Successful Beam Commissioning in STF-2 Cryomodules for ILC

Y. Yamamoto (KEK) on behalf of STF-2 beam commissioning group

Kirk

STF-2 Beam Commissioning Group

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KEK, Hiroshima Univ., Univ. of Tokyo

Outline

- ILC project and status
- STF and STF-2 project
- Construction of STF-2 accelerator
- Maximizing Accelerating Gradient
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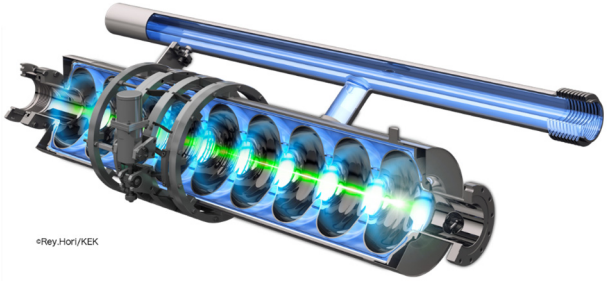
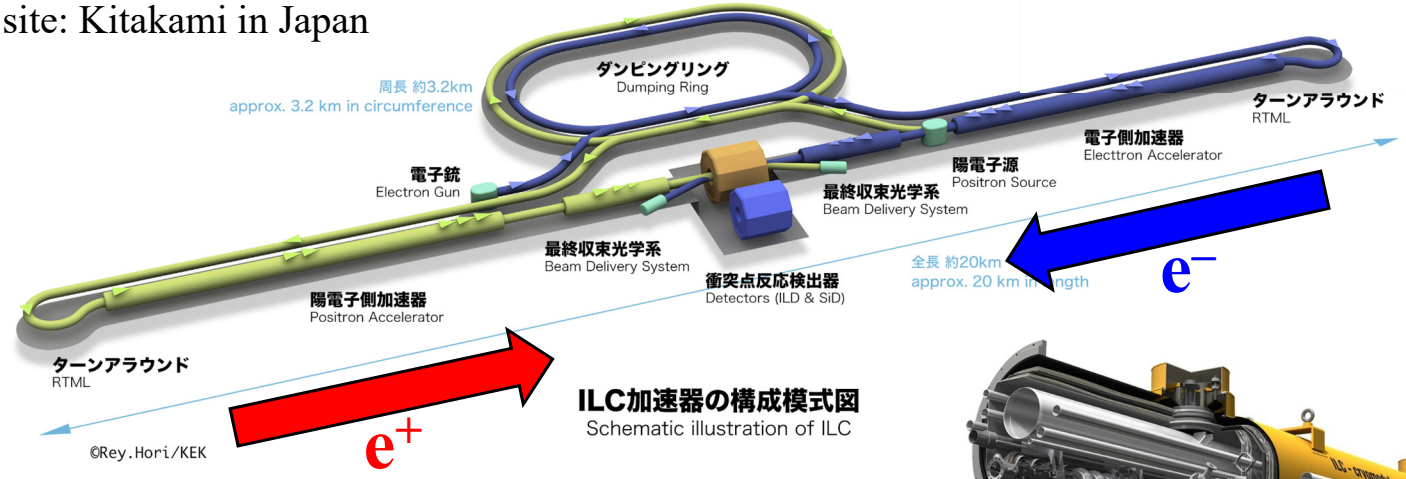
ILC project

- Higgs factory machine (250 GeV @E_{CM})
- Superconducting cavity/cryomodule technology as mass production
  - Based on TESLA technology
  - ~1000 Cryomodules (challenging number, but not impossible!)
- Nano beam technology
- Candidate site: Kitakami in Japan



岩手県一関市の資料をもとに作製



ILC加速器の構成模式図
Schematic illustration of ILC

ILC Spec.	E_{acc}	Q_0
Vertical Test	35 MV/m	0.8 x 10^{10}
Cryomodule test	31.5 MV/m	1.0 x 10^{10}

>90% (successful rate)

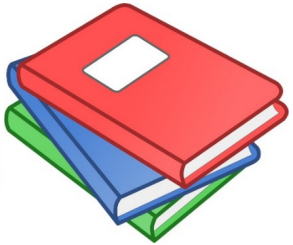
ILC Status (just recently)

Mar/2019
"Expressions of interest" by MEXT
ICFA released statement

Apr/2019
LC Community Meeting @Lausanne

May/2019
European Strategy Open Symposium @Granada
Int. WG established

Aug/2019
ICFA/LCB held in Toronto



Oct/2019
LCWS2019 held in Sendai/Japan

ILC Status (just recently)

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TOKYO 2020

TOKYO 2020
PARALYMPIC GAMES

Oct/201
LCWS2019 held in

Cost sharing

ion

Technical preparation

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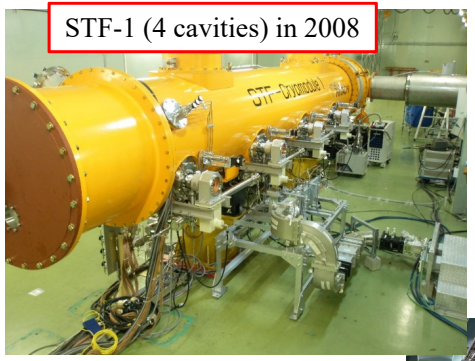
Superconducting RF Test Facility (STF) in KEK

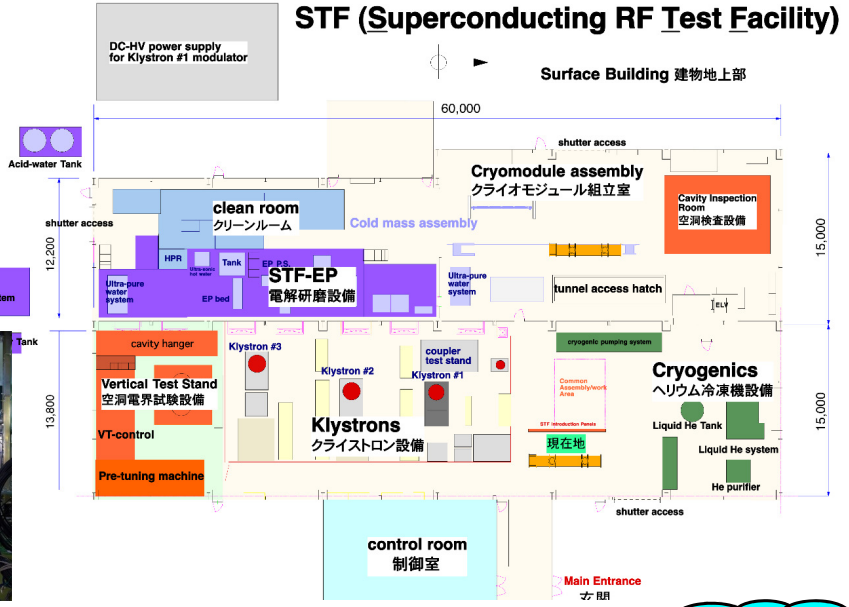
STF-1 (4 cavities) in 2008

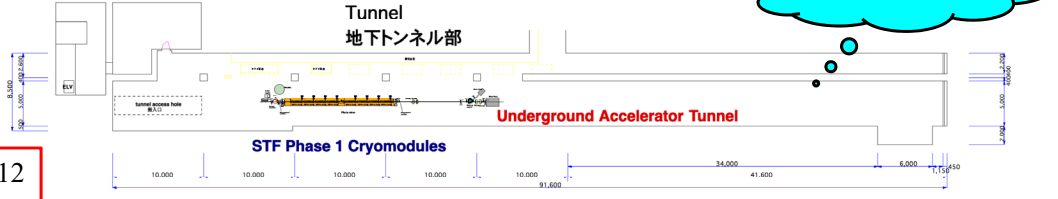


- Started from 2006
- Available for half size of CM
- Multi-beam klystron
- Cryogenics system
- EP system
- VT system

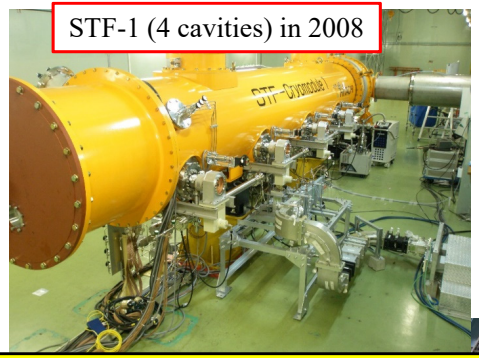
S1-Global (4+4 cavities) in 2010

Quantum Beam (2 cavities) in 2012
Capture CM in STF-2 accelerator





Superconducting RF Test Facility (STF) in KEK



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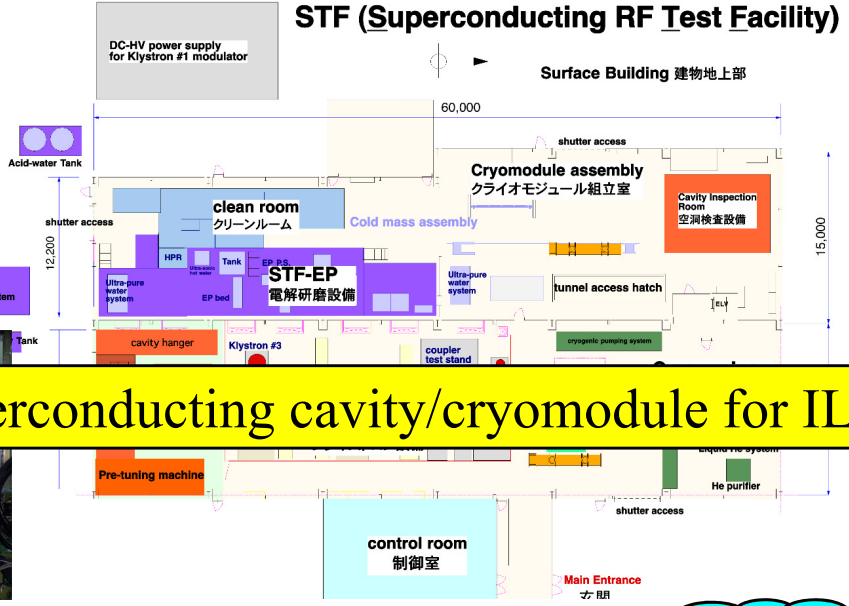
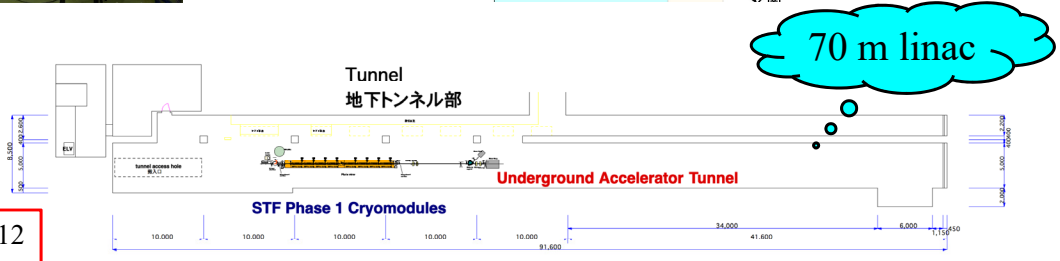


S1-Global (4+4 cavities) in 2010

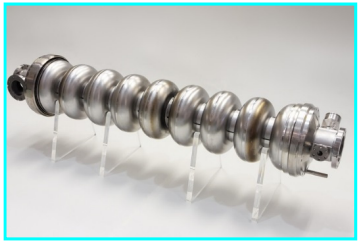
Purpose: Technology demonstration of superconducting cavity/cryomodule for ILC

Quantum Beam (2 cavities) in 2012
Capture CM in STF-2 accelerator

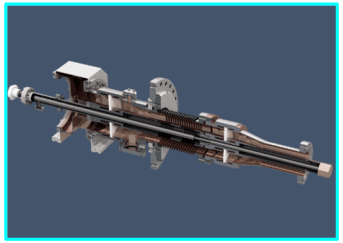


STF-2 project and STF-2 accelerator

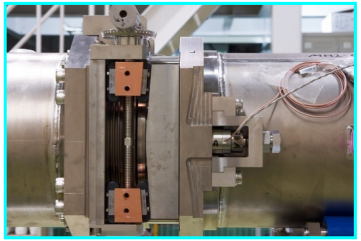
STF Cavity

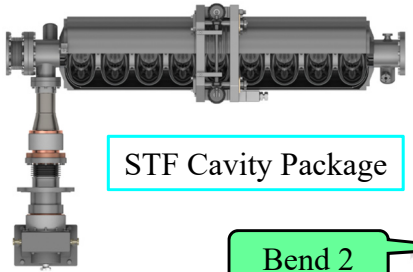


STF-II power coupler



Slide-jack tuner





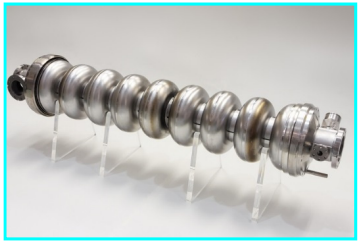
STF Cavity Package

Cooldown	Date	Content
1	Oct/2014 ~ Dec/2014	Low power test
2	Oct/2015 ~ Dec/2015	Single cavity operation, performance check
3	Sep/2016 ~ Nov/2016	Eight cavities operation, LFD and heat load meas., LLRF study
4	Jan/2019 ~ Mar/2019	Beam commissioning, Machine study

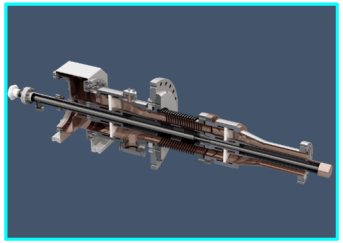
Operational condition
- RF: 1.65 msec/5 Hz (ILC/TDR)
- Temperature: 2K in liq. Helium
- As max. E_{acc} as possible for STF-2 CM

STF-2 project and STF-2 accelerator

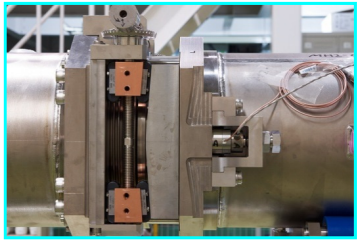
STF Cavity

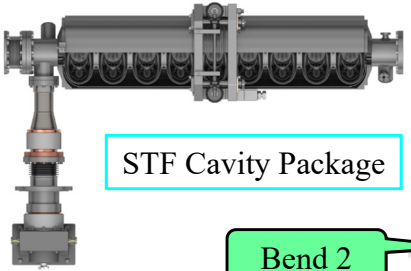


STF-II power coupler



Slide-jack tuner





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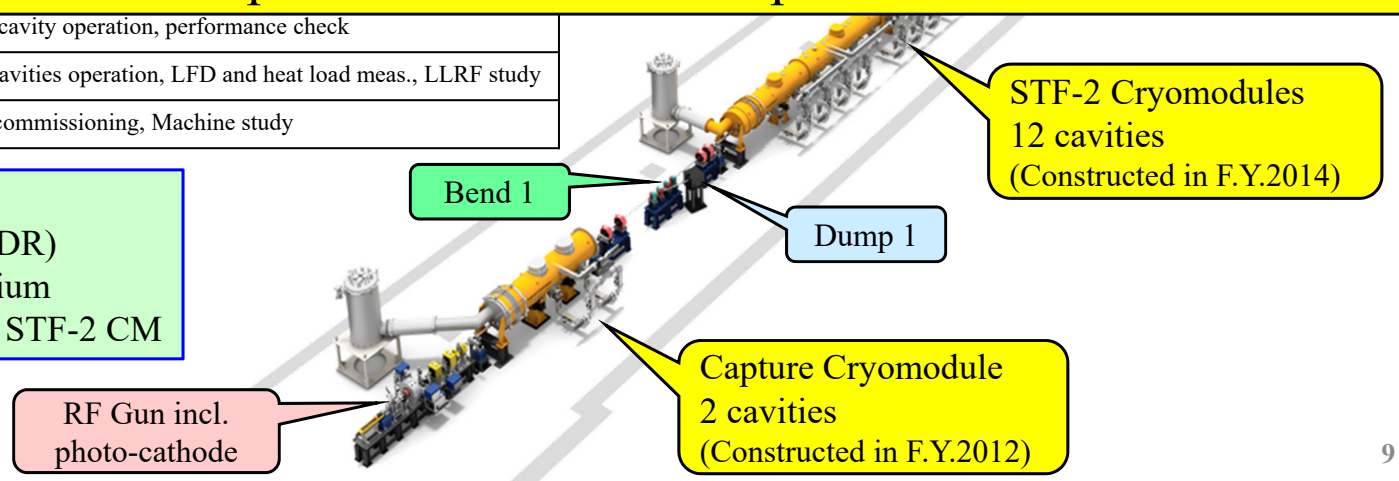
Purpose: Beam operation satisfied ILC specification

Operational condition
- RF: 1.65 msec/5 Hz (ILC/TDR)
- Temperature: 2K in liq. Helium
- As max. E_{acc} as possible for STF-2 CM



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Construction of STF-2 accelerator

Preparation for RF Gun operation

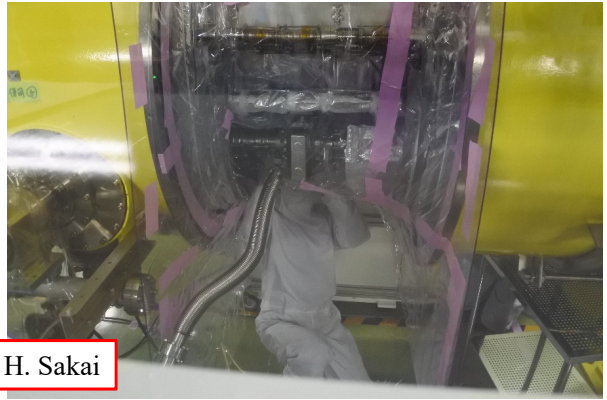
Installation of beam dump #2

Alignment work

Connection of beamlines

TUP104 by H. Sakai

Beampipe reconnection

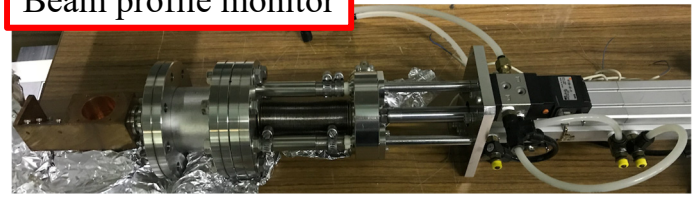


Beamline construction completed!

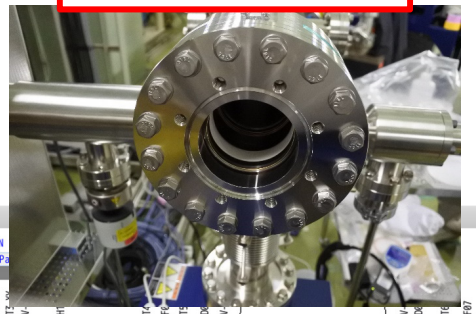
Jan/2019

Beamline components in STF-2 accelerator

Beam profile monitor

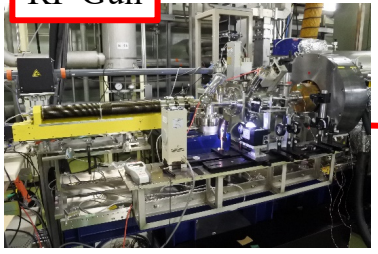


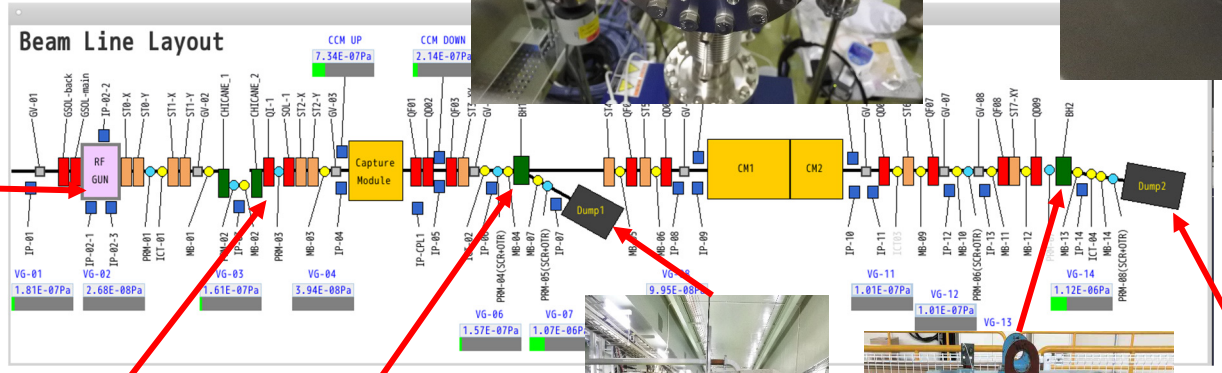
Beam current monitor



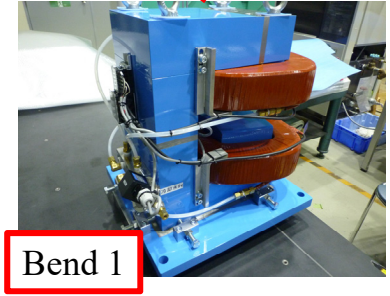
Beam position monitor

RF Gun





Chicane & Solenoid

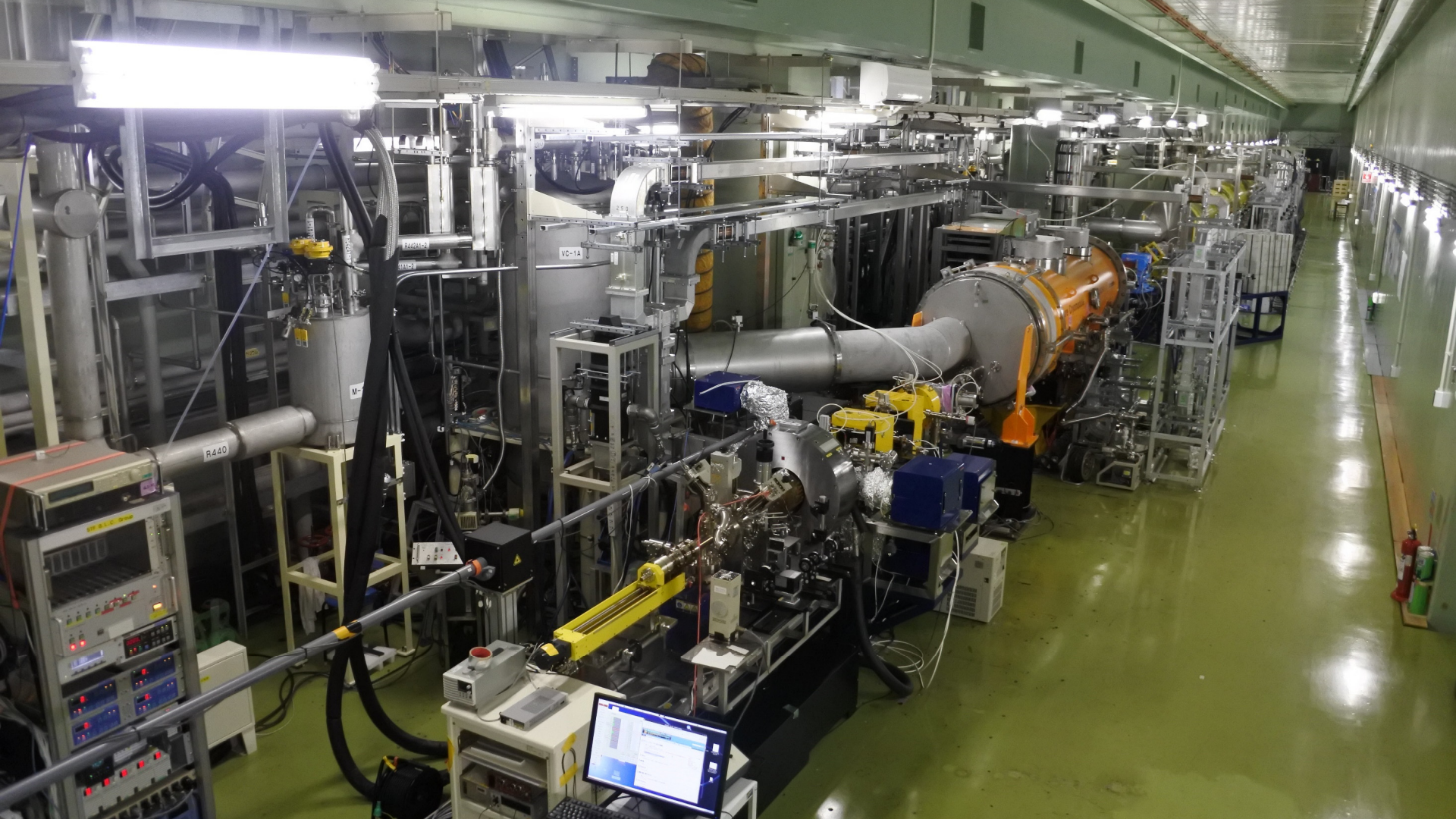


Bend 1

Dump 1

Bend 2

Dump 2


R440
VC-1A

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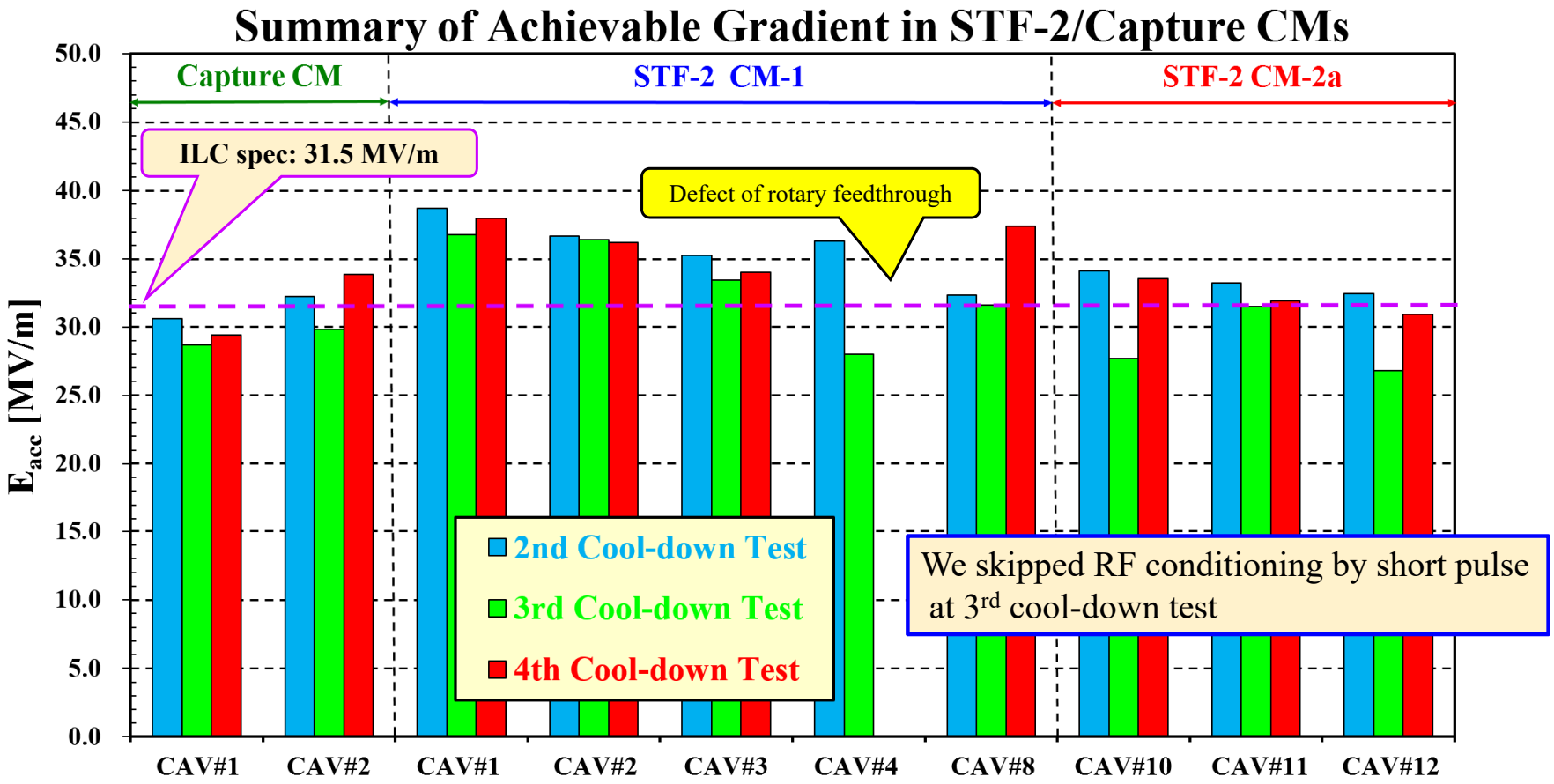
Ready for beam operation

We skipped RF conditioning with short pulse in 3rd cooldown test, because schedule was very tight!

- ✓Tuning cavity frequency
- ✓RF conditioning with short pulse (900 + 100 μs)
- ✓RF conditioning with long pulse (900 + 800 μs)
- ✓Fine tuning by piezo ($\Delta f \sim \pm 50$ Hz)
- ✓Closed-loop operation
- ✓RF Gun/Laser system operation
- ✓Beam commissioning

Summary of Accelerating Gradient in STF-2 CMs



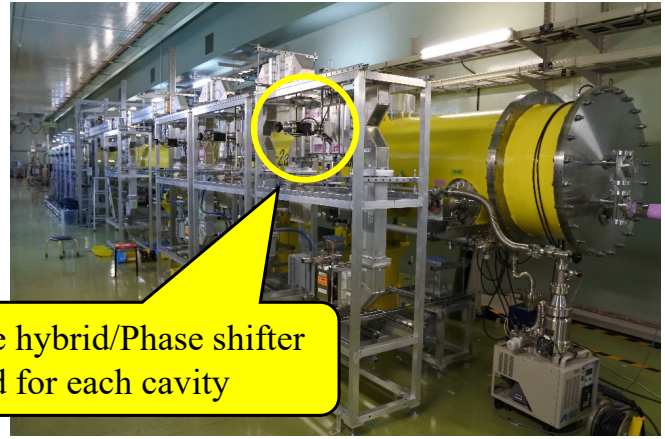
CAV#5, #6, #7, and #9 are not used, because waveguide system is not available

Maximizing accelerating gradient

Power distribution adjustment by variable hybrid

PHASE SHIFTER (CM1,CM2a) — REMOTE

CH	busy	Position monitor	Position set		Position step			limit status ccw	limit status cw	Digital Limit ccw	Digital Limit cw	Digital Limit enable	HW Limit Enable ccw	HW Limit Enable cw	HW Limit 接点 ccw	HW Limit 接点 cw	speed
01:CAV1 HB		-291	0	STOP	10	+	-			0	0	OFF	ON	ON	N.C	N.C	High
02:CAV2 HB		-3327	0	STOP	30	+	-			0	0	OFF	ON	ON	N.C	N.C	High
03:CAV3 HB		418	0	STOP	10	+	-			0	0	OFF	ON	ON	N.C	N.C	High
04:CAV4 HB		-1548	0	STOP	0	+	-			0	0	OFF	ON	ON	N.C	N.C	High
05:CAV1 PS		-140531	0	STOP	5000	+	-			0	0	OFF	ON	ON	N.C	N.C	High
06:CAV2 PS		-99329	-99329	STOP	40000	+	-			0	0	OFF	ON	ON	N.C	N.C	High
07:CAV3 PS		-42759	-22759	STOP	5000	+	-			0	0	OFF	ON	ON	N.C	N.C	High
08:CAV4 PS		60373	0	STOP	0	+	-			0	0	OFF	ON	ON	N.C	N.C	High
09 CAV8 HB		-2070	0	STOP	10	+	-			0	0	OFF	ON	ON	N.C	N.C	High
10:CAV10 HB		-275	0	STOP	10	+	-			0	0	OFF	ON	ON	N.C	N.C	High
11:CAV11 HB		-4340	0	STOP	10	+	-			0	0	OFF	ON	ON	N.C	N.C	High
12:CAV12 HB		3900	0	STOP	50	+	-			0	0	OFF	ON	ON	N.C	N.C	High
13:CAV8 PS		-62447	-62447	STOP	10000	+	-			0	0	OFF	ON	ON	N.C	N.C	High
14:CAV10 PS		6233	6233	STOP	40000	+	-			0	0	OFF	ON	ON	N.C	N.C	High
15:CAV11 PS		31290	-8710	STOP	20000	+	-			0	0	OFF	ON	ON	N.C	N.C	High
16:CAV12 PS		-58844	0	STOP	20000	+	-			0	0	OFF	ON	ON	N.C	N.C	High



Variable hybrid/Phase shifter attached for each cavity

Best parameters after adjustment

Cavity Monitor (CM1,CM2a) — 2019/03/25 16:01:20

	#1	#2	#3	#4	#8	#10	#11	#12
Pf (W):	86.63kW	87.01kW	70.42kW	41.71kW	83.97kW	63.13kW	56.69kW	51.13kW
Pf Eacc(MV/m):	39.25	39.00	35.42	0.00	37.50	33.92	32.21	30.25
Pt(W):	14.06W	10.09W	7.33W	469.67uW	12.97W	7.99W	9.46W	6.46W
Pt Eacc(MV/m):	36.71	35.41	33.57	0.20	36.46	32.69	31.42	30.32
Electron(mV):	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Arc(mV):	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

He flow rate

2K:	55.225 m³/hour
5K:	0.000 m³/hour

Heat Load

2K:	64.429 W

He pressure

2K:	3.01 kPa
4K:	124.41 kPa

He level

4K:	51.29 %
2K:	54.41 %
CM2a End:	22.50 %

Vacuum

Capture Upstream	5.83E-7 Pa
Capture Downstream	2.04E-7 Pa
Capture Input coupler	3.70E-7 Pa
Capture Inner conductor	1.27E-8 Pa
CM1 Upstream	2.19E-7 Pa
CM1 Input coupler	2.08E-6 Pa
CM1 Inner conductor	2.30E-8 Pa
CM2a Downstream	2.31E-7 Pa
CM2a Input coupler	2.59E-6 Pa
CM2a Inner conductor	4.05E-8 Pa

Power

KLY3 上 Pf	2.36MW
KLY3 下 Pf	2.31MW
Pt Eacc sum	236.57MV/m
Pt Eacc ave.	33.80MV/m
Input Volt	3.15V
Feedback	ON

Temperature

4K Pot:	4.64 K
2K Pot:	1.69 K
80K anchor#1:	124.350 K
80K anchor#2:	130.250 K

Radiation

	Up	Mid	Down
High:	935.390 uSv/h	979.485 uSv/h	796.114 uSv/h
Low:	4.607 mSv/h	8.194 mSv/h	25.183 mSv/h

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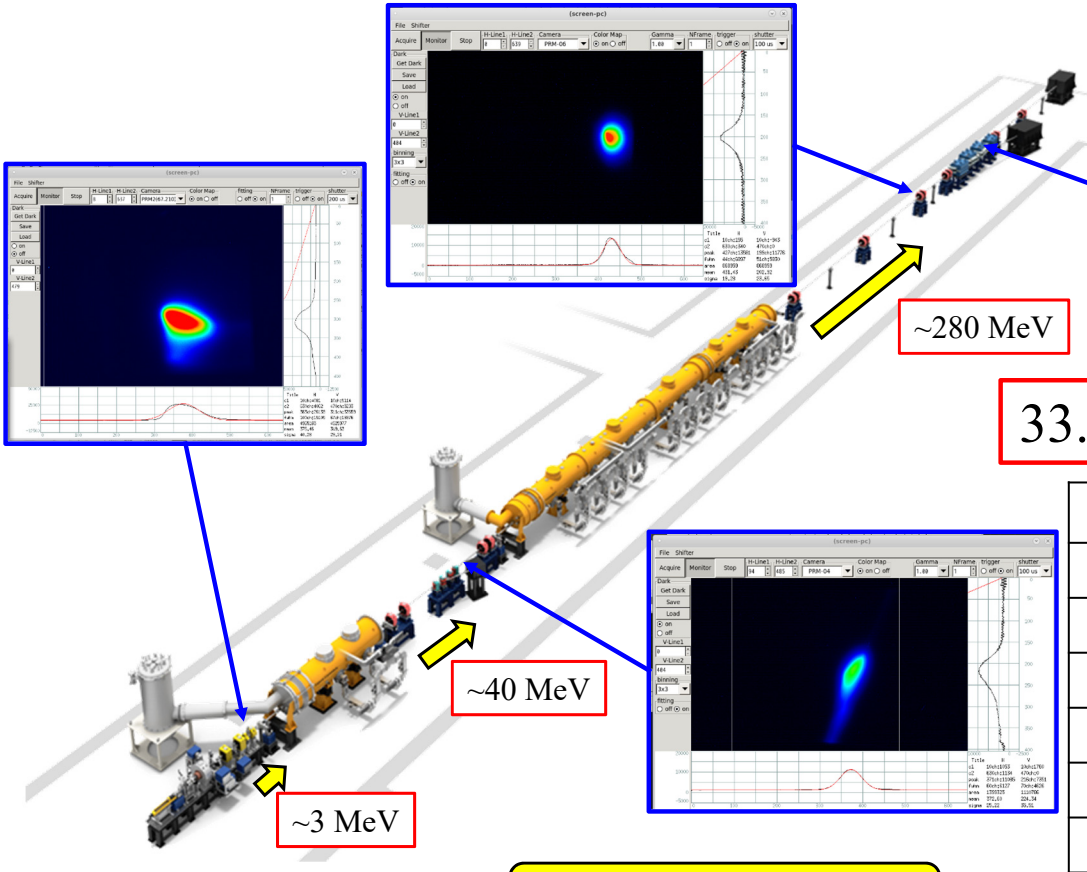
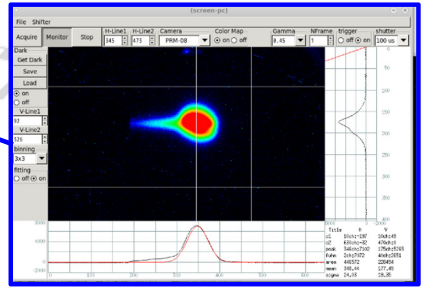
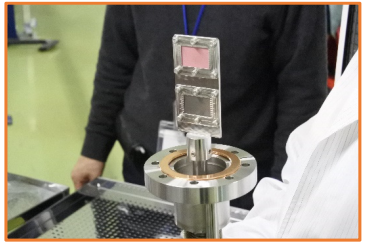
Accelerating gradient estimated from beam energy





Beam profile monitor



33.1 MV/m (averaging for 7 cavities)

Achievements in STF-2 beam commissioning	
Beam energy	280 MeV
Beam power	75 W
Beam current	275 nA
Charge	55 nC/pulse
# of bunches	1000 / pulse
Average gradient estimated from beam energy	33.1 MV/m
Average gradient measured by power meter	33.8 MV/m

Consistent within 2%!

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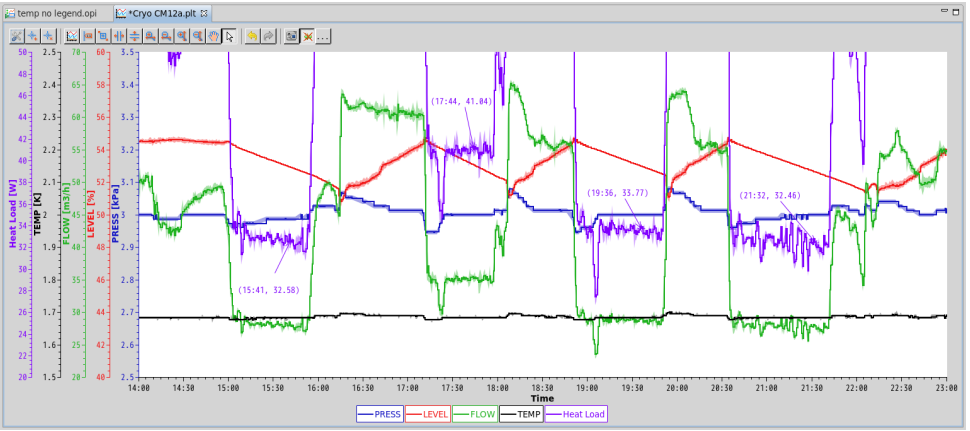
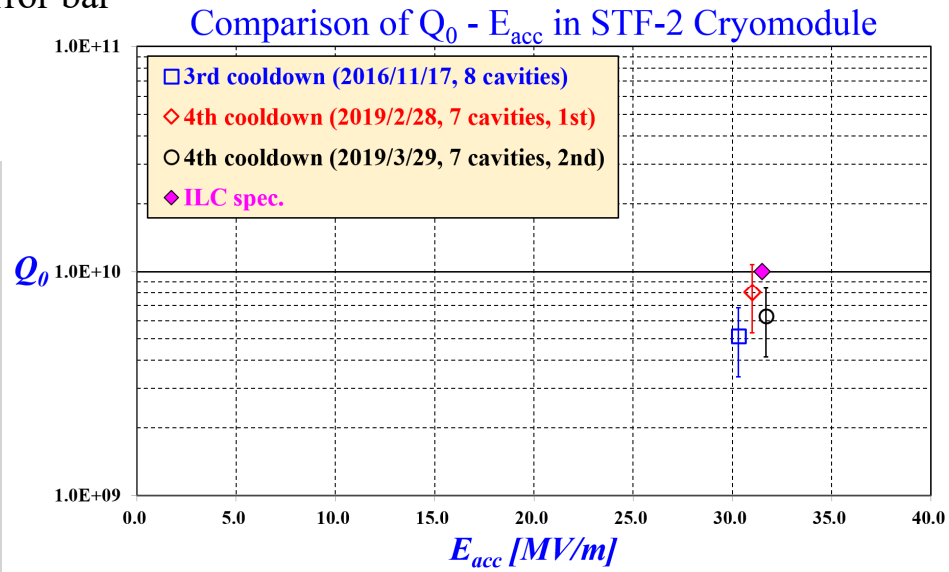
Dynamic heat load in STF-2 CM

- Estimated from helium mass flow rate
- Meas. Flow: Static → Dynamic (cavity) → Dynamic (coupler) → Static
- Systematic error: 20~30% (RF duty < 1%)
- Well-reproducible for three measurements
- Consistent with ILC spec. within error bar

static | dynamic (cavity) | dynamic (coupler) | static





ILC spec.	E_{acc}	Q_0
Cryomodule test	31.5 MV/m	1.0×10^{10}

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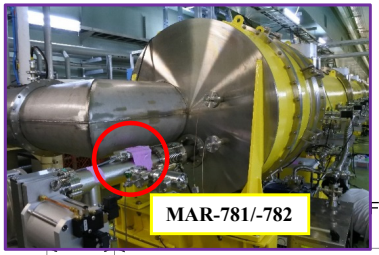
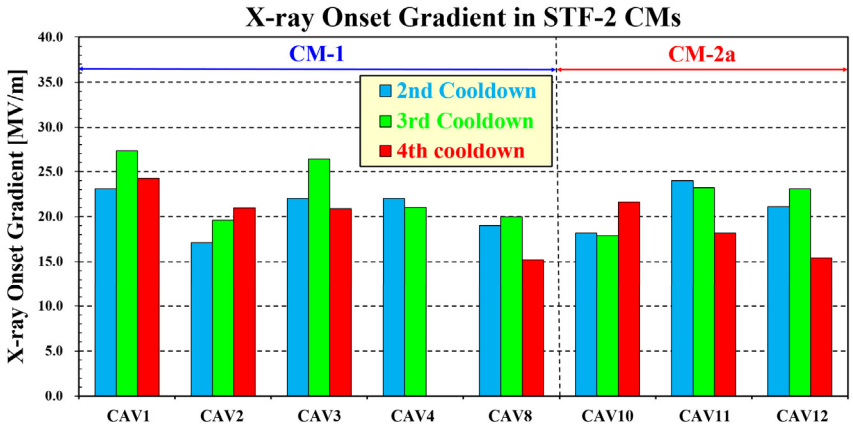
- Troubles, Next step, Summary

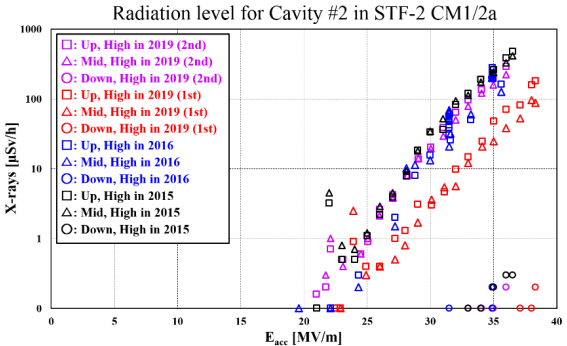
History of radiation level

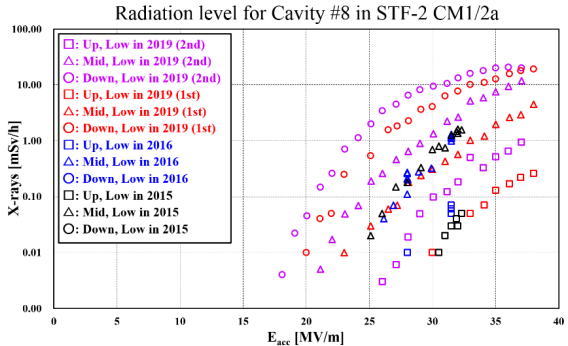


High sensitivity detector

Low sensitivity detector







- Some cavities had higher radiation level in this test
- One cavity had a little bit higher after beam commissioning
- Other cavities had same level

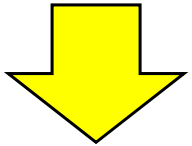
Outline

- ILC project and status
- STF and STF-2 project
- Construction of STF-2 accelerator
- Maximizing Accelerating Gradient
- Comparison of cavity voltage and beam energy
- Heat load measurement
- History of Radiation Level
- Troubles, Next step, Summary

Troubles in this commissioning

- Cooling water system down due to defect of pumping system (solved)
- IEGT fault in modulator for multi-beam klystron (solved)
- Spark in waveguide system for multi-beam klystron (solved)
- Breakdown of resistor in DRFS modulator (solved)
- Temporary (twice) warm-up/cool-down by cryogenic system fault (solved)
- Not worked tuner system for CAV#4 (solved)
- QF/QD cable mismatch (solved)
- Cavity quench after GV opened (solved)
- Worse vacuum at upstream beamline of Capture cryomodule (should be baked)

We lost 5 days due to these troubles!



Every trouble was solved, but some maintenance work is necessary till next beam operation

Towards next beam commissioning in F.Y. 2020

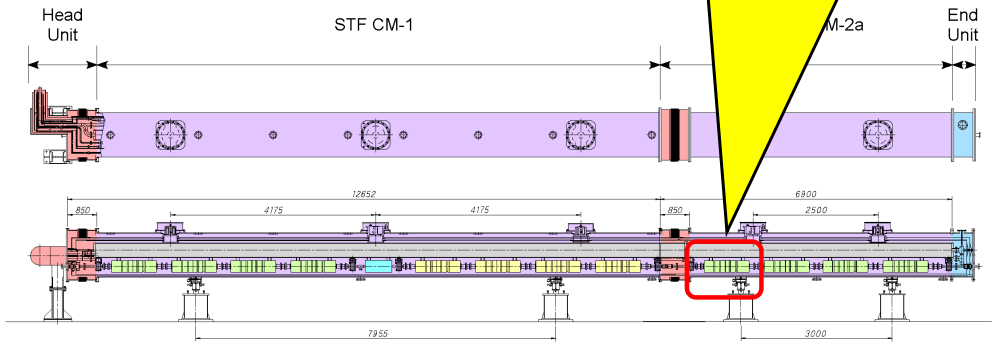
- Cavity exchange in CM2a
- Laser system upgrade (not easy!)
- Improvement of beam dump system
- Power upgrade for RF Gun
- RF pulse data storage in last 30 sec for CM1/2a
- IEGT board for klystron #3
- Power control system upgrade for DRFS
- Pumping system repair for cryogenics
- Maintenance for cooling water system

Challenging work for us (first time!)

Cause for very low beam current

Request from radiation security center

New surface treatment technology
- N-infusion
- Low temp. baking



Summary

- **Beamline in STF-2 accelerator was successfully constructed**
- **Accelerating gradient of 33.1 MV/m estimated from beam energy was achieved!**
- **Heat load measurement was well-reproducibly done, consistent with ILC spec.**
- **Radiation level increased for some cavities, but performance recovered**
- **Defect of ultra-high vacuum rotary feedthrough for CAV#4 tuner system**
- **Cavity exchange in CM2a will be done in F.Y. 2019**

Announcement

LCWS2019 will be held in Sendai!

http://epx.phys.tohoku.ac.jp/LCWS2019/

Thank you very much for your attention!

Acknowledgement: K. Harada, M. Tawada, M. Masuzawa, S. Nagahashi, M. Asano, S. Imada, H. Yamada, T. Tainaka, S. Ishihara, K. Ishimoto, N. Numata, K. Tsutsumi, T. Okada, M, Iitake, A. Hayakawa, R. Terajima