Status of BNL SRF guns

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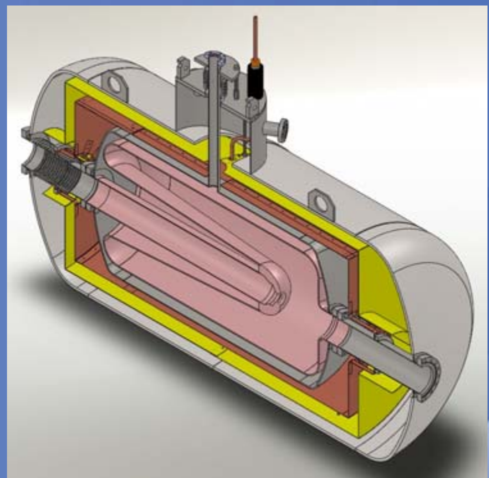

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Acknowledgements

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Overview

- Superconducting RF (SRF) guns are based on merging several complex technologies: high QE photocathodes, superconducting RF, high repetition rate synchronizable lasers.
- Among challenges imposed by these technologies are maintaining UHV environment for the cathodes, maintaining cleanliness of the cavity RF surfaces while allowing operation and replacement of the cathodes, designing low RF loss and low heat leak interface between the cold cavities and warmer cathodes, synchronizing high repetition rate lasers with RF.
- In this talk we address only issues related to SRF technology.
- Two SRF guns are under active development at BNL.
- The first gun, ½-cell elliptical shape, belongs to the first generation of SRF guns. It operates at 703.75 MHz and is designed to produce high average current electron beams for the ERL prototype.
- The second gun, of a Quarter-Wave Resonator (QWR) type, operates at 113 MHz. This gun is designed to generate high charge, low repetition rate beam for the Coherent electron Cooling (CeC) experiment as well as to be used for photocathodes studies.
- We will briefly describe the gun designs, present recent test results and status and discuss plans.

R&D ERL

- The R&D ERL facility at BNL aims to demonstrate CW operation of ERL with average beam current in the range of 0.1-1 ampere, combined with very high efficiency of energy recovery.
- Gun-to-5-cell cavity (G5) setup is the first stage of the ERL beam commissioning.
- The goal of the G5 setup is to test critical ERL components with the beam and characterize the beam produced by the gun.

	High Current	High charge
Charge per bunch, nC	**0.7**	**5**
Energy maximum/injection, MeV	20/2.5	20/3.0
R.m.s. Normalized emittances ex/ey, mm*mrad	1.4/1.4	4.8/5.3
R.m.s. Energy spread, dE/E	$3.5x10^{-3}$	$1x10^{-2}$
R.m.s. Bunch length, ps	18	31
Bunch rep-rate, MHz	700	9.383
Gun/dumped avrg. current, mA	500	50
Linac average current, mA	**1000**	**100**
Injected/ejected beam power, MW	1.0	0.150
Numbers of passes	1	1

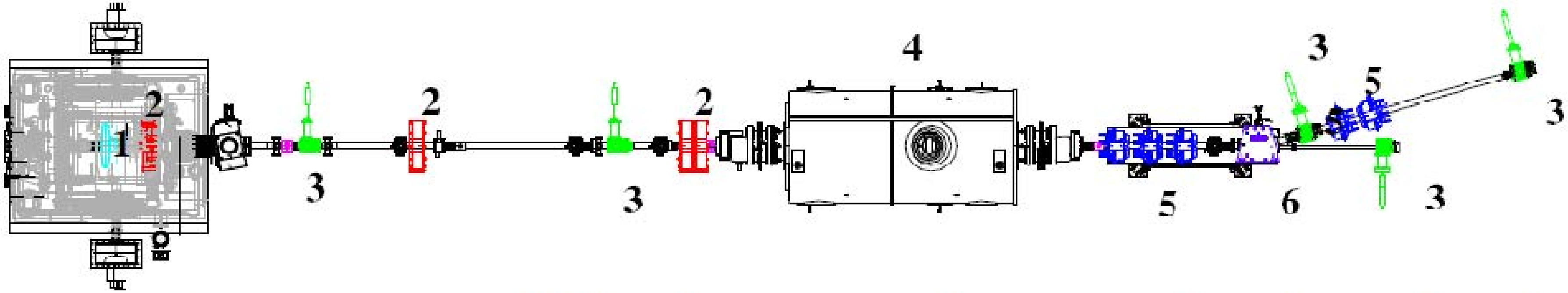
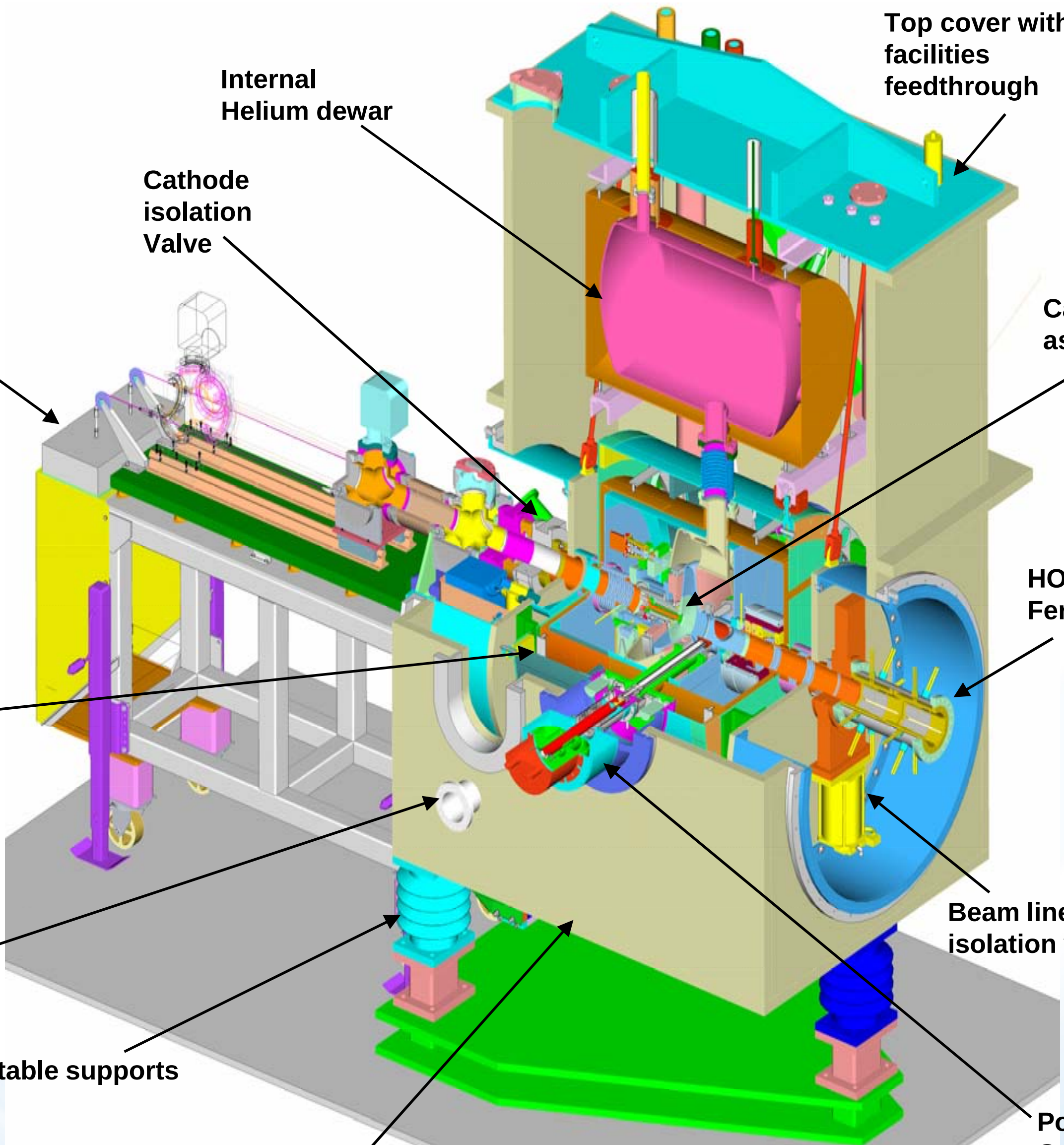


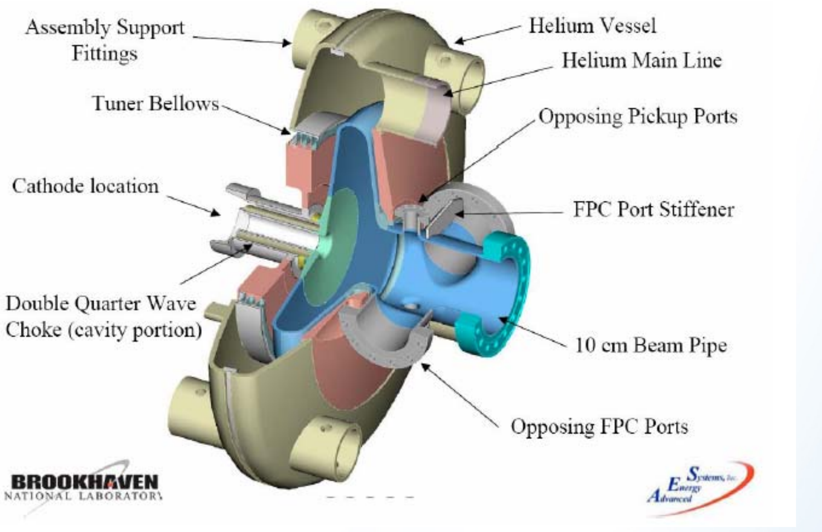
Figure 2: Detailed drawing of G5-test: 1 - 703MHz SRF gun; 2 – solenoids; 3 - beam profile monitors; 4- 5cell SRF cavity; 5-quadrupoles; 6-dipole magnet. 2.5 MeV electron beam from SRF gun propagates through a straight section with beam diagnostics: BPMs, pepper-pot, YaG/OTR screens. Then beam is accelerated in 5-cell cavity to 20 MeV.

703.75 MHz SRF gun

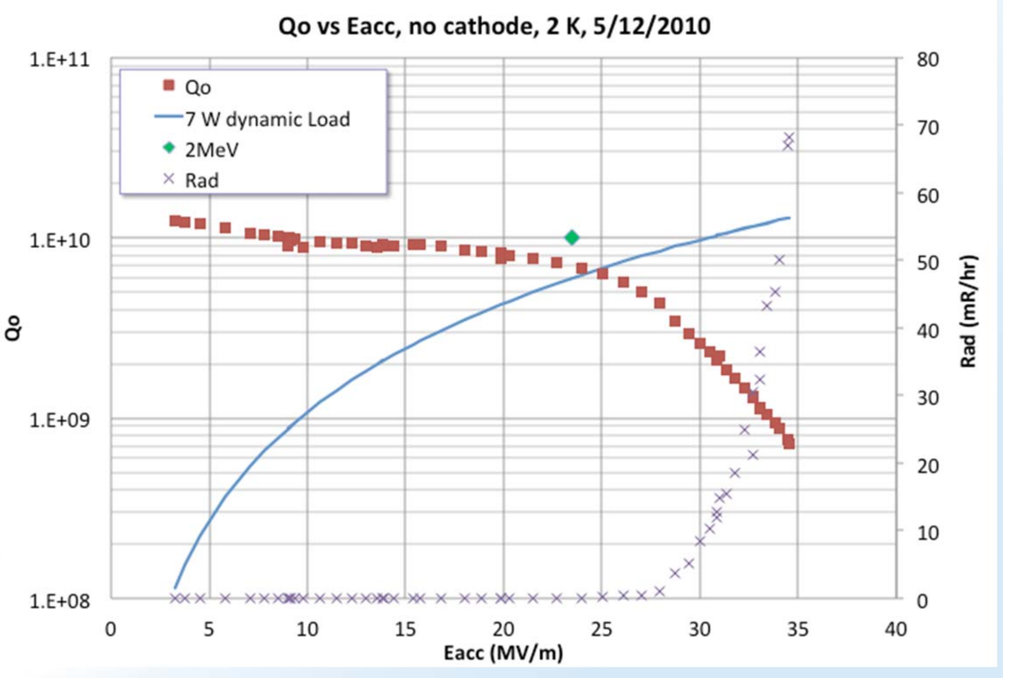


- The 703.75 MHz half-cell SRF gun has two Fundamental input Power Couplers (FPCs) allowing to deliver 1 MW of RF power to 0.5 A electron beam at energy gain of 2 MeV.
- R/Q = 96.2 Ohm, cavity active length is 8.5 cm, tuning range is 1.2 MHz (1 mm of cavity deformation).
- HOM damping is provided by an external beamline ferrite load with ceramic break.
- The gun and its cryomodule were designed and fabricated by AES.
- FPCs are manufactures by CPI/Beverly.

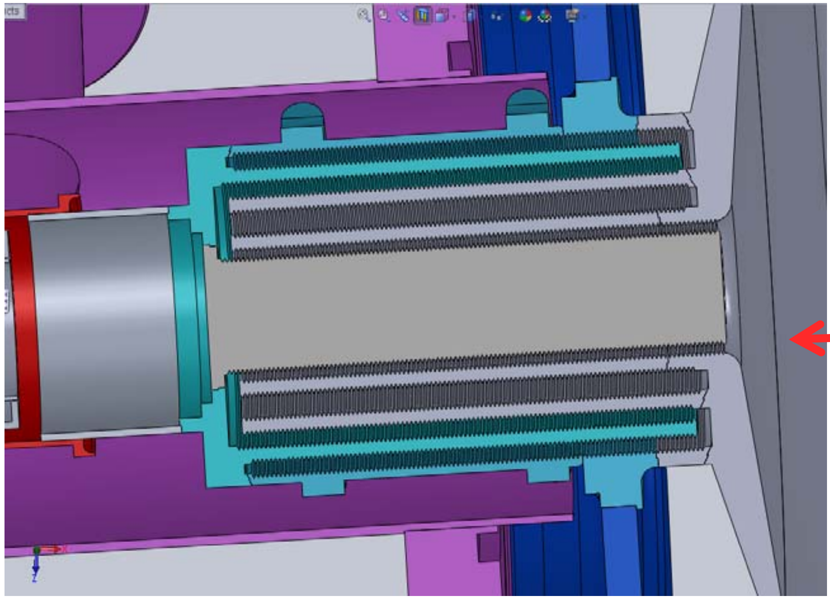
SRF gun cavity

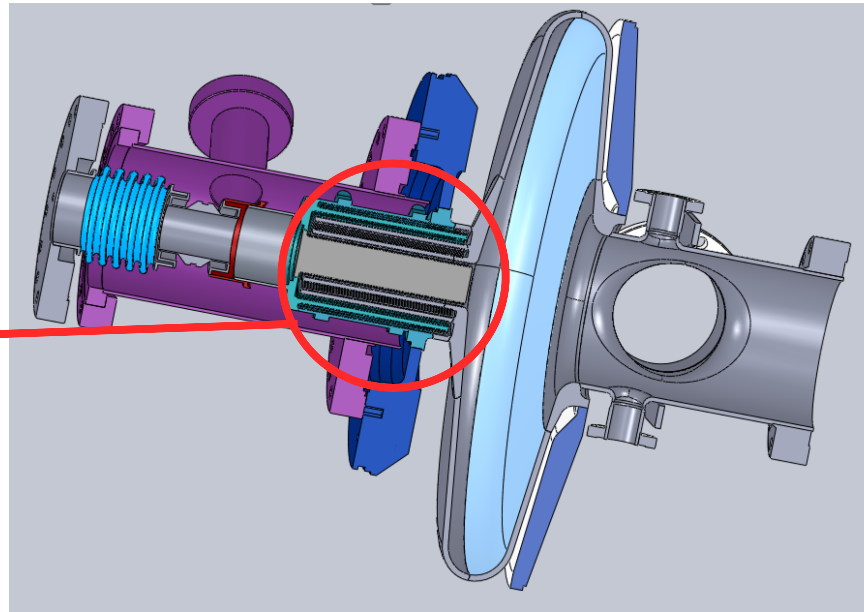


- The gun cavity underwent the following processing: ~120 um BCP, HPR, 60-hrs bake at 200° C (to reduce SEY of Nb as opposed to standard 24-hrs bake at 120° C).
- After that the cavity was tested in a vertical cryostat several times last year.
- Tests without the cathode stalk were good.
- At 23.5 MV/m (corresponding to 2 MV) the cavity dynamic loss was less than 7 W.



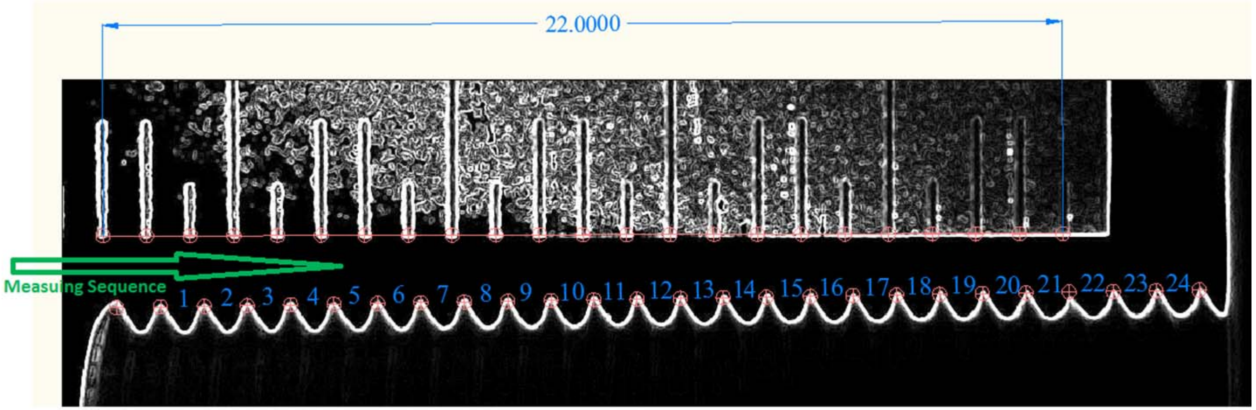
MP in the grooved choke joint

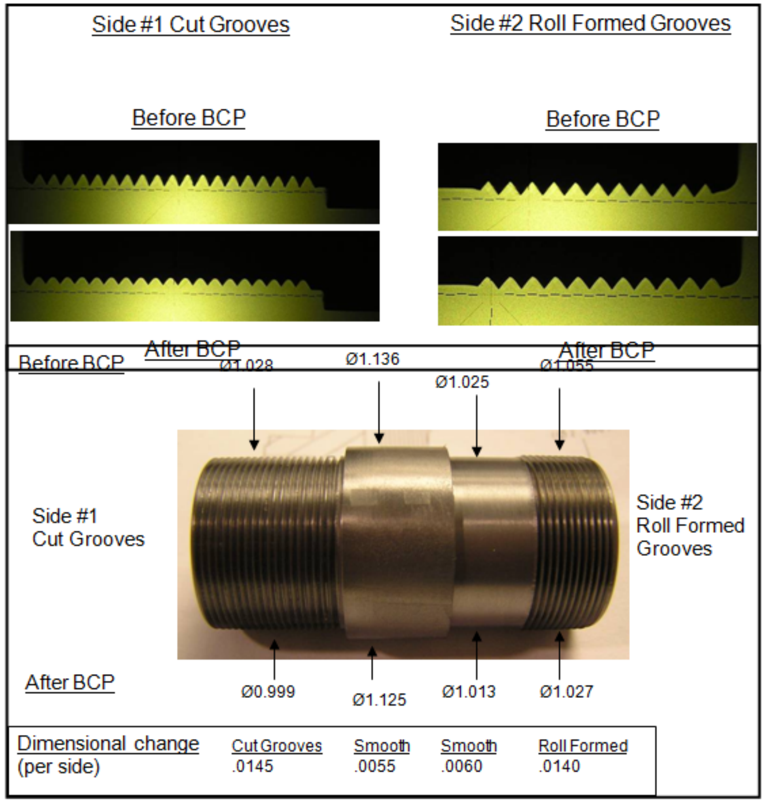




- A folded coaxial choke joint is grooved to prevent multipacting (MP).
- Tests with the stalk (made of high RRR Nb) suffered from multipacting (MP) in the choke joint region and were limited to ~3 MV/m.
- Baking helped to increase the field to ~6 MV/m, where another barrier prevented further progress.
- It was not possible to overcome MP due to RF power limit.
- MP simulations were performed using FishPact. No MP was found with ideal triangular grooves.

Rounding of the grooves after BCP

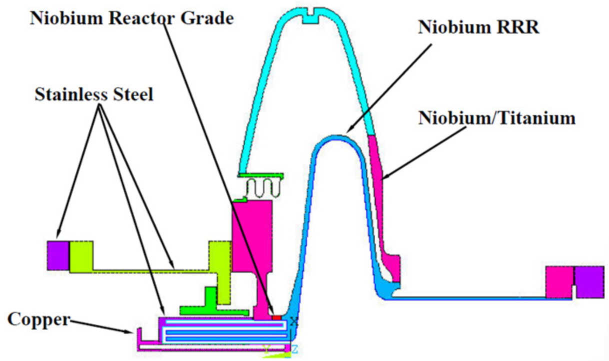




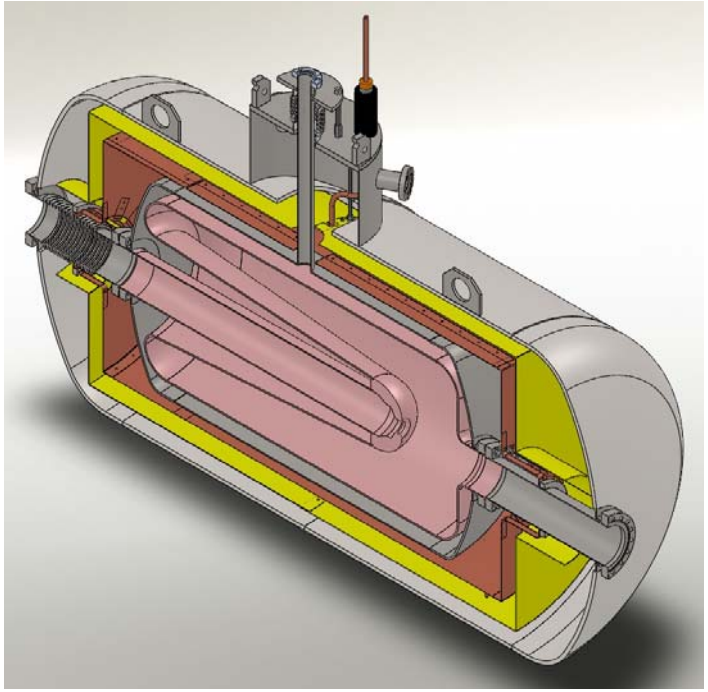
- However, due to BCP etching, the groove valleys became rounded.
- Simulations with rounded grooves (0.2 mm rounding radius) found MP barriers at 3 MV/m, 6 MV/m, and 11 MV/m.
- Studies indicate that roll formed grooves sustain BCP better than cut grooves.
- We have devised a special experiment to further study conditioning of MP in the choke joint. A spare (large-grain) gun cavity in the vertical test dewar will be used.

SRF gun assembly status

- Thermal analysis incorporating heat load due to MP was performed. The results indicate that 3 MV/m barrier should be the most difficult to overcome. This is very encouraging as we were able to process this barrier during the cavity tests.
- The gun assembly is going forward. In the cryomodule the cathode is made of copper and cooled by liquid nitrogen. We expect that MP can be conditioned.
- The cavity has been cleaned, the cavity string assembled at JLab, and shipped to BNL.
- Fundamental Power Couplers (FPCs) were tested with max power of 125 kW CW in SW (more details in my WG3 talk on Thursday).
- Assembly of the cryomodule at BNL has begun at BNL.
- The plan is to finish the cryomodule assembly in early 2012, following by the gun installation in ERL and cold test.
- First beam will be generated with a metal cathode, following by experiments with CsK_2Sb.

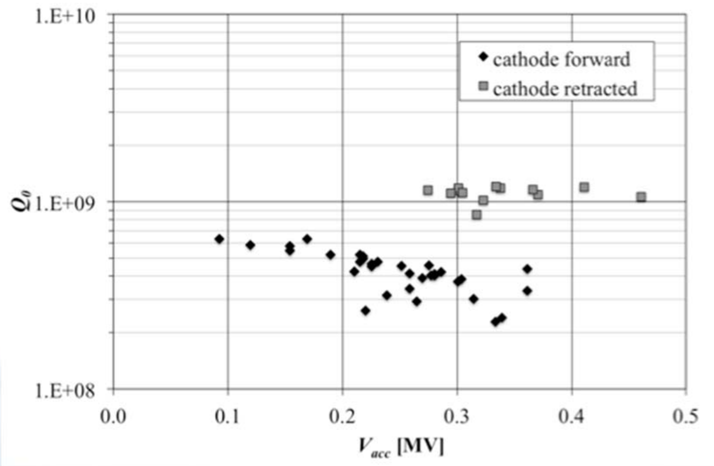


Quarter Wave Resonator SRF gun



- Superconducting 113 MHz QWR was developed 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 (DOE SBIR project).
- Why 113 MHz?
  - ✧ 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.
  - ✧ Simulated emittance of ~3 mm × mrad at 2.7 MeV

113 MHz SRF gun cold test & plans

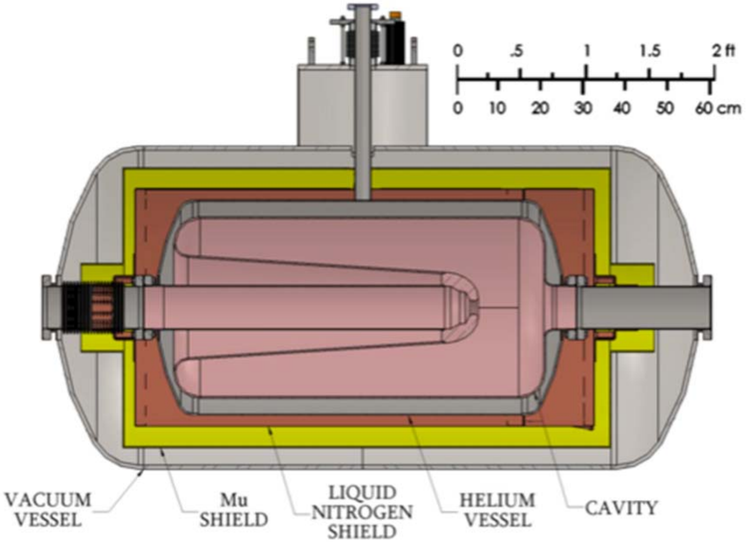


- First cold test was successfully performed at Niowave, Inc. in December of 2010.
- Observed multipacting barriers were easy to process.
- Reached about 0.5 MV with Q_0 of 10^9
- Field was limited due to radiation safety requirement of <2 mrem/hr (no dedicated radiation shielding around the cryomodule).
- Measured sensitivity of the cavity resonant frequency to helium bath pressure of 10 Hz/mbar.
- Estimated upper limit for the static heat leak: 7 W.
- This gun is now a baseline option electron gun for the Coherent electron Cooling Proof-of-Principle (CeC PoP) experiment at BNL. The experiment is scheduled for installation in RHIC in 2013.

QWR SRF gun parameters

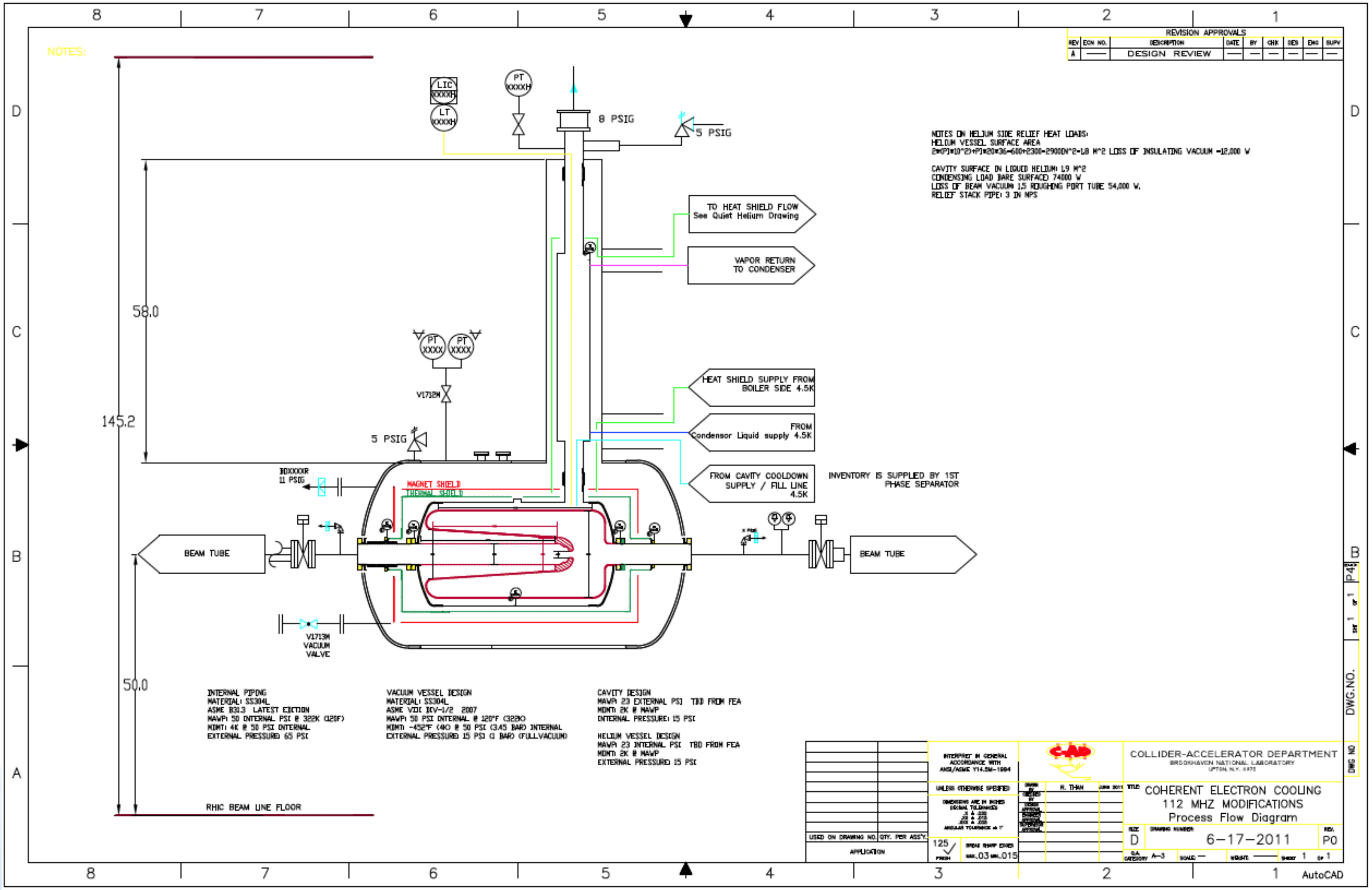
Parameter	QWR SRF gun
Frequency [MHz]	113.04
Aperture (beam tube) [cm]	10
Cavity diameter [cm]	42
Cavity length [cm]	110
V_{acc} per cavity, max [MV]	2.0
Peak electric field [MV/m]	38.2
Peak magnetic field [mT]	72.8
Field at the cathode [MV/m]	14.5
R/Q [Ohm]	126
Geometry factor [Ohm]	38.2
RF power loss at 4.5 K [W]	12.3
RF power loss at RT in cathode stalk [W]	62.3
Beam power [W]	156
RF power per cavity [kW]	2

SRF gun upgrades/modifications



- Replacing the low carbon steel vacuum vessel with the stainless steel one.
- Modify cryogenic connections for compatibility with BNL cryogenics.
- Frequency pre-tuning mechanism inside the cryostat.
- Re-design cavity support.
- Low RF loss, low heat load cathode stalk.
- Load lock system for multi-alkali photocathodes.
- Combine function FPC/tuner assembly.
- Copper plate stainless steel bellows and beam pipes to reduce RF losses.

QWR gun PFD



NOTES:
LIC XXXXH
LT XXXXH
PT XXXXH
8 PSIG
5 PSIG
NOTES ON HELIUM SIDE RELIEF HEAT LOADS:
HELIUM VESSEL SURFACE AREA
2*(PI*10^2)+PI*20*36=600+2300=2900IN^2=1.8 M^2 LOSS OF INSULATING VACUUM =12,000 W
CAVITY SURFACE ON LIQUID HELIUM: 1.9 M^2
CONDENSING LOAD BARE SURFACE) 74000 W
LOSS OF BEAM VACUUM 1.5 ROUGHING PORT TUBE 54,000 W.
RELIEF STACK PIPE: 3 IN NPS
TO HEAT SHIELD FLOW See Quiet Helium Drawing
VAPOR RETURN TO CONDENSER
58.0
145.2
50.0
V1712M
HEAT SHIELD SUPPLY FROM BOILER SIDE 4.5K
FROM Condensor Liquid supply 4.5K
FROM CAVITY COOLDOWN SUPPLY / FILL LINE 4.5K
INVENTORY IS SUPPLIED BY 1ST PHASE SEPARATOR
11 PSIG
MAGNET SHIELD
THERMAL SHIELD
BEAM TUBE
BEAM TUBE
V1713M VACUUM VALVE
INTERNAL PIPING
MATERIAL: SS304L
ASME B31.3 LATEST EDITION
MAWP: 50 INTERNAL PSI @ 322K (120F)
MDMT: 4K @ 50 PSI INTERNAL
EXTERNAL PRESSURE: 65 PSI
VACUUM VESSEL DESIGN
MATERIAL: SS304L
ASME VIII DIV-1/2 2007
MAWP: 50 PSI INTERNAL @ 120°F (322K)
MDMT: -452°F (4K) @ 50 PSI (3.45 BAR) INTERNAL
EXTERNAL PRESSURE: 15 PSI (1 BAR) (FULLVACUUM)
CAVITY DESIGN
MAWP: 23 EXTERNAL PSI TBD FROM FEA
MDMT: 2K @ MAWP
INTERNAL PRESSURE: 15 PSI
HELIUM VESSEL DESIGN
MAWP: 23 INTERNAL PSI TBD FROM FEA
MDMT: 2K @ MAWP
EXTERNAL PRESSURE: 15 PSI
RHIC BEAM LINE FLOOR
REVISION APPROVALS
DESIGN REVIEW
COLLIDER-ACCELERATOR DEPARTMENT
BROOKHAVEN NATIONAL LABORATORY
COHERENT ELECTRON COOLING
112 MHZ MODIFICATIONS
Process Flow Diagram
R. THAN
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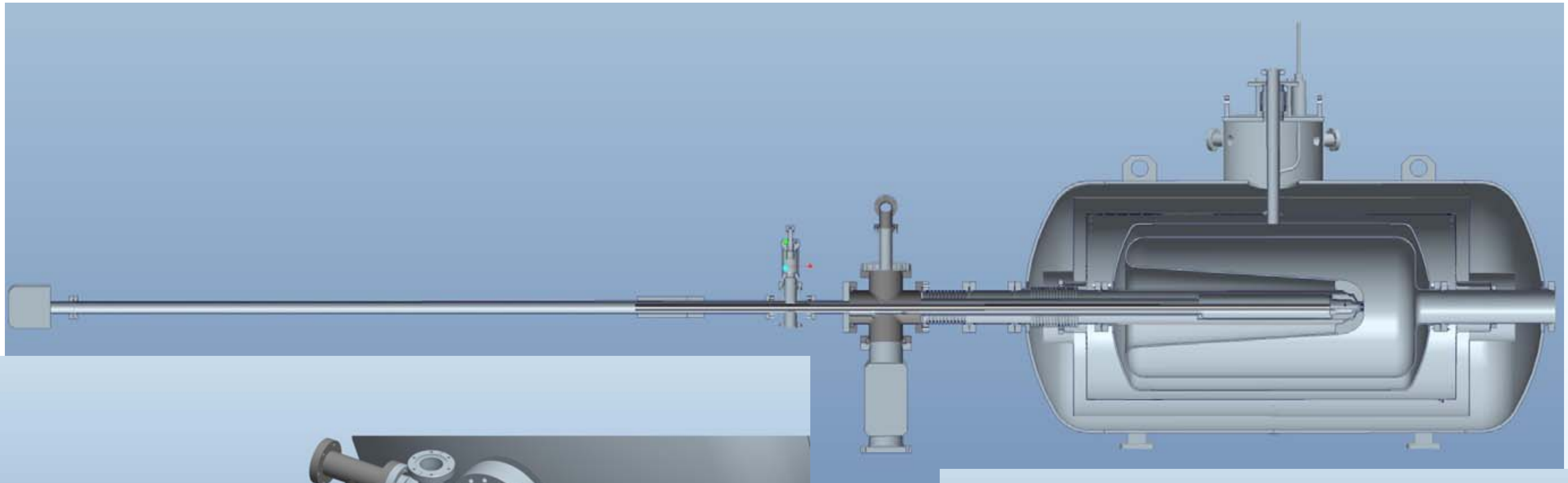
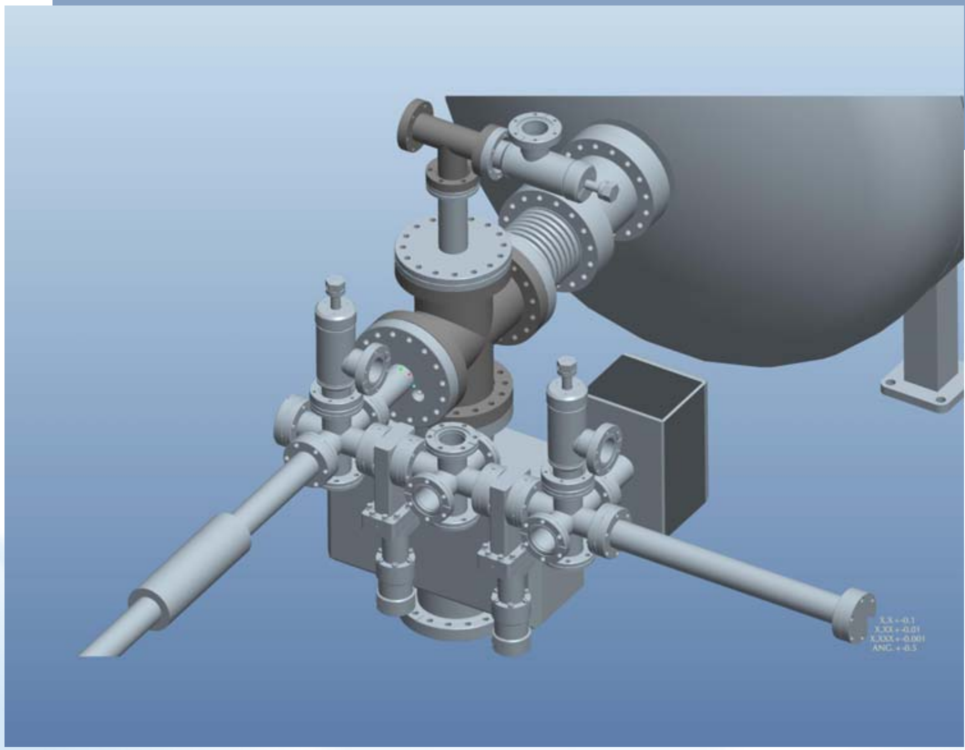
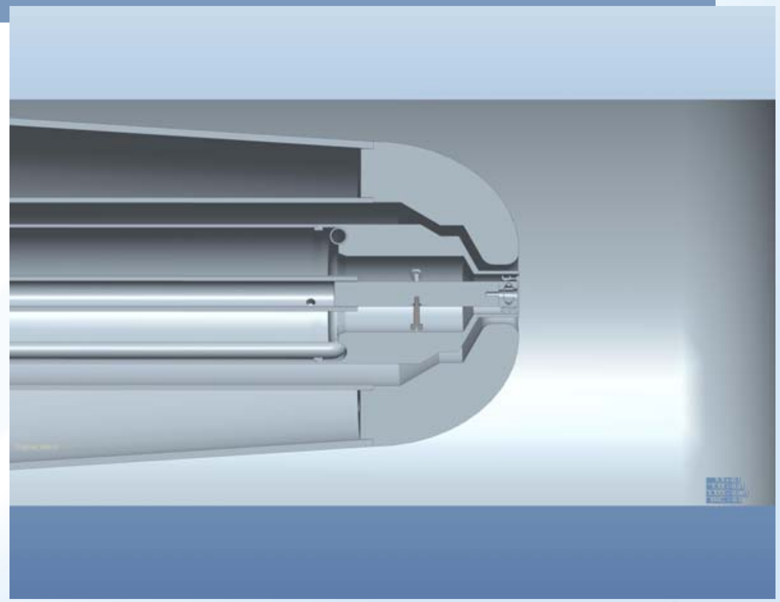
AutoCAD

Cathode stalk and load lock system







QWR gun upgrade status

- The cathode stalk and load lock system are designed and fabrication has started.
- The design of other upgrades/modifications is in progress.
- The modification of the QWR SRF gun is expected to be completed and the first experiments to begin in 2012.