# LHC e-cloud simulations Meeting – Draft Minutes

Date: 09 August 2011
Meeting Room: 6-2-004

**Attendees:** Chandra Bhat (CB), Elena Benedetto (EB), Alexey Burov (AB), Octavio Dominguez (OD), Wolfgang Hofle (WH), Giovanni Iadarola (GI), Kevin Li (KL), Elias Metral (EM), Kazuhito Ohmi (KO), Claudio Rivetta (CR), Giovanni Rumolo (GR) and Frank Zimmermann (FZ).

**Excused:**

## Agenda

1. Minutes and actions from the previous meeting (29$^{th}$ July 2011). Round table
2. Update on LHC scrubbing-run benchmarking, **Octavio Dominguez**
3. Progress on PS e-cloud simulations, **Chandra Bhat**
4. Quick Summary of SPS HeadTail simulations, **Kevin Li**
5. SPS e-cloud feedback simulations, **Kazuhito Ohmi**
6. US-LARP+CERN project/simulations on feedback to control e-clouds and TMCI in SPS, **Claudio Rivetta**

## Minutes and actions of the last meeting (27$^{th}$ July 2011)

Corrections to the slides and summary of the talk of GI (2.1 μs instead of 2.1 μm).

GI also reported that a bug in ECLOUD found by Jim Crittenden has been confirmed. The corrected version has been posted on svn.

John Fox and Claudio Rivetta have been added to the e-cloud meeting mailing list.

- Outstanding **actions** for HM:
  - Horizontal **displacement of daughter particles**, still pending (potential **ACTION** for Ubaldo Iriso or HM).
  - Simulate **heat load for beam conditions during the 2010 scrubbing run** with 9 x 12 bunches [heat load for this case was 40 mW/m initially].
  - Concerning the question whether at 3.5 TeV 1.1 μs spacing between trains is enough to clear the e- cloud, **remake the plots in a logarithmic scale** to see whether the first batches of each double train are indeed equal, **launch simulations with 2, 4 and 6 batches** to see the **e$^-$ energy distribution after each “double train”** passage, and **look at the losses versus time** (from qlosswh.data file in ECLOUD) with and without energy cut.

- In addition to heat-load, complete computation of the **central electron density for 25 and 50 ns spacing** with different values of $N_b$, SEY and R. Add density points for SEY=1.3 at 25 ns spacing; repeat the density curves for 50 ns bunch spacing
- Complete **sawtooth/no-sawtooth heat-load scans for ultimate bunch intensity** - Priority
- **Aperture scan for a non-round beam** repeat this
- **Aperture scan for 25 ns spacing**
- Write a **draft note** summarizing results of LHC simulations for heat load and density in the LHC arcs, including sawtooth, starting from a comparison with measurements.

- Outstanding **actions** for OD:
  - Study the **solenoid "resonance" effect**, e.g. by varying parameters like the bunch length and bunch spacing
  - Check the **$e^-$ energy distribution in arcs and larger-aperture straight sections**, in particular their differences, expecting higher-energy electrons in the arcs.
  - Complete the **note** (ongoing).

- Other outstanding actions:

  - Implement **simulations with different feedback bandwidth to ~1.0 GHz** & compute kick strength - how much power? Repeat simulation for new SPS optics (KO, FZ). This would be addressed in the coming month during the visit of Kazuhito Ohmi. Part of it will be address in the present meeting.
  - Understand **increase of electron cloud density with increasing beam size in PS** simulations (CB and OD). Partially addressed during this meeting.

## Update on LHC scrubbing-run benchmarking

**Octavio Dominguez** presented an update on simulations for LHC pressure measurements in November 2010.

The range of the grids has been changed so that the fits got better. The lines corresponding to large spacings are almost the same and parallel to each other. This would be consistent with the assumption that the memory of the cloud is lost for gaps larger than 8.85 μs.
When observed pressure values are adjusted to estimated (not measured) steady-state values in the simulations, the revised $\delta_{max}$ and R values are very close to those found for the 6$^{th}$ April data, just before the scrubbing run took place.
OD remarked the importance of waiting until the steady state vacuum pressure is reached for any further experiment.

Suggestions for bunch spacing combinations for the next MD were made, for either 25 ns or 50 ns spacing.

**ACTION: Proposal of a filling scheme for the next MD with 25 ns bunch spacings (OD)**

The MD is presently scheduled for 26-27 August 2011.

## Progress on PS e-cloud simulations

**Chandra Bhat** addressed the dependence of e-cloud build up on the beam size. The latter had been varied from 0.75 mm to 1.75 mm in the simlation. A new plot of e-cloud density as a function of transverse beam size was presented over a larger range.

KO asked for the beam line density. CB answered that 1.15e11 ppb was the bunch intensity used. The corresponding proton line density was 1.5e10 $m^{-1}$. AB suggested comparing e- density with proton peak density and average density.

In the PS the primary electrons are produced by ionization. Simulations for different pressure and different beam sizes were presented. Density prior to saturation scales with the vacuum pressure. Larger beam size introduces stronger nonlinear component. The conclusion is still the same as in the previous meetings: the larger the transverse size the stronger is the build-up.

The version of the ECLOUD code used was distributing 10% of the electrons uniformly across the chamber.

OD recalled that he had done a study and varied the 10% to 5%, 1% and 0%, for the SPS. The results had been reported in an earlier meeting. With 0 and 1% there had been no stripes anymore.

**ACTION: Check x-y distribution of electrons (CB)**

**ACTION: Rerun simulations without including 10% uniform seed electrons (CB)**

Simulations show that 36 double bunches give different results from 72 single bunches.

CB pointed out that ECLOUD should be modified to handle situations in which the number of slices for a bunch passage is larger than the number of slices for the space between bunches. At the moment, in such cases (nbstep > nistep), the PS simulations do not seem to work. KO suggested that ten slices per e- oscillation period should be sufficient.

Answering to GA, CB said that for time periods larger than 12 μs saturation is reached. GA pointed out that this is the first indication of a multi-turn build-up effect.
WH asked what should be the mitigation strategy for the PS if there is a limitation coming from PS. GA answered that scrubbing is more difficult in the PS than for SPS and LHC. A first approach could be running with 25 ns at intensities of 2-3e11 ppb and then observing what happens when afterwards injecting bunches at 50 ns. He recalled past discussions with Erk Jensen, according to which the cavities can only be pulsed for a short period. Magnets cannot run at 26 GeV for longer time periods either. WH added that Heiko Damerau had studied shorter bunch rotations.

CB remarked that the PS e-cloud effect has been also seen at transition energy with LHC beam.

## Quick summary on SPS head-tail simulations

**Kevin Li** recalled the motivation for this study. He compared parameter of the proposed new low-gamma_t and the nominal SPS optics. The effect of the optics change on the electron cloud behavior was the question of interest. First he presented the parameters used for both optics. KL pointed out that the correct horizontal tune for the nominal optics should be 26.18.

Two regimes have been identified, each yielding different instability thresholds and emittance growth. The coherent regime can be identified for densities below 5e11 $m^{-3}$, although the thresholds are not always uniquely defined. In this regime, the larger the electron density, the lower is the threshold and faster the emittance growth. On the other hand, for electron densities above 6e11 $m^{-3}$ we are in the incoherent regime, where simulations are more sensitive to numerical parameters (number of kicks, number of grid points…). In this regime, emittances tend to evolve towards a more or less steady state value, and even show an unexpected monotonic decrease for higher density values. The reason for the reduced growth at higher electron density is not clear yet. It could be due to additional tune spread enhancing Landau damping mechanisms. AB pointed out that a similar stabilizing effect was seen at RHIC due to the collisions.

KO asked if constant beta functions are assumed. KL elaborated that he considered 192 interaction points with constant beta functions.

The transition to the incoherent regime is presently defined from the behavior observed in the density scan.

At the moment KL is focusing on the coherent regime. No other nonlinearities but e-cloud are included. A smooth approximation for the beta functions has been used. KO and FZ proposed to redo the study with different beta functions.

**ACTION: Include beta variation or real SPS Twiss parameters (KL)**

EB suggested checking snapshots of head-tail motion to distinguish the coherent and incoherent regimes.

**ACTION: Inspect simulation snapshots for signatures of coherent motion (KL)**

Next, scaling laws were presented. There is a good agreement of simulated thresholds with a simple scaling law (which predicts a threshold proportional to $Q_s$ and inversely proportional to beta function). Comparison of both optics shows about a factor of two of improvement in the threshold density as a function of bunch intensities both in field-free regions and in dipole fields. In both cases the studies have been done at 26 GeV (SPS injection energy).

AB proposed performing studies on the coupling resonance, which could reduce the instabilities. Specifically, he suggested simulations with equal tunes and introducing skew quadrupoles to see if this reduces the emittance growth.

WH proposed to carry out a practical test to confirm the merits of the new optics.

**ACTION: Experimental test in the SPS for both optics with lower chromaticity and/or high intensity**

Simulation results were similar for linear and nonlinear RF buckets.

## SPS e-cloud feedback simulations

**Kazuhito Ohmi** discussed the e-cloud in the SPS. The parameters shown correspond to the average beta functions in the MBB dipoles. He showed a formula for the threshold which is based on a coasting beam approximation where slippage gives Landau damping. It assumes peak values at the center of the bunch. The parameter product "KQ" is taken as equal to, or proportional to, omega $\sigma_z/c$, where K is the amplitude of the wake field and Q the quality factor. The value for $\omega_e\sigma_z/c$ is not particularly large. Only the nominal SPS optics has been explored until now.

**ACTION: Update slides to include definition for KQ (KO)**

The instability threshold predicted by the coasting beam formula is 1.4e11 $m^{-3}$, which is consistent with the simulated threshold. The code and some parameters are different from the ones used by KL in his simulations, but the conclusions are similar. For high densities the instability signal is smeared.

GR pointed out that MBB parameters were chosen since the e-cloud threshold is lower in MBB.

In the case of instabilities in the bending magnets, the vertical threshold is about a factor of 2 higher than for the field-free case. There are no instabilities in the horizontal plane. A non monotonic behavior with the beam intensity is observed.

Next, KO presented simulations of SPS feedback system for the bending sections. A gain of G=0.02 is not sufficient for damping. AB asked about the negative slope for low intensity values. KO answered that that this “stochastic cooling” effect is due to the feedback.

The feedback kick strength is computed along the z direction. For the feedback bandwidth a step function filter, $dz=\pm c/(2\cdot f_r)$ is considered. The feedback works well for 1 GHz bandwidth. A bandwidth greater than 700 MHz is necessary for a density of 5e11 $m^{-3}$.

EM asked for the electron oscillation frequency. It is 355 MHz, about half. WH clarified that in the past a 700 MHz signal had been due to the SPS pick up. EM asked if a reactive feedback can be used instead of a resistive feedback. WH answered that a huge gain may be needed. The present effort is on a resistive feedback. WH suggested testing a reactive feedback in the LHC with TMCI.
EM commented that in the SPS one could reduce the bunch length to reach a situation where modes 0 and 1 are coupled to cause TMCI.

AB highlights that if SC is strong the TMCI picture changes dramatically. EB commented that the effect of the electron cloud is similar to SC.

For a higher density of 1e12$m^{-3}$ a bandwidth of 1 GHz is needed in dipoles.

AB pointed out that the feedback gain is another parameter in addition to the bandwidth.

Next, checks for stochastic cooling, bunch profile and residual amplitude as a function of z for different feedback bandwidth were presented. The absolute values of the strength are determined by the simulation noise level. A kicker strength of $\theta=0.45$ μrad /sqrt(β) is needed. A wider dynamic range may be required.

GA pointed out the different conclusions achieved by a study made by Joel Thompson, who had found that a 400 MHz bandwidth was sufficient. WH recalled that the previous study had been done for 55 GeV. WH confirmed that for higher gain less bandwidth may be needed.

GA asked if Joel Thompson's simulations could be rerun with the same parameters. GR confirmed that there is a version of HEADTAIL which includes the feedback. WH expressed confidence in the simulation presented. However, the significance of 1% emittance growth is difficult to judge. The dependence on the number of macroparticles is relevant.

EM wondered whether above the threshold for incoherent instability we would also find some coherent component.

AB asked what would happen when injecting the beam with a larger beam size from the beginning, i.e. whether the initial injected emittance has an influence on the saturation value. KO answered that new simulations have to be done to answer this question. EM asked whether we can use the final value of the emittance to infer the electron density. AB suggested performing a simulation with larger beam size. GR clarifies that the grid size is dynamically adjusted in HEADTAIL. But there are enormous uncertainties, like the distribution of the electron cloud around the machine. FZ proposed adding collimators in the simulations and to compare the simulated and measured intensity losses.

**ACTION: Redo simulations with larger initial emittance to check uniqueness of final emittance (KO, KL)**

## US-LARP+CERN project/simulations on feedback to control e-cloud and TMCI in SPS

**Claudio Rivetta** presented the simulations and feedback models, MD preparation and preliminary results. The plan is to have a prototype before the first shutdown. The ultimate goal is to develop a feedback to control e-cloud and TMCI effects in SPS and LHC. SPS has longer bunches than the LHC and would allow for machine studies with the new feedback. Dynamical models are used for the bunches that are useful for designing the feedback system. The models are validated by SPS measurements.

Feedbacks have been incorporated to the codes. A kicker signal is added. It takes information from the beam transverse position in the BPMs. The power needed for the kicker can be obtained from the simulation.

The feedback channel is made out of 3 blocks: Receiver, Processing channel and DAC.  Limiting factors in frequency for receiver, amplifier and kicker are taken into account as a frequency response in the pertinent matrices.

There are two types of statistical errors, one is in the vertical displacement and the other one is the error in the interaction. Simulations are done with 300k macroparticles.

An extreme motion at the head and tail of the bunch due to limited statistics is observed in the simulations. There are options to have the same number of particles per slice or having regular slices. A tradeoff between head and center of the bunch has to be found. The LARP-CENR team was now in the process of estimating error bounds for vertical displacement and kicker signal.

The near-term plan is to validate feedback models with beam measurements including pick-up and kicker response with beam.

It is necessary to benchmark C-MAC, WARP and HEADTAIL codes for different operations in the SPS. The inclusion of a realistic feedback channel in HEADTAIL is mandatory. It has to include also an estimate for the kicker strength for different operation conditions.

EM suggested doing single-bunch studies, e.g. damping a head-tail instability, m=1. CR clarified that they are now working in an open loop looking at the beam response to the signal applied. WH elaborated that the hardware for the processing channel does not yet exist, but would be available only in 2012.

During the MD individual sections of the bunch are being excited. The experiment confirmed that substantial bunch motion can be generated by the feedback kicker system, when exciting at a synchrotron sideband frequency. CR showed some preliminary results. A 100 V peak voltage was generated between the kicker plates. Sine waves at 200 MHz and 400 MHz were being used during the last MD, but these were not yet synchronized with the accelerator RF, since the “excitation box” is still traveling to CERN.

WH pointed out that the kicker response drops off like 1/f. At higher frequency there is less kick strength. He added that the chromaticity was very low, between 0 and 1.

Next, CR showed a movie where a clear excitation of head-tail motion is shown. This demonstrates that oscillations can be excited and measured.

Conclusions: Realistic models for the feedback system in macro-particle have been successfully included in some simulation codes (C-MAD, WARP) and its inclusion in the HEADTAIL code for further benchmarking will be the next step. It is necessary to be able to drive the bunch with different modal signals to analyze the vertical motion of the bunch in response to these signals.

Further plans include more specific MDs, to study bunch dynamics near instability threshold, to see the effect of synchrotron motion of the bunch centroid, etc.

GA asked about current means to excite the beam, and the possibility to qualify part of the loop. He pointed out that the part not exactly known is the impedance. GA and FZ suggested one could use this new tool to find the frequency shifts of different modes. WH replied that now they are concentrating on single bunch studies (parallel MDs). It is indeed possible to look at tune shift of specific modes using the available system.

GA asked for the values for the bandwidth of kicker and noise in the detection system, and whether it would be possible already to compare many aspects with simulations. WH answered that 800 MHz is the theoretical bandwidth.

**ACTION: Study tune shift of different single-bunch modes (WH, CR, EM, GA)**

## AOB

The next e-cloud meeting will be held in about two weeks and will be announced in due time.

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Reported by Octavio Dominguez and Frank Zimmermann