Beam-Beam Long-Range Compensation in the LHC

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Beam-Beam Effects

On each side of the interaction points of the LHC, the counter-rotating beams share a **common beam pipe**, leading to the so-called **Beam-Beam Long-Range (BBLR) interactions** [1] which:

- Introduce **an undesirable tune spread** due to the non-linear forces;
- **Limit the performance of the collider**, in particular the maximum luminosity achievable.

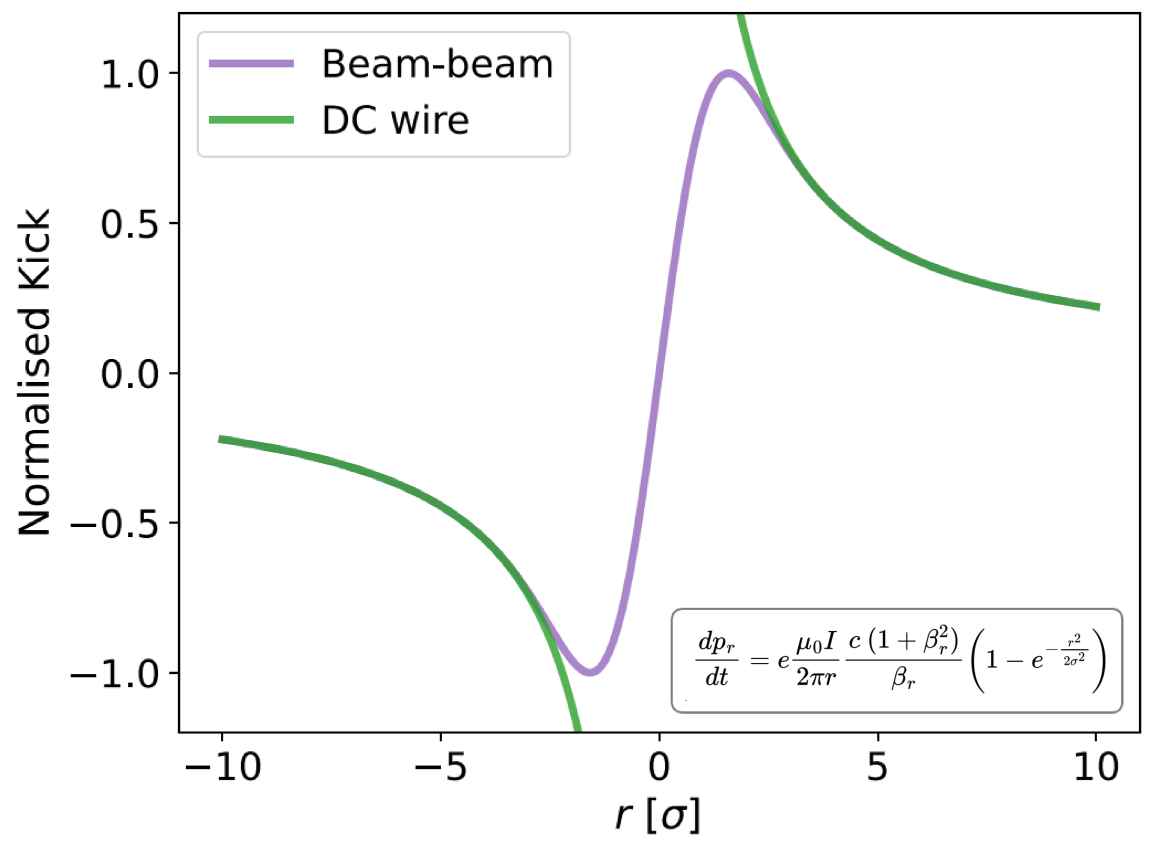
Beam-beam effects are present in **most colliders** (SPS, RHIC, Tevatron, DAFNE) and represent an important limitation for the performance of **future colliders** like HL-LHC.

Compensation

Studies have already shown the possibility of using DC wires on both sides of the interaction points **to compensate BBLR effects** [2].

Through **numerical simulations** and **machine development** experiments in the LHC, this work aims at developing a **systematic compensation** scheme and a **fundamental description** of BBLR compensation in view of HL-LHC.

Beam-Wire Equivalence



Normalised kick from beam-beam effect and DC wire.

The kick from a **DC wire** is completely equivalent to the kick from the other beam, provided that the observation point is **sufficiently far away**. Fortunately, this is the case for **Long-Range interactions**.

Multipolar Tune Spread

One can expand the magnetic field from the wire (and from the beam) in its **multipolar components** to study the tune spread:

$$K_{N_n} + iK_{S_n} = -\frac{\mu_0 (IL)}{2\pi \cdot B\rho}\,\frac{n!}{(r_w e^{i\phi_w})^{n+1}}$$

- The quadrupole term K_{N_1} leads to a tune shift;

$$\delta Q_{1,x} = \frac{1}{4\pi} K_{N_1}\beta_x$$

- The octupole term K_{N_3} leads to a tune spread.

$$\delta Q_{3,x}(J_x, J_y) = \frac{3}{8\pi}\left(\frac{K_{N_3}}{3!}\right)\left[\beta_x^2 J_x - 2\beta_x\beta_y J_y\right]$$

The main challenges lie in:

1. Compensating **as many terms as possible** (including higher orders);
2. Compensating the effect of numerous bunches with a **single DC wire**.

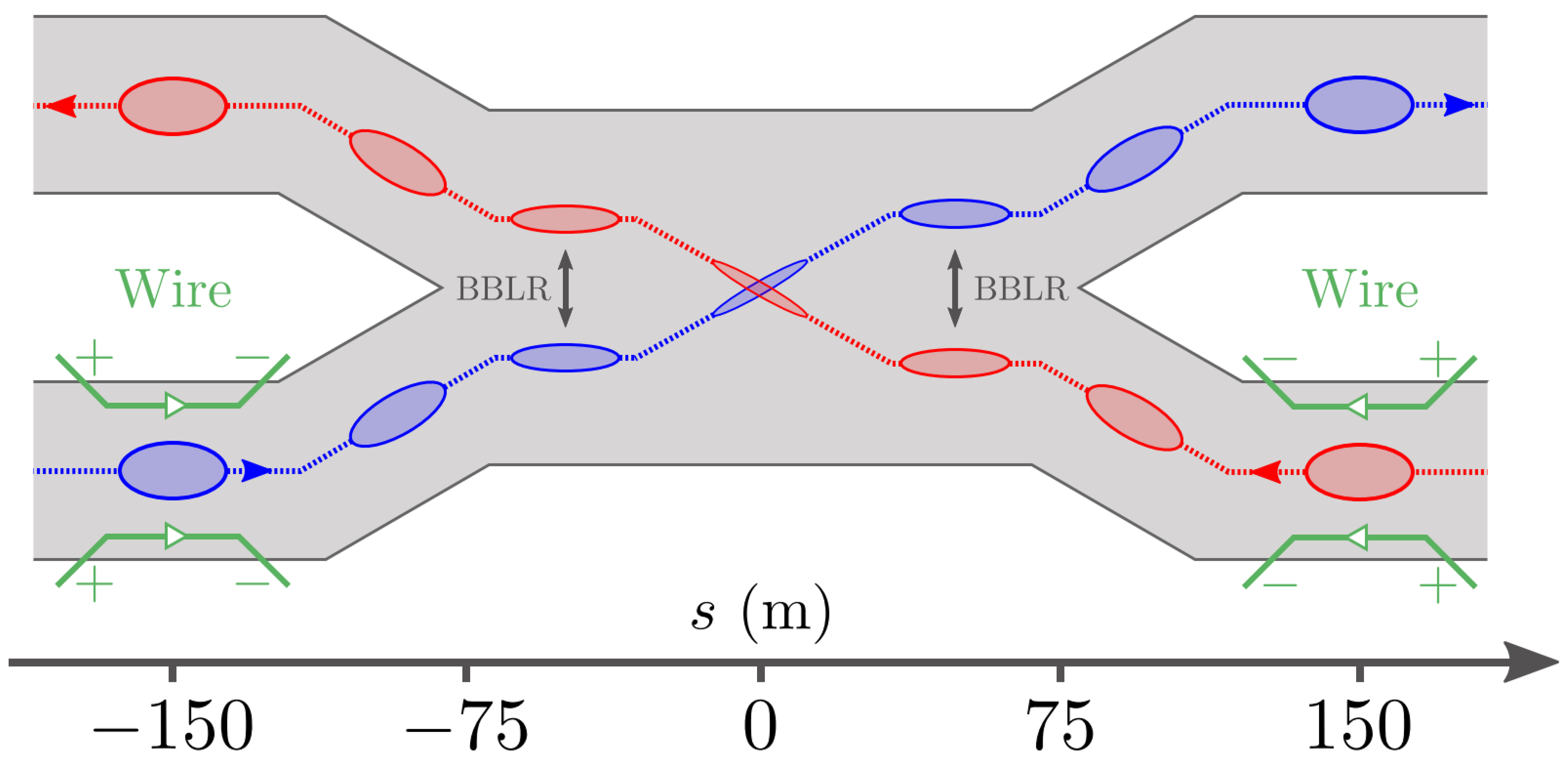
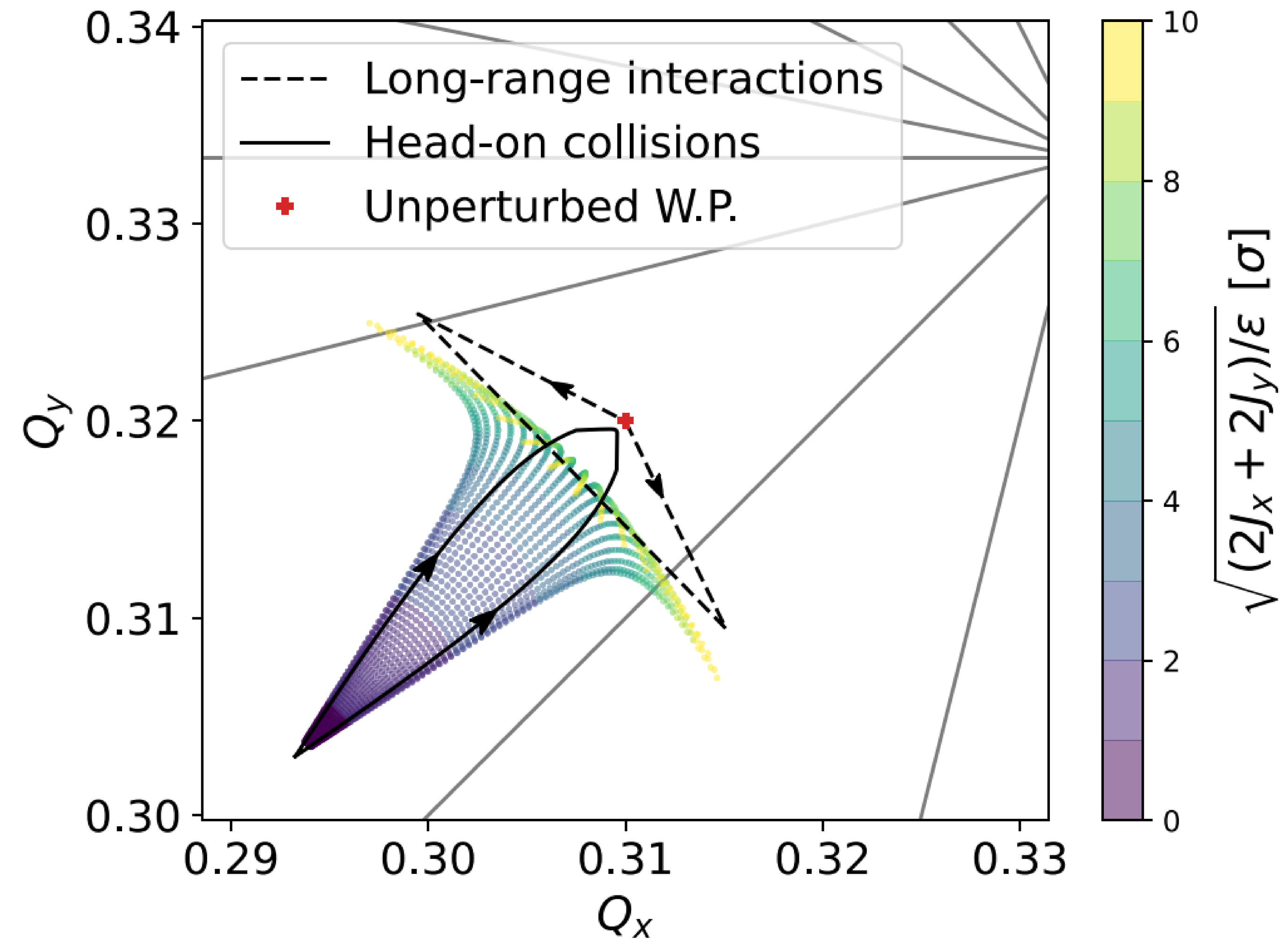


Illustration of Long-Range Beam-Beam interactions on each side of the interaction points (IPs) of the LHC. DC wires are installed upstream of the IP for both beams to compensate the tune spread.



Perturbed tunes from head-on collisions and Long-Range interactions after one LHC turn as a function of the particle amplitude.

The Objective

The **lateral wings** of the tune footprint need to be compensated **to avoid resonances**:

- Sufficiency of **octupole magnets** versus DC wire is under study;
- Long-term **particle stability** needs to be studied for several **operational scenarios**, especially for an implementation in HL-LHC.

References

[1] W. Herr et al. Beam-Beam Effects, https://cds.cern.ch/record/1982430

[2] G. Sterbini et al. First Results of the Compensation of the Beam-Beam Effect with DC Wires in the LHC, https://cds.cern.ch/record/2693922

Discovery, accelerated