Beam Commissioning of the 56 MHz QW Cavity in RHIC

Qiong Wu

On behalf of all who worked on the project

Brookhaven National Laboratory

Outline

- Introduction of the cavity
  - Cavity and couplers
  - Installation in RHIC and cavity operation
- First beam operation – 2014
  - Luminosity increase
  - Bunch profile change
  - Coupler redesign
- Second beam operation – 2015
  - HOM measurement
  - Cavity conditioning
- Conclusion and future plans

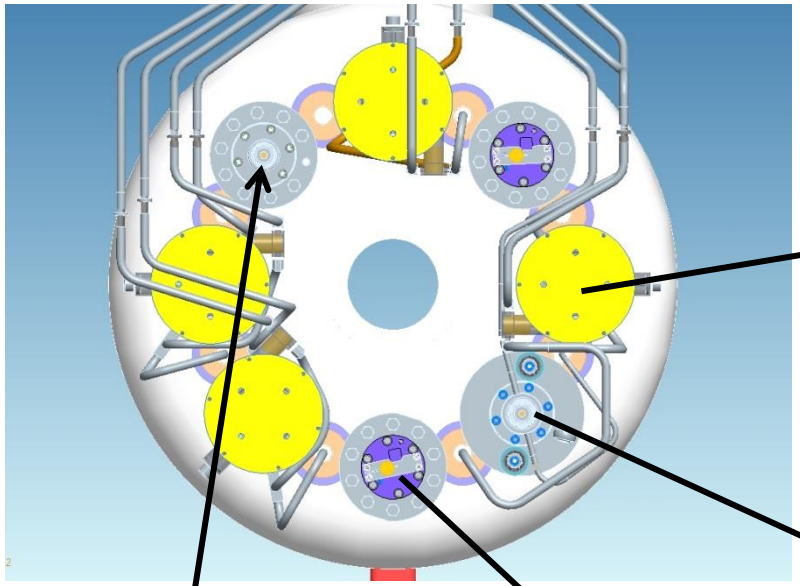
The Cavity

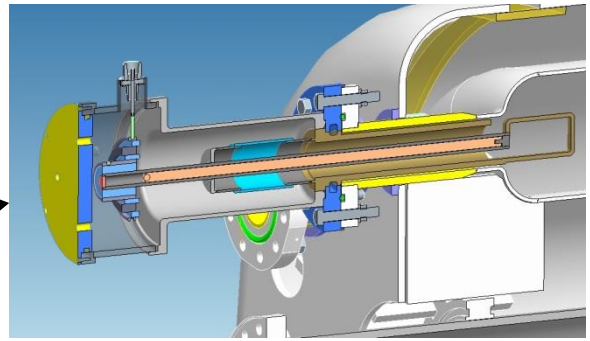
- The 56 MHz cavity is a niobium superconducting quarter wave resonator. It is a beam driven cavity.
- The 56 MHz cavity will increase the RHIC luminosity by providing very large RF buckets to combat IBS diffusion.
- The cavity does not have sufficient tuning range to follow the large frequency change during the energy ramp, so it is turned on only after reaching store.
- The cavity fundamental mode is detuned and strongly damped during injection and acceleration.
- A 1 kW amplifier is connected to the cavity to :
  i) achieve required amplitude and phase stability;
  ii) provide conditioning capability.
- At store, the fundamental damper is withdrawn and then the cavity frequency is tuned (approaching from below the beam h=720 line) to achieve an operating voltage of 2.0 MV.

Cavity Design Parameters

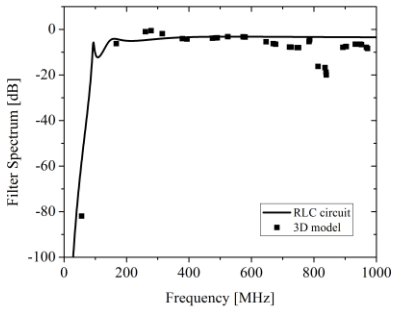
Frequency	56.29	MHz
R/Q	80.5	Ohm
Length	1342	mm
Aperture	100	mm
Max diameter	500	mm
Gap	85	mm
Gap voltage	2	MV
Stored energy	140	J
Q_0	2.5E9	
E_{pk}/V_{acc}	17.5	m^{-1}
B_{pk}/V_{acc}	42	mT/MV

RF Couplers

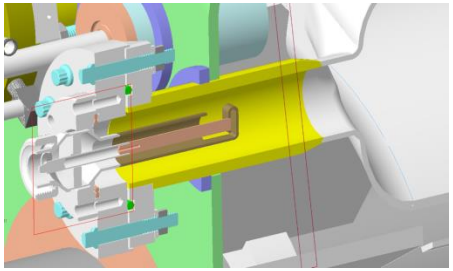




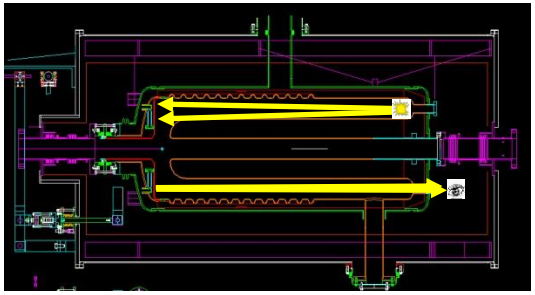
HOM couplers with high pass filter

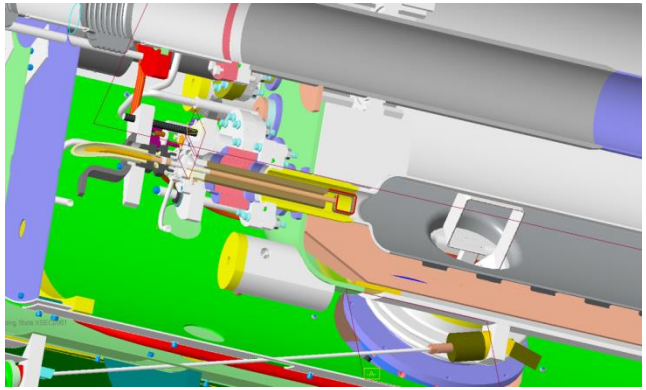


Pick-up

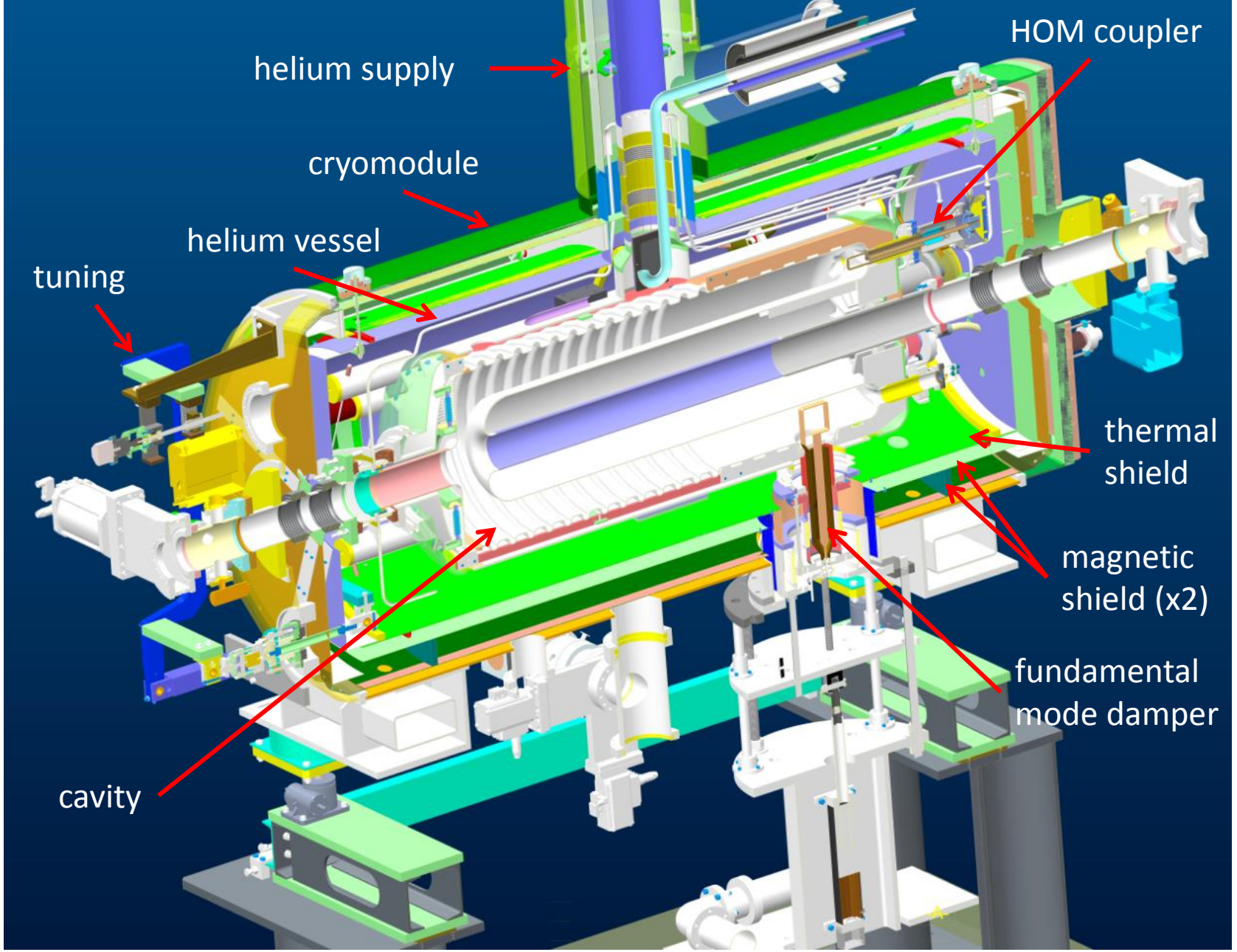


IR detectors

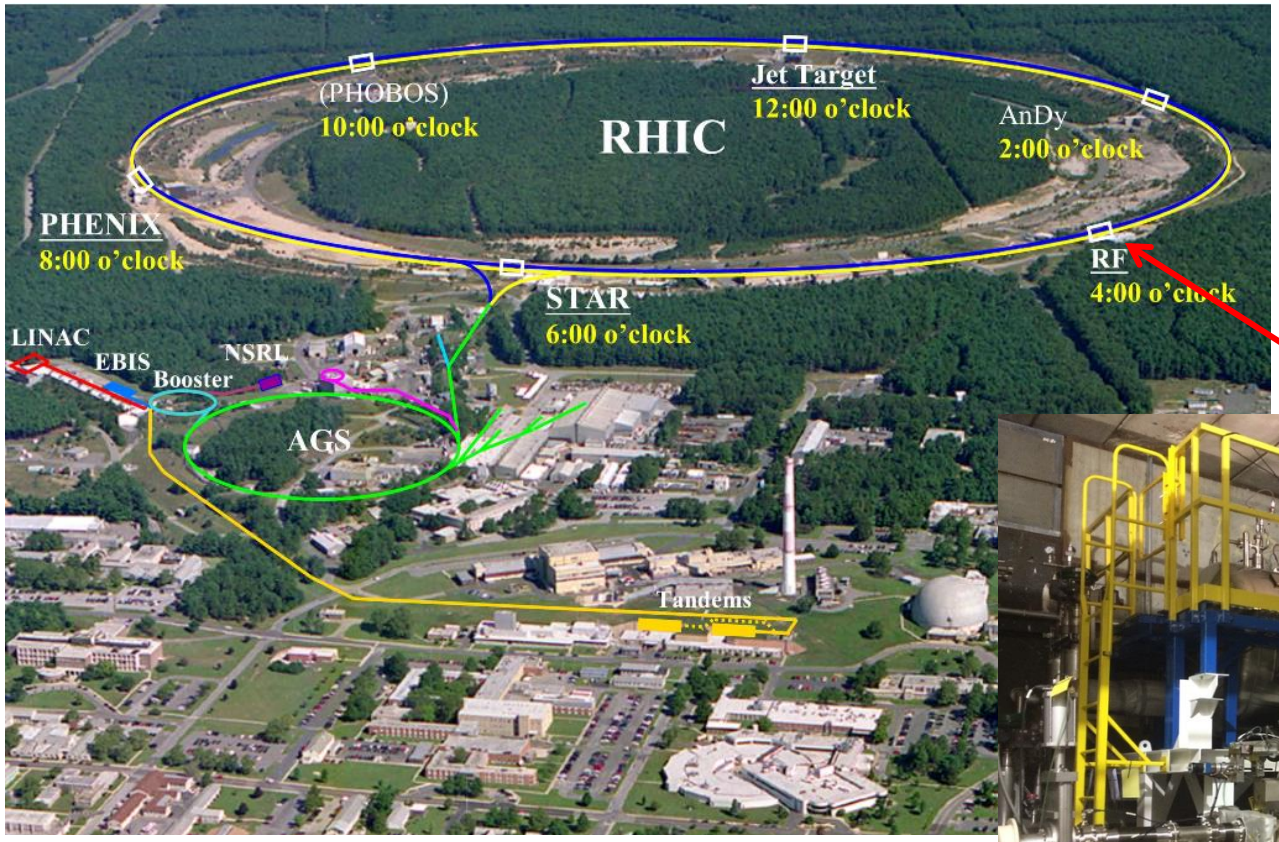




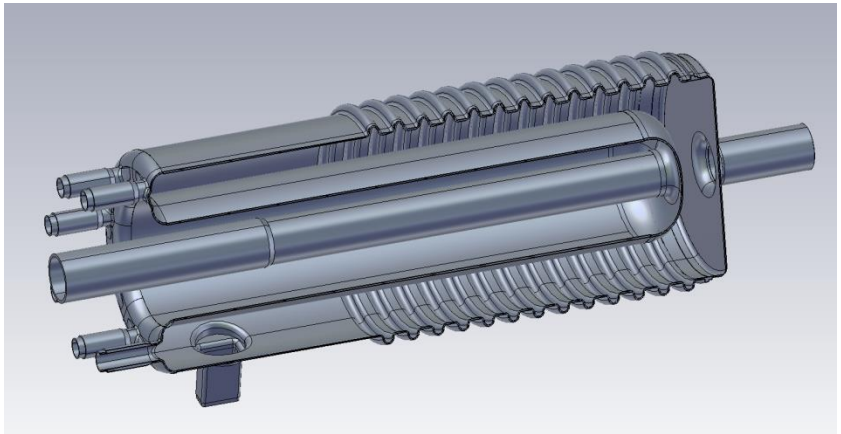
FPC with motion system


helium supply
HOM coupler
cryomodule
helium vessel
tuning
thermal shield
magnetic shield (x2)
fundamental mode damper
cavity

Installation in RHIC



Cavity Operation

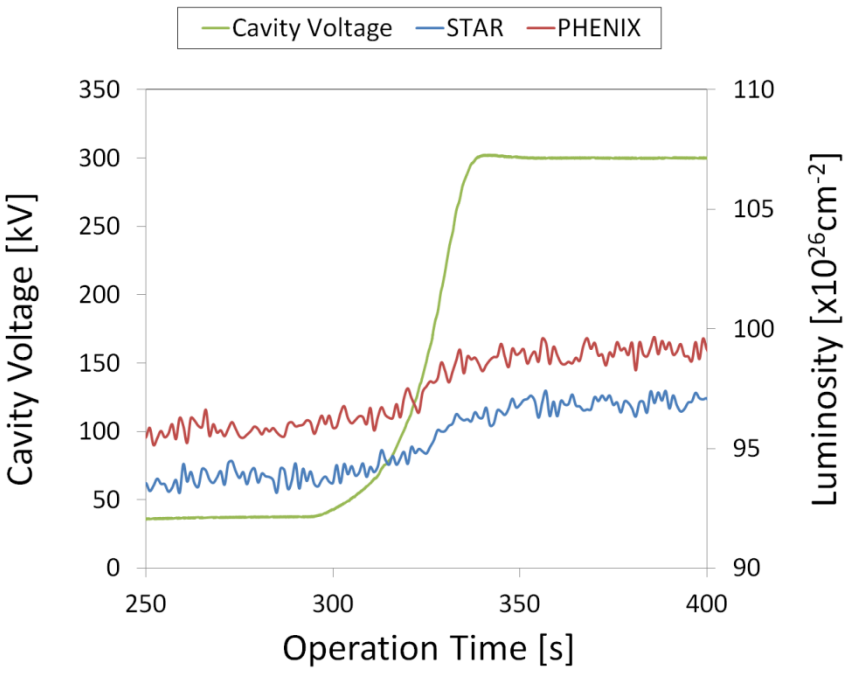


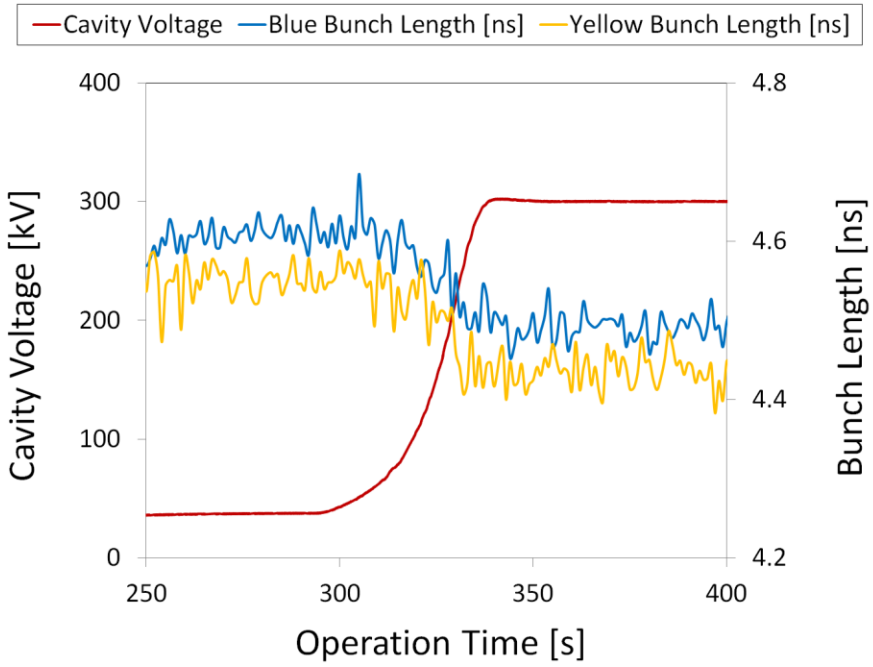
- The cavity is installed in the common area of RHIC, i.e. shared by both rings.
- The low frequency ensures adequate RF acceptance to long bunches without re-bucketing.
- The cavity operates at 4.5 K cooled by a quiet liquid helium source.
- The designed operation voltage is 2 MV.
- Frequency tuning range of the cavity can cover all particle species available in RHIC.

First Beam Operation – 2014

- The cavity had its first beam operation on June 12, 2014. It was gradually brought to resonance after the particles are accelerated to their peak energy.
- The cavity operated with two different beam scenarios:
  - Au + Au @ 100 GeV
  - Au + He3 @ 100 GeV
- The cavity operation was integrated into the RHIC automatic startup sequencer and has continuously operated for 18 days.

56 MHz Cavity effect on beam:

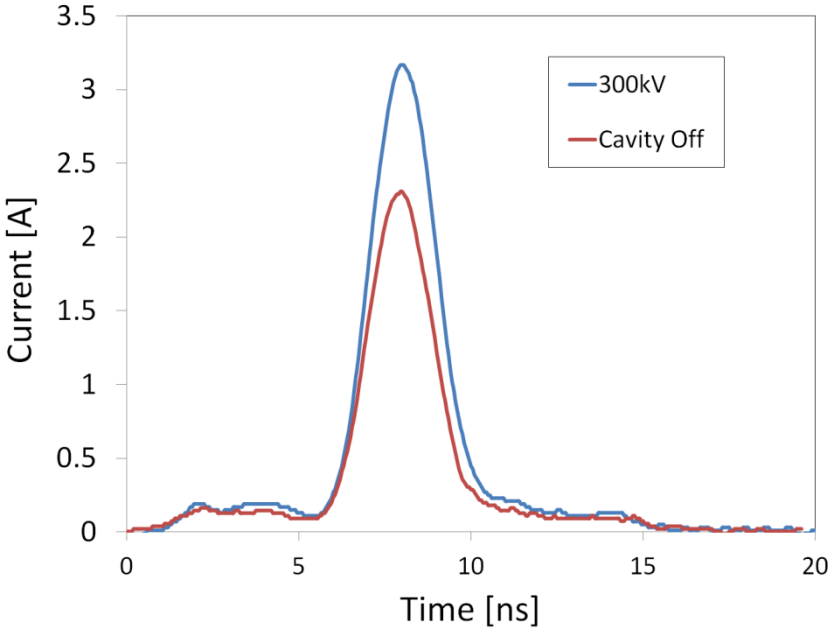




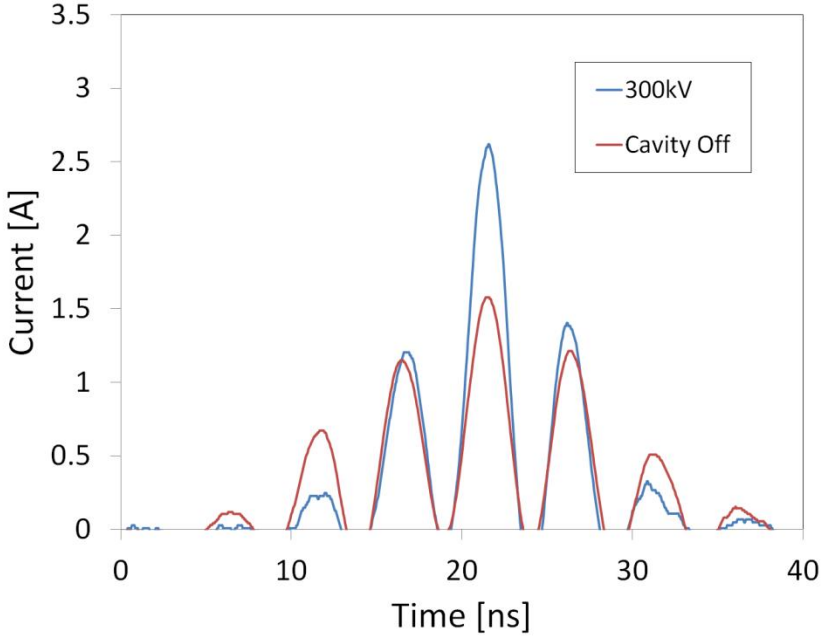
We observed change in the luminosity (increased by ~3%) as well as bunch length (decreased by ~4.5%) in both rings with the cavity slowly turned on.

Profile Comparison in Asymmetrical Beam

He3

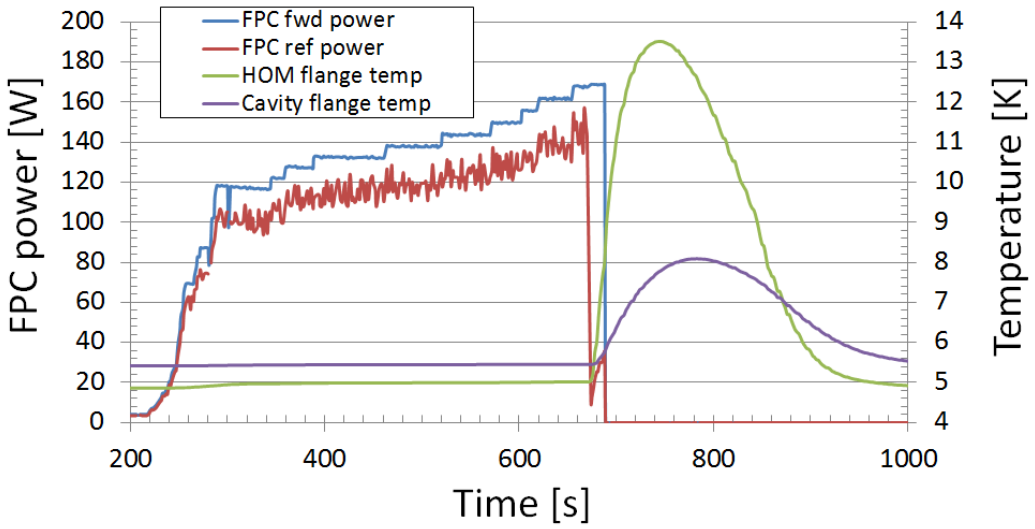


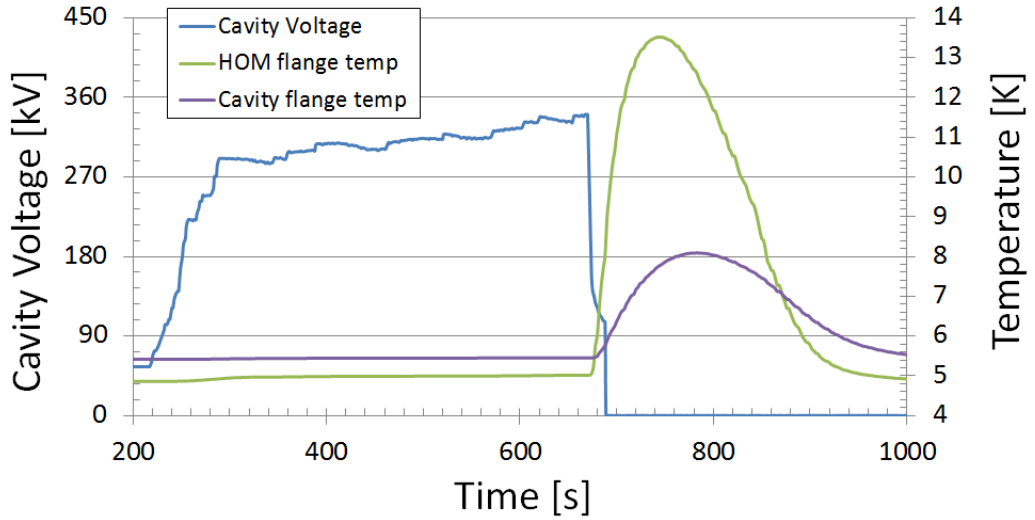
Au



During the asymmetrical collisions, the cavity also operated at 300 kV. The population of Au beam in the satellite buckets is squeezed towards the center.

HOM Coupler Quench

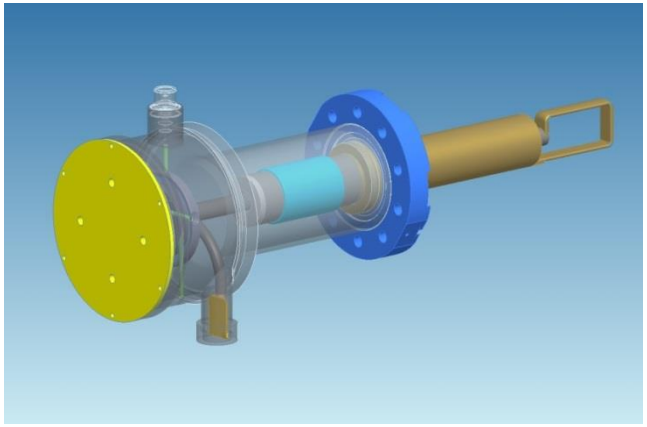


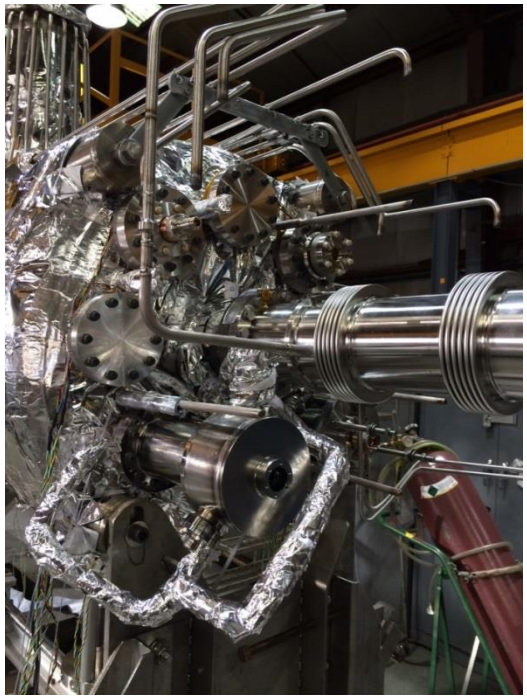


The cavity voltage was limited by a quench in the HOM coupler assembly. The maximum reached cavity voltage was:

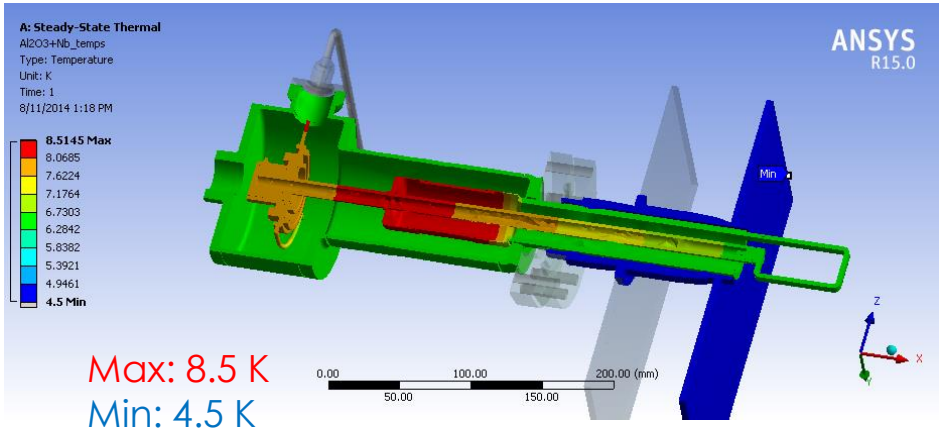
- 350 kV DC
- 550 kV pulsed with amplifier

Thermal analysis of the HOM coupler quench





The HOM coupler has a sapphire RF window that is designed for separating the high-pass filter section from the cavity vacuum.

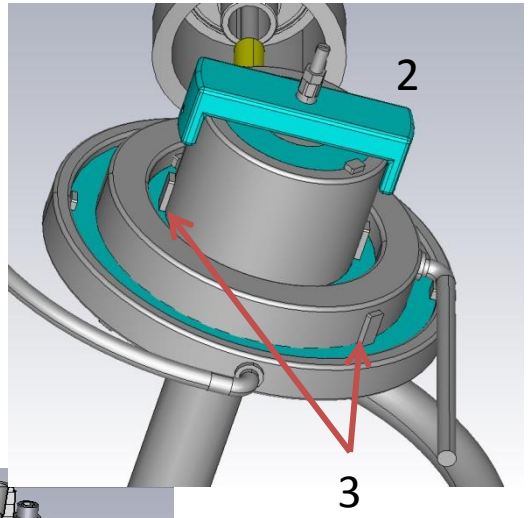


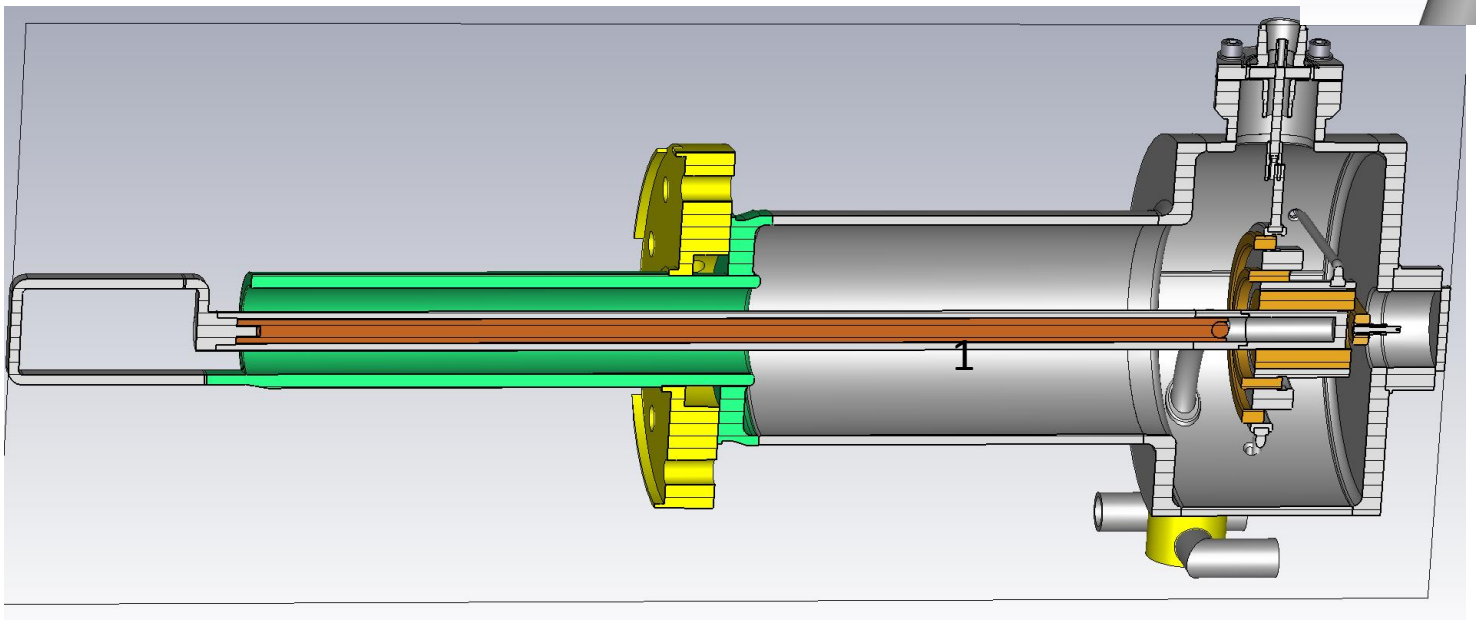
The braze material at the sapphire – Nb cuff joint is InCuSil, which is normal conducting at 4.5 K.

Thermal analysis (Steve Bellavia) shows that at 330 kV, the InCuSil material would bring the adjacent Nb (T_C = 9.2 K) to 8.5 K. It is currently our best candidate for the quench.

New Design of HOM Couplers

- Removal of the sapphire window
  - eliminate the normal conducting braze material
- Add tuning bridge at the end of the filter stack
  - For locking of the tuned position
- Replacing the Stycast with stoppers
  - eliminate the outgassing of Stycast in UHV





The fabrication of the new HOM couplers will be reported in the poster session by Naeem Huque, ID THPB063.

Second Beam Operation – 2015

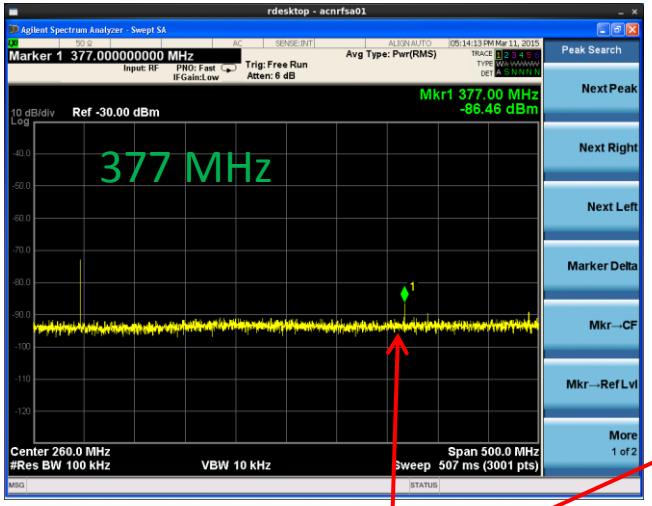
Cavity status:

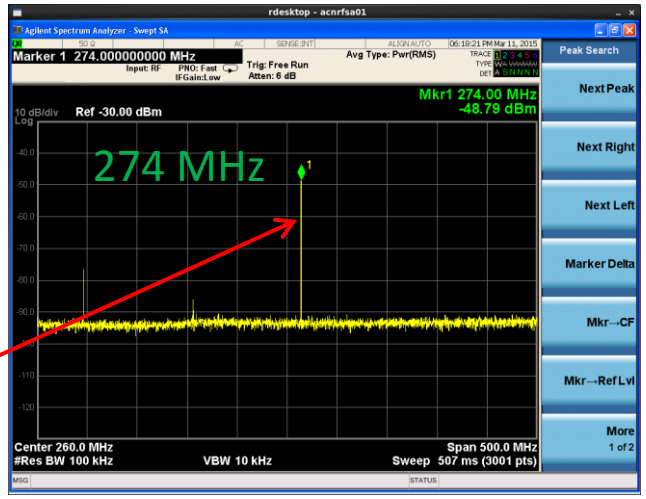
- No HOM couplers installed
- The fundamental power coupler can be connected directly to an external load to provide limited (~2 orders of magnitude higher Qext than damping from single HOM coupler) damping to the HOMs.
- The tuning range of the cavity will sweep through several HOM resonance frequencies.

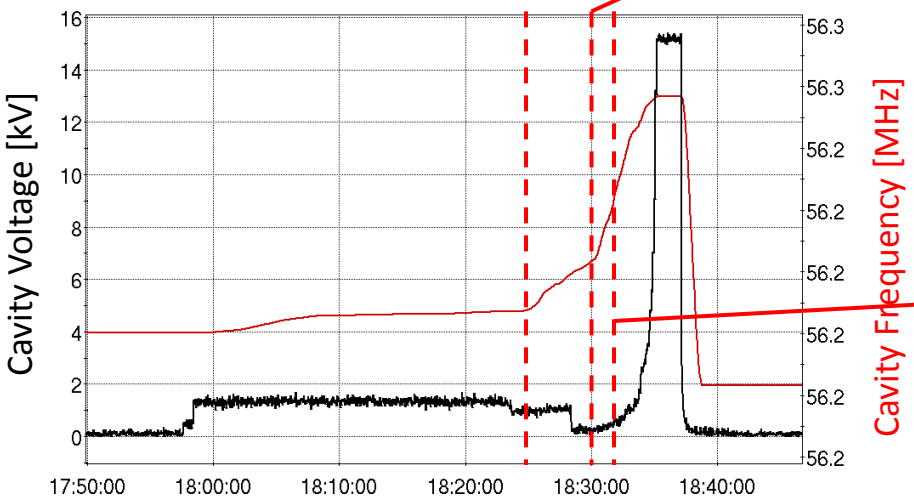
Beam experiments with no or limited HOM damping was planned for the cavity. Limited HOM damping can be provided by the fundamental power coupler, which is connected directly to an external load.

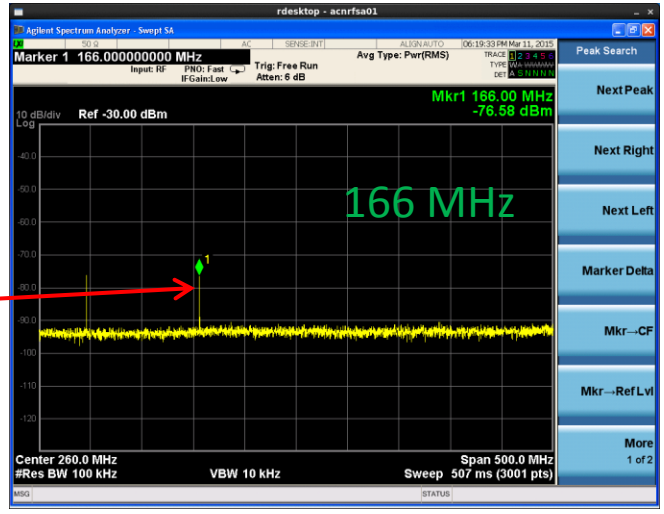
HOM Excited inside the Cavity during Tuning

11 bunches of proton in a 12-bunch pattern. Total intensity: 2.39e12



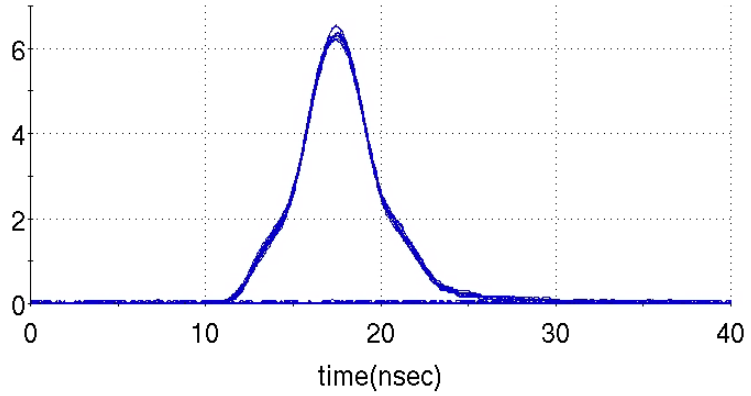




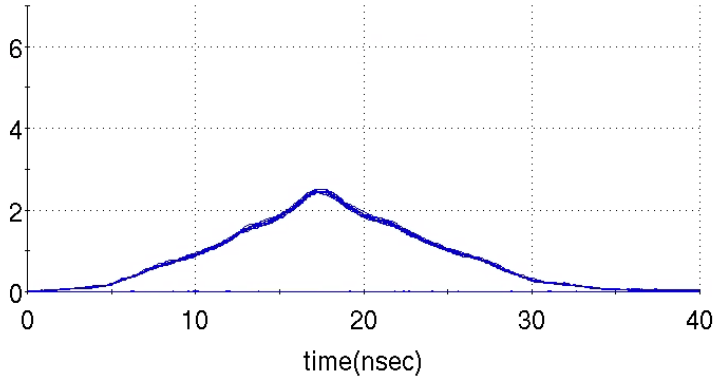


Beam Profile Comparison

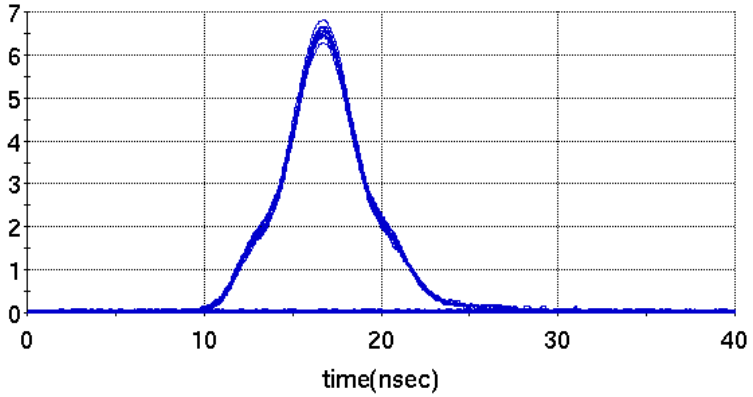
Before tuning in the cavity

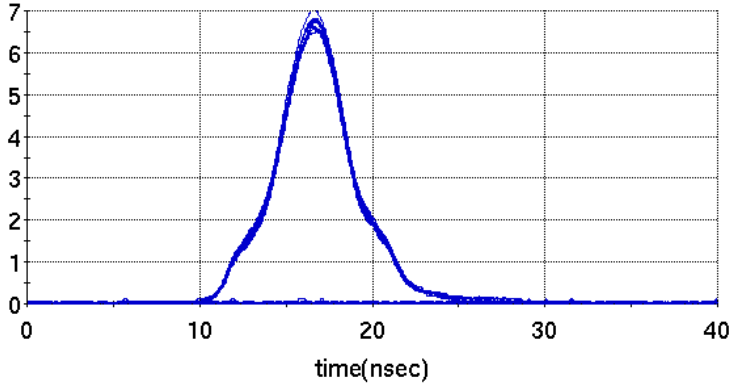


After tuning in the cavity



No HOM Damping



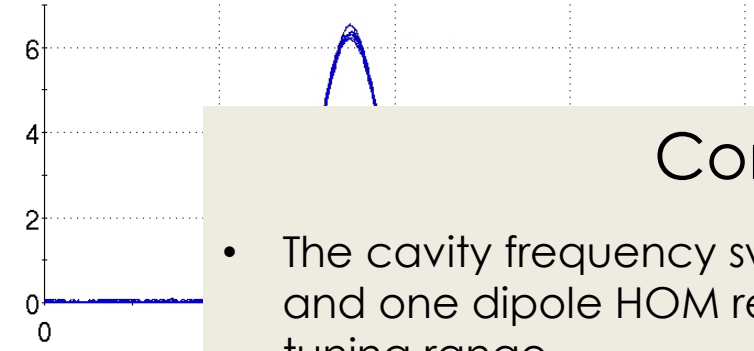


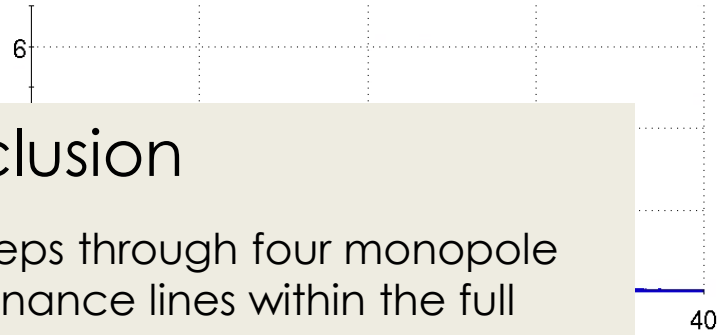
FPC Damping HOMs

Beam Profile Comparison

Before tuning in the cavity

After tuning in the cavity

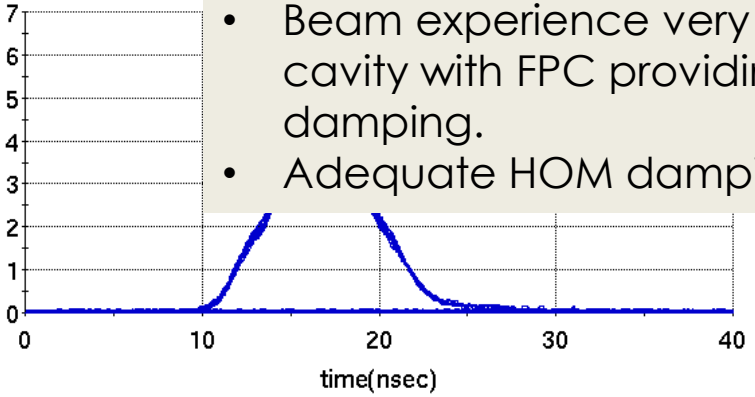


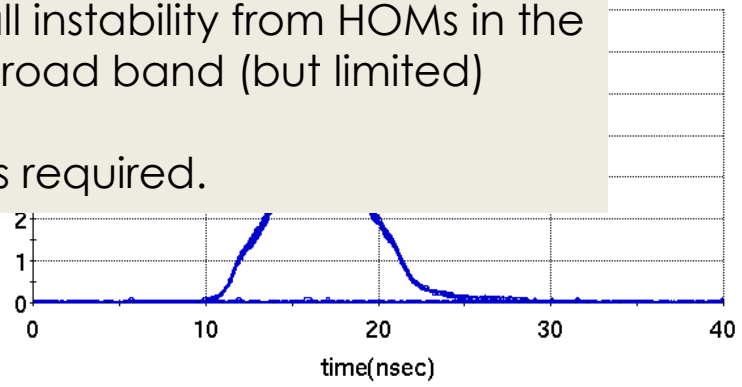


No HOM Damping

Conclusion

- The cavity frequency sweeps through four monopole and one dipole HOM resonance lines within the full tuning range.
- Beam is affected greatly by the excited HOMs in the cavity without any damping mechanism.
- Beam experience very small instability from HOMs in the cavity with FPC providing broad band (but limited) damping.
- Adequate HOM damping is required.





FPC Damping HOMs

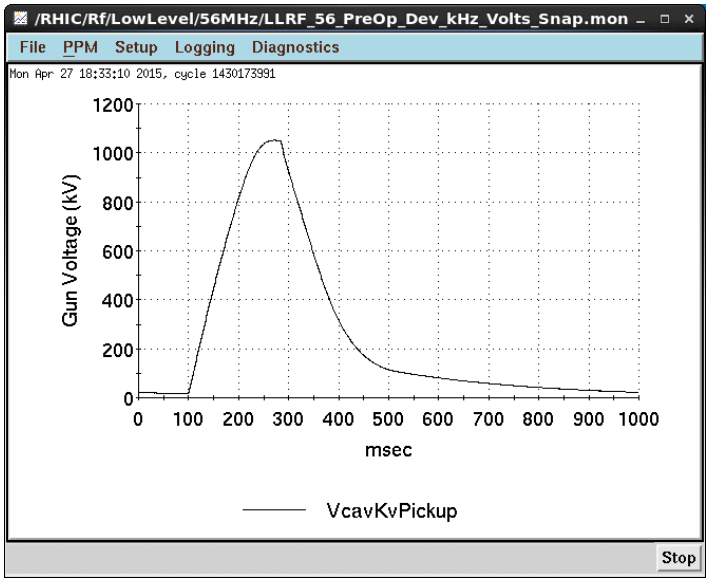
Periodic Conditioning:

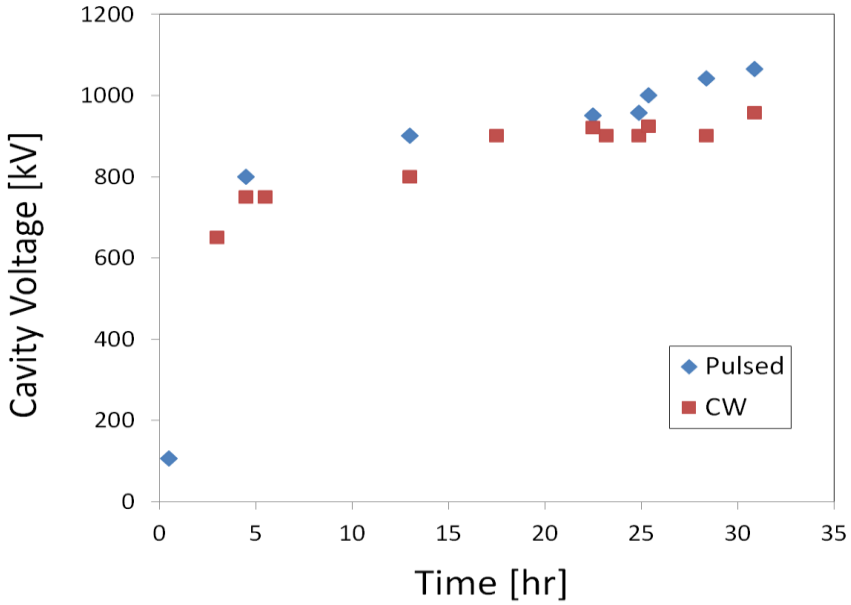
Total conditioning time: 31 hours
Total conditioning periods: 12
Date: 2/5 to 4/27
Condition environment:

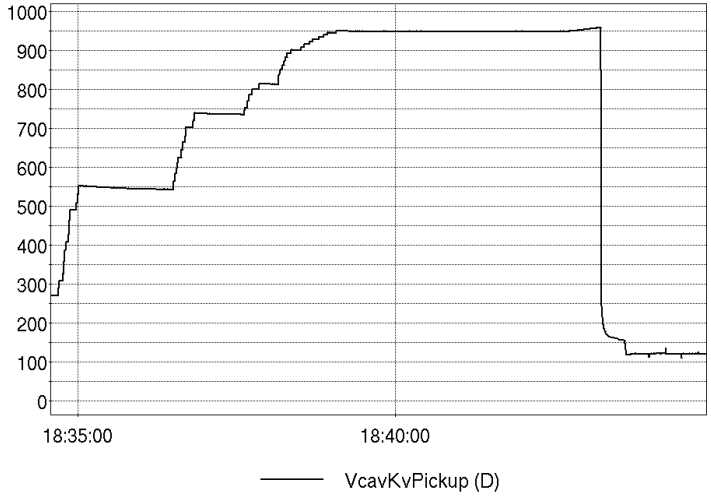
- No helium processing
- 1 kW amp with long cable (~3dB loss)

Achieved:

- *Pulsed: 1.18 MV*
- *CW: 1.05 MV*



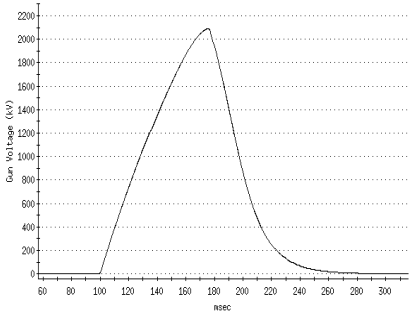




Continuous Conditioning

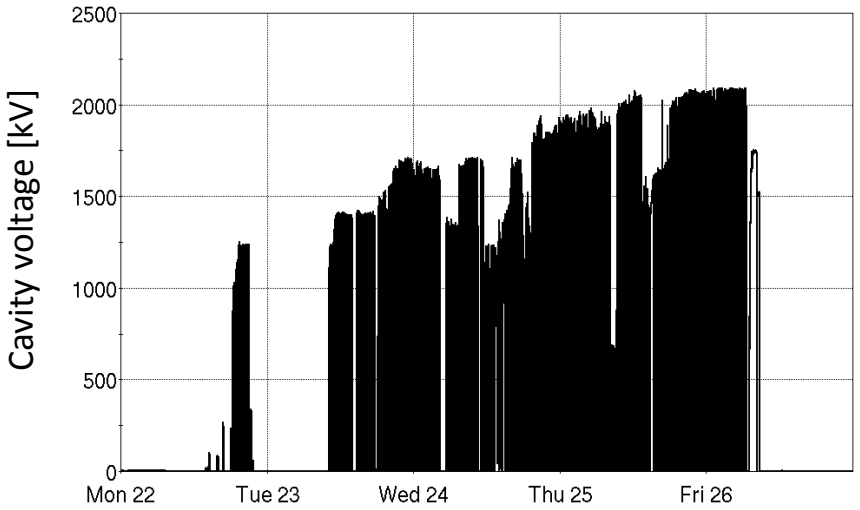
Total conditioning time: 74.5 hours
Total conditioning periods: 1
Date: 6/22 to 6/26
Condition environment:

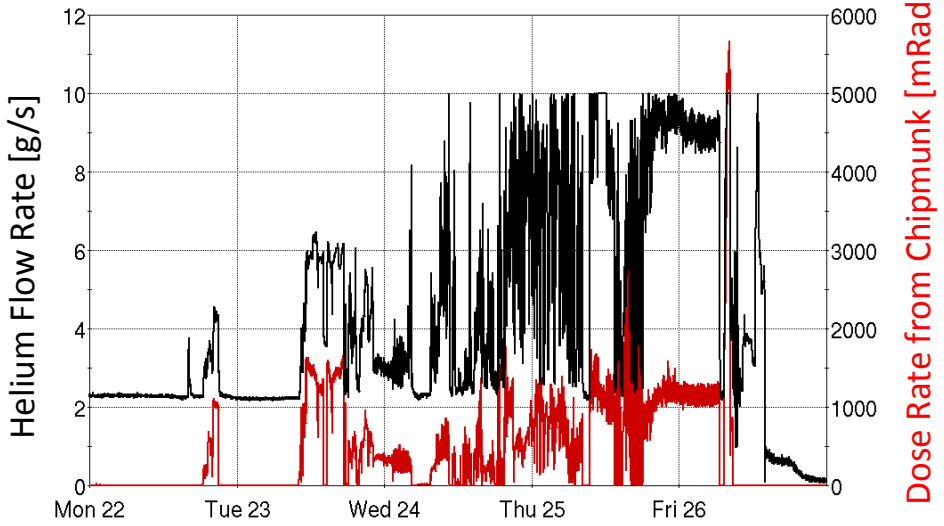
- **Helium gas (1-5e-5Torr)**
- **3.5 kW amp at cavity site**



Achieved:

- *Pulsed: 2.30 MV*
- *CW: 1.93 MV*
- Cavity can park at 1.65 MV in CW without substantial cryogenic consumption (<40W dynamic loss)
- Limited by cryogenic capacity at end





Conclusion and Future Plans

- RHIC luminosity has measurable increasement with the 56 MHz cavity operation, even at 17% of the design field.
- The cavity operation must include sufficient HOM damping to prevent beam instability.
- HOM coupler new design has eliminated the braze material that lead to quenching. New couplers will be installed for next RHIC run.
- With helium gas and high power amplifier, the cavity has been conditioned to 1.93 MV CW and 2.30 MV pulsed.
- Cavity will be cooled to 4.5 K before start of RHIC run to test the achievable RF field with new HOM couplers.
- The cavity will be operational for Au + Au and Au + p runs in 2016.

Acknowledgement

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Ed Daly, Bill Clemens, Naeem Huque, Haipeng Wang, and more…