High Current Superconducting Gun at 703.75 MHz

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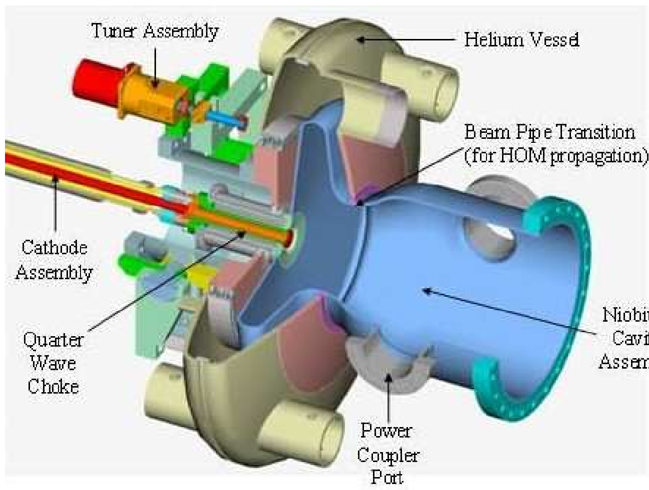
Introduction

Electron cooling of ion beams is the main component in next luminosity upgrade of the Relativistic Heavy Ion Collider (RHIC). A superconducting energy recovery linac (ERL) along with a superconducting electron gun has been identified as the most efficient choice to generate and accelerate high current low emittance electron beams. A $\frac{1}{2}$ cell SRF gun has been proposed as an injector to the 20 MeV ERL prototype as an initial step towards the development of a high current ERLs.



Like any SRF cavity, the design of the gun is effected by peak surface fields, avoidance of multipacting, access to surface chemistry, minimization of welds at critical points, mechanical stiffness and the complexity of manufacturing. High current beams along with high bunch charge pose a siginificant challenge because it necessitates strong damping of HOM wakefields and efficient extraction of the large HOM power. Accelerating ampere CW class beams also require high power fundamental couplers (FPC) capable of delivering megawatts (MW) which is a non-trivial development.
In addition to RF and mechanical requirements, the preservation of very low emittance and energy spread puts strict requirements on the shape of the gun shape. Since, the electrons start from the cathode at rest, a high field on the cathode is necessary to rapidly accelerate the bunches to avoid emittance dilution due to space charge forces. The addition of a replaceble laser-photocathode (for example cesium) in an ultra clean superconcducting environment adds to the overall complexity of design. A 1/4 wave choke design has been been designed for RF isolation of the cathode stem to be at a relatively higher temperature than the SRF gun.

Cavity Designs

An initial design (I) was developed from the Rossendorf $\frac{1}{2}$ cell gun which was scaled to 703.75 MHz with a beam pipe transition to propogate HOMs. Several other designs (2-6) were developed as a result of shape optimization based on both RF and beam dynamics issues. The final design for the proposed 2 MeV injector was chosen to be design 5.

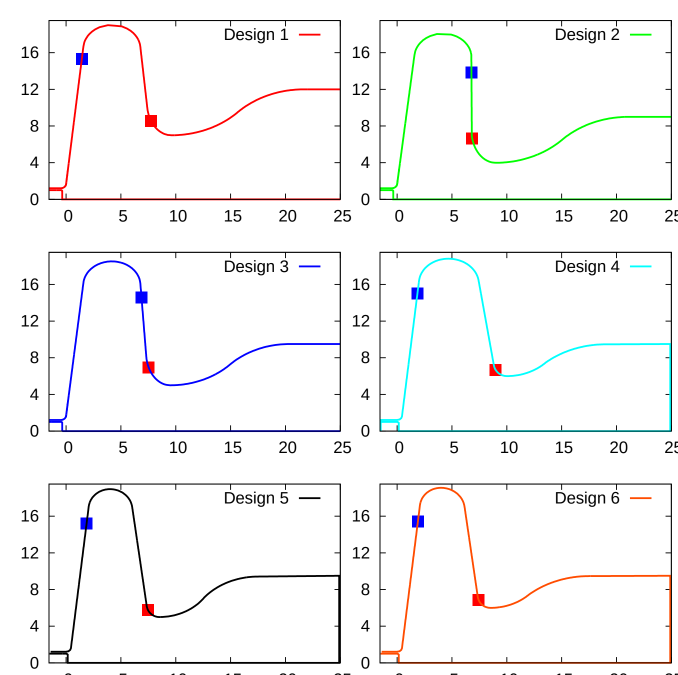


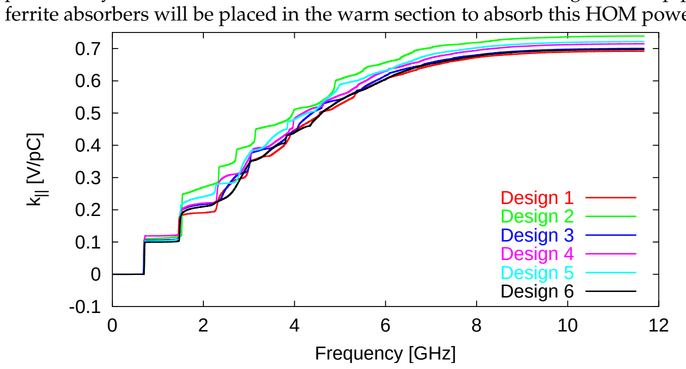
Table below shows a comparison of some relevant RF parameters for the different shapes.

Shape	Iris [cm]	r/Q [Ω]	E_p/E_a	B_p/B_a $[\frac{mT}{(MV/m)}]$
Design 1	7	101.1	3.0	2.4
Design 2	4	105	3.92	2.14
Design 3	6	102.5	3.2	2.34
Design 4	6	112	3.34	2.01
Design 4	5	94.6	4.276	2.03
Design 5	6	92.2	4.176	2.02

RF Issues

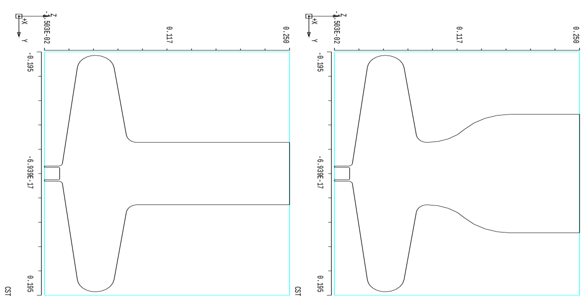
HOM Power

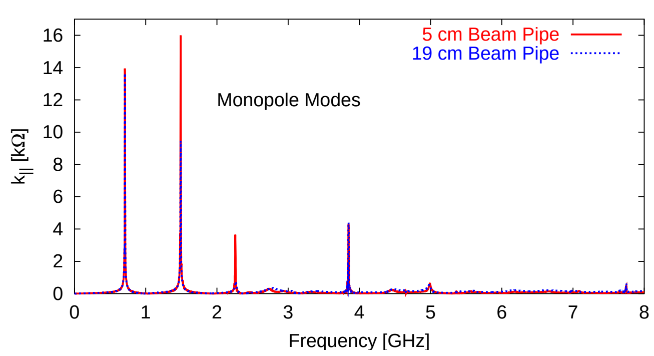
The loss factor for all six designs are similar and the total HOM power is approximately 1.4 KW for 200 mA current and 10 nC bunch charge. Beam pipe ferrite absorbers will be placed in the warm section to absorb this HOM power.

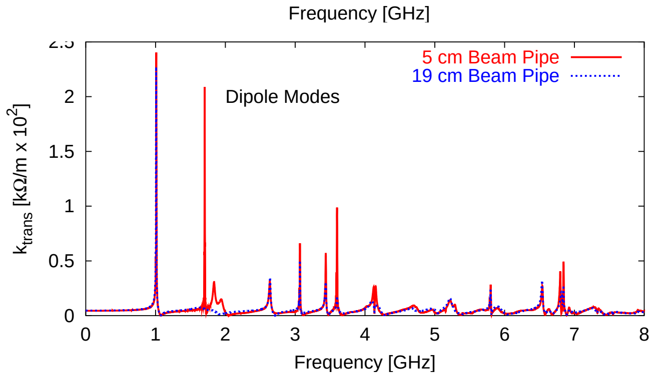


Transition Section

Since, the density of HOMs is small (below 5 GHz), the choice of enlarged beam pipe can be avoided at the cost of having a few undamped modes. This greatly simplfies engineering issues and also allows one to bring the solenoid closer to the gun exit. The impedance spectrum of monopole and dipole modes are seen below.

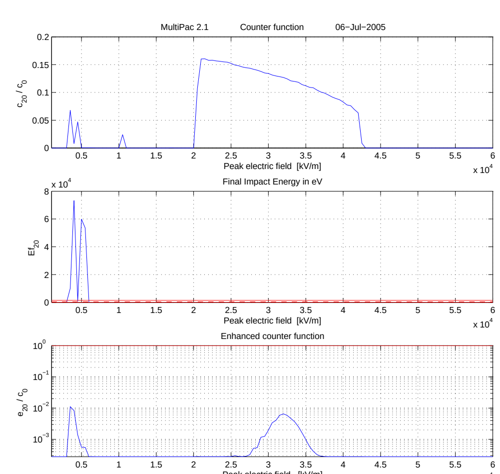


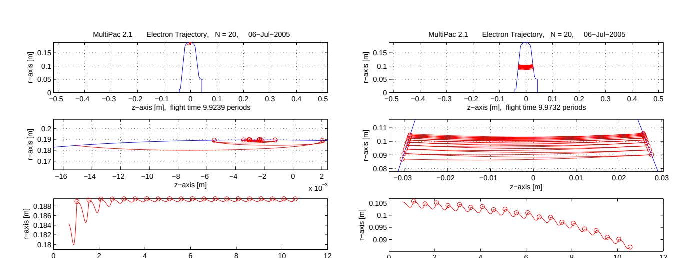




Multipacting

The Helsinki code, MultiPac 2.1, is used to calculate the field levels at which multipacting can be onset and their corresponding trajectories. The enchanced counter function is below "1" indicating the level of secondary electrons to be smaller than primary electrons thus alleviating multipacting.

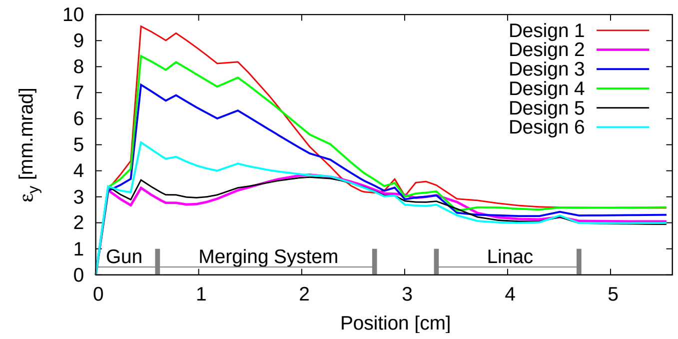




Beam Dynamics

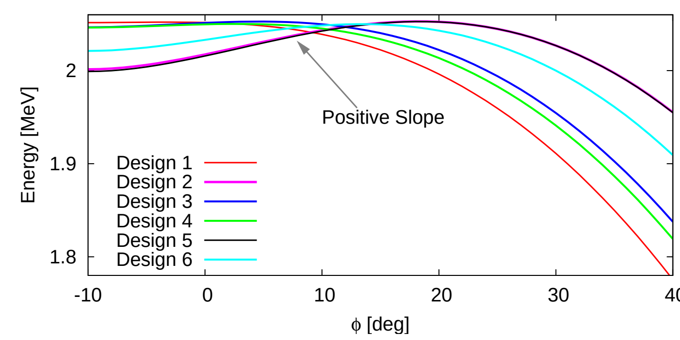
Vertical Emmittance

The evolution of vertical emmittance through the gun, merging system and the 20 MeV linac is seen below. Although, all guns show small emmittances, designs 2 & 5 are significantly better.



Energy Vs. Phase & Energy Spread

The energy vs. intial phase of the emitted electron for the six designs is seen below. Design 2 & 5 show a significant positive slope compared to the others thus providing a larger effective longitudinal focusing and minimize energy spread.



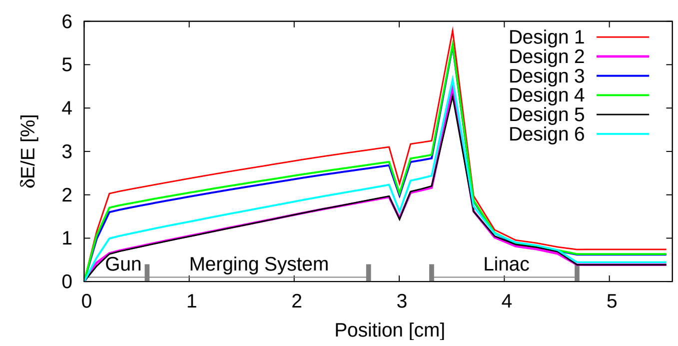


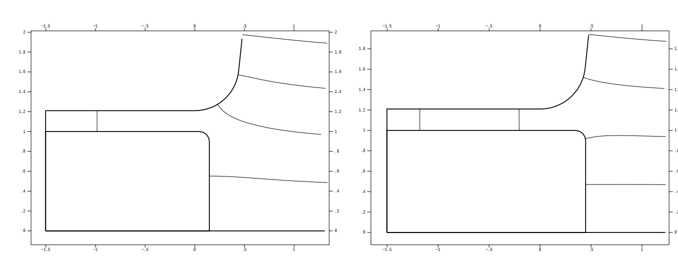
Table below shows loss factors, vertical emmittance and energy spread for the six designs under consideration.

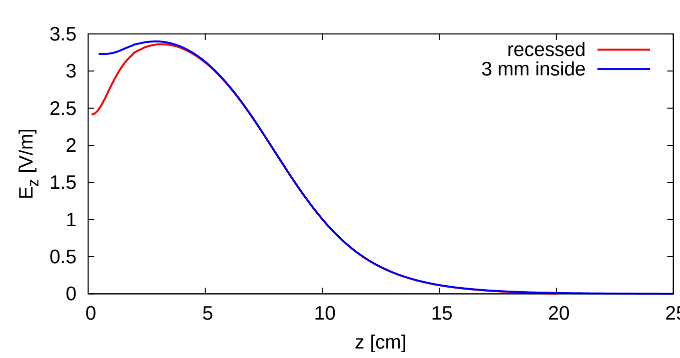
Shape	$k_{\|\|}$ [V/pC]	$k_{\perp}$ [V/pC/m]	ϵ_y [mm.mrad]	$\delta E/E$
Design 1	0.692	49.1	2.569	7.4 %
Design 2	0.7397	31.42	2.053	3.9 %
Design 3	0.7011	31.62	2.306	6.2 %
Design 4	0.7155	32.3	2.595	6.3 %
Design 5	0.7225	31.74	1.944	3.86 %
Design 6	0.6981	32.25	1.993	4.4 %

Cathode Position

From Fig. below one can see that E_{cath}/E_{acc} is significantly larger for the case when the cathode is not recessed. This high field near the cathode region is critical to accelerate the electrons as fast as possible to counteract space charge effects.

Recessed 3mm Inside





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