Results of the EUROTeV Beam-Beam Simulation (BBSIM) Task

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Abstract

This paper is the deliverable of the EUROTeV Beam-Beam Simulation (BBSIM) task and gives an overview of the published results.

1 Introduction

In a linear collider, because of very strong beam-beam effects during collisions, the luminosity performance and background rates from secondary particles emitted at the interaction point depend critically on the specified beam parameters. Accurate predictions, important for several aspects of the design of a linear collider, can usually not be obtained analytically and numerical simulations must be used to describe the combination of electromagnetic and quantum processes involved. Two programs are widely used in the community: GUINEA-PIG and CAIN. The main goals of the BBSIM task were to:

- benchmark physics processes in the GUINEA-PIG simulation against known and trusted physics generators, in order to estimate uncertainties relevant for the design of both the accelerator and detector, and ultimately for the physics program,
- implement spin transport into GUINEA-PIG, also comparing with an already existing treatment in CAIN, and quantifying depolarising effects for different beam parameter sets,
- provide a documented version of GUINEA-PIG containing all implemented improvements and suitable for future maintenance and developments.

The results obtained are described below, emphasising the most important achievements.

2 Study of incoherent pairs and comparison between generators

Secondary e^+e^- pairs are produced copiously from the interaction of both real and virtual photons radiated during collisions. The bulk of these pairs follow the spent beam and are most likely stopped after being over-focusing in the first magnets of the beam transport, on their way out of the interaction region. A small fraction of them have a large enough transverse momentum to reach the first layers of the micro vertex detector directly, where they constitute a quasi-irreducible background.

The work started by comparing the treatments implemented in the GUINEA-PIG and CAIN simulations for the Landau-Lifchitz process, one of the processes involved, with that in BDK, a standalone four-fermion generator which was extensively tested in the context of the LEP experiments at CERN. While in the former, the equivalent photon approximation is used for the (virtual) photon radiation and requires proper adjustment of some internal parameters, the latter relies on fully massive expressions to provide an exact first-order treatment. The study [1] enabled validating the GUINEA-PIG implementation of the Landau-Lifshitz process and to explain the origin of a long-standing factor-of-two discrepancy with the CAIN simulation observed in predictions for direct hits in the micro vertex from incoherent pairs (see Figure 1).

The variation of such backgrounds with different beam parameters, as the bunch width and length, and for detector configurations with different vertex detector radii and magnetic fields, was also checked. The High Luminosity beam parameter set suggested in the ILC optimisation process was for instance found incompatible with the lowest magnetic field options discussed for the detector, as illustrated in Figure 2.

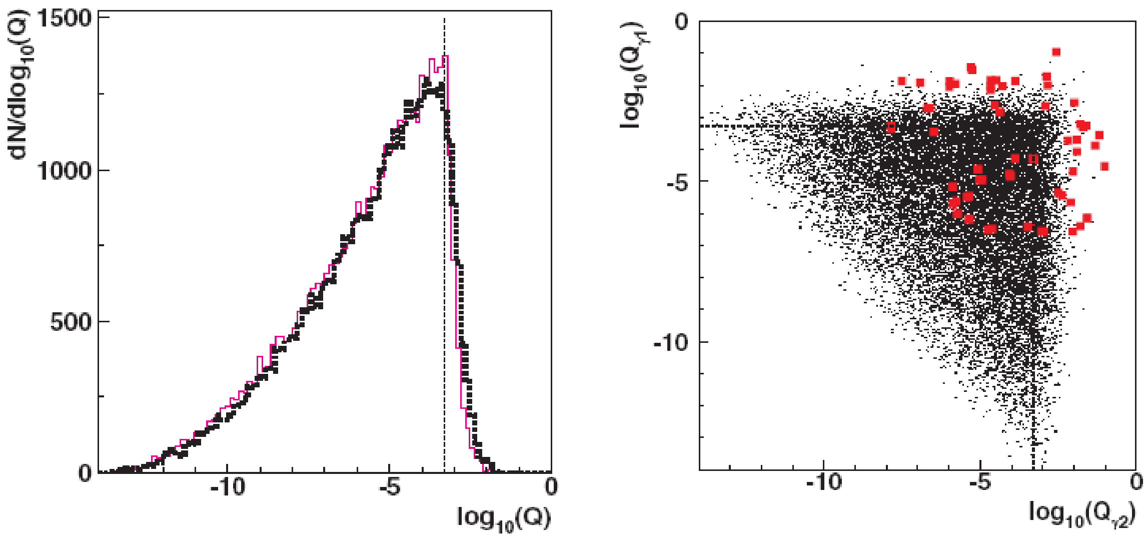

Figure 1: (left) Comparison of GUINEA-PIG (coloured continuous line) and BDK (dashed thick line) photon virtuality spectra for the Laudau-Lifshitz process. (right) Two-dimensional photon virtuality spectrum in BDK. Highlighted points are events with a final state particles reaching the vertex detector. The dashed lines in both plots indicate the value of the electron mass used as a cut in the implementation of the equivalent photon approximation in CAIN.

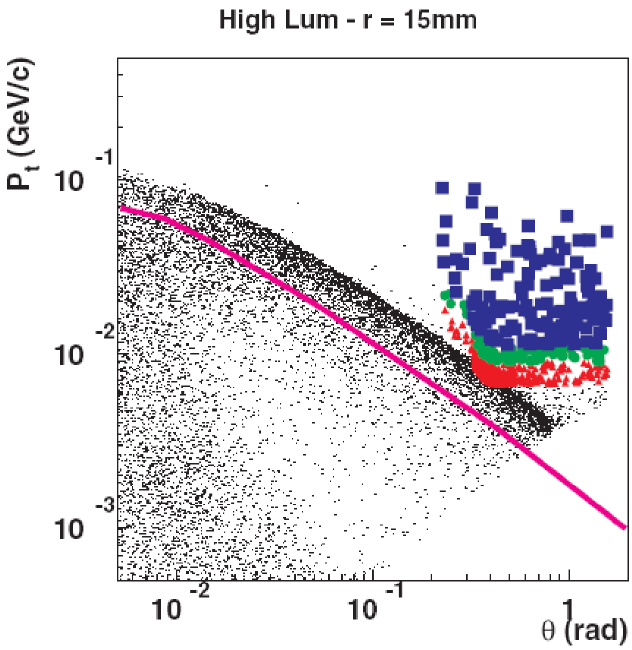

Figure 2: P_t versus θ plane for the background electrons and positrons in the vertex detector, for High Luminosity beam parameter set. The black points are all the incoherent e^+e^- generated with GUINEA-PIG. Blue square-shaped points correspond to the subset reaching the innermost layer of the vertex detector, assuming a radius r = 15mm, for a magnetic field in the detector of 5 Tesla. Adding the green circle-shaped (red triangle-shaped) ones corresponds to the case of a 4 (3) Tesla. For comparison purposes, the thick line indicates the position of the hard edge of generated incoherent particles for the Nominal beam parameter set.

3 Study of biases on the luminosity measurement from beam-beam effects

Much of the ILC physics program involves precision measurements for which the luminosity must be known accurately, typically at levels between 10^{-3} and 10^{-4}, depending on the particular physics study. As in other e^+e^- colliders, Bhabha scattering in the forward region can be used to measure luminosity. In addition to theoretical uncertainties in the calculation of the corresponding cross section, and experimental errors from the measurement procedure, the very strong beam-beam space charge effects present during collisions at ILC lead to large biases in the counting rate, which must be corrected to achieve the required precision. See Figure 3 (left) where the change in scattering angle of the final state Bhabha particles induced by the space charge is illustrated. These effects and their consequences on the luminosity measurement were studied in detail [2-3].

The C++ version of the GUINEA-PIG program, *guineapig*++, was modified to properly track Bhabha events from dedicated external generators in the field of the colliding bunch, taking into account the modified kinematics from beamstrahlung radiation and from initial beam-beam deflections, in order to quantify changes in counting rates in the defined experimental acceptance. It was found that for nominal ILC beam parameters, after applying specially adapted asymmetrical energy and polar angle selection cuts, the residual relative bias on the luminosity measurement was about 1.5%, two thirds of which were from beamstrahlung emissions and the rest from electromagnetic deflections.

Since both the beamstrahlung emissions and electromagnetic deflections vary with the collision energy, bunch length and horizontal size, so do the biases induced on the integrated luminosity. Reconstructing the luminosity spectrum from the scattered Bhabha angles is a good way to measure the amount of beamstrahlung and allows inferring and correcting the corresponding bias. The precision expected from such a procedure was studied. A reduction to below 10^{-3} of the beamstrahlung contribution should be possible. The residual bias after applying such a correction, from electromagnetic deflections, appears however to be harder to control experimentally, in particular when considering variations in bunch length. Keeping luminosity biases from deflections below 10^{-3} will be possible if the bunch length and horizontal size can be monitored with a 20% precision.

The evolution of these effects with the collision energy was also studied. For physics running at the Z boson resonance (the GigaZ option), the bias from electromagnetic deflections is typically several %, i.e. about hundred times the accuracy on the luminosity needed for precision measurements at that energy. An example of this is shown in Figure 3 (right).

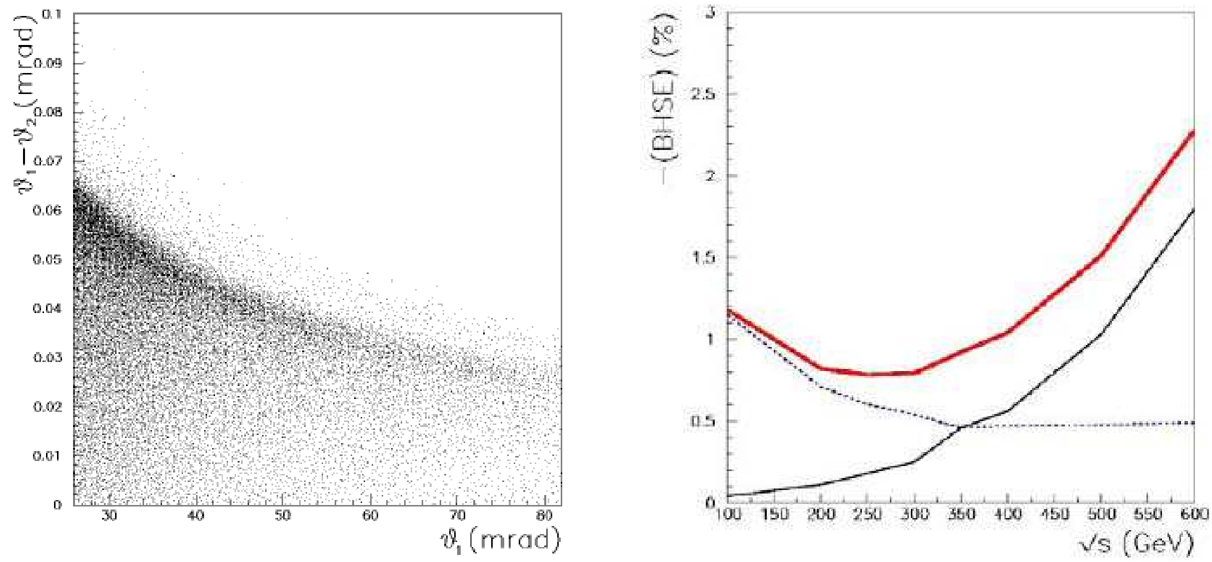

Figure 3: (left) Change in Bhabha scattering final state polar angle due to the deflection induced by the space charge of the opposite bunch as a function of the polar angle at production. (right) Reduction in Bhabha counting rate in the acceptance of the luminosity counter (see [2-3] for details) as function of energy, keeping all other beam parameters constant. The contributions due to beamstrahlung (thin line) and electromagnetic deflections (dashed line) are shown as well as the combined effect (top thick line).

4 Implementation of beam-beam depolarising effects

A precise knowledge of the polarisation state of the beams at the interaction point is required in future linear collider experiments. As for many other beam characteristics, the polarisation is modified by beam-beam effects. The spin motion in an electromagnetic field is influenced by two effects: the classical spin precession, described by the Thomas-Bargmann-Michel-Telegdi (T-BMT) equation and the spin-flip effect arising from beamstrahlung, called the Sokolov-Ternov (ST) effect.

Both of these effects have been implemented as a new development of *guineapig*++, the C++ version of GUINEA-PIG, and tested through comparisons with the CAIN simulations [4]. The comparisons were done both for the polarisation after full beam-beam collisions (see Figure 4) and for the luminosity-weighted polarisation of interacting particles. Results obtained for the various beam parameter sets considered at the ILC showed reasonable agreement between guineapig++ and CAIN predictions, at 90% and 95% levels for the luminosity-weighted and final depolarisations, respectively.

For the nominal ILC conditions at 500 GeV, the simulations predict a luminosity-weighted depolarisation of ~0.23%, dominated by the spin precession contribution. The effect from spin-flip is about five times smaller in this case. However, this ratio depends on the strength of beam-beam effects at the IP. For some beam parameter sets, it can reach up to ~40% of the total depolarisation.

Studies of the energy dependence were also performed, as well as of the sensitivity to beam parameter variations.

The beam-beam simulation *guineapig++* is now available to study depolarising effects at future linear colliders, for either fully or partially polarised input beams, as a complementary tool to CAIN.

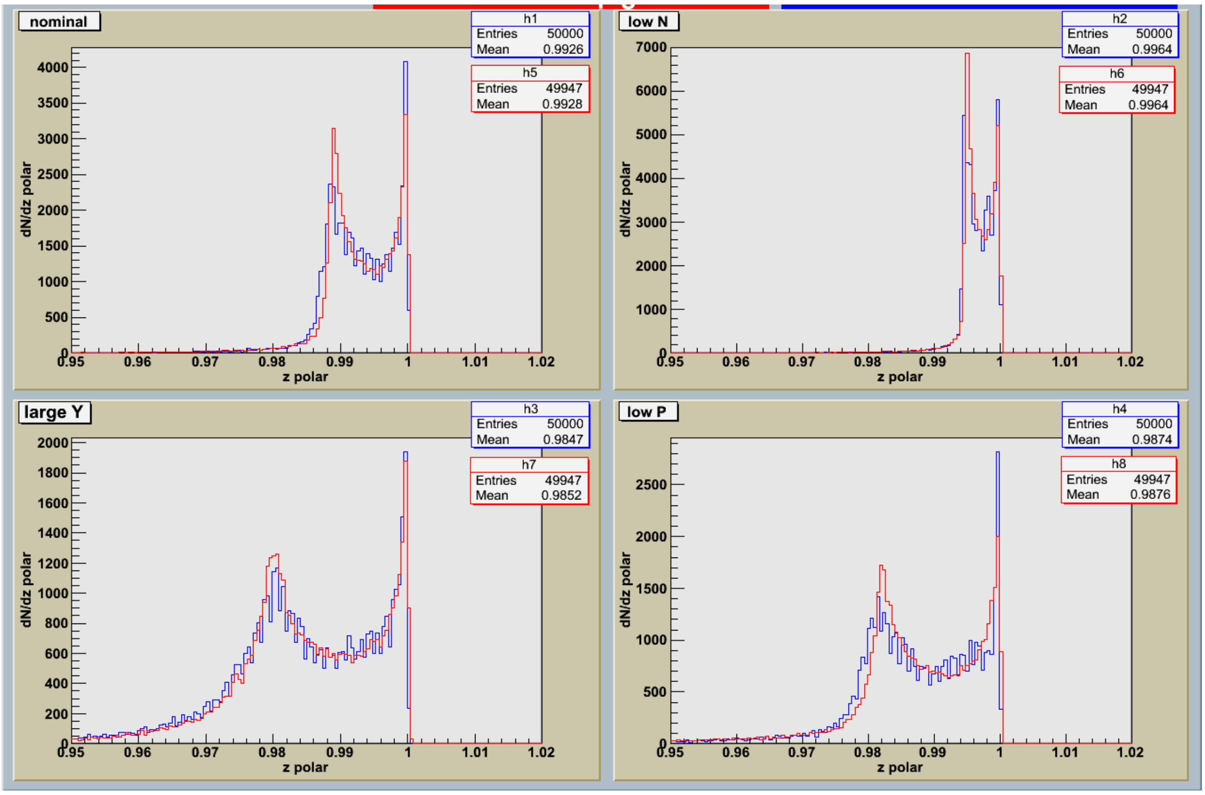

Figure 4: Comparison of projections of particle spin vectors after on the longitudinal axis after collisions, taking into account both precession and spin-flip effects, for Nominal (upper left), Now N (upper right), Large Y (lower left) and Low P (lower right) beam parameter sets. Distributions in red and blue show the predictions from guineapig++ and CAIN, respectively.

5 *guineapig++*, the GUINEA-PIG simulation in C++

An object-oriented C++ version of the beam-beam interaction program GUINEA-PIG has been developed: *guineapig++* [5]. The aim was to facilitate the maintenance and further development of this code already designed in C, making use of up-to-date standards and tools. The development has been achieved in two directions: restructuring of the existing code and implementation of new functionalities.

Concerning the restructuring [6], the algorithms have been kept, but have been inserted in a system of inter-related "classes" such as: BEAM, PARTICLEBEAM, PARTICLE, GRID etc. Conformity with the C-version of the code has been carefully checked. Some improvements have also been introduced. The random generation of beam particles was extended to 64-bit machines and the seed mechanism is now under the control of the user. An interface with the latest version (3.1) of the high-performance fast Fourier transform FFTW was implemented in order to accelerate the field calculations. An abstract input/output interface has been designed. This interface concerns all the input and output files which are, at the moment, in ASCII format. The data are now decoupled from the input/output formats (the latter defined as classes) so that formats other than ASCII can be easily plugged.

As a new functionality the beam-beam effects can be applied to Bhabha events that are provided in a dedicated input file. An automatic grid sizing has been designed in order to avoid errors due to unmatched grids. Indeed, when the size of the grid is less than the size of the beam, the field is not calculated for the more ex-centred particles and the computation can be fully meaningless. With the new function an approximate matching is insured. This function takes into account the size and divergence of the initial beam together with the disruption angle. The number of grid cells is also adjusted. This procedure is still being tested and improved based on feedback from users.

The most significant new functionality is the treatment of the polarisation which did not exist at all in the C-version of GUINEA-PIG. Two possibilities are proposed at the moment (for electrons/positrons only): the semi-classical effects as described by the T-BMT equation and quantum effects known as "spin-flip". An initial polarization can be specified by the user or the whole polarized beam can be entered as an input file.

The maintenance, development, documentation and distribution of the code are achieved using dedicated computer tools. The versioning is ensured by Subversion (SVN; http://subversion.tigris.org). The code configuration is managed by CMT (Configuration Management Tool; https://trac.lal.in2p3.fr/CMT/). Through the TRAC tool (http://trac.edgewall.org/), a dedicated wiki web site is available in order to provide the documentation, downloads and support.

6 List of publications

[1] C. Rimbault et al., Incoherent pair generation in a beam-beam interaction simulation, EuroTeV-Report-2005-016-1, Published in PRSTAB 9, 034402 (2006)
[2] C. Rimbault et al., Impact of beam-beam effects on precision luminosity measurements at the ILC, EuroTeV-Report-2007-017, Published in JINST 2, P09001 (2007)
[3] C. Rimbault et al., Bias on Absolute Luminosity Measurements at the ILC from Beam-Beam Space Charge Effects, EuroTeV-Report-2007-055
[4] C. Rimbault et al., Implementation of beam-beam depolarising effects in GP++, EUROTeV-Report-2008-066, in preparation
[5] G. Le Meur et al., Description of guineapig++, the C++ upgraded version of the GUINEA-PIG beam-beam simulation program, EuroTeV-Report-2008-067, in preparation
[6] C. Rimbault et al., GUINEA-PIG++: An Upgraded Version of the Linear Collider Beam-Beam Interaction Simulation Code GUINEA-PIG, EuroTeV-Report-2007-056

Acknowledgement

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