Results Of The 2015 Helium Processing Of CEBAF Cryomodules

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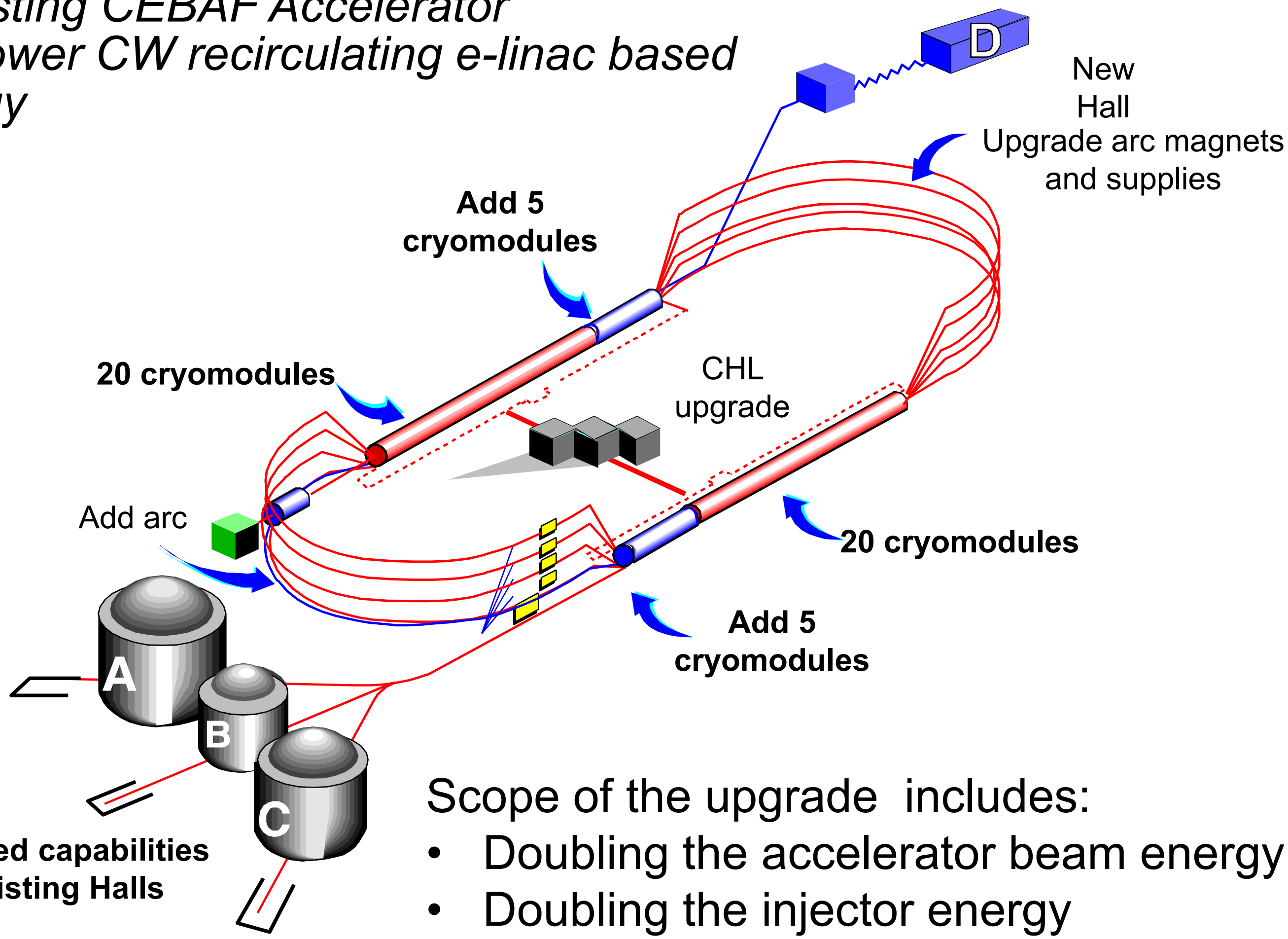
Outline

- Background
- Benefits of Field Emission Reduction
- Equipment and Procedures
- Problems Encountered
- Results

Background: 12 GeV Upgrade

Built upon the existing CEBAF Accelerator
First large high-power CW recirculating e-linac based on SRF technology



Scope of the upgrade includes:

- Doubling the accelerator beam energy
- Doubling the injector energy
- New Hall and beam-lines
- Upgrades to existing Experimental Halls

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Background

- Summer 2015
  - All C100 cryomodules installed and commissioned
  - 12 GeV Beam Commissioning Completed
    - 02/05/2014 Eight hour run with beam at 2.2 GeV per pass
    - Average 50 % availability

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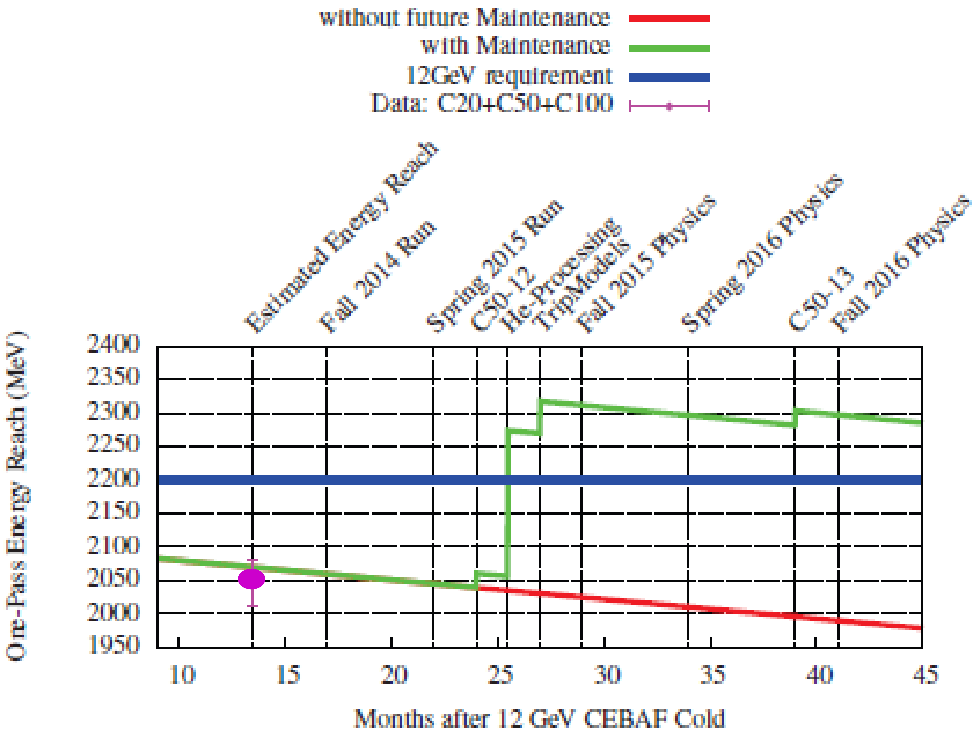
Background



Installed linac cryomodules

- 29 C20's
- 11 C50's (refurbished C20's)
- 10 C100's

- Spring 2015- Estimated Energy Reach ~2.05 GeV / single pass
- Original cryomodules have measureable energy degradation of ~34 MeV/yr
- Helium Processing one of several activities designed to establish robust energy gain to support 12 GeV program

(A. Freyberger, Commissioning and Operation of 12 GeV CEBAF, in *Proc. Int. Part. Accel.* Conf. 2015, Richmond, Virginia (2015), pp. 1-5.)

BackGround – Helium Processing

- Helium processing - method used for electron field emission reduction in SRF cavities.
- Established technique for many years – while the exact mechanism remains unclear, potential mechanisms include:
  - FE current locally ionizes the helium gas, forming a local plasma which heats and melts the emission source
  - Provides microscopically directed helium ion bombardment of the source
  - Enhances the local field to the point of drawing out current densities sufficient to explode the emitter.

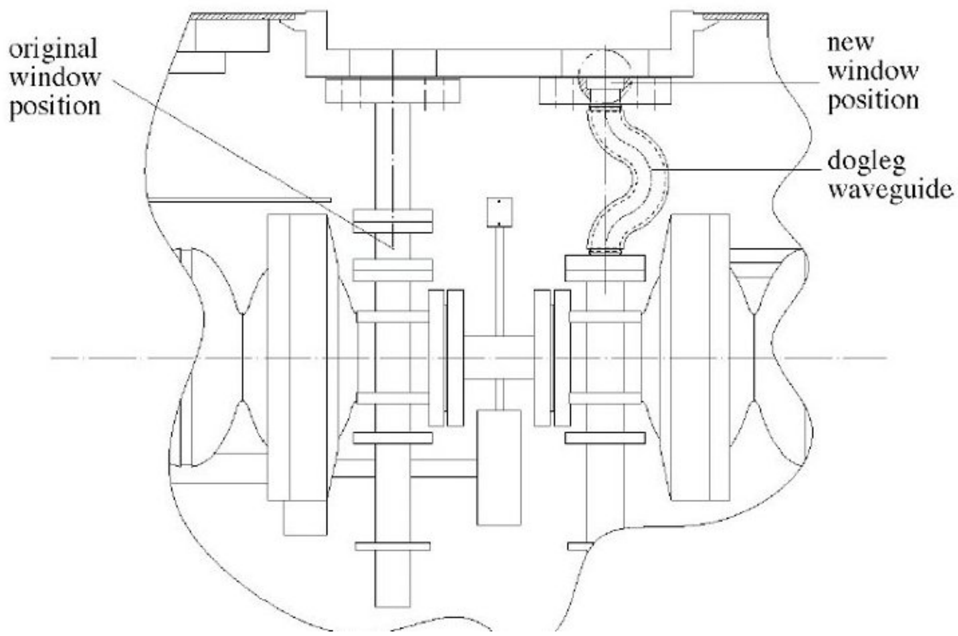
C. Reece, M. Drury, M. G. Rao, and V. Nguyen-Tuong, Improvement of the Operational Performance of SRF Cavities via In Situ Helium Processing and Waveguide Vacuum Processing, Proc. 1997 Part. Accel. Conf., (1997).

Benefits of Field Emission Reduction

Arc Rate Reduction

Original C20 FPC Design suffers from periodic arcing in vacuum space between RF windows.

- Field emission related charging of cold window
- Discharge causes arc
- Rate of arcing varies but is directly related to field emission rates
- Usable gradient limited to minimize trip rates
- Usable gradient reduced by 20-30% or more (per arcing cavity)
- **Reduce field emission – increase usable gradient**

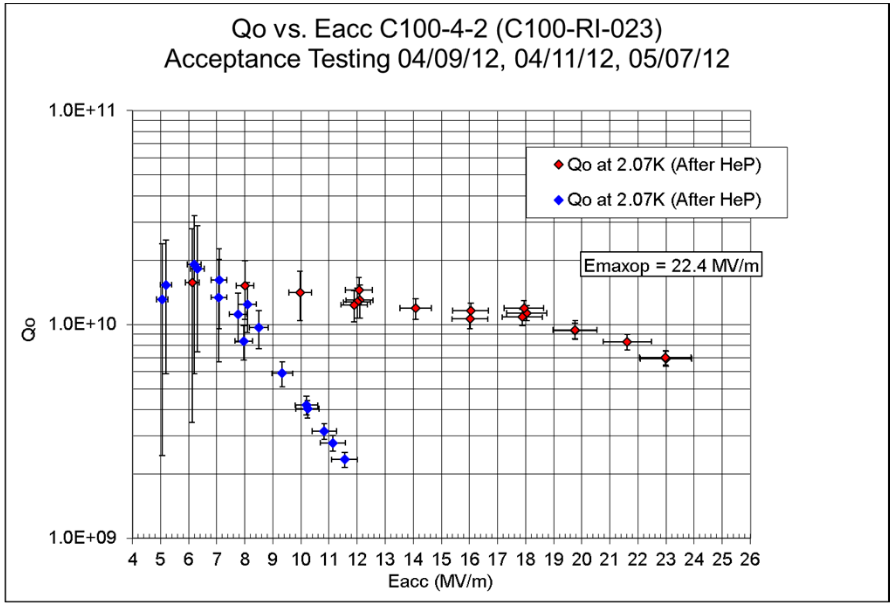


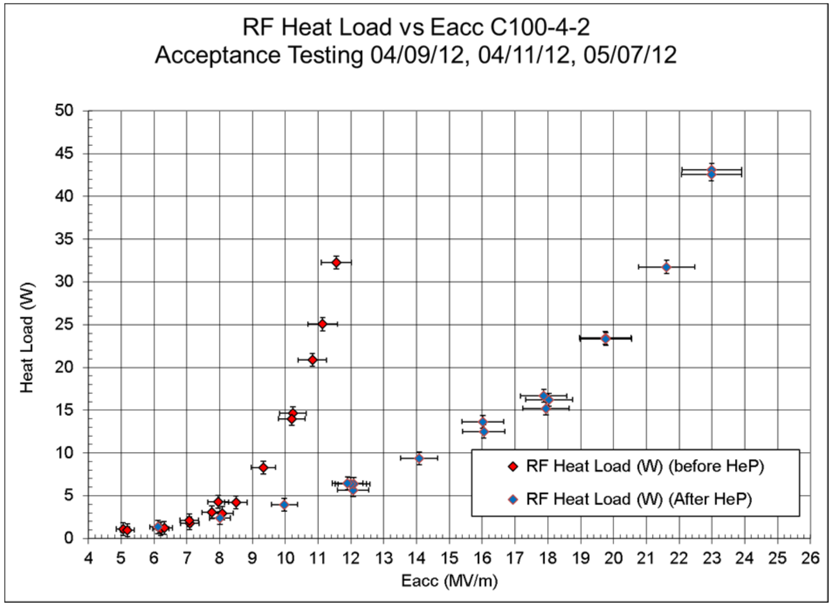
P. Kneisel, *et al.*, Response of CEBAF's cold RF Window to Operation in FE-Regime of a Cavity, CEBAF Tech-note TN94-029.

C20 → C50 FPC Design

Benefits of Field Emission Reduction

- Reduced Field Emission = Reduced Dynamic Heat Load
  - In some cases, reduced heat load leads to higher gradients





Processing of a C100 cavity after beamline vacuum event - 2012

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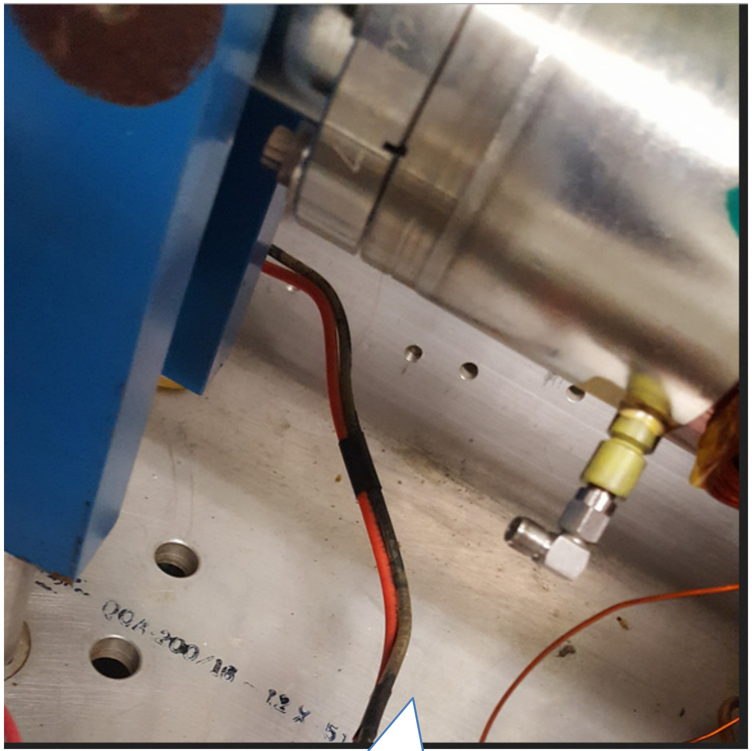
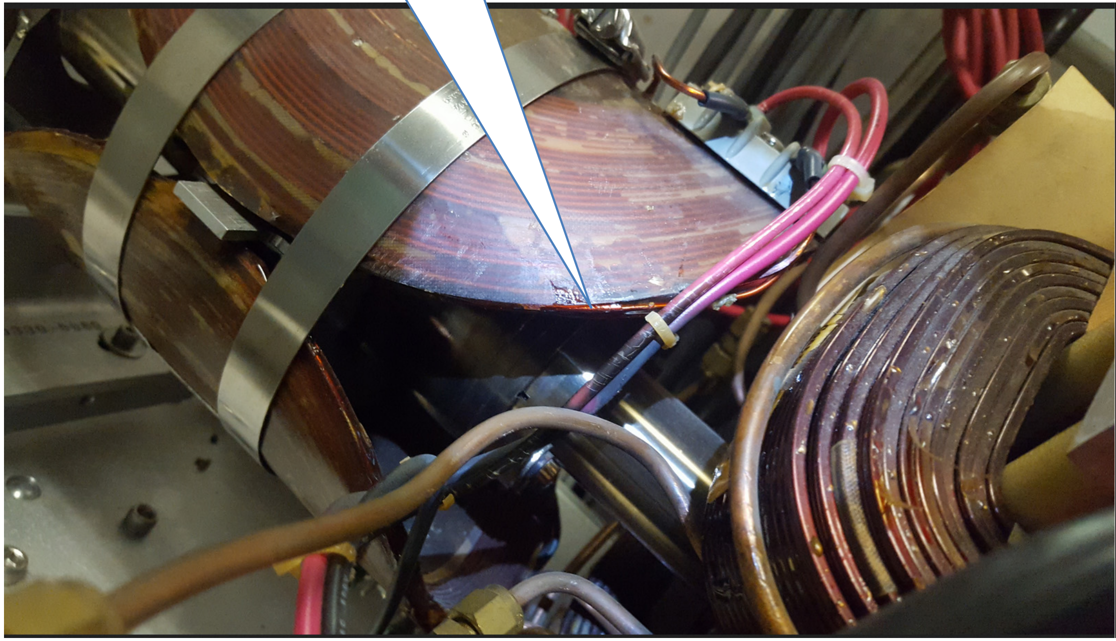
Benefits of Field Emission Reduction

- Reduced material activation and material damage due to FE radiation around the C100 cryomodules.
- Less radiation on the Viton seals means longer lifetime for beamline valves.
- Longer lifetime for electronic hardware.
- Reduced beamline outgassing in the warm beamline sections between cryomodules.
  - Ability to operate at higher gradients with fewer beamline vacuum faults

Benefits of Field Emission Reduction



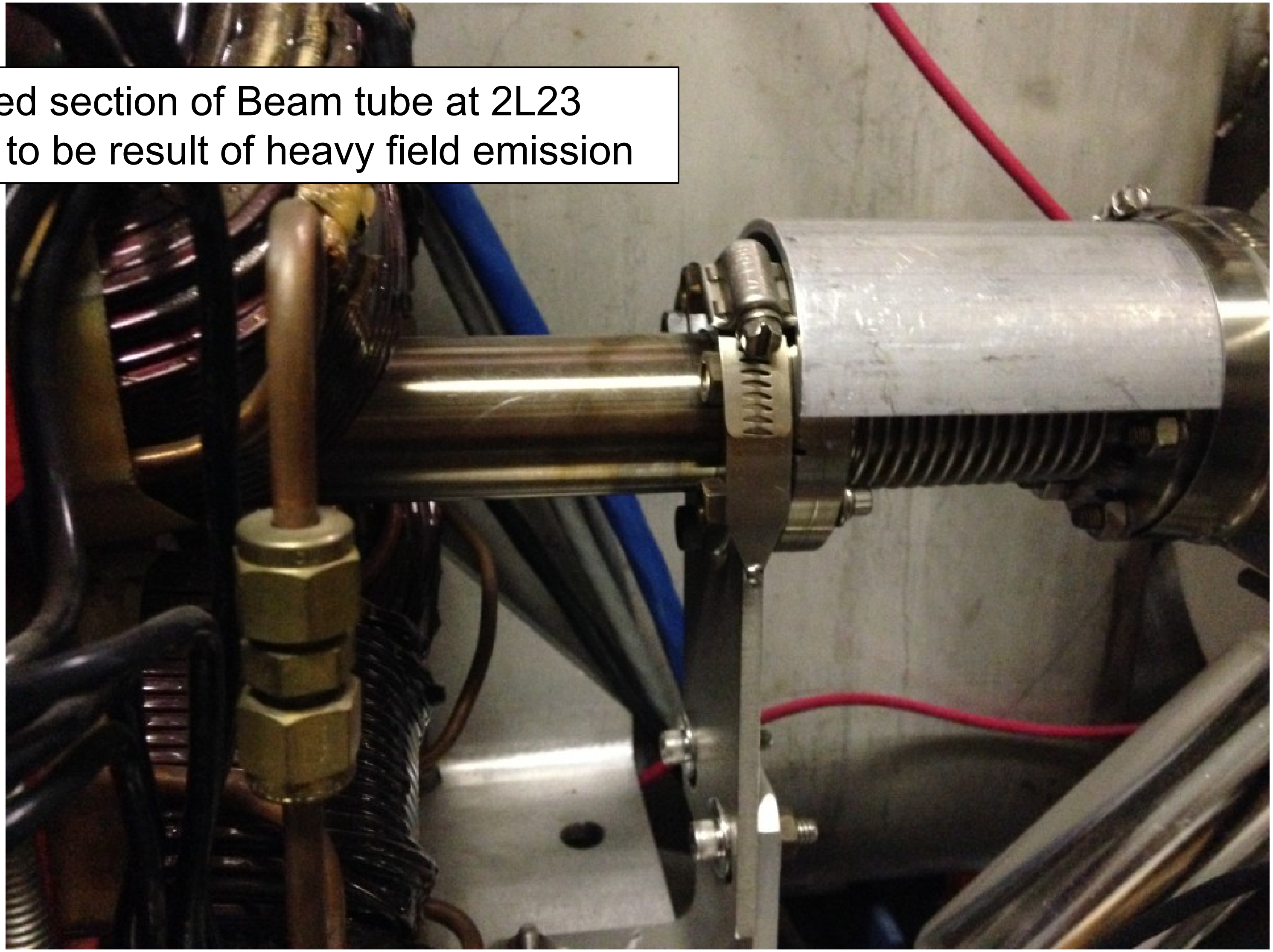
Damaged Insulation
Discolored and brittle



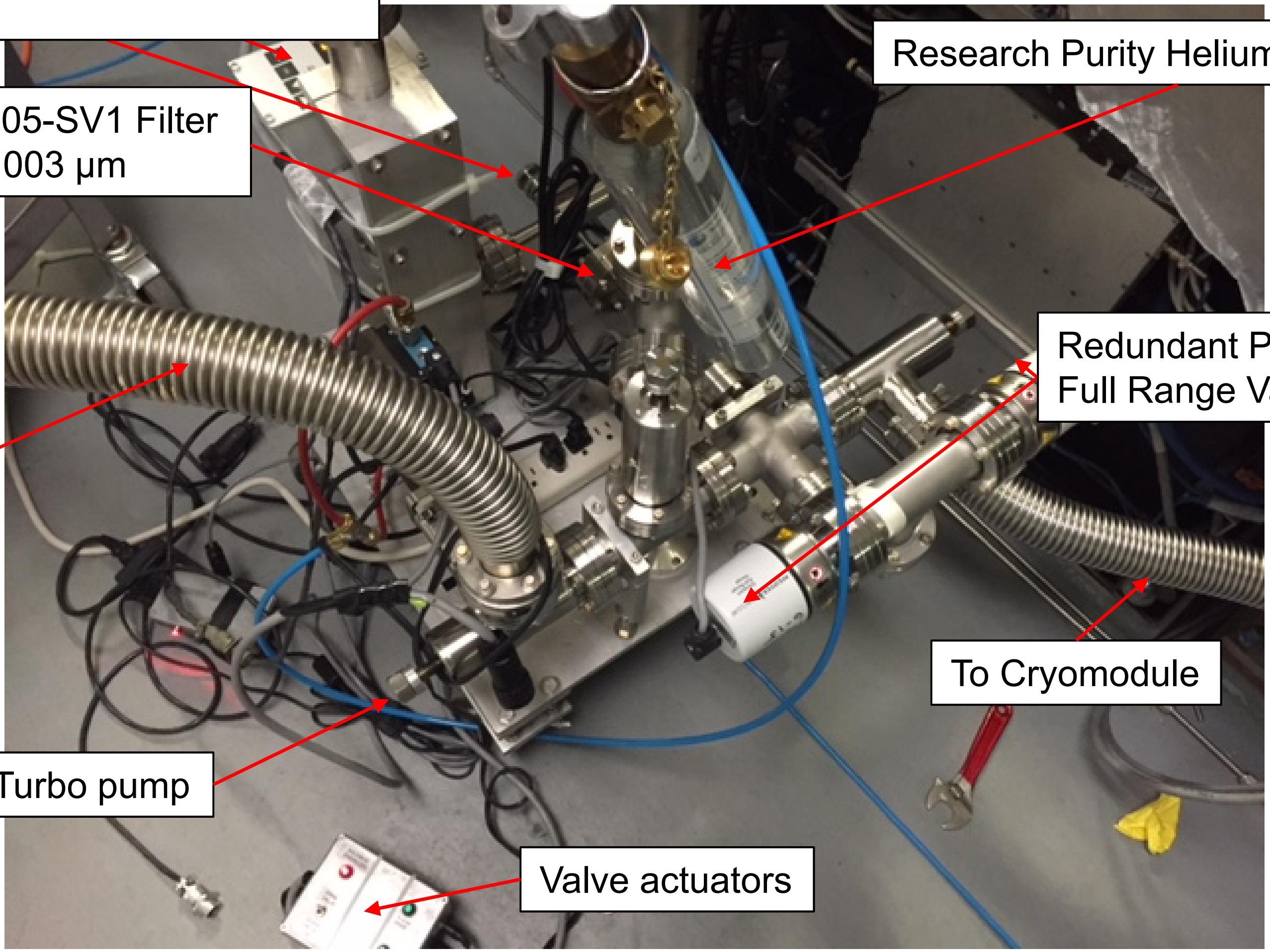
Damaged Insulation
Discolored and brittle

Benefits of Field Emission Reduction

Discolored section of Beam tube at 2L23
Thought to be result of heavy field emission



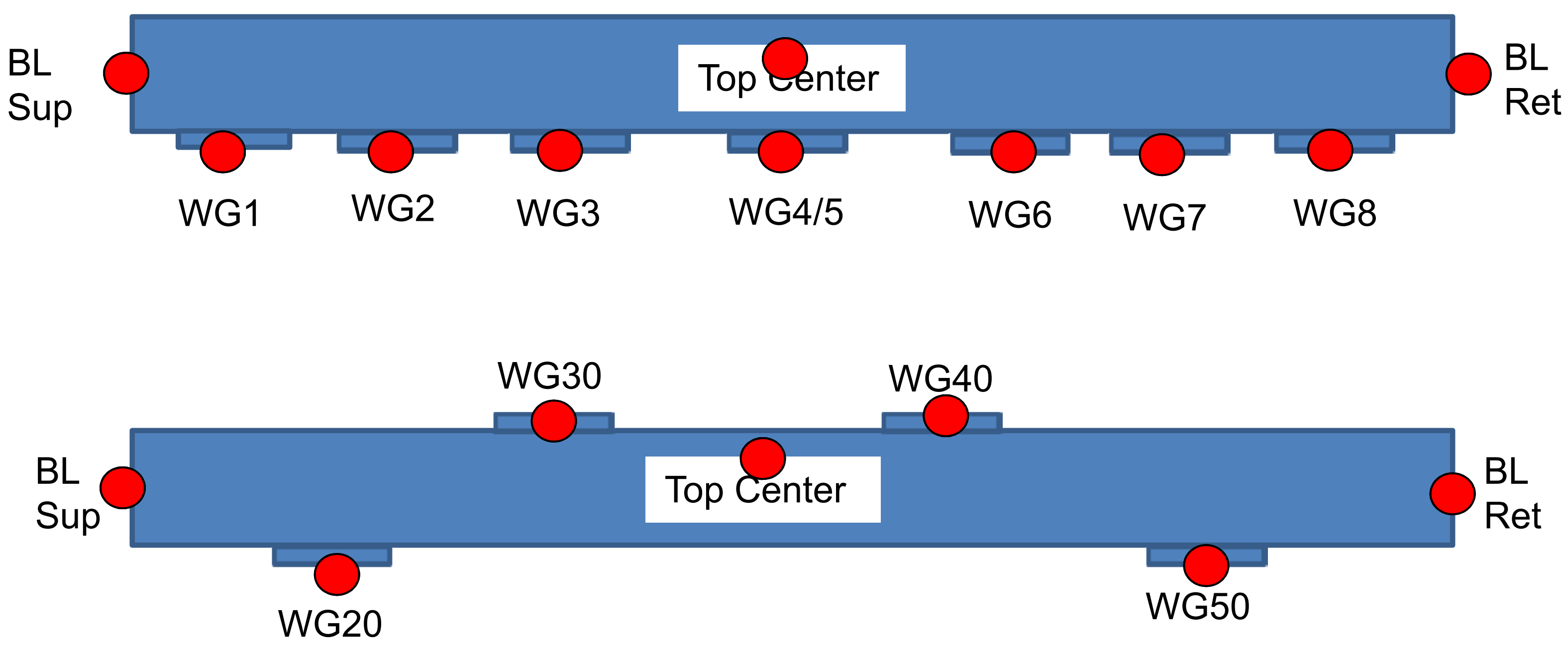
He Processing Pump Cart



He Processing Control Station

- Windows PC running Labview
- Communicates with EPICS (accelerator control system)
- and a variety of hardware:
  – Three Power meter channels
  – Frequency counter or spectrum analyzer
  – C100 style Field Control Chassis used as Self-Excited Loop
  – DecaRad -10 channel GM tube system

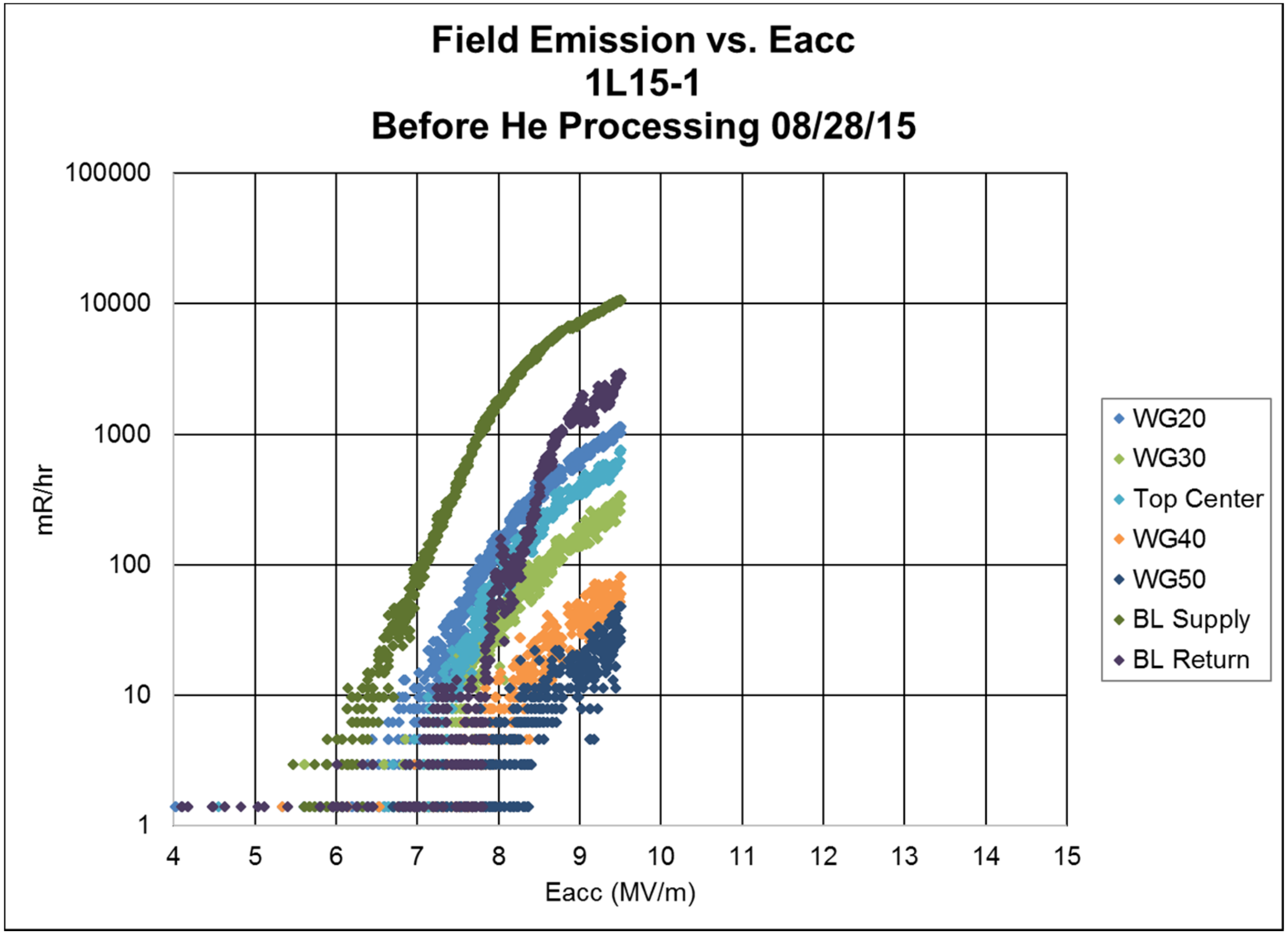
GM Tube Locations



WG tubes placed at Fundamental Power Couplers
BL tubes placed on the beam-pipe

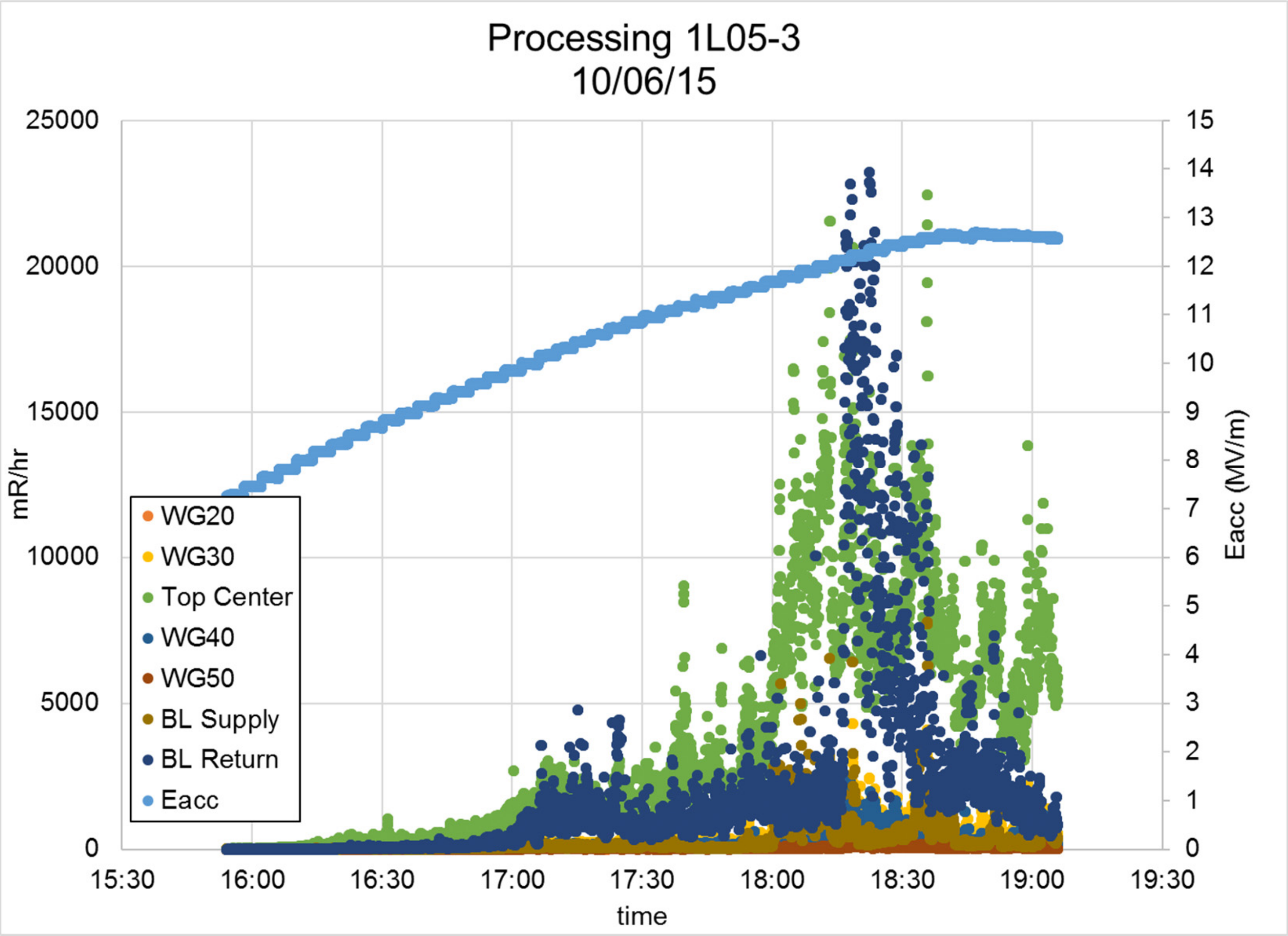
Procedure

- Four Major Steps in the procedure
- Step 1: Baseline field emission measurements (1 – 2 Shifts)



Procedure

- Step 2: Inject Helium and process (~ 3 shifts)



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Procedure

- Step 3 – Partial Warm up of the cryomodule to remove helium.
- Warm up proceeds until cavities temperatures are in the vicinity of 40K while pumping with turbo pump.
- 24 hours to complete.

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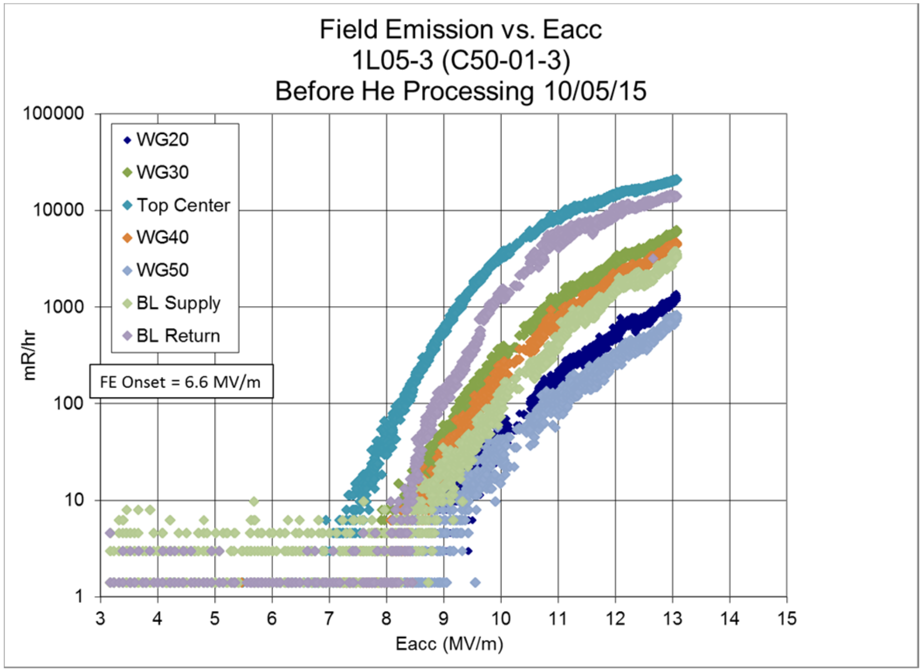
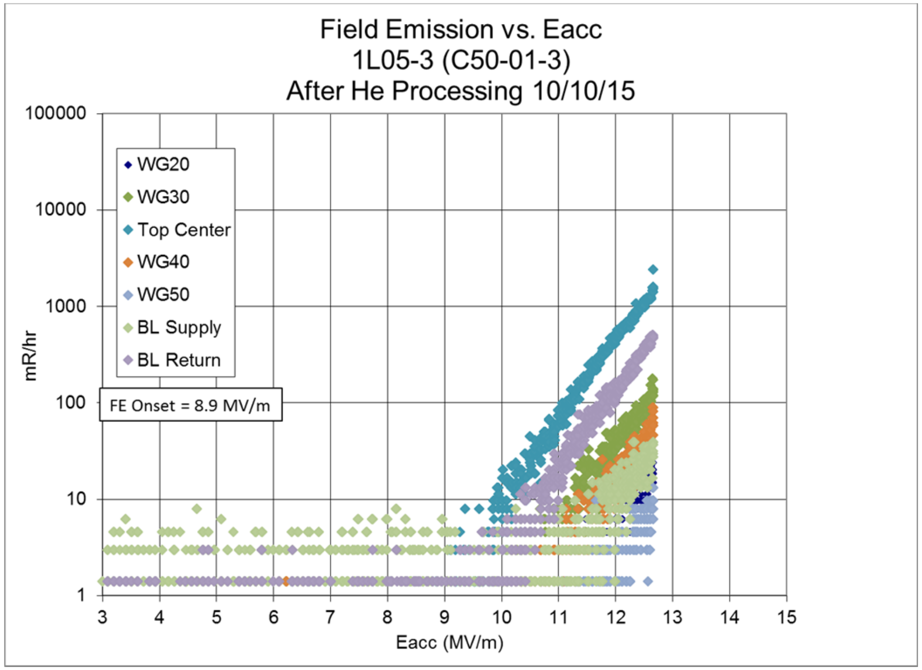
Procedure

- Final Step – Re-measure field emission

Increase in Onset Gradient of 2.3 MV/m
FE Radiation decreased by ~order of magnitude





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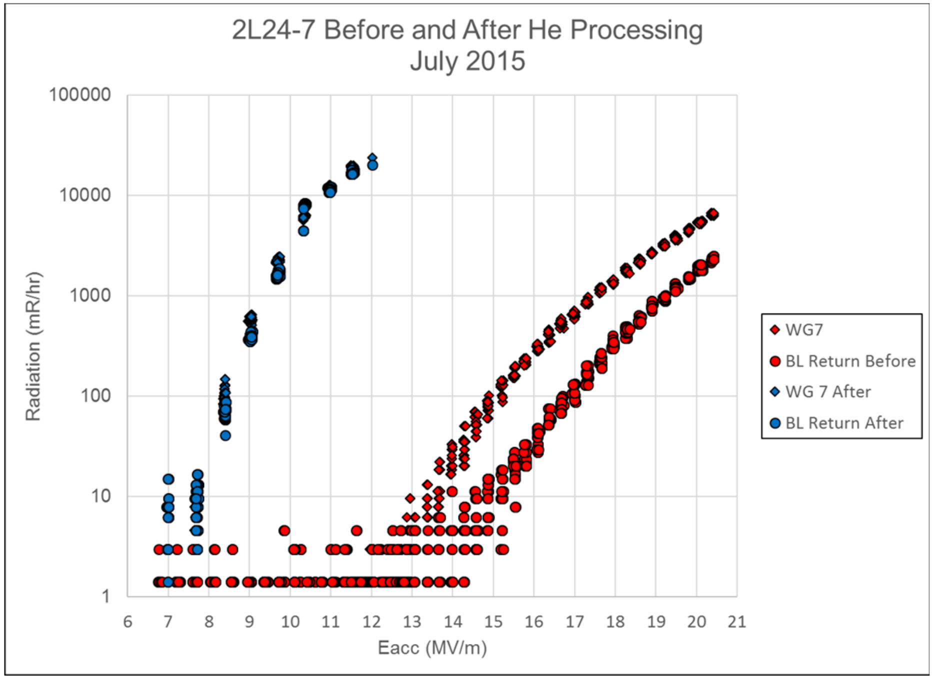
Obstacles to Processing

- Vacuum Leaks
  - Cold RF window leaks
    - Helium migrates into waveguide vacuum.
    - Difficult or impossible to establish gradient because of arcing.
    - Attempts to pump out just removes helium from beam line vacuum.
  - Beam line valve leaks
    - Difficult to maintain desired partial pressure of helium.
    - Effectiveness of processing lowered.

Obstacles to Processing

- C100 Cavities
  - Several cases of new field emitter creation
  - Large increase in Field Emission
  - Lowered Quench Gradient
  - Risks seemed to high and C100 processing was stopped.
  - Further study in needed



Results

- To gauge the effectiveness of the processing effort:
- Look for changes in the field emission onset gradient.
- Changes in the magnitude of field emission.
- Most importantly, the resulting change in the energy reach of the accelerator.

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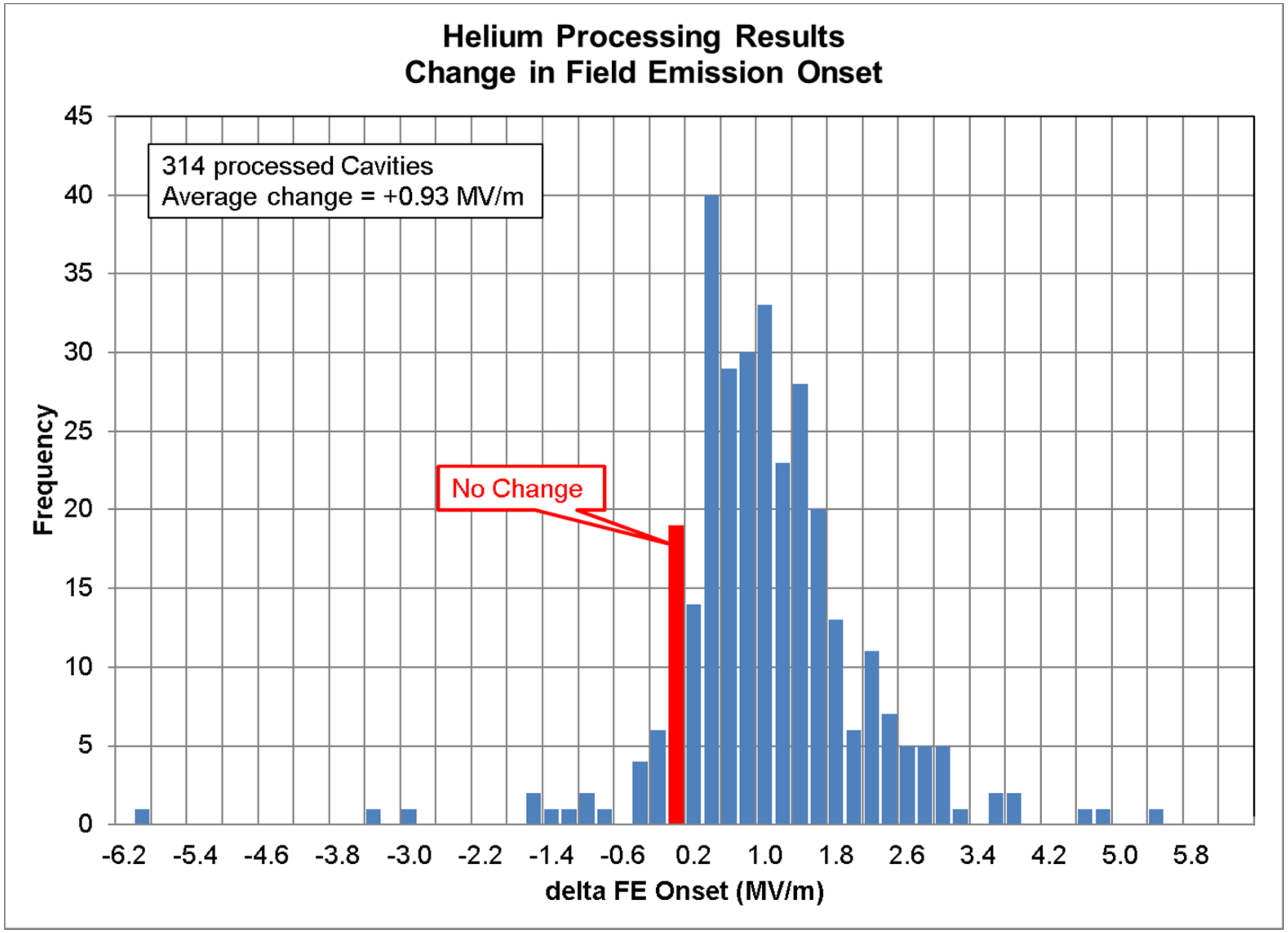
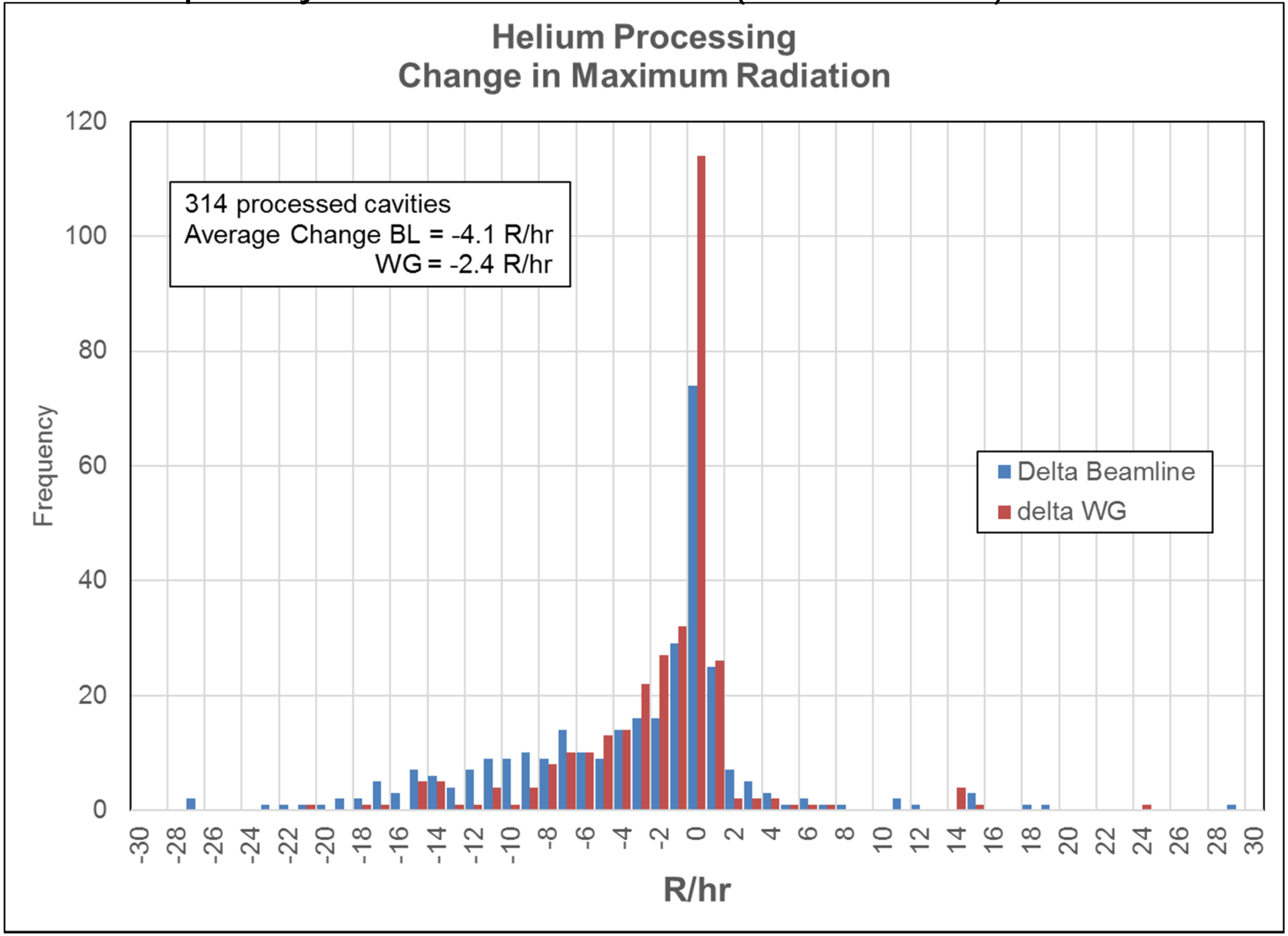
Change in Field Emission Onset Gradient

Average increase of 0.93 MV/m for processed cavities.
Roughly 12 % of cavities unchanged or saw a decrease in Onset Gradient

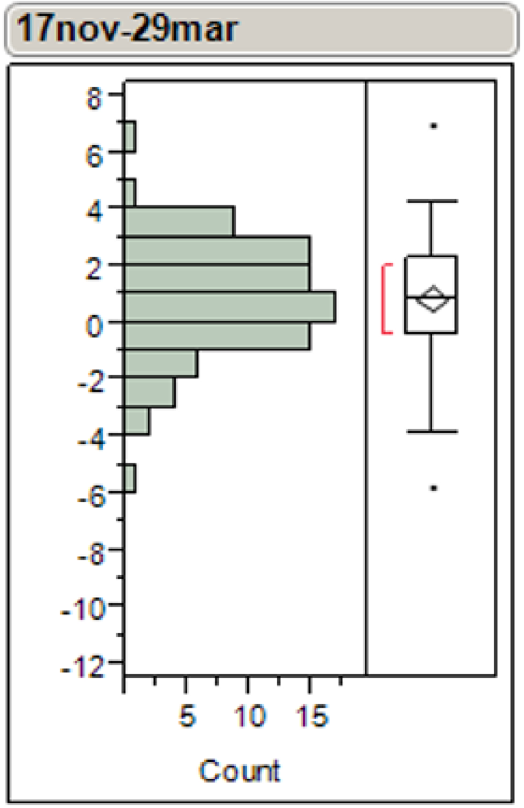


Changes in Field Emission Magnitude

Results Grouped by GM tube Locations (see slide 14)



Changes in Gradient Setpoints



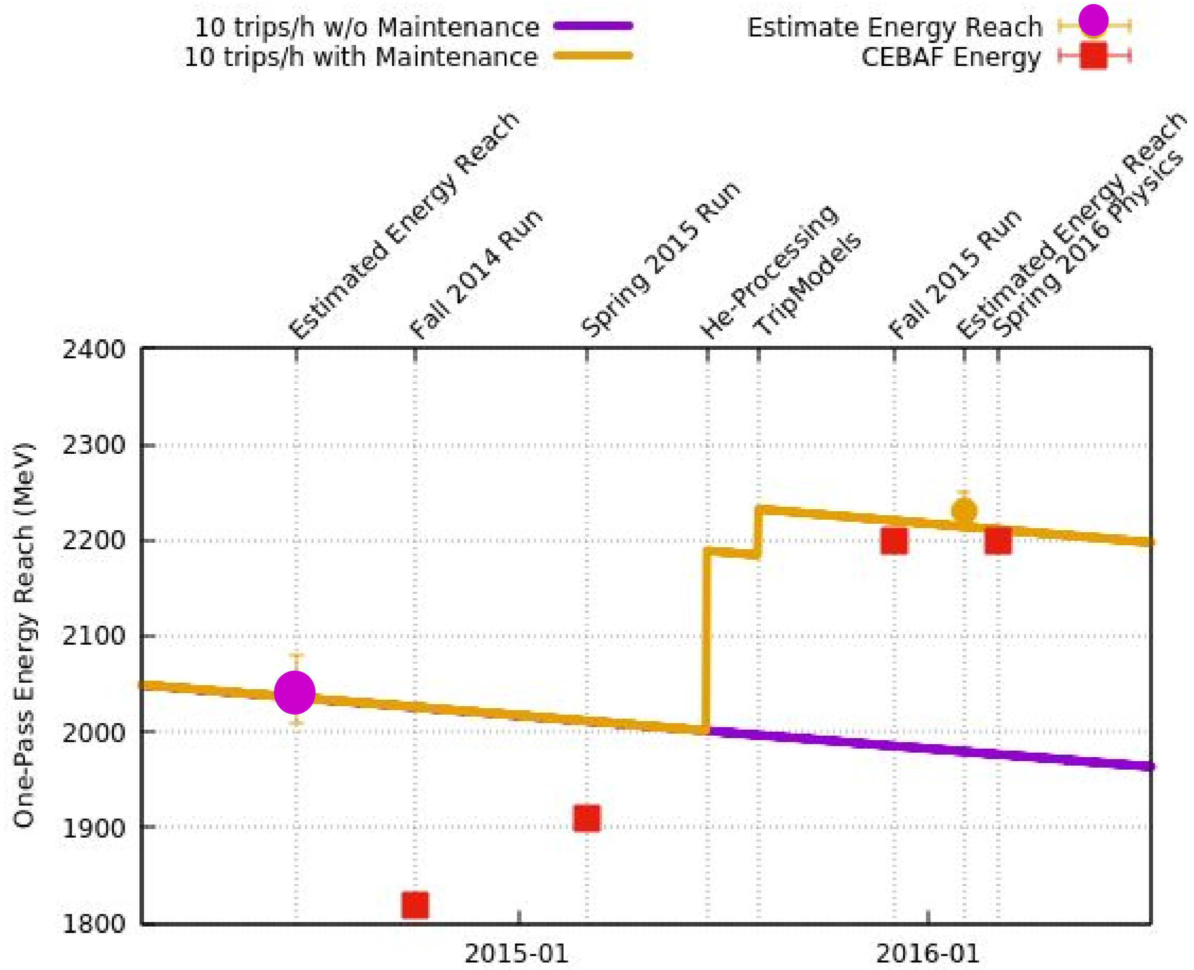
Moments

Mean	0.8654641
Std Dev	1.9984158
Std Err Mean	0.2154947
Upper 95% Mean	1.2939253
Lower 95% Mean	0.4370028
N	86

- Distribution of changes to Gradient Settings for 86 C20 cavities (Arc rate limited cavities)
- Before helium processing (3/29/2015) and after (11/17/2015)
- Average change = +0.87 MV/m

(J. Benesch, "Trip Rate Impact from 2015 Helium Processing", presented at Ops StayTreat, Jefferson Lab, June 2016)

Changes in Energy Reach



~ 201 MeV gain in energy per pass at 10 trips / hour

Summary

- In the summer of 2015, 314 cavities in 45 cryomodules were subjected to helium processing.
- This effort was undertaken to address the energy needs of the upcoming 12 GeV program which required 2.2 GeV per pass from the linac cryomodules.
- As a result of this effort, the energy reach of the CEBAF accelerator was raised by ~201 MeV per pass making it possible to operate at a more robust 2.2 GeV per pass.

Acknowledgments

This work would not have been possible or successful without the hard work and dedication of the following people:

- Frank Humphry Jr.
- Larry King
- Michael McCaughan
- Anna Solopova

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Supplementary Material

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