Minutes of Beam-Beam and Luminosity Working Group Meeting

3rd March 2017

Chaired by: Yannis Papaphilippou

Update on the Modeling and Measurements of Bunch Profiles at the LHC – Steafania Papadopoulou (Univ. of Crete (GR))

Stefania presented her studies on the modelling of bunch profiles with qGaussian distributions and a comparison with experimental data. A short introduction of the capabilities and usage of the Software for Intra-Beam Scattering (IBS) and Radiation Effects (SIRE) was also presented.

In the case of LHC, the bunch profiles seem to have heavier tails than a Gaussian distribution. To describe them more accurately the q-Gaussian probability distribution is used. The q-Gaussian is a generalization of the simple Gaussian, and arises from entropy maximization of systems far from statistical equilibrium. It is favored when the sampled distribution has different tails than the generic Gaussian would assume. The distribution is a generalization of the Student's t-distribution. The PDF of the q-Gaussian has a two-variable parametrization for $\beta>0$ and the shape parameter $q<3$. The normal distribution is recovered for $q\to1$, while larger values of q represent heavier-tailed distributions.

Stefania showcased the use of the q-Gaussian on the transverse bunch profiles at Flat Top. Three different measurements (Fill 5137) of a bunch profile are taken at a specific time and a FFT cleaning is performed. For each bunch profile, half of the distribution is kept and duplicated to produce the final profiles. Taking the mean of the measured profiles, while also removing a DC offset, and then considering only the distribution up to 3σ, a fit is performed. **Stefania** commented that the cleaning process reaches a point that no further optimisation can be done, but still there is some apparent fluctuations at the tails of the cleaned distribution. **Miriam** at this point commented that she is performing a moving average algorithm procedure with the goal to remove these fluctuations. Furthermore, a discussion arose due to the removal of the DC offset that Stefania is performing when taking the mean profile. **Ilias** pointed out that since this profile is used to calculate emittances and other beam parameters, the number of particles should stay the same, thus this DC offset threshold should be justified. To this **Xavier** commented that the offset is normal for measured profiles. Action: Then both **George** and **Ilias** suggested to Stefania that a check should be done to quantify the effect of this offset. A suggestion was to normalize the distribution to unity and compare the effect by keeping the integral of the distribution constant.
Stefania also presented the range of the q parameter obtained by q-Gaussian fits on bunch profiles taken at various time instances during the Fill 5137. For horizontal bunch profiles the spread of the q parameter is contained and almost constant in time for different bunch trains. On the other hand, for the vertical bunch profiles, the spread of the q parameter is significantly larger. This means that these vertical distributions have heavier tails. However, this needs to be cross-checked to verify if the spread is due to instrumentation or physics.

Stefania went on presenting the SIRE code. The inputs for the code are the optics along the lattice (a MAD Twiss file) and the particle distribution. The latter is the most important for this study, since the existing analytical models describing IBS effects assume Gaussian beam distributions. However, SIRE can calculate the IBS for any given distribution, in this case q-Gaussians are of interest. The code computes the IBS and radiation effects by tracking particles in 6D from point to point in a reduced lattice by their invariants. The intra-beam collisions between pairs of macro-particles are iteratively computed and the invariants are recalculated, also the radiation damping and excitation effects are evaluated at the end of every loop. **Yannis** commented that in order to be exact, all the kicks from radiation and quantum excitation have to be introduced, but at an RMS level the current procedure is ok. Action: Stefania should perform sanity checks for a few turns to evaluate this effect. Finally, the output of SIRE is the updated beam distribution and the RMS beam emittances. For her simulations, **Stefania** used a reduced lattice to speed up the calculation time. The reduction was done by including the minimum number of IBS kicks around the lattice, after considering the IBS growth rates for the full LHC optics with MAD. The result was a 92-point lattice with respect to the 11,000 full one.

At the Flat Bottom where IBS is dominant, **Stefania** presented SIRE simulations for the LHC and HiLumi LHC cases. In both studies, she started from a variety of distributions (Gaussian, Parabolic, q-Gaussian with various q parameters) and tracked them for an hour, fitting the final bunch length distribution with a q-Gaussian fit. The initial (input) distributions should have the same σ. **Yannis** observed a variation on the standard deviations of the initial distributions that can be associated with the probabilistic way (Monte Carlo) with which the distributions are generated. Action: Stefania should try and generate the same distributions with higher statistics, verifying the initial PDFs parameters. The results of the presented fits show that for both the LHC and HL-LHC at Flat Bottom, the bunch profiles of initially different distributions (in terms of PDF) approach the PDF of a Gaussian in 1h of tracking time. Furthermore, the growth rates of the transverse horizontal emittances and energy spreads for different initial distributions were presented. For all initial distributions, the same behavior is observed with slightly different rates. The q-Gaussian with q=1.5 seems to have the fastest growth rate in all cases.

In the discussion that followed these results, **Ilias** asked if the behavior that all the distributions approach a Gaussian is purely statistical due to central limit theorem. **Yannis** and **Xavier** commented that the underlying stochastic process is not the same for all particles. Also, the measured longitudinal profiles are injected with tails due to blow up, and observation shows that they become Gaussian overtime. **Yannis** commented that what is missing from the simulation framework, apart from noise effects, is the inclusion of non-linearities, that are basically deterministic. If these non-linearities are strong, the tails of the distributions may evolve in a different manner. He continued by explaining that the IBS is in principle the exchange of momenta from the longitudinal to the transverse plane, and in a case where the tails of the distributions are removed (i.e. parabola), the particles have less energy spread. In addition, following a question on whether the initially generated particles are allowed to have initial conditions close to the chaotic boundaries, Yannis commented that SIRE is able to perform this tracking of large angles (simulating Touschek for example), allowing studies regarding the losses. However, what Stefania is doing at the moment is to take into account only small angle scattering by applying a cut-off, not allowing particles close to the separatrix. However, this approach would be very useful for studies on SPS for example.

Guido asked how the fit for the transverse emittance is performed. **Stefania** answered that it is a one-parameter fit, since the sigma of a q-Gaussian with q=1 is the same as the simple Gaussian. Finally, **Ilias** suggested that the initial distributions can be generated by a hit-or-miss Monte Carlo.

Continuing her presentation, **Stefania** presented the Flat Top simulations, where the effects of IBS and Synchrotron Radiation are interplayed. The plots show that after an hour of tracking different initial distributions, the profiles remain almost the same for both LHC and HiLumi LHC parameters. **Yannis** commented that at Flat Top SIRE does not take into account the quantum excitation. In addition, the damping time at Flat Top is long, and the effect of IBS is correlated with brightness. Therefore, even if for the LHC case the effect is low, this might not be the case for HiLumi. The plots from **Stefania** show that in the HiLumi case the q parameter, that characterizes the tails, is reduced by almost 5%. This could be an indication that, if tracked for longer time, the distributions would start to approach a Gaussian.

Finally, **Stefania** summarized her next steps in which she plans to run longer (in terms of tracking time) simulations taking into account the beam manipulations during Ramp. The possibility of the non-Gaussian profiles also in the transverse plane will be studied. The main open issues are to identify the time that is needed for a non-Gaussian distribution to approach a Gaussian one, as well as to study the evolution of distributions and their correlation to brightness.

Xavier mentioned that there are available data from an MD with high-intensity bunches which would be interesting for **Stefania** to check. Action: Stefania should communicate with Xavier for the aforementioned data. She should analyze them and compare them with her simulated results. This should provide a way of benchmarking.