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Influence of the ATS-optics on Intra-Beam Scattering for HL-LHC

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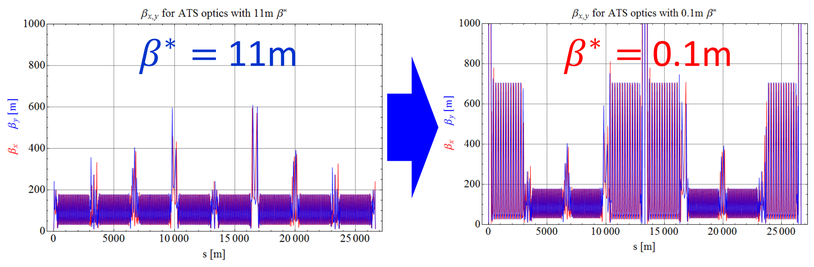
Abstract

In the future High Luminosity (HL-)LHC the influence of intra-beam scattering (IBS) will be stronger than in the present LHC, because of higher bunch intensity N_b, small emittance ϵ_N, and new optics. The new ATS (Achromatic Telescopic Squeeze) optics scheme [1] modifies the lattice in the arcs around the main interaction points (IP) to provide β^* values as small as 0.15m at the IP but these modifications affect the IBS growth rates. In this paper proton IBS emittance growth rates are calculated with MADX and the Collider Time Evolution (CTE) program [2] for two ATS-optics versions, different settings of the crossing angles and required corrections and various beam conditions at injection (450 GeV) and collision (7 TeV) energy. CTE simulations of the expected luminosity L, N_b, ϵ_N and bunch length σ_z, evolution during fills are also presented.

Effect of the ATS-Squeeze on IBS Growth Rates

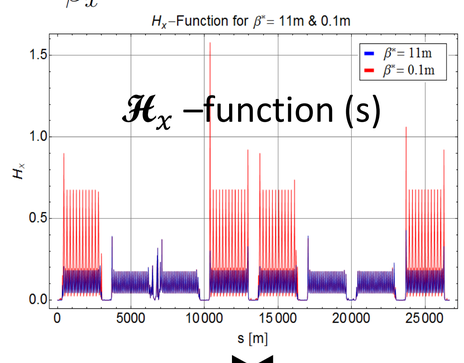
ATS-Squeeze



Squeeze creates high β-values in the arcs around IP1&5 for $\beta^* \leq 0.4$m.

Increase in $\mathcal{H}$ –function in arcs around IP1&5 (depends only on lattice).

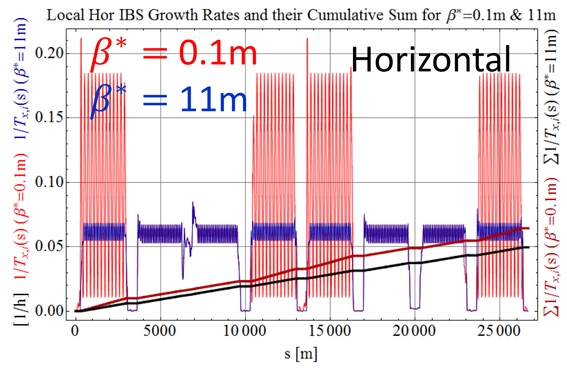
$$\mathcal{H}_x = \frac{D_x^2}{\beta_x}(1+\alpha_x^2) + \beta_x D_x'^2 + 2\alpha_x D_x D_x'$$

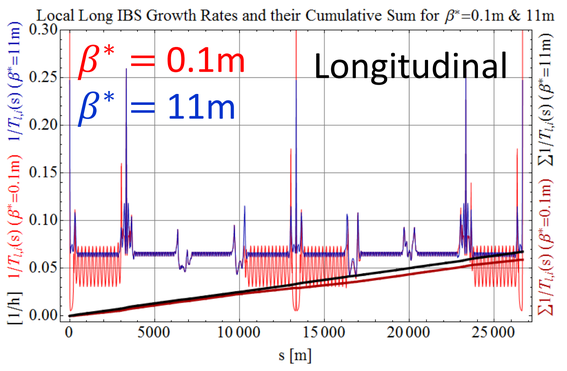


Horizontal IBS growth rate $\alpha_{\mathrm{IBS},x} \propto \mathcal{H}_x$

$$\begin{pmatrix} \alpha_{\mathrm{IBS},x} \\ \alpha_{\mathrm{IBS},l} \\ \alpha_{\mathrm{IBS},y} \end{pmatrix} = A \begin{Bmatrix} \frac{\gamma^2 \mathcal{H}_x}{\epsilon_x} \\ \frac{\gamma^2}{\sigma_\delta^2} \\ \frac{\beta_y}{\epsilon_y} \end{Bmatrix} \int_0^\infty \frac{\lambda^{1/2}}{(\lambda^3 + a\lambda^2 + b\lambda + c)^{3/2}} \begin{Bmatrix} [a_x\lambda + b_x] \\ [a_l\lambda + b_l] \\ [a_y\lambda + b_y] \end{Bmatrix} d\lambda$$

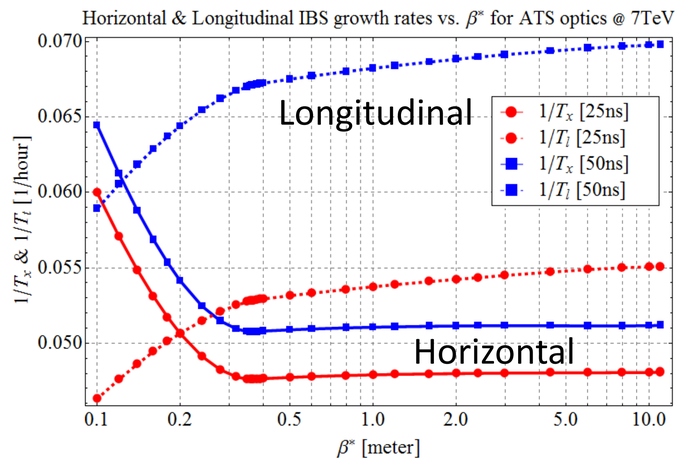
Local IBS Growth Rates





- **Increased IBS contribution** for $\beta^* = 0.1$m in high β-regions.
- Cumulative sum of IBS growth rates (accumulates local growth rates at each element with increasing s) and total growth rate (max value of cumulative sum) are:
  → horizontally increase,
  → longitudinally reduced (dark red lines) by the squeeze.

IBS Growth Rates along the Squeeze



Horizontal growth rate (solid line) **increases** with β^* smaller ~0.4m:
→ due to strong dependence on the $\mathcal{H}$ –function.

Longitudinal growth rate (dashed line) **improves** with smaller β^*:
→ dependence on lattice parameters is less dominant.

Table 2: Summary of the IBS growth rates.

Spacing	25 ns		50 ns	
E [GeV]	450	7000	450	7000
β^*[m]	11	0.15	11	0.15
$\alpha_{\mathrm{IBS},l}$ [1/h]	0.096	0.049	0.124	0.062
$\alpha_{\mathrm{IBS},x}$ [1/h]	0.096	0.054	0.103	0.058
$\alpha_{\mathrm{IBS},y}$ [10^{-4}/h]	-6.4	-0.015	-6.9	-0.016

Beam and Luminosity Evolution

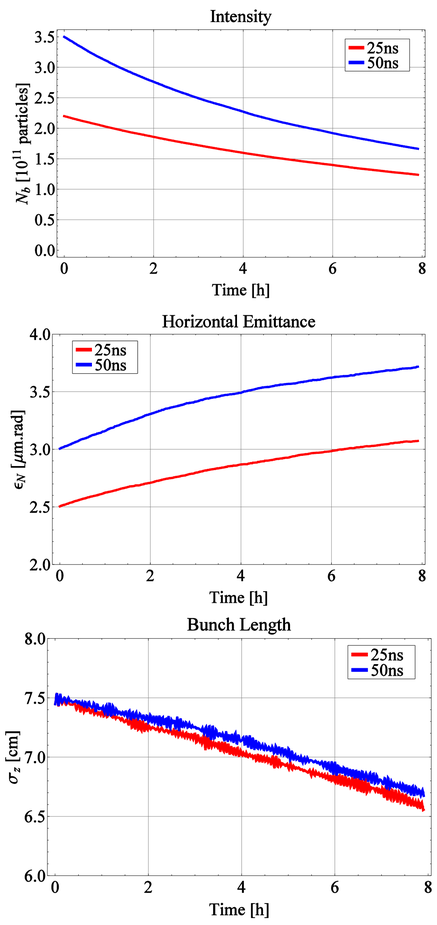
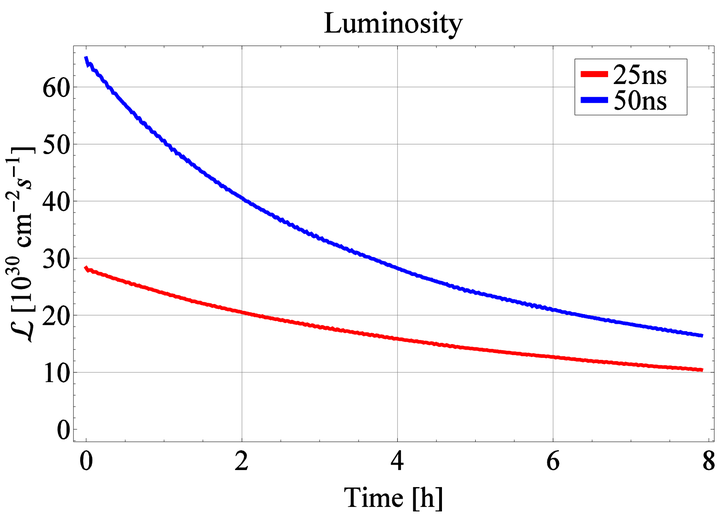


Table 1: HL-LHC Beam Parameters

Parameter		25 ns	50 ns
E	[TeV]	7	7
β^*	[m]	0.1	0.1
N_b	[10^{11} charges]	2.2	3.0
$\varepsilon_n = \varepsilon\gamma$	[μm rad]	2.5	3.0
ε_l	[eVs]	2.5	2.5



- *Simulation Code:* ***Collider Time Evolution (CTE)*** *[2].*
- *Tracking of 2 bunches of macro-particles in time in a collider.*
- *Simulation of IBS, radiation damping, but, eg, no beam-beam.*

- Based on ATS-V6.503 optics of the flat machine with nominal sequence.
- Single bunch evolution for the 2 cases from Table 1.
- Luminosity does not include levelling or crab-cavities,
  → "virtual" single bunch luminosity.
- 50ns scenario - bunches have higher brightness:
  → higher L per bunch-crossing, but also faster burn-off, N_b decay and ϵ_N growth.
- N_b losses dominated by burn-off,
  → debunching losses from IBS <1%.
- Shrinking σ_z due to strong radiation damping at E = 7TeV.

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References:

[1] S. Fartoukh, CERN-ATS-2011-161, (2011).

[2] R. Bruce et al., Phys. Rev. ST Accel. Beams **13**, 091001 (2010).

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