Project name

Simulation Study of Source Issues for the Linear Collider

Classification (accelerator/detector:subsystem)

Accelerator

Institution(s) and personnel

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Project Overview

We propose to conduct a systematic simulation-based review of source issues for the linear collider. We will benchmark simulation codes against measured performance for both DC and RF electron guns, and study beam transport from gun to damping rings in the linear collider reference designs. We will examine the feasibility and utility of an integrated simulation of these systems, as is presently done in the context of x-ray free-electron lasers. We will explore the details of the emittance compensation process in so-called "flat-beam" photo-injector sources, as optimization of this source may lead to mitigation or elimination of electron damping ring requirements for unpolarized beams. We will also study the applicability of our codes to the problems of capture and acceleration in the creation of positron beams. We are interested to explore generalizations of existing simulations that would allow better understanding of device and performance tolerances, and easier connection with experimental results.

Detail

The baseline electron source for physics operation at both NLC and TESLA is the polarized DC photo-cathode gun successfully employed at SLC. Detailed simulation of the NLC design was last performed for the NLC ZDR in 1996. The ZDR and the Tesla TDR both use this model as input in the further design of the bunching systems and injection linacs.

We believe it makes sense at this time to re-address modeling of the NLC injection systems. We have studied NLC ZDR in some detail, and discussed the conclusions there with requisite experts. There is consensus that while the injector outlined in the ZDR is a proof-of-principle, there are many issues still outstanding. For example, there is no modeling of halos and tails. The longitudinal tails typical of DC guns will have poor capture in the bunchers and show up as large losses at the damping ring input. In the high power system of the LC this will lead to a high radiation environment and perhaps charge jitter bunch-to-bunch in the damping rings. Some kind of collimation system can be considered after these effects are modeled. Another example: the ZDR model uses single bunch only: the effects of beam loading and transverse long-range wake-fields in the bunching system have not been considered. Finally, note that since the time of the ZDR the NLC bunch specification has changed, reducing the charge per bunch by a factor of 2. There is much still to get right in the design.

The TESLA TDR describes an injection system somewhat similar to that of the NLC, but we have not critiqued the TESLA study in detail. It may be interesting to compare the results for the similar but non-identical injection systems of NLC and TESLA in a single integrated simulation.

Complementing the DC electron source, the high brightness, low emittance electron beams from an rf-photoinjector may prove invaluable in the commissioning and optimization of the linear collider complex. The development of rf-photoinjectors has been a major focus of the short-wavelength FEL community in recent years. The UCLA group represented on this proposal is an active member of this community, and has developed many computational, theoretical, and experimental tools for understanding and optimizing high brightness electron beams. As an outgrowth of such studies, it has recently been proposed, and shown experimentally at FNPL, that one may emittance compensate a "magnetized" beam (one born inside of a solenoidal field), and then split the transverse emittances in such a system using a skew quadrupole triplet. This opens the door to production of LC-like beams, with large horizontal and small vertical emittances. The first step to understanding the ultimate limitations of this scheme is to make a serious computational study of emittance compensation of a beam with non-zero canonical angular momentum, and the properties of the four-dimensional transverse phase space before and after the emittance-splitting skew quads. This study challenges our codes with a cutting edge problem and furthers progress on source development, while also fitting naturally into our benchmarking program at FNPL.

Positron production is a challenging problem for the Linear Collider. The electron based method described in the NLC ZDR is widely acknowledged to pose severe problems with target survival. The TESLA gamma-ray conversion method is untested. However, the promise of the gamma-ray method is recognized by a group preparing a proposal to prototype the technique in the FFTB at SLAC. Beyond survival of the target, a detailed model for collimation, acceleration and focusing is important to understanding the required aperture and performance of the positron damping rings. The capture and acceleration problem can be addressed with the same simulation tools developed for the electron injector. We would be interested to study the design of the capture system, and perhaps benchmark that simulation against pertinent results of the FFTB prototype.

The group at the University of Michigan has begun to build expertise with the tracking codes ASTRA and PARMELA (UCLA and LANL), benchmarking our understanding against the performance of the FNPL photo-injector at Fermilab. These codes include detailed modeling of space-charge effects, and are particularly applicable in the low energy regime of electron injectors and positron capture and acceleration. However, we look forward to augmenting our repertoire with transport codes and other pertinent simulations as the need arises.

One weakness of the codes we have studied is their dependence on static input parameters, leading to difficulty in deriving in understanding tolerances and regimes of applicability. We propose to address this weakness with the "pseudo-experiment" technique developed for detector and physics simulations. In this technique, the code is run thousands of times, sampling the input parameters according to their expected distributions, producing not only *distributions* in the output, but the ability to assess the relative *probability* of any given output. Adapting this to existing codes will involve not only changes to the code control superstructure, but also a serious look at execution times. To do this, we propose to employ a graduate-level physicist/programmer to perform the extensive code overhaul and systematic sets of physical cross-checks that will be required. In addition to developing the requisite code, this individual will perform comparisons with current data from FNPL and/or the SLC gun, and maintain communication with the authors of the original simulations. We hope that the end product will be a new tool of use to a broad community. A person to carry out this task has already been identified.

Accelerator related simulation is a new undertaking for the Michigan group, and they expect to work in close collaboration with the established simulation and machine communities, including scientists at Fermilab, SLAC and UCLA in developing this project. The UCLA group is very strong on computational accelerator physics, but has not yet deployed significant efforts on LC-related projects, having concentrated on advanced accelerator and FEL-related problems to this point. The combination of a focused, leading effort from Michigan, with a support and expertise from UCLA and the labs, should make for a powerful collaboration. The long lingering injector issues outlined above point to the need for more manpower on machine modeling, and, as mentioned above, we expect to bring some fresh perspective to the problems at hand. Simulation is also well suited to the involvement of students at the universities, and attracting them could serve to begin rebuilding the cadre of accelerator physicists in the U.S.

Description of first year project activities

The program outlined above is ambitious, and obviously the work of several years or a larger team. It represents our first attempt to see the broad matches of our existing abilities and interests with the directed needs of the LC R&D program. In the first year of activities in this proposal, we will concentrate on developing baseline expertise with PARMELA and ASTRA, develop a prototype for the pseudo-experiment approach, and understand whether our best application is in the electron injector, the positron system, or both. We will

- continue our benchmarking against the RF gun at FNPL, where we are part of the existing effort
- understand the current designs for DC polarized guns, and benchmark our simulations against measured performance of those designs, or data from the SLC
- investigate all aspects of emittance compensation and emittance splitting in the the flat-beam production scheme, benchmark against FNPL data, and identify physical mechanisms limiting the performance of this advanced source.
- lay out the program for modeling the NLC injector, and proceed through the bunchers if possible
- investigate the applicability and utility of employing these simulations to study positron production and manipulation
- investigate schemes for the pseudo-experimental technique, and devise an incisive test case for such a scheme

With the exception of the last item, these are ideal projects for student participation, and we are requesting support for a graduate student and an undergraduate physics major at Michigan, and one-half support for a graduate student at UCLA. A second UM undergrad would use this work as the basis for a senior thesis, and comes for free. The UM Physicist Programmer would be employed in the implementation of the code improvements, and the (one term) salary is consistent with existing practice.

Budget

Institution	Item	Cost
Michigan	Graduate student stipend, tuition, fringe	37,000
Michigan	Hourly salary for undergraduate	5,000
Michigan	Physicist Programmer	15,000
Michigan	Indirect costs (56%) (no IC on tuition)	25,700
Michigan	Michigan total	82,700
UCLA	Graduate student stipend, fringe	16,000
UCLA	Indirect costs	8,700
UCLA	UCLA total	24,700