Chapter 8

GEANT3-based simulations of stripline signals

8.1 Simulating stripline signals

8.1.1 Overview

Based on the premise that the stripline signals are the sum of three signals (emission of charges, impaction of charges and the normal stripline response caused from charges passing the upstream end of the stripline as proposed in section 1.5.2 and section 3.1), a set of tools was developed to predict the stripline signal.

The first stage is a GEANT3 simulation of a stripline BPM in background conditions. The charged particles hitting the striplines, leaving the striplines and passing the plane at the z position of the upstream end of the stripline are recorded. The next stage is to create the normal stripline response, the response from emission and the response from impaction, given the information from the recorded particles.

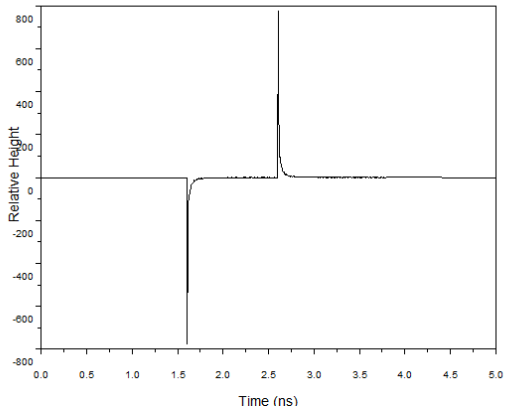
The simulation of stripline signals was tested against the Method A results before being used with ILC GEANT3 simulations to predict the stripline signals of the IP feedback BPM.

8.1.2 Using GEANT3 results to produce the normal stripline response

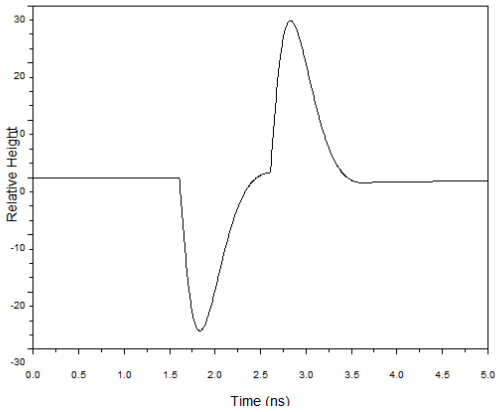
The normal stripline response was calculated using results from the GEANT3 simulation by recording the x-y position of each particle and the time as it passed the upstream end of the stripline BPM.

As described in section 1.5.2, an electron produces a negative voltage pulse as it passes the upstream end of a stripline[1], the magnitude of which is related to its distance from

[1]The type of stripline used here has a shorted downstream end and the signals picked off at the upstream end.



(a) The stripline response as created from simulation results.



(b) The stripline response passed through a 2nd order 900 MHz Butterworth low pass filter to reproduce the effects of the cables from the stripline to the oscilloscope.

Figure 8.1: The stripline response to charges passing its upstream end, created as described in the text from a GEANT3 simulation of Method A with the beam positioned at a radius of 1.55 cm.

the striplines. For each charged particle recorded as going past the upstream end of the stripline, a weighting was calculated per stripline based on its distance from each stripline (and therefore the angle it subtends) and the direction of the response of the stripline. For example, if the electron was at the centre of the beampipe, the weighting was -1/8th for each stripline as each stripline intercepts an eighth of the induced charge (subtending an angle of $\frac{\pi}{4}$), and a negative voltage is produced.

The times of arrival of the electrons at the upstream end of the stripline (from the time of flight parameter in GEANT) were binned in a histogram with the weightings as calculated for each stripline. This signal was inverted and shifted in time by $2L/c$ and superimposed with the original signal, this being the signal reflected off the downstream end of the shorted stripline. Together, the first signal and its reflection produce a bipolar doublet as shown in figure 8.1(a).

The experimental setup included 200 feet long cables with 3.9 dB attenuation per 100 feet at 900 MHz [113] and the signals were recorded with an oscilloscope with an input bandwidth of 1.5 GHz [49]. To make the simulation results match the data, a low pass filter was applied digitally within Scilab [114] to the simulation results as shown in figure 8.1(b). The type of digital filter was chosen purely because the results looked similar to the experimental data.

8.1.3 Response from emission

The emission of charges occurs along the length of the stripline. As a charge is emitted, it causes a signal (in figure 8.2, an electron and the associated positive signal is shown). The signal splits and travels two ways: upstream and downstream. The upstream-travelling

signals essentially appear as a DC offset if there is uniform charge emission along the stripline, as the signals from charges emitted along the stripline arrive at the upstream pick-off over a period of time. The time of arrival at the upstream end can be calculated from the time the charge was emitted from the stripline (this is the time of flight t_{tof} parameter in GEANT) and its position on the stripline (with the assumption that the electric signal in the stripline travels at the speed of light c). That is, the upstream-travelling signal arrives at $t_1 = l/c + t_{tof}$. The difference between the time of arrival of the first charge being emitted (that is a charge at the upstream end) and the time of arrival of the last charge being emitted is approximately $2L/c$ (where L is the length of the stripline, in this case 15 cm) since the maximum distance the signal has to travel in the striplines is L and this emission would be caused by a particle that has to travel approximately an extra L from the upstream end before hitting the stripline.

Each emission also causes a downstream-travelling signal in the stripline which is reflected (and inverted) at the downstream end of this shorted stripline. It arrives at $t_2 = (2L\text{-}l)/c + t_{tof}$. The reflected signals from all charges being emitted from the stripline tend to arrive at the upstream pick-off at the same time since t_{tof} measured with respect to the first strike of a secondary background particle on the upstream end of the stripline is approximately l/c (approximating the velocity of the secondary background particles to be along the z direction at the speed of light). This causes one large spike $2L/c$ after the start of the signal.

Figure 8.3 shows the type of signal that can be constructed using this treatment of simulation data. In this figure, the electrons and positrons that were flagged by the simulation as exiting the stripline were recorded. The signal for each electron leaving has been assigned to be +1 and each positron leaving -1 (according to section 3.1.2) with the assumption made that as soon as the charge is emitted it is removed to infinity. The timing of the signal is the time of flight from the simulation (t_{tof}) plus the time it takes for a signal to travel from the position where the particle was emitted to the upstream end of the stripline (t_1). This was produced as a histogram and added to a histogram similarly created but with the signal timing for the downstream-going part that gets reflected at the shorted end of the stripline (t_2).

The assumption that as a charge was emitted it was removed to infinity was improved upon. It does not hold for particles that go down the beampipe, that is particles that are not quickly removed by hitting the beampipe wall. The improvement involved assigning a weighting between 0 and ± 1 (+ for electrons and - for positrons) depending on its angle and z-position of emission [81]. If the position and angle of ejection resulted in the charged particle travelling alongside a stripline within the beampipe, then the signal it causes is not due to a net change in charge of the full electron or positron. This is because some induced charge remains on the stripline as the charge passes the end of the stripline. The signal corresponds to 1 minus the fraction of induced charge on the stripline as the charge passes the end. Therefore, the weighting is not ± 1 but $\pm(1 - \alpha/2\pi)$ where α is the angle subtended by the charged particle on the stripline as it passes the stripline's end.

Charges that did not pass down the beampipe and instead hit the beampipe wall or another stripline were automatically given the weighting ± 1.

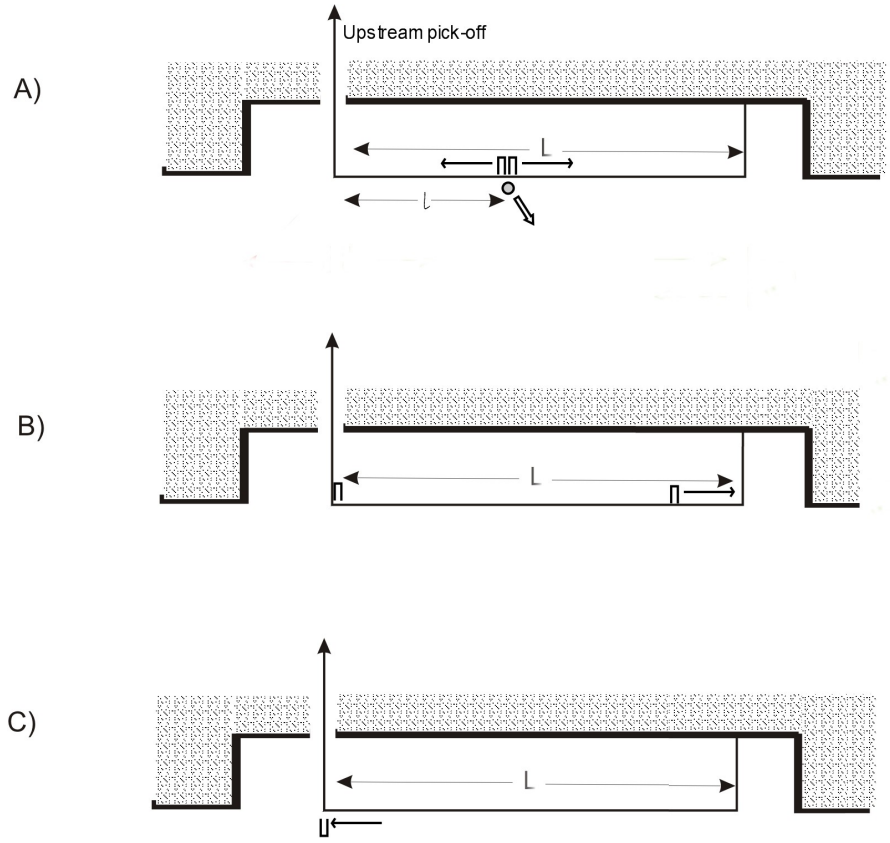


Figure 8.2: A shorted stripline of length L with an electron emitted a distance l along the stripline. The associated signal is positive and travels upstream and downstream as described in the text. A shows $t = t_{tof}$. B shows $t = t_1 = t_{tof} + \frac{l}{c}$. C shows $t = t_2 = t_{tof} + \frac{2L-l}{c}$.

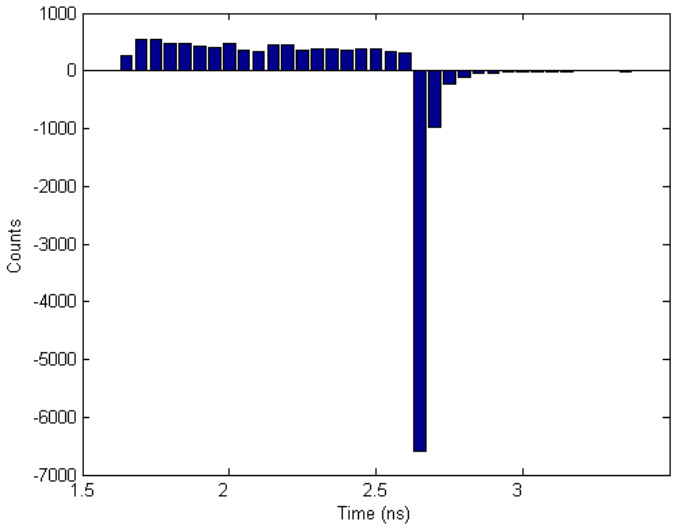


Figure 8.3: The signal caused by charged particles leaving the striplines shown as a histogram. This is based on simulations and created from the treatment described in the text with the approximation that all charged particles leaving give the same amplitude of signal (± 1).

A full electromagnetic solution of this would be ideal as the emitted charges are not relativistic. Therefore the associated electric field is not a "pancake" (as described in section 1.5.2) making the calculation of the amplitude of the induced charge (and its approximation as a delta function) incorrect.

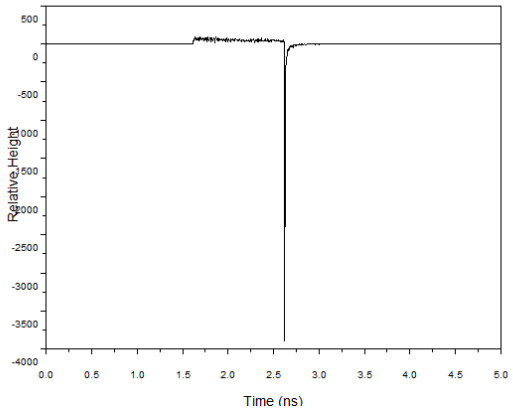
Also, not all the signal on the stripline occurs at t_{tof}, only $\pm\frac{1}{2}$, with the rest of the $\pm(1 - \alpha/2\pi)$ occurring after as the charge moves away from the stripline and the induced charge decreases in magnitude. This suggests that the estimate for the signal due to an emitted charge based on this method will be slightly higher in amplitude and shorter in time than the true signal.

The signal created for the emission (and its reflection off the shorted downstream end of the stripline) was passed through the low pass filter as described for the normal stripline response signal. The result is shown in figure 8.4.

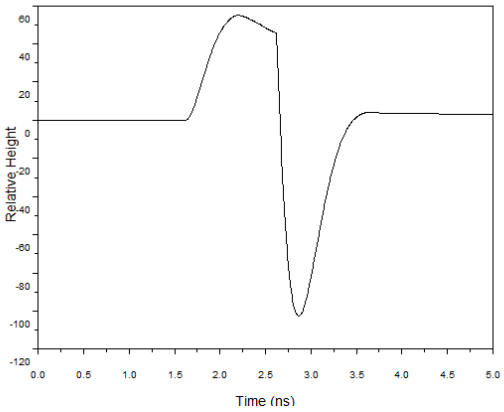
8.1.4 Response from impaction

A first approximation for the response from impacting charged particles is to assign a weighting of ± 1 to each hit (with the sign as given in figure 3.5). However, just as with the emission response, this was improved upon.

The hits on the striplines are predominantly at low angles as shown in figure 8.5 and spend much time close to the striplines before they impact. Therefore, assuming that they come from infinity and immediately impact the stripline is a bad approximation. Figure 8.6 shows three stages where some signal is caused on the stripline. The majority of charges that hit are also included in the normal BPM stripline signal response as they come from



(a) The signal caused by charged particles leaving the striplines.



(b) The signal caused by charged particles leaving the striplines after being passed through a 2nd order 900 MHz Butterworth low pass filter.

Figure 8.4: The signal caused by charged particles leaving the striplines based on simulations and created from the treatment described in the text with consideration given to the fact that not all charges are removed to infinity.

upstream and pass the upstream end of the stripline before they hit. This is stage 1 in figure 8.6. Here, the signal height is related to the angle the charged particle subtends from the stripline ($\alpha/2\pi$) as described above for the normal stripline response. This is a fraction of the signal from the net change of a whole electron or positron charge. The rest of the signal (1 - $\alpha/2\pi$) is deposited as the charge approaches the stripline (stage 2) and when it impacts (stage 3). It is assumed for simplicity that all the remaining signal occurs at the moment of impact (stage 3).

Charges that hit the striplines can also come from emissions from other striplines or the wall of the beampipe. In fact, these made up approximately 50% of the hits. These were assigned weights of ± 1 delivering all of the particle charge when it impacts.

The weights are therefore calculated in the same manner as with the emitted charges but with the sign of the signals reversed as described in figure 3.5. The time for arrival of the signal and its reflection at the upstream end of the stripline are also calculated as they were for the emitted charges.

The resulting signal for charges hitting the striplines was passed through the low pass filter (as with the normal stripline signal) to replicate the effects of the cable and oscilloscope. The results are shown in figure 8.7.

8.2 Simulation of Method A Results

This method of recreating the stripline response based on a GEANT3 simulation was tested and calibrated against the results from Method A.

The existing GEANT3 model of the FONT module was used with an input beam from a

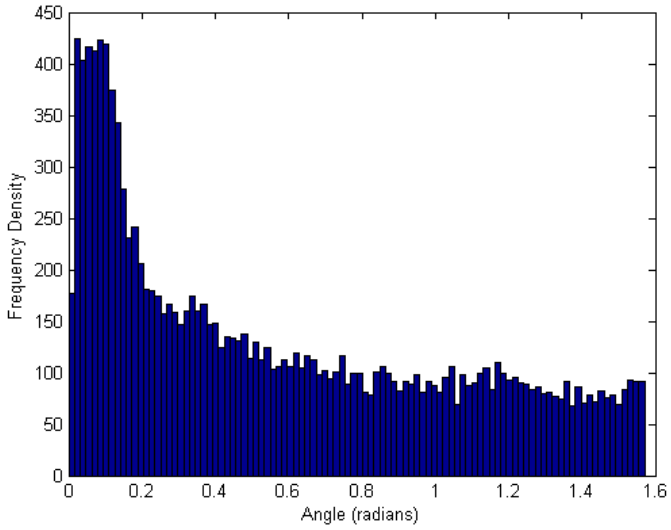


Figure 8.5: The angle of approach of electrons that hit the striplines (measured with respect to the stripline surface). Many approach at low angles and so are near the stripline for relatively long amounts of time.

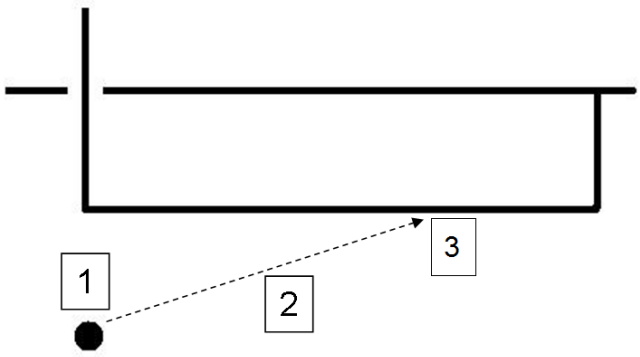
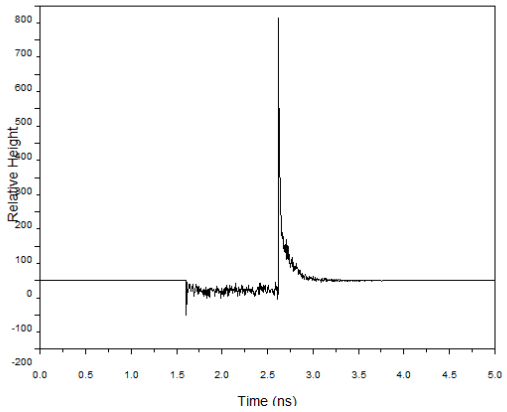
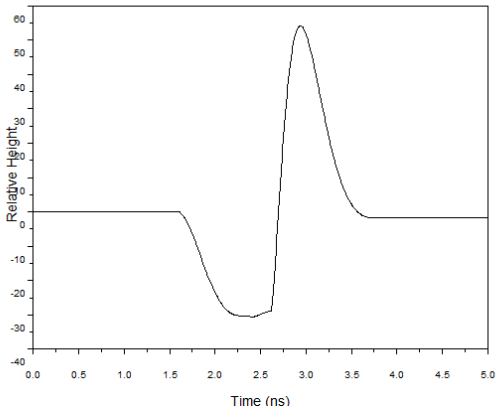


Figure 8.6: 1. Particles that pass the upstream end of the stripline contribute to the signal described in section 8.1.2. 2. The charged particle approaches the stripline. 3. The charged particle hits the stripline.



(a) The signal caused by charged particles hitting the striplines.



(b) The signal caused by charged particles hitting the striplines after being passed through a 2nd order 900 MHz Butterworth low pass filter.

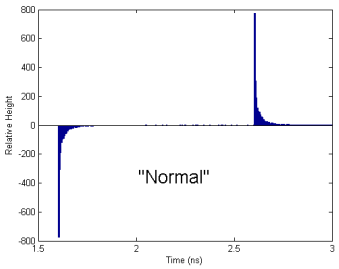
Figure 8.7: The signal caused by charged particles hitting the striplines based on simulations and created from the treatment described in the text.

random number generator within Matlab with parameters matching those used at ESA with Method A. The electrons and positrons crossing the stripline volumes were recorded and flagged depending on whether they were entering or exiting. The charged particles passing the upstream end of the stripline were also recorded. These data were used as described in section 8.1 to simulate the three signals (emission, impaction and the normal stripline response) and sum them together in an attempt to replicate the data observed in the run in July 2006.

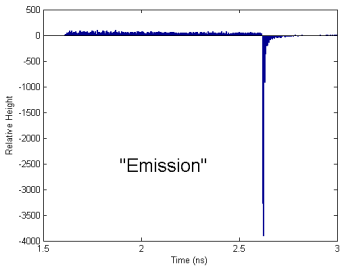
By considering the addition of the normal stripline signal (figure 8.8(a)) to the proposed response for emitted charges (figure 8.8(b)) and impacting charges (figure 8.8(c)), the total stripline response was calculated from simulation only. This result is shown in figure 8.8(d) which was then passed through a digital low-pass filter (figure 8.8(e)).

Shown in figure 8.9 are the results for three positions: x = -1 cm y = 1 cm, x = -1.1 cm y = 1.1 cm and x = -1.25 cm y = 1.25 cm. These can be compared to the Method A results in figures 5.11 and 5.12 (where the beam position is known to ± 0.25 cm). The stripline signal observed in the results of Method A striplines B and D with two negative peaks and a flat, positive region in between, is predicted in the simulations. However, A and C also show this shape in the simulated response (though reduced in amplitude) but in the Method A results, striplines A and C have a negative peak followed by a positive peak with no flat, positive region.

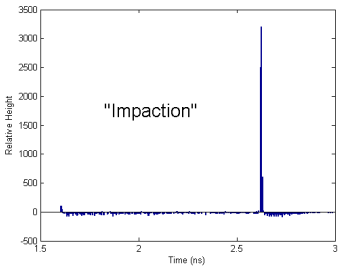
It appears that the amount of hits is the principal cause of the difference between the Method A results and the simulated signals. By increasing the signal from impaction by a factor of 1.3, a set of simulated signals that were a closer match to the Method A results were produced (figure 8.10). Here, the simulation results shown are for the beam position of x = -1.1 cm y = 1.1 cm since this simulation produced results closest to the signals seen in Method A with the beam at x = -1 ± 0.25 cm y = 1 ± 0.25 cm. To achieve an even closer



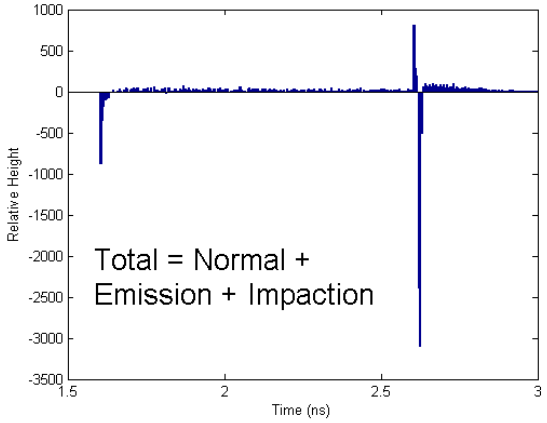
(a)



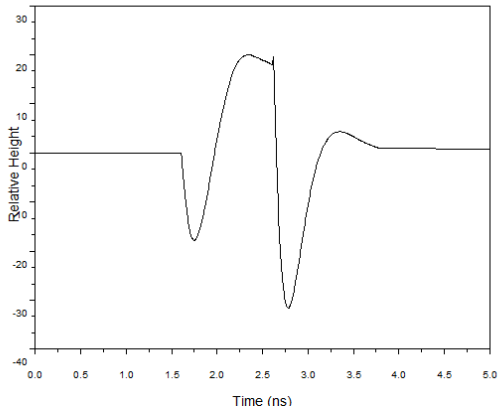
(b)



(c)



(d) The sum of the three simulated signals.



(e) The sum of the three simulated signals after being passed through a 2nd order 900 MHz Butterworth low pass filter.

Figure 8.8: The signal caused by charged particles passing the upstream end of the striplines, leaving the striplines and hitting the striplines based on simulations. This shows the simulated stripline response associated with stripline B with the beam at x = -1 cm, y = 1 cm.

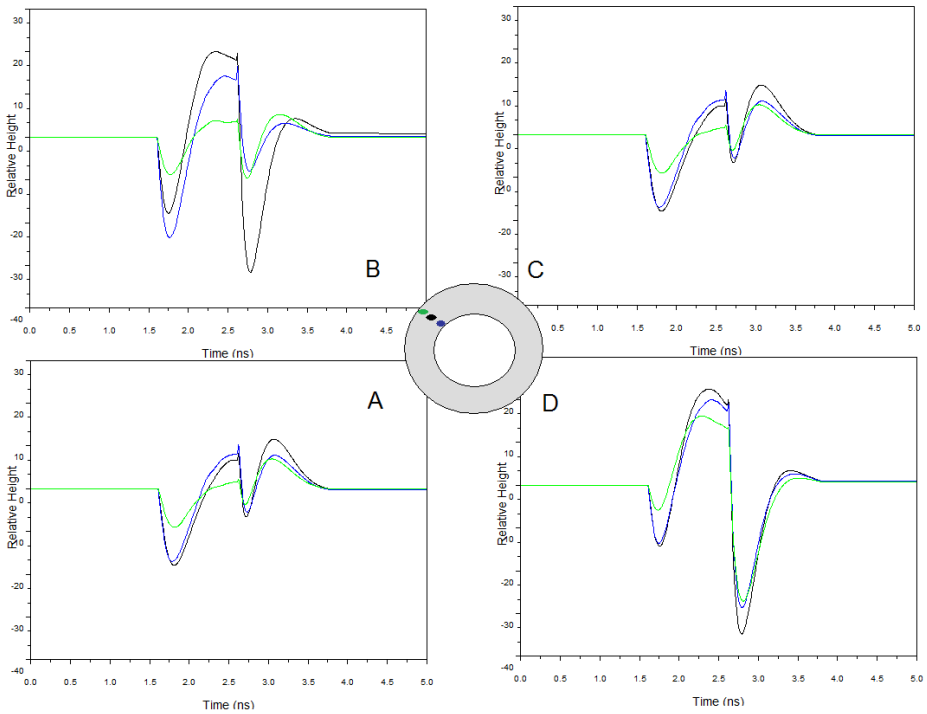


Figure 8.9: The simulated stripline signals predicted for Method A. Shown are the results of the simulations with the beam at position x = -1 cm y = 1 cm (blue), x = -1.1 cm y = 1.1 cm (black) and x = -1.25 cm y = 1.25 cm (green). The simulations are for a beam charge of 1×10^4 electrons.

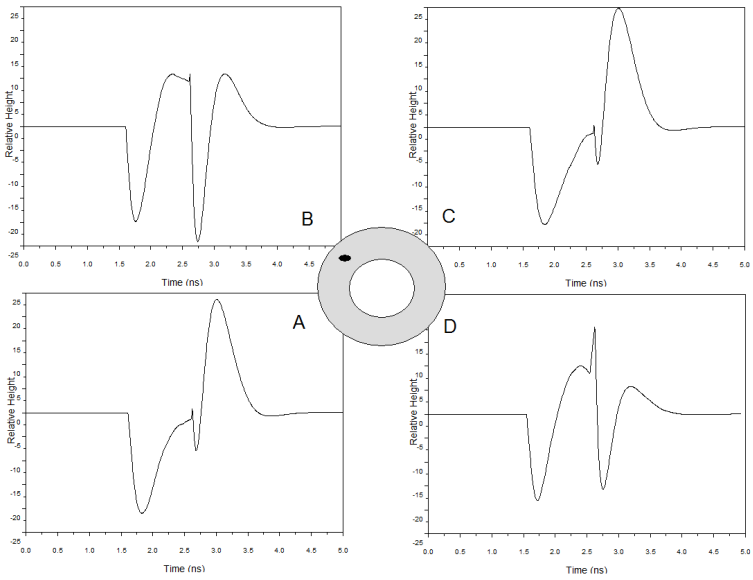
match would require each stripline to be treated differently, i.e. the prediction for stripline B would require a greater contribution from the emission component and the prediction for stripline D would require a lower contribution from the emission component.

This change in contribution could indicate the need for a revision to the weightings system or a GEANT3 simulation with lower energy cuts for all processes.

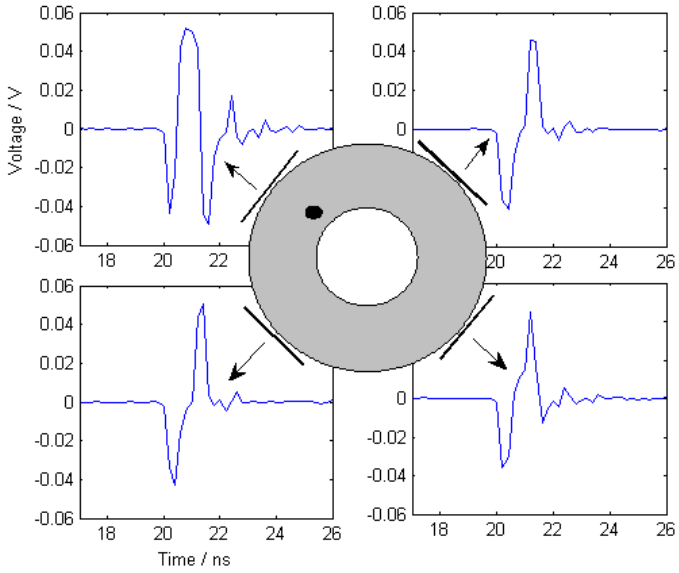
The partial success of the simulations as opposed to total success is not unexpected. The signal shapes are extremely sensitive to many factors including the digital filter used and the precision in time the additions and subtractions of signals were performed. The electrical signals in the striplines were assumed to travel at the speed of light and the particles were assumed to be relativistic. The end result is extremely sensitive to the amplitude and the weightings used were approximated as described. Most importantly though, the processes expected to dominate at the low energies of secondary backgrounds were not simulated at all below 10 keV (the photoelectric effect, ionisation, diffusion of low momentum electrons etc.).

Achieving qualitatively similar signals was reassuring in that the tools required for predicting signals have been developed sufficiently for estimates of magnitude.

The Method A signals were used to calibrate the simulation. The simulations had been done for a bunch charge of 10^4 electrons. These were scaled up to 9×10^6 electrons to match the beam charge used at ESA. The simulated signal for stripline B for position x = -1.1 cm y = 1.1 cm and bunch charge 9×10^6 electrons is shown in figure 8.11(a). The Method A

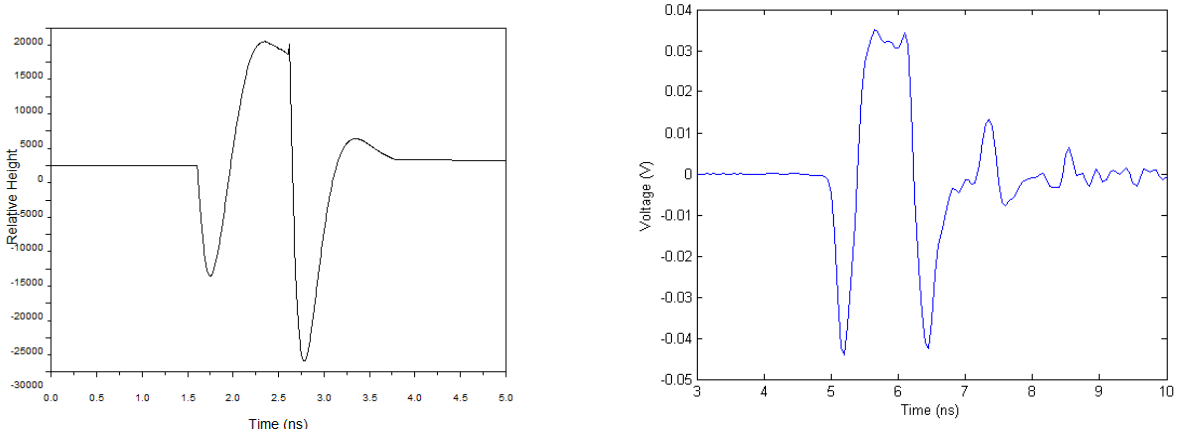


(a) x = -1.1 cm, y = 1.1 cm, 1.3 times hits. Beam charge is 1×10^4 electrons.



(b) Beam on mask (x = -1 cm, y = 1 cm). Beam charge is $(9 \pm 1) \times 10^6$ electrons.

Figure 8.10: The stripline responses for all four striplines before and after the beam hits the low-Z mask as it is moved along x = -y. (a) Simulation (b) Method A data.



(a) Prediction of a Method A stripline signal based on the method of simulating signals as described in the text.

(b) Stripline data from the Method A ESA experiment.

Figure 8.11: Stripline B signals with the beam at x = -1 cm, y = 1 cm.

ESA data for stripline B for position x = -1 ±0.25 cm y = 1 ±0.25 cm and bunch charge $9 \pm 1 \times 10^6$ electrons is shown in figure 8.11(b). Comparing the simulation to the data, there are $(45 \pm 5) \times 10^4$ counts per volt (where the error is from the uncertainty in charge).

8.3 Prediction for the ILC

GUINEA-PIG

For the simulation of Method A signals, an input beam was generated with parameters from beam measurements at ESA during the experiment. For similar simulated signals for the ILC case, it is necessary to start with an input from GUINEA-PIG.

The input chosen was from a GUINEA-PIG simulation of the beam-beam interaction for the scheme 14 accelerator parameter set. The scheme 14 backgrounds were considered for this purpose because it is by far a worse case scenario (see section 3.4.1). This scheme refers to a 1 TeV centre of mass energy and a high beam charge (see table 1.3).

The pairs output from the beam-beam interaction was selected. The photons were not of interest as they went straight down the beampipe without causing secondary backgrounds (see section 1.3.1). The number of pairs produced is at a maximum when the beams collide head-on (i.e. there is no offset) and so to create the worst case scenario for secondary backgrounds, the GUINEA-PIG pairs were used from a simulation of a head-on collision.

GEANT

The GUINEA-PIG pairs input was used with a GEANT3 model of the 14 mrad crossing angle IR [76] adapted to include a 10 cm long stripline BPM downstream of the BeamCal.

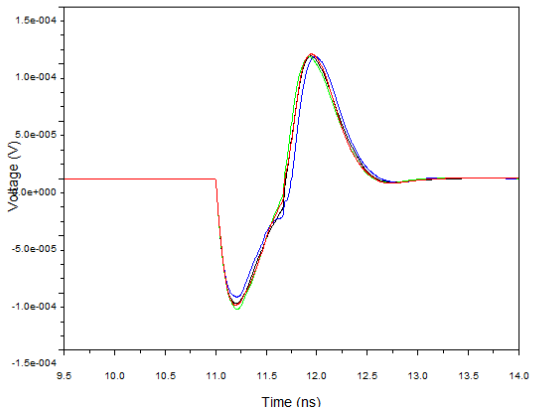


Figure 8.12: Prediction of the ILC IP BPM stripline signals from the secondary background particles caused by pairs from the beam-beam interaction (stripline 1: black, stripline 2: blue, stripline 3: green, stripline 4: red). The scale is in volts, set by the comparison between predicted stripline signals and the data from ESA.

The same modified GEANT3 code (see section 3.3.1) was used for this as has been used throughout this thesis. See section 3.4.4 for details on the GEANT3 simulation of the 14 mrad crossing angle layout.

Electrons and positrons were recorded as they entered the stripline volumes, left the stripline volumes or passed the upstream end of the stripline.

Signal creation

The output from the GEANT stage was manipulated within Matlab to sum the net signals from charges leaving, hitting and passing the striplines. The signals this created were passed though a 2nd order Butterworth digital filter in Scilab [114] with a discrete low pass cut-off frequency at 900 MHz.

The same simulation method was applied to the ILC GEANT data as was applied to Method A. Therefore the height of the resulting signals are directly comparable and the calibration to voltage found in section 8.2 was applied to the result as shown in figure 8.12.

To decrease CPU time to a manageable level, the ILC GEANT simulation was only a 10% simulation of all the input pairs. The final signals were scaled appropriately such that they show the predictions for all pairs from a single bunch crossing.

These signals of 0.11 ± 0.01 mV in amplitude correspond to a position of 13 ± 1 nm using the calibration of the striplines without normalisation by charge (figure 5.6).

With the FONT4 processing electronics, the difference of two striplines is taken. If the two striplines have identical signals from the pair backgrounds, then by taking the difference the issue of the background signal causing a position error is removed (assuming exact subtraction in the processor). Therefore, this estimate of 13 nm error is an upper limit as if none of the pair background signal was removed in the subtraction. Should the noise signals

on paired striplines be of opposite sign from each other, the subtraction could make the magnitude of the noise signal worse by a factor of two. However, the ILC simulated signals showed the signals on all four striplines to be of very similar shape and polarity.

8.4 Summary

Simulations were constructed to recreate the stripline signals based on the premise that all the voltage on the stripline came from three sources: charges passing the upstream end, charges leaving the stripline and charges hitting the stripline.

The tool was used to predict the stripline signals for Method A and then compared with the data as recorded at ESA. There was success in reproducing the shapes such as that shown in figure 8.11. Striplines A and C were slightly less successfully reproduced and required a 30% increase in the signal from impacting charges to produce the bipolar doublet as seen in Method A (figure 8.10).

Despite the uncertainty in the signal shape due to the many assumptions made in the simulations (filter, speeds of charges and signals, EM fields and charge interactions) the reasoning behind the simulated signals seemed firm as the shapes could be reproduced and understood. Using the experimental data for a Method A test with the beam hitting the low-Z mask at a radius of 1.4 cm, the simulated signals were calibrated from the arbitrary counts of the simulation to a signal voltage.

The stripline signals for the IP feedback BPM of the ILC were constructed using the 14 mrad crossing angle SiD IR, untuned anti-DID and accelerator parameter scheme 14. The signal due to the beam-beam pair backgrounds (and the secondary backgrounds they created by interacting with the material in the IR) on one stripline was 13 ± 1 nm, representing an upper limit on the position resolution degradation, assuming that none of the signal is removed on taking the difference of two striplines.

A full electromagnetic solution of charges passing, hitting and being emitted from the striplines would improve the prediction for stripline signals but there is no reason to believe it would greatly affect the stripline signal amplitudes. Therefore the method presented in this chapter is sufficient to draw the conclusion that the backgrounds at ILC in the worst case scenario for beam-beam pair backgrounds do not cause enough noise on the striplines to affect micron-level resolution.