

# DESIGN OF NORMAL CONDUCTING 704 MHz AND 2.1 GHz CAVITIES FOR LEREC LINAC\*

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## Abstract

To improve RHIC luminosity for heavy ion beam energies below 10 GeV/nucleon, the Low Energy RHIC electron Cooler (LEReC) is currently under development at BNL. Two normal conducting cavities, a single cell 704 MHz cavity and a 3 cell 2.1 GHz third harmonic cavity, will be used in LEReC for energy spread correction. In this paper we report the design of these two cavities.

## INTRODUCTION

To map the QCD phase diagram, especially to search the QCD critical point using the Relativistic Heavy Ion Collider (RHIC), significant luminosity improvement at energies below  $\gamma=10.7$  is required, which can be achieved with the help of an electron cooling upgrade called Low Energy RHIC electron Cooler (LEReC) [1].

An electron accelerator for LEReC (linac) consists of the photoemission gun (both the SRF and DC gun options are being developed) and the 5-cell 704 MHz SRF cavity. The SRF gun and 5-cell cavity are presently under commissioning in the R&D ERL [2]. In LEReC Phase I (electron kinetic energies up to 2 MeV) a one cell 704 MHz normal conducting cavity and a 3-cell third harmonic (2.1 GHz) normal conducting cavity will be added to de-chirp the energy spread and to compensate its non-linearity. An additional normal conducting cavity will be added in LEReC Phase II (energies up to 5 MeV with an accelerator working in the ERL mode), which is not covered in this paper.

## CAVITY DESIGN

The optimization of the cavities is performed using CST Microwave Studio®, and the final designs are simulated using ACE3P package.

### A. 2.1 GHz Cavity RF Design

The 2.1 GHz cavity will deliver 200 kV accelerating voltage. It will dissipate about 7.5 kW in its walls and will be fed from a 10 kW solid state RF amplifier. The design frequency is 2.1107 GHz, and the beam pipe diameter is 1.37 inches.

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A pillbox shape cell is adopted as a baseline bare cell in this design. Nose cones with the height  $h$ , shown in Figure 1(c), are used to improve the cavity shunt impedance. Cell-to-cell coupling is determined by slots in the walls between adjacent cells, as shown in Figure 1(b). In this design four slots are added. Each slot has a width of 8 mm and an azimuthal length  $\phi$ . 50 degrees is chosen for  $\phi$  to get 1.2% cell-to-cell coupling for a 3-cell design. Cells with different height  $h$  were simulated, with  $h$  varied from 3 to 6 mm with a 0.5 mm step size. For each simulation the value of  $R_d$  is optimized so that resonance frequency can be set at 2.1107 GHz for  $\pi$  mode. The simulations showed a maximum shunt impedance at  $h = 4$  mm.

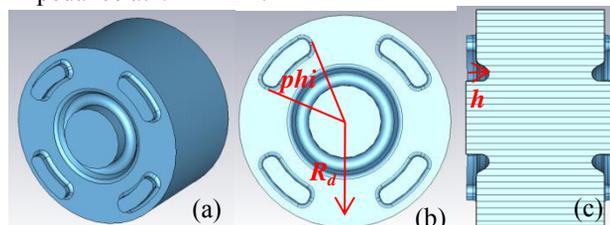


Figure 1: The 2.1 GHz bare cell: (a) perspective view; (b) front view; (c) side view.

This design provided a baseline for the 3-cell cavity. For the end cell with beam pipe, the  $\phi$  value remains at 50 degree, the  $h$  value is re-optimized to maximize the shunt impedance, with a result of  $h = 4$  mm.

For the center cell shown in Figure 2, a 30 mm diameter tuner is added at the bottom of the bare cell, with the tuner's penetration  $L_t$  to be negative while moving out of the cavity and to be positive while moving into the cavity. An FPC port is added opposite to the tuner. 134.42 mm  $\times$  25.04 mm JLab530 rectangular waveguide is used to deliver the RF power. This rectangular waveguide is connected to the cavity with a  $WGHeight + 5$  mm long taper to a 25.04 mm  $\times$  25.04 mm coupling slot. 7.95 mm radius blending is applied to the transition edges. An RF window is not considered in this simulation and is added later to the 3-cell design. With  $h = 4$  mm,  $\phi = 50$  degree, radius of the center cell  $R_{d\_c} = 51.0$  mm, the taper height  $WGHeight$  is chosen to be 92.0 mm to get the external quality factor  $Q_{ext} \sim 3,300$  from the FPC, so that the  $Q_{ext}$  for 3-cell cavity is about 10,000, with the assumption that the stored energy is evenly distributed between cells.

By assembling the two end cells (radius 52.5 mm and cone height 4 mm), and the center cell (radius 51.0 mm

and cone height 4 mm) with the FPC, tuner, and a JLab C100/C50 RF window 2 mm above the 92.0 mm taper, we get a 3-cell cavity, as shown in Figure 2(d). 7.95 mm blending is applied all around the FPC. A vacuum port is added on the vacuum side of the FPC window.

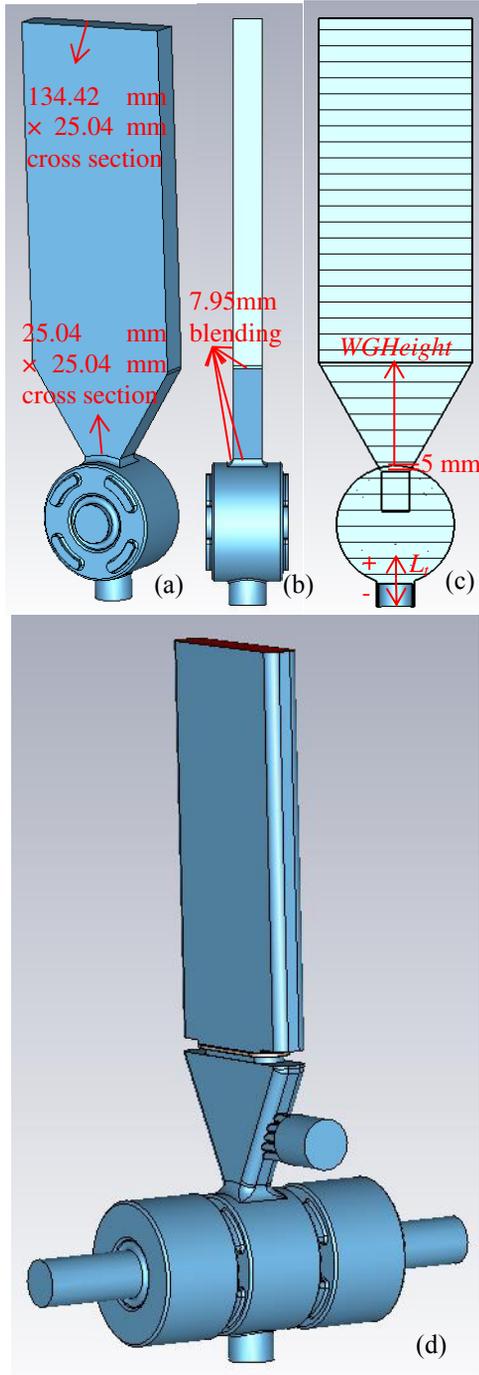


Figure 2: Center cell with the FPC and tuner: (a) perspective view; (b) side view; (c) cross section from front (blending is not shown here); and (d) 3-cell cavity.

This design is simulated for different tuner penetrations, from -6 mm to 12 mm using ACE3P package. Using CST MWS cannot guarantee the resonance frequency to be converged due to the limitation

of the desktop memory on the mesh quality. Simulation results are shown in Table 1, and in Figure 3 we show the field flatness at different tuner insertion  $L_t$ . With the tuner at 0 mm, the resonance frequency is 2.1115 GHz, the quality factor is 14,133. After taking into account a reduction factor of 1.3 due to surface roughness of cavity walls, the quality factor drops to 10,872. The external  $Q$  factor of FPC is 10,948. At  $\beta = 1$ , the  $R/Q$  is 487.6  $\Omega$ . With the tuner varying from -6 mm to 12 mm, the frequency range is 7.26 MHz, the  $R/Q$  varies from 480.3  $\Omega$  to 487.6  $\Omega$ , the quality factor varies from 10,861 to 10,996 after considering the 1.3 factor, and the FPC's external  $Q$  varies from 9,910 to 17,872. The reason for the FPC's external  $Q$  change is due to the field flatness change: with the tuner inserted deeper into the cavity, the field is pushed to the end cells, which makes the coupling weaker and thus gives a higher  $Q_{ext}$ .

Table 1: RF Parameters for Different Tuner Insertion

$L_t$ [mm]	$f$ [GHz]	$Q_0/1.3$	$Q_{ext}$	$R/Q$ at $\beta=1$ [ $\Omega$ ]
-6	2.1100058	10861	9910	484.18
0	2.1115363	10872	10948	487.57
6	2.1145674	10907	13588	488.06
12	2.1172592	10996	17872	480.26

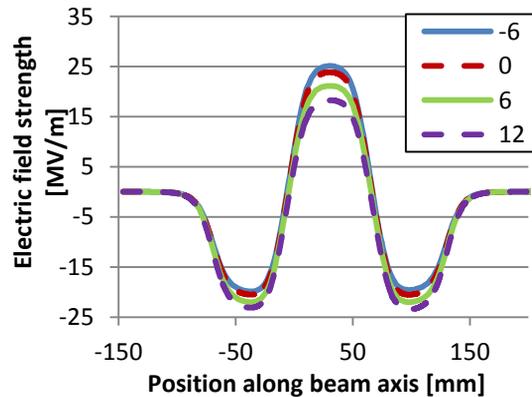


Figure 3: Accelerating component of the electric field on beam axis for the 3-cell cavity, with tuner penetrations at -6, 0, 6, and 12 mm.

### B. 704 MHz Cavity RF Design

The 704 MHz cavity is designed to deliver up to 430 kV accelerating voltage. It will dissipate about 25.5 kW in its walls. The design frequency is 703.567 MHz, and the beam pipe diameter is 1.875 inches.

We started from a pillbox shape cavity design showed in Figure 4(a), and compared it with a toroidal shape (pillbox shape with round blending that merges to a toroidal) that was previously designed for the NLC (Next Linear Collider) project at LBNL [3]. By merging these two designs a cavity with an elliptical shape shows better shunt impedance and is adopted.

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Pillbox shape with a cavity length  $L = \lambda/2$  is evaluated, as shown in Figure 4(a). Similar to the 2.1 GHz design, two nose cones (height  $h$ ) are used to improve the cavity shunt impedance.  $R_d$  is adjusted so that the resonance frequency stays at 703.567 MHz. A maximum shunt impedance is achieved with  $h = 32$  mm and  $R_d = 147.7$  mm.

Toroidal shape with a cavity length  $L = \lambda/2$  is evaluated, as shown in Figure 4(b). Two nose cones (height  $h$ ) are used to improve the cavity shunt impedance. The cavity is blended to toroidal shape using  $L/2$  blending radius.  $R_d$  is adjusted so that the resonance frequency stays at 703.567 MHz. Different values of  $h$  and  $R_d$  are evaluated; a maximum shunt impedance is achieved with  $h = 28$  mm and  $R_d = 172.1$  mm.

Based on the above analysis, the elliptical shape is evaluated with  $h$  fixed at 28 mm, as shown in Figure 4(c). Different ratios between the long radius and short radius, named *RatioEllip*, are evaluated, with  $R_d$  adjusted so that the resonance frequency stays at 703.567 MHz. A maximum shunt impedance is achieved with *RatioEllip* = 1.5.

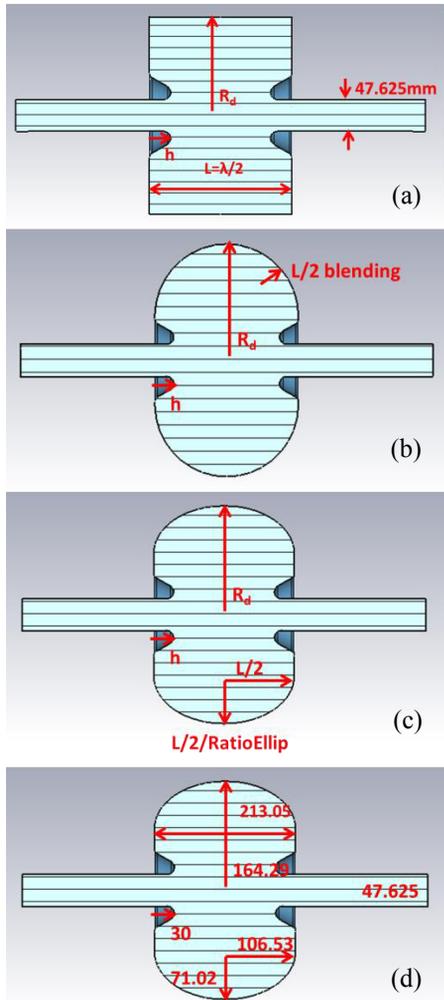


Figure 4: Single cell 704 MHz cavities: (a) pillbox shape; (b) toroidal shape; (c) elliptical shape; (d) optimized elliptical cavity with dimensions in mm.

Further optimizations of  $h$  and the cavity length  $L$  ( $\pm 10$  mm relative to  $\lambda/2$ ) were done for the elliptical cavity with *RatioEllip* fixed at 1.5. A maximum shunt impedance is achieved with  $h = 30$  mm and  $L = \lambda/2$ . The optimized geometry is shown in Figure 4(d).

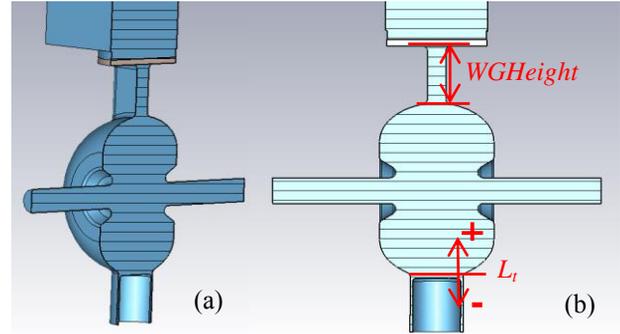


Figure 5: A single cell elliptical cavity with the FPC and tuner: (a) perspective view; (b) side view.

The elliptical cavity with a tuner and FPC is shown in Figure 5.  $h = 30$  mm,  $R_d = 162.6$  mm and *RatioEllip* = 1.5 are used to evaluate the effect of the 90 mm diameter tuner, with tuner penetration  $L_t$  to be -9 to +18 mm. 153.122 mm  $\times$  33.868 mm waveguide, with the short edges blended to be round, is used to connect the cavity with a 381 mm  $\times$  108 mm waveguide, with an NLC window in between [4]. *WGHeight* is chosen to be 105.8 mm, so that FPC's  $Q_{ext} = 26,063$  and  $Q_0 = 26,023$  after considering 1.3 factor due to the surface roughness, at  $L_t = 0$  mm. The cavity performance at different  $L_t$  is shown in Table 2. The tuner insertion will slightly affect the quality factor of the cavity and the FPC's  $Q_{ext}$ .

Table 2: Cavity Performance at Different Tuner penetrations  $L_t$

$L_t$ [mm]	$f$ [MHz]	$Q_0/1.3$	FPC $Q_{ext}$	$R/Q$ at $\beta=1$ [ $\Omega$ ]
-9	703.02	26414	26434	247.89
0	703.58	26023	26063	247.48
9	704.69	25392	25794	247.03
18	706.03	24645	25278	246.47

## CONCLUSIONS

In this paper, we report the RF optimization of the elliptical 704 MHz and 3-cell pillbox 2.1 GHz normal conducting RF cavities. The thermal simulations and mechanical designs will follow to finalize the designs.

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