# Comparison of the CDF and DØ Silicon detectors

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The CDF and DØ experiments will both need to replace their silicon vertex detectors for the Run IIb luminosity upgrades. There are many similarities in the requirements for the two new detectors. Early in preparation for Run IIb the Laboratory recognized that cooperation and communication between the two projects would benefit both the experiments and the Laboratory program. Under the umbrella of the Silicon detector Facility (Sidet), an engineering and design group was established. From its inception, this group has had regular meetings of all the engineers involved in Run IIb. In the earliest stages of the projects these meetings were held weekly as a forum for exchange of ideas and results of engineering studies.

In a similar vein, a task force on "Commonality" was setup with leaders of the two silicon projects as the chairs of the committee. Periodic meetings were held and topics such as
chip design, sensors specifications, and a variety of specific engineering issues were discussed. These meetings laid a foundation for open communications among the experiments and the engineers. This now occurs regularly as more casual conversation rather than formal meetings. We continue to have meetings roughly once a month for more formal presentations and summaries of engineering studies to keep everyone well informed.

The emphasis on cooperation, the periodic meetings, along with the general proximity of personnel, have all encouraged the exchange of ideas and test results and resulted in common technology choices. A list of the common R&D efforts over the past year is given below (Section Joint Engineering R&D). Some examples of the success of these efforts is the use of a common readout chip (SVX4) for both experiments. Another is the essentially identical specifications for the silicon wafers. CDF and DØ have chosen the same technology for the hybrids (ceramic) and the design of the inner detector (L0) is largely based on the design of the Run IIa CDF L00 detector. Common tests of radiation damage and overall functionality of these components will greatly simplify development throughout the project.

There are, however, differences in the external constraints on the CDF and DØ silicon detectors which result in differences in the overall designs. These are driven primarily by the need to fit within the existing infrastructure of the two experiments in terms of space, data acquisition, and the requirements for successful operation in the context of the existing tracking systems (CDF has the COT and ISL, DØ has the fiber tracker).
These are discussed below.

**Space**

Length: CDF must fit into and be supported by fixed mount points in ISL which are 2m apart. Thus the completed SVX must be 2m long. Installation of the CDF silicon system

requires the CDF detector be moved to the assembly hall so that the ISL with the inner silicon detectors can be extracted and moved to SiDet for removal and replacement of the inner silicon layers. DØ can be built in half length sections and can thus be installed in the collision hall saving weeks in the installation schedule.
Radius: CDF and DØ have remarkably similar radial space available and thus have similar radial locations for the layers of the silicon detectors.

| | DØ | | CDF | |
|---|---|---|---|---|
| Layer | Radius (cm) | Type | Radius | Type |
| 0A | 1.9 | Axial | 2.1 | Axial |
| 0B | 2.5 | Axial | 2.5 | Axial |
| 1A | 3.5 | Axial | 3.5 | Axial |
| 1B | 3.9 | Axial | 4.4 | Axial |
| 2A | 5.3 | Axial | 6.0 | Axial |
| 2B | 6.9 | 1.2 deg. | 7.5 | 1.2 deg. |
| 3A | 8.6 | Axial | 9.5 | Axial |
| 3B | 10.0 | 1.2 deg. | 10.9 | 1.2 deg. |
| 4A | 11.7 | Axial | 12.4 | Axial |
| 4B | 13.1 | 1.2 deg. | 13.8 | 1.2 deg. |
| 5A | 14.7 | Axial | 14.8 | Axial |
| 5B | 16.1 | 1.2 deg. | 16.2 | Axial |

As a result, the sensors are quite similar in width, length and numbers for the outer layers.
The radius of the inner layers is driven by the size of the beampipe flange which must pass through the L0 structure. The CDF pipe is longer (the central tracker is longer) and has a larger flange than the DØ pipe.
For layer 0 CDF and DØ will both use sensors identical to the 2-chip wide sensors used for L00 in Run IIa. For the outer layers CDF has axial and small angle (1.2 deg.) stereo sensors. These are 40.5 and 43.1 cm wide respectively and 96.4cm long.
DØ has only axial sensors on the outer layers. For stereo tracking these sensors are tilted by 1.25 or 2.5 deg. depending on the location.
For Layer 1 the CDF and DØ designs differ. CDF uses the outer layer staves for Layer 1 while DØ uses a design more similar to the design of L0, with a 3-chip wide sensor. As a result CDF has slightly more sensors than DØ because the outer layer staves at Layer 1 are double sided.
In summary, the radial and longitudinal constraints on both experiments are similar and result in similar sensor dimensions and numbers. CDF and DØ each have 3 sensor types and have a total of 2304 and 2184 sensors, respectively.

**Data Acquisition:**

CDF has a buffered, online silicon vertex trigger (SVT) at Level 2 and operates the chips in deadtimeless mode (can readout and aquire data at the same time).
The available time for readout of an event (without incurring additional deadtime) is ~20 usec. The impact on the design is that the number of chips in a chain is limited. Tests with the Run IIa detector have indicated that a segmentation of one readout unit per stave (24 chips) will fit within the allowed time. Details are presented in the TDR. At Layer 0 each 2 sensor module is a separate readout chain. The total number of readout units in the CDF Run IIb system is 252 and fits within the available channels (408) of the existing upper DAQ system.

The DØ data acquisition and trigger has different constraints which drive the design to have multiple readout units/stave. DØ uses the chips in SVX2 mode which means the DAQ waits while the chips are being read out. This limits the maximum number of chips in a readout chain to 10. As a result, DØ divides a stave into 4 readout units. At layer 0 occupancy and timing concerns motivate the readout of each individual sensor. This implies twice the number of hybrids and analogue cables for DØ compared to CDF for L0. The total number of readout chains for DØ is 888 and fits within the existing upstream DAQ system of 912 readout channels.

The differences in the DAQ segmentation and the need to interface to the rest of the DAQ systems are reflected in the hybrid designs. However, both CDF and DØ will use BeO substrates for the hybrids and this choice of a common technology will aid in the development of similar testing and assembly procedures for the hybrids and modules. The detailed hybrid designs are somewhat different. CDF uses smaller traces (more aggressive technically, but less aggressive than achieved from the same vendor for L00), and has 4 metal layers. DØ has wider traces and 5 metal layers. Both collaborations are using the same vendor for the hybrid production (CPT) and are exploring the same companies for the surface mounting of the components (Meltronix)

Specifically CDF has two types of hybrid, a 4-chip hybrid for the outer layers and a 2-chip hybrid for the Layer 0. DØ has 2 types of hybrid on the outer layer, double ended 10-chip hybrids for the axial and stereo layers. Layer 1 and 0 have 3-chip and 2-chip hybrids, respectively. CDF has 6 hybrids/stave and a total of 1152 hybrids (1080 are 4-chip and 72 are 2-chip). DØ has 4 hybrids/stave and a total of 888 (including L0 and L1).

**Tracking Context:**

The TDR's of the two experiments describe in detail the performance of the proposed detectors. The primary differences are pitch of the outer layer sensors and the design of Layer 1. For CDF the pitch of the outer layers was driven by: the goal of having only one axial sensor type for all layers, having complete coverage at all layers (with >=10 strip overlap) and keeping the number of chips low enough that one readout chain per stave would fit within the trigger requirements. Tracking studies (documented in the TDR) indicate that the resulting pitch will provide excellent tracking in Run IIb when combined with the tracking capabilities of the ISL and COT.

The design of Layer 1 in CDF is a compromise. It lacks complete coverage and the pitch is not ideally suited to its small radial location. However, use of the outer layer stave at this location reduces both the complexity of the design and the cost of the project. Tracking studies in the TDR document the reduction in performance and, while not desirable, were judged to be an acceptable trade for the simplification of the project.

The DØ design is driven by similar radial constraints as CDF, but the tracking capabilities of the fiber tracker in the Run IIb environment are limited. To retain the full tracking capability of the detector under the RunIIb conditions, Layer 1 has full azimuthal coverage and the Layer 1 sensors have a pitch matched to their radial position. The pitch of the outer layers was driven by the pitch required for Layer 2. In order to keep a uniform design for all outer layers, this same pitch was retained for all layers. The effect of a larger pitch in the outer layers was studied with a full Geant simulation. Increasing the pitch from 60um to 75um increased the cluster hit resolution for 13um to 17um. In addition, an increase of 50% was observed in the number of shared clusters, which are mainly coming from b-jets. Moreover, the $p_T$ resolution in the central region increases by 10%. All these adverse effect outweigh the possible disadvantages of a slightly larger channel count and has led to a uniform pitch of 60um for the outer layer sensors.

The details of CDF and DØ modules and stave designs are driven by the spatial, DAQ, and tracking requirements of each experiment. Although there are some differences, there are also many similarities. In particular, some of the similarities are that both use embedded cooling tubes in the stave core structure; the staves are ~ 60cm long (6 sensors), the staves are assembled into 2 barrels; each group will use fixtures and CMMs for aligning sensors and modules; both groups expect to produce 8 modules/day in production with 2 FTE of technical support. The differences come in the details:

- DØ will have 4 stereo layers, while CDF has 3.
- On the outer layers (1-5) CDF has 75 (80) um pitch axial (stereo) sensors and uses pitch adaptors between the hybrids and the sensors. DØ has 60 um pitch and does not use pitch adaptors. As a result, the number of bonds/channel on the outer layers for CDF modules is a factor of 2 higher than for DØ, but DØ has 7152 chips (on layers 1-5) while CDF has 4320 chips. CDF thus has 20% more bonds to make on layers 1-5.
- On Layer 0 both CDF and DØ use analogue cables to connect the chips to the sensors and thus there are 2 bonds per channel. However, DØ reads out every sensor, while CDF bonds two sensors together and then reads out the two-sensor module. DØ has 288 chips for L0 and CDF has 144. For L0 DØ has 33% more bonds than CDF, but in both cases the total number of bonds is quite small in L0 compared to the outer layers.
- The CDF stave design relies on wirebonding the hybrids to the bus cable on the stave structure. The bus cable passes underneath the silicon sensors. DØ uses connectors from the hybrids to the digital cables and these cables pass above the sensors and hybrids.
- DØ will burn-in modules (since the wirebonding is finished at this stage) and will do quick tests on the assembled staves. CDF will do quick tests on the modules

and will do the longer term burn-in tests on the staves.

- In the stave core DØ uses CF tubing for the cooling tubes while CDF uses PEEK tubing as used in L00 in Run IIa.
- Both experiments hope to use the cooling systems currently in use for the Run IIa detectors. The temperature specifications are derived in a similar manner (the standard conservative factor of 1.5 is used on the fluence). For layer 1, both CDF and DØ set a temperature specification of -5 deg. C. At Layer 0, CDF specifies -5 deg. and DØ specifies -10deg. C. It should be noted that the DØ L0 detector is at a slightly smaller radius. Details of these estimates can be found in CDF notexxx and DØ note 3959. Tests are underway to determine how low the current chiller systems can operate.

While the constraints listed above result in different overall designs for the CDF and DØ Run IIb silicon detectors, similarities in the core components (chips, hybrids, sensors, L0 cables, etc) have been and will continue to be exploited in the R&D, engineering and testing phases of their construction. Below we provide a description of the common engineering projects for the past year. Finally a comparison of the costs of the projects is provided.

## Common Engineering Efforts for Run IIb

The open communication at the engineering level is clearly seen in the basic design choice of staves mounted within barrels, with two barrels. The similarity in the end views of the detectors is also the result of common efforts to understand the available parameter space for the sensor length and width. Several disjoint constraints go into this, some common to the projects and some quite different. The three common constraints are having adequate Z-coverage, having full azimuthal coverage in the outer 4 layers with a common sensor width and keeping the sensor cost under control by requiring that two sensors fit the available space on a substrate in a 6” wafer fabrication line. These constraints alone lead to a small set of possible solutions. In the case of DØ there is an additional constraint imposed by the existing trigger hardware that the azimuthal multiplicity must be divisible by 6, leading to only one solution. The CDF trigger does not have such a constraint, however their readout and trigger systems limit the number of readout chips on a sensor to 4 and the total number of readouts in the full system (DØ has a similar constraint). These constraints also lead to the same solution of sensors roughly 100mm long by 40mm wide. However, the differences in readout systems and pattern recognition capabilities of the integrated tracking systems of the two experiments lead to different readout pitch requirements and longitudinal ganging of sensors within staves. Thus the mechanical layouts of the staves appear very similar while there is significant divergence at the electronic level.

Development of formed PEEK tube as a coolant passage within the staves has been a joint effort of the two groups, and among several technical groups within the lab. Thin wall PEEK was introduced in CDF L00 as a liner inside aluminum tubes that developed leaks during assembly of that device. The excellent mechanical properties and radiation tolerance of PEEK make it a very attractive material for Run IIb. This joint effort has involved development of heat forming methods and tooling at SiDet and Lab3, measurements of PEEK thermal conductivity and heat transfer through assembled stave structures at SiDet and investigation of leak checking and permeability by PAB and SiDet personnel. Low temperature flow and pressure drop studies have been done by both groups to verify analytical calculations. The several subtleties encountered in these studies, as well as the heat transfer studies, have been shared between the groups reducing the effort required to converge at reliable results. SiDet is currently preparing for long-term flow studies with formed PEEK tubes as well as carbon fiber tubes and perhaps other materials that might be utilized in the Run IIB cooling systems, BTeV or elsewhere.

SiDet has played a critical role in understanding available carbon fiber composite materials, has purchased materials for development efforts and made recommendations to the projects for materials for the final systems. Several of the engineers have had prior experience with composite fabrications and this knowledge was drawn together to arrive at the current material choices. There has also been a common SiDet engineering effort involving the measurement of the thermal conductivity of the fibers and finished composites. This information is critical to the thermal management designs of the staves and more importantly the inner layer support structures for Run IIb.

The SiDet engineering group studied carbon fiber cylinder design and tested several prototype cylinders. The focus here was to understand our ability to predict behavior in thin walled cylinders and how to reinforce them to prevent out-of-round distortions that lead to greater displacements of staves within the cylinders. This study verified the importance of the shear deflection component to the total cylinder deflection for certain lay-ups (sets of fiber orientations). This term is typically negligible and therefore is often overlooked. This term has also been found to play an important role in the deflection of the staves themselves unless efforts are made to provide a stiff shear coupling between the two "flanges1" of the stave structures.

The stave mounting has also been a well-discussed topic between the two groups of engineers. This is a critical element in the overall alignment precision and assembly method. While the groups have chosen different solutions, the discussions about tolerance build-up, attainable fabrication tolerances for modules, staves, bulkheads and support assemblies have been quite fruitful for both groups.

The innermost layers of both detectors draw directly from the CDF L00 design and experience. Again due to differences in overall tracking system performance, pattern recognition (occupancy) studies have driven DØ to choose finer longitudinal segmentation than CDF. In addition both groups are actively addressing problems experienced by L00 with analog cable fabrication and noise pickup in these cables. The two projects are working with different vendors so that both may arrive at solutions with

1 The stave structure can be thought of as an I-beam. The carbon fiber plates that provide the majority of the bending stiffness are likened to the flanges of the I-beam. The web of the I-beam carries shear between the flanges. In the case of the CDF stave shear is carried primarily by the Rohacell and this term is non-zero. DØ has engineered a stiff composite C-channel that carries the shear, eliminating shear deflection.

the other vendor as a backup. Initial noise studies have been done by DØ, using spare L00 parts initially, and these results shared with the CDF group at a Liaison meeting. Studies are ongoing by both CDF and DØ and results will continue to be shared between the groups. The support structures are nearly identical to the L00 structure, however the thermal management situation is more demanding than in Run IIa due to the larger integrated radiation dose expected. The U. Washington group on DØ has made significant progress in developing new carbon fiber lay-ups that better address the thermal management issues than the original L00 structure. This information has been passed along to the CDF engineers at Fermilab who are working with Liverpool to develop the CDF structure for Run IIb. Both the UW and Liverpool groups have been supplied with high conductivity carbon fiber prepreg purchased through SiDet for these development efforts. The thermal conductivity measurements from SiDet provide a critical input for the design of these structures.

Tooling design is a large area where ideas have been shared and in some cases plagiarized designs nearly completely. The PEEK tube-bending tool is common to the two projects and the mold designs for flattening the tube, while different to account for differences in final tube geometry, share many common features and fabrication methods. In this case the CDF CAD parts were copied and modified to generate the DØ parts and drawings. Module assembly fixture concepts developed by CDF in Run IIa have been adapted for Run IIb for both CDF and DØ. While the exact implementation is somewhat different, the basic concept has been recycled efficiently. The engineers continue to talk regularly to get ideas and share clever design features so that these can be incorporated into the tooling for both projects. In addition, the technicians that will be using the fixtures in production have been brought into the loop early to provide input based on their Run IIa experience and feedback from experience with prototype Run IIb fixtures, with the goal of producing fixtures that will produce high quality parts with high reliability and efficient use of resources, both human and equipment, particularly the CMMs and wire bonding machines.

## High Level Comparisons: Cost

Costs are compared for parts in the 2 detectors. Labor for testing or design at collaborating institutions is explicitly taken out to make this comparison. These costs are in FY02 dollars with no indirect costs included.

| | DØ ((M$) | CDF (M$) |
|---|---|---|
| Sensors | 2.04 | 1.61 |
| Electrical | 4.25 | 4.26 |
| Mechanical | 1.15 | 1.78 |
| **Total** | **7.44** | **7.65** |
| | | |

## Labor

| | DØ | CDF |
|---|---|---|

| | | |
|---|---|---|
| Physicist | 136,750 | 65,042 |
| Technical (Fermilab) | 110,396 | 72,818 |
| Technical (nonFNAL) | 18,844 | 0 |