PS intensity reach and longitudinal parameters after LIU

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Outline

- Introduction, intensity reach in 2017

- Beam performance reach in 2018
  - RF upgrades during YETS17/18
  - Multi-harmonic feedbacks
  - Landau cavity

- Outcome of studies in 2018
  - Quadrupolar coupled bunch-instability
  - Status of simulations

- Expected performance post-LS2
  - 10 MHz cavities amplifier upgrade
  - Modification of impedance

- Conclusion and plans for LS2
Introduction, intensity reach in 2017

The LIU baseline was not within reach for the PS at the end of 2017…

Optimization 2017

Finemet dipole-mode coupled-bunch feedback

Reach with C10-86/96 coupled-bunch feedback (2005)*

*Intensities >1.3 \cdot 10^{11} \text{ ppb} were delivered <2016, but not with sufficient quality for LHC
RF upgrades during YETS17/18 and ITS18

- New anode power converters 40 MHz and 80 MHz cavities and summing amplifiers for 80 MHz cavities
  - Cavities running reliably at LIU baseline intensity (little margin beyond $N_b = 2.6 \times 10^{11}$ p/b)
  - Expected reduction (~35%) of new summing amplifier in direct feedback loop of cavity C80-88 not visible with beam
  - Saturation of feedback not visible with detected signals?

- New power supplies for Finemet cavity amplifiers
  - Coupled-bunch feedback not tripping anymore
  - Saturation of drive power with previous supplies?

- New pre-driver amplifiers for 10 MHz cavities
  - No effect on direct wide-band feedback

- 200 MHz amplifier upgrade
  - Same coupling of cavities with amplifiers (final stage unchanged), no change expected in beam impedance

- Beam measurements of C80-89 impedance along 2018
  - No visible impedance reduction measured with beam
Multi-Harmonic Feedback (MHFB)

- Successfully implemented on all 40 MHz and 80 MHz cavities in 2018
- Factor 10 impedance reduction on revolution harmonics

- Improves longitudinal emittance along the batch
- As efficient as cavity gap closure

Long. emittance (RMS) at start of flat-top with 3rd 80 MHz gap closed, MHFB on/off

$N_b = 2.4 \cdot 10^{11}$ p/b
Cavities pulsed at harmonic ratio = 4, wrt main rf system (SPS-like)
Can be used from 13 GeV: narrow-band resonator with no tuning. A dedicated rf system was studied in the frame of the PS Landau Cavity Study Group
Significant stabilization using higher-harmonic RF in complement with the Finemet dipole-mode coupled-bunch feedback
Stability margin beyond LIU baseline
Intensity reach, end 2018

Multi-harmonic feedbacks
C40-78 as Landau RF system

Suspected feedback saturation
Optimization 2017

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Beam quality at extraction

- ±5% in longitudinal emittance and intensity at arrival to flat-top
- ±10% in bunch length and intensity at extraction, after all rf manipulation on the flat top
- Bunches at extraction within requirements (<4ns)
- Transient beam loading is responsible of remaining bunch-by-bunch variability, further improvements of the direct feedbacks could help to improve

Extracted bunch intensity variation

$N_b = 2.6 \cdot 10^{11}$ ppb

Extracted bunch length variation

$4\sigma = 4 \text{ ns}$
Margins beyond LIU baseline

- Margin to deliver 10-15% smaller longitudinal emittance to the SPS
- The limit in the PS to reach lower longitudinal emittance is beam loading due to short bunches
- The extracted bunch length is still below 4ns with no major sign of uncontrolled emittance blow-up
Identification of impedance source

Parking + open gap

- Quadrupolar coupled bunch oscillations without C40-78 as Landau cavity
- 10 MHz cavities with closed gap relays are a clear candidate as source of instability

NB: not an operational solution, bigger transient beam loading during splittings
Status of the impedance model:

- RF cavities (C10, C20, C40, C80, HOMs…)
- Kickers (KFAs, BFAs)
- Vacuum equipment (Magnet Units)

- Beam dumps
- Space charge & resistive wall
- Ongoing (remaining kickers and beam instrumentation)
Progress in particle simulations

- Acceleration ramp implemented in BLonD with present PS impedance model
- Stability diagrams (emittance vs. intensity) are already in fair agreement with measurements. Although slightly optimistic, allowed some preliminary studies

Single RF program transition -> flat top

*Instability*
Expected performance post-LS2

- **Upgrade of the 10 MHz cavities amplifier**
  - Shunt impedance reduced by a factor 2
  - Reduced transient beam loading for the first third of the batch and reduced bunch-by-bunch variation in emittance/intensity
  - Influence on instability threshold to be assessed, but expected improvement since 10 MHz cavities are known to drive coupled bunch instabilities

- **Removal of CT extraction kickers**
  - Reduced single bunch effect (not a limitation presently)
  - Influence on coupled-bunch instability to be assessed

- **Addition/Exchange of equipment (wire scanners, internal dump, ralentisseur)**
  - Impedance optimized in collaboration with the Impedance Working Group
  - The overall addition of impedance is expected small in comparison to the present equipment in the machine
  - Quantitative impact of high frequency impedance sources to be assessed
Conclusion

LIU baseline for the beam performance was reached in 2018!
✓ The MHFB and the new anode power converters for high frequency cavities were the main elements in 2018 to reach higher beam intensity with nominal longitudinal emittance
✓ The existing 40 MHz as Landau rf systems allowed to provide margins
✓ The beam is kept stable both in the longitudinal and the transverse planes (NB: large transverse emittance)

Beam performance is already satisfactory and reproducible.
✓ The high frequency cavities do not trip at high intensity with the new anode power converters
✓ The coupled bunch feedback does not trip at high intensity with the new power supplies

Remaining rf upgrades should allow to reduce bunch-to-bunch variation.
  o Amplifiers upgrade in 10 MHz cavities (shunt impedance /2) will reduce transient beam loading

The margin beyond LIU baseline thanks to the 40 MHz as Landau rf systems can allow to reach for smaller longitudinal emittance. The main potential benefit is the PS-SPS transfer, where smaller longitudinal may allow to reduce losses at injection.

Progress in the understanding of the source of coupled bunch instability have been made, and will be used during LS2 to predict post-LS2 performance and define cycle parameters.
Plan for 2019 and LS2

- Coupled bunch instability study and simulations
  - Source of coupled-bunch instabilities and uncontrolled emittance blow-up
  - Further implementation in particle simulations (transition crossing, rf manipulations, mode analysis)
  - Completion of the PS impedance model
  - Completion of data analysis of acquisitions with LHC-type beam in 2018

- Performance prediction for rf upgrades during LS2
  - Remaining transient beam loading and expected bunch-by-bunch variability
  - Evolution of instability threshold with pre and post-LS2 impedance models
  - Optimization of rf parameters (amplitude, phase) for existing 40 MHz cavities as Landau rf systems

- Choice of parameters for post-LS2 era
  - Choice of intermediate plateau for rf manipulations
  - Definition of rf voltage programs
  - Means for optimization of bunch-by-bunch variability (e.g. machine learning)
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$N_b = 2.6 \cdot 10^{11}$ ppb
Longitudinal shaving and PS-SPS transfer

- Post-acceleration and shaving achieved for high intensity BCMS beam in 2018, thanks to new power converters in 40 MHz cavities (only 36b nominal intensity in 2017)
- Shaved beam in PS can be analyzed to quantify halo population
Questions to be answered

• What is the parameter reach in terms of intensity/longitudinal emittance? What was achieved in 2018 and what is expected from simulations with the further LS2 RF improvements?

• What is the contribution of each of the upgrades (coupled-bunch, 1-turn delay, multi-harmonic feedbacks)?

• Which impedance sources mainly excite the observed instabilities?

• Are there any new ideas to further improve the longitudinal beam quality, e.g. bunch shape after rotation, to better suit the SPS?

• What are the observed and expected bunch-by-bunch parameter variations (2018 and post-LIU)?
Outline

• Introduction

• Beam performance reach in 2018
  o Summary plot for intensity reach with all upgrades
    ▪ Multi-harmonic feedback
    ▪ Landau cavity
  o Present beam quality at extraction and margin beyond LIU (smaller long. emittance)

• Outcome of studies in 2018
  o Coupled bunch instability
    ▪ Progress in impedance model and particle simulations
    ▪ Identification of guilty impedance sources (quadrupolar instability)
  o Longitudinal shaving and PS-SPS transfer

• Expected performance post-LS2
  o RF upgrade (10 MHz high-level upgrade)
  o Impedance reduction (removal of CT extraction kickers)
  o New impedance sources (beam dump, etc.)
  o Optimization of the beam quality

• Conclusion and plans for LS2

Questions

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