Large Hadron Collider Project

LHC Project Report 1179

The Impact of Vacuum Gate Valves on the LHC Beam

R.B. Appleby, M. Brugger, F. Cerutti, A. Ferrari, M. Mauri, V. Vlachoudis

Abstract

The LHC vacuum sector valves are located in the straight sections of the LHC ring, and designed to sectorize the LHC vacuum. The valves are interlocked and should trigger a beam dump request if they close on a circulating beam. This report studies the impact on the machine if this request is not made and the valve scrapes the LHC beam halo. Cascade calculations are made using a model of IR7, with several different valve locations, to calculate the downstream energy deposition in superconducting magnet coils and the corresponding signal in beam loss monitors at the quench level. The calculations are done at 7, 5, and 3.5 TeV. It is found that when a downstream magnet reaches the quench level, the neighbouring BLMs see a signal well above the detection threshold. Furthermore, the BLM signal is consistent with the BLM applied threshold settings and a signal is seen in the time domain before the quench level is reached. Therefore the report concludes that the BLMs can see the closing valve and trigger a beam dump before the quench (or damage) level is reached.

CERN, Engineering Department, Geneva, Switzerland

1 Introduction

The Large Hadron Collider (LHC) vacuum sector valves are located in the long straight sections of the machine and sectorize the LHC vacuum in the event of a beam or vacuum incident in the machine. They also allow sectorized work to be done in a specific vacuum region. The valves close in 3s (5s) for a valve with aperture 63mm (100mm), which is a closure speed of 0.02 m/s. The valves are interlocked, and the closing valve should trigger a beam dump request and dump the beam, which will occur in a few turns after the request. The work in this report looks at the impact on the beam if this request was not made and the closing valve scrapes the beam, in terms of downstream magnet quenches and beam loss monitor (BLM) signals. Studies are made of the shower formation as the valve touches the beam halo, to estimate the power deposition in downstream superconducting magnets and in neighbouring BLMs. The calculations are performed with a FLUKA [1] model of a candidate valve in IR7, with BLMs modelled as theoretical BLMs and at beam energies of 7, 5 and 3.5 TeV. Note a study is not made of valve or machine element damage.

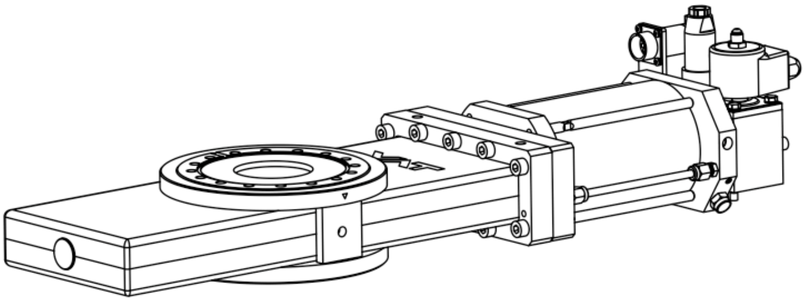

Figure 1: The LHC sector valve design.

There are two aperture variants of sector valve in the LHC: 63 mm and 100 mm, which are referred to as DN63 and DN100. These relate to the identifies in the LHC layout database as

Identifier VVGST: aperture 63
Identifier VVGSF: aperture 63
Identifier VVGSH: aperture 100
Identifier VVGSW: aperture 100

The closure time for a DN63 is approximately 3 s, and the DN100 closure time is approximately 5 s, giving a valve closure speed of 0.02 m/s and 2 um of motion in 1 turn of the LHC (89 us). The operation of valve closure should trigger a beam dump request. The LHC vacuum valve design is shown in figure 1 for the DN63 variant. The stainless steel door closes across the beam to seal the vacuum, and as the valve closes a steel flange of approximately 1.8 cm thickness is placed in the path of the beam. The valve in a half-open configuration is shown in figure 2. This amount of material initially seen by the beam is greater than the ultimate door thickness. Therefore the simulations in this report models the valve door as a homogeneous piece of 1.8 cm thick steel.

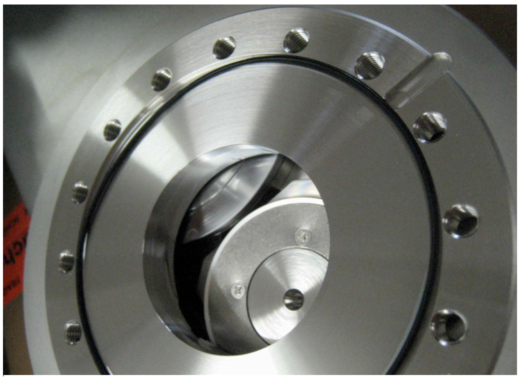

Figure 2: The LHC sector valve in a half-closed configuration.

The calculations were made in the right-hand side of IR7 for beam 1, with valves chosen for study that represented the typical valve geometry in the machine. The candidate valves are located in the region just before MQ7, which is just before the arc and where between MQ6 and MQ7 there are two valve locations:

one in the drift before MQ7 (at 258.57 m from IP7) and one just after MQ6 (but separated from the cold elements by several other elements and located at 235.26 m from IP7). This gives the opportunity to study valve-magnet longitudinal layouts. The valve before MQ7 will be studied as the main valve in this report. Furthermore, a 'study' valve location located immediately before MQ7 (at 262.34 m from IP7) will also be considered to check the impact of a valve immediately before a cold element, although this does not correspond to a valve in IR7 in the real machine. This study valve also allows comparison to previous studies [2] of point-like losses in quadrupoles and the resulting quench limit as a validation of the calculations. The losses on the valve are assumed to be a pencil beam, using a proton beam energy of 7 TeV, 3.5 TeV and 5 TeV. The pencil beam approximation is used in place of the true beam distribution for this work and, while the precise distribution of the shower products will not be accurately modelled, the calculations will give the correct location and order of magnitude of the energy deposition peak. The valve is assumed to be in the closed position, or in an open position with a beam grazing the edge of the material. For the latter, the impact parameter is taken to be the time for 1, 5 and 10 turns multiplied by the valve speed, giving 2 um of valve movement per turn (the valve speed is approximately 6cm/3s, or about 2 um per turn).

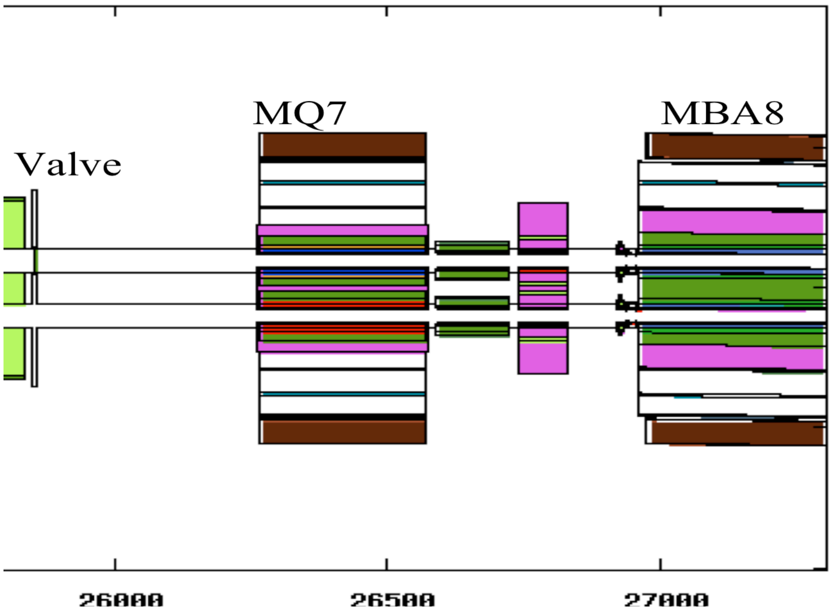

Figure 3: The layout of IR7 on the right side, showing the target valve and the region into the arc.

The layout in this region of IR7 is shown in figure 3 with the MQ7 located around 26500 cm, the bend at the right of the plot is MBA8 and the target valve is located just after the green box at a longitudinal position of 25856.65 cm. The horizontal axis is shown in cm from IP7. Figure 4 shows in the detail the FLUKA model [3] in the region, with an example shower loss pattern overlaid. The valve and the peak of the loss in MBA8 can be seen.

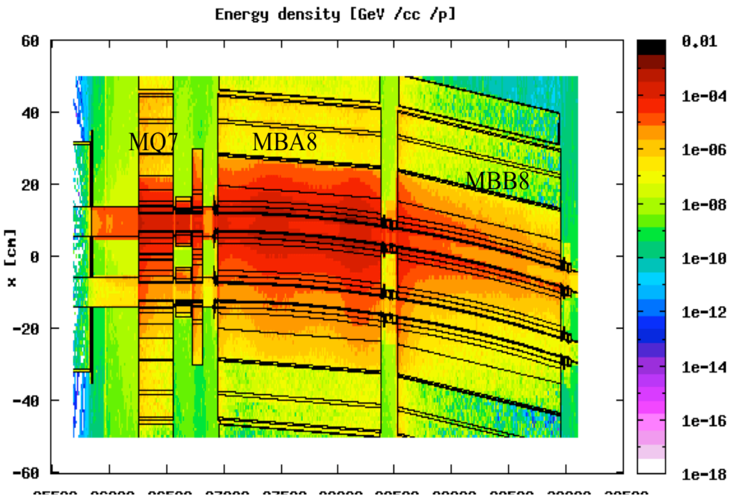

Figure 4: The model of IR7 right, with a shower arising from a proton-valve collision.

The cascade is modelled in FLUKA for a proton beam incident on the target valve (about 10% interact) for the cases of an open and closed valve. The calculation is time independent and the energy deposition in downstream magnet coils and BLMs is calculated and normalised for 1 proton incident on the valve. The energy deposition is scored in the coils of the quadrupoles, the trim quadrupoles and the dipoles, mainly MQ7, MQ8, MBA8 and MBB8. The BLM energy deposition along a theoretical BLM gives the expected BLM signal. The energy deposition in the coils is then inverted and, assuming the quench level, the number of protons needed to quench a magnet can be calculated. At this number of incident protons, the normalised BLM signal is then computed. The number of protons needed to quench a superconducting element can be compared to previous calculations of the quench level [2], where 1E7 to 1E8 protons incident on a target within a magnet was sufficient to cause a quench. The BLMs are modelled as N2 BLMs (standard) located along the entire length of an element and segmented (a 'theoretical' BLMs), with a detection threshold of the order of 1 pC and a typical charge at the quench level of the order of nCs. This latter number can be compared to the calculations made by the LHC BLM team for the standard BLM thresholds. The MB and MQ quench level at 7 TeV is taken to be 1mJ /cc for transient losses, with the peak estimated from a binning of the magnet coils. This quench level is taken to be 3 mJ /cc at 5 TeV and 9 mJ /cc at 3.5 TeV, and all results in this report scale with these assumed levels.

The FLUKA shower analysis calculates GeV /cc /p, which is used to find the number of incident protons required to reach the quench level. For the case of the BLMs, the energy deposition per cc is found from the total number of incident protons on the valve, which is scaled to nC by a factor of 0.16/34.8 nC/GeV and also scaled to account for the differing volumes between the real BLM and the simulation i.e. for the volume ratio for a real BLM (with sensitive volume 1537.42 cm^3) to the volume ratio in the simulation (2837.25 cm^3 for a MB and 567.45 cm^3 for a MQ).

To assist with the analysis of plots in the following sections, the centres of the relevant elements are:

Main target valve	25856.65 cm
Second target valve	23526.15 cm
Study valve	26233.760 cm
MQ7	26417.9 cm
MBA8	27673.397 cm
MBB8	29239.37 cm
MQ8	30324.329 cm

The rest of this report is organised into 3 sections and a conclusion. The first is a detailed study of the 'study' valve located immediately before MQ7. This includes sensitivity studies of beam initial conditions, both for a valve in the closed and open configurations, and studies of the BLM signal at the downstream magnet quench level. The next section makes the same calculations for the target valve located in the drift before MQ7 at 7 TeV. Finally, section 3 makes a study of alternative configurations and of the target valve at 3.5 TeV and 5 TeV and then conclusions are drawn.

2 The 'study' valve at 7 TeV

In this section, the shower analysis is presented for the 'study' valve is presented and analysed. This valve does not correspond to a valve in the LHC, but allows a comparison to previously published results on the magnet quench levels. The section begins with a series of sensitivity studies before making a detailed analysis of the quench levels and BLM signals.

Sensitivity study 1 – Closed valve position scan

To assess the dependence on pencil beam initial position, a sensitivity study on the closed study valve was made for a selection of initial beam horizontal position and the dependence on the coil energy deposition (GeV /cc /proton) calculated. The energy deposition as a function of s is shown in Figure 5.

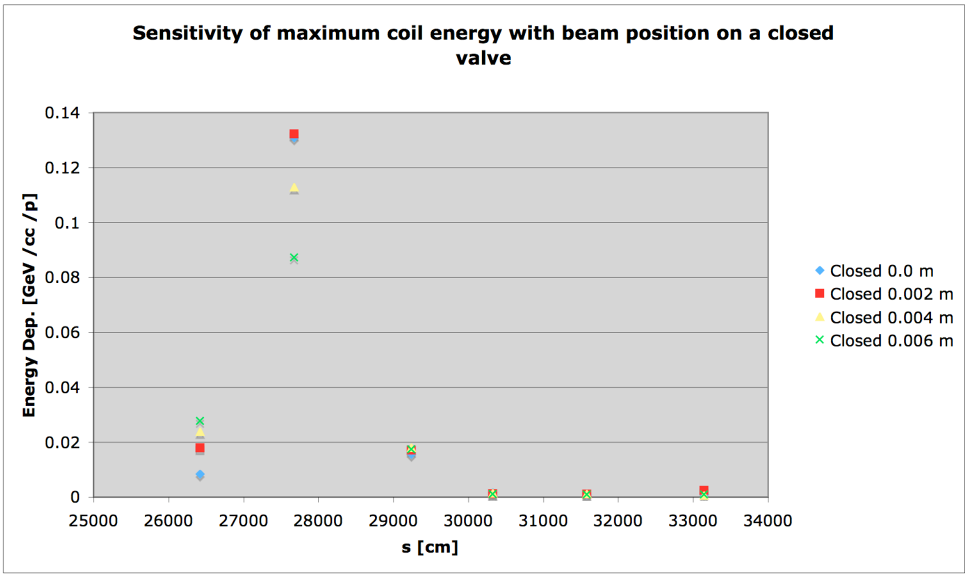

Figure 5: The sensitivity of the coil maximum deposited energy to initial displacement for a closed study valve.

The peak energy deposition along s is plotted, and the valve is located at 26233.76 cm. The first point corresponds to loss in MQ7, and the peak to loss in MBA8. The magnitude of the peak shows some dependence on the initial position, but the peak deposition drops as the beam moves off-axis.

Sensitivity study 2 – Closed valve angle scan

The sensitivity to initial angle of the energy deposition is shown in Figure 6

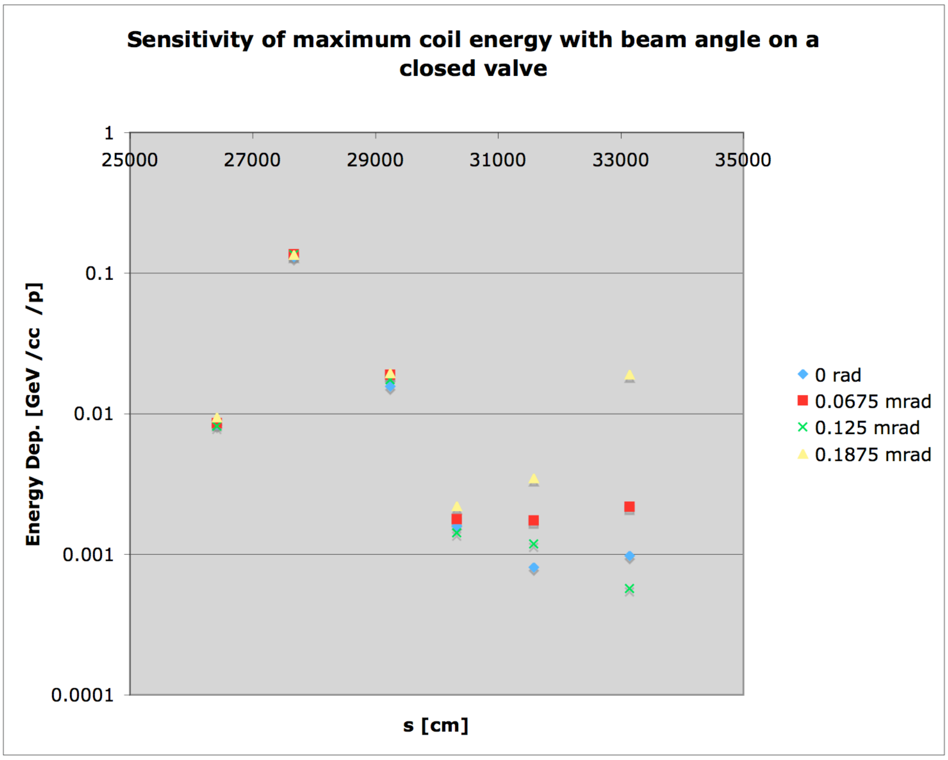

Figure 6: The sensitivity of the coil maximum deposited energy to initial angle for a closed study valve.

The peak energy deposition in s was calculated for a scan of initial angles for a closed valve configuration. The dependence on initial angle is weak at small beam angles. The growth in the energy deposition around

33000 cm, corresponding to MBB9, arises from direct beam impact at largee angles, which can be seen from a detailed coil energy deposition for an angle of 0.25 mrad in Figure 7.

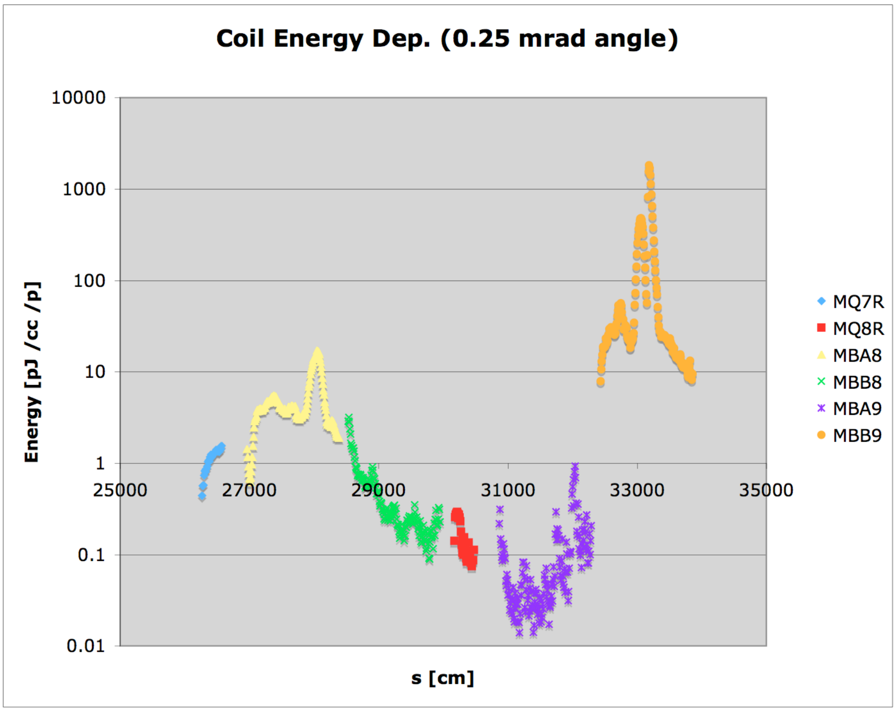

Figure 7: The longitudinal energy deposition for a 0.25 initial angle on a closed study valve.

The shower peak in MBA8 is still present, but a much larger peak in MBB9 (around 33000 cm) now appears due to direct beam impact in the coils. However, an angle of 0.25 mrad is many beam angular σ's at this point, and so a very large angle.

Sensitivity study 3 – Open valve and impact parameter scan

The final sensitivity study concerns an open valve and variation of the impact parameter of the beam, and is shown in Figure 8. The cases chosen correspond to the valve movement in 1, 5 and 10 turns (2 um, 10 um and 20 um).

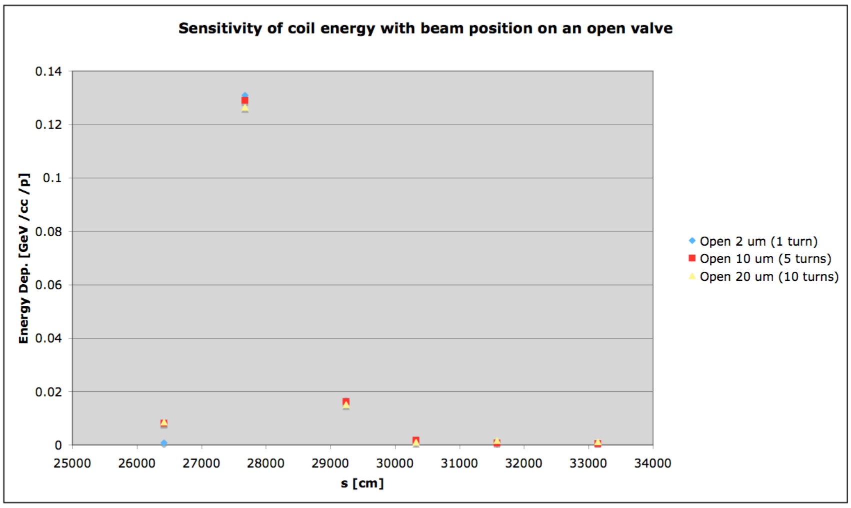

Figure 8: Sensitivity study of the energy deposition for variable impact parameter on an open study valve.

The dependence on impact parameter is weak, and considering the case of 2 um impact parameter is sufficient. Also, the 2 um open valve case gives similar results to the x=0 closed valve case, as shown in Figure 5

Closed valve at 7 TeV for the study valve

The valve in the closed configuration and an incident pencil beam was simulated to check the MQ and MB coil energy deposition and BLM signal at 7 TeV. The beam is located at x=0. The energy deposition scored in the downstream magnet coils is shown in Figure 9.

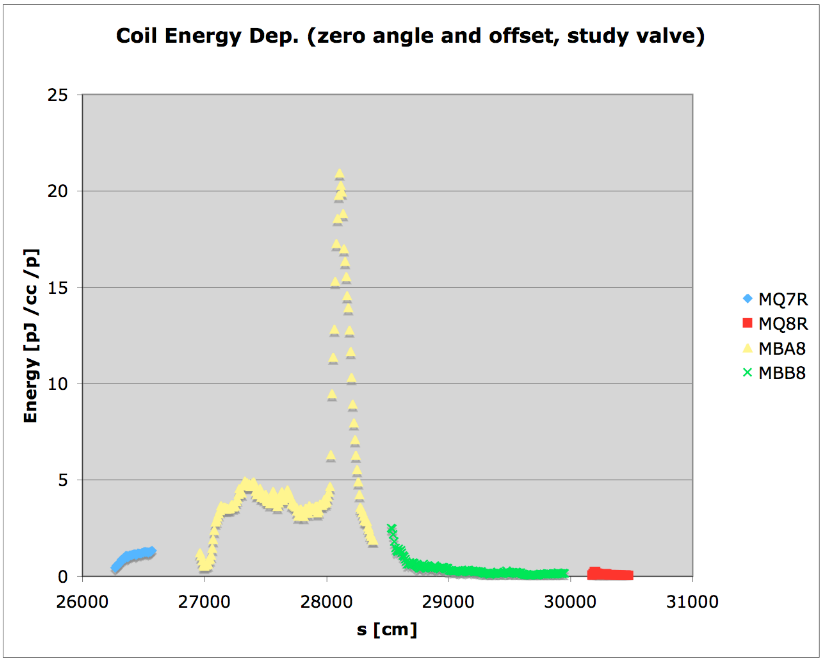

Figure 9: The longitudinal energy deposition for a 7 TeV beam incident on a closed study valve.

The further downstream elements are not shown, as the energy deposition is very small. The peak corresponds to the coils of MBA8, with a peak valve of 20.9 pJ /cc /proton hitting the valve, with an error of 2.6%. Therefore MBA8 will reach the quench level of 1 mJ /cc when 5E7 protons are incident on the valve face. The peaks in the magnet coils exceeds the peaks in other locations e.g. in the interconnects. This number of protons needed to quench MQ7 is consistent with previous published studies of the quench level. The associated BLM signal, scored along the length of all relevant magnets is shown in Figure 10.

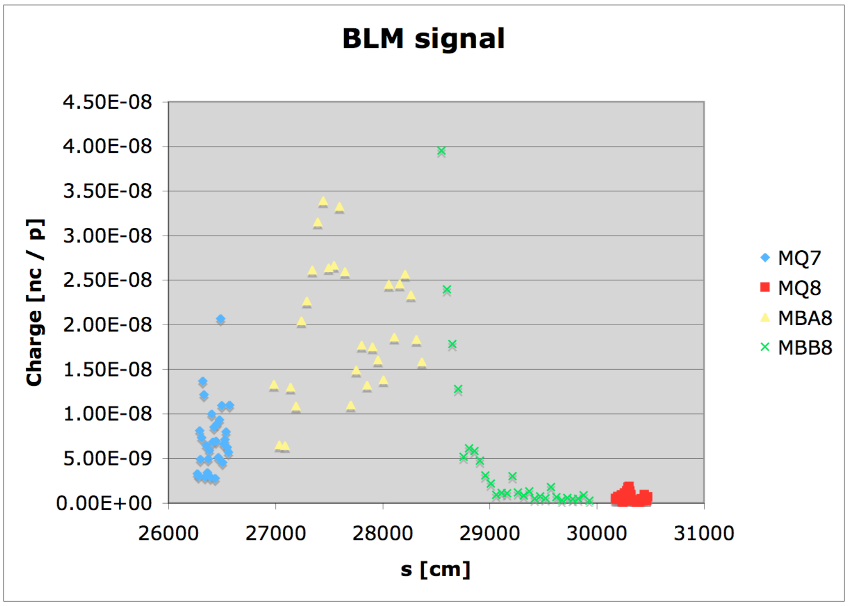

Figure 10: The BLM signal for a 7 TeV beam incident on a closed 'study' valve.

The peak BLM signal of 4E-8 nC /proton is seen in the BLM system of MBB8, with a second peak of 3E-8 nc /proton seen in the BLM system of MBA8. This corresponds to a peak in a theoretical BLM stretching along the length of the magnet and may be slightly larger than the signal seen in the physical BLM. At the quench level of 1 mJ /cc in the coils of MBA8, the BLM signal in MBB8 is 1.9 nC and in MBA8 is 1.6 nC. This is in excess of the BLM threshold and observable.

Open valve at 7 TeV for the study valve

This study was made with an impact parameter of 2 um, corresponding to the distance the valve will close in 1 turn. This was done at 7 TeV. The energy deposition scored in the downstream magnet coils is shown in Figure 11.

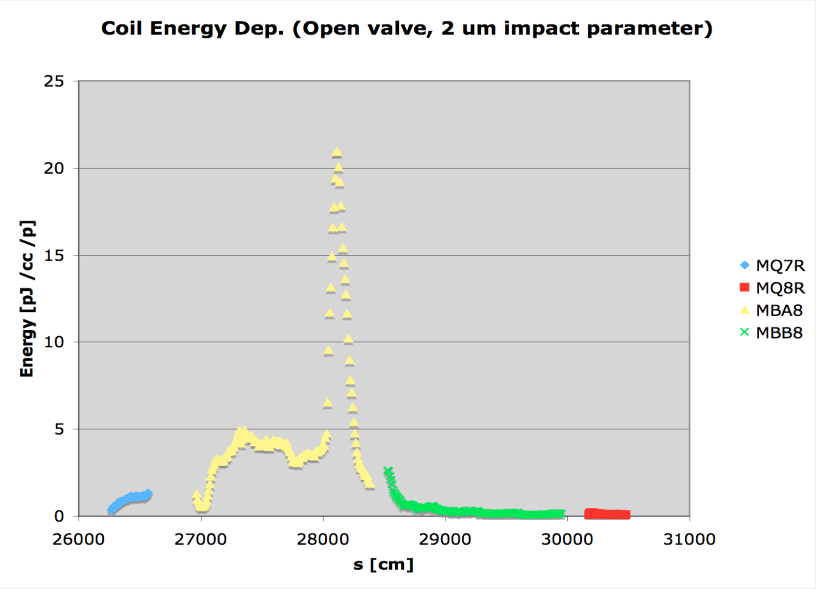

Figure 11: The longitudinal energy deposition for a 7 TeV beam incident on an open study valve.

The further downstream elements are not shown, as the energy deposition is very small. The peak corresponds to the coils of MBA8, with a peak valve of 21.0 pJ /cc /proton hitting the valve, with an error of 2.0%. Therefore MBA8 will reach the quench level when 5E7 protons are incident on the valve face. The peaks in the magnet coils exceeded the peaks in other locations e.g. in the interconnects. The associated BLM signal, scored along the length of all relevant magnets is shown in Figure 12.

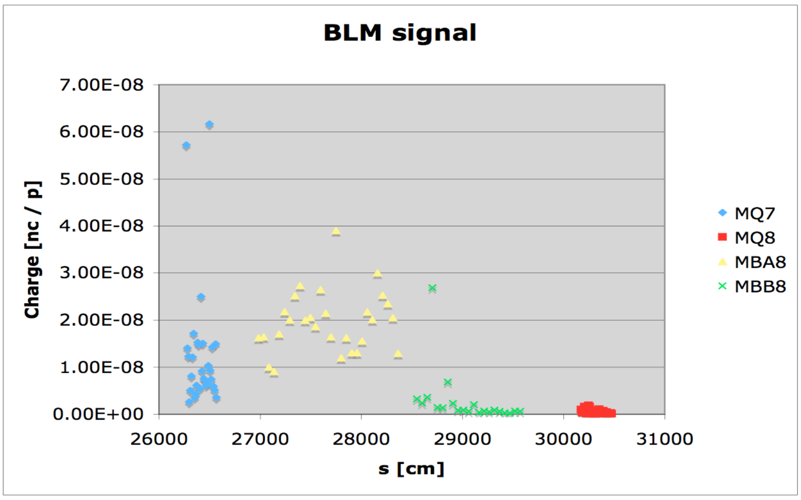

Figure 12: The BLM signal for a 7 TeV beam incident on an open 'study' valve.

In contract to the closed case, the peak BLM signal of 6E-8 nC /proton is seen in the BLM system of MQ7, with a second peak of 4E-8 nc /proton seen in the BLM system of MBA8. This corresponds to a peak in a BLM stretching along the length of the magnet and may be slightly larger than the signal seen in the physical BLM. At the quench level of 1 mJ /cc in the coils of MBA8, the BLM signal in MQ7 is 2.9 nC and in MBA8 is 1.9 nC. This is in excess of the BLM threshold.

3 the target valve in the drift before MQ7 at 7 TeV

In this section, the shower analysis for the main target valve is presented and analysed. The section begins with a partial repeat of the sensitivity studies before making a detailed analysis of the quench levels and BLM signals.

Sensitivity study – Closed valve position scan

To assess the dependence on pencil beam initial position, a sensitivity study on the closed study valve was made for a selection of initial beam horizontal position and the dependence on the coil energy deposition (GeV /cc /proton) calculated.

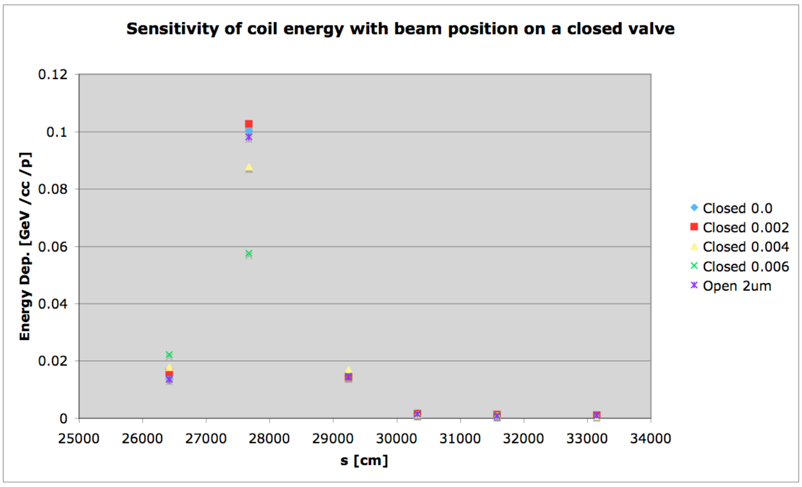

Figure 13: The sensitivity of the coil maximum deposited energy to initial displacement for a closed and open target valve.

The peak energy deposition along s is plotted in Figure 13, and the valve is located at 25856.65 cm. The first point corresponds to loss in MQ7, and the peak to loss in MBA8. The magnitude of the peak shows some dependence on the initial position, but the peak deposition drops as the beam moves off-axis. The study also finds the same conclusion as for the study valve, and the beam incident on an open valve gives very similar peaks to the beam incident on a closed valve.

Closed valve at 7 TeV for the target valve

The valve in the closed configuration and an incident pencil beam was simulated to check the MQ and MB coil energy deposition and BLM signal at 7 TeV. The beam is located at x=0. The energy deposition, with the peak in MBA8 visible, is shown in Figure 14.

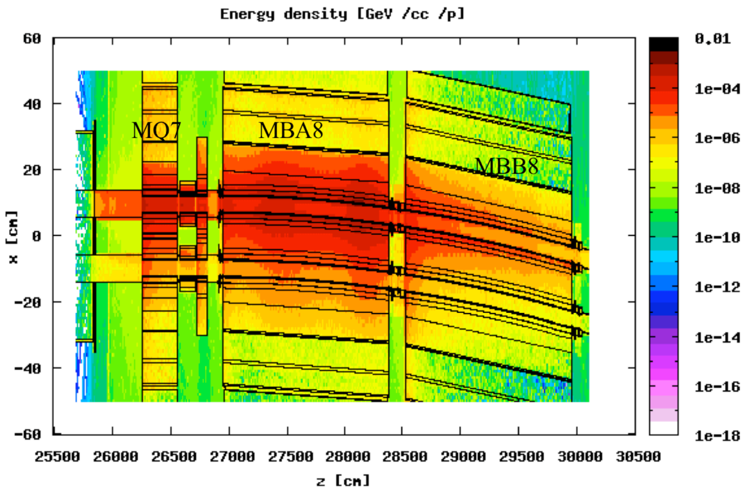

Figure 14: The energy deposition in the downstream magnets for a 7 TeV beam incident on a closed target valve.

The energy deposition scored in the downstream magnet coils is shown in Figure 15.

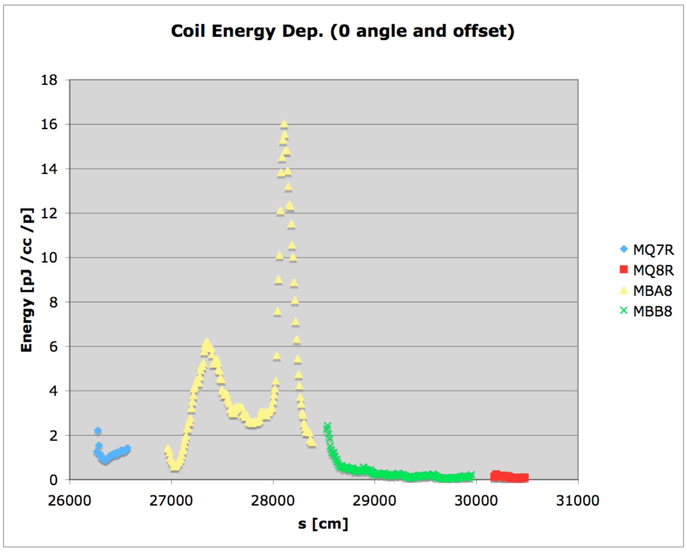

Figure 15: The energy deposition for a 7 TeV beam incident on a closed target valve.

The further downstream elements are not shown, as the energy deposition is very small. The peak corresponds to the coils of MBA8, with a peak valve of 16.1 pJ /cc /proton hitting the valve, with an error of 3.6%. The energy deposited into MBA8 is reduced for the case of the target valve, as this valve is further from MBA8 than the study valve. However the energy deposited into MQ7 has increased by a factor of 2 for the target valve case. MBA8 will reach the quench level of 1 mJ /cc when 6E7 protons are incident on the valve face. The peaks in the magnet coils exceeds the peaks in other locations e.g. in the interconnects. The associated BLM signal, scored along the length of all relevant magnets is shown in Figure 16

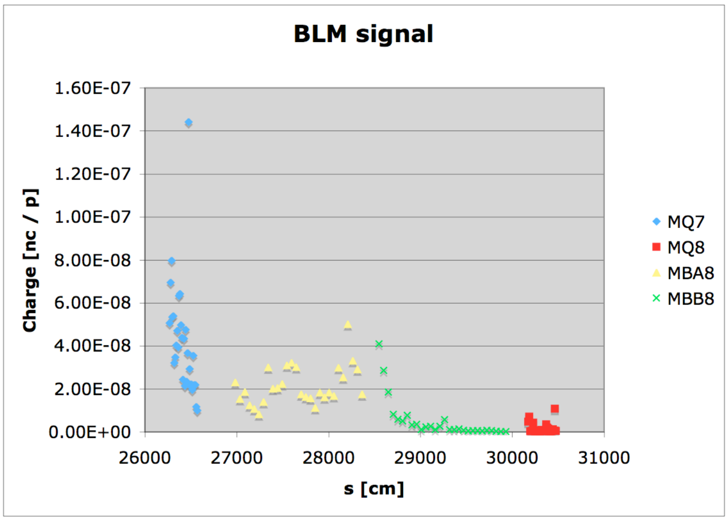

Figure 16: The BLM signal for a 7 TeV beam incident on a closed target valve.

The peak BLM signal of 1E-7 nC /proton is seen in the BLM system of MQ7, with a second peak of 5.E-8 nc /proton seen in the BLM system of MBA8. This corresponds to a peak in a BLM stretching along the length of the magnet and may be slightly larger than the signal seen in the physical BLM. Note the BLM peak is seen in the BLMs of MQ7 for the target valve, as opposed to in MBA8 for the study valve. At the quench level of 1 mJ /cc in the coils of MBA8, the BLM signal in MQ7 is 9.0 nC and in MBA8 is 3.1 nC. This is in excess of the BLM threshold. Note the BLM threshold is also exceeded in the BLM of MBA8. The conclusions for the closed valve will also apply for the open valve with an impact parameter of 2um, as found for the study valve case.

BLM Applied thresholds	7 TeV Applied, uGy	7 TeV, Applied, nC
MB	21	1.1
MQ 1	75	4.1
MQ 2	24	1.3

Figure 17: The applied BLM thresholds in the LHC.

The calculated BLM signals at the quench level can be compared to the applied BLM thresholds (about 1/3 of maximum) set in the LHC BLM. These are shown in **Error! Reference source not found.** for an integration time of 40 us and at 7 TeV. This is done both to check the BLM signals are approximately the same or in excess of the applied thresholds, and also as a crosscheck of the calculations. The calculations in this report show that for a loss in MQ7, the BLM in MB sees 1.9 nC and for loss in front of MQ7, the BLM in MQ sees 9 nC. These are consistent with, and in excess of, the thresholds in **Error! Reference source not found.**.

The BLMs can see a minimum signal of pCs, for an integration time of 40 us. For this case, the BLM sees 1E-7 nC / proton, and so will reach the BLM detection limit of 1 pC when 1.E5 protons are incident on the valve, which is 8.E-7 of a nominal bunch (1.3E11 protons). Similarly, the quench level is reached when 6E7 protons are lost on the valve, which is 5E-4 of a nominal bunch. The beta-function here is 112 m in the horizontal plane, so assuming a normalised emittance of 3.75E-6 m.rad and a Gaussian distributed bunch, the number of incident protons reaches the BLM minimum threshold level when the valve is 1.24 mm from the beam-pipe centre, and the magnet quench level when the valve is 0.78 mm from the beam-pipe centre (assuming a centred beam). Also, the BLM will reach the applied BLM threshold of 1.3 nC (taken from **Error! Reference source not found.**) when the valve is 0.88 mm from the beam centre. In the time between the applied threshold being reached and the quench level being reached, which is the most interesting for machine protection, the valve moves 1.0E-4/0.02 m/s, which is 5 ms. Therefore the BLM sees a signal 5 ms (56 turns) before the quench level is reached. Also the time between the minimum detection of 1 pC and the quench level is 23 ms. This crude calculation assumes a perfectly Gaussian bunch but shows there is sufficient reserve between the BLM applied threshold being reached, triggering a beam dump, and the quench of the first magnet.

4 other cases of interest

In the section the other cases of interest are discussed. This includes at beam energies of 3.5 TeV and 5 TeV and for a valve located very far in front of MQ7.

The target valve at 3.5 TeV and 5 TeV

In this section, the target valve in the drift immediately before MQ7 is studied at beam energies of 3.5 TeV and 5 TeV for the case of a closed valve and a central beam position. For these energies the quench levels are taken to be 3 mJ /cc at 5 TeV and 9 mJ /cc at 3.5 TeV. For the lower energy cases the fields in the magnets and beam energy were scaled by the appropriate amount, but all other normalisation factors remain the same. The location of the coil energy deposition peak for the three energies is shown in Figure 18.

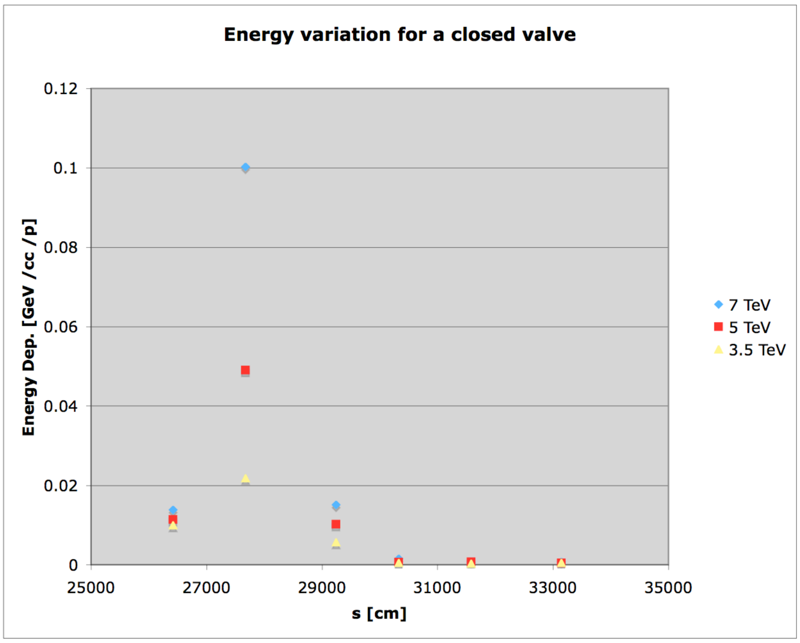

Figure 18: The variation of energy deposition peaks for varying beam energy on a closed target valve.

The first point corresponds to MQ7, and the peak is located in MBA8 for all three energies. The magnitude of the energy deposition falls with decreasing beam energy. The detailed longitudinal energy deposition scored in the downstream magnet coils is for the case of 3.5 TeV beam energy is shown in

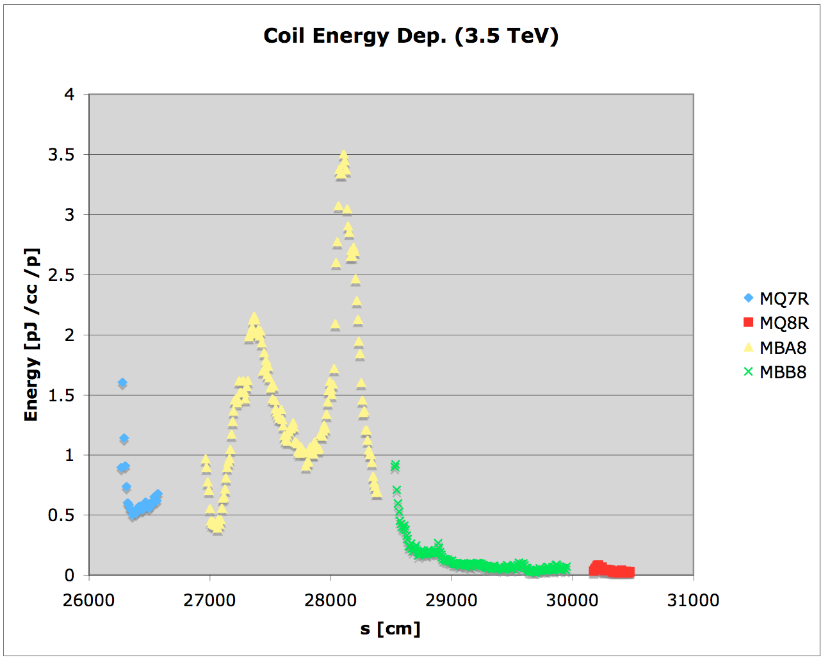

Figure 19: The energy deposition for a 3.5 TeV beam incident on a closed target valve.

The further downstream elements are not shown, as the energy deposition is very small. The peak corresponds to the coils of MBA8, with a peak valve of 3.5 pJ /cc /proton hitting the valve, with an error of 2.8%. Therefore MBA8 will reach the quench level of 9 mJ/cc when 3E9 protons are incident on the valve face. The peaks in the magnet coils exceeds the peaks in other locations e.g. in the interconnects. The associated BLM signal, scored along the length of all relevant magnets is shown in Figure 20.

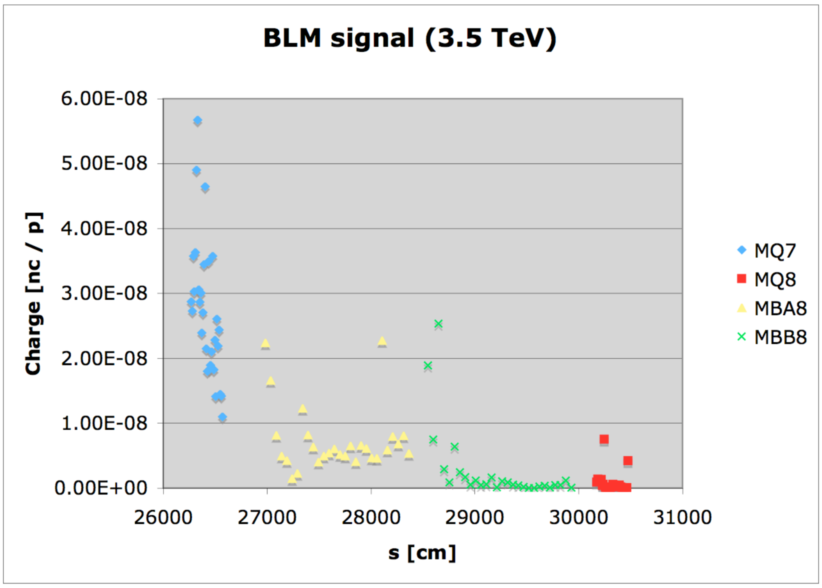

Figure 20: The BLM signal for a 3.5 TeV beam incident on a closed target valve.

The peak BLM signal of 6E-8 nC /proton is seen in the BLM system of MQ7, with a second peak of 3E-8 nc /proton seen in the BLM system of MBB8. This corresponds to a peak in a BLM stretching along the length of the magnet and may be slightly larger than the signal seen in the physical BLM. Note the BLM peak is seen in the BLMs of MQ7 for the target valve at 3.5 TeV, in agreement with the 7 TeV case and opposed to the peak seen in MBA8 for the study valve case. At the quench level of 9 mJ /cc in the coils of MBA8, the BLM signal in MQ7 is 146 nC and in MBB8 is 65 nC. This is well in excess of the BLM detection limit. Note the BLM threshold is also exceeded in the BLM of MBA8. The conclusion of an easily seen BLM signal at the quench level has been made for the 7 TeV case and for the 3.5 TeV case, and hence applies at the 5 TeV case also. Finally, the conclusions for the closed valve will also apply for the open valve with an impact parameter of 2um, as found for the study valve case.

Studies at the second (far) valve location at 7 TeV

In this section the second target valve, located after MQ6 at 23526.15 cm, is studied. This valve is relatively far from the cold elements, and separated from the cold MQ7 by the TCLA collimator. For the case of a 7 TeV beam incident on a closed valve, the energy deposition peak is in MQ7 and MBA8, both with 5.4 pJ /cc /p and errors 8.2% and 3.7% respectively. Therefore to reach the quench level 2E8 protons needs to be incident on the valve. The peak BLM signal is seen in BLMs of the TCLA, where BLSA7R1 sees 7.5E-8 nC / p, and so a signal of 15 nC.

5 Conclusions

In this report, the impact of a vacuum sector valve on the LHC beam has been calculated and analysed. The valves are interlocked so a closing valve should trigger a beam dump request, and a series of shower calculations was made to check the impact on the downstream magnets if this dump request is not made. The calculations checked the energy deposition to the superconducting magnet coils and calculated the signal in the BLMs.

Valve location	Config	Energy	Peak	pJ /cc /p	Error %	Quench level mJ /cc	# p's to quench	BLM sig. peak	BLM sig. at peak nC /p	nC	Time
Study	Closed	7 TeV	MBA8	20.9	2.6	1	5E7	MBB8	4E-8	1.9	1 ms
Study	Open	7 TeV	MBA8	21.0	2.0	1	5E7	MQ7	6E-8	2.9	3 ms
Target	Closed	7 TeV	MBA8	16.1	3.6	1	6E7	MQ7	1E-7	9.0	5 ms
Target	Closed	3.5 TeV	MBA8	3.5	2.8	9	3E9	MQ7	6E-8	146	37 ms*
Target	Closed	5.0 TeV	MBA8	7.8	2.5	5	4E8	MQ7	8E-8	32	30 ms*
Far	Closed	7 TeV	MQ7	5.4	8.2	1	2E8	Coll.	8E-8	15	27 ms*

igure 21: The key results of this study.

A summary of the key results from this study can be found in Figure 21, including the number of incident protons needed to quench a superconducting magnet, the BLM seen at this level and an estimate of the time lag between the BLM reaching the applied threshold of **Error! Reference source not found.** and the first magnet quench. Note the applied quench levels for the 3.5 TeV and 5 TeV cases are not known at the time of writing, so the time for the starred time entries is between the 1 pC minimum of a BLM and the quench level. The margin for these cases between the applied threshold and the quench level will be larger for these cases than for 7 TeV.

For the case of the study valve located immediately before MQ7, the results show that the position of and magnitude of the energy deposition peak is insensitive to the position and angle of the incident beam on a valve. This conclusion is true for a valve in a closed position, or an open position at variable impact parameter. Furthermore, the number of protons incident on the valve to trigger a quench in MQ7 in consistent with previous studies of 1E7 to 1E8, and the BLM signals are consistent with the BLM threshold calculations.

For the case of a 7 TeV beam striking a DN63 valve in the drift before MQ7, the shower peak is seen in MBA8 and reaches 16.1 pJ /cc /proton hitting the valve. At the quench level of 1 mJ /cc, MBA8 quenches when 6E7 protons hit the valve, and at this level the BLM on MQ7 sees a signal of 9 nC. This BLM sees the applied threshold of 1.3 nC 5 ms (56 turns) before the quench level is reached. Therefore the BLM sees a signal above the applied threshold, thus detecting the loss on the valve and triggering a beam dump, and there is a margin before the quench (and later the damage) level is reached. For a 3.5 TeV beam on this valve, the loss pattern is the same and the BLM receives 1 pC 37 ms before the quench level of 9 mJ /cc is reached. The pattern of results and conclusions are the similar for the other cases, as can be seen from Figure 21.

The conclusion of this study is that the BLM sees a signal before the quench level is reached and can react appropriately before a quench occurs. The signal at the quench level is consistent with the BLM quench levels set the by the BLM team is valid for all energies and valves studied.

The principle systematic uncertainties in this study are

1. The beam is modelled as a pencil beam, rather than with a full distribution
2. The MB magnets are modelled piece-wise rather than a continuous curve
3. The actual beam-valve impact occurs at small impact parameter, where large uncertainties are inherent.

The statistical error for the energy deposition in the coils is small (generally a few percent), while the BLM statistical uncertainties are larger.

To complete the study, a calculation should be made of damage levels in both machine elements and to the valve itself (for example, a valve located before a warm collimator section, with correspondingly high BLM threshold), and the valve closure logic checked and perhaps interlocked. Finally, there are interlocked vacuum valves close to all the LHC experiments (between the TAS and Q1, close to Q1), which may need to be checked for possible dangerous scenarios by the experiments themselves.

Acknowledgements

We would like to thank Wim Maan for important input and advice on the vacuum valves, and Daniela Macina, Jorg Wenninger and Rudiger Schmidt for many useful discussions and input.

References

[1] "The FLUKA code: Description and benchmarking", G. Battistoni, S. Muraro, P.R. Sala, F. Cerutti, A. Ferrari, S. Roesler, A. Fasso`, J. Ranft,
Proceedings of the Hadronic Shower Simulation Workshop 2006, Fermilab 6--8 September 2006, M. Albrow, R. Raja eds. AIP Conference Proceeding 896, 31-49, (2007)

"FLUKA: a multi-particle transport code"
A. Fasso`, A. Ferrari, J. Ranft, and P.R. Sala,
CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773

[2] CERN-AB-Note-2007-018 ATB

[3] V. Vlachoudis et al., "Consequences of Regular and Irregular Beam Impact on the LHC Collimators," Proc. Monte Carlo 2005 Topl. Mtg. (MC2005), Chattanooga, Tennessee, April 17-21, 2005, American Nuclear Society (2005)