SRF ACTIVITIES AT JLab

A-M VALENTE-FELICIANO
On behalf of the
JLab Accelerator / SRF S&T Department

Outline

- *SRF developments for projects*
  - EIC
  - ERLs & Synchrotrons – PERLE & BESSY VSR
- *SRF developments for Technology Advances*
  - Bulk Nb Technology
  - SRF Thin Films
    - Nb/Cu
    - Nb_3Sn
    - Other SRF Materials & SIS Structures
  - Beyond SRF- Quantum Applications & others

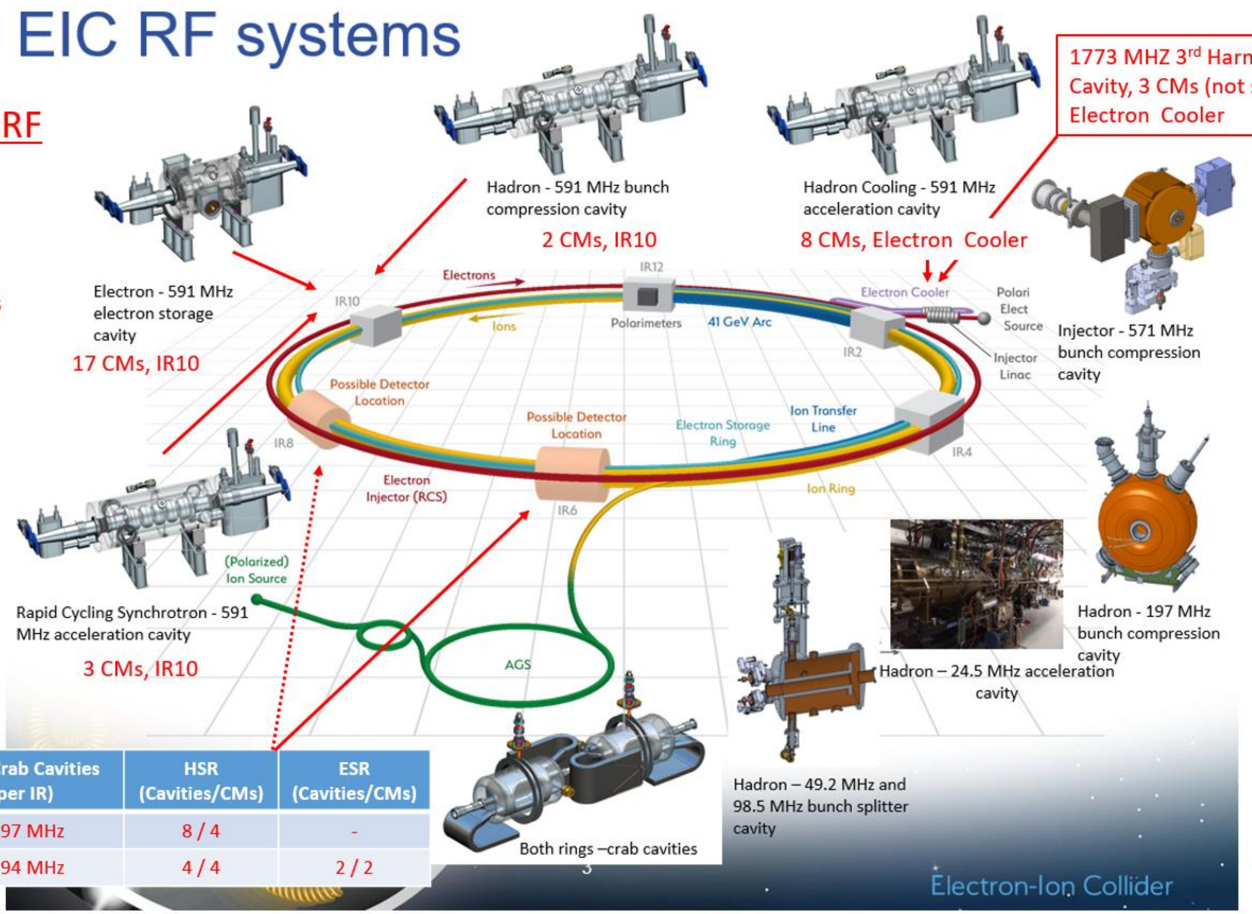
EIC RF systems

- JLab is the major partner in EIC, contributing to and leading a variety of WBS elements
- 2021 JLAAC recommended to prioritize this prototype design
- ***Major single cell R&D activities include***
  - Bare cavity RF and mechanical design/analysis
  - Beam-cavity interaction analysis
  - Bare cavity prototype fabrication design and tooling
  - Fabricate and vertical test one bare cavity prototype
  - Design integration with the fundamental power couplers (FPC) and beamline HOM absorber (BLA)
  - Design integration with the Q_{ext} tuning network
- ***Other EIC RF cavity design activities at JLab not included in the EIC SRF R&D scope***
  - EIC RCS/HSR/SHC-ERL 5-cell 591 MHz
  - SHC ERL 197 MHz QWR, 591 MHz single cell, and 1773 MHz 5-cell
  - RCS injection harmonic RF kickers

Focus on SRF

Baseline
1 Cavity per Cryomodule for all but the 197 MHz Crab Cavities

RHIC Tunnel
3.834 km circumference



Crab Cavities (per IR)	HSR (Cavities/CMs)	ESR (Cavities/CMs)
197 MHz	8 / 4	-
394 MHz	4 / 4	2 / 2

"Design and Impedance of RF Systems", B. Rimmer, 9/22/21

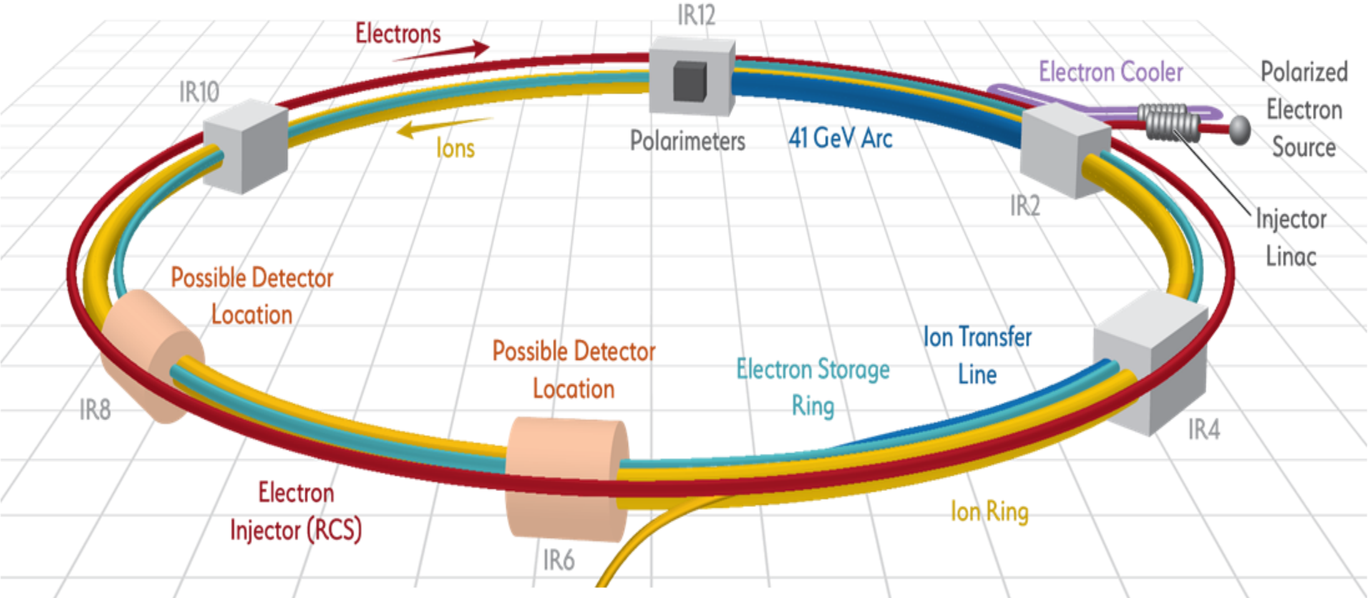
EIC Crabbing Systems

- EIC requires several crabbing systems

	V_t [MV]		No. of cavities (per IP per side)	
System	HSR	ESR	HSR	ESR
197 MHz	33.83	–	4	–
394 MHz	4.75	2.90	2	1/2

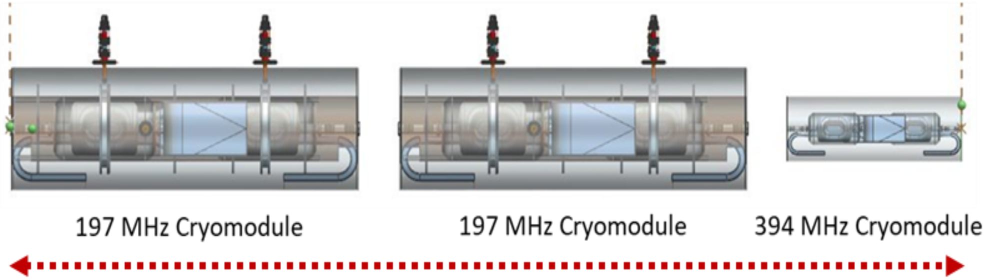
- Primary interaction point is IR6 with secondary IP at IR8
  - Impedance budget is for both IPs

197 MHz crabbing cavity is identified as one of the two R&D cavities to be prototyped for EIC.

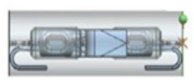


IR-6: Crab Cavity SRF Systems

Crabbing Systems for HSR (per side per interaction point)



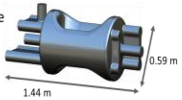
Crabbing System for ESR (per side per interaction point)

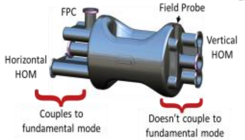


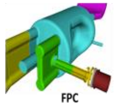
Jefferson Lab

EIC Crab Cavities

- Cavity designed to achieve:
  - Peak surface fields of E_p < 45 MV/m and B_p < 80 mT at 11.5 MV
  - Bare cavity dimensions:
    - Cavity length ≤ 1.5 m
    - Cavity diameter (without couplers) ≤ 0.6 m
- Design includes FPC and field probe
- Cavity with flat poles



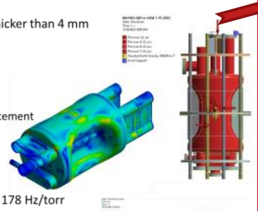


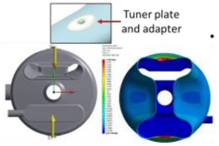


Basic Cavity Properties	Value	
Operating frequency [MHz]	196.643	
1st HOM [MHz]	347.1	
E_p/E_t^*	2.89	
B_p/E_t^* [mT/(MV/m)]	5.20	
B_p/E_p [mT/(MV/m)]	1.80	
G [Ω]	97.2	
R/Q [Ω]	1160.8	
R_tR_s [Ω²]	1.13×10⁵	
* $E_t = V_t/(\lambda/2)$		
V_t [MV]	8.5	11.5
E_p [MV/m]	32.3	43.7
B_p [MV/m]	58.4	79.0
Cavity length [mm] (iris-to-iris)	921.9	
Cavity length [mm]	1435	
Cavity diameter	587.2	

Mechanical Analysis for Prototype Cavity

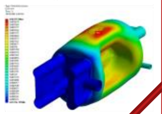
- Cavity body is comprised of 4 mm Nb with some regions thicker than 4 mm
- Stress analysis
  - For VTA test at 22 psi is within allowable stress of 6.3 ksi
- Tuning analysis - Tuning in the magnetic field region
  - Δf = ± 682.3 kHz (Requirement: ± 472 kHz)
  - Tuning sensitivity = 126.4 kHz/mm for a total 5.4 mm displacement
  - 2.7 mm push tuning limit at allowable stress
  - 7400 lb force on each tuner pad (2740 lb/mm)





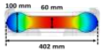
- Pressure sensitivity – 178 Hz/torr

Lorentz detuning:
- Beam pipes fixed → -222.7 Hz/(MV)²
- Tuner fixed → -108.8 Hz/(MV)²
- Beam pipes fixed with support cage → -42 Hz/(MV)²



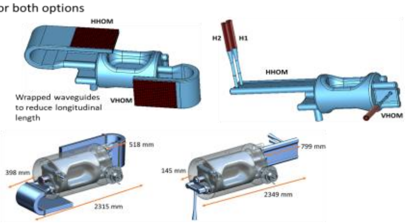
HOM Damping Options

- Cavity has two HOMs: Horizontal HOM (HHOM) coupler and Vertical HOM coupler (VHOM)
- Use dogbone style waveguides to achieve a compact design in extracting the HOMs
- Two design options with waveguide dampers (baseline design) and coaxial couplers
  - Similar longitudinal length for both options



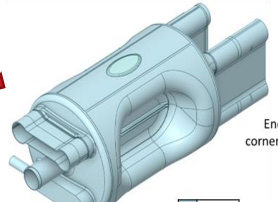
- Cut off frequency – 335 MHz
- 1st HOM – 347 MHz

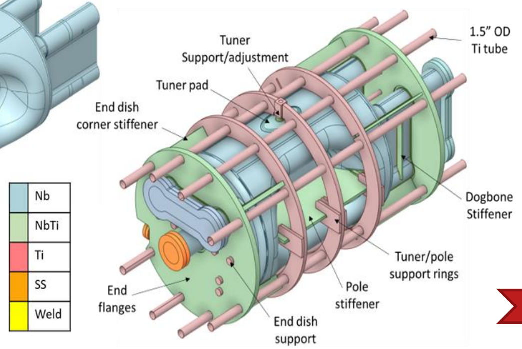
HOM Down Selection (March 2023) – Proceed with coaxial option



197 MHz Crab Cavity Development

Prototype Cavity

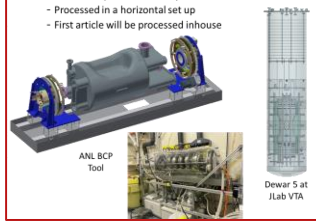




- Design and fabricate bare cavity
  - Cavity with flat poles
- RF processing and testing (warm and cold measurements)
- Preliminary design review – Nov. 2022
  - Finalized requirements and design of the prototype cavity
  - Cavity fabrication in progress

Prototype Cavity Processing and Testing

- Scale of the cavity (size and weight: 5' overall long, 30" OD, ~800 lb) requires upgrade to processing tools at JLab (BCP Cabinet, Furnace, Fume Hoods, etc..)
- Bulk and light BCP will be done at Argonne National Laboratory for the prototype cavity
  - Official Scope of Work is in place
  - Processed in a horizontal set up
  - First article will be processed inhouse

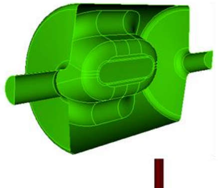


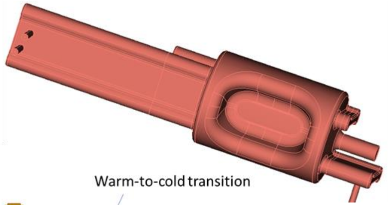
Measurements:
- Cold and warm measurements of HOMs
- RF test at 2 K
  - Q_0 vs V_t
  - Surface resistance (R_s)
  - Lorentz detuning
  - Pressure sensitivity
- Procedures for cavity processing and testing will be completed
- Facilities are planned to be upgraded to process first article cavities

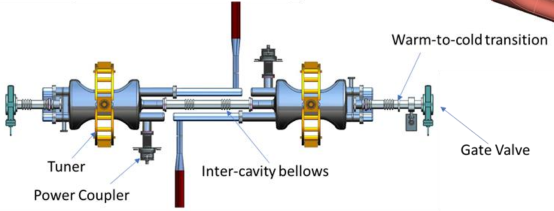
Processing Plan

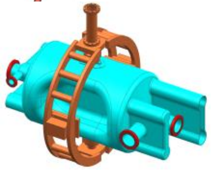
Bulk BCP → Heat Treatment → Light BCP → HPR → Assembly → RF Test

First Article Cavity

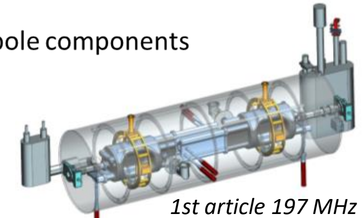








- Cryomodule with 2 197 MHz crab cavities
- Cavity with curved poles to suppress multipole components
- Need to finalize requirements
  - Multipole components
  - Tuning range
  - Pressure vessel systems
- First Article Preliminary Design Review – June 2023

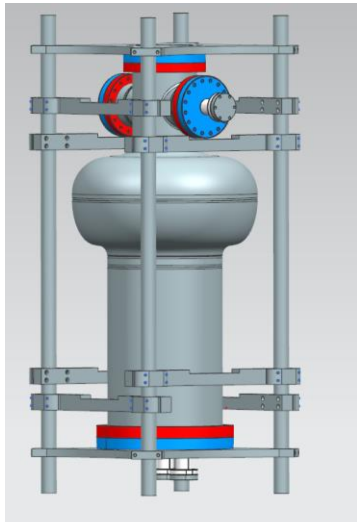


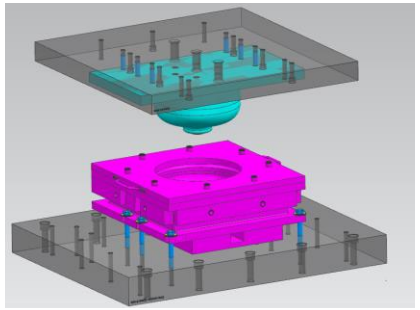
1st article 197 MHz Crab Cavity Cryomodule

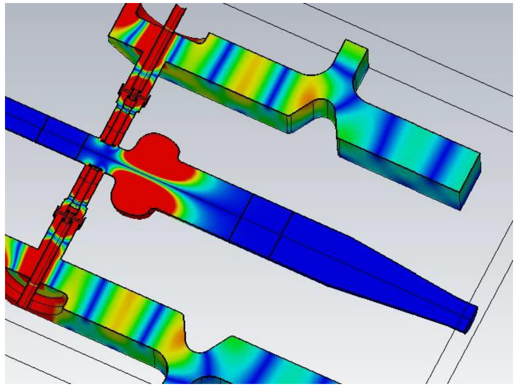
- HSR 197 MHz prototype crab cavity design status:
  - RF design and mechanical analysis is complete
  - Detailed manufacturing plan is in progress
  - Cavity processing plan is implemented
- Primary focus is on the 197 MHz cavity in prototype cavity fabrication (R16: JLAAC 2021)
- 1st article design carried out in parallel
- Developed conceptual 3-D model
- Preparing for down select of HOM damping solution (waveguide vs coax)
- ESR 394 MHz crab cavity design status
  - RF design including HOM damper designs is on-going
  - Multipole analysis is on-going to determine the specifications in designing curved pole shapes
  - Mechanical analysis to be completed
- EIC crab cavity efforts are on track for CD2

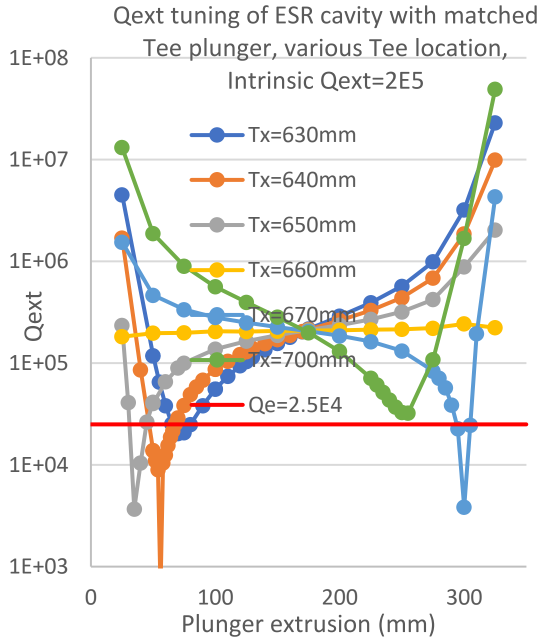
EIC ESR 591MHz single cell cavity prototype

- Cavity prototype technical review in Oct 2022
- First article cavity string PDR and FPC FDR-1 in Apr 2023,
- SSA EDU (2×200 kW units for JLab CM testing and 2×400 kW for BNL CM testing) FDR in May 2023.
- ESR cavity prototype design
  - Cavity body RF design and mechanical analysis complete
  - RF and mechanical design of the bare cavity complete
    - *4mm wall thickness satisfies the stress threshold, but tuner force is higher than usual*
  - RF/HOM/mechanical meet the basic requirements
  - Cavity shape frozen for prototyping.
- Preparing for prototype fabrication and VTA test
  - Fabrication design, especially deep draw analysis and die design
  - Blank-off/antennae RF and mechanical design
  - Die and hardware procurement
  - Trimming fixtures, tuning hardware, VTA test cage
  - Targeted VTA test in Q4 2023
- Ongoing R&D to the first article
  - Integrated RF/thermal simulation with FPC, doorknob transition, BLA, and Qext tuner under various beam loading cases
  - Optimize warm-cold transitions
  - Analysis/design of low impedance/RF shielded bellows and RF seals
  - Prepare the test facility at LERF

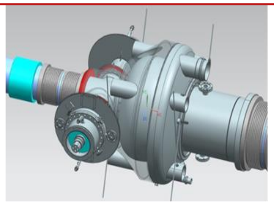






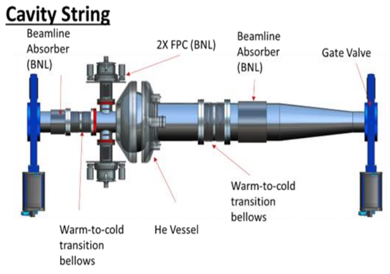


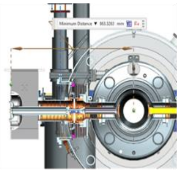
ESR Cryomodule

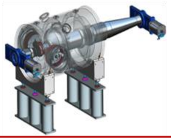


First Article 591 MHz Cavity String

- Kicked off PDR phase for ESR CM
- Developing functional requirements
- Developing heat loads for cryo interface
- Conducting mechanical analyses of internal components including helium vessels and tuners
- Preparing for ESR string PDR in April







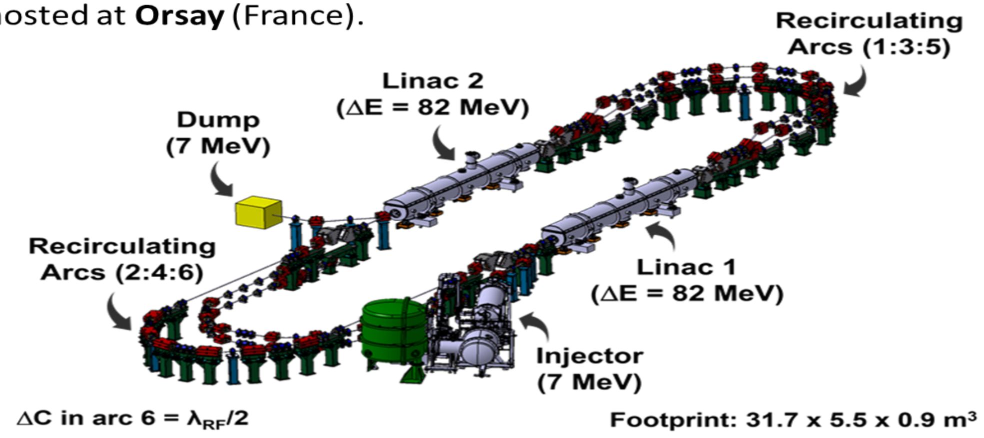
First Article 591 MHz ESR Cryomodule

Jefferson Lab

ERL Based on SRF - PERLE

The PERLE accelerator complex

PERLE (**P**owerful **E**nergy **R**ecovery **L**inac for **E**xperiments): multi-turn ERL (Energy Recovery Linac) based on SRF technology currently under study and later to be hosted at **Orsay** (France).



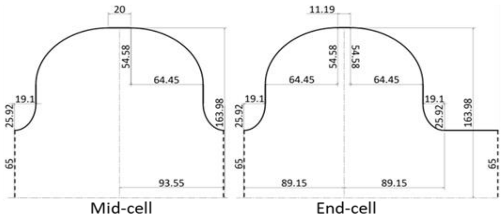
Target Parameter	Unit	Value
Injection energy	MeV	7
Electron beam energy	MeV	500
Normalized Emittance $\gamma\varepsilon_{x,y}$	mm·mrad	6
Average beam current	mA	20
Bunch charge	pC	500
Bunch length	mm	3
Bunch spacing	ns	25
RF frequency	MHz	801.58
Duty factor	CW (Continuous Wave)	

- Testbed for studying a wide range of accelerator phenomena
- 2 Linacs (four 5-cell 801.58 MHz SC cavities)
- 3 turns (164 MeV/turn): 3 passes "up" (E_{max}=500 MeV), 3 passes "down" (energy recovery phase)

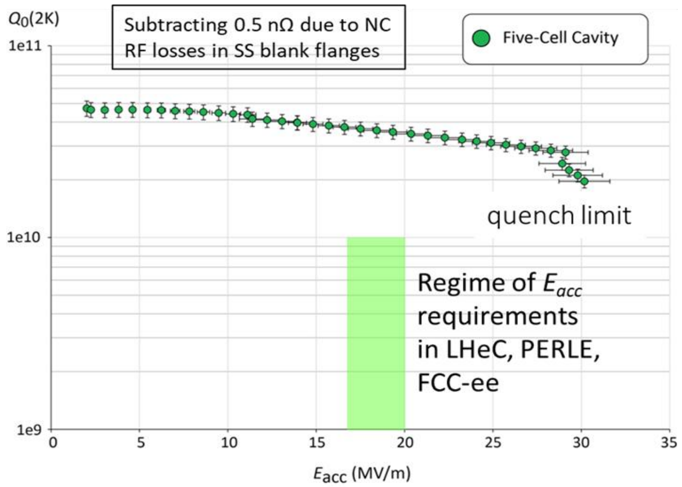
The 5-cell SRF cavity for PERLE

First 801.58 MHz 5-cell elliptical Nb cavity fabricated and successfully tested at JLab in October 2017

Cavity Parameters	Unit	Value
Frequency	[MHz]	801.58
Temperature	[K]	2.0
Cavity active length	[mm]	917.9
R/Q	[Ω]	523.9
Geometry Factor (G)	[Ω]	274.6
B_{pk}/E_{acc} (mid-cell)	[mT/(MV/m)]	4.20
E_{pk}/E_{acc} (mid-cell)	[-]	2.26
Cell-to-cell coupling k_{cc}	[%]	3.21
Iris radius	[mm]	65
Beam Pipe radius	[mm]	65
Mid-cell equator diameter	[mm]	328
End-cell equator diameter	[mm]	328
Wall angle	[degree]	0
Cutoff TE_{11}	[GHz]	1.35
Cutoff TM_{01}	[GHz]	1.77



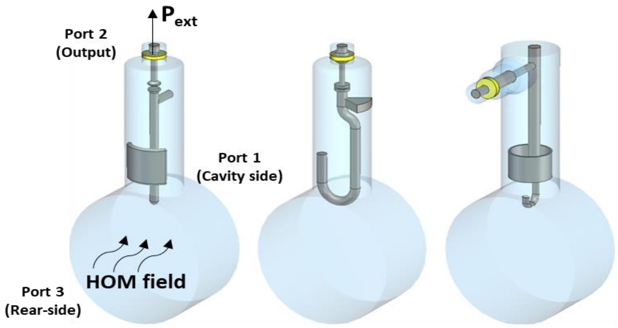
Initially developed in the framework of FCC



Prototype well exceeds E_{acc} requirement with Q_0> 3e10 at 2K

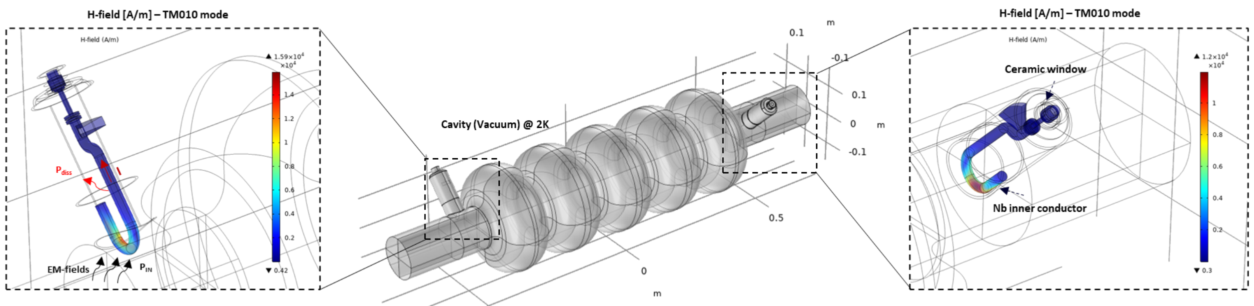
HOM-Damping Studies for PERLE

Courtesy of C. Barbagallo



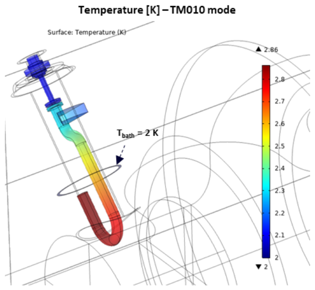
Probe design Hook design DQW design

- HOM couplers are geometrically optimized according to the HOM spectrum ($Z_{||}$ and $Z_{\perp}$)
- The S-parameters between the beam pipe port 1 and port 2 at the coaxial output of the coupler are studied.
- The DQW coupler exhibits a better monopole coupling for TM010 mode than the probe design.
- The hook coupler provides higher damping of the first two dipole passbands (TE111 and TM110)



$B_{FM_{max}} = \mu_0 H_{FM} = 20\ mT$

$B_{FM_{max}} = \mu_0 H_{FM} = 15\ mT$



$T_{max} = 2.86\ K$

- Electric surface current for the i[th] HOM

$$I_i^2 = \int_{S_{coupler}} \boldsymbol{H_i} \cdot \boldsymbol{H_i}^* dS = \int_{S_{coupler}} |\boldsymbol{H_i}|^2 dS\ [A^2]$$

- Power dissipation on the conductor

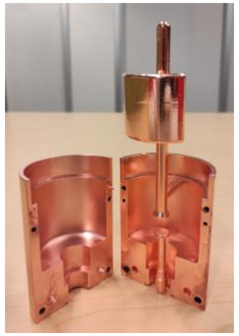
$$P_{\text{diss},i} = \frac{1}{2} R_s(T) I_i^2\ \ [W]$$

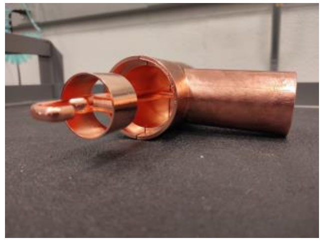
- Evaluation of the maximum temperature

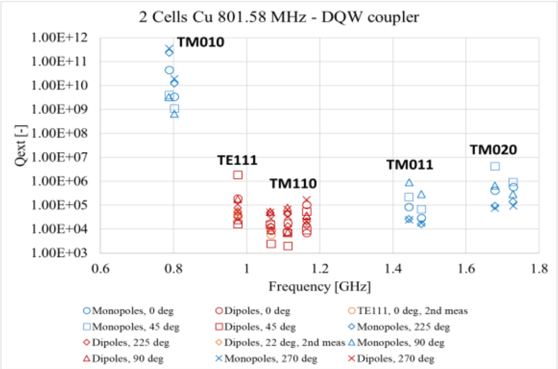
	E_{pk} [MV/m]	B_{pk} [mT]
Hook-coupler	19.63	21.22
Probe-coupler	34.30	31.83
DQW-coupler	45.13	70.27

	$P_{diss-inner}$ [mW]	$P_{diss-outer}$ [mW]	T_{max} [K]
Hook-coupler	3.21	1.57	2.86
Probe-coupler	5.02	1.99	3.03
DQW-coupler	38.11	2.13	4.41

Prototype Coaxial HOM Bench Measurement campaign (Feb 2023) with 2 cell Cu mock-up & 3D printed in epoxy, copper coated couplers (CERN Polymer Lab)







5-cell Cu mockup under way

simulation results verified

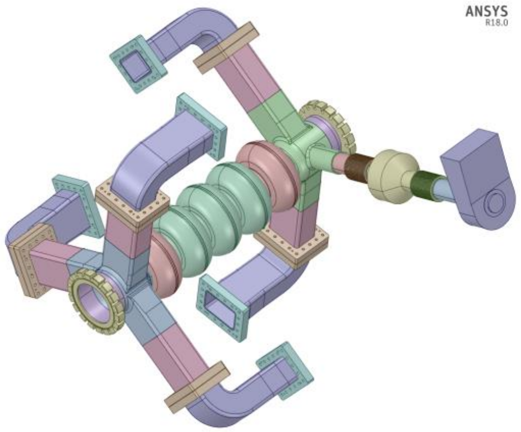
Jefferson Lab

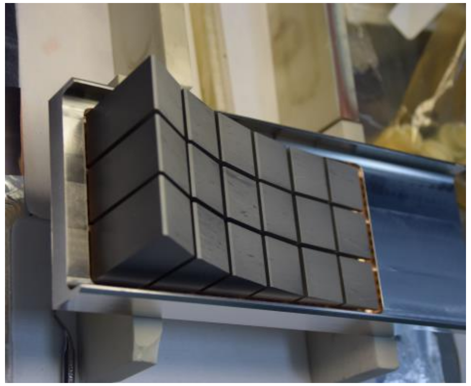
HZB BESSY VSR waveguide HOM load pre-series/series

Courtesy J. Guo, H. Wang et al.

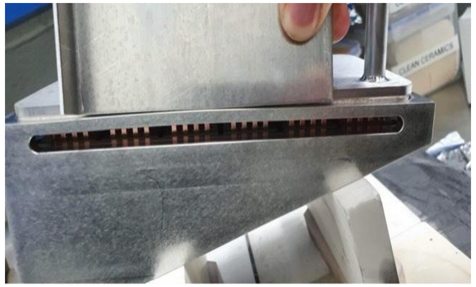
CW high-voltage superconducting RF cavities operating at a harmonic of the 500-MHz accelerating system for dual pulse lengths at high current

- Collaborating with HZB since 2016
- Prototype completed and tested in 2018
- Change in assembly sequence to improve cleanliness and protect flange surface
  - Braze ceramics to bottom first, then close the load assembly with a second braze
- Pre-series parts delivered in Sept 2022 (delayed due to Covid)
- Brazing procedure & fixture development:
  - Item #1, braze step 1 failure due to faulty fixture design, but sub-assembly salvaged and would try braze step 2
  - The warping for item #1 in braze 1 made braze 2 difficult to seal
  - Improved fixture successful on Item #2 braze step 1
  - Item #2 braze step #2 successful

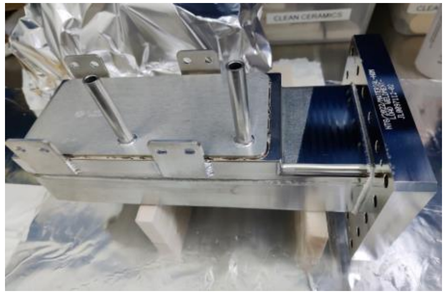




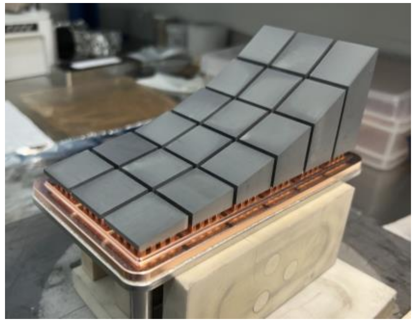
2019 prototype (before weld)



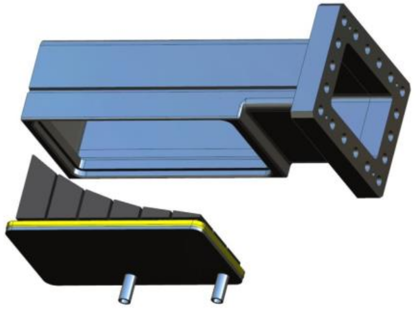
Item #1 step 1, fixture brazed to sub-assembly; warping in sub-assembly



Item #1 step 2, warping led to leaking braze joint



Item #2 step 1, successful braze with new fixture



Changed assembly sequence

HZB Helmholtz Zentrum Berlin

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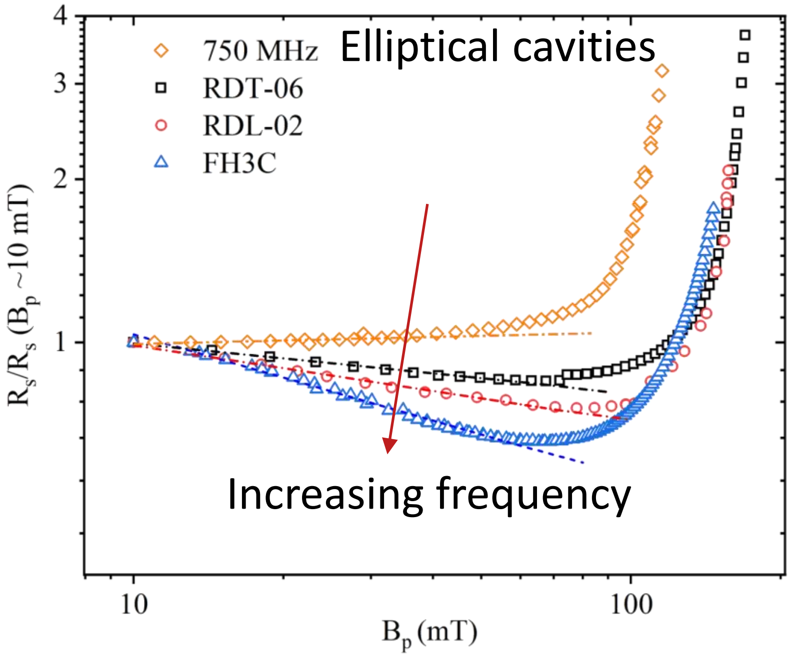
Frequency Dependence of RF Performance for Niobium SRF Cavities

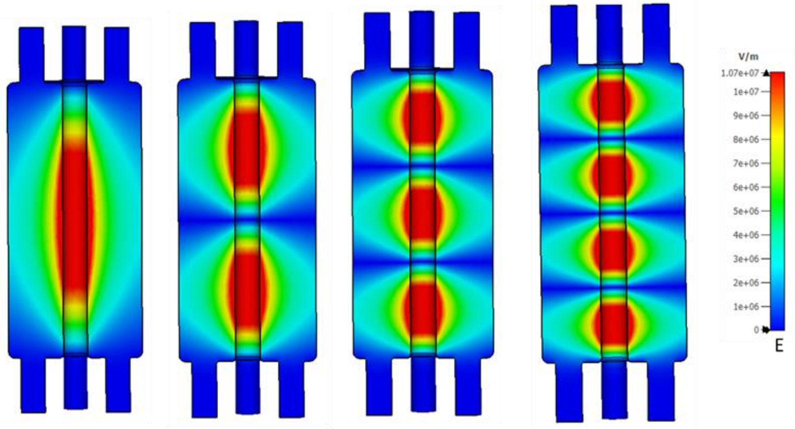
P. Dhakal

Collaboration with ODU

Understand the frequency dependence of Q-rise phenomenon

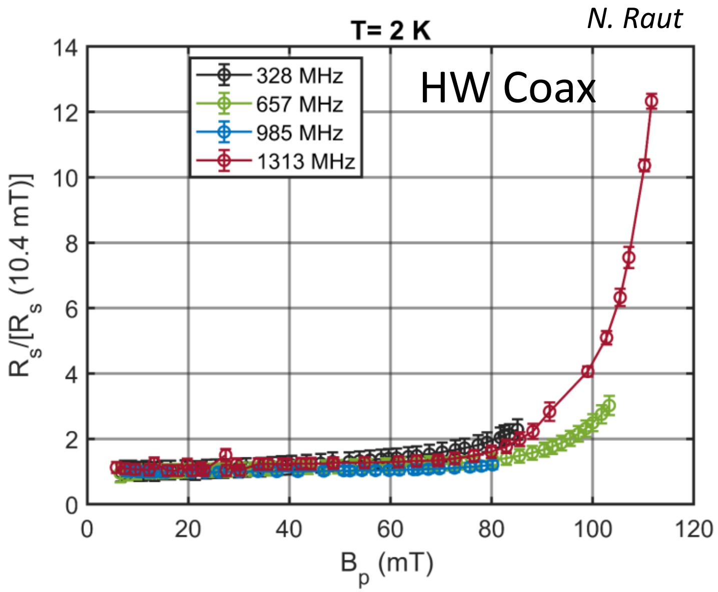
- Treatment applied to several elliptical cavities with frequency ranging from 0.75 - 3.0 GHz, showing the improved quality factor as a result of low temperature nitrogen. The frequency dependence of surface resistance is being analyzed with existing theoretical model.
- To further explore the frequency dependence of surface resistance, half wave coax cavity is considered. The baseline measurements were completed and additional surface preparation are being considered.

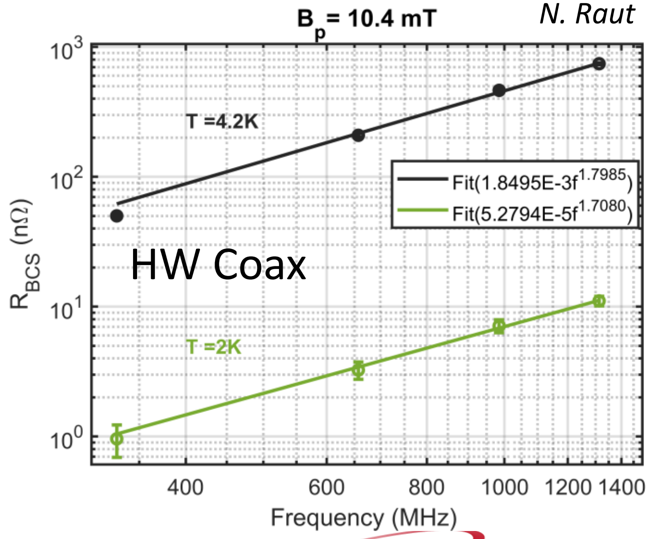




327 MHz | 654 MHz | 981 MHz | 1308 MHz

Baseline





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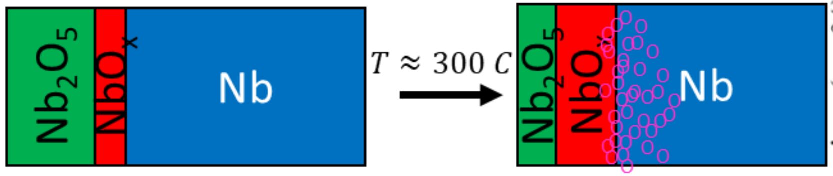
Oxide Dissolution and O diffusion during Mid-T bake

E. Lechner

- Native pentoxide dissolves
- Liberated oxygen diffuses

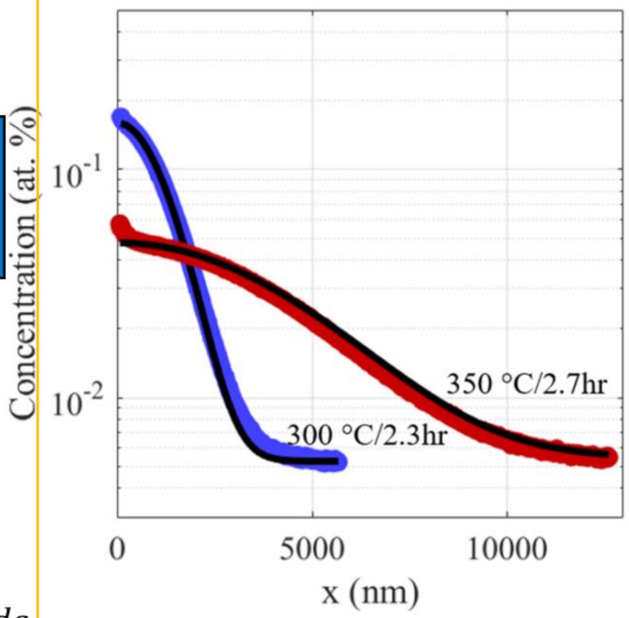


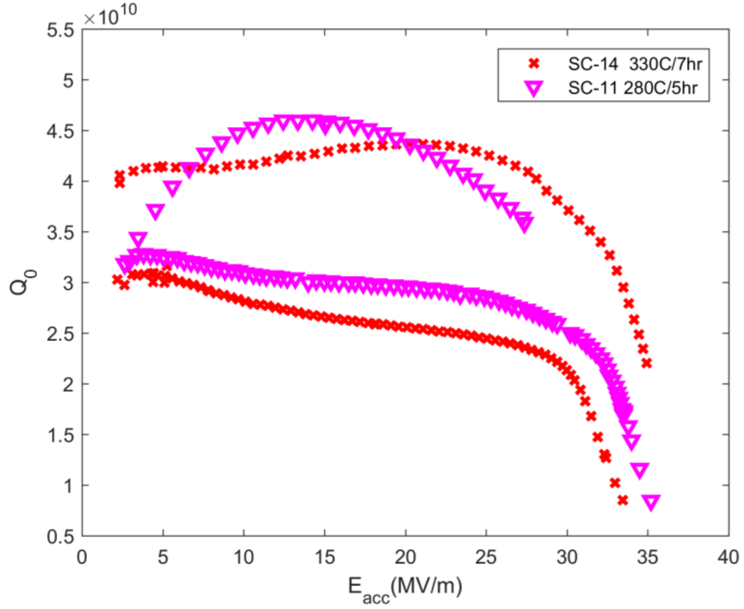
$$\frac{\partial c(x,t)}{\partial t} = D(T)\frac{\partial^2 c(x,t)}{\partial x^2} + q(x,t,T).$$

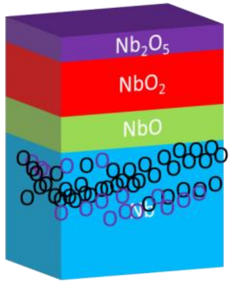
$$c(x,t) = v(x,t) + u(x,t)$$

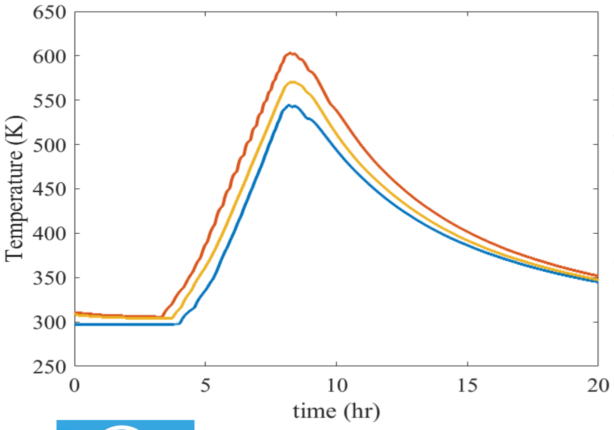
$$v(x,t) = \frac{v_0}{\sqrt{\pi D(T) t}} e^{-x^2/(4D(T)t)} + c_\infty$$

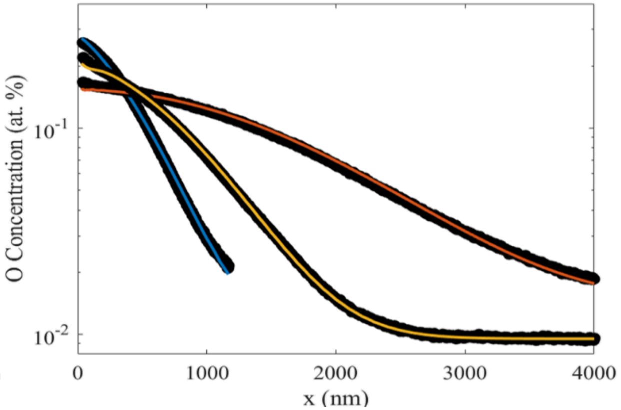
$$u(x,t) = \frac{u_0}{\sqrt{\pi D(T)}} \int_0^t \frac{k(T) e^{-k(T)s}}{\sqrt{t-s}} e^{-x^2/(4D(T)(t-s))} ds$$









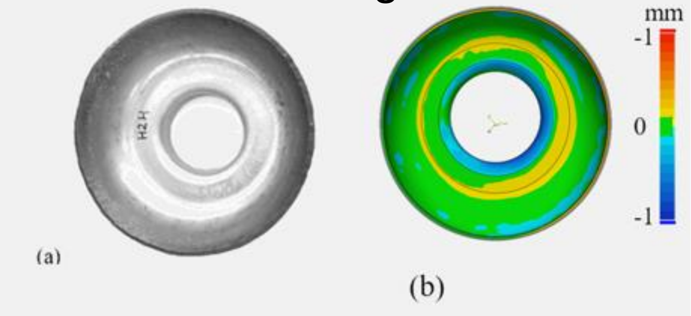


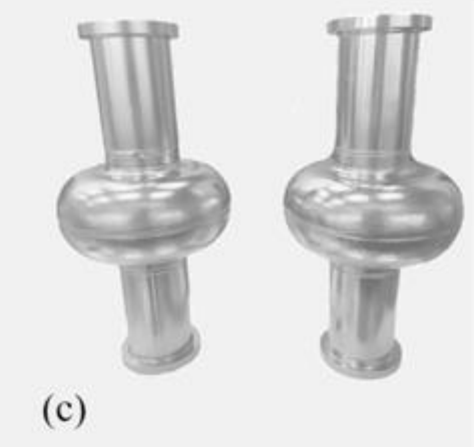
- Progress continues in examining the oxide dissolution and O diffusion process responsible for the performance enhancement in mid-T bake Reproducibly high Q.
- N-alloying requires an additional electropolishing step to remove lossy nitrides.
- May be applied to Nb with substrates incompatible with high temperature heat treatments
- On complicated shapes this may result in non-uniform impurity profiles exposed to the RF surface. No electropolishing required with O-alloying!
- The oxygen source is inherently conformal to the cavity shape

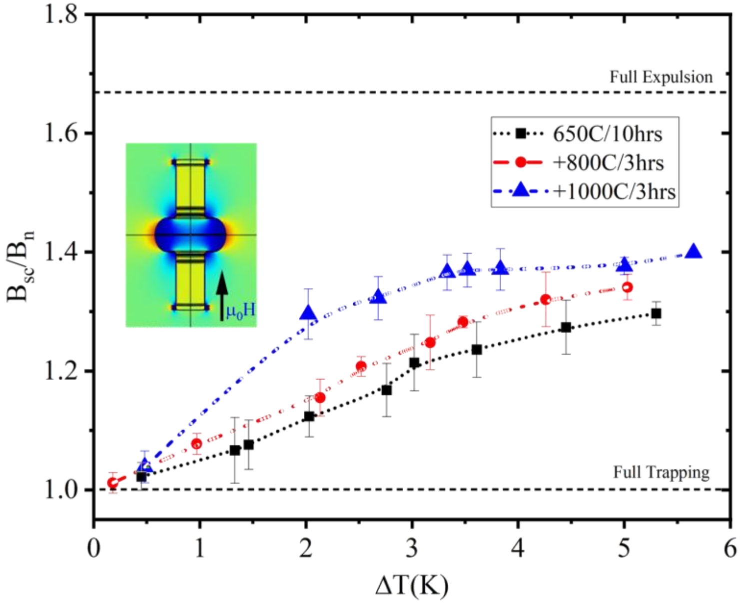
Explore Medium grain forged ingot with grain size few mmm are beneficial for the cost effective as well as may provide better performance for future SRF based accelerators.

- We have successfully fabricated, processed and tested two single-cell 1.5 GHz cavities made from medium purity, MG bulk niobium.
- The cavity made with MG niobium showed poor flux expulsion and higher flux trapping sensitivity compared to FG and LG niobium. To achieve better flux expulsion and lower flux trapping sensitivity, the cavities may require to be heat-treated higher than 1000° C.
- *Research Instruments* is fabricating a C75 5-cell cavity from the same type of material. The cavities will be processed at JLab based on the current findings.

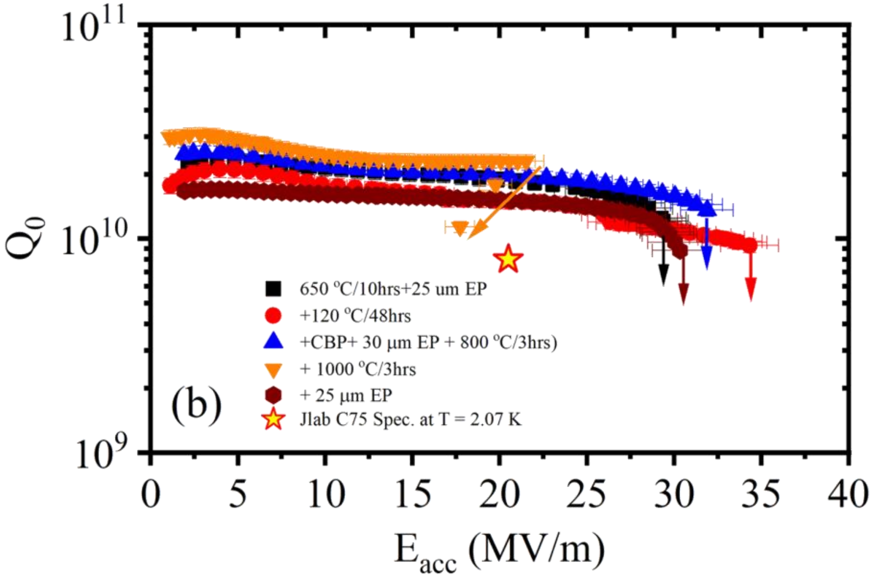
Fabrication of single cell cavities







Flux expulsion ratio, B_{sc}/B_n



Summary of rf results, Q_0 (E_{acc}) at 2.0 K

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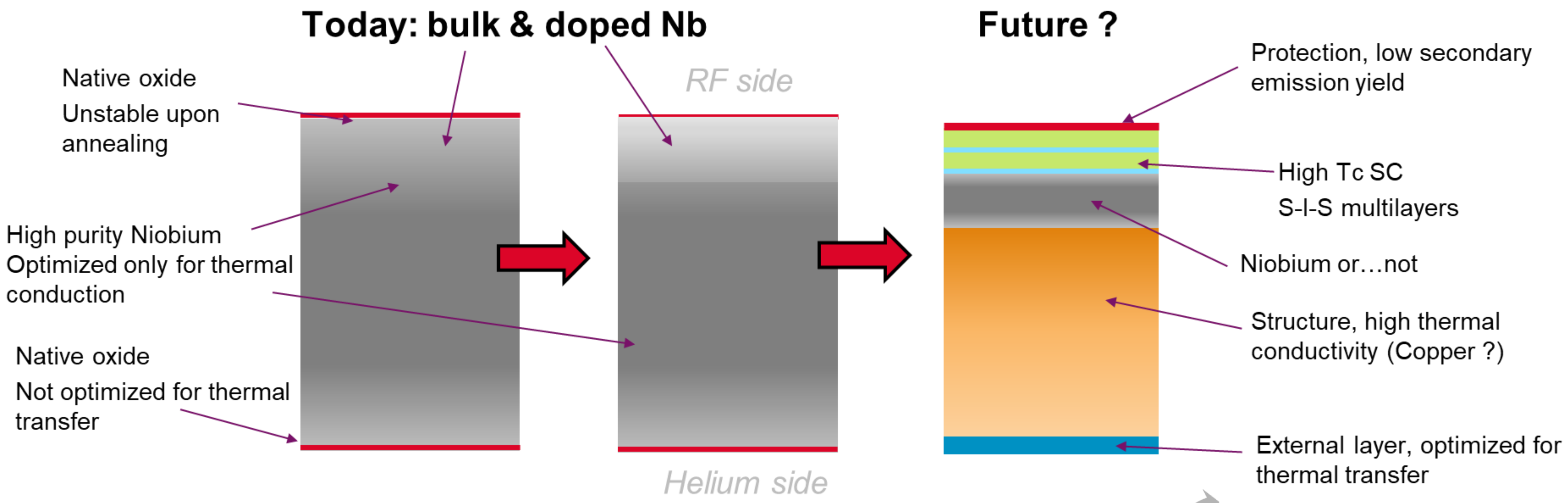
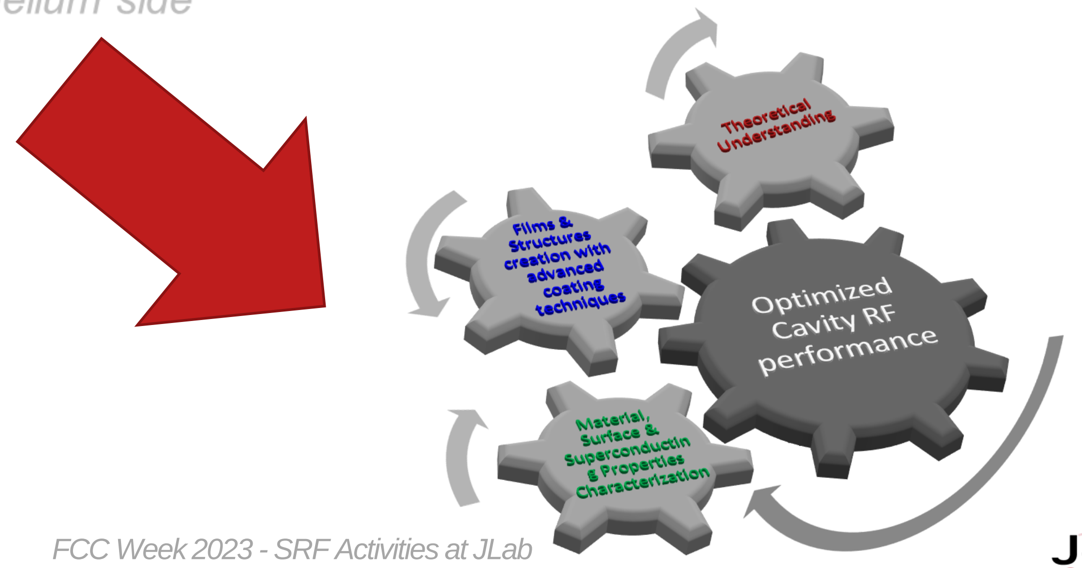
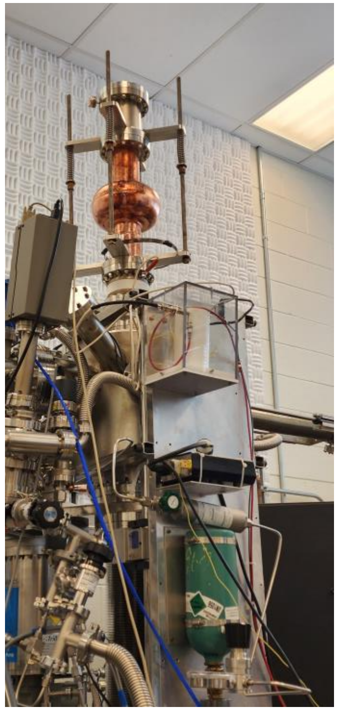
SRF Thin Films for Next-Generation Cavities





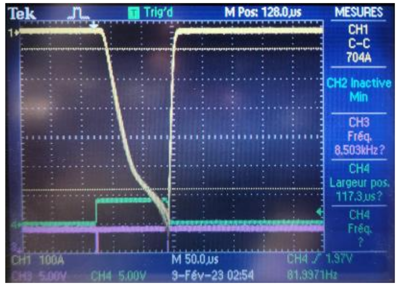
Development of Nb/Cu Cavities by Energetic Condensation

Development of Nb/Cu SRF Surfaces Development (HiPIMS & ECR)

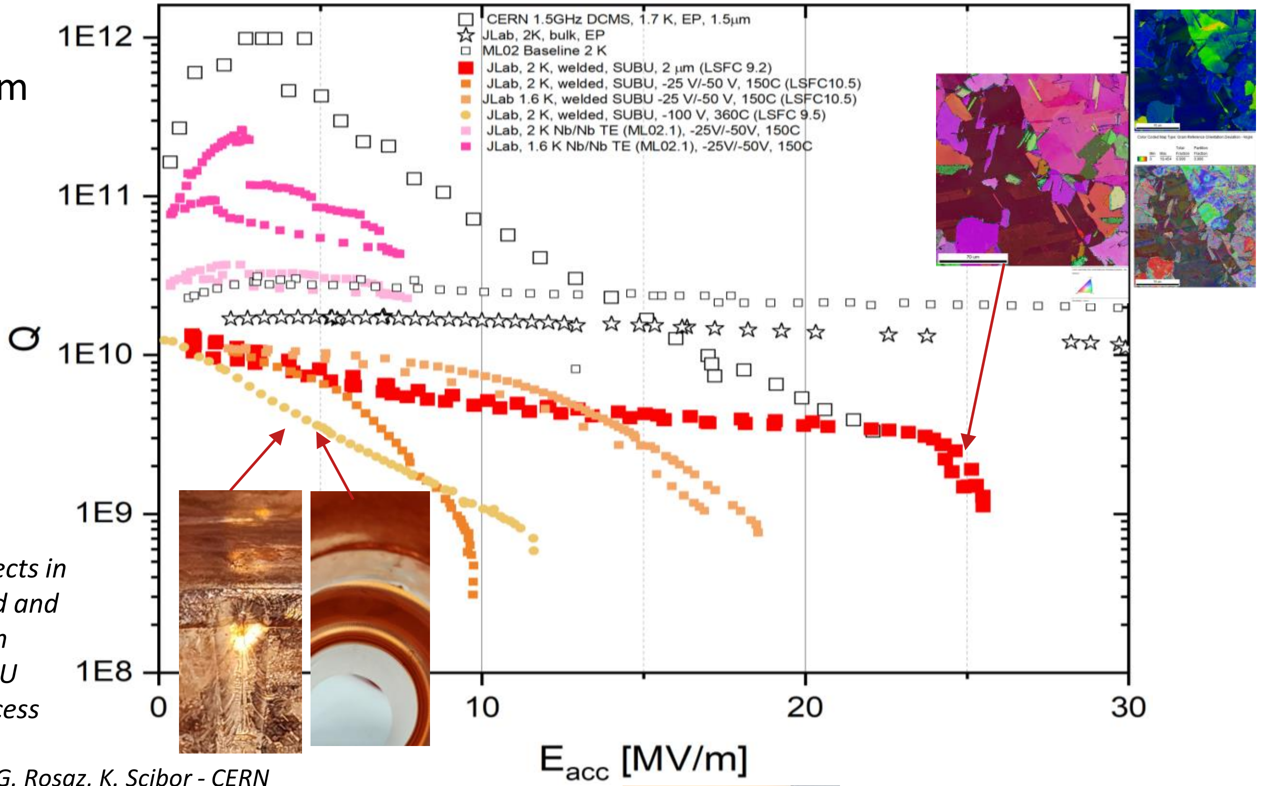


- ❑ HiPIMS cavity coating fully resumed after system rebuild

  Deposition ramped up to 1 cavity/week if substrate available
- ❑ Build a strong RF measurement program
- ❑ lower frequency cavity deposition
  (952.6 & 800 MHz, substrates on hand)



Defects in weld and from SUBU process



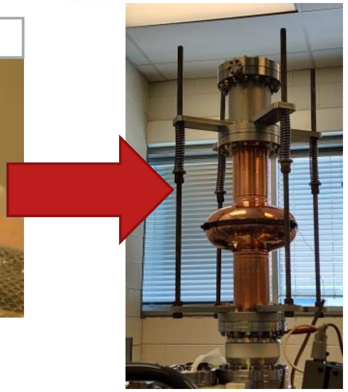
Courtesy: G. Rosaz, K. Scibor - CERN

Quality substrates

- ❑ Cu cavities machined in the bulk as “ideal” substrates (CERN)
- ❑ Cu hydroformed cavities (KEK)

Machined cell

E-beam welded to cut-offs



Received May 23
Mounted May 30
Coating week of June 12

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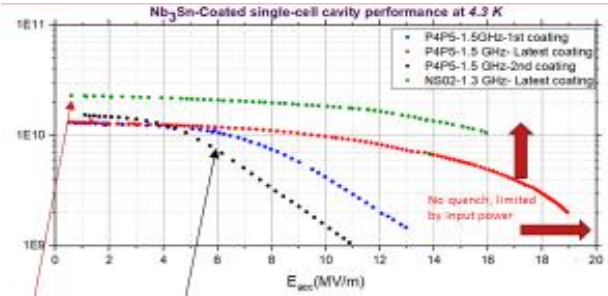
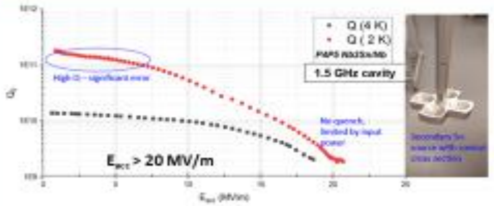
SRF Developments around Nb_3Sn

U. Pudasaini

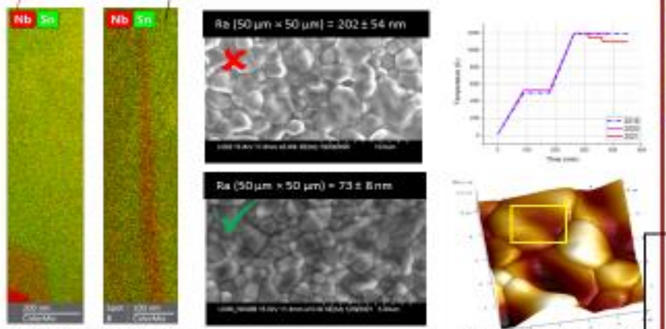
Material studies and development of Nb_3Sn-coated cavities





Several cavities reached to ~ 20 MV/m, material studies and surface improvement is in progress to maintain high Q at high E_{acc}.

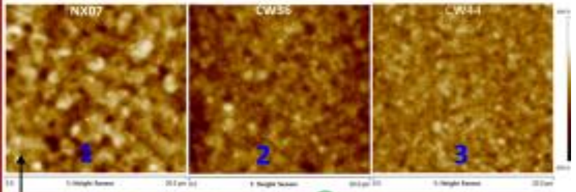
Witness sample analysis correlating RF performance and coating parameters



TEM analysis of grain boundaries with and without Q-slope

Grain size and roughness

Recurrent Sn residues contributing to residual resistance



Expt	1200 C	1150 C	1100 C	Ra (nm)	Grain size (um)	Thickness (um)
00	58 min	45 min	85 min	83.4 ± 3.1	1.15	-
01	10 min	45 min	85 min	69 ± 3	0.93	2.07*
02	10 min	45 min		40 ± 1	0.75	1.0 +/- 0.2
05	10 min			27 ± 2	0.55	0.75
04	10 min		85 min	45.5 ± 1.5	0.6	1.02

- **Coating with small grain sizes, smoother surfaces, and thinner (~ 1 μm) thinner coating with no Sn segregation or deficient grain boundary correlate with better-performing cavities.**
- **Further coating process optimization to enhance cavity performance is in progress.**

- **Several temperature profiles are identified to control roughness and thickness.**
- **Cavity coatings with selected profiles are in progress for potential improvement in RF performance.**

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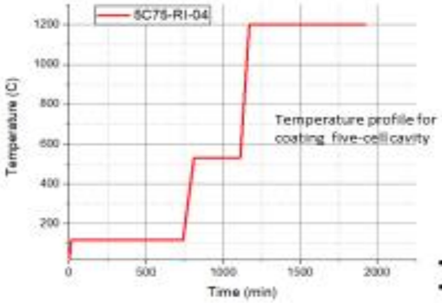
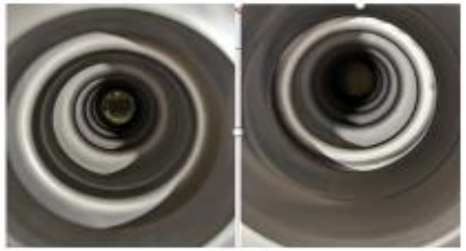
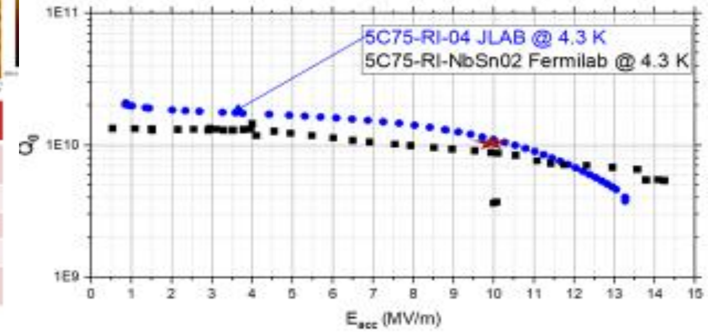
Multi-cell cavity coating and Nb_3Sn QCM





- Spec: 1E10 @ 10 MV/m
- One cavity was coated at Fermilab and another at Jlab.
- Cavity assembled in the pair and subjected to disassembly because of a leak, and assembled again with some degradation in the cavity performance
- Ready to be installed into a quarter module; test in the UITF later this year.



- Original C75 cavity made of ***large grain material***
- Limited by multipacting (no quench)

Based on G. Eremeev's ECA, Jlab cavity work supported by R&D fund.

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Process Developments towards Nb_3Sn cavities in operation

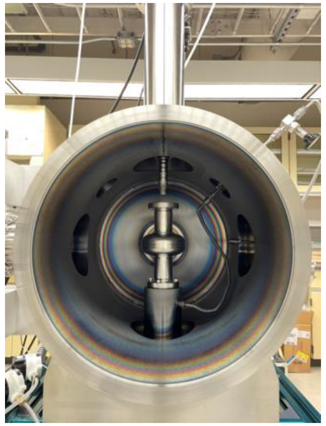
Jefferson Lab

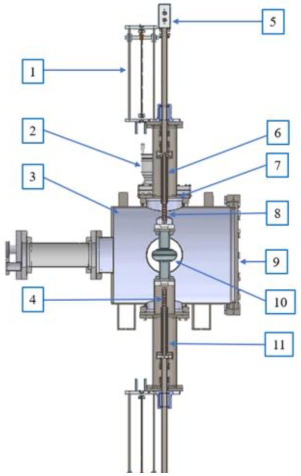
SRF Developments around Nb_3Sn

Cylindrical Magnetron Sputtering of Nb_3Sn coating (2.6 GHz Nb SRF cavity)

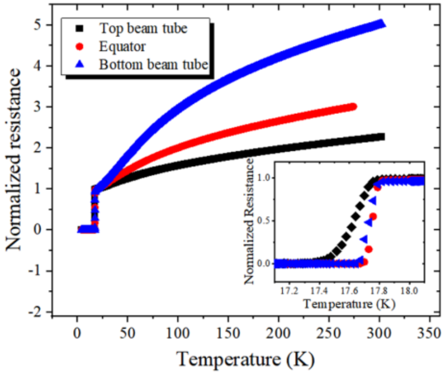
HEP Stewardship

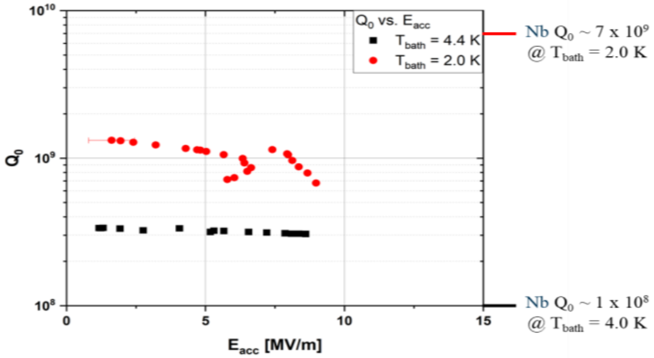
Old Dominion University · Jefferson Lab · Fermilab





Courtesy S. Sharifuzzaman et al.





Results

(Q_0) of 3.2 x 10^8 at E_{acc} = 5 MV/m at T_{bath} = 4.4 K

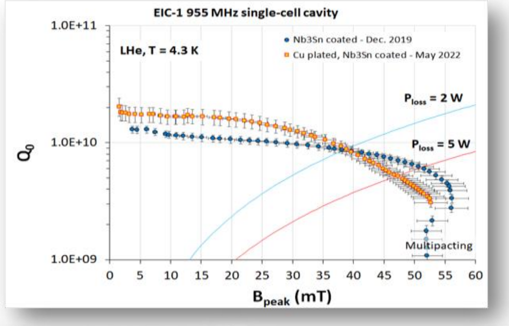
(Q_0) of 1.1 x 10^9 at E_{acc} = 5 MV/m at T_{bath} = 2.0 K

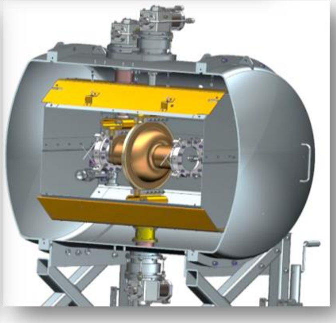
Compact Accelerators for Societal Needs

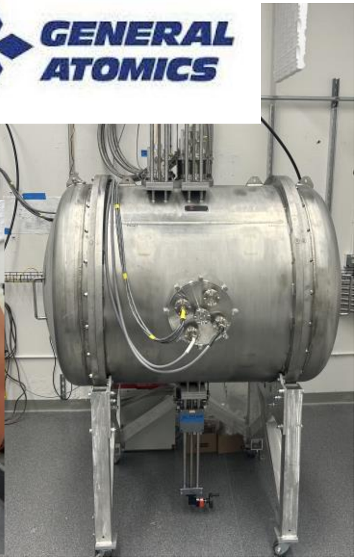
Courtesy G. Ciovati et al.

General Atomics

Development of conduction-cooled SRF cavities







Horizontal Test Cryostat for conduction-cooled SRF cavities

G. Ciovati et al., "Development of a prototype superconducting radio-frequency cavity for conduction-cooled accelerators", arXiv:2302.07201 [physics.acc-ph], 2023

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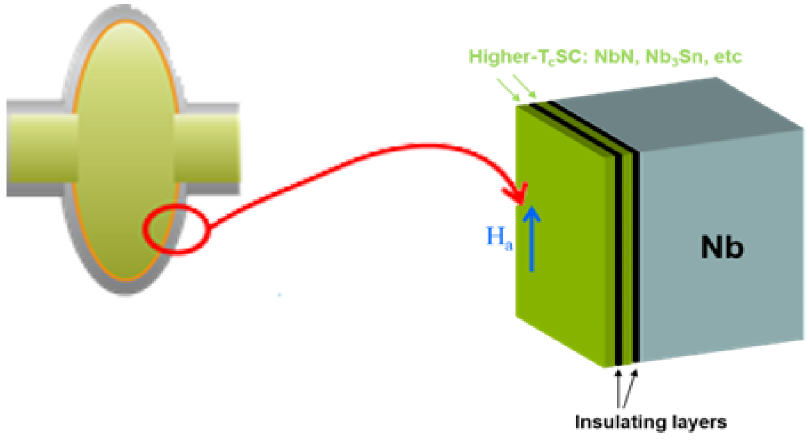
SIS Multilayered Structures

Taking advantage of the high –Tc superconductors with much higher H_c without being penalized by their lower Hc1…

Multilayer coating of SC cavities: alternating SC and insulating layers with $d_{SC} < \lambda$

Higher T_c thin layers provide magnetic screening of the Nb SC cavity (bulk or thick film) without vortex penetration

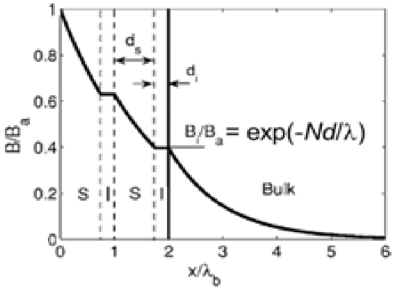
Alex Gurevich, Appl. Phys. Lett. 88, 012511 (2006)



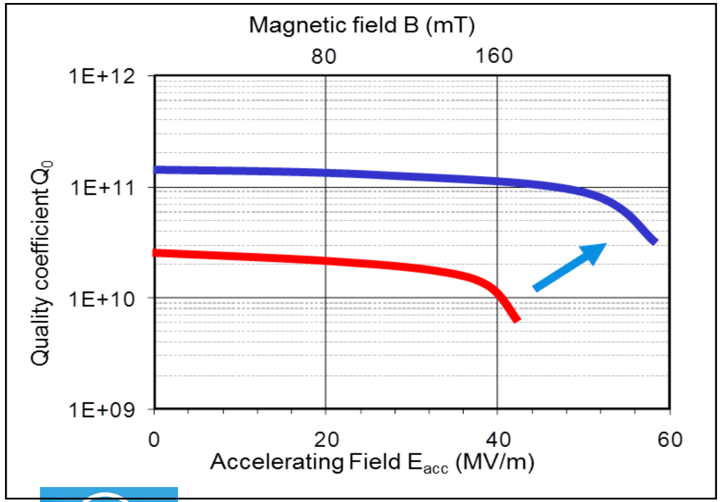
Suppression of vortex penetration due to the enhancement of H_{c1} in a thin film with $d < \lambda$

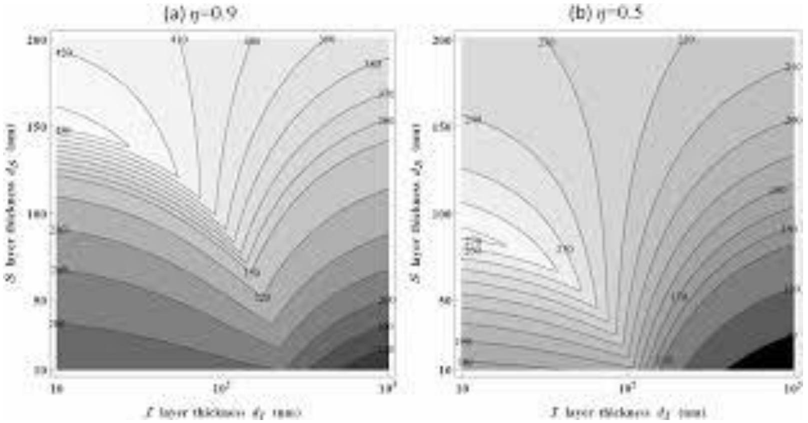
[Abrikosov, (1964)]

$$H_{c1} = \frac{2\phi_0}{\pi d^2}\left(\ln\frac{d}{\xi} - 0.07\right)$$

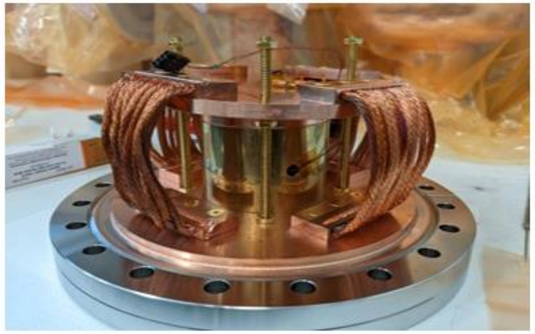


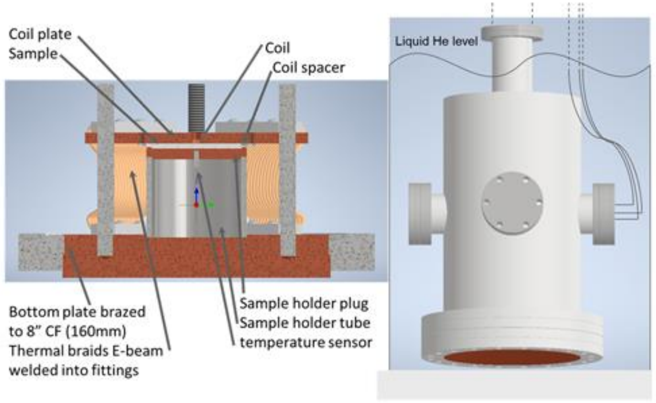
A. Gurevich, Appl. Phys. Lett. 88, 012511 (2006)





A. Gurevich, AIP Advances, 5, 017112 (2015)
T. Kubo, Y. Iwashita, T. Saeki, APL 104, 032603 (2014)
T. Kubo, SUST 30, 023001 (2017)





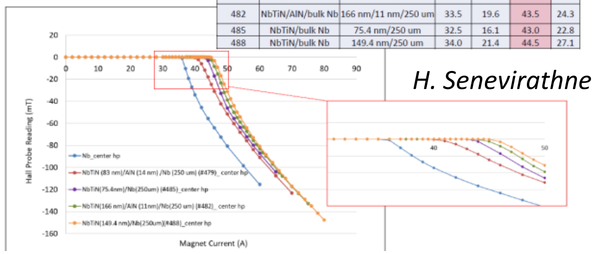
3rd Harmonic Setup for H_{FP} measurement

SIS Multilayered Structures based on NbTiN

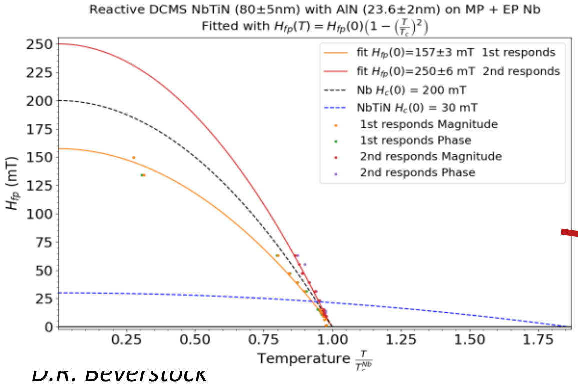
Measurement on NbTiN SIS structures on 1” & 2” Nb substrates

Center Probe at 2.00 K

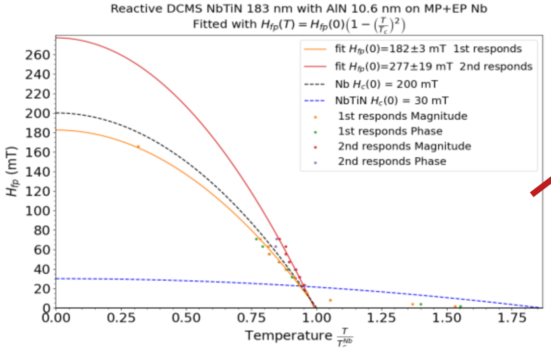
Sample #	Sample	Thickness	Current at first full penetration (A)			
			At the center			
			4.35 K	%	2.00 K	%
3	Nb	250 um	28.0	-	35.0	-
479	NbTiN/AlN/bulk Nb	83nm/14 nm/250 um	30.0	7.1	39.5	12.8
482	NbTiN/AlN/bulk Nb	166 nm/11 nm/250 um	33.5	19.6	43.5	24.3
485	NbTiN/bulk Nb	75.4 nm/250 um	32.5	16.1	43.0	22.8
488	NbTiN/bulk Nb	149.4 nm/250 um	34.0	21.4	44.5	27.1

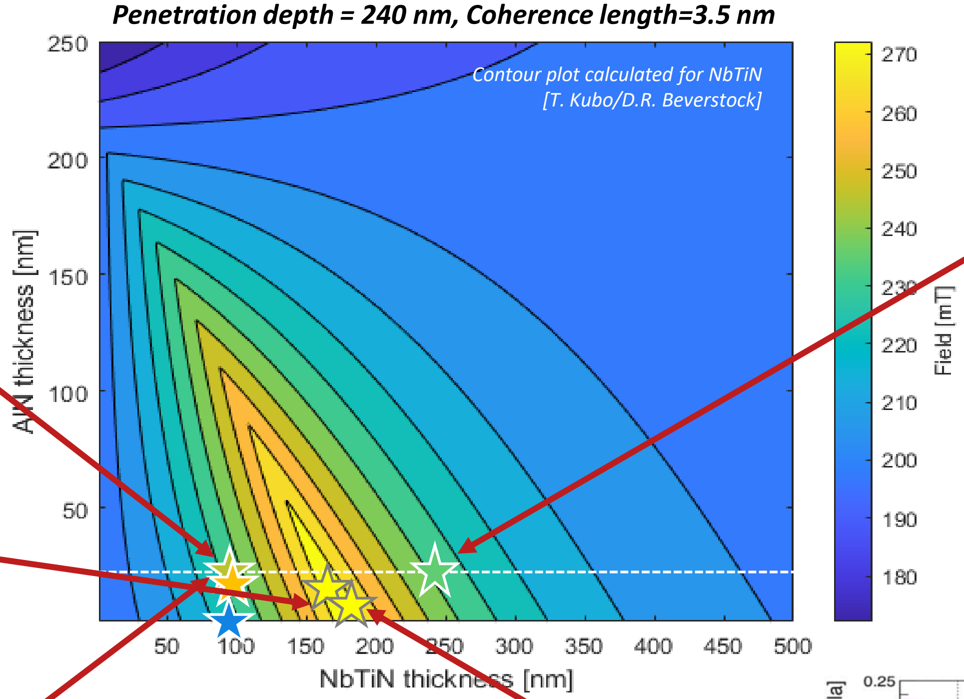


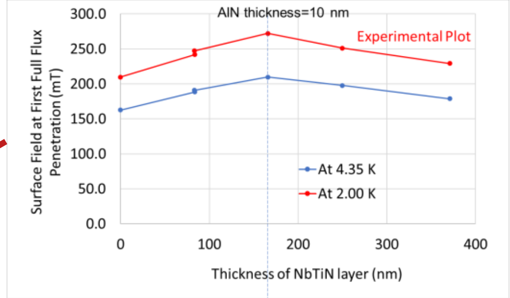
H. Senevirathne

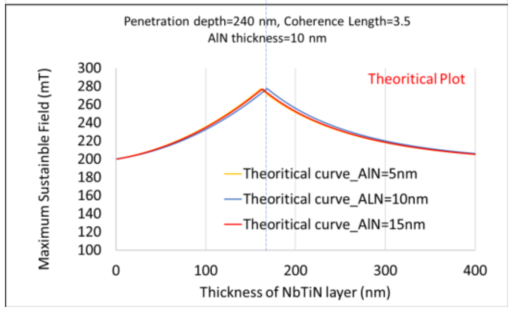


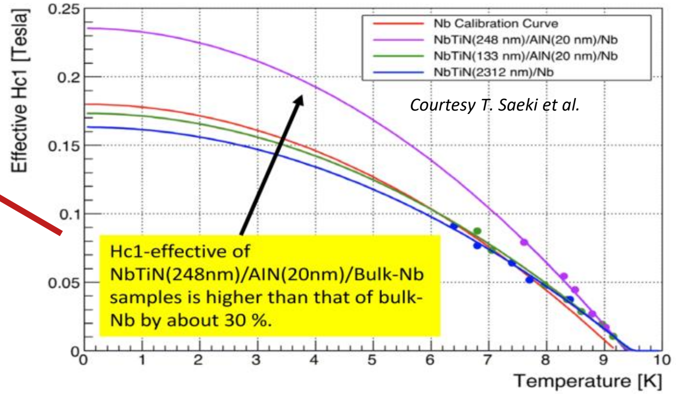
D.R. Beverstock





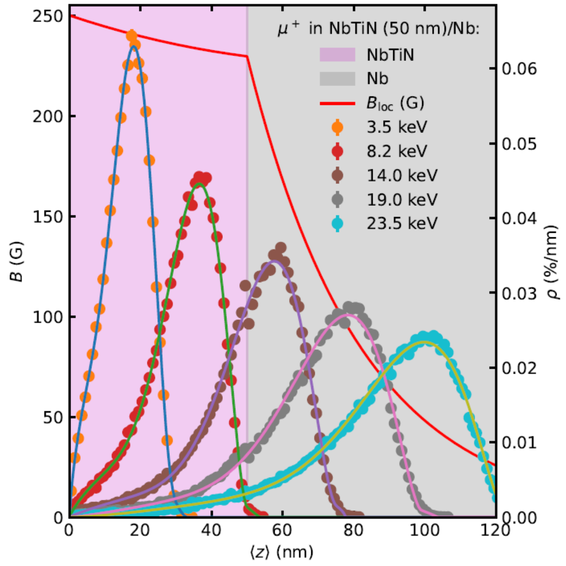






- *Deposited SIS structures fit the theoretical model*
- *3rd harmonic measurements show field enhancement up to 20-60% compared to base bulk Nb .*
- *Effect most sensitive to coherence length*

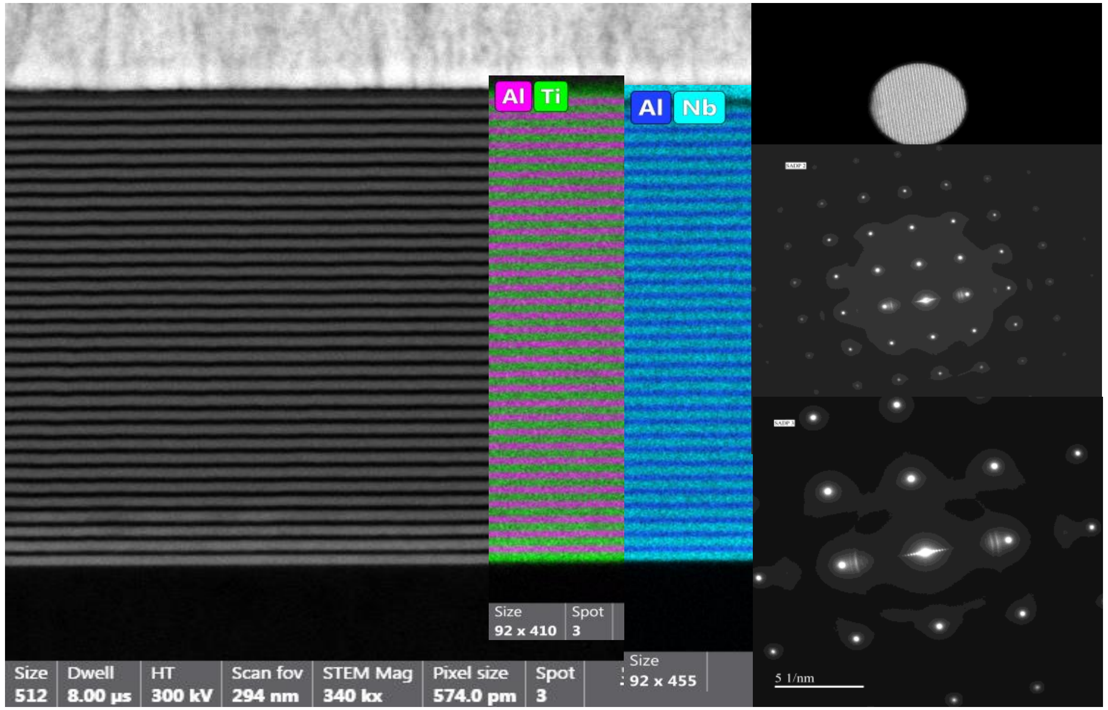
SIS Multilayered Structures based on NbTiN



LE-μSR measurements on NbTiN/Nb

TRIUMF

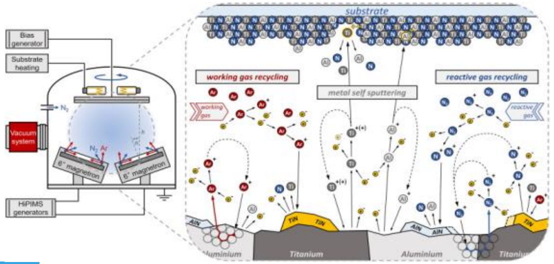
- *μSR measurements demonstrate the requirement of the dielectric layer in the SIS model*
- *High quality SIS structures for thicknesses all the way down to the nm level (Stack of 32 bilayers NbTiN/AlN/NbTiN/MgO is fully crystalline*



Implementation on QPR samples and elliptical cavities for RF evaluation

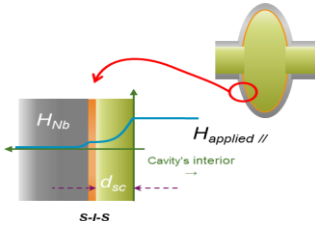
Refine deposition process for denser, more relaxed material in thin layers

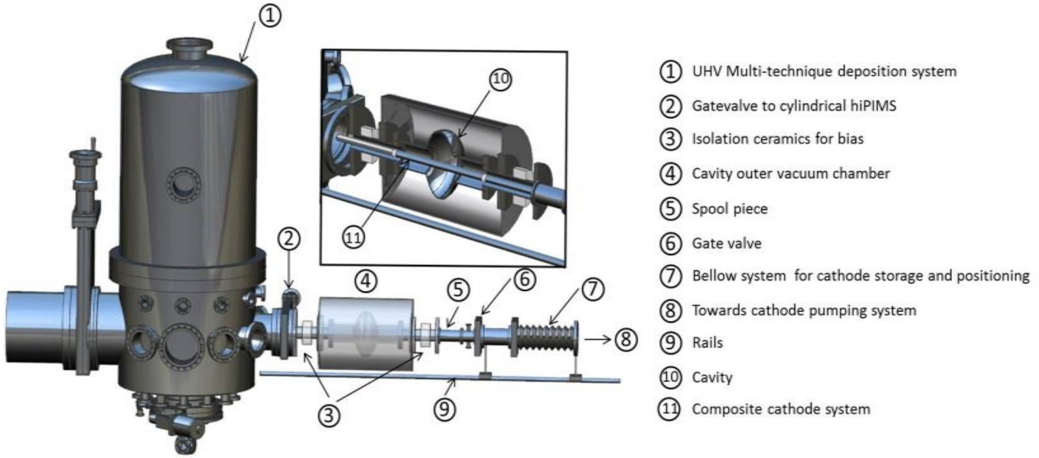
Re-HiPIMS



SIS cavity deposition setup

for elliptical geometries -





Development of Nb_3Sn Based SIS

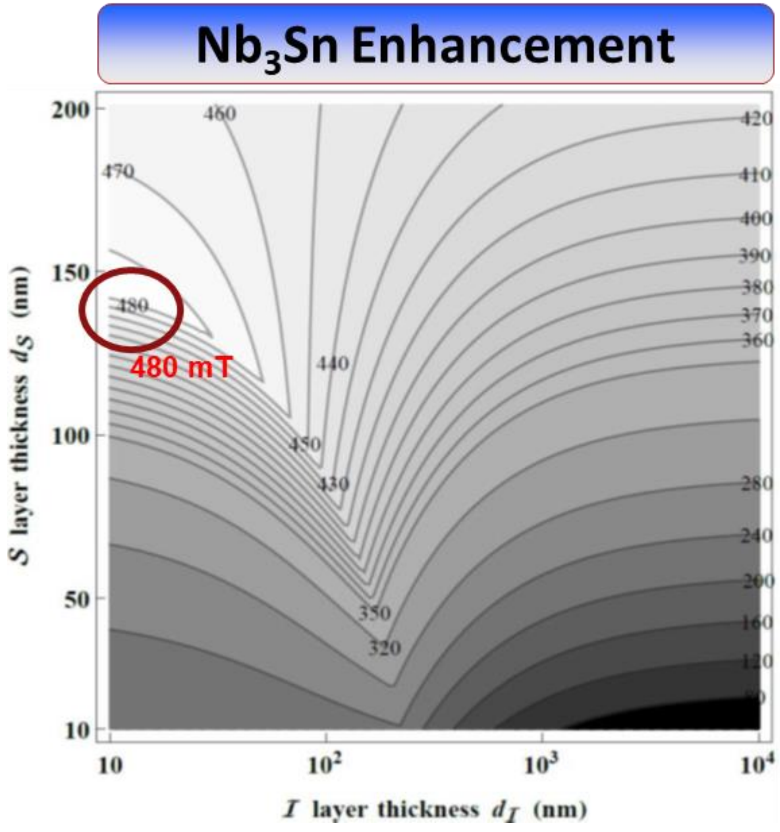
Nb_3Sn based multilayers foreseen to bring the highest enhancement of H_{max} for SIS structures

Nb_3Sn on Nb: $H_s = 0.84H_c$ = 454 mT and λ = 120 nm (moderately dirty):

H_m = 507 mT, E_{acc} = 120 MV/m, d_m = 1.1λ = 132 nm

doubles the superheating field of clean Nb

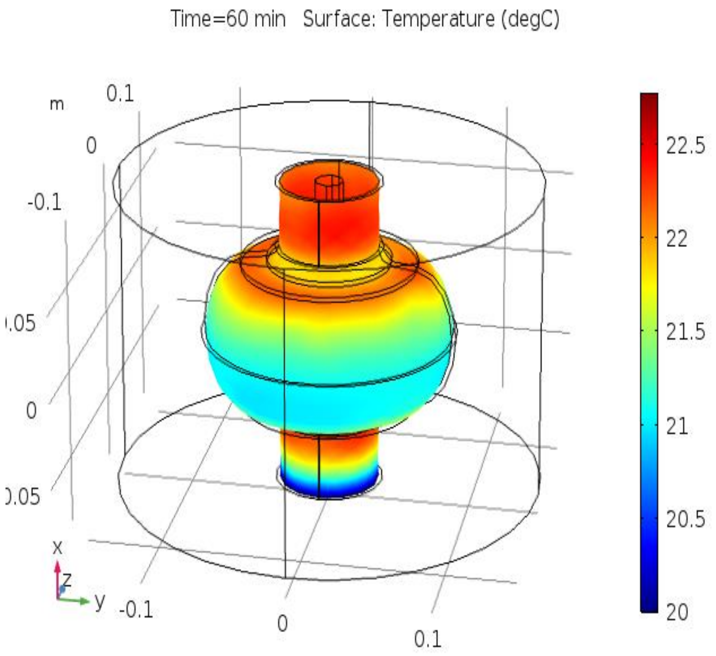
- Current deposition techniques incompatible with integration with many dielectric materials, relying only on thermal energy to achieve the desired A15 phase
- Use HiPIMS/ECR to create dense Nb_3Sn films with high Nb incident ion energy
  - Explore the coating parameter space (ion energy, temperature) for Nb_3Sn with 18-25% stoichiometry
  - Effect of ion energy/temperature on A15 phase formation, differential strain between substrate and film
- Measure H_{C2} for nominal (~ 2µm) coated Nb_3Sn and establish the contour plot S layer thickness versus I layer thickness for the produced Nb_3Sn.
- Thickness series to determine/verify optimum layer thicknesses with H_{fp} measurements
- Magnetic screening measurements with SQUID/3rd harmonic local magnetometry
- Implementation on QPR samples and elliptical cavities for RF evaluation
- Application of thick Nb_3Sn on Cu films for conduction cooled cavities, industrial & environmental accelerators



Surface & Substrate Preparation

Pulsed EP for Nb

M. Ge, H. Tian



- Use analytical electrochemistry and surface characterization to develop alternative safer electropolishing method for Nb cavities and substrates
- Pulsed reversed Bi-polar EP focused on the upgrade of high voltage pulse controller for completely HF Free cavity development
  Single cells (1.5 & 1.3 GHz)
- Implement technique on cavity parts to enable cavity processing without HF
  New setup in R&D Chemroom

Cu EP

S. Bira

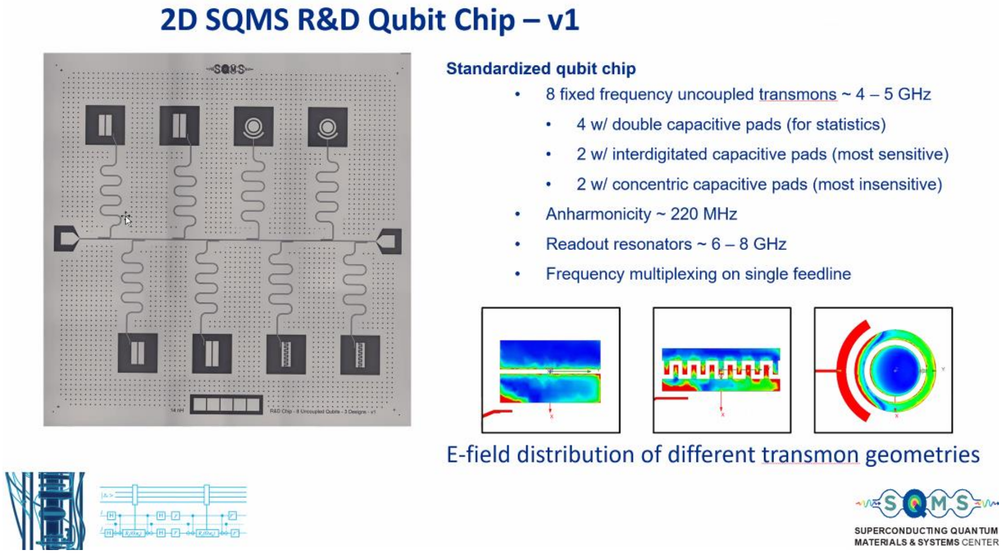
- Use analytical electrochemistry and surface characterization to develop Cu electropolishing method for Cu substrates
- System being design for operation in a walk-in fume hood (R&D Chemroom)
- Interaction with CERN

Beyond SRF – Quantum Information Systems

QIS NP Funding for 3 years

Jefferson Lab · University of Waterloo · Fermilab · SQMS – Superconducting Quantum Materials & Systems Center

- Exploit JLab high quality films deposited by ECR for qubit optimization
  - *Optimization of Nb/Al_2O_3 films in the thickness range of 150-200 nm specific for qubits*
  - *Development and optimization of Nb/Si*
  - *Investigation of other superconducting materials*
  - *Optimization of transmon & flux qubits coherence time*
  - *Optimization of 2D and 3D design concepts*

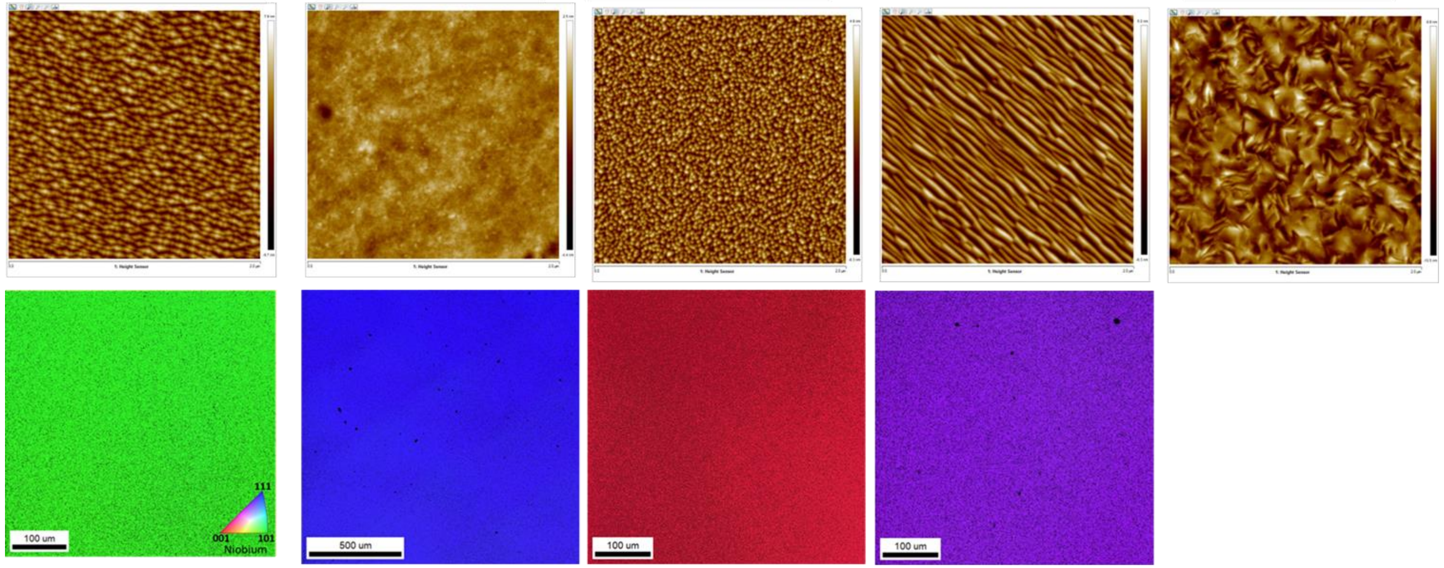


Jefferson Lab

High quality Nb films for Qubits

150 nm ECR Nb films nucleated at 304 eV, subsequent growth at 64 eV

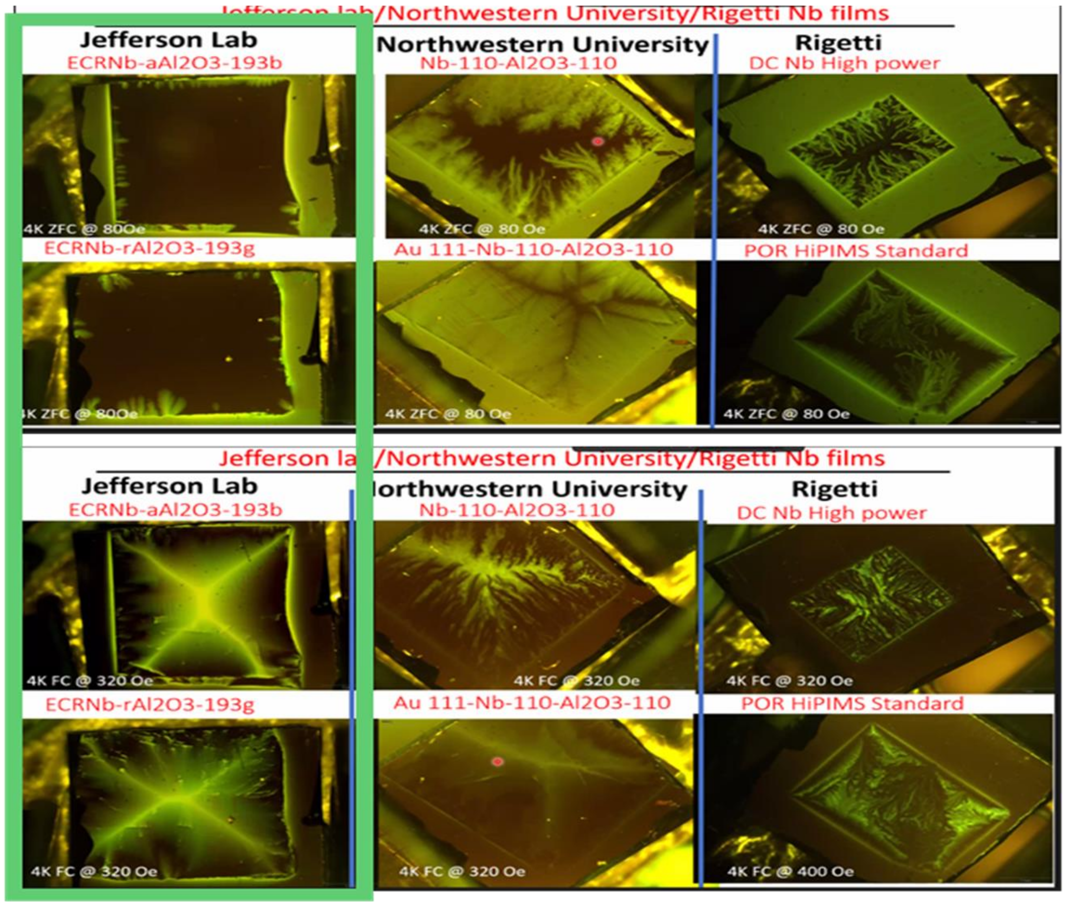
Nb/ Al_2O_3 (11-20) | Nb/ Al_2O_3 (0001) | Nb/ Al_2O_3 (1-120) | Nb/ Al_2O_3 (10-10) | Nb/ fused silica



	Al_2O_3					Fused Silica
R_a [nm]	(11-20)	(0001)	(1-120)	(10-10)	ceramic	
2 um	1.54	0.28	1.03	1.35		1.81
5 um	1.52	0.34	1	1.31		1.86
10 um	1.5	0.47	0.89	1.17		1.84
50 um	0.95	0.55	0.66	0.46		1.69
T_c [K]	9.33	9.33	9.32	9.28	9.29	9.24
ΔT_c [K]	0.07	0.06	0.04	0.05	0.06	0.26
RRR	75.60	79.00	83.00	68.00	39.00	14.00

Magneto-optical Measurements

R. Prozorov et al (Ames)



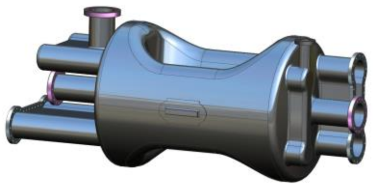
Preliminary work : collaboration with JLab, FNAL, Ames Lab, Temple University

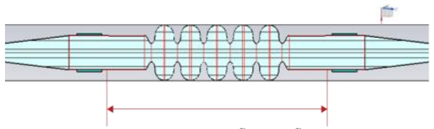
SUMMARY

- SRF Development for Projects

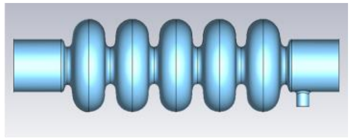
  EIC

  - ESR 591 MHz single cell: *entering prototype phase*
  - ESR 591 MHz 5-cell cavities, starting with RCS.
  - 197 MHz crab cavity: *entering prototype phase*
  - Cooler and pre-cooler: *developing requirements*
  - Harmonic injection for RCS
    - Kicker fabrication, test in UITF





Bare cavity ~1.73m flange to flange
JLab design



BNL 650MHz cavity scaled to 591MHz

  PERLE HOM-Damping Studies converging to a solution (DQW), 5-cell mock-up under way

  BESSY VSR Brazing procedure & fixture development completed

- Technological developments

  Buk Nb– *Refinement and Modeling for different processes to maximize bulk Nb performance*

  Nb/Cu Development – *ECR & HiPIMS continued development, substrate quality critical, towards mitigation of Cu slope*

  Nb_3Sn films on Nb – *Material improvement continues, implementation in QCM and industrial accelerator*

  Alternate superconductors & SIS Development – *towards cavity implementation for NbTiN*

  – Development of SIS based on Nb_3Sn

  Synergistic Applications beyond SRF *: Metamaterials, Quantum Devices, Novel Electronics and Sensors*

Acknowledgement