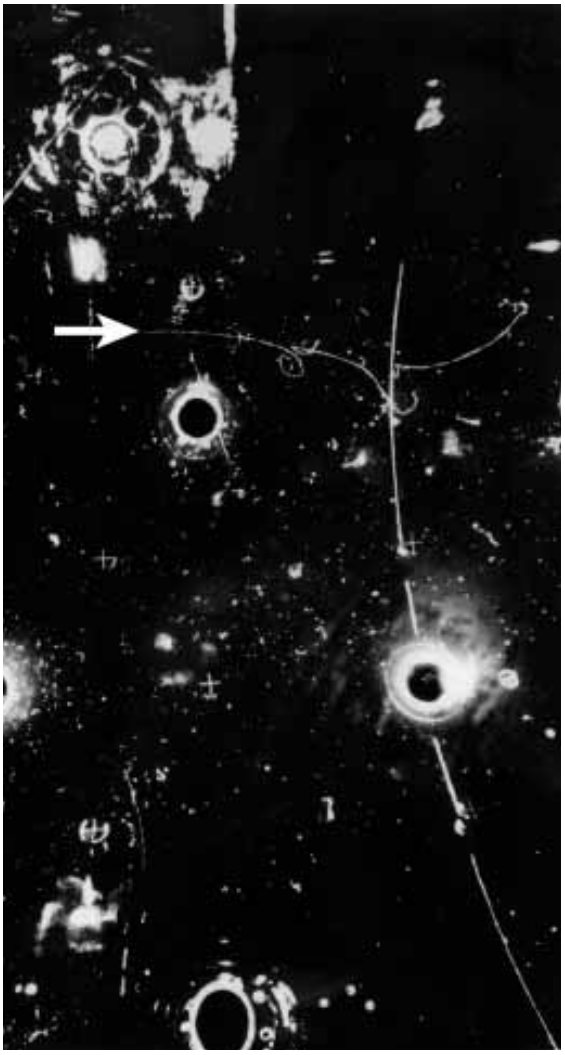

The first single-electron event from Gargamelle. The electron's trajectory goes from left to right, beginning at the arrow's tip. The haloed black circles are lights to illuminate the bubble-chamber liquid. (Courtesy CERN)

QUARKS, LEPTONS, GAUGE FIELDS

Today's elementary particles, the leptons (ν_e, e), (ν_μ, μ), (ν_τ, τ), and the quarks (u,d), (c,s), (t,b), form one of the pillars of our understanding of matter and energy. To the limits of our resolution, they are all spin-$\frac{1}{2}$ particles with no internal structure. The quarks are color triplets that experience the strong interactions. The leptons, which have no color charge, do not.

The top quark has so far been seen in such small numbers that we haven't yet examined it as closely as the others. If top is as ephemeral as we think, with a lifetime less than a trillionth of a trillionth of a second, it is the purest quark—the only one that does not form mesons or baryons. We know a great deal about the tau neutrino from the study of τ and Z decays, but it would still be satisfying to execute a "three-neutrino experiment," in which a beam of tau neutrinos interacts with a target to produce tau leptons that live for a millimeter or two before they decay. The DONUT (Direct Observation of NU-Tau) experiment being commissioned at Fermilab should observe about 150 examples of the $\nu_\tau \rightarrow \tau$ transition.

The other essential foundation for our current understanding is the notion that symmetries—gauge symmetries—determine the character of the fundamental interactions. Like QCD, the electroweak theory fashioned by Sheldon Glashow, Steven Weinberg, and Abdus Salam is a non-Abelian gauge theory. The electroweak theory got its own boost in the summer of 1973 when André Lagarrigue and his colleagues in the Gargamelle bubble-chamber experiment at CERN announced the first observation of weak neutral-current interactions. Although it would take the discovery of the weak-force particles W and Z and many years of study, culminating in the contributions of the Z factories at CERN and SLAC, to show how successful a creation the electroweak theory is, it was clear very soon that the gauge-field-theory approach to the interactions of quarks and leptons was the right path.

The electroweak theory supplies a clue of profound significance: our world must have both quarks and leptons. Unless each pair of leptons (like the electron and its neutrino) is accompanied by a pair of quarks (like up and down), quantum corrections will clash with the symmetries from which the electroweak theory is derived, leaving it inconsistent. I take this constraint as powerful encouragement for a family relationship joining quarks and leptons, and for a unified theory of the strong, weak, and electromagnetic interactions.

Have we found all the quarks and leptons? We do not really know. Precision measurements of the width of the Z resonance assure us that there are no more normal generations with very light neutrinos. But there could well be new families of quarks and leptons in which all the members are too massive to be produced in Z decays. We don't know yet whether the neutrinos have any mass. If they do, we need to learn whether each neutrino is its own antiparticle.

Even if we have already met all the quarks and leptons, we have good reason to be open to the possibility