# MACHINE DEVELOPMENT

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*Abstract*

The experience with the Machine Development studies in the LHC over the year 2016 is reviewed. Some results are highlighted and some difficulties encountered are analysed. A statistical analysis of the Machine Development periods of 2016 is made and a rough inventory of the 2017 requests is presented.

## INTRODUCTION

The Machine Development studies (MD) in 2016 have been very successful, despite some initial difficulties due to rescheduling. As is shown Fig. 1, the MD periods were finally concentrated in the second half of 2016, with the first MD taking place at the end of July, while it was originally foreseen to start two months earlier. On the initial LHC schedule 22 days of MD were foreseen, evenly spread throughout the year. The compressed schedule allowed for 20 days of MD with protons and half a day of MD with ions at the end of the run.

Nevertheless, the MDs have been very successful. This has certainly been helped by the very good machine availability experienced throughout the year, including the MD periods. The effective hours of MD per interest group is shown in Fig. 2. It shows that most MD hours were used by the collimation team (75 hours), followed by the collective effects team (67 hours)

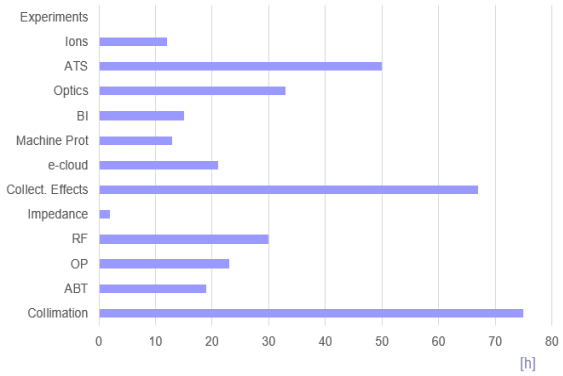


Figure 2: Effective hours used by the different MD teams.

## ORGANISATION

As in recent years the organisation of the MDs has been rather strict. The requests for MDs have first to be filled in at the Website [1], from which a selection is made by the MD coordination. These MDs are then presented at the LHC Studies Working Group [2] in which no-go's can be identified and constructive discussions between different MD participants take place.

The MDs selected are then presented for approval at the LMC, after which written procedure are to be submitted, in general 2 weeks before the MD takes place. The procedures allow to prepare the beam requests for the injectors, presented at the FOM. The procedures are classified in categories A to C, of which the category C MDs are reviewed by the restricted Machine Protection Panel (rMPP).

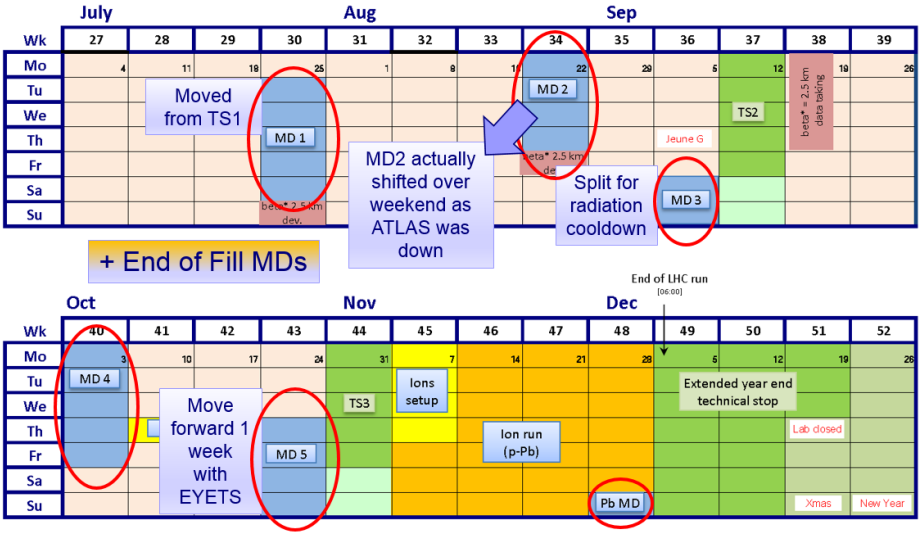


Figure 1: Part of the 2016 LHC schedule with the MD periods highlighted.

The results of the review and the approval of the MDs are documented in EDMS. This approval is generally released a few days before the MD block starts. It has happened in 2016 that an MD has been blocked by rMPP and a spare MD took the liberated time slot.

The year 2016 was the first year in which the MD procedures have been used systematically by the operational team and a printed version was always found on the console in the CCC. As in the previous years, there was no shuffling of the schedule during the MD period. In case of unavailability of the machine the specific MD had to be recovered in a future MD block. It was possibly to stick to this strategy by planning 2 hours of recovery time after each MD taking place at full energy. These 2 hours give a large psychological advantage and for 2016 it is foreseen to include in the planning 2 hour of recovery time for MDs taking place at injection energy.

Results of the MD were presented in the LSWG meetings and a summary was again presented in the LMC. ATS-MD notes were finally written and the collection of the Run II MD notes can be found at [3]. However, at the time of the Evian workshop only 5 MD notes were published from the 56 MDs which had taken place. This can for a very large part be blamed to the large pile-up of MDs towards the end of the year.

## STATISTICS AND AVAILABILITY

In 2016 there have been 20.5 days of MD scheduled. Of these 492 hours, 416 hours were actually on the schedule because of the 2 hours of recovery time after any MD taking place at top energy. 348 hours of scheduled MD took place in 2016 which is and average availability of the machine of 84 %. This is very good and identical to the overall machine availability between the TS2 and TS3 in 2016.

The is very good machine availability does mean that of the 20.5 MD days on the schedule there have been 14.5 net MD days, which is a 'Total Efficiency' of 70 %.

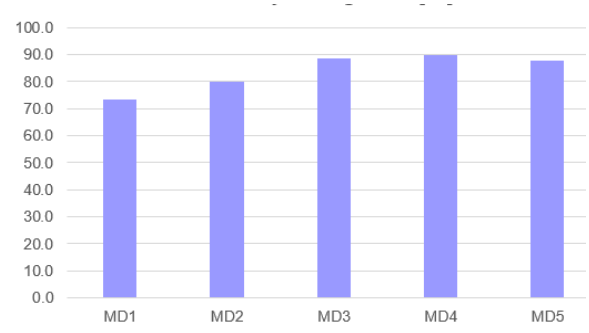


Figure 3: Availability for the different MD blocks in %.

## 2016 MD HIGHLIGHTS AND EXPERIENCE

The highlights of the MDs of 2016 can for a large part be seen throughout many presentation of this Evian workshop. A few of these highlights include the RF bunch flattening with a flattened longitudinal density profile; the DOROS BPMs used for transverse couple correction with a minimum of excitation; single bunch instability studies and the tests with crystal collimation. A reduction of the crossing angle in collision to 140 μrad was applied during physics in 2016, following the good MD results. The full detuning of the accelerating RF cavities, which is crucial for operation with HL beam intensities, was successfully tested. Other MDs worth mentioning are the extraction of chromaticity values from the Schottky sidebands and high pile-up measurements for the high lumi experiments, with record beam-beam tune shifts just below 0.02.

The ATS optics was commissioned over several MD blocks with $\beta^*$ down to 10 cm and down to 33 cm in collisions. This ATS optics is a good candidate for 2017 operation. This is supported by the proven margin on the aperture and collimation settings, with possible primairy collimation settings down to 5.5 $\sigma$.

There have been 15 so called End-of-Fill MDs. For these MD procedures have also been written and approved by rMPP. These MDs have been very useful and is an extremely efficient use of machine time.

There has been a single 12 hour ion MD. However, as the MD was moved with very little notice, the use of the parallel beam was not that well organised and not ideal from a machine protection point of view. These last minutes changes and not well organised MDs (in this case for the parallel beam only) should be avoided in the future.

## INVENTORY OF 2017 MD REQUESTS

A brief survey of the key MD users was made by email concerning their requirements for MDs in 2017. This resulted in a 'request' of 85 different MDs with a total time requirement of 748 hours. Assuming the very good 2016 MD efficiency, this would need 44 days of MDs on the 2017 LHC schedule. There was also a request of 72 hours for End-of-Fill MDs. The distribution of the requested MD time over the different MD users is shown in Fig. 4, together with the numbers for 2016. It are the requests from the ABP group for collective effect studies and for optics studies which have increased the most compared to the 2016 numbers. According to a classification of these MDs by the users and the MD coordinators, 44 % of the MDs are related directly to LHC operation, 45 % to the future HL-LHC and 11 % to FCC.

The 44 days of dedicated MD requests need to be compared to the 15 days of MDs presently on the 2017 MD schedule.

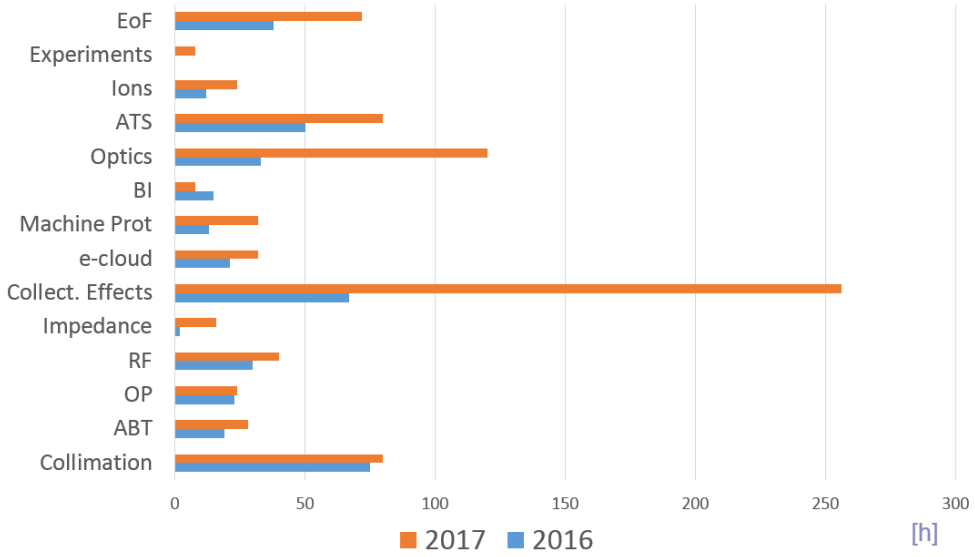


Figure 4: Hours requested by the different MD users.

## CONCLUSIONS

The Machine Development studies in 2016 have been very successful. The net efficiency during the MDs in 2016, taking into account machine availability and recovery time between MDs, was 70 %. The availability during scheduled MD time was 84 %, very similar to availability during normal operation. Many interesting results of the MDs have been presented in this Evian workshop. The results are important for the short term LHC operation, but also for future machines like HL-LHC and FCC.

The recovery and clean-up of settings after the MDs can still be improved. The plan is to be even more explicit in the MD procedures. However, it is the responsibility of the OP team to carefully follow this up and roll-back any changes.

The short MD blocks are easier to manage for the MD participants than the longer MD blocks, which exhaust the people involved in several MDs.

A rough inventory of 2017 MD requests has been made. The requested 44 days of MD time are in strong contrast to the 15 days of MD presently on the schedule. Additional MD time of 3 days, as floating MD, is requested for 2017.

## REFERENCES

[1] MD website: https://md-coord.web.cern.ch.
[2] LHC Studies Working Group website: https://indico.cern.ch/category/3693/.
[3] https://rtomas.web.cern.ch/rtomas/LHC_MD-Notes_Run2.html.