

Time-critical WPs for the ILC construction

IDT-WG2

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(Ver.3,2022-March-11)

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” (TPD)¹ summarized the accelerator work necessary for producing the final engineering design and documentation during the ILC Pre-lab² phase. A total of 18 WPs (3 SRF, 8 Sources, 7 DR/BDS/Dumps) were proposed as illustrated in Figure 1.

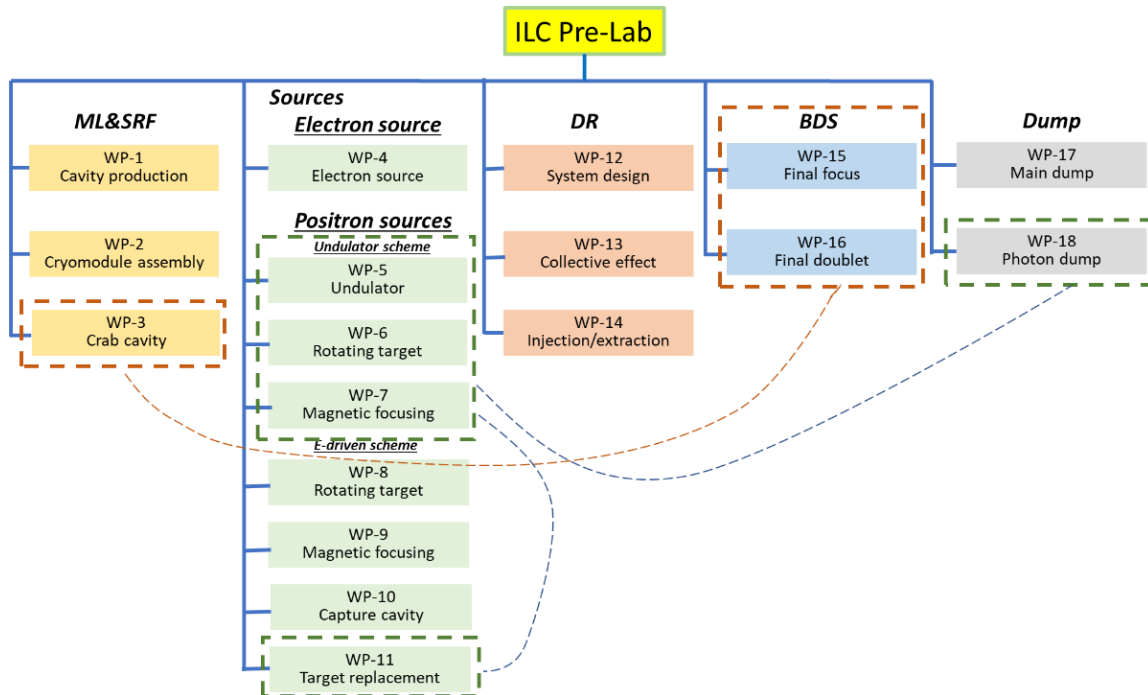


Figure 1: Summary of work packages.

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

¹ <http://doi.org/10.5281/zenodo.4742018>

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

- 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.

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.

	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

We have compiled them into 14 work packages named WP-prime as shown in Figure3. For our consideration here, we have prioritized those that are particularly important and time-consuming from the WP proposals in the Pre-lab.

The total cost is approximately \$13M, 120 FTE-yr, and the plan is to be implemented in 2 to 4 years; the Appendix lists the annual plan and the institutions likely to be involved.

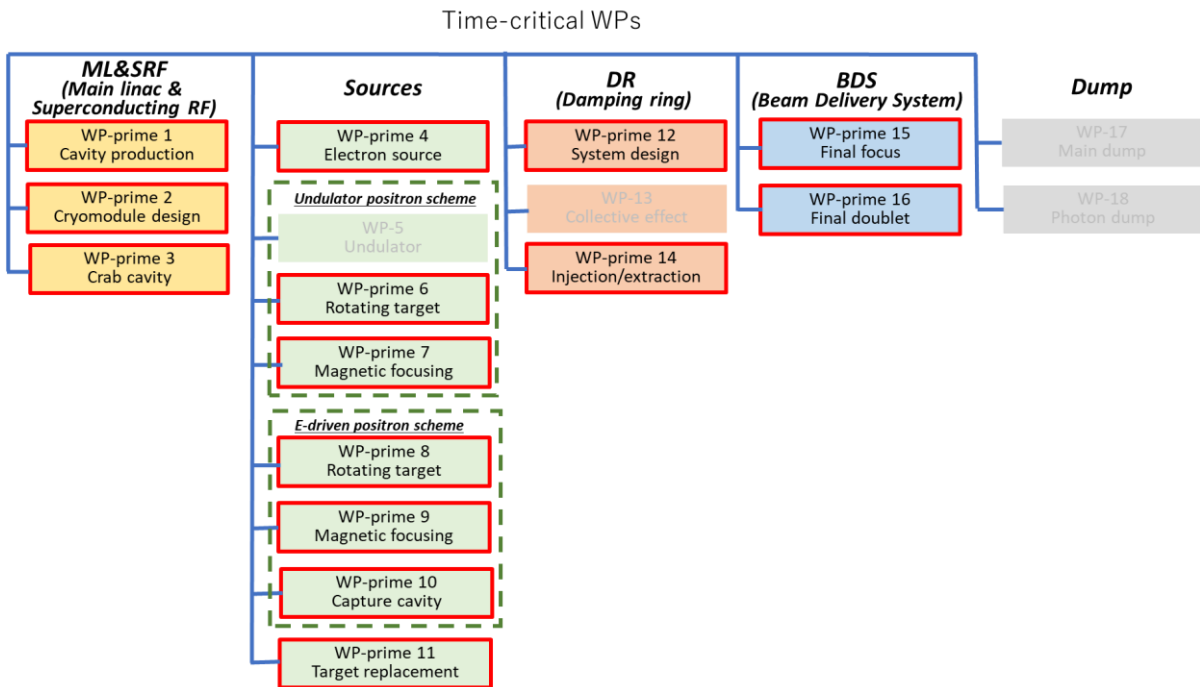


Figure 3: Time-critical WPs

1: ML and SRF

(Ver.2,2022-March-14)

Time-critical WPs in this domain:

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

- WP-prime 1
 - Fundamental research using 1-cell cavity to prepare for 9-cell cavity production
 - High pressure gas safety regulation
 - Procurement/contract of superconducting materials (Nb, NbTi) as in-kind contribution by Japan
 - 9-cell cavity production by common vendors as global effort
 - 9-cell cavity production as domestic contract
- WP-prime 2
 - Finalization of CM drawing including ancillaries like tuner, coupler, SC magnet
 - High pressure gas safety regulation
- WP-prime 3
 - Procurement/contract of superconducting materials (Nb, NbTi) as in-kind contribution by Japan
 - 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 with the budget provided in each region, for a total of 24 cavities in three regions, with satisfying high pressure gas safety (HPGS) regulation in Japan to install into cryomodules (CMs) produced in the Pre-lab phase (Currently assuming it will start in Y3). The process will be to establish common specifications globally agreed, and procurements/contracts with possible common vendors will be implemented individually in each three regions. This process is considered as a model case or practice for the ILC SRF cavity production. It is also assumed that all materials (Nb sheets/discs, NbTi flanges and so on) may be supplied as in-kind contribution from Japan.

As 10 years have passed since the Technical Design Report (TDR), the cavity production process may be updated with some improvement and with more sophisticated process that incorporates more recent methods like 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 with satisfying “plug compatibility” interfaces, as the available infrastructures are 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 24 cavity production above, several additional 1-cell/9-cell cavities may be produced. To prepare for 9-cell cavity production, 1-cell study will be important as the first step in Y1. Japan will plan to produce additional 9-cell cavities on top of eight with individual Japanese funding, because Japan will need more mass-

production experiences. 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 amount of cost and FTE is required for this task.

For WP-prime 3, the content is essentially same as 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 in a low-temperature condition. 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 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 $\sim 3 \times 8$ cavities and the required RF performance achievement to demonstrate the ILC baseline field gradient of 35 MV/m at $Q \geq 0.8 E10$ with $\geq 90\%$ success yield. The cavity production process will be replaced with new and more sophisticated method developed after TDR. These 9-cell cavities don't equip with any helium tank and magnetic shield, because they will not be installed into CM for a while.

Goals of the workpackage

<i>Parameters</i>	<i>Unit</i>	<i>Design</i>
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 $Q \geq 1.6E10$)
Cavity production yield	%	90

List of items:

<i>Priority</i>	<i>Items</i>	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	JP*			
A	Industrial production with globally shared contracts		All	All	
A	1 st vertical test (VT), and further efforts (2 nd 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)

* Note: in-kind contribution by Japan is anticipated

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 used in 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 at beyond Pre-lab phase (after Y5).

Goals of the workpackage

<i>Parameters</i>	<i>Unit</i>	<i>Design</i>
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:

<i>Priority</i>	<i>Items</i>	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.2,2022-March-13)

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 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 $< 2 \times 10^{-12}$ 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 limit 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 geometry (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 feedthrough 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	Optimize 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 support to HV feedthrough with internal shape to accept photocathode 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												
		Fabricate 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 photocathode pucks													
	Fabricate Mo puck for dummy SS substrate puck													
Components ready														
Assembly	Vacuum chamber + NEG modules	Vacuum bake at 400 C for degassing												
		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 attachment support and dummy puck with SS substrate												
		Mount electrode + triple point junction shield + dummy puck and fiducial												
		Install on chamber and align per fiducial												
	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 works related to the undulator positron source include the undulator (WP-5), the rotating target (WP-6), 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 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.

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.

WP-Prime 6 (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).

WP-Prime 7 (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].

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 is therefore 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 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.

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 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 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 the long-term rotation test 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 Flux concentrator and the first accelerator in the downstream 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 will 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 TCWP, 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:

<i>Priority</i>	<i>Items</i>	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 Flux concentrator for ILC and VEPP5(BINP) are summarized in 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. Even though, a long-term operation test with a prototype is desirable to confirm the reliability, because the specification is not fully compatible to that at BINP as shown in Table 1. 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 as the design and the fabrication.

According to the experience of Flux concentrator as the magnetic device in BINP, SLAC, and KEKB, mechanical property is quite important. The mechanical property depends on the structure including fabrication method, material, pre-process such as hardening, temperature etc. Because the device is heavily activated and the maintenance takes a long time including the cooling time, 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 by the beam loss. This heat should be removed from the FC by water channel. The heat load by the beam loss is concentrated on the smallest aperture. We need a special attention to avoid vulnerable due to high temperatures. The collaboration with Kondo equipment Co. and Metal Tech. Lab. in Kitakami, Iwate studies the thermal design of Flux concentrator. The electrical, thermal and mechanical stability is studied by a test module and FEM simulation.

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”.

List of items:

<i>Priority</i>	<i>Items</i>	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 from 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 M Ω /m and 25000, respectively. The biggest reason of the structure is a wide aperture (2a=60 mm) with better RF stability than pi-mode standing wave cavity.

The operation condition of the capture linac is very 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 is moving 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, PIC simulation of the effect will be made. Based on the model, we study the tuning scenario of the linac.

APS cavity is not a new device. L-band APS cavity with 1428 MHz frequency and 37 cells in operation at SACLA, XFEL facility. A stable operation with 9.5 MV/m acceleration field 5 μ s 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 μ s, which is shorter than that in SACLA. There is no required performance of APS cavity in E-Driven system that exceeds those for APS cavity in SACLA. From this point of view, there is no reason to develop a test module, but an operation test with a test 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 shown in Fig. 7. As a klystron, 50 MW power with 2 μ s pulse width is required. Although there is no commercially available klystron which satisfy these requirements, S-band klystron which has better performance exists. Fabricating an L-band klystron by scaling the S-band klystron is desirable for a strong certainty. The design study for the power source should be started as the time critical work package.

Finishing the full RF design is one of the tasks. Concurrently, the thermal design should be made as a collaborative work with Kondo Equipment Co. and Metal Tech. Lab. Metal Tech. Lab. has a 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 at the downstream of the target is larger than that of RF, 10kW. The impact to RF property 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 cooling channel. For the purpose, a small test cavity (cold model) of APS cavity is fabricated to simulate the effect.

Even 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 designed as the time critical work package in rank A and B to start the fabrication in pre-lab with no leading time. The fabrications are postponed to Pre-lab.

List of items:

<i>Priority</i>	<i>Items</i>	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 one in the prelab. 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.

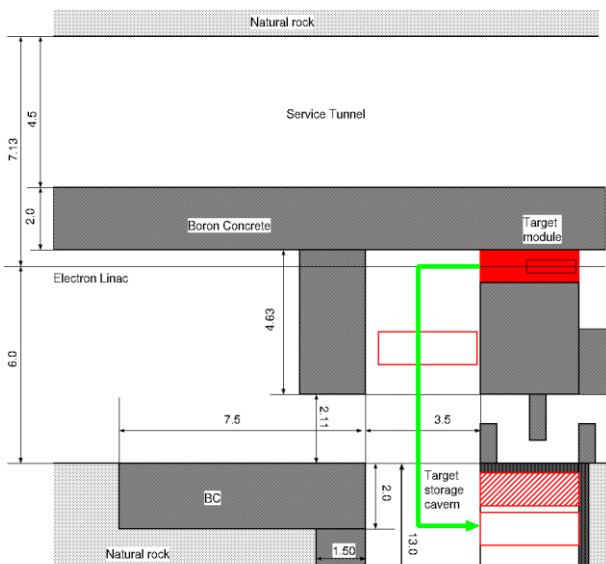


Figure 1: Floor layout of the target section. The center red rectangle is the target module. Shaded gray area is Boronized concrete shield. The lower cavern is the target storage area.

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 Boronized concrete shield as shown in Fig. 1. The red rectangular is the target module. The upper area is the service tunnel where various electronics modules are placed. The radiation to upstream direction (left side in Fig. 1) is also confined with the 2 m thickness concrete. In the upstream, the electron driver linac is placed. The similar shield is placed at the downstream of the capture linac.

The lower cavern in Fig. 8 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 strong radioactivity, the target is assembled as a module with shield as shown in Fig. 9. The target module is assembled with FC module, the first accelerator, solenoid magnet, and shields. The module is mounted on a wagon. The wagon moves on rails along the beam line direction.

By placing these shields, the radiation dose in front of the target module is decreased down to 50 μ Sv/hour. In this area, a man can work. 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.

The target is moved to upstream direction (left direction in Fig. 1 or 2. 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 on a same level as those on the target mount as shown in Fig. 9 and the traverser moves on the rails with a small force. After the target module is mounted on the traverser, the traverser moves transverse direction to the beam line (up-down in Fig. 8) and transport the target module to the target storage area. The target module is then moved to one of the storage area 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 Boronized concrete and 20 cm

iron shield (front side), respectively. Radiation dose in aisle of the cavern is 50 μ Sv/h or less.

During the transportation of the module by the traverser, there is no radiation shield in backside (other side of where man is working), but 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 we are required a strong policy for safety, 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 device such as vacuum seal remotely controllable. The 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:

<i>Priority</i>	<i>Items</i>	Y1	Y2	Y3	Y4
A	Conceptual Design				
B	Fabricate Mockup				
B	Prototyping of critical parts				

3: DR/BDS/Dump

(Ver.3, 2022-March-11)

Time-critical WPs in this domain:

We have identified the following technical preparations that are particularly important and should be started as early as possible before the start of ILC Pre-Lab among the work packages (WP) listed in the technical preparation document (TPD): two technical preparations were selected from damping ring (DR) items and two as beam delivery system (BDS) items. No selections were made from the 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 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 the advancement of beam tuning technology, we have focused on three key areas and picked up the minimum researches 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 affected not only the ILC accelerator design, but also the design of the detectors and their interfaces. Therefore, we selected this item as the time-critical WPS, because we need to come to a conclusion of the effect of the FD vibration before ILC Pre-Lab starts.

Technical preparation items that were not selected for the time-critical WP should be proceeded with after the ILC Pre-Lab has started.

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

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

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 selected as time-critical WP only 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 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 selection. Since the establishment of the basic DR design is also has a significant impact on the other area systems of the ILC, it is essential that this item should be completed within the two years before the ILC Pre-Lab starts by a framework of the international cooperation.

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. When only priority A, damping ring design and dynamic aperture evaluation, is selected as the time-critical WPs, the dynamic aperture evaluation will 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.

<i>Parameters</i>	<i>Symbol</i>	<i>Unit</i>	<i>Design</i>
Normalized emittance	$\gamma\epsilon_x / \gamma\epsilon_y$	$\mu\text{m} / \text{nm}$	4.0 / 20 at N=2E10
Dynamic aperture	$\gamma(A_x + A_y)$	M	0.07 (action variable)
Longitudinal acceptance	$\Delta\delta \times \Delta z$	$\% \times \text{mm}$	$\pm 0.75 \times \pm 33$

List of items:

<i>Priority</i>	<i>Items</i>	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 ILC DR. Although our original plan of the WP-14 is to build several types of kicker power supply prototypes and compare their performance at 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, a half the TDR requirement. It may be possible to meet the ILC requirements by increasing the number of kickers, but since

the experimental results that form the basis of the experience are from 10 years ago, we believe it is important to know exactly what voltage kicker power supplies can achieve with current technology before designing an ILC. The research items on fast step recovery diode power supplies in the TPD includes 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 counted to be a half of the research item on fast 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, and 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.

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

List of items:

<i>Priority</i>	<i>Items</i>	Y1	Y2	Y3	Y4
B+	Confirmation of existing pulse power supply technology based on drift step recovery diode pulser				

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 are proposing various beam tests at the ATF2 beamline in the original WP-15. The technical research of the final focus system for the ILC at ATF2 beamline has been proceeded in international cooperation under the ATF international collaboration and the WP-15 is also considered to be based on the ATF international collaboration, or international collaboration in a form that is an extension of the ATF international collaboration. The time-critical WP should also continue to be based on the ATF international collaboration, or international collaboration in a form that is an extension of the ATF international collaboration.

ATF2 beamline is the only existing test accelerator in the world to test the final focus beamline of the linear colliders, and the study of the final focus beamline at ATF is important for 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 narrow down the items and to perform only the higher priority research topics. Since the research topics described in WP-15 of the TPD are intricately tied to each other, the time-critical WPs are not picked up some items from the items listed in the TPD WP-15, but be rattled off and itemized as new items as those for the time-critical WPs. Therefore, we selected the following 3 research topics as new topics as the time-critical WPs, and

the budgets that are evaluated to be necessary for these items. Furthermore, since each item is 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 ensured to be started before the ILC Pre-Lab starts and should be continued after the start of the Pre-Lab 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.

<i>Parameters</i>	<i>Unit</i>	<i>Design</i>
Beam Energy	GeV	125
Bunch population		2E10
IP beam size (H/V)	$\mu\text{m} / \text{nm}$	0.515 / 7.66
IP position stabilization		$\leq 0.2\sigma_y^*$

List of items:

<i>Priority</i>	<i>Items</i>	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 presumptively occupied experimental detector hall. The vertical beam fluctuation to QD0 must be stable in 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 budget and human resource support under international cooperation, rather than leaving this item to

BNL alone. This time-critical WP should be completed before ILC Pre-Lab starts and should be reflected in the design of the FD, detectors and their interfaces, which will be conducted during the ILC Pre-Lab period.

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.

<i>Parameters</i>	<i>Unit</i>	<i>Design</i>
Vertical vibration	nm	50

List of items:

<i>Priority</i>	<i>Items</i>	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.				