LHC Studies Working Group

Notes from the meeting held on 12th July 2011

The meeting is dedicated to the results of the second LHC MD, which took place from June 29th to July 4th. Agenda and slides of the meeting can be found at the following link: https://indico.cern.ch/conferenceDisplay.py?confId=146925
The presentations on "transverse beam distribution", "combined cleaning" and "R2E" MDs are postponed to the next meeting due to lack of time.

Some MD users noted that the 1-week deadline for the MD note submission is very tight taking into account that the week that follows the LHC MD consists of LHC technical stop and Injectors' MDs, in which some people are heavily involved. R. Assmann answered that a few days delay on the deadline is acceptable in these conditions, but that it remains mandatory that the MD notes are published before the following MD period.

1. Beam-beam head-on and long range limits (W. Herr)

The head-on MD aimed to studying what are the maximum intensities per bunch that can be collided. One bunch per ring of about 2.2e11 ppb for 1.7 um emittances were collided, for a total tune shift of 0.03 for 2 IPs. It was noted that the intensity lifetimes in collision were worse than in the previous MD (down to 1-2 hours), possibly due to the fact that the emittances were bigger to start with. It is proposed to perform a similar MD at the flat top, so to have small beam sizes, and with 2 bunches per ring so to have collisions in the 4 IPs. R. Assmann asked what drives the intensity lifetime drop at the beginning of collisions, W. Herr replied that it is not the beam-beam tune shift.
The second MD aimed at finding the limits coming from Long Range (LR) interactions with operational beam parameters and 1 colliding train of 36 bunches per ring. The crossing angle was reduced in steps (IP1 first, 5 then) and in order to maintain the triplet protection, the TCTs were moved in steps along with the orbit. The luminosity increase as a function of the crossing angle reduction was recorded, it coincides perfectly with the theory and proves another technique for luminosity leveling (even though it is rather cumbersome due to the required TCT movement). The losses as a function of time were recorded and showed a clear dependence on crossing angle changes. It was observed that losses start after some threshold (4 - 5 σ), but that different bunches have different thresholds, giving strong evidence for PACMAN effects. A very strong dependence of losses on the number of LR encounters was also observed, indicating that bunches with half the number of LR interactions have about "1 σ more dynamic aperture". The studies can be continued by colliding 2 trains of 36 per ring so to have collisions in all IPs (doubling the number of LR interactions). From this MD it can be preliminary concluded that 8 σ separation could be enough for operations, provided small emittances. L. Evans wondered why the LHC behaves so differently from the SPS collider, W. Herr guessed that it is due to the non-flat beams and probably the unequal bunches.

2. Working point close to the half integer (R. Calaga)

During the last 15 minutes allocated for the LR MD, it was tried to move the working point close to the half integer. Probe bunches were injected, then the injection protection collimators were move to parking position to avoid aperture bottlenecks. The working point for both beams was first moved from collision tunes (0.31,0.32) up by 0.145. Losses were observed, mostly for beam 1, and the orbit had a negligible rms increase. Analysis of the beta-beating is ongoing, it is about 100% (data for beam 1 missing due to a wrong setting); more time is requested to measure and perform local and global corrections. A second step brought the working point further, at (0.475,0.465), with no significant change in losses or orbit. Lack of time prevented going further. It was also pointed out that the OFB was not used and that the extra space in the tune diagram could be useful if the tune spread given by the LR interaction turns out to be very big; the dynamic aperture was not calculated and no tune scans were performed. F. Schmidt asked whether the AC-dipole was modified, R. Tomas answered that a hardware change would be needed, R. Calaga added that the data taken with the tune kicker was good enough. W. Hofle explained that this new working point would make the operation of the ADT problematic due to stopbands of finite width.

3. "Injection 25 ns" and "quench margin at injection" (C. Bracco)

25-ns spaced beams were injected at the LHC for the first time during this MD (in the SPS: 1.1-1.2e11 ppb, 2.8 um emittances, 7-10% scraping). TL trajectories were as good as for the operational 50 ns beams, losses in the LHC injection region were also similar (some extra longitudinal losses on the TDI). The beams were captured with the nominal RF settings, the bunch-by-bunch phase along the batch shows a ~20 degree spread consistent with the effect of un-compensated transient beam loading in the SPS cavities. The ADT was used with the calculated 25 ns settings, but there was no time for a detailed setup; encouragingly no major problems were noticed. Up to 9 trains of 24 bunches each were injected in the LHC; intensity reduction and emittance blow up across the batch have to be further studied. The beam screen temperatures and the vacuum were also monitored revealing moderate activity (all ecloud solenoids were off). The next step consists of increasing the intensity per injection. E. Shaposhnikova pointed out that a stable phase reduction from the 3rd batch was observed, indicating energy loss and thus possible electron cloud activity.

The “quench margin at injection” MD aimed at studying the loss rate at the Q6.L8 (the worry being that just grazing on the TCLIB could produce enough losses to quench the magnet). In order to have BLM capture buffers from the post-mortem data, the primaries in pt 7 were closed to stop the beam. Pilot bunches (1e10) were injected in these conditions with different TCLIB settings (by moving it further in, in steps), while monitoring BLM and QPS signals. A similar procedure was applied while injecting 2e10 and 3e10 in a single probe. No quenches were observed on the Q6.L8. A second method consisted in injecting on an orbit bump at the Q6.L8: nothing was seen on the QPS equipment though, even when the BLM signal at the Q6 got to 1000% above dump threshold, hinting that there is plenty of margin and probably "BLM sunglasses" are not needed. For a possible next session of the MD it is proposed to increase the current in the Q6.L8. The quench margin was also studied for the Q4.L6 (primary in pt 3 closed, moving the TCSG and for different probe intensities); calibration data for the direct dump BLM in point 6 were taken. A. Nordt pointed out that the only quench with beam of the Q6 was due to the MKI failure. L. Evans pointed out that the Q6 is at 4.5 K, so that the magnet has much more thermal capacity than other magnets.

4. "Longitudinal stability" and "RF and ADT setup for very high intensity single bunches" (E. Shaposhnikova)

The RF team continued the studies on the loss of Landau damping and its dependence on energy and emittance (threshold proportional to E^{-1} and ε^{-2} predicted in the theory). The injected longitudinal and transverse emittances were varied (1.2-1.4e11 ppb). Additionally the phase loop was left as in normal operation, contrary to the previous MD. Plenty of data was recorded and the flat bottom (with different capture voltages) and for one ramp, the analysis is ongoing. Some preliminary conclusions were presented: damping of dipole oscillations on the flat bottom for single bunches with emittance > 0.4 eVs was observed; dipole instabilities during the ramp for bunches with emittance = 0.4 eVs and small, but non-zero initial phase oscillations were observed; both dipole and quadrupole instabilities were observed at the flat top. The phase loop proved to be quite efficient in damping injection oscillations for single bunch injections, some degradation can be expected for multi-bunch injections as different bunches will have different injection errors. Some differences between beam 1 and beam 2 are still to be understood, they might depend on different initial conditions.
R. Assmann asked to look into what is the longest possible bunch length that can be tolerated, in case heating problems come up. L. Evans pointed out that the single beam lifetime dependence on bunch length should be studied and that 2.5 eVs are used in the Design Report for 7 TeV, E. Shaposhnikova answered that scaled to 3.5 TeV that is equivalent to 1.8 eVs.
The RF and the ADT were setup for the high intensity single bunches (2.5-2.8e11 ppb). Concerning the longitudinal motion no worrying instabilities were observed. Concerning the ADT, beam position module settings were prepared for high intensity bunches and tested (delta and sum signals saturate above 3e11 ppb). Both systems were then successfully used for the following MDs.

5. Beam Instrumentation (F. Roncarolo)

The 8 hours of MD time were fully exploited by 5 to 6 teams working in parallel. The fBCT performance was tested with the newly installed 75 MHz filters, indicating that the dependence on bunch length is much reduced (<1%). The DC BCT measurement is not dependent on beam position, while the fBCT has a 0.5-1% residual variation per mm orbit excursion. The BPM system was revalidated after the intensity cards were removed, the intensity dependence is now below 200 um for high and low sensitivity modes in the IR BPMs (apart from 1 bad BPM). The WCM compensation for reflections and AC-coupling was verified proving to be effective; the calibration remains noise limited. The Schottky monitor gives good signals at any beam intensities for B1H, saturation is observed on the other channels. Out of the 4 systems, B1H is the only one showing the expected dependence on the beam position. For the BSRT, studies of magnification and focusing with closed orbit bumps were done while moving the CCD camera, preliminary results seem to indicate a need to further advance the camera. For the wire scanners, the response of the profile integral to the photomultiplier (PM) gain variation was studied indicating that the ADC saturates before the PM does. Also, the emittance was tracked from the PSB to the LHC showing that a significant blow up is seen between consecutive machines (B1 from the SPS to the LHC less blown up though). W. Hofle expressed some doubts on the observed blowup from 1 um at the PSB to 4.5 um at the LHC (the intensity per bunch should be verified). Concerning the BGI, data was taken and the expert application was debugged (some problems concerning the camera gain and gate affected the MD and were fixed during the TS). For the LDM, the knowledge of the after-pulsing correction was improved. Debunching when the RF is turned off was also monitored, showing an anomalous debunching of 1 bunch in B1, where one small bunch kept a stable profile. R. Tomas pointed out that similar observations were done at RHIC, E. Shaposhnikova reminded it has been observed generally in the presence of strong space charge effects though. For the AGM, the linearity has been checked against fBCT and DC-BCTs for both beams, indicating good agreement over an extended range of intensities. The calibration with debunched beam against the DC-BCT also gave good results. Small dependence on beam position was in general observed except of B1H with a +4 mm bump. The energy dependence of the calibration was also studied, the resulting error was of the order of 10% over the full energy range. At the end of the MD, while at the flat top, the chromaticity was increased to 12 and then 22 units but no emittance growth and no transverse instabilities were observed; these findings need to be verified for bunch trains/coupled bunch instabilities.

6. TI2 Injection quality (L. Norderhaug Drosdal)

The effect of the longitudinal beam quality and transverse scraping on injection losses was studied for TI2 (which is more sensitive than TI8). Mostly 12 bunches were injected, plus a few 36 shots, while the transverse line collimators were kept at 4.5 σ. A clean injection (ε_H=2.5 um, ε_V=1.9 um) resulting in 1% dump threshold losses on the MSIB was used as reference. Most cases of degraded longitudinal beam quality gave losses lower or equal to the reference, and the SPS BQM would have anyway blocked in most cases. The main effects on the losses come from scraping. Nominal scraper setting could be found so that the emittance was not affected, while the losses were, implying that only tails were scraped. The emittances were then increased up to 7 um by means of two screens in TT10 so that the scraper would cut into the beam core at all times. In this way, the scraper position could be determined from the remaining intensity (V scraping constant, H scraping scanned), allowing to determine the beam position at the scraper. SPS MD time is requested to further investigate the evolution of the beam position at the scraper and to check the sensitivity to the TL steering. It was also noted that if scraping is set up properly and the beams are Gaussian, then 3.5 um emittances give similar loss levels as the operational beams.

7. UFOs at MKIs (T. Baer)

In parallel to the TI2 injection quality MD, beam 2 was used to understand the UFO production mechanisms or rates at the MKIs. Ring 2 was filled with 1236 bunches, and the MKIs in pt 8 were pulsed 20 times on an empty slot of the machine (13 times all four kickers, 3 times MKI-D only, 4 times MKI-A only). 43 UFOs were observed in total at the MKIs (out of which 16 came within 1 second after the pulse). This shows that the kicker pulses directly induce MKI UFOs. In the beginning many UFOs came after the pulse, later mostly losses during the pulse were observed. The number of UFOs between kicker pulses decreased over time after the last injection with beam. The UFOs occur in or within a few cm around the MKIs, and the asymmetry between the four MKIs is confirmed (most UFOs start in MKI-D, and pulses of MKI-A were not directly followed by UFOs). In two cases a UFO was even seen in the IQC BLM capture buffer (512·40µs long), and these signals denote a very fast acceleration of the possible dust particles. A dedicated MD is requested to improve the understanding.

8. Non-linear dynamics (F. Schmidt)

Two studies were performed in parallel on the two beams. The MD performed on beam 1 consisted in measuring the dynamic aperture via the observation of the intensity/loss evolution. This method is based on an inverse logarithmic scaling law (established with tracking data). The idea is to start from a pilot beam with Gaussian distribution and use octupole and decapole spool pieces (MCOs or MCDs) to make the machine less linear (octupoles off). Transverse and longitudinal emittances and losses were monitored, all collimators were opened to 12 σ (unfortunately the TCDQ was left at 8 σ). Unfortunately, the Gaussian shape was not achieved with the MKA and the MCD were not tested (due to problems with the injectors).
The MD performed on beam 2 aimed at looking at the non-linear chromaticity, at detuning with amplitude and at resonance driving terms. The tune dependence on delta-p/p was measured, systematic kicks were performed with both the aperture kicker (MKA) and the AC-Dipole, nominal and non-linear chromaticity knobs were tried. As a possible explanation to the mismatch between model and measurement of the second order chromaticity and the need to trim the b4 spool-pieces (MCO) by about 6% of their nominal field to correct it, E. Todesco reminded that the MCO are powered with very few A at 450 GeV, and thus their state is not well defined (the hysteresis is huge). S. Fartoukh agreed that the MCO settings were indeed small in absolute at injection (~+/-3A), but not that small in relative term (+/-3%). He also suggested that another explanation could be a systematic octupole component coming from feed-down effects due to an eventual horizontal systematic misalignment of the b5 spool-pieces with respect to the main dipoles (typically 0.4-0.5 mm in the direction of reducing the MB sagitta would fit with the

measurement). This would indeed explain why correcting Q'' also strongly improves the amplitude detuning (since the MCO and MCD spool-pieces are combined) and why at 3.5 TeV no such source of Q'' was observed during the ATS MD (with b5 strongly reduced in the MB's and therefore much less normalised strength in the MCDs). The first explanation (hysteresis effect vanishing at 3.5 TeV) would however also explain the observations made at 3.5 TeV. Stephane then suggested to foresee dedicated measurement for the next non-linear MD, measuring Q'' vs MCD setting, Q' vs MCO settings and dQ vs MCS settings in order to exhibit or not possible systematic feed-down effects from the dipole spool-pieces. F. Schmidt pointed out that presently the measurements do not support the notion that a large feed-down of the b5 could be causing the unexplained large Q''. Within the measurement errors the model predicts (~100 units in Q'') the observed b5 effect on Q''' and a small feed-down. Specifically, the b5 was changed by 25% to adjust Q''', but no significant feed-down effect was seen. Ongoing investigating study the implications of a 0.4-0.5 mm offset of the b5 in the model.

9. ATS (S. Fartoukh)

The Achromatic Telescopic Squeezing scheme consists of an “almost” standard squeeze (called “pre-squeeze”), acting on the IPQs of IR1 and 5, followed by a continuation of the squeeze (called “squeeze”), acting on the IPQs of IR2/8 for IR1 and IR4/6 for IR5 and inducing beta-beating bumps in s81/12/45/56. For the MD, a pre-squeeze beta star of 1.2 m for IP1 and 5 and a final beta star of 30 cm for IP1 were chosen (this implied that the peak beta in sectors 81 and 12 increased by a factor of 4). The dry run was useful to test the full cycle and a few knobs, and allowed to identify a possible showstopper, the trip of RQ4.L2B2 and R8B1, which required the functions to be slowed down to avoid power converter trips. The first ramp with beam was lost due to a bad incorporation that caused the chromaticity to be negative. The second trial ended with a dump after the stop point at 3 m due to the trip of two RSDs in sectors 45 (beam1) and 56 (beam2) (due to the fact that the LSA rounding in/out procedure is not applied for the sextupoles, creating too high acceleration or deceleration for the QPS before or after a stop). The third attempt was fully successful, and a beta star of 30 cm at IP1 was achieved (IP5 stayed at 1.2 m). To be noted that the non-linear chromaticity at 1.2 m was very linear; the off-momentum beta-beating wave induced by the inner triplet is contained in s81/12/45/56 (i.e. IR3 and IR7 are preserved); the beta-beating at 30 cm is < 20% in V and <40% in H, requiring corrections (possibly coming from a longitudinal misalignment of the triplet, IR 8 and 4 are sources of beta-beating). The squeeze was performed with a preventive tune split of 0.03 and this proved a good guess as the coupling increased from 4.4 m to 30 cm, so much that the beam would have been lost in different conditions. Global coupling corrections are needed in the presqueeze. Losses were plot for the last 3 hours of the MD showing that the TCTH/V.L1 became primaries at some point during the squeeze. The good performance of the QFB and OFB during the MD was also stressed. The flexibility of the scheme was highlighted by proposing its application for the nominal LHC, for HL-LHC, for the production of flat optics (with aspect ratio of 4).

L. Evans asked if there is enough strength at the sextupoles, S. Fartoukh explained that they operate at a constant strength below 1.2 m while the beta function at the sextupoles increases. R. Steinhagen asked whether this optics is compatible with a tune working point close to the half integer, S. Fartoukh replied that only for sectors 81/12/45/56 there are constraints on the phase advance, leaving the other 4 sectors free for adjustments of the fractional part of the tune. R. Assmann noted that no non-linear correctors were needed in the triplets, S. Fartoukh replied that in the inner triplets the field quality is excellent so that the expected dynamic aperture is larger than the mechanical aperture: at 30 cm, the mechanical aperture is about 7 σ, while the dynamic aperture is about 9 σ.

Next meeting to be held on July 19th.

Giulia Papotti

List of participants

ASSMANN	Ralph Wolfgang	BE-ABP-LCU
BAER	Tobias	BE-OP-LHC
BARTMANN	Wolfgang	TE-ABT-BTP
BHAT	Chandrashekhara	BE-ABP
BRACCO	Chiara	TE-ABT-BTP
BRUCE	Roderik	BE-ABP-LCU
BRUGGER	Markus	EN-STI
BURKART	Florian	BE-ABP-LCU
CALAGA	Rama	BE-ABP-LCU
CALVIANI	Marco	EN-STI-EET
CALVO GIRALDO	Eva	BE-BI-QP
DEBOY	Daniel	BE-ABP-LCU
DROSDAL	Lene Norderhaug	BE-OP-LHC
EVANS	Lyn	PH-UCM
FARTOUKH	Stephane	BE-ABP-LCU
FUSTER	Nuria	BE-ABP-LC
GODDARD	Brennan	TE-ABT-BTP
GORINI	Benedetto	PH-ADT-DT
HERR	Werner	BE-ABP-CC3
HOFLE	Wolfgang	BE-RF-FB
HOLZER	Eva Barbara	BE-BI-BL
LANGNER	Andy	BE-ABP-CC3
MACLEAN	Ewen Hamish	BE-ABP-LCU
MUELLER	Gabriel Johannes	BE-OP-LHC
NORDT	Annika	BE-BI-BL
PAPOTTI	Giulia	BE-OP-LHC
POJER	Mirko	BE-OP-LHC
RONCAROLO	Federico	BE-BI-PM
ROSSI	Adriana	BE-ABP-LCU
RUMOLO	Giovanni	BE-ABP-ICE
SCHMIDT	Frank	BE-ABP-ICE
SHAPOSHNIKOVA	Elena	BE-RF-BR
SOLFAROLI CAMILLOCCI	Matteo	BE-OP-LHC
STEINHAGEN	Ralph	BE-BI-QP
STRZELCZYK	Marek	BE-ABP-LCU
TODESCO	Ezio	TE-MSC-MDA
TOMAS GARCIA	Rogelio	BE-ABP-CC3
VALENTINO	Gianluca	BE-ABP-LCU
VANBAVINCKHOVE	Glenn	BE-ABP-LCU
VENTURINI DELSOLARO	Walter	BE-OP-LHC
WOLLMANN	Daniel	BE-ABP-LCU