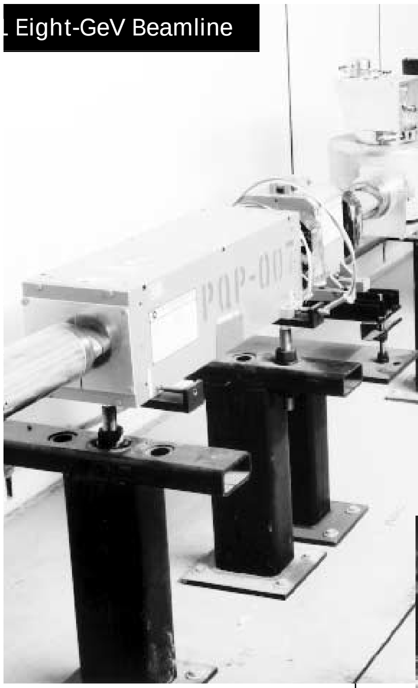
FermiNews

Fermi National Accelerator Laboratory

Volume 21 Friday, August 28, 1998 Number 17

# Buying the Main Injector, Piece by Piece



Eight-GeV Beamline

1,392 Precast Units

424 Dipole Magnets

Photos by Reidar Hahn

## INSIDE

*by Sharon Butler, Office of Public Affairs*

A Fermilab credit card bought the bocci balls that saved the day when the low-conductivity water system needed cleaning.

But multimillion-dollar contracts secured the construction of the tunnel for the Main Injector and just about everything that belongs inside.

There were contracts to assemble and contracts to disassemble; contracts to assess, build, install and expand; contracts to connect, separate, raise and lower; contracts to dig and contracts to fill back in. In all, there were over 80 major contracts and several hundred purchase orders totaling more than $140 million.

*continued on page 2*

Photo by Reidar Hahn

The MI60 service building, at the junction where the Tevatron and the Main Injector meet, was built under two major construction contracts.

## Main Injector

*continued from page 1*

Fermilab's crack procurement staff wrote, negotiated, revised, signed and sealed them all. The team, insists Dave Carlson, deputy head of Business Services, is among the best in the country: its performance matches published cost efficiency standards of world-class commercial organizations.

### From "general grubbing" to magnet installation

According to Rich Farritor, who handled the majority of the construction contracts, procurements for the Main Injector began five years ago with a $12 million contract, awarded to Fluor Daniel, an engineering design firm. That early contract took Fermilab's latest accelerator from concept to specification.

**CRITICAL PATH**

Then followed contracts for preparatory work: first, a "general grubbing," or assessment, of the area where the Main Injector would be built to ensure it could support a concrete tunnel; then the laying of a "hard stand" for a future substation and a staging area for storing precast units (the concrete slabs that would form the tunnel for the Main Injector); and finally, the underground sewers and electrical manholes.

Contracts covered the labor-heavy construction work: the connection between the Main Injector and the Booster; the cooling ponds around the ring; service buildings where equipment would be stored; towers for high-power lines. The largest single contract—in fact, the largest ever in the history of Fermilab—was for $19 million, covering the cost of construction of the Main Injector's concrete tunnel.

Meanwhile, there were contracts for purchasing everything that would go inside: the magnets, the magnet stands, the electrical bus bars for power, the piping for low-conductivity water, the cable tray and cables—pieces big and small.

Finally, about 13 months ago, the installation work began, covered by still more contracts.

### Headaches

Problems arose, inevitable in a project so large and so complex: faulty coils for the dipole magnets (the company had to fly technicians in to make repairs); a defective transformer for the new substation (a replacement is being built).

Routing sometimes got complicated. Coils for the dipole magnets, for example, were shipped from the U.S. to England to be insulated, then sent back to Fermilab for final assembly.

And because federal funding did not arrive in one lump sum, but was doled out in yearly allotments, facilities often had to be constructed piecemeal. The MI60 service building, for example, at the junction where the Main Injector and the Tevatron connect underground, fell under two contracts. First, its underground section was built, and then, later, the top of the building.

The peculiarities of congressional funding also made for some oddly configured contracts. Unable to guarantee the $7.8 million needed to cover the cost of a shipment of magnets, and yet eager to lock in the price at the time of negotiations, Joe Collins, procurement manager, said he wrote one contract for $150,000 containing three options, with deadlines over the next couple of years, for the nearly $8 million balance.

For Rich Farritor, who handled many of the construction contracts, the biggest headaches have been the “change orders,” now arriving in his office at a furious pace to cover overlooked items as the last accelerator parts fall into place.

“It’s like building an autoracer,” said Farritor. “All the people involved are experienced and know there’s a variety of parts—an engine, wheels, a transmission—and that work gets done. But maybe they forget to connect the automatic windshield wiper to the engine.”

There is also the element of surprise—finding when you turned a corner that the low-conductivity water pipe went right through the place where the bus was supposed to be—or an expansion in scope, requiring a change order.

“It could go on for some time,” Farritor said. “As [the Beams Division staff] start testing, they may find things that don’t work, or would work better if certain other things were changed.”

## Procurement reforms

According to Collins, Fermilab benefited from sweeping contract reform measures enacted by the U.S. Department of Energy, just in time for the procurements for the Main Injector. The reforms allowed Fermilab to form in 1993 what was called the Source Evaluation Board—a team of people from the Main Injector Department, the Technical Division and Business Services—to evaluate procurement proposals and decide on contractors for the dipole magnet fabrication. The Board was not required to go with the lowest technically acceptable bidder. Instead, the new rules permitted them to award a contract on the basis of best value, not just cost or technical ability.

*continued on page 11*

Purchases for the Main Injector included every item inside the tunnel, from magnets to clamps, water systems to light bulbs.

Photos by Reidar Hahn

Under contract, workers repaired 4,000 welds in the LCW system.

# Flip-Chip Mating Techniques

…and other advances in microelectronics bring pixels to the fore in the search for new physics.

*by Mike Perricone, Office of Public Affairs*

Would you know a pixel if you saw one?

You should, because you've been watching pixels most of your life. They're the tiny areas lighted up by the scanning cathode ray beam in your television screen or computer monitor.

But pixels (for "picture elements," a term coined around 1969) are moving onto the frontier of high energy physics. They form the heart of a new generation of detectors that can help select increasingly rare events, and thrive in the high-luminosity future.

A pixel is one location in a grid of many millions of such locations. An individual pixel fixes the coordinates of a point in space; an array of pixels forms the picture of an event. The pixels light up, or don't light up, giving us the information needed to track the path of a charged particle. The summation of thousands of pixels on a TV screen tells us we're watching Seinfeld's last episode; the summation of many millions of pixels in a detector may tell us we're watching a collision produce decay particles we've never seen before.

Fermilab's pixel research and development group, formed in January 1997, has been developing detectors using individual pixels that are 50 microns wide by 400 microns long—or two thousandths of an inch wide by 16 thousandths of an inch long. Each individual pixel is attached to its own individual microelectronic circuit, to amplify, judge and transmit the signal it receives.

"A pixel detector is the sum over all the 10 million to 100 million rectangles in the system—which is mind-boggling," said Sheldon Stone of Syracuse University, co-spokesperson for Fermilab's proposed BTeV (B-physics at the Tevatron) experiment, which hopes to use pixel detectors in studying the decays of bottom quarks in Tevatron collisions.

"What makes pixel detectors possible is the miniaturization of electronics," said BTeV co-spokesperson Joel Butler of Fermilab's Experimental Physics Projects (EPP) Department. "With a thousands of channels in one of these little squares, you have to put a circuit behind every channel. That means you have ten thousand circuits in one square centimeter. If you had talked about doing that in 1960, no one would have known what you meant. People would have looked at you like you were from another planet."

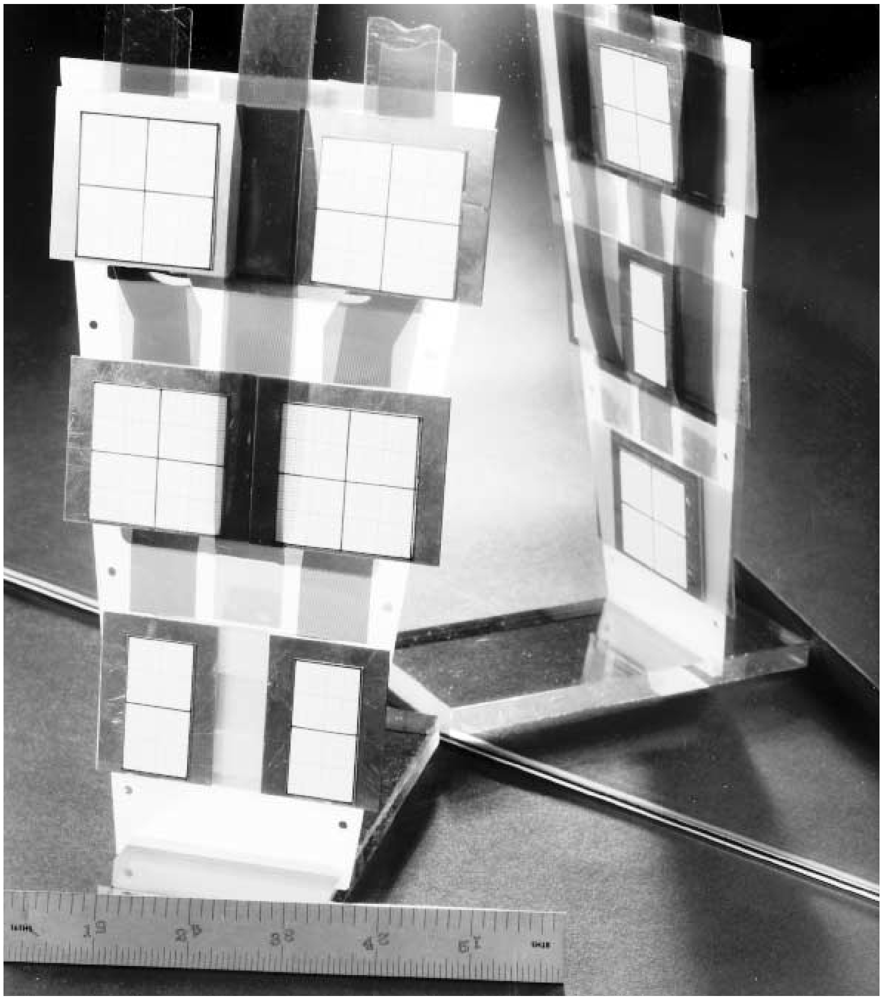
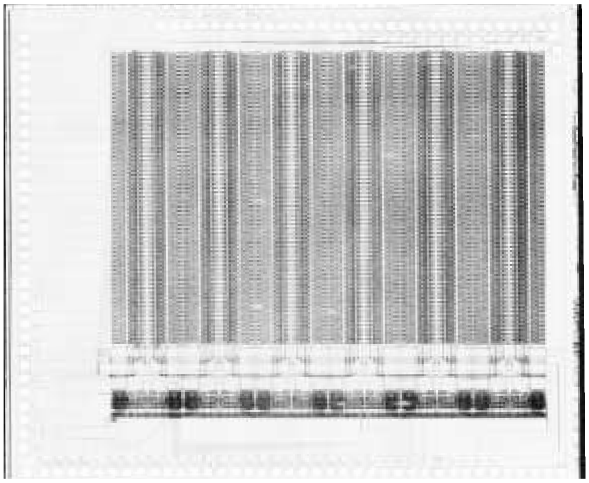


Photo by Reidar Hahn

Fermilab is developing pixel detectors like the one pictured above for CERN, the European particle physics laboratory in Switzerland. The CERN detectors use square pixels, 125 microns on a side (the smallest squares within the larger arrays). Detectors being developed for use at Fermilab will use far smaller pixels, taking advantage of the latest industrial methods for fabricating silicon wafers and readout chips and for bonding them together.



This readout chip, bonded to the back of a sensor chip, measures about 4 centimeters by 6 centimeters.

Particle events are measured in nanoseconds (billionths of a second), requiring ultra-precise witnesses. Miniaturization allows huge gains in the ratio of signal to noise (or useful information to useless information); enhanced pattern recognition, with a simplified method of fixing an event's coordinates in three dimensions instead of using data from multiple layers of two-dimensional detectors; and greatly improved resistance to radiation damage, heightening the detector's performance over its lifetime of bombardment by subatomic particles.

In essence, the pixel takes a long silicon microstrip and chops it into shorter lengths. So instead of unimaginably thin lines that are 50 microns apart but several centimeters long, the result is unimaginably thin lines that crisscross to form a grid of rectangles 50 microns wide and 400 microns long. Each individual rectangle can now locate the "hit" of a particle with the equivalent of both latitude and longitude coordinates—far more precise data than knowing only that a hit lies somewhere along an extended line, and needing several other layers of lines, drawn at different angles on additional silicon wafers, to rule out the possibilities of "ghosts" or false "occupancies."

The previous generation of wafer detectors used long strips, with short wires at the edge to carry the signals from the strips out to the electronics there. Each pixel must connect to its own electronics, and there's no way to run the necessary number of wires out of an array of pixels. The packaging is accomplished by printing all the microscopic circuits on a readout chip and bonding it to the sensor chip in a technique called flip-chip mating. Each pixel detector matches up to the appropriate pixel circuit.

Conventional bonding techniques, such as wire bonding, won't work for pixels because the scale is too small. That drives researchers to the use of flip-chip mating techniques including bump bonding, in which tiny bumps of materials such as indium hold the chips together. Indium forms an electrical bond without being heated, so the two chips can be simply pressed together.

Well, maybe not so simply.

Fermilab physicist Simon Kwan of EPP has been the pixel group's point man in getting the chips fabricated and bonded.

"The search basically covered the whole world before I came up with a few companies," he said. "We're pushing the technology. This is the state of the art."

Kwan has been working on the prototypes with Advanced Interconnect Technology in San Jose, California, which also has production facilities in Hong Kong and Malaysia; and with Rockwell Science Center in Thousand Oaks, California.

The pixel detector's structure is intrinsically radiation resistant. Previous-generation microstrips start out with a signal-noise ratio of over 20:1, and deteriorate from radiation damage to a point where useful signal cannot be extracted. Pixels, because their readout areas are so much smaller, start out with a ratio as high as 150:1; even after extended radiation bombardment, their ratio can be as high as 10:1. They would be perfectly suited for the higher luminosity in Run II of the Tevatron. Since they're placed right on the sensor chip, the readout electronics actually function in the particle beam path instead of out of harm's way.

Jeff Appel, head of Fermilab's pixel development group, cited radiation hardness and pattern recognition capability as the pixel's prized advantages.

"Pixel detectors might actually generate less information (than microstrips), but it's more useful information," Appel said. "This really is a new technology rather than an extension of the old microstrip technology. You could call it a quantum leap in capability." ■

[redacted]