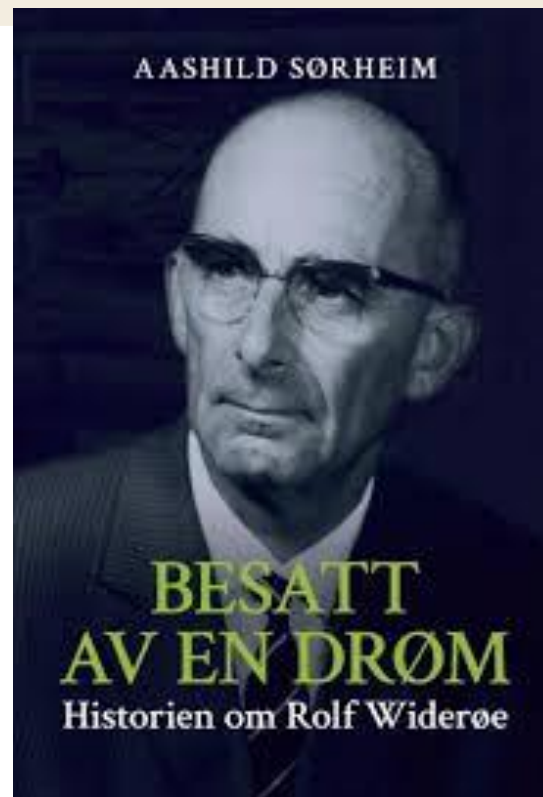


Life and Work of Rolf Widerøe

September 6, 2017



Aashild Sørheim



Obsessed with a Dream

Rolf Widerøe: Life at a Glance

SLAC



1902	Born in Oslo	1952...	Geneva: Consultant at CERN (PS project)
1922	Karlsruhe: Betatron idea	1953...	Zurich: Lecturer at ETH Zurich
1922	1 \$ = 192 German Mark.	1956	Kerst and O'Neill: Re-invention of storage rings
1923	1 \$ = 4,200,000,000,000 German Mark	1956...	Baden: Construction of the Turin synchrotron
1927	Aachen: First linac works	1959...	Hamburg: Consultant at DESY (synchrotron)
1929	Lawrence: First 80 keV cyclotron in operation	1959...	Baden: Megavolt radiation therapy
1929...	Berlin: Construction of distance relays	1960	Frascati: Touschek, AdA, first storage ring
1933...	Oslo: Construction of distance relays	1962	Aachen: Dr. honoris causa at RWTH Aachen
1941	Kerst: First betatron (2.3 MeV) in operation	1964	Zurich: Dr. med. h. c. at Zurich University
1943	Oslo: Storage ring idea, patent	1965...	Baden: Two component theory
1944	Hamburg: 15 MeV betatron works	1969	Remscheid: Röntgen Medal
1945	McMillan, Veksler: Synchrotron	1971	Würzburg: Röntgen prize
1945	Oslo: Synchrotron theory, patent	1973	Oslo: Member of the Norw. Acad. of Science
1946...	Baden: Construction of betatrons at BBC	1973	Madrid: JRC gold medal
1952...	Synchrotrons: Cosmotron, Bevatron, PS...	1992	Washington: Robert R. Wilson Prize of APS
		1996	Died in Obersiggenthal, Switzerland

Special Thanks



People who knew Rolf

- Ralph Eichler, retired ETH&PSI
- John Crawford, retired PSI
- Chris Gerber, retired BBC and PSI
- Werner Joho, retired, PSI

The Organizers

Ralph Assmann, DESY
Achim Stahl, RWTH
Andreas Lehrach, RWTH

The Brothers



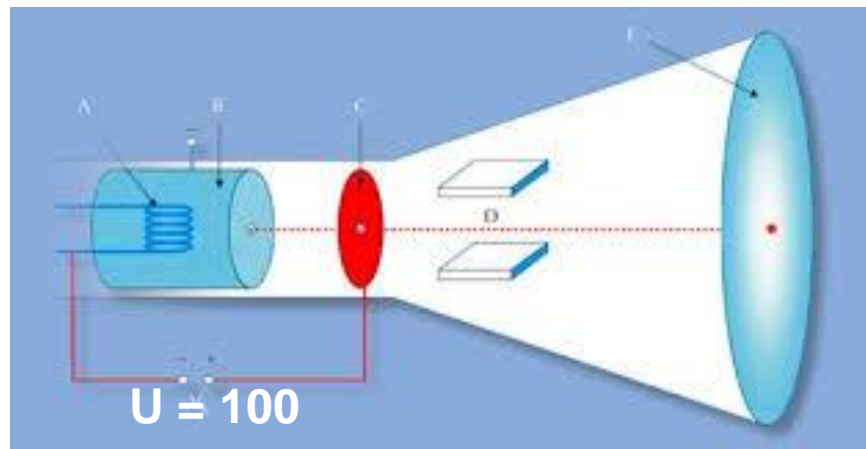
From the movie: “Always Brothers”, based on the book by Aashild Sørheim

How much is an Electron Volt and what is it?

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ Joule}$$

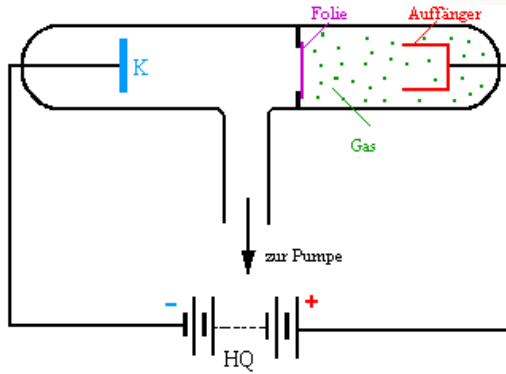
It's how physicist measure the kinetic energy of a particle.

keV	= 1,000 eV
MeV	= 1,000,000 eV
GeV	= 1,000,000,000 eV
TeV	= 1,000,000,000,000 eV

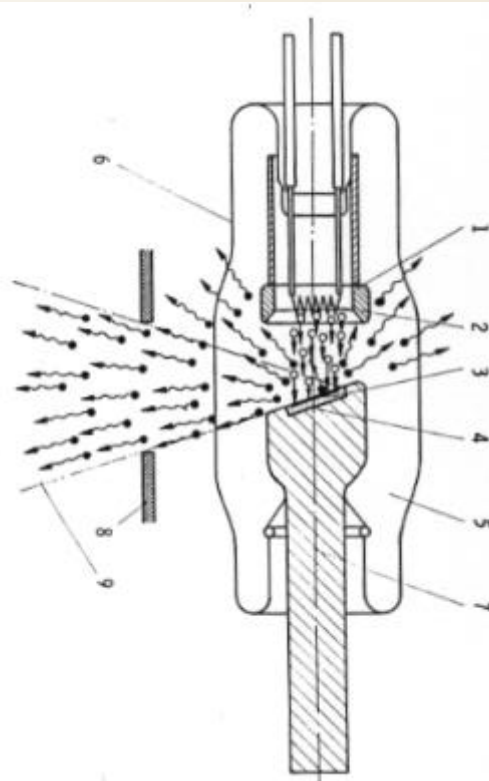


$V = 100 \text{ Volt} \rightarrow$ the electron gains kinetic energy of 100 eV

The rays



G.E. Goldstein
1886 "Kanalstrahlen"



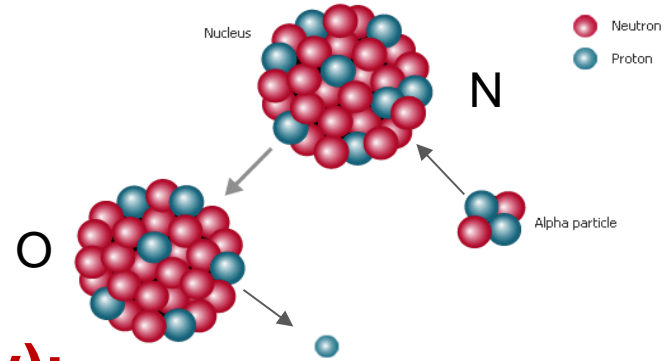
Röntgen's X-rays 1895



P. Lenard
Nobel prize 1905

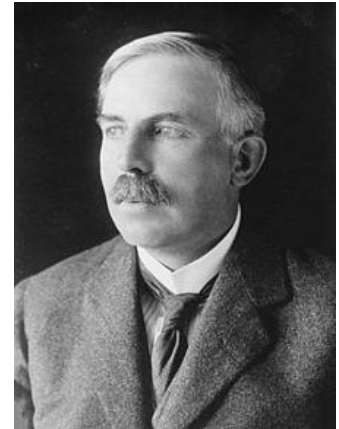
Splitting the atom....

- early experiments to probe matter used naturally occurring radioactive isotopes (a and b particles); Rutherford split atom in 1919.
- upper energy limit ~ 10 MeV for a particles is insufficient to penetrate repulsive electrostatic energy barrier of most nuclei



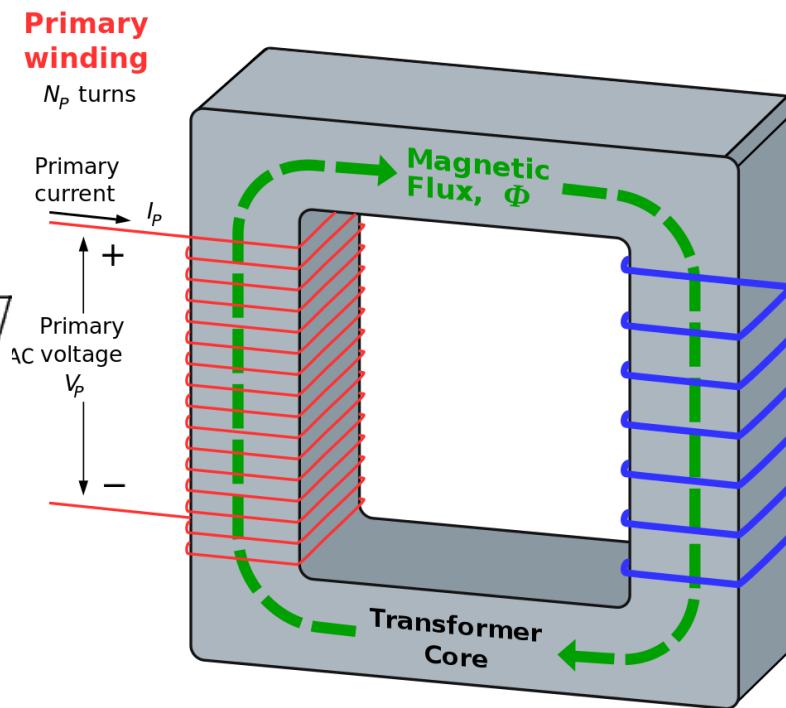
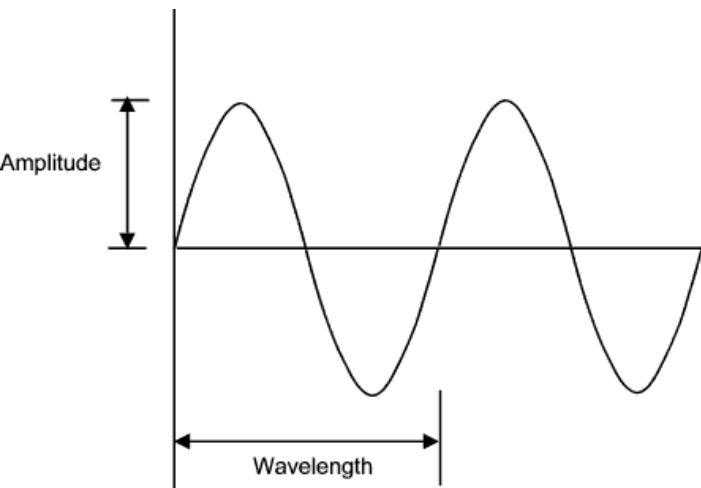
Lord Rutherford (1927 @ Royal Society):

“I have long hoped for a source of positive particles more energetic than those emitted from natural radioactive substances”.

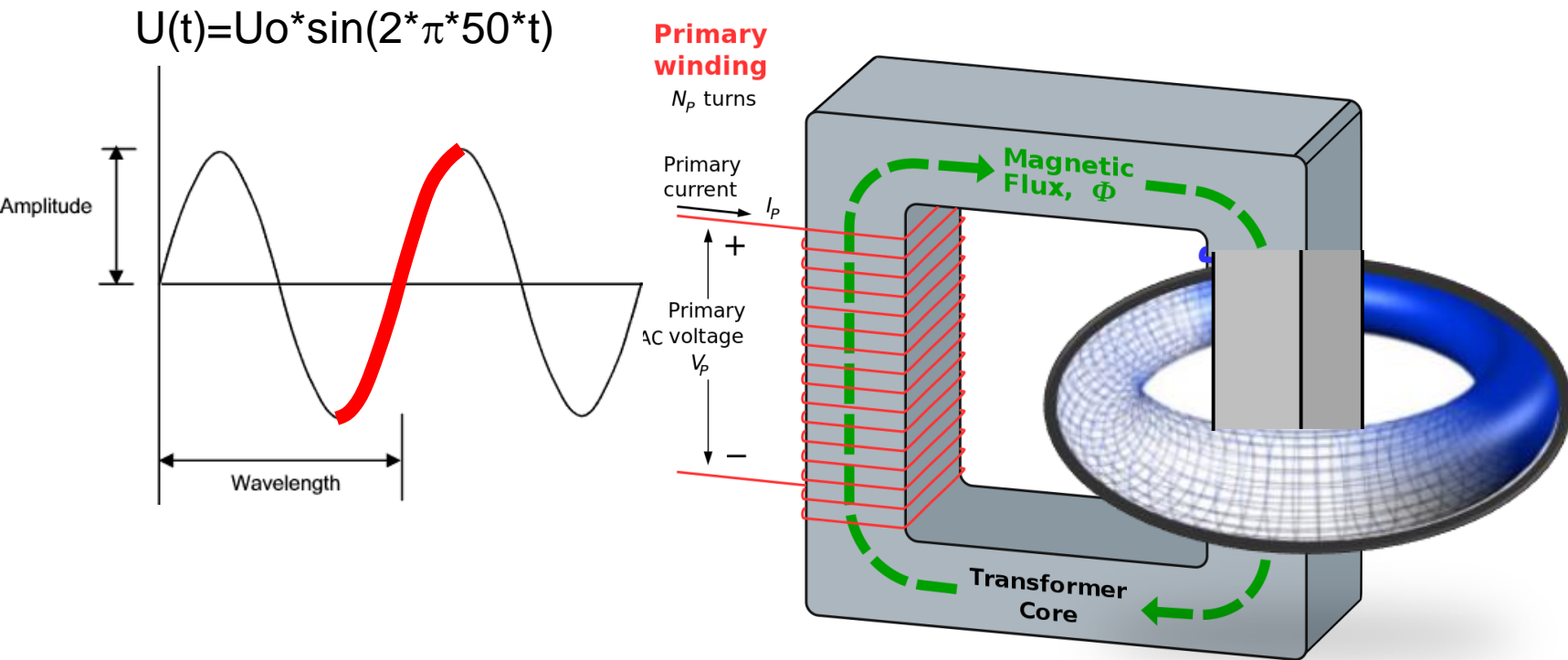


The Transformer - It's really simple!

$$U(t) = U_0 \sin(2\pi \cdot 50 \cdot t)$$

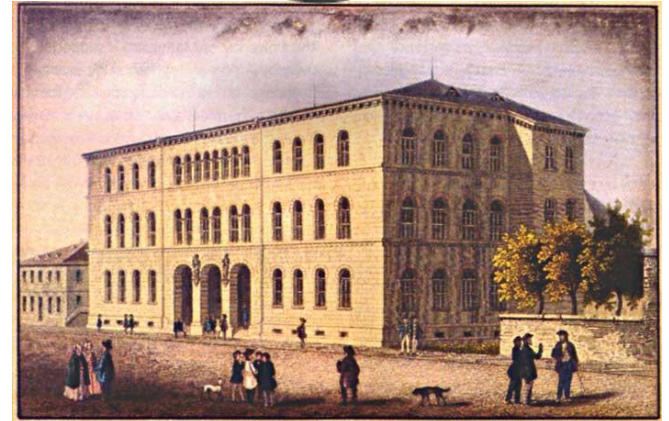
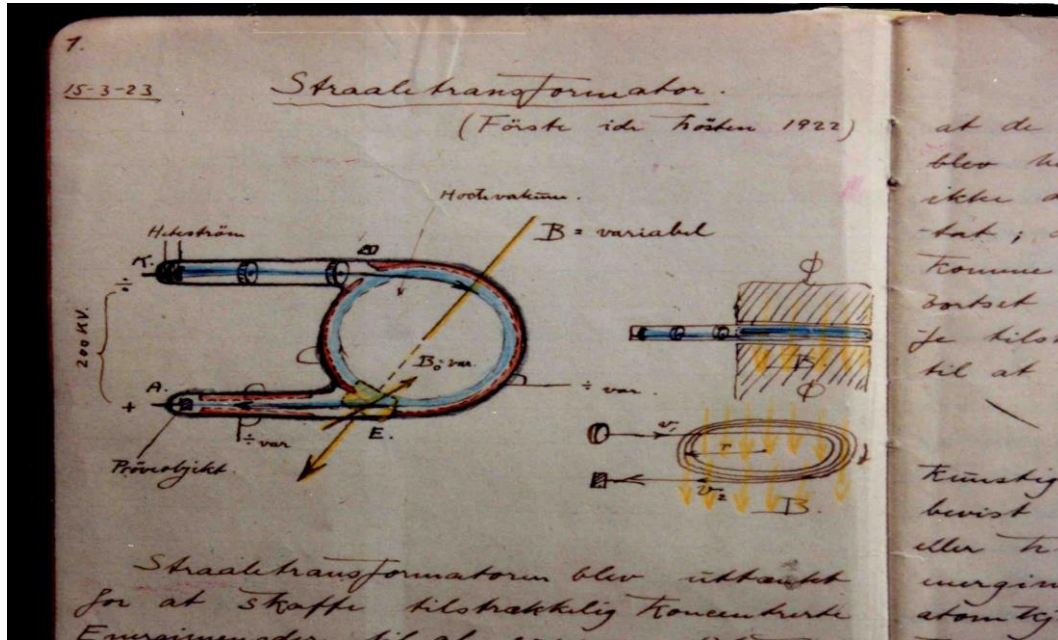


The Transformer - It's really simple!



Widerøe Notebook 1923

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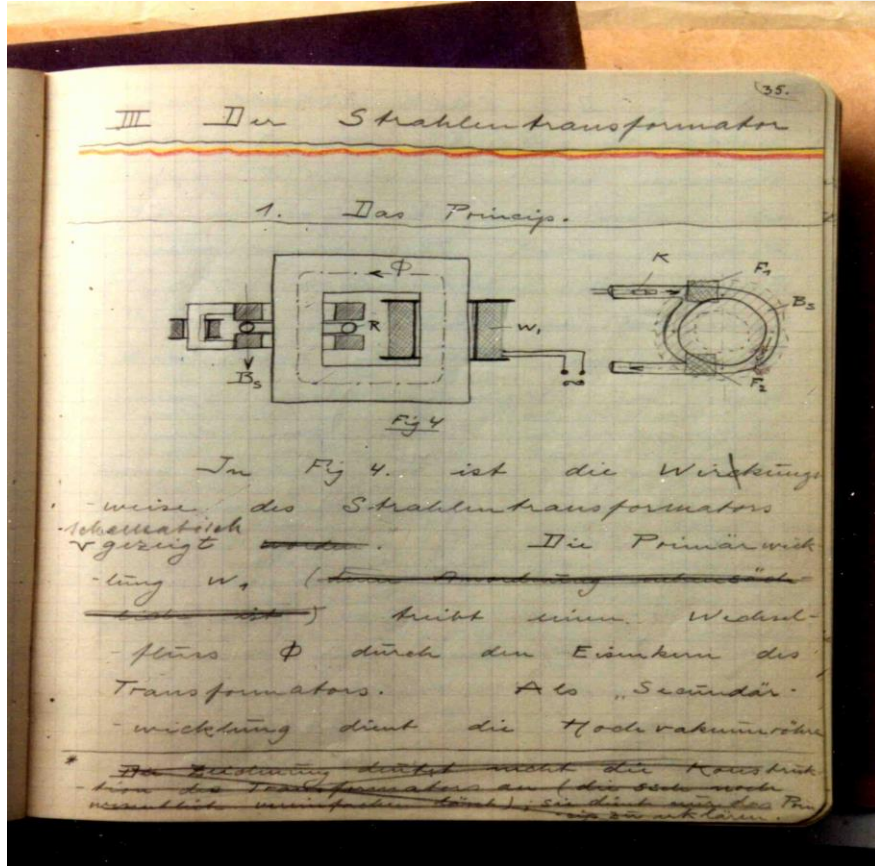


Fridericiana, founded in 1825

While Rolf Widerøe studied in Karlsruhe, he sketched this picture at the age of 20 and described the basic idea of the betatron

1925: First Widerøe thought it would not work ..

SLAC



...neither did Prof. Wolfgang Gaede

1925: Then Widerøe thought it did !

SLAC



As did Prof. Walter Rogowski



PhD Widerøe 1927 in Aachen: Widerøe's grand idea nr. 1

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The Widerøe equation

$$B(r = R) = \frac{1}{2} \cdot \bar{B}$$

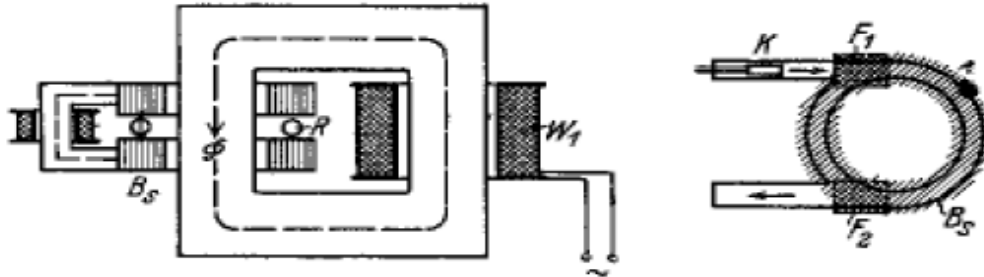


Bild 11. Wirkungsweise des Strahlentransformators.

Die Beschleunigung in Wirbelfeldern würde sehr hohe Spannungen erzeugen können. Das Verfahren scheitert daran, daß die Möglichkeiten fehlen, die Elektronen auf einer Kreisbahn zu binden. Die Lösung dieser Frage scheint zur Zeit große Schwierigkeiten zu bereiten.

Über ein neues Prinzip zur Herstellung hoher Spannungen

Von der Fakultät für Maschinenwirtschaft der Technischen Hochschule zu Aachen

zur Erlangung der Würde eines Doktor-Ingenieurs

genehmigte

Dissertation

vorgelegt von

Rolf Widerøe, Oslo

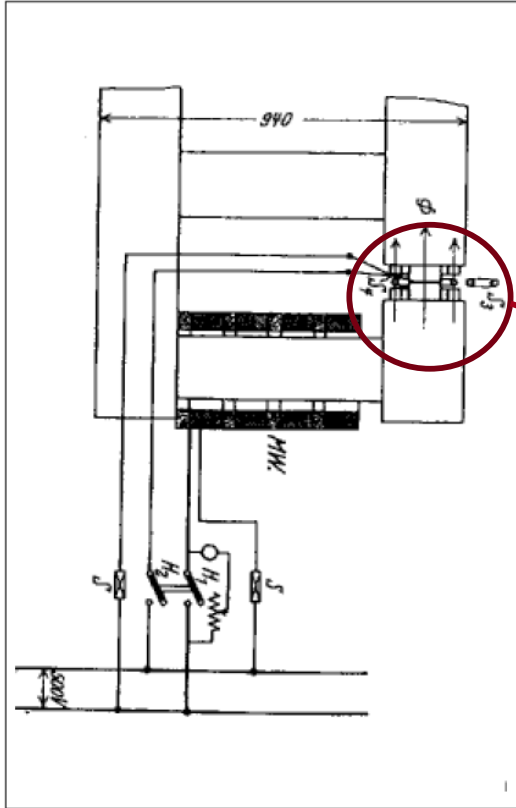
Referent: Professor Dr.-Ing. W. Rogowski

Korreferent: Professor Dr. L. Finzi

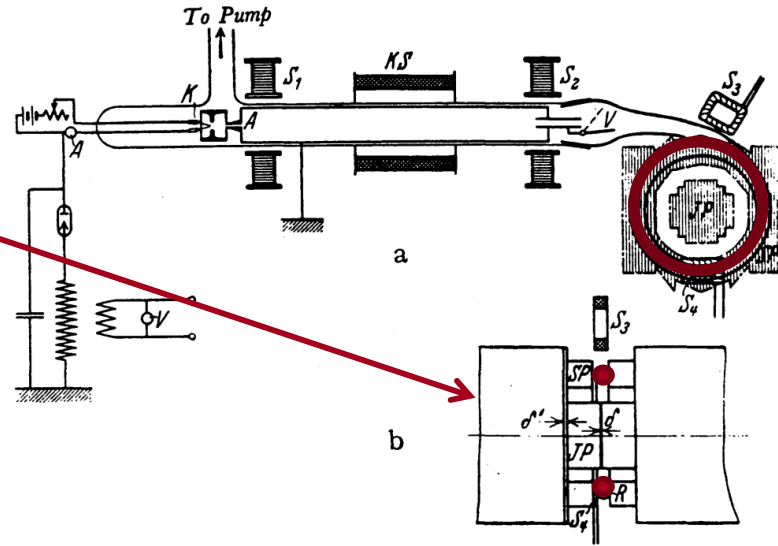
Tag der mündlichen Prüfung: 28. November 1927

Sonderdruck aus Archiv für Elektrotechnik 1928, Bd. XXI, Heft 4
(Verlag von Julius Springer, Berlin W 9)

From idea to reality: Widerøe's Thesis

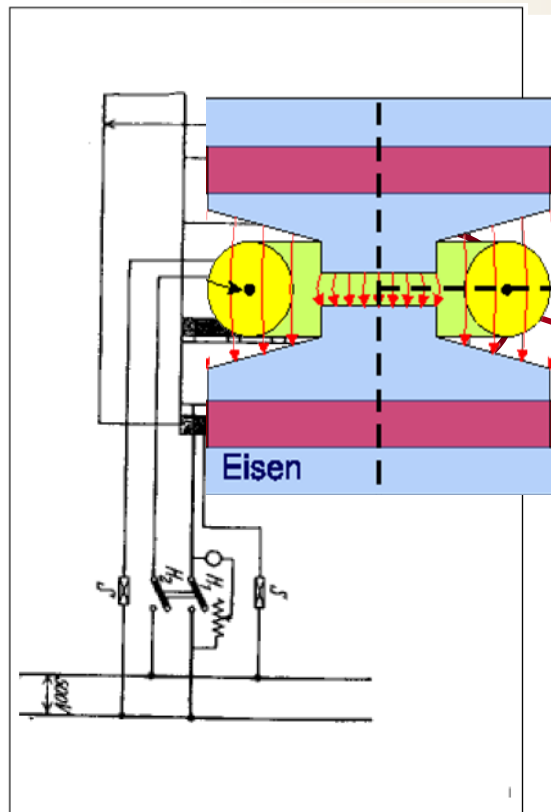


The transformer

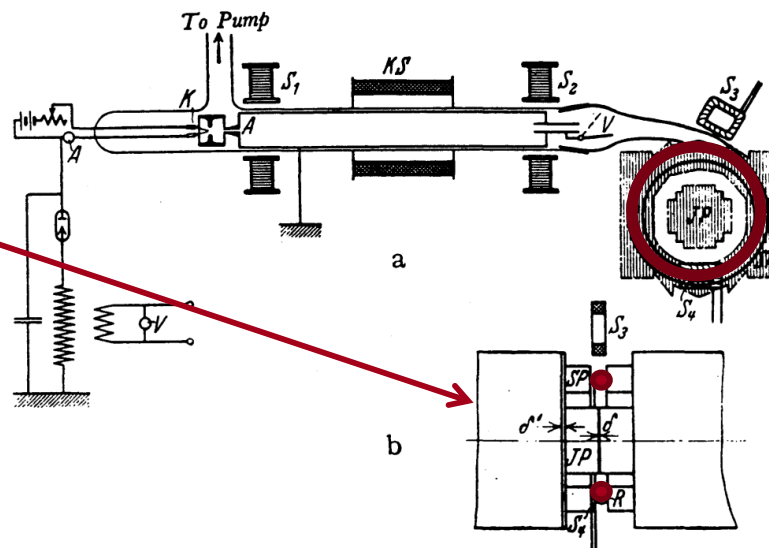


The glass vacuum chamber

From idea to reality: Widerøe's Thesis



The transformer

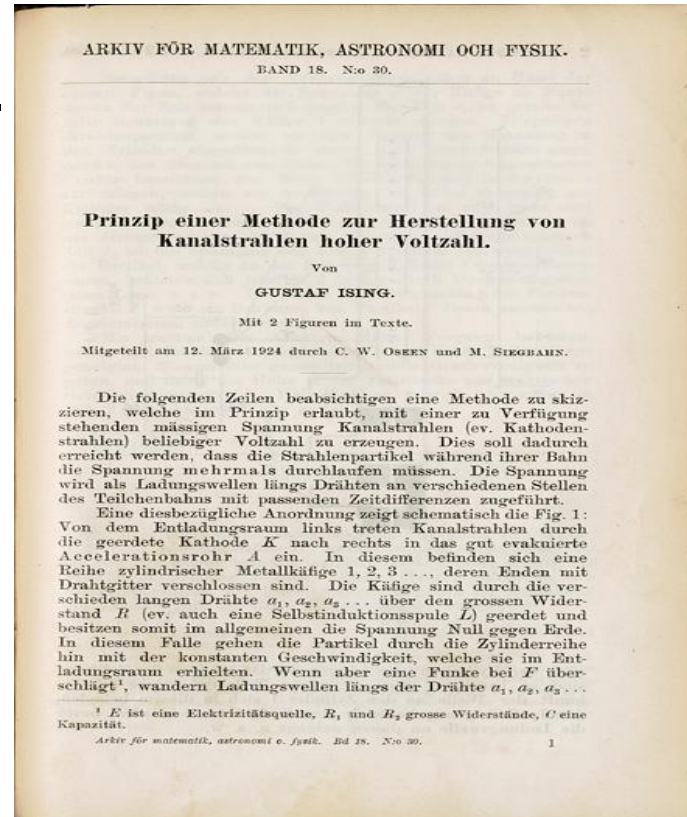
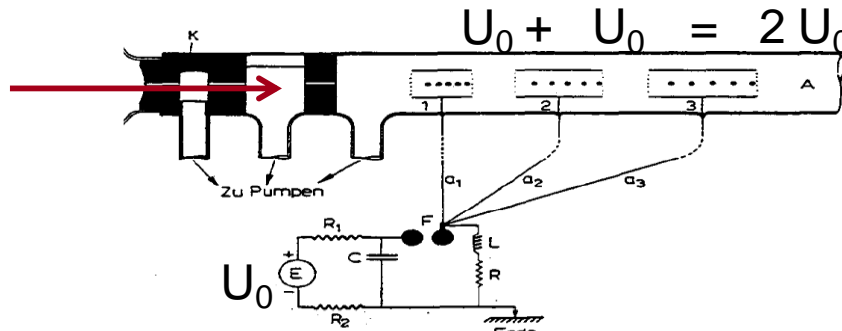


The glass vacuum chamber

Did not work ! – Was Gaede right?

The Idea of Linear Acceleration...

1924: **Gustav Ising** (*19 February 1883 in Finja, Sweden, † 5 February 1960 in Danderyd, Sweden), Prof. at the Technical University Stockholm:
“..multiple acceleration of an ion with a given high voltage: $U_{\text{tot}} \gg U_0$



The RF Linear Accelerator

SLAC

...but it was only plan B for R. Widerøe, and remained that way for his life

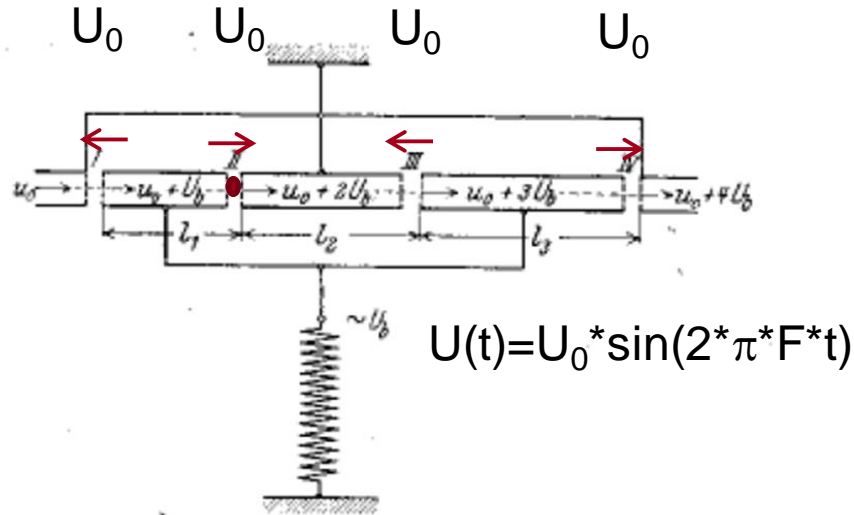
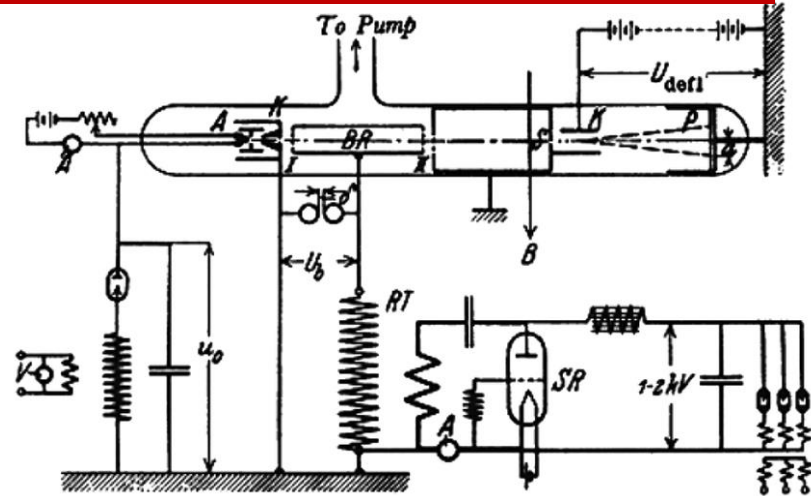


Bild 1. Prinzip der Spannungstransformation mit Potentialfeldern.

How to apply the same voltage several times so it becomes additive → use oscillating voltage



2 x 25 kV with two gaps and accelerated Na and Ka ions. BUT: gap to gap spacing is $\frac{v_{ion}}{2 \cdot F_{rf}}$

“My little machine was a primitive precursor of this type of accelerator which today is called a ‘linac’ for short. However, I must now emphasize one important detail. The drift tube was the first accelerating system which had earthed potential on both sides, i.e. at both the particles’ entry and exit, and was still able to accelerate the particles exactly as if a strong electric field was present.” – Rolf Widerøe

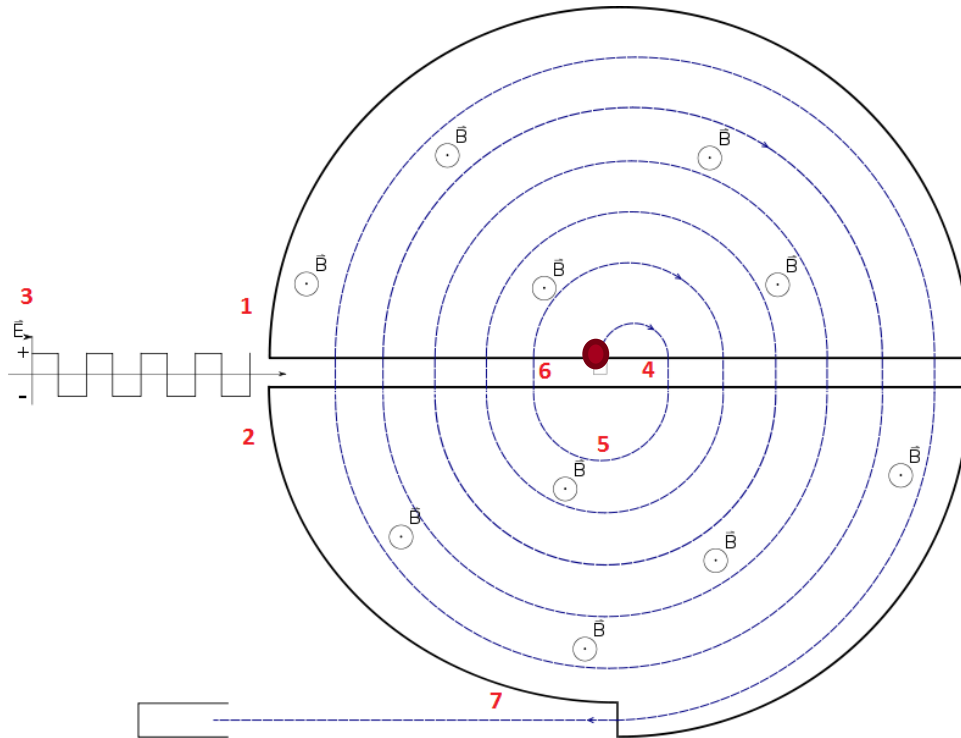


Rolf Widerøe in front of one of the linac models in the Röntgen-Museum in Remscheid, photograph by Ragnhild Widerøe. From: “The Infancy of Particle Accelerators”, P. Waloschek

The rest is history...



The cyclotron:



Ernest Lawrence
Nobel Prize 1939

The cyclotron:



1929: the first cyclotron



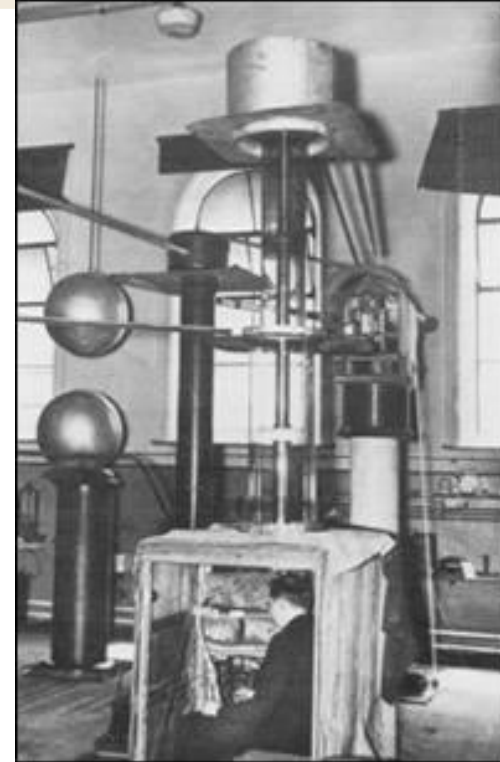
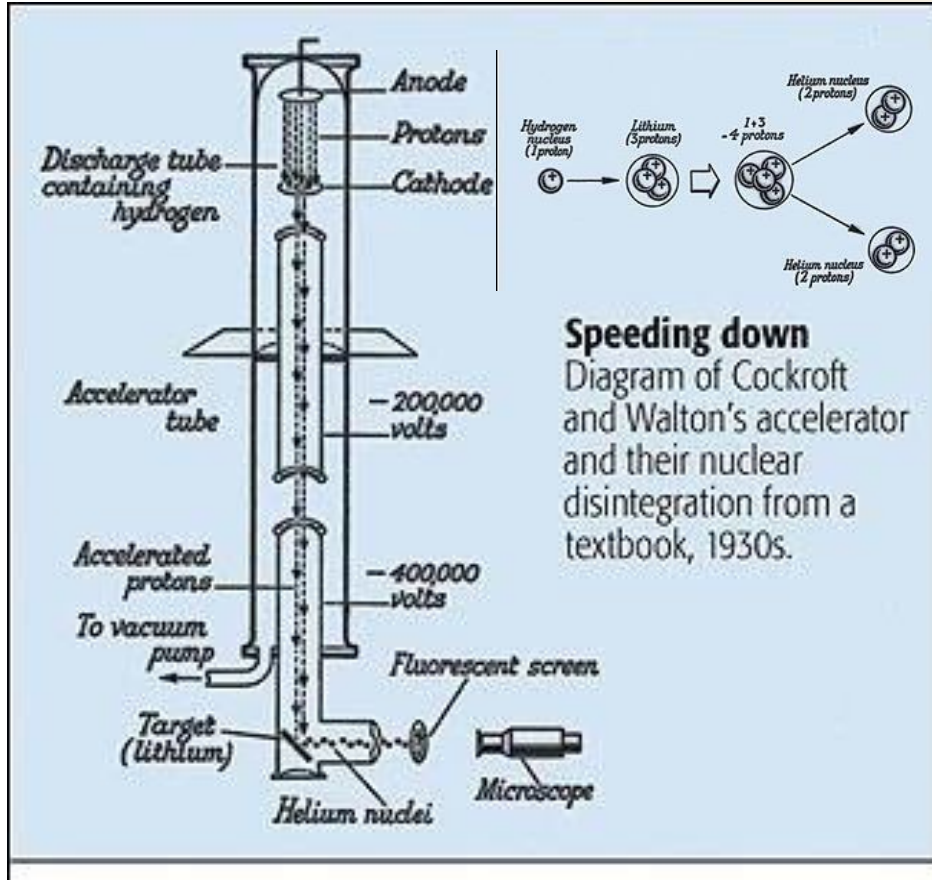
Ernest Lawrence
Nobel Prize 1939

The time in Berlin - the roaring twenties come to an end

- He met:
 - Leo Szilard (“the Hungarian Gentlemen”), Einstein and many others
- He followed the development of accelerators but had written off the Betatron
- 1932: Cockcroft & Walton: First disintegration of a nucleus using electrostatic accelerators
- Xmas 1932: RW returns to Oslo

After receiving his PhD in Aachen Rolf Widerøe (No. 3 from the right) in 1927, he worked at AEG in Berlin and submitted 10 patents.

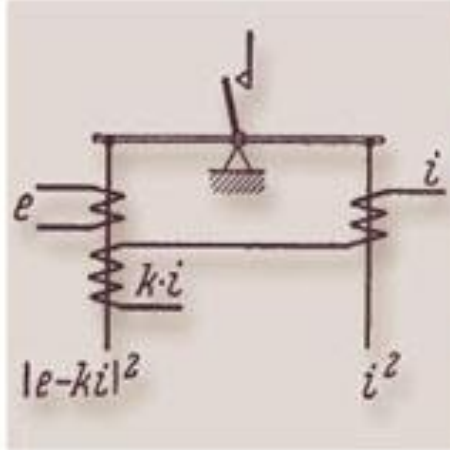
Cockcraft – Walton @ Cavendish Labs: 1932



Walton and the machine used to "split the atom"

“Relays are fun too”

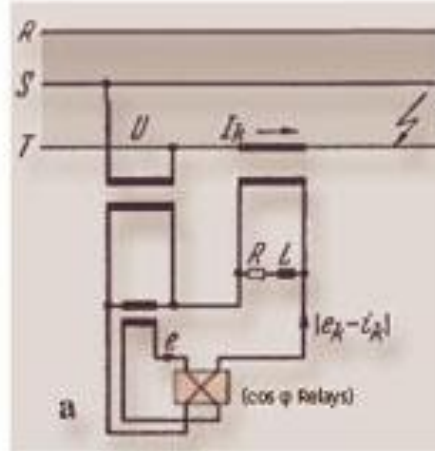
14 Westinghouse & GEC
(Balanced beam relays with shifted circle)



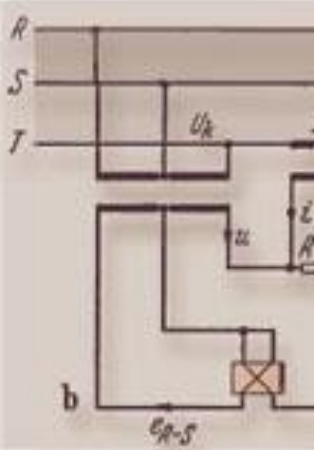
15 Wideroe - Relay, NJEV, 1933



17 Kuusinen's proposal



18 BBC's rotational field relay



1932 +, Rolf Widerøe worked in Oslo on the development of protection relays for the power industry.

The mid '30ies



© From the movie: "Always Brothers"

After finishing the education as a Navy pilot, Viggo starts his own airline. The first one in Norway and still flying today.



The brothers Viggo and Arild in 1934

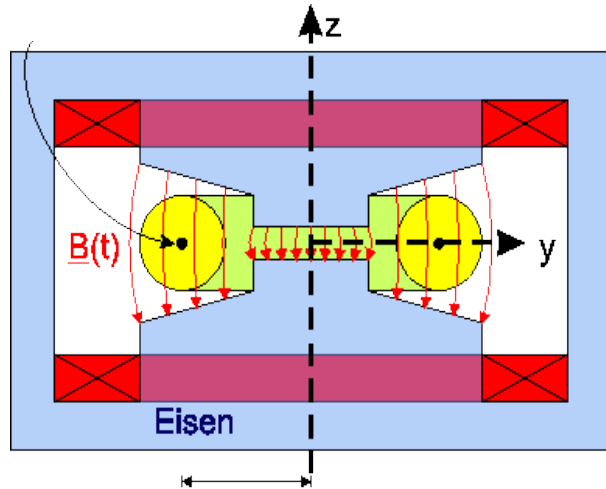


Rolf Widerøe married Ragnhild Christiansen in 1934

The Ray Transformer: The race to build a functioning betatron

$$\text{Orbit stability: } B_z(y) = \frac{B_0}{\left(\frac{R+\Delta y}{R}\right)^n}$$

“Weak Focusing”



Steenbeck, 1937
Kerst / Serber 1941



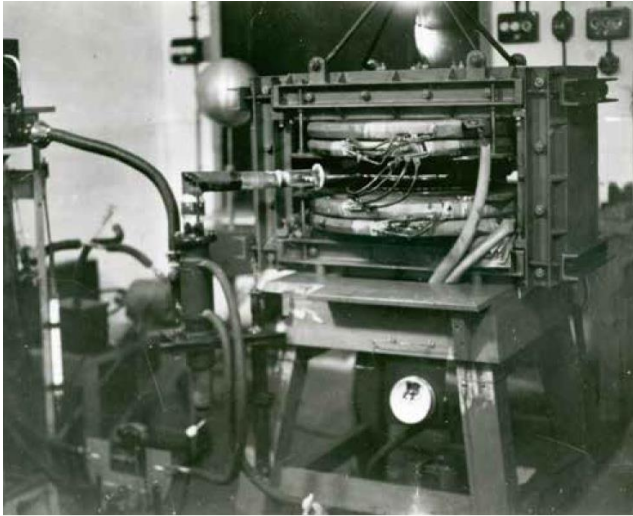
Kerst / Serber 07/15/1940 Univ. of Illinois and GA with 2.3 MeV beam

At the end of the thirties....



From the movie: “Always Brothers”, based on the book by A. Sørheim

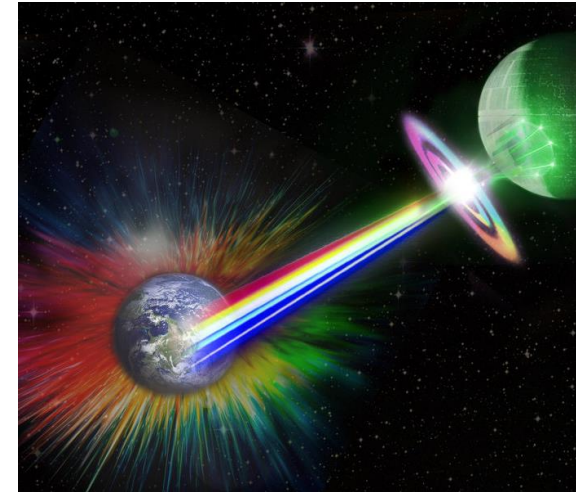
The race to build a functioning betatron



During his stay in Germany '43-'45, Rolf Widerøe build his first betatron, a 15 MeV machine, which the Allies later on confiscated and brought to Britain after it was operated between May '45 and Nov '45 in .



First German betatron, 1942 by Gund, SIEMENS-Erlangen based Steenbecks patent 1934 and research @ SIEMENS Schuckert in Berlin



The German “Wunderwaffe” – “Todesstrahlen”

Different then in the US, a large part of motivating the funding was to develop a weapon and it was driven by the “Reichs-luftwaffenministerium-RLM”

What did just happen?



Grini prison was used by the Wehrmacht.. After the war it was renamed Ilebu. 3440 people, collaborators or seen as such, were imprisoned here by July 1945, as was Rolf Wideroe.

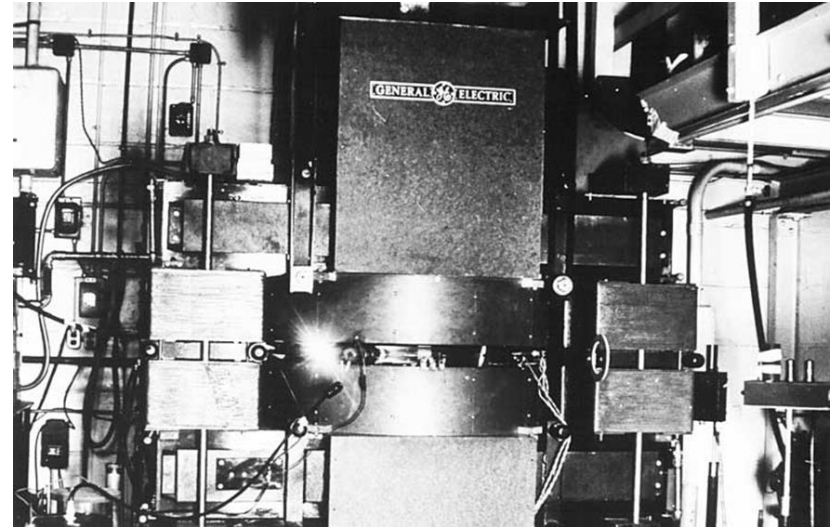


G. Randers

Prof.'s E. Hylleraas, H. Wergeland, G. Randers, R. Tangen are members of the expert commission and clear R. Widerøe from the accusation of building weapon systems for Nazi Germany.... But that's not good enough!

Synchrotrons

This 70 MeV electron synchrotron at the General Electric Co. at Schenectady, built in 1947s. The photograph shows a beam of synchrotron radiation emerging. Luckily, because nobody thought much about shielding.



F. Elder, A. Gurewitsch, R. Langmuir and H. Pollock et.al.

Betatrons for Hospitals: Radiation Therapy



Work on the first hospital betatron, a 31 MeV betatron for the hospital In Zurich which was in use for 5 years until 1950.

On the left: D. Gamper.
More than 70 betatrons were build by ABB worldwide

(Photo: Archives ABB)

Colliders:

Rolf Widerøe consulting for CERN, DESY, SIN etc

SLAC



Brookhaven National Lab

In 1952, a group from Europe visited Brookhaven National Laboratory in preparation for the establishment of CERN. From the left: Frank Goward, Odd Dahl, Rolf Widerøe and Ernest Courant.

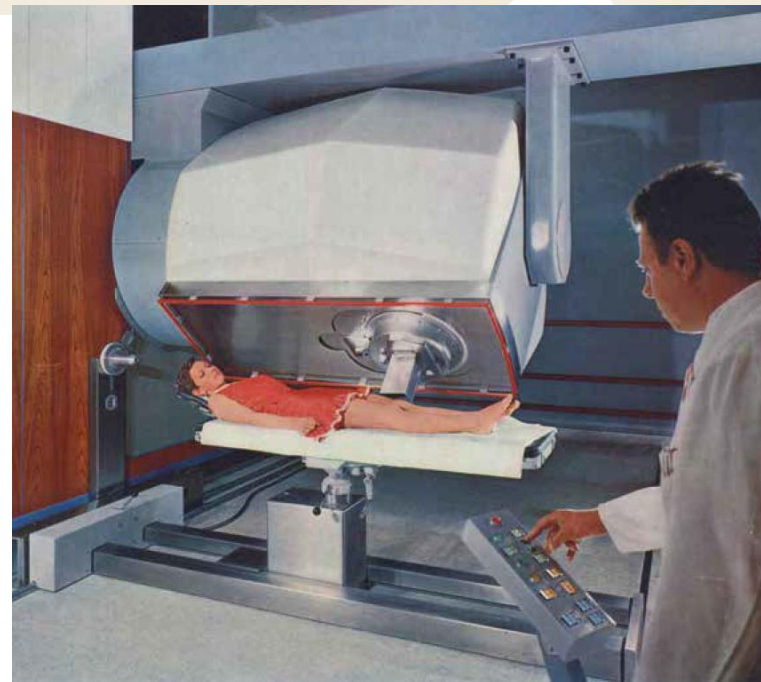
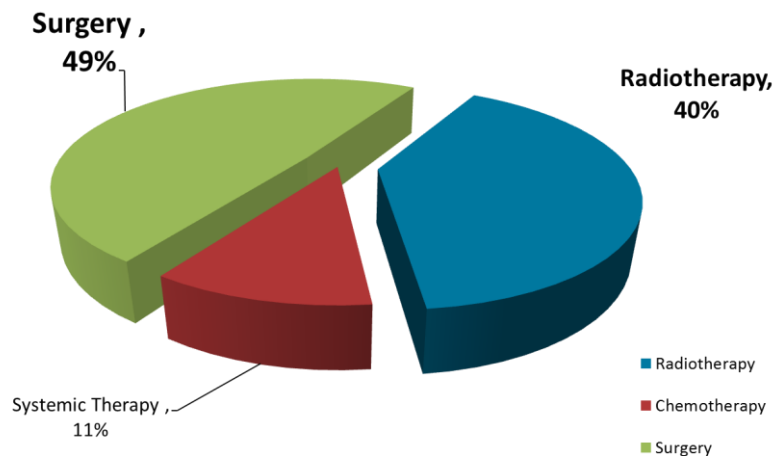
Niels Bohr and Rolf Widerøe participated in an international radiology congress in Copenhagen in 1953.

- **Lecturer at ETH**
- **Rolf Widerøe receives doctoral degrees from three Universities:**
 - **The ETH in Zurich where he taught**
 - **The RWTH Aachen where he mastered his PHD**
 - **The Faculty of Medicine at the University of Zurich**
- **Roentgen Medal**
- **Member Norwegian Acad. of Science**
- **Robert R. Wilson Prize from the APS**

Impact and Recognition

Two Component Theory: The “ α/β model”

- The Bender-Gooch-Widerøe formula, which defines the combined effect of direct irradiation with α (He) and β (e) particles.
- R. Widerøe worked on direct electron irradiation of tumors from '62-'66 with Prof. Schuhmacher from Virchow Hospital in Berlin



In the 1960s and 70s, Rolf Widerøe developed betatrons that could be moved around patient. This is a 45 MeV machine. (Photo: Archives ABB)

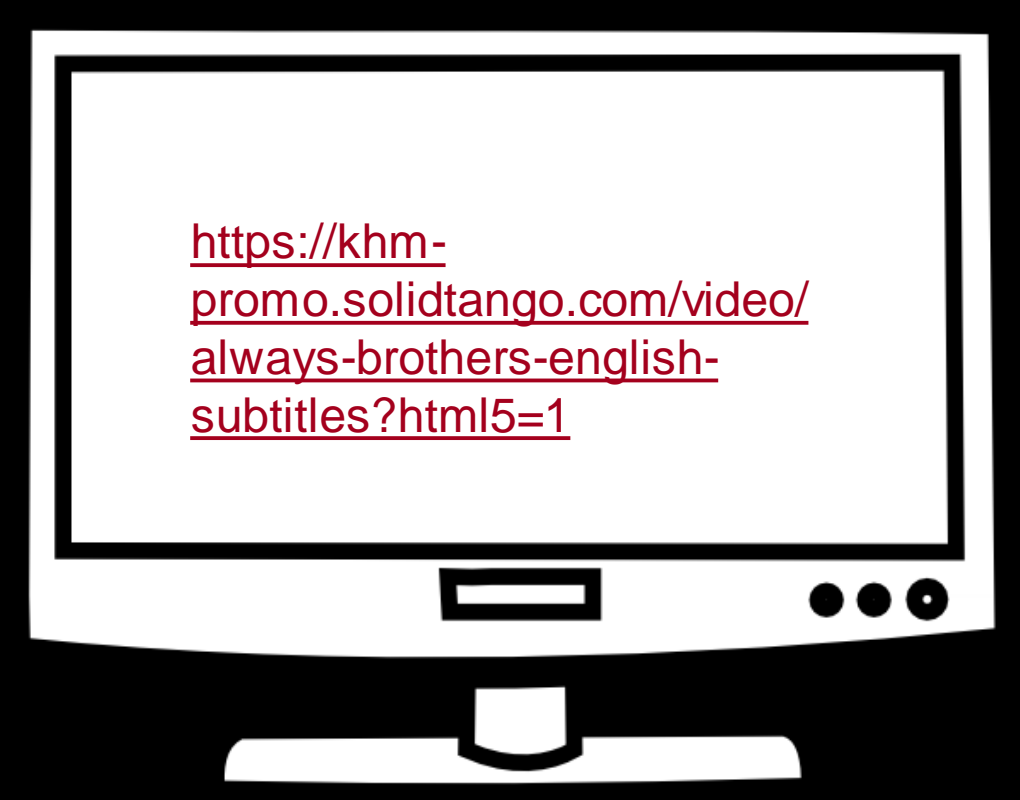
Two Heroes



At age 91, Rolf Widerøe returned to DESY, a consultant since the early '60s, with Professor Gustav-Adolf Voss to the right. (Photo: Pedro Waloschek)

The Movie





[https://khm-
promo.solidtango.com/video/
always-brothers-english-
subtitles?html5=1](https://khm-promo.solidtango.com/video/always-brothers-english-subtitles?html5=1)

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