FROM MD INTO OPERATIONAL USE

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Abstract

The Machine Development studies performed over the last years have been analysed with the aim to assess their merit for operation of the LHC. Special attention is given to those MDs which have found a direct operational use. MDs more indirectly related to operation, like machine protection or hardware development, are also identified. It is also tried to estimate which MDs performed over the last years are expected to find their application in the 2018 operation of the LHC.

INTRODUCTION

The Machine Development studies (MD) performed over the last years had a large effect on the way the LHC has been operated in 2017. One of the most striking examples was the operation with the 8b4e filling pattern to circumvent the UFO like event in 16L2 [1]. This filling pattern by which 8 bunch slots of the 25 ns scheme are followed by 4 empty slots was originally studied in the SPS for electron cloud investigations and used for MDs for the first time in 2015. In 2017 it saved the luminosity production, as for not completely understood reasons it significantly increased the bunch intensity threshold at which the 16L2 beam losses occurred.

Other examples of MDs determining the operational beam parameters are the reduction of beta* at the IPs, pushing the peak luminosity. The beta* limits have been determined in many MDs over the years, taking into account the collimator hierarchy and beam apertures. Related are the minimum crossing angles at the IPs during operation, which have also experimentally been determined during Beam-Beam effect MDs. This was extended to crossing angle levelling studies during MDs and for the first time put in operation in 2017. The faster energy ramp developed during MDs was put in operation for the 5 TeV run. As a last example, the full RF detuning used in 2017 was first developed during MDs as well.

In summary, almost every machine parameter used for luminosity production has first been developed and studied during Machine Development. In this paper we try to estimate the percentage of MDs which has found its way into operation, selected per MD topic.

STATISTICS

In this section the results of categorising all MDs which have taken place in 2015, 2016 and 2017 is shown. For the different MD categories, the individual MDs have been classified as 'Operation' if the MD results have a direct effect on daily LHC operation. If this is not the case the MDs are classified as 'Development'. The total number of MDs analysed over these three years is 155 of which 45 in 2015, 52 in 2016 and 58 in 2017. End of Fill MDs have been excluded. New developments for operations but not maintained (such as DOROS BPMs for coupling measurements) have been categorised as Development. Very few MDs performed in 2017 have been categorised as Operation. An overview of the resulting numbers is given in Table 1. More details on the individual MDs can be found in the individual MD notes of which many are referenced in [2] and the presentations in the LHC Studies Working Group [3].

Beam Instrumentation

In 2015 Beam Instrumentation MDs were often directly applied in operation. However, it can be debated of the calibration of systems, like the BSRT should actually not be MD time but rather be done during operation. Some MDs that did not yet find their way into operation are the DOROS BPMs, Schottky measurements of the chromaticity and Coronagraph measurements. None of the 2016 and 2017 MD results for BI were used in operation.

Collimation

Collimation has had a large number of MDs over the year (see also Table 1). Many MDs are related to the validation of the use of a small beta* in operation: aperture measurements at small beta*; collimation with tighter TCTs, automatic alignment of collimators and loss map optimisation (especially for the off-momentum loss maps).

New collimation hardware was tested for Hl-LHC, which will very likely find its way into normal operation in a later stage: wire collimator; low impedance collimator; active halo control and crystal collimation. Significant studies have been performed on halo scraping and beam excitation.

Operations

It is not surprising that MD requests coming from the operations group are for a large part seen back again in daily operation. Examples of this are the combined ramp and squeeze, which was put in operation in 2016, the anti-levelling with crossing angles used in 2017. The beta* levelling will most likely be put in operation in 2018 as will the faster energy ramp.

Optics

The work carried out on Optics development and corrections by the OMC team in 2015 and 2016 is for a large part found back in operation. A good example is that in 2017 the IR non-linear corrections were for the first time used in operation [4]. Other examples are the automatic coupling corrections and the ballistic optics developed in MD, presently used for BPM calibration.

Table 1: Inventory of 2015 – 2017 MDs. Number of MDs per year classified either as Operation or Development.

	Beam Instrumentation			Collimation			Operations		
	2015	2016	2017	2015	2016	2017	2015	2016	2017
Operation [#]	3	0	0	5	4	1	4	2	1
Development [#]	4	2	3	7	9	16	1	2	4

	Optics			ATS			Instabilities		
	2015	2016	2017	2015	2016	2017	2015	2016	2017
Operation [#]	3	4	0	0	4	0	2	4	0
Development [#]	0	3	9	0	0	5	8	8	8

	Radio Frequency			Machine Protection			Beam Transfer		
	2015	2016	2017	2015	2016	2017	2015	2016	2017
Operation [#]	1	2	0	1	0	1	1	2	0
Development [#]	2	5	4	1	0	4	2	1	2

The more fundamental research of optics MDs consisted of dynamic aperture measurements, investigations of operation at half integer tune and of the DOROS BPMs for coupling measurements.

ATS Optics

A large fraction of MD time in 2016 and 2017 has been devoted to the development of the so-called ATS optics. The development on ATS of 2016 has been used for the 2017 operational optics (weak ATS optics). The 2017 developments have not yet been put in operation, but are part of the HL-LHC baseline developments.

Instabilities

The investigations during MDs on the long range Beam-Beam instabilities resulted in the minimum crossing angle used in operations. The BCMS and BCS beams from the injectors have been used and resulted in a net gain in luminosity, despite the blow-up during the cycle. E-cloud studies determined the scrubbing for operation and the above mentioned 8b4e filling scheme which helped to circumvent the 16L2 beam losses in 2017.

On the other side, the Beam Transfer Functions studies remained more academic, aiming for a better understanding of the instabilities on a longer term. The effect of the Q'' on the beam stability and single bunch instability threshold have been used to improve the global understanding. The impedance localisation with the AC dipole has not yet been used in normal operation.

Radio Frequency

Several MD studies of the RF system have found their way in daily operation: full detuning of the RF cavities, bunch flattening was ready to be used when requested by the LHCb experiment and the longitudinal blow-up as applied during the energy ramp was first developed during Machine Development.

Studies related to longitudinal instabilities are vital for the future HL-LHC operation with increased bunch intensities (both single and coupled). Injection oscillation studies are important for future lifetime optimisation at injection.

The transverse damper was heavily used as support for other MDs and only limited MD time was requested for the ADT itself (only via MPE for characterisation).

Machine Protection

In the years 2015 and 2016 there have been very few Machine Protection related MDs (see Table 1). The number of MDs went up to 5 in 2017. Test of scraping away the beam in case of a non-working beam dump should become operational in the near future. The studies of diamond beam loss detectors in case of an asynchronous beam dump and the studies of injection losses with diamond detectors have been applied in normal operation.

Beam Transfer

Studies at injection concerning emittance preservation and MKI kicker pulse ripple are clearly operation oriented, as are the injection losses studies with diamond BLMs. The MDs on TCDQ – TCT retraction, Q4 quench tests and the injection of 80 bunch batches apply to future operation. The studies of the extraction kicker MKD waveform and the bunched asynchronous beam dump are performed to increase the understanding of present systems, but do not directly affect daily operation.

SUMMARY OF THE YEARS

The data of Table 1 are summarised in Fig. 1 for the different years, adding over the different MD categories discussed above. The figures shows that of the 2015 MDs 44 % found an application in normal operation of the LHC. For 2016 we find a very similar number of 42 %. The year 2017 shows very few MDs which already affected operation in the same year, only 5 %, which is understandable: MDs results are often implemented in the years following the MD. Considering the individual MDs, it is expected that 21 % of the MDs which took place in 2017 will find their application in operation in 2017 and 2018.

DISCUSSION AND CONCLUSIONS

An inventory of MDs performed in 2015 and 2016 shows that more than 40 % of the MDs found a direct application in daily operation in the following years. For the year 2017 this number is far smaller, 5 %, which is expected to go up to 21 % in 2018. This lower number can be explained by the large number of HL-LHC related MDs for which fundamental questions need to be answered or hardware tests performed.

Besides the HL-LHC MDs the MDs that did not find a direct implication can be considered as long term investment, which will bear their fruits after a longer period by increasing the global understanding of the accelerator and its hardware.

A very important MD spin-off is to keep the specialist involved with the running machine. This maintains the understanding and operational tools functional, so in case of any 'emergency' a solution to circumvent specific problems is more likely to be found in a short period. A good example is the 16L2 issue presented.

With this in mind, the Machine Development can be considered as a good short term and long term investment for machine operation.

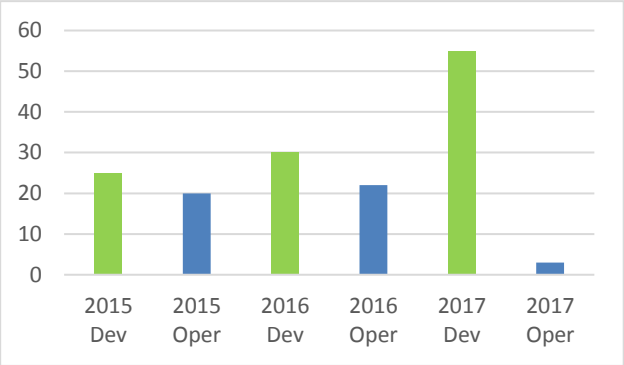

Figure 1: Number of MDs in the years 2015, 2016 and 2017 categorised as either Development or Operation.

REFERENCES

[1] D. Mirarchi, '*16L2 – Post Mortem and lessons learnt*' LHC Performance Workshop Chamonix 29 January – 2 February 2018, CERN Indico event 676124.

[2] R. Tomas et al., '*LHC MDs for 2018*', these proceedings.

[3] Minutes and presentations at the LHC Studies Working Group (LSWG), Indico Event: https://indico.cern.ch/category/3693/.

[4] E. H. Maclean, '*New optics correction approaches in 2017*', these proceedings.