Dimensional tolerances of the SCT module

1 Introduction

ATLAS has already agreed on some alignment requirements which are derived from physics performance arguments [TDR Volume I Table 9-5]. There are also some proposed mechanical tolerances for modules [TDR Volume II, section 11.5.2.2] but the TDR does not go into full detail. The aim of this note is to give detailed tolerances for internal module alignment which can be used as a starting point for engineering discussions. This involves translating from well defined r.m.s. values to tolerances where one knows nothing of the distribution of points within the allowed range. We assume a flat distribution of points within the tolerance range, this is slightly pessimistic but not the most pessimistic assumption. If we were highly pessimistic we would have to reduce the tolerances by a factor 0.6 to be sure of having a low enough r.m.s.

2 Axes

We define a local coordinate system within the module in a way that works for both barrel and forward modules; y is along the direction of the central strip, x is perpendicular to y and in the plane of the module, and z perpendicular to the plane of the module. The directions of x and y are shown in Figure 4 and the direction of z is chosen so as to make a right-handed coordinate system.

3 Physics requirements

The physics depends only on the accuracy with which we finally know the position of each readout strip. Assuming that the errors are random we can tolerate errors of the magnitude shown in Table 1 without significantly degrading the performance of the tracker.

Direction (cyl. coords)	Alignment accuracy r.m.s. (microns)	
	Barrel	Forward
R	100	50
ϕ	12	12
z	50	200

Table 1: Physics requirement for the final alignment errors of SCT strips.

We will assume that the module must be built with internal alignment errors which are small compared with the total errors, because aligning the modules in space will be so difficult that we had better save most of the allowable uncertainty for that part. Somewhat arbitrarily, this can be done by dividing the numbers in Table 1 by three; ie. by choosing that only 1/9 of the total squared error will come from internal alignment uncertainty. In the forward region this is simple because the local coordinates point in the same direction as the cylindrical coordinates. But in the barrel, the ϕ direction is a mixture of the local x and z directions because of the 10 degree tilt of the modules. So for the barrel we must divide the allowed 4 micron r.m.s. in ϕ somehow between x and z such that;

$$4^2 = (\sigma_x \cos 10)^2 + (\sigma_y \sin 10)^2$$

This leads to the tight requirements for the barrel shown in the first column of Table 2. Alternatively, we might relax the requirements in the barrel somewhat and allow 1/9 of the total ϕ error to come from internal x error and another 1/9 to come from internal z error. This would lead to the values in the second column of Table 2.

In principle it would be possible to build the modules less accurately that this and then measure them afterwards, saving a set of internal alignment constants for each module in the database. However we have chosen not to go down this route because of the extra complexity it would add to all future track reconstruction software. Instead

we propose to build the modules sufficiently accurately that the notional "internal alignment constants" can be assumed to be zero.

Local Direction	Alignment accuracy r.m.s. (microns)		
	Barrel	Barrel relaxed	Forward
x	3	4	4
y	17	17	17
z	15	23	66

Table 2: Requirements for the internal alignment of the four wafers in SCT modules.

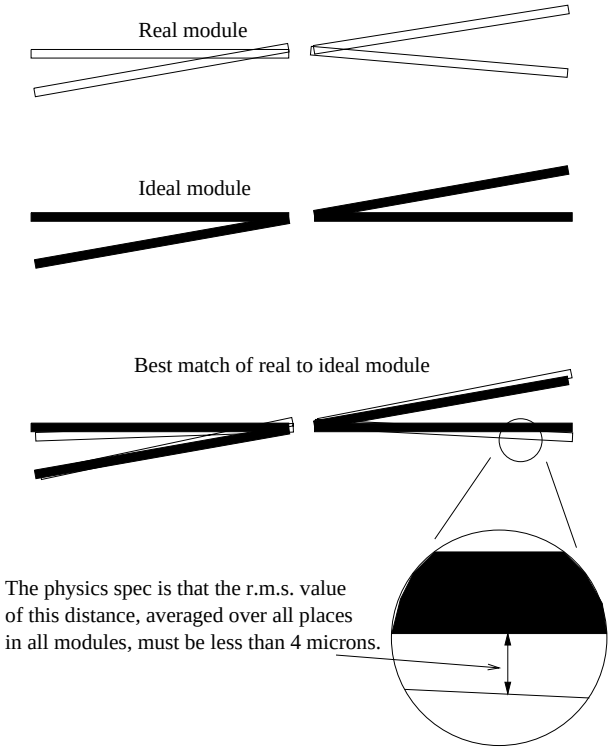

Figure 1: Definition of the r.m.s. x error. Each wafer is represented by its central strip.

3.1 Definition of internal alignment x error.

The 4 micron internal alignment error in the x direction needs to be carefully defined because it will be the most difficult to achieve. We expect that this internal error will only become significant in the last alignment step which will use tracks to reach ultimate precision. In track-based alignment the module is treated as if it had perfect internal alignment and data from hits in any of the four wafers is used to find the position of the module in space. In this procedure there is no preferred wafer; the reference wafer is no longer special. The result will be to find a position for the "ideal" module which best fits the track data. The total error on the strip positions will now be the quadratic sum of the error in the position of the ideal module and the difference between ideal and the real module. Now the ideal module which we must compare with the real one is not one where the reference wafer exactly coincides but one which is positioned so as to minimise the r.m.s. x error. Figure 1 shows this definition of the x error with a series of diagrams which represent each wafer by its central strip. (This representation is

justified because the variation of x error from strip to strip is negligible.) We have not discussed the y error here because 17 microns in the y direction should be achievable with a jig which matches the x requirements.

4 Tolerances in the x, y plane.

In contrast to the previous section, when building and surveying a module it is convenient to define one wafer in a module to be the reference wafer. We define the reference wafer to be one of the pair which faces away from the module mounting surface, so that it will be visible when the module is mounted on the support structure. In forward modules we choose the reference wafer to be the one which is nearer to the hybrid, while in barrel modules we choose the reference wafer to be the one which is not obscured by the bridge hybrid.

Figure 4 defines a number of points, distances and angles in the x, y plane. We must select a set of these dimensions which fully specifies the module without over-constraint. The scheme that we have chosen, in consultation with RAL engineers, is the one which uses only distance measurements on the fiducials and requires the same distance tolerances in both y and x directions. This is natural because the stages and measurement system which we will use to build and survey the modules are expected to have intrinsically the same accuracy in both directions. We use wafer number 1 as the main reference and we assume that the tightest tolerances can be applied to the relative position of a pair of wafers on the same side of a module. Wafer 3 is used as a secondary reference; it is believed that positioning wafer 3 relative to wafer 1 will be the crucial part in building a module within spec. The tolerances required to meet the 4 mircron r.m.s. internal accuracy are specified in Table 3 and the distribution of the internal x error is shown in Figure 2.

Dimension	Engineering Tolerance
Xp12, Yp12 , Yq12 Xp34, Yp34 , Yq34	$\pm$4.0 microns
Xp13, Yp13, Yq13	$\pm$8.0 microns
Xp1H, Yp1H	$\pm$30 microns
A1HS	$\pm$0.5 milliradians

Table 3: Tolerances required for the internal alignment of a module to 4 microns r.m.s. Dimensions are assumed to have a " top hat" distribution within the range allowed by the engineering tolerance.

Figure 2 also gives values for the alignment of the mounting hole and slot relative to the reference wafer. These values were derived by assuming that an adjacent pair of modules should be correctly positioned relative to each other to an accuracy of about 100 microns to maintain enough overlap for track hermeticity.

5 Tolerance in the z direction

The module position in this direction is defined by the surface which makes contact with the cooling block(s). The module is fairly flexible in this direction and its shape will depend on how it is mounted. (is there any significant sag under gravity ??) So our specification must include the mounting method. We propose that the module is mounted without grease on dummy cooling block(s). The dummy block surfaces should have negligible (< 10 microns) deviation from flatness and coplanarity. All details of the mounting, eg dowels, screws, spring clips, torque of screws, etc., should be exact replicas of the real mounting.

When mounted in this way the maximum allowed deviation of the wafer surfaces from the plane of the cooling blocks must then be within some limits as shown in Figure 3. We propose that these limits be $\sqrt{3}$ times the r.m.s. values in Table 2; for the barrel 26 (or 40 ?) microns and for the forward 115 microns. Any reasonable distortion of the module which stays within these limits will have a r.m.s. error in the z direction which is consistent with Table 2.

If it turns out that we can not build modules which meet this z tolerance then we will have to measure the wafer surface at a number of points and record the results in the database.

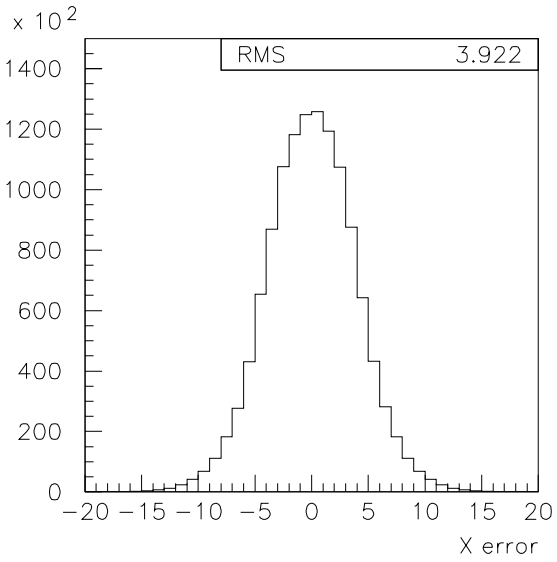

Figure 2: This plot shows the distribution of internal x residuals that would result from using the tolerances given in Table 3 if the build errors had a flat distribution between the tolerance limits. This just goes to show how a few "top-hat" distributions combined together very quickly approach the Gaussian shape.

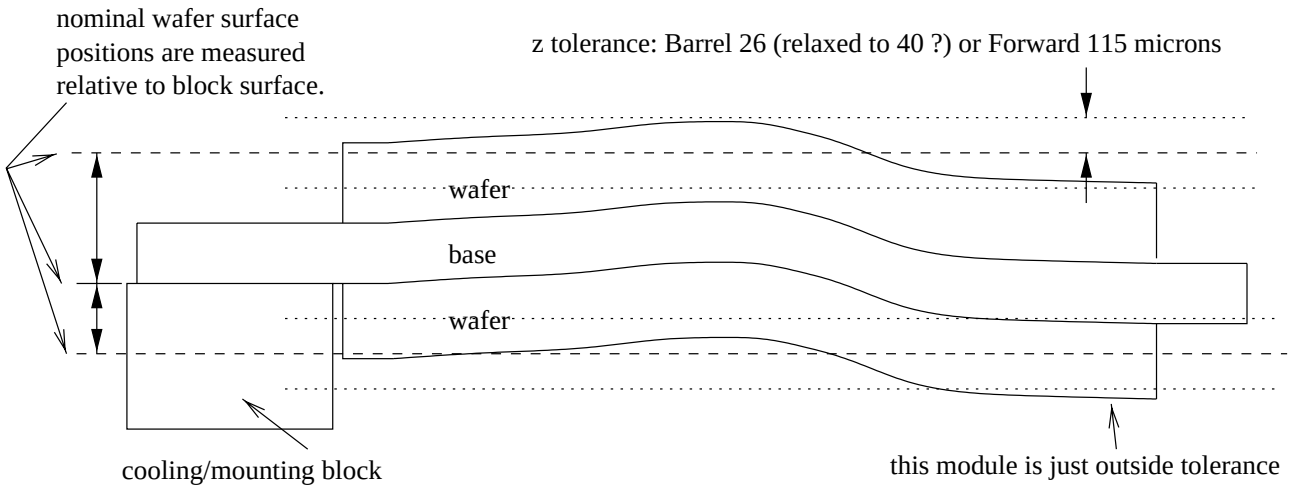

Figure 3: Definition of the z tolerance.

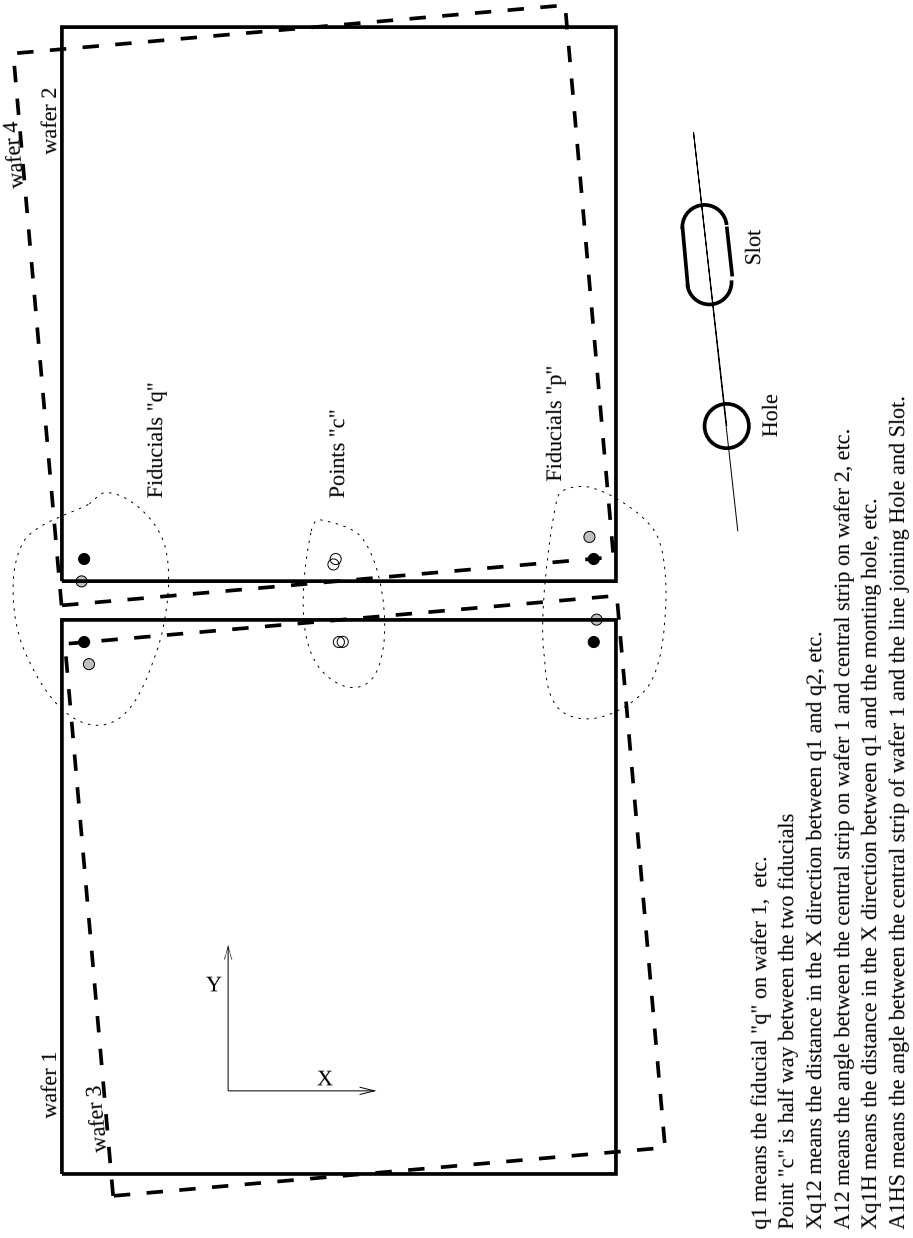

Figure 4: Definition of points on a module.

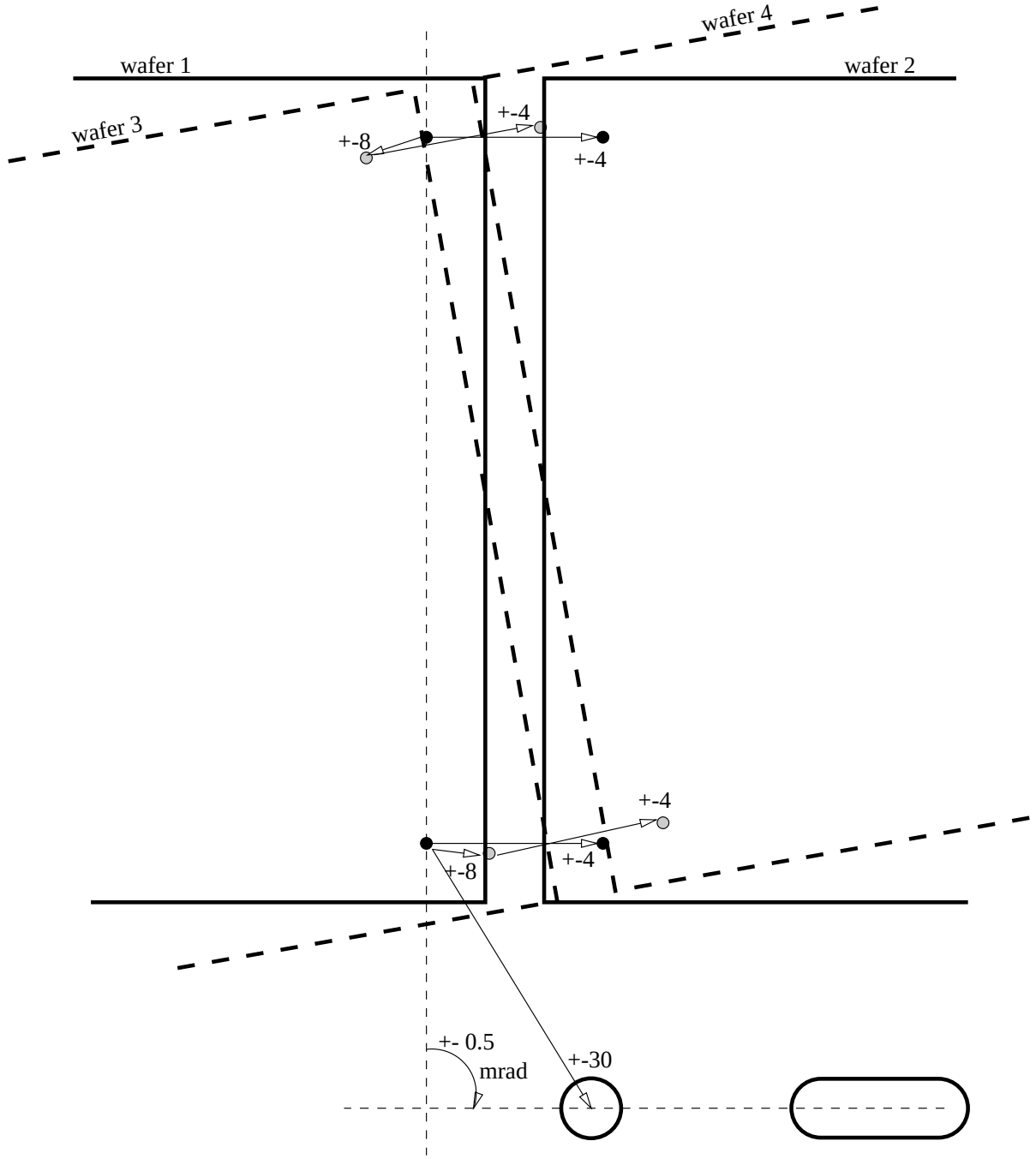

Figure 5: Summary of the tolerances.