MULTI-BUNCH SIMULATIONS OF THE ILC FOR LUMINOSITY PERFORMANCE STUDIES

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Abstract

To study the luminosity performance of the International Linear Collider (ILC) with different design parameters, a simulation was constructed that tracks a multi-bunch representation of the beam from the Damping Ring extraction through to the Interaction Point. The simulation code PLACET is used to simulate the LINAC, MatMerlin is used to track through the Beam Delivery System and GUINEA-PIG for the beam-beam interaction. Included in the simulation are ground motion and wakefield effects, intra-train fast feedback and luminosity-based feedback systems. To efficiently study multiple parameters/multiple seeds, the simulation is deployed on the Queen Mary High-Throughput computing cluster at Queen Mary, University of London, where 100 simultaneous simulation seeds can be run.

INTRODUCTION

As part of the Low Emittance Transport (LET) studies for the ILC, a simulation environment has been set up to study the impact of different error sources applied to the current range of ILC designs. Particularly, this study concentrates on the intra-train dynamics of the ILC beam. The aim is to simulate a 'snapshot' in time of the ILC beam pulse under normal running conditions and study the impact in terms of Luminosity degradation of various error conditions applied to the different designs.

The baseline setup for the ILC simulation is to use a statically aligned linac and Beam Delivery System (BDS) after applying expected levels of survey errors. The linac simulation includes short and long-range transverse and longitudinal wakefield descriptions for the accelerating cavities. The BDS simulation also allows for the inclusion of short-range longitudinal and transverse wakefield descriptions of the beam collimators. These wakefield forces affect both the structure of the beam train and the shape of the bunches themselves depending on their trajectories through these elements.

It is assumed at this stage that the slow pulse-pulse feedback system has done its job perfectly. The design of this system and the implementation of a more thorough time-evolved simulation is currently under way.

From this starting point, a ground motion model is applied to the full accelerator (e- Linac + e- BDS + e+ BDS + e+ Linac). A representation of the beam train is then tracked through the accelerator models, including simulations of the fast feedback systems which keep the bunches colliding on-axis in position and angle at the Interaction Point (IP).

The modelling of the ground motion is done using a simulation package written by A. Seryi [1]. The model applies ATL ground motion [2] plus a fit to measured spectra at various sites. The data used in this study correspond to data set C, which approximates the ground motion conditions seen at DESY (a noisy site). Luminosity loss occurs through the emittance growth of the beams and through the resulting misalignment of the colliding beams at the IP.

The simulation package GUINEA-PIG [5] is used to model the strongly non-linear behaviour of the beam-beam interaction itself. This allows for wakefield effects to be taken into account which lead to non-Gaussian 'Banana' bunches at the IP. This effect only causes emittance growths at the 1-2 percent level, but due to the complexity of the beam interaction, has been shown [4] to lead to up to a third loss in luminosity if not specifically taken into account. The banana-bunch beam leads to a change in the optimal set-up of any intra-train feedback system, so there is a strong link between the modelling of how these bunches form and the ultimate luminosity performance of the ILC.

FAST-FEEDBACK AND LUMINOSITY OPTIMISATION SYSTEMS

Luminosity rapidly drops off at the ILC as the beams become misaligned through the relative motion of magnets as a result of ground motion. The most sensitive magnetic elements in the machine to this effect are the final focussing quadrupoles where a 1-1 correspondence exists between their vertical position and the vertical position of the beam at the IP due to the parallel-to-point focussing. The slower classical feedback systems in use to control the beam orbit cannot address ground motion above approximately the 1 Hz level. To combat the effects of ground motion at smaller timescales, fast-feedback systems are to be employed that operate within the timescale of a single bunch train. In the interaction region to null the vertical beam offsets, an IP fast-feedback is envisioned that comprises of a stripline beam position monitor (BPM) and a stripline kicker. It is possible to read out the BPM, digitally process this signal and calculate a feedback response and to kick the next bunch that comes along.

In addition to the effects of a vertical position offset at the IP, problems arise if a vertical angular offset (significant compared to the IP angular divergence (~10 urad)) exists. This leads to a drop in luminosity although not as pronounced as the position offset effect. It also leads to an additional component of the beam-beam kick that confuses the position feedback leading to an incorrect correction being applied. For the angle feedback, a BPM-kicker system is used upstream where the beta functions are larger than they are close to the IP. The BPM is placed at an IP image point at the entrance to the Final Focus System (FFS). Three 1m stripline kickers are placed upstream from that (90 degrees apart in phase). More details about the fast feedback system can be seen for the case of the TESLA TDR in [9].

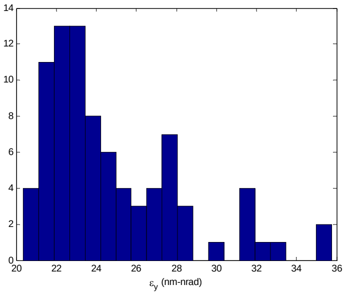

Figure 1: Emittances of beams exiting the Linac after 1-1 steering (100 Seeds).

Short-range wakefield effects cause systematic distortions in the y-z bunch shape (so called 'banana' bunches). Such effects change the behaviour of the beam-beam interaction, and the optimal collision parameters for maximal luminosity. To get the maximum possible luminosity, a luminosity feedback is used to scan in position and angle around the natural settling point of the feedback systems. The ILC fast beam calorimeter provides bunch-by-bunch signals of the integrated energy from electron-positron pairs produced in the beam interaction, which is approximately proportional to luminosity [3].

SIMULATION ENVIRONMENT

The ILC bunch train, depending on the final design and beam energy, consists of 1330-5640 bunches; in this simulation the first 600 only are modelled. This is enough to investigate the full kinematics of the intra-bunch feedback systems and to use the tail end of the simulated part of the train to be representative of the rest of the pulse. This bunch train is tracked through the 14.4 km Linac with PLACET [5] including wakefield effects in the 10,292 9-cell accelerating cavities (only the TESLA TDR linac design is currently modelled). Two different seed sets are used to simulate the electron and positron linacs. Each bunch in PLACET is represented as 31 longitudinal slices; each slice is represented as 11 different energies to model the energy spread of the bunch. A 'typical' bunch train is produced by misaligning the linac structures and BPMs relative to the quadrupole magnets to that expected after beam-based alignment has been performed. RMS errors for the structures are 500 μm in y and 300 μrad in y'. The BPMs are given a 25 μm RMS offset in y. Only the y axis is perturbed in this simulation as this axis is the most sensitive to ground motion effects due to the 100-1 aspect ratio of the beam at the IP. A 1-1 steering algorithm is then applied to the lattice where each quadrupole is moved to centre the beam in each accelerating structure BPM. The steering needs to be performed on the trailing portion of the train due to the disrupted nature of the front 100-150 bunches caused by the long-range cavity wakefields (see example seed in figure 2). 100 different seeds are tracked through the generated lattices. Seeds that correspond to approximately the mean 25% emittance growths through the linac are chosen for the full simulation (see Fig.1). The ground motion model is then applied and 600 bunches are tracked through the resulting lattice.

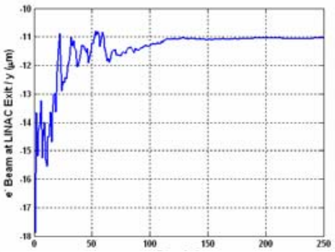

Figure 2: The first 250 bunches exiting the Linac, the disrupted front end of the train corresponds to the HOM damping time.

Each bunch is then binned into 80,000 macro-particles for input into MatMerlin [6], which treats the BDS by ray-tracing the macro-particles through this section of the ILC. Within the BDS simulation, 0.14 % energy spread is added to the electron beam to simulate passage through the positron production undulator. The ground motion model is also applied here to all elements.

Finally, the bunches are passed to GUINEA-PIG [7], which simulates the beam-beam interaction and provides luminosity information in addition to the beam-beam kick and various background products including electron-positron pairs.

The full simulation is run in Matlab, which handles the calls to PLACET and MatMerlin and contains all the simulation parameters. The fast feedback systems are implemented using a Simulink model which includes both IP and angle fast feedbacks. The feedback algorithm is implemented as a PI controller, programmed to give a fast response with good noise rejection to maintain position and angle collisions to within 0.1σ of the desired value. Errors in the feedback systems enter through the resolution limits of the BPMs used and the field stability of the stripline kicker(s). BPM resolutions of 5,2 μm for the IP, angle BPMs were assumed and a 0.1% field stability for the kicker was used. The luminosity optimisation system is modelled using e^+e^- pairs generated with the GUINEA-PIG simulation. The pairs produced are tracked through the magnetic field of the detector solenoid, and the number of hits passing an area where the beamcal is located are counted. This forms the signal to be used for the luminosity optimisation.

To investigate the effects of ground motion and different machine configurations etc. the Queen Mary High Throughput Cluster [8] is used. This allows up to 100 simultaneous seeds to be run on the cluster of P4 2.8 GHz Xeon processors running Fedora Linux.

SOME SIMULATION RESULTS

Some sample results are shown here comparing the performance of the TESLA TDR Linac [3] plus the TDR BDS [3] and with the ILC-IR1 BDS (NLC style 20 mrad crossing angle BDS optics) [10]. The beam parameters used are those corresponding to the TESLA TDR beam optics (23 MV/m accelerating gradient, 0.4mm beta-y*). Figure 3 shows the effect of ground motion on the TDR optics (simplified GM model jittering accelerator elements by an amount approximating the effect of 0.2 s of model-C ground motion). With a higher than expected level of jitter of the beam insertion into the Linac (0.2 sigma y, y'), 8 % luminosity is lost with the feedback systems operating compared to the perfectly aligned jitter free lattice. Note, the beam is simulated as completely flat entering the linac.

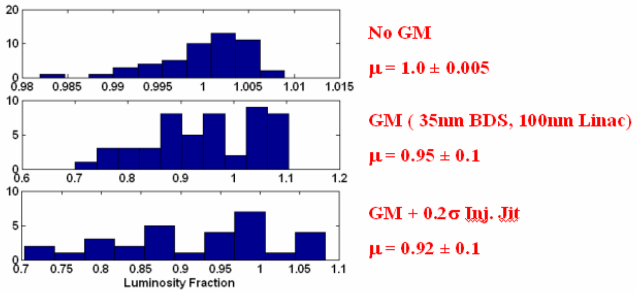

Figure 3: Luminosity histograms for different cases of ground motion and linac injection errors for the TESLA TDR BDS and simplified Ground motion.

Figure 4 shows the luminosities for 100 seeds for the ILC-IR1 and TESLA TDR BDS optics (same Linac optics and simulation). The corresponding mean IP emittances were 26.3/26.7nm (e+/e-) for the ILC-IR1 case and 28/32.9nm for the TESLA TDR case. The emittance growth comes purely from the BDS section, and is compared with values of 23.7/23.5nm from the Linac section exit. The Luminosity feedback was also more effective for the ILC-IR1 case; it gave a mean 13% improvement in Luminosity compared with 7% for TESLA TDR.

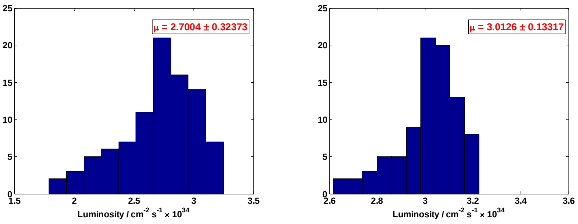

Figure 4: Simulated luminosity for (left) TESLA TDR lattice and (right) ILC-IR1 BDS lattice for 100 GM/error seeds.

Figure 5 shows the luminosity for 100 seeds using the A. Seryi Ground motion model instead of the simplified model of using RMS component jitter in the above results. Other simulation conditions are identical. Ground motion model 'C' was used. The mean luminosity for this simulation was 3.04, agreeing well with the simplified case for the same lattice above.

SUMMARY

The integrated simulation environment described here has so far been used to examine the luminosity performance of the ILC in the presence of fast ground motion with fast feedback systems active. Work is now ongoing to improve the way in which these systems are implemented as well as to develop the simulation environment further. Future development work planned includes the implementation of collimator wakes; the use of crab cavities to perform the angle feedback; the incorporation of lower frequency feedbacks and study of the placement of additional fast feedback systems; study of the effect of crossing-angle crab cavity tolerances and implementation and study of bunch compressor tolerence issues. Other noise sources, such as energy jitter due to klystron phase/amplitude jitter and intra-train effects from collective effects arising from the Damping Rings etc. should also be added. It is envisioned that a comprehensive comparison of the luminosity performance of the various lattices and beam parameters under study for the ILC be completed on the timescale of Snowmass. Data acquired during the running of these simulations is kept on a web site: http://hepwww.ph.qmul.ac.uk/lcdata.

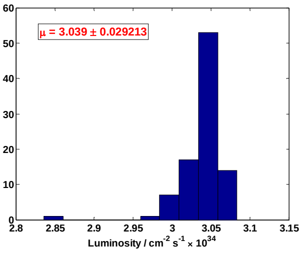

Figure 5: 100 seeds using Ground Motion model 'C' for the ILC-IR1 BDS Lattice.

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