Ver-8: 2022/June/10

Time-critical WPs for the ILC construction

IDT-WG2

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IDT-WG2
(Ver.6,2022-May-12)

The MEXT ILC advisory panel recommends that the development work in key technological areas for a next-generation accelerator should be carried out by further strengthening the international collaboration among institutes and laboratories, putting aside for now the question of hosting the ILC. The panel also states that it is premature to start the ILC Pre-lab at this time.

This document is a re-organized summary of the most time-critical and essential work packages for ILC construction, compiled in order to address key technology issues for a next electron positron collider in the most efficient manner, with a concerted international effort, as suggested by the panel.

A previous document ("Technical Preparation and Work Packages (WPs) during ILC Pre-lab" (TPD)[1]) summarizes 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.

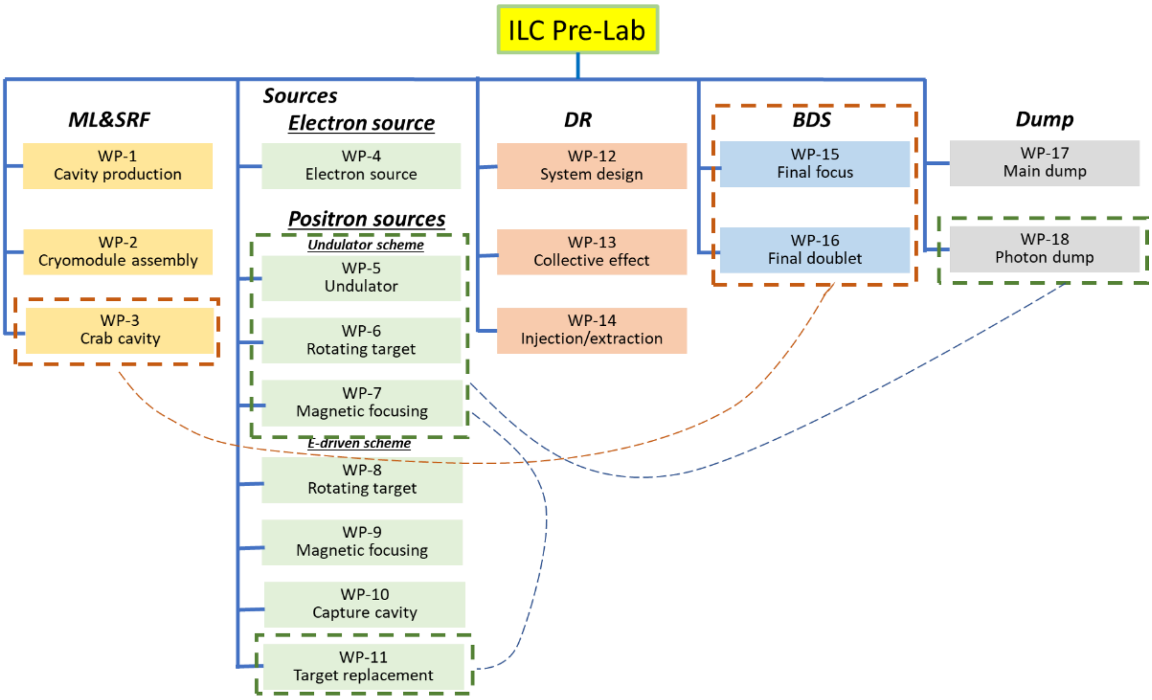

Figure 1: Summary of work packages.

The WPs (so called "time-critical WPs") described below are intended to started early 2023 by international collaboration. We assume here that Pre-lab can start ~2years later. In this way the overall and initial foreseen

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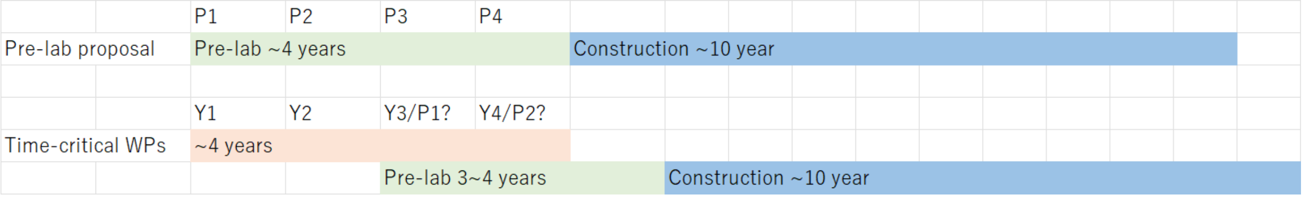
[1] http://doi.org/10.5281/ zenodo.4742018

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

total Pre-lab period can be partly reduced with the time-critical and time-consuming WPs starting in advance. This is illustrated in Figure 2 below.



		P1	P2	P3	P4		
Pre-lab proposal		Pre-lab ~4 years				Construction ~10 year	
		Y1	Y2	Y3/P1?	Y4/P2?		
Time-critical WPs		~4 years					
				Pre-lab 3~4 years			Construction ~10 year

Figure 2: Assumed schedule of 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,
B: WP item that should be started early if possible,
Pre-lab: WP item that can be done during Pre-lab.

We have compiled the work foreseen into 15 priority work packages differentiating them by “WP-prime” as shown in Figure 3. For our considerations here, we have prioritized those that are particularly important and time-consuming, starting from the WP proposals in the Pre-lab document referred to above.

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

The time-critical WPs will be implemented on the basis of MoUs (Memoranda of Understanding) between the participating institutes or funding agencies. It is envisaged that this document shall provide the initial basis for negotiations between the collaborating partners.

The total resources needed for the priority WPs is approximately $13M (material) and 120 FTE-yr (personnel), and the plan is to be implemented in 2 to 4 years. The Appendix lists the annual plan and the institutions that are at this time considered likely candidates.

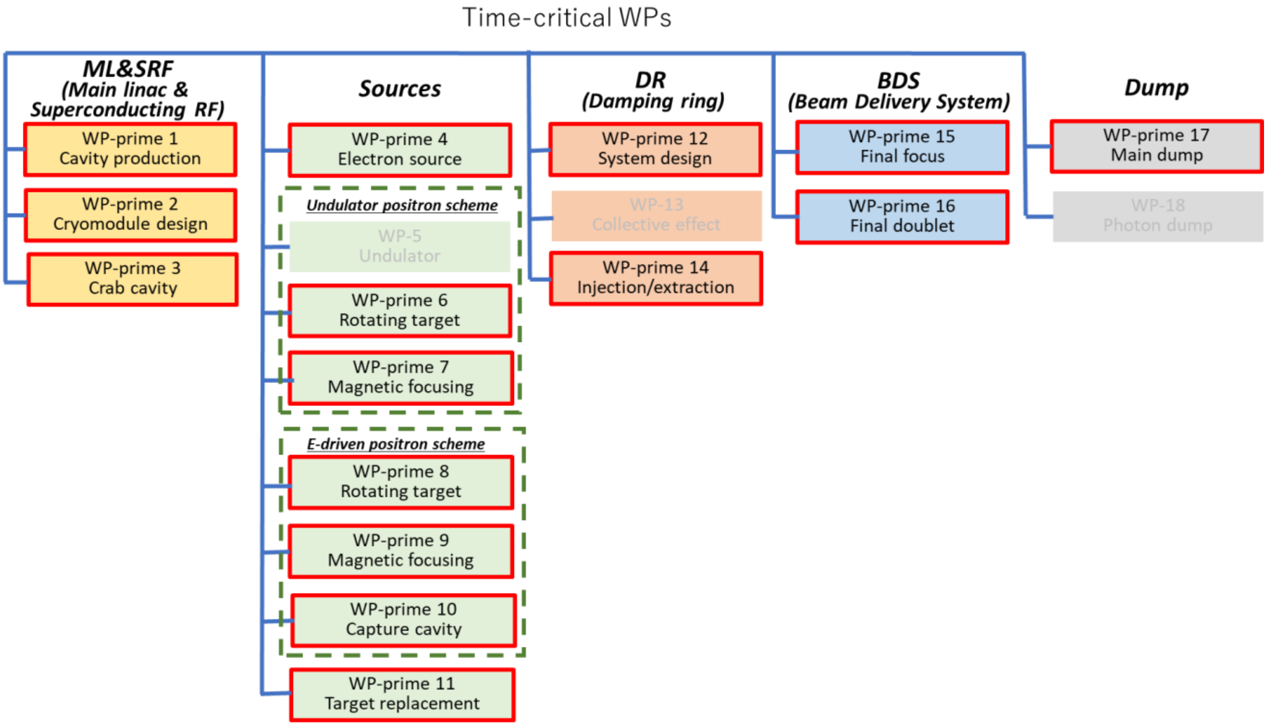


Figure 3: Time-critical WPs

1: ML and SRF

(Ver.4,2022-June-10)

Time-critical WPs in this domain:

WPs-1 to -3 in TPD are dedicated to the SRF ML and BDS-Crab cavity. The Time-critical WPs, (named WP-prime 1, 2, 3) will be preliminary and scaled-down versions of the TPD content. It is assumed that the Time-critical WPs will be implemented in international cooperation with shared contributions to budgets. The brief overview is as follows.

- WP-prime 1
  - Fundamental research using 1-cell cavities to prepare for 9-cell cavity production
  - High pressure gas safety regulation issues to be addressed
  - 9-cell cavity production with common specifications as a global effort
  - 9-cell cavity production as a domestic contract
- WP-prime 2
  - Finalization of CM drawings including ancillaries such as the tuner, coupler and SC magnet
  - High pressure gas safety regulation issues to be addressed
- WP-prime 3
  - Prototype crab cavity production
  - Harmonized test with two crab cavities
  - Final down selection
  - Engineering design of prototype CM

In WP-prime 1, eight 9-cell cavities will be produced in each region with the budgets provided by the regions, for a total of 24 cavities. This number installed into cryomodules (CMs) produced in the Pre-lab phase (currently assumed to start in Y3) will satisfy the high pressure gas safety (HPGS) regulation in Japan. The process will be to establish globally agreed, common specifications. Procurements/contracts will be implemented individually in each of the three regions. This process will provide essential experience for the ILC SRF cavity production.

As 10 years have passed since the Technical Design Report (TDR) was completed, the cavity production process may be updated with some improvement and with more recent sophisticated methods as developed for the European XFEL and LCLS-II. In considering this new production process, if the results of the first vertical test (VT) are not acceptable, a second VT will be performed. However, the additional surface treatments required for this may need to be contracted separately whilst satisfying “plug compatibility” interfaces, as the available infrastructure is different in each institute. The more detailed technical specifications will need to be discussed and decided by the IDT WG2 SRF group.

In addition to the 24 cavity production above, several additional 1-cell/9-cell cavities may be produced. To prepare for 9-cell cavity production, 1-cell studies will be important as the first step in Y1. Japan will plan to produce additional 9-cell cavities on top of the eight with individual Japanese funding, as Japan will need more mass-production experience. These additional 9-cell cavities need to satisfy with the HPGS regulation in Japan. EU and US will plan further, depending on their own judgements.

The VT for 9-cell cavities produced above will be done in each region, and the success yield for 1st pass and

2nd pass will be evaluated. For the 3rd pass and beyond, further discussion is required.

In WP-prime 2, the CM drawings will be finalized by common CAD software in each region. This includes the design of tuners, couplers and SC magnets. Some small cost and FTE is required for this task.

For WP-prime 3, the content is essentially the same as in the TPD: two designs will be pre-selected at the first down-selection in Sep/2022. Two prototype cavities for each design will be produced and synchronously tested at low temperature. Based on the results, a second down-selection will be conducted to choose one design and a prototype CM design will be prepared as the last remaining design work. These will be promoted mainly in Europe and the U.S., however, there is a possibility that Japan will also supply superconducting (Nb and NbTi) materials as an in-kind contribution.

These Time-critical WPs will proceed as follows: material procurement in Year 1, cavity production in Year 2-3, and performance testing and success yield evaluation in Year 3-4, (hopefully) corresponding to ILC Pre-Lab years 1-2.

WP-prime 1: Cavity Industrial-Production Readiness

Program and schedule:

WP-prime 1 aims to prepare for the SRF cavity industrial production readiness. The plan is based on the global cavity fabrication of ~ 3 × 8 cavities with the required RF performance to demonstrate the ILC baseline field gradient of 35 MV/m at $Q \geq 0.8$ E10 with ≥ 90% success yield. The cavity production process will be replaced with new and more sophisticated methods developed since TDR. These 9-cell cavities are not expected to be equipped with helium tanks or magnetic shield, as they will not be immediately installed into CMs.

Goals of the workpackage

Parameters	***Unit***	***Design***
Baseline: Cavity gradient, E, at Q value (Q_0) (Cost-Reduction R&D goal: E, at Q value)	MV/m	35 at $Q \geq 0.8$ E10 (38.5 at $Q \geq 1.6$E10)
Cavity production yield	%	90

List of items:

Priority	*Items*	Y1	Y2	Y3	Y4
A	1-cell cavities: Fundamental research (for establishment of production/surface treatment process)	All	All (half)		
A	9-cell cavities: HPGS regulation issues to be settled	All			
A	Purchasing SC material (Nb, NbTi) contributed by JP	All			
A	Industrial production with globally shared contracts		All	All	
A	1st vertical test (VT), and further efforts (2nd and later cycle process)			All	All
A	Clean room work procedure (Robotics technology to be matured)	All	All	All	All
A	Quality control/assurance	All	All	All	All
Note: 9-cell cavity production is assumed to be continued after Y3 (totally 120 cavities in TPD)					

WP-prime 2:

Program and schedule:

WP-prime 2 aims to finalize the CM envelope drawing including tuner, coupler, SC magnet. The common CAD software is to be used in the three regions. High pressure gas safety regulation related to CM design should be also solved.

Goals of the workpackage

- Finalization of CM envelope drawing including tuner, coupler, SC magnet and the other ancillaries
- Issues related to HPGS should be solved

List of items:

Priority	Items	Y1	Y2	Y3*	Y4
A	Finalization of envelope drawing including tuner, coupler, SC magnet	All	All		
A	High pressure gas safety regulation	All	All		
* Note: CM production is assumed from Y3					

WP-prime 3:

Program and schedule:

WP-prime 3 aims to carry out first down selection, produce prototype cavities for two designs, and perform the synchronized test. After second down selection, single design will be decided, and final CM engineering design will start. Production and testing a prototype CM will be done following Pre-lab phase (after Y5).

Goals of the workpackage

Parameters	***Unit***	***Design***
Crab kick voltage at beam energy of 125 GeV	MV	0.615 @ 3.9GHz 1.230 @ 2.6GHz 1.845 @ 1.3GHz
Uncorrelated phase jitter at 125 GeV (rms)	fs	49

List of items:

Priority	***Items***	Y1	Y2	Y3	Y4
A	Decision of installation location with cryogenics/RF location accelerator tunnel	All			
A	Confirm the complete CC system specifications	All			
A	Development of CC cavity/coupler/tuner integrated design (ahead of Preliminary CC technology Down-selection)	EU, AM			
A	Preliminary CC technology down-selection (2 cavity options)	All			
A/B	CC Model-work and Prototype production and high-power validation of CC cavity/coupler/tuner integrated system (incl HPGS provision) for two primary candidates (ahead of Final CC technology Down-selection)	EU, AM	EU, AM		
B	Perform harmonized operation of the two prototype cavities in a vertical test to verify ILC synchronization performance (cryo insert development and commercial optical RF synchronization system).		EU, AM	EU, AM	
A/B	Final CC technology down-selection			All	
B	Preliminary Crab Prototype CM (pCM) design – confirming dressed cavity integration and compliance with beam-line specification (incl HPGS provision)			EU, AM	EU, AM
B	Final pCM engineering design prior to production			EU, AM	EU, AM
Note: Production of pCM is assumed after Y5 (P3)					

2:Sources

(Ver.4,2022-May-12)

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

Time-critical WPs in this domain:

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).

Program and schedule:

A high voltage photo-gun, meeting the beam specifications of the 90-120 kV SLC gun as specified during the GDE, will be 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. Based upon the inverted insulator geometry, improvements have been made in: a) the high voltage triple point junctions, achieving higher operating voltage while maintaining maximum gradients < 10 MV/m to prevent field emission; b) the cathode-anode geometry to suppress asymmetric fields within the accelerating gap to suppress beam deflection and aberration, and; c) the vacuum design to achieve extremely high vacuum and limiting ion back-bombardment, required for long photocathode quantum efficiency (QE) lifetime.

Additionally, gun voltages >200 kV offer the potential for significant performance improvements. Laser pulse lengths shorter than 1 nsec may relax sub-harmonic bunching requirements. Benefits from reduced ion back-bombardment QE degradation, as 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

Time-critical WPs in this domain:

The required work related to the undulator positron source includes the undulator (WP-5), the rotating target (WP-6) and the magnetic focusing system (WP-7). The most urgent issue in this category is the focusing system and the target.

Overview of the undulator positron source

The baseline design of the positron source no longer has impediments to 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 been successfully performed at SLAC [2]. Furthermore, for several years FELs with very long undulator sections exist have been successfully operating [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.

Among the IDT work packages, for the 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]. Hence, this will not be included in the category A and B and can be done within the Pre-lab phase.

WP-Prime 6 (Rotating target)

Parts of WP6 (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 depends on the final technical specifications of the OMD, this WP6 work can be delayed (category B).

WP-Prime 7 (Magnetic Focusing System)

Within the next 2 years, laboratory tests of a prototype and measurements of the magnetic field for different pulses and of the eddy currents etc., are envisaged to allow the final design of the OMD. 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].

Program and schedule for year 1+2:

WP-Prime 6 (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 can be scheduled towards the end of year 2.

WP-Prime 7 (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 scale pulsed prototype can be started, so that the 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, is envisaged for completion by the end of year two with funding already approved.

List of items:

WP-Prime 6

Priority	*Items*	Y1	Y2	Y3	Y4
B	Design finalization, partial laboratory test, mock-up design		▨		
B	Magnetic bearings: performance, specification, test			▨	▨

WP-Prime 7

Priority	*Items*	Y1	Y2	Y3	Y4
A	Design selection (FC, QWT, pulsed solenoid, plasma lens), with yield calculation	▨	▨		
A	Prototype plasma lens	▨	▨	▨	

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Work Packages for the Electron-Driven Positron Source

This area consists of the rotating target (WP8), magnetic focusing system (WP9) and capture cavity and linac (WP10). There are urgent items in each category.

WP-prime 8: Rotating Target

The aim of the work package is to develop the technical design of the rotating target for the electron-driven positron source (E-Driven e+ source) for ILC. The work package is redefined as five sub-packages: target stress calculation, vacuum seal study, design study for the prototype, fabrication of the prototype, and writing EDR.

For the final confirmation of the target technology, it is essential to create a prototype and conduct its long-term operation test. EDR of the target is established only after the completion of the test experiment. Because the fabrication of the prototype is costly, this part has to be postponed to the pre-lab period.

Currently, a test run of the magnetic fluid seal unit, which is the core part of the target technology, is underway. In long-term rotation tests with a load whose mechanical properties (weight and moment) are equivalent to those of the actual target, good results have been obtained, including holding vacuum pressures in the 10^{-7} Pa range. Test operation of this seal unit will be continued, and a prototype will be designed based on the results. Although the test operation is demonstrating the high vacuum sealing capability, it is necessary to eliminate the possibility that organic molecules contained in the magnetic fluid seal may affect the Flux Concentrator and the first downstream accelerator section by lowering the vacuum discharge threshold, even though the absolute pressure is low. For this reason, magnetic fluid is introduced into the vacuum test chamber to measure the threshold of the test electrode. This test is to confirm the vacuum sealing performance of the magnetic fluid seal and that the fluid molecules do not affect the accelerator performance.

Detailed studies have been conducted on destructive phenomena on the target such as fatigue caused by the beam stress. In addition to this, the effects of stress and heat generated by eddy currents caused by passing through the magnetic field will be included, and stable operation below the destruction limit will be confirmed by time-domain FEM and other methods.

By including the engineering design of the prototype as part of the time-critical WPs, the prototype design work can be completed before the start of the pre-lab, minimizing the overall delay due to the delay in the start of the Pre-lab.

List of items:

Priority	*Items*	Y1	Y2	Y3	Y4
A	Target stress calculation with FEM	▨	▨		
A	Vacuum seal	▨	▨		
A	Target module design	▨	▨		
	Target module prototyping			▨	▨

WP-prime 9: Magnetic Focusing System

The aim of the work package is to develop the technical design of the magnetic focusing system for ILC E-Driven e+ source. The technology is well established because a similar device is already in operation at BINP, Russia. The parameters of the Flux Concentrator for ILC and VEPP5(BINP) are summarized in the Table 1. Maximum magnetic field, electrical current on the conductor, and dynamic force on the conductor are larger for VEPP5(BINP) than those for ILC. On the other hand, the pulse energy, and the average power are larger for ILC than those for VEPP5. A long-term operation test with a prototype is desirable to confirm the reliability, as the specification is not fully compatible to that at BINP as shown in the Table below. For the demonstration, we have to fabricate not only the device, but also the power source and transmission line. To start fabrication right after the pre-lab. is started, the design study for the prototype should be finished as the time critical work package. Therefore, we divide the original work package into the design and the fabrication.

According to the experience of the Flux Concentrator as the magnetic device in BINP, SLAC, and KEKB, the FC mechanical properties are quite important. The mechanical properties depend on the structure including the fabrication method, material and pre-processing such as hardening, temperature etc. Because the device is highly activated during operation and the maintenance takes a long time including the radiation cooling time, the MTBF of the device should be long enough to ensure the high availability.

The heat load to FC is expected as 14 kW by ohmic loss and 4kW from beam loss. This heat should be removed from the FC by a water channel. The heat load by the beam loss is concentrated on the smallest aperture. We need a special attention to avoid vulnerability to high temperatures. The collaboration with Kondo equipment Co. and Metal Tech. Lab. in Kitakami, Iwate studies the thermal design of the Flux Concentrator. The electrical, thermal and mechanical stability are being studied with a test module and FEM simulations.

The sub-work packages of the design work including a fundamental study of electromagnetic and dynamical property of the device are categorized as the time critical work-package in rank A. Other sub-work packages for the prototype fabrications are categorized as “postponed to Pre-lab”.

Table.1. Parameter comparison between FC for ILC and BINP.

parameter	ILC	VEPP5	Unit
Max. B field	5.0	10	T
Current on the cone surface	25	120	kA
Dynamic Force	125	1200	kA.T
Pulse energy	140	90	J
Average power	13.7	4	kW

List of items:

Priority	*Items*	Y1	Y2	Y3	Y4
A	Flux concentrator conductor design	▨	▨		
	Flux concentrator conductor prototyping			▨	▨

A	Power source design	▨	▨		
	Power source prototyping			▨	▨
A	Transmission line design	▨	▨		
	Transmission line prototyping			▨	▨
A	Flux concentrator system design	▨	▨		
	Flux concentrator system operation			▨	▨
	Flux concentrator EDR			▨	▨

WP-prime 10: Capture Cavity and Linac

Capture linac is composed of an L-band APS (Alternate Periodic Structure) cavity. The whole linac is surrounded by solenoid magnets with 0.5 T. It has 11 accelerating cells and 10 idle cells. The length of the accelerating part is 1.265m. The shunt impedance and Q0 value are estimated as 53 MΩ/m and 25000, respectively. The dominant requirement of the structure is a wide aperture (2a=60 mm) with better RF stability than a pi-mode standing wave cavity.

The operation condition of the capture linac is unique. Because we employ the deceleration capture method developed by Kamitani, the positron is initially placed at the deceleration phase and slipped down to the acceleration phase. The RF phase of the positron changes along the linac. The beam loading is then dynamically changed over the linac. This dynamic aspect is enhanced by electrons. This dynamic beam loading perturbs the linac operation and might cause some instability. A study of the beam loading based on a coupled pendulum model showed that the effect is compensated with PM (Phase Modulation) and AM (Amplitude Modulation) on the input RF. As a cross check, a PIC simulation of the effect will be made. Based on the model, we will study the tuning scenario of the linac.

The APS cavity is not a new device. An L-band APS cavity with 1428 MHz frequency and 37 cells is in operation at SACLA, XFEL facility. A stable operation with 9.5 MV/m acceleration field, a 5μs pulse width is achieved. The field flatness was more than 99%. Our structure is 21 cells which is shorter than that in SACLA. The field with beam loading is around 10 MV/m which is similar to that in SACLA. The pulse width is 1.5 μs, which is shorter than that in SACLA. There is no required performance of APS cavity in the E-Driven system that exceeds those of the APS cavity in SACLA. From this point of view, there is no reason to develop a test module, but operation of such a module is desirable to confirm the high reliability of the system.

There is a modulator design based on a solid state power unit by Scandinova Co. As a klystron, 50 MW power with 2 μs pulse width is required. Although there is no commercially available klystron which satisfies these requirements, S-band klystrons with better performance exist. Fabricating an L-band klystron by scaling the S-band klystron is desirable to reduce the uncertainty of such an extrapolation. The design study for the power source should be started as a time critical work package.

Finishing the full RF design is one of the tasks. Concurrently, the thermal design should be a collaborative work with Kondo Equipment Co. and Metal Tech. Lab. Metal Tech. Lab. has rich experience on the thermal design of RF cavity for KEKB, J-PARC, X-band LC, etc. The heat-load by beam loss, especially for the first and second accelerator section downstream of the target is larger than that of RF, at 10kW. The impact on the RF properties through the deformation by the heat is expected to be controllable, but it is desirable to study the effect quantitatively with a real geometry of the structure including the cooing channel. For the purpose, a small test cavity (cold model) of APS cavity is fabricated to simulate the effect.

Even though the technology of APS cavity is well established, the prototype of one RF module (APS cavity and power source) is very useful to confirm the reliability. Not only the cavity, but also the modulator and klystron should be designated as time critical work package in rank A and B to start the fabrication in pre-lab with no lost time. The fabrication is postponed to Pre-lab.

List of items:

Priority	*Items*	Y1	Y2	Y3	Y4
A	APS cavity design and cold model	■	■		
	APS cavity hot model			■	■
A	Capture linac beam loading compensation and tuning method.	■	■		
A	Capture linac operation and commissioning	■	■		
B	L-band klystron design	■	■		
	L-band klystron fabrication			■	■
B	Power unit prototype design	■	■		
	Power unit fabrication			■	■
A	solenoid design	■	■		
	solenoid fabrication			■	■
	Fast BPM			■	■
	Capture linac prototyping and operation test			■	■
	Capture linacEDR			■	■

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 in the Pre-lab Proposal, but it should be divided as 11-1) Conceptual design, 11-2) Technical design, and 11-3) Mockup fabrication, and 11-4) Component prototyping.

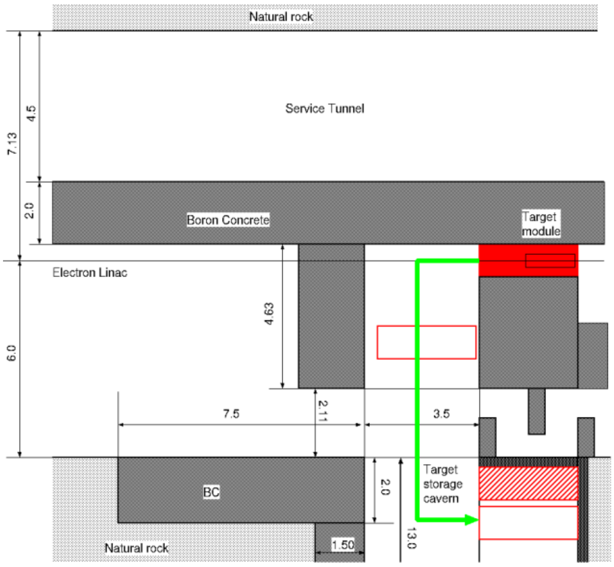

Figure 4: Floor layout of the target section. The center red rectangle is the target module. Shaded gray area is boronized concrete shield. The lower cavern is the target storage area.

Positron production target cause a couple of issues for radiation safety. One is radiation during the operation. Another is the activation of the target and the environment. To confine the radiation from the target, the target module is surrounded by 2 m thickness boronated concrete shielding as shown in Figure 4. The red rectangle is the target module. The upper area is the service tunnel where various electronics modules are placed. The radiation in upstream direction (left side in Figure 4) is also confined within the 2 m thick concrete. The electron driver linac is placed upstream. Similar shielding is placed at the downstream of the capture linac.

The lower cavern in Fig. 1 is the target storage area where the used target is stored. After the operation with 100 hours cooling time, 10 Sv/hour dose is expected at the surface of the target. To shield this radioactivity, the target is assembled as a module with shield as shown in Fig. 1. The target module is assembled with FC module, the first accelerator, solenoid magnet, and shielding. The module is mounted on a wagon. The wagon moves on rails along the beam line direction.

Placement of the shielding decreases the radiation dose in front of the target module 50 μSv/hour, allowing people to work in this area. Many joint connections for RF, electric power, water, control, etc. are assembled on the front panel of the module, then the disconnection of these joints can be done safely without any robotic remote work. This is a fail-safe system.

In the replacement work the target is first moved upstream (left direction in Figure 4). In the transverse aisle, a special wagon called as traverser is placed. The target module is transferred from the target mount to the traverser. Rails are aligned to the same level as those on the target mount and the traverser moves on the rails with a small force. After the target module is mounted on the traverser, the traverser moves in a transverse direction to the beam line (up-down in Figure 4) transporting the target module to the target storage area. The target module is then moved to one of the storage areas as a similar way. In the storage area, the target module is surrounded by 20 cm iron shield (backside), 5 cm iron shield (left and right side), and 30 cm boronated concrete and 20 cm iron shield (front side), respectively. Radiation dose in aisle of the cavern is 50μSv/h or less.

During the transportation of the module by the traverser, there is no radiation shield on the backside (other side of where people are working), as the concrete shield around the target act as shield. The side aisle (chicane) to the downstream of the capture linac will be closed during the transport. If safety requirements demand, the aisle can be completely closed

To develop the engineering design of the target station, we should establish the conceptual design and a detailed design of some critical devices such as remotely controllable vacuum seals. This critical device should be prototyped before the engineering design. A small size mockup of the system should be fabricated to start the engineering design. The engineering design of the system is made in the pre-lab. period. Other sub-work packages are categorized as the time critical work package in rank A and B.

List of items:

Priority	*Items*	Y1	Y2	Y3	Y4
A	Conceptual Design	▨	▨		
B	Fabricate Mockup	▨	▨		
B	Prototyping of critical parts	▨	▨		

3: DR/BDS/Dump

(Ver.6, 2022-June-2)

Time-critical WPs in this domain:

We have identified the following technical preparations as being particularly important and should be started as early as possible among the work packages (WP) listed in the technical preparation document (TPD): two technical preparation projects were selected from the damping ring (DR) items, two from the beam delivery system (BDS) items and one as beam dump.

The first technical preparation item from DR is the baseline design of a damping ring with a normal conducting magnet. This item is included in WP-12 of the TPD, and it is desirable to proceed as soon as possible since it is related to the design of other area systems. The other is a confirmation test of the present level of technology for kicker power supplies using fast step recovery diodes. This is part of the system design of the injection/extraction system from the DR in WP-14 of the TPD.

The first item selected from BDS is the advancing of the beam tuning technology, which will be done at the ATF2 beamline. This is part of WP-15. While WP-15 includes a number of tests related to advancing the beam tuning technology, we have focused on three key areas and picked up the minimum researche required for them as time-critical WPs. The last item is the vibration test of the QD0 cryostat. This is part of WP-16. It will be greatly affects not only the ILC accelerator design, but also the design of the detectors and their interfaces. Therefore, we selected this item as a time-critical WP, because we need to come to a conclusion of the effect of the FD vibration before ILC Pre-Lab starts.

Establishing the engineering design of the main beam dump, included in WP-17, is selected to be done as a key part of ILC designing.

Technical preparation items that were not selected for the time-critical WP should proceed once the ILC Pre-Lab has started.

Time-critical WPs: Area-System DR/BDS/DUMP:

WP-prime-12: System design of ILC damping ring	Optics optimization, simulation of the dynamic aperture with magnet model
	Magnet design : Normal conducting magnet and superconducting wiggler
WP-prime-14: System design of ILC DR injection/extraction kickers	Confirmation of existing pulse power supply technology based on drift step recovery diode pulsar
WP-prime-15: System design of ILC final focus beamline	wakefield mitigation
	mitigation and correction of higher-order aberration
	training for ILC beam tuning (machine-learning etc.)
WP-prime-16: Final doublet design optimization	Assemble QD0 prototype, connect to Service Cryostat and undertake warm/cold vibration stability measurements with a sensitivity of a few nanometers.
WP-prime-17: System design of the main beam dump	Engineering design and component testing of water flow system and window

WP-prime 12:

Program and schedule:

The purpose of WP-12 was to optimize the design of the damping ring (DR), including the use of permanent magnets. We select as time-critical WP the basic design using normal conducting magnets from WP-12. The present design of the ILC DR is a simple design using hard edge magnet model with zero spacing between the magnets. The ILC DR is designed to have a very large dynamic aperture in order to maximize the positron capture yield. However, it is pointed out that the dynamic aperture of the circular accelerator decreases when the fringe field of the magnet is taken into account. Since the spatial distribution of positrons differs depending on the positron capture method, the dynamic aperture is a factor that affects the positron capture yield in each method, and we think it is important to consider it quantitatively before positron source selection. Since the establishment of the basic DR design also has a significant impact on other systems of the ILC, it is essential that this item should be completed (within a framework of the international cooperation) in the two years before the ILC Pre-Lab starts.

The design of the damping ring and the evaluation of the dynamic aperture are designated as priority A, while the design of the normal-conducting magnet and the wiggler are designated as priority B. The dynamic aperture evaluation can be performed using the fringe field model of typical magnets, since the basic design of the ILC DR does not use any special magnet, we believe that the evaluation can be done at least using a typical fringe field model.

Goals of the workpackage:

System design of the baseline beam optics for the ILC DR. The DR specifications are as follows.

Parameters	***Symbol***	***Unit***	***Design***
Normalized emittance	$\gamma\varepsilon_x/\ \gamma\varepsilon_y$	µm / nm	4.0 / 20 at N=2E10
Dynamic aperture	$\gamma(A_x + A_y)$	M	0.07 (action variable)
Longitudinal acceptance	$\Delta\delta \times \Delta z$	% × mm	$\pm 0.75 \times \pm 33$

List of items:

Priority	***Items***	Y1	Y2	Y3	Y4
A	Optics optimization, simulation of the dynamic aperture with magnet model	▨	▨		
B	Magnet design : Normal conducting magnet and superconducting wiggler	▨	▨		

WP-prime 14:

Program and schedule:

The purpose of WP-14 is the system design of a kicker system for the ILC DR. The original plan of the WP-14 is to build several types of kicker power supply prototypes and compare their performance at the kicker test station. We considered the performance evaluation of the kicker power supply using the fast step recovery diode technology, which has been successfully used in beam extraction experiments at KEK ATF in the past, to be the most important priority for this work package.

The technical demonstration of the beam extraction with fast kicker has been done by the ATF roughly 10 years ago. However, the voltage of the kicker power supply during that experiment was 5 kV, half the TDR requirement. It may be possible to meet the ILC requirements by increasing the number of kickers. Since the experimental results that form the basis of the experience are 10 years old, we believe it is important to know exactly what voltage kicker power supplies can be achieved with current technology before designing an ILC. The research items on fast step recovery diode power supplies in the TPD include a section on confirming the current technology and a section on long-term stability test, of which only the former should be conducted. The budget of this item is also expected to be half that estimated forfast step recovery diode pulser in the TDR WP-14. Fast step recovery diode power supplies should be confirmed prior to the start of the ILC Pre-Lab. Other research items in the original WP-14, development of kicker power supplies using other technologies and long-term stability testing, should be conducted during the ILC Pre-Lab period.

Goals of the workpackage:

Confirmation of existing pulse power supply technology required for the ILC fast kicker system. The specifications of the DR beam injection/extraction are as the follows.

Parameters	***Unit***	***Design***
Number of bunches in DR	Bunches	1312 / 2625 (optional)
Repetition rate	Hz	5

List of items:

Priority	***Items***	Y1	Y2	Y3	Y4
B+	Confirmation of existing pulse power supply technology based on drift step recovery diode pulsar	▨	▨		

WP-prime 15:

Program and schedule:

The purpose of WP-15 is the system design of the ILC BDS and the advancing of the beam technology required for it. For this purpose, we propose various beam tests at the ATF2 beamline from the original WP-15. The technical research of the final focus system for the ILC at ATF2 beamline has proceeded with international cooperation under the ATF international collaboration. WP-15 must also be based on the ATF international collaboration, or an international collaboration extension of the ATF international collaboration. The time-critical WP should also continue to be based on the ATF international collaboration, or its extension .

ATF2 beamline is the only existing test accelerator in the world to test the final focus beamline of linear colliders and is important for the ILC. However, since some of the items listed in the WP-15 can be performed after the ILC Pre-Lab start, it is appropriate for the time-critical WP to select only the higher priority research topics. The research topics described in WP-15 of the TPD are intricately tied to each other. Thus the time-critical WPs cannot be easily selected. Thus new items have been defined for the time-critical WPS. We have selected the following 3 research topics as new topics as the time-critical WPs along with their existing budgets.

Furthermore, since items are deeply related to each other, it would be difficult to set a priority for each item, so all were grouped together as priority A.

1. wakefield mitigation
2. mitigation and correction of higher-order aberration
3. training for ILC beam tuning (machine-learning etc.)

These three items should be started before the ILC Pre-Lab starts and should be continued into the Pre-Lab period along with the other research topics in TPD WP-15.

Goals of the workpackage:

Advancing the beam tuning technology for the ILC BDS system design. The specification of the ILC FF beamline is designed using the following parameters.

Parameters	***Unit***	***Design***
Beam Energy	GeV	125
Bunch population		2E10
IP beam size (H/V)	μm / nm	0.515 / 7.66
IP position stabilization		$\leq 0.2\sigma_y^*$

List of items:

Priority	***Items***	Y1	Y2	Y3	Y4
A	wakefield mitigation	▨	▨	▨	▨
	mitigation and correction of higher-order aberration	▨	▨	▨	▨
	training for ILC beam tuning (machine-learning etc.)	▨	▨	▨	▨

WP-prime 16:

Program and schedule:

The purpose of WP-16 is to design the final doublet (FD) of the ILC and to evaluate the associated QD0 cryostat vibration. In the TDR baseline, the 1.9 K superfluid helium supply for QD0 and the interface to external magnet power leads are via the Service Cryostat. The Service Cryostat connects to QD0 via a long He-II cryogenic line that must pass through a labyrinth in the end Pacman radiation shielding to avoid having a direct path for beam line radiation to the experimental detector hall. The vertical beam fluctuation to QD0 must be stable to the order of 50 nm, to stay within the capture range of the intra-train collision feedback. It will be greatly affected not only the ILC accelerator design, but also the design of the detectors and their interfaces, so we need to come to a conclusion of the effect of the FD vibration before ILC Pre-Lab starts.

Since BNL has been taking the lead in the investigation of FD at the ILC, it is expected that BNL will be the main laboratory of this vibration experiment. However, we think it is important to build a framework that can provide the budget and human resource support via international cooperation agreement rather than leaving this item to BNL alone. The QD0 magnets are integrated into the detectors and thus vibration / stabilization studies need input from and thus should be conducted together with the detector concept and MDI groups.

Goals of the workpackage:

Evaluation of the QD0 vibration via the Service Cryostat for the system design of the FD system. The specification of the QD0 cryostat is designed using the following parameters.

Parameters	***Unit***	***Design***
Vertical vibration	nm	50

List of items:

Priority	***Items***	Y1	Y2	Y3	Y4
A	Assemble QD0 prototype, connect to Service Cryostat and undertake warm/cold vibration stability measurements with a sensitivity of a few nanometers.	■	■		

WP-prime 17:

Program and schedule:

The design of the main beam dump has been conducted by following the experience of water dumps at SLAC and JLAB. WP-prime17 aims to tighten the engineering design of the main beam dump. This includes the design of the vortex water flow system in the dump vessel, the beam window and its remote exchange system. Each of the main components will be developed in small-scale prototyping. The technical design of safety measures against accidents such as earthquakes and a leakage of radioactive water will be performed. The main beam dump is assumed to have a maximum beam power of 17 MW, including a 20% margin for 1 TeV collisions, and 2.6 MW for 250 GeV nominal operation.

Goals of the workpackage

- Finalization of the engineering design for main beam dump system

Parameters	***Unit***	***Design***
Maximum beam power assuming 1TeV collision	MW	17

List of items:

Priority	***Items***	Y1	Y2	Y3	Y4
A	Engineering design of water flow system	■	■		
A	Engineering design and small-scale prototyping of vortex water flow system in the dump vessel.	■	■	■	■
A	Engineering design and small-scale prototyping of beam window and its remote exchange system.	■	■	■	■

A	Design of the countermeasure for failures / safety system	▨	▨		