Probing Atomic Nuclei for Quark Effects

Challenge

A major area of study for nuclear physicists involves understanding how protons and neutrons stay together inside atomic nuclei. By causing high-energy particles to collide with nuclei and break them apart, physicists have devised a kind of "flashlight" that allows them to "see" inside the nuclei. The more energy the probing particles have, the more detailed information the physicists can collect. This leads to the possibility that particles of sufficiently high energy might enable scientists to begin "seeing" the influence of quarks.

Protons and neutrons each contain three fundamental particles called quarks. Quarks — tiny even by atomic standards — are building blocks of matter that never appear alone. Yet they should leave telltale signs of their presence in the way protons and neutrons scatter upon being hit by high-energy photons. One goal is to find the particle-beam energy at which quark effects become noticeable. Another is to provide data that may help theoretical physicists understand how quarks manipulate proton and neutron trajectories behind the scenes.

Argonne's Role

Argonne scientists are collaborating with other researchers in studying how the protons and neutrons inside deuterium nuclei behave when struck by high-energy photons. The deuterium nucleus was chosen because of its simplicity, consisting as it does of a single proton and neutron bound together. Photonuclear reactions are ideal because very large amounts of momentum can be transferred to the protons and neutrons during the reactions. In the experiments, the scientists focused on measuring the dynamic characteristics (such as momentum and recoil angle) of the protons that were scattered as a result of the collisions.

Approach

In experiments at the Thomas Jefferson National Accelerator Facility (Figure 1), in Newport News, Virginia, Argonne scientists fired a high-energy electron beam at a copper target to produce a cone of high-energy photons. The photons then struck a deuterium target, breaking up deuterium nuclei into their constituent protons and neutrons (Figure 2). Trajectory characteristics of the scattered protons were measured by using Jefferson's High-Momentum Spectrometer.

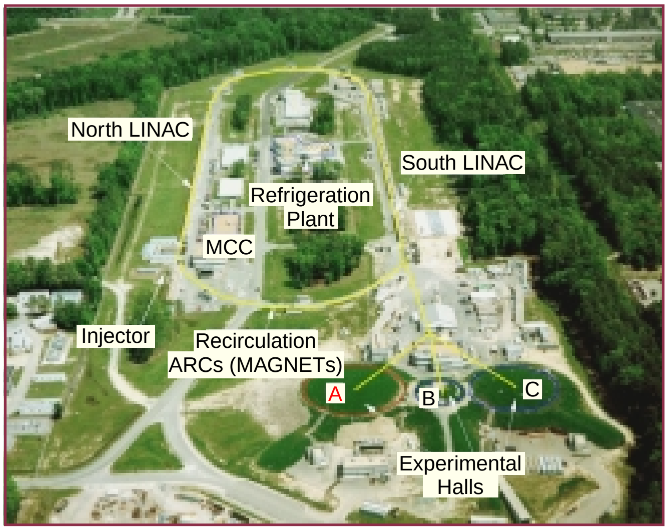

Figure 1: The quark effects were seen in Hall C of Jefferson Lab's Continuous Electron Beam Accelerator Facility.

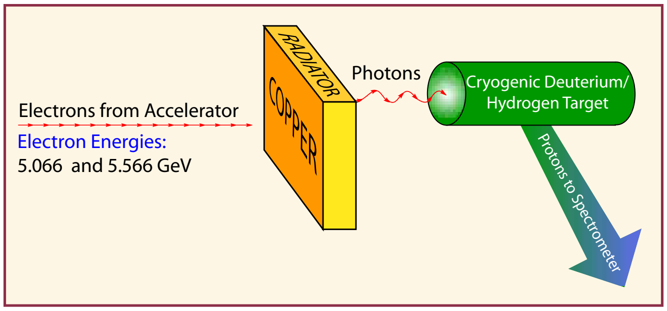

Figure 2: High-energy photons were created and then used to break up deuterium nuclei.

Accomplishments

The researchers studied protons that were scattered at various angles with respect to the direction of the incoming photon beam. They began to notice quark effects when the protons that were scattered at a 90º angle had a momentum ≥1 GeV/c. These effects became evident when scientists' graphs "flattened out" — the quantities they were graphing stayed the same regardless of photon energy, within the limits of experimental error (Figure 3). This was the first time that scientists saw evidence of a threshold for the onset of quark effects. The minimum momentum value of 1.3 GeV/c translates to interactions with deuteron nuclei on a distance scale of 0.14 fermi (10^{-16} m), which is about a tenth of the width of a proton. This means that individual quarks, rather than entire deuterium nuclei, were involved in the collisions. This finding was surprising because the 0.14-fermi distance scale is larger than many current theories predict as the point at which quark effects will become important in nuclear reactions.

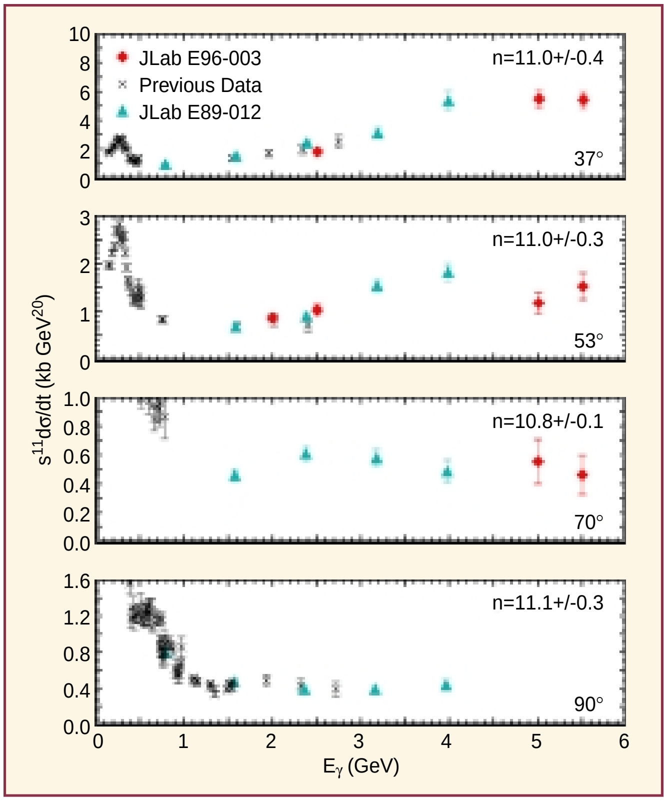

Figure 3: The threshold for quark effects showed up as plotted points that took on constant values, within the limits of the experimental error for photon energies: 4 GeV and greater at 37º, 3 GeV and greater at 53º, 2 GeV and greater at 70º, and 1 GeV and greater at 90º.

Sponsors

Thomas Jefferson National Accelerator Facility
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