An Approach to Chemical Free Surface Processing for High Gradient Superconducting RF Cavities

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FMT Capabilities

- Founded in 1987, FM Technologies, Inc. (FMT) is a technology company with expertise in: charged particle beams, particle accelerators, plasma physics, electron/ion/microwave beam interaction with materials, microwave source development, pulsed power, and integration of these areas
- FMT has several projects approaching the commercial development stage
  - Ceramic/Ceramic & Ceramic/Metal joining for use in high temperature chemical conversion processes
  - Self-Bunching Electron Guns with/without Current Amplification for Accelerators and RF sources
  - Microwave Plasma Torches for various applications

Project

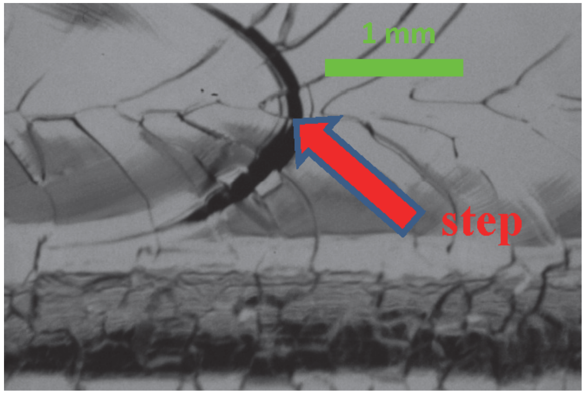
- SRF Cavity chemical treatment is expensive and complex.
- After treatment surfaces still have numerous bubbles and pits.
- Quench-producing weld defects and contamination, result in significant scatter of the Nb SRF cavities performance.
- Cost &Performance scatter are the major manufacturing problems.
- FMT proposes to develop an internal electron beam (IEB) system that will perform electron beam melting over the entire interior surface of Nb SRF cavities
- Resulting in a surface that is smooth, void/bubble free, and without imperfections.
- This may allow manufacturing of the Nb SRF cavities with a reduction in chemical treatment and increase the cavities high gradient performance.
- FMT will design, build, test the new IEB system and process samples/cavities and Thomas Jefferson Laboratory will measure RF performance of processed samples/cavities.

Seven-Cell Nb SRF Cavity at Thomas Jefferson National Accelerator Facility

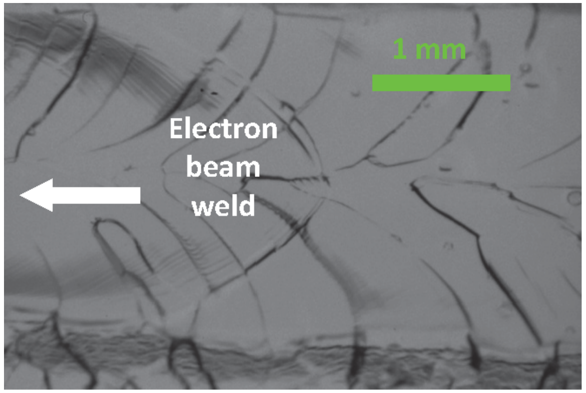
International Linear Collider alone needs 22,000 cavities at $210k (avg.) /cavity=$4.62 Billion.

Typical SRF Cavity Defects

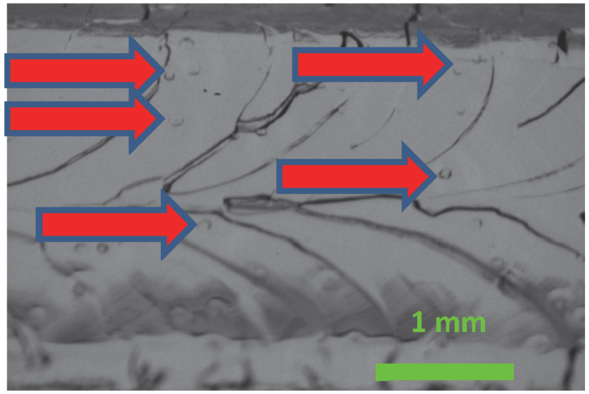
Pictures show typical defects inside Nb SRF cavities around the equator EBW overlaps and remain after chemical treatment:



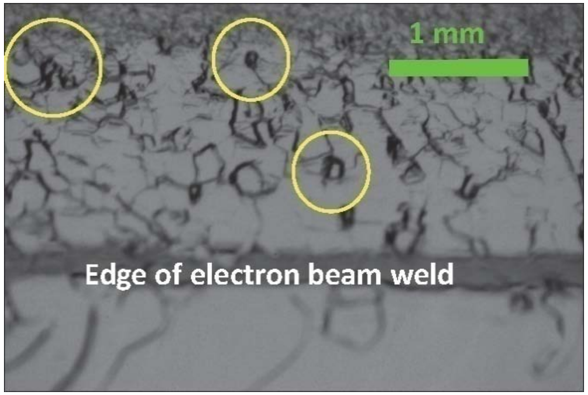
- Irregularity (step) near equator EBW overlap of cell #7 from waveguide



- Two cells have less pronounced features; four cells have no recognizable features



- Many "bubbles" sporadically present inside the weld



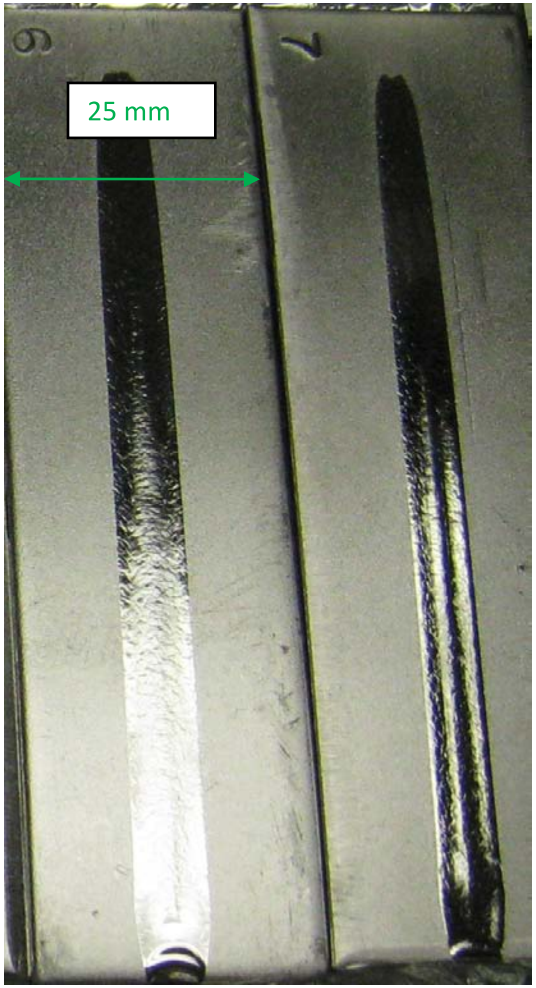
- Many apparent "deep pits" in heat affected zone

Study of Beam Processing for Cavities

Objectives:

- Achieve a smooth surface with minimal defects and impurities
- Achieve a low strain surface to reduce corrosion
- Final goal is to attain reproducible high Q ($>10^{10}$) and high field (40MV/m) cavities

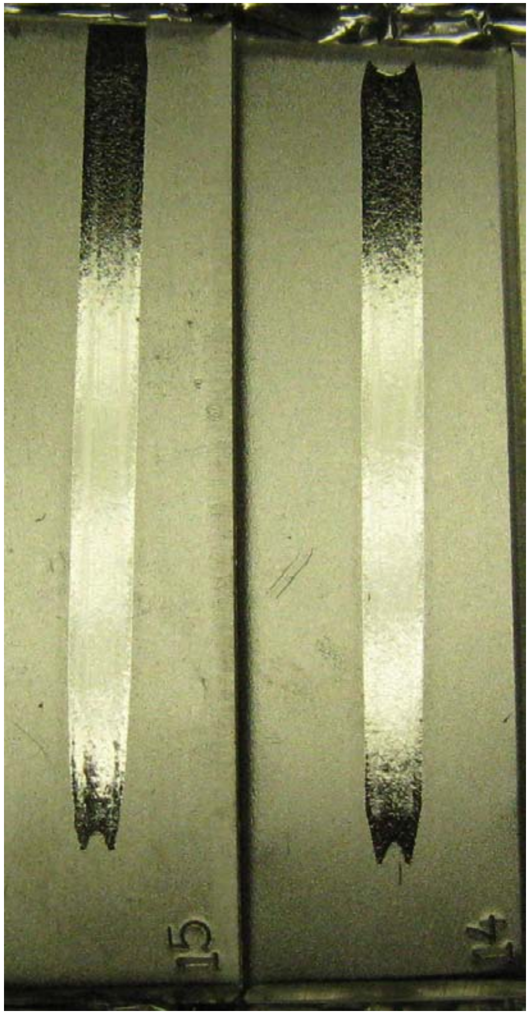
Electron Beam Melted Nb Samples Using J-lab SCIAKY Welder



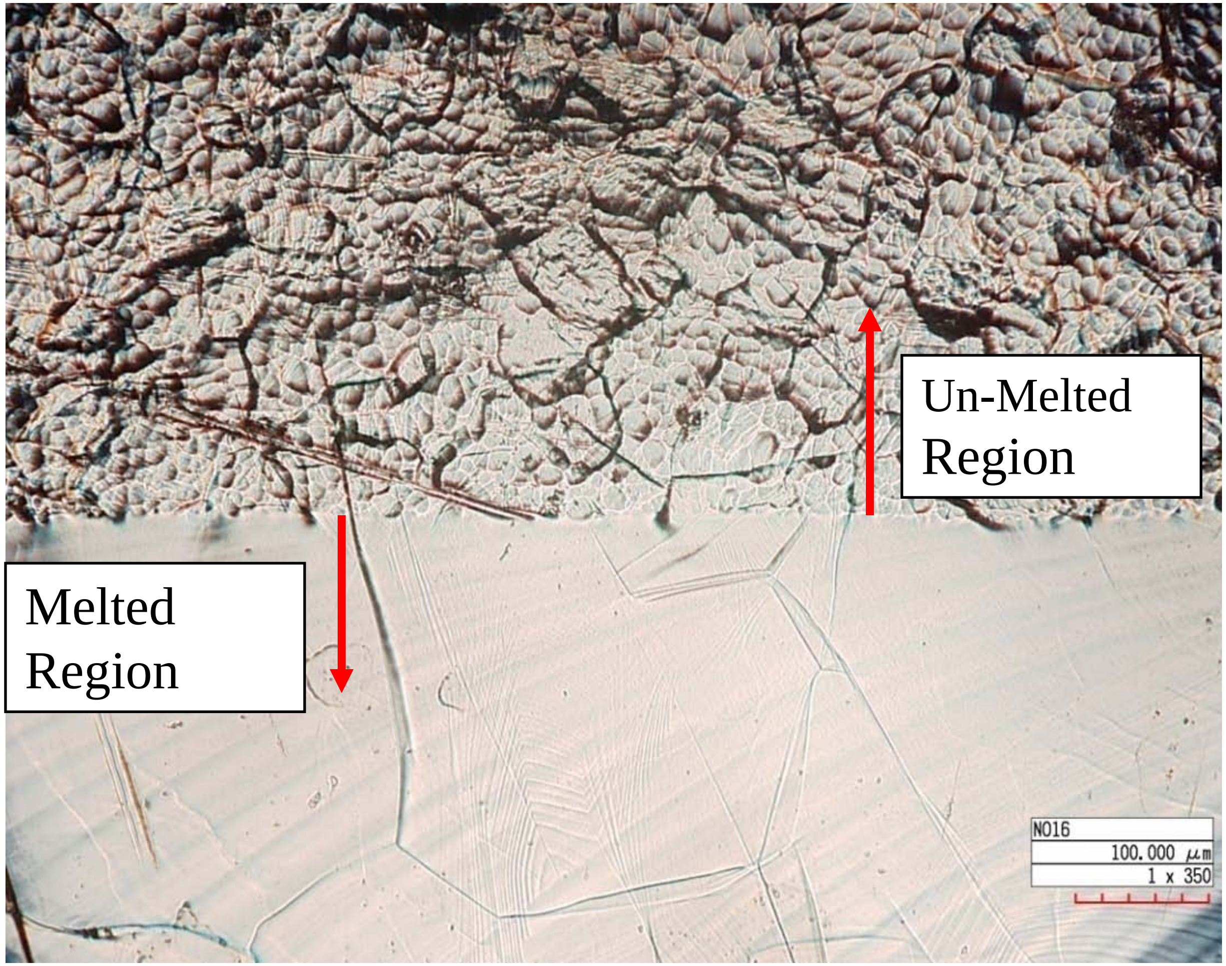
Each single pass melt region is about 6 mm x 74 mm x 0.1-0.2mm deep

A 10 kHz circular to elliptical raster with 0.5-1 mm beam diameter with a particle energy of 50 keV.

28 plates of Nb with dimensions 3 mm thick x 25.4 mm wide x 88.9 mm long



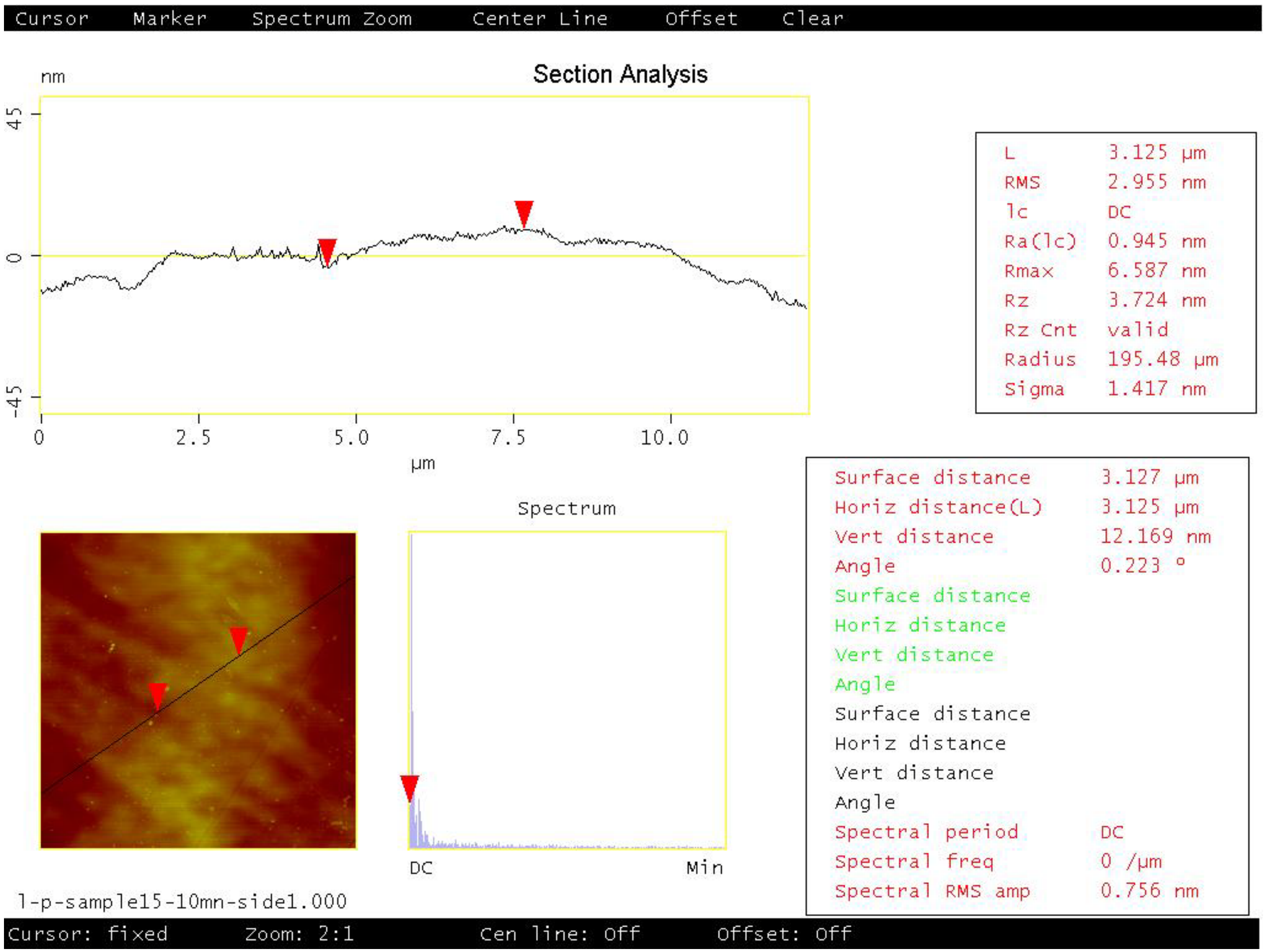
Magnification of Melt Zone



HIROX digital microscope view of sample #6

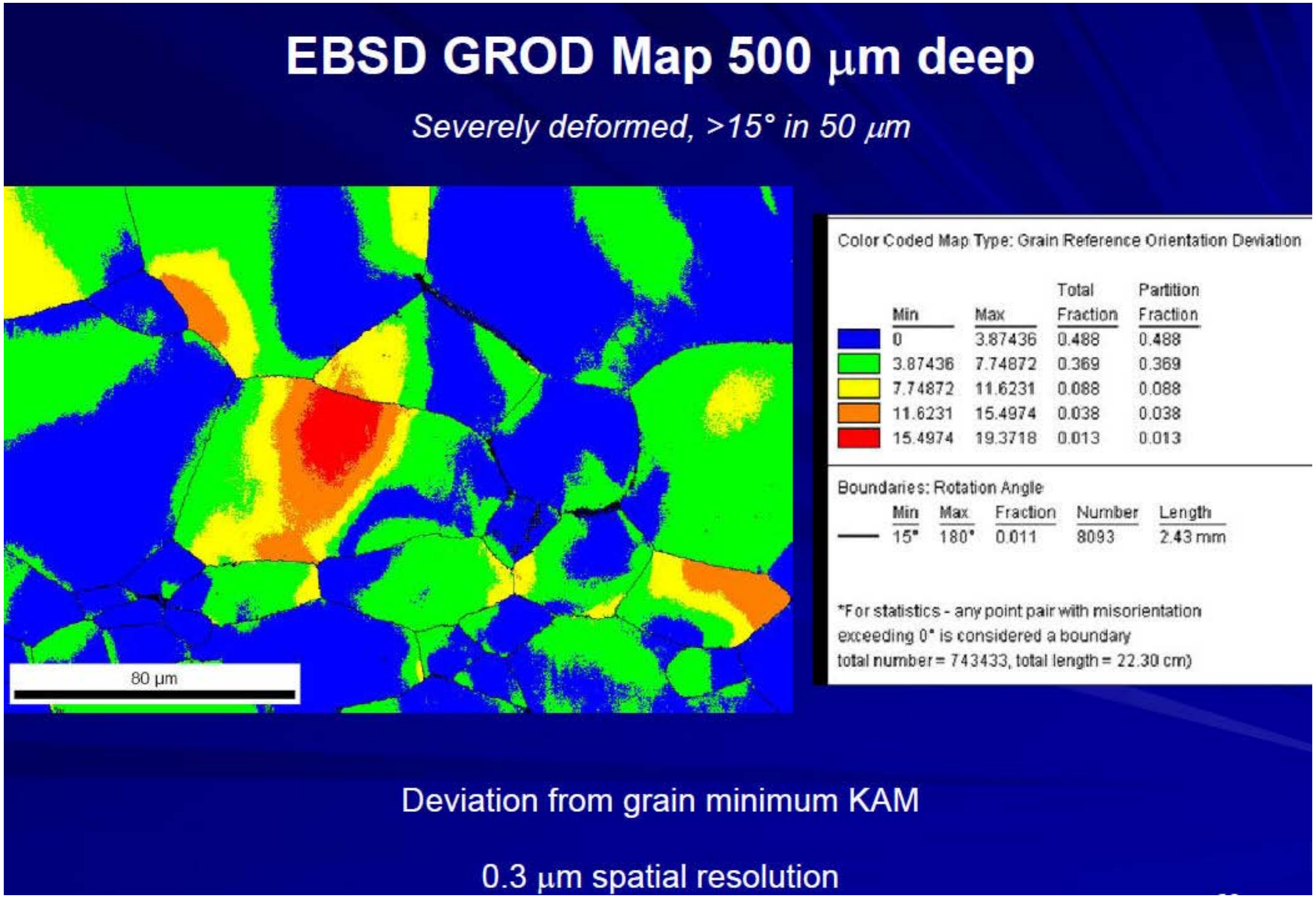
Bottom half of image shows the smooth melted region that highlights the grain size of about 300-400 μm, while upper half of the image shows the rough un-melted small grain region

AFM of Sample #15



AFM RMS value of less than 3 nm, which is 1/20 of what can be accomplished by electro-polishing and much less than the superconducting layer for Niobium at =42 nm @ 2K.

Grain Reference Orientation Deviation (GROD) Map for Deep Drawn Half Cell



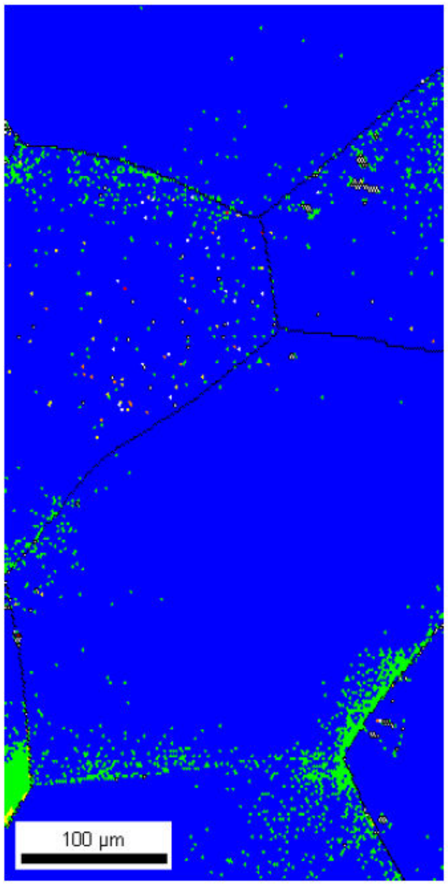
Courtesy of Dr. Roy Crooks of Black Laboratories

The section is taken from 3 mm from the equator

The GROD map shows extreme lattice distortion up to an angular rotation of about 20 degrees

No chemical etching has occurred

Grain Reference Orientation Deviation (GROD) Map for Nb Flat Sample #15



No. 15

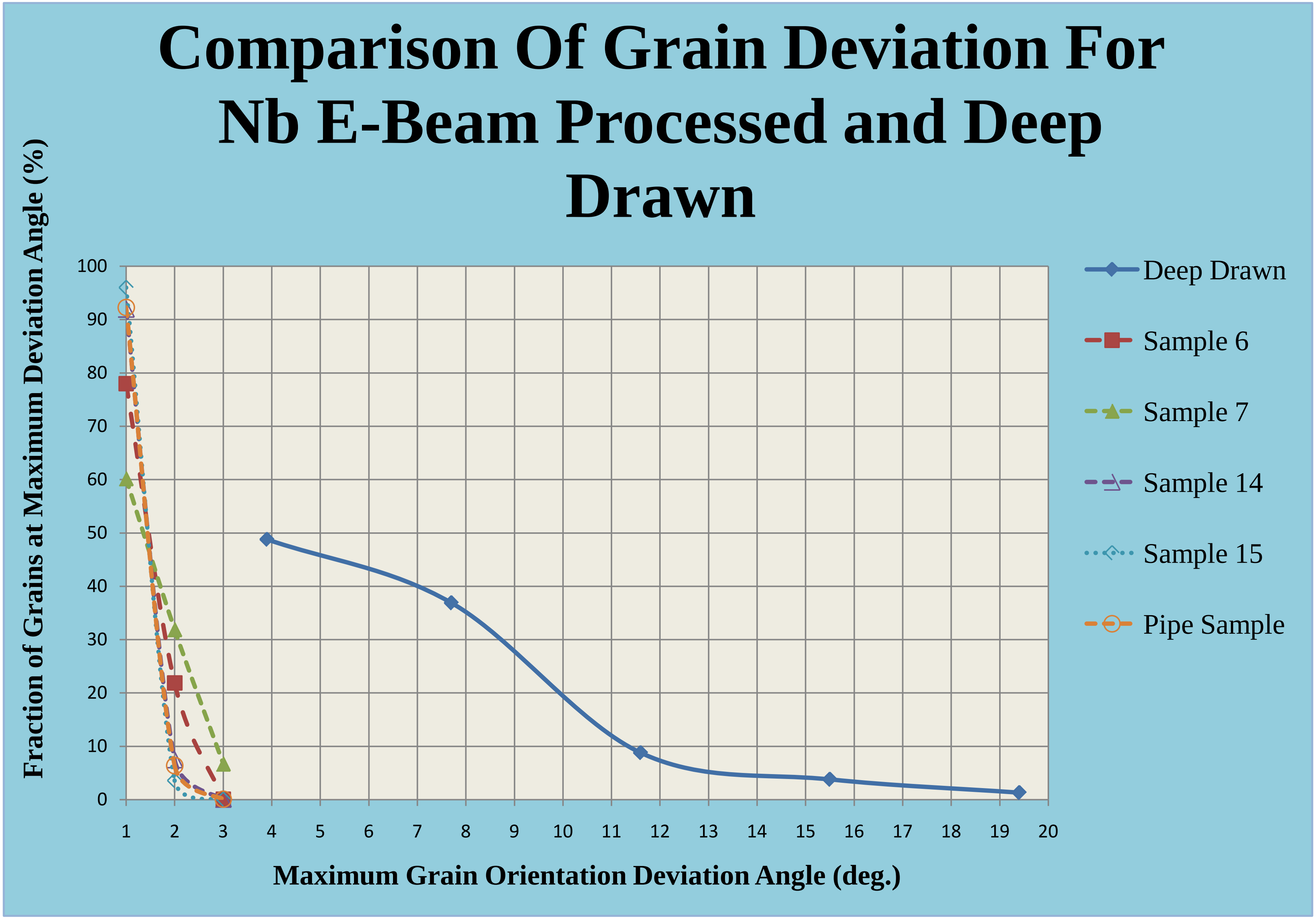
GROD

Color Coded Map Type: Grain Reference Orientation Deviation

	Min	Max	Total Fraction	Partition Fraction
Blue	0	1	0.960	0.960
Green	1	2	0.036	0.036
Yellow	2	3	0.001	0.001
Orange	3	4	0.000	0.000
Red	4	5	0.000	0.000

Samples #14 and #15 show less lattice distortion compared to samples #6 and #7 as measured by GROD from 0 – 2 with the majority of distortion less than 1 over 100 – 300 µm

No chemical etching has occurred



Comparison Of Grain Deviation For Nb E-Beam Processed and Deep Drawn
Fraction of Grains at Maximum Deviation Angle (%)
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Maximum Grain Orientation Deviation Angle (deg.)
Deep Drawn
Sample 6
Sample 7
Sample 14
Sample 15
Pipe Sample

Summary of Beam Results for A Smooth Low Strain Surface

- Both HIROX & AFM suggest that a smoother surface is attained at lower beam energy dose

- EBSD (GROD) maps suggest a lower strain surface is attained at lower beam energy dose

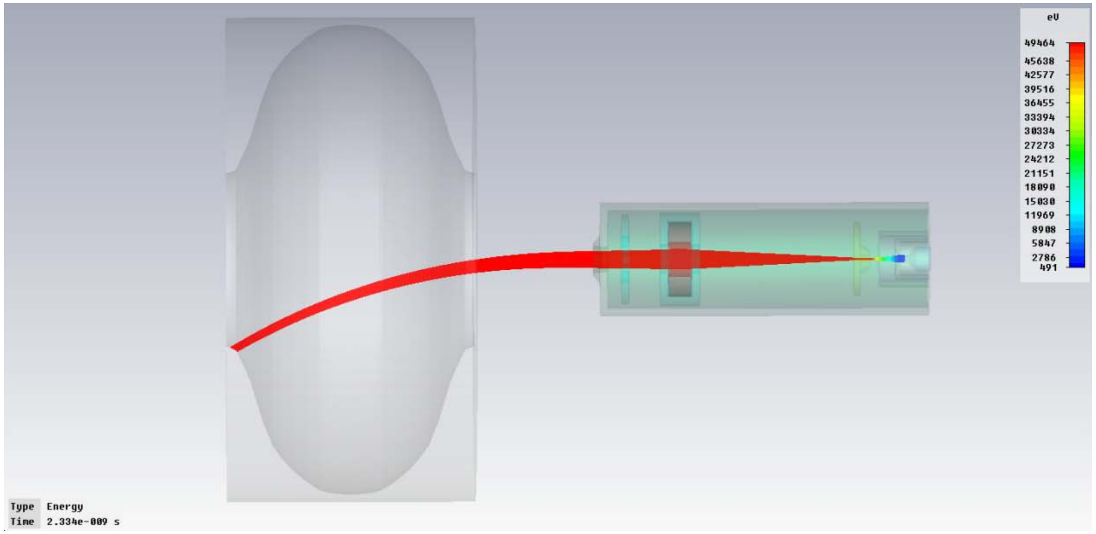
Electron Gun and Beam Transport Design

- Two Strategies: Ballistic Focusing and Magnetized Beam

CRITERIA:

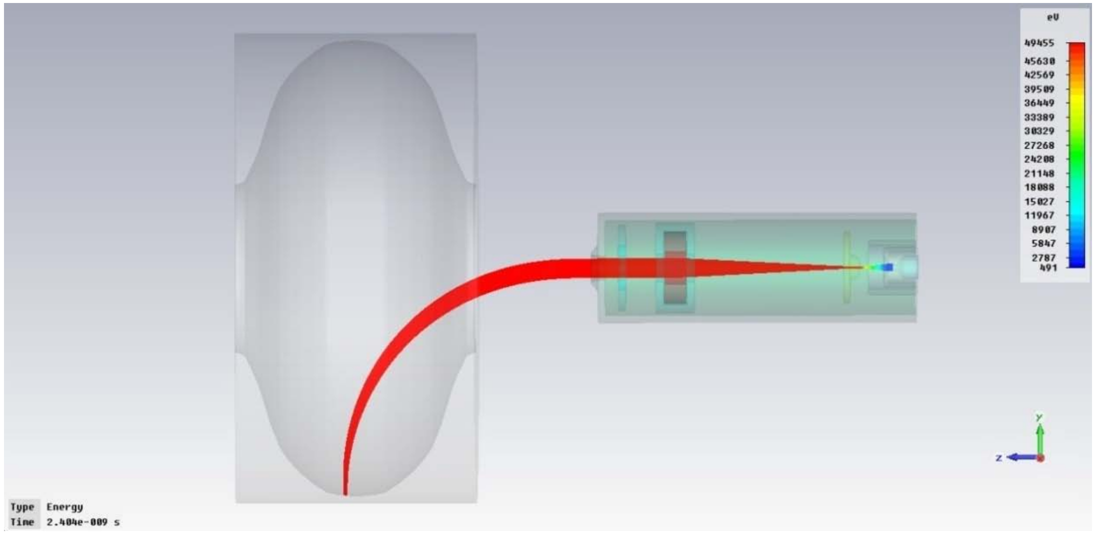
- – Can process from iris to equator and circumference
- – Prevent Nb vapor arcing
- – Can tolerate beam induced thermal radiation & filament heat load
- – Electron Gun Characteristics: ~50keV, beam spot 0.5-1mm, gun diameter<cavity iris (<50mm), focal length 30-100cm and current control independent of focus.

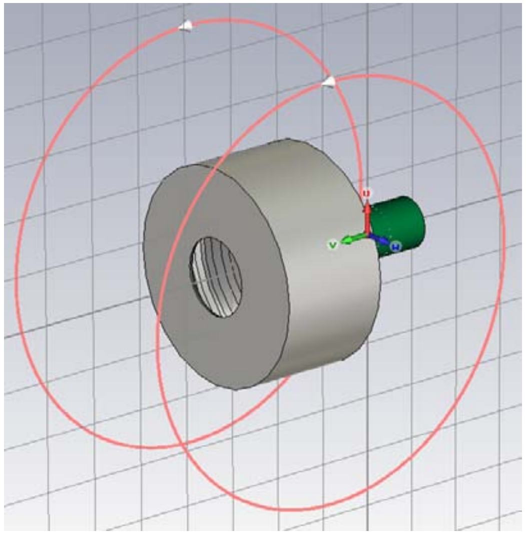
Ballistic Focusing Gun-Electron Beam Trajectory



Helmholtz coils provide R-Z beam scanning from iris to equator

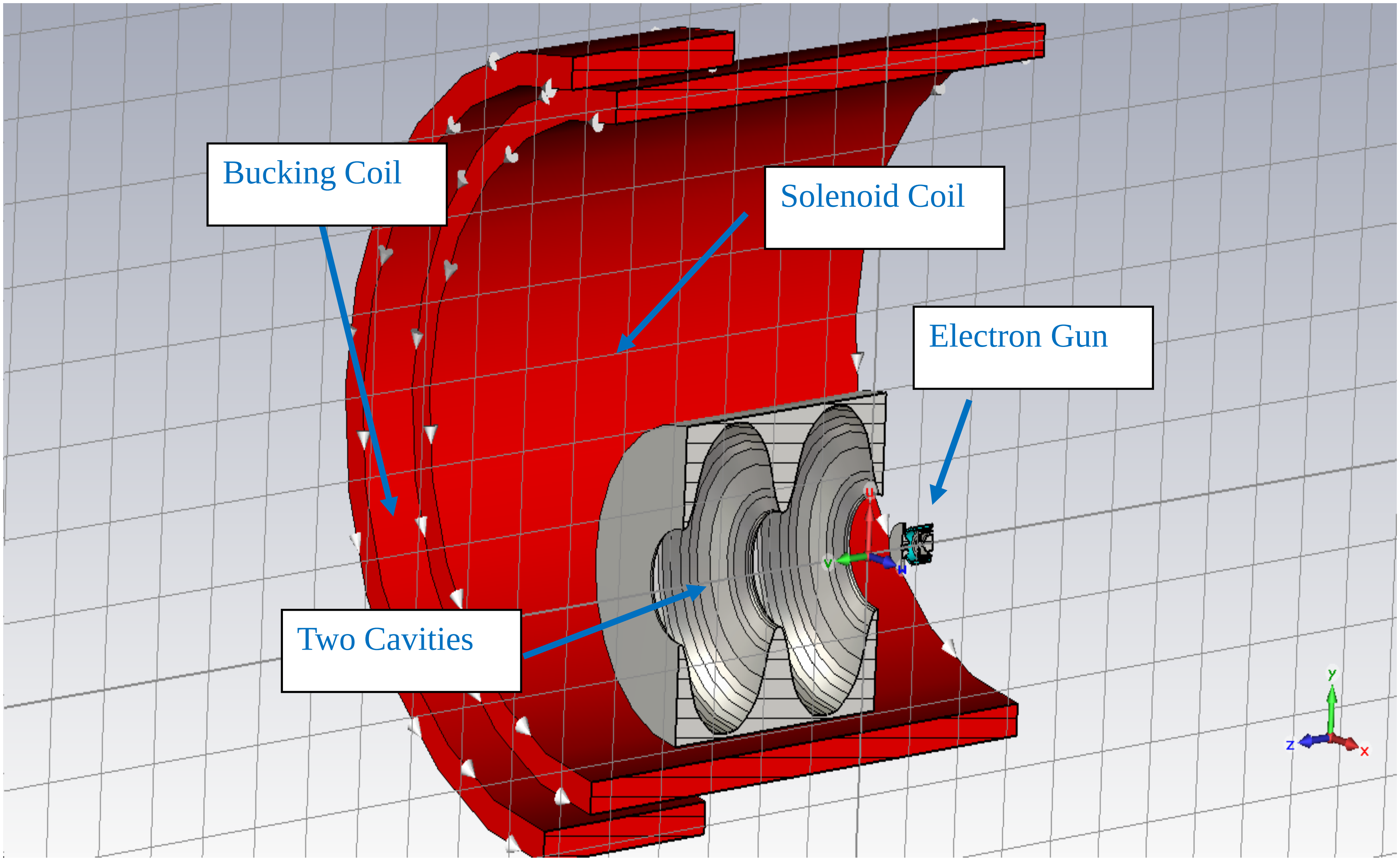
Azimuthal scanning provided by rotating either the cavity or Helmholtz coils or field about the Z-Axis



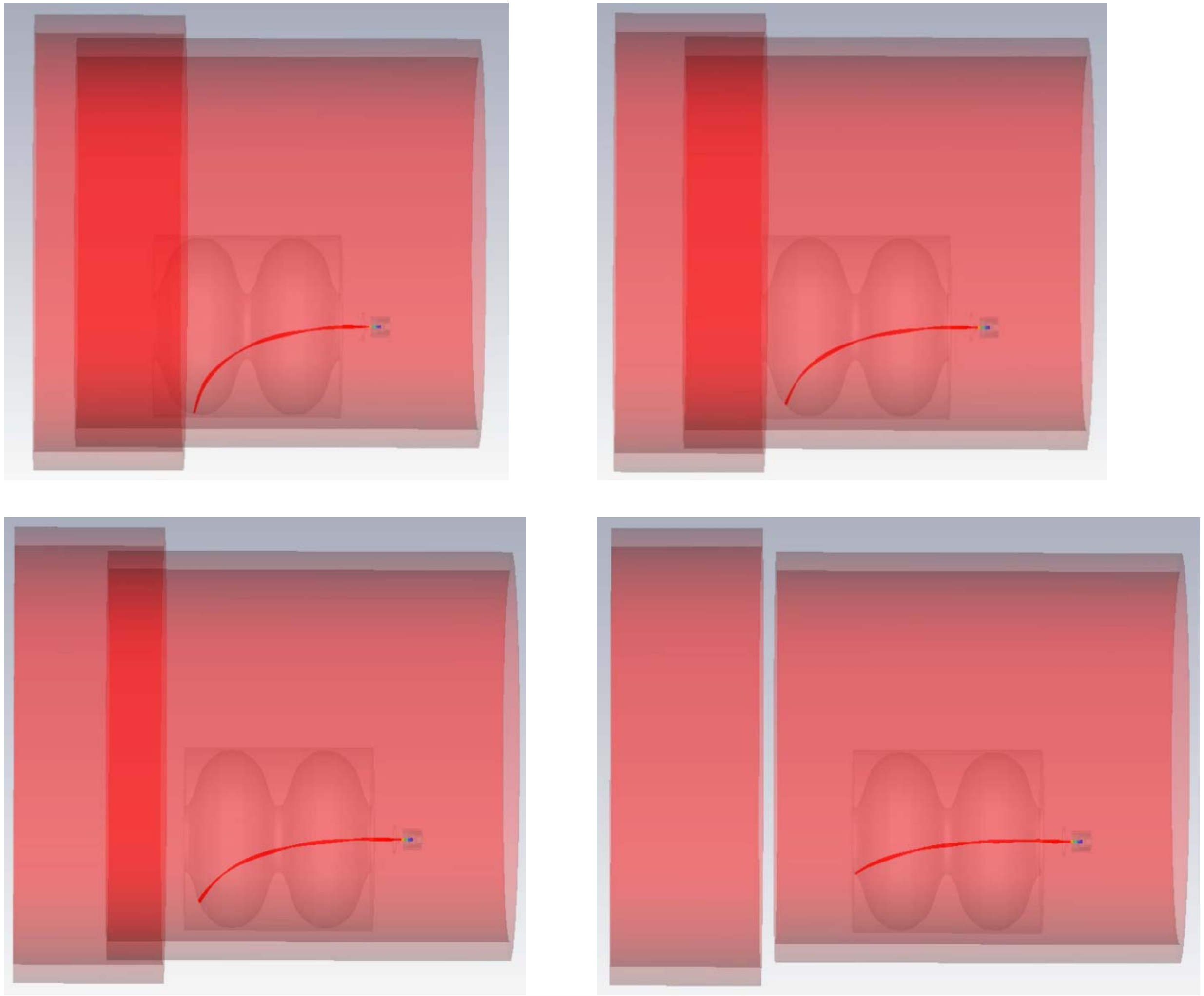


Magnetized E-Beam Gun

Simple Gun Design Only Needs Cathode, Grid & Anode



Magnetized E-Beam Gun-Electron Beam Trajectory

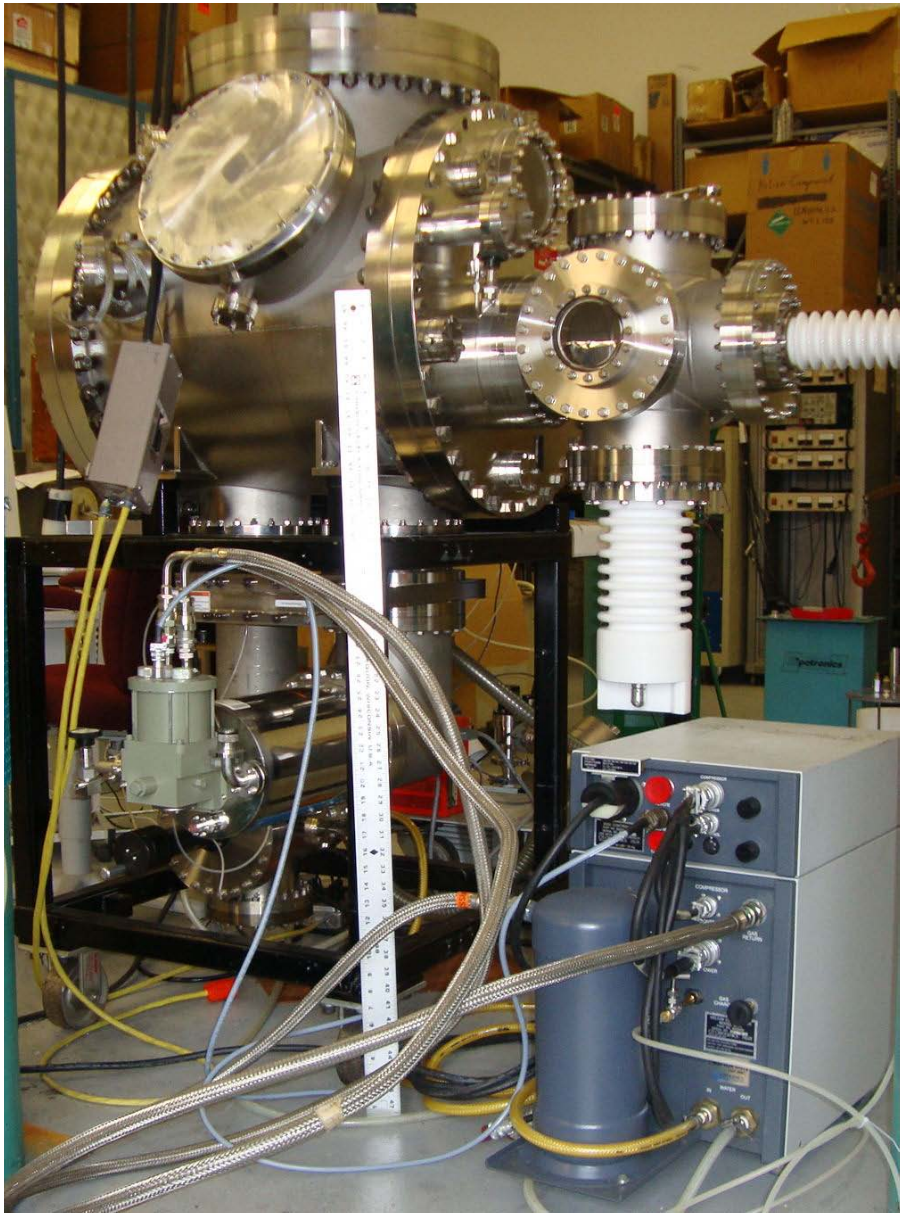


Bucking coil position/current provides R-Z beam scanning from iris to equator.

Azimuthal scanning provided by rotating cavity.

Advantage over ballistic gun much longer focal length but more complex magnetics.

Stainless Steel Test Chamber



Chamber reaches 10^{-8} Torr in ~2hr with turbo and cryo-pumps.

Chamber Ready for Gun Installation and High Voltage.

Chamber Suitable for Time Dependent Magnetic Fields- Magnetic Diffusion Time ~13ms.

Summary and Status

- Beam parameters have been determined to give a smooth low strain surface using a conventional rastered beam

- Two gun designs examined (ballistic & magnetized beams) to meet the requirements with and without rastering for both internal and external gun operation

- Stainless Steel Vacuum Ready for High Voltage and E-Gun and Suitable for Time Dependent Magnetic Fields

- Prototype Ballistic Gun Designed and Ready for Fabrication

- Next Step will be to Surface Melt Nb Flat Strips with New E-Gun