

# A New Thermionic RF Electron Gun for Synchrotron Light Sources\*

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- Motivation
- Experience with the existing guns
- Requirements for a new thermionic gun
- Electromagnetic design
- Cathode back plate design
- Fabrication progress
- High power test stand

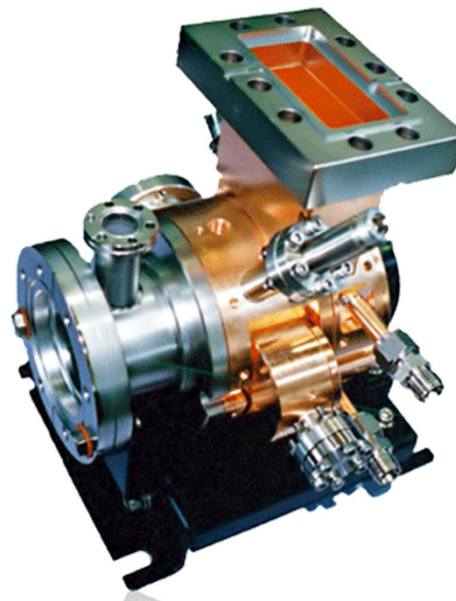
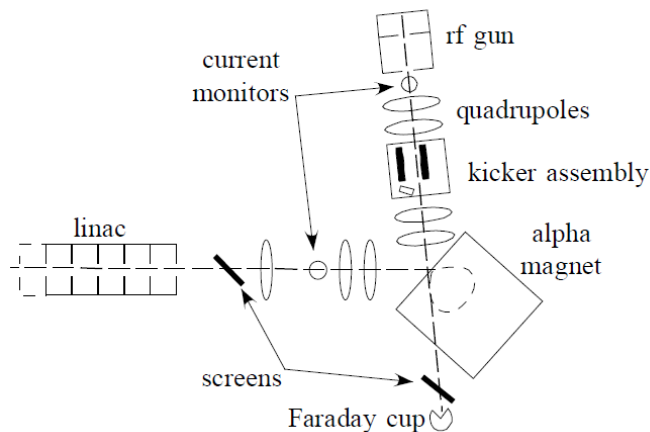
- Thermionic guns are conventional and very widespread source of electron beams, where electrons are released from materials by heating.
- RF guns can accelerate electrons to few MeV energy over few-cm distance

Pros	Cons
Simplicity of use, reliability and availability of the long bunch trains	Gets very hot when operating at high duty cycle regime
Beam is less sensitive to space charge forces due to a higher energy	The vacuum level can often be of a poor quality
Eliminates a need for a buncher cavity due to the pre-bunching the beams	Relatively large emission area implies intrinsically large thermionic emittance

- Thermionic radio-frequency injection system has been historically a working horse of the third generation light sources, such as APS at Argonne

# Injector at Advanced Photon Source

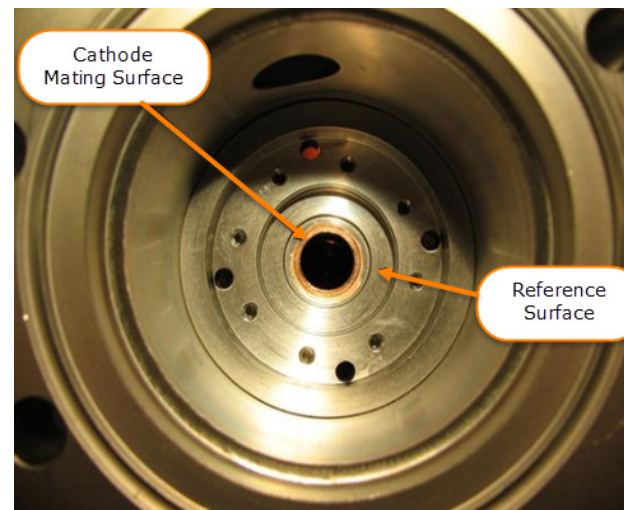
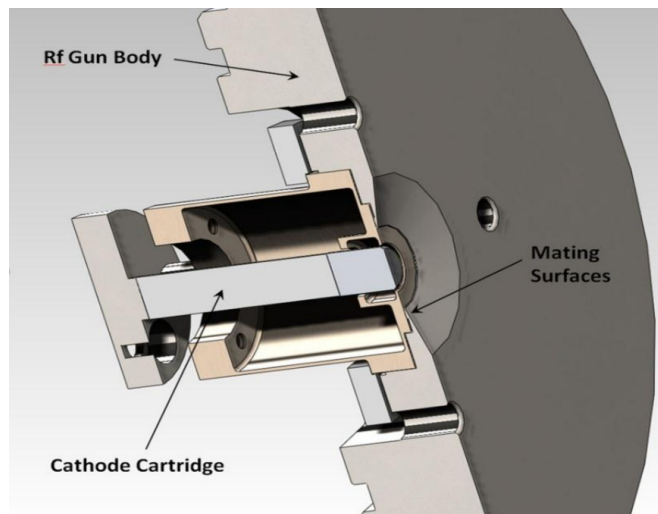
- The RF thermionic gun serves as an injector for the APS storage ring
- The injector system consists of a thermionic RF gun, a fast kicker for beam current control, and an alpha magnet for bunch compression and injection into the APS linac line



Number of cells	1.6
Frequency	2856 MHz
Beam energies	$\leq 4.5$ MeV
Peak currents	up to 1.3 A
Pulse length*	$\sim 1$ $\mu$ s
Rep. Rate*	$\sim 15$ Hz

\* Practical values

- APS procured three new RF guns in 2001 and found that:
  - Difficult in installation and easily detuned;
  - Geometry is very sensitive to the thermal expansion cycle.
- The problems come from the distortion of the mating surfaces of the gun back plate and the cathode



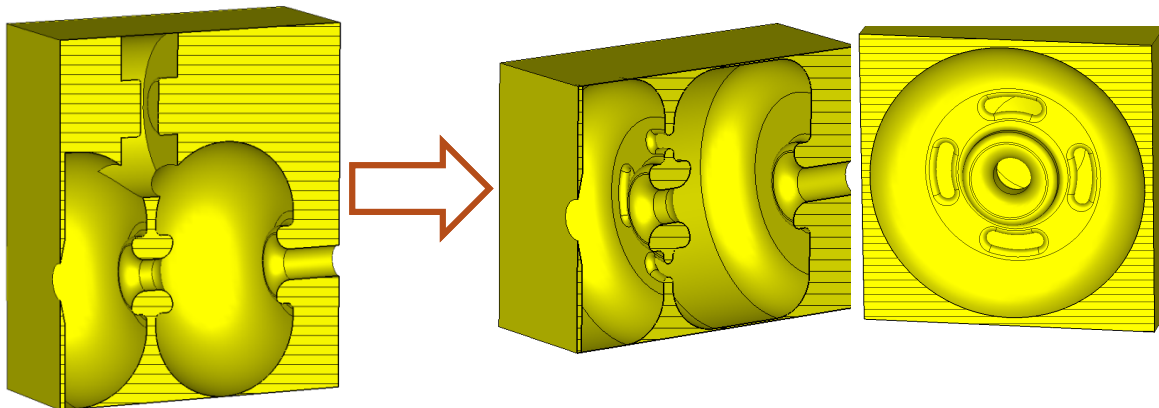
More details in W. Jansma, "RF Electron Gun Mechanical Repair", 2013 APS Accelerator Systems Division Seminar Series

- The new gun must have improved RF and mechanical design, by incorporating the following proposed innovations and improvements:
  - Proper longitudinal phase space chirp suitable for APS alpha magnet
  - Robust interface between the gun back plate and cathode insertion
  - Tunability of the cavity resonance frequency:
  - Higher repetition rates and pulse length.
  - Drop-in replacement

Operating frequency	2856 MHz
Output energy	up to 3 MeV
Accelerated current,	up to 1A
RF power	5 MW
Repetition rate	up to 100 Hz

# Electromagnetic Design

- The existing thermionic RF gun has a side coupling cell.
  - Required to tune the field ratio between the cells
  - Increases frequency mode separation in the cavity
  - Breaks the symmetry of the structure (dipole modes)
  - The peak surface magnetic field is strong in the coupling slot (shorter pulses)
- We propose a  $\pi$ -mode structure design with magnetic coupling slots
  - Electrode shapes are the same (beam parameters)
  - Peak fields are smaller (longer pulse)
  - No dipole components
  - Can be tuned by pin-tuners

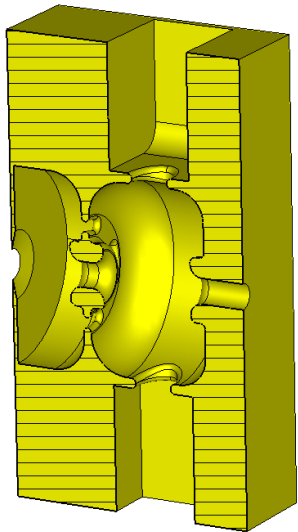


Structure	$\pi/2$	$\pi$
$E_{full}$ , MV/m	70	70
$\Delta f$ , MHz	48	22
$R_{sh}$ ( $\beta=0.999$ ), $M\Omega/m$	62.5	60
$E_{peak}$ , MV/m	145	142
$T_{pulse}$ , $\mu s$	1.5	3.1

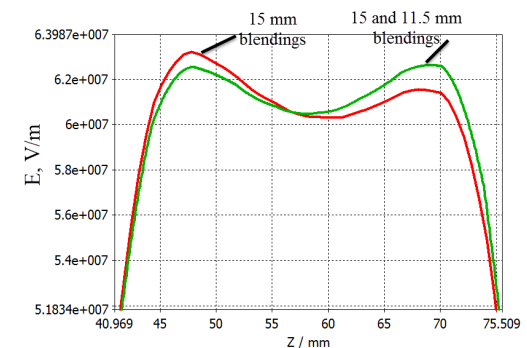
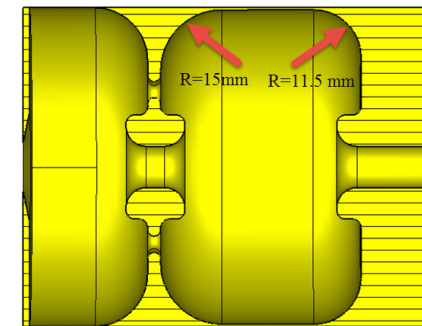


# Field Symmetry

- Four coupling slots ensure symmetry and eliminate dipole and quadrupole components
- Cell roundings have to be different to ensure the longitudinal field distribution symmetry
- Symmetrical waveguide has been added to the design to eliminate dipole components

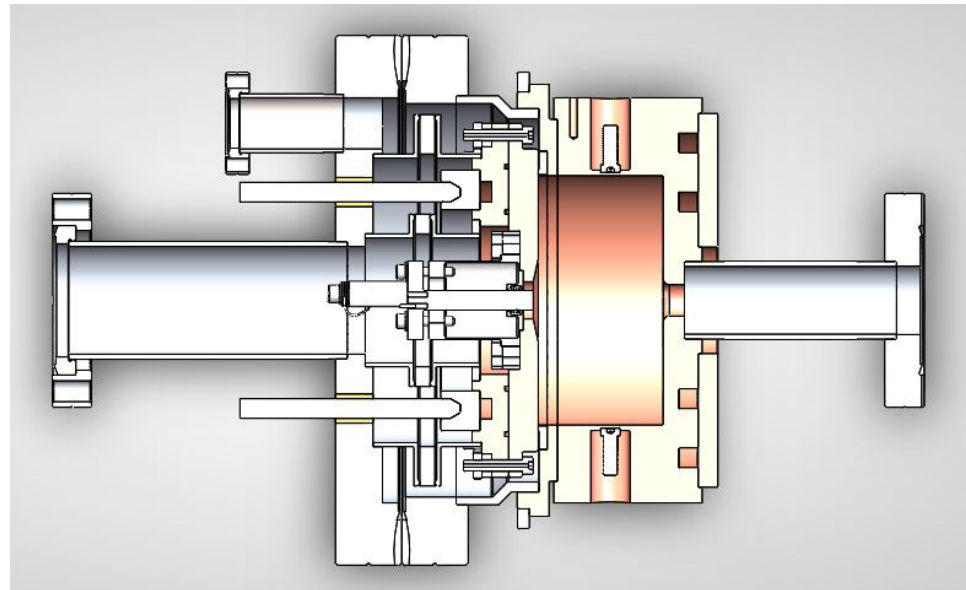
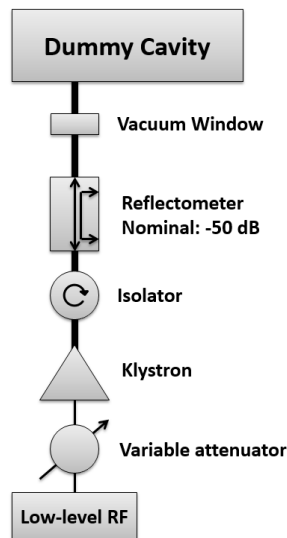


Transverse Kick		
$\beta$	Old Design	New Design
0.9	27 kV	0.49 kV
0.7	20 kV	0.37 kV
0.5	9 kV	0.18 kV



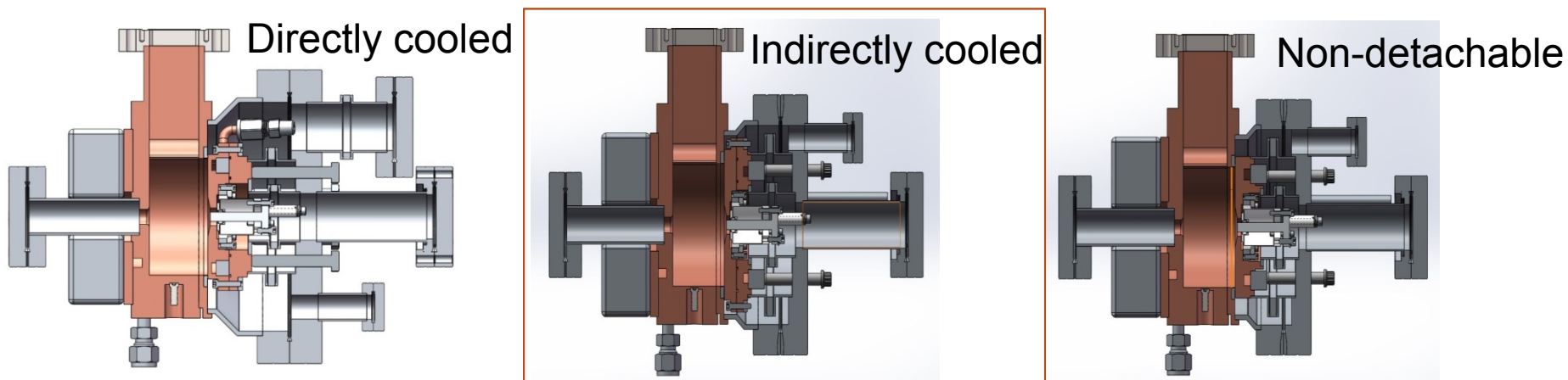
# High Power Test Stand

- The goal of the first Phase of the project is to create a high power test stand for cathode assembly and back plate tests
- The test stand is based on the dummy cavity tuned to 2856 MHz, connected to the klystron
- The cathode assembly is detachable
- Diagnostics include thermal sensors and Faraday Cup



# Cathode Back Plate Design

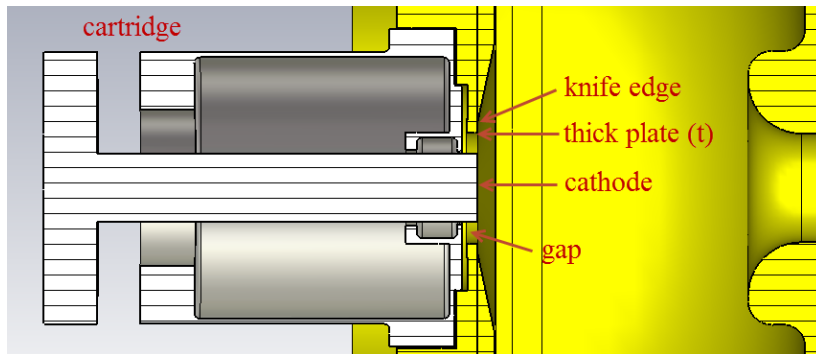
- Three different designs were explored.
- The indirectly cooled detachable back plate was chosen
  - The average power dissipation would not be high in the Phase I test,
  - Permitted flexibility of back plate modifications and experimentation.



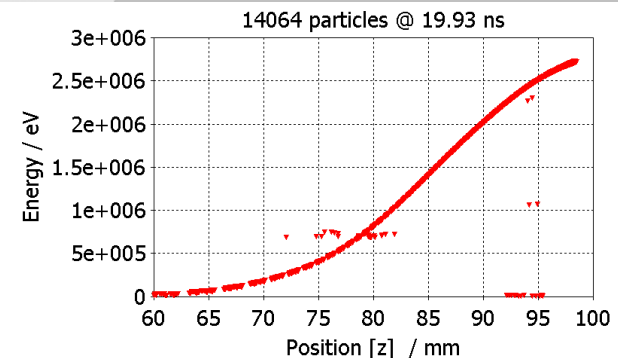
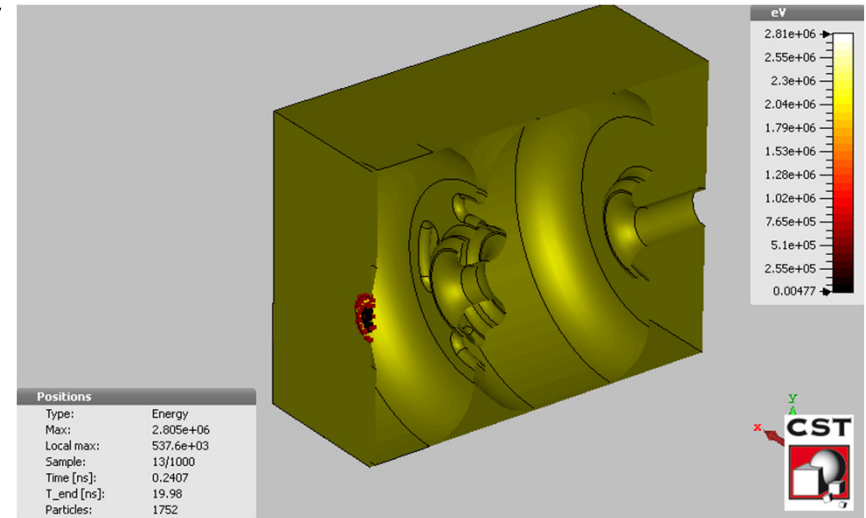
- Upon experimental validation, the final gun design may utilize a non-removable back plate

# Knife Edge Design

- Thickening the knife edge of the cathode back plate improves structural stability significantly



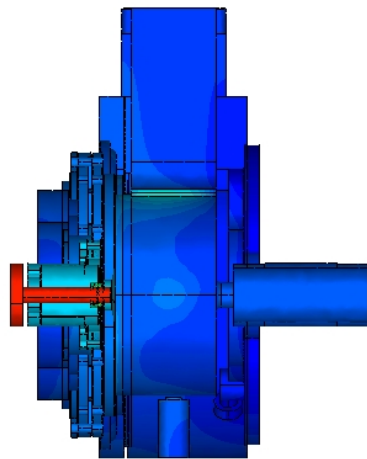
Length taken for bunch leading part	$\epsilon_n$ [ $\mu\text{m}$ ] L=0.6m	$\epsilon_n$ [ $\mu\text{m}$ ] L=2.4m
Full	26.1	8.4
1 cm	4.29	1.97
2.39 mm	0.93	0.4



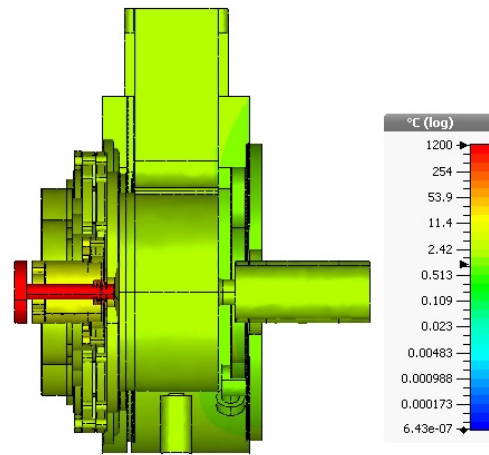
- Emittance and capture for different edge thicknesses is relatively negligible

# Thermal Analysis

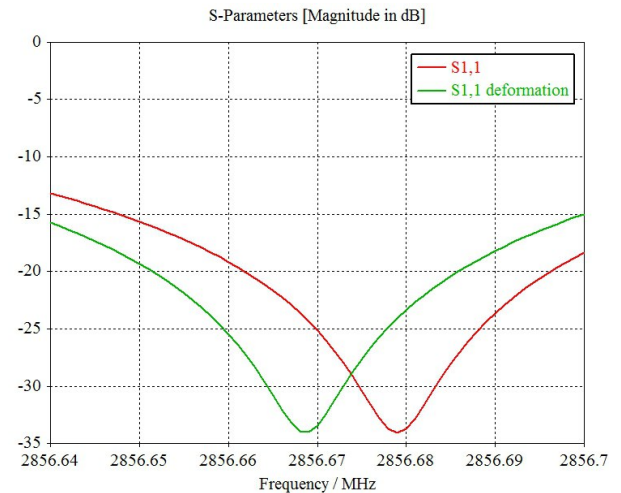
- Thermal losses come from RF heating, conductive and radiation heating from the cathode, and back bombardment



From RF heating



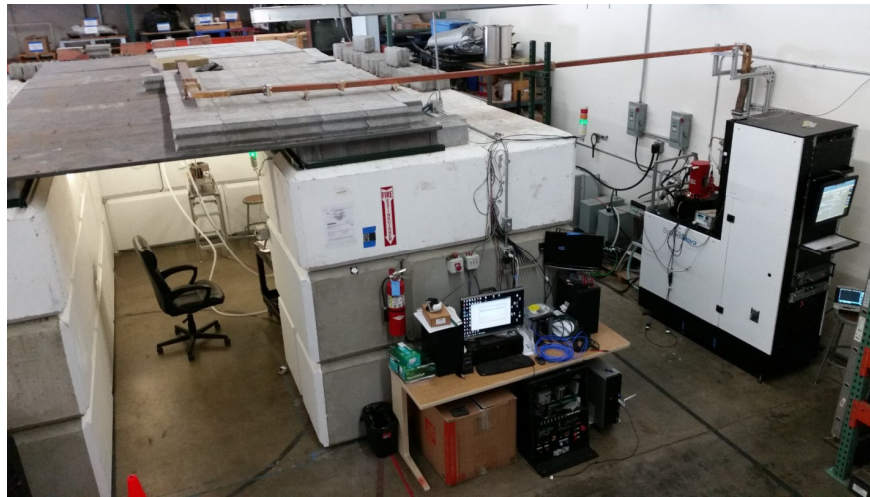
All losses



- The simulations show plausible heating at 100 Hz 3  $\mu$ s regime at the operation field levels

# Preparations for High Power Tests

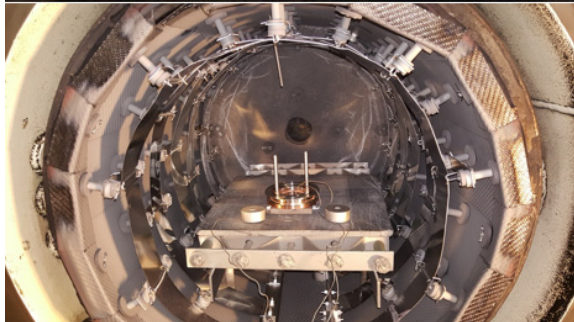
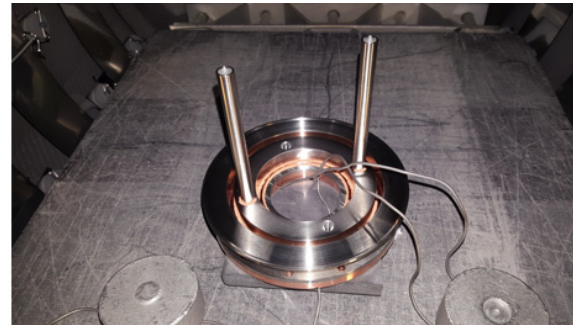
- The test will take place in the bunker at RadiaBeam
- The high power RF system for this experiment is based on a CPI VKS-8262F2 S-band klystron.
  - 5 MW peak power, and 36 kW average power.
  - Driven by a ScandiNova K1-P solid-state modulator.
  - A Microwave Amps Ltd. model AMS10-2.85S-52R provides the low-level RF source and preamp for the input of the klystron



- All components are in-house and have been tested to verify performance requirements

# Fabrication Progress

- All the components required for the cathode cooling plate braze were machined, checked dimensions per print, fitment checks done, cleaned, brazed and leak checked.
- Necessary parts for the welding have been machined, fitment checks done, cleaned and sent out for welding.
- Braze as well as post braze machining sequence finalized.



- We designed a pi-mode RF gun that provides more robust performance than the side-coupled gun, easier to manufacture and free of dipole field component.
- We designed a mechanically stable cathode assembly back-plate with active water cooling
- Conceptual tuning mechanism is developed
- Heatwave 61280 commercial cathode was chosen for operation for its proven reliability and availability. We discussed the possible upgrade of this cathode with vendor in Phase II
- We designed high power test setup including the dummy cavity with an input coupler and diagnostic tools
- All hardware RF components were ordered and received. The klystron was tested, and the bunker is prepared for RF gun test
- Waiting for fabricated parts. Other equipment is ready for high power tests