Sealing wax and string at $250 million

Miranda Robertson discusses the contribution that the Fermi National Accelerator Laboratory (pictured at bottom) is making to high energy physics.

THE dedication last month of the National Accelerator Laboratory (FNAL) to Enrico Fermi was a tribute to the man and an acknowledgement of the traditional link between the Chicago laboratory which saw the first nuclear chain reaction and the laboratory at Batavia, 35 miles west of Chicago, which now houses Fermi's original Chicago cyclotron (demoted to muon focussing) as well as the world's most powerful proton accelerator.

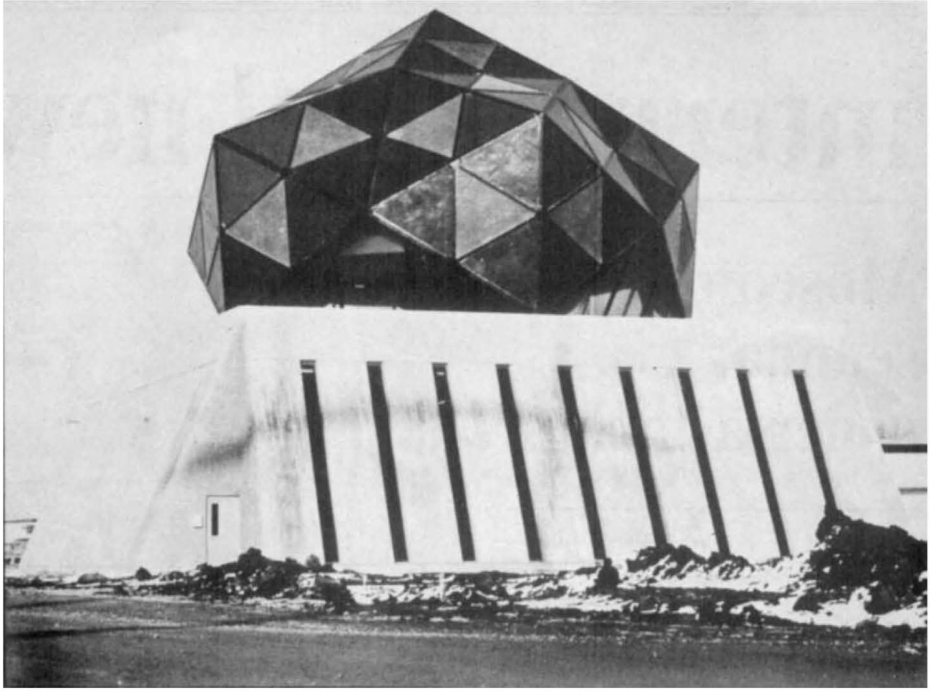
But historical links apart, the laboratory must stand as a monument to its director Robert Wilson, one of many ex-colleagues or students of Fermi now working at Batavia. When he agreed in 1967 to undertake the task of constructing the machine, Wilson brought to an already controversial project not only the experience he had gained in building the Cornell accelerator, but his own controversial approach—a latter-day, $250-million version of the sealing-wax-and-string tradition combined with a willingness to take a venture on the chance of greater dividends.

Robert Wilson: controversial

The commitment of funds to so expensive a project was a problem from the start. Wilson's achievement has been to do more than was planned with less than was hoped: to build a 500-GeV accelerator instead of a 200-GeV one with an initial commitment of $250 million instead of $350 million. A second source of early contention was the siting in America's middle West of what was to be an important international research centre. The geodesic dome of the bubble-chamber assembly building, the curved and corrugated roof of the meson area, and the main building with its trapezoid tower and ground floor forest are all part of a conscious attempt to mitigate the otherwise somewhat featureless Illinois landscape and avoid the standard laboratory concrete block.

Wilson's brave innovations have created problems of their own. One of the least of these is the leaky roof of the meson building, actually made of sections of sewer; what is adequate to contain sewage, it turns out, is not adequate to withstand wind and rain. More serious problems connected with the functioning of the machine itself are candidly documented by Wilson in a recent article (*Scient. Amer.*, **230**, 72; 1974) tracing the progress of the project from its inception until pretty well the moment that the article went to press, when the situation was still changing. At that time, infuriatingly for the scientific community, the proton beam was only operational for about half the time. Moreover, operation at more than 300 GeV threatened to become a source of grievance to the local community by causing a 1% voltage drop in the Commonwealth Edison power lines which feed the machine.

By the time of the dedication, however, the voltage drop had been reduced to within an acceptable 0.5% by means of further capacitors and the accelerator was running at 485 GeV. Better still, it is now operational most of the



The geodesic dome at FNAL: red, white and blue fibreglass panels containing 120,000 'beverage cans' donated by the public.

time and the beam intensity has shifted up from 6×10^{12} to 1×10^{13} protons per pulse close to the goal of 5×10^{13}.

Not that either the teething troubles of the laboratory or its tradition of bold innovation are now at an end. Within days of the dedication ceremony, a new transformer inexplicably failed, setting the machine back to an upper energy limit of 300 GeV for most of the summer. On the other hand, a project budgeted at between $4 million and $9 million is under way to test the feasibility of doubling the beam energy yet again. Wilson's path to the tera electron volt would be through superconducting magnets (more new technology), possibly housed within the existing tunnel (more penny saving). So far, because of the technical uncertainties, plans extend only as far as a protodoubler, to be inserted into a small section of the ring through which part of the beam could be run. Experience with the protodoubler should make it possible to gauge the problems of construction, refrigeration and installation of the superconducting magnets, as well as the possible damaging effects of radiation.

Superconducting magnets also enter into plans, still awaiting proton beams and one electron beam approval, for three intersecting storage rings to contain two, and known as POPAE: protons on protons and electrons. But meanwhile, important new phenomena in high energy physics are emerging at an alarming rate from other laboratories, in particular CERN in Geneva and SLAC at Stanford where the last year has seen the first evidence for a unified theory of the weak and electromagnetic interactions (*Nature*, **245,** 119; 1973), and the quark in a curiously paradoxical position—strongly supported by some recent results and equally seriously threatened by others. At this exciting and critical phase in fundamental particle research and with only two years to go before the new CERN accelerator achieves comparable energies, what has FNAL, as the principal sink for high energy funds in the United States, to offer?

The answer lies in the range of high energy secondary particles produced by the collision of the proton beam with its target. FNAL neutrinos and mesons come out at higher energies than those at CERN, and the Batavia synchrotron is the only source of really high energy muons, whose existence as a kind of massive electron is one of the outstanding puzzles of fundamental particle physics. Colliding beams, which have produced all the surprises, produce secondary particles of only relative low energy.

Many of the most recent results promise to support the efforts of theoretical physicists to find a unified explanation of the four physical forces, and to tie together within some fundamental relationship the embarrassing plethora of particles that comes hurtling out of the nucleus when it is hit with particles of energy more than a GeV or so. But some of the very latest threaten to leave them gasping. FNAL should be in a unique position to fill in the emerging picture in three areas.

The first is that opened up by CERN experiments with a neutrino beam on a stationary target of liquid freon in the giant bubble chamber Gargemelle, where the apparent observation of neutral currents represented evidence for the unity of the weak and the electromagnetic force, as proposed by Steven Weinberg and Abdus Salam. FNAL, with its much higher energy neutrino beam, has already corroborated the CERN result (*Nature*, **249,** 211; 1974) and should now be able to contribute a more quantitative understanding of the phenomenon.

Preliminary data should soon be available on a second question, raised this time by CERN's proton-proton colliding beams. Quite unexpectedly, the interaction probability (or cross section) of the protons, instead of remaining constant, turned out to increase with increasing energy. Investigations at FNAL with other kinds of strongly interacting particle, which seem to be subject to the same non linearity, will concentrate on the problematic transition energy between constant and rising cross section.

The third question is that of the structure of the hadron: are all the strongly interacting particles made up of combinations of two or three quarks, according to the theories independently developed by Zweig and Gell-Mann? Both the neutrino scattering experiments and the colliding beams of protons on protons say yes, they could be, although the existence of internal structure in the hadron has to be inferred from the distribution of the emerging particles: no force has yet succeeded in ejecting a quark from its nucleon. Both high energy neutrinos and muons are available at FNAL for probing the interstices of the proton in more detail than before, and at a time when experiments with colliding beams of electrons and positrons at SLAC have produced results which stretch quark theory to the limits of its plausibility. The simplest version of the theory (and the pursuit of simplicity is the vocation of the theoretical physicist) predicts a constant ratio of emerging hadrons to muons as collision energy rises. But the SLAC experiment revealed a hadron/muon ration that increased with energy with no sign of levelling off at the highest reached. Some increase can be accommodated in more complex versions of quark theory, but if the curve goes up any further it will leave even the most elaborate quarks behind.

FNAL should be able to provide the answers to some of the new questions posed by the current spate of exciting and baffling results, and take its place as a focus of scientific, rather than political or administrative, controversy.