Observations from LHC operation

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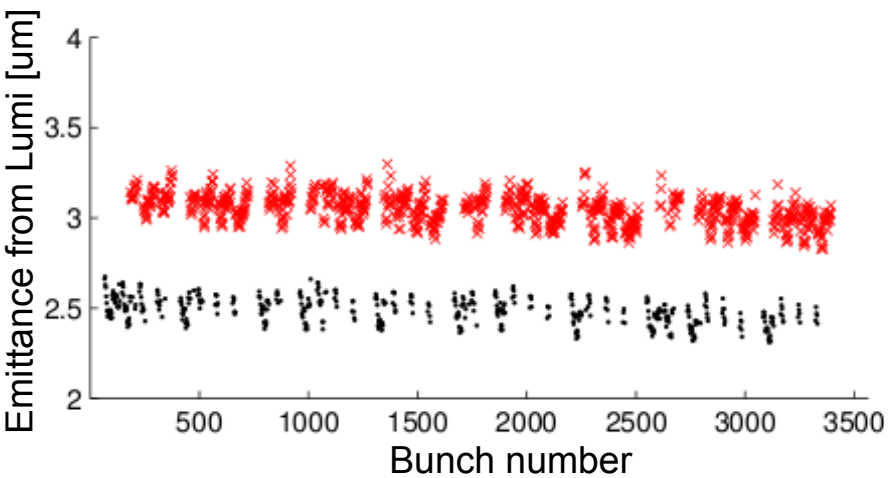
Acknowledgments to G. Arduini, W. Herr, T. Pieloni, the LHC OP crew and the LHC beam-beam team

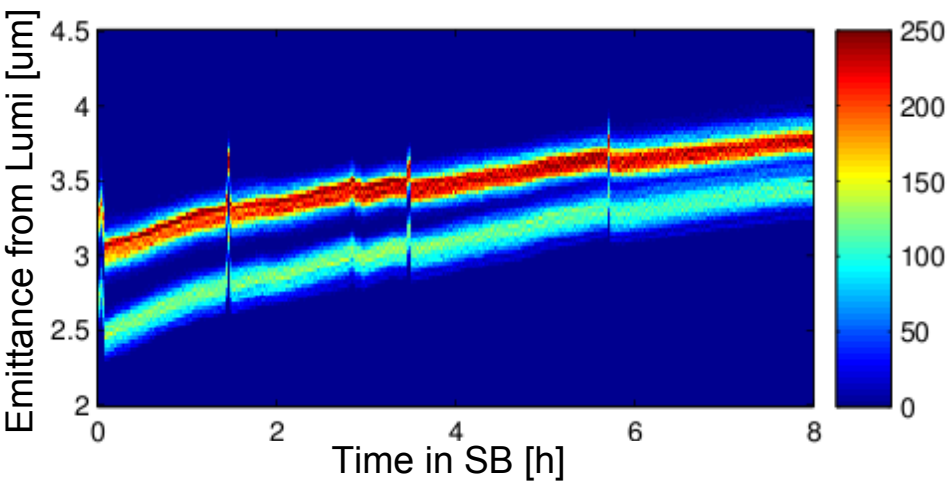
Outline

- Bunch parameter evolution after end-of-Squeeze instabilities
  - Transverse emittance
  - Losses
  - Bunch length
- Loss pattern of LHC Beam 1
  - Introduction on LHC filling scheme
  - 144-bunch loss pattern reproducibly observed
  - Effect on luminosity lifetime

Selective emittance blowup

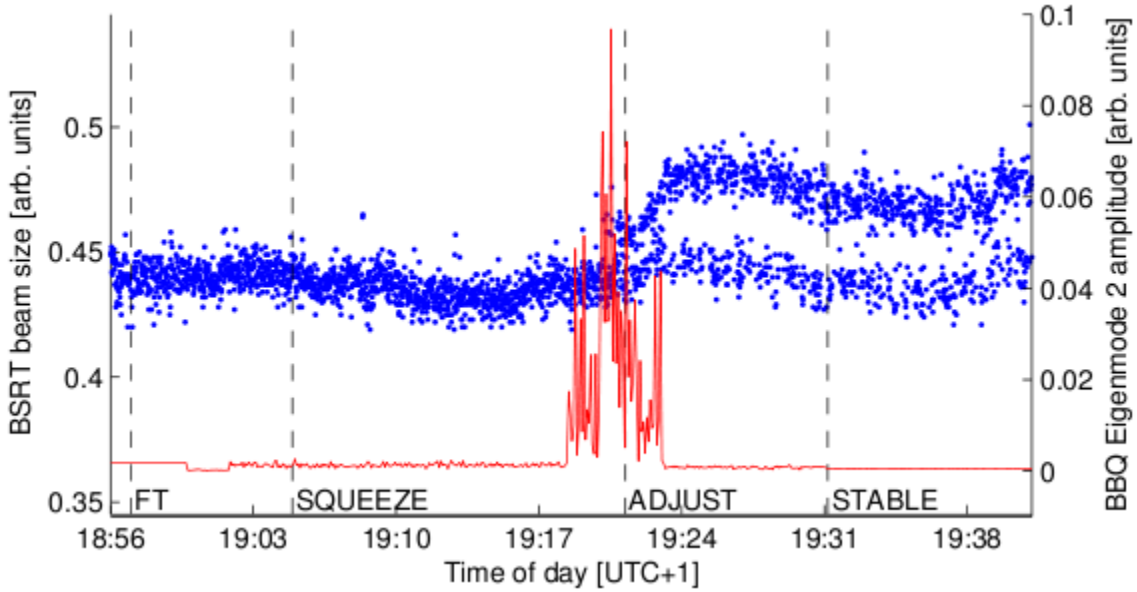
- In the second half of 2012, emittance blowup on selected bunches was observed
  - From a few to 80% of bunches affected
- Typical emittances (derived from Luminosity) at the start of Stable Beams:
  - ~2.5um for non-blown-up bunches
  - ~3.0um for blown-up bunches
- Once in SB: Independent evolution of both families





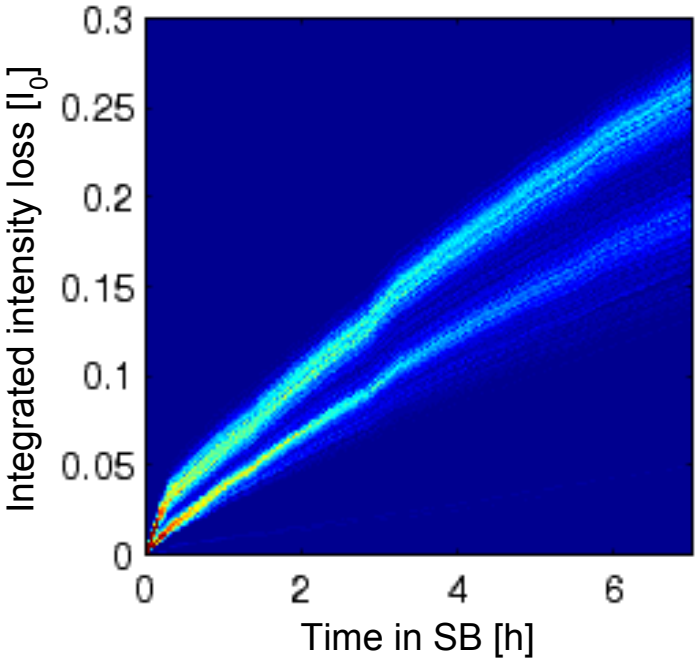
Selective emittance blowup

- Probable cause: Instabilities observed at the end of Squeeze
- Vertical tune signal amplitude increase observed
- Beam 1 horizontal emittance increase observed by the Synch Light Telescope
  - No vertical emittance measurement available

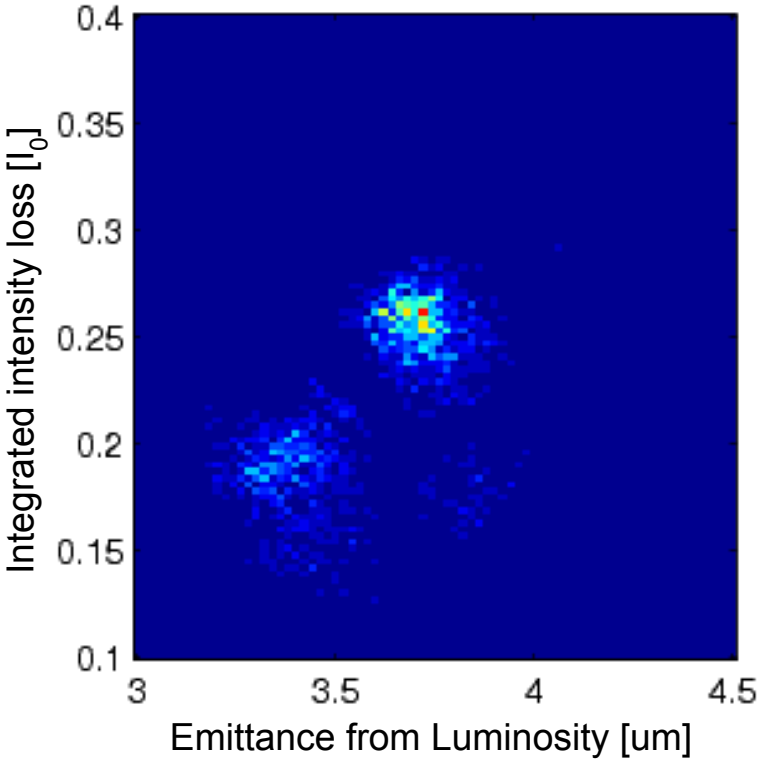


Loss evolution

- Bunches with higher transverse emittance lose more intensity over the fill

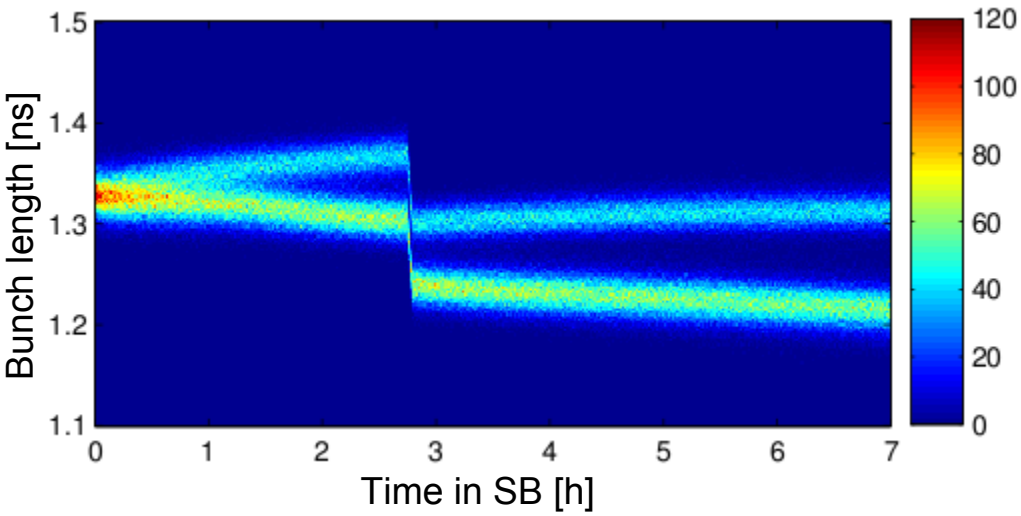


After 7h in Stable Beams:

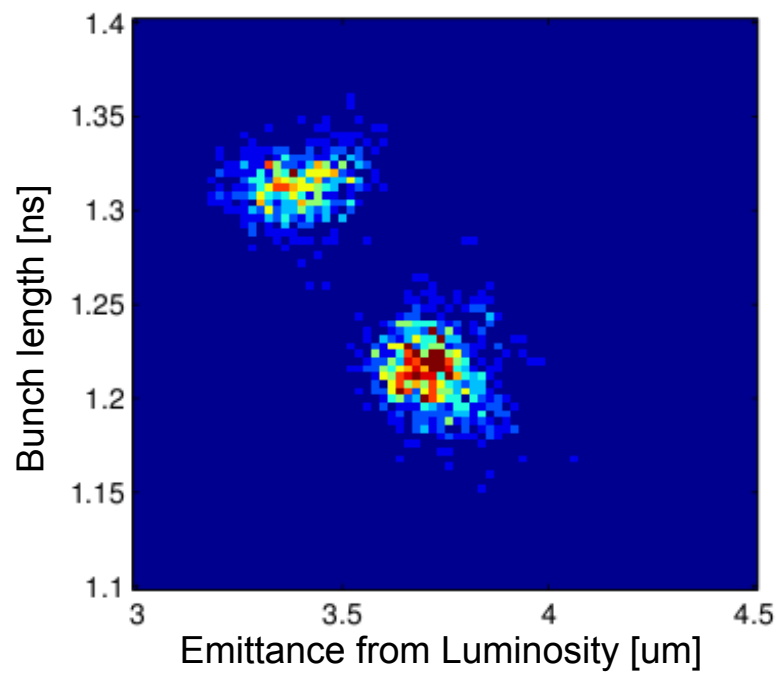


Bunch length evolution

- Bunches with higher transverse emittance develop lower bunch length over the fill
  - Disregard the total RF voltage increase after ~3h



After 7h in Stable Beams:



Summary

- Instabilities at the end of the Squeeze affect bunch parameters of some bunches
  - Transverse Emittance of affected bunches is blown up by ~0.5um
- Two families of bunches evolve during Stable Beams
  - Blown-up bunches develop higher losses and less longitudinal growth

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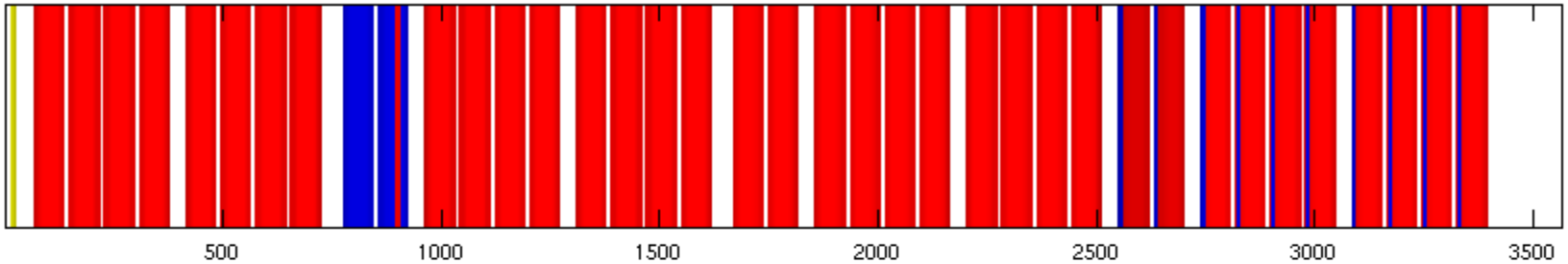
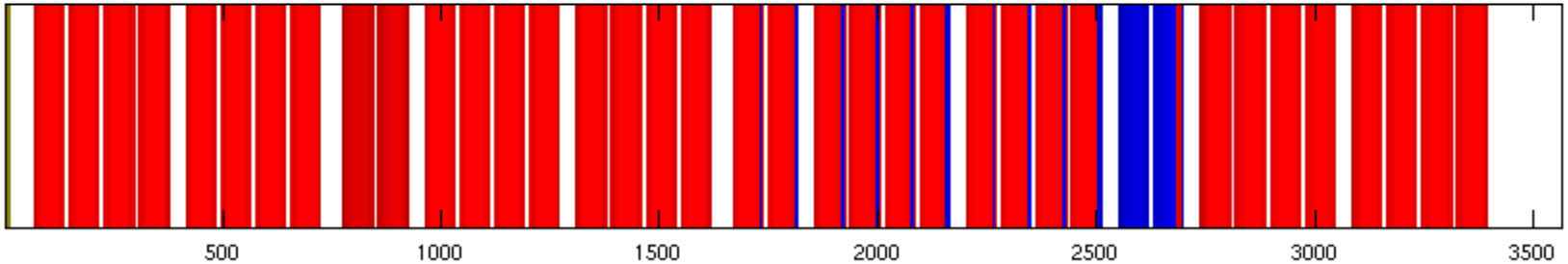
LHC filling scheme(s) of 2012

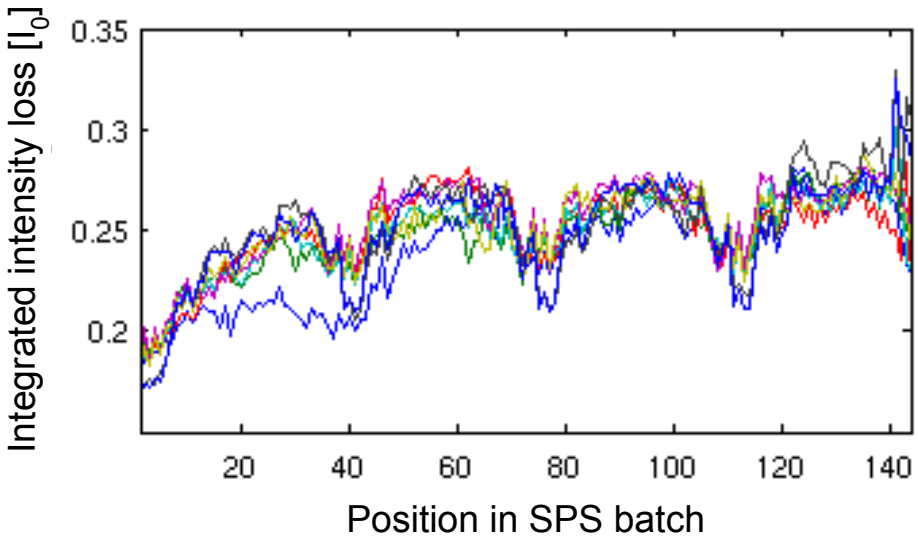
- h=35640, 2.5ns RF buckets, 3564 bunch *slots*
  - In 2012: 50ns bunch spacing
- SPS *batches* of either 2 or 4 trains of 36 bunches from the PS
  - 72 or 144 bunches per batch injected into the LHC
  - 1374 bunches per beam

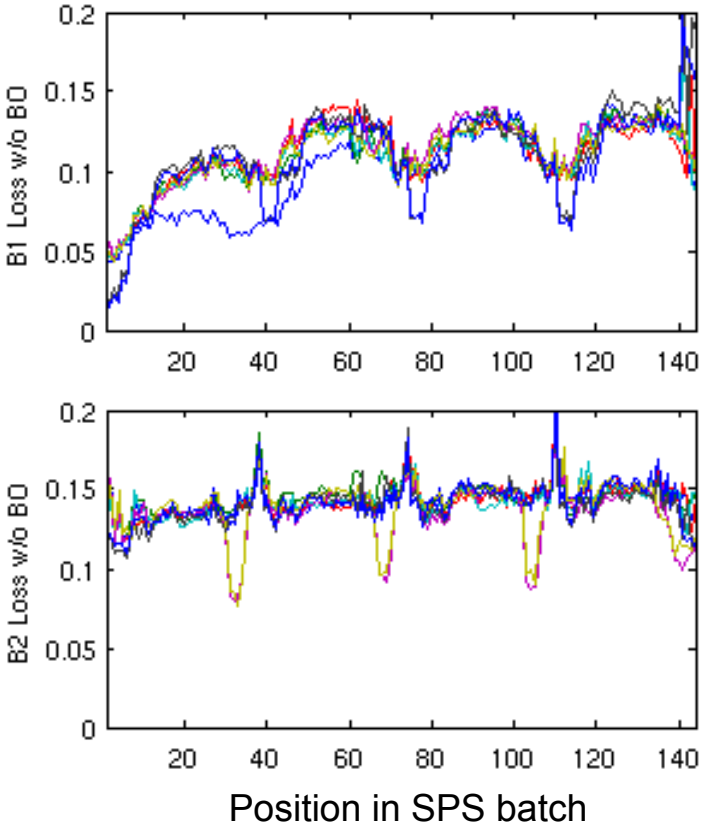




Loss pattern of LHC Beam 1

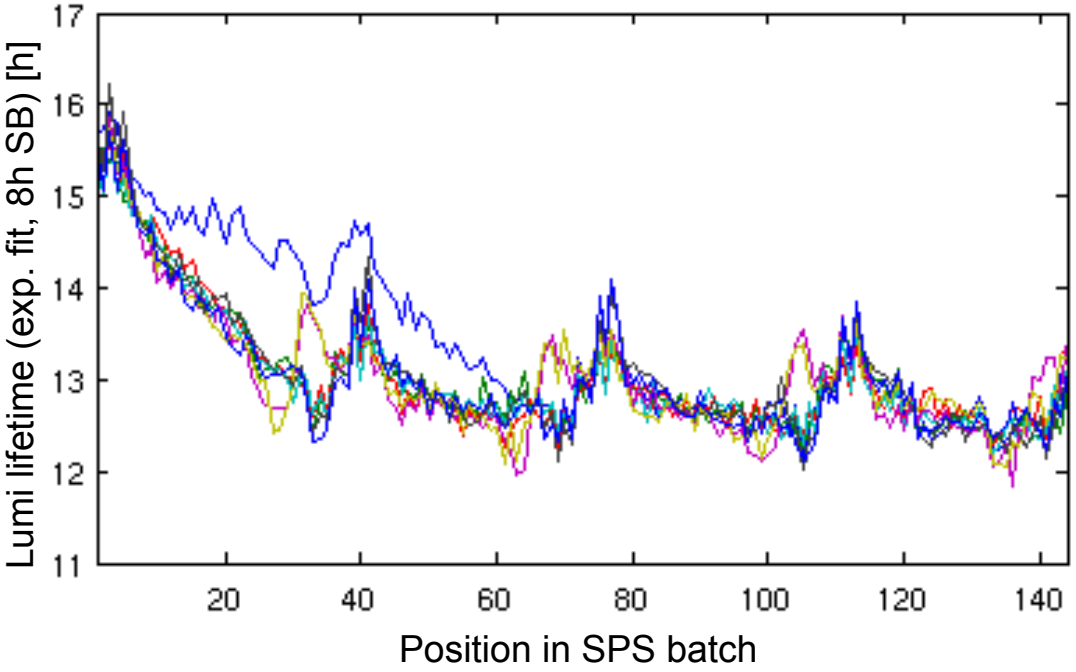
- First ~30 bunches of each SPS batch in Beam 1 lose up to 10% less in ~11h of Stable Beams (SB)
  - Reproducible for Beam 1, negligible for Beam 2
- No final explanation yet
  - not a burn-off effect





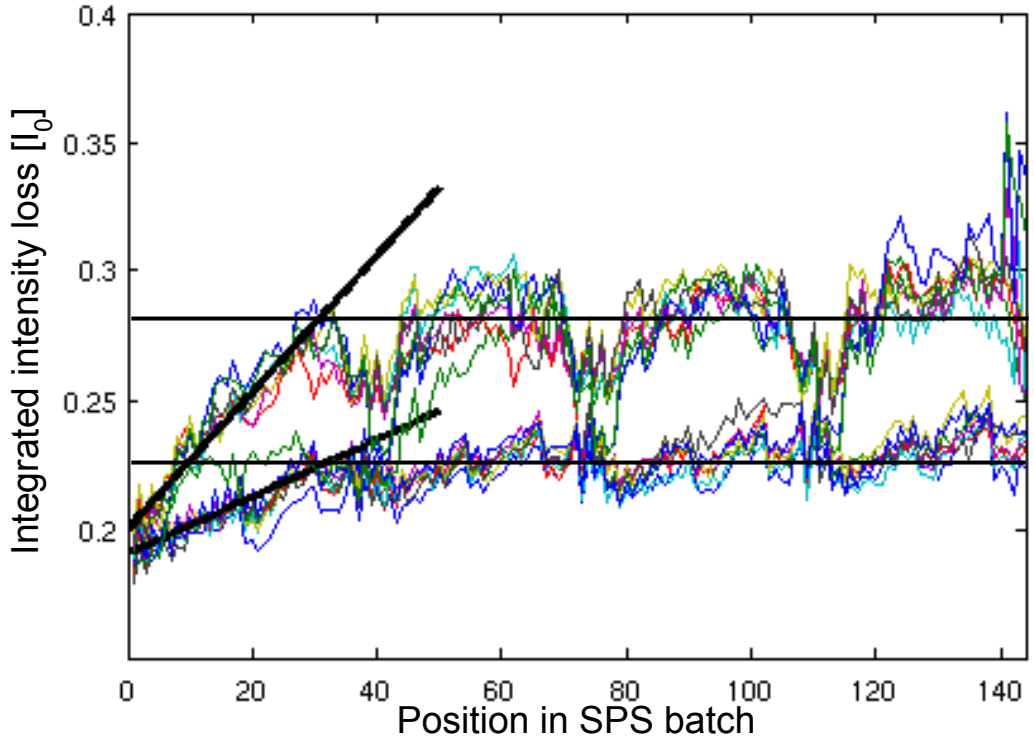
Loss pattern and luminosity lifetime

- Increased losses for the bunches later in the batches lead to lower luminosity lifetime of collision pairs including those bunches
- After some hours: Luminosity lifetime shows a clean "mirror image" of the beam 1 loss pattern



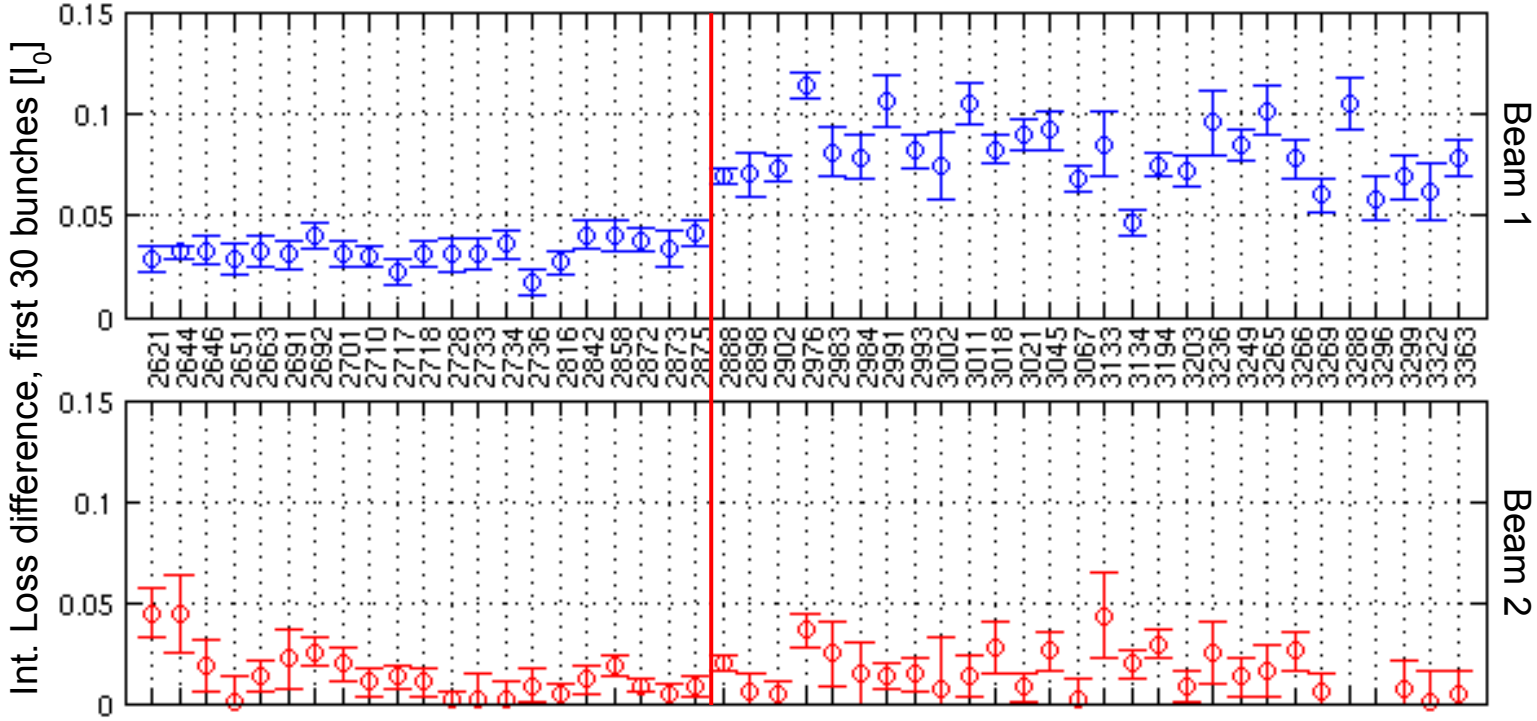
Loss pattern: Quantification

- Slope: Linear fits over the first 30 bunches of each SPS batch
- Total losses: Average over all SPS batches
- Obvious change of the slope and the total losses over the year



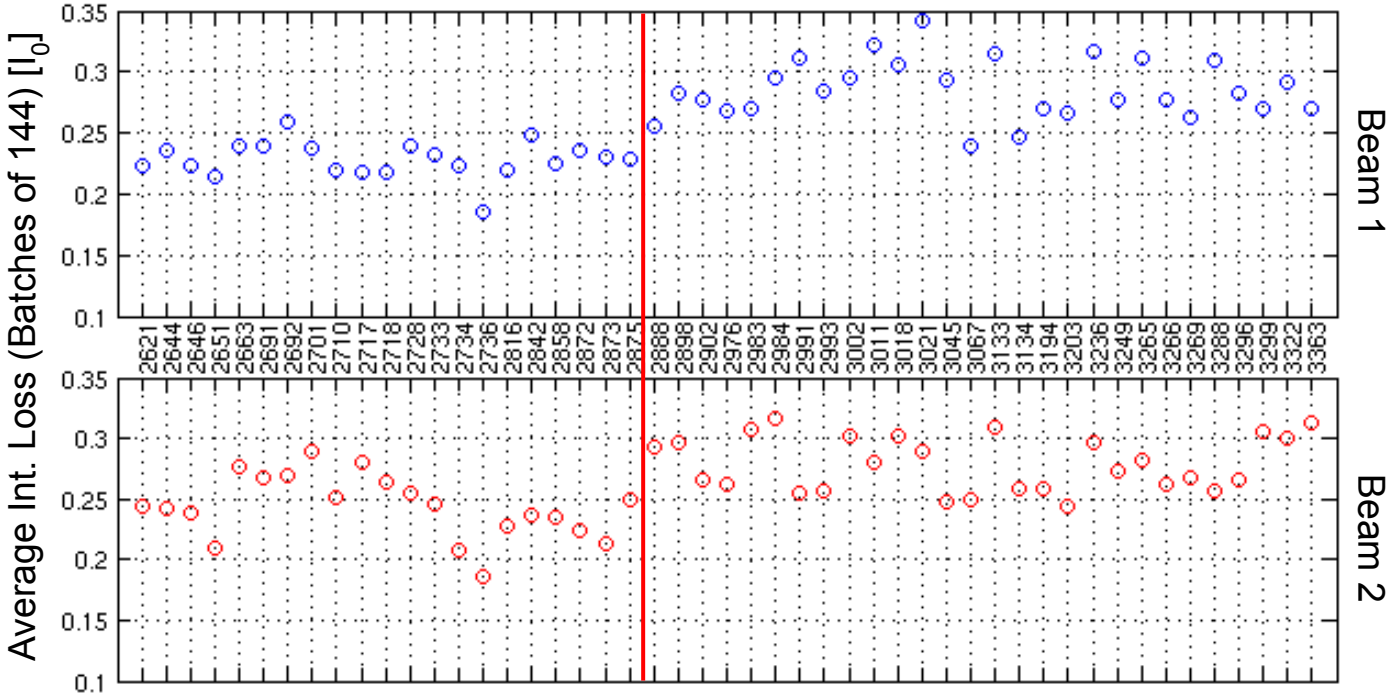
Loss pattern: 2012 Statistics

- Statistics for long fills (11h or more) of 2012 show a significant increase of the difference after fill 2875
- Increase in bunch length after Fill 2880
  - Longitudinal blow-up bunch length target for the ramp increased from 1.2ns to 1.3ns



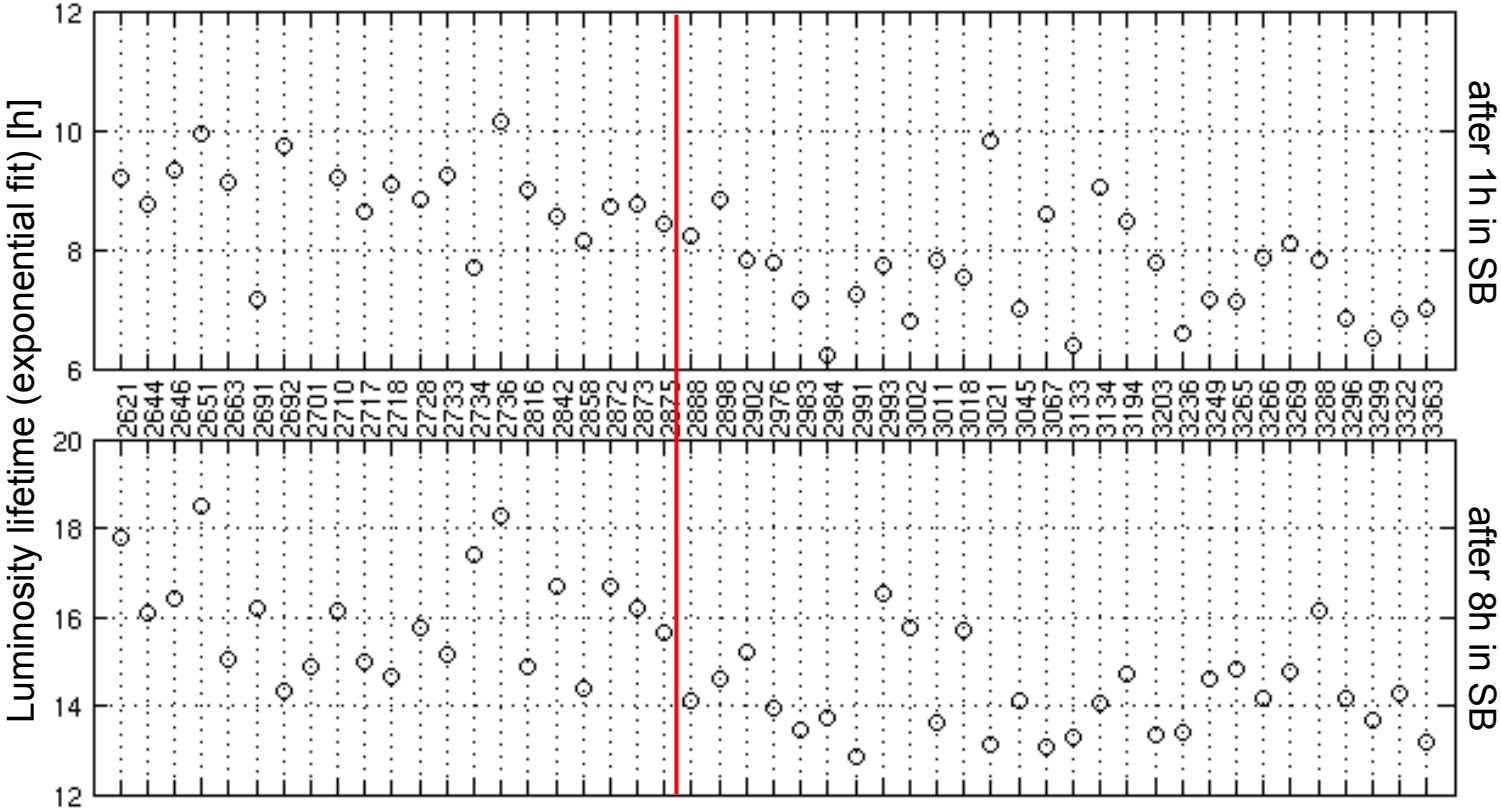
Loss pattern: 2012 Statistics

- Loss of the first bunches did not change significantly
  - Increase of the overall intensity loss!



Losses, Luminosity lifetime in 2012

- Increased overall losses degrade luminosity lifetime, effect visible (~1h less lifetime)



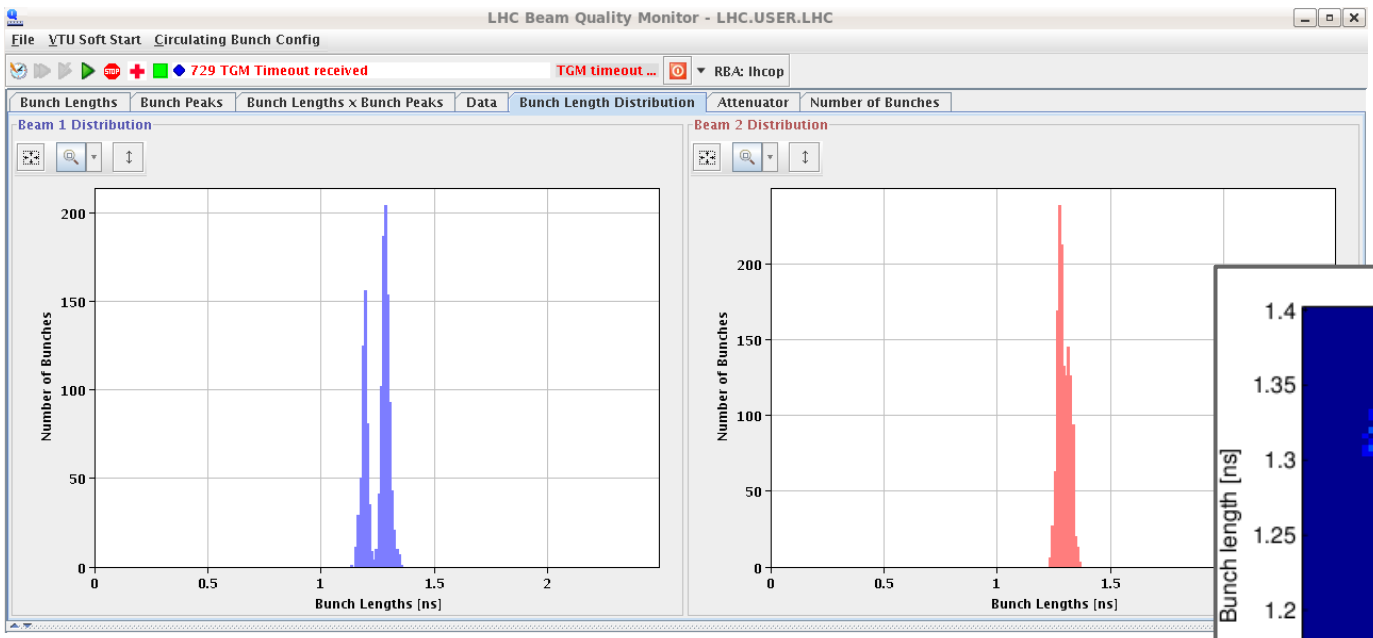
Summary

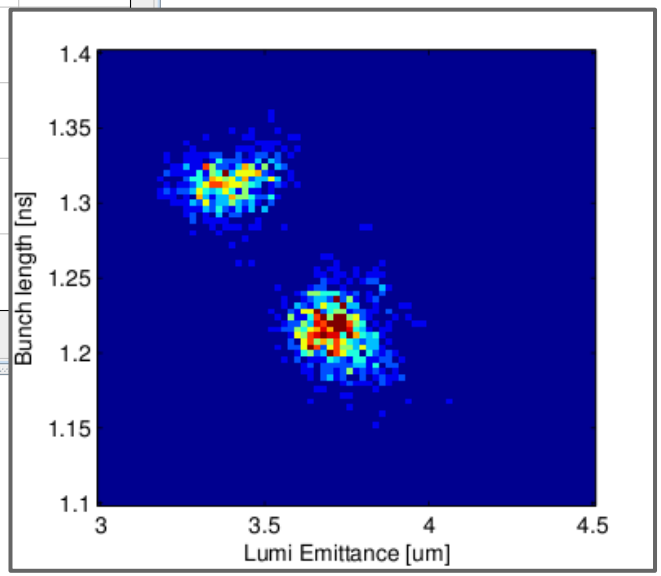
- Very reproducible loss pattern observed on Beam 1 batches, negligible on B2
- Probably correlated to the longer bunch length
  - Blow-up target changed from 1.2ns to 1.3ns
  - Longer bunches give higher losses
    - Beam 1: ~10% in 11h
    - Beam 2: <5% if present at all, no structure visible
- Increased losses degrade the luminosity lifetime by ~1h
- No final explanation for the pattern of Beam 1 losses

Thank you!

Bunch length histogram splitting

- Bunches with higher transverse emittance grow slower longitudinally
- Selective emittance blowup leads to two bunch length families: 'Bunch length histogram splitting' observed on fixed displays





Loss pattern: 2012 Statistics

- Statistics for long fills (11h or more) of 2012 show a significant increase of the difference after fill 2875
- Starting from fill 2880, the longitudinal blow-up bunch length target was increased from 1.2ns to 1.3ns
- Loss of the first bunches did not change significantly
  - Increase of the overall intensity loss!