THE DESIGN OF THE POSITRON SOURCE FOR THE INTERNATIONAL LINEAR COLLIDER

J.A. Clarke[1,2,3], I.R. Bailey[2,3], E. Baynham[4], V. Bharadwaj[5], T.W. Bradshaw[4], A. Brummitt[4], A. Bungau[2,6], F.S. Carr[4], N.A. Collomb[1], J. Dainton[2,3], R. Dollan[7], W. Gai[8], J. Gronberg[9], A.F. Hartin[10], S. Hesselbach[13], K.M. Hock[2,3], Y. Ivanyushenkov[8], L.J. Jenner[2,3], K. Laihem[11], A. Lintern[4], W. Liu[8], T. Lohse[7], O.B. Malyshev[1,2], L.I. Malysheva[2,3], A.A. Mikhailichenko[12], G.A. Moortgat-Pick[2,13], W.T. Piggott[9], S. Riemann[11], J. Rochford[4], N.C. Ryder[1,2,14], A. Schaelicke[11], D.J. Scott[1,2], J.C. Sheppard[5], A. Ushakov[11], L. Zang[2,3].

[1] STFC Daresbury Laboratory, Warrington, UK

[2] Cockcroft Institute, Daresbury Science and Innovation Campus, Warrington, UK

[3] Department of Physics, University of Liverpool, Liverpool, UK

[4] STFC Rutherford Appleton Laboratory, Didcot, Oxfordshire, UK

[5] Stanford Linear Accelerator Center, Stanford, CA, USA

[6] University of Manchester, Manchester, UK

[7] Humboldt University Berlin, Germany

[8] Argonne National Laboratory, Argonne, IL,USA

[9] Lawrence Livermore National Lab, Livermore, CA, USA

[10] John Adams Institute, Oxford University Physics, Oxford, UK

[11] DESY Zeuthen, Berlin, Germany

[12] Cornell University, LEPP, Ithaca, USA

[13] Institute of Particle Physics Phenomenology, University of Durham, Durham, UK

[14] Department of Physics, University of Bristol, Bristol, UK.

Abstract

The high luminosity requirements and the option of a polarized positron beam present a great challenge for the positron source of a future linear collider. This paper provides a comprehensive overview of the latest proposed design for the baseline positron source of the International Linear Collider (ILC). We report on recent progress and results concerning the main components of the source: including the undulator, capture optics, and target.

SOURCE OVERVIEW

The positron source is a highly challenging subsystem of the ILC. The intense luminosity requirements imply positron numbers per macropulse approximately three orders of magnitude beyond that delivered by any previous positron source. Another requirement of the ILC is that the source design must allow for a future upgrade to provide highly-polarized positrons (up to 60%) and this imposes restrictions on the possible solutions available. In the solution adopted the electron main linac beam passes through a long helical undulator to generate a multi-MeV photon beam which then strikes a thin metal target to generate positrons in an electromagnetic shower. The positrons are captured, accelerated, separated from the shower constituents and unused photon beam and then are transported to the Damping Ring. Although the baseline design only requires unpolarized positrons, the positron beam produced by the baseline source will have a polarization of ~30%, and beamline space has been reserved for an eventual upgrade to ~60% polarization.

A recent proof of principle experiment at SLAC has demonstrated the feasibility of this technique by generating 6 MeV positrons with >80% polarisation [1].

Table 1. ILC Positron source main parameters.

Parameter	Value
Positrons per bunch	2×10^{10}
Bunches per pulse	2625
Pulse repetition rate	5 Hz
Electron drive beam energy	150 GeV
Electron beam energy loss in undulator	3.0 GeV
Positron polarization	30%, upgradeable to 60%
Undulator period	11.5 mm
Undulator field strength	0.86 T
Photon Energy	10 MeV (1st harmonic)
Target Material	Ti-6%Al-4%V
Target Thickness	14 mm (0.4 Rad Lengths)

The positron source must perform three critical functions:

- generate a high power multi-MeV photon production drive beam in a suitable short period, high K-value helical undulator;
- produce the needed positron bunches in a metal target that can reliably deal with the beam power and induced radioactivity;
- capture and transport the positron bunch to the ILC Damping Rings with minimal beam loss.

The key parameters of the Positron Source are listed in Table 1 and Figure 1 shows the major elements of the positron source. The photon beam is produced by passing the main electron linac beam through a long undulator. This photon beam is transported ~500 meters to the positron source target hall where it hits a 0.4 radiation length thick Ti-alloy target producing showers of electrons and positrons. The resulting beam is captured using an optical matching device (OMD) and normal conducting (NC) L-band RF with solenoidal focusing and accelerated to 125 MeV. The electrons and remaining photons are separated from the positrons and dumped. The positrons are accelerated to 400 MeV in a NC L-band linac with solenoidal focusing. They are transported ~5 km to the central damping ring complex, where they are boosted to 5 GeV in a linac using superconducting (SC) L-band RF and injected into the positron damping ring.

The positron source system also includes an auxiliary source to generate a low intensity positron beam that can be injected into the SC L-band linac. This will be used for commissioning and also to allow various beam feedbacks to remain active if the main electron beam, and hence the undulator based positrons, is lost. This source uses a 500 MeV electron drive beam impinging on a tungsten-rhenium target to produce positrons which are then captured and accelerated to 400 MeV similar to the main positron source. The auxiliary source is presently designed to produce 10% bunch intensity for the full 2625 bunch ILC pulse train at 5 Hz though this specification is currently under review.
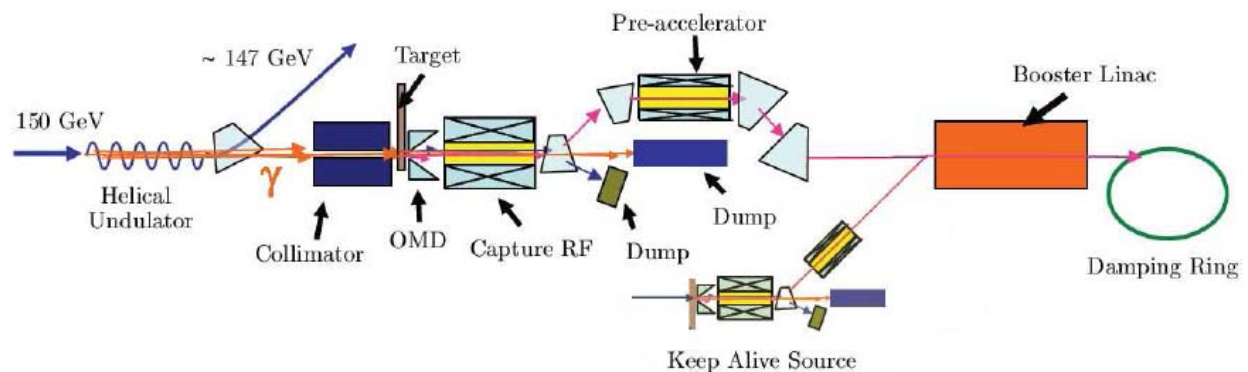

Figure 1: Schematic layout of the undulator-based positron source showing the key components.

UNDULATOR

The undulator must be superconducting to achieve the required parameters of high field and short period [2] (see Table 1). Two interleaved helical windings of NbTi spaced half a period apart generate the transverse helical field. The undulator will consist of 4 m long cryomodules containing two separate undulators with an active undulator length per cryomodule of 3.5 m. A number of short superconducting prototypes have been constructed to help select the optimum undulator parameters. A full scale 4 m long cryomodule is now in the final stages of manufacture at Rutherford Appleton Laboratory [3].

The 1.75 m long undulators have been successfully measured magnetically in a vertical cryostat. The tests show that both magnets can deliver the nominal design current of 216A corresponding to 0.86 T. The maximum observed quench current was 301 A and 306 A for magnets 1 and 2 respectively (see Figure 2). Magnet 1 exhibited little quench training but magnet 2 needed extensive quench training, the reason for the difference between these two identical undulators is not yet understood.
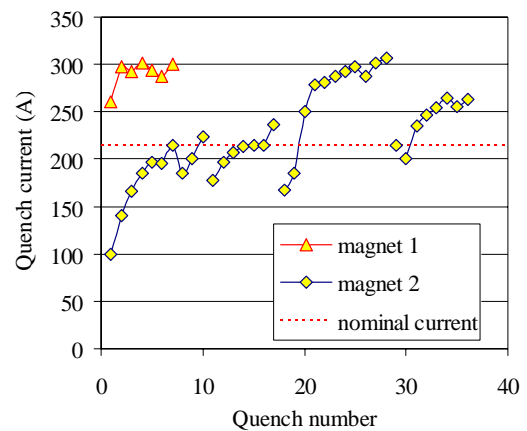

Figure 2. Magnet quench behaviour for the two nominally identical undulators, showing the current required to quench the magnets on successive occasions.

TARGET

The positron production target is a rotating wheel made of titanium alloy. The photon beam is incident on the rim of the spinning wheel, whose diameter is 1 m and thickness is 14 mm. During operation the outer edge of the rim moves at 100 m/s. This combination of wheel size and speed offsets radiation damage, heating and the shock-stress in the wheel from the ~130 kW photon beam. A shaft extends on both sides of the wheel with the motor

mounted on one shaft end, and a rotating water union on the other end to feed cooling water. The target wheel sits in a vacuum enclosure at 10^{-8} torr (needed for the adjacent NC RF operation). The rotating shaft penetrates the enclosure using two vacuum feed-throughs, one on each end. The OMD is mounted on the target assembly, and requires an additional liquid nitrogen cooling plant. The motor driving the target wheel is sized to overcome forces due to eddy currents induced in the wheel by the OMD.

Several numerical eddy current simulations of the wheel moving in the field of the OMD have been carried out using alternative codes and techniques. Whilst broad agreement is found between these studies, showing power loading on the target of ~10 kW for a static 1 T field, it has been decided that this is such a crucial issue that a target prototype has been developed at the Cockcroft Institute and this will be used for eddy current benchmark measurements [4]. A view of the target test stand is shown in Figure 3. Whilst understanding of the exact eddy current losses is important, equally vital will be the demonstration of stable full speed operation.
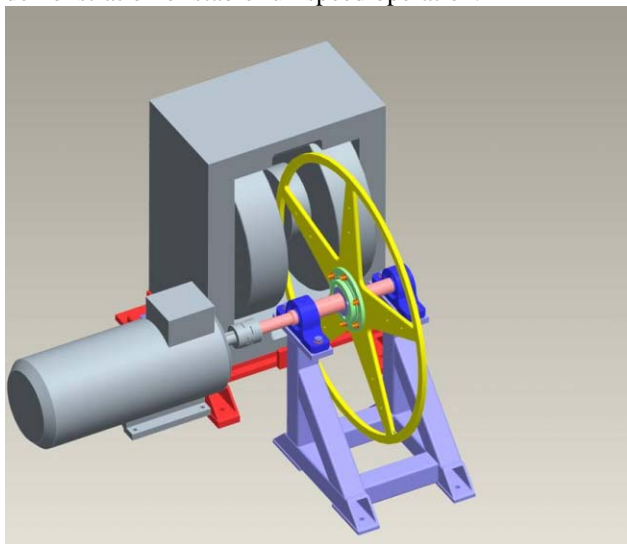

Figure 3. Target wheel test rig set up.

CAPTURE OPTICS

Immediately after the target wheel is the OMD which is a specially tailored magnet and a normal conducting RF linac that are jointly optimised to capture as many of the positrons as possible. The magnetic field profile of the OMD has a strong impact on the positron yield and, broadly speaking, the higher the magnetic field on the target, the higher the capture efficiency. The baseline OMD is a normal conducting pulsed flux concentrator which generates a solenoidal magnetic field which peaks in strength at 5 T close to the target and falls off to 0.5 T to match the solenoidal field at the entrance of the RF capture section. This flux concentrator increases the capture efficiency by a factor of two.

A promising alternative to the flux concentrator solution is the use of a lithium lens [5], a technique which is presently used by CERN and FNAL for antiproton collection. Such a system could improve the positron capture efficiency by up to another factor of two, if it can be shown to be feasible. The main concern is the survivability of the windows which separate the lithium from the RF system vacuum. The full power photon beam and secondary positrons and electrons will traverse the windows so they will suffer some level of radiation damage, thermal cycling, and have to cope with the shock waves. In addition cavitation within the lithium might also be an issue. However, the benefit of such a lens system is significant (effectively halving the required length of undulator) and so further studies on this system are essential to address these potential issues.

FUTURE PLANS

The positron source is an extremely challenging part of the ILC facility and demands a major increase in performance over any existing sources. The undulator-based solution has been demonstrated to be feasible and our future work is now focussed on minimising risk, value engineering, and system integration.

The risk minimisation is being facilitated through the use of prototyping where appropriate (eg the undulator and target) and this has already successfully shown that the undulator parameters, though demanding, are practical. Further studies are required on the capture magnet (flux concentrator or lithium lens) and a prototype of the selected option will be essential in the medium term.

System integration is now underway which aims to build on the established solution by generating an engineered and fully self-consistent source design. Furthemore, a number of detailed design options will be assessed as part of this exercise with the aim of maximising performance and reliability whilst minimising overall cost.

ACKNOWLEDGEMENTS

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