SUMMARY REPORT: 1 SEPTEMBER 2006 – 15 APRIL 2007

Longitudinal phase space monitors for the ILC Injectors and Bunch Compressors

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Principal Investigator: P. Piot

Project Overview

The project aims at developing several simple, operation and commissioning-oriented, longitudinal phase space diagnostics techniques for ILC. The main emphasis is to develop tools capable of helping an operator setting up and checking most of the ILC longitudinal phase space manipulations. This includes the longitudinal bunching schemes in the injectors, the energy compressor located before the damping rings and magnetic bunch compression downstream of the damping rings. Two directions of R&D are explored: (1) the measurement and use of longitudinal transfer functions (LTF), and (2), at high energies, the use of coherent radiation diagnostics. The work is being performed by the Beam Physics and Astrophysics Group (BPAG) at Northern Illinois University (NIU) in collaboration with personnel from the Argonne Wakefield Accelerator facility (AWA) in Argonne.

Progress Report

The project currently involves Mr. Timothy Maxwell, graduate student who presently works as a laser physicist in BPAG new Laser Laboratory. Mr. Maxwell currently works on setting up a THz-radiation source (based on optical rectification) that would mimic the electric field generated by electron (or positron beam). He also developed a wavefront propagation program that can, from first principle, generate the electromagnetic fields associated to transition radiation and propagates these fields to the bunch length diagnostics; see below. Mr. Marwan Rihaoui (not funded by the present grant) is another graduate student. He is stationed at the Argonne Wakefield Accelerator facility in Argonne and is presently working toward his PhD, under the local supervision of Dr. John Power. Mr. Rihaoui is contributing to the phase detector experimental tests. Finally Dr. Daniel Mihalcea (not funded by the present grant) is also contributing to this project via his expertise on autocorrelation techniques of coherent radiation emitted by charged particle bunches.

Coherent radiation diagnostics (CRD)

Coherent radiation emitted by a bunched electron (or positron) beam can either be used as an absolute bunch length diagnostics and or as a bunch length monitor (i.e. to track drift in bunch length without providing an absolute value). A popular configuration for absolute measurement is the use of a Michelson interferometer: the coherent part of the radiation emitted by the bunch (i.e. portion of the radiation emitted at wavelength larger or of the order of the bunch length) is detected and auto-correlated. We have such a device in hands and have been studying its limitations using the electron beam provided by the Fermilab/NICADD photoinjector [Mihalcea, *et al*., *Phys. Rev. ST Accel. Beams* **9**, 082801 (2006)]. In particular a scheme to generate a "two-macroparticle" bunch was developed with the idea of experimentally investigating the resolution of this autocorrelation method [P. Piot, *et al*., *Phys. Rev. ST Accel. Beams* **9**, 053501 (2006)]; see Figure 1. Unfortunately the technique was not successful to experimentally determine the resolution of the interferometer within the capability of the Fermilab/NICADD photoinjector (mainly due to bunch-to-bunch parameters jitter). We are therefore currently exploring the limitation of such an interferometer numerically: a simulation program that propagates wavefronts in a set of user-defined optical elements has been written. Presently the program is able to generate, from first principle, transition radiation and propagate the radiation in simple elements; see Figure 2. A numerical model of the interferometer, currently being implemented in the program, will support numerical investigation of the frequency response of the interferometer. Contrary to a common assumption, the collection optics of the optical transport line to the Michelson interferometer, is not a fortiori in the far field and this introduces wavelength-dependent effects which alter the overall frequency response of the diagnostics. This can be a major effect in the THz regime see [T. Maxwell, *et al.* to be presented at the *PAC 2007 conference* – poster ID 2053].

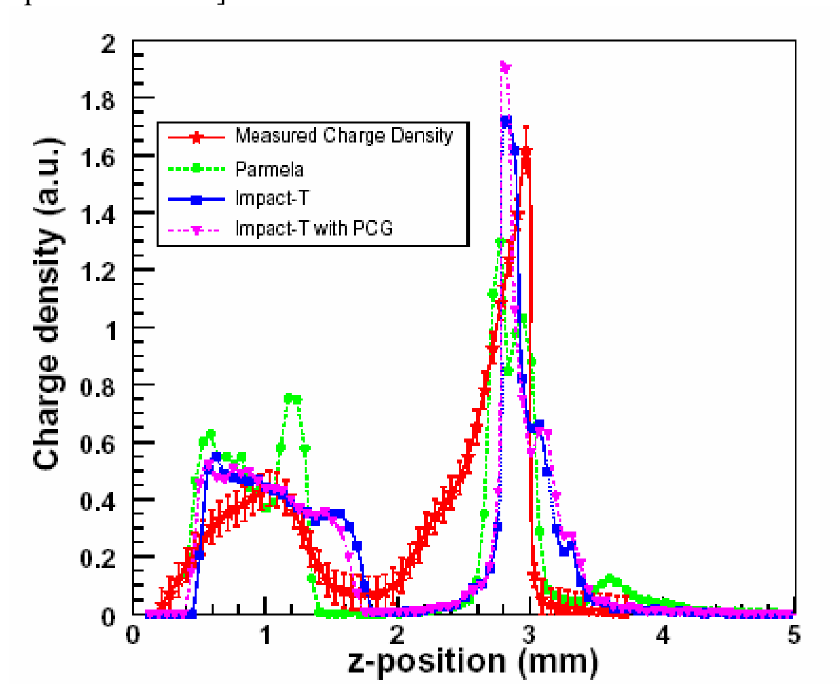

Figure 1: Reconstruction of the charge density associated to the 3.2 nC bunch produced at the Fermilab/NICADD photoinjector and comparison with three different beam tracking programs: "Parmela" from B. Young at Los Alamos, "Impact-T" from J. Qiang Lawrence Berkley lab. "Impact-T with PCG" is the NIU-version of Impact-T it uses a wavelet-based space-charge algorithm; see Reference [B. Terzic, *et al*., *Phys. Rev. ST Accel. Beams* **10**, 034201 (2007)].

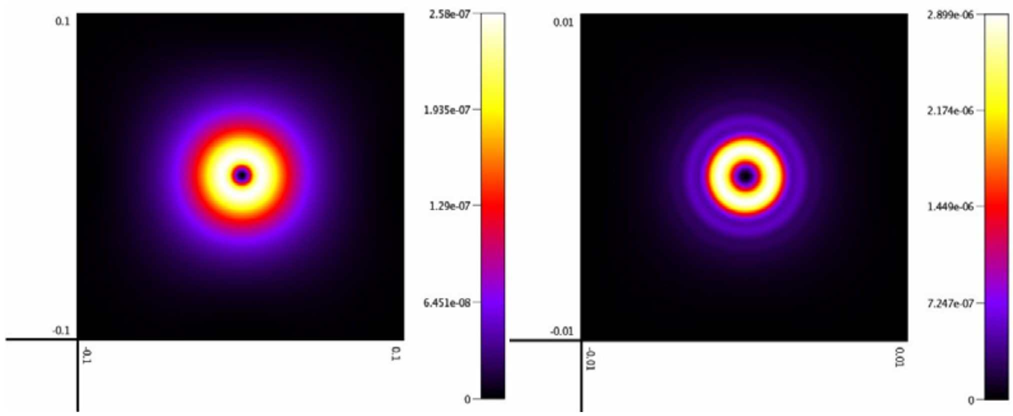

Figure 2: Far-field (left) and near-field (right) intensity distribution associated to transition radiation emitted by a 25 MeV (γ=50) electron beam. The horizontal and vertical axes correspond to the transverse positions in meters. In the near field, the transition radiation pattern deviates from the usual donut-shaped distribution with maximum at $1/\gamma$ (which is actually derived in the far-field approximation). The wavelength is 100 μm, the far field and near field observation points are respectively located 50 and 2.5 cm away from the transition radiation source.

Longitudinal Transfer Function (LTF)

The measurement of longitudinal transfer function would be of great help for setting up the longitudinal phase space gymnastic in ILC. The technique provides a measurement of the lattice function (either the compression, R_{55}, or the momentum compaction, R_{56}, map elements) and can therefore be used to make sure the lattice perform accordingly to design. The method consists in perturbing a parameter affecting the longitudinal phase space manipulation and measuring the beam's response downstream (either the energy change or relative time-of-arrival with respect to the nominal value of the parameter being altered). This technique was pioneered at Jefferson Lab in the CEBAF recirculation linac and the IR-Demo energy-recovering free-electron laser [G.A. Krafft, *AIP conf. proc.* **367**, 46-55 (1996); P. Piot, et al., *Phys. Rev. ST Accel. Beams* **6**, 030702 (2003)]. Based on the latest injector design (presented in the ILC RDR the lattice file were provided by Dr. Feng Zhou of SLAC) we have undertaken sensitivity studies of the impact of various components (sub-harmonic buncher(s), accelerating sections prior to energy compressor, etc…) on the LTF between various locations. Preliminary results confirm that a time-of-arrival detector capable of 0.5 ps should be sufficient for ILC injectors – such resolution can be reached by standard rf-mixing techniques.

In addition we carried out numerical simulations of an experiment planned at the NML facility at Fermilab. The purpose of the experiment is to measure the absolute phase jitter between the beam and electric field in ILC modules. We found that a resolution of 0.1 ps is needed to unambiguously demonstrate the required 0.25 deg phase jitter in ILC linacs. Such a high resolution calls for more advanced phase detectors (compared to the one envisioned in the present project for the ILC injectors) probably based on electro-optical sampling techniques.

Finally an experimental test of the LTF is in preparation at AWA: we will copy the electronics associated to the phase detectors installed in the Advanced Photon Source storage ring. This electronics will be installed in the AWA facility using a pick-up from a standard beam position monitor. The phase detector will be used to measure compression factor in the AWA facility.

Final year Project Activities and Deliverable

Based on the anticipated funding period (September 1^{st}, 2006 to August 31^{st}, 2008) we believe we are on track with the deliverables for both FY2006 and FY2007.

During the summer semester, and in close interaction with the RDR electron injector designers, we plan on producing a technical paper explaining the possible implementation of the longitudinal transfer function measurement and its use as a commissioning tool for the electron injector and for the electron (and positron) bunch compressors located downstream of the damping ring. A detailed numerical analysis of some limitations of the bunch length diagnostics based on interferometry of coherent radiation will be presented at PAC 2007 in June of this year.

The final year project activities and deliverables will include:

- Simulations of LTF technique for electron and positron injectors,
- Measurement of longitudinal transfer functions in the AWA facility. We especially plan to investigate time-of-arrival dependence on photocathode drive laser phase shift,
- Simulation of coherent radiation emitted at 5 GeV and evolution of the bunch form factor for different settings of the ILC bunch compressors and design of the bunch length monitor (along with a possible single-shot version of a bunch monitor).