Possible increase of bunch intensity in the SPS for HL-LHC

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with input from the SPSU-BD WG

Motivation for intensity increase in the SPS

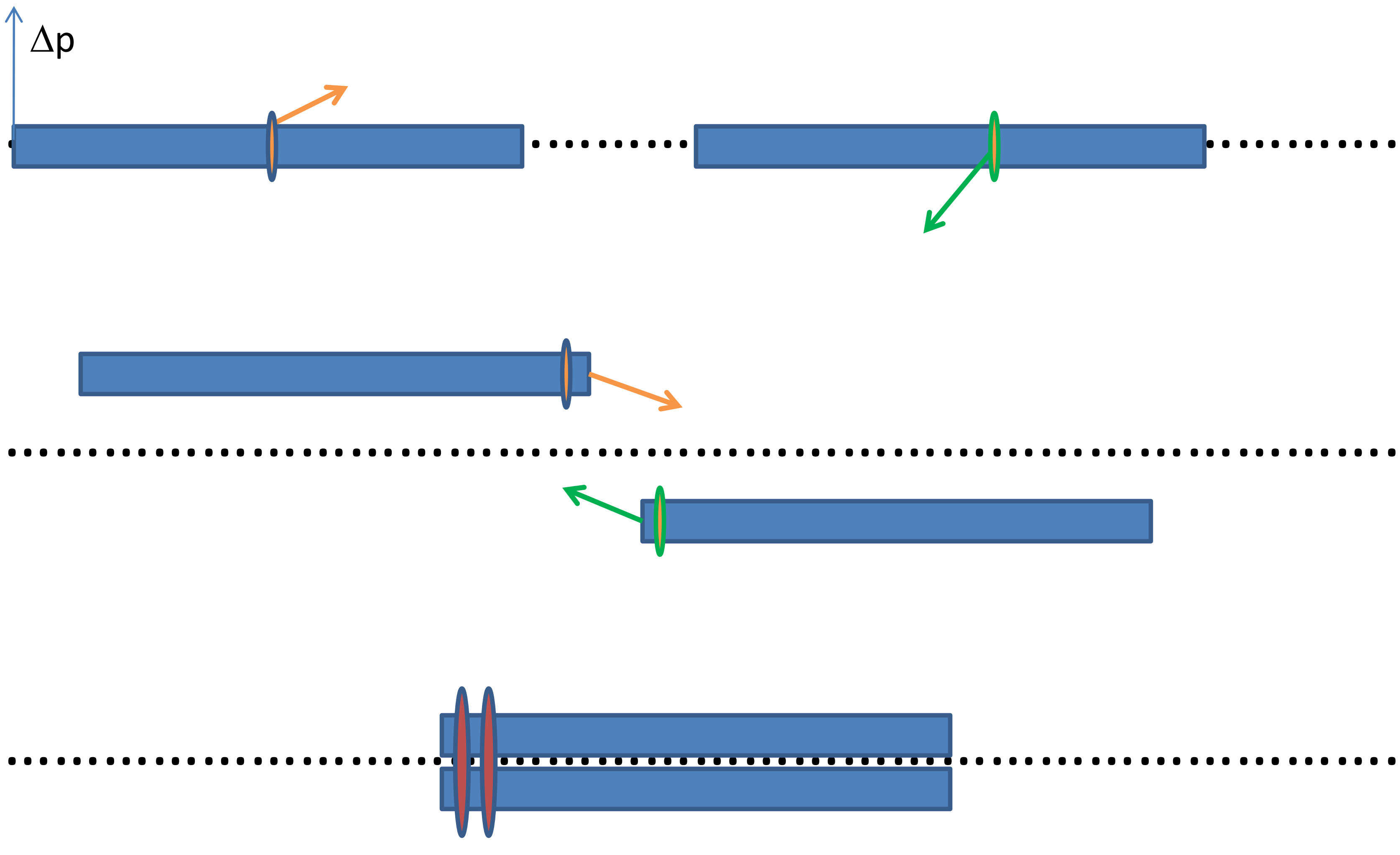
- High single bunch intensity in some HL-LHC scenarios
- Limited single bunch intensity N_b @50 ns from the SPS injectors ($< 3 \times 10^{11}$)
- Avoid RF gymnastics in the LHC $\rightarrow$ SPS
- All present LHC beams fill only a half of the SPS ring $\rightarrow$ increase N_b by merging the two halves
- Space charge (&TMCI in the Q20 optics) limitation at the SPS injection $\rightarrow$ increase N_b later
- Longitudinal coupled-bunch instabilities during the ramp in the SPS with threshold ~$1/E_s$. Cured by controlled long. emittance blow-up ($E_s > 200$ GeV) and use of the 800 MHz RF system (Landau cavity) $\rightarrow$ increase N_b and emittance before

$\rightarrow$ Momentum slip stacking in the SPS at ~ 200 GeV?

Momentum slip stacking

- Fill whole SPS ring (8 batches)
- Merge 4+4 batches on the intermediate flat portion during the cycle (~ 200 GeV) to have 4 batches with twice higher bunch intensity
  - Use 2 from 4 200 MHz RF cavities to capture 4 batches separately (required beam control doesn't exist)
  - Accelerate one group of 4 batches and decelerate another by f_{rf} variation
  - Let the two parts of the beam drift for some time towards each other
  - Bring two parts back to initial $f_{rf} + \Delta f_{rf}$ (orbit) by deceleration (acceleration)
  - capture two bunches in one RF bucket

Momentum slip stacking



Momentum slip stacking

- This technique is possible in principle with the wide-band 200 MHz TW RF system of the SPS (Q=130):
  - cavity bandwidth $\Delta f_{rf} = f_{rf}/(2Q)=0.7$ MHz $\rightarrow$ transient time of 600 ns, voltage can be modulated to act at this distance on the two parts of the beam separately (at initial stage)
  - to accelerate (decelerate) the beam by Δp_o: $\Delta f_{rf}/f_{rf}= \eta\Delta p_o/p$

Possible issues

- The 800 MHz RF system is required for beam stability → the same gymnastics? Possible in principle (low Q, 2 cavities, but need new beam control)
- Beam loading in all RF systems with low 200 MHz voltage required during gymnastics
- Long. emittance blow-up with final emit > 1 eVs (0.9 eVs needed for stability in SPS and 0.7 eVs in LHC for $N_b=4\times10^{11}$) → 200 MHz capture RF system in the LHC + …?
- Particle losses at high energy due to gymnastics
- New beam control needed (could be included in the RF upgrade but no tests possible before)
- e-cloud and trans. damper with variable bunch spacing

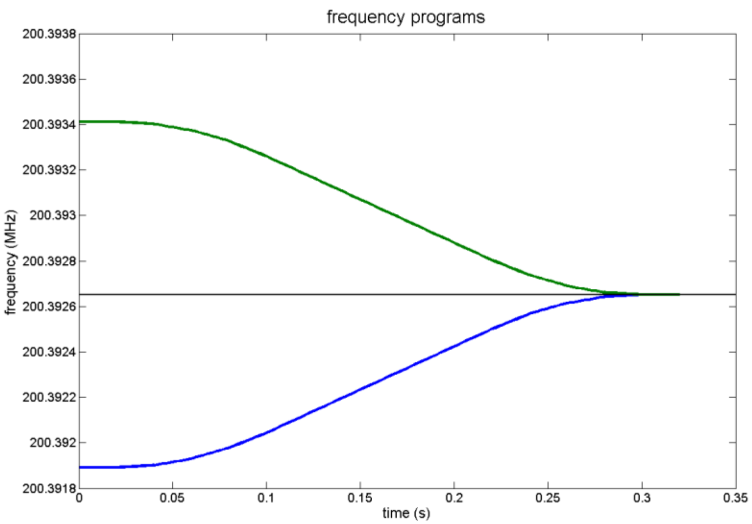
Example (work in progress)

- Frequency (momentum) program for acceleration (deceleration) by Δp=400 MeV/c @ 200 GeV/c
  (ΔR=4 mm or Δf_{rf}=650 Hz)
- Voltage program for emit=0.5 eVs, q_p=0.9, V ~ 1 MV
- Particle simulations with ESME (T. Argyropoulos):
  - code debugging (new release), still some problems
  - particle losses < 4%
  - total time for gymnastics ~ 0.5 s
  - initial long. emit = 0.5 eVs, final emit > 1.2 eVs (?)

  $\longrightarrow$ further optimisation needed + intensity effects

Momentum slip stacking at 200 GeV/c in the SPS

Frequency program



Voltage program