SRF R&D overview

R. Rimmer
For
SRFR&D Dept.

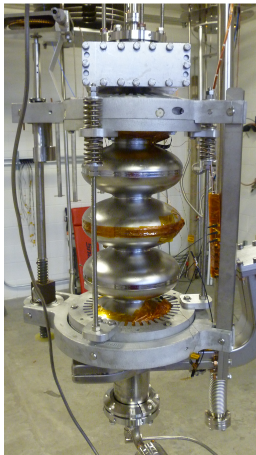
Overview

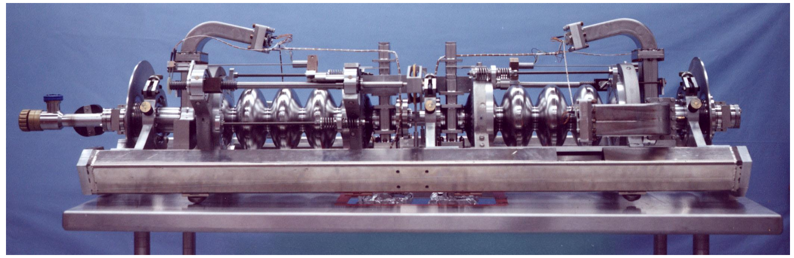
- CEBAF support
- JLab EIC
- Partnerships/WFO
- SRF Core R&D
  - Efficiency, Energy, Intensity frontiers
- Education

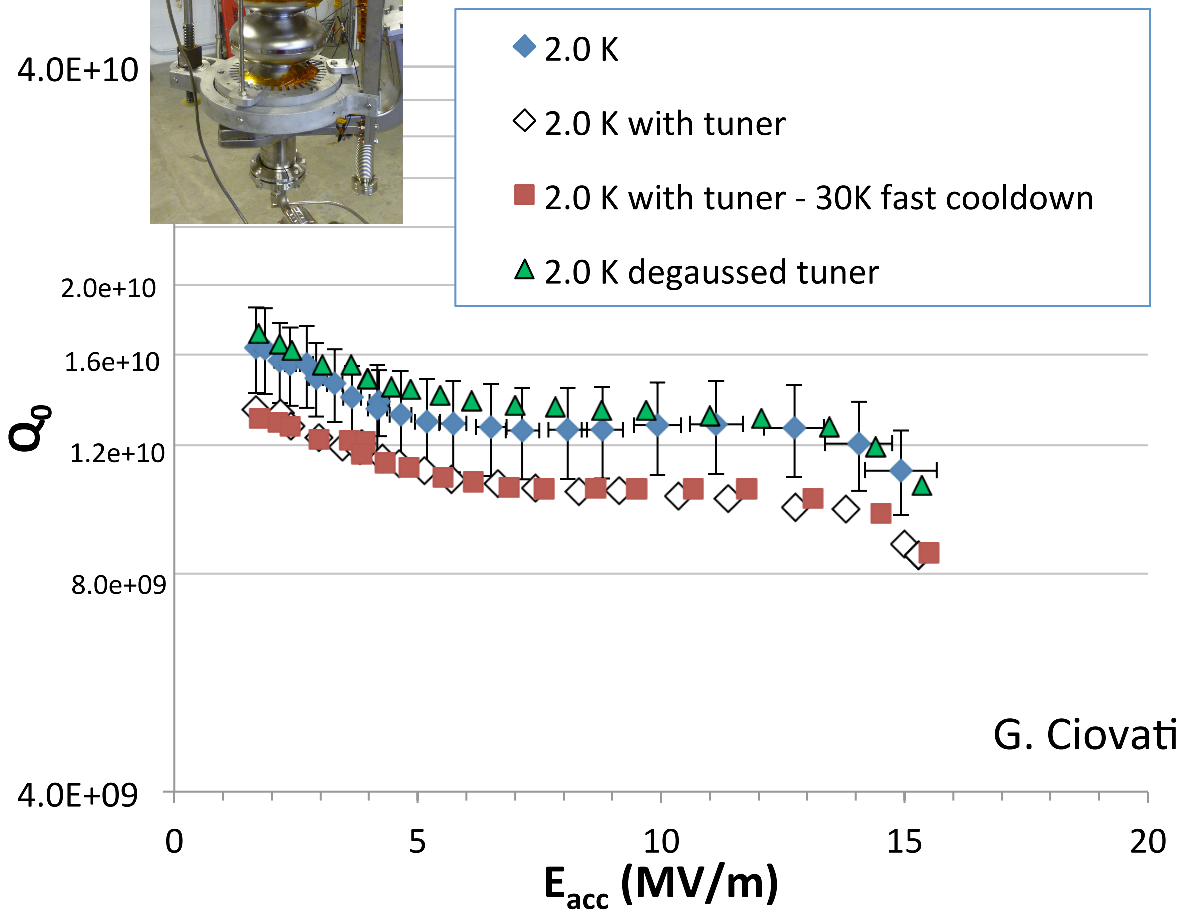
CEBAF support

- **“C75” cavity R&D**
  - New cell shape, ingot material, minimal changes to cryomodule
- **Investigating gradient loss in CEBAF**
  - New field emitter turn on, improved particulate control
- **Investigating Q loss in CEBAF-style modules**
  - “Magnetic hygiene”, search for sources of trapped flux
  - Possible contributions from coupler losses
- **Helping to maximize C100 and overall linac availability**
  - Support linac PIT, helium processing etc.
- **Other RF or SRF development projects**
  - 750 MHz separators, new Quarter CM, new warm capture, etc.

Investigation of low-Q in CEBAF cryomodules







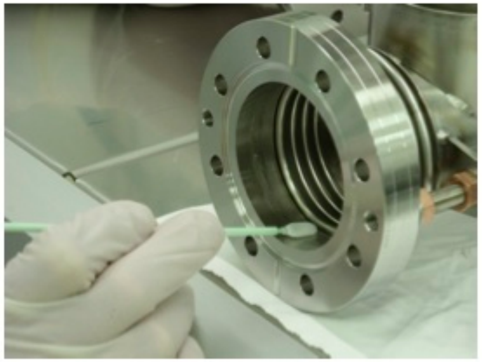
- Systematic investigation of the impact of residual magnetic field on Q_0 of 5-cell cavity in the VTA
- ~15% additional losses from trapped residual field from magnetized tuner components
- Q_0 successfully recovered by degaussing tuner components
- Investigating other possible contributions such as waveguide and cold window losses

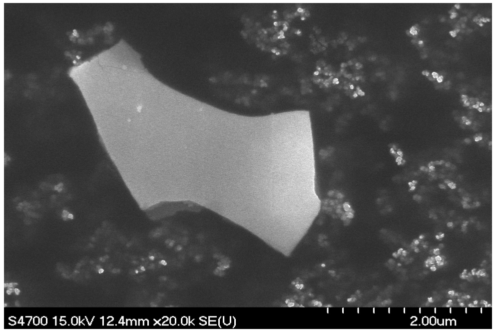
Field emission study, improved particulate control

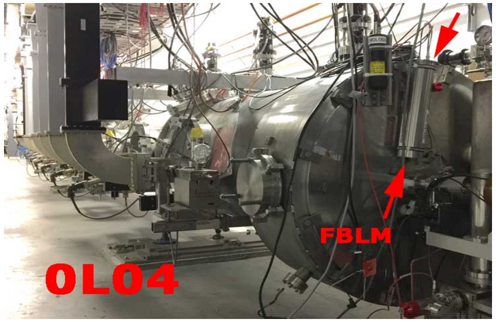
R. Geng

- Turn-on of new field emitters in cavities in CEBAF tunnel causes trip rate increase.
- Running at Eacc=15-20 MV/m, new C100 cavities more vulnerable if cause the same.
- A new initiative aims to understanding sources of problem and provide knowledge-driven mitigation.
  - First result: Pointing to particulates generated by beam line ion pumps (SRF2015 poster).
  - First test of new diagnostics: Fast X-ray detection near C100 module.
- A mini-workshop was organized on February 29, 2016 with a focus on the beam-line particulate field emitters.

https://www.jlab.org/indico/conferenceDisplay.py?confId=139



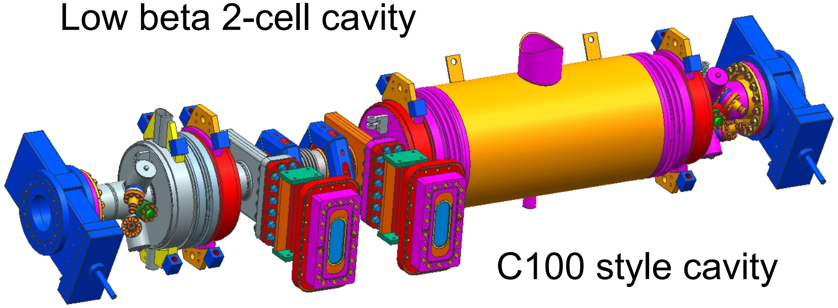




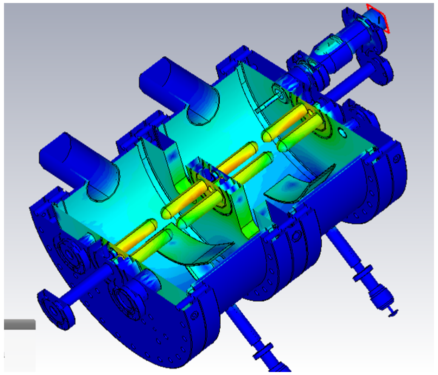
CEBAF RF development projects

- Improved "quarter" cryomodule with accelerating capability of up to 10 MeV
- 750 MHz (4-hall) separator cavities
- New graded-beta Cu capture cavity
- "new" C75 cavity (HC cell shape)

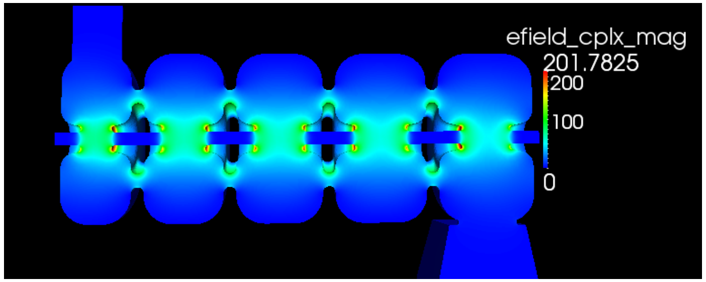
Low beta 2-cell cavity



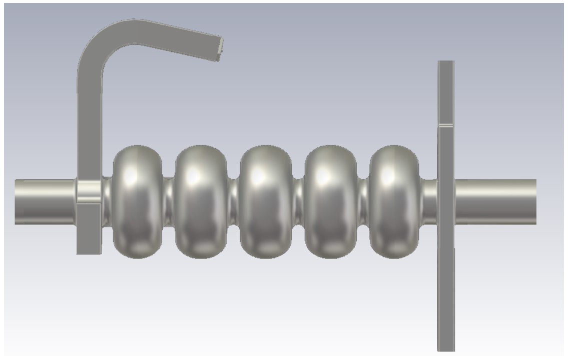
C100 style cavity



750 MHz 4-rod



New warm capture cavity

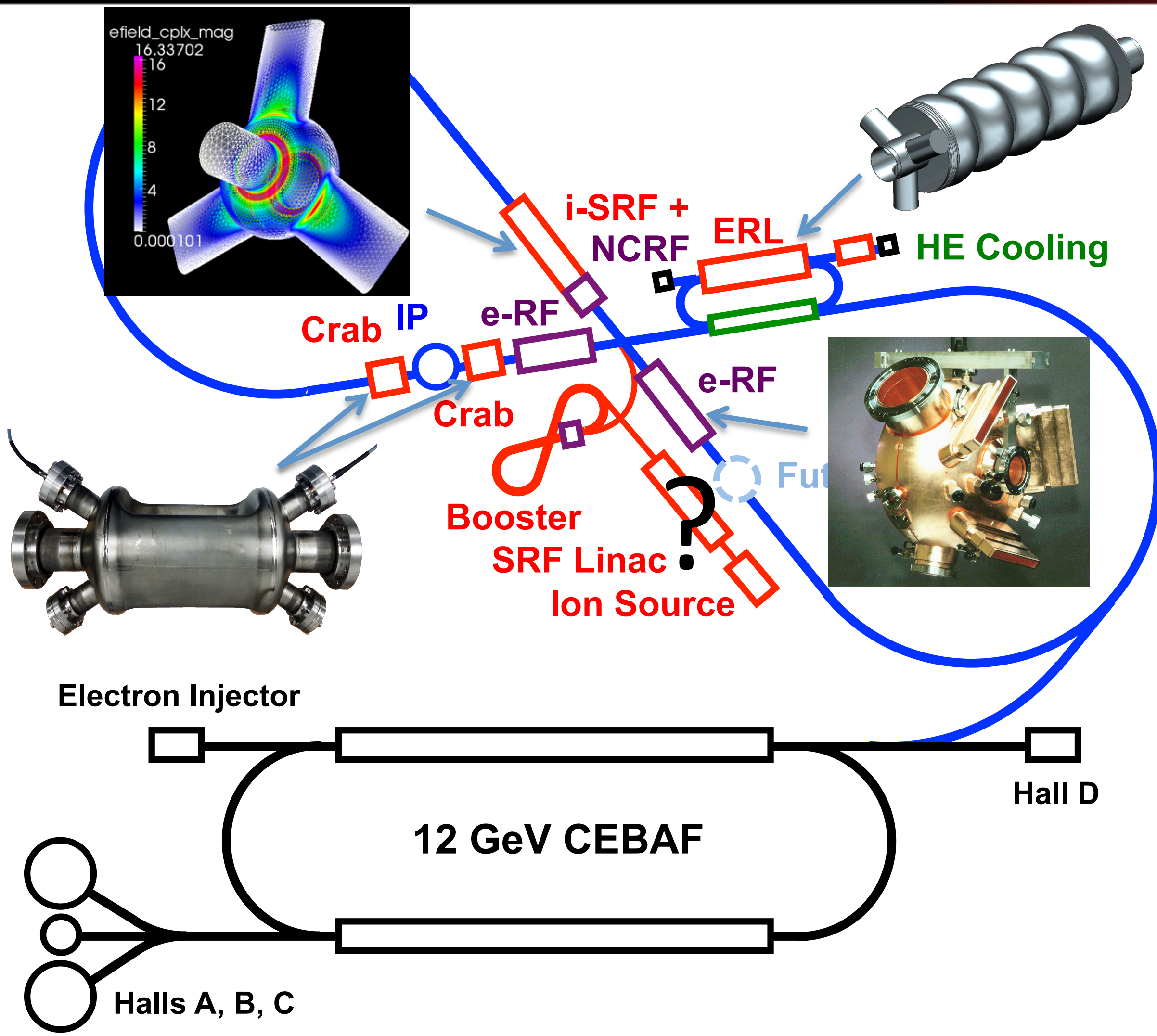


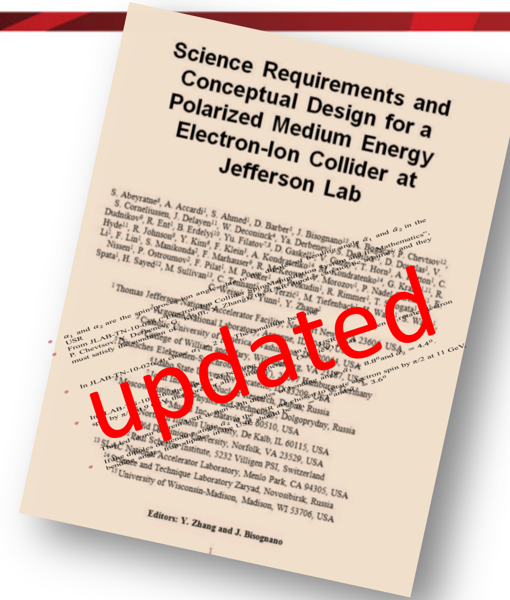
C75

JLab EIC RF Systems

- JLab EIC baseline design updated in Jan 2015
- **Electron ring**: PEP-II warm RF adopted
  - Proven technology, low cost
  - Enough cavities and klystrons available
  - 476.3 MHz buckets can be filled from CEBAF linac with simple timing system
  - Upgrade to 952.6 SRF in future
- **Ion ring**: new 952.6 MHz SRF plus ~ 1MHz ramping cavities (e.g. J-Parc Metglas loaded)
- **Crab cavity system** now 952.6 MHz
- **Cooler source and ERL** now 952.6 MHz
  - Cooler baseline became 200 mA, no circulator ring
- Ion injector chain not affected

JLab EIC Conceptual Design





Stage I EIC

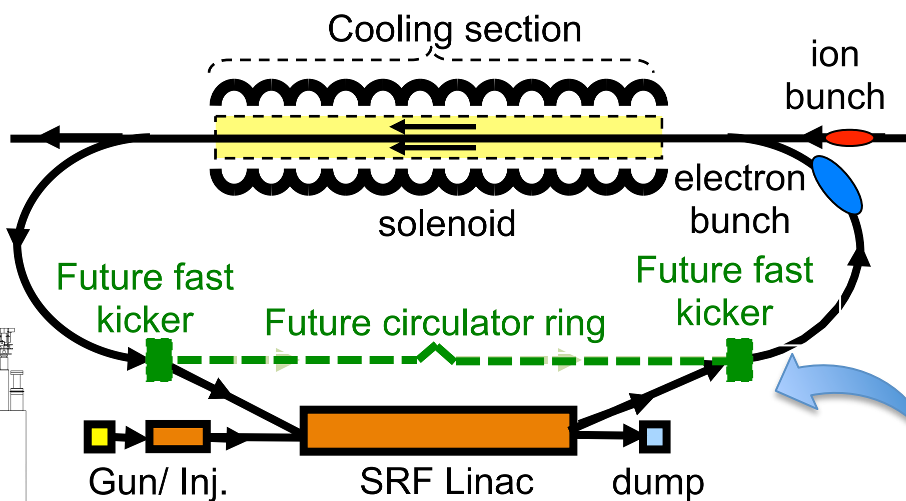
- CEBAF as full-energy e^-/e^+ injector
- 3-10 GeV e^-/e^+
- 8-100 GeV protons
- <40 GeV/u ions

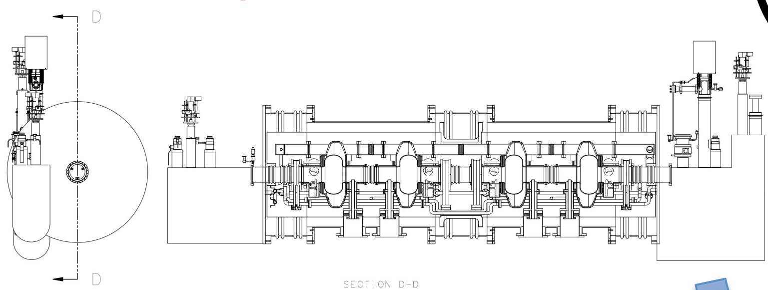
Stage II EIC

- up to 20 GeV e^-/e^+
- up to 250 GeV protons
- up to 100 GeV/u ions

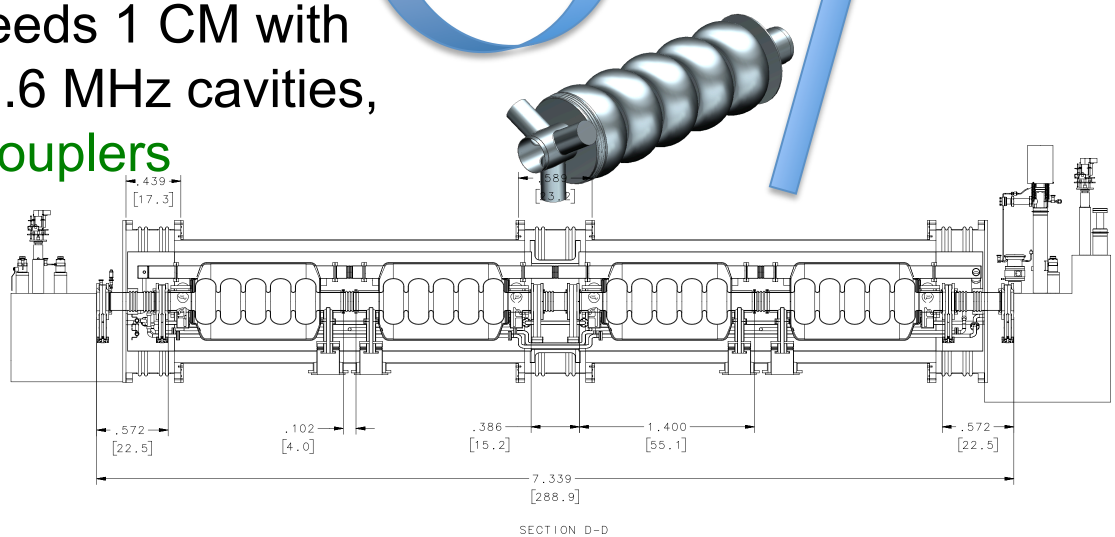
e-cooler ERL

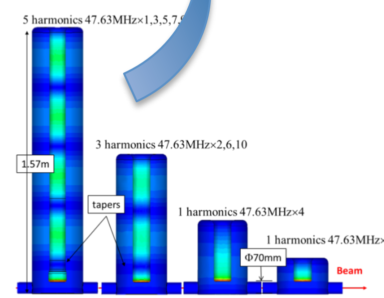
Injector Cromodule similar to storage ring, 1 CM, 4 x 1-cell 952.6 MHz cavities, high-power couplers.





ERL LINAC needs 1 CM with four 5-cell 952.6 MHz cavities, lower-power couplers

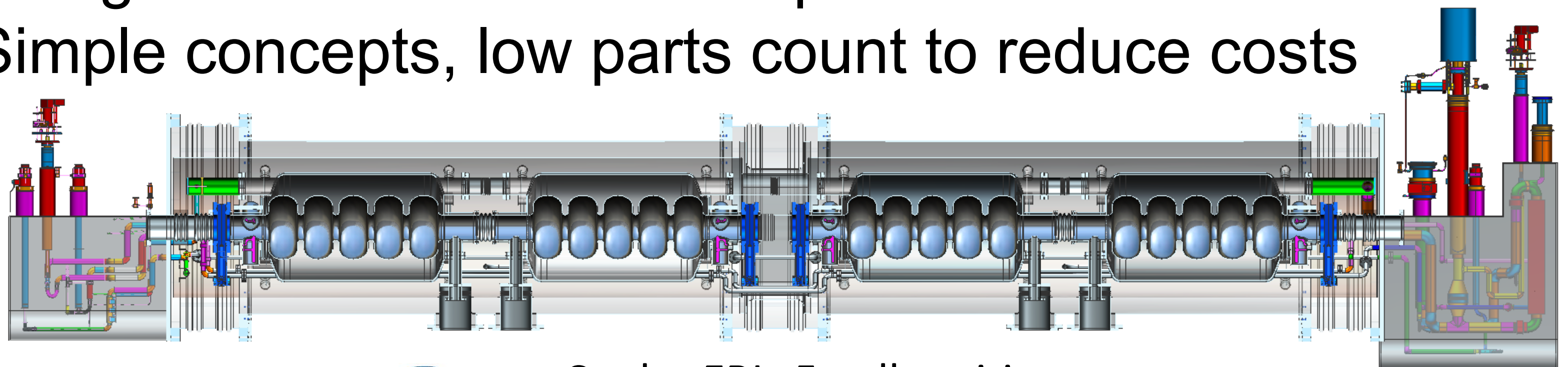




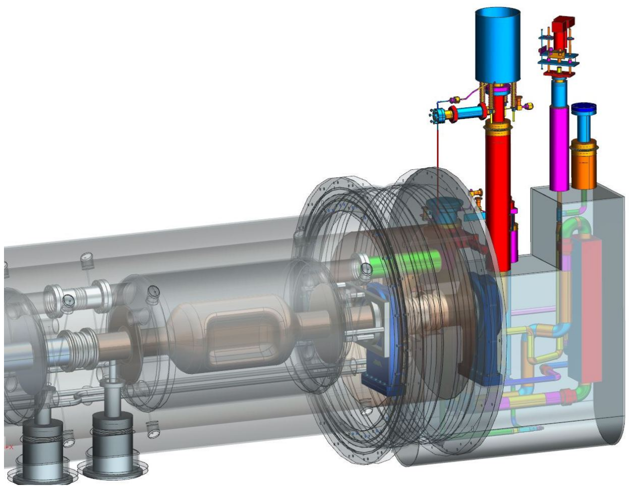
Harmonic kicker system (Y. Huang)

Modular Cryostat

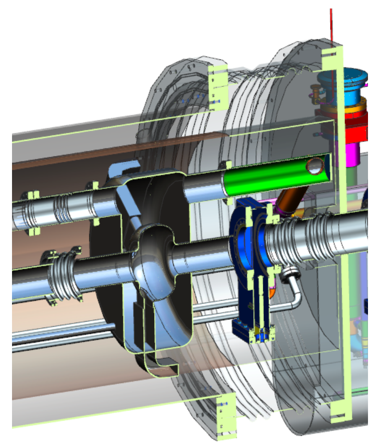
- Take the best features of previous JLab designs
- Modular approach to hold various different cavities
- Design suitable for industrial production
- Simple concepts, low parts count to reduce costs



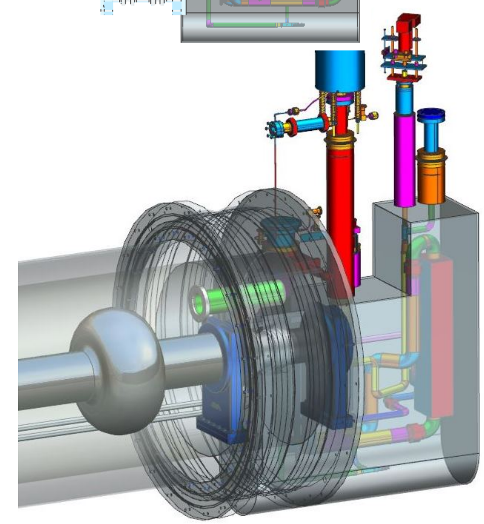
Cooler ERL, 5-cell cavities



476.3 or 952.6 MHz Crab cavity



952.6 MHz Ion ring concept



476.3 MHz 1-cell?

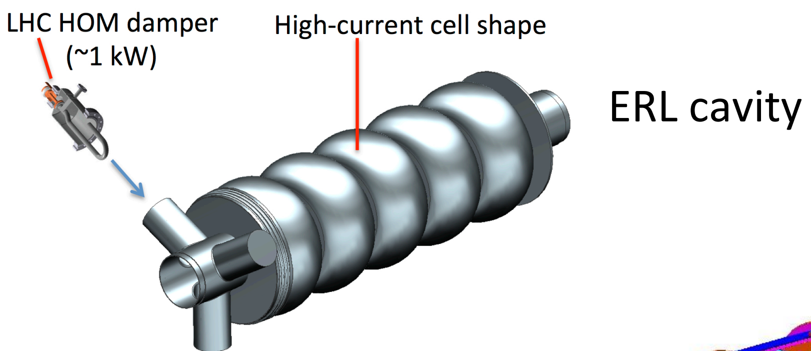
Partnerships / WFO

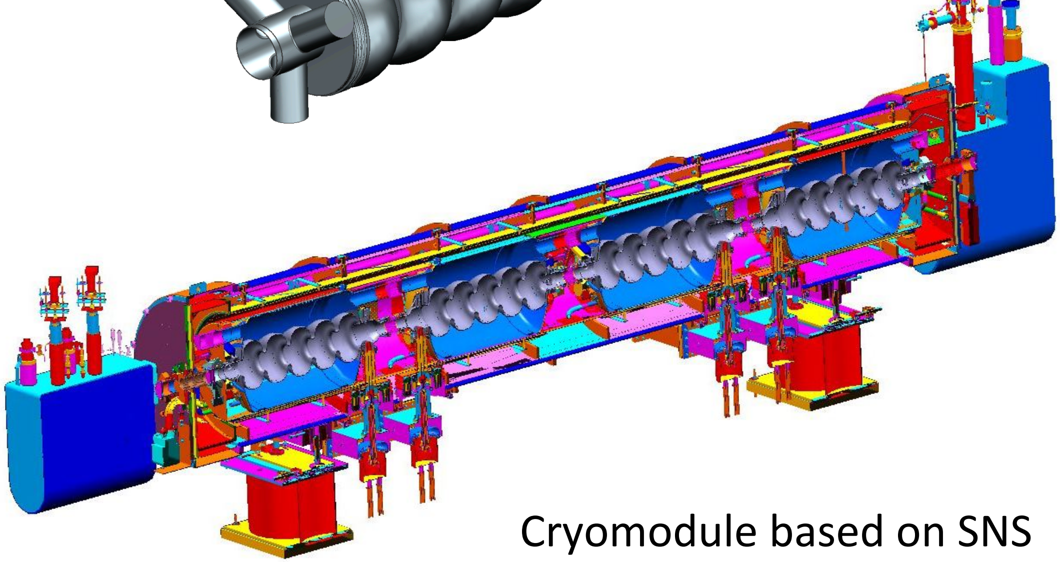
- Support of **LCLS-II** project at SLAC (Joe's talk)
  - Multi-lab optimization of N_2 doping, vendor qualification, etc.
- SRF gun, booster and ERL cavity development with **HZB** BerlinPro (now also BESSY VSR)
- **US-LARP** and **LHeC** at CERN – synergy with JLab **EIC**
- **Project-E** (based on our advanced ERL/FEL technology)
- Various small **SBIR** projects
  - Thin film coating
  - Hydroformed and 3D printed cavities
  - High-efficiency RF source development

Collaboration with CERN on SRF for LHeC

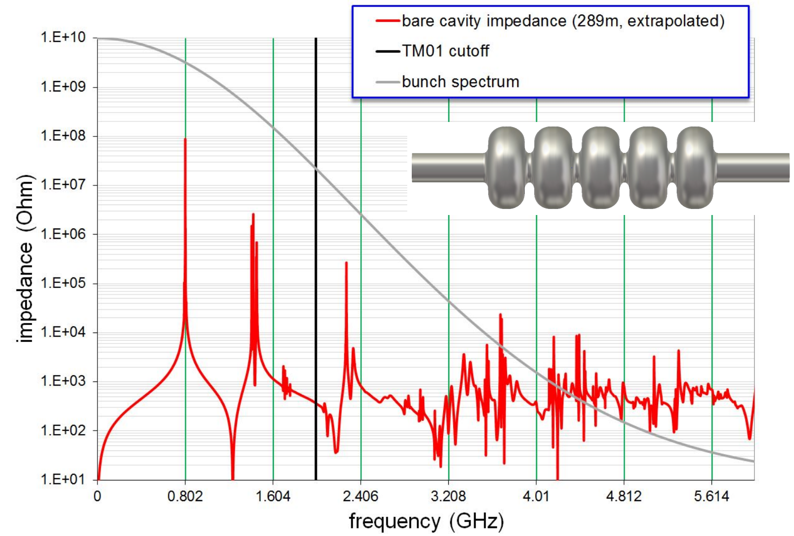
Collaboration on 802 MHz SRF for LHeC

- ERL cavity design and prototype
- Joint study on cryomodule

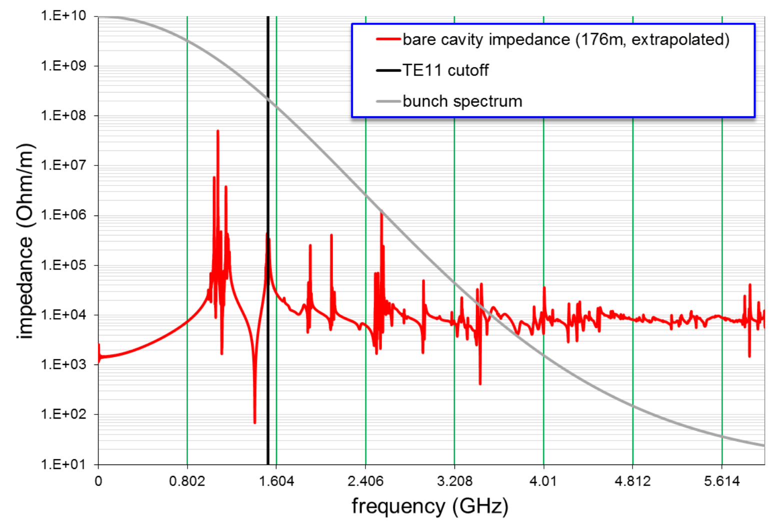




Cryomodule based on SNS



HOM spectrum looks good



SRF Core R&D

JLab has a long-standing in-depth core competency in SRF in both R&D and projects

- CEBAF, SNS, FEL, ILC, APS-SPX, 12 GeV, LCLS-II, etc.

Main R&D focus areas are:

- **Improved efficiency:**
  - Higher Q_o, lower costs, safer processes, new materials
- **High intensity:**
  - ERL's, Proton drivers, high current storage rings, now **EIC**
- **Higher energy:**
  - Jlab played a key role in the ILC SRF R&D program
- **Education:**
  - This is a great place for students to do SRF R&D!

Improved efficiency: Ti and N doping for Q_0

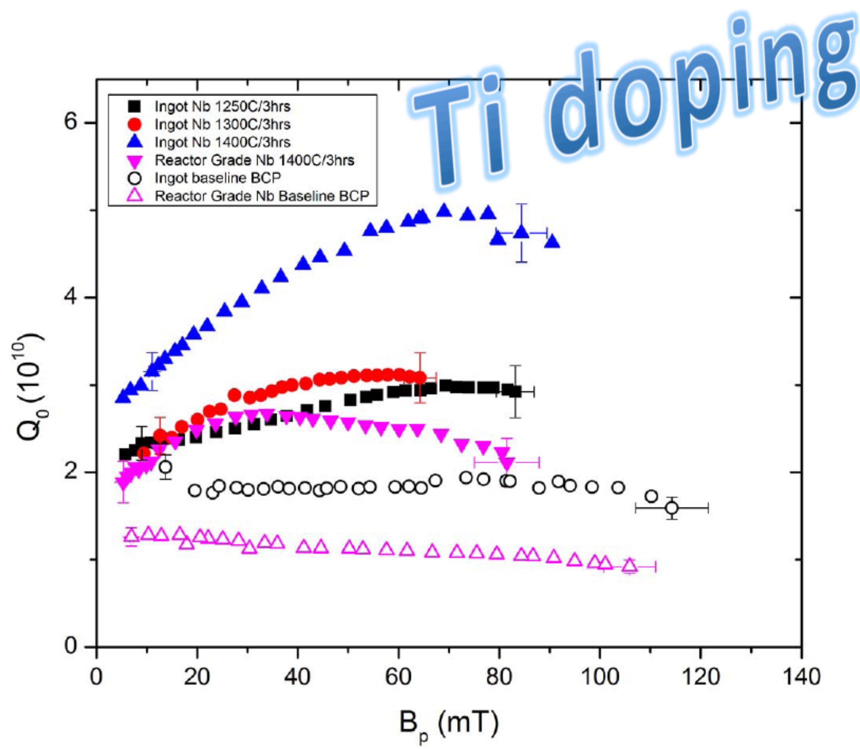


Fig. 1. Q_0(2 K) versus B_p for the ingot and reactor grade Nb 1.5 GHz ($B_p/E_{acc} = 4.43$ mT/(MV/m)) SRF cavities heat treated in titanium environment in temperature range of 1250–1400 °C. These rf tests were limited by cavity quench. About 20 μm inner surface of ingot cavity was removed by BCP before each heat treatment.

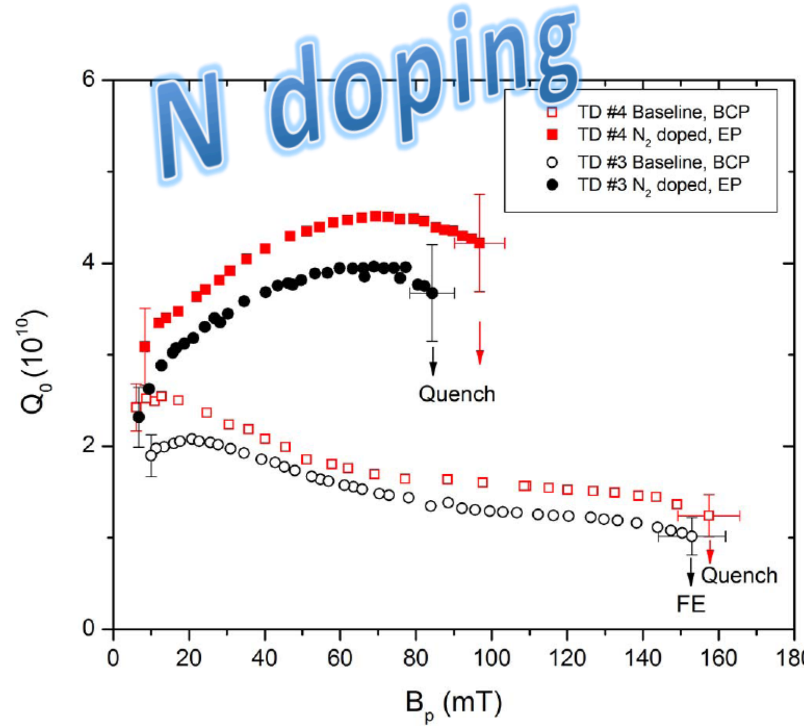


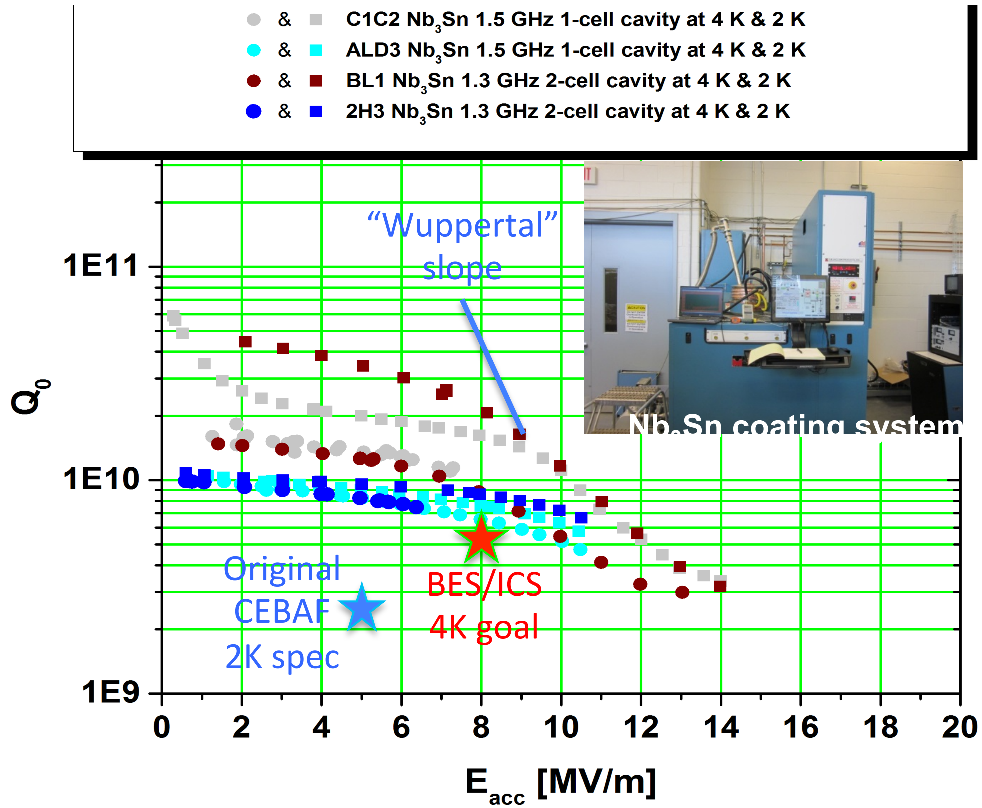
Fig. 3. Q_0(2 K) versus B_p for ingot Nb with RRR > 300 1.3 GHz ($B_p/E_{acc} = 4.33$ mT/(MV/m)) cavities heat treated in the presence of nitrogen gas followed by ~10 μm EP.

- Q_0 improved by up to a factor of 2 at medium fields by doping
- N-doping recipe more “robust” than Ti-doping

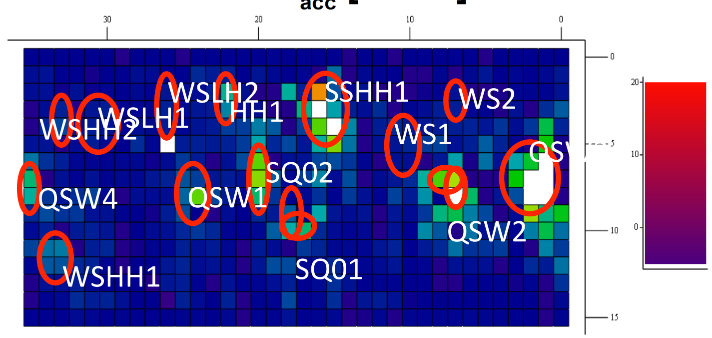
P. Dhakal et al., IEEE Trans. Appl. Supercond. **25**, 3500104 (2015)

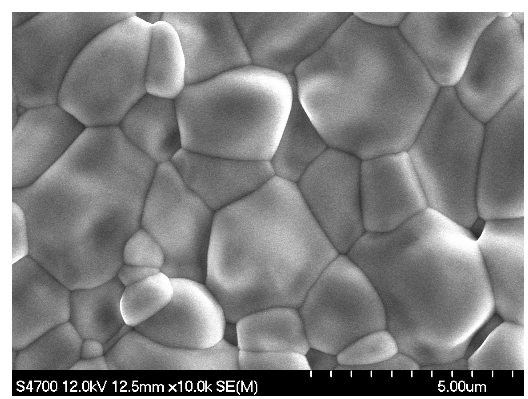
Improved efficiency: Nb_3Sn progress

G. Eremeev et. al.



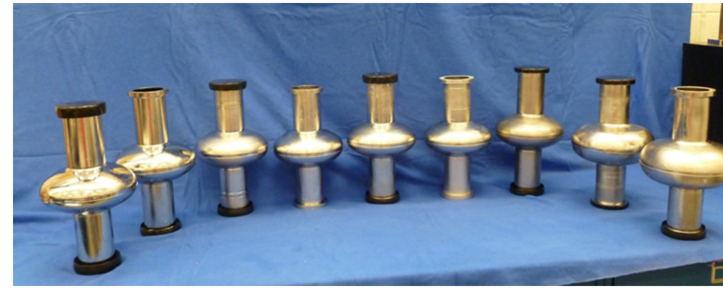
- 1.5 GHz 1-cell, 1.3 GHz 1-cell, and 1.3 GHz 2-cell seamless cavities have been coated.
- All cavities had the transition temperature of about 18 K with the low field Q_0 of about 10^{10} at 4.3 K.
- The best cavities reached E_{acc} above 10 MV/m limited by localized defects and "Wuppertal" slope.
- Small coated samples and cutouts from a 1.5 GHz cavities are being analyzed towards understanding of present limitations.



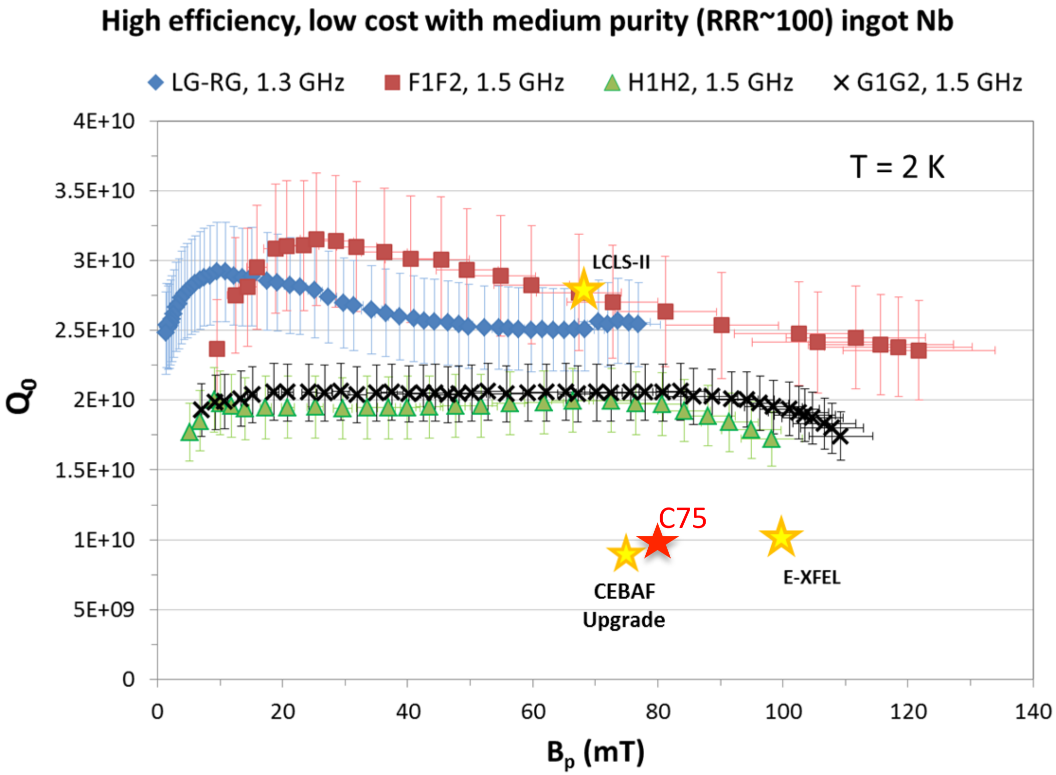


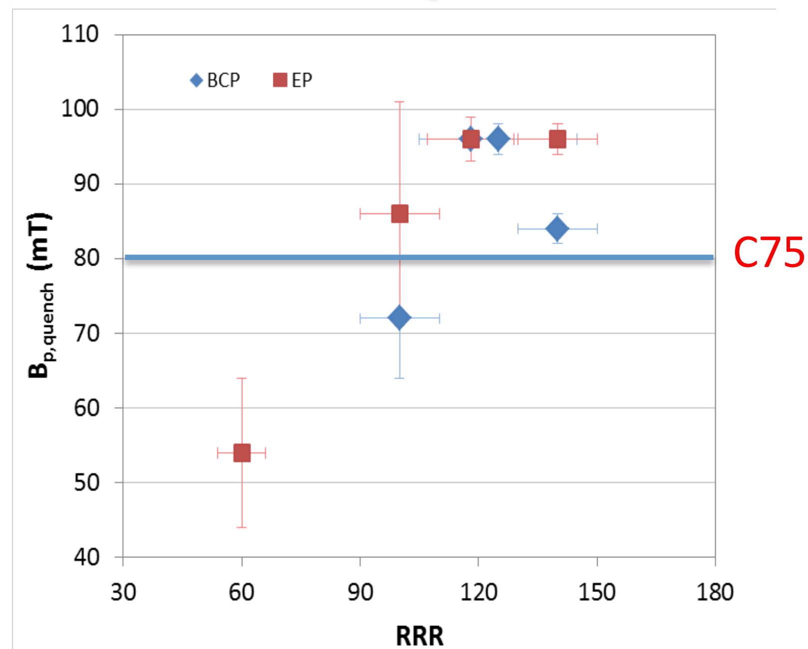
High efficiency at low cost: ingot Nb

Medium-purity ingot Nb is a good material to build SRF cavities operating at medium gradients with higher efficiency and potentially lower cost (~1/3) than standard high-purity, fine-grain cavities.



Proposed for new C75 cells





G. Ciovati et al., SRF'15, MOPB001 (2015).

HF-Free Electropolishing Niobium

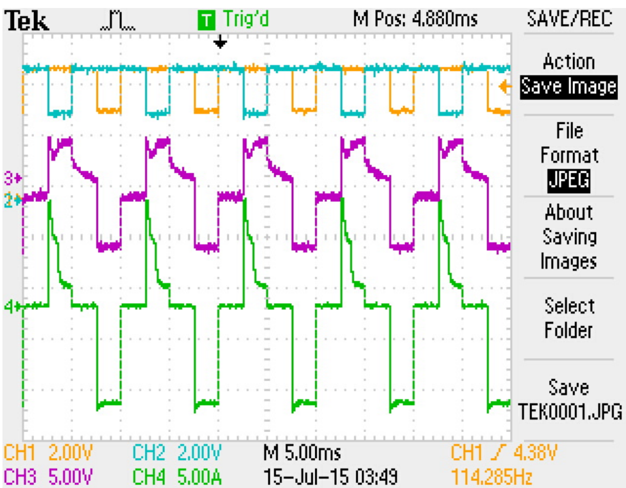
Pulse-reversed process demonstrated effective on single cell cavity by Faraday Technology using sulfuric acid alone

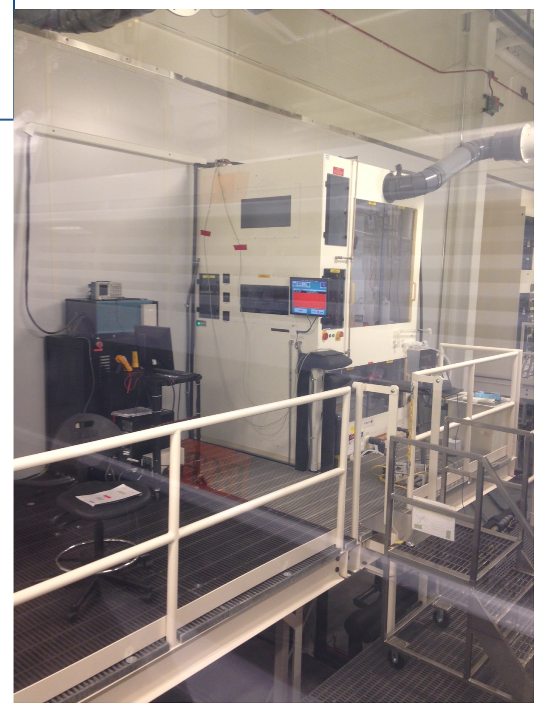
E.J. Taylor et al., SRF2013
A.M. Rowe et al., SRF2013

Completed setup of first vertical EP cabinet for HF-free cavity processing

- Ready for commissioning in FY16

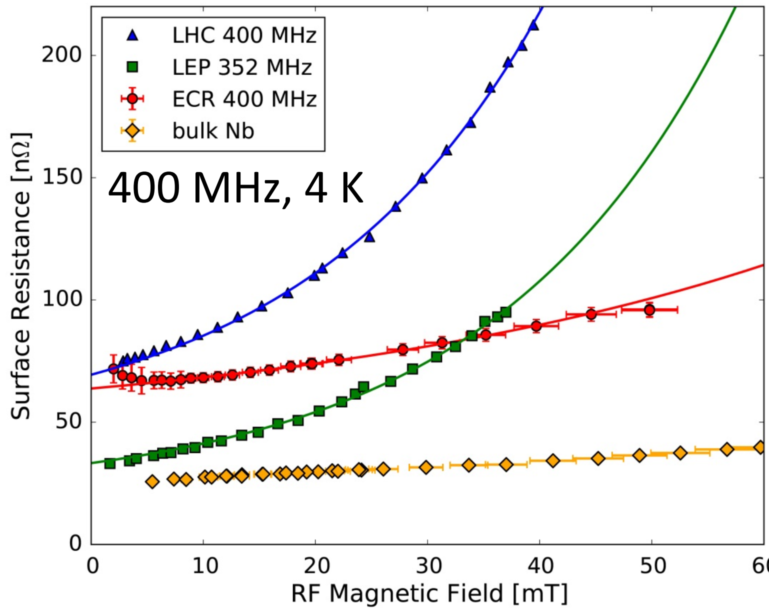
JLab is providing detailed electrochemical analysis and process characterization with varied concentration and pulse structure

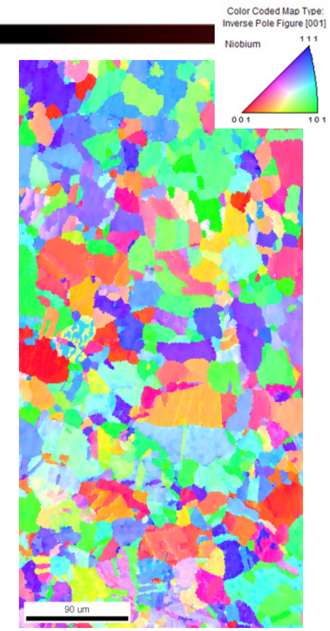


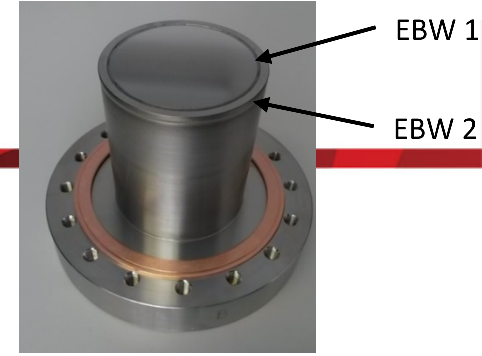


H. Tian, et. al.

Nb/Cu films by Energetic Condensation







	R_{res} [nΩ]	λ(0K) [nm]
400 MHz	46.6 ± 0.8	40 ± 2
800 MHz	79 ± 2	38 ± 1
1200 MHz	156 ± 11	38 ± 1

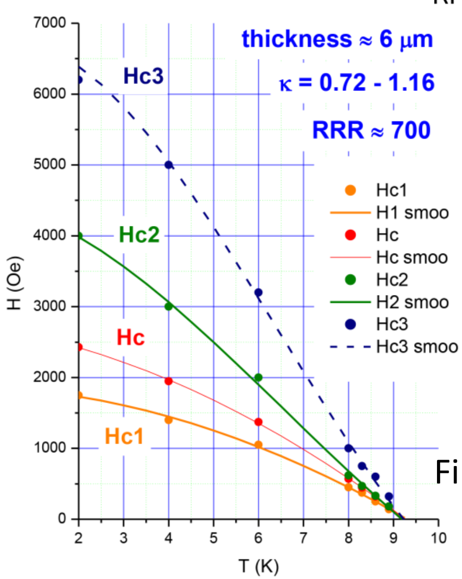
ℓ* [nm]	RRR
144 ± 20	53 ± 7

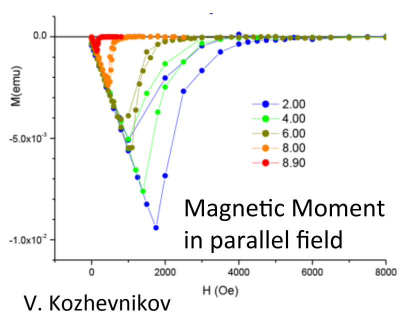
* with λ_L = 32 nm and ξ_0 = 39 nm

ECR Nb/Cu film shows a much reduced slope compared to sputtered Nb/Cu cavities.

The residual resistance is high due to the post-coating e-beam welding (EBW 2) to the support structure.

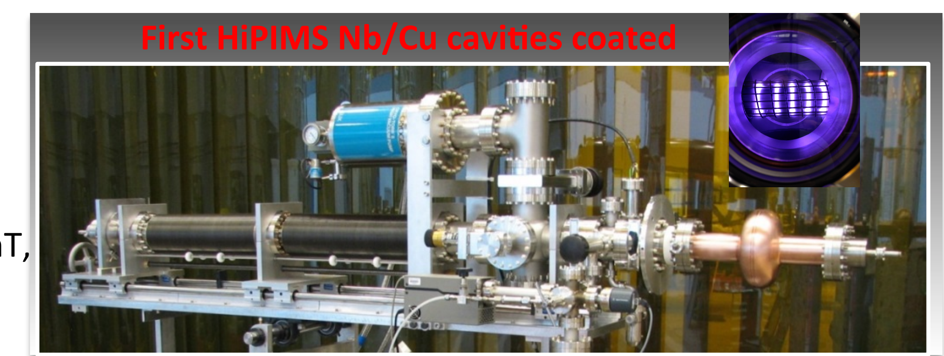
Series of QPR sample coating/measurement underway





V. Kozhevnikov

Magnetic field phase diagram for ECR Nb/ (1-120) Al_2O_3
First flux Penetration @ 2 K ~ 180 mT, showing superior behavior to measured bulk Nb (130 mT)



High Intensity: examples

750 MHz MW-class FEL

650 MHz Project X

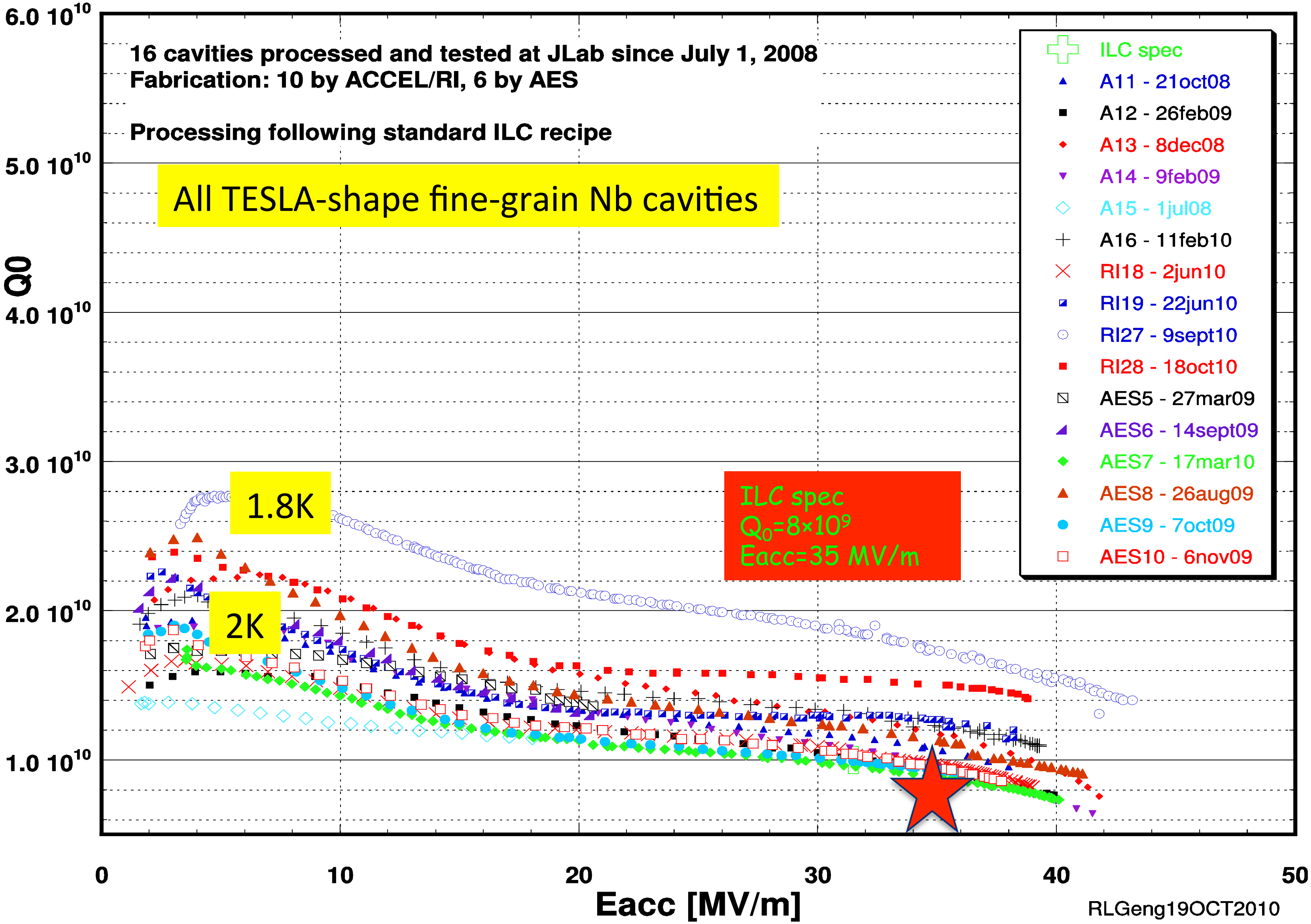
ANL-SPX storage ring crab cavities

Present focus is on JLab EIC storage rings and electron cooler

ILC High Gradient R&D at JLab

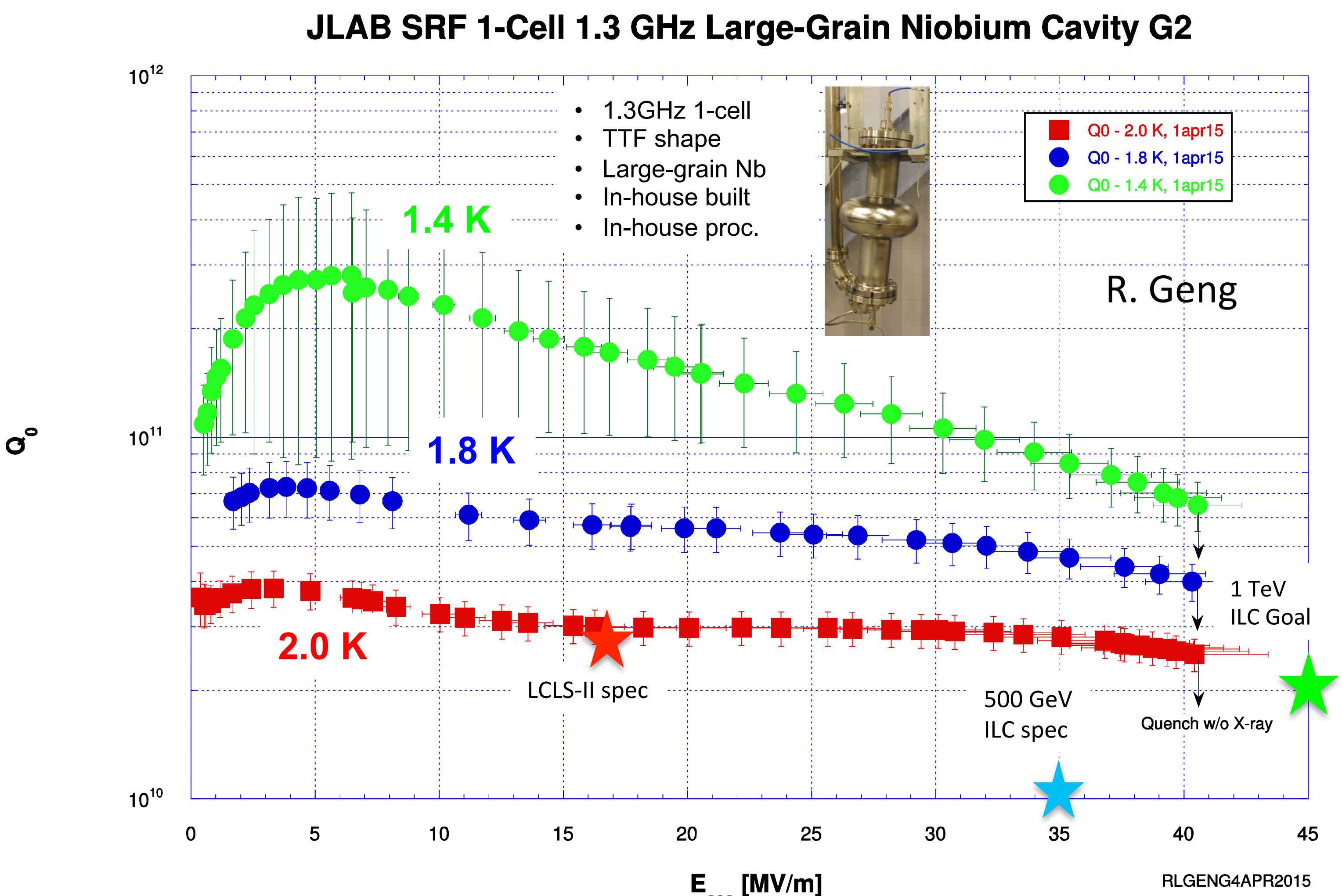
- Nearly 60 distinct 9-cell cavities.
- 120 EP cycles; 200 cryogenic cavity vertical testing.
- Cavities manufactured by industries, laboratories and universities in three regions world wide
  - Europe: ACCEL/RI, Zanon, DESY
  - US: AES, Niowave/Roark, JLAB
  - Aisa: MHI, KEK, PKU, IHEP
    - Later 7-cell CEBAF upgrade cavities by OSTEC
- Personnel exchanges/training with international collaboration
  - Many young scientists, including 5 from KEK, came to JLab for extended visit working on SRF technology.

Achieved ILC Cavity Performance at JLAB (2008-2010)



High Gradient: Recent Results and Next Steps

Purpose: achieve high gradient with high efficiency, at a low cost and high reliability
Approach: Low-Surface-Field Shape* + Large-grain Niobium material + advanced processing



Future cavities: LSF* cavity

Prototypes:
- Two each 1-cell built and tested
- Two each 3-cell and one each 9-cell in process of fabrication.

*Z. Li at SLAC

Path Forward

- High efficiency high gradient (HEHG) SRF a fundamental accelerator physics and technology issue with applications to ILC as well as many other machines
  - Better cavity shapes (RE, LL/ICHIRO, LSF)
    - “immediate” gain in gradient
    - “guaranteed” saving in cryo capital cost & accelerator operation cost
  - Better material (Large-Grain/Medium-Grain ingot niobium)

Use the same successful ILC baseline cavity processing technology which is already well practiced in world-wide labs as well as in industry and has been successfully applied to CEBAF accelerator and E-XFEL project.

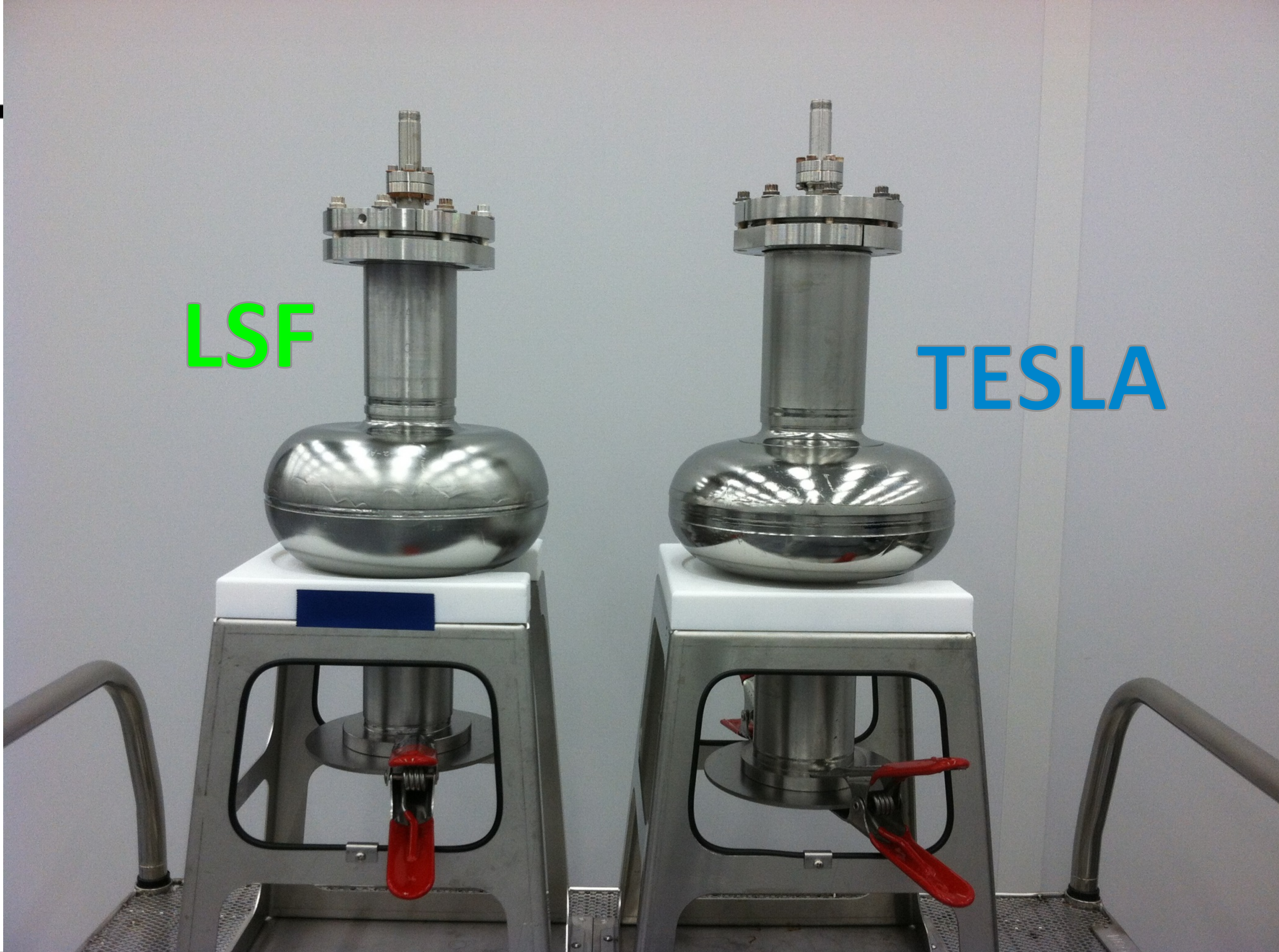
HEHG Cavity Shapes: Design

		TESLA	Low-loss/ICHIRO	Re-entrant	Low-surface-field
frequency	MHz	1300	1300	1300	1300
Aperture	mm	70	60	60	60
Epk/Eacc	-	1.98	2.36	2.28	1.98
Hpk/Eacc	mT/(MV/m)	4.15	3.61	3.54	3.71
Cell-cell coupling	%	1.90	1.52	1.57	1.27
G*R/Q	Ω^2	30840	37970	41208	36995

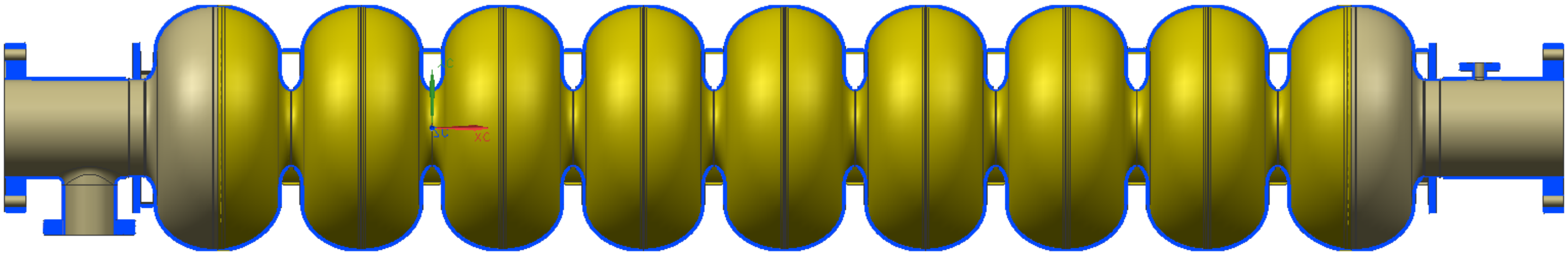
Z. Li, C. Adolphsen, A New SRF Cavity Shape with Minimized Surface Electric and Magnetic Fields for the ILC, LINAC08 (2008).

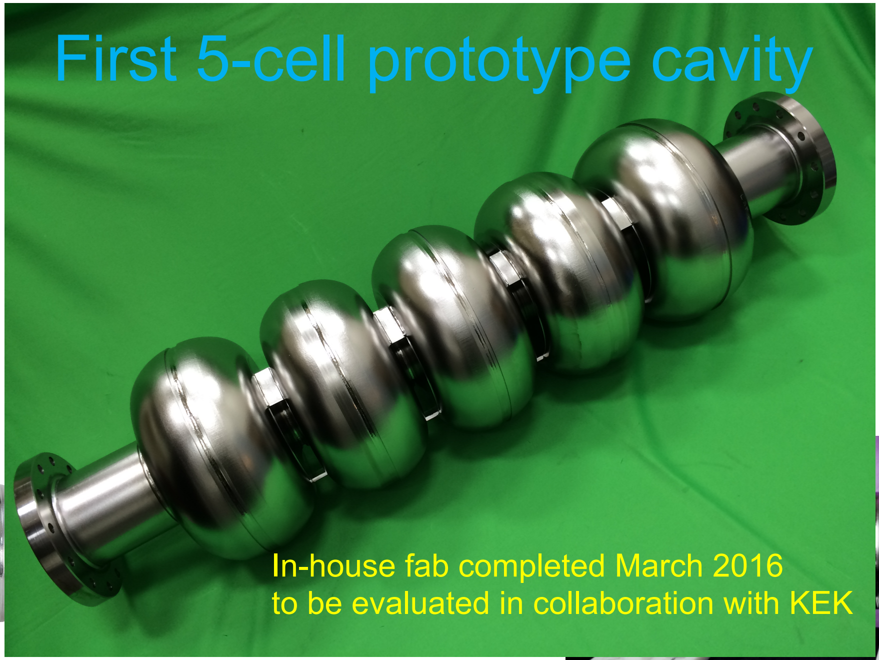
R.L Geng et al., Development of Ultra High Gradient and High Q0 Superconducting Radio Frequency Cavities, IPAC13 (2013).

- 50 MV/m capable due to lowered Hpk/Eacc
- 20% more efficient as compared to TESLA shape
- Lowered risk in field emission by keeping Epk/Eacc the same as TESLA shape

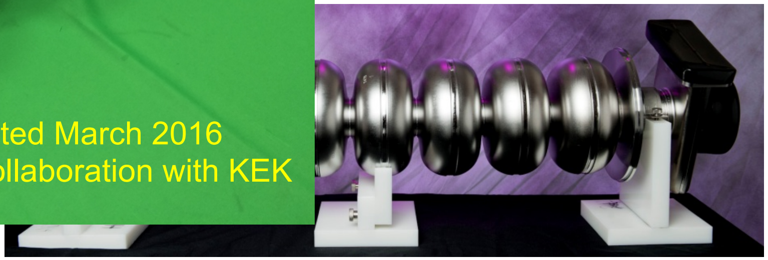

LSF
TESLA

Right Cavity Shape: LSF for ILC





Tesla shape for E-XFEL



LL shape for CEBAF

R.L. Geng, April. 26, 2016

Work to be Done Next

- Reduce field emission up to Epk ~ 100 MV/m
  - Critical for all SRF machines, in particular stable operation
- Eliminate Q-slope up to Hpk ~ 200 mT
  - Origins still unclear, even for Nb
  - Key issue to viability of any “new” material
- Recent progress in high Q_0 cavity for medium gradient (Hpk ~ 70 mT) shown good results
  - Can these good results extended to high gradient?

SRF Student Program 2016

Shichun Huang
Chinese Academy of Sciences, Institute of Modern Physics
Factors limiting the SRF cavity performance

Quintin D. Lassiter, Jr.
New Horizons Governor's School for Science and Technology
Prototype Electropolishing Wireless Thermometry System

Matthew Burton
The College of William and Mary
Superconducting Thin Films for SRF Cavities

Yulu Huang
Institute of Modern Physics, Chinese Academy of Science
Harmonic Resonant Kicker Design

Salvador Sosa Guitron
Old Dominion University
SRF Materials Characterization

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Nitrogen-Doped cavities

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Nb_3Sn Material Development

Summary

- Actively engaged in **CEBAF** operational support
  - 12 GeV Commissioning & optimization
  - C75 upgrade program
  - Other structure development and analysis as needed.
- Developing concepts and prototypes for a future **EIC at JLab**
- Ensuring success in our **WFO** commitments
  - Project scale or R&D
- Advancing SRF technology through **focused R&D**
  - Efficiency, Energy, Intensity frontiers
- Applying lessons learned to future projects
  - TESLA > LL (12 GeV/Ichiro) > LSF > **MaRIE?**
- **Training the next generation** of SRF scientists and engineers

Thank You