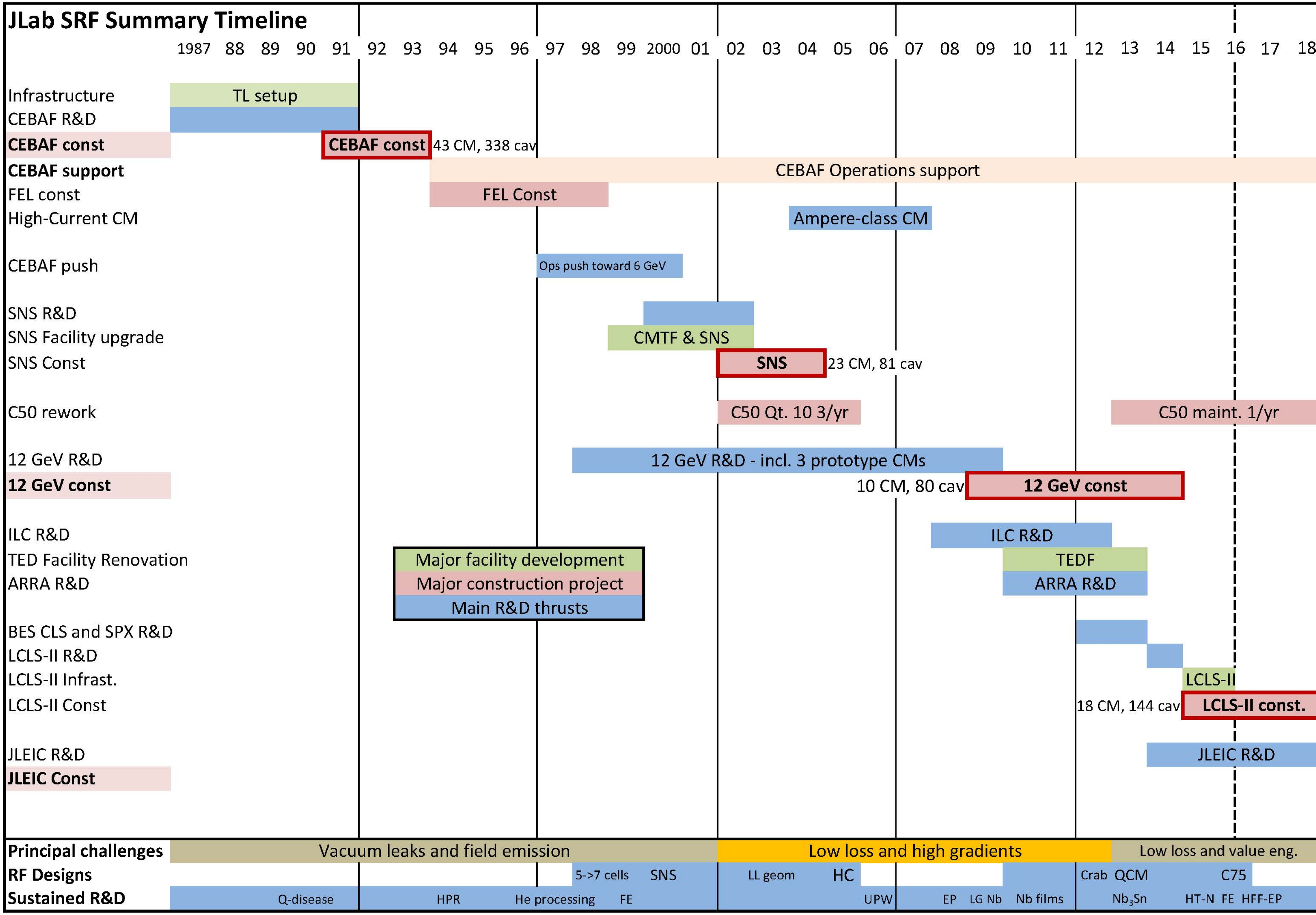
SRF Research at Jefferson Lab

Larry Phillips

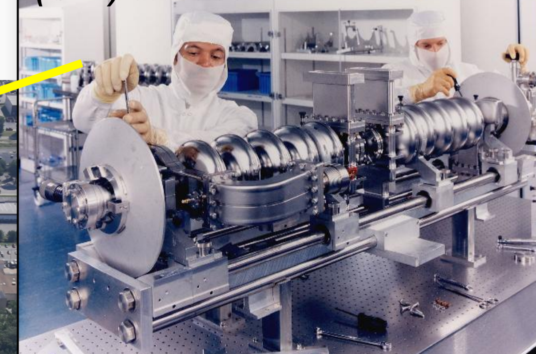
January 10, 2017


JLab SRF Summary Timeline
1987 88 89 90 91 92 93 94 95 96 97 98 99 2000 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18
Infrastructure
TL setup
CEBAF R&D
CEBAF const
CEBAF const
43 CM, 338 cav
CEBAF support
CEBAF Operations support
FEL const
FEL Const
High-Current CM
Ampere-class CM
CEBAF push
Ops push toward 6 GeV
SNS R&D
SNS Facility upgrade
CMTF & SNS
SNS Const
SNS
23 CM, 81 cav
C50 rework
C50 Qt. 10 3/yr
C50 maint. 1/yr
12 GeV R&D
12 GeV R&D - incl. 3 prototype CMs
12 GeV const
10 CM, 80 cav
12 GeV const
ILC R&D
ILC R&D
TED Facility Renovation
TEDF
ARRA R&D
ARRA R&D
Major facility development
Major construction project
Main R&D thrusts
BES CLS and SPX R&D
LCLS-II R&D
LCLS-II Infrast.
LCLS-II
LCLS-II Const
18 CM, 144 cav
LCLS-II const.
JLEIC R&D
JLEIC R&D
JLEIC Const
Principal challenges
Vacuum leaks and field emission
Low loss and high gradients
Low loss and value eng.
RF Designs
5->7 cells
SNS
LL geom
HC
Crab
QCM
C75
Sustained R&D
Q-disease
HPR
He processing
FE
UPW
EP
LG Nb
Nb films
Nb3Sn
HT-N
FE
HFF-EP

Jefferson Lab Accelerator Complex

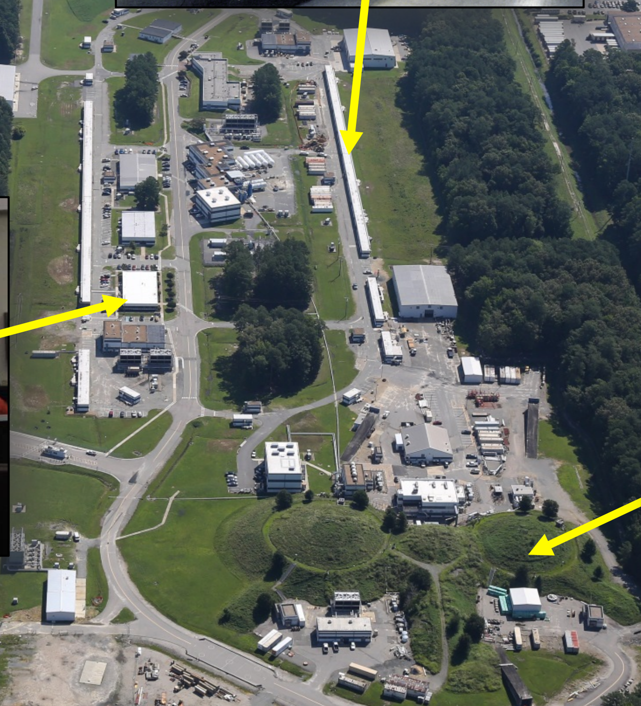
Cryomodules in the accelerator tunnel

Superconducting radiofrequency (SRF) cavities

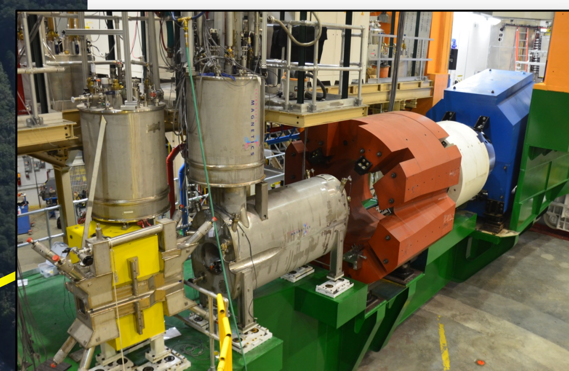


Hall D

Machine Control Center

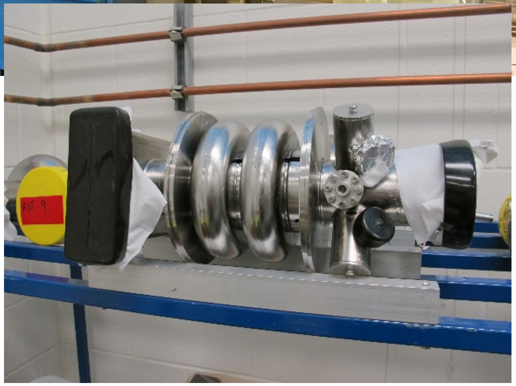


An aerial view of the recirculating linear accelerator and 4 experimental halls.



Hall C

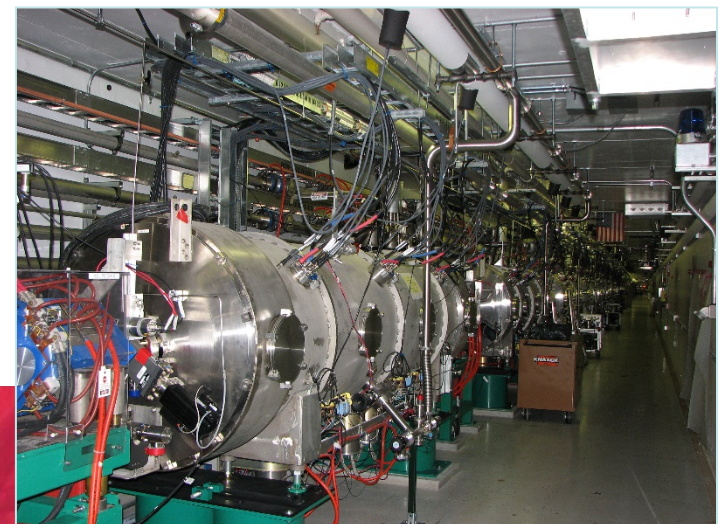
Cavity Design Innovations



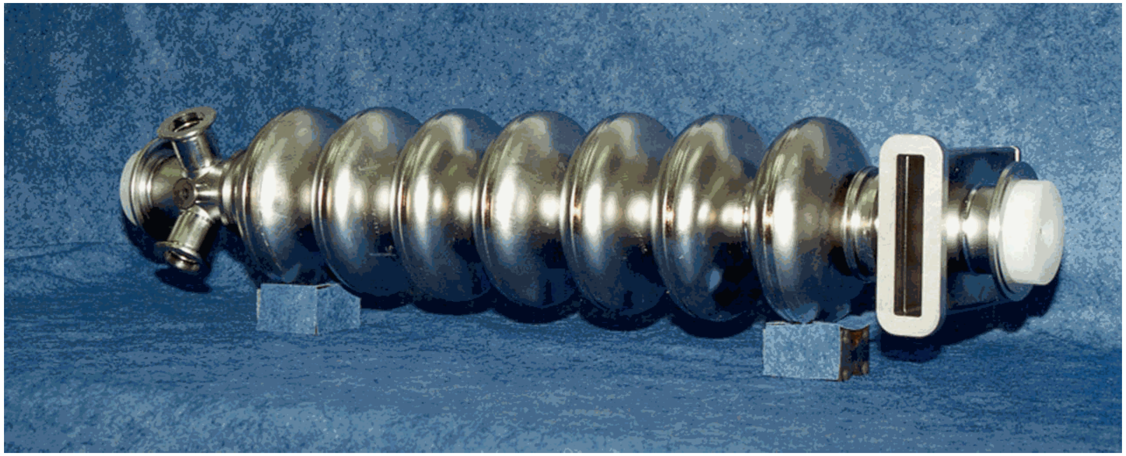
Various cavity shapes are developed for different applications

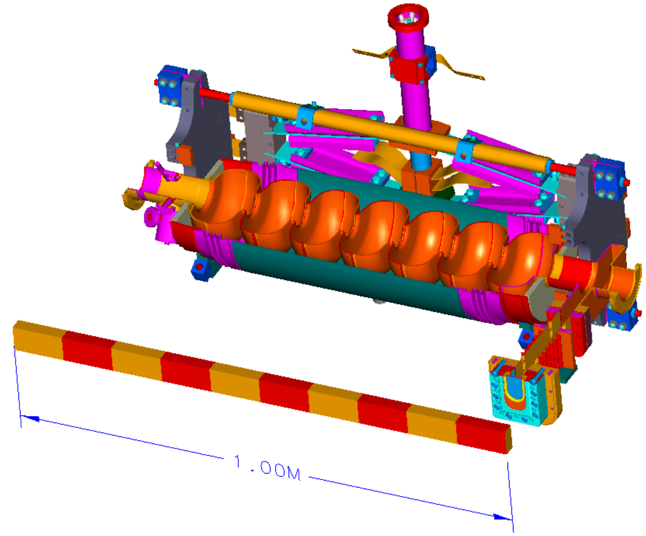
SNS Construction

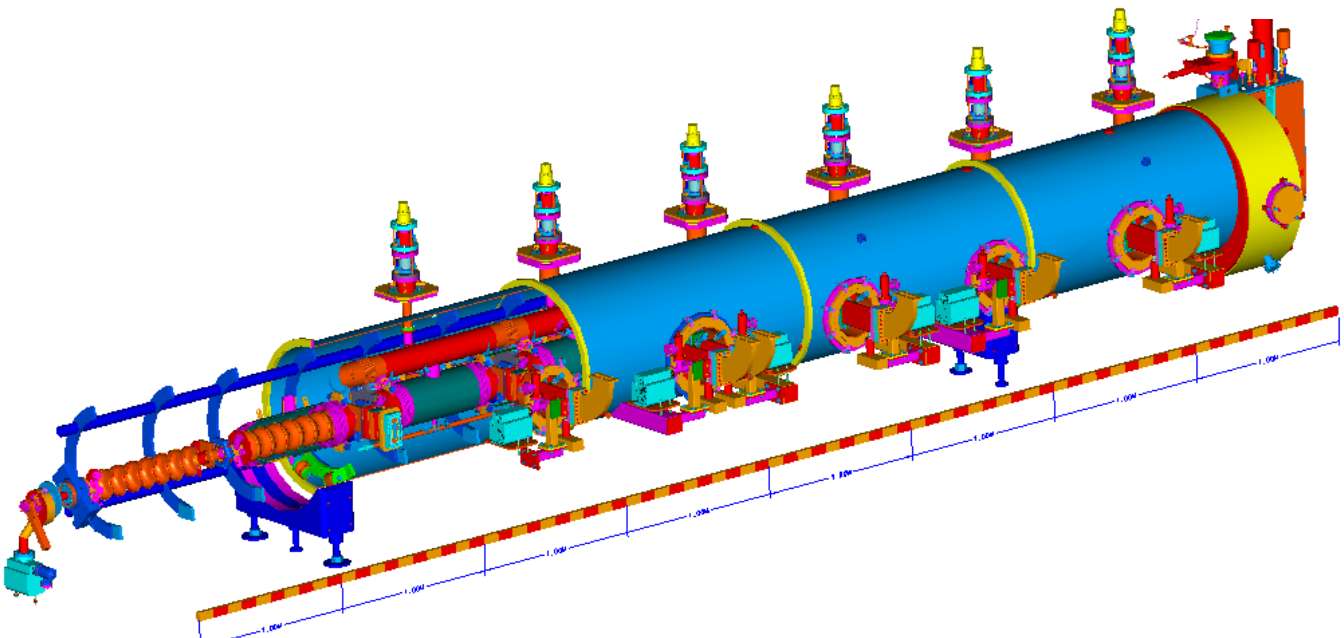
- Designed and prototyped β= 0.61 & 0.81 cavities with international collaboration
- Designed cryomodules based on CEBAF endcans and CEBAF upgrade spaceframe concept
- Assembled, tested and delivered 23 cryomodules containing 81 cavities



"C100" Cryomodule for CEBAF 12 GeV Upgrade



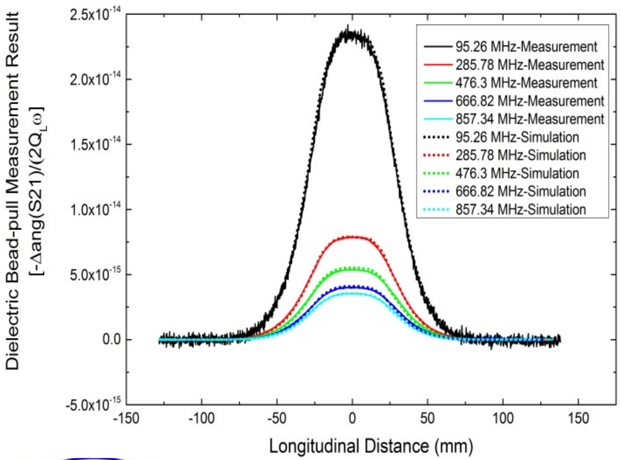


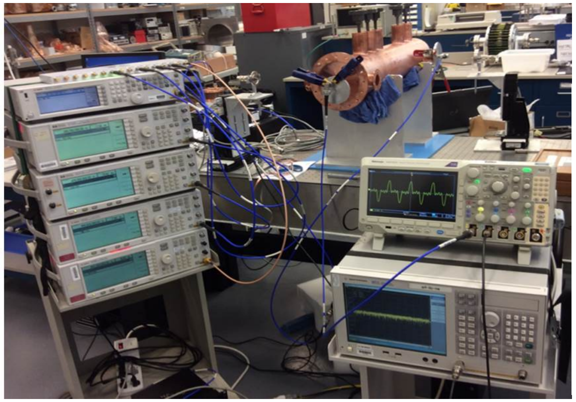


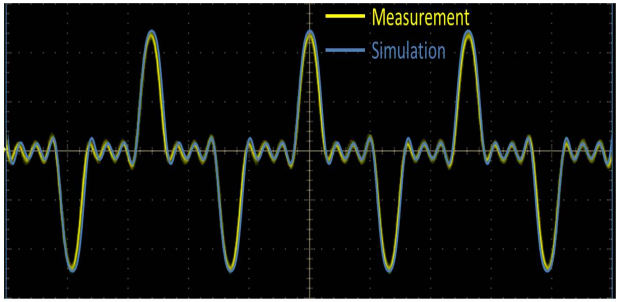
JLEIC Harmonic fast Kicker Development

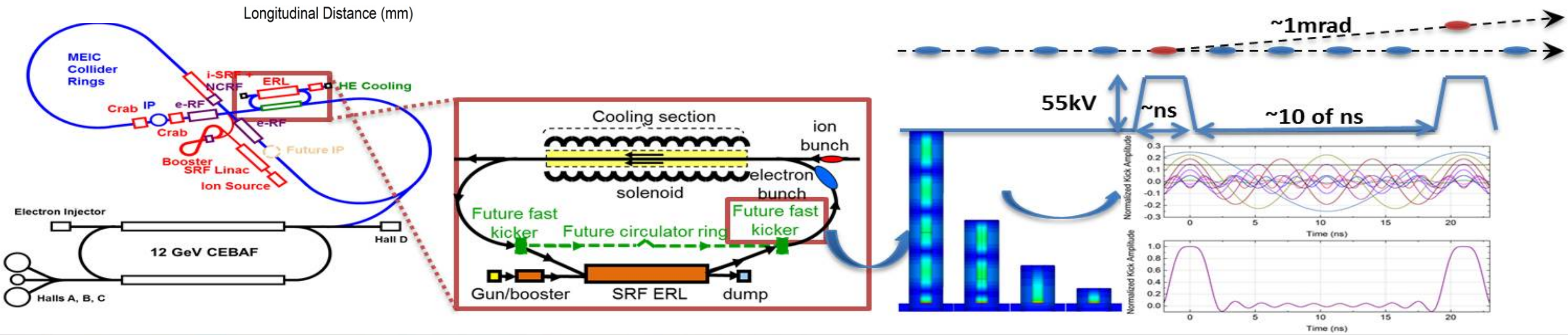
Y. Huang

- Built a half-scale **5-mode** copper prototype;
- RF bench tests match well with the simulation;
- Get the desired kicking pulse in the mode combination experiment with 5 harmonics combined together.



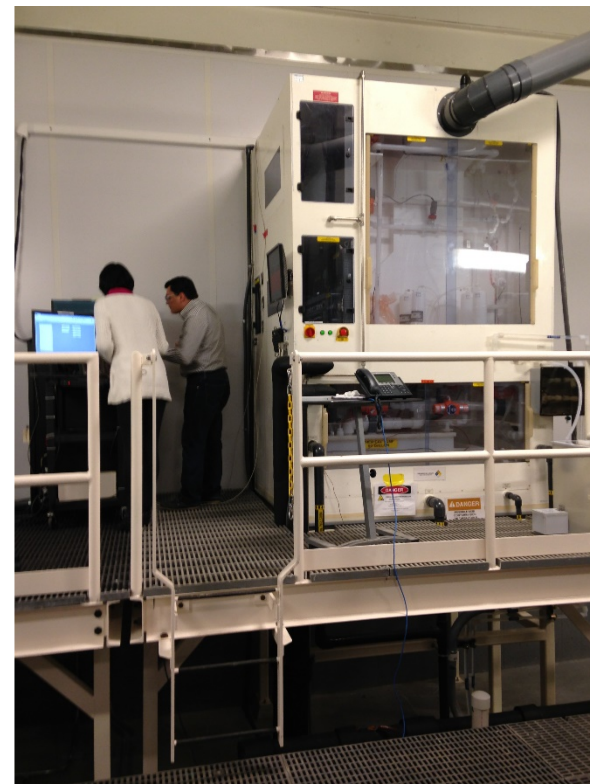






Cavity Process Innovations

- To support very high surface magnetic fields, the Nb cavity interior surface must be very pure and smooth.
  - Electropolish > 30 μm with HF/H_2SO_4 – present standard
  - New HF-free process under development with Faraday Technologies, Inc.
    - R&D100 Award finalist 2016



Cavity Process Innovations

- *In-situ* **helium processing** to reduce field emission
  - Application to CEBAF cryomodules increased the maximum operating energy from 5.2 GeV to 5.7 GeV
- HPR
  - Championed early use of **high pressure rinse** with ultra-pure water to fight field emission – now standard
- Electropolishing Nb
  - Tian PhD mastered the electrochemistry process dynamics - informs production parameter choice – used for 12 GeV

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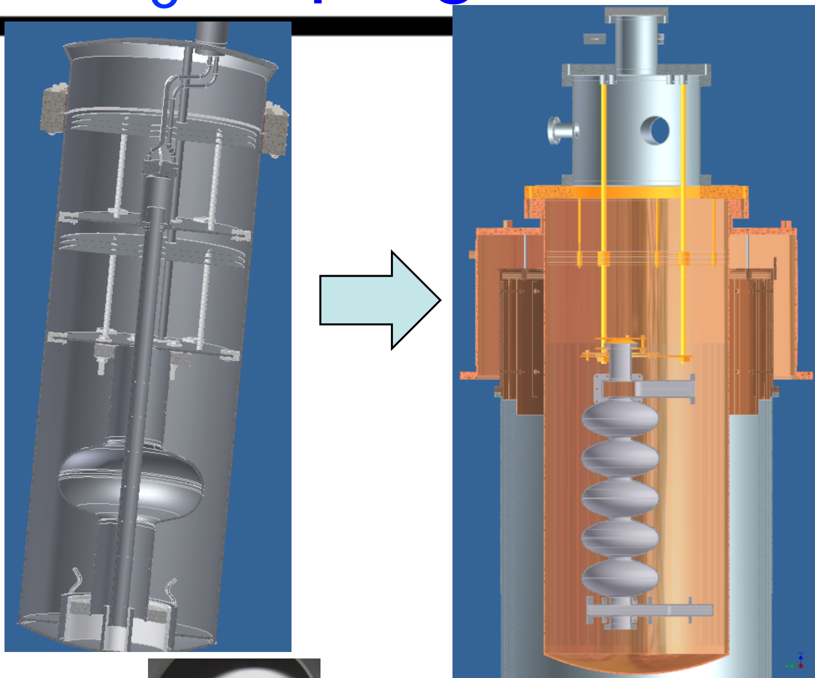
- Improved US and 2^{nd} HPR cleaning – further FE reduction

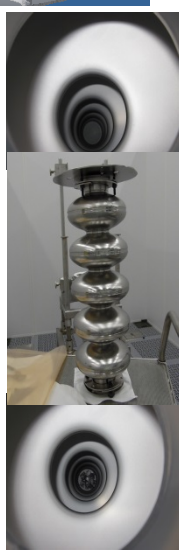
* 120°C bake

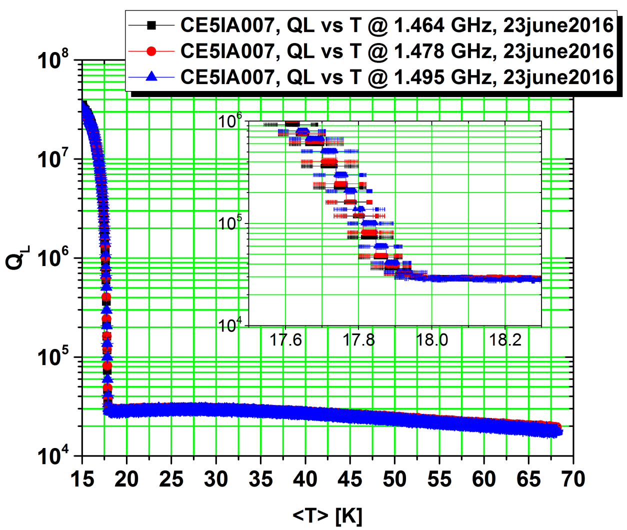
- high field *Q* drop cure for EP'd cavities, PhD

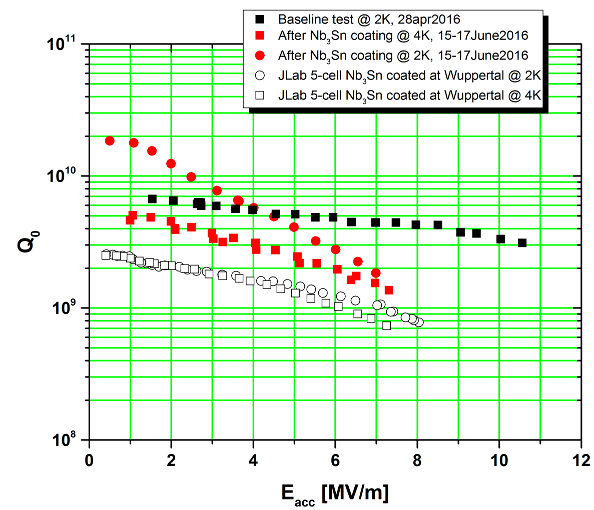
Nb_3Sn progress



- New 17" OD x 40" furnace insert is being built to coat 5-cell CEBAF cavities
- First bare 5-cell cavity coated and tested
- No up-down asymmetry observed, coating is similar to 1- and 2-cell coatings
- Transition temperature is around 18 K
- Limited by a strong slope in RF test, likely due to defects in the substrate







Cavity Process Innovations

- development of ingot niobium technology for low cost, high-efficiency cavities [1]
- - studies of high-temperature annealing of bulk Nb cavities for increased efficiency [2]
- [1] P. Kneisel et al., "Review of ingot niobium as a material for superconducting radiofrequency accelerating cavities", Nucl. Inst. Meth. Phys. Res. A 774 (2015) p. 133.
- [2] P. Dhakal et al., "Effect of high temperature heat treatments on the quality factor of a large-grain superconducting radio-frequency niobium cavity", Phys. Rev. Accel. Beams 16, 042001 (2013).

- Improved US and 2nd HPR cleaning – further FE reduction
- 120°C bake
  - high field *Q* drop cure for EP'd cavities, PhD

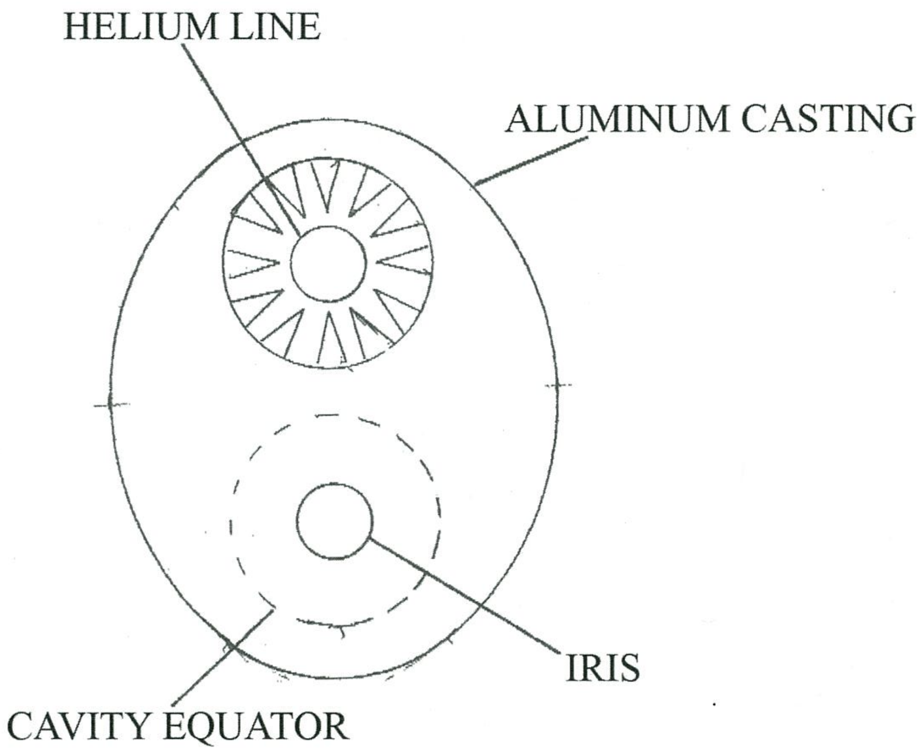
Motivation for Thin Film Cavity Development

- Linac cost in volts per dollar is the only driver.
- Thin film niobium cavity substrates are of highly formable metals, such as copper or aluminum.
- This enables integration of many system functions in a single low-cost structure, i.e. an aluminum casting.
- Integrated functions:
  - Cavity RF surface definition
  - High thermal conductivity substrate
  - Helium vessel
  - Cryogenic manifold with heat exchanger
  - Cavity stiffening

Motivation for Thin Film Cavity Development, continued

- High precision and stability compared to sheet metal
- Field flatness and cell alignment built in.
- Very small tuning range required (small local perturbation or reactive tuner)
- Not sensitive to helium pressure variations
- Insensitive to Lorentz force detuning and microphonic
- No need to waste RF power for microphonic headroom

Aluminum Casting Example



Thin Film Cavity Deposition Program

- Goal: To develop superconducting films on appropriate cavity substrates which consistently meet or exceed bulk cavity performance
  - For niobium films, we must understand and eliminate non-quadratic RF losses , or Q-drop with increasing Eacc.

Issues:

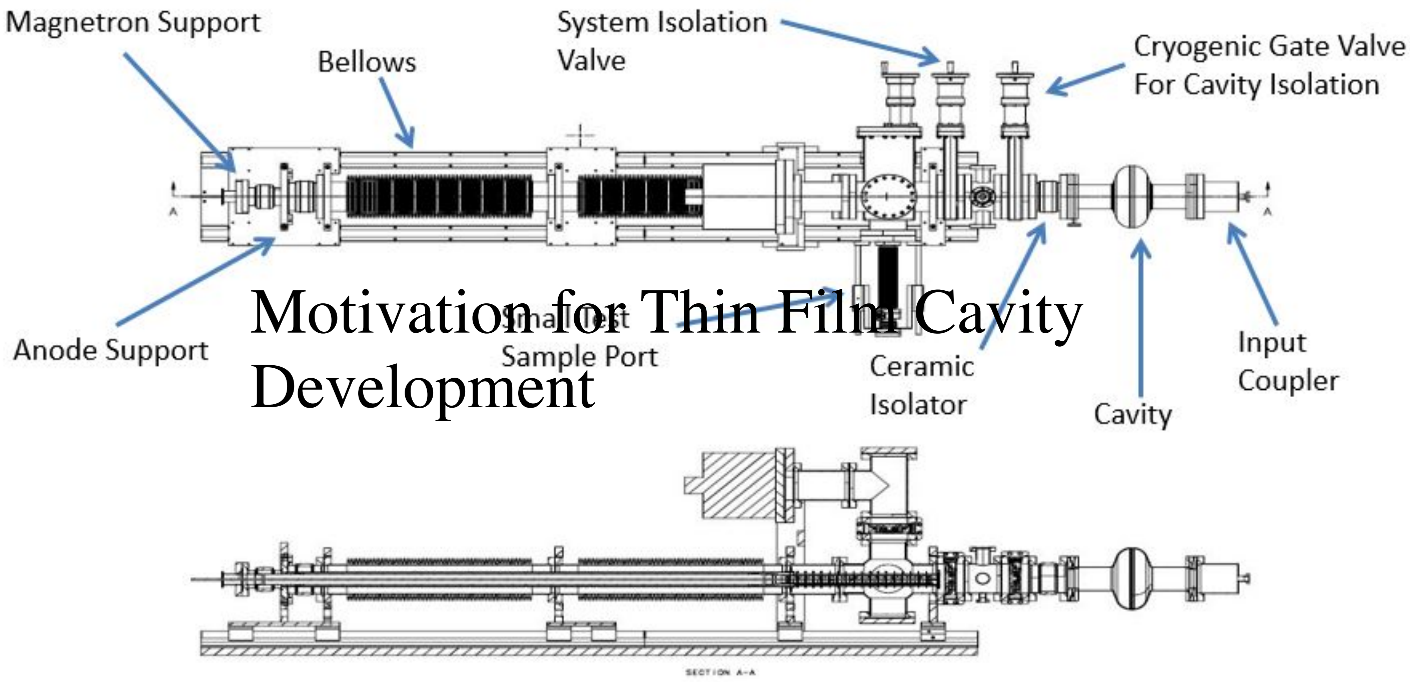
1. Poor film microstructure→ B field enhancement at sharp surface features
2. Thermal impedance issues between film and substrate.
3. Possible entry of Josephson vortices at corroded high energy grain boundaries
4. High vortex density in films due to stray B fields during cooldown or thermoelectric currents at the Nb/Cu interface

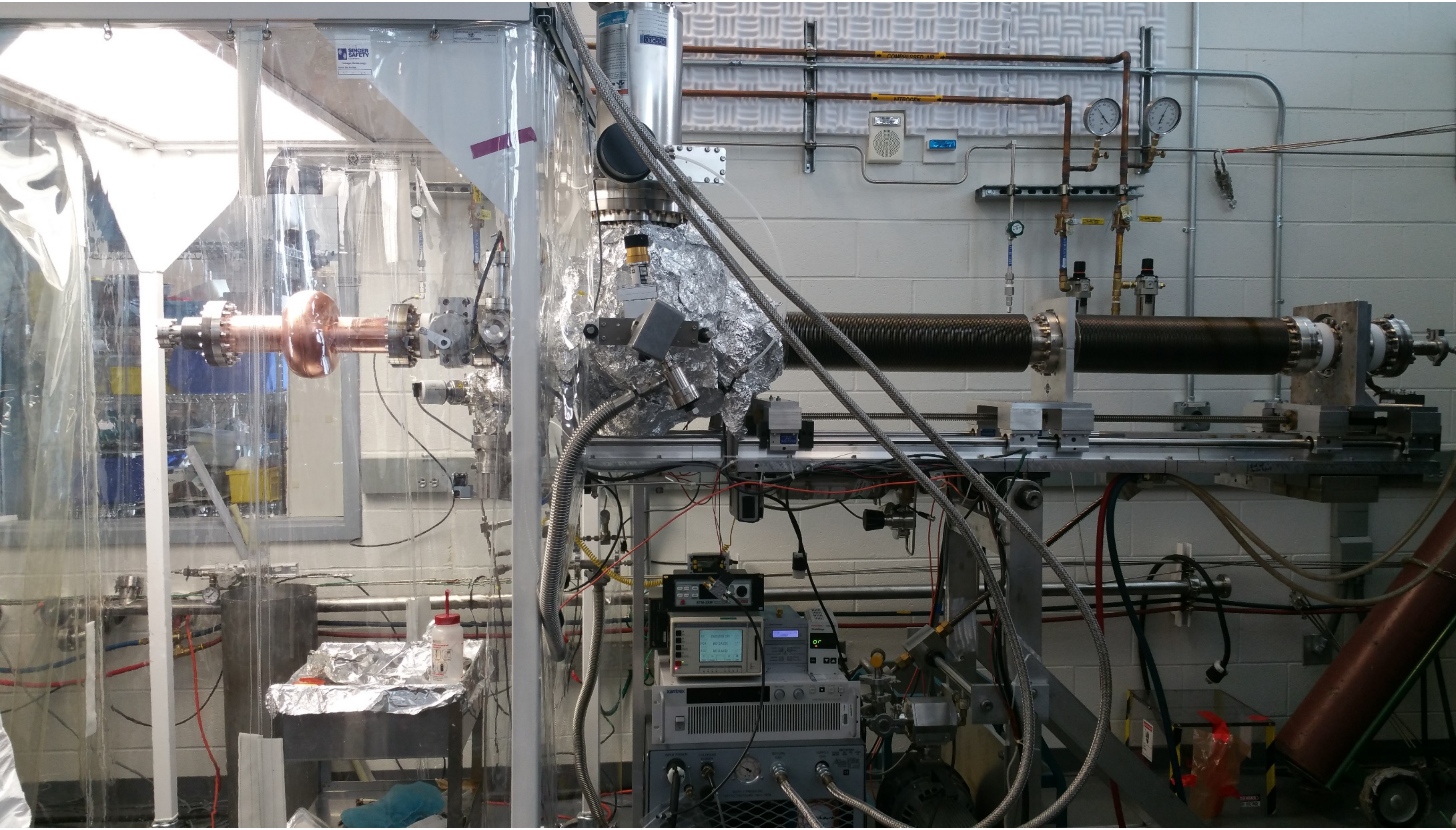
Jlab Cavity Deposition Program (cont.)

- Current status:

1. Energetic condensation (HIPIMS, etc.) produces smooth dense films both by computer simulation and by small sample studies
2. Ion stitching produces a graded interface with high shear strength
3. The spectrum of grain boundary energies is shifted upward in films compared to bulk material, potentially leading to grain boundary corrosion and lowering the barrier to Josephson vortex entry
4. Currently, little is known about the residual flux content of Nb/Cu cavities. A number of small sample studies are planned using magneto-optical techniques.

Motivation for Thin Film Cavity Development

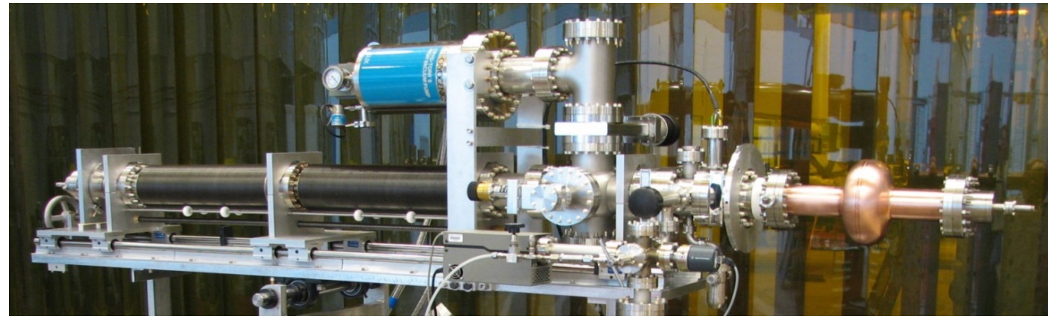




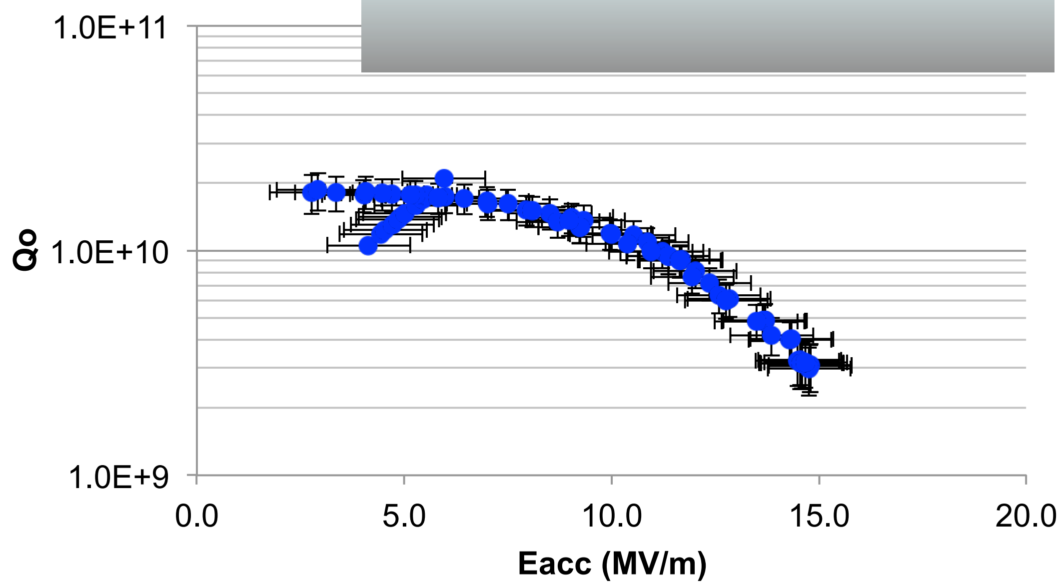
Nb Deposition on cavities

M. Burton, A. Palczewski, L. Phillips

- **HiPIMS** cylindrical coating system for single cell **commissioned**
- Encouraging result for Nb on bulk Nb
- System relocated to make room for LCLS-II production – recently recommissioned
- Eagerly awaiting high quality copper substrates



HiPIMS Nb/ bulk Nb coated
Q0 > 10^{10}, Quench @ 16.5MV/m, 2.0k



SUMMARY

- Future applications of SRF linacs for which cost is a driver: ILC, FCC, ADS, medical, light sources, etc., will benefit from the development of thin film SRF cavities.

Of these, the ADS proton linac may be the first major industrial accelerator market in the world, giving potential companies two valuable opportunities:

1. They will see a large ongoing market
2. They can not only own the technology, but own as well their own internal resources for innovation to compete in that market.