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# BENCHMARKING OF TRACKING CODES (BDSIM/DIMAD) USING THE ILC EXTRACTION LINES \*

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## Abstract

The study of beam transport is of central importance to the design and performance assessment of modern particle accelerators. In this work, we benchmark two contemporary codes - DIMAD and BDSIM, the latter being a relatively new tracking code built within the framework of GEANT4. We consider both the 20 mrad and 2 mrad extraction lines of the International Linear Collider (ILC) and we perform tracking studies of heavily disrupted post-collision electron beams. We find that the two codes mostly give an equivalent description of the beam transport.

20 mrad crossing angle [3], one must deal with technical difficulties such as large crab-crossing corrections or the construction of compact super-conducting quadrupoles for the incoming beam lines, as well as with the passage of the beams through the solenoid field with an angle. For the design of the ILC extraction lines, it is essential to have a reliable simulation program for particle tracking. In this study, we present a comparison between two codes, DIMAD [4] and BDSIM [5], using the present versions of the ILC post-collision lines for benchmarking purposes, in both large and small crossing angle cases.

## INTRODUCTION

In a high-energy  $e^+e^-$  linear collider such as ILC [1], the beams must be focused to extremely small spot sizes in order to achieve high charge densities and, in turn, to reach the desired luminosity. This leads to large angular divergence and energy spread for the disrupted beams, as well as to the emission of beamstrahlung photons. A careful design of the extraction lines must therefore be performed to transport these outgoing beams from the interaction point to their dumps with small losses. At ILC, two configurations are being studied for the crossing angle at the interaction point and, as a result, for the design of the post-collision lines. With a 2 mrad crossing angle, the main challenge is the extraction of the disrupted beam, which has to be achieved by sending the outgoing beam off-center in the first large super-conducting defocusing quadrupole of the final focus beam line, as well as in the two nearby sextupoles [2]. On the other hand, with a

The DIMAD program specifically aims at studying the behaviour of particles in beam lines, by computing their trajectories using the second order matrix formalism [6]. The present version of the code ensures that the matrix treatment is correct to all orders for energy deviations [4]. This is important, as the ILC disrupted beams downstream of the interaction point can have very large energy spreads. As for the BDSIM program [5], it uses the closed solutions in linear elements, whilst for higher-order elements, a GEANT4-like stepper integration method is used. The program is written in GEANT4 [7] and provides a toolkit to simulate interactions of particles with the surrounding matter once they have left the vacuum pipe. However, for the purpose of this study, we only aim at comparing the tracking procedures in DIMAD and BDSIM.

## DIMAD AND BDSIM TRACKING IN THE 20 MRAD EXTRACTION LINE

For this benchmarking study, we use the nominal beam parameters for ILC at 500 GeV, for which the beam transport from the interaction point to the dump is almost loss-free (at least with the low-statistics input files that we use). The particle distributions for the disrupted beams at

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the interaction point were obtained with GUINEA-PIG [8] and then transported, with DIMAD or BDSIM, along the ILC 20 mrad extraction line. The optics used for this study consists of a DFDF quadruplet, followed by two vertical chicanes for energy and polarization measurements and a long field-free region that allows the beam to grow naturally, with two round collimators to reduce the maximum beam size at the dump, see Figure 1.

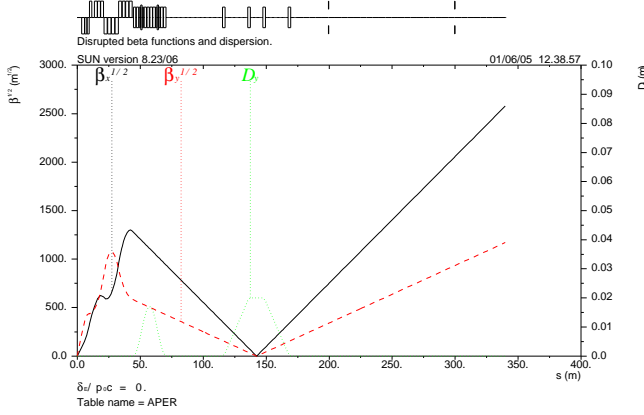


Figure 1: *Betatron functions and vertical dispersion along the ILC extraction line with a 20 mrad crossing angle.*

At several locations of interest, we project the transverse beam distributions obtained with each program into binned histograms and we compare them quantitatively. An illustration of this procedure is shown in Figures 2 and 3 for the transverse beam distributions obtained respectively at the secondary focus point Mexfoc, located at  $s = 142.4$  m (where  $\beta_x$  and  $\beta_y$  are very small, with a vertical dispersion of 2 cm) and at the dump. The open circles show the ratio between the number of events found by DIMAD or BDSIM in a given histogram bin and the error bars account for the limited number of events per bin (very few events are found in the tails, which explains the large error bars there). The transverse distributions of the disrupted beams were also computed with DIMAD and BDSIM at several other locations in the 20 mrad extraction line. Their comparison also showed excellent agreement.

## DIMAD AND BDSIM TRACKING IN THE 2 MRAD EXTRACTION LINE

When the colliding beams cross with a small horizontal angle of 2 mrad, the outgoing disrupted beam passes off-axis through the bore of the final quadrupole QD0, both final sextupoles, but not the second-to-final quadrupole QF1. However, the outgoing beam sees the pocket field of this latter magnet. Following this doublet, the beam is focused with a series of large bore quadrupoles. These are followed by a vertical energy clean-up chicane, diagnostic chicanes for the purpose of energy spectrometry and polarimetry,

and finally a long field-free region to allow the beam to grow to the dump, in the same way as in the 20 mrad scheme. Note that, in the 2 mrad scheme, separate dumps are used for the charged beam and for the beamstrahlung photons.

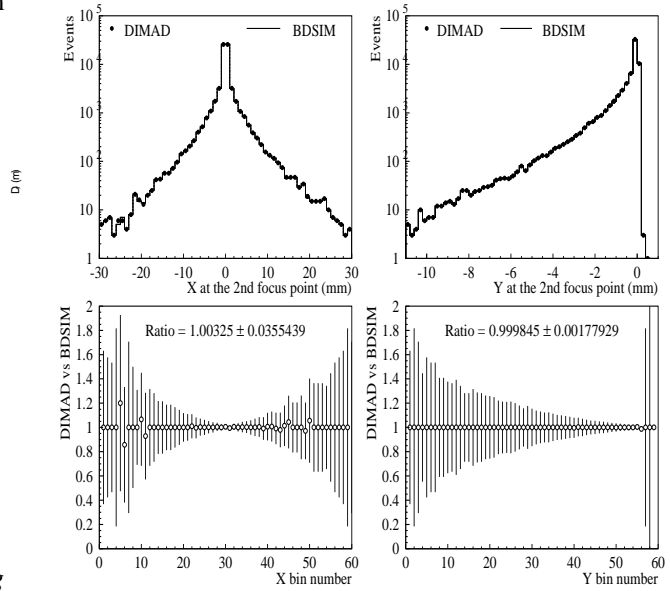


Figure 2: *Comparison of the transverse beam distributions obtained with DIMAD (full circles) and BDSIM (full line) at the secondary focus point Mexfoc. Both upper plots are distributed over 60 bins. The bottom plots show the ratio of the DIMAD and BDSIM distributions (see text for details).*

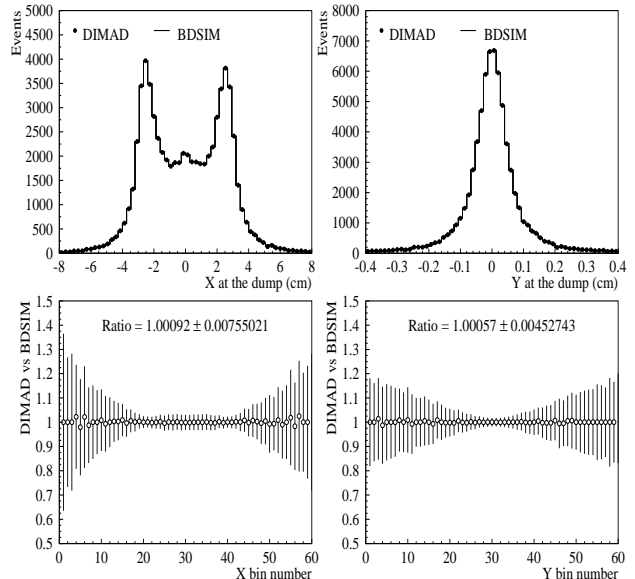


Figure 3: *Same as Figure 2, obtained at the end of the 20 mrad extraction line.*

The version of the linear optics used for this study is shown in Figure 4.

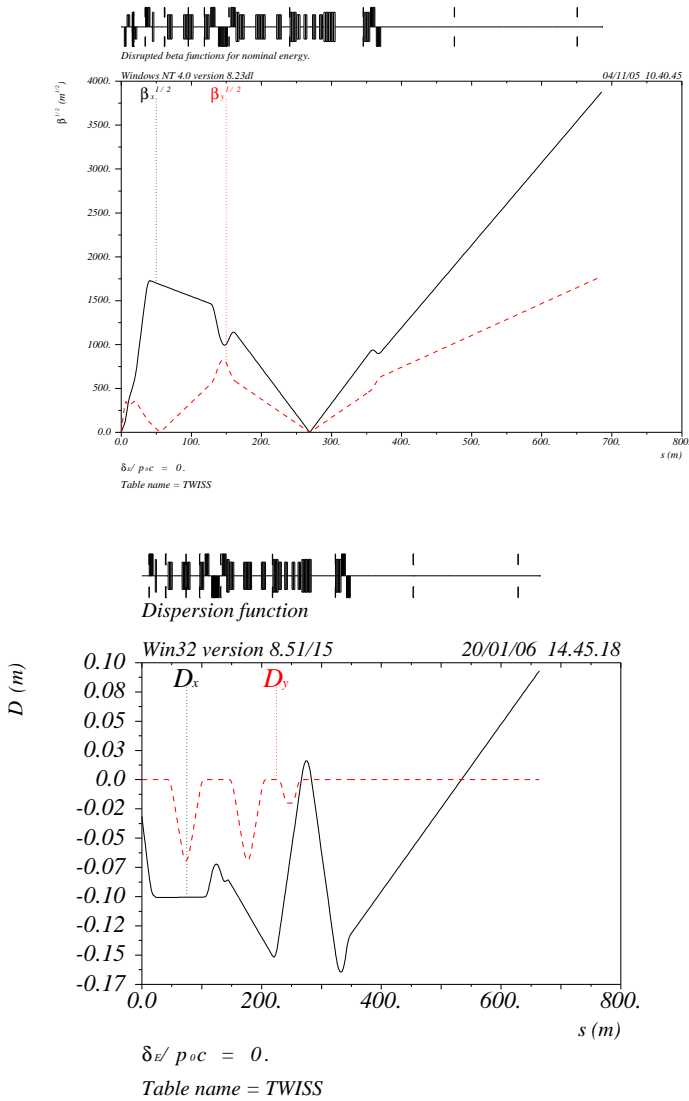


Figure 4: Betatron functions along the ILC 2 mrad post-collision line (top) and dispersion functions downstream of the final doublet of the incoming beam line (bottom).

Following the BDSIM/DIMAD comparison in 20 mrad scheme, we now simply describe the results obtained for the 2 mrad case, using exactly the same beam. Figures 5 to 7 show the results of the comparison at three locations along the 2 mrad extraction line. Figures 5 and 6 show the comparison at Mexfoc1 (located just after the energy clean-up chicane) and at Mexfoc2 (the secondary focus of the polarimetry chicane), respectively. As for Figure 7, it shows the comparison at the beam dump.

In these plots, we have projected the transverse beam distributions obtained from the particle tracking into bins, and we have then formed the ratio of the DIMAD prediction to the BDSIM prediction. As in the previous section, the open circles show the ratio, with the error bars accounting for the limited number of events in a given bin. All diagrams show a good agreement between DIMAD and BDSIM for the ILC 2 mrad extraction line, except at the secondary focus of the polarimetry chicane (Mexfoc2), where slight

discrepancies are visible. These may be due to different treatments of the high-order effects in the optical transport through non-linear elements.

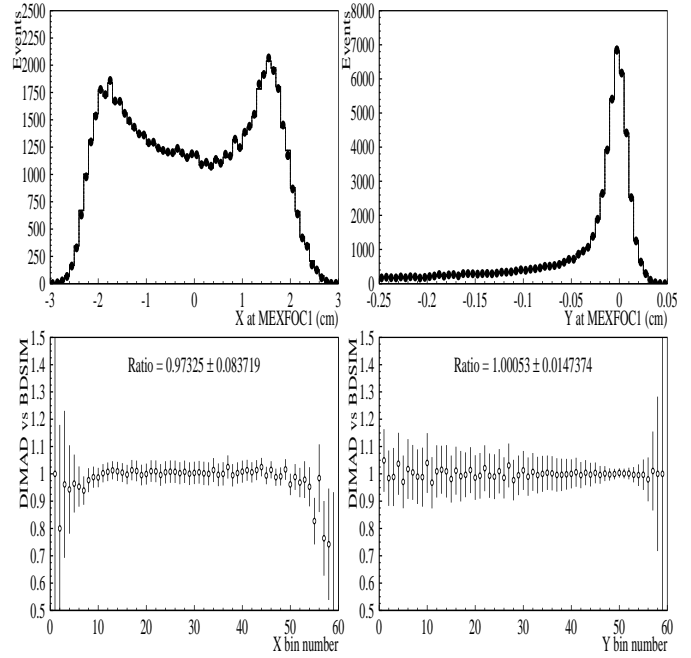


Figure 5: Comparison of the transverse beam distributions obtained with DIMAD (full circles) and BDSIM (full line) at Mexfoc1. Both upper plots are distributed over 60 bins. The bottom plots show the ratio of the DIMAD and BDSIM distributions.

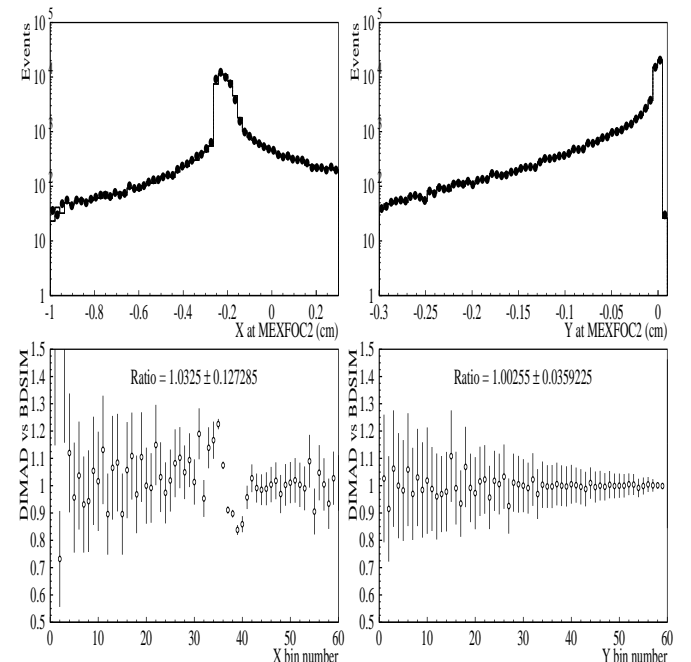


Figure 6: Same as Figure 5, obtained at Mexfoc2.

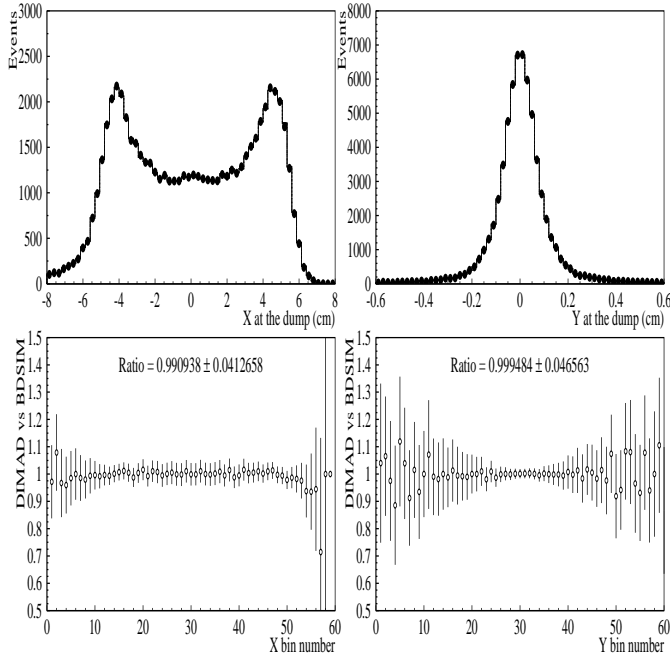


Figure 7: Same as Figure 5, obtained at the dump.

## CONCLUSION

In this paper, we performed a detailed benchmarking study of two particle tracking codes, DIMAD and BDSIM. For this purpose, we have considered the ILC extraction lines with a crossing angle of 2 mrad or 20 mrad and, in each of these two configurations, we have performed tracking studies of disrupted post-collision electron beams. Here, only the nominal luminosity case of the 500 GeV machine was studied. We find that both programs give an equivalent description of the beam transport in all parts of the post-collision lines, except at the secondary focus for the 2 mrad design, where a small difference is visible.

## REFERENCES

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