ACCELERATOR PHYSICS

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Links

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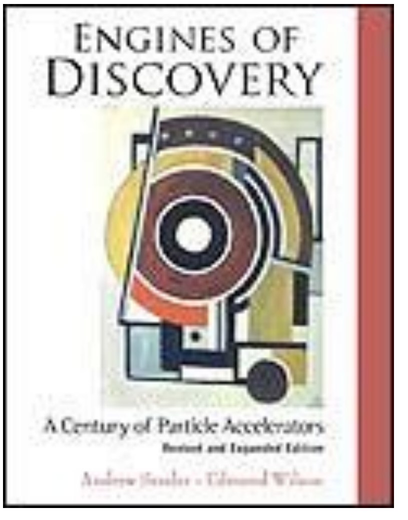
General Book on Accelerators



“Engines of Discovery”:

http://www.worldscientific.com/worldscibooks/10.1142/8552

Text book for this course:

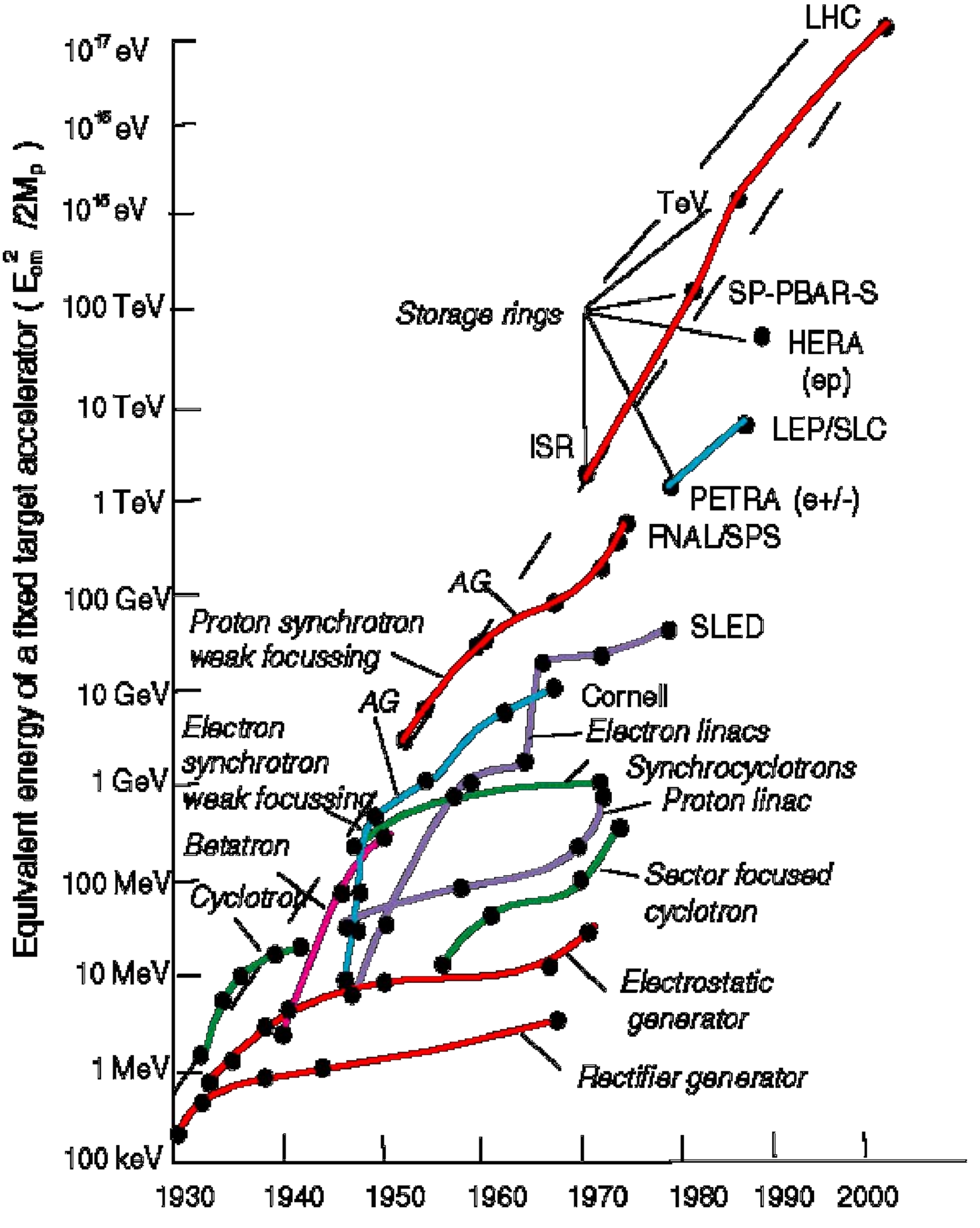
“Particle Accelerators”

http://www.oup.com/uk/catalogue/?ci=9780198508298

Summary Lecture 1 - Overview of Accelerators I

- The history of accelerators
- Need for Accelerators
- The race to high energies
- Cockcroft and Walton - Electrostatic
- Van der Graaf
- Linear accelerator
- Wideroe's Linac
- Fermilab linac (400MeV)
- Inside the Fermilab linac
- The Stanford Linear Accelerator
- The International Linear Collider (ILC)
- Cyclotrons –an inspired discovery
- Magnetic Rigidity
- Vertical Focusing
- Discovery of the Synchrotron
- Components of a synchrotron
- Phase stability
- Cosmotron
- Weak focusing in a synchrotron

The history of accelerators



Need for Accelerators

Why do we need accelerators? (2)

Resolution of "Matter" Microscopes:

Wavelength of Particles (Photon, Electron, Proton, ...): (de Broglie, 1923)

$$\lambda = h / p \qquad (= 1.2 \text{ fm} / p \ [\text{GeV/c}])$$

The higher the momentum, the shorter the wavelength, the better the resolution

Energy to Matter:

Einstein (1905):

$$E = mc^2 = \frac{m_o c^2}{\sqrt{1 - \frac{v^2}{c^2}}} = \gamma m_o c^2$$

Higher energy means we can produce more massive particles

When particles **approach** the speed of light, they get **more massive, but not faster**

3

The race to high energies

- **Rutherford fired the starting pistol**

  At the Royal Society in 1928 he said

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

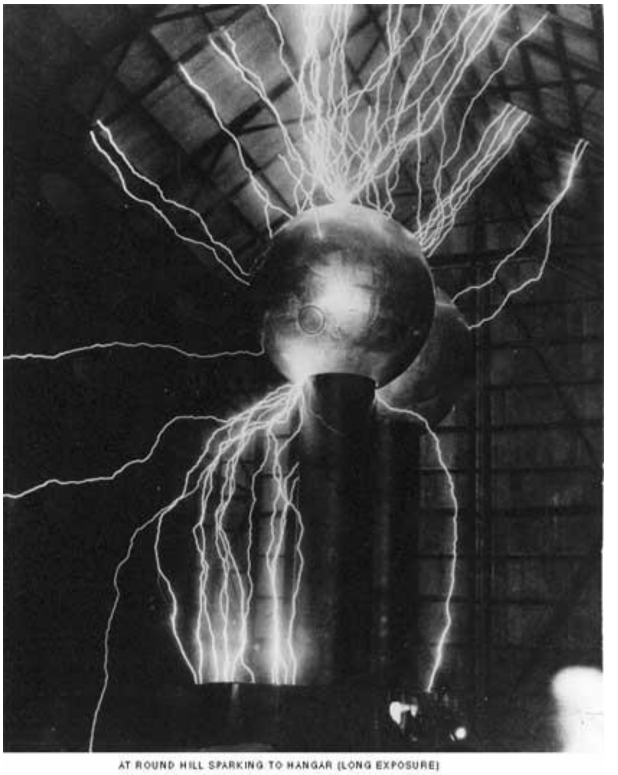
Cockcroft and Walton - Electrostatic

Walton and the machine used to "split the atom"

J.A.I.

Van der Graaf

THE GENERATOR IN THE HANGAR AT ROUND HILL

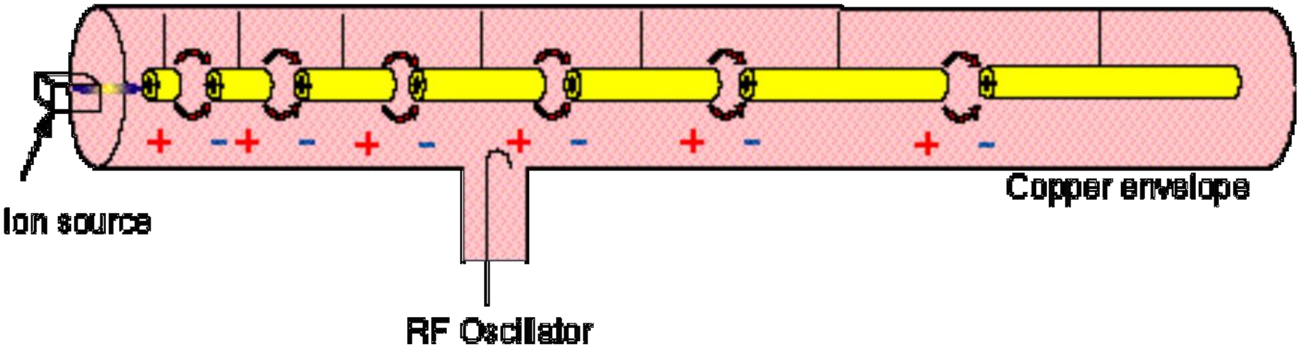


AT ROUND HILL SPARKING TO HANGAR (LONG EXPOSURE)

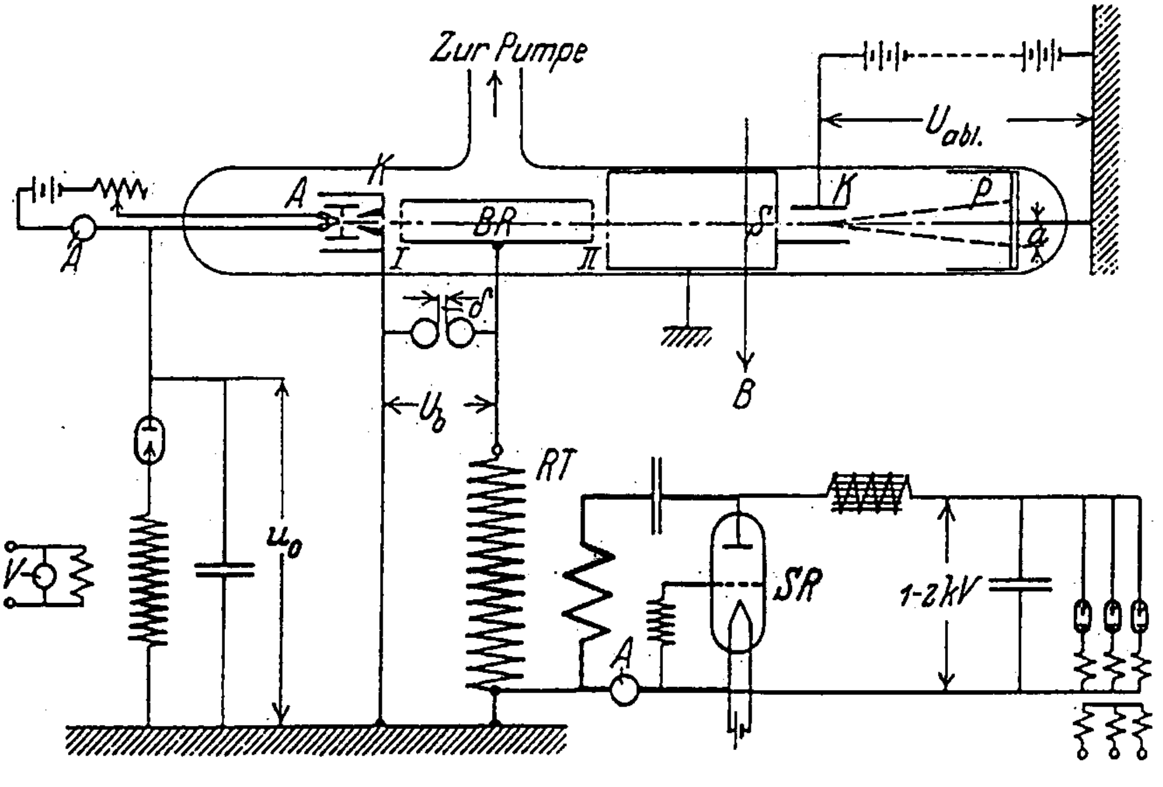
Van de Graaff was a Rhodes Scholar at Oxford when he first thought about electrostatic machines. This is very large accelerator built at MIT's Round Hill Experiment Station in the early 1930s.

Under normal operation, because the electrodes were very smooth and almost perfect spheres, Van de Graaff generators did not normally spark. However, the installation at Round Hill was in an open-air hanger, frequented by pigeons, and here we see the effect of pigeon droppings.

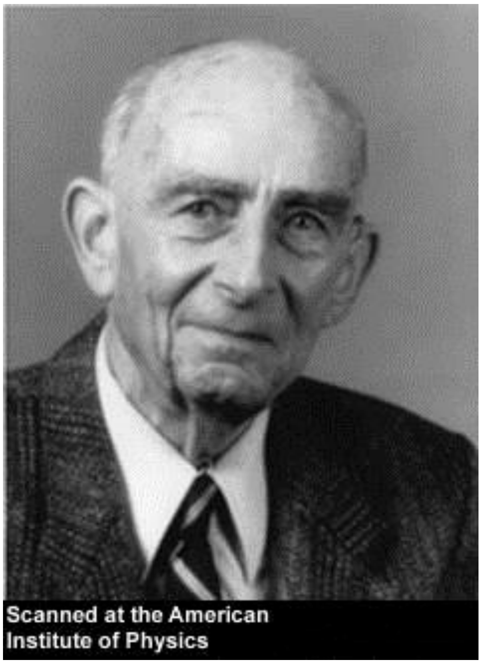
Linear accelerator

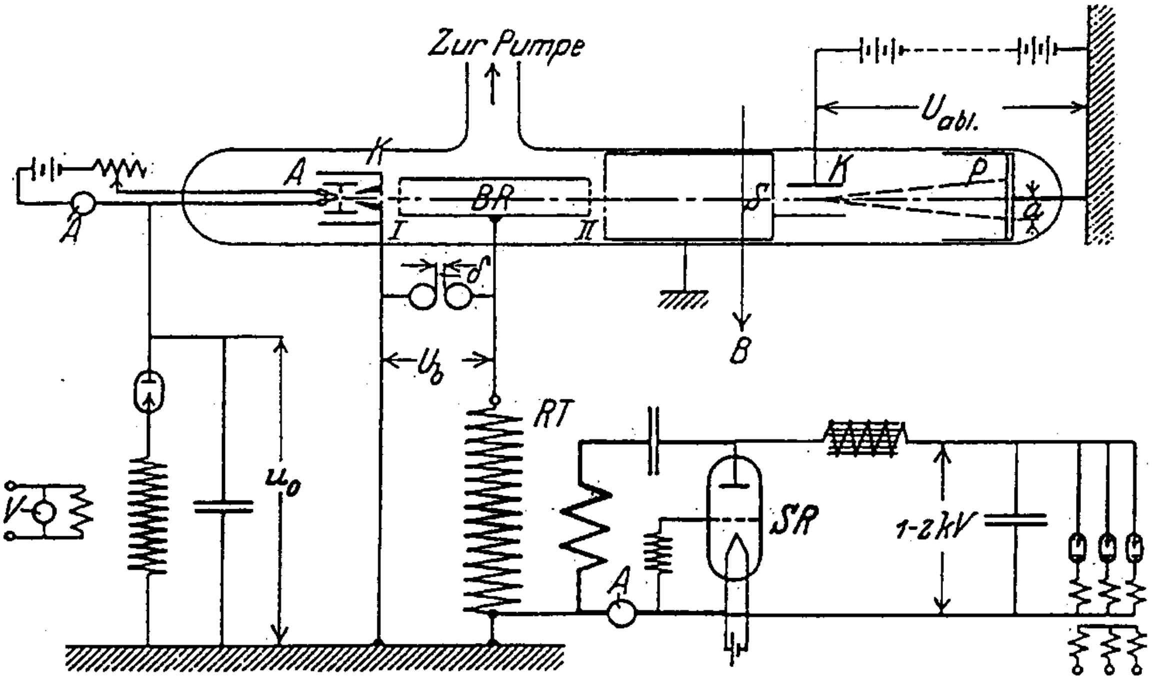


- Particle gains energy at each gap
- Lengths of drift tubes follow increasing velocity
- Spacing becomes regular as v approaches c
- Wideroe's first linac:



Wideroe's Linac

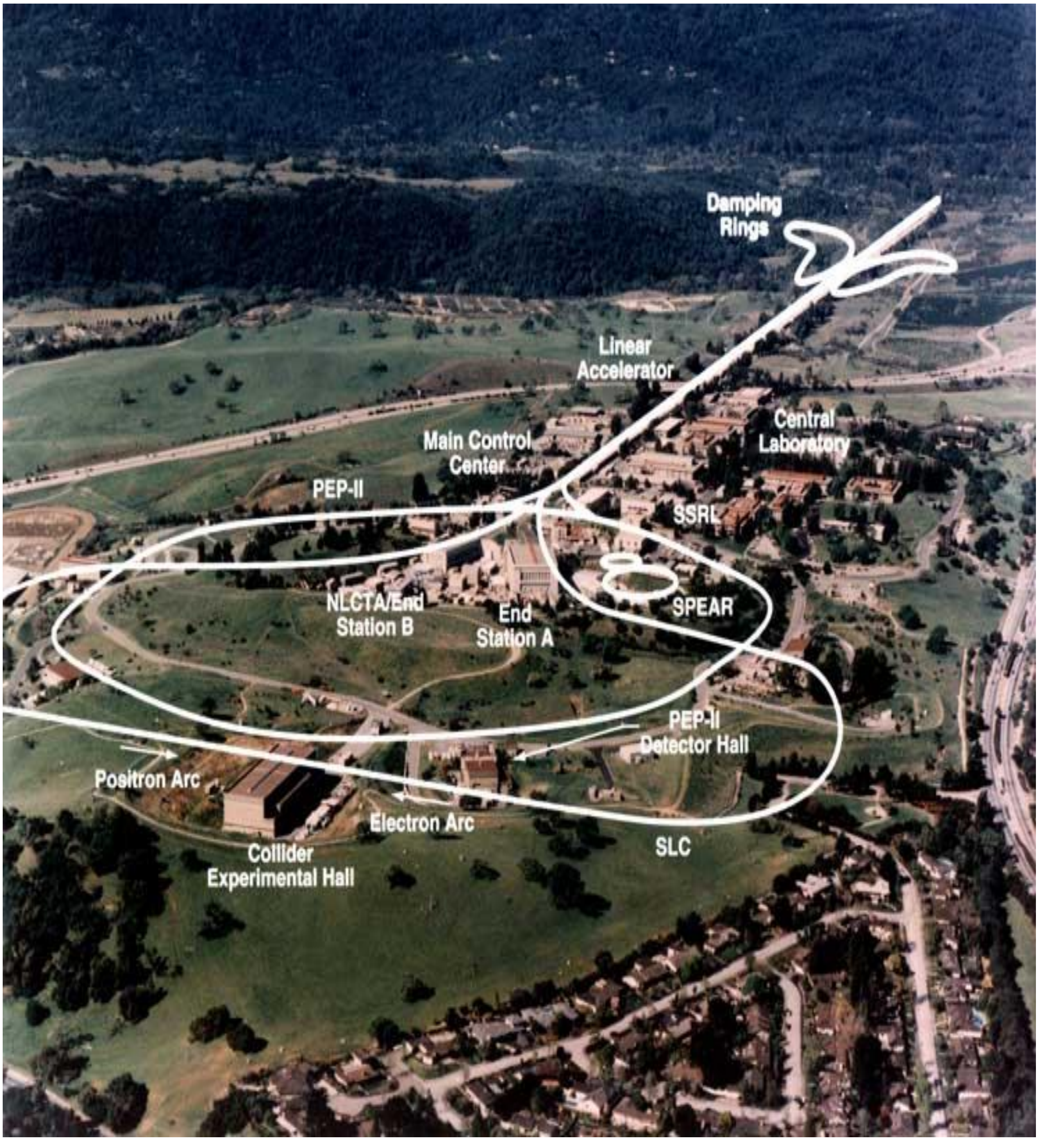




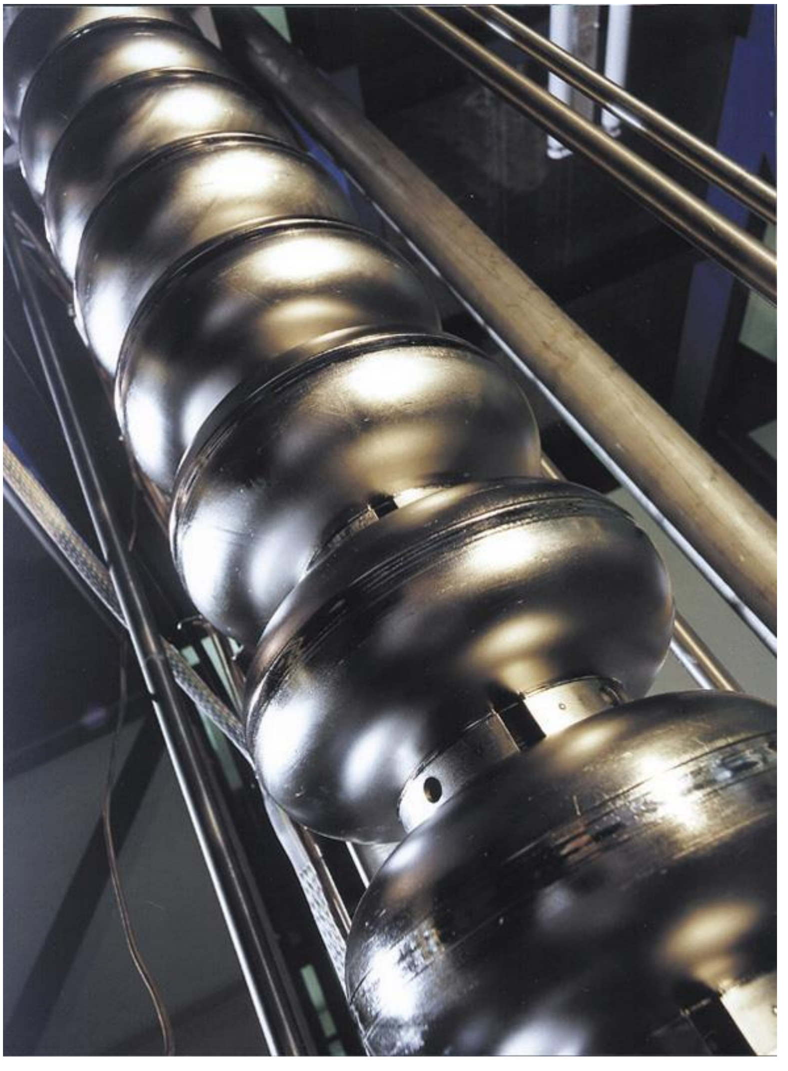
Fermilab linac (400MeV)

Inside the Fermilab linac

The Stanford Linear Accelerator

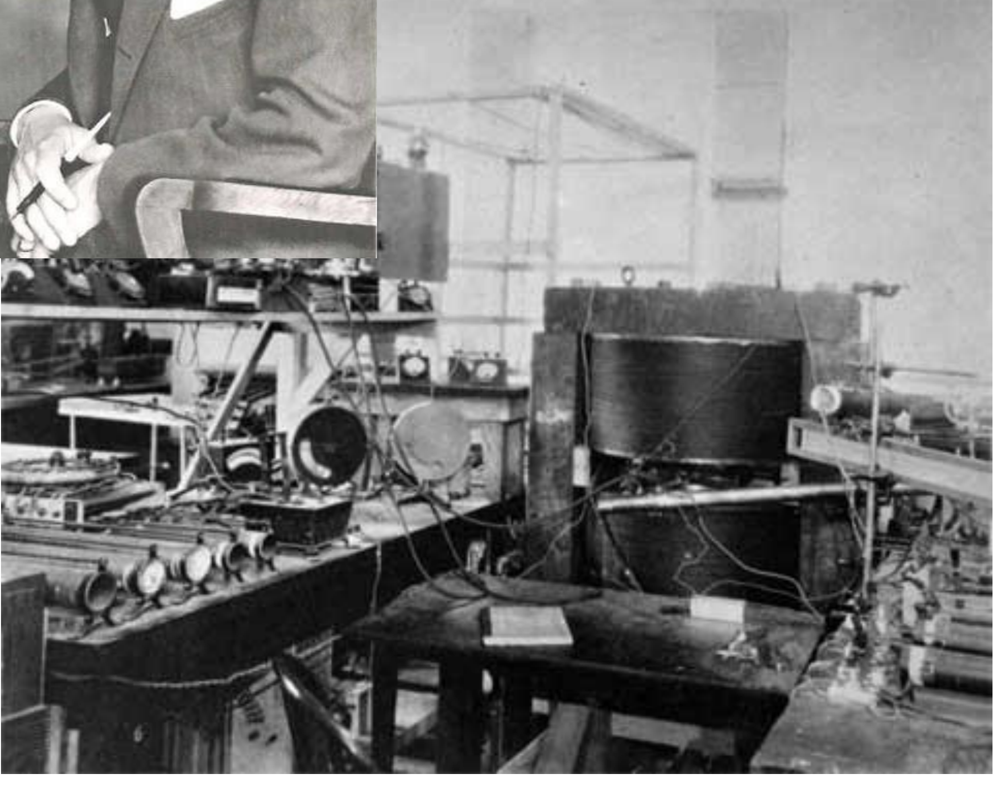


The International Linear Collider (ILC)



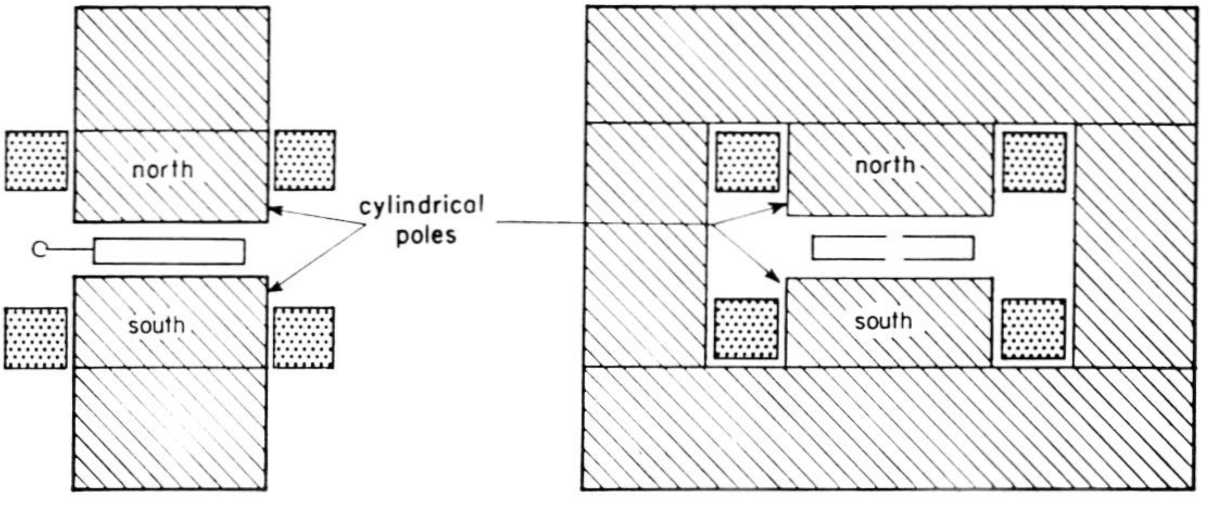
TESLA technology: these superconducting accelerator structures are built of niobium, and are the crucial components of the International Linear Collider.

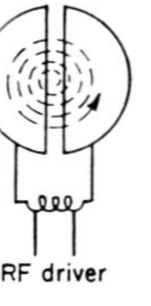
Cyclotrons –an inspired discovery

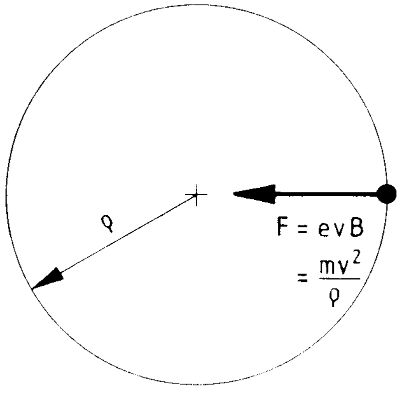


A picture of the 11-inch cyclotron built by Lawrence and his graduate students, David Sloan and M. Stanley Livingston, during 1931.

Cyclotron







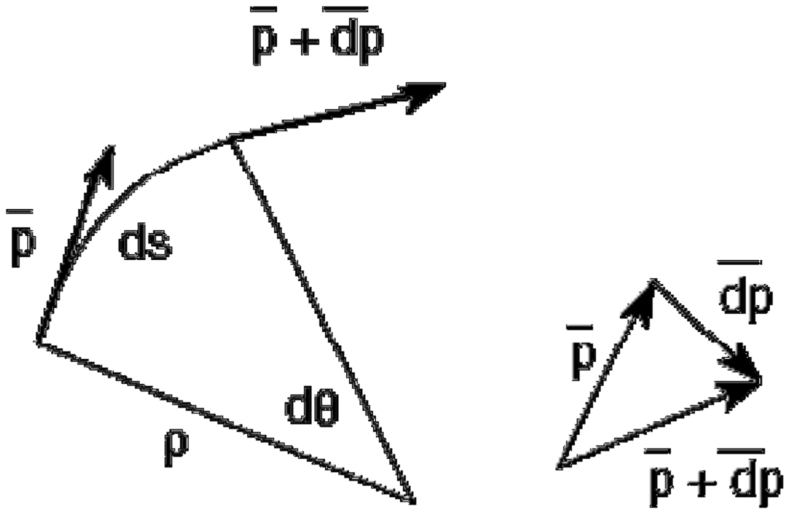
Magnetic rigidity

$$B\rho = \frac{mv}{e} = \frac{p}{e}$$

Constant revolution frequency

$$f_{rev} = \frac{v}{2\pi\rho} = \frac{v}{2\pi}\frac{eB}{mv} = \frac{eB}{2\pi m}$$

Magnetic Rigidity



$$e \ \mathbf{v} \times \mathbf{B} = \frac{d\mathbf{p}}{dt}$$

- from resolution of momenta that:

$$\frac{d\mathbf{p}}{dt} = |\mathrm{p}|\frac{d\theta}{dt} = \frac{|\mathrm{p}|}{\rho}\frac{ds}{dt}$$

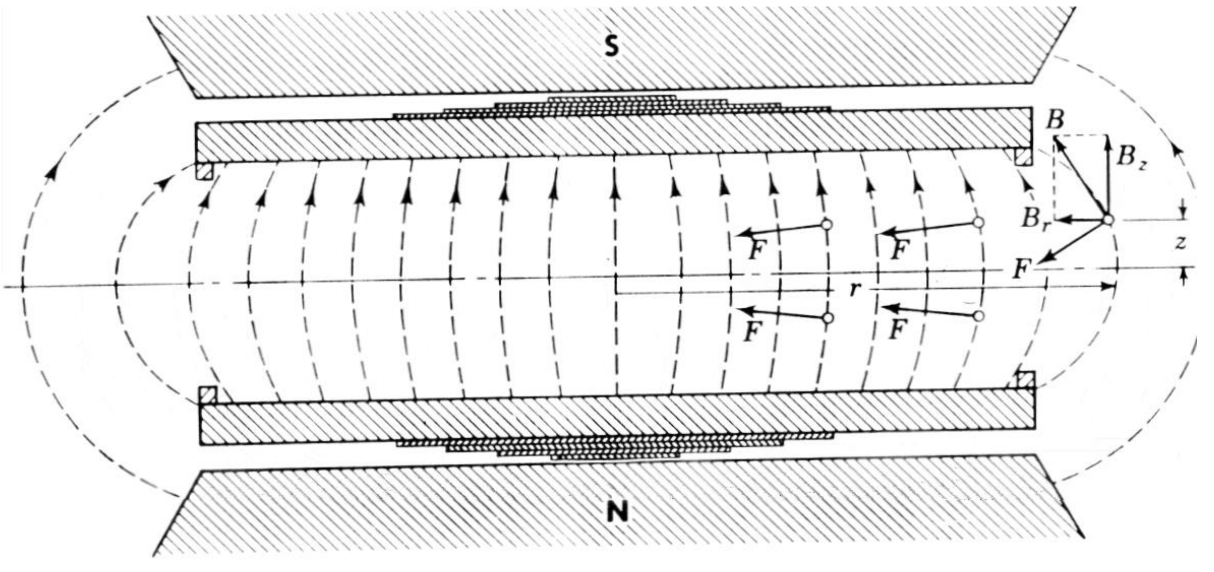
- the magnitude of the force may be written:

$$e|\mathbf{v} \times \mathbf{B}| = e|\mathrm{B}|\frac{ds}{dt}$$

- Equating the right hand sides of the two expressions above, we find we can define a quantity known as magnetic rigidity:
- A common convention in charged particle dynamics is to quote pc in units of electron–volts. Whereupon:

$$(B\rho)[T.m] = \frac{pc[eV]}{c\left[m.s^{-1}\right]} = 3.3356(pc)$$

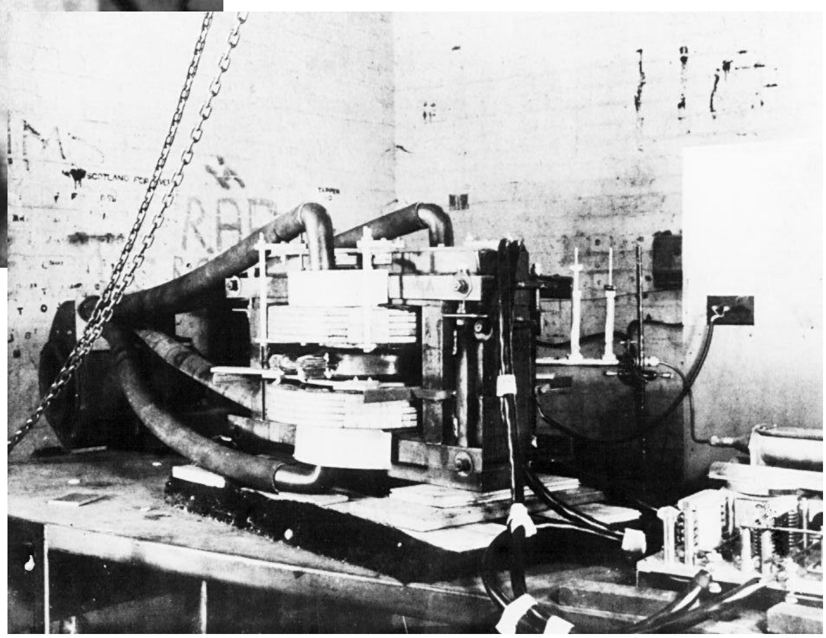
Vertical Focusing



- People just got on with the job of building them.
- Then one day someone was experimenting
- Figure shows the principle of vertical focusing in a cyclotron
- In fact the shims did not do what they had been expected to do
- Nevertheless the cyclotron began to accelerate much higher currents

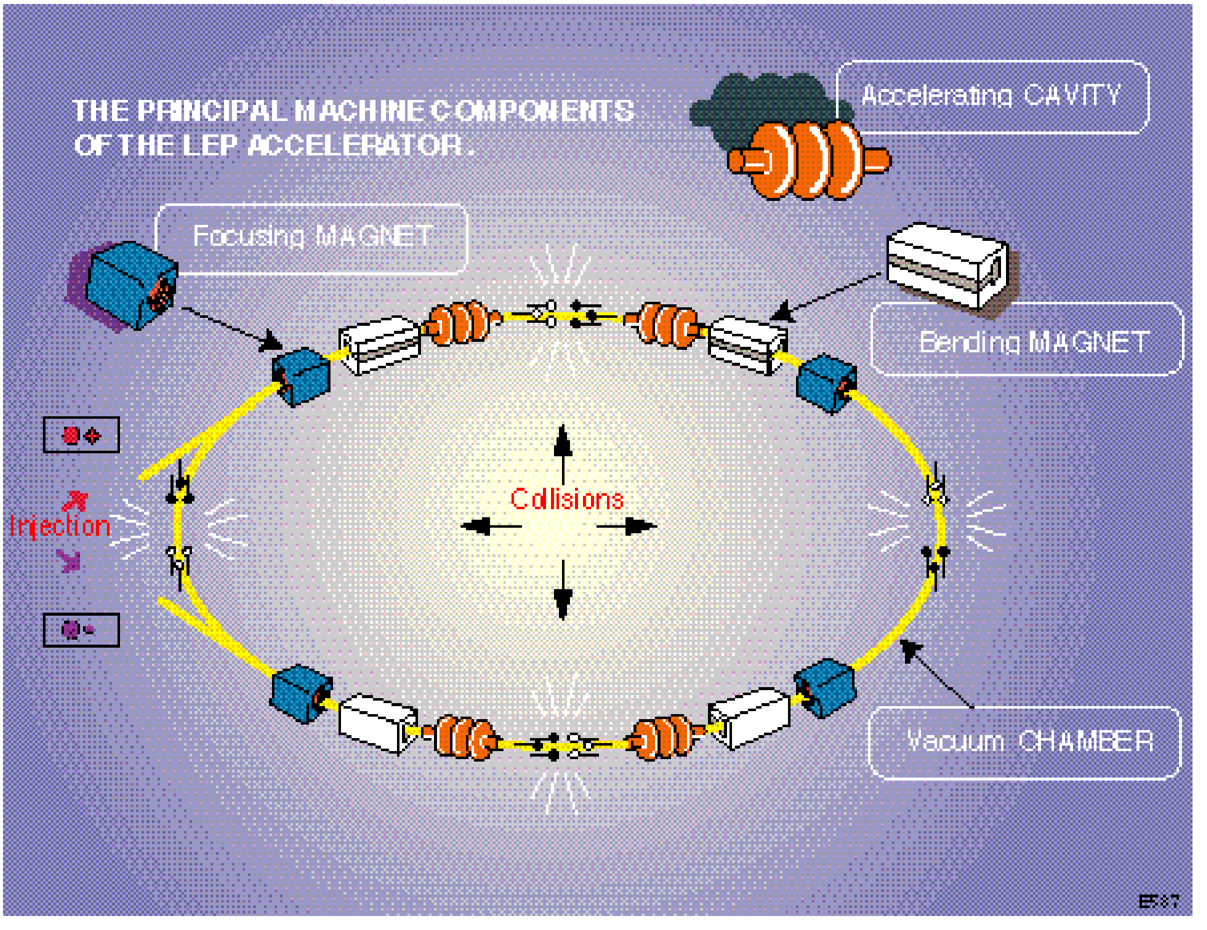
Discovery of the Synchrotron

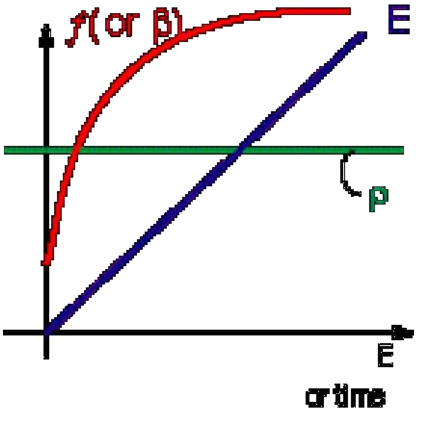
- **Marcus Oliphant – an Aussie – later to become Governor of South Australia**

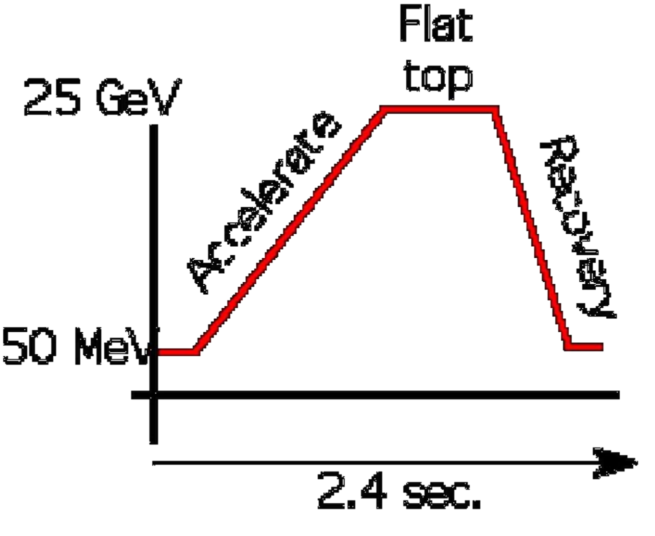


- **The Arsenal Synchrotron- Late in World War II the Woolwich Arsenal Research Laboratory in the UK had bought a betatron to "X-ray" unexploded bombs in the streets of London. <u>Frank</u> Goward converted the betatron into the <u>first "proof of principal"</u>**

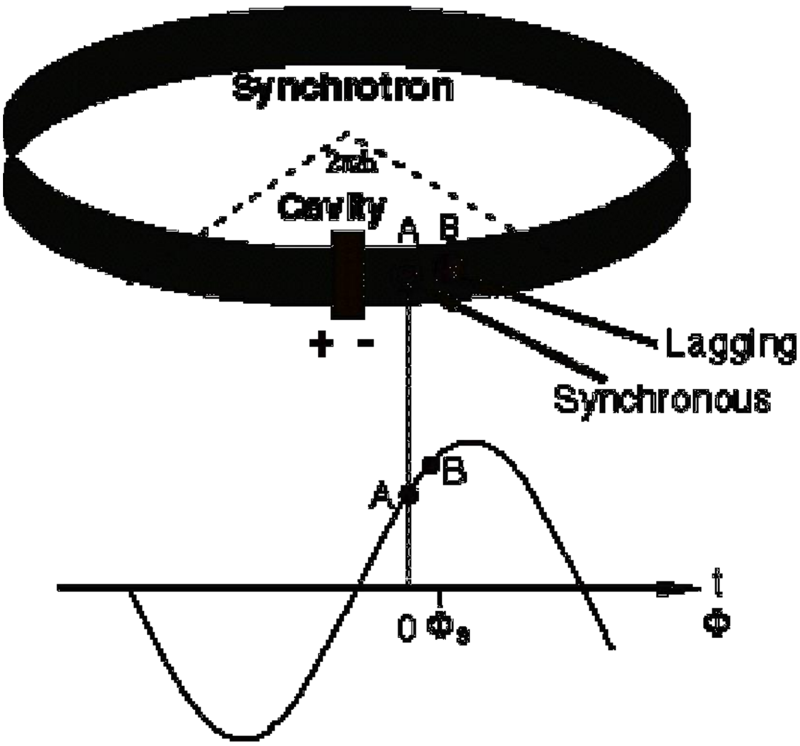
Components of a synchrotron



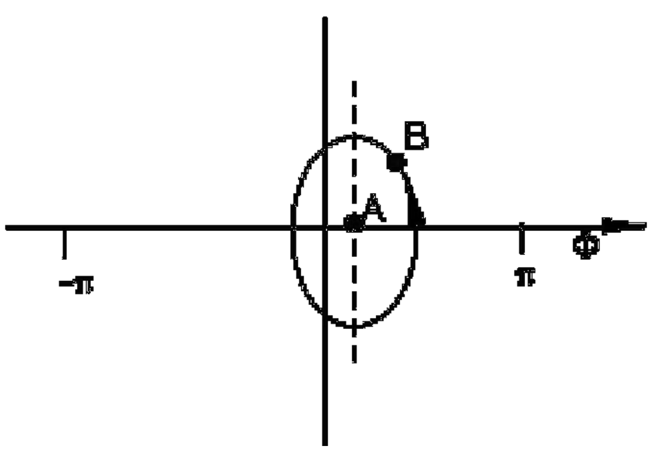




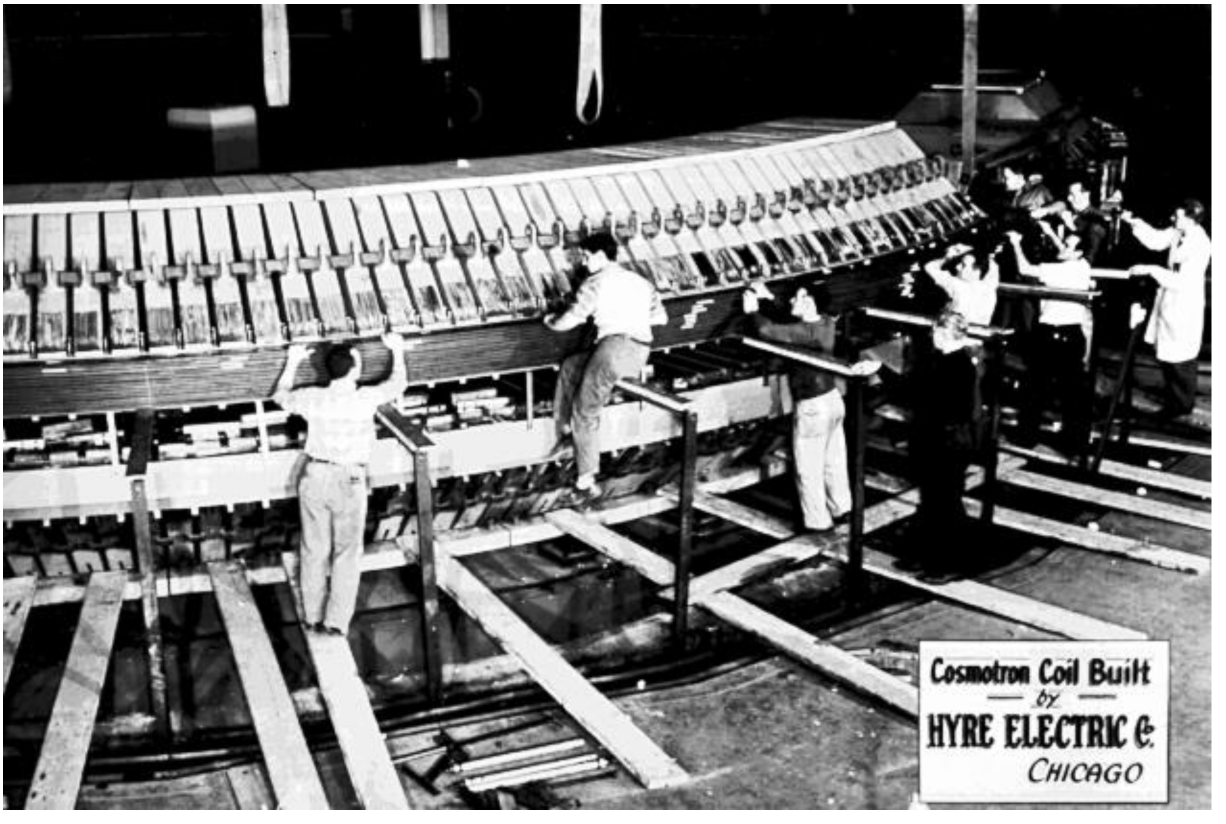
Phase stability



$$V = V_0 \sin(2\pi f_a + \phi_s)$$

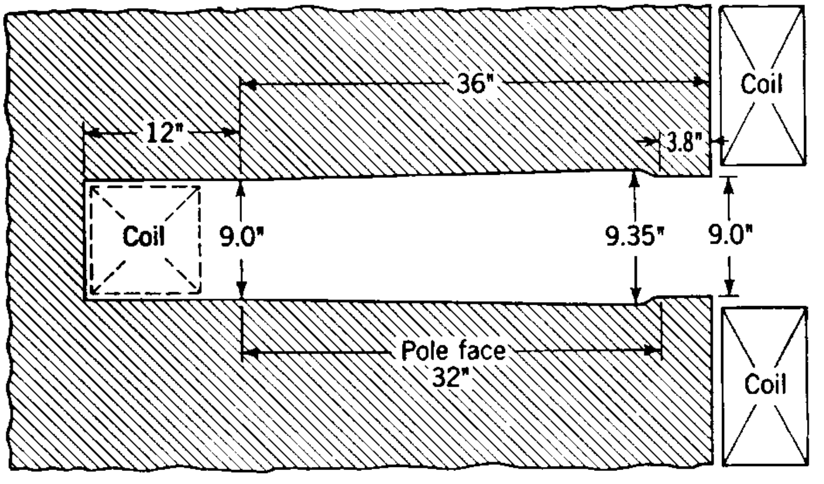


Cosmotron

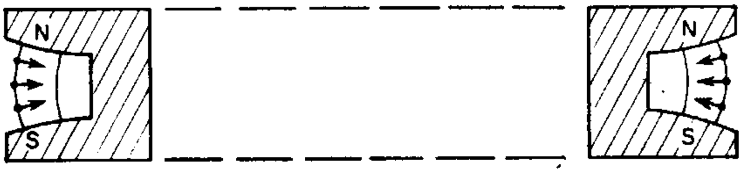


COSMOTRON.PCT

Weak focusing in a synchrotron



The Cosmotron magnet



- **Vertical focusing comes from the curvature of the field lines when the field falls off with radius (positive n-value)**
- **Horizontal focusing from the curvature of the path**
- **The negative field gradient defocuses horizontally and must not be so strong as to cancel the path curvature effect**

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