Observations from LHC operation

M. Hostettler, G. Papotti

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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:

- Integrated intensity loss $I_0$
- Emittance from Luminosity [um]
Bunch length evolution

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

![Graph showing bunch length evolution over time](image)

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 \( \sim 0.5 \text{um} \)
- 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!

![Graph showing the intensity loss of the first bunch and the overall intensity loss for beams 1 and 2.](image-url)