SESSION 2: MACHINE STUDIES

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Abstract

This document summarizes the talks and discussion that took place in the second session of the Chamonix 2012 workshop concerning results from machine studies performed in 2011. The session consisted of the following presentations: "LHC experience with different bunch spacings" by G. Rumolo; "Observations of beam-beam effects in MDs in 2011" by W. Herr; "Beam-induced heating/bunch length/RF and lessons for 2012" by E. Metral; "Lessons in beam diagnostics" by R. Jones; "Quench margins" by M. Sapinski; "First demonstration with beam of the Achromatic Telescopic Squeeze (ATS)" by S. Fartoukh.

LHC EXPERIENCE WITH DIFFERENT BUNCH SPACINGS

It was recalled that the observables that indicate the presence of electron cloud are: pressure rise; power deposited on the chamber wall measured as an increase in the cryogenics load or as a shift in the synchrotron phase; coherent instabilities (single or coupled bunch) affecting only the last bunches of each batch; incoherent emittance growth causing degrading lifetime and slow beam loss (typically associated with bunch shortening and loss pattern increasing along the batch). While there was no e-cloud observation with 75 ns beams in 2011, a dedicated scrubbing run was carried out with 50 ns beams in April 2011 and machine studies were dedicated to the 25 ns beams in June, August and October.

After the 25 ns MDs, the LHC beam chambers were cleaned to $\delta_{\max}$ values well below the build up threshold for nominal 50 ns beams. If the present level of machine conditioning is preserved during the Christmas stop, ecloud-less operation of the LHC with 50 ns beams up to high intensities should be possible in 2012. Only 2-3 days of scrubbing with 25 ns beams for 50 ns operation could be sufficient to clean the parts of the LHC that were opened to air and to check the conditioning of the arcs. Scrubbing of the arcs for 25 ns operation could take up to 2 weeks of machine time (including test ramps).

L. Rossi wondered how 8 h of beam time became an estimation of 2 weeks of length for the scrubbing run. G. Rumolo answered that a factor 5 was taken into account to go from beam time to machine time, plus extra time was added for setting up (e.g. for injection of 71, 144, 288 bunches). He added that 10 h would be needed to reduce the Secondary Electron Yield (SEY) by one order of magnitude, but more time would be needed to get rid of other effects like emittance growth. He also quoted V. Baglin's presentation in the first session of this workshop where 80 h of machine time had been needed in 2011 for 17 h of effective scrubbing.

L. Rossi asked whether, had a 12.5 ns beam been available in the injectors, that could help scrubbing for 25 ns beams. G. Rumolo answered that it would.

O. Brüning inquired about the intensity per bunch used in the 25 ns scrubbing estimate. G. Rumolo clarified that the measured beam parameters from the last 25 ns MD were used.

B. Holzer asked whether effective scrubbing could be performed while delivering physics. G. Rumolo answered that during scrubbing the quality of the beam would not be particularly good, G. Arduini recalled that the transverse emittances were 8-10 µm at the end of the 25 ns studies run.

R. Assmann asked about the usefulness of 50 ns scrubbing in 2012. G. Rumolo answered that the parts of the machine that had been opened during the Christmas stop will need some scrubbing, G. Arduini added that the question is still open about whether the conditioning is partly lost after a long stop, or whether the low SEY is conserved. He added that for this reason the first 2012 measurement should come as early as possible in the run.

L. Tavian asked whether synchrotron radiation and image currents had been taken into account in the heat load calculation; G. Rumolo confirmed it, adding that their contribution for the 50 ns beams was non negligible.

S. Fartoukh suggested the possibility of running with less bunches per batch (e.g. 48 or 72) or increased gaps in order to be able to tolerate higher thresholds.

R. Assmann asked what the precision of the SEY calculations is, G. Rumolo answered that the measurements are precise in relative terms but the absolute values are model dependent (e.g. the reflectivity of the electrons at zero energy).

S. Myers stressed the importance of the best possible estimation of the required machine time, as two weeks are probably not acceptable from the experiments' point of view, but two three days could be discussed.

M. Jimenez added that the 25 ns scrubbing will be needed after the first long shutdown with the increase in beam energy (due to the additional presence of photoelectrons), implying that measurements before the shutdown starts, in 2012, would allow an evaluation.

OBSERVATIONS OF BEAM-BEAM EFFECTS IN MDS IN 2011

W. Herr recalled the main observations concerning beam-beam effects: large head-on tune shifts above nominal (as defined in the LHC Design Report) were obtained during MD sessions, and twice the nominal value is standard in daily operation; the effects of long range interactions are clearly visible (losses, dynamic aperture), but no data was acquired yet on 25 ns spacing; the number of head-on and long range interactions is important for losses ("PACMAN" effects).

In order to achieve high luminosities, operation should aim for high head-on beam-beam parameter (high brightness, but avoiding noise or modulations) which is very unlikely to be the limiting factor; avoiding any increase of long range beam-beam effects by providing sufficient separation (large crossing angle), and by avoiding larger number of long range interactions. Additionally PACMAN effects and bunch-to-bunch fluctuations should be minimized. Beam-beam effects should allow higher than nominal luminosity at 7 TeV.

S. Myers asked if levelling at IP1 and 5 by transverse offset would be possible in case the pile-up with 50 ns would be excessive for the experiments. W. Herr answered that he thought that to be possible. J. Wenninger added that separations up to 3 σ and subsequent re-optimizations were done routinely during operation for the Van der Meer scans.

O. Brüning recalled that the alternating crossing symmetry would be broken in the case in which LHCb would have a tilted crossing angle and wondered whether that could cause problems. W. Herr answered that it should not be the case as the long range effects in IP2 and 8 are much smaller than in IP1 and 5 (additionally in IP1 and 5 the same bunches collide, so that all higher order compensations are in place there).

L. Rossi stressed that the major problem with a smaller crossing angle would be the losses. Then, in case the losses could be tolerated, less separation could be sufficient for operation and luminosity could improve (as the the emittance hardly varied during the MD, indicating a loss from the tails which do not contribute to the luminosity). W. Herr replied that the lost amount of 25 ns physics beam at 7 TeV would be much higher than during the MD. So it is suggested to have at least 6-7 σ dynamic aperture through a 10 σ separation (which would not cost much in luminosity).

BEAM-INDUCED HEATING/BUNCH LENGTH/RF AND LESSONS FOR 2012

E. Metral recalled observations of beam-induced heating, and discussed mainly the RF heating out of several possible sources. A summary of the affected equipment was presented by B. Salvant in Evian, including: TCP and TCTVB (temperature); TDI (vacuum temperature); MKI (temperature, rise time and delay); beam screen (heat load); ALFA pots (temperature); VMTSA (a broken vacuum spring). Since Evian, new VMTSA modules were installed, a deformation of the TDI beam screen was observed during visual inspection; the TCTVB was removed from the machine. Common solutions to avoid RF heating are an increase of the distance between the beam and the equipment, coating with a good conductor; a closure of large volumes (to avoid resonances at low frequency) and smoothed transition (e.g. RF fingers); the addition of ferrites; a bunch length increase (resulting though also in a reduction of the luminosity geometric factor and possible higher losses from the bucket).

Concerning the VMTSA, no impedance problem should be present if the RF contacts are not damaged. Concerning the TDI, the jaws should be "in" only during injection, and then fully retracted for the rest of the cycle. Concerning the MKI, recent impedance simulations are in very good agreement with past measurements; unfortunately a few hours might be needed before injection to wait for cool down. Note that the MKI8D should be changed in August 2012 with 24 screen conductors (now 15). The ALFA detector might need to be removed for high intensity operation.

R. Assmann asked whether the damage to the TDI could have been caused during scrubbing, when the TDI was "in beam" position with high intensity beams in the machine for extended periods of time. E. Metral commented that the jaws should be cooled, G. Rumolo added that 50 ns beams in physics are probably worse than a single ring 25 ns beam given that the location is a common region.

R. Losito explained that the TDI cooling is able to cope with 200-300 W, but not with 20 kW. He added that the TDI design was adapted to re-using vacuum vessels from the kickers, but later it proved difficult to handle such long jaws. If a redesign is required, then a design with more than one shorter TDI could be thought of.

H. Burkhardt suggested to monitor the temperature of the cooling water to foresee problems before damage occurs. M. Jimenez added that it is difficult to compare the cooling of the TDI with normal collimator jaws cooling as the configuration is very different (the water circulates on the aluminium frame on the side of the jaw, while the power is deposited on the borum nitride which is a bad conductor). R. Assmann added that the collimators are brazed so to avoid loss of contact in case of thermal deformation, while the TDIs are not (cooling contact could be lost with deformation).

T. Mastoridis asked about the dependence on bunch length for the TDI effects. R. Assmann answered that the bunch length had been changed to ease the margins on a collimator temperature sensor and to reduce the load on the cryogenic system, not for TDI problems.

F. Caspers commented on the heat transfer from ceramic to metal in vacuum: it can be very poor unless the ceramic is brazed even when the mechanical contact is good. Emissivity of stainless steel should be increased e.g. possibly by amorphous carbon coating.

G. Arduini reported that, following the suggestion of P.

Collier and B. Salvant, the evolution of the vacuum pressure at the TDI was analyzed for various periods:

- 50 ns scrubbing: the vacuum behaviour (decreasing versus time in spite of the increasing intensity) indicate no significant heating but simply the scrubbing of the TDI surface.
- Stable beam periods with TDI gap at $\sim$ 40 mm (before 16 October 2011 when the gap was increased to 110 mm): the largest pressure rises were observed during this period with time constants of a few hours. This could be an indication of the temperature rise of the TDI.
- During the last hour of the MD with 25 ns on 25 October. A pressure rise was observed (only on TDI in point 2) although smaller than that observed during physics fill.

G. Arduini added that during any future scrubbing period the TDI should be retracted if injection is stopped. This will imply an additional overhead for the scrubbing.

LESSONS IN BEAM DIAGNOSTICS

R. Jones introduced the performance, the studies and the foreseen improvements in the LHC beam instrumentation:

- BPM: the temperature dependence will be solved during LS1 through the use of temperature controlled racks (achieved stability $<$ 1°C on a test rack over a 3 day period).
- feedbacks: aim at considerably reducing dumps in 2012 (increase QPS thresholds for RQTF/Ds circuits to mask spurious QPS triggers, but note that this is not a long-term sustainable solution); a BBQ hardware optimisation is foreseen to reduce saturation sensitivity, together with a long list of controls integration and GUI improvements.
- BCT: the bunch pattern dependence and saturation effects were corrected, resulting in a system with an uncertainty $\sim$0.3% in the absolute calibration.
- fBCT: the bunch length dependence was mitigated with 70 MHz low-pass filters; the bunch position dependence is at 1% per mm (but effectively $<$ 1% thanks to the orbit stability).
- LDM: a dynamic range of up to 10^5 was achieved with an integration time of a few minutes; for 2012, further developments aim at finalizing the software and adapting the optical system to eliminate the dependence on the transverse bunch size.
- BSRT: a gated mode was implemented in 2011 to be able to acquire bunch-by-bunch measurements; a ten fold increase in scan speed is being investigated for 2012. Work is still ongoing on the calibration aiming at getting to corrected sigmas within $\pm$10% at injection and top energy.
- WS: a noise source on beam 1 could not be identified, but could be corrected for by using the abort gap signal. Note that they are vital for cross-check with other beam size measurement devices.

Note that broken RF contacts were found on most of the BTVs, it was proposed to lock them in the "circulating beam" configuration to avoid risking aperture restrictions and vacuum leaks.

R. Assmann stressed the importance of reliable emittance measurements. R. Jones replied that some issues remain but that it is a high BI priority to improve both the synchrotron light and the beam gas ionization measurements.

QUENCH MARGINS

The quench limit is defined as the amount of energy which can be deposited locally in the magnet coil without quenching the magnet; for steady state losses it is equivalent to the amount of power. The word "quenchino" was coined to indicate a self-recovering quench. During a quench test, BLM signals and the lost beam intensity are measured, then Monte Carlo simulations allow to conclude about quench limits. So far 13 quenches happened with beam in the LHC, 3 during injection and 10 due to tests.

From the tests with an orbit bump in 2010, it was deduced that the thresholds were about a factor 3 too high for the 5 s running sum, and this was corrected for the 2011 run. It is proposed to repeat a similar test, which is a reference measurement, to have steady state losses for about 1 minute. Quench tests with wire scans are the closest to the UFO timescales: it is proposed to repeat one at the end of the 2012 run with more intensity than in 2010. It is also proposed to allow UFO-generated quenches in a chosen sector by raising the BLM thresholds. The dispersion suppressor quench test provoked no quenches with nominal collimation conditions. It is proposed to repeat the test in 2012 to approach the limit for losses above 1 s duration, this being important for HL-LHC and the collimation upgrade. It is likely that beam-induced quenches will not be an issue for operation in 2012 but they might be after LS1.

B. Holzer stressed the importance of having as little quenches as possible, and in particular asked how many quenches are proposed in total. M. Sapinski replied that he counted four quenches in total.

R. Schmidt recalled that the worrisome part are the quenches in the arcs with weak interconnects, adding that each quench study proposal needs to be carefully evaluated also depending on the proposed location. R. Assmann added that quench tests are quite time consuming and it is unlikely that it will be possible to schedule all in 2012. M. Sapinski pointed out that the knowledge is important in view of operation at higher beam energy, before LS1.

L. Bottura stressed the importance of a program of measurements in the laboratory complementary to the ones in the machine. M. Sapinski agreed but at the same time stressed the fact that the ultimate tests are with beam.

L. Rossi asked whether an "adiabatic" increase in BLM thresholds would be a viable way to probe the limits (admitting that it would be a practical way which would not focus on understanding the phenomena). M. Sapinski replied that he personally believes that would lead to even more quenches. The understanding would improve by little as at the quench location there would not be the additional instrumentation that is normally used during an MD; additionally the loss pattern would not be known, while plenty of simulations exist in the case of MDs. E. B. Holzer added that only the BLM monitoring factor could be changed during an adiabatic increase, while the shape of the threshold curve could not be changed so easily.

S. Myers added that maybe quench tests could be postponed to after LS1 when the interconnect problems will be solved. He also recalled that it is very likely that despite many controlled experiments the machine might give something completely different. L. Rossi recalled that for the recombination dipoles not many spares are available. F. Bordry suggested to perform the tests towards the end of the 2012 run. S. Myers concluded that careful proposals should be prepared and and be decided upon.

FIRST DEMONSTRATION WITH BEAM OF THE ACHROMATIC TELESCOPIC SQUEEZE (ATS)

The ATS scheme allows achieving very low β^* (e.g. 10 cm) by solving optics limitations coming from the overall ring, e.g. the optics matchability to the arcs and the correctability of the induced chromatic aberrations (Q', Q", Q"', off-momentum b-beating). The ATS scheme is based on a new injection optics ($\sim\ \pi/2$ FODO lattice with new integer tunes), an "almost" standard squeeze ("pre-squeeze") which acts on the matching quads of IR1 and IR5 (until some limits are reached, e.g. in the sextupoles or matching section) and a further reduction of β^* ("squeeze") which acts on IR2 and 8 to squeeze IR1 and IR4 and 6 for IR5 by inducing beta-beating bumps in sectors 81/12/45/56.

A total of 23 h of MD with beam and 8 h of dry runs were spent in 2011 for ATS. In the first MD block, the new injection optics and ramp were successfully tested. In the second block, the pre-squeeze to $\beta^* = 1.2$ m in IR1 and 5 was achieved (no crossing angle), and the telescopic squeeze was demonstrated for IR1 by reaching $\beta^* = 30$ cm. During the fourth MD block, IR1 and 5 reached $\beta^* = 40$ cm with the pre-squeeze (no crossing angle), unfortunately the beam was lost when preparing the squeeze (due to problems between the tune feedback and the new tune knobs).

The plans for 2012 include a clean 40 cm pre-squeezed optics (measured and corrected for coupling and beta-beating; no crossing angle) and $\beta^* = 10$ cm in IR1 and 5 with pilot beams. Note that a pile-up of $\sim$120 events per crossing can be reached if the 40 cm pre-squeeze optics is coupled to tight collimator settings and high brightness bunches.

P. Campana asked whether with the ATS scheme there would be limitation in the β^* for IP2 and IP8. S. Fartoukh answered that they would be limited to 4-5 m, but this could possibly be improved with further studies.

L. Rossi asked about a possible study on ATS and chromatic limits. S. Fartoukh answered that there is a joint request with the collimation team on chromatic aberrations to find the limits at which the collimator hierarchy would break down (at injection energy).

R. Assmann concluded by highlighting the fact that a completely new optics was commissioned in 3 MD sessions only.