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A Helical Undulator Based Positron Source for the International Linear Collider

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Abstract

Several methods for producing the high-intensity positron beam needed for the future International Linear Collider (ILC) have been proposed by the accelerator community. A helical undulator-based design is currently considered to be the most viable approach for producing the required intensity [1], and has the added advantage of being able to produce polarised positrons. In the proposed design, a helical undulator is employed to produce a gamma-ray drive beam from the linear collider's main electron beam, and positrons are then produced from the interaction of the gamma-ray beam with a Bethe-Heitler pair-production target.

The "heLiCal" collaboration and our international collaborators are working on the design and proof of principle of key components of an undulator-based positron source. Short prototype superconducting and permanent magnet undulators have been built by the collaboration and their characteristics are being evaluated. This report gives a brief summary of ongoing work on the undulators and related studies of ILC spin-dynamics.

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1 Introduction

There is a wide consensus within the particle physics community on the need to develop a future TeV-scale e^+e^- collider, the International Linear Collider (ILC), to complement and extend the physics programme of the Large Hadron Collider being constructed at CERN, Switzerland [2].
This report summarizes the "heLiCal" collaboration's role in developing a helical undulator-based positron source which can meet the ILC's intensity requirements of 10^{14} positrons per second, and can optionally produce the positrons in a spin-polarised state. In this concept [3], electrons from the main linac pass through an undulator causing them to describe helical trajectories and radiate intense circularly-polarised synchrotron radiation on axis. The radiation is then collimated prior to passing through a thin (0.4 radiation length) titanium alloy target. Positrons emitted from the back of the target are focussed by a tapered axial magnetic field before being accelerated and injected into a damping ring at 5 GeV. The proof-of-principle of the undulator-based positron source has recently been demonstrated by the E166 [4] experiment at SLAC, where undulator technology was used in conjunction with a target to successfully produce polarised positrons, although at a lower intensity than required for the ILC.
The undulator-based source's ability to produce a polarised positron beam would maximise the ILC's potential for new physics searches at the TeV scale, as well as maximising the precision with which electroweak parameters could be determined [5].

2 Undulator Design and Parameters

Helical undulator insertion devices consist of arrays of magnets or current elements which generate a helical magnetic field on axis. The deflection parameter * of the device must be close to unity to maximise the on-axis brightness of the undulator radiation [6].
The currently recommended ILC positron source design uses between 100 m and 200 m of undulator with a deflection parameter of 1, a period of 1 cm and an on-axis magnetic field strength of approximately 1.1 T, generating radiation of 10 MeV from a 150 GeV electron beam. To date, the heLiCal collaboration has constructed two prototype undulator modules with parameters approaching the ILC ideals: a superconducting module and a permanent magnet module.
The superconducting prototype [7] was designed to give twenty 14 mm periods of helical magnetic field on axis with a peak on-axis field strength of 0.8 T. It consists of an aluminium former in the shape of a hollow cylinder into which was machined two parallel helical grooves. The inner diameter of the cylinder is 4mm. A superconducting wire ribbon formed from 8 superconducting wires was wound 8 layers deep into the two grooves, and the wires in the ribbon were joined giving a multilayered, continuous, double-helical winding.
Computer simulations were used to optimise the winding geometry to avoid high magnetic fields inside the superconductor which could cause it to quench. The supercon-

*The energy-normalised peak angular deflection of electrons passing through the undulator.

ducting winding in the prototype is predicted to reach about 94% of short sample at an operating current of 226 A.
Preliminary measurements of the magnetic flux on axis were made at both room and superconducting temperatures. The radial field was measured using a small Hall probe which was driven along the undulator length by a stepper motor. The cooled undulator reached 225 A (the maximum current of the power supply) without quenching, and the radial field was shown to reach its nominal value of 0.8 T on the undulator axis. The first field integral of the device was measured to be of order 10^{-4}Tm, compared with zero for an ideal device. Although small enough for the undulator to operate effectively, the largest contributions to the first field integral are thought to be due to variations of order 0.1 mm in the depth of the groove machined in the former. The field measurements will shortly be repeated with an improved data acquisition system.
The permanent magnet undulator prototype [8] was built from rings of NdFeB magnets mounted in a support structure about a common axis. Each ring was made up of eight trapezoids of NdFeB which were magnetised so as to give a dipole field on axis. Neighbouring rings were rotated with respect to one another such that the dipole field also rotated spatially along the length of the undulator - approximating a helical field on axis with a period of 14 mm (corresponding to eight rings) and a peak on-axis field of 0.8 T. The undulator was designed to be divisible into two halves laterally for ease of accessing the beam pipe. Initial field measurements using a Hall probe have confirmed that the on-axis field is helical in nature, but more accurate measurements using a pulsed-wire technique have yet to be performed.
Based on the preliminary field measurements and on operational considerations, the decision has been made to continue development of the superconducting undulator design whilst no new permanent magnet prototypes are planned. The main consideration in this choice was the ease with which the superconducting undulator's deflection parameter could be adjusted by varying the current running through the windings. Two further short superconducting undulators are already in construction to evaluate the effects of changing the winding geometry and of including iron around the superconducting wires. In addition, a 4 m long superconducting undulator module consisting of two 2 m modules in a single cryostat is currently being designed.

3 ILC Spin Dynamics

The advantages of a polarised positron beam in extending the physics reach of the ILC can only be realised if the depolarisation of the positrons (and electrons) as they propagate from their source to the interaction point(s) is minimal and well-modelled. The heLiCal collaboration is developing spin-tracking simulation computer codes and is applying them to regions of the ILC, with the eventual goal of carrying out cradle-to-grave simulations.
Depolarisation can occur through spin precession and through stochastic photon emission in the presence of inhomogeneous fields leading to radiative spin diffusion. Initial

studies have concentrated on modelling depolarisation in the damping rings and bunch-bunch effects in the interaction region.
The damping ring studies are being carried out using the SLICKTRACK [9] software package which incorporates Monte Carlo and analytical models. Current results support the findings of an earlier damping ring study [10] which predicted negligible depolarisation effects. More sophisticated calculations are planned, and SLICKTRACK will also be developed for use in modelling other areas of the ILC including the beam delivery system.
Studies of bunch-bunch effects at the interaction region are being carried out using the CAIN [11] software package. Following an initial commissioning study, in which the CAIN code was applied to the ILC beam parameters and run on a variety of computer platforms, higher-order theoretical calculations are now in progress which will be used to establish CAIN's reliability in producing the high-precision results needed for the ILC.

4 Conclusion

The heLiCal collaboration is involved in a range of activities related to the design of the ILC positron source with special focus on the development of a suitable helical undulator, and the modelling of the spin dynamics of polarised positrons produced by the source. Although not described in this report, members of the collaboration are also involved in the design of the undulator vacuum system, as well as the design of a pair-production target and a photon collimator for the source.
Two undulator prototypes have already been successfully constructed by the collaboration, and further superconducting undulator prototypes are in construction. Field measurements and simulations of these undulators, in addition to insights gained from heLiCal's other activities, will form important inputs into the future ILC technical design report.

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