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Superconducting RF: HWR Status

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PIP-II Machine Advisory Committee Meeting

15-17 March 2016

Overview

- **Work scope.**
- **Status reports:**
  - **Half-wave resonators.**
    - **Fabrication/Processing.**
    - **Cold testing.**
  - **Sub-systems.**
    - **RF couplers.**
    - **Solenoids.**
    - **Tuners.**
    - **BPMs.**
  - **Cryomodule.**
    - **Testing.**
    - **Assembly.**
- **Progress toward FY2016 deliverables.**
- **FY2017 plans.**
- **Summary.**

162.5 MHz β = 0.11 Half-Wave Resonator (HWR)

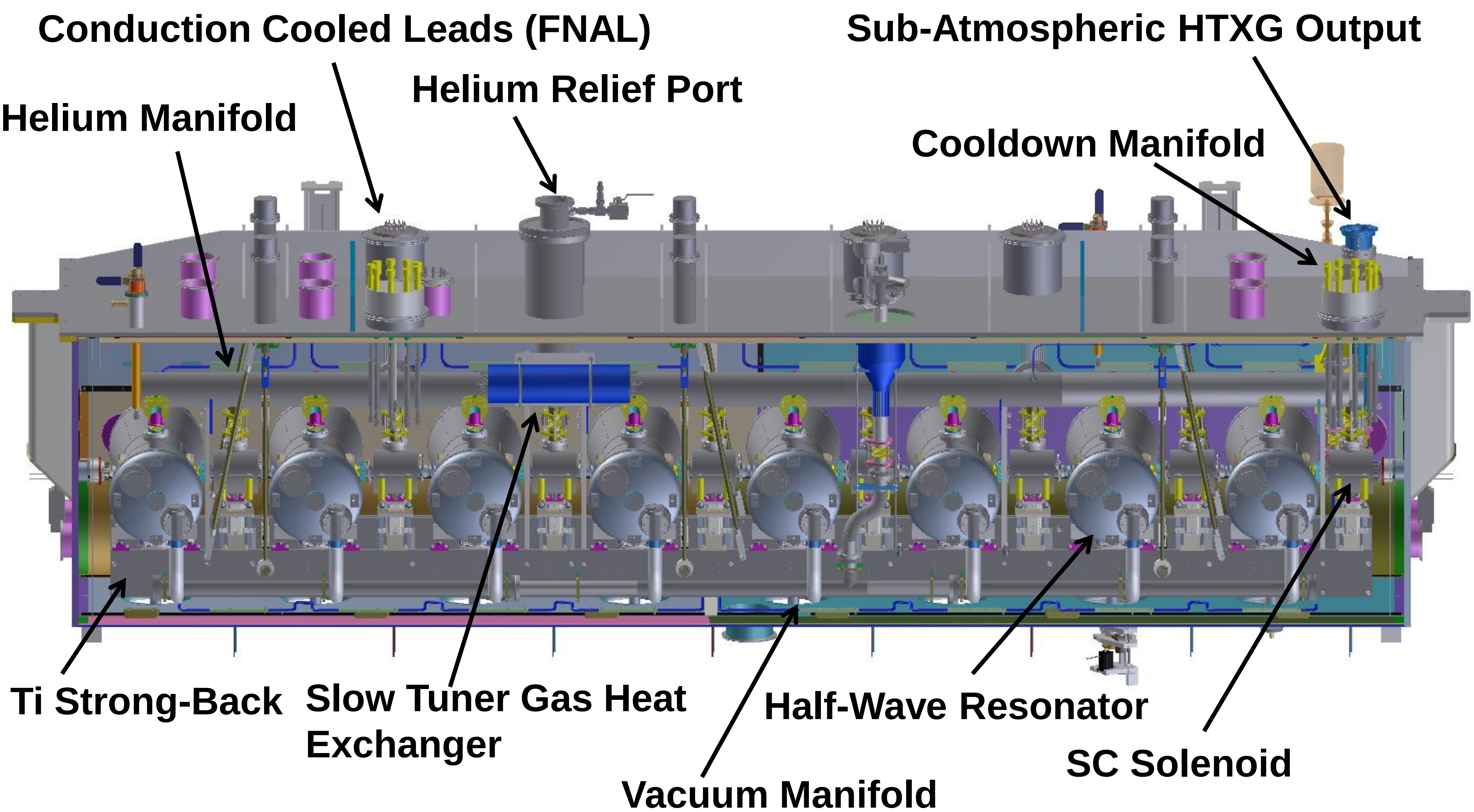
48” (122cm)

Fermilab PIP-II

Scope of Work

- Provide FNAL with a 2 K superconducting half-wave resonator cryomodule operating at 162.5 MHz for the acceleration of H^- beams from 2.1 to 10.3 MeV.
  - Delivered to PXIE for beam commissioning starting in 2018.
- HWR Cryomodule Major Tasks:
  - Develop the 2 K design, build the hardware (except the conduction cooled magnet leads), off-line pre-commission, deliver and install the cryomodule.
  - The cryomodule will have 8 162.5 MHz half-wave resonators, 8 6 T superconducting solenoids with integral return and steering coils and 8 beam position monitors (BPMs).
  - Satisfy all functional requirement specifications and Interface Document conditions.

Half-Wave Resonator Cryomodule



2.2 m X 2.2 m X 6.2 m

Technical Developments

- **Novel design of half-wave resonators: double conical structure to reduce peak fields and cryogenic load while providing a high shunt impedance.**
- **Integrate into the superconducting solenoid a return coil and x-y steering coils without additional magnetic shielding.**
- **Cold, low-particulate clean, beam position monitors.**
- **Compact lattice suitable for the acceleration of several mAs of H^- or proton beams.**
- **When finished the half-wave cryomodule will be the first superfluid helium cooled TEM-class cryomodule.**

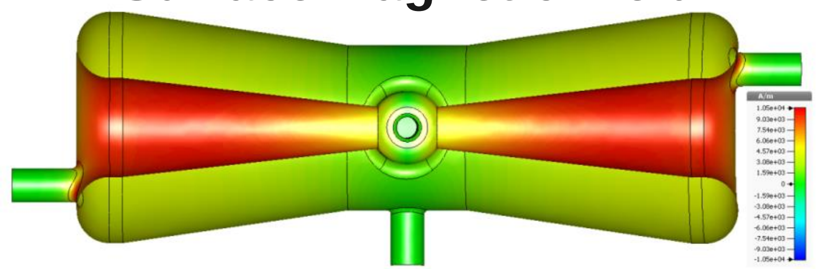
What goes into a half-wave cavity?

- **Cavity Design Parameters:**
  - Beam physics design.
  - RF Performance.
  - Fabrication.
  - Polishing.
  - Cleaning.
  - Assembly.
  - Safety standards.

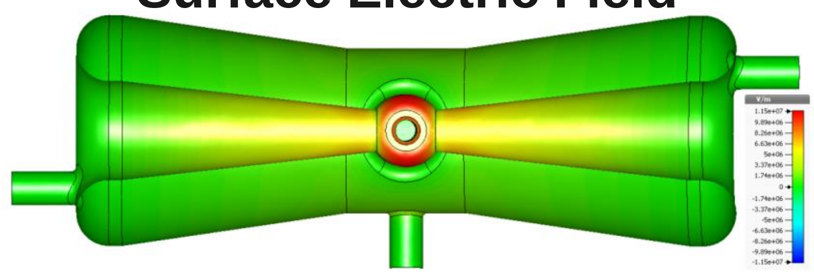
Formed Parts for 7 Cavities

Cavity Type	HWR
Freq. (MHz)	162.5
β	0.112
l_{eff} (cm, $\beta\lambda$)	20.68
E_{pk}/E_{acc}	4.7
B_{pk}/E_{acc} (mT/(MV/m))	5.0
QR_s (Ω)	48.1
R_{sh}/Q (Ω)	272

Surface Magnetic Field



Surface Electric Field



Half-Wave Resonator Fabrication Status

- We are building 9 total resonators.
  - The two prototypes are finished.
  - The remaining 7 production cavities are at various stages of finished:
    - All fabrication is finished. Only processing remains.
    - The first unit tested last month.
    - The second unit is ready for cold testing. Test will take place in the next several weeks.
    - Two units are ready for final light polishing (20 μm).
    - Three units are ready for hydrogen degassing at FNAL. After the hydrogen degassing they will be tuned and made ready for the final light polishing.
- Next:
  - Recent cavity test results.
  - Frequency tuning progress.

HWR EP

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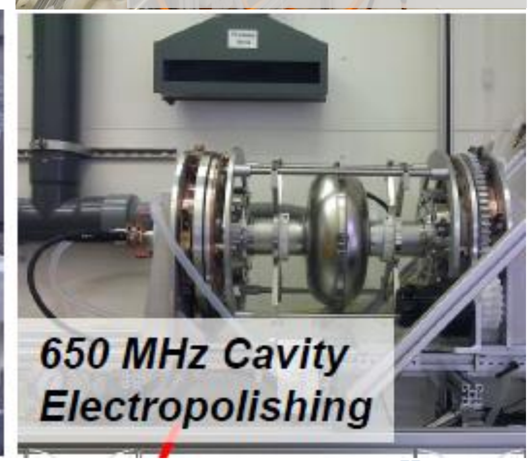
ANL-FNAL Collaboration on SRF Cavity Processing

Clean facilities for HPR & Assembly

72 MHz Cavity Electropolishing

1.3 GHz Cavity Electropolishing, 325 MHz BCP



650 MHz Cavity Electropolishing

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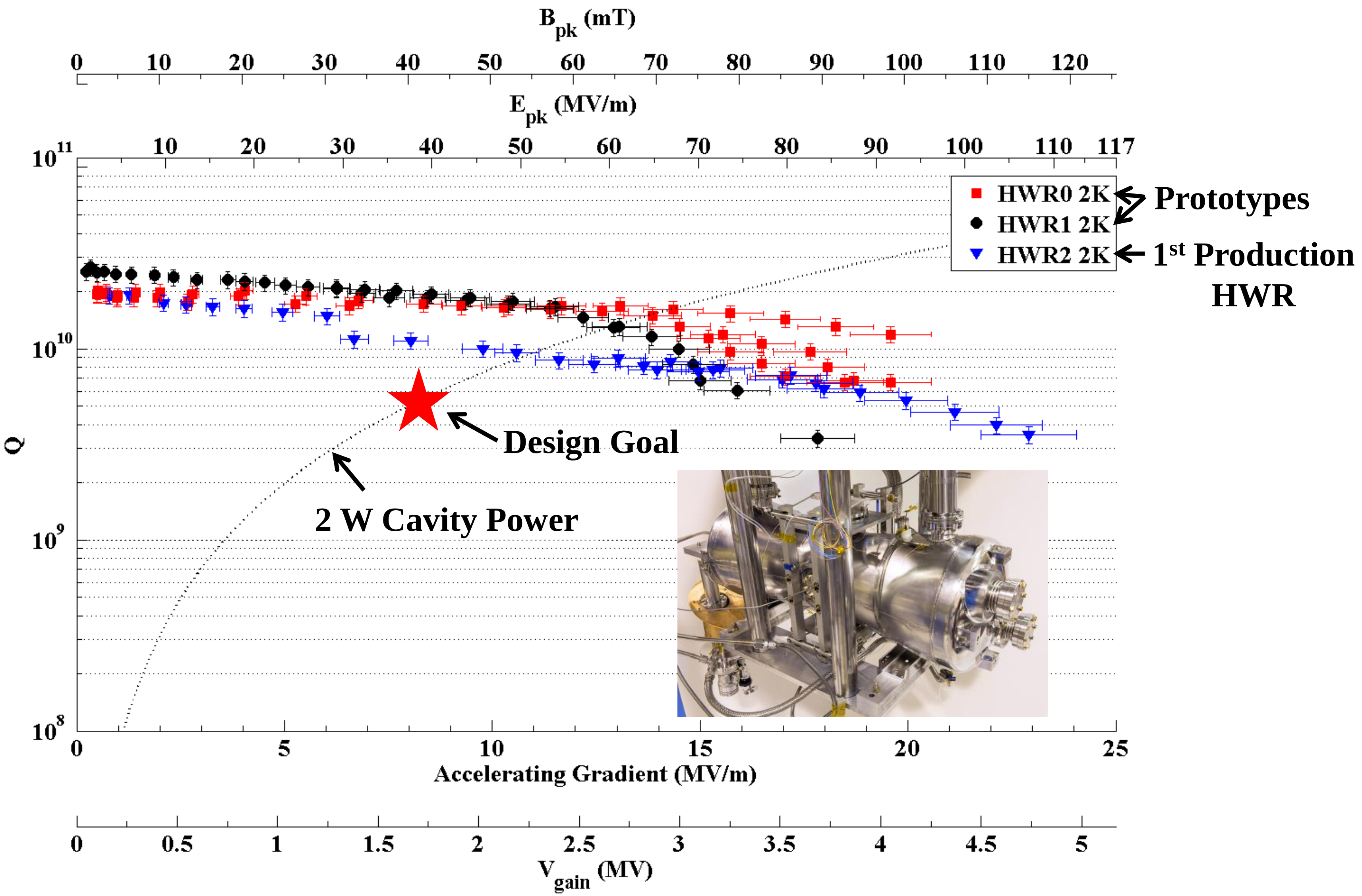
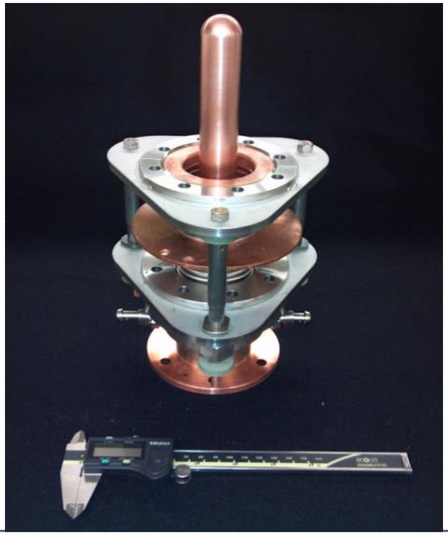
Half-Wave Resonator Q Curves



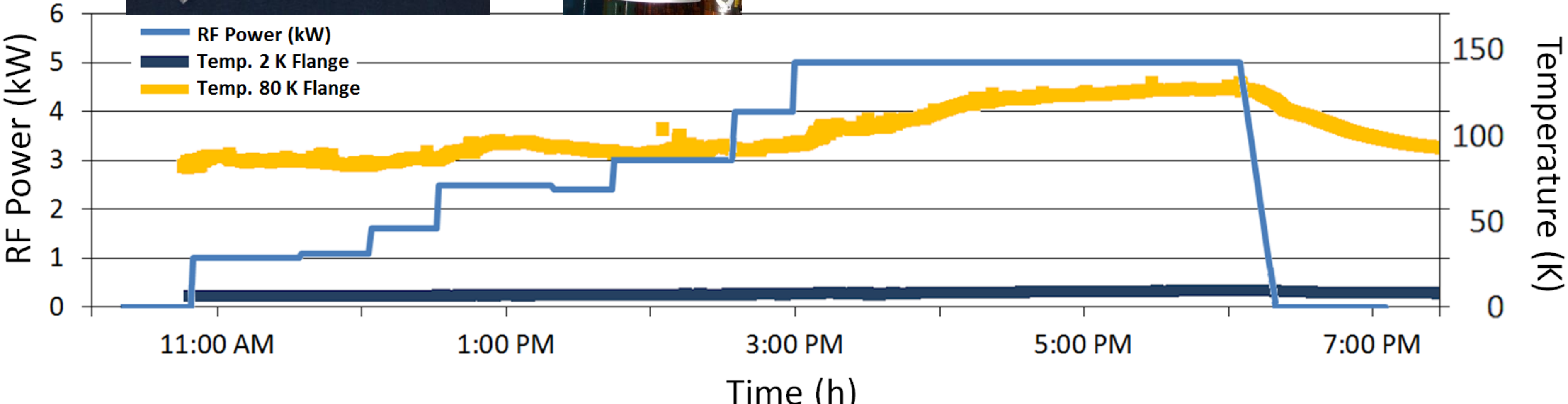
RF Power Couplers



Left – Cold RF window and bellows assembly

- **The '2 K' flange is the upper CF flange in this view**
- **The '80 K' flange is the lower CF flange**

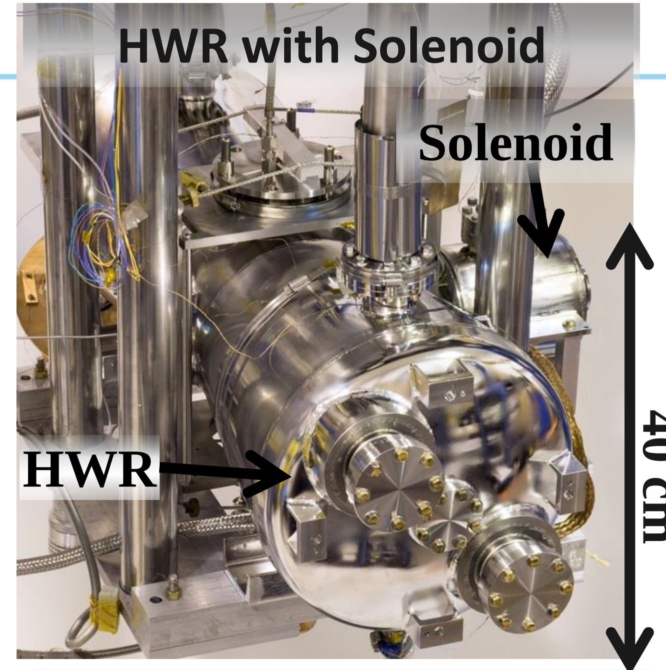
Right – Complete coupler assembly as viewed from below the half-wave cavity

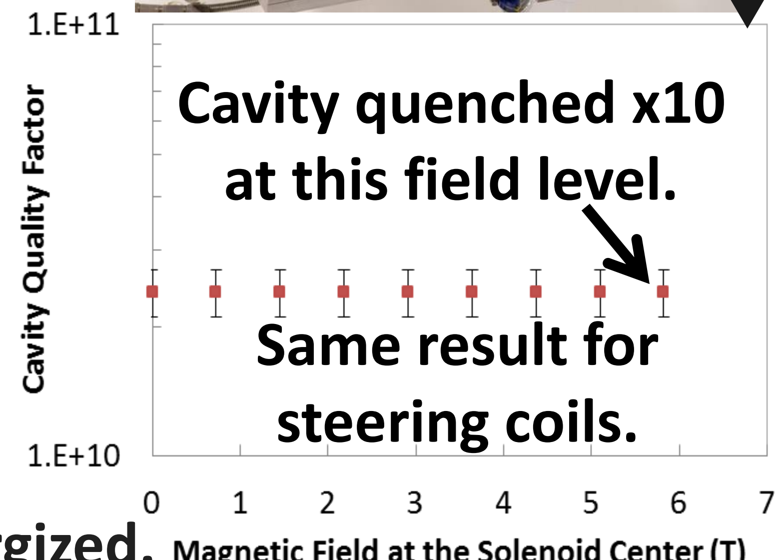


- **1st Coupler assembly was thermally stable and tested at RF powers up to 5 kW. Currently testing the remaining coupler assemblies.**

Half-Wave Resonators & Solenoids

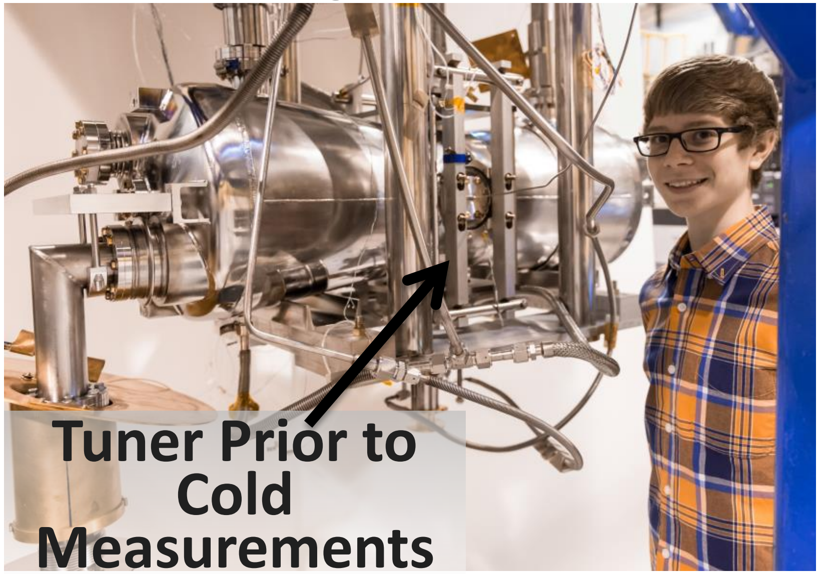
- **Solenoid package integrates x-y steering coils.**
- **Important design issue:**
  - **Minimize stray field @ the RF cavity to prevent performance degradation due to trapped magnetic flux.**
- **Measured RF surface resistance with a sensitivity of ±0.1 nOhm before and after each quench of the cavity.**
- **The cavity was quenched with the solenoid and the steering coils energized.**
- **No quantifiable change measured in the cavity RF surface resistance with the magnets energized.**





Tuners and BPMs

- **All of the tuners have been fabricated.**
  - **A tuner was tested on the cavity during the last test to finalize the cavity frequency tuning numbers.**
  - **The remainder of the off-line cavity tests will have the production tuners included too.**
- **The BPMs are fabricated but not welded into their bellows/flanges. To be finished by the end of FY2016.**



BPM
3.7" Per Side

Half-Wave Resonator Frequency Tuning

- Target frequency at 2.0 K = 162.500 MHz.
  - Includes ½ range of slow-tuner = 60 kHz.
  - Full slow tuner range = 120 kHz.

- During the last 2.0 K test the frequency = 162.461 MHz.
  - Need to tune frequency higher by 40 kHz.
  - This is due to a 40 kHz pre-load being applied to the slow-tuner during installation.

- The second production cavity test will confirm the above number. Then we will fine-tune all of the cavities and confirm the correct f_0 during subsequent tests.

Cryomodule Assembly Status

- **We have aligned and installed the Ti strong-back in the cryomodule.**
- **We are preparing to cool this assembly down to:**
  - **Measure alignment changes.**
  - **Quantify the 70 K heat leak.**
  - **Initial cold leak checking.**
- **After this we will perform a “mock” assembly to verify our procedures.**

Cryomodule Alignment and Assembly

Fiscal Year 2016 Deliverables

	Deliverables	Status
1	Complete fabrication of magnet assemblies.	Finished
2	Complete fabrication of sub-systems (RF couplers, slow tuners and BPMs)	In progress.
3	Engineering cool down of the cryomodule to 80 K.	Going on right now.
4	Complete RF surface processing of 7 production cavities.	In progress ~75% finished.
5	Testing of 7 production cavities individually in the test cryostat.	In progress.

Fiscal Year 2017 Deliverables

	Deliverables	Status
1	Assembly of the cryomodule.	Not started.
2	Vacuum and cryogenic testing of the cryomodule at LN2 temperature, 77 K.	Not started.
3	Delivery and installation at FNAL	Not started.

We are currently on target to meet our FY17 delivery goal.

Summary

- **Progress is being made on all aspects of the cryomodule fabrication.**
- **We are in the early stages of the cryomodule assembly while we finish the cavities, couplers and sub systems.**
- **We are on track to deliver the cryomodule in FY17 in preparation for FY18 beam commissioning.**