Particle Accelerators

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How to perform particle physics experiments

Overview

A particle physics experiment needs:

1. Particles to collide together and create interactions
2. A detector which can detect the outcome of these interactions

Today; particles to collide together:

Cosmic rays

Linear accelerators

Circular accelerators

Particles used in accelerators

Cosmic rays

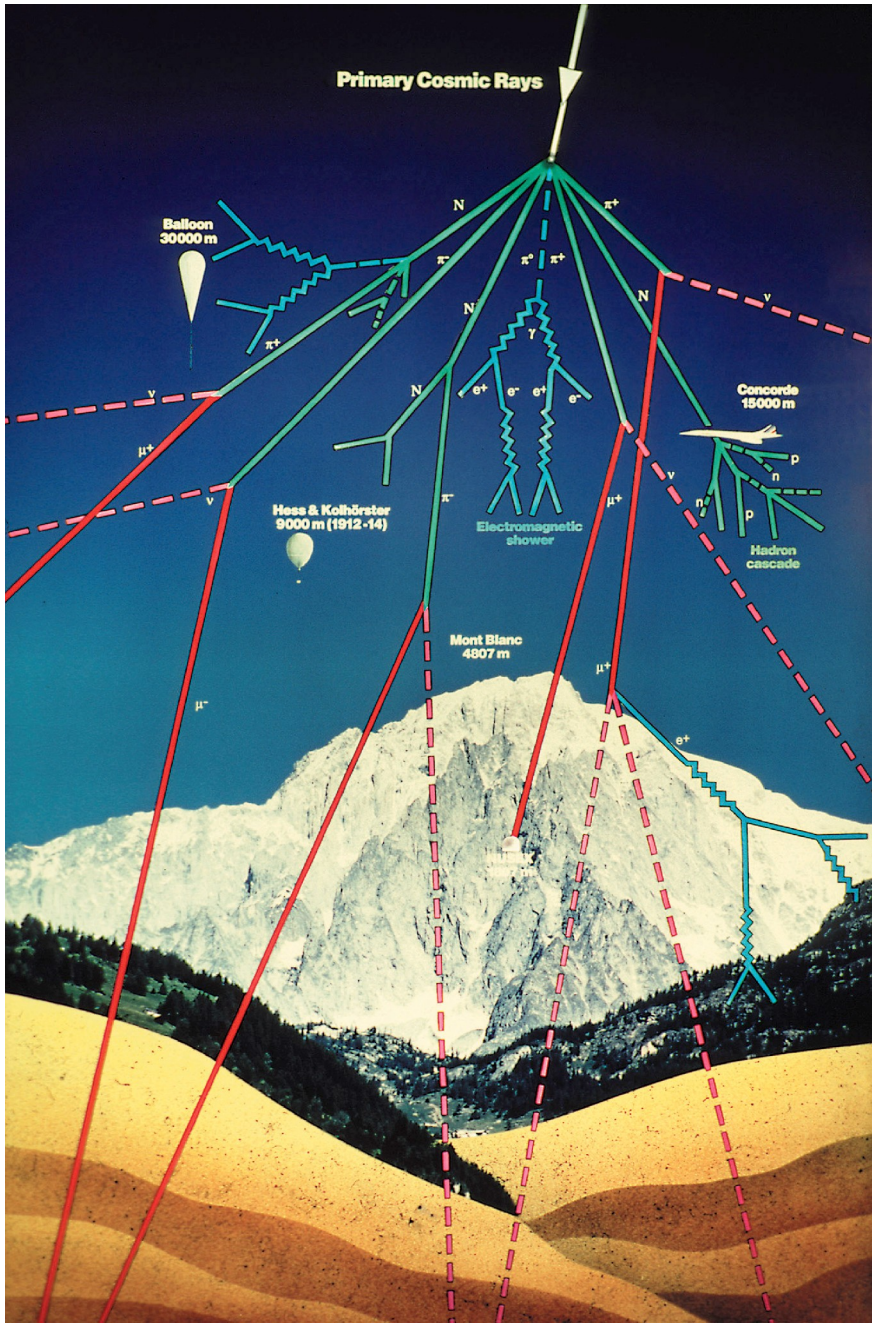
Cosmic rays – extra terrestrial particle accelerators!

Sources of high energy rays: galactic, extra-galactic

85% protons, 12% α, e, nuclei

Particle showers on entry to atmosphere

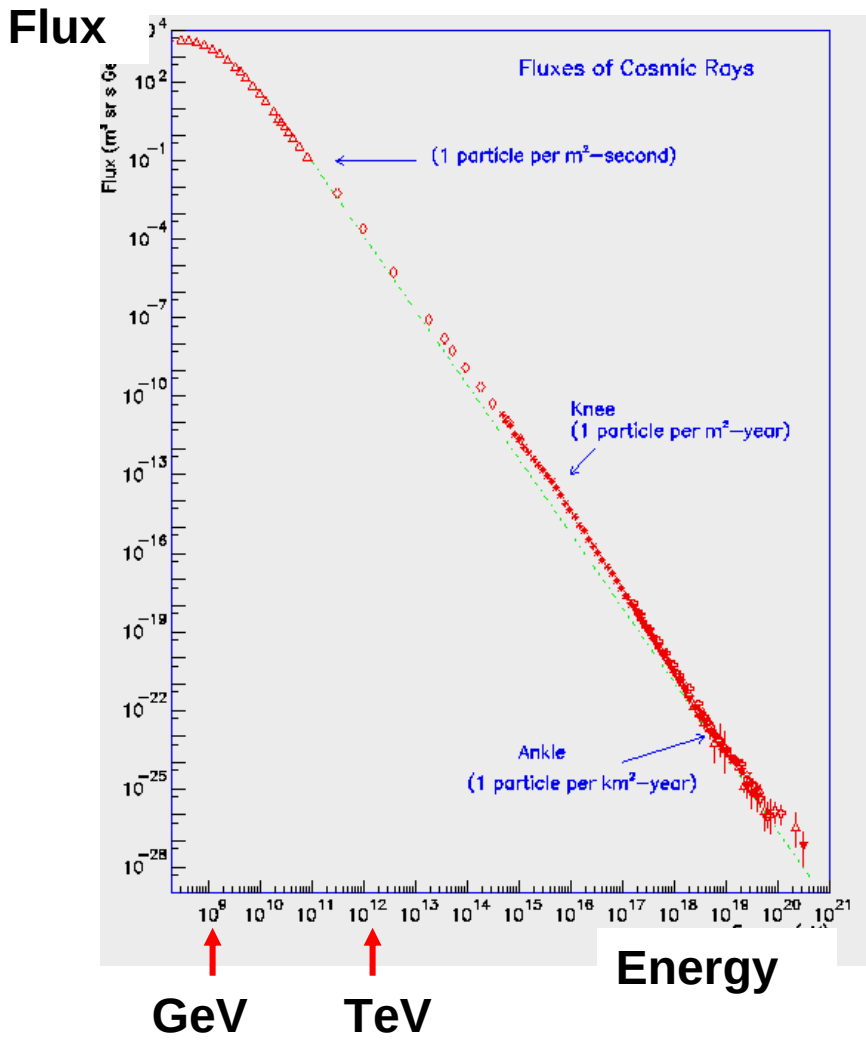
Muons live long enough to be detected at earth's surface



Cosmic rays

Advantages:

Disadvantages:



Accelerators

Machines that accelerate beams of particles to a specific energy

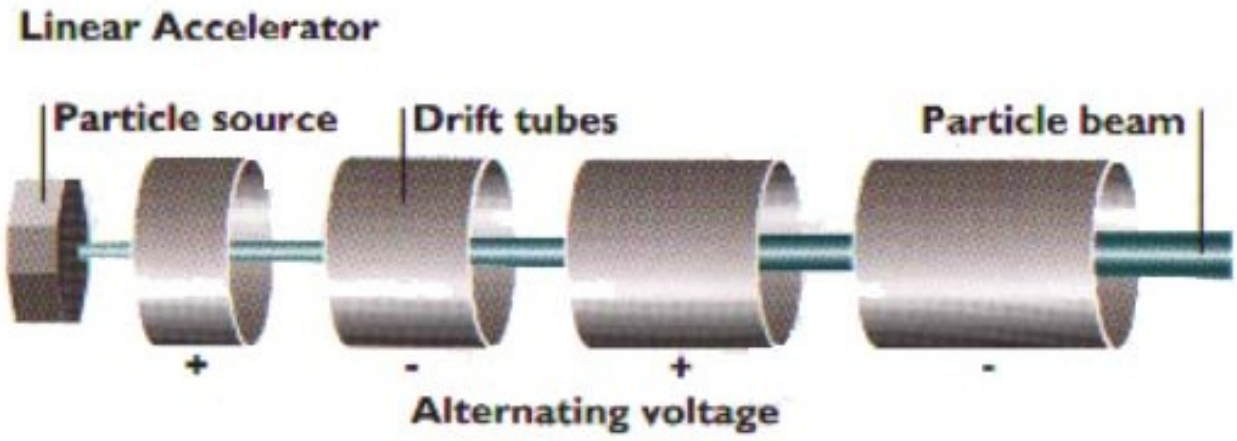
Machines use electromagnetic force to boost particle energy

Can be **linear ("linac")** or **circular ("synchrotron")**

Advantages:

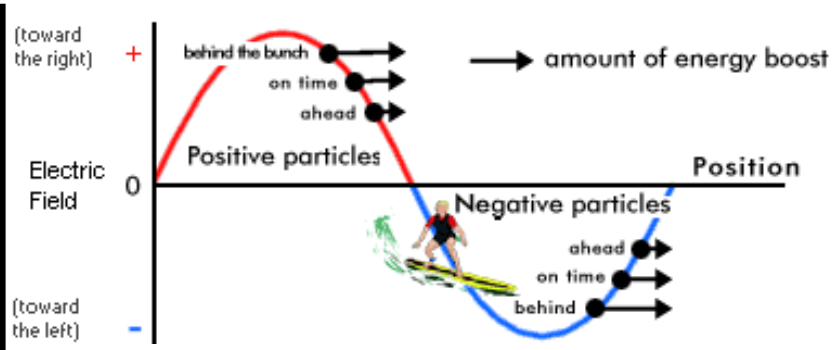
Disadvantages:

Linear accelerators



Radio frequency field sets up moving em wave for acceleration

Essentially waveguide, with periodic cavities.



Wave travels down accelerator

Sec. 3.1.1 Martin & Shaw

Linear accelerators

Accelerating power limited by length:

Protons:

- **70m → ~200 MeV**
- **input to circular accelerators**

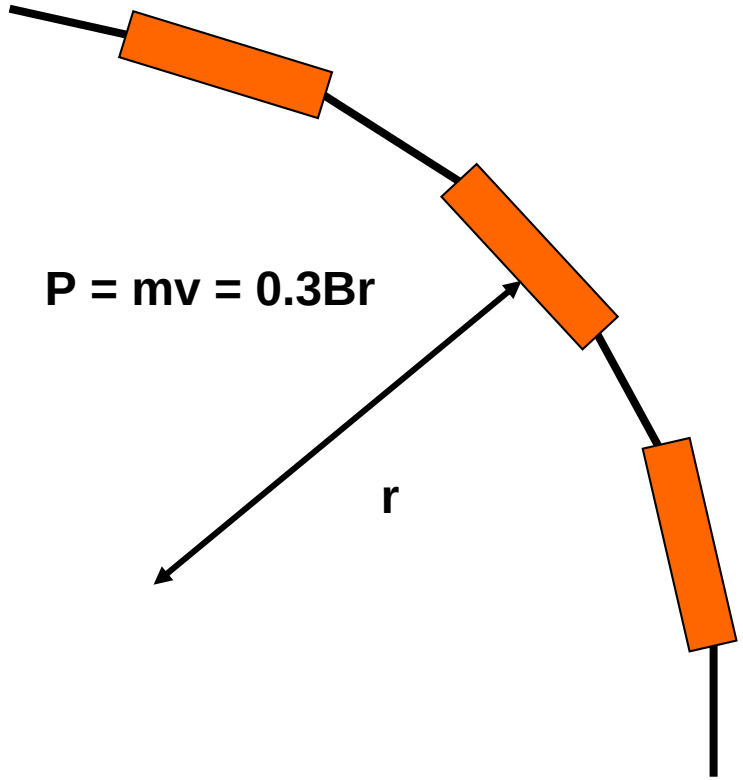
Electrons:

- **2 miles → 45 GeV (SLAC)**

Next generation of accelerators will be electron linear collider (~500 GeV)

Circular accelerators

Same principle as linacs (but circular)



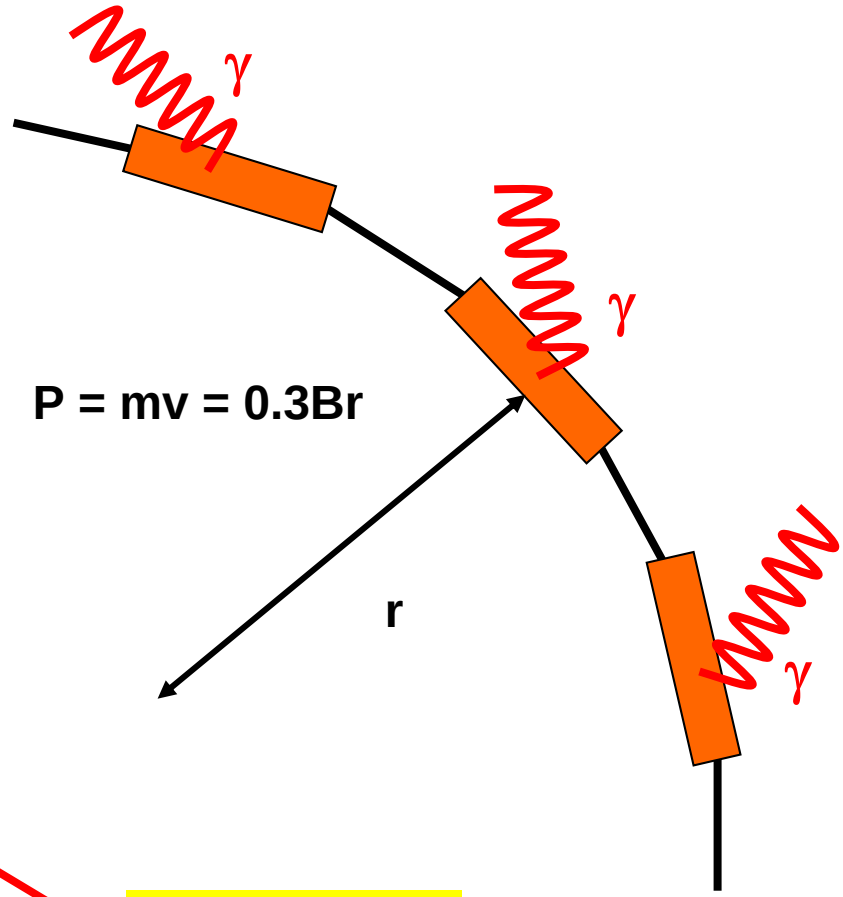
Circular accelerators

Circular path ⇒ particle accelerates ⇒ synchrotron radiation emission

Energy lost / turn:

$\Delta E = 4\pi q^2 \beta^3 \gamma^4 / (3\varepsilon_0 r)$

- **q = charge, r = path radius**
- $\beta = v/c$, $\gamma = 1/\sqrt{(1-\beta^2)}$ **(= E/m)**
- ε_0 **= permittivity of free space**

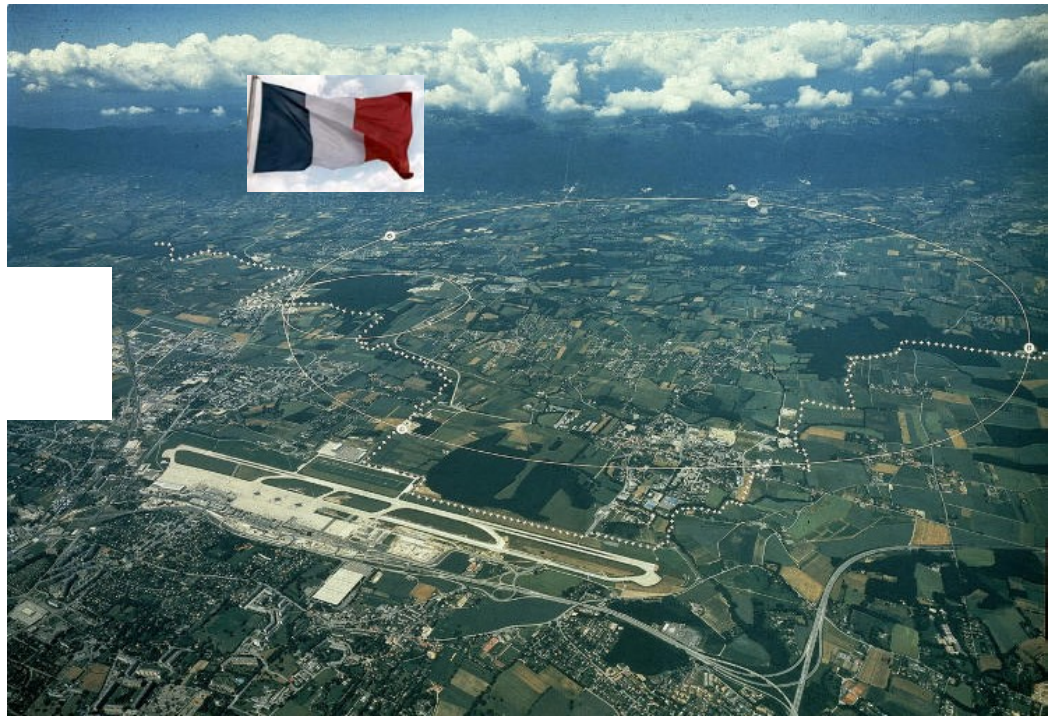


$\Delta E \propto 1/m^4$ **!**

Eg. LEP/LHC

27 km ring: r = 4.3 km

- **LEP (e^+e^-):**
  - 1989 – 2000
  - electron energy 45 – 101 GeV
  - 8 bunches of 4 $.10^{11}$ particles; ~0.5 MW dissipated at 45 GeV!
  - 4 experiments
- **LHC (pp):**
  - 2007 →
  - proton energy 7 TeV
  - 5 experiments



Eg. Tevatron

4 mile ring: r = 1km

- Fermilab, Chicago, USA
- Proton – anti-proton collider
- 2 experiments: CDF, D0

Beam energy = 0.98 TeV

Operational 2001 $\rightarrow$

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