ermilab report

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88/9 **Fermi National Accelerator Laboratory**

On the cover: *The members of the Neutrino Group in 1962. Their discovery of the second neutrino won the 1988 Nobel Prize for Physics. From left to right in photograph: Jack Steinberger, Konstantin Goulianos, Jean-Marc Gaillard, Nariman Mistry, Gordon T. Danby, Warner Hayes, Leon M. Lederman, and Melvin Schwartz. (Photograph by Jim Cleary, Nevis Labs, courtesy of Norman Gelfand)*

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A Nobel for the Second Neutrino

Dr. Leon M. Lederman, Fermilab's Director since 1979, has been named one of three 1988 Nobel Laureates in Physics for the Columbia University Neutrino Group's discovery, in 1962, of the muon neutrino at the Brookhaven National Laboratory AGS (alternating gradient synchrotron) accelerator. Lederman shares the $390,000 award with his two co-leaders on that experiment, Melvin Schwartz (founder of Digital Pathways, Inc., in San Francisco, California) and Jack Steinberger (Senior Scientist at CERN). All three will receive their awards on December 10, 1988, in Stockholm, Sweden.

Lederman's first reaction to the call from Stockholm was laughter; he then began calling family members with the news. The day's festivities began in earnest when a small group of well-wishers, including Accelerator Division Head Helen Edwards and Collider Detector at Fermilab Co-Spokesman Alvin Tollestrup, arrived at the Lederman home at 7:00 a.m. bearing champagne.

Once at work, the Director fielded phone calls in his office from the press and colleagues while a celebratory crowd of Fermilab staffers filled all the available space on the east side of Wilson Hall's second floor. At about 10:00 a.m., Lederman faced members of the press.

"Of all the recognitions one can get," he began, "there's something very spooky about the Nobel Prize. It has its own special aura, because people like Albert Einstein and Enrico Fermi and so many others who we venerate so much and who are our intellectual heritage are all part of this group [of Nobel Laureates]. Clearly, it's a sobering experience.

(Fermilab photograph 88-1027-29

Meet the press.

"It is also a great day for the field of elementary-particle physics and for Fermilab, because this award recognizes exactly the type of work that we're doing here today. I think this is just the first of a large number of Nobels that will be won at Fermilab. Be patient!

"To me, the most encouraging aspect of an award such as this is that young people will hear about it and be inspired to carry on this most basic type of research. Those are the people who will figure out how to solve the problems society faces, such as acid rain and the greenhouse effect. Neutrinos are part of a body of knowledge called basic research, and that body of knowledge will certainly be called upon to supply the technology that will improve the quality of life for the entire planet. The TEVATRON and the SSC and many other scientific tools are needed to encourage young aspirants to science to pitch in and help to advance science across the entire frontier."

* * * * * * *

An overflow crowd of Fermilab staff and visiting scientists in the Ramsey Auditorium greeted the Director with a standing ovation at 4:00 p.m. on the afternoon of October 19. Looking up from the stage at his friends and colleagues, Lederman said:

"The biggest thrill of all is this one, standing in front of all of you and seeing how we are sharing in this really tremendous event. The rewards of a life in physics are ample. It's true that back then, when we recorded our data with quill pens and used slide rules, it was easier [to do physics] than it is now, but I don't think the fun of doing physics has changed.

(Fermilab photograph 88-1066-16)

"In the late 1950s, particle physics was in a very confused state. There were lots of particles that had been discovered with the new accelerators. I was working at Columbia University, and the largest accelerator in the world was the mammoth 30-GeV AGS accelerator out in Long Island at Brookhaven National Laboratory. At the time, my colleagues at Columbia were Jack Steinberger and Mel Schwartz. There was a lot of discussion about the particular crisis in particle physics at the time. As I remember it, there were two particular problems that were besetting the advance of particle physics. One had to do with the fact that a certain reaction did not take place. That was the decay of a mu meson into an electron and a gamma ray. Now, all theoretical aspects of this said that this reaction should take place, because it conserved energy, it conserved momentum, it conserved angular momentum, it conserved all possible rules, and yet it didn't take place.

"At that time, there was something called a totalitarian rule in physics that said anything that wasn't forbidden was compulsory. Since this reaction wasn't forbidden, it should have been compulsory, yet it wasn't happening. In fact, many of the most precise experiments of the period were being done at Columbia's cyclotron, and whereas this reaction should have taken place with a probability of 1 out of 10,000, the experiments had gone down to 1 out of 100,000,000 and no such events took place. If you examine the chain of logic which led to the prediction that this reaction had to take place, it turned out that there were steps you had to question, since it wasn't taking place. One of the steps had to do with neutrinos and a complexity in our understanding of neutrinos, and that perked up the interest in neutrinos as an entity to look at.

"The other crisis had to do, in fact, with a general understanding of the high-energy behavior of weak interactions. At that time, weak interactions were one of the more mysterious of the forces of nature. In particular, the funny thing about weak interactions was that as you raised the energy at which particles would make collisions, the theory said the weak interactions would get stronger and stronger, and in fact, if you raised the energy high enough, the weak forces would get so strong that the theory would predict nonsense.

"Both crises merged in the discussions at Columbia in late 1959. We had the habit in those days of being very argumentative; the three of us, Schwartz, Steinberger, and myself, although we loved each other very dearly, would always be fighting, and usually, it was two against one. Sometimes it was Jack and I against Mel, sometimes it was Mel and Jack against me, we always varied in our arguments. We were arguing very vigorously about these various things. There had been some preceding ideas about neutrinos, one by Bruno Pontecorvo, who had published a key suggestion, but which never would have worked, about how you look at neutrinos. Mel Schwartz himself had a much better idea about how to do neutrinos, but he ended up concluding that a practical experiment needed a brand new accelerator. We kept arguing that maybe one didn't have to wait too long, maybe the Brookhaven accelerator was good enough, and ultimately, we hit on a scheme for doing the research.

"Neutrinos are unique in that they have no electric charge. They have no strong force, they only have the weak force, and the weak force is very weak.

When we calculated the thickness of steel it would take to stop a neutrino, we got a number like 100 million miles. We felt we couldn't afford that. It was the first sign of humility in high-energy physics. But then cooler heads prevailed, and we realized that we didn't really need 100 million miles of steel, because you had more than one neutrino. If you had ten neutrinos, you'd only need a 10th of that, and in fact, it turned out that the Brookhaven accelerator (and this was one of the tricky issues) could produce enough neutrinos so that an affordable detector could be built. We hit on a number, the biggest number we New Yorkers could think of for a neutrino detector: 10 tons! It is to laugh these days, 10 tons! But that was the biggest number we could think of and we built a detector consisting of 10 tons of aluminum.

"I think that I won't go into this in too much more detail, except to say that we had to convince all sorts of people that this was a good experiment. There were committees, and there was the Director of the Brookhaven Laboratory; boy, those directors, they're just the pits. He didn't understand anything that we were talking about. We'd explain it to him slowly and carefully, that's how you have to speak to a director. It's a lesson for all of you. We presented him with a written paper and we noticed he was pointing to each word. I'm kidding, I'm kidding.

"At any rate, our experiment was approved, and then the question was to do the experiment in such a way that we got a clean beam of neutrinos. To get a clean beam of neutrinos, in principle, was simple. The protons from the AGS accelerator hit a target, and then you leave some space for the pions and kaons and some of that debris to decay, and occasionally in the decay process, there will be a few neutrinos. These pions and kaons and protons, and a few neutrinos, strike a steel wall. We used a steel wall about 50 feet thick, made out of steel from the battleship *Missouri*, cut up elegantly into nice pieces. I remember we had a cannon from the *Missouri*, which we had to use. The trouble with the cannon was that it had riflings, and one of the graduate students at that time, who was part of the Neutrino Group, Nariman Mistry, was asked to crawl into the cannon and put some lead wool in all the riflings so that we wouldn't have all these grooves. He spent about two hours, and then he crawled out and he said, 'I quit! I don't want to do this any more.' And I said, 'You can't quit, where will we find a student of your caliber?'

"These are some of the adventures of getting the experiment done. I remember also that the head of the [Brookhaven] accelerator division, Ken Green, had this brand new accelerator, and we wanted to stack this rusty steel very close to the accelerator. Ken said, 'Over my dead body will you stack that close to the accelerator.' We decided that would make an unsightly lump in the shielding, so we tended to compromise. But we stacked it as close as we could and eventually got the whole experiment running. In fact, from late 1959, when we decided in principle what we wanted to do, until the end of the experiment, took a total of less than two years, maybe about 18 months.

"We had a large group of seven people. There were three graduate students, Dino Goulianos, who is now a professor at Rockefeller University and a member of CDF; I mentioned Mistry, who is a senior physicist at Cornell. The other one was Jean-Marc Gaillard, who got his degree at the University of Paris and is now a senior scientist at CERN competing with us to try to find the top quark. And Mel Schwartz, Jack Steinberger, and I, and one Gordon Danby, a senior physicist at Brookhaven. That was the team. Another two I should mention are Ken Gray, who is now here at Fermilab, and was a brand new technician we had just hired to help us assemble the chambers, and Warner Hayes, who was the senior technician in the group. He's been a great help in our experiments for many years.

"This motley group did the experiment. It took us eight months to collect the data, and we got 50 neutrino events. In the last run of the neutrino beam at Fermilab we collected 50 neutrino events in a few minutes! That shows a sign of progress. Those 50 events did two things: First, they went a long way toward resolving the problem of the neutrinos. They showed that there are, in fact, two kinds of neutrinos, one kind of neutrino that's very closely related to the electron, and another type of neutrino that is very closely related to the muon. I think it was the first step in getting us to what we now call the Standard Model, because it suddenly set up a familial relationship between electrons and neutrinos. It is what we now call 'flavor.' After quarks were invented a few years later, the neutrinos and the electrons and the muons and the quarks all fit into the family grouping of the Standard Model.

"The other important thing was that by developing the ability to do neutrino experiments, we created what has become a cottage industry, with hot and cold running neutrinos in all the laboratories. Brookhaven started a program of neutrino physics, our friendly competitors at CERN got into neutrino physics, and Fermilab's mainstay for many years has been neutrino physics. Every place that had a big enough accelerator was doing neutrino physics. These high-energy neutrino beams turned out to be very important probes. They taught us a lot about the weak force, because they're unique; any other particle has a mixture of forces and you have to sort them out. Neutrino scattering has been very important, its been a very fruitful device for letting us understand more about particle physics, about the nature of quarks, about the way quarks bind in protons and neutrons, and it is still giving us a lot of surprises. At the present time, the interesting question about neutrinos is whether they have any slight mass. In general, in those days, we thought the neutrino would have zero mass. Nowadays, the astronomers are very concerned about neutrinos having some mass, because it is possible that the famous Dark Matter, where 90% of the mass of the Universe is supposed to be invested, could conceivably be made up of neutrinos. Experiments at Fermilab have paid some attention to this, although they've not yet been successful. We had a workshop last month on the future of neutrino physics at Fermilab, so it is still a brisk and invigorating business, and we expect to see many more surprises.

"I'll conclude by saying that getting an award like this is really a lot of fun; it made my whole day. I recommend it. The nice thing implicit in this is some recognition of the field of high-energy physics, evidence that the field is appreciated globally, and that the U.S. is still in the game of high-energy physics. I hope it will bring a lot of attention to the TEVATRON and to our Collider program."

New Developments at the Fermilab Advanced Computer Program (II.): The ACP Multi-Array Processor System for Theorists

T. Nash, H. Areti, R. Atac, J. Biel, A. Cook,
J. Deppe, M. Edel, M. Fischler, I. Gaines, R.Hance, D. Husby,
M. Isely, M. Miranda, E. Paiva, T. Pham, and T. Zmuda
Fermilab Advanced Computer Program

E. Eichten, G. Hockney, P. Mackenzie, H. B. Thacker, and D. Toussaint
Fermilab Theoretical Physics Department

The Advanced Computer Program (ACP) Multi-Array Processor System (ACPMAPS) is a highly cost effective, local-memory parallel computer designed for floating point intensive grid-based problems. The project is a joint effort of the ACP and Fermilab's Theoretical Physics Group. Processing nodes of the system are single-board array processors based on the FORTRAN and C programmable Weitek XL chip set. They are connected by a network of very-high-bandwidth, 16-port crossbar switches. The architecture is designed to achieve the highest possible cost effectiveness while maintaining a high level of programmability. At Fermilab the primary application of the machine will be lattice gauge theory.

To obtain some estimates of the computing needs of lattice quantum chromodynamics (QCD) one can consider the calculation of the deconfining temperature in SU(3) gauge theory without quarks, which is one of the most solid four dimensional calculations done so far. Something like 500,000 MFlops - hours (peak, ~70% delivered) were used on a Star ST-100 array processor. This calculation required a lattice spacing of less than 0.1 fermi and a volume of close to (2 fermi)^3, resulting in lattices with spatial sizes of up to 19^3. It is virtually certain that calculations with quarks will require even larger lattices than this for comparable accuracy. Lattices with space-time sizes 32^4 to 64^4, requiring 1-20

This article is a continuation of "New Developments at the Fermilab Advanced Computer Program. . ." which appeared in the July/August 1988 issue of Fermilab Report. *It is based on a talk given by T. Nash at the "Workshop on Computational Atomic and Nuclear Physics at One Gigaflop" at Oak Ridge, Tennessee, April 14-16, 1988, and is also available as Fermilab preprint Conf-88/97.*

GBytes of data memory, are a reasonable guess. Calculations of hadron masses in the approximation of ignoring dynamical quarks have not yet achieved a reasonable understanding of calculation errors, even on Cray-sized supercomputers. Although algorithms for the inclusion of dynamical quark effects have made tremendous progress in the last few years, at present they still seem to require at least two orders of magnitude more computer time than comparable calculations without quarks. It is thus clear that large increases in combined CPU power *and* algorithmic power are still required even for simple QCD calculations.

The aim for the new ACPMAPS machine is to deliver such large amounts of memory and CPU power at the lowest possible cost, without compromising the programmability required for rapid algorithm development, which is just as important as raw computing power in achieving the goals of lattice gauge and other problems in theory.

A 16-node system is being built. Two switch prototypes are working and tested. Four Floating Point Array Processor (FPAP) node modules are also working and undergoing rigorous testing. They have successfully run extensive physics code. Fermilab intends to proceed to a 256-node (5 GFlop for about $1 million) system as soon as the 16-node system is operational. Parts are being procured for this system, which will be assembled at the end of the year. Given the communications bandwidth noted below and the large amount of memory per node, it has been calculated that performance for appropriate lattice gauge algorithms should increase linearly well past 256 nodes. Maximum system size is 2048 nodes. The system is being designed in the ACP tradition to be commercialized and available to other institutions.

Architecture Overview

A block diagram of the system is shown in Fig. 1. The individual single board FPAP's have peak performance of 20 MFlops. Performance of key kernels (SU(3) multiplies) have been measured on the prototypes to exceed 15 MFlops/node. For lattice gauge physics, a performance standard is the link update time. Using the Kennedy-Pendleton heat bath algorithm (pure gauge) a single FPAP has been clocked at under 800 μsec per link update. Depending on the algorithm, this corresponds to a real performance of 4-10 MFlops/node. Each FPAP contains 8 MBytes of data and 2 MBytes of program memory. (In the event of memory shortages, the FPAP's can be configured with a minimum of 4 MBytes for data.)

The FPAP's are plugged into a crate whose backplane is a 16-fold bidirectional high-speed crossbar. This is the Branchbus Switch Crate described in

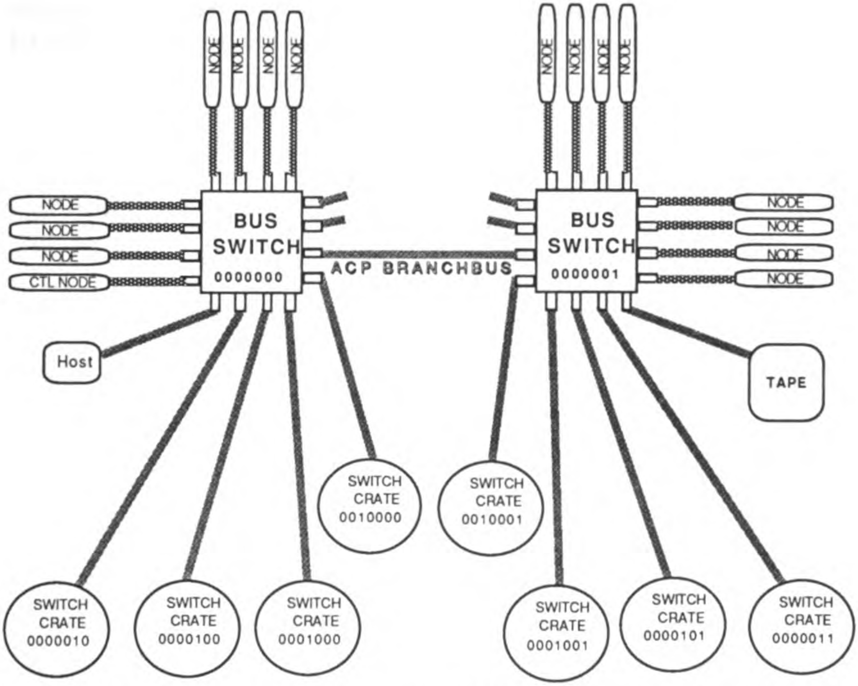

Fig. 1. *The ACP Multi Array Processor System: 256-node configuration*

the previous issue of *Fermilab Report*. The nodes can speak with each other in pairs at a full 20 MBytes/sec simultaneously. The architecture of ACPMAPS is a hypercube network of such crossbar switch crates, each supporting 8-16 FPAP's. In a typical configuration, eight array processor nodes will be plugged into each switch crate along with up to eight BSIB I/O modules (also described in an earlier section) that interconnect crates in a hypercube (or better, if extra interconnects are desired).

Processing nodes do not participate in any communication activity other than their own. This is an important distinction from traditional hypercube implementations. The switches handle intra and intercrate routing automatically. The system therefore does not operate with all node programs (and/or communications) in lock step like an SIMD machine, as is the case in most of the other projects of this type (Columbia, IBM GF11, and APE). It also does not strongly favor local communication (as existing hypercubes do). It thus allows for any conceivable new lattice algorithm unconstrained by synchronous or local communication requirements. Despite its algorithmic flexibility the system ranks as the best (or nearly so, we won't argue) in terms of cost effectiveness of MFlops/$.

In addition to the flexible global architecture of the system, there are two important aspects of the FPAP itself that distinguish it from the CPU's of the other, more special-purpose lattice gauge processors. First, the FPAP memory is neither too large nor too small, but is ideally matched to the FPAP performance and communication capabilities and to the demands of lattice gauge (and presumably other site-oriented) problems. Secondly, the FPAP sticks closely to the Weitek XL architecture, using only one floating point processor per board. This allows the use of C and FORTRAN compilers and greatly simplifies the microcode.

The asynchronous communication and MIMD (multiple instruction, multiple data) processing architecture, in distinction to the more common synchronous communication, SIMD (single instruction, multiple data) approach, is one of the most important features of the system. There are many advantages to this type of architecture. It is very flexible: it can handle problems which are awkward or impossible in synchronous SIMD such as, in the case of lattice gauge, heat bath and incomplete LU decomposition algorithms and random lattice problems. The allowed sizes and shapes of the lattices are independent of the details of the hardware. The node structure of the machine can be made invisible in much or all of the high-level user code, resulting in improved programmability. This also results in improved fault tolerance, since the system can be reconfigured readily if a node fails, without requiring changes in user software or allocating nodes as spares. Complications which have to be faced include the potential for synchronization conflicts. This requires care in designing and understanding the communications system. In addition, a non-trivial system software design effort is required to ensure that overheads associated with the communications software are kept to acceptable levels.

A major new package of software (CANOPY) has been developed for this system. Theorist users need think only in terms of sites and fields on sites. The system automatically allocates sites to nodes and handles all site-to-site communication whether on the same node or another. Thus, users do not have to know details of the hardware for effective use of the system. Routines that are used heavily will be microcoded. The skeleton of all applications are written in FORTRAN or C using a series of special subroutine calls that make the programs particularly readable for lattice gauge theorists and others with site oriented algorithms. In this way, despite ease of use and flexibility, the system can approach 10 MFlops/$4000 node in FORTRAN or C. The CANOPY system software is described in more detail below.

The Floating Point Array Processor Module, Communication, and I/O

The initial ACPMAPS FPAP nodes are single-board, floating point array processors using the Weitek XL chip set which contains a 32-bit, 20-MFlop (peak) floating-point unit, an integer processor, 32 floating point and 32 integer registers, and an instruction sequencer. The chip set as a whole is programmable in FORTRAN and C, at some sacrifice in performance. Thus, these modules incorporate the functions of a high-level language programmable single board computer and a high-performance floating point array processor. No external CPU is required as a controller for these standalone floating point engines.

The FPAP modules (Fig. 2) contain the XL chip set, the data and code memory, and the interface logic and input and output queues for communicating with the crossbar switch crates. One floating point unit is used per node, in contrast to the designs of most of the other machines aimed at lattice gauge theory. In addition to being a flexible and sensible design for a wide variety of problems, this was dictated by the desire to be able to use the Weitek FORTRAN and C compilers for the XL chip set.

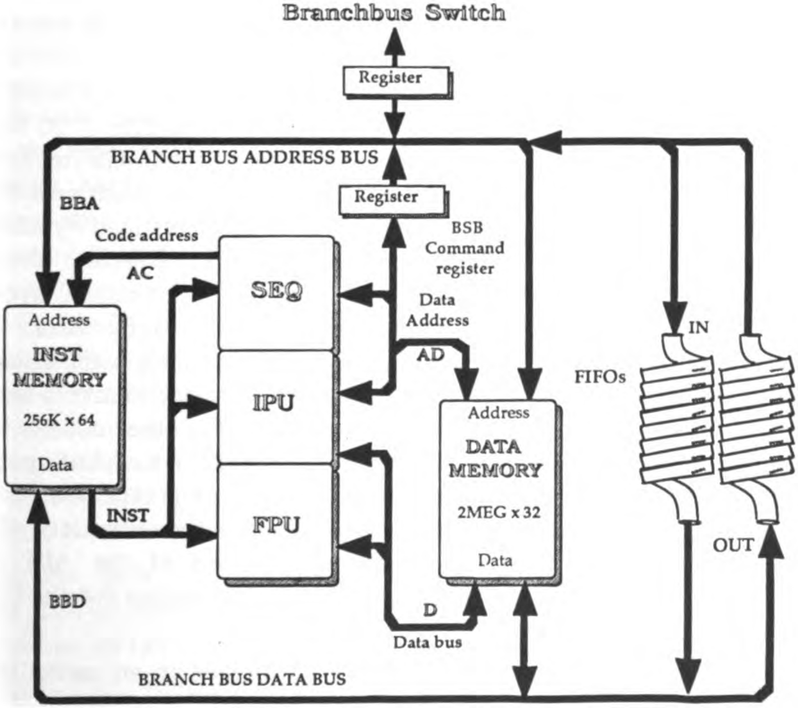

Fig. 2. Schematic design of the Floating Point Array Processor.

The 2 MBytes of program memory and 8 MBytes of data memory is made from 1-Mbit 80-nsec access time page (or static column) mode dynamic RAM chips. In page (or static column) mode these memory systems can deliver data at a rate of one word per 100 nsec. This rate is fast enough that little additional efficiency would be gained in most lattice algorithms by replacing some of the DRAM by faster, more expensive static RAM. The memory chips constitute at least a third of the total cost. The memory-to-power ratio provided (8 MBytes to 20 MFlops) is larger than that provided by most other machines of this type, and is larger than is required by presently existing algorithms for simulating full QCD, including internal fermion loops. It is approximately appropriate for calculations in the valence approximation, ignoring fermion loops. Algorithmic improvements over the next few years will certainly change the required ratio. It seems likely that the possibilities which will increase the required ratio (preconditioning and Fourier acceleration of quark propagator calculation, Fourier acceleration of gauge simulation) are currently more promising than those which reduce the amount of memory required per CPU cycle (such as adding nonlocal operators to the action to reduce finite lattice spacing errors) and that the large amount of memory could easily become crucial in the years to come.

The nodes are plugged into a network of Branchbus Switch Crates whose backplanes handle full 16-port crossbar switching at bandwidths of 20 MBytes/second per connection. This yields a total bandwidth of 2.56 GBytes/sec for a 256-node machine. A cluster of 8-12 nodes is attached to each switch. The switches are connected in a hypercube, which may be augmented by additional communication channels along heavily used paths. This structure allows the nodes to communicate as if they were connected in a conventional hypercube arrangement, but more than this, it allows any node to communicate at full speed with *any* other node, allowing efficient running of algorithms requiring nonlocal communications. The switch crates allow any node to access any other node's data memory without needing to know where the other node is located on the network. With the current switch crate hardware, systems of up to 2048 nodes are possible before this transparent non-local communication feature is lost. The Branchbus Switch Crates will also be used in a variety of high-performance experimental particle-physics applications of the ACP Multiprocessor System, including the level-3 programmable trigger for the Collider Detector at Fermilab.

The Exabyte video technology tape drives, described in an earlier section, will be used for check pointing long calculations and for archiving of gauge fields and propagators. One drive will be attached to every switch crate, enabling all of memory to be stored in under five minutes.

CANOPY System Software

Lattice gauge theories are part of a large class of grid-based problems derived from discretization of a set of differential equations which are very suitable for a parallel architecture like this one. The natural breakdown of the problem is to assign a certain subset of the sites in the space or spacetime to each node, which stores the data for the field variables defined on the sites assigned to it in its local memory and does calculations for its sites. The system software, CANOPY, has been designed to shield the user as much as possible from the hardware dependent node structure of the parallel architecture. The user thinks in terms of sites, not nodes.

User programs are divided conceptually into two pieces: the control program, which is called from a MicroVAX host or mainframe VAX and runs on the control node, and site subroutines, which run on the individual nodes. The control program manages the execution of lattice-wide tasks. It is typically written in ordinary FORTRAN or C augmented by a set of system subroutines for dealing with global concepts (e.g., field memory, lattice-wide tasks) which are distributed over all the nodes and require special treatment. The beginning of the control program includes statements like the following:

```
call define_periodic_lattice ( ndims, sizes, lat1 )
call define_field ( lat1, quarksize, q )
call define_field ( lat1, quarksize, q1 )
call complete_definitions
```

The routine `define_periodic_lattice` tells the system that our problem contains one lattice called `lat1` of `ndims` dimensions with the size of each dimension contained in the array `sizes` and with standard hypercube connectivity. More general user-defined connectivity are allowed. It is possible to define several lattices in the same program for block spin renormalization group or multigrid algorithms. The routine `define_field` tells the system that memory will be required for storing two fields identified by `q` and `q1`, each with `quarksize` components for each site of `lat1`. The routine `complete_definitions` calls routines which assign specific sites to specific nodes, allocate memory in the nodes for the field data and site structures, and set-up structures for each site pointing to the memory areas of adjacent sites of the lattice.

A control node subroutine which operates on a field `q` with an operator `dslash_` and stores the result in another field `q1` would be written as follows:

```
subroutine dslash ( q, q1 )
        .
        .
        .
call do_task ( dslash_, lat1,
```

```
        pass$, q, 1,
        pass$, q1,1,
        end$)
return
end
```

The system subroutine **do_task** passes to all the nodes a pointer to a subroutine **dslash_** which operates on a single site and a pointer to a list of sites on which to operate, which may be the entire lattice **lat1** or some previously defined set of sites such as **red_sites**. A system routine on the node, invisible to the user, calls **dslash_** for all the sites in the set of sites which have been assigned to the node. **do_task** may also be used to pass **(pass$)** to the nodes parameters required by the site subroutine (like the field identifiers **q** and **q1**) and to integrate **(integrate$)** data returned from the individual nodes.

The site subroutines access and replace data from global fields with subroutines like:

```
call get_field  ( q,  site, qtemp )
call put_field  ( q1, site, qtemp )
```

which determine if the desired data is already resident on the node and open a channel to the communications hardware if necessary.

Most site subroutines can be written in FORTRAN or C. CPU-intensive kernels such as SU(3) matrix multiplication and essential routines like **dslash_** will be microcoded for maximum efficiency. We expect that lattice gauge algorithms prepared in this way will run at up to 10 MFlops per node.

The main interest of the Fermilab lattice group in using CANOPY and the ACPMAPS system is the application of lattice gauge theory to QCD and "beyond the Standard Model" phenomenology. However, since site-oriented problems involving numerical solutions of differential equations pervade all of science and engineering, the hardware and software we have just described clearly have a much broader applicability than just high-energy theory.

Future Directions

To a large extent, future ACP directions, given the apparently insatiable demand of high-energy physicists for computer cycles, will be driven by the extremely fast pace at which microprocessor performance is increasing. Reduced Instruction Set Computer (RISC) processors running at clocks upwards of 50 MHz, with performance at 50 and even 100 MIPS, now seem assured within only two years or so. Technically this puts a big demand on cache systems and on the speed of static rams used in caches. This problem must be solved by the processor companies since it is universal for their customers.

The other issue the extraordinary performance of these devices will raise in multiprocessor environments is the inadequacy of busses to support their communication requirements. It will not be a matter of picking a slightly faster bus than VME (like Multibus II or even FASTBUS). The bus concept itself will be obsolete and will have to be replaced by point to point communication. For the ACP this appears to mean that future processors, even those for experimenters, will have to plug directly into the Branchbus Switch Crate. This will provide the communication bandwidth they need, but no longer in a commercial crate standard where the marketplace delivers a large and always improving variety of I/O controllers and other essential peripheral devices. The Branchbus Switch is the same height as VME, but deeper. It is therefore likely that the ACP will develop an interface card that will allow VME devices to be plugged transparently into the Branchbus Switch.

With very-high-performance RISC processors in the Branchbus Switch Crate, the experimenter's ACP system seems likely to merge with that designed for theorists. However, the processors may continue to differ because large theoretical problems, with their very regular accesses to memory, tend to have a very high cache miss rate in conventional cache designs. Multi-level cache may be the answer to this problem in an approach that could be equally effective for both classes of high-energy physics problems. (In fact this may be the way in which manufacturers solve, in an affordable way, the static ram speed requirements mentioned earlier.) An alternative approach, which adds significant software and hardware complexity, could be called "anticipatory" cache. In regular theoretical problems the data that will be required from memory is known well ahead of time. Means could be devised to have programs inform the hardware of anticipated memory fetches so the data could be moved from slow memory to cache before it is needed.

The way in which the huge anticipated increases in computing are going to be brought into online systems for data acquisition and triggering for the high-rate Superconducting Super Collider-era detectors is very likely going to be the subject of ACP development work over the next few years. There is also under way a project to develop particularly efficient work station tools for doing analysis. Clearly, when the new processor systems reduce the turn-around time to pass through a DST data base from days to less than an hour, it will be inappropriate to continue spending days lining up calls to HBOOK (a histogramming package) for a next analysis run. Macintosh-like human interfaces, adjusted to physicist needs and abilities, will be used on Apple or, perhaps, Sun or other workstations.

It is clear that the opportunity exists to continue development of usable, extremely high-performance, yet affordable, parallel machines for high-energy physics and other sciences hungry for computer power. This opportunity is really an obligation given the strongly felt need.

The Fermilab Upgrade

Leon M. Lederman

Introduction

In 1978, Fermilab set out a goal of building a superconducting accelerator (Energy Saver) which would raise the proton energy to close to 1000 GeV for operation in two modes. TEVATRON I (TeV I) would provide proton-antiproton collisions at a total CM energy of near 2.0 TeV to study the particle mass domain beyond 100 GeV. TEVATRON II (TeV II) would provide extensive facilities for the programmatic study of Standard Model physics in an upgraded fixed-target program. There was, of course, the realization that with the right mixture of precision and imagination, the Collider could add significantly to Standard Model physics (e.g., W and Z physics; W, Z pairs; B-physics), and that the fixed-target program could explore beyond the Standard Model (e.g., Rare K-decays, CP violation). In 1988, we are engaged in setting out the future program of the Laboratory based upon the success of the Energy Saver, TeV I, and TeV II construction programs. This future program assures that operation of the TEVATRON facility for physics is the overriding priority between now and perhaps 1993, and it also assumes that the Superconducting Super Collider (SSC) will be funded for construction in 1990 and will begin producing physics by 1999.

A "brief history" of upgrades is presented at the end of this article.

History

The notion of going to higher luminosity in the Collider and more intensity and quality for the fixed-target program has been around since the start of TeV I and TeV II. The simply stated goal in collider physics is to increase the mass range, which can be searched for new phenomena, and in the fixed-target program to enhance the precision and the detail of our Standard Model base. In Laboratory presentations we have proposed a Superbooster (1980), Dedicated 4-TeV Collider (1983), Brightness Enhancer (January 1984), Source Brightener

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This article (prepared for the proceedings of the 1987 DPF Summer Study: Snowmass '88, High Energy Physics in the 1990s, Snowmass, Colorado, June 27-July 15, 1987, and available as Fermilab TM-1536), is based upon the work of many people over a long period of time. In particular, Steve Holmes and Estia Eichten have been most helpful.

(September 1984). Upgrade plans and funding profiles were presented in the 1986, 1987, and 1988 institutional plans. Responses from HEPAP have been positive going back to 1982 (see End Notes). Experience with the first engineering run of TeV I in 1985 and the 1986 construction year led to a thorough review of the entire accelerator complex. A Collider upgrade plan was submitted (short form 44) with a total projected cost of $267M in January 1986.

As the first phase, the Linac Upgrade was submitted in January 1987 and resubmitted in February 1988. The plan has emerged into two stages: an adiabatic series of improvements which will bring the peak luminosity of the $\bar{p}p$ Collider to about $5x10^{30}$ cm^{-2} sec^{-1}. This should also make over $3x10^{13}$ ppp available to the fixed target, an improvement of almost a factor of two. The Collider energy would be 1.0 TeV and the fixed-target energy near 900 GeV. Given reasonable R&D funds and the Linac line item, all of this should be available for a D0 and Collider Detector at Fermilab (CDF) run of $\int Ldt > 10$ pb^{-1} in 1992.

In the period until 1993, there would be no planned shutdown in excess of several months for installation of upgraded components. This period would also see modest upgrades to CDF and some decisions on major new detectors and upgrades for the fixed-target program. In 1993, one can contemplate a 6-10 month shutdown for the second phase of the upgrade. This would be designed to deliver in excess of 100 pb^{-1} per run to the collider detectors and in excess of $4x10^{13}$ ppp for the fixed-target program. Given enough protons, it will pay to improve the fixed-target duty cycle even more - perhaps from 30% to 60%.

There are now several competing elements for the second phase of the upgrade. The purpose of this note is to review these which, at this writing, are evolving out of extensive high-energy physics (HEP) community discussion.

Review of Upgrade Motivation

The Fermilab Collider is the highest energy machine in the world. Until SSC or LHC or the Soviet 3-GeV x 3-GeV collider turn on and begin to produce physics data, this will remain so. We believe we have a time window that will go to 1999 or so, since it will take several years for any of the above machines to go from commissioning to real physics. The window is not only an opportunistic window, it is essential that there be continuity in the production of physics results. Whereas, if SSC is proceeding towards, say, a completion date of 1997/8, a fairly large community will be occupied there by 1992, but one cannot put graduate students, new postdocs, and pre-tenure professors on many of the SSC detectors until they are much closer to physics. This is borne out by CDF and D0 experience. The Fermilab Collider physics in the period 1994-1999 will

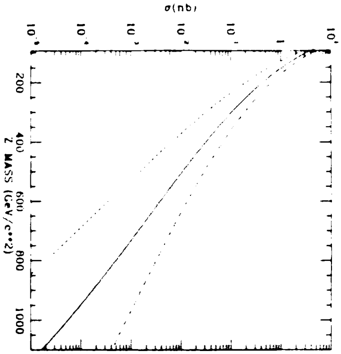

Fig. 1. Production of heavy Z^0. The mass reach is determined by the integrated luminosity and the discovery level required, e.g., 100 produced events. See Chart I for results.

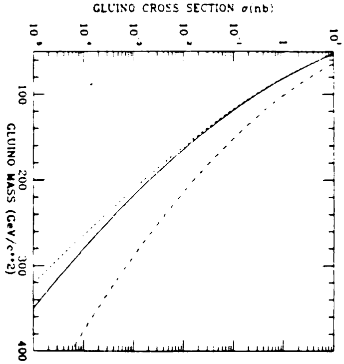

***Fig. 2.** Production of gluinos.*

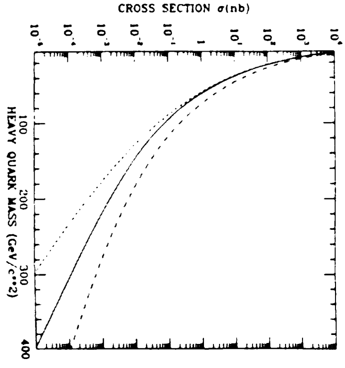

***Fig. 3.** Production of heavy quarks.*

also be invaluable as a guide to SSC both from the point of view of collider and detector technology, but also from the physics knowledge base. Since a year of SSC is worth $250M (1988), it is terribly cost effective to be as well prepared for the SSC era as one can possibly be. Finally, we note that there *may* well be niches of physics for which TEVATRON energy is well enough above threshold; a vast increase in energy may then only increase backgrounds.

The knowledge base will come from both the Fermilab Collider *and* the fixed-target program, especially those experiments which illuminate high-rate technology and those which use precision and detail to test and extend the Standard Model.

To present a glimpse of the relative merits of the various upgrade options we present a series of graphs calculated by E. Eichten (Figs. 1-3). We stress that, whereas the optimum plan is not yet clear, what is perfectly clear is *that the design goals are such as to double the discovery limits*, i.e., equivalent to doubling the effective machine energy. Furthermore, it makes possible the collection of huge amounts of data for particles in the W, TOP, e.g., ≤ 125-GeV mass range.

A doubling of the mass reach could be compared to building a 400-GeV e^+e^- machine with sufficient luminosity to double the mass reach of LEP II. Another comparison scale is the

Chart I.

Numbers of produced events in a five-month ($3x10^6$ sec) year based on assumed Lp

Lp→	**No Upgrade**	**Phase I**	**Phase II**		
|	$3x10^{29}$	$4x10^{30}$	$4x10^{31}$ A.	$2x10^{32}$ B.	$1x10^{31}$ C.
CM Energy	2 TeV	2 TeV	2 TeV	2 TeV	≥ 3 TeV
Int *L*	$\bar{p}p$ $1pb^{-1}$	$\bar{p}p$ $10pb^{-1}$	$\bar{p}p$ $100pb^{-1}$	pp $500pb^{-1}$	$\bar{p}p$ $30pb^{-1}$
			Z'		
Mass	Discovery Limits			"Factory" Regime	
200	500	5000	50 K	100 K	20 K
400	30	400	4 K	3.5 K	2.4 K
600	---	40	400	200	300
800	---	7	70	15	75
1000	---	---	10	---	30
			TOP		
75	300	3000	30 K	150 K	30 K
100	70	700	7 K	25 K	6 K
125	20	200	2 K	5 K	1.8 K
150	8	80	900	2 K	900
175	3	30	300	500	380
200	1	10	100	250	150
250	---	---	---	25	---
			Gluino		
100	300	3000	30 K	150 K	30 K
150	20	200	2000	10 K	3 K
200	2	20	200	800	500
250	---	3	30	100	90
300	---	---	5	10	30
			W-Pairs		
W^+W^-	5	50	500	1000	240
Z^0Z^0	---	7	70	150	40
W^+Z^0	0.7	7	70	200	30
			Technipions		
50	800	8000	80 K		62 K
100	200	2000	20 K		18 K
150	70	700	7 K		6.5 K
200	30	300	3 K		3 K
250	12	120	1.2 K		1.4 K

current attention to B-physics and proposals for electron-positron B-factories. An upgraded TEVATRON has impressive capabilities here, although the issue is complicated by backgrounds.

The potential for discovery of new physics by our upgrade, or for the clarification of discoveries which may be made in the early stage of TEVATRON, are very significant. We also stress the important support this kind of data gives to SSC, where the parameter $M/\sqrt{s}$ will very rarely reach the upgrade goal of ~0.4.

Advancing fixed-target physics will be critically dependent upon advancing the art of detectors. Exploiting higher luminosity in the Collider also requires confidence that the detectors are up to resolving signal and background in the high-rate environment.

Upgrade: Phase I

Goal 5×10^{30} cm^{-2} sec^{-1} and 3×10^{13} ppp - 1988-1993.

The first phase involves a series of steps:

1. Replace Cockcroft-Walton by rfq, new first tank on linac.
2. Replace last five linac tanks by side-coupled cavity type of tank at 800 MHz (instead of 200 MHz). This will raise the energy of protons injected into the Booster to 400 MeV. The transverse emittance should go to 12π mm.mr or even as low as 6π at 1×10^{10}p.
3. Strong low-β quadrupoles for D0, CDF; Goal $\beta^* = .25$m.
4. Possible shorter bunches.
5. Pbar Source and cooling improvements.
6. Dipole magnet development for separator space; goal is 6.6T dipoles.
7. Cryogenic developments to achieve about 3.9°K TEVATRON for 900-GeV fixed-target and 1000-GeV Collider operations.
8. Electrostatic separators - helical orbits. 50 kV/cm for 2.5 cm gap.

These steps, carried out by AIP, R&D, and Linac Line Item funding, can and should be complete in time for a 1992 run of CDF and D0 with a goal of ≥ 10pb^{-1}. Included here are already scheduled improvements in the CDF detector, completion of the D0 detector, and new starts on a major fixed-target spectrometer, given PAC approval. Other fixed-target activity involves continued upgrades of major existing detector facilities.

Upgrade Phase: II

Goal 5×10^{31} cm^{-2} sec^{-1} and 4×10^{13} ppp at >50% Duty Factor - 1994-1999.

Introduction

We have looked in some detail at several approaches to this next factor of ten. The luminosity *goal* is designed to keep the CDF and D0 detectors from melting, but this luminosity will require substantial upgrades to both detectors. These involve replacement of front-end electronics, perhaps central tracking and perhaps some calorimetry improvements. Consideration is also being given to a possible third collider detector, which would be specifically designed to do B-physics. What is also open is whether this gets its own collision region or goes in to alternate with CDF, say. Finally, considerable weight is given to the fixed-target program and how it is benefited from the various options. Whereas the TEVATRON Collider mode may be supplanted by SSC, the fixed-target program will probably extend well into the SSC era, taking advantage of SSC detector R&D, the almost certain need for more precision and detail, and the continuous need for test beams. We now list the options as currently understood and later indicate some variations and phasing possibilities.

A. $\bar{p}p$ with Superboosters

Here, in order to supply two IR's with 5×10^{31} luminosity, we need an improved source fed by an improved Main Ring (MR) and a place to store 3×10^{12} $\bar{p}$'s. Some means of recovering $\bar{p}$'s which have diffused is also useful.

The major devices here are two 20-GeV rings; one, the proton superbooster, injects into the Main Ring at 20 GeV yielding high transmission, small emittance ($\leq 12\pi$), good lifetime, and high proton intensity for proton production. The second ring, a $\bar{p}$ ring, is an antiproton depository. This would also involve 8-16 GHz cooling in the $\bar{p}$ Accumulator and depository. The total cost, including R&D, pre-op is $124M. The technical problems of actually achieving 5×10^{31} are formidable. A more conservative goal is to have a five-month run (repeated annually) to yield an integrated luminosity of 100 pb^{-1}.

B. pp Option

This suggests a pp option, where more than 5×10^{31} is assured and overall efficiency of twice the $\bar{p}p$ option seems reasonable. We then assume that we can collect 500 pb^{-1} in a Collider portion of one year's run. High luminosity, i.e., 2×10^{32}, can be achieved for special purposes *not including* the normal operation of the CDF and D0 detectors. Another virtue of pp is the small interaction diamond which benefits all short lifetime experiments, e.g., B-physics. The pp option, as an accelerator project, is not particularly challenging. However, it requires removing the MR from the tunnel (it becomes the Main Injector) and providing a 120- to 150-GeV tunnel into which MR components would go. All overpasses and other TeV-MR hindrances would disappear. The new injector could also be a p producer and be organized to provide 150-GeV test beams during Collider operation. MR removal would allow space for a second superconducting magnet string. Longer straight sections would be needed in order to bring beams into collision. This could be done with small displacements of the CDF and D0 detectors. The total cost estimate here is about $240M.

C. $\bar{p}p$ High-Energy Option

A third option removes the MR and/or the TEVATRON from the old tunnel and replaces it with a ring of 6.6 to 8T superconducting magnets of the SSC/HERA style. This would permit $\bar{p}p$ operation at 3 to 3.5 TeV in the CM. Since there would be no superboosters, the luminosity would be only slightly better than the 5x10^{30} that was achieved in Phase I. Both CDF and D0 detectors would work well here with much less extensive upgrades than option B. The mass reach of such a 3.5-TeV $\bar{p}p$ collider is about that of a 2.0-TeV collider at > 5x10^{31}. The fixed-target program can gain substantially from a higher energy extracted beam and/or the higher intensity of secondary and tertiary beams. The improvement factors come from the benefits of a re-designed Main Ring (Main Injector) and the luminosity gain due to the higher energy (1.5-1.8 TeV). We take 10^{31} as the design luminosity and therefore an integrated luminosity of 30 pb^{-1} per year. The energy increase could be a significant help in many fields, e.g., in heavy-quark studies, in hyperon research, and in structure function data. Open questions here have to do with the removal of the MR and the cost of higher field magnets. This will probably come to about the cost of the pp option.

Selection Criteria

Which of the three options (or none of them) to choose will depend on a number of criteria:

(1) Physics reach in the collider mass domain "beyond the W, Z"

(2) Implication for advancing fixed-target physics

(3) Cost

(4) Time and downtime to implement

(5) Detector implications

(6) Technology experience relevant to SSC

(7) B-physics

Many of these criteria are not simple. Physics reach with high luminosity is clouded by backgrounds, pile-up, etc. It may be useful to assume the following about detectors:

(1) CDF requires new electronics at $\geq 5\times10^{30}$ @ \$10M

(2) D0 requires new electronics at 5×10^{31}

(3) CDF will require new tracking, vertex, etc., at $\sim10^{31}$

(4) Both detectors will require much more major upgrades at $>5\times10^{31}$. However, even these upgrades, at an estimated total cost of \$25M each, are much less in time, money, and people than starting over.

(5) With SSC demands, it makes no sense to contemplate a brand new "standard" 4π detector. New ideas, however . . .

Phased Options

As Phase II in the upgrade one can consider building a new Main Ring of 120-150 GeV in its own tunnel with new magnets but, initially, only minimal power supplies. This could be constructed and commissioned without interference with the on-going program. Its objectives: i) excellent injector into TEVATRON; ii) excellent $\bar{p}$ producer, e.g., 2 sec/cycle; iii) provides 150-GeV beams to fixed-target program during Collider runs, saving two months of calibration, timing, commissioning of fixed-target experiments; iv) may provide very intense neutrino and k-beams for special experiments. This would also free CDF and D0 from Main Ring backgrounds and provide a space for another interaction hall at E0. Also, it frees space in the existing tunnel for another superconducting ring. When completed and commissioned, there would be a shutdown for tunnel connections, moving of MR power supplies, etc., and perhaps removing MR magnets. This may be ~3 months. Options B or C would follow as Phase III.

Other phases, as demanded by physics and allowed by resources, would be to upgrade from the modest luminosity of the 3-TeV option to perhaps $3\text{-}5\times10^{31}$ using Option A devices. Alternatively, if the original TEVATRON ring is still in the tunnel, pp collisions (1.5 TeV x 1.0 TeV) can be contemplated, especially for the B-detector, but perhaps for additionally upgraded CDF/D0.

Summary: Physics

Our options as of July 1988 are now recapitulated. We assume a five-month Collider run, five-month fixed-target run, and two months of changeover, studies, etc.

A. $p\bar{p}$ $\sqrt{s} = 2$ TeV $\int L\,dt = 100\ \text{pb}^{-1}$/year

B. pp $\sqrt{s}$ = 2 TeV L dt = 500 pb^{-1}/year

C. $\bar{p}$p $\sqrt{s} \geq$ 3 TeV L dt = 30 pb^{-1}/year

The physics graphs and Table I take into account the different quark content of pp and $\bar{p}$p.

From the graphs and from the Table, it is clear that the TEVATRON upgrade has two physics benefits. Any of the options extends the discovery potential for a characteristic subset of theoretical speculations by a factor of two in mass: It permits a thorough exploration of the interesting 200 to 400-GeV mass domain - "the foothills of the TeV summit." Recall that in new technicolor theories, the crucial parameter is F_π = 246 GeV.

Equally significant, for masses near the lower end, it provides "factory" potential. TOP is an excellent illustration. If, as some theorists intimate, the TOP mass is under 125 GeV, then the upgrade makes tens of thousands of TOP quarks per year and thus defines a TOP factory. This applies to many of the potential discoveries - one will be able to exploit the discovery of a GLUINO or TECHNIPION in some detail if the masses are not too high. Perhaps all the theories are wrong - still, the exercise indicates that whatever nature has in the 50-400 GeV mass domain, the TEVATRON upgrade will be a powerful tool to guide particle physics on the correct road from the Standard Model toward the ultimate unification.

We have not yet listed some of the obvious "goodies" that have been widely discussed elsewhere:

b-quarks: The upgrade will result in of the order of 10^{10} $B\bar{B}$ per year pairs with option B giving 10^{11} $B\bar{B}$'s. Fermilab proposal P-784 has under design a detector which can carry this to the observation of CP violation.

W+Z's: The 100 pb^{-1} luminosity yields 10^6 W's per year and $2x10^5$ Z^0's. With precise Z^0 masses derived from e^+e^- machines and a highly precise mass ratio of W to Z, one can derive unique values for important radiative corrections which involve the Higgs mass.

Compositeness, Drell-Yan, Fourth Generation, and many other processes and issues will also be addressed.

Fixed target: Although we have stressed the benefits to the Collider, the gains to the fixed target are also important, with Option C probably having the largest influence. Here even a modest increase in energy gives a very large increase in, for example, photoproduced B's (factor ~20). Secondary beams gain in energy and intensity, hyperon beams also gain from the increase in laboratory lifetime.

Funding Scenarios

In our firm, unalterable 15-year plans we have presented funding profiles which have not noticeably produced cardiac arrest among Department of Energy readers. Table X (Profile I) out of the 1988 Institutional Plan is typical. Below this is an alternative plan which assumes less civil construction and more R&D in the realization of the upgrade program. It assumes we do something between the costs of $\bar{p}p$ and pp or $\bar{p}p$ at high energy. The difference is ± \$10M/year. It includes funds for detector upgrades *and* fixed-target initiatives.

Table X
Profile I
Laboratory Funding Summary
(\$ in Millions)
Fiscal Years

	FY 87	FY 88	FY 89	FY 90	FY 91	FY 93	FY 93	FY 94
DOE Effort	135.4	145.0	151.3	169.9	171.01	174.0	180.0	181.0
Work for Others	3.4	5.7	1.1	0.6	0.6	0.6	0.6	0.6
TOTAL OPERATING	138.8	150.7	152.4	170.5	171.7	174.6	180.6	181.6
Capital Equipment	27.5	25.3	30.8	37.0	34.0	32.0	40.0	42.0
Program Construction	8.2	11.2	4.6	43.4	63.4	30.3	0.0	0.0
AIP/GPP	8.4	9.1	9.5	17.0	14.0	14.0	14.0	14.0
General Purpose Equip	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0
TOTAL LABORATORY FUNDING	182.9	196.3	197.3	267.9	283.1	250.9	238.6	237.6
PROPOSED CONSTRUCTION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL PROJECT FUNDING	182.9	196.3	197.3	267.9	283.1	250.9	283.6	237.6
*Outyear Escalation Rates (Base Year - FY 89)				3.6%	3.3%	2.8%	2.3%	2.3%

Constraints

In guiding this discussion we have, in fact, made a number of constraining assumptions:

1. The non-SSC funding level of \$560M will not be increased during SSC construction.

2. SSC physics will be in full swing with first physics publications by ~1999.

3. The upgrade over the period 1989-1994 should require increments to the Fermilab budget of less than \$50M/year.

4. No new 4π detector can be contemplated. CDF and D0 may be upgraded but

not replaced. A special-purpose new detector for B-physics *is* conceivable if its cost is modest compared to original CDF/D0 costs.

5. The upgrade should begin to produce physics by 1994-1995.

6. Until 1993 we plan no shutdowns in excess of six weeks.

7. CDF and D-Zero must have at least 10 pb^{-1} of good data before a long (6-10 month) shutdown.

A History of Upgrades

A. **Cornell**

300 MeV	1949
1 GeV	1954
2 GeV	1964
10 GeV	1968 (SLAC 20 GeV Linac)
8x8 GeV	1979
8x8 GeV Upgrade	1988

B. **BNL**

AGS 30-GeV Upgrade (Linac)
1970 (Fermilab 200 GeV)
AGS Upgrade (Booster, etc.) 1988

C. **SLAC**

Linac	1967
Spear	1973
PEP	1979
SLC	1988
400 GeV e^+e^- ?	1992

D. **CERN**

Cyclotron	1958
PS	1960
ISR	1971
SPS	1976
S$\bar{p}$pS	1981
S$\bar{p}$pS → ACOL	1988 (TeV I going)
LEP I	1989
LEP II	1992
LHC	?

E. **DESY**

DORIS	1974
PETRA	1977
DORIS Upgrade	1985
HERA	1990

F. **Fermilab**

400 GeV	1972
TeV I	1987
TeV II	1984
UPGRADE →	1993 proposed

Re´sume´ of Upgrade Virtues

1. Physics is first rate with very large discovery potential and strong programmatic power.

2. The TEVATRON is the highest energy machine in the world. It deserves the full exploitation compatible with realistic costs, time scale, and manpower needs. It represents an investment of $500M in R&D, equipment, construction, and AIP funds. The history of upgrades also speaks eloquently to this.

3. High-energy physics must maintain its excitement and its vitality, especially during the long construction schedule for the SSC. Discoveries, press releases, etc., will serve to keep the flow of new students and will insure the attention which is needed to secure a decent SSC funding profile.

4. The learning curve of new physics and of handling Collider subtleties alone will pay the upgrade costs. These can modulate SSC detector design and will be relevant up to turn-on and beyond. CDF and D0 *must* learn to cope with subtle signatures at the level of 10^{-10} of the total cross section. No amount of simulation substitutes for *learning by doing*. This acquired skill becomes the experience base of the SSC and is terribly cost effective at SSC annual costs of $250M/year. CDF and D0 at $> 10^{31}$ luminosity are *unique* sources of this learning curve.

End Notes

January 1982: Subpanel on Long Range Planning - Excerpts (p. 29) "The achievement of a luminosity greater than 10^{30} cm^{-2} sec^{-1} will, in our judgment, take some years of operational experience. On the other hand, a number of improvements seem possible. Thus, an ultimate goal of $L = 10^{31}$ appears reasonable to us."

"The TEVATRON projects will be the focus of a major part of the U.S. program. . . they will open up entirely new areas of physics and accelerator development and will be essentially unique in the world."

July 1983: Subpanel on New Facilities (p. 51) "The viability of the [TEVATRON] facility after about 1992 will depend on the physics interest and the availability of other facilities. If the level of research activity remains high, then an upgrade of the facility and its detectors may be warranted, with a consequent extension of the useful life of the machine for perhaps another five years."

September 1985: Report of the 1985 HEP Study (p. 27) "Because new phenomena may not conform to our current expectations, it is natural to expect the configuration of these detectors [CDF-D0] to evolve in response to our growing understanding. . . A program of detector upgrades and accelerator improvements will be an essential part of the hadron collider physics program."

In fixed-target experiments. . . experiments can be grouped in terms of the physics questions. . .
(1) CP violation in Kaon Decays
(2) Rare Kaon Decays
(3) Heavy Quark Physics
(4) Hadron Dynamics Other than Perturbative QCD
(5) Neutrino Oscillation Experiments
(6) Particle Searches with Beam Dump

Experimental Notes

CDF: Watching W's On-line

With 30 inverse nb on tape and a number of papers already published from the last run, the Collider Detector at Fermilab (CDF) is immersed in a full-blown physics run that is a big success. Initial preparations for the present run began back in December 1987 and the big CDF detector was checked out and rolled into the collision hall in June of 1988. Since it began running during the first week of July, the TEVATRON's performance has been spectacular, with the design luminosity of 10^{30} $cm^{-2}sec^{-1}$ being reached on September 7, 1988. In the weeks that followed, the TEVATRON achieved a new record initial luminosity of 1.59×10^{30} $cm^{-2}sec^{-1}$. The largest $\bar{p}$ stack equaled 81.25E10, with the peak stacking rate equaling 1.898E10 in a single hour. The integrated luminosity delivered by the accelerator to date (November 14) is 2.3 inverse picobarns.

By mid-July, CDF had verified that the level-1 trigger was operating properly and began shaking down the level-0, level-2 and level-3 components of the trigger hardware, the "brains" of the CDF detector (only the level-1 trigger was operating during the last run). The addition of the level-2 and 3 triggers are already paying big dividends in regard to rate capability. In a given crossing of the $p\bar{p}$ beams there are about 40,000 $\bar{p}p$ collisions per second of which only one or two events can be written to tape. (Another way to describe this is in regard to the trigger cross-section, which is about 40 mb, of which only 1 to 1-1/2 μb can be written to tape.) One of the main goals of the multi-level trigger is to dig out the low cross section physics that CDF is interested in from an enormous background of higher cross section physics events.

This formidable problem has been taken well into hand by the new multi-level trigger system. The level-0 trigger discerns whether there was an interaction in a particular crossing of the beam. If an interaction is detected, the trigger blanks out the next crossing to enable the level-1 trigger to decide whether the event is potentially interesting. The level-1 trigger imposes loose cuts on transverse energy sums over the entire detector and on muon candidates, reducing the trigger rate to 1000 Hz. This allows the sophisticated level-2 trigger enough time to search for clusters of energy deposition, stiff tracks, muons, and electrons. The level-2 trigger passes up to 10 events per second to the level-3 trigger. By selecting events marked by level-3, even the casual observer can watch W's being recorded on-line!

Because the level-2 trigger purifies the data in a physics selective way, it can be set for a wide mix of triggers such as QCD, electroweak, top quark, and missing E_T physics. QCD physics events trigger on clusters of energy. Five different jet triggers allow coverage of a wide range of P_t and an enrichment of multi-jet events. Also on the CDF physics agenda are electroweak effects, identified by electron energy deposition in the electromagnetic calorimeter or muon identification in coincidence with a fast track. In addition, the signature of neutrinos is missing E_T, which can be detected by looking at the overall energy balance in the detector. The 1μb of cross section accepted by the trigger is divided between the various physics categories in order to balance the physics objectives.

Because the CDF Collaboration had expected a luminosity of only 3×10^{29} $cm^{-2}sec^{-1}$ for this run, CDF had planned to use the level-0, 1, and 2 triggers, with the level-3 trigger used only as a tagging system, making on-line calculations. But as Dennis Theriot (Deputy Manager of CDF) remarked, "The machine came on like gang-busters!" which made a speedy shakedown of the level-3 trigger extremely important. The level-3 trigger is a system of about 50 Advanced Computer Program (ACP) nodes in which all the event information is available in a digital form, allowing the selection of data cuts based on software programmed algorithms.

Presently, CDF is taking good data and bringing the level-3 trigger on-line. The strategy being used is to develop the algorithms off-line with the data that has been taken thus far, perform off-line checks on the programs, then put them on-line in a tagging mode so that their operations can be carefully checked and calibrated. Once the algorithms pass this on-line test, they are turned on as a filter to reject events. The experiment has taken about 1500 data tapes in September and November 1988 that contain over 800 inverse nanobarns of luminosity.

Ongoing CDF goals include increasing the operating efficiency of putting data on tape. This will involve decreasing the down-time of the new parts of the data acquisition system. It will also include decreasing the dead times by getting the level-3 trigger operating at full speed, thereby increasing the overall efficiency rate. Presently, on a good shift CDF can write as much as 70% of the luminosity delivered to tape. With the original physics goal of accumulating 1 inverse picobarns on tape set last year, the increased TEVATRON luminosity and the successful operation of the data acquisition system promise to yield 2-3 inverse picobarns on tape given the present rate of operation. Congratulations CDF and Accelerator staffs! - *Mark Bodnarczuk*

Conference on New Directions in Neutrino Physics, September 14-16, 1987...

After two successful fixed-target runs in the TEVATRON in 1985 and 1987, the approved neutrino program at Fermilab has drawn to a close with good agreement among the experiments and with the Standard Model. The long-standing discrepancy in the neutrino-nucleon cross section between CDHS and CCFR has been resolved so that the experiments now agree. The CCFR TEVATRON run of 1985 found the same-sign dimuon rate to be consistent with the Standard Model (only about 1σ higher than the best QCD calculation) and demonstrated no threshold effects at TEVATRON energies; the analysis of the 1987 run will double the statistics and allow more precise determinations of the backgrounds. In addition, the 1985 and 1987 data combined will provide high-statistics structure functions at the largest Q^2 yet measured. With the deep-inelastic scattering data largely settled, it was an appropriate time to review the data at hand and examine possibilities for the future.

A review of our status and ideas for the future were thus the motivation for the "New Directions in Neutrino Physics at Fermilab" conference. It was attended by approximately 110 physicists from the U.S. and abroad over three days, September 14-16, 1988.

The conference began with advice from Fermilab Director Leon Lederman in the form of a joke: the punch line was to throw the theorists (along with their advice) out the window. W. Smith (University of Wisconsin) began a summary of the experiments with a report on the production of same- and opposite-sign dimuons at the TEVATRON. The opposite-sign data, which arises from charm production, is the only direct measurement of the strange-sea distribution. CCFR now has approximately 1800 opposite-sign events analyzed from E-744 (to be doubled by the 1987 run of E-770), and CDHS and CCFR agree on the important physics. The long-standing like-sign dimuon puzzle has gone away: with a careful measurement of muoproduction in hadronic showers and new QCD estimates, the data is now only about 1σ higher than predictions, with no new effects at TEVATRON energies. J. Morfin (Fermilab) summarized our knowledge of structure functions, both from μN and νN data, and discussed the agreement and disagreements among CCFR, CDHS, EMC, and BCDMS. He also announced the formation of a study group at Snowmass dedicated to producing up-to-date and consistent versions of all deep-inelastic structure function data. M. Peters (University of Hawaii) summarized the limits on ν_τ production from the 15-ft Bubble Chamber. M. Tartaglia (Michigan State University) presented new results on a search for WIMPS using time-of-flight techniques in the FMMF detector in a mass range >4 GeV/c^2. R. Brock (Michigan State University) gave an excellent review of DIS measurements of $\sin^2 \theta_w$ and presented a reasoned argument for continuing such measurements at the TEVATRON's higher Q^2, far away from charm-threshold effects.

Paul Langacker (University of Pennsylvania) summarized our theoretical understanding of neutrino oscillations and masses from the "see-saw" mechanism and other models. He also pointed out what many people have overlooked: the possibility of non-orthogonal neutrino species, so that neutrinos will mix without having mass. M. Shaevitz (Columbia University) reviewed the experimental situation, with a thorough discussion of the errors associated with each of the experimental techniques. S.P. Rosen (Los Alamos National Laboratory) described interesting precision tests in $\nu\mu e$ scattering, explaining tests of universality and observable distinctions between Dirac and Majorana neutrinos. S. Parke (Fermilab) closed the first day by summarizing the data from SN1987A and from the Davis experiment.

The second day was devoted to examining new options. It began with an old idea: a muon storage ring as a neutrino source. W. Lee (Columbia University) discussed the oscillation and cross section physics one could examine with such a facility and D. Neuffer (Los Alamos National Laboratory) presented design parameters for such a ring, pointing out that the Pbar Source/Debuncher is already nearly ideal. R. Bernstein (Fermilab) described a tagged neutrino experiment using K_L semileptonic decays to provide neutrinos, where the neutrino species is determined event-by-event. The experiment would provide precise cross section and oscillation measurements for νe and $\nu\mu$. Such a beam would require nearly 10^{15} K_L decays: J. Donoghue (University of Massachusetts, Amherst) summarized current thinking on the most interesting rare K_L decays and B. Winstein (University of Chicago) outlined the necessary experimental techniques. S. Denisov (Serpukhov) and I. Savin (Dubna) described a tagging experiment using charged kaons at UNK (3 TeV): Denisov discussed oscillation experiments and Savin examined the possibilities for deep-inelastic scattering studies. F. Borcherding (Fermilab) presented a list of possible improvements to the TEVATRON which might be useful in neutrino experiments. Perhaps the most interesting is the 150-GeV "Main Ring Injector." While the machine is being designed in order to produce a higher intensity injector for the TEVATRON and a source of 150-GeV protons for the existing fixed-target experimental areas during Collider operations, it could also be used for physics.

At a cycling rate of 2.5 sec it could deliver 10^{19} protons/month. A very interesting possibility for the ring would be a high-statistics study of $\nu_\mu \rightarrow \nu_T$ oscillations using the emulsion techniques of E-531. N.W. Reay (Ohio State University) investigated the possibilities and saw no experimental limitation to order-of-magnitude improvements in existing measurements. T. Kitagaki (Tohoku) closed the session with new results on the EMC effect from the heavy-liquid bubble chamber. For events with nuclear breakup, one sees the EMC effect; for coherent recoils, one does not.

The final day began with some ideas for long-baseline oscillation measurements. J. Bjorken (Fermilab) described an inexpensive two-distance experiment using the Earth as a target and fleets of trucks equipped with Iarocci tubes placed hundreds of miles from each other and from the neutrino source as detectors. He stated that "any improvement of the limits by a factor of ten, be it in mixing angle or mass, is worth the effort," supplying a new unit for rating oscillation proposals. M. Koshiba (Tokai University) discussed a Kamiokande II style of experiment which could be performed in the proposed Main Injector, using a megaton of water. It would be sensitive down to Δm^2 of 10^{-4} for $\nu_\mu \rightarrow \nu_e$ oscillation, a region we must search in order to determine whether the MSW mechanism explains the solar neutrino problem. A rough cost estimate of $30 million was suggested.

The final session was devoted to plans and results at the other laboratories. The CHARM II collaboration, of course, has an important and vital program to determine $\sin^2 \theta_w$ in $\nu_\mu e$ scattering. J. Panman (CERN) presented results from the CHARM I narrow-band run of 1984: $\sin^2 \theta_w$, and $d\sigma/dx$ for neutral-current scattering, along with future options for oscillation experiments at CERN. A. Capone (CERN) discussed the aim of CHARM II, a 0.5% measurement of $\sin^2 \theta_w$ in $\nu_\mu e$ scattering and presented a status report on the first run. There are now approximately 20×10^6 neutrino interactions from the 1987 and 1988 runs and the full analysis is under way. Brookhaven National Laboratory has had a long and critical series of oscillation experiments: R. Seto (Columbia University) presented the final results of BNL-776 narrow-band data: no evidence of oscillations is seen. He also gave projections for the WBB analysis, which should improve present mixing-angle limits. J. Dumarchez (University of Paris) reported on BNL-816: a 2σ effect is seen but discounted. S. Aronson (BNL) forcast the likely future of the Brookhaven neutrino program and mentioned a new proposal by the E-776 group for a two-detector, large L/E experiment. Finally, D.H. White (Los Alamos National Laboratory) explained the LCD proposal: a large water Cernekov detector which could see a total of 70K $\nu_\mu e$

and $\nu_e e$ scattering events at a low energy, and measure $\sin^2 \theta_w$ to 0.9% in a different Q^2 region from CHARM II.

W. Marciano summarized the conference: he stressed the importance of precision measurements of $\sin^2 \theta_w$ and of pushing oscillation limits in as many ways as possible. He asked the experimentalists not to give up, and when we finally do find oscillations, to thank the theorists before throwing them out the window. - *Robert Bernstein and Drasko Jovanović*

Butler, White Appointed Computing Dept. Associate Heads...

The Computing Department has been growing in size and responsibilities. Moreover, the complexity of issues and opportunities have increased as well. These changes are evident in the Laboratory's ongoing computer operations. In this environment, the need for more and better communications and planning has gone up dramatically. In response to these developments, Joel Butler and Vicky White have been appointed as additional Associate Heads in the Computing Department.

Joel Butler will concentrate on Central Computing Applications. Jack Pfister continues as Associate Head, concentrating on Communications, Systems, and Operations.

In the Online and Data Acquisition area, Vicky White will concentrate on Software and User Group Liaison. Peter Cooper continues as Associate Head, concentrating on Hardware and Vendor Liaison.

We hope that these changes will lead to increased department responsiveness, planning, and flexibility. After all, it is our support of you, our users, which measures our success. - *Jeffrey A. Appel*

F. T. Cole Retires from Fermilab...

Francis T. Cole's name has graced the masthead of *Fermilab Report* off and on since this periodical's first appearance, as the National Accelerator Laboratory *Monthly Report of Activities*, on May 1, 1968, when he was the report's sole author. Frank has retired from the Laboratory to devote his full energies to developing the Loma Linda University Medical Center proton therapy accelerator. His contributions to this Laboratory from its very inception, as well as to the fields of high-energy physics and accelerators, are far-reaching. His editorial wisdom will be missed by those entrusted with *Fermilab Report*.

prepared or presented from September 10, 1988 to October 31, 1988. Copies of Fermilab TM's, FN's, and preprints (exclusive of Theoretical and Theoretical Astrophysics preprints) can be obtained from the Fermilab Publications Office, WH 6NW, or by sending your request to (DECnet) FNAL::TECHPUBS or (BITnet) TECHPUBS@FNAL. For Theoretical Physics or Theoretical Astrophysics preprints, contact those departments directly. For papers with no Fermilab catalogue number, contact the author directly.

Experimental Physics Results

Experiment #691
J. C. Anjos et al., "Charm Photoproduction Results from E691," (FERMILAB-Pub-88/125-E; submitted to Phys. Rev. Lett.)

Experiment #741/CDF
C. Newman-Holmes et al., "Measurement of the Magnetic Field of the CDF Magnet," (FERMILAB-Pub-88/126-E; submitted to Nucl. Instrum. Methods A)

Experiment #743
A. G. Nguyen, "Characteristics of Charm Particles Produced by 800 GeV p-p Collisions," (Ph.D. Thesis, 1988, Michigan State University, East Lansing, Michigan)

General Particle Physics

J. D. Bjorken, "Spin Dependent Decays of the Λ_c," (FERMILAB-Pub-88/133; submitted to Phys. Rev. D)

Accelerator Physics

J. D. Cossairt et al., "A Study of the Production and Transport of Muons through Shielding at the TEVATRON," (FERMILAB-Pub-88/147; submitted to Nucl. Instrum. Methods A)

J. D. Cossairt et al., "A Study of the Transport of High Energy Muons through a Soil Shield at the TEVATRON," (FERMILAB-Pub-88/146; submitted to Nucl. Instrum. Methods A)

A. J. Elwyn et al., "The Monitoring of Accelerator-Produced Muons at Fermilab," (FERMILAB-Conf-88/107; to be presented at the 22nd Midyear Topical Meeting of the Health Physics Society, San Antonio, Texas, December 4-8, 1988)

R. W. Hanft et al., "Studies of Time Dependence of Fields in TEVATRON Superconducting Dipole Magnets," (TM-1542; presented at the 1988 Applied Superconductivity Conference, San Francisco, California, August 21-25, 1988)

D. A. Herrup et al., "Time Variations of Fields in Superconducting Magnets and Their Effects on Accelerators," (TM-1543; presented at the 1988 Applied Superconductivity Conference, San Francisco, California, August 21-25, 1988)

M. Kuchnir and A. V. Tollestrup, "Flux Creep in a TEVATRON Cable," (TM-1544; presented at the 1988 Applied Superconductivity Conference, San Francisco, California, August 21-25, 1988)

L. M. Lederman, "The Fermilab Upgrade," (TM-1536; submitted to the proceedings of the DPF Summer Study: Snowmass '88, High Energy Physics in the 1990s, Snowmass, Colorado, June 27-July 15, 1988)

S. Machida and D. Raparia, "Design Study of a Medical Proton Linac for Neutron Therapy," (TM-1541; to appear in part in papers presented at the 1988 Linear Accelerator Conference [Linac 88], Williamsburg, Virginia, October 3-7, 1988)

J. A. MacLachlan, "Reference Design for the Fermilab Linac Upgrade," (FERMILAB-Conf-88/138; to appear in the proceedings of the 1988 Linear Accelerator Conference [Linac 88], Williamsburg, Virginia, October 3-7, 1988)

J. A. MacLachlan et al., "Transition Section Between a 200 MHz Drift Tube Linac and a High Gradient Coupled Cavity Linac for the Fermilab Upgrade," (FERMILAB-Conf-88/137; to appear in the proceedings of the 1988 Linear Accelerator Conference [Linac 88], Williamsburg, Virginia, October 3-7, 1988)

S. R. Mane and G. Jackson, "Studies and Calculations of Transverse Emittance Growth in Proton Storage Rings," (FERMILAB-Pub-88/136; submitted to Nucl. Instrum. Methods A)

N. V. Mokhov and M. Harrison, "Internal Beam Abort System for the TEVATRON Upgrade," (prepared for the DPF Summer Study: Snowmass '88, High Energy Physics in the 1990s, Snowmass, Colorado, June 27-July 15, 1988)

K.-Y. Ng, "Copper Coating the TEVATRON Beam Pipe," (FN-496)

K.-Y. Ng, "Minimum Propagating Zone of the SSC Superconducting Dipole Cable," (FN-491; [SSC-180])

K.-Y. Ng, "Shielding the TEVATRON Bellows," (FN-494)

N. Merminga and K.-Y. Ng, "Hamiltonian Approach to Distortion Functions," (FN-493)

R. Stefanski, "Fixed Target Issues for the TEVATRON Upgrade," (TM-1538; prepared for the DPF Summer Study: Snowmass '88, High Energy Physics in the 1990s, Snowmass, Colorado, June 27-July 15, 1988)

M. J. Syphers, "Prospects of TEVATRON Upgrade," (FERMILAB-Conf-88/114; presented at the 7th Topical Workshop on Proton-Antiproton Physics, Fermilab, Batavia, Illinois, June 20-24, 1988)

L. C. Teng, "Considerations of Using Siberian Snakes for Very Strong and Very Weak Resonances," (FN-497; contributed to the 8th International Symposium on High Energy Spin Physics, University of Minnesota, Minneapolis, Minnesota, September 12-17, 1988)

Theoretical Physics

W. A. Bardeen, "Dynamics of Symmetry Breaking in Strongly Coupled QED," (FERMILAB-Conf-88/149-T; presented at the 1988 International Workshop: New Trends in Strong Coupling Gauge Theories, Nagoya, Japan, August 24-27, 1988)

W. A. Bardeen, "Weak Decay Amplitudes in Large N_c QCD," (FERMILAB-Conf-88/156-T; presented at the Workshop on Hadronic Matrix Elements and Weak Decays, Ringberg Castle, Bavaria, April 17-23, 1988)

J. D. Bjorken, "Topics in B-Physics," (FERMILAB-Conf-88/134-T; talk given at the IV Workshop on Recent Developments in High Energy Physics, Orthodox Academy of Crete, Chania-Crete, Greece, July 1-20, 1988)

S. Boukraa, "New Topological Invariants for Non-Abelian Antisymmetric Tensor Fields from Extended BRS Algebra," (FERMILAB-Conf-88/128-T; submitted to the proceedings of the XVII ICGTMP, June 22-July 2, 1988, St. Adele, Canada)

L. Chatterjee, "Phase Space Effects on Sticking in Muon Catalysed d-t Fusion," (FERMILAB-Pub-88/159-T; submitted to the SLAC Summer Institute)

J. Collins et al., "What Can We Understand About the Muon Anomalies in High Energy Showers from Point Sources?" (FERMILAB-Pub-88/122-T; submitted to Phys. Rev. D)

A. Duncan and M. Moshe, "Nonperturbative Physics from Interpolating Actions," (FERMILAB-Pub-88/99-T; submitted to Phys. Rev. Lett.)

R. K. Ellis, "The Status of Perturbative QCD," (FERMILAB-Conf-88/161-T; talk given at the XXIV International Conference on High Energy Physics, Munich, Germany, August 1988)

T. Filk et al., "An Order Parameter That Tests the Existence of Charged Vector Bosons in the Georgi-Glashow Model," (FERMILAB-Pub-88/144-T)

G. F. Giudice and E. Roulet, "A Supersymmetric Solution to the Solar Neutrino and Dark Matter Problems," (FERMILAB-Pub-88/129-T; submitted to Phys. Rev.)

B. Grinstein and L. Randall, "The Renormalization of G^2," (FERMILAB-Pub-88/148-T; submitted to Phys. Lett. B)

H. Harari, "Light Neutrinos as Cosmological Dark Matter - A Crucial Experimental Test," (FERMILAB-Pub-88/98-T; submitted to Phys. Lett.)

H. Itoyama and H. B. Thacker, "Integrability and Virasoro Symmetry of the Noncritical Baxter/Ising Model," (FERMILAB-Pub-88/49-T; submitted to Nucl. Phys. B)

I. G. Koh and P. Sorba, "Fusion Rules and (Sub)-Modular Invariant Partition Functions in Non-Unitary Theories," (FERMILAB-Pub-88/104-T; submitted to Phys. Rev.)

J. M. Maillet and F. Nijhoff, "On the Algebraic Structure of Integrable Systems in Multidimensions," (FERMILAB-Conf-88/130-T; submitted to the proceedings of the XVII ICGTMP, June 22-July 2, 1988, St. Adele, Canada)

J. M. Maillet and F. Nijhoff, "The Tetrahedron Equation and the Four Simplex Equation," (FERMILAB-Pub-88/71-T; submitted to Phys. Lett. A)

M. Mangano, "Four Jet Production at the TEVATRON Collider," (FERMILAB-Pub-88/119-T; submitted to Zeit. fur Phys. C)

L. McLerran, "Anomalies, Sphalerons and Baryon Number Violation in Electro-Weak Theory," (FERMILAB-Pub-88/93-T; three lectures delivered at Crakow School of Physics, Zakopane, Poland, July 1988; submitted to Acta. Phys. Pol.)

L. McLerran, "Can the Observed Baryon Asymmetry Be Produced at the Electroweak Phase Transition?" (FERMILAB-Pub-88/121-T; submitted to Phys. Rev. Lett.)

W.-K. Tung, "Small-x Behavior of Parton Distribution Functions in the Next-to-Leading Order QCD Parton Model," (FERMILAB-Pub-88/135-T; submitted to Phys. Rev. D)

Theoretical Astrophysics

W. D. Arnett et al., "On Relative Supernova Rates and Nucleosynthesis Roles," (FERMILAB-Pub-88/118-A; submitted to Astrophys. J.)

D. P. Bennett, "Cosmic Strings," (FERMILAB-Conf-88/85-A; presented at the 20th Yamada Conference: Big Bang, Active Galactic Nuclei, and Supernovae, University of Tokyo, Japan, March 28-April 1, 1988)

A. Burrows, "Axions and SN1987A," (FERMILAB-Pub-88/105-A; submitted to Phys. Rev. D)

F. R. Bouchet et al., "Microwave Anisotropy Patterns from Evolving String Networks," (FERMILAB-Pub-88/96-A; submitted to Nature)

R. N. Boyd et al., "Photoerosion and the Abundances of the Light Elements," (FERMILAB-Pub-88/132-A; submitted to Astrophys. J.)

E. Copeland, "Cosmic Strings and Superconducting Cosmic Strings," (FERMILAB-Pub-88/108-A; 2nd Erice on Dark Matter in the Universe, Erice, Italy, May 4-14, 1988)

H. M. Hodges and M. S. Turner, "Effects of Ordinary and Superconducting Cosmic Strings on Primordial Nucleosynthesis," (FERMILAB-Pub-88/115-A; submitted to Phys. Rev. D)

K. Lee et al., "Gauged Q-Balls," (FERMILAB-Pub-88/139-A; submitted to Phys. Rev. D)

D. Mitchell et al., "The Decay of Highly Excited Open Strings," (FERMILAB-Pub-88/78-A; submitted to Nucl. Phys. B)

K. Griest, "Cross Sections, Relic Abundance, and Detection Rates for Neutralino Dark Matter," (FERMILAB-Pub-88/74-A; submitted to Phys. Rev. B)

C. T. Hill et al., "Cosmological Structure Formation from Soft Topological Defects," (FERMILAB-Pub-88/120-A; submitted to Comm. Nucl. Phys.)

P. Jetzer, "Stability of Self-Gravitating Bosons," (FERMILAB-Conf-88/88-A; submitted to the Fifth Marcel Grossman Meeting on Recent Developments in Theoretical and Experimental General Relativity, Gravitation, and Relativistic Field Theories, Perth, Australia, August 8-12, 1988)

T. Pacher and J. A. Stein-Schabes, "On the Locality of the No Hair Conjecture and the Measure of the Universe," (FERMILAB-Pub-88/100-A; submitted to Classical and Quantum Gravity)

M. S. Turner et al., "Isocurvature Baryon Number Fluctuations in an Inflationary Universe," (FERMILAB-Pub-88/28-A; submitted to Phys. Rev. Lett.)

N. Turok, "Phase Transitions as the Origin of Large Scale Structure in the Universe," (FERMILAB-Conf-88/116-A; lectures presented at the 27th Internacionale Universitatswochen fur Kernphysik, Schladming, Austria, February 22-March 3, 1988)

Computing

T. Nash, "Computing Possibilities in the Mid 1990s," (FERMILAB-Conf-88/117; talk given at Future Directions in Detector R&D for Experiments at pp Colliders, Snowmass, Colorado, July 5-7, 1988)

G. Rabinowitz, "HEPnet Technical Coordinating Committee Meeting Minutes, September 17-18, 1987, Brookhaven National Laboratory," (FN-476)

Colloquia, Lectures, and Seminars

by Fermilab staff, at Fermilab, September-October 1988, unless otherwise noted.

August 15

J. A. MacLachlan: "Use of the Circulating Beam in the Fermilab Antiproton Accumulator for Experiments," 1988 Divisional Meeting of the Division of Particles and Fields of the American Physical Society, Storrs, Connecticut

September 1

B. Cox: "Fermilab Fixed Target Beauty Experiments," Conference on Glueballs, Hybrids, and Exotic States, Brookhaven National Laboratory, Upton, Long Island, New York

C. Johnstone: "The A-Dependence of Leading Particle Production"

September 6

R. Gerig and S. Mane: "Tracking and Reality in the Main Ring"

September 7

D. Anderson: "Detectors for the Non-Physicist"

M. Turner: "Dark Matter in the Universe"

September 9

Y.-B. Hsiung: "Measurement of ε'/ε at Fermilab," 9th European Symposium on Antiproton-Proton Interactions and Fundamental Symmetries, University of Mainz, West Germany

September 11

C. James: "A Review of Weak Radiative Hyperon Decays," 8th International Symposium on High Energy Spin Physics, University of Minnesota, Minneapolis, Minnesota

September 12

K.-B. Luk: "CP Violation Using Hyperons," 8th International Symposium on High Energy Spin Physics, University of Minnesota, Minneapolis, Minnesota

September 14

L. M. Lederman: Opening remarks, New Directions in Neutrino Physics, Fermilab

September 19

L. M. Lederman: Speaker at the International Colloquium on "Science, Culture, and Peace" in honor of Victor Weisskopf, CERN

H. B. Prosper: "The Neutron Electric Dipole Moment; the Grenoble Experiment," Department of Physics, University of New Hampshire

September 22

G. Jackson: "Tune Spectra in the TEVATRON Collider"

September 26

R. Pisarski: "Scattering Amplitudes in Hot Gauge Theories," VIIth International Conference (Quark Matter '88), Lennox, Massachusetts

K. Griest: "Neutralino Dark Matter and Its Detection"

September 27

J. Biel: "Plans for the Second Generation of ACP"

F. Mills: "Crystal Beams and Low-Energy Beam Transport"

September 29

M. Harrison: "Next Steps in the TEVATRON Upgrade - Separated Beams, More Than Six Bunches"

A. L. Read: "Polarization Experiments at Fermilab," IHEP, Serpukhov, U.S.S.R.

September 30

G. Dugan: "TEVATRON Collider: Machine Performance and Prospects"

L. M. Lederman: "How the Activities at Fermilab Impact Society," keynote speaker, American Interprofessional Institute General Council Meeting

October 1

A. Lennox: "Neutrons Against Cancer: The Clinical Experience at Fermilab," Illinois Science Teachers Association Conference, Naperville, Illinois

October 3

R. Pisarksi: "Damping Rates in Hot Gauge Theories," Workshop on Thermal Field Theories, Case Western Reserve University, Cleveland, Ohio

October 4

L. Teng: "What Does It Take to Get Polarized Beam in the Tevatron?"

October 5

B. Grinstein: "Weak Radiative B Meson Decays," Ohio State University

R. Niemann: "Technologies for the 1990s," Aerotech '88, Anaheim, California

October 6

B. Grinstein: "Wormholes and the Hierarchy Problem"

K. Koepke and S. Lackey: "Quench Protection for the D0 Low-Beta System"

K.-B. Luk: "Strangeness Production in High-Energy p-Nucleus Collision," Hadronic Matter in Collision, Tucson, Arizona

S. Parke: "Solar Neutrinos," University of Kentucky

October 7

R. Johnson: "The Fermilab Collider; Present and Future Plans," CERN, SPS Division

October 10

R. Johnson: "The Fermilab Collider; Present and Future Plans," CERN

October 13

G. Dugan: "Antiproton Yield vs. Energy"
D. Herrup: "TEVATRON Chromaticity Measurements"

October 14

H. Prosper: "The Grenoble Experiment on the Electron Dipole Moment of the Neutron"
R. Johnson: "Recent Developments in Accelerators," University of Pavia, Italy

October 17

R. Johnson: "The Fermilab Collider; Present and Future Plans," INFN, Pisa, Italy

October 18

T. Nicol: "SSC Dipole Magnet Design and Performance Update," 11th Cryogenic Structural Materials Workshop, Colorado Springs, Colorado

October 19

M. Kuchnir: "Research and Development of Superconducting Magnets for the Fermilab TEVATRON and the SSC," American Society for Metals International - Electronic Materials Chicago Chapter Meeting, Des Plaines, Illinois

October 21

A. Lennox: "Treatment of Cancer with Neutrons," Joint Meeting of the Illinois Academy of Science and the Illinois Section of the American Association of Physics Teachers, Bradley University, Peoria, Illinois

October 24

R. Johnson: "Absolute Luminosity and Energy Determination in Bunched Colliding Beam Machines," Joint USA-CERN School on Accelerator Physics, Capri, Italy

October 25

G. Goderre: "Results of Helical Orbit Studies in the TEVATRON"
C. Hojvat: "Recent Results from E-735 at the TEVATRON Collider," CERN

October 27

R. Johnson: "The Fermilab Collider; Present and Future Plans," XIth All-Union Conference on Charged Particle Accelerators, Dubna, U.S.S.R.
M. Martin: "Fermilab D0 Central Tracking Electronics"

October 28

R. Johnson: "The Fermilab Collider; Present and Future Plans," Leningrad Institute of Nuclear Physics, Gachina, U.S.S.R.

Dates to Remember

May 19-20, 1989

Fermilab Users Annual Meeting. For information, contact Phyllis Hale, Fermilab Users Office, (312) 840-3111 or BITnet: USERSOFFICE @ FNAL