Technical Preparation：SCRF cavity and cryomodule production

Outline：SCJ and MEXTs' ILC Advisory Panel had technical concerns about maintaining cavity quality during mass production and cryomodule assembly. This plan is proposed to demonstrate prototype manufacturing using new cost-effective production methods on the scale of 1% of the full production, corresponding to about 100 cavities in the main preparatory phase. Half of the cavities will be produced in Japan and the other half in other regions/countries. The performance of the cavities will be evaluated to confirm their yields, and plug-compatibility will be checked. Other components, such as couplers and tuners, are also expected to improve (in terms of) their performances; they will also be manufactured, and their yields will be evaluated. Overall testing after assembling these parts into a cryomodule will be the final step of evaluating the performance as an accelerator component. The US and Europe have accumulated significant experiences in cavity production and in formulation of countermeasures against performance degradation after cryomodule assembly. It is anticipated that Germany and the US will work on cost reduction of the cavity fabrication process, and on reproducibility and high yield of cavity performance at the design gradient, while France could play a leading role in automation of cryomodule assembly.

Goals of the technical preparation:

Parameters	Unit	Design
Baseline: Cavity gradient, E, at Q value (Q0) Cost-Reduction R&D goal: E and Q	MV/m	31.5 (±20%) at Q ≥1E10, 35 at Q ≥0.8 E10 35 at Q ≥ 2E10, 38.5 at Q ≥ 1.6E10
Cavity production yield	%	90

Items:

- total ~ 100 nine-cell cavities will be produced with international collaboration.
- 9-cell Cavity production by cost effective methods
- RF performance, success yield to be evaluated, under plug-compatible fabrication conditions, with an expected statistics (for example, 20 ~ 30 cavitiy statistics, with fixed fabrication conditions in each region), and enabling to satisfy "high pressure code regulation".
- Ancillaries production (power coupler, tuner, HOM antenna, etc.)
- Cryomodule (CM) production (Prototype, Type A, Type B)

Expected cost:

Issue	*Tasks*	*Cost*	*Human Resources (FTE)*
Mass production	*Performance/ mass production technology*	*k$*	

(not including corresponding cost of human resources)

Candidates:

DESY, CEA-Saclay,FNAL、J-LAB

Appendix

(Current status)

The beam commissioning for the STF-2 accelerator was successfully done in March 2019 at KEK's Superconducting RF Test Facility (STF). The maximum beam energy achieved was 280 MeV, and the average accelerating gradient estimated from the beam energy was 33.1 MV/m, exceeding the ILC specification of 31.5 MV/m. DESY and FNAL have also demonstrated cryomodule operation satisfying the requirements of the ILC.

At KEK's Cavity Fabrication Facility (CFF), single-cell, 3-cell, and 9-cell cavities have been fabricated in collaboration with some local companies since 2012. CFF is equipped with an electron beam welding (EBW) machine, a chemical polishing (CP) system, and a mechanical pressing machine. Cavity fabrication conforming to Japanese high-pressure gas regulations is in progress.

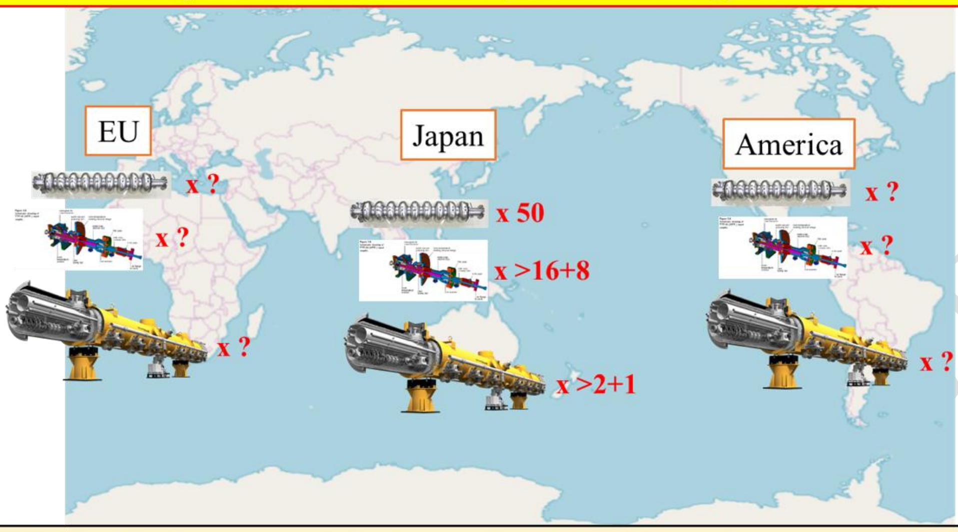
Concerning cryomodules, cavities and other components manufactured in three different regions (Asia, Europe, and Americas) with a common interface design have been brought together and assembled into a cryomodule at the KEK Superconducting Test Facility (STF), and the cryomodule's performance has been tested and successfully demonstrated with the common interface design for the ILC.

Since 2017, the US and Japan have been collaborating on cost reduction. There are two ways to reduce/save the cost of cavities. One is cost reduction of the niobium material. Another is to improve cavity performance, enabling to reduce the required number of cavities. Research on improvement of cavity performance by new surface treatment such as "nitrogen-infusion" is underway worldwide.

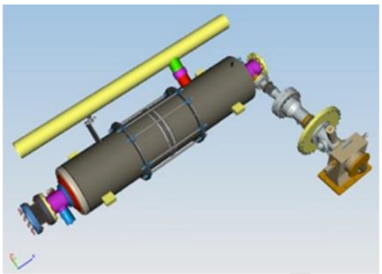
Technology for mass production for the ILC is ready, as demonstrated by successful construction of an accelerator with a few hundred cavities housed in a few tens of cryomodules for the European XFEL and for a similar accelerator currently under construction for LCLS-II in the US. In both cases, after cryomodule assembly, modules were transported on the ground and installed in the tunnel with no major issues caused by the transportation. However, marine/ship transport of cryomodules between two different regions across a sea, and the performance test after transport are yet to be carried out. This will be done as a part of crucial technical preparation in the main preparatory phase.

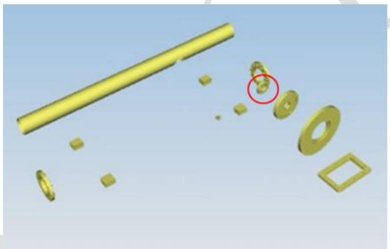
(Add some figures to explain visually)

Before mass production starts, tuner design should be fixed!!



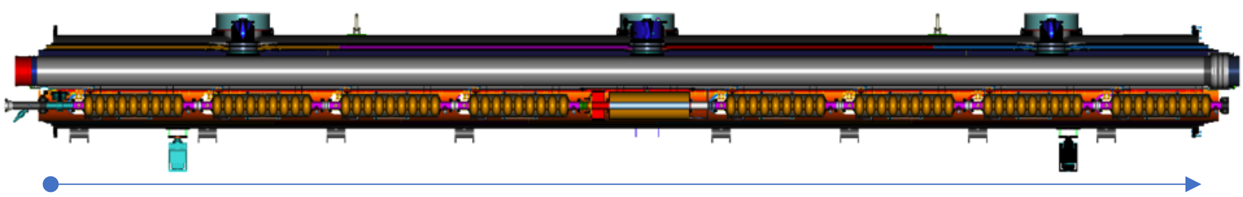
Which lab. is responsible for cavity, power coupler, tuner, CM, etc.?
How many cavities, couplers, CMs are produced?





Item	Variation	TDR Baseline
Cavity shape	TESLA / LL	TESLA
Length		Fixed
Beam pipe flange		Fixed
Suspension pitch		Fixed
Tuner	Blade/ Slide-Jack	Blade
Coupler flange (cold end)	40 or 60	40 mm
Coupler pitch		Fixed
He –in-line joint		Fixed

L=1,247 m



12,562 m (flange to flance, to be checked)

(Add a list of parameters common to issues and deleted unnecessary ones)

ILC parameter list

Parameter	Unit	Requirement	Design	Achieved	Facility
Electron Source					
Bunch Charge	nC	3.2	4.8	8	SLAC -SLC
Average Beam current	mA	21	42	1000	JLAB
Beam current in pulse	mA	5.8	11.6	60	Cornell U.
Polarization	%	80	80	90	Nagoya, SLAC, KEK
Quantum Efficiency	%	0.5	0.5	2.2	Nagoya
Drive Laser (in pulse)	W	1.8	10	>10	Commercially available
Positron Source					
Bunch Charge	nC	3.2	4.8	8	SLAC SLC (E-Driven)
Undulator scheme					
Undulator pitch	mm	11.5	11.5	2.5	SLAC E166
Positron Polarization (optional)	%	30	30	80	SLAC E166
Ti alloy Target Heat Load (PEDD)	J/g		61	160	Estimated from physics constant table
QWT peak field	T	1		2.3	KEK
Target radius	mm	500			
Target weight	kg	50			
Target tangential velocity	m/s	100			
Target rotation	rpm	2000			
Beam heat load	kw	2			
Vacuum pressure	Pa	10^-6			
E-driven scheme					
W-Re Target Heat Load (PEDD*)	J/g		34	70	SLAC SLC (E-Driven)
Flux Concentrator Peak field	T	5		10	BINP
Target radius	mm	250			
Target weight	kg	65			
Target tangential velocity	m/s	5			
Target rotation	rpm	200			
Beam heat load	kw	20			
Vacuum pressure	Pa	10^-6			
APS cavity					
SCRF					
Module gradient	MV/m	31.5 (+/- 20%)		~31.5	DESY, FNAL, JLab, Cornell, KEK,
Cavity Q value (Q0)		10^10		~10^10	
Cavity gradient	MV/m	35 (±20%)		33.4 MV/m	
Cavity production yield	%	90			
Beam current	mA	5.8		> 5.8	DESY, KEK
Number of bunches		1312		1312	DESY
Bunch charge	nC	3.2		3	
Bunch interval	ns	554		333	
Beam pulse width	μs	730		800	DESY, KEK
RF pulse width	ms	1.65		1.65	DESY, KEK, FNAL
Repetition	Hz	5		10	DESY
DR					
Horizontal Emittance(ε_x)	nm	0.4	0.4	0.34	MAX-IV
Vertical Emittance (ε_y)	pm	2	2	<2	SLS, Australian LS, Diamond LS
Normalized Emittance($\gamma\varepsilon_x/\gamma\varepsilon_y$)	μm/nm	4/20	4/20	4/15	ATF
Fast Ion instability					SuperKEKB
Electron Cloud Instability					SuperKEKB/CesrTA
Kicker Rise Time	ns	< 6.15	< 3.07	2.2	ATF
Kicker Voltage	kV	±10	±10	±10	ATF
Kicker Voltage stability		0.0007	0.0007	0.00035	ATF
Kicker Frequency	MHz	1.8	2.7	3.25	ATF
Fast Kicker extraction test					ATF
BDS					
ATF2 beam size (σ_y^*)	nm	37		≤41	ATF2
ILC beam size	nm	7.7			ATF2
Feedback position stability	% of beam	12	10	4	ATF2
Feedback latency	ns	< 554	< 366	133	ATF2
Beam Dump					
ILC 250GeV	MW	2.6	17	-	Designed for 500GeV beam
SLAC 2mile LINAC	MW	-	2.2	0.75	ILC beam dump prototype