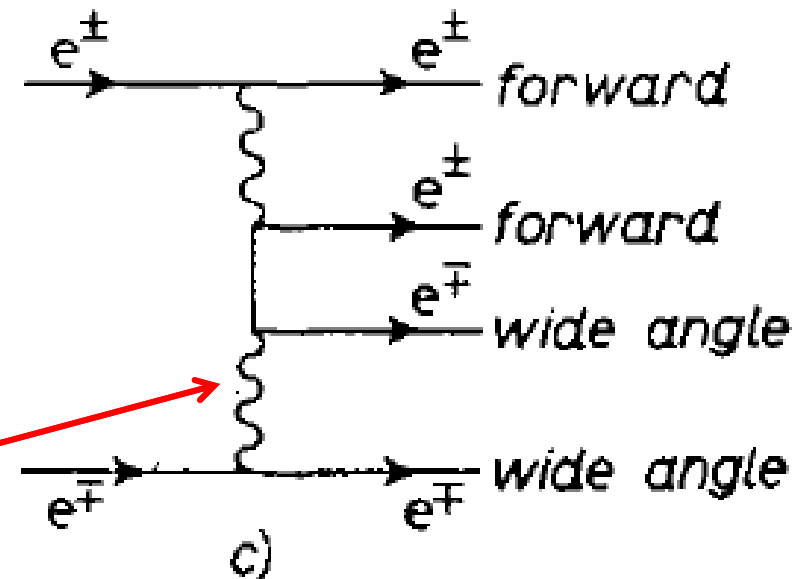
(7) \bar{K}^0, K^0 : Charge exchange interaction between K-mesons.

(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

Two photon interactions at ADONE 1971-73

- The explored energies per beam were
 - 950 MeV
 - 970 MeV
 - 1050 MeV
 - 1400-1500 MeV
- Hard photon propagator events were observed
- Electrons/positrons but also non showering tracks were observed



Two photon physics at ADONE

LETTERE AL NUOVO CIMENTO

VOL. 3, N. 18

29 Aprile 1972

Gamma-Gamma Interaction Processes at Adone e^+e^- Storage Ring. Measurement of the Reaction $e^+ + e^- \rightarrow e^+ + e^- + e^+ + e^-$.

C. BACCI, G. PENSO and G. SALVINI

Istituto di Fisica dell'Università - Roma

Istituto Nazionale di Fisica Nucleare - Sezione di Roma

R. BALDINI-CELIO, G. CAPON, C. MENCUCCINI,
G. P. MURTAS, A. REALE and M. SPINETTI

Laboratori Nazionali del CNEN - Frascati

B. STELLA (*)

Istituto Tecnico Industriale « Enrico Fermi » - Frascati

(ricevuto il 16 Marzo 1972)

$$e^+e^- \rightarrow e^+e^- \gamma\gamma \rightarrow e^+e^- \mu^+ \mu^-$$

Two groups

- Bacci et al.
- ADONE energy per beam
1400-1500 MeV
- August 1973 preprint-unpublished
- Barbiellini et al.
- ADONE cm energy 2.7 GeV
- PRL received December 1973

LNF-73/50
23 Agosto 1973

C. Bacci^(x), R. Baldini-Celio, G. Capon, R. Del Fabbro, C. Mencuccini, G. P. Murtas, G. Penso^(x), G. Salvini^(x), M. Spinetti, B. Stella^(x) and A. Zallo: FURTHER RESULTS ON REACTIONS $e^+e^- \rightarrow e^+e^- e^+e^-$ AND $e^+e^- \rightarrow e^+e^- \mu^+ \mu^-$ WITH ADONE STORAGE RING AT 1400-1500 MeV. -

Muon Pair Production by Photon-Photon Interactions in e^+e^- Storage Rings

G. Barbiellini, S. Orito, T. Tsuru, and R. Visentin

Laboratori Nazionali del Comitato Nazionale per l'Energia Nucleare, Frascati, Rome, Italy

and

F. Ceradini, M. Conversi, S. d'Angelo, M. L. Ferrer, L. Paoluzzi, and R. Santonico
Istituto di Fisica dell'Università di Roma and Sezione di Roma dell'Istituto Nazionale di Fisica Nucleare, Rome, Italy

(Received 10 December 1973)

The photon-photon interaction has been investigated by e^+ and e^- collisions at about 2.7-GeV total energy. Evidence based on 34 well-identified events has been obtained for the process $e^+e^- \rightarrow e^+e^-\mu^+\mu^-$, hitherto unobserved. Such a process is found to occur in agreement with theoretical predictions based on the equivalent-photon approximation. Results on 74 events from the process $e^+e^- \rightarrow e^+e^-e^+e^-$ are also reported.

Electron colliding beams provide a means, at present unique, for investigating the photon-photon interaction at high energy, as pointed out by

many authors.¹ In the present experiment the outgoing e^{\pm} are detected at very small angles with respect to their incident directions, in coinci-

where X is a system with $C = +1$. In our experiment X is a pair of WA particles present in the final state as a result of one of the annihilation processes:

$$\gamma\gamma \rightarrow \mu^+\mu^-, \quad ($$

$$\gamma\gamma \rightarrow e^+e^-, \quad ($$

$$\gamma\gamma \rightarrow \pi^+\pi^-. \quad ($$

These particles, emitted at angles θ_1, θ_2 , with momenta p_1, p_2 , are detected by a system of two WA telescopes as sketched in Fig. 1.

The experiment has been carried out with the

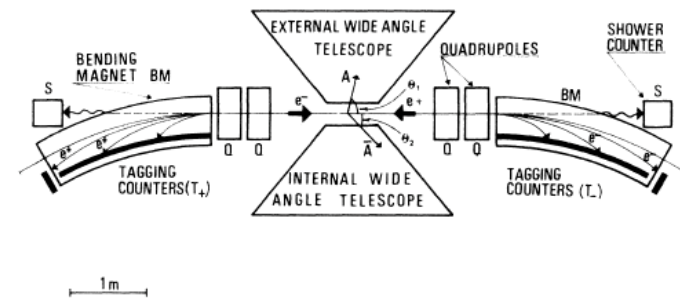


FIG. 1. Schematic view of the general setup. The "shower counters," S, were used to veto events involving photons from real bremsstrahlung. A and \bar{A} are WA particles.

In conclusion : Bruno Touschek's scientific legacy

- **In Italy**

- 1960-1964 proposing AdA, observing collisions in Orsay
- 1968-1993: commissioning and operation in Frascati of the electron-positron collider **ADONE** a Frascati, proposed by Touschek in **November 1960**, even before AdA started. From **ADONE** there came
 - 1971-72-73 $e^+e^- \rightarrow e^+e^- \gamma\gamma \rightarrow e^+e^- e^+e^-$
 $e^+e^- \rightarrow e^+e^- \mu^+ \mu^-$
 - the discovery of multiple particle production in 1972,
 - The confirmation of the discovery of the J/Psi in 1974,
 - synchrotron light experiments
- 1957-> **training** of a generation of theoretical particle physicists in Frascati and at University of Rome, Nicola Cabibbo and Francesco Calogero among the first ones, Paolo di Vecchia, Mario Greco, Giancarlo Rossi in Frascati, and many others. Importance of soft photon **resummation**
- 1990-> the phi-factory **DAFNE** in Frascati is an electron-positron collider following Touschek's idea of particle-antiparticle annihilation

Thanks

- To my collaborator Luisa Bonolis for work on Touschek and Wideroe
- To Frederic Kapusta for hospitality in Paris
- To the Touschek Family for family photoes and letters
- To Valery Telnov for help with two photon interaction bibliography
- To Simon Eydelman and other Novosibirsk friend for support

The story of AdA in Orsay is told in a documentary by GP and Luisa Bonolis, INFN 2013

Fin