Geometry of the LHCb Outer Tracker (Part I)

May 25, 2003

Abstract

The geometry of the Outer Tracker of the LHCb detector is discussed. In particular, the active lengths of the detector modules, as desired to achieve the required angular acceptance, are calculated.

LHCb Technical Note

Issue	Final
Revision	2
Reference	LHCb-2003-035
Created	November 6, 2002
Last Modified	May 25, 2003

Prepared by Sebastian Bachmann
Physikalisches Institut, University of Heidelberg, Germany

Antonio Pellegrino
NIKHEF, Amsterdam, The Netherlands

Contents

List of Tables

List of Figures

1 Introduction

This document describes the geometry of the Outer Tracker (OT) of the LHCb detector [1]; in particular, the active lengths of the detector modules are calculated. Throughout the document we shall use the LHCb coordinate system, with the origin in the nominal interaction point, the z-coordinate points along the beam line, the x-axis is horizontal, and the y-axis vertical.

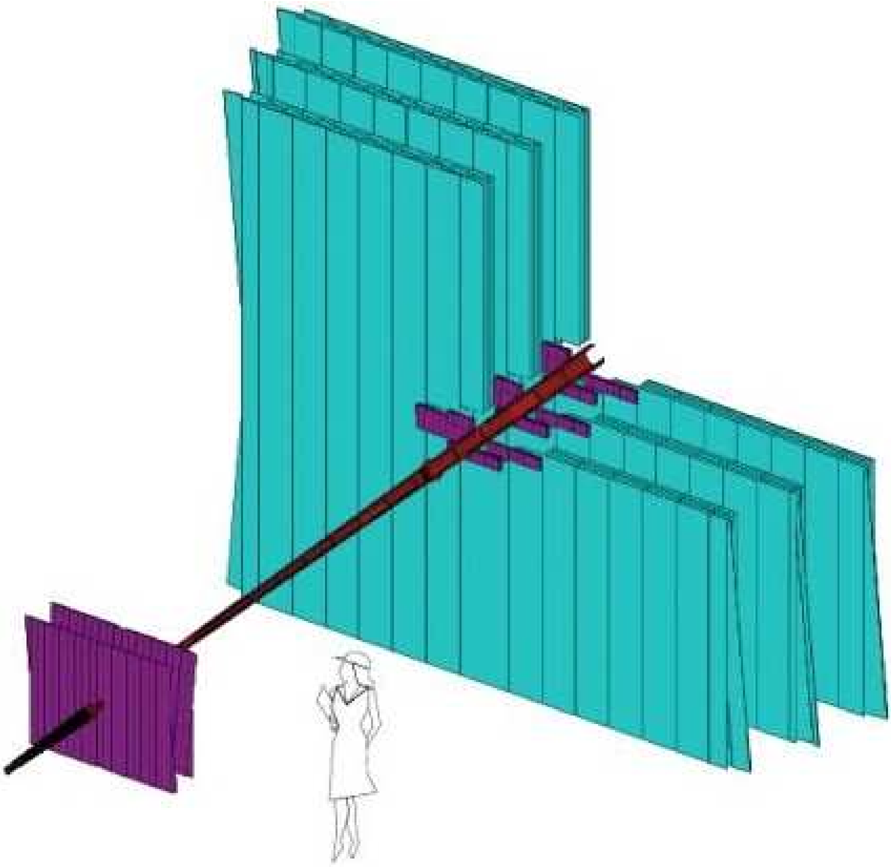

Figure 1: Overview of the LHCb Tracking System, IT and OT.

2 Detector Design

The OT geometry is based on the following design:

1. As shown in Fig. 1, the tracking stations ST1 – ST3 consist of inner and outer tracking stations. The OT covers the whole vertical (250 mrad)

and horizontal (300 mrad) acceptance, except the innermost part that covered by the Inner Tracker (IT). The IT "cross-geometry", shown in Fig. 2, is described in detail in the IT TDR [2]. The IT parameters relevant to our discussion are summarised in Table 1.

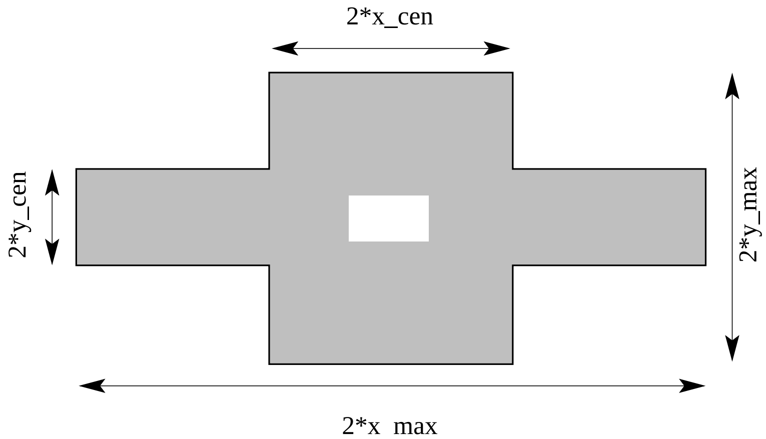

Figure 2: Inner Tracker cross geometry.

	x_{cen}	y_{cen}	x_{max}	y_{max}
ST1	264.5	109	621	200
ST2	264.5	109	628	207
ST3	264.5	109	635	214

Table 1: Parameters of Inner Tracker cross geometry.

2. An overlap between IT and OT is mandatory to allow their alignment with respect to each other. On one hand, the overlap has to be sufficient for that purpose; on the other hand, it should be as small as possible to minimise the OT occupancy and the material budget.

3. Every tracking station consists of four measurement planes. Their orientation is X/U/V/X. X planes measure the x-coordinate of the impact point of charged particles; the U (resp. V) planes are tilted by $+5^\circ$ (resp. -5°) with respect to the X planes. Each plane consists of two layers of straw tubes.

Additional constraints result from more technical details of the detector design:

1. The design of the OT is modular, as shown in Fig. 1. The width of the modules is defined by the pitch and number of straw tubes per module and by some additional space reserved for the side walls of the module boxes. A clearance between adjacent modules is foreseen to accommodate tolerances in the production and placement of the module boxes.

2. The number of modules types should be minimised to keep the mass production of the modules simple.

3. The total length of the modules is bigger than their active length: the additional space is foreseen for the module interface to the Front-End Electronics, the module services (gas, cooling, cables, etc.), and the module support system.

3 Arrangement of OT modules

The z position of the X,U,V,X planes in the tracking stations is shown in Fig. 3. Denoting with H the thickness of the detector modules and with ΔS the space between layers, the position in z of the front face of each layer in a tracking station is given by

$$z_{layer}(n) = z_{min}^{station} + n \times (H + \Delta S)\,, \quad (1)$$

with $n = 0, 1, 2, 3$ denoting the $X1$, U, V and $X2$ modules, respectively. The z-positions of all layers are given in Table 2.

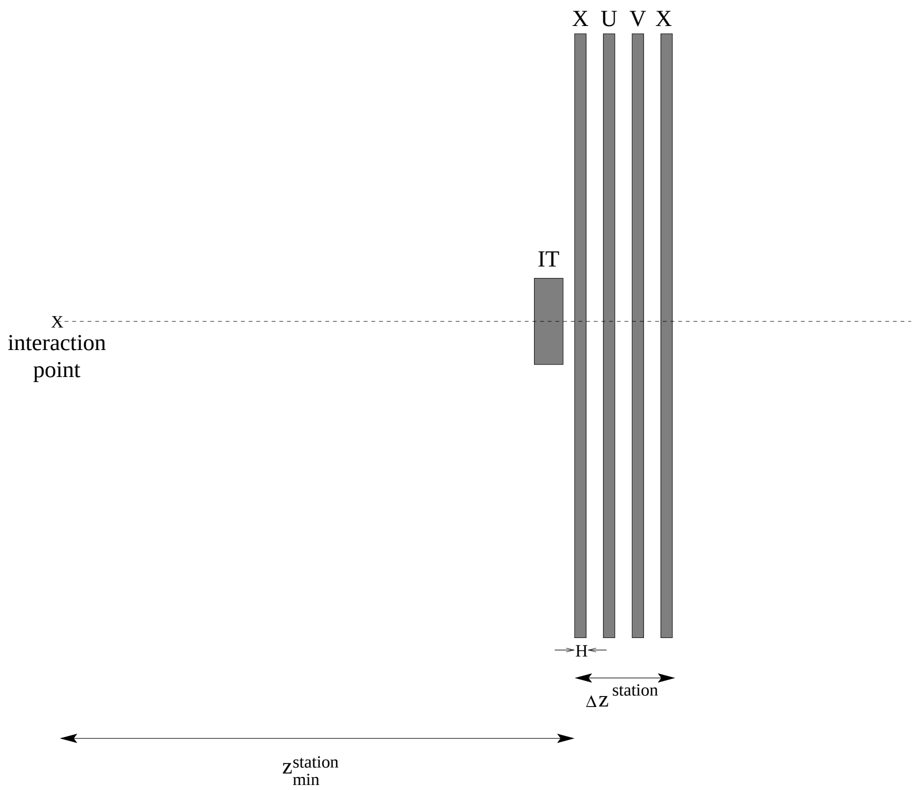

Figure 3: Position of the X,U,V,X planes of a tracking station along z.

The arrangement of the detector modules in the (x,y) plane is shown in Fig. 4. Due to the cross geometry of the inner tracker, seven different types of detector modules exist: F, S1U and S1L, S2U and S2L, S3U and S3L. Modules in U (resp. V)-layers are tilted by an angle of +5° (resp. -5°) with respect to modules in X-layers. The rotation axis is for every module at $y = 0$ at the centre in x of the module. The detailed arrangement of the

	Inner tracker	Inner tracker	Outer tracker	Outer tracker
	z_{min}[mm]	z_{max}[mm]	z_{min}[mm]	z_{max}[mm]
ST1	7673	7828	7838	8038
X1			7838	7869
U			7894	7925
V			7951	7982
X2			8007	8038
ST2	8360	8515	8525	8725
X1			8525	8556
U			8581	8612
V			8638	8669
X2			8694	8725
ST3	9050	9205	9215	9415
X1			9215	9246
U			9271	9302
V			9328	9359
X2			9384	9415

Table 2: Positions of detector layers along z according to Eq.(1).

"short" modules is shown in Fig. 5: to minimise the material near the beam-pipe, modules S2 and S3 are mirrored between the top and bottom half of a station, as well as between U- and V-layers.

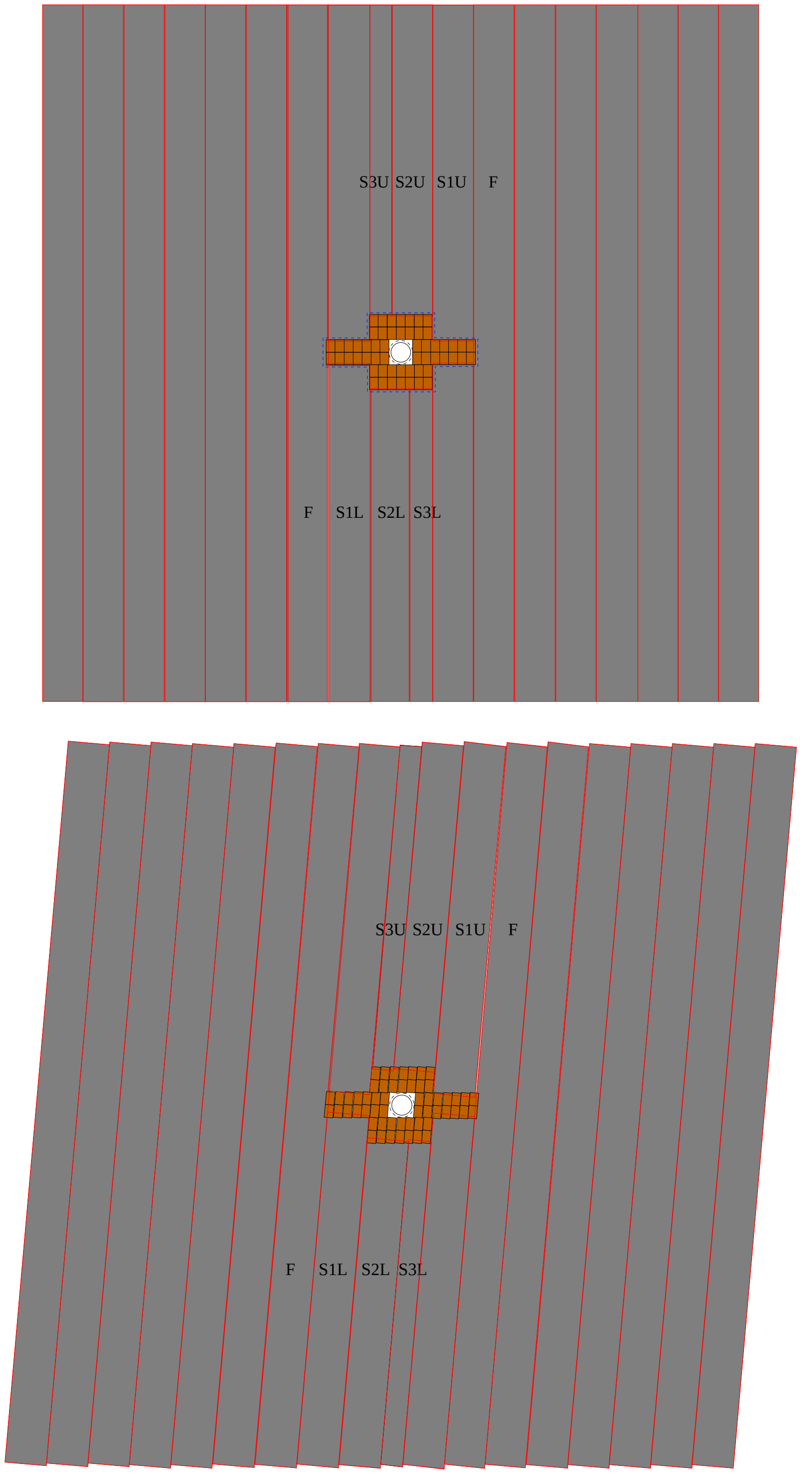

Figure 4: Arrangement of X (top panel) and U (bottom panel) modules in the (x,y) plane.

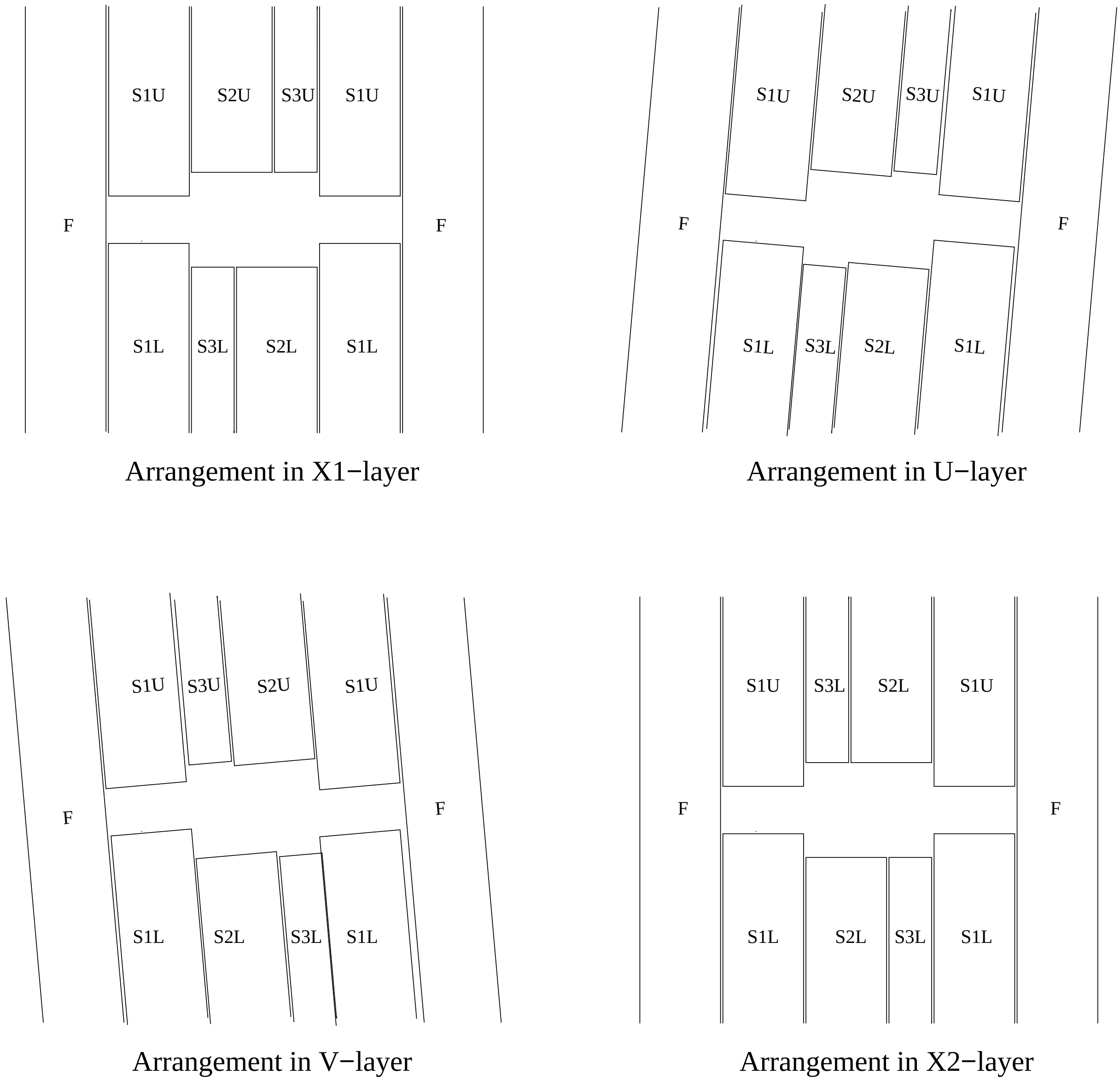

Figure 5: Module arrangement in the OT inner region.

4 Active length of detector modules

In this section the vertical acceptance of the OT modules shall be discussed. The starting point for this discussion is the 250 mrad vertical angular acceptance required of the tracking system. Using the spherical coordinates associated to the Cartesian LHCb system:

$$\begin{cases} x &= r\cos\phi\sin\theta \\ y &= r\sin\phi\sin\theta \\ z &= r\cos\theta \end{cases}, \tag{2}$$

it is easy to show that, for a given $\tilde{z}$, the requested angular acceptance θ_{max} translates into a vertical acceptance

$$\begin{cases} \tilde{y}_{min} &= -\tilde{z}\,\tan\theta_{max} \\ \tilde{y}_{max} &= \tilde{z}\,\tan\theta_{max} \end{cases} \tag{3}$$

Using for $\tilde{z}$ the values of the station z_{max} in Table 2 one obtains the vertical boundaries in Table 3.

	z_{max}[mm]	y_{min}[mm]	y_{max}[mm]	Δy[mm]
ST1	8038	-2052.44	2052.44	4105
ST2	8725	-2227.86	2227.86	4456
ST3	9415	-2404.04	2404.04	4808

Table 3: Vertical boundaries of each station according to Eq.(3).

Translating the values in Table 3 into actual active module length and position $(y^{mod}_{min}, y^{mod}_{max})$ requires taking into account the design constraints discussed in Sect. 2:

1. minimise the amount of modules types: this can be simply achieved by using as a starting point the figures for ST3 in Table 3: $(y_{min}, y_{max}) = (-2404.04, +2404.04)$;

2. to obtain the y boundaries of the S modules, one needs to take into account the IT geometry in Table 1 and the requirement of IT/OT

overlap discussed in Sect. 2. This can be achieved as follows:

$$\left\{\begin{array}{lcrcl} \tilde{y}^{S1U}_{min} & = & y^{IT}_{cen} & - & \Delta y_{IO} \\ \tilde{y}^{S2U,S3U}_{min} & = & y^{IT}_{max} & - & \Delta y_{IO} \\ \tilde{y}^{S1L}_{max} & = & -y^{IT}_{cen} & + & \Delta y_{IO} \\ \tilde{y}^{S2U,S3U}_{max} & = & -y^{IT}_{max} & + & \Delta y_{IO} \end{array}\right. . \quad (4)$$

Using the figures for ST3 in Table 3, $(y_{min}, y_{max}) = (-2404.04, +2404.04)$, and using Eq. 4 with an IT/OT overlap $\Delta y_{IO} = 10\,\mathrm{mm}$, results in the y active boundaries in Table 4.

Station	Module	y^{mod}_{min}[mm]	y^{mod}_{max}[mm]	Δy^{mod}[mm]
ST1	F	-2404.04	2404.04	4808
	S1U	99.00	2404.04	2305
	S2U	190.00	2404.04	2214
	S3U	190.00	2404.04	2214
	S1L	-2404.04	-99.00	2305
	S2L	-2404.04	-190.00	2214
	S3L	-2404.04	-190.00	2214
ST2	F	-2404.04	2404.04	4808
	S1U	99.00	2404.04	2305
	S2U	197.00	2404.04	2207
	S3U	197.00	2404.04	2207
	S1L	-2404.04	-99.00	2305
	S2L	-2404.04	-197.00	2207
	S3L	-2404.04	-197.00	2207
ST3	F	-2404.04	2404.04	4808
	S1U	99.00	2404.04	2305
	S2U	204.00	2404.04	2200
	S3U	204.00	2404.04	2200
	S1L	-2404.04	-99.00	2305
	S2L	-2404.04	-204.00	2200
	S3L	-2404.04	-204.00	2200

Table 4: Active y boundaries of the X modules.

Notice that the different values of y^{IT}_{max} in Table 1, due to the conical shape of the beam pipe, gave rise to different values of the active length of the S2 and S3 modules in the three tracking stations. Having all modules S2U,S2L,S3U,S3L of the same length will cause a step in the module contour. We propose to choose the S2U,S2L,S3U,S3L module lengths as not to have any step in the middle station ST2, as shown in Fig. 6. The result of this will be a step of the same size (7 mm), but in different directions, in the contour of ST1 and ST3. The new y active boundaries are given in Table 5. In particular, the active lengths of all modules will be the ones shown in Table 6.

Station	Module	y^{mod}_{min}[mm]	y^{mod}_{max}[mm]	Δy^{mod}[mm]
ST1	F	-2404.04	2404.04	4808
	S1U	99.00	2404.04	2305
	S2U	190.00	2397.04	2207
	S3U	190.00	2397.04	2207
	S1L	-2404.04	-99.00	2305
	S2L	-2397.04	-190.00	2207
	S3L	-2397.04	-190.00	2207
ST2	F	-2404.04	2404.04	4808
	S1U	99.00	2404.04	2305
	S2U	197.00	2404.04	2207
	S3U	197.00	2404.04	2207
	S1L	-2404.04	-99.00	2305
	S2L	-2404.04	-197.00	2207
	S3L	-2404.04	-197.00	2207
ST3	F	-2404.04	2404.04	4808
	S1U	99.00	2404.04	2305
	S2U	204.00	2411.04	2207
	S3U	204.00	2411.04	2207
	S1L	-2404.04	-99.00	2305
	S2L	-2411.04	-204.00	2207
	S3L	-2411.04	-204.00	2207

Table 5: Active y boundaries of the X modules.

The last step in translating the values in Table 3 into actual active module length and position $(y^{mod}_{min}, y^{mod}_{max})$ consists in evaluating the effect of the $\pm 5°$ tilt of the U,V modules. As discussed in Sect. 2, this is equivalent to a $\pm 5°$ rotation in the (x,y) plane around $(x^{mod}_{center}, 0)$. Such a rotation is described

Station	Module	Δy^{mod}[mm]
ST1,ST2,ST3	F	4808
	S1U,S1L	2305
	S2U,S2L,S3U,S3L	2207

Table 6: Active lengths of the X modules.

by

$$\begin{pmatrix} x_{\mathrm{U,V}} \\ y_{\mathrm{U,V}} \\ z_{\mathrm{U,V}} \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha & 0 \\ -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_{\mathrm{X}} \\ y_{\mathrm{X}} \\ z_{\mathrm{X}} \end{pmatrix}, \tag{5}$$

where $\alpha = \pm 5^\circ$ and $(x_{\mathrm{X}}, y_{\mathrm{X}}, z_{\mathrm{X}})$ are all referred to $(x^{mod}_{center}, 0)$. In particular, the y coordinate of any point of an U,V module will be displaced, with respect to the y boundaries of an X module, by

$$y_{\mathrm{U,V}} = -\sin\alpha\, x_{\mathrm{X}} + \cos\alpha\, y_{\mathrm{X}}. \tag{6}$$

E.g. the two central points on the y boundaries of an X modules, $(0,y^X_{min})$ and $(0,y^X_{max})$, will be displaced in y by

$$\left\{ \begin{array}{lcl} y^{U,V}_{min} & = & \cos\alpha\, y^X_{min} \\ & & \\ y^{U,V}_{max} & = & \cos\alpha\, y^X_{max} \end{array} \right. . \tag{7}$$

In order to have all modules of each type of the same length, while at the same time covering the vertical acceptance $(y_{min}, y_{max}) = (-2404\,\mathrm{mm}, 2404\,\mathrm{mm})$, we propose to scale the active lengths in Table 6 by the factor $1/\cos\alpha$, with $\alpha = 87.3\,\mathrm{mrad}$, as shown in Fig. 7; the resulting active lengths of all modules are then summarised in Table 7.

Station	Module	Δy^{mod}[mm]
ST1,ST2,ST3	F	4826
	S1U,S1L	2314
	S2U,S2L,S3U,S3L	2215

Table 7: Active lengths of the OT modules as proposed in this write-up.

Although the exact dimensions are closely related to the details of the mechanical design and thus not completely fixed at the time of the present write-up, the final module dimensions will not deviate significantly from those in Table 7.

References

[1] LHCb Outer Tracker, Technical Design Report.

[2] LHCb Inner Tracker, Technical Design Report.

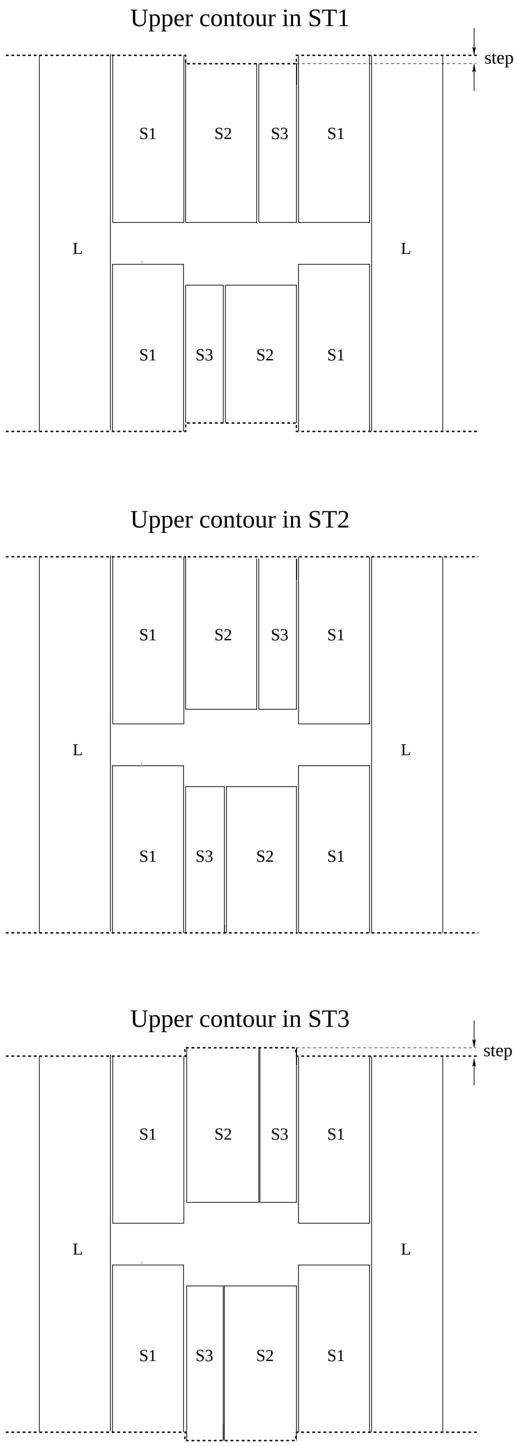

Figure 6: Upper contour of modules near the beam-pipe.

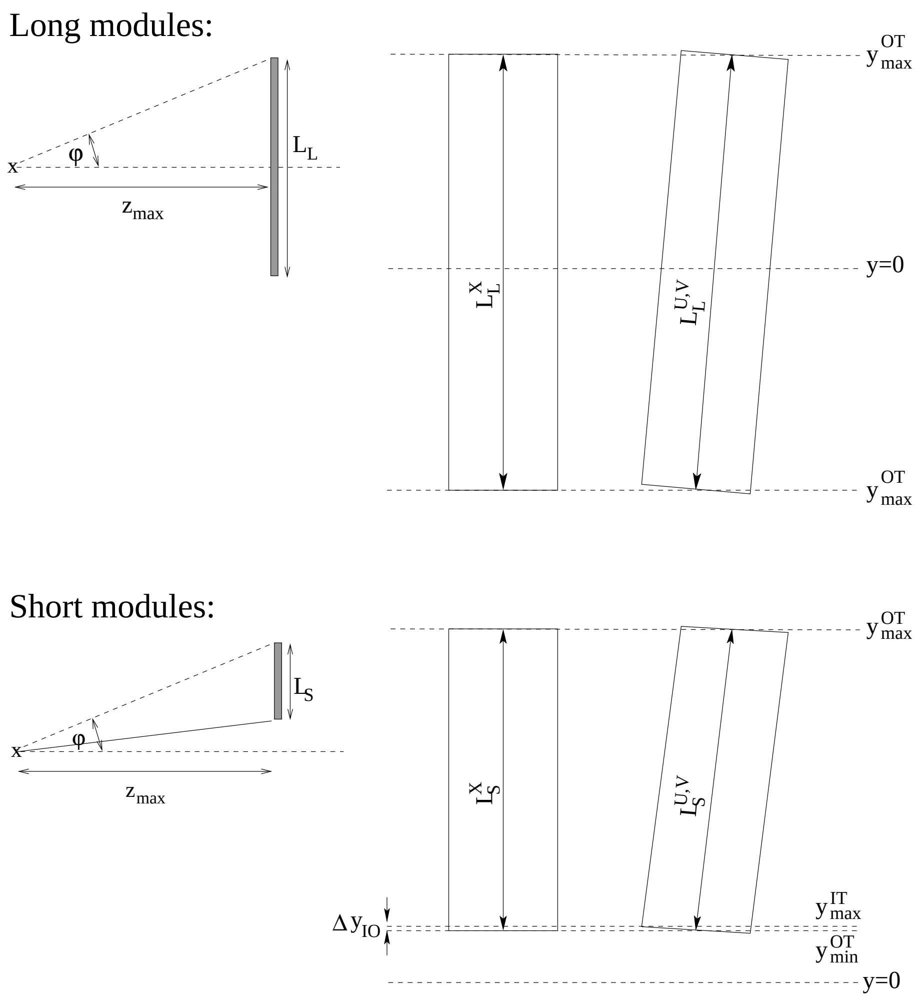

Figure 7: Active regions of the X,U,V module types.