Report of SRF 2021

Kenji Saito
SRF2021 Conference Chair

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SRF2021
Very Successful Virtual Conference

- SRF2021: Held from June 28th to July 2nd, 2021 hosted by MSU/FRIB
  - Tutorial, June 23 – 25, 76 participants
  - Student poser session, June 27 (Sunday), 47 posters, the best poster prize
  - SRF2021 virtual conference due to COVID-19 pandemic, registrations: 416
  - Very successful, even our first experience. Visit SRF2021 website https://indico.frib.msu.edu/event/38/
- 5 hours working time due to global time zoon
  - 3 hour oral invitation session, Monday – Friday, total 43 invited talks
  - 1 hour poster session, Monday – Thursday,
  - 1 hour discussion time with invited speaker
- FRIB live tour, virtual tours for other labs: KEK, Saclay, BNL, LCLS-II(SLAC) on Friday after closing
- 230 posters including student posters (47), to publish the proceedings
- **Chair:**

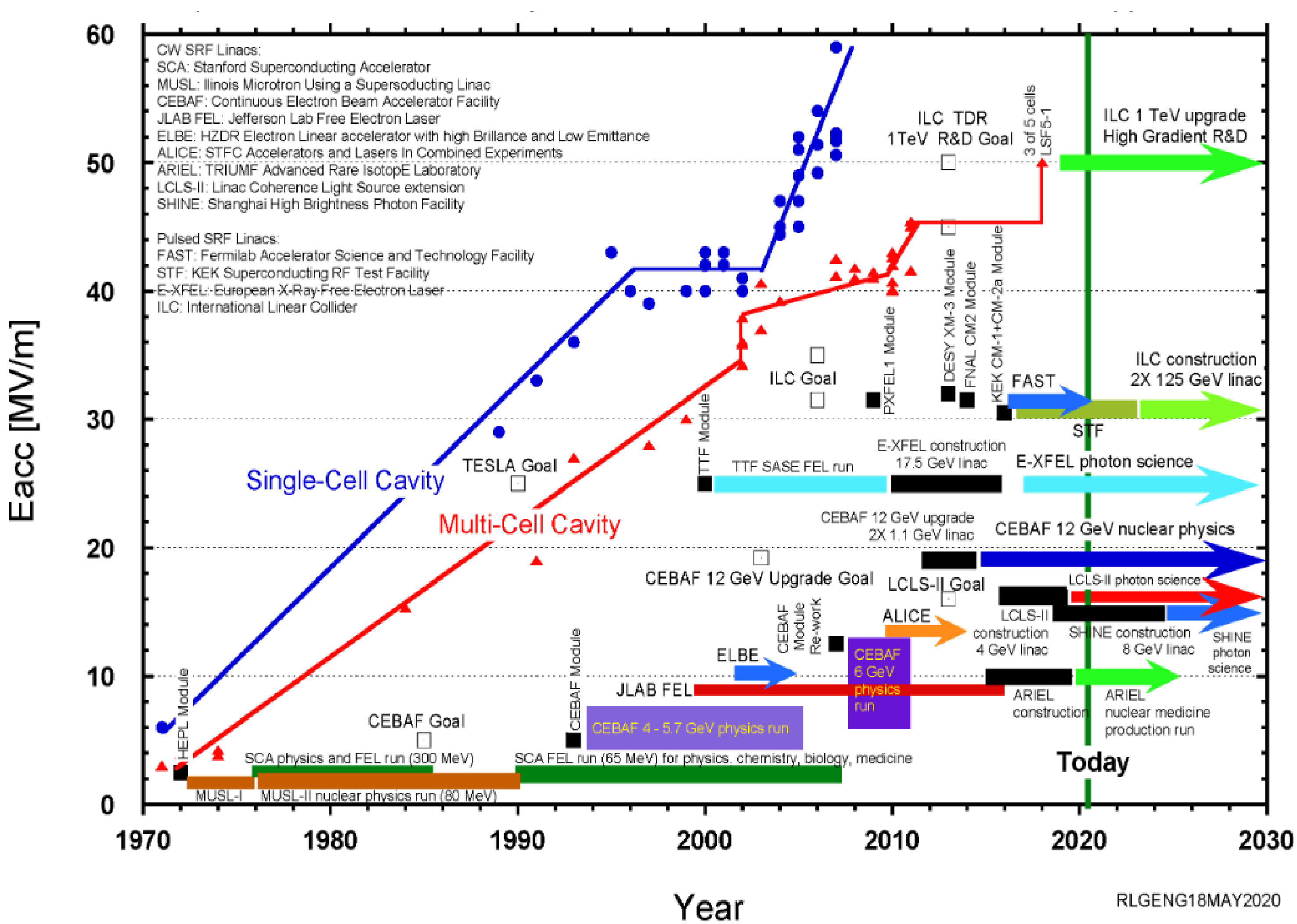
  Conference Chair/Science Program Chair: Kenji Saito (MSU/NSCL)

  Local chair Ting Xu (FRIB),

  Alexa Allen (IT technology/Admin), Anastasia Lesage (JACoW/Admin), Walter Hartung, Laura Popielarski, John Popielarski, Sang-hoon Kim (FRIB live tour), Chang Wei, Hiroyuki Ao, Sam Miller, Chris Compton, Peter Ostroumov, Wei Chang, Yoshishige Yamazaki and Kenji Saito

Big Picture of SRF Community

Cavity performance improvement continues very steadily

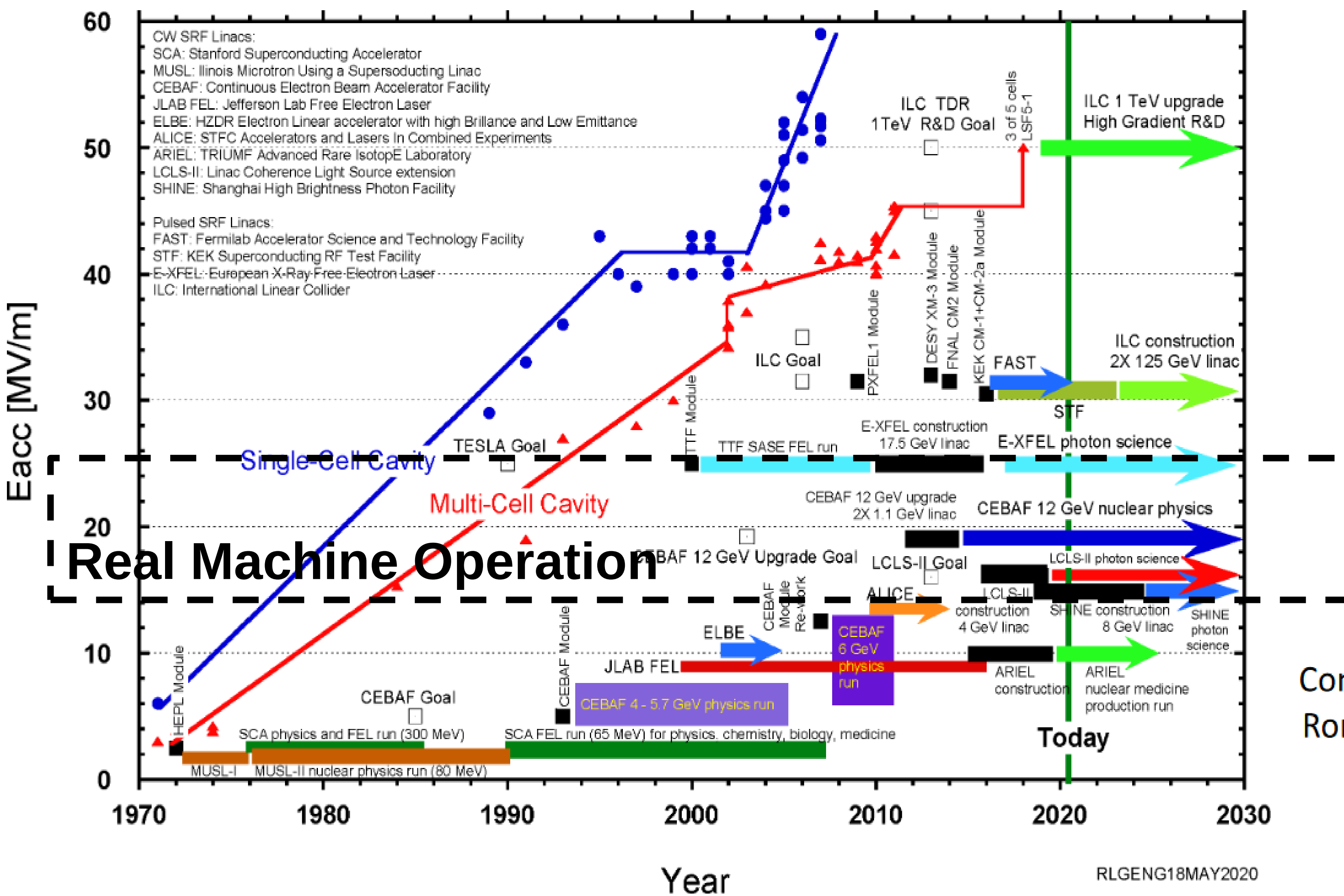


Composed by Rong-Li Geng

Great Advance of SRF since Last Decade

- Continue steady SRF performance improvement, HQ/HG
  - Understanding of performance limitation for Nb cavity
  - New material beyond Nb
- Enhance the reliability in fabrication and also explore the cost-effective way
- Use SRF from low frequency to higher frequency
  - Low/medium/high beta structures for heavy ion accelerators
- Use SRF from injection to acceleration structures, every where
  - SRF-gun, for electron accelerator
- Explore more commercial applications
  - 4K operation using Nb_3Sn cavity
  - ERL

Machine Operation at Half of The Potential



Composed by Rong-Li Geng

SRF Future Scope

- Push up the operational performance in real machines
  - Understanding of causes of the limitation
  - Lessons learned from the existing machine operations
  - Develop in-situ cleaning technologies against SRF performance degradation in the machines
    - »Plasma cleaning
    - »Helium processing
    - »Dust control
- R&D of new material beyond Nb

List of the Highlights in SRF 2021

H-1: SRF is a mature technology in the accelerator projects, continue the large scale project constructions, SRF community is very busy.
FRIB, RAON, PIP-II, ESS, LCLS-II, LCLS-II HE…

H-2: Rapid global expanding
- India, In-kind cryomodule production for PIP-II
- Poland, PolFEL project, 185 MeV SRF linac
- 13 countries to have potential SRF cryomodule production, now

H-3: Established high gradient cryomodule production for CW medium field (16MV/m) operation by N-doping

H-4: Demonstrated higher gradient cryomodule for CW operation (23MV/m) by upgraded N-doping + cold EP, LCLS-II HE

H-5: Demonstration of ILC cryomodule pulse beam operation at 33 MV/m @Qo=0.8E10, at STF KEK

H-6: Many lessons learned from the existing machine operational experiences, and developed in-situ cleaning

XFEL, CEBAF-12GeV, RIKEN, SNS, CAFE ……

List of the Highlights in SRF 2021, continued

H-7: R&D to enhance the fabrication reliability and reduce the cost

- High speed temperature mapping system
- X-ray tomography
- LG/MG cavity, mid-T baking (Oxygen doping)

H-8: Commercial application

- ERL at ZDB, S-DALINAC at Darmstadt, cERL at KEK

It's time to consider the ERL technology for ILC to mitigate the beam dump issue and enhance the green policy

- Conduction cooling with Nb_3Sn cavity

H-9: New concept for ILC upgrade to 2 - 3 GeV

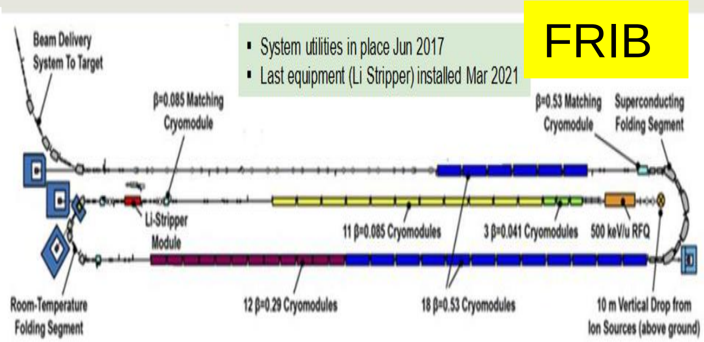
- Travelling wave structure

H-10: SRF Gun current status

H-11: Many R&Ds on niobium and beyond Nb

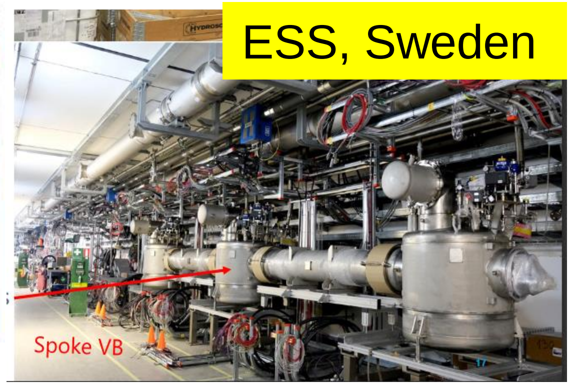
- Oxygen doping
- Nb_3Sn, MgB_2, film cavity by SIS,…..

H-1: SRF is a mature technology in the accelerator projects, continue the large scale project constructions, SRF community is very busy

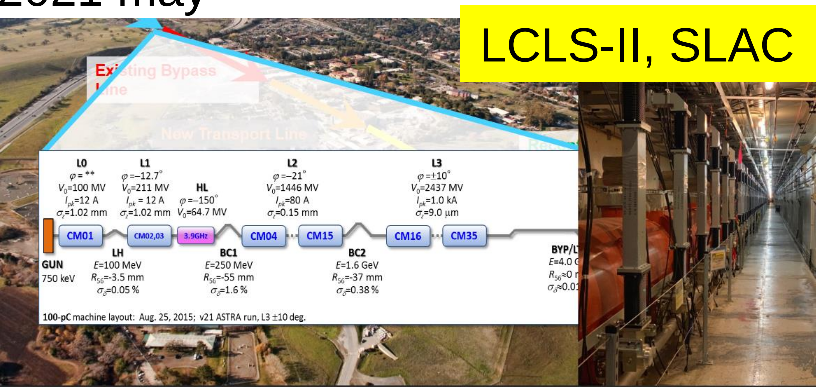


SRF heavy ion beam accelerator, 80.5MHz QWRs, 322 HWRs Driver SRF LINAC completed 2021 may

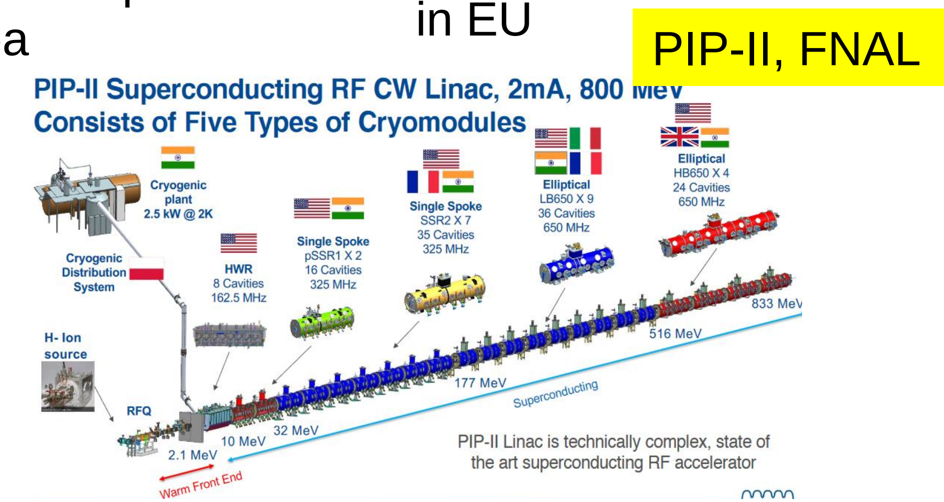
Simulate to FRIB, 80.5MHz QWRs, 322 HWRs, First phase to be completed in end 2025, Korea



Ongoing 2GeV SRF proton machine for SNS in EU



Electron SRF XFEL machine at SLAC, 1.3GHz ILC type 9-cell 330 cavities, to start beam commissioning from Sep. 2021

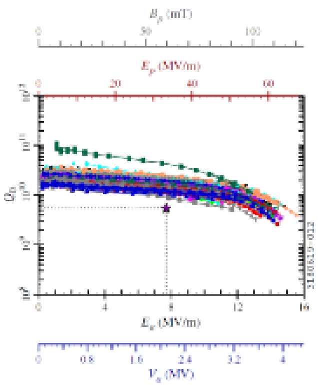


Ongoing project at FNAL, 1.2MW @120 GeV proton machine for a world-class neutrino program

Cryomodule Performance In Linac

- Cavity performance tracked: cavity test (VTA); cryomodule test (bunker); linac tunnel. No Q_0 degradation observed.

VTA Q_0 measurement example: β = 0.29 HWRs

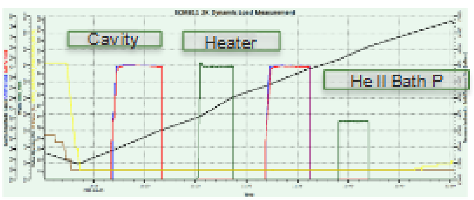


Design goal: LS2 dynamic load ≤1 kW at 2 K

Bunker tests: Q_0 was measured by *dP/dt* of He-II; benchmarked with heater

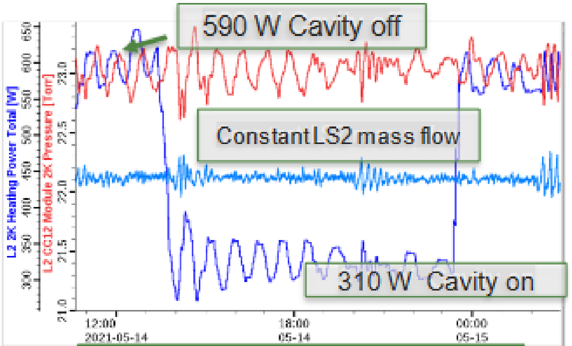
CM Type	CM Tested	Q_0 in CM at 2K: Spec	Measured*	Heat load** [W]
0.29 HWR	12	5.5E+09	1.9 E+10	1.0
0.53 HWR	17	7.6E+09	2.5 E+10	2.4

* Average of tested cryomodules
** Dynamic heat load per cavity



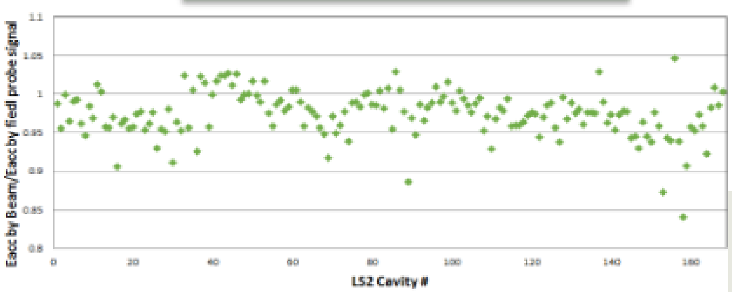
Bunker tests indicate 302 W dynamic load for LS2

Tunnel: dynamic load was obtained with heater power to compensate RF off with constant 2 K flow



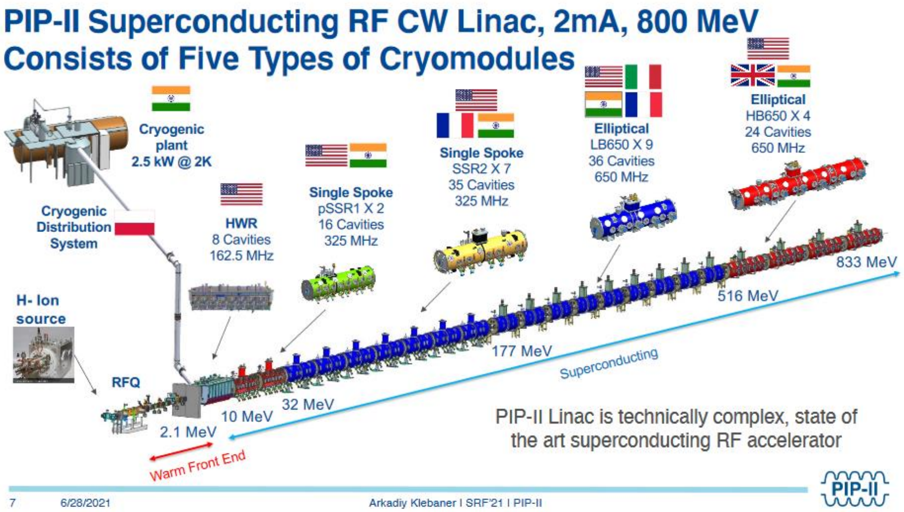
LS2 total dynamic heat load based on compensation heater is 280 W

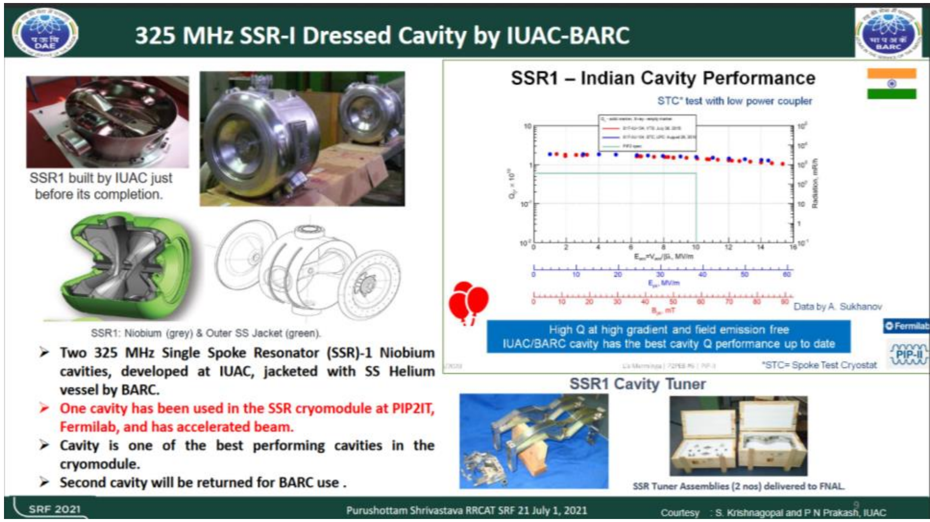
- Cavity field measured from RF and from beam are generally in good agreement. BPM signal has higher noise to signal ratio toward end of LS2.

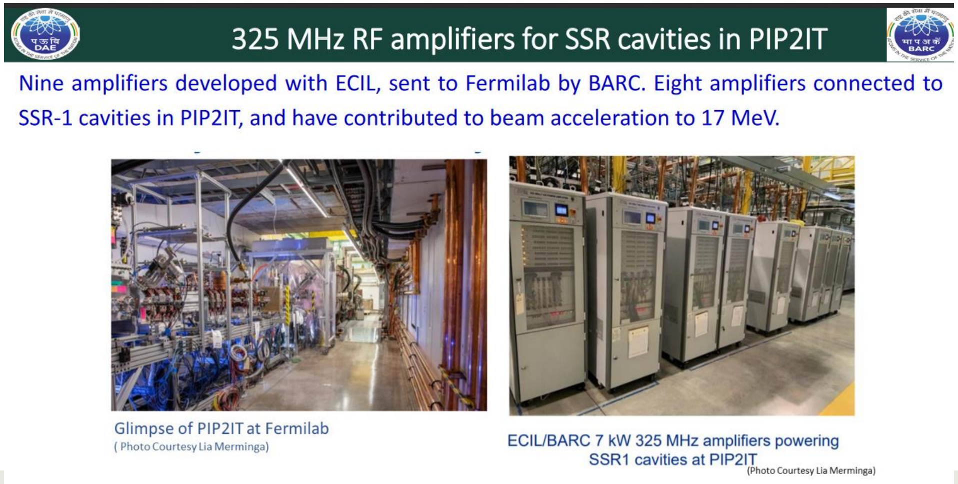


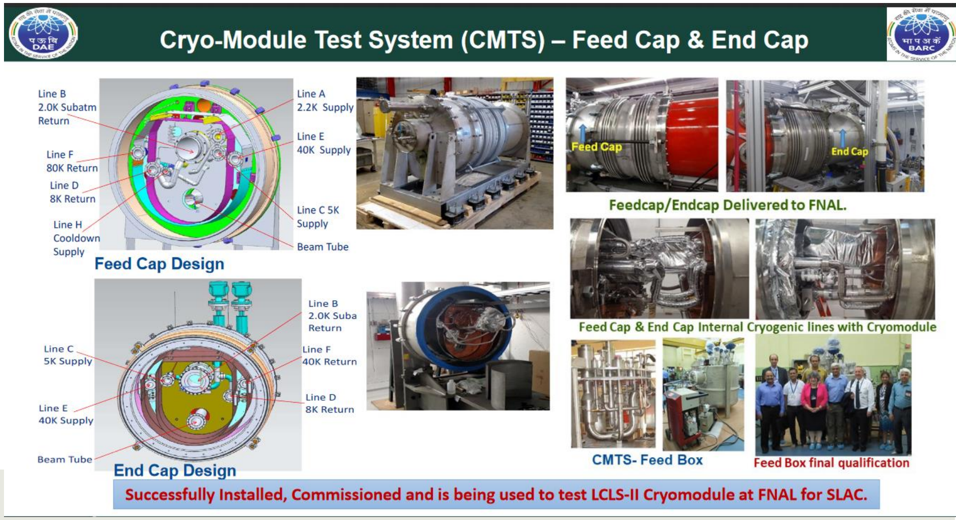
H-2: Rapid global expanding
Example: India, In-kind cryomodule production for PIP-II

THOTEV03, P. Shrivastava, RRCAT









FRIB Facility for Rare Isotope Beams
U.S. Department of Energy Office of Science
Michigan State University

H-3: Established high gradient cryomodule production for CW medium field (16 MV/m) operation by N-doping

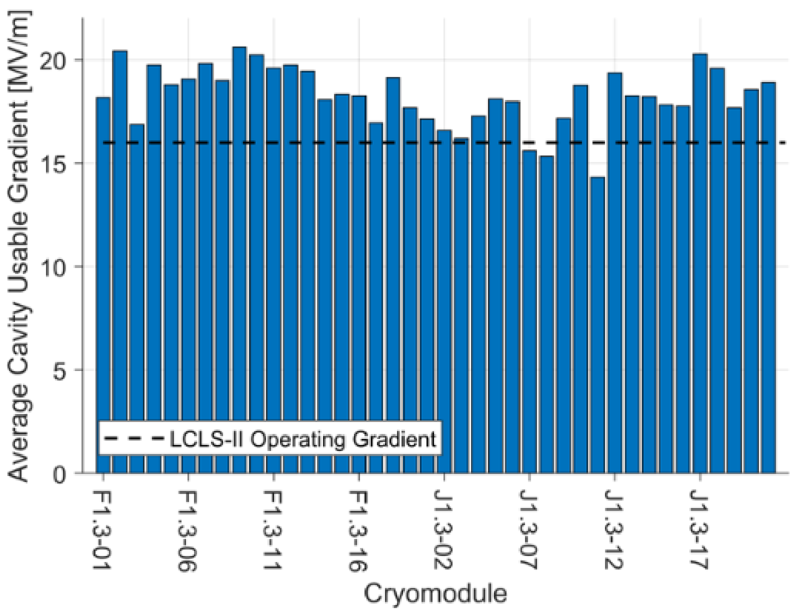
MOOFAV07, A. Burrill, SLAC

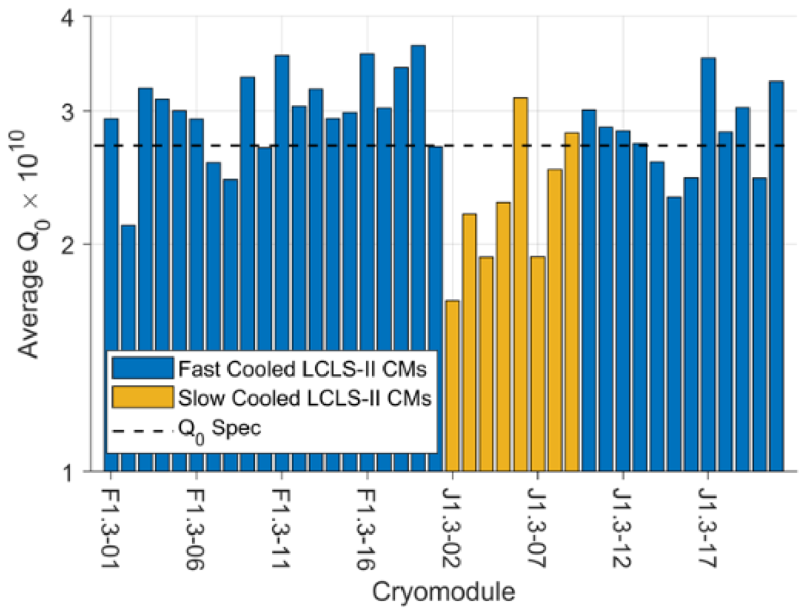
All testing performed at Jefferson Lab and Fermilab

Courtesy of Dan Gonnella 7

Overall Cryomodule Performance – Individual Tests

SLAC





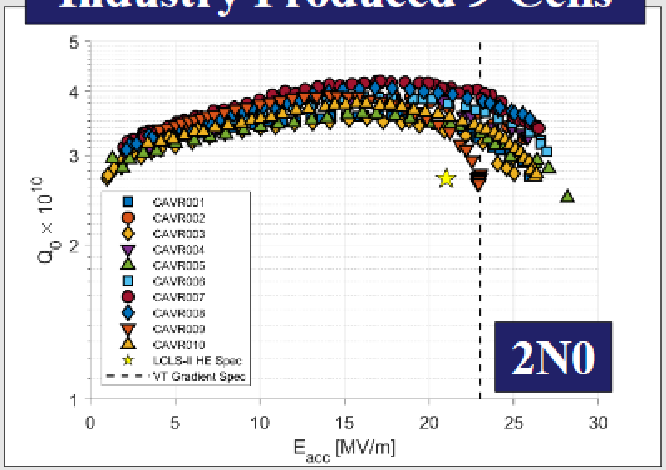
Successful demonstration of the first large scale nitrogen doped SRF cavity production by Industry

H-4: Promising higher gradient cryomodule for CW operation (23MV/m) by upgraded N-doping+ cold EP, LCLS-II HE

THOTEV08, M. Martinello, FNAL

- Demonstration of 23MV/m CW Cryomodule in industrial production for LCLS-II HE
- N-doping recopy: 2N0 + Cold EP

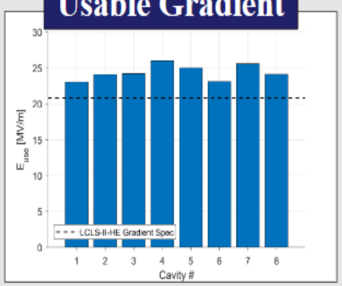
Industry Produced 9-Cells



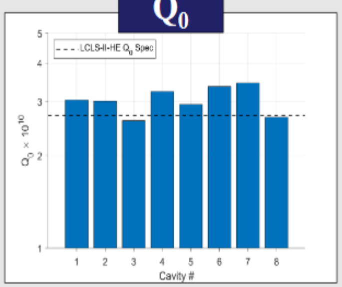
All industry produced 9-cells exceed HE spec!

Cryomodule Results

Usable Gradient

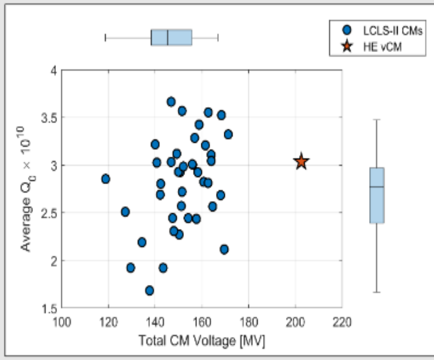


Q_0



- The 8 best 2N0 cavities from RI were assembled into a *verification* cryomodule (vCM)
- No cavities were limited by field emission in CM test
- Total integrated voltage of 202 MV!
- Measured Q_0 was on par with LCLS-II CMs

vCM Compared to LCLS-II

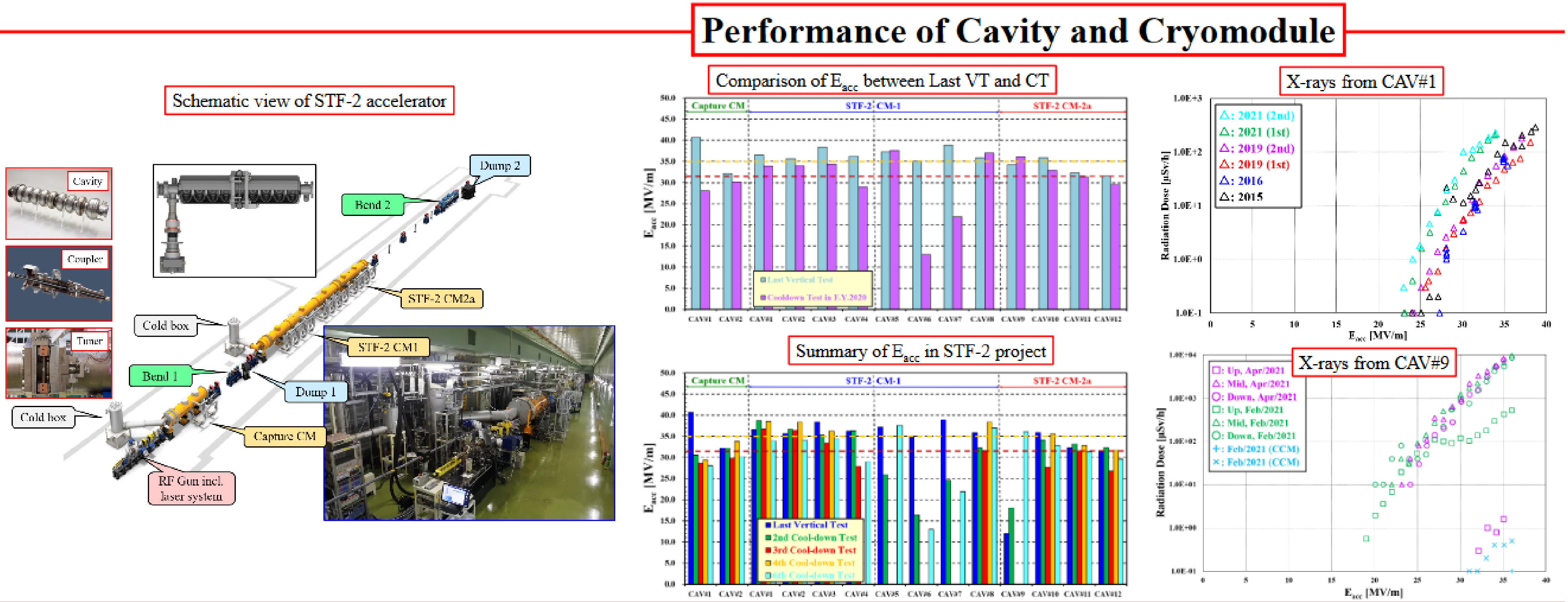


Highest CW cryomodule ever produced!

H-5: Demonstration of ILC cryomodule pulse beam operation at 33 MV/m @Qo=0.8E10, at STF KEK

TUPFAV003, Y. Yamamoto, KEK

- Realized Eacc = 33 MV/m in the ILC type cryomodule



KEK STF-2 Beam Test,
Great Milestone for ILC

TUPFAV003, Y. Yamamoto, KEK

- Beam operation at STF-2

  In the 6th cooldown test, beam acceleration test with 14 cavities including CCM was carried out, and it was confirmed that the average accelerating gradient obtained from the beam energy reached 32.9 MV/m, and the maximum beam energy reached 384 MeV.

Summary of Beam Operation in 6^{th} Cooldown Test

Parameters	**Mar/2019**	**Apr/2021**
Number of cavities incl. CCM used for operation	7 + 2	12 + 2
Beam energy	280 MeV	384 MeV
Beam intensity	0.28 μA	1.8 μA
Beam power	78 W	677 W
Total charge per pulse	56 nC	360 nC
E_{acc} from beam energy	33.1 MV/m (7 cavities)	32.9 MV/m (9 cavities)
E_{acc} from RF power (P_{tra})	33.8 MV/m (7 cavities)	33.0 MV/m (9 cavities)

H-6: Lessons learned from the existing machine operation experiences

MOOFAV06, J. Branlard, DESY

Example 1, XFEL Operation Experience

- 4 years successful operation, 776 1.3GHz 9-cell cavities
- Vector sum operation, one high power 10 MW MBK for 32 cavities
- Pulse operation, 750μs fill + 650 μs flat top
- ΔA/A < 0.01% (typically 0.007%, ΔP < 0.01%, typically 0.007 deg., Bandwidth 37 Hz
- Reduced-V run: 18.4 MV/m Qo=1.04E+10, High-V run:22.5 MV/m @ Qo=0.98E+10
- 100% availability for one week May 2021
- Going to auto control

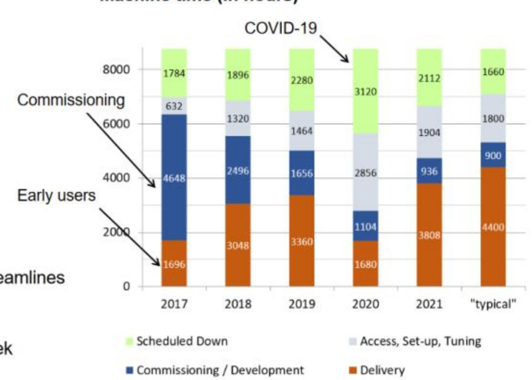
Introduction

XFEL : user facility

Milestones (some)

- Dec. 2016 Cool down
- Apr. 2017 First beam
- May 2017 First SASE
- Sep. 2017 First users
- Jul. 2018 Max energy: 17.5 GeV
- Oct. 2018 3 SASE beamlines
- Nov 2018 Max bunch (2700)
- Jan. 2019 Parallel user run in all 3 beamlines
- Feb. 2020 30 keV photon energy
- May 2021 100% availability for 1 week

Machine time (in hours)



DESY. | 4 years of operations at EuXFEL | Julien Branlard, 28.06.2021 Page 4

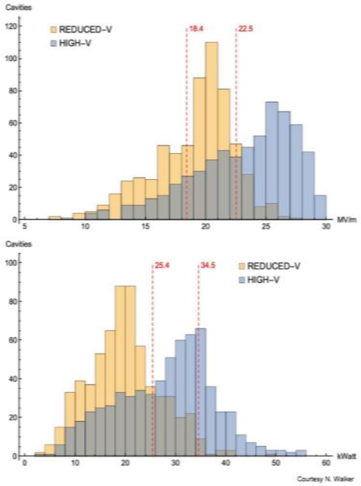
Cavity operation

776x 1.3 GHz TESLA cavities

Typical operation conditions

- Average gradient + spread
- Coupler power (x4 for peak power)
- Measured $Q_0 = 1 \times 10^{10}$

RF CONFIG	Time Frame	Average Dynamic Load (W)	Effective average Q_0
REDUCED-V	01.09—15.10.2020	400	1.04×10^{10}
HIGH-V	20.10—15.11.2020	600	0.98×10^{10}



DESY. | 4 years of operations at EuXFEL | Julien Branlard, 28.06.2021 Page 12

Example 2
CEABAF-12GeV

Tutorial, C. Reece, Jlab

SRF Long Operation Experience and Issues to Be Resolved

SRF 2021

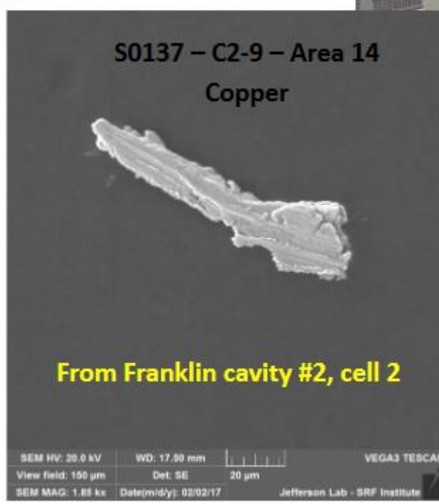
Analysis of particulates from CEBAF

- **#12 – Collecting dust**
  - Systematic particulate sampling (>340) from CM and girders removed from CEBAF
  - Examination using new SEM with elemental analysis
  - Many copper and steel particles found > 40 µm
  - Large assortment of other materials found
  - Clearly inconsistent with current standards
  - Responsible for CEBAF's energy reach limitation
  - Feedback for process improvement

Examples

S0320 - C6-18 - Area 7

Steel



Valente-Feliciano, Spradlin, Trofimova

19 - 25 June 2021

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Jefferson Lab

Feedback of the Past Lessons Learned

Tutorial, C. Reece, Jlab

SRF Long Operation Experience and Issues to Be Resolved

SRF 2021

- **#15 – We learn to do better**
  - While there are many legacy issues, the community continues to learn and standards tighten.
  - The latest CEBAF C100 CM ran 104 MV field emission free, limited by RF power.
  - LCLS-II and the latest "vCM" for LCLS-II-HE demonstrate excellent progress in contamination control.

C1006R – 21 MV/m, CW

(Recovered full performance from contamination by **HPR only**)

HE vCM – 25 MV/m, CW

(To be reported next week)

8

25 - 25 June 2021

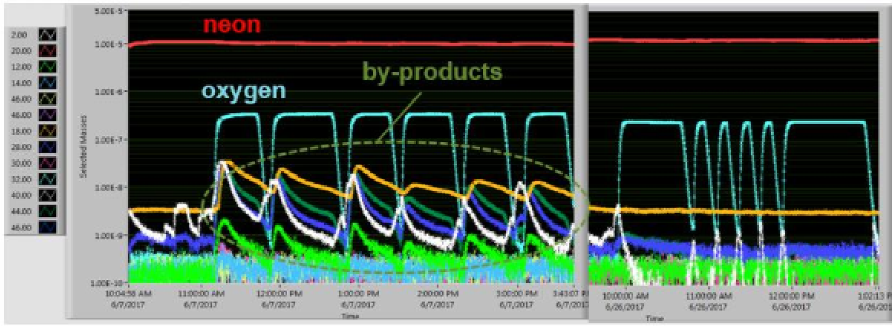
Jefferson Lab

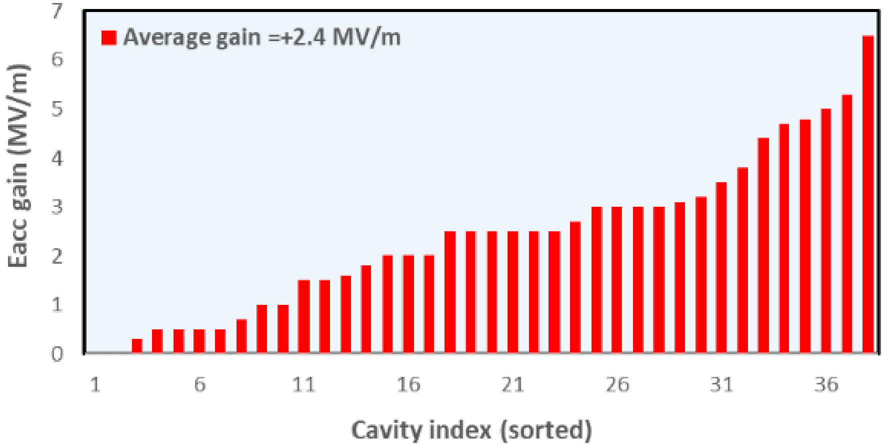
In-Situ Plasma Cleaning at SNS

WEOTEV01, B. Giaccone, FNAL

Plasma processing at ORNL-SNS

- 10 cryomodules plasma processed at SNS either in offline facilities or directly in the linac tunnel
  - 8 High-beta CMs
  - 2 Medium-beta CMs
- Cleaning of the cavity surfaces revealed by the significant reduction of by-products' partial pressures over time
- 38 cavities plasma processed at SNS with an average E_{acc} increase of 2.4 MV/m



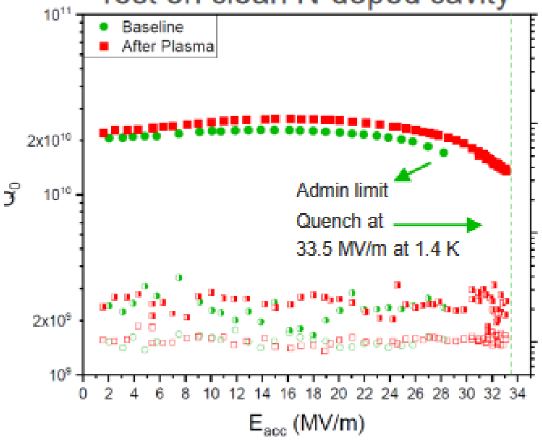


Plasma Cleaning for LCLS-II (N-doped cavity)

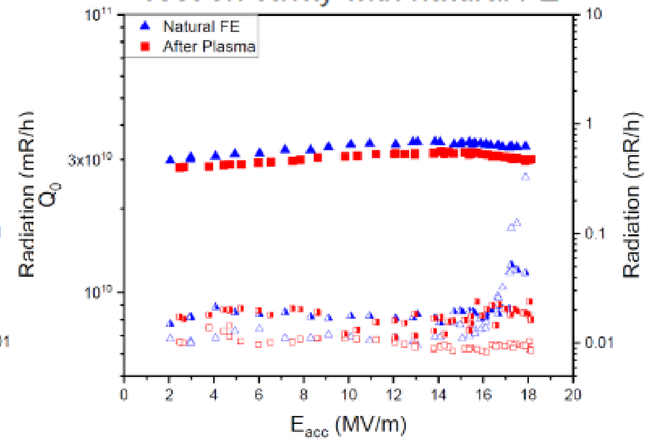
WEOTEV01, B. Giaccone, FNAL

Plasma processing at FNAL for LCLS-II: RF cold tests results

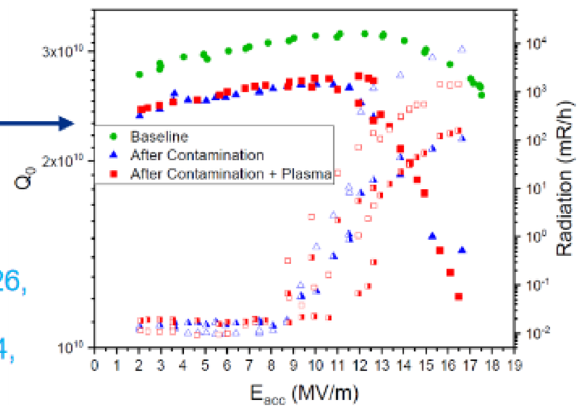
Test on clean N-doped cavity



Test on cavity with natural FE



Test on cavity subjected to vacuum failure simulation from HV to atmospheric presssure



Multiple 1.3GHz cavities have been subjected to plasma processing, showing positive results on FE caused by hydrocarbon contamination. Moderate or no improvement in performance was observed on cavities with FE likely caused by metal particles

P. Berrutti, B. Giaccone *et al.*, J. Appl. Phys. 126, 023302 (2019)
B. Giaccone *et al.*, Phys. Rev. Accel. Beams 24, 022002

Fermilab

FRIB Facility for Rare Isotope Beams
U.S. Department of Energy Office of Science
Michigan State University

H-7: R&D to increase the ***fabrication reliability*** and develop the cost-effective way

Example: X-ray Tomography (CT)

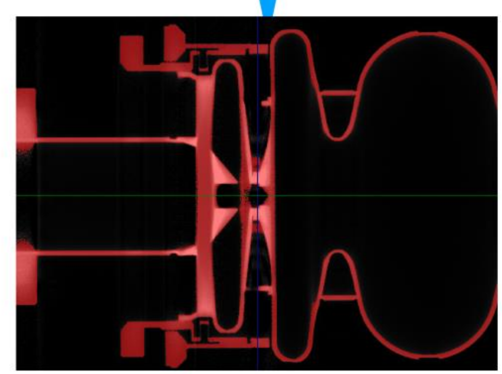
THOTEV07H. Glock, HZB

- A kind of X-ray CT
- Easily fond out the welding defects
- Cavity production reliability will be improved very much

X-ray tomography: setups

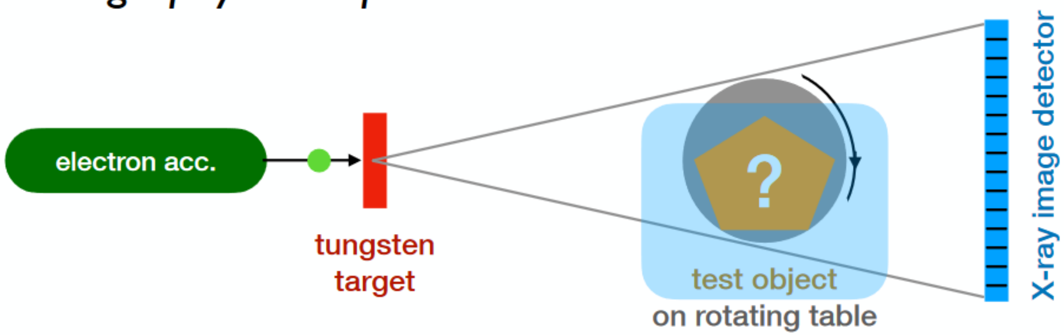
Tomographic Inversion (proprietary algorithm)

cubic voxel volume representation in 2^{16} intensity-scale values (.rek-file, ~ 10 GB)



bERLinPro Gun1.1 @Fraunhofer EZRT, 9 MeV

X-ray tomography: absorption

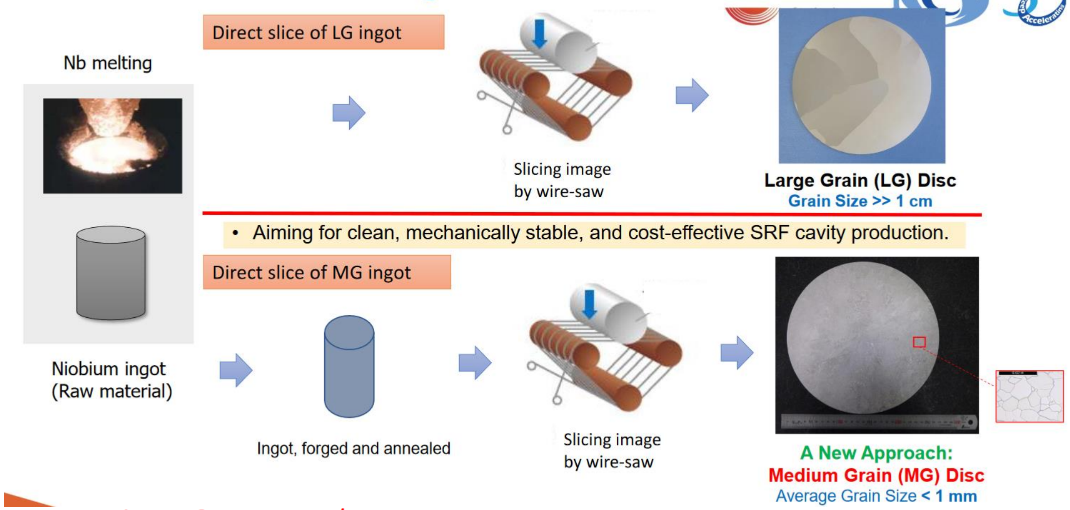


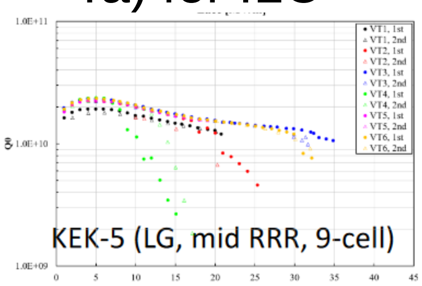
H-7: R&D to increase the fabrication reliability and develop the *cost-effective way*

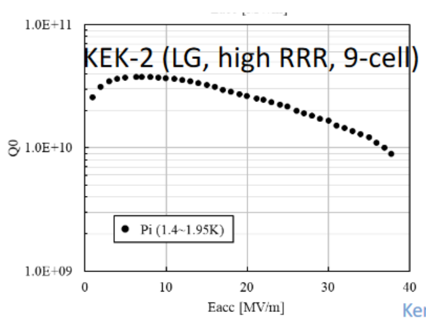
WEOCVA01Umemori, KEK

- Large grain (LG)/Middle grain cavity R&D
- Even the MG cavity could provide a excellent performance
- MG material would be cost-effective due to the easy production control
- KEK has selected MG/LG Nb material with high RRR (low Ta) for ILC

Manufacture method of Large and Medium-Grain Nb discs







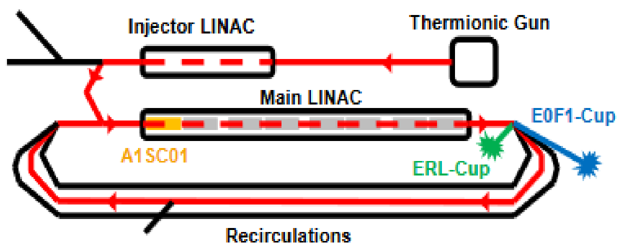
Results of KEK LG/MG cavities

	R1	R5	KEK-2	R10/ R10b	KEK-4/ KEK-5	R-16/ R16b	R-17/ R-17b	R-18/ R-18b
Supplier	Tokyo Denkai	CBMM	Tokyo Denkai	CBMM	CBMM	ULVAC	ULVAC	ATI
Grain size	LG	LG	LG	LG	LG	LG	LG	MG
# of cells	Single	Single	9-cells	3-cells	9-cells	3-cells	3-cells	Single
RRR (RT/Tc)	496	107	496	242 ～ 298	242 ～ 298	500	363	494
Ta-content	Low	High	Low	High	High	Low	High	Low
Results (π-mode)	42 MV/m	31 MV/m	38 MV/m	38 / 42 MV/m	34 / 32 MV/m	-- / -- MV/m	-- / -- MV/m	39 / -- MV/m

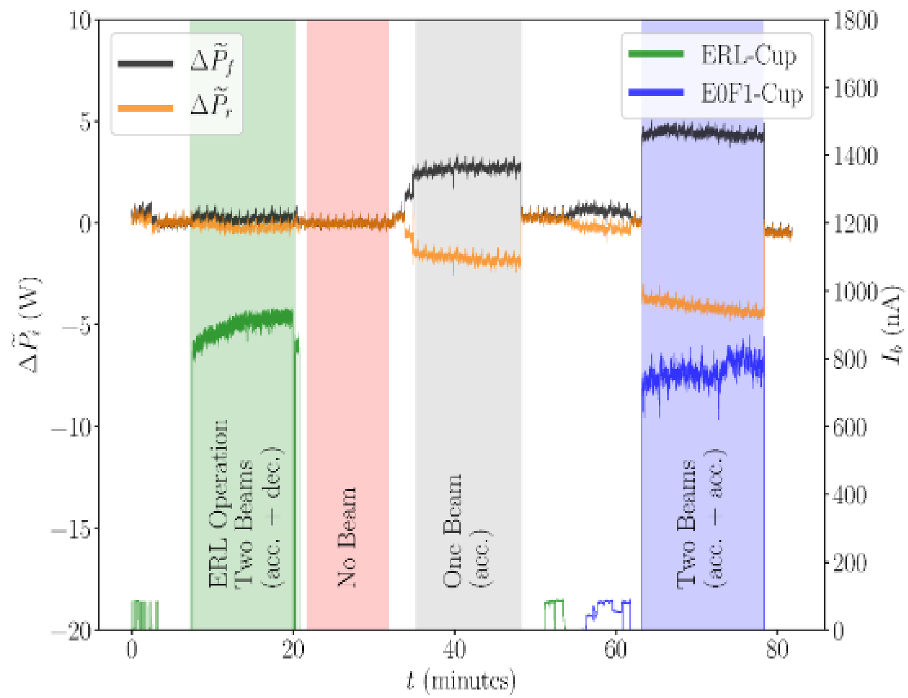
※ R-16/16b, R-17/17b, R-18b are under processing
※ Plan to fabricate high-RRR LG 9-cell & MG 9-cell cavities

Once-Recirculating ERL Operation

TUOFAV01, M. Arnold, Darmstadt



- Energy gain injector: 2.5 MeV
- Energy gain LINAC: 20.0 MeV
- Current (I_{in}): 1.2 μA
- RF-recovery effect: $(90.1 \pm 0.3)\%$



- 1st ERL in Germany (August 2017)
- 1 of only 3 running SRF ERL worldwide (D, USA, J)

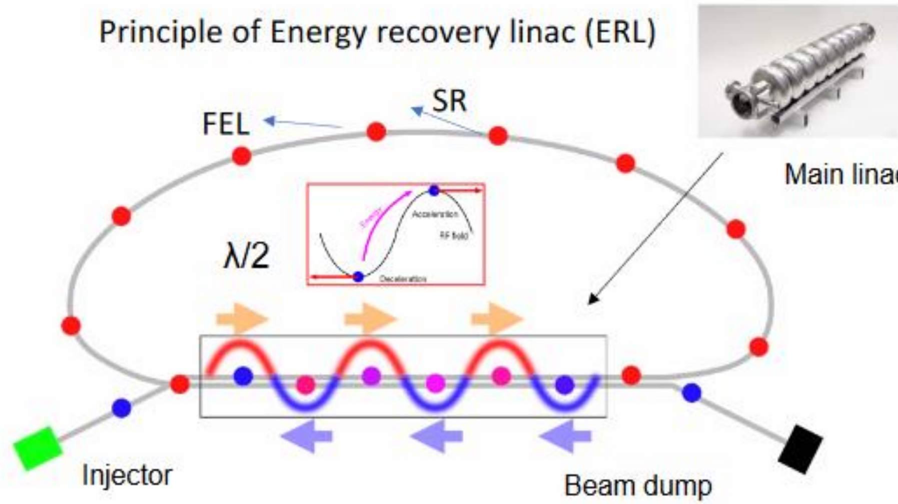
M. Arnold et al., Phys. Rev. Accel. Beams ***23****, 020101 (2020).*

cERL at KEK

THOTEV02, H. Sakai, KEK

Compact ERL (**cERL**) has been constructed in 2013 at KEK to demonstrate energy recovery with low-emittance, high-current CW beams of more than 10 mA for future multi-GeV ERL [1]. **1mA ERL achieved in 2016 at cERL [2].**

Principle of Energy recovery linac (ERL)



To demonstrate 100% energy recovery stably, stable SRF operation is important under high current beam operation

[1] M. Akemoto, *et al.*, "Construction and commissioning of the compact energy-recovery linac at KEK", Nucl. Instrum. Meth. A, **877**, 197-219 (2018)
[2] T. Obina, *et al.*, "1 mA Stable Energy Recovery Beam Operation with Small Beam Emittance", Proc. of IPAC2019, (Melbourne, Australia) p1482-1485, (2019)

It's time to consider ERL technology in ILC machine design to resolved the beam damp issue and enhance the green policy !!

H-8: Commercial Applications

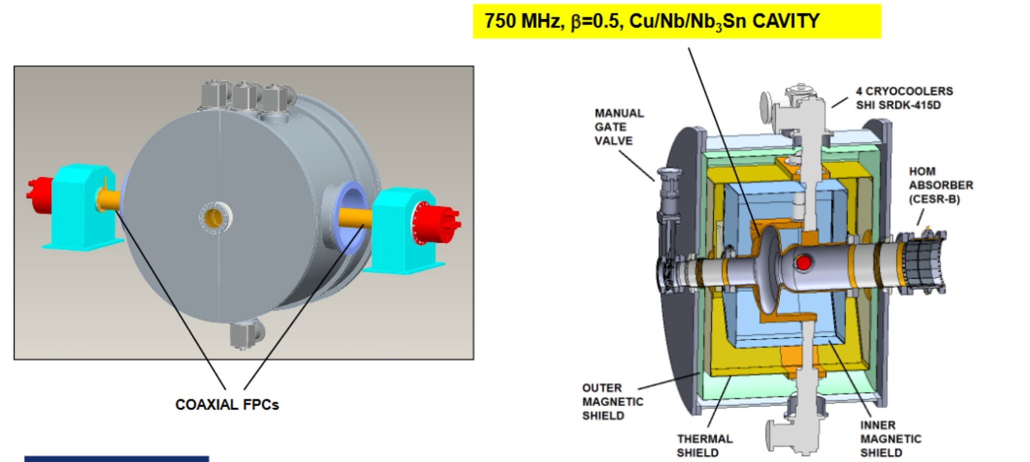
Conduction Cooling

WEOTE02, G. Ciovati, Jlab

- Nb_3Sn cavity can operate at high Qo (>1E+10) at 4K
- Conduction cooling simplifies the cryogenics, by using a cryocooler
- Combine these two and develop the compact injector, and other applications
- Current R&D Status
  - Still need to improve cooling efficiency, but very promising

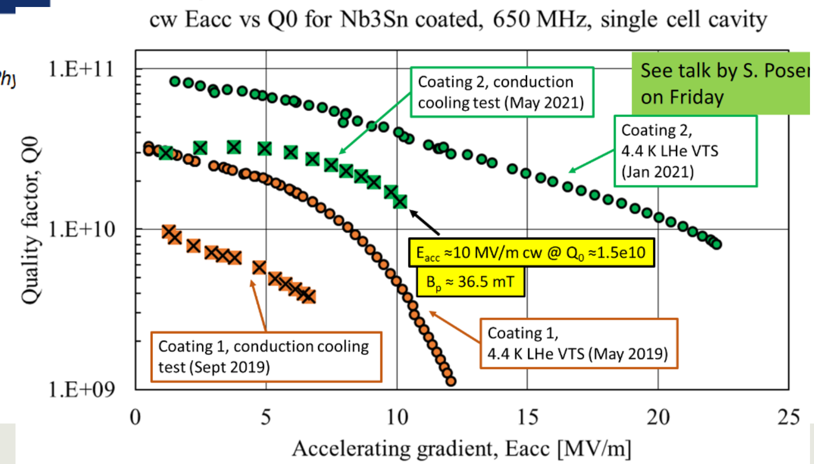
Design of 1 MeV, 1 MW conduction cooled cryomodule at JLab

- Designed for a CW e- accelerator for environmental remediation



GENERAL ATOMICS & T. Schultheiss, J. Rathke

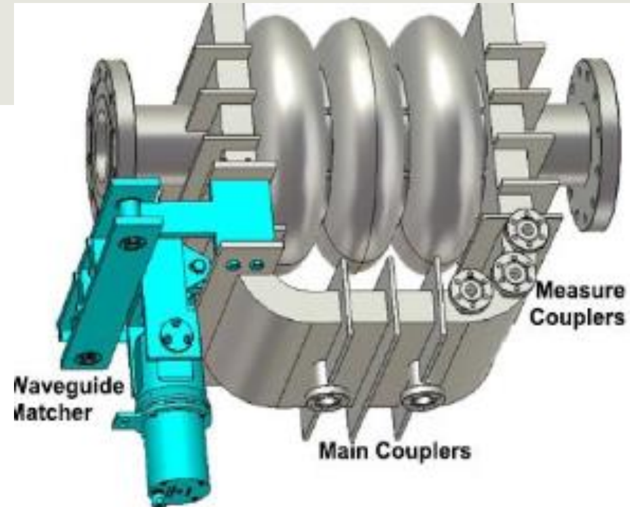
G. Ciovati *et al.*, *Phy*



Dhuley *et al.*, *Supercond. Sci. Technol.* **33**, 06LT01 (2020)

H-9: New Concept for ILC Upgrade to 2 - 3 GeV
Traveling Wave Structures

- Potential to enhance the SRF performance by a factor 2, Higher gradient > 70 MV/m, and Less RF dynamic load
- Nb bulk technology
- Capital cost will be cheaper than CLIC 3 TeV
- Lower AC power than CLIC 3 TeV



ADVANTAGES OF TW STRUCTURES

- Travelling wave (green wave) lowers BOTH *Bpk/Eacc* and *Epk/Eacc*
  - RF power returns NOT through the accelerating structure
    - to form a standing wave with harmful peaks
  - But power returns through a separate return Nb waveguide
- + Travelling wave structures offer 2X higher *R/Q*
  - lowers Cryo power and RF power
- By choosing the Low-Loss cell shape + reduced aperture (see below) it is possible to lower *Hpk/Eacc* by 48% over the TESLA structure!
- Opening the door to *Eacc* > 70 MV/m with Niobium !!
  - *Hpk* = 200 mT, *Epk* = 120 MV/m
  - Smaller aperture is allowed because bunch charge for 3 TeV ILC upgrade will about 3 X less to get acceptable IP background…
  - Resulting in much lower wakefields in accelerating structure
- Putting SRF on the Road to ILC => 2 TeV and 3 TeV with Niobium
- No need to struggle with exotic new superconductors (sorry!) or overlayers
- Higher group velocity makes field profile tuning easier than for SW

PARAMETERS FOR ILC 2 TEV AND 3 TEV
(DETAIL PARAMETERS AVAILABLE IN POSTER)

COMPARE TO CLIC 3 TEV

		ILC1 From TDR	ILC2 From 1 TeV	ILC3 TeV From 1 TeV	CLIC 3 TeV	
Energy	TeV	1	2.0	3.0	3.0	
Luminosity	$X10^{34}$	4.9	7.9	6.1	5.9	
AC Power	MW	300	245 -315	453	590	AC power much less than CLIC
Cap Cost	BILCU	13.3	+4.9 – 5.2 (18.2-18.5)	+ 11.5 (24.8 Total)	24.2 total BCHF	Total cost comparable to CLIC
Gradient	MV/m	45	70	70	72/100	
Q of new linac	10^{10}	2	2	2	5700	

See: WEPFAV006 *ILC Energy Upgrade Paths to 3 Tev*
H. Padamsee

Challenges in TW Structures

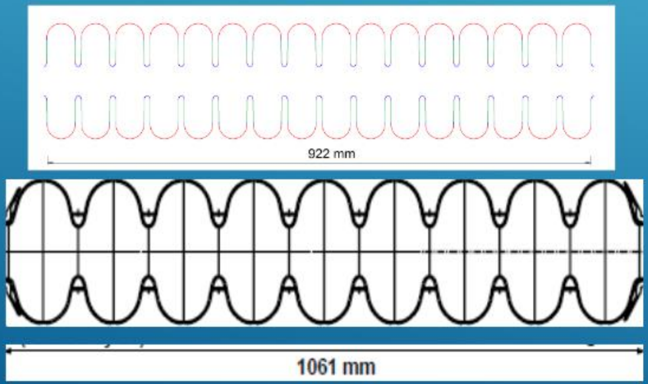
WEOCAV04, H. Padamsee, Cornell

CHALLENGES FOR TW - 1

- Requires twice the number of cells per meter to provide the proper phase advance (about 105 degrees)
- Cavity fabrication and surface processing procedures and fixtures must deal with (roughly) double the number of cells per structure.

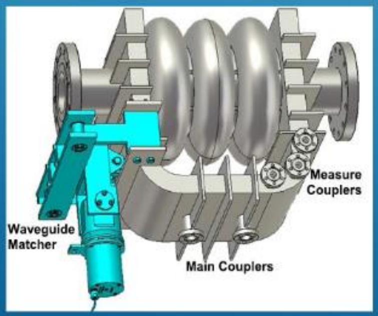
TW

SW
TESLA



Challenges for TW - 2

- A feedback waveguide for redirecting high power from the end of the structure back to the front end of accelerating structure
- The feedback requires careful tuning to compensate reflections along the TW ring to obtain a pure traveling wave
- Multipacting has been studied
- HOM propagation and HOM damping study started – results encouraging



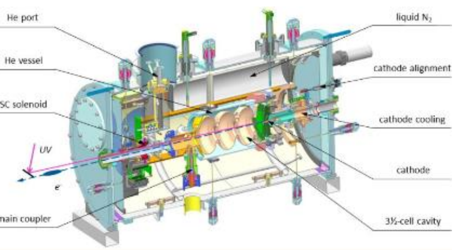
3-cell unit prepared at Fermilab by Euclid Corp – not yet tested

H-10: SRF-Gun Status

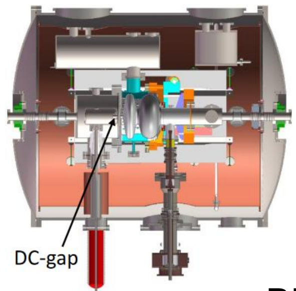
THOFDV01, T. Konomi, KEK

20 - 30 MV/m operation has been realized

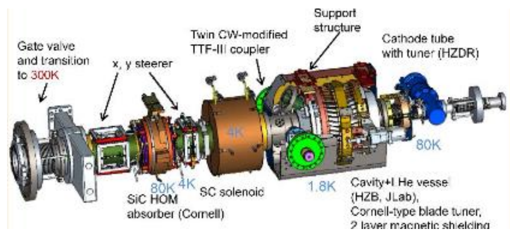
HZDR(Gun-II)



PKU(Gun-II)

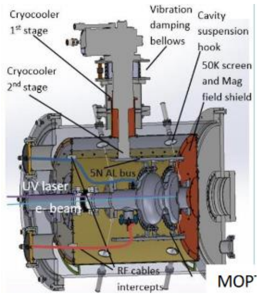


HZB

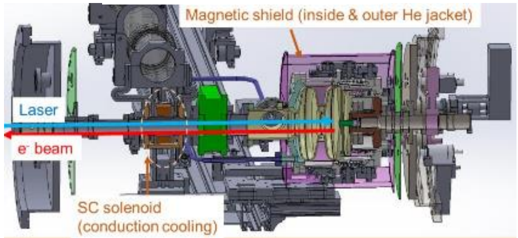


DESY

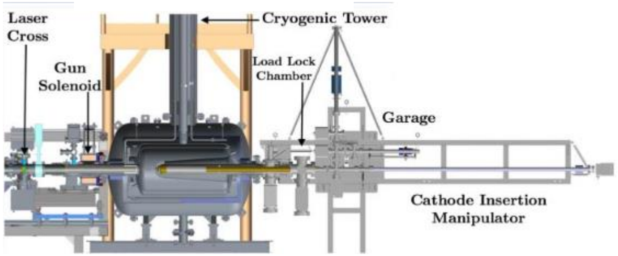
Euclid



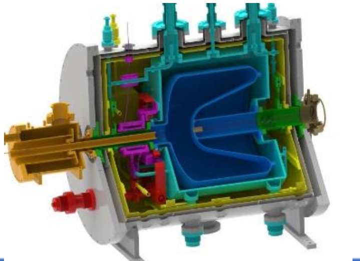
KEK (Gun-#2)



BNL (QWR)



SLAC (under design)



Parameter		HZDR (Gun-II)	PKU (Gun-II)	HZB (Gun 2.0)	DESY	Euclid	KEK (Gun#2)	BNL (QWR)	SLAC
RF frequency		1.3 GHz	1.3 GHz	1.3 GHz	1.3 GHz	1.3 GHz	1.3 GHz	113 MHz	185.7 MHz
Operation temperature		2 K	2 K	1.8 K	2 K	4 K	2 K	4.2 K	4.2 K
Geometrical factor		224 Ω	212 Ω	174 Ω	210 Ω	232 Ω	135.6 Ω	38.2 Ω	77 Ω
Ep on axis (E0)	Design	50 MV/m	28 MV/m	30 MV/m	40 MV/m	20 MV/m	31.5 MV/m	19.7 MV/m	30 MV/m
	VT	41 MV/m	45 MV/m	39.7 MV/m	**57 MV/m**	-	56.25 MV/m	18 MV/m	-
	HT	25 MV/m	-	**32.8 MV/m**	-	-	21 MV/m (w/o cathode)		-
	After Long operation	**20.5 MV/m**	-	-	-	-	-	18 MV/m He condition once/two years	-
Surface treatment		BCP	BCP	BCP	BCP or EP	Nb3Sn coating	EP	BCP	EP

H-11: Many R&Ds on Niobium and Beyond Nb

FROFDV05, S. Posen, FNAL

- Nb_3Sn Cavity
  - So far limited < 23 MV/m, but high Qo > 1E+10 at 4K
  - Developing 9-cell coating, 16MV/m @ Qo= 1E+10 at 4.4K
  - Concentrates more the 4K operation using cryocooler (conduction cooling)

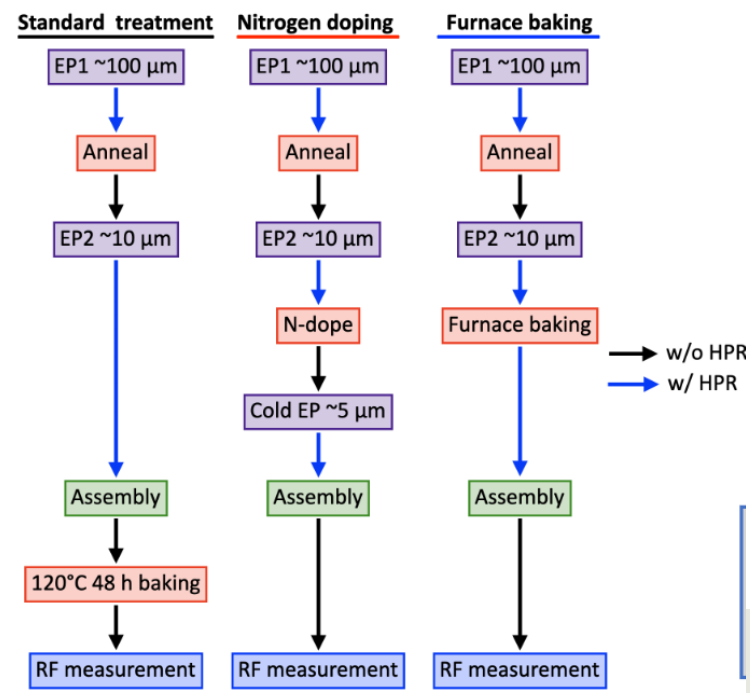
TUPTEV03, S. Posen, LANL

- MgB_2 Cavity
  - Still sample evaluation stage
  - Going to cavity coating

- Oxygen doping discovered at KEK
  - After the final EP, just take furnace baking at 200 – 300^{O}C for several hours

FROFDV01, H. Ito, KEK

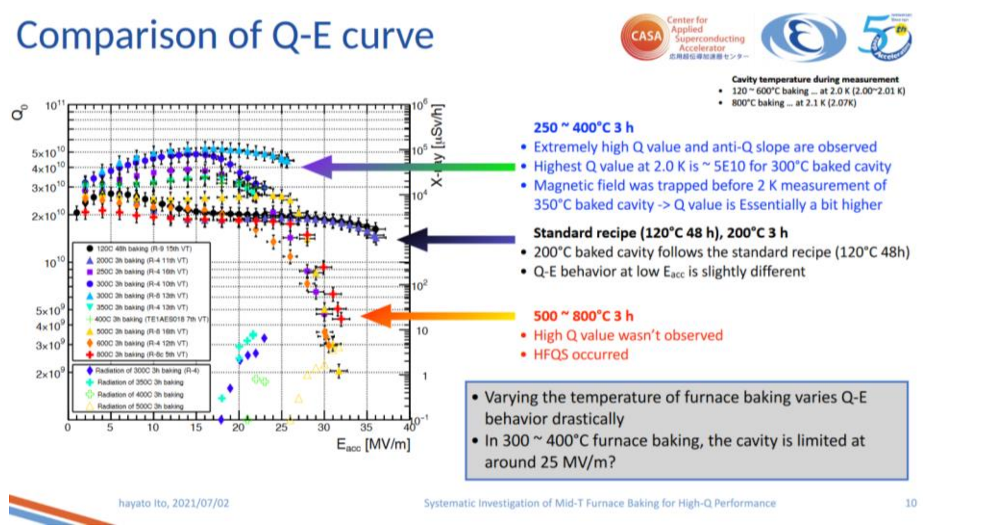
  - This method simplifies the processing very much, and results in a cost reduction, keeping HQ/HG performance

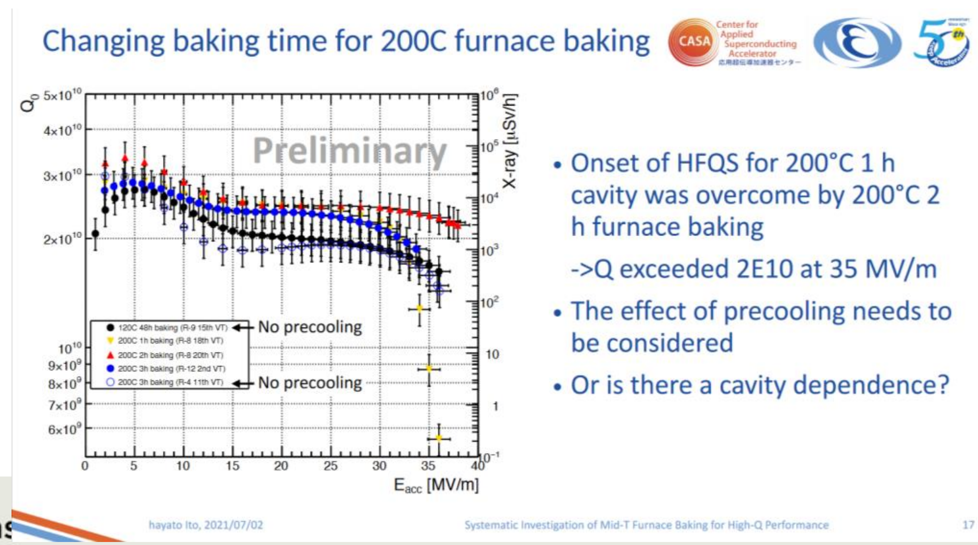


Promising HQ/HG with Oxygen Doping

FROFDV01, H. Ito, KEK

- Oxygen doping has similar anti-Q behavior as the N-doping
- Optimization is the baking at around 300 ^{O}C for 3hr, but gradient is limited < 25 MV/m
- However, even 200 ^{O}C x 1 hr has a potential to reach Eacc > 35 MV/m @ Qo > 2E+10, which reduces the RF dynamic load by a factor 2.5 in the current ILC cavity design





Summary

- SRF community continues to push up the performance steadily since last decade
- SRF is a major technology for accelerator projects, many world-class SRF projects are ongoing, and some of them have been completed on schedule
- SRF is utilized in all structures from low beta to high beta (proton, heavy ion), and also from injector to accelerator module for electron
- Continues the operational lessoned learns, and well fed back, various in-situ cleaning technologies are being developed to cure the performance degradation during a long term operation
- ILC Nb bulk cavity has a potential to operate at Eacc = 35MV/m @ Qo > 2E+10, which can reduce the RF dynamic loss by a factor 2.5 in the current ILC design
- Nb bulk cavity technology could improve the gradient double with less RF dynamic loss by travelling wave scheme.
- Nb_3Sn cavity can simplify the 4K cryogenic system using cryocooler, and cut open the many applications
- New material R&D continues, in order to push up the operation gradient > 100 MV/m
- SRF2023 is looking forward to see outcomes from the ongoing R&Ds