What's in a proton?

Whether a proton is made of identifiable subunits —as a lot of theorists would like—or whether it isn't, is a subject of two new experiments at SLAC

by Dietrick E. Thomsen

Physicists now tally more than 100 subatomic particles, and it sometimes seems as if a new one is added to the list every week. The number is embarrassingly high, and it raises in acute form the question of what is elementary.

Some theorists, who prefer a world in which there are not so many particles with equal claim to being elementary, have worked out theories in which there is a simpler fundamental level underlying the present particles. All the present particles would be constructed in various ways out of a few subentities. The long-sought quark is one kind of proposed subunit.

The experimental question is whether or not actual particles exhibit the kind of structure proposed in these theories. Is a proton, for example, built up out of identifiable subunits or is it a single undifferentiated body?

Recent experiments in which other particles have been scattered off protons can be interpreted both ways. One reading indicates that protons may be composed of subunits and that the probe particles tend to bounce off one of these constituents. Whether the constituents correspond to any of the theoretically proposed subentities is not clear, and Richard P. Feynman has given them the neutral name "partons." Another interpretation favors models in which the proton's innards are not granular. In this case the proton acts on a beam of incoming particles in a way analogous to the diffraction of a light beam by a block of glass: these models therefore go by the term diffractive.

Two experiments now nearly ready to run at the Stanford Linear Accelerator are designed to find out more about what happens in high-energy collisions of other particles and protons. One approaches the question from the parton side and one from the diffractive-model side. They may find that partons do exist and discover something about their properties, or they may not.

The evidence for the parton side goes back particularly to experiments done at SLAC and first reported in 1969 (SN: 8/30/69, p. 164). In these experiments, called deep inelastic scattering, in which the electrons excited the target nucleon to high energies and in which a large amount of momentum was transferred from the electrons to the targets, appeared a simplification of the results that has since become famous as scaling. In these results at high levels of momentum transfer the mathematical expression that represents the structure of the proton no longer depends separately on the energy transferred to the proton from the electrons and on the momentum transferred, but rather on a simpler combined quantity, their ratio.

One possible explanation of this scaling is that the proton has a grainy structure so that the incoming particle interacts with one part (hence the term parton) rather than with the whole proton. Since 1969 experiments using other kinds of projectiles—pi mesons, K mesons and gamma rays—have shown possibly related scaling phenomena.

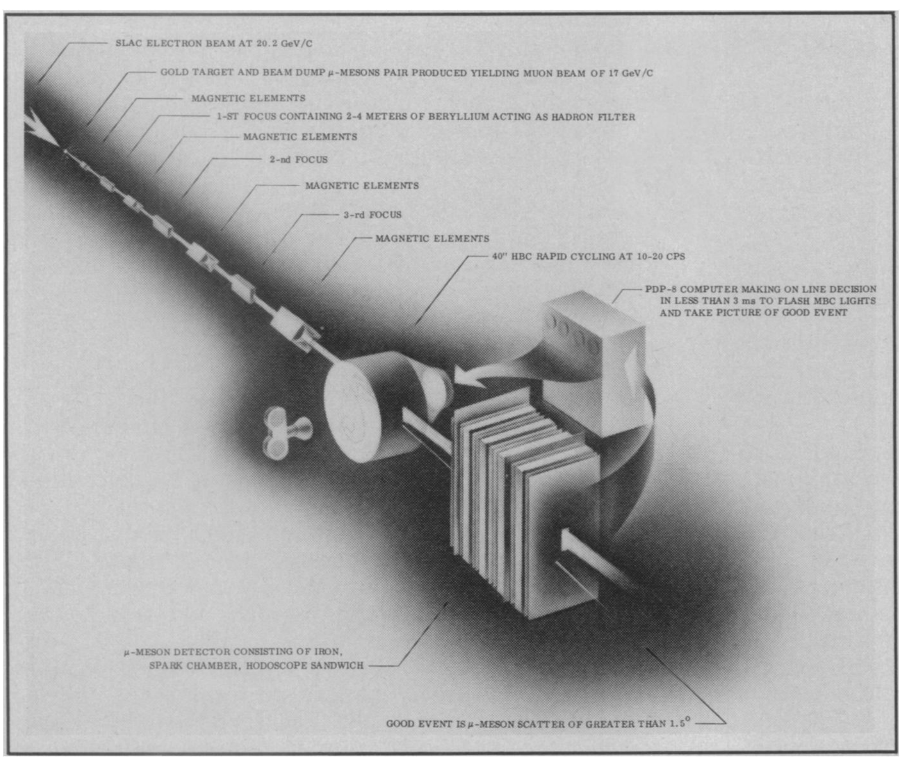
At the same time other phenomena more compatible with diffractive models were coming to light in experiments in which high-energy photons were struck against protons. In these cases the photon, as it approaches the proton, appears to turn itself into one of three vector mesons, rho, phi or omega, and it is the transformed particle that interacts with the proton. The theory that describes this transformation is called vector meson dominance or rho dominance (about 75 percent of the time the change is to a rho), and it is one of the diffractive models.

One of the new SLAC experiments, which will use mu mesons as projectiles, continues the procession of the scaling-law or possible-parton experiments. (It is being done by a collaboration of three SLAC groups: Elliot D. Bloom, R. L. Cottrell, H. DeStabler, L. Gershwin, M. Mestayer, C. Prescott, S. Stein of Group A; J. Ballam, T. Carrol, G. Chadwick, M. DeLaNegra, K. Moffet of Group B; and L. Keller of Experimental Facilities group.)

The other experiment is more concerned with the possibility of meson dominance. It will use a beam of electrons as projectiles. (The experimenters are J. Dakin, B. Dieterle, G. Feldman, W. Lakin, F. Martin, E. Petraske, M. L. Perl and William T. Toner.)

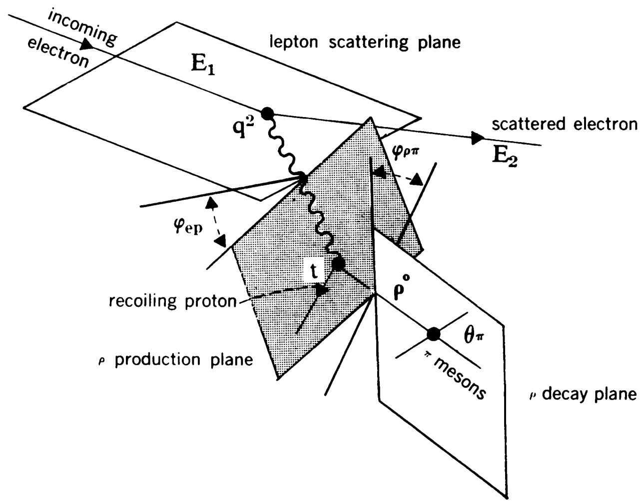
What both experiments hope to learn is what happens when a proton and a virtual photon meet, a situation that will occur in both cases.

A virtual photon can have very different properties from a real one. A real photon is one that is flying free and can be detected, in a light beam or an X-ray beam, for instance. A virtual photon is one that is emitted and absorbed so quickly that its existence cannot be detected. In both these experiments it is virtual photons that will carry energy and momentum between



Photos: SLAC

Arrangement of equipment in muon-proton experiment (artist's impression).



Rho-meson production and decay in electron-proton experiment. Electron radiates virtual photon (wiggly line) which produces rho on approach to proton. Rho decays to pi mesons.

the impinging particles and the proton targets.

Because of their unobservability virtual photons are allowed to have properties that real ones cannot have. (The unobservability is not an accident of imprecise measuring apparatus, and it will not be overcome someday. It comes from a basic characteristic of patricle physics; that particles are also in some way waves. The wave quality introduces fundamental uncertainties in the measurement of the particles.)

Because their important characteristics cannot be precisely measured, virtual particles are theoretically allowed to violate fundamental physical laws such as conservation of energy and to have properties that real particles cannot have. Real photons have zero mass; virtual photons have mass that is represented by an imaginary number. (In the terminology of special relativity, this amounts to a spacelike mass; real particles that do not have zero mass have real or timelike mass.)

A virtual photon is thus in many respects quite a different body from a real one, and both SLAC experiments are interested in finding out whether these differences mean a difference in what happens in collisions with protons.

One of the things that the mu-meson experiment wants to find out is what happens when a spacelike virtual photon meets a parton, if partons exist. The experimenters will study the final states, the things that come out of the collision, in the hope of determining the details of the interaction and possibly thereby some characteristics of partons.

In the attempt to sort out the two kinds of models, the experimenters want to find out whether effects that can be attributed to diffractive models go away as the amount of momentum transferred approaches the level where scaling begins. The alternative would be that diffractive processes continue to dominate the situation here as they do at lower momentum transfer. A related question is whether rho mesons (which are associated with vector-dominance models) form an important part of the final states.

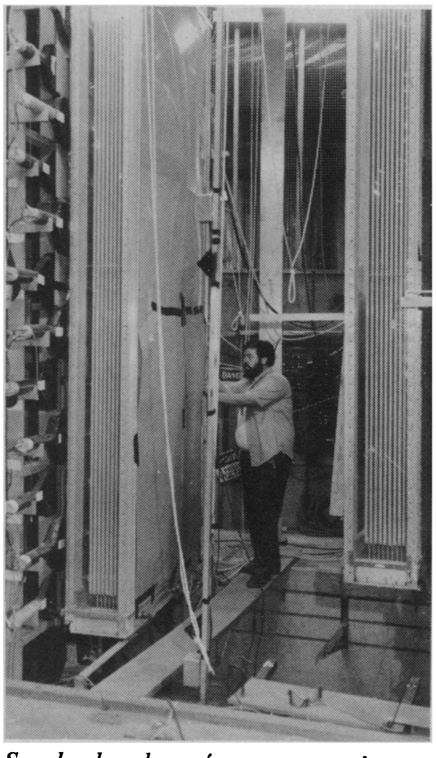
The kind of interactions that this experiment is looking for are fairly rare compared to other things that may happen when mu mesons strike protons. To record them in useful numbers the experimental group had to rebuild a 40-inch bubble chamber so that it can operate at the rate of 20 expansions per second. In the bubble chamber, the particles whose tracks are to be measured run through pressurized hydrogen. When the pressure is suddenly released, bubbles of vapor form along the track, where the particle has ionized atoms. After photographing the tracks, the apparatus reimposes the pressure for the next go.

To run the chamber indiscriminately at this rate would produce a mammoth number of photographs—the experimenters contemplate 300 hours of running time—that would require a heavy expenditure of time and labor for scanning. Therefore the experimenters have designed a triggering system so that the chamber will take pictures only of events that promise to be of the type sought. The deflection of the muons after the collision is the key to telling whether the desired event has taken place, and an array of scintillation counters before and behind the bubble chamber will determine this. When they record a proper muon, they will trigger the bubble chamber. Further analysis by an off-line computer will select those events that look interesting.

The electron-scattering investigation wants to find out whether virtual photons approaching a proton do the same as real ones. The rho-photon analogy seems to be part of the story for real photons, says Toner. The question is, is it for virtual ones? Of course if protons are made of partons, the rho mesons should be too, he says, and some indication of that could show up, but he himself is not so keen on partons. He shakes his head dubiously when they are mentioned, "It is a simplified picture and may not be the whole story."

For more precise data-taking this experiment too will use a triggering system. Electrons that have scattered through a significant angle will be recorded by an array of lead-lucite shower counters, and this will trigger two optical spark chambers to record angles and momenta of the secondaries or final-state particles produced in the collision. A magnetic field will deflect the scattered electrons and the other particles produced in the inelastic collision so that their momenta can be measured, but the experimenters do not want this to happen to some much more common background particles. Since these unwanted secondaries come off in the forward direction of the original beam, their deflections will be prevented by putting a tube wrapped with superconducting material around that line of flight. The superconductor will prevent the magnetic field from entering the volume inside the tube.

In the desired events the equipment will measure the longitudinal and transverse momenta of charged particles that are recorded and infer those data for the unrecorded "missing masses"—mostly uncharged particles. "We propose to compare these distributions of momenta with a Monte-Carlo simulation of what we would see in our geometry if virtual photons behave like real photons," says the group's proposal to the SLAC management. . . . "It seems probable that we should observe qualitative differences if the constituent models are correct." □



Spark chambers for e-p experiment.