The Inner Tracker detector description and its implementation in the XML database

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Abstract

The LHCb Inner Tracker has undergone many changes with respect to its original design. Furthermore its software description used to generate Monte Carlo samples before 2006 was rather simplified and not realistic enough. Therefore, a new detector description in Geant4 was needed. In this note the updated design will be described as well as its implementation in the software. Finally, the thickness of the Inner Tracker in terms of radiation length will be estimated.

1 Introduction

The LHCb Inner Tracker, located just behind the bending magnet, covers the region closest to the beam pipe. Each of the three stations consists of 4 detector boxes each having 4 layers of silicon sensors. Electrical signal cables connect the detector boxes to the service boxes which are outside the acceptance. Most of these cables, as well as the cables containing the cooling fluid are however in the LHCb acceptance.

An important issue to understand the data that we will soon be taking is the interaction of the studied particles with the material which is in the acceptance. This will be simulated in Monte Carlo programs. Charged particles traversing a material loose a part of their energy and undergo multiple scattering. They can also interact in the material and produce secondary particles. Therefore, a precise description of the detector geometry is mandatory. A precise placement of the sensors in this description is also of great importance as it will be used in the track reconstruction.

The material implementation of the detector description is done in different steps. First, a detailed list of all the different materials of the whole detector, including the support frames, the cables, the cooling pipes etc., is made. Then, the detector is divided into “logical volumes” to which a single type of material is assigned. Because of the large number of volumes and the requirement that each volume has a fast access, a tree structure is implemented with as few branches per node as possible. This is done using the XML (eXtensible Markup Language) language.

In the following sections a description of the detector will be given and its division in logical volumes justified. In Section 3 the XML database structure will be given. Finally, the thickness in radiation length of the implemented full detector will be studied and the distribution of the simulated hits in the Inner Tracker sensors will be shown.
2 Detector description

The Inner Tracker is composed of 3 stations placed behind the magnet and before second RICH detector. Each station consists of 4 individual detector boxes, which are arranged around the beam pipe. The boxes placed at the sides of the beam pipe host modules built out of two silicon sensors bonded together to form a 22 cm long detector, while the modules above and below the beam pipe consist of one single sensor only. Each box houses 28 modules which are placed in 4 layers allowing $x,u,v,x$ coordinate measurements. The $u$ and $v$ layers are being rotated along the $y$ axis by $-5^\circ$ and $+5^\circ$ respectively (see Fig. 1).

![Figure 1: The Inner Tracker design: Station T1 (left) and a side detector box (right) the latter will be placed in on the support frame upside down.](image)

To implement the Inner Tracker in the LHCb software, we have divided the detector in different “logical volumes”. A logical volume is a three-dimensional volume which has a width (corresponding to the LHCb $x$-coordinate), a height ($y$) and a thickness ($z$) and contains the information about its shape (rectangular box, cylinder...). Each logical volume is a mixture of different materials characterised by the relative amount of elements included, given in percentage of the mass, and it has an average density.

For each logical volume, which is a sort of an envelope around the little pieces of material that are not simulated individually, we have calculated the exact material composition and found a real mass and a real volume. The “real” mass (volume) is the sum of the masses (volumes) of all the elements contained in the area defined by the logical volume. The “density” of a logical volume is the real mass divided by the real volume. The width or the height of a logical volume is taken as the largest width or height of the elements contained in this volume. Hence, its thickness is an average given by the real volume divided by a maximized width times height. In some cases, the thickness is fixed to the real thickness and the density is averaged, as done for example for the box walls (see Section 2.2.4).

In this section we will describe the different logical volumes which compose the Inner Tracker. All the volumes and calculations are available at: http://lphe.epfl.ch/~lhcb/itproduction/Materialbudget.
2.1 Sensor modules

Silicon sensors are glued on a sandwich made up by 4 layers: 25\(\mu\)m of kapton [1] used here for electrical insulation purposes, 200\(\mu\)m of heat conducting carbon fiber (Mitsubishi K13D2U [2]), 1 mm of foam (Airex R82 [3]) and once more 200\(\mu\)m of carbon fiber. The ensemble which constitute a module is also called “ladder”. The front-end electronics, i.e. the three Beetle chips, resistors and capacitors, are mounted on a hybrid circuit which is glued on an aluminium piece called “balcony”. This balcony, whose width is 10 mm less than the ladder’s one, is inserted in the sandwich support and glued to the carbon layers with heat-conducting silver glue.

![Logical volumes of an IT ladder](image)

In the detector description each module is described with 4 logical volumes (see Fig 2 and table 1):

- **LadderTop**: composed of the kapton-hybrid with its SMD components, solders, the silver glue and the sandwich support. Its width is defined by the minimum width of the ladder, its height is the distance between the top of the ladder and the balcony, and its thickness is averaged.

- **Balcony**: composed of the aluminium balcony itself, the hybrid part where the readout chips are located, the sandwich support, the pitch adaptor and the silver glue. The width of this volume is given by the width of the balcony, the height is the height of the balcony plus the pitch adaptor and its thickness is an average one.

- **LongSupport** and **ShortSupport**: composed of the rest of the sandwich support, the sensor glue and the wire bonds. Width and height are defined by the rest of the ladder support and the thickness is averaged.

- **LongSensor** and **ShortSensor**: composed of the silicon sensors. These volumes are the sensitive volumes, whereas all the rest are passive volumes. The dimensions are the ones of the silicon sensors, plus 150\(\mu\)m in the case of the long ladders.
<table>
<thead>
<tr>
<th>Volume</th>
<th>Height [cm]</th>
<th>Width [cm]</th>
<th>Thickness [cm]</th>
<th>Density [g/cm³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>LadderTop</td>
<td>1.8500</td>
<td>7.2000</td>
<td>0.1725</td>
<td>1.0390</td>
</tr>
<tr>
<td>Balcony</td>
<td>2.4500</td>
<td>7.0000</td>
<td>0.1852</td>
<td>2.3946</td>
</tr>
<tr>
<td>LongSupport</td>
<td>22.2000</td>
<td>8.0000</td>
<td>0.1474</td>
<td>0.5153</td>
</tr>
<tr>
<td>ShortSupport</td>
<td>11.1000</td>
<td>8.0000</td>
<td>0.1474</td>
<td>0.5152</td>
</tr>
<tr>
<td>LongSensor</td>
<td>22.0150</td>
<td>7.8000</td>
<td>0.0410</td>
<td>2.3284</td>
</tr>
<tr>
<td>ShortSensor</td>
<td>11.0000</td>
<td>7.8000</td>
<td>0.0320</td>
<td>2.3300</td>
</tr>
</tbody>
</table>

Table 1: Dimensions of the logical volumes composing an IT ladder.
2.2 Detector box

In the detector box (see Fig. 1), we have four layers of 7 modules (named ladders in XML code) attached to two cooling rods. The purpose of the cooling rods is to cool the front-end electronics and the sensors. The signals as well as the HV and LV supplies are brought in/out to the modules through kapton tails and four PCBs with connectors. The cooling rods are supported by carbon columns. A cover and the walls of the box complete the description of the detector box. In the XML code, these parts of the box form individual volumes.

2.2.1 Cooling rods

The two cooling rods are two aluminium pieces with a complicated shape (see Fig. 3). On each rod a 6 mm outer-diameter aluminium pipe (thickness 0.4 mm) is glued with silver and aluminium glue. In LHCb, the cooling fluid will be $\text{C}_6\text{F}_{14}$ [4]. In the XML description, the cooling rods have a parallelepipedal shape. The width of this logical volume corresponds to the maximum width of the real rod and its thickness is the minimum distance between the two module layers. The height is the average height, i.e. real volume divided by the width times the thickness. Each logical volume for the cooling rod contains aluminium, screws, glue, aluminium pipe and coolant. These volumes are called $\text{CoolingRodSide}$ for a side box and $\text{CoolingRodCenter}$ for a center box (see Table 2).

![Figure 3: Design of the cooling rods.](image)
The two pipes glued on the cooling rods exit the box on the same side. They are represented by 2 vertical cylinders composed of a mixture of aluminium and C$_6$F$_{14}$. Their height is given by design and their diameter is 6 mm. The name of those logical volumes is Pipe.

<table>
<thead>
<tr>
<th>Volume</th>
<th>Height [cm]</th>
<th>Width [cm]</th>
<th>Thickness [cm]</th>
<th>Density [g/cm$^3$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CoolingRodSide</td>
<td>0.7320</td>
<td>57.0000</td>
<td>0.9000</td>
<td>2.3290</td>
</tr>
<tr>
<td>CoolingRodCenter</td>
<td>0.7283</td>
<td>57.5000</td>
<td>0.9000</td>
<td>2.3275</td>
</tr>
</tbody>
</table>

Table 2: Dimensions of the logical volumes of the cooling rods.

### 2.2.2 Printed Circuit Boards (PCBs)

The signals and supplies are brought to and from the hybrids through a single PCB for each detector plane. These PCBs will have connectors to the kapton tails and to the signal cables outside the detector boxes. Due to limited space, the heights of the PCBs have to be different to accommodate the connectors on the signal cables side. There are two type of PCBs: 2 “long” ones (70 mm height) in the middle of the cover and two “short” ones (50 mm height) on both sides. A single Amphenol connector allows to bring individually HV to the sensors. To describe this structure in the XML code, the long and short PCBs are divided into 3 and 4 logical volumes, respectively (see Fig. 4 and Table 3).

![Logical volumes of a short PCB.](image)

- **KaptonFlexConnector**: this is composed of the 7 male and female connectors inside the box and between the PCB and the modules, in addition to the PCB material. The width is the real width of the PCB and the height is defined by the dimensions of the connectors.

- **ShortPCB or LongPCB**: between the inner and outer connectors, there is the PCB part which is only of PCB material. The dimensions are the real width of the PCB and the vertical distance between the 2 connectors. This height is different for long and short PCBs. The thickness is again given by the real volume of material divided by the width times the height.

- **Connector**: the connector zone is composed of the 7 connectors for signal cables (male and female), one HV connector (male and female) and the PCB material which is essentially epoxy, glass fiber, and copper traces. Its width is defined by the width of the PCB, its height is the distance between the top of the signal connectors and the bottom of the female connectors which are fixed on the PCB. The thickness is an average thickness.

- **ShortCablePCB**: for the short PCBs, a volume was added above the connector volume outside the box, which is composed of 7 signal cables and one HV cable\(^1\) (see Section 2.4).

\(^1\)In the March 2006 version, the material used for the cables in this logical volume has not the correct density as the empty space inside the cable is not included (see Section 2.4.1)
The width corresponds to the width of the PCB, the height is the height difference between long and short PCBs, and the thickness is averaged.

<table>
<thead>
<tr>
<th>Volume</th>
<th>Height [cm]</th>
<th>Width [cm]</th>
<th>Thickness [cm]</th>
<th>Density [g/cm³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connector</td>
<td>5.1000</td>
<td>50.6000</td>
<td>0.2833</td>
<td>2.5206</td>
</tr>
<tr>
<td>ShortPCB</td>
<td>3.5500</td>
<td>50.6000</td>
<td>0.1600</td>
<td>3.0650</td>
</tr>
<tr>
<td>LongPCB</td>
<td>5.5500</td>
<td>50.6000</td>
<td>0.2779</td>
<td>2.9475</td>
</tr>
<tr>
<td>KaptonFlexConnector</td>
<td>1.2000</td>
<td>50.6000</td>
<td>0.2700</td>
<td>2.0733</td>
</tr>
<tr>
<td>ShortCablePCB</td>
<td>2.0000</td>
<td>50.6000</td>
<td>0.1125</td>
<td>2.3976</td>
</tr>
</tbody>
</table>

Table 3: Dimensions of the logical volumes of the PCBs.

### 2.2.3 Kapton flex part

Each module is connected to its PCB by a kapton tail. In this region, there is no other material but 28 kapton tails (kapton and copper traces), the carbon columns maintaining the cooling rods and the connection between the 2 cooling rods (see Fig. 5). To simplify the XML description, only one logical volume, KaptonFlexCenter for the center boxes and KaptonFlexSide for the side ones (see Table 4), with fixed dimension and an average density was defined.

<table>
<thead>
<tr>
<th>Volume</th>
<th>Height [cm]</th>
<th>Width [cm]</th>
<th>Thickness [cm]</th>
<th>Density [g/cm³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>KaptonFlexCenter</td>
<td>6.6400</td>
<td>50.6000</td>
<td>6.4000</td>
<td>0.0396</td>
</tr>
<tr>
<td>KaptonFlexSide</td>
<td>6.6400</td>
<td>50.6000</td>
<td>6.4000</td>
<td>0.0396</td>
</tr>
</tbody>
</table>

Table 4: Dimensions of the “kaptonflex” volumes.

Figure 5: The KaptonFlexSide volume.
2.2.4 Box walls and Cover

All the elements in the box (cooling rods, PCBs, ...) are attached to the cover which in turn is attached to the IT support. The cover is a sandwich of two 200 µm layers of carbon fiber tissue glued with standard Araldite on either side of a 12 mm slice of Airex R82 foam [3]. Stesalite inserts are glued on this cover plate to allow its mounting to the detector box. Side and center covers have different sizes. The design of the cover is complex as the PCBs and cooling pipes are fed through it. To simplify the description, one material for each cover type (side and center) is defined as a mixture of all the contributing materials. The cover is divided in 4 parts (see Fig. 6 and Table 5) which are composed of those specific materials. Dimensions and densities are fixed in those logical volumes to avoid any overlap in the XML code.

<table>
<thead>
<tr>
<th>Volume</th>
<th>Height [cm]</th>
<th>Width [cm]</th>
<th>Thickness [cm]</th>
<th>Density [g/cm³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SideCover1</td>
<td>0.6500</td>
<td>7.7000</td>
<td>8.0000</td>
<td>0.2243</td>
</tr>
<tr>
<td>SideCover2</td>
<td>0.6500</td>
<td>58.7500</td>
<td>1.8100</td>
<td>0.2243</td>
</tr>
<tr>
<td>SideCover3Pipe</td>
<td>0.6500</td>
<td>9.7500</td>
<td>8.0000</td>
<td>0.2243</td>
</tr>
<tr>
<td>CenterCover1</td>
<td>0.6500</td>
<td>9.0000</td>
<td>8.0000</td>
<td>0.2233</td>
</tr>
<tr>
<td>CenterCover2</td>
<td>0.6500</td>
<td>59.3500</td>
<td>1.8100</td>
<td>0.2233</td>
</tr>
<tr>
<td>CenterCover3Pipe</td>
<td>0.6500</td>
<td>10.6500</td>
<td>8.0000</td>
<td>0.2233</td>
</tr>
</tbody>
</table>

Table 5: Dimensions of the logical volumes of the cover of a side box.

![Figure 6: Logical volumes of a cover.](image)

The box wall is a sandwich of glass fiber on either side of a 8 mm of polyisocyanurate (PIR [5]) foam (3 mm on the beam side). The electromagnetic noise shielding is ensured by 2 foils of 25 µm aluminium. The side and center boxes are each divided into 5 logical volumes: the four sides and the bottom² (see Fig. 7 and Table 6). A gas channel made of glass fiber has been included in the box wall. The dimensions of all the logical volumes of the box wall are fixed and their density is an average.

<table>
<thead>
<tr>
<th>Volume</th>
<th>Height [cm]</th>
<th>Width [cm]</th>
<th>Thickness [cm]</th>
<th>Density [g/cm³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SideBox1</td>
<td>38.7000</td>
<td>62.4000</td>
<td>0.8000</td>
<td>0.1027</td>
</tr>
<tr>
<td>SideBoxBeam</td>
<td>37.9000</td>
<td>0.3000</td>
<td>6.4000</td>
<td>0.2244</td>
</tr>
<tr>
<td>SideBox4</td>
<td>37.9000</td>
<td>0.8000</td>
<td>6.4000</td>
<td>0.2055</td>
</tr>
<tr>
<td>SideBoxBottom</td>
<td>0.8000</td>
<td>62.4000</td>
<td>6.4000</td>
<td>0.1835</td>
</tr>
<tr>
<td>CenterBox1</td>
<td>25.6500</td>
<td>63.9000</td>
<td>0.8000</td>
<td>0.1027</td>
</tr>
<tr>
<td>CenterBox4</td>
<td>25.3500</td>
<td>0.8000</td>
<td>6.4000</td>
<td>0.2172</td>
</tr>
<tr>
<td>CenterBoxBeam</td>
<td>0.3000</td>
<td>63.9000</td>
<td>6.4000</td>
<td>0.2468</td>
</tr>
<tr>
<td>CenterBoxBottom³</td>
<td>25.3500</td>
<td>0.8000</td>
<td>6.4000</td>
<td>0.1100</td>
</tr>
</tbody>
</table>

Table 6: Dimensions of the logical volumes of the box walls.

²The bottom of the box is defined as the part opposite to the cover.
³The name of this volume is not consistent with our nomenclature. It will be change to CenterBox3 in a future version.
2.3 Support

Each station is built as separate left and right sides. Each side is composed of two 6 m carbon and glass fiber pillars, 2 large plates with a 1 m² sandwich structure composed of a 8 mm honeycomb [6] layer and two 0.5 mm carbon fiber layers which hold two detector boxes, and several short CF-sandwich bars\(^4\) to re-inforce the whole structure (see Fig. 1). Signal cables, HV cables and cooling lines are attached on this structure. As we have only introduced in this description the part which is in the LHCb acceptance, the external dimensions are different for each station. To simplify the XML code, each station is divided in 3 parts:

- the area between the 2 pillars of the right part
- the area between the 2 pillars of the left part
- the area in the middle of the structure, where the detector boxes are positionned.

Each pillar consists of one logical volume with fixed dimensions: the height is the height in the acceptance, the width and the thickness are 76 mm and the density is an average\(^5\). The small CF-sandwich bars are considered as a logical volume as they fit into the area defined by the two pillars. Their height and width are fixed by the real design while the thickness is an average. The large plates have to be divided in a part between the two pillars and another in the center part. Their dimensions are fixed to the geometrical dimension except for the thickness which is an average. Cables and cooling lines are distributed in different layers and divided into many logical volumes.

\(^4\)The bars at 50° on the top of the structure (see Fig. 8) were not implemented in the XML code.

\(^5\)The pillar logical volumes will be changed to a square tube with the real density to be more realistic in the future version (see Section 2.4.2).
2.4 Cables and cooling lines

The signal cables and the cooling tubes are connected to the detector boxes and pass through the acceptance of the experiment. They represent an important amount of material because of the large number of signal cables. The design has been made to minimize the length of the cables and to avoid “hot spots” due to overlapping cables within a station. Twenty eight signal cables [7], one HV cable, one cable for the temperature probes in the box and two different cooling lines (inlet 9 mm inner diameter, outlet 14 mm inner diameter) are connected to a detector box. The 28 signal cables and the temperature cable are grouped together, while the cooling lines and the HV cable form a separate group. The cooling lines are composed of reinforced nitril rubber tubes [8] with Armaflex insulation [9] and C₆F₁₄ coolant liquid.

Figure 8: Station T1 left version March 2006: description of the ElecCable volumes (left), description of the CoolingCable volume (right).

The definition of the cable logical volumes is done in two steps: first, the material is defined via the density and atomic composition of the various materials of a cable. Second, the logical volume are defined, where the previously defined material is used. The same strategy applies for the cooling lines.

As these cables represent an important amount of material, the description of the logical volumes must be very precise. An important effort was put to reduce the amount of material, which has caused frequent design changes. The latest version was released in March 2006 and accounts for all the efforts done so far. Two versions will be presented in this Section:

- the “March 2006 version”⁶ uses a simple factor to account for the thickness of the cables.
- the “future version”, which will possibly be released in summer 2006, will include a precise positioning of the cables on the support and a more precise description of the material of the cables ⁷.

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⁶The March 2006 version complies to the v30r1 of DDDB.
⁷The position of the cables will be measured during the installation of the detector and a sample of the latest version of the signal cable will be then weighted to adjust the amount of material.
The thickness in terms of radiation length is expected to be very similar in the two versions.

2.4.1 March 2006 version

a) The material definition

The signal cable is described with 68 copper conductors (AWG30) insulated in a halogen-free plastic, a thin aluminium shielding and an external halogen-free plastic insulation. The thickness of this insulation was estimated to be 0.75 mm and the total diameter to be 8 mm. The actual cable volumes are not completely filled with material, but contain about 30% of empty space between individual conductors. This has been taken into account in the volume definition.

For the HV cable, the temperature sensor cable and the cooling lines, the calculations are done in the same way.

b) The volume definition

The \textit{ElecCable} logical volumes contain 28 signal cables and the cable for the temperature sensors (see Fig. 8). Each \textit{ElecCable} volume contains twenty-eight 8 mm diameter cylinders for the signal cable material and one 5 mm diameter cylinder for the temperature sensor cable. Its height is defined by the design, its width corresponds to the total width of the 29 cylinders (22.9 cm). The width and the height of the volume can be swapped in order to describe horizontal and vertical sections of the cable tree. The thickness is fixed (corresponding to an old version of the cable). The average parameter is the density. The empty space inside the cables is accounted for in this density parameter.

The inlet and outlet cooling tubes and the HV cable compose the \textit{CoolingCable} logical volumes (see Fig. 8). Like \textit{ElecCable}, each line and cable is treated as a cylinder. The height and the width of this type of logical volume are given by the design, width or height, depending on the position in the acceptance, is the sum of the inlet and outlet cylinder diameter (11.5 cm in total). The HV cable is placed between the two cooling lines. Its thickness is fixed and the density is averaged. The empty spaces represent 2% inside cooling lines and 20% inside a single HV cable.

The position of each \textit{ElecCable} volume and \textit{CoolingCable} volume is defined by the design of the detector. Their exact positions will only be known after the final installation in the pit.

2.4.2 Future version

a) The material definition

In the future version and in order to obtain a precise description of the final signal cables [7], we will dismantle a piece of the cable and determine the mass of the individual components. The cable for the temperature sensor will be more realistic with less material than in the present version. We will also account for the empty spaces in the definition of the densities of the cables and tubes.

b) The volume definition

The final position of the cables and cooling lines will be measured on the detector support in the pit. The new \textit{ElecCable} logical volumes position will be more realistic. The way to define the logical volumes will be simpler: the height/width will be defined by the measurements, and adjusted to the new cables diameters, and their thickness averaged. The density will be defined as previously.

c) Additional modifications

In future versions, the connection between the cooling pipe from the detector box and the nitril rubber tubes will be added. It represents a substantial amount of material. The glue in the ladder support will be changed, leading to an adjustment of the density of this
logical volume. The density of \textit{KaptonFlexCenter} and \textit{KaptonFlexSide} volumes will also be changed due to the modification of the cooling connectors. The connectors parts in the PCBs, i.e. \textit{KaptonFlexConnector} and \textit{Connector}, will have their dimensions fixed by the March 2006 version and the density averaged according to their material composition.

The aluminium inserts and the screws on the support are not implemented in our material budget. They might represent some amount of material locally, but their implementation is too complicated to be done in a realistic way. An estimation of the material outside the acceptance (support fixations on the rails, service boxes, cable chain ...) has been performed but has not yet been implemented.
3 Detector database structure

Storing the logical volumes in the detector database has to be done in such a way that information from a given volume can quickly be retrieved. Therefore, the structure has to fulfill certain requirements. Logical volumes are placed with respect to a bigger mother volume. This is an artificial volume without any material and whose dimensions are set to include the daughter volumes. This placement is done by defining the position of the center of the logical volume with respect to the center of its mother volume.

3.1 Material list

An inventory list has been made, containing the material of each chosen logical volume. The logical volume is described as a homogeneous artificial material, with a density computed as the weighted average of the densities of the materials contained in this volume. Furthermore, the atomic composition or the fractional mass of each sub-material was given. When the material of a logical volume is defined with fractional masses (for example, a ladder support contains 4.6% of kapton, 7.9% of Airex [3], ...) then in a further stage the atomic composition and the densities of the submaterials have to be defined as well (for example a kapton molecule is build up out of 10 Hydrogen atoms, 2 Nitrogen atoms, ...).

3.2 Catalog files

Catalog files are made in order to simplify the structure of the different logical volumes. Logical volumes that have no need to be described independently in the database can already be grouped together. These are volumes that for example don’t need to be aligned separately or don’t have any sensitive area. Catalog files were made of the ladders without sensors (ITLadderVols.xml), the PCB’s (ITLayerVols.xml) and the support (ITSupportVols.xml). The PCB catalog places the three or four elements of a PCB, i.e. ShortCablePCB, Connector, ShortPCB (or LongPCB) and KaptonFlexConnector in a pcbbig or pcbsmall mother volume. The support catalog contains the cooling lines, the electrical cables and the carbon support that are contained between the two big pillars.

3.3 Geometry and structure description

The logical volumes are placed with respect to their mother volumes. Two hierarchy trees are made: a geometry tree and a structure tree. The first one defines logical volumes by their geometry (rectangle, tube, ...) and the relative positions of its daughter logical volumes. Once a logical volume is placed in the geometry tree it is referred to as a physical volume. An example of the geometry tree of a central box is given.

```xml
<logvol name="lvITFullCenterBox" material = "Air">
  <box name="ITFullCenterBox"
       sizeX ="FullBoxCenterWidth"
       sizeY ="FullBoxCenterHeight"
       sizeZ ="FullBoxCenterThickness" />

  <physvol logvol="/dd/Geometry/AfterMagnetRegion/T/IT/Box/lvCenterBox1"
           name ="pvCenterBoxfront">
    <posXYZ x ="0.0*mm" y ="-4.6*cm" z ="3.585*cm"/>
  </physvol>

  <physvol logvol="/dd/Geometry/AfterMagnetRegion/T/IT/Box/lvCenterBox1"
           name ="pvCenterBoxback">
    <posXYZ x ="0.0*mm" y ="-4.6*cm" z ="-3.585*cm"/>
  </physvol>

  ...
</logvol>
```
In this example, two detector box walls are placed in a central detector box mother volume. However, no information is given on which of the 12 detector boxes this one is. This is because the geometry tree only contains information on placements of general elements: 7 ladders in a layer which itself is placed in a box in a station in an IT logical volume.

In the structure tree, every volume is placed in the correct hierarchy within the appropriate mother volume, without holding any the absolute coordinates. On this stage every single logical volume is placed in the tree, i.e. the 336 ladders are one by one placed with respect to a layer,...

The information on the correct position is given by referring to how a ladder is placed in a layer in the geometry tree. The structure tree also contains some helpful facilities like the definition of parameters or the geometry information, version and author tags.

The lowest volume in the tree is the sensitive material of the single- or double-sensor. This logical volume is then placed with the top ladder (LadderTop), hybrid (Balcony) and ladder support (LongSupport or ShortSupport) in the ladder mother volume (see Section 2). Like in reality, the top of the ladders is smaller in width than the bottom. This was done to enable an as close as possible positioning of the 5° ladders to the beam side. In the detector description this feature is taken into account by subtracting two rectangles of the mother volume of the top of the ladder and by giving a smaller width to the top part of the ladder which resembles the size of the hybrid above the balcony.

Then seven ladders are placed next to each other (i.e. at the same y position) but with an alternating z-step in a layer mother volume. For the u and v layers the ladders are rotated around their centers by 5° before their placement. Note however that the u and v layers had to be defined separately as the positions of the sensor modules in a layer are different for each layer.

The layers are placed in the mother volume of a side or center box, together with the other elements of a box. These are: the box walls, the cover, the PCB’s, the kapton flex part, the cooling rods and the cooling pipe. These volumes can either be mono-volumes, e.g. kapton flex volume, or they can contain more sub-volumes underneath, e.g. the PCB, which consists of four PCB parts (see Section 2.2.2). The tree presented in Fig. 9 is a representation of the geometry box description.

![Figure 9: Geometry tree of a top box.](image)

The support geometry and structure tree are split into three parts: the regions on the right and left contained between the two right or two left pillars and the region in the center of the support (see Section 2.3). This was done as the description of the volumes between the two right or left pillars can be split up in three layers in z: the carbon support description, the signal cable description and the cooling tube description (see Fig. 10). In reality, however, the signal and cooling cables are waved in the carbon fiber support structure, but as the effect on the radiation or nuclear length is fairly insensitive to a small change (order of cm) of the positioning of a material in z, the option of splitting the support in three and making the structure tree lighter was chosen.
The description of the support structure between the beam pipe and the closest vertical pillar could not be split in three $z$-regions as the position of the boxes had to be exact and overlap the three regions in $z$. Due to this difficulty the middle section of the support contains many more ungrouped volumes.

The three stations, together with the Radiation Monitor [10], are the elements of the IT volume which is located in the T volume, as illustrated in Fig. 11.

It is useful to give shortly some of the conventions that were used. Right (boxes, stations, ...) refers to the region between the beampipe and the cryogenics in the LHCb pit, while left means the direction of the barracks behind the concrete shielding wall. Top and bottom are logically the regions above and below the beampipe, respectively. In the structure files a parameter is included with the ladder number, which increases with increasing $x$ in the LHCb coordinate system. The layer number increases with increasing $z$. The boxes are named as follows: right (1), left (2), bottom (3), top (4). Finally, stations are numbered 1, 2, 3 in increasing $z$. The beamtilt is taken into account by rotating each station mother-volume around its x-axis at the central $z$-position, extra care is taken to make sure the detector boxes are at the correct position in a tilted station.

Our tree structure does not strictly follow the recommended structure of three branches per node - which would be ideal from the point of view of access speed - as creating illogical artificial mother volumes would have complicated the relative placements.

4 Testing

There are different methods to test the structure implementation. One of them is a visual check of the volume representation in Panoramix [11]. Examples of a station and a detector box as seen in Panoramix is given in Fig. 12 and 13. By running the Panoramix script the linking of the volumes in the structure tree to their corresponding logical volumes in the geometry tree is

Figure 10: Geometry tree of the support volume.

Figure 11: Geometry tree of a T volume.
checked. A second test is performed with the DecDeckChecker tool, which verifies that no logical volumes overlap with each other or extend beyond their mother volume.

Figure 12: Visual representation of the second Inner Tracker station with beam pipe in Panoramix.

Figure 13: Visual representation of the box area and beam pipe with Panoramix.
5 Results

Using a standalone Python script, straight tracks originating from the interaction point, were generated. For each logical volume that was crossed by a track, the corresponding thickness in radiation length was calculated. In Fig. 14 the thickness in radiation length as a function of the pseudo-rapidity and the azimuthal angle $\phi$, is presented. As one can see on the position of the sensors, at high $\eta$, the amount of material is very low, the average thickness in radiation length being less than 3.5%. Some heavier components are found near the top of the box where the cooling rods and the connectors on the PCB’s are. The latter represent around 15% of radiation length in the regions without overlaps, while in the cooling rods up to 30% of radiation length is accumulated. This area however represent a very small surface in the detector. The rods had to be made out of metal structure in order to assure heat conductivity and ladder stability.

At lower $\eta$, the carbon fiber pillars, signal cables and cooling tubes are visible, the carbon fiber support is too light to be distinguished on this scale. A big effort was put into reducing the material induced by the signal cables such as turning the boxes upside down and optimizing the cable shielding and insulation. The Inner Tracker signal cables will represent around 4.5% of a radiation length, per station.

In Fig. 15 the integrated thickness in terms of radiation length as a function of $\eta$ is given. A comparison with the previous design, used for DC04, is given with the dotted line. This figure shows that at the level of the boxes hardly any material is added. The cooling rods represent about the same amount of material as before but it is contained in a much smaller region. The signal cable connectors on the PCB’s, however, cause a significant increase of material around $\eta = 3.7$. The cable area is thicker in the lower $\eta$ regions, although on average a thickness of less than 2% of radiation length is achieved.

Finally, the hit distribution in the sensitive area of the three stations Tracker is shown in Fig. 16. These plots are obtained by using the Gauss v24r3 simulation. The hits appear at the expected location and no sensor is wrongly placed or missing.
Figure 15: Total thickness (in %X₀) of the second IT station in radiation length as a function of η (expressed in degrees).

Figure 16: Hit distribution in the sensitive area of the IT: station 1(a), station 2(b), station 3(c).
6 Summary

A new and realistic description of the design and material of the Inner Tracker has been implemented and tested. This description will be used for the DC06.

References