Preliminary MD results for a low transition energy in the SPS

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MD participants

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Thanks to all members of the OP group!

Outline

- Motivation for changing transition energy
- How to change transition energy in SPS
  - General properties
  - Comparison of optics
- Present status of the new SPS cycles
- Measurements done so far
  - Measurement of synchrotron tunes
  - Confirmation of optics
  - Nonlinear chromaticity
- Studies with high intensity in the flat bottom cycle
  - Injection losses
  - Bunch length and bunch profile
  - Transverse emittances
- Preliminary studies with acceleration
- Open questions – possible future MD activities

Why is it interesting to change transition energy in SPS?

- Intensities of single bunch proton beams in SPS limited in the transverse plane by TMCI (Transverse Mode Coupling Instability)
  - Nominal SPS optics (transition energy γ_t~23) for LHC type of beams, threshold for TMCI is about 1.6E11 p/b (with low vertical chromaticity)
- Transverse instability thresholds usually scale linearly with slippage factor η

$$\eta = \frac{1}{\gamma_t^2} - \frac{1}{\gamma^2}$$

  - Higher slippage factor (smaller transition energy) translates to higher synchrotron frequency Ω_s, i.e. faster longitudinal motion and damping of instabilities

$$\Omega_s \propto \sqrt{|\eta| V_{RF}}$$

  - Increasing slippage factor means lowering transition energy γ_t
- However, required RF-voltage for obtaining the same longitudinal parameters scales with η – possible limitation

How to change transition energy in SPS?

- How can transition energy be changed?
  - Transition energy γ_t defined by dispersion function in the bending magnets

$$\frac{1}{\gamma_t^2} = \frac{1}{C} \oint \frac{D(S)}{\rho(s)} ds$$

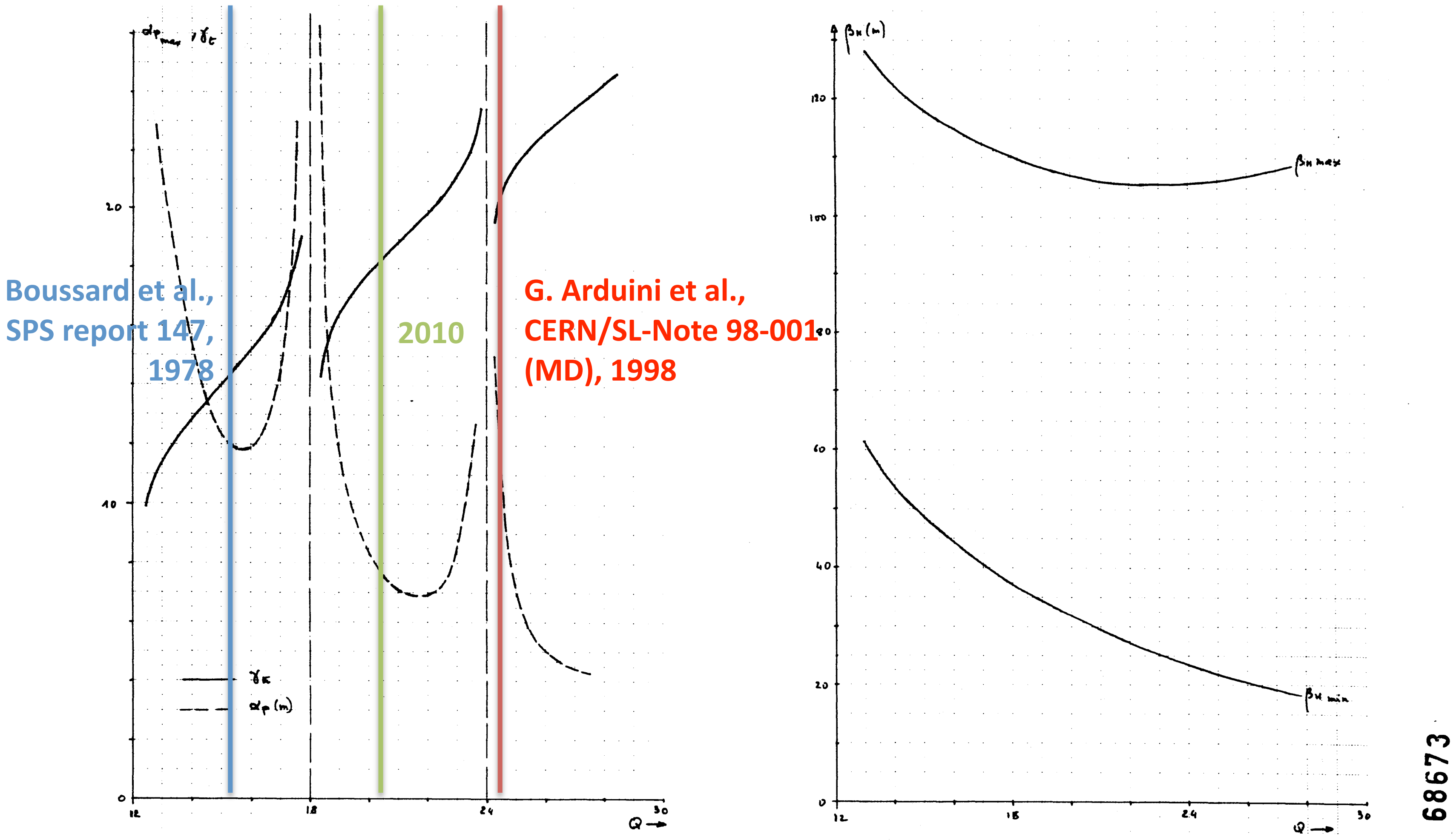
  - In FODO lattice (like the SPS), transition energy scales roughly with the horizontal tune

$$\gamma_{t_{FODO}} \approx Q_x$$

Lowering γ_t by reducing Q_x!

- Changing betatron tunes by a few units for lowering γ_t recently suggested by Y. Papaphilippou
  - Changing transition energy in SPS not new!
  - Already in 1978, Lyn Evans et al. changed transition energy

Change of tunes – change of transition energy



a) αp max and γ_T b) βmax and βmin

Figure 1 - Variation of some lattice parameters over a wide range of Q_H

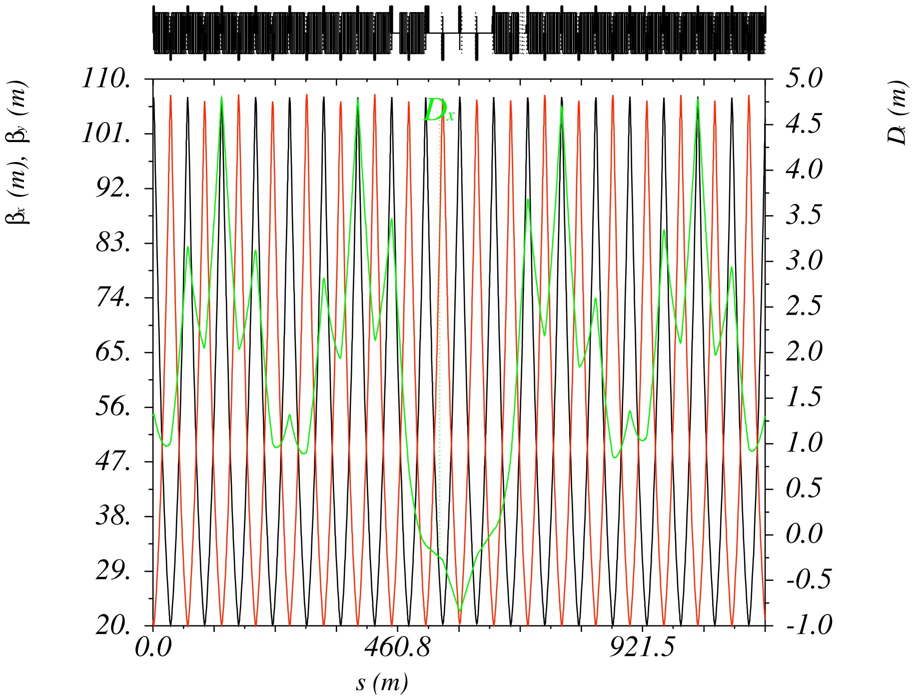
D. Boussard et al., SPS improvement report No 147, Nov. 1978

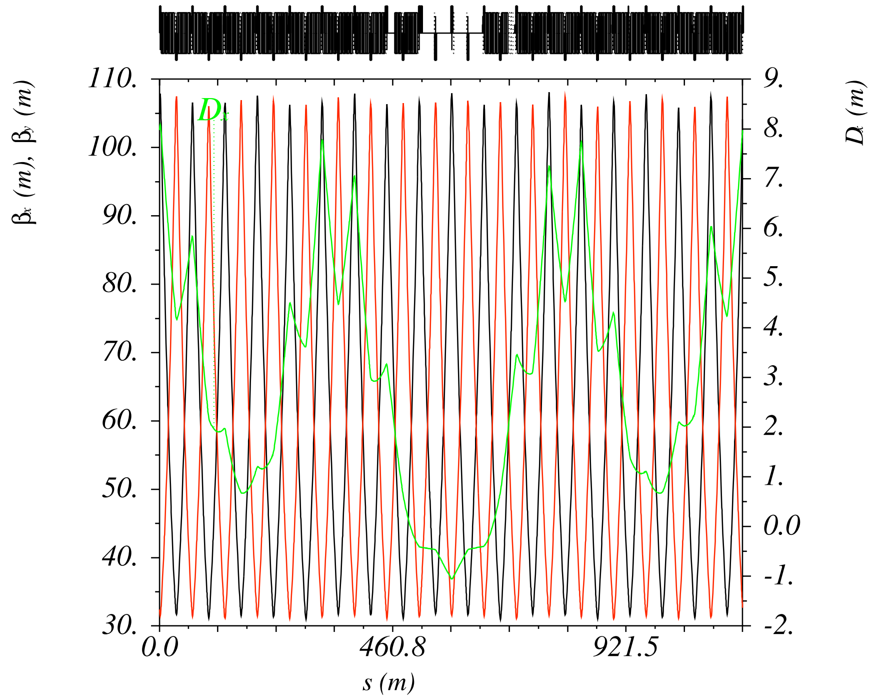
Comparison of optics

! Big change in η @ injection (factor 2.8) by reducing γ_t a few units !

Q26: Qx=26.13, Qy=26.18
- Maximal β-functions: 108m
- Mininam β-functions: 20m
- Maximal dispersion: 4.8m
- γt: 22.8
- η @ 26GeV: 0.63E-3
- η @ 450GeV: 1.9E-3

Q20: Qx=20.13, Qy=20.18
- Maximal β-functions: 108m
- Minimal β-functions: 30m
- Maximal dispersion: 8m
- γt: 18
- η @ 26GeV: 1.8E-3
- η @ 450GeV: 3.1E-3



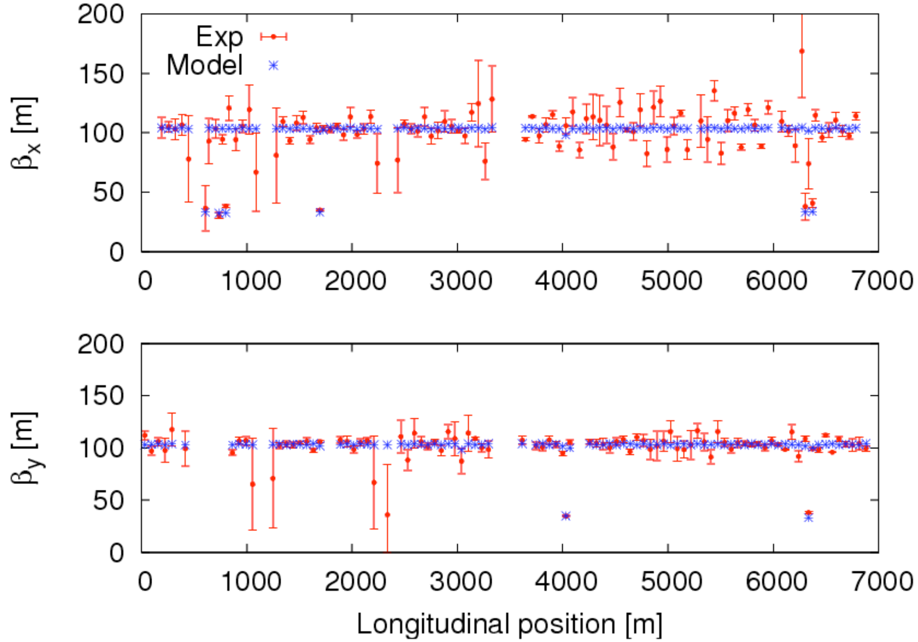


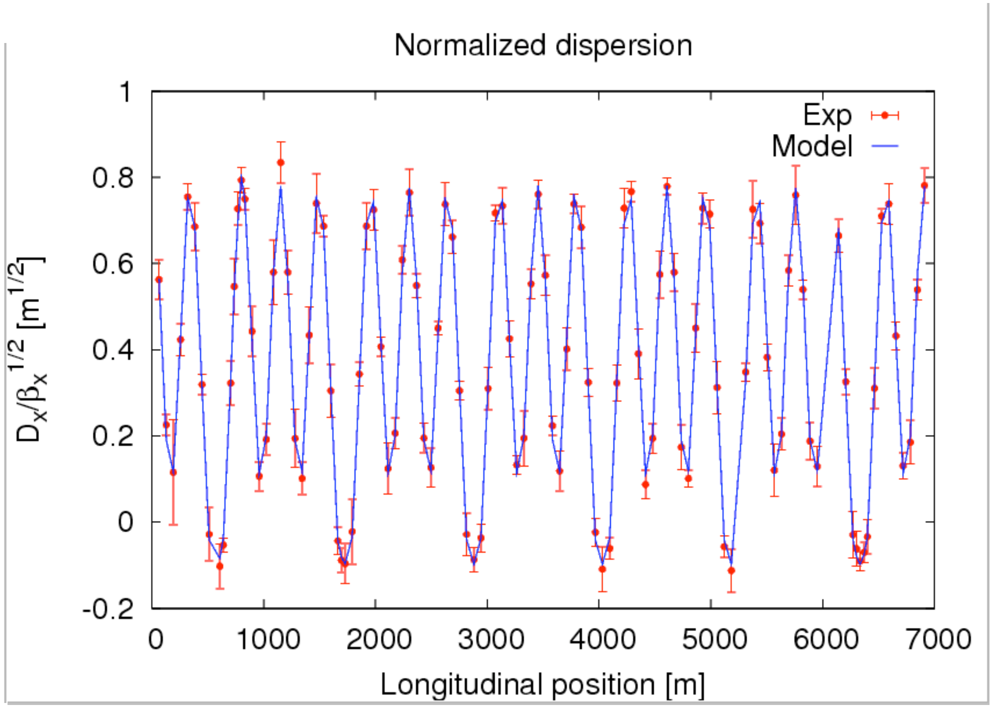
Setup of 2 SPS cycles with new tunes

- Prepared 2 cycles with integer tunes of 20
  - MD1 with a long flat bottom of about 3.7s, then beam is dumped
  - LHCfast3 with short flat bottom of 60 ms and acceleration up to 450GeV
- Present status
  - Machine model with $Q_{x,y}$~20 entered into the SPS database
  - New zero-chromaticity values and knob parameters defined
  - RF program slightly adapted from Q26 cycle
  - Most of the machine controls can be used (some parameters are still based on the nominal Q26 lattices, e.g. for RF radial steering)
  - Tunes and chromaticity are corrected along the ramp of the new LHCfast3 Q20 cycle
  - Transferline TT2/TT10 not yet matched to new optics
- Many thanks to the operators for preparing the cycles and helping us with the setup

Experimental confirmation of the new optics*

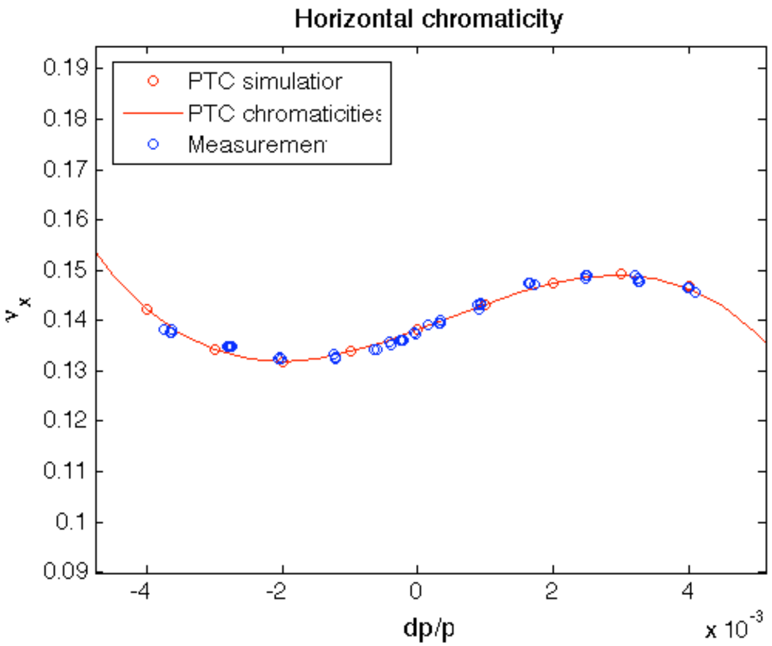
* measured by R. Tomas and G. Vanbavinckhove

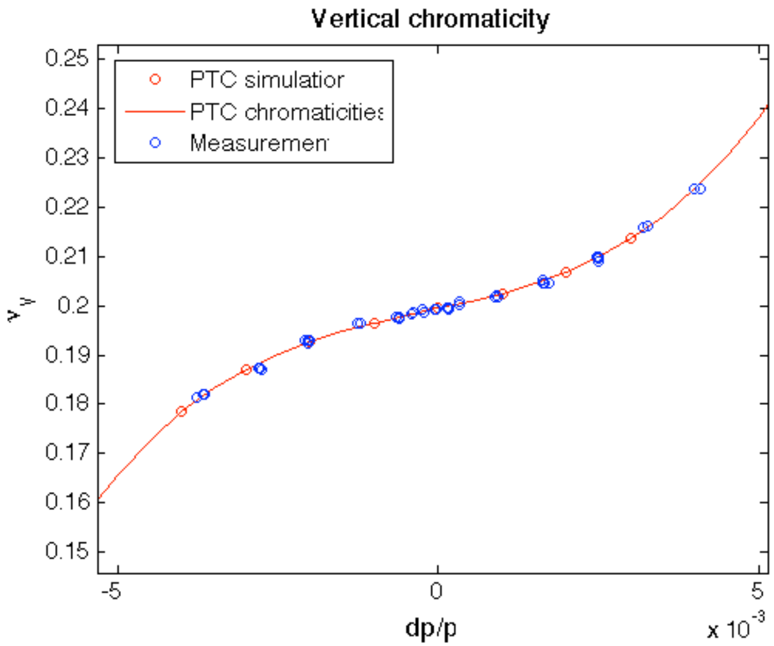




- Optics functions of the new lattice
  - Beta beating around 20% in horizontal and 10% in vertical plane
  - Normalized dispersion in striking agreement with the model

Nonlinear chromaticity in the new lattice

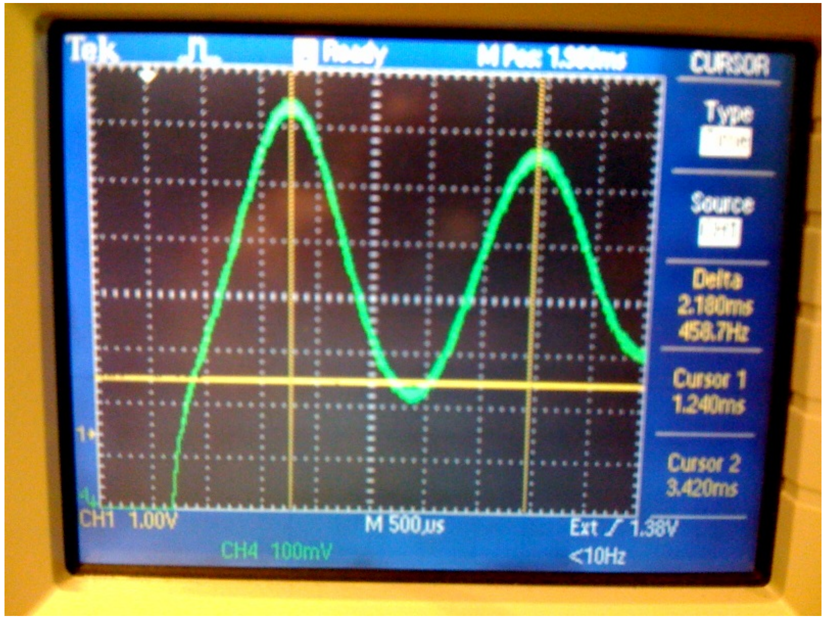




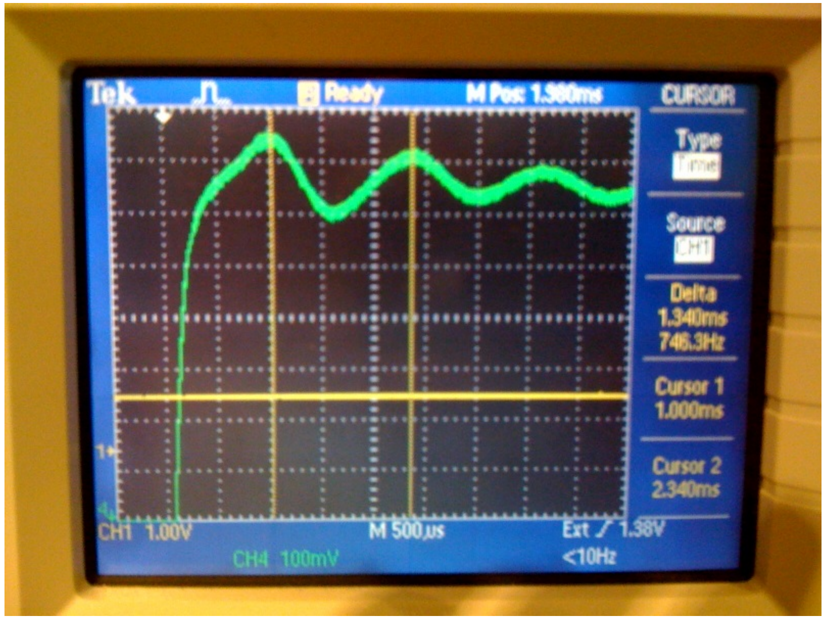
- Sextupole strengths set with new chromaticity knobs
- MADX-PTC nonlinear model of SPS adapted/fitted to the measurements with the new optics
- Further studies will include measurements on tune-shift with amplitude and recalibration of dp/p with RF-frequency variation
- Combined with measurements on the Q26 lattice a global approach to the nonlinear model may allow for a better understanding of the machine nonlinearities

Higher synchrotron frequency

- Measured synchrotron frequency from quadrupolar oscillations at injection
  - Set RF-voltage to 2.2 MV for both optics in the MD1 cycle
  - “Over-focusing” RF-bucket in both cases
- Ratio of Synchrotron frequencies ~ 1.63 corresponds to an increase in slippage factor η by factor 2.65 (MADX prediction: 2.86)



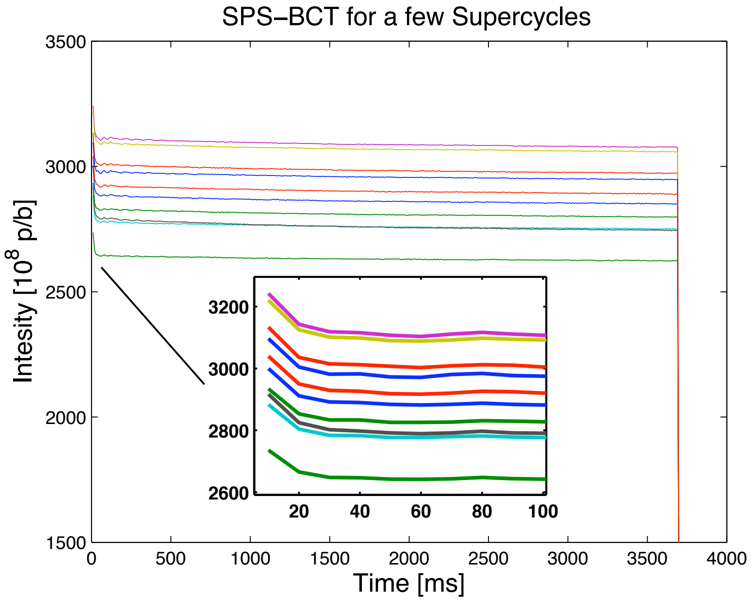
Q26:
Fs=458/2=229 Hz
Qs=0.0106/2=0.0053

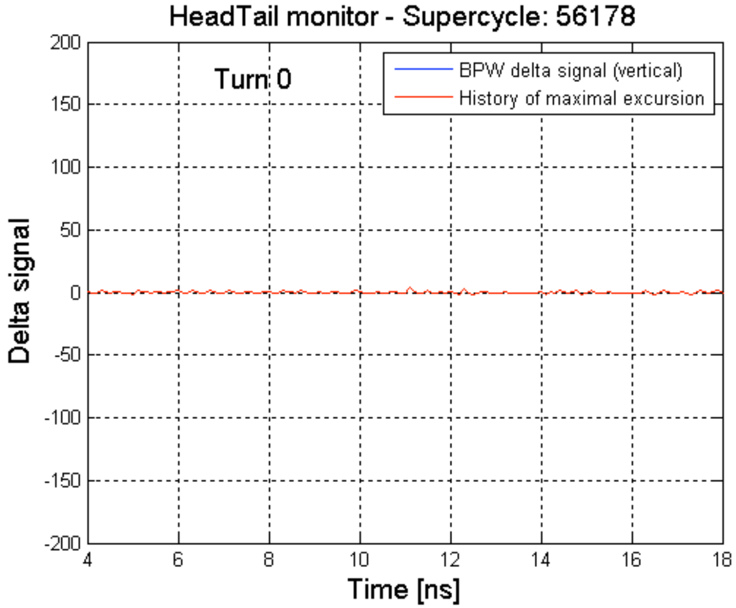


Q20:
Fs=746/2=373 Hz
Qs=0.0172/2=0.0086

Observations at injection – MD1 – 10.Nov

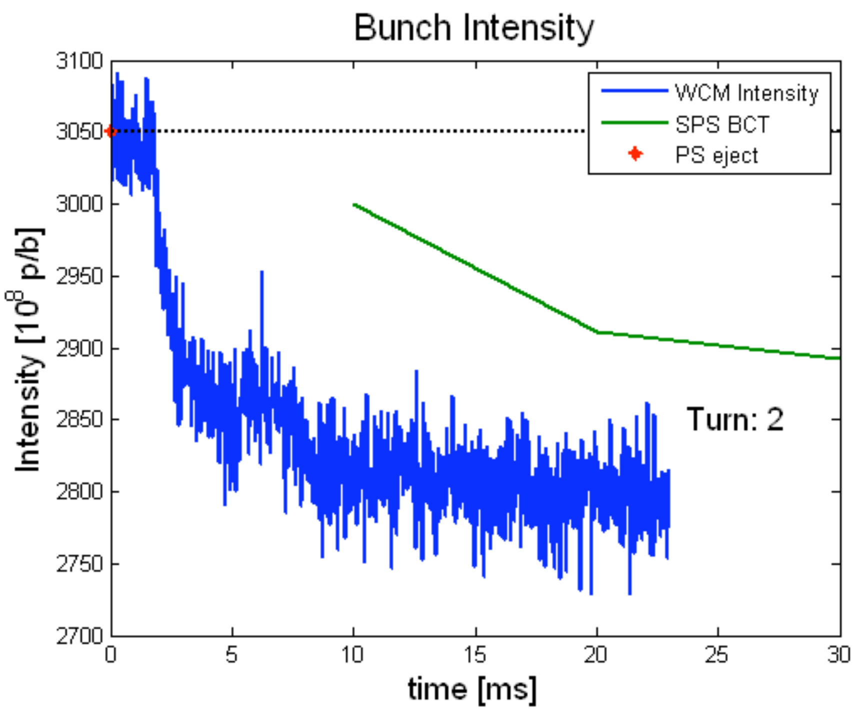
- Machine settings
  - Tunes close to Q_x=20.13 and Q_y=20.16 (a bit low, nominal 20.18)
  - Chromaticities ξ_x~0.2, ξ_y~0.03 (settings used in Q26 for instability studies)
  - RF voltage 1.8MV, second harmonic off
  - Octupoles switched off
- Intensity from PS between 2.7E11-3.3E11 p/b
- Systematic losses within the first 30ms after injection
  - No signature of Transverse Mode Coupling instabilities

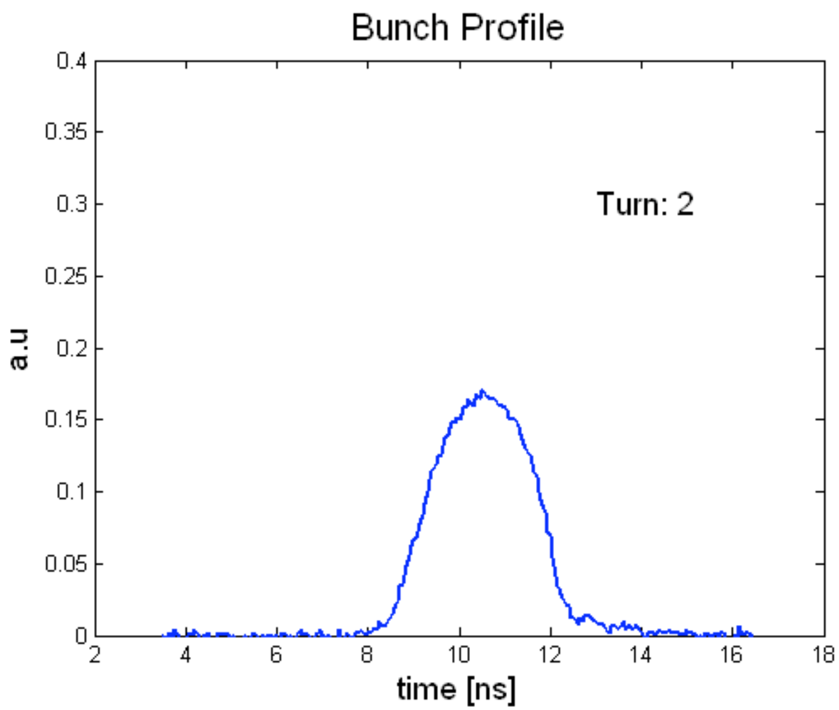




Bunch profile and bunch intensity – MD1 – 10.Nov

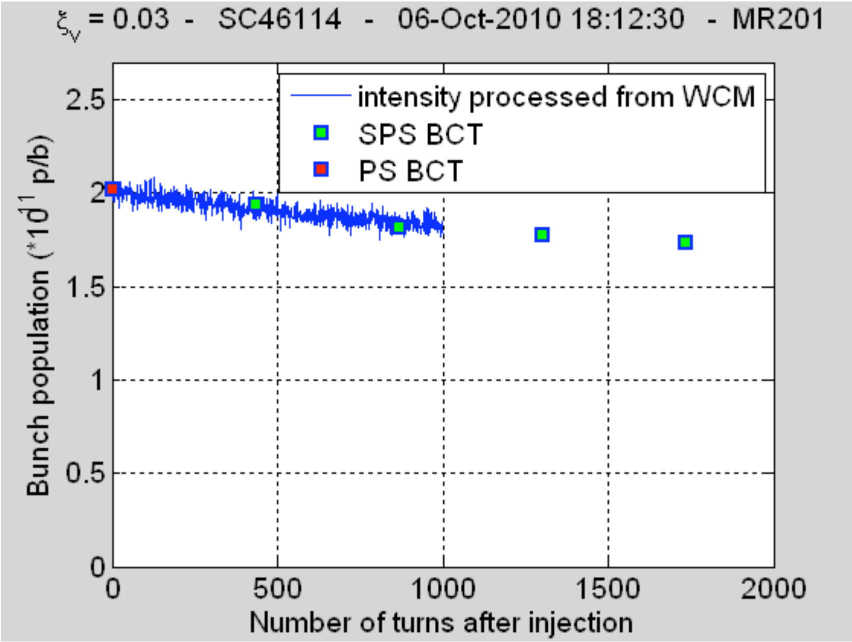
- Intensity obtained from integrated bunch profile
  - Signal of WCM normalized to intensity delivered by PS
  - Even bigger losses (~10%) out of the bunch within first 5ms
  - Maybe the RF-voltage was too low for this intensity
  - First measurement of SPS BCT at 10ms!
  - Problem of normalization of integrated bunch intensity…



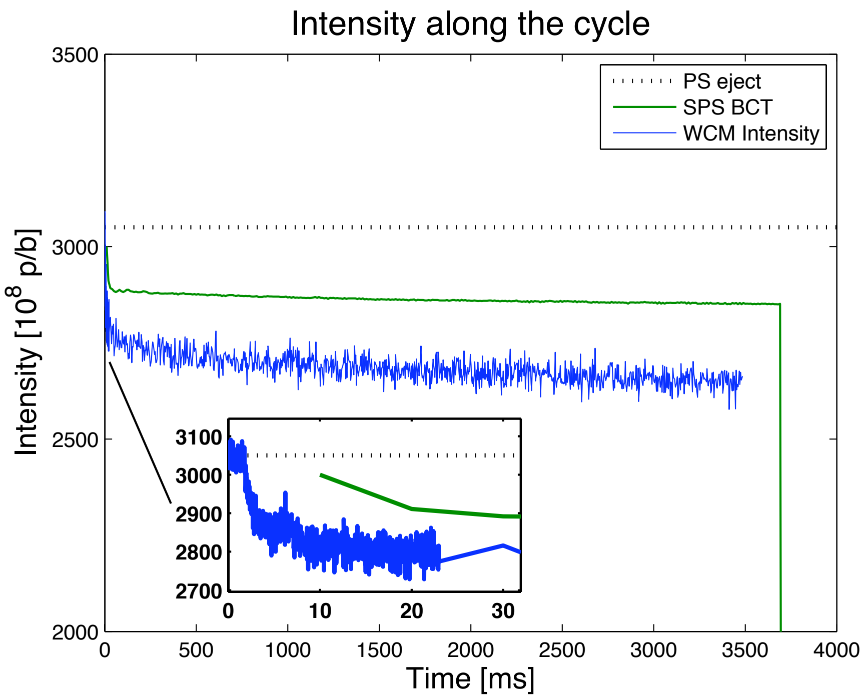


Previous results with the Q26 cycle

Previous results with Q26



Recent results with Q20



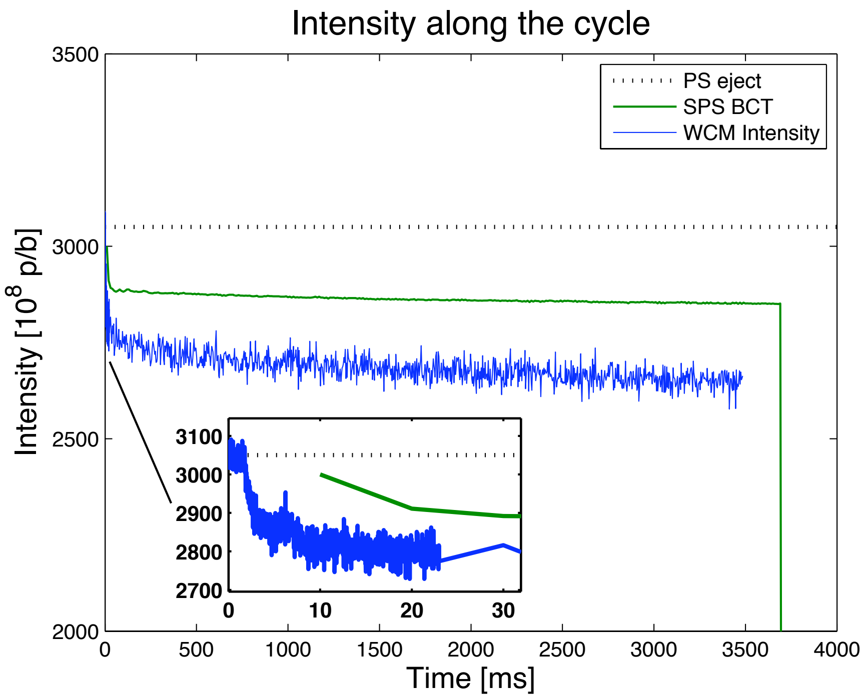
→Calibration between PS BCT, SPS BCT and integrated WCM seems to work

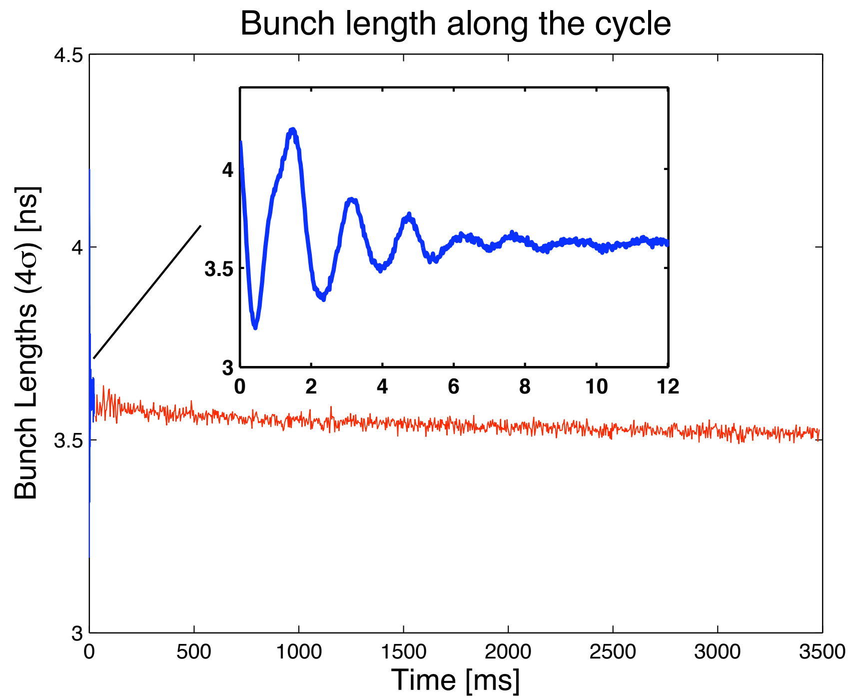
→Is the discrepancy caused by the calibration between PS BCT, SPS BCT and integrated WCM?

If the calibration is ok, it seems like we lose out of the bucket!

Bunch length – MD1 – 10.Nov

- Bunch intensity integrated from WCM shows continuous loss along the flat bottom
  - Possible reasons: working point (slightly too low in vertical), space charge effects, RF-voltage
- Bunch length calculated from bunch profile
  - Quadrupolar synchrotron oscillations observed right after injection
  - Slight reduction of bunch length with time due to losses



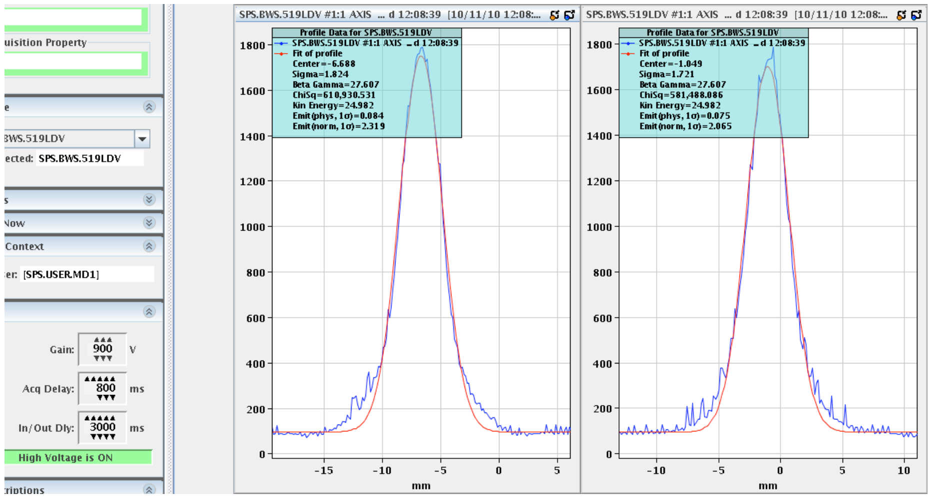


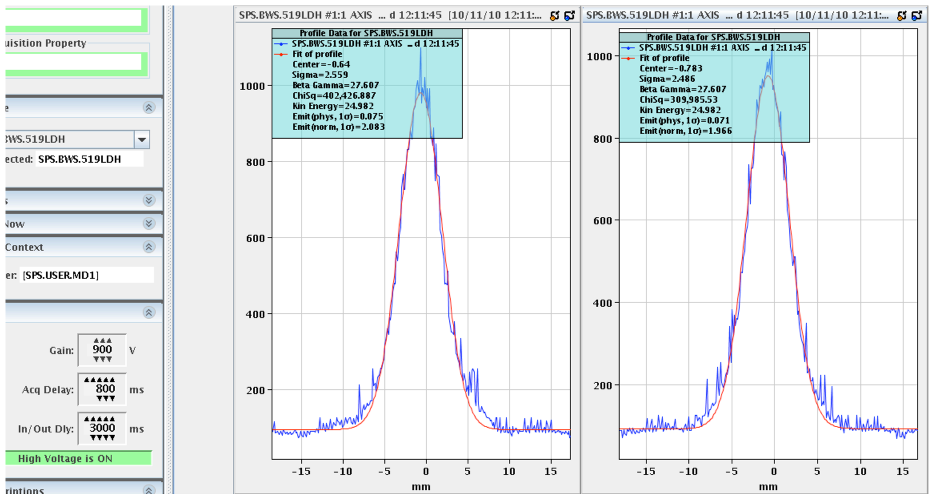
Transverse emittances - MD1 – 10.Nov

- Machine parameters
  - Tunes close to Q_x=20.13 and Q_y=20.16 (a bit low, nominal 20.18)
  - Chromaticities ξ_x~0.2, ξ_y~0.03
  - RF voltage 1.8MV, second harmonic off
  - Octupoles switched off

- Emittances at beginning of flat bottom (measured with in-scan)
  - **E_h~1.9-2.1 mm.mrad, E_v~2.2-2.4 mm.mrad @ 2.6E11 p/b**
  - **E_h~2.4-2.6 mm.mrad, E_v~2.6-2.7 mm.mrad @ 3.3E11 p/b**

- No significant blow-up at the end of flat bottom (measured with out-scan)
  - Emittances at the end of FB always gave smaller values than at the beginning of FB
  - Systematic error of out wire scan (gives about 0.2 mm.mrad smaller values)





Preliminary comparison of the cycles: Q26 – Q20

Q26

- Well studied and optimized cycles
- TMC instability threshold about 1.6E11 p/b with low vertical chromaticity
- Difficult to avoid significant transverse emittance blow-up for high intensities
- Acceptable longitudinal parameters for LHC

Q20

- TMC instability threshold seems to be higher than 3E11 p/b
- Even the headtail instability for negative chromaticity seems to be damped for significant intensities
- Without much optimization, transverse emittance blow-up seems very small
- Still many parameters left to optimize and to explore
- Acceptable longitudinal parameters for LHC ?

Achievements with the LHCfast3 cycle

- Corrected tunes all along the cycle
- Accelerated single bunches with intensities up to 2.5E11 p/b up to flat top without major losses (only small losses <5% right after injection and at beginning of acceleration)
- Transverse emittances (norm, 1σ) **E_h~2.4 mm.mrad, E_v~2.9 mm.mrad** **@ 2.4E11 p/b**
- Bunch length measured at extraction about 1.5 ns
- RMS-Orbit within usual limits
- Chromaticity knobs at that point still based on the nominal Q26 lattice

Open questions – Possible future MD activities

- MD1 flat bottom studies
  - Instability thresholds for the new Q20 cycles are higher than for the nominal Q26… but where?
  - Can we improve losses at injection by changing the RF-voltage?
  - How big is the impact of the optics mismatch at injection
- LHCfast3 acceleration cycle
  - How about emittances at flat top for very high intensities?
  - Can acceptable beam parameters be reached with the current maximal RF-voltage available?
  - Is there any other limitation?
- Possible future MD activities
  - Try to answer questions from above
  - Inject LHC bunch trains with high intensity for studying electron cloud and other multi-bunch instabilities
  - New cycles could be very useful to study the localization of the impedance sources of the machine
  - Further studies on the nonlinear machine model
  - Match transferline TT2/TT10