Advanced Accelerator Physics

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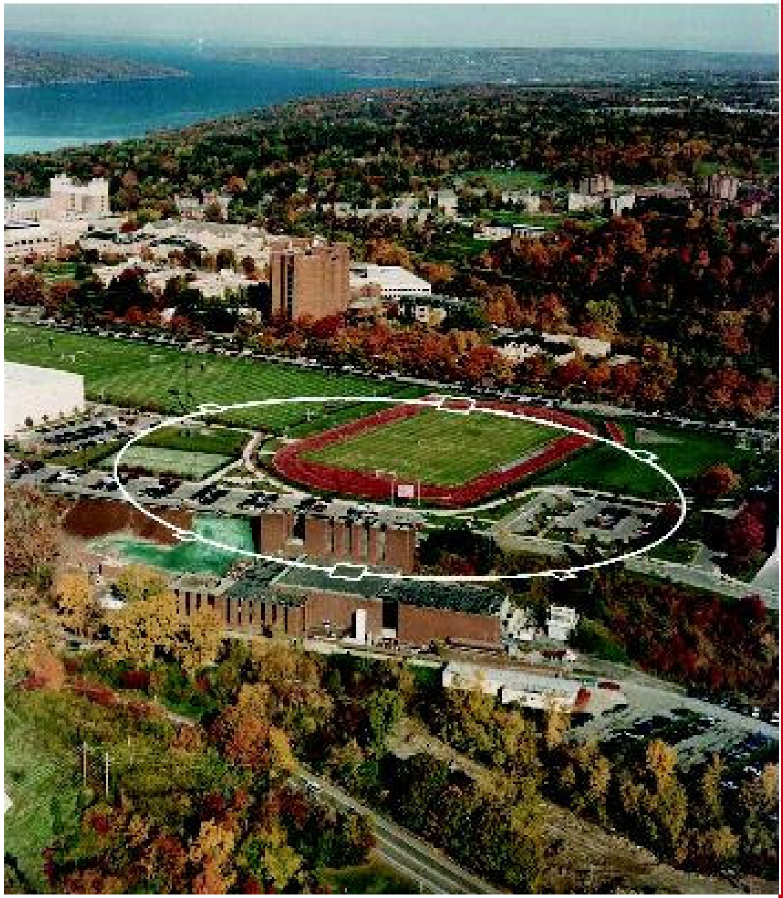

Literature

Required:
The Physics of Particle Accelerators, Klaus Wille, Oxford University Press, 2000, ISBN: 19 850549 3

Optional:
Particle Accelerator Physics I, Helmut Wiedemann, Springer, 2nd edition, 1999, ISBN 3 540 64671 x

Related material:
Handbook of Accelerator Physics and Engineering, Alexander Wu Chao and Maury Tigner, 2nd edition, 2002, World Scientific, ISBN: 981 02 3858 4

Particle Accelerator Physics II, Helmut Wiedemann, Springer, 2nd edition, 1999, ISBN 3 540 64504 7

What is accelerator physics

Accelerator Physics has applications in particle accelerators for high energy physics or for x-ray science, in spectrometers, in electron microscopes, and in lithographic devices. These instruments have become so complex that an empirical approach to properties of the particle beams is by no means sufficient and a detailed theoretical understanding is necessary. This course will introduce into theoretical aspects of charged particle beams and into the technology used for their acceleration.

- Physics of beams
- Physics of non-neutral plasmas
- Physics of involved in the technology:
  - Superconductivity in magnets and radiofrequency (RF) devices
  - Surface physics in particle sources, vacuum technology, RF devices
  - Material science in collimators, beam dumps, superconducting materials

Different accelerators

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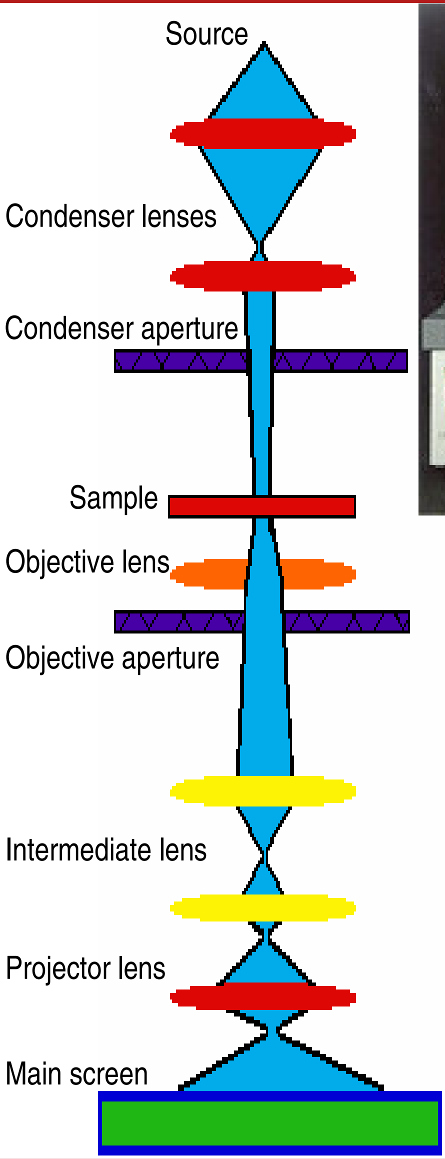

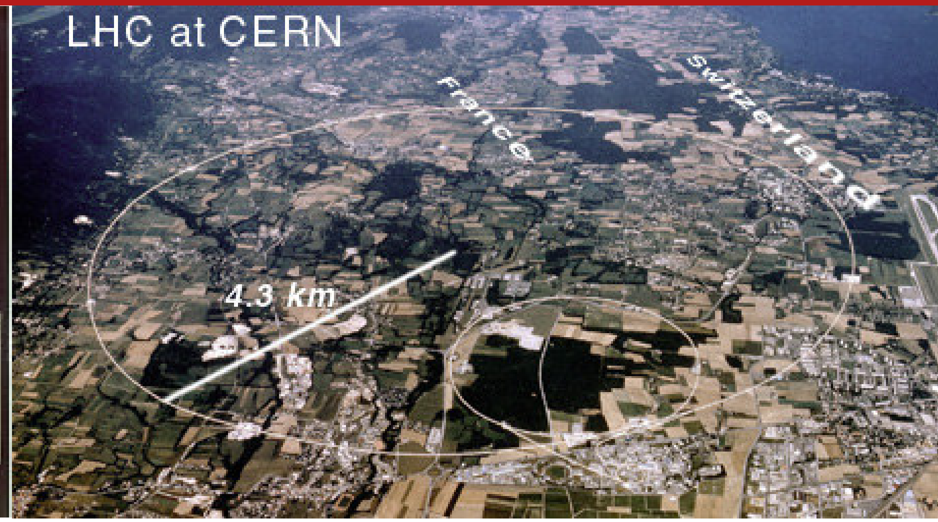

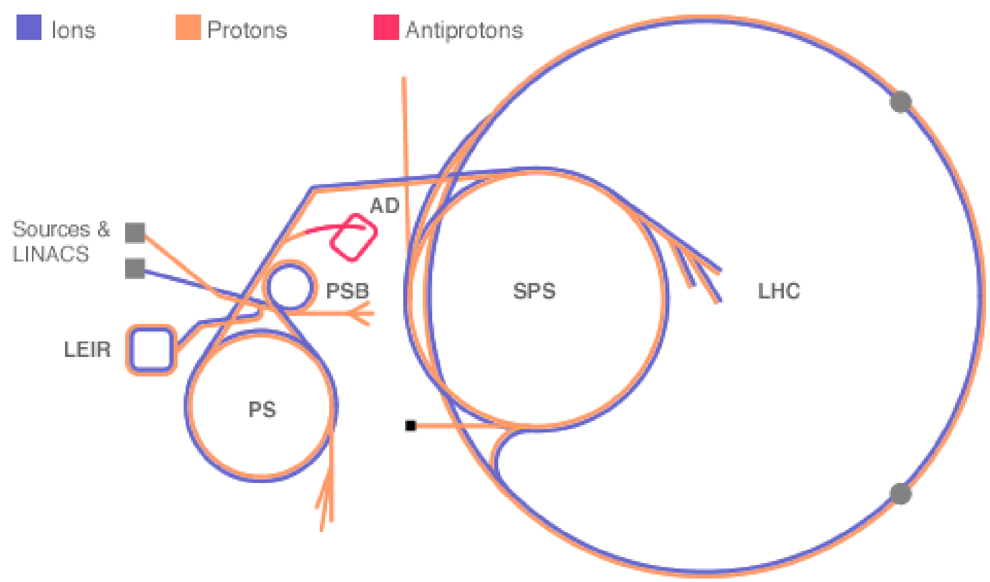

A short history of accelerators

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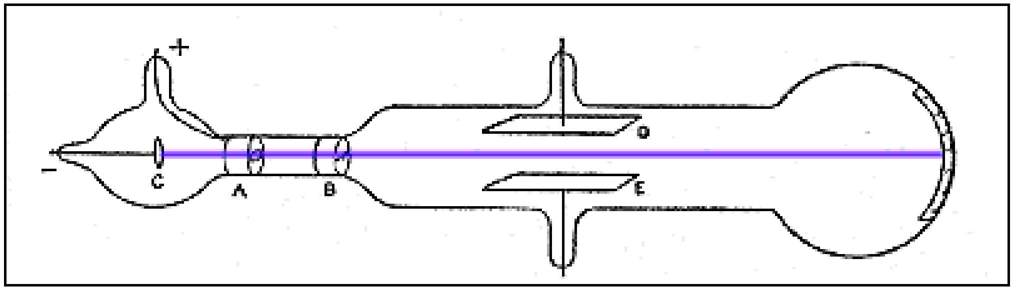
- 1862: Maxwell theory of electromagnetism
- 1887: Hertz discovery of the electromagnetic wave
- 1886: Goldstein discovers positively charged rays (ion beams)
- 1894: Lenard extracts cathode rays (with a 2.65um Al Lenard window)
- 1897: JJ Thomson shows that cathode rays are particles since they followed the classical Lorentz force $m\vec{a} = e(\vec{E} + \vec{v} \times \vec{B})$ in an electromagnetic field
- 1926: GP Thomson shows that the electron is a wave (1929-1930 in Cornell, NP in 1937)

NP 1905

Philipp E.A. von Lenard

Germany 1862-1947



NP 1906

Joseph J. Thomson

UK 1856-1940

A short history of accelerators

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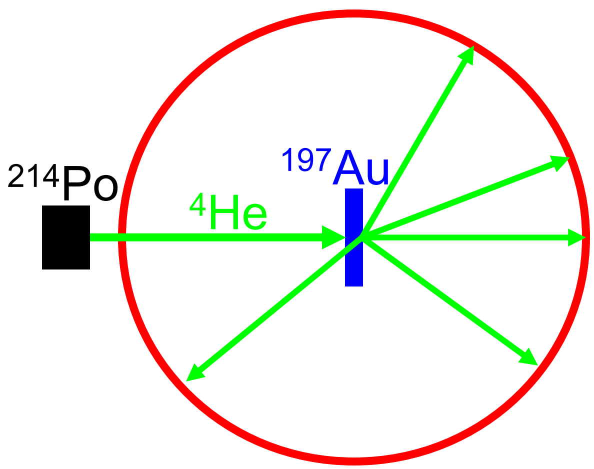
- 1911: Rutherford discovers the nucleus with 7.7MeV ^{4}He from ^{214}Po alpha decay measuring the elastic crossection of ^{197}Au + ^{4}He $\mapsto$ ^{197}Au + ^{4}He.



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

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

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

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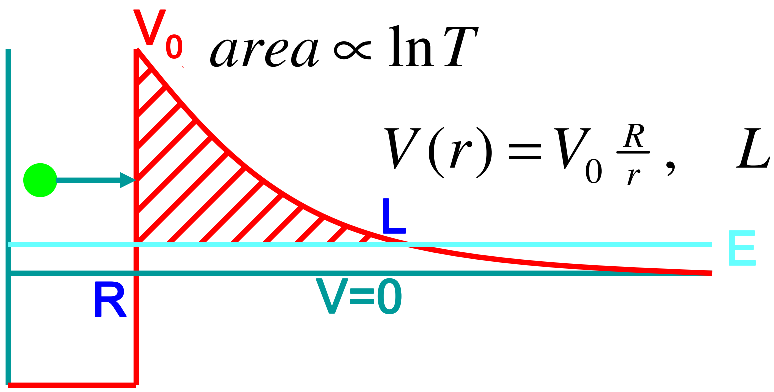
- 1928: Explanation of alpha decay by Gamov as tunneling showed that several 100keV protons might suffice for nuclear reactions

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.

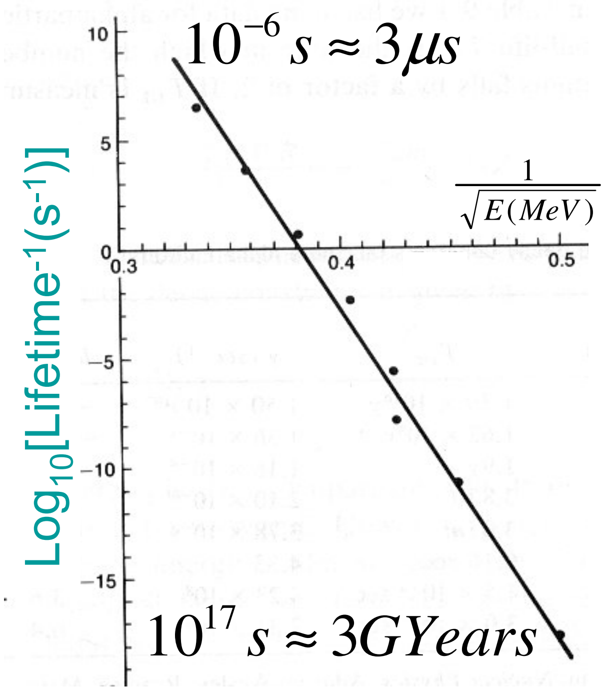


$area \propto \ln T$

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

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

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



$10^{-6}s \approx 3\mu s$

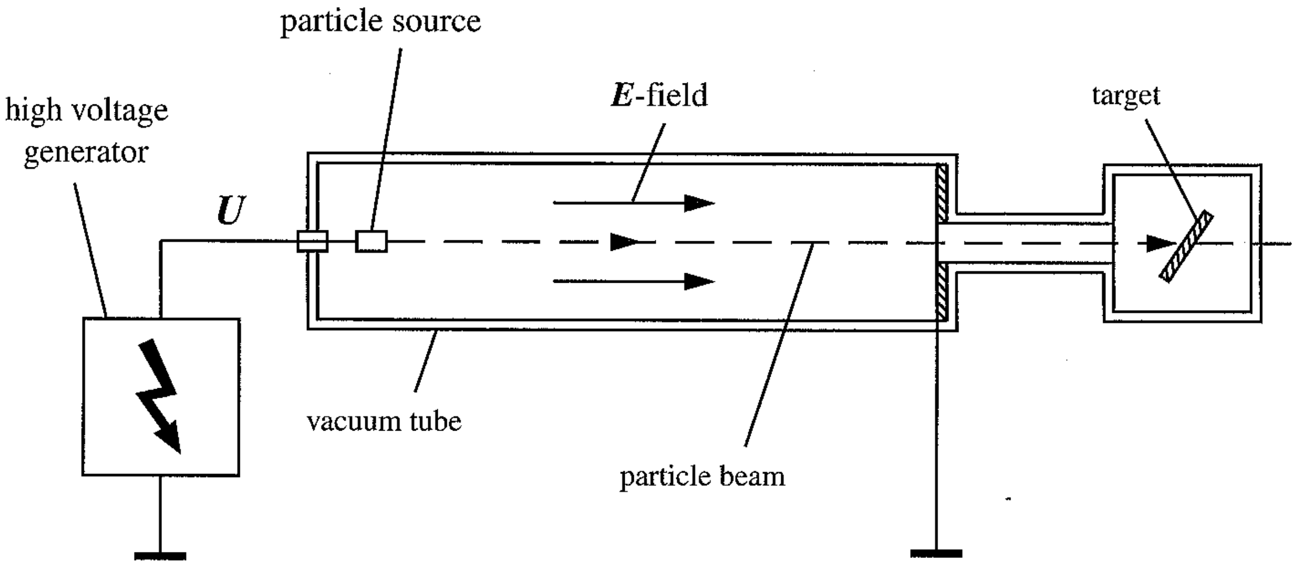
$\frac{1}{\sqrt{E(MeV)}}$

$10^{17}s \approx 3GYears$

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.