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Survey and Alignment of the Fermilab D0 Detector: From Assembly to Roll-in

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ABSTRACT

The Fermilab D0 detector was used for the discovery of the top quark during Run I in 1996. It had been upgraded to exploit the physics potential to be presented by the Main Injector and the Tevatron Collider during Run II. The upgrade of the D0 detector was fully commissioned on March 1, 2001, and thus marked the official start of the Run II experiment. The detector, which weighs about 5500 tons, was assembled in the Assembly Hall and then rolled into the Collision Hall. Some of the essential elements of this upgrade are the upgrade of the Solenoid Magnet, the Central Fiber Tracker, the Preshower Detectors, the Calorimeter System, and the Muon System. This paper discusses the survey of the Collision Hall and the alignment of the detectors using a combination of the Laser Tracker, BETS, V-Stars, and other Optical systems to within the specified accuracy of ±0.5mm.

1. INTRODUCTION

The D0 experiment at the Fermilab Tevatron proton-antiproton collider is a general purpose collider detector experiment, built to study proton-antiproton collisions at the center-of-mass energy of 1.8 TeV. It is one of two collider detectors at Fermilab (Figure 1). Following the successful operation of the D0 detector during Run I, it received substantial upgrade modifications in preparation for Run II. The D0 detector consists of several systems, such as the Solenoid Magnet, the Central Fiber Tracker, the Preshower Detectors, the Calorimeter System, the Muon System, etc. An overall view of the D0 detector is shown in Figure 2 with the primary detector systems indicated. The upgrades were made to the detector while it was in the D0 assembly hall. Immediately prior to the beginning of Run II it was rolled into the D0 collision hall ("roll-in") where the proton-antiproton collisions take place.

2. THE FERMILAB D0 DETECTOR

The D0 detector consists of several unique detector subsystems each specifically provided to measure the properties of one or more classes of elementary particles. Among the subsystems are the Liquid Argon Calorimeters, the Solenoid Magnet, the Central Fiber Tracker, the Preshower Detectors, the Muon System, etc. The D0 detector is designed in layers like a "Russian Doll"; successive layers of detectors cover the innermost detectors. An overall view of the D0 detector is shown in Figure 2 with the primary detector subsystems indicated.

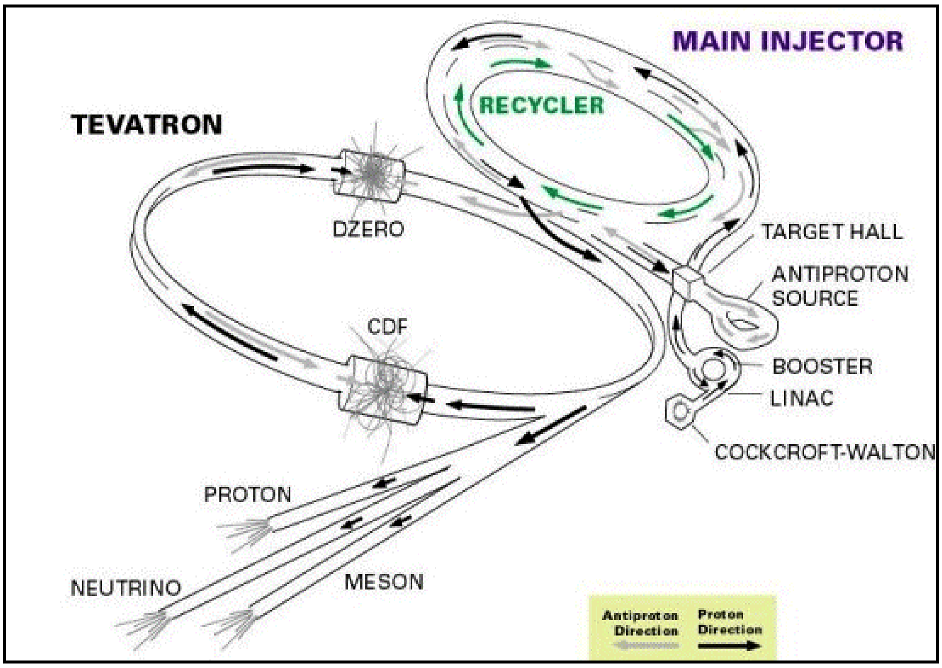
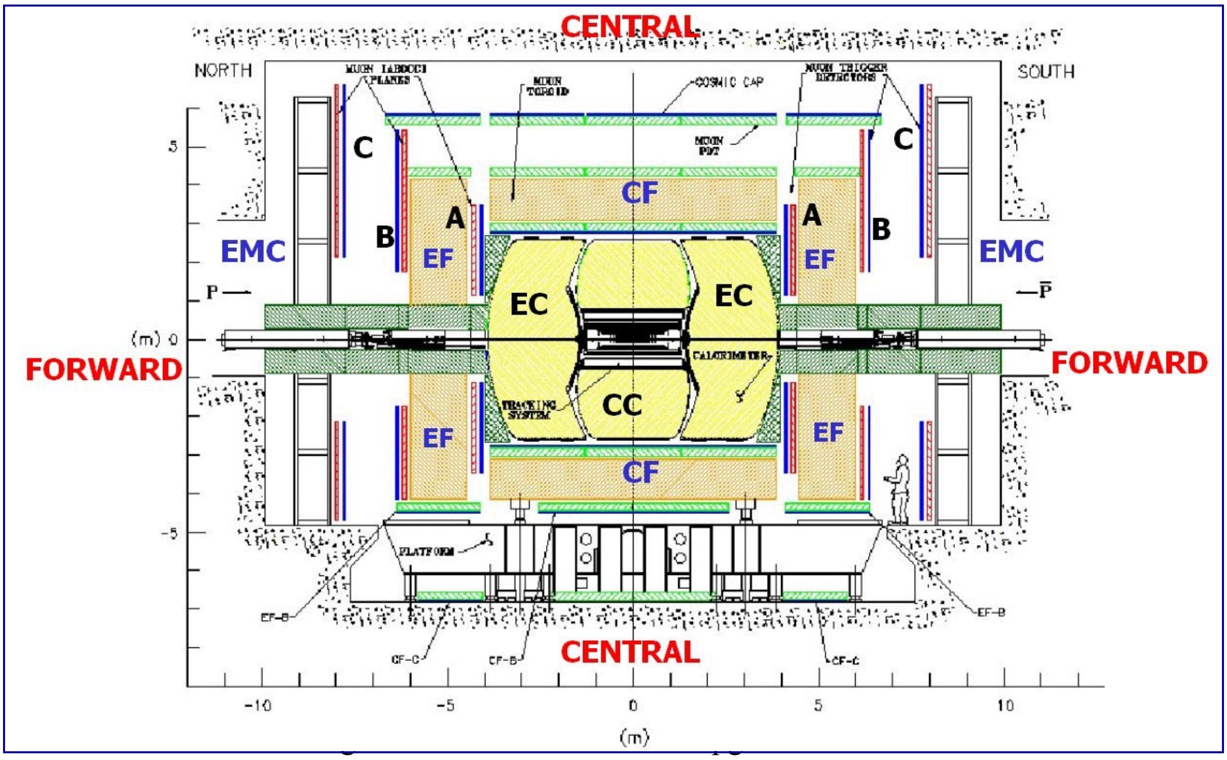


Figure 1. Fermilab's Accelerator Chain

One of the salient components of the D0 detector is a highly stable, liquid argon calorimeter. It consists of three units: Central Calorimeter (CC), and two End-cap Calorimeters (EC) (Figure 3). The calorimeter system provided excellent energy resolution of both pions and hadrons during Run I and is retained for Run II. A major new component of the upgraded detector is a 2 Tesla superconducting solenoid magnet newly fabricated for Run II. It is the first thin solenoid for a particle physics detector, which operates at 2 Tesla (Figure 3). Another important element of the upgraded detector is the new Run II Central Preshower Detector, also called the Central Fiber Tracker (Figure 4). It consists of scintillating fibers mounted on eight concentric cylinders, all superimposed on a thin lead radiator. After the Central Preshower Detector was installed on the outer diameter of the solenoid cryostat, the magnet and preshower detector were installed into the center bore of the existing Central Calorimeter cryostat. The Forward Preshower detector, also new for Run II, is located in front of each End-cap Calorimeter (EC) (Figure 4). It consists of a lead radiator and four scintillator layers numbered from 1 to 4, starting with the layer closest to the interaction point.



The upgraded muon system for Run II has three active layers. The three layers are designated A, B, and C, where the A-layer is closest to the interaction region and a toroid magnet (consisting of a thick layer of magnetized steel) is located between the A and B layers (Figure 7). Contained in the A and B layers are the three basic subsystems of the upgraded muon system – the Proportional Drift Tube (PDT) chambers (Figure 5), the Mini-Drift Tubes (MDTs) (Figure 8) and the Pixel Counters (Figure 9). The muon system is geographically divided into two detectors: the central muon detector and the forward 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. The central toroid magnet (sometimes referred to as the CF steel), 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 a base for the calorimeters and tracking chambers. It is called the centerbeam (CB) (Figure 6). To complete the CF toroid, there are two C-shaped sections (east and west CF toroid), which can be moved horizontally, perpendicular to the centerbeam, to gain access to the detectors within (Figure 7).

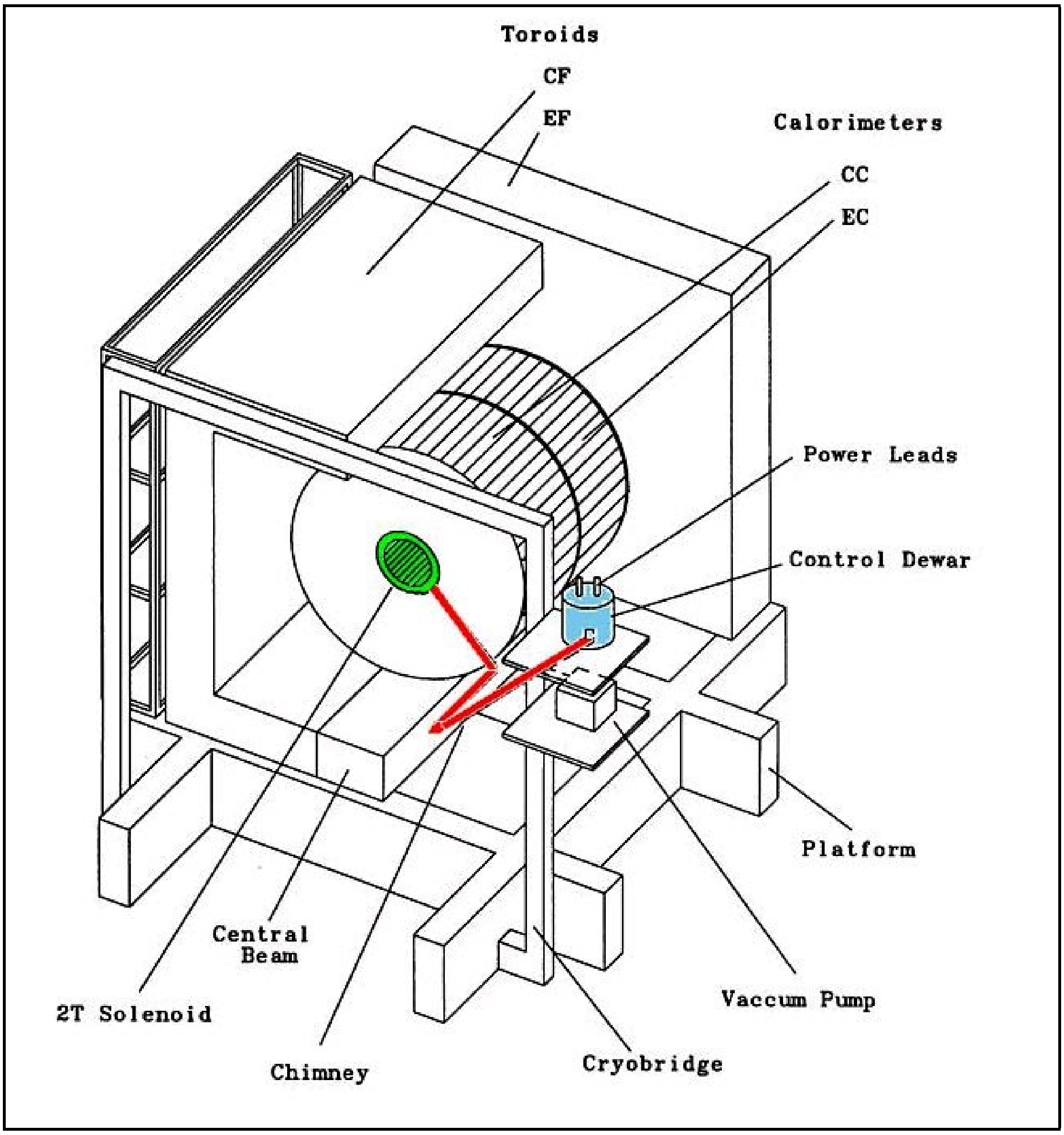


Figure 3. Three-dimensional view of the D0 detector

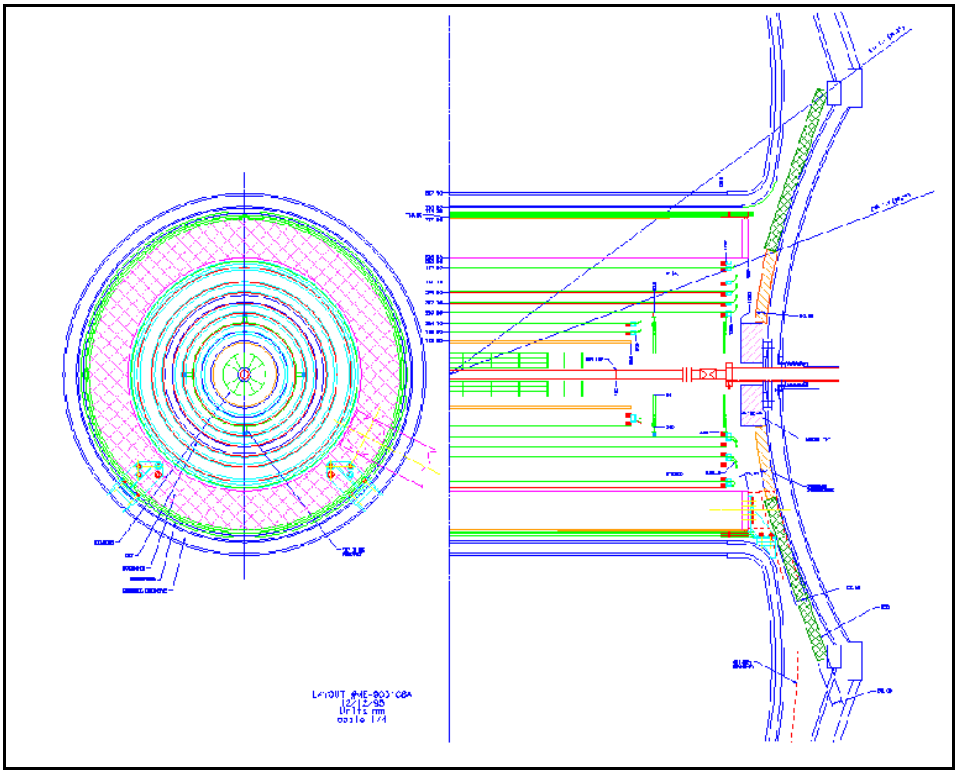


Figure 4. The Central Fiber Tracker and the Forward Preshower

The forward muon detector consists of a toroid magnet, three layers of Mini-Drift Tubes (MDTs) for muon track reconstruction, and three layers of Pixel Counters for triggering on events with muons. The forward (EF) toroid magnet between the A and B layers is 160 cm thick The forward muon detector is geographically divided into in two identical sections, the North and South sections of the detector. Both can be moved horizontally, parallel to the centerbeam, to gain access to the detector systems within.

The EMC (End Muon Chamber) Truss is a 40-foot high metal structure that is used to hold the forward B- and C-layer MDT and Pixel planes. The north and south EMC trusses are located on the sidewalks next to the north and south walls of the collision hall (Figure 10).

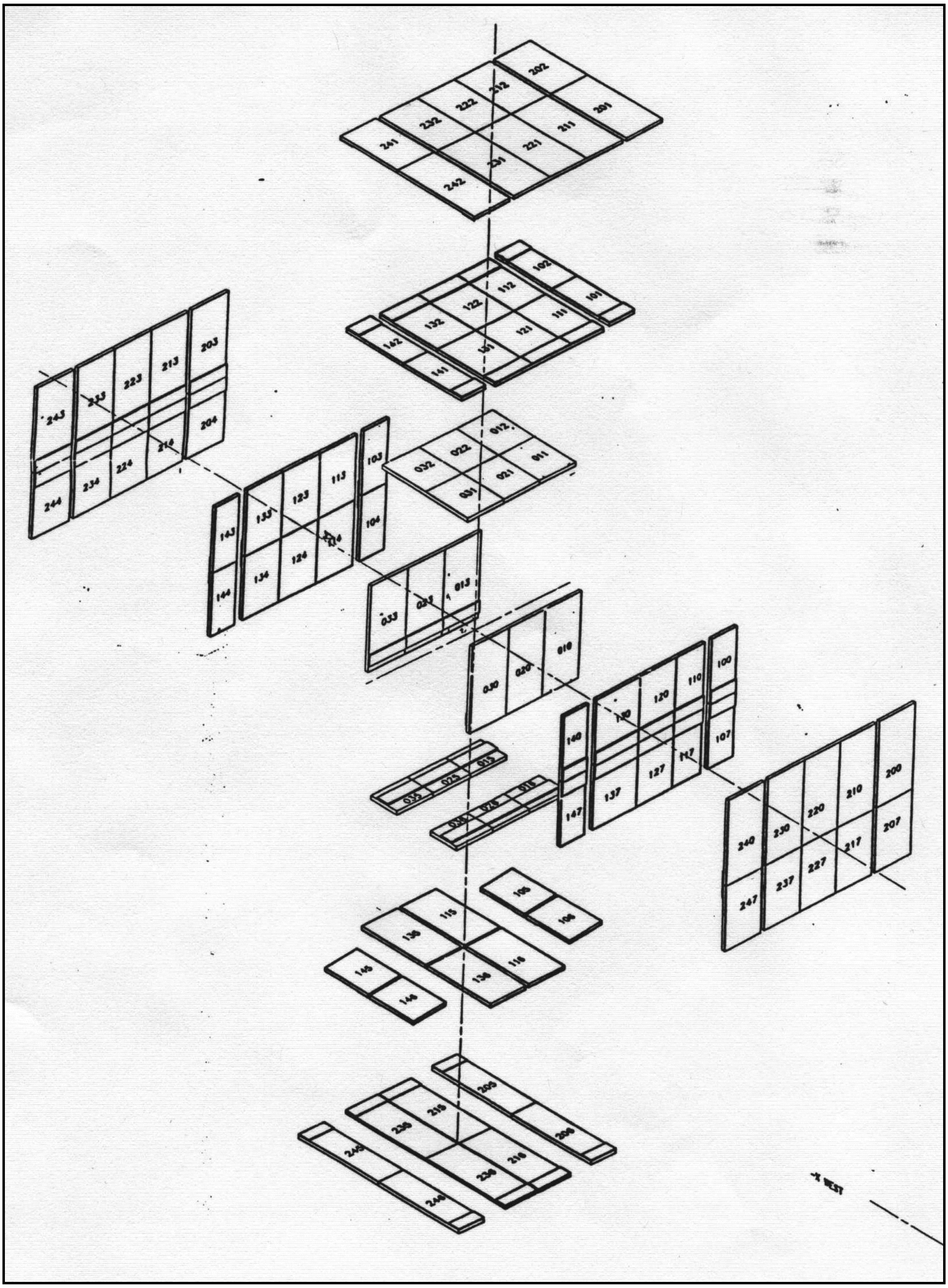


Figure 5. The layout of the PDT chambers.

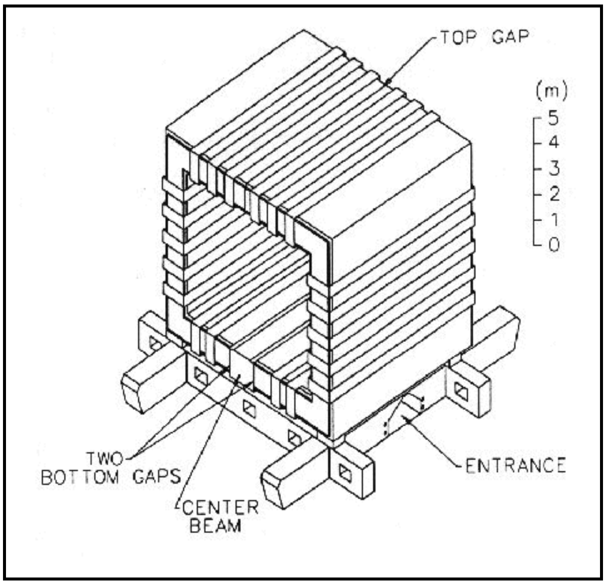


Figure 6. View of the central muon toroid showing the coils, the Center beam, and the seams for opening and closing the detector.

Figure 7. Muon Detector showing CF Toroid surrounded by PDT chambers.

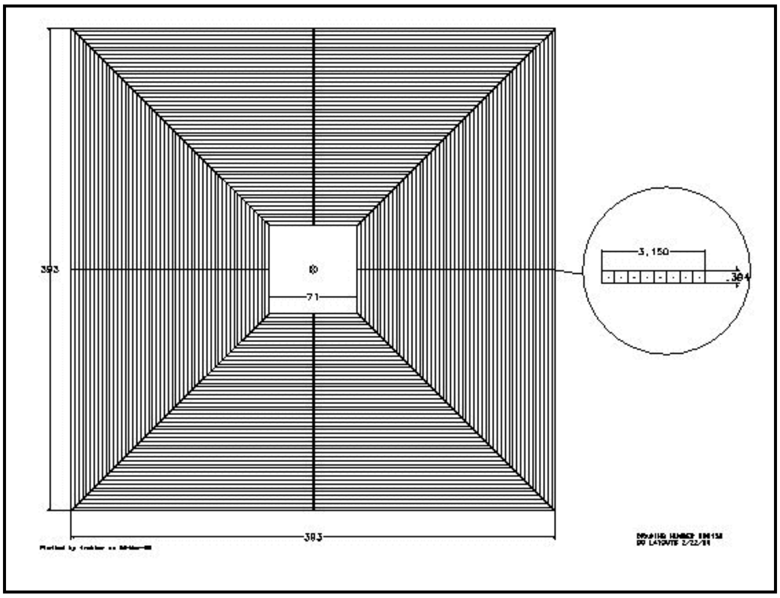


Figure 8. Mini-Drift Tubes: individual 8 tube module and one complete plane.

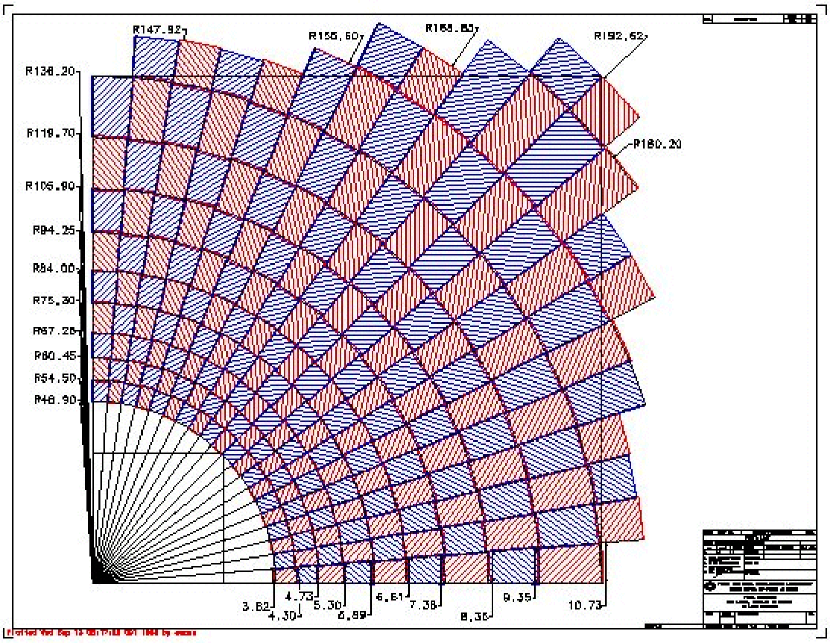


Figure 9. One quadrant of scintillation pixel plane

3. THE D0 COLLISION HALL

The Fermilab Tevatron proton-antiproton collisions take place in the collider detector inside the D0 collision hall (Figure 10). The dimensions of the hall are 777.89 in (19.758 m) in the north-south direction, 600.0 in (15.24 m) in the east-west direction, and 534.0 in (13.56 m) from the floor to the ceiling. The hall consists of two sidewalks, which are 120 in (3.04 m) wide in the north-south direction and 90.0 in (2.286 m) above the floor of the hall (Figure 11). The lower section of the hall below the sidewalks is referred to as the "pit" and is 588.89 in (14.958 m) in the north-south direction. Figure 12 shows the D0 detector in the collision hall after roll-in. The north, south and west walls are permanent concrete walls of the D0 building and the collision hall. The east wall consists of shielding block wall that separates D0 the collision hall from the D0 assembly hall. The shielding blocks are removed prior to rolling the detector into the collision hall, and are rebuilt after roll-in (Figure 13).

Figure 10. D0 Collision Hall

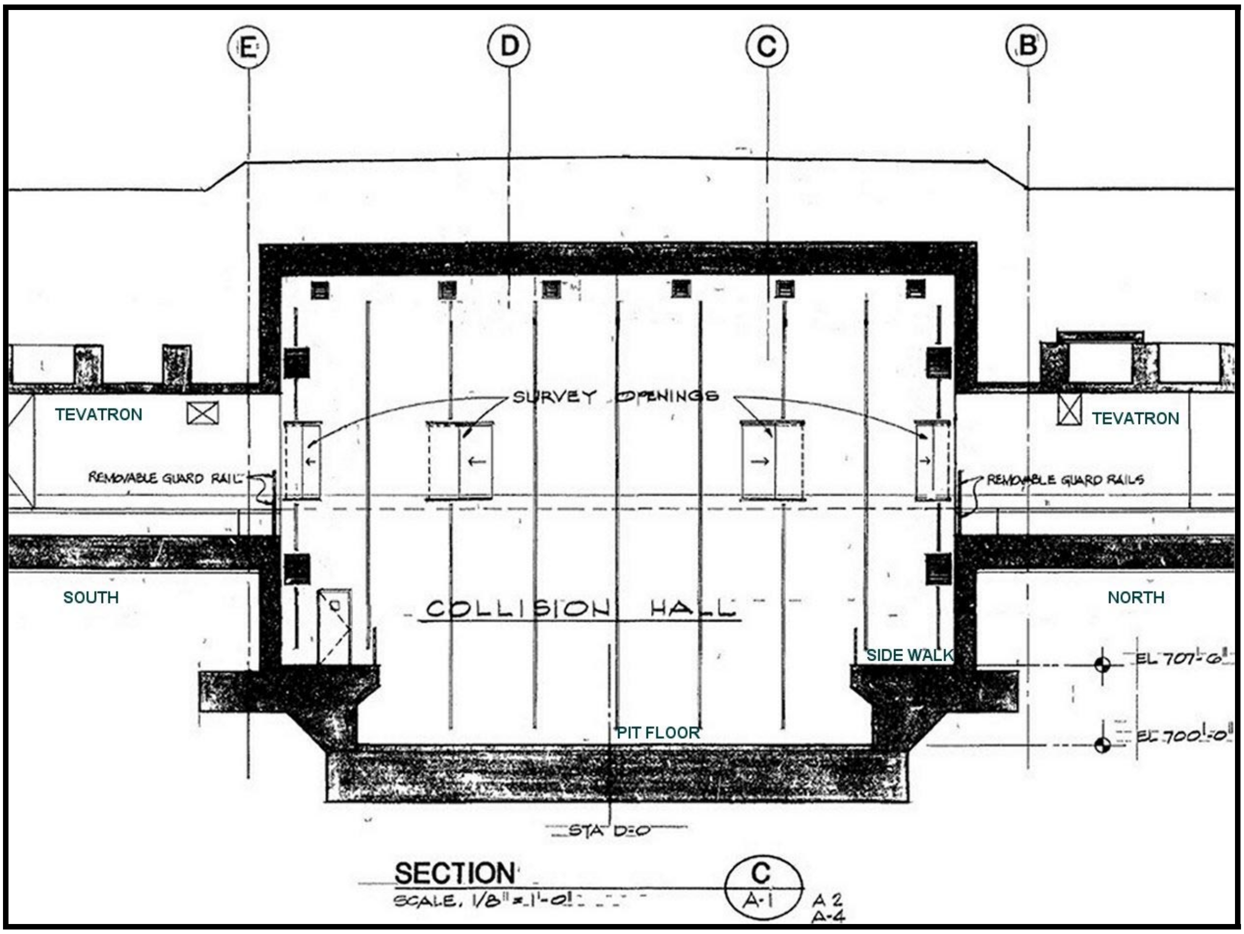


Figure 11. Cross Section of D0 Collision Hall

The north and south end walls of the upper section of the collision hall each contain a 162 in x 162 in. (4.11 m x 4.11 m) hole in the center leading into the Tevatron tunnel. The west wall contains several doors ("survey openings" or "rifle slits") leading into the Tevatron tunnel. All survey ties between the Tevatron and the collision hall are done through this openings (Figure 11).

Figure 12. D0 Detector inside the Collision Hall

Figure 13. Detector inside Collision Hall and the East Shielding Block Wall

4. ALIGNMENT AND SURVEY METHODOLOGY

The SMX Laser Tracker and its associated software 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 proprietary software to calculate, store and display the real-time three-dimensional position of a mirrored target positioned on the desired point or feature. The mirrored target is a spherically mounted retroreflector (SMR). The Laser Tracker is used to establish most of 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 cabling and a theodolite interface module. The computer has software that can display real time three-dimensional coordinates and statistical information. The BETS system is used to connect the entire K+E target and tooling balls used in Run I to the new control survey 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 software. To measure an object, the camera(s) are used to photograph the object from various directions. The digital images are processed immediately by the 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.

Optical (Wild N3) and electronic (Leica NA3000) levels are used for elevations and stick micrometers ("stick-mics") for distances between very close points. Optical Tooling techniques are sometimes used for making measurements from the detector to the control points.

5. SURVEY OF THE D0 DETECTORS

The layered "Russian Doll" design of the D0 detector meant that successive layers of detectors covered the innermost detectors as D0 was constructed, and were not available for survey measurements after D0 was completely assembled. The survey of the D0 detectors was done in three phases. Phase I was the initial survey and referencing of all the internal features of individual detector components. Phase II was the measurement of the relative locations of the detectors as they were assembled on the detector centerbeam. The individual components were surveyed to points fixed to the exteriors of the detectors. The Phase I and Phase II surveys were done in the assembly hall and were completed in the Fall of 2000 [8]. The required accuracy for both phases was specified as better than 0.5 mm for most of the components.

5.1 D0 Global Coordinate System - Assembly Hall

The D0 global coordinate system used in the assembly hall survey 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 beam direction
Z-axis - Positive up and perpendicular to both X- and Y-axes.

5.2 Detector Control Points

Since the Center Beam (CB) was fixed to the detector platform and the Central Calorimeter (CC), several reference markers have been established as control reference points on the CB and CC [8]. Several control points were also on the north EC (ECN) and south EC (ECS), and the CF toroid magnet. Additional control points were added on the trusses between the B- and C-layers outside the CF toroid magnet. More reference markers were added as control points on and around the EF toroid magnets on both sides of the detector. There were several types of reference markers used for control points which include 2 x 2-in (5.08 x 5.08-cm) construction plates, with 0.25-in (6-mm) holes in the center, welded to the magnet. On the CF toroid magnet, a 4-in (10.16-cm) long pedestal with 1.5-in (3.8 cm) diameter and 0.25 in hole in the center was used. A 12-in (30.48 cm) long pedestal was used for the EF toroid magnet. Some of the K+E targets used for Run I were also used as control points.

5.3 Survey of D0 Calorimeter

For Run II, tooling balls on the CC and the survey markers on the legs of the EC were surveyed with the Laser Tracker using the CB Prism mounts as reference. Eight additional plates with 0.250 in (6 mm) holes were mounted the ECN (four inside and four outside). The ECN markers, the beam pipe location, and the 4 four outside plates were surveyed with the Laser Tracker using the CB Prism mounts as reference. The beam pipe location on the inside the EC and the four inside plates were surveyed with V-Stars. Same survey was repeated for the South EC (ECS).

5.4 Survey of D0 Solenoid Magnet

There were twelve 0.250-in (6-mm) holes (six on each North and South) drilled on the surface of the Solenoid magnet as survey markers. These holes were initially referenced to the center of the Solenoid magnet with the Laser Tracker. After the Solenoid was inserted into the center bore of the CC, the survey markers were surveyed using the Tooling balls on the CC as reference. All Solenoid re-surveys were done with V-Stars.

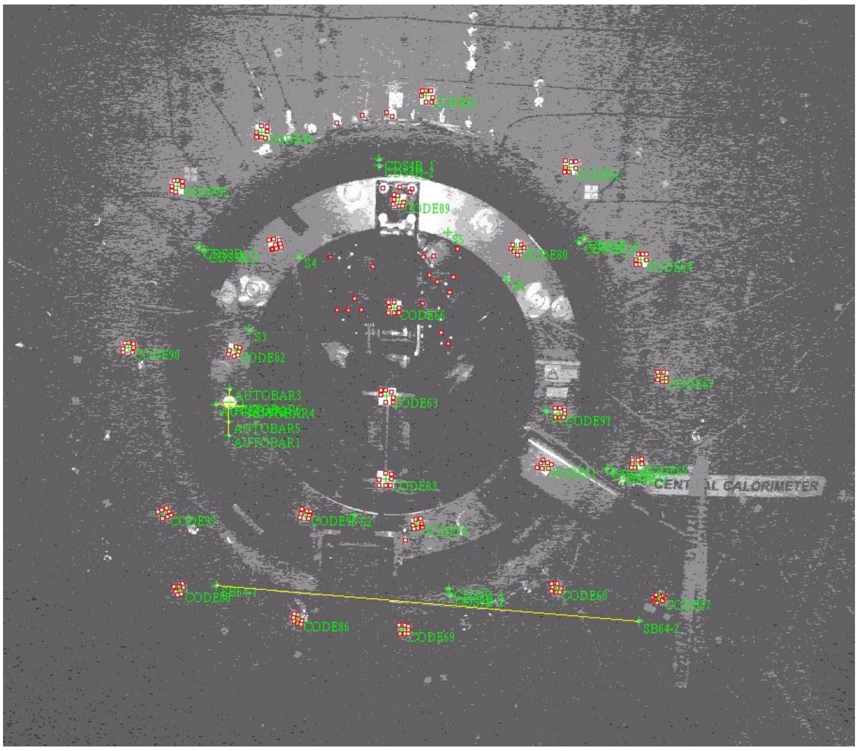


Figure 14. Solenoid and Central Calorimeter Survey

5.5 Survey of Forward Preshower (FPS)

The main hanging frame south FPS was centered around the beam pipe on the surface of the ECS using the Laser Tracker. There are four layers of FPS. Each layer consists of 8 sectors and each sector has four K+E targets that were referenced by CMM. Four 6mm V-Stars adhesive targets were place next to the K+E targets. All 32 targets have been measured to the referenced K+E targets by CMM. Each layer was surveyed with V-Stars using the 4 inside plates on the ECS. After layer #1 was surveyed, layer #2 was mounted on top of layer #1 and the surveyed. Same procedure was used for layers #3 and #4. Same survey is repeated for the North EC (ECN).

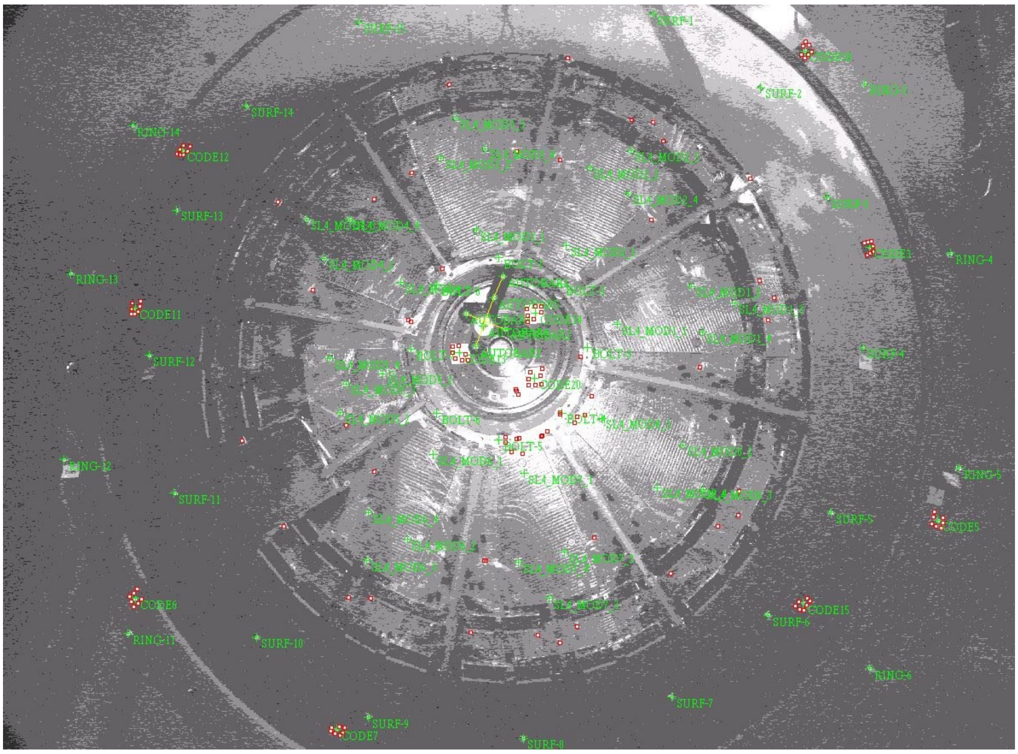


Figure 15. Forward Preshower Layer 4 Survey

5.6 Survey of Central Fiber Tracker (CFT)

Twelve 6-in pedestals (6 on each North and South) with 3 mm V-Stars target were mounted on the surface of the CFT and were initially referenced with V-Stars. The targets were also measured with CMM. After CFT was placed inside the Solenoid, the pedestals were surveyed with V-Stars using the Tooling balls on the CC as reference and the holes on the Solenoid magnet.

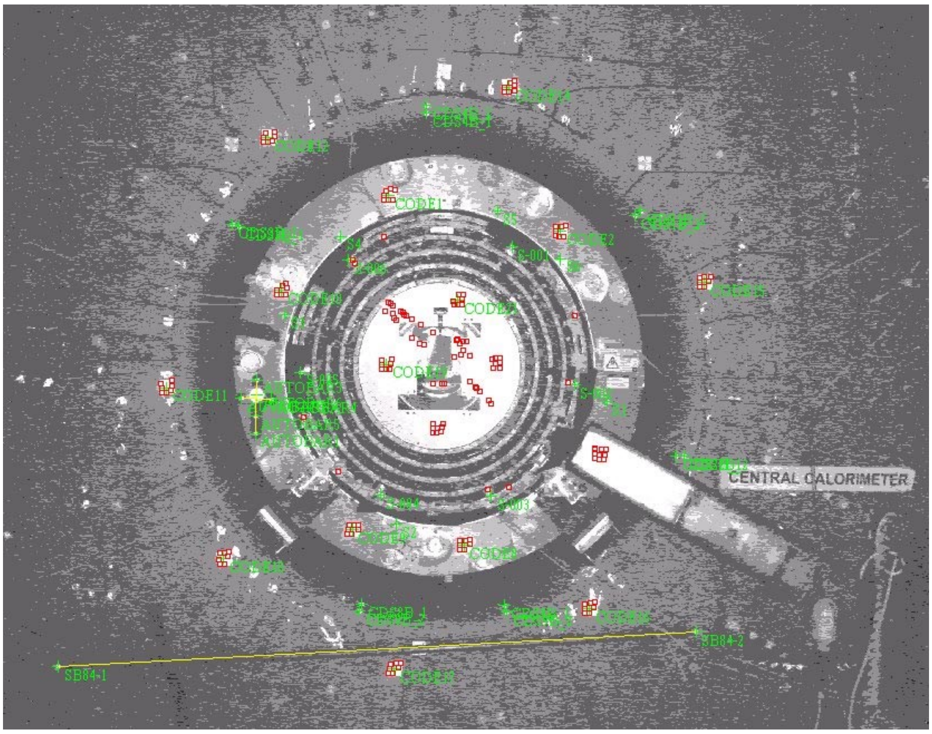


Figure 16. CFT and Solenoid Survey

5.7 Survey of D0 Muon Detector

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

5.7.1 Phase I Survey

The V-STARS system was primarily used for the Phase I survey. The Phase I survey was the referencing of the new 0.250-in (6 mm) diameter bushing holes and Run I tooling balls on the PDT relative to the wire position. Each PDT chamber had two end plates with precise holes, which locate the sense wires. The Laser Tracker was used to measure the relative position of the reference holes and the bushing holes on each of the PDT chambers.

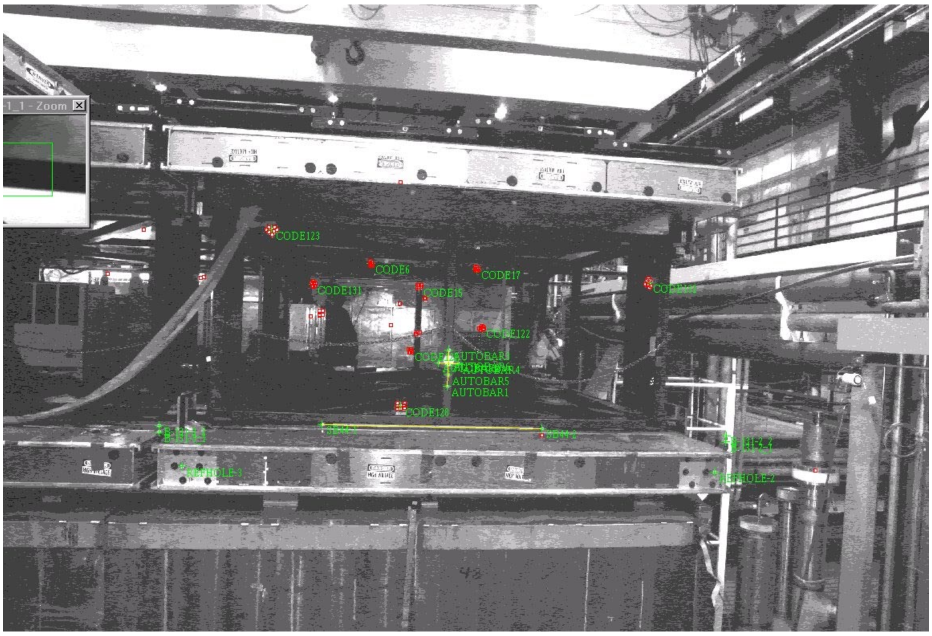


Figure 17. Phase I PDT Survey

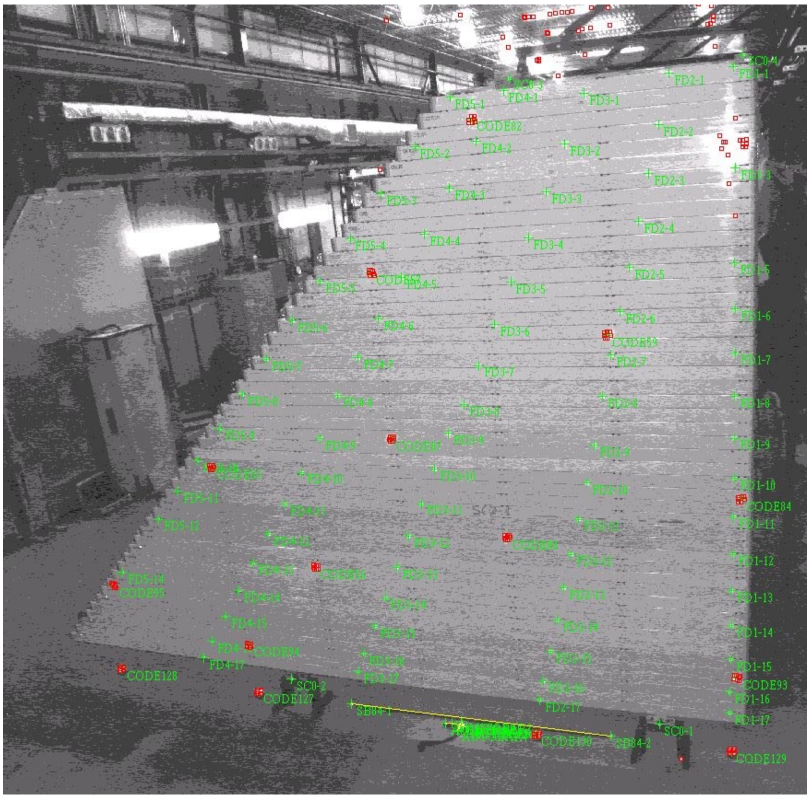


Figure 18. MDT Phase I Survey with V-STARS.

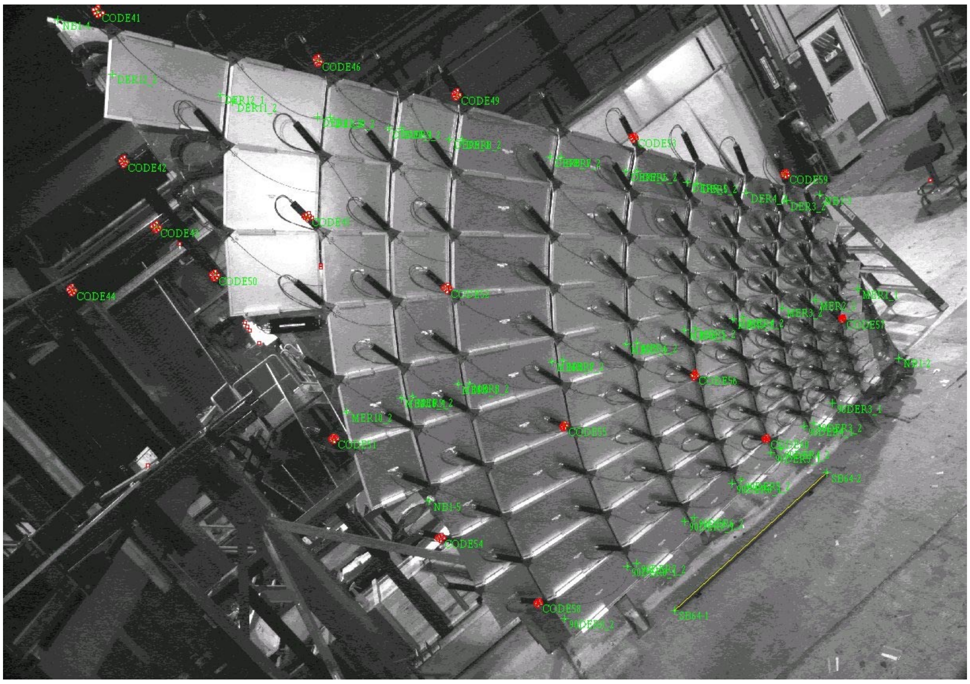


Figure 19. Scintillation Pixel Counter Octant with V-STARS.

There were total of 47 PDT chambers were referenced. There were a total of 48 MDT octants, eight in one octant plane. Each octant had four 0.25 in bushing holes drilled on the front side of the octant. Individual MDTs were mounted on both sides of the octant. The survey was used to check the accuracy of placement for a small sample of the octants to insure that that the drilling system was working properly. There were a total of 48 Pixel Counter octants, six in each Pixel plane. Each octant had four 0.25 in bushing holes drilled on the front side of the octant. Individual Pixel Counters were mounted on the front sides of the octant. A small sample of octants was surveyed to verify the precision of the counter placements. The location of the counter grid with respect to the bushings was later measured.

5.7.2 Phase II Survey

Phase II survey was done using the V-STARS system. The Phase II survey was 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 locations of all the bushing holes and tooling balls were 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.

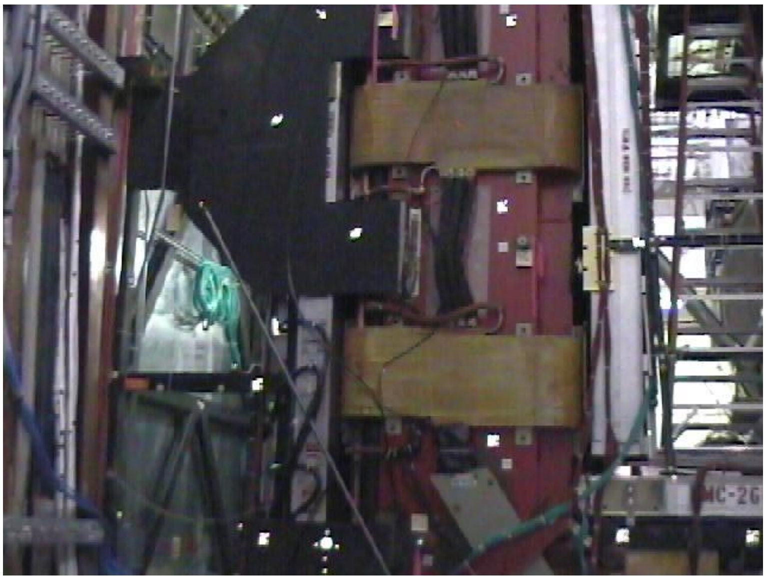


Figure 20. PDT Phase II Survey

The assembled MDT octants were assembled into planes and mounted onto the D0 detector. After the octants had been mounted, the relative position of all octants of one plane were measured relative to each other and the reference control markers on the EF iron and the EMC trusses. The locations of all bushing holes were tied to the previously established control points defined in the D0 global coordinate system.

Figure 21. MDT Phase II Survey

The assembled Pixel Counter octants were assembled into planes and mounted into the D0 detector. After the octants had been mounted, the relative position of all octants of one plane were measured relative to each other. The locations of all bushing holes were tied to the previously established control points.

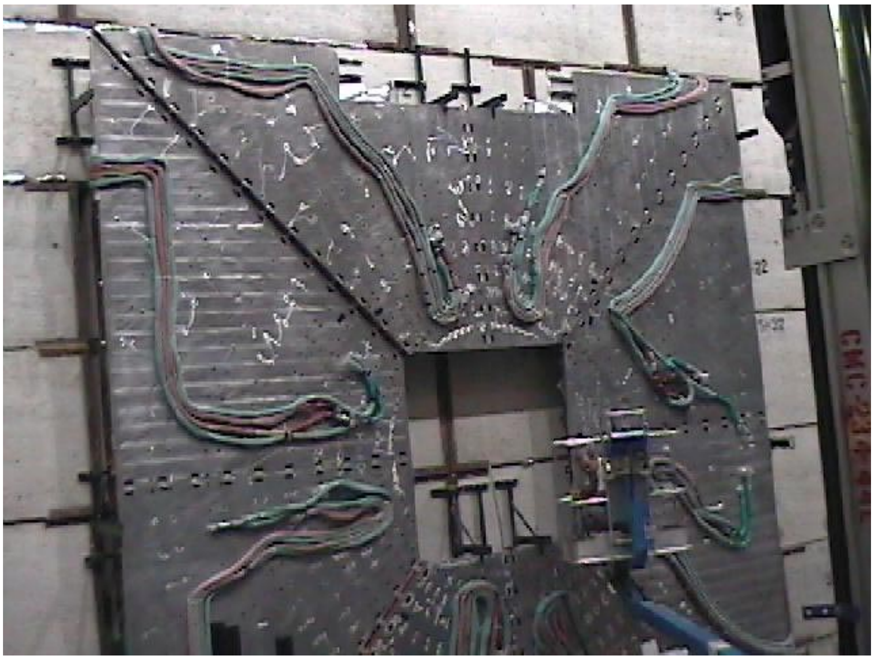


Figure 22. Pixel Phase II Survey

5.7.3 Phase III Survey

The Phase III survey was 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. It was also used to determine the position of each MDT octant in the collision hall. Since the octants were covered up in the collision hall, the survey was done by measuring to the points on the EF toroid and the EMC trusses. The survey was repeated after each toroid magnet opening. This survey was also used to determine the position of each Pixel counter octant in the collision hall. The survey was repeated after each toroid magnet opening and/or pixel counters plane movement to get access to the MDT planes. The Phase III survey was done with the V-STARS system. It was planned to have electronic monitoring of the location of the EF toroids, CF toroid, and EMC trusses so that surveying would not be necessary after the first few surveys [7].

The Phase III survey required that the collision hall be precisely surveyed. The survey of the collision hall is described in the next chapter.

5.7.4 EMC Truss Survey

The EMC (End Muon Chamber) Truss was 40-foot high metal structure that was used to hold the B- and C-layer MDT and the Pixel planes. It consisted of two top and bottom halves. There are fourteen 20-in (50.8 cm)long pedestals (seven on top half, seven on bottom half) mounted on the truss used as survey reference; each pedestal had a 0.25-in hole. The top and bottom sections of the Truss were first surveyed separately before being put together. The whole unit was later surveyed in the collision hall.

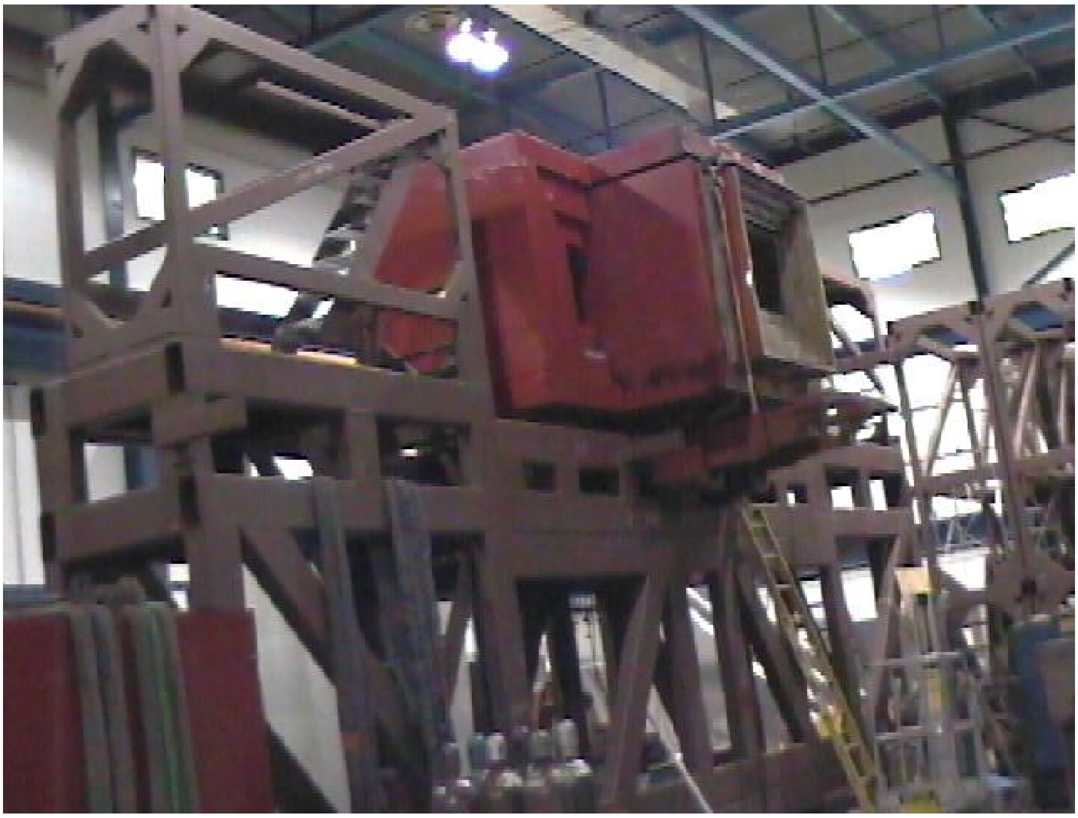


Figure 23. EMC Truss and Shielding Survey

6 SURVEY OF THE D0 COLLISION HALL

The Phase III survey was used to determine the position of the components in the collision hall. In order to do the Phase III survey several points must be established and surveyed in the collision hall. The Phase III survey was the final measurement made in the collision hall and must be repeated with each opening/closing of the D0 detector. The survey method that was used depended on the accessibility and space constraints at the time of survey. The required accuracy for the Phase III survey was specified as better than 0.5 mm.

The purpose of surveying the collision hall was to be able to do the Phase III measurements. This section discusses the survey of the Collision Hall using a combination of the Laser Tracker, BETS, V-Stars, and other Optical systems to within the specified accuracy.

6.1 D0 Global Coordinate System

The Tevatron based D0 global coordinate system used in the collision hall survey is a right-handed Cartesian coordinate system defined as follows:

Origin - Tevatron Beam Centerline as defined by the center of the D0 Low Beta Quads at elevation of 8680.414 in (220.483 m) and the Interaction Point of the detector.

X-axis - EAST axis. Positive to the right and perpendicular to the Y-axis

Y-axis - NORTH axis. Positive along the anti-proton beam direction

Z-axis - Positive up and perpendicular to both X- and Y-axes.

6.2 Collision Hall Control Points

During Run I, the Tevatron system was defined horizontally by a network of 25 brass points in the collision hall sidewalks and pit floor and vertically by elevations of the low beta quads transferred into the hall and tied to several tie-rods [10]. The network was surveyed in the Fall of 1992 using the BETS system. It also included existing tooling balls and tie-rods on the west wall. The brass point is a flat flushed brass surface with a very small punched hole in the middle (Figure 24a). A floor centering plate is used to set over a brass point (Figure 24b); a pin nest and a target fixture sit on the floor plate.

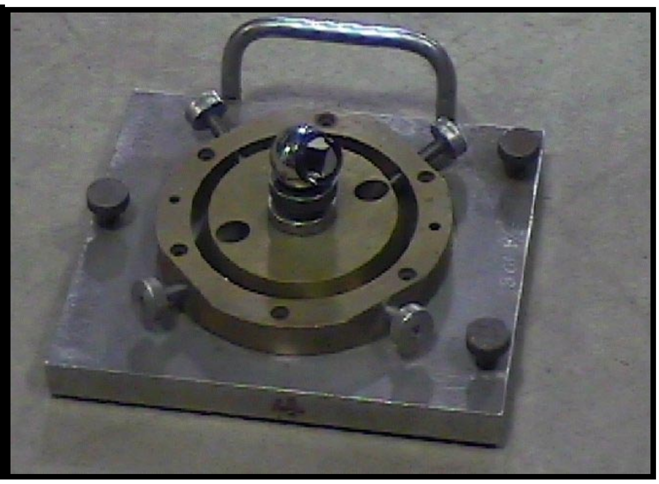


Figure 24a. Brass Control Point. Figure 24b. Centering Plate with Nest and SMR over Brass

For the Run II survey, the Run I 1992 network was densified with 38 new control points in the collision hall sidewalks, the north, south and west walls, and the pit floor (Figures 27 through 32). To avoid using floor-centering plates over brass points, a dead bolt with a 0.250-in (6-mm) hole was used for control point (Figure 25a). The dead bolt is a modified ¾ x 10 in (1.9 x 25.4 cm)

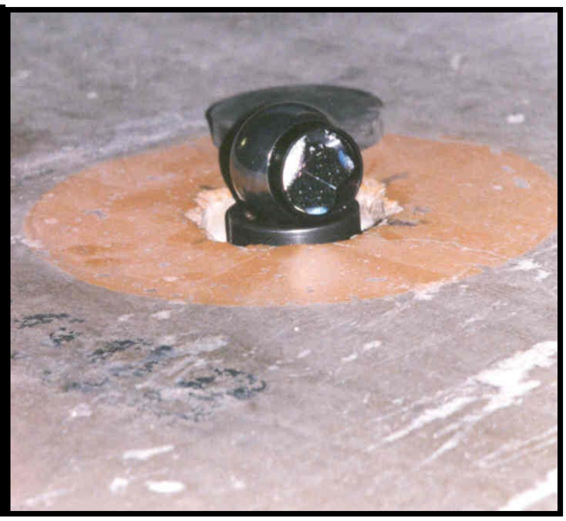


Figure 25a. Exposed Dead Bolt. Figure 25b. Dead Bolt with Nest and SMR

Figure 26a. Nest, Adapter and SMR on Tie Rod.

Figure 26b. Stick-Mic Adapter and Nest on Dead Bolt

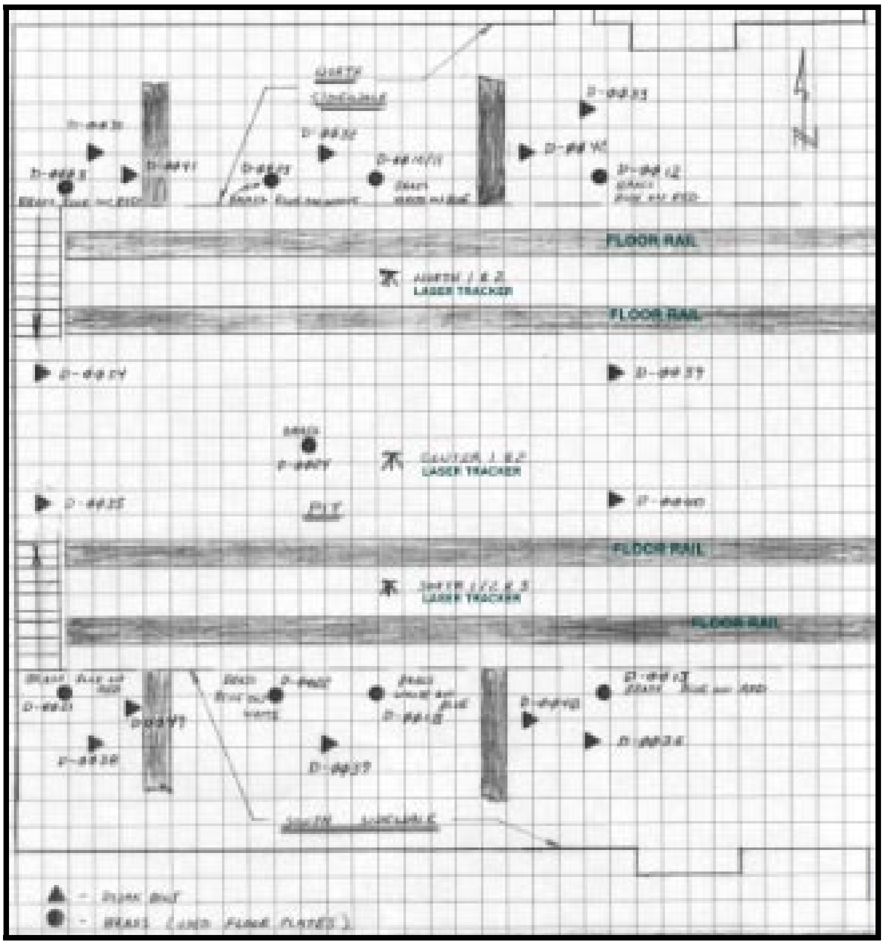


Figure 27. Collision Hall Laser Tracker Network; Plan view

stainless steel hex head bolt, machined to provide a high accuracy, repeatable point of monumentation. It is used as a sub-surface, corrosion resistant, low cost, horizontal and vertical monument that is easily installed. The 0.250-in (6-mm) hole provides a receptacle for Laser Tracker and optical tooling fixtures (Figures 25b and 26b). Figure 26a shows a tie-rod used for elevation monumentation and the fixture used on the tie-rod for measurements.

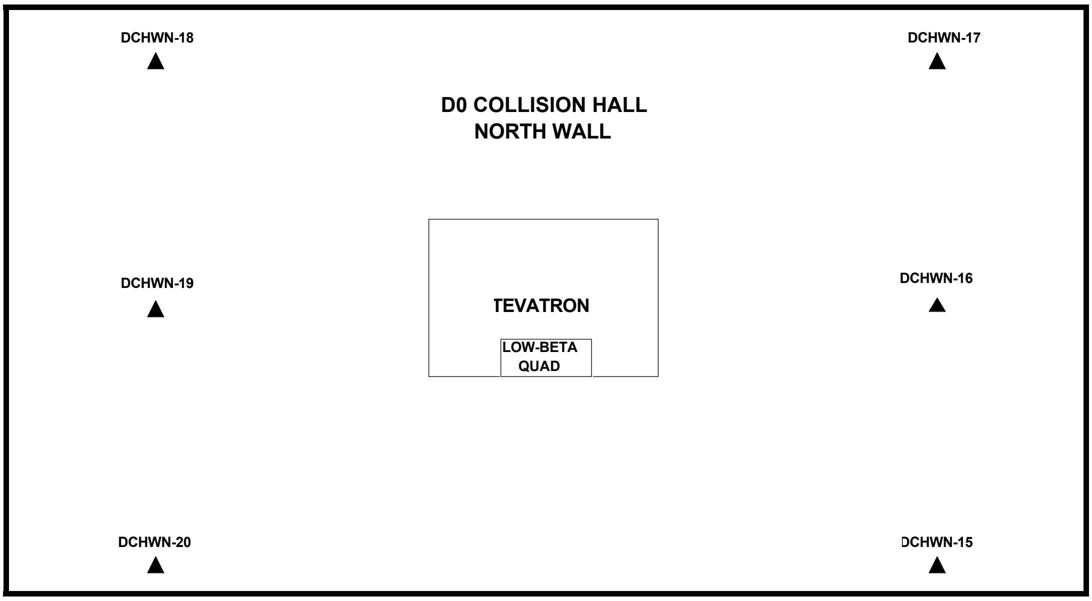


Figure 28. Collision Hall North Wall with Controls

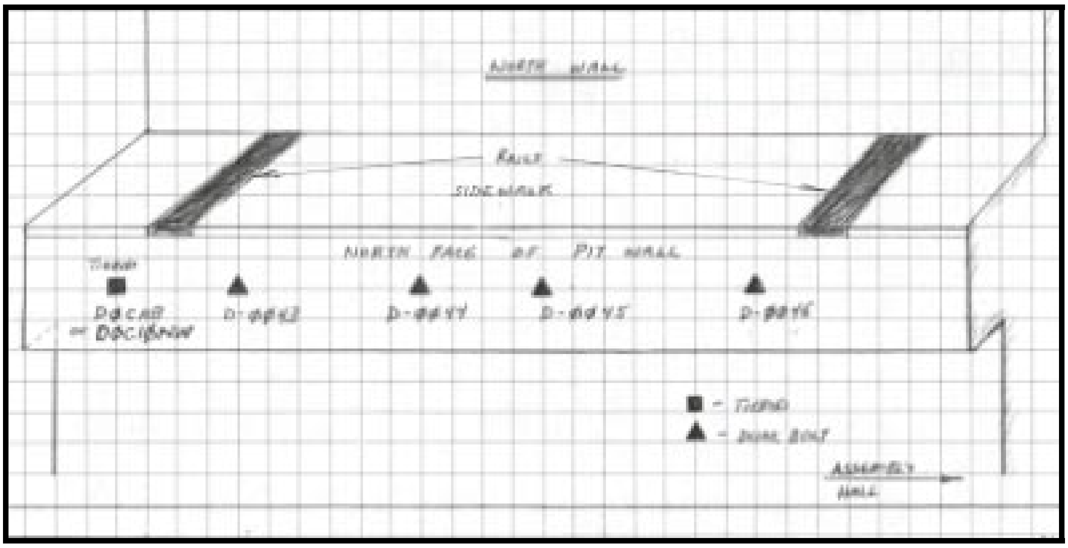


Figure 29. North Face of Pit Wall of Collision Hall with Controls

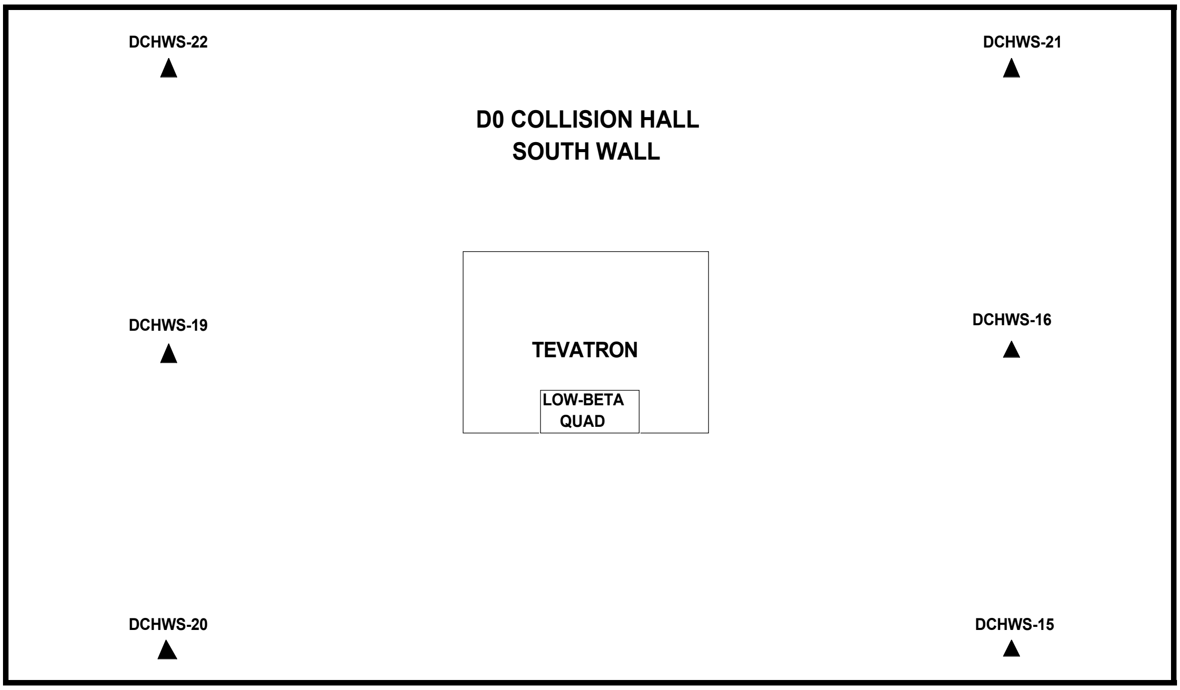


Figure 30. Collision Hall South Wall with Controls

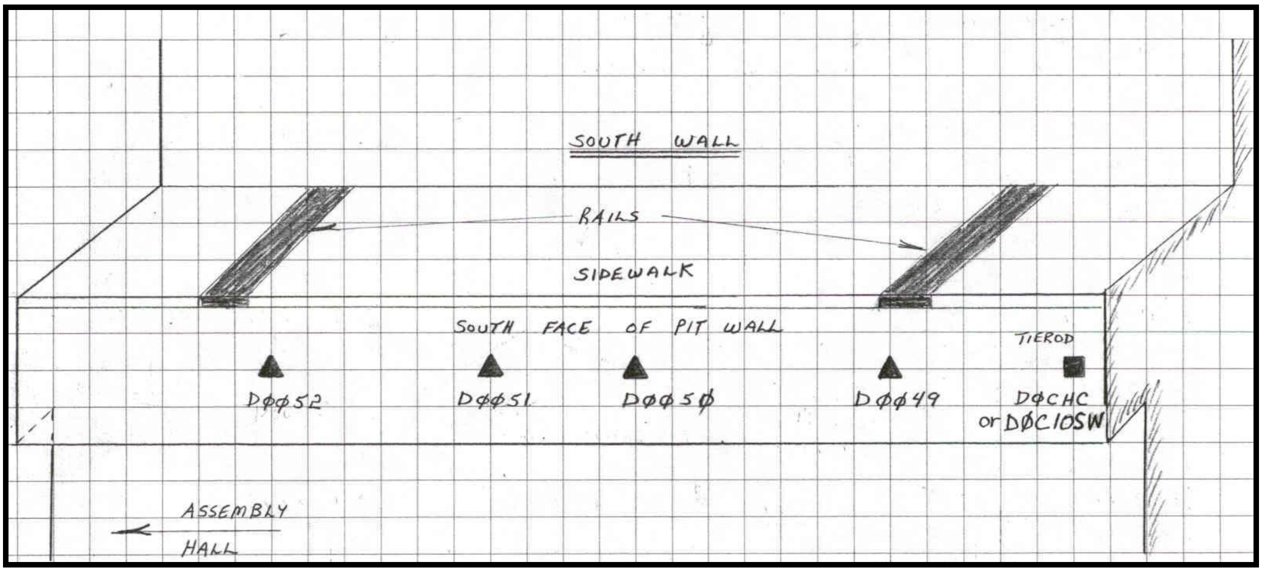


Figure 31. South Face of Pit Wall of Collision Hall with Controls

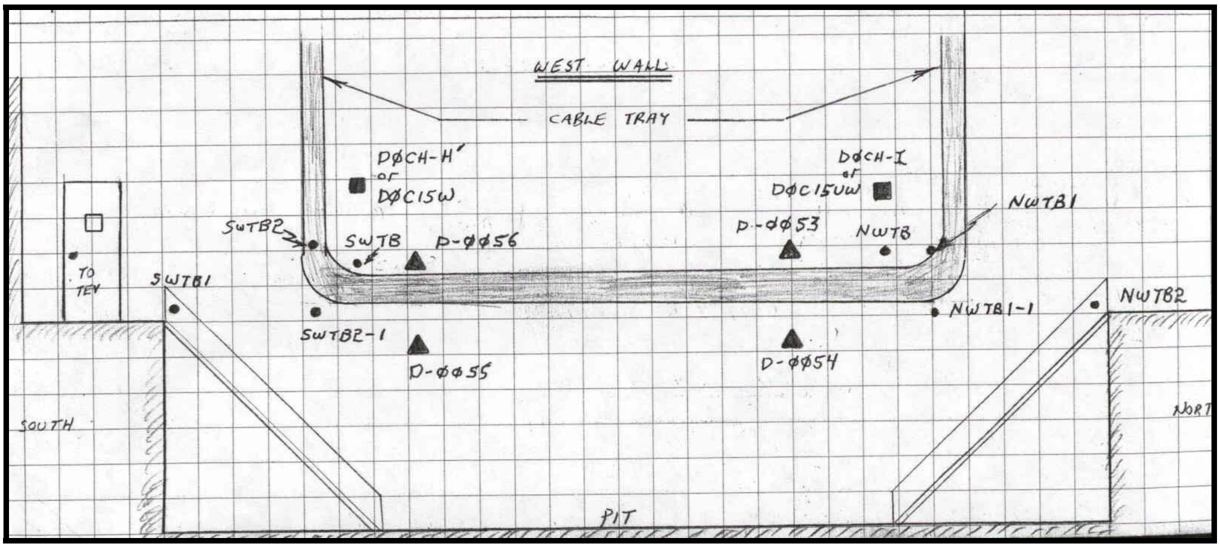


Figure 32. Collision Hall West Wall with Controls

6.3 Survey Measurements

By the end of November 2000 the EMC trusses had been rolled into the collision hall on the north and south sidewalks (Figure 10). As part of the survey of the EMC trusses, the highest points on the north and south walls were installed and surveyed using the V-Stars system. The highest points were targeted using the articulating arm “Blue Genie” lift from the sidewalk. There was no way to get the Genie lifts onto to the collision hall floor because of the east shielding block wall. The V-Stars measurements were recorded in rectangular Cartesian coordinates (X, Y, Z).

By the end of January 2001 more control points had been added, the east shielding block wall had been removed, and the north and south wall control points above the side walk had been covered by the EMC trusses. Using the Blue Genie lift, a Laser Tracker survey was performed. In order to cover the whole area of the collision hall and to have redundant measurements, there were two Tracker setups on the north side of the pit floor, three setups in the center of the hall, and three setups on the south side of the pit floor (Figure 10). All data sets were combined into the North, Center and South data sets. Since the Laser Tracker was not a gravity-based coordinate system, data was collected in the internal Tracker head coordinate measuring system. The Laser Tracker survey included nine Run I 1992 brass control points which were used to transform the Tracker measurements into the D0 global coordinates system.

Laser tracker measurements were recorded in both rectangular Cartesian coordinate (X, Y, Z) and polar coordinate (r, θ, ϕ) systems, where r is the radial interferometric distance, θ is the horizontal (azimuth) angle, and ϕ is the vertical (elevation) angle. The relationship between the two systems is given by [9],

$$X = r \cos\theta \sin\phi$$
$$Y = r \sin\theta \sin\phi$$
$$Z = r \cos\phi$$

The distance between the coordinates of two points is given as:

$$d = [(X_2-X_1)^2 + (Y_2-Y_1)^2 + (Z_2-Z_1)^2]^{1/2}$$

or in polar coordinates as [9]:

$$d = \{r_1^2 + r_2^2 - 2r_1r_2 [\cos\phi_1 \cos\phi_2 + \sin\phi_1 \sin\phi_2 \cos(\theta_2-\theta_1)]\}^{1/2}$$

The à priori standard error for the spatial distances used for weighting in the adjustment is computed by error propagation as follows [9]:

$$\sigma_d = [(\partial d/\partial r_1)^2\sigma^2_{r_1} + (\partial d/\partial r_2)^2\sigma^2_{r2} + (\partial d/\partial \theta_1)^2\sigma^2_{\theta 1} + (\partial d/\partial \theta_2)^2\sigma^2_{\theta_2} + (\partial d/\partial \phi_1)^2\sigma^2_{\phi 1} + (\partial d/\partial \phi_2)^2\sigma^2_{\phi 2}]^{1/2}$$

where the à priori standard error for radial distance $\sigma_{r1} = \sigma_{r2} = 35$ microns, the à priori standard error for horizontal angle $\sigma_{\theta 1} = \sigma_{\theta 2} = 1$ arcsecond, and the à priori standard error for vertical angle $\sigma_{\phi 1} = \sigma_{\phi 2} = 1$ arcsecond.

Spatial distances computed from the measured (X,Y,Z) coordinates at each Tracker station were used in a trilateration network adjustment. The final data analysis was completed by numerical optimization which transforms the measured (Laser Tracker, V-Stars) coordinate system into the D0 global coordinate system. To rotate the measured coordinate system to the D0 global coordinate system, a seven-parameter transformation was performed using the following expression:

$$\underline{\mathbf{X}}_G = \underline{\mathbf{X}}_{Trans} + S * \mathbf{R}(\varepsilon_X,\varepsilon_Y,\varepsilon_H) * \underline{\mathbf{X}}_M$$

where $\underline{\mathbf{X}}_G$ is the vector containing the (XYZ) coordinates in the D0 global coordinate system; $\underline{\mathbf{X}}_M$ is the vector containing the measured (XYZ) coordinates; $\underline{\mathbf{X}}_{Trans}$ is the vector containing the translation parameters in XYZ; $\mathbf{R}(\varepsilon_X,\varepsilon_Y,\varepsilon_H)$ is the rotation matrix; and S is the scale. For this survey the scale is fixed at S = 1.000000. The optimum rotation matrix R and transformation vector X is obtained by minimizing a chi-square formed between selected measured points in both data sets.

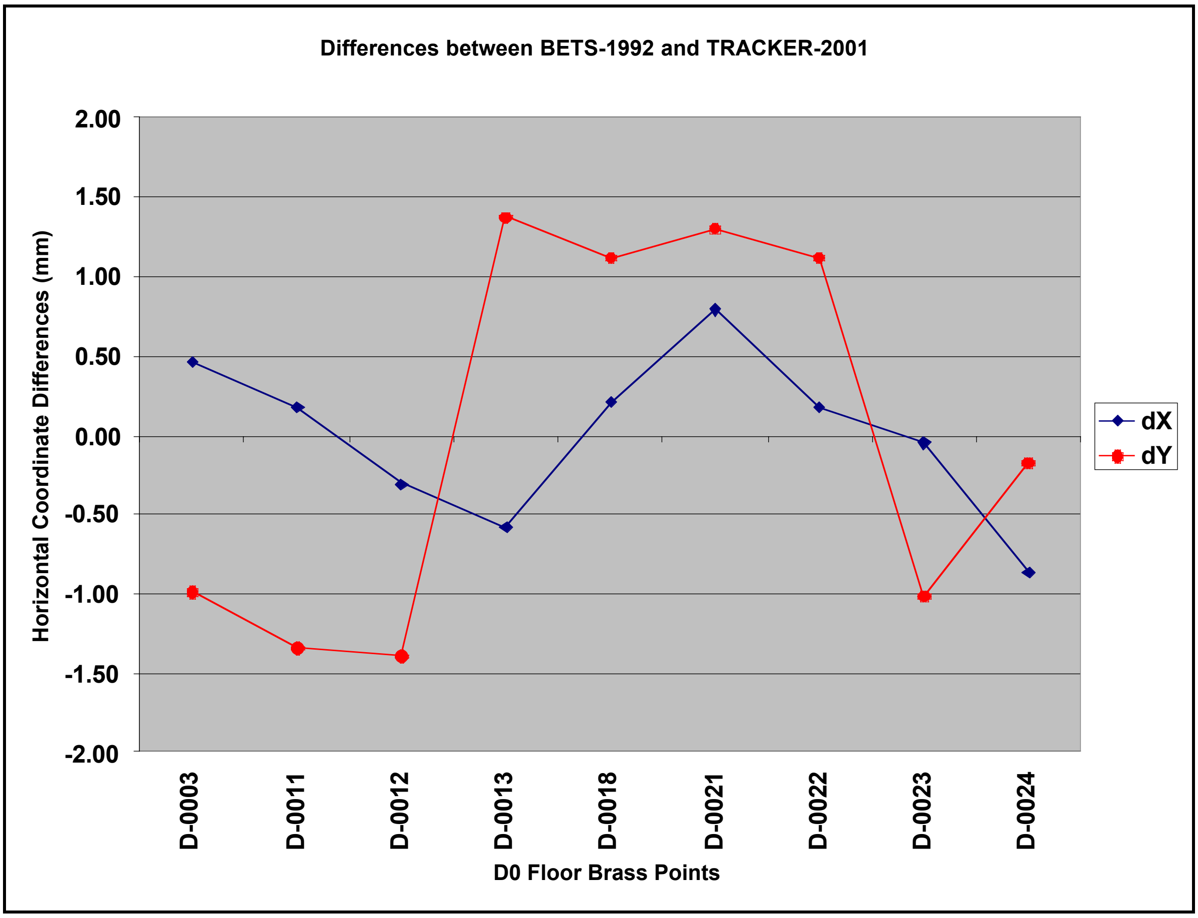


Figure 33. Differences between BETS-1992 and TRACKER-2001

In the transformations for this survey, the gravity based elevations of the tie-rods and new control points were constrained to their measured values. Figure 33 shows the differences between the Run I BETS-1992 survey and the Tracker-2001 survey, which range from -0.86 mm to +0.78 mm (–0.034 to 0.031 in) in X and -1.40 mm to 1.37 mm (-0.055 to 0.054 in) in Y. The differences show that there is a systematic shift between the BETS-1992 survey and the Tracker-2001 survey. A lot of activities had taken place in the collision hall since the Run I experiment, including the removal and replacement of the 3000 ton shielding wall, and the 5500 ton detector.

6.4 Elevation Measurements

An elevation run was performed starting from station C-49 in the Tevatron tunnel on the north side of the collision hall and elevation was transferred to tie rod D0C15UW on the west wall through the survey opening (Figures 10 and 32). Another elevation run started from station D-11 in the Tevatron tunnel on the south side of the collision hall and elevation was transferred to tie

rod D0C15W on the west wall (Figure 32). Finally an elevation run was carried out to two other tie-rods and eight floor control points. The elevations of the four tie-rods and the eight control points were held fixed in the network adjustment. After roll-in, other elevation runs were performed toward the end of February and May 2001.

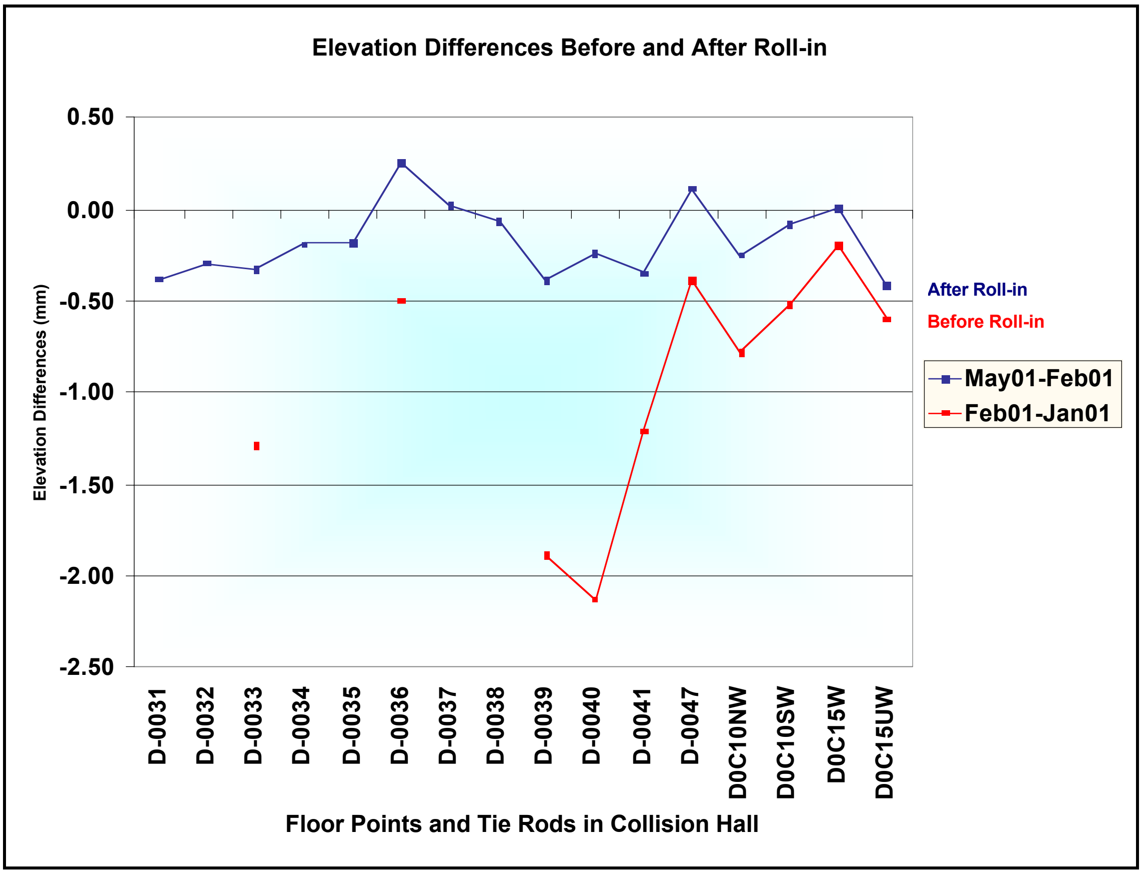


Figure 34. Elevation Differences Before and After Roll-in

The elevations from the elevation run of January 24, 2001 were those used in the network adjustment and transformations. The measured elevations take precedence over any other computed or derived elevations. Figure 34 shows the elevation differences of all the tie-rods, floor and sidewalk points measured before and after roll-in. The results show that the collision hall sank after the D0 detector was rolled into the hall. The largest deformation was at the east end of the hall close to the shielding block wall.

7. MEASUREMENTS AFTER ROLL-IN

New tie-rods were installed on the east wall for elevation ties, after the detector was rolled into the collision hall and the shield block wall was rebuilt on the east side of the hall. The centerbeam was surveyed relative to the new control points and tie-rods, and the elevation of the tie-rods measured relative to the low beta quads. Due to the large weight of the detector continuous elevation runs must be performed for monitoring elevation deformation. Since time and space were very limited in the collision hall to survey these new positions of the components, distance measurements with stick-mics, and the V-Stars system were used to make the measurements for the horizontal coordinates.

After the D0 detector was closed for the start of Run II, the magnet-on east-west position of the CFs was measured for the new centerbeam position by measuring stick-mic distances to the new control points and tooling balls on the west wall. The V-Stars system was used to measure new centerbeam position using the new control points on the north and south pit walls. Stick-mic distances were also measured between points on the EMC trusses and the north and south walls of the collision hall. These measurements would be repeated continuously at any opportune time during the shutdown periods (short periods of interrupted Tevatron operation).

8. CONCLUSIONS

The D0 detector had been upgraded for the Tevatron Run II. The detector was assembled and surveyed in the Assembly Hall and was rolled into the Collision Hall in January 2001. The Phase I and Phase II surveys were done in the assembly hall and were completed in the Fall of 2000. Prior to moving the detector to the Collision Hall, the existing survey monuments were densified with new monuments. These monuments were surveyed and tied to the Run I 1992 brass coordinates in the Tevatron D0 global coordinate system. The initial phase III survey of the detector, which was the survey of the detector relative to the collision hall, was also completed. The Phase III survey would be repeated as required during the upcoming shutdowns. The upgrade of the D0 detector was fully commissioned on March 1, 2001, and thus marked the official start of the Run II experiment.

9. ACKNOWLEDGMENT

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