Ver-1：2022/March/2

Time-critical WPs for the ILC construction

(For Sources Only)

IDT-WG2

Time-critical WPs for the ILC construction

IDT-WG2

(Ver.1,2022-March-2)

The MEXT ILC advisory panel recommends that the development work in the key technological issues for the next-generation accelerator should be carried out by further strengthening the international collaboration among institutes and laboratories, shelving the question of hosting the ILC. This document is a re-organized summary of the time-consuming work packages for ILC construction.

The previous "Technical Preparation and Work Packages (WPs) during ILC Pre-lab"[1] summarized the accelerator work necessary for producing the final engineering design and documentation during the ILC Pre-lab[2] phase. A total of 18 WPs (3 SRF, 8 Sources, 7 DR/BDS/Dumps) were proposed as illustrated in Figure 1.

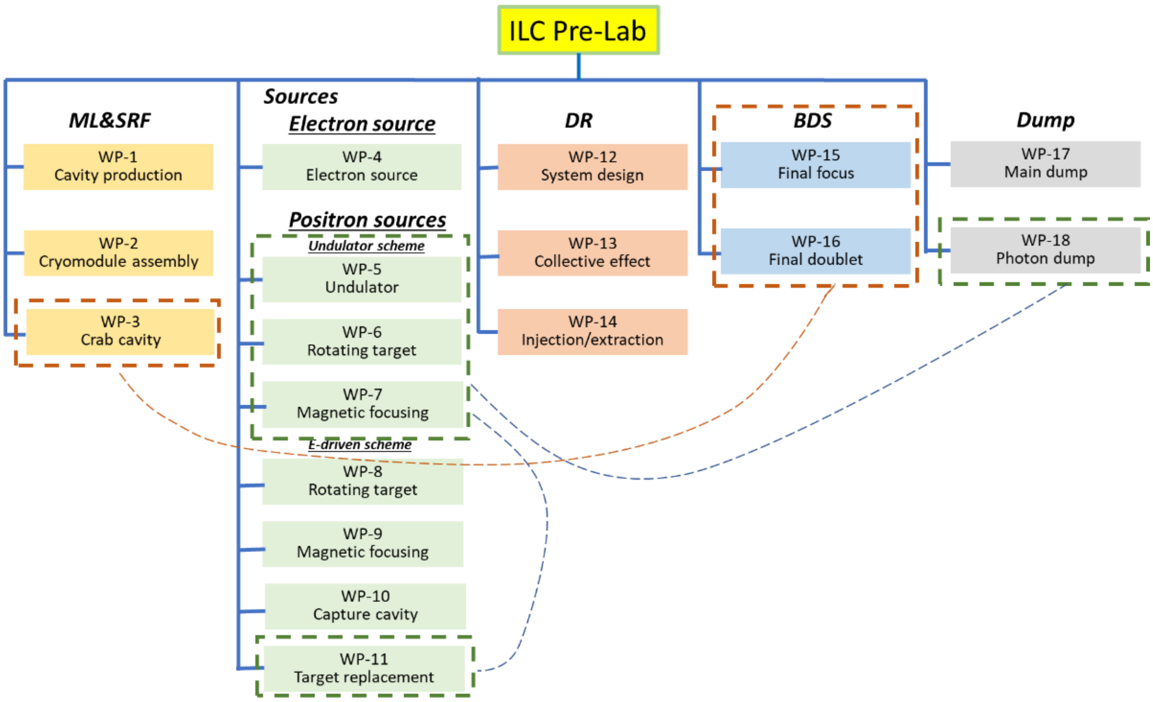

Figure 1: Summary of work packages.

Some essential (and time-consuming) WPs (so called "time-critical WPs") start earlier by international collaboration. We assume here that Pre-lab will start ~2years later. (Total Pre-lab period can be squeezed since the time-consuming WPs started in advance.) Figure 2 shows the schedule assumptions for the time-critical WPs.

The Pre-lab work-packages are categorized by "A", "B" and "Pre-lab" where

A: Essential and higher-priority WP item,

[1] http://doi.org/10.5281/ zenodo.4742018

[2] Proposal for the ILC Preparatory Laboratory (Pre-lab), https://doi.org/10.5281/zenodo.4884744

B: WP item that should be started early if possible,
Pre-lab: WP item that can be done during Pre-lab.

In this document, only Priority A and B are summarized. The required budget, FTEs, etc. are summarized in the Appendix.

The time-critical WPs will be implemented on the basis of the MoUs between the international Institutes. It is envisaged that this document will be used for negotiations between the candidate Institutes.

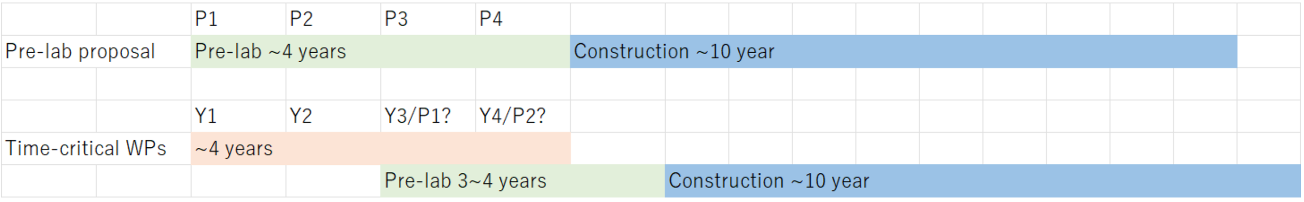

Figure 2: Assumed schedule of the time-critical WPs

2:Sources

(Ver.1,2022-March-2)

WP-prime 4: Higher voltage ILC Photo-gun R&D

Program and schedule:

WP4 consists of the drive laser system, high-voltage photo gun and GaAs/GaAsP Photocathodes. Among these the photon gun is the most urgent item. It is selected as WP-prime 4 (category B).

A high voltage photo-gun meeting the beam specifications of the 90-120 kV SLC gun was required during the GDE, with increased voltage, reduced vacuum and no field emission. Jefferson Lab built two ILC prototype guns, adopting an inverted geometry high voltage insulator design. The first gun was operated to 225 kV after gas-conditioning, and the second gun was commissioned to 200 kV and then operated at 130 kV since 2010. Both guns would meet the requirements of the TDR, providing 4.8 nC bunches within a pulse duration of 1 nsec from a laser with diameter of 1 cm at the photocathode.

However, experience during the past 10 years motivates further improvements to the ILC gun technical design. Still, based upon the inverted insulator geometry, improvements have been made a) improving the high voltage triple point junctions, to achieve higher operating voltage while maintaining maximum gradients < 10 MV/m to prevent field emission, b) for improving the cathode-anode geometry to suppress asymmetric fields within the accelerating gap to suppress beam deflection and aberration, and c) for improving the vacuum design to achieve extreme high vacuum and limiting ion back-bombardment, required for long photocathode quantum efficiency (QE) lifetime.

Additionally, gun voltages >200 kV offer the potential for meaningful performance improvements, by a) exploring laser pulse lengths shorter than 1 nsec to relax sub-harmonic bunching requirements, and b) exploring the benefit of reduced ion back-bombardment QE degradation, because the ionization cross section decreases rapidly with electron beam energy.

The proposed work over a 2 year period includes,

- beam dynamics simulations of shorter <1 nsec, higher peak current bunches that define the allowable initial longitudinal and transverse laser pulse shapes,
- an electrostatic design which maximizes gradient at the photocathode while limiting gradient on the electrode surfaces to < 10 MV/m when operating at voltage ~300 kV,
- a triple point junction shield design to linearize potential along the inverted insulator,
- a tilted biased anode design to correct for the asymmetric electrostatic field created by the insulator,
- vacuum modeling to achieve static vacuum <2 x 10-12 Torr, and
- a biased anode design to limit ion back-bombardment from entering the cathode anode gap, to extend photocathode operating lifetime.

The scope, tasks and projected timeline are detailed in the table below.

Main task	Sub-task	Detailed task	Year 1				Year 2				Year 3			
			Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Beam dynamic simulations	Explore laser pulse & shape	Determine laser 3D profile for short, high peak current bunches + large XY to limt ion damage (GPT ion module)												
Electrostatic design	Electrode	Define electrode size to accommodate laser transverse size (CST)												
		Maximize gradient at the photocathode < 10 MV/m: Define flat or focusing geoemtry (CST+GPT)												
	Anode-cathode gap	Design biased anode and drift tube to limit ion-bombardment. (CST+GPT)												
		Design anode to compensate beam deflection. (CST+GPT)												
	HV Feedthrough	Design HV Feedthrough compatible with 350 kV commercial cable												
		Define HV chamber size based on HV feedhtough and electrode size, and on anode-cathode gap												
		Design triple point junction shield to linearize potential along HV feedthrough keeping E<10 MV/m at 350 kV												
Vacuum modeling	NEG modules	Define pumping scheme to achieve <1E-12 Torr												
	Anode support	Optimzie anode drift tube to limit photocathode ion damage (MOLFLOW+GPT+CST)												
Electrostatic + vacuum design ready														
Engineering design	Vacuum chamber + NEG modules	Design and produce engineering drawings												
	HV Feedthrough	Work with vendor to develop engineering design and drawings												
	Electrode + triple point junction shield	Design electrode + shield + front and back ends												
	Electrode support structure	Design electrode suppoort to HV feedthrough with internal shape to accept photocathe pucks												
		Design puck for dummy SS substrate puck												
	Anode + support frame	Design anode + drift tube + support frame												
Engineering drawings ready														
Fabrication	Vacuum chamber + NEG modules	Procure, vendor makes NEG modules												
		Procure, vendor fabricates vacuum chamber												
	HV Feedthrough	Procure HV feedthrough												
		Vendor fabricates HV feedthrough												
	Electrode + triple point junction shield	Fabricate electrode												
		Fabicate triple point junction shield												
	Anode + support frame	Fabricate anode and drift tube												
		Fabricate anode support frame and biasing/mounting hardware												
	Electrode support structure	Fabricate electrode attachment to HV feedthrough with internal shape to accept photocathe pucks												
		Fabricate Mo puck for dummy SS substrate puck												
Components ready														
Assembly	Vacuum chamber + NEG modules	Vacuum bake at 400 C for deagassing												
		Install NEG modules, screen, extractor gauge												
	Electrode + triple point junction shield	Vacuum degass to 900 C												
		Polish												
		Clean												
	HV Feedthrough	Weld to flange + leak check												
		Clean electrode attachamnet support and dummy puck with SS substrate												
		Mount electrode + triple point junction shield + dumy puck and fiducial												
		Install on chamber and align per fiducal												
	Anode assembly	Vacuum degass to 900 C												
		Polish												
		Clean												
		Assemble and install on chamber and fiducial												
Gun ready for vacuum bake														

Work Packages for the Undulator Positron Source

Overview

The baseline design of the positron source no longer has impediments to its further progress. A full-scale working superconducting ILC undulator module has been successfully demonstrated and tested [1]. A prototype experiment for an undulator-based polarised positron source has already been successfully performed at SLAC [2]. Furthermore, several years of successfully operating FELs with very long undulator sections exist [3] and their alignment requirements exceed by far the requirements of the undulator-based e+ source. The ILC baseline design has been described in detail in the ILC TDR (Vol 3-II, Chapter 5, 2013) including a remote-handling scheme for the target assembly as well as a low-intensity auxiliary source for commissioning purposes. A few final design choices and engineering works have yet to be completed. Since the ILC positron working group report [4] was made in 2018, substantial progress had been achieved in the following areas: successful experimental tests of thermal target stress, the detailed design of radiative target cooling, and the design of an optical matching device (OMD), a pulsed solenoid, for securing the required yield overhead factor of 1.5 [13]. The undulator positron source IDT work packages are listed below.

WP5 (Undulator)

minor design choices of the undulator parameters and its masks design, alignment requirements and optimized undulator parameters for the 250-GeV phase, will be finalized soon [6]. This will not be included in the category A and B.

WP6 (Rotating target)

Parts of WP6 items (Full wheel validation) concern engineering issues and some technical specifications, for instance those of the magnetic bearings or target tests [8], have been done already, see also [9,10,12]. But since the engineering design for the full wheel validation depend on the final technical specifications of the OMD, this WP6 will be accomplished subsequently (category B).

WP7 (Magnetic Focusing System)

Within the next 2 years, laboratory tests of a prototype and lab measurements of the magnetic field for different pulses, the eddy currents etc. are envisaged so that the final design of the OMD is finished. This is the most urgent work (Category A).

A prototype for an alternative OMD design, based on new accelerator technologies, using plasma lens as focusing system, have already secured funding from the German BMBF and are envisaged within this time period as well (Category A) [11].

Concrete Plans for year 1+2

WP7 (Magnetic Focusing System)

Detailed simulations (magnetic forces, stresses and temperatures in the coil conductor, including retaining bolts, yield calculations with varied target-solenoid gaps below 4mm, increased magnetic field at the target) for the pulsed solenoid are already ongoing so that the principal design for a prototype pulsed solenoid can be specified in the first half of year one.

Based on those results the production engineering for the 1:1 scaled pulsed prototype can started, so that the actual measurements can already be started in the second phase of year one. Envisaged are field measurements with 1kA (pulsed and DC) and with 50kA both in a single pulse mode and finally in a 5ms pulsed mode. These measurements are envisaged to take about one year so that the final OMD design can be finished within the second year.

Also the prototype for an alternative OMD design, the plasma lens, will be envisaged until the end of year two with already approved funding.

WP6 (Target)

The 'priority B' items, the engineering design and vendor negotiations for the magnetic bearings as well as the mock-up for the radiation cooling of the rotating wheel is therefore be scheduled towards the end of year 2.

References:

[1] D J Scott et al, Demonstration of A High Field Short Period Superconducting Helical Undulator Suitable for Future TeV-Scale Linear Collider Positron Sources, PRL 107, 174803 (2011).

[2] G. Alexander, J. Barley, Y. Batygin, S. Berridge, V. Bharadwaj, G. Bower, W. Bugg, F. J. Decker, R. Dollan and Y. Efremenko, 29et al., Observation of Polarized Positrons from an Undulator-Based Source, Phys. Rev. Lett. **100** (2008), 210801; G. Alexander, J. Barley, Y. Batygin, S. Berridge, V. Bharadwaj, G. Bower, W. Bugg, F. J. Decker, R. Dollan and Y. Efremenko, et al., Undulator-Based Production of Polarized Positrons, Nucl. Instrum. Meth. A, **610** (2009), 451-487.

[3] Heung-Sik Kang et al, Journal of Synchrotron Radiation, Vol 26, p1127-1138, July 2019; H-D Nuhn, Proceedings of FEL 2009, p714, https://accelconf.web.cern.ch/FEL2009/papers/thoa02.pdf

[4] Positron Working Group Report, May 23, 2018, http://edmsdirect.desy.de/item/D00000001165115.

[5] S. Riemann et. al., 2002.10919 [physics:acc-ph].

[6] K. Alharbi, et al., 2001.08024 [physics.acc-ph]

[7] K. Fujii et al., 1801.02840 [hep-ph], PhD Thesis, R. Karl, Hamburg University, 2019, J. Beyer et al., 2002.02777 [hep-ex])

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

[9] I. Bailey et. al, EUROTeV-Report-2008-028-1, EPAC08 (MOPP069). I. Bailey et al., IPAC2010 (THPEC033).

[10] S. Antipov et al., PAC07 (THPMN087).
[11] M. Formela et al., 2003.03138 [physics.acc-ph].
[12] M. Breidenbach et al., PoS ICHEP2016 (2016) 871.
[13] C. Tenholt, talk at ICLX workshop, Nov. 2021; M. Fukuda, G. Loisch, M. Mentink, G. Moortgat-Pick, T. Okugi, S. Riemann, P. Sievers, C. Tenholt, K. Yokoya, in preparation.

Work package	***Items***
WP- 5: Undulator	Simulation (field,errors, masks, alignment, optimisation for 250GeV)
WP- 6: Rotating target	Design finalization, partial laboratory test, mock-up design
	Magnetic bearings: performance, specification, test
	Full wheel validation, mock-up
WP- 7: Magnetic focusing system	Design finalisation for the pulsed solenoid, including yield calculation
	OMD with fully assembled wheel

Work Packages for the Electron-Driven Positron Source

WP-prime 8: Rotating Target

The aim of the work package is to develop the technical design of the rotating target for E-Driven e+ source for ILC. It consists from three sub-packages: Target stress calculation, vacuum seal study, and target module prototyping. The first two sub-packages should be proceeded with a high priority, and the prototyping is made at a low priority.

WP-prime 9: Magnetic Focusing System

The aim of the work package is to develop the technical design of the magnetic focusing system for E-Driven e+ source for ILC. The prototyping of the device should be executed with a low priority. Other sub-work packages for the conductor study mainly by FEM simulation, and a conceptual design study for the transmission line should be proceeded at a high priority.

WP-prime 10: Capture Cavity and Linac

The aim of the work package is to develop the technical design of the capture linac including the APS cavity and the operation. The all prototype work should be executed at a low priority. Other sub-packages for the beam loading compensation and the operation should be proceeded at a high priority.

Work Package common to the Undulator and e-Driven system

WP-prime 11: Target Maintenance

The aim of the work package is to complete the technical design of the target exchange system as a common effort for E-Driven and Undulator positron sources. This WP is defined as one in the prelab. Proposal, but it should be divided as 11-1) conceptual design, 11-2) Technical design, and 11-3) Component prototyping. 11-1) and 11-3) should be executed at a high priority, and 11-2) at a low priority.