A symmetrical Single Cathode Read Out and Symmetrical Double Cathode Read Out MWPCs for the LHCb muon system

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Abstract

We present results of measurements made with a four gap MWPC prototype for the inner region of the LHCb muon station one (M1R1). The prototype consists of two double gaps with different designs. The first double gap has asymmetric distances between the wire and the cathode planes. The second double gap has cathode pad read out on both sides of each gap. We measured efficiencies, cross talk rates and cluster sizes in the T11 beam line with 3.6 GeV/c pions. The properties of the chamber are well understood. The two designs are promising candidates for M1R1.
1 Introduction

The requirements for a multi wire proportional chamber (MWPC) in the innermost region of the LHCb muon station one (M1R1) are the following [1, 2]:

**Rate Capability:** The detector should stand a rate of up to 460 kHz/cm².

**Cluster Size:** Only due to geometrical effects (depending on the average crossing angle of the muons in the detector) one expects a geometric cluster size of 1.07 in M1R1. To minimise any additional deterioration of the intrinsic detector resolution, cross talk between read out channels should be minimised such that it does not add significantly to the total cluster size.

**Ageing:** The accumulated charge should not be much larger than 1 C/cm in ten years of LHC operation.

**Radiation Length:** The radiation length of a double gap should be around 0.15\(X_0\).

The LHCb MWPC design with an anode-cathode distance of 2.5 mm would fulfil the rate requirement but lead to a cluster size of about 1.3 and an accumulated charge of 2.4 C/cm (3.2 C/cm) for 1.5 mm (2 mm) wire pitch\(^1\). The cluster size can be reduced if the anode wires are placed asymmetrically between the two cathodes [3, 4]. The larger induced charge on the cathode (see Fig. 1) allows to operate the chamber at a factor two lower gas gain, which reduces the accumulated charge to about 1.2 C/cm (1.6 C/cm) for 1.5 mm (2 mm) wire pitch. The mean signal height is reduced by 20% [4]. A reduction of the gas gain by a factor of two is also achieved if cathode pads are read out on both sides of a symmetric gap with distances of 2.5 mm between the anode wire layer and the two cathodes. This provides a signal that is twice as large as with only one pad read out on one side of the gap at the same gas gain. Throughout this article we will use the following abbreviations for the different detector designs:

**Sym.SCRO:** Symmetric Single Cathode Read Out. The wires are in the center of a 5 mm gap and cathode pads are read out on one side of the gap.

**As.SCRO:** Asymmetric Single Cathode Read Out. The wires are placed asymmetrically between the two cathodes in a 5 mm gap and cathode pads are read out on one side of the gap.

**Sym.DCRO:** Symmetric Double Cathode Read Out. The wires are in the center of a 5 mm gap and cathode pads are read out on both sides of the gap.

The active area of the detectors in M1R1 is 24x20 cm². The read out pad dimensions are 1x2.5 cm², leading to 24x8=192 read out pads per layer (Fig. 2).

We designed and built a four-gap chamber that uses the two discussed designs: one As.SCRO double gap and one Sym.DCRO double gap. The next sections will give details on the design and test results.

2 L0 Trigger Performance, Definition of Plateau Length

Semileptonic \(B \rightarrow \mu\) decays are used in LHCb for the \(B\)-tagging of events. The dependency of the \((B \rightarrow \mu)\)-trigger-efficiency on the detection efficiency in M1 has been discussed in [5], where it has been shown that the relative \((B \rightarrow \mu)\)-trigger-efficiency is above 95 % for detection efficiencies larger than 60 % (85 %) for a single (double) layer in M1. The relative \((B \rightarrow \mu)\)-trigger-efficiency as a function of the M1 detection efficiency is in first approximation

\[^{1}\text{Assuming an average luminosity of } 2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}\text{ over ten LHCb years, one calculates a particle rate of } r = 184 \text{ kHz/cm}^2 \text{ in M1R1 [1]}. \text{ From this value we get an accumulated charge } q \text{ of } 2.4 \text{ C/cm (3.2 C/cm), which is calculated as } q = r \cdot \langle q \rangle \cdot t \cdot p, \text{ where } \langle q \rangle = 0.88 \text{ pC is the average charge per hit, } t = 10^8 \text{ s is the experiment running time (10 LHC years), and } p = 1.5 \text{ mm (p = 2.0 mm) is the wire pitch.} \]
Figure 1: a) The plot shows the induced charge distribution for a Sym.SCRO and an As.SCRO gap at the same gas gain. b) A plot of the integrals of the curves in a). They give the total induced charge as a function of the distance from the position of the wire with the avalanche. A negative distance means that the wire is outside the pad area on which the charge is induced. The data is obtained using GARFIELD [7]. 'near' refers to the cathode with smaller distance to the wire plane and 'far' to the cathode with the larger distance to the wire plane.
independent of the L0-$\mu$-trigger band width. Cluster size and chamber inefficiency effects on the L0 trigger performance are investigated in [6]. It turns out that at 85\% double layer detection efficiency in M1 and a cluster size of 1.0 the relative ($B \rightarrow \mu$)-trigger-efficiency is 0.95. The same value is achieved by a double layer in M1 with 100\% detection efficiency and a cluster size of 1.4. Following those considerations we define the operational plateau for a double layer in M1 to be the region that results in a relative ($B \rightarrow \mu$)-trigger-efficiency above 95\%. The lower limit of the operational plateau is then given by an efficiency above 85\% and the upper limit is given by a cluster size of 1.4. The robustness of this definition against varying background conditions has still to be studied. However, we consider it a convenient definition for the results presented in this note.

3 Design of the Prototype Chamber

A prototype for the innermost region was built during spring and summer 2002. The panels were made of a honeycomb structure sandwiched between the single and double sided printed circuit boards (PCBs). The honeycomb is used to reduce the radiation length of the device with respect to foam. The PCBs with the plain cathode plane for the As.SCRO gaps are one-sided while the PCBs with the read out pads are two-sided with the pad structure on one side and the read out traces to the connectors on the other. The pad structure is shown on Fig. 2. The wires have 1.5 mm pitch and are segmented into eight wire pads of 20 wires each. The wire pads have an area of about $3 \times 22 = 66 \text{ cm}^2$.

Fig. 3 shows a cross section of the chamber. The chamber consists of four gaps and the gaps are electrically connected in pairs before the read out chip giving two independent double gaps. The first double gap uses the As.SCRO design: The gap width is the standard 5 mm and the wires are on positive high voltage. One cathode plane is segmented into the 192 read out pads, the other cathode plane has no read out pads but is segmented into four parts in order to localise possible sparks. It is set on a negative high voltage. The wire plane is placed at a distance of 1.25 mm to the cathode plane with the read out pads and 3.75 mm to the other cathode plane. The potentials of the wire plane and of the cathode at 3.75 mm distance have the same absolute value but opposite sign, which results in a symmetric electric field configuration in the gas gap (Fig. 4). A picture of an opened As.SCRO gap is shown on Fig. 6. The read out scheme is plotted schematically in Fig. 5.

The second double gap uses the Sym.DCRO design (Fig. 7). A schematic image of the read out scheme for a single Sym.DCRO gap is shown in Fig. 5. The current from the two cathode pads is returned to the detector ground and the anode wire. The Sym.DCRO design is an interesting alternative also for other regions of the LHCb muon system. The advantages are the reduced high voltage in the gaps leading to a point of operation at a reduced accumulated charge.

The Chamber was closed with two different O-rings. The thinner ones for the Sym.DCRO double gaps were made of natural rubber [8] while the O-rings for the As.SCRO double gaps were made of 5 mm diameter NBR50 [9]. The final choice on the O-ring material has still to be made.

The two As.SCRO gaps are named A1 and A2 while the two Sym.DCRO gaps are called S1 and S2. The outer gaps have the number 1, the inner gaps are numbered 2.

4 Dark Currents

Until July problems with dark currents were observed. The measured dark currents had values of $\approx 500 \text{ nA}$ at 3.4 kV (S1,S2) which would be unacceptable for the final design. The dark currents were not stable in time and the problems were only present with normal air, not
Figure 2: Layout of the cathode planes of the tested prototype. The O-ring, the ten spacers, the loading resistors for the wires (bottom edge of the chamber) and the capacitors that connect them to ground (top edge) are visible. The wires are running vertically.

Figure 3: Cross sections of the chamber. Left: The wire fixation bar where the loading resistors (100 KΩ) are situated. Right: The opposite wire fixation bar with the capacitors that connect the wires to ground (680 pF). The wires are glued and soldered to the wire fixation bars. The read out connectors are placed on the edges of the panels.
Figure 4: Some electron drift lines in the gap of an asymmetric MWPC (top) and the total value of the electric field across the gap towards a wire (bottom) simulated with GARFIELD.

**Asymmetric Single Cathode RO scheme**

**Symmetric Double Cathode RO scheme**

Figure 5: Read out schemes for the As.SCRO geometry (top) and for the Sym.DCRO geometry (bottom).
Figure 6: A gap with As.SCRO design. Left: the panel with the cathode pads and the wire plane at 1.25 mm distance. Right: the panel with the second cathode plane.

Figure 7: A gap with Sym.DCRO design. Left: the panel with the cathode pads and the wire plane at 2.5 mm distance. Right: the panel with the second cathode pad plane.
when the chamber was flushed with dry gas in a plastic box. This indicated that the device was vulnerable to humidity. Covering the HV resistors and capacitors with varnish minimised the problems.

The final dark currents at voltages close to the plateau ends for the two double gaps were:

<table>
<thead>
<tr>
<th>Double Gap</th>
<th>HV (kV)</th>
<th>dark current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sym.DCRO</td>
<td>+3.3</td>
<td>10 nA</td>
</tr>
<tr>
<td>As.SCRO (wires)</td>
<td>+2.2</td>
<td>80+20=100 nA</td>
</tr>
<tr>
<td>As.SCRO (cathodes)</td>
<td>-2.2</td>
<td>200-500 nA</td>
</tr>
</tbody>
</table>

The remaining cathode dark current for the As.SCRO gap is a linear resistive current and is caused by the small cathode-ground distance. Glue entering the active area during the gluing of the wire fixation bars caused some problems in two of the gaps. Especially in the corners glue under the nose of the wire fixation bars leads to a high electric field strength and to sparking in those regions. In the gap S1 some wires had to be removed (about 18 % of the active area), the gap A1 trips faster and has a larger dark current.

A 200 µm guardwire was used. With previous chambers we measured a gas gain increase in the region of the guard wire (at the chamber border). Increasing the guard wire diameter lowers the gas gain in the border region.

5 Simulation Results

In this section we present results on simulations on the topic of cluster sizes. We simulated an As.SCRO and a Sym.SCRO double gap with straight tracks like under test beam conditions and tracks with the expected angular distribution in the bending plane of muons from B-events in M1R1. In the direction of the bending of the muons the pads in M1R1 have 1 cm periodicity. The angular distribution alone gives a geometric cluster size of 1.07, which will not be present at beam tests if the beam is perfectly perpendicular to the chamber. The capacitive X-talk rate is varied from 0 % to 6 % by adding that percentage of the signal height on each pad to its neighbor pads.

The simulations show that at half the gas gain the mean signal height is 20 % smaller for the As.SCRO double gap as compared to a Sym.SCRO double gap. Simulated efficiencies and cluster sizes for an As.SCRO double gap at 2 kV and for straight tracks are shown in Fig. 8. We find 99.5 % efficiency at a threshold of ≈17 % of the mean signal (truncated mean). The following table gives the values for the cluster sizes obtained with the simulation for this threshold. In brackets are the values for the simulation of a Sym.SCRO double gap.

<table>
<thead>
<tr>
<th>angular distr.</th>
<th>HV [kV]</th>
<th>CLS at 2 % capacitive X-talk</th>
<th>CLS at 6 % capacitive X-talk</th>
</tr>
</thead>
<tbody>
<tr>
<td>straight tracks</td>
<td>2 (3.15)</td>
<td>1.19 (1.31)</td>
<td>1.37 (1.40)</td>
</tr>
<tr>
<td></td>
<td>2 (3.15)</td>
<td>1.18 (1.25)</td>
<td>1.34 (1.35)</td>
</tr>
</tbody>
</table>

The cluster size at the mentioned threshold and capacitive X-talk rate is around 1.2 for the As.SCRO double gap. For the Sym.SCRO double gap we find a cluster size around 1.3. The improvement in cluster size is only 9 %.

6 Test Beam Setup

The chamber was tested in the T11 test beam facility at CERN in August and September 2002. Two 16-channel front end ASDQ++ boards were mounted on the chamber. All tests

2) In terms of cluster size the Sym.SCRO and Sym.DCRO designs are similar.
Figure 8: Efficiencies and cluster sizes at different thresholds simulated with GARFIELD for the standard gas mixture, three 1 cm pads, and perpendicular tracks that are randomly distributed. 
a) As.SCRO double gap, HV = ±2 kV, b) Sym.SCRO double gap, HV = +3.15 kV.
Beamline Setup

![Beamline Setup Diagram]

Figure 9: The setup in T11.

Figure 10: The different beam positions on the chamber and the different positions of the read out electronics. The larger rectangle marks the position where the cluster size studies and the horizontal scan were performed.
have been done with the Ar/CO$_2$/CF$_4$ (40/40/20) gas mixture. Most measurements were done with three trigger scintillators: S1+S2 are the large scintillators and S3 is a small finger scintillator used to scan small areas of the chamber. Only for cross talk studies S3 was taken out of the trigger. The setup in the T11 experimental zone is shown in Fig. 9. The beam consisted mainly of 3.6 GeV pions. The beam focus was 10 m behind the nominal focus which lies 2.5 m behind the last magnet, i.e. just about where the first scintillator S1 was situated. The beam particle rate (as seen in S1 or S2) was between 150 and 180 kHz.

7 Test Beam Results

The beam tests had the main goals to investigate

1. the usability of the As.SCRO double gap design for the LHCb muon station M1R1. The probability for trips and/or sparks might be increased by the small anode-cathode distance in the As.SCRO double gap design.
2. the usability of the Sym.DCRO design for M1R1 but also for other detector regions.

We tested different pads of the chamber which were read out by front end electronics at different positions on the chamber (Fig. 10).

7.1 Double Gap Efficiencies and Time Resolution

The measured efficiencies shown in this section are for single pads. The threshold applied on the ASDQ++ chip was 6.5 fC. Efficiencies and time resolutions for time windows of 15 ns, 20 ns and 25 ns on read out position 2 are shown in Fig. 11. 85 % efficiency in a 20 ns time window are reached at 1.85 kV (2.7 kV) by the As.SCRO (Sym.DCRO) double gaps. 99.5 % efficiency are reached at 1.95 kV (2.85 kV). The working points are 2 kV (2.9 kV). The time resolution is similar for both designs: At 1.85 kV (2.7 kV) it is around 6 ns (r.m.s.), at 1.95 kV (2.85 kV) it is around 4 ns and at the working points it is around 3.75 ns. At higher voltages it is going below 3 ns. Both double gaps show a robust behaviour. The maximum high voltages are 2.3 kV (3.35 kV) for the As.SCRO (Sym.DCRO) double gap.

7.2 ADC spectra

ADC spectra are shown in Fig. 12. The values of the most probable signal charge versus the high voltage for the As.SCRO (left) and the Sym.DCRO (right) double gaps together with an exponential fit are shown in Fig. 13. To double the signal height we need to increment the high voltage by 150 V ± 20 V (As.SCRO) and 135 V ± 20 V (Sym.DCRO).

7.3 Uniformity

We measured eight different pads on four different read out positions. Fig. 14 shows the histogrammed voltages at which the double gaps reach 95 % efficiency in a 20 ns time window on a single pad. The mean values are 1935 V (2795 V) and the r.m.s. are 20.6 V (22.6 V) for the As.SCRO (Sym.DCRO) double gaps. This corresponds to a gain variation around 15 % for both designs which is well within the specifications mentioned in the technical design report [1].

7.4 Threshold scan

Plateau curves for three different thresholds at read out position 5 are shown in Fig. 15. The difference between 6.5 and 8.9 fC threshold is not large, while a threshold of 11 fC reduces the efficiencies and cuts the plateau length quite a lot.
Figure 11: Single pad efficiencies in 15, 20, 25 ns time windows and time resolutions for double gaps. a) As.SCRO, b) Sym.DCRO.
Figure 12: ADC spectra for the As.SCRO double gap at 1.85 kV (left) and for the Sym.DCRO double gap at 2.8 kV (right) together with the pedestals (offscale).

Figure 13: The values of the most probable signal charge versus the high voltage for the As.SCRO (left) and the Sym.DCRO (right) double gaps.
Figure 14: Histograms of the high voltage value at which the double gaps reach 95% efficiency. a) As.SCRO double gap, b) Sym.DCRO double gap.

Figure 15: Efficiency curves for three different thresholds in a 20 ns time window. 240 mV correspond to 6.5 fC, 300 mV to 8.9 fC and 350 mV to 11 fC. The front end electronics is mounted on position 5. Left: As.SCRO. Right: Sym.DCRO.
7.5 Cross Talk and Cluster Size

In this section we investigate cross talk rates and cluster sizes. Directly induced and capacitive cross talk between the cathode pads have implications for the LHCb L0 muon trigger performance. In the following results for cross talk to one or more adjacent pads and cluster sizes are presented.

7.5.1 Cross Talk

We investigated in- and out-of-time cross talk. It was calculated looking at hits in all pads in a 50 ns time window. We focused the beam on the center of a cathode pad using the small finger scintillator S3 and one horizontal hodoscope strip. However, due to the small pad sizes some direct cross talk will still be present.

An example of cross talk hits at the working point of the As.SCRO (Sym.DCRO) double gap is shown in Fig. 17 (Fig. 18). The front end board is on position 2 and the positions of the pads connected to the different read out channels are shown in Fig. 16. The beam selection is on channel 3 (14). Channels 2 (13) and 4 (15) are neighbours along the short edges of the pads and are capacitatively coupled to channel 3 (14) via the read out traces and the wires. Channel 7 (10) is the neighbour pad sharing the long edge of the pads and channels 6 (9) and 8 (11) are neighbours only at the corners.

We investigated the cross talk at read out position 2 in two directions:

- vertical to the read out traces and wires along the long edges of the cathode pads (‘transverse cross talk’)
- and parallel to the read out traces and wires along the short edges of the cathode pads (‘longitudinal cross talk’).

The threshold was 6.5 fC. The average cross talk rates for the two different directions are
Figure 17: The time distributions for hits in the As.SCRO double gap in six channels around the beam selection (channel three) in a 50 ns time window.
Figure 18: The time distributions for hits in the Sym.DCRO double gap in six channels around the beam selection (channel 14) in a 50 ns time window.
shown in Fig. 19. Some numbers for the As.SCRO and the Sym.SCRO chamber are given now:

<table>
<thead>
<tr>
<th>HV As.SCRO</th>
<th>Efficiency (in 20ns)</th>
<th>X-talk transverse</th>
<th>X-talk longitudinal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.95 kV</td>
<td>96.0 %</td>
<td>(0.7±0.3) %</td>
<td>(4.7±0.7) %</td>
</tr>
<tr>
<td>2.05 kV</td>
<td>98.4 %</td>
<td>(3.5±0.6) %</td>
<td>(5.3±0.7) %</td>
</tr>
<tr>
<td>2.15 kV</td>
<td>98.7 %</td>
<td>(11.3±1.1) %</td>
<td>(14.3±1.1) %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HV Double</th>
<th>Efficiency (in 20ns)</th>
<th>X-talk transverse</th>
<th>X-talk longitudinal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cathode RO</td>
<td>2.85 kV</td>
<td>97.0 %</td>
<td>(2.5±0.5) %</td>
</tr>
<tr>
<td></td>
<td>2.95 kV</td>
<td>98.9 %</td>
<td>(6.4±1.0) %</td>
</tr>
<tr>
<td></td>
<td>3.05 kV</td>
<td>99.1 %</td>
<td>(12.7±1.4) %</td>
</tr>
<tr>
<td></td>
<td>97.0 %</td>
<td>(2.5±0.5) %</td>
<td>(4.5±0.6) %</td>
</tr>
<tr>
<td></td>
<td>98.9 %</td>
<td>(6.4±1.0) %</td>
<td>(6.4±1.0) %</td>
</tr>
<tr>
<td></td>
<td>99.1 %</td>
<td>(12.7±1.4) %</td>
<td>(21.1±1.3) %</td>
</tr>
</tbody>
</table>

### 7.5.2 Cluster Size

We assume that the beam of particles is evenly distributed on the small pads. We investigated the cluster size in two different ways:

- The crucial number for the M1R1 detector performance in the LHCb L0 trigger is the cluster size in the bending plane of the muons. We irradiated two pads as is shown in Fig. 20a. The cluster size is calculated only with regard to the four neighboring pads. For all events that are efficient on those four pads we count the number of pads that have a hit in 50 ns. The obtained number we can compare with the simulation results in section 5. We call it the ‘horizontal’ cluster size.

- We irradiate a larger area as shown in Fig. 20b. For all events that are efficient on the 16 pads we count the number of pads that have a hit in 50 ns. We call this number the ‘full’ cluster size.

The results for the two cluster sizes at different high voltages and a threshold of 8.9 fC are shown in Fig. 21. Because of the new threshold we also show an efficiency curve. The working point is now 50 V higher than with the lower threshold. The Sym.DCRO double gap contained one noisy channel. Fig. 21b shows the measured ‘full’ cluster size for this double gap as well as data that is corrected for that channel. Some numbers for the As.SCRO and for the Sym.DCRO double gaps are given now. In the case of the full cluster size for the Sym.DCRO double gap the corrected values are stated.

<table>
<thead>
<tr>
<th>HV As.SCRO</th>
<th>Efficiency (in 20ns)</th>
<th>CLS horizontal</th>
<th>CLS all</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.95 kV</td>
<td>92.2 %</td>
<td>1.10</td>
<td>1.15</td>
</tr>
<tr>
<td>2.05 kV</td>
<td>98.5 %</td>
<td>1.22</td>
<td>1.30</td>
</tr>
<tr>
<td>2.15 kV</td>
<td>98.7 %</td>
<td>1.41</td>
<td>1.58</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HV Sym.DCRO</th>
<th>Efficiency (in 20ns)</th>
<th>CLS horizontal</th>
<th>CLS all</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.85 kV</td>
<td>93.9 %</td>
<td>1.16</td>
<td>1.22</td>
</tr>
<tr>
<td>2.95 kV</td>
<td>98.6 %</td>
<td>1.27</td>
<td>1.37</td>
</tr>
<tr>
<td>3.05 kV</td>
<td>98.8 %</td>
<td>1.44</td>
<td>1.62</td>
</tr>
</tbody>
</table>

### 7.5.3 Plateau Length

Using the definition that is given in section 2, we find a plateau of around 200 V length for both designs. The plateau starts at around 1.92 kV (2.83 kV) for the As.SCRO (Sym.DCRO)
Figure 19: The cross talk results for the two directions. Left: As.SCRO double gap. Right: Sym.DCRO double gap.

Figure 20: The selected beam positions for the two different cluster size studies.
Figure 21: The Cluster Size results for the two different selections together with an efficiency curve. a) As.SCRO double gap. b) Sym.DCRO double gap. The triangles show the ‘full’ cluster size data corrected for one noisy channel.
Figure 22: Efficiency for two neighboring pads as a function of the beam position. The resolution is limited by the thickness of the scintillator S3 (2-3 mm). Left: As.SCRO double gap. Right: Sym.DCRO double gap. We used two different values for the high voltage.

Figure 23: The ‘horizontal’ cluster size during the same scan as in Fig. 22. Left: As.SCRO double gap. Right: Sym.DCRO double gap.
double gap, where we find efficiencies of around 85 % and cluster sizes around 1.1 (1.15). Towards higher voltages the plateau is limited by the increasing cluster sizes. The upper limit is around 2.15 kV (3.03 kV) for the As.SCRO (Sym.DCRO) double gap. The efficiencies at those voltages are around 98.8 %. The difference in the cluster size between the two designs is only around 5 % at the working points (2.05 kV and 2.95 kV).

7.6 Scans of the Chamber

Two scans of the chamber in the direction across the wires have been carried out. In this direction the pads are 10 mm wide. We used two front end boards and two TDCs to read out the chamber signals. The front end electronics was mounted on positions six and seven (Fig. 10). The As.SCRO double gap was set to 2.05 kV and 2.15 kV. The Sym.DCRO double gap was set to 3.0 kV and 3.15 kV. The threshold was 8.9 fC. The finite width of the small finger scintillator S3 limits the resolution on the small pad dimensions. A point-like beam would be favourable. The efficiencies over the pads are shown in Fig. 22. Fig. 23 shows the ‘horizontal’ cluster size measured during the scan. The slight asymmetry in this scan indicates that the beam might not have been perfectly perpendicular to the chamber.

7.7 Usability for M1R1

With regard to the usability of the designs for M1R1 the four requirements to be met (section 1) concerned the rate capability, the cluster size in the bending plane of the muons, ageing issues and radiation length.

- The maximum expected rate of 460 kHz/cm$^2$ poses no problem to both designs. Space charge effects are negligible. We expect a 5 V/cm drop of the field due to space charge fields at a gain of $10^5$ and even less at half the gain.
- The horizontal cluster sizes are around 1.22 (1.27) for the As.SCRO (Sym.DCRO) double gaps at the working points of 2.05 kV (2.95 kV). Using the definition from section 2, we find an operational plateau of around 200 V length for both designs.
- Ageing tests have not been performed with the tested chamber. The accumulated charge will be around 1.2 C/cm for both designs in ten LHC years. Only a global test over several LHCb years would allow significant statements about ageing issues. For MWPCs in general the achievements in global ageing tests are 0.3 C/cm (CMS EMU) and 0.25 C/cm (LHCb). This corresponds to around 2.5 LHC years in M1R1. A prolonged test should be done with the tested chamber, but it will be impossible to achieve ten LHC years in a reasonable time. However, if it could be shown that the two designs ‘survive’ 0.4 C/cm, the usability for at least 3 LHC years is ensured. In the worst case, an exchange of the chambers with the highest particle flux after 3 years is feasible.
- With the honeycomb technology the average thickness of the detectors in M1 reduces from 0.33$X_0$ to 0.15$X_0$.

Both designs are promising candidates for the use in M1R1 and would have the advantage that only one detector technology with only one gas system would be used in the muon system.

8 Summary and Conclusions

We have tested two different designs for their usability the LHCb muon station M1R1: an asymmetric MWPC (As.SCRO) and a symmetric MWPC with Sym.DCRO. Both designs were implemented in one four gap chamber. In this note we described the design, simulation and test results of the chamber. The properties of the chamber are well understood. We summarize:
Both double gaps show a very robust behaviour. No trips (sparks) were observed in the beam tests up to 2.3 kV (3.35 kV) for the As.SCRO (Sym.DCRO) double gap.

No instabilities due to a reduced detector ground in the fully symmetric gaps were observed, we even observed improved time distributions (no bumps).

We observed a similar performance on the ‘capacitor’ and ‘resistor’ sides of the chamber. The current return on the resistor side causes no problems.

We find cluster sizes of 1.22 (1.27) for the As.SCRO (Sym.DCRO) double gaps at the working points of 2.05 kV (2.95 kV).

We observe a usable plateau of around 200 V length.

The uniformity is within specifications. The points at which the double gaps reach 95% efficiency are distributed with an r.m.s. of about 20 V, which corresponds to a gas gain variation of 15%.

It has been shown that both designs are promising candidates for M1R1. For a final decision on the usability of the two tested technologies a prolonged ageing test should be done. A test up to the accumulated charge of 1.2 C/cm expected in ten LHCb years can not be done in a reasonable time. However, if it can be shown that the designs stand an accumulated charge of 0.4 C/cm, the technologies can be used because an exchange of the chambers after a few years is feasible. The Sym.DCRO design is also an alternative for other regions of the LHCb muon system to decrease the accumulated charges.

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References


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