Physics Impact of Tracking Detector Contingency Plans

DØ Collaboration

April 24, 2000
(Updated May 25, 2000)

Abstract

In the light of potential schedule risk we discuss the physics impact of the absence or presence of certain components of the DØ Upgrade tracking system.

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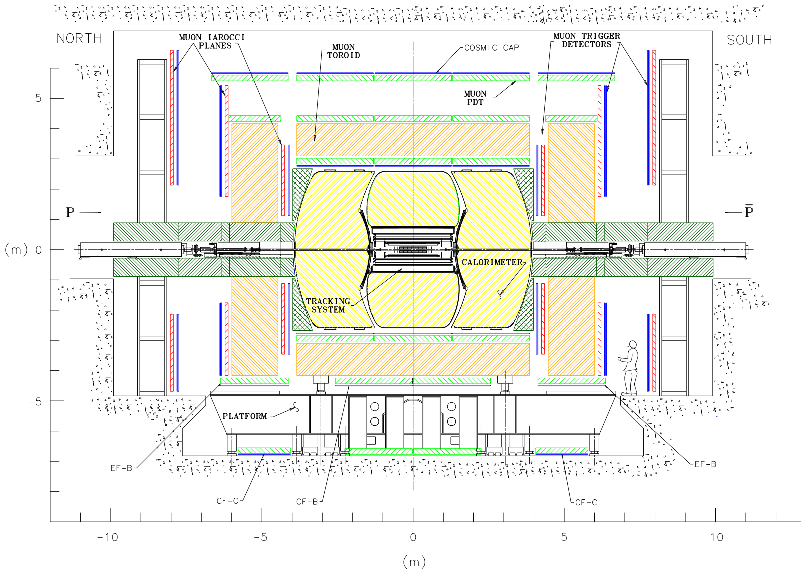


Figure 1: The upgraded DØ apparatus.

1 Introduction

Since the fall of 1999, there have been extensive discussions between the Fermilab Directorate and DØ, CDF and the Beams Division in order to establish a schedule for the completion of the detector and accelerator upgrades and to establish a start date for Run II. The date chosen, and defined as the date at which the detectors will be installed in the collision halls and ready to take collisions, is March 1, 2001.

The Fermilab Directorate and the DOE take that stance that, having had the extensive discussions to establish the date, DØ should manage its upgrade fabrication and installation in order to optimize the performance of the detector at that time, even if delays or constraints on resources dictate that the detector be incomplete.

In this document we discuss the tracking system. In terms of DØ Upgrade WBS-speak, this is WBS 1.1. The emphases are driven by the perceived relative schedule risk to the relevant components.

In Section 2, we recap briefly some of the salient features of the DØ Tracker Design, trying to make contact with physics performance and concentrating particularly on the silicon detector. We associate particular detector subsystems with particular aspects of the performance. The silicon detector design considerations have been revisited[1] and where possible have been refined with performance estimators based on the current reconstruction software.

In Section 3, we posit a strategy. This strategy includes the deployment of detectors which are not perfect and hence leads to some degradation of performance, albeit much less than that engendered by the complete absence of a detector element.

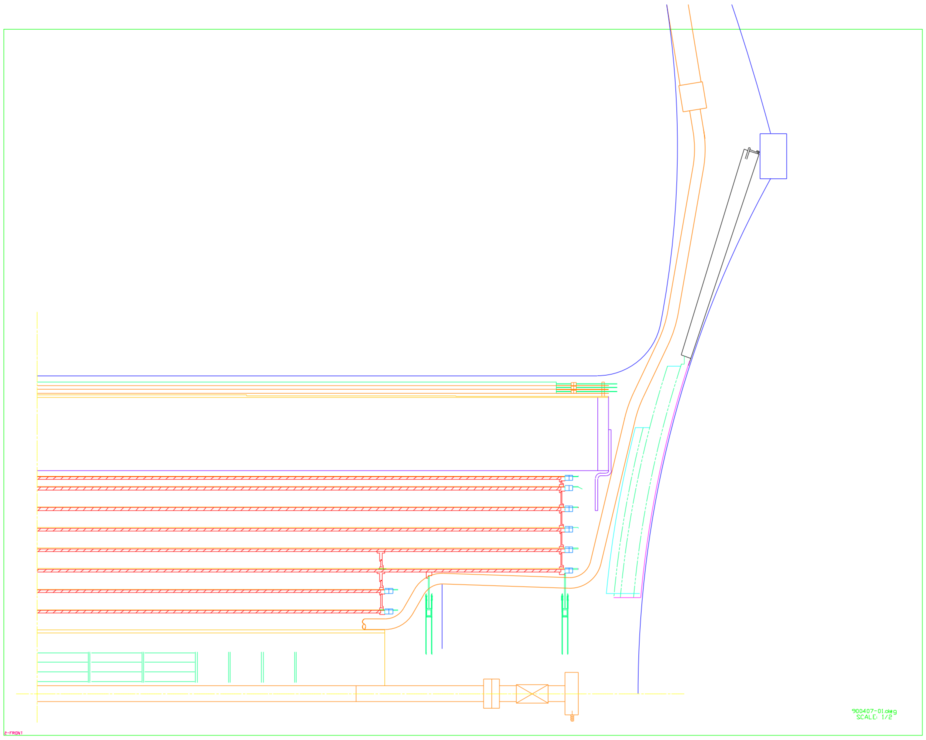


Figure 2: The DØ Tracker.

This document is written with some appreciation of the current status of the detector elements and of the installation schedule. However we leave integration into a coherent schedule to a different document.

Advice has been sought from a committee (CPP) chaired by Ken Johns which reports to the Spokesmen. The current state of this document reflects a decision which followed a recommendation from that committee made on April 19, 2000, that a plan which first chooses to remove F disks 3&10 is appropriate. The choice on which further disks to remove, should that be necessary, is still not clear.

2 DØ Upgrade Tracker Design

2.1 General Considerations

The DØ Upgrade detector, Fig. 1, is designed to be all purpose in the sense that it is not directed at a single physics topic. We anticipate making measurements within the standard model in all sectors, QCD, electroweak and flavor physics. We will also search for phenomena beyond the standard model, including the Higgs boson as well as new strong interaction particles expected in most non-standard models of electroweak symmetry breaking.

Many processes are characterized by the need for good performance at high transverse momenta and central rapidity $|\eta|\leq 2$. Archetypal processes are $t\bar{t}$ and WW production. Signals of SUSY, for example the trilepton signal, dictate good performance, at least for leptons, at lower transverse momenta ($p_T > 5$ GeV) and over a somewhat larger $|\eta|$ range. Finally, the status of B physics gives DØ the opportunity to make significant contributions, for example to the determination of the CP violation parameter sin2β and to B_S mixing. These processes put a premium on low transverse momenta and and even larger $|\eta|$ range.

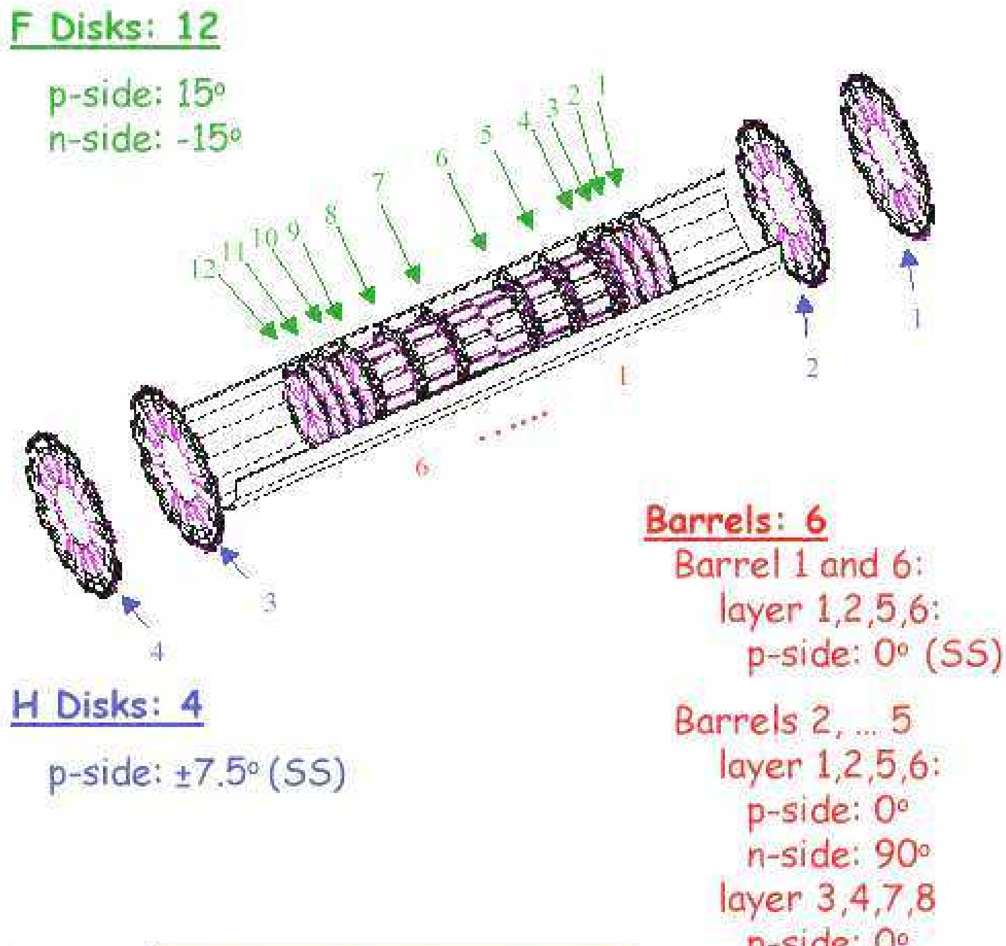
The luminous region at the Tevatron extends along the beam direction(z) with $\sigma \simeq 30$ cm. This strongly influenced the initial design of the DØ Upgrade tracker, (see Fig. 2 and Fig. 3), and along with the physics considerations, led to a silicon design which incorporates both barrel and disk modules. One can think about this problem starting from a design with only disks or starting from one with only barrels. In either case the limitations rapidly become evident, hence the final hybrid design. The issues are well illustrated in DØ Note 3451[3].

Beyond the silicon detector we have chosen a primary tracker of scntillating fibers which provides full coverage for $|\eta|\leq 1.6$. In this range the silicon detector complements the fiber tracker in the task of finding tracks. At higher η, tracks no longer intersect all the planes of the fiber tracker and the forward F and H disks of the silicon play more strongly in the track finding.

Key objects in any $\overline{p}p$ experiment are stable charged leptons, particularly muons and electrons. There are primary subsystems dedicated to identification of both. For the muons we have an outer shell of detectors, and for the electrons we have the calorimeter and preshower detectors. However, the ultimate performance for each of these is enhanced by the association of tracks found in the tracking system over $|\eta| < 2$ for muons and $|\eta| < 3$ for electrons. In addition there is a central preshower detector wrapped on the outer surface of the 2 Tesla solenoid and forward preshowers mounted on the end calorimeter surfaces.

The fiber tracker also contributes to the trigger discrimination at Level 1 by identifying tracks in the axial layers of the fiber tracker. The preshower detectors use their double layer design to indicate electrons, also at Level 1. Finally at Level 2, the Silicon Track Trigger enhances the track trigger and uses impact parameter measures to identify vertices detached from the primary interaction collision point.

The high integrated luminosity leads to a radiation field which is strongly dependent on radius from the beam. The inner layer of silicon will experience approximately 0.4 MRad for each 1 fb^{-1}. The density of hits from both tracks and from general radiation is highest at small radii and is relatively independent of z. Any strategy which we might develop for fallbacks should take appropriate cognizance of both potential radiation damage and the occupancies anticipated.



	Barrels	F-Disks	H-Disks
Channels	387120	258048	147456
Modules	432	144	96
Inner R	2.7 cm	2.6 cm	9.5 cm
Outer R	9.4 cm	10.5 cm	26 cm

Figure 3: The DØ Silicon Microstrip Tracker.

2.2 Silicon Detector

The silicon detector, (see Fig. 3), consists of six central barrel modules in z. All barrel modules have double-sided small-angle (2 degree) stereo detectors in Layers 2 and 4. The four barrels at lowest $|z|$ have double sided large-angle (90 degree) stereo in Layers 1 and 3. The two barrels at largest $|z|$ have single sided detectors in Layers 1 and 3.

Each barrel module has an associated F-disk at the end of the module furthest from the center of the interaction region. The presence of these disks increases the distance between barrel modules by a few millimeters. In addition there are two end assemblies, each with three F-disks. From the track reconstruction, as compared to detector construction, point of view there are therefore four internal, interleaved, central F-disks and eight (2×4) end disks.

The initial design of the silicon support system featured a single carbon fiber cylinder. The silicon support cylinder will now be divided into SMT-S(outh) and SMT-N(orth) at $z = 0$. This move generates considerable schedule contingency.

Acceptance studies have utilized track distributions uniform in η, distributions of particles from top decay, and of particles from $b\bar{b}$ production with subsequent decay to $J/\psi K_s^0$.

2.2.1 Barrels

The barrels provide acceptance at relatively low η and for central values of z_{vtx}. As $|z|$ increases the acceptance limit in η is decreased for large η with the same sign as the z and is increased for those η of the opposite sign. There is a loss of acceptance between the barrel modules. At $z = 0$, the gap is small but not zero because the strips on the detectors terminate short of the physical limit. When a disk is interleaved between two barrels the gap is larger but, except for $\eta \simeq 0$, the disks pick up this gap. Early studies[4] showed that if the central disks were not present, the central (eg $t\bar{t}$) acceptance could be increased by several percent by moving the barrels closer together. Recent studies[5] also suggest that at the single track level the acceptance recovered by minimizing the gaps is at the level of 3-5%. This assumes 4 hits in the silicon are required per track; if three are sufficient the differences are less. This is consistent with the results of studies[7] of the acceptance for complete B decays which assumed four hits per track were needed.

The same B physics studies concluded rather clearly that the loss of the large angle stereo detectors results in an unacceptably poor measurement of sin2β because of degradation of acceptance, tagging efficiency and decay time resolution.

The silicon module supports are inserted in penetrations through the walls of the silicon support cylinder. Similarly, penetrations allow the low mass cables to exit through holes in the cylinder. If we are to maintain the assembly schedule, it is necessary to define and make these penetrations before any silicon modules are installed in the half-cylinders. Currently this work is planned for April-May to mesh the pre-installation of the silicon support cylinder, with dummy loads, in the fiber tracker with the fiber tracker installation schedule. Therefore a decision to close the gaps would need to be made now, in advance of our understanding the complement of F-disks available.[1]

[1] On April 26, the decision was made to cut the openings in the support cylinder in such a way as to accommodate the full complement of disks. This does not then permit the later closing of the gaps between the barrels.

Omission of a single barrel module leads to a 6-7% loss of acceptance; this is less than one sixth because the barrel lost will be at higher $|z|$ where there are fewer interactions. Depending on the length of the luminous region, this impact is further reduced by 1-2% overall (one sixth of the loss) if the remaining modules were recentered about $z = 0$. However the decision to split the barrel support cylinder in two half-cylinders precludes such recentering.

- Small Angle Stereo Ladders

  The small angle stereo detectors are crucial for pattern recognition. We have not considered omission of these except to the extent that they could lead to the omission of a complete barrel module.

  The Layer 2 detectors will suffer significant radiation damage. This will be mitigated by choosing detectors with higher depletion voltages for installation in that layer.

  The production of these detectors has been slowed somewhat due to the usual array of problems with sensors, HDIs and testing. It is likely these devices will eventually control the schedule. The immediate issue is to make sure that adequate numbers of the different sub-types with different HDI tail lengths are in hand for barrel assembly. At the moment the production is staying ahead of the needs.

- Large Angle Stereo Ladders

  The Layer 1 detectors experience the highest radiation field. At the time when this exercise was started, there were several concerns.

  - Some of the sensors for these detectors have manufacturing defects (p-stop 'shorts').
  - There were fears that it would not be possible to adequately bias at a high enough voltage to give an adequate lifetime.
  - Some studies[2] using the extant reconstruction software showed that for a significant fraction (30%) of found tracks, the high occupancy coupled with the double-metal multiplexing scheme renders the z information essentially unusable.

  A contingency plan to resort to single sided detectors everywhere was posited. Studies since then bear upon this issue.

  Understanding of the p-stop defects has progressed and the number of strips lost from a single such defect is between 1 and 2%. Use of these existing detectors, which has significant schedule impact, will therefore lead only to a modest and acceptable loss of performance.

  Studies have been made[6] of a large-angle stereo detector which had been irradiated with the equivalent of 6–7 fb^{-1} and which had not been maintained at low temperature so had suffered extensive reverse annealing. It was possible to bias the detector with different split-bias schemes to 140 volts. Given the dose, the detector was not fully depleted and the consequent degradation in performance was studied using the laser stand. The observed performance was not good enough to claim that it would be a useful contributor to physics after that dose. However, its performance corresponded to expectations and suggest that Layer 1 equipped with such detectors would survive approximately 3–4 fb^{-1}.

The difficulties of associating the Layer 1 z-hits in some classes of events remains. Subsequent studies[7] of B-physics measures have been made. The absence of the Layer 1 z capability from all events degrades the proper time resolution for the B_d decay from 95 to 150 fs. Similarly the effective tagging efficiency is reduced by more than 10%. Together these lead to a 10-12% degradation in the projected error on the CP-violation parameter, $\sin 2\beta$. Studies of track finding issues continue along with attempts to improve that software.

- Single Sided Ladders

  The single sided ladders are slightly non-planar with a maximum out of plane excursion of about 125 μm for the worst. A procedure to improve the planarity has been established. Nevertheless these distortions have been modeled in a simulation of the silicon track trigger (STT) and the degradation quantified. The conclusion is that provided the standard deviation of the out-of-plane excursions have a standard deviation of 70 μm or better the increase in rates is acceptable[8]. The ladders currently being installed in the first of the outer-z barrels have distortions with a standard deviation of 60 μm.

  There are no issues of availability of components for the single-sided detector construction.

2.2.2 Disks

- F Disks

  The F disk sensors are supplied by two vendors, the delivery from one is complete and there may be extra sensors available from that vendor. However completion of the full twelve F-disks depends on deliveries of adequate detectors from the second vendor. Currently there is some uncertainty involved. The F-disks have the most complex combination of sensors, high-density interconnects and readout chips of all the DØ silicon detectors. A first disk has been successfully assembled from sub-standard parts. The start of assembly of detector grade disks has been slow, partially as a result of safety reviews, but is now underway.

  Acceptance issues for the F-disks were discussed in 1998[3] and revisited[5] recently. The results of these studies suggest that the silicon tracker design is relatively robust, as far as single particle acceptances are concerned, against the loss of F-disks. If the required number of SMT hits is three, the removal of all the central four disks gives a barely perceptible effect. However, if hits in four detectors are required, then the single-track acceptances with and without the central four F disks differ by a few percent.

At the present time, the pattern recognition studies do not give a clear indication as to the requirements which we will need to impose in the real experiment.

Recent studies[7] suggest that the loss of either all the central F-disks, or of all the end disks, leads to a degradation of about 10-12% in the projected error on the CP parameter sin2β.

In the absence of the central disks the 4-hit **acceptance** of fully reconstructed $B \rightarrow J/\psi K_s^0$ is reduced by $\simeq$ 15%. This loss is approximately the fourth power of the single-track losses and so is consistent with the single-track studies. In contrast, the end disks influence the tagging primarily and the proper time resolution secondarily. For the proper time resolution which may be particularly important for B_s physics, the degradation was of 5% for the loss of the central disks and of 8% for the loss of the end disks.

We can carry the result on full reconstruction over to central, high p_T physics and suggest that reconstruction of the decay of a B meson in that phase space, or of the tracks in a jet, would suffer a similar, 15%, degradation. Such a conclusion would be consistent with the earlier studies[4] which suggested a few percent loss of acceptance for $t\bar{t}$ events as a result of the increased inter-barrel gaps.

In conjunction with the H disks the F disks provide tracking at large $|\eta|$ and thereby improved electron and photon identification. In Run I, DØ used the end calorimeters and high $|\eta|$ electron identification to good effect in precision electroweak studies and in searches for new phenomena. The use of both CC and EC calorimeters for the determination of the W-boson mass reduced the dependence on the parton distribution function uncertainties by about one sixth. The SUSY trilepton signal from cascade decays leads to forward-going leptons with relatively low transverse momenta. This importance of this DØ capability is not likely to be reduced for Run II.

- H Disks

  The H-disks affect the acceptance and resolutions for $\eta \geq 2$[5]. However there appears to be little schedule risk. Detector fabrication and assembly are well advanced. Further the modules can be readily installed very late, even after the detector is ensconced in the collision hall.

3 DØ Upgrade Tracker Fallback Strategy

3.1 Silicon Detector

The studies described above show measureable degradation of physics if complete detectors, or complete sides of detectors are missing. However, by extrapolation, these studies would have shown barely perceptible degradation for detectors missing as many as 10% of the strips either because of noise problems or because of the strips being dead. Studies of resolution or of the STT trigger rate using measured mechanical distortions of completed ladders suggest that the overall quality is acceptable and that remedial work need only be contemplated for a small fraction of the ladders.

These studies and measurements confirm that the primary variables which should be tuned to meet the schedule are, for all species of device, the detector acceptance criteria.

A grade detectors have less than 2% bad strips, B grade up to slightly over 5% and C grade have greater than 5% bad strips. There are sufficient detectors graded at this time to broadly predict the distribution of quality of devices which will ultimately be available. The great majority of detectors are at least of B grade. The deployment strategy being employed is therefore to only use C grade detectors *in extremis* and to avoid successive B grade detectors, as seen by the particles, wherever possible.

The anticipated lifetime as a result of radiation damage is higher if the detector starts life with a higher depletion voltage. The radiation field falls approximately as the inverse of the radius from the beam axis but is almost independent of the z position. Therefore detectors with depletion voltages in the higher range are deployed in the inner layers of the barrel modules.

F disks are assembled from wedges with similar depletion voltages and this permits the deployment of higher depletion voltage disks in sites which are deemed more critical.

At the time of writing this process of rationalization has been exercised in the choice of detectors for installation in the first barrel and in assignment of devices for the first F Disk.

3.1.1 Barrels

As mentioned earlier, the decision has been made to split the silicon microstrip detector and its support cylinder into two halves, SMT-S(outh) and SMT-N(orth) at $z = 0$. This maximizes the schedule contingency. The remedial gains from symmetrization of an odd number of barrels do not justify retention of the single support cylinder. The decision on how many barrel modules to accomodate cannot be delayed beyond the end of April.[2]

- Small Angle Stereo Ladders

  The impact of a loss of a few % of channels or the presence of slight mechanical imperfections is acceptable and detectors with such defects should be installed if the schedule is threatened.

- Large Angle Stereo Ladders

[2]On April 26, the decision was made to cut the support cylinder so as to accommodate the full complement of barrels.

The possibility of reverting to single sided detectors for Layer 1 is essentially excluded simply on the grounds of fabrication times for new single sided components.

Acceptance of the impact of an extra 1-2% bad channels as a result of installing sensors with one p-stop defect is the proposed primary contingency measure.

- Single Sided Ladders

  There is no schedule risk associated with the single sided ladder fabrication. The installation of a few ladders with mechanical(non-planar) defects has a modest impact on the STT trigger rate. The primary contingency measure will therefore be the installation of such ladders should the schedule be threatened.

3.1.2 Disks

- F Disks

  As for all detectors, modest detector imperfections are acceptable and should be exploited to maintain the schedule.

  As discussed above, if an **immediate** decision had been made to remove F disks 4, 5, 6 & 7, a modest improvement in the central acceptance could have been recovered by reducing the gaps between barrel modules. The size of the potential gains did not appear to justify such a decision.

  The studies described above suggest that if we were to remove up to four disks from the central region, we would lose several (∼15)% of acceptance for ALL physics requiring reconstruction of multi-particle systems. Alternatively if we were to remove end disks we would suffer up to 15% loss in B-tagging efficiency with 2-3% degradation in time resolution.

  We therefore propose that, IF there is a need to reduce the complement of F-disks installed, we sacrifice first disks numbered (3&10) which leaves a well spaced triplet at each end which may suffice. Good acceptance is retained over the complete barrel region.

  IF it is necessary to sacrifice a second pair, the choice is less clear and more studies need to be made in order to put the choice on a solid footing. The studies most needed are full pattern recognition studies, $B \to \psi K_s^0$ reconstruction for the central region and tgging of B mesons in the forward region.

- H Disks

  As for all detectors, modest detector imperfections are acceptable and should be exploited to maintain the schedule.

  The contingency plan for the H disks is to install the modules late. If necessary this could be done with the DØ detector in the collision hall.

3.1.3 Silicon Support Systems

The full support cylinder is largely complete. It will be cut into the two half-cylinders and the needed penetrations made.

The scheme to support of the silicon half-cylinders in the fiber tracker has been designed. This includes the support system at $z = 0$, which is new and the reinforcement of the inner fiber barrel to support the $z = 0$ load.

Preinstallation of the loaded cylinders must precede the installation of the fiber tracker in the experiment.

There is no physics impact of contingency plans in this area.

3.2 Fiber Tracker

The construction of the fiber tracker detector, mounting of ribbons and nesting and fixing of cylinders, will be complete in a few weeks.

The production of the clear fiber waveguides is underway but the schedule has some potential for delay. Priority will be given to the fiber tracker waveguide production in preference to the forward preshower.

The VLPC cassette production has recently been established. There is some risk in the production schedule. Initial QC of the installation of clear waveguides on the tracker can be accomplished without a full complement of cassettes.

Ultimately individual cassettes could be installed with the DØ detector platform in the collision hall.

There is no physics impact of contingency plans in this area.

3.3 Central Preshower

The central preshower is installed on the calorimeter and the production of the clear waveguides is complete.

There is no physics impact of contingency plans in this area.

3.4 Forward Preshower

The forward preshower modules are complete and were installed in the detector.

If the clear fiber waveguide production suffers delays, the forward preshower guides will be given lower priority and may lead to a late installation of those guides.

The impact of late installation of these lightguides could be the later access to physics with the forward preshower detector.

3.5 Tracking Electronics

There is a schedule risk associated with the fiber tracker, central preshower and forward preshower front-end electronics. There are two species of board, one associated with the fiber tracker axial and some stereo fibers, the other associated with the rest of the stereo fibers and all of the preshowers. There is competition for resources to complete the fabrication of the two boards.

The central tracker axial readout and trigger will be given priority. The impact of a schedule delay is that the preshower readout would be at risk for the initial months of operation of the detector. This ensures that commissioning of the core central systems is not endangered.

4 Summary

In this document we have considered the physics impact of various contingency measures associated with the final stages of fabrication of the DØ tracking system. The risks and the complexities are primarily associated with the silicon detectors. Nevertheless, studies have confirmed that we have a relatively robust design.

We have adopted the two half-cylinder support scheme this generates schedule contingency in the installation dates.

In the event that choices do have to be made, we will:

- Accept less than perfect detectors in order to keep to the nominal schedule as far as possible to avoid the need to omit complete barrel or disk modules.
- Selectively omit up to four F disks from the ends of the detector, initially numbers 3&10, with the second pair still to be decided.

We believe that those choices, while not desirable in any absolute sense, maximally preserve the physics capability of the detector to operate at the start of Run II. We believe that the central high p_T physics capability would not be dramatically degraded by any of the proposed measures.

References

[1] http://www-d0.fnal.gov/ mont/d0_private/tracking_fallback/fallback.html

[2] Ela Barberis, Slava Kulik see Ref. [1]

[3] Ulrich Heintz, DØ Note 3451, June 2, 1998.

[4] Ann Heinson, see Ref. [1]

[5] Regina Demina & Alexander Khanov, DØ Note 3730, Feb. 25, 2000.

[6] Frank Lehner, Talk at the Run 2b Workshop, March 2, 2000, *http://129.130.5.241/WWW/Miniwrk/Lehner/sili_rad_files/v3_document.htm*

[7] Rick Jesik, March 17, 2000, seeRef. [1].

[8] John Hobbs, SMT Meeting, March 16, 2000.