

Department of Physics and Astronomy

University of Heidelberg

Master thesis

in Physics

submitted by

Patrick Fahner

born in Mannheim

September 2015

# A study of the decay

$$\Lambda_b^0 \rightarrow D^0 p \mu^- \bar{\nu}_\mu X$$

with the LHCb experiment

This Master thesis has been carried out by (Name Surname)

at the

(institute)

under the supervision of

(Frau/Herrn Prof./Priv.-Doz. Name Surname)

**(Titel der Masterarbeit - deutsch):**

(Abstract in Deutsch, max. 200 Worte. Beispiel: [?])

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquid ex ea commodo consequat. Quis aute iure reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint obcaecat cupiditat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

Duis autem vel eum iriure dolor in hendrerit in vulputate velit esse molestie consequat, vel illum dolore eu feugiat nulla facilisis at vero eros et accumsan et iusto odio dignissim qui blandit praesent luptatum zzril delenit augue dui dolore te feugait nulla facilisi. Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed diam nonummy nibh euismod tincidunt ut laoreet dolore magna aliquam erat volutpat.

Ut wisi enim ad minim veniam, quis nostrud exercitation ullamcorper suscipit lobortis nisl ut aliquip ex ea commodo consequat. Duis autem vel eum iriure dolor in hendrerit in vulputate velit esse molestie consequat, vel illum dolore eu feugiat nulla facilisis at vero eros et accumsan et iusto odio dignissim qui blandit praesent luptatum zzril delenit augue dui dolore te feugait nulla facilisi.

**(Title of Master thesis - english):**

(abstract in english, at most 200 words. Example: [?])

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquid ex ea commodo consequat. Quis aute iure reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint obcaecat cupiditat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

Duis autem vel eum iriure dolor in hendrerit in vulputate velit esse molestie consequat, vel illum dolore eu feugiat nulla facilisis at vero eros et accumsan et iusto odio dignissim qui blandit praesent luptatum zzril delenit augue dui dolore te feugait nulla facilisi. Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed diam nonummy nibh euismod tincidunt ut laoreet dolore magna aliquam erat volutpat.

Ut wisi enim ad minim veniam, quis nostrud exercitation ullamcorper suscipit lobortis nisl ut aliquip ex ea commodo consequat. Duis autem vel eum iriure dolor in hendrerit in vulputate velit esse molestie consequat, vel illum dolore eu feugiat nulla facilisis at vero eros et accumsan et iusto odio dignissim qui blandit praesent luptatum zzril delenit augue dui dolore te feugait nulla facilisi.

# Contents

<b>1</b>	<b>Introduction</b>	<b>5</b>
<b>2</b>	<b>The LHCb detector</b>	<b>6</b>
2.1	Tracking detectors . . . . .	7
2.1.1	Vertex Locator (VELO) . . . . .	7
2.1.2	Trigger Tracker / Tracker Turicensis (TT) . . . . .	7
2.1.3	Inner Tracker (IT) . . . . .	10
2.1.4	Outer Tracker (OT) . . . . .	10
2.1.5	Track classification . . . . .	10
2.2	Particle identification . . . . .	10
2.2.1	Ring Imaging Cherenkov Detector (RICH) . . . . .	10
2.2.2	Calorimeter system . . . . .	10
2.2.3	Muon chambers . . . . .	10
2.3	Trigger . . . . .	10
2.3.1	L0-Trigger . . . . .	10
2.3.2	High Level Trigger (HLT) . . . . .	10
<b>3</b>	<b>Data reconstruction and selection</b>	<b>11</b>
3.1	Trigger requirements . . . . .	11
<b>I</b>	<b>Appendix</b>	<b>12</b>
<b>A</b>	<b>Lists</b>	<b>13</b>

# 1 Introduction

## 2 The LHCb detector

Most parts of this chapter are taken from [1]

The LHCb experiment is one of the four big experiments, currently running at the Large Hadron Collider (LHC) of the European Organization for Nuclear Research CERN in Geneva, Switzerland. In contrast to the other three experiments – ATLAS and CMS are searching for direct hints of new physics, ALICE investigates the Quark-Gluon-Plasma – LHCb is dedicated to look indirectly for physics beyond the Standard Model (see section ??) by the study of hadrons containing either a heavy  $b$ - or  $c$ -quark.

...

The layout of the LHCb detector can be seen in figure 2.1. It is built as a single-arm forward spectrometer. The reason for this choice is, that at LHC energies of  $\sqrt{s} = 14 \text{ TeV}$  at the maximum,  $b$ - and  $\bar{b}$ - hadrons are predominantly produced in the forward (or backward) region.

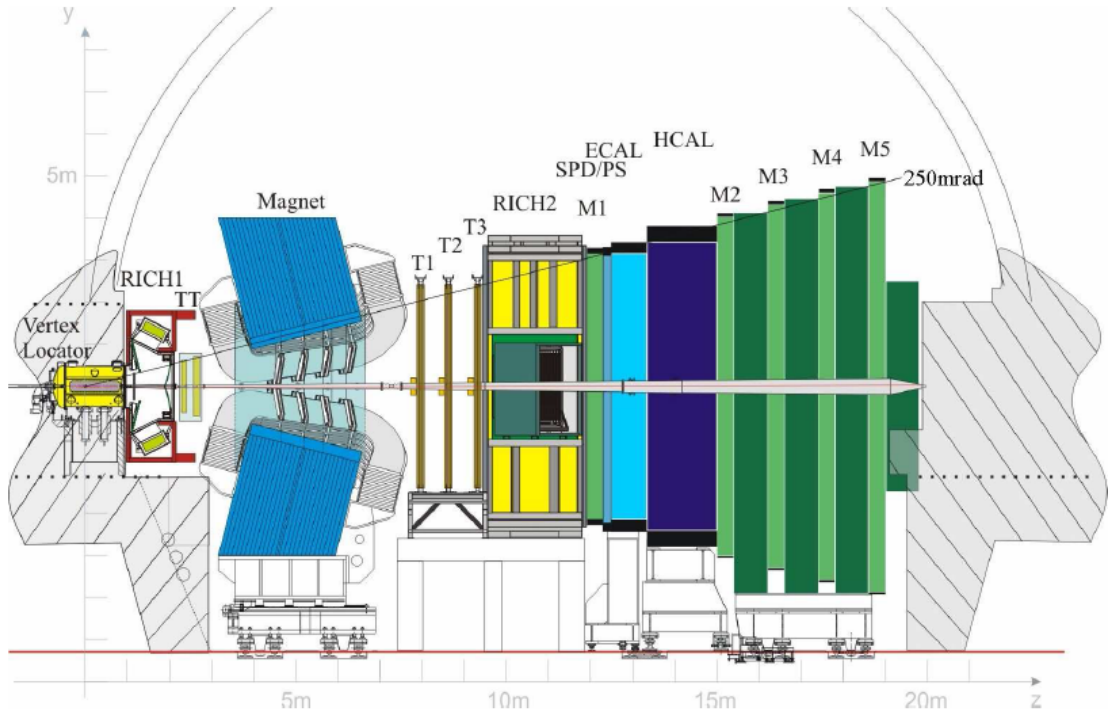


Figure 2.1: The LHCb detector.

## 2.1 Tracking detectors

Tracking describes the whole procedure to reconstruct the trajectories of the (charged) particles produced in the proton-proton collision. If there's a magnet in use, the particles' charges and momenta can be determined as well. For that purpose, a system of several subdetectors is aligned up- and downstream the dipole magnet, namely the Vertex locator (VELO), the Trigger Tracker (TT) and the Trigger stations (T1-T3) built-up by the Inner Tracker (IT) and the Outer Tracker (OT).

### 2.1.1 Vertex Locator (VELO)

The VERtex LOcator (VELO) is placed directly around the primary interaction point. Its task is to precisely measure the track coordinates of charged particles and separate the proton-proton interaction point from other vertices, namely either other primary vertices (so called pile-up events) or secondary vertices. The latter ones are typically for  $b$ - or  $c$ -hadron decays [2] and a good separation and resolution of these vertices is crucial for the LHCb physics programme. As an example serves the measurement of particles' decay length and time for the determination of the rapid  $B_s^0 - \bar{B}_s^0$  oscillation frequency [3].

The VELO is built up by silicon modules due to the high particle flux and thus high radiation in the interaction region. It is placed only 7 mm apart from the beam. This is closer than the required aperture of the LHCb beam pipe at injection. Thus, the VELO sensors are made of silicon microstrips shaped as slightly overlapping half-discs. The two halves can be moved in  $x$ - and  $y$ -direction to avoid radiation damages unless the beam is stable.

Each module provides a measurement of the  $r$ - and  $\phi$ -coordinates. The sensors for these measurements are correspondingly called  $R$ - and  $\Phi$ -sensor, which can be seen in figure 2.2. An overview over the VELO system with its modules is shown in figure 2.3. Around the nominal interaction region, the modules are placed closer to each other. Upstream there are two  $R$  sensors dedicated to veto pile-up events. Figure 2.3 furthermore shows the VELO in closed and opened position. With this setup the VELO reaches a track finding efficiency above 98%. Its resolution on vertices is  $13\text{ }\mu\text{m}$  in the transverse plane and  $71\text{ }\mu\text{m}$  along the beam axis for vertices with 25 tracks. The resolution on the impact parameter is smaller than  $35\text{ }\mu\text{m}$  for particles with a transverse momentum larger than 1 GeV [1, 2, 4].

### 2.1.2 Trigger Tracker / Tracker Turicensis (TT)

The Tracker Turicensis or formerly the Trigger Tracker is located in front of the entrance of the LHCb magnet. It is used for several tasks:

- deliver transverse momentum information for Level-1 trigger,
- reconstruct trajectories of long-lived neutral particles decaying outside the VELO

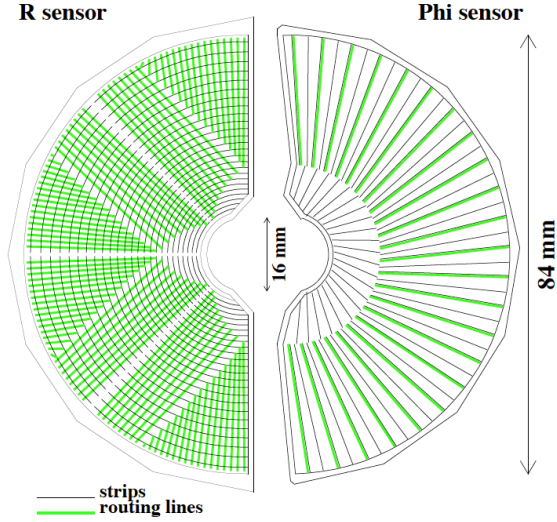


Figure 2.2: Schematic representation of an  $R$  and a  $\Phi$  sensor. The  $R$  sensor strips are arranged into four approximately  $45^\circ$  segments and have routing lines perpendicular to the strips. The  $\Phi$  sensor has two zones with inner and outer strips. The routing lines of the inner strips are orientated parallel to the outer strips. Figure and caption taken from [4].

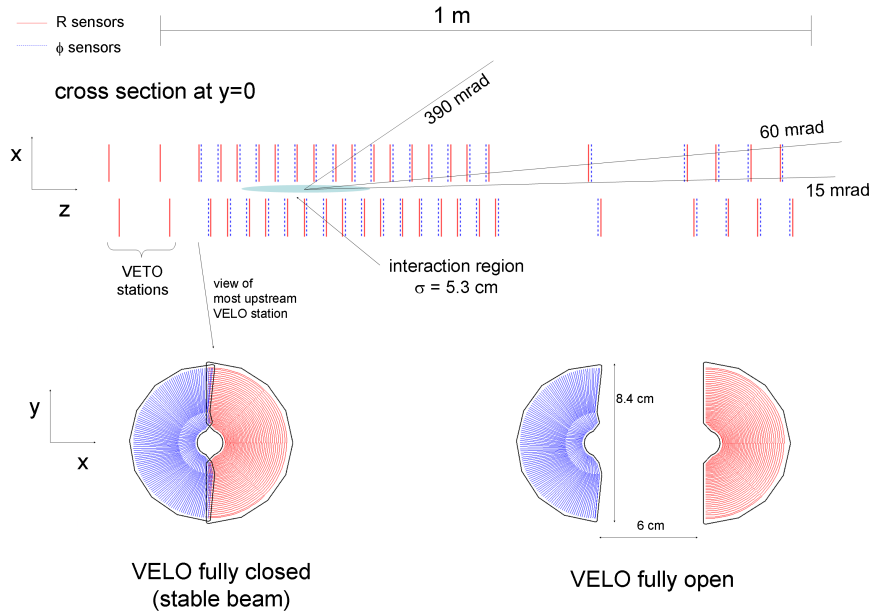


Figure 2.3: Cross section in the  $(x, z)$  plane of the VELO silicon sensors, at  $y = 0$ , with the detector in the fully closed position. The front face of the first modules is also illustrated in both the closed and open positions. The two pile-up veto stations are located upstream of the VELO sensors. Figure and caption taken from [1].



- reconstruct low-momenta particles bent out by the magnet before reaching the station T1-T3.

The TT makes completely use of silicon microstrip detector. It consist of one station made of four planes along the beam axis. The first and the fourth layer have vertical readout strips ( $x$ -layer), while the second and third are rotated by an angle  $\pm 5^\circ$  to get a high resolution in the bending plane and additional information in  $y$ -direction. Between the  $u$  and  $v$  layer there is a gap of around 30 cm. Figure ?? shows schematically the layout of the TT.

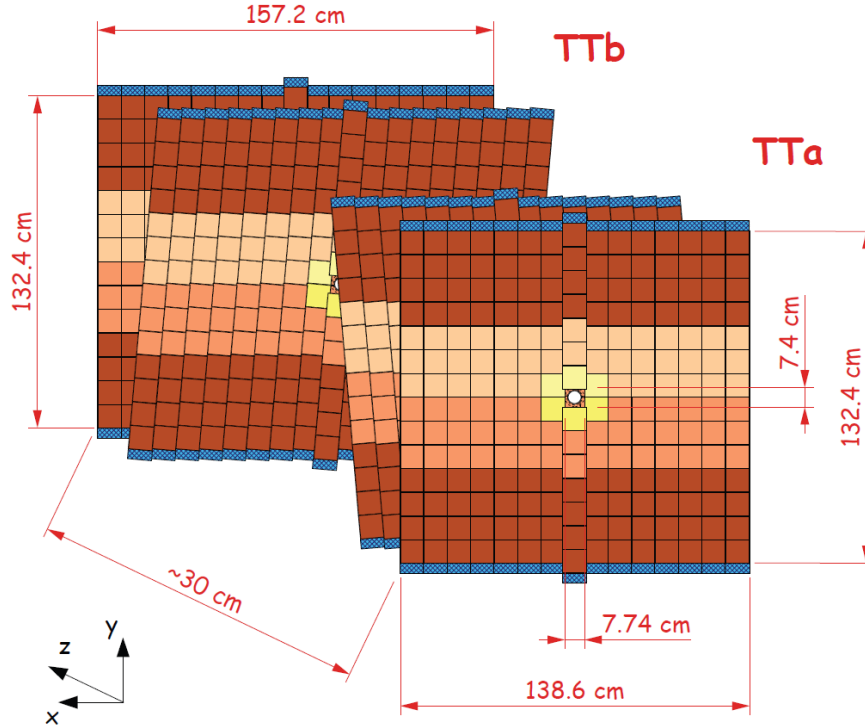


Figure 2.4: Layout of the Tracker Turicensis (TT). Figure taken from [5].

2.1.3 Inner Tracker (IT)

2.1.4 Outer Tracker (OT)

2.1.5 Track classification

2.2 Particle identification

2.2.1 Ring Imaging Cherenkov Detector (RICH)

2.2.2 Calorimeter system

2.2.3 Muon chambers

2.3 Trigger

2.3.1 L0-Trigger

2.3.2 High Level Trigger (HLT)

## 3 Data reconstruction and selection

The analysis of the decays  $\Lambda_b^0 \rightarrow D^0 p \mu^- \bar{\nu}_\mu X$  (signal channel) and  $\Lambda_b^0 \rightarrow \Lambda_c^+ \mu^- \bar{\nu}_\mu$  (normalization channel) requires the reconstruction and selection of possible signal candidates. The term “signal candidates” implies, that a data sample doesn’t contain only the desired signal events after reconstruction and selection, but is also polluted by events from different sources, albeit looking like signal. These backgrounds can have several reasons: One possibility is that the final state particles are randomly combined but fulfil all the applied criteria. This kind of background is also known as combinatoric background. There are furthermore the so-called physical backgrounds. With this term one summarises physical decays where one either misidentifies a final state particle or only partially reconstruct an event und thus leading to a wrong interpretation of the decay. As an example for the misidentification consider the decay  $\Lambda_b^0 \rightarrow D^0 p \pi^-$ . If the  $\pi^-$  is now misidentified as a muon this decay looks exactly like the signal channel of this analysis. Partially reconstructed events play an important role in the normalisation channel  $\Lambda_b^0 \rightarrow \Lambda_c^+ \mu^- \bar{\nu}_\mu$ . There exists also semileptonic  $\Lambda_b^0$  decays into excited  $\Lambda_c^{*+}$  states,  $\Lambda_b^0 \rightarrow \Lambda_c^{*+} \mu^- \bar{\nu}_\mu$ . Subsequently, these excited  $\Lambda_c^{*+}$  states decay into an  $\Lambda_c^+$  and additional pions or photons. If one misses these pions and photons the decay looks exactly like  $\Lambda_b^0 \rightarrow \Lambda_c^+ \mu^- \bar{\nu}_\mu$ .

Since such misidentified decays or combinatoric backgrounds distort the measurement of physical quantities, the event reconstruction and above all the selection aims to reduce these backgrounds as much as possible while keeping as much signal as possible. At LHCb, this procedure is done in several steps, described for the present analysis in this chapter, namely the Trigger, the preselection (or stripping) and the offline selection. Nonetheless not every background source can be easily eliminated. The handling of such issues is part of chapter ??.

### 3.1 Trigger requirements

Trigger requirements are already applied during data taking to reduce the arising data to a recordable amount. There exists so called trigger lines for different physics purposes. These trigger lines then contain the requirements on the particles’ properties.

For the  $\Lambda_b^0 \rightarrow D^0 p \mu^- \bar{\nu}_\mu X$  channel the muon has pass the L0Muon\_TOS line at L0 level. TOS is the abbreviation for Trigger On Signal, i.e.

# Part I

## Appendix

# A Lists

# List of Figures

2.1	The LHCb detector. . . . .	6
2.2	Schematic representation of an $R$ and a $\Phi$ sensor. The $R$ sensor strips are arranged into four approximately $45^\circ$ segments and have routing lines perpendicular to the strips. The $\Phi$ sensor has two zones with inner and outer strips. The routing lines of the inner strips are orientated parallel to the outer strips. Figure and caption taken from [4]. . . . .	8
2.3	Cross section in the $(x, z)$ plane of the VELO silicon sensors, at $y = 0$ , with the detector in the fully closed position. The front face of the first modules is also illustrated in both the closed and open positions. The two pile-up veto stations are located upstream of the VELO sensors. Figure and caption taken from [1]. . . . .	8
2.4	Layout of the Tracker Turicensis (TT). Figure taken from [5]. . . . .	9

# List of Tables

# Bibliography

- [1] LHCb collaboration, A. A. Alves Jr. *et al.*, *The LHCb detector at the LHC*, JINST **3** (2008) S08005.
- [2] LHCb Collaboration, *LHCb VELO (VERtex LOCator): Technical Design Report*, Technical Design Report LHCb, CERN, Geneva, 2001.
- [3] LHCb, R. Aaij *et al.*, *Precision measurement of the  $B_s^0$ - $\bar{B}_s^0$  oscillation frequency with the decay  $B_s^0 \rightarrow D_s^- \pi^+$* , New J. Phys. **15** (2013) 053021, [arXiv:1304.4741](#).
- [4] R. Aaij *et al.*, *Performance of the LHCb Vertex Locator*, JINST **9** (2014) 09007, [arXiv:1405.7808](#).
- [5] LHCb Silicon Tracker Group, J. Luisier, *Performance of LHCb Silicon Tracker Detector in the LHC*, Phys. Procedia **37** (2012) 851.



Erklärung:

Ich versichere, dass ich diese Arbeit selbstständig verfasst habe und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe.

Heidelberg, den (Datum) .....