LHCb Muon System by Numbers

LHCb Technical Note

Issue: 1st Version
Revision: 1

Reference: LHCb 2000-089
Created: 21th July 2000
Last modified: 14th September 2000

Prepared By: LHCb Muon Group
Burkhard Schmidt / Editor

Abstract

This note summarises, mainly in the form of tables, the present configuration of the muon system. It is meant as a working document of the muon group and will be updated as the project progresses.

Document Status Sheet

Table 1 Document Status Sheet

1. Document Title: [Project Name Qualification] User Requirements Document			
2. Document Reference Number: [Document Reference Number]			
3. Issue	**4. Revision**	**5. Date**	**6. Reason for change**
Draft	0	21.07.2000	Initial version
1st Version	1	14.09.2000	Suggested modifications to draft included

Table of Contents

1. INTRODUCTION AND OVERVIEW 2

2. PHYSICAL LAYOUT 4

2.1. CHAMBERS 4
2.2. PHYSICAL CHANNELS 5

3. LOGICAL LAYOUT 8

4. FE-ARCHITECTURE 12

5. LEVEL 0 MUON TRIGGER 15

5.1. TRIGGER INTERFACE AND FAST IDENTIFICATION PROCESSOR 15
5.2. TRIGGER ALGORITHM AND DETAILED MUON PROCESSOR 16

6. BACKGROUND 17

7. SYSTEM PERFORMANCE 19

8. REFERENCE 21

1 Introduction and Overview

The concept of the LHCb detector and its muon system is discussed in the LHCb Technical Proposal [1]. Since that report, the layout of the LHCb detector has been modified. The optimization of the muon detector layout [2], the new magnet design [3] and the shorter hadron calorimeter [4] are of importance for the muon system, of which the present configuration is summarized in this note.

The muon system consists of 5 detector stations, interleaved in a longitudinally segmented shield, as shown in Figure 1-1. The total thickness of the absorber is 21λ (nuclear interaction lengths). To penetrate the shield and reach station M5 a muon must have an energy of at least 5 GeV. The allocated space for the muon stations is 40cm, besides for station 1, where the allocated space is only 37cm. The thickness of the absorber material is 80cm. The muon stations are divided into 4 regions of different granularity. The inner and outer acceptance (horizontal × vertical) of the muon detector is 20mrad × 16mrad and 318mrad × 257mrad.

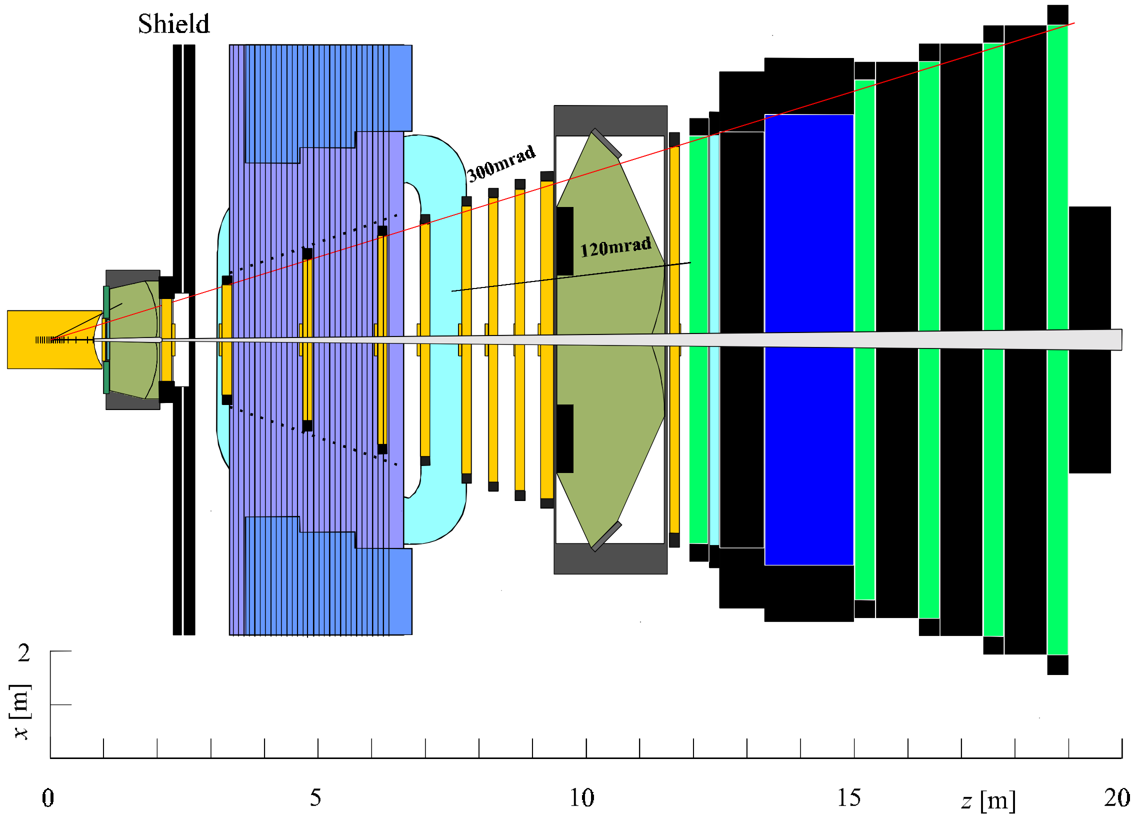

Figure 1-1

Detector Surface (m^2)	Station 1	Station 2	Station 3	Station 4	Station 5	Sum
Region 1	0.6	0.9	1.0	1.2	1.4	5.1
Region 2	2.3	3.6	4.2	4.8	5.5	20.5
Region 3	9.2	14.4	16.8	19.3	22.1	81.8
Region 4	36.9	57.7	67.2	77.4	88.3	327.3
Sum (single layer)	49.0	76.6	89.2	102.7	117.2	**434.7**
Sum (double layer)	97.9	153.3	178.4	205.5	234.4	**869.5**

Table 1-1

Table 1-1 shows the detector surface area for a single and double layer of chambers. The total surface of a single layer for regions 3 and 4 of stations 4 and 5 will be equipped with RPC detectors and corresponds to a surface area of **207m²**. The total area to be equipped with MWPC corresponds to **224.8m²**. The inner part of station 1, for which no technology has been chosen yet, corresponds to **2.9m²** only. Table 1-2 gives the central position of each station and the region dimensions.

Region Dimensions (cm)	Station 1	Station 2	Station 3	Station 4	Station 5
z- pos. (centre)	1215	1520	1640	1760	1880
Region 1 (horiz.)	24	30.0	32.4	34.8	37.1
Region 1 (vert.)	20	25.0	27.0	29.0	30.9
Region 2 (horiz.)	48	60	65	70	74
Region 2 (vert.)	40	50	54	58	62
Region 3 (horiz)	96	120	130	139	149
Region 3 (vert.)	80	100	108	116	124
Region 4 (horiz.)	192	240	259	278	297
Region 4 (vert.)	160	200	216	232	248
Outer (horiz.)	384	480	518	556	594
Outer (vert.)	320	400	432	464	495

Table 1-2

2 Physical Layout

2.1 Chambers

Technology	Station 1	Station 2	Station 3	Station 4	Station 5
Region 1	No Technology chosen so far	MWPC, AW and CP- RO	MWPC, AW and CP- RO	MWPC, CP-RO	MWPC, CP-RO
Region 2	No Technology chosen so far	MWPC, AW and CP- RO	MWPC, AW and CP- RO	MWPC, CP-RO	MWPC, CP-RO
Region 3	MWPC, CP-RO	MWPC, CP-RO	MWPC, CP-RO	RPC	RPC
Region 4	MWPC, AW-RO	MWPC, AW-RO	MWPC, AW-RO	RPC	RPC

Table 2-1

Most of the muon system will be equipped with Multi-Wire –Proportional-Chambers (MWPC) with Anode-Wire (AW) readout (RO), Cathode-Pad (CP) readout, or a combined AW-CP readout. The outer part of stations 4 and 5 will be equipped with two single- or one double- gap Resistive-Plate-Chamber (RPC).

Number of Chambers	Station 1 (one 4-gap/ two 2-gap)	Station 2 (one 4-gap/ two 2-gap)	Station 3 (one 4-gap/ two 2-gap)	Station 4 (one 2-gap/ two 2-gap in region 4)	Station 5 (one 2-gap/ two 2-gap in region 4)	Sum
Region 1	3	3	3	3	3	15
Region 2	6	6	6	6	6	30
Region 3	12 / 24	12 / 24	12 / 24	12	12	60 / 96
Region 4	24 / 48	24 / 48	24 / 48	24 / 48	24 / 48	120 / 168 / 192 / 240
Sum/Quadrant	45 / 81	45 / 81	45 / 81	45 / 69	45 / 69	225 / 273 / 333 / 381
Sum	180 / 324	180 / 324	180 / 324	180 / 276	180 / 276	**900 / 1092 / 1332 / 1524**

Table 2-2

No technology has been chosen yet for the inner part of station 1 (IP-M1), where rates above 100 kHz/cm^2 are expected. Despite this situation, some assumptions for the layout had to be made in the simulation program SICB. For the sake of simplicity, the same number of chambers (cf. Table 2-2) has been assumed for IP-M1 as for the inner part of the other stations.

For the inner part of the muon system 4-gap chambers have been suggested, which allow to minimize the distance between the two sensitive layers foreseen in each station. Furthermore, 4-gap chambers allow the combination of physical channels of the two layers on the chambers. Using them also in the outer part of the system and RPCs of the same size as the wire chambers results in a total number of **900** chambers for the whole system (576 MWPC, 288 RPC, and 36 for IP-M1). In case RPCs of the same length in regions 3 and 4 of stations 4 (5) are used, the number of chambers goes up to **1092** (480 RPC) [5]. Using two 2-gap chambers in regions 3 and 4 of stations 1-3 in conjunction with RPCs of the same length in region 3 and 4 leads to **1524** chambers in total (1008 MWPC, 480 RPC, 36 IP-M1), while the combination with RPCs of the same length as wire chambers leads to **1332** chambers (1008 MWPC, 288 RPC, 36 IP-M1).

Chamber sensitive area (cm)	Station 1	Station 2	Station 3	Station 4	Station 5
Region 1 (horiz. x vert.)	24 x 20	30 x 25	32.4 x 27	34.8 x 29	37.1 x 30.9
Region 2 (horiz. x vert.)	48 x 20	60 x 25	64.8 x 27	69.5 x 29	74.3 x 30.9
Region 3 (horiz. x vert.)	96 x 20	120 x 25	129.6 x 27	139 x 29	148.5 x 30.9
Region 4 (horiz. x vert.)	192 x 20	240 x 25	259 x 27	278 x 29	297 x 30.9

Table 2-3

2.2 Physical Channels

The size of physical channels has to match the logical layout described in chapter 3. Furthermore, the size of physical channels is limited by:

- The maximal possible input capacitance of a preamplifier channel. Recent measurements with the ASDQ++ chip show that an input capacitance larger than 250pF is possible if anode wire readout is used [6]. In terms of channel surface, the maximal size of pads is therefore: $A_{Ch\text{-}AW} < 200cm^2$ for anode readout, and $A_{Ch\text{-}CP} < 100cm^2$ for cathode readout.

- The rate per channel. With a pulse-width of 50ns and a rate of 800 kHz the inefficiency due high occupancy is already about 3% [7]. Therefore channels have been split into two in cases where the rates would have exceeded 800 kHz.

Phys. ch. surface (cm^2)	Station 1	Station 2	Station 3	Station 4	Station 5
Region 1 (wire strip)	-	15.7	18.2	-	-
Region 1 (cath. pad)	1.25	11.7	13.7	10.5	12.0
Region 2 (wire strip)	-	31.3	36.4	-	-
Region 2 (cath. pad)	2.5	23.5	54.7	42.0	47.9
Region 3	10	31.3	36.4	83.9	95.8
Region 4	40	125.2	145.8	167.9	191.5

Table 2-4

Phys. ch. rate (kHz)	Station 1	Station 2	Station 3	Station 4	Station 5
Region 1 (wire pad)		783	729		
Region 1 (cath. pad)	700	587	547	252	287
Region 2 (wire pad)		751	146		
Region 2 (cath. pad)	800	563	219	84	77
Region 3	800	250	29	50	57
Region 4	800	125	29	25	115

Table 2-5

Tables 2-4 and 2-5 summarize the values obtained for the surface and the maximal rates of physical channels per region. The rate per physical channel is based on the new background estimation [8], a peak luminosity of 5×10^{32} $/cm^2/s$ and the conservative approach and safety factor the muon group agreed upon. Details on the background are given in chapter 5.

Physical channel dimensions (mm)	Station 1	Station 2	Station 3	Station 4	Station 5
Region 1 (wire strip)	-	6.3 x 250	6.7 x 270	-	-
Region 1 (cath pad)	10 x 12.5 (?)	37.5 x 31.3	40.5 x 33.7	29 x 36	31 x 39
Region 2 (wire strip)	-	12.5 x 250	13.5 x 270	-	-
Region 2 (cath pad)	10 x 25 (?)	75 x 31.3	162 x 33.7	58 x 72	62 x 77
Region 3	20 x 50 (?)	25 x 125	27 x 135	58 x 145	62 x 155
Region 4	20 x 200	50 x 250	54 x 270	58 x 290	62 x 309

Table 2-6

The corresponding sizes of physical channels per region are summarized in Table 2-6, and the resulting combination of physical- to logical channels for one layer in Table 2-7.

Physical ch. / logical ch.	Station 1	Station 2	Station 3	Station 4	Station 5
Region 1 (wire pad)		1	1		
Region 1 (cath pad)	2	1	1	1	1
Region 2 (wire pad)		1	1		
Region 2 (cath pad)	4	4	2	1	1
Region 3	4	1	1	2	2
Region 4	4	1	1	4	4

Table 2-7

Table 2-8 shows the number of physical channels per quadrant and layer, and Table 2-9 the total number of physical channels.

Physical channels	Station 1	Station 2	Station 3	Station 4	Station 5	Sum
Region 1 (wire pad)		144	144			288
Region 1 (cath pad)	1152	192	192	288	288	2112
Region 2 (wire pad)		288	288			576
Region 2 (cath pad)	2304	384	192	288	288	3456
Region 3	2304	1152	1152	576	576	5760
Region 4	2304	1152	1152	1152	1152	6912
Sum/Quad/Layer	8064	3312	3120	2304	2304	19104
Sum	64512	26496	24960	18432	18432	**152832**

Table 2-8

Physical channels	Station 1	Station 2	Station 3	Station 4	Station 5	Sum
Region 1	9216	2688	2688	2304	2304	19200
Region 2	18432	5376	3840	2304	2304	32256
Region 3	18432	9216	9216	4608	4608	46080
Region 4	18432	9216	9216	9216	9216	55296
Sum	64512	26496	24960	18432	18432	**152832**

Table 2-9

3 Logical Layout

The logical layout summarized in the following tables corresponds to the optimized layout, referred to as “March 2000 Layout” [2]. Figure 3-1 shows as an example the logical layout of station 2.

In most of the regions physical pads are used to measure a space point. This allows to avoid an additional AND of chamber signals in the trigger logic. However, in order to keep the number of logical channels low while retaining good granularity, physical pads are combined to logical strips, of which the dimensions are given in Table 3-3. The crossing of two logical strips provides the final granularity of the logical pads as indicated in Table 3-1. Table 3-2 gives the granularity, downscaled to the granularity in station 1.

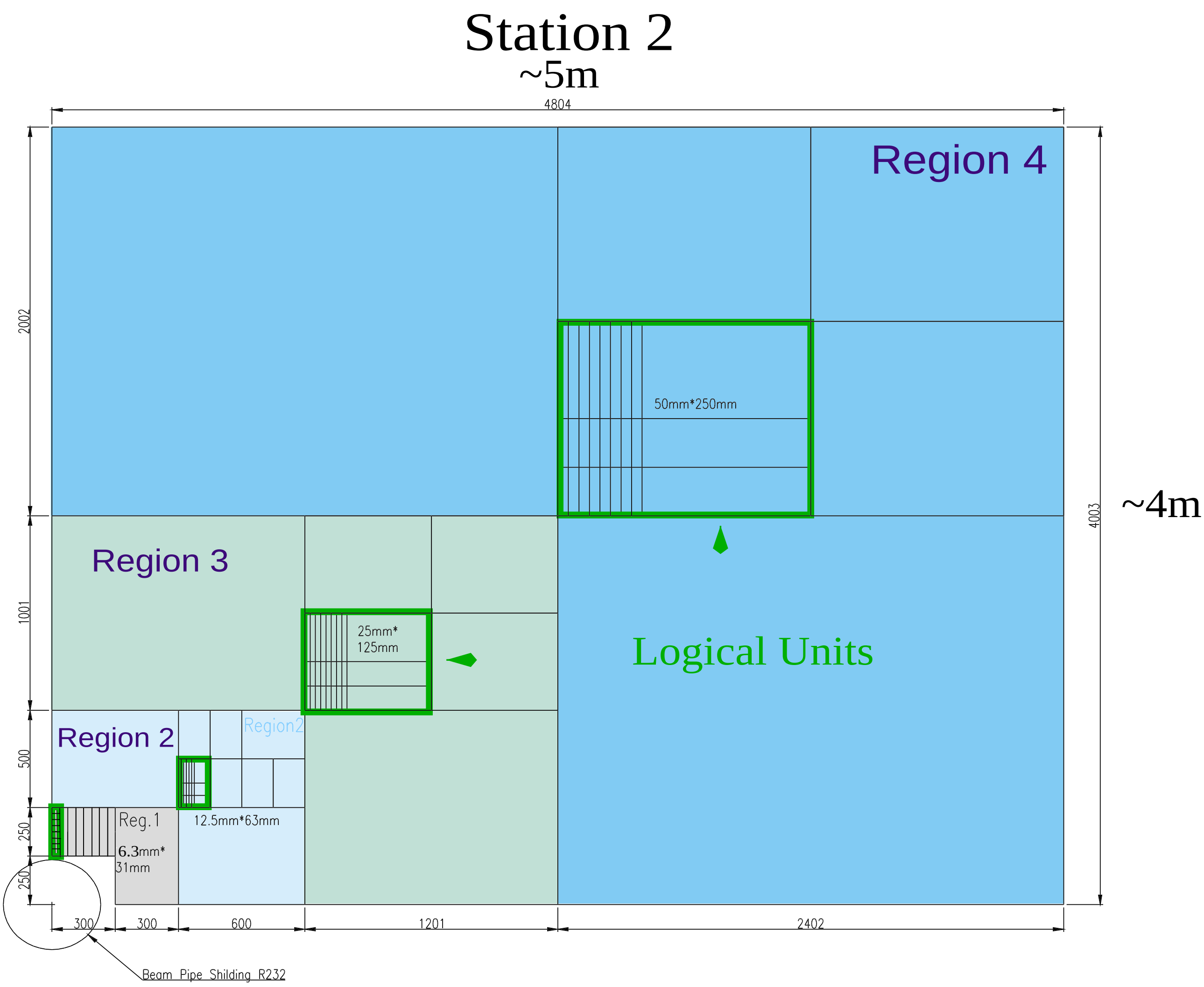

Figure 3-1

Logical Pad Granularity (mm)	Station 1	Station 2	Station 3	Station 4	Station 5
Region 1	10 x 25	6.3 x 31.3	6.7 x 33.7	29 x 36	31 x 39
Region 2	20 x 50	12.5 x 62.5	13.5 x 67.5	58 x 72	62 x 77
Region 3	40 x 100	25 x 125	27 x 135	116 x 145	124 x 155
Region 4	80 x 200	50 x 250	54 x 270	232 x 290	248 x 309

Table 3-1

Logical Pad Granularity (mm)	Station 1	Station 2	Station 3	Station 4	Station 5
Region 1	10 x 25	5 x 25	5 x 25	20 x 25	20 x 25
Region 2	20 x 50	10 x 50	10 x 50	40 x 50	40 x 50
Region 3	40 x 100	20 x 100	20 x 100	80 x 100	80 x 100
Region 4	80 x 200	40 x 200	40 x 200	160 x 200	160 x 200

Table 3-2

Logical Channel Size (mm)	Station 1	Station 2	Station 3	Station 4	Station 5
Region 1 (horiz. x / y)	-	37.5 x 31.3	40.5 x 33.7	-	-
Region 1 (vert. x / y)	-	6.3 x 250	6.7 x 270	-	-
Region 2 (horiz. x / y)	-	150 x 62.5	162 x 67.5	174 x 72	186 x 77
Region 2 (vert. x / y)	-	12.5 x 250	13.5 x 270	58 x 290	62 x 309
Region 3 (horiz x / y)	-	600 x 125	648 x 135	695 x 145	743 x 155
Region 3 (vert. x / y)	-	25 x 500	27 x 540	116 x 579	124 x 619
Region 4 (horiz. x / y)	-	1201 x 250	1296 x 270	1391 x 290	1485 x 309
Region 4 (vert. x / y)	-	50 x 1001	54 x 1080	232 x1159	248 x 1238

Table 3-3

The regions where no value is given for the logical strip size have directly logical pads without going through the intermediate step of logical strips. This is the case for all regions in station 1 (due to very high occupancies), and for region 1 of stations 4 and 5 (because the logical units could not be made projective with the chosen granularity and the overall gain of logical channels would be marginal (~3%)). The length of logical strips defines the logical unit size as summarized in Table 3-4.

Logical Unit Size (cm)	Station 1	Station 2	Station 3	Station 4	Station 5
Region 1 (horiz. x vert.)	-	3.75 x 25	4.05 x 27	-	-
Region 2 (horiz. x vert.)	-	15 x 25	16.2 x 27	17.4 x 29	18.6 x 30.9
Region 3 (horiz. x vert.)	-	60 x 50	65 x 54	70 x 58	74 x 62
Region 4 (horiz. x vert.)	-	120 x 100	130 x 108	139 x 116	149 x 124

Table 3-4

Number of Logical Units	Station 1	Station 2	Station 3	Station 4	Station 5	Sum
Region 1	-	24	24	-	-	48
Region 2	-	24	24	24	24	96
Region 3	-	12	12	12	12	48
Region 4	-	12	12	12	12	48
Sum (Quad)	-	72	72	48	48	240
Sum	-	288	288	192	192	**960**

Table 3-5

Table 3-5 shows the number of logical units. Due to the large occupancy in the inner part of the muon system the size of logical units there is proportionally smaller than in the outer part of the system.

Number of Logical channels	Station 1	Station 2	Station 3	Station 4	Station 5	Sum
Region 1(h-st/pad)	576	192	192	288	288	1536
Region 1(v-strip)	-	144	144	-	-	288
Region 2 (h-st/pad)	576	96	96	96	96	960
Region 2 (v-strip)	-	288	288	72	72	720
Region 3 (h-st/pad)	576	48	48	48	48	768
Region 3 (v-strip)	-	288	288	72	72	720
Region 4 (h-st/pad)	576	48	48	48	48	768
Region 4 (v-strip)	-	288	288	72	72	720
Sum/Quadrant	2304	1392	1392	696	696	6480
Sum	9216	5568	5568	2784	2784	**25920**

Table 3-6

Number of Logical channels	Station 1	Station 2	Station 3	Station 4	Station 5	Sum
Region 1	576	336	336	288	288	1824
Region 2	576	384	384	168	168	1680
Region 3	576	336	336	120	120	1488
Region 4	576	336	336	120	120	1488
Sum/Quadrant	2304	1392	1392	696	696	6480
Sum	9216	5568	5568	2784	2784	**25920**

Table 3-7

Table 3-6 and 3-7 finally summarizes the number of logical channels in the whole muon system. Compared to the layout as presented in the LHCb Technical Proposal [1], the number of logical channels has gone down by about 20k channels.

4 FE-Architecture

In our present understanding we distinguish three parts in the FE-Architecture.

- The FE-board with the Amplifier–Shaper-Discriminator chip;
- The Intermediate board (IM), where the channel reduction from physical to logical channels and the synchronization takes place;
- The OFF-Detector-Electronics board (ODE), where the L0-Pipeline, L1-Buffer and the Trigger- and DAQ-Interfaces are positioned.

The details about the FE-Architecture are discussed elsewhere [9]. Table 4-1 summarizes the grouping of physical channels to logical channels within the IM-boards. The number of input channels has been limited to a maximum of 192, while the maximum number of output channels is limited to 32. For most of the regions where logical units exist (cf. Table 3-1) this is a natural choice, as it allows to combine signals of one logical unit within one IM-board. In regions 1 and 2 of stations 2 and 3 the signals from two logical units are grouped within one intermediate board. Similarly, for region 2 (3) of stations 4 and 5 the signals from four (two) logical units are grouped within one IMB.

Logical / Physical channels (per IM-board)	Station 1	Station 2	Station 3	Station 4	Station 5
Region 1	24 / 96	28 / 56	28 / 56	24 / 48	24 / 48
Region 2	24 / 192	32 / 112	32 / 80	28 / 96	28 / 96
Region 3	24 / 192	28 / 192	28 / 192	20 / 192	20 / 192
Region 4	24 / 192	28 / 192	28 / 192	10 / 192	10 / 192

Table 4-1

Logical channels (per ODE-board)	Station 1	Station 2	Station 3	Station 4	Station 5
Region 1	192	168	168	144	144
Region 2	192	192	192	168	168
Region 3	192	168	168	120	120
Region 4	192	168	168	120	120

Table 4-2

Table 4-2 shows the grouping of logical channels on the ODE-boards. Also here the number of input channels per ODE-board has been limited to a maximum of 192. Furthermore, to avoid complications in the data flow, no sharing of ODE-boards by logical signals of different regions is foreseen.

FE-boards	Station 1	Station 2	Station 3	Station 4	Station 5	Sum
Region 1	144	42	42	38	38	304
Region 2	288	84	60	36	36	504
Region 3	288	144	144	36	72	720
Region 4	288	144	144	144	144	864
Sum/Quadrant	1008	414	390	290	290	2392
Sum	4032	1656	1560	1160	1160	**9568**

Table 4-3

IM-Boards	Station 1	Station 2	Station 3	Station 4	Station 5	Sum
Region 1	24	12	12	12	12	72
Region 2	24	12	12	6	6	60
Region 3	24	12	12	6	6	60
Region 4	24	12	12	12	12	72
Sum/Quadrant	96	48	48	36	36	264
Sum	384	192	192	144	144	**1056**

Table 4-4

ODE-Boards	Station 1	Station 2	Station 3	Station 4	Station 5	Sum
Region 1	3	2	2	2	2	11
Region 2	3	2	2	1	1	9
Region 3	3	2	2	1	1	9
Region 4	3	2	2	1	1	9
Sum/Quadrant	12	8	8	5	5	38
Sum / Halfplane	24	16	16	10	10	76
Sum	48	32	32	20	20	**152**

Table 4-5

Tables 4-3 to 4-5 summarize the number of FE-boards, IM-boards and ODE-boards required. It has been assumed that 16 FE-channels are grouped on one FE-board and 192 logical channels on one ODE-board, as mentioned before.

5 Level 0 Muon Trigger

The Level 0 muon processor (L0 (μ)) is organized in two steps [10],

1. *The Fast Identification Processor (FIP)*, where a muon candidate is localized using only coarse information (sectors).

2. *The Detailed Muon Processing (DMP)*, which performs fine track finding using the logical channels returned by the FE-electronics. It looks for a muon track within predefined fields of interest and computes the transverse momentum for each candidate.

5.1 Trigger Interface and Fast Identification Processor

A good match between the logical units, IM-and ODE-boards on one hand and the FIP entities (called sectors) on the other is very important. Studies of various implementations showed that an optimal performance is obtained with sectors of 6x2 logical pads (in terms of logical pad size in M1). Assuming sectors that are projective to the interaction point in all 5 stations leads to 48 sectors per quadrant, region and station, thus 192 per region and station, 768 per station and 3840 sectors in total. Each logical unit in regions 1 and 2 (3 and 4) of stations 2-5 is split into 2 (4) sectors respectively. The fact that sectors are of finer granularity than the logical units provides an additional handle against background and ghost hits, because the FIP algorithm requires a hit in the projective sectors of each station. The number of logical channels per sector and their size are summarized in Tables 5-1 and 5-2.

Sector size (cm)	Station 1	Station 2	Station 3	Station 4	Station 5
Region 1 (horiz. x vert.)	6 x 5	7.5 x 6.25	8.1 x 6.7	8.7 x 7.2	9.3 x 7.7
Region 2 (horiz. x vert.)	12 x 10	15 x 12.5	16.2 x 13.5	17.4 x 14.5	18.6 x 15.4
Region 3 (horiz. x vert.)	24 x 20	30 x 25	32.4 x 27	34.8 x 29	37.2 x 30.9
Region 4 (horiz. x vert.)	48 x 40	60 x 50	64.8 x 54	69.6 x 58	74.4 x 61.8

Table 5-1

The FIP uses only the sector information of muon stations 2-5. Each FIP-board processes the sector information of one quadrant and within the same region of muon stations 2-5. Hence, 4 FIP-boards are required per quadrant and 8 per half-station and 16 in total. All these bards will be accommodated within one VME-crate per half-station, together wit the boards for the DMP and the related controllers.

Number of Logical channels / sector	Station 1	Station 2	Station 3	Station 4	Station 5
Region 1	6 x 2	12 + 2	12 + 2	3 x 2	3 x 2
Region 2	6 x 2	12 + 2	12 +2	3 + 2	3 + 2
Region 3	6 x 2	12 + 2	12 + 2	3 + 2	3 + 2
Region 4	6 x 2	12 + 2	12 + 2	3 + 2	3 + 2

Table 5-2

5.2 Trigger Algorithm and Detailed Muon Processor

The starting point of the algorithm is a pad hit in station 3. From the pad position in M3, the position of the track is extrapolated to stations 2, 4 and 5, assuming a straight line coming from the interaction point. Next, a hit is searched for within a field of interest (FOI) in these stations. The size of the FOIs for default background is summarized in Table 5-3 and 5-4. Optimization studies have shown that the FOIs are the same for the 4 regions within a station [1]. However, they depend on the minimum bias (MB) retention aimed for. A particle is considered as a muon if a track in stations2-5 can be formed. Using the hits in stations 2 and 3 the track is then extrapolated to station 1 and the nearest hit is searched for within a FOI. Finally, the transverse momentum is calculated/read from a look-up-table (LUT) using the pads in stations 1 and 2.

FOI in x (pad units)	Station 1	Station 2	Station 3	Station 4	Station 5
1% MB-retention	±1.5	±2.5	-	±1.0	±1.0
2% MB-retention	±2.5	±3.5	-	±1.0	±2.0

Table 5-3

FOI in y (pad units)	Station 1	Station 2	Station 3	Station 4	Station 5
1% MB-retention	±0.5	±0.5	-	±0.5	±0.5
2% MB-retention	±0.5	±0.5	-	±0.5	±0.5

Table 5-4

The trigger performance for $B\rightarrow \mu X$ events with default background is shown in Table 5-5. The efficiency is given for prompt muons, normalized to the number of $B\rightarrow \mu X$ events in 4π.

	P_T cut	$B\rightarrow \mu X$ Efficiency	Purity
1% MB-retention	1.3 GeV/c	9.2±0.2	91%
2% MB-retention	0.9 GeV/c	12.0±0.2	89%

Table 5-5

6 Background

A new background estimation using the GCALOR package with low thresholds has been done [6]. The maximal hit densities per cm^2 and interaction for each region are summarized in Table 5-1. Based on this table and assuming

- a peak luminosity of 5×10^{32} /cm^2/s,
- a safety factor of 2.5 for stations 2-5 and 2 for station 1,
- a scaling factor of 2 resulting from a comparison between GCALOR and MARS (which predicts in average rates which are a factor two larger),

the numbers summarized in Table 5-2 are obtained. The values in Table 5-2 are used for the rate calculation per physical channel as given in Table 2-5.

Hit Densities (dN/dA /cm^2/int)	Station 1	Station 2	Station 3	Station 4	Station 5
Region 1	7.0E-03	2.5E-04	2.0E-04	1.2E-04	1.2E-04
Region 2	4.0E-03	1.2E-04	2.0E-05	1.0E-05	8.0E-06
Region 3	1.0E-03	4.0E-05	4.0E-06	3.0E-06	3.0E-06
Region 4	2.5E-04	5.0E-06	1.0E-06	7.5E-07	3.0E-06

Table 6-1

Hit Densities (HLCASF,kHz/cm^2)	Station 1	Station 2	Station 3	Station 4	Station 5
Region 1	560	50	40	24	24
Region 2	320	24	4	2	1.6
Region 3	80	8	0.8	0.6	0.6
Region 4	20	1	0.2	0.15	0.6

Table 6-2

An additional safety factor two has been applied to the chambers behind the calorimeters in order to determine their rate capability, summarized in Table 5-3. This is motivated by the fact that particles cross these chambers often at large angles and release significantly more energy than particles crossing the chambers perpendicularly.

Hit Densities (rate cap.) (kHz/cm^2)	Station 1	Station 2	Station 3	Station 4	Station 5
Region 1	560.0	100	80	48	48
Region 2	320.0	48	8.0	4	3.2
Region 3	80.0	16	1.6	1.2	1.2
Region 4	20.0	2	0.4	0.3	1.2

Table 6-3

In order to estimate the effect of background hits to the muon system, it is important to note that some of the hits are of very low energy and affect only one layer, while other particles are able to penetrate both layers. The fraction of single and double hits per region is summarized in Table 5-4.

Hit Parameterisation (Number)	Station 1	Station 2	Station 3	Station 4	Station 5
Region 1(single)	0.45	0.80	0.70	0.83	0.80
Region 1(double)	0.55	0.20	0.30	0.17	0.20
Region 2 (single)	0.29	0.39	0.54	0.55	0.58
Region 2 (double)	0.71	0.61	0.46	0.45	0.42
Region 3 (single)	0.28	0.34	0.38	0.43	0.55
Region 3 (double)	0.72	0.66	0.62	0.57	0.45
Region 4 (single)	0.28	0.43	0.30	0.38	0.67
Region 4 (double)	0.72	0.57	0.70	0.62	0.33
Average (single)	0.33	0.49	0.48	0.55	0.65
Average (double)	0.68	0.51	0.52	0.45	0.35

Table 6-4

7 System Performance

A detailed study of the system performance requires obviously a full simulation of the muon system. However, based on the following ingredients, an estimate of the efficiency for muons from $B \rightarrow \mu X$ events with a realistic muon system can be obtained:

- The double gap chamber efficiency ε_{Ch} (99% have been assumed in Table 6-1);
- The efficiency ε_{occ} due to the occupancy for a given pulse width (50 ns have been assumed as pulse width in Table 6-1);
- The fraction of single f_{single} and double f_{double} hits from the background estimation (cf. Table 5-4).

The efficiency for each region can be calculated then as follows:

$$\varepsilon = (1-(1-\varepsilon_{Ch})^2) \times [(1-(1-\varepsilon_{occ})^2)\times f_{single} + \varepsilon_{occ} \times f_{double}]$$

For regions 1 and 2 of stations 2 and 3 an additional factor enters due to the logical AND made in the trigger between x- and y-strips, which are from independent FE-channels.

Table 6-1 shows the efficiencies and their product together with the total system efficiency, giving each region its proper weight as determined from the muon efficiency in $B\rightarrow\mu X$ events from the full system simulation.

Efficiency	Station 1	Station 2	Station 3	Station 4	Station 5	Product	Fraction $B \rightarrow \mu X$ ev.
Region 1	0.984	0.979	0.983	0.998	0.997	0.943	0.161
Region 2	0.976	0.967	0.993	0.998	0.999	0.934	0.233
Region 3	0.976	0.993	0.999	0.999	0.999	0.966	0.293
Region 4	0.976	0.997	0.999	0.999	0.998	0.970	0.313
Overall						**0.956**	1.000

Table 7-1

Figures 6-1 and 6-2 show the overall efficiency as function of the chamber efficiency for single and double layers, and the efficiency as function of the pulse width of the ASD-chip.

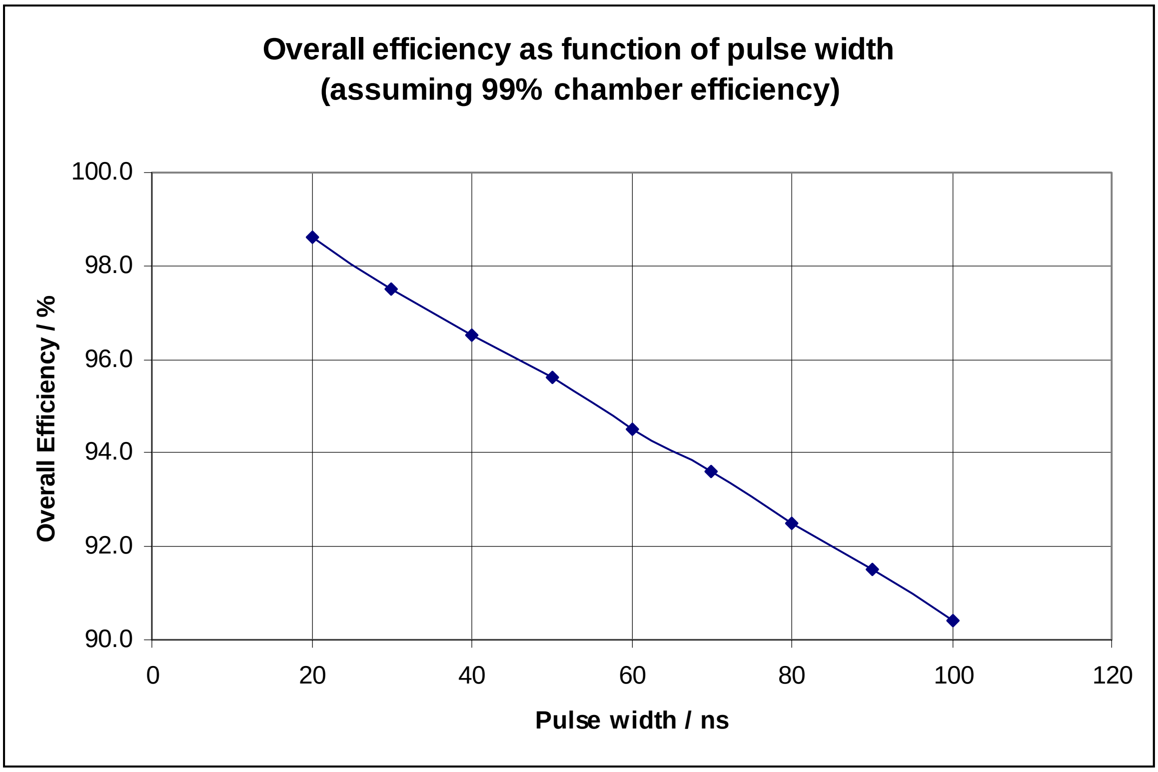

Figure 7-1

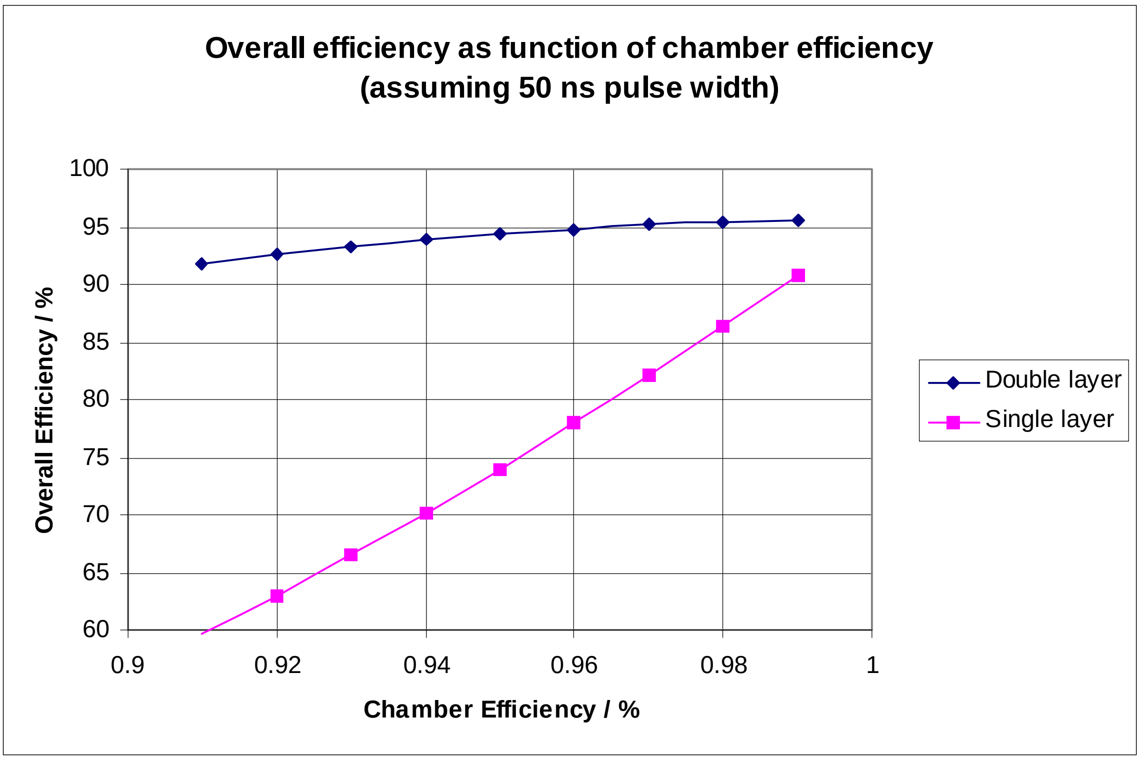

Figure 7-2

8 Reference

[1] LHCb Technical proposal, CERN/LHCC 98-4, LHCC/P4, 20 February 1998

[2] Muon System Optimization, P. Colrain and B.Schmidt, LHCb-Muon-2000-16 (LHCb 2000-016)

[3] LHCb Magnet Technical Design Report, CERN/LHCC/2000-007, LHCb TDR 1

[4] LHCb Hadron Trigger and HCAL cell size and length optimization, LHCb 1999-035

[5] Proposal for the RPC muon detector of LHCb, M.Adinolfi et al., (LHCb 2000-053)

[6] Performance study of MWPC prototypes with the ASDQ chip, A.Kachtchouk et al., (LHCb 2000-062)

[7] MWPC parameters, W.Riegler, (LHCb 2000-060)

[8] Muon system parametrised background, A.Tsaregorodtsev, (LHCb 2000-011)

[9] Muon detector FE-Architecture, A. Lai et al., (LHCb 2000-017)

[10] The Level 0 Muon Processor, E.Aslanides et at., (LHCb 1999-008)