A short history of accelerators

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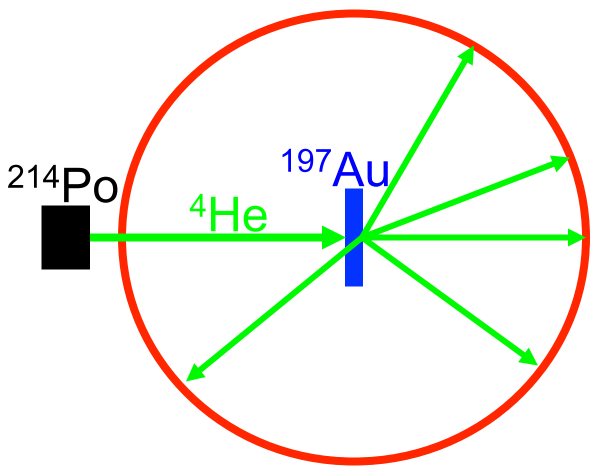
- 1911: Rutherford discovers the nucleus with 7.7MeV ^{4}He from ^{214}Po alpha decay measuring the elastic crossection of $^{197}Au + {}^{4}He \mapsto {}^{197}Au + {}^{4}He$.



$$E = \frac{Z_1 e Z_2 e}{4\pi\varepsilon_0 d} = Z_1 Z_2 m_e c^2 \frac{r_e}{d},$$

$$r_e = 2.8\mathrm{fm}, \quad m_e c^2 = 0.511\mathrm{MeV}$$

d = smalles approach for back scattering

- 1919: Rutherford produces first nuclear reactions with natural ^{4}He
  $^{14}N + {}^{4}He \mapsto {}^{17}O + p$
- 1921: Greinacher invents the cascade generator for several 100 keV
- Rutherford is convinced that several 10 MeV are in general needed for nuclear reactions. He therefore gave up the thought of accelerating particles.

Tunneling allows low energies

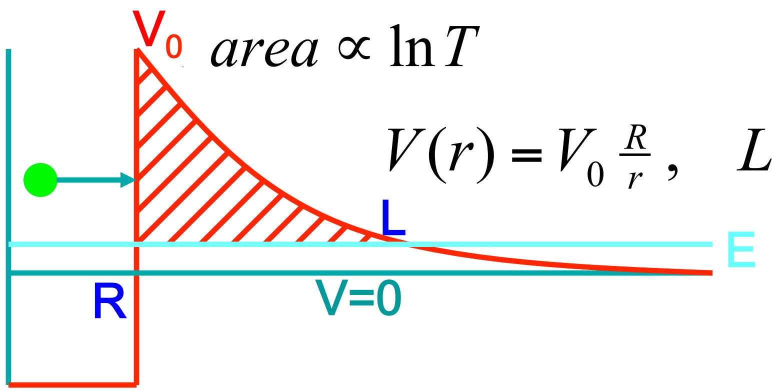
- 1928: Explanation of alpha decay by Gamov as tunneling showed that several 100keV protons might suffice for nuclear reactions

Schroedinger equation: $$\frac{\partial^2}{\partial r^2}u(r) = \frac{2m}{\hbar^2}[V(r) - E]u(r)\,, \quad T = \left|\frac{u(L)}{u(0)}\right|^2$$

The transmission probability T for an alpha particle traveling from the inside towards the potential well that keeps the nucleus together determines the lifetime for alpha decay.

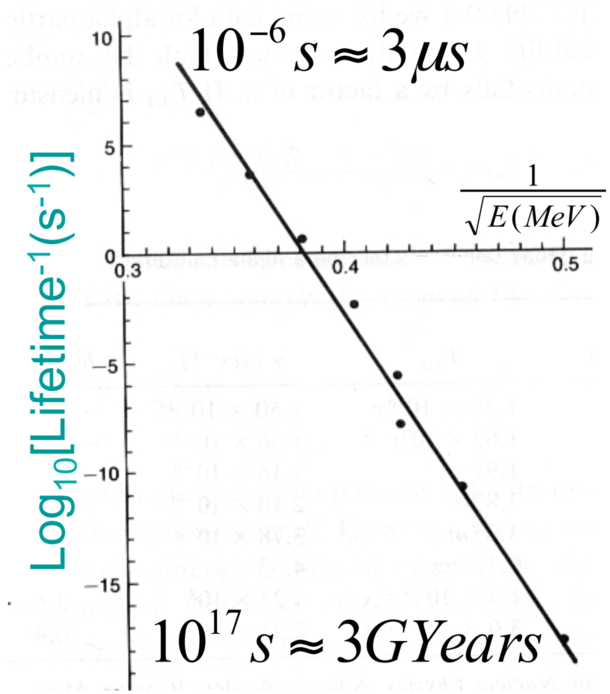
$area \propto \ln T$

$$V(r) = V_0\frac{R}{r}\,, \quad L = \frac{V_0}{E}R$$



$$T \approx \exp[-2\int_R^L \frac{\sqrt{2m[V(r) - E]}}{\hbar}dr]$$

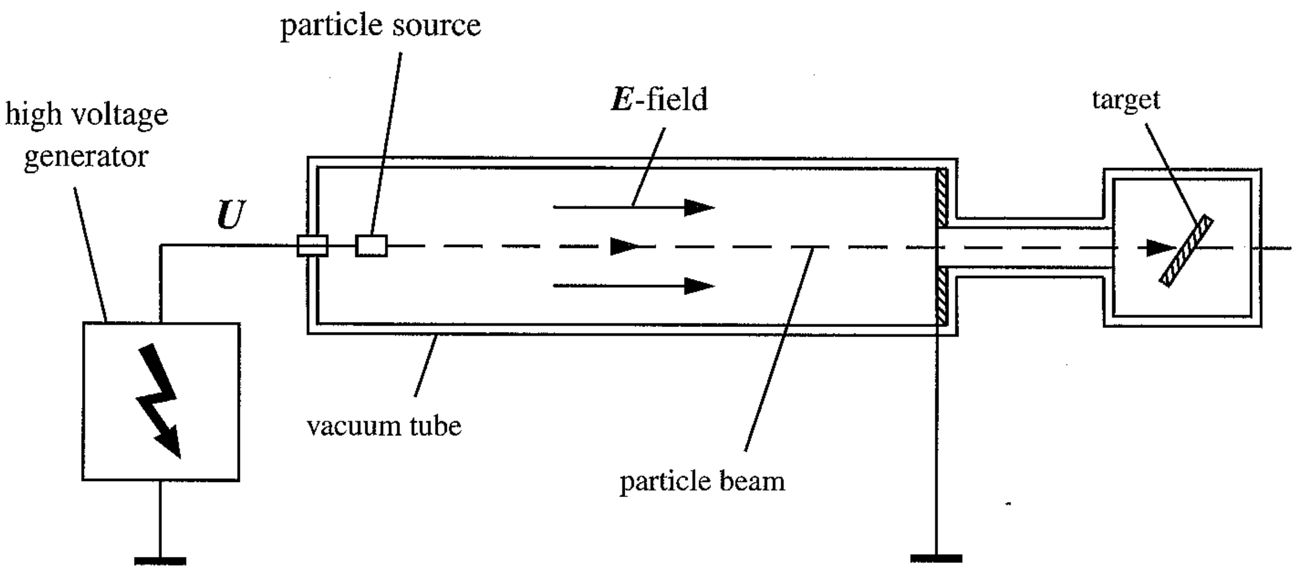
$$\ln T \approx A - \frac{C}{\sqrt{E}}$$



Three historic lines of accelerators

Direct Voltage Accelerators

Resonant Accelerators   Transformer Accelerator



Voltage 1MV

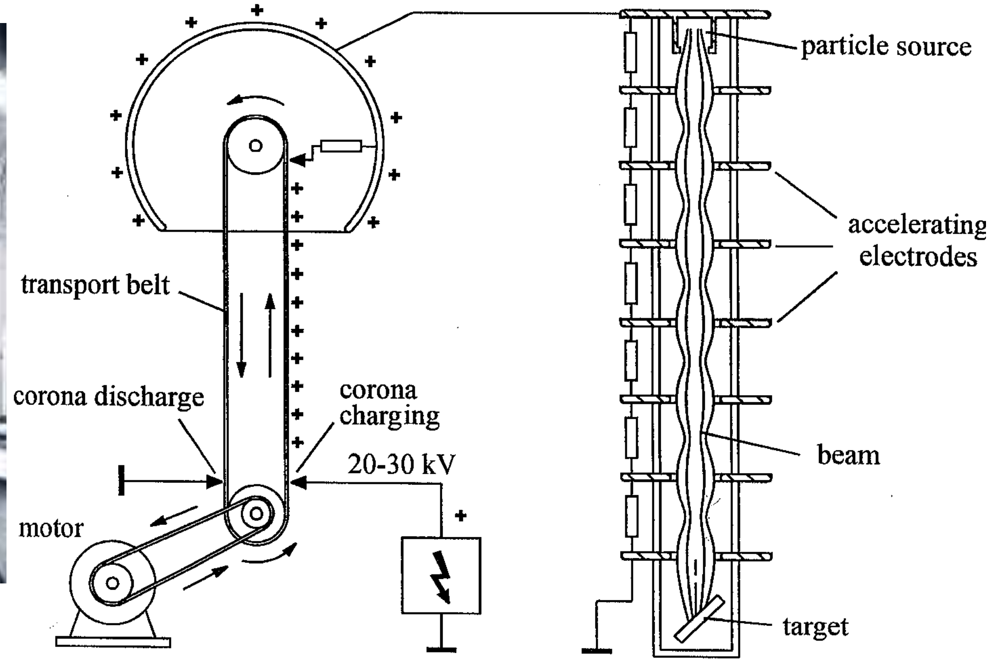
Charge Ze

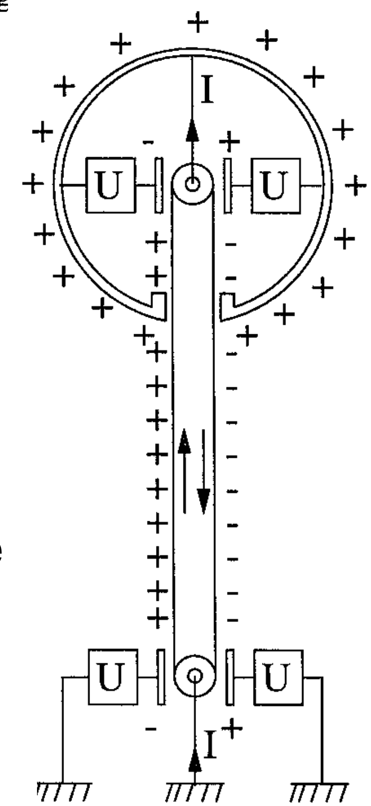
Energy Z MeV

The energy limit is given by the maximum possible voltage. At the limiting voltage, electrons and ions are accelerated to such large energies that they hit the surface and produce new ions. An avalanche of charge carries causes a large current and therefore a breakdown of the voltage.

The Van de Graaff Accelerator

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



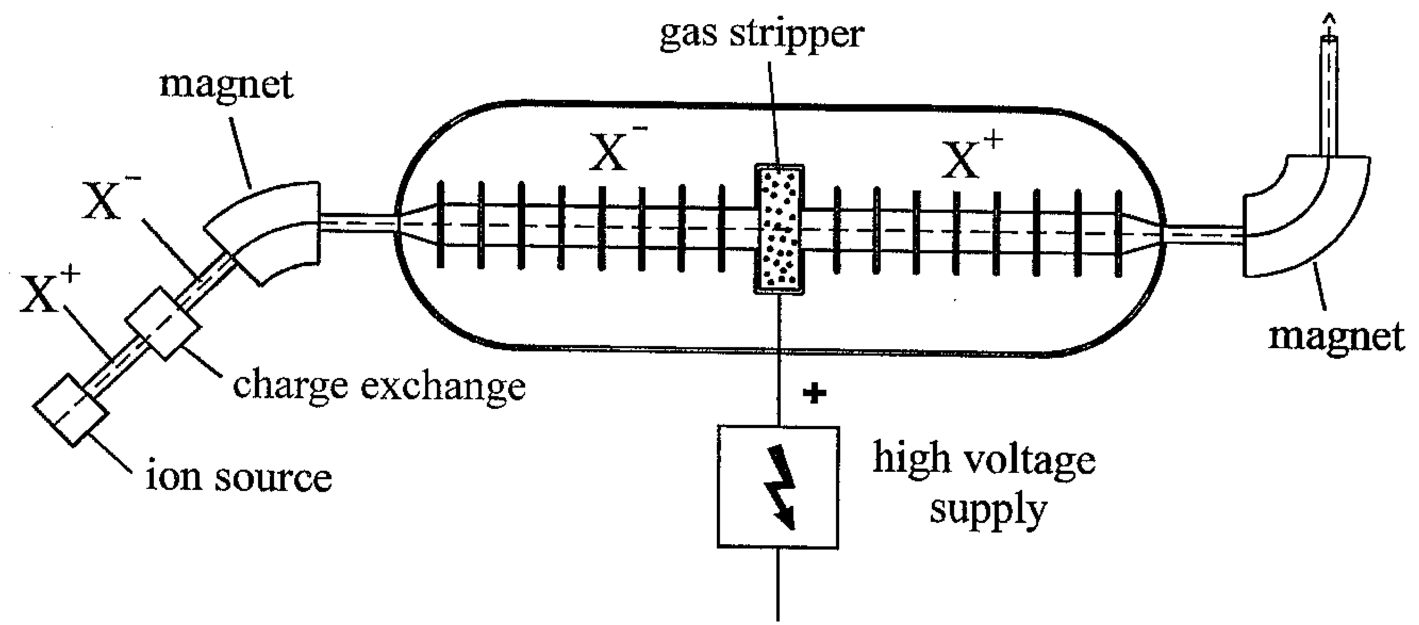


Van de Graaff

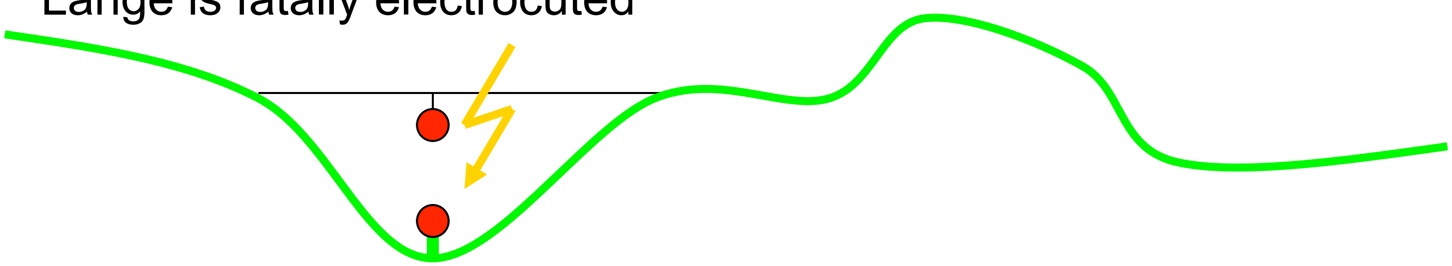
- Today Peletrons (with chains) or Laddertron (with stripes) that are charged by influence are commercially available.
- Used as injectors, for electron cooling, for medical and technical n-source via $d + t \mapsto n + \alpha$
- Up to 17.5 MV with insulating gas (1MPa SF_6)

The Tandem Accelerator

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

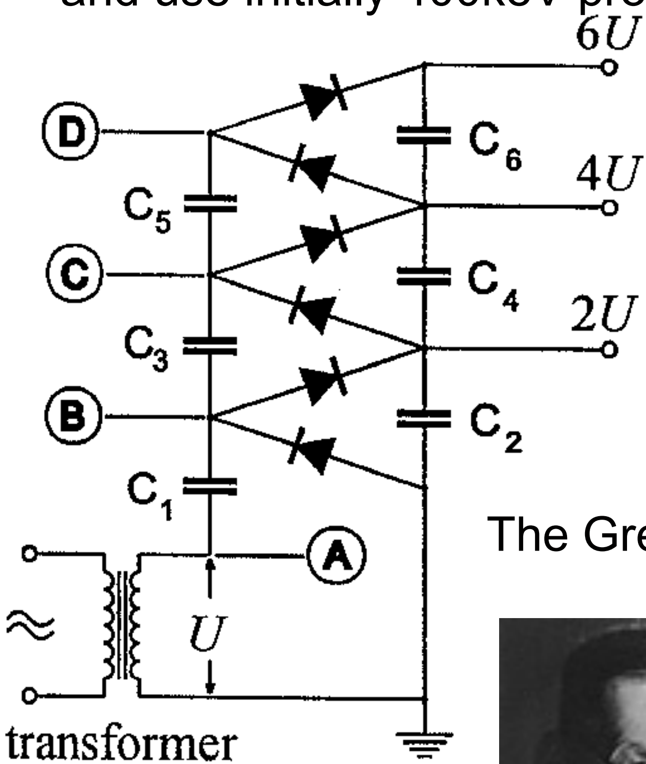


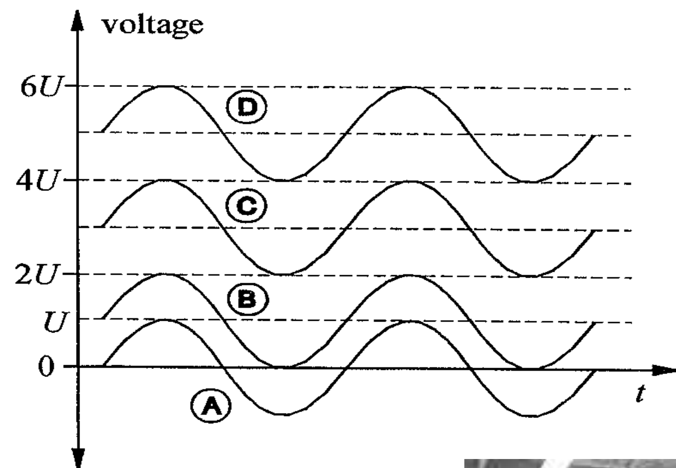
- 1932: Brasch and Lange use potential from lightening, in the Swiss Alps, Lange is fatally electrocuted



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 $^7Li + p \mapsto {}^7Be + n$





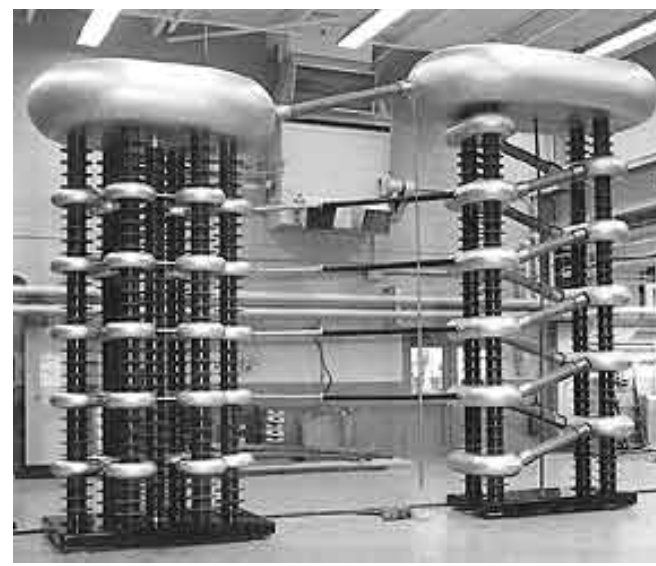
The Greinacker circuit

Up to 4MeV, 1A

NP 1951

Sir John D Cockcrof

Ernest T S Walton



The Marx Generator

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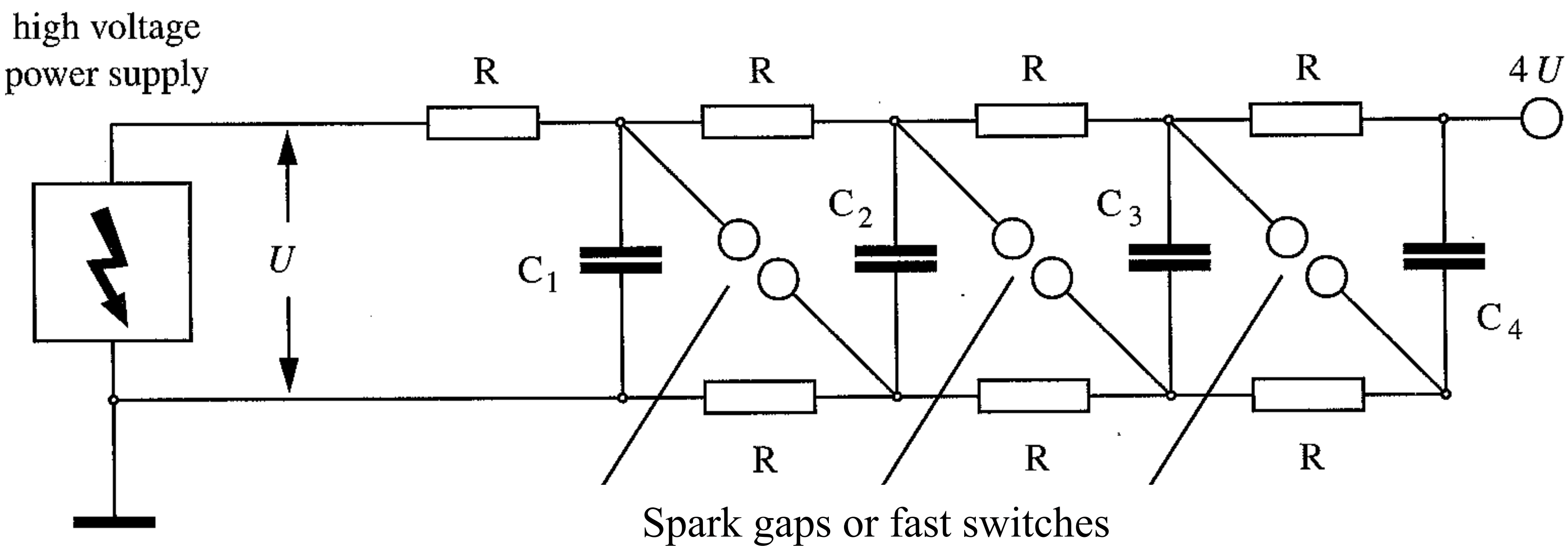
- 1932: Marx Generator achieves 6MV at General Electrics



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

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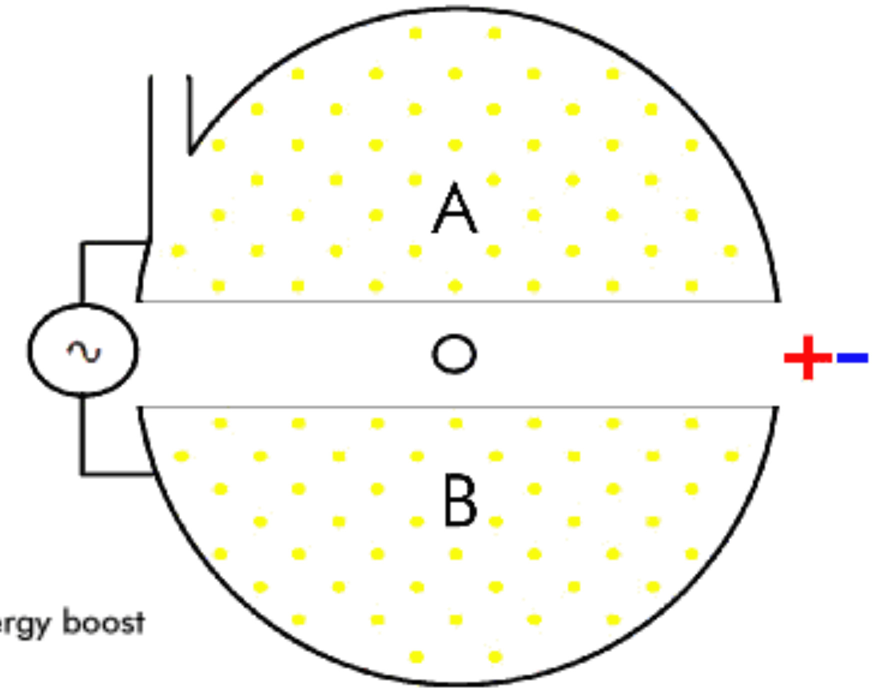
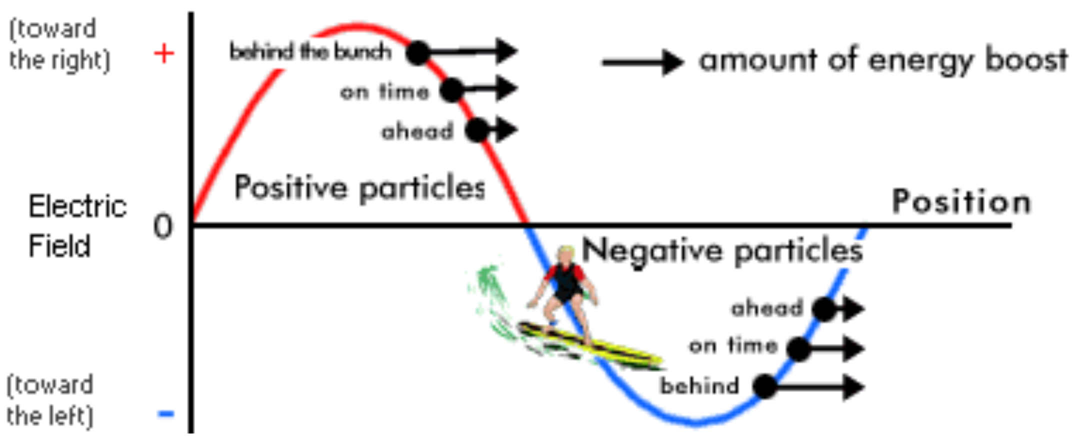
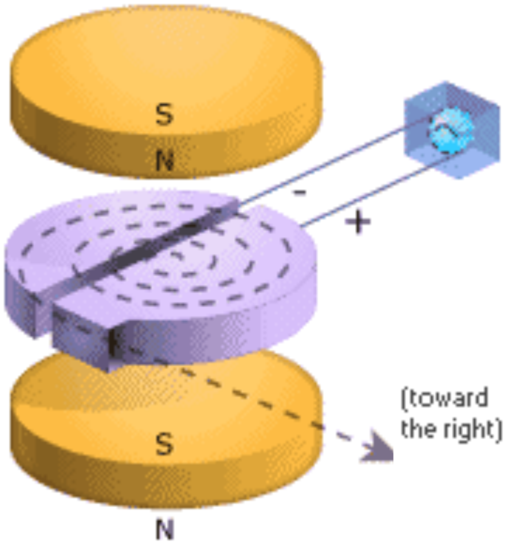


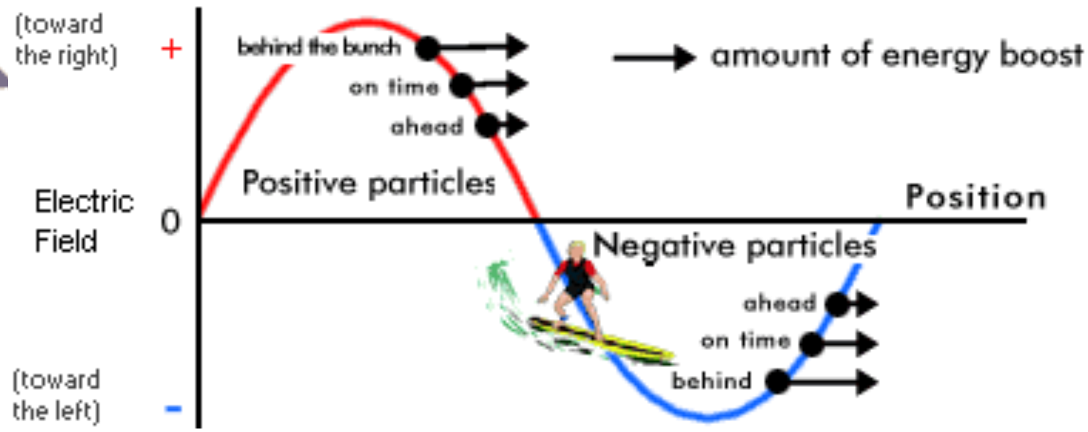


Particles must have the correct phase relation to the accelerating voltage.

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



NP 1939
Ernest O Lawrence
USA 1901-1958

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

M Stanley Livingston
USA 1905-1986

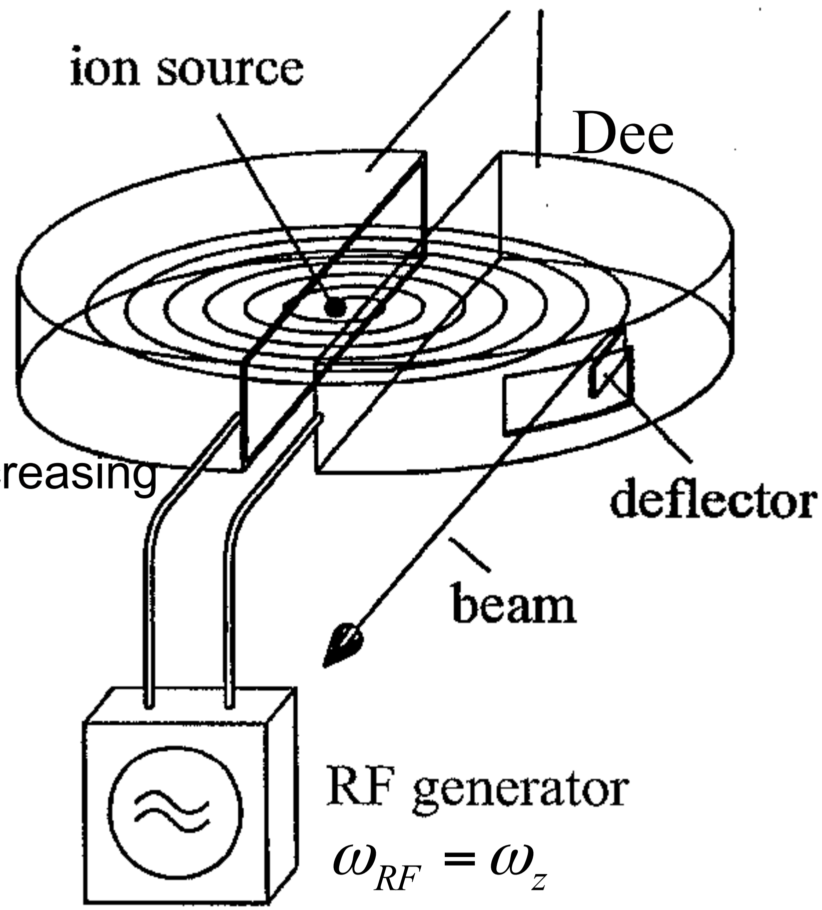
The cyclotron frequency

CHESS & LEPP

$$F_r = m_0 \gamma \omega_z v = q v B_z$$

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

Condition: Non-relativistic particles.
Therefore not for electrons.



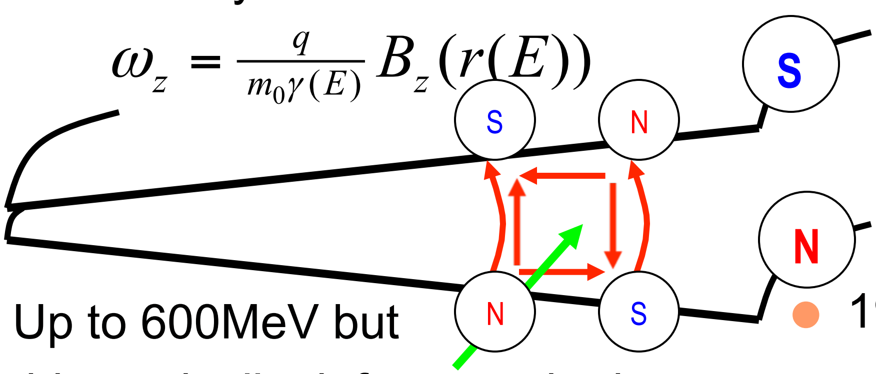
- The synchrocyclotron:

  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