Proposed conventions for module survey.

Steve Snow. December 1999

The SCT community clearly needs to adopt a standard method of surveying modules, analysing the data and storing the result in the assembly database. So here is a proposal, based on some experience of surveying modules and on discussions with several ATLAS colleagues.

1 General principles

In principle any standard which fully defined the geometry of a module could be acceptable but I think there is some advantage in choosing one which makes allowances for human errors and survey machine errors.

I propose that we should treat the in-plane (x, y) survey and the flatness (z) survey completely independently. This is possible because, for any module which is anywhere near the flatness specifications, the influence of the z coordinate on the x, y measurements is completely negligible. Seperating the two surveys like this will make the geometry easy to describe and easy to understand. We can draw on flat paper without the ambiguity of trying to represent the third dimension. It would also allow us to use different machines to do the two different surveys, though I think this should not be necessary.

For the z survey I propose a simple grid of points covering each detector. From the data that I have seen on detector bowing I estimate that a 5×5 grid will be enough to allow interpolation of the z value at any point on the detector surface to better than 10 microns. It may turn out that the z shape of a module can be described with much fewer than the 100 numbers which I propose here.

For the (x, y) survey I propose a system where we measure the center point of each wafer, then base the module center point and module axis on the measured wafer centers. The wafer positions, mounting point positions and wafer orientations are then described relative to the module center and axis. This is a roundabout way of doing things, however it has two significant advantages. Firstly it treats all four wafers equally, whereas other schemes, such as the one I have used up till now, have a slight bias in favour of one wafer or one side of the module. We may be grateful in the distant future to avoid any systmatic bias even if it is only a few microns. Secondly, the proposed scheme describes deviations of the real module from an ideal module shape, where the real module is "fitted" so as to make the deviations as small as possible. This means that in the initial phases of the experiment we can treat the modules as if they had the ideal shape and get the module-to-module alignment correct. Then, when we switch on the internal module corrections, it should not spoil the module-to-module alignment but should only improve residuals.

Although I used the word fitted above, I have avoided using any iterative fitting procedures. Instead I have used simple arithmetic which gives almost identical results to a fit and has the advantage of being unambiguous.

This proposed scheme for describing the geometry of a module is different from the one that we use during wafer alignment. However there is a simple enough relation between them, so that we will be able to look at the result of a module survey and use it to diagnose a problem in the module assembly.

I propose that the database stores the 13 numbers which define the (x, y) geometry and the 100 numbers which define the module z profile in fully standardised fields. We should certainly also store the raw survey data somewhere, but since there may be different ways of collecting and analysing the raw data I doubt if these is any point in storing it in the central database. Each institute should be responsible for storing its own raw data and knowing how to analyse it to obtain the 113 numbers. The best way to check that different institutes are producing consistent results will be to have the same module measured in different places and to compare their database entries.

In principle only two points need be measured on each detector to find its position and orientation, but I think it is worth using four as a check for errors. Some people favour using the four-spot fiducials near the corners of the wafers and others like the type A fiducials on the centre lines, so I have allocated labels for all eight points. Similarly, only two transparent fiducials are needed in principle but four are better.

2 Receipe for the x, y survey.

First, make yourself a survey frame something like the ones indicated in Figures 1 and 2 [2]. It should hold the module flat with both wafers visible from both sides and the module mounting hole and slot should also be visible from at least one side, I have assumed the front. The frame should have up to four transparent fiducials distributed around the perimeter. They can be made from a glass piece with a chrome pattern on it, or a thin foil with a pinhole in it, or ... etc.

Next, measure the module in its frame, from both front and back. If everyone will use the point labelling scheme shown in Figures 1 and 2 it will have the advantage that different people will be able to understand each other's raw data files, if necessary. Also I will provide a program to analyse the data in the standard way. The standard format is that the first line contains the "item type name" used in the database followed by the Atlas serial number of the module. The remaining lines contain the point label followed by the measured x and y coordinates of the point. The origin and orientation of the two coordinate systems used for the front and back survey are irrelevent because they will be related to each other through the transparent fiducials. The only constraint is that they must have the conventional handedness, as indicated in the figures. Below is an example of a file in the standard format, all the data are real measurements of Manchester module No. XX, apart from point 50 which was not measured so dummy values are entered.

```
fmModuleOut   881923
   1 122.6350  27.6870
   3  57.6550  31.7650
   5  57.6580 -31.7760
   7 122.6390 -27.6930
  11  56.9570  31.7640
  13   0.0030  35.3490
  15  -0.0030 -35.3510
  17  56.9540 -31.7750
  41 111.7760  56.8920
  42  39.1400 -56.3030
  43  36.8140  55.6340
  49 137.4320   1.4850
  50 -10.0000   1.0000
  51 122.6500 -27.6990
  53  57.6650 -31.7810
  55  57.6680  31.7620
  57 122.6300  27.6840
  61  56.9550 -31.7760
  63  -0.0030 -35.3510
  65   0.0040  35.3510
  67  56.9600  31.7640
  91 113.9990 -54.8500
  92  36.9300  55.3740
  93  39.0460 -56.5700
```

2.1 Analysis of survey

First we need to transform the points measured on the back of the module into the same coordinate system as the front survey. A convenient way to do this is to reflect the back points about one axis (I arbitrarily choose $y \to -y$). Then apply the translation which brings the average position of the back transparent fiducials to match the average position of the front transparent fiducials. Finally rotate around the average fiducial position by the angle which brings the transformed back fiducials as close as possible to the front fiducials. Having found the best transformation I apply it to all points of the back survey and check to see how well the back view of the transparent fiducials matches wit the front view. If there was a mis-match of more than 2 microns I would say that this was evidence for problems in the survey and I would recommend repeating the measurements.

From here onwards I work only with the front view of all points. The centre of each wafer is calculated, either from the average of the four corner points or the average of the four edge points, whichever is available. My program assumes that the surveyor has consistently measured either corner or edge points, not a mixture. The orientation of each wafer is also determined from either the corner or edge points.

Figure 3 explains the folowing paragraph in diagram form. The origin and orientation of the module-centred coordinate system (x_m, y_m) is defined from the positions of the four wafer centres. The origin is simply the average of the four wafer positions. The direction of the x_m axis is defined to be parallel to the line which bisects the angle between the line joining wafer 1 to wafer 2 and the line joining wafer 3 to wafer 4. The mounting hole and slot are defined by their x_m, y_m coordinates, named **mhx, mhy, msx** and **msy** in the database. The stereo angle of the front pair of wafers **stereo** is defined as the angle between the line joining wafer 1 to wafer 2 and the x_m axis, and the stereo angle of the back pair is **-stereo** by definition so it does not need to be stored. The mid-point between the two front wafers is specified by its position in x_m, y_m coordinates and is named **midxf, midyf** in the database. The mid-point between the two back wafers is by definition equal to (**-midxf, -midyf**), so it does not need to be saved. The seperation between the two front wafers (**sepf**) and between the two back wafers (**sepb**) are also stored. Finally the orientation of the four wafers are described by the angles, $a1$ to $a4$, between their central axis and the line defining the strereo angle on that side.

I aim to provide fortran and LabVIEW implementations of the proposed analysis. So far, only the fortran version exists [4] and when run on the example file it gives this output:

```
Database parameters for this module
-----------------------------------

Position of mounting hole; mhx,mhy
 -78.1348     0.0266

Position of mounting slot; msx,msy
  69.2777    -2.4194

Centre of front pair; midxf,midyf
  -0.0009    -0.0379

Seperation of front pair, back pair; sepf,sepb
  61.6690    61.6742

Stereo angle (mrad); stereo
 -19.8968

Rotation angles of wafers (mrad); a1-a4
   0.0648    -0.0569    -0.1760     0.0082
```

2.2 Special case for short forward modules

The forward modules of the inner ring and on wheel 8 consist of just two detectors, so they need to be treated differently. We can use the same test tables in the database for short modules as are used for standard modules. A subset of the database fields can be used, with almost the same meaning as for standard modules. I propose that the front detector on this type of module be labelled 'wafer 1' and the back detector be labelled 'wafer 3'. Then the same lablelling of the survey points can be used, as for the standard modules shown in Figure 1.

Parameter	Module type Barrel	Outer	Middle	Inner
mhx	-6.500	-78.143	-63.121	-51.500
mhy	-37.000	0.000	0.000	0.000
msx	38.500	63.737	66.129	40.880
msy	-37.000	0.000	0.000	0.000
midxf	0.000	0.000	0.000	0.000
midyf	0.000	-0.040	0.054	0.000
sepf,sepb	63.660	61.668	59.449	n/a
a1 - a4	0.000	0.000	0.000	n/a
stereo	-0.020	-0.020	-0.020	-0.020

Table 1: Nominal values of module geometry parameters.

The same transformation of the back points to the front coordinate system can be used as before. From here on I use only the front coordinate system and the reader can refer to Figure 4. The origin of the module-centred coordinate system is simply the mid-point of C1 and C3. The direction of the x_m axis is given by the line which bisects the angle between the two wafer orientations. The positions of mounting hole and slot are given in the module-centred coordinates as before; **mhx, mhy, msx** and **msy**. The center of wafer 1 is also given in module-centered coordinates as **midxf,midyf** and the center of the back wafer is by definition at **-midxf,-midyf** The parameter **stereo** now refers to the angle between the orientation of wafer 1 and the x_m axis. The angle of wafer 3 is now by definition **-stereo** and the other parameters of the standard module are not used.

2.3 Nominal values and tolerances

The nominal values of the 13 parameters describing the x, y geometry of a module can be derived from the module drawings. Table 1 shows the values.

I have computed the tolerances that must be placed on each of the geometry parameters using a similar method to that in an earlier note [3]. I make the pessimistic assumption that there will be a flat distribution of errors within the tolerance limits. I simulate a module with randomly distributed geometry errors and simulate a single hit which is randomly distributed within the module's sensitive area. The strip coordinates of this hit in this imperfect module are then calculated. A reconstructed hit is then derived from the strip coordinates assuming a module with perfect geometry. The distance between the generated and reconstructed hit is then histogrammed in the ϕ and z projections, with the results shown in Table 2.

As in my earlier note, I aim for an r.m.s. error in the ϕ direction of 4 microns. My argument for distributing the error budget among the parameters in the way shown in Table 2 is as follows. My previous note defined two eight micron square target boxes for placing two fiducials of one wafer relative to a coordinate system fixed in the other wafer on the same side. This target has proved to be difficult but achievable with the equipment that people are presently using to assemble modules, therefore I want an equivalent sized target in the new scheme. Since the two fiducials are about 60 mm apart this allows a relative wafer-to-wafer rotation of about 0.13 mrad, so I set this as the tolerance for the nearest equivalent parameters; the angles **a1-a4**. The only other parameters which influence the ϕ resolution are **midyf** and **stereo**. They both involve the relative position of the front to the back pair of wafers so I assume that they are both equally difficult to align well and I divide the remaining error equally between them.

3 Receipe for z survey

For the z survey the module should be mounted in a measuring frame in exactly the same way as it will be mounted on the final support structure. The measuring frame should have the same geometry and the same sort

Parameter	Tolerance	Influence on σ_z (μm)	Influence on σ_ϕ (μm)
mhx,mhy,msy	30 μm	n/a	n/a
msx	100 μm	n/a	n/a
sepf,sepb	10 μm	0.	0.0
midxf	10 μm	0.	0.0
midyf	5 μm	144.	2.9
a1 - a4	0.13 mrad	47.	1.3
stereo	0.13 mrad	132.	2.6
TOTAL		201.	4.1

Table 2: Tolerances of module geometry parameters.

of pins/dowels should be used. Screws should be at the same torque, etc. The one exception may be that we will not want to put grease on to the mounting surface.

Before starting one should first know the plane of the mounting surfaces (grey areas in Figure 5a). This can be done either by measuring these surfaces immediately before putting the module into the survey frame, or by constructing the frame so that some other features, such as the transparent fiducials, are at a known position relative to the mounting surfaces. All z measurements of the module should be made relative to the plane of the module mounting surfaces. When measuring the back of the module it is possible to know the plane of the mounting surfaces either by using the transparent fiducials or by measuring directly a part of the module which you are confident is clamped against the mounting plane, such as the grey areas in Figure 5b.

The (x, y) coordinates of the points at which z is measured are calculated by linear interpolation between the corner fiducials. A 5×5 array of points is used on each wafer. For example on wafer 1 the corner fiducials are at $\mathbf{r_1}, \mathbf{r3}, \mathbf{r5}$ and $\mathbf{r_7}$ so the interpolated points are at;

$$\frac{1}{16}((4-i)(4-j)\mathbf{r_1} + (4-i)j\mathbf{r_7} + i(4-j)\mathbf{r_3} + ij\mathbf{r_5})$$

where integers i,j run from 0 to 4. On wafer 4 the z values would be measured at;

$$\frac{1}{16}((4-i)(4-j)\mathbf{r_{61}} + (4-i)j\mathbf{r_{67}} + i(4-j)\mathbf{r_{63}} + ij\mathbf{r_{65}})$$

The points can be labelled in the database as **Znn** where nn is a two digit integer made up from (wafer No. - 1)*25 + j*5 + i.

4 Unfinished

To do list...

- Add more checks to surv4.f and extend it to analyse 2-wafer modules.
- Dupicate it in LabVIEW
- Go into more detail about the z survey.
- More detail on the database. Suggest setting warning level at +/- 1* tolerance, reject level at +/- 2* tolerance.
- get barrel people to check default parameters.
- put in default paramaters for new forward module design, when agreed.

References

[1] http://hepwww.ph.man.ac.uk/groups/atlas/module/specs.html The link new conventions points to this note.

[2] Put links here for drawings of standard module survey frames when/if they exist.

[3] http://hepwww.ph.man.ac.uk/groups/atlas/module/specs.html The link old version.

[4] http://hepwww.ph.man.ac.uk/groups/atlas/module/specs.html The links fortran program and example data file.

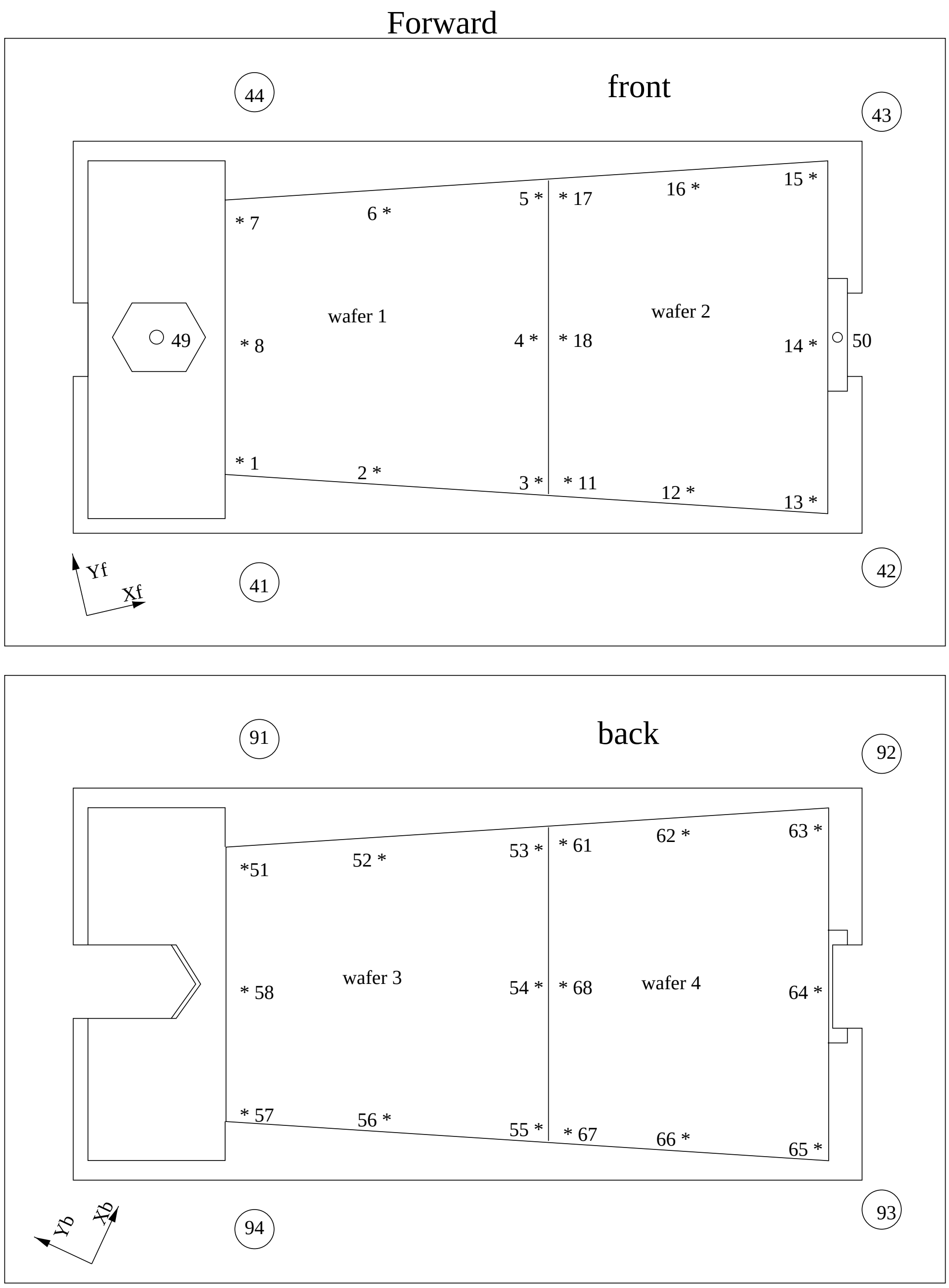

Figure 1: Survey points on a forward module. Wafers 1 and 3 are the ones nearest to the hybrid. Asterisks represent the fiducials on the wafers. Point 49 is the centre of the mounting hole. Point 50 is the centre of the mounting slot. Points 41-44 and 91-94 are transparent fiducials. The coordinate systems for the front and back surveys are drawn at odd angles to emphasise that their only constraint is that they should have the conventional handedness.

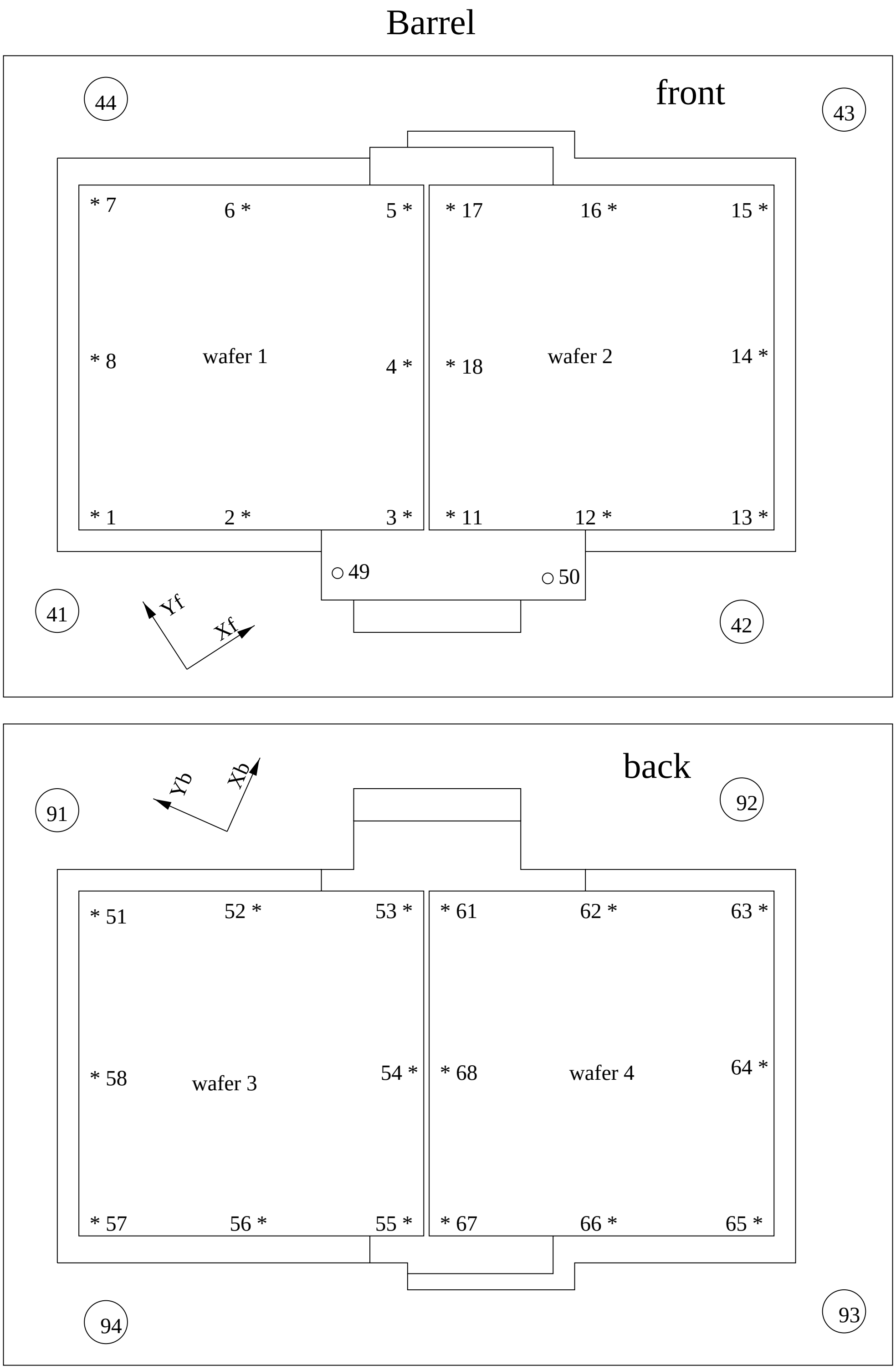

Figure 2: Survey points on a barrel module. Wafers 1 and 3 are on the left when the module is drawn in the conventional orientation. Asterisks represent the fiducials on the wafers. Point 49 is the centre of the mounting hole. Point 50 is the centre of the mounting slot. Points 41-44 and 91-94 are transparent fiducials. The coordinate systems for the front and back surveys are drawn at odd angles to emphasise that their only constraint is that they should have the conventional handedness.

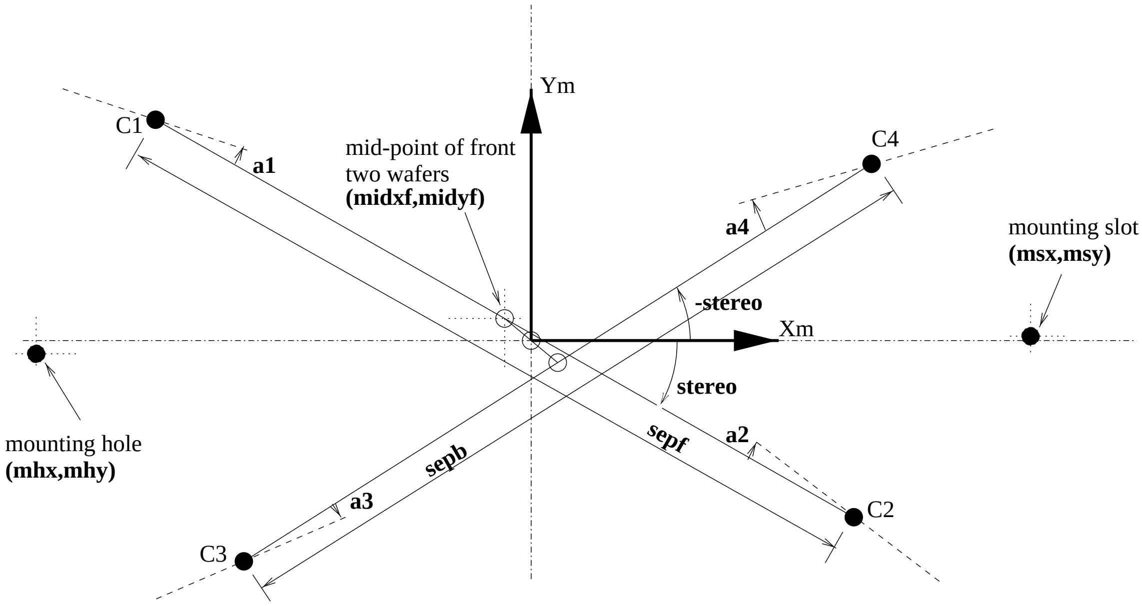

Figure 3: Definition of the parameters which describe the geometry of a standard module. Black circles C1 to C4 are the measured centers of the four wafers. The dashed line through each center gives the measured orientation of each wafer. Open circles are the center points of lines. The module is described in the database with 13 numbers: three coordinate pairs in the X_m, Y_m system (**mhx,mhy**), (**msx,msy**) and (**midxf,midyf**), two wafer seperations **sepf**, **sepb** the angle **stereo** and four wafer angles **a1, a2, a3, a4**. Stereo angle is measured from the X_m axis and wafer angles from the stereo axis, with anti-clockwise rotation being positive.

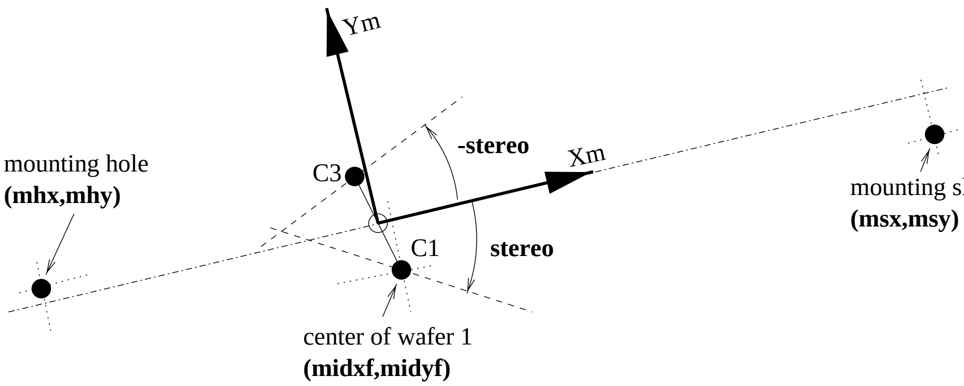

Figure 4: Definition of the parameters which describe the geometry of a two-wafer module. Black circles C1 and C3 are the measured centers of the two wafers. The dashed line through each center gives the measured orientation of each wafer. Open circles are the center points of lines. The module is described in the database with 7 numbers: three coordinate pairs in the X_m, Y_m system (**mhx,mhy**), (**msx,msy**) and (**midxf,midyf**) and the angle **stereo**.

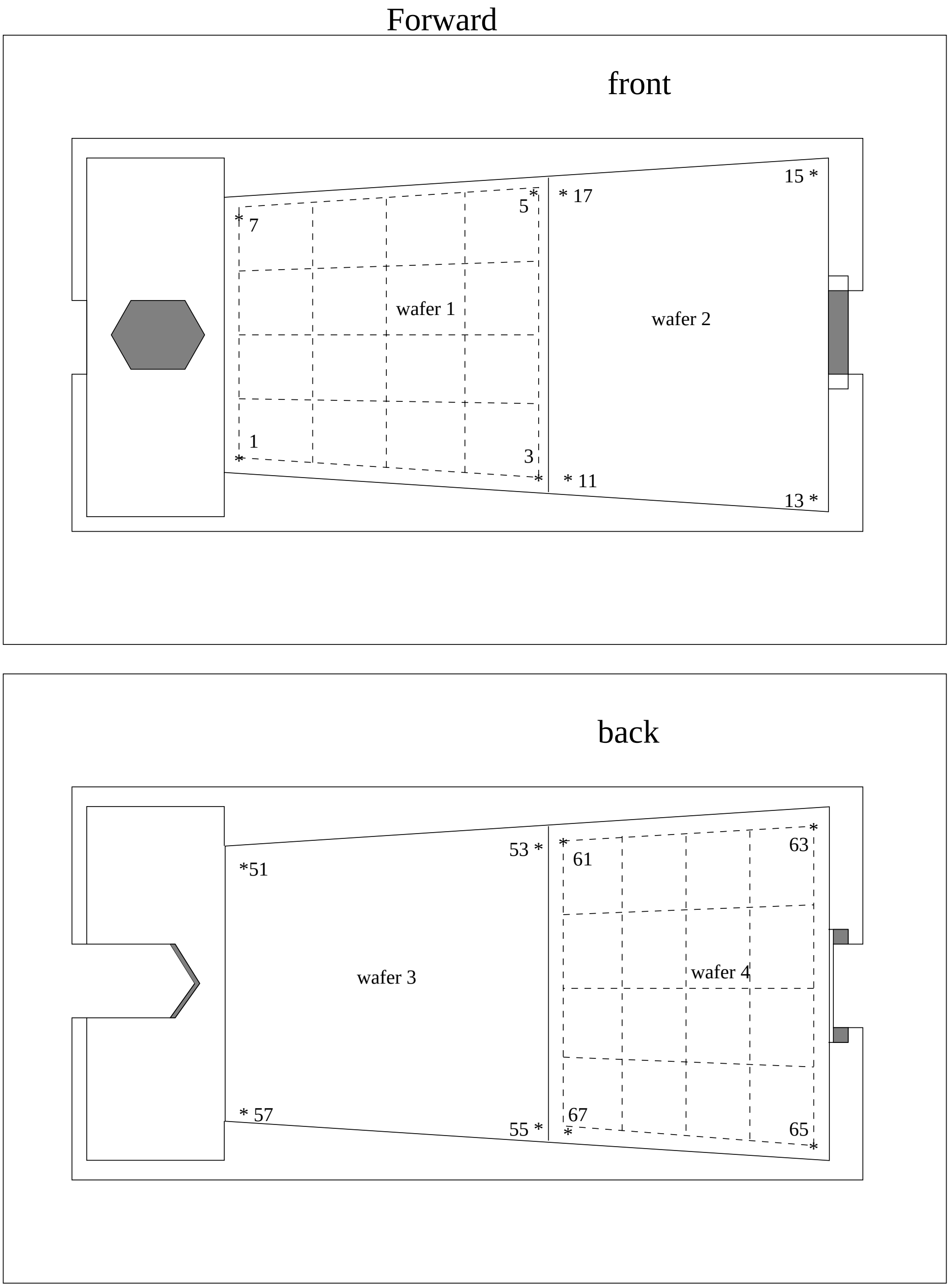

Figure 5: Z survey points on a barrel or forward module. The (x, y) coordinates of the points at which z is measured are calculated by linear interpolation between the corner fiducials. A 5×5 array of points is used on each wafer. For example on wafers 1 and 4 the points are at the intersections of the dashed lines.