PROJECT DESCRIPTION

Longitudinal phase space monitors for the ILC injectors and bunch compressors

Personnel and Institution(s) requesting funding
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Project Overview

This proposal aims to develop a longitudinal phase space diagnostic system capable of monitoring the bunching scheme of the ILC injectors and bunch compressors. Both numerical simulations and hardware development along with experimental tests with beam will be performed. Our goal is to develop a set of tools to help an operator setting the key components of ILC for longitudinal phase space manipulation (bunching system in the injector, energy compressor(s) prior to injection in damping ring and bunch compressors downstream of the damping rings). The proposed bunching diagnostics package would consist of two components:

(1) Development of techniques for measuring the longitudinal transfer functions in the ILC injectors at key locations: the method consists of impressing a perturbation (e.g. photocathode drive-laser phase shift, phase or amplitude variation of a radio frequency cavity) around its nominal operating point and measuring the associated effect on the time-of-arrival of the electron bunch using phase detectors located at key locations in the accelerator. This technique was pioneered in the CEBAF recirculating accelerator at Jefferson Lab [1] and later implemented in an energy recovering free-electron laser [2]. The method is applicable for both the electron and positron injectors. In the case of the positron injector, the impact on the diagnostics of the intricate coupling between longitudinal and transverse dynamics (in the adiabatic matching section) remains to be studied.

(2) Improvement of the analysis of coherent radiation produced by the electron and positron bunches downstream of the post-damping-ring bunch compressor for monitoring the bunch

length and possible drift in the bunch compressor sub-systems. Interferometry and spectrometry of coherent radiation emitted by the bunch have proved to be powerful diagnostics; however, in the ILC regime, the interesting wavelength range of the coherent radiation emitted by the bunch after the bunch compressor ($\sigma_z \in [150 - 500]$ μm depending on the mode of operation [3]) is sub-mm, a range where diffraction effects significantly alter the response function of the bunch length diagnostics based on coherent radiation. We propose to develop new measurement scheme to monitor the bunch length downstream, based on our present work with a coherent transition radiation interferometer and on the possible use of a single-shot bunch monitor to directly measure specific frequencies associated with the bunch form factor (the Fourier transform of the bunch longitudinal charge distribution). This latter device would consist of a grating that diffracts the coherent radiation emitted by the bunch onto an array of detectors.

Broader Impact

Most of the development work will be performed on the Northern Illinois University (NIU) campus and will contribute to the development of the recently started experimental accelerator physics program (including an on-campus beam diagnostics laboratory). This proposal will provide funding for one graduate student, and help strengthen our beam physics academic program, and eventually attract students to pursue their PhD in beam physics. NIU has a strong outreach program, and the beam diagnostics laboratory located on campus will be accessible for tours to students and broader communities. Dekalb is situated ~30 miles from Fermilab and ~60 miles from Argonne. The present proposal is an opportunity for enhancing the collaboration between the beam physics group of NIU and these two national laboratories. Collaborators at both laboratories are interested in the diagnostics described in this proposal, and will certainly use them once they are perfected. The results of our work will be disseminated at various conferences (e.g. particle accelerator conferences, beam instrumentation workshops) and in topical journals. Finally the two diagnostics described have a wider range of uses than ILC, e.g., in other machines with scientific applications such as light-source drivers.

Results of Prior Research

Coherent radiation: A coherent radiation interferometer was developed in collaboration with Prof. Uwe Happek of University of Georgia. The interferometer has been installed on the Fermilab/NICADD photoinjector beamline, data analysis algorithms were developed and the instrument was used to measure the electron bunch length downstream of a magnetic bunch compressor chicane. Our main effort has concentrated on trying to understand the limitation of this coherent radiation interferometer, especially trying to perform a direct measurement of the frequency response of the apparatus: diffraction effects (due to the long wavelength similar to ILC) alter the response function of the instrument and render the method hard to utilize for precise bunch length measurement [4]. In order to investigate these limitations, we have use the capability of generating double-peaked bunches [5] to test our algorithm to reconstruct longitudinal charge-density profile. Figure 1 presents an example of recorded interferogram for such a "two-macroparticle" bunch along with the reconstructed longitudinal distribution.

Longitudinal transfer functions (LTF): Preliminary simulations of the ILC electron injector baseline[1] were performed to investigate the possible use of LTF as a way to set-up the

[1]we used the injector lattice presented in Ref. [6].

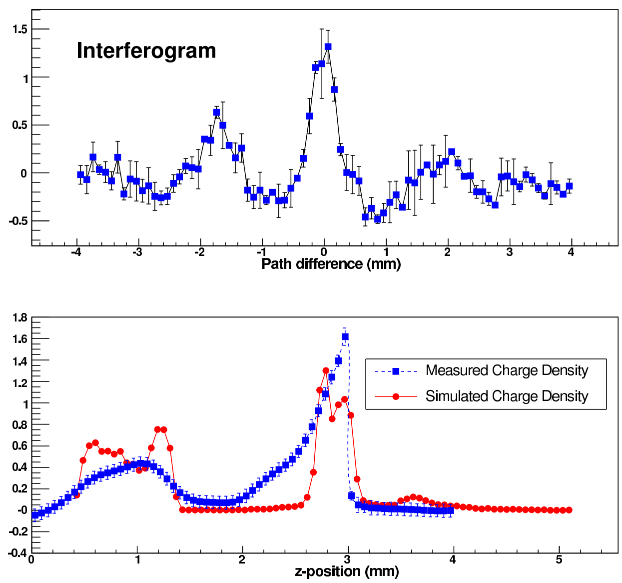

Figure 1: An example of measured autocorrelation for a two-macroparticle bunch [two 0.5 nC bunches placed in the same rf-bucket and initially separated by 15 ps (at emission)]. The reconstructed longitudinal distribution shows the double bunch.

bunching system in the electron injector: an example of simulated compression efficiency patterns is presented in Fig. 2 for the nominal setting of the bunching setting, and for two cases of mis-tuning of the injector sub-harmonic buncher. It is seen that different parameters affect the LTF in different ways. Such feature demonstrate the usefulness of the LTF measurement for troubleshooting the longitudinal phase space manipulation in the ILC injectors.

Facilities, Equipment and Other Resources

The Beam Physics and Astrophysics Group (BPAG) in NIU's Department of Physics is actively pursuing both the theory and generation of high-brightness charged-particle beams (http://www.nicadd.niu.edu/research/beams). To date, BPAG has its own state-of-the-art 112 CPU computer cluster that, when running in parallel, provides 243 GHz of operational capability, and the Group is now building and equipping a new Beam Diagnostics Laboratory (BDL). This is a large lab ($> 2,000$ sq. ft.) that will house a thermionic electron gun and a new femtosecond-class titanium-sapphire laser, both of which will be used to develop innovative diagnostics for measuring detailed properties of charged-particle beams. The laboratory is currently equipped with generic equipment (including network and spectrum analyzers). The NIU Physics Department owns and staffs a fully equipped machine shop that is available to BPAG without charge. In addition our group has strong collaborations with the two neighboring national laboratories: Argonne National Laboratory and Fermi National Accelerator Facility. We plan to use beam from the Argonne Wakefield Accelerator, the Advanced Photon Source (APS) Injector test facility at Argonne, and possibly from the ILCTA facility at FNAL (if available within the time frame of the present proposal).

FY2006 Project Activities and Deliverables

Activities: We propose to develop a first version of the electronic for the phase detector needed

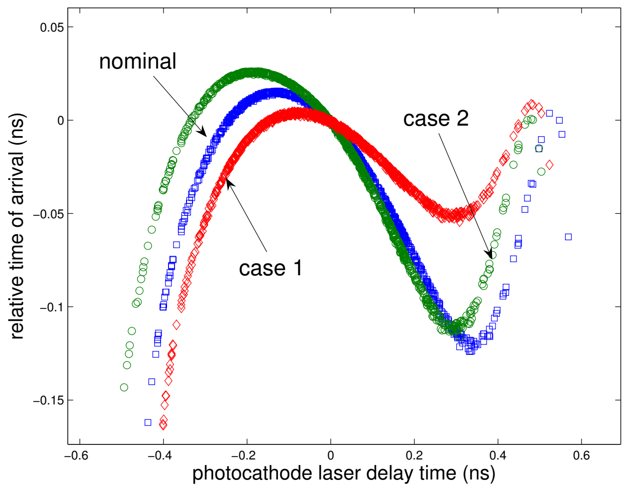

Figure 2: An example of the sensitivity of longitudinal transfer function (LTF) on the bunching system of the electron injector for the nominal setting, the case when the first subharmonic buncher amplitude is detuned by 20% (case 1) and the case when the second sub-harmonic bunch phase is changed by -20° (case 2). In the present simulations, the photocathode drive-laser phase was varied and the corresponding time-of-flight from the photocathode to the detector located downstream of the bunching section was measured.

for the LTF measurement and test it with e- beam. We plan to perform detailed numerical simulations regarding the use of the LTF method to set up the longitudinal beam dynamics in the ILC electron injector, along with the potential applications to the ILC positron injector. In parallel to this work, we will continue our experimental work pertaining to the limitations of the coherent radiation interferometer apparatus and start developing a single shot version of the coherent radiation monitor.

Deliverables: technical paper on applications of the LTF method to ILC injectors, numerical simulations of ILC injectors, technical paper on the limitations associated to the coherent radiation interferometer and first version of the electronics associated with the phase measurement.

FY2007 Project Activities and Deliverables

Activities: With a first version of the electronics in hand for the LTF measurement, we will perform measurements of the LTF in an e- injector (first at Argonne Wakefield Accelerator and eventually at ILCTA at Fermilab if the latter is available within the time frame of our proposal), and demonstrate the impact of various key parameters on the transfer map. If possible we will try also to study the impact of magnetic bunch compression on the LTF measurement. If needed we will work on improving the electronics associated with the LTF (potential need to improve the time resolution). We will also perform simulation of coherent radiation spectrum emitted by the bunch (either via transition or synchrotron radiation) downstream of the bunch compressor (after the damping ring) and especially study the impact of key parameters (off-crest phase, off-set energy, etc...) on the bunch form factor. In parallel we will develop and do first tests of a simplified version of a single shot coherent radiation bunch length monitor.

Deliverables: technical paper on application of the LTF method in the bunch compressors area of ILC, technical paper on simulation of coherent radiation downstream of the bunch compressor and its use to monitor drift in the bunch compressor area.

Budget justification: We anticipate the entire project to consist of numerical simulations (30%), hardware development (30%) and test with beam at a nearby facility (40%). We request funding for one graduate student and for one month of P. Piot's salary. During the three years we will contribute to the purchase of various materials needed for the electronic of the LTF measurement (rf components) and for the modification of the coherent radiation bunch monitor (optics and detectors). We anticipate the cost of hardware to amount to approximately 10 k$ per year. NIU will contribute with hardware, two postdoctoral research associates working part time on the present proposal in collaboration with Fermilab (Manfred Wendt) and Argonne (Drs. Wei Gai and John Power) personnel. We request a travel budget of 5 k$ to attend workshops and/or conferences.

Institution: Northern Illinois University

Item	FY2006	FY2007	Total
other professionals	7.000	7.280	14.280
graduate students	20.000	20.800	40.800
total salaries & wages	27.000	28.080	55.080
fringe benefits (12.5%)	0.875	0.910	1.785
total salaries/benefits	27.875	28.990	56.865
travel	5.000	5.000	10.000
materials & supplies	10.000	10.000	20.000
total other direct costs	15.000	15.000	30.000
total direct costs	42.875	43.990	86.865
indirect cost & 26% TMDC	11.148	11.437	22.585
TOTAL	54.023	55.427	109.450

Two-year budget: 109.45 K$

References

[1] G. A. Krafft, *Proceeding of micro-bunches workshop*, AIP conference proceedings No. 367, pp. 46-55 (1996).

[2] P. Piot, D.R. Douglas and G.A. Krafft, *Phys. Rev. ST Accel. Beams* **6**, 030702 (2003).

[3] A list of operation modes with the corresponding specifications is presented in T. Raubenheimer, "Suggested beam parameters for ILC", available at http://www-project.slac.stanford.edu/ilc/acceldev/beampar/.

[4] D. Mihalcea *et al.*, *Proceedings of 2005 IEEE Particle Accelerator Conference* (PAC 05), Knoxville TN, pp. 4254-4256 (2005). such a capability is available at Argonne Wakefield Accelerator.

[5] R. Tikhoplav *et al.*, *Proceedings of 2004 Linear Accelerator Conference* (LINAC 2004), Lübeck Germany, pp. 147-149 (2004).

[6] A. Curtoni and M. Jablonka, TESLA-report No. 2001-22 (2001).