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Development of a Helical Undulator for ILC Positron Source

Abstract. The long-term goal of this research is the development of a polarized positron source able to satisfy the demands of the International Linear Collider (ILC).

As recently accepted, the base line for the positron production scheme is an undulator based source. This source includes the undulator, target for gammas, collection optics and collimation system. In *this* project we concentrate on the undulator system.

Personnel and Institution requesting funding

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Collaborators

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Scientists from Cornell and from Daresbury have close scientific contacts at International Conferences and Workshops and TV meetings.

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Project Overview

High energy electron-positron collisions are essential for understanding the fundamental properties of matter. In pursuit of this understanding, the world physics community has put forward as the next instrument of choice the International Linear Collider (ILC). Although the basic idea of such collider is rather simple the technology is challenging. One of the challenges is the production of positrons sufficient for the required luminosity. A new approach not possible at the energies of previous e+e- colliders has been adopted for the Baseline Concept Design (BCD) and involves as its essential component a short period undulator. *This project focuses on design and development of the undulator itself.*

In this approach electrons/positrons of main beam, pass through an undulator, generating of circularly polarized photons. These photons are used further for conversion into positrons in a thin target. The scheme of positron production with gammas, obtained from (helical) undulator [1] is represented in Fig.1.

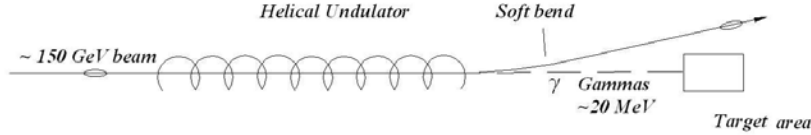


Figure 1: General scheme of conversion system.

Here high energy electrons (or positrons) after reaching ~ 150 GeV in the linear pass through the undulator and then return to the main linac for further acceleration and collision at the IP. Gammas radiated in the undulator are directed to a thin ($\sim 0.5X_0$, i.e. half radiation length) target. Positrons from electron-positron pairs are collected by a short focusing lens, accelerated in a “pre-accelerator and directed to the damping ring for further cooling. This method have been tested recently [2] and demonstrated polarized positron production in quantities as predicted. A more detailed view is presented in Fig.2 (taken from [3]).

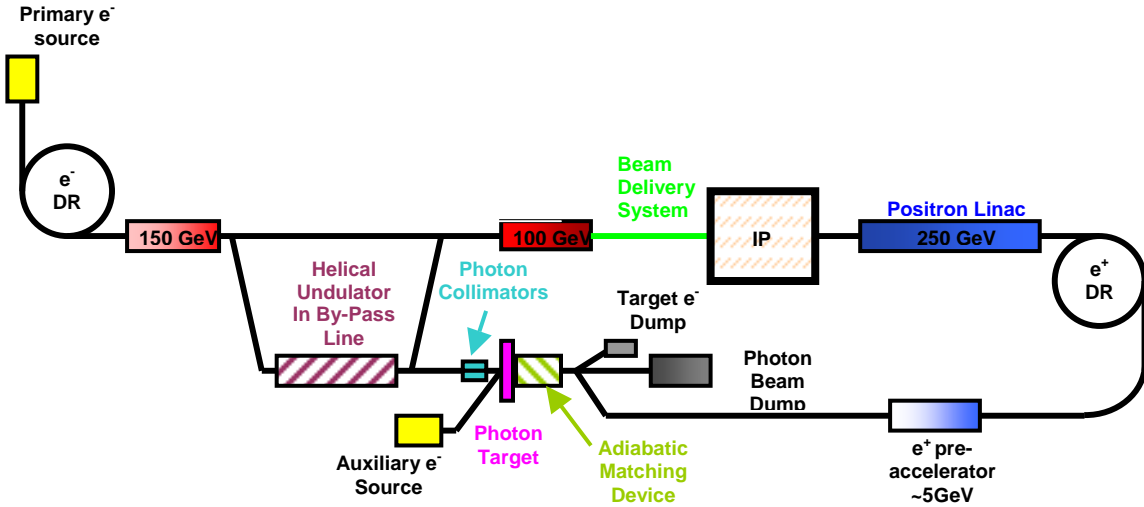


Figure 2: Schematic overview of Undulator Based Positron Source in which the undulator is located at the 150GeV point in the electron main linac.

The project being proposed here leads to development and test 0.3-m long helical undulator model having period $\lambda_u = 10$ mm with aperture diameter 8 mm and $K=0.7$ ¹.

The main component of the project at the beginning stage is the optimization of the helical undulator design, including optimization of coil size and the fringe region. The latter is important for proper entrance/exit from helical field to minimize emittance perturbations to the linac beam. The requirements on maximum emittance and steering perturbation allowed will be derived from BCD parameters as part of this project.

The aperture will be kept as large as possible and the field will be as high as possible-with this contradiction to be resolved by optimization.

¹ K -factor is a measure of undulator strength: $K = eH_{\perp}\lambda_u / (2\pi mc^2) = 93.4H_{\perp}[T]\lambda_u[m]$

Ultimately, we envision 4-m long modules will be used for assembling an ~ 200 m-long undulator for polarized positron production. The importance of polarized electron-positron collisions is widely recognized [4]. The module must be optimized for best performance, such as emittance and spin perturbations, as well as for minimization of cost and for facilitation of assembly. An artist's view of three 4-m modules is shown in Fig. 3

The short model fabricated and tested in this project could be implemented in a full scale 4-m long module. This module will be equipped with all elements necessary for future operation.

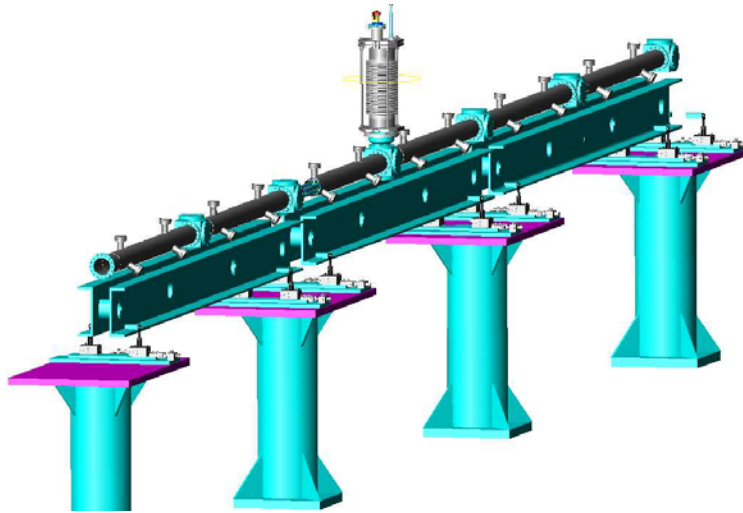


Figure 3: 3 module segment of ~ 200 -m long undulator for ILC.

The project discussed here will accommodate one graduate student and one undergraduate student giving them practical as well as theoretical experience in producing handling and measuring polarized electrons or positrons.

Broader Impact

The helical undulator with short period can be widely useful as an insertion device in storage rings [5] and in linac based synchrotron radiation sources. The possibility to change the undulator field by changing the current makes operation over a large wavelength range easy with the added advantage that the number of radiated photons is twice the number in a planar undulator of the same period and length. The big aperture, ~ 8 mm, by itself is unique for 1 cm period. It would be not a problem to construct a helical undulator for longer period allowing larger aperture or higher K value. Utilization of an undulator with small period would also permit reduction of drive beam energy with consequent cost saving.

Results of Prior Research

In August 2005 we successfully tested a 30 cm SC undulator model made by A. Mikhailichenko in 1986 as discussed below. This will serve as a *basis* for further improvement with this project.

This earlier device has 6 mm aperture diameter and it has Iron-core helical yoke. The technology was relatively primitive and the SC wire parameters were modest as

compared with present day products. Figs. 4 and 5 show the model and test apparatus. Fig. 5 shows the measured magnetic field.

The model to be constructed in this project will use wire fabricated with newest technology combined with the fabrication possibilities of Cornell machine shop. This will permit us to implement the latest ideas about optimization. The optimization will include shape of iron yoke and the coil ends and body.

The numerical computer 3D code, MERMAID is in hand and has been used successfully in the design of the SC wiggler for CESR. An upgrade will be needed for the helical undulator work.

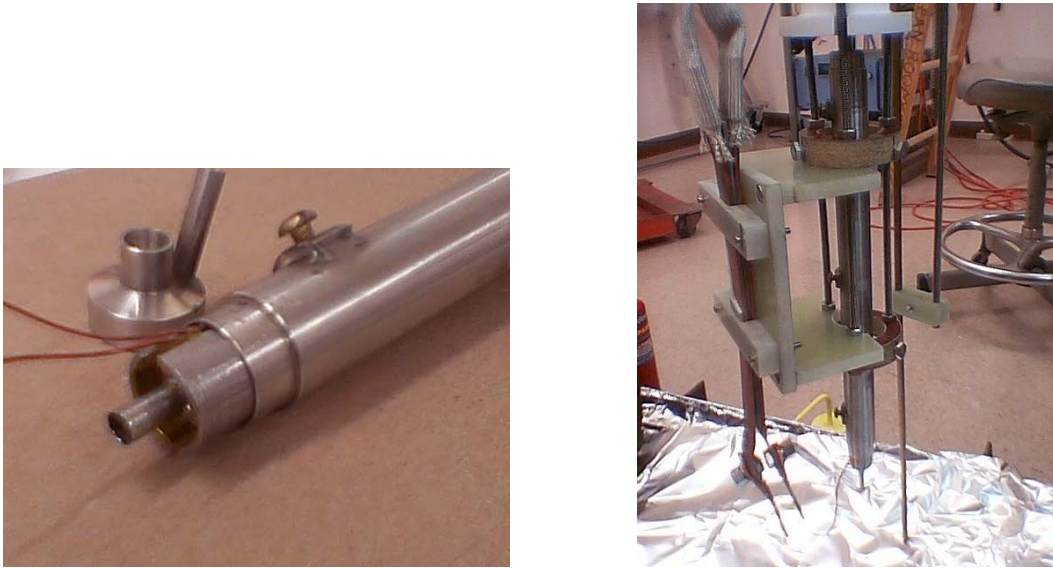


Figure 4: Left: Cold mass. Diameter of tube is 6mm. Right: Cold mass of undulator installed in Dewar for test in LHe.

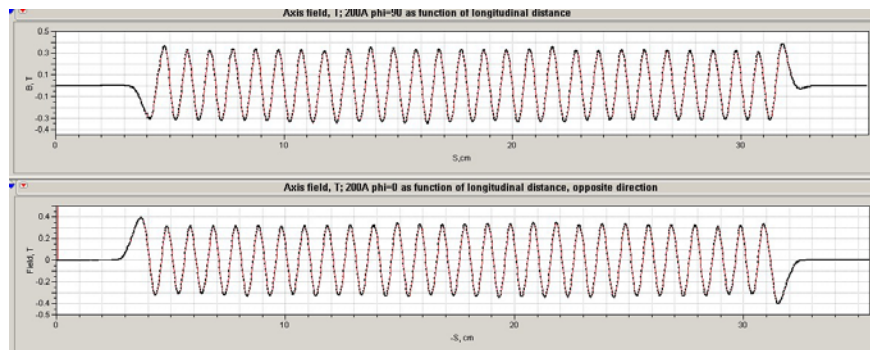


Figure 5: Transverse fields in undulator model as functions of longitudinal coordinate, measured in LHe with Hall probe for two orthogonal orientations for a feed current of 200A, $K=0.33$ (optimal value for highest polarization) .

The undulator was tested for 400 A maximum current, where it reached $K \cong 0.6$. For best polarization of positrons, an undulator must work with a lower field, $K \cong 0.33$ with

appropriate increase of its length or with utilization of second target. This target would be installed in series.

In this project we concentrate on the parameter $K \cong 0.7^2$, which is conservative. This is tradeoff between aperture and period. Other values will be evaluated as part of the optimization. Note that for best polarization $K \sim 0.4$ required.

Facilities, Equipment and Other Resources

Equipments required for this project are: Dewar with LHe level meter, two power supplies with electronics for main winding and corrector feeding. A Computer with electronics is required for controls and field measurements.. Materials for fabrication of 0.3 m model (SC wire, thin wall tubes, etc) must be acquired on the market. Resources of the Lab. machine shop will be used for fabrication of yoke and other elements. The helical winding will be made by hand at this stage.

FY2006 Project Activities and Deliverables

The project begins with the optimization of prototype(s) having ~ 8 mm aperture and 10 mm period, $K \sim 0.7$. Calculations of emittance and alignment perturbations in the undulator will be completed in this year. Materials and equipment required for fabrication and test of 30 cm long models will be obtained.

FY2007 Project Activities and Deliverables

Fabrication and assembling the 0.3-m long model will be accomplished in this year. The model will be tested in LHe. Design of Hall probe system for the field measurements in 4-m long module will be accomplished. Note that the field measurements must be done in vacuum at cryogenic temperature. Design of 4-m long module will also be accomplished in this year.

Budget Justification

Materials needed: SC wire (we are planning to use the SC wire with rectangular cross section for packing efficiency), iron for helical yoke fabrication, power supplies and complementary electronics. Yoke tooling and construction will require design and machine shop time. For the magnetic calculations an upgrade of MERMAID will be needed. In addition we require 30 days of machine shop time, 60 days of technician time and 75 days of designer/engineer time.

Other direct costs involve custom cutting tools for the winding fixture and electroplating for the undulator components.

² For $K=0.7$ intensity of the first harmonics in radiation reaches its maximum.

Two-year Budget, in then-year K\$

Table 1.

Item	FY2006	FY2007	Total
Other Professionals	24.12	36.96	61.08
Graduate Students	33.89	34.9	68.79
Undergraduate Students	5.0	5.2	10.2
Total salaries and Wages	63.01	77.06	140.1
Fringe Benefits	20.79	25.43	46.22
Total Salaries, Wages and Fringe Benefits	83.80	102.5	186.3
Equipment	15	45	60
Travel and transportation	3	2	5
Materials and Supplies	15	5	20
Other direct costs	7	10	17
Subcontract	0	0	0
Total direct costs	123.8	164.5	288.3
Indirect costs	15	10.2	25.2
Total direct and indirect costs	138.8	174.7	313.5

References

- [1] V.E. Balakin, A.A. Mikhailichenko, “*The Conversion System for Obtaining Highly Polarized electrons/positrons at High Energy*”, Preprint BINP79-85, 1979.
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- [4] G. Moortgat-Pick *et al.*, “*The Role of Polarized Positrons and Electrons in Revealing Fundamental Interactions at the Linear Collider*”, SLAC-PUB-11087, CERN-PH-TH-2005-036, DESY-05-059, FERMILAB-PUB-05-060-T, IPPP-04-50, KEK-2005-16, PRL-TH-05-01, SHEP-05-03, Jul 2005, 149pp., e-Print Archive: hep-ph/0507011.
- [5] “High Resolution Helical Undulator Soft X-Ray Beamline”, see
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