Present Status of SRF Technology for the ILC

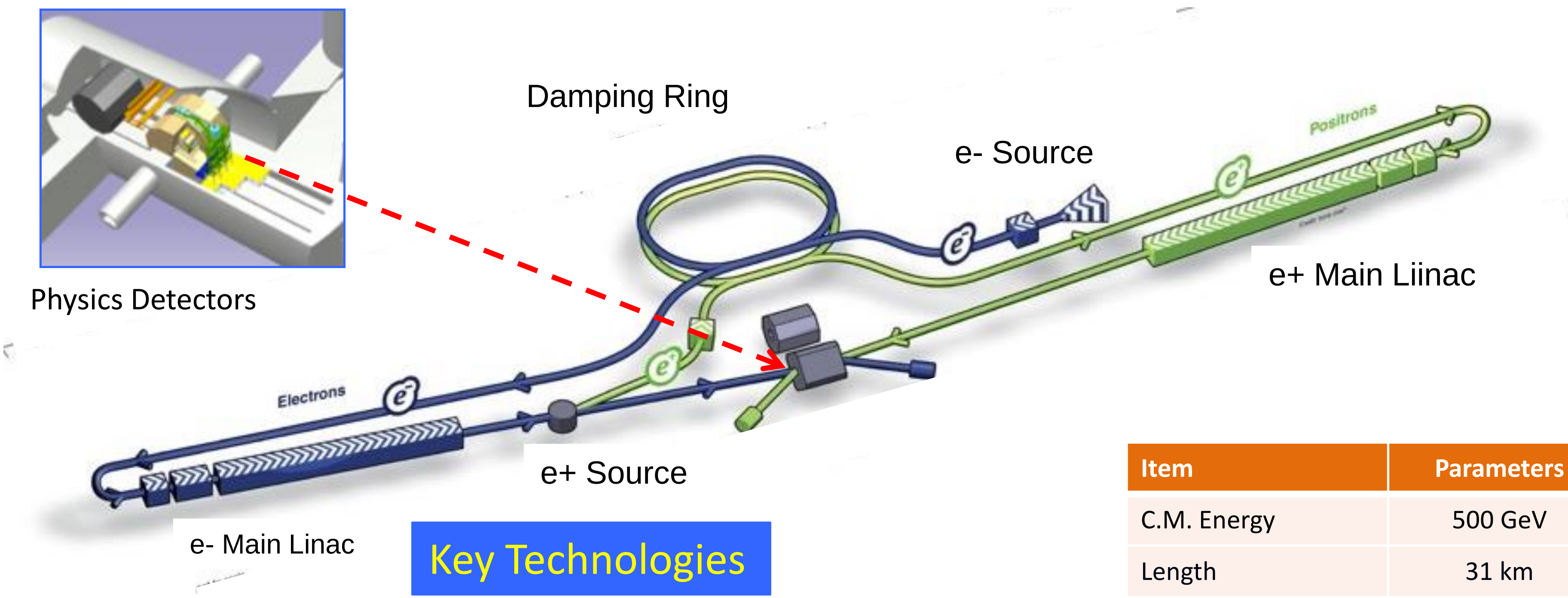
Akira Yamamoto
(KEK and CERN)

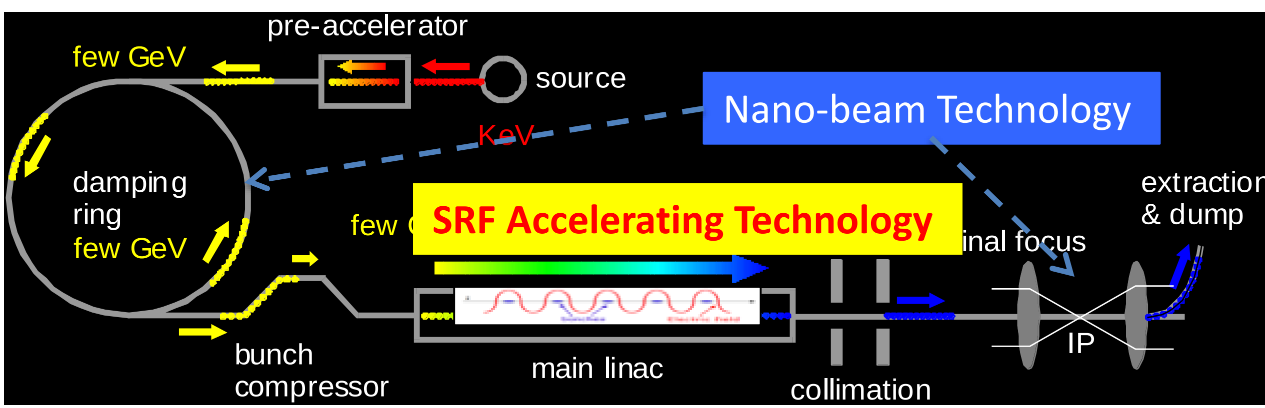
1. Progress highlighted
2. Prospect for realizing the ILC

Outline

1. **SRF Progress highlighted**
   - Progress in cavity gradient
   - RF Input-Coupler with new ceramic window
   - Marx Generator for RF Power Supply
2. **Prospect for realizing the ILC**
   - SRF Cavity development
   - "Global (SRF) Cryomodule" proposal

ILC Acc. Design Overview (in TDR)





Item	Parameters
C.M. Energy	500 GeV
Length	31 km
Luminosity	1.8 x10^{34} $cm^{-2}s^{-1}$
Repetition	5 Hz
Beam Pulse Period	0.73 ms
Beam Current	5.8 mA (in pulse)
Beam size (y) at FF	**5.9** nm
SRF Cavity G. Q_0	**31.5** MV/m Q_0 = 1x10^{10}

Progress in SRF Technology in TDR and after

Global Progress in TDR (~ 2013)

- **SRF cavity gradient:**
- G-max = **37 MV/m and an Yield of 94 % at > 28 MV/m**
- **SRF beam acceleration:**
  - Beam current: **9 mA (at DESY-FLASH)**
  - Pulse duration: **1 ms (KEK-STF)**

Regional Progress (~ 2015) :

- **European XFEL:**
  - SRF Cavity production 100% (of 800) , with G= ~ 30 MV/m (av).
  - Cryomodule (CM) assembly, > 70% (of 100) completing
- **Fermilab** : CM reached the ILC gradient specification of > 31.5MV/m (av.)
- **KEK:** A full CM (8) + a half-CM (4) in preparation for beam acceleration
  - CM (8-string) aiming beam acceleration at > 31.5 MV/m (av).

Major Accelerators Under Construction 2010 ~ 2020

Project	Notes	# cavities	year
CEBAF-JLAB (US)	Upgrade 6.5 GeV => 12 GeV electrons	80	
XFEL-Hamburg (EU)	18 GeV e – for Xray Free Electron Laser	840	~ 2015
LCLS-II – SLAC (US)	4 GeV electrons –CW XFEL	300	~ 2019
SPIRAL-II (France)	30 MeV, 5 mA protons -> Heavy Ion	28	
FRIB – MSU (US)	500 kW, heavy ion beams	340	
ESS (Sweden)	1 – 2 GeV, 5 MW n-Source ESS - pulsed	150	
PIP-II–Fnal (US)	High Intensity p-Linac for Neutrino Beams	115	
ADS- (China, India)	R&D for accelerator drive system	> 200	
Global sum		> 2000	

Media.xfel.au, Dec. 2015

European XFEL Progressing

Progress:

2013: Construction started

2015: SRF cav. (100%) completed

CM (70%) progressed

Further Plan:

2016: E-XFEL acc. completion

2017: XFEL beam to start

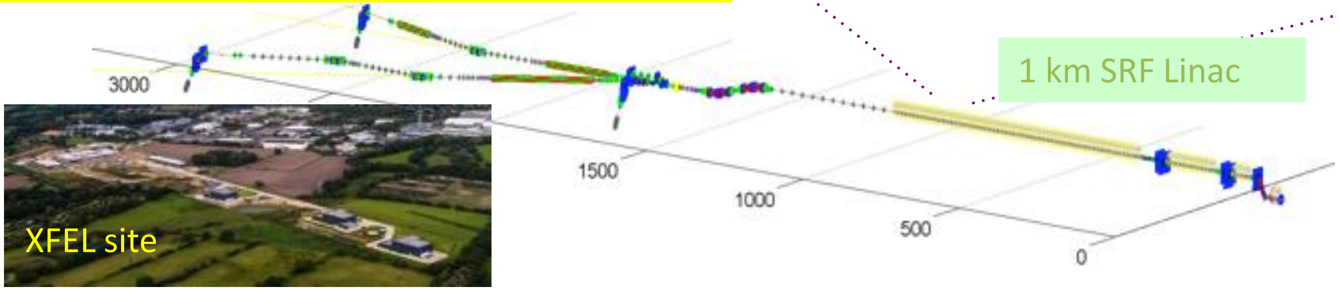
Acc. : ~ 1/10 scale to ILC-ML's

SRF system: ~ 1/20 to ILC SRF's

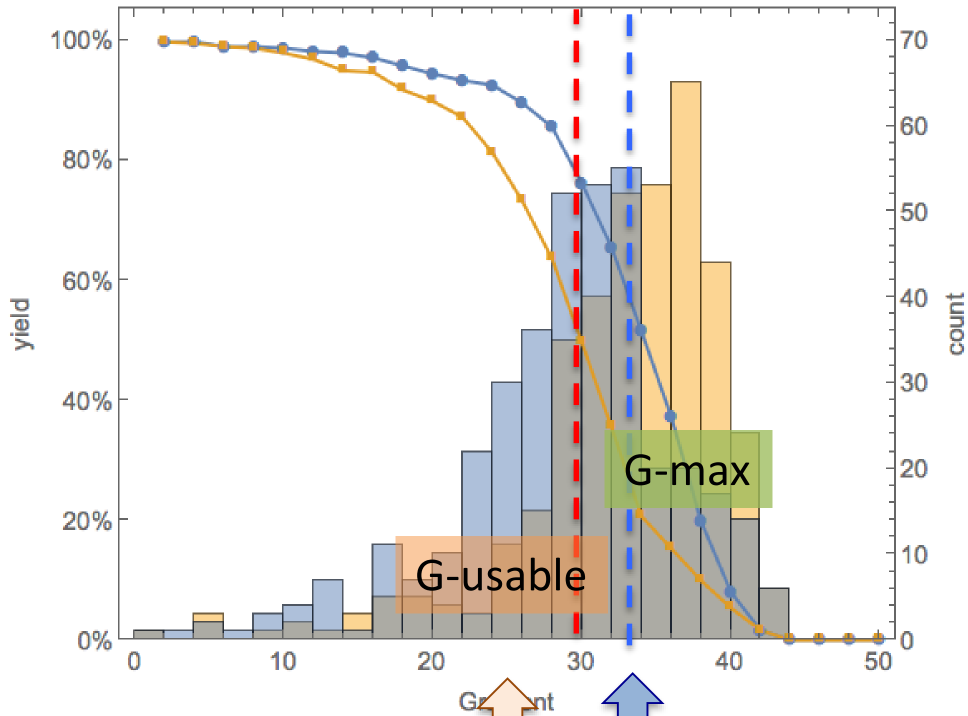
1.3 GHz / 23.6 MV/m

808 SRF acc. Cavities

101 Cryo-Modules (CM)



E-XFEL: SRF Cavity Performance (as received)



SRF cavity production/test ;

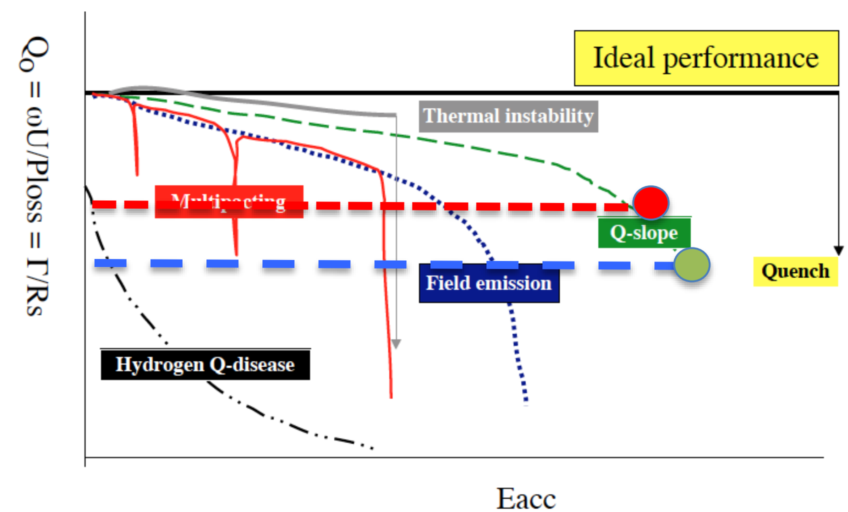
 # RI Cavities, 373 (as of Sept. 2015)

- Final process: 40 μm EP.
  - The same recipe to ILC-SRF
- Tested at DESY-AMTF

Notes::

- "Ultra-pure water rinsing as the 2nd process improving the gradient performance (~10%) for lower-performed cavities (not shown here).

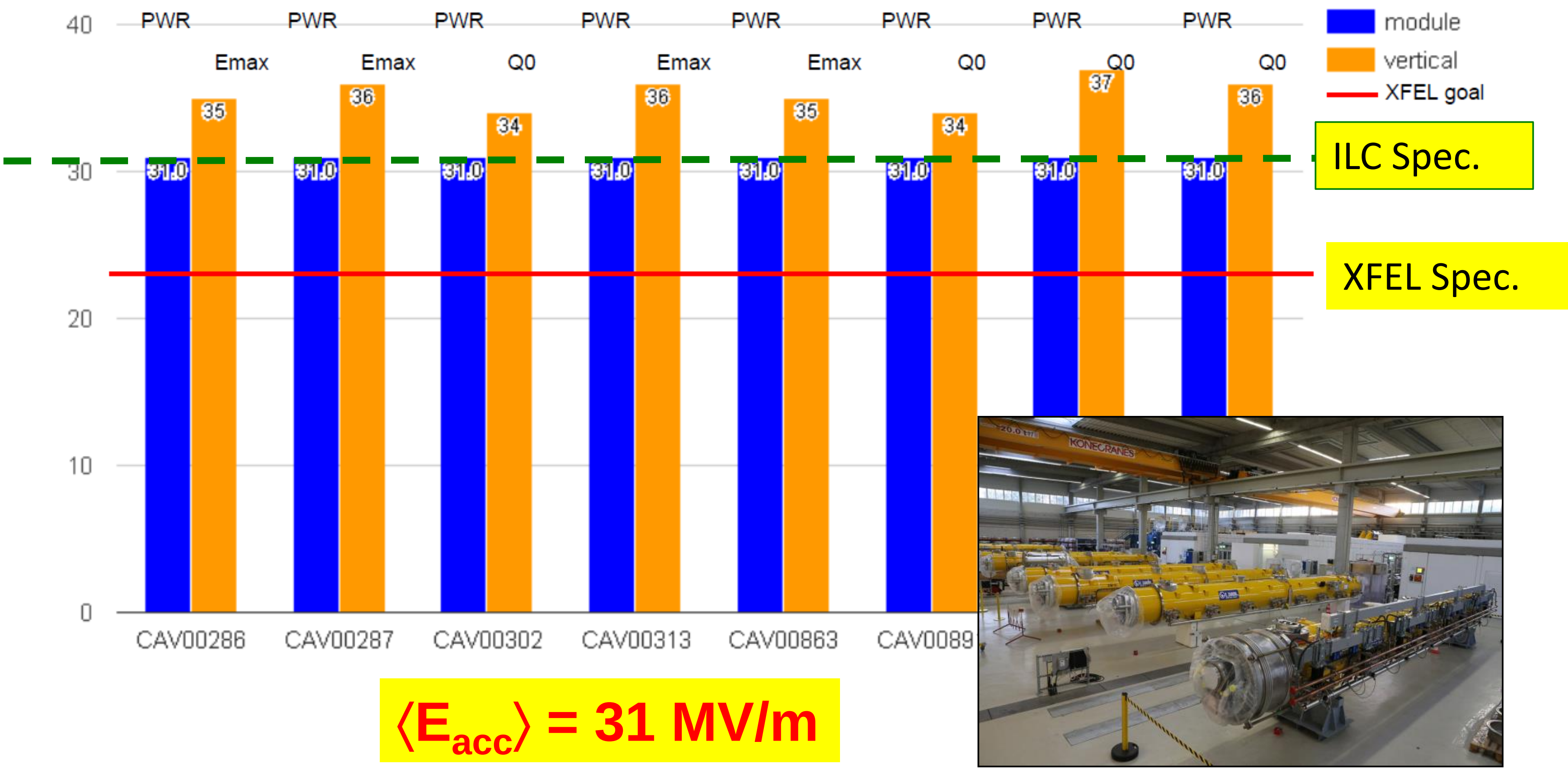
	G-usable (Q_0> 10^{10})	G-max	(ILC)
<G> MV/m	29.4	33	(35)
Yield at 28MV/m	66%	86%	(90%)



Cryomodule Performance : XM59

E_{acc} [MV]

Cryomodule Operating gradient



$\langle E_{acc} \rangle = 31$ MV/m

XM59 is an excellent module, assembled after the change of CR procedure.

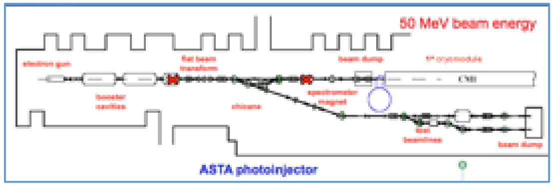
Fermilab : CM2 reached <31.5 MV/m >

CERN Courier December 2014

ACCELERATORS

ILC-type cryomodule makes the grade

For the first time, the gradient specification of the International Linear Collider (ILC) design study of 31.5 MV/m has been achieved on average across an entire ILC-type cryomodule made of ILC-grade cavities. A team at Fermilab reached the milestone in early October. The cryomodule, called CM2, was developed to advance superconducting radio-frequency technology and infrastructure at laboratories in the Americas region, and was assembled and installed at Fermilab after initial vertical testing of the cavities at Jefferson Lab. The milestone – an achievement for scientists at Fermilab, Jefferson Lab, and their domestic and international partners in superconducting radio-frequency (SRF) technologies – has been nearly a decade in the making, from



CM2 in its home at Fermilab's NML building, as part of the future Advanced Superconducting Test Accelerator. (Image credit: Fermilab.)

Cavity	Gradient (MV/m)
1	31.9
2	30.8
3	31.8
4	31.7
5	31.5
6	31.3
7	31.6
8	31.4

Cryomodule test at Fermilab reached < **31. 5** > MV/m, exceeding ILC specification

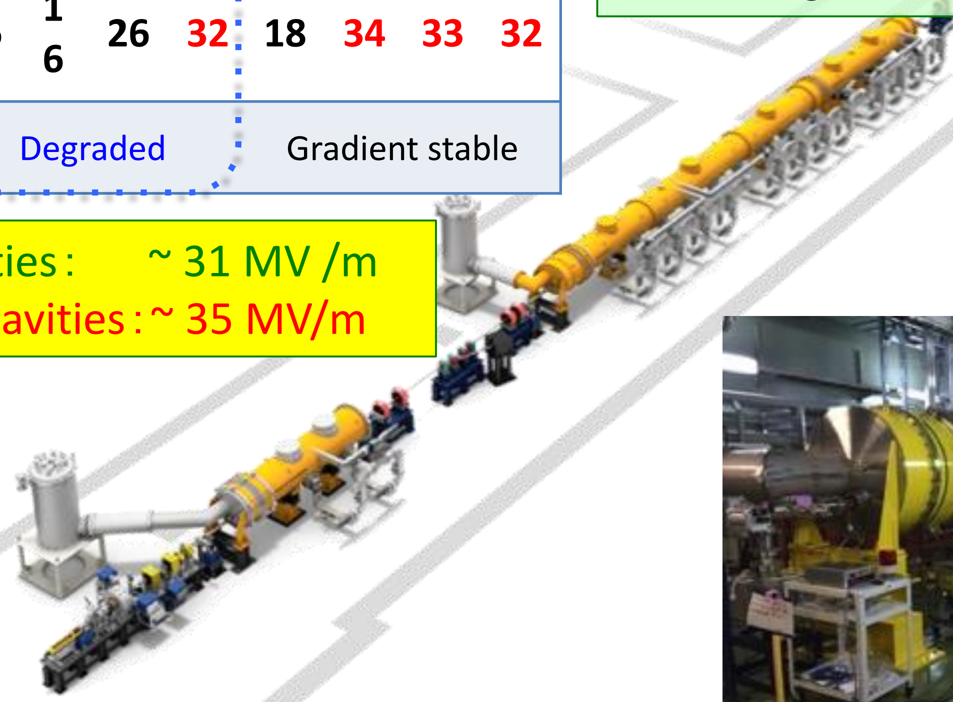
KEK-STF: Cavity Performance after CM Assembly
Beam Acceleration w/ 8 cavity string in JFY2016

SRF cavity performance before/after CM Assembly

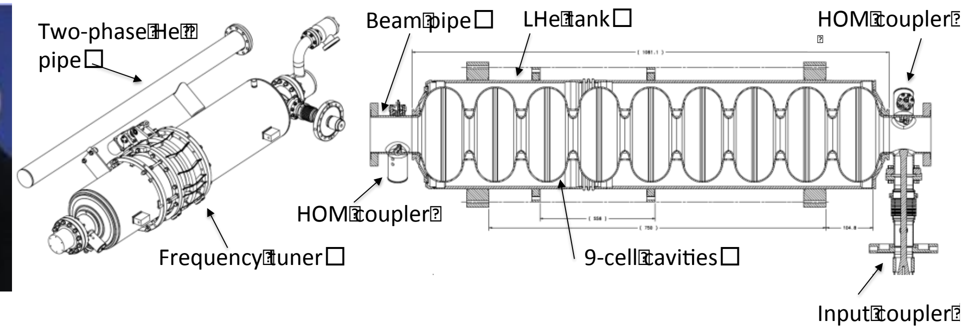
Module	CM1a				CM1b				CM2a			
Cav. #	1	2	3	4	5	6	7	8	9	10	11	12
空洞単体 [MV/m]	37	36	38	36	37	35	39	36	12	36	32	32
CM内 (pulse) [MV/m]	**39**	**37**	**35**	**36**	**26**	**16**	**26**	**32**	**18**	**34**	**33**	**32**
	Gradient stable				Degraded				Gradient stable			

FY14: CM1+CM2a (8+4) assembly
FY15: Cavity individually tested in CM
RF power system in preparation
FY16: 8-cavity string to be RF tested
Beam Acceleration
（w/ a goal to reach > 250 MeV)

*Gradient(av) w/ 12 cavities : ~ 31 MV /m
Gradient (av) w/ best 8 cavities : ~ 35 MV/m



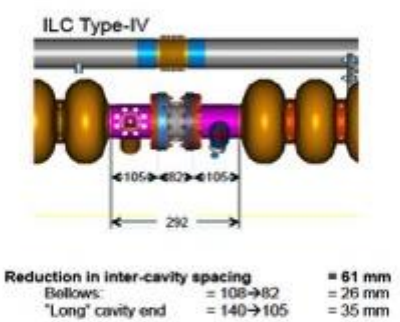
ILC SRF ML Parameters

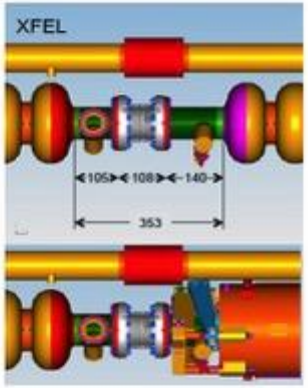


1.3 GHz Nb 9-cellCavities	16,024
Cryomodules	1,855
SC quadrupole pkg	673
10 MW MB Klystrons & modulators	436/378 *

* site dependent

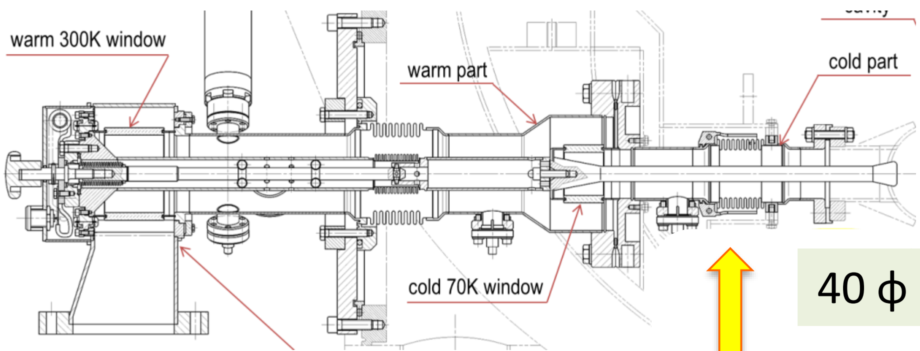
A Possibility for the cost effective ILC Cavity Integration





Longitudinal interconnect constraint for the ILC and EFXEL cavity string

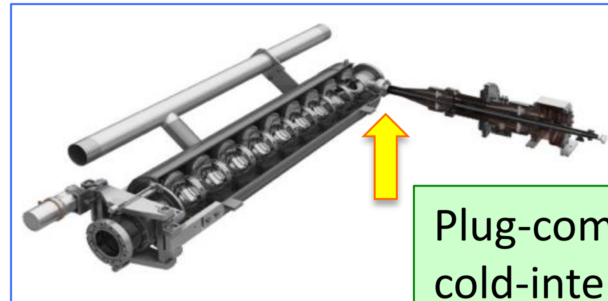
RF-Power Coupler Development
w/ low-SEE coefficient ceramic window



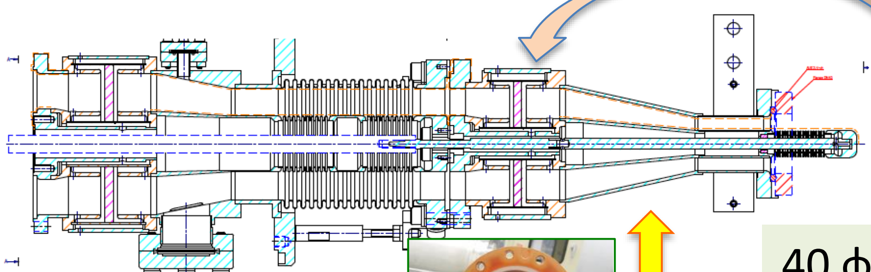
40 ϕ

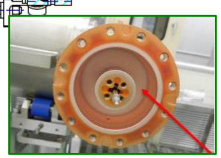
TTF-III/E-XFEL Coupler

w/ bellows



Plug-compatible, cold-interface





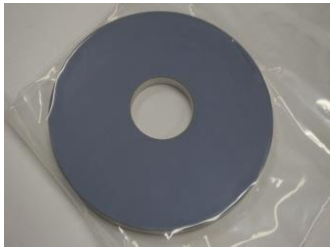
40 ϕ

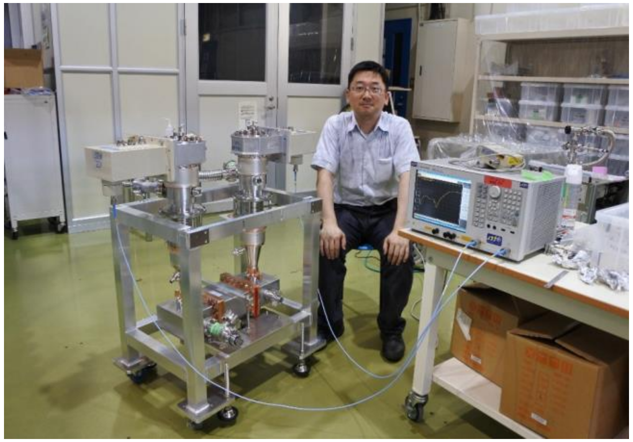
w/o bellows

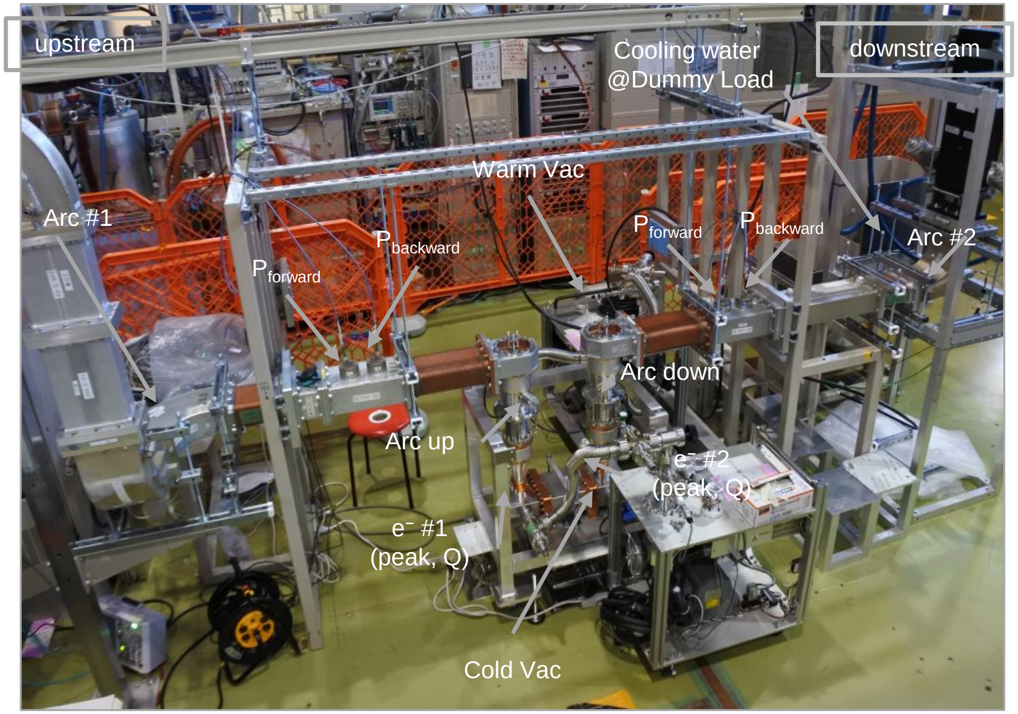
New, KEK-STF Coupler

	STF-40-A	STF-40-B*
Cold end-flange	40 mm	40 mm
Ceramic window	A479	AH100A
SEE coefficient	11.2	4.6
Coating	yes	no
Conditioning time	86 hrs	In progress

* CERN-KEK Cooperation



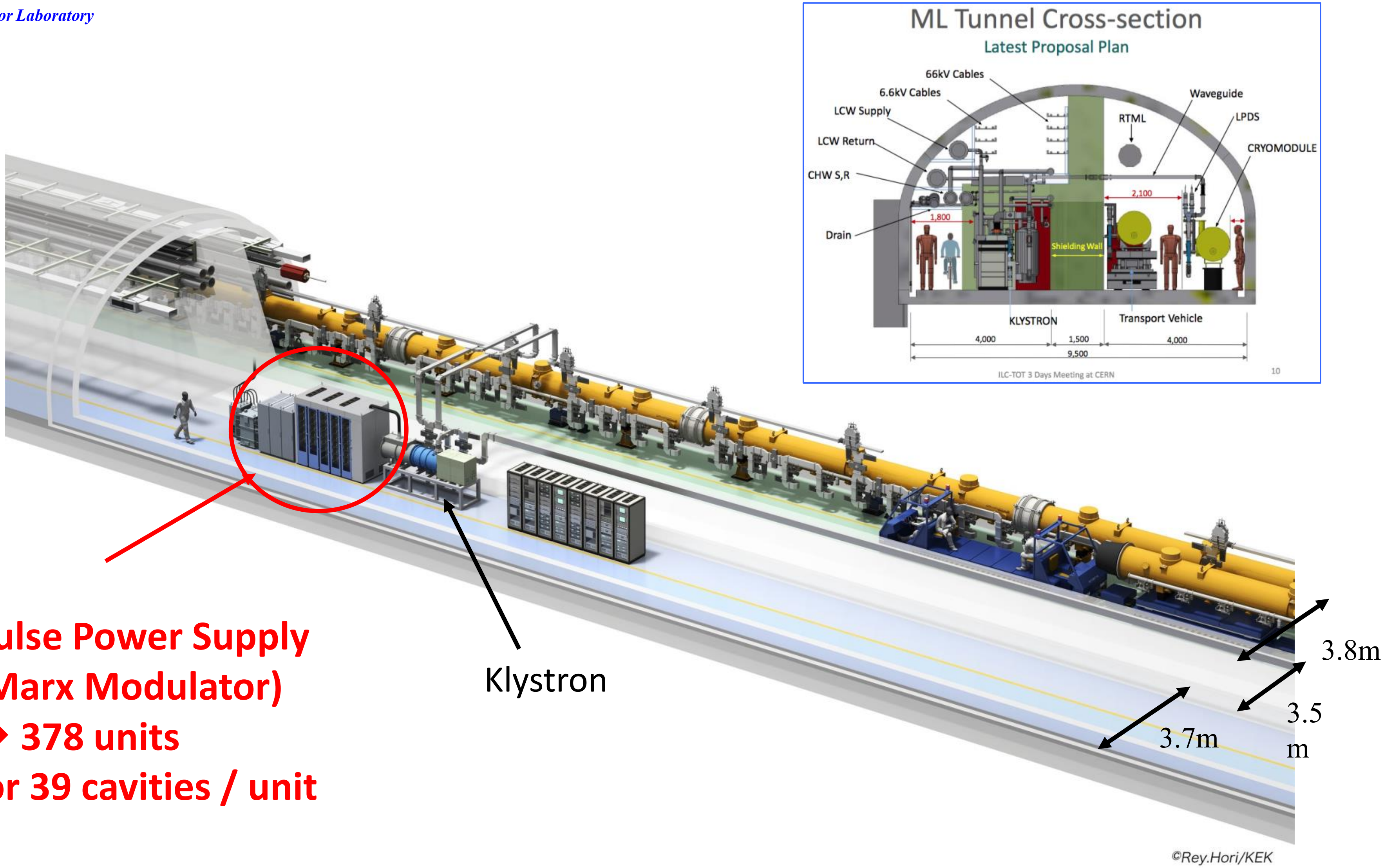



upstream
Cooling water
@Dummy Load
downstream
Warm Vac
Arc #1
P backward
P forward
P forward
P backward
Arc #2
Arc down
Arc up
e⁻ #2
(peak, Q)
e⁻ #1
(peak, Q)
Cold Vac

High-Level RF System for ILC

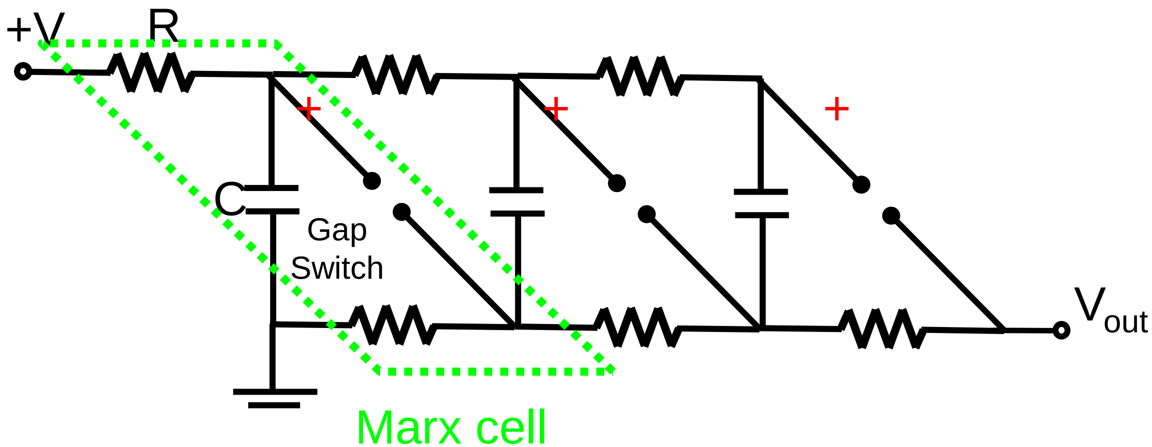
LINEAR COLLIDER COLLABORATION

Accelerator Laboratory



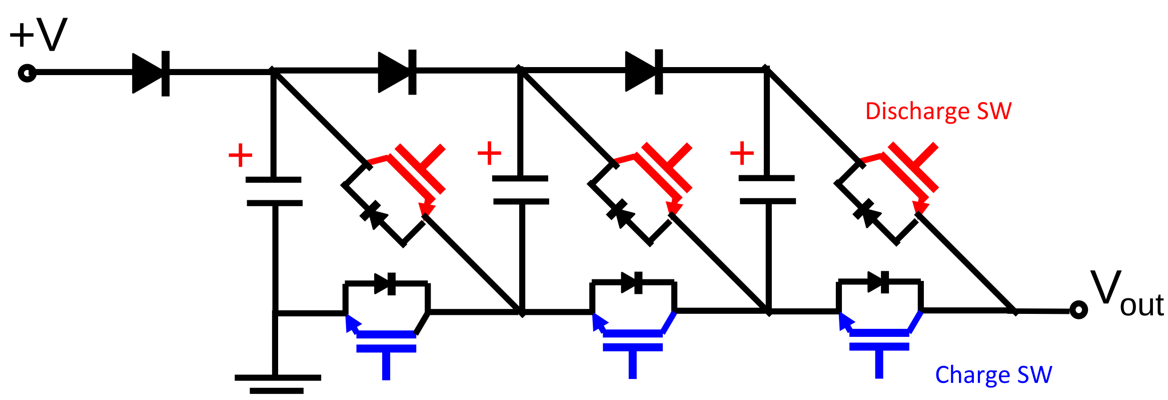
Marx Circuit Concept

- Classic Marx circuit（1923 invented by Erwin Marx）



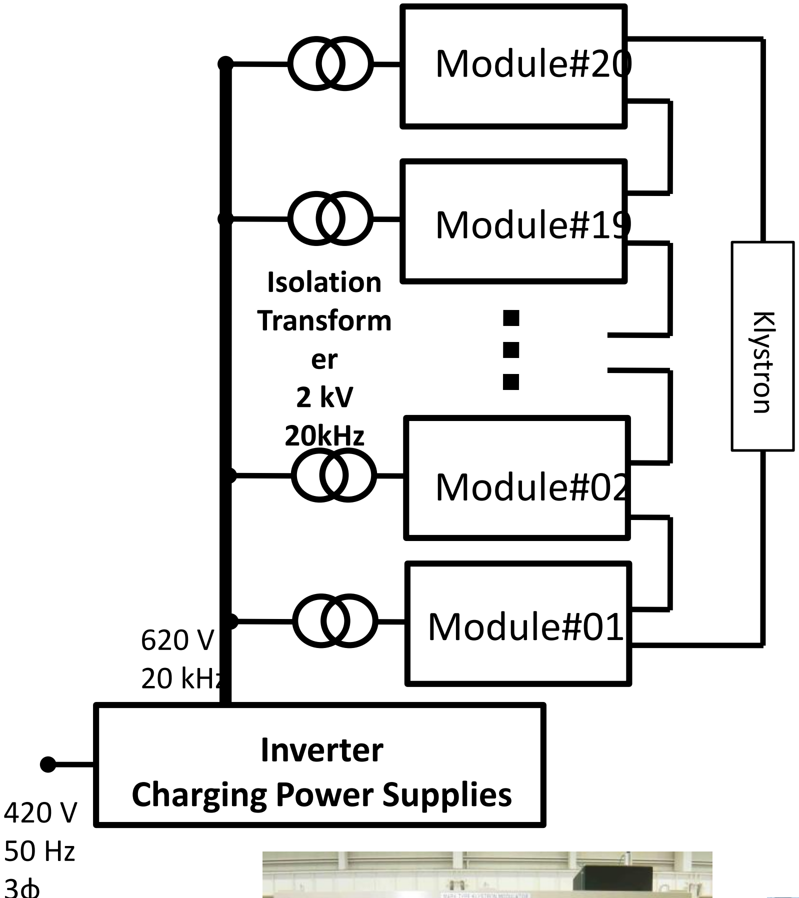
- Charge in Parallel
- Discharge in series
- V-out = n V-in

- Solid state Marx circuit（2000, by A. Krasnykh)

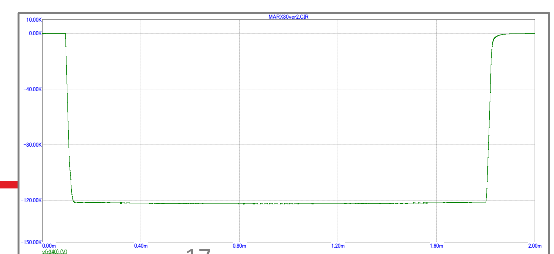


Marx Generator digitized

KEK ILC Modulator Development



- Marx Topology and Design Concept :
  - Charge in parallel, discharge in series
- Specification:
  - 120 kV, 140 A, 1.7 ms, 5 Hz
- Modules:
  - 6.4 kV pulse output with Marx circuit
  - Cell having a step-down chopper circuit with a switching frequency of 50 kHz
- Design Considerations:
  - Modular design with high availability
    N+1 Redundancy
  - Cost effective
    Components and modular design
  - Easy maintenance
    Oil-free design
  - Compact
    No output transformer



Outline

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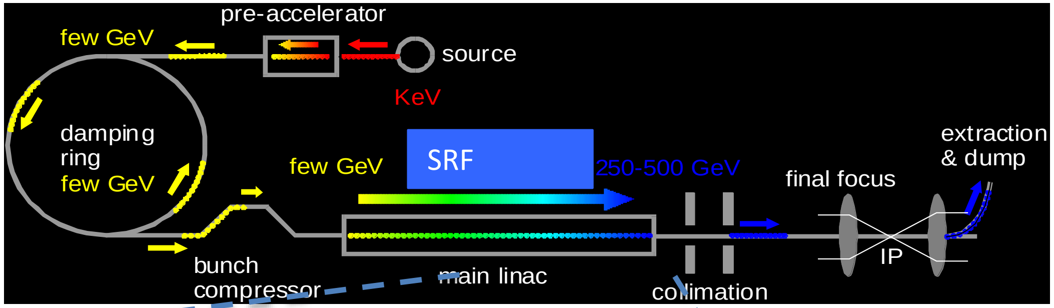
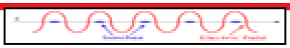
   - Progress in cavity gradient
   - RF Input-Coupler with new ceramic window
   - Marx Generator for RF Power Supply
2. **Prospect for realizing the ILC**
   - SRF Cavity development
   - "Global (SRF) Cryomodule" proposal

Further Technical Issues to prepare for the ILC

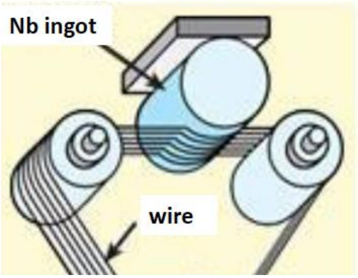
The. Field	Subject	Global Cooperation
ADI	Optimize Acc. Design and Integration	LCC-ILC-ADI Global Team
SRF	Improve Gradient and Stability Establish three regional contribution - **Industrialization** - **Hub-lab functioning**	**TTC: TESLA Tech. Collaboration:** **Three regional effort and experience** - EU : European XFEL - AMs: LCLS-II - AS : KEK-STF as Asian Hub.
Nano-beam	Realize ultra-low emittance (in DR), and nano-beam size and stability at FF	**ATF: Acc. Test Facility Collab:** - Global collaboration with KEK-centered

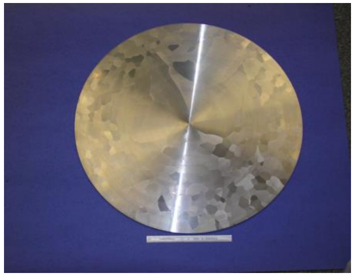




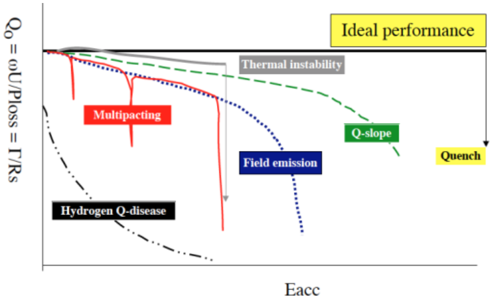
SRF Cavity development anticipated

- **High Gradient**
- Ingot sliced Nb for high-gradient cavities
  - Advantage: Cleanest Nb surface
  - Subject to be settled: mechanical stability
- Possible solution : direct slicing medium-grain ingot

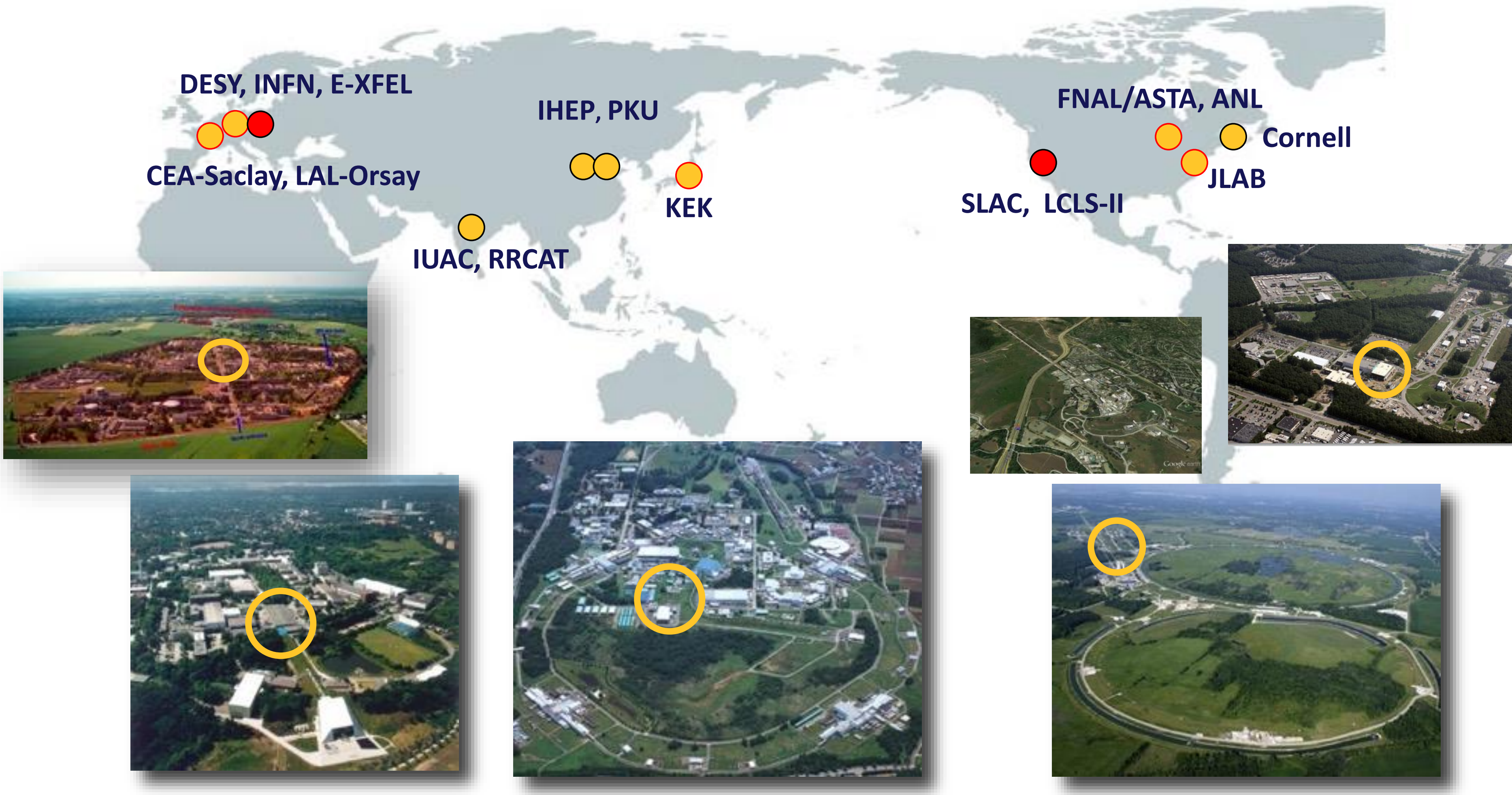




- **High Q**
- Lowering operational temperature (2.0 → 1.8 K)
  - Saving AC power in balance
- N2 doping and other surface treatment
  - Future subject to be investigated even for high gradient
  - Referring work originated at Fermilab



SRF Facilities anticipated for Hub/Consortiums



AMTF @DESY, E-XFEL @ CEA, *STF @ KEK* *ASTA @ FNAL, TEDF @ JLab*

A proposal: "Global SRF Cryomodule" Program

Objectives:

Establish system-engineering to realize **Global Cryomodules** (globally compatible cryomodule) including:

- Industrial technology, with optimum **plug-compatibility**/standardization,
- Safety regulation (such as "high-pressure-code") with inter-regionally compatible authorization,
- Gradient performance reproducibility **after inter-regional transportation.**

Global Cooperation:

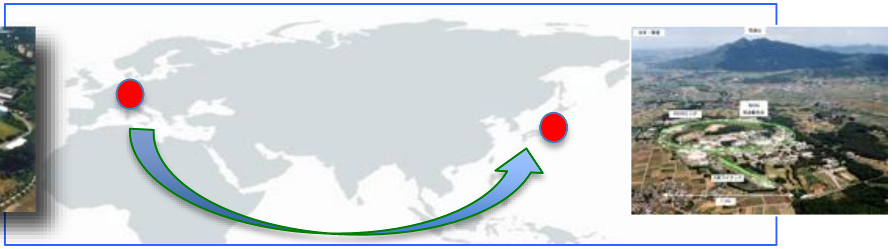
EU (AM) **contributes a full cryomodule** including manufacturing and performance test,

EU (AM), and JP work together for **inter-regional transportation** and safety regulations to be compatibly authorized,

JP contributes to the cryomodule performance test **and** to **reproduce the performance**,

Time-line:

The program to be realized in the ILC main preparation phase of 4 years, and the preparation should start soon, to negotiate with legal authorities and to learn E-XFEL CM qualification process,



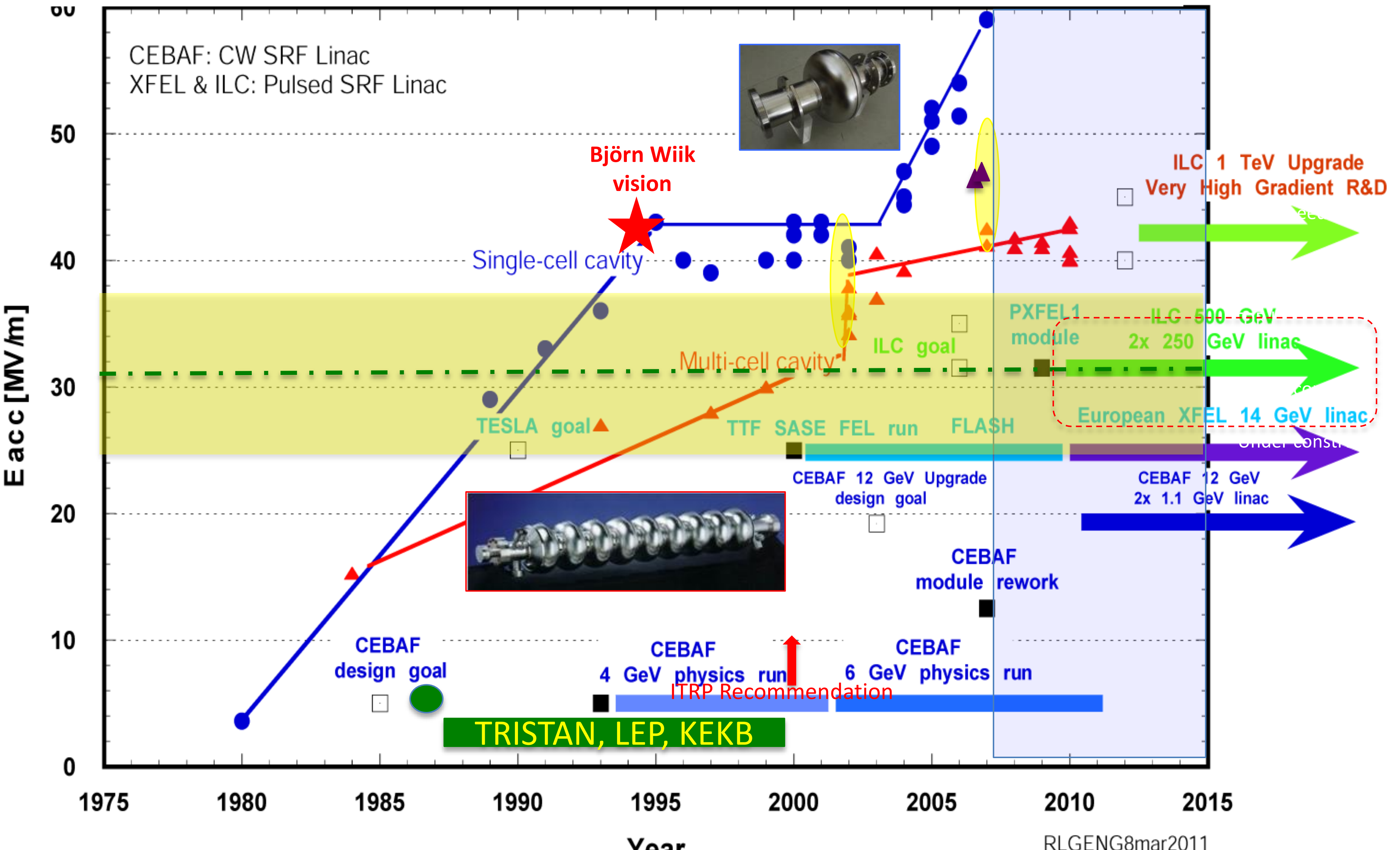
Summary

- International Linear Collider (ILC) is an energy frontier e+e- colliding accelerator to reach 500 GeV extendable to 1 TeV.
- The SRF technology well globally demonstrated and matured, specially by European XFEL, functioning prototype works.
- ILC SRF technology to be further advanced for reliable and cost-effective.

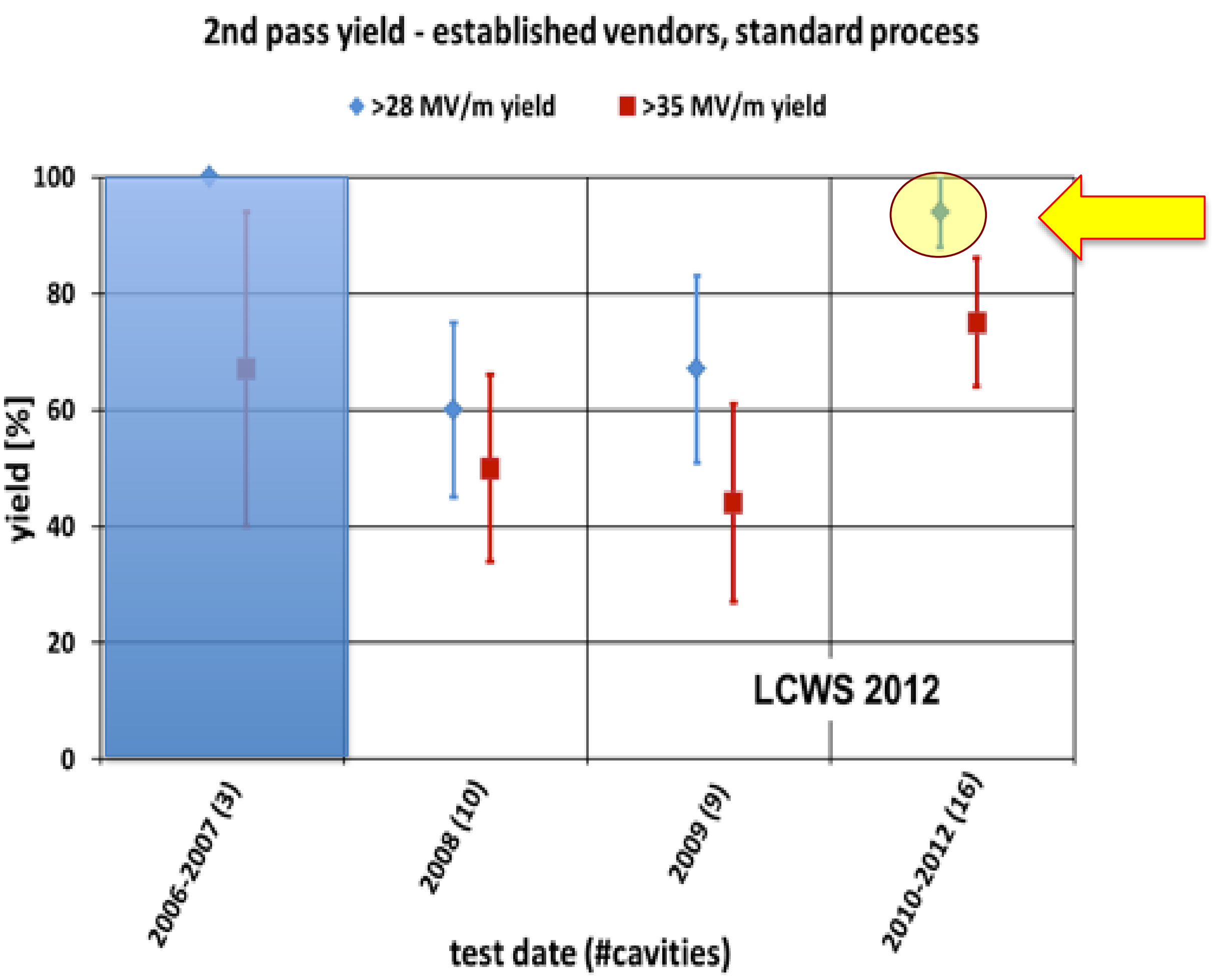
Progress/Prospect in SRF Cavity Gradient

for Frontier Particle Accelerators

R. Geng



Progress in SRF Cavity Production Yield during ILC – Technical Design Stage



Production yield:
94 % at > 35+/-20%

Average gradient:
37.1 MV/m

> R&D goal of 35 MV/m

reached (2012)

Material Design Concept

Purpose	Discharge Effecting Factor	Material Approach
High Resistance for Creeping Discharge	Electron Multiplication	Low Secondary Electron Emission Coefficient(SEEC)

Status for Material

Low SEE →

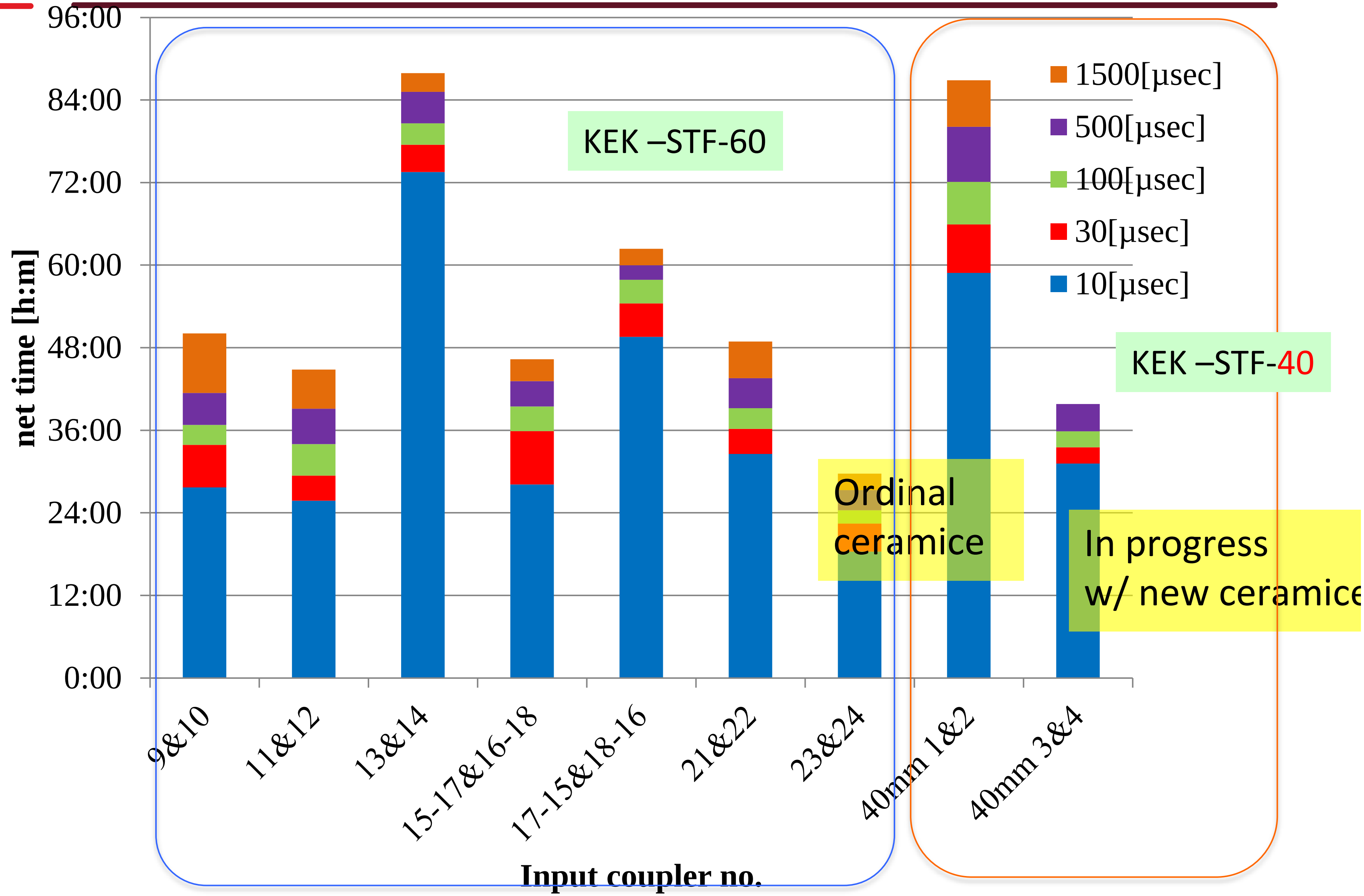
SEEC : 11.2
$10^{14}\Omega \cdot cm$
99% Alumina
KYOCERA A479

SEEC : 4.6
$10^{14}\Omega \cdot cm$
New Alumina
KYOCERA AH100A

On a commercial basis

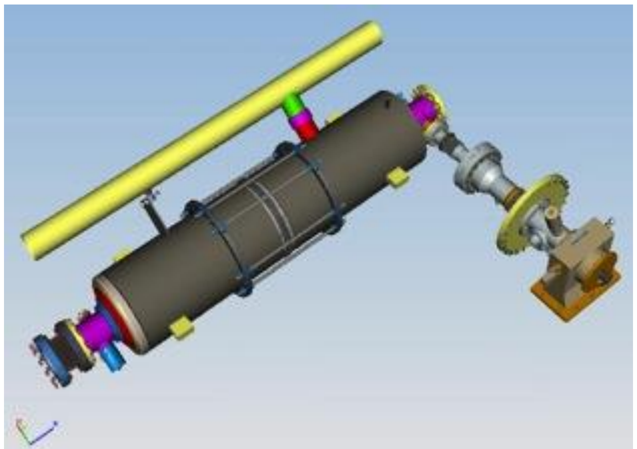
↓

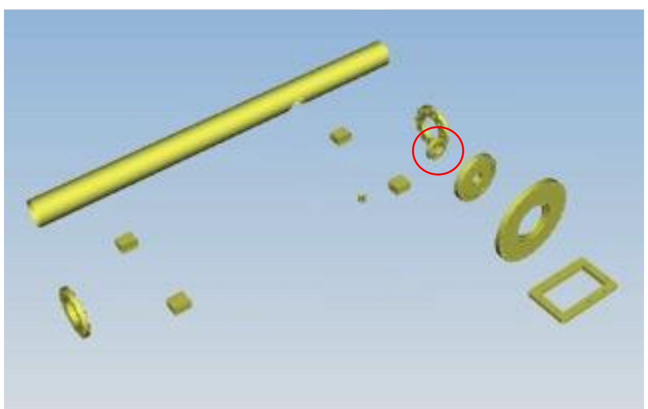
Introduction of AH100A



96:00
84:00
72:00
60:00
48:00
36:00
24:00
12:00
0:00
net time [h:m]
KEK –STF-60
KEK –STF-40
1500[μsec]
500[μsec]
100[μsec]
30[μsec]
10[μsec]
Ordinal ceramice
In progress w/ new ceramice
9&10
11&12
13&14
15-17&16-18
17-15&18-16
21&22
23&24
40mm 1&2
40mm 3&4
Input coupler no.

ILC SCRF Cavity Plug-compatible Conditions discussed in the Technical Design Phase

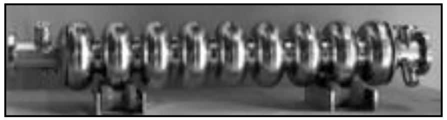




Item	Varieties	Baselines in ILC-TDR
Cavity shape	TESLA / LL	TESLA
Length		Fixed
Beam pipe flange		Fixed
Suspension pitch		Fixed
Tuner	Blade/ Slide-Jack	Blade
Coupler flange (cold end)	40 (60 at KEK)	40 mm
Coupler pitch		Fixed
He –in-line joint		Fixed

SCRF Procurement/Manufacturing Model

ILC Host-Lab



Technical Coordination for Lab-Consortium

Regional Hub-Lab: A

Regional Hub-Lab: E, & …

World-wide Industry responsible to **‘Build-to-Print’ manufacturing**

Regional Hub-Lab: B

Regional Hub-Lab: D

Regional Hub-Lab: C: **responsible to Hosting System Test and Gradient Performance**

Regional hub-laboratories responsible to regional procurements to be open for any world-wide industry participation

: Technical coordination link

: Procurement link

KEK-STF: Cavity Performance after CM Assembly
Beam Acceleration w/ 8 cavity string in JFY2016

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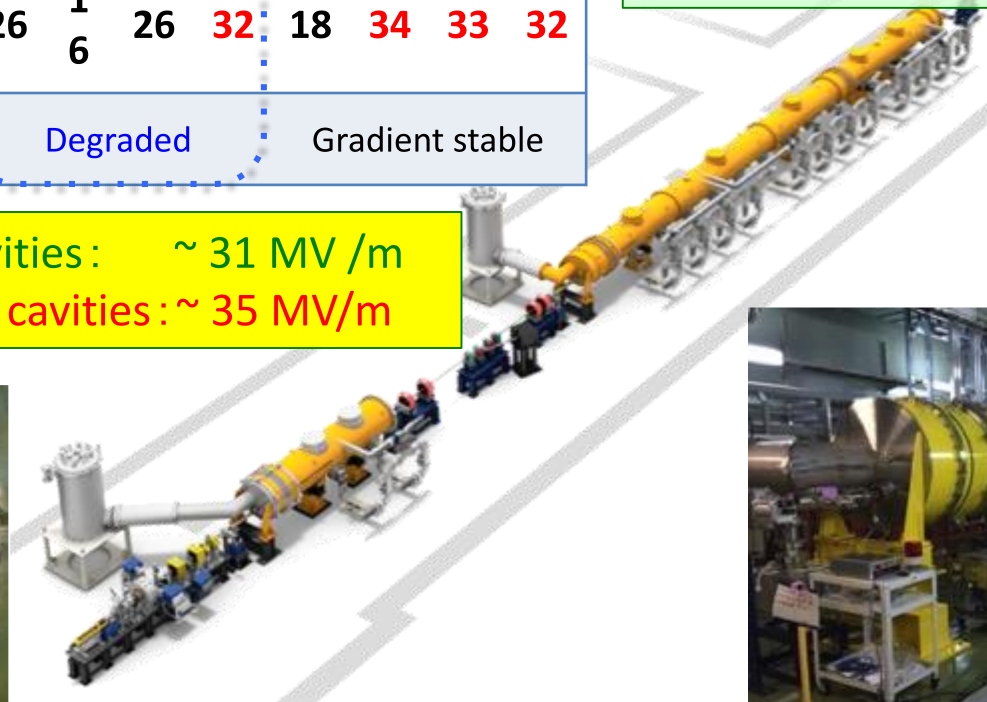

Technical Issues to be settled during the ILC Preparation Phase

Table 2. Technical issues to be settled during the ILC accelerator preparation phase

	Pre-preparation Phase	Main Preparation Phase			
	Present	P1	P2	P3	P4
ADI	Establish main parameters	Verify parameters w/ simulations			
SRF	Accelerate beam with SRF cavity string and cryomodule	Demonstrate mass-production technology and stability Demonstrate Hub-lab functioning and global sharing			
Nanobeam	Achieve the ILC beam-size goal	Demonstrate the nanobeam size and stabilize the beam position			
Positron source	Demonstrate technological feasibility	Demonstrate both the undulator and e-driven e+ sources			
CFS	Pre-survey and basic design	Geology survey, engineering design, specification, and drawings			
Common technical support	Support engineering and safety	Common engineering supports (network, radiation safety, etc.)			
Administration	Project planning and promotion Preparation for the ILC pre-lab	General affairs, finance, international relations, public relations Establishing the ILC pre-lab and managing the ILC preparation			

Global Cryomodule Program