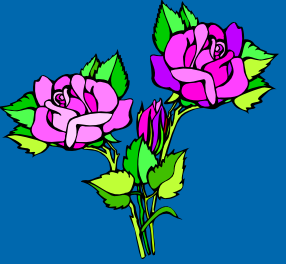


More Robust SPS Filling Scheme

LHCCWG

December 4th 2007

M. Gruwé and E. Métral

Layout

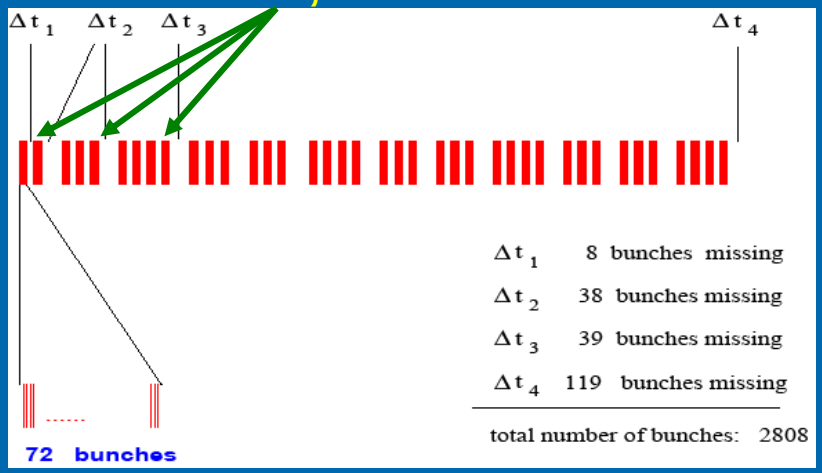
- Introduction:
  - Why?
  - What?
- MD results:
  - Comparison of 4x72 bunches and 5x48 bunches filling schemes
- Conclusions
- Extra:
  - Nominal filling scheme with lower intensity

Why?

- During the whole of 2006, the LHC beam in the PS showed instabilities at extraction:
  - See
    - Presentation in 75th APC (December 15th 2006) by R. Steerenberg:
      - Observations of the high energy instability in the PS
    - Presentation in 20th LHCCWG (February 14th 2007) by E. Metral:
      - Implications for the injectors
  - Reason was the use of two cavities behaving differently (delivering different voltages for the same reference). Problem solved by re-calibration.
  - Still: investigations started to find solution to such problems.
  - Proposed solutions:
    - Presentation in 75th APC (December 15th 2006) by H. Damerau:
      - Double step rotation bunch: RF Gymnastics in the PS with the 40 and 80 MHz cavities
    - Presentations in 20th LHCCWG (February 14th 2007) by E. Metral and W. Herr:
      - Alternative filling schemes
      - Implications for the injectors

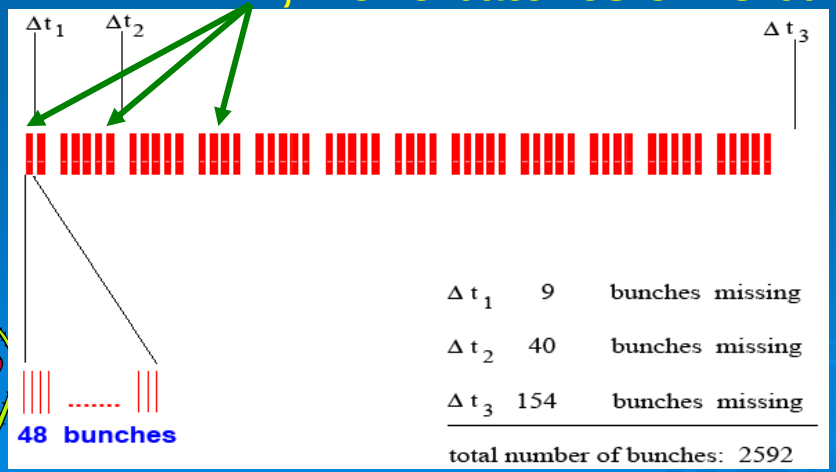
What?

2, 3 or 4 batches of 72 bunches



- Current bunch filling scheme: batches of 72 bunches

2, 4 or 5 batches of 48 bunches



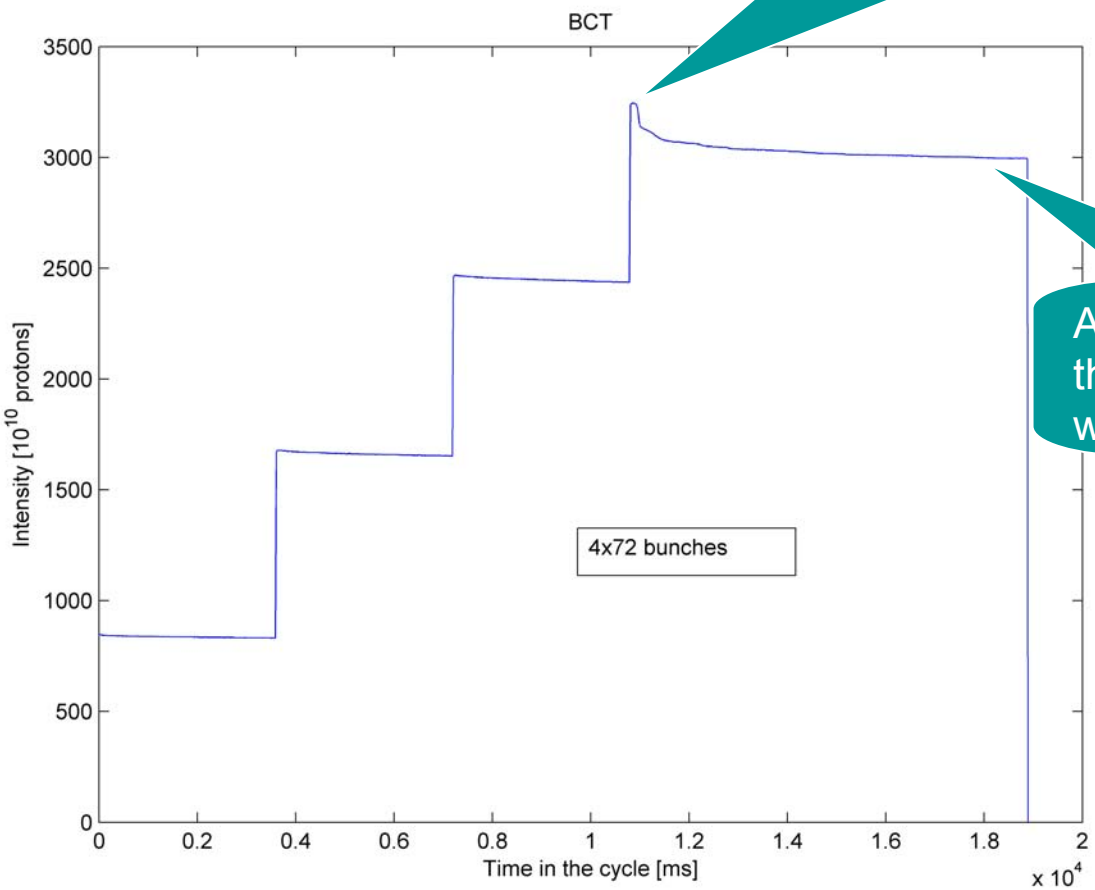
- Alternative filling scheme: batches of 48 bunches

SPS MD

- On October 17th-18th:
  - Comparison of the two SPS filling schemes:
    - 4 injections of 72 bunches
    - 5 injections of 48 bunches
  - Swap from one filling scheme to the other.
    - Same intensity per bunch
    - Same length of supercycle, no optimization.
    - Change only timings so that we can get 5 injections.
  - Note:
    - Intensity was ~1.1 10^{11} p/bunch at end of flat top
    - 1.1 10^{11} p/bunch == 10% lower than nominal
    - Expect 1.15 10^{11} p/bunch in LHC, thus aim for ~1.2 10^{11} p/bunch at end of SPS flat top
  - Therefore we have also looked at:
    - 5 injections of 48 bunches, with intensity ~1.2 10^{11} p/bunch at end of flat top

4x72 bunches SPS BCT

Total injected: 3.24 10^{13} p

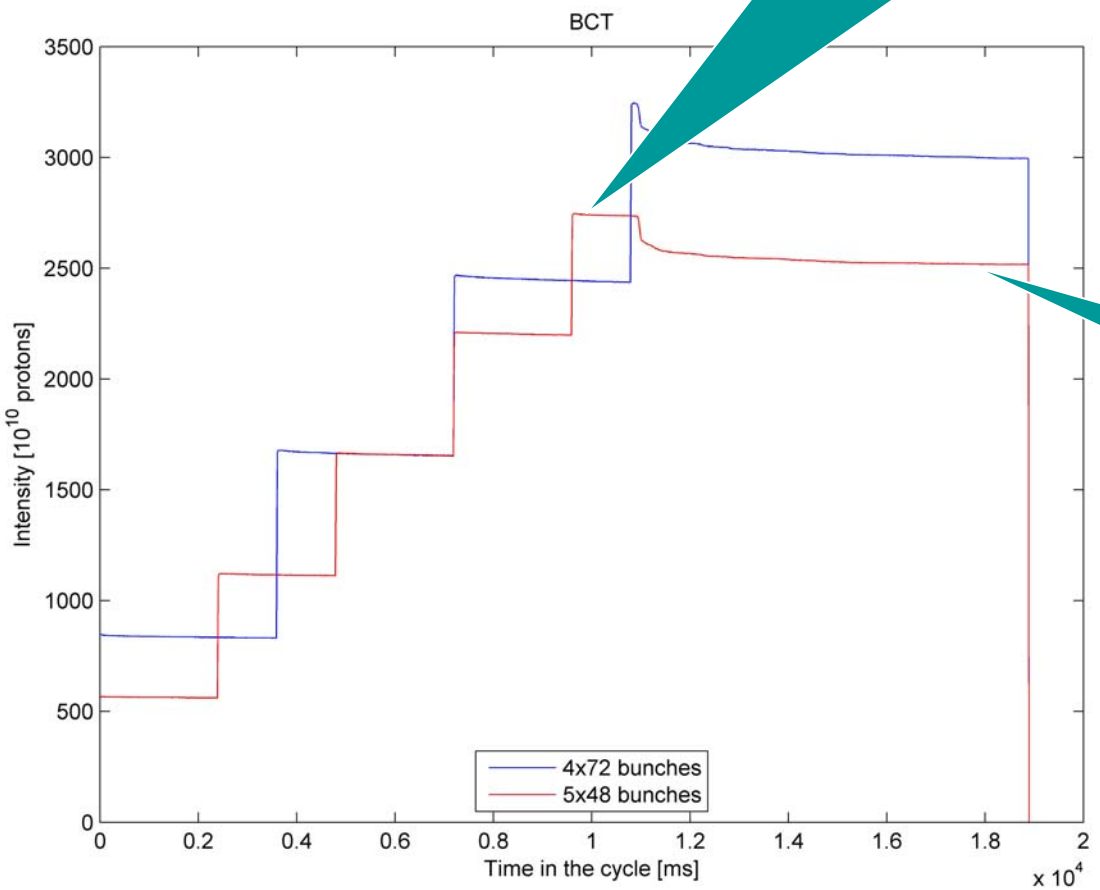


At 450 GeV: 3.01 10^{13} p, that is, 4x72=288 bunches with 1.1 10^{11} p/bunch

Total injected: 3.24 10^{13} p
Total at end: 3.01 10^{13} p
Beam loss: 7%

5x48 bunches SPS BCT

Total injected: 2.74 10^{13} p

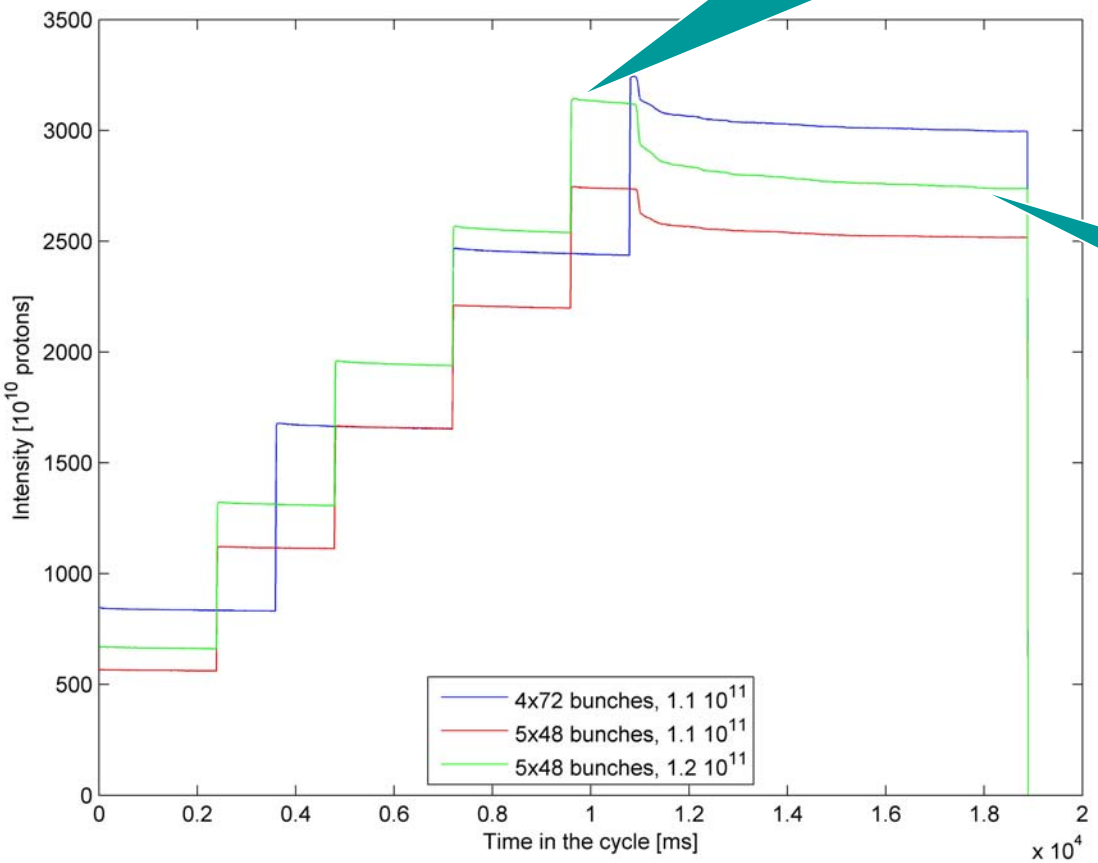


At 450 GeV: 2.56 10^{13} p, that is, 5x48=240 bunches with 1.1 10^{11} p/bunch

Total injected: 2.74 10^{13} p
Total at end: 2.56 10^{13} p
Beam loss: 6.6%

5x48 bunches SPS BCT

Total injected: 3.1 10^{13} p



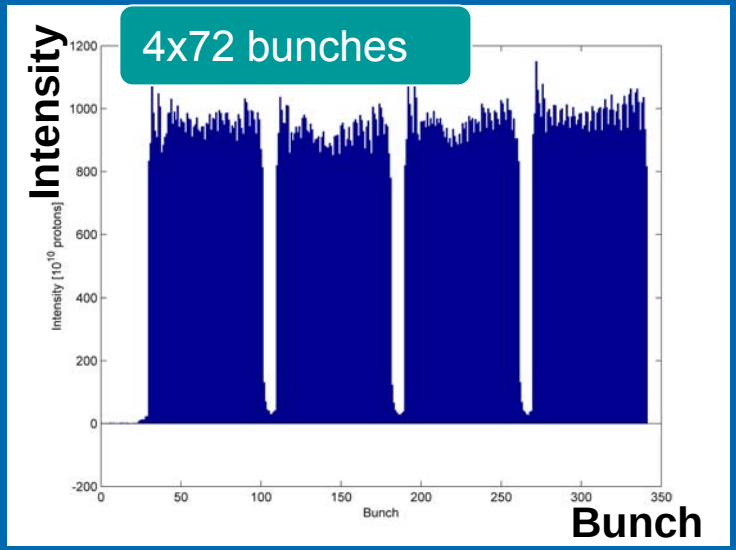
At 450 GeV: 2.7 10^{13} p, that is, 5x48=240 bunches with 1.2 10^{11} p/bunch

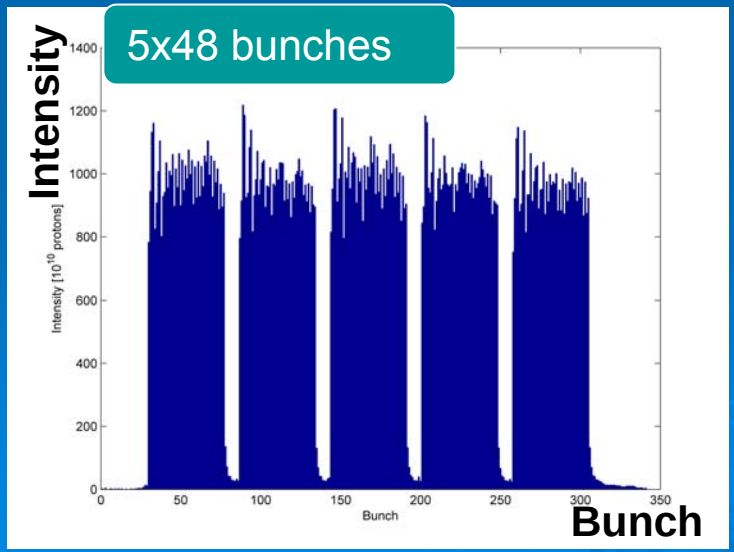
Total injected: 3.1 10^{13} p
Total at end: 2.7 10^{13} p
Beam loss: 12.3%

SPS BCT

- Similar beam losses in case of 4x72 bunches scheme or 5x48 bunches scheme (with similar intensity per bunch):
  - About 7% loss between total injected in SPS and total at 450 GeV, for 1.1 10^{11} p/bunch
- No comparison possible for higher (~ nominal) intensity per bunch:
  - Throughout the whole year, we have never managed to have 4x72 bunches with nominal intensity in SPS.
    - Due to abnormal outgassing of the dump kicker MKDV1
  - For 5x48 bunches, no problem. Beam loss is then about 12.3% between total injected in SPS and total at 450 GeV, for 1.2 10^{11} p/bunch

FBCT



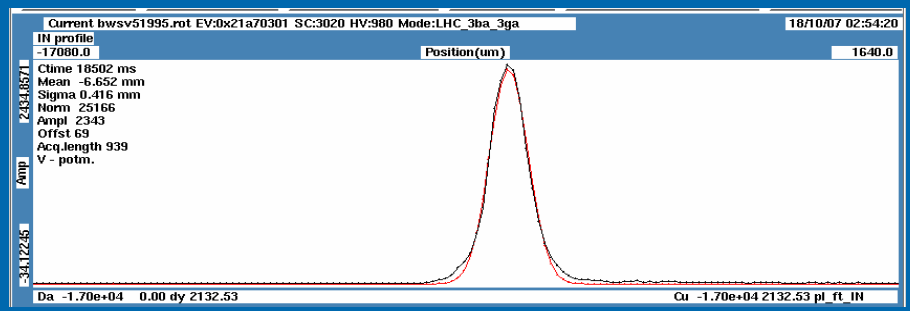


- Checked if any significant/systematic difference in behavior:
  - None.

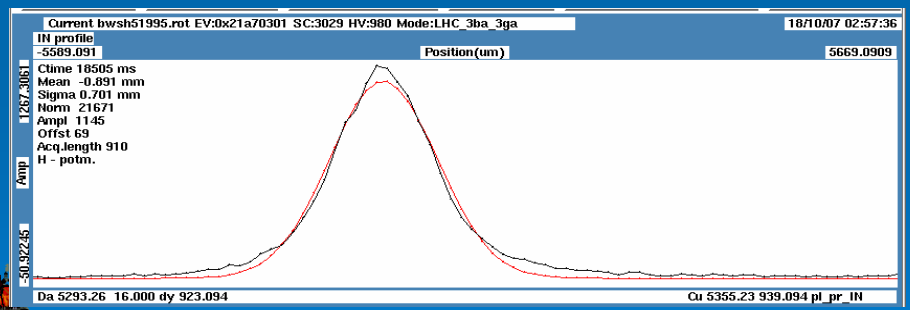
Emittances in SPS

Wire scans:

- vertical



- horizontal



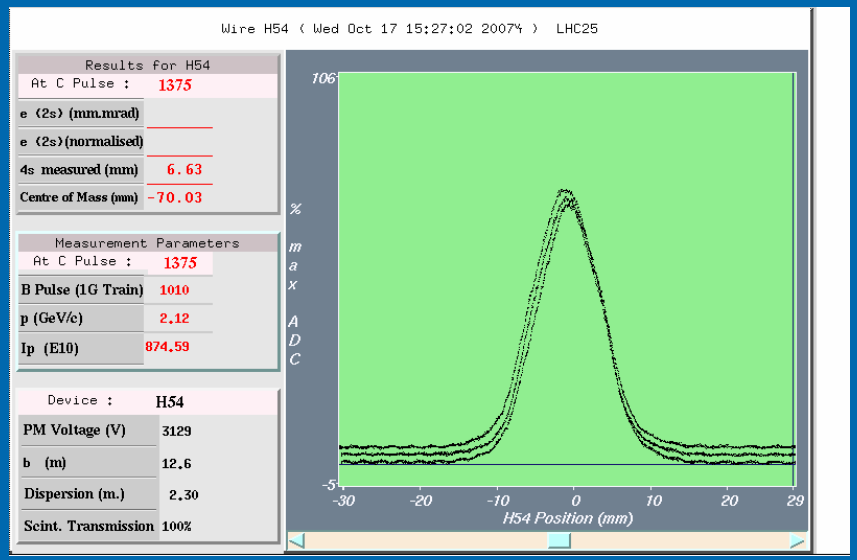
- 4x72 bunches, 1.1 10^{11} p/bunch:
  - ε_x = 2.8 mm.mrad
  - ε_y = 3.1 mm.mrad
- 5x48 bunches, 1.1 10^{11} p/bunch:
  - ε_x = 2.9 mm.mrad
  - ε_y = 3.0 mm.mrad

- 5x48 bunches, 1.2 10^{11}p/bunch
  - ε_x = 3.2 mm.mrad
  - ε_y = 3.4 mm.mrad

- **For same bunch intensity, similar emittances**
- **For nominal bunch intensity: emittances still in specifications**

Emittances in PS

Wire scan:

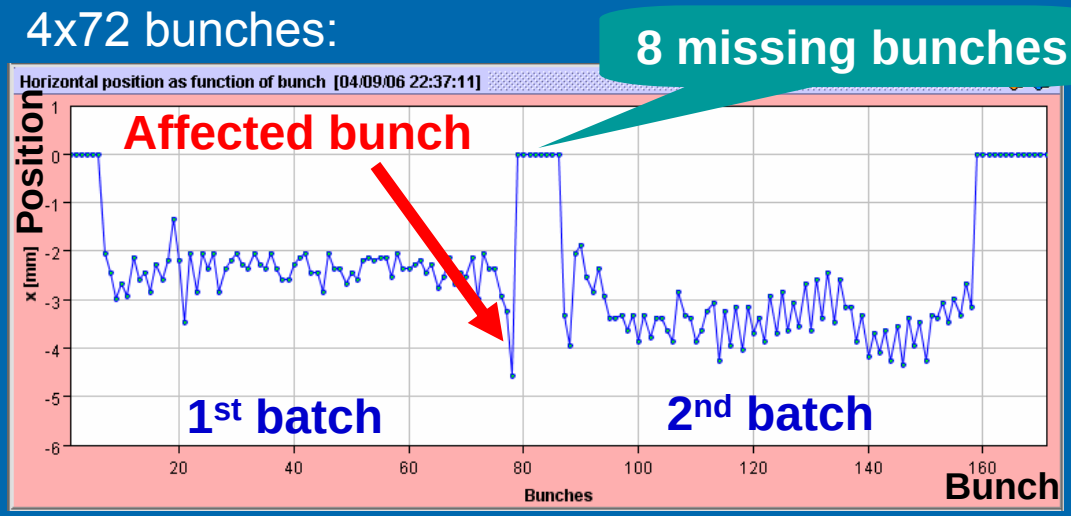


- 72 bunches:
  - Just after injection:
    - ε_H = 1.84 mm.mrad
    - ε_V = 2.38 mm.mrad
  - At extraction:
    - ε_H = 2.87 mm.mrad
    - ε_V = 2.35 mm.mrad

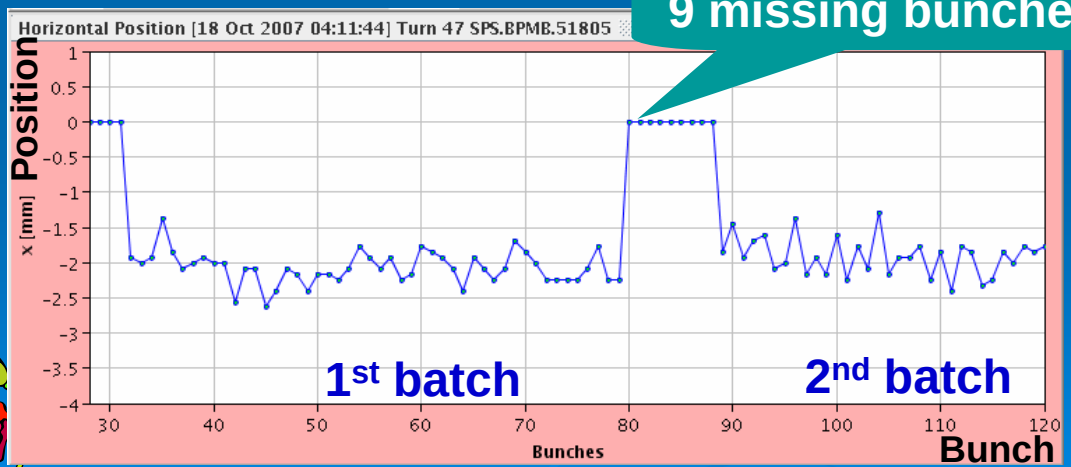
- 48 bunches:
  - Just after injection:
    - ε_H = 1.5 mm.mrad
    - ε_V = 2.4 mm.mrad
  - At extraction:
    - ε_H = 2.4 mm.mrad
    - ε_V = 2.45 mm.mrad

BPM readout

4x72 bunches:



5x48 bunches:



- 4x72 bunches:
  - 8 missing bunches between two injected PS batches: 225 ns
  - Not enough time available for the rise time of the injection kickers (really at the edge).
  - One always hits either the last bunch of the circulating batch or the first bunch of the injected bunch.
- 5x48 bunches:
  - 9 missing bunches between two injected PS batches: 250 ns
  - More time available for the rise time of the injection kickers
  - Last bunch of circulating batch and first bunch of injected batch are not affected

Conclusions (I)

- Note:
  - During the MD, going from 4x72 bunches to 5x48 bunches was very easy and done in a few minutes only.
- Differences of 5x48 filling scheme with respect to 4x72 filling scheme:
  - Intensity:
    - This year, we couldn't reach nominal intensity in SPS with 4x72 bunches.
    - But no problem with the 5x48 bunches scheme.
  - Emittances: similar (for similar bunch intensity)
  - More time for the ramp of the injection kickers
  - Instantaneous luminosity: lower by 8%
  - Shorter cycle:
    - PS:
      - PS cycle only 2 basic periods (2.4s), instead of 3 basic periods (3.6s).
      - Only one injection in PS: no waiting time after first injection: no loss at that stage; no fine tuning on PS injection plateau (drift of magnetic field, etc…)
    - SPS cycle could be reduced to 20.4s (instead of 21.6s)
    - Shorter LHC filling time

Conclusions (II)

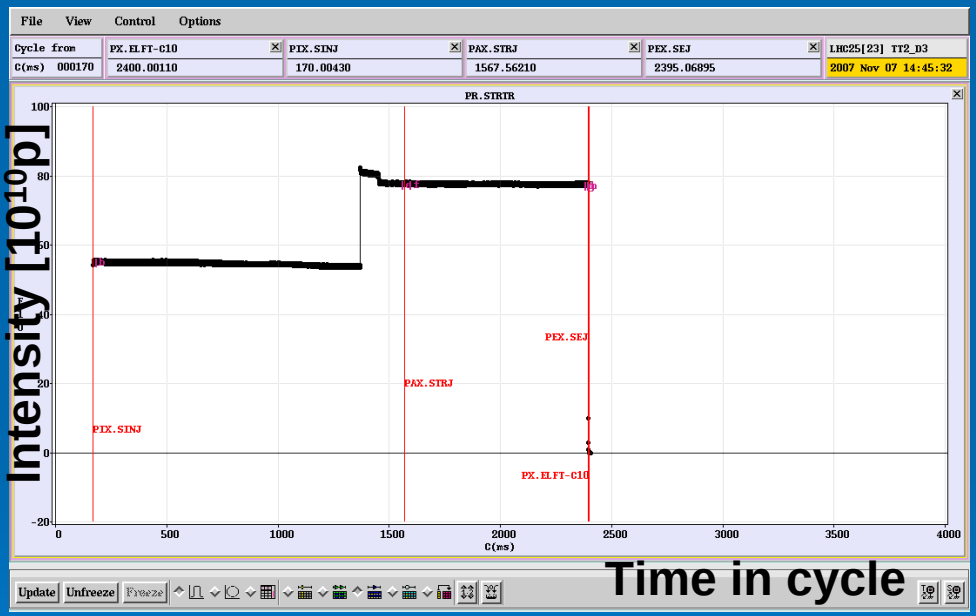
- Main reason for suggesting the alternative filling scheme was the instabilities at extraction in the PS.
  - Instabilities at extraction in PS have been solved now (were due to mis-calibrated cavity).
  - Even if instabilities would appear again, a solution has been studied: double step bunch rotation.
- Other problems/instabilities might still occur in the injector chain… in which case we could use the alternative filling scheme as a backup solution
- Possibly, use this scheme as part of the beam commissioning, before the nominal 2808 bunches (2592 bunches), in case of problems.
- Note:

  For steps in beam commissioning: consider the nominal filling scheme (with batches of 72 bunches), but with lower intensity bunches

See next slide…

LHC25 with lower intensity

For steps in beam commissioning:
nominal filling scheme,
but with lower intensity bunches



Time in cycle

- The intensity on LHC25 cycle has been decreased in the PS Booster by a factor of ~ 10 (factor of 5 from the sieve and factor of 2 from the vertical shavers).
- Small optimizations were required in both longitudinal and transverse planes.
- Transverse emittances (rms, norm):
  - 1.9 and 1.3 micrometers near extraction
  - Note that tails larger than for the Gaussian are observed
- Nominal 72 bunches beam can easily be provided with 10 times lower intensity