WP2 Meeting #171

Tue 24 Mar 2020, 14:00 – 17:00

Chair: Gianluigi Arduini

Speakers: Serge Claudet, Rogelio Tomás, Davide Gamba

Participants: Gianluigi Arduini, Xavier Buffat, Serge Claudet, Riccardo De Maria, Ilias Efthymiopoulos, Davide Gamba, Massimo Giovannozzi, Giovanni Iadarola, John Jowett, Sofia Kostoglou, Giuseppe Lerner, Alessio Mereghetti, Elias Métral, Nicolas Mounet, Yannis Papaphilippou, Stefano Redaelli, Benoît Salvant, Michaela Schaumann, Galina Skripka, Kyriacos Skoufaris, Guido Sterbini, Rogelio Tomás, Frederik Van Der Veken, Carlo Zannini

AGENDA

MEETING ACTIONS

Rogelio Check the impact on luminosity performance for the LHCb L_{lev}=1.5*10^{34} cm^{-2}s^{-1}

Task Leaders Use 2.5*10^{34} cm^{-2}s^{-1} as initial luminosity when going in collision

GENERAL INFORMATION (GIANLUIGI ARDUINI)

Gianluigi went through the minutes of the last two meetings. On the meeting 169 Davide gave a review of the corrector budget for optics v1.5. He went through the considerations for the circuits and ramp rates. Action for **Davide** is to verify with Magnet Circuit Forum colleagues the new design of the QPS that is being developed. Jorg reviewed the status of the orbit feedback. Ezio went through the status of the correctors (ramp and acceleration rates). Action for **Davide, Ezio, Jorg, Riccardo and Paolo** is to check which magnetic tests could be done on the MCBRD and MCBXF in order to verify if the required ramp and acceleration rates are feasible. Ezio also gave an update on the b4 correction in the LHC triplets. There has been a review of the field errors and the effect of the beam screen on the field quality was added. Some discrepancies between the model and beam-based measurements are still present. **Ezio** will organize a WP3 meeting to recap what is the available information for HLLHC, in particular beam screen impact on the field quality. Riccardo gave a talk on a possibility of shifting the triplets in order to minimize the radiation. Based on Riccardo's study (maximum displacement that can be applied) an Action for **Marta and Riccardo** is to update the results on the reduction of radiation to the triplet.

The meeting 170 was related to impedance and coherent effects. Benoît gave an update on the status of impedance studies. An Action for **Paolo and Massimo** is to provide input on the offsets expected for the deformable finger bellow, to estimate possible effect on impedance. Another Action for **Mike** is to update the intensity limits for MKI for the expected operational cycle. **Nicolas** gave an update on the HL-LHC impedance model including the MKI and triplet beam screen. He will investigate the difference between the new model and the old one created by Sergey A.. **Carlo** gave a talk on the expected Laslett tune shift for HLLHC. He will look at the tune separation along the bunch train to check the implications for the tolerances on the coupling. Xavier reviewed the present understanding and measurements of the impedance. There are discrepancies observed on one of the TCP collimators between 2015 and 2018 measurements. **Nicolas** will check if this can be explained by the installation of the new collimator equipped with the new type BPM buttons. **Xavier** gave another talk on the octupole requirements for stability in HLLHC. The situation will be rechecked for the positive polarity accounting for the latest impedance model because some partial compensation could be present.

Today there are three talks. Serge will present the scenarios for the luminosity ramp-up in the beginning of the fill from the cryogenics point of view. Rogelio will talk about HL-LHC luminosity performance. Davide will give a follow-up on the impact of flux jumps in 11T dipoles on ions (Action meeting #168).

1 HL-LHC WP9 CRYOGENICS, PROCESS STUDIES, COPING WITH PEAK LUMI (RAMPS) (SERGE CLAUDET)

This talk is a follow-up of the presentation given on the WP2 meeting 160. Starting with a short recap of the context. The heat load during the current ramp will triple, but when going into collision due to the secondary particle losses the heat load is rapidly increasing by factor ten. The usual way of coping with these heat loads is to use stored liquid helium for cooling and then recover it by going through the cold compressors. There is a limitation on the acceleration of the cold compressors. The maximum pressure and the equivalent boiling temperature of the magnets were calculated for different accelerations of cold compressors with or without pre-load. To deal with change in heat loads a feed-forward and a pre-load (electrical heaters) are required. The heaters should withstand high levels of radiation over the lifetime of HLLHC. This is not reliable at the moment. Another technique to cope with a fast change of heat loads would be a luminosity ramp. The situation with strategies of coping the heat load transients is the following:

- Cold compressor acceleration increase – already reached maximum
- Pre-load and active control – improvements on the technology and control technique with time
- Luminosity ramp-up – some flexibility is expected

Four luminosity scenarios are presented considering the cold compressors control and mass-flow adjustments. In "feasible" from cryogenics point of view is a scenario when luminosity is continuously ramped during 40 minutes. This scenario is not acceptable from the beam optics and collision side. The vertical rise of the peak luminosity was studied to estimate the maximum possible value acceptable by the heat load management. From this value the ramp can be done. In "present target" scenario the $2.5*10^{34}$ peak luminosity can be reached in a step, then a 10 minutes pause is needed to recover on the mass flow with the cold compressors, and another 20 minutes to ramp up to the ultimate peak luminosity. This scenario is quite conservative and would work without heaters and feed-forward. With experience in controlling the loops and understanding the system behavior the reduction of the pause can be done and the maximum luminosity can be reached by a "step+ramp" combination. The "ultimate goal" is to reach the peak luminosity in a single step.

A beam dump could be as brutal as a rapid luminosity ramp for the system. This is however slightly easier since the system will overcool the magnets whereas overheating at ramp-up is not acceptable.

- **Gianluigi** asked if there are any tests planned to verify the lifetime of the heaters in radiation conditions. **Serge** confirmed that the testing is planned for the current heaters. Additionally, there is a plan to develop new heaters using materials tolerant to radiation.
- **Gianluigi** asked if there is any risk that there is a trip of triplets because the cryo conditions are lost due to the beam dump. **Serge** replied that in this situation 30-40% of integrated luminosity will be lost and this is not acceptable.
- **Ilias** asked how sensitive is the cooling system to variations in luminosity during the emittance scan. **Gianluigi** agreed that this is important and asked if for every fill the system can handle going to half the luminosity and back within 5 minutes. **Serge** replied that the cryo system only will react to the averaged value it is not a problem. The situation at the start of the luminosity ramp is different since the starting value is zero. **Serge** also added that possibly the scan can be done within the 10 minutes pause during the luminosity ramp. **Rogelio** and **Ilias** said that it is usually done at peak luminosity.

2 HL-LHC LUMINOSITY RAMP-UP (AT THE START OF THE FILL AND OVER YEARS) (ROGELIO TOMÁS)

The talk covers the impact of fill luminosity ramp-up with cryo considerations and HL-LHC Baseline and Ultimate luminosity performance. The "feasible" case presented by Serge today is discarded since the ramp starts from zero luminosity. For operation with the baseline peak luminosity of $5*10^{34}$ $cm^{-2}s^{-1}$ the "present target" ramp-up scenario presented by Serge leads to 1.2% loss in integrated luminosity with more loss for shorter fills. For some systems in HL-LHC this is non-negligible, though might look like a small number. The scenario, which can be reached with some experience, will result in a 0.4% loss in integrated luminosity. For the Ultimate peak luminosity of $7.5*10^{34}$ $cm^{-2}s^{-1}$ the "present target" ramp-up scenario leads to 2.7% loss in integrated luminosity and, after some experience, it can be reduced to 1.3% loss, which is still a significant loss for HL-LHC. One has to keep in mind that all the shorter fills ending in beam dumps will increase the loss in integrated luminosity.

Assuming no limitations given on a luminosity ramp-up by cryo (the "ultimate goal" ramp-up scenario) for the IP1&5 the standard values are used for the performance estimation:

- 262 fb^{-1} in 160 days with Baseline peak luminosity
- 405 fb^{-1} in 200 days with Ultimate peak luminosity
- 50% efficiency
- 350 fb^{-1} at the end of Run3 (to be revised!)

The plan is to start Run4 with 30 cm β* and run 220 days in proton physics without MDs or ion runs starting form 2027 onwards. The baseline 15 cm will be reached in 2033. In the HL-LHC era the total number of days in proton physics is 2090. The first two years the machine will operate at reduced efficiency of 40% with beam intensity close to Run3 values ($1.7*10^{11}$ p/bunch). The target efficiency and bunch intensity will be reached in 2029 when ideally the crab cavities (CCs) and the hollow electron lens (HEL) are expected to be working. Taking all this into account, for the Baseline performance the integrated luminosity is surpassing the baseline of 3000 fb^{-1} and reaches more than 3500 fb^{-1}. In the ultimate case, the goal of 4000 fb^{-1} at the end of HL-LHC operation is exceeded by ~4%.

For LHCb ($L_{lev}=2*10^{33}$ $cm^{-2}s^{-1}$) with the Baseline performance the foreseen integrated luminosity will be ~140 fb^{-1} and 10% lower in the Ultimate case.

In case β* = 15 cm cannot be reached and the operation continues with 20 cm, for the Baseline case the integrated luminosity is still well above the goal, but for the Ultimate case the goal is achieved with zero margin.

Accounting also for the extra ion runs in Run5 and Run6 the total number of days in proton physics is reduced to 1850. There is a significant reduction in the integrated luminosity for the Baseline performance and it is barely above the goal of 3000 fb^{-1}, whereas for the Ultimate case the integrated luminosity is reduced by 11% .

In summary, the goals are at reach in the new Baseline. The Ultimate goal is reached with only 4% margin which is lost if the β* is above 15cm or if the cryo request on the luminosity ramp-up takes some of this margin (other effects on the luminosity, like emittance growth, need to be studied). Ion runs in Runs 5&6 reduce the total integrated luminosity by 11%. The cryo request to ramp-up the luminosity should be faster than 20 min to lose less than 1% in Ultimate case.

- **Gianluigi** said that it would be good to evaluate the effect for LHCb $L_{lev}=1.5*10^{34}$ $cm^{-2}s^{-1}$ (value from the last Coordination Meeting). **Rogelio** replied that he would estimate it (**Action:** **Rogelio**).
- **Stefano** pointed out that the HEL should be operational in the first year of Run4, especially if Run 3 showed some limitation with spike losses. **Gianluigi** replied that in 2027 the operation will only last for half a year according to the best plans and all the systems would have to be commissioned. Very likely there simply will be not enough time to commission HEL in 2027 and it will be done in 2028.
- **Stefano** asked why not to go to β* =15 cm in the beginning of operation and then push the intensity. With the current plan the design value is reached only after years of operation, which is maybe non-optimal implementation of the project. **Gianluigi** replied that in Run1 first the intensity was pushed and only then the β* was reduced. The control of field non-linearities was achieved only in 2017. With HL-LHC situation will be similar to having a new machine, the IRs are dominating the field quality. Additionally pushing the intensity has a larger positive impact on integrated performance more than reducing β*. **Ilias** said that for experiments in the beginning it would be difficult to accept small β*. **Rogelio** agreed and added that aiming for β* =15 cm in 2030 will not be significant in terms of absolute performance.
- **Riccardo** asked if the $2.5*10^{34}$ $cm^{-2}s^{-1}$ given by Serge is a stable number to be used in developing a new operational scenario. **Serge** replied that it is the maximum that can be managed. Anything below can be used. (**Action: For all task leaders use this value as initial luminosity when going in collision**)

3 UPDATE ON IMPACT OF FLUX JUMPS IN 11T DIPOLES IN RUN3 (DAVIDE GAMBA)

This is an update on the effect of the flux jumps in the 11 T dipoles in Run3 and what is the risk of damping the beam if they occur.

The information available for the 11 T dipoles is either measured or estimated. The amplitude of the jumps is measured to be 0.2 units average and 0.6 units peak. The reaction of the trim power converter was estimated to be 6 ppm in rms with respect to the rated current of a 600 A power converter. The duration of a flux jump is estimated to be 120 ms FWHM and the beam energy at which most of the jumps occur is measured to be below 3 TeV. These and other parameters on flux jumps were presented at previous WP2 meetings (#144, #167) and in a paper by L. Coello de Portugal *et al.*.

Since the flux jumps are given in units the amplitude of the kick in rad is constant and independent of energy and the orbit distortion, in $\sigma_{beam,}$ is increasing with energy due to adiabatic damping of the beam size. A flux jump in any of the four installed 11 T units will cause an orbit jump, which could cause beam losses at the IR7 collimators. For the worst-case scenario a simultaneous 0.6 units jump in all 11 T magnets is assumed. A worst ratio between orbit jump and σ_{beam} is considered (3TeV and 1.18TeV/A energy for protons and $^{208}Pb^{82+}$, respectively).

A Double Gaussian beam distribution is used for both protons and ions. For the proton beam this distribution is confirmed by the scraping measurements, whereas for ions there is no available information on the beam halo. A 5.7 σ (ε_N=3.5 μm) setting is considered at TCPs for protons, which, in mm, is equal and the setting for ions. Considering a conservative value for the beam emittance of 2.5 μm for both beams (typically measured in LHC 2 μm for protons and estimated 1.65 μm for nominal LIU ion beam), and the different γ of the two beams, the actual collimator settings are going to be: 6.7 σ_{beam} for protons and 4.27 σ_{beam} for ions.

Based on the listed assumptions and beam parameters the maximum orbit jump at TCPs and particles lost on collimators were estimated. The maximum orbit jumps at TCP are 5.9% σ_{beam} and 3.7% σ_{beam} for protons and ions, respectively. Considering the nominal beam intensities of 3.9e14 for protons and 2.2e11 for ions in 2021, the maximum numbers of particles lost at TCPs are estimated at 1.6e10 protons and 1.6e8 ions. These vales are just below the present dump thresholds of the BLM system for both protons and ions. Once again, one should keep in mind that these values for the particle losses are obtained by taking the worst-case scenario values for the jumps and for the particle distributions.

Following the discussion of the last meeting the observables were reviewed. The loss-maps performed during an energy ramp with proton beams showed tighter thresholds than what they could be according to the most recent simulations of allowed number of protons impacting the collimation system (the BLM Threshold WG is presently carrying out a thorough review of the BLM thresholds at collimators independently from the flux jump consideration). In 2018 run some ground-motion-induced orbit jumps of ~10% σ_{beam} were observed. They were stronger than those expected for the flux jumps and occurred at top energy. The losses they have induced were 1e10-2e10 protons, which is five times below the dump thresholds on BLMs. During the ramp, collimator jaws move in steps of ~2% σ_{beam} on a timescale much shorter than 100 ms, following the beam size reduction. This has not caused any critical BLM spikes. The observation of ion losses, when crystal collimators were inserted ~20% σ_{beam}, is compatible with the assumption for tail population of ion beams (assumption of Double Gaussian distribution). Looking at the data for the 10 Hz ion-fill dumps, it was concluded that they were triggered by orbit distortion of ~15% σ_{beam} and have hit 110% BLM thresholds. If re-scaling this observation down to the flux jump case, this gives 66% BLM thresholds at full energy 2.51 TeV/A. Going down to 1.18 TeV/A would give more margin.

To conclude, there are many unknowns but the known margins were used. In the worst-case scenario a maximum orbit jumps of 5.9% σ_{beam} and 3.7% σ_{beam} for protons and ions respectively should be expected. Considering current BLM thresholds and taking the very pessimistic assumptions on flux jumps, the induced losses will be just below the dump thresholds. It is possible to gain margin by working on the threshold settings. The installation of the 11 T dipoles in LHC is considered safe regarding flux jumps, and this gives an opportunity to evaluate the impact of RQX in HLLHC.

- **Gianluigi** said that the observations are confirming that the assumptions made in the study are very conservative. A summary on the flux jumps to the TCC should be reported. After that a list of the unknowns for the HL-LHC triplet should be made. **Davide** commented that for the triplets a similar study was made taking into account the realistic values but not the worst-case assumptions. **Gianluigi** said that for the triplets there was a series of questions, like the behavior of nested power converters, and it will be good to list what has to be learned in Run 3 to be better prepared for the HL-LHC.

- **Nicolas** pointed out that the previously given value for the BLM threshold RS06 was much larger (6 times higher). **Davide** replied that a value given now is re-evaluated from loss-maps by Alessio and it is more realistic. **Alessio** commented that the previous numbers were based on the model from 2008/09 used to set the thresholds. Thresholds during the ramp have been set using that model, whereas at flattop the thresholds are aligned to the measured loss-maps, which is not done for the ramp thresholds. The loss maps taken during the energy ramp of the beam give the opportunity to determine a more realistic BLM response.

4 AGENDA OF NEXT MEETING (GIANLUIGI ARDUINI)

The next WP2 meeting will be on April 7th, starting at 10:00. The agenda will be

- Update on the b4 (Ezio Todesco)
- The effect from b2 and b3 in D1/D2, including feed-down and beta-beating (Frederik Van Der Veken)
- Optimization of the D1 misalignment and possibility to avoid the beam screen modification (Riccardo De Maria)
- Filling scheme update (Giovanni Iadarola)

Reported by G. Skripka