were free, independent objects when examined by energetic electrons, why didn't the quarks come out and show themselves? Gell-Mann derided Feynman's picture as the "put-on" model. Many theorists of my generation found great sport in showing that Bjorken's scaling law, which was implied by the parton model, wasn't possible in this or that interacting field theory. Like the quark model of the hadron resonances, the parton model could explain many things, but it couldn't explain itself.

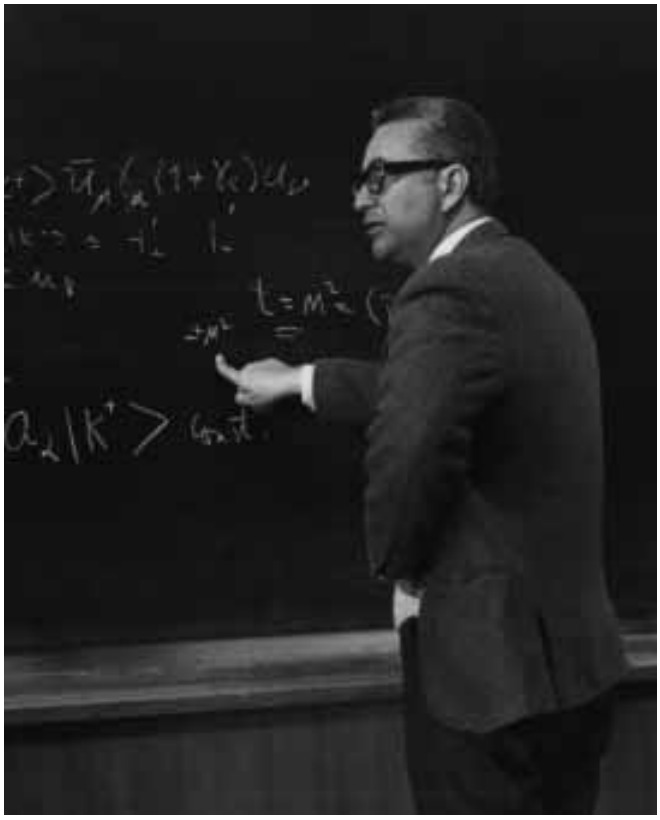
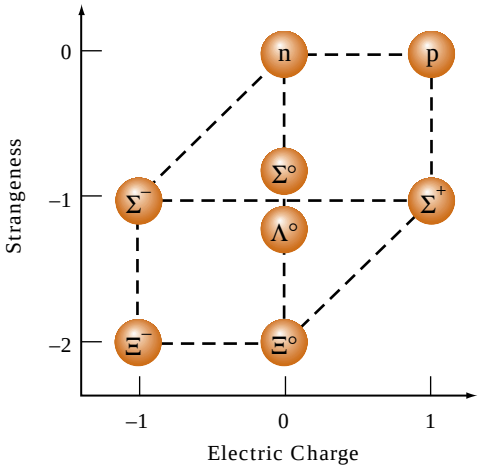
DYNAMICS, DYNAMICS, DYNAMICS!

Some of the reasons why it took so long for the idea of quarks to be accepted have to do with the human frailties of obtuseness, or obstinacy, or preoccupation with other matters. But others, the reasons of real importance, reflect the standards of scientific evidence. The repeated failure to find any free quarks sustained the idea that quarks were computational fictions. The main sticking-point was the absence of any understanding of how quarks behave as free and independent objects in hard collisions, and yet form composites in which they are permanently confined. Without an understanding of dynamics, quarks were a story, not a theory.

The great illumination came in 1973, when David Gross and Frank Wilczek in Princeton and David Politzer at Harvard found that, alone among field theories, non-Abelian gauge theories could reconcile the permanent confinement of quarks with the relative independence the parton model presumes. In these theories the interaction between two quarks diminishes when they are close together, but becomes an ineluctable pull when the quarks move apart. This "asymptotic freedom" of the strong interaction is just what was needed to understand the MIT-SLAC results—not just in a useful cartoon, but in a real theory.

In what seemed like the blink of an eye, a new theory of the strong interactions was codified. Gell-Mann named it quantum chromodynamics (QCD) to celebrate the central role of color as the strong-interaction charge and perhaps to express the hope that it would become as fertile and robust as quantum electrodynamics, the phenomenally successful theory of electrons and photons. Soon precise predictions emerged for the subtle deviations from Bjorken scaling that QCD predicted.

Even before the scaling violations implied by QCD were established through painstaking experimental effort, asymptotically free gauge theories gave us license to take the quark model and the parton picture seriously. All at once, what we had gingerly called "as-if" models took on new meaning. Now, the J/ψ was such a thunderbolt that it needed no theoretical stage-dressing to help it set the community of particle physicists on its ear. Yet it was the insight of asymptotic freedom that prepared us to read the clues charmonium offered, and change forever the way we think about the structure of matter.



Murray Gell-Mann in 1972. (Courtesy CERN)