PLACET BASED START-TO-END SIMULATIONS OF THE ILC WITH INTRA-TRAIN FAST FEEDBACK SYSTEM*

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Abstract

Integrated simulations are important to assess the reliability of the luminosity performance of the future linear colliders. In this paper we present multi-bunch tracking simulation results for the International Linear Collider (ILC) from the start of the linac to the interaction point. The tracking along the linac and the beam delivery system is done using the code PLACET. This code allows us to introduce cavity wakefield effects, element misalignment errors and ground motion. Static beam based alignment of the linac is also considered. The luminosity and beam-beam parameters are calculated using the code GUINEA-PIG. In the framework of the Feedback On Nano-second Timescales (FONT) project, we describe and simulate an updated fast intra-train feedback system in order to correct for luminosity degradation mainly due to high frequency ground motion.

INTRODUCTION

The luminosity goal for the International Linear Collider (ILC) [1], operating with a centre-of-mass energy of 500 GeV, is very demanding. It requires very small transverse beam size and sub-nanometre level beam stability at the interaction point (IP). In this context, integrated simulations, covering different sub-systems and time-scales of the collider, can be helpful to asses the reliability of the design luminosity. In this paper we present a simulation model of the ILC main linac plus the beam delivery system based in the tracking code PLACET [2], using the nominal beam parameters from Ref. [1]. For the BDS we have used the 14 mrad crossing angle optics (version 2007). Moreover static and dynamics imperfections have been inserted in the model. To combat the emittance dilution caused by the static errors the use of beam based alignment and tuning techniques are required. In order to reduce the emittance growth in the main linac we have applied 1-to-1 and dispersion free steering (DFS) with the PLACET code. In addition, dynamics imperfections, e.g. ground motion (GM) can strongly degrade the luminosity. To keep the beams in collision feedback (FB) systems are required in different parts of the machine. In this paper we study the performance of a fast intra-train feedback system at the IP for the ILC in order to correct both position and angle jitter. Benchmarking with earlier start-to-end simulations [3] may be useful to achieve reliable predictions.

SIMULATION SET UP

A schematic of the simulation set up is shown in Fig. 1. The model for particle tracking through the linac and the BDS is based in the code PLACET.

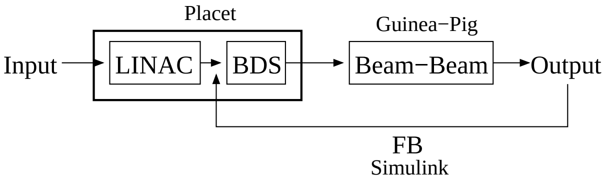

Figure 1: PLACET and GUINEA-PIG based simulation scheme set up.

The nominal ILC bunch train consists of 2625 bunches. For the sake of computing time we simulate only the first 300 bunches of the train. Sliced bunches are tracked along the linac. Each bunch slice represents 11 different energies with $0.1\ \%$ energy spread. The linac simulation includes also short and long-range transverse and longitudinal wakefields descriptions for the accelerating cavities.

For the tracking through the BDS each bunch is binned in 50000 macro-particles.

The code GUINEA-PIG [4] provides the luminosity, the beam-beam offset and the electromagnetic background generation at the IP. Fig. 2 shows the luminosity and the vertical beam-beam deflection curve for the ILC with nominal beam parameters.

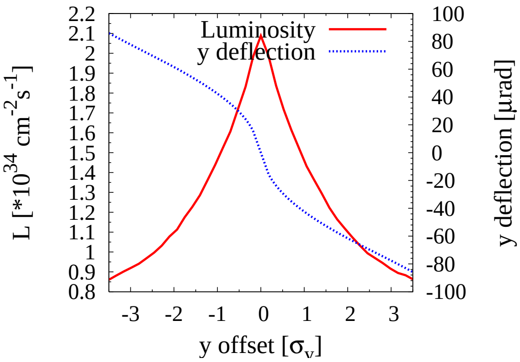

Figure 2: Luminosity and beam-beam deflection versus beam-beam offset at the IP from GUINEA-PIG simulations.

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Beam-Based Alignment in the Main Linac

In order to perform realistic simulations the model uses the static errors of Table 1 for the main linac. In the misalignment only the y axis is perturbed, since it is most sensitive to errors due to the transverse flatness of the beam ($\sigma_y/\sigma_x \approx 1/100$). In addition, to preserve the emittance, we apply beam based alignment techniques, e.g. 1-to-1 correction and dispersion free steering (DFS), assuming a BPM resolution of 1 μm. An example is shown in Fig. 3 for an average of 100 simulated machines. Considering an initial (exit from damping ring to RTML) vertical normalised emittance of 24 nm, after applying DFS the emittance growth at the end of the main linac is of about 20 %, clearly below the emittance dilution budget (50 %).

Table 1: Assumed initial static errors with respect the module axis in the main linac.

Error	value
Cavity offset	300 μm
Cavity tilt	300 μrad
Quadrupole offset	300 μm
Quadrupole roll	300 μrad
BPM offset	200 μm

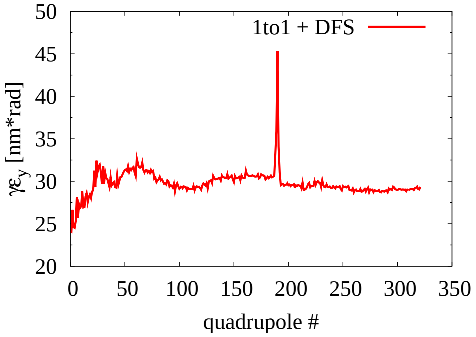

Figure 3: Emittance dilution in the ILC e^- main linac after applying 1-to-1 and DFS correction. The peak corresponds to the undulator position, whose alignment still remains an open issue.

Fig. 4 shows the corresponding normalised emittance distribution at the exit of the linac for 100 random seeds of applying misalignments, static and also ground motion (model C) [5], giving a mean value of 28.65 nm·rad and a standard deviation of 3.26 nm·rad.

Intra-Train Fast Feedback System

In order to combat the bunch-to-bunch position and angle jitter caused by dynamics effects as GM and vibrations of the components, intra-train IP position and angle FB corrections are applied using a stripline kicker located near the interaction point in the incoming beamline between the sextupole SD0 and the final quadrupole QF1. At $\pi/2$ phase advance downstream of the IP a BPM measures the beam positions to determine the deflection angle of the beams. Usually BPM resolutions of 1 μm are sufficient for these measurements. On the other hand, to correct the angle, a stripline kicker is located at the entrance of the final focus system with a downstream BPM at $\pi/2$ phase advance.

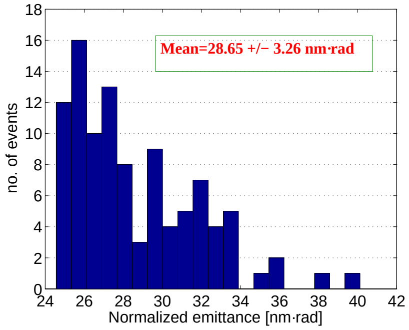

Figure 4: Vertical emittance dilution for 100 seeds of applying misalignments (static and GM).

Here we use the same FB system algorithm embedded in Simulink (MATLAB) as the one used in Ref. [3]. It is based in a proportional and integral (PI) controller algorithm. This Simulink model is linked to the PLACET model of the beamline by a MATLAB script.

Alternatively, we have also implemented a similar PI algorithm using Octave (a free clone of MATLAB), which is easily callable from within PLACET (and vice versa).

The corresponding hardware for an intra-train fast FB system has been designed by the FONT (Feedback systems On Nanosecond Timescales) group and successfully tested in accelerator test beam facilities as ATF at KEK [6].

LUMINOSITY RESULTS

We have studied the performance of the FB system to correct the position and angle jitter generated by ground motion. As initial conditions we have considered a scenario with 40 % emittance dilution in the main linac, and additional rms component jitter for the quadrupoles of 25 nm in the BDS and 50 nm in the linac. Also an initial injection jitter (from damping ring to RTML) of 0.1 σ has been assumed. Using the Andrei Seryi's GM models [5], which are well implemented in PLACET, 0.2 s of GM is further applied to both e^- linac+BDS and e^+ linac+BDS.

The result of the luminosity for a single seed of GM as a function of bunch number in a train is shown in Fig. 5, where different scenarios of GM are compared. For the noisiest site (model C), applying fast position and angle FB stabilisation, a recovery of the luminosity up to 85 % of the nominal value (2×10^{34} cm^{-2}s^{-1}) is obtained, in agreement with results from earlier studies [7]. On the other hand, for quiet sites (models A and B) practically the 100 % of the nominal luminosity would be achievable.

It is important to mention that for the present ILC linac simulations the short-range wakefield effects are much smaller than for earlier ILC linac simulations [3], where they were overestimated. Practically no "banana" effect is observed, as shows the Gaussian longitudinal profile (y vs

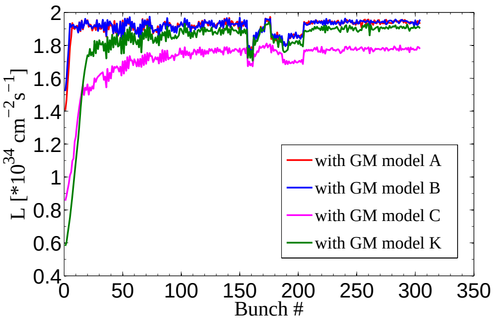

Figure 5: Example for a single random seed for different models of ground motion: A, B, C and K.

z) of both e$^-$ and e$^+$ bunches at the IP (Fig. 6). In this case the luminosity is maximum when luminosity-vertical kick gradient is zero (see Fig. 2), so then no significant improvement from offset and angle scan has been expected.

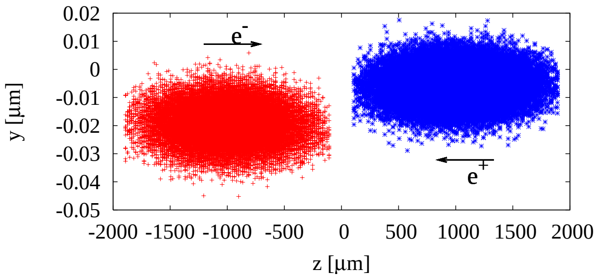

Figure 6: Example of the longitudinal profile (y vs z) for one electron and positron bunch at the IP.

In addition to the the GM effect, we have also studied the sensitivity to an additional position jitter generated at the entrance of the BDS. Fig. 7 shows the luminosity versus this jitter for the case without FB (initial input L), and with FB correction: L_{total} corresponds to the luminosity averaged over 300 bunches, and L_{max} the luminosity averaged over the last 75 bunches. With a initial jitter of $\approx$ 10 σ_y at the entrance of the BDS and applying GM model C, the FB system can only recover the 50 % of the nominal luminosity. For initial jitter $\gtrsim$ 14 σ_y the total luminosity is lost.

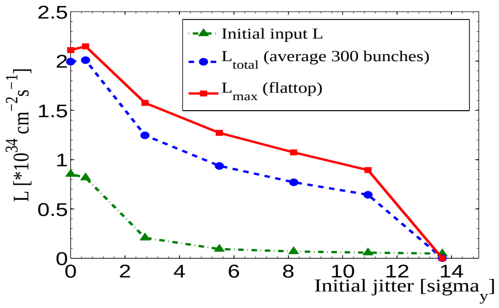

Figure 7: Luminosity versus additional position jitter generated at the entrance of the BDS.

Concerning the statistical fluctuation of the luminosity, Fig. 8 shows the luminosity distribution for 100 random seeds, considering the GM model C. The blue histogram corresponds to the average luminosity over the first 300 bunches of the train, giving a mean value $\mu = 1.768 \times 10^{34}$ cm^{-2}s^{-1} ($\simeq$ 88 % of the nominal luminosity) with a standard deviation of 0.052×10^{34} cm^{-2}s^{-1}. The red histogram represent the maximum achieved luminosity with $\mu = 1.831 \times 10^{34}$ cm^{-2}s^{-1} ($\simeq$ 92 % of the nominal value) and standard deviation of 0.045×10^{34} cm^{-2}s^{-1}.

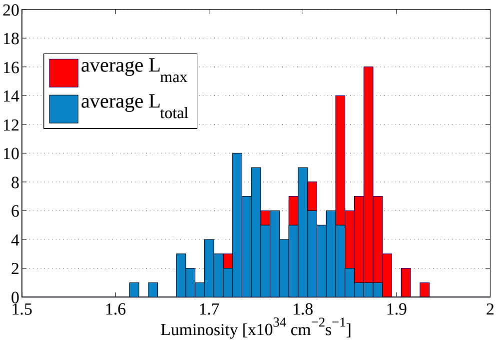

Figure 8: Example of luminosity distribution for 100 random seeds considering the ground motion model C.

SUMMARY AND OUTLOOK

In the context of low emittance transport and beam stability studies for the ILC, we have presented a PLACET based model to perform multi-bunch tracking simulations from the start of the main linac to the IP. The aim is to make realistic simulations including different static and dynamics errors. The model includes also beam based alignment algorithms in order to preserve the emittance in the main linac. On the other hand, fast intra-train feedback systems are applied to mitigate the high frequency ground motion effects ($\sim$ 1 MHz). In particular, we have studied a fast feedback systems for both position and angle correction at the IP. We plan to improve the model including other sub-systems, e.g. RTML, positron source and crab cavities. Also the interaction with other FB systems which operate at lower frequency, e.g. inter-pulse FB (5 Hz), should be studied in detail.

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