Developing Quarter Wave SRF Cavities for Hadron Colliders

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On behalf of the SRF group @ BNL

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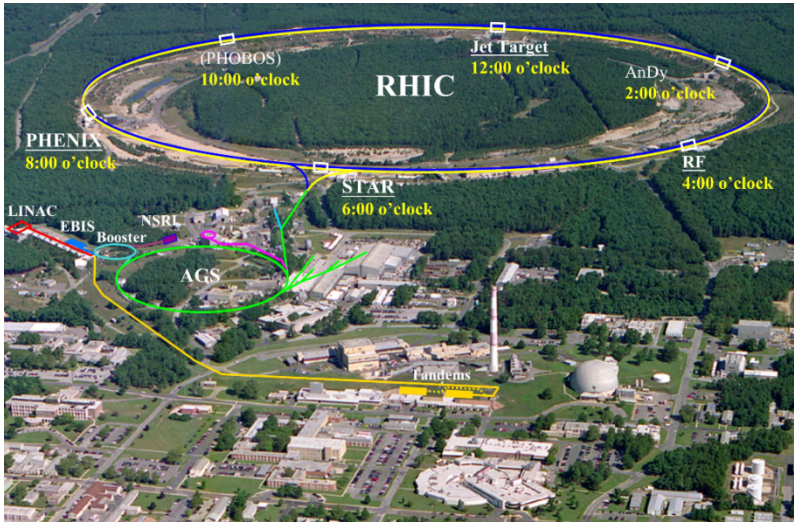
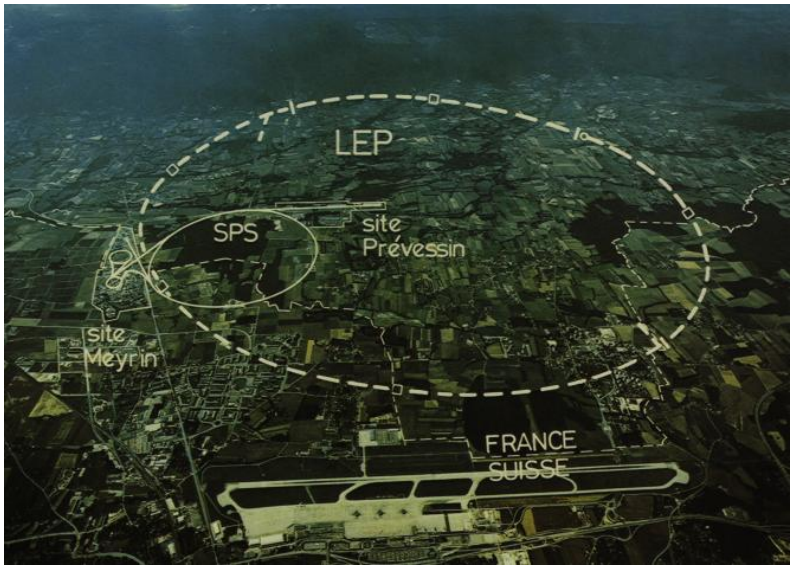
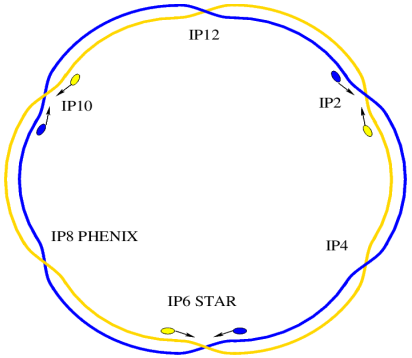
Outline

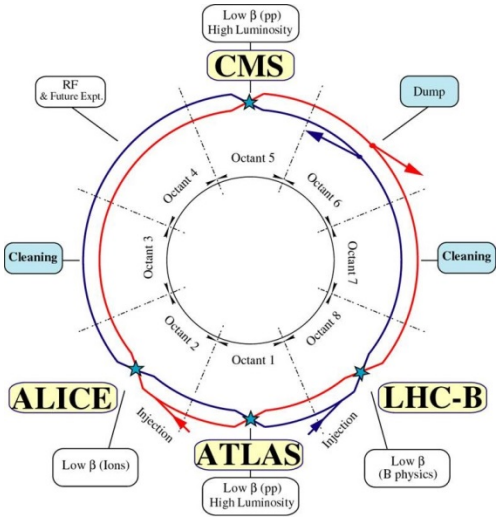
- Introduction
- Storage Cavity for RHIC (56 MHz)
- Crab Cavity for LHC (400 MHz)
- SRF for Hadron Collider Supporting Projects
  - Electron gun for CeC (112 MHz)
  - Electron gun and booster cavity for LEReC (84.5 MHz)
- Summary

Introduction









RHIC @ BNL

LHC @ CERN

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Storage Cavity for RHIC (56 MHz) THP031

- 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 5 times larger buckets.
- The cavity does not have a large tuning range to follow the large frequency change during particle acceleration, so it is turned on only after that for re-bucketing.
- A 1 kW amplifier is connected to the cavity to serve to: i) achieve required amplitude and phase stability; ii) provide conditioning capability; iii) make up power for intrinsic losses.
- At the energy of experiment, the cavity will be operating at 2 MV.
- A piezo tuner will be employed to compensate any fast frequency changes.
- This is cavity is fabricated by Niowave Inc. BCP and HPR were done at AES, Inc.

Cavity parameters

Parameter		Unit
Frequency	56.29	MHz
R/Q (accelerator notation)	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

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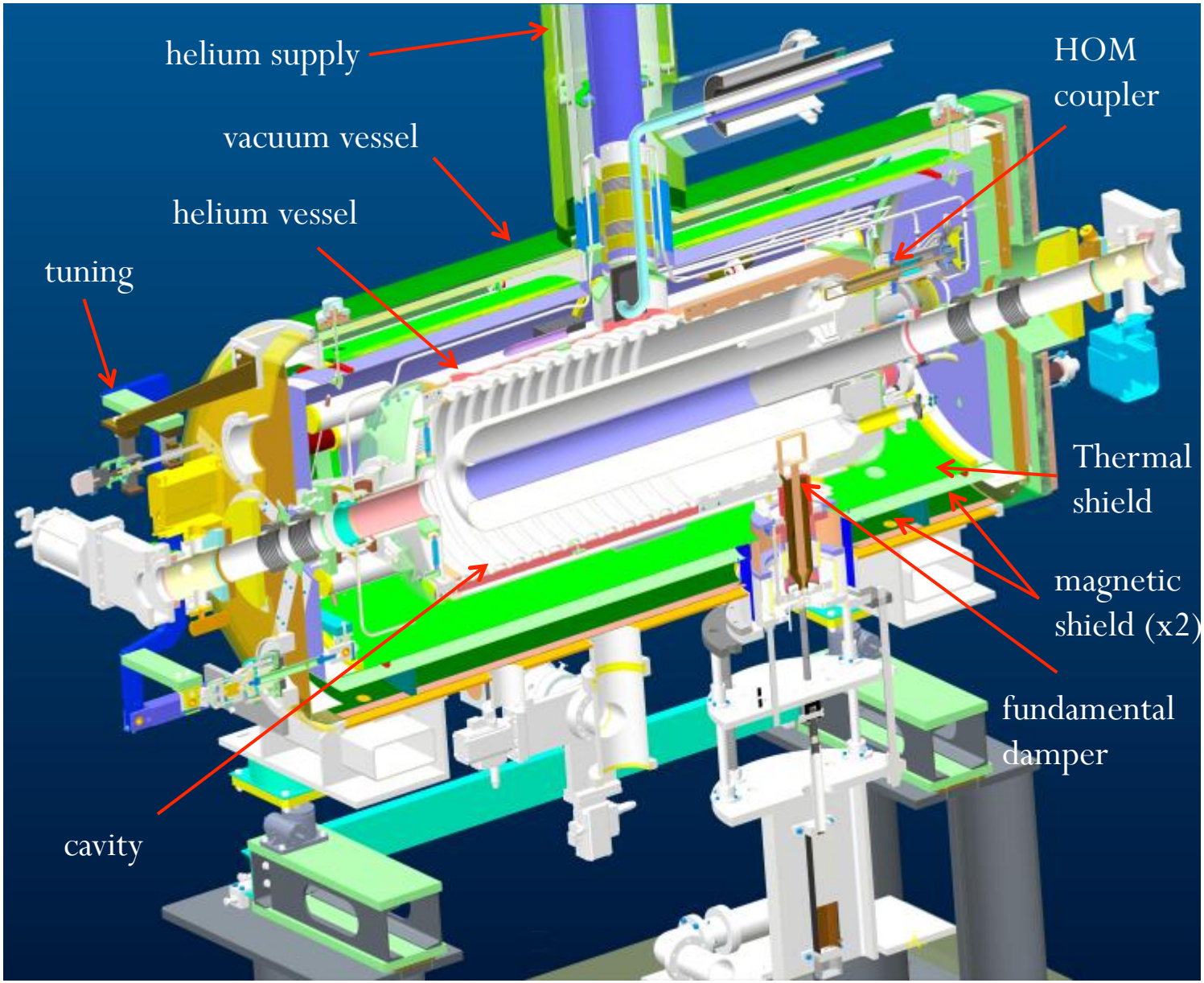

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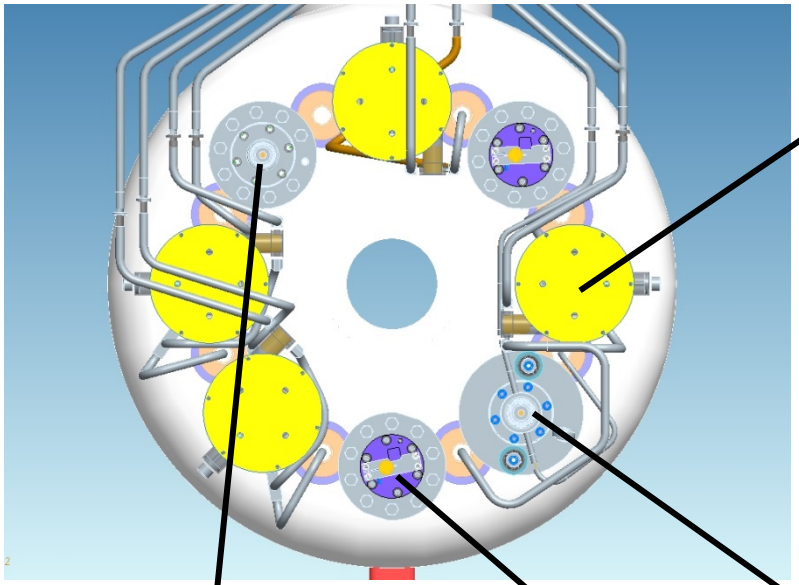
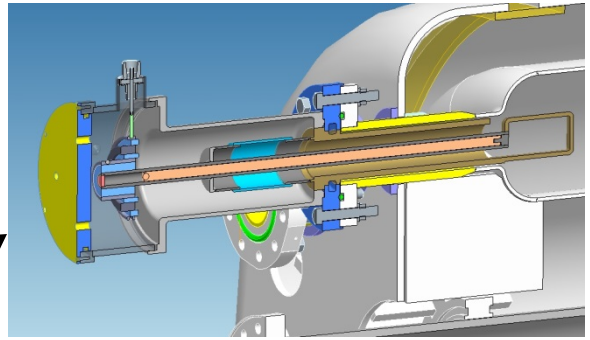
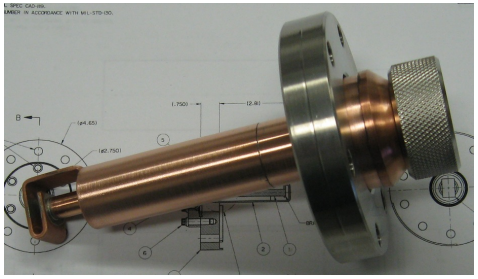
Components



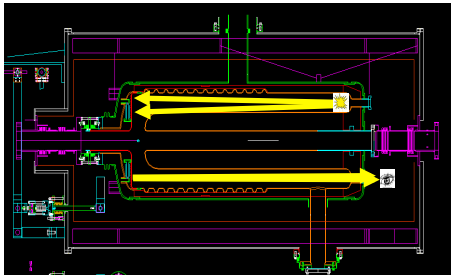


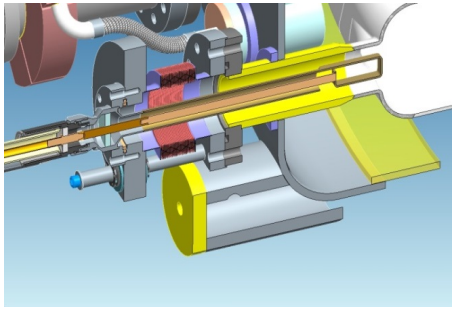
HOM couplers with high pass filter

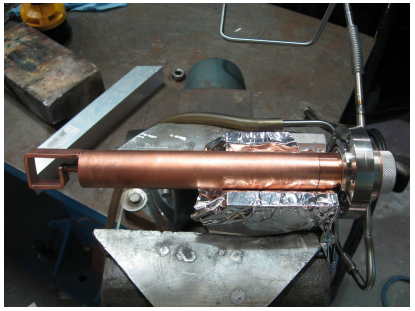
Pick-up



IR detectors







FPC with motion system

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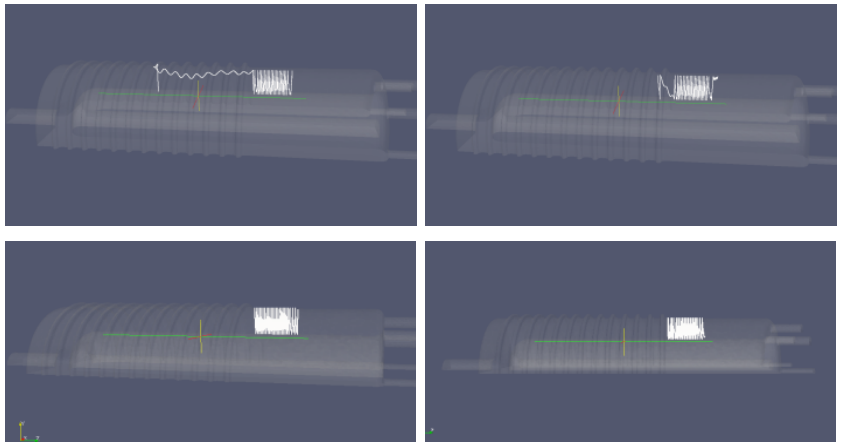
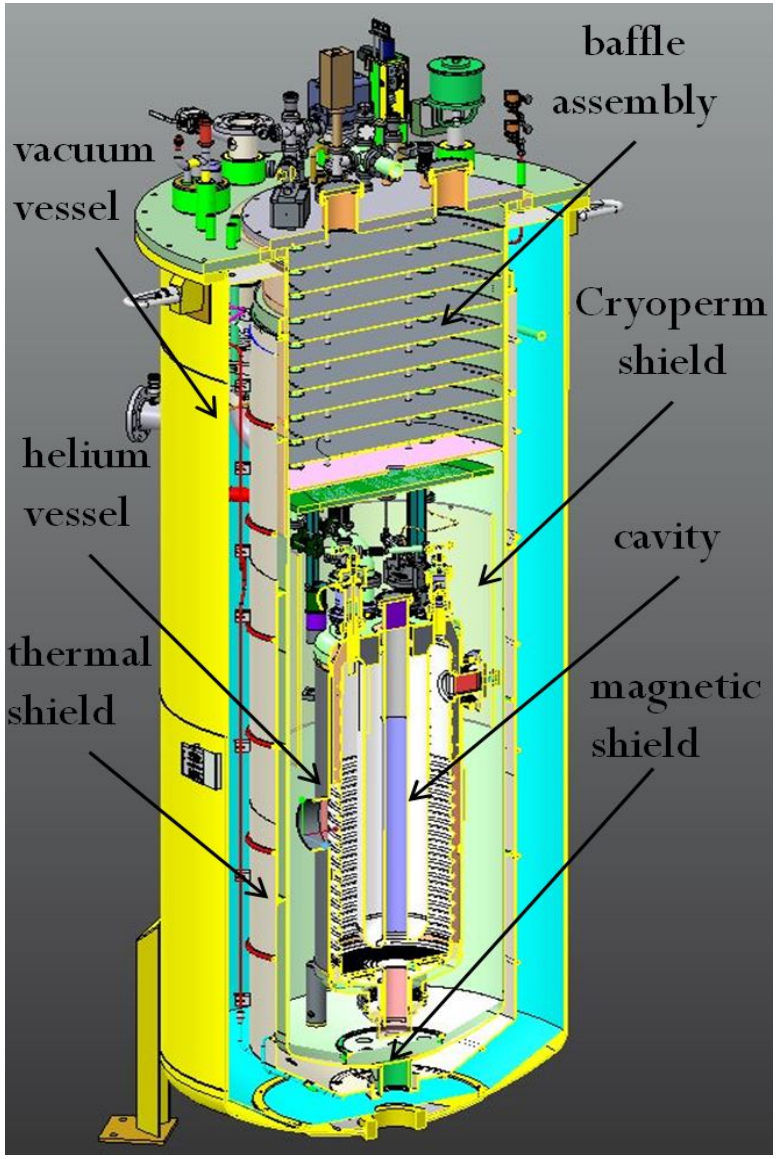
Cavity testing

- We encountered a multipacting (MP) zone at a gap voltage around 1 kV, corresponding to a 19 kV/m peak surface electric field. At such low field in the cavity, the conditioning of the MP is very slow as it is very difficult to efficiently couple RF power to the MP-loaded cavity.
- 3D simulations of the MP with ACE3P shows electrons will bounce between the parallel surfaces, and move slowly towards the high magnetic field region.
- With low temperature baking at 100C in situ of the dewar, we were able to reach 31 kV gap voltage at CW.





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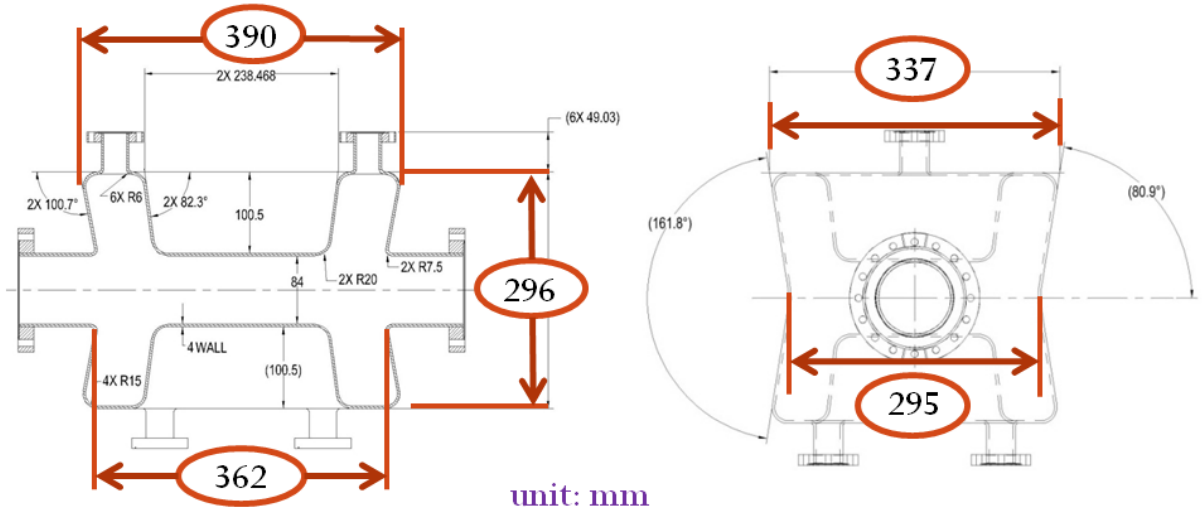
Crab cavity for LHC (400MHz)

THP041, 43, 44, FRI0A01

- A new concept of using a double quarter wave superconducting cavity at 400 MHz was proposed for the Large Hadron Collider (LHC) HiLumi upgrade.
- The double quarter wave structure is very compact in all dimensions
- Each cavity will provide 3.3 MV deflecting voltage for LHC beam



unit: mm

For Proof of Principle cavity

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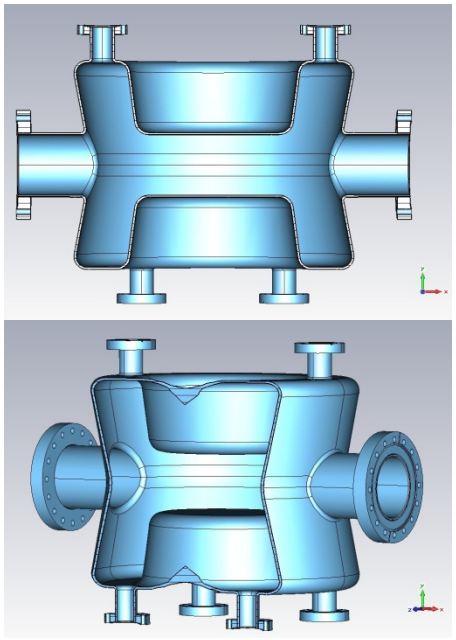
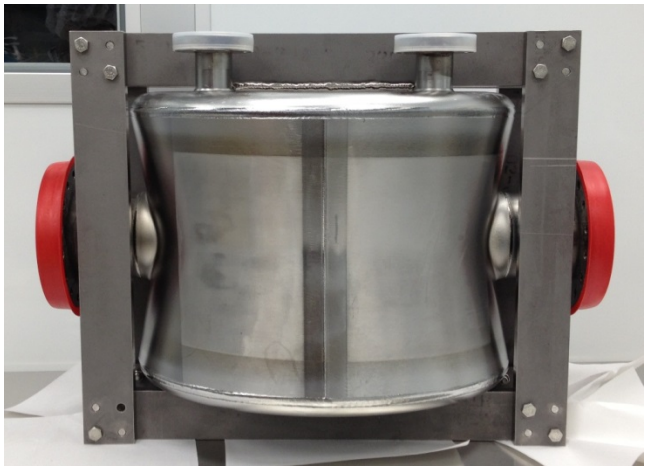
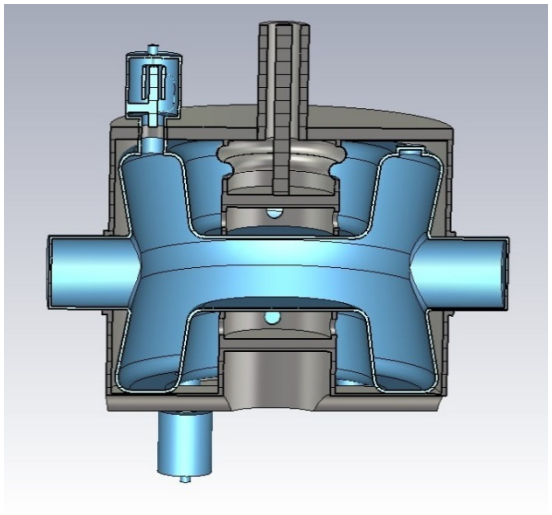
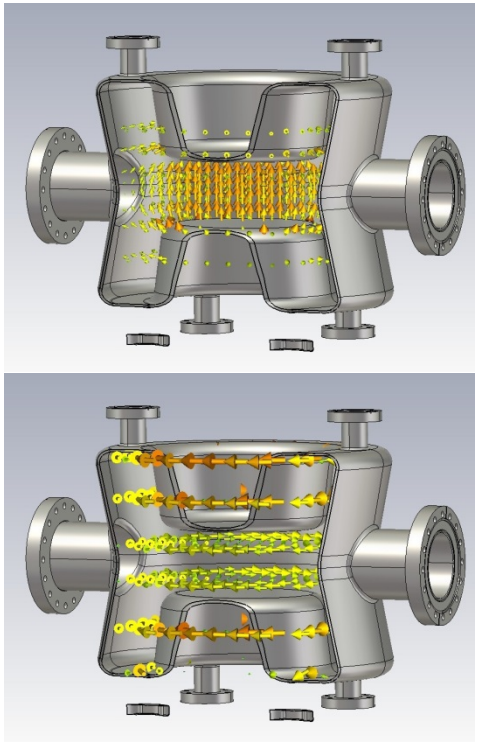
Proof of Principle cavity









Designed for testing the novel idea of a quarter wave resonator for deflecting cavity.

Electric field (top) and magnetic field (bottom) of fundamental mode.

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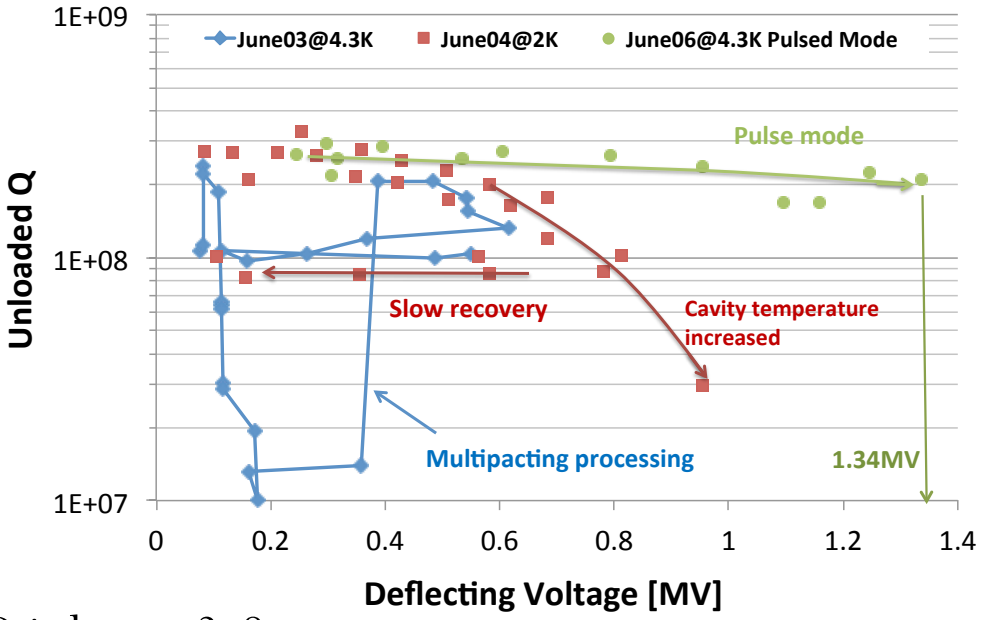
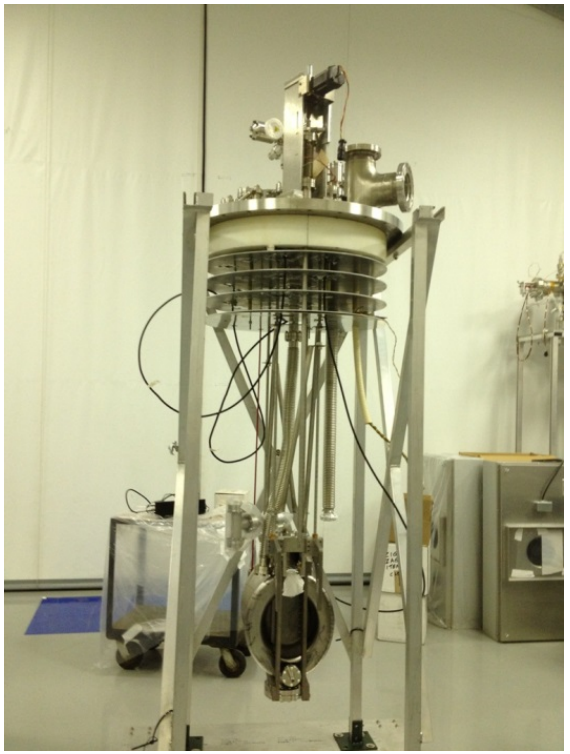
Testing results





- Q is low, ~3e8
- Q did not change after slow cool down. No hydrogen Q disease.
- Measured 0.96 MV in CW before thermal quench. Measured 1.34 MV in pulsed mode
- Chemical residual marks were found at high magnetic field region.
- Simulations show non-negligible thermal losses at couplers and flanges
- Another round of BCP + HPR cleaning @ Argonne
- Prepared for second round of test

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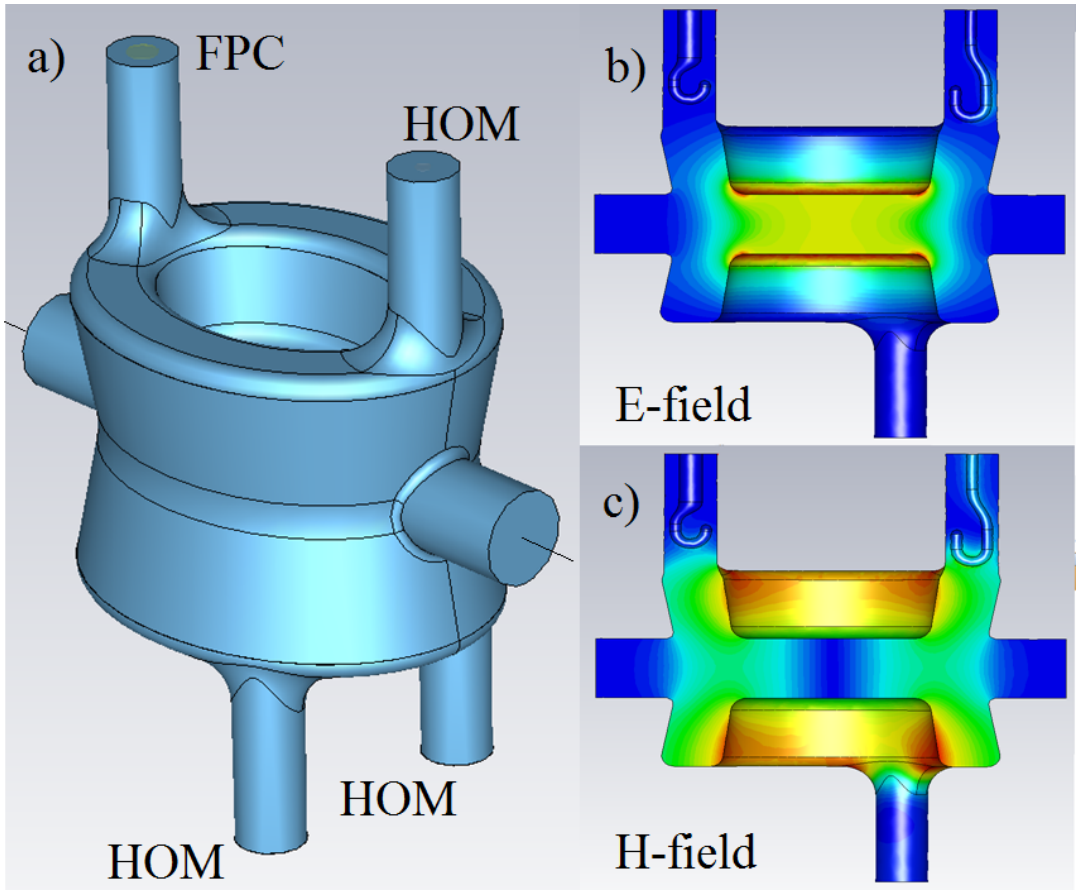
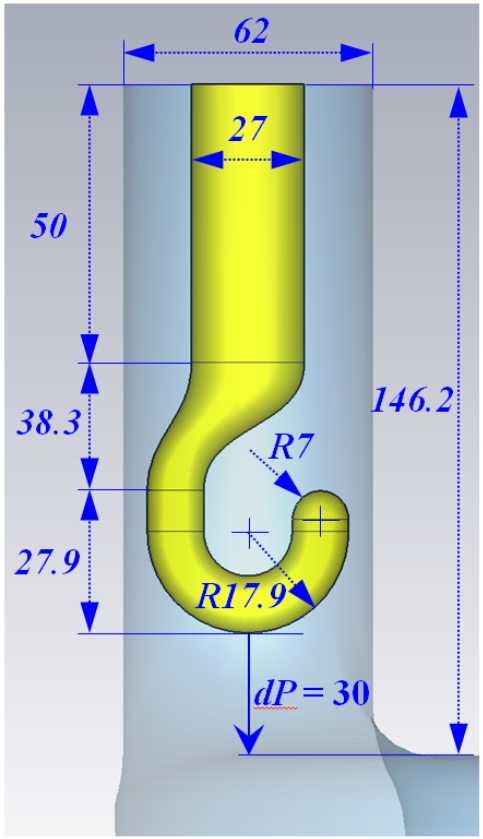
Final design for SPS test





FPC hook. All dimensions are in mm.

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Cavity parameters

Geometrical parameter *(at 300K)*		Unit
Cavity length L	344	mm
Cavity width W	278	mm
Cavity height H (w/o ports)	278	mm
Crab mode frequency f_0	400	MHz
Nearest mode frequency f_1	581	MHz
Deflecting voltage V_t (1)	3.3	MV
Accelerating voltage V_{acc} (2)	0.015	MV
Center offset	0.04	mm
Peak surface electric field E_{pk} (2)	37	MV/m
Peak surface magnetic field B_{pk} (2)	68	mT
Stored energy U (2)	10	J
R_t/Q	426	

(1) Nominal deflecting voltage per cavity. (2) For a nominal deflecting voltage Vt of 3.3 MV.

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Electron provider for RHIC supporting projects

- CeC – Coherent Electron Cooling

  Coherent Electron Cooling is cooling ion beams through amplification of charge distributions in electron beams. This method promises extremely fast cooling virtually independent of energy of the ions.

- LEReC – Low Energy RHIC Electron Cooling

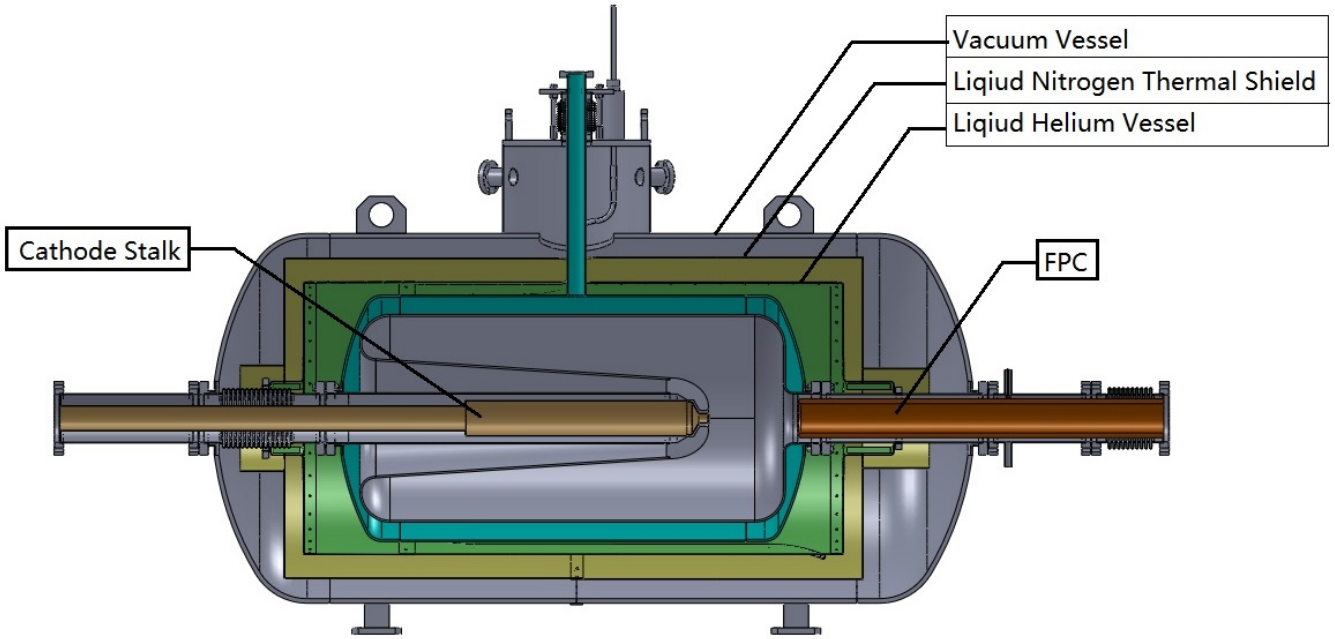
  Electron cooling of ion beams in RHIC at energies below 10 GeV/nucleon. The electron cooling will utilize bunched electron beams form an SRF linac at energies from 0.9 to 5 MeV.

Electron gun for CeC (112 MHz)

MOIOB03, MOPO16

- QWR SRF electron gun tested at the frequency of 112 MHz for the Coherent Electron Cooling (CeC) of RHIC.
- This long wave length allows the generation of long electron bunches, thus minimizing space charge effects and enabling a high bunch charge.

The 112 MHz QWR gun was designed, fabricated and cold-tested at 4.5 K in collaboration between BNL and Niowave.



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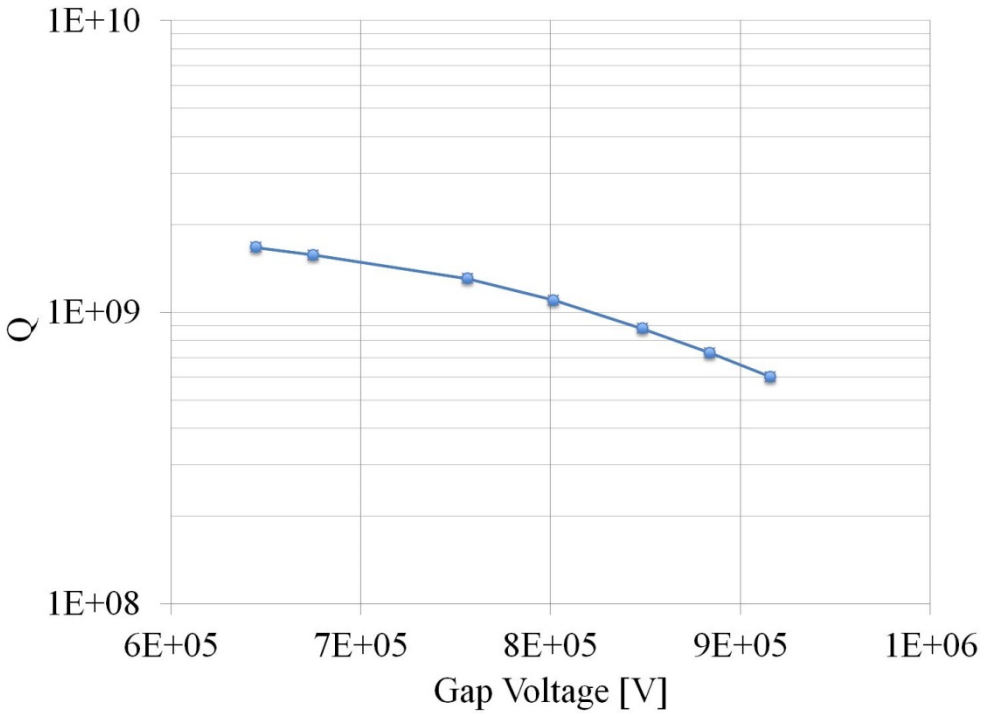
Cavity parameters

Parameter		Unit
Frequency	112	MHz
R/Q (accelerator notation)	126	Ohm
Q_0	3.5e9	
Length	670	mm
Aperture	100	mm
Gap	150	mm
Max diameter	420	mm
E_{pk}/V_{acc}	19.1	m^{-1}
E_{pk}/E_{cath}	2.63	
B_{pk}/V_{acc}	36.4	mT/MV

Testing results

- The cavity Q_0 measured as high as 1.7×10^9 at the gap voltage of 0.65 MV.
- The test was seized at 0.92 MV due to the limit in radiation shielding.
- No cavity quench was seen at high field.

The designed value of the gap voltage is 1.5 to 2.5 MV, and cavity will be tested at BNL with better radiation shielding.



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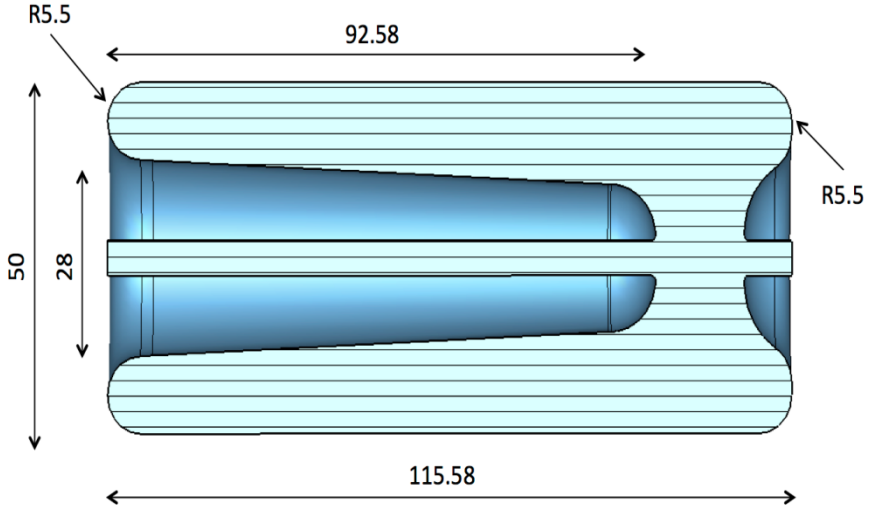
Electron gun and booster cavity for LEReC (84.5 MHz)

MOP17

- The frequency is at 84.5 MHz for both cavities
- The cavities are the accelerating units for electrons used to cool the injection ions of RHIC to a lower energy.
- The SRF structures will be housed in a single cryomodule with a focusing superconducting solenoid placed between them.



all dimensions are in cm

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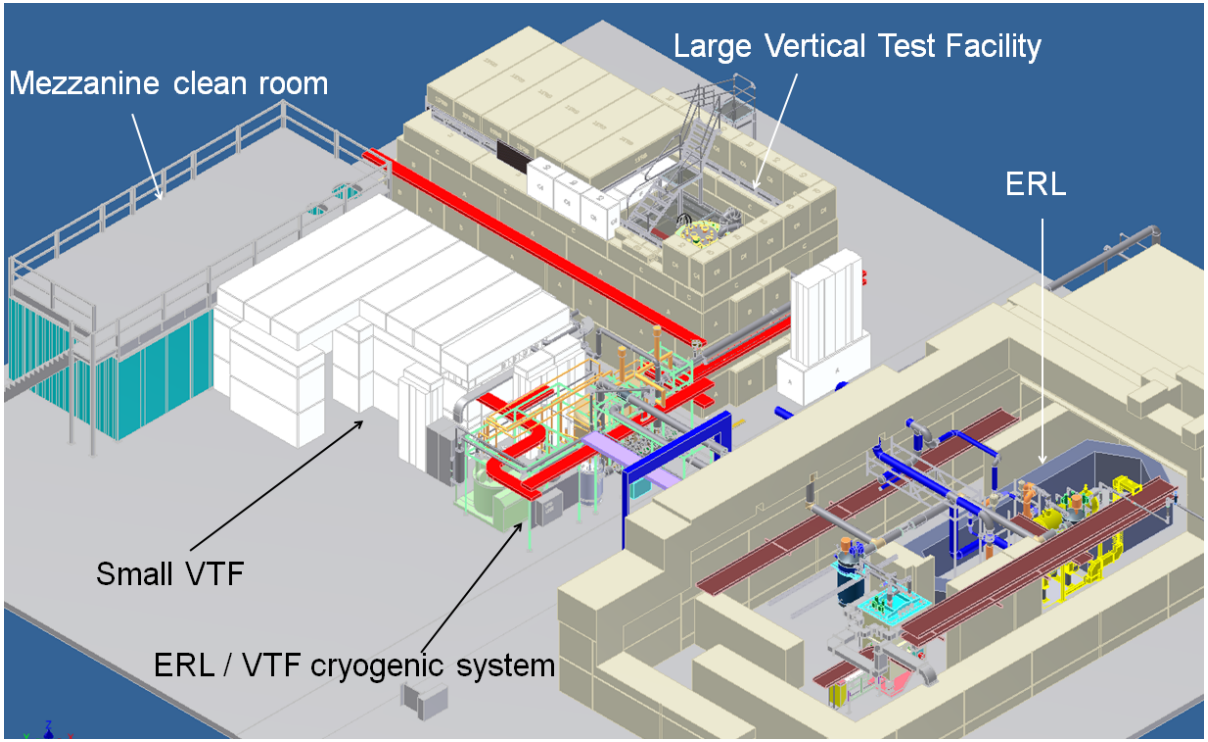
Cavity parameters

SRF parameters			
RHIC RF frequency	4.55 MHz	4.67 MHz	28.03 MHz
SRF frequency	84.48 MHz	84.47 MHz	84.47 MHz
Gun voltage	1.65 MV	2.58 MV	2.58 MV
E_{pk}	25.7 MV/m	40.3 MV/m	40.3 MV/m
B_{pk}	52.5 mT	82.2 mT	82.2 mT
R/Q	122.7 Ohm	122.7 Ohm	122.7 Ohm
Geometry factor	34.7 Ohm	34.7 Ohm	34.7 Ohm
Cavity Q factor at 4.5 K	2.7e9	2.7e9	2.7e9
Gun RF power	30.7 kW	84.9 kW	92.5 kW
Harmonic cavity frequency	506.9 MHz	506.9 MHz	506.9 MHz
Harmonic cavity voltage	63.4 kV	198 kV	198 kV

Summary

- The QWRs have proved their high standard performance as accelerating cavities in various low energy scenarios .
- The big advantage in compactness also gained this type of cavities an essential role in hadron colliders.
- The QWRs make feasible of
  - low frequency and better acceptance RF buckets for long bunch beams
  - generating electrons with high bunch charge
  - providing high gradient deflection

SRF @ BNL



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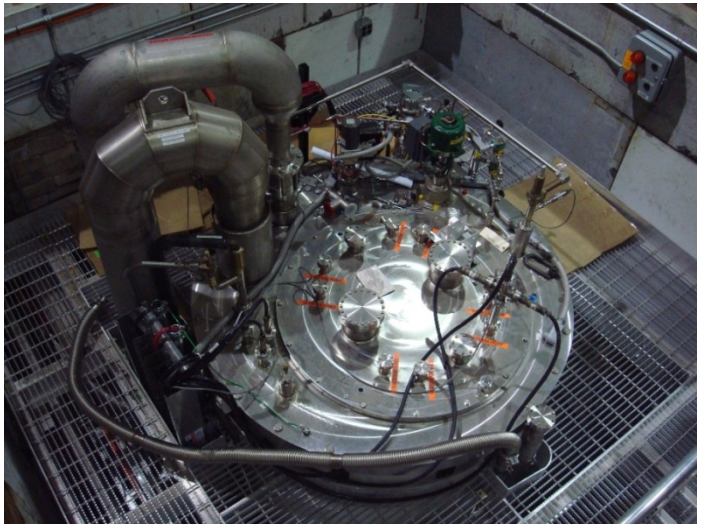
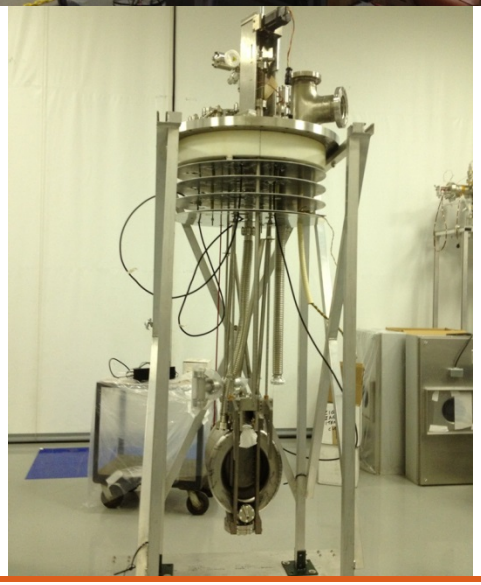
Vertical Test Facility



Small Vertical Test Facility



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