International Development Team

ILC accelerator R&D proposal for the PreLab phase

Benno List, DESY
ILC@DESY Project Meeting
15.1.2021

Accelerator activities at ILC Pre-lab phase

Technical preparations /performance & cost R&D [shared across regions]

Technical preparation

- SRF performance R&D
- Positron source final design and verification
- Nanobeams (ATF3 and related): Interaction region: beam focus, control and Damping ring: fast kicker, feedback
- Beam dump: system design, beam window, cooling water circulation
- Other technical developments considered performance critical

Final technical design and documentation [central project office in Japan with the help of regional project offices (satellites)]

Engineering Design Report (EDR)

- Engineering design and documentation, WBS
- Cost confirmation/estimates, tender and purchase preparation, transport planning, mass-production planning and QA plans, schedule follow up and construction schedule preparation
- Site planning including environmental studies, CE, safety and infrastructure (see below for details)
- Review office
- Resource follow up and planning (including human resources)

Preparation and planning of deliverables [distributed across regions, liaising with the central project office and/or its satellites]

Mass-production

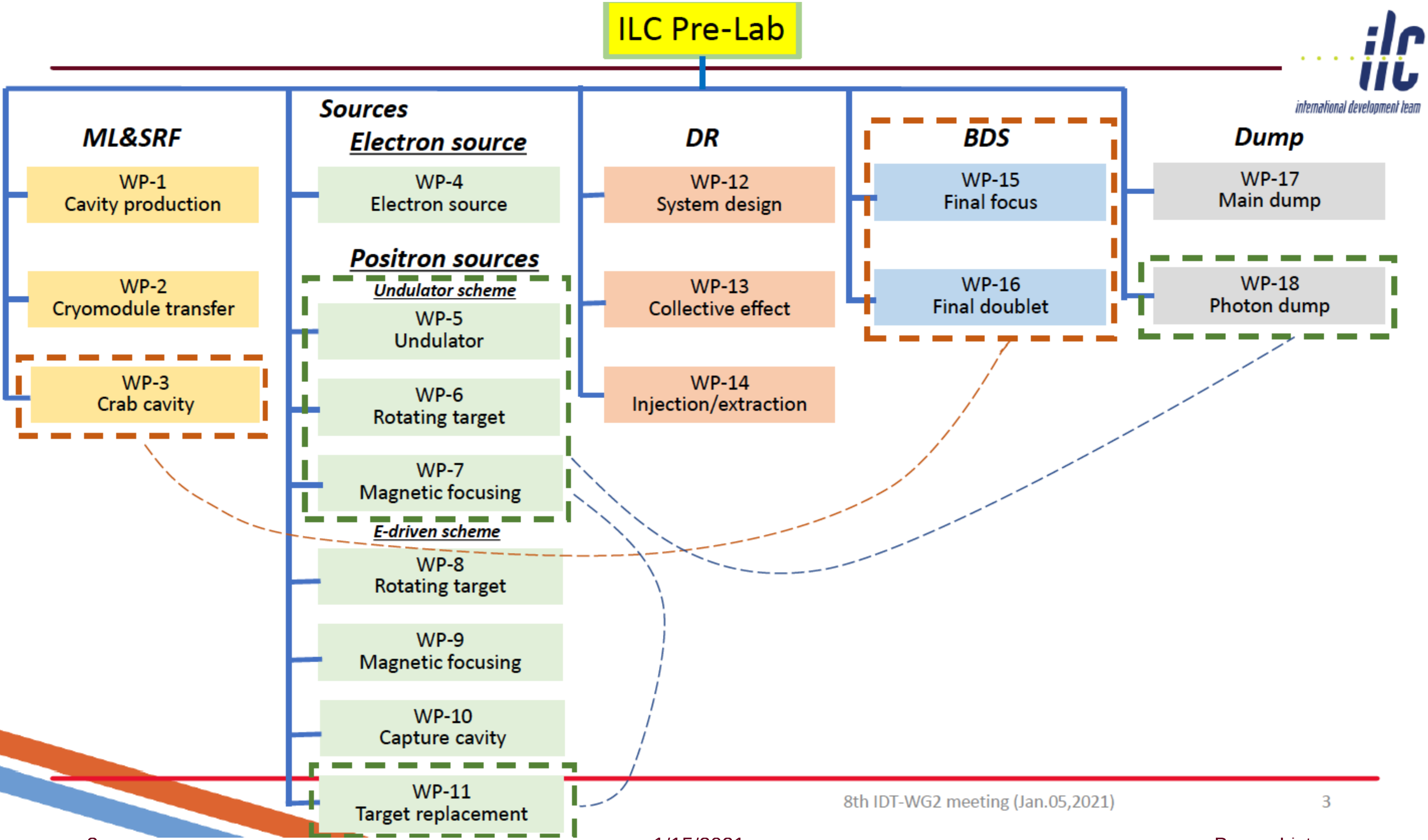
- Prototyping and qualification in local industries and laboratories, from SRF production lines to individual WBS items
- Local infrastructure development including preparation for the construction phase (including Hub.Lab)
- Financial follow up, planning and strategies for these activities

CE, local infrastructure and site [host country assisted by selected partners]

Civil engineering

- Engineering design including cost confirmation/estimate
- Environmental impact assessment and land access
- Specification update of the underground areas including the experimental hall
- Specification update for the surface building for technical scientific and administrative needs

ILC Pre-Lab



ML&SRF
- WP-1 Cavity production
- WP-2 Cryomodule transfer
- WP-3 Crab cavity

Sources

Electron source
- WP-4 Electron source

Positron sources

Undulator scheme
- WP-5 Undulator
- WP-6 Rotating target
- WP-7 Magnetic focusing

E-driven scheme
- WP-8 Rotating target
- WP-9 Magnetic focusing
- WP-10 Capture cavity
- WP-11 Target replacement

DR
- WP-12 System design
- WP-13 Collective effect
- WP-14 Injection/extraction

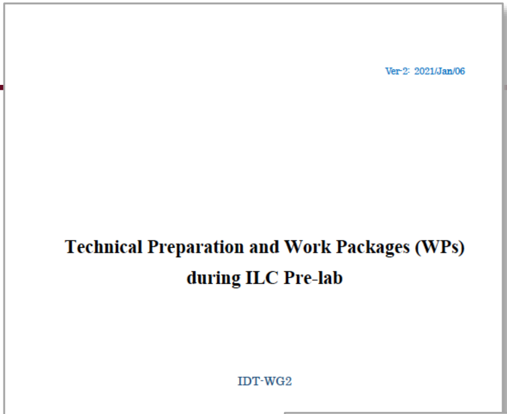
BDS
- WP-15 Final focus
- WP-16 Final doublet

Dump
- WP-17 Main dump
- WP-18 Photon dump

IDT

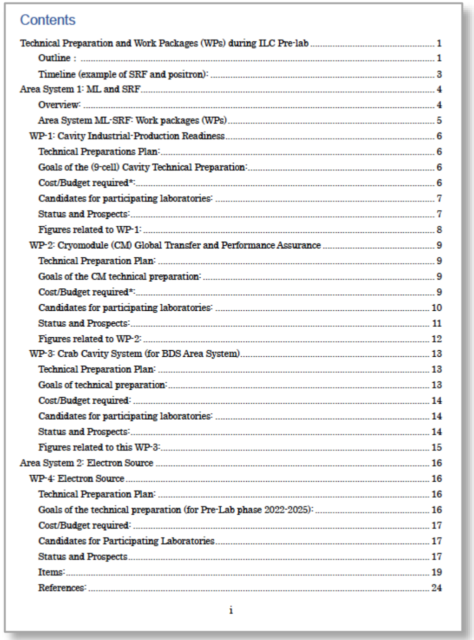
Proposal Document

- All proposals in one document
- 83 pages
- Not yet public


Ver-2: 2021/Jan/06

Technical Preparation and Work Packages (WPs)
during ILC Pre-lab

IDT-WG2


Contents

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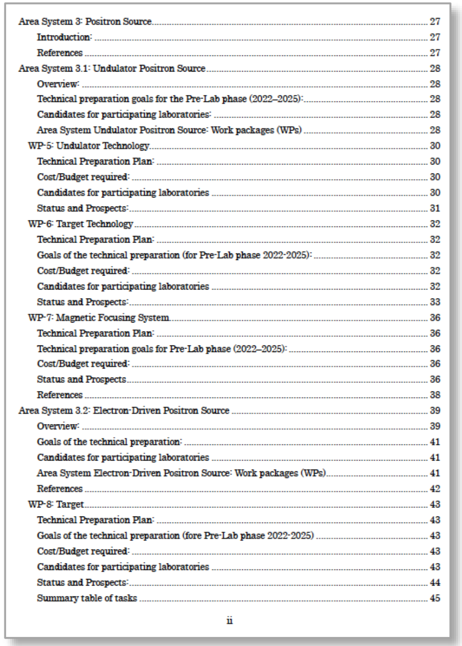

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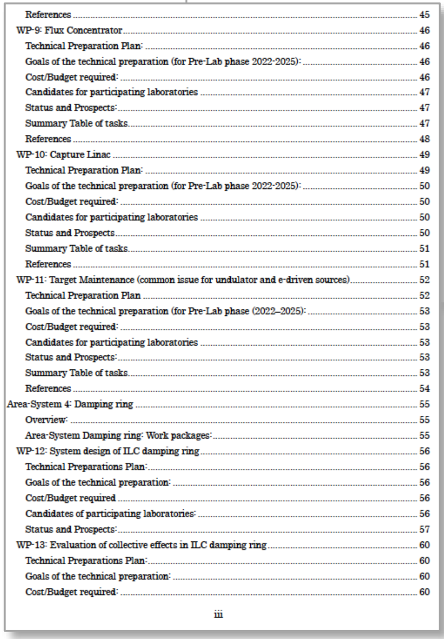

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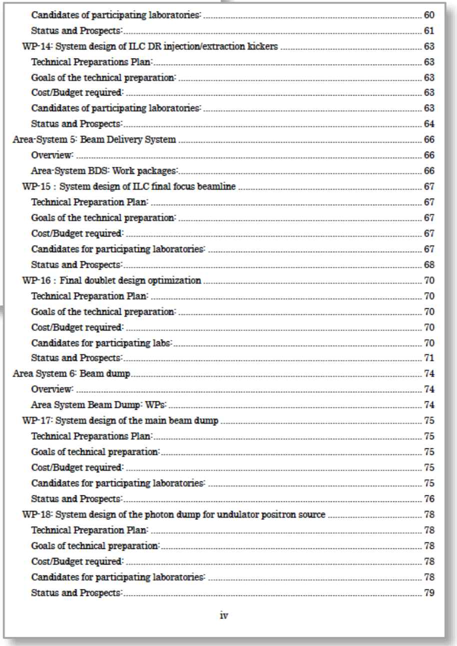

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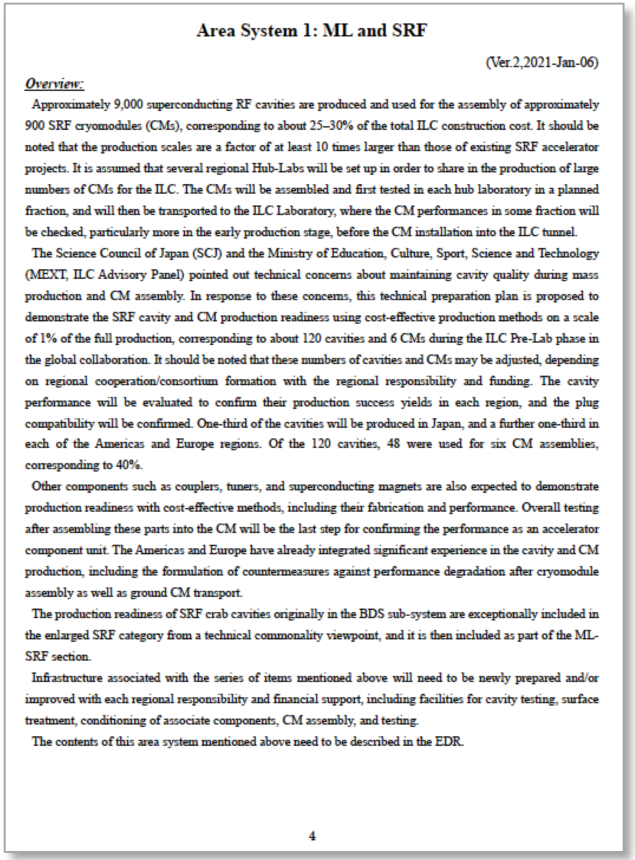
Area 1: Main Linac and SRF



Area System 1: ML and SRF

(Ver.2,2021-Jan-06)

Overview:

Approximately 9,000 superconducting RF cavities are produced and used for the assembly of approximately 900 SRF cryomodules (CMs), corresponding to about 25–30% of the total ILC construction cost. It should be noted that the production scales are a factor of at least 10 times larger than those of existing SRF accelerator projects. It is assumed that several regional Hub-Labs will be set up in order to share in the production of large numbers of CMs for the ILC. The CMs will be assembled and first tested in each hub laboratory in a planned fraction, and will then be transported to the ILC Laboratory, where the CM performances in some fraction will be checked, particularly more in the early production stage, before the CM installation into the ILC tunnel.

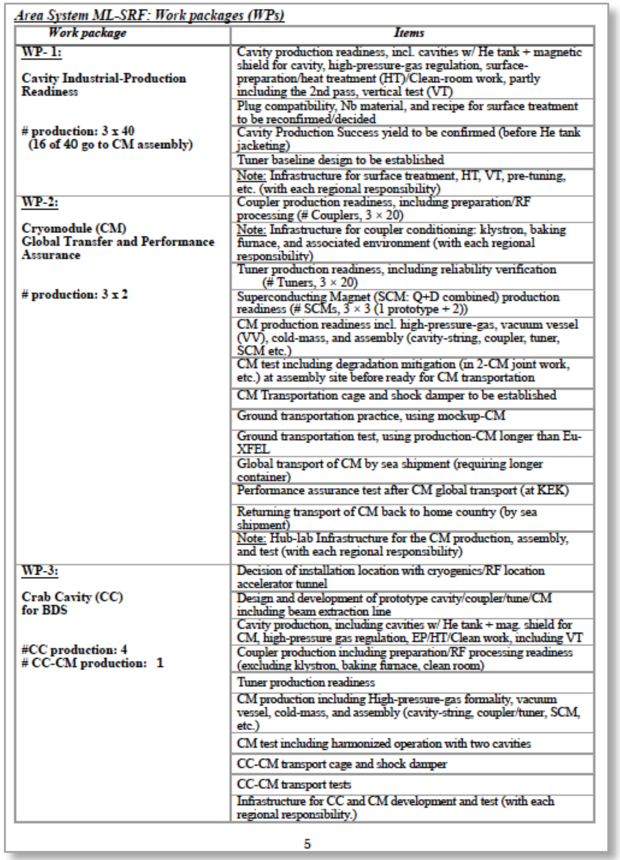
The Science Council of Japan (SCJ) and the Ministry of Education, Culture, Sport, Science and Technology (MEXT, ILC Advisory Panel) pointed out technical concerns about maintaining cavity quality during mass production and CM assembly. In response to these concerns, this technical preparation plan is proposed to demonstrate the SRF cavity and CM production readiness using cost-effective production methods on a scale of 1% of the full production, corresponding to about 120 cavities and 6 CMs during the ILC Pre-Lab phase in the global collaboration. It should be noted that these numbers of cavities and CMs may be adjusted, depending on regional cooperation/consortium formation with the regional responsibility and funding. The cavity performance will be evaluated to confirm their production success yields in each region, and the plug compatibility will be confirmed. One-third of the cavities will be produced in Japan, and a further one-third in each of the Americas and Europe regions. Of the 120 cavities, 48 were used for six CM assemblies, corresponding to 40%.

Other components such as couplers, tuners, and superconducting magnets are also expected to demonstrate production readiness with cost-effective methods, including their fabrication and performance. Overall testing after assembling these parts into the CM will be the last step for confirming the performance as an accelerator component unit. The Americas and Europe have already integrated significant experience in the cavity and CM production, including the formulation of countermeasures against performance degradation after cryomodule assembly as well as ground CM transport.

The production readiness of SRF crab cavities originally in the BDS sub-system are exceptionally included in the enlarged SRF category from a technical commonality viewpoint, and it is then included as part of the ML-SRF section.

Infrastructure associated with the series of items mentioned above will need to be newly prepared and/or improved with each regional responsibility and financial support, including facilities for cavity testing, surface treatment, conditioning of associate components, CM assembly, and testing.

The contents of this area system mentioned above need to be described in the EDR.



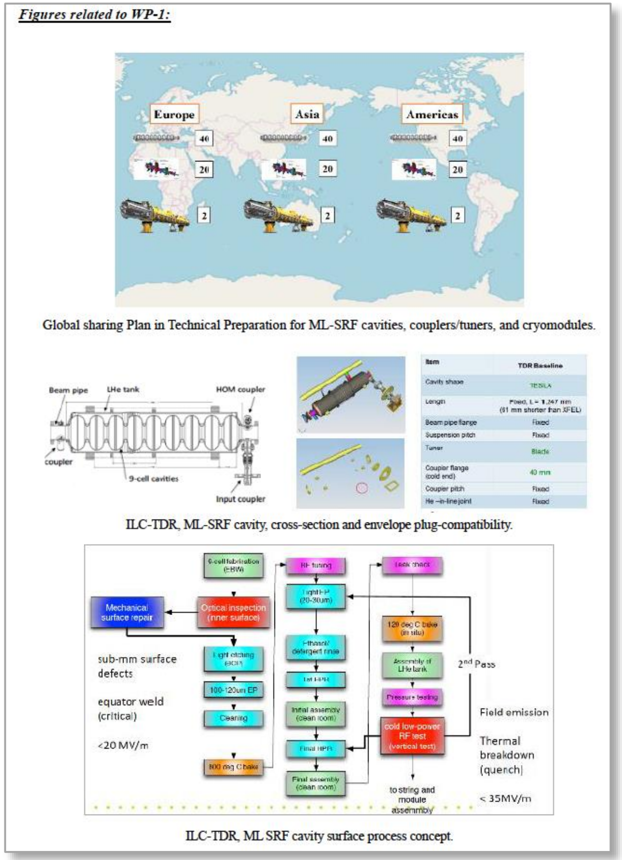
Area System ML-SRF: Work packages (WPs)

Work package	*Items*
WP- 1: **Cavity Industrial-Production Readiness** **# production: 3 x 40** **(16 of 40 go to CM assembly)**	Cavity production readiness, incl. cavities w/ He tank + magnetic shield for cavity, high-pressure-gas regulation, surface-preparation/heat treatment (HT)/Clean-room work, partly including the 2nd pass, vertical test (VT)
	Plug compatibility, Nb material, and recipe for surface treatment to be reconfirmed/decided
	Cavity Production Success yield to be confirmed (before He tank jacketing)
	Tuner baseline design to be established
	Note: Infrastructure for surface treatment, HT, VT, pre-tuning, etc. (with each regional responsibility)
WP-2: **Cryomodule (CM)** **Global Transfer and Performance Assurance** **# production: 3 x 2**	Coupler production readiness, including preparation/RF processing (# Couplers, 3 × 20)
	Note: Infrastructure for coupler conditioning: klystron, baking furnace, and associated environment (with each regional responsibility)
	Tuner production readiness, including reliability verification (# Tuners, 3 × 20)
	Superconducting Magnet (SCM: Q+D combined) production readiness (# SCMs, 3 × 3 (1 prototype + 2))
	CM production readiness incl. high-pressure-gas, vacuum vessel (VV), cold-mass, and assembly (cavity-string, coupler, tuner, SCM etc.)
	CM test including degradation mitigation (in 2-CM joint work, etc.) at assembly site before ready for CM transportation
	CM Transportation cage and shock damper to be established
	Ground transportation practice, using mockup-CM
	Ground transportation test, using production-CM longer than Eu-XFEL
	Global transport of CM by sea shipment (requiring longer container)
	Performance assurance test after CM global transport (at KEK)
	Returning transport of CM back to home country (by sea shipment)
	Note: Hub-lab Infrastructure for the CM production, assembly, and test (with each regional responsibility)
WP-3: **Crab Cavity (CC) for BDS** **#CC production: 4** **# CC-CM production: 1**	Decision of installation location with cryogenics/RF location accelerator tunnel
	Design and development of prototype cavity/coupler/tune/CM including beam extraction line
	Cavity production, including cavities w/ He tank + mag. shield for CM, high-pressure gas regulation, EP/HT/Clean work, including VT
	Coupler production including preparation/RF processing readiness (excluding klystron, baking furnace, clean room)
	Tuner production readiness
	CM production including High-pressure-gas formality, vacuum vessel, cold-mass, and assembly (cavity-string, coupler/tuner, SCM, etc.)
	CM test including harmonized operation with two cavities
	CC-CM transport cage and shock damper
	CC-CM transport tests
	Infrastructure for CC and CM development and test (with each regional responsibility.)

IDT

WP1: Cavity Industrial Production Readiness

- Goals:
  - Prepare cavity mass production
  - **Produce 3x40 cavities (40 / region),**
    3 x 16 for cryomodule installatioon (WP2)
  - Decide tuner design
  - Establish plug-compatible interface
  - Develop recipe for cavity treatment
  - **(Try to) Establish improved cavity gradient / Q0**
- Resources
  - 24MILCU + 40 FTE-y



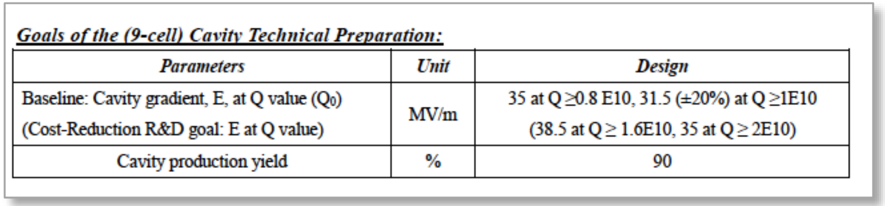
Figures related to WP-1:

Global sharing Plan in Technical Preparation for ML-SRF cavities, couplers/tuners, and cryomodules.

Item	TDR Baseline
Cavity shape	TESLA
Length	Fixed, L = 1,247 mm (61 mm shorter than XFEL)
Beam pipe flange	Fixed
Suspension pitch	Fixed
Tuner	Blade
Coupler flange (cold end)	40 mm
Coupler pitch	Fixed
He –in-line joint	Fixed

ILC-TDR, ML-SRF cavity, cross-section and envelope plug-compatibility.

ILC-TDR, ML SRF cavity surface process concept.

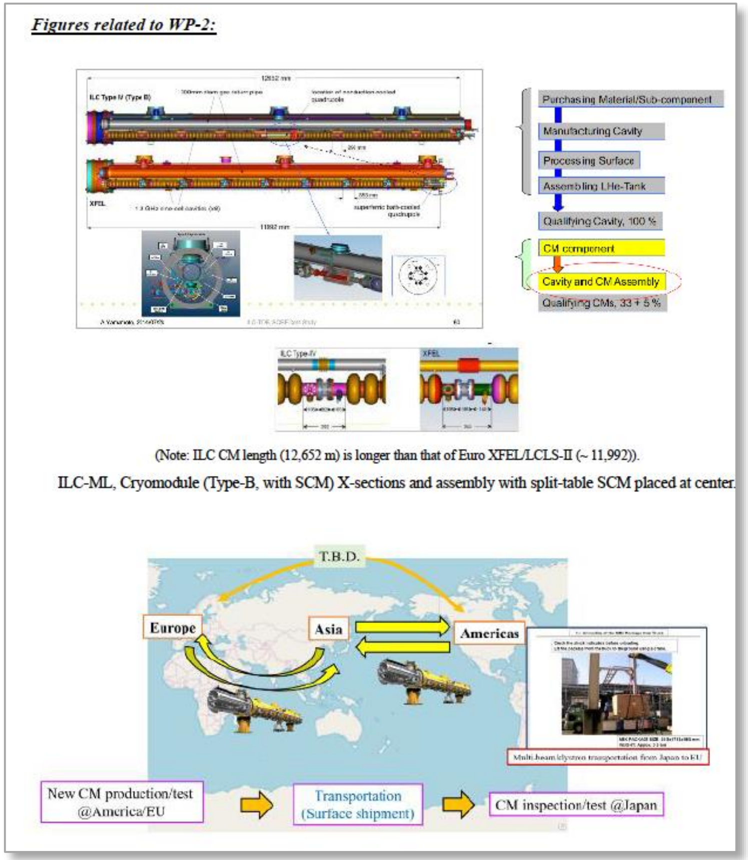


Goals of the (9-cell) Cavity Technical Preparation:

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 ≥0.8 E10, 31.5 (±20%) at Q ≥1E10 (38.5 at Q ≥ 1.6E10, 35 at Q ≥ 2E10)
Cavity production yield	%	90

WP2: Cryomodule Global Transfer and Performance Assurance

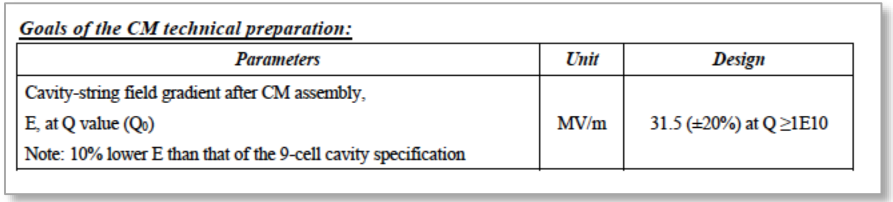
- Goals:
  - **Produce 3x2 ILC type cryomodules (2 / region)**
  - Develop and prototype all parts: cold mass, coupler, magnet package
  - Develop transport container / cage
  - ”**CM Global Transfer Program**”: ship 1 CM/region to Japan,
  - Demonstrate performance in Japan
- Ressources
  - 15,4 MILCU + 200 FTE-y


Figures related to WP-2:

(Note: ILC CM length (12,652 m) is longer than that of Euro XFEL/LCLS-II (~ 11,992)).

ILC-ML, Cryomodule (Type-B, with SCM) X-sections and assembly with split-table SCM placed at center.

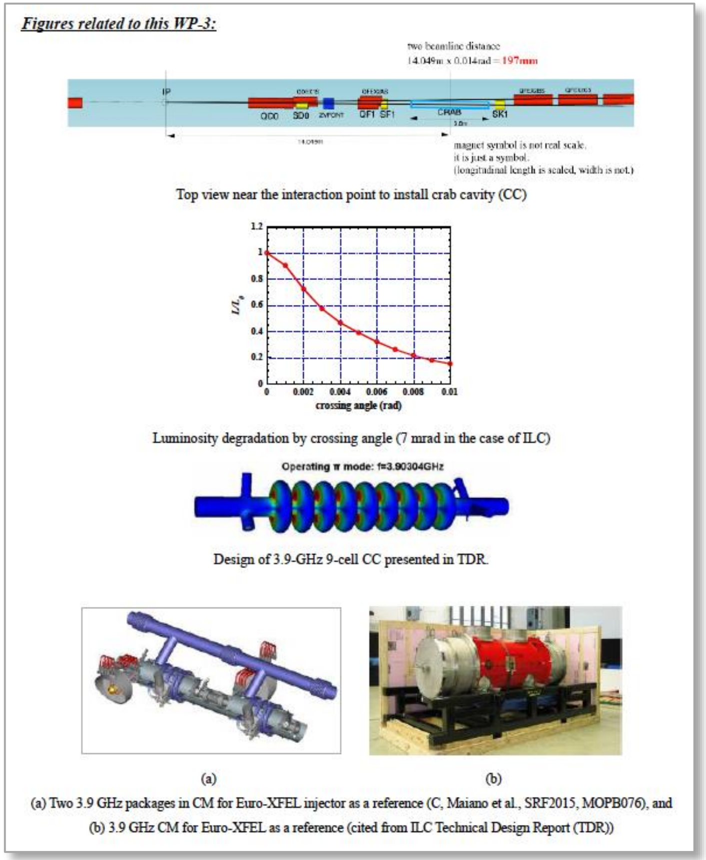
New CM production/test @America/EU → Transportation (Surface shipment) → CM inspection/test @Japan


Goals of the CM technical preparation:

Parameters	*Unit*	*Design*
Cavity-string field gradient after CM assembly, E, at Q value (Q_0) Note: 10% lower E than that of the 9-cell cavity specification	MV/m	31.5 (±20%) at Q ≥1E10

WP3: Crab-Cavity System

- Goals
  - Design, produce and test prototype cryomodule: cavity, coupler, tuner, cryomodule
- Ressources
  - 2,3 MILCU + 29 FTE-y



Figures related to this WP-3:

Top view near the interaction point to install crab cavity (CC)

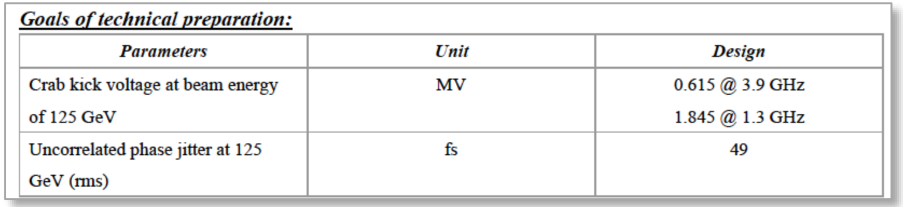
Luminosity degradation by crossing angle (7 mrad in the case of ILC)

Design of 3.9-GHz 9-cell CC presented in TDR.

(a)

(b)

(a) Two 3.9 GHz packages in CM for Euro-XFEL injector as a reference (C, Maiano et al., SRF2015, MOPB076), and (b) 3.9 GHz CM for Euro-XFEL as a reference (cited from ILC Technical Design Report (TDR))

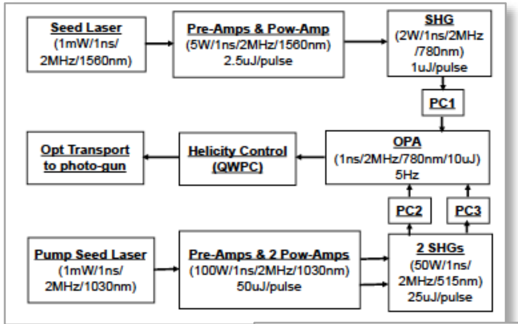


Goals of technical preparation:

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

Area 2 = WP4: Electron Source

- Goals
  - Reevaluate the drive laser design and cost, build a prototype to demonstrate the beam pattern,
  - Design a higher voltage gun 350 kV with greater reliability/headroom, and build it,
  - Evaluate if higher gun voltage and shorter laser pulse length relaxes harmonic bunching,
  - Produce GaAs/GaAsP photocathodes with P>90%, QE>1%, work with vendor to commercialize
- Ressources
  - 2,6 MILCU + 6 FTE-y



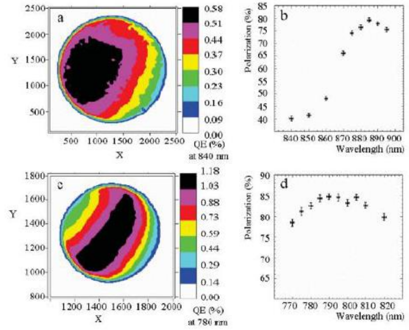
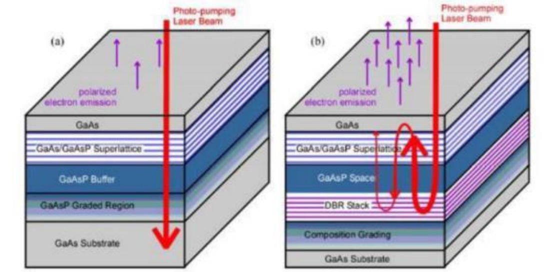


Fig. 2. Quantum efficiency and polarization versus wavelength for commercial photocathodes: (top) Single-strained layer GaAs/GaAsP photocathode fabricated by SPIRE/Bandwidth Semiconductor, (bottom) strained-superlattice GaAs/GaAsP photocathode fabricated by SVT Associates.

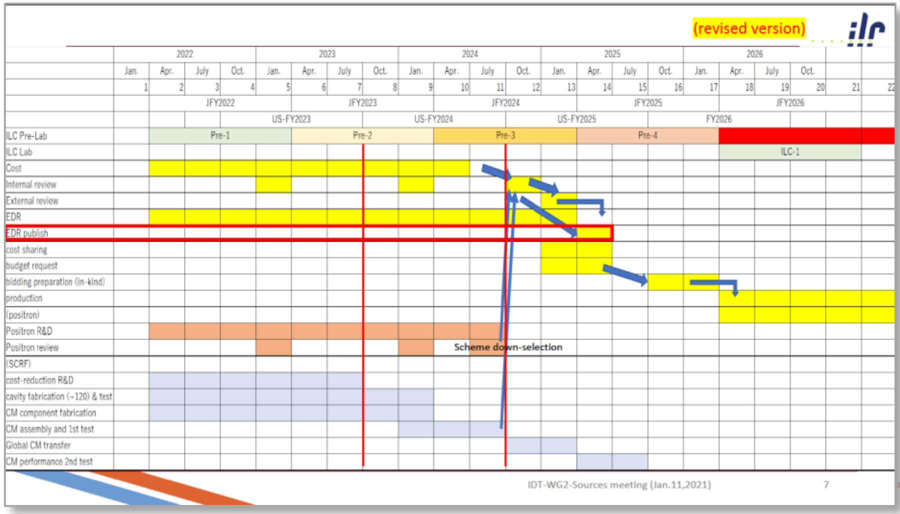


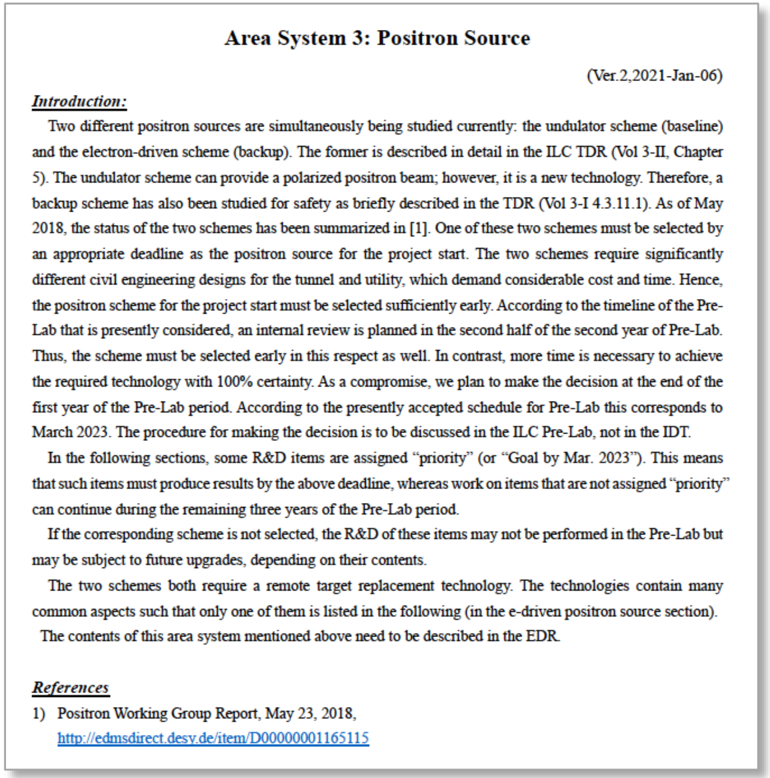
In a standard single-pass photocathode structure over 90% of laser energy is wasted and converts to unwanted heat.

In a photocathode with integrated reflector laser energy is redirected to make multiple passes through the superlattice active layer, increasing quantum efficiency and/or reducing parasitic heat.

Area System 3: Positron Source

- 2 Concepts:
  - Undulator source (baseline)
  - Electron driven source (backup)
- **Downselect during prelab phase**
  -> now planned for **mid-24**





Area System 3: Positron Source

(Ver.2,2021-Jan-06)

Introduction:

Two different positron sources are simultaneously being studied currently: the undulator scheme (baseline) and the electron-driven scheme (backup). The former is described in detail in the ILC TDR (Vol 3-II, Chapter 5). The undulator scheme can provide a polarized positron beam; however, it is a new technology. Therefore, a backup scheme has also been studied for safety as briefly described in the TDR (Vol 3-I 4.3.11.1). As of May 2018, the status of the two schemes has been summarized in [1]. One of these two schemes must be selected by an appropriate deadline as the positron source for the project start. The two schemes require significantly different civil engineering designs for the tunnel and utility, which demand considerable cost and time. Hence, the positron scheme for the project start must be selected sufficiently early. According to the timeline of the Pre-Lab that is presently considered, an internal review is planned in the second half of the second year of Pre-Lab. Thus, the scheme must be selected early in this respect as well. In contrast, more time is necessary to achieve the required technology with 100% certainty. As a compromise, we plan to make the decision at the end of the first year of the Pre-Lab period. According to the presently accepted schedule for Pre-Lab this corresponds to March 2023. The procedure for making the decision is to be discussed in the ILC Pre-Lab, not in the IDT.

In the following sections, some R&D items are assigned "priority" (or "Goal by Mar. 2023"). This means that such items must produce results by the above deadline, whereas work on items that are not assigned "priority" can continue during the remaining three years of the Pre-Lab period.

If the corresponding scheme is not selected, the R&D of these items may not be performed in the Pre-Lab but may be subject to future upgrades, depending on their contents.

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

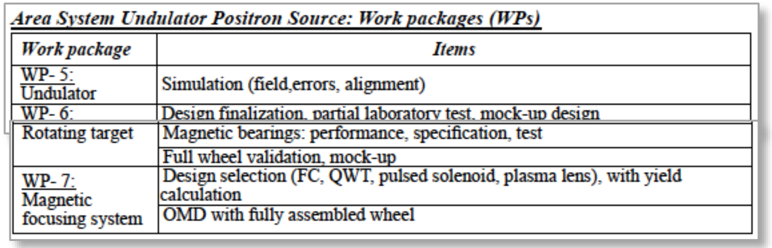
The contents of this area system mentioned above need to be described in the EDR.

References

1) Positron Working Group Report, May 23, 2018,
http://edmsdirect.desy.de/item/D00000001165115

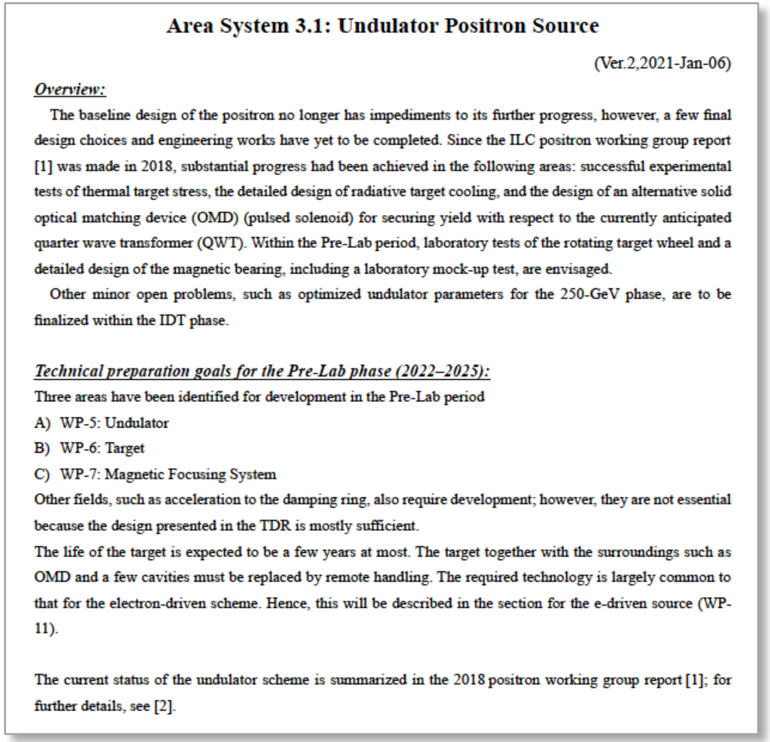
Area System 3.1: Undulator Positron Source

- 3 Work Packages:



Area System Undulator Positron Source: Work packages (WPs)

Work package	*Items*
WP- 5: Undulator	Simulation (field,errors, alignment)
WP- 6: Rotating target	Design finalization, partial laboratory test, mock-up design
	Magnetic bearings: performance, specification, test
	Full wheel validation, mock-up
WP- 7: Magnetic focusing system	Design selection (FC, QWT, pulsed solenoid, plasma lens), with yield calculation
	OMD with fully assembled wheel



Area System 3.1: Undulator Positron Source

(Ver.2,2021-Jan-06)

Overview:

The baseline design of the positron no longer has impediments to its further progress, however, a few final design choices and engineering works have yet to be completed. Since the ILC positron working group report [1] 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 alternative solid optical matching device (OMD) (pulsed solenoid) for securing yield with respect to the currently anticipated quarter wave transformer (QWT). Within the Pre-Lab period, laboratory tests of the rotating target wheel and a detailed design of the magnetic bearing, including a laboratory mock-up test, are envisaged.

Other minor open problems, such as optimized undulator parameters for the 250-GeV phase, are to be finalized within the IDT phase.

Technical preparation goals for the Pre-Lab phase (2022–2025):

Three areas have been identified for development in the Pre-Lab period

A) WP-5: Undulator

B) WP-6: Target

C) WP-7: Magnetic Focusing System

Other fields, such as acceleration to the damping ring, also require development; however, they are not essential because the design presented in the TDR is mostly sufficient.

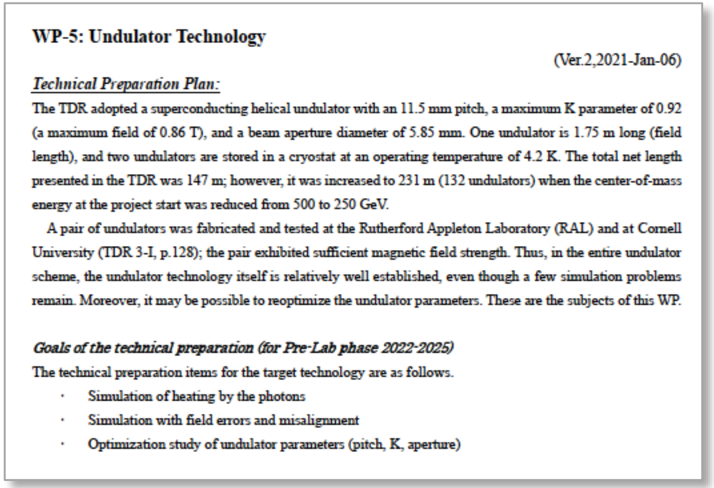
The life of the target is expected to be a few years at most. The target together with the surroundings such as OMD and a few cavities must be replaced by remote handling. The required technology is largely common to that for the electron-driven scheme. Hence, this will be described in the section for the e-driven source (WP-11).

The current status of the undulator scheme is summarized in the 2018 positron working group report [1]; for further details, see [2].

WP5: Undulator Technology

- Undulator regarded as mature
- Goals:
  - Simulation of heating by the photons
  - Simulation with field errors and misalignment
  - Optimization study of undulator parameters (pitch, K, aperture)

- Ressources
  - None (outside work done in contributing labs)



WP-5: Undulator Technology

(Ver.2,2021-Jan-06)

Technical Preparation Plan:

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

A pair of undulators was fabricated and tested at the Rutherford Appleton Laboratory (RAL) and at Cornell University (TDR 3-I, p.128); the pair exhibited sufficient magnetic field strength. Thus, in the entire undulator scheme, the undulator technology itself is relatively well established, even though a few simulation problems remain. Moreover, it may be possible to reoptimize the undulator parameters. These are the subjects of this WP.

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

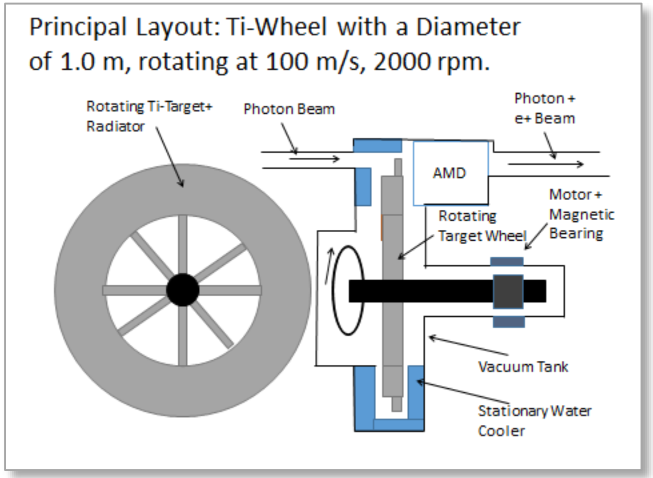
The technical preparation items for the target technology are as follows.

- Simulation of heating by the photons
- Simulation with field errors and misalignment
- Optimization study of undulator parameters (pitch, K, aperture)

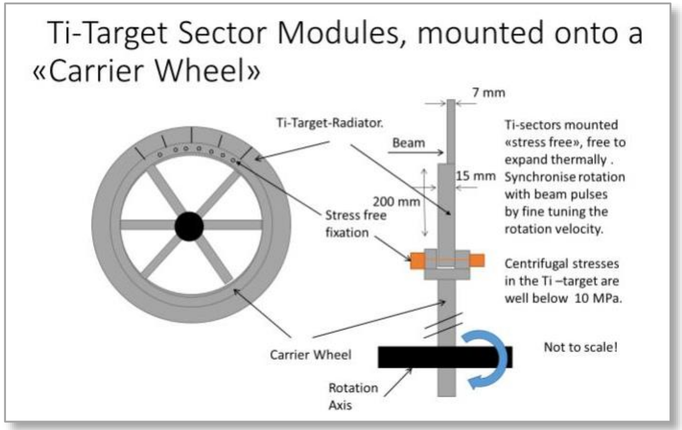
WP6: Target Technology

- Goals
  - Design finalization of the rotating wheel with radiative cooling design and laboratory test of a stationary sector model. This is labelled as “priority” item.
  - Magnetic bearings, feasibility study
  - **Fabrication of full model**

- Ressources
  - 0,4 MILCU + 5 FTE-y



Principal Layout: Ti-Wheel with a Diameter of 1.0 m, rotating at 100 m/s, 2000 rpm.



Ti-Target Sector Modules, mounted onto a «Carrier Wheel»

Ti-sectors mounted «stress free», free to expand thermally . Synchronise rotation with beam pulses by fine tuning the rotation velocity.

Centrifugal stresses in the Ti –target are well below 10 MPa.

WP7: Magnetic Focussing System

- Goals:
  - Final design choice among the possible focusing devices with yield calculation
  - Construction of the prototype of OMD and the rotating wheel
- Ressources:
  - 0,5 MILCU + 4 FTE-y

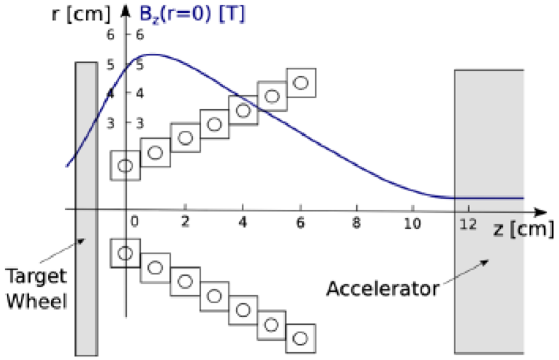


Fig. 2 OMD: Pulsed solenoid and generated B-field.

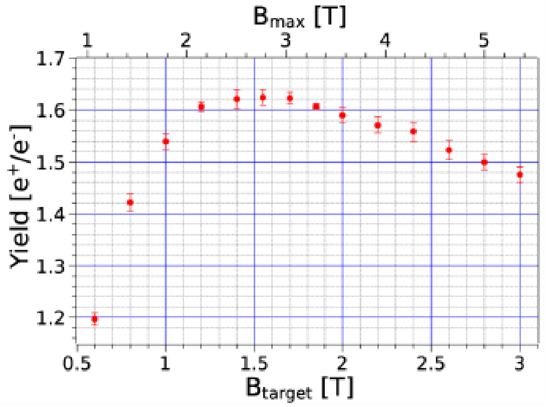
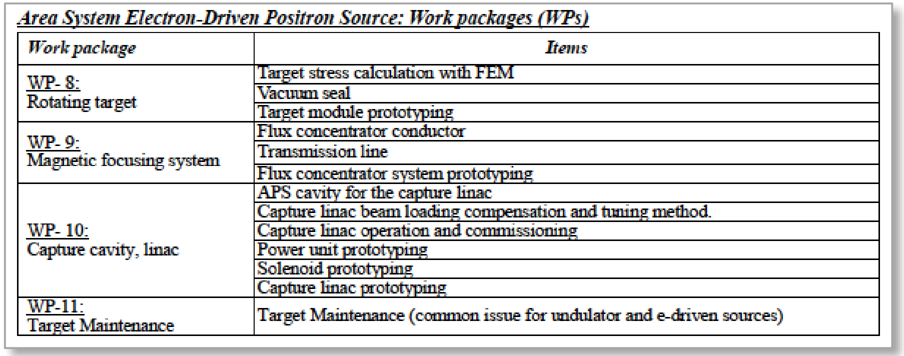


Fig. 3 Expected e+ yield depending on the B-Field at the target exit

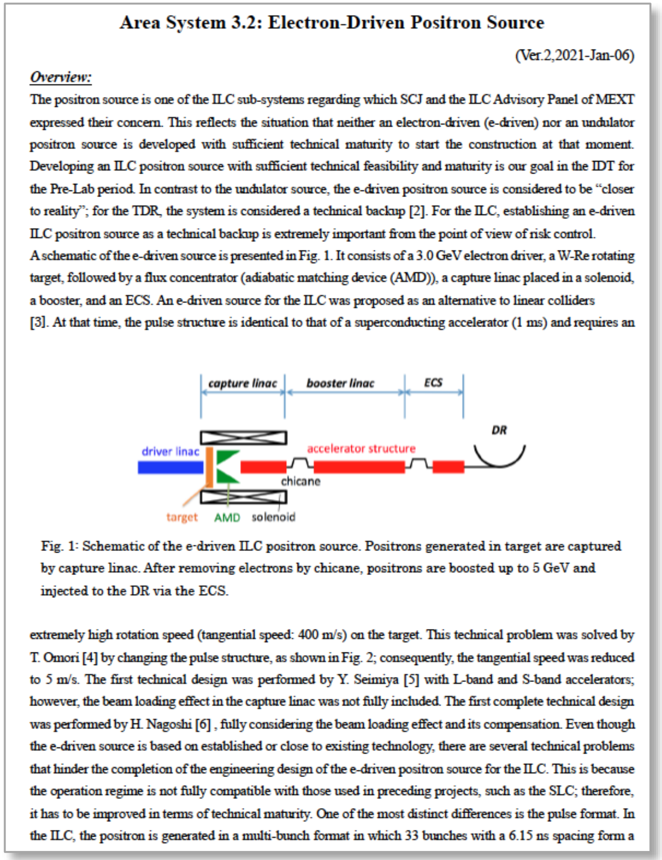
Area System 3.2: Electron-Driven Positron Source

- 4 Work Packages
  - 3 electron driven specific
  - 1 for target handling: both concepts



Area System Electron-Driven Positron Source: Work packages (WPs)

Work package	*Items*
WP- 8: Rotating target	Target stress calculation with FEM Vacuum seal Target module prototyping
WP- 9: Magnetic focusing system	Flux concentrator conductor Transmission line Flux concentrator system prototyping
WP- 10: Capture cavity, linac	APS cavity for the capture linac Capture linac beam loading compensation and tuning method. Capture linac operation and commissioning Power unit prototyping Solenoid prototyping Capture linac prototyping
WP-11: Target Maintenance	Target Maintenance (common issue for undulator and e-driven sources)



Area System 3.2: Electron-Driven Positron Source

(Ver.2,2021-Jan-06)

Overview:

The positron source is one of the ILC sub-systems regarding which SCJ and the ILC Advisory Panel of MEXT expressed their concern. This reflects the situation that neither an electron-driven (e-driven) nor an undulator positron source is developed with sufficient technical maturity to start the construction at that moment. Developing an ILC positron source with sufficient technical feasibility and maturity is our goal in the IDT for the Pre-Lab period. In contrast to the undulator source, the e-driven positron source is considered to be "closer to reality"; for the TDR, the system is considered a technical backup [2]. For the ILC, establishing an e-driven ILC positron source as a technical backup is extremely important from the point of view of risk control.

A schematic of the e-driven source is presented in Fig. 1. It consists of a 3.0 GeV electron driver, a W-Re rotating target, followed by a flux concentrator (adiabatic matching device (AMD)), a capture linac placed in a solenoid, a booster, and an ECS. An e-driven source for the ILC was proposed as an alternative to linear colliders [3]. At that time, the pulse structure is identical to that of a superconducting accelerator (1 ms) and requires an extremely high rotation speed (tangential speed: 400 m/s) on the target. This technical problem was solved by T. Omori [4] by changing the pulse structure, as shown in Fig. 2; consequently, the tangential speed was reduced to 5 m/s. The first technical design was performed by Y. Seimiya [5] with L-band and S-band accelerators; however, the beam loading effect in the capture linac was not fully included. The first complete technical design was performed by H. Nagoshi [6] , fully considering the beam loading effect and its compensation. Even though the e-driven source is based on established or close to existing technology, there are several technical problems that hinder the completion of the engineering design of the e-driven positron source for the ILC. This is because the operation regime is not fully compatible with those used in preceding projects, such as the SLC; therefore, it has to be improved in terms of technical maturity. One of the most distinct differences is the pulse format. In the ILC, the positron is generated in a multi-bunch format in which 33 bunches with a 6.15 ns spacing form a

Fig. 1: Schematic of the e-driven ILC positron source. Positrons generated in target are captured by capture linac. After removing electrons by chicane, positrons are boosted up to 5 GeV and injected to the DR via the ECS.

WP8: Target

- Goals:
  - More accurate calculation of the target stress and fatigue effect to improve the design
  - The required high vacuum (in the order of e−6 Pa at the accelerator) should be maintained for a long time.
  - Stable target prototype operation; the test operation of the target prototype is set to start in the Spring of 2021.
- Ressources:
  - 1,6 MILCU + 1,3 FTE-y

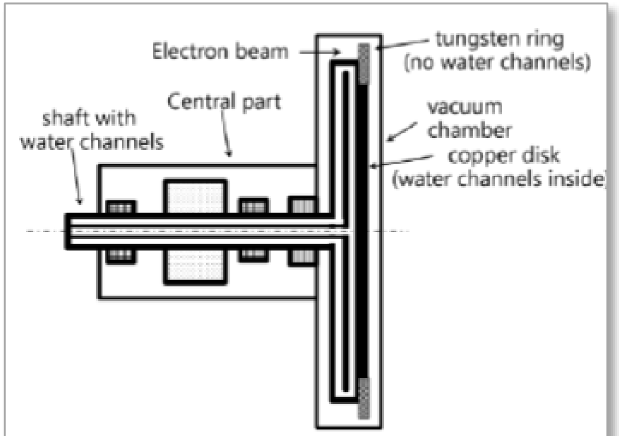


Fig. 3: Schematic of the target cross section. [1]

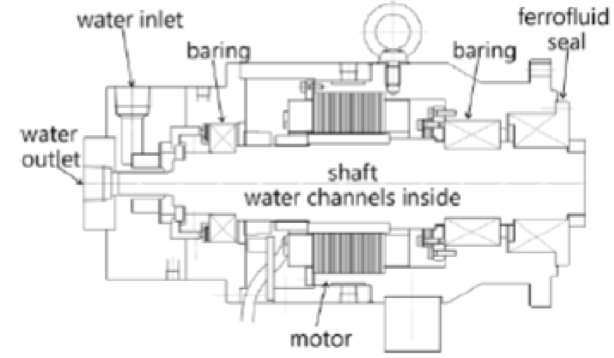


Fig. 4: Design of the central shaft of the target. [1]

WP9: Flux Concentrator

- Goals:
  - The electrical, thermal, and mechanical properties of the FC conductor should be verified through simulations
  - Transmission line design
  - Power source design
  - FC system (FC conductor, transmission line, and power source) **prototyping and test operation**
- Ressources
  - 1,07 MILCU + 1,4 FTE-y

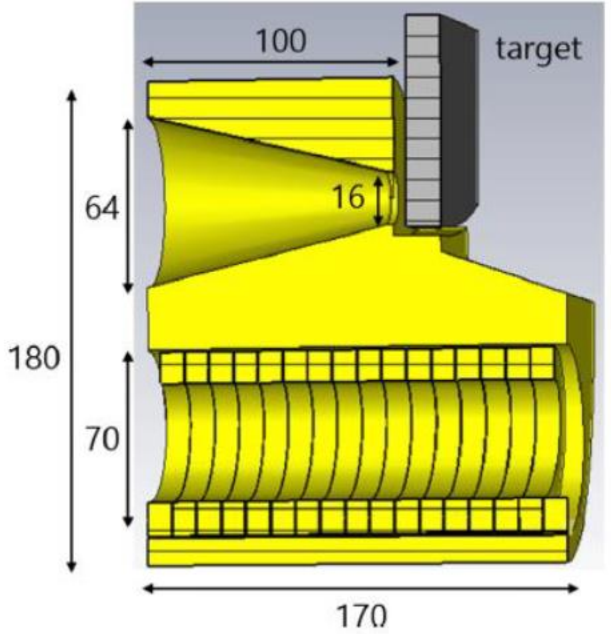


Fig. 5 Flux Concentrator Design.

WP10: Capture Linac

- Goals:
  - RF design of APS cavity
  - Establish beam loading compensation and linac tuning method
  - Power unit design and prototyping (L-band klystron + modulator)
  - Solenoid magnet design
  - Test operation of APS cavity with developed power source
- Ressources:
  - 1,66 MILCU + 1,8 FTE-y

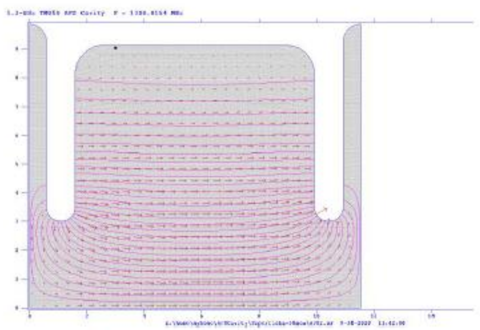


Fig. 6: Field map of APS cavity calculated by

Fig. 7: K300 modulator by Scandinova Co. for L-band APS cavity.

WP11: Target Maintenance (both source concepts)

- Goals
  - Complete the technical design
  - Fabricate a mock-up to confirm the function
  - Develop a fail-safe system
- Ressources
  - 0,02 MILCU + 0,5 FTE-y

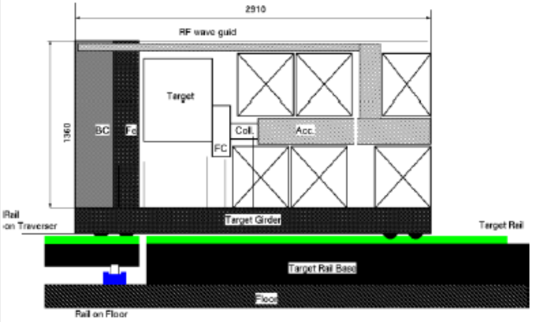


Fig. 9: Side cross-sectional view of target module on rails for easy transportation: front side (upstream of beam), 30 cm boronized concrete shield and 20 cm Fe shield placed for protection.

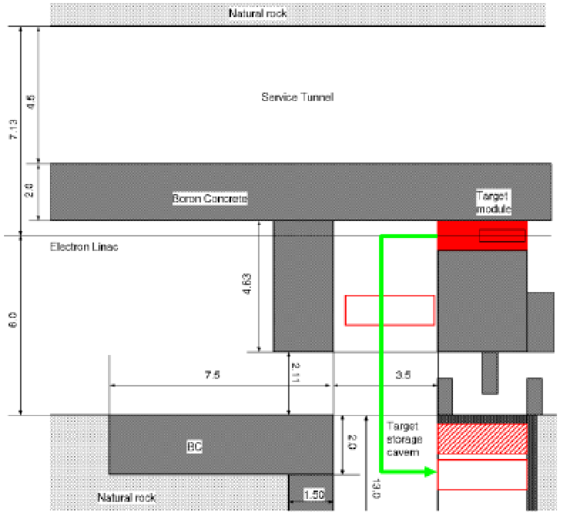
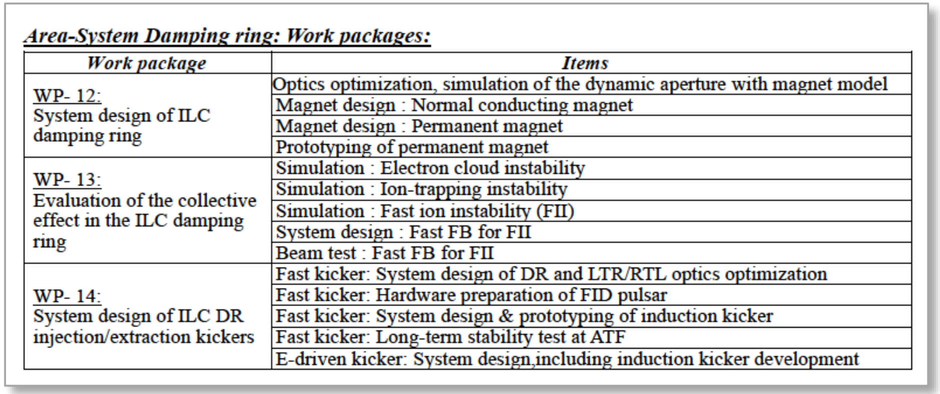


Fig. 8: Floor layout of the target section: the central red rectangle is the target module: the shaded gray area is boronized concrete shield: the lower cavern is the target storage area.

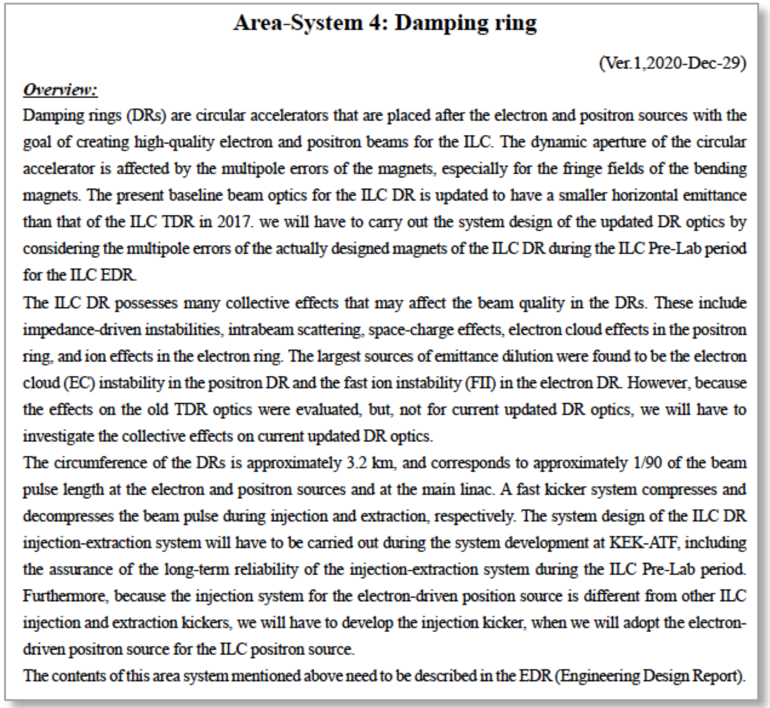
Area System 4: Damping Ring

- 3 Work Packages



Area-System Damping ring: Work packages:

Work package	*Items*
WP- 12: System design of ILC damping ring	Optics optimization, simulation of the dynamic aperture with magnet model
	Magnet design : Normal conducting magnet
	Magnet design : Permanent magnet
	Prototyping of permanent magnet
WP- 13: Evaluation of the collective effect in the ILC damping ring	Simulation : Electron cloud instability
	Simulation : Ion-trapping instability
	Simulation : Fast ion instability (FII)
	System design : Fast FB for FII
	Beam test : Fast FB for FII
WP- 14: System design of ILC DR injection/extraction kickers	Fast kicker: System design of DR and LTR/RTL optics optimization
	Fast kicker: Hardware preparation of FID pulsar
	Fast kicker: System design & prototyping of induction kicker
	Fast kicker: Long-term stability test at ATF
	E-driven kicker: System design,including induction kicker development



Area-System 4: Damping ring

(Ver.1,2020-Dec-29)

Overview:

Damping rings (DRs) are circular accelerators that are placed after the electron and positron sources with the goal of creating high-quality electron and positron beams for the ILC. The dynamic aperture of the circular accelerator is affected by the multipole errors of the magnets, especially for the fringe fields of the bending magnets. The present baseline beam optics for the ILC DR is updated to have a smaller horizontal emittance than that of the ILC TDR in 2017. we will have to carry out the system design of the updated DR optics by considering the multipole errors of the actually designed magnets of the ILC DR during the ILC Pre-Lab period for the ILC EDR.

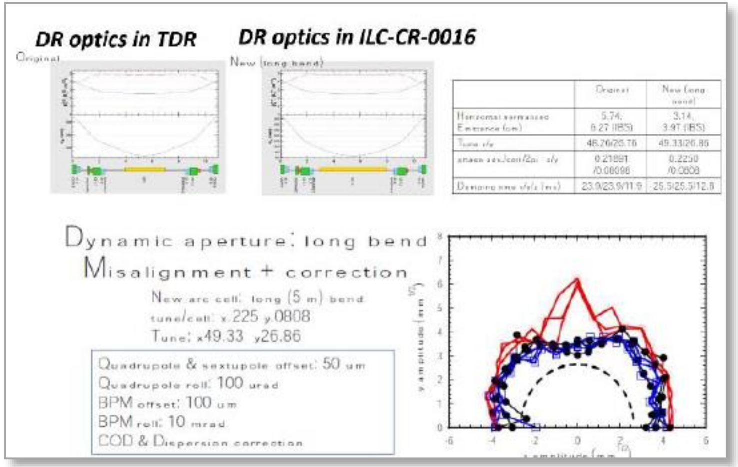
The ILC DR possesses many collective effects that may affect the beam quality in the DRs. These include impedance-driven instabilities, intrabeam scattering, space-charge effects, electron cloud effects in the positron ring, and ion effects in the electron ring. The largest sources of emittance dilution were found to be the electron cloud (EC) instability in the positron DR and the fast ion instability (FII) in the electron DR. However, because the effects on the old TDR optics were evaluated, but, not for current updated DR optics, we will have to investigate the collective effects on current updated DR optics.

The circumference of the DRs is approximately 3.2 km, and corresponds to approximately 1/90 of the beam pulse length at the electron and positron sources and at the main linac. A fast kicker system compresses and decompresses the beam pulse during injection and extraction, respectively. The system design of the ILC DR injection-extraction system will have to be carried out during the system development at KEK-ATF, including the assurance of the long-term reliability of the injection-extraction system during the ILC Pre-Lab period. Furthermore, because the injection system for the electron-driven position source is different from other ILC injection and extraction kickers, we will have to develop the injection kicker, when we will adopt the electron-driven positron source for the ILC positron source.

The contents of this area system mentioned above need to be described in the EDR (Engineering Design Report).

WP12: System Design of ILC Damping Ring

- Goals
  - Optimize beam optics
  - Evaluate effect of magnet field errors
  - Investigate Potential to use permanent magnets: build prototypes
- Ressources
  - 0,7 MILCU + 8 FTE-y



DR optics in TDR Original

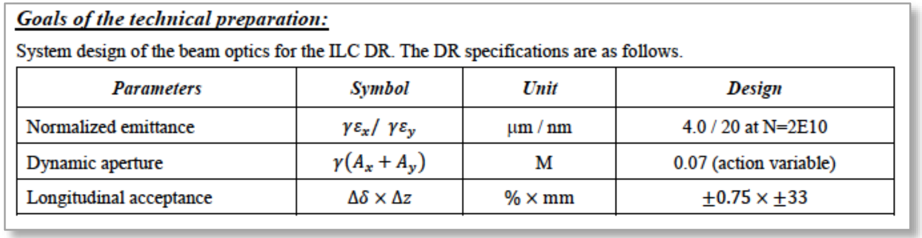
DR optics in ILC-CR-0016 New (long bend)

	Original	New (long bend)
Horizontal normalized Emittance (um)	5.74, 6.27 (IBS)	3.14, 3.97 (IBS)
Tune x/y	48.26/26.76	49.33/26.86
phase adv./cell/2pi x/y	0.21991 /0.08098	0.2250 /0.0808
Damping time x/y/z (ms)	23.9/23.9/11.9	25.5/25.5/12.8

Dynamic aperture: long bend
Misalignment + correction

New arc cell: long (5 m) bend
tune/cell: x.225 y.0808
Tune: x49.33 y26.86

Quadrupole & sextupole offset: 50 um
Quadrupole roll: 100 urad
BPM offset: 100 um
BPM roll: 10 mrad
COD & Dispersion correction



Goals of the technical preparation:

System design of the 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	±0.75 × ±33

ESRF Fixed field

Sirius Small adjustment (~3%)

CBETA Fixed field

ZEPTO Variable field (factor 2)

CBETA Fixed field

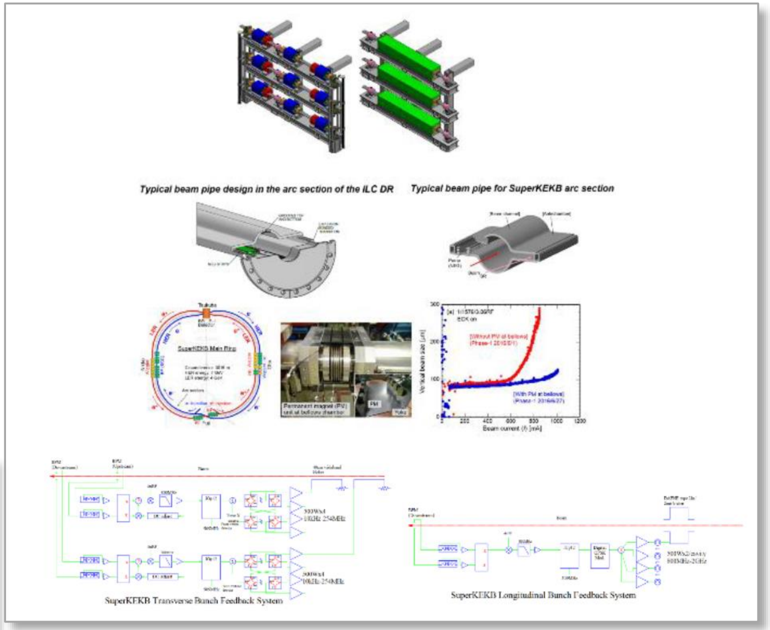
QUAPEVA (Soleil) Factor of 2 tuning

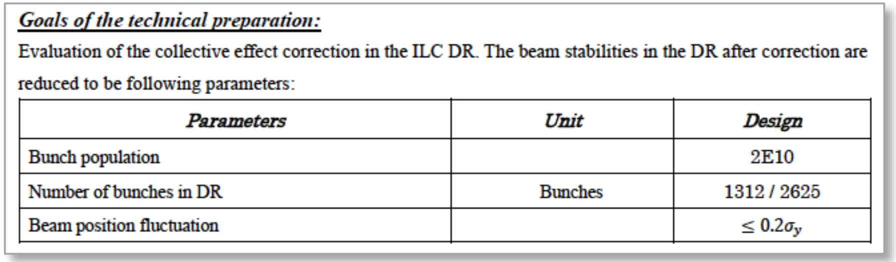
ZEPTO-Q1 High strength Factor of 4

ZEPTO-Q2 Lower strength Very large adjustment range

WP13: Evaluation fo collective effects in ILC damping ring

- Goals
  - Investigate (simulate) electron cloud (EC) and Fast Ion Instabilities (FII)
  - Develop high-resolution fast feedback system
- Ressources
  - 1 MILCU + 12 FTE-y





Goals of the technical preparation:

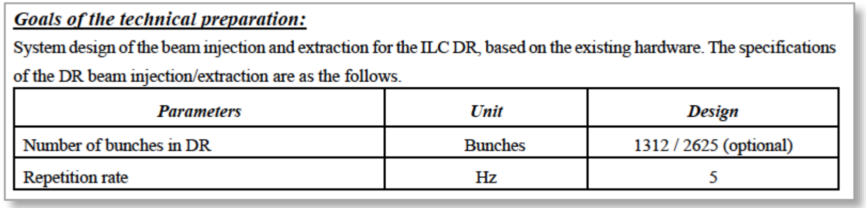
Evaluation of the collective effect correction in the ILC DR. The beam stabilities in the DR after correction are reduced to be following parameters:

Parameters	***Unit***	***Design***
Bunch population		2E10
Number of bunches in DR	Bunches	1312 / 2625
Beam position fluctuation		$\leq 0.2\sigma_y$

IDT

WP14: System design of ILC DR injection/extraction kickers

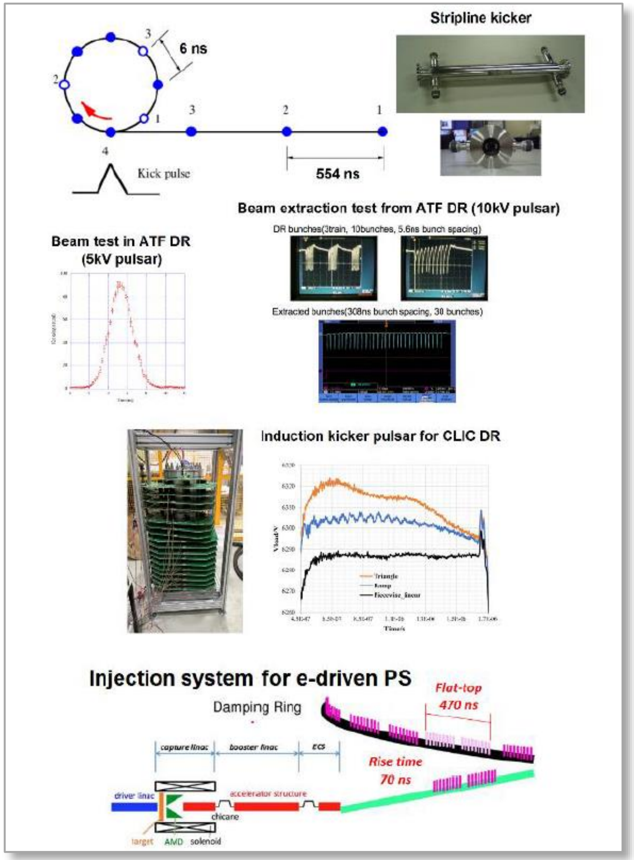
- Goals
  - Perform long-term stability test of fast kicker system at ATF
  - Develop injection kicker system for electron driven source
- Ressources
  - 0,805MILCU + 8,5 FTE-y



Goals of the technical preparation:

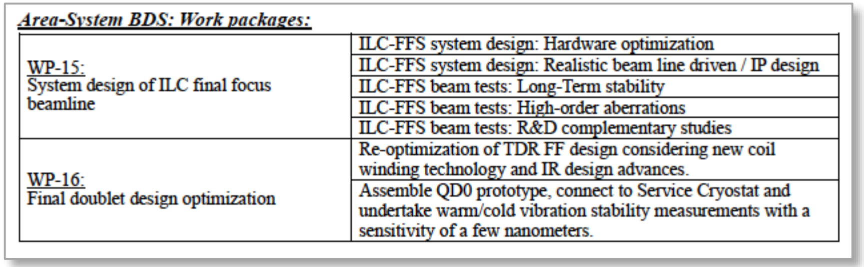
System design of the beam injection and extraction for the ILC DR, based on the existing hardware. The specifications of the DR beam injection/extraction are as the follows.

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



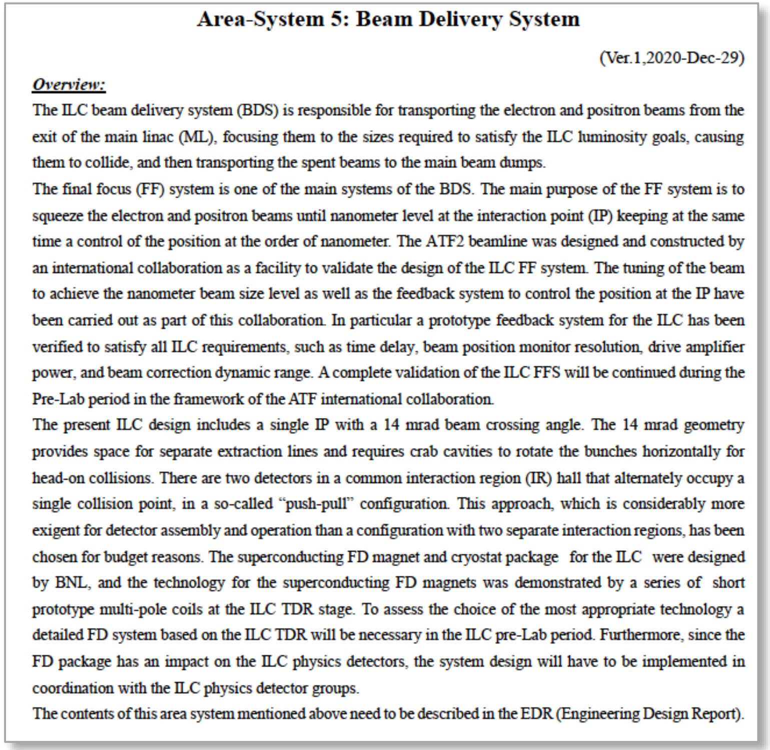
Area System 5: Beam Delivery System

- 2 Work packages



Area-System BDS: Work packages:

WP-15: System design of ILC final focus beamline	ILC-FFS system design: Hardware optimization
	ILC-FFS system design: Realistic beam line driven / IP design
	ILC-FFS beam tests: Long-Term stability
	ILC-FFS beam tests: High-order aberrations
	ILC-FFS beam tests: R&D complementary studies
WP-16: Final doublet design optimization	Re-optimization of TDR FF design considering new coil winding technology and IR design advances.
	Assemble QD0 prototype, connect to Service Cryostat and undertake warm/cold vibration stability measurements with a sensitivity of a few nanometers.



Area-System 5: Beam Delivery System

(Ver.1,2020-Dec-29)

Overview:

The ILC beam delivery system (BDS) is responsible for transporting the electron and positron beams from the exit of the main linac (ML), focusing them to the sizes required to satisfy the ILC luminosity goals, causing them to collide, and then transporting the spent beams to the main beam dumps.

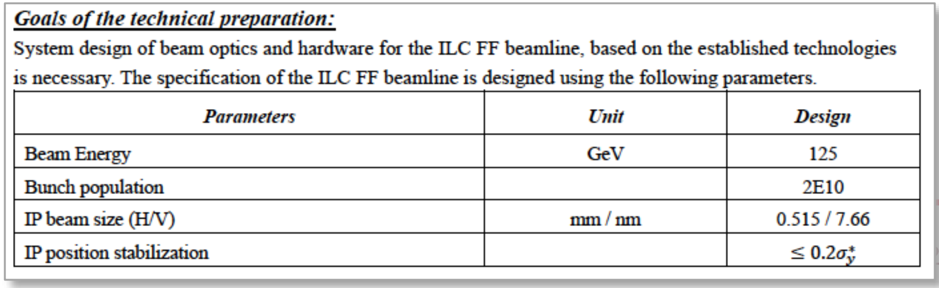
The final focus (FF) system is one of the main systems of the BDS. The main purpose of the FF system is to squeeze the electron and positron beams until nanometer level at the interaction point (IP) keeping at the same time a control of the position at the order of nanometer. The ATF2 beamline was designed and constructed by an international collaboration as a facility to validate the design of the ILC FF system. The tuning of the beam to achieve the nanometer beam size level as well as the feedback system to control the position at the IP have been carried out as part of this collaboration. In particular a prototype feedback system for the ILC has been verified to satisfy all ILC requirements, such as time delay, beam position monitor resolution, drive amplifier power, and beam correction dynamic range. A complete validation of the ILC FFS will be continued during the Pre-Lab period in the framework of the ATF international collaboration.

The present ILC design includes a single IP with a 14 mrad beam crossing angle. The 14 mrad geometry provides space for separate extraction lines and requires crab cavities to rotate the bunches horizontally for head-on collisions. There are two detectors in a common interaction region (IR) hall that alternately occupy a single collision point, in a so-called “push-pull” configuration. This approach, which is considerably more exigent for detector assembly and operation than a configuration with two separate interaction regions, has been chosen for budget reasons. The superconducting FD magnet and cryostat package for the ILC were designed by BNL, and the technology for the superconducting FD magnets was demonstrated by a series of short prototype multi-pole coils at the ILC TDR stage. To assess the choice of the most appropriate technology a detailed FD system based on the ILC TDR will be necessary in the ILC pre-Lab period. Furthermore, since the FD package has an impact on the ILC physics detectors, the system design will have to be implemented in coordination with the ILC physics detector groups.

The contents of this area system mentioned above need to be described in the EDR (Engineering Design Report).

WP15: System design of ILC final focus beamline

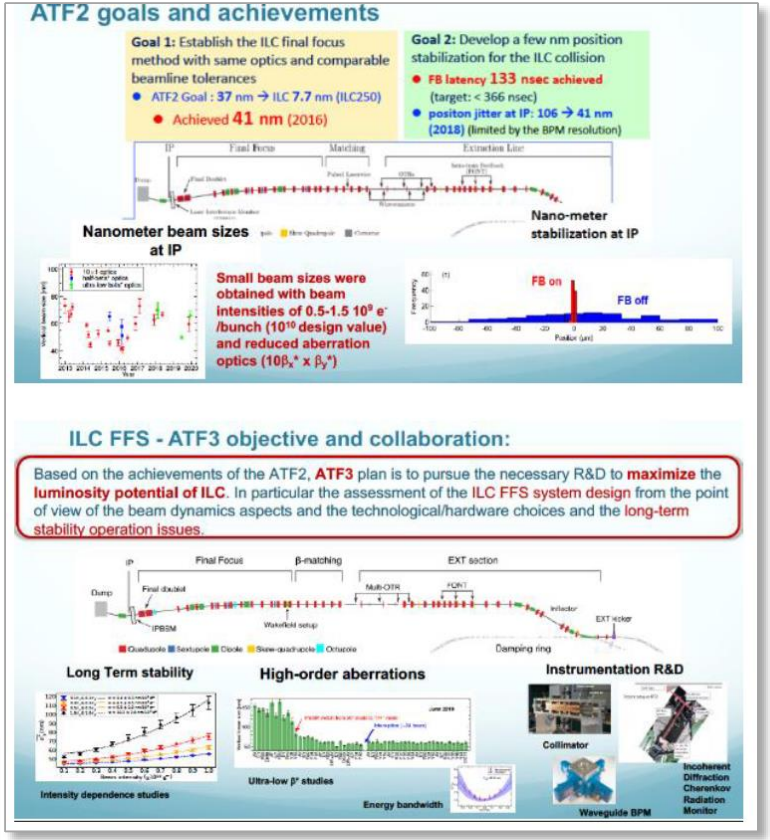
- Goals
  - Further develop Final Focus System
  - Test the concepts at ATF-3
    - **ATF3 ILC-FFS assessment system design**
    - Hardware optimization: vacuum chambers, magnets, IP-BSM laser, CBPMs, IP-BPMs
    - Realistic S2E “beam-dynamics-driven” design and IP optimization
    - **ATF3 ILC-FFS oriented beam tests**
    - Long-term stability: nominal ($10\beta_x^*\times\beta_y^*$) routine operation assessment
    - High-order aberrations
    - Other ILC R&D complementary studies: ILC collimation issues, ILC type CPBMs, new instrumentation
- Ressources
  - 1,86 MILCU + 12 FTE-y



Goals of the technical preparation:

System design of beam optics and hardware for the ILC FF beamline, based on the established technologies is necessary. 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)	mm / nm	0.515 / 7.66
IP position stabilization		$\leq 0.2\sigma_y^*$



ATF2 goals and achievements

Goal 1: Establish the ILC final focus method with same optics and comparable beamline tolerances
- ATF2 Goal : **37** nm → ILC **7.7** nm (ILC250)
- Achieved **41** nm (2016)

Goal 2: Develop a few nm position stabilization for the ILC collision
- **FB latency 133 nsec achieved** (target: < 366 nsec)
- **positon jitter at IP: 106 → 41 nm (2018)** (limited by the BPM resolution)

Nanometer beam sizes at IP

Nano-meter stabilization at IP

Small beam sizes were obtained with beam intensities of 0.5-1.5 10^9 e- /bunch (10^{10} design value) and reduced aberration optics ($10\beta_x^* \times \beta_y^*$)

ILC FFS - ATF3 objective and collaboration:

Based on the achievements of the ATF2, **ATF3** plan is to pursue the necessary R&D to **maximize** the **luminosity potential of ILC**. In particular the assessment of the ILC FFS system design from the point of view of the beam dynamics aspects and the technological/hardware choices and the long-term stability operation issues.

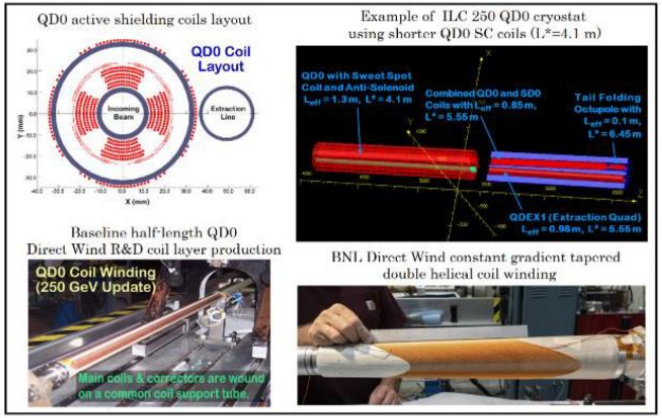
Long Term stability

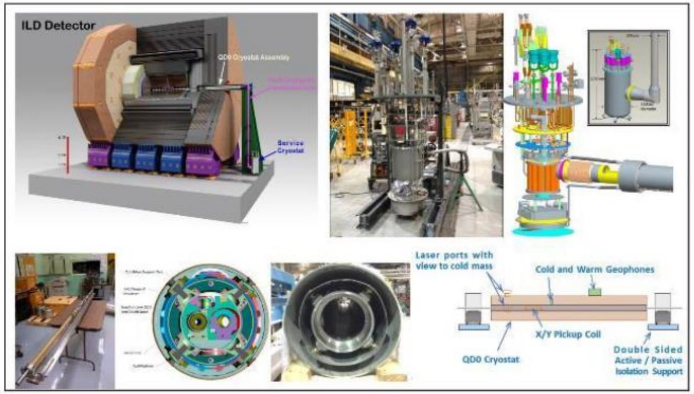
High-order aberrations

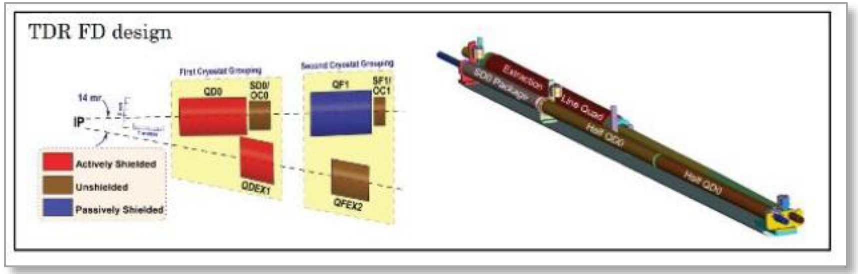
Instrumentation R&D

WP16: Final Doublet Design Optimization

- Goals
  - Design final focus magnets for 250GeV
  - Build prototype
- Ressources:
  - 0,36 MILCU + 4,5 FTE-y

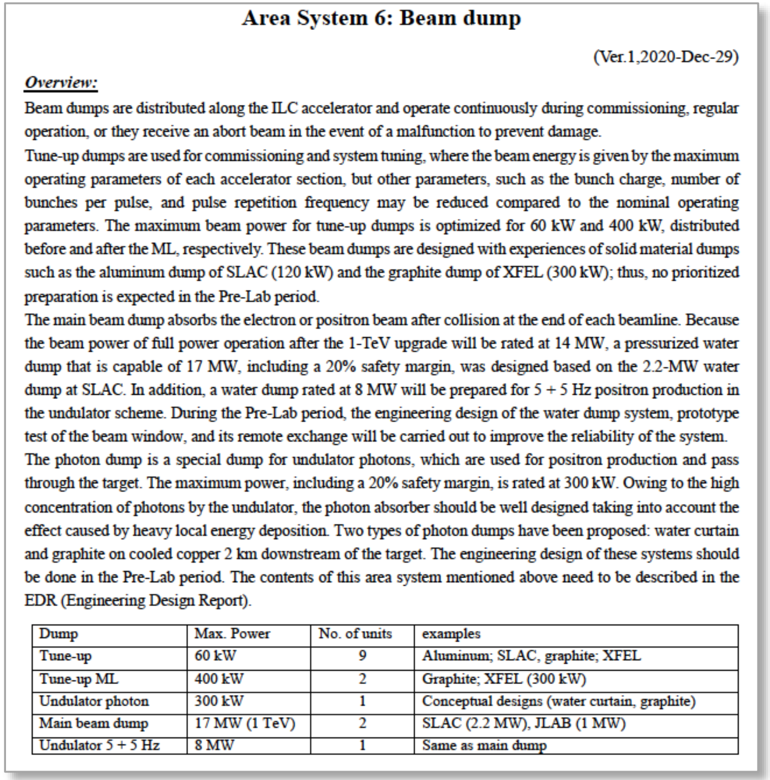






Area System 6: Beam Dumps

- 2 Work packages



Area System 6: Beam dump

(Ver.1,2020-Dec-29)

Overview:

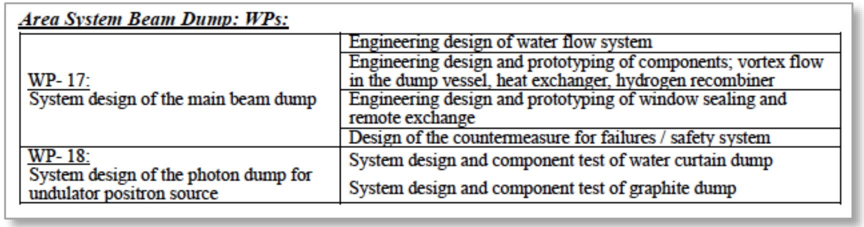
Beam dumps are distributed along the ILC accelerator and operate continuously during commissioning, regular operation, or they receive an abort beam in the event of a malfunction to prevent damage.

Tune-up dumps are used for commissioning and system tuning, where the beam energy is given by the maximum operating parameters of each accelerator section, but other parameters, such as the bunch charge, number of bunches per pulse, and pulse repetition frequency may be reduced compared to the nominal operating parameters. The maximum beam power for tune-up dumps is optimized for 60 kW and 400 kW, distributed before and after the ML, respectively. These beam dumps are designed with experiences of solid material dumps such as the aluminum dump of SLAC (120 kW) and the graphite dump of XFEL (300 kW); thus, no prioritized preparation is expected in the Pre-Lab period.

The main beam dump absorbs the electron or positron beam after collision at the end of each beamline. Because the beam power of full power operation after the 1-TeV upgrade will be rated at 14 MW, a pressurized water dump that is capable of 17 MW, including a 20% safety margin, was designed based on the 2.2-MW water dump at SLAC. In addition, a water dump rated at 8 MW will be prepared for 5 + 5 Hz positron production in the undulator scheme. During the Pre-Lab period, the engineering design of the water dump system, prototype test of the beam window, and its remote exchange will be carried out to improve the reliability of the system.

The photon dump is a special dump for undulator photons, which are used for positron production and pass through the target. The maximum power, including a 20% safety margin, is rated at 300 kW. Owing to the high concentration of photons by the undulator, the photon absorber should be well designed taking into account the effect caused by heavy local energy deposition. Two types of photon dumps have been proposed: water curtain and graphite on cooled copper 2 km downstream of the target. The engineering design of these systems should be done in the Pre-Lab period. The contents of this area system mentioned above need to be described in the EDR (Engineering Design Report).

Dump	Max. Power	No. of units	examples
Tune-up	60 kW	9	Aluminum; SLAC, graphite; XFEL
Tune-up ML	400 kW	2	Graphite; XFEL (300 kW)
Undulator photon	300 kW	1	Conceptual designs (water curtain, graphite)
Main beam dump	17 MW (1 TeV)	2	SLAC (2.2 MW), JLAB (1 MW)
Undulator 5 + 5 Hz	8 MW	1	Same as main dump



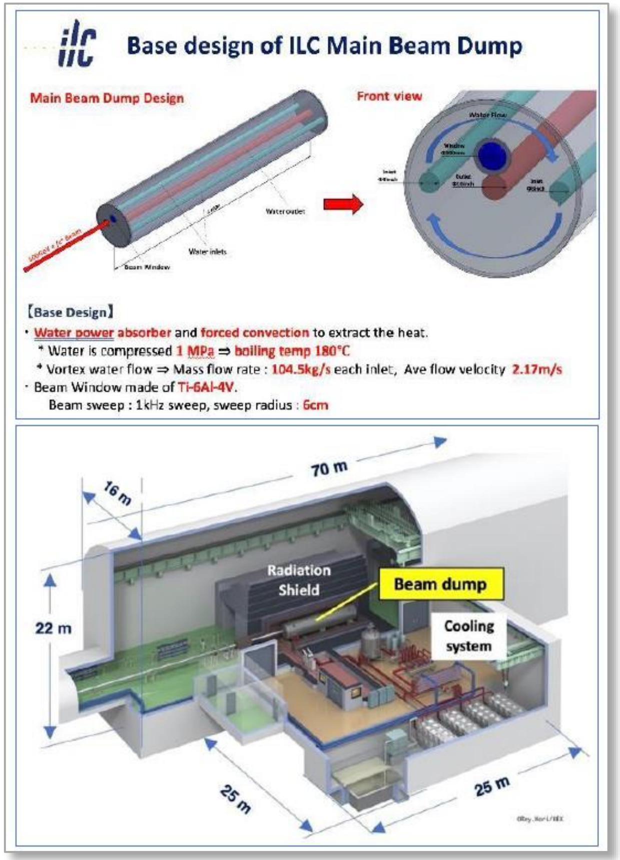
Area System Beam Dump: WPs:

WP- 17: System design of the main beam dump	Engineering design of water flow system
	Engineering design and prototyping of components; vortex flow in the dump vessel, heat exchanger, hydrogen recombiner
	Engineering design and prototyping of window sealing and remote exchange
	Design of the countermeasure for failures / safety system
WP- 18: System design of the photon dump for undulator positron source	System design and component test of water curtain dump
	System design and component test of graphite dump

IDT

WP17: System design of the main dump

- Goal:
  - Establish the engineering design of the whole dump system.
- Ressources:
  - 2,8 MILCU + 8 FTE-y



Base design of ILC Main Beam Dump

Main Beam Dump Design

Front view

【Base Design】

- **Water power absorber** and **forced convection** to extract the heat.
  - * Water is compressed **1 MPa** ⇒ **boiling temp 180°C**
  - * Vortex water flow ⇒ Mass flow rate : **104.5kg/s** each inlet, Ave flow velocity **2.17m/s**
- Beam Window made of **Ti-6Al-4V**.
  Beam sweep : 1kHz sweep, sweep radius : **6cm**

WP18: Design of photon dump for the undulator positron source

- Goal:
  - The system design of the photon dump is established at an engineering level, including the photon absorption structure, infrastructures for cooling, and the maintenance of the activated equipment
- Ressources:
  - 0,4 MILCU, 8 FTE-y

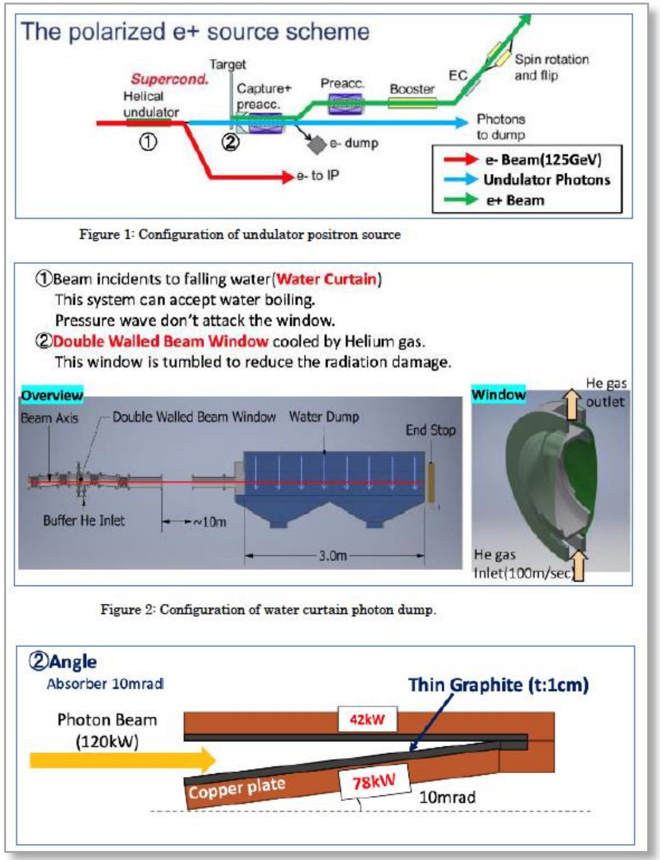
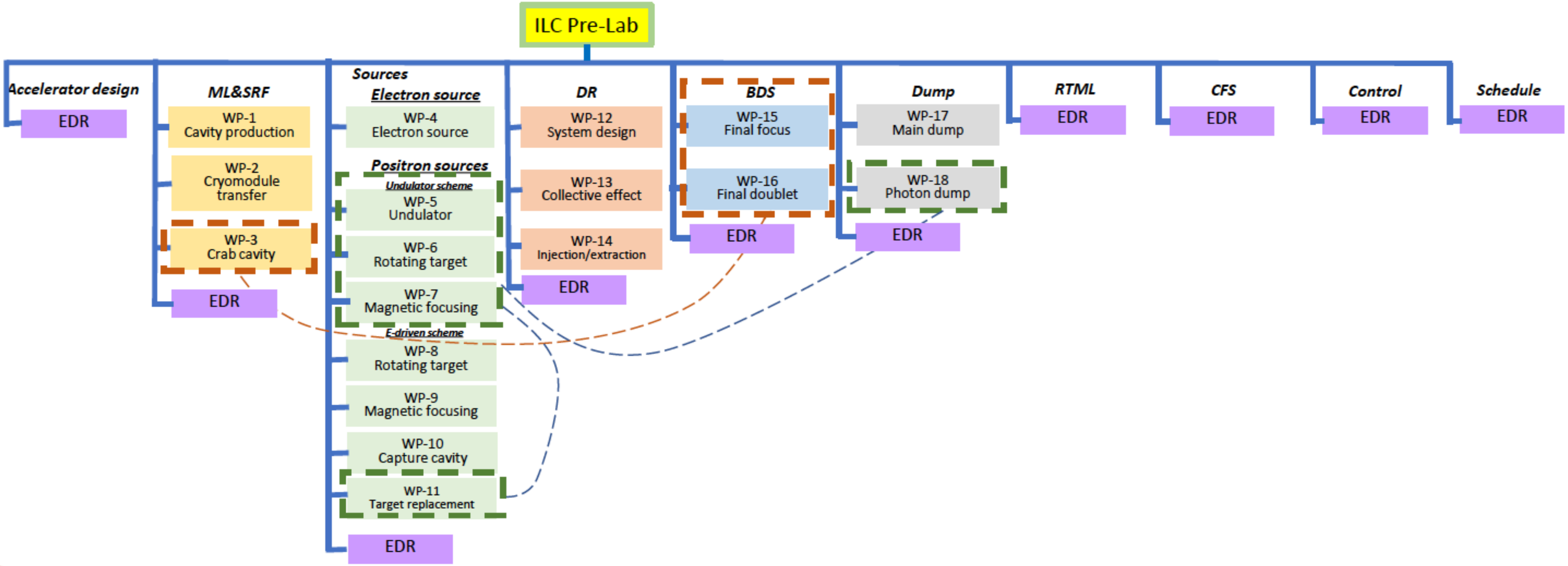


Figure 1: Configuration of undulator positron source

①Beam incidents to falling water(**Water Curtain**)
This system can accept water boiling.
Pressure wave don't attack the window.
②**Double Walled Beam Window** cooled by Helium gas.
This window is tumbled to reduce the radiation damage.

Figure 2: Configuration of water curtain photon dump.

Towards the Engineering Design Reports EDR



ILC Pre-Lab

Accelerator design
EDR

ML&SRF
WP-1 Cavity production
WP-2 Cryomodule transfer
WP-3 Crab cavity
EDR

Sources
Electron source
WP-4 Electron source
Positron sources
Undulator scheme
WP-5 Undulator
WP-6 Rotating target
WP-7 Magnetic focusing
E-driven scheme
WP-8 Rotating target
WP-9 Magnetic focusing
WP-10 Capture cavity
WP-11 Target replacement
EDR

DR
WP-12 System design
WP-13 Collective effect
WP-14 Injection/extraction
EDR

BDS
WP-15 Final focus
WP-16 Final doublet
EDR

Dump
WP-17 Main dump
WP-18 Photon dump
EDR

RTML
EDR

CFS
EDR

Control
EDR

Schedule
EDR

Summary and Conclusions

- R&D Program for the Prelab Phase has been formulated
- Money-wise, focus is on SRF, especially high gradient cavities and cryomodule transport
- New activity on electron source
- Positron source in focus, technology decision schedule provides time for (re)formation of R&D efforts
- Damping ring design continues, permanent magnet option of interest -> would fix beam polarity (no e-e-)
- BDS R&D continues – boosts ATF-3 programme, synergies with CLIC
- Dumps are a critical R&D item

- Next step: From R&D to design: Take up the overall accelerator design again
  - Design complete accelerator systems
  - Value engineering of important (in terms of volume or value) components and subsystems
  - Provide input to management (cost and schedule) and civil engineering (power, cooling)