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Future Thin Film Deposition Efforts at FNAL

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Recommendations from HEPAP Subpanel

- Recommendation 4. Direct appropriate investment in superconducting RF R&D in order to inform the selection of the acceleration technology for the multi-MW proton beam at Fermilab.

- Recommendation 6. Increase funding for development of superconducting RF (SRF) technology with the goal to significantly reduce the cost of a ~1 TeV energy upgrade of the ILC. Strive to achieve 80 MV/m accelerating gradients with new SRF materials on the 10-year timescale.

Presentation purpose

- Recently an LDRD to start a thin film R&D project at Fermilab was granted to Dr. Genfa Wu

- The main goal of such R&D program is to produce thin SRF film technology exploiting niobium and new materials in order to meet the recommendations from HEPAP subpanel

- Currently we are in the initial stage of assembling the deposition system and developing a research plan in collaboration with JLab and Cornell

- The presentation will be therefore centered on the reasons why we are considering the thin films technology and on the future efforts we plan to make at Fermilab

Why Thin Films?

SRF Accelerator Cost Drivers

- SRF Accelerator
  - Cryomodule ⟵
    - Cavity ⟵
    - Coupler
    - Tuner
  - Cryogenic plant
    - Cavity dynamic heat load ⟵
  - RF Power Source
  - Controls

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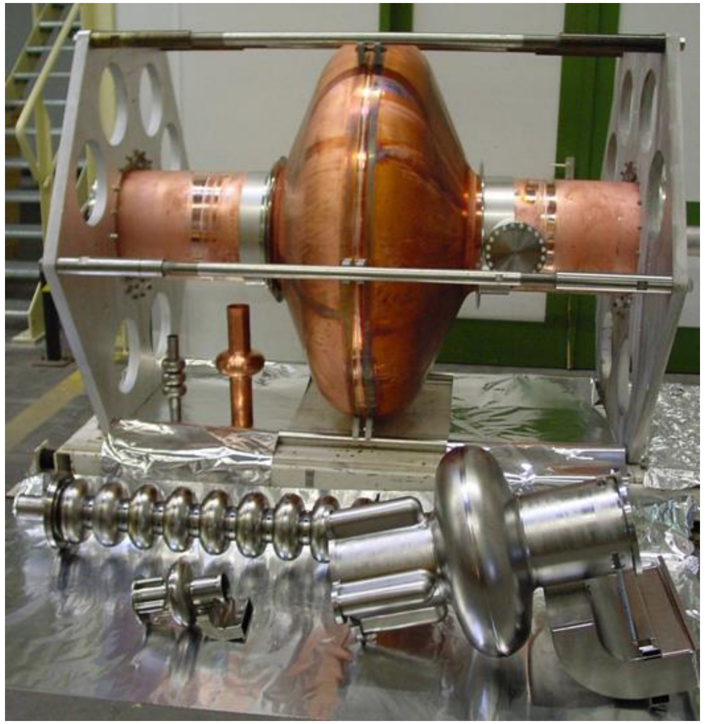
Nb/Cu



Metal cost per pound

Copper	$2.37
Niobium	$150.00

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Lower Cost

Low frequency SRF accelerators may benefit from thin film technology:

- Cavity dimensions inversely proportional to frequency
- Larger size cavity requires thicker material

- PIP-III is one good example
  - 650 MHz Linac material cost is ~$20M

- FCC 400 MHz cavity option renews the interest in film cavities
  - 600 x 400 MHz SRF cavities material cost is ~$480M

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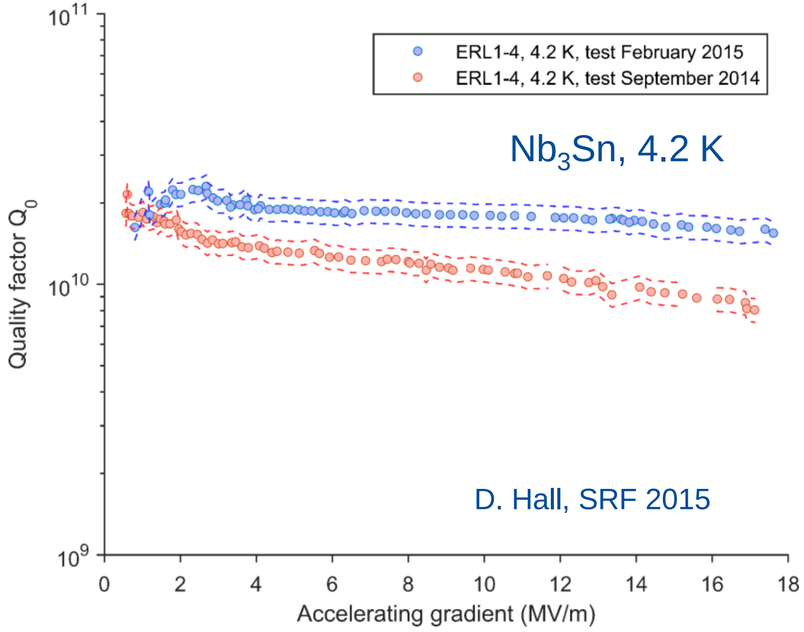
Higher T_c Materials



- Nb_3Sn, NbN, etc.
- Higher operational T
- Lower R_{BCS} (higher T_c)

Fermilab Effort in Thin Films Deposition

Superconducting Coatings @ Fermilab

Coating Goals

- Niobium coating on elliptical copper cavity
  - Thicker film (~ 20-50 µm) for EP and doping to achieve high Q-factors
- Alternative material coating on niobium substrate and/or copper substrate
  - Nb_3Sn/Nb
  - Nb_3Sn/Cu
  - NbN
  - MgB_2
- Field emission suppression coating
  - Al_2O_3, AlN, …

Superconducting Coatings @ Fermilab

Coating Methods

- ECR deposition
- HiPIMS deposition
  - Explore self sufficient niobium sputtering in vacuum (or minimize the inert gas pressure)

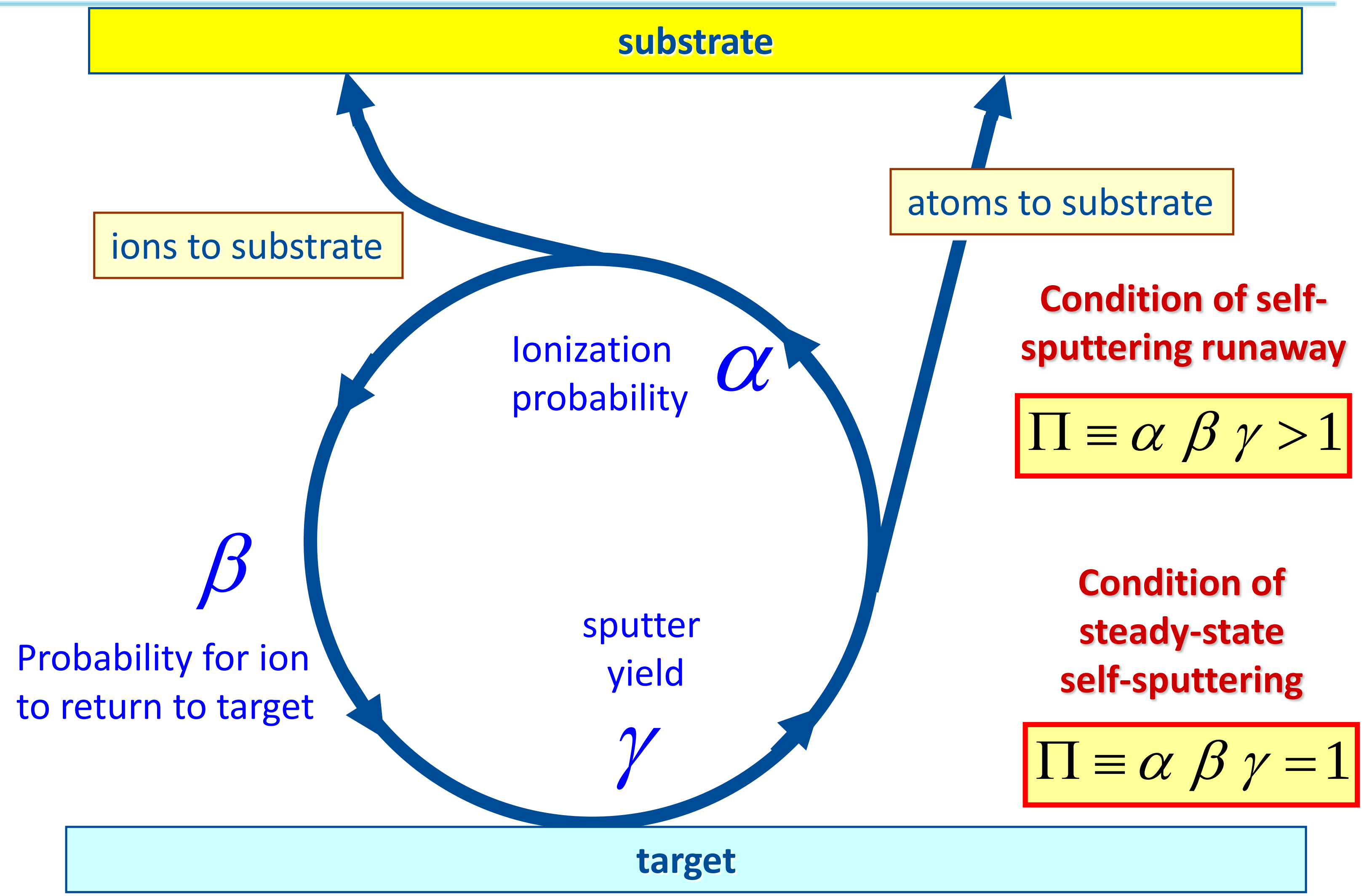
Post processing of thick film

- Annealing to remove crystal defects
- Doping to reduce BCS resistance
- Electro-polishing to remove surface layer

Design a mechanically strong substrate cavity to satisfy the pressure safety requirement

HiPIMS Deposition

- HiPIMS Principle
  - High power pulses at the target
  - Neutrals atoms sputtering
  - Partial ionization of neutrals
  - Ions returns to the target
  - Self sputtering (metals ions sputter metal neutrals)

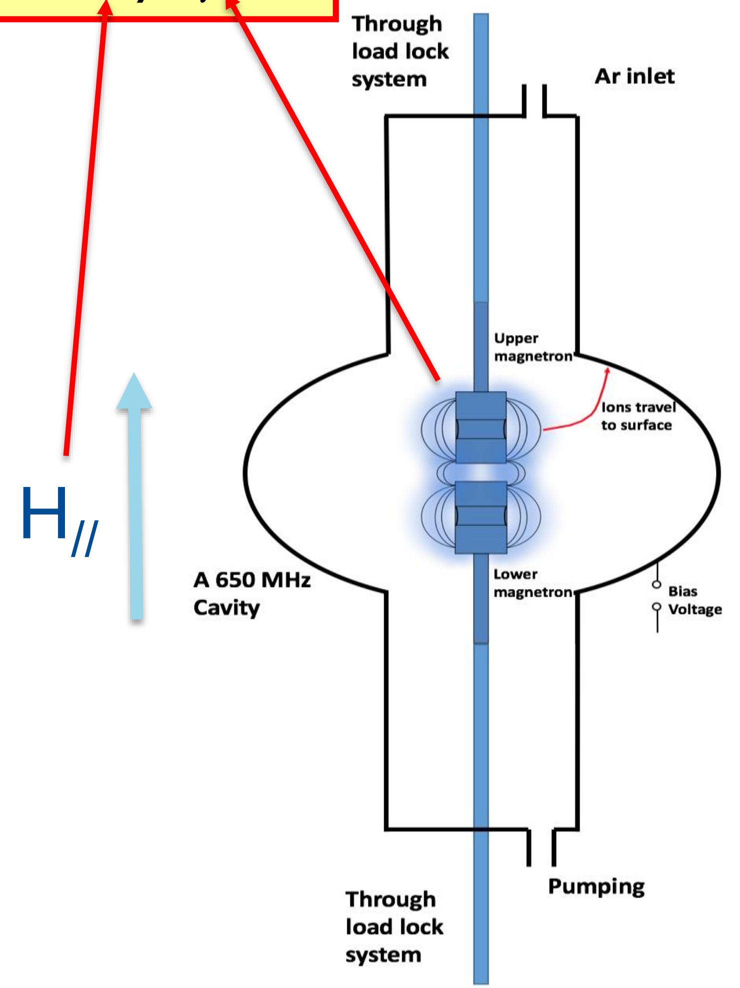


A. Anders, Surf. Coat. Technol. **205** (2011) S1.

HiPIMS deposition plans @ Fermilab

- Research on Niobium Self Sputtering in Vacuum
  - Using external magnetic field to increase ionization coefficient
  - Design the magnetron to increase the self sputtering yield of niobium
- Introducing an insulating layer
  - Improve adhesion
  - Eliminate thermal EMF due to bimetallic interface
  - Allows fast cool down for magnetic flux expulsion
- New materials

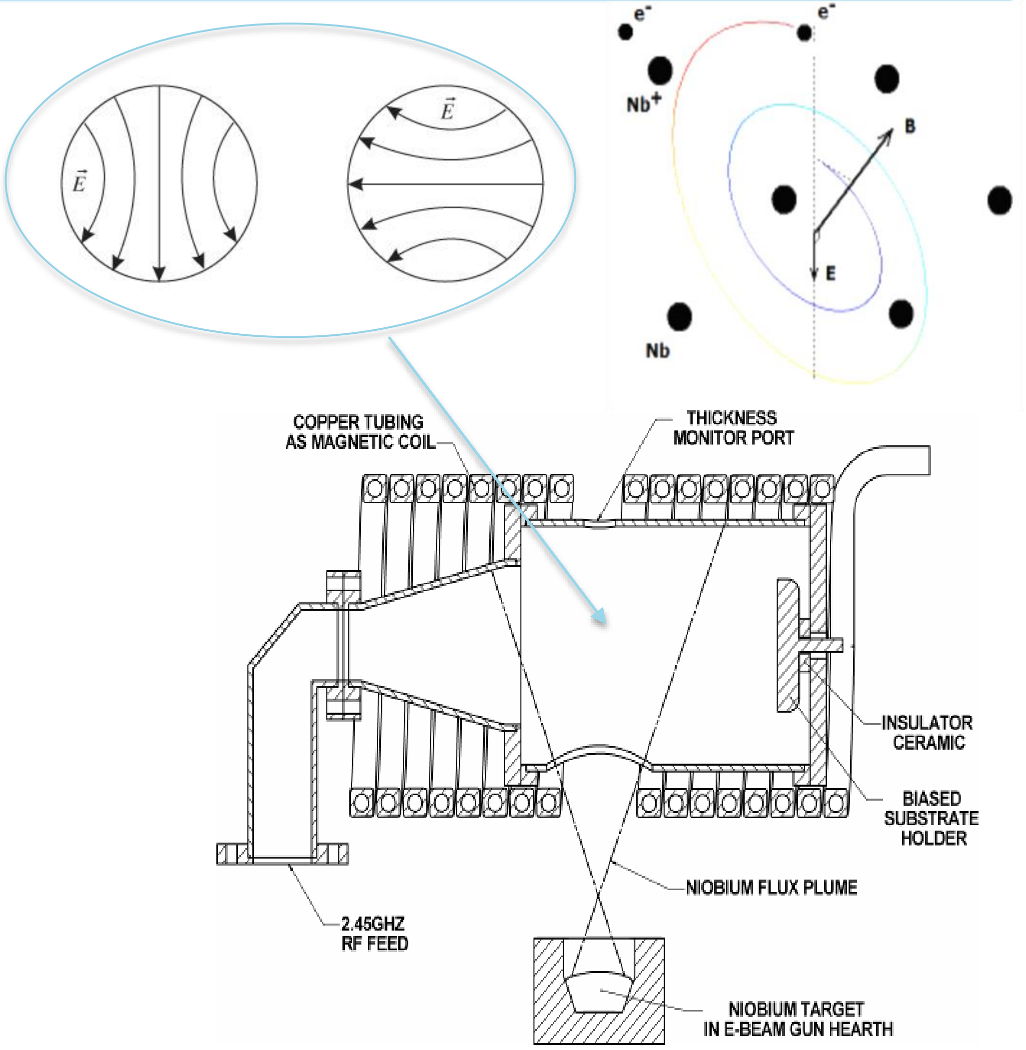
$$\Pi \equiv \alpha\,\beta\,\gamma > 1$$



ECR Deposition

- Plasma generation
  - Neutral Nb vapor generated by electron beam
  - Electron cyclotron resonance:
    - RF power (@ 2.45GHz)
    - Static B ⊥ E_{RF}
  - Neutral Nb vapor ionized

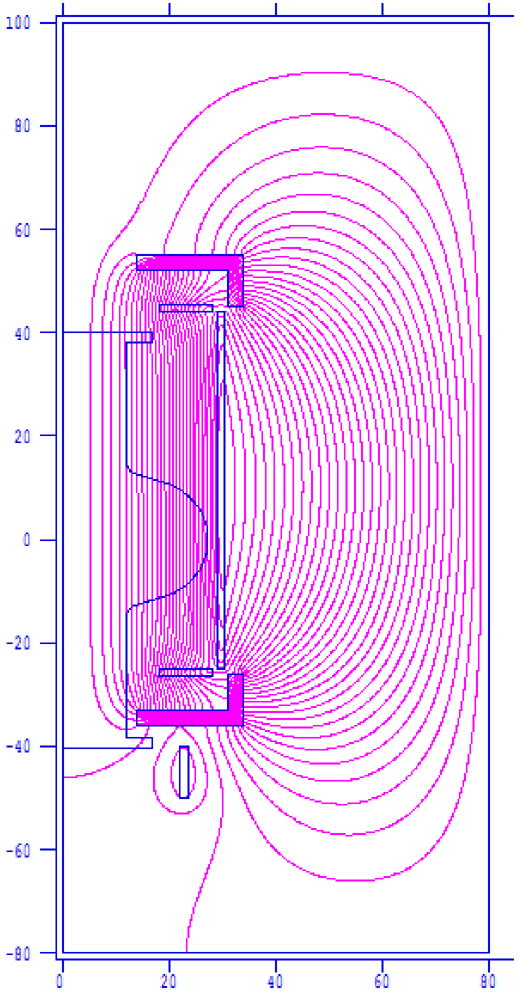
- Pros
  - No working gas
  - Ions produced in vacuum
  - Singly charged ions 64eV
  - Controllable deposition energy with Bias voltage
  - Excellent bonding
  - No macro particles
- Cons
  - So far limited to niobium

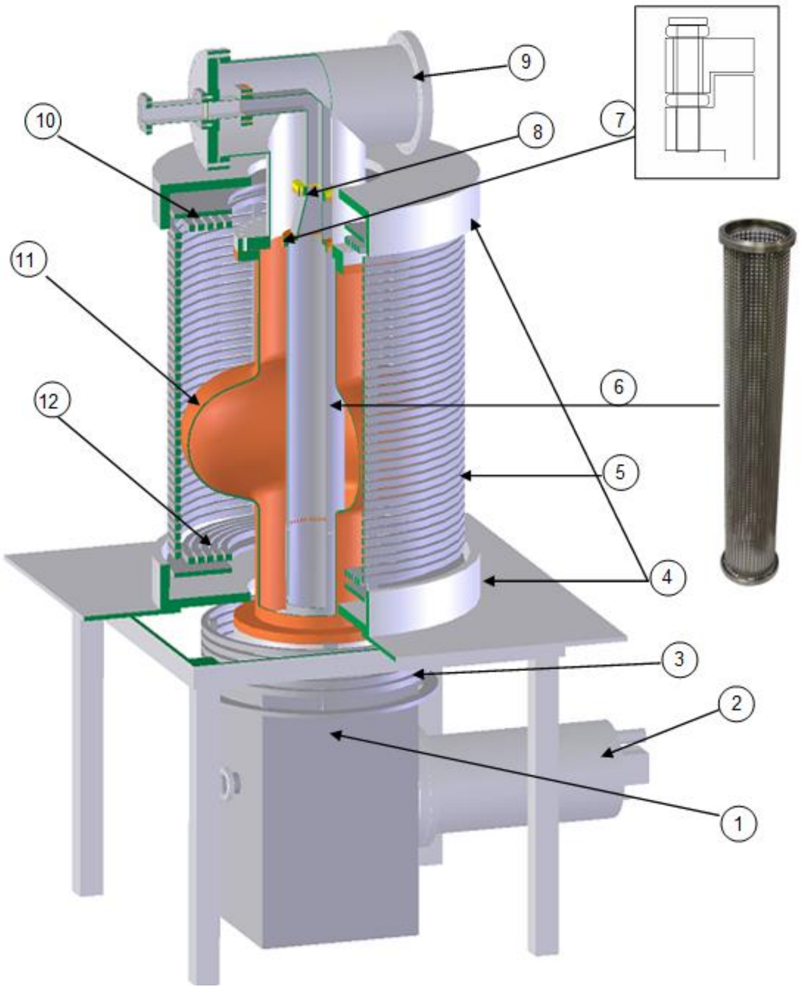


G. Wu, et al. J. Vac. Sci. Technol. A 21 (2003)

ECR Cavity Deposition System

Potential use for surface cleaning and Nb_3Sn, NbN coatings

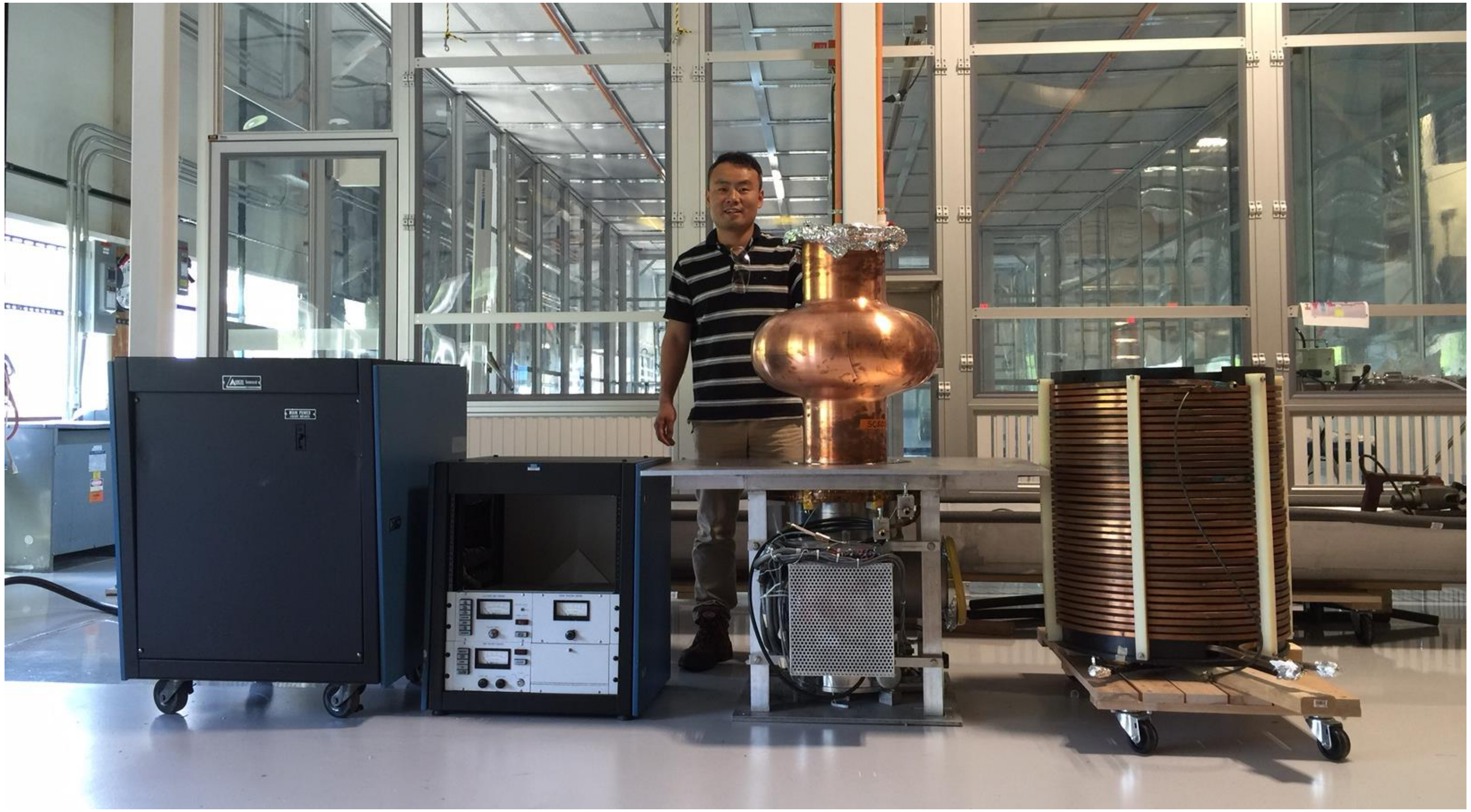




(1) 14kW rod-fed E-gun
(2) 9000 l/s cryopump system
(3) bucking coil for E-gun
(4) top and bottom iron yokes (outer iron shield is removed for illustration)
(5) center coils
(6) Nb grid tube
(7) bias insulator
(8) WR284 waveguide E-bend and horn to the grid tube
(9) “T” vacuum chamber
(10) top pancake coil
(11) Cu cavity
(12) bottom pancake coil.

ECR Cavity Deposition System Moved to Fermilab

JLAB



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Summary for Superconducting Coatings for Future SRF

- HiPIMS deposition R&D will be pursued in order to achieve performing film-based SRF cavities, implementing:
  – Self sputtering
  – Thick film
  – Processing technology of bulk niobium cavities

- ECR coating showed promising results on samples. Fermilab is collaborating with JLab and Cornell to coat a copper cavity to test

Acknowledgments

- Hasan Padamsee for his pivotal work on gluing together the collaboration
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Thank you