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Status Report on the Survey and Alignment Activities at Fermilab

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ABSTRACT

This report presents the major survey and alignment activities at Fermilab during the period of 2000 to 2004. Future projects, in addition to the status of the current projects, are also presented.

1. INTRODUCTION

The surveying and alignment activities at Fermilab are the responsibility of the Alignment and Metrology Group. The Group supports and interacts with physicists and engineers working on any particular project, from the facility construction phase to the installation and final alignment of components in the beam line.

One of the goals of the Alignment and Metrology Group is to upgrade the old survey networks in the tunnel using modern surveying technology, such as the Laser Tracker for tunnel networks and GPS for the surface networks. According to the job needs, all surveys are done with Laser Trackers and/or Videogrammetry (V-STARS) systems for spatial coordinates; optical and electronic levels are used for elevations, Gyro-Theodolite for azimuths, Mekometer for distances and GPS for baseline vectors. The group has recently purchased two new API Laser Trackers, one INCA3 camera for the V-Stars, and one DNA03 digital level.

This report presents the projects and major activities of the Alignment and Metrology Group at Fermilab during the period of 2000 to 2004. It focuses on the most important current projects, especially those that have to be completed during the currently scheduled three-month shutdown period. Future projects, in addition to the status of the current projects, are also presented.

2. CURRENT PROJECTS

In the past four years, there have been several new experiments taking place such as the Electron Cooling project, the NuMi/MINOS experiment, and the MIPP experiment, which has just recently completed data taking. The Alignment and Metrology Group supports the installation and alignment of these experiments. Other activities in the group have been the upgrade of the survey networks with modern surveying technology for the Tevatron and Booster accelerators.

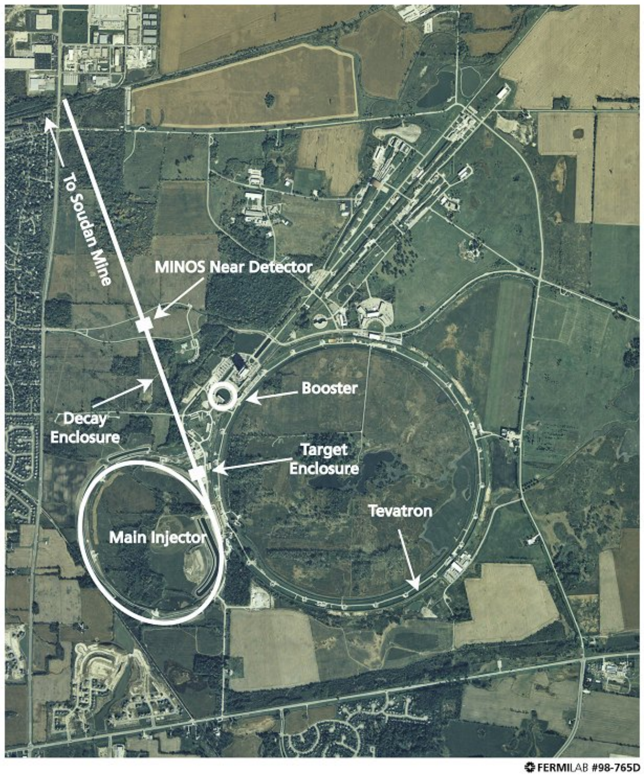

Figure 1. Overview of Fermilab

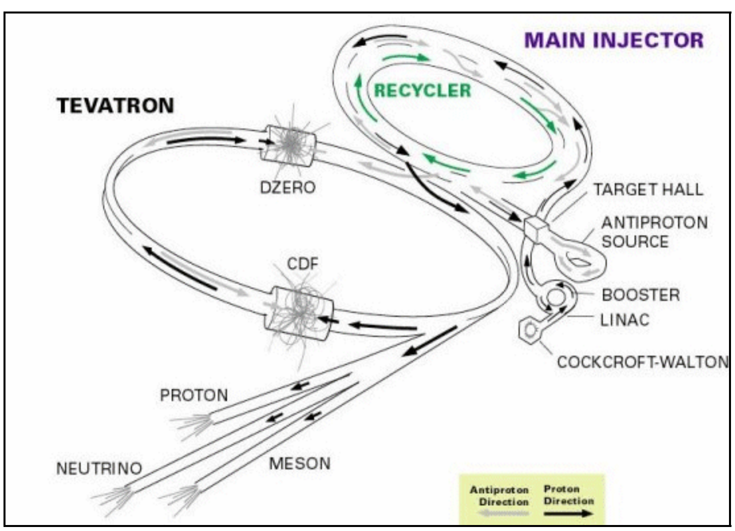

Figure 1. Fermilab's Accelerator Chain

2.1 Electron Cooling Experiment (E-Cool)

The Electron Cooling project is currently driving the recent scheduled shutdown at Fermilab. The goal of achieving the Tevatron luminosity of 5×10^{32} $cm^{-2}s^{-1}$ for RunIIb requires Electron Cooling in the Recycler Ring to provide an increased flux of antiprotons [1]. The Electron Cooling project involves interacting a 4.3 MeV electron beam with 8.9 GeV/c antiprotons. This interaction takes place through a 20-meter long cooling section, which consists of ten 2-meter long solenoid modules. The electron beam is generated in an electrostatic Pelletron accelerator, and then transported to the cooling section, and then returned back to the high voltage terminal. The schematic layout of the Electron Cooling system is shown in Figure 3.

From January 2001 to June 2004, a full-scale prototype of the Electron Cooling system was built and tested at the Wide Band Lab with support from the Alignment and Metrology Group. The system is now being moved to its new location during the current scheduled shutdown. The Pelletron was installed in the MI-31 service building in June 2004 (Figure 4). Starting in August 2004, all components are being installed inside the Main Injector tunnel in the Recycler beamline. The Recycler Ring is a fixed 8 GeV kinetic energy storage ring that was fully commissioned in June of 1999, but was re-aligned in 2001. The cooling section solenoids will be located between the quadrupoles Q307 and Q305 on the Recycler beam line in MI-30 section. Figure 5 shows the installed stands and magnets for the Electron Cooling system.

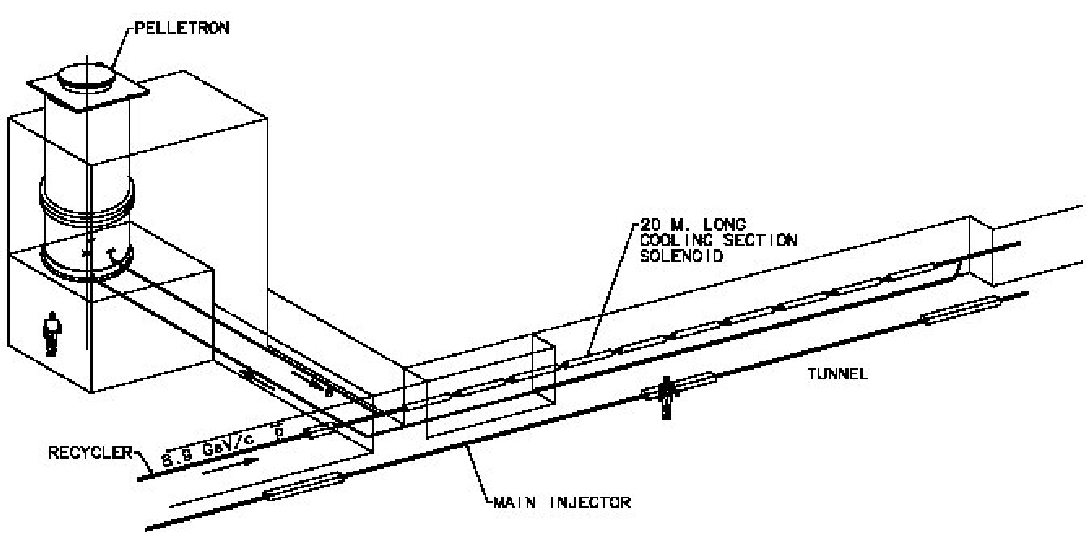

Figure 3. Schematic of Fermilab Electron Cooling System

2.1.1 Survey and Alignment Review

A Laser Tracker network was established to bring in horizontal and vertical controls into the MI-31 building before the Pelletron was installed. This network has been tied to the existing network in the Main Injector tunnel through two 20.32-cm x 20.32-cm (8-in x 8-in) openings in an 3.352-meter (11-foot) long steel shielding that separates MI-31 and MI-30. The Alignment and Metrology Group is currently pre-aligning the components to the beam line as they are installed (Figure 6). The final alignment will be performed later using the Laser Tracker. All the installation and final alignment of the beam line components must be completed by November 2004 when the shutdown ends.

Figure 4. View inside MI-31 showing the fully assembled Pelletron tank.

Figure 5. Installed stands and magnets for the Electron Cooling System in the Main Injector Tunnel.

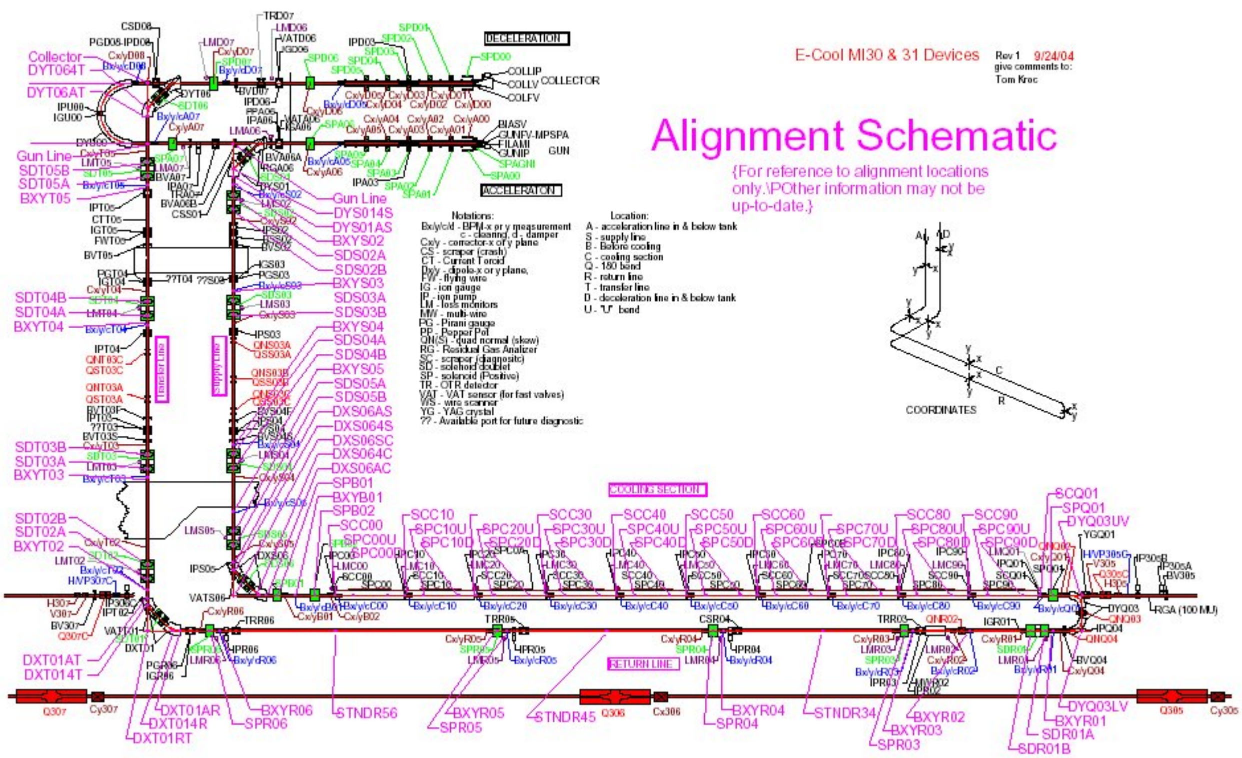

Figure 6. Alignment Schematic (From Tom Kroc, Fermilab)

2.2 NuMi/MINOS Experiment

The Neutrinos at the Main Injector (NuMI) and the Main Injector Neutrino Oscillation Search (MINOS) experiment will perform the first high-precision measurements of the neutrino physics parameters, guiding and directing future research. NuMI is a facility at Fermilab, which uses protons from the Main Injector accelerator to produce an intense beam of neutrinos to enable a new generation of experiments whose primary scientific goal is to definitively detect and study neutrino oscillations. The beam of neutrinos is aimed at the Soudan Mine in northern Minnesota. The NuMI Facility includes the underground enclosures (tunnels and halls) as well as two service buildings located on the surface. Figure 7 shows the layout of the NuMI Facility underground enclosures.

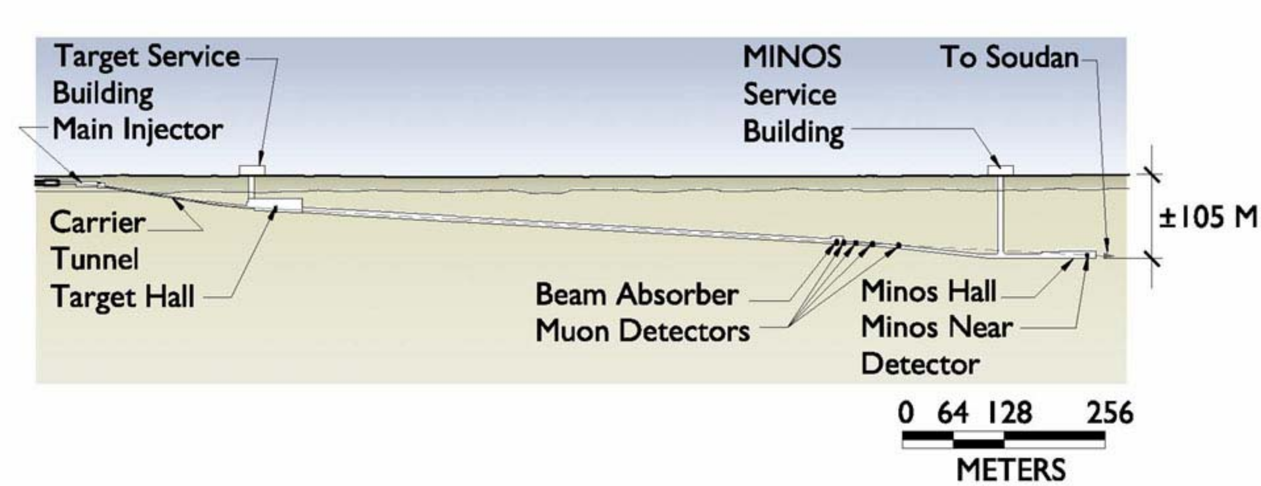

Figure 7. Layout of the NuMI Facility.

MINOS is a long-baseline neutrino experiment, which seeks to observe the phenomena of neutrino oscillations, using two detectors; the "near" detector is at Fermilab and the "far" detector is 735 km away at the Soudan Underground Mine 710 m below surface in Soudan Minnesota. Figure 8 shows the trajectory of the neutrino beam between Fermilab and Soudan.

Figure 8. Trajectory of the neutrino beam between Fermilab and Soudan, Minnesota.

2.2.1 Survey and Alignment Review

The success of the NuMI/MINOS experiment depends on precise, accurate surveying and alignment of the beamline, especially the production target, magnetic focusing elements, decay pipe, and the two detectors. Currently, all the beam components, the target module and two horns have been installed and "pre-aligned". The construction of both detectors is completed and the installation of the neutrino beam monitoring system is underway. The final alignment of the NuMI beamline will take place during the current shutdown. The NuMI project will enter the commissioning phase in December 2004 and will be delivered to experimenters in March 2005. Virgil Bocean [3] has reviewed the concepts, methodology, implementation, and current results of the geodetic surveying and precise positioning efforts necessary for the construction, installation, and alignment of the NuMI particle beamline and the two MINOS detectors.

2.3 MIPP Experiment

The Main Injector Particle Production (MIPP) experiment (E907) is used to measure hardronic particle production in the Meson area using primary and secondary beams from the Main Injector. The goals of the experiment are i) to verify a general scaling law of hardronic fragmentation, ii) to measure particle production off NuMi targets using 120 GeV/c protons with sufficient accuracy to predict the NuMi neutrino spectrum, and iii) to collect a comprehensive dataset that would have a profound impact on related physics issues, such as atmospheric neutrino flux estimates, neutrino factory design, and simulations of hardronic showers for high energy colliders [4]. Figure 9 shows the cutaway view of the experiment, with tracks from a simulated event. The beam particles enter from the upper left, where they hit a target just in front of the Time Projection Chamber (TPC), which sits inside the Jolly Green Giant magnet. Following the TPC, there is a Cerenkov counter, a Time of Flight wall, a second magnet called Rosie, a Ring Imaging Cerenkov counter, and a Neutral Calorimeter. Interspersed between these detectors is a set of Drift Chambers.

2.3.1 Survey and Alignment Review

The surveying and alignment of the MIPP experiment started in 2002 and was completed in 2004. The Alignment and Metrology Group supported the installation and alignment of the components. Prior to the installation of all the components, a Laser Tracker network was established in the experimental hall. Each component was individually referenced to the fiducials located on the exterior of the component. All the beam line components have been installed and final aligned. The MIPP experiment was commissioned phase in June 2004. The experiment is currently running beam.

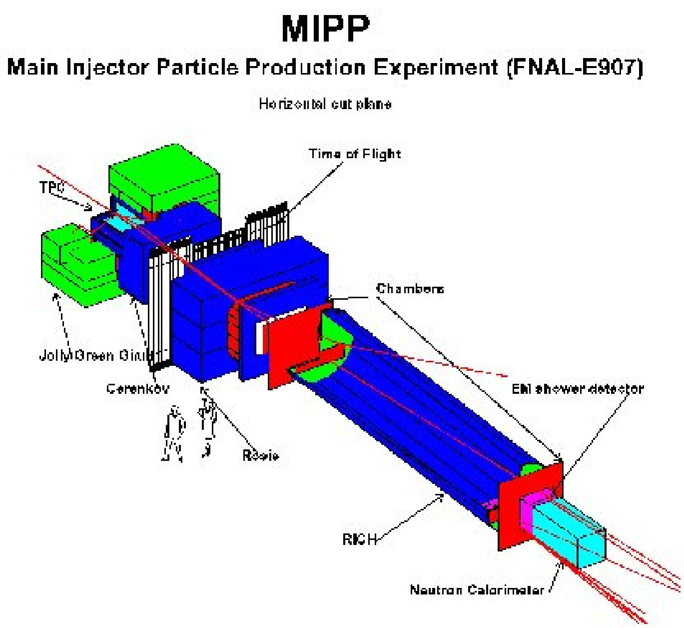

Figure 9. The MIPP experiment.

2.4 The Tevatron

Fermilab's Tevatron is the world's highest-energy particle accelerator and collider. The Tevatron has 6.28 km circumference and can accelerate particles to energy of up to 1 TeV (one trillion electron-volts). Since the Tevatron installation in 1981-1983 there had been several upgrades to improve its luminosity. The Tevatron consists of 972 dipoles, 254 quadrupoles and other components.

2.4.1 Survey and Alignment Review

The alignment method that has been used since installation is the Murphy Line method. The Murphy Line method employs a series of 200 unconnected offset lines. The only measurements available in the horizontal plane are the local offsets relating each Tevatron magnet to the floor plug line (known as Murphy Line) to which they were originally aligned [5]. The optical tooling techniques are the only method of alignment employed. The Murphy Line method does not yield a reliable orbit. In 2003, in order to ensure a reliable orbit at increased energy levels, a decision was made to upgrade the survey and alignment technology for the Tevatron and this led to the creation of a Tevatron Network (TeVNet).

The TeVNet consists of a surface geodetic control network of both horizontal and vertical networks, defined by concrete monuments around the around the Tevatron and the Main Injector rings (Figure 10). It is a trilateration network of GPS baseline and Mekometer distance measurements. Vertical measurements were made with the digital levels. A combined GPS and terrestrial network adjustment of the network has been completed in the Fermilab Site Coordinate System (FSCS) [6]. Eventually this network will be tied to the HARN (High Accuracy Reference Network).

The surface geodetic control coordinates were transferred to the tunnel by the establishment of a tunnel control network. Twelve sight risers were provided around the ring for transferring the coordinates from the surface network. The tunnel network is constraint network, which include the sight riser drop points in the tunnel. It is a system of braced quadrilaterals between the floor monuments in the tunnel, the sight riser drop points, pass points, and the bench marks (tie rods). The entire tunnel control network was measured with the Laser Tracker. The fiducials on all the components in the Tevatron beam line were also measured with the Laser Tracker and digital levels. A new TeVatron Coordinate System (TeVCS), similar to that defined for the Main Injector [6], will be defined for the Tevatron with the origin at the center of the ring.

Other activities going on in the Tevatron is the survey to measure rolls of the Tevatron magnets. This was done using digital levels on fixtures that mated to fiducials on the Tevatron dipoles and quadrupoles. The physicists later compared these measurements to the mechanical roll measurements.

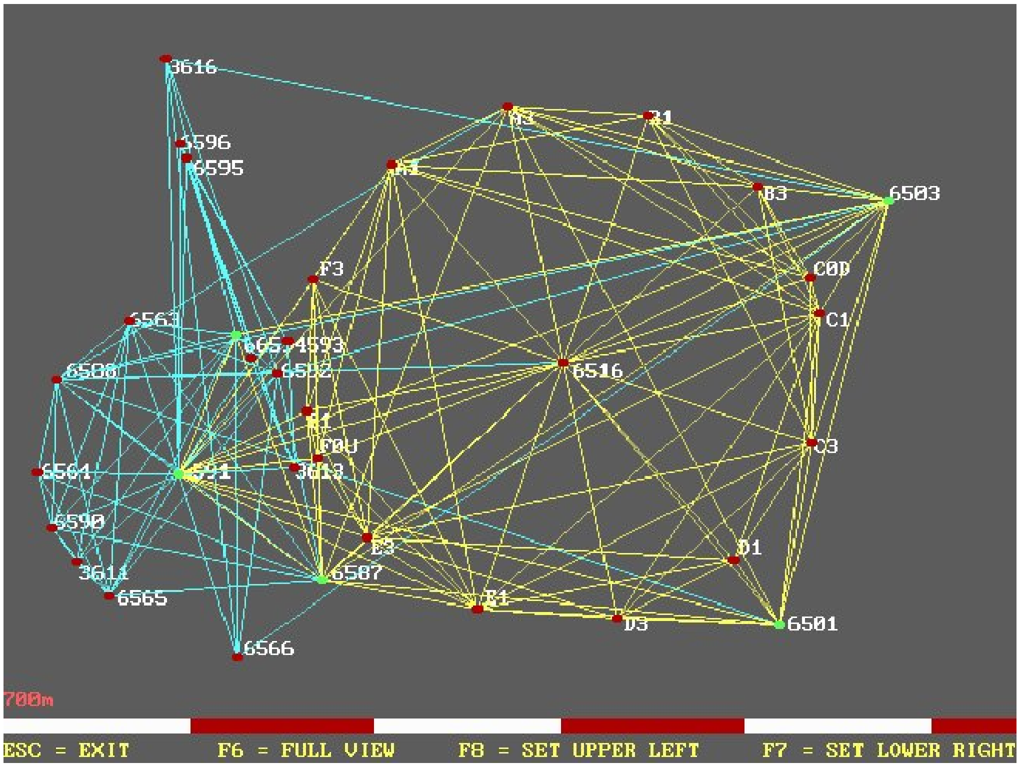

Figure 10. Tevatron Network (TeVNet).

2.5 Booster Accelerator

The Fermilab's Booster accelerator is the lowest energy level synchrotron at Fermilab. The Booster accepts the 400 MeV protons from Linac, accelerates to 8 GeV and sends it to the MiniBooNE or the Main Injector. The Booster, which was originally built in 1970, is a circular accelerator of about 472 meters in circumference with a 24-fold period lattice. Each period has a 6-meter long straight section and a 1.2-meter short straight drift section, and 4 combined function magnets, two horizontally focusing (F magnet) and two horizontally defocusing (D magnet). Each dipole has four fiducials. The Booster also consists of 19 RF cavities, several BPMs and other components, such as the septum, kicker and dog-leg magnets. Figure 11 shows a section of the Booster ring.

2.5.1 Linac

The Fermilab Linac is a negative hydrogen ion, accelerator. The Linac provides beam for Booster operation at frequencies from 0.1 to 5 Hz. Portion of the Linac 400 MeV line is located inside the Booster ring.

Figure 11. Booster Tunnel.

2.5.2 Survey and Alignment Review

Currently there are 24 brass steel monuments and 24 tie rods. The last survey was done in 1993 and all magnet fiducials were coordinated. Since then horizontal magnet moves were made with offsets to randomly established lines. This method of magnet move does not permit the documentation of the magnet fiducial coordinates. The optical tooling techniques were the only method of alignment employed. In 2004, a decision was made to upgrade the survey and alignment technology for the Booster and this led to the establishment of a Booster Network (BooNet). The ring was densified with 59 floor monuments. The tunnel network is a system of braced quadrilaterals between the floor monuments in the tunnel, pass points, and the benchmarks (tie-rods). The entire tunnel control network was measured with the Laser Tracker. Vertical measurements were made with the digital levels. Azimuths and distances on some lines between the floor monuments would be measured, using the Gyro-Theodolite and Mekometer respectively. No surface network was established for the Booster, but the tunnel network was tied to the adjacent existing 8GeV transfer line network established in 1998.

The fiducials on all the components in the Booster beam line were also measured with the Laser Tracker and digital levels. All the RF cavities and other components were re-aligned using optical tooling techniques. A new Booster Coordinate System (BCS) is being defined for the Booster with the origin at the center of the ring. All data collection and data processing must be completed by November 2004 when the shutdown ends.

2.5.2.1 Linac Alignment

The last survey done in the Linac was in 1993. While in the Booster ring, as-founds of all the Linac 400 MeV line components were performed using the Laser Tracker. The components in the remainder of the line was as-found using optical tooling techniques.

2.6 MiniBooNE Experiment

The major goal of the MiniBooNE experiment is to confirm or refute the LSND evidence for neutrino oscillations. LSND is the Liquid Scintillator Neutrino Detector experiment at the Los Alamos National Laboratory. The MiniBooNE experiment consists of two geographically separated parts: the Neutrino Beam and the Detector. The Neutrino Beam consists of four sections: the target, the focusing system, the decay region, and the beam absorber (Figure 12). It began its two-year data collection run in August 2002.

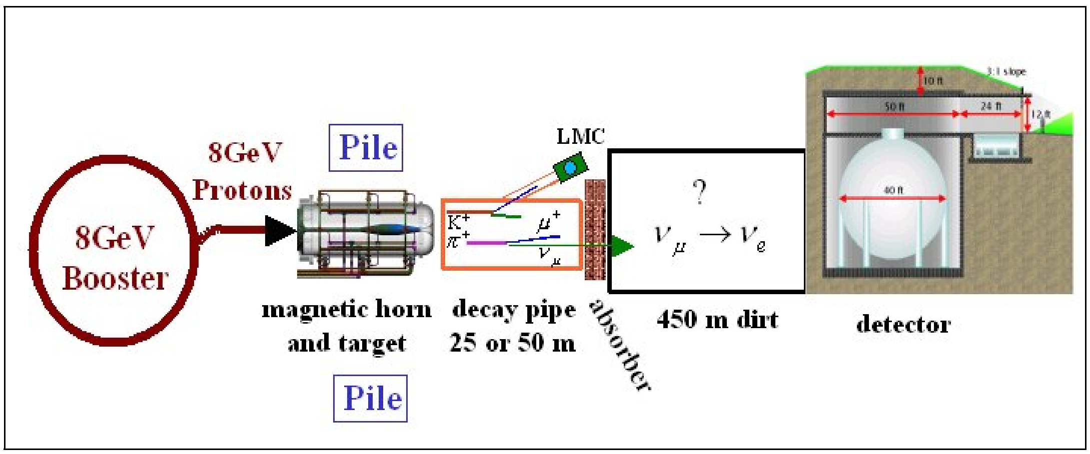

Figure 12. An Overview of the MiniBooNE Experiment.

2.6.1 Survey and Alignment Review

In order to precisely align the MiniBooNE beamline components and survey the detector in the Fermilab site coordinate system, it was essential to first establish a geodetic surface control network. This was followed by establishing a secondary tunnel constraint network tied to the surface network. The surface control network consisted of both horizontal and vertical networks. The surface horizontal network was performed using the GPS baseline and Mekometer distance measurements. A combined GPS and terrestrial network adjustment was done in the performed. The vertical control network was measured using the Leica NA3000 level instrument. All components were then aligned or surveyed to these control points.

2.7 Collider Upgrades

Two existing Fermilab collider detectors at D0 and CDF (Figure 13) have been used to determine Top Quarks of the Standard Model Parameters. The upgrades of the CDF and D0 detector were fully commissioned in 2001, and thus marked the official start of the Run II experiment.

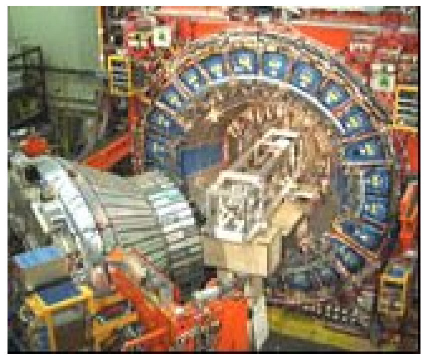

Figure 13. Fermilab Collider Detectors at D0 (left) and CDF (right)

2.7.1 Survey and Alignment Review

The alignment of the detectors used a combination of the Laser Tracker and the V-Stars, and other optical systems to within the specified accuracy of ±0.5mm. Both detectors are now in the maintenance mode, with access only during scheduled shutdowns.

2.8 Other Activities

The Alignment and Metrology Group has also been maintaining the main Injector, Recycler, and the Antiproton Source (Pbar). The Group is also responsible for all non-experiment surveys on the Fermilab site.

3. FUTURE PROJECTS

3.1 BTeV

A third detector called BTeV (Beauty at the TeVatron) will be located at the C0 Interaction Region of the Tevatron proton-antiproton collider at Fermilab (Figure 14). The BTeV experiment is designed to challenge the Standard Model explanation of CP violation, mixing and rare decays of beauty and charm quark states. The major goal of BTeV is to perform an exhaustive search for physics beyond the Standard Model and make precise measurements of the Standard Model parameters. Figure 15 shows the layout of the BTeV Detector. The approved BTeV experiment is still being developed. The installation is scheduled to start in 2006, followed by commissioning in 2008, and data taking begins in 2009.

The goal of the Alignment and Metrology Group is to align and survey the BTeV Detector to the Tevatron beam line in the C0 Collision Hall to within the specified accuracy.

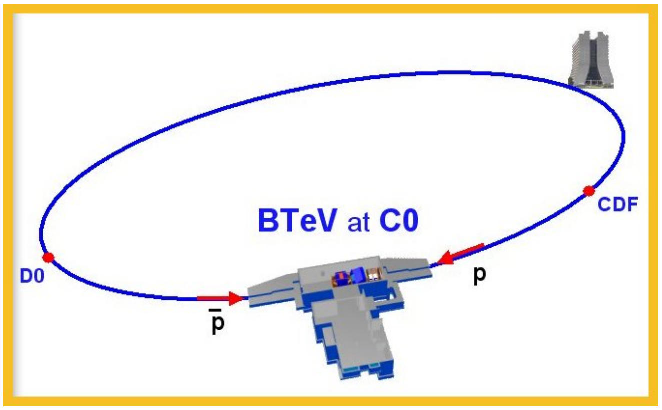

Figure 14. BTeV at C0

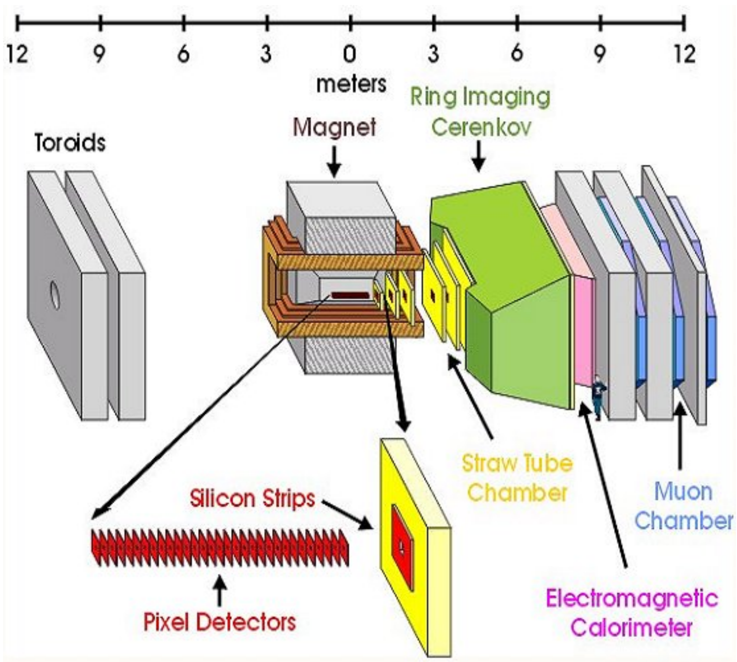

Figure 15. BTeV Detector Layout

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4. CONCLUSION

The Alignment and Metrology Group is supporting many projects such as E-Cool, NuMI/MINOS and MIPP. Survey network upgrades of the Tevatron and the Booster are also taking place using modern survey technology, such as the Laser Tracker for tunnel networks and GPS for the surface networks.

5. ACKNOWLEDGMENT

I would like to thank the Alignment and Metrology Group members, especially the technicians who actually do work.

6. REFERENCES

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