# PROJECT DESCRIPTION

## Time-dependent electron/positron transverse bunch properties measurements

**Personnel and Institution(s) requesting funding**
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**Collaborators**
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Dr. Wei Gai, Argonne National Laboratory
Dr. Yuelin Li, Argonne National Laboratory
Dr. John Power, Argonne National Laboratory
Dr. Nikolai Vinogradov, Northern Illinois University

**Project Leader**

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**Project Overview**

This proposal ultimately aims to develop a novel diagnostic capable of measuring transverse beam parameters (i.e. transverse position and beam moments) over time scale shorter than the bunch length. Such a diagnostics could have numerous applications in ILC: for instance it could be used to diagnose time-correlation in the transverse phase space and help curing transverse wakefield-induced bunch deformation (the so-called "banana effect"). Numerical simulations and theory, hardware development along with experimental tests with beam will be performed.

The proposed beam diagnostics centers on the electro-optical (EO) sampling. As a charged-particle beam passes near an electro-optic material, its electric field induces anisotropy in its index of refraction by way of the Pockels effect. This occurs because retardation (a phase shift) is introduced between two orthogonally polarized components of a pulse of light traversing the crystal. This retardation becomes apparent when simultaneously probing the material with an external laser; it will, for example, convert linearly polarized laser light into elliptically polarized light. If the laser is fast (femtosecond-class), it will reveal a changing electric field due to a nonuniform charge distribution in the beam. This is known as "electro-optic (EO) sampling". A single crystal of such material will enable measurement and monitoring of the longitudinal charge distribution in a noninvasive fashion. An azimuthal array of crystals will enable measuring and monitoring the transverse charge distribution and/or the steering of the beam (for an off-center beam would lead to an asymmetric electric field). We propose to develop this diagnostic.

In principle, the EO-sampling technique permits direct time-domain measurements of both beam-induced wake-fields and the electric field from a single bunch itself. The design of the vacuum chamber housing the EO crystal (interaction chamber) is key to measuring the direct field of the beam. One possibility is to use a tapered vacuum chamber for low wakefields. Part of our proposal will consist in designing, building, and (in collaboration with Argonne personnel) testing such a chamber. Three variations of this diagnostics have been proposed and tested by various groups: (1) the delay-scan method [1], (2) the wavelength detection of frequency-chirped probe beam [2], and (3) the cross-correlation of chirped probe beam [3]. Only the second and third methods can provide a single shot measurement of the bunch time-profile. We aim at developing these methods further by also being able to encode the transverse distribution of the electron beam. A possible concept appears in Figure 1: a chirped[1] hollow laser beam is propagated though a hollow EO-crystal, while the electron bunch travels along the crystal axis. Let's assume for sake of simplicity the laser is frequency chirped, then after decoding the frequency spectrum, we would have access to the electric field $\mathbf{E}_\perp(r_{laser}, \theta, z)$. Integrating over $\theta$ yields the longitudinal bunch profile. However, by accessing, for various longitudinal slices, the angular distribution of the beam's electric field, one obtains information on the slice positions and sizes. This method uses the same principle as do conventional electromagnetic beam position monitors (BPMs) [4]. However, unlike conventional BPMs, the EO-sampling diagnostic would provide transverse parameters over time scales less than the bunch length. Ultimately we aim at reconstructing the transverse distribution of a bunch slice (using a moment analysis). We should stress that Figure 1 should be taken as a concept: it is presently unclear whether this is the optimum solution. A first version of the apparatus for a proof-of-principle experiment might be conceptually similar to conventional BPM and just consists of four EO-crystal located 90 degrees apart. A refinement of the proposed concept need thorough numerical simulations of the optical system; this will be performed during FY 2006. Development of this diagnostic clearly requires collaboration with a laser expert.

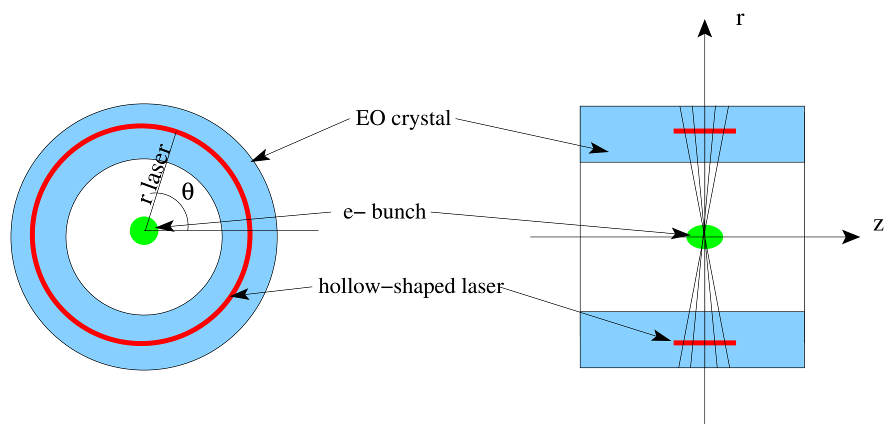


Figure 1: Concept for EO sampling measurement of time-dependent (within the bunch) of transverse bunch parameters.

We will collaborate with Yuelin Li of Argonne National Laboratory (ANL), who is a laser expert who shares our strong interest in this technique. Development work will initially be done at NIU using the fs-class Ti:Saph laser NIU is presently procuring. The laser system

[1]the chirp can either be a frequency or spatial chirp, the former type of chirp have some limitation

will then be moved to ANL, after which further development and testing will be done by both NIU and ANL (Drs. Wei Gai, Yuelin Li, and John Power) at the Argonne wakefield accelerator (AWA) facility. Ultimately, the diagnostics may be moved (depending on construction schedule) to the ILC test accelerator (ILCTA) planned to be built at Fermilab in 2007.

### 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 diagnostics described in this proposal has also application for optimizing the performance of single-pass free-electron lasers based on the self-amplified simultaneous emission principle; in these latter devices, the transverse emittance has to be known over sub-picosecond bunch slices (so-called slice emittance).

### 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: Install and commission a femtosecond laser (laser currently being procured by Northern Illinois University). The commissioning activities will include development of an autocorrelation diagnostics, injection in fiber, chirping and compression of the laser. Perform numerical simulations of the full diagnostics and study its performance. Design a low impedance interaction chamber and begin its fabrication in the NIU workshop.
Deliverables: technical papers on the laser characterization, and on simulation of the pro-

posed design for the time-dependent transverse bunch properties measurements. Design of a low impedance chamber

**FY2007 Project Activities and Deliverables**
Activities: Install the laser system developed during FY2006 at the Argonne wakefield accelerator, work on synchronization between laser and electron bunch and commission a first version of the EO sampling diagnostics. The low impedance interaction chamber will then be installed and a simple proof-of-principle test of beam position measurement within the bunch will be performed.
Deliverables: technical paper on first results on EO sampling diagnostics and low impedance interaction chamber.

**Budget justification:** We anticipate the entire project to consist in numerical simulations and theory (20%), hardware development (40%) and test with beam at Argonne (40%). We request funding for one graduate student for the three years. During the three years we will need to purchase various materials [an intensified CCD camera ($\sim$ 45 k$ for FY 2006), and some minor optical components (10 k$ for FY2007)]. NIU will contribute with hardware, one postdoctoral research associate and Philippe Piot working part time on the present proposal in collaboration with Drs. Wei Gai, Yuelin Li and John Power of Argonne. We also request 5 k$ a year for attendance to conferences and/or workshops.

**Institution: Northern Illinois University**

| Item | FY2006 | FY2007 | Total |
|---|---|---|---|
| Graduate Students | 20.000 | 20.800 | 40.800 |
| Total Salaries and Wages | 20.000 | 20.800 | 40.800 |
| Fringe Benefits | 0.000 | 0.000 | 0.000 |
| Total Salaries, Wages and Fringe Benefits | 20.000 | 20.800 | 40.800 |
| Travel | 5.000 | 5.000 | 10.000 |
| Materials and Supplies | 45.000 | 10.000 | 55.000 |
| total direct costs | 50.000 | 15.000 | 65.000 |
| Total direct costs | 70.000 | 35.800 | 105.800 |
| Indirect costs & 26% TMDC | 18.200 | 9.308 | 27.508 |
| Total direct and indirect costs | 88.200 | 45.108 | 133.308 |

**Three-year budget 133.31 K$**

## References


[1] X. Yan *et al.*, Phys. Rev. Lett. **85**, 3404 (2000).

[2] I. Wilke *et al.*, Phys. Rev. Lett. **88**, 124801 (2002).

[3] G. Berden, *et al.*, Phys. Rev. Lett. **93**, 114802 (2004).

[4] R. Miller *et al.*, Proc. 12th Int Conf. High Energy Accelerators (HEAC'83), Fermilab USA 1983, p 602.