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 $N_b @50 \text{ ns}$ 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 $\sim 1/E_s$. 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 $\sim 200$ 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 $\Delta p_o$: $\Delta f_{rf}/f_{rf} = \eta \Delta p_o/p$
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 \( N_b = 4 \times 10^{11} \)) → 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 $\Delta p=400$ MeV/c @ 200 GeV/c ($\Delta R=4$ mm or $\Delta f_{\text{rf}}=650$ Hz)
• Voltage program for $\text{emit}=0.5$ eVs, $q_p=0.9$, $V \sim 1$ MV
• Particle simulations with ESME (T. Argyropoulos):
  – code debugging (new release), still some problems
  – particle losses < 4%
  – total time for gymnastics $\sim 0.5$ s
  – initial long. emit = 0.5 eVs, final emit > 1.2 eVs (?)
→ further optimisation needed + intensity effects
Momentum slip stacking at 200 GeV/c in the SPS

**Frequency program**

**Voltage program**