Brightness Evolution for LHC Beams during the 2012 Run

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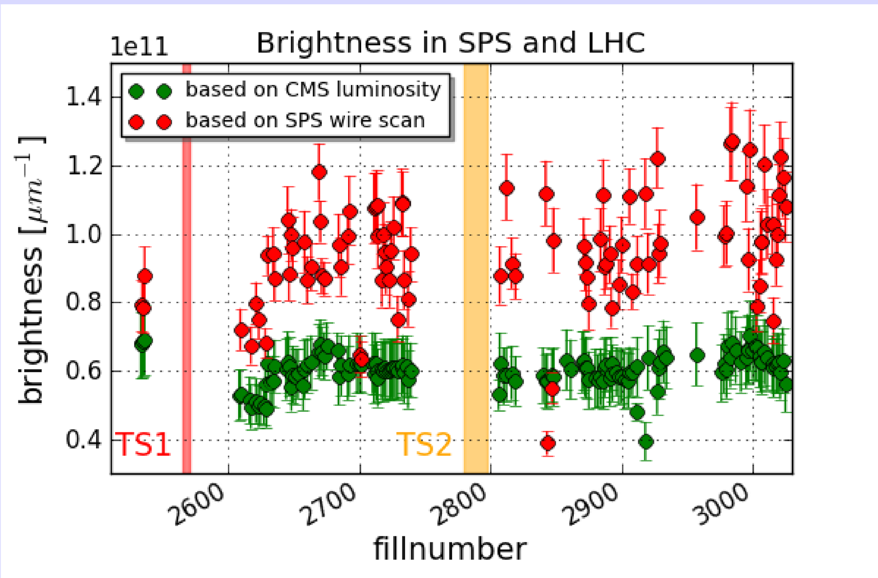
Abstract

One of the reasons for the remarkable achievements of the LHC is the excellent performance of the LHC injector chain. The evolution of the brightness in the injectors and at LHC collision in 2011 and 2012 is discussed. During certain run periods, the brightness from the beam provided by the injectors was lower than usual. Some of the issues have been identified so far and will be reported. The latest results on emittance blow-up investigations through the 2012 LHC cycle will also be presented and compared to the 2011 data. Possible implications for LHC upgrade scenarios will be mentioned.

Brightness Evolution



There is a problem with brightness conservation in the LHC.

- Emittance blow-up between SPS extraction and LHC collision
- physics beams blow-up by ~ 0.7 µm through the LHC cycle for ~ 1.7 µm initial convoluted emittance
- but the emittances measured with wire scanners for low intensity fills are smaller than the emittances from luminosity

Brightness calculated from instantaneous luminosity in CMS during LHC collisions assuming 15 % error on β* and 5 % error on the crossing angle. The beam intensity is measured by the Fast Beam Current Transformer (FBCT) in the LHC. Emittance in SPS determined with wire scanners assuming a 10 % measurement error. Vertical bars represent technical stops TS1 and TS2.

Brightness from the Injectors

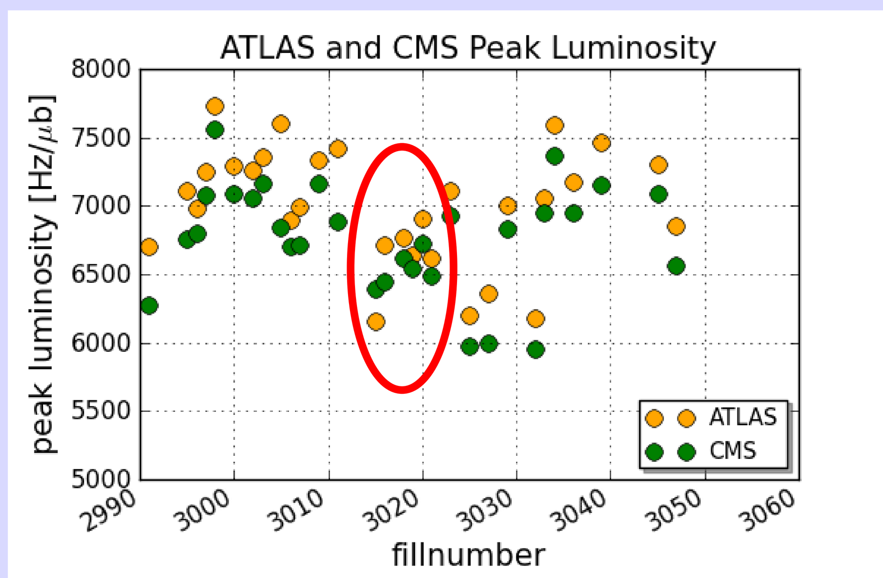
After a period of reduced brightness coming from the injectors at the beginning of 2012, an investigation during the first technical stop detected a mismatch at extraction from the PS.

⟶ mismatch caused long beam tails and large emittances

⟶ since then continuous logging of emittances and bunch intensities in the injectors

⟶ injectors cannot always produce stable brightness beams

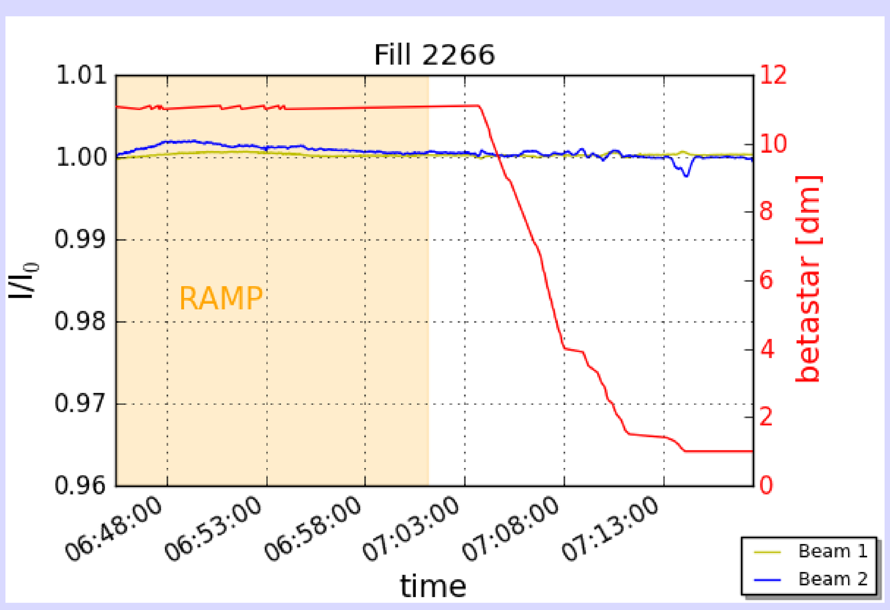
⟶ transverse emittance has to be monitored in injectors to produce high peak luminosities in LHC

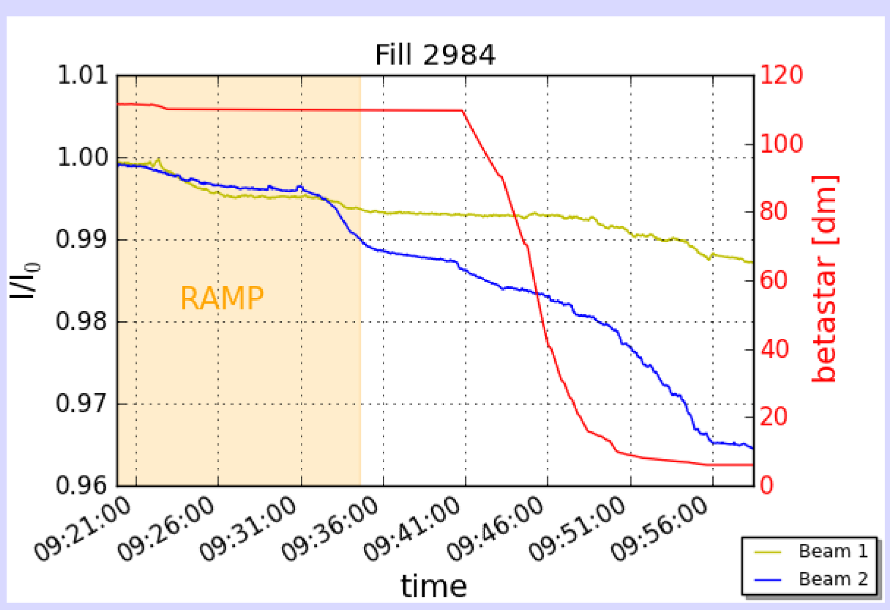


Peak luminosity in ATLAS and CMS for a period with larger horizontal emittances coming from PS, in red circle.

Brightness Reduction in the LHC

The transmission through the LHC cycle in 2011 is excellent. Intensity losses are negligible. In 2012 the transmission through the LHC ramp and squeeze is not as good due to tighter collimator settings. About 4 % of the intensity is lost during the LHC cycle.

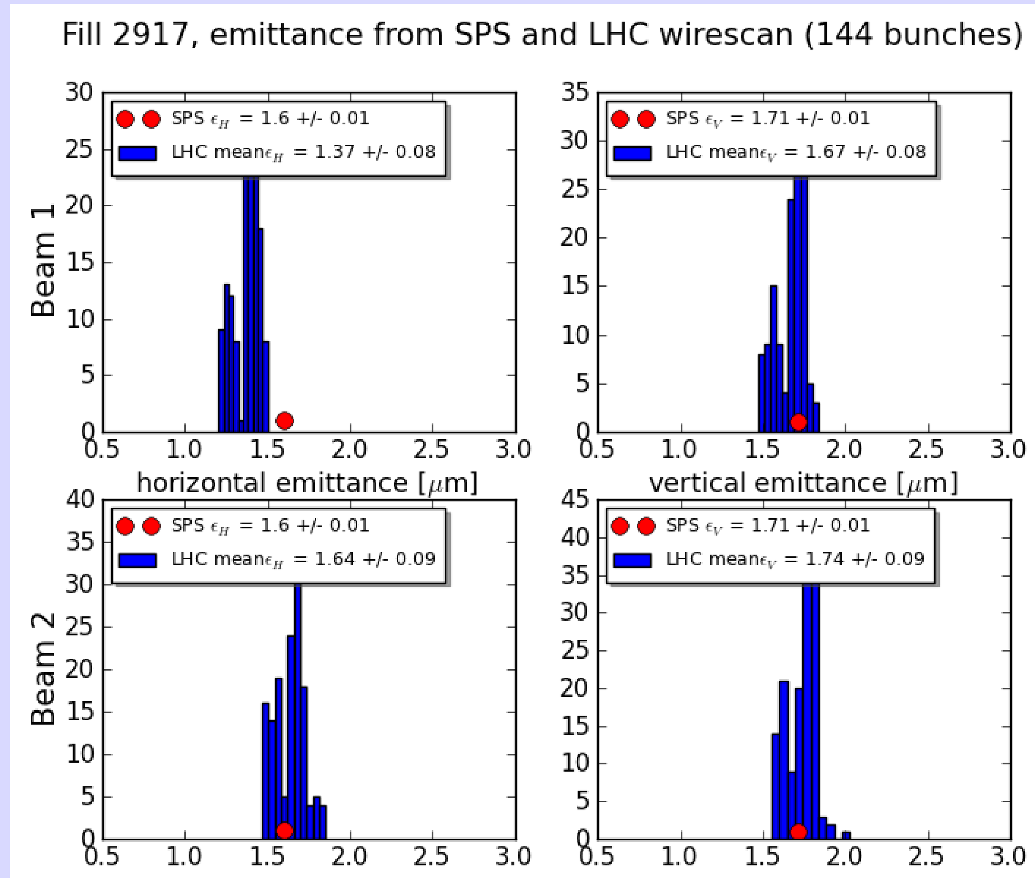




Relative intensity change for beam 1 and beam 2 during acceleration and β* squeeze in the LHC measured with the FBCT for fill 2266 in 2011 and for fill 2984 in 2012.

2012 LHC Emittance Preservation

The LHC Injection Plateau



Wire scans of normalized averaged emittance of 144 bunches at SPS extraction compared to bunch-by-bunch emittance from wire scans at LHC injection. The cores of the transverse profiles are fitted with a Gauss.

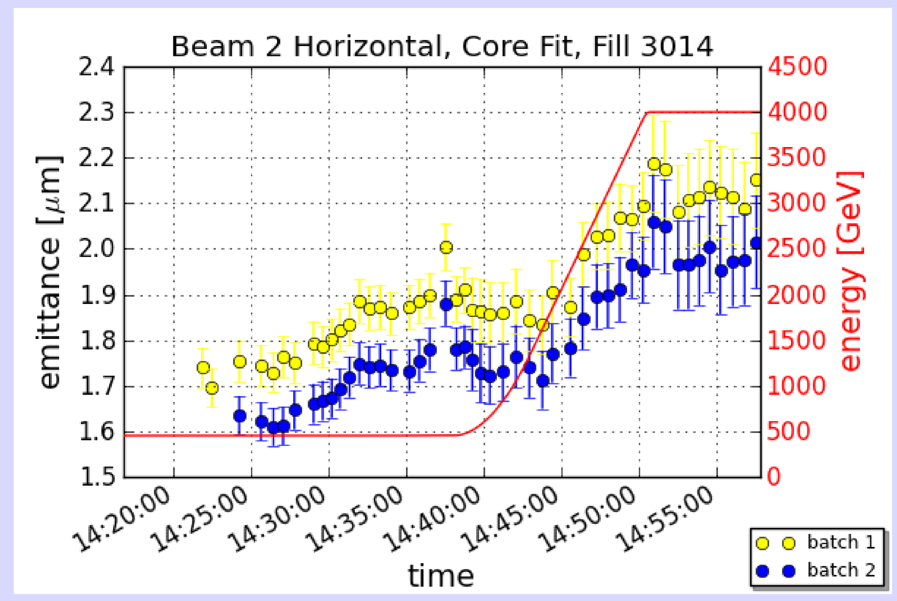
Within the measurement accuracy of ± 10 % the normalized transverse emittances stay constant at the injection process.

During the LHC filling time the emittances grow slightly depending on the time the bunch batches stayed at the injection plateau. This blow-up is the smallest contribution to emittance growth in the LHC cycle. Possible cure: RF batch-by-batch blow-up to lengthen bunches.

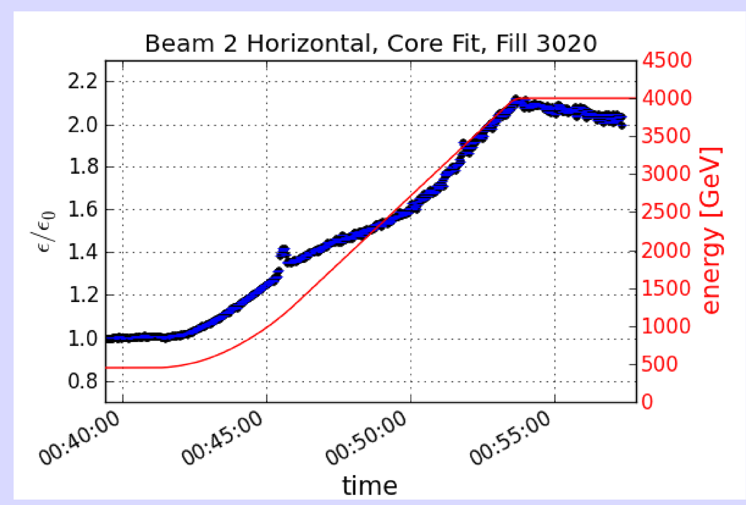
Blow-up in the horizontal plane ➡ Intra beam scattering (IBS)

The LHC Ramp

- beam 2 horizontal grows significantly during the ramp about 15 – 30 %
- very small growth for beam 1 horizontal
- no growth for vertical plane
- BGI also shows growth for beam 2 horizontal
  - not calibrated yet



Wire scans of beam 2 horizontal during injection and ramp for fill 3014 with 2 batches of 6 bunches each. The cores of the transverse profiles are fitted with a Gauss. Error bars include statistical error from averaging, fitting error and beta function error. Emittance growth at injection is 10 % and during ramp 14 % for this fill.



Beam gas ionization profile monitor (BGI) measurement of beam 2 horizontal during ramp of physics fill 3020 with 1374 bunches. The cores of the transverse profiles are fitted with a Gauss. Error bars indicate error in measured beta function and fitting error.

Possible source for emittance blow-up during the ramp:

- noise
- reduced transverse damper gain
- also uncertainties on optics at instruments

The LHC Squeeze

Unlike to 2011 no growth seems to occur during the squeeze. BSRT expert fast scans of physics bunches show no increase of the beam size, within measurement errors, during the squeeze.

Implications for LHC Upgrade

⟶ reducing the filling time to suppress IBS

⟶ total absolute emittance growth seems to be independent of bunch intensity and initial emittance ➡ spoils the performance of future 1 µm beams

LHC run config. in 2012:

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	1.6×10^{11}	12	12 (+1 pilot)	~ 30 min	136839/1262	4 TeV	7.7×10^{33}