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Detector Benchmarking for the 2012 DBD

ILC PEB Benchmarks Task Force

In September 2010, Sakue Yamada set up a task force to precisely define the detector benchmarking exercise that will be reported on in the 2012 Detailed Baseline Design (DBD) document. The member of this task force are: Mikael Berggren (representing ILD), Tim Barklow (representing SiD), Akiya Miyamoto and Norman Graf (representing the Software common task group), Keisuke Fujii, Michael Peskin, and Georg Weiglein (representing the Physics common task group) and Francois Richard (representing the Research Directorate). Peskin is serving as the convenor. The members of the task force had a number of email discussions about the issues involved in this exercise, and a face-to-face meeting on October19 during the International Workshop on Linear Colliders. In this note, we give the conclusions from these discussions.

The conclusions will be presented under the following headings:

1. Processes to be studied and goals for the analyses of these processes.
2. Generation of physics events.
3. Treatment of machine-related backgrounds.
4. Cooperation between ILD and SiD in physics analysis.

We believe benchmarking exercise should be as realistic as possible, taking into account the full complexity of doing physics at the ILC. This is important not only to prepare for the ILC, but also for the general discussion in the high-energy physics community of TeV-scale lepton colliders. The physics reach of each technology depends on the precision that can actually be achieved in its environment, taking all associated backgrounds into account. The ILC detector studies should set the standard to which other studies can be compared.

On the other hand, the resources for the exercise, both in manpower and computing power, are limited. In this document, we have tried to balance these two principles, that is, to construct an exercise with a great deal of realism that is feasible to complete with existing resources by 2012. In addition, it is of great interest to develop as sharp a comparison as possible between the capabilities of the two validated detectors ILD and SiD. Several points in our design will help to achieve that.

Detector benchmarking is a different exercise from the presentation of the physics program and goals of the ILC. Both appropriate detector benchmarks and a clear statement of the ILC physics opportunities should appear in the DBD. However, they should be presented in different chapters, in contributions of different structure. We will give some ideas about the presentation of the ILC physics in the DBD at the end of this report.

1. Processes to be studied and goals for the analyses of these processes.

We suggest the following new processes for study for the 2012 DBD:

1. $e^+e^- \to \nu\bar{\nu}h^0$ at $E_{\rm CM} = 1$ TeV, where h^0 is a Standard Model Higgs boson of mass 120 GeV, in the final states $h^0 \to \mu^+\mu^-$, $b\bar{b}$, $c\bar{c}$, gg, WW^*. The goal is to measure the cross section times branching ratio for these reactions.

2. $e^+e^- \to W^+W^-$ at $E_{\rm CM} = 1$ TeV, considering both hadronic and leptonic (e,μ) decays of the W. The goal is to use the value of the forward W pair production cross section to measure in situ the effective left-handed polarization $(1 - P_{e^-})(1 + P_{e^+})/4$ for each of two polarization configurations.

3. $e^+e^- \to t\bar{t}h^0$ at $E_{\rm CM} = 1$ TeV, where h^0 is a Standard Model Higgs boson of mass 120 GeV, in the final state $h^0 \to b\bar{b}$. The reaction involves final states with 8 jets and final states with 6 jets, one lepton, and missing energy. The goal is to measure the Higgs boson Yukawa coupling to $t\bar{t}$.

We also ask that the detector groups each repeat one analysis from the 2009 LOI using the final detector configuration and the up-to-date simulation software. It is not necessary that the two groups study the same analysis.

The studies at 1 TeV should be carried out with an event sample of 1 ab^{-1}. They should assume an electron and positron polarization consistent with the estimate from the GDE for 1 TeV, replacing the values of 80% and 30% used for the LOIs. (We expect that these values will be close to 80% and 20%.) The sample should be equally divided between the configurations (-/+) and (+/-). The studies at 500 GeV should be redone with the same event sample as for the 2009 LOI, that is, 0.5 ab^{-1} of data at 500 GeV, equally divided between the polarization configurations (-80/+30) and (+80/-30). Since all three of the new reactions are dominated by the $e^-_L e^+_R$ channel, the equal division of luminosity is not the optimal one for these particular analyses. However, the large sample of background events generated in this exercise will be used for other purposes, including the difficult study of the measurement of the triple Higgs coupling at 1 TeV. The sample will be more generally useful if contains a large supply of background in the $e^-_R e^+_L$ channel.

The motivation for our choice of reactions is that the most important open questions for the detectors after the studies done for the 2009 LOIs is the scaling of the detector performance to the higher energy of 1 TeV. A minimal plan to understand this question already saturates the available resources.

The reaction $e^+e^- \to \nu\bar{\nu}h^0$ is intended to test the detector capabilities in the simplest context, with only 2 particles or jets in the final state of the complete event.

The study of W pair production will complement that study in two respects. First, W pair production leads to higher-energy jets. Whereas the lab-frame jet energy from the Higgs decays peaks at about 300 GeV, W pair production gives a population of jets all the way up to the maximum energy of 500 GeV. Second, W pair production has a large cross section in the forward direction and thus allows benchmarking of the forward elements of the detectors. These two features were called out by the IDAG, who asked that this process should be included among the new benchmarks. We are concerned that the physics of W pair production is very rich, with many interesting physics questions to be addressed, and few people to do the work. For the benchmarking exercise, we have narrowed these questions to just the simplest one, concentrating on a kinematic region in which the W pair cross section should be very close to the Standard Model prediction in any scenario, and in which the $e^+e^- \to W^+W^-$ reaction is a unique probe of the detector capabilities.

The third reaction $e^+e^- \to t\bar{t}h^0$ is meant to address another question. One of the strong points for e^+e^- annihilation as a probe of new physics is the ability to reconstruct a complete event and measure final-state angular distributions and correlations in detail. As events grow in complexity, this becomes more difficult. Jets overlap or merge and may swallow otherwise isolated electrons and muons. If there are new particles at the 500 GeV ILC, the physics at 1 TeV will contain events with those new particles and additional quarks, leptons, and bosons. More generally, the complexity of interesting events grows as the energy increases. The reaction $e^+e^- \to t\bar{t}h^0$ will test the capability of the detectors to analyze complex events with up to 8 jets in the final state. We believe that the study of this or an analogous reaction is essential to prove the capability of the ILC to address the physics program at 1 TeV. The ILC results will also set a standard to which studies at other, higher-energy, lepton colliders can be compared.

In addition to this general consideration, the measurement of the top quark Yukawa coupling is an essential part of the ILC physics program in any scenario. Indeed, the DBD should discuss the complete set of measurements that determine the Higgs boson profile, with the most difficult of those measurements simulated as realistically as possible. The measurement of $e^+e^- \to t\bar{t}h^0$ is too close to threshold, and, therefore, is marginal at 500 GeV. It requires higher energy to achieve the full potential of the ILC.

2. Generation of physics events.

Tim Barklow, Mikael Berggren, and Akiya Miyamoto have developed a semi-automated system for generating particle-level events using WHIZARD. This program allows generation of Higgs signal events, Standard Model e^+e^- background, and Standard Model two-photon background, including backgrounds from beamstrahlung photons. Barklow, Berggren, and Miyamoto have agree to take responsibility for generating a common sample of physics and background events to be used by both ILD and SiD in the exercise.

As a matter of principle, all relevant physics backgrounds should be included. For e^+e^- annihilation backgrounds, the process $e^+e^- \to t\bar{t}h^0$ requires simulating Standard Model background processes with up to 8 partons in the final state. It may be that Standard Model processes with higher numbers of final partners also leak into the sample to be analyzed. Barklow, Berggren, and Miyamoto will generate these additional, more complex, events as time and computing resources allow. In any event, ILD and SiD will use the same background event samples, as described below.

For the analyses to be redone at 500 GeV, only the backgrounds relevant to those analyses need to be re-simulated.

Barklow, Berggren, and Miyamoto will also simulate a large sample of $\gamma\gamma$ events, including low-energy events with large cross sections. In the simulations, an appropriate number of these low-energy $\gamma\gamma$ events will be overlaid. See the next section for more details.

Events will be generated in four samples, corresponding to initial states with 100% electron and positron polarization (-/+, +/-, -/-, and +/+). The final physics events will be written to a file in stdhep format. Each event record should contain the specification of the initial state, including the momenta of all initial electrons, positrons, and photons. Each event record should contain a global event ID for easy identification. All events should have weight 1.

For the final physics analyses, ILD and SiD should analyze *the same sample of events*. Events will differ between ILD and SiD not only because of differences in the detectors but also because different machine backgrounds will be overlaid and because of differences in decay lengths and interaction locations chosen randomly by GEANT. However, we feel that it will be instructive to compare the treatment of individual events by the two detectors, and we hope that this method will facilitate such comparisons.

3. Treatment of machine-related backgrounds.

An appropriate set of particles representing machine-related backgrounds should be overlaid on the physics events described in the previous section before detector simulation. These particles will be drawn from separate simulations of the electron and positron bunches and their halos interacting with the ILD and SiD detectors. The overlays will therefore be different for ILD and SiD.

It is obviously not feasible to do a complete bunch crossing simulation for each event, or to pass all particles generated by such a simulation through the detector simulations. However, the simulation should overlay the particles likely to be relevant, using a common philosophy for the treatment of these backgrounds in ILD and SiD.

We propose the following arrangement: Norman Graf and Mikael Berggren (or another representative of ILD) will prepare a pool of beam collision events using GuineaPig. There will then be three samples of simulated events, the physics signal and background events, the low-energy $\gamma\gamma$ events, and the beam collision events containing electrons, positrons, and γs. The events of each sample will be separately processesed through the SiD and ILD detector simulations. Then appropriate numbers (drawn from Poisson distributions) of $\gamma\gamma$ and beam collision events will be superposed on the physics events. The average numbers in these distributions will be chosen for each detector and for each subdetector element separately, to include bunch collisions within the time window of the subdetector and to include only particles energetic enough to be relevant to that subdetector.

We suggest that the machine backgrounds be included in this way in the study of the two new 1 TeV reactions. In the LOI study, the effect of machine background was evaluated for the Higgs recoil mass measurement and found to be negligible. However, machine backgrounds will increase at higher energies and could have more serious effects, particularly for the complex reaction $e^+e^- \to t\bar{t}h^0$. We are thus particularly interested in seeing a realistic simulation of machine effects included in that analysis.

4. Cooperation between ILD and SiD in physics analysis.

Because the two detector groups ILD and SiD have been validated and are not in competition in the DBD study, and because the number of physicists available to carry out the physics analyses is limited, it makes sense for ILD and SiD to carry out these analyses in cooperation. We suggest that ILD and SiD carry out the same high-level analyses – on, as we have suggested above, the same sample of events – and perform the same fits to extract the final results. While it is too much to ask that ILD and SiD group members understand the physics analysis framework of the other detector, we consider it useful that the members of the two analysis groups working on the same 1 TeV reaction remain in communication during the benchmarking exercise and work together to find the most effective analysis method for their reaction. At the end of the exercise, our community will be in a much better position to assess the relative strengths and weaknesses of the ILD and SiD designs.

5. Presentation of the ILC physics case in the DBD.

As we have stated at the beginning of this note, it is important to make a clear distinction between the goal of understanding and demonstrating the capabilities of the detectors to do the physics and the goal of presenting the ILC physics case. We recommend that the DBD chapters on the detectors concentrate on the first of these goals. The DBD should include a separate chapter that presents the ILC physics case, explaining the major points anew to the audience for the DBD. This chapter should not attempt to duplicate the lengthy physics document prepared for the RDR, but it should bring the story for the major points of the case up to date, including especially the results of the 2009 LOIs and the current study at 1 TeV. It should include the most up-to-date estimates of the ability of the ILC to measure the properties of the Standard Model Higgs boson and the top quark. In addition, if new physics signals are seen at the LHC in the 2011 run, this chapter should include a section discussing models for those signals that would be addressed by the ILC physics program.

Michael Peskin has offered to coordinate the writing of this document. We envision chapters on W boson physics, the Standard Model Higgs, extended Higgs sectors, the top quark, supersymmetric, extra-dimensional, and other exotic particles, and Z' bosons and other possible heavy resonances. The coordinators for these chapters, at least one experimenter and one theorist for each, would be drawn from the PEB Physics Panel and other interested members of the community.