CEI section meeting 16-05-2024

Present: Chiara Antuono, Xavier Buffat, Elena de la Fuente Garcia, Lorenzo Giacomel, Dora Gibellieri, Fredrik Grønvold, Gianni Iadarola, Peter Kicsiny, Erik Kvikne, Christophe Lannoy, Szymon Lopaciuk, Elena Macchia, Lotta Mether, Elias Métral, Nicolas Mounet, Konstantinos Paraschou, Josephine Potdevin, Giovanni Rumolo, Luca Sabato, Carlo Zannini

Excused: David Amorim, Nicolò Biancacci, Roxana Soos

Scientific secretary: Elena Macchia

General information (G. Rumolo)

Arising matters

- The date of the ABP BBQ has been finally fixed to May 31; there is a file with the list of the tasks, and there are still a few people missing for some of them, so if there are volunteers, they should let Giovanni know. Gianni confirms his presence.
- CERN relay race will take place in two weeks, on May 30, and registrations are open until May 28. The relay is made of six stages, so six people are needed to form a team. On the slides there is a link with all the information.
- There is an upcoming CERN alumni event, which could be of interest for those in their early careers; there will be a Virtual Company Showroom with ESS (European Spallation Source), the link is on the slides.

IPP Meeting on Wednesday 8.5.2024

- On May 8 there was an IPP meeting, the discussion was about the proton sharing among physics users in HI-ECN3 era. In particular, there were two presentations by Tirsi and Rende, who presented an analysis on the impact on all physics users and the supercycle composition.

- Long-term schedule of CERN: now we are in Run 3, then at the end of 2025 there will be the beginning of Long Shutdown 3 (LS3), which is going to be 3 years long for the LHC, because it will take up until the end of 2028 and the LHC will be back for recommissioning and operation in 2029; for the injectors, LS3 will only last one year and a half, and they (up to the PS) will be back to operation in 2027, while the SPS will come back into operation in 2028. Then there will be Run 4 and Run 5 for the LHC, which will be high luminosity runs, with some other long shutdowns in between. During LS3 + 2029-31 there will also be the construction and commissioning of the SHiP experiment in ECN3, which is one of the experimental areas in the north area. ECN3 receives the beam directly from the SPS, so there is a proton beam that goes on the target and that is split among different users, which make use of what comes out of the interaction of the beam with several targets.

- The construction and commissioning of ECN3 is expected to take up to 2031, and then the operation will start in 2031 and it will continue beyond 2040, as it’s expected to last about 15 years if SHiP will get what they want, that is 4e19 protons on target per year (POT). That is quite an ambitious goal, and assumes a spill intensity of 4.2e13

which is a conservative request. The cycles will be quite short because the spill length is 1-1.2 seconds flat-top, so basically this means that it takes lots of space in supercycles and there is little space left for the other physics users of PS and SPS.

- Tirsi did a nice analysis to see, with the typical supercycle that we can have, how much space we lose for other users, and it usually is in the order of 6-7%, but there is also an important loss of available time for non-SPS users, around 11%. This means that, to fulfill the requests, we might be short of protons for another series of users like TOF and ISOLDE.
    - We should explore how to increase intensity per shot on ISOLDE: now it runs 40% of the cycles and with a certain intensity on the target, so if we have less cycles, we can imagine that we have more intensity per cycle. There are limitations to be explored, like how much we can accept on the target, extraction losses, yield on the target and so on. No limitation is expected on the accelerator side, because now we can already make 1.6e13 protons per ring in the booster, which is 60% more than before LS2
    - More intensity per shot has to be explored for TOF too, there is little margin on the dedicated cycle, but more can be gained when TOF comes parasitically together with the east cycle.
    - Higher intensity on ECN3 and the north area in general can be explored (so, instead of 4.2e13, we can imagine to go up to 7e13 protons per spill), and this also could have the potential to alleviate the supercycle composition.
    - Finally, we should also explore strategies to use unused PSB rings when serving the PS, e.g. when TOF goes to the PS, only one ring of the PSB is used, so we could imagine to use the other three rings for ISOLDE, but this implies some hardware updates so everything is more complicated and it involves both machine development and investment of money.

- Kostas asked if ISOLDE already needs more protons and Giovanni answered that it receives what it needs and it will not require more later on, because the average current will be the same so we would have more current per pulse with fewer cycles.

- Gianni asked about the reason for the delay in the recommissioning of the SPS in 2028 and Giovanni answered that it is related to the north area consolidation and ECN3 construction.

2024 injectors schedule v2.0

- This week the first three days were for the LHC MDs, with no dedicated or long parallel MDs in the injectors.
- Preparation of BCMS beam across the chain is what is mainly going on.
- There is a need to carefully compare standard and BCMS all along the chain in the 3x36b configuration, which is the one used to fill the LHC, because the switch to BCMS into LHC is expected sometime early next week.

2024 LHC schedule v2.0

- From Monday to Wednesday this week there were LHC MDs, and there were some interesting measurements for our section:
    - Schottky measurements for single bunches of various intensities were done, both for the longitudinal and transverse spectra. Christophe said that the data looked promising, especially regarding the longitudinal plane.

    - MD in which Lorenzo, Xavier and Nicolas took part, about the tune shift with the new IR7 optics. Lorenzo said that they measured the impedance-induced tune shift between high intensity and a lower intensity bunch, with the standard IR7 optics; they were expecting a 10% improvement, and the measurements seemed to show a higher improvement, but in the right order of magnitude, so that was a good confirmation of the model. The measurements weren't finished because the beam was damped prematurely towards the end, but the MD time (12 hours) was efficient despite one hour lost to some vacuum issue in the beginning and one hour and a half lost at the end.
    - Return to physics production on Friday evening, then the first three days after coming back to operation will keep using the standard beam, as it was before the MD block, and then after Monday we switch to BCMS up until the next MD block, in order to make a back to back comparison of the BCMS versus standard beam. We'll also see direct measurements of the emittance in the LHC and then the implications in terms of peak luminosity to see if there is a difference in terms of gain that we can have by using BCMS. The main thing that we don't like about BCMS is that the flat bottom in the SPS is much longer for the BCMS, because there are three injections spaced by 3.6 seconds instead of 2.4 seconds, which could potentially affect the beam. Howoever, wiith 3x 36b the degradation should still be acceptable.

Where we are standing for LHC: luminosity and heat load

- Looking at the curve of luminosity and comparing how it is going and how it was foreseen, we can see that we are perfectly on prediction, but in reality there are some stops that weren't expected and then a faster curve, so if fewer stops were present then it would be higher, but the slope already takes it into account.
- Looking at the heat load, we can see that there is a maximum around 175 W/half-cell, which is much lower than what the cryogenic capacity of sector 78 was expected to be, i.e. 215 W/half-cell. Howoever, this is currently the maximum they can handle, cryo are investigating why. After the peak heat load we saw an effect on the bunch length and scrubbing, which all result in a downward trend, which probably will be clear when we have more points. In general, now we are running with the maximum number of bunches in this configuration and according to cryo we can't go higher with 25 ns beams (possibly with hybrid scheme, to be considered later on).

Where we are standing for LHC: intensity and emittance

- We have 1.6e11 ppb at injection and slightly less than that at beginning of stable beams, as we wanted to have this year, and the emittance is ok, it seems that we are around 2 um at the beginning of stable beams.

Characterisation of low-beta impedances (E. Macchia)

Introduction and simulation technique for non-ultrarelativistic beams
Elena introduced the concept of beam-coupling impedance and the contribution of direct and indirect space charge effects to the impedance for non-ultrarelativistc β.
She then described a numerical technique that can be used to remove the direct space charge impedance from CST simulations, that consists in doing two simulations with the same mesh, one for the device under test and one for the bounding box, and then subtracting the results of the second one from the first.

Simulations of a resistive wall chamber

- Description of the resistive wall beam chamber and of the challenges posed by the necessary use, for non-ultrarelativistic simulations, of the direct integration method.
- Examples of application of the numerical cancellation technique on the longitudinal impedance and on the longitudinal wake potential for $\beta=0.5$. The impedance obtained is clearly what we expect from a resistive wall chamber.
- It was observed that the longitudinal and transverse wake potential scale with $\beta^{\frac{3}{2}}$. For the longitudinal case, some more information about this dependance can be found in Diego Quatraro's PhD thesis.
- It was observed that, as expected from theory, the longitudinal impedance doesn't change with β while the transverse impedance scales with it.

Simulations of a pillbox cavity with the Eigenmode and Wakefield solvers

- Example of application of the numerical cancellation technique on the imaginary part of the longitudinal impedance for $\beta=0.5$, with analytical calculation and removal of the indirect space charge contributions.
- Comparison on the two different approaches that have to be used in order to study the impedance with the Wakefield and Eigenmode solvers.
- Parametric study of the longitudinal beam coupling impedance with the two solvers: there is good agreement for both the first and second resonant modes, that was not obvious since the Eigenmode solver takes into account the particle velocity only in post-processing.
- The behavior of the peak impedance with β can be explained analytically through the transit time factor.
- Description of the two different ways of simulating the transverse impedance with the two solvers.
- Parametric study of the transverse beam coupling impedance with the two solvers: there is good agreement for both the first and second resonant modes. The first mode is mainly quadrupolar, and this explains why for $\beta=1$, being the quadrupolar impedance equal to zero, the generalized impedance is so small.

Conclusion

- Low beta simulations are challenging for various reasons, e.g. the mesh convergence, the need to use the direct integration method for non-ultrarelativistic beams and numerical techniques for the removal of the direct space charge contribution.
- The numerical cancellation technique was benchmarked with a resistive wall beam chamber.
- The simulations done on a pillbox cavity show that there is good agreement between the Eigenmode and Wakefield solvers, so Wakefield simulations are accurate and Eigenmode's approximation of using the particle velocity only in post-processing is accurate too.

Next steps

- The simulations are going to be repeated with wakis in order to address the fact that we don't know which formulas CST uses to calculate the wakefields and where the experienced numerical issues come from.
- The study conducted on the pillbox cavity will be repeated on the realistic 3D model of the PSB FINEMET's cavities.

Discussion

- Kostas asked why, during the numerical cancellation done to remove the direct space

charge impedance, the indirect space charge impedance of the bounding box isn't automatically removed. Elena said that the indirect charge impedance of the bounding box is removed, but in the first simulation we only have the indirect space charge impedance of the device, and these two quantities are different and have to be compensated separately, at least for simple structures; for complex structures, the indirect space charge impedance of the device is taken into account in the impedance model.

- Nicolas wondered if everyone agrees that the indirect space charge is the impedance when the boundary is a perfect conductor, and everyone does, and he guessed that the bounding box is a perfect conductor in CST. Lorenzo asked if the simulation can be done with open boundaries in order not to care about this, but Giovanni observed that the indirect space charge of the bounding box is easy to calculate analytically so it is not a problem, and Carlo said that using open boundaries in CST for all of the bounding box is typically never done. Nicolas said that typically he considers the indirect space charge impedance in the impedance model, and Carlo agrees that it is the typical approach, but also that direct space charge instead is enormous compared to the impedance, especially at low β, so removing it analytically doesn't bring to accurate results and the described numerical approach is used instead, but this implies that there is the need to compensate the indirect space charge of the bounding box.
- Giovanni asked about the comparison of the obtained scaling of the wake potential of the resistive wall chamber with Diego Quatraro's PhD thesis, and remarked that he was talking about wake functions instead of wake potentials, so a convolution would be needed in order to properly compare the results.
- Elias observed that, having obtained that the transverse impedance of a resistive wall chamber scales with β, we should obtain the same results for the wake potential; he then showed an expression that confirms this and said that probably a different expression is used. Elena and Carlo confirmed that the scaling was an unexpected result and it is one of the reasons for which they want to repeat the simulations with Wakis and check where some coefficients including $beta$ in the relation between impedances and wakes may come from.
- Giovanni observed that the broad band resonator model can't actually be used for non-ultrarelativistic beams, because in that case the wake function doesn't have causality. Elena said that the reconstruction of the whole spectrum was not the focus of the study and that she only reconstructed it for $\beta=1$. Carlo and Chiara said that it can be studied later and Giovanni added that there is some information about this in Diego Quatraro's thesis; Nicolas added that Sebastien investigated this too.
- Elena dIFG said that she had the idea of making a model for the direct space charge directly in Wakis because, since it depends on the mesh, the direct space charge impedance could be extrapolated without having to run two simulations.
- Nicolas observed that direct space charge is fully known analytically in the frequency domain, but Carlo and Elena said that doing the correction analytically leads to inaccurate results, because direct space charge is so much bigger than the rest that the results are dominated by noise.
- Lorenzo asked if there is a reason for the larger discrepancy for β from 0.45 to 0.6 on slide 28 and Elena said that it was investigated varying the mesh and the number of points used for the FFT, but since the relative error is actually very small it just looks like there is a bigger discrepancy because in that range the impedance values are higher. Carlo said that this doesn't happen for β close to 1 because the space charge contribution is smaller.

AOB

No other business. Next meeting will be next Thursday (23/05/2024), in which Nicolas will present outstanding CEI studies for HL-HLC WP2.