Long-range beam-beam effects during injection oscillations

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- Long-range beam-beam separation at injection
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Observation at LHC

➢ The ADTObsBox often triggered on the oscillations of the circulating beam at injection (see also L. Carver, et al. @ LBOC 22.08.2017)

➢ The pattern associated with PACMAN effect (i.e. long-range beam-beam interaction) is clearly visible in the individual bunches’ oscillation amplitude

➢ Such a pattern is however not observed in the emittances at flat top
   → The impact on the emittance is either not measurable or masked by other effects

➢ It is still the case for HL-LHC ? If not, shall we use the aperture margin to increase the crossing angle at injection ?
Normalised separation at injection

In the baseline, the normalised separation at the long-range interactions is similar in all IRs at injection (crossing and separation bumps)

\[ d = \sqrt{\left(\frac{x_{B1} - x_{B2}}{\sigma_x}\right)^2 + \left(\frac{y_{B1} - y_{B2}}{\sigma_y}\right)^2} \]
Normalised separation at injection

➢ In the baseline, the normalised separation at the long-range interactions is similar in all IRs at injection (crossing and separation bumps)

➢ Increasing the crossing angle in IPs 1 and 5 to 500 μrad brings their contribution in the shadow of IPs 2 and 8.

\[ d = \sqrt{\left(\frac{x_{B1} - x_{B2}}{\sigma_x}\right)^2 + \left(\frac{y_{B1} - y_{B2}}{\sigma_y}\right)^2} \]

IPs 1 (x) and 5 (●)

IPs 2 (x) and 8 (●)

295 μrad
500 μrad
170 μrad
Orbit re-matching

➢ Numerical model (COMBI):
  ➢ One bunch per beam, $\varepsilon = 1.7 \mu$rad, $N = 2.2 \times 10^11$, $E = 450$ GeV
  ➢ 33 long-range interactions lumped into 1 (one IP), $d = 16\sigma$
  ➢ $Q_{xy} = 0.31/0.32$, $Q' = 15$, $Q_s = 0.0023$
  ➢ Octupole current 40A
  ➢ Damper gain 0.02 ($\tau = 10$ turns)
  ➢ Soft-Gaussian coherent beam-beam interaction, including orbit effect
  ➢ Injection on ‘ideal’ orbit

➢ Even with a perfect injection, the closed orbit is modified by the long-range interactions leading to emittance growth by filamentation
  → This effect can only be mitigated by increasing the normalised separation
**Orbit re-matching**

- **Numerical model (COMBI):**
  - One bunch per beam, $\varepsilon = 1.7 \mu$rad, N=2.2E11, $E = 450$ GeV
  - 33 long-range interactions lumped into 1 (one IP), $d=16\sigma$
  - $Q_{xy} = 0.31/0.32$, $Q' = 15$, $Q_s = 0.0023$
  - Octupole current 40A
  - Damper gain 0.02 ($\tau = 10$ turns)
  - Soft-Gaussian coherent beam-beam interaction, **including orbit effect**
  - Injection on ‘ideal’ orbit

- Even with a perfect injection, the closed orbit is modified by the long-range interactions leading to emittance growth by filamentation
  - This effect can only be mitigated by increasing the normalised separation

- For an orbit effect of $\pm \sigma/4$, the emittance growth remains at the permil level
Transmission of the oscillation

- Numerical model (COMBI):
  - One bunch per beam, \( \varepsilon = 1.7 \mu \text{rad}, N = 2.2 \times 10^{11}, E = 450 \text{ GeV} \)
  - 33 long-range interactions lumped into 1 (one IP), \( d = 16 \sigma \)
  - \( Q_{xy} = 0.31/0.32, Q' = 15, Q_s = 0.0023 \)
  - Octupole current 40A
  - \( G = 0.02 (\tau = 10 \text{ turns}) \)
  - Soft-Gaussian coherent beam-beam interaction (w/o orbit effect)
  - Injection off by 2\( \sigma \)

- Depends on quality of the injection steering
Transmission of the oscillation

- **Numerical model (COMBI):**
  - One bunch per beam, $\varepsilon=1.7\mu$rad, $N=2.2E11$, $E = 450$ GeV
  - 33 long-range interactions lumped into 1 (one IP), $d=16\sigma$
  - $Q_{x/y} = 0.31/0.32$, $Q' = 15$, $Q_s=0.0023$
  - Octupole current 40A
  - $G=0.02$ ($\tau=10$ turns)
  - Soft-Gaussian coherent beam-beam interaction (w/o orbit effect)
  - Injection off by $2\sigma$

- Depends on quality of the injection steering

- The emittance growth resulting from the transmission of the oscillation remains significantly smaller than in the injected beam
Reduction with the separation

- As expected the orbit re-matching dominates at high separations (~1/d) and the transmission dominates at small separations (~1/d^2).

- The mitigation of the emittance growth resulting from the increase of the crossing angle from 295 to 500 μrad (~20σ to ~35σ) is marginal due to the weak dependence of the orbit part.