# SUMMARY OF SESSION 4: "LHC EMITTANCE PRESERVATION"

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*Abstract*

This session shows an overview of the studies related to beam emittance and luminosity during 2017 at the LHC. The session is divided in four talks covering topics from the instrumentation used to measure the transverse emittance to the measurements of emittance evolution over the LHC cycle, analyzing differences over fills and different beam types. The LHC luminosity model is also discussed. The luminosity measured by the experiments is explained with special emphasis on the estimation of the errors of the online and post-processed data.

## G. TRAD: INSTRUMENTATION PERFORMANCE AND LIMITATIONS

The different techniques to measure the LHC emittance were reviewed: wire scanners, synchrotron radiation monitors (BSRT) and beam-gas vertex detectors (BGV). In all cases, the beam size is measured and the emittance is calculated using the machine optics. The wire scanners are mainly used to provide reference data for the BSRT and in some MDs, and there are upper limits on the allowed intensity during the measurement.

The BSRT was successfully shifted to a digital camera system, allowing a faster acquisition rate. Three BSRT calibrations had to be carried out in 2017. The BSRT had a few issues in 2017, e.g. aging of the image intensifier and a slow gain speed of the micro-channel plate (MCP), and mitigations for 2018 are under study.

The BGV detector, presently installed only on B2, has been fully commissioned and data were taken parasitically during 2017. It will continue to be an expert tool in 2018. More regular data taking is proposed for 2018 to better compare with the other emittance measurement techniques.

**Discussion:**

**W. Kozanecki** asked about the status of the interferometer to measure the projected beam size. **G. Trad** replied that it was foreseen to operate the interferometer throughout 2017 to acquire reference data. However, it was found that the light splitting, that was to split the light between the interferometer and the BSRT, degraded the image quality and had to be taken out. Therefore the interferometer was not operated routinely.

The question was raised whether other techniques, such as pixel chips, were considered in order to avoid the aging of the MCP. **G. Trad** replied that with the recent improvements in resolution, pixel chips could potentially be considered in the future. Another improvement under consideration is instead a system that measures profiles relying on a slit scanner, where the aging will only give an attenuation and not affect the quality of the profile. **E. Bravin** commented that the only way to get light with the high extinction ratio needed to gate on one bunch is the MCP photo-catode, as most cameras still cannot gate on 25 ns.

## J. BOYD: LUMINOSITY MEASUREMENTS AND SYSTEMATICS

An overview was given of the luminosity measurement techniques at ATLAS and CMS, where leveling was not applied. Understanding limitations of the luminosity measurements is important not only for the calibration of the physics measurements, but also for the benchmarks of the LHC luminosity model. In general, the luminosity is measured by the rate of events in dedicated detectors, which are calibrated on an absolute scale during van-der-Meer (vdM) scans. Uncertainties arise both from the precision of the vdM measurements (non-factorizable beams, orbit drifts, beam-beam deflections, ghost charge, and length scale uncertainties) as well as from the transfer of the calibration to the high-luminosity physics runs (e.g. pileup dependence, detector ageing, and long term drifts in the calibration). Usually the most well-calibrated luminosity measurements are available about a year after the run and have an uncertainty of about 2.5%, while the luminosities published during the run have typical uncertainties of 5–10%. Additional information that help understanding the luminosity measurements are emittance scans, luminous region information, and the number of produced Z-bosons. Finally it was mentioned that the significant luminosity imbalance between ATLAS and CMS that was seen in 2016 has not been observed in 2017.

**Discussion:**

**O. Brüning** asked whether the observation that there is no longer any luminosity imbalance between ATLAS and CMS is valid for all periods of 2017. **J. Boyd** confirmed that this is the case.

**R. Bruce** asked whether we are sure that the imbalance is no longer seen, even if the uncertainty on the presently available luminosity measurements is 5%. **J. Boyd** confirmed that the final calibration is needed to draw the final conclusions. He also clarified that in 2016, the imbalance was initially thought to be larger (around 10%) but it went down to around 6% after the final calibration.

**G. Arduini** asked whether the few 2017 fills that had a large luminosity imbalance could be correlated to other phenomena, e.g. beam blowup. **J. Boyd** answered that this is not clear, and that the deviations could possibly be attributed to special runs or very short fills with insufficient data. **W. Kozanecki** added that ATLAS had an issue with the published luminosity during the intensity ramp-up.

**S. Fartoukh** asked why the ATLAS/CMS luminosity imbalance shifted from just below one to just above one when beta* was decreased to 30 cm. **J. Boyd** agreed that there seems to be a small effect, however, as several parameters were changed around the same time (also 8b4e, BCS beams, bunch intensities, ATLAS/CMS leveling) it is hard to disentangle the effects. **W. Kozanecki** commented that the change in bunch pattern to 8b4e could have an effect on the ATLAS side.

## M. HOSTETTLER: EMITTANCE OBSERVATIONS

This contribution collected and combined the measured data of beam emittances from different devices. It gave an overview of the emittance evolution over the LHC cycle, from injection to collisions comparing many 2017 fills. A special emphasis was made on the comparison of the emittance for different filling schemes. It was shown that BCMS beams were injected initially with emittance of about 1.9 $\mu$m and later with 1.7 $\mu$m, 8b4e beams were injected with emittance of about 1.9 $\mu$m and 8b4e-BCS beams with very small emittances of 1.2 $\mu$m. At injection energy, where the emittance growth is dominated by intra-beam scattering (IBS) the measured extra-growth (additionally to the IBS prediction) for BCMS-type beams was found to be about 0.6 $\mu$m/h, while for 8b4e-type beams it was about 0.2 $\mu$m/h. It is thought that this extra growth could be linked to electron cloud. During the rest of the cycle, the largest emittance growth occurs during the ramp, in particular for the high-brightness 8b4e-BCS beams, where it reached up to 0.6 $\mu$m. In collisions, unlike in 2016, the beams are more round (similar emittances in horizontal and vertical plane), this could be one of the reasons why the luminosity imbalance between ATLAS and CMS is smaller.

**Discussion:**

**J. Wenninger** commented that the analysis of the 2.51 TeV special ramp was very interesting for the emittance measurements and added that it could be interesting to have energy ramps to other intermediate energies in the future. **B. Salvachua** added that what could be also interesting is to understand the losses that we observed during the ramp which come after 3 TeV energies at the match points.

**W. Kozanecki** pointed out that Beam 1 and Beam 2 emittances can be mathematically distinguished using the luminous region data. **M. Holstettler** replied that the luminous region is not bunch-by-bunch which is what he is using in these analysis.

**E. Bravin** commented that there were dedicated fills where emittance measurement with the wire scanners were done during the ramp up of energy. He remarked that there was a commitment from **R. Tomas** to measure beta functions during the ramp. **V. Kain** added that the evolution of emittance through the ramp was also measured with wire scanners in **M. Kuhn** thesis.

**I. Efthymiopoulos** commented that the emittance blowup observed during the ramp could be due to uncertainties in the optics and is worth investigating.

## S. PAPADOPOULOU: EMITTANCE, INTENSITY AND LUMINOSITY MODELING EVOLUTION

A description of the LHC luminosity model was given. The model presented included the effect on the emittance growth due to several mechanisms: intra-beam scattering, synchrontron radiation, elastic scattering and luminosity burn-off. A comparison between 2017 data during collisions and the model predictions were shown.

At collisions it was observed that there is an extra transverse emittance blow-up (on top of IBS, synchrotron radiation and elastic scattering). In 2017, this extra blow-up is less than 0.05 $\mu$m/h for the horizontal plane and around 0.1 $\mu$m/h for the vertical plane. The analysis showed also that during the first hour of stable beams, like in 2016, losses are more pronounced for Beam 1 than for Beam 2.

**Discussion:**

**B. Holzer** asked about the peak of losses observed towards the end of the fills. **S. Papadopoulou** answered that it occurs mainly in the last step of the crossing angle change.

**J. Wenninger** asked what was the expected gain with the crossing angle steps taking into account the extra losses. **Y. Papaphilippou** answered that from the models of dynamic aperture by **D. Pellegrini** we gained half of what we could have gained, so it was still worth it, although it could still be optimized.

**G.Iadarola** commented that in the future one could base the crossing angle change on a feedback, meaning that one changes the crossing until losses reach a limit with respect to the burn-off. **Y. Papaphilippou** added that the crossing angle steps in 2017 were too aggressive, next year should be smoother.