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Survey Of The A, B and C Layers Of The Fermilab D0 Muon Detector System

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ABSTRACT

The Fermilab D0 detector is currently being upgraded to exploit the physics potential to be presented by the Main Injector and the Tevatron Collider during Run II in the Fall of 2000. One of the essential elements of this upgrade is the upgrade of the Muon detector system. The Muon detector system consists of the Central Muon Detector and the Forward Muon Detector. The Central Muon Detector consists of three detector systems: the Proportional Drift Tube (PDT) chambers which were used in Run I, the B- and C-layer Scintillation Counters, and new the A-layer Scintillation Counters. The Forward Muon Detector consists of the Mini-Drift Tubes (MDTs) and the Scintillation Pixel Counters. There are three layers, designated A, B, C, of the Muon detector system. The A-layer is closest to the interaction region and a toroid magnet is located between the A- and B-layers. This paper discusses the methods currently employed to survey and align these PDTs, MDTs, and the scintillation pixel counters in the three layers of the Muon detector system within the specified accuracy. The accuracy for the MDTs and PDTs is ±0.5 mm, and ±2.0 mm for the scintillation pixel counters. The Laser Tracker, the BETS, and the V-STARS systems are the major instruments used for the survey.

1. INTRODUCTION

The Fermilab D0 detector is currently being upgraded. The goal of the D0 upgrade is to exploit the physics potential to be presented by the Main Injector and the Tevatron Collider during Run II [1]. The D0 detector consists of several systems, such as the Solenoid Magnet, the Silicon Vertex Detector, the Scintillating Fiber Tracker, the Preshower Detectors, the Calorimeter System, the Muon System, etc. An overall view of the D0 detector is shown in Figure 1 with the primary detector systems indicated.

One of the essential elements of this upgrade is the upgrade of the D0 Muon detector system [2].

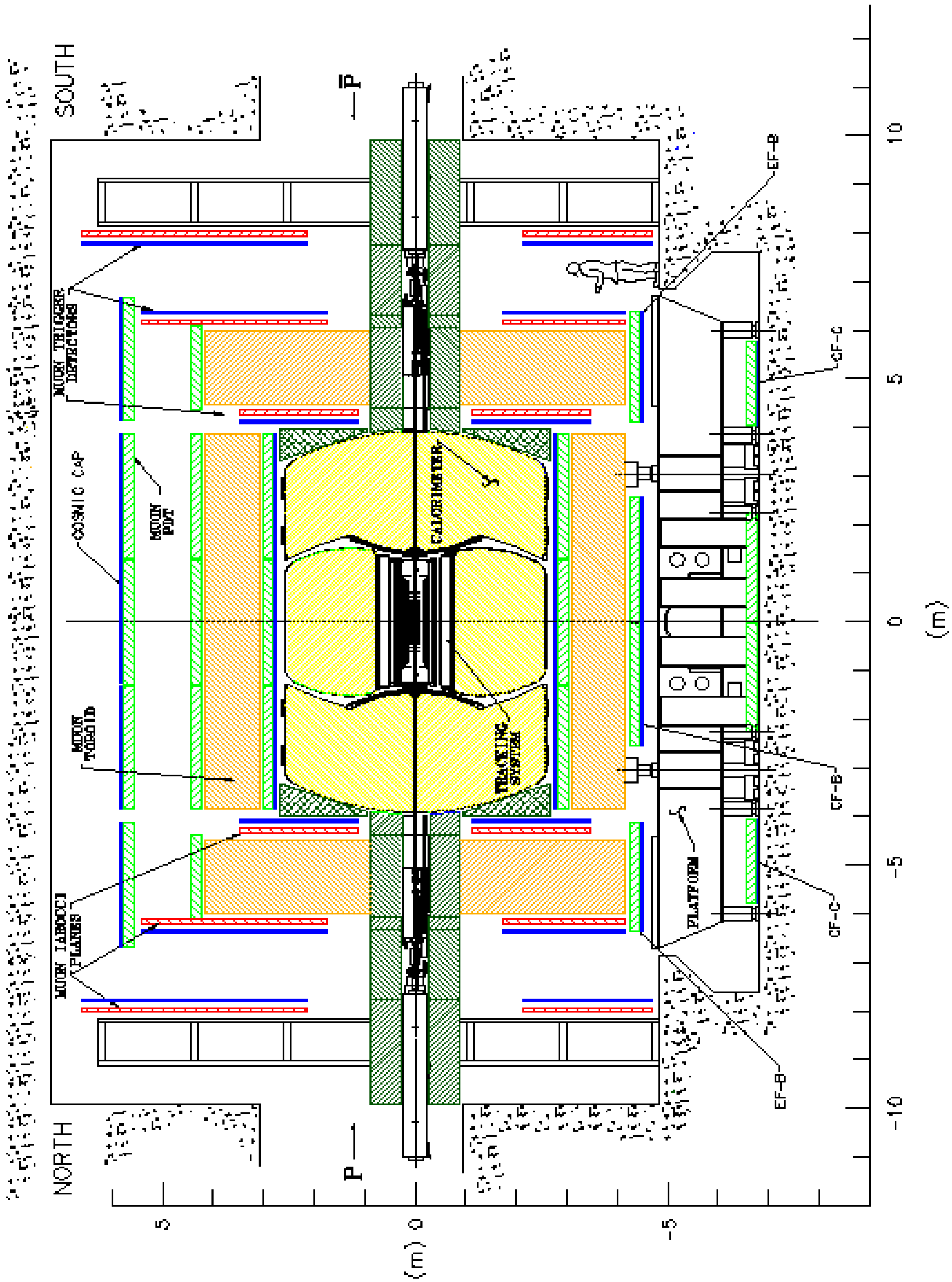

Figure 1. Side view of the D0 upgrade detector including various elements of the upgraded muon system.

2. THE D0 MUON SYSTEM

The design of the upgraded D0 muon system is driven by the D0 Run II physics goals and by the higher event rates and background expected in Run II. The upgraded muon system for Run II has three layers. The three layers are designated A, B, C, where the A-layer is closest to the interaction region and a toroid magnet is located between the A and B layers. Contained in these layers are the three basic subsystems of the upgraded muon system which include the Proportional Drift Tube (PDT) chambers, the Mini-Drift Tubes (MDTs) and the Scintillation Counters

The muon system consists of two detectors: the central muon detector and the forward muon detector. The toroid magnet in the central muon detector is sometimes referred to as the central toroid magnet or CF iron. The toroid magnet in the forward muon detector is sometimes referred to as the forward toroid magnet or EF iron.

2.1 The Central Muon Detector

The central muon detector consists of a toroid magnet, large PDT drift chambers, the C-layer counters, the CF Bottom B- and C-layer counters, the EF Bottom B-layer counters, and the A-layer scintillation counters. Table 1 shows the channel count for the central muon detector. The toroid magnet, PDT chambers and C-layer counters were used in Run I. The B- and C-layer Bottom and A-layer scintillation counters are added for Run II.

Table 1. Channel count for the Central Muon Upgrade Detector

	Layer			
Item	A	B	C	Total
PDTs	18	38	38	94
C-layer Counters	-	16	240	256
B- and C-layer Bottom Counters	-	68	36	104
A-layer Counters	630	-	-	630

2.1.1 Central Toroid Magnet

The central (CF) toroid magnet, Figure 2, is a square annulus 109 cm thick weighing 1973 metric tons. It is built in three sections in order to allow access to the inner parts of the detector. The center-bottom section is a 150 cm wide beam, fixed to the detector platform, providing base for the calorimeters and tracking chambers. It is called the center beam (CB). To complete the toroid, there are two C-shaped sections (east and west CF toroid), which can be moved perpendicular to the center beam.

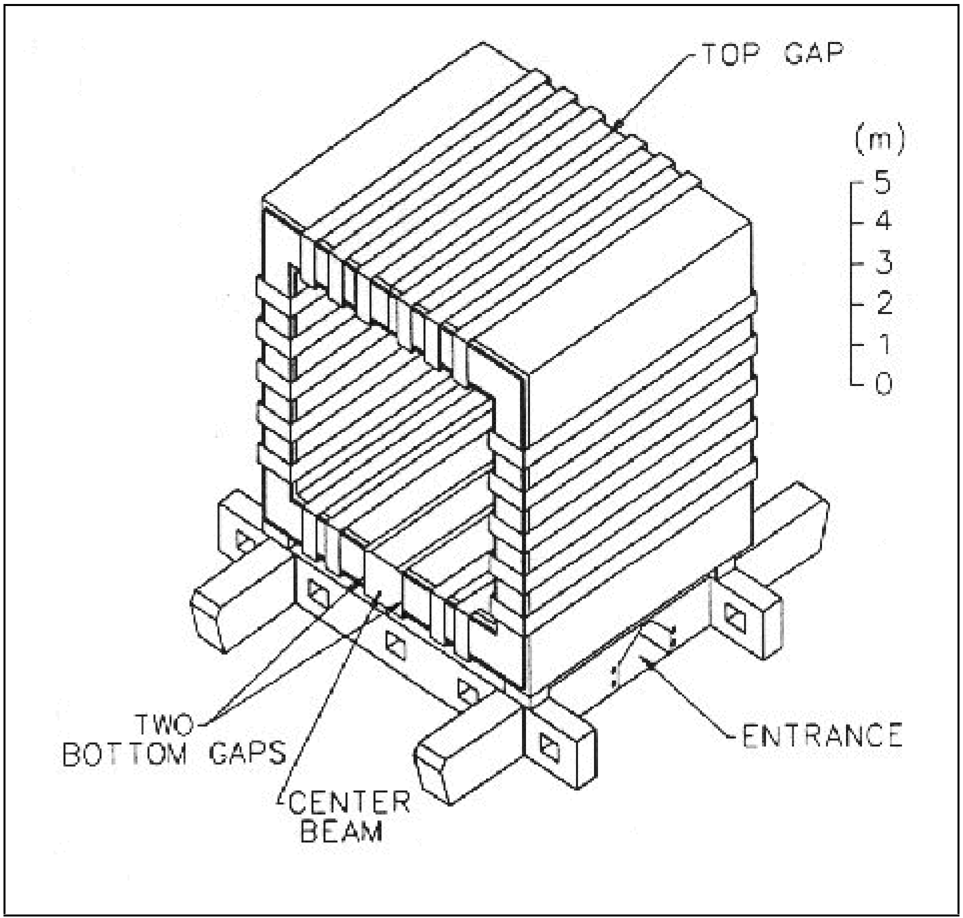

Figure 2. View of the central muon toroid showing the coils, the Center beam, and the seams for opening and closing the detector.

2.1.2 PDT Chambers

The PDT chambers provide measurements for all muons traversing the central toroid magnet or the outer edge of the forward toroid magnet. The PDT chambers consists of three layers of drift chambers, one layer inside (A) and two layers (B and C) outside the central toroid magnet. Approximately 65% of the central region is covered by three layers of PDTs, close to 90% is covered by at least two layers. The PDT chambers are constructed from rectangular extruded aluminum tubes and are of varying size with the largest being approximately 100 x 225 in^2. The PDTs outside the toroid magnet (B- and C-layers) have three decks of drift cells and the layer inside the toroid (A-layer) has four decks with the exception of the bottom PDTs (these have 3 decks). The cells are 10.1 cm across, with typically 24 columns of cells per chamber. The

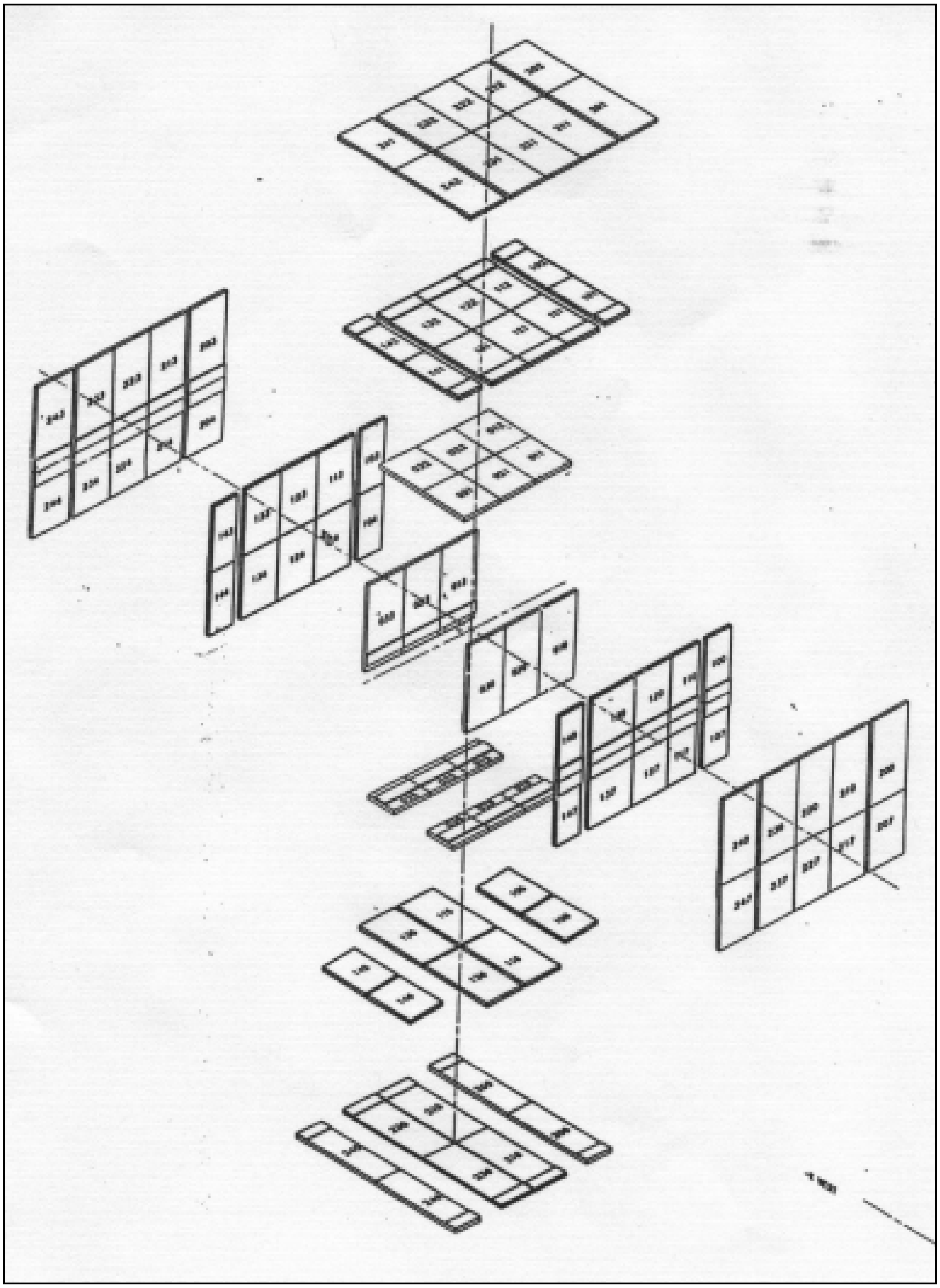

Figure 3. The layout of the PDT chambers.

chamber wires are oriented along the toroid magnetic field direction to provide the position of the bend coordinates for the muon momentum measurement. Figure 3 shows the layout of the PDT chambers.

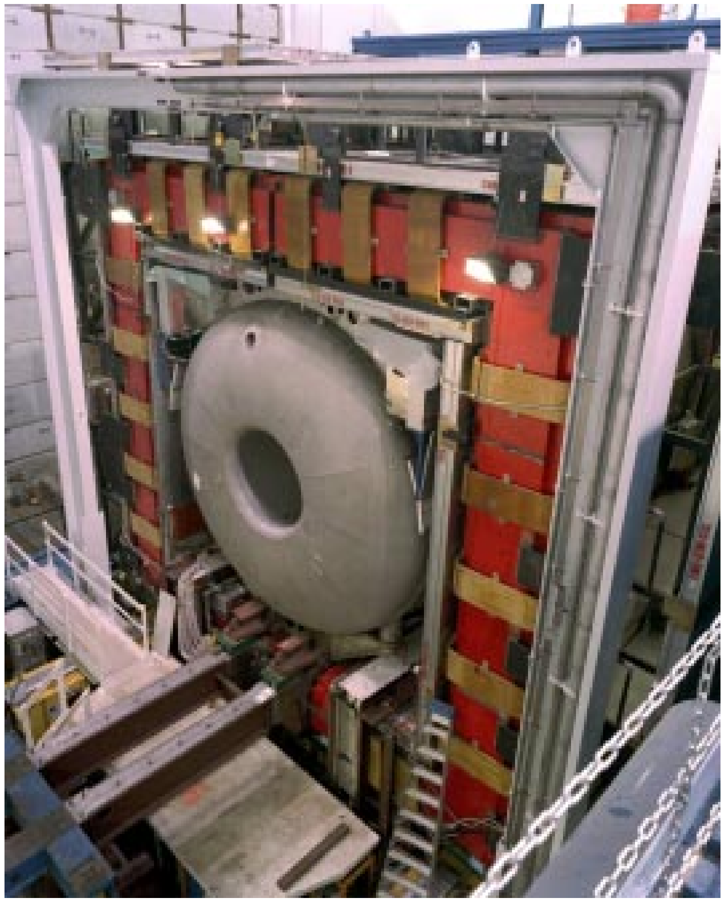

Figure 4. Muon Detector showing CF Toroid surrounded by PDT chambers.

2.1.3 Central B- and C-Layer Scintillation Counters

The C-layer scintillation counters cover the top and sides of the of the central region PDT C-layer and were used in Run I. The counters on the top are 113 inches long. The counters on the sides are 108.0 or 81.5 inches long, with the shorter counters close to the floor. All of the counter are 25 inches wide, which gives eight scintillation counters per PDT.

The central muon scintillation “Bottom” counters includes CF Bottom B- and C-layers counters and the EF Bottom B-layer counters. Thirty two counters are located on the B-layer chamber underneath the CF muon toroid. There are 4 counters under the center beam. The EF B-layer bottom consists of 32 counters 88.00 x 15.75 in^2 in size and are located on the PDTs underneath the north and south EF toroid magnets. The total number of B- and C-layer counters is 360.

2.1.4 A-Layer Scintillation Counters

The A-layer scintillation counters are located in between the central calorimeter and the central A-layer PDTs. The counters are divided into rows. Each row contains nine counters that cover three 100 inch wide PDTs. The counter width varies from 10 to 17 inches. There are a total of 630 counters.

Figure 5. A-Layer PDT chambers and Scintillation counters on CF Toroid.

2.2 The Forward Muon Detector

The forward muon detector consists of a toroid magnet, three layers of Mini-Drift Tubes (MDTs) for muon track reconstruction, and three layers of Scintillation Pixel Counters for triggering on events with muons. The forward muon detector is contained in two sections, the North and South sections of the detector.

2.2.1 Forward Toroid Magnet

The forward (EF) toroid magnet is 63 inches thick. There are two sections of the EF magnet, one in the North end and one in the South end of the forward region.

2.2.2 Mini-Drift Tubes

The mini-drift tubes are arranged in three layers (A, B and C) that consist of three (B and C-layers) or four (A-layer) planes. The A- layer is near the inner surface of the toroid magnet, the B-layer is near the outer surface of the magnet, and the C-layer is the most distant from the center of the detector (Figure 1). The planes are made up of several tubes. An individual tube has eight cells, each with a 9.4x9.4 mm^2 internal cross section with a 50 micron anode wire in the center. The accuracy of wire position within a tube is 160 microns. Figure 6 shows one complete MDT plane.

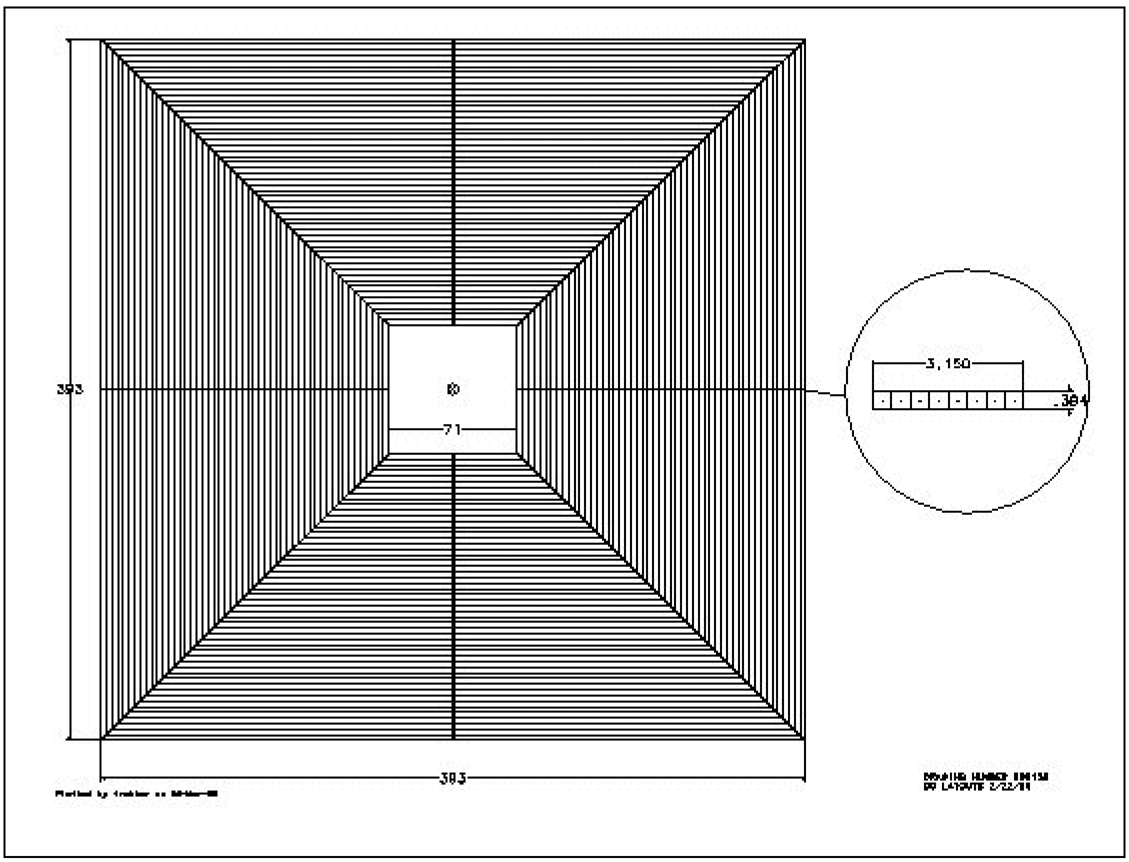

Figure 6. Mini-Drift Tubes: individual 8 tube module and one complete plane.

Each layer is divided into 8 octants. Each octant contains tubes of different lengths and is an independent assembly unit. The A-layer has a cut in the two bottom octants to accommodate the calorimeter support. The bottom octants of layers B and C are shorter than others because their size is restricted by the collision hall floor. Layers A and B are mounted directly on the EF toroid. The C-layer will be mounted on the EMC (End-iron Muon Chamber) support structure. The tubes are oriented along the magnetic field lines. Each octant is assembled and tested separately, then moved to D0 for assembly into planes.

2.2.3 Scintillation Pixel Counters

There are three layers (A-, B- and C-layers) of scintillation counters on each side of the detector. The A- layer is the closest to the interaction region, then B-layer, and the C-layer is the most distant from the detector center. Each layer of counters is divided into 8 octants with 96 counters per octant. The size of the largest C-layer is 12x10 m^2. Each octant is assembled and tested separately, then moved to D0 for assembly into planes. Each plane of counters is mounted in the D0 detector with the support at the top of the frame and is movable along the beamline in order to get access to MDT planes [5]. The C-layer does not move. Figure 7 shows one quadrant of a scintillation pixel plane.

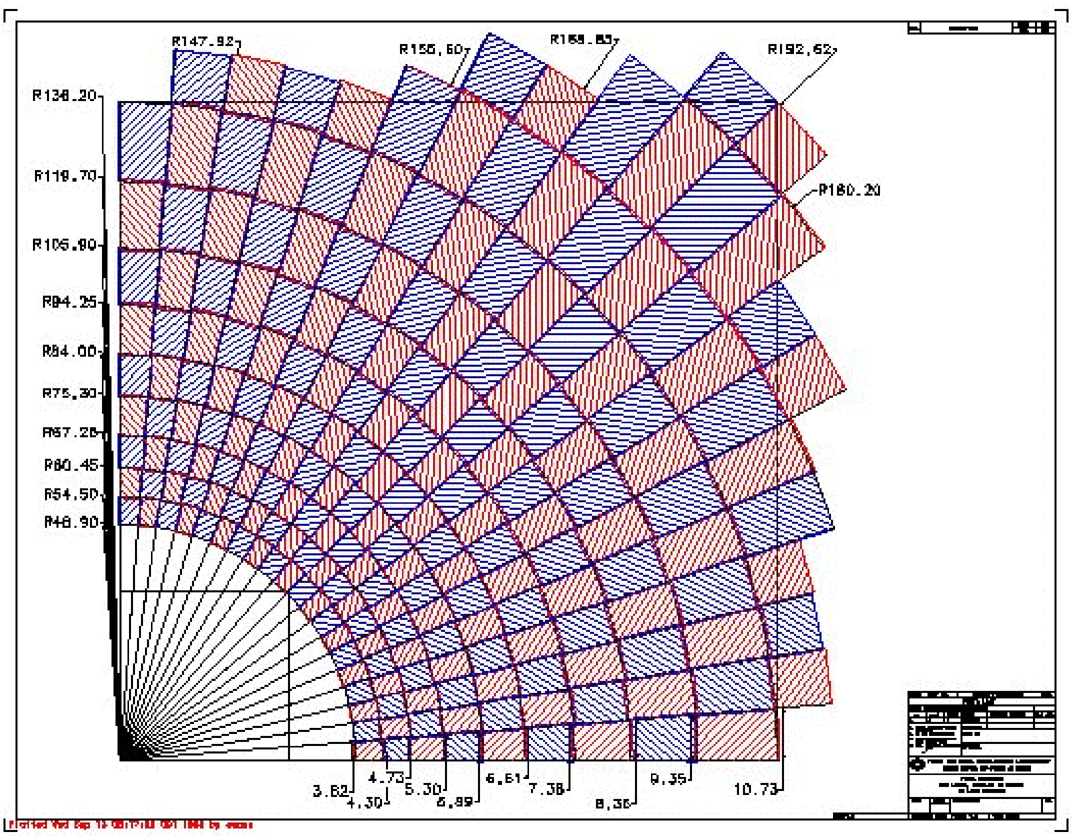

Figure 7. One quadrant of scintillation pixel plane.

3. SURVEY OF THE D0 MOUN DETECTORS

3.1 D0 Global Coordinate System

The survey global coordinate system is a right-handed Cartesian coordinate system defined as follows:

Origin - Center of D0 Detector
X-axis - EAST axis. Positive to the right and perpendicular to the Y-axis
Y-axis - NORTH axis. Positive along the anti-proton direction
Z-axis - Positive up and perpendicular to both X- and Y-axes.

3.2 Control Points

Since the center beam (CB) is fixed to the detector platform and the and center calorimeter (CC), several reference markers have been established as control reference points on the CB and CC. Several points have also been established on the CF toroid magnet. These points have been measured with the CF toroid magnet opened in the east-west direction and with the magnet in the closed position. In the magnet closed position, these points were also measured with the toroid magnet ON and OFF. The coordinates of all the measured points were transformed into the D0 global coordinate system. Additional control points have recently been added on the trusses between the B- and C-layers outside the CF toroid magnet. It is in the works to establish more reference markers as control points on and around the EF toroid magnets on both sides of the detector.

There are several types of reference markers used for control points which include 2x2 in^2 construction plates, with 0.25 inch holes in the center, welded to the magnet. On the CF toroid magnet, a 4 inch long pedestal with 1.5 inch diameter and 0.25 inch hole in the center is used. This will also be used for the EF toroid magnet. Some of the K+E targets used for Run I are also used as control points.

3.3 Survey Methods

The Laser Tracker, SMX Tracker4000 and its associated software Insight™ are used for establishing control points. The Laser Tracker is a device that makes three-dimensional measurements. It uses a laser distance meter, two precision angle encoders and a proprietary software to calculate, store and display the real-time three-dimensional position of a mirrored target situated over the desired point or feature. The Laser Tracker is used to establish most of the control points.

The V-STARS system is a portable non-contact, three-dimensional digital photogrammetric system. The system consists of one or two digital cameras and a V-STARS software. To measure an object, the camera(s) are used to photograph the object from various directions. The digital image are processed immediately by the V-STARS software to provide three-dimensional coordinates and statistical information. The software is based on photogrammetric-bundle- triangulation methods. The V-STARS system is used to connect all the component points to the control points.

The BETS (Brunson Electronic Triangulation System) is a portable non-contact, three-dimensional coordinate measuring system. The system consists of precision electronic theodolites connected to a computer via Brunson cabling and theodolite interface module. The computer has a Brunson software that can display real time three-dimensional coordinates and statistical information. The BETS system is used to connect all the K+E target and tooling balls used in Run I to the new control survey points.

3.4 Survey Requirements

The survey of the D0 muon detectors is being done in three phases for the PDT chambers, the MDTs, and the Pixel Counters. Phase I is the initial survey and referencing of the individual components. Phase II is the measurement of the relative locations of the components on a common support. Phase III survey is used to determine the position of the components in the collision hall. The required accuracy for all phases is ±0.5 mm for the PDTs and the MDTs and ±2.0 mm for the Pixel Counters. No survey is required for the C-layer Counters, the B- and C-layer Bottom Counters, and the A-layer Scintillation Counters. Table 2 summarizes the survey requirements.

Table 2. Survey Requirements.

Item	Quantity	Survey Required	Accuracy mm
PDTs	94	Yes	±0.5
C-layer Counters	256	No	±3.0
B- and C-layer Bottom Counters	116	No	±3.0
A-layer Counters	630	No	±3.0
MDTs	48	Yes	±0.5
Pixel Counter	48	Yes	±2.0

3.5 PDT Chambers Survey

3.5.1 Phase I Survey

The Phase I survey is the referencing of the new bushing holes and old tooling balls on the PDT relative to the wire position. Each PDT chamber has two end plates with precise holes which locate the sense wires. Drilled in each plate are two 0.25 inch diameter alignment reference holes. The position of all the sense wires relative to these four reference holes is known from the PDT chamber design and construction technique. The reference holes are usually covered up when the PDT chambers are installed. Therefore, four 0.25 inch diameter bushing holes (eight for the C-layer chambers) were drilled near the corners of the chamber. On some chambers, 0.50 inch diameter tooling balls are mounted near the corners. For the A-layer the holes were drilled into 0.50 x 0.50 in^2 stainless steel bars attached to the sides of the PDT channel extrusions. There are 3 or 4 holes per bar, two on top near each end, one on the end of the bar, and one on the side for some bars. The Laser Tracker was used to measure the relative position of the reference holes and the bushing holes on each of the PDT chambers. In addition to the bushing holes, the locations of the old Run I tooling balls were measured for comparison with Run I measurements. Also measured are the locations of the V-wheel and Cam wheel.

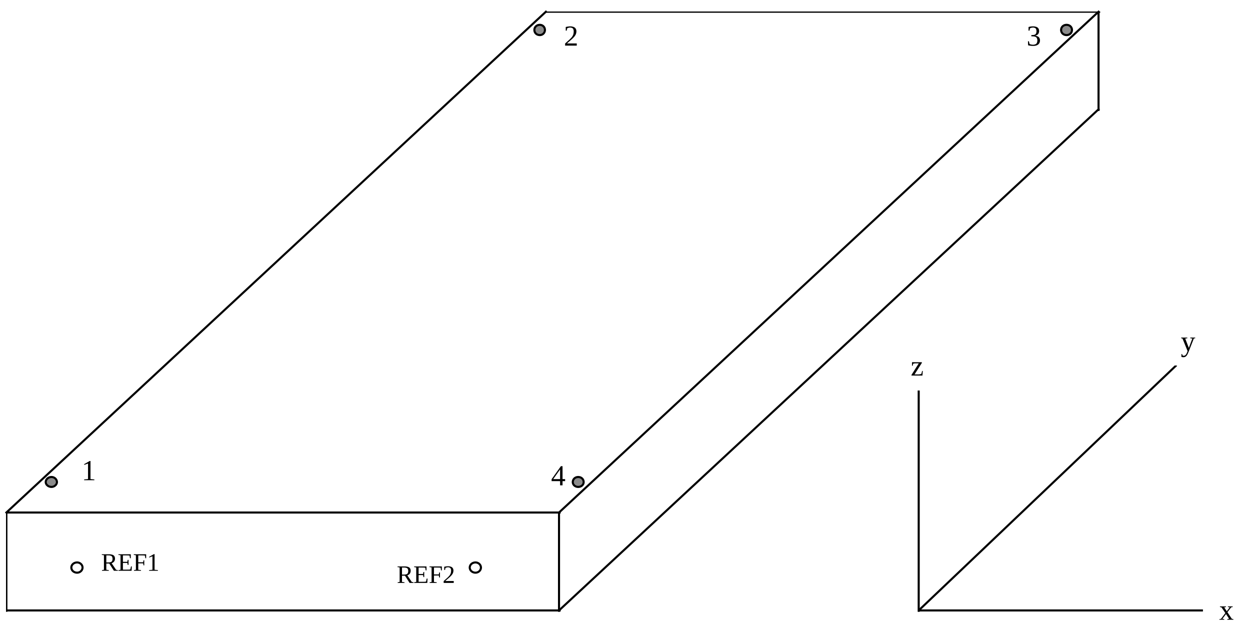

Figure 8. PDT chamber local coordinate system.

All measurements are made in the PDT chamber local coordinate system. The top bushing holes are numbered 1 through 4 and the bottom holes are numbered 5 through 8 (Figure 8). REF1 through REF4 are the reference holes. It is a right-handed Cartesian coordinate system defined as follows:

- Origin - Center of left reference hole (REF1)
- x-axis - Positive to the right in the drift direction
- y-axis - Positive outward in the wire direction and perpendicular to the x-axis
- z-axis - Positive up and perpendicular to both x- and y-axes.

All of the Phase I survey of the PDT chambers have been completed for all the A-, B-, and C-layers. There are five chambers to be surveyed in situ with the V-STARS system. The required accuracy for the Phase I survey is ± 0.5 mm.

3.5.2 Phase II Survey

The Phase II survey is a global survey of a set of PDT chambers mounted on each piece of the muon toroid magnet with respect to each other. In this survey, the location of all the bushing holes and tooling balls are tied to the previously established control points defined in the D0 global coordinate system. The Laser Tracker and the BETS system were used to establish the control points. Phase II survey is currently in progress using the V-STARS system. The required accuracy for the Phase II survey is ± 0.5 mm.

3.5.3 Phase III Survey

The Phase III survey is the final measurement, made in the collision hall, which references the position of the groups of PDT chambers relative to each other and to the other detector systems. The Phase III survey must be repeated with each opening/closing of the detector. A quick analysis of the survey data is required so that the most current PDT chamber positions can be used in the software trigger and reconstruction [3]. The survey method to be used depends of the accessibility space constraints at the time of survey. The required accuracy for the Phase III survey is ± 0.5 mm.

3.6 Central B- and C-Layer Scintillation Counters

No survey is required for the C-layer Counters and the B- and C-layer Bottom Counters. The mounting system ensures that the counter relative position are fixed to within about 1/8" (3 mm). After installation, the position of each counter is measured to 0.125 inch (3 mm) accuracy.

3.7 A-Layer Scintillation Counters

No survey is required for the C-layer Counters and C-layer Bottom Counters. The mounting system ensures that the counter relative position are fixed to within about 1/8" (3 mm). After installation, the position of each counter is measured to 0.125 inch (3 mm) accuracy.

3.8 MDT Survey

3.8.1 Phase I Survey

There are a total of 48 MDT octants. Each octant has four 0.25 inch bushing holes drilled on the front side of the octant. For the MDT modules, the supports are installed using a precision jig to drill holes for rivets which positions the counter support. Individual MDTs are mounted on both sides of the octant. The V-STARS system is used for the Phase I survey. The survey is used to check the accuracy of placement for a small sample of the octants to insure that that the drilling system is working properly. Three adhesive reflective V-STARS targets are carefully placed on every fourth MDTs on both sides of the octant. In addition, reflective targets are placed at each end of the individual MDTs. The location of the targets with respect to the bushings are measured with the V-STARS system. The model coordinates of the four bushing holes is known from the MDT octant design and construction technique. A transformation between the model coordinates and the measured coordinates yields the coordinates of the MDT points in the model coordinate system. The required accuracy for the Phase I survey is ±0.5 mm.

Figure 9. MDT Phase I Survey with V-STARS.

3.8.2 Phase II Survey

The assembled MDT octants are assembled into planes and mounted into the D0 detector. After the octants have been mounted, the relative position of all octants of one plane will be measured relative to each other and the reference control markers on the EF iron and the EMC trusses. In this survey, the location of all bushing holes are tied to the previously established control points defined in the D0 global coordinate system. The Phase II survey will be done with the V-STARS system. The required accuracy for the Phase II survey is ± 0.5 mm.

3.8.3 Phase III Survey

The Phase III survey is to determine the position of each octant in the collision hall. Since the octants are covered up in the collision hall, the survey is done by measuring to the points on the EF toroid and the EMC trusses. This survey will be repeated after each toroid magnet opening. The Phase III survey will be done with the V-STARS system. The required accuracy for the Phase III survey is ± 0.5 mm.

3.9 Scintillation Pixel Counter Survey

3.9.1 Phase I Survey

The installation of scintillation counters into octants are done with accuracy of 2 mm. These accuracy is 1% or less of the counters size. There are a total of 48 Pixel Counter octants. Each octant has four 0.25 inch bushing holes drilled on the front side of the octant. Individual Pixel Counters are mounted on the front sides of the octant. The counters are held by supports which are installed using a precision jig for drilling holes to mount and locate the supports. The V-STARS system is used for the Phase I survey for a small sample of octants to verify the precision of the counter placements. Adhesive reflective V-STARS targets are carefully placed on the Pixel Counter grid along the 90° edge sector, along the Middle sector, and along the Diagonal sector. There are two targets per counter. The location of the counter grid with respect to the bushings are measured with the V-STARS system. The model coordinates of the four bushing holes are known from the Pixel Counter octant design and construction technique. A transformation between the model coordinates and the measured coordinates yields the coordinates of the Pixel Counter points in the model coordinate system. The required accuracy for the Phase I survey is ± 2.0 mm.

3.9.2 Phase II Survey

The assembled Pixel Counter octants are assembled into planes and mounted into the D0 detector. After the octants have been mounted, the relative position of all octants of one plane will be measured relative to each other. The accuracy for locating the Pixel counter octant position is ± 2.0 mm. In this survey, the location of all bushing holes are tied to the previously established control points defined in the D0 global coordinate system. The Phase II survey will be done with the V-STARS system. The survey data will be used for the final trigger tables and off-line data analysis.

3.9.3 Phase III Survey

The Phase III survey is used to determine the position of each octant in the collision hall. This survey will be repeated after each toroid magnet opening and/or pixel counters plane movement to get access to the MDT planes. The survey for the pixel movement will only be done few times to check repeatability but not every time [7]. The Phase III survey will be done with the V-STARS system. It is planned to have electronic monitoring of the location of the EF toroids, CF toroid, and EMC trusses so that surveying will not be necessary after the first few surveys [7]. The required accuracy for the Phase III survey is ±2.0 mm.

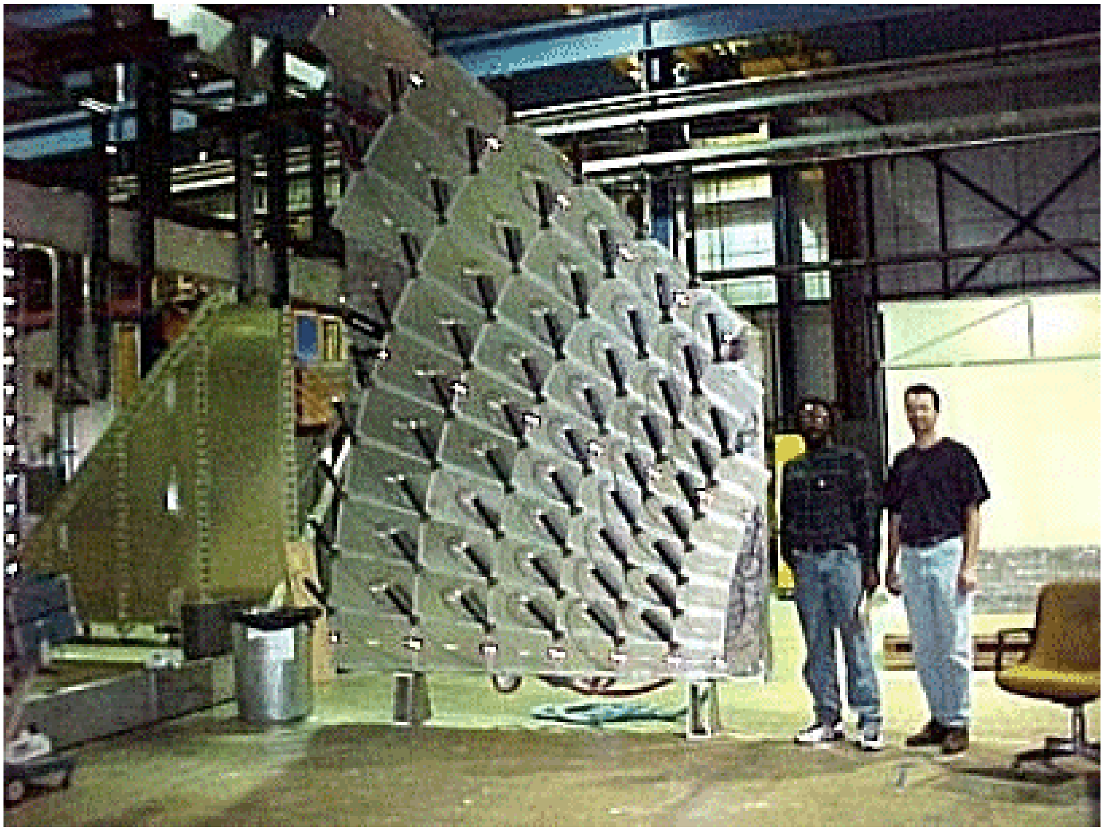

Figure 10. Scintillation Pixel Counter Octant with V-STARS target ready fir survey.

4. D0 MUON DETECTOR SCHEDULE AND COMMISSIONING

The current working schedule to completion of the D0 muon detector upgrade and the survey project are shown in Table 3 [9]:

Table 2. D0 Muon Detector Upgrade Schedules.

Task	Start	Finish
MUON CENTRAL DETECTOR	1/27/95	7/10/00
PDT		
Phase 1 Survey EFB Bottom	1/21/99	1/27/99
Phase 1 Survey CFB Bottom West	1/28/99	2/3/99
Phase 1 Survey CFC Bottom West	2/15/99	2/17/99
Phase 1 Survey CFC East and CFB East	2/18/99	2/24/99
Perform A-Layer PDT Phase 2 Align	9/20/99	10/15/99
Perform B-and C-Layer PDT Phase Alignment	10/18/99	11/30/99
PDT Commissioning Complete	6/9/00	6/9/00
A-LAYER SCINTILLATION COUNTERS	9/3/96	7/10/00
B- AND C-LAYER SCINTILLATION COUNTERS	11/27/95	4/13/00
MUON FORWARD MINI-DRIFT TUBE (MDT) DETECTOR	8/1/96	9/1/00
Survey Assembled Octants	10/19/99	7/14/00
Survey A-Layer North MDT Planes	4/20/00	5/3/00
Survey A-Layer South MDT Planes	5/4/00	5/17/00
Survey B-Layer North MDT Planes	5/18/00	6/1/00
Survey B-Layer South MDT Planes	6/2/00	6/15/00
Survey C-Layer North MDT Planes	6/16/00	6/29/00
Survey C-Layer South MDT Planes	7/24/00	8/4/00
MDT Commissioning Complete	9/1/00	9/1/00
MUON FORWARD TRIGGER DETECTOR	1/27/95	7/10/00
Survey A-Layer North Pixel Planes	5/11/00	5/24/00
Survey A-Layer South Pixel Planes	5/11/00	6/8/00
Survey B-Layer North Pixel Planes	6/9/00	6/15/00
Survey B-Layer South Pixel Planes	6/23/00	6/29/00
Survey C-Layer North Pixel Planes	7/10/00	7/21/00
Survey C-Layer South Pixel Planes	8/14/00	8/25/00
Pixel Commissioning Complete	9/25/00	9/25/00

5. CONCLUSIONS

The upgrade of the D0 muon detector for Tevatron Run II have been described. The upgrade has three layers, A, B, and C. Contained in these layers to be surveyed are the PDT chambers, MDT octants, and the Pixel Counters octants. The survey is done in three phases (Phase I, II, III). The required s survey accuracy for all phases is ±0.5 mm. Three different surveying methods are used for the survey, the Laser Tracker, the BETS, and the V-STARS systems. The Phase I survey of the PDTs have been completed. Currently in progress are the Phase II survey of the PDT chambers, Phase I survey of the MDT octants, and the Phase I survey of the Pixel counters octants. The upgrade of the D0 muon detector is expected to be fully commissioned September, 2000.

6. ACKNOWLEDGMENT

I would like to thank Dr. Albert Ito for all his useful comments, suggestions and for proofreading this paper.

7. REFERENCES

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