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**

- Image of a tandem accelerator with a Cockcroft-Walton accelerator sitting in a Faraday cage.

**Oxygen Beam Implanter**

- Image of an oxygen beam implanter with a graphical representation of a Faraday cage.

**750 keV Cockcroft-Walton**

- Description: Sits in a Faraday cage; components with rounded edges to minimize arcs.

**Radio Frequency (RF) Wave**

- Diagram showing amplitude and wavelength.
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.
**Coupled Cavity**

- 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** $E = 2\sqrt{\gamma_1 \gamma_2 m_0 c^2}$
  - 10GeV proton on 10GeV proton is ~20 GeV effective

  - **Fixed target effective energy** $E = 2\gamma_1 m_0 c^2$
  - Need ~200GeV proton on proton target to get 20GeV effective

**Relativistic Effects**

- $\beta = v/c$
- $\gamma = \frac{1}{\sqrt{1-\beta^2}}$
- $E_{KE} = m_0 c^2 (\gamma - 1) = mc^2$
- $m_0 c^2 \approx 0.511 MeV$ for an electron
- $m_0 c^2 \approx 938 MeV$ for a proton

- **Length contraction:** $L = L_0 / \gamma$
- **Time dilation:** $\Delta t = \gamma \Delta t_0$

**Why Colliding Beams**

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

**Circular Machines**

- **Colliding beam effective energy** $E = 2\sqrt{\gamma_1 \gamma_2 m_0 c^2}$
- 10GeV proton on 10GeV proton is ~20 GeV effective

- **Fixed target effective energy** $E = 2\gamma_1 m_0 c^2$
- Need ~200GeV proton on proton target to get 20GeV effective

WOW! Really hard in comparison
Types of RF Accelerators

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

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

High Power Linac Basics

- Gas Bottle
- Injector
- DC Beam
- Buncher
- Gentle Accel.
- Acceleration
- Focusing
- Shape
- High Field Acceleration
- Sets
- Parameters

Ion Linac Necessity - RFQ

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

Focusing in a DTL

- F - Focus (Blue)
- D - Defocus (Red)
- Accelerate (Green)
e\(^-\) and p Linacs

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

- Proton/neutron therapy

Linac Injectors

Loma Linda Synchrotron

- Proton therapy

U of Tsukuba 250 MeV
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.”
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.
**RHIC (1)**

- Booster
- AGS ring
- Experimental Area

**RHIC (2)**

- AGS
- Siberian Snake

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**Fermi National Accelerator Laboratory**

- FNAL - Tevatron  *Coupled Cavity Linac*

- Dipole Construction

- Drift Tube Linac

**Tevatron (2)**

- Fermilab’s Accelerator Chain

- Main Injector
1st hardware for LHC from USA (5)

CERN (6)

RIA Facility

- Rare Isotope Accelerator