**Abstract**

About 30 % of the potential luminosity performance is lost through the different phases of the LHC cycle, mainly due to transverse emittance blow-up. Measuring the emittance growth is a difficult task with high intensity beams and changing energies. Improvements of the LHC transverse profile instrumentation helped to study various effects. A breakdown of the growth through the different phases of the LHC cycle is given as well as a comparison with the data from the LHC experiments for transverse beam size. In 2012 a number of possible sources and remedies have been studied. Among these are intra beam scattering, 50 Hz noise and the effect of the transverse damper gain. The results of the investigations are summarized in this paper. Requirements for transverse profile instrumentation for post LHC long shutdown operation to finally tackle the emittance growth are given as well.

**Introduction – Total Emittance Growth**

Substantial transverse emittance blow-up through the LHC cycle
- High performing injectors: emittances as small as 1.5 μm for bunch intensities of up to 1.7×10^{11} ppb
- Blow-up in the LHC: up to 40 % until collision
  - 0.7 (for intensities < 1.5×10^{11} ppb) – 1 μm (for intensities > 1.5×10^{11} ppb)

**Predictions for post LS1:**
- 0.8 – 1 μm total emittance growth
- With same filling time, 6.5 TeV ramp, bunch intensities not larger than 1.5x10^{11} ppb

**Emittance Blow-up through the LHC Cycle**

- **LHC injection process:** emittances in the vertical and horizontal plane are conserved.
- **LHC injection plateau:** emittance growth in the horizontal plane is well predicted with IBS, but slightly faster than the simulation. A possible explanation is 50 Hz noise.
- **LHC ramp:** emittance blow-up larger in the horizontal plane (15 – 30 %) than the vertical plane (∼ 5 %) and more pronounced for beam 2 than for beam 1 during 4 TeV ramp in 2012.
- **LHC squeeze:** Towards the end of 2012 small blow-up at the end of the squeeze for beam 1 horizontal

**Comparison with Data from LHC Experiments**

- Large discrepancy between values from wire scanners and experiments
  - Smaller emittances from wire scans
  - Possibly photomultiplier saturation
  - Systematic difference between SMOG data and emittances from ATLAS
  - Emittance from experiments most trustable

**Possible Sources and Remedies**

**IBS at the LHC Injection Plateau**

- Solution for intra beam scattering (IBS) at 450 GeV: longitudinal RF batch-by-batch blow-up
- Batches left to natural blow-up suffer more from emittance growth
  - 20 % e growth in 20 min
- RF blow-out batches: effect of IBS clearly reduced
  - 10 % e growth in 20 min

**Influence of 50 Hz noise at 450 GeV**

BF1 time, LHC injection tune sits on top of 50 Hz noise → beam slightly excited
- Changing the horizontal tune has effect on the emittances in both planes
  - For this fill: high betatron coupling
- Vertical plane: blow-up almost vanishes with a tune far away from 50 Hz line
  - Horizontal plane: IBS dominates

**Effect of higher ADT Gain during the LHC Ramp**

- Injection: high transverse damper (ADT) gain
- Ramp: low ADT gain for sufficient tune signal
- Test: higher damper gain during the ramp to
  - Improve specific luminosity
  - Reduce emittance blow-up
- **No visible effect** on specific bunch-by-bunch luminosity

**Requirements for Post LS1**

- LHC wire scanners must be able to measure 288 bunches at injection
  - Understand wire scanner systematics to calibrate other instruments
- Reliable emittance measurements through the entire LHC cycle
  - Also for physics beams
- BSRT needs to be complemented with an operational BG1 during the ramp
- Installation of a Beam-Gas Imaging Vertex Detector (BGV) following the principle of LHCb SMOG under discussion