

Accelerators 101

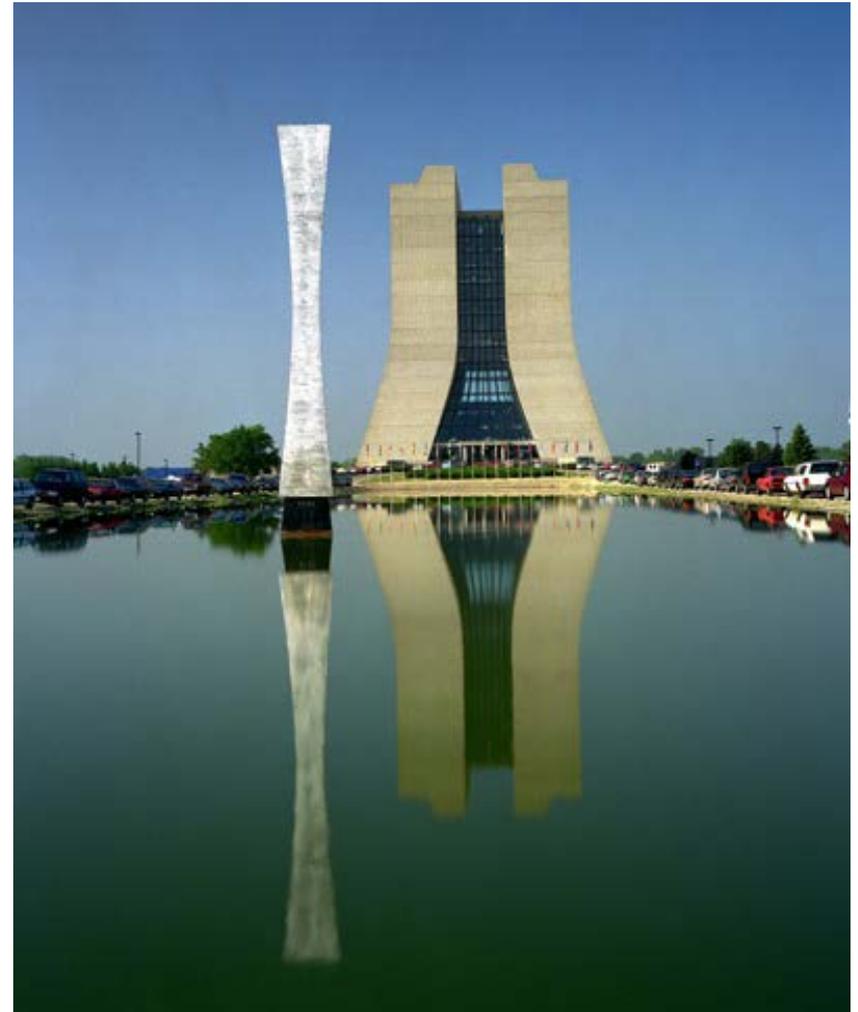
Ask-A-Scientist

5 October 2014

David Harding



Operated by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

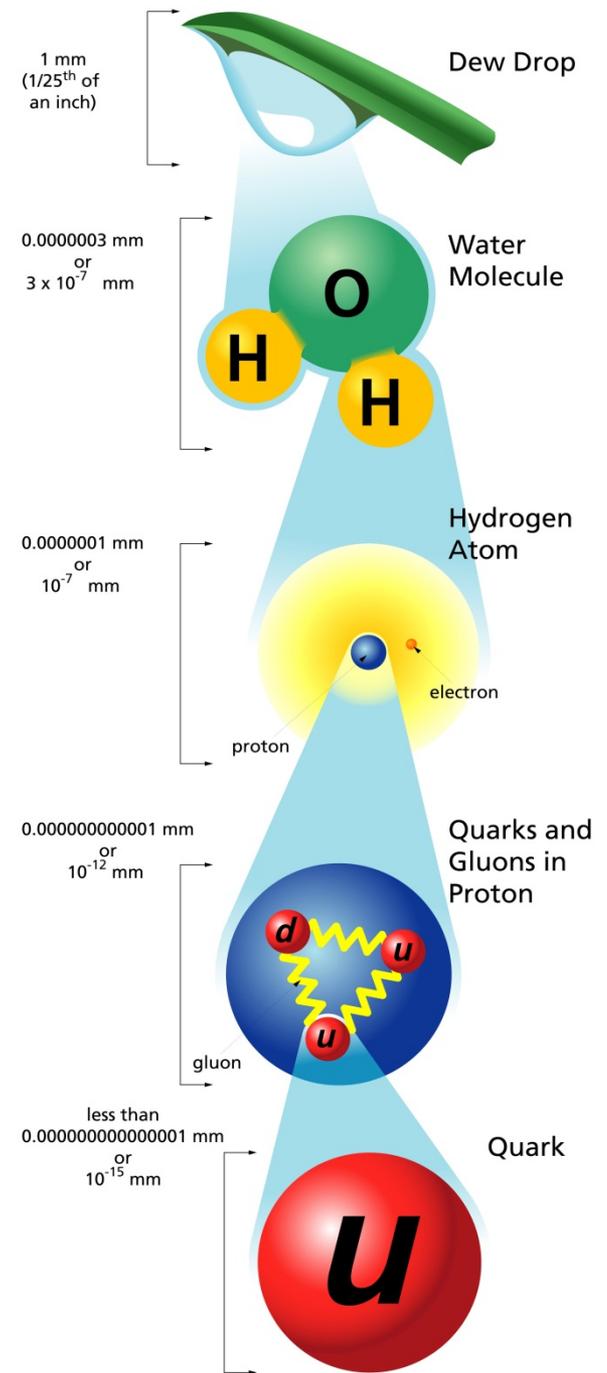


Particle Accelerators

- What are particle accelerators?
- How do they work?
- How have they changed?
- How are they used?

Particle Accelerators

- Particle
 - Molecule
 - Atom
 - Nucleus
 - Elementary particle
- Accelerator
 - Makes go faster
 - (Not physics definition)

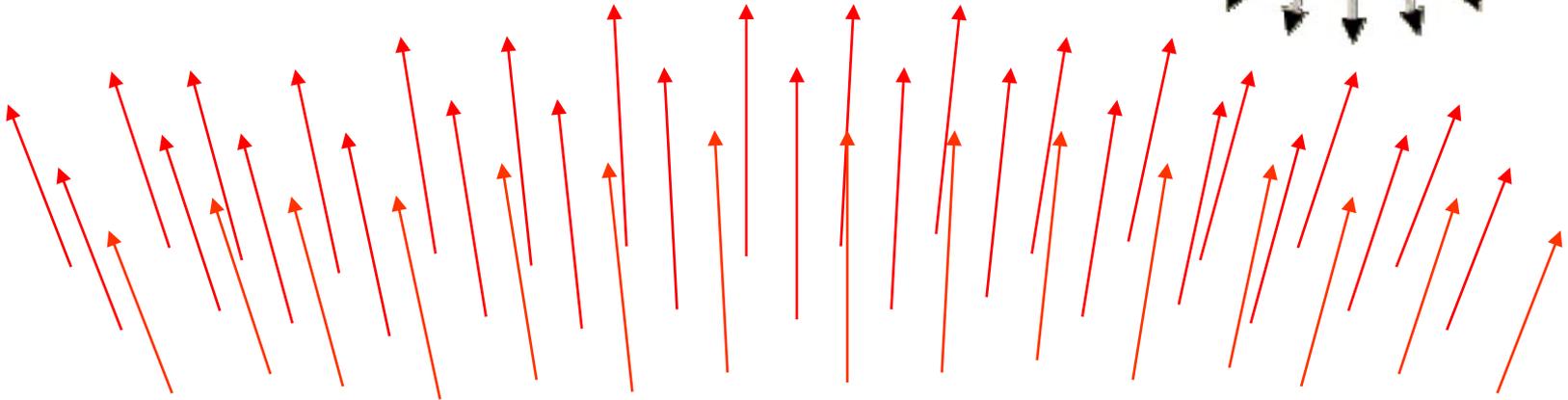
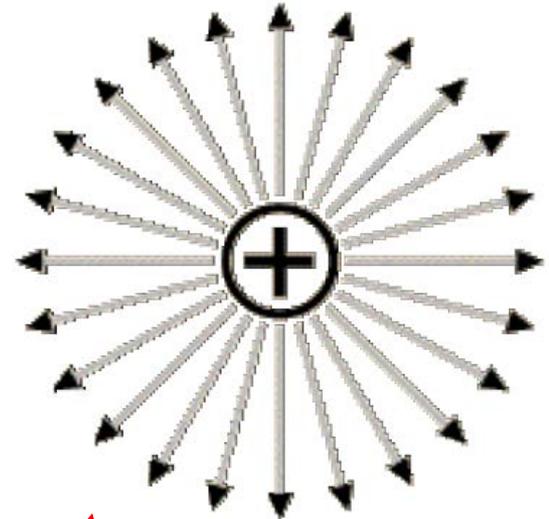


Newton's Second Law of Motion

$$F = ma$$

Force from electric field

- Opposite charges attract
- Like charges repel
- Describe as field

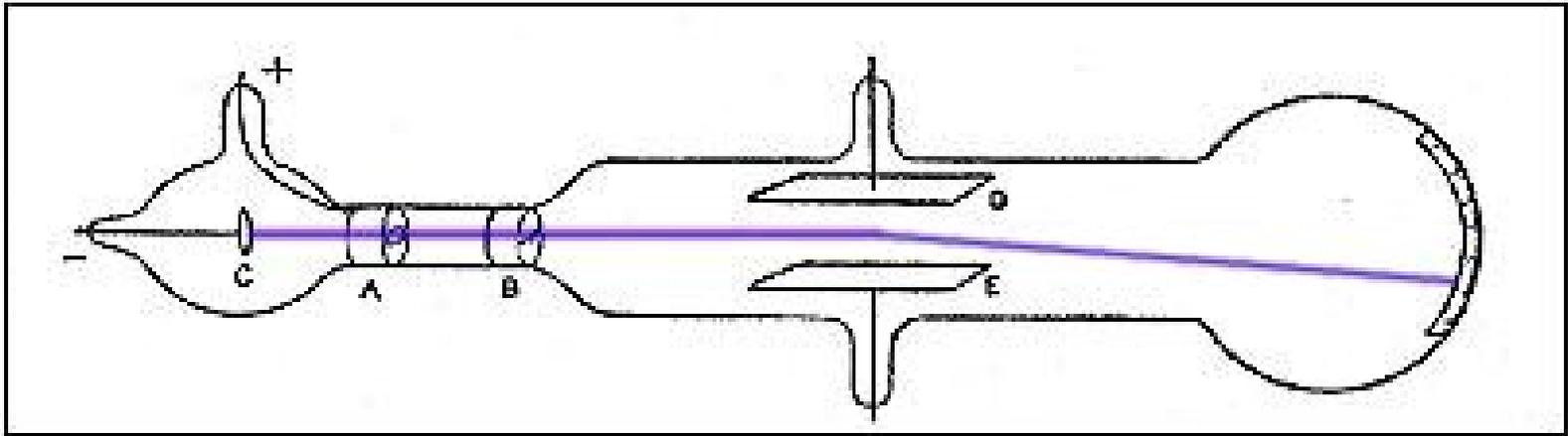


A charged particle in an electric field feels a force

The force is in the direction of the field

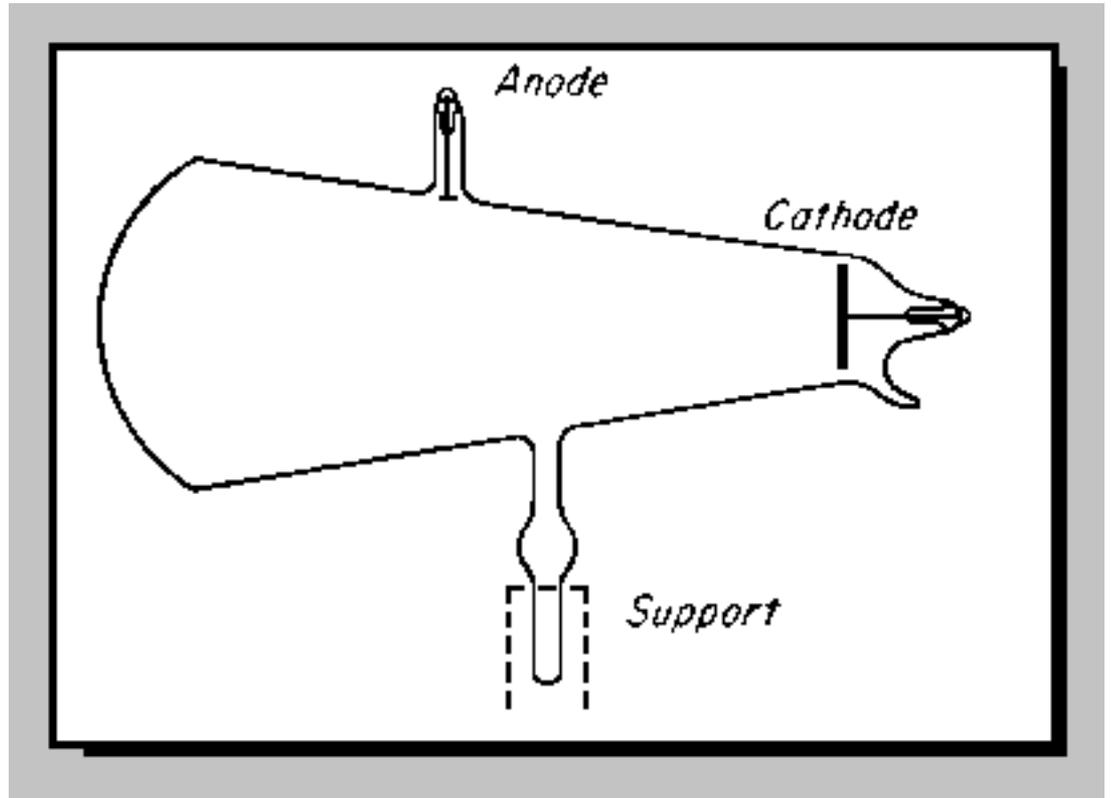
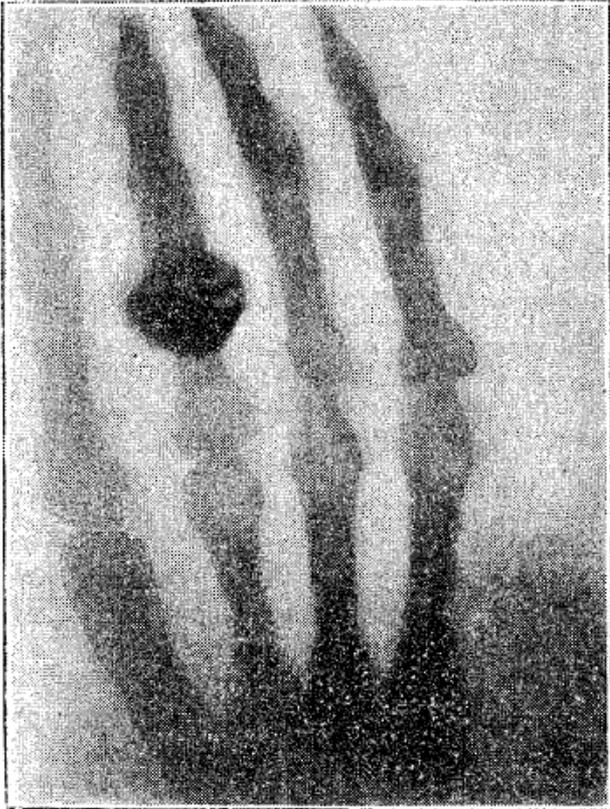
- Big electric field, big force
- Energy given is force times distance
- Voltage is electric field times distance
- To increase energy, push in direction of motion

Cathode rays



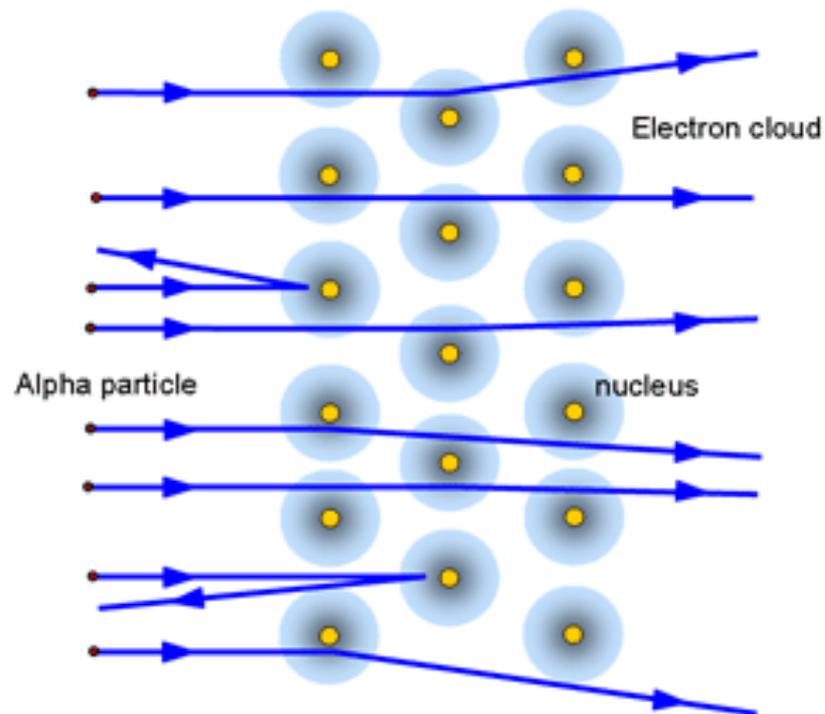
J.J. Thomson experiment 1890's

X-Rays



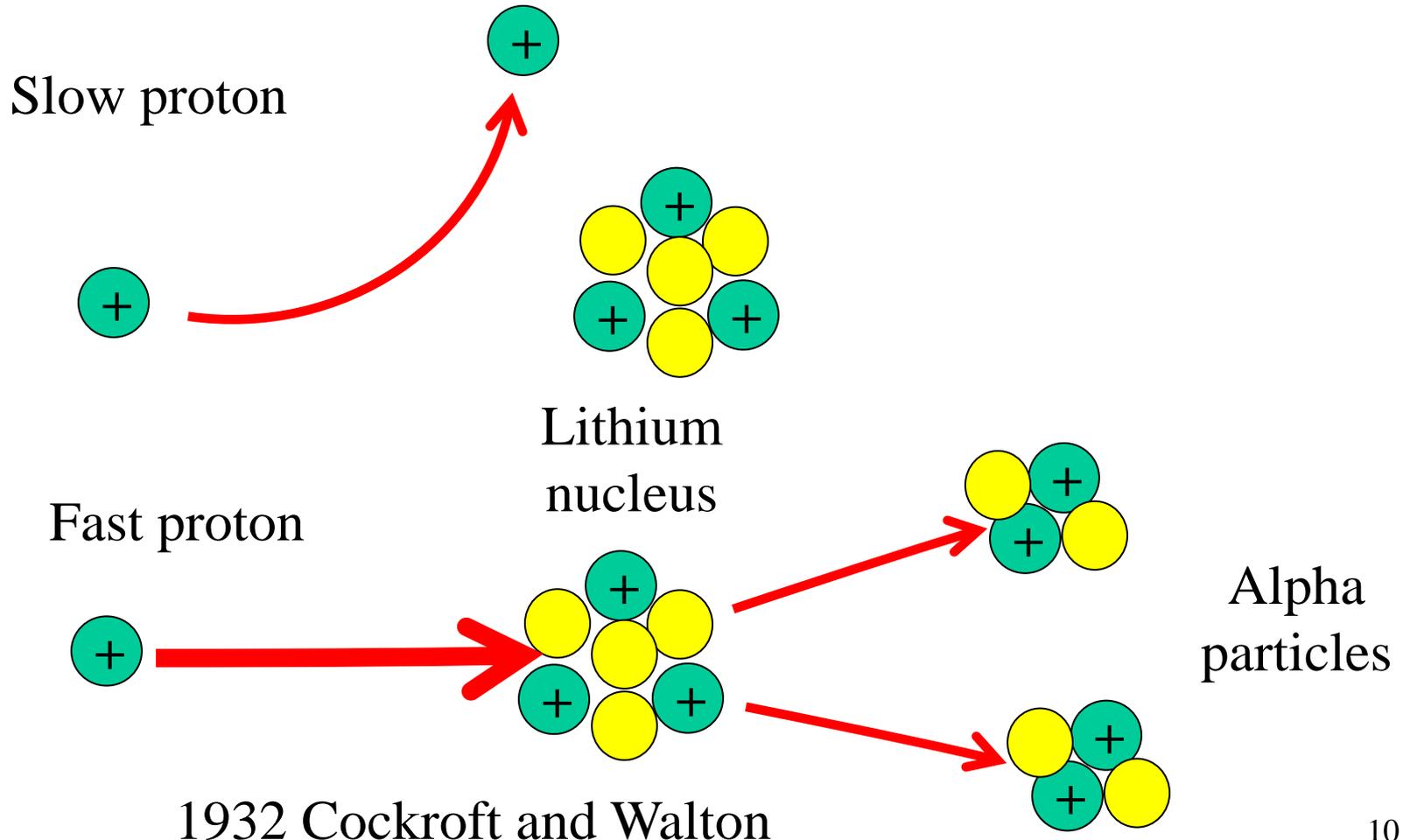
Wilhelm Röntgen 1896

Particle Beams Probe the Structure of Atoms

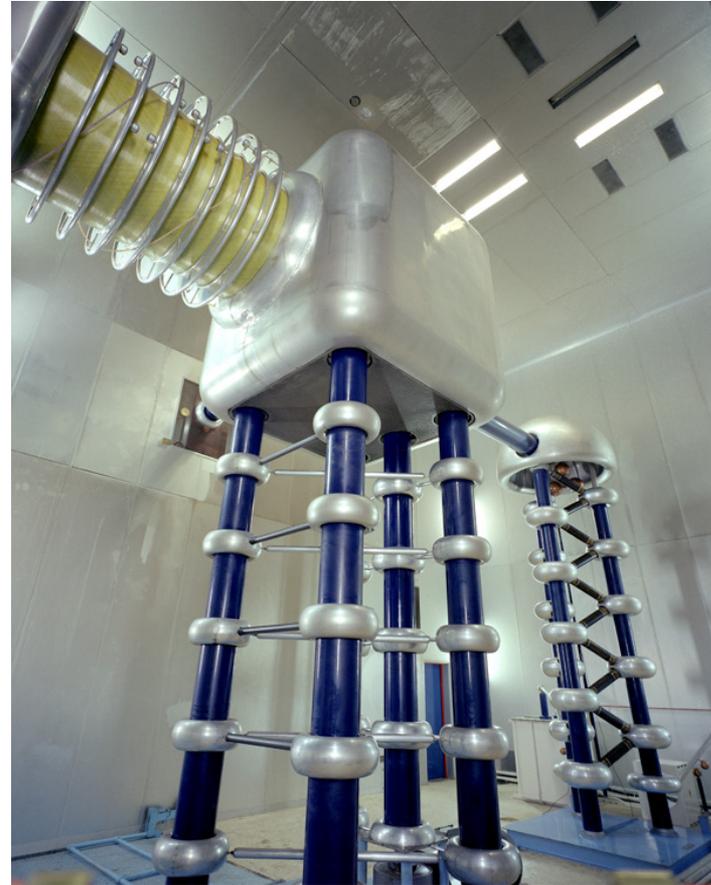
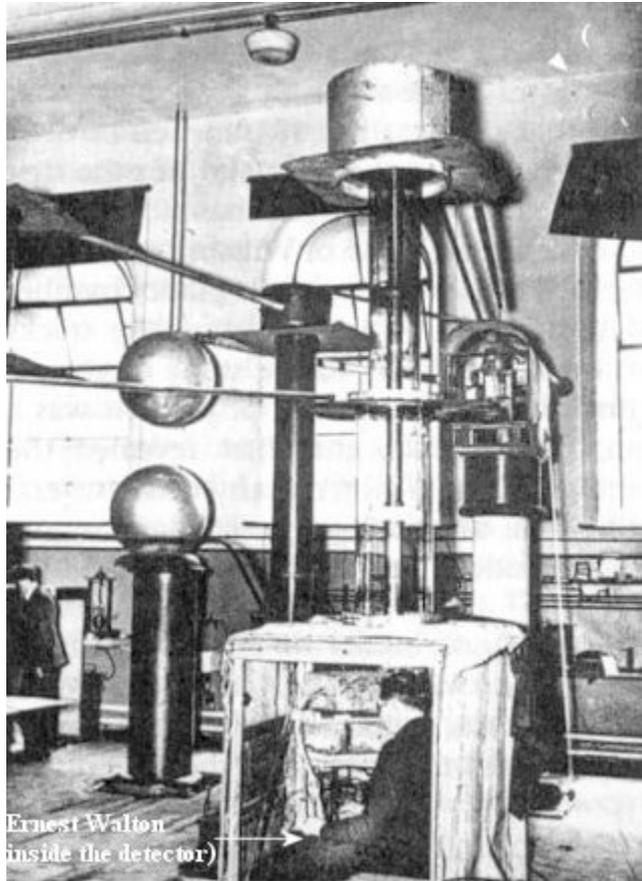


1909 Rutherford, Geiger, Marsden

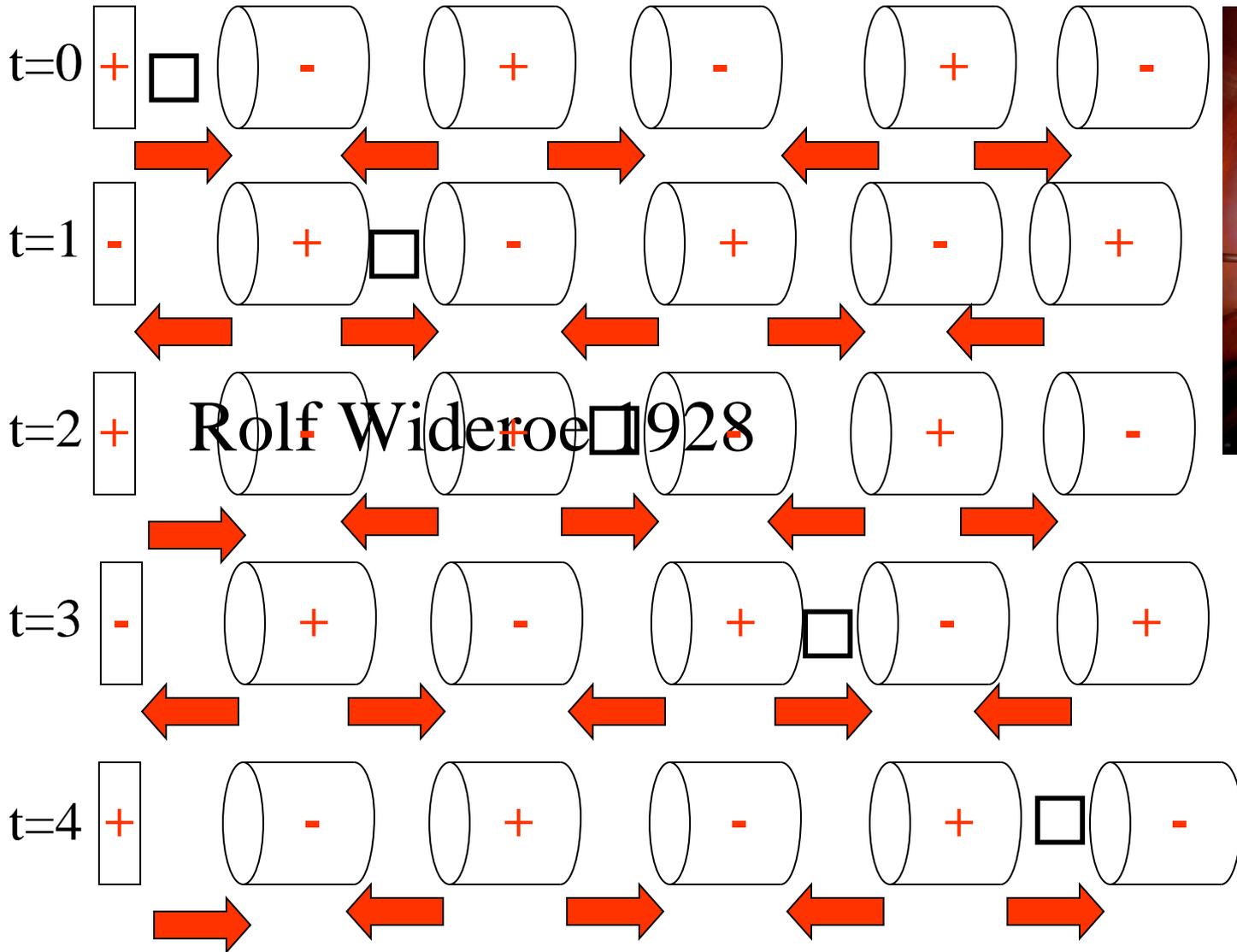
Particle Beams Probe the Structure of the Nucleus



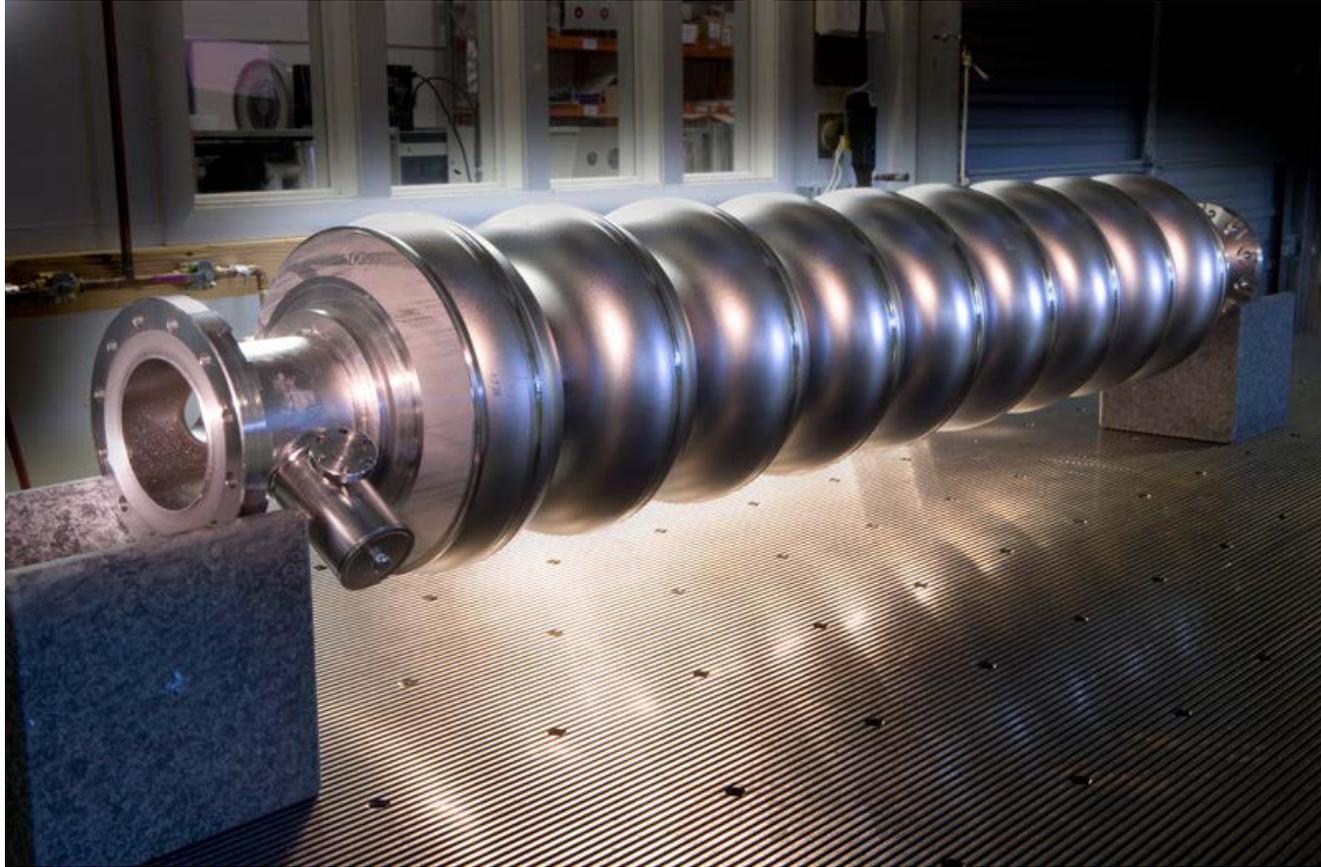
Cockcroft-Walton Accelerators



Drift Tube LINAC



Superconducting Radiofrequency Accelerating Cavity



Magnetic Fields



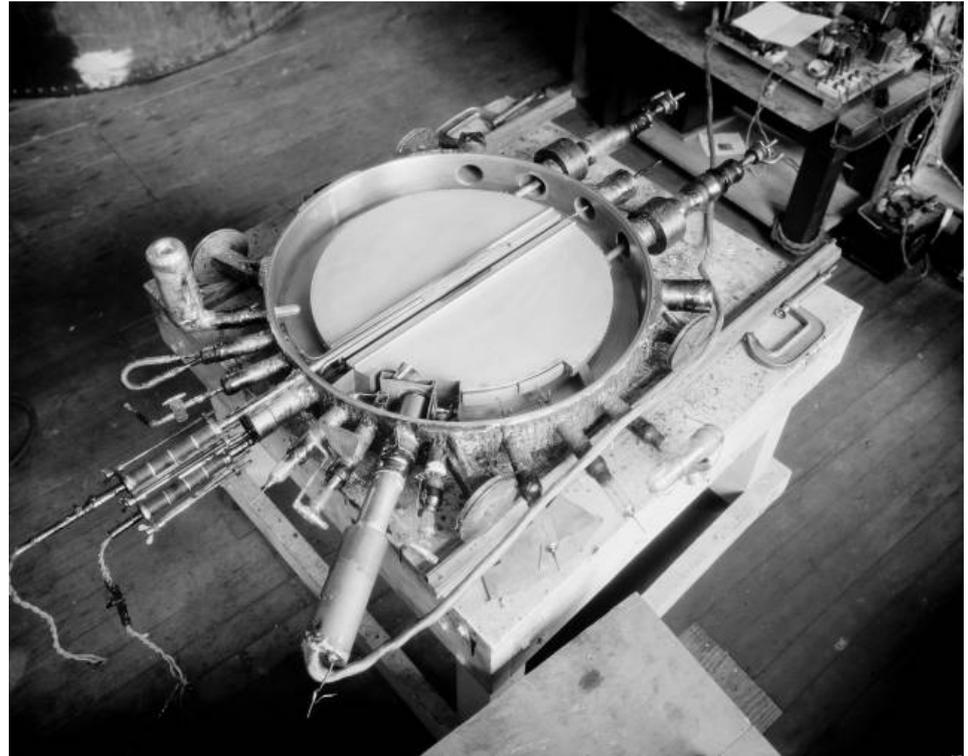
A charged particle moving in a magnetic field feels a force

The force is sideways

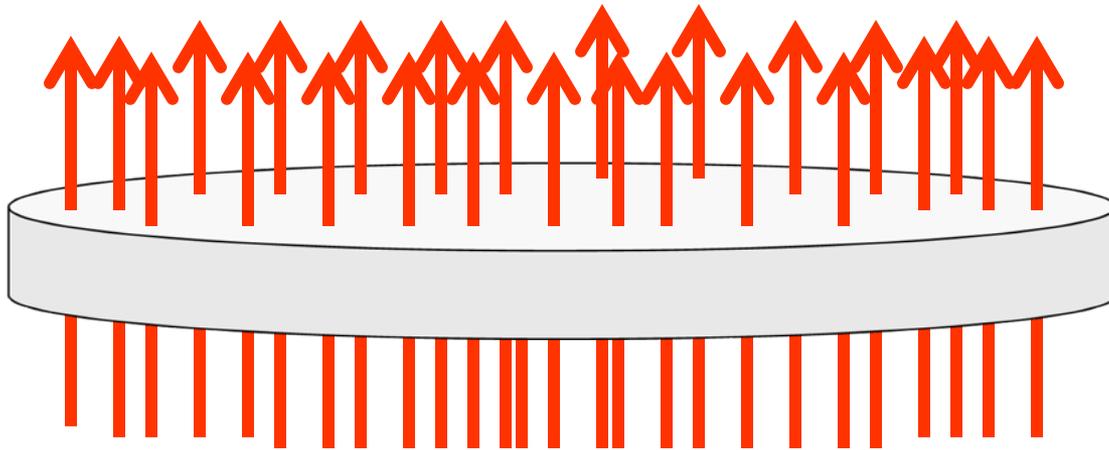
⇒ The particle bends in a circle

- Strong magnetic field, small circle
- High momentum particle, big circle

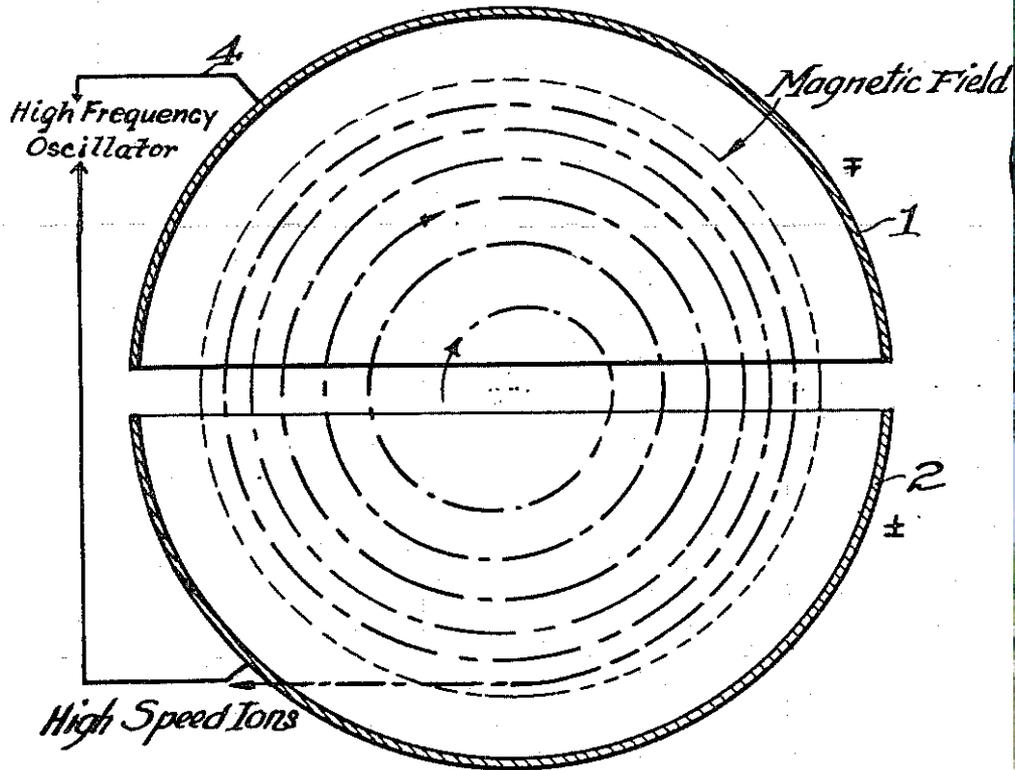
Cyclotron Accelerator



Cyclotron Accelerator



Cyclotron Accelerator



Cyclotrons Today

- Nuclear physics research
- Radioactive isotope production
- Chemical analysis
- Medical therapy



Synchrotrons

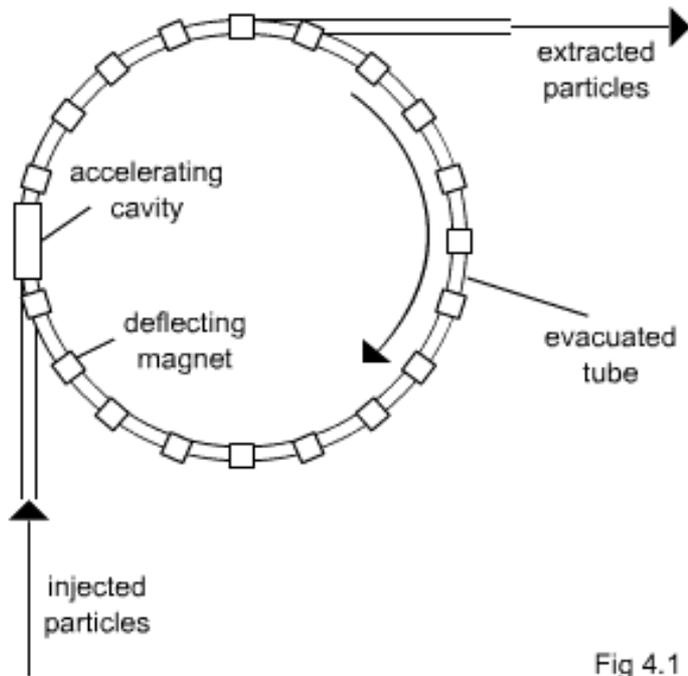


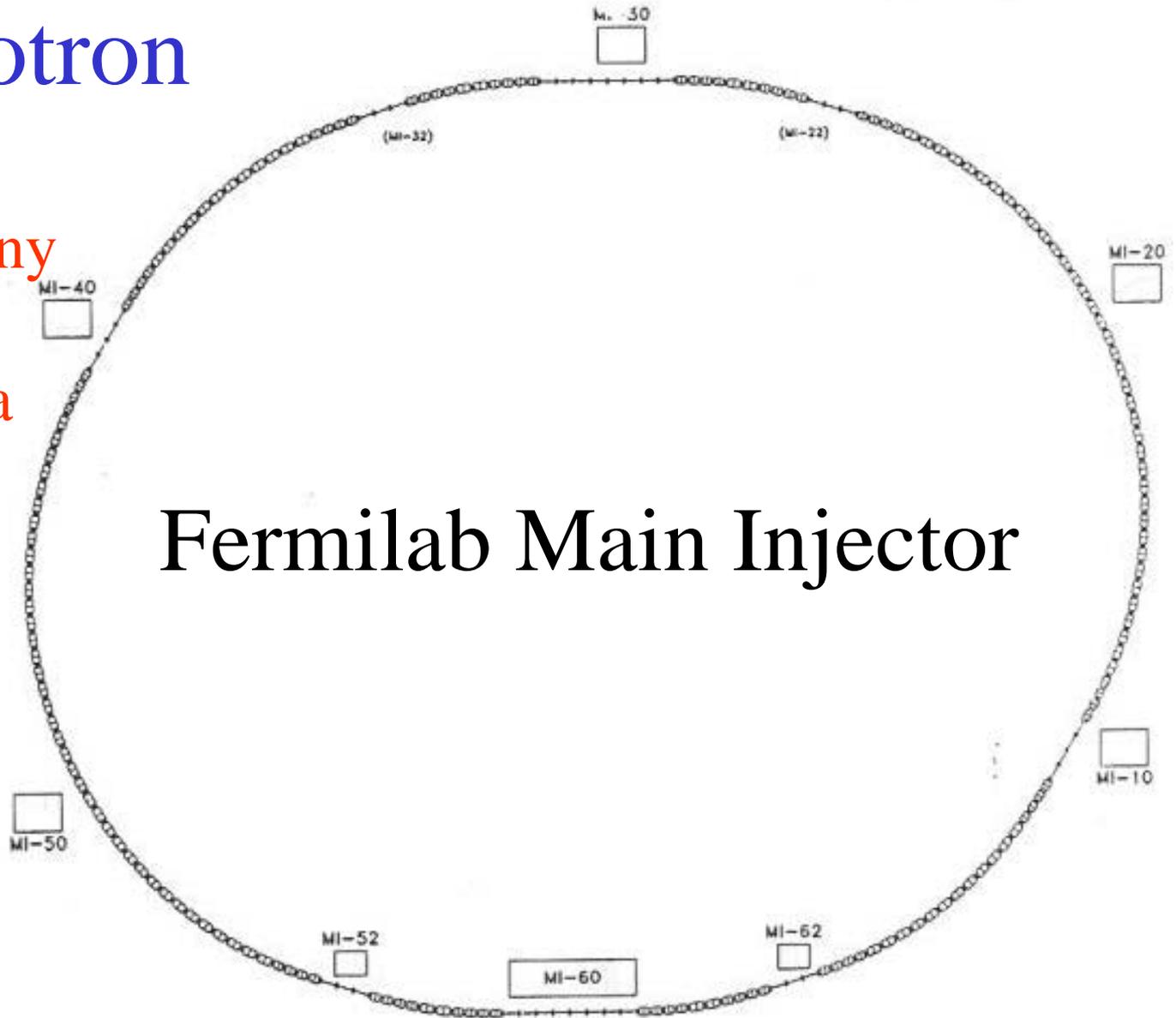
Fig 4.1



Purdue University 1946-1952

Synchrotron

String
together many
long skinny
magnets in a
big ring.



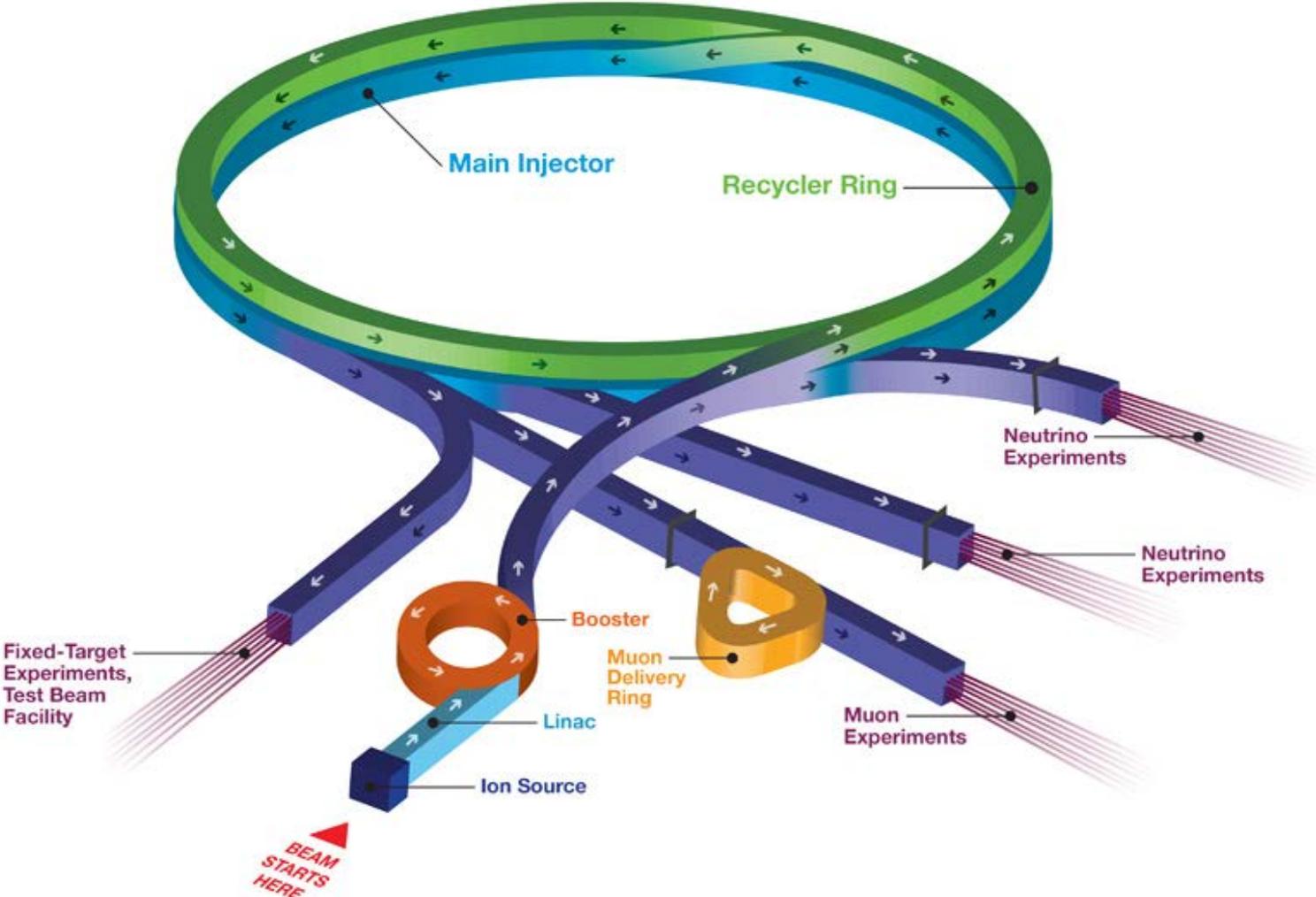
A Synchrotron Magnet



Magnets in Main Injector



Fermilab Accelerators

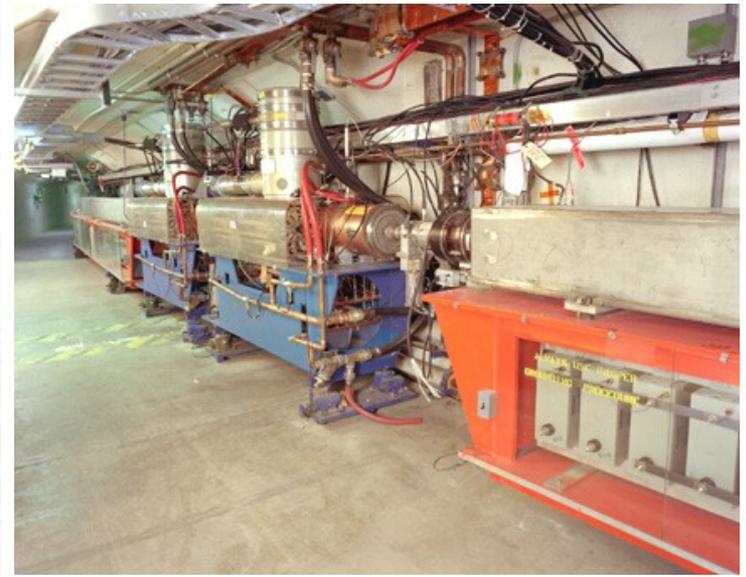




Cockcroft-Walton 750 KeV
velocity = 0 *0.04 c*



LINAC 400 MeV
0.71 c



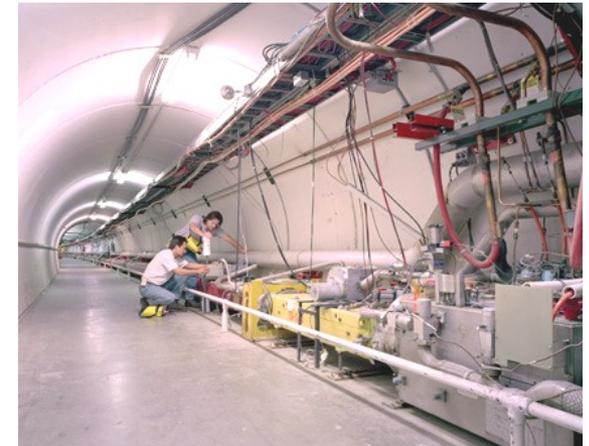
Booster 8 GeV
0.994 c



Main Injector 150 GeV
0.994 c *0.99998 c*



Antiproton "Bottle"
@ 8 GeV

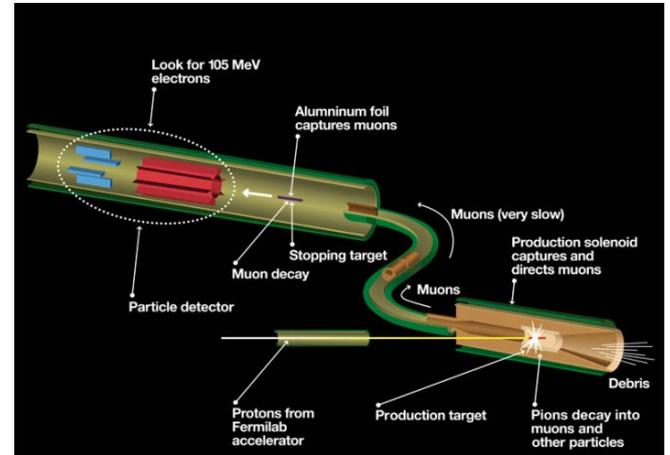
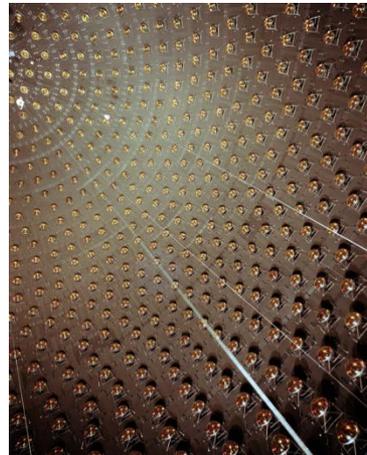
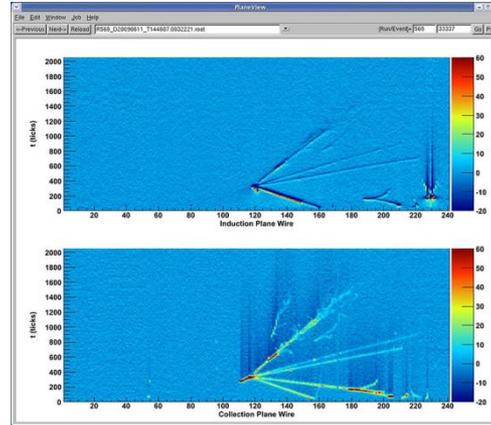


Tevatron 1000 GeV = 1 TeV
0.99998 c *0.9999995 c*

Einstein's Equation

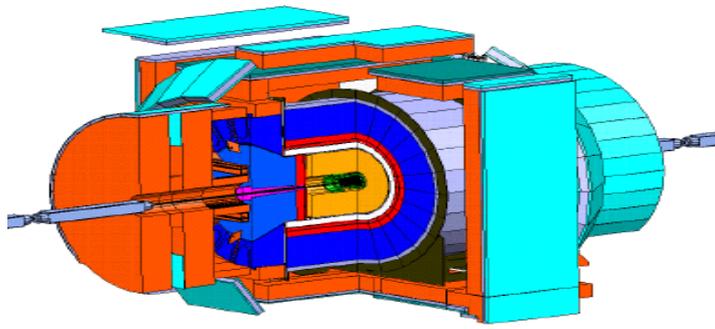
$$E = mc^2$$

Fermilab High Intensity Experiments

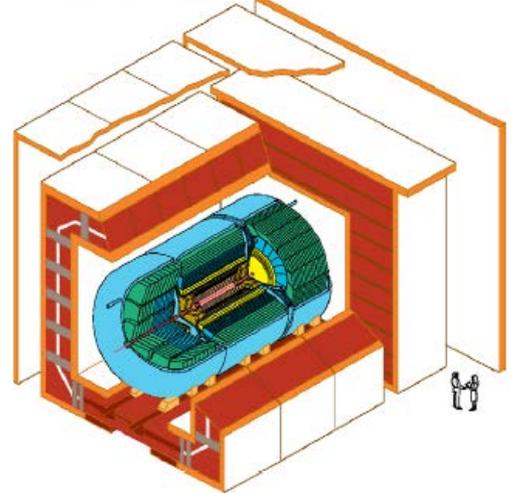
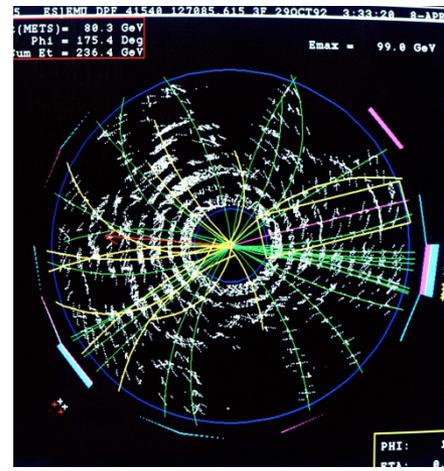
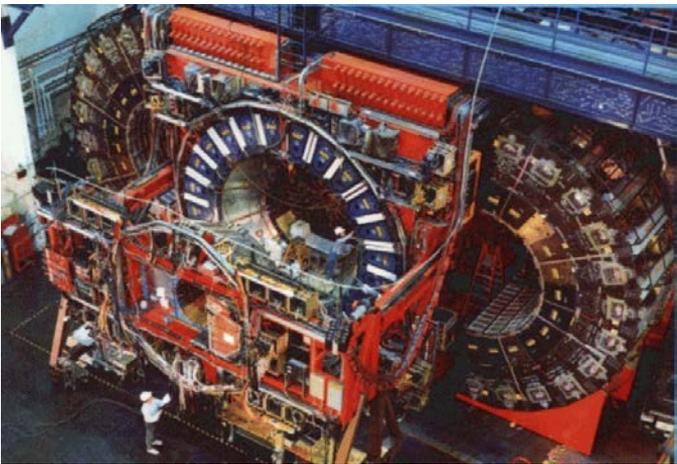
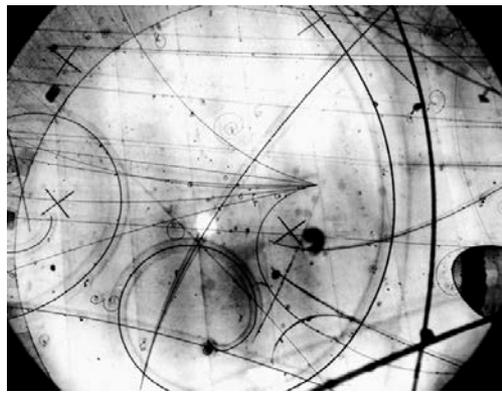


Fermilab Collider Experiments

CDF and D-Zero

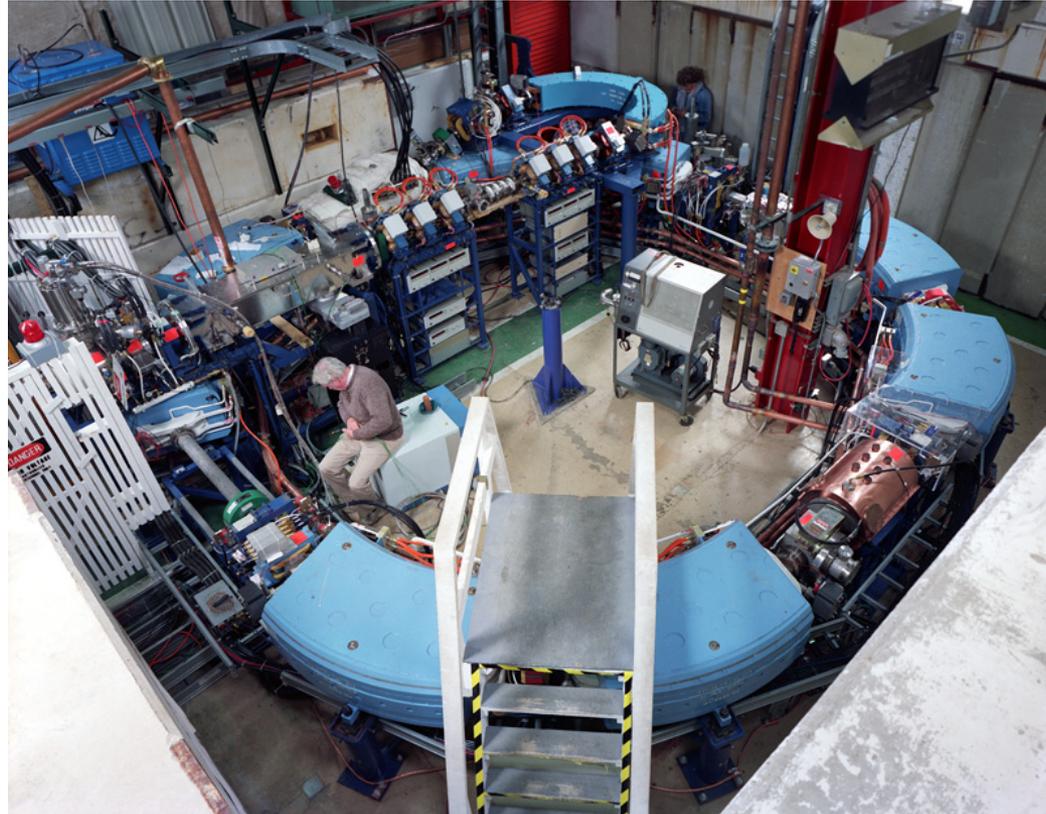


CDF Detector



DØ Detector

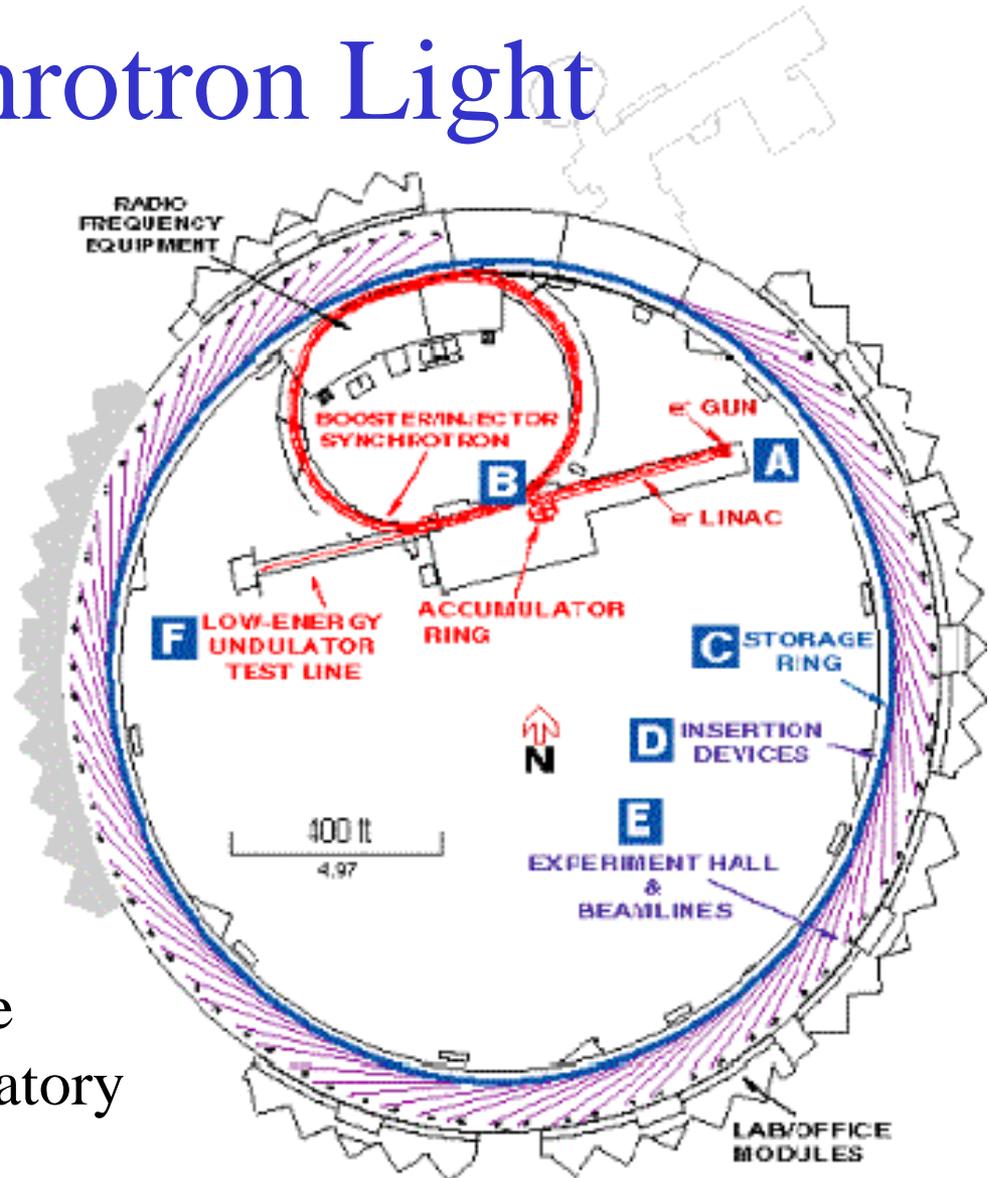
Medical Synchrotrons



Loma Linda Medical Center

Synchrotron Light

- Material science
- Crystallography
- Spectroscopy
- Photolithography

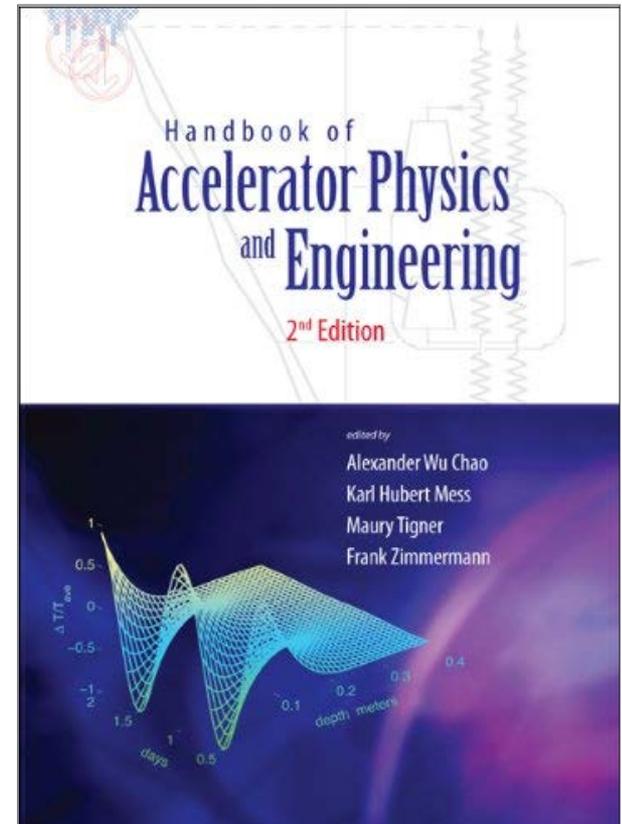
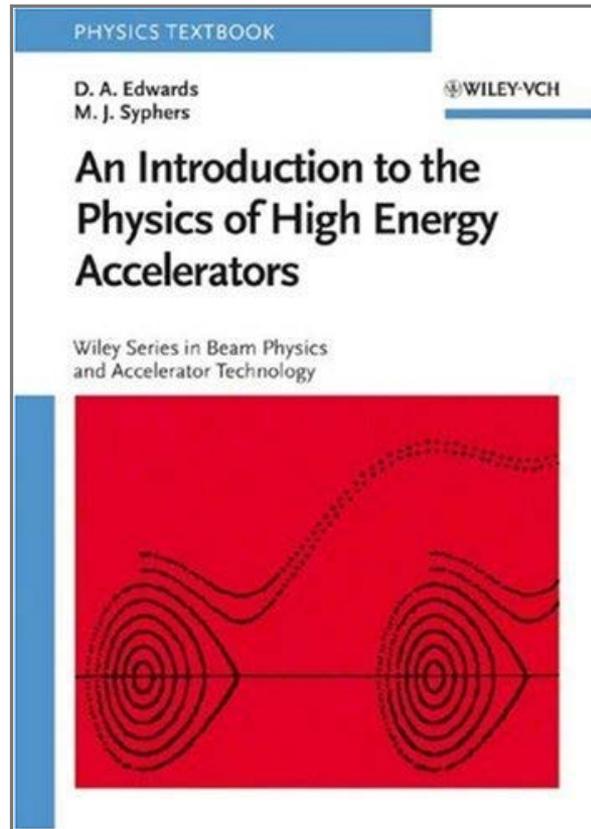
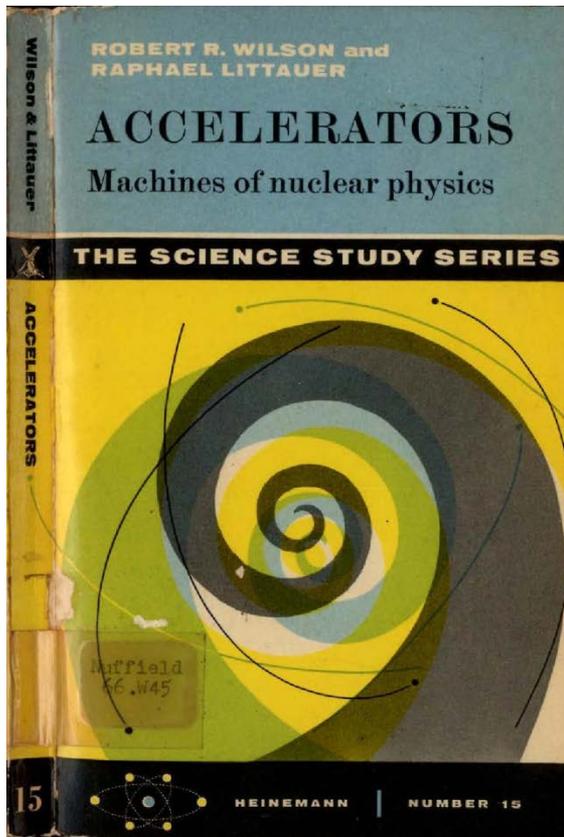


Advanced Photon Source
Argonne National Laboratory

Particle Accelerators

- Particle accelerators work by clever use of the physics of electricity and magnetism
- Major advances in accelerator technology come from pursuing basic physics research
- Particle accelerators of all kinds are used in many other fields of science and in industry

My Favorite Accelerator Books



More to do at Fermilab

- www.fnal.gov
- Lederman Science Center
- Buffalo, prairie viewing
- Bicycling, walking
- Concerts, dancing
- Lectures, seminars
- Educational programs



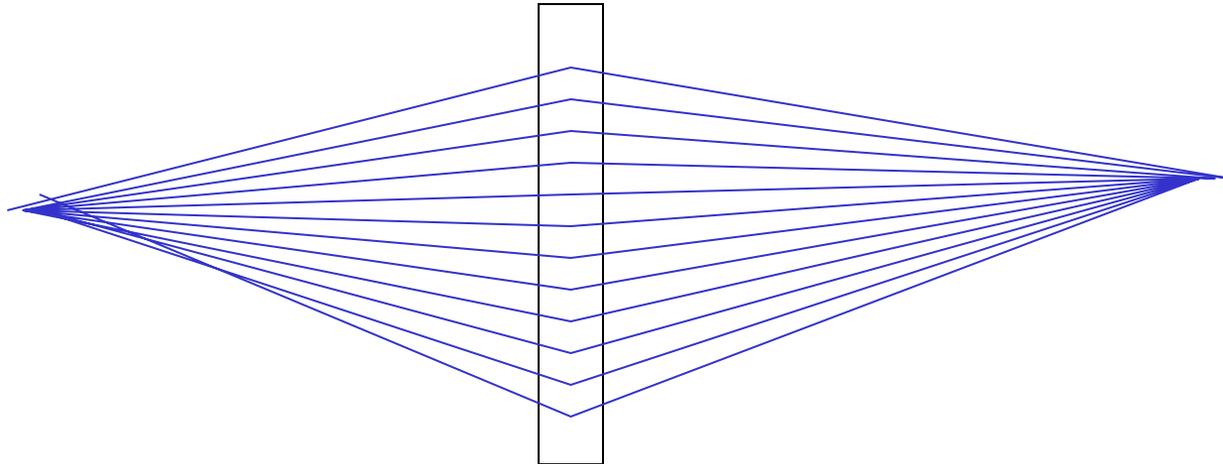
Medical use of a LINAC



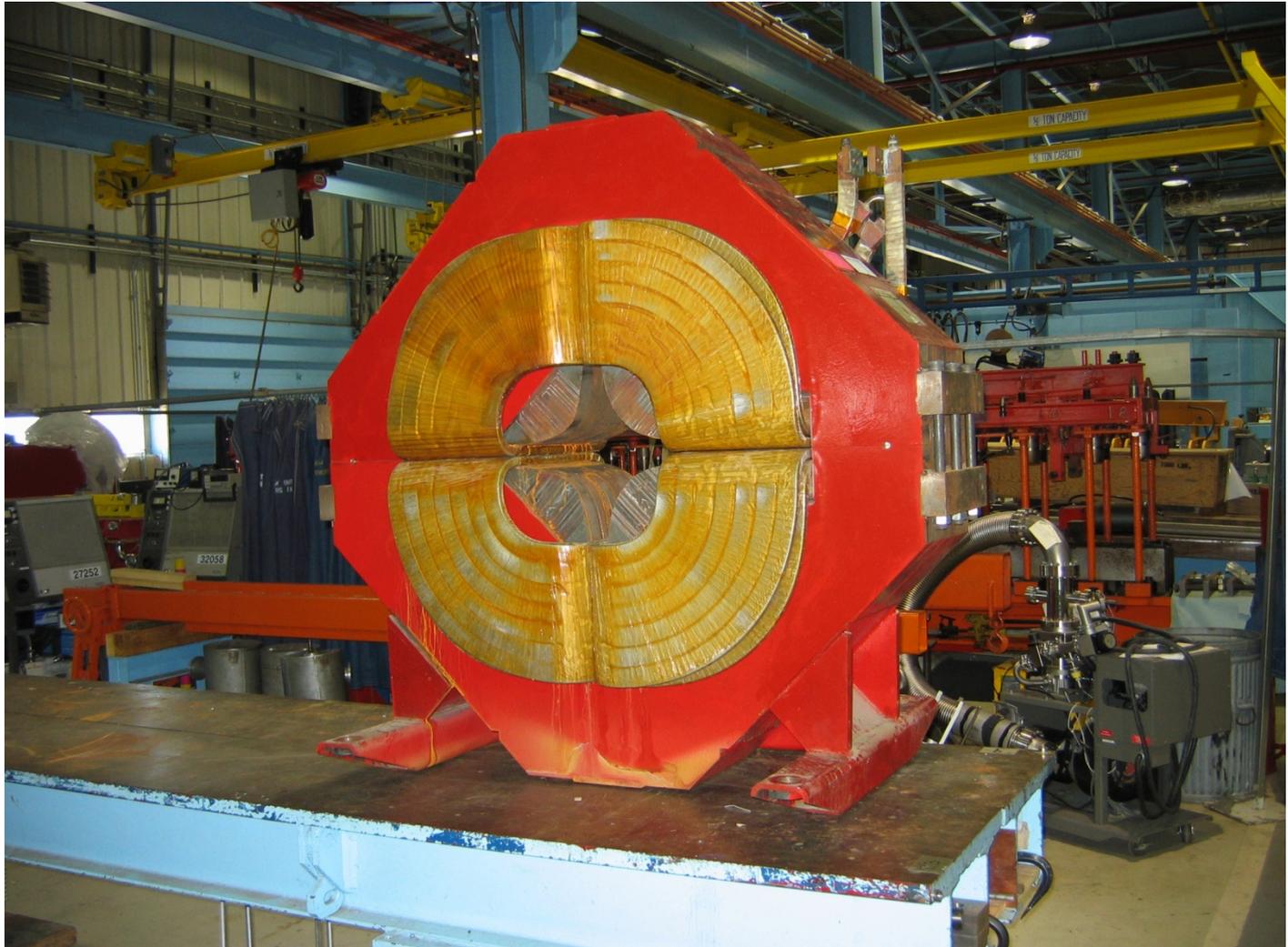
Fermilab Neutron Therapy Facility

Focusing magnets

- Beam tends to spread out
- Must constantly focus the beam
- Special magnets do the job



Focusing magnet



Quadrupole Magnet

