LHCb Collaboration

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Detector Geometry
Vertex Locator Test-Beam Software Description

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Abstract

The test-beam software classes describing the mapping of data acquisition channel numbers to detector strip positions are described. The local detector and global test-beam co-ordinate systems are given. A description of the detector geometry of the Hamamatsu PR-01 and Micron PR-02 prototype detectors as implemented in the test-beam software is provided.

If you require up-to-date information on the features in the current code, please use the automatic documentation class reference guide at
http://lhcb.cern.ch/vertexdetector/beamtest/Software/velo_html/ClassIndex.html

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1 Detector Routines Introduction

This note contains a description of the classes in the veloroot test-beam software that describe the detector and test-beam geometry and the mapping from the physical strips to the DAQ channel numbers. The structure of the configuration file used to set-up a test-beam in the software is described. This file lists the types of detector used and their order in the DAQ output.

The location of the physical strips on individual detectors is represented in the local geometry system as explained in section 2.

The location of a detector relative to the other detectors in the test-beam is described in the global geometry system, see section 3. The alignment files used in the local to global transformations are also discussed in this section.

Section 4 provides detailed information on the geometry of the prototype detectors.

An overview of the classes in this part of the test-beam software, and their relationships, is given in section 5.

The input and output to all routines use c.m. for distances, and radians for angles.

Example routines used to test the features of the code are provided in the file macro/TestDetectorGeometry.C.

2 Local Detector Geometry

The local co-ordinate system used in the detector classes is shown in Figure 1.

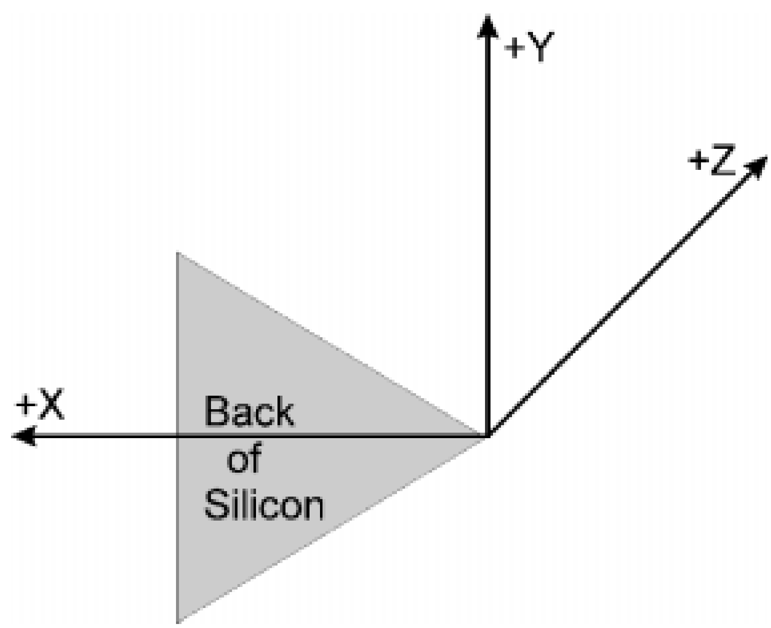


Figure 1: The local co-ordinate system used for describing individual detectors.

$Z = 0$ is the centre plane of the detector, a 300μm thick detector has its front surface at $+150\mu$m, and its back surface at -150μm.

All strip co-ordinates are at +x

A Phi detector contains strips at +y and a positive angle, the last at -y with a negative angle.

In the local frame both the Cartesian (x,y,z) and cylindrical (R,ϕ,z) co-ordinate systems are used.

3 Global Test-Beam Geometry

The global co-ordinate system is shown in Figure 2, this is used in the files of alignment constants and by the `transform` and `alignment` classes.

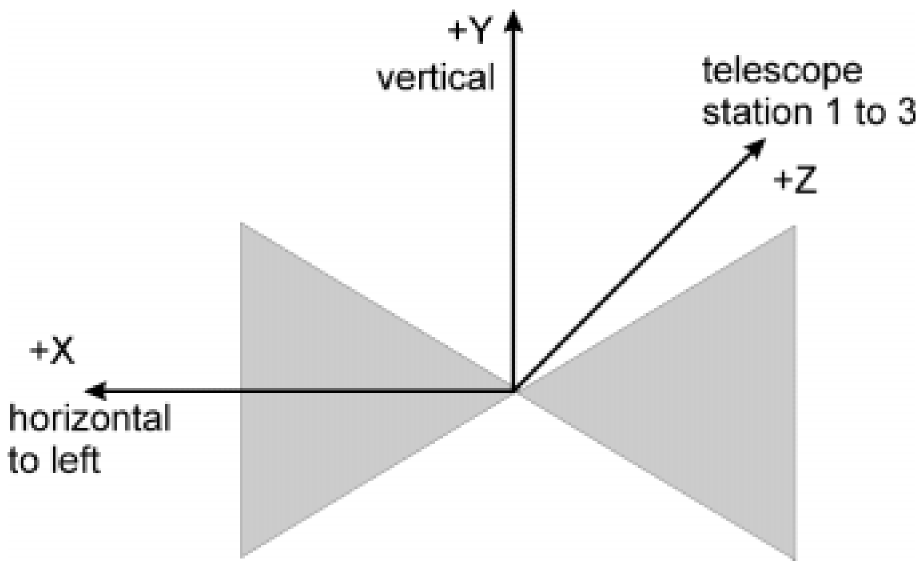


Figure 2: The global co-ordinate system used for describing the relative positions of the detectors.

The Z axis runs along the beam, with +z being the direction from station 1 of the telescope to station 3 of the telescope.

The X axis runs horizontally, with +x being to the left when looking along the Z axis direction.

The Y axis runs vertically, with +Y being upwards. Thus forming a right handed set of co-ordinates.

The initial alignment files took the origin of the coordinate system as the centre of the entrance hole of the support frame of the telescope.

The local strip coordinates are transformed to the global coordinate system by applying appropriate rotations of π rads (flips) and by translations and additional fine rotations.

In the global co-ordinate frame only the Cartesian co-ordinate system is used.

Example:

In the Spring 1998 test-beam, the local x/y coordinates for the R detector in the middle station left hand (+x) side and the Phi detector in the first station on this left side agree with the nominal ones in the global coordinate system : *i.e.* no flips are required.

3.1 Transformation Procedure

This section describes the transformation procedure from the local to the global coordinate system.

3.1.1 Alignment Files

Two standard ASCII text alignment files (kept in the config directory) are required:

- **FLIP**- this file has the suffix **.flip** . This specifies the 180 degree flips necessary to position detectors on the left hand or right hand side of the telescope, with the active silicon surface towards or away from the beam. Normally this file need not be altered by the user. It will generally contain no linear displacements (shifts).

- **ROTATE** - this file has the suffix **.rot** . This specifies the small angle deviations, and the linear displacements that take the detectors to their true positions in a test-beam. It is the values in this file that will generally be altered when the software alignment is performed.

  Each file contains six numbers per detector (3 displacements and 3 rotations). The detector constants are listed in the same order as the detectors appear in the .config file (see section 5)

  Overloaded constructors are provided to allow the user to read from the default alignment files, or to specify the files which should be read.

3.1.2 Transformations

The flip file transformations are performed first, followed by the rotate file transformations.

Within each of these transformation sets the rotations are performed before the linear shifts.

Rotations

Here we describe the conventions adopted in this software for Euler angle rotation. The rotations are performed about axes through $0, 0, 0$ in the global geometry.

We label the original axes as x, y, z, the intermediate x', y', z' and x'', y'', z'' and the final rotated axes x''', y''', z'''

We label the rotation angles α, β and γ. When performing the transformation from the local frame to the global frame we perform them in the order α then β then γ.

α is a rotation around the z axis
β is a rotation about y'
γ is a rotation about x"

This particular choice of transformations was made to facilitate an intuitive understanding of the alignment constants for small angle rotations around the x,y,z axes.

α **matrix**

$$\begin{pmatrix} \cos\alpha & \sin\alpha & 0 \\ -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

β **matrix**

$$\begin{pmatrix} \cos\beta & 0 & -\sin\beta \\ 0 & 1 & 0 \\ \sin\beta & 0 & \cos\beta \end{pmatrix}$$

γ **matrix**

$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\gamma & -\sin\gamma \\ 0 & -\sin\gamma & \cos\gamma \end{pmatrix}$$

Thus a local point (x, y, z) is rotated to a point (x''', y''', z''')

$$(x''', y''', z'') = \alpha\ matrix \times \beta\ matrix \times \gamma\ matrix \times (x, y, z) \tag{1}$$

Displacements

The global co-ordinates are obtained by applying shifts to the rotated point.

$$X_{global} = x''' + X_{shift} \tag{2}$$
$$Y_{global} = y''' + Y_{shift} \tag{3}$$
$$Z_{global} = z''' + Z_{shift} \tag{4}$$

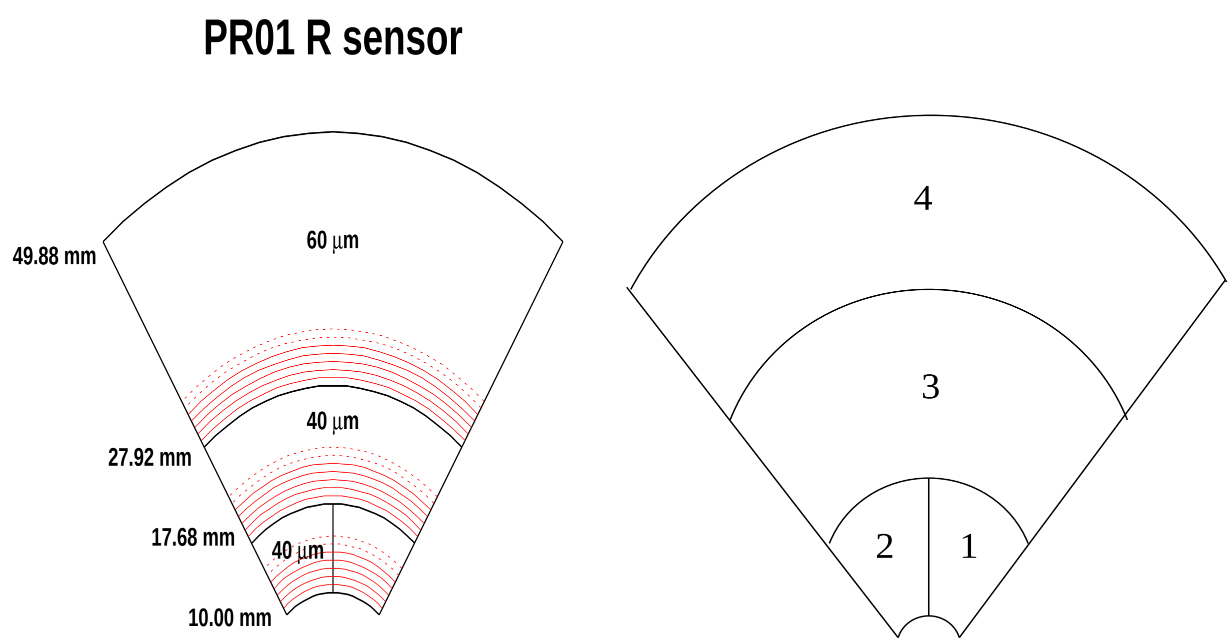
4 Detector Geometry

4.1 PR-01 First Prototype R Detector (Hamamatsu n strip device)

The Hamamatsu R detector is divided into 4 regions see Figure 3. Regions 1 and 2 consist of 40 micron pitch half-length strips, region 3 of 40 micron pitch full-length strips and region 4 of 60 micron pitch full-width strips; the pitch between the last strip of region 3 and the first of region 4 is 50 microns. The pitches and strip radii have been thoroughly checked with microscope measurements. The full detector subtends 72 degrees. The detector is divided into eight areas of consecutive routing line read-out, these are shown on Figure 4. The 1006 strips are uniquely identified by the strip and region number, the strip numbering starts from 0 within each region. The routing line numbers run from 1 to 1006, and are marked on the silicon. These routing line numbers run in ascending order from left to right of the detector with respect to Figure 4. Table 1 is provided as a reference guide to the strip layout of the detector.

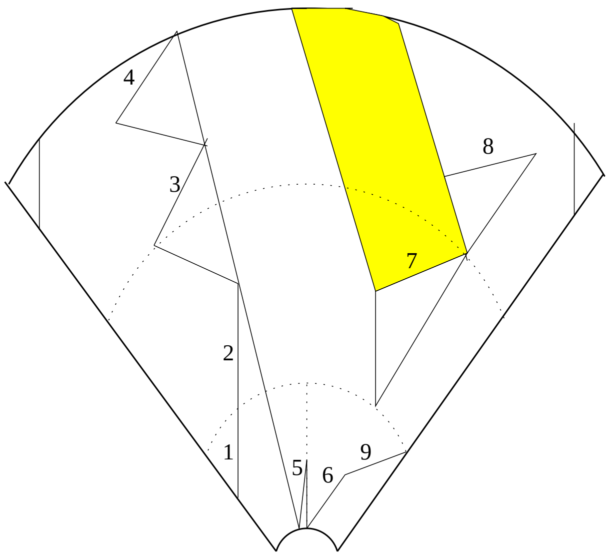
Routing Line	Strip Number	Detector Region	Routing Area	R	Phi low	Phi2 high
1	64	2	1	1.258	0	0.628319
128	191	2	1	1.766	0	0.628319
129	0	3	2	1.77	-0.628319	0.628319
256	127	3	2	2.278	-0.628319	0.628319
257	0	4	3	2.795	-0.628319	0.628319
384	127	4	3	3.557	-0.628319	0.628319
385	256	4	4	4.331	-0.628319	0.628319
494	365	4	4	4.985	-0.628319	0.628319
495	0	2	5	1.002	0	0.628319
558	63	2	5	1.254	0	0.628319
559	0	1	6	1.002	-0.628319	0
622	63	1	6	1.254	-0.628319	0
623	128	3	7	2.282	-0.628319	0.628319
750	255	3	7	2.79	-0.628319	0.628319
751	128	4	8	3.563	-0.628319	0.628319
878	255	4	8	4.325	-0.628319	0.628319
879	64	1	9	1.258	-0.628319	0
1006	191	1	9	1.766	-0.628319	0

Table 1: The Hamamatsu PR-01 R Detector strip Layout. The strips at which a transition occurs between regions or the routing line areas are listed.

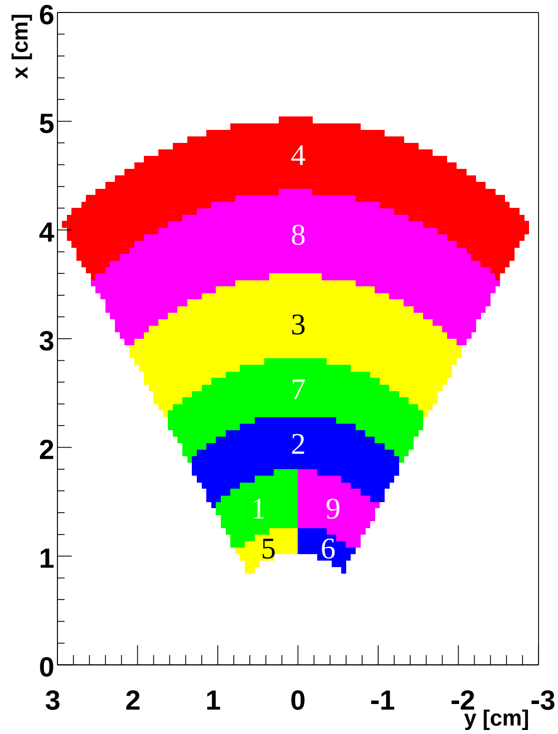


(a) (b)

Figure 3: The division of the 1998 Hamamatsu PR-01 prototype R detector into regions with strips of constant pitch. The diagrams shows the front surface of the detector, in the local geometry system the X-axis runs vertically along the centre line of the detector and the Y-axis to the left. Routing line number 1 is at the top left and number 1006 at the top right.



(a)



(b)

Figure 4: The routing line read-out scheme of the 1998 Hamamatsu PR-01 prototype R detector. The marked numbers indicate the division into routing line areas. The lines next to the numbers in Figure (a) represent the contact points between the strips and the routing lines. As an illustration, the shaded area shows the path of the routing lines that read the outer strips in the 40 micron pitch region. In Figure (b) the strips that are read out by each routing line area are shaded in bands. Area 4 contains 110 strips, areas 5 and 6 each have 64 strips, all other areas have 128 strips. The diagrams show the front surface of the detector, in the local geometry system the X-axis runs vertically along the centre line of the detector and the Y-axis to the left. Routing line number 1 is at the top left and number 1006 at the top right.

4.2 PR-01 First Prototype Phi Detector (Hamamatsu n strip device)

The Hamamatsu Phi detector is divided into 2 regions see Figure 5. The inter-strip pitch at the inner radius in each region is 45 and 44 microns respectively. A stereo angle is introduced to the strips by tilting around the centre point of the strip by 5 degrees; the sense of the twist is such that the phi angle of the strip is increased at its inner radius and decreased at its outer radius. The strip phi angles, the centre point of each strip and the stereo angle were obtained from the Hamamatsu diagrams: these were checked with microscope measurements. The full detector subtends 72 degrees. The detector is divided into six areas of consecutive routing line read-out, these are shown on Figure 6. The 1024 strips are uniquely identified by the strip and region number, the strip numbering starts from 0 within each region. The routing line numbers run from 1 to 1024, and are marked on the silicon. These routing line numbers run in ascending order from left to right of the detector with respect to Figure 6. Table 2 is provided as a reference guide to the strip layout of the detector.

Routing Line	Strip Number	Detector Region	Routing Area	Phi	R low	R high	Pitch
1	0	2	1	0.608817	2.80076	4.98679	0.0044
128	127	2	1	0.409636	2.80076	4.98679	0.0044
129	0	1	2	0.598936	1.0036	2.78654	0.0045
256	127	1	2	0.0263964	1.0036	2.78654	0.0045
257	128	2	3	0.408067	2.80076	4.98679	0.0044
512	383	2	3	0.00813742	2.80076	4.98679	0.0044
513	384	2	4	0.00656907	2.80076	4.98679	0.0044
768	639	2	4	-0.393361	2.80076	4.98679	0.0044
769	128	1	5	0.0218882	1.0036	2.78654	0.0045
896	255	1	5	-0.550651	1.0036	2.78654	0.0045
897	640	2	6	-0.394929	2.80076	4.98679	0.0044
1024	767	2	6	-0.59411	2.80076	4.98679	0.0044

Table 2: The Hamamatsu PR-01 Phi Detector strip Layout. The strips at which a transition occurs between regions or the routing line areas are listed. The phi angle of the strip is given at the centre point of the strip. The inter-strip pitch is given at the inner radius of the strip.

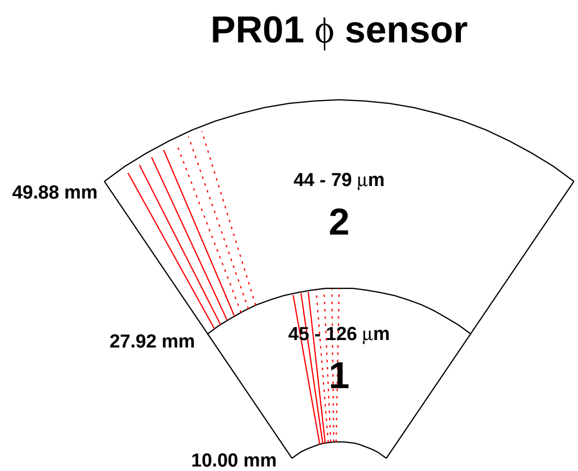
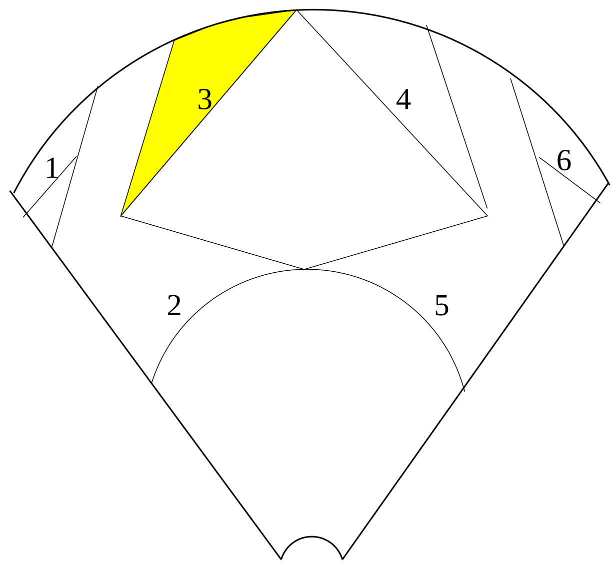
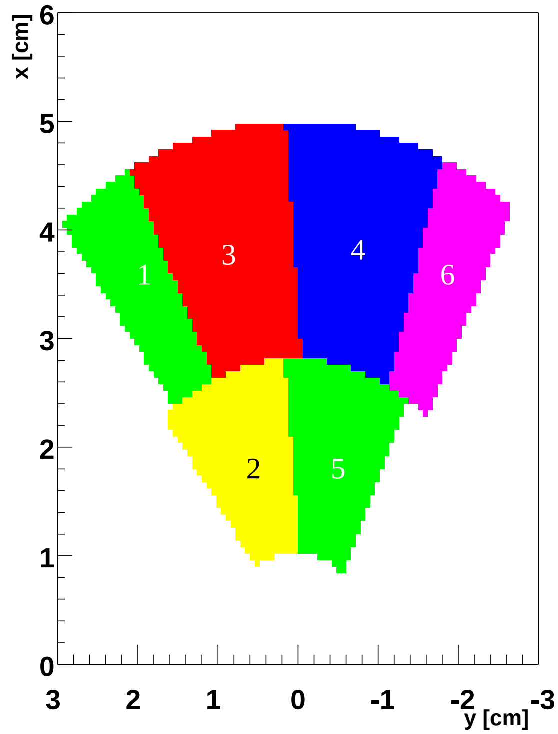


Figure 5: The division of the 1998 Hamamatsu PR-01 prototype Phi detector into the inner and outer regions of strips. The diagram shows the front surface of the detector, in the local geometry system the X-axis runs vertically along the centre line of the detector and the Y-axis to the left. Routing line number 1 is at the top left and number 1024 at the top right.



(a)



(b)

Figure 6: The routing line read-out scheme of the 1998 Hamamatsu PR-01 prototype Phi detector. The marked numbers indicate the division into routing line areas. The lines next to the numbers represent the contact points between the strips and the routing lines. As an illustration, the shaded area shows the path of the routing lines that read the outer region phi strips with an angle between 0 and 0.4 radians. In Figure (b) the strips that are read out by each routing line area are shaded in bands. Areas 3 and 4 each contain 256 strips, all other areas have 128 strips. The diagram shows the front surface of the detector, in the local geometry system the X-axis runs vertically along the centre line of the detector and the Y-axis to the left. Routing line number 1 is at the top left and number 1024 at the top right.

4.3 PR-02 Second Prototype R Detector (Micron p strip device)

The Micron PR-02 R detector is divided into 6 regions see Figure 7. Regions 1,2,3,4 consist of approximately 46 degree arc strips, and regions 5,6 of full-length (approximately 91 degree) strips. The strips in regions 1 to 4 are numbered inside each region from 1 to 384. The strips in regions 5,6 are numbered 385 to 640. There are 2048 strips in total. The full detector subtends 182 degrees.

The strip pitch for strip numbers 1 to 188 is 32.5 microns. From strip numbers 189 to 640 the pitch is proportional to the radius.

For the strip centre radii this gives:

For n is 1 to 189

$r_n = 7994.5 \; + \; 32.5 \; \times \; n$

For n is 190 to 640

$r_n = 14137 \; + \; (\frac{14137}{14137-32.5})^{(n-189)}$

The pitches and strip radii have been obtained from the Liverpool mask designer Phil Turner [2].

The detector is divided into eighteen areas of routing line read-out, these are shown on Figure 8. In areas 1,2,3,4,6,7,8,9,10,11,12,13,15,16,17,18 (regions 1-4) adjacent routing lines read out alternate strips, whereas in areas 5,15 (regions 5,6) adjacent routing lines read out adjacent strips: this pattern is illustrated in Figure 9. These routing line numbers run in ascending order from left to right of the detector with respect to Figure 8. Table 3 is provided as a reference guide to the strip layout of the detector.

[2] phil@hep.ph.liv.ac.uk

Routing Line	Strip Number	Detector Region	Routing Area	R	Phi low	Phi2 high	Strip pitch
1	384	1	1	2.21448	0.794125	1.58825	51.0267
64	258	1	1	1.65702	0.794125	1.58825	38.1815
65	383	1	2	2.20939	0.794125	1.58825	50.9094
192	129	1	2	1.2187	0.794125	1.58825	32.5
193	256	1	3	1.64941	0.794125	1.58825	38.0061
320	2	1	3	0.80595	0.794125	1.58825	32.5
321	127	1	4	1.2122	0.794125	1.58825	32.5
384	1	1	4	0.8027	0.794125	1.58825	32.5
385	640	5	5	3.99172	0	1.58825	0
640	385	5	5	2.21958	0	1.58825	51.1443
641	384	2	6	2.21448	0	0.794125	51.0267
704	258	2	6	1.65702	0	0.794125	38.1815
705	383	2	7	2.20939	0	0.794125	50.9094
832	129	2	7	1.2187	0	0.794125	32.5
833	256	2	8	1.64941	0	0.794125	38.0061
960	2	2	8	0.80595	0	0.794125	32.5
961	127	2	9	1.2122	0	0.794125	32.5
1024	1	2	9	0.8027	0	0.794125	32.5
1025	384	3	10	2.21448	-0.794125	0	51.0267
1088	258	3	10	1.65702	-0.794125	0	38.1815
1089	383	3	11	2.20939	-0.794125	0	50.9094
1216	129	3	11	1.2187	-0.794125	0	32.5
1217	256	3	12	1.64941	-0.794125	0	38.0061
1344	2	3	12	0.80595	-0.794125	0	32.5
1345	127	3	13	1.2122	-0.794125	0	32.5
1408	1	3	13	0.8027	-0.794125	0	32.5
1409	640	6	14	3.99172	-1.58825	0	0
1664	385	6	14	2.21958	-1.58825	0	51.1443
1665	384	4	15	2.21448	-1.58825	-0.794125	51.0267
1728	258	4	15	1.65702	-1.58825	-0.794125	38.1815
1729	383	4	16	2.20939	-1.58825	-0.794125	50.9094
1856	129	4	16	1.2187	-1.58825	-0.794125	32.5
1857	256	4	17	1.64941	-1.58825	-0.794125	38.0061
1984	2	4	17	0.80595	-1.58825	-0.794125	32.5
1985	127	4	18	1.2122	-1.58825	-0.794125	32.5
2048	1	4	18	0.8027	-1.58825	-0.794125	32.5

Table 3: The Micron PR-02 R Detector strip Layout. The strips at which a transition occurs between regions or the routing line areas are listed.

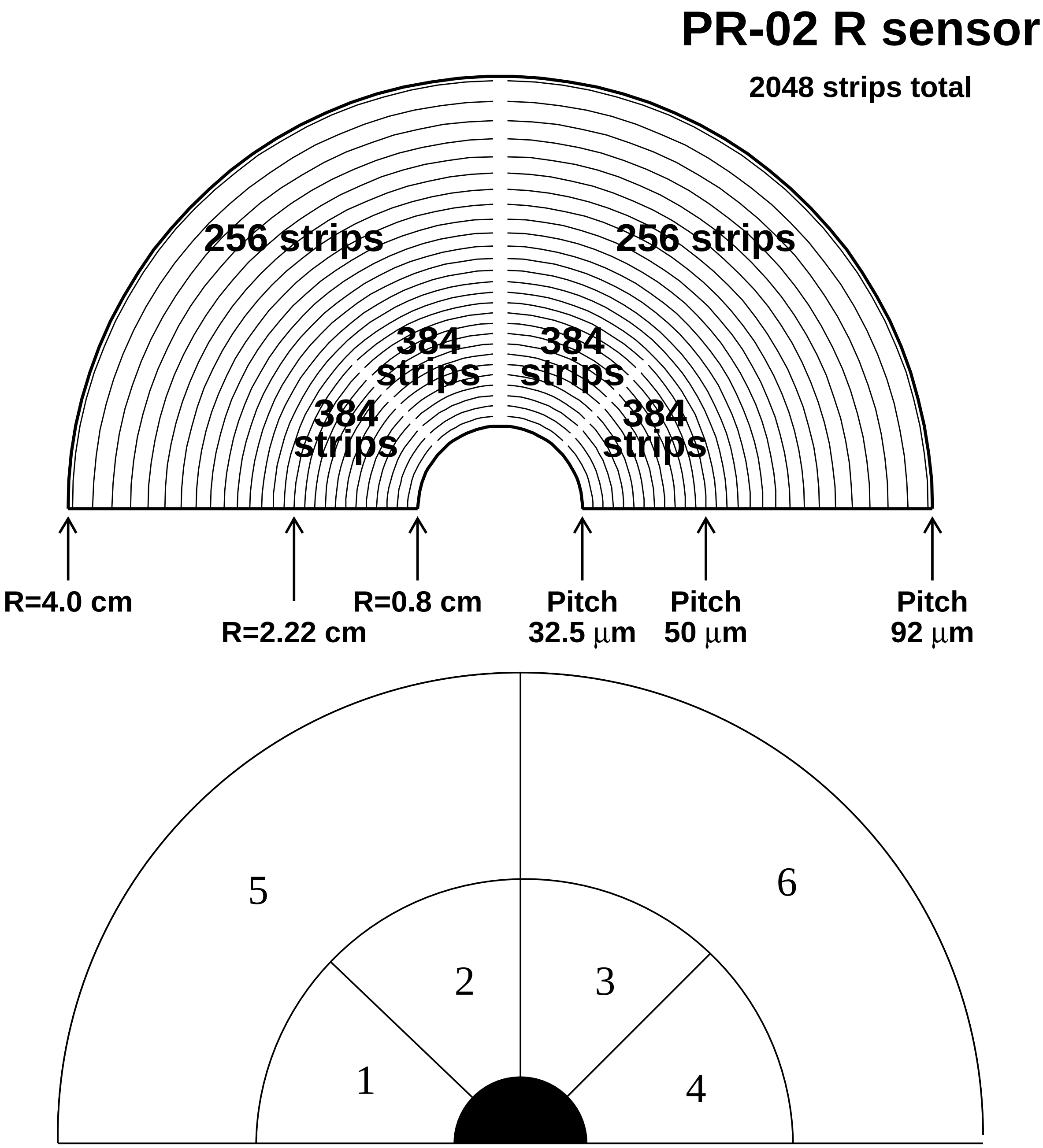


Figure 7: The division of the 2000 Micron PR-02 prototype R detector into regions with strips which subtend the same angle. The diagrams show the front surface of the detector, in the local geometry system the X-axis runs vertically along the centre line of the detector and the Y-axis to the left. Routing line number 1 is at the left and number 2048 at the right.

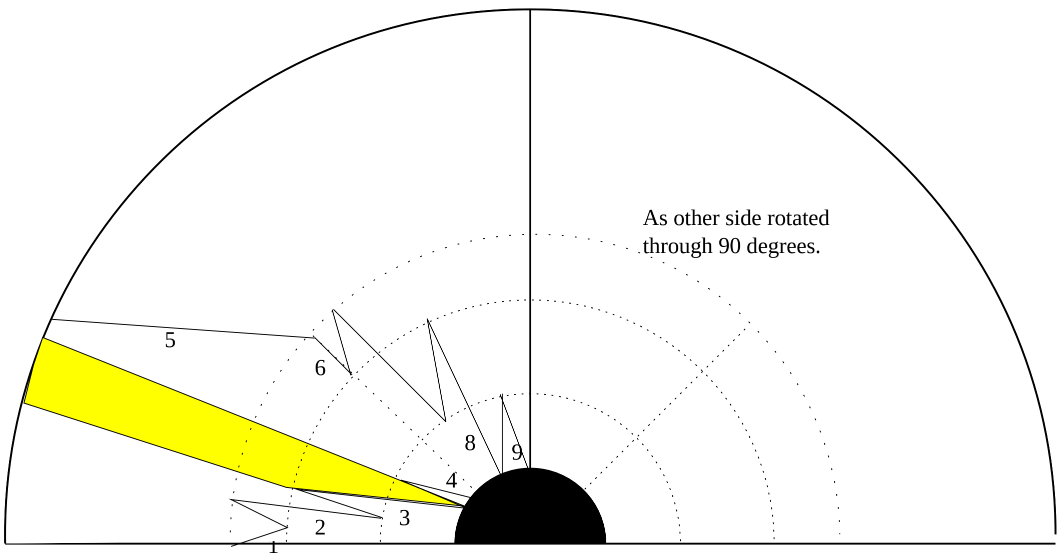


Figure 8: The routing line read-out scheme of the 2000 Micron PR-02 prototype R detector. The marked numbers indicate the division into routing line areas. The lines next to the numbers represent the contact points between the strips and the routing lines. As an illustration, the shaded area shows the path of the routing lines that read some of the inner strips in the first quadrant of the detector. The diagram shows the front surface of the detector, in the local geometry system the X-axis runs vertically along the centre line of the detector and the Y-axis to the left. Routing line number 1 is at the left and number 2048 at the right.

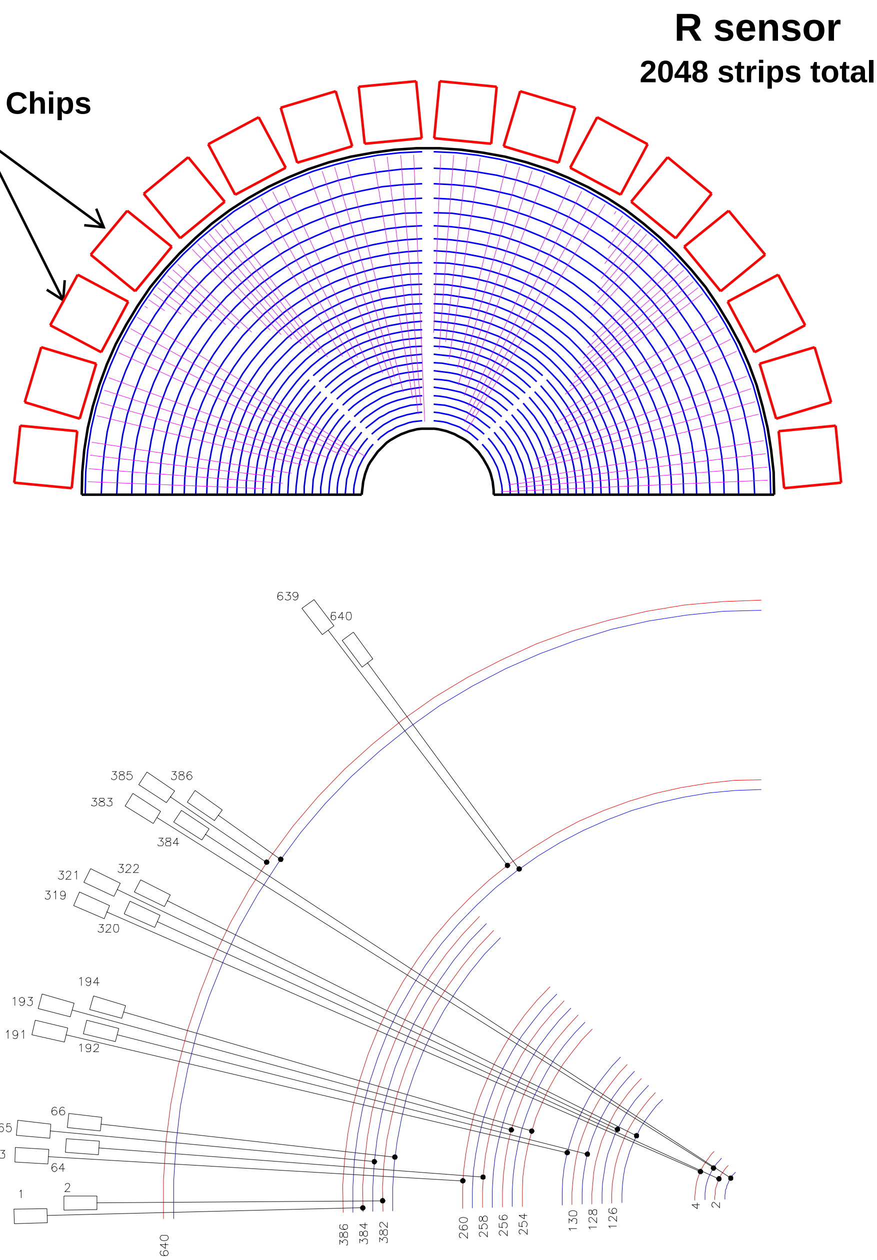


Figure 9: The routing line read-out scheme of the 2000 Micron PR-02 prototype R detector. Note that in the inner areas of the detector adjacent routing lines read out alternate strips. The diagrams show the front surface of the detector, in the local geometry system the X-axis runs vertically along the centre line of the detector and the Y-axis to the left. Routing line number 1 is at the left and number 2048 at the right.

4.4 PR-02 Second Prototype Phi Detector (Micron p strip device)

The Micron PR-02 Phi detector is divided into 2 regions see Figure 10. The inter-strip pitch at the inner radius in each region is 24.4 and 55.5 microns respectively. There are 1024 strips in each region, the strips in the inner and outer regions are collinear. The strip numbering starts from 1 within each region. The routing line numbers run from 1 to 2048, and are marked on the silicon. These routing line numbers run in ascending order from left to right of the detector with respect to Figure 10. A stereo angle is introduced to the strips by tilting the strips such that there is a 9 degree angle between the line from the centre of the detector to the outermost end of an outer region strip, and the line from the centre of the detector to the innermost end of the corresponding inner region strip. The sense of the twist is such that the phi angle of the strip is increased at its outer radius and decreased at its inner radius: this is illustrated in Figure 10. The strip location information was obtained from the Liverpool mask designer Phil Turner [3]. The full detector (centre of the first to centre of the last strip) subtends 182 degrees, the phi at the inner point on the first and last strips in the inner region are defined to be ± 91 degrees.

The detector routing line areas are identical to the regions. A continuous routing pattern is maintained over the whole detector where strips are read alternately from the inner and outer regions: the first strip is read from the inner region. The inner and outer region implants are collinear. The inner region routing lines lie between the outer region strips and curve just before making the contact to the inner region strips, as shown in Figure 11. Table 4 is provided as a reference guide to the strip layout of the detector.

[3] phil@hep.ph.liv.ac.uk

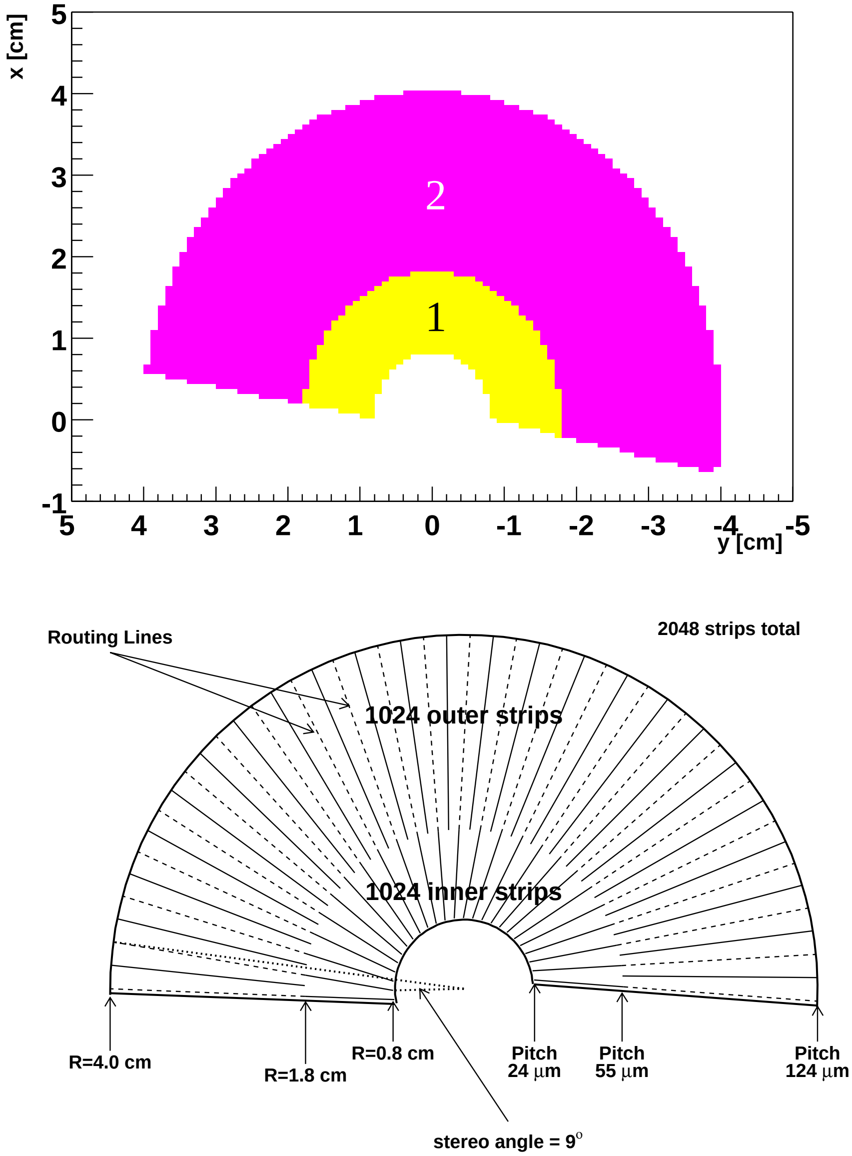


Figure 10: The division of the 2000 Micron PR-02 prototype Phi detector into the inner and outer regions of strips. The effect of the stereo angle is reflected in the shape of the perimeter of the detector. In the upper diagram the second metal layer routing lines of the inner region strips through the outer region are also shown. The diagrams show the front surface of the detector, in the local geometry system the X-axis runs vertically along the centre line of the detector and the Y-axis to the left. Routing line number 1 is at the left and number 2048 at the right.

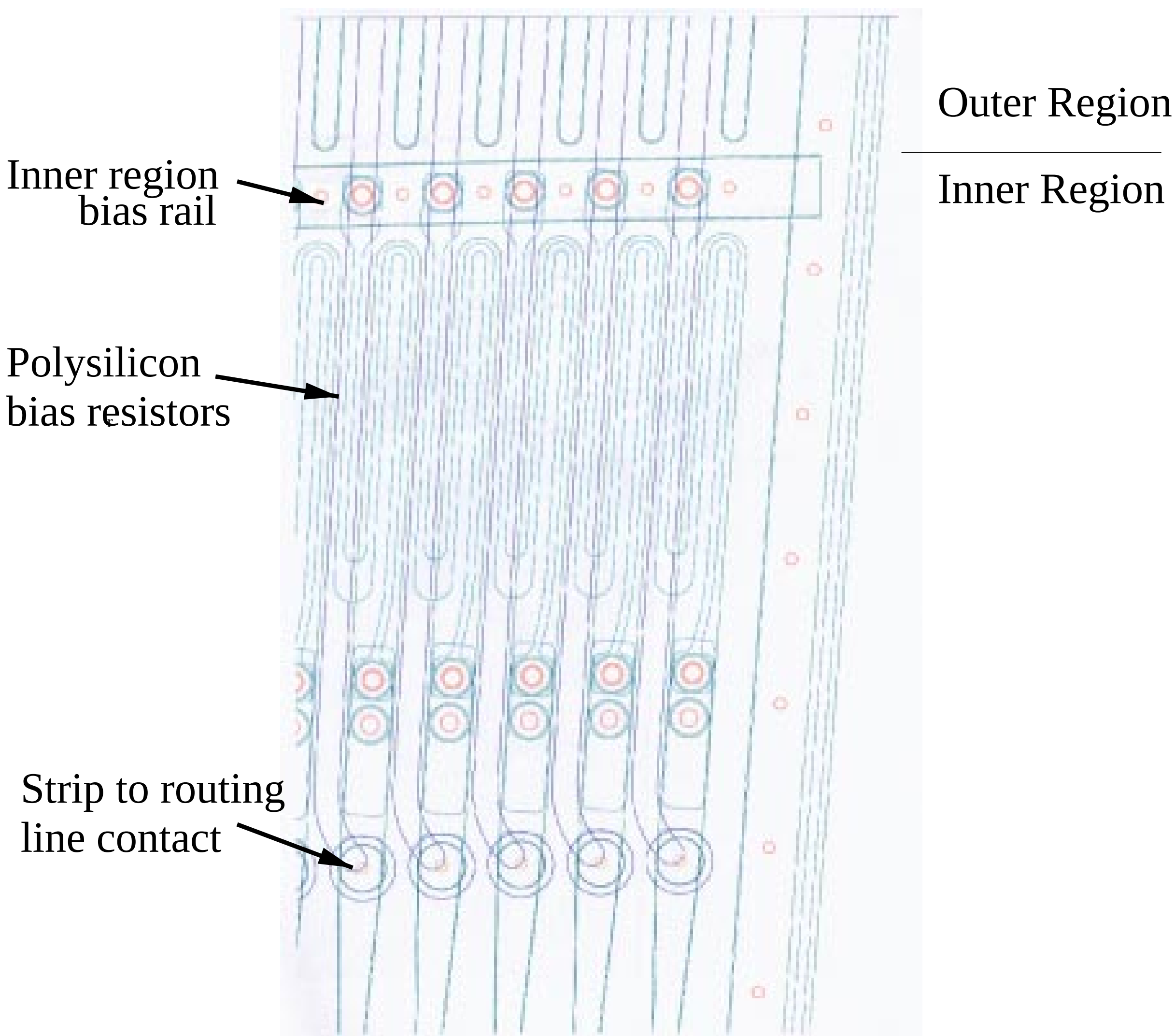


Figure 11: The design drawing of the Micron PR-02 Phi Prototype detector, showing the boundary between the inner and outer regions.

Routing Line	Strip Number	Detector Region	Routing Area	Phi	R low	R high	Strip pitch
1	1	1	1	1.51299	0.8	1.78985	0.00248
2	1	2	2	1.44607	1.78985	4	0.00555
128	64	2	2	1.25055	1.78985	4	0.00555
129	65	1	1	1.31436	0.8	1.78985	0.00248
256	128	2	2	1.05192	1.78985	4	0.00555
257	129	1	1	1.11573	0.8	1.78985	0.00248
384	192	2	2	0.85329	1.78985	4	0.00555
385	193	1	1	0.917106	0.8	1.78985	0.00248
512	256	2	2	0.654662	1.78985	4	0.00555
513	257	1	1	0.718478	0.8	1.78985	0.00248
640	320	2	2	0.456034	1.78985	4	0.00555
641	321	1	1	0.51985	0.8	1.78985	0.00248
768	384	2	2	0.257406	1.78985	4	0.00555
769	385	1	1	0.321222	0.8	1.78985	0.00248
896	448	2	2	0.0587776	1.78985	4	0.00555
897	449	1	1	0.122594	0.8	1.78985	0.00248
1024	512	2	2	-0.139851	1.78985	4	0.00555
1025	513	1	1	-0.0760346	0.8	1.78985	0.00248
1152	576	2	2	-0.338479	1.78985	4	0.00555
1153	577	1	1	-0.274663	0.8	1.78985	0.00248
1280	640	2	2	-0.537107	1.78985	4	0.00555
1281	641	1	1	-0.473291	0.8	1.78985	0.00248
1408	704	2	2	-0.735735	1.78985	4	0.00555
1409	705	1	1	-0.671919	0.8	1.78985	0.00248
1536	768	2	2	-0.934363	1.78985	4	0.00555
1537	769	1	1	-0.870547	0.8	1.78985	0.00248
1664	832	2	2	-1.13299	1.78985	4	0.00555
1665	833	1	1	-1.06918	0.8	1.78985	0.00248
1792	896	2	2	-1.33162	1.78985	4	0.00555
1793	897	1	1	-1.2678	0.8	1.78985	0.00248
1920	960	2	2	-1.53025	1.78985	4	0.00555
1921	961	1	1	-1.46643	0.8	1.78985	0.00248
2047	1024	1	1	-1.66196	0.8	1.78985	0.00248
2048	1024	2	2	-1.72888	1.78985	4	0.00555

Table 4: The Micron PR-02 Phi Detector strip Layout. Information is provided for every 128/129th strip. The phi angle of the strip is given at the centre point of the strip. The inter-strip pitch is given at the inner radius of the strip.

5 Software Implementation

Each of the classes, or types of classes, in this branch of the software is described below. The relationship of these classes is shown in Figures 12 and 13.

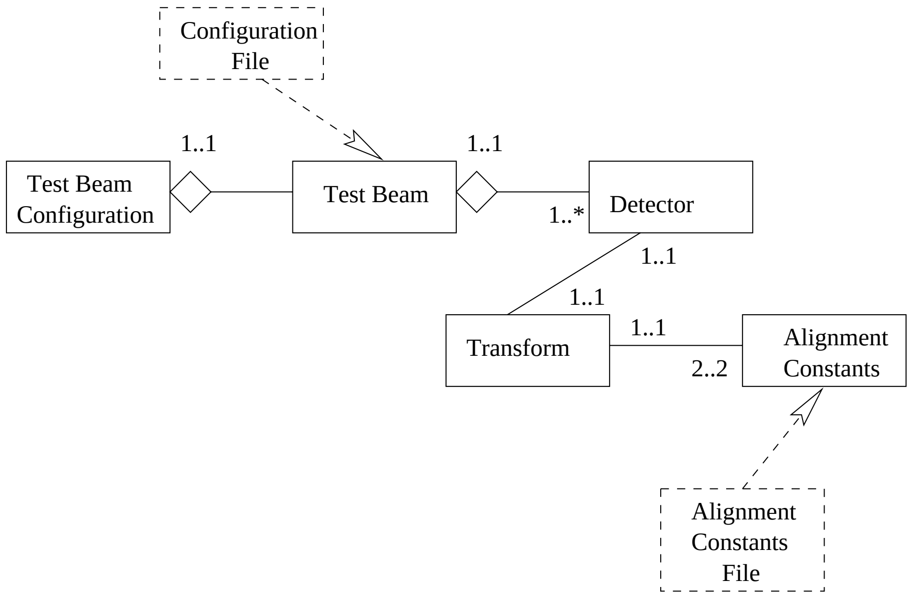


Figure 12: UML diagram of the `Test-Beam Configuration` class and related software. A `Test-Beam` is instantiated using a configuration file, and corresponding files of alignment constants.

5.1 Test-Beam Configuration

This class provides the main access point for this suite of routines. A call must be made to the class constructor stating which test-beam data is to be analysed. The `Test-Beam Configuration` then sets-up and stores the required `Test-Beam`. The test-beam set-up is controlled by a configuration file (see below).

Using the member functions of this class all the general `Test-Beam` properties can be accessed and the `Detectors` in the `Test-Beam` obtained.

`TestBeamConfiguration` is the class the user interfaces with, but the decoding of the commands in the configuration file is handled by the companion class `TestBeam`.

5.2 Configuration File

These simple ascii files are stored in the config directory, and have the suffix '.config'. The recognised commands are given in table 5.

The list of detectors in the .config file is required to be in the order in which they are read out in the DAQ. It is assumed that detectors equipped with VA2 chips are read out before SCTA equipped detectors. If there are any unused ADC inputs, which are read out into the DAQ, an 'EMPTY' detector must be declared in the .config file for each unoccupied position.

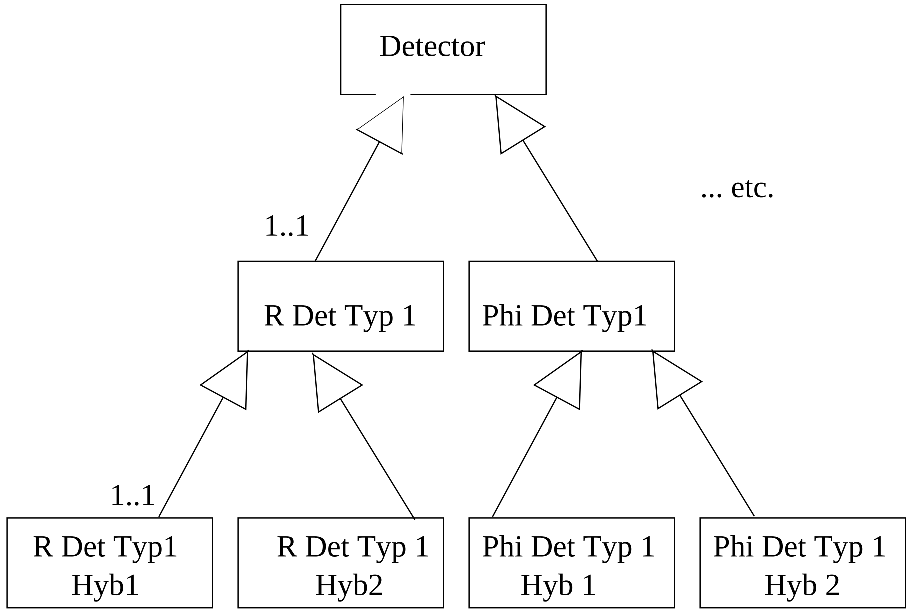


Figure 13: UML diagram of the ABC class `Detector` and its inheritance tree. The classes in the second layer represent particular detectors (e.g. Hamamatsu Prototype R detectors), and those in the final layer represent hybrids for these detectors (e.g. eight chip VA2 hybrid for the Hamamatsu R detector)

Note that the SCIP command expects a list of how many CRAM ADC inputs are used per SCTA equipped detector, whereas the VCIP command accepts only one number and assumes all VA2 detectors use the same number of CRAM inputs.

5.3 Detector

The Detector class has two roles:

- It holds the location of the detector in the global frame (i.e. relative to the other test-beam detectors), this is stored as a `Transform` object (see below).
- It is the interface class for the `Detector Types`. The user accesses the functions stored in the `Detector Types` through this `Detector` interface class.

The detector must be initialised to return information for a particular channel using the member functions setChipChannel() and setDAQChannel(). All subsequent information retrieved from that detector will concern the selected channel until the active detector channel is reset to a new value.

There are four types of channel used in the Detector software.

DAQ Channel	ADC channel number (0 to number of ADC channels read out)
Chip channel	front-end chip channel (0 to number of chips $\times$ channels per chip)
Routing Line	Number of the bond pad on the silicon detector
Strip Number	A numbering reflecting the physical position of a strip

Command	Description
NAME	text identifier for the test-beam (one word only)
NDET	How many detectors are present (Empty detectors count)
NUMB	Detector number always followed by information on its type
TYPE	Detector Type e.g. RTYPE1HYBRID1
NVA2	Number of CRAM inputs with detectors using VA2 (or similar) chips connected
VCIP	Number of CRAM inputs occupied by all detector of VA2 type
NSCT	Number of CRAM inputs with SCTA detectors
SCIP	List of number of CRAM inputs occupied by each detector of SCTA type
SAMP	number of samples taken, that is how many SCTA pipe-line locations were read out
CALI	number of calibration words read out per detector blocklet
TDCD	if TDC data was or was not read out
MISS	Number of DAQ channels missed and for which detectors
	Negative channels missed means last channels of detector missed
	Negative detectors means apply to all detectors

Table 5: The recognised commands in the test-beam configuration file.

The strip number is not unique and must be used in conjunction with a detector region number.

The detectors are subdivided into regions which contain strips of similar geometry, and routing areas which contain strips from a single region that are read out with the same routing line pattern. A description of the strip locations and routing line structure for the Hamamatsu and Micron detectors is provided in section 4.

Integer channel numbers are used to refer to the centre of the metal layer of a strip. When we consider clusters of hit strips we can no longer refer to the equivalent channel of the centre of the cluster using an integer number. Hence, floating point numbers are used to represent points between strips, the range -0.5 to +0.5 around the strip centre represents the range from halfway to the previous strip (the one at smaller radius or more negative phi) to halfway to the next strip (the one at larger radius or more positive phi). Remember that due to the complex routing structure of the detectors consecutive chip channels and routing lines frequently do not represent physically adjacent strips. The choice adopted of defining the boundary range for a strip from -0.5 to 0.5 minimises problems due to rounding errors. Also, note that the sense of the floating point part of the chip, DAQ or routing channel number follows increasing R/Phi irrespective of the general read-out pattern of the detector: for Hamamatsu R detector R increases with increasing routing line number, but for Micron detectors R decreases with increasing routing line number. This is undoubtedly confusing, future software would be better to use only integer channel numbers for hits and refer to the centre of clusters purely by their spatial positions.

The strip pitch on an R detector is used to refer to the inter-strip pitch to the next strip at larger radii. Note that for a phi detector the strip pitch varies as a function of the radius.

5.4 Detector Type

These classes are named in the style Geometry-Typ-number. RTyp1 and PhiTyp1 describe the R and Phi geometry Hamamatsu manufactured first prototype detectors, RTyp2 and PhiTyp2 the Micron PR-02 prototypes. The functions provided by these classes are accessed by the user through the `Detector` interface class. These functions include accessing the local geometry location of a strip, and locating the adjacent strips. These classes do not contain the mapping from the routing lines to the DAQ channels found in the raw data, this is a property of the `Hybrid` (see below).

A special type of detector 'Empty' is provided simply to fill a space in the DAQ, this can be used where channels are stored into the FZ file but no detector is connected to this ADC input.

5.5 Hybrid

Each `Detector Type` must have at least one `Hybrid` that inherits from that type. The Hybrid class provides functions to determine which DAQ line was used to read out a given channel of a front-end chip and to determine to which routing line this chip channel is bonded.

Example:

`RTyp1Hyb1` and `RTyp1Hyb2` are both `Hybrids` for use with `Detector Type RTyp1`: the former describes the bonding of the detector to an eight VA2 chip hybrid while the latter describes the bonding pattern fo a four SCT128A chip hybrid.

Note that a better implementation would have been for the `Detector` to use containment rather than inheritance for the `Hybrid`.

5.6 Transform

The `Transform` class performs the transformation from the local detector geometry to the global frame. The alignment parameters that describe the transformation are stored in `Alignment` objects. Each `Transform` object stores two `Alignment` objects, known as the flip and the rotate alignments.

These store the alignment parameters corresponding to the six degrees of freedom of positioning a plane (three displacements and three rotations).

The flip alignment parameters describe the transformation that will rotate (but not shift) the detector into its expected (i.e. ideal) orientation in the test-beam.

The rotate alignment parameters describe the transformation to take the detector from its ideal position to the actual location. The rotation angles in this transformation should therefore be relatively small.

The code performing the transformations is split between the `Transform` and `Alignment` classes. The details of the transformation procedure are described in Section 3.1.

5.7 Point Array

This holds a set of three-dimensional points. The array of points can be stored in X, Y, Z or $R\phi Z$ form, and can be converted between the two forms. The local and global `Detector` geometry routines accept inputs and return outputs using this form.

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