228th HiLumi WP2 Meeting

Tuesday 2nd July 2024, 10:00 – 12:00

Chair: Rogelio Tomas

Speakers: Benjamin Bradu, Lotta Mether, Sofia Kostoglou

Participants (15): Yannis Angelis, Hannes Bartosik, Benjamin Bradu, Xavier Buffat, Andrea Fornara, Massimo Giovannozzi, Sofia Kostoglou, Kevin Li, Lotta Mether, Nicolas Mounet, Kyriacos Skoufaris, Guido Sterbini, Rogelio Tomas, Michail Zampetakis, Markus Zerlauth;

AGENDA

MEETING ACTIONS

WP2: Bring up the strong motivation to use hybrid in 2025 to prepare for HL-LHC and to increase Run 3 performance.

1. GENERAL INFORMATION (ROGELIO TOMAS)

Rogelio reviews the minutes of the 227th WP2 meeting that took place on the 28th of May. **Rogelio**:

- mentioned the open action for WP2 to start preparing a review of the HL-LHC baseline based on the experience gained with BCMS and standard in Run 3 and the lessons learned from the hierarchy breakage.
- contacted the project leader for the choice of the crossing plane in Run 4 and the conclusion is that we can wait until April 2025 to compare and decide between the HV and VH options.
- A discussion on the Non-Linear Beam Dynamics working group was organised where several recommendations were presented in order to avoid DA deviations above 0.5 sigma when comparing different configurations.

2. ARC CRYOGENIC CAPACITY IN THE HL-LHC ERA (BENJAMIN BRADU)

Benjamin presented an overview of the cryogenics infrastructure in the HL-LHC era and the impact on the arc cryogenics capacities. The LHC cryogenics are organised in cryogenic islands that consist of Cryoplant A and B. Cryoplant A supplies low load sectors that are not connected to the high-luminosity triplets of points 1 and 5. **Benjamin** mentions that no changes are planned for these sectors apart from the upgrade in S34 that took place in LS2 in view of HL-LHC. Cryoplant B handles the high-load sectors connected to high-luminosity triplets. Post-LS3, the new HL-LHC triplets will be disconnected from cryoplant B and will be managed by a new cryoplant infrastructure. This change will allow to recover some capacity in the existing cryoplant B.

Benjamin shows that the cryoplant capacity is divided into basic and dynamic heat loads. No change is foreseen in the basic heat load, which accounts for 70% of the capacity. The dynamic heat loads will change depending on the luminosity, the beam energy, the bunch intensity and the filling scheme. The high-luminosity triplet disconnection in HL-LHC will result in an increase of the arc cooling power by 25 W/hc in S12, S45, S56, S81.

Benjamin summarises the beam screen cryogenic heat load averages in each arc measured during a nominal fill of the 2024 run (2352 bunches, 3x36b and 1.6e11 ppb). The comparison with the beam screen capacities shows that we are at the limit in S78. It must be noted that each sector has a different capacity and loads.

Although the capacities of the high luminosity sectors will increase by 25 W/hc in HL-LHC, the heat loads will also increase with the HL-LHC beams. At the same time, there is possible degradation of the beam screen surface that might take place in LS3 based on experience gained from the past long shutdowns. Electron-cloud simulations by **Lotta** show that we will exceed the cryogenic capacity if we reach a bunch intensity of 2.3e11 ppb with a filling scheme of 4x72 or 5x48. In particular, it is foreseen that 5 out of 8 sectors will exceed the limits, with the main bottleneck being S78.

The proposed solution is the Beam Screen Treatment (BST) project. 100 half-cells, spread around the different sectors, will be treated with a thin Amorphous Carbon coating in LS3. This solution will allow to remain below the cryo capacity in all sectors with a margin of 15%. Benjamin emphasises that this margin is necessary to account for several uncertainties such as possible degradation in LS3 and treatment efficiency.

Discussion:

- **Rogelio** asks if the cryo capacity limit for S78 is around 170 W/hc. **Benjamin** confirms that this is the case.
- **Guido** asks if the calculations were done with a beam energy of 6.8 TeV or 7 TeV and if the impact of increasing to 7 TeV is negligible for the heat loads. **Benjamin** replies that there will be a small but non-negligible increase at 7 TeV. **Lotta** mentions that the e-cloud simulations were done with 7 TeV.
- **Lotta** asked about the revision of the cryo capacities at the beginning of this year's run and if this points to a possible degradation. **Benjamin** replies that this was due to a configuration change between 2022 and today. In the past, we had more capacity in S78 but at the expense of a decreased capacity in S81. The present configuration is more limited in S78 and improved in S81 but offers better availability. **Benjamin** mentions that with the past configuration we would be limited by sector 81 with this year's beams. **Rogelio** asked about the uncertainty on these estimates and if it would be possible that the old configuration would be more convenient globally. **Benjamin** replied that there is indeed some uncertainty but the better availability is a major argument in favour of the current configuration.
- **Rogelio** asks if there is any news on the prospect of coating more than 100 half cells. **Benjamin** replies that depending on the speed of the treatment project in LS3, 20 additional half cells might also be coated. The selection of the additional half cells will be based on statistical analysis of the degradation in LS2.
- **Guido** asks if we can continue with 3x36 next year and increase the bunch intensity to 1.8e11 ppb. **Benjamin** replies that this is not possible and we will need to move to hybrid filling schemes. **Guido** asks if a compromise in instantaneous luminosity can be helpful. **Benjamin** replies that the main bottleneck is sector 78 that is not connected to a high-luminosity triplet. He also adds that the possible upgrade of LHCb in LS4 will also have an impact and that this is not included at the moment.
- **Benjamin** mentioned that the cryo needs in the RF system with higher RF voltage should be reviewed. After the meeting **Rogelio** contacted WP4 to clarify this point.

3. REVIEW OF FILLING SCHEMES FOR THE HL-LHC (LOTTA METHER)

Lotta presents the potential filling scheme for HL-LHC, mentioning that the heat load predictions for Run 4 are based on cell-by-cell heat load estimations with 2.3e11 ppb and 2748 bunches with and without BST treatment. The results are then used for the selection of the half-cells that will be coated and the determination of the cryo margins.

Lotta summarises the two proposals for the half-cell selection. The first proposal involves coating the top 100 cells but results in S76 exceeding the cryo capacity limits. The second optimised proposal results in at least a 25 W/hc margin in all sectors. In this second proposal, no treatment is planned for S34, S45, and S56. However, a degradation of these sectors during LS3 cannot be excluded. These sectors have similar average and cell-by-cell heat loads to the one of S78 in Run 2, which degraded during LS2, and it cannot be excluded that they will degrade to a similar extent.

Lotta presents the integrated luminosity foreseen for the different scenarios. Considering a degradation of S56 or S45 similar to the one of S78 in LS2 results in 6% and 12% loss of integrated luminosity, respectively, with respect to the baseline. In the absence of BST treatment a reduction of 21% is foreseen. In the case of an important degradation we can fall-back to a 8b4e filling scheme, at the cost of a 30%

integrated luminosity reduction. **Lotta** then summarises the iterations that took place to converge to the half-cell selection for the beam screen treatment.

For a bunch intensity of 1.6e11 ppb, the number of bunches can be increased by approximately 5% with the hybrid filling scheme compared to the 25 ns options. At 1.8e11 ppb, the only options to avoid exceeding the cryo capacity are the 6x24 and hybrid-36b, with the hybrid scheme allowing for approximately 10% more bunches. However, Lotta emphasises that other factors apart from the number of bunches must be considered when comparing the impact of hybrid and 25 ns filling schemes on integrated luminosity, such as emittance and losses.

Discussion:

- **Rogelio** asks if the two alternative scenarios for HL-LHC in case of degradation of S56 and S45 are the hybrid with 2590 and 2460 bunches. **Lotta** confirms that this is the case.
- **Nicolas** asks why a 25 ns option with 36 bunches was not considered. Lotta replies that the hybrid schemes are better suited to optimise luminosity due to the increased number of bunches. **Nicolas** asks if the caveats that we have in Run 3 for the hybrid scheme such as the long flat bottom are also valid for Run 4. **Lotta** replies that indeed this is the case. **Rogelio** mentions that these caveats can be identified and estimated if we gain experience with a hybrid filling scheme in Run 3. **Lotta** adds that, when reaching higher bunch intensity, the difference between hybrid and 25 ns becomes more significant and it will be difficult to find a 25 ns filling scheme with a reasonable number of bunches and with a cryo capacity within the limits.
- **Rogelio** asks if there is additional information from the injectors concerning the hybrid caveats. **Hannes** replies that if it is needed for HL-LHC, effort will be made before LS3 to get better prepared for the hybrid. **Kevin** adds that we can possibly use next years' run to obtain more experience with hybrid and improve it. **Lotta** adds that if we want to increase the bunch intensity, hybrid is the only way. **Rogelio** adds that for Run 3, the decision of hybrid should be discussed with the experiments (**Action**: **WP2** to bring up the strong motivation to use hybrid in 2025 to prepare for HL-LHC and to increase Run 3 performance).
- **Kevin** asks if the hybrid will be with standard or BCMS. **Lotta** replies that from the point of view of electron-cloud this does not have an impact.
- **Nicolas** asks if the basic heat loads were ever measured in the machine, especially the intensity dependence. **Benjamin** replies that the only way to measure the basic heat loads is when we operate with 50 ns, for which electron cloud is negligible. Such a fill was done in 2017 with 1200 bunches and the measurements were benchmarked against the model. **Benjamin** notes that, in the absence of electron-cloud, the heat loads were found to be equal in all sectors.

4. PERFORMANCE ESTIMATES FOR THE NEW HL-LHC BASELINE AND VARIANTS (SOFIA KOSTOGLOU)

Sofia presents the performance estimates for the new HL-LHC baseline and alternative scenarios. The current baseline, as summarised in the DMR document, includes round optics down to 15 cm from Run 5 onwards, a maximum pile-up of 132 and a 25 ns filling scheme with standard beams. The crossing plane in IP1/5 is H/V and no ion operation is foreseen beyond Run 4. The LHCb upgrade after LS4, which will increase luminosity in LHCb, is not included in these performance estimates. However, past estimates indicate that this upgrade will result in up to 3% loss of integrated luminosity for ATLAS and CMS.

Sofia summarises the luminosity model used for the performance estimations. The model does not consider unknown sources of emittance blowup observed in the LHC but it does include extra losses beyond burn-off. For the intensity ramp-up phase, the number of bunches is gradually increased to the maximum and then the bunch intensity is increased during the first days of physics operation.

Sofia then summarises the observations from the operation with BCMS during the 2024 run. The BCMS achieved 20% lower emittance when injected into the LHC, 15% lower at the end of injection and 10% lower at the start of Stable Beams. BCMS fills had also 2% higher bunch intensity compared to the standard. The combination of lower emittance and higher bunch intensity increased the levelling time, resulting in an 8.2% gain in integrated luminosity for fills that reached or exceeded the optimal fill length of 8 h (after the meeting it has been computed that this number reduces to 5% if the increase in bunch intensity is removed). These observations open the possibility of using BCMS also for HL-LHC due to their improved performance. She also presents results from the MD on the non-factorization of VdM beams, where it was shown that bunches with heavy-tailed transverse profiles resulted in an increased effective cross-section compared to Gaussian bunches.

Sofia gave an overview of the various scenarios and their impact on integrated luminosity with respect to the baseline. The baseline results in approximately 2500 fb^{-1} from Run 4 to Run 6. Reaching 15 cm at the end of Run 4 increases the integrated luminosity by 3.4% per year. A gain of 1% is expected with BCMS and a gain of 3% with flat optics. However, there will be a loss of 9% if the ion run extends beyond Run 4, 11% with the hybrid filling scheme and 19% when hybrid scheme is combined with an extended ion run.

Discussion:

- **Nicolas** asks if the blowup in the ramp is included based on the fact that we start Stable Beams with an emittance of 2.5 µm. **Sofia** clarifies that the emittance blowup that is not included is the emittance growth at collisions due to unknown sources observed in Run 3 and we start from 2.5 µm to have some margin. **Rogelio** clarifies that we are considering a 15% margin on blowup for HL-LHC for the whole cycle but in Run 3 we observe about 30% and there is a PhD student that will work on the understanding of the emittance growth.
- **Nicolas** asks if the transverse bunch profiles in the model are assumed to be Gaussian. **Sofia** replies that the luminosity model uses Gaussian bunch profiles for the IBS estimations and for the luminosity.
- **Rogelio** asks if the 8% gain in integrated luminosity with BCMS also includes the unwanted 2% increase of bunch intensity. **Sofia** replies that indeed this is the case. **Rogelio** asks if this number can be reported without the bunch intensity increase (after the meeting Sofia computed that removing the effect of bunch intensity the luminosity gain between Standard and BCMS is 5%). **Rogelio** asks if this 2% increase of bunch intensity was wanted. **Hannes** replies that it was not intentional and it is more difficult to control the exact bunch intensity with the number of turns in the PSB for the BCMS beam, which was probably the reason for the increase in intensity when switching to BCMS.
- **Markus** asks if these numbers will change if the beam energy is 6.8 TeV instead of 7 TeV. **Sofia** replies that the numbers will change but she does not have an exact estimation. **Rogelio** mentions

that past calculations show that the expected impact is about 1% (as presented by **Rogelio** in the Chamonix workshop 2022).

5. AoB

The next WP2 meeting will be announced in due time.

Reported by Sofia Kostoglou