9 mA Meeting

Status and Plans at KEK STF: The Quantum Beam Project and STF-2

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Content

- The Qantum Beam (QB) Project at STF
- Test Operations during the QB Project
- STF-2
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Superconducting RF Test Facility (STF) Quantum Beam Project (QBP)

STF

- Development and demonstration of high gradient superconducting accelerator technology aimed for ILC

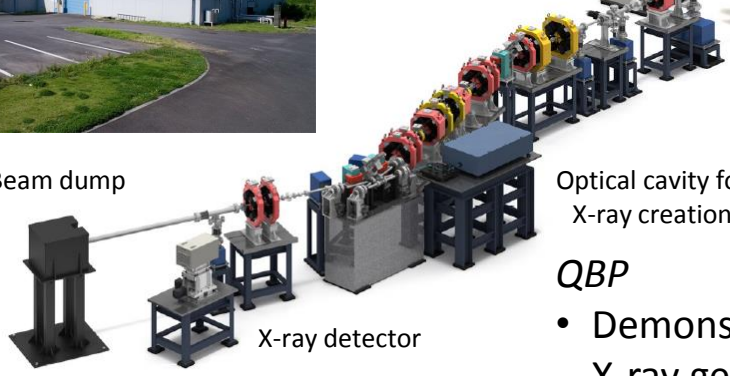
KEK

STF ***QBP***

(Apr. 2012 – Mar. 2013)

Normal conducting photo-cathode RF gun*
(5 MW Klystron on ground level)

Two superconducting 9-cell cavities within capture cryomodule (CCM)
(800 kW klystron in the tunnel)*



Beam dump

Optical cavity for X-ray creation

X-ray detector

*operated using digital LLRF control techniques

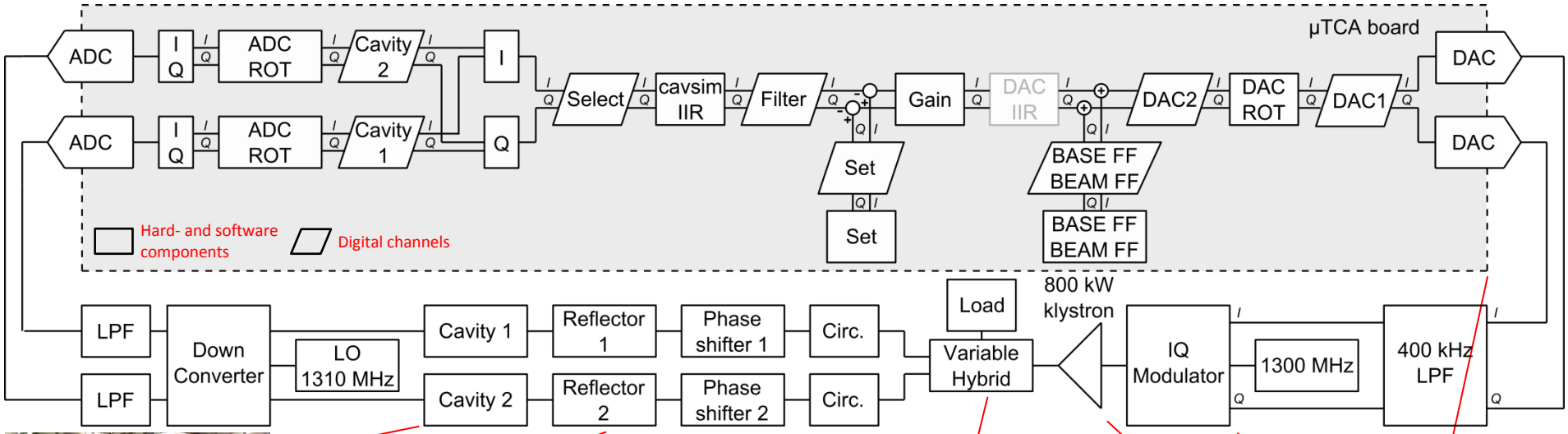
QBP

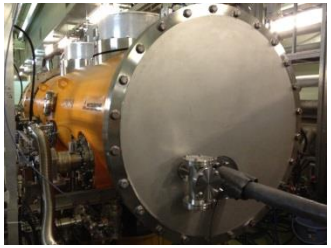
QBP

- Demonstration of high brightness X-ray generation by inverse laser Compton scattering.

Cavity gradient:	*(20±20%) MV/m*		
Loaded Q:	*3e6*		
Bunch number:	*162500*	*Bunch spacing:*	*162.5 MHz*
Operation mode:	*pulsed*	*Beam current:*	*10 mA*
Repetition rate:	*5 Hz*	*Energy:*	*40 MeV*
Pulse length:	*1 ms*	*Charge:*	*62 pC*

LLRF Control Loop

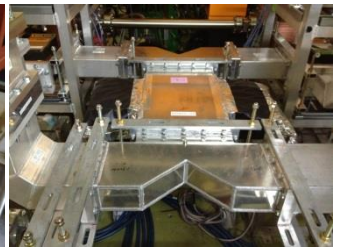




Capture cryomodule
(2 SC cavities)

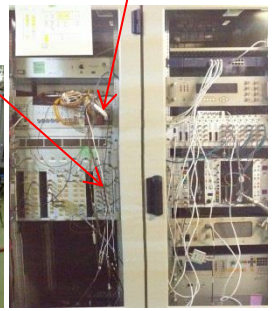
Reflector
(Q_L adjustment)

Phase shifter
(cavity phase)



Variable hybrid
(RF power ratio)

800 kW klystron
(RF power creation)



19-inch rack

- The Qantum Beam (QB) Project at STF
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Nominal Operation

RF Parameter

V_{Cav1} = 16 MV/m

V_{Cav2} = 24 MV/m

Q_{L1} = 3e6

Q_{L2} = 3e6

Filling time = 540 µs

*Beam compensation active

Beam Parameter

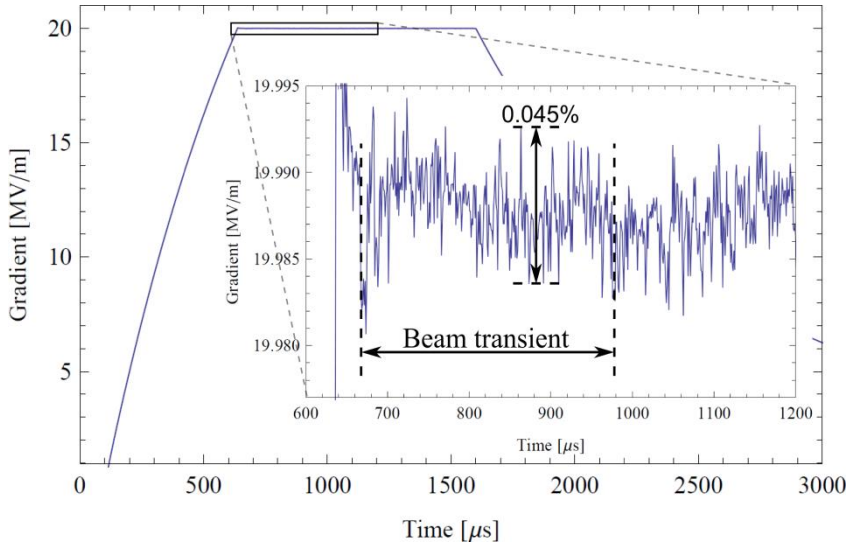
Pulse Length = 615 µs

Current = 6.6 mA

ILC Stability Requirements

ΔA/A = 0.07%

Δϕ = 0.24°



Beam	6.6mA* (60 mins)	Off (20 mins)
ΔA/A (cav1)	-	0.042%
ΔA/A (cav2)	-	0.045%
ΔA/A (vector sum)	0.009%	0.008%
Δϕ (cav1)	-	0.027°
Δϕ (cav2)	-	0.021°
Δϕ (vector sum)	0.009°	0.008°

All stabilities are estimated for the beam transient time.

High Q_L Operation

ILC requirements

- Operation intended at Q_L values in a range of 3e6 to 10e6

- Bandwidth becomes very narrow (e.g. 32Hz at Q_L=2e7), detune becomes severe
- Microphonics maybe problematic to deal with
- Demonstration only possible at KEK STF due to wide Q_L range (2e6~5e7)

High Q_L operation at STF

- Q_L adjustment with waveguide reflectors
- Automated detune compensation via piezo tuners

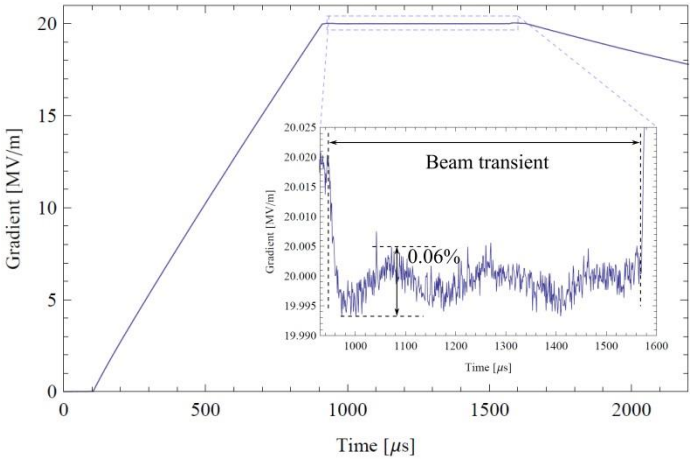
High Q_L Operation

RF Parameter

V_{Cav1} = 20 MV/m
V_{Cav2} = 20 MV/m
Q_{L1} = 2e7
Q_{L2} = 2e7
Filling time = 800 µs
*Beam compensation active

Beam Parameter

Pulse Length = 615 µs
Current = 6.1 mA



	High Q_L		Nominal	
Beam	6.1 mA* (60 mins)	Off (20 mins)	6.6 mA* (60 mins)	Off (20 mins)
ΔA/A (cav1)	0.121%	0.030%	-	0.042%
ΔA/A (cav2)	0.160%	0.032%	-	0.045%
ΔA/A (vector sum)	0.011%	0.008%	0.009%	0.008%
Δϕ (cav1)	0.033°	0.027°	-	0.027°
Δϕ (cav2)	0.028°	0.027°	-	0.017°
Δϕ (vector sum)	0.015°	0.014°	0.009°	0.008°

All stabilities are estimated for the beam transient time.

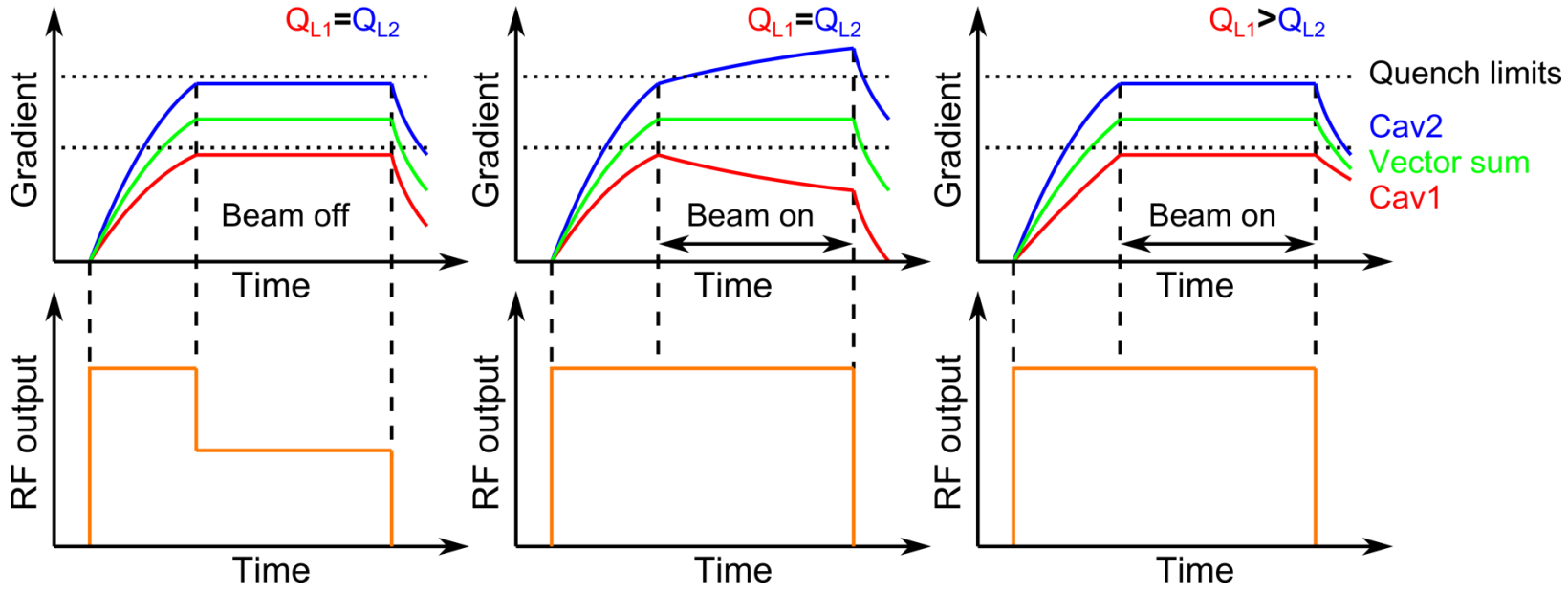
- Detuning stayed constant during 1h operation
  → Microphonics are not severe
- Fulfills ILC stability requirements (ΔA/A = 0.07%, Δϕ = 0.24)

P_kQ_L Control

ILC requirement: Operation with flat flattops

- Beam optics requirements for stable beam acceleration (Cavity tilts and RF fluctuations induce transverse beam orbit changes)
- High gradient operation near quench limit during whole flattop for all cavities

Operation of multiple cavities driven by a single klystron combined with beam loading leads to gradient tilts → **P_kQ_L Control**



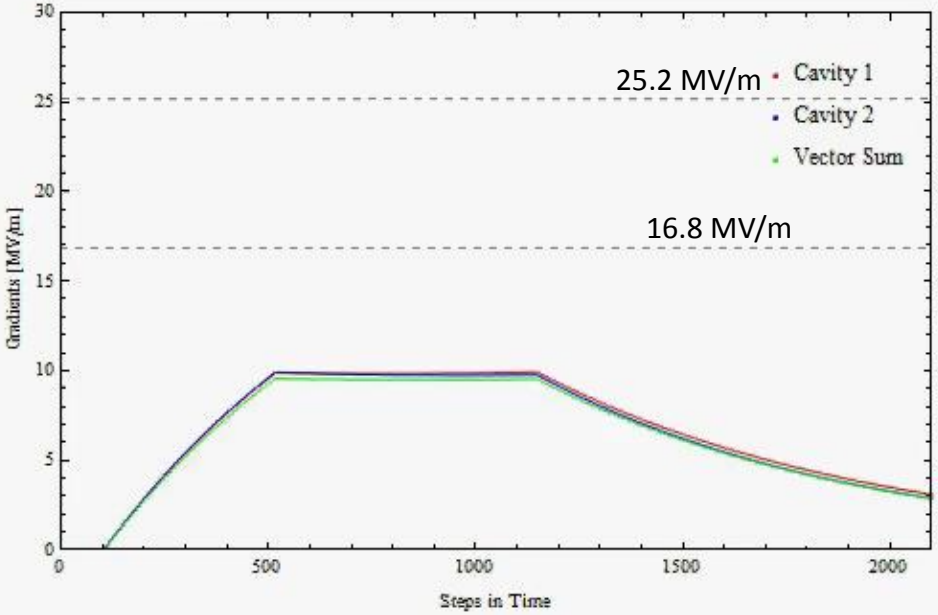
P_kQ_L Control Goal

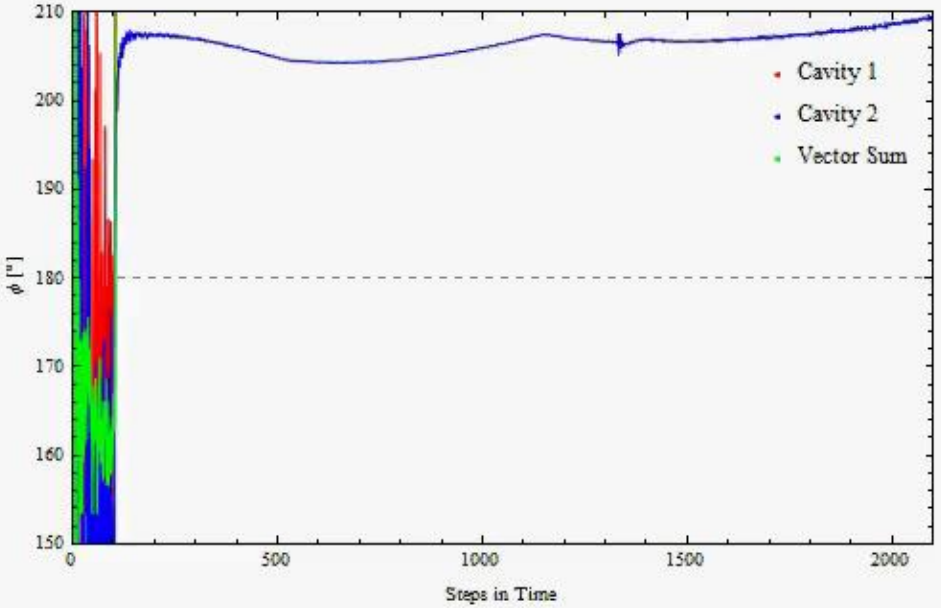
ILC requirements

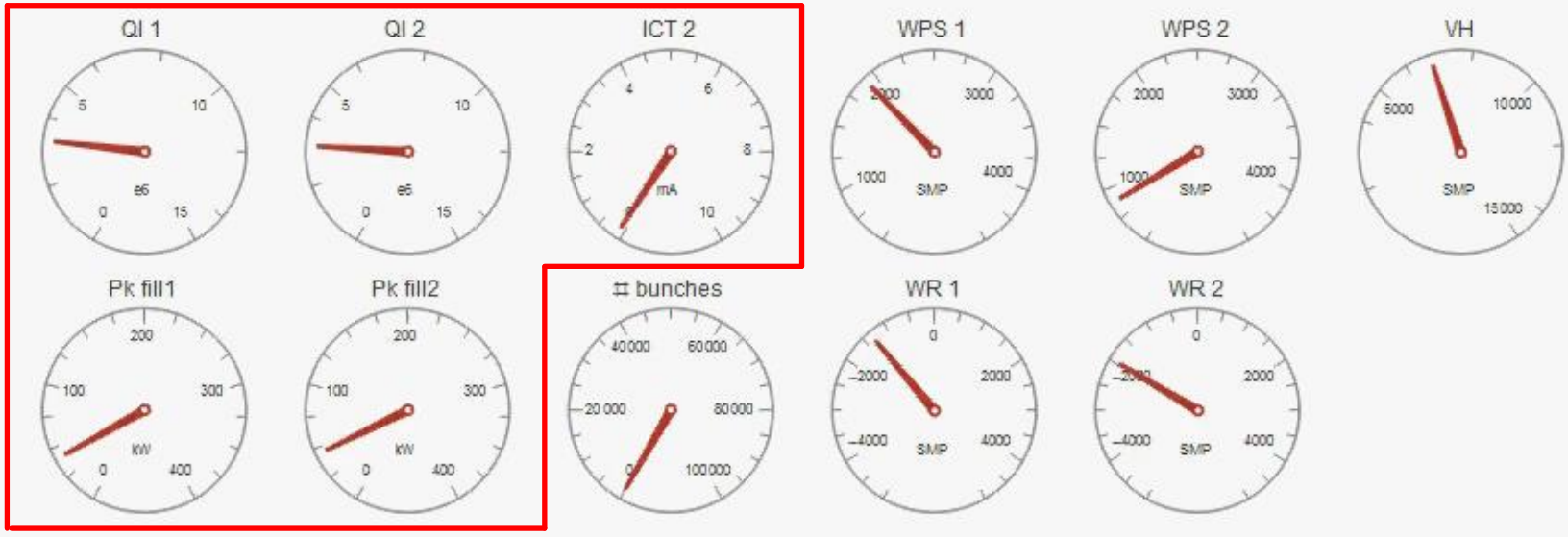
- Fully automated P_kQ_L operation (~16000 cavities)
- Cavity gradient spread ±20% (e.g. 16 MV/m and 24 MV/m)
- Cavity gradients 5% below of respective quench limits
- Cavity gradients must never exceed quench limits
- Cavity vector sum stabilities $\Delta A/A = 0.07\%$ and $\Delta\phi = 0.24°$

Steps to engage in P_kQ_L operation

- Determination of working point for adjustment of cavity RF input powers (P_k) and Q_L values respective to the beam current
- Fully automated P_kQ_L setting procedure


25.2 MV/m
16.8 MV/m
Cavity 1
Cavity 2
Vector Sum
Gradients [MV/m]
Steps in Time


Cavity 1
Cavity 2
Vector Sum
ϕ [°]
Steps in Time


QI 1
QI 2
ICT 2
WPS 1
WPS 2
VH
Pk fill1
Pk fill2
bunches
WR 1
WR 2
e6
mA
SMP
kW

P_kQ_L Operation Stabilities

RF Parameter

V_{Cav1} = 16 MV/m

V_{Cav2} = 24 MV/m

Q_{L1} = 9e6

Q_{L2} = 3e6

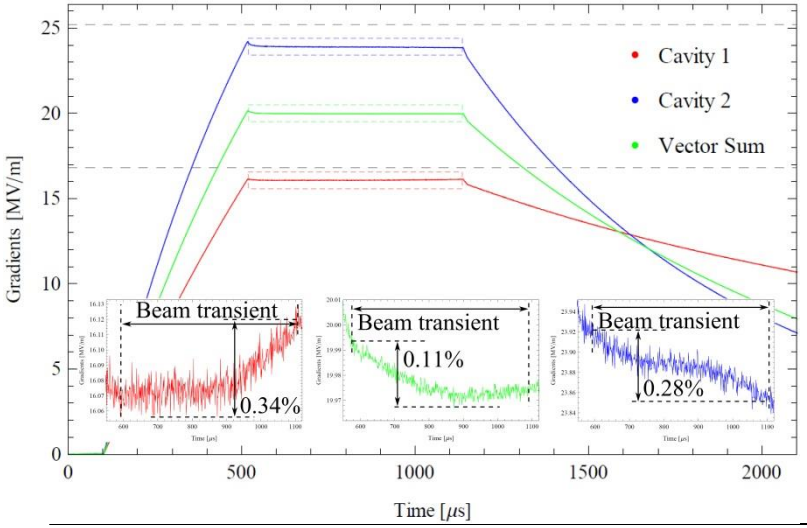
Filling time = 410 µs

*Beam compensation active

Beam Parameter

Pulse Length = 615 µs

Average current = 6.4 mA



	P_kQ_L	Nominal	
Beam	**6.4 mA* (60 mins)**	**6.6 mA* (60 mins)**	**Off (20 mins)**
ΔA/A (cav1)	0.041%	-	0.042%
ΔA/A (cav2)	0.031%	-	0.045%
ΔA/A (vector sum)	0.009%	0.009%	0.008%
Δϕ (cav1)	0.042°	-	0.027°
Δϕ (cav2)	0.031°	-	0.021°
Δϕ (vector sum)	0.009°	0.009°	0.008°

All stabilities are estimated for the beam transient time.

- First actual P_kQ_L operation
- Vector sum stabilities comparable with nominal operation
- Fulfills ILC stability requirements (ΔA/A = 0.07%, Δϕ = 0.24)

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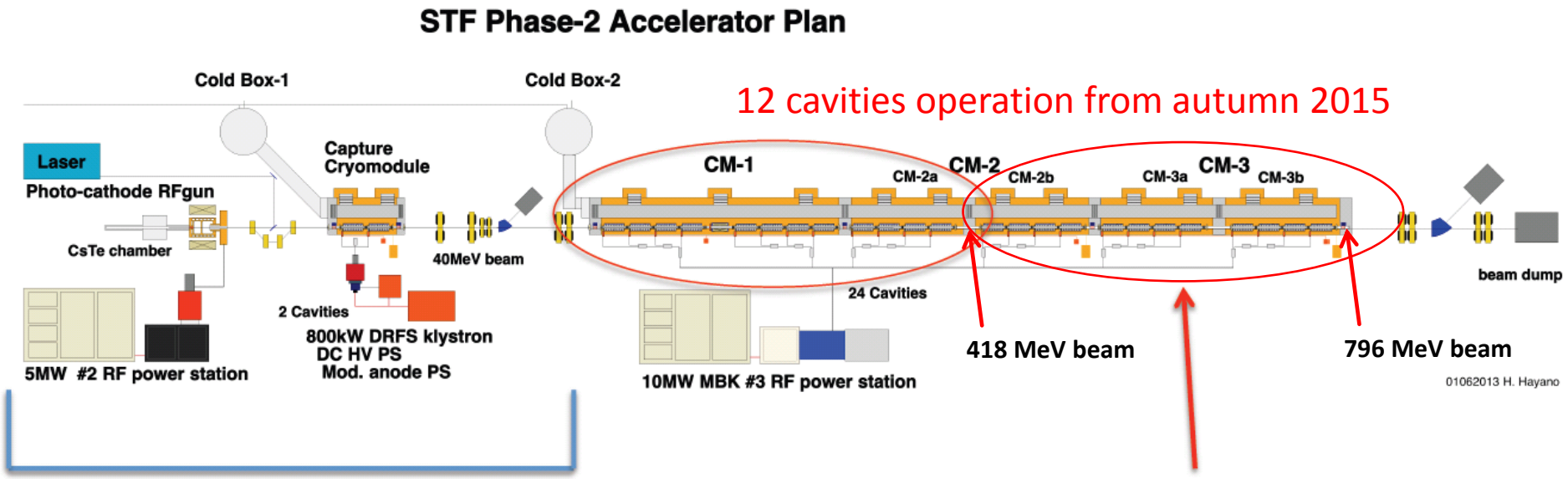
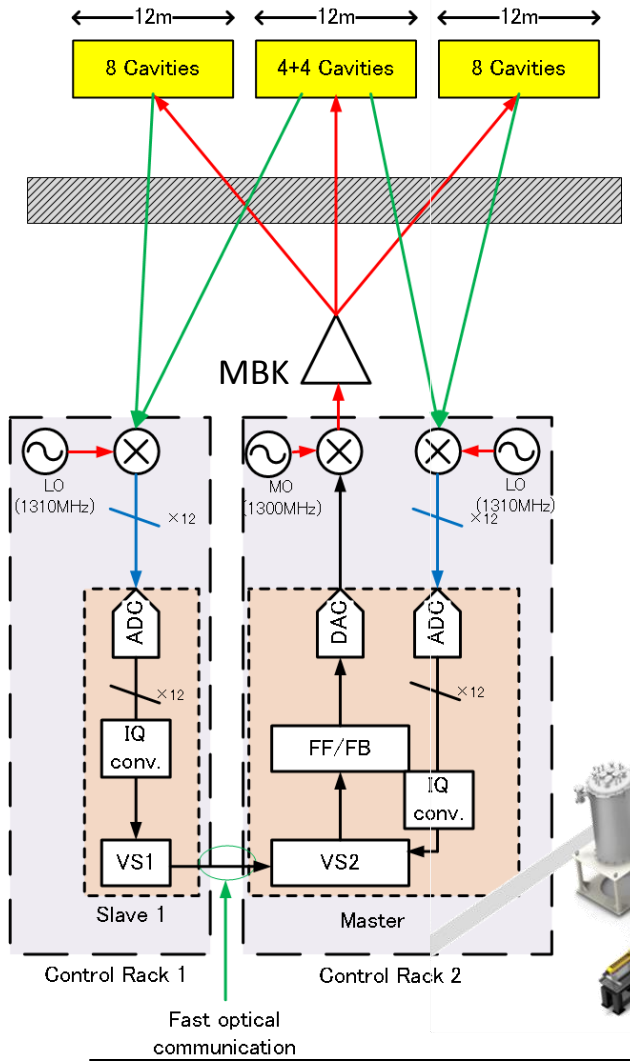
Schematic of STF-2



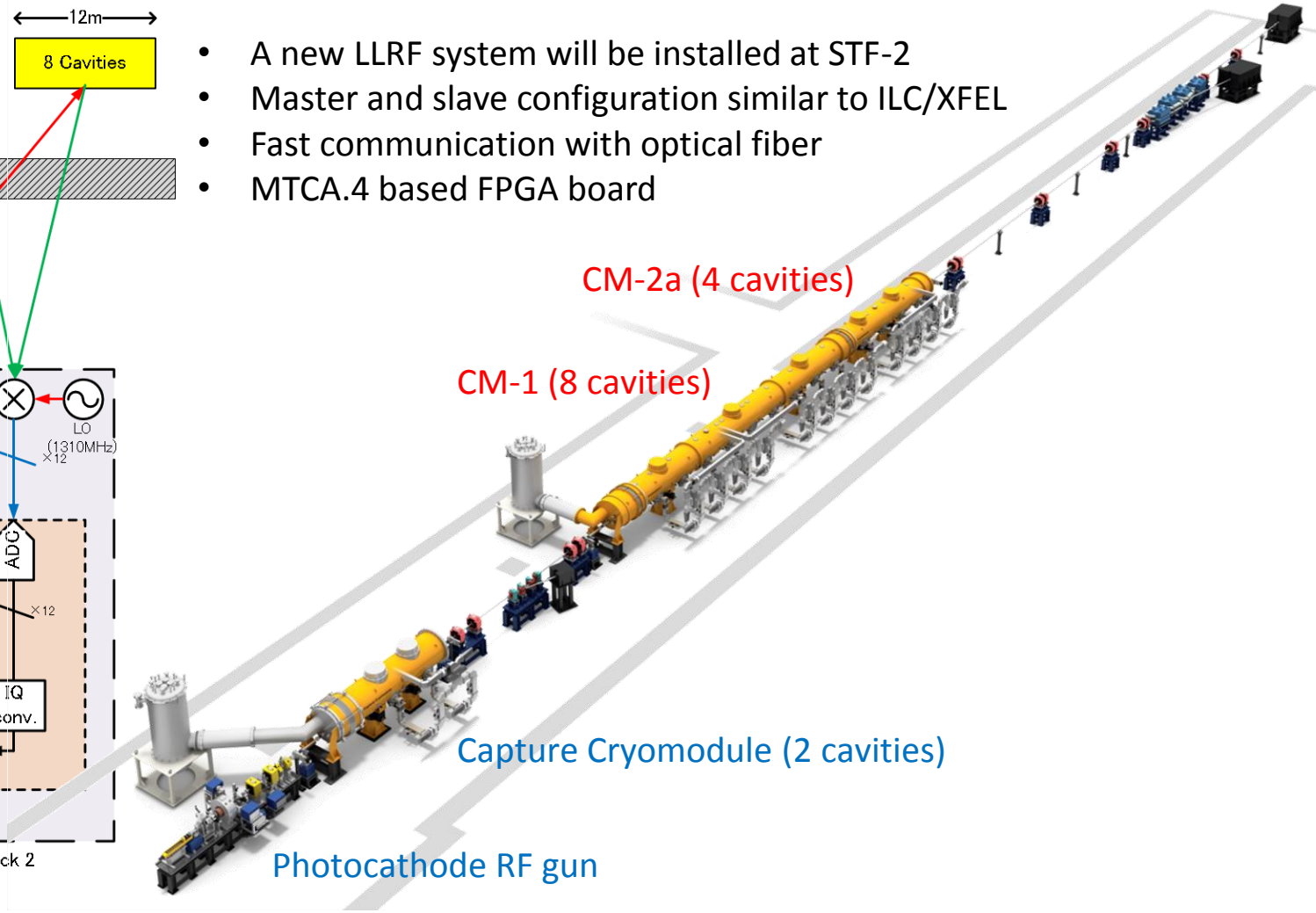
STF-2 consists of

- RF gun (~9 mA)
- Capture cryomodule (2 cavities)
- 12 cavities (CM-1, CM-2a)
- Additional 12 cavities (CM-2b, CM-3) by 2017

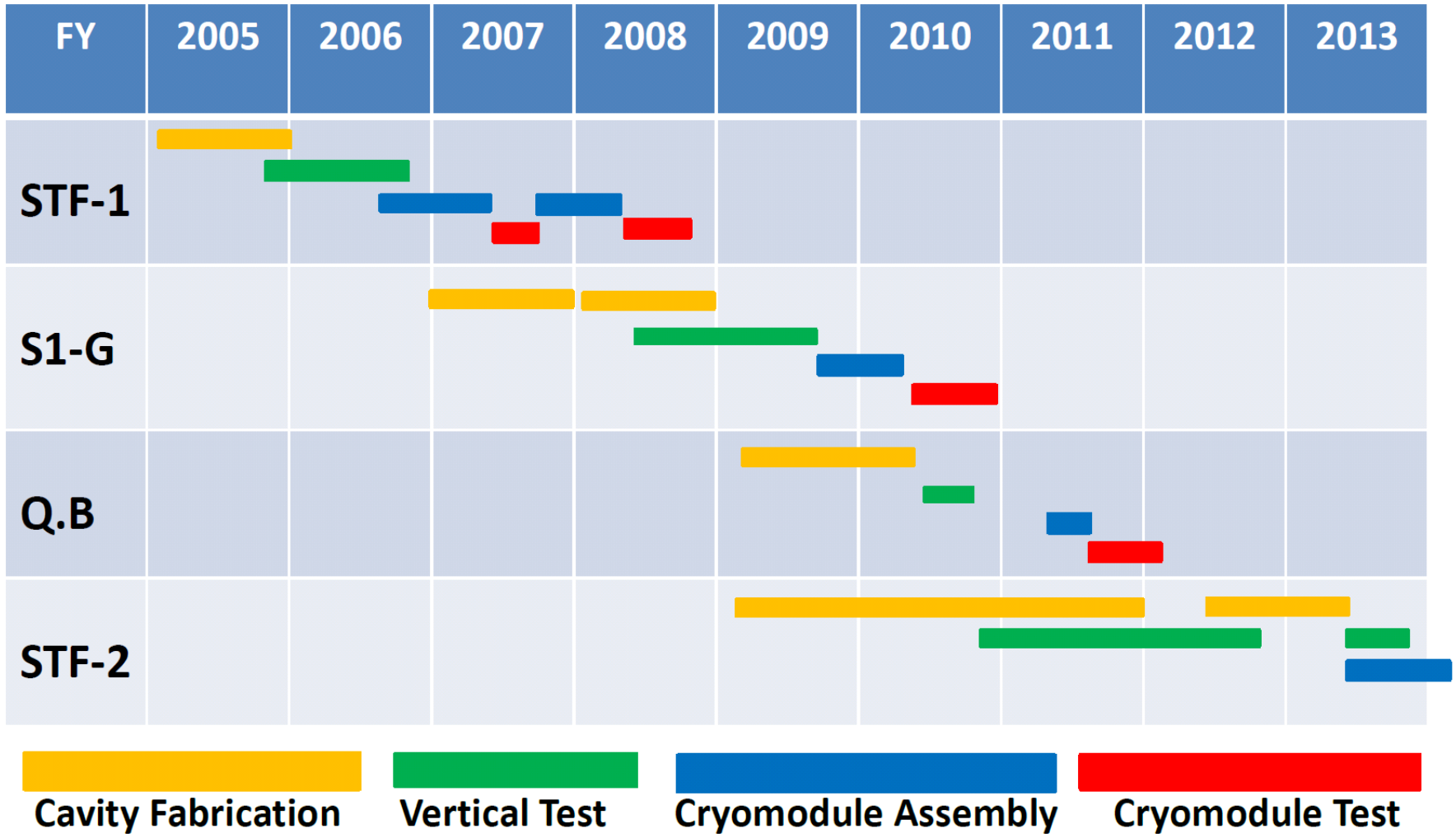
RF Configuration



- A new LLRF system will be installed at STF-2
- Master and slave configuration similar to ILC/XFEL
- Fast communication with optical fiber
- MTCA.4 based FPGA board



Time Schedule of STF-1, S1-Global, QB and STF-2



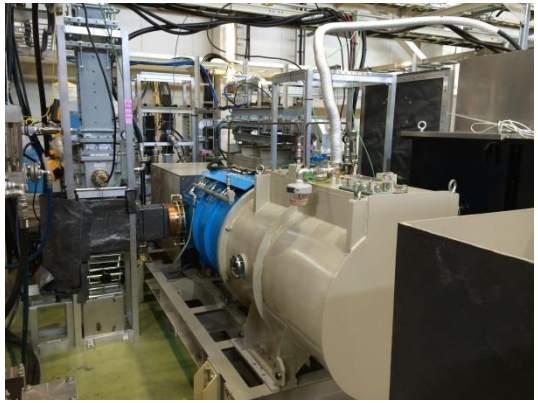
Schedule of STF-2

- 2014: Installation of cryomodule, RF system
- ~April 2015: High power test of 12 cavities
- ~September 2015: Beam operation

- 2016~2017 (?): Installation of additional 12 cavities

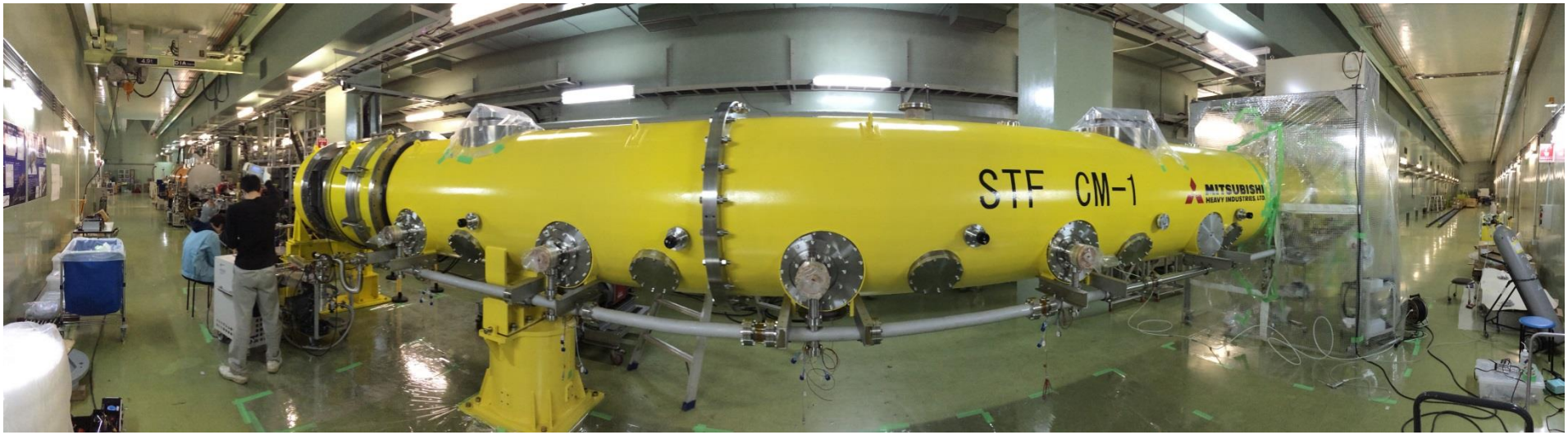
Pictures as of 2014/02/17 (Mon)

10 MW MBK *(ground floor)*



RF Gun and Capture Cryomodule *(accelerator tunnel)*

CM-1 *(accelerator tunnel)*



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Summary

- QB Project: RF Gun, 2 SCCs driven by single 800 kW klystron in DRFS scheme, beam energy up to 40 MeV
- Successful demonstration of high Q_L (2e7) operation with stabilities comparable to nominal operation
- First successful demonstration of an automated ILC-like PkQL operation with stabilities comparable to nominal operation
- STF-2: RF Gun, 2 SCCs in the CCM, 12 SCCs in CM-1 and CM-2a driven by a single 10 MW MBK, beam energy up to 418 MeV, beam operation from Sep 2015
- Upgrade 2016~2017 with additonal 12 SCCs

Questions?

Thank you very much for your attention!