Memorial Symposium, 2-4 December 2021

BRUNO TOUSCHEK (1921 – 1978) THE PATH TO ELECTRON-POSITRON COLLISIONS

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A EUROPEAN SCIENTIST









Vienna



Hamburg - Berlin



Göttingen

Glasgow





Bruno Touschek and AdA, the first electron-positron collider











Orsay



Frascati

Rome



CHILDHOOD AND EARLY YOUTH IN VIENNA





Lise Meitner

Ludwig Boltzmann

Otto Wagner: the birth of modern architecture





Gustav Mahler

The streets of Vienna are paved with culture, the streets of other cities with asphalt





Ernst Mach



Egon Schiele





Sigmund Freud

Gustav Klimt

Karl Kraus

Adolf Loos Project for Josephine Baker House

Karl Kraus





INTELLECTUAL AND FAMILY ROOTS



Glass vases designed by Milla Weltmann



Bruno with his mother Camilla Weltmann



WERKSTÆTTE









Josef Hoffmann, Stoclet House, Brussells



Josef Margold, Ella's husband and Hoffmann's collaborator

Embroidery by Ella Weltmann

Doctor Oskar Weltmann Bruno's maternal uncle Self-portrait

100 ~ 1



LEARNING TO DRAW BY MASTER PAINTERS



Russian High Command, Drawing by 6-years old Bruno Touschek, March 31, 1927

Bruno Touschek, Self-portrait and examples of his typical "expressionist" portraits

Oskar Kokoschka

1938 : "ANSCHLUSS"!

Hitler announces the Anschluss, Heidenplatz, Vienna 15 March 1938

"Reunification of Austria with the German Empire"

Nazis ban Jews from the University of Vienna in 1938

UNIVERSITY YEARS IN VIENNA

Interschrift des Paßinhabers

BT around 1938-1939

Marietta Blau

Victor Hess Richard von Mises

Ludwig Boltzmann

Erwin Schrödinger

Ernst Mach Wolfgang Pauli

Hans Thirring

Paul Ehrenfest

MOVING TO GERMANY PROTECTED BY ARNOLD SOMMERFELD

Otto Stern and Wolfgang Pauli

Wolfgang Pauli and Arnold Sommerfeld

Hans Jensen

Wilhelm Lenz

1942: IN HAMBURG

Paul Harteck, of Austrian origin

IN BERLIN: 1943–1945

Heisenberg and Carl Friedrich von Weizsäcker in the 1930s

Max Planck Institute for Physics Berlin-Dahlem

Uranverein physicists Later interned at Farm Hall, UK.

> Bombing of Berlin, November 1943 Drawing from a letter to his father

HITLER'S CONQUEST OF EUROPE

BUILDING A 15-MEV BETATRON WITH ROLF WIDERØE

Pläne: Ich will in ingendeinem nordischen Staat mein bok of in rieg nheinlich Oslo. Diesbezügliche Verhandlungen sind noch im rieg

Wahr cheinlich Gelo. Diesbezügliche Verhandlungen sind noch im rieg von Widerde mit Prof. Hylereas geführt worden. Erst möchte ich aber für atma 2 Monste nach Wien. Bis i Meine Existenz scheint vorläufig recht ges chart zu sein -im Vergleich mit anderen. Im übrigen sind je alle Voraussetzungen für ein gutes Vorwärtskommen in der neuen Welt gegebn. Seit dem Waffe still tend habe ich 2 Brisfe bakommen. Einen von Maria die in Nordhausen gedolmetscht hat und die ich in den nächs-ten Tagen im Itzehee (l4km von hier) erwarte. Ein anderer von Gehaimret Som arfeld, in dem die er sich nach dem Verbleib seines Sohnes, der währe meine mit mit er ziemer in Kellinghusen bewohnte und dann idiotischerweis sozussen mit dem letzten Schoff soch Berlin gefehret und seither verscho ist ist, erkundigt. Hoffentlich h bt ihr die Sache such so gut überstani sie Maria. Die Engländer hier sich schr watze korrekt und einstendig. Sie is karis. Die Engländer hier sint sahr waten korrekt u.d anständig. Wie at is m t eurar Besstzung?

Ser.

Biste schreibt m r irsandwid.

Early 1943

Bruno Touschek reads proofs of an article written by Rolf Widerøe submitted to the journal Archiv für Elektrotechnik R. Widerøe, Der Strahlentransformator

This article was never published and the 15-MeV betatron became a secret project financed by the Luftwaffe

1945, March 13th : The betatron was moved from Hamburg to Kellinghusen

March 16th : Touschek travels back to Hamburg, as he wrote after the end of the war:

Around midnight I reached Hamburg during the alarm and after the alarm...I went back to sleep to be waken up at 7.30 in the morning by two gentlemen. I was so sleepy that when they said: "Secret state police!" I answered: "Yes, but at midnight?"...

Abb. 2. Photo des 15-MV-Betatrons.

SURVIVING GESTAPO CAPTIVITY AND DEATH MARCH TO KIEL

Sie waren wegen antifaschistischer Äußerungen, Widerstandsaktivitäten oder anderer politischer Vergehen zu langjährigen Haftstrafen verurteilt worden.

Entrance to Fuhlsbüttel Prison which also served as a concentration camp and initial point of incarceration for prisoners to be sent on to other camps

Wübbo Sielmann (1886–1945), A communist from East Friesland:

"Every morning the weakest prisoners were shot"

"All prisoners who lag behind or attempted to flee were to be shot "

STRAFANSTALTEN FUHLSBÜTTEL

Unter nationalsozialistischer Herrschaft 1933-1945 waren im Gefängnis und Zuchthaus Fuhlsbüttel zahlreiche politische Gegner inhaftiert.

Vom Juli 1943 bis Kriegsende gab es auf dem Gelände der Strafanstalten außerdem ein Außenlager des KZ Neuengamme.

Commemorative plate

1945, April 12, March to **Kiel concentration camp**

1946 – IN GÖTTINGEN WITH HEISENBERG AND THE OTHERS

September 28, 1945 B. Touschek to Sommerfeld from Kellinghusen: ... At present I am still making betatron calculations, a bit of neutrino theory and a bit of **radiation damping**...

BT reports to British Intelligence on the betatron theory in 1945

On the Starting of Electrons in the Betatron

Die magnetische Linsenstrasse und ihre Anwendung auf den Strahlen-Transformator

Zur Frage der Strahlungsdämpfung im Betatron

June 1946 : Touschek gets his laurea degree with a thesis on the theory of the betatron

Heisenberg with von Laue and Hahn, after their release from British captivity in Farm Hall, early January 1946

	Dinlom
	Dipiom
Herr Bruno T o u	schek, cand.phys, geboren am 3.F
in	, Kreis
hat am26	Juni 1946 die Diplom-Hauptprüfun
gemäß der Prüfungs	ordnung vom 7. August 1942 — WJ 1980/42, E V
Gesamturteil sehr	gut an der Universität Göttinge
A-6 C	(in Worten)
Aur Grun	
	Diplom-Physiker
91 - 194 194	verliehen
Göttingen, den 26	Juni 19 46
JUTVISS	Der Vorsiter des Prüfungsa Hauptprüfung für Studi an der Georg-August-Univ
KL Reithesie	erell a
and the second sec	
nversiti	at Column

Dirac, Pauli and Peierls in 1948

BT with Samuel Curran around 1948

workers features on a model of the new synchrotron block to be built at Glasgow University. Others are (left to right) Mr. A. C. Robb, Dr. S. C. Curran and Mr. B. Touschek.

Glasgow had built a 30 MeV electron synchrotron in view of a 300 MeV machine

NO

BENEFIT what are likely to

of it naturally, rather that hat we direct our efforts to

MOVING TO GLASGOW

This thesis represents a review of the work on electron excitation carried out by the author in collaboration with Dr. I. N. Sneddon during the years 1947 to 1949....

COLLISIONS

DANGER TO CITY FROM A-PLANT

Physics faculty University of Glasgow 1952

IN GLASGOW (1947–1952) THE MAKING OF A THEORETICAL PHYSICIST

- I.N. Sneddon and B.Touschek, "Nuclear models" (1948)
- B. Touschek, "Note on Peng's treatment of the divergency difficulties in quantized field theories" (1948)
- I.N. Sneddon and B. Touschek, "A note on the calculation of the spacing of energy levels in a heavy nucleus" (1948) B. Touschek, "Zur Theorie des doppelten Beta Zerfalls" (1948)
- B. Touschek, "Zum analytischen Verhalten Schrödinger'scher Wellenfunktionen" (1948)
- I.N. Sneddon and B. Touschek, "The excitation of nuclei by electrons" (1948)
- I.N. Sneddon and B. Touschek, "The production of mesons by electrons" (1949)

B. Touschek, "**Das Synchrotron**" (1949)

J.C. Gunn, E.A. Power and B. Touschek, "The production of π mesons in proton-proton collisions" (1951)

J.C. Gunn, E.A. Power and B. Touschek, "The production of mesons in proton-proton collisions" (1951)

W. Thirring and B. Touschek, "A covariant formulation of the Block-Nordsieck method" (1951)

UNHAPPY IN GLASGOW

o't of Nat.Phil University

5/10/50

Sehr geehrter Herr Geheimrat!

Es war mir leider nicht möglich auf meiner Rück**r**eise über Deutschland in München anzuhalten, da sich die Abreise aus Oesterreich durch falsche Auskunft über den Zugverkehr fast um einen Tag verzögert hatte.

Ich habe viel über Ihren Münchener Vorschlag nachgedacht wobei sich die Sache auf das Problem Geist gegen Materie reduziert hat: Ich rerdiene hier genug um meine Eltern - denen es in Wier geht – halbwegs unterstützen zu können ndererseits habe ich doch gefunden, dass ich mich in utschland und Oesterreich wohler fühle als in Schott und dass ich in Göttingen in einem Monat mehr gehabe als in Glasgow in einem Jahr. Ich möchte lso gern das folgende vorschlagen: Wenn Professor. eisenberg nach München kömmt und mich haben will. dam will ich auch, wenn es sich nur irgendwie finanziell nachen lässt. Allerdings werde ich sicher noch bis Sommer in Glasgow bleiben, da ich die Universität meinen zahlreichen Vorlesungspflichten nicht gern m Stich lassen will.

guter Gesundheit sind und ich brauche wohl nicht zu vie sehr ich mich gefreut Hatte Sie wiederzusehen gern ich Sie, sehr geehrter Herr Geheimrat, en wiedersehen möchte.

Bitte geben Sie die besten Empfehlungen an Ihre Frau Gemahlin und an Ihren

Ihr dankbarer Houseleck

BT to Sommerfeld, October 5, 1950

... I have found that I am more comfortable in Germany and Austria than in Scotland, and that I have learned more in Göttingen in a month than in Glasgow in a year.... If Professor Heisenberg comes to Munich and wants me, then I want him too, if it can be done somehow financially.

In Summer 1951, BT travels through Europe with his new motor cycle and visits Rome in July.

1951, May, submission of A perturbation treatment of closed states in quantized field theories (citing Ferretti and Dyson)

1951, November 8, BT to his father:

I have applied for a job in Rome... Only masochists can live in England in the long run...

PARTICIPATING IN THE RECONSTRUCTION AND REVIVAL OF ITALIAN PHYSICS

BT with Occhialini and Dilworth at the Pisa Conference on Elementary Particles in 1955

B. Touschek and M. Sands. 1953. Alignment errors in the strong-focusing synchrotron G. Morpurgo and B. Touschek. 1953. Remarks on the validity of the Tamm-Dancoff method E. Fabri and B. Touschek. 1953. La vita media del mesone Tau B. Touschek. 1954. A speculation on the capture mechanism for K-mesons M. Cini, G. Morpurgo, B. Touschek. 1954. A non-perturbation treatment of scattering and the "Wentzel-Example" E. Amaldi et al. 1954. Report of the committee on Tau-mesons G. Stoppini and B. Touschek. 1956. Phenomenological description of photo-meson production

Amaldi and George Placzek

TOWARD ELECTRON-POSITRON COLLISIONS

Without him [Pauli] for me physics is only half interesting...

BT with T.D. Lee and Pauli, Padova-Venezia International Conference, 1957

B. Touschek. 1957. The mass of the neutrino and the non-conservation of parity L. Radicati, B. Touschek. 1957. On the equivalence theorem for the massless neutrino M. Cini, B. Touschek. 1958. The relativistic limit of the theory of spin 1/2 particles B. Touschek. 1958. The symmetry properties of Fermi Dirac fields B. Touschek. 1959. A note on the Pauli trasformation

- G. Morpurgo, B. Touschek, L. Radicati. 1954. On time reversal
- G. Morpurgo, B. Touschek. 1955. Remarks on time reversal
- G. Morpurgo, B. Touschek. 1955. Space and time reflection of observable and non-observable quantities in field theory
- G. Morpurgo, B. Touschek. 1956. Space and time reflection in quantum field theory
- B. Touschek. 1957. Parity conservation and the mass of the neutrino

W. Pauli and B. Touschek. 1959 Report and comment on F. Gürsey's "Group Structure of Elementary Particles"

COLLIDING BEAMS IN THE 1950'S...

D. W. Kerst et al. 1956. Attainment of Very High Energy by Means of Intersecting Beams of Particles O'Neill 1956, Storage-Ring Synchrotron: Device for High-Energy Physics Research

HEACC 1959, Geneva. High-Energy Accelerators and instrumentation W. Panofsky. 1959. The future of high-energy accelerators in physics L. W. Jones. 1959. Experimental utilization of colliding beams O'Neill.1959. Experimental methods for colliding beams O'Neill. 1959. Storage Rings for Electrons and Protons

Princeton-Stanford e-e- collider to test QED

Gersh Budker's collider Vep-I

Stanford e-e- project

Nicola Cabibbo: "It was after the seminar that Bruno Touschek came up with the remark that an e⁺e⁻ machine could be realized in a single ring, 'because of the CTP theorem' "

Raoul Gatto: "Bruno kept insisting on CPT invariance, which would grant the same orbit for electrons and positrons inside the ring"

At the time I felt rather exhausted from an overdose of work which I had been trying to perform in the most abstract field of theoretical research: the discussion of symmetries which had been opened up by the discovery of the breakdown of one of them, parity, by Lee and Yang. I therefore wanted to get my feet out of the clouds and onto the ground again, touch things (provided there was no high tension on them) and take them apart and get back to what I thought I really understood: elementary physics ...

Fall 1959, Pief Panofsky's seminar (Rome-Frascati), presenting the US Princeton-

FROM CPT TO ADA

1960, February 17 Meeting in Frascati. Touschek proposed to re-convert the electron-synchrotron and use it for electron-positron collisions

Nicola Cabibbo: "Touschek emphasized the creative character of e⁺e⁻ collisions, i.e. the possibility of a complete transformation of the collision energy in the creation of new particles, and this through a channel with well defined quantum numbers, those of a photon...

Carlo Rubbia: ... in his mind electron-positron collisions were nothing else than the way of realizing in practice the idea of symmetry between matter and antimatter, in the deep sense of the Dirac equation... His boundless enthusiasm for particle-antiparticle collisions was dominated by a sense of perfect and intellectual esthetics...

Giorgio Ghigo suggested to build a small dedicated machine The day after Touschek started a new notebook, SR, for Storage Ring

-	1
	18.2.60.
555533	State of affoirs. Discussed plan with Apripo Decided for "subside" storage. G. proposed use of y - beam also for electrons. Typical possibility:
	× × × × ×
	X= X-beau, T= touget H, = separating request, St.= Storage runguet, C = too. ar wit.
	Basic formula
14	$q = N^2 (v\tau)^2 \frac{\sigma}{q} \cdot \frac{c}{\pi R}$
	N= number of particles socephed per pulse $V =$ repetition ple of the Synch ($V = 20$)

BT with E. Amaldi

Director Giorgio Salvini showing the electron synchrotron and Frascati Labs to Prince Ranieri and Grace of Monaco

THE GARDEN OF EDEN OF ELECTRON-POSITRON ANNIHILATIONS

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

The first Bruno Touschek, Giorgio Ghigo, AdA team: Carlo Bernardini, Gian Franco Corazza

Experiment proposed mesone. $(e^+e^-):(\mu^+\mu^-):(\pi^+\pi^-)$ Able Gallo, street can be conned from this messurement!

Raoul Gatto and Nicola Cabibbo enter the "Garden of Eden" of the e⁺e⁻ annihilation channel

 $e^{+} e^{-} \qquad \overrightarrow{\mu^{+}} \mu^{-} \qquad (A)$ $\mu^{+} \mu^{-} \qquad (B)$ $\pi^{+} \pi^{-} (2\pi^{\circ}) \qquad (C)$

I prefer to think of it as an experiment rather than as a machine...

1961, February 27, first electrons accumulated in AdA

AdA as a "circus" : Visitors were able to "see" with naked eye a single circulating electron (or positron?)

ADA IN ORSAY AT LAL

AdA close to the Frascati synchrotron

Linear accelerator at LAL

burn Sunneh.

Discussions about which were the electrons and which were the positrons circulating in AdA.

Touschek considered such a dilemma definitely irrelevant, as he saw the whole question just as an obvious 'manifestation of CPT'

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)

e+e- -> e+e- + gamma

The interaction rate ... was found to be in good agreement with the hypothesis that there is a complete overlap between the two beams...

LIFETIME AND BEAM SIZE IN A STORAGE RING

C. Bernardini, G. F. Corazza, G. Di Giugno, and G. Ghigo Laboratori Nazionali del Sincrotrone, Frascati, Roma, Italy

and

J. Haissinski and P. Marin Laboratoire de l'Accelerateur Lineaire, Orsay, France

and

R. Querzoli Laboratori Nazionali del Sincrotrone, Frascati, Roma, Italy

and

B. Touschek Istituto Nazionale de Fisica Nucleare, Roma, Italy (Received 1 April 1963)

Discovery of the *Touschek effect*

November 1960

Even before AdA had showed the feasibility of electron-positron collisions, opening the way to higher energy and luminosity, Touschek prepared a draft plan for a bigger and more powerful accelerator

January 27, 1961. F. Amman, C. Bernardini, R. Gatto, G. Ghigo and B. Touschek, Storage ring for electrons and positrons (ADONE), LNF internal report with the proposal for the construction of a storage ring with beam energy of 1.5 GeV

ADONE

A DONE - 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 suggested 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 'alementary particles' so far known, with the exception of the neutrino, which only becomes accessible via a woak 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) 2χ . This is the only reaction in which the much intermediate state is 'quasi real' and in which therefore there should be no 'radiative corrections'. This reaction should serve as a 'monitor'. The crosssection is 2.6 10^{-31} cm⁴.

(2) et, 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 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) 2x°: charge exchange interaction for pionpion scattering.

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

(7) To, Ko : Charge exchange interaction between K-mesons.

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

(9) n,n : same as (8) but for the charge exchange reaction.

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

1960s - 1970s

SIF Catania, 1964

1969 "Enrico Fermi "Summer School directed by Bruno Touschek **Physics with intersecting storage rings**

BT with LNF directors R. Querzoli, I.F Quercia

1977–1978 AT CERN IN GENEVA

Visiting scientist while SppS was being put in motion and LEP was being planned, but still far in the future...

CERN 79-01 Volume 2 14 February 1979

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

PROCEEDINGS OF THE LEP SUMMER STUDY

Les Houches and CERN 10-22 September 1978

These Proceedings are dedicated to the memory of Bruno Touschek, whose name is so closely associated with the early development of electron storage rings

