211th HiLumi WP2 Meeting

Tuesday 17th January 2023, 09:00 – 12:00

Chairs:	Rogelio Tomas
Speakers:	Massimo Giovannozzi, Lorenzo Giacomel, Riccardo De Maria, Sofia Kostoglou, Roderik Bruce, Guido Sterbini
Participants: 21	Hannes Bartosik, Xavier Buffat, Roderik Bruce, Rama Calaga, Riccardo De Maria, Lorenzo Giacomel, Massimo Giovannozzi, Gianni Iadarola, John Jowett, Ivan Karpov, Sofia Kostoglou, Kevin Li, Lotta Mether, Michele Modena, Nicolas Mounet, Kostas Paraschou, Stefano Redaelli, Giovanni Rumolo, Guido Sterbini, Rogelio Tomas, Frederick Van Der Veken, Carlo Zannini, Markus Zerlauth (Excused: Elias Metral)

AGENDA

MEETING ACTIONS

Actions from 13/12/2022: Gianni mentioned that the faulty heat probe data were verified and confirmed to be erroneous. He added that the ramp up scenarios can not be defined as precisely as the action suggests due to unknowns in the scrubbing process. Some flexibility is required to maximise the efficiency while scrubbing.

Massimo To present an update on the potential gain of sorting before next WP2 PSM, 9/3/2023.

Sofia To explore DA versus intensity at the start of physics and at the end of levelling.

(see action list on the WP2 webpage, for the complete list of current actions).

1. NEWS ON BENEFITS OF SORTING (MASSIMO GIOVANNOZZI)

Massimo presented some preliminary considerations on the benefit of magnet sorting. The installation of the LHC dipoles was significantly delayed with respect to their production, allowing to generate a large batch of stored dipoles and quadrupoles that could be installed using sorting. This should not be the case for HL-LHC, yet the planning is arranged such that sorting of a large fraction of magnets is possible until 2025. To allow sorting, the magnets need to be systematically measured and the corresponding data available well in advance. The symmetries around the vertical axis may be exploited for sorting (to be confirmed by Ezio). In the LHC case, the triplet had a tendency to have a banana-like deformation and this has been a criterion to select the installation slot. In HL-LHC it could be considered to maximise the physical aperture taking into account the crossing angle with round optics. Sorting according to the field quality is done with the flexibility left after the constraints from physical aperture and transfer function were taken into account. The main criterion could be to minimize the strength among the magnets in the corrector package. The Q1s and Q3s are installed with a rotation (due to the choice of the coil connection side) allowing for compensation of the systematic magnetic errors and possibly the random part if the cold masses can be matched. The 2 Q2s should be matched to one another already for compensating the transfer function differences. These options should be discussed with WP3. Studies to assess the efficiency of these strategies are needed by 2024. **Massimo** concluded that a number of sorting aspects should be discussed with Ezio to confirm the actual options available.

Discussion:

- **Rogelio** mentioned that HL management would like an assessment of the benefits to allocate the resources. He suggested digging out results from LHC sorting. **Massimo** agreed and added that, if needed, **Thomas** could perform a preliminary study for that purpose (**Action: Massimo**).
- **Rogelio** said that due to the possibility to exchange the crossing angle plane and the crab cavities in IPs 1 and 5, the considerations on the crossing angle and the physical aperture may not be applicable.
- **Massimo** mentioned that independently of sorting, resources are needed to support the Magnet Acceptance Board in taking decisions in accepting the magnets, considering installation shifts, etc.
- **Michele** mentioned that the schedule of the work required for the interconnection is rather tight and cannot start prior to full magnet installation of one side of an IR, such that last minute changes will be difficult. **Massimo** mentioned that, in any case, as of 2025 the cryostating will prevent any significant magnet sorting as the hardware will be specialised and the number of compatible slots

will be very limited. **Paolo** added that the IR magnets have to be installed in order starting from the IP.

- **Paolo** mentioned that vertical rotations are not possible due to the busbars. **Massimo** specified that he would modify the rotation of the magnet itself in the cryostat without changing the connection layout. **Paolo** said that this information has to come early, since it impacts the work on the busbars. He added that some triplets are put in a single cryostat in the US, sorting should also be planned early with them.
- **Paolo** pointed out that an exchange of the triplets are excluded, only the crab cavities will be exchanged between IP1 and 5 when swapping the crossing planes. **Rogelio** agreed.
- **Markus** highlighted the need to study and present the performance benefit of sorting. He would also consider a lightweight sorting based only on the mechanical aperture. **Massimo** added that the transfer functions are also important as they have an impact on the beta-beating.

2. UPDATE FROM THE IMPEDANCE AND INSTABILITIES STUDIES (LORENZO GIACOMEL)

Lorenzo presented an update on the impedance and instability studies. The impedance of the HL-LHC at flat top is lower than the LHC's thanks to the collimator upgrade. Additional peaks are caused by modes in the crab cavities, the MKI's and the detectors. Recommendations were given concerning new Q4 vacuum valves and the BBLR compensator. The impedance model was updated with the impact of the non-Cu-coated Y-chambers, the BGV, the stainless steel part of the warm pipe on each side of IPs 1 and 5, Inermet tertiaries (instead of Cu-coated CuCD) and Cu-coated graphite secondaries (instead of Mo-coated MoGr). The new collimator's taper resistivity is not yet included in the model and is under study.

In spite of the lower impedance, the octupole current needed to stabilise the beams is higher in the HL-LHC w.r.t. the LHC due to the higher brightness at the most critical phase of the cycle, the flat top. Multibunch effects were negligible in the LHC, but become significant in the HL-LHC due to the narrow modes driven mostly by the crab cavities. The required thresholds for the LHC and HL-LHC are affected by the latency which is not taken into account by DELPHI. An MD comparing a slow vs a fast instability threshold measurement concluded that the latency impacts the instability threshold by a factor 2. This factor is taken into account in the HL-LHC design. The measured absolute value of the octupole threshold is in good agreement with the model for low chromaticites but is appreciably lower at larger chromaticities.

The crab cavity fundamental mode including RF feedback still contributes to the impedance with a large narrow peak driving coupled bunch instabilities requiring unacceptably large octupole strength to reach stability. Mitigations strategies are under study, based on flat optics, a comb filter for the RF feedback and an amplitude feedback based on an additional transverse pickup.

Discussion

- **Riccardo** asked whether he should design optics with a higher teleindex at flat top to boost the strength of the octupoles. **Xavier** pointed out that the strength of the octupole is mainly limited by DA, not by the magnet strength.

- **Rogelio** mentioned that flat optics are considered for the mitigation of their impedance at flat top, but these optics are also useful for other purposes such as the mitigation of the impact of the crab cavity noise.
- **Rogelio** highlighted the importance of tails, given that there will be no hollow electron lens in Run 4, that the collimators will be retracted and currently LIU beams exhibit significant tails. **Stefano** argued that the population of the tails should not be coupled to hollow electron lens or collimator settings due to the uncertainties in their population. **Xavier** added that indeed the population beyond 6sigma does not contribute significantly to Landau damping. **Rogelio** concluded that there is no strong reason to expect a change of the relevant tail characteristics between 3 and 6 sigma between Run 3 and Run 4 (in the past HEL was specified to allow cleaning from 3.5 sigma). **Stefano** suggested considering the present uncertainties and possibly updating the strategy.

3. STATUS OF RUN 4 BASELINE CONFIGURATION (RICCARDO DE MARIA)

Riccardo presented the status of Run 4 baseline configuration. The operational scenario of Run 4 will significantly be impacted by electron clouds. In order to recover the performance, various margins have to be used, such as increasing the pile up or reducing beta*. The high bunch intensity is critical in all scenarios to achieve the performance. **Markus** mentioned that the assumed intensity is 2.2E11 not 2.3E11. **Riccardo** replied that indeed a bunch intensity of 2.2E11 is assumed in collision, however the injected bunch intensity is 2.3E11 to account for losses during the cycle. Depending on the further degradation of the beam screen surface, the 8b4e proportion varies between 65% to 100%. Only actions on the beam screen to reduce the SEY could allow for a full nominal beam without 8b4e.

The performance estimate now takes into account the slow ramp up of the luminosity at the start of the fill imposed by cryogenics.

The current BETS does not allow TCDQ movements at flat top, limiting the optics flexibility and beta* reach which becomes critical to compensate for the loss of performance due to electron clouds. A hardware upgrade would be needed.

The FRAS is needed to maintain the orbit corrector strength and orbit excursions to a reasonable level. It is planned to first use the FRAS during the commissioning with safe beams to reduce the corrector strength and then a full alignment would be performed once collisions are established. A re-alignment is foreseen during year-end technical stops and during the run in case tolerances are exceeded. More frequent alignments would improve the stability of the machine and ease commissioning, e.g. of the non-linear corrections.

- **Markus** clarified that it is ok to assume that BETS upgrade will be formally adopted in the coming months.

4. DA FOR FLAT OPTICS (SOFIA KOSTOGLOU)

Sofia presented the DA for flat optics. The DA is OK for with beta* of 0.5 / 1 m and 300A in the octupoles at start of levelling. With beta* of 7.5 / 18cm the DA is also OK at the end of levelling with 100 A.

Discussion:

- **Rogelio** mentioned that the intensity at start of levelling could be 2.3E11 and 1.4E11 at the end (**Action**: Sofia).

5. IONS - RUN 3 CONFIGURATION (RODERIK BRUCE)

Roderik presented the Run3 configuration for ions. One month of ion run is foreseen at each end of year during the runs. The 2022 lead-lead run was skipped and the physics time was cut by 20% for the rest of the run, yet the targets for Run 3 have not changed. Pb-Pb runs have priority, yet if the performance is good enough in 2023, a p-Pb run would take place either in 2024 or 2025. A week of O-O and p-O collisions could take place in 2024. HL-LHC upgrades for ions were implemented in LS2, such that performance could be reached already in Run 3. Crystal collimation is required to maintain a good availability in the presence of lifetime drops (e.g. 10 Hz oscillations), numerous uncertainties remain on the achievable availability. If there are limits due to these losses, it is preferable to run with lower energy (6.37 Z TeV) to increase the availability and thus the integrated luminosity. Without issues due to lifetime drops, a higher energy (6.8 Z TeV) is favourable for integrated luminosity and physics potential. (2-3% integrated luminosity loss at 6.37 Z TeV)

A new TCLD was installed in IR2 to mitigate BFPP losses, allowing for higher luminosities. However there is a non-conformity of the RF fingers that needs to be solved and is currently under study. After the meeting, **Roderik** pointed out that at a recent LMC, X-rays showing the crossing of two RF fingers were presented, however, this is not believed to be a show-stopper for operation and no intervention is planned

Slip stacking was successfully used in 2022 to produce 8 bunch trains featuring 50ns spacing. It is planned to use 56b trains in Run 3. The 75ns beam could also be used in case of issues, leading to 25-30% integrated luminosity loss.

Integrated luminosity goals are within reach yet very challenging given uncertainties on availability, allocated physics time and beam parameters in collision.

The commissioning time is estimated to be 5 days based on past experience, yet only 4 days are allocated. An additional day of optics commissioning could be included during the proton run spread into 3 shifts.

MDs are proposed to investigate quench limits, beam-beam effects with reduced crossing angle and optimised crystal collimation methods.

An Oxygen run of about 1 week would be needed to meet the request from the experiments. Two energy options are on the table for both O-O and p-O. Depending on the energy choice, the Pb-Pb cycle could be re-used. Otherwise it could be envisaged to stay within the safe beam limit given the low luminosity required.

Discussion:

- **Gianni** suggested highlighting the priorities for the MDs in 2023, given that the list provided does not fit the time allocated for Gianni's presentation.
- **Rogelio** asked whether beta* levelling was considered to improve the integrated luminosity. **Roderick** answered that given the unknowns on the beam quality it is not clear whether target luminosity will be achieved with the 1m beta*. **John** added that the crossing angle has to be reversed at the end of the squeeze which could complicate the setup. **Rogelio** said that the cycle could be kept for a few years such that the investment in the setup could eventually pay off. **Roderik** mentioned that the cycle needs to be re-validated every year, the additional complexity could be an issue.
- **Rogelio** said that the physics time is reduced by 20% for 2023 only. **Markus** commented that according to **Mike**'s annual presentation there could be shortening for the next years also.

6. LONG RANGE BEAM-BEAM COMPENSATION EXPERIENCE IN 2022 & OUTCOME OF WS (GUIDO STERBINI)

Guido presented the experience with beam-beam compensation during the 2022 Run. Following successful demonstration of long-range beam-beam compensation with wires in MDs, it was proposed to use the BBLR compensator in operation during Run 3. To ensure machine protection, compensations of linear effects were implemented together with the requested interlocks, requiring about 3 shifts during commissioning. The compensator was routinely operated for 22 physics fills until an earth fault occurred. An improvement of the beam lifetime linked to the compensation was observed in B2 but not in B1. In MDs the beneficial impact of the compensation was also observed (only in B2, since B1 demonstrator was faulty). The compensation is most effective at lower crossing angle (more beam-beam to compensate) and on bunches experiencing most LRs. The compensation is also beneficial for PACMAN bunches. 6 dumps occurred due to the BBLR, most of them due to the earth fault. They are possibly due to cracks in the connectors outside of the vacuum tank which move with the jaw position. The heating of these cracks by electrical current may result in contacts with the connector jacket. Consequently, the wires need to be repaired and consolidated. In-situ repairs could occur during the present YETS or the next EYETS..

The integrated luminosity gain for HL-LHC thanks to the wire is about 2-3 % with crab cavities and 6-12% without. With crab cavities, the gain is more important in the initial part of Run 4 prior to the commissioning of the cavities. Different scenarios are envisaged to bring the wires closer to the beam during Run 4.

A low cost demonstrator of the new design based on a bare Mo wire on a ceramic insulating support was built, its thermo-mechanical behaviour was validated. Integration in the IR area is under study. Cabling is a critical issue, as there seems to be no space for additional cables from the galleries to the machine tunnel. No show stoppers were identified in terms of impedance and heating of the device, nevertheless an RF shielding is recommended. No issues were identified in terms of irradiation dose either.

A 3D magnetic map is available for tracking studies.

The construction of a full scale prototype is planned at TRIUMF.

Discussion:

- **Rogelio** asked for clarifications on TRIUMF's contribution**.** Depending on the outcome of the review, TRIUMF may contribute with the construction of the compensators. They will not contribute to the cost linked to integration.
- **Rogeglio** said that an integration of the wires in the layout version 1.7 seems needed to allow for its installation in LS3 as vacuum is starting procurement and to make sure that no decisions are taken that would later prevent the wire integration.
- **Guido** said that the forward physics in CMS could impact the wire compensation. One may study the impact of a partial compensation only in ATLAS.
- **Rogelio** suggested emphasising the fact that the wires could enable mitigation of the performance limitations due to e-cloud.
- **Riccardo** mentioned that a new bore between the gallery and the tunnel for cabling might be costly. **Rogelio** suggested obtaining a statement on the feasibility and cost of the cabling. **Guido** added that the present shortage of space for cabling is rather unfortunate for this new infrastructure and is likely to become problematic for the machine upgrade flexibility in the future, irrespective of the wire integration.

Reported by Xavier Buffat