STATUS OF ILC

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Abstract

The International Linear Collider (ILC) is anticipated to be the next energy-frontier electron-positron accelerator based on superconducting radio-frequency (SCRF) technology, and to accelerate electron and positron beams up to 250 GeV each with having extend-ability up to 500 GeV each. This paper describes the progress of the technical design and R&D efforts progressed in the ILC Technical Design phase since 2007 and includes further effort after the completion of Technical Design Report (TDR) in 2012.

INTRODUCTION

The International Linear Collider (ILC) is proposed as the next energy-frontier electron-positron accelerator to be built with a global effort [1 - 3]. The ILC accelerator is based on SCRF accelerator technology, as recommended by the International Technology Recommendation Panel [4] and endorsed by the International Committee for Future Accelerators. The ILC Global Design Effort (ILC-GDE) was launched to advance the accelerator design and R&D efforts. It published the Reference Design Report (RDR) in 2007 [2]. The ILC design assumes an averaged cavity field gradient of 31.5 MV/m to achieve a center-of-mass energy of 500 (=2 x 250) GeV with two 11-km long main linacs. The technical design work and R&D efforts have significantly progressed during the Technical Design (TD) phase started in 2007 and are completed with the Technical Design Report (TDR) in 2012.

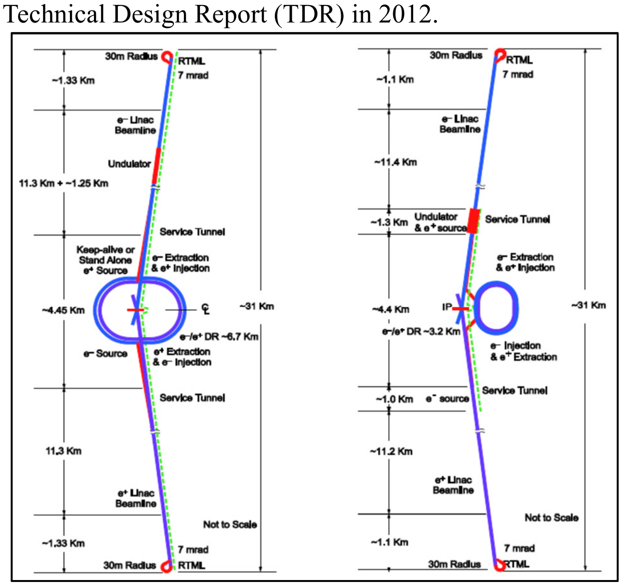


Figure 1: Layouts of ILC in RDR (left) and TDR (right).

A major update of the accelerator design has been made for TDR, seeking for the best cost-effective design with a 'cost-containment' guideline [5]. Figure 1 shows the TDR accelerator layout with the RDR accelerator layout, and Table 1 summarizes the main parameters.

Table 1: ILC accelerator and SCRF requirement.

Parameter	RDR	TDR
Energy (cms: GeV)	500	500
L ($cm^{-2}s^{-1}$)	2 x 10^{34}	1.5 x 10^{34}
Beam current (mA)	9	5.8
Beam Rep. (Hz)	5	5
Bunch spacing (ns)	369	554
Bunch train length (μs)	1.000	0.727
Numbers of bunches	2625	1312
Cav. Grad. (MV/m)	31.5	31.5
# 1.3-GHz, 9-cell cavity	15,941	16,024
# 1.3-GHz, Cryomodule	1,824	1,855
# 10-MW Klystron	646	413+α / 378+β (KCS/DKS)

GENERAL DESIGN UPDATES

The ILC accelerator design has been updated in the middle of the Technical Design Phase [5]. It has been motivated by i) overall cost containment and balancing among sub-system, ii) improved understanding of system functionality, iii) more complete and robust design, and iv) re-optimized R&D plans. The major design update includes:

- A Main Linac length consistent with an *average* accelerating gradient of 31.5 MV/m with a spread within +/-20%, and maximum operational beam energy of 250 GeV,
- A single-tunnel solution for the Main Linac and RTML, with two possible variants for the High-Level RF (HLRF) configuration:
  - Klystron cluster scheme (KCS):
  - Distributed Klystron scheme (DKS).
- Undulator-based positron source located at the end of the electron Main Linac (250 GeV),
- A lower beam-power parameter set with the number of bunches per pulse reduced by a factor of two,
- Reduced circumference Damping Rings (~3.2 km) at 5 GeV with a 6 mm bunch length,

ISBN 978-3-95450-122-9

- Integration of the positron and electron sources into a common “central region beam tunnel”, together with the Beam Delivery System, resulting in an overall simplification of civil construction in the central region.

R&D PLAN AND PROGRESS

In the Technical Design phase, four critical main linac R&D topics were identified and have been pursued as follows [3,5, 6]:

- **S0:** SCRF cavities to exceed a gradient of 35 MV/m in individual performance test in vertical position,
- **S1:** Cavity-string in cryomodule to perform at 31.5 MV/m on average.
- **S2:** Cryomodule-string to perform with beam acceleration, including associated systems such as HLRF, LLRF, cryogenics, and beam diagnostics.
- **Industrialization:** Study and preparation for cost-effective production of SCRF accelerator components.

The notation of *S0, S1, and S2* refers to the shorthand for the individual goals introduced in the RDR period. Figure 2 shows the general SCRF R&D plan in the TD phase together with the foreseen development.

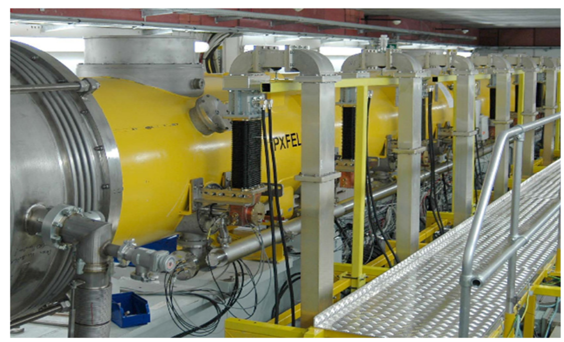
Year	07	2008	2009	2010	2011	2012
Phase	TDP-1			TDP-2		
Cavity Gradient in test to reach 35 MV/m	→ Yield 50%			→ Yield 90%		
Cavity-string to reach 31.5 MV/m, with one-cryomodule		Global effort for string assembly and test (DESY, FNAL, INFN, KEK)				
System Test with beam acceleration		FLASH (DESY) , NML/ASTA (FNAL) QB, STF2 (KEK)				
Preparation for Industrialization			Production Technology R&D			
Communication with industry:	1st Visit Vendors (2009), Organize Workshop (2010) 2nd visit and communication, Organize 2nd workshop (2011) 3rd communication and study contracted with selected vendors (2011-2012)					

Figure 2: The main goals and timeline for SCRF R&D established at the beginning of the TD phase.

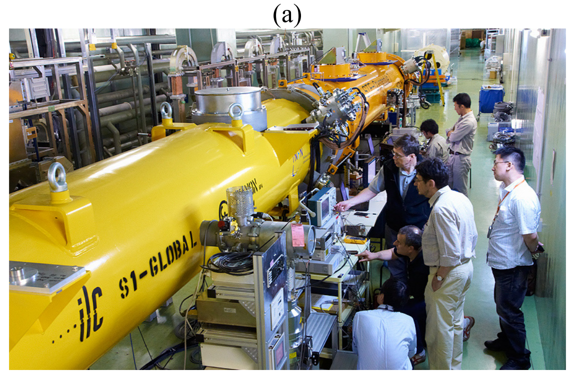
The highlighted results from the SCRF R&D are summarized as follows:

- Successful construction and functioning of SCRF facilities at FLASH at DESY [7], FNAL-ANL [8-10, JLab [11], and KEK [12].
- Identification of the preferred process for consistent production of 35 MV/m cavities (worldwide), and ultimately a successful demonstration of the TDP goal of a *production yield* of 90% [13].
- Encouragement of new cavity vendor participation, in cooperation with laboratories, for qualification in the Americas and Asia, to complement those already existing in Europe, so as to scope global mass production for the ILC.
- International collaboration on the construction of a cryomodule (S1-Global) hosted at KEK, enabling exploration of plug-compatible design philosophies and comparisons of technologies [14]. Construction and testing of cryomodules with beam acceleration, such as FLASH at DESY, ASTA/NML at Fermilab, and STF at KEK.
- Study of SCRF mass-production, including R&D for cost-effective industrialization.
- Associated system R&D such as HLRF/LLRF, cryomodule including quadrupoles and beam position monitor, and cryogenics.

Worldwide activities addressing these goals may be recognized with the progress of cavity and cryomodule developments and the facilities extended at DESY, FNAL and KEK as shown in Fig. 3: (a) TTF-FLASH at DESY, (b) STF/S1-Global at KEK, and (c) NML/ASTA at Fermilab. The cryomodule activity at KEK stands out in its truly global nature of cryomodule assembly.



(a)



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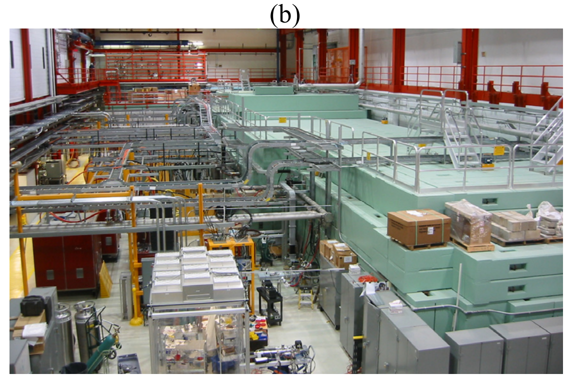

(c)

Figure 3: Photos of SCRF and accelerator beam test facilities progressed at (a) FLASH at DESY, (b) STF/S1-Global at KEK, and (c) NML/ASTA at Fermilab.

PROGRESS IN SUBSYSTEM

The progress in each subject is summarized as follows.

Cavity (S0)

- Establishment of the baseline sequence of cavity fabrication and surface preparation, based on the TESLA cavity design, and development a production yield evaluation scheme.
- Understanding of the field limitation and overcoming quench and field- emissions as major reasons for gradient limitation.
- Achievement of a production yield of ~70% at 35 MV/m, as described above, and ~80% with allowing gradient spread of 35 MV/m +/-20% (from 28 MV/m ~42 MV).

Figure 4 shows the progress of the ILC-SCRF 1.3 GHz cavity gradient R&D systematically monitored by the ILC SCRF global data base team led by C. Ginsburg: (a) integrated production yield in the 2nd pass of the surface process with the data available since 2006, and (b) differential production yield in each 1 ~ 2 years [9]. The production yield evaluation has been updated, six times during a period of 2009 through 2012, with the most recent updated time in April. 2012. In the 2nd pass, (69±13)% of cavities achieve >35 MV/m; and (92±7)% of cavities achieve >25 MV/m considering only cavity tests taking place in 2010-2012 [9]. It should be noted that the production yield reaches ~80 % with an interpolation and as the most practical evaluation, if the gradient spread of 35 MV/m +/-20 % would be applied.

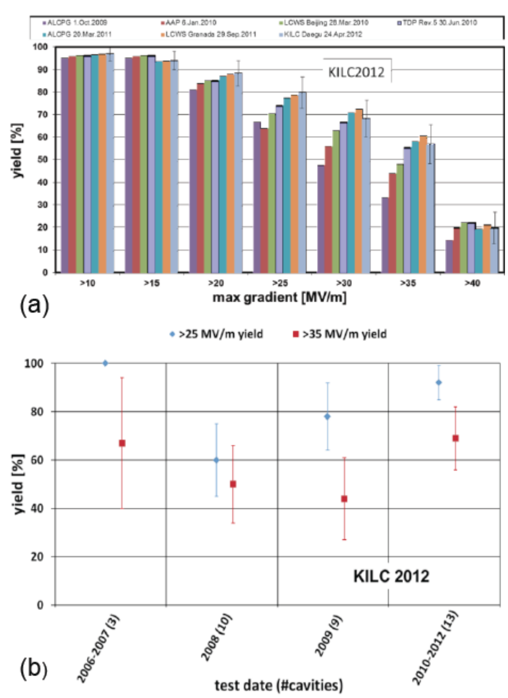

Figure 4: Progress of the ILC-SCRF 1.3 GHz cavity gradient R&D (a) integrated production yield in the 2nd pass process, with the data available since 2006, and (b) differential production yield. [9]. The blue points are for >25 MV/m yield and red points are for >35 MV/m yield.

Ongoing efforts to improve cavity production yields include applying mechanical tumbling [15] or localized grinding [16] for removal of known performance-limiting defects and centrifugal barrel polishing to the baseline cavity processing recipe. Many (~12) cavity repairs have been achieved through these two methods; however, at this time, cavity performance after these repairs is still to be discussed how we include these repaired cavities in yield plots, hopefully in near future [17].

Several manufacturers have engaged in the production of cavities [6]. While originally only two companies provided cavities qualifying for the ILC demands we now see companies in all three regions successfully manufacturing high-gradient cavities as updated in Table 2. The number of successfully tested cavities achieving the ILC specification has now reached several dozen.

Table 2: Progress in SCRF cavity vendors/laboratories and their successes in achieving the 35 MV/m gradient goal in fabrication.

Year / # cavity	Cavity manufactures	Laboratories
2006 / 10	Accel, Zanon	DESY
2011 / 41	RI, Zanon, AES, MHI	DESY, JLab, Fermilab, KEK
2012 / 45	RI, Zanon, AES, MHI, Hitachi	DESY, JLab, Fermilab, KEK, Cornell-U

Cavity String in Cryomodule (S1)

- A prototype cryomodule for the European XFEL program achieved an averaged field gradient of 32 MV/m [7].
- A cryomodule was assembled and tested in an international effort (S1-Global hosted at KEK) with contributions of FNAL, SLAC, DESY, INFN and KEK. S1-Gobal succeeded in realizing 26 MV/m on average in a 7- cavity string operation. The plug-compatible assembly of various cavities and the respective interfaces has been verified successfully [14, 18, 19].
- The cavity string assembly in the cryomodule, CM1, achieved 24 MV/m at Fermilab [10].

Figure 5 shows recent progress in the cryomodule performance test at (a) DESY/FLASH, (b) KEK/S1-global, and (c) Fermilab/NML-ASTA. The figure shows the cavity field gradient performance per each cell, measured in the vertical test and in the horizontal test (in case of Fermilab) and in the cyromodule test [7, 14, 10]. As an important message, the gradient degradation has been observed after installation into the cryomodules, and it will be an important subject to be settled as a major subject beyond TDR.

ISBN 978-3-95450-122-9

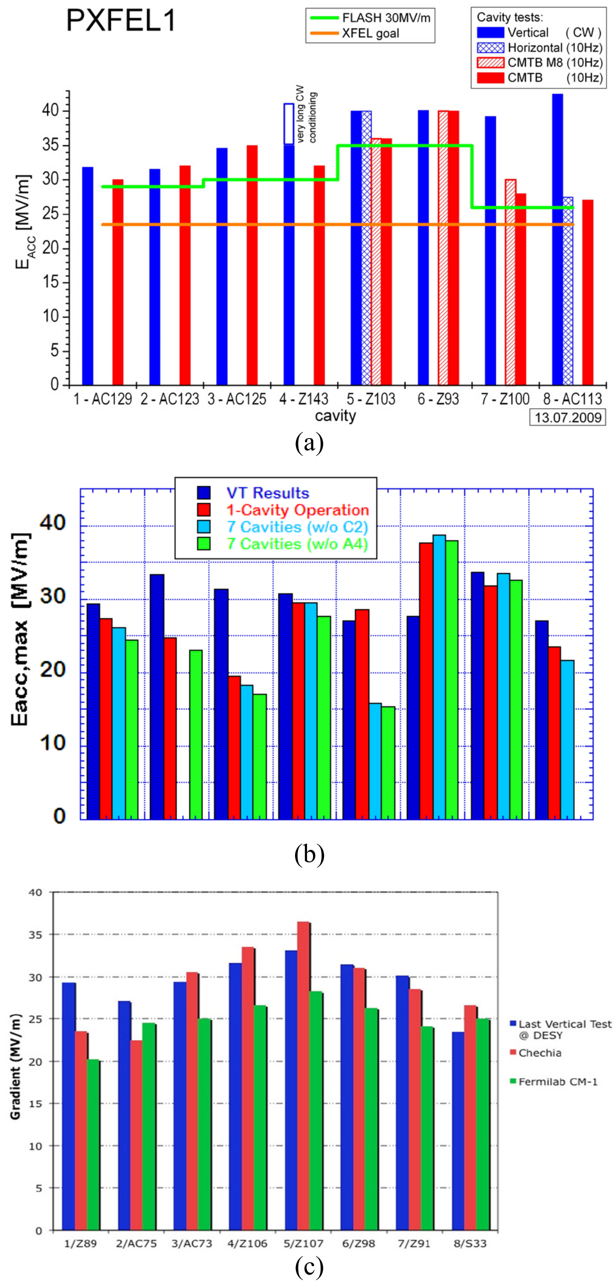

Figure 5: Field gradient achieved in cryomodules developed at (a) DESY/FLASH-PXFEL1 [7], (b) KEK/S1-Global [14], and (c) Fermilab/NML/ASTA-CM1 [10].

Cryomodule and HLRF Design

- The ILC cryomodule system design has been fixed with two design variants: a longer design consisting of an 8-cavity string plus 1 quadrupole at the centre, and a shorter design consisting of an 8-cavity string.
- The removal of the bottom 5 K shield has been explored; the shield is retained for TDR [20, 21].
- The R&D for superconducting magnet using condition cooling has been successfully made [22, 23]. It will help to assemble the magnet separately from the cavity string assembly that require specially arranged clean rooms.
- The Klystron Cluster System (KCS) for flat-land topography has been proposed; the R&D continues [24].
- The distributed RF with 800-kW klystron has been proposed for a mountainous topology, has been demonstrated during the S1-Gloabal program at KEK [25]. Finally, the Distributed Klystron scheme (DKS) with 10 MW klystrons has been chosen as the baseline for the mountainous topography.
- Marx modulator development has been successfu3 at SLAC as the baseline power source [26].
- The LLRF control study succeeded in adapting various cavity tuner designs [27,28], and demonstrated successful handling of cavity string performance variation and proved the general feedback operation with a RF power overhead margin below 10% [29, 30].

The KCS and DKS HLRF power system concepts are shown in Fig. 6, and Fig. 7, respectively.

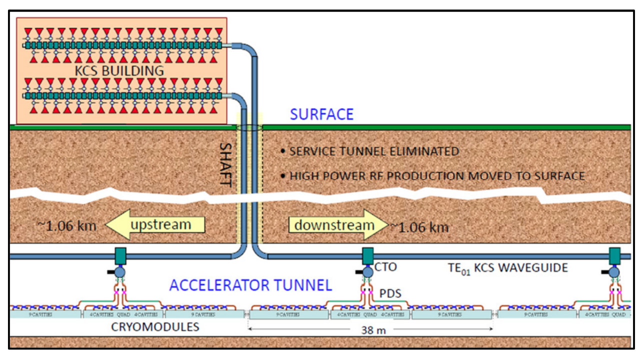

Figure 6: The KCS concept for the main linac HLRF power distribution system considered in flat-land site topography.

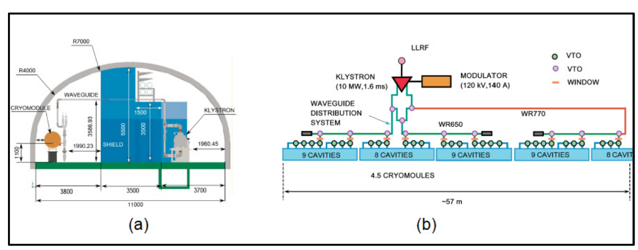

Figure 7: The DKS concept for the main linac HLRF power distribution system considered in mountainous site topography finalized in TDR.

PROGRESS IN BEAM-TEST FACILITIES

The beam acceleration tests by using SCRF beam test facilities have progressed at DESY/FLASH and KEK/STF, will be realized soon at Fermilab/NML-ASTA. Major progresses are summarized in Table 3 [29, 30].

Table 3: Progress in Beam Test Facilities to Demonstrate the ILC Beam Parameters

Subject	R&D goal	Achievement	Facility
- High beam power and long bunch trains (Feb. 2009)			
Pulse current	9 mA	9 mA	FLASH
Bunches per pulse	2400 x 3 nC	1800 x 3 nC 2400 x 2nC	FLASH
Cavity gradient	31.5 MV/m +/-20 %	> 30 MV/m with 4 cavities	FLASH
- Gradient operating margins (Feb. 2012):			
Gradient flatness	2%ΔV/V (0.8ms, 5.8mA)	<0.3% ΔV/V (0.8ms, 4.5mA)	FLASH
Gradient margin	3 % to quench limit	5% to limit (0.8ms, 4.5mA)	FLASH
Energy stability	0.1% rms	<0.15%(0.4ms) <0.02% (5 Hz)	FLASH
- Beam duration (April 2012) :			
Pulse width	1 ms	1ms	STFQB

EFFORTS BEYOND TDR

Technical R&D has progressed as described above, and the TDR as the progress report is to be completed by in 2012, as the time chart shown in Fig. 8.

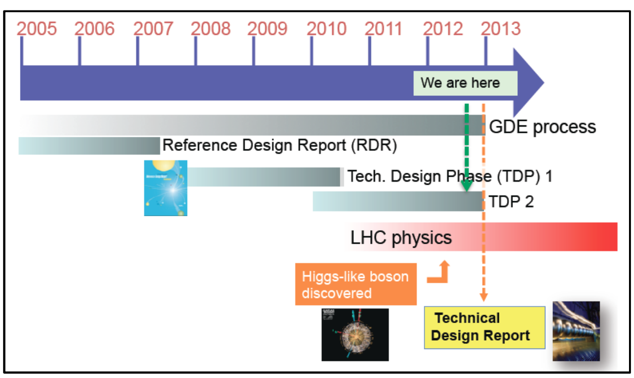

Figure 8: The ILC time line for Technical Design Report.

Further R&D efforts beyond TDR completion are discussed as follows:

- Higher gradient with an R&D target of 45 MV/m, motivated with further cost-effective cavity production including the energy upgrade phase,
- Mitigation of the field gradient degradation the cavity after installation into the cryomodule.
- Preparation for industrialization in optimization of mass-production models in close communication with industry.

SUMMARY

The ILC TD phase has been successfully carried out, and the TDR will be completed in 2012. ILC can be realized, based on the TDR technology.

We may consider multiple scenario of the ILC construction including staging the energy starting with lower energy depending on the physics output from LHC experiments, discovering Higgs-like boson in an energy range of 126 GeV.

Beyond the TDR completion, further R&D shall be extended, focusing on preparation of industrialization of major components with international industrial cooperation keeping plug-compatible mass-production with the best cost-effective approach.

ACKNOWLEDGMENT

We would thank all of worldwide ILC-GDE Collaborators for their cooperation to proceed the Technical Design and R&D effort carried out in the Technical Design Phase.

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