A tribute: the discovery of proton constituents

by Jack Steinberger

catalysis using new stable particles, with all its implications for power generation, to prospecting for oil and minerals using neutrino beams.

Particle physics is clearly a particularly fruitful source of spin-off at every level from short term feedback to industry through to the seeding of whole new technologies. This success arises from the fact the field is concerned with fundamental science and stretches high technology to the limit. Prediction is notoriously unreliable but history demonstrates how frequently discoveries which have been regarded at the time as utterly remote from any kind of application have turned out to be of the greatest practical importance. We have no reason to believe that the future will be different.

It is sometimes profitable to turn away from the preoccupations of current research to relive the discoveries of yesteryear. Last year, the retirement of Wolfgang ('Pief') Panofsky as Director of the Stanford Linear Accelerator Center was marked by a special 'Pief-fest' when friends and colleagues from all over the world paid tribute (see November 1984 issue, page 389).

One of the speakers was Jack Steinberger of CERN, who described the scientific achievements made with SLAC's electron beams and their context in current thinking. This extract from his talk covers the realization that the proton, far from being an indivisible particle, has a definite composite structure. As with most physics breakthroughs, this did do not happen overnight, at least for most people.

Jack Steinberger (left), seen here with Klaus Tittel.

'We honour 'Pief' Panofsky because we are his friends, and we recognize and admire his contributions to physics and to society. Among these achievements is the creation of the Stanford Linear Accelerator Center (SLAC). Under the direction of Pief, SLAC has become a great Laboratory, a focus and centre for particle physics and physicists. And SLAC can congratulate itself on two fundamental discoveries, one of which I will cover. These successes are not only to the credit of the experimenters responsible, but also in large measure to the credit of Pief, as father of the Laboratory, as director, as guru, and as a participant. In our early days Pief and I had the pleasure of working together, in the days when interesting physics could be done in a few weeks by one or two people.

Before embarking on the story of the electron scattering experiments at SLAC which are responsible for our understanding of nucleon structure, it is necessary at least to mention the electron scattering experiments performed here at Stanford by Hofstadter and colleagues and which found the nuclear form factors.

Among the earliest inelastic lepton-hadron experiments were those of Panofsky and others on electroproduction of pions at the Stanford University 800 MeV linear accelerator in the mid 1950s. In the light of subsequent developments, one of the more interesting results was the realization that it is of greater interest to detect the (inclusive) final electron than the produced pion, the method followed previously.

In the early sixties the energy of electron beams was increased by a factor of ten, to 6 GeV with the turn-on of the Cambridge Electron Accelerator (CEA) and of the Deutsches Elektronen-Synchrotron (DESY). The inelastic electron scattering work then centred on the dynamics of the production of baryon resonances.

Design of the SLAC 20 GeV and 8 GeV spectrometers began soon after construction of the two-mile 20 GeV electron accelerator had started in 1961. These massive and very carefully designed instruments reflect the fact that from the beginning of the project it was anticipated that inclusive scattering would play a dominant role in the experimentation at this machine, characterized by high intensity and small duty cycle.

The discovery of proton constituents

Inelastic measurements at SLAC began in the summer of 1967. The first important results were presented at the Vienna meeting in 1968, showing what happens when electron beams probe deep inside nucleons. Kinematic dependence of the reaction rate is quite flat, in marked contrast to the form-factor dependence observed for elastic scattering and resonance production. Just such results had however been predicted by J. D. Bjorken for nucleons with 'elementary constituents' in 1967. To quote two of his sentences: 'I also think the problems raised here are quite fundamental, dealing, in what seems to be a direct way, with the question of whether there are any 'elementary constituents' within the nucleon. Use of the lepton as a probe is a unique and possibly powerful way of attacking the problem'.

Panofsky, in his rapporteur's talk at the Vienna meeting said: 'Therefore theoretical speculations are focused on the possibility that these data might give evidence on the behaviour of pointlike, charged structures within the nucleon.' However, the understanding of the impact of these early results at the time of the Vienna Conference was not yet clear. Recalling later the climate of those days, R. Taylor wrote in 1980: 'Even by the time of the Liverpool Conference in 1969 many eminent theorists believed that 'Vector Dominance' was the most sensible explanation of this deep scattering. The confirmation of Bjorken's conjecture was gradual rather than a sudden event on a given date.

It was probably R. Feynman who was the first to see the meaning of these first results in the way they are presently understood. Bjorken recalls: 'Feynman visited SLAC in the midst of the first ('scaling') data presented at Vienna. He had been doing the parton model for hadron-hadron collisions and instantly (overnight) recognized what was behind the new ideas, and went beyond where I had gone (at least in some directions). After he left, Manny Paschos and I did our paper on partons. I expected Feynman to write something on his own, and was too shy to suggest a joint paper or call him up and discuss what to do. Feynman in turn didn't write up his ideas until later.'

For mortals the appreciation came more gradually. At the Kiev Conference in 1970, more data were shown, presented in a new way. The fact that the proton contains quasi-free pointlike constituents was finally established and accepted.'

J.D. Bjorken—predicting the outcome of experiments with electron beams probing deep inside nucleons.