Module 2: Quark Structure of Matter

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Class 1: Structure of Matter

- Current picture of atomic structure
- Experimental nuclear physics at Jefferson Lab
- The discovery of the nucleus
- Homework
Structure within the Atom

Quark
Size $< 10^{-19}$ m

Nucleus
Size $= 10^{-14}$ m

Electron
Size $< 10^{-18}$ m

Neutron and Proton
Size $= 10^{-15}$ m

Atom
Size $= 10^{-10}$ m

If the protons and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.
Scale of Atomic Structure
Nuclear Physics Research at Jefferson Lab

- The goal of the research program at the Thomas Jefferson National Accelerator Facility (Jefferson Lab) is to understand the quark-gluon structure of the atomic nucleus.
- The technique employed is to probe the nucleus with high-energy beams of electrons and photons from Jefferson Lab’s unique Continuous Electron Beam Accelerator Facility (CEBAF).
The Continuous Electron Beam Accelerator Facility (CEBAF)

- CEBAF is a 6-GeV electron accelerator
- Electrons are accelerated with superconducting resonators and travel around a 7/8-mile racetrack
- Three simultaneously electron beams can be directed into in 3 experimental halls
HOW CBAF WORKS

Each linear accelerator uses superconducting technology to drive electrons to higher and higher energies.

Magnets in the arcs steer the electron beam from one straight section of the tunnel to the next for up to five orbits.

The electron beam begins its first orbit at the injector. At nearly the speed of light, the electron beam circulates the 7/8 mile track in 30 millionths of a second.

A refrigeration plant provides liquid helium for ultra-low-temperature, superconducting operation.

The electron beam is delivered to the experimental halls for simultaneous research by three teams of physicists.
END STATION B
Large Acceptance Spectrometer

- "4\pi" spectrometer
- Six segment toroidal field
- \int B \cdot dl \sim 2.5 \text{ Tesla-meter}
- Maximum luminosity \sim 10^{34} \text{ cm}^{-2} \text{ sec}^{-1}
- Momentum resolution \leq 1\%
CLAS in Hall B
Particle Tracks in CLAS
Union College Beowulf Computing Cluster

- Large quantities of complex data require high-performance computing facilities for processing
- One such facility is the Union College Beowulf computing cluster
- 20 CPUs + 2.4-TByte fileserver
- Used to analyze CLAS data and perform Monte Carlo simulations of the detector response
Setting the Stage for the Discovery of the Nucleus

- 1895 - The discovery of X-rays by Roentgen while investigating the properties of cathode rays
- 1896 - The discovery of the radioactivity of uranium by Becquerele while investigating fluorescence properties of uranium salts
- 1897 - The discovery of the electron by J. J. Thomson while investigating the nature of cathode rays
Plum Pudding Model of Atom

- Popular model of the atom at the beginning of the 20th century
- Developed by J. J. Thomson
- The atom is modeled as a spherically shaped mass of positive charge in which negatively charged electrons are embedded

*Spherically shaped mass of positive charge*
Rutherford’s Experiments

- Rutherford and his collaborators, Geiger and Marsden, performed the first scattering experiments
- Polonium, a radioactive material, used as a source of \(\alpha\)-particles
- The \(\alpha\)-particles bombarded a thin gold foil target
- The angular distribution of the scattered \(\alpha\)-particles was determined using a movable fluorescent screen as a detector
Results of Rutherford’s Experiments

- Most $\alpha$-particles passed through the target without deflection
- Others were deflected at various angles
- Some were even backscattered to very large angles
- These observations are incompatible with the plum pudding model of the atom - such an atom can only give small deflections to the $\alpha$-particles
Rutherford’s Model of the Atom

• In 1911 Rutherford developed a model of the atom that was consistent with his observations

• In this model all the positive charge and nearly all the mass are concentrated in a small region of space at the center of the atom

• Light electrons exist in the empty region outside the "nucleus"

• The negative charge of the electrons balances the positive charge of the nucleus
Homework

- Read Chapter 1 of A Tour of the Subatomic Zoo (TSZ)
- Read the Discovery of the Electron on the Web at http://www.aip.org/history/electron/