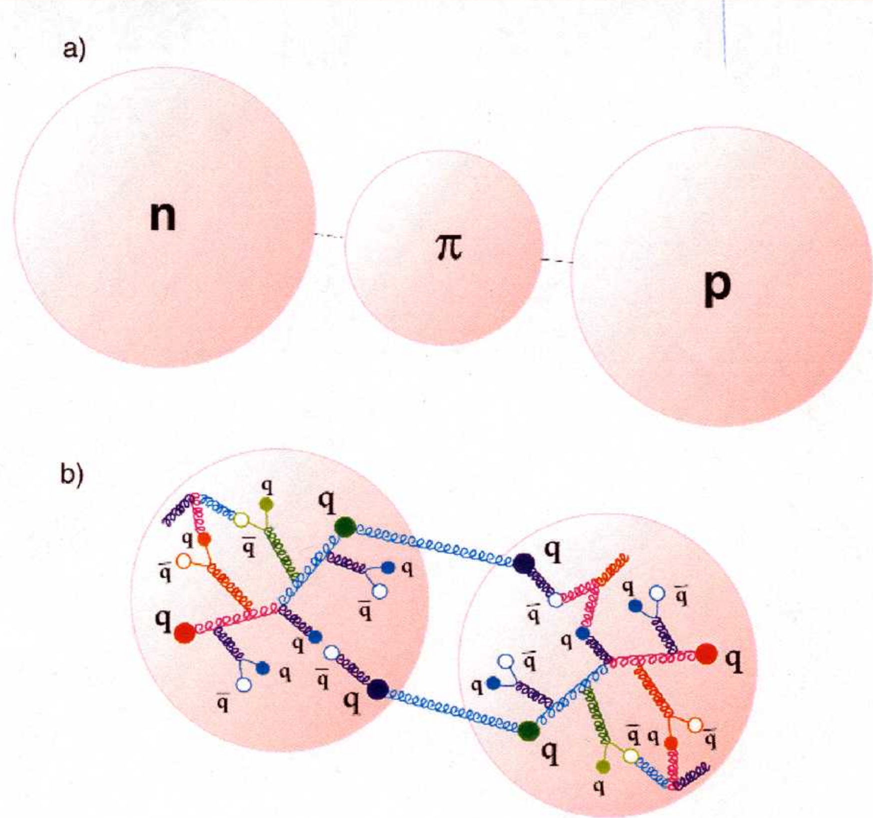
Evidence for the Onset of Quark Effects

American Institute of Physics



Above: Graphic adapted from "Nuclear Physics, The Core of Matter, the Fuel of Stars," National Research Council, 1999.

Evidence for the onset of quark effects in a nuclear reaction has been observed for the first time. When a particle strikes a nucleus at low energies, one can effectively describe the resulting behavior of the nucleus in terms of its constituent nucleons (neutrons and protons) and the mesons which hold them together. At low energies, one does not have to worry about the fact that each nucleon is itself made of three quarks held together by gluons (Illustration a).

When a particle strikes a nucleus at high energies, however, it penetrates the nucleus so deeply that this "effective theory" breaks down, and one must describe the nuclear action in terms of only quarks and gluons (Illustration b). There is a middle ground, alas, where neither descriptive picture can do the job completely.

Just as urbanologists strive to locate where a city truly ends and its suburbs begin, physicists wish to find the boundary at which nucleon-based descriptions give way to quark-based ones. Towards this end, researchers study the behavior of the deuteron, the simplest nucleus, made of a proton and a neutron bound together.

In experiments at Jefferson Lab, a multi-institutional collaboration fired a high-energy electron beam at a copper target, which decelerated the electrons, creating high-energy photons as a result. In a process known as "photodisintegration," the photons impinged upon a deuterium target, and broke apart deuterons into their constituent protons and neutrons.

The researchers then studied the properties of protons emitted at various angles from the collision. When the emitted proton has at least 1 GeV/c of momentum perpendicular (transverse) to the incoming beam, the data were best described by quark-counting rules, which take into account the behavior of individual quarks.

The transverse momentum translates to an interaction with the nucleus at a distance scale of 0.1 fermi (10^{-16} m), about a tenth of the width of a proton. In this situation, an individual quark, rather than the entire nucleon, absorbs the momentum of the collision. This was surprising, since the 0.1-fermi distance scale is larger than many current theoretical expectations for the onset of quark-counting-rule behavior.

Editor's note: Results from this experiment were published in the Sept. 3, 2001 issue of Physical Review Letters by E. C. Schulte et al.