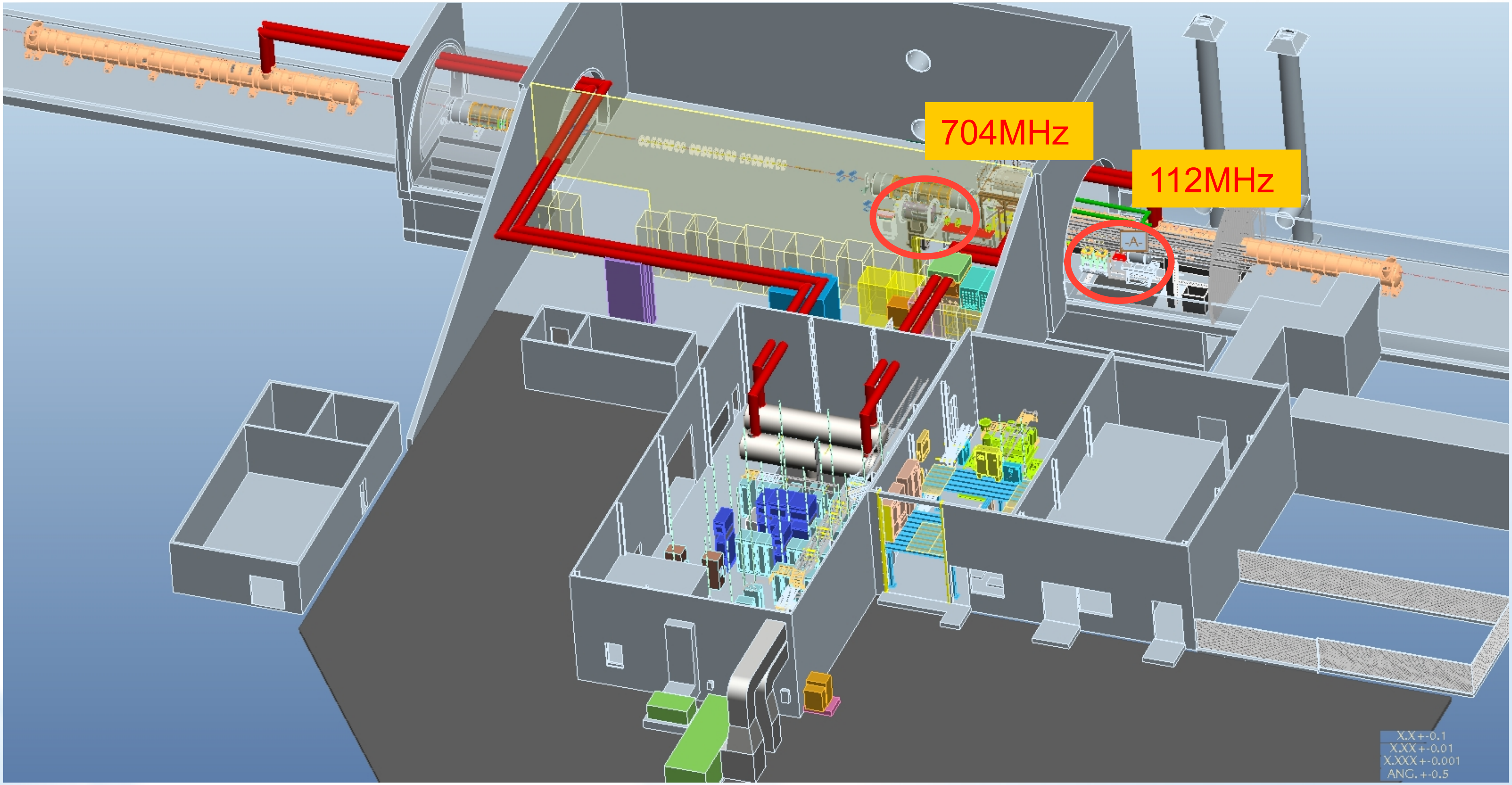
SRF systems for CeC PoP Experiment in RHIC

BROOKHAVEN NATIONAL LABORATORY

a passion for discovery

U.S. DEPARTMENT OF ENERGY | Office of Science

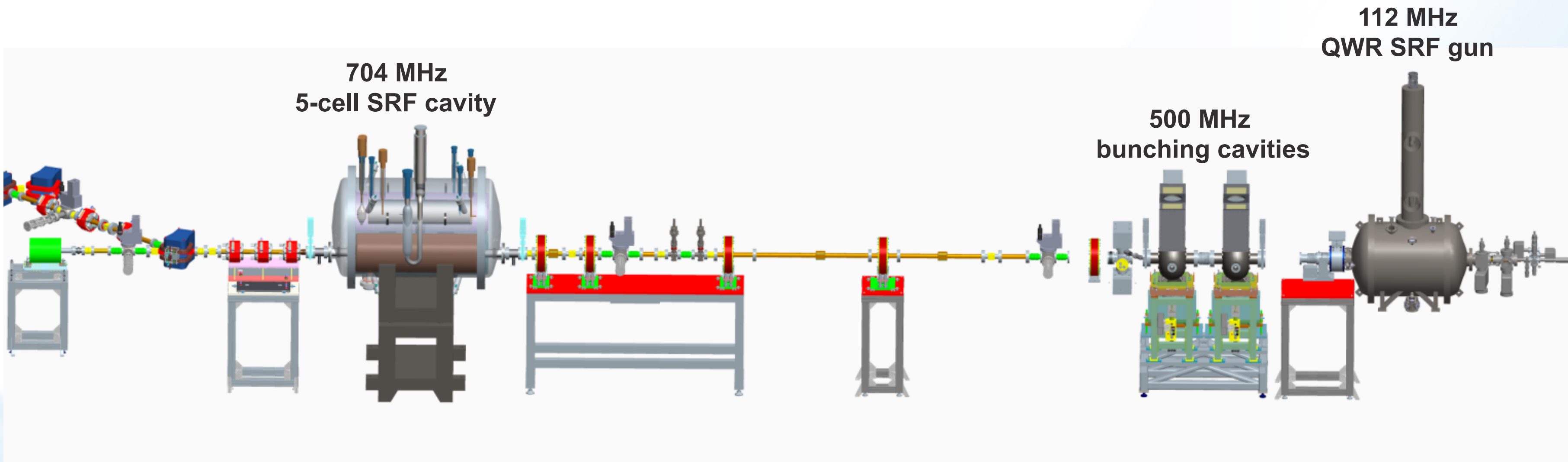
Locations of the SRF cavities at IP 2



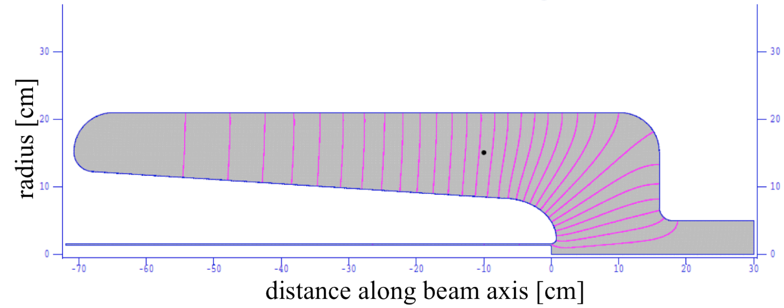
Overview

There are two SRF systems in CeC PoP linac set up:

- A Quarter-Wave Resonator (QWR) type SRF gun, operating at 112 MHz. This gun will generate 2-MeV, high charge (several nC), low repetition rate (78 kHz) electron beam.
- A 704 MHz 5-cell SRF cavity (BNL3) to boost the energy of electrons to 22 MeV.



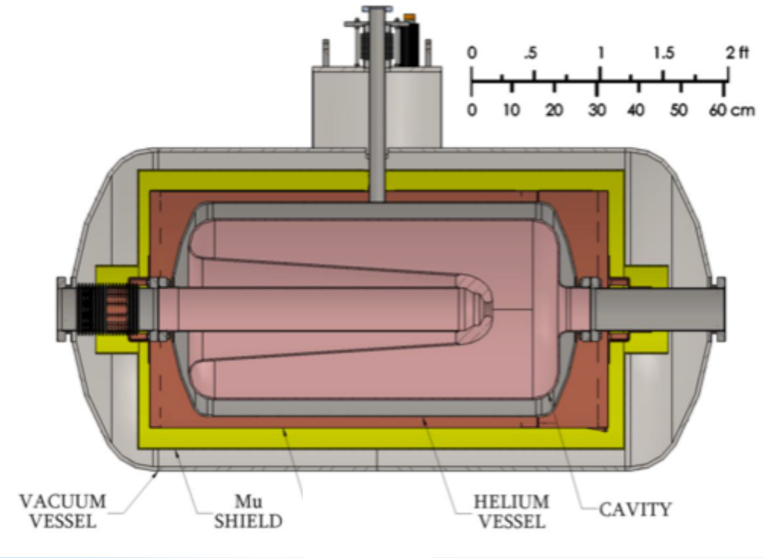
Quarter Wave Resonator SRF gun



- Superconducting 112 MHz QWR was developed originally for electron gun experiments by collaborative efforts of BNL and Niowave, Inc.
- Design, fabrication, chemical etching, cleaning, assembly and the first cold test were done at Niowave as part of DOE SBIR project.

Why 112 MHz?

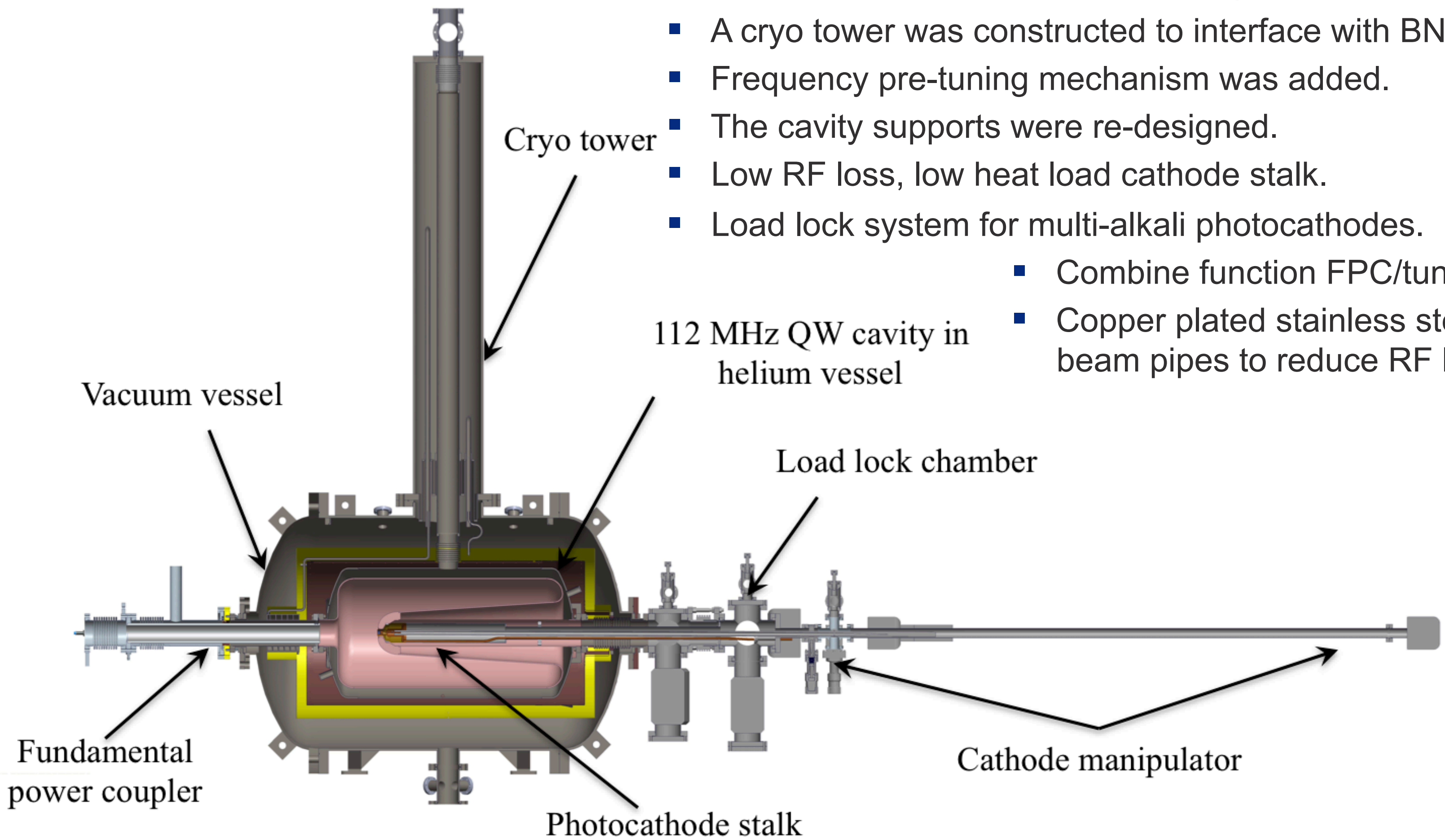
- A harmonic of RHIC's 28 MHz RF ➔ for use in electron cooling experiments.
- Low frequency: long bunches ➔ reduced space charge effect.
- Short accelerating gap: accelerating field is almost constant.
- Superconducting cavity: suitable for CW, high average current beams.
- Cathode does not have to be mechanically connected to SRF structure: flexibility in cathode types.



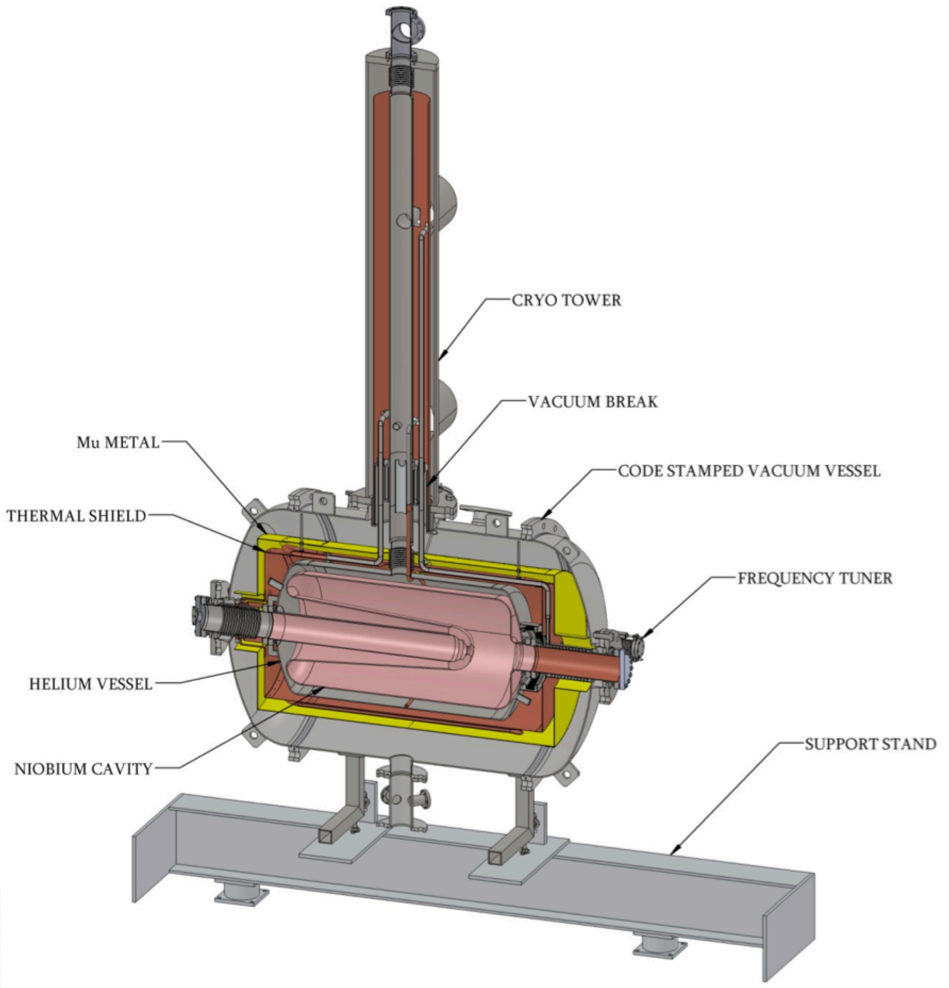
SRF gun upgrades/modifications

For installation in CeC PoP, the gun has to satisfy BNL safety requirements (ASME pressure vessel code). Some other modifications were necessary as well:

- A low carbon steel vacuum vessel was replaced with a stainless steel ASME section VIII code stamped vessel.
- A cryo tower was constructed to interface with BNL cryogenics.
- Frequency pre-tuning mechanism was added.
- The cavity supports were re-designed.
- Low RF loss, low heat load cathode stalk.
- Load lock system for multi-alkali photocathodes.
- Combine function FPC/tuner assembly.
- Copper plated stainless steel bellows and beam pipes to reduce RF losses.

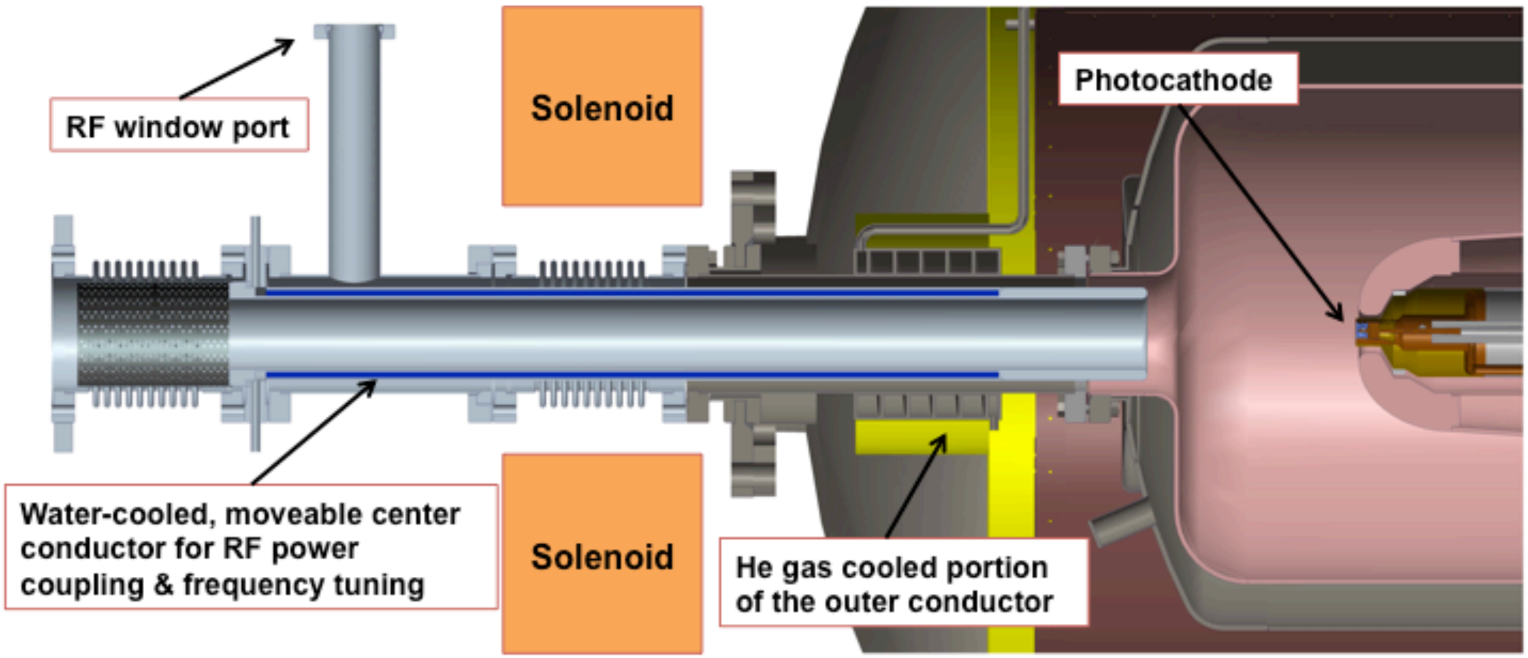


QWR SRF gun parameters



Parameter	QWR SRF gun
Aperture (beam tube) [cm]	10
Cavity diameter [cm]	42
Cavity length [cm]	110
V_{acc} [MV]	2.0 max
Peak electric field [MV/m]	38.2
Peak magnetic field [mT]	72.8
Field at the cathode [MV/m]	14.5
R/Q [Ohm]	127
Geometry factor [Ohm]	38.2
Q_0	10^9
RF power loss at 4.5 K [W]	12.3
Bunch charge [nC]	1 to 5
Bunch rep. rate [kHz]	78
Beam power [W]	780 max
Q_{ext}	10^7
Peak detuning due to microphonics [Hz]	6
Available RF power [kW]	2
Operating temperature [K]	4.5

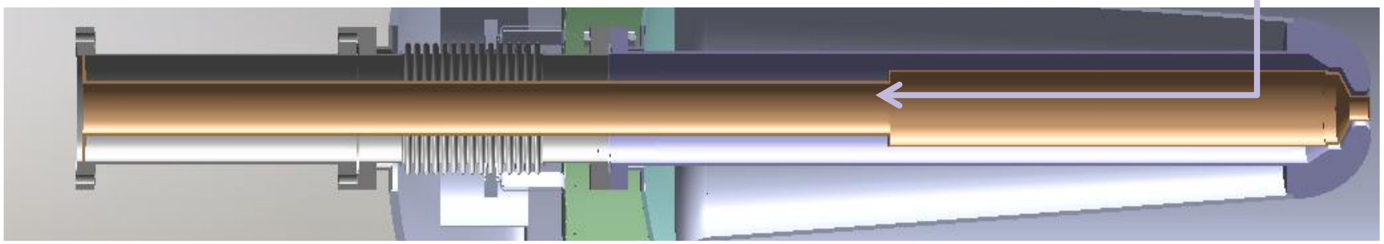
Fundamental Power Coupler / frequency tuner

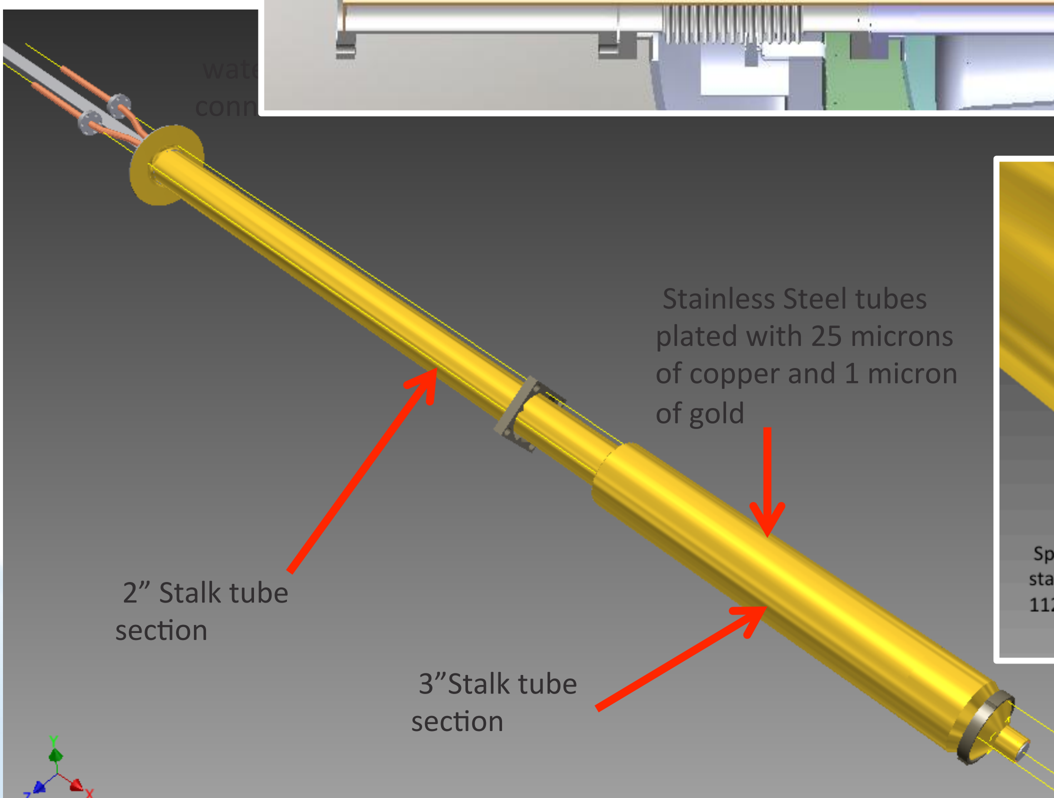


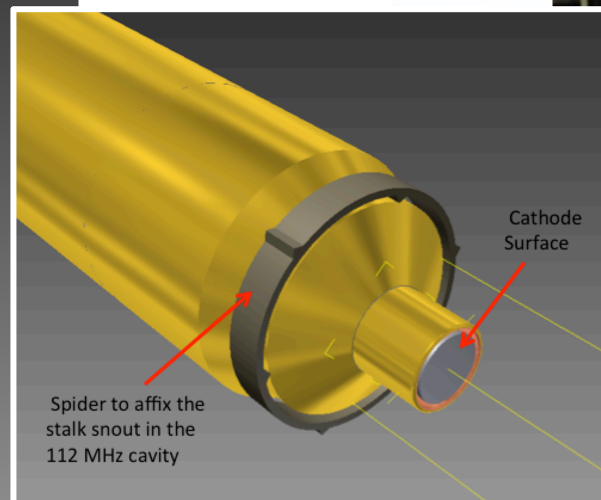
- Fundamental RF power coupling and fine frequency tuning is accomplished via a coaxial beam pipe at the beam exit port.
- With the travel of ±2 cm, the tuning range will be ~4 kHz.
- The cooling of this assembly is quite challenging as in the extreme position (about 1 cm from the cavity gap) the dissipated power will exceed 1 kW.

Cathode stalk design

- The cathode stalk is a hollow center conductor of the coaxial line formed by the stalk and the cavity.
- The stalk is shorted at one end and is approximately half wavelength long. It will be permanently installed in the gun.
- A step at λ/4 from the short creates a quarter-wave impedance transformer and reduces RF losses in the stalk from ~65 W to ~25 W.
- The gold plating is aimed to reduce radiation heat load from the RT stalk to the cold (4.5 K) niobium.
- A small cathode puck is inserted inside the stalk and can be replaced when necessary with a new one.

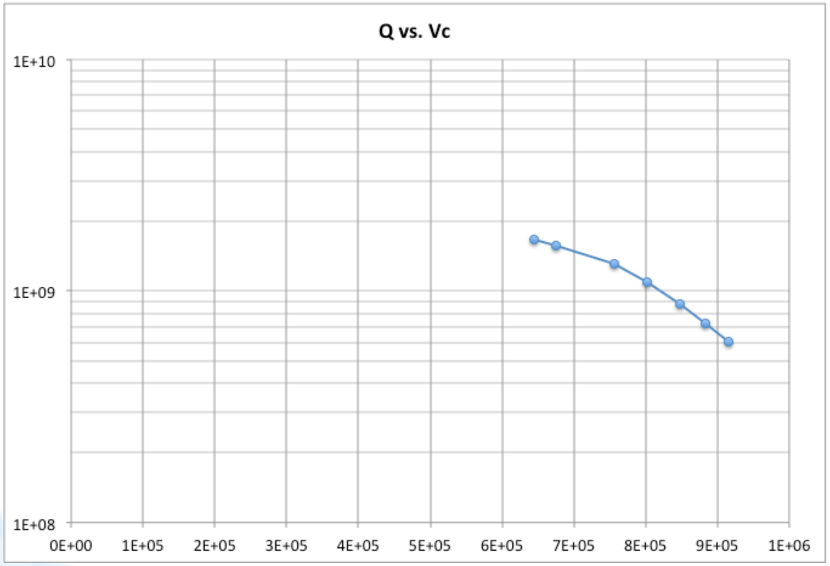


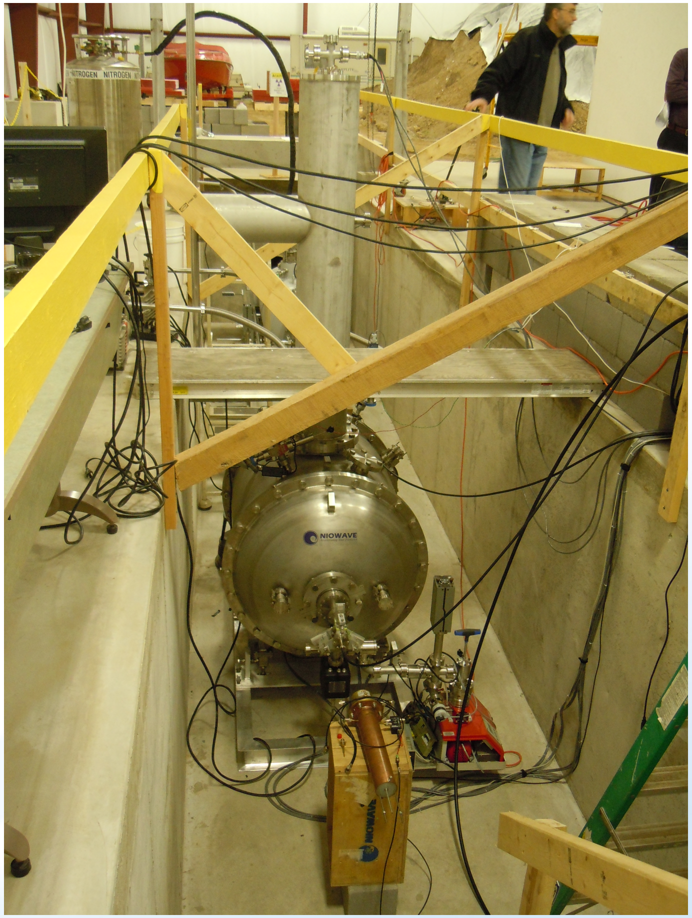




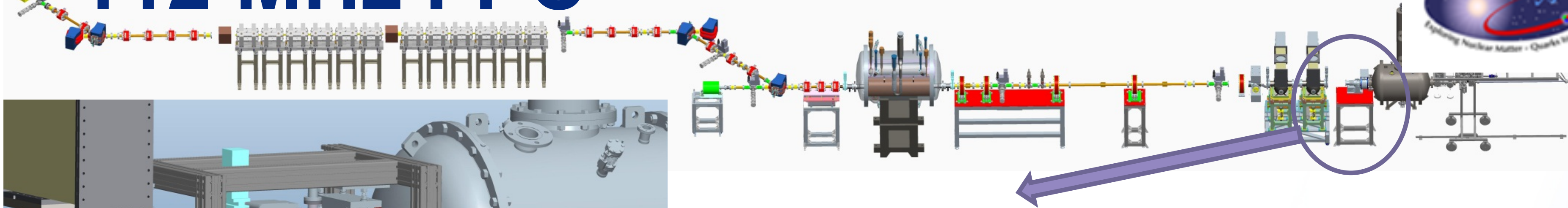
SRF gun upgrade status & test plans

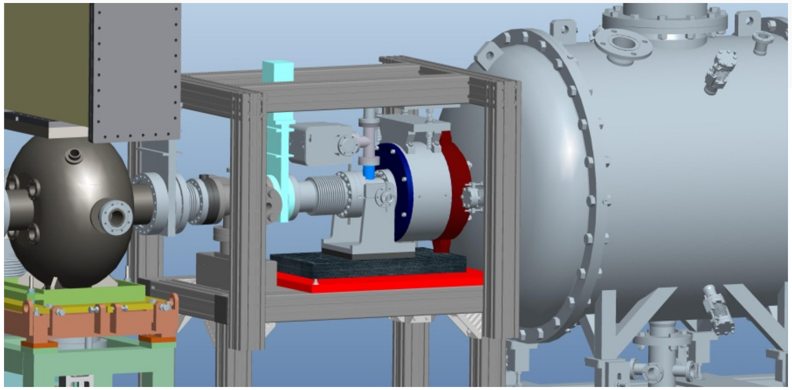
- The cathode stalk and load lock system are designed and fabricated.
- The new FPC/fine tuner assembly is designed at BNL.
- The modification of the SRF gun cryostat and fabrication of the cryo tower is now complete.
- The gun was successfully tested at Niowave (w/o the cathode stalk and FPC).
- The gun voltage was limited to 0.92 MV CW due to insufficient radiation shielding
- A beam test at BNL is being planned.



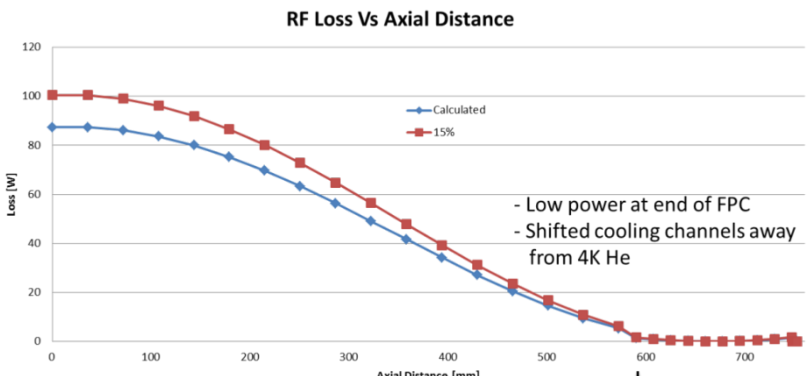


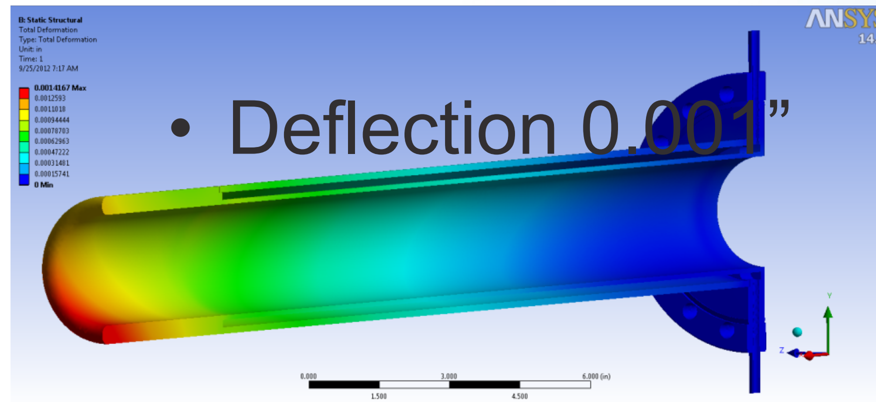
112 MHz FPC



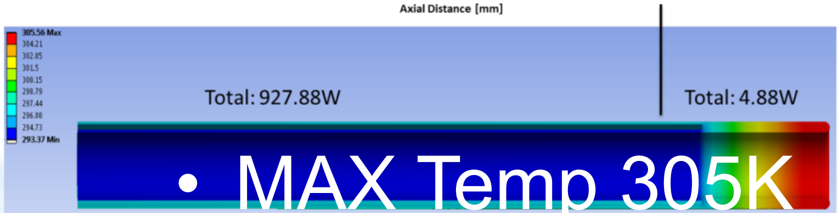


- Stress ~ 2600psi



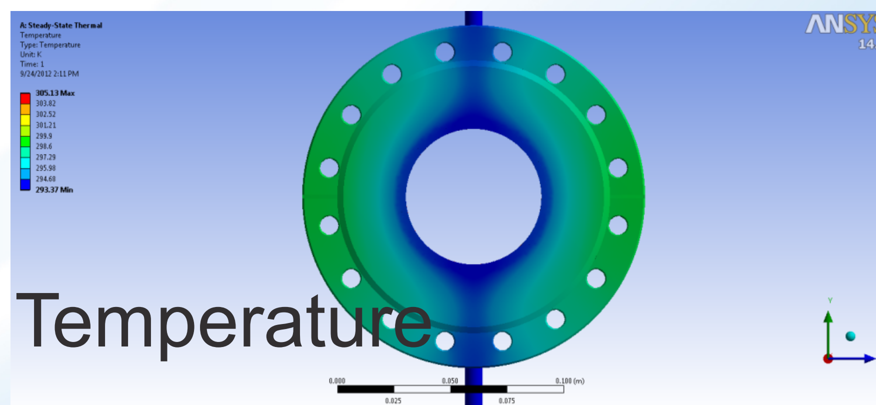


- Deflection 0.001"



- MAX Temp 305K

Water Volume Flow Rate, Q	4.0023	gpm
Pressure Drop	< 2	psi
Inlet - Outlet Temp Difference	0.8805	K
Top and Bottom Inside Wall Temp Difference	0.4402	K
Temperature Difference between Fluid and Inside Surface	2.0648	K
Local heat transfer coefficient h =	3217.3941	W/m^2-K



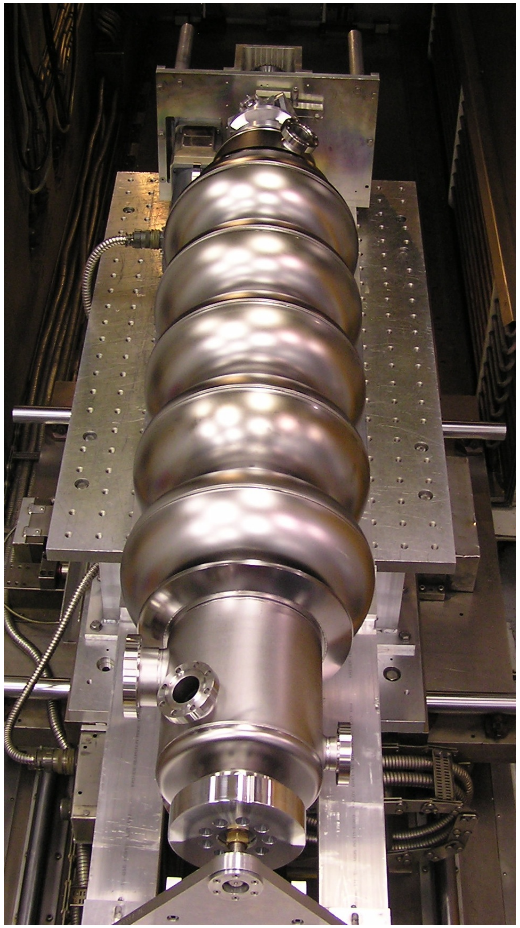
- Temperature

704 MHz accelerating cavity

BNL3-2 at Niowave

- The 5-cell SRF cavity (BNL3) was originally developed for high-current applications such as e-RHIC, SPL, ESS with funding provided via BNL/Stony Brook University Center for Accelerator Science and Education (CASE).
- There are three ports at each large beam pipe of the cavity for HOM couplers, which will be blanked off in CeC PoP linac as there is no need for HOM damping.
- AES fabricated a full-scale copper model and the first niobium cavity (BNL3-1).
- Bulk BCP (120 um) of BNL3-1 is complete at AES, the cavity was baked at BNL at 600°C for 24 hrs. It is back at AES for light BCP and HPR.
- The first VTF testing – later this year.
- The second cavity, BNL3-2, and a cryomodule for CeC PoP are on order from Niowave. Fabrication of the cavity was completed recently.
- The best of two cavities will be integrated in the cryomodule.

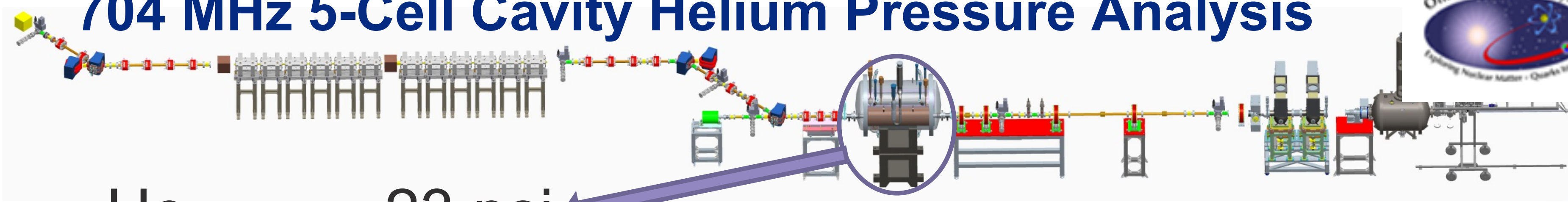
Parameters of BNL3 cavity



BNL3-1 at AES

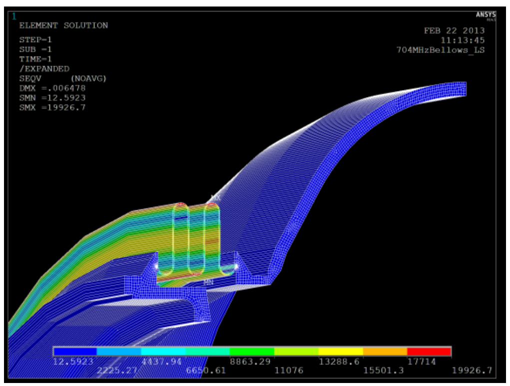
Parameter	704 MHz BNL3 cavity
V_{acc} [MV]	20
No. of cells	5
Geometry Factor	283
R/Q [Ohm]	506.3
E_{pk}/E_{acc}	2.46
B_{pk}/E_{acc} [mT/MV/m]	4.26
Q_0	$> 2 \times 10^{10}$
Length [cm]	158
Beam pipe radius [mm]	110
Max. beam power [kW]	7.8
Peak microphonics detuning [Hz]	12
Q_{ext}	2.8×10^{7}
Available RF power [kW]	20
Frequency tuning range [kHz]	> 78
Operating temperature [K]	1.9

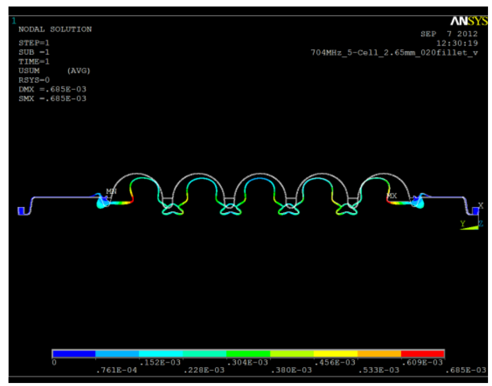
704 MHz 5-Cell Cavity Helium Pressure Analysis

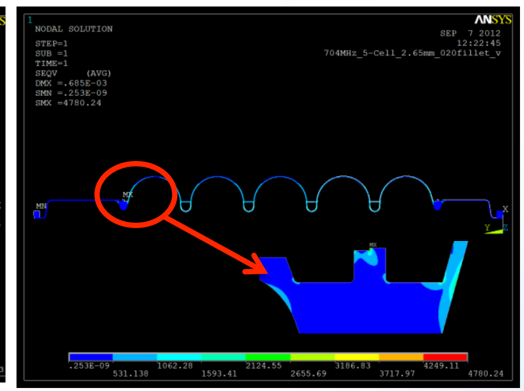


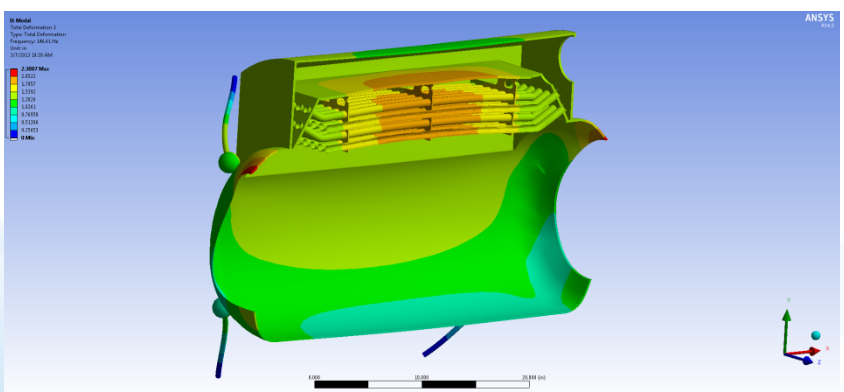
- He Pressure 23 psi

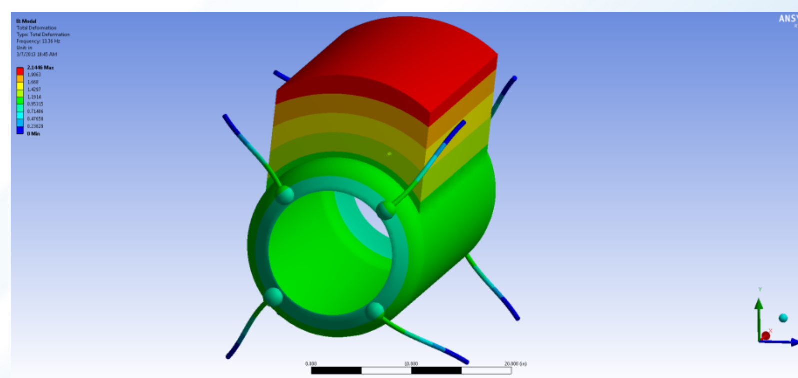
- No plastic deformation anywhere in the shell
- Stress 4780.24 PSI
- Deformation .0006”



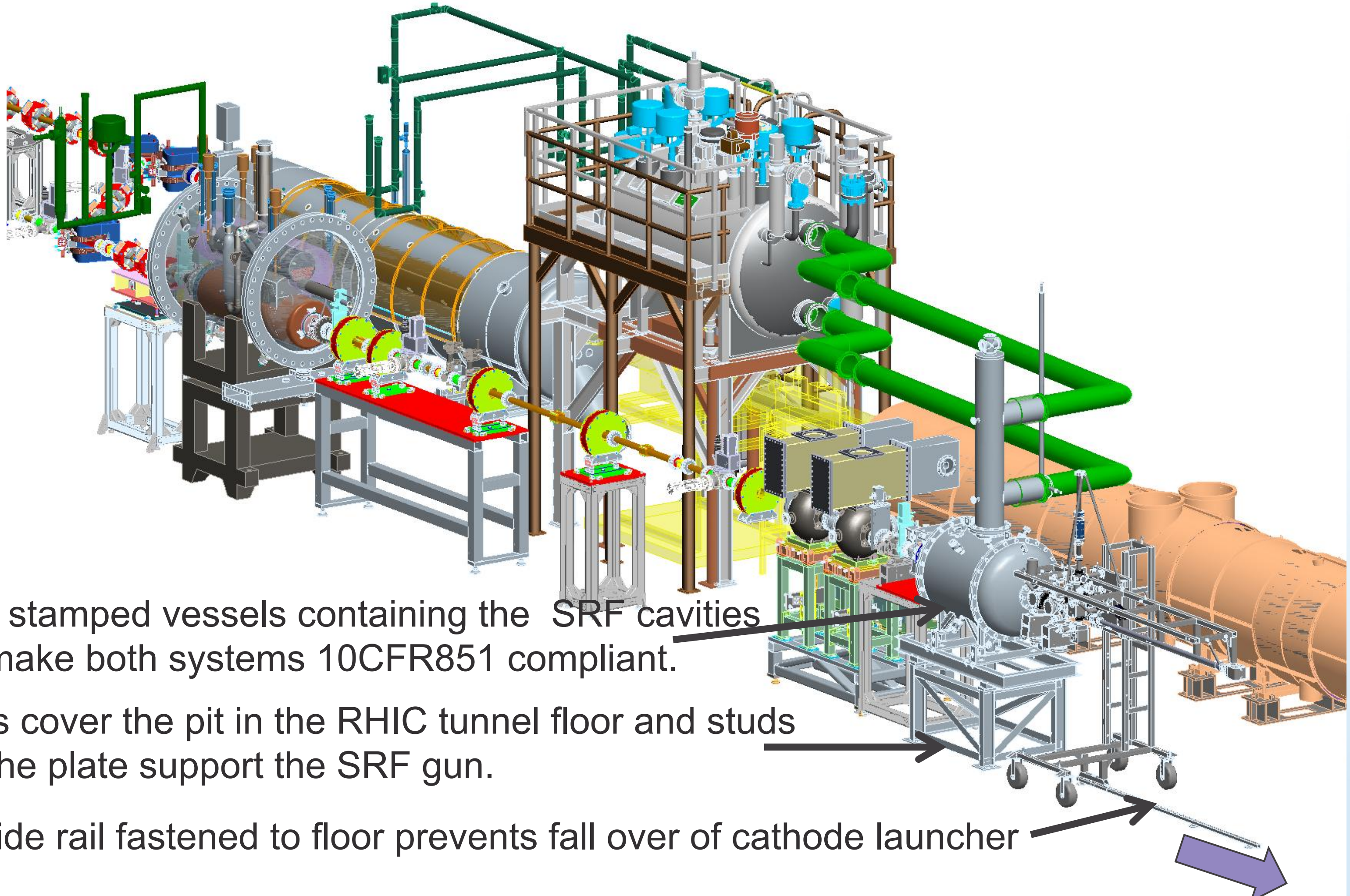








Safety aspects of the SRF systems



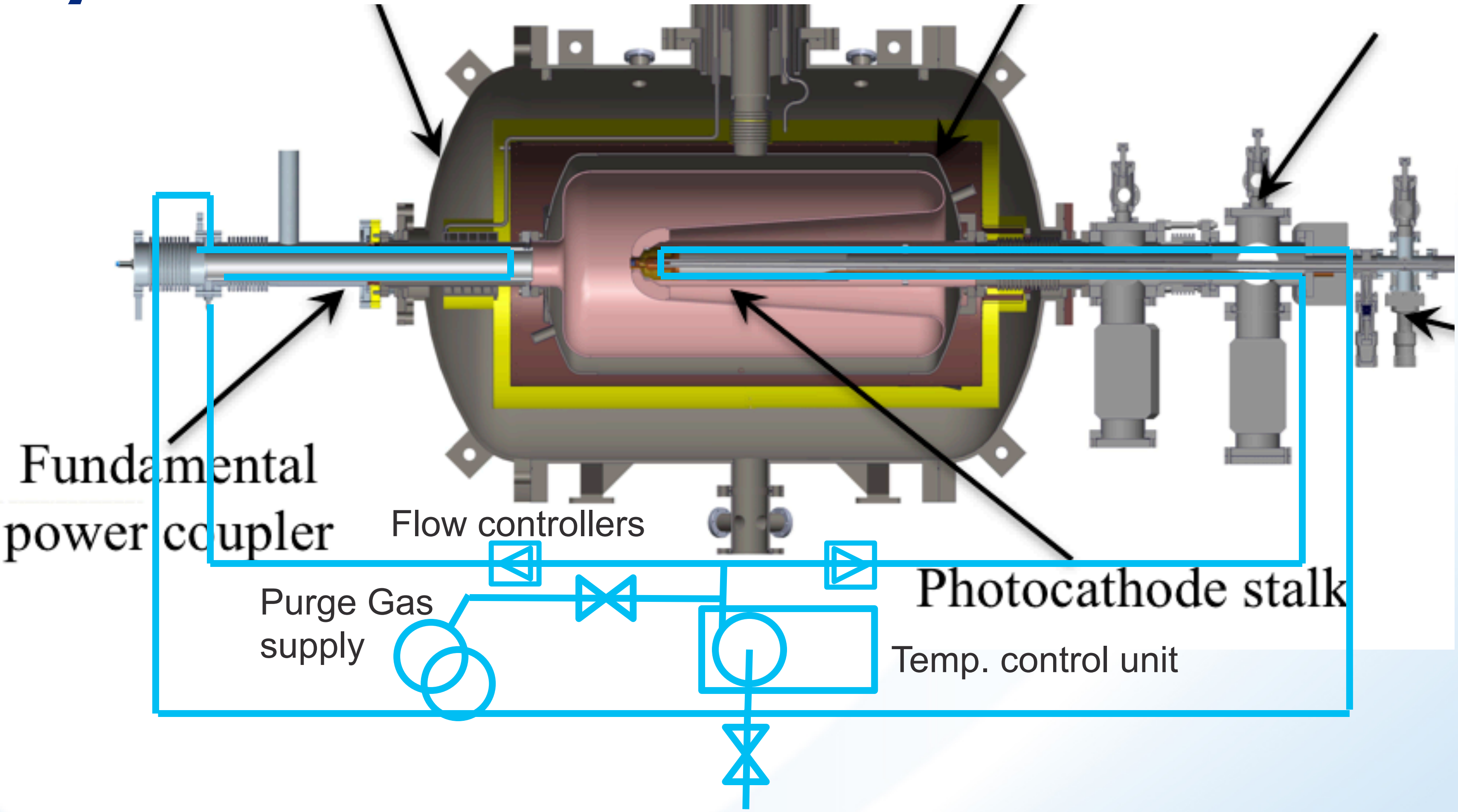
ASME code stamped vessels containing the SRF cavities and reliefs make both systems 10CFR851 compliant.

Steel plates cover the pit in the RHIC tunnel floor and studs welded to the plate support the SRF gun.

Unistrut guide rail fastened to floor prevents fall over of cathode launcher

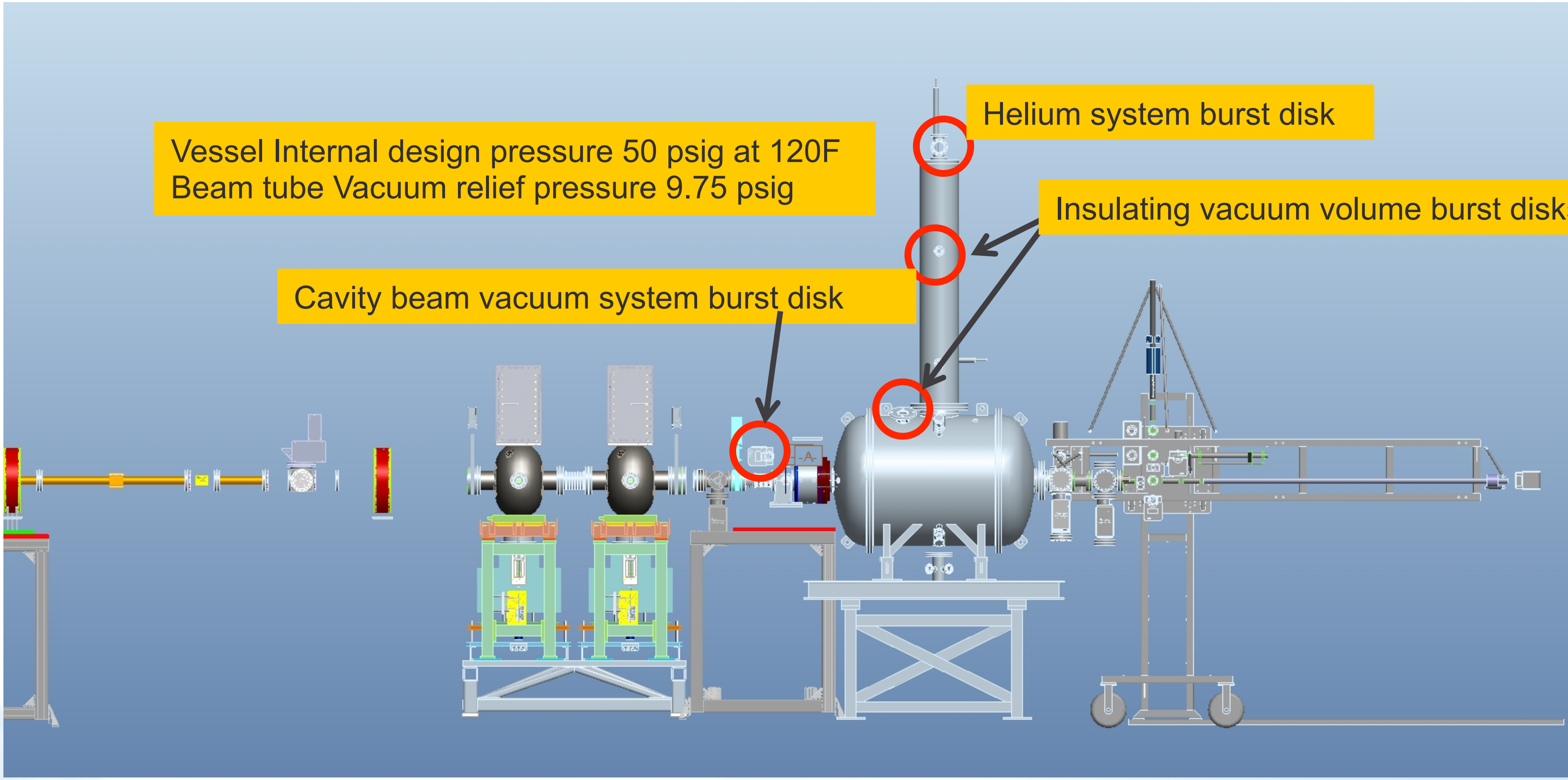
Tunnel safety cage and gate is moved back into the RHIC tunnel approx. 20 ft.

FPC and Stalk temperature control system

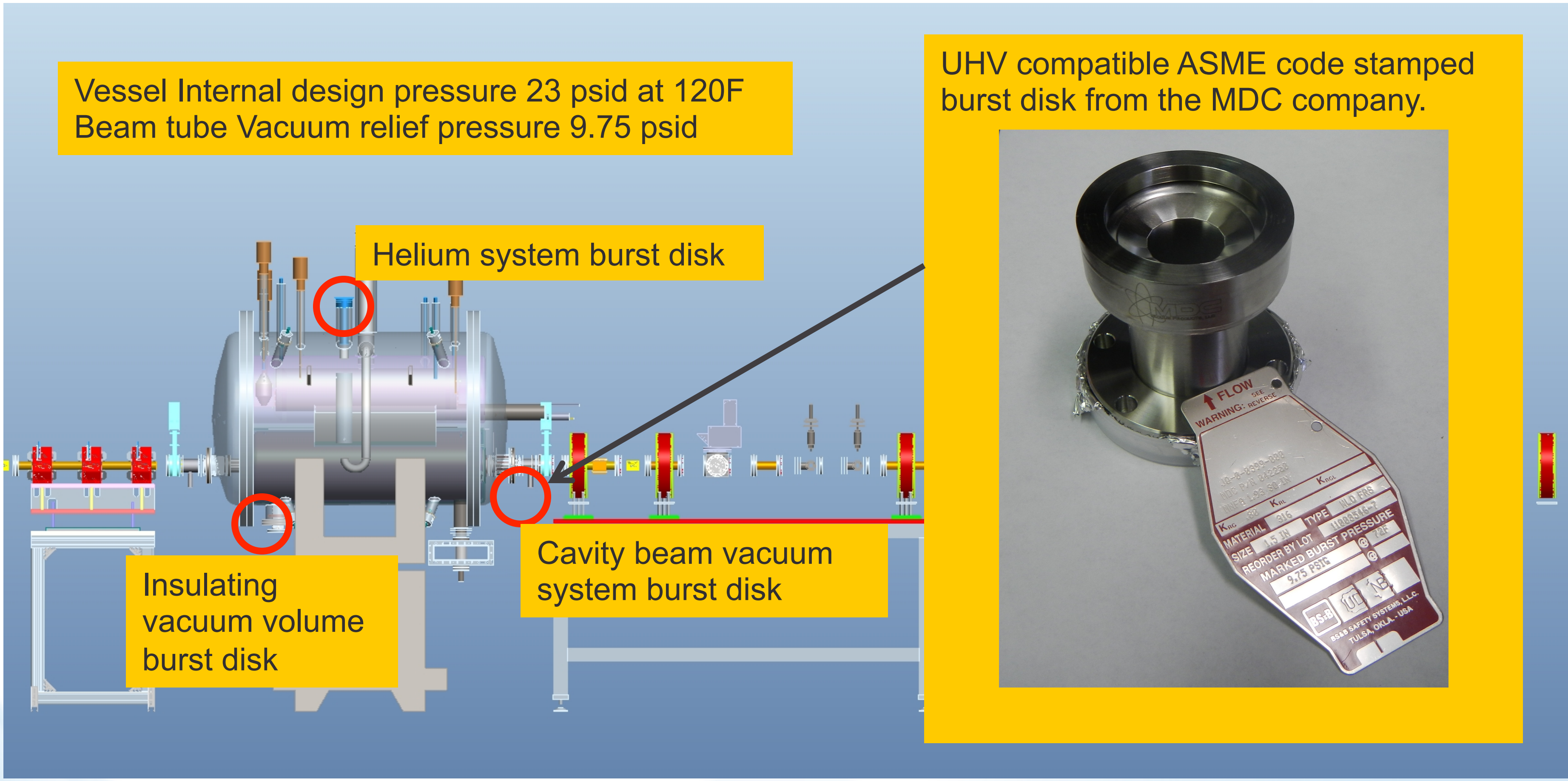


The temperature of the Stalk and FPC must be controlled to minimize heat load into the SRF Cavity
Flow controllers maintain proper flow to critical surfaces. If flow meter indicates a blockage developing a purge gas source is activated that blows out the fluid and shuts down RF. All components shall comply ASME B31.3.

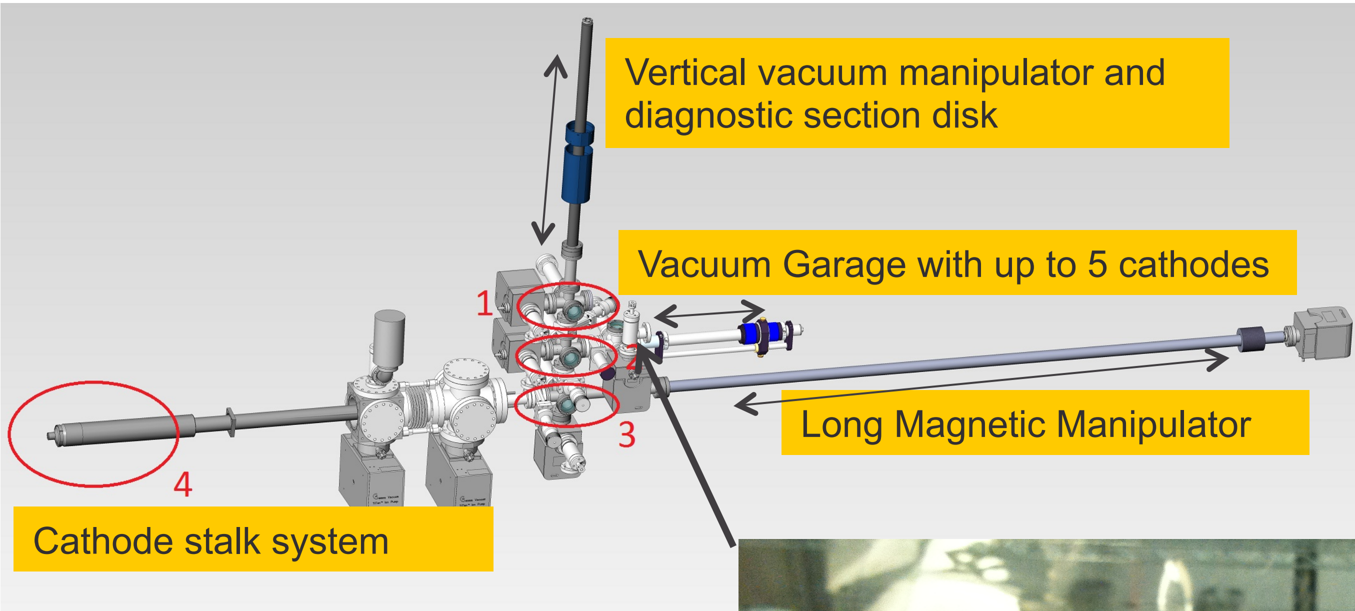
Pressure Relief devises on the 112Mhz SRF cryostat



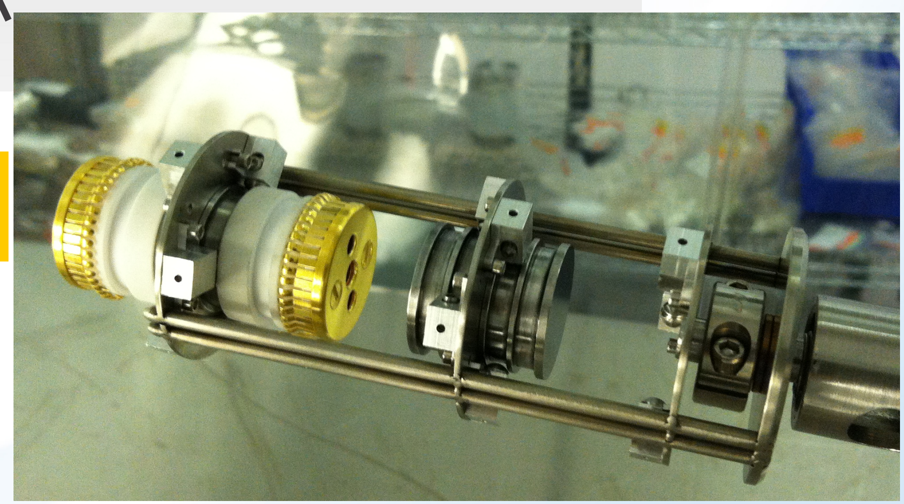
Pressure Relief devises on the 704Mhz SRF cryostat



Stalk and Cathode injection system



Vacuum garage cage containing multiple cathodes



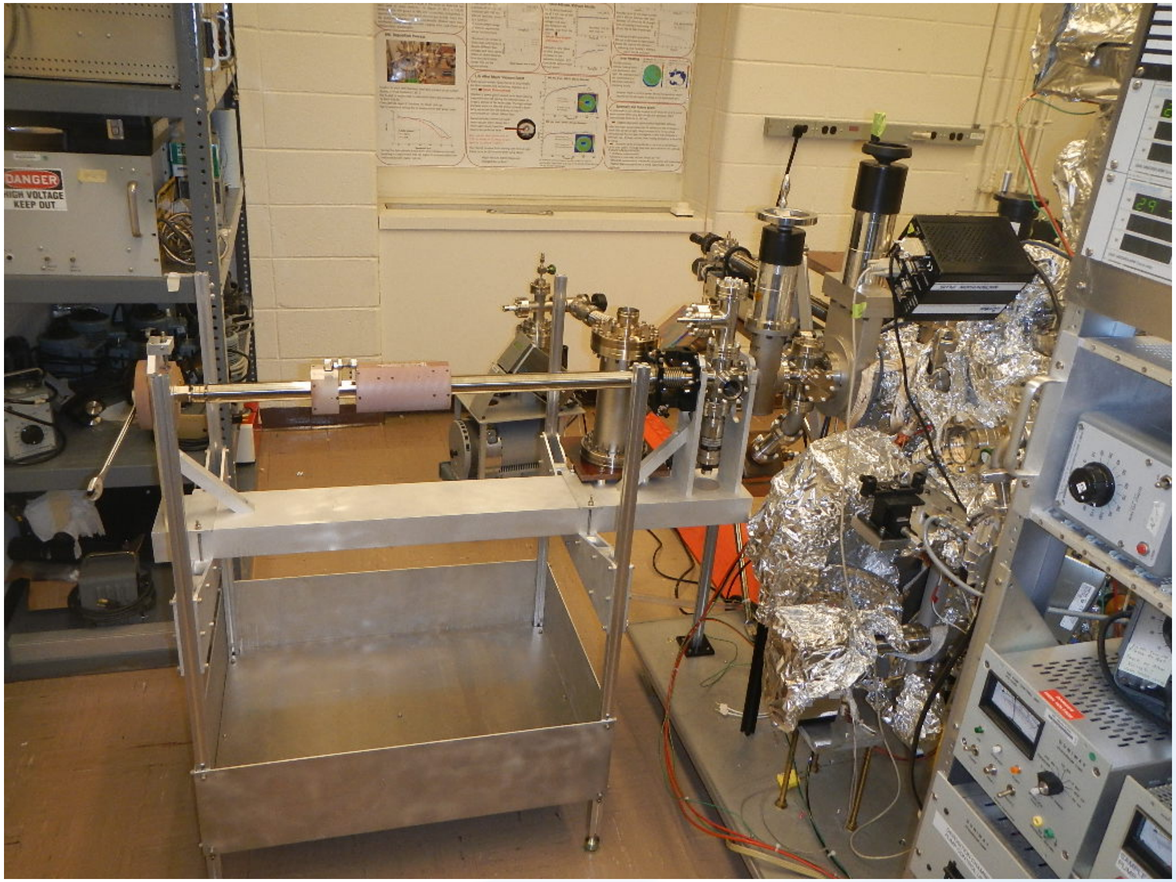
View of the assembled Stalk and cathode injection system for the CeC experiment

Guide is captured by Unistrut track that prevents tip over.

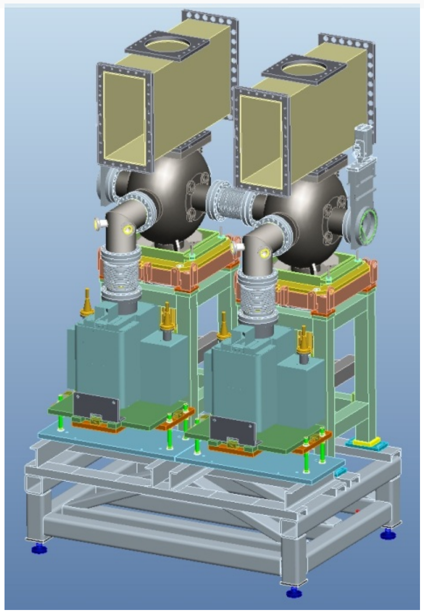
Summary of SRF safety for CeC PoP Experiment in RHIC

- Two Superconducting RF cavities will be used in the CeC PoP experiment. A 112MHz SRF photocathode gun will operate at 4.2 K liquid helium, and one 704 MHz 5-cell will operate in 1.9 K super fluid.
- Analysis of the cavities indicate they will operate safely with in planned operating criteria.
- The vacuum envelopes of both cavities are ASME code stamped pressure vessels.
- All ambient boundary pressure relief devices are code stamped burst disks, located on the helium volume, the insulating vacuum volumes, and the UHV beam tube volume of each cryostat assembly.
- Analysis,code stamped vessels and relief system assures compliance to FAR 10CFR851
- The 112MHz SRF photocathode gun cavity cryostat was successfully tested by the contractor without incident. And will arrive at BNL the beginning of April.
- The 704 MHz 5-cell has been completed and the detailed design of the cryostat is underway at Niowave with scheduled delivery spring 2014.
- The temperature of the stalk and FPC are controlled with a temperature maintained fluid loop that has provision to guard against freeze up, all lines will conform to ASME B31.3.
- The stalk and Cathode injection system is constructed and was tested by the vendor to provide operation. A track that is anchored to the floor eliminates any tipping hazard.

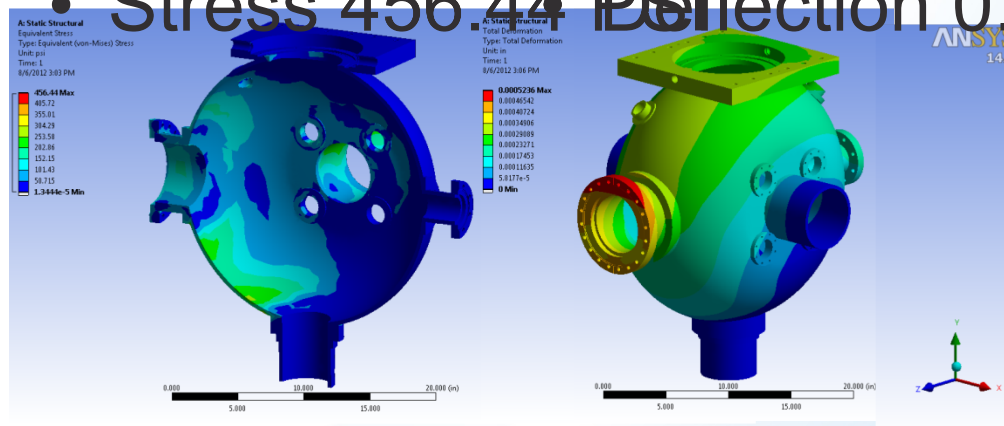
Vacuum suite case and system that creates the Multi-alkali cathodes in BNL's instrumentation division.

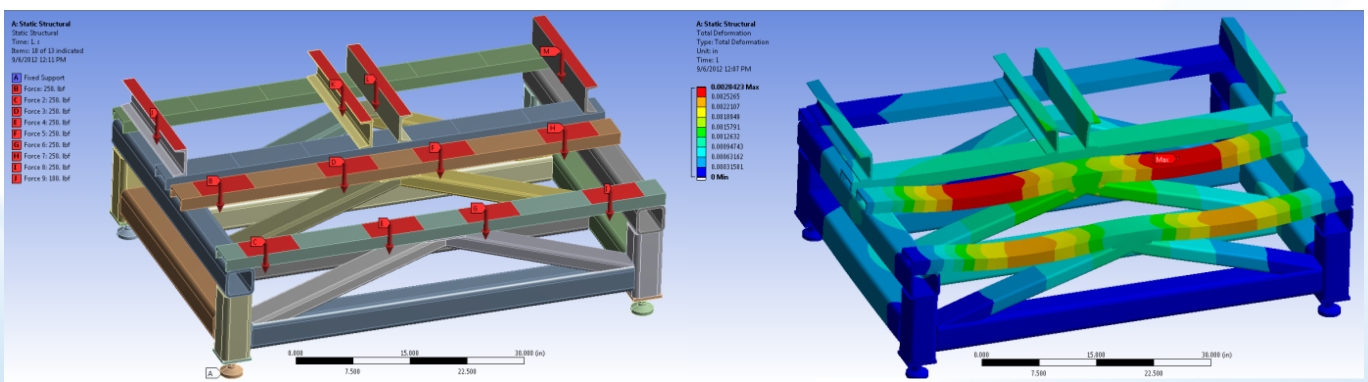


500MHz Buncher Cavity System



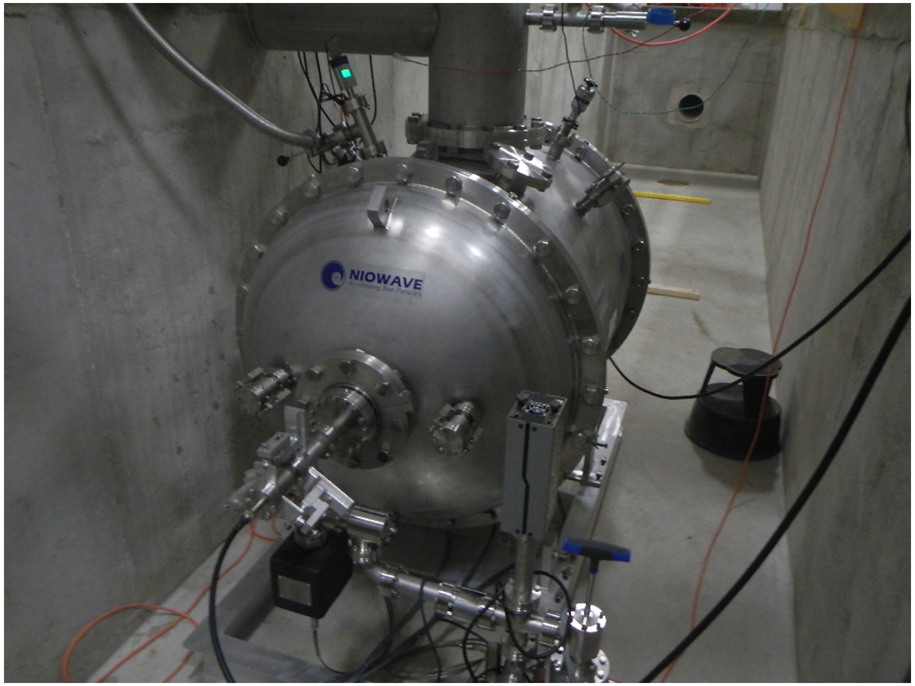
- Stress 456.44 PSI
- Deflection 0.0





- Stress 6547.
- Deflection 0.

Views of the 112NHz vessel and experiment at Niowave



Views of Gold plated Stalk assembly taken in SBU clean room