Improvements in ITk Strip Module Metrology

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Abstract

The LHC, as the highest energy facility in the world, will be at the frontier of high energy physics for a long time. At the end of 2023, the LHC will be significantly upgraded and perform in the High Luminosity LHC phase with the replacements of the components of the major detectors. The new Inner Tracker of ATLAS will take the place of the current one, and the instantaneous luminosity of it will be up to 5 or 7 times what was designed. Since the ITk strip modules are important components, they require high quality and performance, which leads to the need for high accurate metrology. This report starts from the problems encountered in the measurements with the smart scope, and a new method has been found out. Then some conditions are considered, and some tests are made to find out if they influence the results. Finally, it is confirmed that measurement precision has been significantly improved with the new method.

Contents

1 Introduction

1.1 High Luminosity LHC (HL-LHC)

The Large Hadron Collider started up on 10 September 2008. And in 2012, It discovered a new particle which was confirmed to be a Higgs boson. As the world's highest energy scientific facility, the LHC will still be at the forefront of high energy physics for the next two decades.

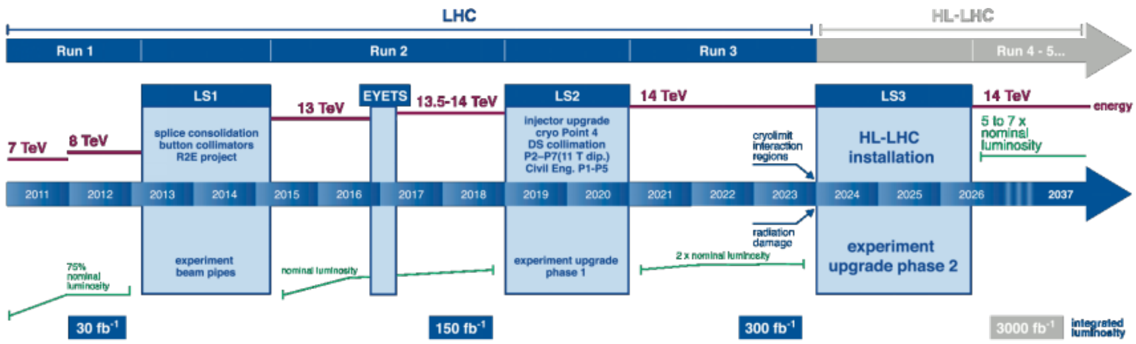


Figure 1: Updated status of the LHC.

As shown in the Figure 1, there are three long shutdowns during the operation of the LHC, and the LS1 was already completed in 2015 [1]. Now the integrated luminosity of ATLAS is about 150 fb^{-1}, and the center-of-mass energy is 14 Tev. The LS2 will start from 2019 or 2020, after that ATLAS will be significantly upgraded (Phase-I) and the LHC will be further improved. At the end of 2023, the LS3 will start. Several major components of ATLAS will be replaced (Phase-II), and the accelerator of LHC will be upgraded. After the LS3, High Luminosity LHC (HL-LHC) will be operated beyond the performance which it was designed with a nominal (ultimate) instantaneous luminosity of $\mathcal{L} = 5 \times 10^{34}\ \text{cm}^{-2}\text{s}^{-1}$ ($\mathcal{L} = 7.5 \times 10^{34}\ \text{cm}^{-2}\text{s}^{-1}$) [1].

1.2 The new ATLAS Inner Tracker (ITk)

The current ATLAS Inner Tracking Detector was designed with a instantaneous of $\mathcal{L} = 1.0 \times 10^{34}\ \text{cm}^{-2}\text{s}^{-1}$. After the LS3, it will be replaced by the new ATLAS Inner Tracker, which is called ITk. The ITk is shown in the Figure 2.

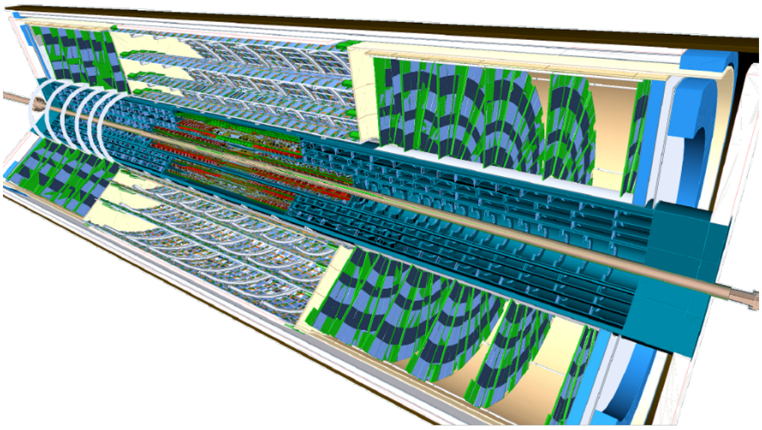


Figure 2: The visualisation of the ITk for the HL-LHC phase of ATLAS.

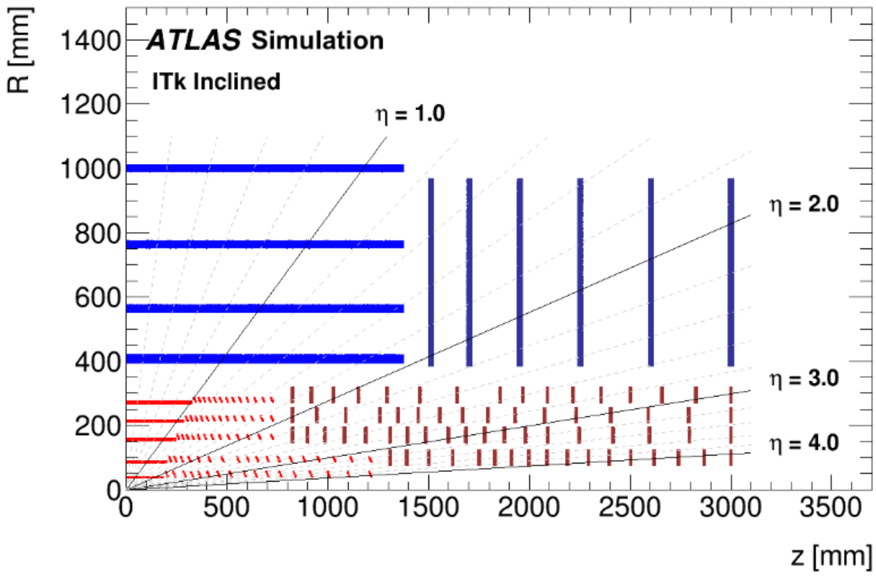


Figure 3: The layout of the ITk for the HL-LHC phase of ATLAS.

As the Figure 3 shown, blue and red lines represent strip and pixel detectors. And the horizontal lines are the barrel, and the vertical lines are the end-caps. The basic mechanical building blocks of the barrel are staves while that of end-caps are petals, which are shown in the Figure 4. There are 392 staves in the barrel, and 14 modules are on each stave side. Each disk of the strip end-caps has 32 petals, in each of which there are nine modules on each side (Shown in the Figure 5) [1]. The R0 module is what this report works on.

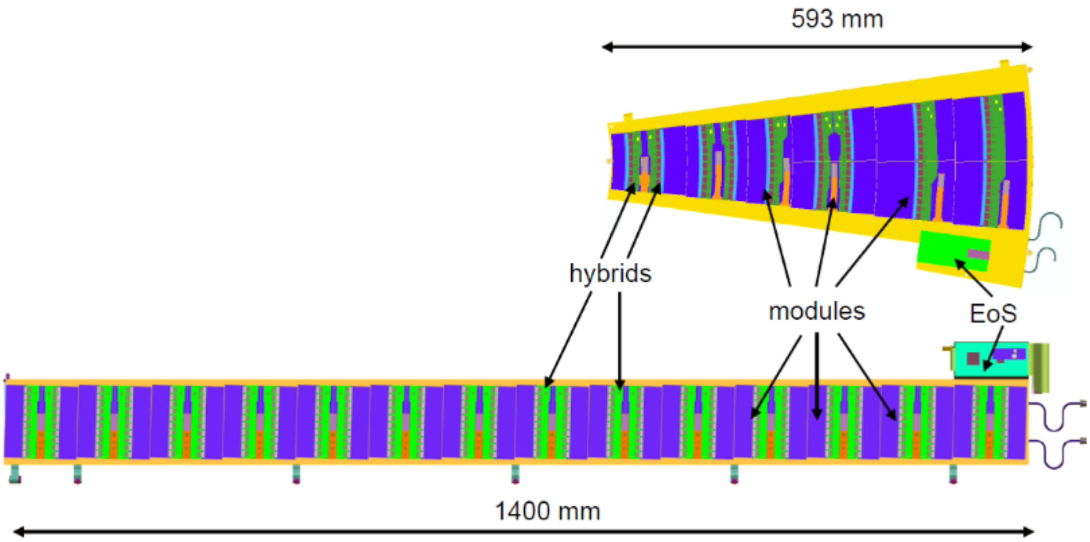


Figure 4: End-cap petal (upper) and barrel stave (lower).

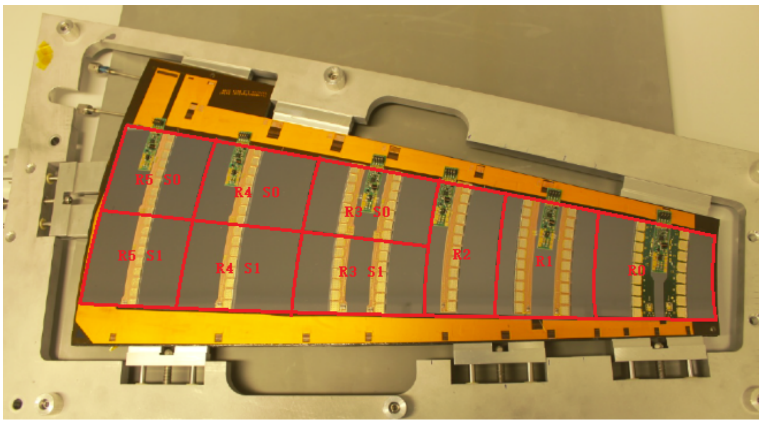


Figure 5: Modules on one end-cap petal.

1.3 Module

A module is made up of one sensor and one or two hybrids. The hybrids are low-mass PCBs, and there are several read-out chips on each of them. The Figure 6 is the exploded view of one short-strip barrel module, and the components of long-strip modules and end-cap modules are the same. They are assembled with glue.

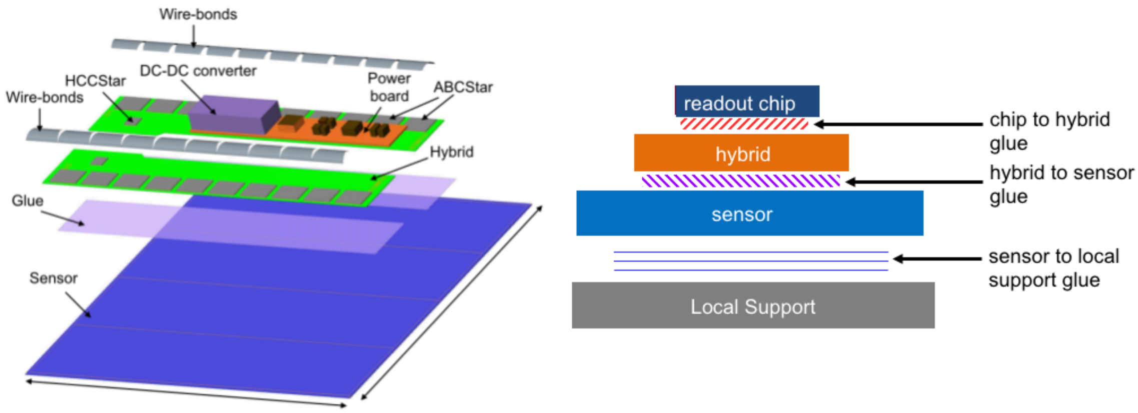


Figure 6: Exploded view of a short-strip barrel module with all relevant components. Different glue layers for the module assembly.

Actually, the R0 modules this report works on is not real but plastic (Shown in the Figure 7).

Figure 7: A plastic R0 module.

The plastic modules are used to find out how much glue can we get the height required. Because only the amount of glue can be controlled during the gluing, the heights with different weights of glue should be measured to find out the appropriate amount of glue.

2 Measurement

The heights this report measured are the chip + glue + hybrid (Shown in the Figure 8). Taking in count the glue height tolerance, the expected value is from 660 to 740 μm.

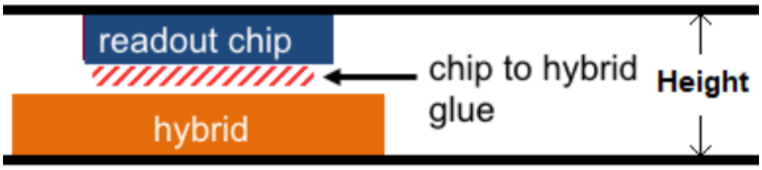


Figure 8: Heights: chip + glue + hybrid.

2.1 Smartscope

The smart scope (Figure 9) is used to measure the heights. The hybrid is fixed to the jig by the vacuum pump (Shown in the Figure 10).

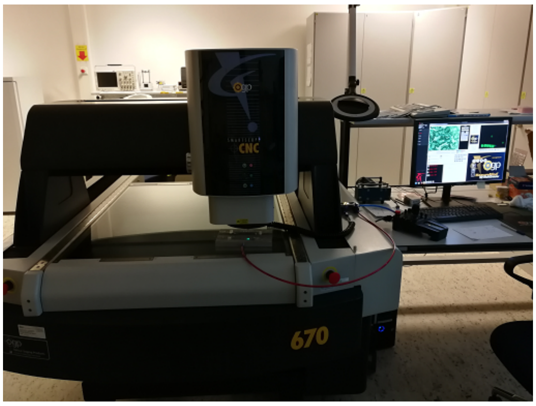


Figure 9: Smartscope.

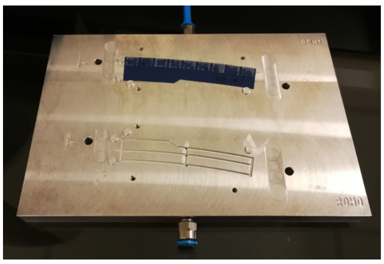


Figure 10: Hybrid and jig.

As shown in the Figure 11, there are ten zoom levels, and in different zoom levels, the magnifications are different. The maximum magnification can get in zoom level 10. Also, there are three different kinds of lights can be used. Usually, the second light is used to measure points on the jig while the first light with the grid is used to measured the points on chips.

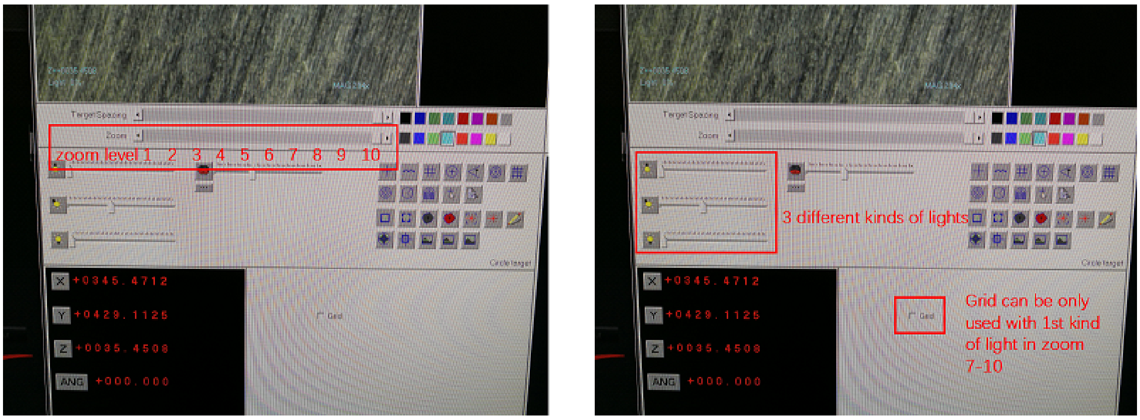


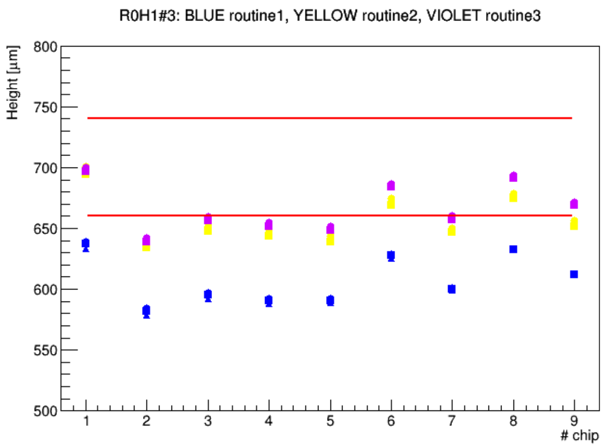
Figure 11: Zoom levels and lights.

2.2 Steps

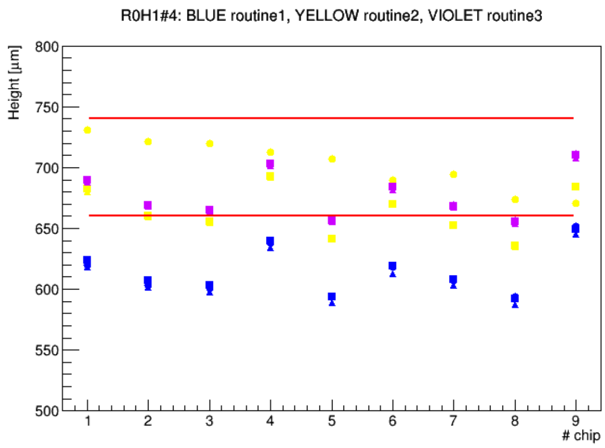
In the beginning, the rough alignment should be made before we do the routine.
Firstly, a point (the first point) close to the rough alignment origin should be chosen as the datum z origin. Secondly, four lines should be drawn along the edge of two corners of the jig. Thirdly, two intersections got from these four lines should be set as datum x and y origin and datum x-axis. Then, more than ten points should be chosen to create the datum plane. Chip planes can be got using the same method. Finally, the heights are the relative heights between the datum plane and the chip planes.
All the steps should be done in one routine.

2.3 Plots and problems

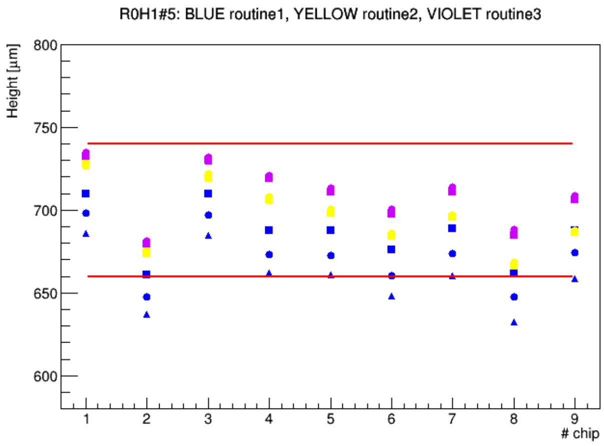
Here are plots of 4 different R0H1 hybrids (Figure 12). Three different routines (routine1, routine2, and routine3) were made to measure the heights, and each routine ran three times. Different routines are in different colors. The "FullCircle" markers are the heights measured in the first run, the "FullSquare" markers are that in the second run and the "FullTriangleUp" markers are that in the third run. The two red lines represent the upper and lower limits of the expected value.



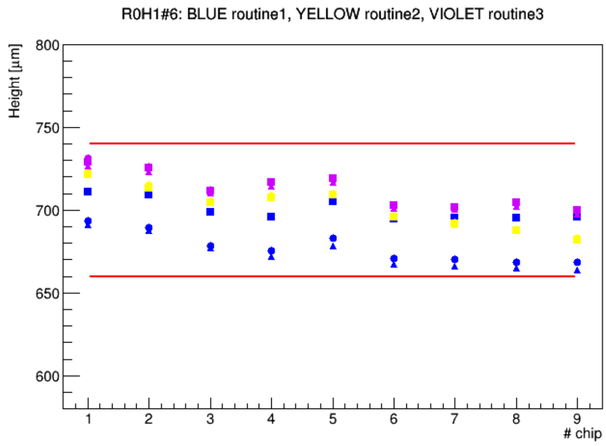
(a) R0H1#3



(b) R0H1#4



(c) R0H1#5



(d) R0H1#6

Figure 12: Plots.

As shown in Figure 12, the variation is very big, about 50 or 60 μm. What is more, the heights in routine1 are always much lower than that of others. It is a big problem, so actions were taken to try to solve it.

3 New method

After checking the routines, we found that the first point of routine1 is much farther from the rough alignment origin than other routines. Also, The zoom level used during making the datum plane is 1, which in other routines are all 10.
In old routines, the datum plane is thought as the surface plane. However, because the datum plane is very dependent on the first point and the points on jig chose to make the datum plane, it is not actually the surface plane.

3.1 Surface plane

To avoid the effect from the first point, we added a new surface plane. The points which are used to create the surface plane is around and very close to the edge of the hybrid (Shown in the Figure 13).

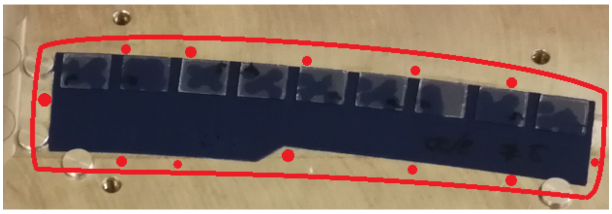


Figure 13: Surface plane.

Then four new routines were made to check if the surface plane works. These routines are all the same except the position of the first point.

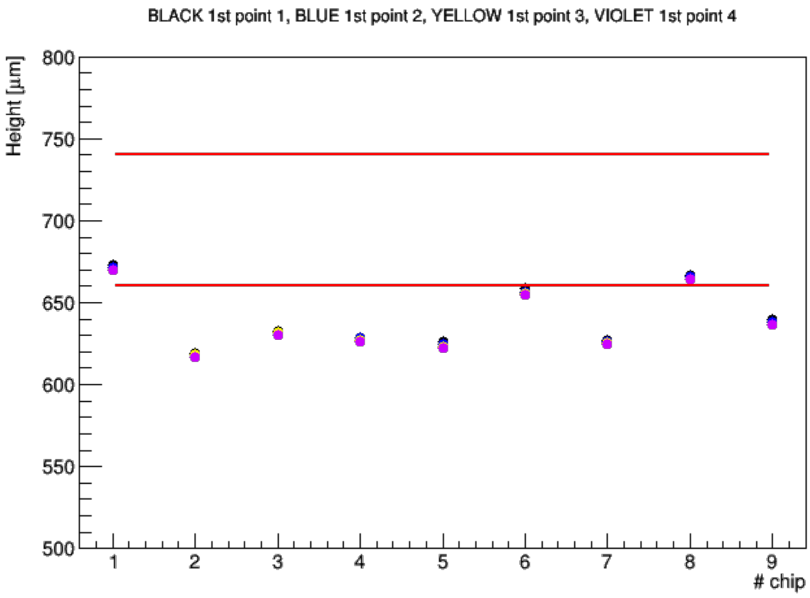
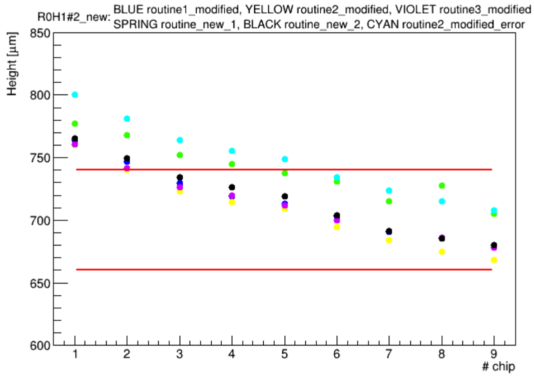


Figure 14: Checking if the new surface plane works by changing the first point.
1st point 1 : (0.2803, -0.2243, 0.0552) (mm)
1st point 2 : (0.4932, -0.5482, -0.0477) (mm)
1st point 3 : (1.2439, -1.6875, -0.0446) (mm)
1st point 4 : (6.4799, -6.6843, -0.0498) (mm)

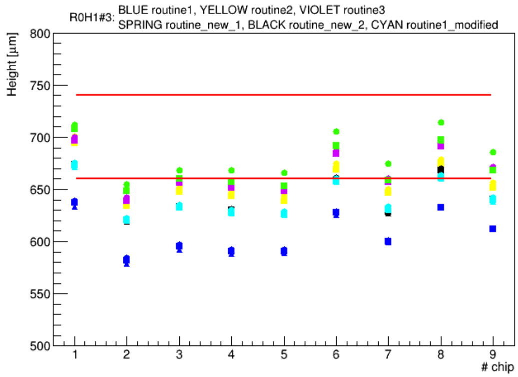
The result (Figure 14) shows that the surface plane really works. After adding the new surface plane, the heights are not dependent on the datum now.

3.2 New problem

Since the surface plane woks, the old routines were modified by adding the new surface plane, and some new routines were made (Shown in the Figure 15).



(a) R0H1#2



(b) R0H1#3

Figure 15: Plots with and without surface plane.

It shows that the variation is still big. So more conditions should be considered.

3.3 Light condition

Firstly, the light condition was considered. The heights of some points on the jig and chips were measured many times by adjusting the light. Then we found that the heights did not change with different lightness (Plots are not made). And then another kind of light condition was considered. In the Figure 16, there are four different light conditions. First of all, just the first row of lights was turned on. Secondly, the curtain was opened. Then the second row of lights was turned on. Finally, the last row of lights was turned on.

The result (Shown in the Figure 17) shows that this change of light condition still has no effect on the heights.

(a) Light 1 (b) Light 2

(c) Light 3 (d) Light 4

Figure 16: Different light conditions.

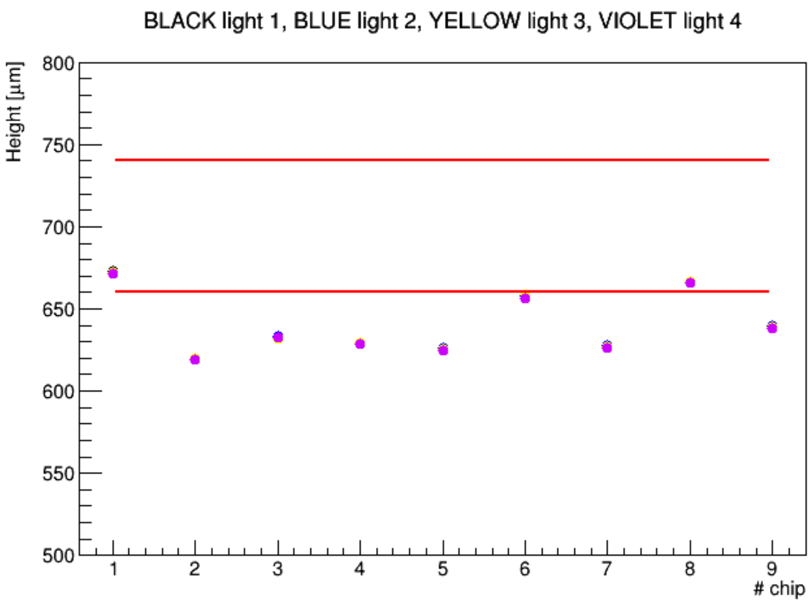


Figure 17: Heights with different light conditions.

3.4 Other conditions

Since light condition does not affect the results, after many experiments, there are 24 different conditions considered (Shown in the Table 1).

Table 1: Different conditions.

Condition	Zoom	Light	Grid	Condition	Zoom	Light	Grid	Condition	Zoom	Light	Grid
1	1			11	1						
2	2			12	2						
3	3			13	3						
4	4			14	4						
5	5	2nd	no	15	5	1st	no				
6	6			16	6						
7	7			17	7			21	7		
8	8			18	8			22	8	1st	yes
9	9			19	9			23	9		
10	10			20	10			24	10		

Five points on the jig and five points on the chips were chosen and the heights of them were measured in these 24 conditions (Shown in the Figure 18).

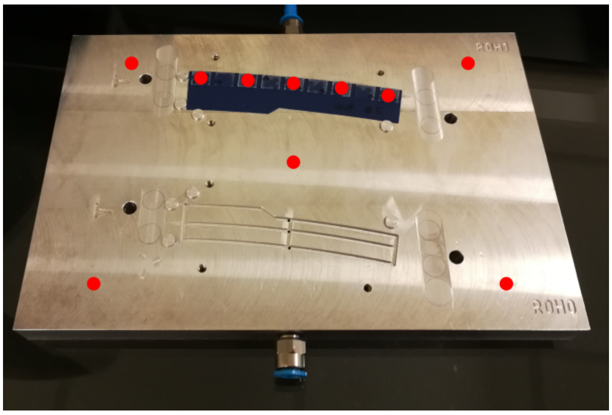
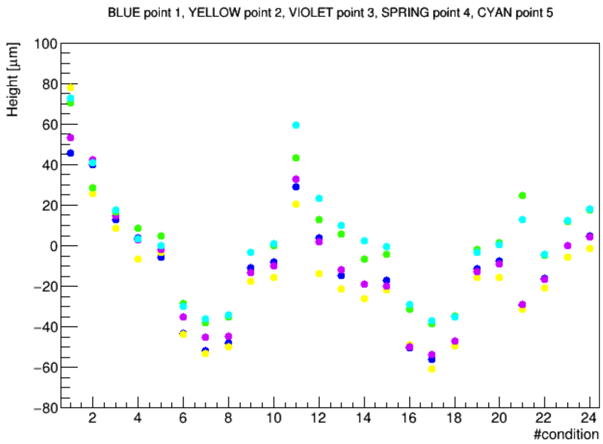


Figure 18: Points on jig and chips.

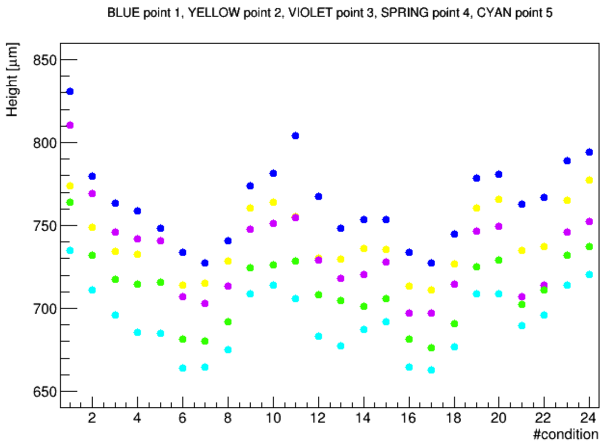
The results are shown in the Figure 19. Heights of different points are in different colors. The relative heights are between each condition and No.10 condition. The yellow regions are deviations. From the results:

- The heights got in those conditions with small zoom (1,2,3,4,5) level are less stable.
- The behaviors of jig and chips are similar but not the same.
- The heights got with the grid are not stable, too.

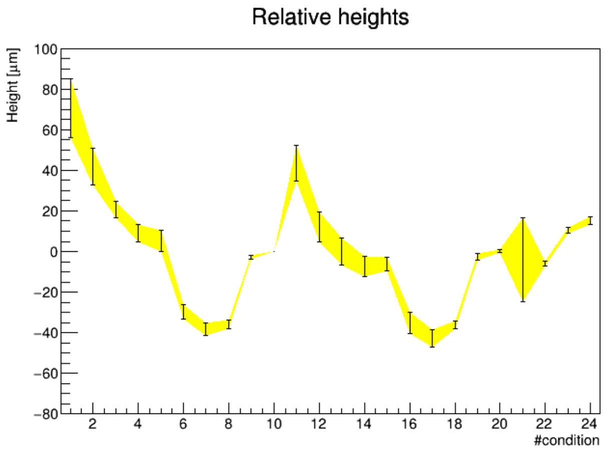
- In those condition in big zoom (6,7,8,9,10) without the grid, it seems that the kind of light has no influence on the relative heights.



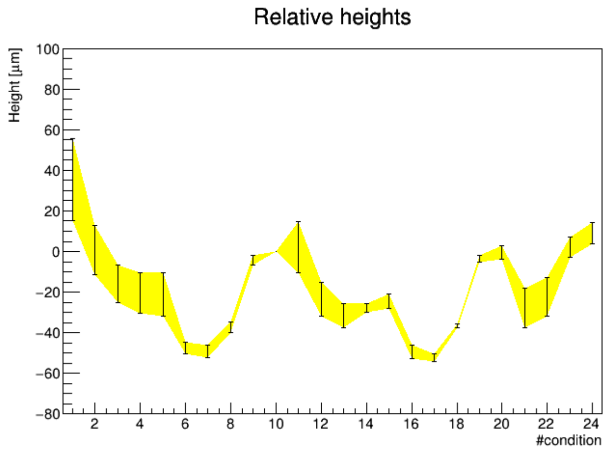
(a) Heights of 5 points on jig



(b) Heights of 5 points on chips



(c) Relative heights on jig



(d) Relative heights on chips

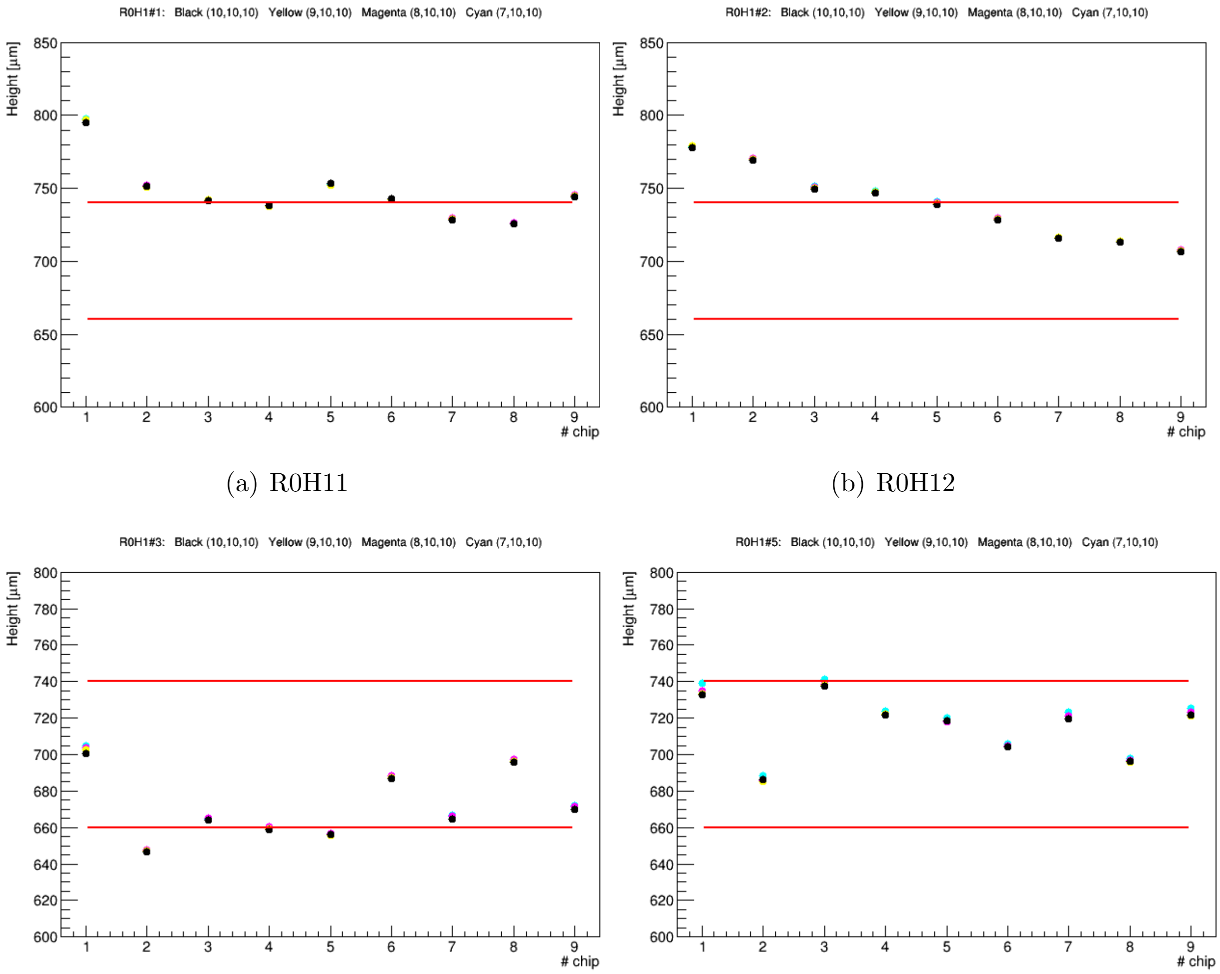
Figure 19: Heights and relative heights on jig and chips.

3.5 Three numbers to describe one routine

Three numbers are used to describe one routine. n_1 is the zoom level used during making the datum plane. n_2 is the zoom level used during making the new surface plane. n_3 is the zoom level used during making the chip planes. Then routine(n_1, n_2, n_3) can be used to describe one routine easier.

3.5.1 Only n_1 changed

Routine(10,10,10), routine(9,10,10), routine(8,10,10) and routine(7,10,10) were created to remeasure the hybrids.
As shown in the Figure 20, the heights are consistent with each other, which further confirms that the surface plane really works.



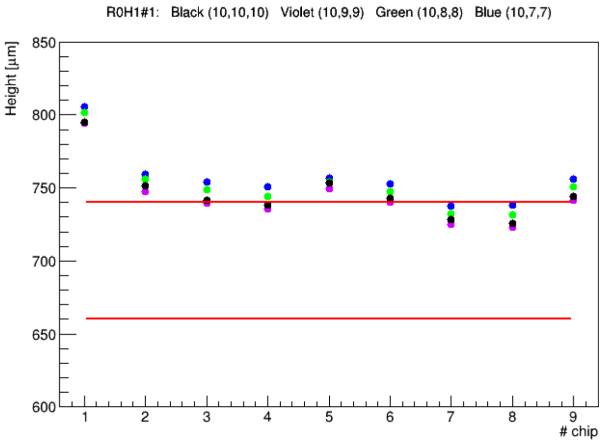
(a) R0H11 (b) R0H12

(c) R0H13 (d) R0H15

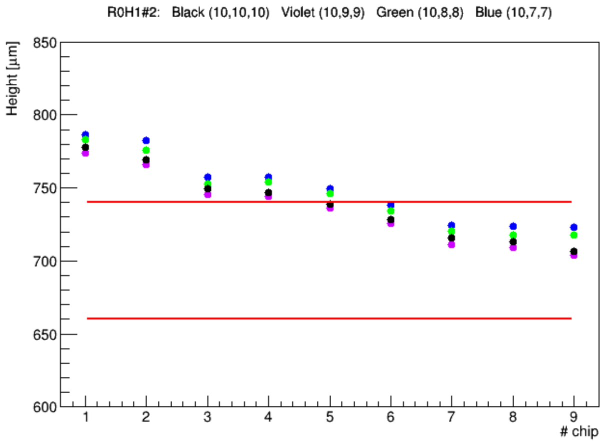
Figure 20: Only n_1 changed.

3.5.2 Only n_1 unchanged

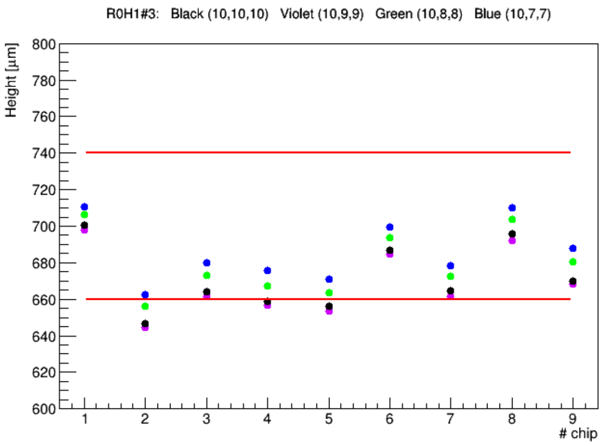
Routine(10,10,10), routine(10,9,9), routine(10,8,8) and routine(10,7,7) were created to remeasure the hybrids.
As shown in the Figure 21, the variation still remains nut it is about 20 μm now.



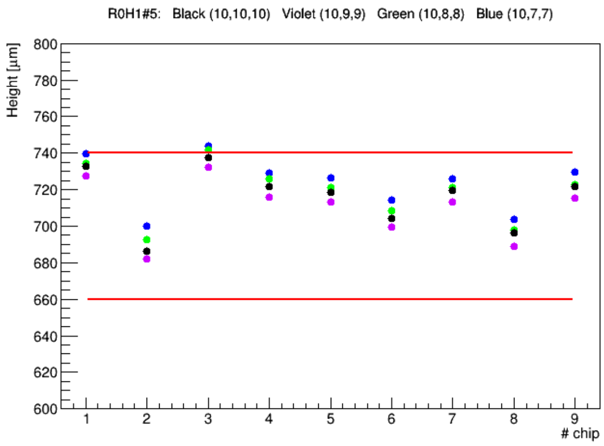
(a) R0H11



(b) R0H12



(c) R0H13



(d) R0H15

Figure 21: Only n_1 unchanged.

4 Summary

The measurements are now much better understood:

- Light does not affect the measurements.
- Zoom level has a significant impact on the results.

Measurement precision has been significantly improved:

- The new surface plane removes dependence on the datum plane.
- Consistent choice of zoom value ensures consistent measurements.
- Though there is still 20 μm variation between different zoom levels, the variation in results is reduced by about 2/3 comparing the old routines.

Maximum zoom probably provides the most accurate value.
Measurements on real chips will probably be more precise because they are flatter and non-transparent.

References

[1] ATLAS Collaboration. Technical design report for the atlas inner tracker strip detector. Technical report, 2017.