## Electron cloud meeting #62, 08/11/2018 (indico)

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**e-cloud MDs during LHC MD4** (G. Iadarola)

Gianni presented the first outcome of LHC MDs performed during the MD4 block.

- **MD4203 - intensity scan with trains of 12b at 450 GeV:**
  - The goal of the MD was to collect heat load data with different bunch intensities with trains of 12b. A filling scheme with 1020b was used, with injections of 4x12b.
  - The MD started with a fill performed with the highest bunch charge available from the injectors, i.e. 1.9e11 p/bunch. For a few hours at the beginning, there were problems in getting the beam injected, also due to the fact that the extraction from the SPS cycle could not be tested beforehand. Careful longitudinal adjustments had to be performed in the SPS before the beam could be sent to the LHC. Measurements could only start after ~5h of setting up and optimization. Still, in order to inject 1.9e11 p/bunch, due to high longitudinal losses it was needed to pulse the MKI without beam before each injection. Lower intensities were significantly easier. Fills were performed with 1.9e11, 1.5e11, 1.2e11, 0.8e11 p/bunch.
  - The dependence of the heat load on the bunch intensity could be clearly measured and it qualitatively behaves as expected from simulations (it levels off at high intensity). Quantitative comparisons will be shown by Galina in her presentation.
  - Very interestingly the highest bunch intensity could be kept stable with octupoles off (which provided very high beam lifetimes) while with the lowest bunch intensity vertical instabilities were observed even with 50 A in the octupoles. This could be driven by the electron stripes in the dipoles getting closer to the beam for lower intensity (as observed in 2016 at high energy, documented here).

- **MD2484 - high intensity 8b+4e**
  - The intensity from the injectors was ~1.6e11 p/bunch. The start of the MD was significantly delayed due to RF problems in the SPS. The beam was dumped a few times due to losses at injection for B1 (probably showers from the TCDI). This could be mitigated by increasing the transverse scraping in the SPS and optimizing the trajectory in TI2.
  - Fill 7365: in these conditions (still with quite large losses) we could inject 852b and accelerate to 6.5 TeV using the cycle with the large telescope. At flat-top the beams were kept separated at beta*=65cm for 30 mins for heat load measurements. Then collisions were established and a quick lifetime study was

performed as a function of the crossing angle. Towards the end of the ramp the lifetime dropped below 10h and losses at the tertiary collimators reached 70% of the dump threshold on the long running sums. For this reason it was decided to switch to the nominal hypercycle for the next fill.

- Fill 7366: At the beginning of the fill the trajectory in TI2 was further optimized. This allowed to fully mitigate the losses at injection. Filling with trains of 96b was very smooth. The beams were accelerated to 6.5 TeV and kept at flat-top for 30 mins for heat load measurements. Then the rest of the operational cycle was performed bringing the beams into collision. The beams were kept there for 30 mins to collect bunch-by-bunch lifetime data.

**Update on comparison of MD data against simulations** (G. Skripka)

- In Run 2 the large heat loads were observed on the beam screens of the LHC arcs. These heat loads are different on the arc-to-arc level, cell-by-cell level and even among magnets within the same cell. Various mechanisms of the heat transfer from the beam to the beam screen were investigated in the past leaving e-cloud as the main suspect responsible for the observed heat.
- The hypothesis that these differences are due to different Secondary Electron Yields (SEY) in the different sectors was tested by means of numerical simulations. The average heat-loads measured in each sector with the standard beam at 6500 GeV were compared to simulation results in order to find the corresponding SEY, assuming that the SEY is uniform along each sector. The following SEY values were found.

| | | | | |
|---|---|---|---|---|
| Sector | S34 | S45/S56/S67 | S23/S78 | S12/S81 |
| SEY | 1.20 | 1.25 | 1.30 | 1.35 |

- This model was validated using other beam configurations both at 450 GeV and 6.5 TeV, including data collected with higher bunch intensity using the 8b+4e and the 12b pattern. Good agreement is observed especially in sectors with higher load. The next step will be to test a more complex model where it is assumed that the "SEY degradation" is concentrated in the dipoles.
- The hypothesis of having a non-uniform SEY was tested also for the instrumented cell 31L2, where we can measure the heat load on individual magnets. The first attempt was to build a model for the dipoles based on the assumption that the measured heat loads come only from the dipole region (14.3 m). Similar to the arc case, the SEY values were estimated from data collected with the standard beam at 6500 GeV. The fitted SEY model was found to be valid for the 8b4e beam but inconsistent with the cases at injection energy, suggesting that a more advanced model is required. This was built as follows:

- By looking at the build-up simulations for different magnetic field configurations, it was noticed that the heat load does not change much with the energy for the dipoles but significantly differs in the drifts. It was also noted that in the drifts with 8b+4e beams at injection energy there is no multipacting happening for plausible values of the SEY. It is know that the temperature probes in the instrumented cells measure some of the drift length. Assuming these probes are centered between the dipoles we fixed the 'effective drift length' of 1.36 m.
- Based on the assumption above, it was possible to define a model of the instrumented dipole magnets assuming that the measured heat load comes from the dipole and the drift. Starting with the case of the 8b4e beams at injection, it is possible to fit the SEY of the dipole region, since according to simulations the drift should not contribute. Using the other filling schemes we could fit the SEY of the dipole, allowing a satisfactory reproduction of the measured data. The following combination of SEY values was found for the D2 and D3 dipoles that show a significant heat load:

| | SEY_dip (14.3 m) | SEY_drift(1.36 m) |
|---|---|---|
| 31L2_D2 | 1.5-1.55 | 1.5 |
| 31L2_D3 | 1.3-1.35 | 1.6 |

- The model is found to describe well the data for the standard and 8b4e beam at injection energy as well as with standard beam at 6500 GeV. The case of 8b4e beam at high energy should be investigated in more detail, since some discrepancies were found for the 2017 and 2018 data.
- The model needs to be checked also with 12b beam at injection energy (MD4 data).

**Single bunch instability simulations: basic checks and convergence** (L. Sabato)

- These convergence studies aim at findin the lower acceptable values for the following numerical parameters: the number of slice of the bunch, the number of Macro Particles (MPs) per slice, and the number of segments in the ring.
- The numerical parameters used in the past for the instability studies for the LHC were: number of slice of the bunch = 150, number of MP = 700,000 , corresponding to 4,700 MP / slice, and number of segments = 8 or 16.
- The study is focused on the 7 TeV configuration for the nominal bunch intensity of 1.2e11 p/bunch.
- The main findings when studying instabilities driven by e-cloud in the arc quadrupoles were the following:
  - From a first convergence study with respect to the number of slices (length = 7%, beta = 600 m, MP/slice = 4,700, segments = 16, scan in slices from 150 to 1,000), we can conclude that 150 slices

are not enough, while 500 slices are needed to achieve convergence.
    - A more general study was conducted with MPs/slice = 5000, segments = 16, scan in slices from 150 to 1000, scan in beta from 50 m to 600 m, scan in length from 7% to 26%. This study confirmed the conclusions of the first study, showing that 500 slices are needed to achieve convergence in all cases.
    - Similar studies were conducted with respect to the number of bunch macroparticles. These showed that 2,500 MP/slice are enough to achieve convergence.
    - Similar studies were conducted with respect to the number of e-cloud interactions. These showed that 16 segments are enough to achieve convergence.
- A similar study is running for the arc drifts. From preliminary results a larger number of macroparticles per slice seems to be needed. Similar studies should be performed in also for the dipole magnets. More detailed results should be presented in the coming meetings.
- In order to better understand the results presented before, the trajectories of individual electrons were analyzed. At first, it was decided to simplify the problem by focusing of the case of drift spaces and by using a rectangular longitudinal bunch profile.
- Differences were observed when using 150 and 500 longitudinal slices. With 150 slices, the oscillations of the electrons are amplified (not foreseen from the theory) and there is a slight difference in the oscillation frequency compared to the case 500 slices.
- The assumption of the theoretical approach is a linear electric field. This is true when the initial position of the electron MP is near the centre of the bunch.
- Increasing the initial distance from the centre (in the linear region), the frequency decreases slightly. Outside the linear region, a smaller number of oscillations can be observed.

**Dependence of electron cloud build-up on the beam position** (E. Wulff)

- PyECLOUD simulations were used to study the dependence of the e-cloud buildup on the beam position in a circular chamber having a 42 mm diameter at a beam energy of 450 GeV. No magnetic field was used and the simulations were initialized with a uniform electron density.
- Three parameters were scanned: the $SEY_{max}$ from 1.0 to 2.9, the bunch population from 0.5e11 to 2.5e11 p/bunch and the beam offset w.r.t. the center of the chamber from 0 mm to 18 mm. With the beam centered, simulations showed that the SEY threshold is larger for higher intensities. However, with the beam displaced by 12 mm or more the situation is reversed and for a higher intensity a lower SEY threshold is observed.
- Both heat load and current on the chamber walls were observed to decrease monotonically with increasing beam offset at a bunch population of 1.1e11 p/bunch and to have a maximum at a non-zero beam offset at a bunch population of 2.2e11 p/bunch.
- The current distribution on the chamber walls showed that the parts of the walls closer to the beam receive a higher current.

**Bunch length dependence for the electron cloud build-up in circular drift tubes** (E. Wulff)

- PyECLOUD simulations were used to study the bunch length dependence for the electron cloud build-up in circular drift tubes. The simulations were done with a bunch population of 1.1e11 protons per bunch and a beam energy of 450 GeV.
- No magnetic field was used and the simulations were initialized with a uniform electron density. The SEY parameter was scanned from 1.0 to 1.8 and the bunch length from 0.7 ns to 1.8 ns. The chamber used in the simulations was a circular drift tube with a radius of 40 mm.
- All simulations showed the same SEY threshold of 1.4, indicating that the bunch length does not have a significant effect on the SEY threshold. Furthermore, the current on the chamber increases linearly with the bunch length for all scanned SEY values.
- The heat load had a slightly more complex dependence on the bunch length and the SEY. It increases with bunch length for the lower SEY values but decreases with bunch length for higher SEY values.