SUPERCONDUCTING 56 MHz CRYOMODULE FOR sPHENIX

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On behalf of the BNL Collider Accelerator Department & RF Group

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BROOKHAVEN NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

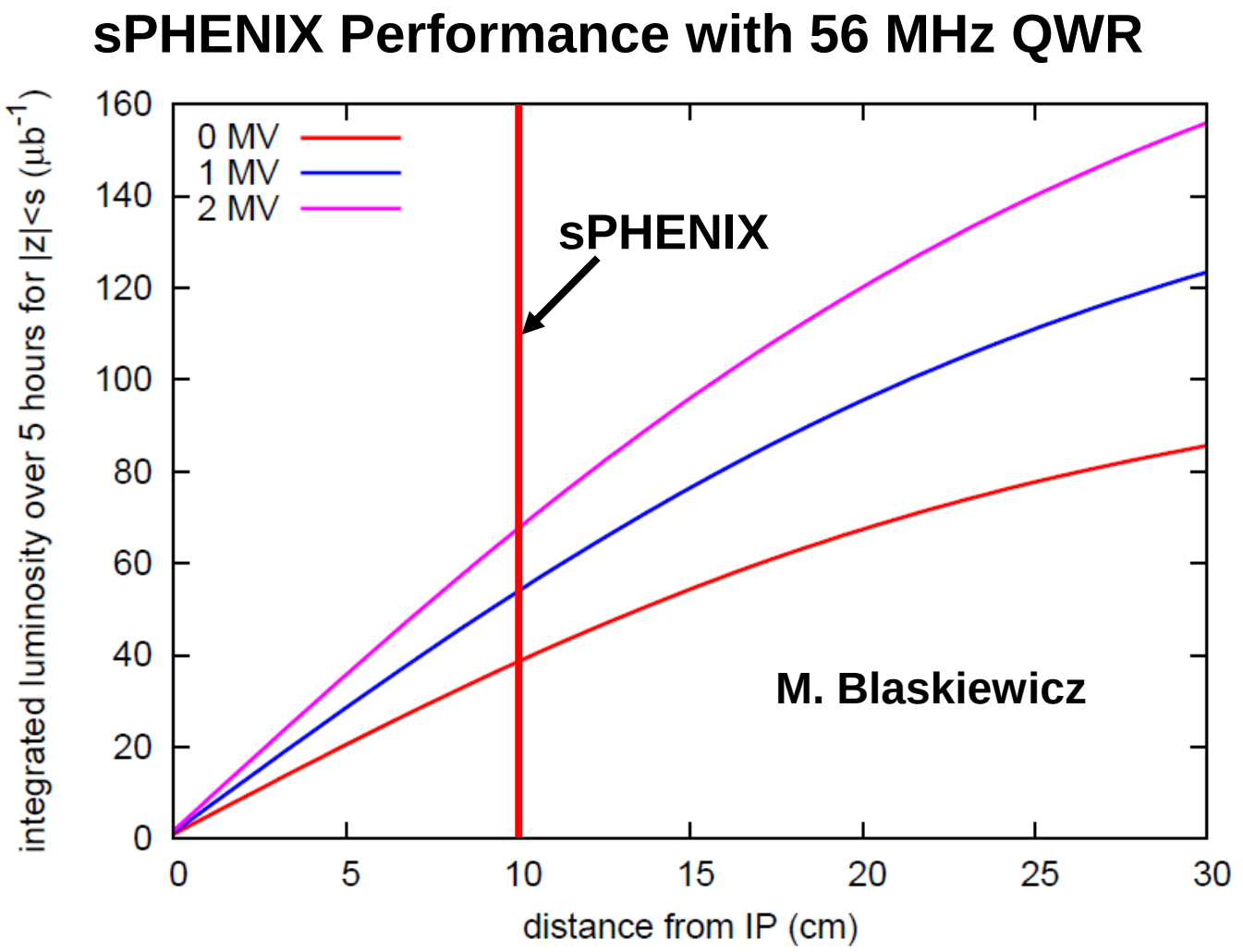
BROOKHAVEN SCIENCE ASSOCIATES

Overview

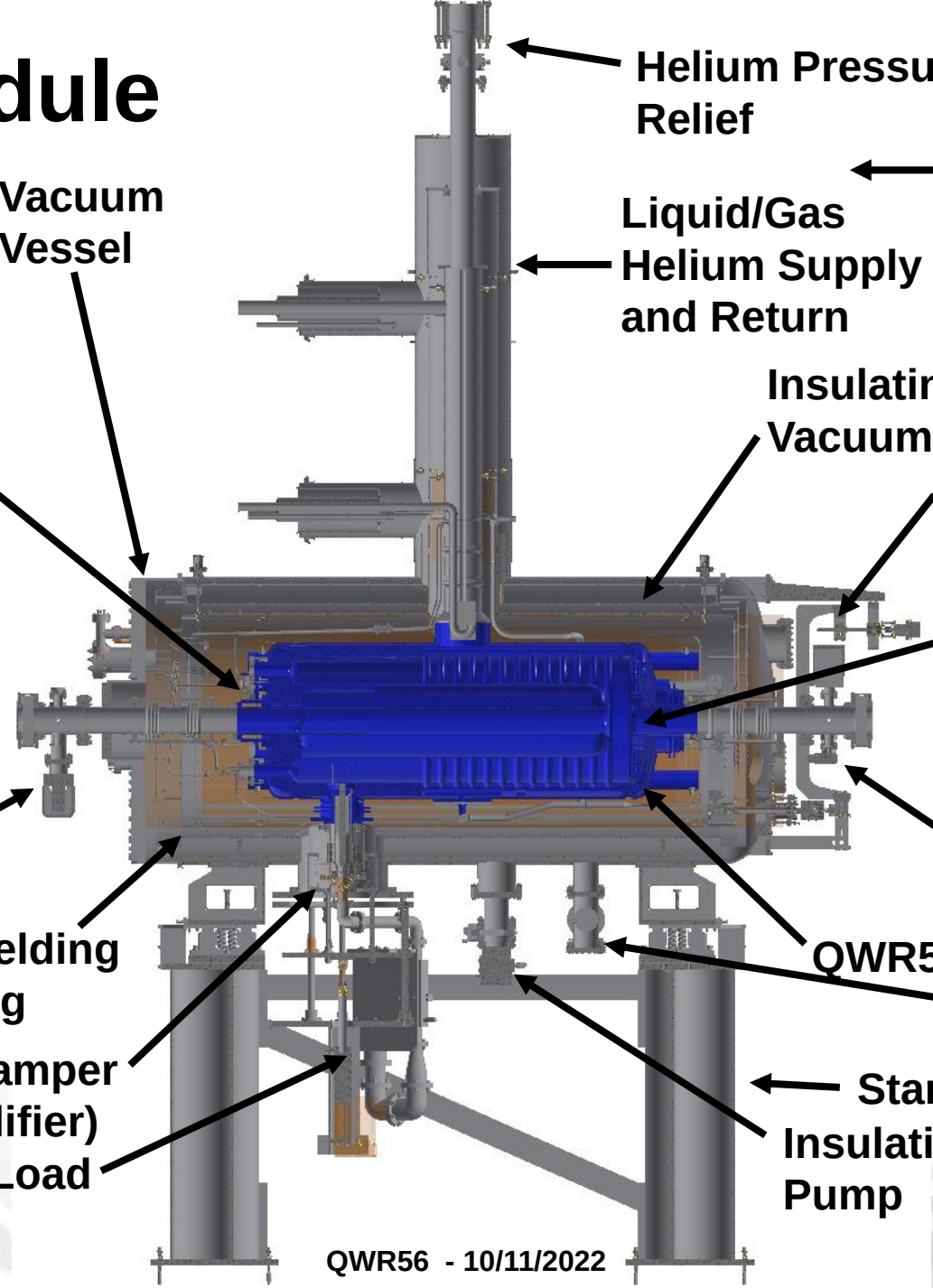
- Purpose of the 56 MHz System
- 56 MHz System
- sPHENIX Changes
- Status Update
- Future Schedule

56 MHz Quarter-Wave Resonator Cryomodule (2 Days Ago)

sPHENIX Impact

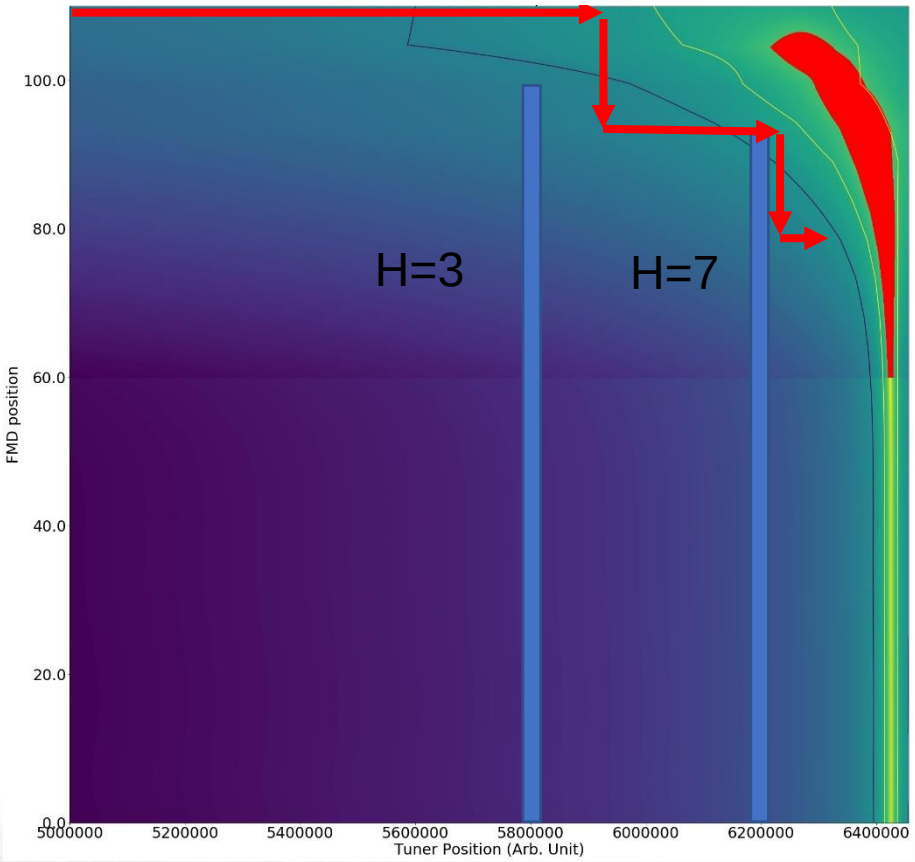


Cryomodule


Helium Pressure Relief
67”
Vacuum Vessel
Liquid/Gas Helium Supply and Return
Fundamental Power Coupler (3 kW Amplifier)
Insulating Vacuum
Frequency Tuner
Cavity Vacuum (Beam Line Vacuum)
Cavity Vacuum Pump
Cavity Relief
Magnetic Shielding Heat Shielding
QWR56
Insulating Vacuum Relief
Cavity Damper (No Amplifier) Passive Load
Stands/Supports
Insulating Vacuum Pump

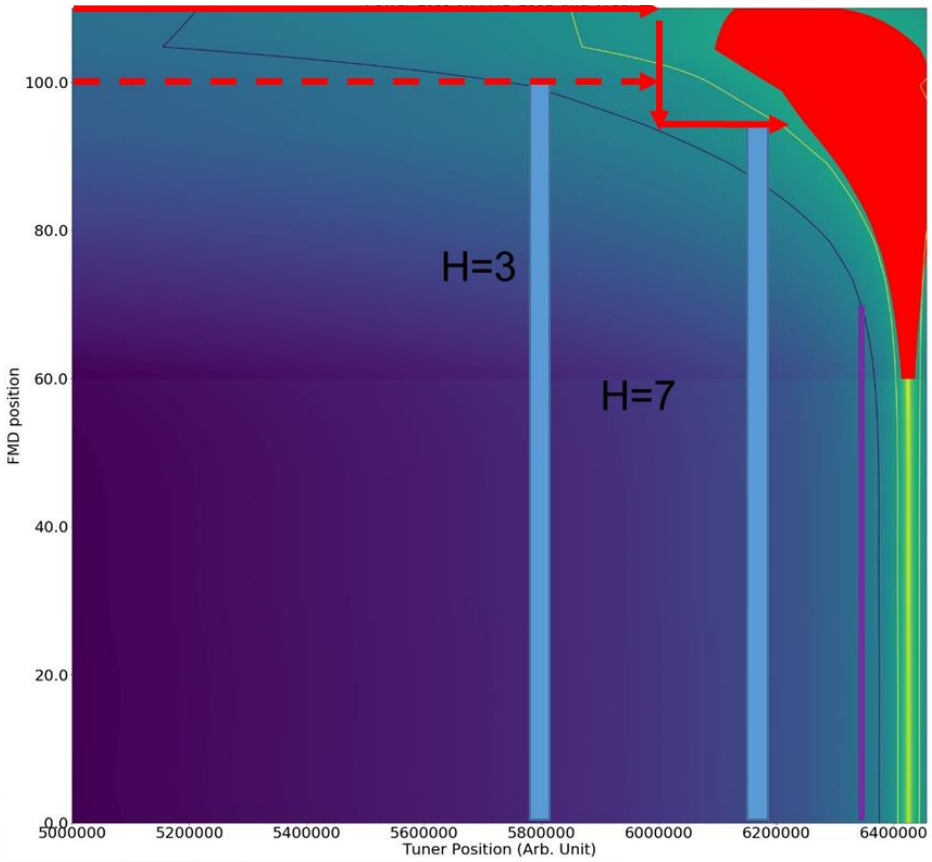
56 MHz Operation: Power Loss on FMD Loop and V_{real}

Simulated Operation During Successful RHIC Run @ 1 MV (Fill 19940)



S. Polizzo, Presentation @ 2016 MAC Review

Planned Operation For sPHENIX Run @ 2 MV



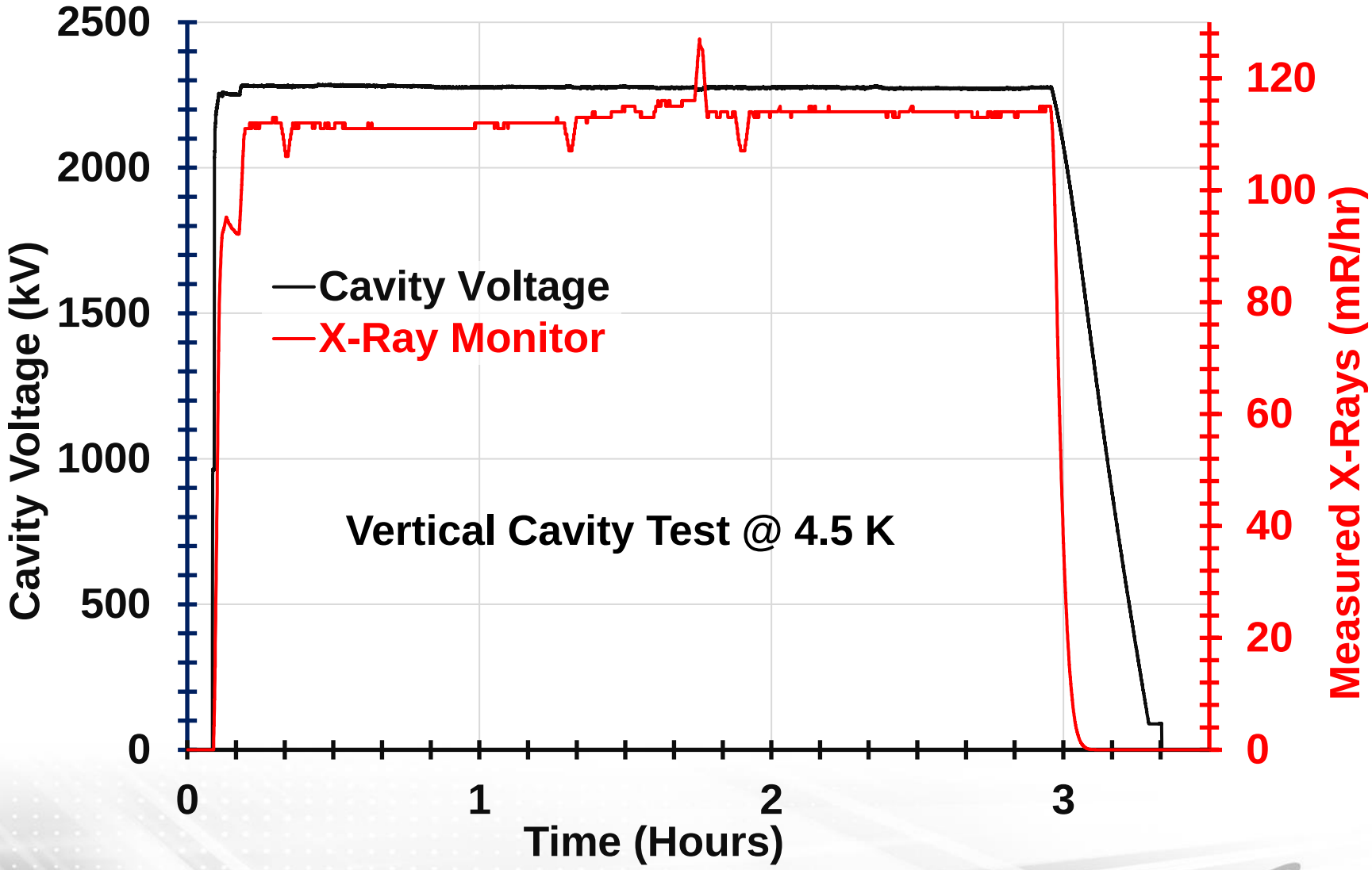
T. Xin, S. Polizzo & M. Blaskiewicz

56 MHz Cryomodule

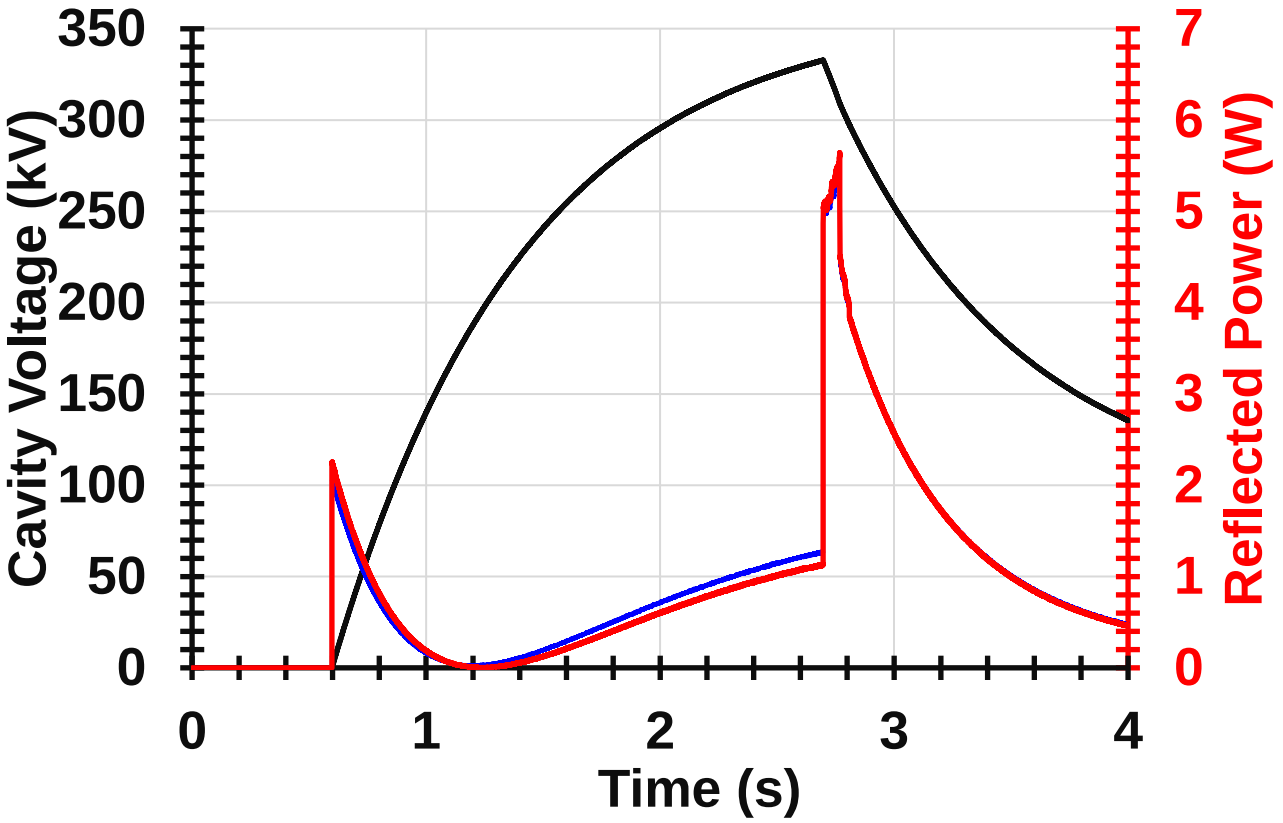
What do we need?

- **Cavity operation = 2 MV**
- **Support a 50% greater effective beam current.**
  - **Longitudinal instability growth rate due to a single HOM ~** $Q_L * I_b = Constant$
  - **Fundamental Mode Damper (FMD) ~ 126 kW**
    - **Also an HOM damper.**
  - **Fundamental Power Couplers (FPCs) ~ 2 X 3 kW**
    - **Also HOM dampers.**
    - **Ponderomotive Instabilities.**
- **Improved SRF cleaning and cryomodule preparation.**
- **Previous operation described in: Q. Wu et al, "Operation of the 56 MHz superconducting rf cavity," PR-AB 22, 102001 (2019)**

Cavity Operation > 2 MV?



Cavity Vertical Test - II



Loaded τ_V = 26.6 s

$Q_L = 4.7 \times 10^9$

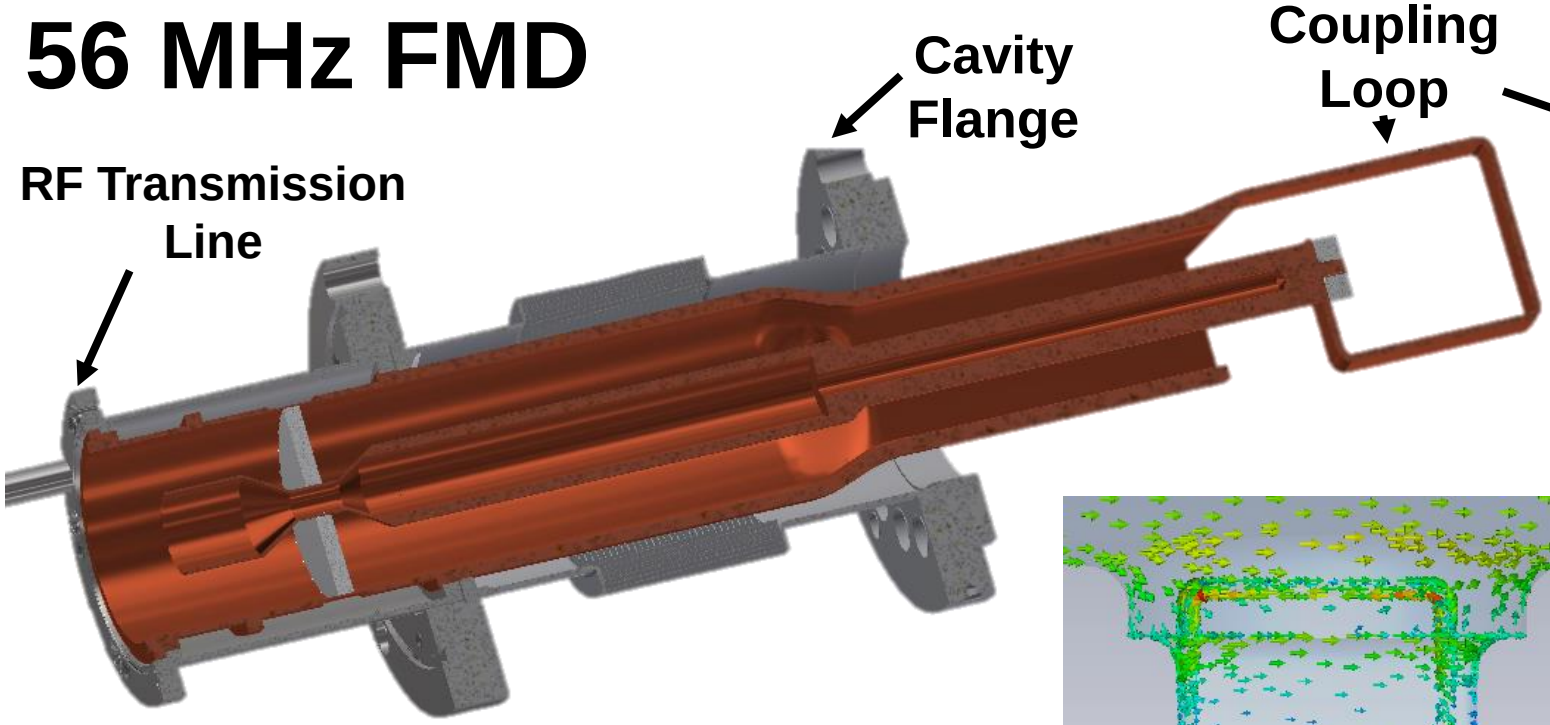
$\beta > 30$

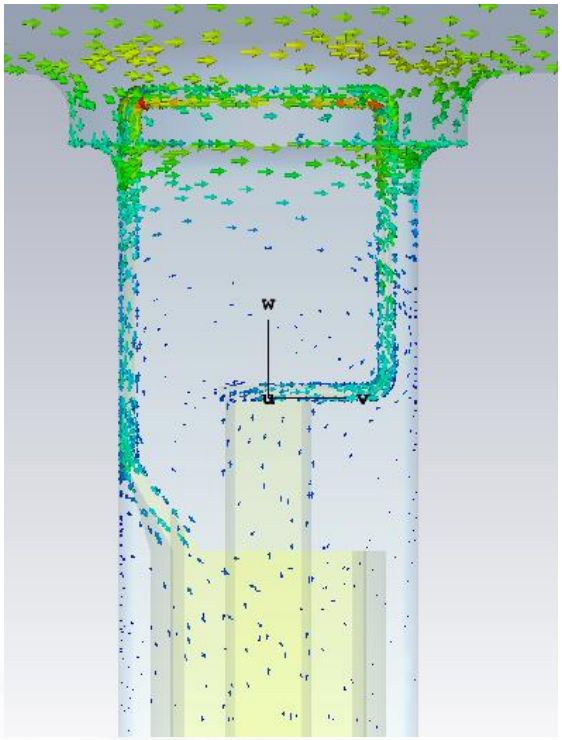
$Q_0 \sim 4 \times 10^9$ @ 4.4 K

Residual Surface Resistance ≤ 1.5 nΩ

Cryomodule test will have variable coupler and can check this measurement.

56 MHz FMD



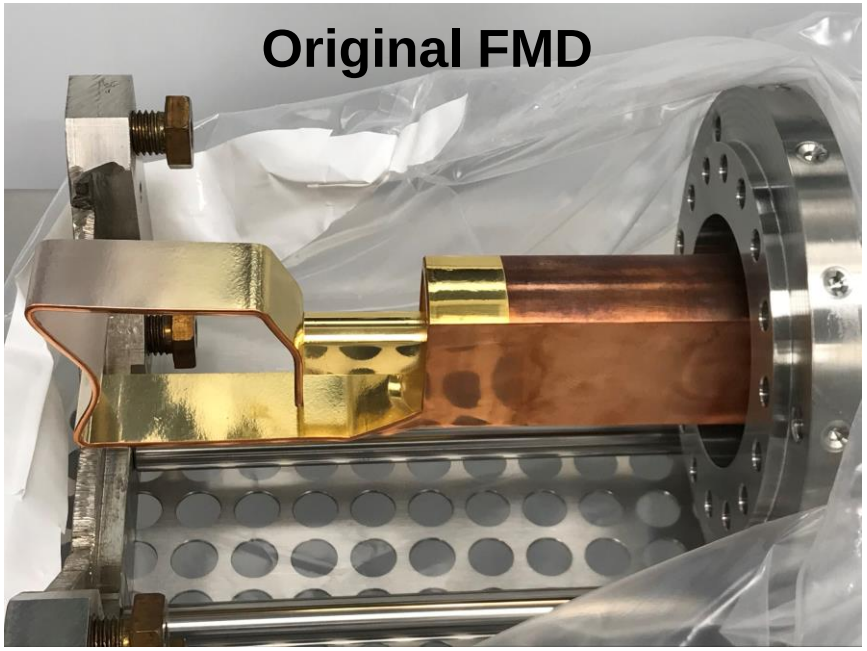


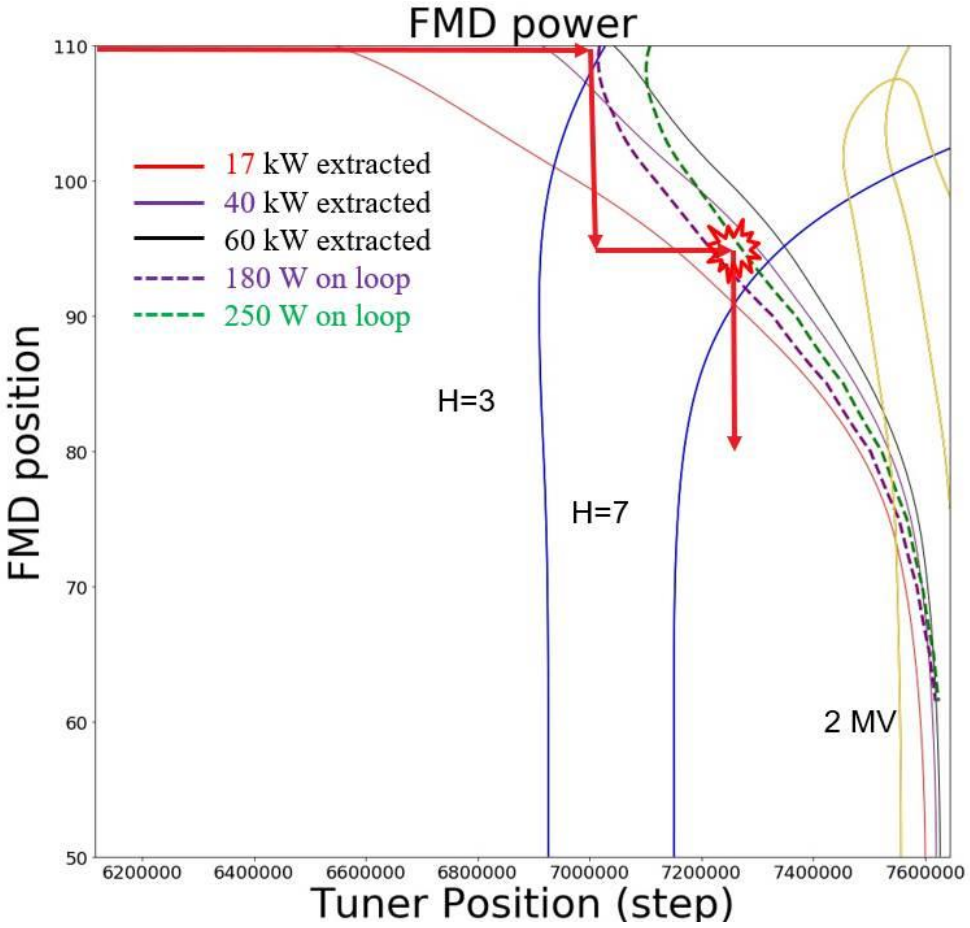
$$P_b = \frac{\frac{R}{Q} * Q * I_b * I_b}{1 + 4Q^2\left(\frac{\Delta f}{f}\right)^2} \propto \frac{I^2}{Q} \propto I^3$$

Assuming same path (same $\frac{\Delta f}{f}$) and large detuning angle.

$$P_{new} = 1.5^3 * \frac{27.2\ kW}{0.9^3} = 126\ kW$$

56 MHz FMD

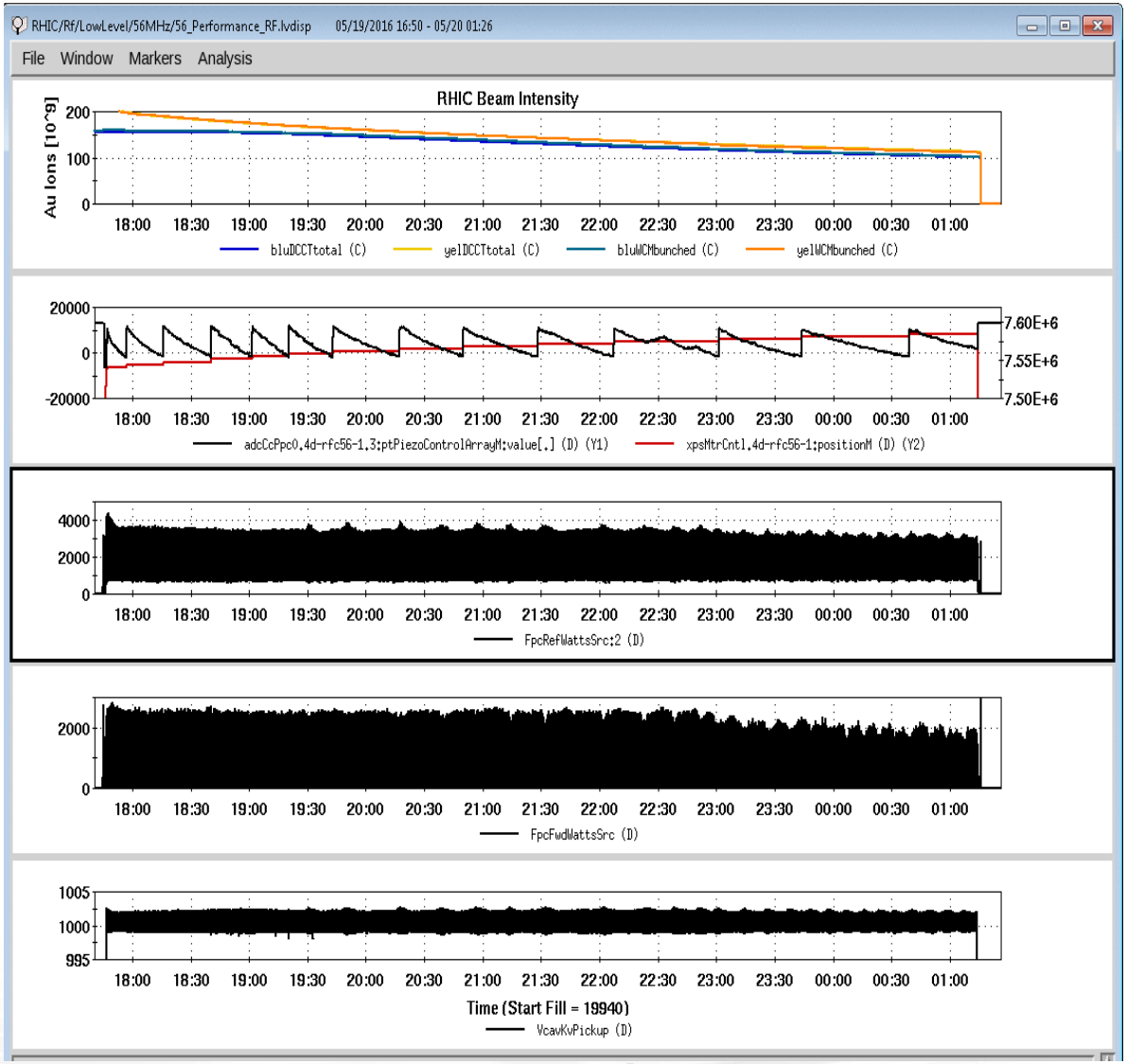




- **Maximum FMD heating at Q_{ext} = 1.8x10^4 ~400 W/cm^2**
- **Whatever cooling we choose the copper will start to evaporate if the FMD stays in a position close to this, in spite of the water cooling.**
- **This coupler will be moved through this region in ~30 seconds while heating at ~10^{0}C/s (heat capacity + thermal conduction)**

Improved LL & HL RF Dynamics

- Cavity has active tuning.
- Active tuning is no where near as strong as the beam phase jitter!
- Previous run
  - ~ 10 Hz_{p-p} noise.
  - P_{for} = 3 kW
  - Circulator not stable
  - I/Q Feedback loop to compensate both amplitude and phase errors.
    - Ponderomotive instabilities.
    - Saturated the amplifier



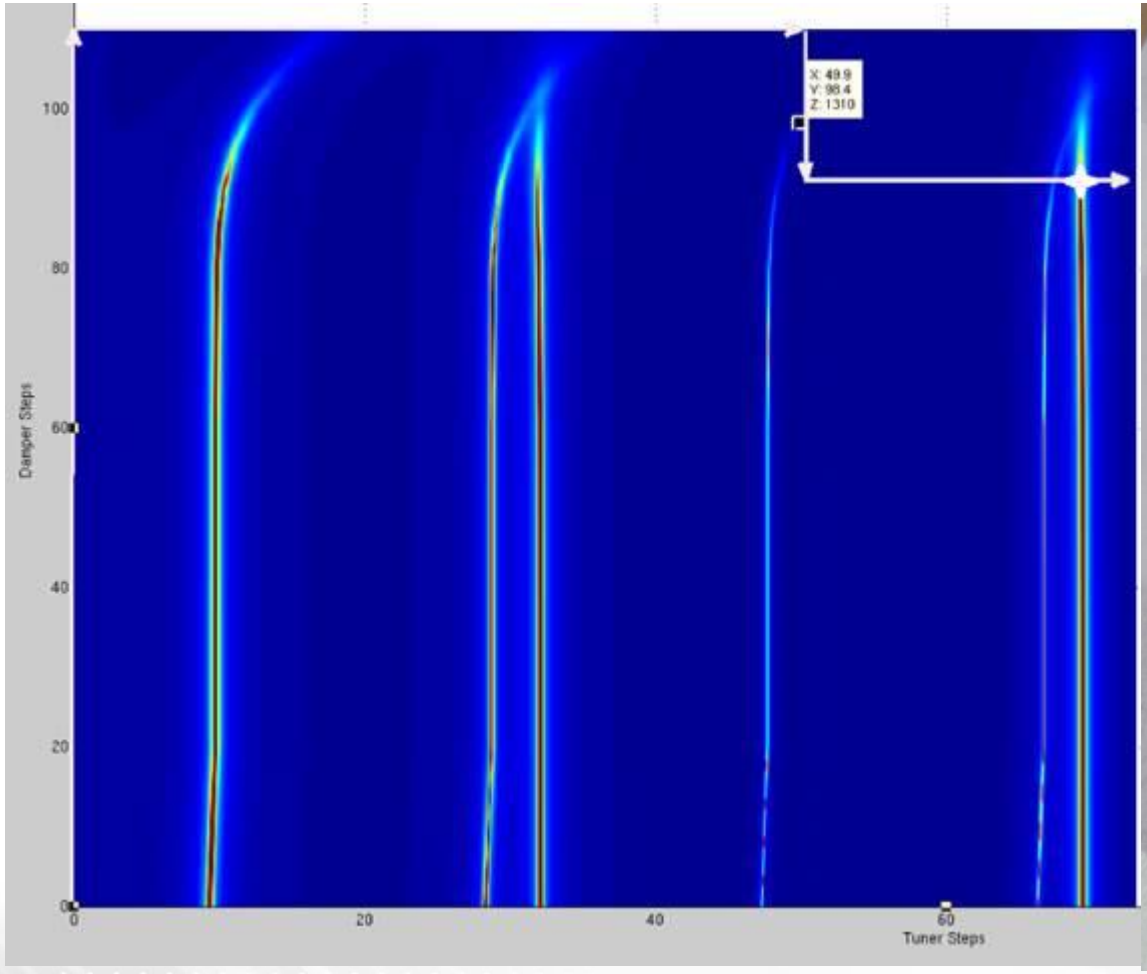
F. Severino

Improved LL & HL RF Dynamics

- 2 new FPCs instead of 1 and a new 6 kW amplifier.
  - Higher beam current and improved ponderomotive control.
  - Couplers capable of 3 kW each, will start with single coupler operation and upgrade system with a hybrid splitter and phase shifter to feed both in parallel if needed.
- Ordered new 56 MHz 25 kW circulator and expect delivery in January 2023.
- New AC coupled feedback loop on amplitude only, RF system will no longer try to correct phase errors.
  - Drive feedback loops to be implemented around both the amplifier and circulator. Circulator to also have dedicated chiller for temperature stability.
  - Combined improvement should reduce RF drive by a factor of 2.

Fundamental Power Couplers

Real Beam Tuning Path



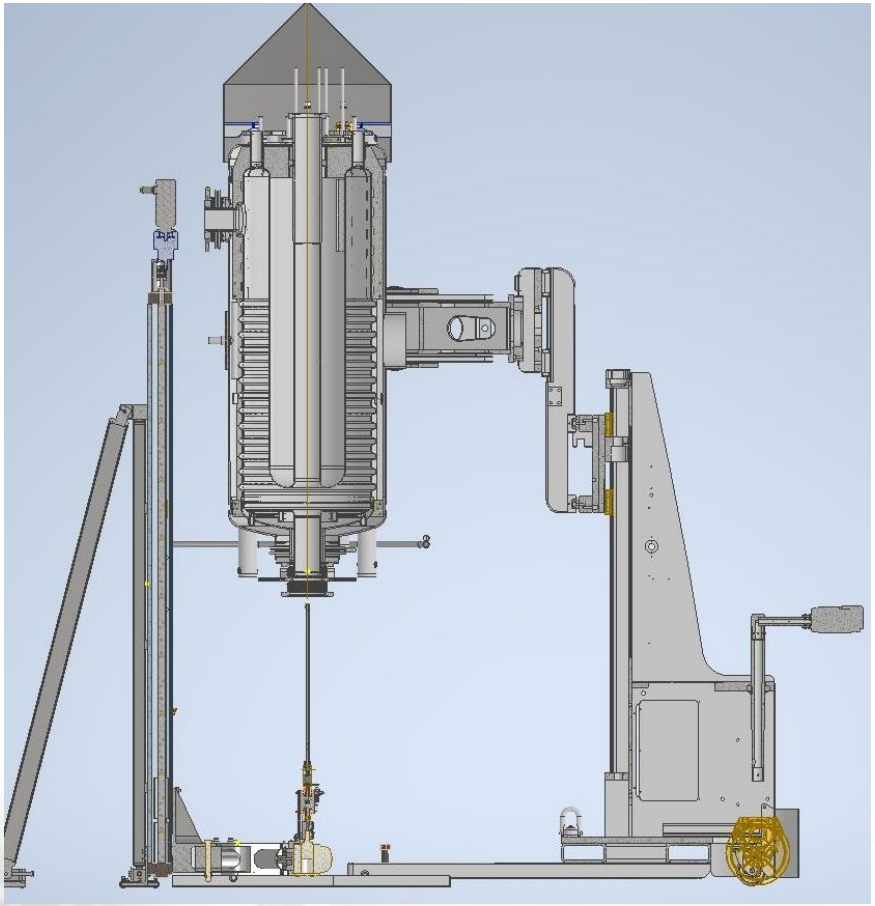
K. Mernick, S. Polizzo

FPCs

D. Holmes

Improved SRF Processing - HPR

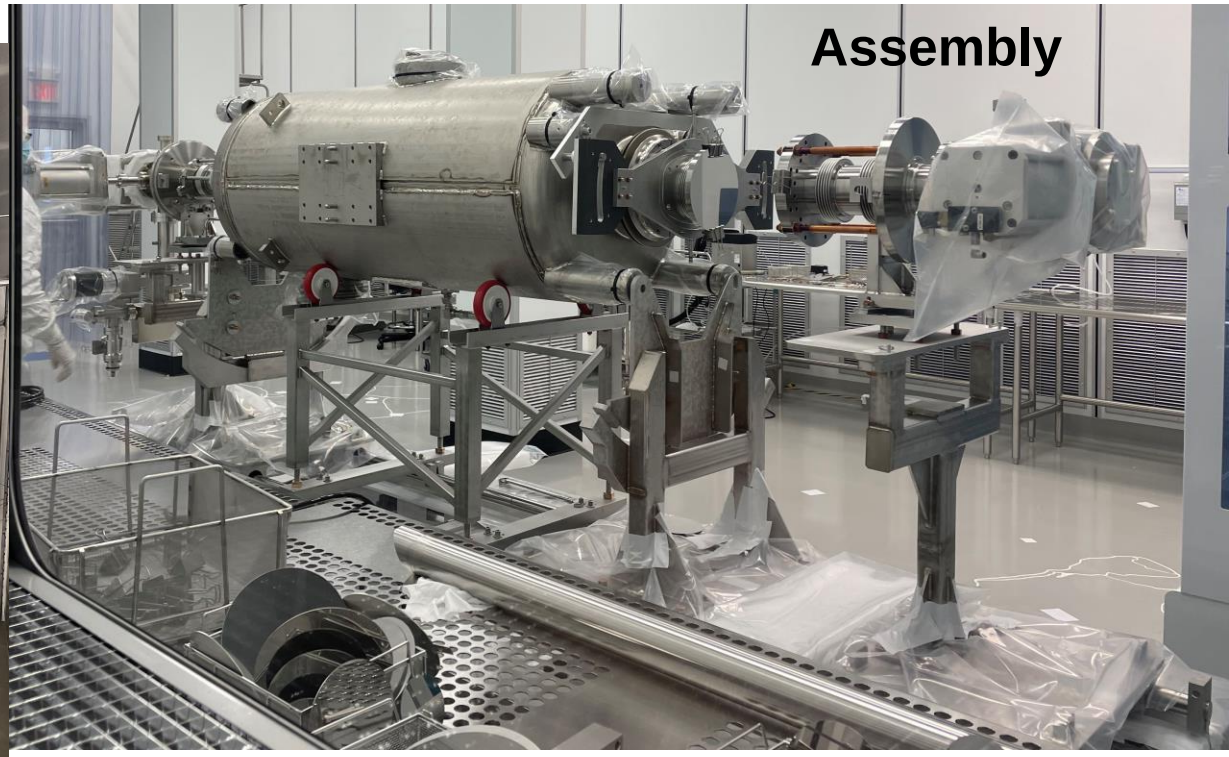
New BNL HPR Tool
(Sized for Largest EIC Cavities, too bad the clean room is not!)



HPR Wand Shuttle Clamp

Improved SRF Processing - II

120^{0}C Bake



- **All beam line components HPRed during build-up.**
- **Assemblies then HPRed after installation on assembly tooling.**
- **Cavity HPR once**

Closing Comments

- **Upgrading the existing RHIC 56 MHz SRF system for sPHENIX.**
- **Multiple activities to support this**
  - **higher power fundamental mode damper,**
  - **higher power and redundant fundamental power couplers,**
  - **improved SRF processing and assembly,**
  - **improved subsystem control**
  - **(not discussed: coupler and FMD motion positioning and noise during operation improved, improved cryogenic cooling, secured microphonic sources inside of cryomodule...)**
- **Avoid melting copper couplers.**
- **Need to test and, if successful, install in RHIC!**

Acknowledgments

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