BLM THRESHOLD EVOLUTION AND 2016 PROPOSAL

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Abstract

In total, over 5700 changes to the BLM thresholds were made during 2015. The new thresholds are based on the operational experience from Run 1, on new simulation models and on results from quench tests performed so far. Following the first experiences with operation at 6.5 TeV, a series of adjustments were made throughout the first operational year of Run 2. An overview of the main changes since the start of the LHC operation and their impact on the machine protection will be presented, focusing on the impact on availability during operation in 2015. The paper will conclude by discussing the remaining main updates, and by proposing a threshold strategy for the start-up in 2016.

BEAM LOSS MONITORING SYSTEM

At the beginning of Run 2, the beam loss monitoring (BLM) system had 3929 detectors out of which 3518 were connected to the Beam Interlock System (BIS). Although there are three types of detectors employed by the LHC BLM system, only Ionization Chambers (IC) are connected to BIS. The two other types, LIC (108 in LHC) and SEM (191 in LHC) are currently installed for additional measurement purposes [1].

Among the changes to the BLM system between Run 1 and Run 2, there were the relocation of 816 detectors from the side of MQ magnets to on top of the interconnects of the MB magnets in ARCs and DSs, and the replacement of SEMs with LICs in the injection regions (IR2 and 8).

RUN 2 THRESHOLDS

For Run 2, most of the detectors got new threshold settings. New methods to calculate threshold values were based on improvements in FLUKA [2-3] and QP3 [4] simulations [5-6] and experience from Run 1 [7-8]. In total 75 new threshold families were created.

One of the goals for Run 2 was to reduce the number of threshold families. This was done by regrouping and by combining threshold families that had the same settings. In Run 1 there were 176 threshold families. For Run 2 this number has been reduced to 119 mainly by combining beam 1 and 2 families into single families with new thresholds as described above. Nevertheless, the number of families is expected to increase in 2016 to fulfil operational requirements and apply lessons learnt during 2015.

In addition to the initial threshold changes based on the new models and Run 1 results, the thresholds were also adjusted during 2015 for operational reasons. Increased losses from collision debris in interaction regions and collimation leakage around IR7 collimators required modifications to the threshold values [9-10].

Figure 1 shows an example of threshold values increase. During LS1, TOTEM introduced on each side of IP5 one new Roman Pot with cylindrical geometry [11]. The new design reduced the impedance but increased the material budget. This in combination with the new collimation settings increased the steady state losses that were measured by the detectors around TOTEM [12]. To avoid potential beam dumps the thresholds were increased for RS7-12 above the level of the next limiting detector on the MQM magnet. The short running sums were kept unchanged to keep the protection level against fast losses.

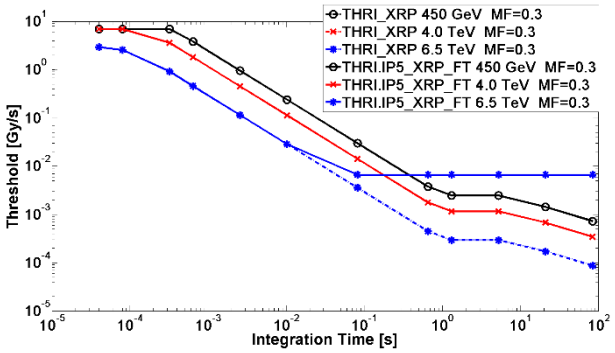

Figure 1: Increase of thresholds for ICs on TOTEM Roman Pots. Dashed lines show the thresholds before the changes and the solid line after the changes. For TOTEM BLMs the changes were applied only to top energy where the debris could have started to limit the operation.

The second main reason for the threshold adjustments during 2015 was losses from UFOs. These changes were required all around the machine [13-15]. An example of the changes due to UFO losses can be seen in Fig. 2. In the beginning of Run 2, TOTEM and ALFA BLMs had identical threshold settings. However increased UFO activity was seen close to one of the ALFA Roman Pots even with device retracted. To avoid unnecessary limitations, the thresholds for the ALFA RP BLMs were modified for the short and intermediate RS and the very long ones were kept intact to protect the device during the special runs when it is inserted.

The debris corrections were made initially for threshold energy levels for 6.5 TeV operation and above, but it was later realized that the ion run at 6.37 Z TeV falls into the previous energy level, thus further modifications for the debris corrections were required. In addition, new

families for ion operation were created [16]. The detectors for ion operation were installed already in the beginning of Run 1 but did not have ion dedicated thresholds.

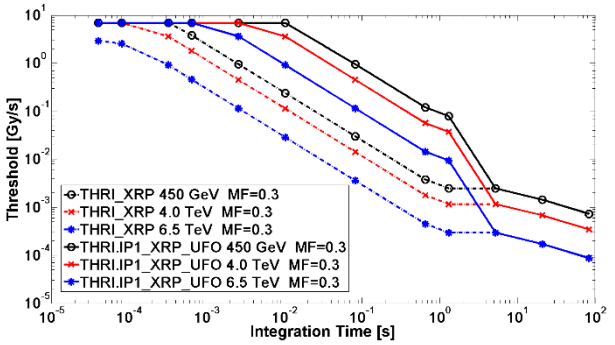

Figure 2: Threshold modifications for the BLMs on ALFA RPs due to UFO losses. The dashed lines show the original XRP BLM thresholds and the solid lines the modified threshold values.

In total over 5700 changes to the thresholds were made during 2015. In addition to operational modifications, a series of temporary changes for MDs were required. For all the permanent changes Engineering Change Requests (ECR) describing the reasoning and the details of the changes were written. For the 2015 changes, 7 ECRs for operational changes, and 2 ECRs for MD changes were approved.

IMPLEMENTATION

During Run 1, the threshold values were calculated with a C++ library containing classes and data files describing the knowledge about the energy deposition by particle showers in the BLMs and in the LHC elements and about the critical values of energy deposition in elements. The final product was a full threshold table that was sent to BLM threshold-comparator electronics [17-18].

For Run 2 the calculation methods were completely revised. A new tool that allows making calculations directly on the database level was introduced [19-20]. The threshold calculation methods that were created for Run 1 were copied to the new implementation for validation of the SQL based calculations. Detailed verification processes verified that the new tool was able to reproduce the Run 1 models.

After the validation of the tool, new threshold models were introduced to the database. Differing from Run 1, the energy deposition to the elements can be taken directly from tables, such as output from QP3 calculations, which are uploaded to the database. For Run 2, new underlying models are introduced with templates to the database. The templates define the equations to calculate the number of lost protons, energy deposition and in the case of cold elements, the QP3 table that is used in the calculations. Figure 3 shows an example of the parameters and the formulas of the underlying model for the BLMs on top of the interconnect between MB magnets. In addition to creating new families via templates, already implemented formulas and parameter tables can also be combined to create a new family.

After the underlying parameters for a family are selected, various corrections are added to families and the actual calculations to create the threshold tables are launched. The corrections are used to adjust the master tables for missing features or inaccuracies in the models, or modification requests based on operation, as can be seen in Figs. 1 and 2. The underlying models for both cases are identical, but the additional corrections differ due to different requirements.

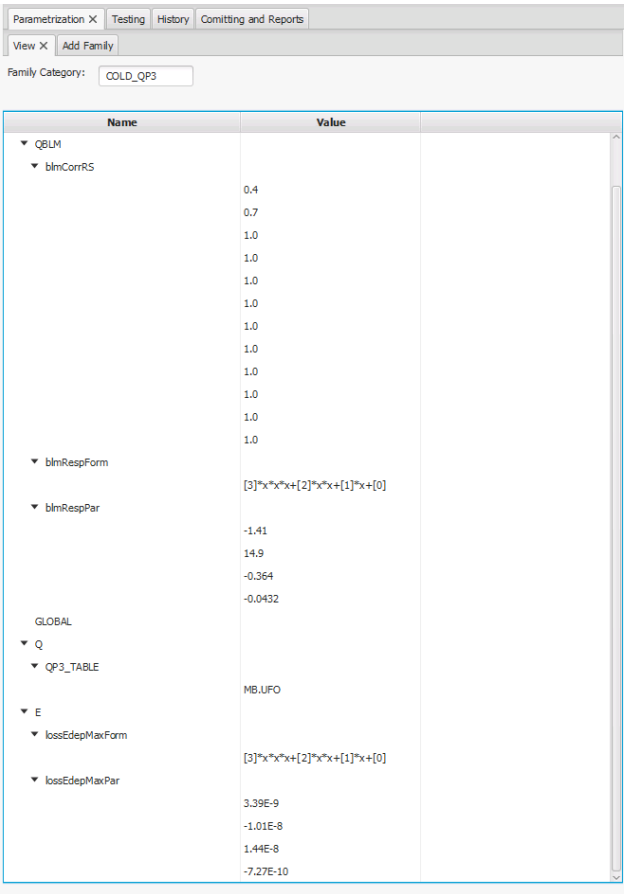

Figure 3: Parameterization view of the threshold calculator application.

The tool allows to immediately check the new values and families and to compare them against other threshold values. In addition to the current threshold values, comparison with historic values is also possible. This can be done for either master or applied table values. Figure 4 shows an example of comparison of two families with the application.

After the threshold modifications are written to the LSA master tables or when changes are made to MFs, a dedicated check [21] is executed to verify those changes. In addition to verifying the changes after planned modifications, this python based process is executed automatically as a daily watchdog to catch unscheduled changes to the threshold values in the database. The process compares the thresholds values, setup flags, filter

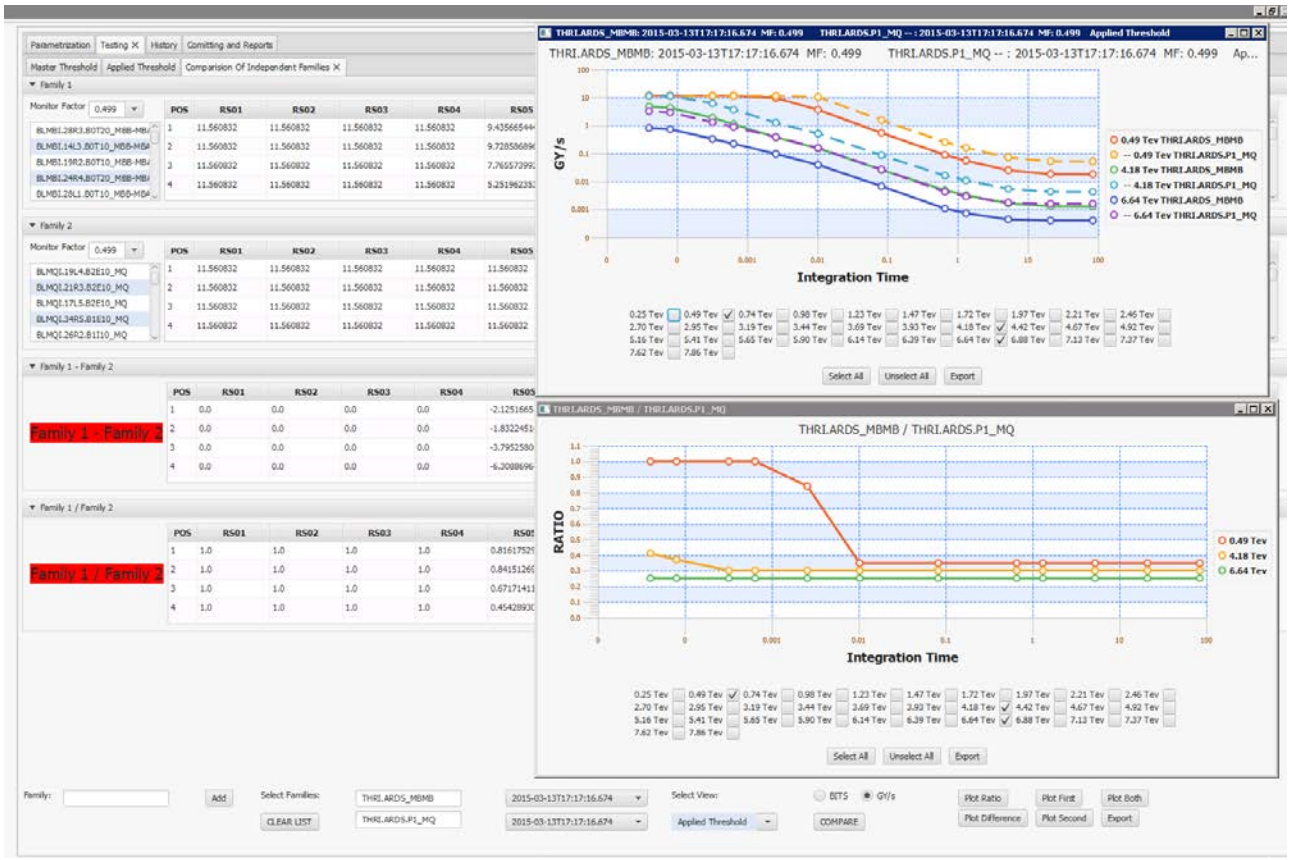

Figure 4: Comparison of two threshold families with the thresholds calculator application.

values, and the family compositions between two timestamps and generates a report which lists all the differences.

TIME EVOLUTION

For the cold magnets, the initial threshold settings for start-up in 2008 were based on the assumptions reported in [22]. These values were later corrected in 2011 based on the operational experience during Run 1, quench test analysis and the requirements set by UFO activity. As described above, for Run 2 completely new models were calculated. The Run 1 thresholds were used as for reference and for verification that the new values are not limiting the operation.

For collimators, the underlying models from 2008 are mainly still in use. The differences to the original models are due to various ad-hoc and scale corrections that have been implemented based on limitations arising during operation.

Figure 5 shows, as an example, the time evolution of BLM thresholds of position 1 detectors on MQ magnets. The top left plot shows the initial threshold values. Based on the first operational results, the thresholds were adapted to losses by slightly lowering short running sums and by increasing long running sums (top right).

After the first year of operation the UFO losses were beginning to dominate as cause of beam dumps. To increase availability, the Monitor Factors (MFs) of the detectors were increased from 0.1 to 0.3 in 02/10/2010 (mid left). For the start-up in 2011 all the previous MFs' increases due to UFOs and the results from the quench test of 2011 were incorporated directly in the master thresholds. This allowed lowering the MFs back to 0.1 (mid right) [23].

For 2015 the thresholds were calculated directly on the UFO scenario. The MFs were set to 0.333, which set the applied threshold level to the assumed quench level. However during the operation in 2015 it was found that the thresholds were causing unnecessary beam dumps and that the initial values underestimated the quench level on UFO losses. As mitigation, for the final two weeks of the proton operation, the MFs were increased to 0.499.

TESTING

The BLM thresholds can be evaluated and validated with quench tests. In those tests, the operational thresholds are increased high enough to allow quenching a magnet in a selected location [24-25].

In 2015 two heavy-ion quench tests were made, both inducing a quench in a superconducting magnet [26-28]. In addition, one collimation quench test was carried out with proton beams, but that was not able to quench a magnet. Despite not quenching any magnet, the test was still able to give new information on threshold levels in various locations [29-30].

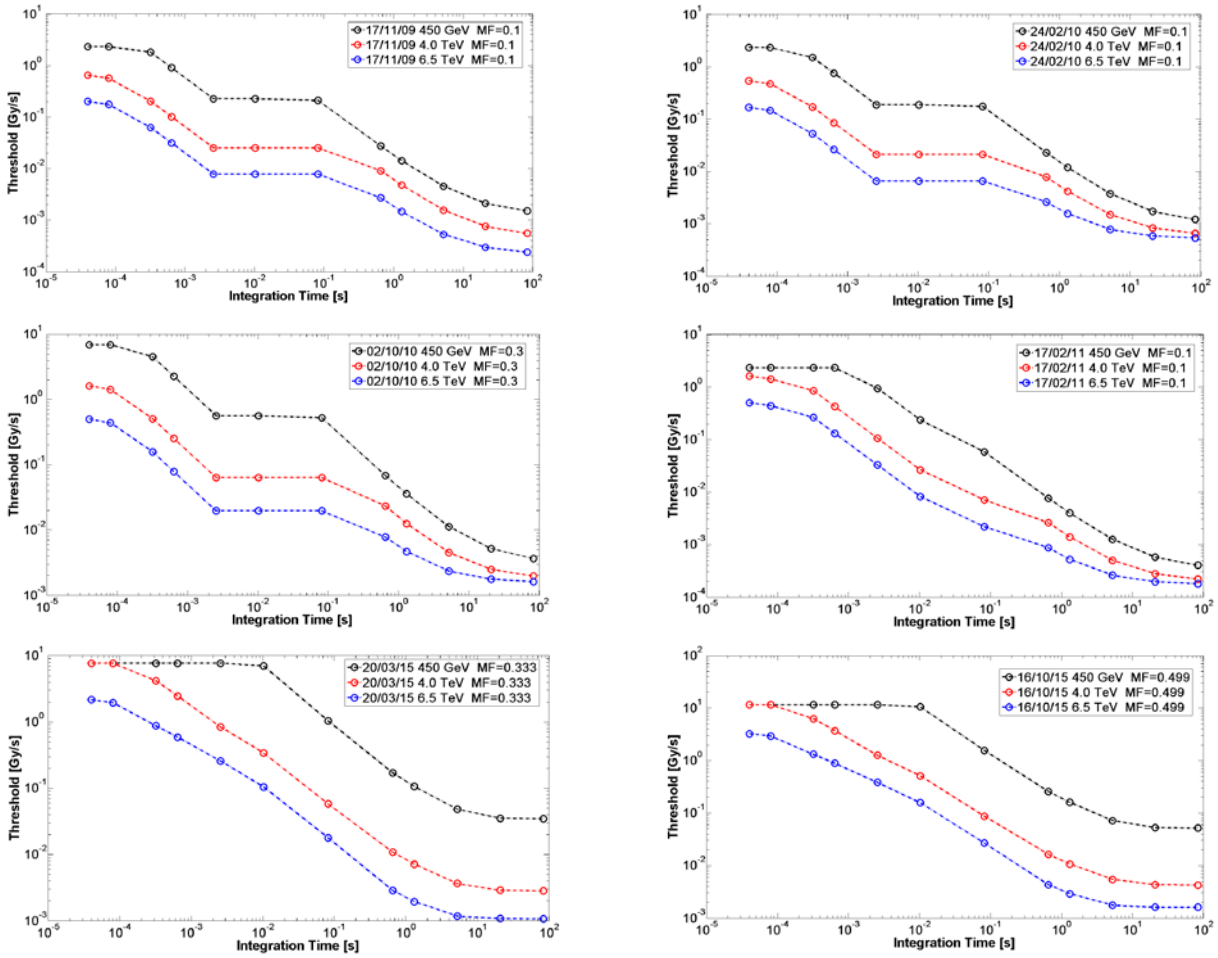

Figure 5: Time evolution of threshold values for detectors located in position 1 on MQs in ARCs. Time proceeds from left to right and from top to bottom.

Figure 6 shows a ratio between the measured losses during the heavy-ion collimation quench test and the operational applied threshold values of BLMEI.09L7.B2I30_MBB detector. The largest signal to threshold ratio was measured for RS10 where the signal values crossed the threshold values by factor 3.5 before quenching the magnet. From this it can easily be concluded that the operational thresholds for a detector at this location clearly underestimate the steady state quench levels for heavy ions.

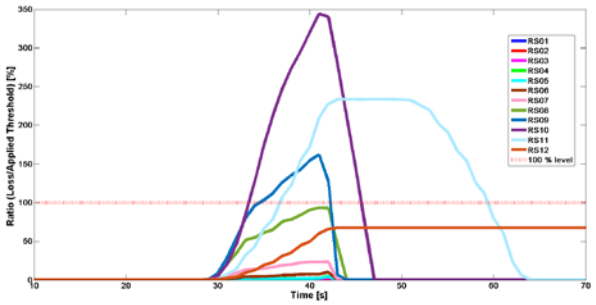

Figure 6: Signal to threshold ratio of the BLMEI.09L7.B2I30_MBB detector during the heavy-ion collimation quench test of 13/12/2015.

All detectors in Cell 9L7 are listed in Table 1 For two locations the thresholds are crossed by factor three or more. This implies that the threshold settings for heavy-ion operation underestimate the steady state quench levels and a correction to the thresholds at these locations should be made. This can be done for instance by creating specific families for heavy-ion operations. It could be beneficial to have separate proton and ion thresholds for specific BLM families.

From the BFPP quench test it can be seen that the thresholds that were set specifically to protect against BFPP losses overestimate the quench level for long running sums. The long running sums are to be reduced by factor two for 2016 operation.

PROPOSAL 2016

From the ion quench tests, and from operational experience, it can be seen that separate threshold families for ion operations are needed. The ion operation would have the same family structure, but with additional ION families that would have additional ion specific corrections that are required for operation. For ion-proton operation this implies that B1 and B2 may need different threshold settings and that the detectors could need to be moved in and out from the ION families when the beams are swapped.

Table 1: Maximum signal to threshold ratio during collimation quench test in 13/12/2015. From the values it can be seen that the threshold values underestimate the quench level for losses from heavy ions. The highest signal to threshold ratios can be seen in monitors on top of interconnect between the magnet and in the monitor located right after the interconnect. The values with red background would have dumped the beam and the values on yellow would have appeared to be above warning levels in the BLM display during standard operation.

% of thresholds	B2I21_MQ	B2I10_MQ	B2I25_MBA	B2I24_MBA	B2I23_MBA	B2I22_MBA	B2I21_MBA	B2I30_MBB	B0T10_MBB-MBA	B2I22_MBB	B2I21_MBB
RS01	0.2	0.4	0.7	0.6	1.3	0.6	0.7	2.0	0.9	0.4	0.6
RS02	0.1	0.3	0.6	0.6	0.8	0.6	0.7	2.0	0.9	0.4	0.6
RS03	0.2	0.6	0.9	0.8	0.8	0.8	0.9	2.7	1.6	0.5	0.8
RS04	0.3	0.9	1.7	1.6	1.6	1.5	1.8	5.1	2.3	1.0	1.5
RS05	0.5	1.8	1.4	1.3	1.3	1.2	1.5	4.2	4.6	0.8	1.2
RS06	0.8	2.8	3.6	3.2	3.3	3.1	3.7	10.4	7.0	2.0	3.0
RS07	3.0	10.0	8.3	7.4	7.6	7.3	8.6	23.6	25.3	4.7	6.6
RS08	16.7	55.6	33.0	29.5	30.5	29.0	34.3	93.5	139.0	18.4	26.3
RS09	24.1	80.3	57.6	51.4	52.8	50.5	59.4	162.2	199.8	32.0	45.2
RS10	35.1	117.0	122.3	108.6	111.8	107.6	126.5	344.8	293.7	68.0	96.7
RS11	17.2	57.2	82.7	73.9	76.0	72.9	85.6	233.3	143.2	46.5	66.0
RS12	4.3	14.5	23.9	21.3	22.0	21.1	24.8	67.4	36.3	13.5	19.1

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