Large Hadron Collider Project

LHC Project Report 1175

ALICE Injected Beam Accidents

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Abstract

The ALICE (point 2) interaction region is sensitive to beam orbit errors arising from magnet setting errors on injection. In this report, beam accident scenarios under injection for ALICE are described, focusing on ultra- fast error injection scenarios for the interaction straight correctors and dipoles. Beam 1 and beam 2 accident scenarios are considered, where the errors can lead to beam orbits striking the ALICE vacuum chamber or elements of the machine. The required thresholds for magnet current interlocks are calculated to avoid machine and detector risk.

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1 Introduction, simulation procedure and scenarios

The high beam intensities of the LHC require control of beam losses, and a detailed consideration of possible beam accident scenarios. In particular beam losses in the experimental insertion could result in significant damage to the detector systems. Of particular concern are ultra-fast losses, which arise in less than 1 turn of the machine, and should be contrasted to circulating beam failures, which generally occur on a longer timescale. These injection turn scenarios can arise from incorrectly set magnets on injection or from faulty hardware, and require controlled injection procedures and magnet current interlocks. In this report, beam accident scenarios are considered for the ALICE interaction region on injection. The accident scenarios are ultra-fast, and correspond to the potential loss of a pilot bunch of 5×10^9 protons on the turn of injection due to an error in the setting of a magnet. Magnet failures will be considered in future work. The techniques used and conclusions drawn for point 2 are also applicable to point 8 and the machine protection of LHCb, which will be contained in a separate report.

The ALICE accident scenarios are dependent on the geometrical aperture in the interaction region, which is composed of the vacuum chamber and the machine element apertures. The ALICE interaction region contains a central region (CS) [1], the main component of which is a 4m beryllium tube. The central section is connected on the upstream side (towards IP1) to the RB24 section, and on the downstream side (towards IP3) with the RB26 section, consisting of conical tubes up to 450 mm in diameter. The beam pipe sections provide the aperture restriction in this region. The aperture model used for this work is shown in figure 1, where the solid line shows the vacuum chamber and the stars show the aperture restrictions from magnetic elements (both are plotted as a cross-check of the aperture model). The aperture model is generated from the ALICE interface specification note [1], and the beam line element apertures are taken from the LHC optics [2]. Figure 2 shows the magnets in the interaction region relevant to this study. The final triplet quadrupoles Q1 around IP2, MQXA.1L2 and MQXA.1R2, provide an aperture restriction dependent on the orientation of the beam screen. These magnets have a beam screen in the H orientation, with a circular aperture of 48mm in the vertical plane and a flat aperture of 38mm in the horizontal plane [3]. This smaller flat aperture will impact the computation of horizontal orbit distortion and beam loss.

The magnet setting errors can occur when the corrector coils attached to the low-β quadrupole Q1, MCBXH and MCBXV, are incorrectly set on injection.These orbit correctors play a role in setting the beam crossing angle and parallel separation on injection, with ALICE having a vertical crossing beam crossing angle and a horizontal beam separation for injection. The injection optics horizontal and vertical orbit bumps across ALICE for beam 1 are shown in figure 3 and the hardware parameters and angles on injection are shown in table 1. The possible orbit excursions when these coils are set up to their maximum field on injection will occur in the horizontal plane (MCBXH) and in the vertical plane (MCBXV).

The incorrect settings of the D1 (MBX.4L2) and D2 (MBRC.4L2) horizontal separation dipole magnets can also cause beam accident scenarios to hit elements of the interaction region. These magnets are used to separate and re-combine the beams, and cause the transition from separate beam pipes to a shared beam pipe. They are both 9.45m long and are superconducting, with a single set of coils in the cryostat (in contrast to the magnets in points 1 and 5, where D1 is normal conducting). The bend angles are -0.001533 rad for D1 and +0.001533 rad for D2, for beam 1, and the opposite for beam 2. The role of D2 is to send the beam towards the centre of the ring, and D1 provides

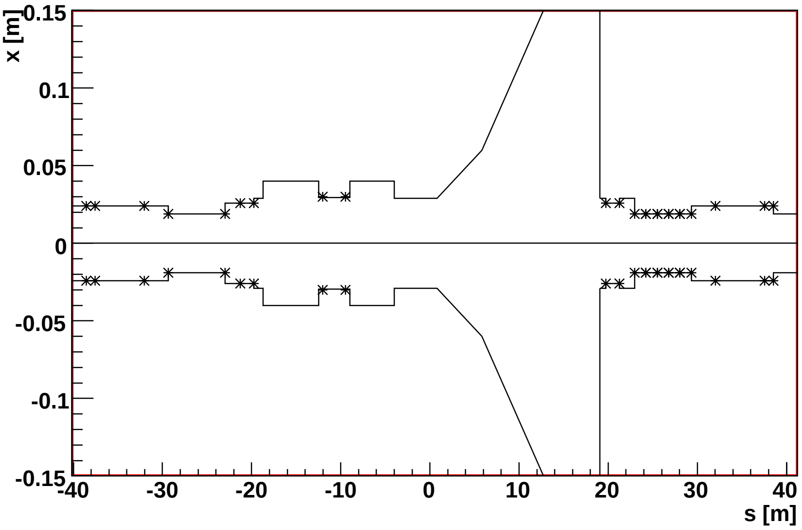

Figure 1: The beampipe template used for the ALICE aperture restrictions. The solid line shows the vacuum chamber, and the stars show dipole and quadrupole apertures.

an opposite kick towards the outside of the ring. The maximum bend angle is 0.02383896 rad for the injected beam at maximum magnet current.

Coil name	Length [m]	Angle [μrad]
MCBXH	0.45	1011
MCBXV	0.48	1042

Table 1: The lengths and maximum bend angles at 450 GeV for the H and V corrector coils in MCBX in Q1 [5].

The simulations are made for LHC injection optics version 6.5, with MADX [4], and are made for both beam 1 and beam 2. The method of orbit analysis follows [5], where the orbit error from the incorrectly set magnet is modelled by the addition to the lattice of a virtual corrector close to the wrongly set magnet. The wrongly set magnet is then kept at the nominal strength. This method requires the addition of two further virtual corrections, downstream of the error location, which correct the orbit distortion back to the nominal orbit. This ensures the optics for the rest of the machine are undisturbed, and the orbit distortion from the error is confined to the region close to the error. The justification is that the machine orbit correction will correct the orbit deviation, and only local deviations are relevant to interaction region accident scenarios. In this work, the location of the orbit correction is taken to be the correctors on Q1, around 21m from the IP, which is sufficiently downstream of the beam errors. Note the calculated beam orbit around the correcting magnets depends on their exact location. The simulation procedure is to compute the periodic optics of the ring, introduce the virtual corrector modelling the corrector error, compute the orbit distortion and correction for a single pass, injection turn (computing the orbit and Twiss parameters for a single pass machine) and calculating whether the distorted orbit exceeds the vacuum chamber or magnetic element aperture restrictions. The procedure calculates the motion of the beam centroid, which is used to calculate beam strikes, and ignores the small transverse size of the beam. Practically,

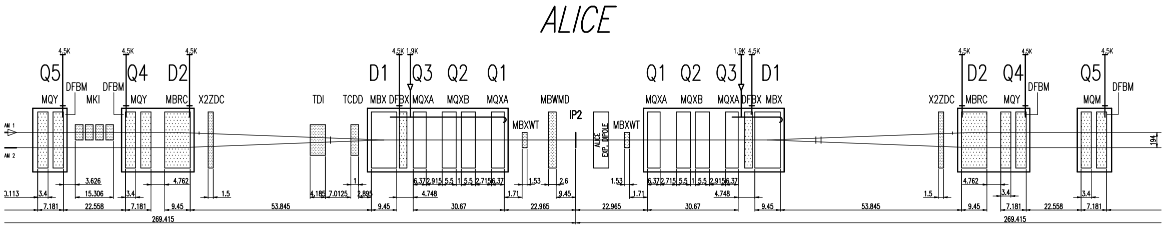

Figure 2: The LHC magnets in the interaction region around ALICE, including the final triplet quadrupoles and the separation dipoles D1 and D2.

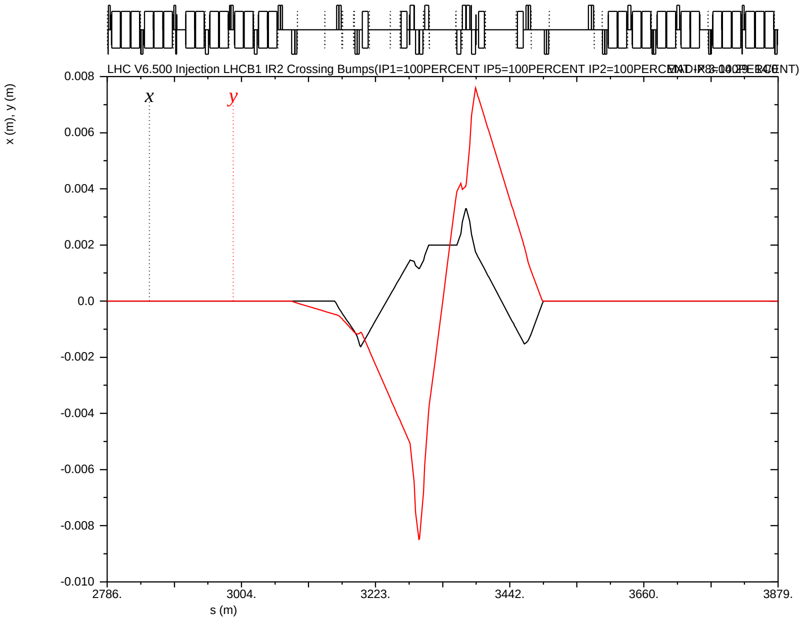

Figure 3: The injection optics horizontal and vertical orbit bumps across ALICE for beam 1 and v6.5 optics. Note the crossing angle for ALICE is in the vertical plane.

MADX is driven with a ROOT [6] macro, controlling the levels of orbit distortion and handling analysis.

The scenarios for the wrong settings of the magnets are now discussed, using MCBXH as an example. The scenarios are summarised in table 2, where the scenarios apply to all possible incorrectly set magnets. The first beam accident scenario for MCBXH is a wrong setting of nominal to injection, up to the maximum strength of the magnet, on the nominal polarity side. This corresponds to an angle of typically +37 μrad (6.4% of maximum), to an angle of +1011 μrad (100% of maximum) for MCBXH. Note the maximum angle at 450 GeV corresponds to an angle of 1011 μrad at the top energy. Scenario 2 is similar to scenario 1, with the polarity of the magnet reversed. Hence the dipole angle ranges from -37 μrad, to the maximum angle of -1011 μrad for +1011 μrad. Scenario 3 considers the case of a zero current into the magnet (the most probable scenario for machine startup), and scenario 4 presents the situation of an inverted power supply (opposite polarity). These scenarios can be applied to all the wrongly set magnets considered in this work. For example, scenario 3 for MCBXV corresponds to zero current in this particular corrector.

Scenario	Description	Angle of MCBXH
1	Nominal to + maximum	+37 μrad → +1011 μrad
2	Reverse polarity to - maximum	-37 μrad → -1011 μrad
3	Turned off	0mrad
4	Reversed polarity	-37 μrad

Table 2: The magnet scenarios, using the corrector as an example. Note scenario 1 corresponds to a corrector strength with it's nominal polarity. The nominal setting for MCBXH corresponds to +37μrad on injection.

2 Beam accident scenario results for beam 1

In this section, the wrong settings of the magnets MCBXH, MCBXV, MBX and MBRC are considered on the injection turn for beam 1 and for accident scenarios 1 to 4. These scenarios are particularly interesting as beam 1 is injected immediately upstream of ALICE.

2.1 MCBXH (beam 1)

The results for scenario 1 with beam 1 for MCBXH are shown in figure 4, where the corrector is set from the nominal injection strength to maximum strength. This corresponds to an angle of +37μrad to +1011μrad. The range of magnet settings in the cone show those which could be dangerous to the interaction region beam pipe or elements. The calculations show this dangerous region is defined by MCBXH being set to 0.32 mrad to maximum angle, which is equivalent to 31.3% to 100% of maximum current. The figure shows the beam can hit the ALICE beam pipe or the final triplet magnets MQXB.A2R2 or MQXA.1R2 (Q1 or Q2), and the beam hits the vacuum chamber hit at positive x (which corresponds to the outer wall of the vacuum chamber). Note the beam screens around IR2 are H-type in the final triplet quadrupoles, and thus provide a smaller aperture in the horizontal plane then the vertical plane. The situation for ALICE can be contrasted to a similar study performed for ATLAS [5], where a similar range of beam accidents were considered for the corrector magnet MCBX. It was found the mis-setting of the magnet resulted in pilot beam loss in the ATLAS beam pipe or the TAS collimator. There is no TAS collimator in ALICE, and hence there is possible beam loss in MBXWS or MQXA.

The scenario 2 results for MCBXH are shown in figure 5. The range of dangerous currents is -32.5% to -100% (recall the magnet is nominally set at +37μrad, so these currents correspond to a negative bending angle), which causes a vacuum chamber hit at negative x (which corresponds to the inner wall of the vacuum chamber).

Figure 6 show the resulting beam orbit distortion for scenario 3, when MCBXH is turned off for injection. The calculation shows there is no danger to the experiment from this scenario.

Finally, figure 7 show the resulting beam orbit distortion for scenario 4, when MCBXH has an inverted power supply. The calculation shows there is no danger to the experiment from this scenario.

2.2 MCBXV (beam 1)

The vertical corrector on Q1, MCBXV, is set to zero current on injection for IR2 and hence the possible scenarios are 1 (zero to maximum positive angle) and 2 (zero to

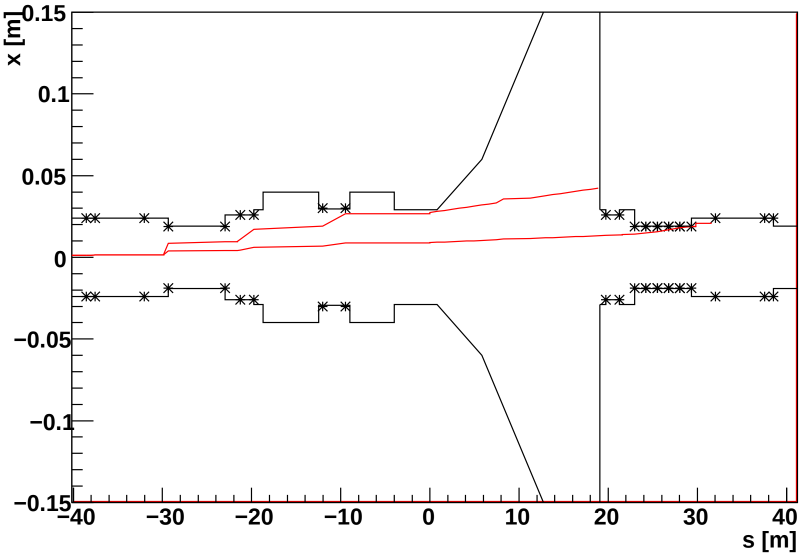

Figure 4: The range of MCBXH corrector settings which are dangerous for the ALICE beam pipe and interaction region magnets, for corrector setting scenario 1 and beam 1.

maximum negative angle).

The results for scenario 1 with beam 1 for MCBXV are shown in figure 8, where the corrector is set from zero strength to maximum strength. This corresponds to a vertical bend angle of 0μrad to +1042μrad. The range of magnet settings in the cone show those which could be dangerous to the interaction region beam pipe or elements. The calculations show this dangerous region is defined by MCBXV being set to 30.6% to 100% of maximum strength. The figure shows the beam can hit the ALICE conical beam pipe or, for a few settings of the magnet, the beam screen of Q1 (the beam trajectory can hit the element MQXA).

The scenario 2 results for MCBXV are shown in figure 9. The range of dangerous currents is -43.0% to -100%.. which causes a vacuum chamber hit at negative y. The larger asymmetry between the scenarios for MCBXV than for MCBXH is due to the large crossing angle bump being in the vertical plane for ALICE.

2.3 MBX.4L2 [D1] (beam 1)

The high field strength of MBX.2L8 means the incorrect settings can pose considerable danger of machine vacuum chamber around ALICE. It is nominally set to -1.533 mrad on injection (equal to 6.4% of maximum current), and a scenario 1 mis-settings of at least -1.85 mrad on injection would send the beam into MQXB.A2R2 (Q2) on the far side of the experiment at large positive x. This corresponds to 7.7% of maximum current, and arises because a larger negative bend sends the beam to the outside of the vacuum chamber i.e. to larger positive x. The MBX.4L2 mis-setting which causes beam loss in Q2 is shown in figure 10. It should be noted that D1 is a very strong magnet, and a small change in current can cause a beam accident. The studies for D1 and D2, which are errors on dipole magnets, need to take care of the MADX and LHC coordinate system. The MADX coordinate system coincides with beam 1, where moving out of the ring (away from the centre) corresponds to positive x and a positive dipole bend angle bends to the right, or negative x. Conversely positive angle corrector magnet increases p_x and hence

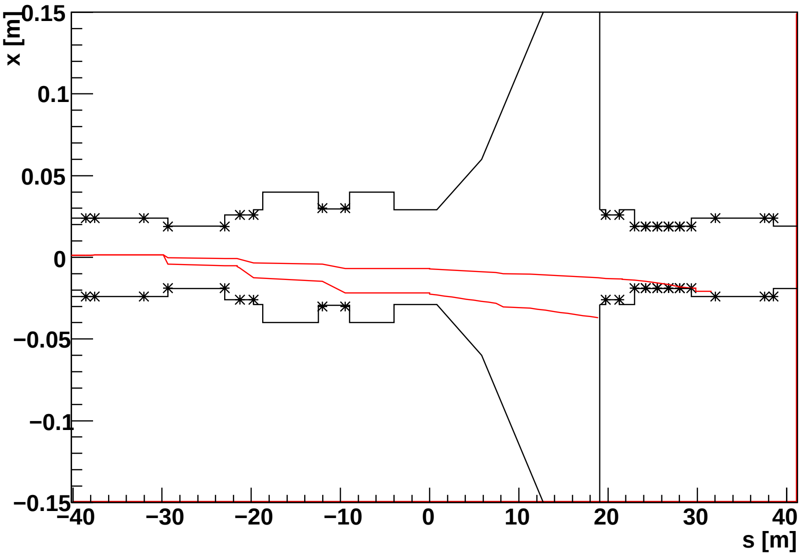

Figure 5: The range of MCBXH corrector settings which are dangerous for the ALICE beam pipe and interaction region magnets, for corrector setting scenario 2 and beam 1.

the spatial coordinate x after a drift. Therefore an increased current in a positive bend dipole is modelled with a negative angle corrector for beam 1, and vice versa.

For scenarios 2, 3 and 4, the beam will impact in the first aperture restriction on the far side of the IR, MQXA.1R2 (Q1) if the bending field of MBX.4L2 drops below -1.12 mrad, which corresponds to 4.7% of maximum current. Therefore scenarios 2, 3 and 4 (magnet turned off and any reverse polarity) will cause beam loss in the machine or detector vacuum chamber. The beam orbit arising from a magnet current of just below 4.7% of maximum (just below xxx mrad) is shown in figure 11, showing a beam impact in MQXA.1R2. This arises because a reduced field negative bend will move the beam to the inside of the ring i.e. to smaller x.

2.4 MBRC.4L2.B1 [D2] (beam 1)

In a similar way to MBX.4L2, the high field strength of MBRC.4L2.B1 means the incorrect settings can pose considerable danger of the experimental region and machine beam pipe of ALICE (the maximum bend angle of D2 is 0.02383896 mrad at injection). It is nominally set to +1.533 mrad on injection (equal to 6.4% of maximum current), and a scenario 1 mis-settings of at least 1.953 mrad on injection would send the beam into Q1 on the near side of the experiment, MQXA.1L2, which forms the first aperture restriction after MBRC.4L2 and effectively screens the IR region from errors in this magnet. The beam strikes at negative x, and D2 is a positive bend magnet and an excess current will bend the beam to the right i.e. to negative x. This corresponds to 8.2% of maximum current. This accident scenario is shown in figure 12.

For scenarios 2, 3 and 4, the beam will impact in the first aperture restriction after the magnet, MQXA.1L2 if the bending field of MBRC.4L2 drops below +1.19 mrad, which corresponds to 5.0% of maximum current. Therefore scenarios 2, 3 and 4 (magnet turned off and any reverse polarity) will cause beam loss in the machine or detector vacuum chamber. This is shown in figure 13, where the beam loss occurs on MQXA.1L2, which effectively screens the interaction region elements from beam loss in these scenarios.

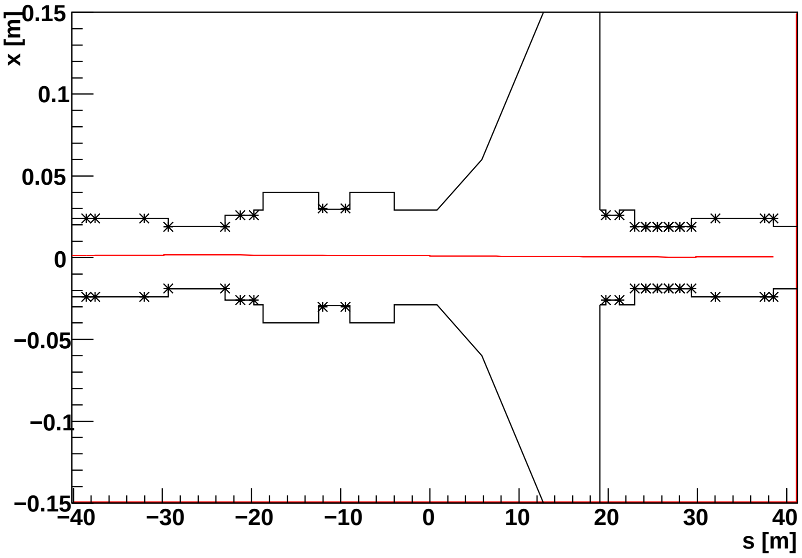

Figure 6: The range of MCBXH corrector settings, which are dangerous for the ALICE beam pipe and interaction region magnets, for corrector setting scenario 3 and beam 1, corresponding to a zero magnet current. This scenario is not dangerous for the interaction region.

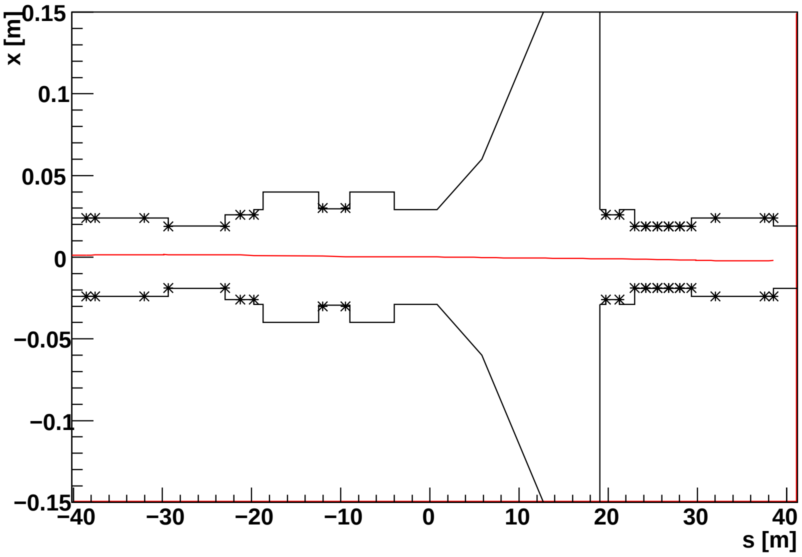

Figure 7: The range of MCBXH corrector settings, which are dangerous for the ALICE beam pipe and interaction region magnets, for corrector setting scenario 4 and beam 1, corresponding to a reversed nominal polarity setting. This scenario is not dangerous for the interaction region.

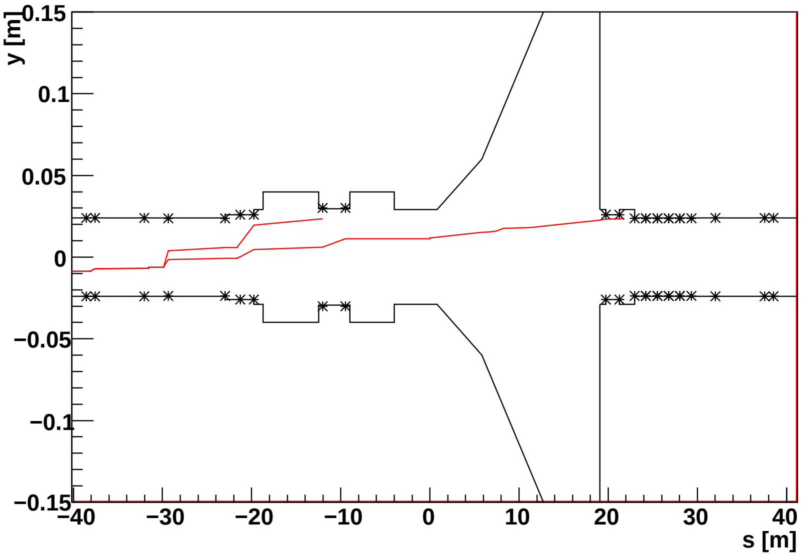

Figure 8: The range of MCBXV corrector settings, which are dangerous for the ALICE beam pipe and interaction region magnets, for corrector setting scenario 1 and beam 1.

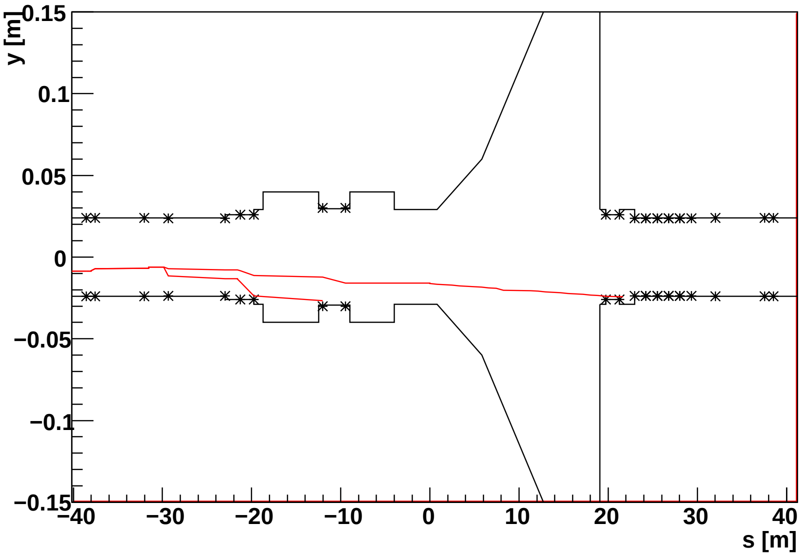

Figure 9: The range of MCBXV corrector settings, which are dangerous for the ALICE beam pipe and interaction region magnets, for corrector setting scenario 2 and beam 1.

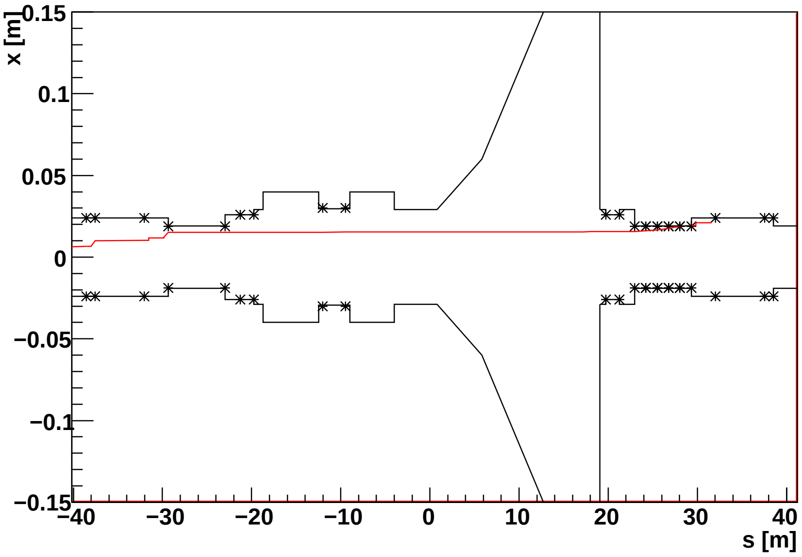

Figure 10: A possible MBX.4L2 dipole settings which is dangerous for the ALICE beam pipe and interaction region magnets, for magnet setting scenario 1 and beam 1.

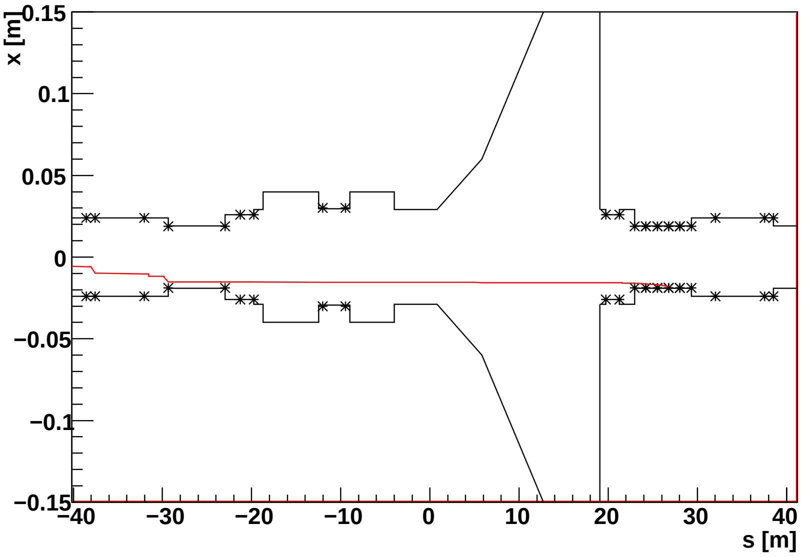

Figure 11: A possible MBX.4L2 dipole settings which is dangerous for the ALICE beam pipe and interaction region magnets, for magnet setting scenario 2 and beam 1.

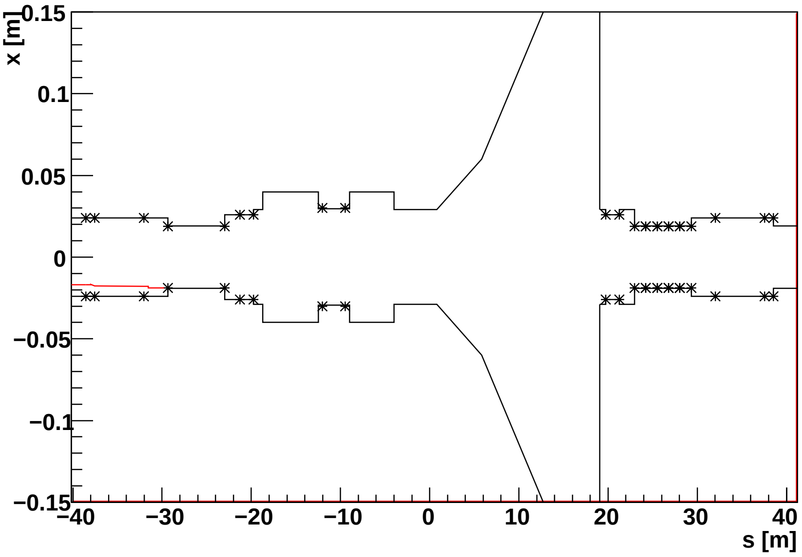

Figure 12: A possible MBRC.4L2 dipole settings which is dangerous for the ALICE beam pipe and interaction region magnets, for magnet setting scenario 1 and beam 1.

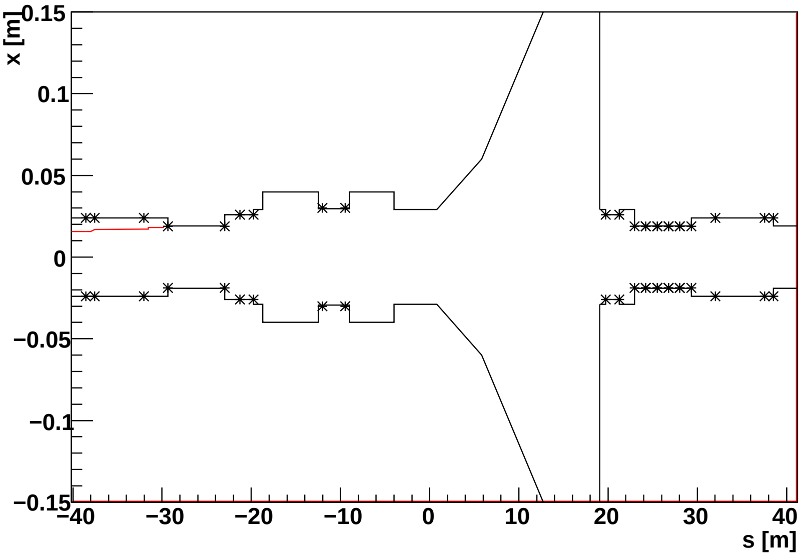

Figure 13: A possible MBRC.4L2 dipole settings which is dangerous for the ALICE beam pipe and interaction region magnets, for magnet setting scenario 2 and beam 1.

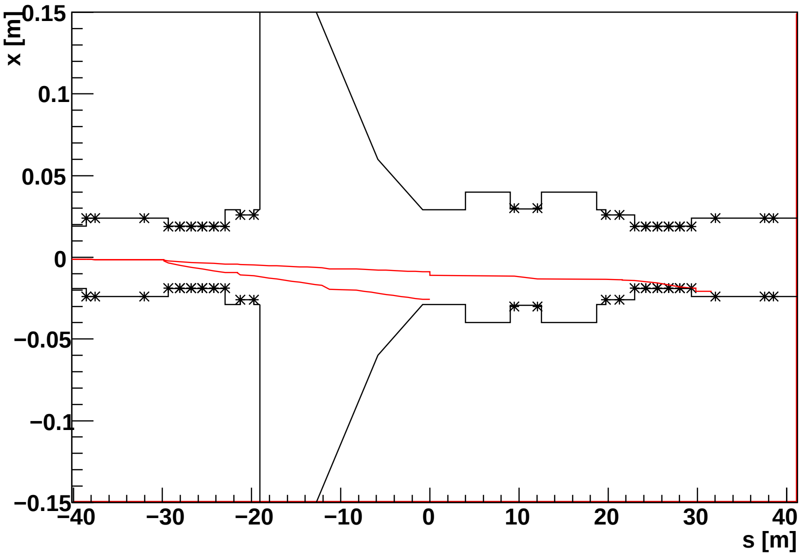

Figure 14: The range of MBXWH corrector settings which are dangerous for the ALICE beam pipe and interaction region magnets, for corrector setting scenario 1 and beam 2.

3 Beam accident scenario scenario results for beam 2

In this section, the wrong settings of the magnets MCBXH, MCBXV, MBX and MBRC are considered on the injection turn for beam 2 and for accident scenarios 1 to 4.

3.1 MCBXH (beam 2)

The results for scenario 1 with beam 2 for MCBXH are shown in figure 14, where the corrector is set from the nominal injection strength to maximum strength. This corresponds to an angle of -36μrad to -1011μrad. The range of magnet settings in the cone show those which could be dangerous to the interaction region beam pipe or elements. The calculations show this dangerous region is defined by MCBXH being set to 31.3% to 100% of maximum strength, with positive (nominal) polarity. The lower bound corresponds to an angle of -0.32 mrad. The figure shows the beam can hit the final triplet magnets Q1 or Q2 (MQXA.1L8 or MQXB.A2L2) or parts of the ALICE conical beam pipe.

The scenario 2 results for MCBXH are shown in figure 15. The range of dangerous currents is -32.5% to -100% (recall the magnet is nominally set at -36μrad, so these currents correspond to a positive bending angle). The lower bound corresponds to an angle of 0.33 mrad. The figure shows the beam can hit the final triplet magnets Q1 or Q2 (MQXA.1L8 or MQXB.A2L2) or parts of the ALICE conical beam pipe.

Scenarios 3 and 4 for MCBXH beam 2 are shown in figures 16 and 17. There is no danger to the experimental regions from these accident scenarios.

3.2 MCBXV (beam 2)

In common with beam 1, the vertical corrector on Q1, MCBXV, is set to zero current on injection for IR2 and hence the possible scenarios are 1 (zero to maximum positive angle) and 2 (zero to maximum negative angle).

The results for scenario 1 with beam 2 for MCBXV are shown in figure 18, where the corrector is set from zero strength to maximum strength. This corresponds to a vertical bend angle of 0μrad to 1042μrad. The range of magnet settings in the cone show those

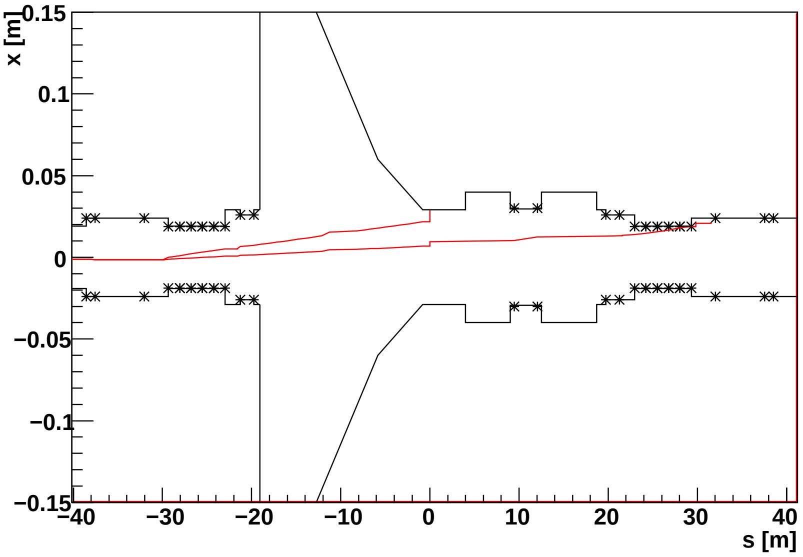

Figure 15: The range of MBXWH corrector settings which are dangerous for the ALICE beam pipe and interaction region magnets, for corrector setting scenario 2 and beam 2.

which could be dangerous to the interaction region beam pipe or elements. The calculations show this dangerous region is defined by MCBXV being set to 29.2% to 100% of maximum strength, with positive (nominal) polarity. The figure shows the beam can hit the ALICE conical beam pipe or, for a few settings of the magnet, the beam screen of Q1 (MQXA.1L2).

The scenario 2 results for MCBXV are shown in figure 19. The range of dangerous currents is -41.6% to -100% (recall the magnet is nominally set at 0μrad, and these currents correspond to a negative bending angle). The current limits are set the narrow aperture of the beam screen in MQXA.1L2 (48mm), where the first beam strike occurs as current increases. The beam can also strike the ALICE vacuum chamber.

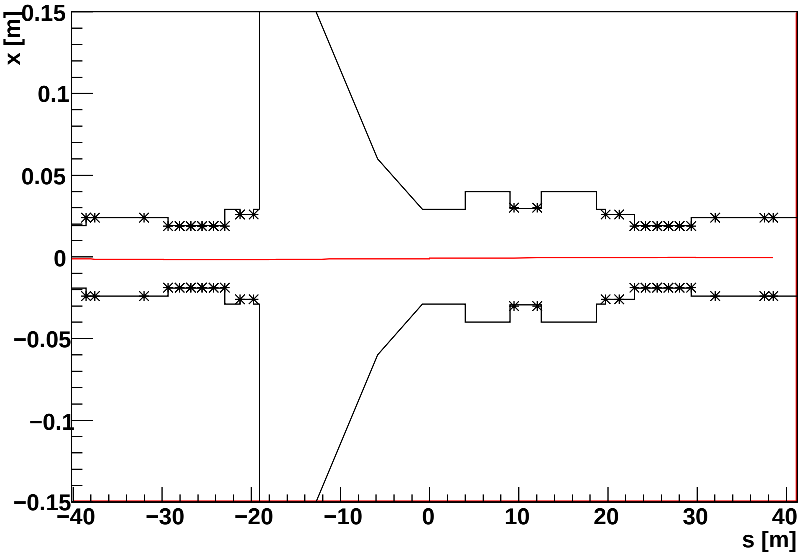

Figure 16: The range of MBXWH corrector settings which are dangerous for the ALICE beam pipe and interaction region magnets, for corrector setting scenario 3 and beam 2.

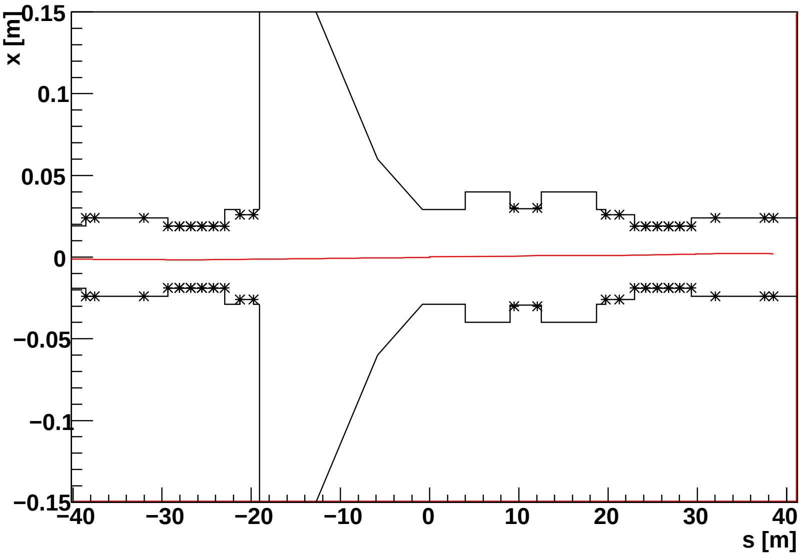

Figure 17: The range of MBXWH corrector settings which are dangerous for the ALICE beam pipe and interaction region magnets, for corrector setting scenario 4 and beam 2.

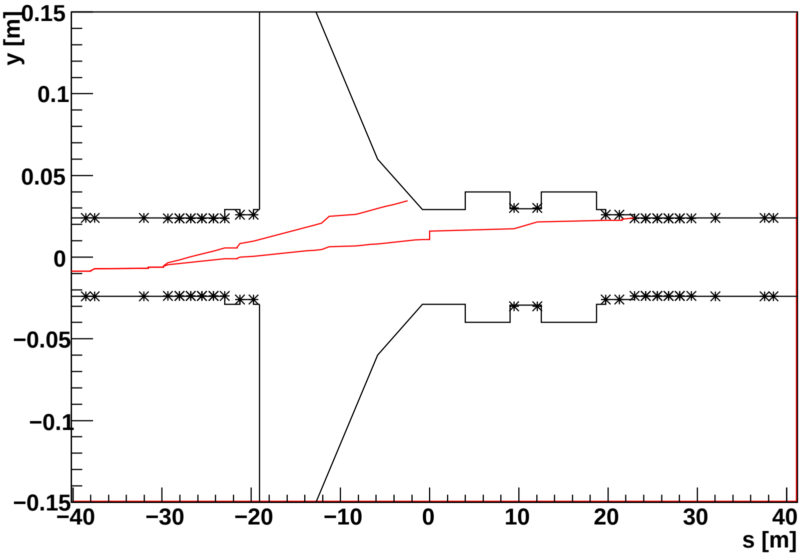

Figure 18: The range of MCBXV corrector settings which are dangerous for the ALICE beam pipe and interaction region magnets, for corrector setting scenario 1 and beam 2.

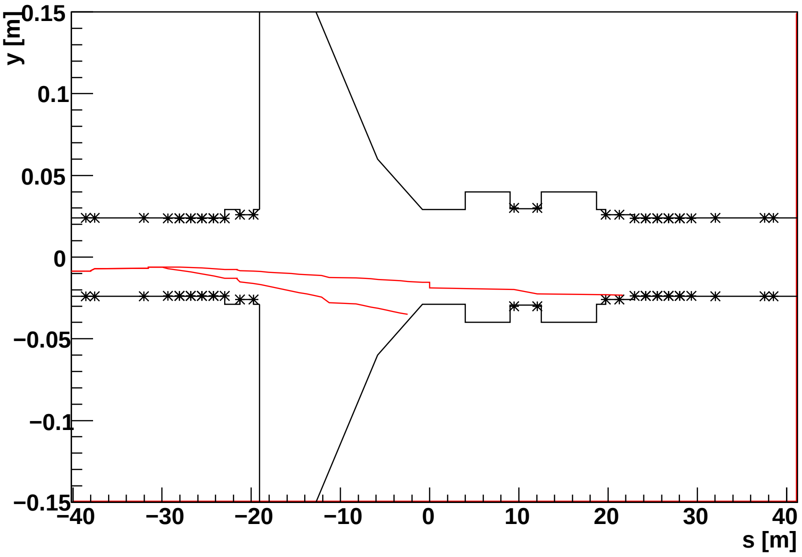

Figure 19: The range of MCBXV corrector settings which are dangerous for the ALICE beam pipe and interaction region magnets, for corrector setting scenario 2 and beam 2.

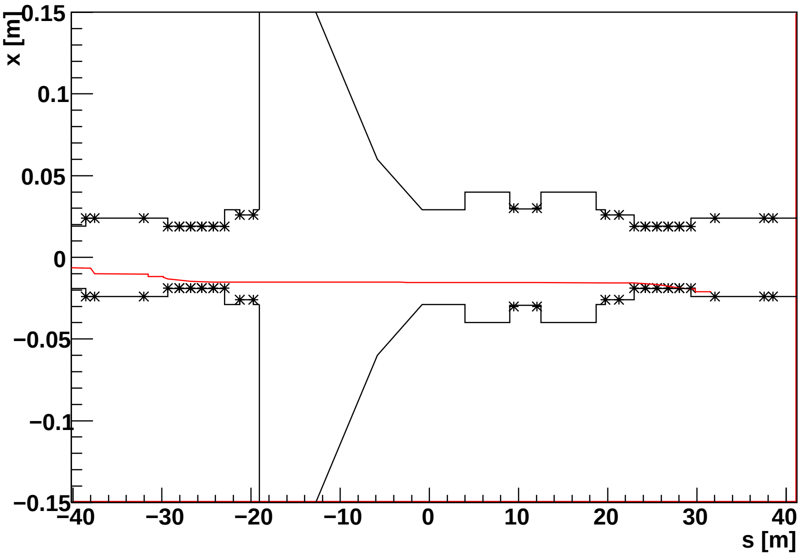

Figure 20: A possible MBX.4R2 dipole settings which is dangerous for the ALICE beampipe and interaction region magnets, for magnet setting scenario 1 and beam 2.

3.3 MBX.4R2 [D1] (beam 2)

The high field strength of MBX.4R2 means the incorrect settings can pose considerable danger of machine vacuum chamber around ALICE. It is nominally set to +1.533 mrad on injection (equal to 6.4% of maximum current), and a scenario 1 mis-settings of at least +1.85 mrad on injection would send the beam into the final triplet magnets Q1 and Q2 on the far side of the experiment, MQXA.1L2 and MQXB.A2L2. This corresponds to 7.7% of maximum current, and arises because a larger positive bend sends the beam to the outside of the machine i.e. to larger negative x (for beam 2). Larger mis-setting would cause beam loss in elements closer to the IP. The MBX.4Rw mis-setting which causes beam loss in MQXB.A2L2 is shown in figure 20. The studies for D1 and D2, which are errors on dipole magnets, need to take care of the MADX and LHC coordinate system. For beam 2, moving out of the ring (away from the centre) corresponds to negative x. Note the sign change between dipole and corrector angles is still needed for beam 2 in MADX.

For scenarios 2, 3 and 4, the beam will impact Q1 on the far side of the experiment, MQXA.1L2, where the beam screen flat aperture is is 38mm, if the bending field of MBX.4R2 drops below 1.12mrad, which corresponds to 4.7% of maximum current. Therefore scenarios 2, 3 and 4 (magnet turned off and any reverse polarity) will cause beam loss in the machine or detector vacuum chamber. The beam orbit arising from a magnet current of just below 4.7% of maximum (just below 1.12mrad) is shown in figure 21, showing a beam impact in MQXA.1L2.

3.4 MBRC.4R2.B2 [D2] (beam 2)

In a similar way to MBX.4R2, the high field strength of MBRC.4R2.B2 means the incorrect settings can pose considerable danger of the experimental region and machine beam pipe of ALICE. It is nominally set to -1.533 mrad on injection (equal to 6.4% of maximum current), and a scenario 1 mis-settings of at least -1.93 mrad on injection would send the beam into Q1 on the near side of the experiment, MQXA.1R2, which forms the

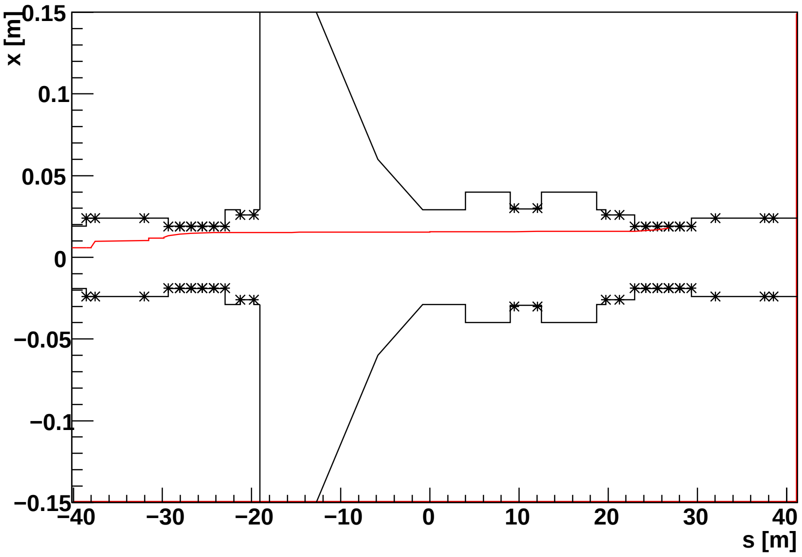

Figure 21: A possible MBX.4R2 dipole settings which is dangerous for the ALICE beampipe and interaction region magnets, for magnet setting scenario 2 and beam 2.

first aperture restriction after MBRC.4R2 and effectively screens the IR region from errors in this magnet. The beam strikes at positive x, and D2 is a negative bend magnet and an excess current will bend the beam into the inner side of the vacuum pipe (positive x for beam 2). This corresponds to 8.1% of maximum current. This accident scenario is shown in figure 22.

For scenarios 2, 3 and 4, the beam will impact in the first aperture restriction after the magnet, MQXA.1R2, where the diameter is 38mm in the horizontal plane, if the bending field of MBRC.4R2 drops below -1.21 mrad, which corresponds to 5.1% of maximum current. Therefore scenarios 2, 3 and 4 (magnet turned off and any reverse polarity) will cause beam loss in the machine or detector vacuum chamber. This is shown in figure 23, where the beam loss occurs on the outer side of the vacuum chamber of MQXA.1R2, which effectively screens the interaction region elements from beam loss in these scenarios.

4 Summary of current thresholds and software interlocks

The resulting magnet current thresholds for beam 1 to avoid beam orbits striking the vacuum chamber are shown in table 3, as a a fraction of the maximum field and expressed as integer percentiles. These current thresholds should be considered as maximum permissible currents to avoid injection turn beam accidents, and should be considered as part of the current software interlocks to avoid beam strikes on the aperture restrictions of the final triplet magnets or the vacuum chamber of ALICE.

The resulting magnet current thresholds for beam 2 to avoid beam orbits striking the vacuum chamber are shown in table 4, as a fraction of the maximum field and expressed as integer percentiles. Similar comments apply to this table, as to the table for beam 1.

The current thresholds to avoid beam loss calculated for the various accident scenarios can be used to set the magnet current interlocks on injection. These interlocks are done in software and controlled by the Software Interlock System (SIS). The interlocks can be bypassed by all engineers-in-charge (EIC), and are protected by the role-based ac-

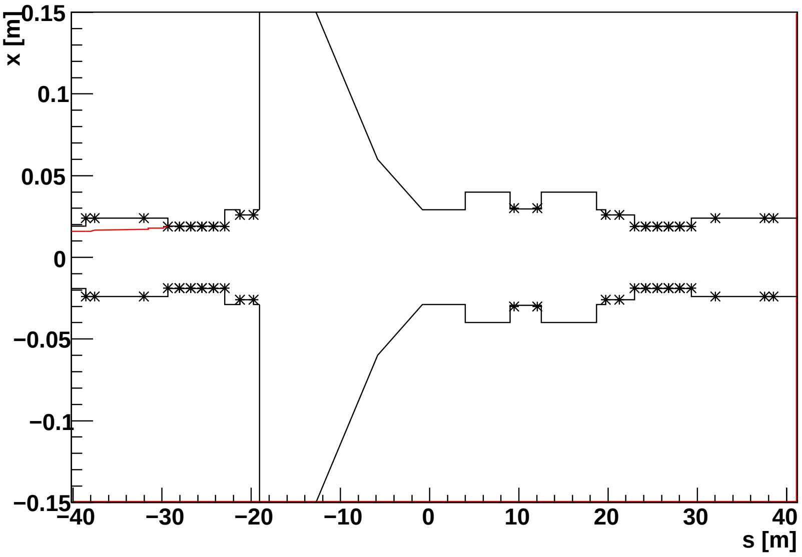

Figure 22: A possible MBRC.4R2 dipole settings which is dangerous for the ALICE beampipe and interaction region magnets, for magnet setting scenario 1 and beam 2.

Magnet	Nom. angle [μrad]	Max angle [μrad]	Threshold (nom. pol.)	Threshold (rev. pol.)
MCBXH	+37	+1011	31% (313μrad)	-33% (-334μrad)
MCBXV	0	+1042	31% (323μrad)	-43% (-448μrad)
MBX.4L2	-1533	-23,837	7.7% (1835μrad)	4.7% (1120μrad)
MBRC.4L2	+1533	+23,837	8.2% (1955μrad)	5.0% (1192μrad)

Table 3: The required thresholds of the magnets to avoid beam accident scenarios on injection, rounded to a integer percentile, for beam 1.

cess system. At the present settings [7], the orbit correctors are interlocked to a tolerance of approximately 100 μ rad around the nominal current, until the injected beams have been steered. This is equivalent to about 10% of nominal current. The separation dipoles (D1 and D2) have an injection current tolerance of 3% of the nominal injection current.

For the beam separation dipoles for beam 1 and beam 2, a current interlock of 3% of nominal injection current would corresponds to a bend angle change of 46 μrad, or 0.19% of maximum current. Consideration of tables 3 and 4 show there is no danger to the experimental region if this software interlock is maintained. For the corrector magnets, a tolerance of 100 μrad corresponds to approximately 10% of maximum current. Again, consideration of tables 3 and 4 show there is no danger to the experimental region if this software interlock is maintained. These conclusions are correct for the scenarios considered in this report, and for the case of single magnet incorrect setting. The case of a double magnet setting error was discussed for the simulations performed for LHCb, and the conclusions, valid for ALICE, shall be repeated here. For the case of a double magnet setting error on injection, a reduction in the current of MBRC.4R2 by 3% and an increase in the current of MBX.4R2 current by 3% is the worst case consistent with the interlocks. These errors are at the limit of the software interlock tolerance and both act to move the orbit to the outside of the vacuum chamber i.e. the errors act coherently. The LHCb

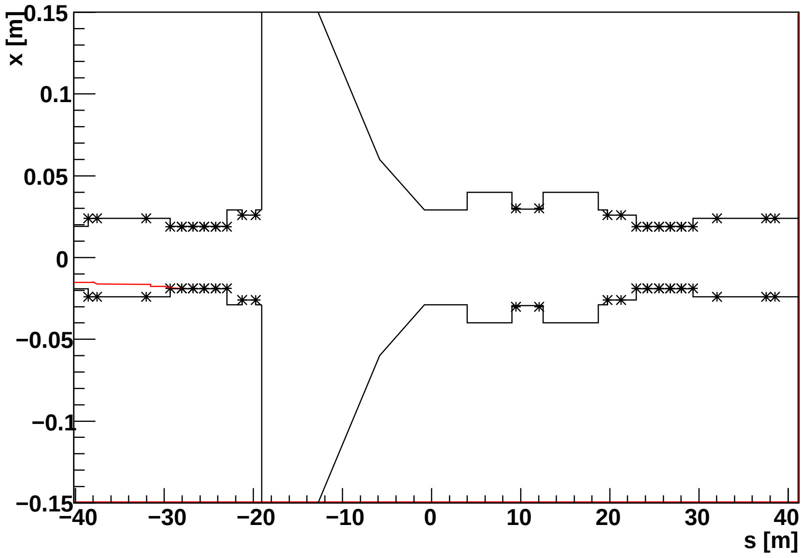

Figure 23: A possible MBRC.4R8 dipole settings which is dangerous for the ALICE beampipe and interaction region magnets, for magnet setting scenario 2 and beam 2.

Magnet	Nom. angle [μrad]	Max angle [μrad]	Threshold (nom. pol.)	Threshold (rev. pol.)
MCBXH	-36	-1011	31% (-323μrad)	-33% (334μrad)
MCBXV	0	+1042	29% (302μrad)	-42% (-438μrad)
MBX.4R8	+1533	+23,837	7.7% (1835μrad)	4.7% (1120μrad)
MBRC.4R8	-1533	-23,837	8.1% (1931μrad)	5.1% (1216μrad)

Table 4: The required thresholds of the magnets to avoid beam accident scenarios on injection, rounded to a integer percentile, for beam 2.

calculation showed there is no danger to the experimental area for such double magnet errors, when the currents stay within the interlock thresholds, and this conclusion is valid for ALICE. For the corrector errors, the calculated tolerances to avoid beam loss are several times greater than the 100 μrad of software interlock threshold. Hence no danger is expected to the experimental areas while the interlocks are maintained.

5 Conclusion

In this report, the beam accident scenarios for machine elements around ALICE are discussed for beams 1 and 2, focusing on the correctors MCBXH, MCBXV and the separation dipoles D1 and D2, for both beam 1 and beam 2. For each magnet four magnet setting scenarios were considered, covering all possible magnet current settings. It was found it is possible for beam accidents on injection to strike elements of the ALICE beam pipe or elements of the machine, due to incorrect settings of magnets. Magnet current thresholds were calculated to avoid beam strikes under injection conditions. Finally, the software current interlocks were discussed, and it was shown these interlocks are adequate for single magnet setting errors and for double magnet separation dipole errors.

An extension to this work is a detailed consideration of the spot of beam impact to understand the potential impact. For example, beam loss in the vacuum chamber would lead to showers which could impact the detector systems, or even cause physical damage to the ALICE vacuum chamber under repeated strikes by a pilot beam. Also, specific elements like vacuum chamber bellows may be particularly vulnerable to beam loss. The beam strikes will cause showers in the vacuum chamber and machine elements, and the results presented here can be used at the starting point for such shower calculations. The simulations can then be used to understand the potential fluxes in the beam condition monitors, to understand which detectors see the beam loss first and calibrate the beam loss monitor threshold and response.

Finally, the method of calculation and general results presented here for ALICE also apply to LHCb, although the detailed geometry of point 8 will determine the precise level of magnet current thresholds required. The calculations for LHCb have been presented in a separate report.

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