Minutes of Beam-Beam and Luminosity Working Group Meeting
24th February 2017
Chaired by: Yannis Papaphilippou

Burn-Off Cross Section - Helmut Burkhardt (CERN)

Helmut presented the studies on the cross-section of protons that are relevant for burn-off. The cross-section estimate is deemed important for the realistic predictions of pile-up, beam & luminosity lifetime, that in their turn are major inputs for the planning and the optimization of running schemes for LHC, HL-LHC, etc. **Helmut** mentioned that some calculations (in particular for HL-LHC) use the total proton cross-section of above 100mb. This is highly pessimistic and it describes a scenario where an induced lifetime limitation is included beyond burn-off.

The ideal situation would be to have a simple and analytic model that depends only on the center of mass energy and the beam parameters. The event generator for this model is required to be easily interfaced with the machine tracking and to be tuned to data, in order to have in the end an estimate of the uncertainties.

In addition, unpublished data from TOTEM for the β*=90m run in 2015 were presented. These show the differential elastic cross-section as a function of Mandlestam's t, or of the θ polar angle. The data can be modelled as the result of an interference of two exponentials. This model is easy to parametrize and generate, at the 10% level. The parametrization by two exponents is physical but the interference is something to be further understood. **Helmut** mentioned that there are also other models for this parametrization that include pomerons and additional interference terms.

Helmut concluded that for low β* the inelastic cross-section is also relevant for burn-off calculations. The inelastic cross-section also includes a diffractive part (about 10mb). This diffractive part describes the energy loss and is very small. This energy loss shows that there can be a mechanism for blow-up in the longitudinal plane, but it still stays in the machine. The diffractive part does not contribute in the collisions at the IPs, since they stay in the beam, but at 5σ they do not provide any luminosity.

Next step for this study is to try and calculate the inelastic cross-section by removing this diffractive part. Detailed implementation for tracking with SixTrack has started by **Kyrre**, who will present his status and future plans in the HSS meeting. **Yannis** asked about the possibility of includinging **Helmut's** calculation in SIRE. **Action: Stefania & Fanouria should communicate with Kyrre to iterate on this possibility.**
Additional Info: The code for the generator of Helmut is appended in the backup slides of his talk.

On 2016 emittances from ATLAS luminous region and the BSRT – Michi Hostettler (Univ. Bern (CH))

Michi showed a few plots from the 2016 emittance data. The comparison between the BSRT data and the luminous region from ATLAS is presented in detail. For the ATLAS data, the luminous region looks rounder (less H-V imbalance) at the beginning of the fill, while the evolution over the course of the fill looks different in calculations from ATLAS luminous region and the BSRT data. The discrepancy is more apparent for the horizontal emittances.

On the other hand, the vertical emittances are in agreement within the errors. **Michi** mentioned that the absolute scale depends on the absolute calibration of the BSRT, but the evolution should not. Consequently, he wondered if this discrepancy comes from the assumption that beam 1 and beam 2 are equal, but even without this assumption **Michi** reproduces the observed discrepancy. A few statistics were collected that represent all fills in 2016 (~10hours) and used in order make a linear fit on the distribution of luminous region growth over time. The slope from the fit shows that in the vertical plane the luminous region growth is in agreement between the ATLAS and BSRT data. However, in the horizontal plane a clear discrepancy is observed which is independent of the BSRT calibration. **Michi** commented that the distribution of the data points for the slope from ATLAS appear as if they have a lower cut-off, but there is no apparent reason for this. Maybe there is a systematic offset on the ATLAS data with respect to the BSRT. A similar study for the CMS is not yet done, since CMS has to reprocess some data.

Fanouria commented that the fact that over the course of the fill the luminosity region for ATLAS and CMS tend to agree better with respect to the beginning, may be a coincidence. In addition, she commented that the BSRT data are used in the model to calculate luminosity as well as bunch length evolution, with a very good agreement. The estimated values follow closely the observed, thus the BSRT before the calibration seem to be consistent.
Action: Michi will report in a future meeting on further analysis including the CMS data.

*Additional Info: **Witold** commented on the updated Massi files, that the average value of the 2016 integrated luminosity only changes at about a 1% level. However, the μ dependence is not negligible. He recommended to use the old version of the Massi files.*

LHC Luminosity Follow-Up for 2016 – Fanouria Antoniou (Univ. Liverpool (UK))

Fanouria presented an overview of the 2016 LHC luminosity studies. She started off with the model description. This is used for the calculation of emittance, bunch length and bunch intensity evolution and includes the effects of Intra-Beam Scattering (IBS), Synchrotron Radiation (SR) and elastic pp collisions. The model uses a Gaussian beam approximation (**Stefania** works on extending the model on this respect). The model can be applied bunch-by-bunch for both colliding and non-colliding bunches, as well as both at injection and flat top energies. Different assumptions can be taken into account, using the pure model or empirical data (taken by fBCT, BSRT, BQM and ATLAS & CMS Luminosity detectors "Massi Files"). Moreover, automatized analysis scripts for the beam quality and luminosity evolution have been developed and are fully functional.

The presentation continued with **Fanouria** presenting the Injection to Stable Beams (SB) analysis. In the plots of the horizontal and vertical emittances, for both Beam 1 and Beam 2, versus the fill numbers, one can deduce that in 2016, the LHC started with large injected emittances, which over the year (and after the transition to BCMS) they became smaller. In addition, a blow-up is present, which is induced during the Ramp, and it cannot be explained only by IBS+SR. In more details, the plots showing the emittance growth comparison for the model and the BSRT data as a function of the Fill number were presented. These plots were done for both beams, both planes and at Flat Top and Flat Bottom energies. The extra emittance blow up, compared to the model, is apparent. At this point **Witold** asked which is the dominant factor of the model, which is IBS, and why it is not so apparent in the vertical plane. To this **Fanouria** and **Helmut** responded that it is due to the much smaller vertical dispersion. **Yannis** also commented that in the model there is a spurious vertical dispersion included, but there is no coupling, which could have an extra contribution. **Fanouria** commented that it would be interesting to confirm if this extra emittance blow-up arises due to noise effects.

Moving on to the SB analysis, **Fanouria** presented the comparison between the average peak luminosity that the experiments (ATLAS, CMS) have recorded and the calculation from the beam parameters. A fairly good agreement is shown, especially in the first part of the year. After the change to BCMS beams, the calculated values are larger than what the experiments measure, but the luminosity imbalance calculated by the model and measured by the experiments is very similar. For the final part (140μrad configuration), the imbalance seems very different between what has been calculated and what has been observed. The experiments seem to observe rounder beams. At this point, **Witold** asked which Massi files were used for these plots, to which **Fanouria** answered that they were the last ones before Evian. **Witold, suggested that these plots should be rechecked with the new Massi Files.**

Fanouria continued, by presenting comparison plots between the model and the data for the same fill. The plots included emittances, and luminosities as a function of time. Using for the model only the initial values for the transverse emittance, bunch length and bunch intensity, a larger emittance blow up is observed than the one expected. The prediction is also not good for bunch length and bunch intensity. The comparison for the luminosity is also showing this discrepancy, which when empirical inputs are introduced in the model, is greatly reduced. This indicates that there are missing sources of extra emittance blow up and losses, that have to be understood.

Regarding the extra emittance blow-up and comparing the colliding and the non-colliding bunches and the correlation of the blow-up to the brightness, it appears that the effect is different for the two types of bunches. The effect of the extra emittance blow-up is also shown when using the model, but its effect is smaller for non-colliding bunches with respect to colliding ones. Moreover, the correlation to brightness reveals that for the colliding bunches, in the horizontal plane there is no correlation, while in the vertical there is some correlation. On this point, **Helmut** commented that vibrations and growth should be similar for both planes, but their effect should be stronger in the smaller plane, in this case the vertical. He also suggested that a test can be made in which noise is injected and the effect is

re-evaluated. On the other hand, for non-colliding bunches there seems to be no correlation with brightness.
Finally, **Fanouria** also presented the analysis for the extra losses during collisions. Theoretically, the losses should be burn-off dominated. However, from observations it appears that there is an additional mechanism that contributes to the losses, but it mainly apparent at the beginning of the fill, while the losses over the course of the fill flatten to the expected burn-off limit. This is something to be understood, and **Helmut** commented that there is also the effect of beam-gas, but its effect should be very small. Looking at the losses for the whole year, the contribution of the extra emittance blow-up is constant, but it is clear that the losses depend strongly on the machine changes, such as the transition to BCMS and the crossing angle change. Especially for the crossing angle change, a study has been performed for the signature of the long-range beam-beam effects on the instantaneous beam losses. For large crossing angles, more losses at the end of each train are observed. However, for small crossing angle, the losses become larger in the middle part of the train. This indicates the effect of long-range beam-beam interactions, as well as of e-cloud.

For reference, a summary of the to-do item list of Fanouria for the Luminosity follow-up (for 2017 and on) includes:

Emittance evolution from Injection to stable beams:

- *Add the model during the ramp (for the LHC parameters the effect of the order of 2-3%);*
- *Estimate the peak luminosity loss per fill due to the extra emittance blow up during the cycle (almost done).*
- *Understand if the observed extra emittance blow-up is due to noise effects.*

Stable beams analysis:

- *Repeat plot of the peak luminosity along the year using a different set of BSRT calibrations, as requested by Jamie and Christoph (the physics coordinators). Also rescale the middle part (BCMS) to the last calibration factors;*
- *Follow-up with the experiments to understand their limitations;*
- *For the peak luminosity along the year, verify with other set of BSRT calibration factors and check within the same calibration periods.*
- *Understand if the non-brightness dependent part is coming from noise effects.*

Extra losses during collisions:

- *Further investigations of the observations are on-going.*
- *Check the convergence limit by performing more detailed bunch-by-bunch analysis.*
- *Estimate the integrated losses bunch-by-bunch and fill-by-fill at different time instants and at the end of each fill.*
- *Extend the analysis trying to verify correlations with long range beam-beam effects.*

Suggested studies to be done:

- *Application of the analysis to the 2015 data and compare the observations*
- *Can the Run II results be put all together and compared?*
- *Perform the same analysis with the Run I, 2012 data.*