



Bruno Touschek

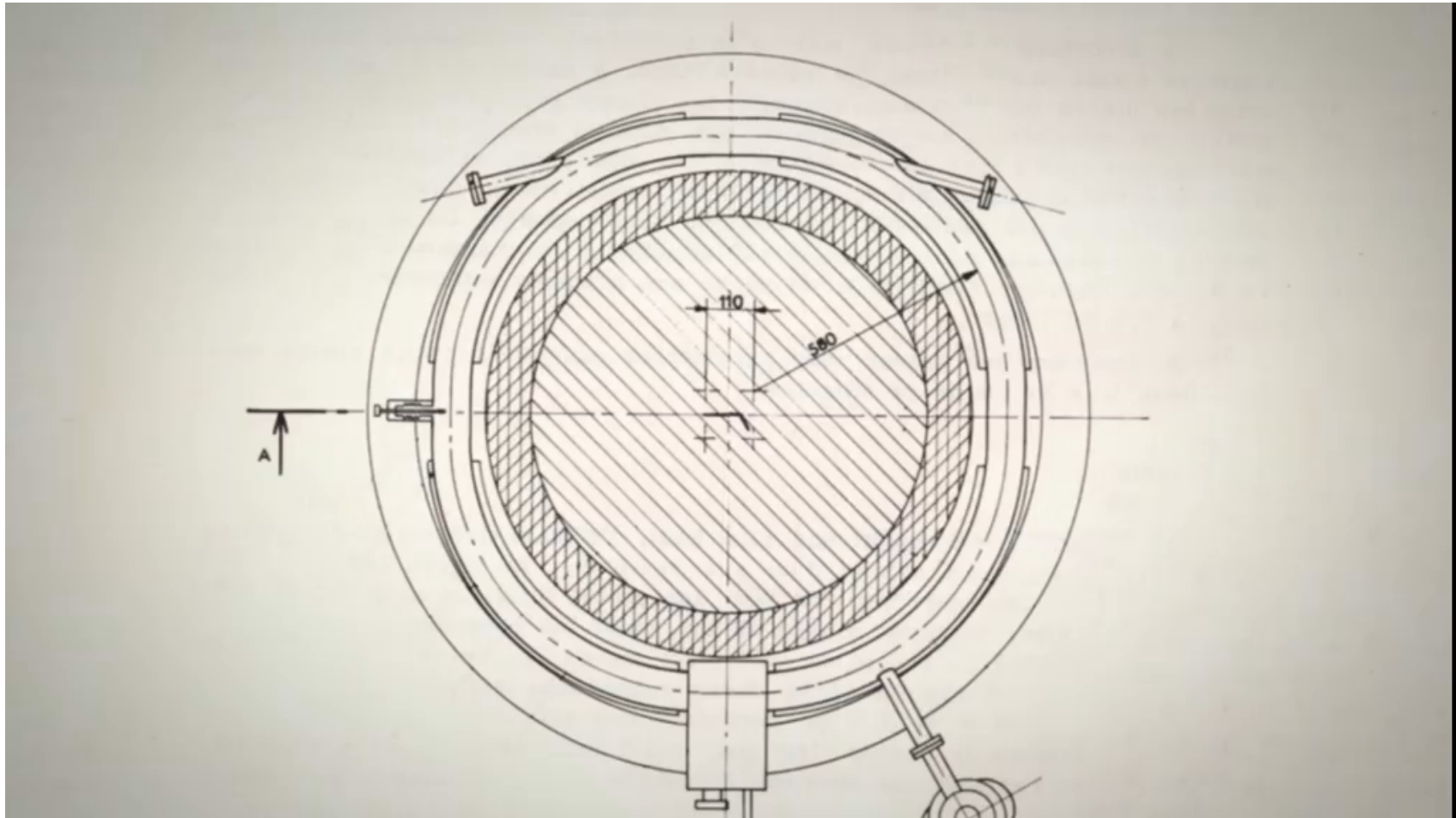
and his
extraordinary journey from death
rays to matter-antimatter colliders

Giulia Pancheri

LFC2021 – ECT* Trento

6 September 2021

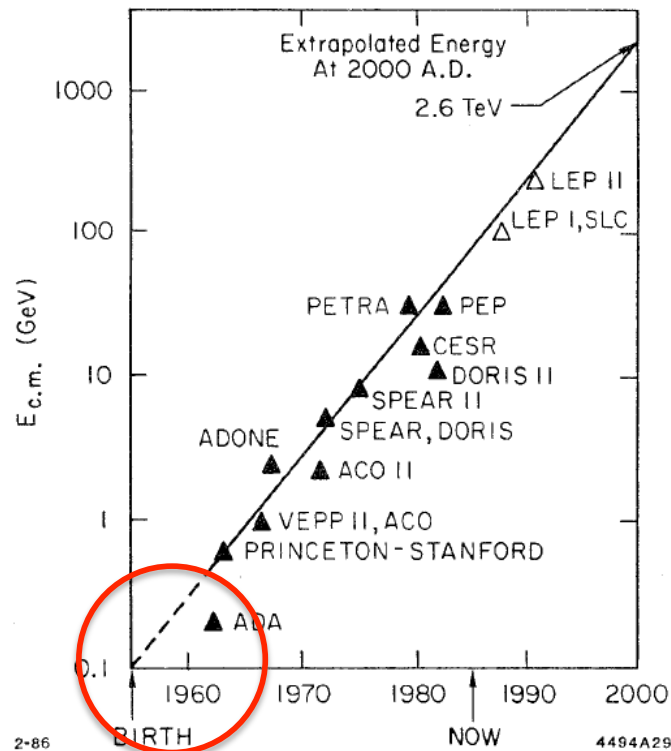
Bruno Touschek is the father of electron-positron colliders
=>
the particle physics discovery tool of the XXth century



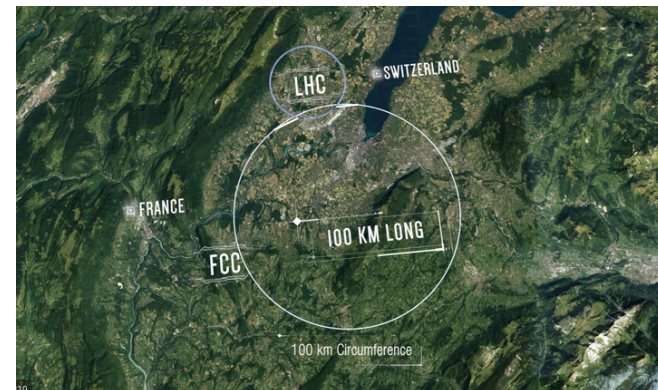
The long march of particle colliders year 2000



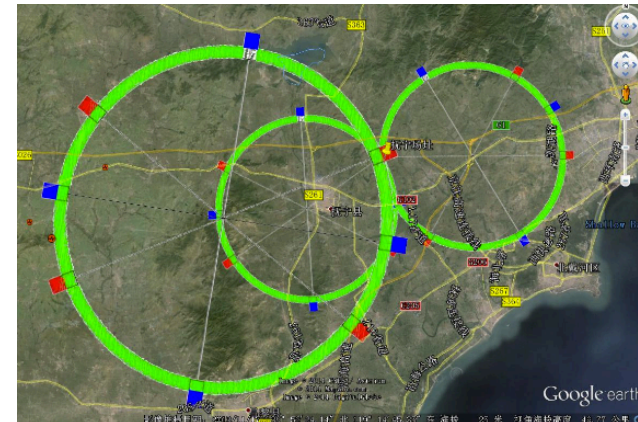
2012: LHC
-> 13 TeV
27 Km
around



Future colliders ≥ 2040 , ~ 80 KM, 100 TeV



CERN

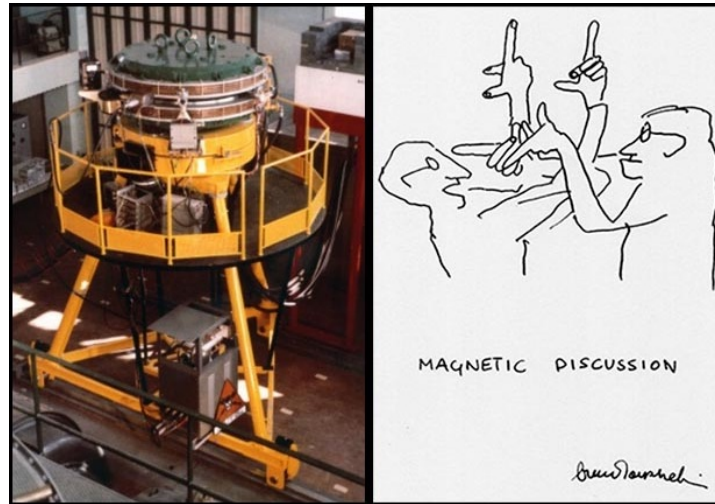


China

1961: AdA = Anello di Accumulazione
400 m around, 500 MeV c.m. energy

The story of Europe's particle colliders begins with Touschek and **AdA**

AdA : **A**nello di **A**ccumulazione
Storage Ring



AdA's Legacy

ADONE, ACO, SPEAR,
VEPP-2...

LEP, HERA, LHC

New quarks: charm,
[bottom], top

"The forces": W-Z,
Gluon, Higgs...

Austria
Vienna

Norway
Rolf Widerøe

Germany
Munich
Hamburg
Berlin
Göttingen

United Kingdom
Glasgow
Edinburgh

Italy
Rome
Frascati

France
Orsay

ECT* - 6-10 September 2021-LFC2021

Bruno came from Vienna(1921-1978)

100 years since the birth of the father of matter-antimatter colliders

- Bruno Touschek's work and life cross Europe in space and time:
 - from Austria to Germany 1921-46
 - to the United Kingdom 1947-52
 - Italy 1953-1977
 - France between 1962-64
 - CERN 1977-78

and ultimately back to Austria



- Through World War II and the reconstruction of European Science
- Up to the beginning of the great particle discoveries of the 1970s

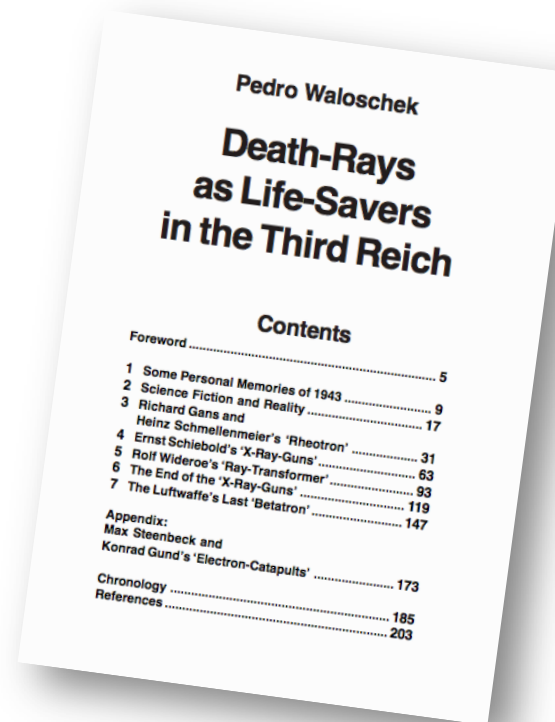
About Touschek's life - 1

Main Archive consultation:

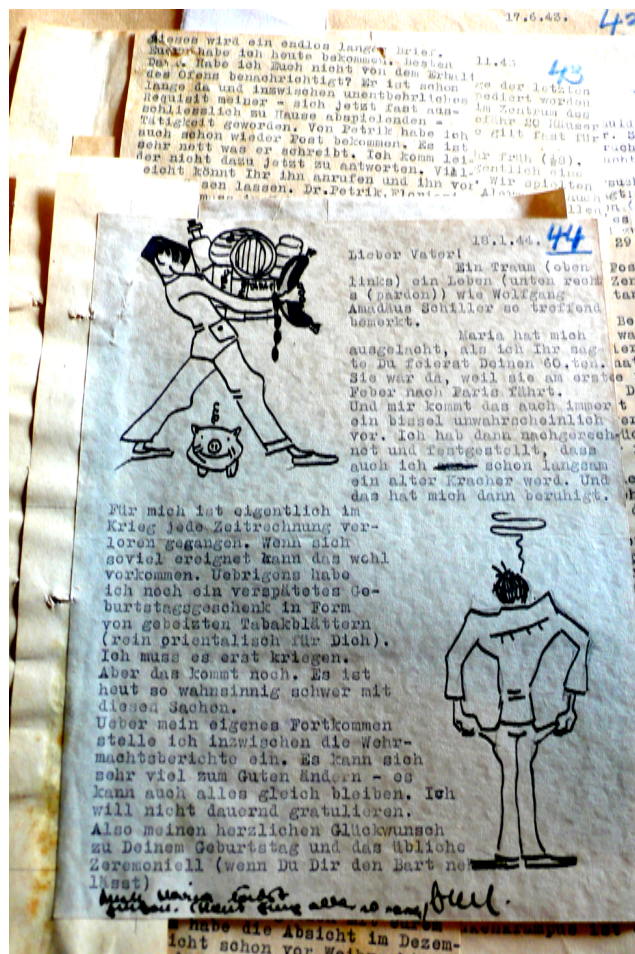
- Deutsches Museum Munich
 - => BT- Arnold Sommerfeld correspondence
- Amaldi Archives Sapienza University Rome
- University of Glasgow Archives Collection
- Churchill Archives, Cambridge University =>
 - => BT-Max Born letters
- Archives of the Max Planck Society =>
 - => BT- Werner Heisenberg correspondence

Major Published sources :

- E. Amaldi, The legacy of Bruno Touschek, 1981 CERN Yellow Report
- R. Widerøe, The infancy of particle accelerators, DESY 1994
- L. Bonolis and G. P., Bruno Touschek father of e+e- colliders, EPJH 36 (2011) 1-6
- P. Waloschek Death rays as Life-Savers during WWII, 2012
- A. Sørheim, Rolf Widerøe: obsessed by a dream, 2020



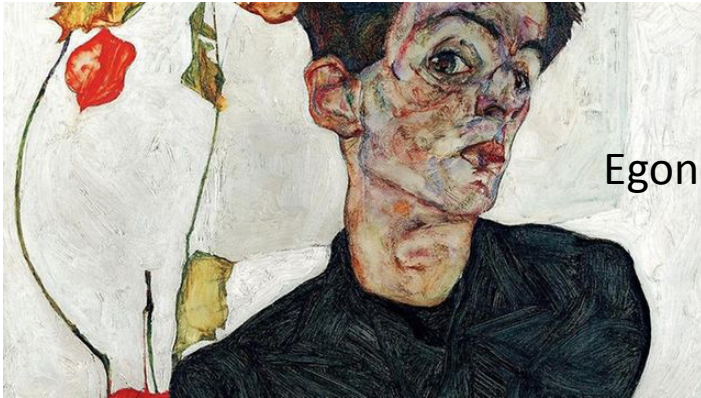
About Touschek's life - 2



Unpublished Touschek's personal letters

- A cache of over 200 letters from Bruno to his father from 1939, into 1961 and then 1969 to 1971, was made available to L. Bonolis and G.P. by the late Mrs. Elspeth Yonge Touschek.
- These letters lifted a veil on his WWII work on a secret project financed by the ReichsLuftwaffeMinisterium, under the sponsorship of General Milch, a close collaborator of Goering

Bruno grew up in Vienna



Egon Schiele

- Secession cultural Influences
- Karl Kraus
- Egon Schiele
- Oskar Kokoschka with whom Bruno studied drawing as a child



Karl Kraus



Monogram and trademark of the Wiener Werkstätte



Work by Josef Emanuel Margold
Artist of the Wiener Werkstätte Circle
and family member from maternal side

Early life: losses and sorrows



- Jewish from mother's side
- Check-Austrian from father's
- Lost mother as 10 years old (1931)
- Maternal Uncle Oskar Weltmann, doctor and a painter: suicide in 1934

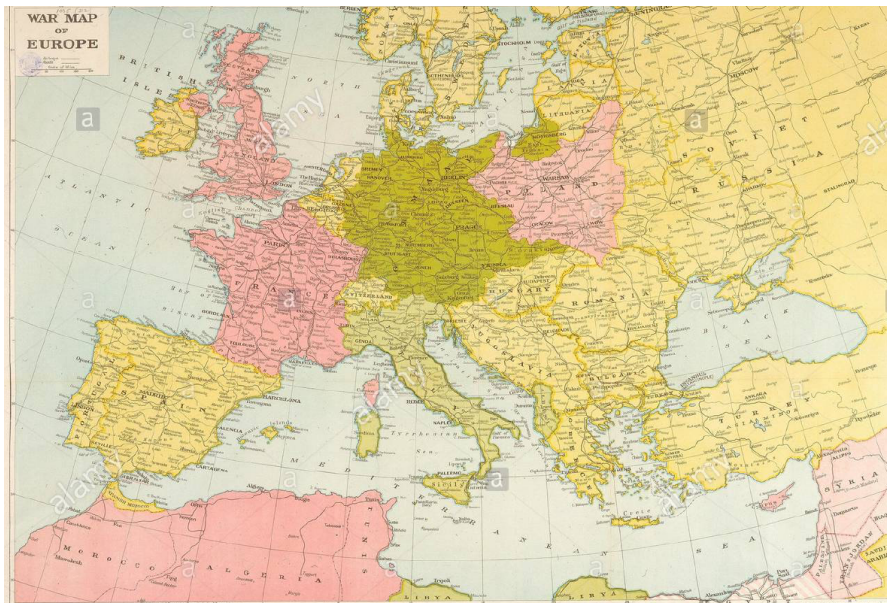


- After the **Anschluss**, BT was dismissed from Vienna Piaristen Gymnasium 'for racial-political reasons' in December 1938 => *Matura* from a catholic school
- March 1939: tried (unsuccessfully) to emigrate to England
- December 1941 : expelled from University of Vienna
- 1942: Maternal grandmother Josefine Weltmann was arrested, deported to Theresienstadt, where she died (1943)

Bruno often visited Rome



Aunt Ada's home



Europe : 1939

• March 1939 from Rome:

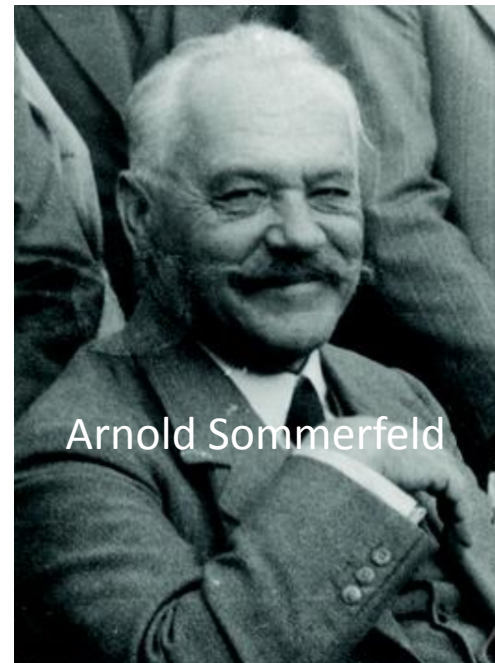
*The time here goes by very slowly.
The visa from England could already come.*
Bruno Touschek, letter to his father

- September 1939: Bruno enrolls in Physics at University of Vienna
- June 1940: denied further enrollment
- December 1941: renews application, definitively expelled as a “**mischling**”

1941-1943 : Bruno goes to Germany

Austria -> Germany: February - November 1942

- November 1941: Bruno visits Sommerfeld in Munich, with Paul Urban
- December 1941: Correspondence with Sommerfeld
- February 1942 : Tuschek leaves Vienna for Munich where he receives Sommerfeld's blessings and advice
- March: in Hamburg he works in an electronic firm and attends lectures at U. Hamburg, Paul Harteck (Uranverein) his sponsor



Arnold Sommerfeld

Germany: The war years - 1



- *It was the first attack on Lubeck...*
Letter to father, **Hamburg** April 1942

November 1942: he leaves **Hamburg** for **Berlin** to work at Loewe Opta, klystrons and stuff for German Army, also reviews for *Archiv für Elektrotechnik*



Flak Tower in Berlin:
Anti-aerial defense



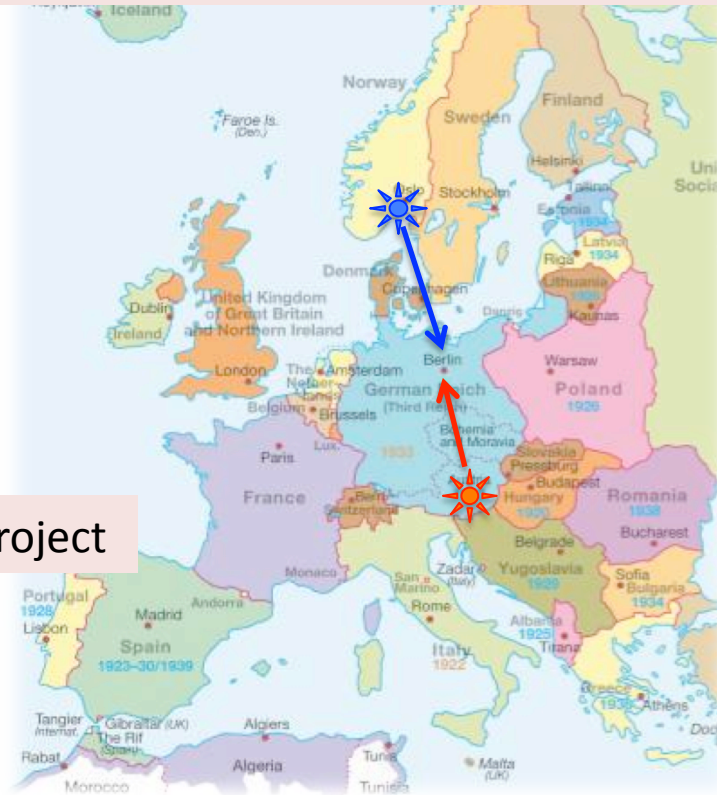
Drawing in Letter to father, **Berlin**
November 1943

In 1942, a journey through war and destruction and dreams started

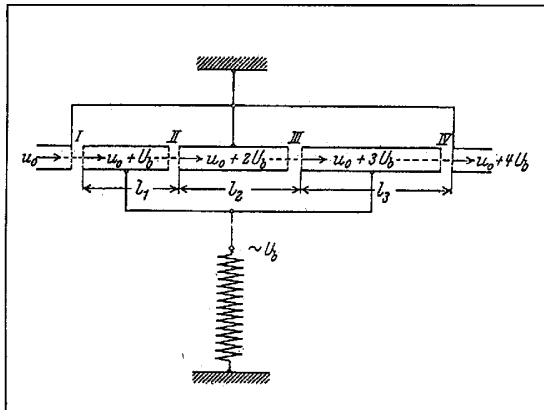
In February 1942, Touschek left Vienna and went to **Germany**, first to Hamburg and then to Berlin, trying to go on with his studies, protected by Arnold Sommerfeld and his former students, earning a living at various electronic firms working with the military

In 1943 Widerøe came to Germany to fulfill his dream to build a betatron

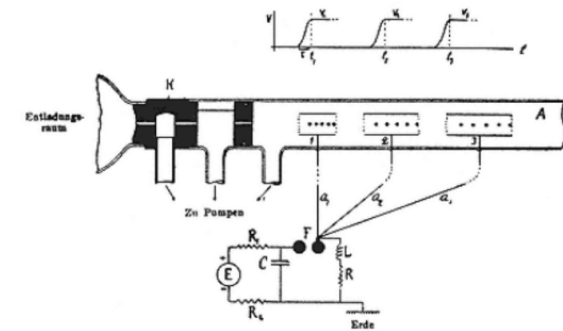
And Bruno joined the project



The road from the North (Norway, Sweden)
Rolf Widerøe and the art of making accelerators

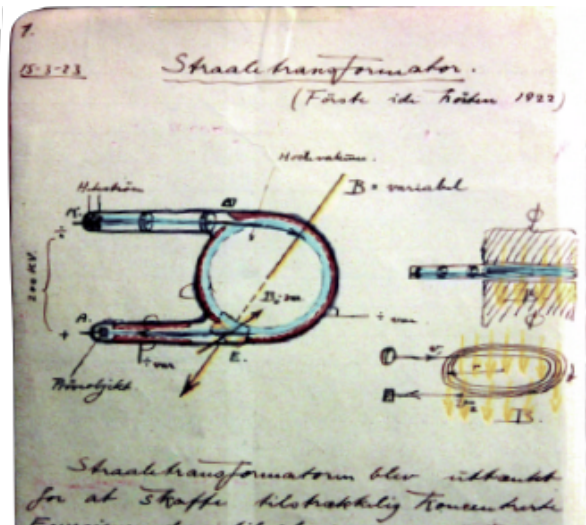


Principle of “drift-tube” Widerøe’s thesis (1928)



Gustav Ising inventor of the linear accelerator concept in 1924: Prinzip Einer Methode Zur Herstellung Von Kanalstrahlen Hoher Voltzahl.

Arkiv för matematik, astronomy och 18 (30): 1



As a student in Germany, Rolf Widerøe drew a sketch of his idea for a betatron (ETH Library in Zurich) (*Photo* Pedro Waloschek)



Rolf Widerøe at the control panel of a 31 MeV betatron operating since 1952 at the Norwegian Radium Hospital (Aashild)

Medical uses after the war

1941-1943 : Rolf **W**ideröe



Wideröe in 1920
(1902-1996)

Norway: July 1941- September 1942



Donal Kerst, 1948

- July 1941: **Kerst and Serber** announce construction of first betatron in Illinois - 6 MeV
- Fall 1941 : Phys Rev article is read in Trondheim by Tangen => presented in December at a physics group in Oslo: **W** is in the audience!
- September 1942 : **W** submits his own proposal for 15 MeV to *Archiv für Elektrotechnik*

Bruno meets Widerøe (W)

Berlin 1943

- February :
 - Lowe Opta , Archiv Editorial office,
 - Touschek reviews an article (W's) about a "cyclotron"
 - and discusses it with his boss K. Egerer
- March-April :
 - death ray projects at the ReichLuftwaffe Ministerium (RLM)
 - Egerer approaches RLM about W's betatron proposal

Norway : 1943

- Spring :
 - Widerøe talks with German officers in Oslo and
 - W is flown to Berlin to discuss his project
- **RW** exchanges correspondence with BT about relativistic corrections to electron's orbits

June 17 1943

BT's objections are included in W's project, approved as secret project financed by RLM

August 1943

=> Betatron to be constructed in Hamburg

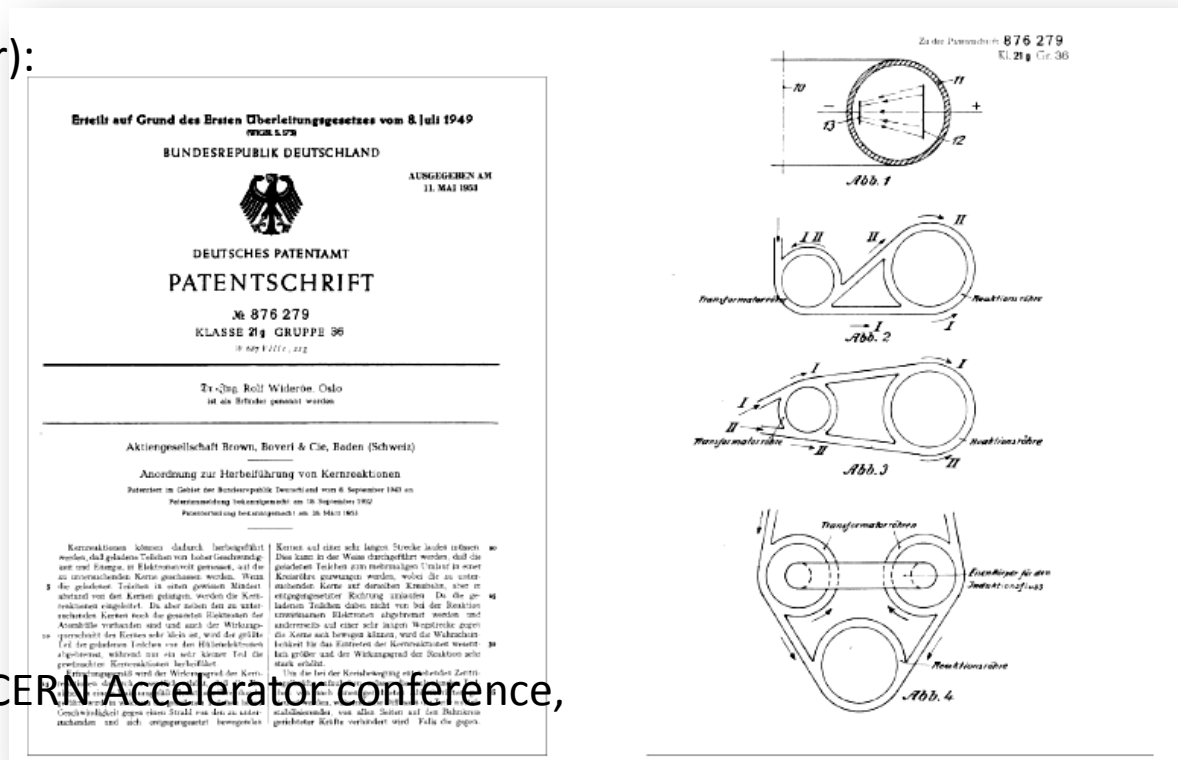
When Touschek first heard about the colliding beam idea

September 1943 (or a bit later):

- Widerøe tells Bruno of his idea of colliding particles
In the center of mass
and applies for a patent

- Registered after the war
in 1953

- “I have got a patent!” 1956 CERN Accelerator conference,
after O’Neill’s talk

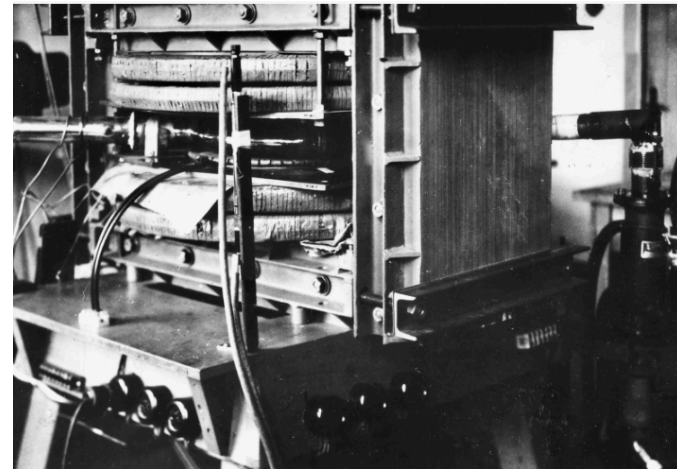


The dark years : *Yesterday I signed my death warrant...*

Bruno's letter to father, Berlin, October 29th,



1944-45

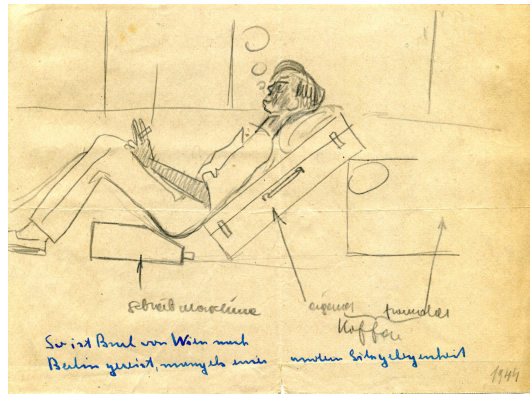


In **Berlin**, Tuschek worked for the electronics firm Loewe Opta, whose offices were moved to the top floor of one of the Flak Towers in the Tiergarten, after 1944

In **Hamburg**, BT worked with Rolf Wideroe to build a 15 MeV betatron for the ReichLuftwaffeMinisterium, a classified project. After the war, the Allies took the betatron as war booty to Woolrich, UK.

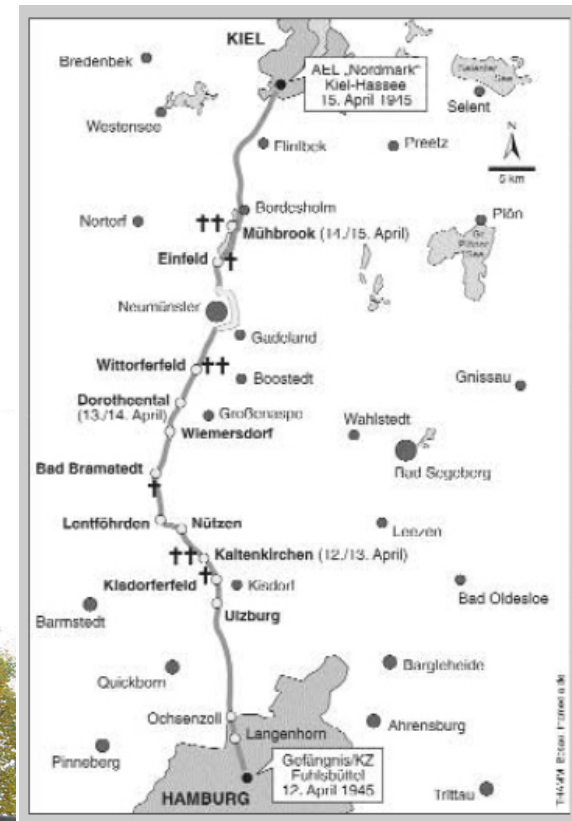
A death warrant?

- Touschek was free to visit his family in Vienna, Wideroe often went to Norway
- Wideroe 15 MeV betatron : an important secret project, of “war interest”
- Todt Organization (forced labor Under Minister Albert Speer): summoned Touschek at least 3 times in 1944-45 all postponed until ...
- Betatron work over on March 15 1945, BT arrested
- April 15 : 200 on forced march
- BT collapse, is shot, left as dead
- Hospital and Altona prison
- Freed on April 30, 1945



Fulsbüttel Prison

ECT*- 6-10 September 2021-LFC2021



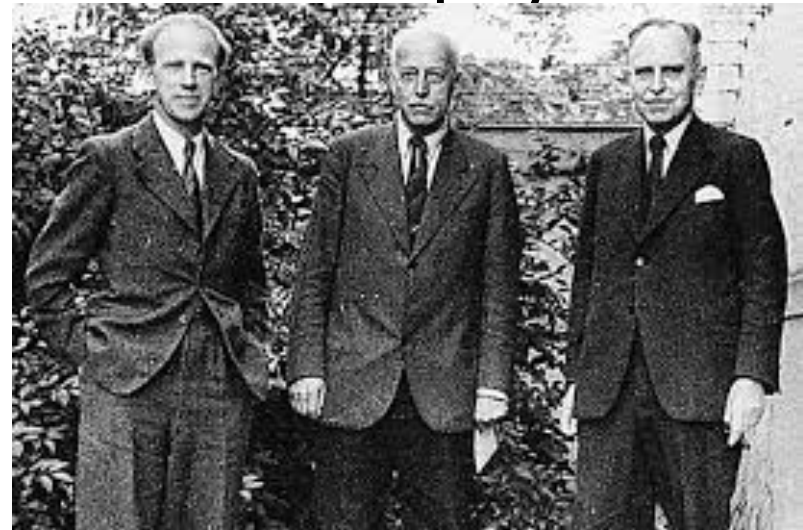
U. Fentsahm, 2004
Der “Evakuierungsmarsch” von Hamburg-Fuhlsbüttel nach Kiel-Hassee (12.–15. April 1945).

Göttingen: on the way to become a physicist

I want to become a physicist

Ich will Physiker werden.

Bruno Touschek to father,
May 9th, 1946



From Fall 1945 to March 1946, the Allied T-force takes charge of the betatron project and Bruno's future:

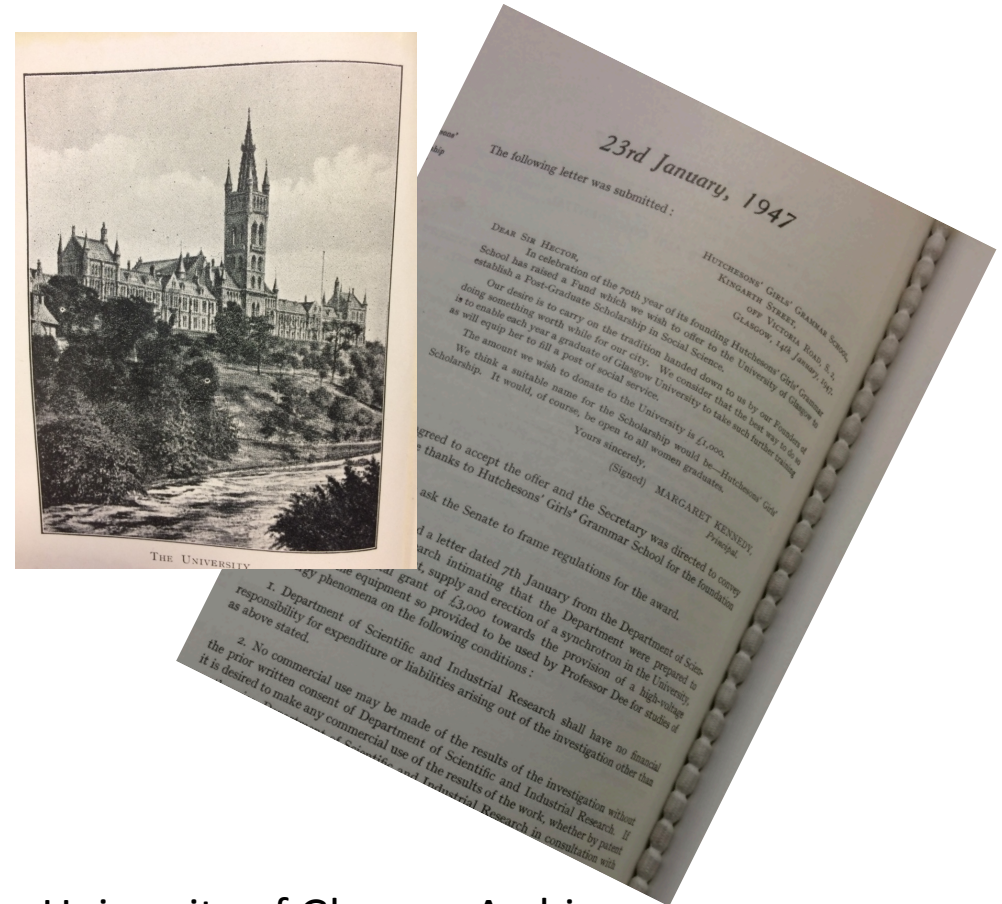
- Dissertation at University of Göttingen on the betatron => Diploma in Physics June 1946
- 6-months assistantship with Werner Heisenberg
- Doctorate and research at University of Glasgow => 300 GeV synchrotron to build

Werner Heisenberg, Max von Laue and Otto Hahn back in Germany from Farm Hall in early 1946:

LB&GP Arxiv [1910.09075](https://arxiv.org/abs/1910.09075)
on Germany 1946

Post war reconstruction in the UK and the Glasgow synchrotron

- Cyclotrons -> betatrons -> synchrotrons : particle accelerators became the tool for nuclear physics research
 - 1946 UK Government Committee to build new accelerators in : Birmingham, Cambridge, Liverpool, Oxford, and Glasgow
 - Allied T-force was interested in Bruno, one of very few experts in accelerator physics in Europe (Wideroe had come back to Norway)
- ➔ BT should go to Glasgow where Philip Dee was planning to construct a 500 MeV synchrotron



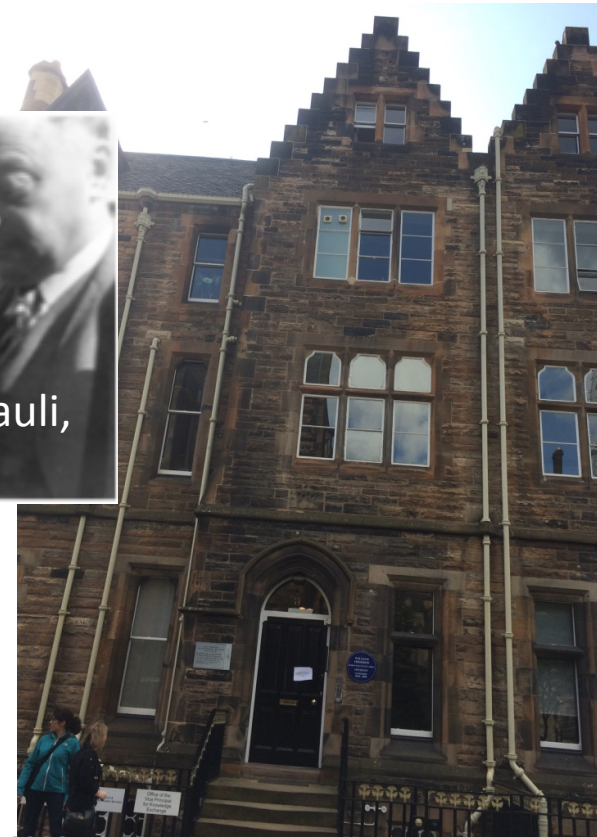
University of Glasgow Archives

GP&LB, ArXiv:2005.04942

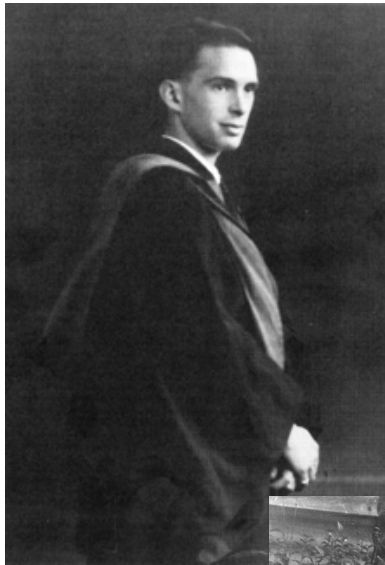
The Glasgow years

The making of a theoretical physicist

- in April 1947 Bruno was admitted at the University of Glasgow as a research student, joining the new generation of young people returning from the war
- From 1948-1951 lived with the Philip Dee and his family at 11 University, whose first occupant had been Lord Kelvin



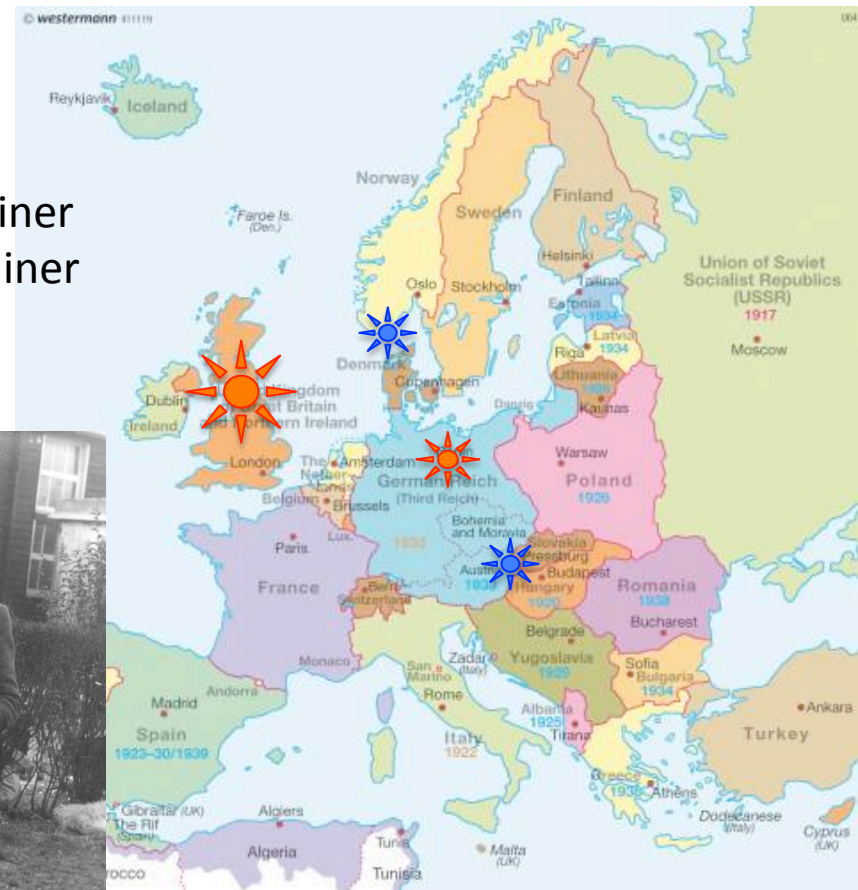
UK : from betatrons and synchrotrons => theoretical physics



PhD, 1949

J.C. Gunn internal examiner

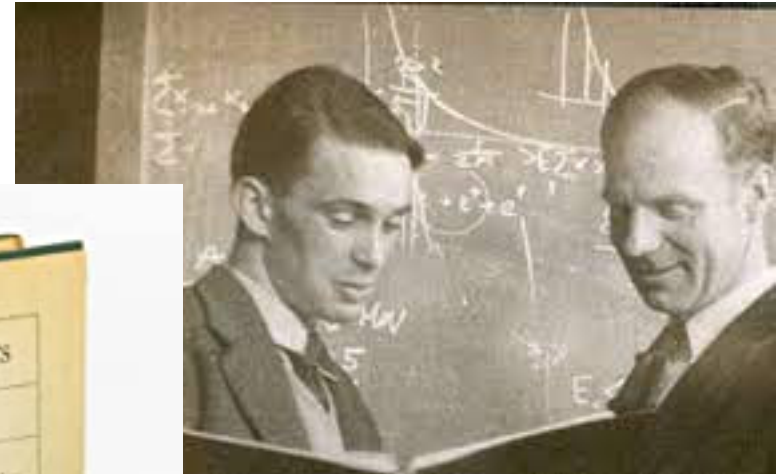
R. Peierls external examiner



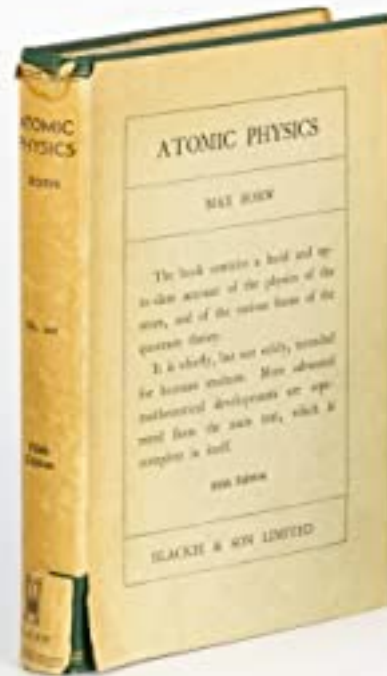
Glasgow days 1947-1952

In January, I worked with M Born in Edinburgh and wrote a chapter and an appendix for him. That was quite entertaining.

Bruno Touschek, letter to father, Glasgow, February 13th, **1950**.



In Glasgow with Samuel Curran



1951 : Work with Walter Thirring
Bloch Nordsieck theorem on
infrared catastrophe

1950-52 : A two years correspondence
between Touschek and Max Born
is kept in Chirchill archives in Cambridge

Leaving Glasgow

The Fuchs affair made life difficult
for all foreign born scientists
(in particular Germans, Peierls was
his mentor and close friend)

1952: Touschek came in touch with
Bruno Ferretti, from U. of Rome,
who had worked with Peierls
in Birmingham, on radiation problems



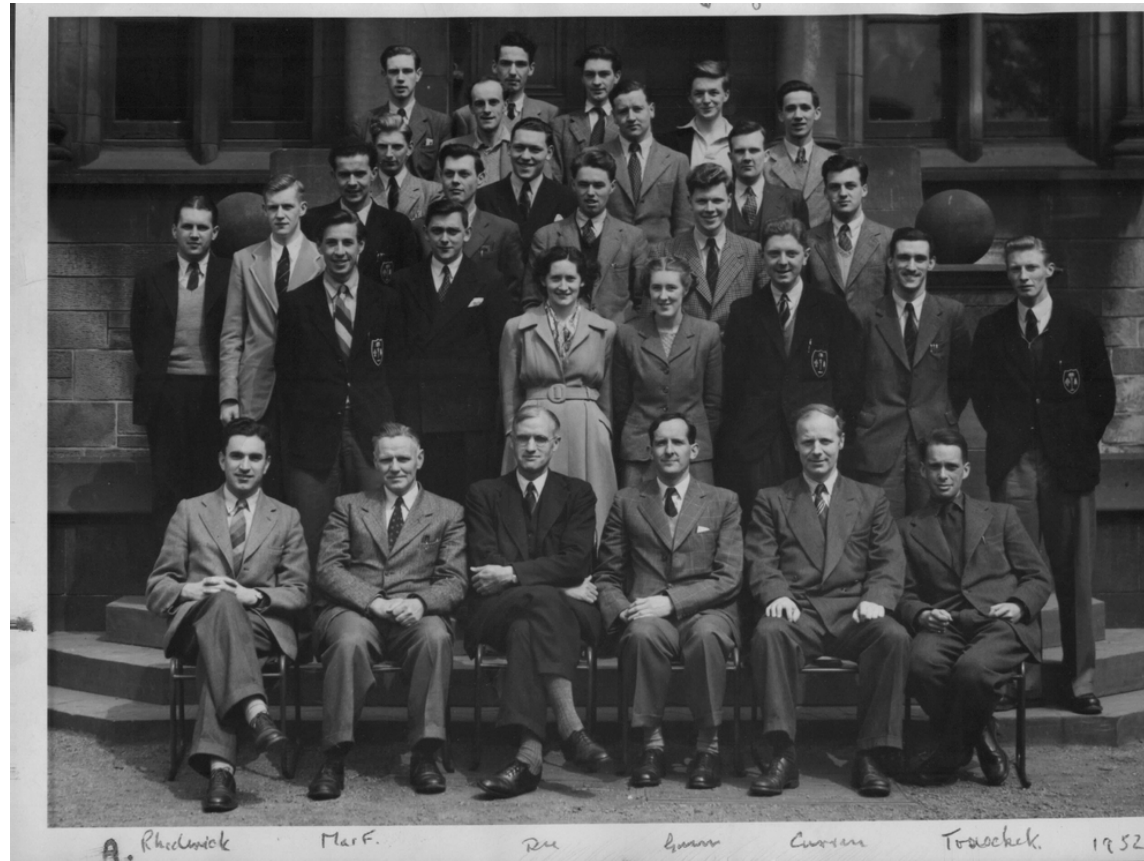
Bruno tried to leave

- visited Copenhagen (invited by Niels Bohr)
- applied for position in Oxford (no answer)
- regretted not having stayed in Germany



Ferretti, Bhabha, Pauli, 1958

The Department of Natural Philosophy at University of Glasgow in 1952.



The Glasgow period gave Bruno the pause he needed to recover from the tragedies of the past. In the quiet setting of University life, learning from his peers made him into a theoretical physicist. He could now go back to Europe, where his future creative life would develop, first in Rome and then in Frascati.

How Touschek went from Glasgow to Rome



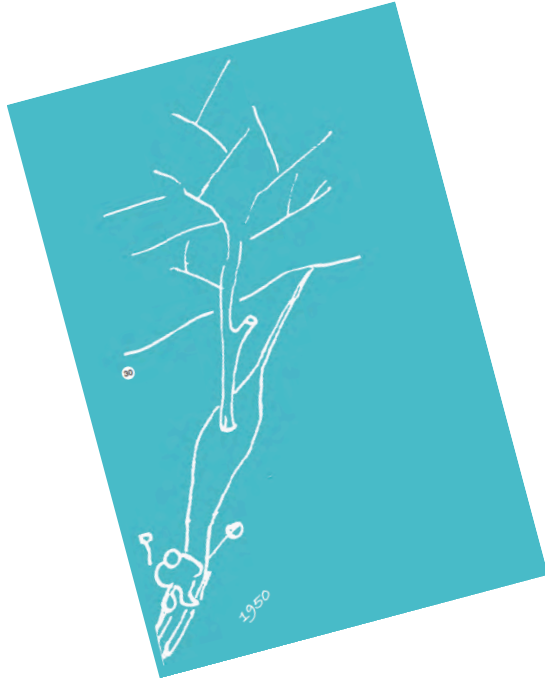
Edoardo Amaldi and Bruno Ferretti
both from Enrico Fermi's group before
1938, brought Touschek from Glasgow
to University of Rome in 1953

This fitted in Amaldi's plan for the
post-war Europe's scientific reconstruction:

- creation of CERN
- Italy full fledged member of the world
accelerator club
- Rome particle physics group development

Basilea-1949
Giorgio Salvini, LNF future director,
Edoardo Amaldi, Bruno Ferretti

From Glasgow to Rome



Bruno Touschek (center), in Italy in 1953, at Tusculum hills with Edoardo and Ginestra Amaldi to his right

Italy : 1953

- The institute is quite excellent. At the moment there are two Nobel Prize winners (Pauli and Blackett) and a candidate and the other people are very interesting as well ... *BT to father, 30 Dec. 1952*
- The area around Rome is a fairy tale, and nothing has changed in the last two thousand years... *BT to father, 30 April 16th. 1953*



In Rome Touschek's unique formation as **theorist** and **accelerator** physicist found the perfect synthesis

- **Theoretical physics**

- Vienna School : Hans Thirring
- The great German School
 - Arnold Sommerfeld – Munich 1941-42
 - Werner Heisenberg – Berlin and Göttingen 1945-47
 - Max Born – Edinburgh 1947-52
 - Wolfgang Pauli – Rome 1953-1958



Arnold Sommerfeld



Werner Heisenberg

- **How to build an accelerator** from scratch under worst circumstances (bombing and destruction 1943-45) with a master of the field Rolf Widerøe => first linear accelerator & betatron principle (1928)



M.Born and W.Pauli-1925

And he also found a laboratory on the making to host a synchrotron near Rome

- January 1953: INFN decision to start building an accelerator of a type not yet decided => electron synchrotron (summer)
- Enrico Fermi's old dream, before leaving Italy for the US in 1938
- In 1954 the place was agreed to be in Frascati near Rome
- In 1957 a national laboratory was operational, and the synchrotron parts began to be assembled



Building the synchrotron gave Italian S&T a quantum jump towards modern physics and the entrance to the club of countries which could build particle accelerators



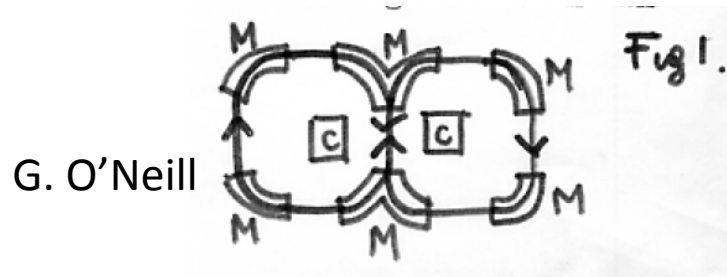
- 1954: A **team** came together in Pisa and the synchrotron parts started to be constructed
- 1957: **Two trucks** brought people and equipment to Frascati
- And the work **to assemble the synchrotron** started...

In parallel : towards the first matter-antimatter collider

Theorists worked symmetries

- CPT Theorem 1950-57
- Parity Non Conservation and Discovery of antiprotons – New York 1956
- BT on neutrino, and chiral symmetry – 1957-58

Ideas about colliders are vented at conferences (Geneva 1956)

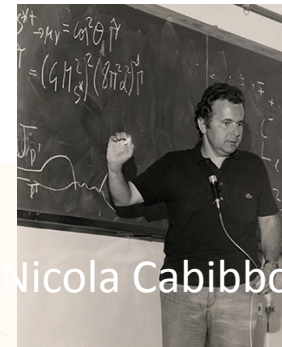
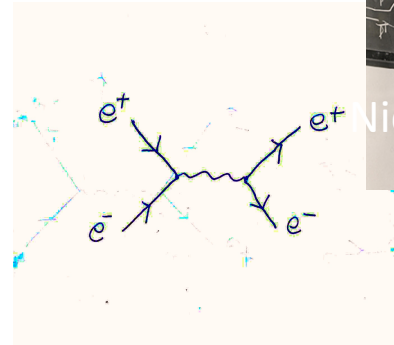
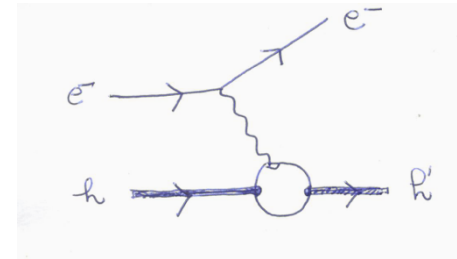
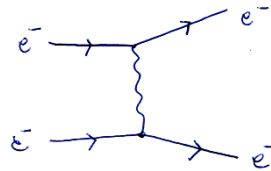


Bruno Touschek, T. D. Lee and Wolfgang Pauli in September 1957.

Touschek's humorous drawing about T. D. Lee and Parity violation.

1958-1960 and the making of AdA

- **December 1958** : Wolfgang Pauli dies, Bruno loses his major theoretical physics companion
- **April 1959**: the Frascati synchrotron starts working
- **July 1959**: at Kiev Conference
 - projects for electron-electron colliders were presented, BT was attending
 - Hofstadter experiments presented
- **October 1959**:
 - A seminar in **Rome** by W. Panofsky => Touschek lunches the idea for electron positron collisions as tools for new physics discoveries
 - In **Novosibirsk** G. Budker and V.N. Baier discuss colliding electrons and positrons



Phys. Rev. Lett. March 1960

February 17th 1960 Bruno proposes to the Frascati laboratories to build an electron positron collider

It had occurred to Bruno that...

- If electrons circle clockwise in a magnetic field, its antiparticles –the positrons- will circle anti-clockwise
- If one can make them clash, they will annihilate
- All the energy will be available to create new state of matter, if they exist
- And this would be an experiment worth making!
- The challenge of course consisted in having the first machine in which particles which do not naturally live in the world which surrounds us can be kept and conserved.
- Bruno believe that it could be done, that the CPT theorem would ensure they would meet
- And then carried his idea through ...

Idea of annihilating matter against anti-matter

why? To explore the quantum vacuum created in the annihilation

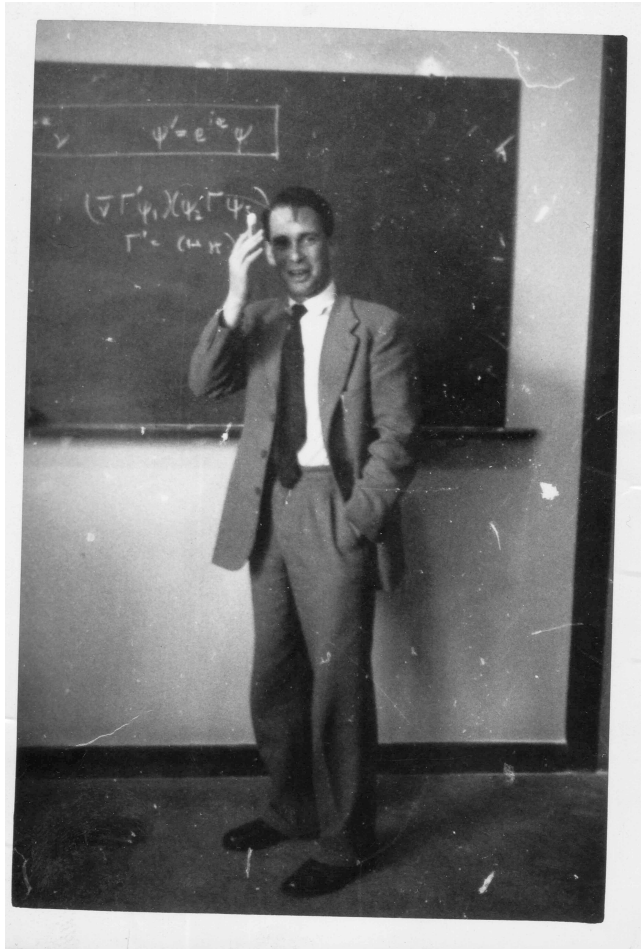
What would one learn from it?
What is beyond the world of stable particles , electrons, protons, neutrons...

How to do it?

..... Could it be done?



And Bruno started calculating



18.2.60.

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

γ = γ -beam, T = target, M_1 = separating
 magnet, St. = Storage magnet, C = Acc.
 circuit.

Basic formula

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

N = number of particles accepted per pulse
 v = repetition rate of the Synch ($v=20$)

18.2.60

$$e^+e^- \rightarrow ??? \rightarrow \pi's, \mu's, K's \dots$$

sec^{-1} , τ lifetime of the beam, σ effective x-section of the circulating beam, $\sigma = \text{x-section for the process to be observed}$. $c = \text{velocity of light}$, $\pi R = \text{half circumference of the storage magnet}$.

Experiment proposed measure:

$$(e^+e^-) : (\mu^+\mu^-) : (\pi^+\pi^-)$$

Ask Gatto, what can be learned from this measurement!

The preparation of the experiment has the following phases (we are mainly concerned with what enters q quadratically)

(A) Determination τ

- (1) Bremsstrahlung electron — ^{rays} gas atoms
- (2) Bremsstrahlung electron position *
- (3) Scattering electron — gas rays
- (4) Scattering electron — position *

(A2, & 4) are not strictly positive & can be considered as forcing part of the experiment.

- (5) Quantal Synchrotron radiation
- (6) Damping?

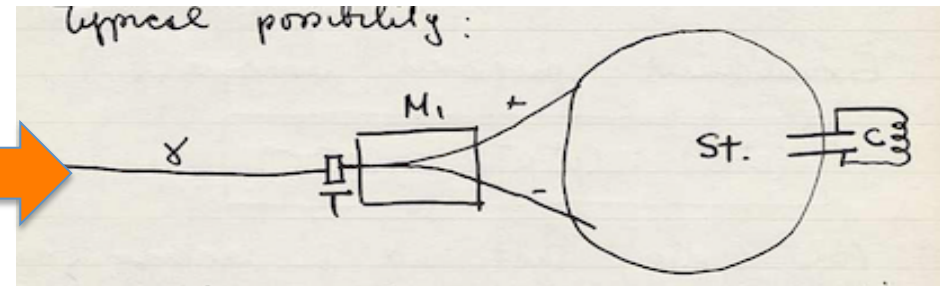
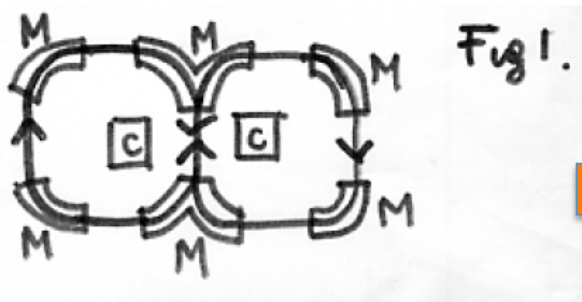
(B) Geometry and Mechanics of Injection.

- (1) "Ideal energy" (is it really 250 MeV?)
- (2) Optical problem if a separating mag is used.
- (3) Possibility of "mechanical" (rotating) converters.
- (4) RF injectors?

(C) What can be learned from the proposed experiment
[theoretical] viz.: Cabibbo & Gatto.

AdA : the perfect synthesis

between state-of-the art accelerator physics



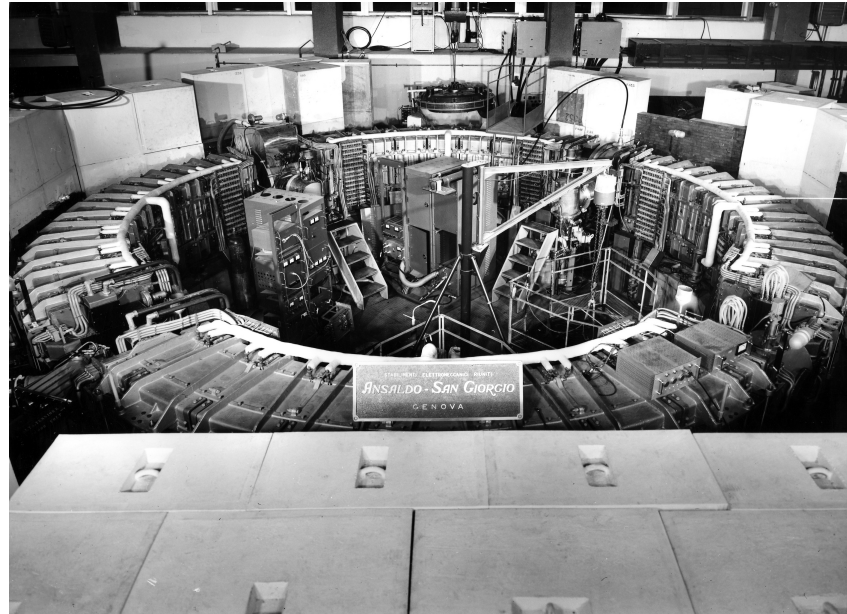
new ideas in theoretical and experimental **particle physics**

QED, symmetries, CPT theorem, anti-particles created in the laboratory

Technology available through synchrotrons (Frascati) and Linear accelerators (Orsay)

AdA at the synchrotron

- **March 1960:**
approval and construction
-> AdA
- **November 1960 :** Touschek
proposes to build a bigger and
better machine -> ADONE
- **February 1961 :**
Electron (or positron?) beams
circulate in AdA



But a problem occurred:
the electron and positron beams were
too feeble for the probability of
collisions to be observed

problem of injection!!!

The making of AdA

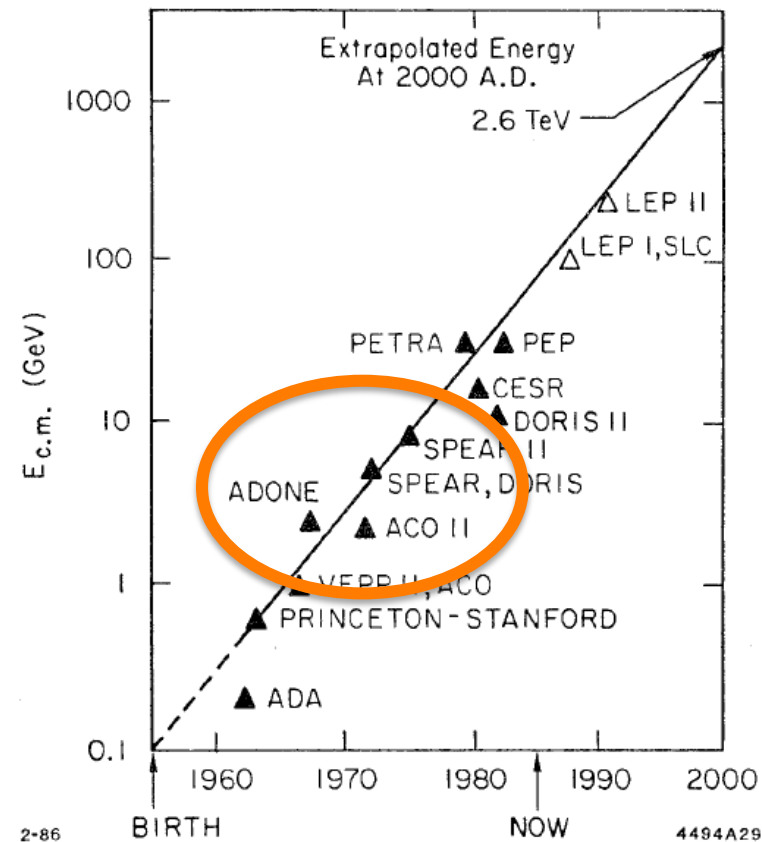
Ada the storage ring will be waiting for me on Monday when I return to Frascati. But then the peace is gone. In November, December we have to measure the magnet and in January it gets really serious. From the reports of my spies I learn that we are really the first in this area: the American competition won't bother us for a year

Bruno Touschek, letter to father
Rome, November 6th, 1960

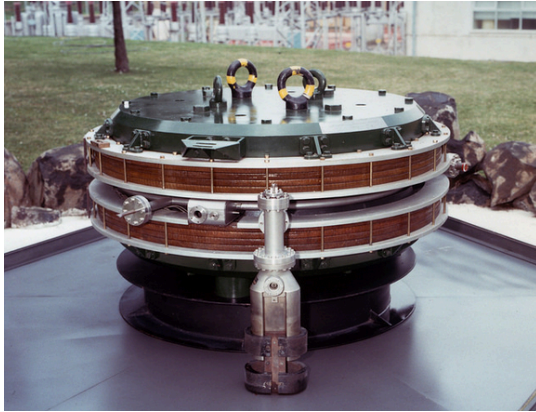


The road to particle coliders...

- In February 1960 BT proposed to build an electron-positron collider **AdA** = Anello di Accumulazione
- in November 1960 BT proposes **ADONE**, a better bigger AdA
- In 1963 the **Touschek effect** was discovered, after AdA had been transported to Orsay, France
- in 1964 collisions were proved to have taken place
- ADONE started in 1969, and discovered multihadron production, but by this time new generation colliders took over and in 1974 the American competition won the race...discovering a new particle, the J/Psi, and a new quark, charm.



AdA and ADONE: an European story

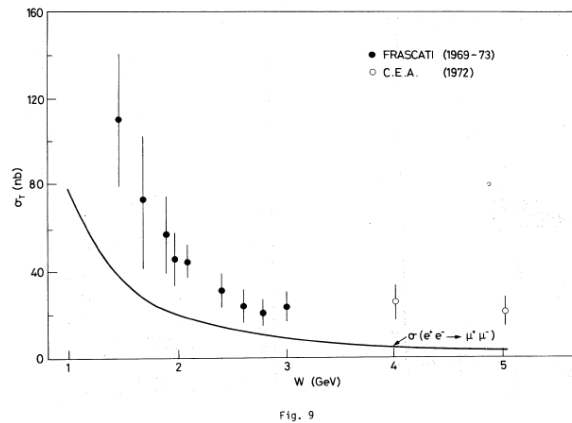


AdA in Frascati now



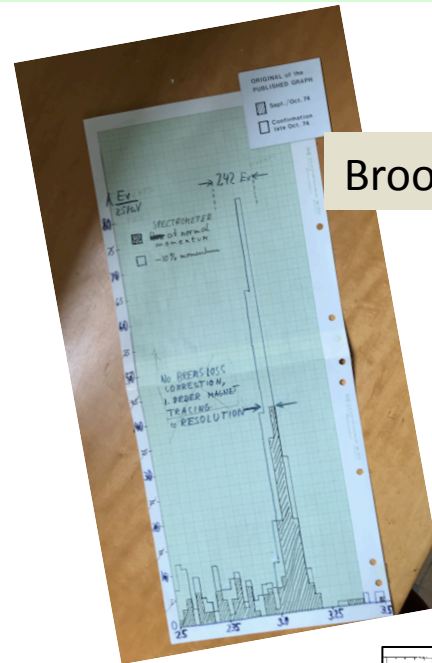
Old site
where AdA
was built

New states of matter appeared after 1969 in electron-positron collisions : ADONE, CEA , SPEAR

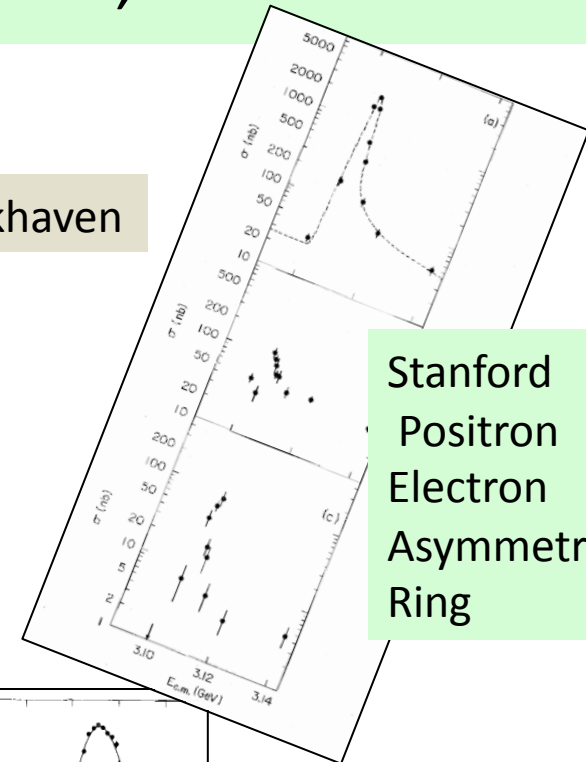


More final state particles than expected

Frascati ADONE 1969

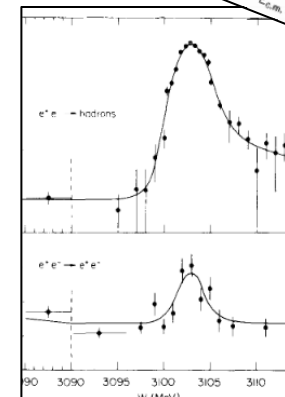


Brookhaven



Stanford
Positron
Electron
Asymmetric
Ring

J/Psi



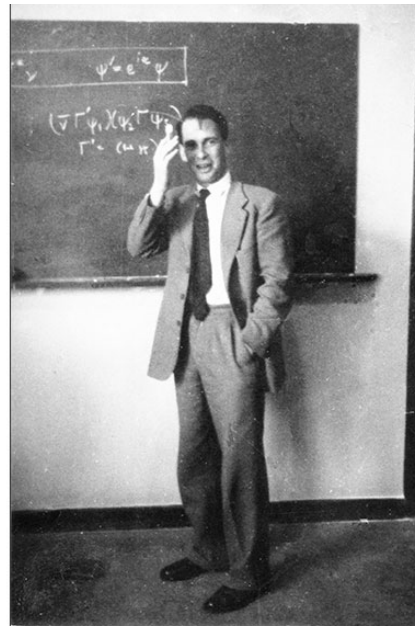
ADONE

November 1974. A bound state of new quarks appeared

ECT* - 16-10 September 2022 - JLF2022

Why did Touschek miss the Nobel Prize?

In 1976 Burton Richter and Sam Ting were awarded the Nobel Prize 'for their **pioneering** work in the discovery of a heavy elementary particle of a new kind' -> J/Psi



Thanks

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Yogendra Srivastava

Galileo Violini

And many more friends and colleagues

To come

- a Symposium In Rome and Frascati on December 2-3-4 2021
- a book in progress