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Updated geometry description for the LHCb Trigger Tracker

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Abstract

The XML based detector description for the Trigger Tracker (TT) station has been updated. A more realistic version has been implemented in which volumes for frames, readout cables, balconies, jackets, cooling plates and elements have been added in addition to a detailed description of the detector modules. In this note an overview of the updated description is presented.

1 Introduction

The LHCb Trigger Tracker station (TT) is located downstream of RICH1 immediately in front of the LHCb magnet. It is used in the Level-1 trigger to determine the transverse momentum of charged tracks and in the offline tracking to reconstruct the decay products of long-lived neutral particles. The TT station consists of four planar detection layers of silicon micro-strip detectors that cover the complete detector acceptance. The layers are grouped into two pairs (TTa and TTb) separated by ~ 30 cm along the beam axis. The first and the last layers have vertically orientated silicon strips (X layers) whilst the second and the third layers have strips rotated by a stereo angle of $-5°$ and $+5°$, respectively. The latter are refered to as the U and V layers. The detector is enclosed in a single box providing electrical and thermal shielding. A detailed description of the detector layout can be found in [1].

To study the detector perfomance, a detailed description of the TT station geometry is needed in the Monte Carlo simulation. This is done using an Extensible Markup Language (XML) [2]. Since the relevant design parameters are now fixed it has been decided to update the detector description in the XML. The new description discussed in this note is available in the package XmlDDDB from version v30r0 onwards.

2 Detector description overview

The XmlDDDB database for the detector description is divided into three parts:

- **Geometry.** This is used for the geometry tree description. It describes a hierarchy of logical and physical volumes and their shapes and contents.
- **Structure.** This contains the logical structure of the detector and describes a tree of detector elements.
- **Materials.** This part is used to describe the properties of the materials needed for the detector simulation. The properties of the materials used in the TT station are described in [3].

More information about the LHCb detector description framework can be found in [4, 5].

2.1 Geometry tree overview

The geometry tree in XML is constructed from logical volumes and physical volumes. A logical volume contains information about its shape, dimensions and material content. However, it does not have any information about its absolute position in the LHCb coordinate system. A physical volume is a logical volume that has been positioned inside another logical volume. Hence, a physical volume knows its own position relative to the coordinate system of its parent.

In the detector description for the LHCb TT station there are three categories of logical volumes — Box, Module and Cable logical volumes. The Box volumes describe inactive elements of the TT station box. The Module and Cable volumes are used to describe the sensitive elements of the detector and its readout cables, respectively.

The geometry tree for the TT station is shown in Fig. 1, where the solid arrows show the hierarchy of logical volumes and the dashed arrows represent the usage of the Box, Module and Cable logical volumes in the description of the top level elements of the detector tree.

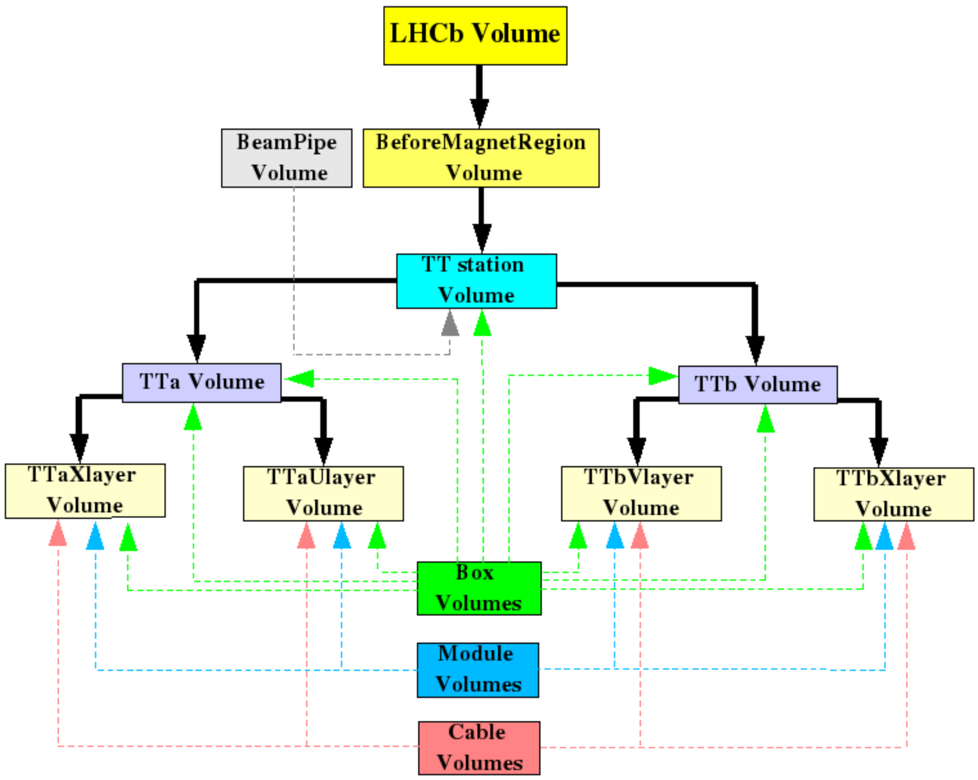

Figure 1: The geometry tree for the TT station.

It can be seen that the TT station volume is located inside the 'BeforeMagnetRegion' envelope of the LHCb detector. It has the shape of a box and contains physical volumes for TTa and TTb as well as detector Box volumes such as the frame, walls, cooling plates, cooling elements and the jacket surrounding the beam pipe in the gap between TTa and TTb.

The logical volumes for TTa and TTb consist of physical volumes for the layers and for the jackets surrounding the beam pipe between the two layers and between the layers and the walls. The TTa and TTb logical volumes and their daughter logical volumes for the layers are defined as a boxes with a central hole for the beam pipe.

The logical volume for each detection layer consists of physical volumes for half-modules, which are the sensitive elements of the detector, for readout cables and balconies, which are inactive elements of the TT station box.

The basic detector unit of the TT station – the half-module – forms the building block of the layer geometry. It consists of seven 500 μm thick silicon sensors ganged together. Two different types of half-modules exist. In the innermost part of the detector around the beam pipe, where the occupancy is highest, the seven sensors on each half module are divided into three readout sectors, consisting of one, two and four sensors which will be separately read out (the KLM half-module). The half-modules placed outside the beam pipe region are electronically split into two readout sectors consisting of three and four sensors (the LM half-module). Each half-module has two carbon fiber rails which are glued along the sides of the sensors to provide mechanical stability and a Kapton cable that runs over the back of the half-module to supply the sensors with bias voltage.

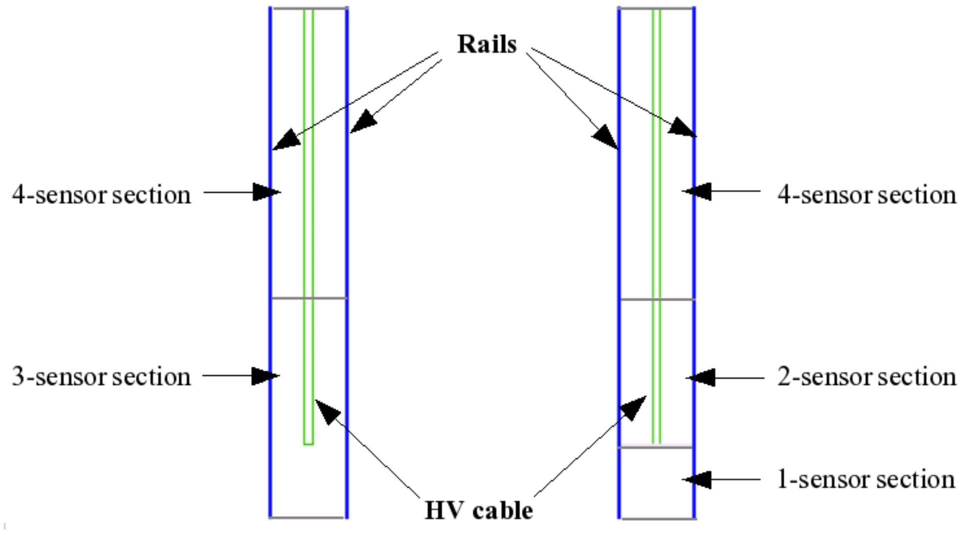

Figure 2: The LM(left) and KLM(right) half-modules.

In the geometry description a half-module is defined as an assembly of two physical volumes for the four- and three-sensor sections in case of the LM half-module or three physical volumes for the four-, two- and one-sensor sections in case of the KLM half-module. It also includes passive physical volumes for the support rails and the high voltage cable. The volumes for the sensor sections are defined as boxes of silicon and are the sensitive elements of the detector. The logical volumes for the LM and KLM half-modules are shown in Fig. 2. The drawings were obtained using the visualisation application Panoramix [7].

Every layer of the TT station consists of 6 KLM half-modules surrounding the beam pipe and 24 or 28 LM half-modules for TTa and TTb, respectively. Fig. 3 and Fig. 4 show a front view of the layers as produced by Panoramix.

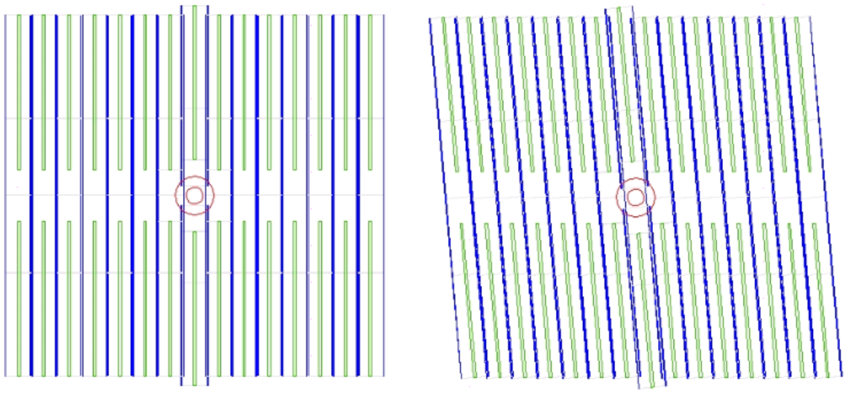

Figure 3: Front view of the X(left) and U(right) layers of TTa.

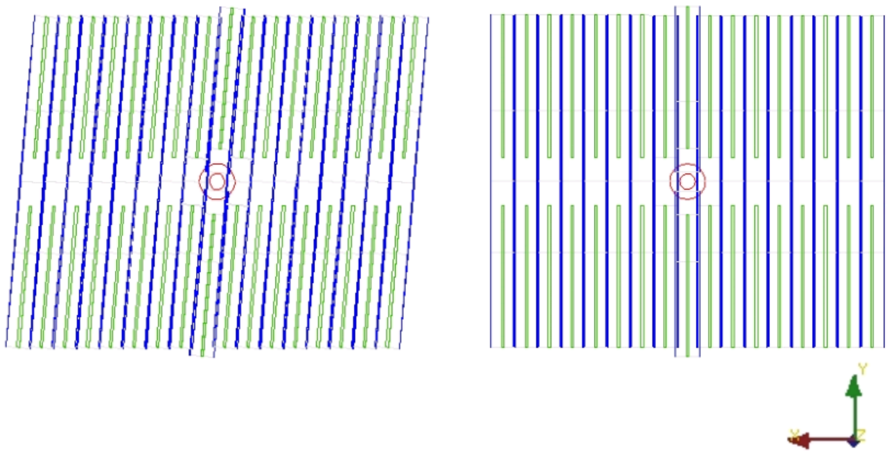

Figure 4: Front view of the V(left) and X(right) layers of TTb.

The bottom half-modules were placed at their positions after rotation of the volumes by an angle of 180 degree around the Z axis. The half-module volumes for the U and V layers are rotated around the Z axis by a stereo angle of $-5°$ and $+5°$, respectively.

To avoid acceptance gaps, adjacent half-modules in the TT station will be staggered. The two innermost half-modules directly above and below the beam pipe have a overlap of 0.95 cm as measured from edge to edge of the silicon area of the neighbouring half-modules. The overlap of the other half-modules is 0.35 cm for the first three half-modules to the left and to the right of the beam pipe and 0.40 cm for half-modules farther away from the beam axis. The distance in z between adjacent half-modules within a detection layer is 0.45 cm with the exception of the two half-modules above and below the beam pipe which are positioned 0.12 cm apart from the neighbouring modules due to space limitations. All this is taken into account in the detector description.

Two types of interconnect Kapton cables are used to read out the inner sensor sections. These are called "K-cable" and "L-cable". The "K-cable" has a length of 39 cm and is used to read out the three and two sensor sections of the LM and KLM half-modules.

The "L-cable" is used to read out the one sensor section of the KLM half-module and has a length of 58 cm. Both cables have a thickness of 0.010 cm and a width of 6 cm.

To reduce the number of volumes, it was decided to simplify the description of the readout cables. First, the width of the individual cable is set to the full width of a sensor. Second, for the modules to the left and right of the beam-pipe, cables are not simulated individually. Instead, the cables in each quadrant of the detector are modelled as one large volume as shown in Fig. 5. This simplification reduces the

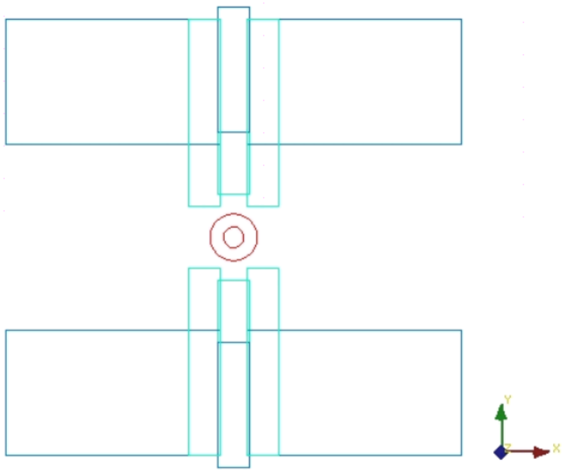

Figure 5: The cable volumes for X-layer of the TTa half-station. The blue color indicates the K-cables and the light cyan color indicates the L-cables.

number of volumes needed for the description of the K-cables from 128 to 24. For the U and V layers, the cable volumes are rotated by the corresponding stereo angle.

The balconies, cooling plates, cooling elements, insulating walls, beam pipe jackets and the TT station frames are inactive elements of the TT detector box. They provide mechanical support as well as electrical and thermal shielding. The balconies are made of aluminium and are located outside of the detector acceptance. They are used to provide thermal contact between the cooling plate and the readout hybrids which are placed at the end of the half-modules. The cooling plates are placed at the top and at the bottom of the detector and are made out of aluminium. They contain the cooling ducts in which the liquid coolant is circulating at low temperature. To increase the efficiency of the cooling of the detector volume, the TT station contains additional cooling elements which are made out of copper and are located at the left and at the right side of the detector box, along the beam axis.The cooling elements and cooling plates are presented as a boxes without piping to simplify the detector description. The TT station frame is located outside the LHCb acceptance and is made out of aluminium with a thickness of 1.5 cm. There are two insulating walls placed at the beginning and at the end of the detector perpendicular to the beam axis. The walls are 40 mm thick and are made out of airex foam coated with aluminium and kevlar. Insulation around the beam pipe hole is provided by a so-called beam pipe jacket that consists of the same material as the walls. The passive volumes for the TT station box can be seen in Fig. 6 . The volumes for the balconies, which are parts of the layers, are also shown here. Fig. 7 shows an enlarged view of the beam pipe jacket. The different sections of the jacket between the walls and the detection layers, between two detection layers and between TTa and TTb can be recognized.

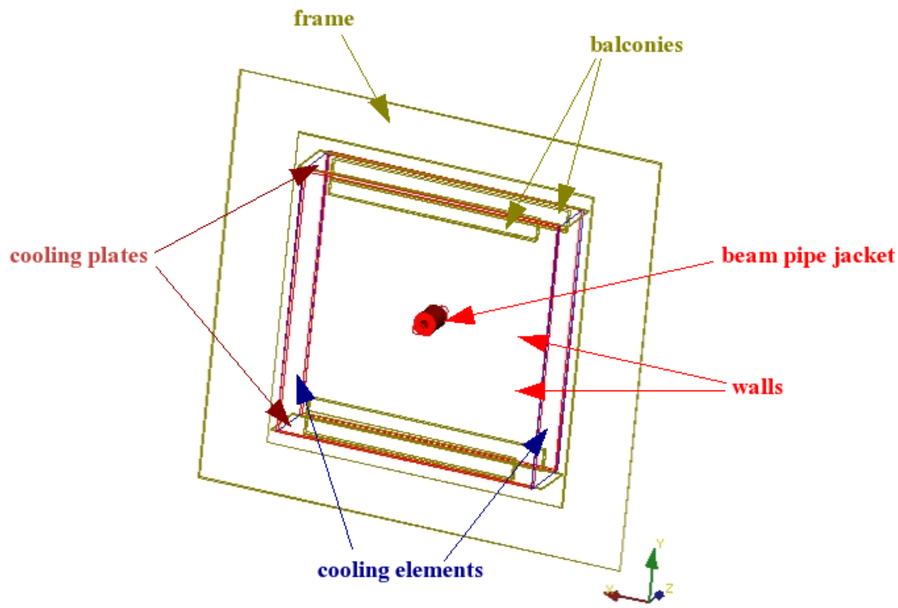

Figure 6: The inactive volumes of the TT station box.

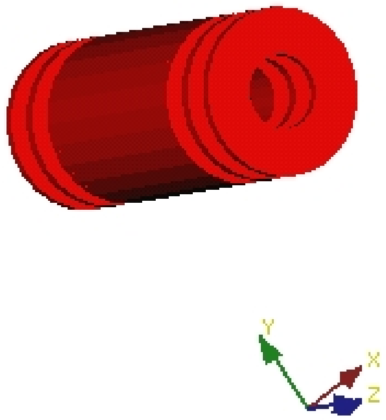

Figure 7: The beam pipe jacket of the TT station box.

The geometry parameters used in the TT detector description are summarized in Table 1. The list of the logical volumes which are used in the detector description of the TT station, including their shape and material, are summarized in Table 2. The table also indicates the names of the XML files in the directory $LHCB-HOME/software/releases/DBASE/ Det/XmlDDDB/v30r0/DDDB/TT/ in which the corresponding logical volumes have been defined.

Geometry parameter	Description	Value
HalfWidth	Half of the TT station width	84.4 cm
HalfHeight	Half of the TT station height	84.3198 cm
BoxThickness	TT station thickness	43.0 cm
StationThickness	Half-station thickness	8.0 cm
SplitInZ	Distance between TTa and TTb	27 cm
LayerThickness	Layer thickness	2.6 cm
SplitLayersInZ	Distance between layers in the half-station	1.825 cm
DzLayer	Layer z-position into the half-station	3.65 cm
SensorHeight	Si-sensor height	9.4326 cm
SensorWidth	Si-sensor width	9.6344 cm
SensorThickness	Si-sensor thickness	0.05 cm
bondGap	Gap between sectors for bonds	0.024 cm
moduleHeight	Half-module height	66.1722 cm
RailWidth	Rail width	0.2 cm
RailHeight	Rail height	66.0282 cm
RailThickness	Rail thickness	0.55 cm
HVCableHeight	HV cable height	56.5956 cm
HVCableWidth	HV cable width	1.0 cm
HVCableThickness	HV cable thickness	0.01 cm
Angle	Stereo angle	5.0 degree
HoleX	Hole size X	3.87 cm
HoleY	Hole size Y	3.70 cm
JacketInnerRad	Inner radius of the jacket	3.1 cm
JacketOuterRad	Outer radius of the jacket	7.1 cm
BigJacketLength	Big jacket length	18.99 cm
Jacket2Length	Length of the jacket between two layers	1.050 cm
Jacket1Length	Length of the jacket between the layer and wall	0.875 cm
BoxWallThickness	Thickness of the wall	4.0 cm
Overlap1	Overlap between half-modules	0.35 cm
Overlap2	Overlap between half-modules	0.4 cm

Table 1: The geometry parameters used in the detector description.

Volume	Description	Shape	Material	XML file
lvTT	TT station volume	Box	Air	geometry.xml
lvTTa	TTa half-station volume	Subtraction	Air	TTaGeometry.xml
lvTTb	TTb half-station volume	Subtraction	Air	TTbGeometry.xml
lvTTaXLayer	TTa X-Layer volume	Subtraction	Air	TTaXLayerGeometry.xml
lvTTaULayer	TTa U-Layer volume	Subtraction	Air	TTaULayerGeometry.xml
lvTTbVLayer	TTb V-Layer volume	Subtraction	Air	TTbVLayerGeometry.xml
lvTTbXLayer	TTb X-Layer volume	Subtraction	Air	TTbXLayerGeometry.xml
lvModuleLM	LM half-module volume	Assembly	–	ModuleGeometry.xml
lvModuleKLM	KLM half-module volume	Assembly	–	ModuleGeometry.xml
lvLadder1	1-sensor ladder volume	Box	Silicon	ModuleGeometry.xml
lvLadder2	2-sensor ladder volume	Box	Silicon	ModuleGeometry.xml
lvLadder3	3-sensor ladder volume	Box	Silicon	ModuleGeometry.xml
lvLadder4	4-sensor ladder volume	Box	Silicon	ModuleGeometry.xml
lvRail	Rail volume	Box	Composite	ModuleGeometry.xml
lvHVCable	HV cable volume	Box	Composite	TTCableVols.xml
lvKCableTB	K-cable volume above/below of the beam pipe	Box	Composite	TTCableVols.xml
lvKCableLRTTa	K-cable volume left/right of the beam pipe in TTa	Box	Composite	TTCableVols.xml
lvKCableLRTTb	K-cable volume left/right of the beam pipe in TTb	Box	Composite	TTCableVols.xml
lvLCable	L-cable volume	Box	Composite	TTCableVols.xml
lvWall	volume for the walls	Subtraction	Composite	TTBoxVols.xml
lvPlateTB	cooling plates volume	Box	Aluminium	TTBoxVols.xml
lvPlateLR	cooling elements volume	Box	Copper	TTBoxVols.xml
lvBigJacket	volume for the big jacket	Tube	Composite	TTBoxVols.xml
lvSmallJacket	volume for the jacket between layers	Tube	Composite	TTBoxVols.xml
lvWallJacket	volume for the jacket between layer and wall	Tube	Composite	TTBoxVols.xml
lvTTaBalcony	balcony volume in TTa	Box	Aluminium	TTBoxVols.xml
lvTTbBalcony	balcony volume in TTb	Box	Aluminium	TTBoxVols.xml
lvTTFrame	TT station frame volume	Subtraction	Aluminium	TTBoxVols.xml

Table 2: Logical volumes used for the detector description of TT-station.

2.2 Structure overview

The hierarchy of the elements of the detector is described in structure catalogues. Each element within the structure can be converted into an instance of a corresponding C++ detector element class used in the Monte Carlo simulation. The tree of the detector elements for the TT station is shown in Fig. 8. As can be seen, the detector element

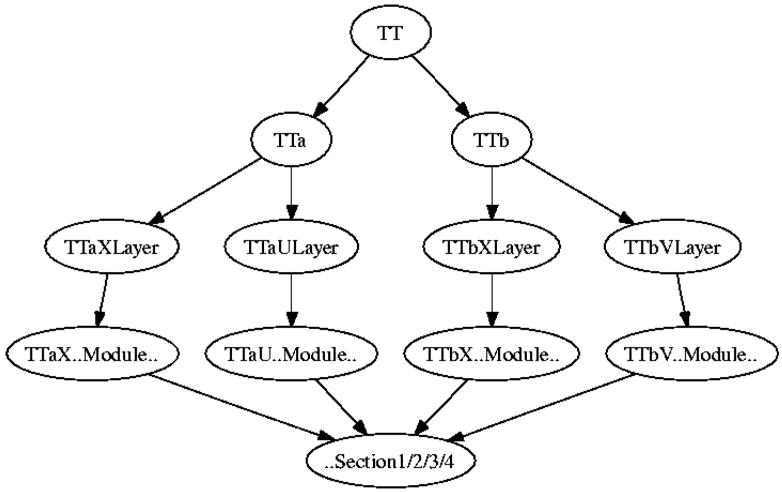

Figure 8: A tree of the detector elements for TT station.

for the TT station includes two detector elements for TTa and TTb. These consist of detector elements for the detection layers, which contain detector elements for the half-modules. Each half-module has its own detector element consisting of the basic detector elements for one, two, three and four sensor sections. The detector elements related to the TT station are summarized in Table 3.

Detector element	classID	XML File
TT	9101	structure.xml
TTa	9102	TTaStructure.xml
TTb	9102	TTbStructure.xml
TTaXLayer	9103	TTaXLayerStructure.xml
TTaULayer	9103	TTaULayerStructure.xml
TTbVLayer	9103	TTbVLayerStructure.xml
TTbXLayer	9103	TTbXLayerStructure.xml
Module	9110	Entity file
Ladder4	9120	Entity file
Ladder3	9120	Entity file
Ladder2	9120	Entity file
Ladder1	9120	Entity file

Table 3: The detector elements for TT station used in the detector description.

Using entities, the XML files describing the structure of the half-modules are linked to the "TTModuleLMStructure.ent" and "TTModuleKLMStructure.ent" files where the detector elements for LM and KLM half-modules are defined. They are located in the directory $LHCBHOME/software/releases/DBASE/Det/XmlDDDB/v30r0/DDDB/ TT/Modules/. The detector elements for one, two, three and four sensor sections are defined within the detector elements for LM and KLM half-modules. Structure parameters can be attached to individual detector elements. These are typically variables that are needed in the reconstruction or digitization but not at the level of the Geant4 based simulation. The parameters for the detector elements corresponding to the one, two and four sensor sections are given in Table 4.

Type	Number of sensors	Pitch [mm]	Number of strips	Capacitance [pF]	Vertical Guard Ring [mm]
TT1	1	0.18337	512	38	1.415
TT2	2	0.18337	512	44	1.415
TT3	3	0.18337	512	57	1.415
TT4	4	0.18337	512	55	1.415

Table 4: The parameters used in description of detector elements for one, two, three and four sensor sections.

To provide a unique numbering for the readout channels of the TT station, the following parameters were introduced to tag every readout section: "detRegion", "Module","firstReadoutSector" and "type". As can be seen in Fig. 8, the detection layer is

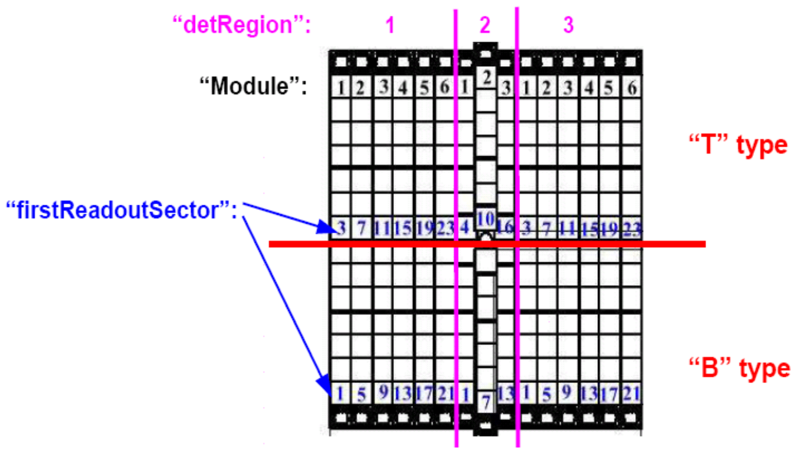

Figure 9: The half-module numbering for TTa station.

divided into three detection regions. The first and the third "detRegion" consist of 6 (7) top and 6 (7) bottom half-modules in TTa (TTb). The second "detRegion" consists of 6 half-modules surrounding the beam bipe. The "Module" and the "firstReadout-Sector" give the number of each half-module and of its first readout section within the detection region, respectively. The "type" parameter indicates the position of the half-module, which can be top or bottom. This structure allows to identify every readout channel of the TT station properly. More information about the TT numbering and the detector element tree for the TT station can be found in [10, 11].

3 Checks

Some basic checks have been made to validate the correctness of the updated description. First, it has been checked that no overlaps occur between the detector volumes. This check has been performed using the DetDescChecks tool [8], which is distributed with the LHCb software project. No overlapping volumes were found.

The simulation program of the LHCb experiment – Gauss [9] based on the Gaudi framework – has been used to simulate 500 minimum bias events with the new geometry description. Fig. 10 and Fig. 11 show the distribution of the impact points of particles on the sensitive volumes of TTa and TTb as determined by Geant4.

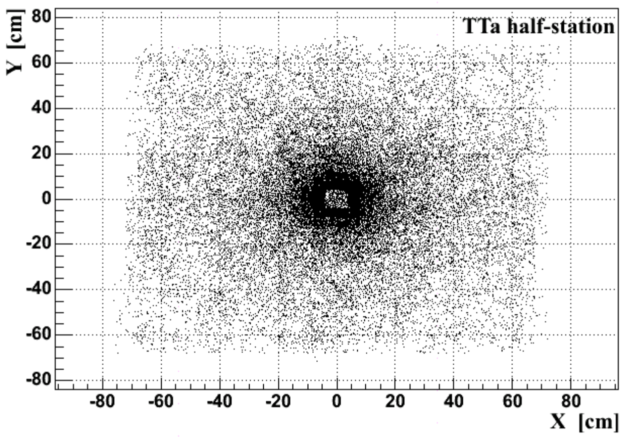

Figure 10: The distribution of hits in TTa.

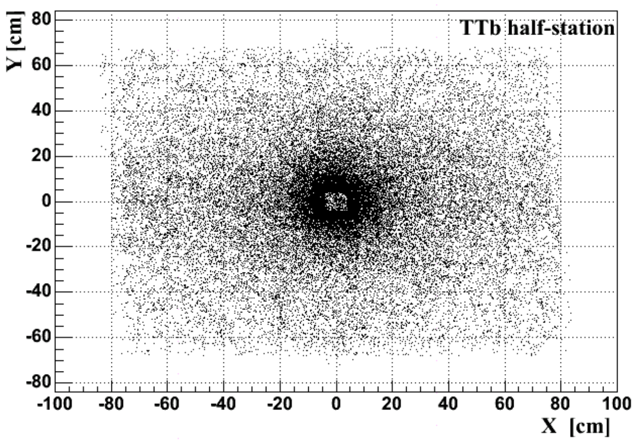

Figure 11: The distribution of hits in TTb.

As can be seen, the physical dimensions of the half-stations are reproduced reasonably and the expected high particle density around the beam pipe is observed. However it can also be seen that there are hits outside the sensitive detector volume, inside the beam pipe hole. This is a known feature of the Monte Carlo program, which is under investigation. Other physics parameters which were obtained with the current simulation, such as the energy loss in a silicon layer and the time-of-flight of particles, are shown in Fig. 12 and Fig. 13. They are consistent with expectations [1].

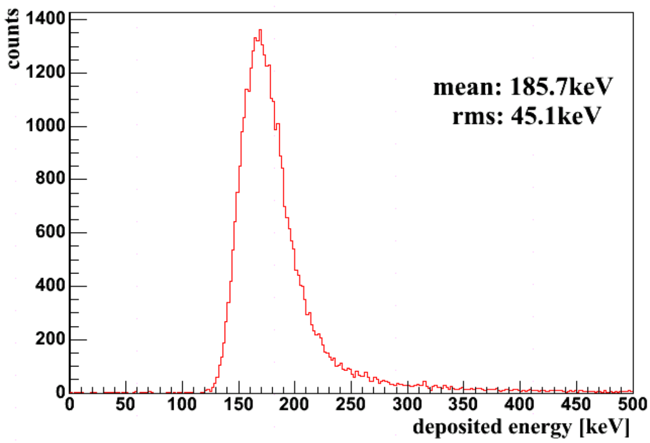

Figure 12: Energy deposited by particles from the primary proton-proton interaction in the silicon sensor with a thickness of 500 μm, as given by Geant4.

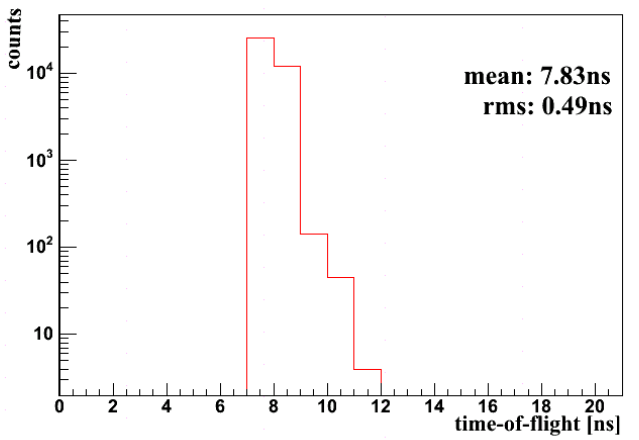

Figure 13: Time at which particles from the primary proton-proton interaction traverse the TTa and give hits. The primary proton-proton interaction occurs at t = 0 ns.

[1] It should be noted that as seen in previous studies [12] the magnitude of the deposited energy given by Geant is 20% higher than expected based on available data and theorectical calculations.

Another important test that has been performed was to scan the material distribution in the detector description, using the Transport Service [4]. Fig. 14 shows the radiation length X_0 as a function of pseudo-rapidity η and azimuthal angle ϕ whilst Fig. 15 shows the X_0, averaged over ϕ, as a function of η.

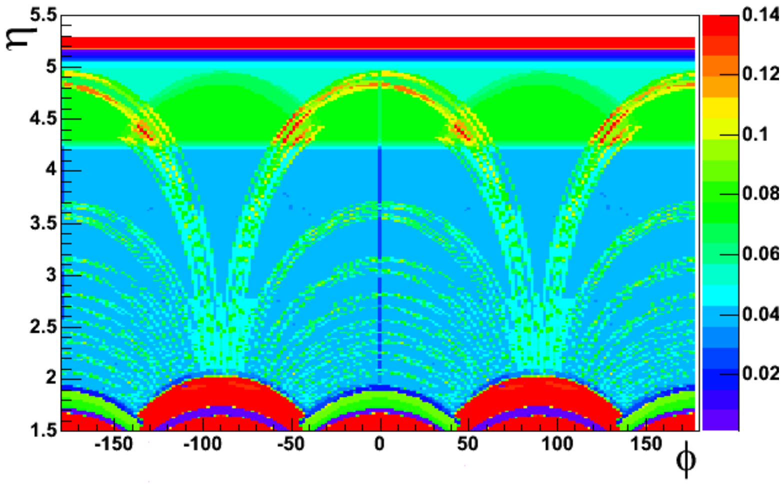

Figure 14: Radiation length as a function of η and ϕ.

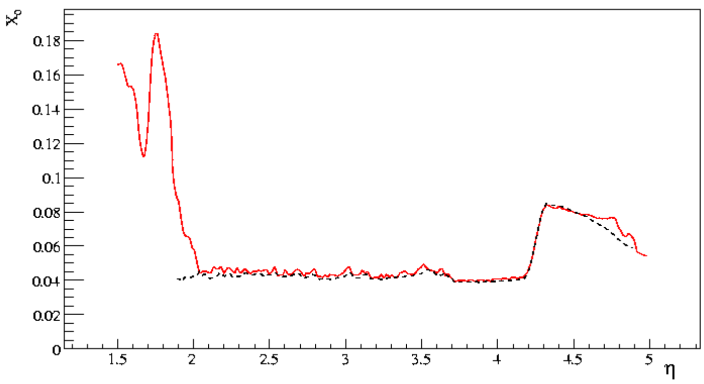

Figure 15: Radiation length averaged over ϕ, as a function of η. The solid line is with the current implementation, the dotted line represents the expectation from the studies described in [3]

These results are consistent with a calculation of the material budget of the TT station using a stand-alone Monte Carlo program which is described in [3]. The main difference is in the radiation length at low η, outside of the detector acceptance. This is due to the cooling plates, balconies and TT station frame that were not taken into account in the earlier study. Some supports may need to be added to fix the ends of the half-modules just above and below the beam-pipe. These have not been included in the detector description, since a mechanical design of these supports does not exist yet.

4 Summary

The detector description for the LHCb Trigger Tracker has been significantly improved. It provides a realistic geometry description of the active and passive elements of the detector. In the future, a more detailed modeling of the detector components outside of the acceptance could be performed by including in the description the material of the service boxes and readout hybrids. However, no significant effect on occupancies or other relevant physics quantities is expected, since these detector elements are located outside of the LHCb active area and the material budget in these regions is dominated by other elements of the LHCb detector (RICH1, Magnet). The results of a few basic checks demonstrate the correctness of the updated detector description.

References

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