DØ Note XXXX

Alignment Strategy for the SMT Barrel Detectors

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Abstract

When DØ begins run II data taking, one of the first tasks will be to determine the positions of all detectors starting from initial positions derived from survey. The alignment process uses data taken with the detector in place to refine (or, minimally, to corroborate) the survey information. The alignment process is necessarily iterative. The limited statistical power of an initial data sample limits the number of free parameters that can be considered. As more data is taken, the original constants can be refined and additional types of misalignment can be looked for.

This note describes a strategy for determining the alignment of the silicon tracker(SMT) barrels. There are six sections. The first section outlines the basic strategy. The second section has coordinate definitions, and the third contains the initial and target alignment precision. The fourth section gives formulas for internal and external residuals. Additional constraints are also discussed. The fifth section discusses data samples and effects of the magnetic field. The final section has an estimate of the running time needed to perform the first–pass alignment.

This note is primarily a guide. One strategy is described and trigger and data samples considered. The final numbers for the time taken to accumulate enough data to get a given precision are intended as approximations. In practice, there are a number of effects which could change the details of these numbers. The effects include at a minium a worse collider environment than expected, worse initial survey precision and systemtic effects from the simplicity of the simulations used to determine rates. The time estimates may be improved before data taking as better simulations become available.

1 Introduction

The alignment will proceed in a series of phases driven by the data sample size and current alignment precisions. A rough description of the phases is given in this section.

The first modest event sample will be used to establish the relative positions of the SMT and rest of DØ.[1] For this phase, the entire SMT can be treated as a rigid body. The purpose of this step is to enable reasonably efficient track finding and reliable track–to–hit assignments. Given the expected assembly tolerance[2] this should be only a cross check. If a large enough data sample is obtained quickly, the relative average barrel–to–barrel positions and orientations may also be determined.

The next phase will use a minimum of external information[3], and the goal is to refine the positions of the ladders in a given barrel relative to each other. There will be several passes to this phase, each time looking at an additional aligment degree of freedom. The initial pass will consider only the dominant degree of freedom. For the ladders these are the offsets in the measurement direction, δx for the axial layers and δz for the 90^o stereo layers. Once this has been fixed, the next dominant term in the residual will be considered. The results in section 4 give the sensitivity of the residual to different types of motion. These, along with the initial survey, will be used to choose the order in which the remaining alignment parameters will be determined.

In performing an internal alignment, a set of hits must be identified as belonging to a single track. One typically selects this track–to–hit association based on (external) track–fit χ^2 criteria. However, if the detector positions are poorly known, then the χ^2 will be biased and may not represent the quality of the hit assignment. Because of this, in the initial alignment, it is useful to select "tracks" with isolated hits. This implies that the hit association is relatively simple and need not depend on a χ^2. As the alignment precision improves, a shift toward hit–to–track assignment based on track fit χ^2 will occur. The rate of "isolated" tracks is thus especially important in initial running, and it is discussed in section 5 below.

At this point, a reasonably accurate, precise alignment will exist. Further refinements will be made, for example, to look for more subtle effects or to monitor time dependence. These will be iterative, and must use both internal and external alignment procedures. As always, the key to having a systematic–free alignment will be frequent comparision of results from both internal and external alignments. After (or during) the internal alignment, the results must be compared with a control sample containing both low– and high–p_T particles.

2 Coordinate Systems

For the alignment we assume that ladders are perfect planes, and that the individual detectors forming the ladder are perfectly aligned[4]. For the alignment, the local coordinate system shown in figure 1 will be used. The relation between the local coordinate system for each ladder and global DØ coordinates for a perfectly assembled detector can be found elsewhere[1]. This has been included in GEANT[2] and in the geometry used in event reconstruction[3].

[1] We adopt the terminology that an alignment process which depends heavily on other portions of DØ is an "external aligment", and that a process which uses primarily SMT information is an "internal alignment".

[2] See section 3 below.

[3] We may choose to use only κ and hit–to–track associations determined from the CFT.

[4] Either of these assumptions can be relaxed as the alignment proceeds. Out–of–the–plane distortions can be accomodated with no change to SMT code. Introduction of misalignment of the individual detectors on

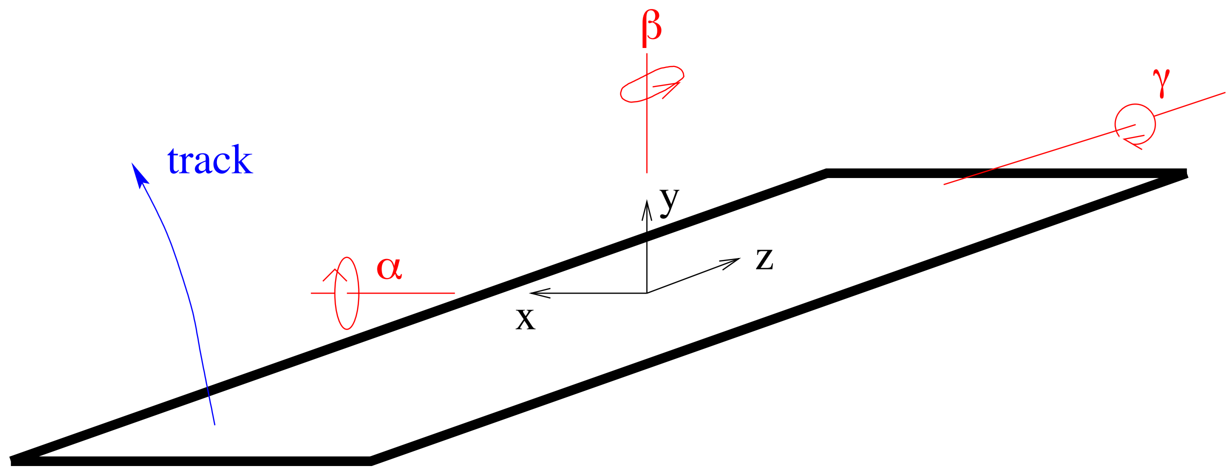

Figure 1: Local coordinates describing ladder positions. Deviations from the nominal position at $x = 0$, $y = 0$, and $z = 0$ are denoted δx, δy and δz respectively. For the ideal geometry $\delta x = \delta y = \delta z = \alpha = \beta = \gamma \equiv 0.0$. The angle ϕ is the angle a track makes with the normal to the ladder in the xy plane, and the angle θ is the angle a track makes with the normal to the ladder in the yz plane. The sign conventions for ϕ and θ follow those of γ and α respectively.

3 Required Alignment Precision

The target alignment precision is derived from the condition that alignment errors have a negligible effect on track parameters. This eliminates the need to have alignment uncertainty included in the overall hit position resolution, thereby removing the difficult problem of errors correlated between tracks which intersect the same set of ladders. The intrinsic hit resolution is expected to be approximately 10 μm in $r\phi$ and 30(350) μm in rz for $90^o(2^o)$ stereo. The required ladder alignment precision can be determined using the residual formulas in section 4.1. We require that the error on hit positions increase by no more than 10% when all alignment uncertainties are included. Since there are six alignment parameters, this implies that each parameter contribute no more than $10\%/\sqrt{6}$. For cases in which the residual is proportional to a ladder coordinate, we assume the average of the absolute value of the coordinate. The resulting precision for each of the six alignment coordinates defined in figure 1 is:

- δx to better than 1 μm
- δy to better than 6(25) μm for an inner(outer) layer ladder
- δz to better than 4(130) μm
- α to better than 0.2 mrad
- β to better than 0.04 mrad

a ladder will require modest changes to the geometry code.

Ladder Coordinate	*expected Precision*	
	Assembly	Survey
δx	5 μm	5 μm
δy		
δz	5 μm	5 μm
α	40 μrad	40 μrad
β	40 μrad	40 μrad
γ		
Strip Pitch		
Barrel–to–barrel		
δZ	50 μm	50 μm
δY	50 μm	50 μm
δZ		
Φ_B		
τ_B	0.4 mrad	0.4 mrad
$\Phi_{B\tau}$		

Table 1: Assembly tolerances and initial survey precision. The angular tolerances were computed using the end–to–end position offsets and the lengths to define an angular tolerance. The coordinates for the ladder–to–ladder section are defined in Figure 1. The coordinates for the barrel–to–barrel section are global DØ coordinates.

- γ to better than 0.8 mrad

These are tighter than is necessary to retain precision on (*e.g.*) the impact parameter because the track parameters average over a set of ladders. A back–of-the-envelope estimate implies that each of the contraints could be relaxed by a factor of two while maintaining 10% precision in impact parameter. This assumes, however, that the ladder–to–ladder alignment uncertainty is purely statistical with no coherent systematic effects.

The SMT ladders and barrel assemblies will be surveyed prior to installation in DØ. Table 1 gives the expected absolute assembly tolerance, and the precision on the measurements from the assembly survey[4].

4 Residual Formulas

The assembly and initial survey precisions in table 1, imply that the alignment corrections will be small. Given this, residual formulas were derived using small angle approximations of the full transformations[5]. Residuals are defined as the difference between the reconstructed hit position $\vec{x}_{hit}$ and the position at which the interpolation of a track intersects the ladder, $\vec{x}_{track}$. We choose to compute the residual in local detector coordinates to simplify the relation between the residuals and alignment parameters. A fully general formulation of multi–dimensional residuals is found elsewhere[6].

As previously mentioned, tracks used in alignment should be determined in a manner to avoid [5] from other detectors. As an extreme case, only SMT information could be used, but at a practical minimum, CFT information can be used to assign hits to tracks in complicated environments. Given the eight layer geometry with significant overlap, it may be possible to avoid any use of the CFT except for hit assignment.

4.1 Individual Ladders

The hit-track residual Δx in the direction perpendicular to the axial strips is given by

$$\Delta x \equiv x_{track} - x_{hit} = \delta x + z \sin\beta + \tan\phi(\delta y + z\sin\alpha + x\sin\gamma) - f(\vec{B}, \phi) \qquad (1)$$

and for the direction parallel to the axial strips (in double–sided ladders)

$$\Delta z \equiv z_{track} - z_{hit} = \delta z + x \sin\beta + \tan\theta(\delta y + z\sin\alpha + x\sin\gamma) \qquad (2)$$

Here the angle ϕ is the angle a track makes with the ladder in the $r\phi$ plane, and the angle θ is the angle a track makes with the ladder in the rz plane. The function $f(\vec{B}, \phi)$ represents systematic uncertainty in the Lorentz drift correction, and it is odd under reversal of the magnetic field $\vec{B}$. Misalignment is a second order effect in $f(\vec{B})$.

The simplest approach to determining the alignment parameters is to use the means of the following histograms(for the Δx case):

1. the distribution of residuals integrated over y, z, and ϕ, which gives δx directly,
2. the residual vs. z which gives $\sin\beta$,
3. the residual vs. $\tan\phi$ which gives δy,
4. the residual/$\tan\phi$ vs. x which gives $\sin\gamma$,
5. and the residual/$\tan\phi$ vs. z which gives $\sin\alpha$.

This method, based on the mean of the individual distributions, treats all tracks with equal weight. It should be used if the track errors are systematically biased. It is not understood at what level it matters whether the track parameters used in the residual are computed with or without the using the particular hit appearing in the residual. This is an iterative process, repeated until (*e.g.*) the alignment parameters do not change significantly when an additional pass is made.

When track errors are meaningful and the alignment is known reasonably well, a more comprehensive method is to minimize $\chi^2 = \Sigma_{hits}(\Delta x/\sigma_{\Delta x})^2$ as a function of the alignment parameters. Here $\sigma_{\Delta x}$ is the residual error containing terms from silicon hit resolution and track parameter error matrix. In practice, statistics and convergence criteria may imply that not all parameters are allowed to vary simultaneously. Also, the approach in the preceeding paragraph is simply the χ^2 approach in the limit of identical track errors and a sequential minimization for one parameter at a time. A similar expression is used for the Δz calculation.

[5] Random effects which increase the residual width but do not introduce bias are acceptable. The resulting wider residual distributions imply, of course, that more data will be needed to achieve the target alignment precision.

4.2 Internal Coherent Effects and Further Constraints

In addition to locating the ladder absolution positions using the formulas of section 4.1, it is useful to consider additional means of establishing ladder–to-ladder relative positions using geometrical constraints. The large geometrical ϕ overlap of ladders in adjacent layers automatically introduces ϕ coupling between ladders within a layer. The methods described in this section serve two purposes: (1) tests of systematics arising from the ladder–to–ladder alignment and (2) methods to enhance precision by combining information. It also important to consider whether constraints on the coherent effects give higher intrisic statistical power than individual ladder–by–ladder constraints.

The topologies of particular interest are:

- ϕ correlations using a vertex constraint, and
- effective radius of a barrel layer, to improve the δy precision

4.2.1 ϕ Correlations and Vertex Constraints

The internal alignment described above depends primarily on correlations between ladders at similar ϕ and different radii. The ϕ overlap of "adjacent" ladders in a "layer" introduces a weak coupling between the alignment constants for these ladder and can thus establish the relative position of ladders at very different ϕ positions. An alternate more direct measure can be obtained by introducing a vertex constraint between tracks and computing residuals for tracks fit with this constraint.

If one fits tracks to sets of n_i hits to determine the track parameters (b, κ, ϕ_0) and the position (r_v, ϕ_v) of a vertex common to the tracks, the residuals contain information about the relative postions of the ladders. The vertex constraint implies that the impact parameter b' can be written as a function of the two remaining track parameters and the vertex position.

Given a set of N tracks from a common vertex and denoting the initial 2D track parameters $\{b, \kappa, \phi_0\}_i,\ i = 1, N$, the χ^2 refit of the track under a vertex constraint can be written as

$$\chi^2 = \Sigma_{hits} \frac{r_j^2}{\sigma_j^2} + \Sigma_{tracks} \vec{v} C \vec{v} \qquad (3)$$

in which r_j is the residual of the j-th hit to its track, $\vec{v} = (b'(\vec{x}_v, \kappa', \phi_0') - b, \kappa' - \kappa, \phi_0' - \phi_0)$ is a vector of the differences between the original(unprimed) and refit(primed) track parameters and C is the covariance matrix from the original track fit. The function $b'(\vec{x}_v, \kappa', \phi_0')$ is given by a solution to the quadratic form

$$0 = (b')^2 + [\frac{1}{\kappa'} + 2r_v \sin(\phi_v - \phi_0')](b') + r_v[r_v - \frac{\sin(\phi_v - \phi_0')}{\kappa'}] \qquad (4)$$

4.2.2 Effective Radius Constraint

An average "radius" of a layer can be determined by assuming the n ladders in a given layer form a regular n–sided polygon. Let δs_i be the difference in local coordinates between hits on two tracks near opposite edges of the same ladder. Further select events such that the hit at smaller ϕ on ladder $i + 1$ is on the same track as the higher ϕ hit on ladder i. If the ladders truly formed an n–sided regular polygon, the radius r of the largest circle which can be inscribed in the polygon is related to the δs values[6] by

$$2nr\tan\frac{\pi}{n} = \Sigma_{i=1}^{n}\delta s_i. \tag{5}$$

Let the radius be defined as $r \equiv r_0 + \delta y$ with r_0 the nominal radius and δy the ladder alignment parameter. This is rewritten to give δy as

$$\delta y = \frac{\Sigma_{i=1}^{n}\delta s_i}{2n\tan(\pi/n)} - r_0. \tag{6}$$

The resulting precision is

$$\sigma_{\delta y} = \frac{\sqrt{2}\sigma_{SMT}}{2n\tan(\pi/n)} \tag{7}$$

Using the nominal ladder geometry, this gives a precision of

$$\sigma_{\delta y} \approx 50/\sqrt{N}\mu\mathrm{m}. \tag{8}$$

with N the number of tracks traversing a pair of adjacent ladders.

The regular polygon assumption has only a second order dependence on β. This is negligible for all tracks if $\beta < 25$ mrad, or about 0.85 mm difference in radius side–to–side. The effect of the track curving in the gap between layers (or having non-zero impact parameter) giving wrong effective δs will average to zero as long as the geometrical acceptance is unbiased with respect to particle charge and impact parameter.[7]

This should be compared to the precision on δy obtained from the individual ladder method of section 4.1. For that method, the strongest constraint comes from large ϕ_l tracks. For tracks with $p_T > 5$ GeV crossing an innermost(outermost) ladder at a distance halfway to the edge of the ladder, $\phi_l < 0.18(0.05)$ rad. For this case, $\delta y = \Delta x/\tan\phi_l$. If the mean of the residual is measured to 5 μm and all other effects are negligible, the effective radius is known to 27(100) μm for a ladder in the innermost(outermost) layer.

In choosing which of the two methods to use, there is a trade–off between intrinsic precision and frequency of a specific topology. Both methods will be used, with the more precise result determining the radial alignment constant, and the second method providing a cross–check.

4.3 Barrel–to–Barrel and External Alignment

The previous residual formulas related to the internal alignment of a silicon detector barrel. An alignment to position SMT barrels with respect to each other or to position the SMT with respect to the rest of DØ will also have to be performed. This section gives the residual

[6]For our geometry, with two sublayers in a single layer, the δs values for ladders in the "outer" radius sublayer must be scaled by the ratio of the nominal radius of the "inner" sublayer to the nominal radius of the outer sublayer.

[7]These can be neglected without resorting to an average by choosing tracks having $p_T > 10$ GeV coming from the primary vertex.

formulas for positioning the a detector as a rigid body with respect to an external coordinate system corresponding to either a different barrel(barrel–to–barrel) or to the global DØ coordinates(external). Coordinates in capital letters denote an external coordinate system with X, Y, Z cartisian coordinates with Z corresponding to the proton beam direction and X corresponding to a horizontal direction perpendicular to Z and away from the center of the Tevatron. Y is then defined to complete a right–handed system. The tracks used here should not have used the SMT information in determining the trajectory, and residuals for this type of alignment are best expressed in terms of the global system. The residuals for the six rigid body coordinates are:

- For an offset perpendicular to beam, $(\Delta X, \Delta Y) = (\delta R \sin(\Phi - \delta\Phi), \delta R \cos(\Phi - \delta\Phi))$,
- For an offset along beam, $\Delta Z = constant$,
- For a rotation about nominal beam axis, $\Delta\Phi = constant$
- tilt of angle τ with respect to beam axis making an angle $\delta\Phi_\tau$ in (R, Φ) plane, $(\Delta X, \Delta Y) = (Z \sin\tau \sin(\Phi - \delta\Phi_\tau), Z \sin\tau \cos(\Phi - \delta\Phi_\tau)$.

5 Data Samples and Rates

Having established the required alignment precision and the residual formulas, the data samples used to perform the alignment are now considered. The effect of the solenoid field on the alignment strategy is also discussed.

5.1 Cosmic Ray Muons

The total muon cosmic ray flux[8] at sea level is $\approx 0.02/\mathrm{cm}^2/\mathrm{s}$, with an angular distribution $\propto \cos^2\theta_a$[8]. Here θ_a is the muon angle with respect to vertical. Considering only μ's which pass within 2 mm of the nominal beam line[9], the integrated muon rate for inner and outer layer ladders is given in table 2.

5.2 Minbias and p_T Selection

Collider data will also be used for alignment. At design luminosity, the rate from $W \to e\nu$ and $W \to \mu\nu$ will be 2 hz total or roughly 0.02 hz per four ladder tower. These events will provide slightly better statistical precision than cosmic ray muon data, and the flat ϕ distribution gives all ladders equal statistical weight. They also have high p_T tracks thus minimizing multiple scattering effects.

Higher statistics samples can be obtained from minimum bias (or jet) triggers. The tracks in these events have falling p_T distributions, so a trade off between rate and multiple scattering effects will occur. The lower p_T tracks have broader residuals and thus the precision of the measurement of the residual mean is lower. The cross–over between resolution

[8] There is a charge asymmetry of 1.25 μ^+ for every μ^-.

[9] The currently planned triggers have a strong bias to particles passing near the beamline. Relaxing this would allow additional handles for alignment and should be considered.

Ladder Position		Rate
Radius (cm)	ϕ (degress)	(10^{-3} hz)
2.7	0	5
2.7	60	20
10.0	7.5	1
10.0	37.5	7
10.0	67.5	14

Table 2: Cosmic ray rates for specific ladders. The computation required the particle to pass within 2 mm of the beam line and to traverse only a single barrel. The column labelled ϕ gives the azimuthal angle of the center of the ladder in DØ global coordinates.

dominated by multiple scattering and resolution dominated by measurement errors occurs at $p_T \approx 4$ Gev.

Estimates of L1 trigger rates[7] give 5 hz(physics) for isolated single tracks with $p_T >$ 10 GeV in single–interaction events at a luminosity of $2 \times 10^{32}/\text{cm}^2/\text{s}$. The rate grows non–linearly with increasing luminosity indicating a high fake rate. An event generator estimate gives physics rates[10] at $L = 2 \times 10^{32}/\text{cm}^2/\text{s}$ of 440 hz, 300 hz and 130 hz for tracks having $p_T > 3$ GeV, $p_T > 5$ GeV and $p_T > 7$ GeV respectively and which are isolated from other tracks in all silicon layers by at least 1.5 mm.[11] These tracks are uniformly distributed in η and ϕ for the range of (η, ϕ) space covered by the fiber tracker, and the events were required to pass a trigger requirement of two or more tracks with $p_T \geq 5$ GeV. The corresponding rates per four–ladder tower are 4 hz, 2.8 hz and 1.4 hz. If only tracks with $p_T > 5$ GeV are used, this rate is two to three orders of magnitude larger than the cosmic ray rate. This rather strict isolation requirement will be needed only in the first phase of alignment. Once the positions are established to something approaching the intrinsic resolution of the detectors, a switch to a track χ^2 selection can be made, and the isolation requirement can be eliminated.

5.3 Magnet State

Non-zero average residual in the SMT can arise not only from misalignment, but also from an incorrect calibration of the Lorentz drift of the electron cloud in the silicon. The alignment procedure could simply determine an "effective" position of the SMT without separating the alignment and drift effects. However, this would imply a different "alignment" for different magnetic fields. It seems cleaner to determine the two effects separately, thereby giving an alignment which is independent of the magnetic field.

There are two possible strategies for achieving a field–independent alignment. The first

[10] The available trigger bandwidth to tape is 20 hz. Even at luminosities significantly below design, the trigger will be saturated.

[11] This assumes no detector noise or physics induced hits, (*e.g.* from δ rays). Clearly these will reduce the rate. The 1.5 mm requirement is approximately 3σ on the projection of a CFT track into the silicon. This is also slightly looser than the $\pm 4.5^o$ sector isolation in the trigger.

is to take data with the magnet turned off. There will then be no Lorentz drift, and the alignment would be purely geometrical. A disadvantage arising from this is the inabiliity to bend away low p_T tracks. Not only does the multiple scattering from such tracks broaden residual distributions, it may also confuse the pattern recognition. A different trigger strategy would also have to be used. The second possibility is to perform two alignments with the field reversed between the two data sets. An average of the mean of the "alignment+Lorenz effect" residuals will then give the mean of the alignment residual. An obvious disadvantage of this is the need to take additional data. The relative power of the two methods will be studied, but at this time, the reversed field method appears to be the most straightforward for alignment.

6 Approximate Time Scales

Given the information above, the time it takes to complete the first two phases of the alignment can be determined. The calculations use the expected initial survey precision and target alignment precision (section 3), the data rates (section 5), and assume the alignment precision is determined by the error on the mean of the residual distributions. This error depends linearly on the width of the residual and has the usual $1/\sqrt{N}$ statistical dependence. However, the width of the residuals will depend somewhat on the initial alignment precision. We take the expected initial values to compute the residual widths.

The first alignment phase is a global alignment of the SMT and the rest of DØ, mainly the CFT. The error on CFT-only track parameters projected into the SMT dominates the residual, and corresponds to roughly 500 μm. We wish to establish the initial SMT–CFT relative alignment to 50 μm, allowing a comparision with the initial survey precision. Assuming the SMT is a rigid body, and using the formulas in section 4.3, one finds that 200 tracks are required to determine the δR and $\delta\Phi$ offsets to this precision, δZ to this precision and the angular measurements to the same precision. These counts were derived assuming that no SMT hits were used in the track fitting, and that running with both field polarities is required to cancel Lorentz effects.

If the initial luminosity is low, or we have time for cosmic ray running, this step of the alignment will be performed using cosmic rays. The asymmetery in global ϕ of cosmic rays implies that the time needed depends on $\delta\Phi$. The time is maximized if the misalignment has $\delta\Phi = 90^o$ (a shift in global y), and minimized if the misalignment has $\delta\Phi = 0$ (a shift in x). The crude calculation given here assumes the worst case shift $\delta\Phi = 90^o$ and that only tracks which pass through the innermost ladders at $\phi = 60^o$, 120^o are used. This was chosen for simplicity with the understanding that the ladders at $\phi = 90^o$ contribute very little for the worst–case shift, and that the rate through the ladders near $\phi = 0$ is extremely low. Of course, data through all ladders will be used, so the time here is an overestimate. The exposure time T is approximately

$$T = \frac{N_T}{N_B * 2 * \cos(\phi) * R} = \mathbf{30} \text{ minutes}$$

Here $N_T = 200$ is the number of tracks required, $N_B = 6$ is the number of barrels, R is the rate through a single ladder at ϕ, and the factor of two arises because detector symmetry

Sample	Time (days)
Cosmics, Inner Layer, $\phi = 0$	7
Cosmics, Inner Layer, $\phi = 60^o$	2
Cosmics, Outer Layer, $\phi = 7.5^o$	30
Cosmics, Outer Layer, $\phi = 67.5^o$	2
Minbias Collider Data ($p_T > 5$ GeV)	0.3
$W \to (e, \mu)\nu$	3

Table 3: Exposure time needed to achieve the desired alignment precision for the first pass internal alignment. The minbias results assume constant $dN/d\eta$ for tracks within $|\eta| < 1.6$ and 20 hz trigger rate (a prescale of 15 on the physics rate at design luminosity). The times given are to accumulate enough data to align all ladders including the factor of two to allow for reversed field running. Each track is assumed to traverse four layers.

implies there are ladders at ϕ and $\pi - \phi$. Establishing the same set of constants for each barrel requires a factor of six increase in data.

The internal ladder–to–ladder alignment target precisions are given in section 3. If we assume that the tracks used for the internal alignment have SMT information with geometrical information at the precision expected from the survey, the residual width will be less than 15 μm for the axial sides and less than 45(550) μm for the rz $90^o(2^o)$ stereo sides. This implies that 3000 $p_T > 5$ GeV tracks per ladder are [12] are required to achieve the target precision in each variable. The residual width is taken as the quadrature sum of the hit resolution and track positition uncertainties. We assume that the data are split between opposite polarities of the field, allowing cancellation of the Lorentz drift effect in the residuals. Table 3 gives the exposure times for cosmic ray and collider data samples.

7 Summary

A method to align the SMT ladders has been described, including the evolution in methods as the data sample increases and the alignment precision improves. It is found that an initial alignment of the entire SMT with the rest of DØ requires less than one day of cosmic ray data. A precision alignment of the ladders will require less than a week of cosmic ray running or collider running at design luminosity. The collider rates are based on saturating trigger bandwidth using dedicated or physics triggers. These results assume data is taken with two opposite polarity settings of the DØ solenoid in order to cancel Lorentz drift effects, and that only isolated tracks are used. The numerical results presented here will be updated based on detailed Monte Carlo studies to be performed over the next six months.

[12] If the maget–off method is used, the p_T selection cannot be made, and all isolated tracks will be used. This implies that multiple scattering will increase the width. For 1 GeV tracks the resolution is a factor of three worse than for 5 GeV tracks. The track p_T based triggers will not work. For cosmic ray data this is not a problem, but for collider data, a different trigger scheme would be needed.

References

[1] See http://www-d0.fnal.gov/∼meena/d0_private/silicon/coords/smt-numb/sld001.htm

[2] *Geant Simulation of the DØ Silicon Microstrip Tracker*, M. Narain, B. Pawlik.

[3] http://www-d0.fnal.gov/d0dist/dist/packages/silicon_geometry/devel/doc

[4] Private Communication, Bill Cooper.

[5] See *Mechanics*, H. Goldstein, 2^{nd} Edition, Addison Wesley. The small angle forms of transformations are in section 4-8. The roll, pitch, yaw coordinate system and the resulting rotation matrix are described in Appendix B.

[6] *Silicon Microtracker Graphical Alignment*, available at http://d0lblt.lbl.gov/wwwtrippe/SMTgraphicalAlignment.ps.

[7] DØ-Note 3636, Y. Gershtein.

[8] The basic information used here comes from section 21 of *Particle Physics Booklet*, extracted from *Review of Particle Properties*, C. Caso, *et. al.*, Eur. Phy. J. **C3**(1998) 1.