Technical Preparation : Positron Source in General

Two different positron sources are being studied in parallel right now: undulator scheme (baseline) and e-driven scheme (backup). The former can provide a polarized positron beam but it is a new technology. Therefore, a backup scheme has also been studied for safety. The status of the two schemes as of May in 2018 has been summarized in 1). One of these two schemes has to be selected by an appropriate deadline as the ILC machine to be built at the project start. The two schemes require significantly different civil engineering designs of the tunnel and utility, which demands large amount of cost and time. Hence, the selection must be made early enough. According to the timeline of the Pre-Lab presently considered, a cost review is planned in the second half of the second year of Pre-Lab. Thus, the selection of the schemes must be done early in this respect, too. On the other hand, we need some more time to reach the required technology with 100% certainty. As a compromise, we are planning to make the decision at the end of the first year of the Pre-Lab period. The procedure of the decision will be the subject to be discussed in the ILC Pre-Lab.

In the following sections some R&D items are assigned "priority". This means such an item must get a result by the above deadline. Those items that are not assigned "priority" can be done during the remaining three years of the Pre-Lab period. In the case the corresponding scheme is not selected, the R&D of this item may not be done.

The two schemes both require a technology of the remote target replacement. The technologies contain many common aspects so that only one of them is listed up in the following (in the e-driven section).

Technical Preparation: Undulator Positron Source

Outline :

The baseline design of the positron does not have showstoppers any more, however, a few final design choices as well as mainly engineering work has yet to be done. With respect to the ILC positron working group report[1)] substantial progress in the following areas has been done: Successful experimental tests of the thermal target stress, detailed design of radiative target cooling as well as a design of an alternative solid OMD (Optical Matching Device) design (pulsed solenoid) for yield securing with respect to the currently foreseen QWT (Quarter Wave Transformer). Within the Pre-Lab period the laboratory tests of the rotating target wheel and a detailed design of the magnetic bearing including a lab mock-up test are envisaged.

Further minor open issues, as for instance, optimised undulator parameters for the 250 GeV phase, are finalised within the IDT phase

Goals of the technical preparation (for Pre-lab phase 2022-2025):

We identify 3 areas for the development in the Prelab period, namely

A) Undulator
B) Target
C) Magnetic focusing System

There are other fields such as the acceleration to the damping ring but they are not essential since the design in the TDR is mostly sufficient.

The current status of the undulator scheme is summarized in the positron working group report 2018[1)], for more details see also 2)

Candidates for the participating labs

STFC Daresbury Laboratory,
STFC Rutherford Appleton Laboratory,
DESY,
University of Hamburg,
University of Mainz,
Helmholtz-Zentrum Geesthacht,
Karlsruhe Institute of Technology,
University of Frankfurt,
ANL?, JLAB?, SLAC?, LLNL, still under discussion

Technical Preparation：Undulator Technology

Outline：

The TDR adopted the superconducting helical undulator with the pitch 11.5mm, the maximum K parameter 0.92 (maximum field 0.86T), and the beam aperture 5.85 mm (diameter). One undulator is 1.75m long (field length) and 2 undulators are stored in a cryostat with the operating temperature 4.2K. The total net length is 147m in TDR but has been increased to 231m (132 undulators) when the center-of-mass energy at the project start was reduced from 500GeV to 250GeV.

A pair of undulators adopted was fabricated and tested at Rutherford Appleton Laboratory (RAL) and at Cornell University (see TDR 3-I, p128). It showed a sufficient magnetic field. Thus, among the whole area of the undulator scheme, the technology of the undulator itself is relatively well established. There still remain a few simulation issues. It may also be possible to re-optimize the undulator parameters. These are the subject of this WP.

Expected cost and human resources for the prelab phase:

Issue	Tasks		Cost (k$)	Human Resources (FTE, man-year)
Undulator	Simulation (field errors, alignment)		0	1

(not including corresponding costs for human resources)

Candidates for the participating labs

DESY,

University of Hamburg, Daresbury Lab.

Status and Prospects

Undulator prototypes at European XFEL: There are three long undulator systems in stable and routine operation at European XFEL, two planar undulator systems of about 200m length and a undulator system of about 120m length. The beam alignment requirement shot to shot is extremely tight in order for the FELs to lase and sophisticated feedback systems ensure that this is met routinely. All other X-ray FELs (LCLS, SwissFEL, FERMI@Elettra, SACLA, PAL XFEL) similarly operate with very long undulator systems and tight electron beam alignment control. A prototype ILC undulator module has been successfully produced and tested at STFC Rutherford Appleton Laboratory.

The remaining works of simulation.

(1) Detailed simulation studies concern the protection of the undulator walls from photons via masks (keeping the energy deposition below 1 W/m). The masks (Cu material) have an aperture radius of 2.2mm and are placed behind the quadrupoles. The total energy deposition in the masks is up to 300 W at the end of the undulatory. These studies will be finished within the IDT phase, more details see 3).

(2) Detailed simulation studies including the field errors and misalignment of the undulators

(3) Further undulator optimisation for the ILC 250 GeV stage
The study of the possibilities of higher K-value (K≤0.92) and smaller Undulator aperture (≤6.85 mm) at full undulator length of 231 m is foreseen for the IDT phase. Also the possibility of shorter pitch undulator can be studied. It will increase the pair production efficiency when the initial positron energy is low resulting in a yield enhancement or a decreasing of the active undulator length. Both intense simulation but also engineering study is planned for the final optimization.

The current positron baseline design offers a e+ beam polarisation of about 30% and is required to fulfil the physics goals already at the ILC 250 GeV stage (otherwise the systematic uncertainties can not be controlled, more details see 4). Including variations in undulator parameters (K, λ variation taken from undulator prototype) can result in a maximal reduction of polarisation to 27%. Ongoing studies show that this effect will be mitigated by a more uniform K and λ set-up along the undulator modules.

The feasibility of the final design for approaching a yield of 1.5 e+/e- even with a 125 GeV drive-beam is the goal within the prelab phase. The operation of the undulator at higher energies is straight forward, enhances the yield and even facilitates the operation. Concerning the luminosity upgrade no show stoppers are expected.

References

1) Positron Working Group Report, May 23, 2018, http://edmsdirect.desy.de/item/D00000001165115
2) S. Riemann et. al., 2002.10919 [physics:acc-ph].
3) Alharbi, K. et al., 2001.08024 [physics.acc-ph]
4) Fujii et al., 1801.02840 [hep-ph], PhD Thesis R. Karl, Hamburg University 2019, J. Beyer et al., 2002.02777 [hep-ex])

Technical Preparation: Target Technology

Outline：

TDR adopted target made of a titanium alloy (Ti6Al4V) of 0.4 radiation length (14mm) thick. It is mounted at the rim of a wheel of 1m diameter, rotating at 200 rpm (100m/s at the rim). This wheel must be located in a vacuum of ~10^{-6} Pa. The heat deposit by the beam is about 2kW.

The main issue is the cooling. TDR adopted water-cooling with magnetic fluid as the vacuum seal. However, R&D stopped due to the vacuum leak through the seal. Since then, a target with the radiation cooling mechanism has been studied. Up to now there has been on design works. This package aims from the design finalization to the fabrication of a full model.

Goals of the technical preparation (for Pre-lab phase 2022-2025):

Technical preparation items for the target technology are

- Design finalization of the rotating wheel with radiative cooling, and the laboratory test of a partial model. "Priority" is assigned on this issue.
- Magnetic bearings, feasibility study
- Fabrication of the full model

Expected cost and human resources for the prelab phase:

Issue	Tasks		Cost (k$)	Human Resources (FTE, man-year)
Rotating target wheel	Design finalization, partial lab test, mock-up design	priority	200	2
	Magnetic bearings : performance, specification, test		100	2x0.5
	Full wheel validation, mock-up		100	1+1 Engineers

(not including corresponding costs for human resources)

Candidates for the participating labs

Status and Prospects

a) Target Material Tests

Experimental tests were performed with the electron beam of the Microtron in Mainz (MAMI) to simulate the cyclic load as expected during ILC operation. The results of the irradiation tests at MAMI, including comprehensive material analyses (surface as well as structure) via laser scanning and synchrotron diffraction methods and comparison with detailed simulation studies with ANSYS showed that the expected load at the ILC positron target is below the material limits (more details, see [5]). The experiment has shown that the chosen material Ti-alloy is well suited for ILC operation. Nevertheless further target test at MAMI with alternative target materials (SF61, WF) are still foreseen in 2020 and will be finalized within the IDT phase.

Currently involved Institutes on this item:

DESY,

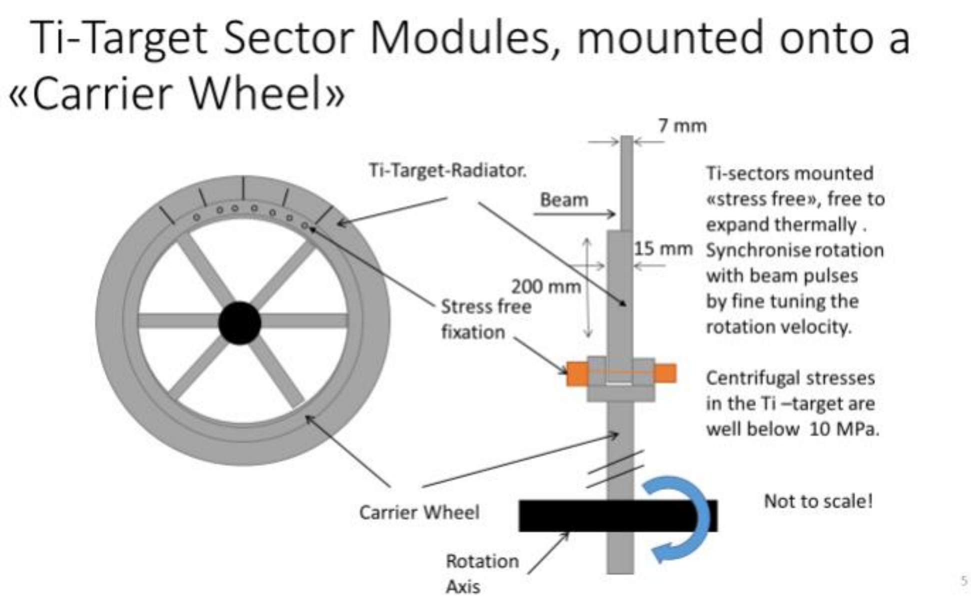
Hamburg University,

Mainz University,

Helmholtz-Zentrum Geesthacht.

b) Cooling by thermal radiation

Shown in the attached figure is the design for radiation cooling of the rotated wheel (without the cooler, Figure will be updated). No technical show stoppers are expected, the engineering design has been further revisited for optimisation reasons only.



The deposited power in the target is 2kW (nominal luminosity) and the heat radiates from the spinning target in vacuum to a stationary water-cooled cooler. The efficiency of cooling depends on temperature, radiating surface and surface emissivity and is determined by the thermal conductivity of the Ti-alloy (low thermal conductivity of about 0.06-0.15 K/cm/s). A monolithic Ti-target/radiator unit is assumed, so that no thermal interface with different material is required. The heat is accumulated in the rim near to the beam path. With nominal load (1312 bunches/pulse), the peak temperature in a Ti6Al4V target wheel reaches ~500 C; the maximum average temperature (along beam path at the target) is about 460 C. Although the experimental target tests at MAMI simulating the cyclic impact at the ILC (mentioned above) have shown that the target endures the load, it is foreseen to further optimise the device. For instance, extending the wheel radius to about 55.-60. cm with beam impact at 50 cm. could give a substantial reduction. Increasing the Ti-thickness from 0.7 cm to 1.5 cm, —outside the beam impact area— is in principle equivalent to a substantial increase of thermal conductivity. Detailed further simulations are planned within the IDT period. Concerning a luminosity upgrade: mounting a special radiator (Cu for instance) to the target rim is foreseen for such upgrades.

For the IDT and the first year of the prelab phase, it is planned to do an experimental mock-up test and test the cooling efficiency with a small sector of the wheel under vacuum. This should confirm that the cooling works as expected considering emissivity and special cooling surface design and to check the average temperatures.

c) Rotating target

Detailed ANSYS simulations are to be performed to verify dynamic effects, stress waves and vibration modes of the wheel, providing the specifications for the final drive and bearing of the rotating target designed by engineers within the prelab phase.

d) Magnetic bearings

Radiation cooling allows magnetic bearings. Magnetic bearings are vacuum-tight and can be operated over long time without maintenance at high rotation speed. Magnetic bearings are widely used and are standard components and can easily be adapted to our needs by industry (, for instance SKF in Germany, Jülich Kernforschunszentrum). For the prelab phase a feasibility study and proto-typing with the respective supplier is envisaged. The feasibility test is planned in vacuum with a subunit consisting of realistic axis, weight and preferable with the correct moment of inertia, accomplishing the expectations about vibrations and required velocity control.

Currently involved Institutes on this item so far:

STFC Daresbury Laboratory&Lancaster University

(ILC target wheel prototype in 2011, see [6]),

DESY,

Hamburg University,

possible further candidates: JLAB? SLAC?, LLNL?

References:

(5) F. Dietrich et al, 1902.07744 [physics.acc-ph], A. Ushakov et al., IPAC2017 (TUPAB002) and T. Lengler, BaThesis, Hamburg University 2020)

(6) I.R. Bailey et. al, EUROTeV-Report-2008-028-1, EPAC08 (MOPP069)

Technical Preparation：Magnetic Focusing System

Outline：

The positrons created at the target must quickly focused right after the target. TDR adopted the Flux Concentrator as the Optical Matching Device (OMD) with the peak field 3.2 Teslas. It must have a field flat-top around 1 ms. However, it turned out later that the time dependence of the field is inevitable due to the long pulse.

In the latest design the QWT (Quarter Wave Transformer) with the peak field about 1 Tesla is adopted as the OMD. However, it does not seem to give a sufficient the positron yield. The choice of the OMD is essential for the positron source of the undulator scheme.

The possible candidates of the OMD are:

(a). Pulsed solenoid
(b). Plasma lens
(c). QWT with increased field
(d). Flux Concentrator

First, the choice among these must be made with realistic considerations of the engineering and with full simulations of the positron yield.

Goals of the technical preparation (for Pre-lab phase 2022-2025):

Technical preparation items for the magnetic focusing system (OMD: Optical Matching Device)

- Final design choice among the possible focusing devices with yield calculation
- Construction of the prototype of OMD and the rotating wheel

Expected cost and human resources for the prelab phase:

Issue	Tasks		Cost (k$)	Human Resources (FTE, man-year)
Magnetic focusing	Design selection (FC, QWT, Pulsed solenoid, Plasma lens), with yield calculation	priority	0	1
	OMD+wheel fully		500	2

	assembled			

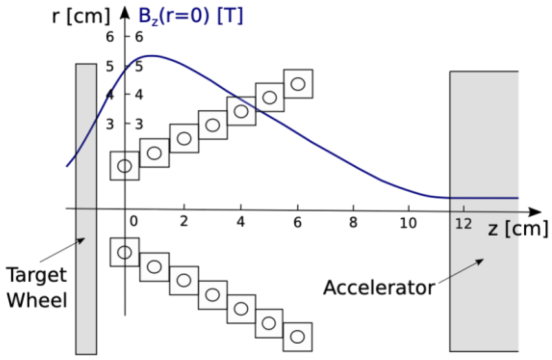
(not including corresponding costs for human resources)

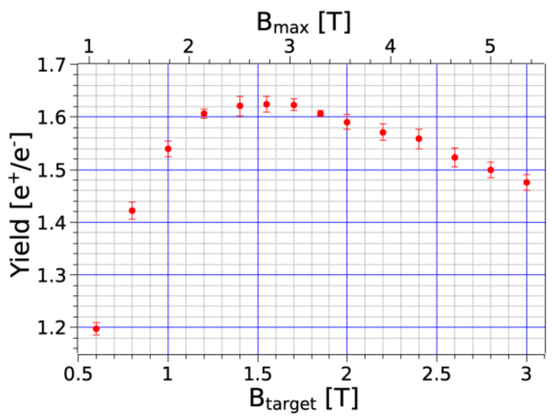
Status and Prospects

We describe here each of the OMD candidate.

a) Pulsed solenoid

As shown in the two figures below, using a pulsed solenoid as OMD will provide a sufficiently high magnetic field in the capture section to provide a yield of e+/e-=1.5. The main engineering issues were studied and no showstoppers found. The interaction, i.e., the interference of the pulsed solenoid with the fast-rotating Ti-wheel have been estimated and less than 200W in average are expected to be deposited in the wheel. Further more detailed simulations are currently ongoing. Within the IDT phase these simulations will be accomplished via yield calculations including also possible field deformations due to the fast-rotating target wheel.





b) Plasma lens:

New studies exploit the current progress made in plasma technologies and apply a plasma lens of 3000 A as OMD for the ILC e+ source. Simulations predict about a two times higher yield than the QWT (see more detail (7)). This progressive technology is just rising, involving new parts of the community leading to possible new contributors in the field. Grant application with respect to prototype experiments for such plasma lens has been submitted. Depending on the approval the prototype experiments would still happen within the prelab phase and could be envisaged as alternative OMD at a later stage.

c) QWT (Quarter Wave Transformer):

The QWT considered so far (ANL) provides a matching device with zero magnetic field at the target and a maximum magnetic field of 1T. However, the expected yield seems not to be sufficient with the current set-up (yield below 1). No engineering study has been performed.

d) Flux Concentrator

The TDR design adopted the flux concentrator with the peak field > 3 Teslas. However, it turned out there is a time dependence of the field within the beam pulse length ~1 ms due to the skin depth at the low frequency. Nonetheless, there may still be a chance to develop a better flux concentrator.

Highest priority as OMD is the pulsed solenoid. Within the IDT phase and the first year of Pre-Lab period detailed simulation shall result in precise specification required for the engineering design planned for the prelab phase.

Currently involved Institutes on this item so far:
DESY,
CERN,
University of Hamburg,
Karlsruhe Institute of Technology,
University of Frankfurt,
Mainz University,
possible further candidates: SLAC?

References

(7) M. Formela et al., 2003.03138 [physics.acc-ph]

Technical Preparation: e-Driven Positron Source