Integrative Studies in Physical Science ISP209

Fall Semester 2005
December 1 Lecture
Section 001

Professor Stan Schriber

The Mystery of the Physical World

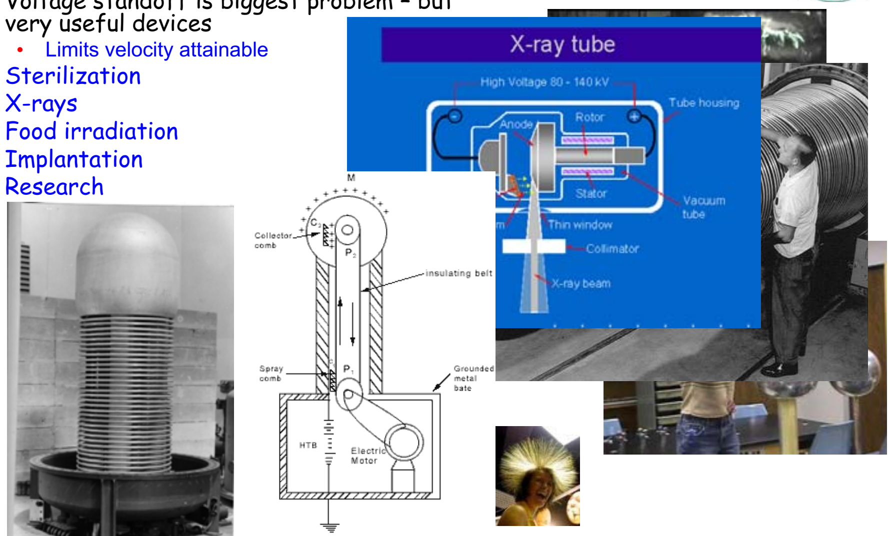
- **ISP 209**
  - ***Accelerator Physics today!***
  - ***No Quiz***
- **Homework?**
  - ***Two problems***
- **DOCS:**
  - ***Lecture VGs one day early***
- **Questions?**

What is an Accelerator

- A device that speeds particles to high velocities.
  - Types:
    - DC
    - RF
  - DC Examples
    - X-ray Tubes
    - Ion Sources
    - Van de Graff
    - Tandem Accelerator
  - RF Examples
    - Linear machines
    - Circular Machines

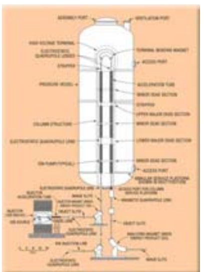
DC Devices are Limited

- Voltage standoff is biggest problem – but very useful devices
  - Limits velocity attainable
- Sterilization
- X-rays
- Food irradiation
- Implantation
- Research

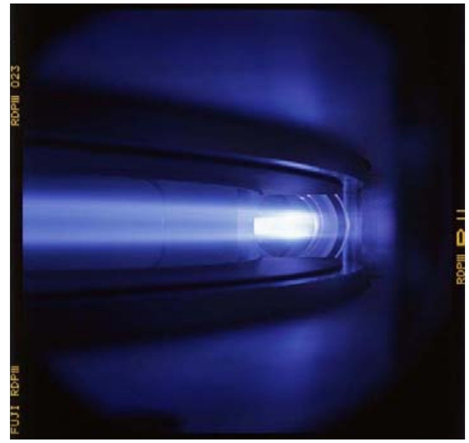


DC Example - Tandem Accelerator

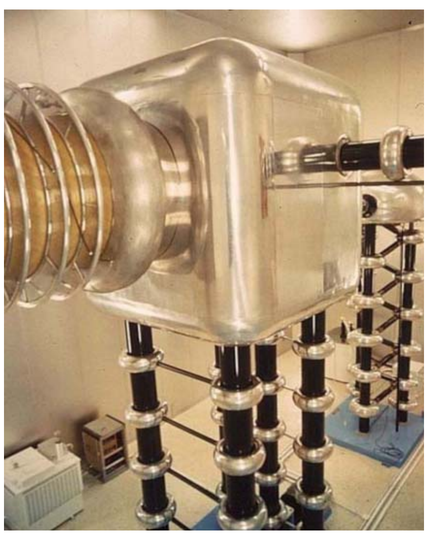





Oxygen Beam Implanter

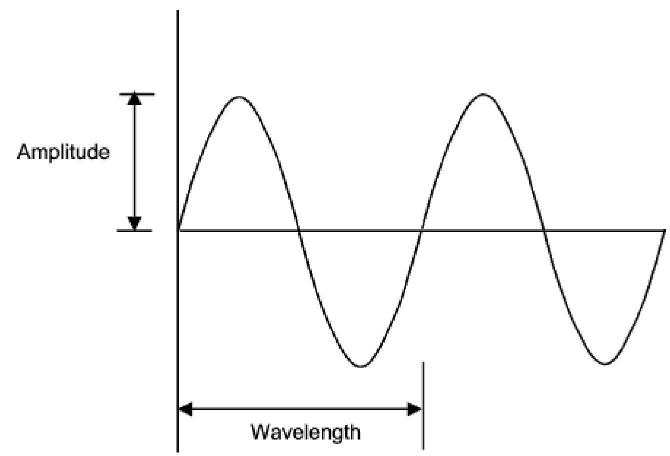


750 keV Cockcroft- Walton

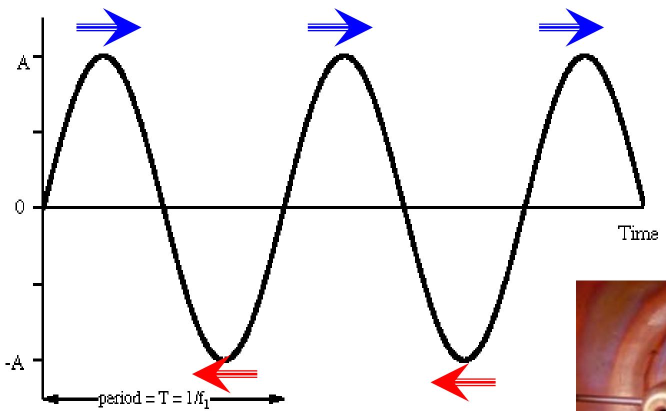


Sits in a Faraday Cage; components with rounded edges to minimize arcs

Radio Frequency (RF) Wave



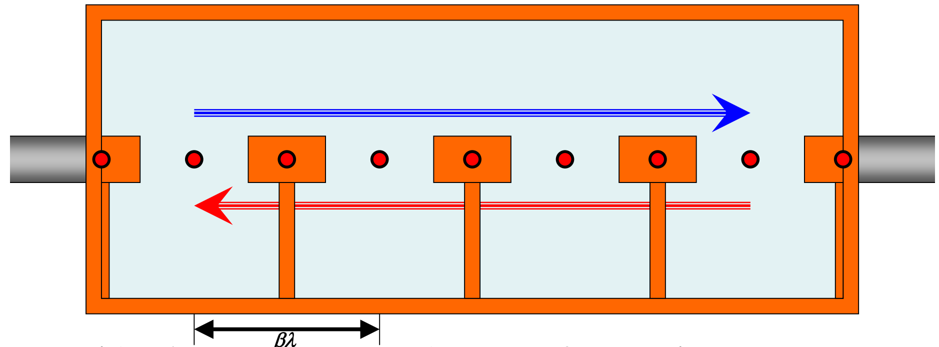
RF Field in Cavity as a Function of Time



Drift Tube Linac

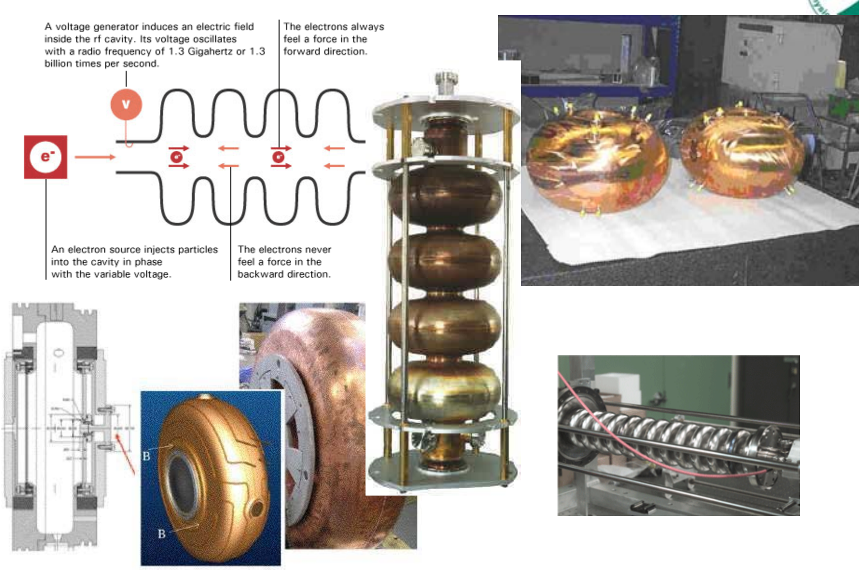
Drift Tube Linac

- The reason for drift tubes with an oscillating rf system

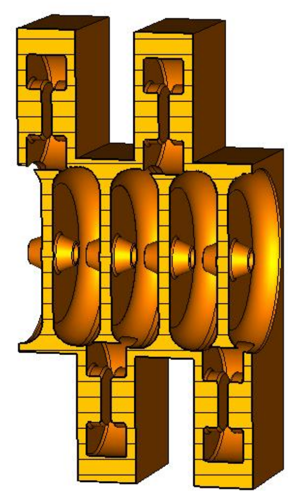


- Fields when in the wrong direction for acceleration are shielded by the drift tubes.
- Particles get accelerated at each gap between drift tubes.

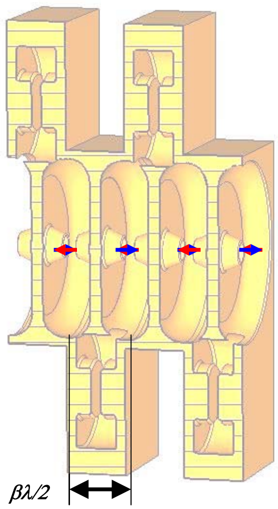
Cavity Examples



Coupled Cavity



Coupled Cavity



Relativistic Effects

$\beta = v/c$

$\gamma = \frac{1}{\sqrt{1-\beta^2}}$

$E_{KE} = m_0c^2(\gamma - 1) = mc^2$

$m_0c^2 \approx 0.511 MeV$ for an electron

$m_0c^2 \approx 938 MeV$ for a proton

Length contraction: $L = L_0/\gamma$

Time dilation: $\Delta t = \gamma \Delta t_0$

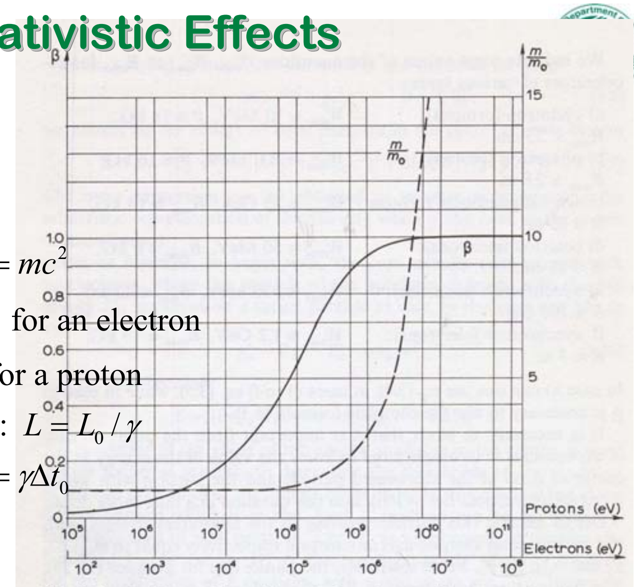


Fig. 3. Graph of the variation of the velocity and mass of electrons and protons as a function of their kinetic energy.

Why Colliding Beams

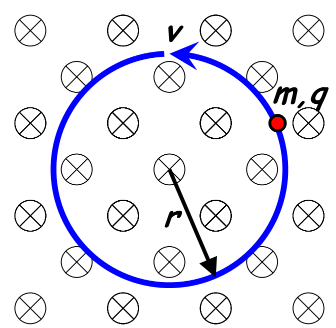
- Colliding beams are much more effective in obtaining a high energy for the collision in the center of mass frame as compared to colliding on a fixed target.
  - **Colliding beam effective energy** $E \simeq 2\sqrt{\gamma_1\gamma_2}\, m_0c^2$
- 10GeV proton on 10GeV proton is ~20 GeV effective
  - **Fixed target effective energy** $E \simeq \sqrt{2\gamma_1}\, m_0c^2$
- Need ~200GeV proton on proton target to get 20GeV effective

WOW! Really hard in comparison

Circular Machines

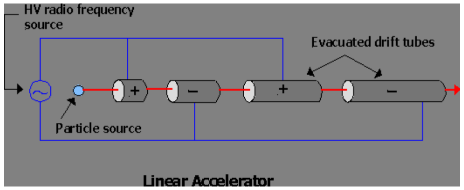
- Match centripetal force with magnetic force on the ions to keep particles in a circular orbit.

$$\frac{mv^2}{r} = qvB$$

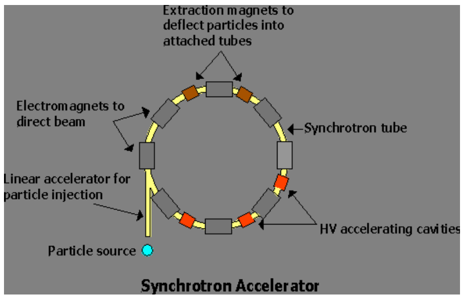


Particle with mass m (kg) and positive charge q (C) moving at velocity v (m/s) in a magnetic field pointing into the page of intensity B (T) follows a circular orbit of radius r (m).

Types of RF Accelerators



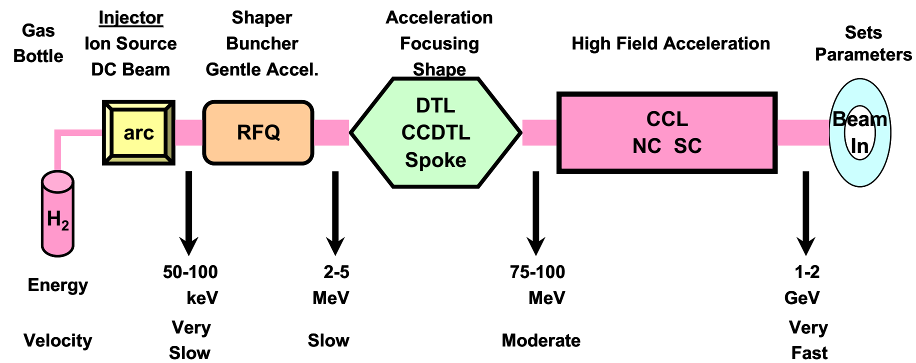
Linacs



Circular

- *Betatron*
- *Microtron*
- *Cyclotron*
- *Synchrotron*
- *Storage Ring*
- *Accumulator Ring*

High Power Linac Basics

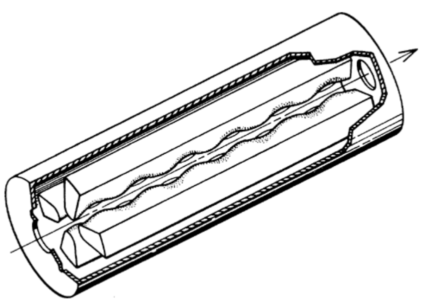


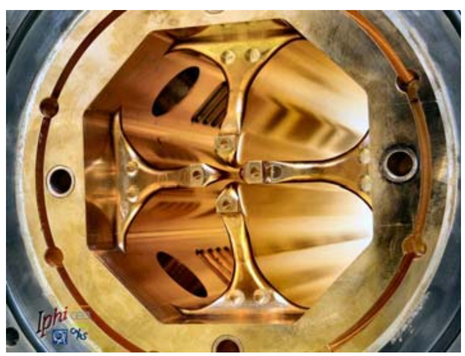
Many important components not shown: rf, cooling, controls, diagnostics, chopper, support, magnets, power supplies, kickers, etc.

Maintain focusing periodicity throughout (soft dough and F0D0)

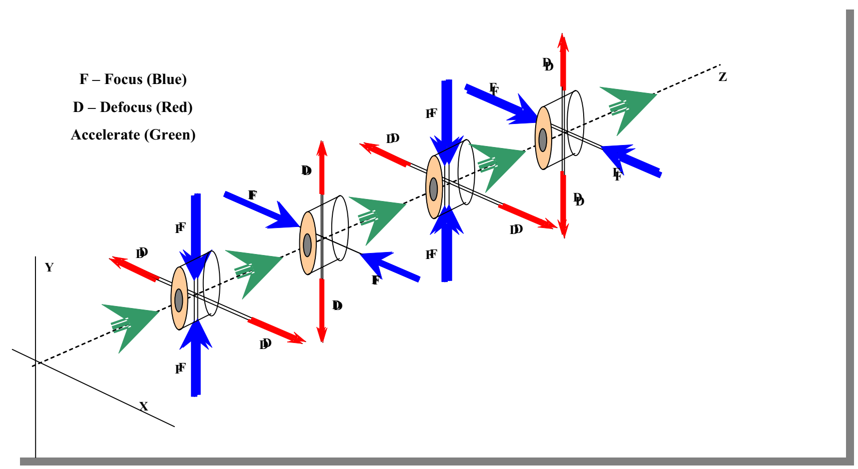
Ion Linac Necessity - RFQ

- Radio Frequency Quadrupole (RFQ) *1979*
  - Matches, Bunches, Gently & Adiabatically, Accelerates

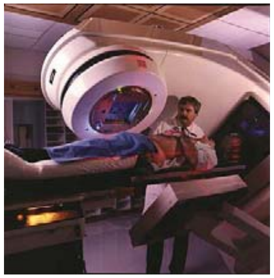




Focusing in a DTL

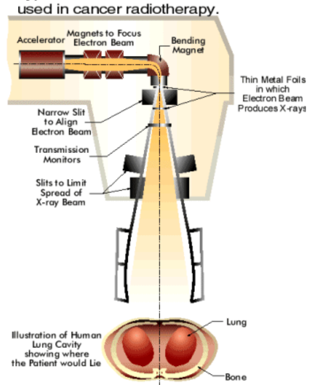


e⁻ and p Linacs



- Cancer Therapy (1000's)
- Structural Investigation
- Oil well logging
- Isotope Production
- PET systems
- MRI
- Sterilization

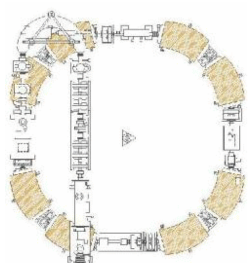
Schematic diagram of a typical medical accelerator used in cancer radiotherapy.



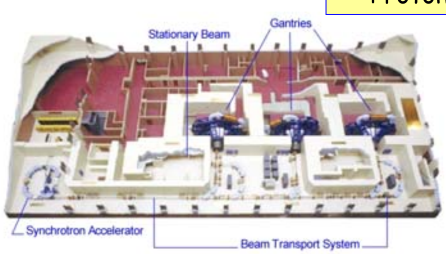
- Proton/neutron therapy

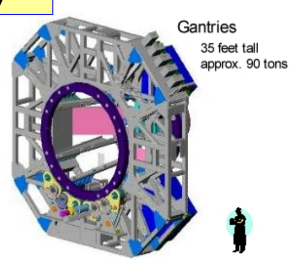
Linac Injectors

Loma Linda Synchrotron

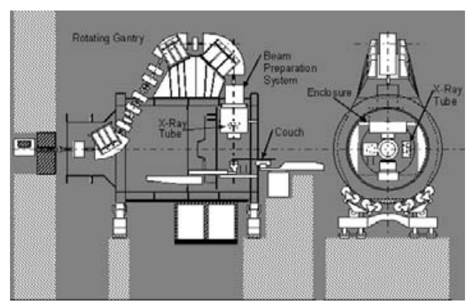


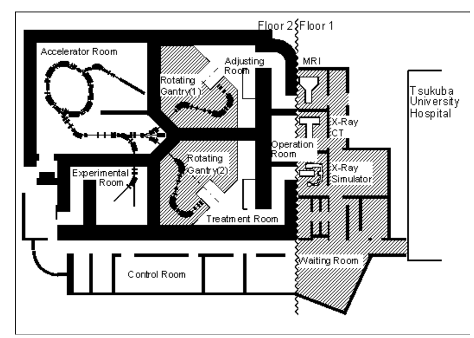
- Proton therapy



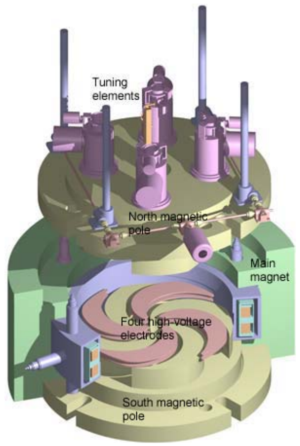


U of Tsukuba 250 MeV





Superconducting Cyclotron for Neutron Therapy (Detroit - MSU)



Superconducting Cyclotrons

- Movie from Nova program "The Nucleus Factory"

MSU Cyclotron

K500

NSCL Fly-by

K1200 + K500

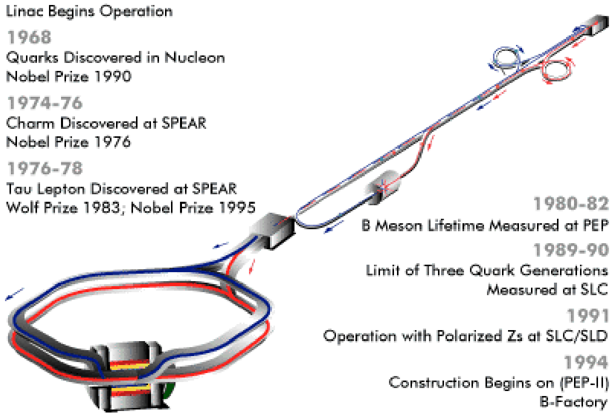
Stanford Linear Accelerator Center SLAC (1)

- ON THE CHILLY SPRING evening of April 10, 1956, a number of boxy Fords and Chevrolets began pulling up in front of the rambling, ranch-style Los Altos Hills home of a young Stanford physics professor named Wolfgang K. H. Panofsky. About 20 earnest-looking young and middle-aged men with short-cropped hair got out and walked into the house. Neighbors thought nothing of this convergence-- Panofsky had been hosting regular Monday night bull sessions with students for several years. But this was not a Monday night, and it certainly was no ordinary bull session.
- Gathered in Panofsky's living room that night were the top professors in Stanford's electrical engineering, microwave and high-energy physics laboratories. For these normally cautious men of science, the concept under discussion was breathtaking. "All other physical sciences, and probably all life sciences, must ultimately rest on the findings of elementary particle physics," Panofsky, known since childhood as "Pief," would later write. "We cannot afford to be ignorant of the most fundamental type of structure on which everything else depends." On this April night, these men were setting out on a quest to find that fundamental structure--the basic building blocks of the universe.
- Encouraged by early experiments on subnuclear matter obtained using the University's 220-foot long Mark III electron accelerator, Panofsky and the others had begun dreaming about a massive scale-up. Their audacious vision: a machine that would generate 50 times the power of the Mark III and extend in a straight line over two full miles. As physics professor and Nobel laureate Felix Bloch, an initial skeptic, later told Panofsky, "Pief, if you must build a monster, build a good monster."

SLAC (2)

SLAC (3)

1962
SLAC Ground Breaking
1966
Linac Begins Operation
1968
Quarks Discovered in Nucleon
Nobel Prize 1990
1974-76
Charm Discovered at SPEAR
Nobel Prize 1976
1976-78
Tau Lepton Discovered at SPEAR
Wolf Prize 1983; Nobel Prize 1995



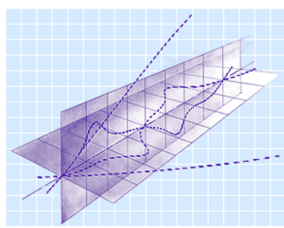
1980-82
B Meson Lifetime Measured at PEP
1989-90
Limit of Three Quark Generations Measured at SLC
1991
Operation with Polarized Zs at SLC/SLD
1994
Construction Begins on (PEP-II) B-Factory

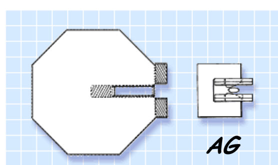
Alternating Gradient Synchrotron AGS at BNL

- In the early 1950's, scientists knew that achieving the higher energies needed for future research was going to be a difficult problem. Calculations showed that, using existing technology, building a proton accelerator ten times more powerful than the 3.3-billion electron volt (GeV) Cosmotron would require 100 times as much steel. Such a machine would weigh an astronomical 200,000 tons. Brookhaven physicists Ernst Courant, M. Stanley Livingston, and Hartland Snyder overcame this barrier by co-inventing the alternating gradient or strong-focusing principle of propelling protons.

AG Big Break Through

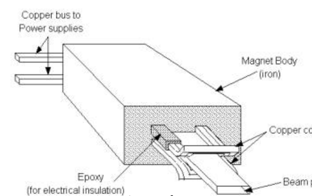
- In the Cosmotron, all the magnets were C-shaped, with the open side and the magnetic field, facing outward. The breakthrough occurred by alternating the orientation of these magnets, so some of their field gradients faced outward and some inward. Brookhaven physicists found that the net effect of alternating the field gradient was that both the vertical and horizontal focusing of protons could be made strong at the same time, allowing tight control of proton paths in the machine (right). This increased beam intensity while reducing the overall construction cost of a more powerful accelerator.





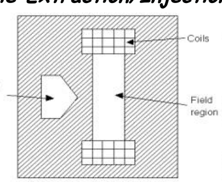
Old way

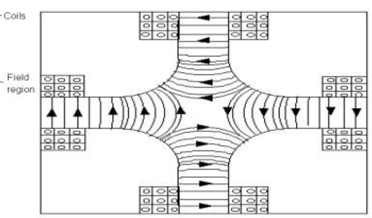
Magnets



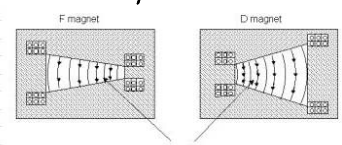
Dipole

Dipole Extraction/Injection

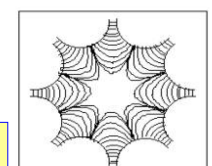




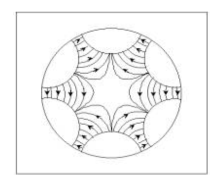
Quadrupole



Alternating Gradient Concept



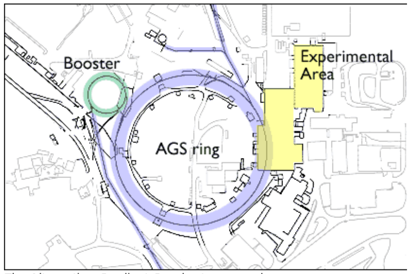
Octupole



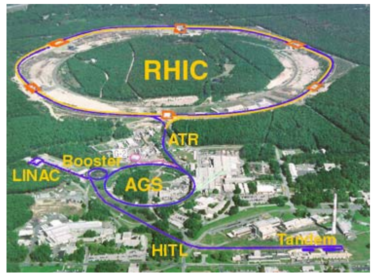
Sextupole

Magnet Issues
- *Synchrotron radiation*
- *Beam pipe and vacuum*
- *Superconducting coils*
- *Radiation environment*
- *Enormous forces from magnetic fields*
- *Materials and alignment*

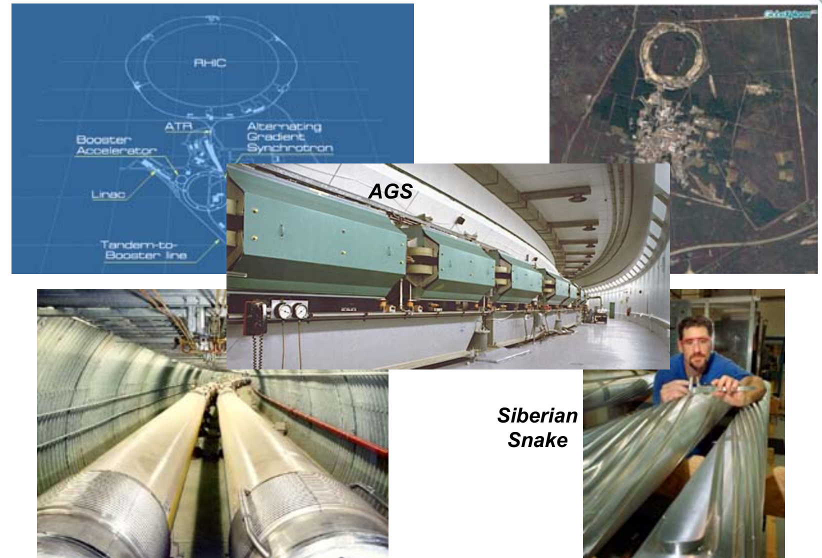
RHIC (1)



The Alternating Gradient Synchrotron complex



RHIC (2)



Siberian Snake

Fermi National Accelerator Laboratory

- FNAL - Tevatron

Coupled Cavity Linac

Drift Tube Linac

Dipole Construction

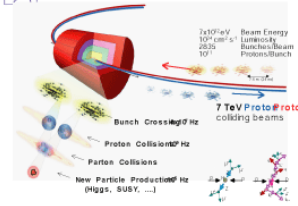
Tevatron (2)

CERN (1)

CERN in numbers

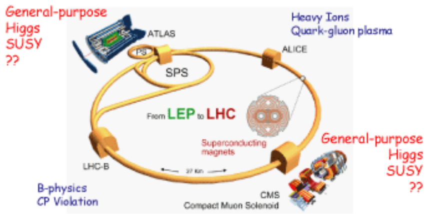
- Financed by 20 European countries
  - Special contributions also from other countries:
    - USA, Canada, China, Japan, Russia, etc.
- 1000 CHF (650 M€) budget to cover operation + new accelerators
- 2,200 staff (and diminishing)
- 6,000 users (researchers) from all over the world
  - broad visitor and fellowship program

Collisions at the Large Hadron Collider



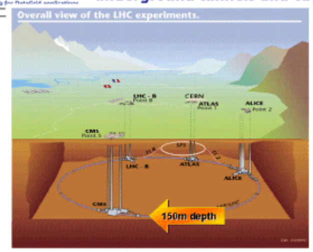
Introduction to CERN David Barney, CERN

LHC Detectors

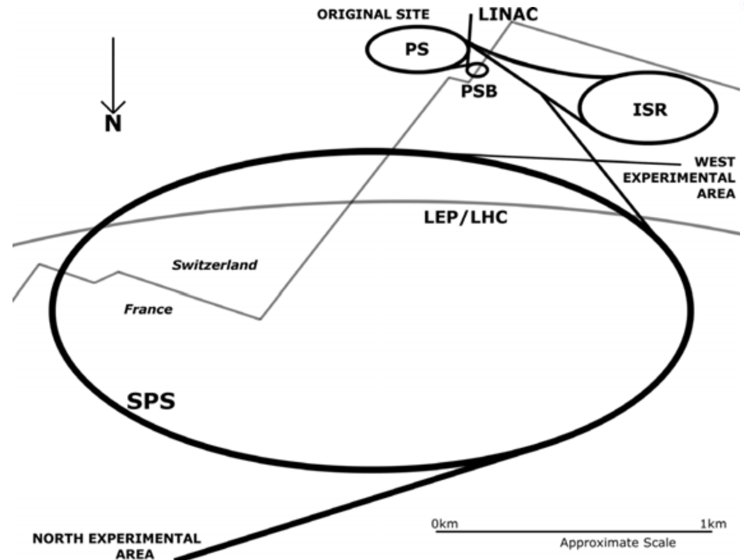


Introduction to CERN David Barney, CERN

Accelerators and detectors in underground tunnels and caverns



CERN Beam Gymnastics (2)

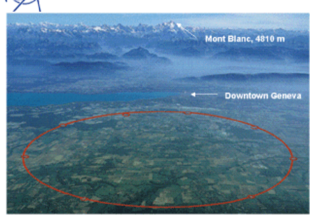


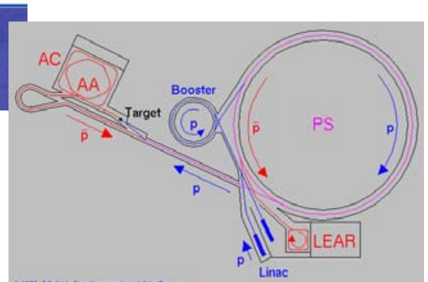
CERN (3)

What is CERN?

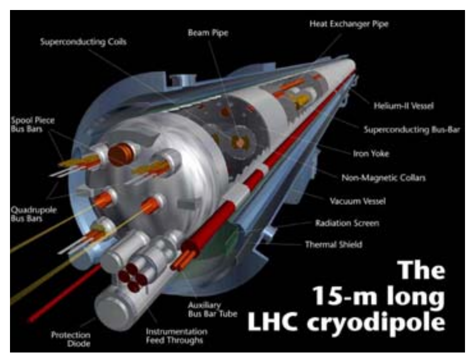
- Physicists smash particles into each other to:
  - identify their components
  - create new particles
  - reveal the nature of the interactions between them
  - create an environment similar to the one present at the origin of our Universe
- What for? To answer fundamental questions like: *how did the Universe begin? What is the origin of mass? What is the nature of antimatter?*

CERN Site

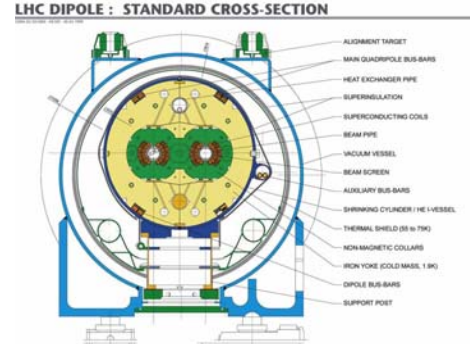




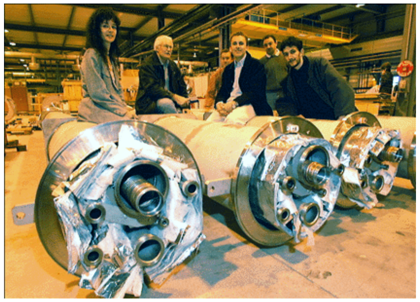
CERN (4)



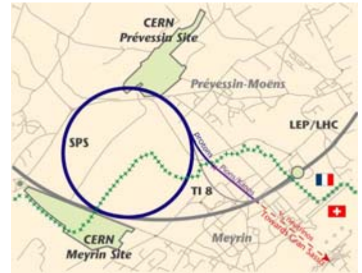
LHC DIPOLE : STANDARD CROSS-SECTION



1st hardware for LHC from USA (5)



CERN (6)



Map of CERN sites and LHC access points

RIA Facility

- Rare Isotope Accelerator