Module Overlaps in the SCT and Pixels

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July 2002

Abstract

This short note summarises extent of the overlaps in the Barrels and Wheels of the SCT and Pixel silicon trackers. These overlaps are very valuable for the Offline Alignment.

ATL-INDET-2002-016
05/08/2002

1. Introduction

1.1 The Significance of Overlaps

The Offline Alignment of the Inner Detector will be performed using tracks from collision data [1]. The Alignment Constants will be obtained by minimising hit residuals. The tracks which connect sets of silicon detectors can be thought of as being like metal rods, providing transverse rigidity; although with no longitudinal constraint, as if the rods were only constrained by holes through the detectors. Tracks passing through the overlaps between adjacent Modules provide particular stiff constraints because there is less uncertainty in the track extrapolation arising from uncertainty in the track parameters and, in particular, multiple-scattering. The *difference of the residuals* for tracks which are contained in the overlap of a pair of Modules gives the relative azimuthal shift of one Module relative to the other.

When the overlaps are considered for the Modules in complete rings on either Barrels or Wheels, there is the very powerful constraint arising from the fact that in evaluating the alignment corrections all the way around the ring, having "completed the circle", there must be consistency. Lack of consistency can be interpreted as a change in the mean radius of the ring. If an overlap is lost at any point in the ring (due to no overlap or a dead Module), then it is impossible to "complete the circle". Of course, all is not lost – the concept of an "overlap" is a relative one: adjacent Modules in the same ring on a given Barrel or Wheel will be very close (few mm), but the overlaps can be extended to Modules on the next Barrel or Wheel which may be a few cm away. Nevertheless, the ability to consider the consistent alignment of Modules within a single Barrel or Wheel, which will be more stable than a complete Barrel sub-detector or End-cap, is very appealing.

Currently, two approaches to the Offline Alignment are being investigated:

1. Simple approach in which the overlaps will be considered explicitly [2].
2. Complex approach where a χ^2 containing all residuals, irrespective of where they have come from, will be minimised. In this approach, there will be no special handling of the overlaps, but the statistical power which they contain will be exploited [3].

How much overlap is needed? It was shown in the Physics TDR [4] that a 1% overlap is sufficient to obtain satisfactory alignment precision on a suitable time-scale. Further, it would be desirable to have at least 10 strips/pixels. It should also be borne in mind that single hits cannot be used in the edge strips/pixels (since it is unclear whether all the charge deposited in the silicon is collected by the active diodes) and there will be positioning errors, which for the SCT will be of the order of 100-200 μm for one Module relative to its neighbour. So ideally the overlaps should be ≥ 10 strips/pixels.

1.2 Beam Displacement and the Relevant Track Momenta

A further consideration for the overlaps is the fact that the cavern and hence ATLAS may move relative to the beam-line. A vertical displacement of the beam will mean that at one horizontal position, the overlaps seen from the beam spot will be reduced while diametrically opposite, the overlap will be increased, with little change in the vertical plane. It has been proposed that we should consider the effects of a 10 mm movement of the beam which is uncorrected.

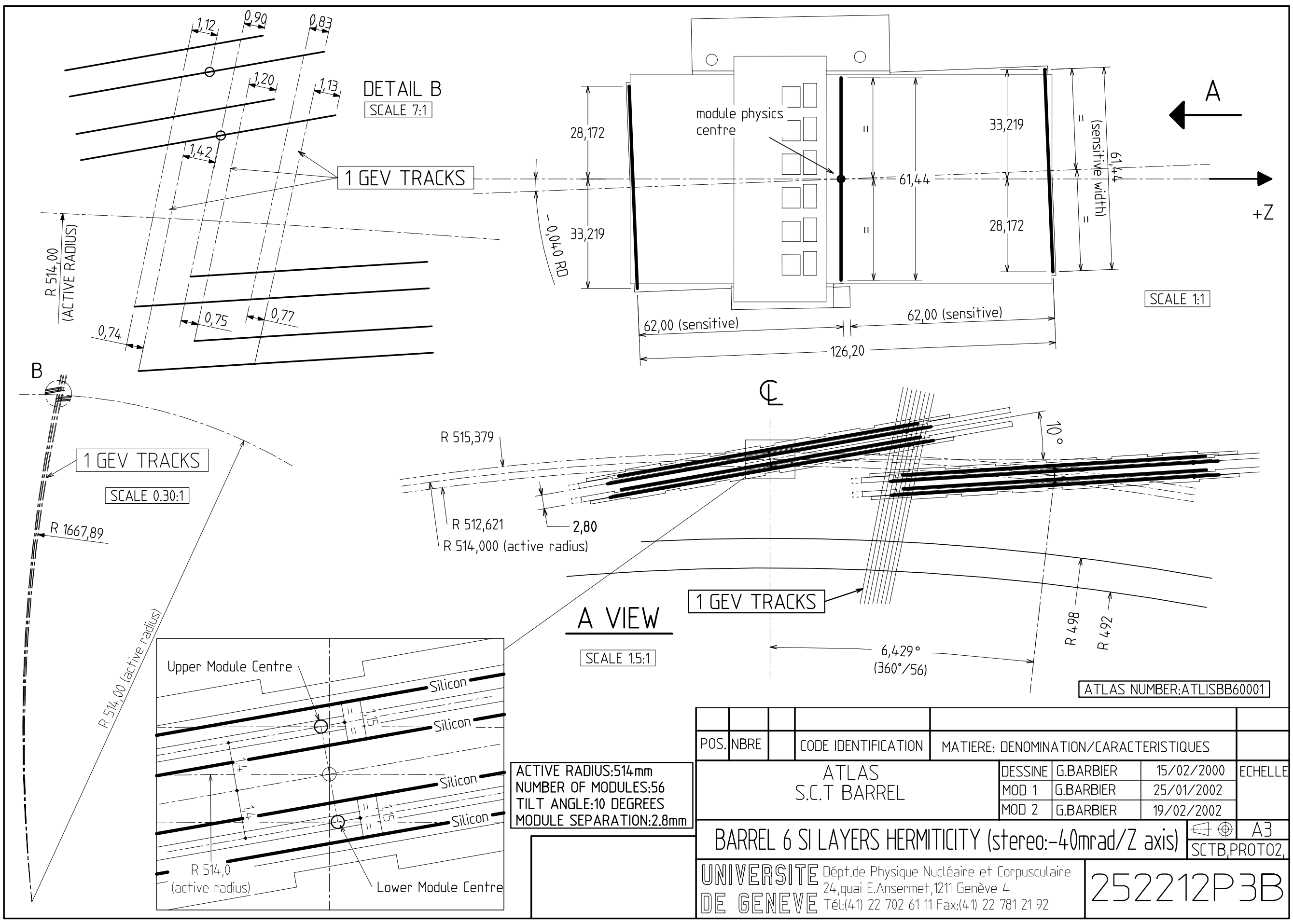
For the alignment, the best information will come from the high-momentum tracks – although there will be fewer of them, they will not suffer so badly from multiple-scattering. Nevertheless, it will be useful to use the high statistics provided by lower-momentum tracks (down to 2 GeV) – the statistical precision of the high and low-momentum samples will be comparable [4]. To avoid potential systematic effects, it would be good to use a mixture of positive and negative-charged tracks; nevertheless there will be more of one change sign of tracks passing through the overlaps, depending on the sign of the Module tilt. If a satisfactory overlap is seen by radial (infinite momentum tracks), then there will be plenty of tracks of one sign. Hence, for the alignment, the emphasis is placed on high-momentum tracks – but for hermeticity, one should consider down to 1 GeV for both signs of charge. The dependence on momentum is proportional to $1/p_T$, hence the overlap for a 2 GeV track will be half way between that for a radial and 1 GeV track.

2. SCT

2.1 Barrel

The SCT Barrel geometry is quite complicated since the Modules consist of two planes of silicon, one of which is rotated in-plane by the stereo angle of 40 mrad. Various relevant drawings can be found in CDD [5], an example of which (drawing 252212P3B) is shown in Figure 1.

Figure 1: SCT Barrel 6 with 10° tilt (Geometry #1). Overlaps are shown in top left corner.



To understand the geometry and to investigate different tilt angles and radii, I wrote a small program, allowing for:

- Module positions, including tilt angles
- Silicon dimensions
- Silicon separation
- Tilt angles

Allowance was made for

- Track momenta
- Vertex displacement from y=0

Four different geometries were considered:

Geometry #1. Old default geometry with 10.0^o tilt

Geometry #2. 10.5^o tilt

Geometry #3. 11.0^o tilt

Geometry #4. 11.0^o tilt and radius of Barrel 3 increased from 299 to 299.5 mm

The results are shown in the Table 1. For some of the numbers, the corresponding numbers can be found on the Engineering drawings and generally are in excellent agreement. However, there are some exceptions where there are differences of 160 μm (2 strips), and I suspect the numbers on the drawings are wrong.

The most important numbers for the alignment correspond to the overlaps seen on the axial (phi) strips by the high-momentum tracks. It can be seen that these overlaps are in the range 1-2 mm for no vertex displacement and above 0.8 mm (10 strips) for a 10 mm shift. If two edge strips are excluded from the overlap, this corresponds to 0.160 mm, and the placement precision of one Module to its neighbour should be better than 0.1-0.2 mm.

From the table, it can be seen that there are some holes for low-momentum (of one sign), in particular, for the stereo layers and also if the vertex is displaced by as much as 10 mm.

Conclusion

The overlaps in Geometry #4 are satisfactory and reasonably robust to vertex displacement.

Table 1: Overlaps in the SCT Barrels.

Barrel SCT Overlaps (mm)

Layout	Tilt	p_T	y vtx	Barrel 3				Barrel 4				Barrel 5				Barrel 6			
	deg	GeV	mm	Axial	Stereo	Axial	Stereo	Axial	Stereo	Axial	Stereo	Axial	Stereo	Axial	Stereo	Axial	Stereo	Axial	Stereo
1	10	1	0	**1.044**	**0.774**	**0.513**	**0.242**	**1.056**	**1.179**	**0.633**	**0.756**	1.263	1.07	0.912	0.719	**1.206**	**1.281**	**0.907**	**0.981**
1	10	1000	0	2.024	1.752	1.49	1.218	2.27	2.393	1.845	1.968	2.716	2.52	2.362	2.166	2.894	2.968	2.591	2.665
2	10.5	1	0	**0.901**	**0.631**	**0.372**	**0.102**	**0.902**	**1.024**	**0.48**	**0.603**	**1.097**	**0.905**	**0.748**	**0.555**	**1.03**	**1.104**	**0.732**	**0.806**
2	10.5	1000	0	1.929	1.658	1.398	1.126	2.176	2.298	1.752	1.875	2.621	2.425	2.268	2.073	2.799	2.873	2.498	2.571
2	10.5	1	10	0.514	0.248	-0.007	-0.272	0.591	0.712	0.176	0.297	0.834	0.644	0.489	0.299	0.804	0.877	0.509	0.582
2	10.5	1000	10	1.546	1.278	1.021	0.753	1.87	1.99	1.45	1.571	2.363	2.169	2.014	1.82	2.578	2.651	2.28	2.352
3	11	1	0	0.753	0.484	0.226	-0.043	0.743	0.865	0.324	0.446	0.926	0.735	0.579	0.387	0.849	0.923	0.552	0.626
3	11	1000	0	1.829	1.559	1.3	1.03	2.077	2.198	1.655	1.777	2.521	2.326	2.17	1.975	2.7	2.773	2.4	2.473
3	11	1	10	0.347	0.083	-0.17	-0.435	0.418	0.538	0.005	0.125	0.652	0.462	0.309	0.119	0.613	0.685	0.32	0.392
3	11	1000	10	1.428	1.161	0.906	0.639	1.756	1.876	1.339	1.459	2.251	2.058	1.904	1.711	2.469	2.541	2.171	2.243
4	11	1	0	0.651	0.383	0.124	-0.144	0.743	0.865	0.324	0.446	0.926	0.735	0.579	0.387	0.849	0.923	0.552	0.626
4	11	1000	0	1.729	1.459	1.2	0.93	2.077	2.198	1.655	1.777	2.521	2.326	2.17	1.975	2.7	2.773	2.4	2.473
4	11	1	10	0.247	-0.017	-0.271	-0.535	0.418	0.538	0.005	0.125	0.652	0.462	0.309	0.119	0.613	0.685	0.32	0.392
4	11	1000	10	1.328	1.061	0.807	0.539	1.756	1.876	1.339	1.459	2.251	2.058	1.904	1.711	2.469	2.541	2.171	2.243

Notes:

- The *Axial* strips are the "phi-strips"; the overlaps for the *Stereo* are averaged over the two ends – differ by ±0.2 (0.1) mm at inner (outer) radii.
- For each Barrel, the first pair of numbers relate to a lower Module (smaller radius); the second pair to a higher Module.
- The *bold* numbers have been cross-checked with the drawings on CDD and agree to 0.010 mm; those which are *underlined* disagree by 0.160 mm (2 strips).
- My calculations are only accurate to O(0.010) mm.
- The effect of the vertex shift in y is given at the worst position in azimuth.

2.2 Wheels

The SCT End-cap Modules have a "key-stone" geometry – that is, the phi strips point to the nominal beam line. The geometry is described in [6].

There are 40 Modules, each of 768 active strips of 0.20700 mrad each in the Inner and Middle Rings, giving rise to an overlap of 9.2 strips.

There are 52 Modules, each of 768 active strips of 0.16150 mrad each in the Outer Rings, giving rise to an overlap of 19.8 strips.

The relative placement of the Modules should be better than 0.1 mm (~1 strip).

The effect of different momenta can be seen from:

$$\Delta\varphi = 0.3R\frac{\Delta z}{z}\Delta\frac{1}{p_T}$$

where R is the radius of the Module, z is its position, Δz is the separation between the high/low Modules. The effects are largest on the 1st Wheel (low z) at the largest radius. In going from high-momentum tracks to p_T = 1 GeV, the overlap changes:

Middle Modules: 9.2 → 5.2 strips

Outer Modules: 19.8 → 13.6 strips

The effect of a vertex shift Δy can be seen from:

$$\Delta\varphi = \frac{\Delta y}{R}\frac{\Delta z}{z}$$

For a 10 mm vertex shift, the largest change in the overlap is seen at the inner radius of the 1st Wheel:

Inner Modules: 9.2 → 8.1 strips

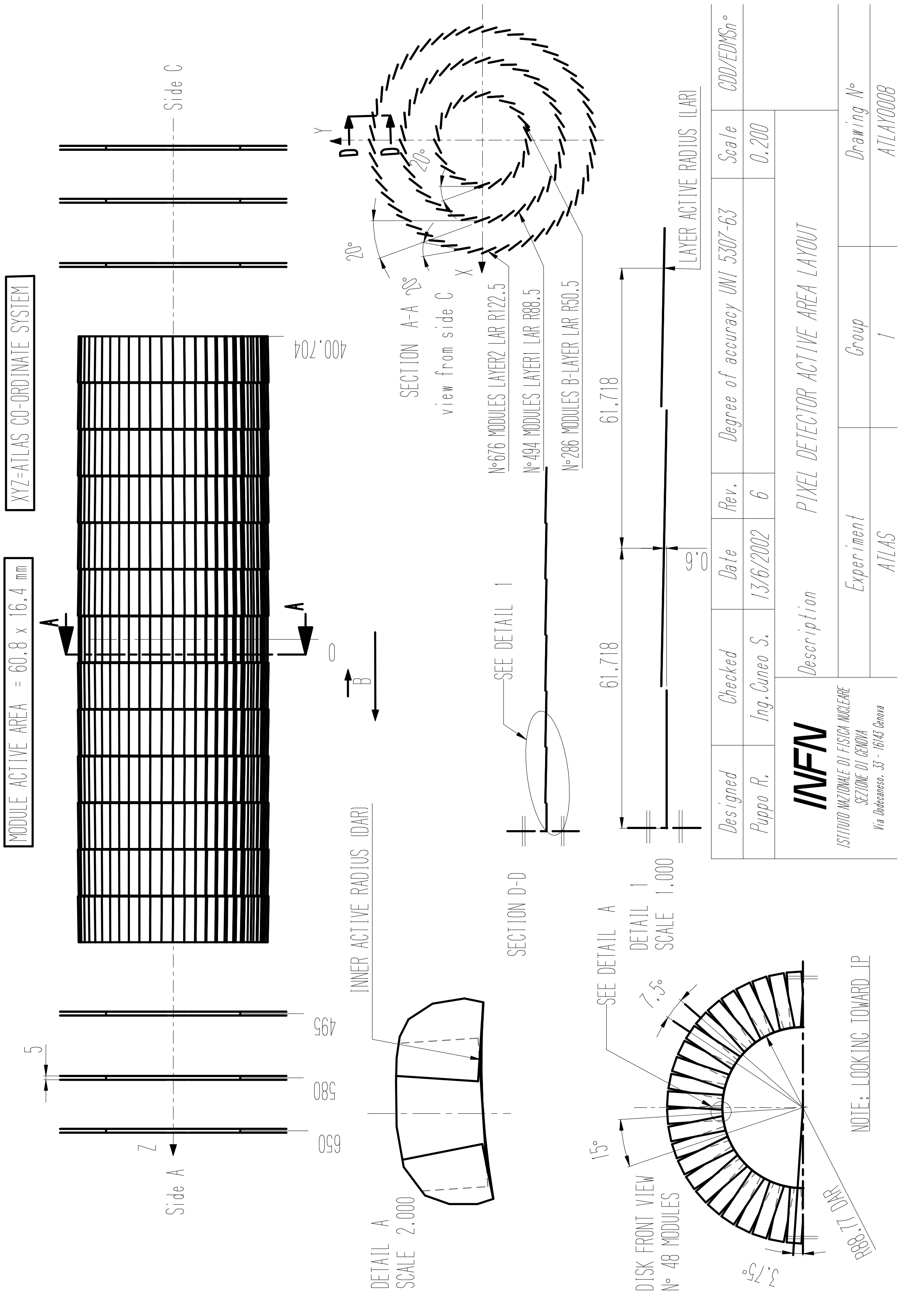
Conclusion

The overlaps are at the limit of what is OK in the Inner and Middle Rings, but fine in the Outer Rings. They are reasonably robust to vertex displacement.

3. Pixels

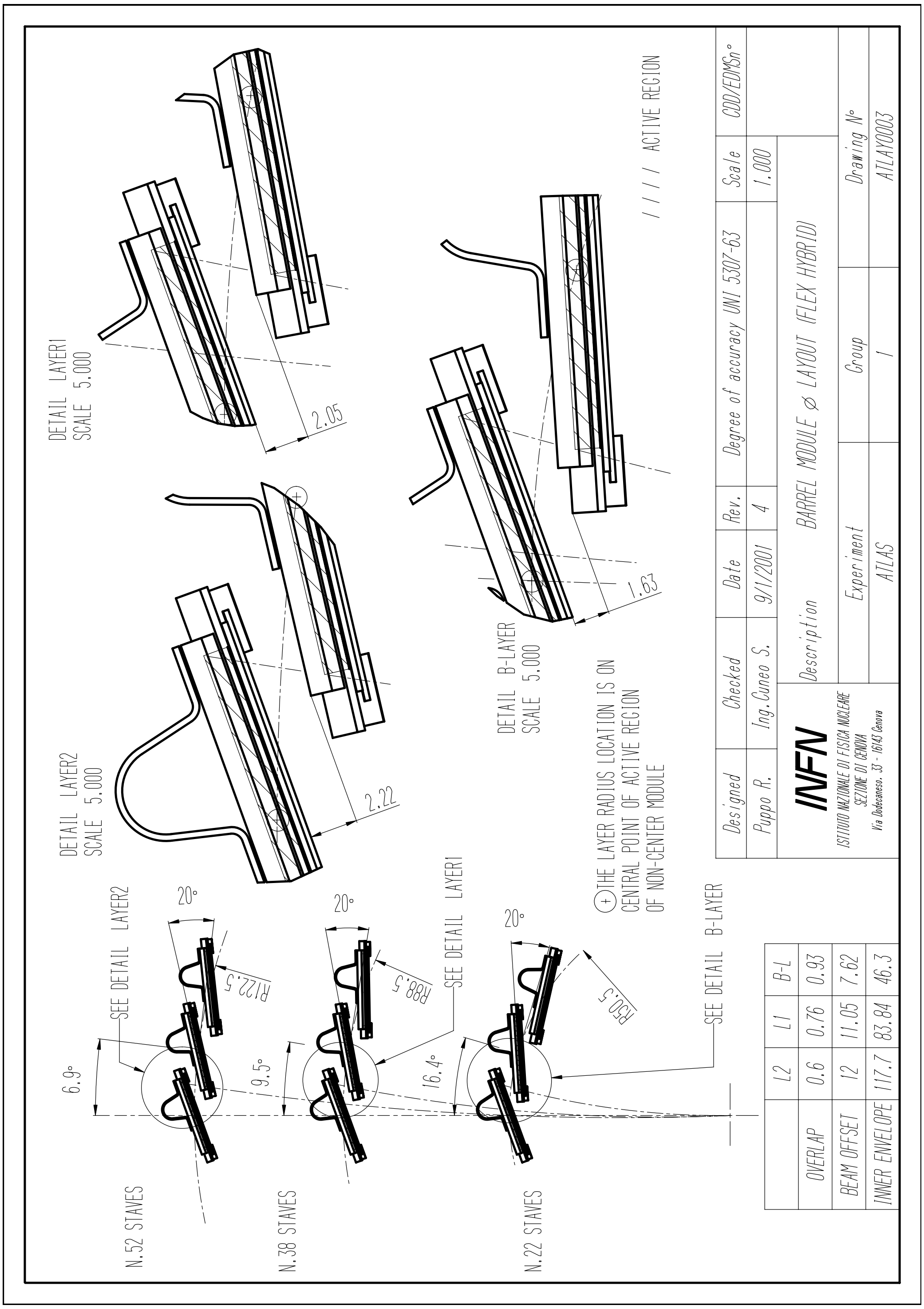
The Pixel Geometry can be found on EDMS [7].

Figure 2: The Pixel geometry.



3.1 Barrel

Figure 3: Pixel Barrel Modules.



The Barrel geometry is complicated by the "shingling" of the modules (see Figure 2), corresponding to a tilt by 1^{o} in the R-z plane (z<0 Modules are tilted one way; z>0 Modules are tilted the other way; those at z=0 are not tilted). I have attempted to evaluate the overlaps at the Module centre in z using my program. I estimate the variations along the module in the overlap are ±0.15, 0.09 and 0.06 mm for the layers B0, B1 and B2 respectively.

The drawing gives the overlaps for radial tracks of 0.93, 0.76 and 0.60 mm for layers B0, B1 and B2 respectively. These numbers should be compared with my calculations of 0.977, 0.781 and 0.612. Further, the vertex displacements for which the overlap is lost (at one azimuth) are given on the drawing as: 7.62, 11.05 and 12 mm for layers B0, B1 and B2 respectively – to be compared to my calculations of 8.4, 12.0 and 13.0 mm. So there are some small differences between the calculations shown on the engineering drawing and my numbers, but these are probably explained by an inadequacy of my description of the geometry. I conclude that the level of agreement is sufficient to trust the following results.

Table 2: Overlaps in the Pixel Barrels.

p_T	y vtx	Barrel Pixel Overlaps (mm)		
(GeV)	(mm)	Barrel 0 (B-layer)	Barrel 1	Barrel 2
1	0	0.887	0.627	0.401
1000	0	0.977	0.781	0.612
1	10	–0.273	–0.027	–0.068
1000	10	–0.182	0.128	0.143

Conclusion

The overlaps are at the limit of what is OK – it would be preferable if they were at least 0.600 mm. They are **not** robust to vertex displacement.

3.2 Wheels

The layout of the Modules on the Pixel Wheels can be seen in Figure 2. There is significant overlap at lower radii, with significant holes at higher radii. This is good for the alignment, although less good for hermeticity.

Conclusion

The overlaps are satisfactory and robust to vertex displacement.

4. Summary

Table 3: Qualitative summary of overlaps in the SCT and Pixels.

	Overlap for nominal beam position	Effect of significant beam displacement
SCT Barrels	Good	Robust
SCT Wheels	Just OK	Robust
Pixel Barrels	Just OK	Not robust
Pixel Wheels	Good	Robust

5. References

[1] S. Haywood, "Offline Alignment and Calibration of the Inner Detector", ATL-INDET-2000-005

[2] D. Hindson in Alignment Meeting on 21/2/02, http://atlasinfo.cern.ch/Atlas/GROUPS/INNER_DETECTOR/PERFORMANCE/ALIGN/meet/020221/danny.ps

[3] P. Bruckman in Alignment Meeting on 26/10/02, http://pbruckma.home.cern.ch/pbruckma/ID_align/ID_align_stat_261001.pdf

[4] S.Peeters in "Detector and Physics Performance Technical Design Report", CERN/LHCC/99-14

[5] On CDD: LHC Experiments → ATLAS → ID → SCT → Barrels 3, 4, 5 or 6

[6] T. Jones, "Forward SCT Silicon Microstrip Detector Layout", available at http://hep.ph.liv.ac.uk/~jonest/Silicon.html

[7] http://edms.cern.ch/document/107600/5