Intensity-Dependent Effects in the ILC BDS

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Abstract

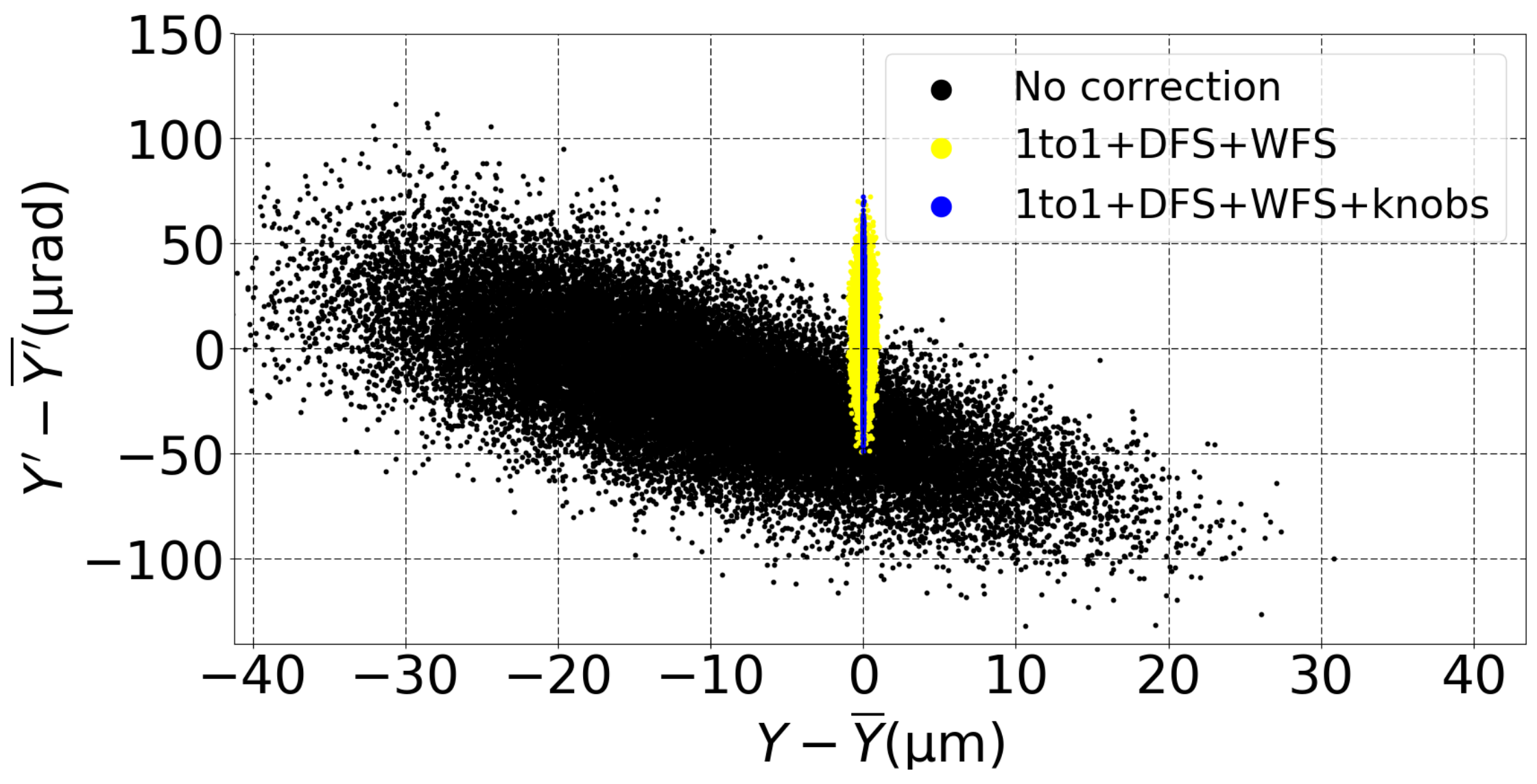
The International Linear Collider (ILC) is an electron-positron collider being considered for the post-LHC era. Its Beam Delivery System (BDS) receives the beam from the main linac. This beam is then focused to the nanometer scale after going through collimators, beam diagnostic systems, strong magnets, etc. Effects such as wakefields due to resistive-wall, BPMs and collimators make the system very sensitive to the beam intensity. Understanding these effects is crucial in order to demonstrate that the nominal beam size at the Interaction Point (IP) can be reached in realistic scenarios. In this paper, results of the intensity dependence effects in the ILC BDS, simulated with PLACET, are presented.

ILC BDS parameters

Parameter	**Symbol**	**Value**
Centre-of-mass energy	E_{CM}	500 GeV
Number of bunches	n_b	1312
Bunch population	N	2.0×10^{10}
RMS bunch length	σ_z	0.3 mm
Bunch separation	Δt_b	554 ns
IP RMS beam sizes	σ_x^*/σ_y^*	474/5.9 nm

Single-bunch wakefield

- The efficiency of the Beam-Based Alignment correction and knobs in the ILC BDS was studied with **PLACET**, a tracking code developped at CERN.
- **Simulation conditions:**
  - **Misalignment** and **roll error** of quadrupoles, Cavity BPMs and sextupoles by respectively 50 µm rms and 200 µrad rms and quadrupoles, sextupoles **strength error** of 1.0 x 10^{-4} rms.
  - 100 random seeds
  - **Short range wakefield**: multiple wakefield sources (wakepotentials calculated with GdfidL).
- **Corrections applied**:
  - **One-to-one correction** that steers the beam and minimizes the transverse displacements measured by BPMs.
  - **Dispersion-Free Steering**, to cancel the unwanted dispersion introduced by misaligned quadrupoles. This correction steers the beam through the center of the BPMs and simultaneously minimizes the difference between the trajectories of two beams with different energies.
  - **Wakefield Free Steering** correction, which minimizes the difference of orbits between beams with different charges.
  - **Tuning knobs** are applied at the IP. These knobs remove the correlations between the following pairs: <y,x'>, <y,y' >, <y,E> and <y,xx'>, <y,x'y'> <y, x'E>. The results are shown in the figure and the table.



Correction	$\overline{\sigma_y^*}$ $2 \times 10^9 e^-$	$\overline{\sigma_y^*}$ $2 \times 10^{10} e^-$
No correction	12669 nm	12882 nm
1to1	451 nm	458 nm
1to1 + DFS	354 nm	367 nm
1to1 + DFS + WFS	352 nm	365 nm
1to1 + DFS + WFS + knobs	6.6 nm	6.8 nm

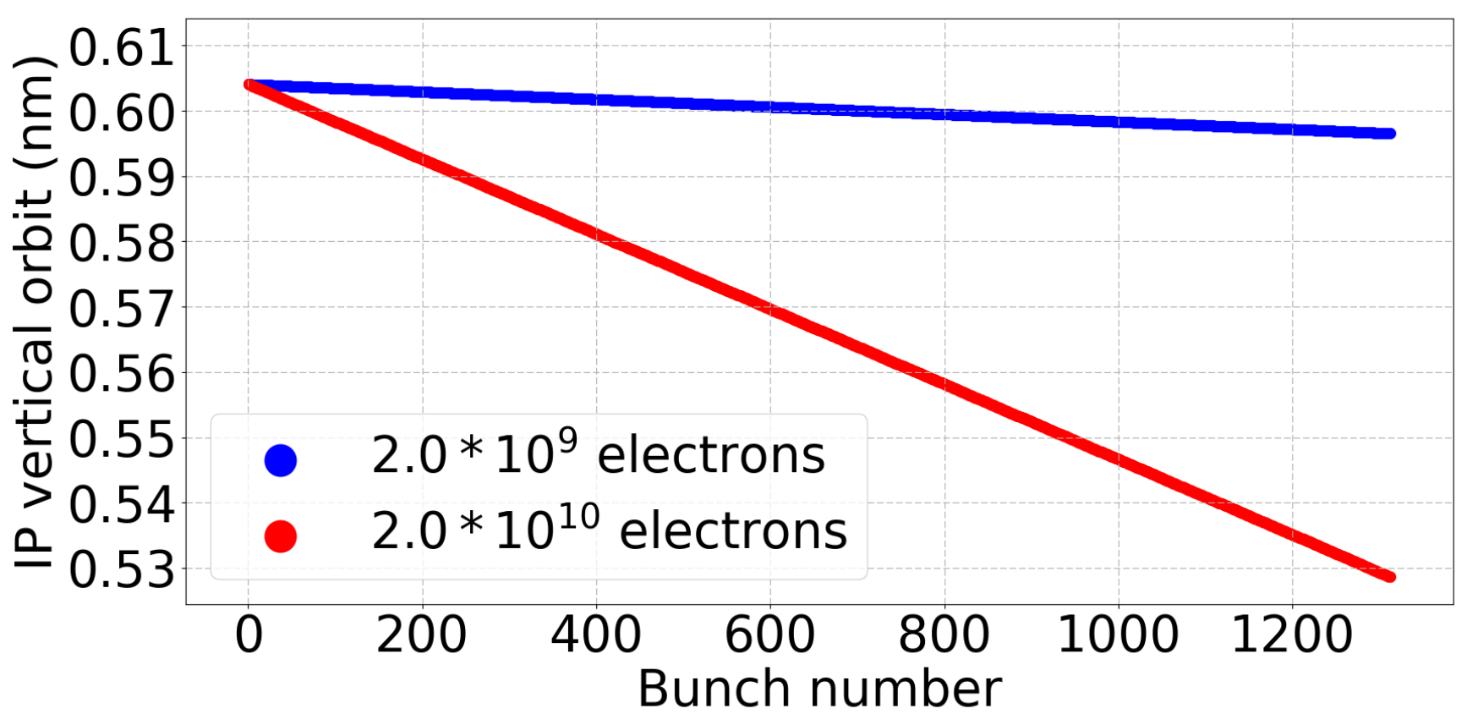
Multi-bunch wakefield

In order to study the multi-bunch intensity dependence effects in the ILC BDS, one should consider **long-range wakefield** such as the ones generated by resistive walls. The ILC BDS copper coated beam pipe has an aperture between 10 mm and 30 mm. The resistive walls wake function used in the simulations is defined as follows:

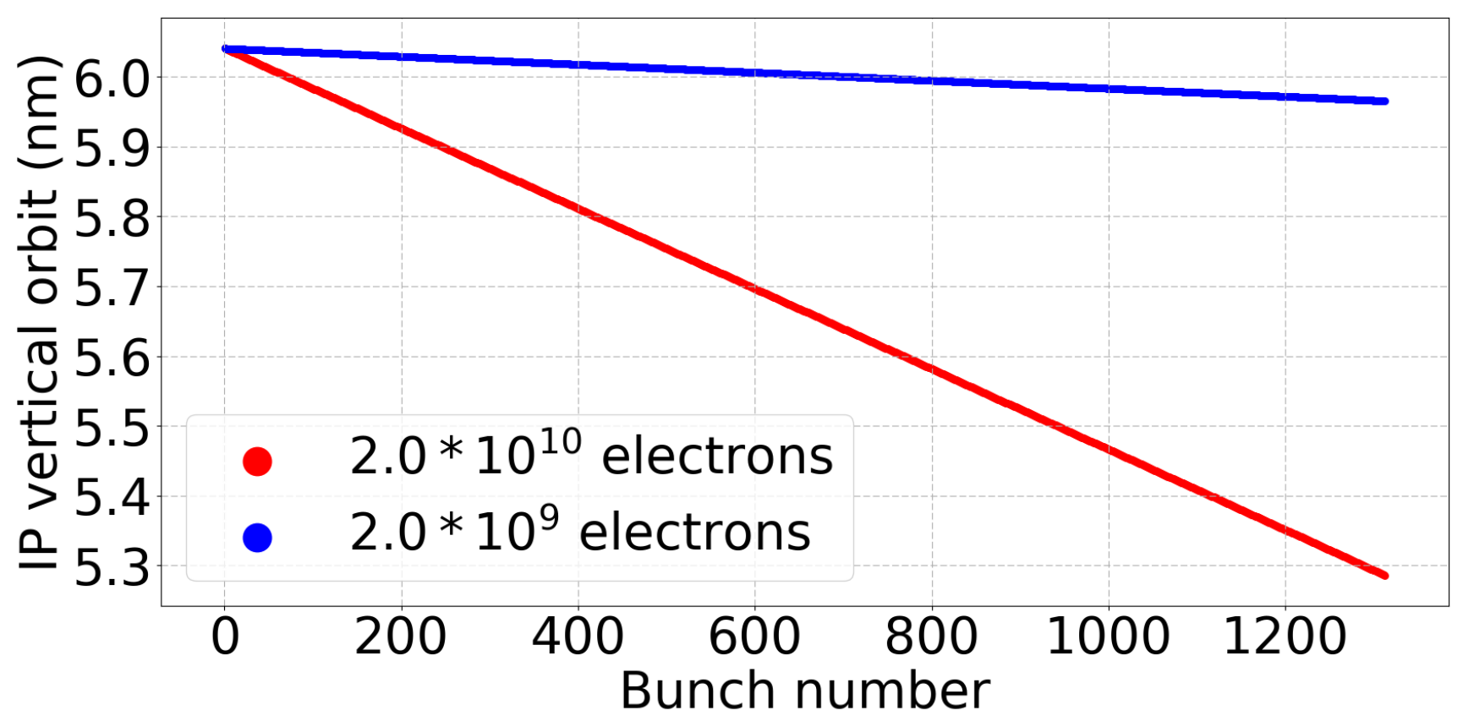
$$W_1(z) = -\frac{c}{\pi b^3}\sqrt{\frac{Z_0}{\sigma_r \pi z}}L$$

where *b* is the radius of the beam pipe,
Z_0 is the impedance of the vacuum,
σ_r the conductivity of the pipe,
L the length of the beam line segment.

The effect of the resistive wall effects has been simulated with PLACET using one macro particle per bunch. The consecutive 1312 bunches are injected in a perfectly aligned machine with the same offset. The bunches are tracked all the way to the IP. This study is done for initial offsets of $0.1\sigma_y$ and $1.0\sigma_y$ in position and $0.1\sigma_{y'}$ and $1.0\sigma_{y'}$ in angle. The vertical orbits at the IP of the consecutives are shown in the following figures:

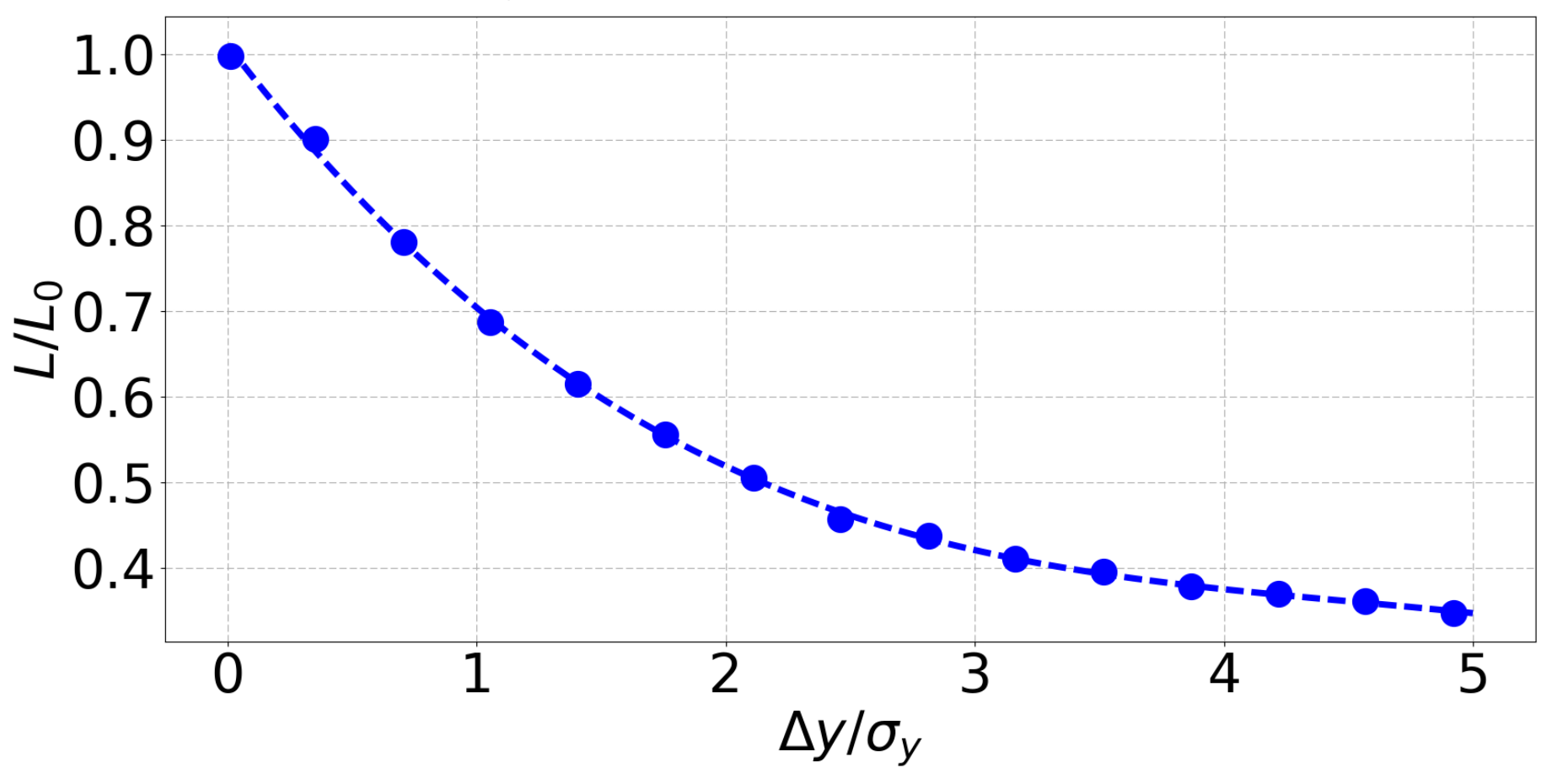


$0.1\sigma_y$ in position



$1.0\sigma_y$ in position

These vertical angle and position offsets at the IP degrade the luminosity of the collided beams. At low beam intensity (2.0 x 10^9 e^-) the impact of an incoming position or angle offset has a negligible impact on the luminosity. However, at high beam intensity (2.0 x 10^{10} e^-), an incoming position offset of $1.0\sigma_y$ leads to a luminosity loss of 3.6% and an incoming angle offset of $1.0\sigma_{y'}$ leads to a luminosity loss of 9.9% if uncorrected. In realty, such a position drift at the IP would be compensated with an intra-train feedback, neutralizing its effects on the luminosity.



Incoming Y	**Intensity**	Δ_y **at IP**	$L\,/\,L_0$
$0.1\sigma_y$	$2.0 \times 10^9 e^-$	0.008 nm	~ 1.0
$0.1\sigma_y$	$2.0 \times 10^{10} e^-$	0.076 nm	0.998
$1.0\sigma_y$	$2.0 \times 10^9 e^-$	0.075 nm	0.998
$1.0\sigma_y$	$2.0 \times 10^{10} e^-$	0.755 nm	0.964
Incoming Y'	**Intensity**	Δ_y **at IP**	$L\,/\,L_0$
$0.1\sigma_{y'}$	$2.0 \times 10^9 e^-$	0.019 nm	~ 1.0
$0.1\sigma_{y'}$	$2.0 \times 10^{10} e^-$	0.20 nm	0.992
$1.0\sigma_{y'}$	$2.0 \times 10^9 e^-$	0.19 nm	0.996
$1.0\sigma_{y'}$	$2.0 \times 10^{10} e^-$	2.03 nm	0.901

Conclusion

For 100 imperfect machines, the average of vertical IP beam size growth compared to the nominal vertical IP beam size of 5.9 nm is respectively 11% and 13%. The implemented long-range wakefields due to resistive walls in a perfect machine induce a significant vertical offset at the IP and thus a luminosity degradation. The luminosity loss is 3.6% considering a train of 1312 bunches with an incoming vertical position offset of $1.0\sigma_y$ and almost 10% for a train with an incoming angle offset of $1.0\sigma_{y'}$. This luminosity loss can be compensated with appropriate IP intra-train feedback.

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