

FEEDBACK ON NANO-SECOND TIMESCALES: FAST FEEDBACK SIMULATIONS

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Abstract

The FONT group (based at QMUL and Oxford Universities) are responsible for the design of the IP fast intra-train feedback system to be implemented in the IR of the future linear collider. This system is intended to correct for luminosity loss due to high frequency ground motion. The work presented here was carried out to test the feasibility of such a feedback system and to investigate, through simulation, the optimum design and operating parameters.

INTRODUCTION

All of the proposals for the future linear collider require similarly challenging final beam spot sizes: TESLA [1] 5nm, NLC/JLC [2] 2.7nm and CLIC [3] 1nm, are the proposed vertical bunch spot sizes at the Interaction Point (IP). This places very rigorous stability requirements on all three designs. The most severe tolerance is for the final focusing quadrupole magnets. To keep the luminosity loss to within 2 percent, the beams need to be kept in collision to within 40% and 60% of the final beam spot size for NLC and CLIC respectively. This implies a tolerance on the final quadrupoles of about 1nm and 0.6nm for NLC/JLC and CLIC respectively.

The limiting factor for stability along the beamline for the linear collider is that of ground motion. There has been a considerable effort undertaken into the study of the magnitudes and effects of ground motion at different possible sites for the linear collider which are covered in detail elsewhere[4]. If uncorrected, ground motion causes a total loss of luminosity at the linear collider within seconds through beam misalignment and emittance growth. To combat this, a program of passive and active support systems to stabilise the beamline elements, together with different levels of beam-based feedback systems, is being pursued.

Three levels of beam-based feedback system are being developed. A slow feedback will move quadrupoles and structures onto the beam trajectory about every 30 minutes to compensate for low frequency ground motion. An inter-pulse feedback acts in a few locations to correct accumulated errors that occur in between the action of the slow system, and also to provide the possibility of straightening the beam. Finally, a fast intra-train feedback system acting at the IP keeps the beam in alignment, correcting for high frequency cultural ground motion moving the final quadrupoles. For TESLA, a second intra-train system will be used further upstream to additionally remove any incoming angle jitter which also leads to a loss in luminosity.

BEAM SIMULATIONS INCORPORATING FAST-FEEDBACK SYSTEMS

The fast feedback systems are designed to remove beam jitter that occurs at frequencies comparable with the repetition rate of the machine by measuring the first few bunches in the train and correcting the following bunches within that train. The bunch structure thus dictates the operating requirements for the system. For NLC/CLIC designs there are 192/154 bunches per train separated by 1.4/0.7 ns. TESLA will have 2820 bunches separated by 337 ns. The NLC/CLIC case requires a much more aggressive design requiring, at present, a purely analogue electronic approach. The TESLA scheme allows for a more complex digital based algorithm to be employed. Simulations of the fast feedback systems are written in the Matlab/Simulink environment. The feedback system for NLC and CLIC is based on the system designed by S. Smith at SLAC [5].

SIMULATION RESULTS

NLC

The effect of vertical beam offsets at the IP of the NLC-H 500GeV machine was studied with different variants of the feedback design implemented in the Simulink model, using the GUINEA-PIG [6] modelling package to calculate the beam-beam kick effects and luminosities. In the simulation, the BPM and kicker are assumed to be positioned at a distance of 4.3m from the IP at the same side of the IP, where the beam deflection is measured on one beam, and the other incoming beam is then kicked. This is possible at NLC (and CLIC) due to the non-zero crossing angle. Although, at the NLC, with mechanical stabilisation systems active, the IP offsets are expected to be small ($\Delta y < 5\sigma$) - the effect of offsets of up to 40 times the vertical IP beam spot size were investigated to see the full capabilities of the system. Fig. 1a shows the results of running the simulation over one full bunch train (192 bunches) with different initial offsets. Shown in the filled-in region is the case with no feedback, where the luminosity quickly drops off as the beams are offset, with 60% luminosity loss for a $5\sigma_y$ offset. The top two curves show the effect of the standard feedback algorithm with a single gain stage set at 2 different levels ('low' and 'high'). Low gain is better at low offset, high at larger offsets due to the non-linearity of the beam-beam kick vs. beam offset function. In an attempt to remove this effect, a linearisation step is included in the simulation where the gain is chosen based on the incoming BPM signal. The third curve shows the effect of a 3-stage linearisation to the predicted beam-beam kick curve. The last curve shows the effects of incorporating a further gain

stage in the feedback loop to damp down the oscillatory effects arising from having a too high gain for the given offset.

Being closely integrated into the Interaction Region (IR) close to the IP, the feedback system is forced to operate in an environment of background particles generated at the IP during beam collisions. This could potentially lead to damaging effects to the system itself, and also, through secondary production and scattering of background particles, to the sensitive particle detectors (principally the vertex and central tracking systems). To model the potential impact of the feedback system in the IR, GEANT3 [7] and FLUKA99 [8] models of the IR were taken and the material making up the feedback system was added. Fig. 2 shows the positioning of the BPM and kicker of the feedback system within the IR of the NLC as implemented in the models. The source of background modeled was that of the coherent e^+e^- pairs which were generated with the GUINEA-PIG model and then tracked through the GEANT and FLUKA models. Fig. 3 shows just a few e^+e^- pairs and the associated scattered secondaries tracked on one side of the IP. Fig. 4 shows the intercepted electromagnetic background in the strips of the feedback BPM strips. According to S. Smith[5], the feedback system will be sensitive to intercepted EM radiation at the level of 3pm of Δy^* (at the IP) resolution per electron knocked off the BPM strips. The background radiation would thus present a significant source of noise in the feedback system if an intercepted spray of particles at the BPM at the level of 10^5 per bunch crossing existed. As can be seen in Fig. 4, the expected level is much less than this. Fig. 5 shows the rate of secondary EM particles hitting the layers of the vertex and central tracking detectors with and without the BPM and kicker of the feedback system included in the GEANT model. As can be seen, the inclusion of the system has very little impact on the background levels. This is due to the positioning of the system behind the masks and LCAL system which are designed to shield the IP from scattered secondaries. Modeling of the system forward of this mask where the system is clearly within the field of pairs confined by the solenoid field seen in fig. 3 shows a large increase in detector backgrounds. Fig. 6 shows the neutron flux in the vertex tracking layers, again- this positioning of the feedback system has little impact on the background levels. The integrated flux with the FB system included is $6.6 \pm 1.3 \times 10^9$ 1 MeV equivalent neutrons per cm^2 per year. The default value without the FB system is $5.5 \pm 0.8 \times 10^9$.

CLIC

For the CLIC simulation, the same system is used as in NLC. The curves in fig. 1b show the effect of offset beams on luminosity for the cases of no feedback, and the system as described in the above section with the 3-stage linearisation, placed at a distance of 4.3m as in NLC and closer, 1.5m as maybe possible with the CLIC IR design. As can

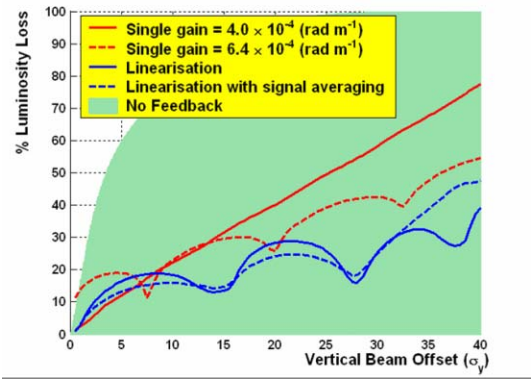


Figure 1: Simulation of luminosity loss at NLC-H (left) (500 GeV) with varying initial beam offsets at the IP.

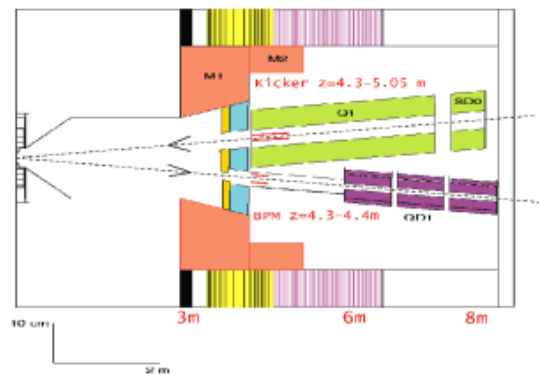


Figure 2: GEANT model of NLC IR showing the positioning of the IP feedback kicker and BPM components.

be seen, the CLIC luminosity is very dependent on highly aligned beams, the smaller train length and shorter bunch spacing gives the feedback system less tries at correcting the offsets. The latency of the system is dominated by the time of flight of the beams between IP and feedback components.

As in the NLC case, G.Myatt at Oxford has begun to look at the backgrounds for the CLIC case in a GEANT CLIC IR model. Fig.8 shows the CLIC interaction region with the feedback system placed in a 'near' position inside the mask, and a 'far' position outside of the protective mask. A

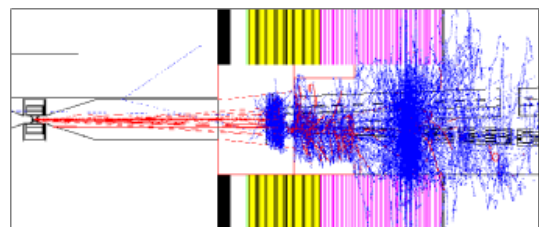


Figure 3: GEANT model of NLC IR with 20 tracked e^+e^- background pairs. Charged particles are shown in red and photons in blue.

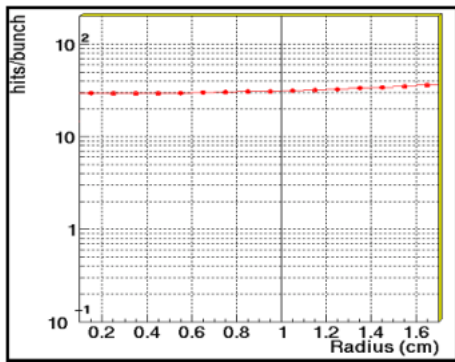


Figure 4: EM background flux at the z location of the feed-back BPM. The stripline radius is shown as 1 cm in the plot.

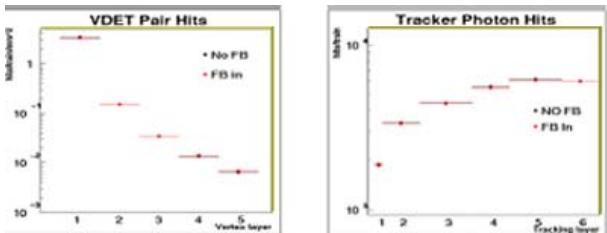


Figure 5: Background particle flux in the vertex (left) and central (right) trackers. The predominant backgrounds of charged particles in the vertex tracker and photons in the TPC are plotted for the IR with and without the feedback material included.

sample train of CLIC background e^+e^- pairs were fed into the GEANT model and tracked. Initial studies show that the far position gives about 2 extra hits per mm^2 per train in the vertex detector (compared with no feedback system present). The near position produces negligible extra hits in the vertex detector but produces considerable extra neutral background radiation in the end of the unprotected TPC. Further studies will continue for the CLIC case.

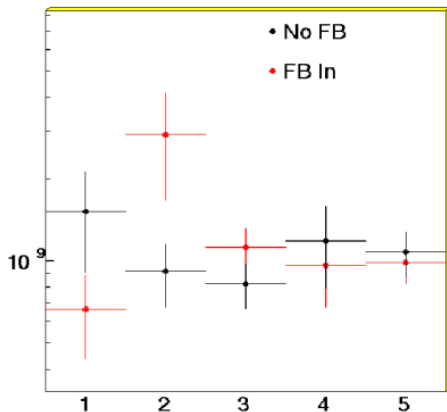


Figure 6: The neutron flux in the 5 layers of the vertex tracker with and without the feedback system included in the IR FLUKA99 model.

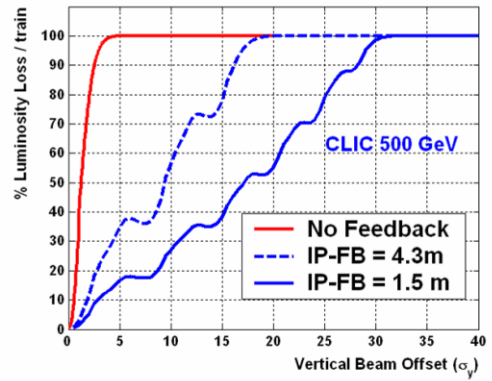


Figure 7: Simulation of luminosity loss at CLIC 500 GeV machine with varying initial beam offsets at the IP.

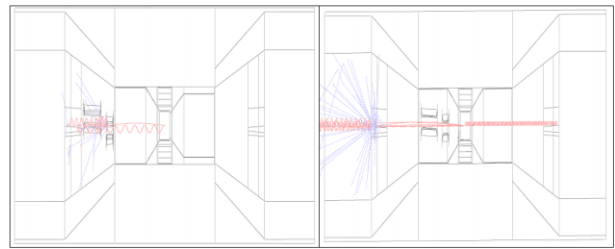


Figure 8: Two positions for the CLIC feedback system- 'near' and 'far', inside and outside the mask region.

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