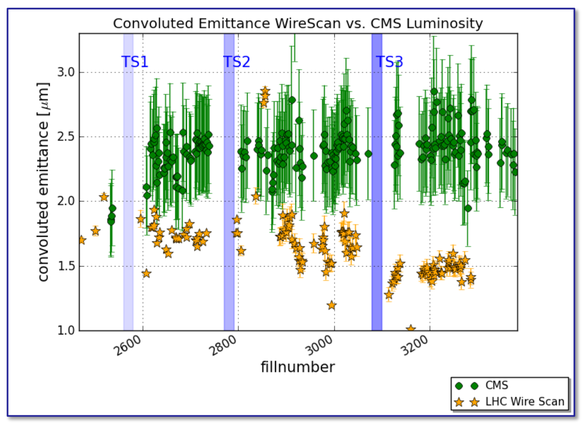
Investigations of the LHC Emittance Blow-Up during the 2012 Proton Run

M. Kuhn (University of Hamburg, Germany), G. Arduini, P. Baudrenghien, J. Emery, A. Guerrero, W. Hofle, V. Kain, M. Lamont, T. Mastoridis, F. Roncarolo, M Sapinski, M. Schaumann, R. Steinhagen, G. Trad, D. Valuch, CERN, Geneva, Switzerland.

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



Convoluted, average emittance of the first 144 bunch batch measured with wire scanners at LHC injection (yellow stars) compared to the emittance calculated from CMS peak luminosity (green dots).
After Technical Stop (TS) 3: Q20 optics in SPS
→ smaller emittance at injection, but emittance at collision stayed the same

Substantial transverse emittance blow-up through the LHC cycle

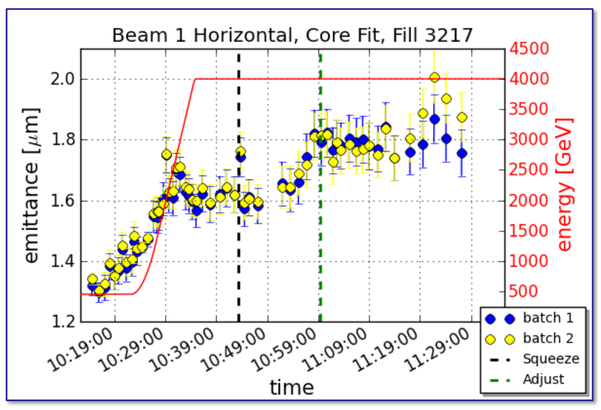
- High performing injectors: emittances as small as 1.5 μm for bunch intensities of up to 1.7×10^{11} ppb
- Blow-up in the LHC: **up to 40 %** until collision
  - 0.7 (for intensities < 1.5×10^{11} ppb) – 1 μm (for intensities > 1.5×10^{11} ppb)

Predictions for post LS1:

- 0.8 – 1 μm total emittance growth
- With same filling time, 6.5 TeV ramp, bunch intensities not larger than 1.5×10^{11} ppb

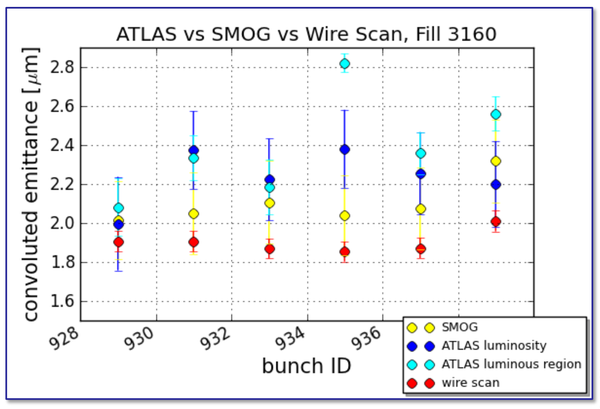
Emittance Blow-up through the LHC Cycle

- ***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



Average emittance of 6 bunches per batch through the LHC cycle for beam 1 horizontal measured with wire scanner, Fill 3217. Batch 1 is colliding at LHCb, batch 2 in ATLAS and CMS.

Comparison with Data from LHC Experiments



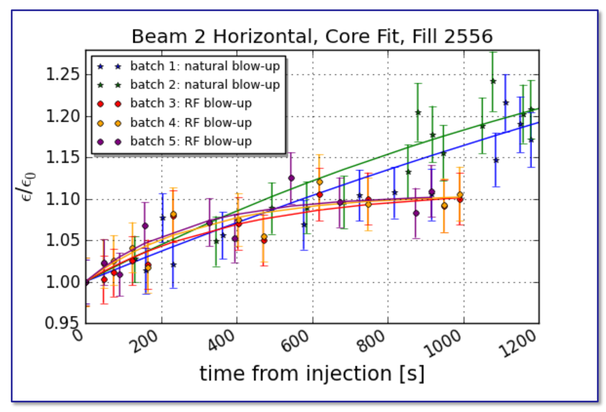
- Large discrepancy between values from wire scanners and experiments
  - Smaller emittances from wire scans
  - Possibly photomultiplier saturation
- Systematic difference between SMOG data and emittances from ATLAS
- **Emittance from experiments most trustable**

Convoluted bunch emittance from SMOG, wire scanners, ATLAS luminosity and luminous region, Fill 3160.

Possible Sources and Remedies

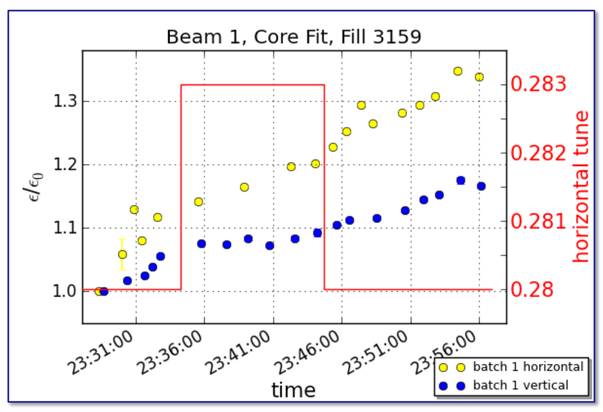
IBS at the LHC Injection Plateau

- 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 % ε growth in 20 min
- RF blown up batches: effect of IBS clearly reduced
  - 10 % ε growth in 20 min



RF batch-by-batch blow-up test with 5 batches of 12 bunches. Batches 1 and 2 are left to natural blow-up. Batches 3, 4 and 5 are longitudinally blown up (target bunch length = 1.6 ns). Relative emittance growth measured with wire scanner (dots) with exponential fit (line). ε_0: emittance at injection into the LHC.

Influence of 50 Hz noise at 450 GeV



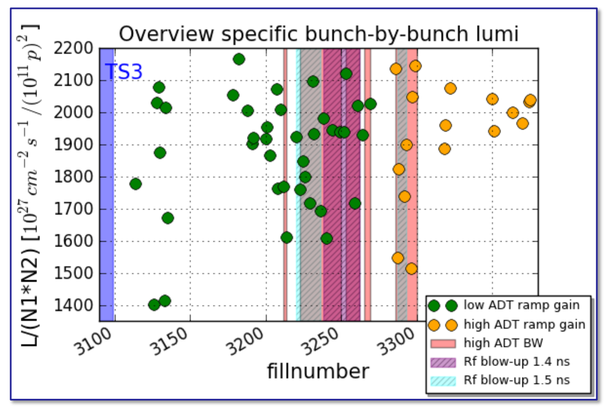
Relative average emittance growth of 6 bunches at injection energy for beam 1 horizontal and vertical measured with wire scanners, Fill 3159.

LHC horizontal 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



Most-probable average specific bunch-by-bunch luminosity for fills after TS3 in 2012. Measures such as high bandwidth transverse damper (high ADT BW) and RF batch-by-batch blow with target bunch lengths of 1.4 and 1.5 ns are also displayed.

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 **BGI** during the ramp
- Installation of a **Beam-Gas Imaging Vertex Detector (BGV)** following the principle of LHCb SMOG under discussion

2012 LHC run configuration:

Total number bunches for fill	Max number bunches injected	Bunch spacing [ns]	Intensity/bunch	Intermediate intensity [bunches]	Number of injections per fill and beam	Filling time	Number collisions (ATLAS+CMS/ALICE/LHCb)	Collision energy per beam	Max luminosity achieved [$cm^{-2}s^{-1}$]
1374	144	50	$1.1 – 1.7 \times 10^{11}$	12	12 (+1 pilot)	~ 30 min	1368/0/1262	4 TeV	7.7×10^{33}