

A STUDY OF EMITTANCE MEASUREMENT AT THE ILC

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The measurement of the International Linear Collider (ILC) emittance in the ILC beam delivery system (BDS) is simulated. Estimates of statistical and machine-related errors are discussed and the implications for related diagnostics R&D are inferred. A simulation of the extraction of the laser-wire Compton signal is also presented.

INTRODUCTION

In the ILC, the luminosity will depend on maintaining the emittance (especially in the vertical plane) delivered by the damping rings. It is proposed to use laser-wires (LWs) in the BDS to measure the beam sizes for both emittance diagnostics and coupling correction. The accuracy of the beam size measurement depends upon several factors *viz.*; the beam size at the LW and other errors in the measurement such as beam jitter, spurious dispersion functions, coupling of the beams, laser pointing stability *etc.*

This paper discusses the effects of these errors on the emittance measurement accuracy and considers the skew correction procedure. The skew correction method relies on scanning the strength of each skew quadrupole while measuring the beam profile with the LWs. The rate will be limited by the magnet response time; the actual correction time may take up to a few seconds. Thus, for the skew correction procedure, a multi-point laser scan with several measurements per train (as envisaged at present) looks reasonable.

The simulations show that the emittance measurement accuracy is dominated by machine and jitter errors. Since the length of the optics section must increase significantly (to increase the ratio of electron to laser spot sizes via an increased beta function) in order to improve the intrinsic measurement accuracy from a given LW system, such a step – or a major improvement in LW technology – may not be justified unless the machine-related contributions to the emittance measurement error can first be reduced.

SKEW CORRECTION AND EMITTANCE MEASUREMENT

A beam can be described by a 4×4 symmetric matrix. The projected two dimensional beam emittances, ϵ_x and ϵ_y

are defined as the square roots of the determinants of the 2D on-diagonal 2×2 submatrices. The non-zero off-diagonal terms give the information about the coupling between the two transverse planes. In the ILC BDS, the coupling correction section starts at the exit of the linac, which is then followed by four LWs. The ideal skew correction section is provided by an interlaced FODO lattice that contains four skew quadrupoles separated by appropriate betatron phase advances. Figure 1 shows the optics of the skew correction and emittance measurement section in the ILC baseline design. This scheme allows total correction of any arbitrary linearly coupled beam.

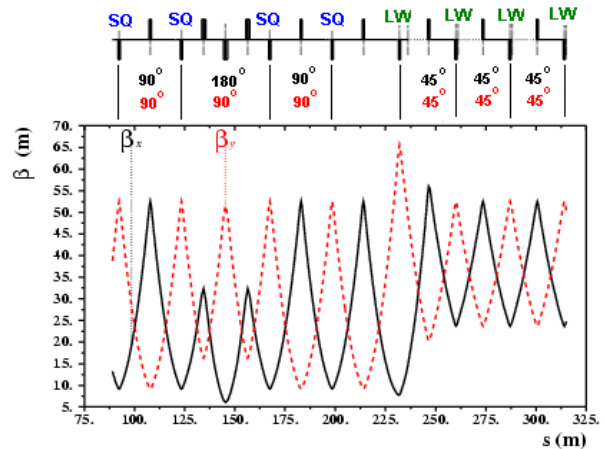


Figure 1: The optical layout of skew correction and emittance measurement section for the ILC.

The ideal emittance measurement section would comprise six LWs, with three scanning directions each, to measure ten coupled beam parameters: ϵ_{xy} , β_{xy} , α_{xy} , and 4 x - y correlation terms. It was shown [1] that a simpler method using only four scanners with two wires each is in fact preferable, since it occupies less space and requires less instrumentation. In this case, the coupling is inferred from the differences between the measured and calculated projected emittances, a procedure that is robust to measurement errors.

An optimised 2D emittance measurement section contains four LWs separated by 45° of betatron phase advance in both planes. Each LW will measure both the x and y profiles. There are in total three beam parameters to determine (ϵ , β and α) and four beam size measurements in each plane, which leaves one degree of freedom in the analysis. Figures 2 and 3 show simulations of the 2D analysis and the estimated projected emittance in the vertical plane. The input beam is coupled in both

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cases. Two measurement errors 5% and 20%, as described in the next section, have been assumed in these simulations. The error on the emittance measurement as a function of the measurement error is shown in Figure 4.

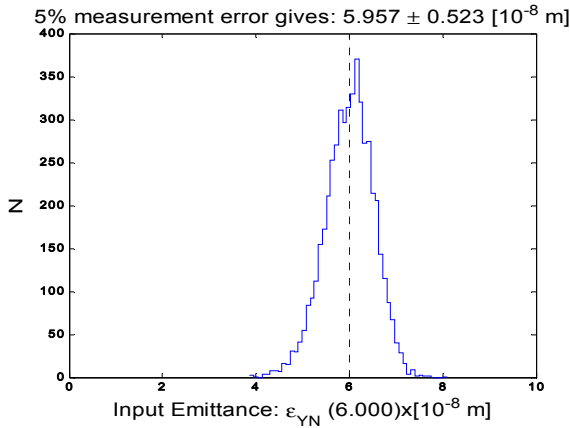


Figure 2: Reconstructed emittance measurements for 5% measurement error

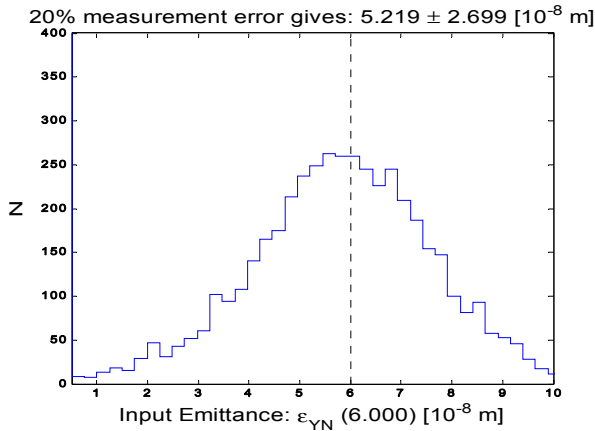


Figure 3: Reconstructed emittance measurements for 20% measurement error.

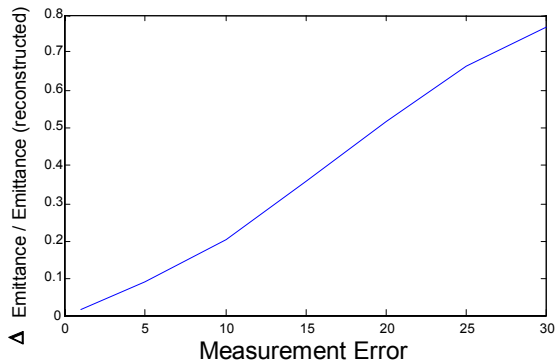


Figure 4: Measurement error vs. projected emittance

COUPLING CORRECTION IN THE PRESENCE OF ERRORS

The skew correction procedure works by iterating through the skew quadrupoles and scanning across small range B-field settings, until the measured emittance at the LWs is minimised, see Figure 5. The process is iterative but can diverge if the resolution of the measurement is too

poor. This problem can often be compensated for in part by making more measurements, or by increasing the number of steps in the scan; both are time consuming undertakings.

A number of separate measurements of the emittance are made each time. The error bars shown in Figure 5 are indicative of the uncertainty in the reconstruction of the emittance after the resolution smearing has been applied. The reconstructed emittances for each point are plotted together and a Gaussian fitted to the results, yielding the best determination of the correct answer.

Table 1 gives the contribution of measurement errors of beta function, spurious dispersion, beam jitter, laser spot size, laser pointing error *etc* to the total measurement error. Considering the optimistic value of the measurement error is 23.8%, it can be seen that in general the procedure works satisfactorily, as shown in Figure 6. Initially the beam is set up such that the ratio of the projected to intrinsic emittance is 3.8, a number arrived at from linac simulations [2]. After two scans of each skew quadrupole, the ratio is about 1.3.

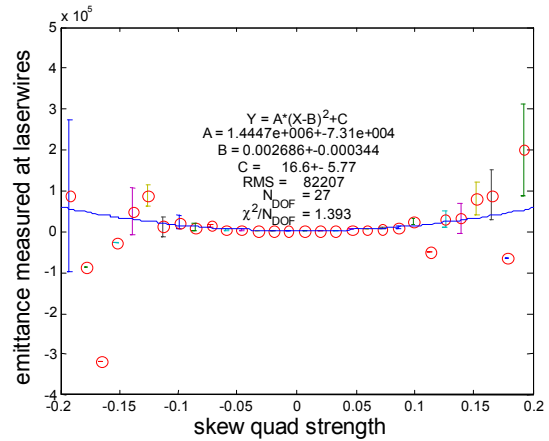


Figure 5: Scanning across the skew quadrupoles and then fitting a parabola yields a minimum

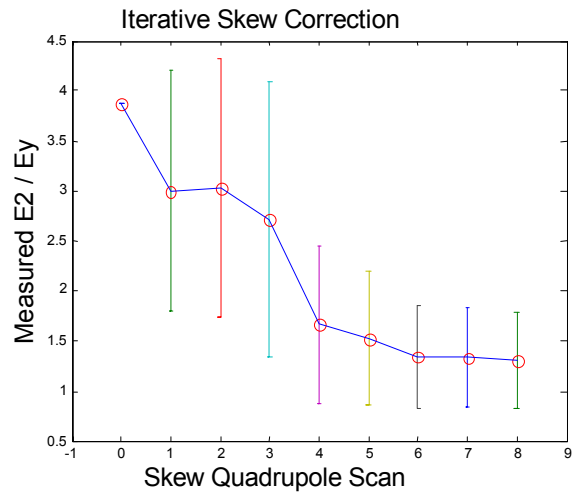


Figure 6: Skew correction procedure. The error bars arise from deviations in the reconstructed values of the emittances

Table 1: Representative measurement errors (and the precision of their values), as inputs to the emittance error estimates

| Relative Error on Parameter | Pessimistic Estimate | Optimistic Estimate |
|-----------------------------|----------------------------|---------------------------|
| β function at the LW | 3% | 1% |
| LW readout error | 2% | 1% |
| Laser spot waist | 10% | 10% |
| Laser Pointing Jitter | 15 μ m, 10% | 0.5 μ m, 10% |
| Beam Jitter | 1.0 σ_e , 10% | 0.5 σ_e , 10% |
| Residual Dispersion | 2.5mm, 10% | 0.5mm, 20% |
| Beam Energy Spread | 1.5x10 ⁻³ , 20% | 1.5x10 ⁻³ , 1% |
| Total Error | >100% | 23.8% |

LASER-WIRE

The key technical challenges for the ILC LWs are being addressed by an international R&D programme [3]. One of the many technical challenges is to achieve laser spot sizes that are small compared to the vertical size of the electron beam, which in the most challenging scenario will be of order 1 μ m in the later phases of the ILC. Some of the basic laser optics issues are discussed elsewhere [4], but to date many of the machine-related errors have not yet been fully addressed, which is the main point of this paper.

Signal Extraction

In addition to the fundamental LW and optics challenges, the Compton signal must be extracted from the beam-line. The signal consists of back-scattered photons and also electrons that, having lost energy by the scattering, leave the beam after being over-focussed by downstream magnets. For typical commercial pulsed lasers using green light, approximately 1000 Compton events per bunch can be expected at maximum overlap (the exact value will depend on the laser eventually employed and on the beam size at the LW location).

LW Compton events have been simulated using a dedicated full-simulation program (BDSIM [5]) in order to determine the energy losses along the beam-line and to identify possible locations of Compton detectors. For a 250 GeV beam and using the baseline ILC BDS optics, approximately 98% of the Compton scattered photon energy exits at the downstream energy diagnostics chicane, shown in Figure 7. This means that up to about 113 TeV of energy per bunch will reach the detector. A similar energy per bunch will arise from SR in the chicane; this will require either installing shielding before a calorimeter or by using instead a Cherenkov detector.

In principle the scattered electrons can also be detected downstream of the LW. The energy loss due to these electrons is shown in Figure 8, the maximum loss of 380 GeV occurring at a betatron collimator. The statistical

detection resolution should be much better from the photon signal than from the electrons, because all the photons can be cleanly measured at a single location.

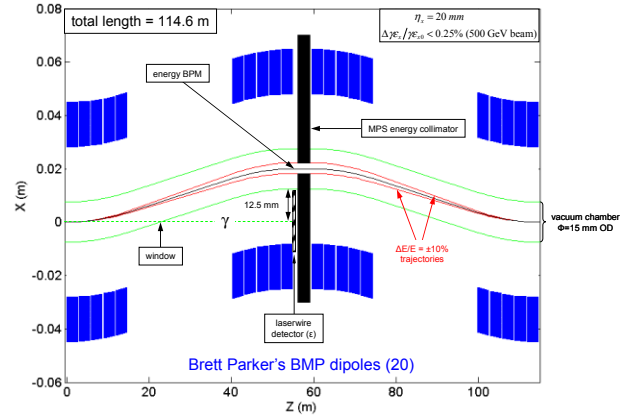


Figure 7: Energy diagnostics chicane, including possible location of LW photon detector.

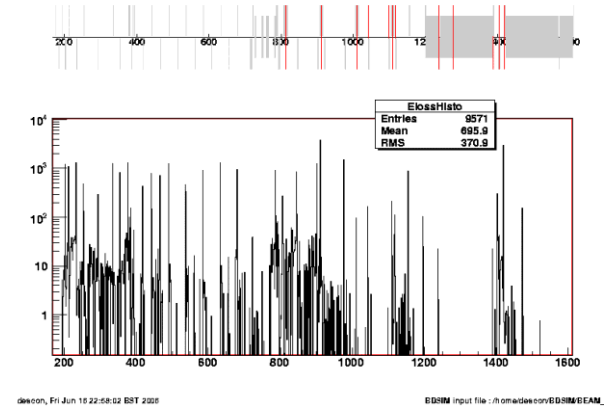


Figure 8: Energy loss (GeV per m) arising from LW Compton electrons vs. distance (in m) from the linac. The main losses occur at downstream collimators.

CONCLUSIONS

This study is still preliminary, however it is clear that the machine-related errors are significant and may dominate those coming from the LW itself; further work is necessary. The extraction of the LW signal is also under investigation, using full simulation tools. The energy-diagnostics chicane provides a good location for a detector for the Compton scattered photons, where a very large signal will emerge.

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