The Van de Graaff Accelerator

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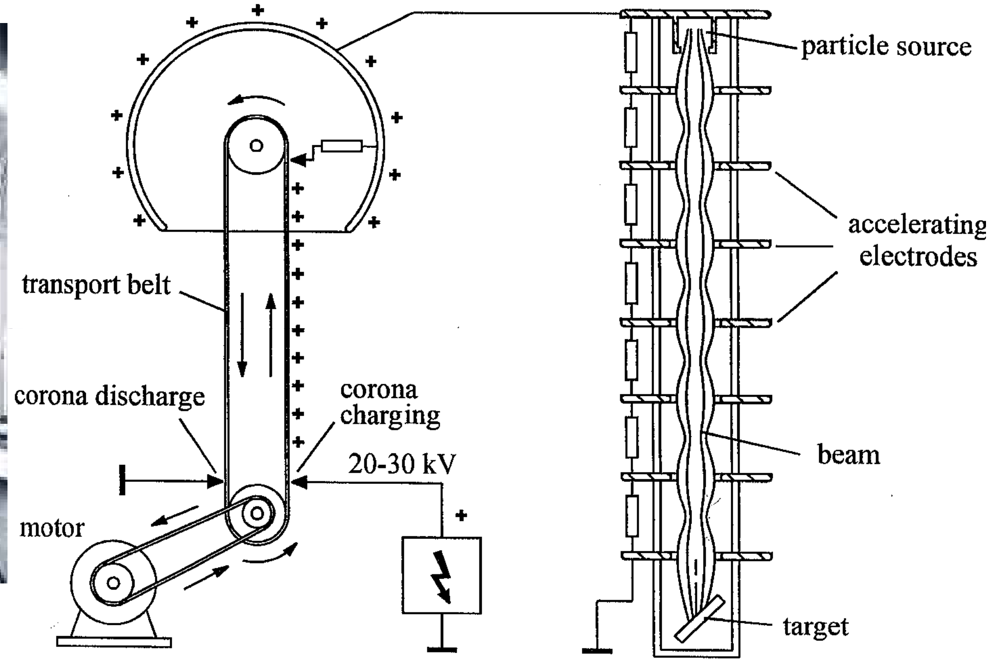
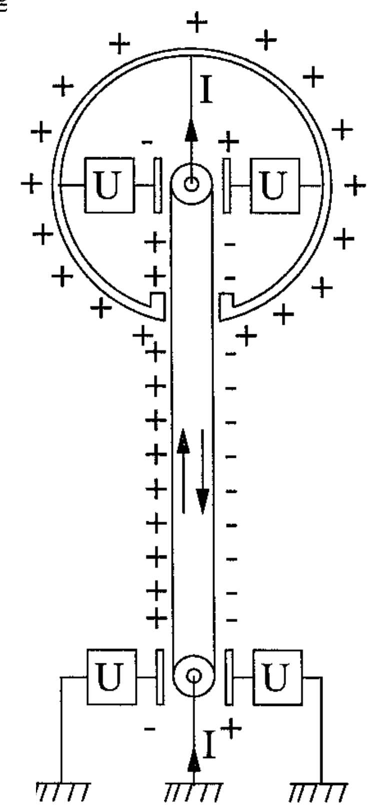
- 1930: van de Graaff builds the first 1.5MV high voltage generator



Van de Graaff



- Today Peletrons (with chains) or Laddertron (with stripes) that are charged by influence are commercially available.
- Used as injectors, for electron cooling, for medical and technical n-source via $d + t \mapsto n + \alpha$
- Up to 17.5 MV with insulating gas (1MPa SF_6)

The Tandem Accelerator

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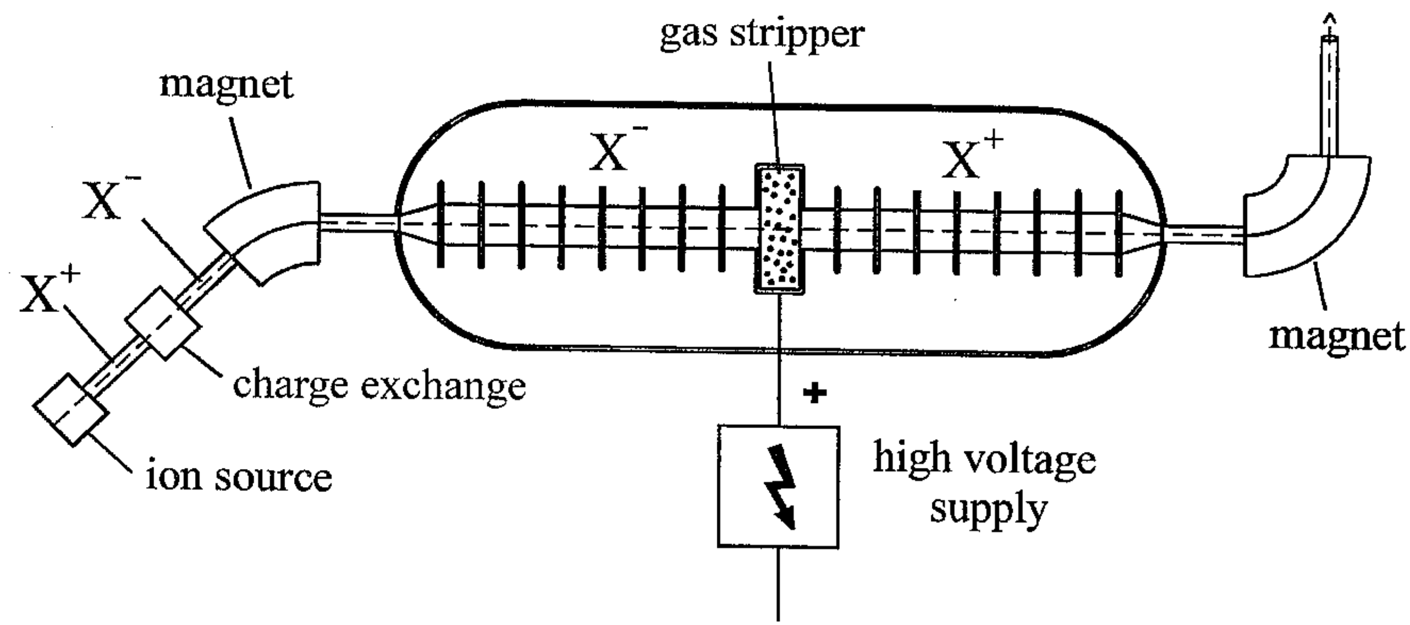
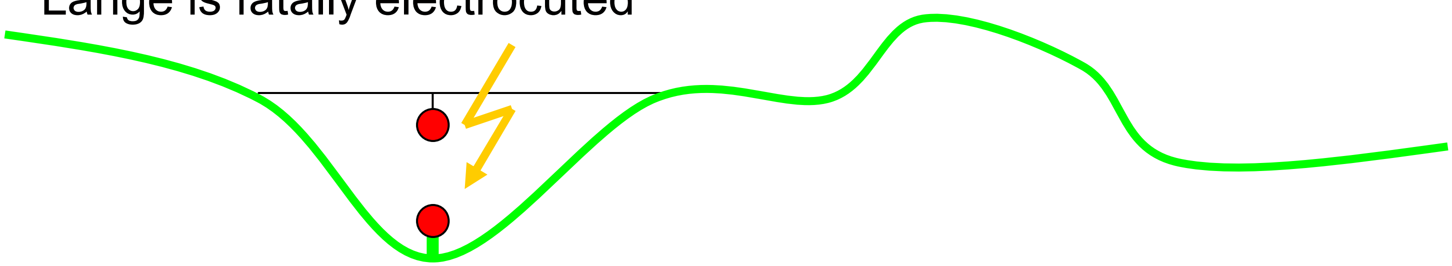
- Two Van de Graaffs, one + one –
- The Tandem Van de Graaff, highest energy 35MeV

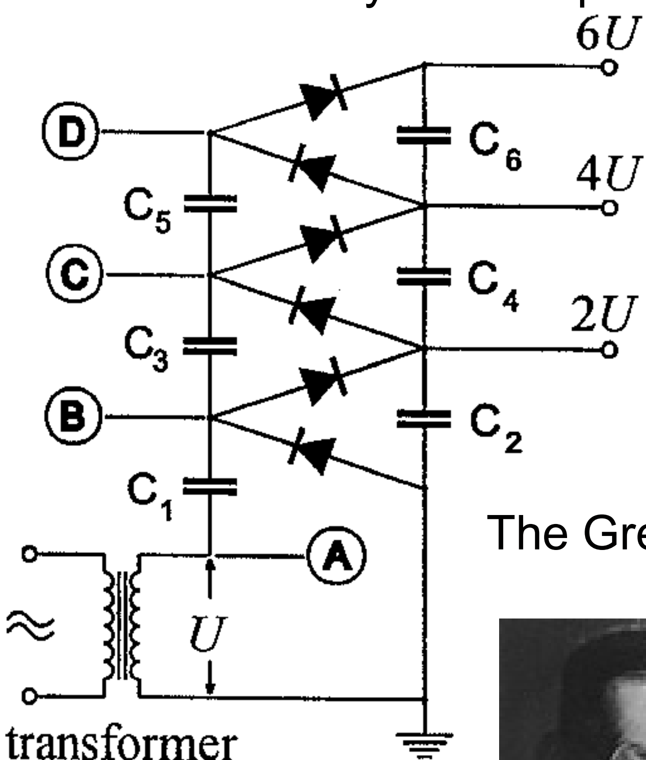


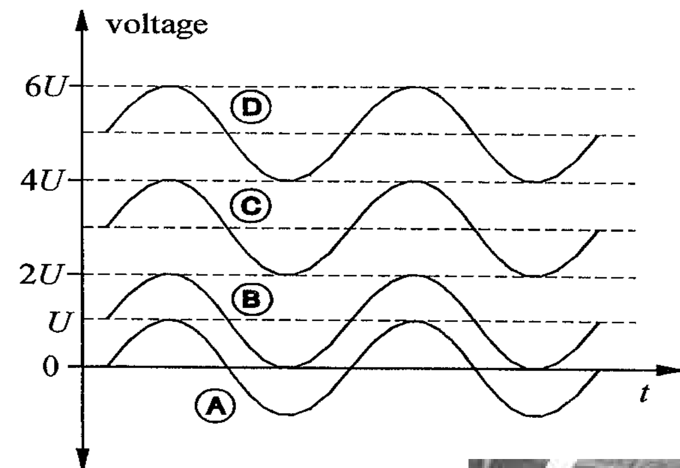
- 1932: Brasch and Lange use potential from lightening, in the Swiss Alps, Lange is fatally electrocuted



The Cockcroft-Walton Accelerator

1932: Cockcroft and Walton 1932: 700keV cascate generator (planed for 800keV) and use initially 400keV protons for $^7Li + p \mapsto {}^4He + {}^4He$ and $^7Li + p \mapsto {}^7Be + n$





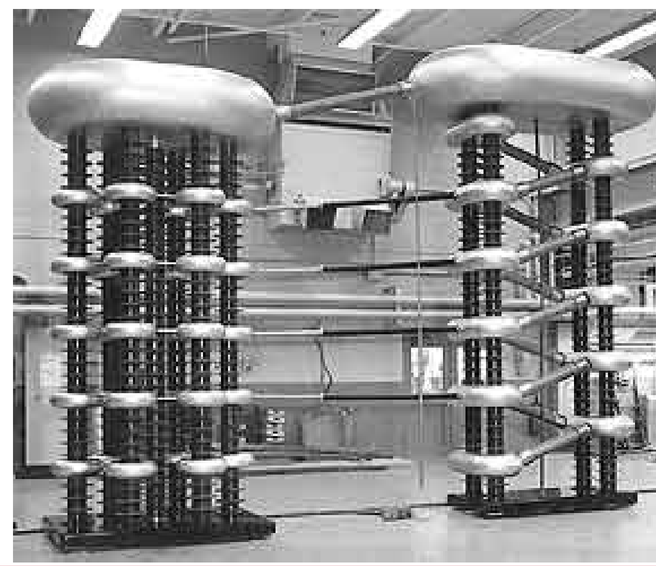
The Greinacker circuit

Up to 4MeV, 1A

NP 1951

Sir John D Cockcrof

Ernest T S Walton



The Marx Generator

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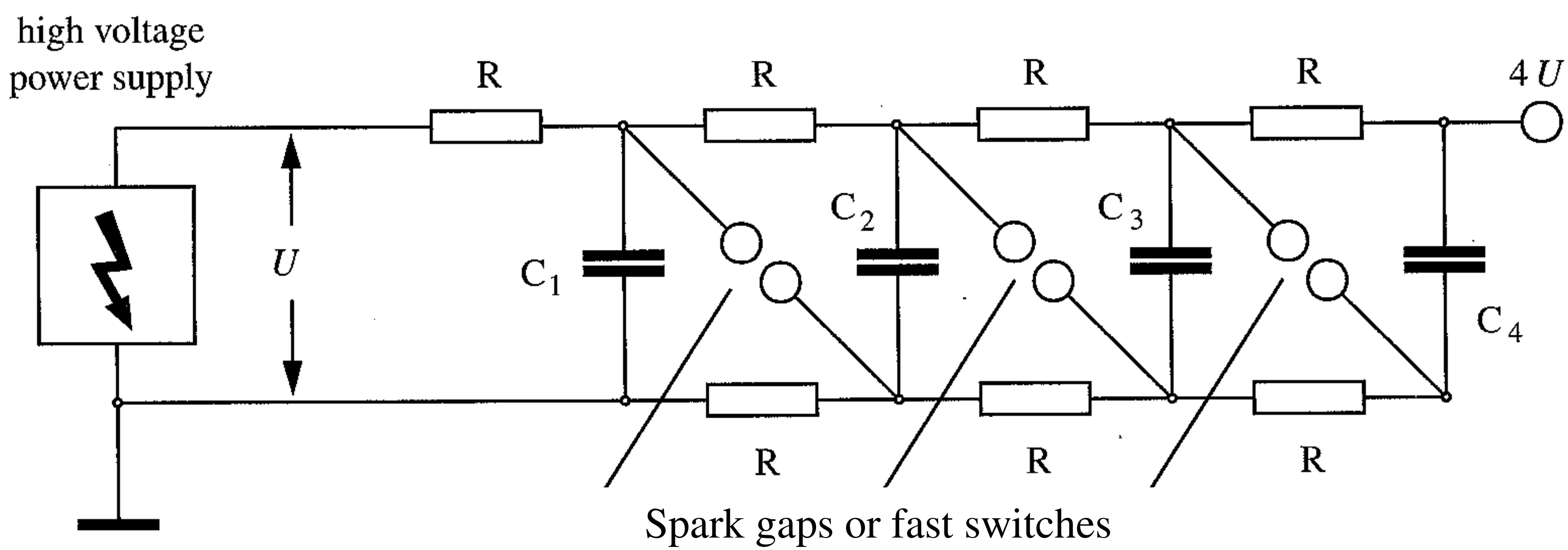
- 1932: Marx Generator achieves 6MV at General Electrics



After capacitors of around 2uF are filled to about 20kV, the spark gaps or switches close as fast as 40ns, allowing up to 500kA.

Today:
The Z-machine (Physics Today July 2003) for z-pinch initial confinement fusion has 40TW for 100ns from 36 Marx generators

Three historic lines of accelerators

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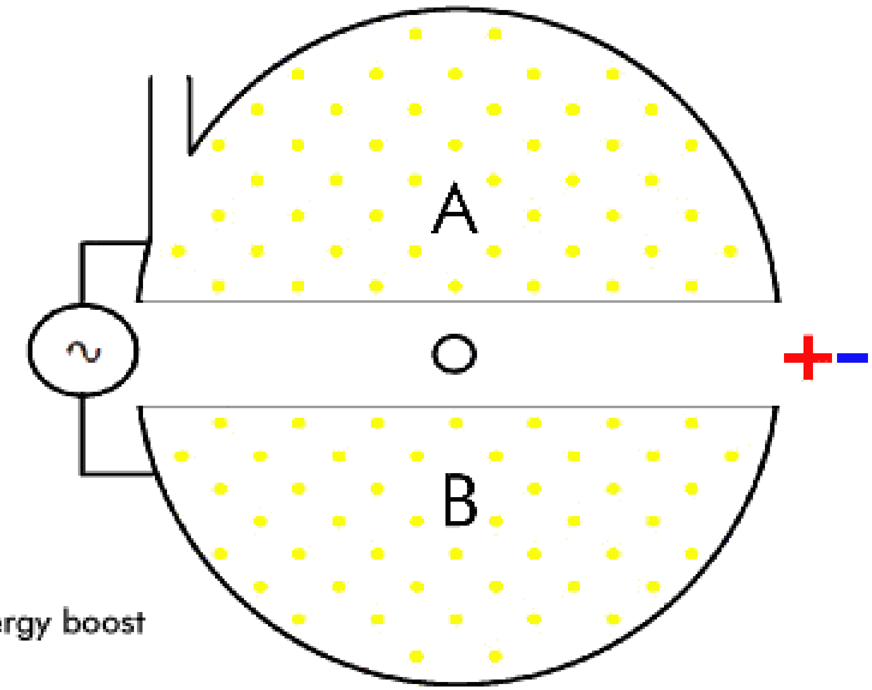
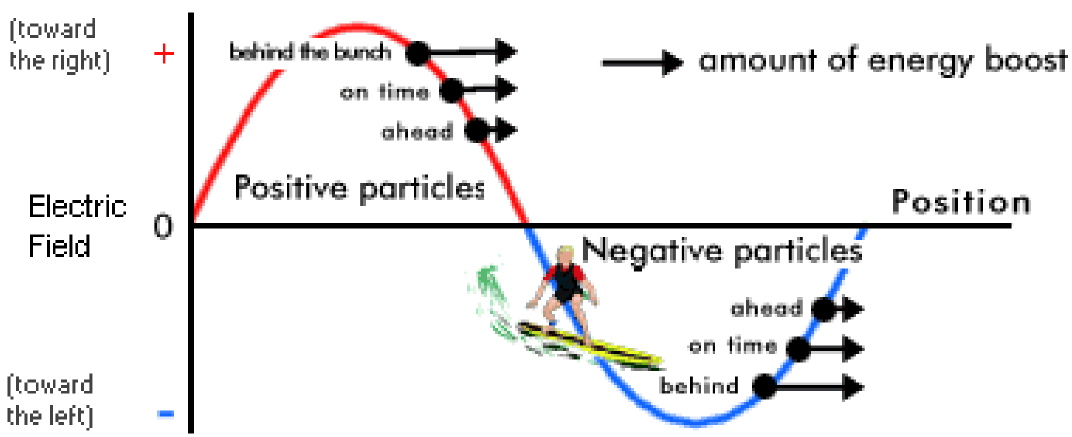
Resonant Accelerators

Direct Voltage Accelerators

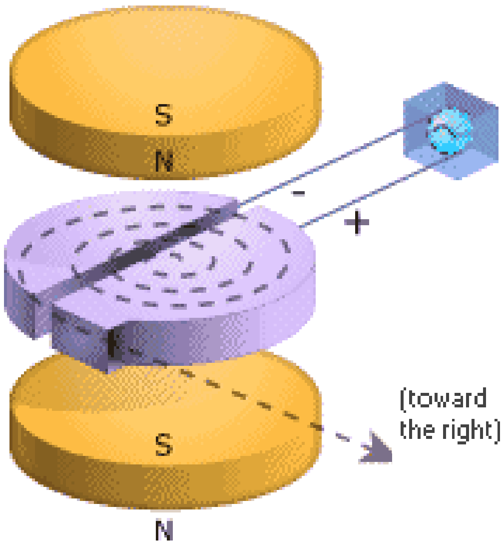
Transformer Accelerator



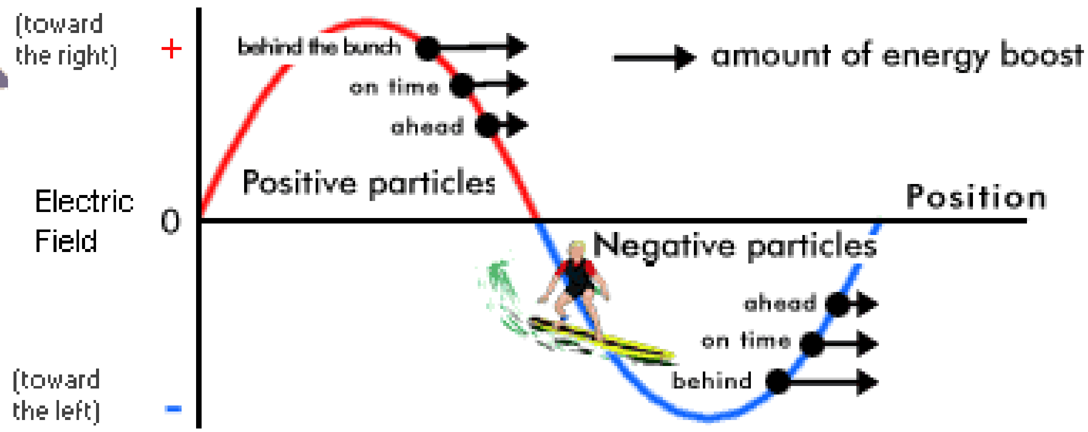


Particles must have the correct phase relation to the accelerating voltage.

The Cyclotron



- 1930: Lawrence proposes the Cyclotron (before he develops a workable color TV screen)
- 1932: Lawrence and Livingston use a cyclotron for 1.25MeV protons and mention longitudinal (phase) focusing



- 1934: Livingston builds the first Cyclotron away from Berkely (2MeV protons) at Cornell (in room B54)

NP 1939

Ernest O Lawrence

USA 1901-1958

M Stanley Livingston

USA 1905-1986

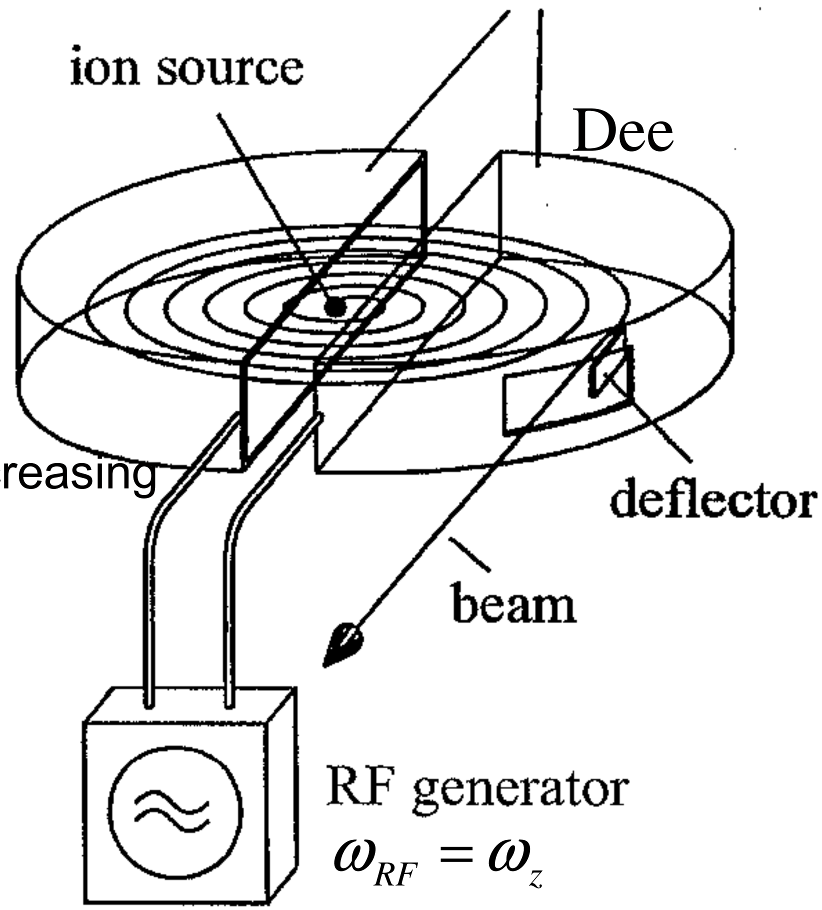
The cyclotron frequency

$$F_r = m_0 \gamma \omega_z v = qvB_z$$

$$\omega_z = \frac{q}{m_0\gamma} B_z = \text{const}$$

Condition: Non-relativistic particles.

Therefore not for electrons.



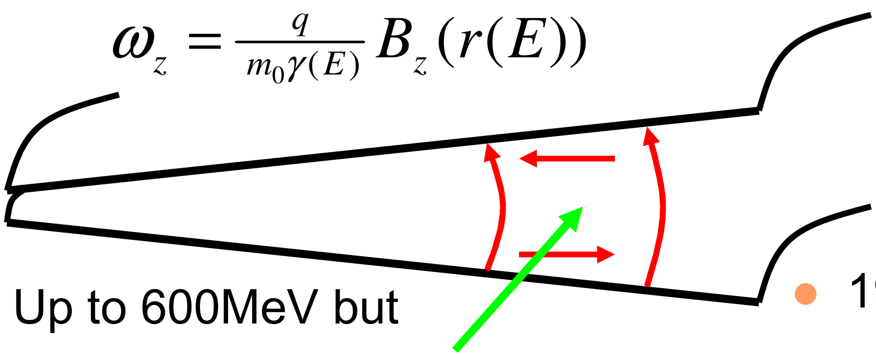
- The synchrocyclotron:

  Acceleration of bunches with decreasing

$$\omega_z(E) = \frac{q}{m_0\gamma(E)} B_z$$

- The isocyclotron with constant

$$\omega_z = \frac{q}{m_0\gamma(E)} B_z(r(E))$$



Up to 600MeV but

this vertically defocuses the beam

- 1938: Thomas proposes strong (transverse) focusing for a cyclotron

First Medical Applications

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- 1939: Lawrence uses 60’ cyclotron for 9MeV protons, 19MeV deuterons, and 35MeV 4He. First tests of tumor therapy with neutrons via $d + t \mapsto n + \alpha$
  With 200-800keV d to get 10MeV neutrons.

Modern Nuclear Therapy

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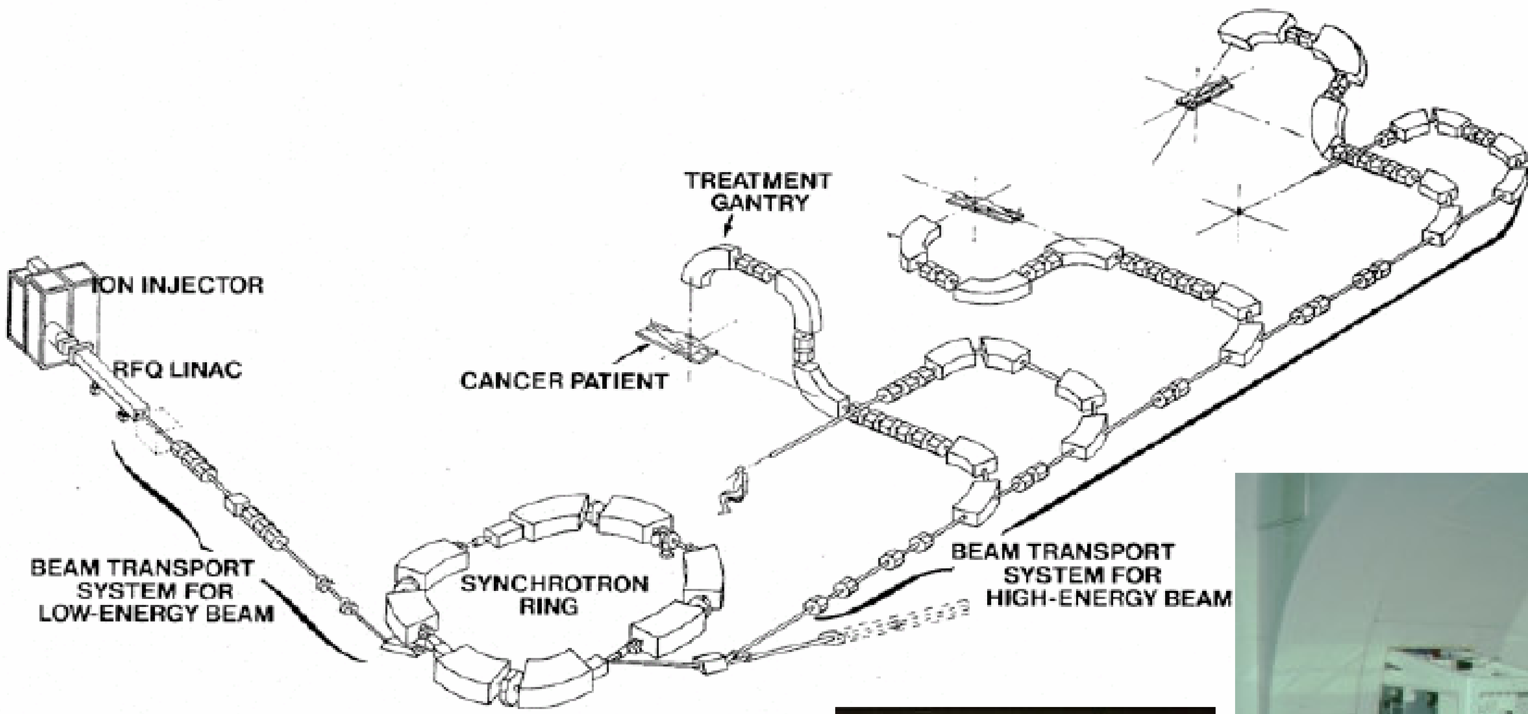
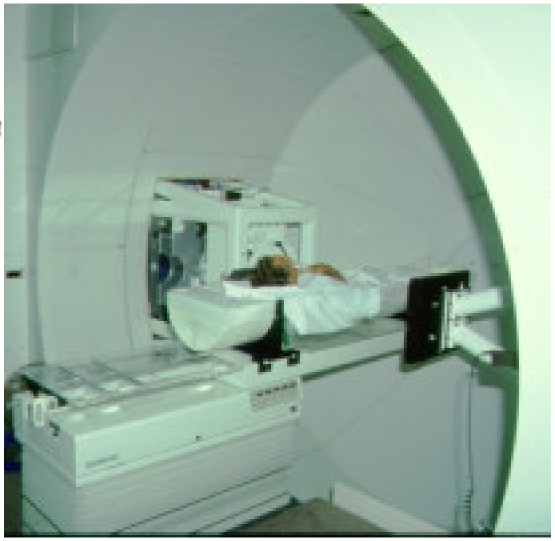
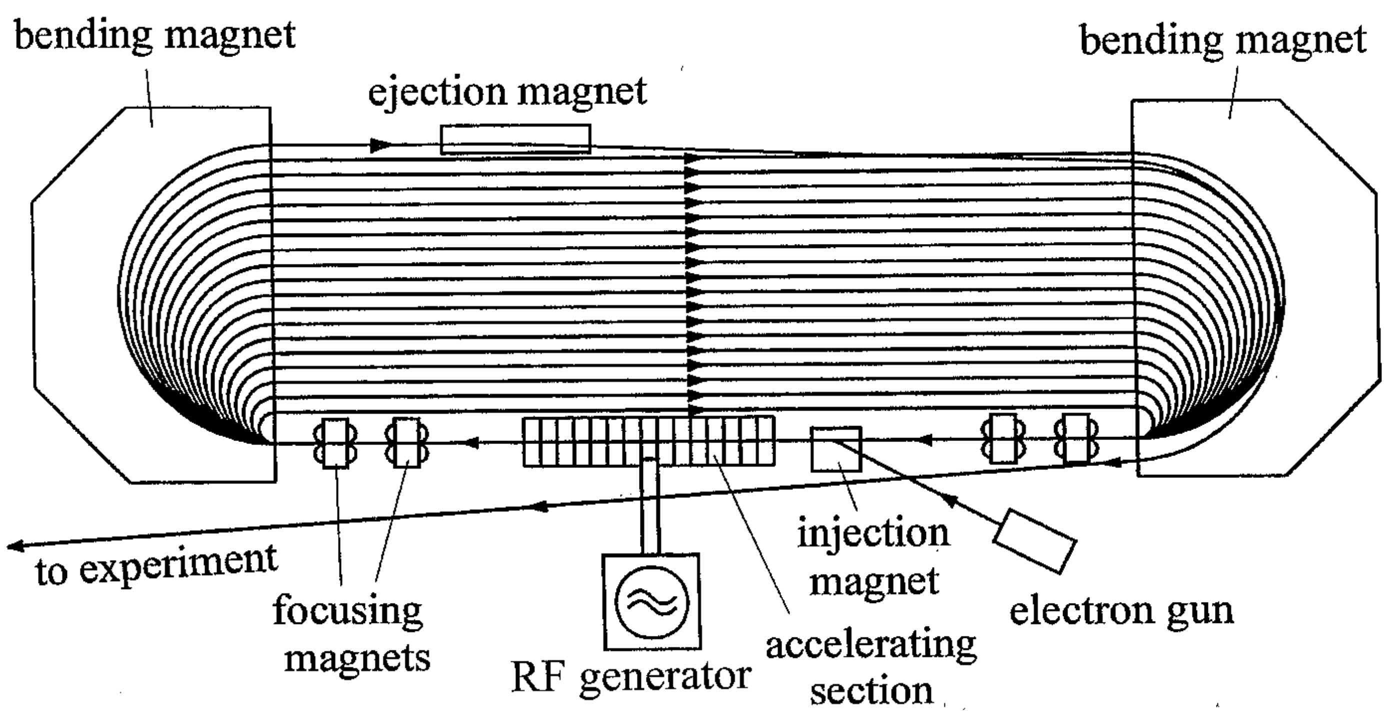
The Loma Linda proton therapy facility





The microtron

- Electrons are quickly relativistic and cannot be accelerated in a cyclotron.
- In a microtron the revolution frequency changes, but each electron misses an integer number of RF waves.

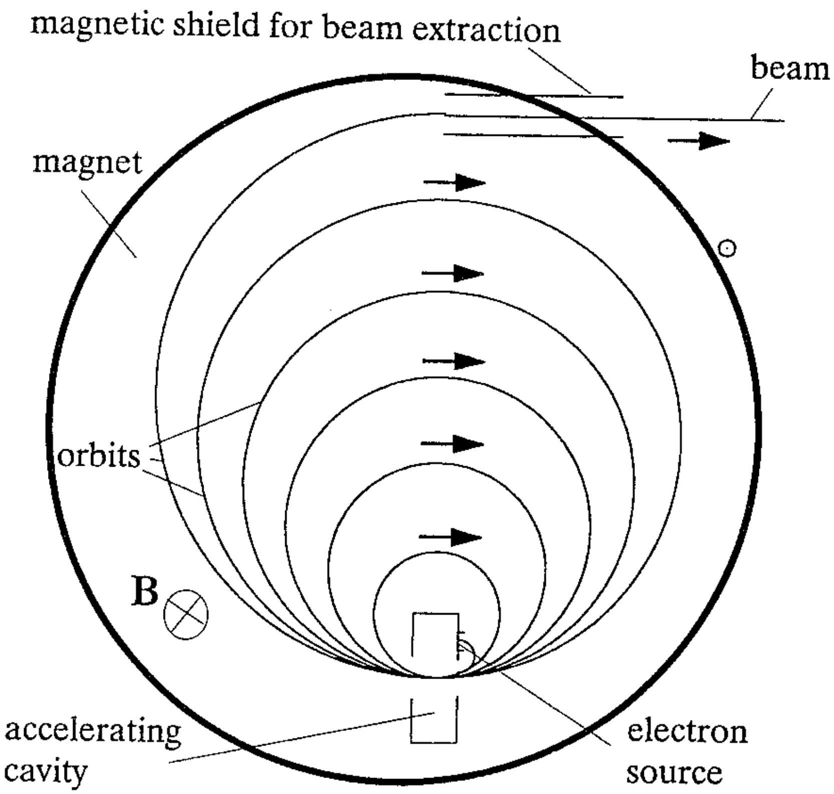


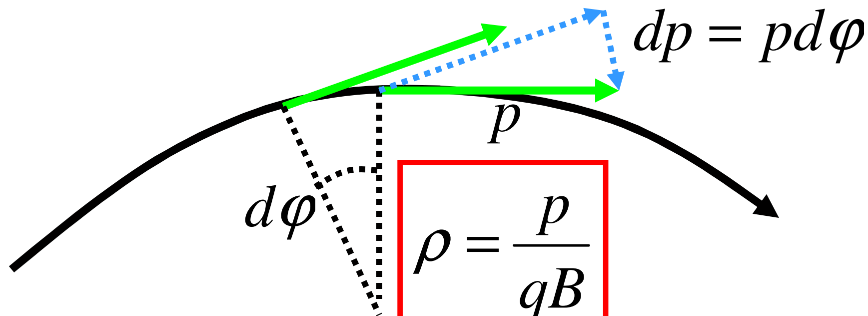
- Today: Used for medical applications with one magnet and 20MeV.
- Nuclear physics: MAMI designed for 820MeV as race track microtron.

The microtron condition

- The extra time that each turn takes must be a multiple of the RF period.

$$\frac{dp}{dt} = qvB \Rightarrow \rho = \frac{dl}{d\varphi} = \frac{vdt}{dp/p} = \frac{p}{qB}$$





$$\rho = \frac{p}{qB}$$

$$\Delta t = 2\pi\left(\frac{\rho_{n+1}}{v_{n+1}} - \frac{\rho_n}{v_n}\right)$$

$$= \frac{2\pi}{qB}(m_0\gamma_{n+1} - m_0\gamma_n) = \frac{2\pi}{qBc^2}\Delta K$$

$$\Delta K = n\frac{qBc^2}{\omega_{RF}}$$ for an integer n

B=1T, n=1, and f_{RF}=3GHz leads to 4.78MeV

This requires a small linear accelerator.