Fermi National Accelerator Laboratory

It will have been obvious from our recent issues that the Fermi National Accelerator Laboratory has rapidly established itself among the finest research centres in the field of high energy physics. It is operating the world's highest energy, highest intensity proton accelerator and, until it is joined by the CERN SPS, has a monopoly on some almost completely unexplored regions of physics.

This is reflected in the vocabulary of the high energy physicists at the FermiLab where the word 'excitement' is one of the most common. In addition, there is something about the atmosphere of the Laboratory which is new and stimulating. Both aesthetically and managerially it is different from any of the established high energy physics research centres. Aesthetically, a site of great attractiveness has emerged from the corn fields of Illinois. Managerially, a way of operating the Laboratory which is not in line with practices elsewhere has been implemented. Behind these features is the personality of the Director, R.R. Wilson, who set very ambitious goals and reached for those goals with his own distinctive style. There have been problems en route but the Fermi Laboratory has emerged with stature from its formative years.

Performance of accelerator

Research is based on the use of the synchrotron which is able to accelerate protons to energies between 200 and 400 GeV. Acceleration to 500 GeV will be attempted again when repair of a commercial transformer is completed. The design intensity is set at the high level of 5×10^{13} protons per pulse.

Since the report given at the Stanford Accelerator Conference (see June issue page 199) reliable machine operation at 300 GeV energy (over 75 % average operational efficiency during high energy physics runs) continued through May and June. A 400 GeV run during intense heat rocked the boat a little and the machine has taken time to settle down again (efficiencies down to 50 %) even though operating back at 300 GeV. In August a two week run with a 200/300 GeV beam pulse using a front porch was successfully accomplished with two experiments doing physics with slow spill at both energies during the same beam pulse. The next 400 GeV run will wait several months until the transformer is back in service.

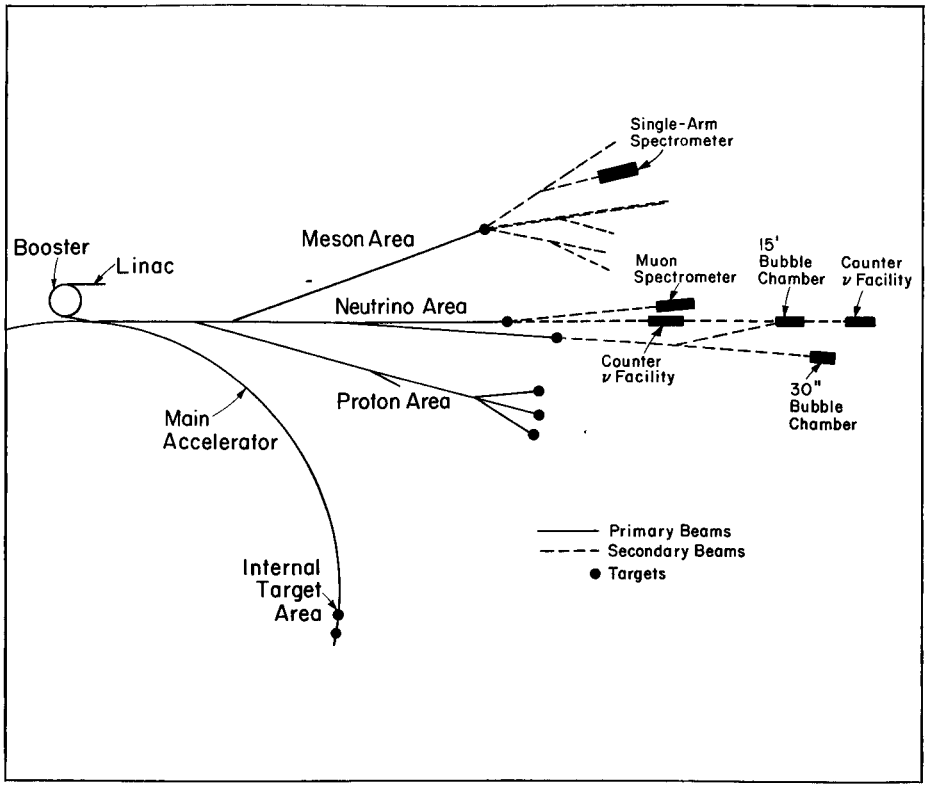
The recent reliability difficulties have been caused by a series of seemingly disconnected faults and, in addition, the growing beam intensity is bringing problems in its wake — both in terms of beam instabilities and of the effect of the intense beams (particularly on the extraction septa). Since the Stanford Conference, the peak beam intensity has been increased by 40 % to 1.4×10^{13} protons per pulse and there have been some extended runs at 10^{13} with the accelerator operating reliably.

Installation of a debuncher, to reduce the energy spread in the 205 MeV beam from the linac to the 8 GeV booster, has enabled about 20 % more protons to be fed through the booster. It has also improved the quality of the beam so that with single-turn injection into the booster virtually all the beam from the booster can be accelerated in the main ring and with two-turn injection about 90 % can be accelerated. Efficient four-turn booster injection is the ultimate aim. Another intensity gain came from injecting a thirteenth pulse from the booster to fill the main ring circumference; until recently only twelve had been manageable.

The higher intensities are provoking beam instabilities in both the booster and the main ring and there are signs of collective phenomena. Work on control of resonances has been successful in holding down the instabilities so far. Further help should come from horizontal and vertical super-dampers (which feed back voltage signals fast enough to deal with fluctuations in individual bunches) due to be installed in the main ring in October. R.f. system beam loading problems and related longitudinal space charge problems are also being attacked.

These improvements are expected to take the peak intensity to around 2×10^{13} by the end of the year. After that, the climb higher is likely to be much harder. There is a problem of low acceptance in the booster and its ejection system will be redesigned to take the septum further out of the vertical aperture. Also in the booster, the r.f. cavity supplies need attention to increase the voltage they can supply at the lower end of the frequency spectrum. Two special cavities will be installed by the end of the year just to help at this lower end which should increase the acceptance of the booster by 40 %.

In the meantime, the high intensities have improved the ability to wipe out electrostatic ejection septa in the main ring by depositing too many protons on the septum wires and the protection system to prevent this happening, now in the process of upgrading, is having a hard job keeping pace with the growing numbers of protons. In a bad spell, a couple of septa were seriously damaged within a week. They are similar in design to those developed for the CERN SPS with spring wires to pull any broken septum wire out of the path of the beam. A technique of machine winding the plane of septum wires has been tried; it gave a plane accurate to one part in a thousand and took only one day to wind. If this septum works well in the accelerator, machine



Schematic representation of the beam layout in the experimental areas at the FermiLab. The Meson Area takes a variety of secondary beams from a single target bombarded by protons up to 300 GeV energy. The Neutrino Area has detection systems for neutrinos generated by protons up to 500 GeV energy and muons up to 150 GeV. The Proton Area can take protons up to 500 GeV energy.

winding will become the standard method.

It looks as if the accelerator requires a progressive shakedown as each new energy and intensity peak is scaled. Nevertheless, the accelerator team are obviously capable of taking the problems in their stride and each advance brings a fresh gleam to the eyes of the high energy physicists who are well aware that they are sitting on a physics gold mine.

Layout of experimental areas

On the main ring itself is an internal target area where studies on proton interactions over the whole range of energies from 8 GeV to 400 GeV are possible. A hydrogen jet target built by a group of Soviet scientists from Dubna has been the major installation and there are also thin fibre targets.

The ejected beam serves three experimental areas known as Proton, Meson and Neutrino. During normal operation all three are fed with protons every pulse; usually there is slow ejection over a one second flat-top at the peak machine energy and then a short burst to the Neutrino Area for the bubble chambers. There can also be a 'front porch' at lower energy (say 200 GeV during a 300 GeV run) should some experiments require it. At peak intensities it is possible to have 10^{13} protons sent to the Neutrino Area and still leave several times 10^{12} for each of the other Areas.

The ejected beam is split first (taking off a vertical slice with an electrostatic septum and several Lambertson type septum magnets) to bend protons off to the Proton Area. This Area is designed for experiments using primary protons of energy up to 500 GeV and intensities up to 10^{13} protons per pulse. Thus the shielding problems are severe and experiments are installed in channels below ground level to take advantage of earth shielding. Three of these subterranean channels exist (Proton-East, Proton-Centre, Proton-West) and are fed by a splitting station which either splits the proton beam to any channel, sends it to Centre and East or sends it to Centre and West. Eventually splitting to feed all channels will be installed. Proton-East is used to generate a neutral beam for photoproduction experiments (using a 30 m deuterium filter, a beam with only one neutron per 500 gammas is obtained) and further downstream an electron-photon facility is about halfway to completion (experiments are expected next year). Proton-Centre is used for a lepton production experiment. Proton-West is still being brought into action. Eventually the Proton Area is likely to be a source of the highest energy secondary beams beyond the range which can be comfortably handled in the Meson Area.

After the ejected beam has had a fraction peeled off towards the Proton Area, a second vertical split is performed to send protons off towards the Meson Area. This area is operated for experiments with secondary beams coming from a single target bombarded by a primary beam of energy up to 300 GeV and intensity up to about 10^{13} protons. About ten experiments can be set up simultaneously using six fixed beam-lines (M1-280 GeV/c medium resolution which has a second branch; M2-300 GeV/c diffracted protons; M3 - neutrons; M4 - neutral kaons; M5 - test beam; M6 - 200 GeV/c high resolution which also has a second branch). In general the charged beams have branches to accommodate more experiments and the neutral beams have experiments lined up in series. The meson detector hall houses the bulk of the equipment for the experiments with some pre-fabricated tunnels extending out on its downstream end. Extending the ability of the beamline to the target (probably using superconducting magnets) will eventually enable the area to draw secondary beams from 400 GeV protons.

Primary proton beam remaining after the two splits to the Proton and Meson areas continues on to the Neutrino Area. This area is designed to use up to 500 GeV protons at the design intensity of 5×10^{13} protons per pulse. The neutrinos are generated from pions and kaons allowed to decay over 400 m from the target bombarded by the proton beam. Focusing systems point the pions and kaons towards neutrino detectors including the 15 foot bubble chamber which can take hydrogen, deuterium or neon fillings. After the decay region, 1000 m of earth shielding filters out the particles other than neutrinos so as to avoid flooding the neutrino detection systems with other particles, particularly muons.

The Meson hall which houses the bulk of the detection systems for experiments on secondary beams with energies up to 300 GeV. The beams, emerging from a single target, enter from the left and 'fingers' to accommodate additional detectors protrude behind the building on the right.

By varying the target and focusing system (run in on train loads on a narrow gauge rail system), the parameters of the neutrino beam can be changed. The beam can be either a 'broad-band' spectrum of neutrino energies with a 100 μs spill via two pulsed focusing horns (this is not compatible with running muon experiments), an alternative broad-band spectrum using focusing quadrupoles which are not pulsed (which allows muon experiments) or a dichromatic beam selecting pions and kaons of energy less than 200 GeV.

The muons are collected as a byproduct to the neutrino beam and used in a separate experimental facility off-set from the neutrino line. A large spectrometer incorporating the magnet of the former Chicago cyclotron magnet is used in the muon experiments. Alongside the muon spectrometer is the first of two electronic detector set-ups (an iron calorimeter) for neutrino experiments; the second (a liquid scintillator calorimeter) is downstream of the 15 foot chamber.

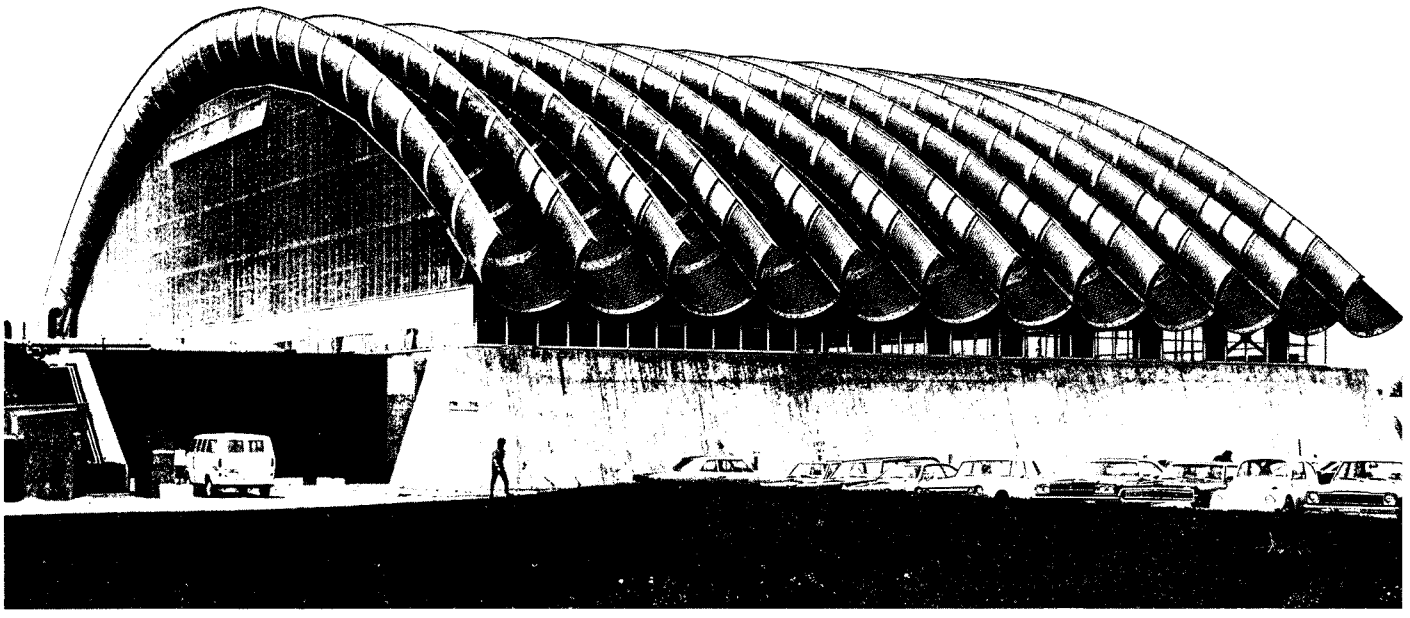
Also in the Neutrino Area is the 30 inch bubble chamber formerly at Argonne. In association with a tagging system, this is in use with a hadron beam-line N3 of high resolution capable of handling particles up to 500 GeV. A branch N5 takes hadrons around the neutrino shield to the 15 foot chamber.

Experimental programme

The FermiLab has a user community of about 1150 high energy physicists. Of these up to 250 will be at the Laboratory taking part in experiments at any one time. As all the beam-lines are brought into full action, this number may rise to 350 or higher though the money available to finance operation at this level may intervene to set the top limit rather than the interest in the experimental programme. The physicists are predominantly from the USA but there is a strong participation from other countries, particularly the Soviet Union, and the flags of twenty nations were flying at the dedication ceremony of the Laboratory last May.

Sixty experiments have been completed, about 30 others are set up in the experimental areas either in a state to take data or testing and another 30 are in the pipe-line for installation during the next year. In a normal week of operation about 25 experiments will receive some beam, a third of them taking data at any one time. This latter figure is another which will rise as the experimental areas 'shake down' and as still higher beam intensities are reached.

The first series of experiments included many of the 'search and survey' type, looking in the newly available energy range for such things



as the magnetic monopole and the isolated quark. There are still searches of this type going on but the emphasis is swinging to more detailed studies of the behaviour of the different types of interaction at high energies. Elastic and inelastic scattering experiments are growing in number as are experiments with multiparticle detection systems and, further off, hyperon and neutral kaon experiments.

As examples of what is under way: In the Meson Area the total cross-section experiment of the Brookhaven / FermiLab / Rockefeller team continues. They have already seen that the region over which the strong interaction acts, grows as the energy increases for all hadrons (except for the antiproton where the energies investigated are probably not yet high enough). They are now running at lower energies to link up the new data with results from the CERN PS and Brookhaven and then hope to extend to the highest possible energies of the FermiLab particularly to confirm that the antiproton behaves like all the other hadrons. Another experiment is studying charge exchange at high energies in the interaction between the negative pion and the proton (giving a neutral pion and a neutron or an eta meson and a neutron) using a sophisticated neutral pion detector developed by a Berkeley/Cal. Tech. team. The conversion between protons and neutrons is an obvious candidate for helping to understand the strong interaction.

In the Neutrino Area, a muon experiment of the missing mass type, gathering information only on the incoming and outgoing muons, has been completed and the muon spectrometer is now able to study the emerging hadrons and electrons as well. Data has already been collected by a FermiLab/Oxford/Rutherford team using hydrogen and deuterium targets and the difficult analysis task has begun. The two neutrino experiments using electronic detection systems of Cal. Tech./FermiLab and Harvard/FermiLab/Pennsylvania/Wisconsin are continuing in this completely unexplored field and are being joined by the 15 foot bubble chamber whose present status is described below. The 30 inch chamber which did such fruitful work in the first years of accelerator operation will fade in importance as the 15 foot comes on.

In the Proton Area, the lepton experiment of the Columbia/FermiLab team, which was one of those to spot the unexpected very high rate of production of leptons from hadron collisions, is continuing with a detection system adapted to catch both emerging leptons. A photoproduction experiment of Columbia/FermiLab/Hawaii/Illinois is now setting up and will also have an unexplored field to investigate.

The detection systems (with the exception of the 15 foot chamber) are tailored to the requirements of specific experiments rather than being large multipurpose systems such as are being devised for a large part of the CERN SPS experimental programme. This may prove to be a logical sequence in that the more quickly built special systems at the FermiLab will be taking a first look at phenomena in this new energy range while comprehensive, general systems will be in action for broader, more detailed studies when the SPS comes on in a few years' time.

15 foot bubble chamber

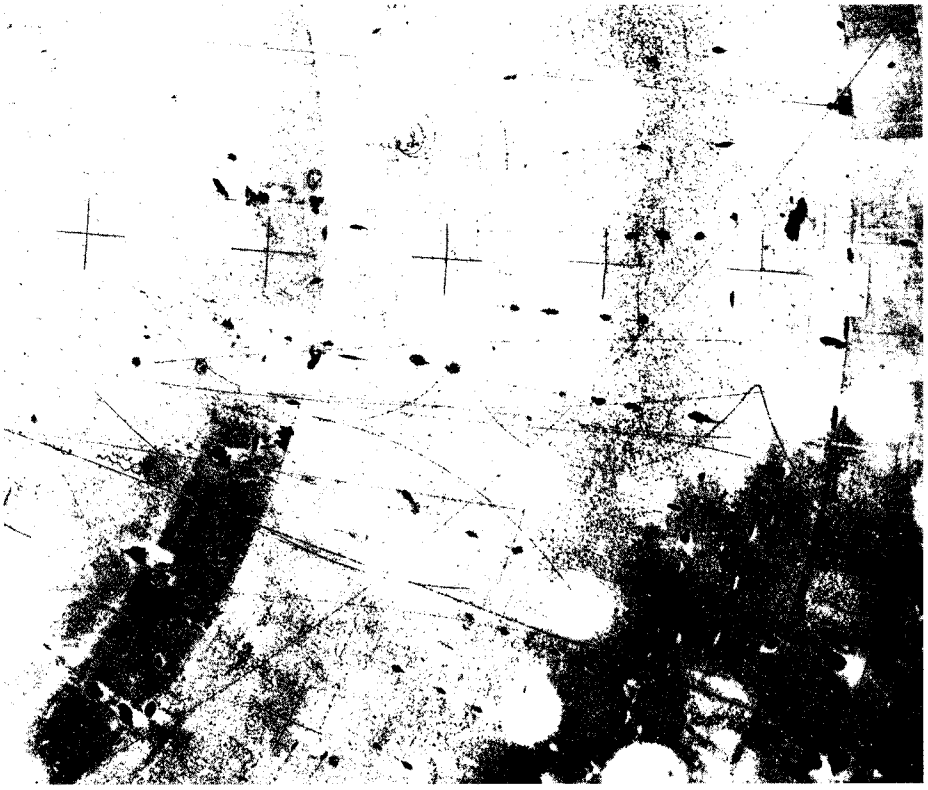
At the end of July the 15 foot bubble chamber took its first pictures for physics. Two experiments collected a few thousand photographs, one studying neutrino interactions and the other studying hadron interactions.

The chamber operated for the first time in September 1973 (see vol. 13, page 336). Its major design parameters are — volume of 30 000 litres about 4.5 m along the beam direction, capable of operating with hydrogen, deuterium or neon in a 3 T magnetic field produced by a surrounding superconducting magnet, piston plunging from below at rates up to four times per accelerator cycle, two sets of three cameras positioned on top.

As is usual with these large complicated systems, the first engineering run uncovered a number of problems. The fish-eye windows through which the cameras see the chamber volume were chipped. They have been newly designed but only four are installed to confirm that the trouble has been cleared before the last two are made. (The two sets are intended to operate independently of one another so that neutrino and hadron pictures can be interleaved.) The piston and its seal were a source of dirt which spoiled the pictures. A new surface (fibreglass filled teflon) on the piston and a chrome plated seal seems to have cleared this. The cameras were not operating properly because the stray field of the superconducting magnet was affecting the motors which pull the film. This has been corrected (initially over-corrected, tending to pull the film too hard — the motors had to be turned down).

The chamber was cooled again in June when the modifications were complete. The superconducting magnet was then brought on successfully though the field has been limited to 1.8 T until extra refrigeration can be applied. The magnet is being handled rather gingerly after the experience of the 3.7 m European bubble chamber, BEBC (see page 294). The contact between the teams bringing in the 15 foot and BEBC has, incidentally, been very helpful to both sides.

Fairly reliable chamber operation was achieved over several runs giving



A probable neutrino interaction (the three tracks emerging from the vertex on the left of the picture where the invisible neutrinos have entered) photographed during the July/August run of the 15 foot bubble chamber.

reasonable quality pictures. The track resolution is at the level of 300 μm (the film grain resolution limit being 100 μm) under the following operating conditions — temperature 25.5 K, chamber pressure minimum of 22 psi, flash operated as fast as 3 ms after passage of the beam giving an unusually short time for bubble growth and, hence, very good resolution. There is still some fogging due to dirt in the chamber and on the fish-eyes but it is expected that this will get progressively better. Baffles may be needed to hide bubbling at Scotch-lite joints. The coated metal piston remains in place and eddy currents in the metal are a significant load on the chamber refrigeration system. This limits the picture taking rate at present to one per machine cycle and to approach the design rate it will be necessary to install a plastic piston. Such a piston, consisting of a plastic mushroom around a light stainless steel frame, is on site being tested.

The chamber has been warmed up again for a wash and brush up while the 30 inch chamber is back in action, and work on the helium refrigeration system will attempt to improve the magnet performance. Installation of the plastic piston and additional optics will probably await the next warm up so that multi-pulsing on one accelerator cycle will not take place before next year. The chamber is due back on the air about the end of October with the two horn focusing system installed to help on the neutrino pictures. It is then hoped to have extended physics runs.

The first experiments include a 50 000 picture study of hadron interactions by a FermiLab team using a 250 GeV negative pion beam. This will be used as a test experiment to check the performance of the chamber. The neutrino experiment is a collaboration of FermiLab and Michigan with physicists from ITEP Moscow and Serpukhov participating as part of the FermiLab team. They will gather 300 000 pictures (hoping soon to be seeing an event about once every twenty pictures) for a comprehensive investigation of neutrino interactions at high energies. Results are likely to come from this data over several years but some important information might emerge in a few months. For example, the possibility of a new class of particle with associated 'charm' quantum number could result in single strange particles being produced in the neutrino events. The 'signature' for this in terms of track configuration is rather clear in the neutrino pictures and it may be possible to say something about charm rather quickly. The chamber could also catch intermediate bosons up to a mass of about 7 GeV and will add to the knowledge on neutral currents. The speed of analysis depends greatly on being able to determine the neutron background.

Additional detectors around the chamber include an external muon identifier — a blanket of multiwire proportional chambers built by a Berkeley/Hawaii collaboration which are being tested and will be brought into action later in connection with the neutrino studies to spot muons emerging from the chamber volume. A novel way of learning the energy distribution of the neutrino beam going into the chamber has been proposed by the Soviet scientists involved in the neutrino experiment. It is a Cherenkov counter which can pick out muons from a high background of other particles by using fine straws to convey the Cherenkov light to photomultipliers. Only particles travelling along the neutrino beam direction, or at a very small angle to it, will produce light which will make its way to the photomultipliers. By setting the pressure in the counter it can also be made to select muons as well as giving their momentum (and thus the momentum of the neutrino produced in the same decay). The technique is being tested and looks promising.

The Energy Doubler/Energy Saver/Beam Stretcher

Future developments at the FermiLab seem almost certain to be closely bound to the progress in mastering the phenomenon of superconductivity. Physical sizes, construction and operation costs of 'conventional' magnet/power systems make it unreasonable at present to go any other than the superconducting way to build and power the next generation of proton accelerators and storage rings. Thus there is growing interest in building up expertise in the field of superconductivity and in tackling practical projects as soon as is feasible. The next few topics indicate how this is being done.

With the conventional magnets

installed in the main ring, the highest possible field is 2.25 T, which means that the ring can hold protons up to a peak energy of 500 GeV. Pulsed superconducting magnets, based on the use of niobium-titanium superconductor, are usually designed for about 4.5 T maximum field. Thus, a complete set of such superconducting magnets installed in the FermiLab tunnel would hold protons up to a peak energy of 1000 GeV. This project is known as the Energy Doubler.

The Doubler could serve other purposes also. Power consumption is a serious problem in operating the existing machine at high energies. For example, even at the 300 GeV, 6 s repetition rate, the average power required is 40 MW. To run at 400 GeV with a short cycle time and a reasonably long flat-top could easily take the average power above 80 MW. The Doubler could be used to do the last 100 GeV's worth of acceleration with the conventional machine taking the protons to 300 GeV in 2 s and passing them to the Doubler for further acceleration over 5 s plus a 2 s flat-top for a total pulse of 12 s but a slightly improved duty factor. This would absorb 20 MW average power. The Doubler could also be used as a 'beam-stretcher' between 200 and 500 GeV simply to hold the beam so that it could be drawn off to experiments over many seconds thus greatly increasing the duty cycle of the machine and increasing its potential for experiments.

There are several parameters of the Doubler which lead to considerably different design approaches to those used elsewhere when considering superconducting synchrotrons. The first is that slow rates of rise of the magnetic field to the 1000 GeV level are envisaged giving a cycle time close to 100 s. The conventional machine, having fed the Doubler, could continue lower energy operation in the meantime. The slow pulse rate eases the burden on the refrigeration system (a.c. losses are expected to be about 2 W per metre) and imposes less stringent requirements on the superconductor itself. The second important Doubler parameter is the project cost. Since almost 2000 km of superconductor would be needed to build the thousand magnets of the complete ring, this cost restriction involves buying superconductor for less than $3 a metre and requires a high current density design for the magnets. It also involves establishing simple production techniques to keep magnet fabrication costs down.

The Doubler will be installed in the main ring tunnel suspended from the roof 1 m inside and 1 m above the existing ring. It will repeat the magnet lattice which has 780 bending magnets (dipoles 6 m long) and 150 quadrupoles. The bending magnets are seen as cold bore, warm iron with an elliptical cross-section about 20 × 30 cm². The aperture for the beam is set by the needs of resonant ejection and is an ellipse about 5 × 3 cm².

Twelve refrigerators, each of 1500 W at 4.2 K equivalent cooling capacity, will sit on top of the ring tunnel next to the existing Service Buildings. The helium to cool the magnet coils to superconducting temperature has to be conveyed around almost 6000 m of the tunnel circumference. A novel system has been invented where the helium flows through the coil region from magnet to magnet over a distance of 120 m. It then passes through a valve, boils and returns to the refrigerator in an annular space surrounding the magnet vessel acting as a heat exchanger. No separate helium transfer lines are then needed in the tunnel.

Both the magnet design and the refrigeration scheme are being tested. A series of dipoles have been built to investigate production techniques. They have an inner stainless steel vacuum tube surrounded by molded fibreglass epoxy which positions the first layer of the superconducting coil and has cooling channels cut into it.

Two further layers are added, with intervening cooling passages and steel bands are then clamped around to give mechanical rigidity.

The superconductor has been of two types so far: solid wire 0.375 × 0.2 cm² containing 2300 filaments of niobium-titanium superconductor 35 μm diameter and 7 strand Rutherford-type cable soldered into rectangular cross-section, as above, containing 1120 filaments 20 μm diameter for each strand. About ten different types of wire of improved construction are to be tried in the near future as pilot production runs in preparation for the first 300 km production run next Spring.

Recently about ten different 0.75 m dipoles have been tested. All but two using the solid wire conductor. The magnets using solid wire have all shown severe training but those made from the cable conductor do not. The peak field has been 4.1 T but no measurement of field quality in this recent series has been done yet since the primary purpose is to establish design concepts for the dipoles and to formulate training criteria. Three 6 m dipoles have been built using the solid wire conductor and have fallen well short of design field but are put to use in the refrigeration tests. (Two 0.75 m dipoles constructed the same way as the 6 m dipoles exhibited the same low field performance.) The combined achievements of the present 0.75 m dipole series, namely, an improved structural system capable of supporting fields of 4.1 T and magnets from cables which exhibit little training, have encouraged the group to move on to a 3 m dipole using cable. This magnet will be built in a manner that will allow the field quality

measurements to be made as was the case earlier in the original short dipole series of a year ago.

Many of these tests are being carried out in the model section of main ring tunnel, known as the Protomain. Component layout can also be checked there since conventional main ring magnets and their supplies are also in position. The intention is to install eight 6 m dipoles and two 2 m quadrupoles and to cool them using the 600 W refrigerator which has been installed and tested. So far a 120 m length of co-axial pipe has been fed with helium from this refrigerator with a 6 m dipole replacing the inner pipe at one end. The cooling system tests, particularly with the powered 6 m magnet in place, have been encouraging.

When these development stages bear fruit, the next step will be to build enough magnets to install a loop of the Doubler in a sixth of the main ring. This will be cooled, powered and fed with protons ejected from the ring.

Energy transfer system

Some of the early decisions in the design and construction of the accelerator at the Fermi Laboratory were based on the parameter of 200 GeV as the machine energy. Thus, the cables which link the substation, where power arrives on the site, to the magnets of the main ring were built to be comfortable when transferring energy equivalent to 200 GeV operation. They are 13.8 kV cables which are thermally rated for 60 MVA. For higher than 200 GeV operation the machine pulses are lengthened, keeping the power flowing through the cables down to acceptable levels. Some 400 GeV runs have been tried with the cables carrying current equivalent to an 80 MVA thermal rating and a couple of failures indicated that not much more could be squeezed out of them.

The ducts where the cables run cannot accommodate sufficient additional cable, so some new exercise is needed to make the system comfortable for 500 GeV operation at 100 MVA equivalent. Although installing conventional cables in a new cable duct would be the cheaper approach in terms of immediate investment, so much of the possible future programme at the Laboratory is dependent on the use of superconductivity that it was decided to build a superconducting energy transfer line between the substation and the main ring — a distance of 500 m. If this line is mastered successfully at the 100 MVA level, it would also make a contribution to the development of large-scale systems to carry power in national electricity networks. The line could also pay for itself in about five years in terms of operating costs for power compared with additional conventional cables.

To run the superconducting cable d.c. would be very costly because of the necessary terminations — the electrical plant needed to shape the power from the line into the pulse for the accelerator magnets and vice-versa. The line will therefore be a.c. with six co-axial conductors (two three-phase links) each capable of carrying 6250 A.

The design of the cable absorbs some ideas from previous work on superconducting power transmission, particularly that done at Brookhaven National Laboratory and at the Linde Division of Union Carbide. The inner conductor will be pure niobium covering a convoluted copper tube of a type already commercially available. There is then tape-wound insulation and an outer niobium layer on larger tube. This gives a reasonable degree of flexibility so that the cable could be wound on a drum. Rather than attempt to link sections of cable with the attendant problems of superconducting joints, it has been decided to run long lengths of cable and to pull sections of cryostat around it, making the junctions between these cryostat sections. Cooling will be by liquid helium and it is estimated that the refrigeration plant will have to cope with about 200 W. An adequate refrigerator is already available at the Laboratory.

The project is not really in line with the interests of the power companies. They will want to use superconducting lines at some hundreds of kV rather than the 13.8 kV of the FermiLab line. Nevertheless, the currents are comparable and any practical experience accumulated in this field, will be useful. It will also serve to continue to stimulate industry for the production and application of superconducting materials.

The project was given the go ahead at the end of July for a sum of $ 0.5 million. It is hoped to have the superconducting energy transmission line in operation early next year.

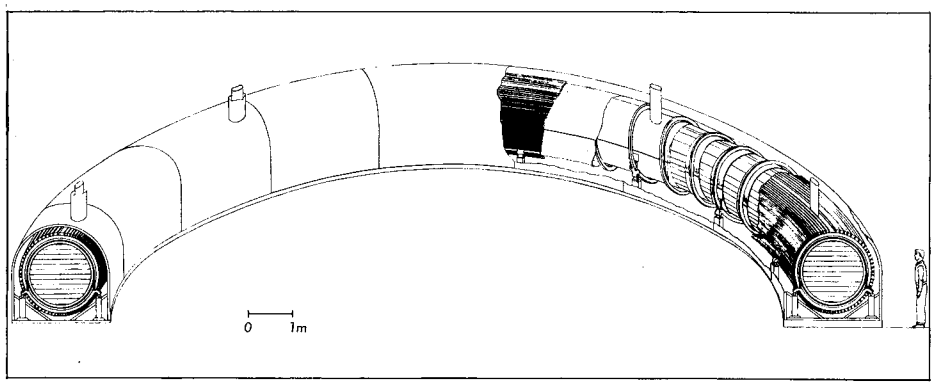
Superconducting energy storage

Superconductivity could also ease another problem at the Fermi Laboratory and at the same time convey some important information to the electrical power industry which could have great influence on its evolution in the years to come.

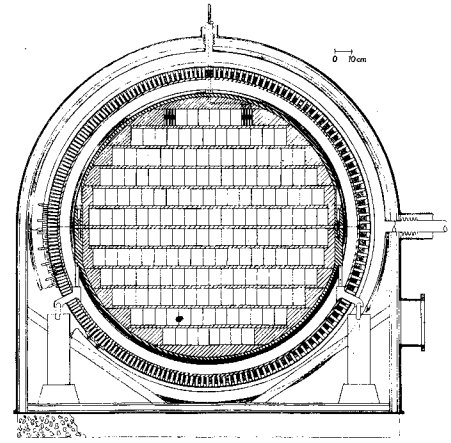
The Laboratory problem is to ease the pain of pulsing the accelerator to 500 GeV. This involves surges of power to and from the main ring magnets over a time interval of about 10 s. The power is drawn direct from the Commonwealth Edison grid in the Chicago region and a special 'static compensator' system (see vol. 8, page 108) is inserted between the accelerator and the grid to prevent the reactive power surges from swinging the voltages on the grid to an extent that troubles other users. By 500 GeV

1. A cut away drawing of the superconducting energy storage coil which has been proposed by a Wisconsin/FermiLab collaboration to store 10 MWh. It would provide power for the proton synchrotron.

2. Cross-section of the energy storage coil. The 188 turns of superconductor (10 × 1.2 cm²) are in the central region and around the outside is the aluminium conductor which will take the brunt of the power surges.



1.



2.

the real power surges are in the 0.1 MWh region and the effect on the grid is becoming uncomfortably high. It would be nice to have a power store on site and to draw on it for the accelerator pulses while the store is fed in a steady way from the grid.

The power industry's problem is on a much more dramatic scale. They have to install sufficient generator capacity to cope with peak demand for electricity during the day and yet the demand drops by about a half during the night. There is thus a vast investment in equipment which functions well below full capacity for much of its life. In addition, some plants (such as present nuclear reactors, the proposed breeder reactor and coal stations) cannot easily have their output turned up and down. Gas and oil stations are therefore usually used for 'peaking' to meet high demand. Unfortunately, these are the expensive sources of power. If methods could be found to store huge amounts of power, generating plant could be built adequate only to meet the demand averaged over 24 hours.

Several techniques of energy storage are under study (involving, for example, banks of batteries or compressed gases) and one technique is in use at hydroelectric plants (water is pumped up in off-peak hours so that it can fall to drive turbines again during peak demand). The idea of storing energy in superconducting coils is the one that interests us here. It will probably not be the cheapest technique in terms of capital investment, but looks potentially the most efficient of all. The University of Wisconsin and Los Alamos have been interested in this idea for several years and other studies include those of M. Ferrier of the Electricité de France.

In August 1973, the Wisconsin people (particularly R.W. Boom, H.A. Peterson and W.C. Young) got together in a study group (chaired by F. Mills) with the Fermi Laboratory to design a storage system appropriate for the 500 GeV accelerator. The aim is to construct a 1 MWh store which could be tapped for 0.1 MWh over a 10 s cycle. A scheme has emerged involving a coil about 9 m in radius and of circular cross-section, 0.7 m radius, with 188 turns of superconductor (each turn having 4 parallel conductors) carrying 80 kA. The geometry ensures that no severe stresses are experienced in the coil. The superconductor is niobium-titanium in copper, giving a conductor 10 × 1.2 cm² of similar type to that used on the 15 foot bubble chamber.

A key feature is that the superconducting coil is surrounded by a shield coil which is connected in parallel to it. The electrical parameters of the two coils ensure that it is the shield coil which gives almost all the 0.1 MWh to the accelerator pulse from the 10 MWh stored. Thus, it is the shield which experiences the temperature rise due to a.c. losses. It is wound of 188 turns of hollow aluminium conductor cooled by helium gas to 40 K. Its heat rise will require 0.8 MW of room temperature refrigeration to be installed. The power grid can make up the power taken from the coils in comparatively leisurely fashion and it has been calculated that the effect of the grid of pulsing the accelerator at 500 GeV will be less than that now experienced at 200 GeV.

The power industry would eventually require huge systems to store up to 10 000 MWh but their cycle times would not have the complications experienced in use at an accelerator. The Wisconsin/FermiLab device would be an excellent test bed for large power storage systems and industry has already expressed interest in a pilot project of this scale.

Preliminary cost estimates are in the region of $ 20 million and it is unlikely that all this money could be found from within the high energy physics budget in these belt-tightened days. It is hoped, therefore, that the power industry and energy agencies will provide some financial support for the work. Support for research and development is needed during the next year with the intention of beginning construction of the superconducting power store in 1975.

One of the FermiLab's most popular features — the herd of buffalo. It is touches like this and the 'prairie project' which show concern for environment and for the tradition of this region of America. It is also fun.

POPAE

For the much longer term, ideas are being shuffled around concerning very high energy storage ring systems. The operation is under the code name 'POPAE' standing for Protons on Protons and Electrons.

The tentative aim is to have colliding beams of protons in the 1000 GeV range in two intersecting rings and another ring of electrons in the 20 GeV range. With some modifications for producing electrons, the existing (or energy doubled) accelerator could be the source of all the particles. Luminosities in the 10^{34} per cm^2 per s region are dreamed of.

Just how POPAE will evolve is heavily dependent on the progress of work on superconducting magnets and on the Energy Doubler. Many of the basic parameters — magnet field strengths, ring sizes, injection energies — would change if the Doubler can be brought into operation. Nevertheless, T. Collins and D. Edwards are already working to string consistent sets of figures together so as to get the thinking on the project on the move. A study was held in September, involving storage ring specialists from other Laboratories also.

The scheme is obviously a major exercise which is unlikely to take the form of a firm proposal for several years. It will then be judged alongside developments at other Laboratories and against the alternative of building a much larger synchrotron to raise peak proton energy, for example, to 5000 GeV. And finally, the USA government would need to be persuaded to provide the spinach to get POPAE really going.

Medical facility

A possible non high energy physics off-shoot in a completely different area concerns the use of particle beams in medical therapy and diagnostics. The linac is able to supply intense beams of protons up to an energy of 200 MeV at a rate of 15 pulses per second. The booster needs them for only about one second in every six, in line with the total accelerator cycle, and there are thus potential protons (which would be expensive to provide elsewhere) for other purposes if this should prove useful.

Medical applications of particle beams have been touched on in our pages before. For cancer therapy there is interest in using pions (the LAMPF machine at Los Alamos will soon provide particles for treatment of its first patient), heavy ions (such as are becoming available at Berkeley) and neutrons (such as are used at the Hammersmith Hospital in the UK and at three centres supported by the National Cancer Institute in the USA). Protons are also of interest particularly for diagnostic work (see the report from Argonne, page 303).

The linac at the FermiLab could obviously provide 200 MeV protons for tumour diagnosis and neutrons for therapy. Neutrons produced by a 66 MeV proton beam (which emerges from tank 3 of the linac) would be capable of irradiations of 1 rad per second at a distance of 1 m from the target. L. Cohen from a Chicago hospital has been prominent among the medical community concerned with developing these possibilities and D. Young and M. Awschalom have led the studies in the Laboratory.

Thoughts first turned to the building of a clinical facility at the output end of the linac so as to have 200 MeV protons and neutrons produced from 66 MeV protons which have drifted (still being focused) through the last tanks. Cost estimates for the full clinical facility looked high and it would have taken several years to



A night view from the top of Hi-Rise which again illustrates the architectural attractiveness of the site. It shows the 8 GeV booster with its central cooling pond and services building. In front of it is the cross-gallery, housing the control room, and on each side are the symmetric arms of the linac (on the right) and the link to the main ring (on the left).

(Photos FermiLab)

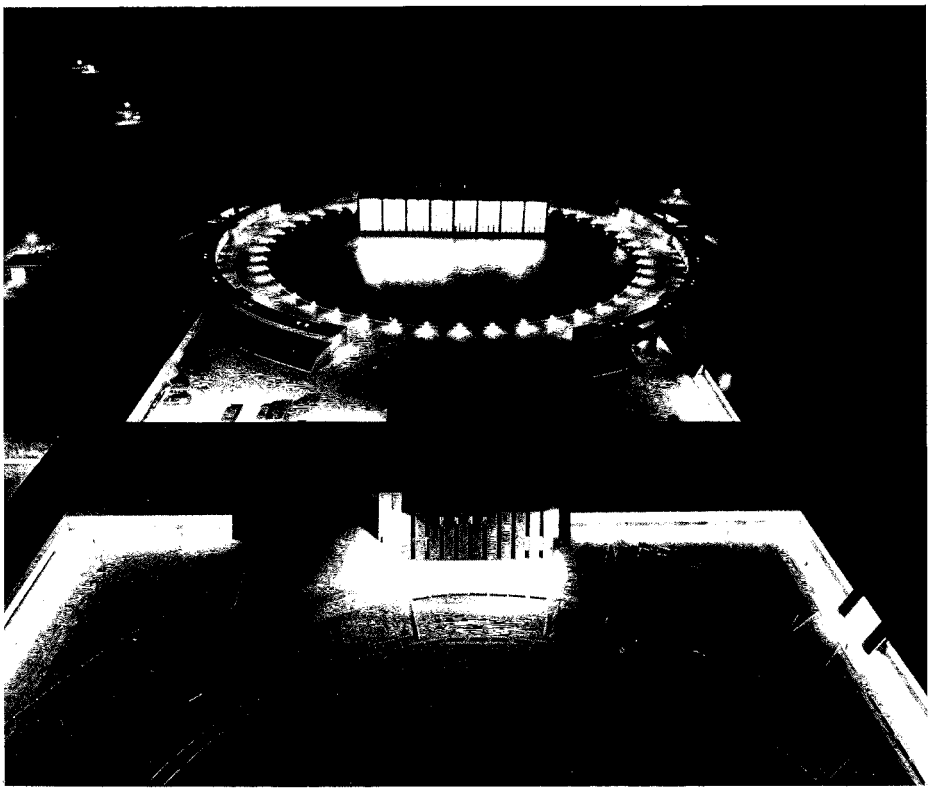
bring into action; present authorization has therefore been limited to tapping 66 MeV protons to do a series of studies on neutron beams. These will involve measurements of target efficiencies, design of neutron collimators and the calibration of neutron doses in relation to the doses available at other treatment centres. Whether this 66 MeV test facility will be set up close to the downstream end of tank 3 or at the output end of the linac, is still under discussion.

Any subsequent development to a full clinical facility to receive patients will obviously await the results of the tests. A national advisory committee has been set up to ensure that the FermiLab work is co-ordinated with other efforts in the USA on the medical applications of particle beams.

This review of present activities at the FermiLab will carry with it some of the flavour of the Laboratory. The high energy of the accelerator is reflected in the high energy of the staff. Drive and enthusiasm characterize almost all that goes on.

Of course, the Laboratory is new and it has for several years a monopoly on a wide range of physics. It would be difficult for the atmosphere to be stale in these circumstances. Nevertheless, there is a conscious effort to sustain enthusiasm and to avoid as far as possible becoming institutionalized. Staff numbers (about 1300 at present) are being kept low, staff mobility is being kept high. New, challenging projects are stimulated as much as possible.

However, for the first time, fiscal year 1975 which began in July brought no new construction money into the FermiLab. More is needed in order to build up the accelerator and the experimental areas to cope with the full 500 GeV, 5×10^{13} potential. Operating money (covering salaries, general materials and the high power bill) is at $ 35.6 million for FY 1975 (whereas about $ 60 million is calculated as necessary for full operation). To this is added $ 11.3 million for equipment such as detectors and beam-line components. $ 96.1 million has been projected for the total Laboratory needs of FY 1976.



Leaving aside these major concerns which will greatly influence the Laboratory's future, we can give a little space to mentioning other features of the FermiLab which deserve articles in themselves.

A special effort has been made to establish a framework of equal employment opportunity. The Laboratory Policy Statement says categorically 'in any conflict between technical expediency and human rights, we shall stand firmly on the side of human rights'. Thus positive steps are taken to encourage the recruitment and training of staff from minority groups.

A spectacular site has been created. The architectural attractiveness of the central Hi-Rise building, the auditorium, the layout of the accelerator, the experimental halls, etc. all lead to the suspicion that the FermiLab is sponsored by Kodak Ltd as well as the US Atomic Energy Commission.

Use is also being made of the site to preserve features of the region or to re-establish an ecological environment that has been lost. A herd of buffalo enjoys one field, a herd of Angus cattle (surely the most attractive creatures of their genre) enjoys another. The centre of the ring is being given over to a long-term (ten year) project to restore an area of prairie to its pre-urbanization state. It will be the biggest nature reserve of its type in the world.

Quite apart from the central task of high energy physics research, the FermiLab is contributing to the enrichment of the scene in many other ways.