SiD Tracker Material
V0.23

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1 Introduction

This document describes the current understanding of material necessary for an ILC tracking detector based on the SiD detector concept and utilizing short silicon readout modules. While no description of detector material is ever complete or perfectly precise, a reasonable model of this material is necessary to estimate multiple scattering and secondaries that impact the physics mission of the tracker. The detector components will be described briefly, accompanied by an accounting of the material these they represent.

2 Description of Components

The detector itself is divided into two segments, barrel and endcap. In addition, there are various components necessary for mechanical support, power supply and electronic readout. These three groups of material are discussed separately in the following sections.

2.1 Barrels

The material in the barrels includes the cylindrical carbon fiber supports, the modules (including the silicon sensors) and module mounts, and the readout cables that service the modules. These cylinders and the components that cover their outer surfaces are described in the following sections.

2.1.1 Barrel Supports

The barrel supports are continuous cylinders formed from a sandwich of pre-impregnated carbon fiber composite around a Rohacell core. The rough dimensions of these cylinders are given in Table 1. Table 2 summarizes the material in these cylinders.

Layer	Radius(m)	Half-length(m)
1	0.200	0.267
2	0.463	0.617
3	0.725	0.967
4	0.988	1.317
5	1.213	1.617

Table 1: Geometry of the SID tracker barrels from March 2001.

Component	Material	X_0(mm)	Thickness(mm)	Coverage	Average Thickness (mm)	Average $\#X_0$(%)
Inner skin	CF	242	0.25	1.0	0.25	0.103
Core	Rohacell	13800	13	1.0	13	0.0942
Outer skin	CF	242	0.25	1.0	0.25	0.103
Total	—	—	—	—	—	0.300

Table 2: Material summary for barrel support cylinders.

2.1.2 Modules

The modules are the smallest functional unit of the silicon tracker. The design discussed here utilizes small, 10cm×10cm modules to tile the outside surface of the cylinder. Modules are comprised of a carbon-fiber composite frame with rohacell/epoxy cross-bracing and have a single-sided silicon sensor bonded to the outer surface. Modules are attached to the cylinder using a PEEK mounting clip. The readout chips and cables are mounted directly to the outer surface of the silicon sensors. The cables supply power and control to the readout chip from electronics located at the ends of the barrel, as described in Section 2.3.1. Table 3 summarizes the material in the modules and modules mounts. Table 4 summarizes the material in the readout cables. It should be noted that overlaps in ϕ and z must be assumed: simple factors can be applied to the averages shown to arrive at estimates that account for this effect. Additionally, due to inactive regions at the edges of sensors

Component	Material	X_0(mm)	Thickness(mm)	Coverage	Average Thickness (mm)	Average $\#X_0$(%)
Mounting Clip	PEEK	287	1.0	0.2	0.2	0.070
Frame	CF	242	4	0.04	0.16	0.066
Bracing	Rohacell	13800	4	0.35	1.4	0.010
Adhesive	Epoxy	290	0.5	0.35	0.175	0.060
Sensor	Silicon	93.6	0.3	1.0	0.3	0.321
Chip	Silicon	93.6	0.3	0.016	0.0048	0.005
Total	—	—	—	—	—	0.532

Table 3: Material summary for barrel silicon modules. Materials are listed roughly in inside-out order, and are applied to the outside of all cylinders.

Component	Material	X_0(mm)	Thickness(mm)	Coverage	Average Thickness (mm)	Average $\#X_0(\%)$
Layer 1 Cable	Kapton	284	0.1	0.38	0.038	0.013
Layer 1 Traces	Copper	14	0.017	0.22	0.0038	0.027
Layer 2 Cable	Kapton	284	0.1	0.51	0.051	0.018
Layer 2 Traces	Copper	14	0.017	0.30	0.0052	0.037
Layer 3 Cable	Kapton	284	0.1	0.64	0.064	0.023
Layer 3 Traces	Copper	14	0.017	0.38	0.0065	0.046
Layer 4 Cable	Kapton	284	0.1	0.78	0.078	0.027
Layer 4 Traces	Copper	14	0.017	0.46	0.0079	0.056
Layer 5 Cable	Kapton	284	0.1	0.91	0.091	0.032
Layer 5 Traces	Copper	14	0.017	0.54	0.0093	0.066
Average/Layer	—	—	—	—	—	0.069

Table 4: Material summary for barrel silicon cables.

Layer	$\|z\|$(m)	Inner Radius(m)	Outer Radius
1	0.300	0.040	0.250
2	0.650	0.079	0.513
3	1.000	0.118	0.775
4	1.350	0.156	1.038
5	1.650	0.189	1.263

Table 5: Geometry of the SID tracker endcap disks from March 2001.

approximately 104% module coverage must be provided simply to achieve 100% coverage of active silicon.

2.2 Endcaps

The material in the endcaps includes annular carbon-fiber/Rohacell disks for module support, modules and module mounts, and readout cables that service the modules.

2.2.1 Endcap Disk Supports

The endcap silicon is supported by annular disks that close the ends of the barrel cylinder supports. In similar fashion to the barrel supports, these disks are formed from a sandwich of pre-impregnated carbon fiber composite around a Rohacell core. The geometry of these disks is summarized in Table 5. Table 6 summarizes the material in these disks.

Component	Material	X_0(mm)	Thickness(mm)	Coverage	Average Thickness (mm)	Average $\#X_0$(%)
Inner skin	CF	242	0.39	1.0	0.39	0.16
Core	Rohacell	13800	25	1.0	25	0.18
Outer skin	CF	242	0.39	1.0	0.39	0.16
Total	—	—	—	—	—	0.500

Table 6: Material summary for endcap support disks.

2.2.2 Endcap Silicon Modules

No detailed design currently exists for the forward sensor modules, however it is presumed that they will be very similar to those used in the barrel. The baseline concept for forward tracking requires double-sided modules. As a result, the silicon and readout material must be duplicated for the forward sensor modules. For the time being the material discussed in Section 2.1.2 is assumed to exist on the outer surface of the disks and is accompanied by the material required to make these modules double-sided. This includes additional sensors and readout chips as shown in Table 3 and a second set of cables as in Table 4. Note that no adjustment is currently made to account for a larger cable count at small radius in the case that the module size depends upon radius. In addition, cable lengths, and thus material, are assumed to be the same as those in the barrel. These details can be refined as the design of the forward tracking matures.

2.3 Support Material

In addition to the barrel and endcap material described in the previous sections, there are other components necessary for the mechanical support, power supply and electronic readout of the tracker. These include the barrel support rings that tie together the barrels along with the power and readout distribution system for the detector.

2.3.1 Barrel Support Rings

Annular rings extend radially outward from the ends of the cylinders (the edges of the endcap disks) to the next barrel for support. The geometry of these rings is summarized in Table 7. Table 8 summarizes the material in these support rings. Although no detailed design exists, it is assumed that these rings will be “spoked” to reduce material and allow access to the barrel silicon modules. While this may reduce the material in these rings, the current estimate does not yet include mounting hardware and other material in the region needed to support power and readout distribution boards for the endcap disks. Such an addition to the disks would presumably occupy the region where material would be removed from the support rings.

Layer	$\|z\|$(m)	Inner Radius(m)	Outer Radius
1	0.267	0.200	0.463
2	0.617	0.463	0.725
3	0.967	0.725	0.988
4	1.317	0.988	1.213
5	1.617	1.213	1.27

Table 7: Geometry of the barrel support rings based upon the March 2001 geometry.

Component	Material	X_0(mm)	Thickness(mm)	Coverage	Average Thickness (mm)	Average $\#X_0(\%)$
Support Ring	CF	242	1.5	1.0	1.5	0.62
Total	—	—	—	—	—	0.62

Table 8: Material summary for barrel support rings. This accounting likely overestimates material in the support rings but does not currently include necessary mounting hardware or a mounting location for endcap power and readout distribution.

2.3.2 Readout and Power Distribution

Mounted on the annular barrel-support rings are electronic circuit boards and cables that distribute power to and readout from entire segments of the detector. It is taken as given that a single power cable and board will service at least one ϕ segment in a barrel layer: that it will be capable of supplying $\approx$20 modules. Further, endcap modules are assumed to have the same area as barrel modules for radii larger than 0.25m: 100 cm^2. At smaller radii, endcap modules are taken to be 25 cm^2. Finally, these modules are taken as double-sided and thus have two power/readout cables per module. Assuming the need to accommodate as much as 5% overlap in both dimensions covered by the modules, the approximate number of readout boards required is shown in Table 9.

To obtain a rough estimate of the material necessary, it is assumed that each will require a 100cm^2 G10/FR-4 printed circuit board that is 3mm thick and contains a complete layer of copper with

Layer	# Barrel Readout Boards	# Endcap Readout Boards	Layer Total
1	4	6	10
2	17	16	33
3	25	24	49
4	68	44	112
5	84	64	148
Totals	198	154	352

Table 9: Number of power and readout distribution boards needed to service the barrel and endcap modules of each layer in groups numbering no more than twenty. These estimates can accommodate 5% overlap in both dimensions covered by the modules of the barrels and endcaps.

Component	Material	X_0(mm)	Thickness(mm)	Coverage	Average Thickness (mm)	Average $\#X_0(\%)$
L1 Circuit Board	G10	194	3.0	0.19	0.57	0.29
L1 Circuit Board	Copper	14	0.2	0.19	0.038	0.27
L2 Circuit Board	G10	194	3.0	0.34	1.02	0.53
L2 Circuit Board	Copper	14	0.2	0.34	0.068	0.49
L3 Circuit Board	G10	194	3.0	0.36	1.08	0.56
L3 Circuit Board	Copper	14	0.2	0.36	0.072	0.49
L4 Circuit Board	G10	194	3.0	0.62	1.86	0.96
L4 Circuit Board	Copper	14	0.2	0.62	0.124	0.89
L5 Circuit Board	G10	194	3.0	0.82	2.46	1.27
L5 Circuit Board	Copper	14	0.2	0.82	0.164	1.17

Table 10: Material summary for power and readout electrons mounted on barrel support rings. Materials are listed roughly in inside-out order. The material is assumed to be spread evenly over the surface of the annular rings.

0.2mm thickness. In order to reduce the material needed to provide power to the detector, we envision supplying these boards with DC power at a higher voltage and converting to the necessary low-voltages at the boards. It is currently thought that the components necessary, including the supply cables, are negligible compared to the material represented by the circuit boards themselves. The resulting estimate of the material necessary for power and readout distribution is summarized in Table 10. For layers one through four, this material is mounted on the outside of the annular barrel support rings. Due to the small size of the outermost support ring (that supports the entire tracker), the power and readout distribution for layer five must be mounted separately. For layer five, this material is assumed to be spread over an annular region that is similar to the barrel support for layer four but at larger z: $|z| = 1.65$ m, inner radius = 0.988 m, outer radius = 1.213 m.

3 Undocumented Material

This section serves as a placeholder and reminder for components of the tracker that have not yet been modeled, but which contribute significantly to the material. Of these, the most important element for which no material estimate exists is the mounting hardware that attaches the various barrels and disks to their supports. This material is concentrated in the same region that hosts the readout and power distribution electronics, and it is in this area that more work is needed to gain a real understanding of the material budget for the SiD tracker.