185 MHz QWR-based SRF gun cavity development: vertical test results of First Cavity without cathode port

Taro Konomi
Superconducting Radio Frequency Staff Physicist,
SRF and Superconducting Magnet Department

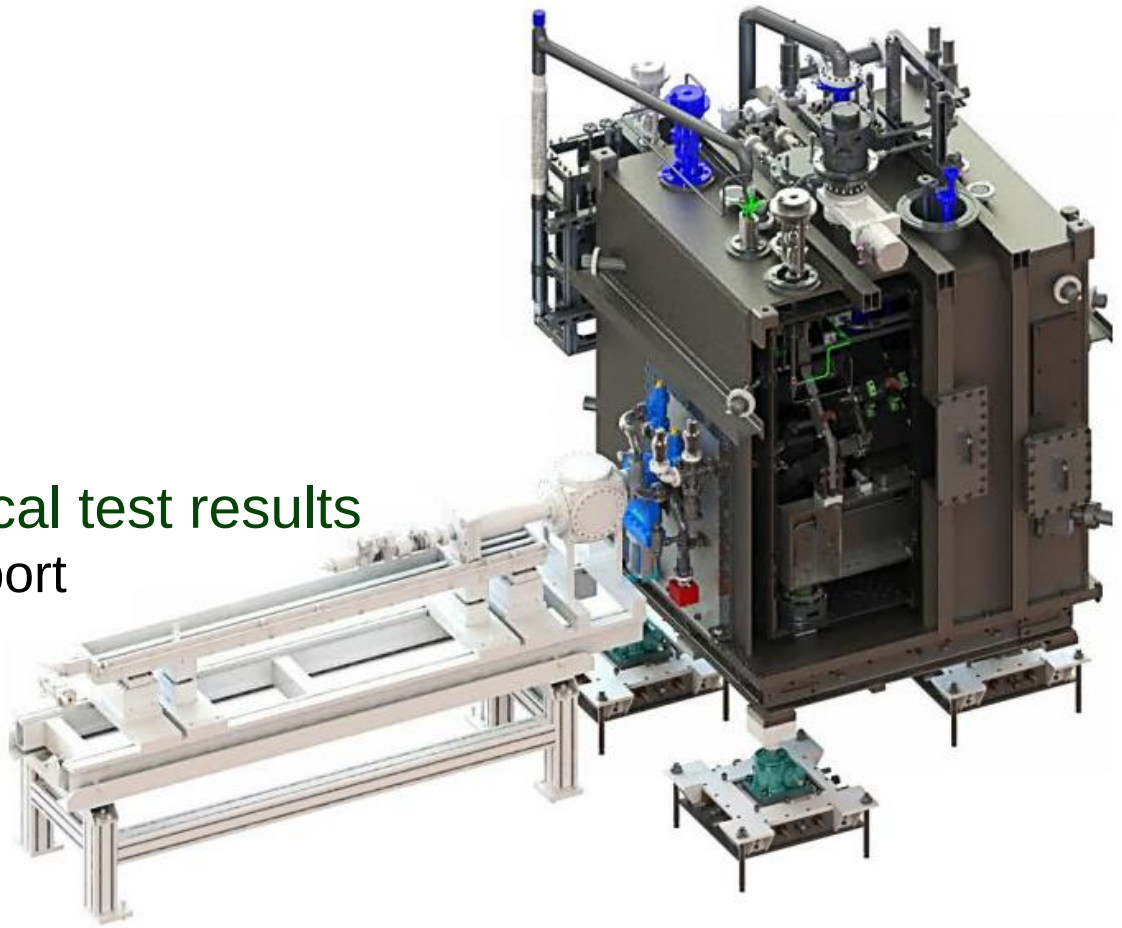
MICHIGAN STATE UNIVERSITY

U.S. DEPARTMENT OF ENERGY | Office of Science

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics and used resources of the Facility for Rare Isotope Beams (FRIB), which is a DOE Office of Science User Facility, under Award Number DE-SC0000661.

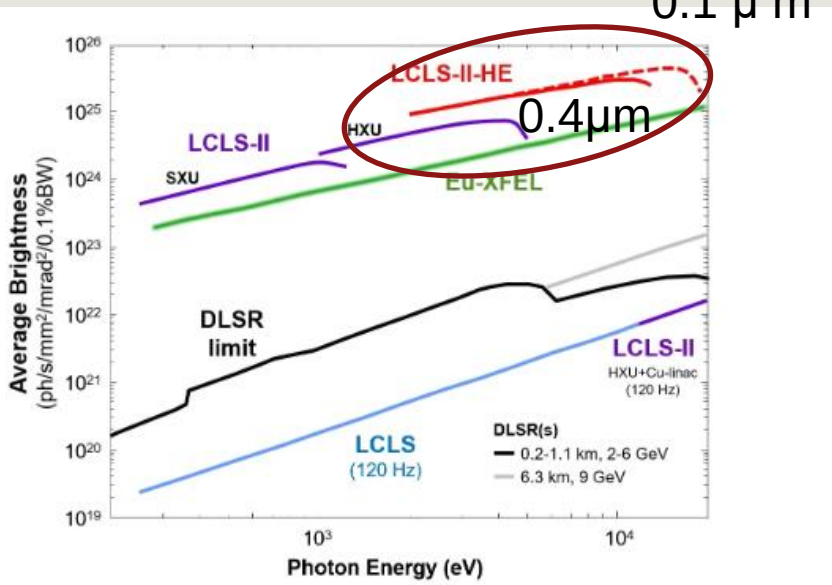
Outline

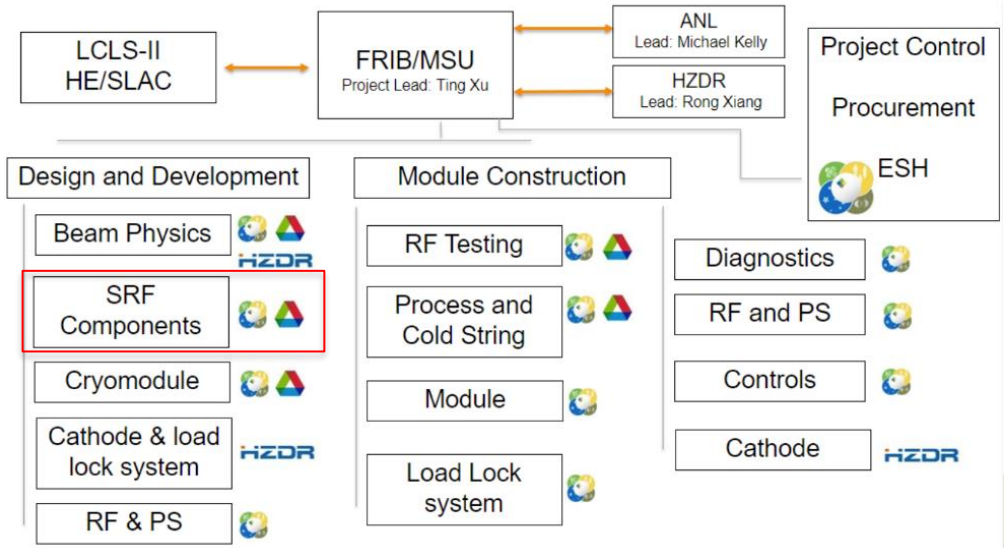
- Introduction
  - Motivation and Collaboration
  - Cryomodule
  - Cavity Parameters
- Cavity Design
  - Low-field MP barrier
  - High-field MP barrier
  - FPC port
- Surface treatment and vertical test results
  - First cavity without cathode port
  - Electropolishing
  - Ultrasonic Cleaning
- Summary



Motivation and Collaboration for the Low Emittance Injector (LEI)

- Provide lower emittance beams to extend photon energy reach, enabling a broader photon physics program for LCLS-II HE
- Electric field on cathode **30 MV/m** is required to achieve 0.1 μm emittance.
- Leverage world expertise in the field
  - FRIB and ANL have the most Quarter Wave Resonator (QWR) experience in the USA
  - HZDR has the most operating experience with Superconducting Radio Frequency (SRF) guns
- All deliverables: final assembly and testing at MSU



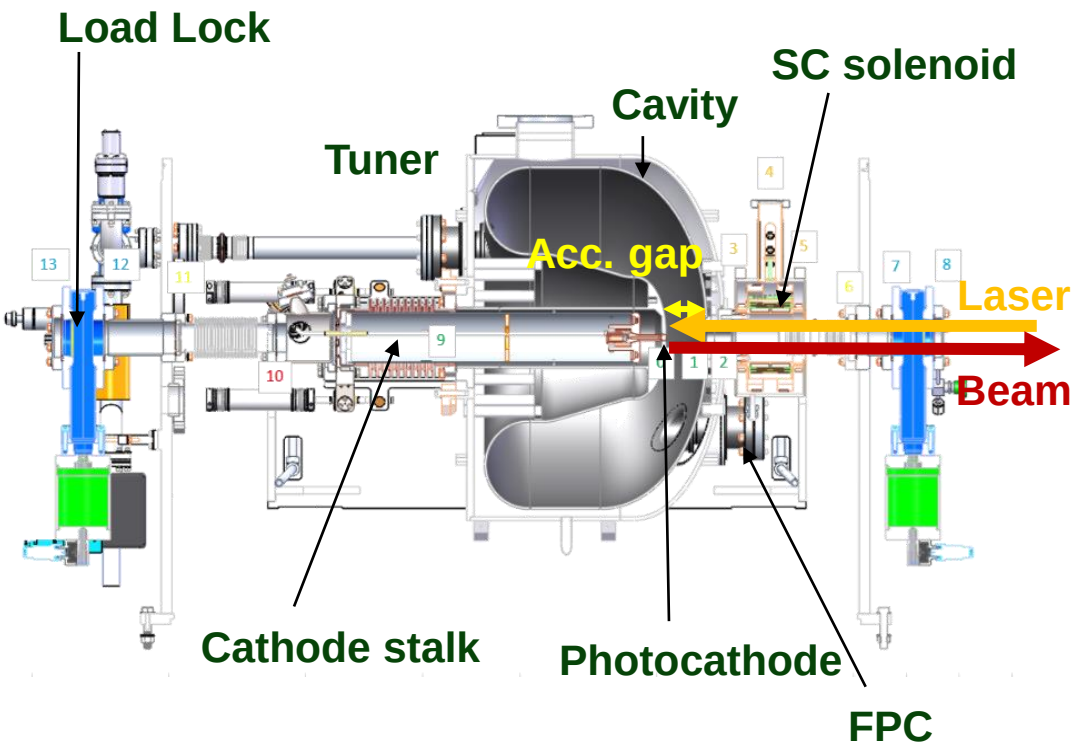


FRIB Facility for Rare Isotope Bea
U.S. Department of Energy Office of Science
Michigan State University

T. Konomi, TTC 2023, QWR SRF gun cavity, Slide 3

Layout: Cryomodule and Cold Mass

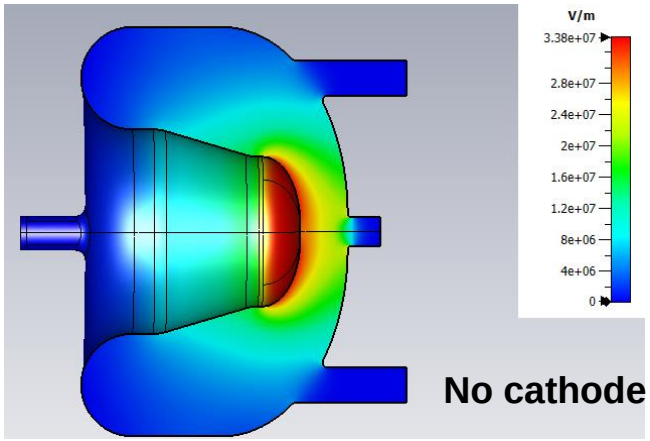
- **Goal:** run SRF gun cavity integrated with the cathode system at 30 MV/m cathode field
- **Dome shape for anode** to suppress low-field cavity MP
- **4 ports for EP and HPR**; and use for FPC, pickup, pumping during operation
- **Off-beam-axis compact FPC with DC bias** to eliminate coupler MP impacts on the beam and reduce potential contamination
- Particulate-free insertion of cathode plug
- Cathode stalk with DC bias to suppress potential MP



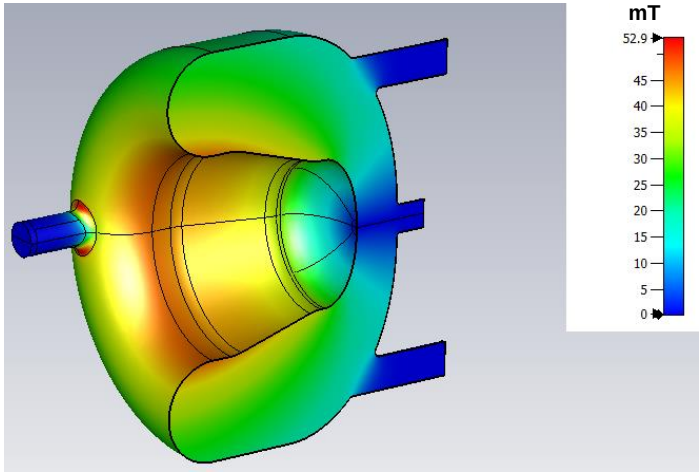
SRF gun Cavity Parameters

Cavity Parameters	Value
RF frequency f_0 (MHz)	***185.75***
Geometry factor (Ω)	84.5
Quality factor Q_0 at 4.4 K(1)	**1.3×10^9**
Geometric shunt impedance r/Q(2) (Ω)	131
E_c (MV/m)	**30**
Stored Energy U (J)	21.4
B_{peak} (mT)	52.9
E_{peak} (MV/m) with cathode	**33.7**
Cavity wall dissipation power P_w(1) (W)	20
Gap Voltage V_0(2) (MV)	1.81
Accelerating Voltage V_{acc} (β = 1) (MV)	1.80
df/dP (Hz/torr)	-3.95
df/dx (kHz/mm)	-435
dF/dx (kN/mm)	44.6
Tuning Force for 60 kHz, 15 psi, 4 K (kN)	8.4
LFD (Hz/J)	-29
Modes 1-4 (Hz)	157, 182, 191, 227

E-field at E_c = 30 MV/m, E_{peak} = 33.7 MV/m



B-field at E_c = 30 MV/m, B_{peak} = 52.9 mT

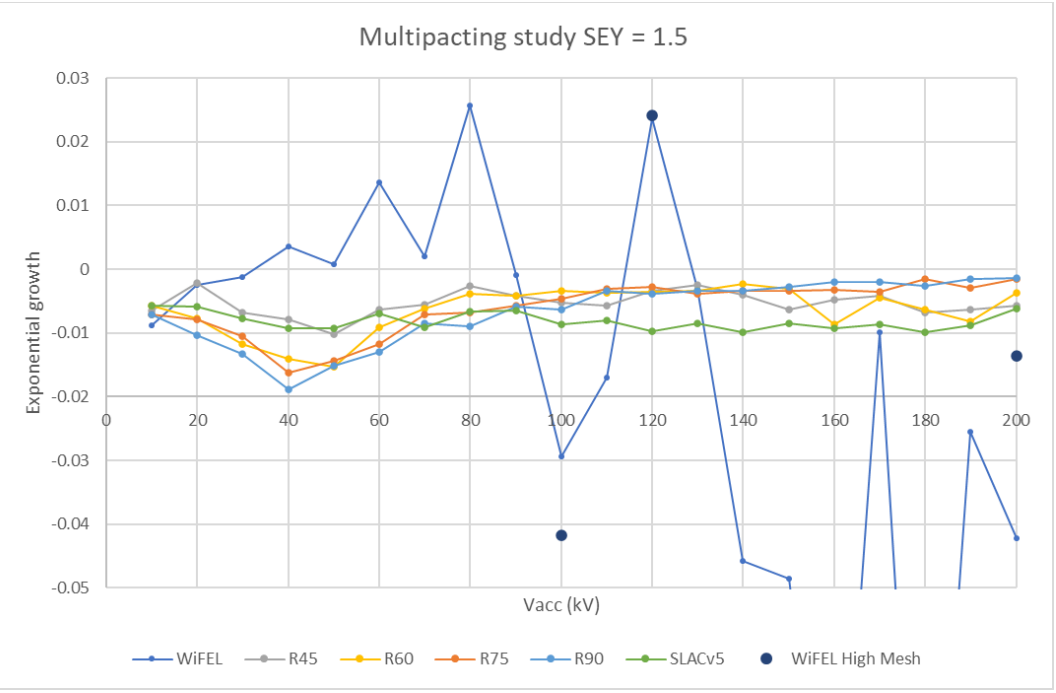


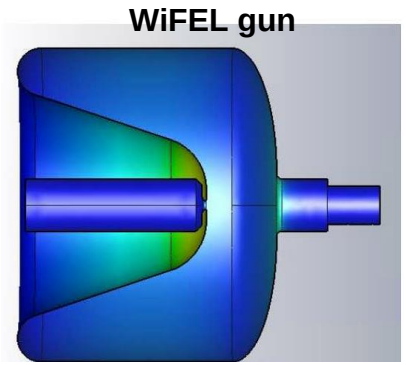
(1) Estimated R_s is 66 nΩ at 4.4 K, no 120 ºC baking case.

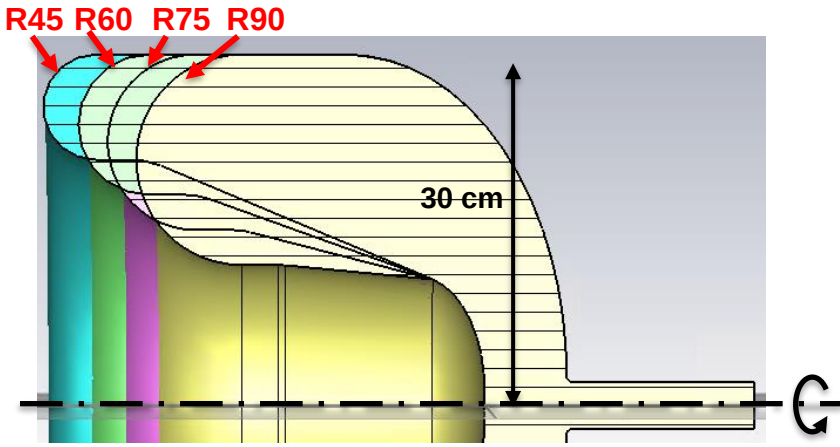
(2) $V_0 = \int E_z(z)dz$, geometric shunt impedance = $\frac{V_0^2}{P_w}\frac{P_w}{\omega_0 U}$

Cavity Shape
Optimized for Low-field multipacting barrier

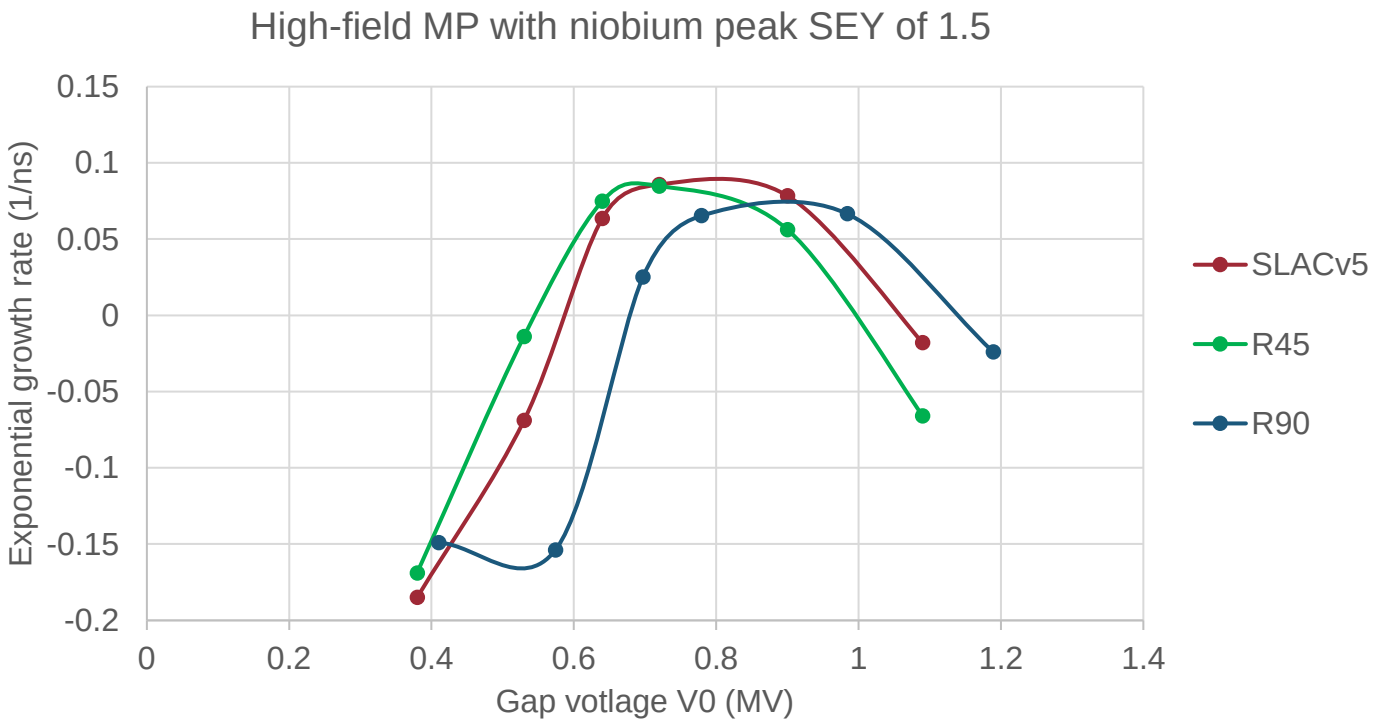
- Design evolved from the WiFEL gun
- Anode-side plate: large curvature to suppress low-field multipacting (MP) barrier
- Cathode-side short plate: *R* = 75 mm short ‘plane’ to reduce the cavity length and reduce the strength of low-field MP barrier







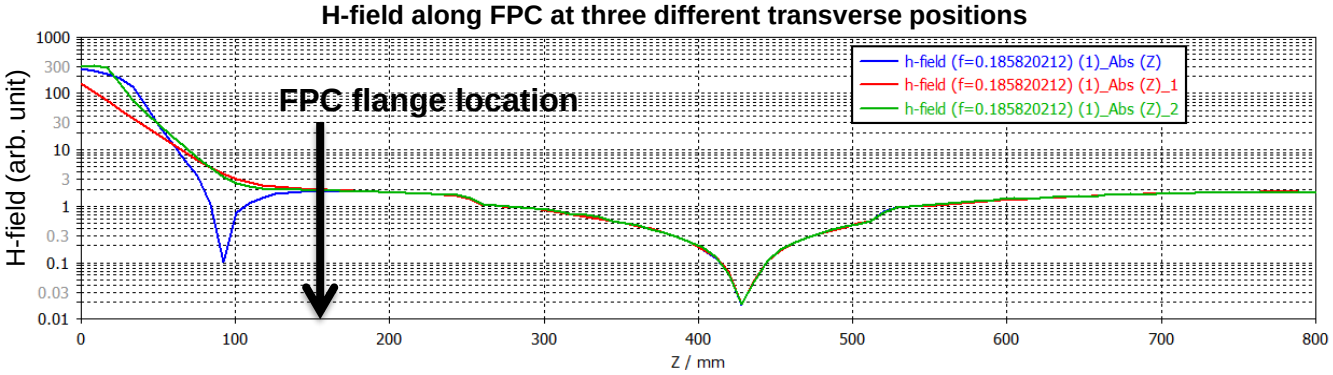
High-field multipacting barrier
No Issues are Expected Based on FRIB Experience

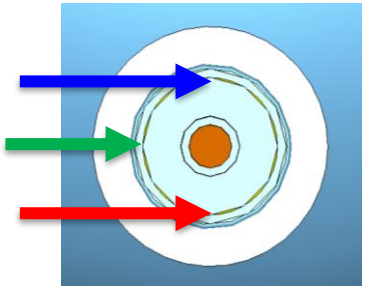


- High-field MP barriers are predicted to be weaker than that of FRIB HWR53s; ~150 HWR53s have been operating in the FRIB linac with no issues after initial MP conditioning - 10-30 minutes in Constant-Wave (CW)

FPC Port
Long Enough not to Introduce Unexpected Heat Loads

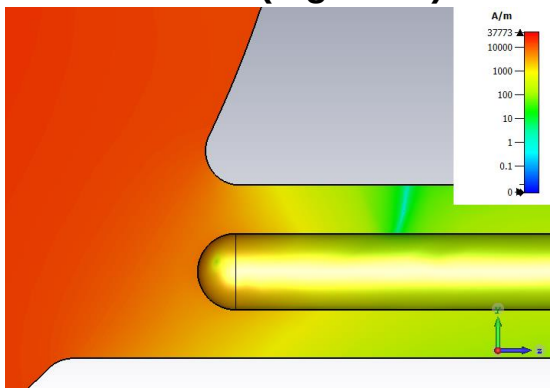
- FPC port length was chosen such that only ‘transmission-line’ field is excited in non-SC structures



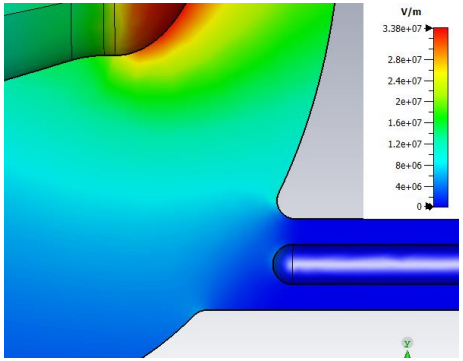


- No problematic E-field or H-field enhancement is observed

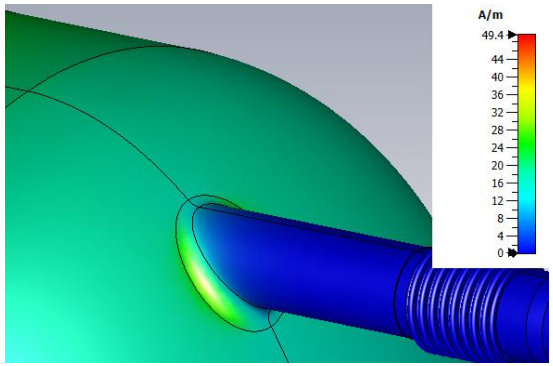
H-field (log scale)



E-field

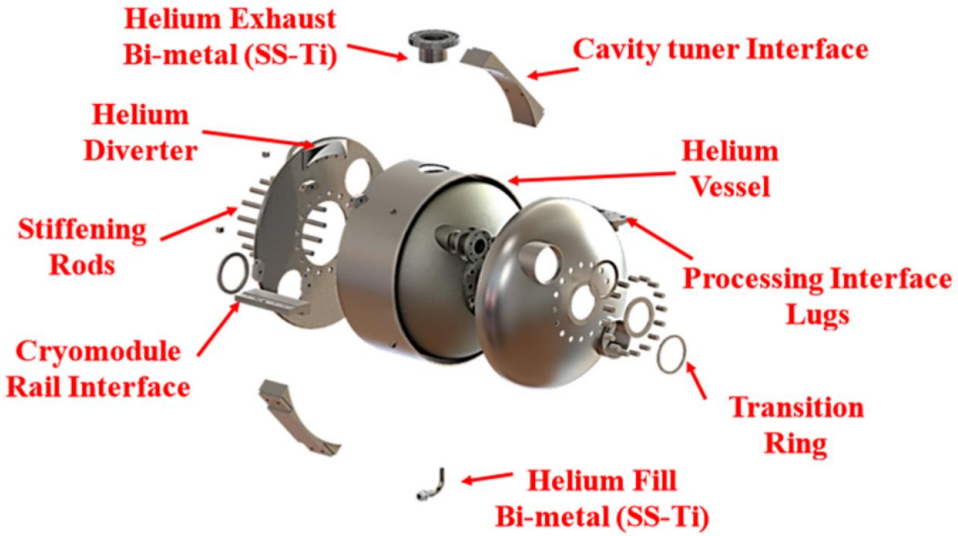


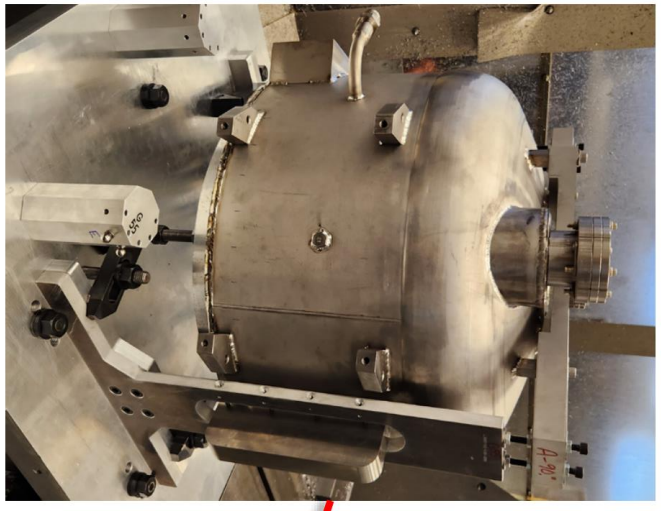
B-field



First Cavity without cathode port

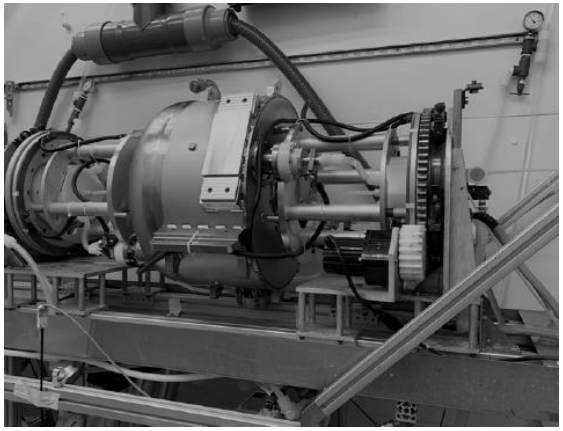
- First cavity (dummy cavity) was fabricated without cathode port to verify SRF performance from components to cryomodule
- 150+120 um bulk EP, hydrogen degassing: 350ºC 12 hour + 600ºC 10 hour, 20 um light EP
- HPR and clean assembly at ALN and FRIB
- Vertical test at FRIB
  - Measured at 4.3 K, 2.0 K

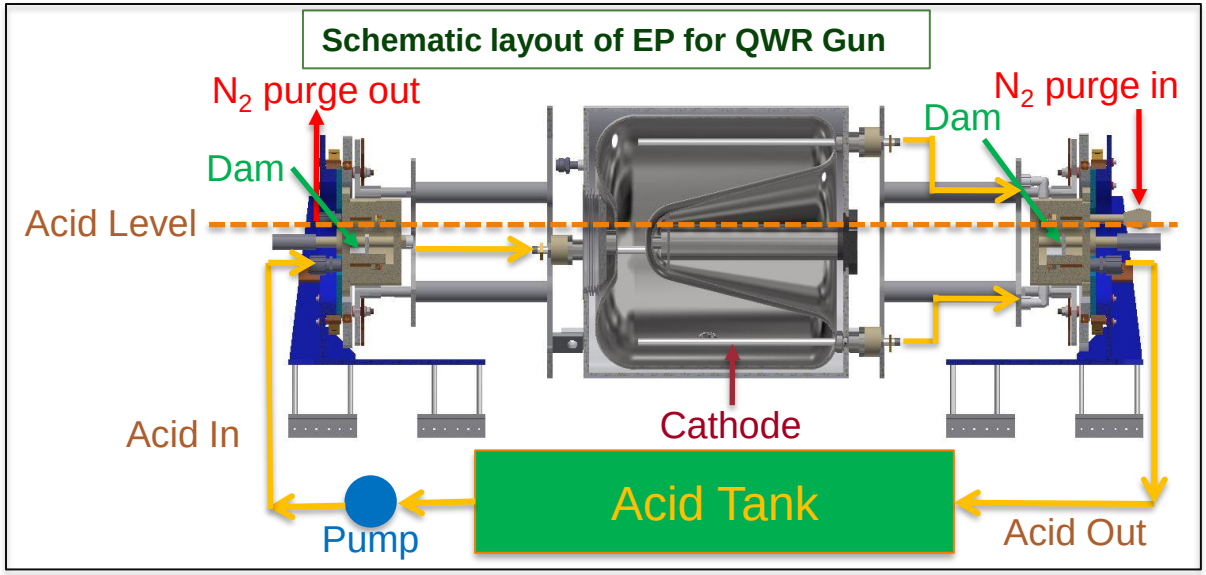




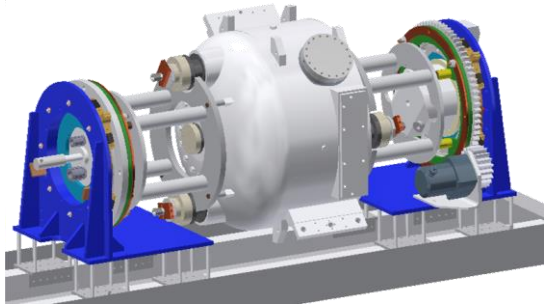
Electropolishing (ANL)

- Horizontal rotational EP
  - Constant rotation, no trapped liquid or gas volumes
  - Basis for PIP-II HWR results with E_{PEAK}> 100 MV/m
- 2-Step process, bulk 120 μm, degas, final 20 μm
  - Latest features including external/internal water cooling & cold EP

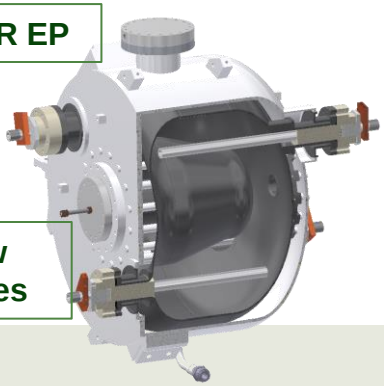




T. Reid, B. Guilfoyle



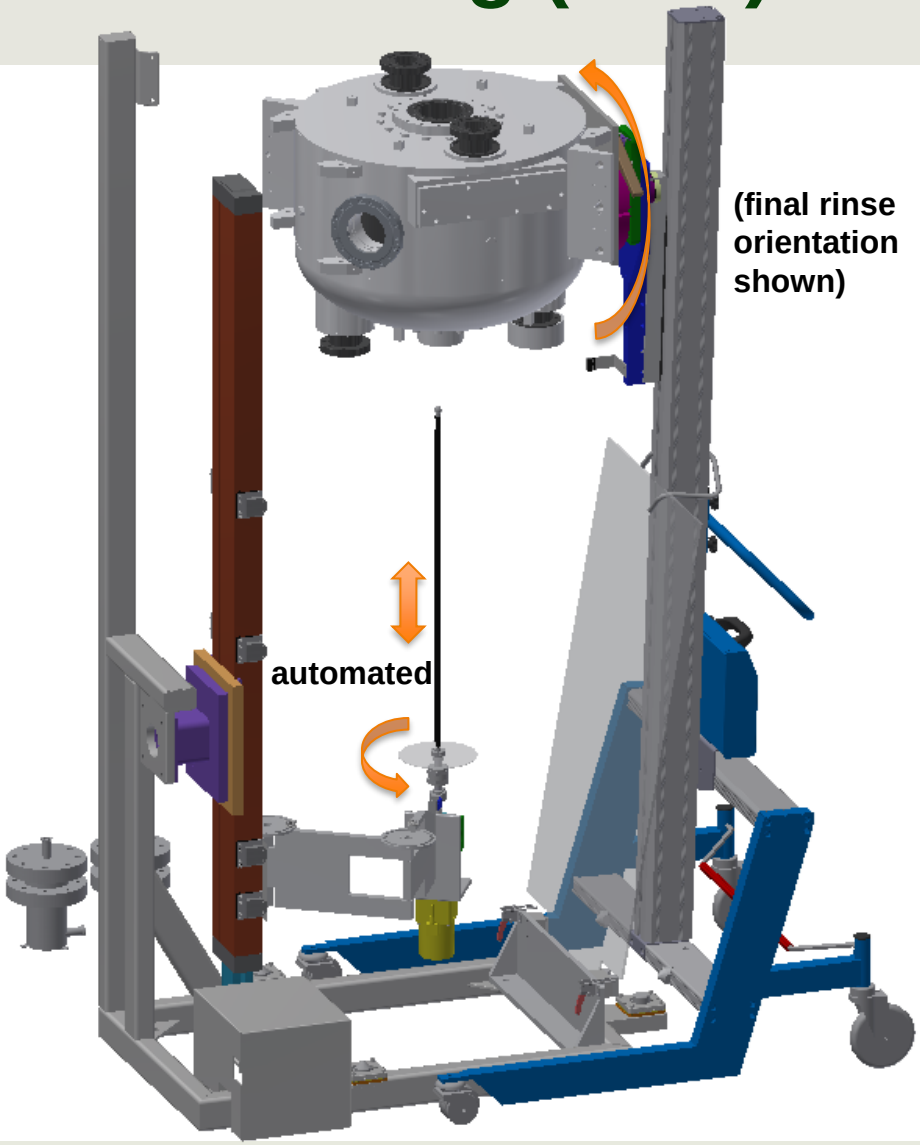
185 MHz QWR EP



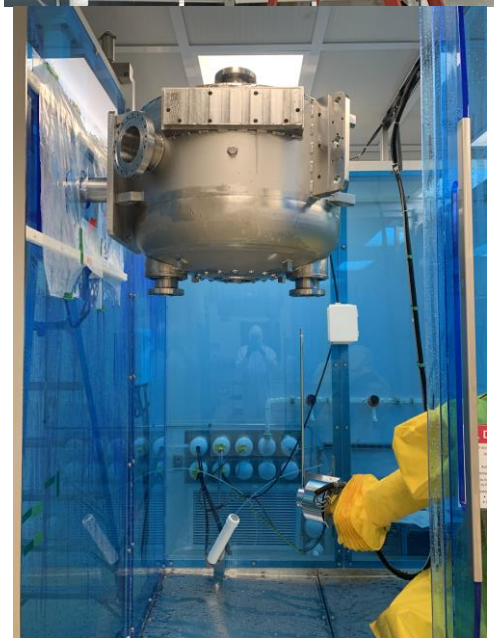
Section view with cathodes

High-pressure Water Rinsing (ANL)

- Processing: manual pre-rinse of entire assembly with manual sprayer, then rinse thru each of five ports
- 12 lpm water @ 80 bar
- PLC programmable rotation and translation of wand
- Typically ~1 hour rinse per port
- Existing Back Tech Cart holds cavity fixed
- Manual (360^{o}) rotation of cavity (manual)
- Two-Hinged Arm manually positioned underneath port to be rinsed (manual)
- Arm travels on motorized rail operated from outside clean room

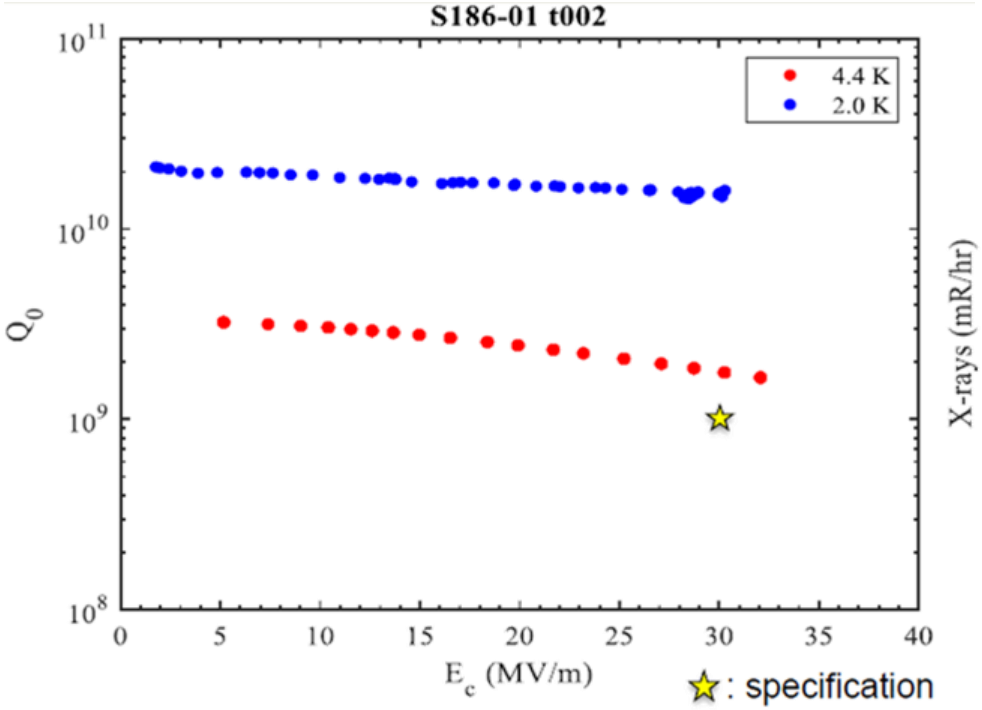


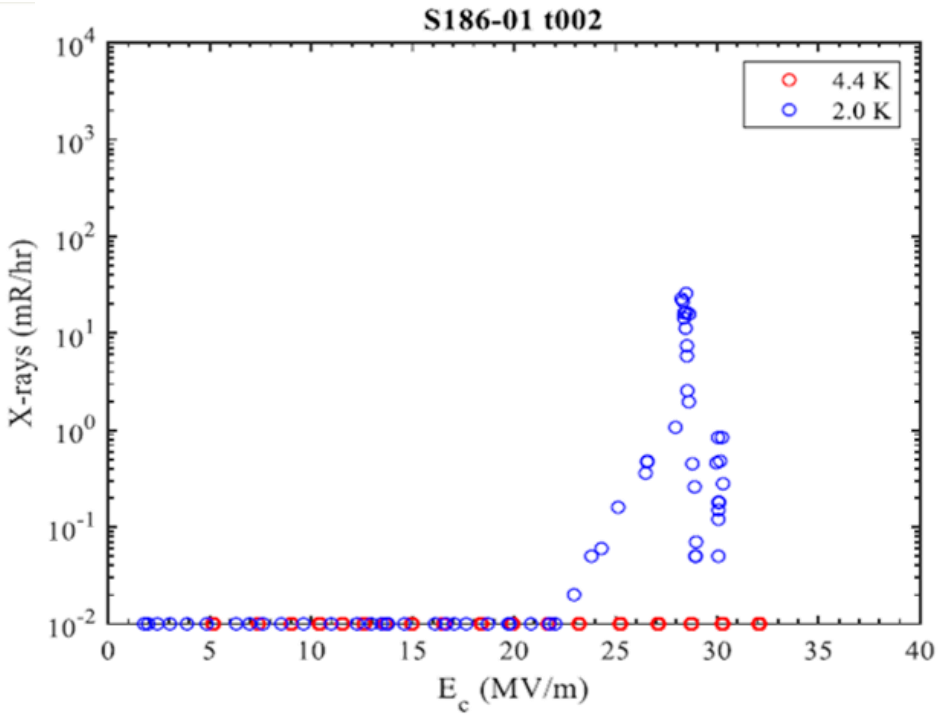
High-pressure Water Rinsing (FRIB)



Vertical test result

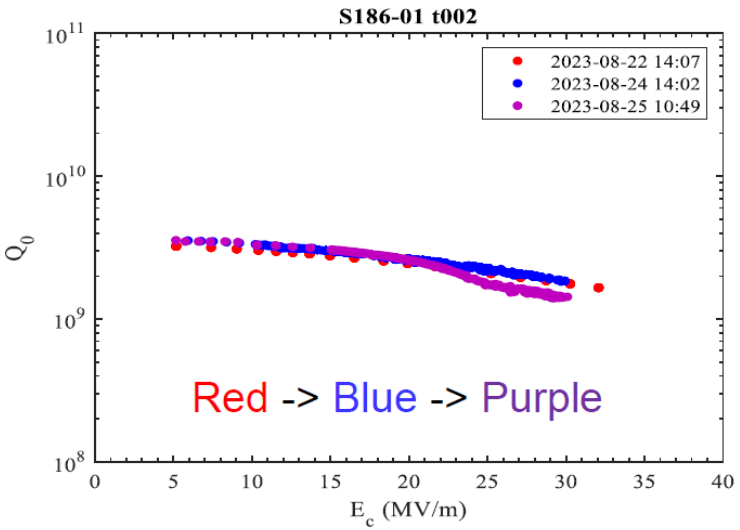
- Achieved Qo of 1.8e9 at 30 MV/m Ec
- Maximum Ec was 32 MV/m which was limited by a field-emission (FE) degradation event.
- FE was then recovered such that no noticeable Qo drop is observed even at 2k Q curve: X–ray does rate measured outside of the test dewar was about 30 mR/hr

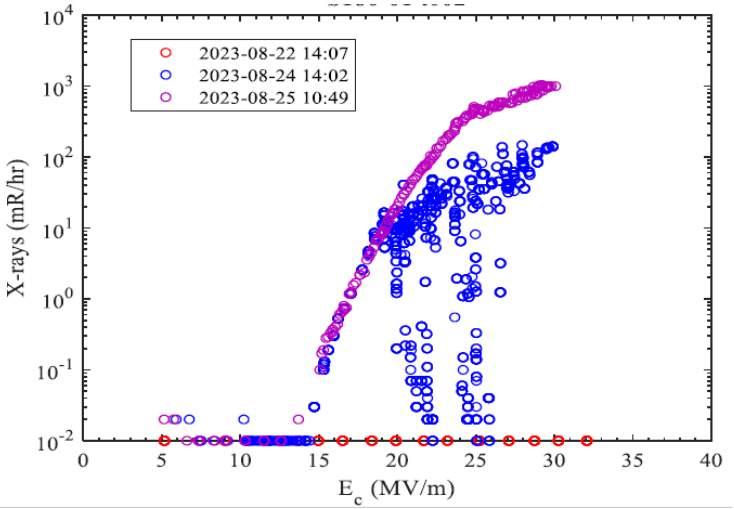




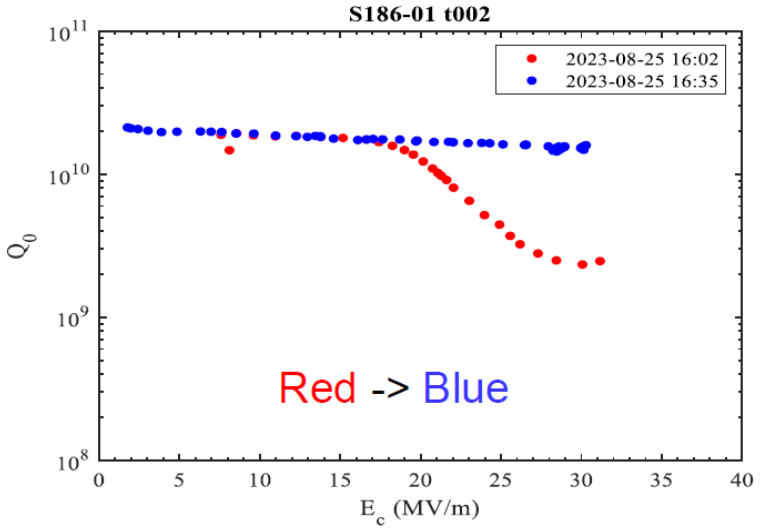
Field emission degradation and recovery

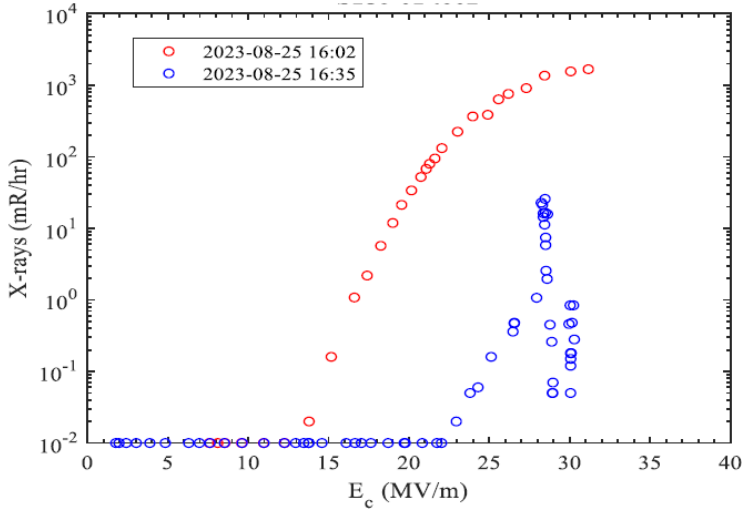
4.4K
Day1-4





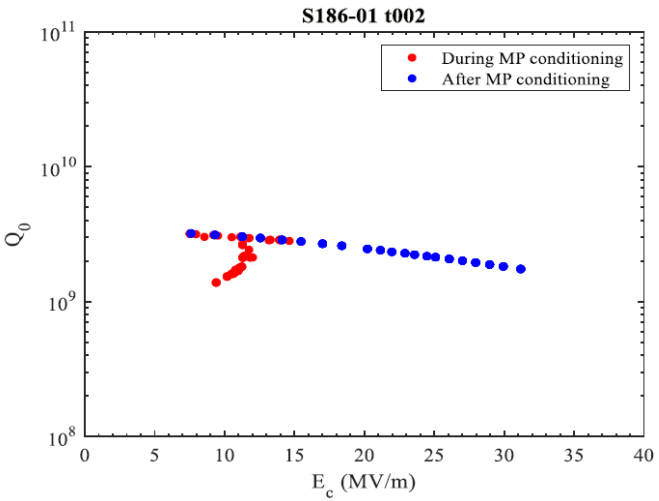
2K
Day4

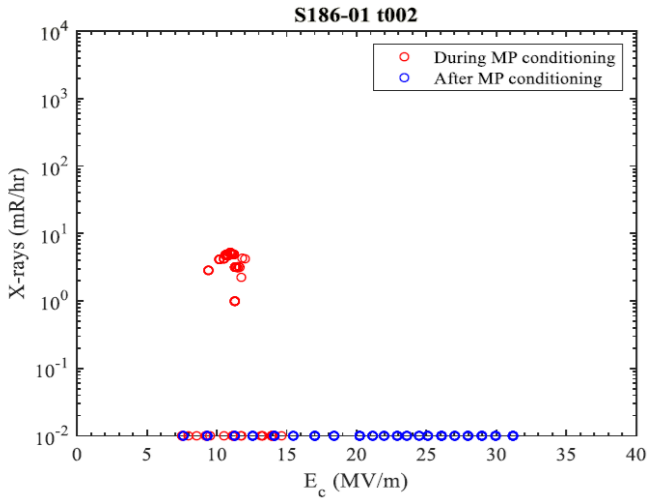


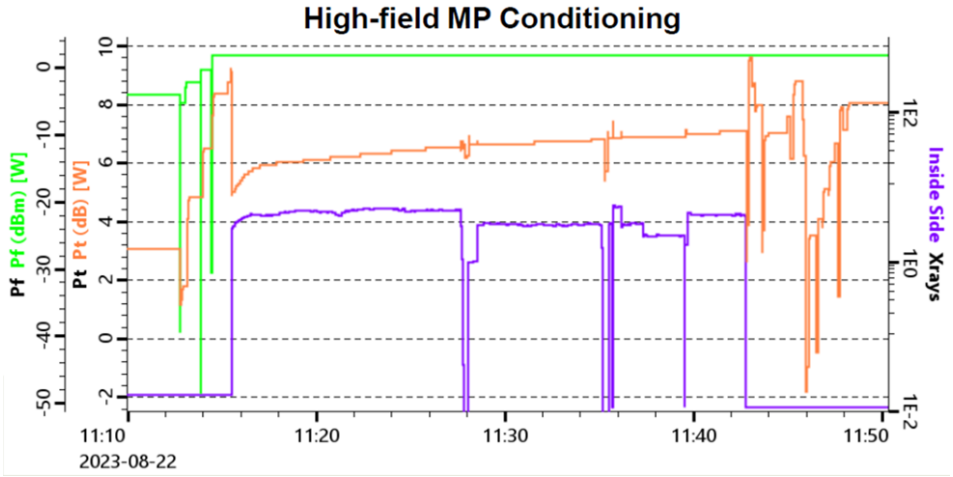


High multipacting barrier

- Exists at ~11 MV/m Ec ~0.7 MV Vacc, 12 mT B_{surf}
- Conditioned within 30 min in the CW mode; the dissipation power at multipactors was 1 W or less.
  - Expected to be faster in the cryomodule equipped with the FPC
- Did not show up again until the next thermal cycle (warm-up and cooldown)
- No issues are expected from operational standpoints

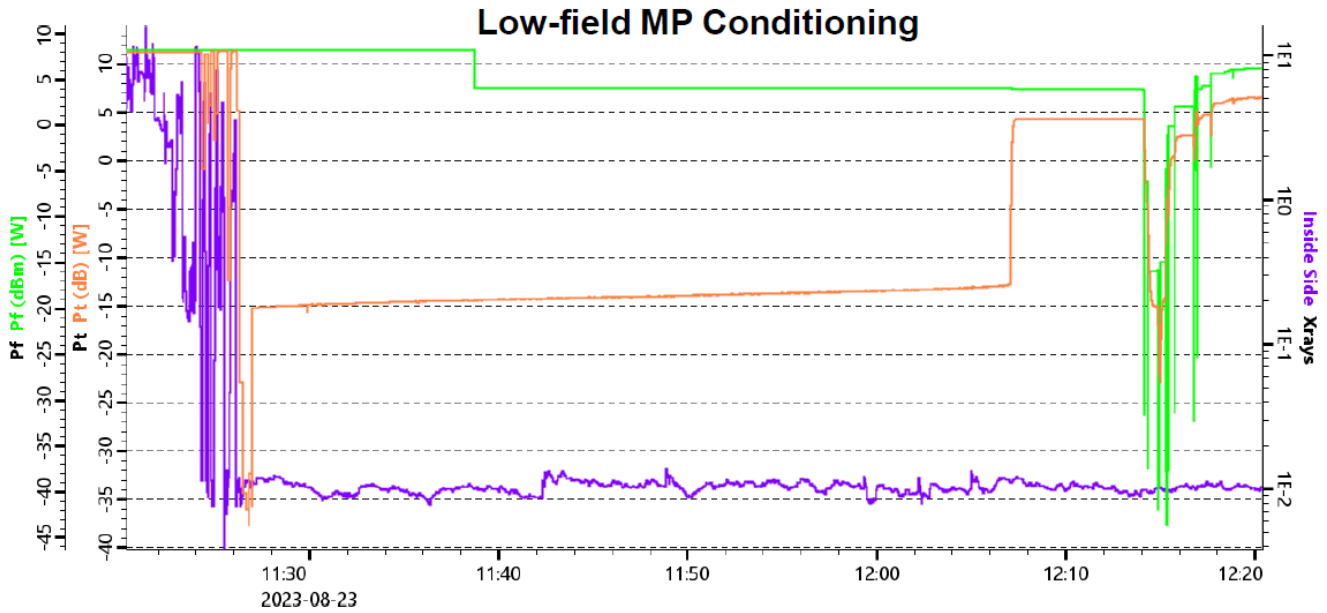






Low multipacting barrier

- Did not appear initially.
- Appeared once at ~0.9 MV/m Ec (~50 kV Vacc), which was after FE excitation. But it was conditioned within ~30 min at P_{fwd} of ~0.5 W.
- Coaxial MP, which seems to be much weaker than other QWRs, as designed.
- If excited in the cryomodule equipped with the FPC, conditioning would be much faster.
- No issues are expected from operational standpoints.



Summary

- 185 MHz SRF gun was start developing for LCLS-II HE LEI with collaboration of FRIB/ANL/HZDR/SLAC.
- Cavity was designed to achieve 30 MV/m on cathode to achieve 0.1 μm emittance.
  - Dome shape for anode to suppress low-field cavity MP barrier
  - 4 ports for EP and HPR; and use for FPC, pickup, pumping during operation
  - Off-beam-axis compact FPC with DC bias to eliminate coupler MP impacts on the beam and reduce potential contamination
- First cavity was fabricated at FRIB and EP at ANL and HPR at FRIB/ANL.
- Vertical test: Achieved Ec = 32 MV/m, Q0 =1.8E9.
  - Field emission degradation event happened in the middle of the test. But it was then recovered. Did not push to higher Ec, instead decided to move to the integration test at ANL.