A CW L-Band Micro-Pulse Klystron

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FM Technologies, Inc., Chantilly, VA, USA

FMT Capabilities

- Founded in 1987, FM Technologies, Inc. (FMT) is a technology company with expertise in: charged particle beams, particle accelerators, plasma physics, electron/ion/microwave beam interaction with materials, microwave source development, pulsed power, and integration of these areas
- FMT has several projects approaching the commercial development stage:
  - Ceramic/Ceramic & Ceramic/Metal joining for use in high temperature chemical conversion processes
  - Self-Bunching Electron Guns with/without Current Amplification for RF Accelerators and RF sources

FMT Facilities/Equipment

- Headquartered in Chantilly, VA, FMT has 10,000 ft^2 of laboratory and office space available.
- Offices equipped with multi-core workstations with a variety of simulation and design software.
- Laboratory has a full machine shop & plasma processing equipment:
  - Conventional & CNC lathes with high speed tool post grinder
  - Conventional & 4-axis CNC milling machines
  - Grinding and sanding equipment
  - Acetylene, arc and spot welders
  - Plasma cutting torch, RAM EDM
  - Vertical & horizontal band saws
  - Diamond saws
  - Small (digital) & large drill presses
  - Microwave assisted chemical vapor deposition system
  - RF and DC 3-gun sputtering system
  - 2473K brazing/joining furnace

FMT Facilities/Equipment

- Experimental hardware owned by FMT includes:
  - Pulsed Power Electron Beam and RF sources
    - Electron Beam System (1MV x 40kA x 0.1μs)
    - L-band (0.5 and 5 MW pulsed)
    - S-band (0.8, 1, 2.6 and 13 MW pulsed; 1, 2 & 6 kW CW)
    - X-band (0.25, 0.75 & 1.5 MW pulsed)
    - Broadband Amplifiers (50-2500 MHz, 50-900W CW)
  - MEIJI optical microscope w/ video out (400x, 2.5μm resolution)

– Oscilloscopes
  - Ten 100-400MHz digital scopes
  - One 50GHz sampling scope

– Pulsed & DC magnetic coils to 2T

– Cryo pump

– Nine vac-ion pumps, 2-400 L/s

– Seven turbo pumps, 60-400 L/s

– Fourteen roughing pumps

– 1.5 MJ Capacitor bank

– High-power RF components
  - Circulators L-Ka
  - Isolators L-X
  - Phase/amplitude adjusters
  - 0.1-1 MV pulse modulators

– Chemicals and glassware

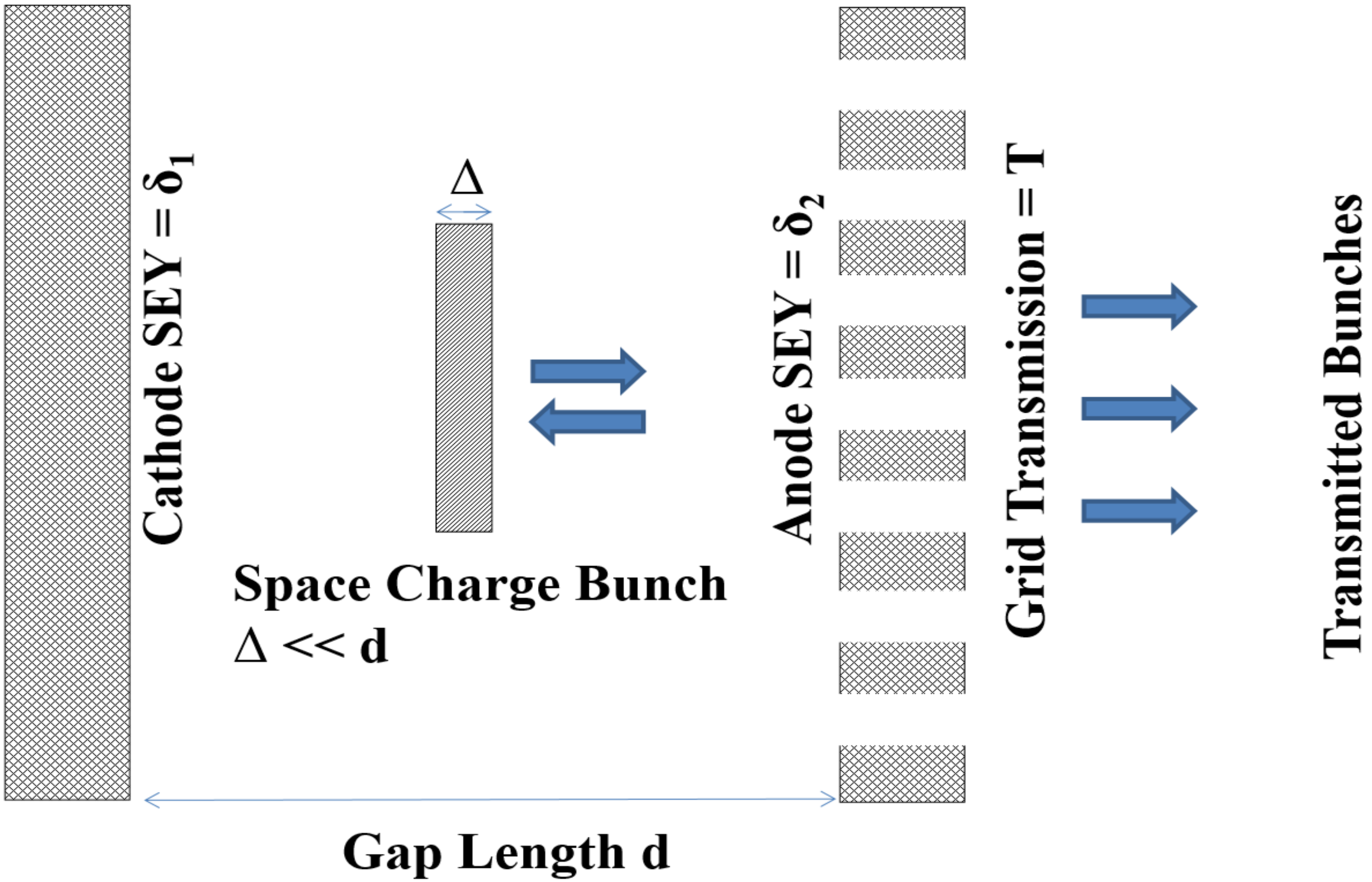
– 0.1-100kW Power supplies and other test equipment and electronics

Project Rationale and Approach

- Conventional CW Klystrons are expensive and inefficient
- FMT has been developing a self-bunching electron gun, known as the micro-pulse gun or MPG, for use as a driver for both RF sources and linacs
- RF fed into the MPG produces narrow electron bunches that are 3-5% of the RF period; electron current is proportional to the input RF power
- A post accelerated MPG beam sent into a cavity tuned to its RF input frequency produces very high RF powers, this klystron like configuration is called a micro-pulse klystron or MPK
- Narrow bunches from the MPG allow the MPK to achieve a wall-plug efficiency near 80%
- The MPK can reduce wasted energy by a factor of eight compared to a conventional CW klystron (JLAB), suggesting the MPK is a green technology
- Thomas Jefferson Laboratory could be one beneficiary of the MPK, reducing their annual electric bill from $5.77M to $2.38M.
  - Assumptions: 340 8kW tubes at 33% efficiency, electricity $0.1/kW-hr operating 7000hrs/year

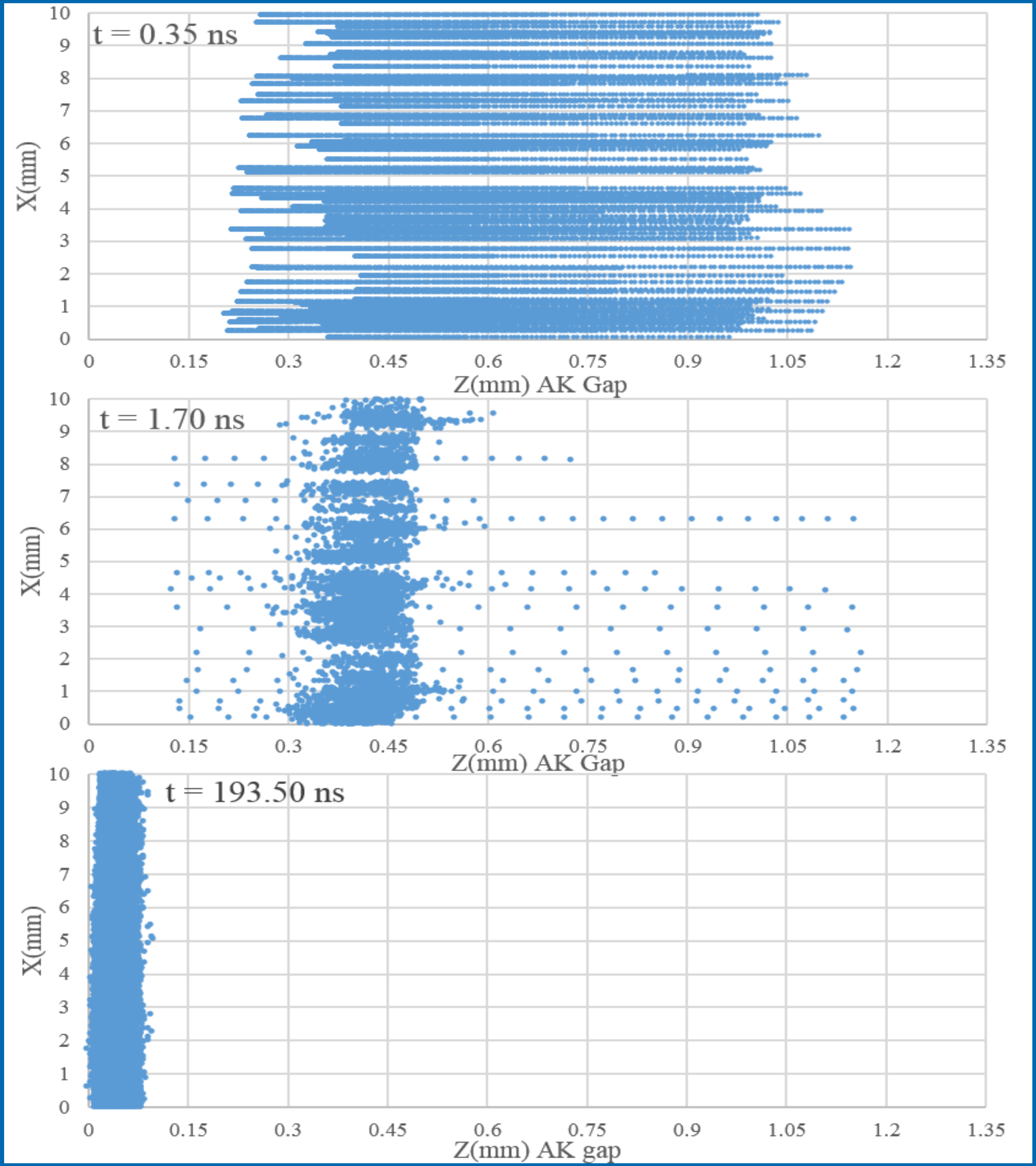
MPG Model

Model for Self-Bunching Electron Gun

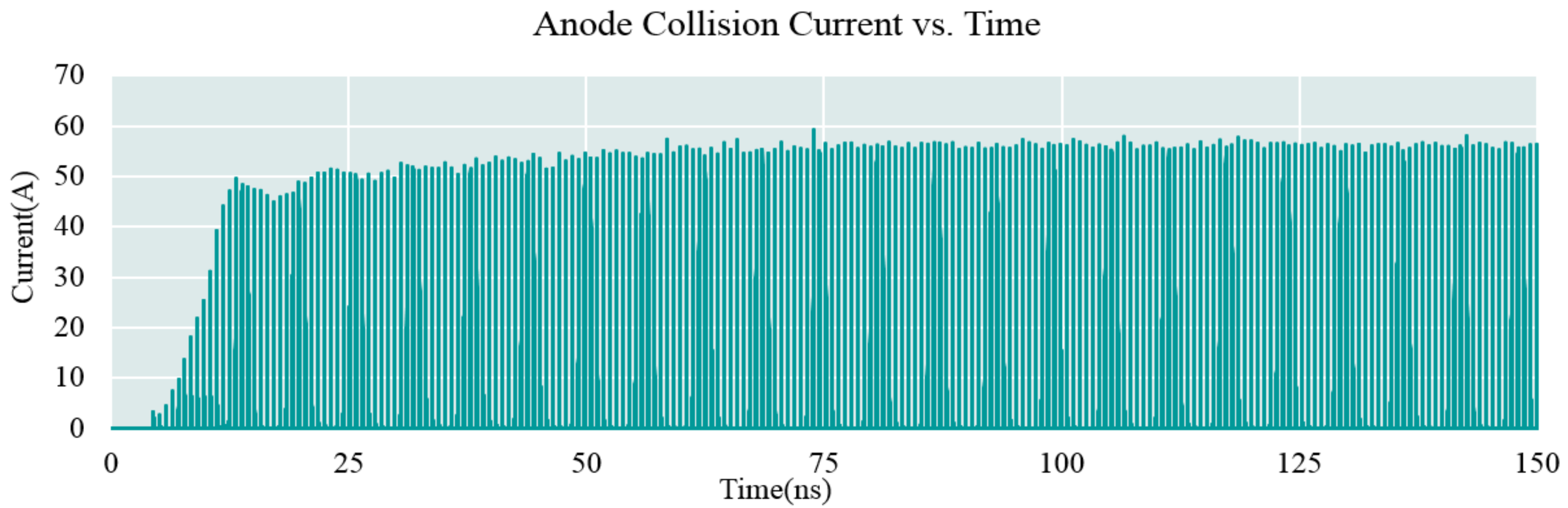


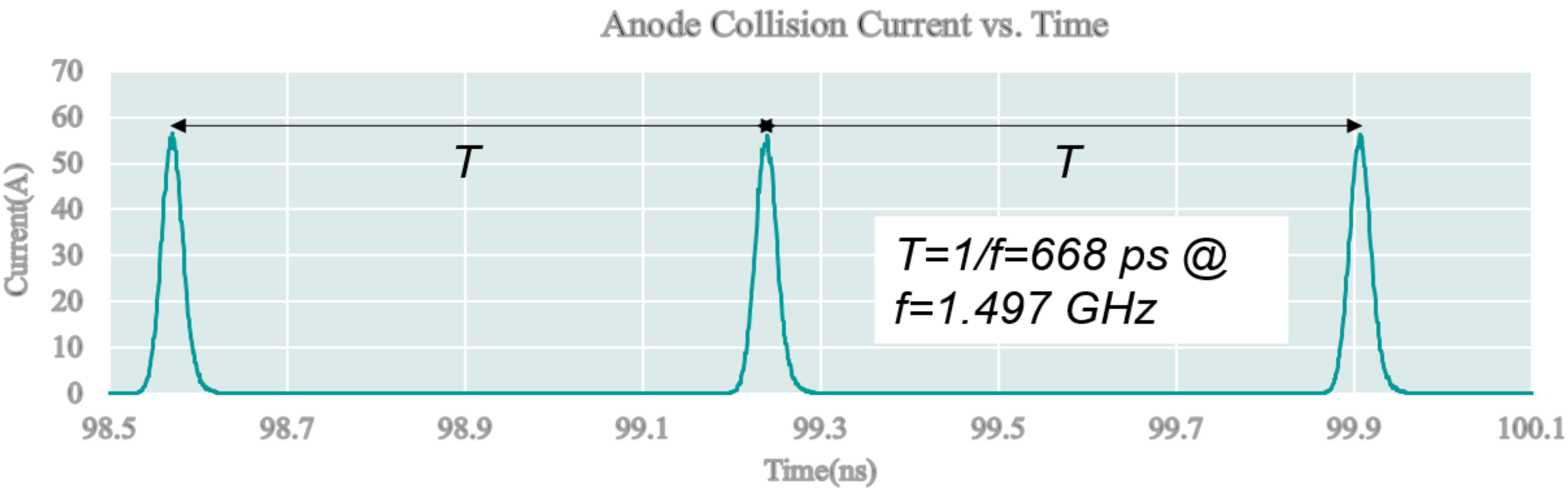
Gain Condition: $\delta_1\delta_2(1\text{-}T) > 1$, which leads to exponential growth in electrons limited by space charge.

MPG Self-Bunching

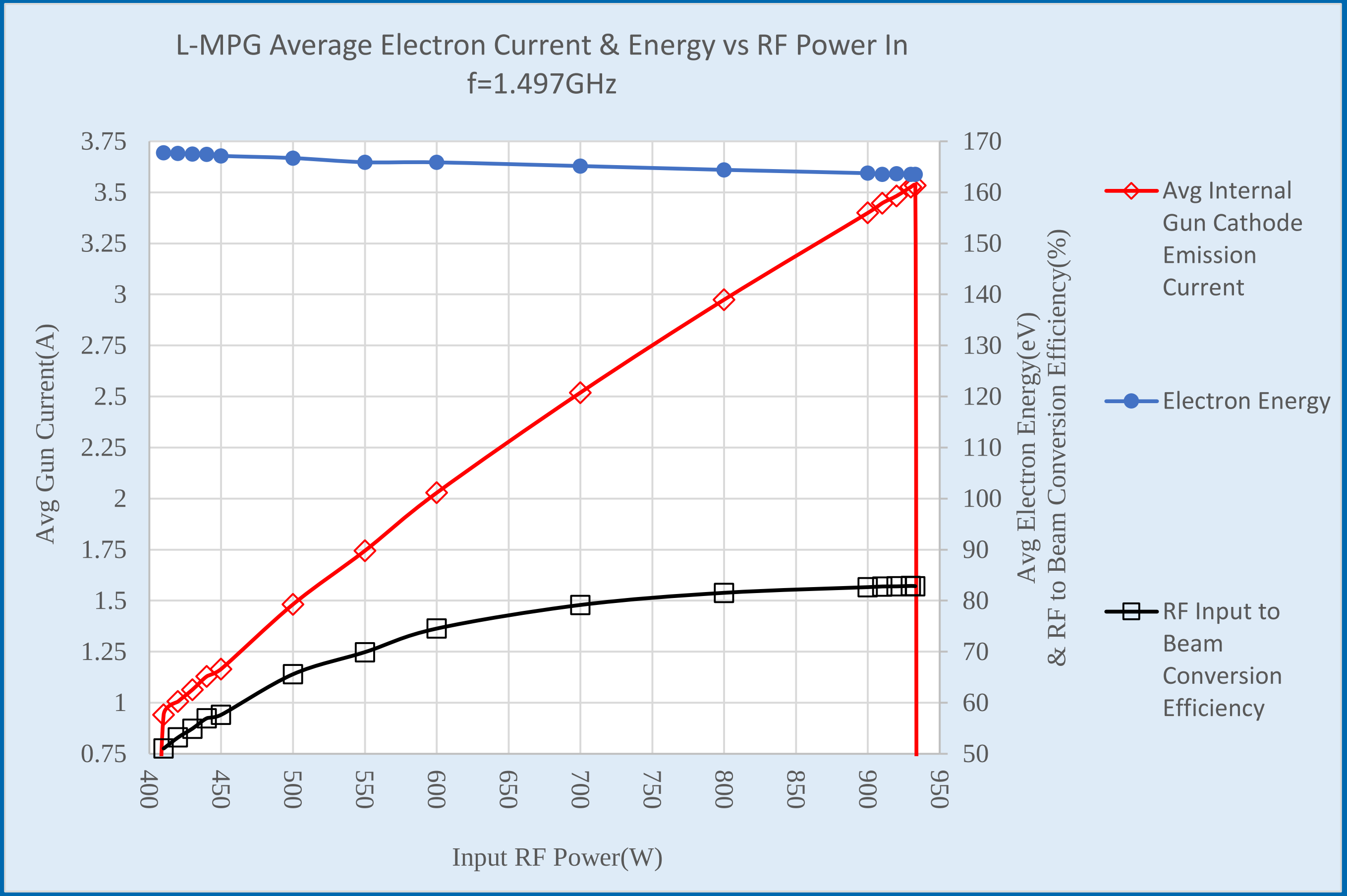


L-MPG Bunching Characteristics



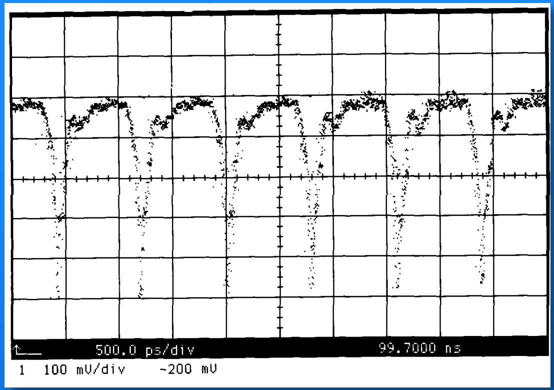


CW L-MPG Performance



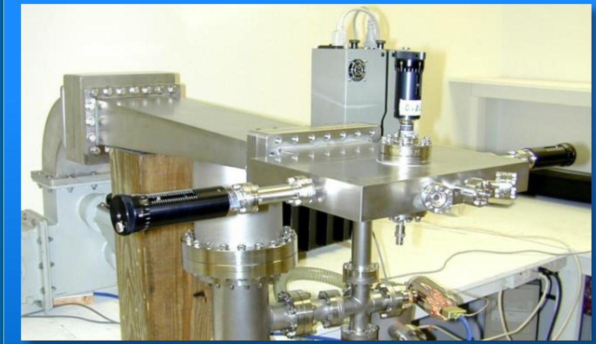
Technology Readiness

Experimental Verification of MPG Bunching

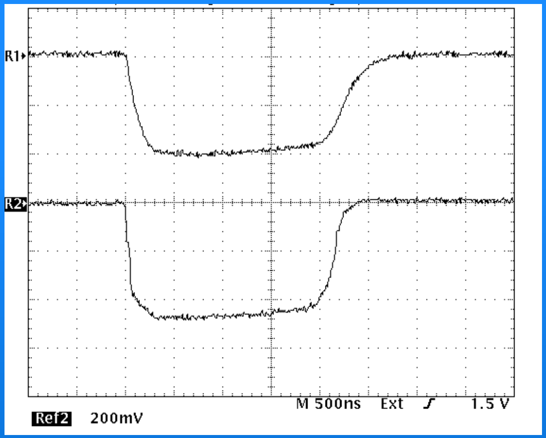


Current trace of L-band MPG micro-bunches showing one bunch per RF period

- pulse width ~40 ps
- peak current density ~22 A/cm^2



L-band experiment showing tapered waveguide and L-band MPG

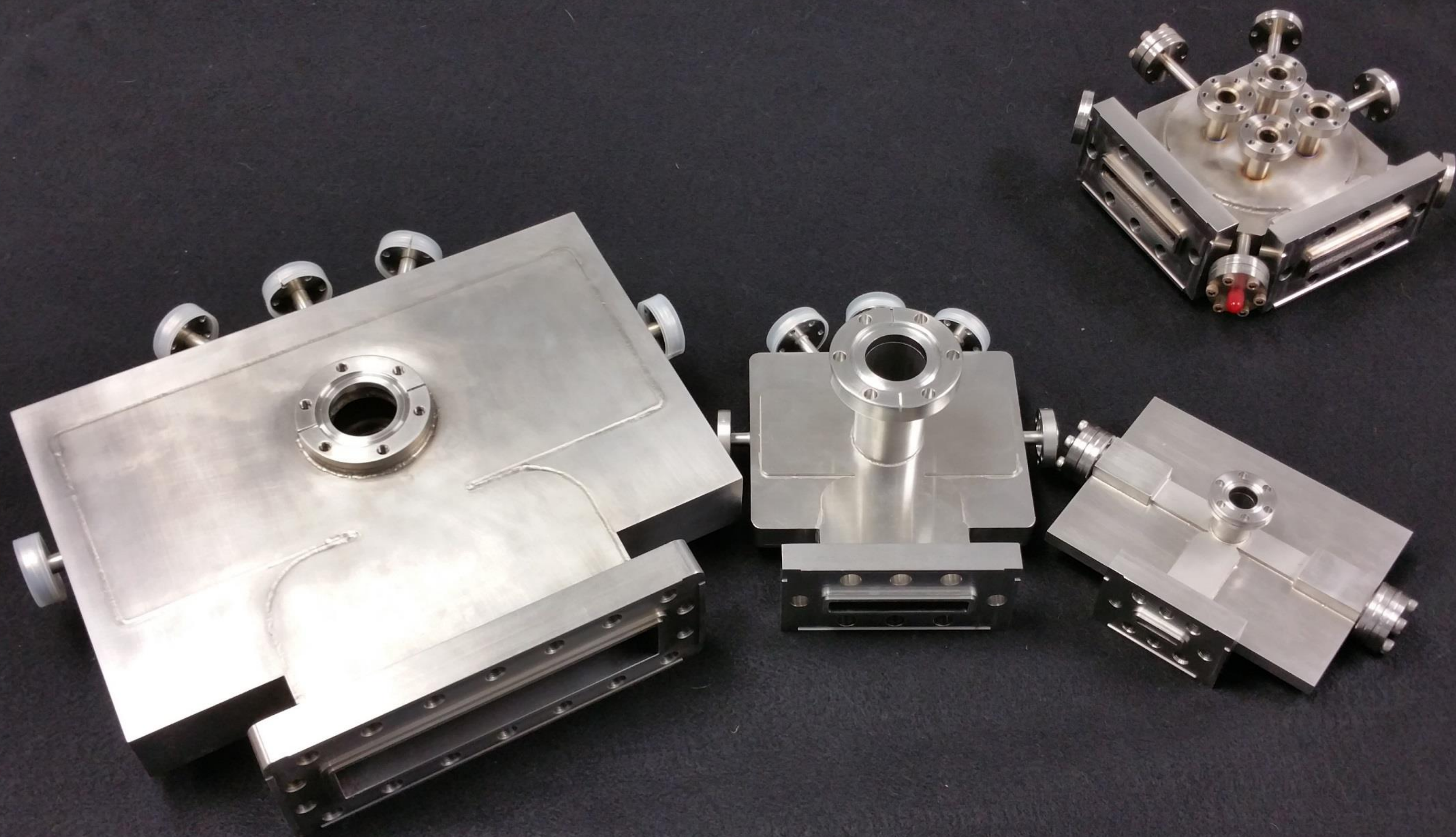


Applied RF power in cavity (top)

20 A/cm^2 transmitted macro-pulse at S-band (bottom)

Peak micro-bunch current is about 20x higher than average

Examples of L-X MPG's and a Gatling MPG



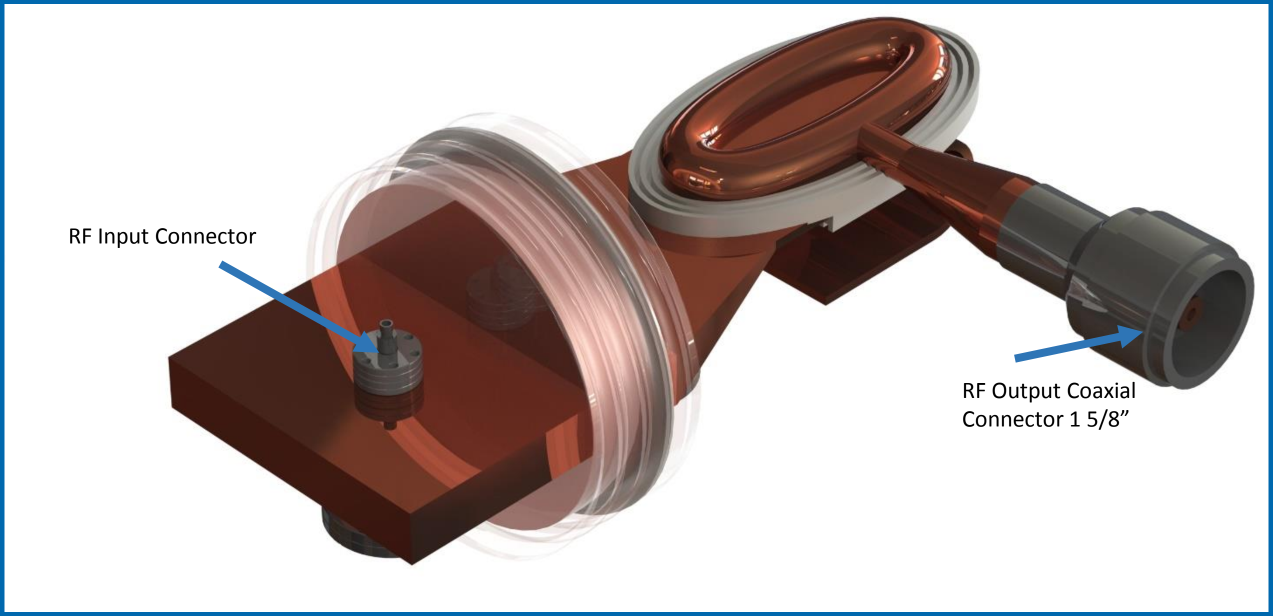
Two Primary Applications for the MPG: Microwave Tubes and Accelerators

Objectives for L-band CW MPK

- Achieve a high (~80%) wall plug efficiency with reasonable gain (~38dB includes solid state driver)
- Achieve an 8-12kW RF CW Output
- Achieve a low (<15kV) accelerating potential
- Final goal is to achieve a buildable and practical design

FMT The L-MPK, A CW L-Band Klystron

- Output Power: 11.5 kW CW
- Beam Voltage: -12 kV (assume 95% efficient)
- Beam Current: 1.04 A
- Drive Power: 500 W (assume solid state amplifier with 24dB gain & 45% efficient)
- Frequency: 1497 MHz
- Wall Plug Efficiency & Gain: 80.7% & 37.6dB
- Existing Technology Efficiency: ~33%
- L-MPK waste energy is 12.3% of the existing technology, suggesting the L-MPK is a Green Technology



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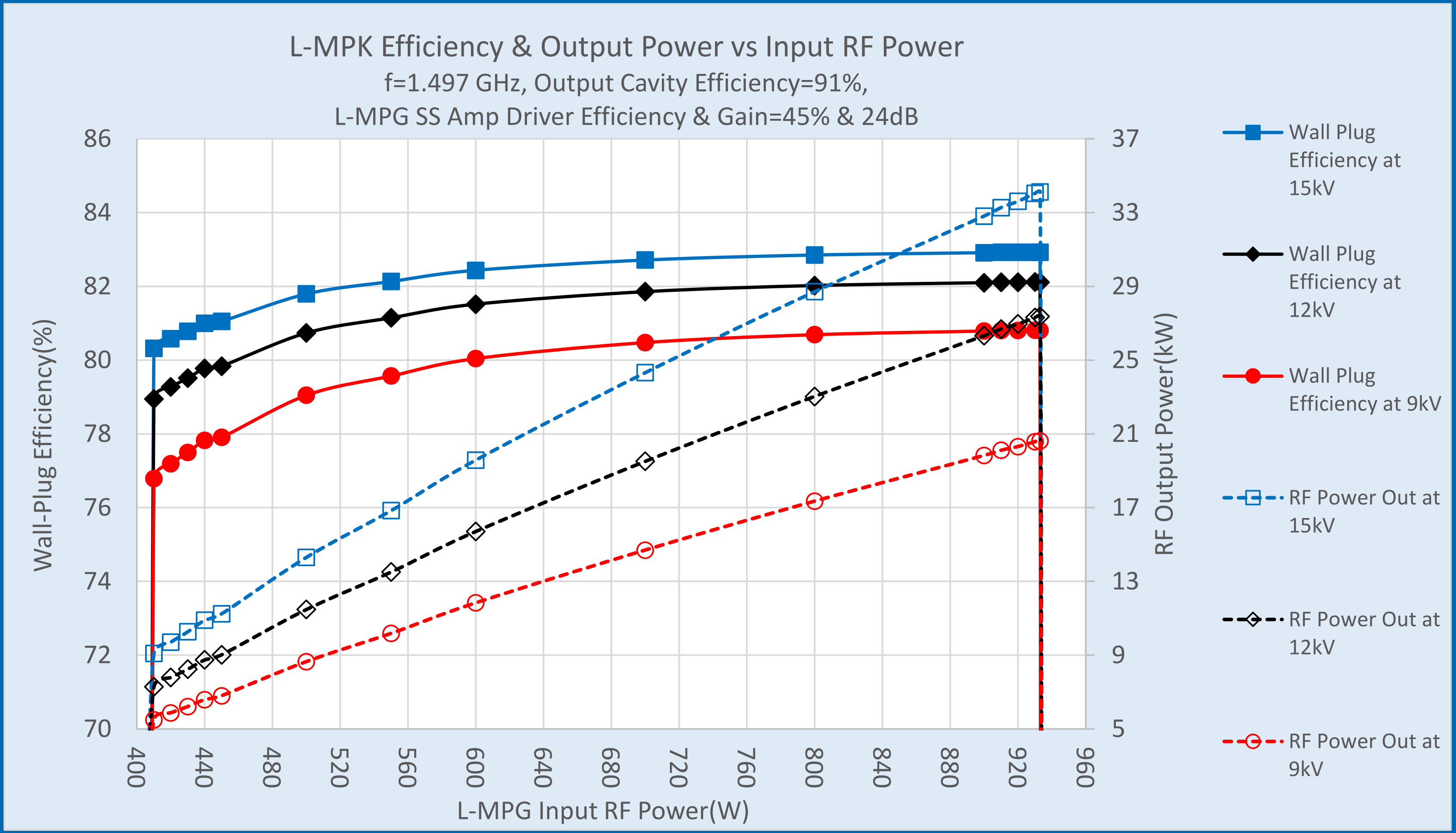
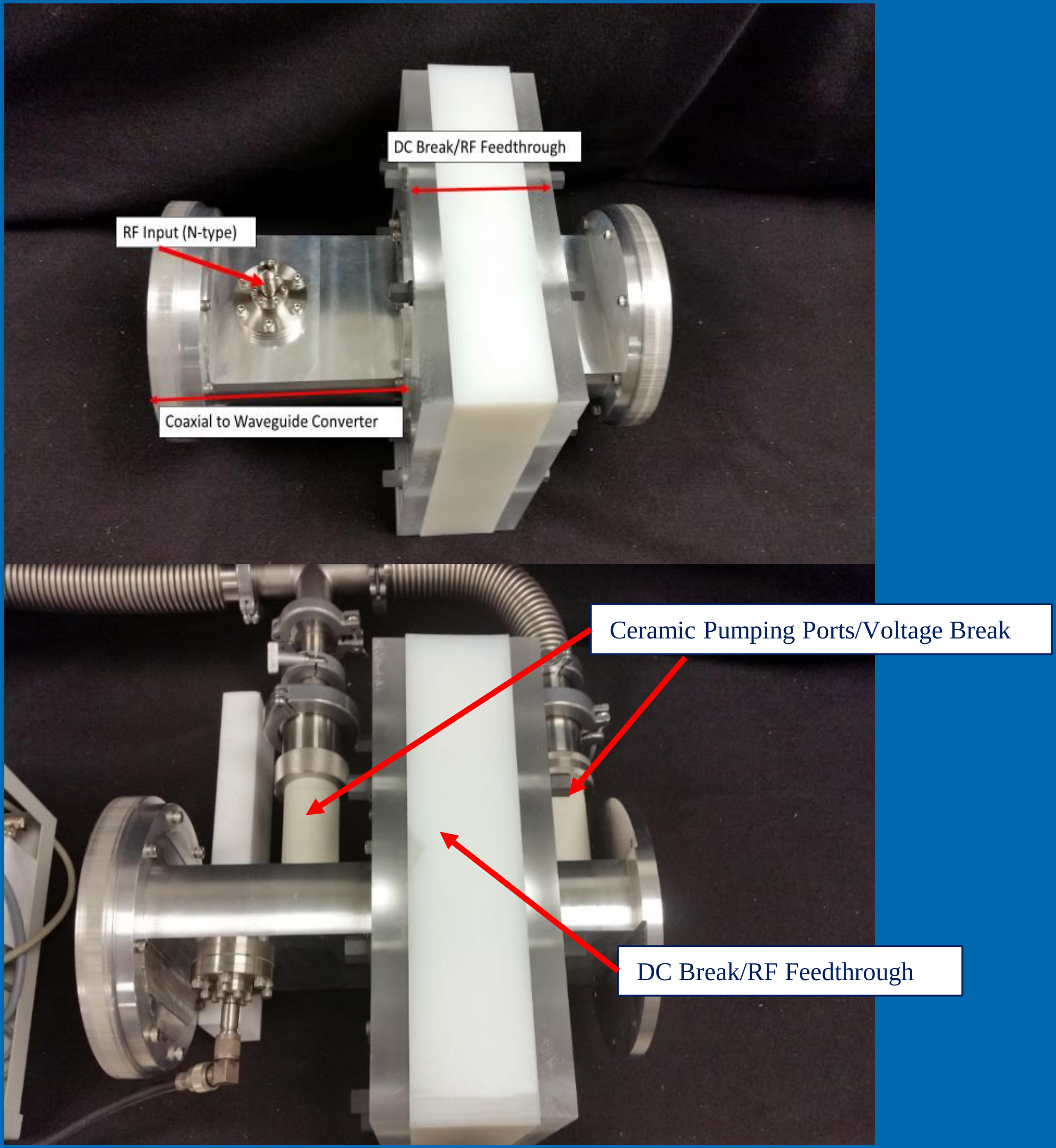
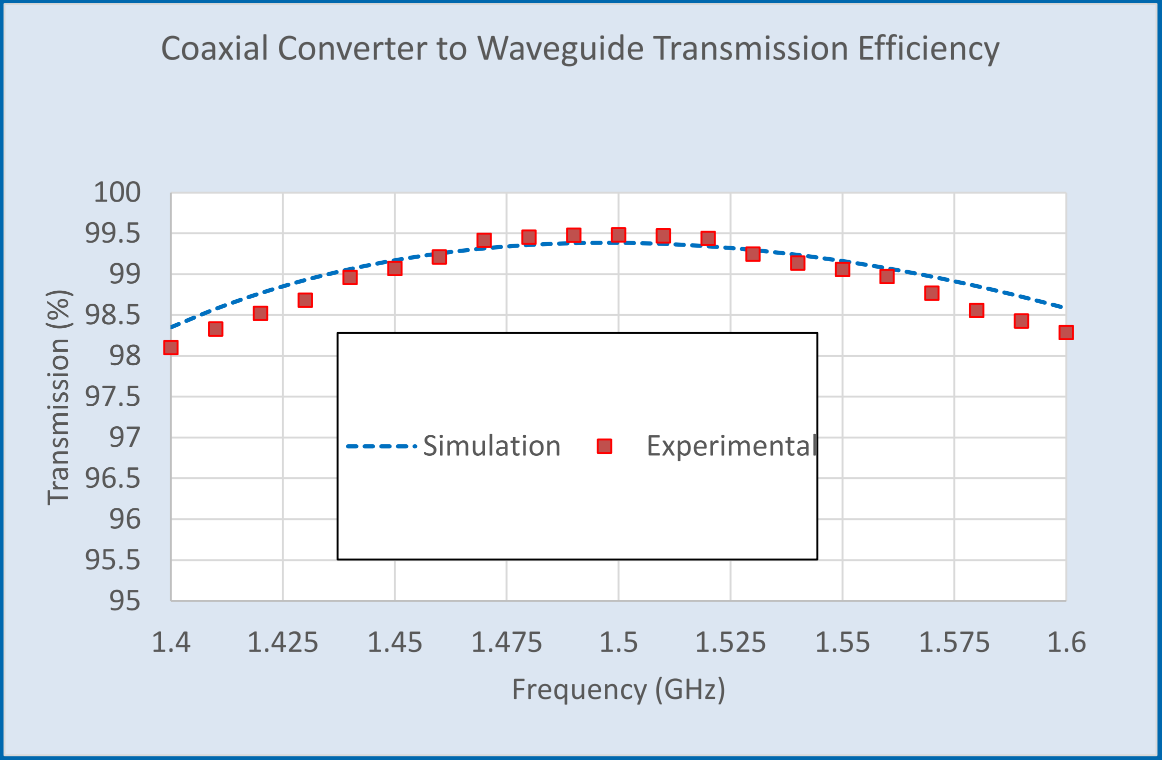
Wall Plug Efficiency & RF Power Out vs RF Power In



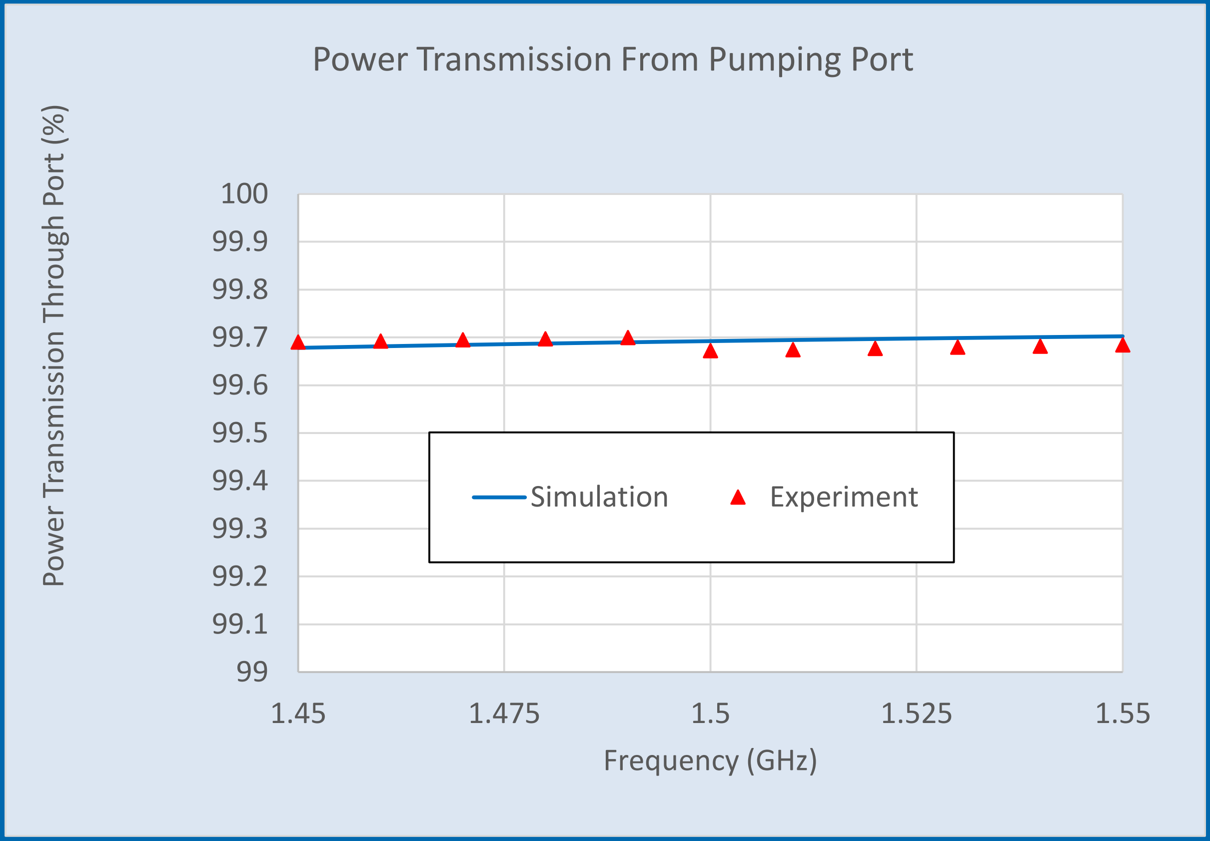
Front End of L-MPG with DC Break/Feedthrough



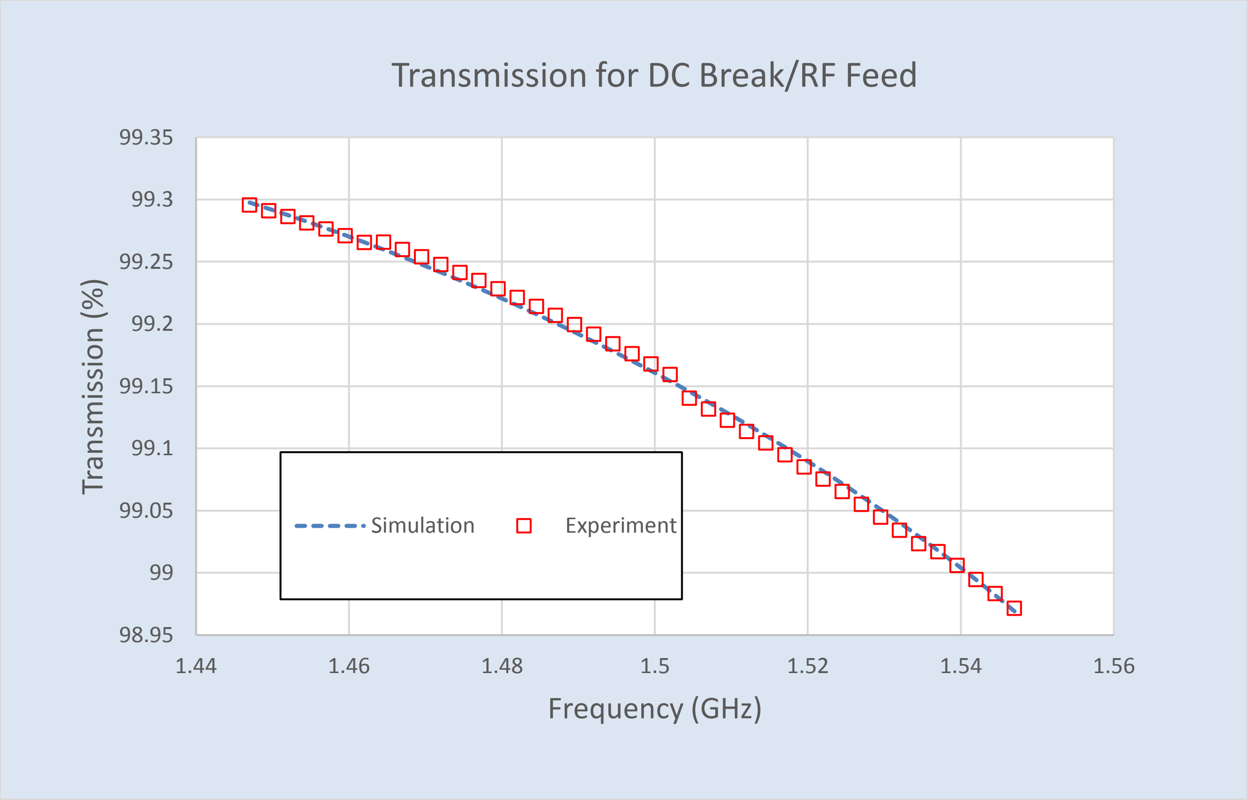
Coaxial to Waveguide Transmission



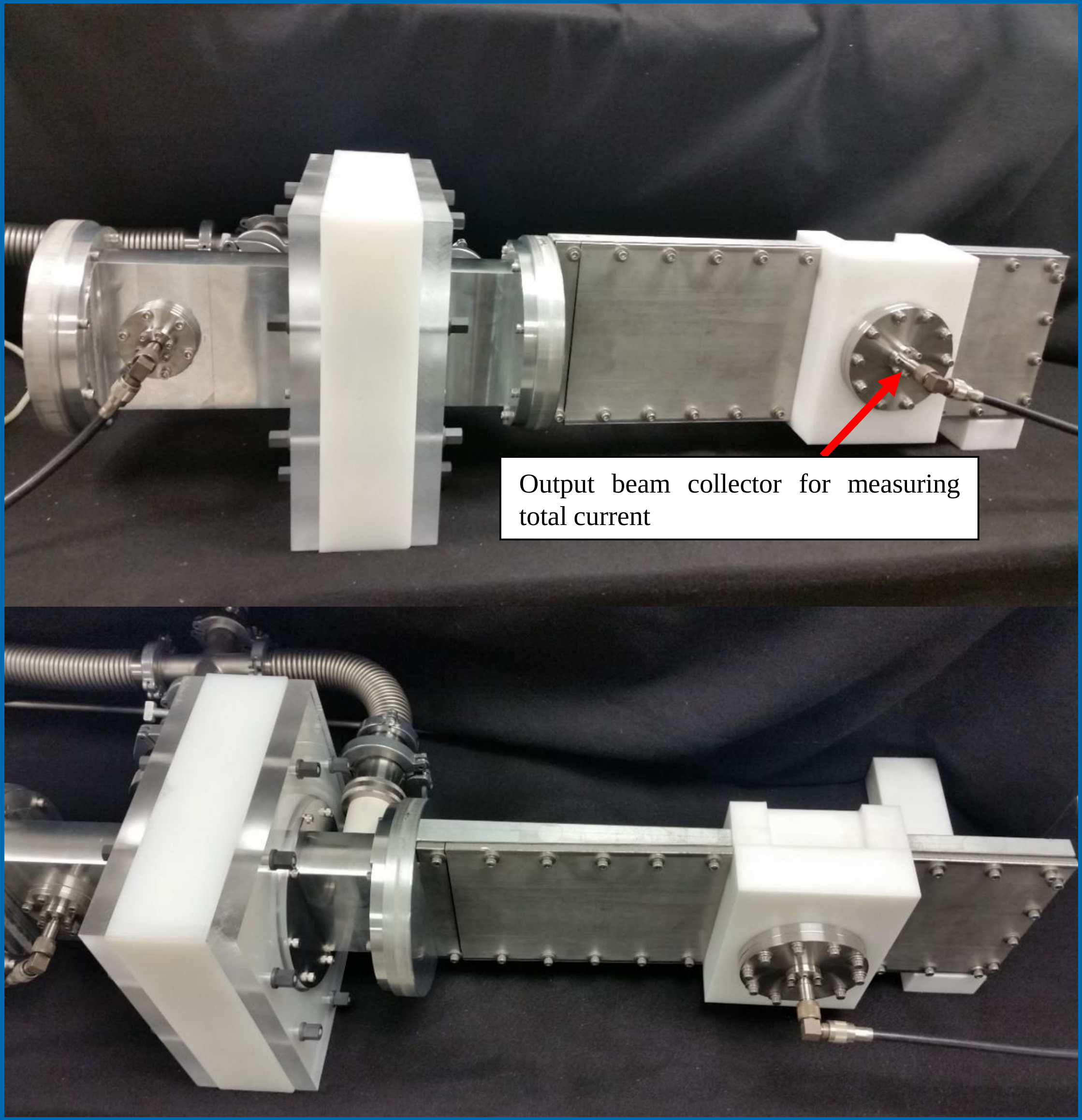
Transmission Past Pumping Ports



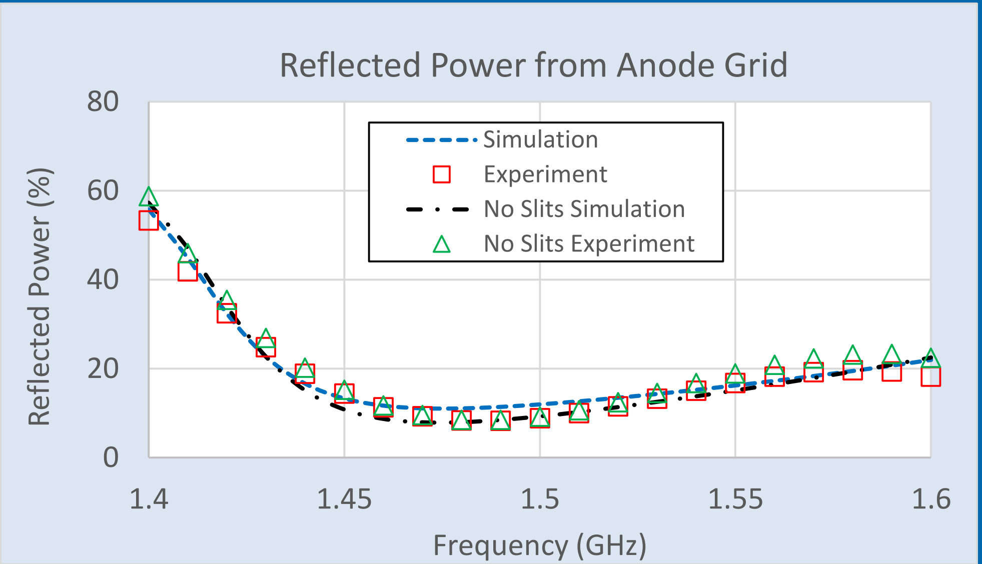
DC Break/RF Feedthrough Transmission

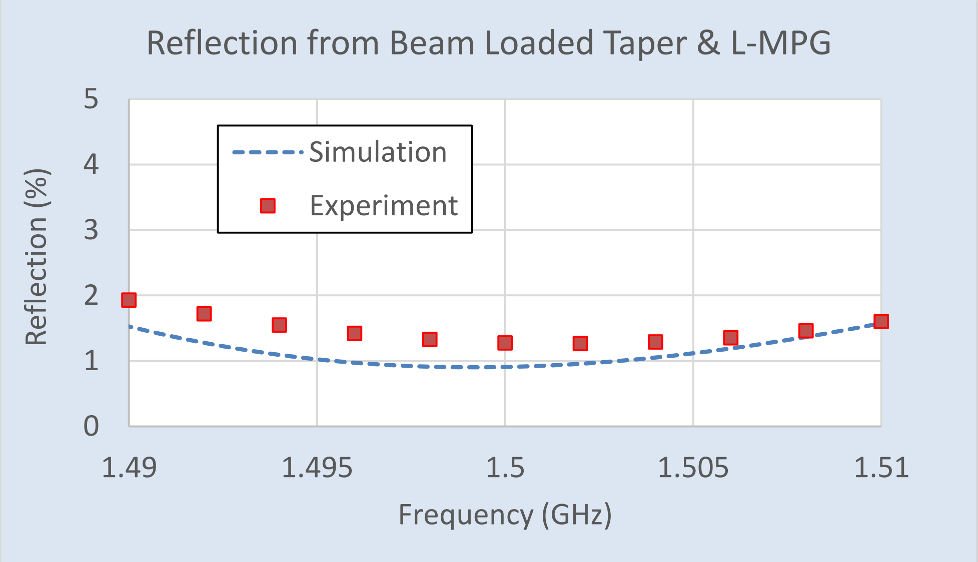


L-MPG with DC Break & Feedthrough

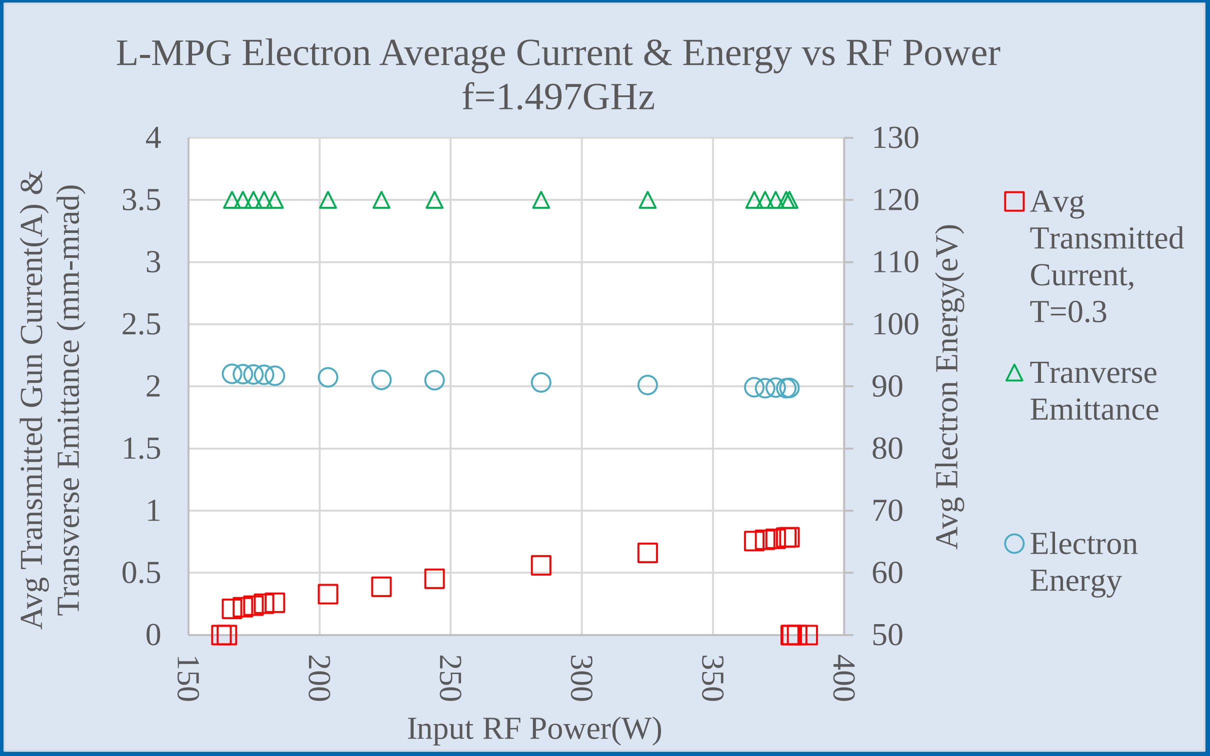


RF Reflected Power Without & With Beam

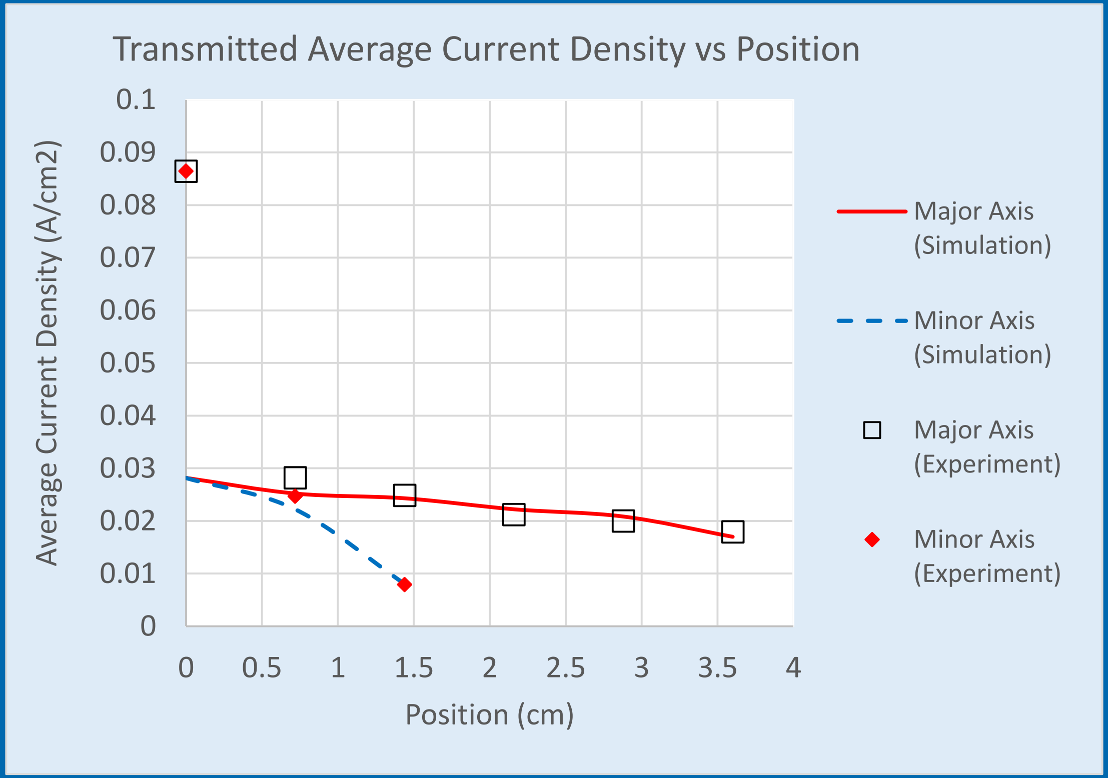




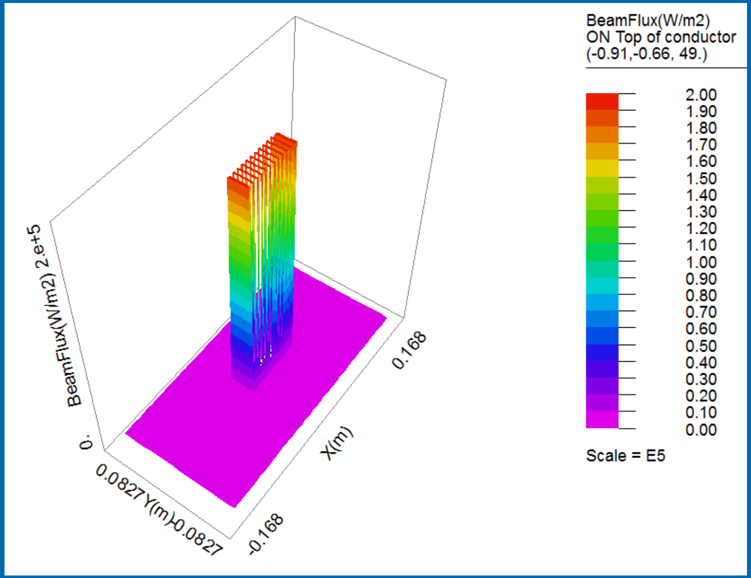
L-MPG Performance

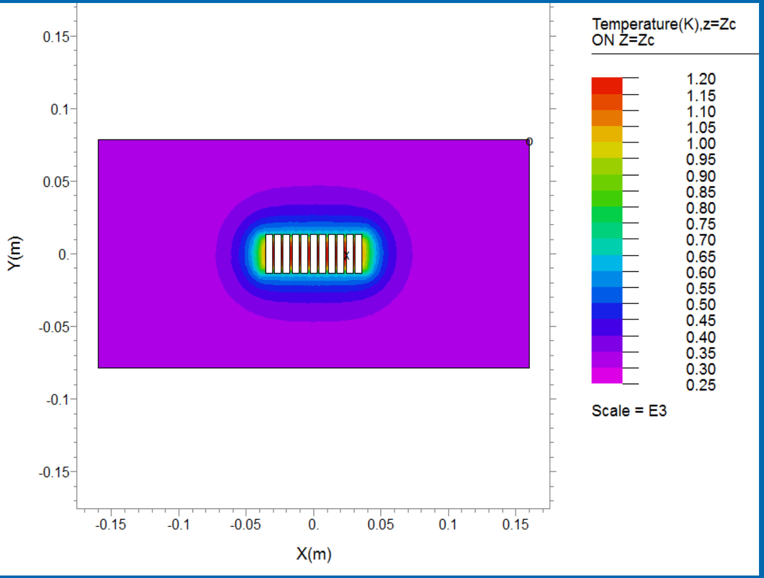


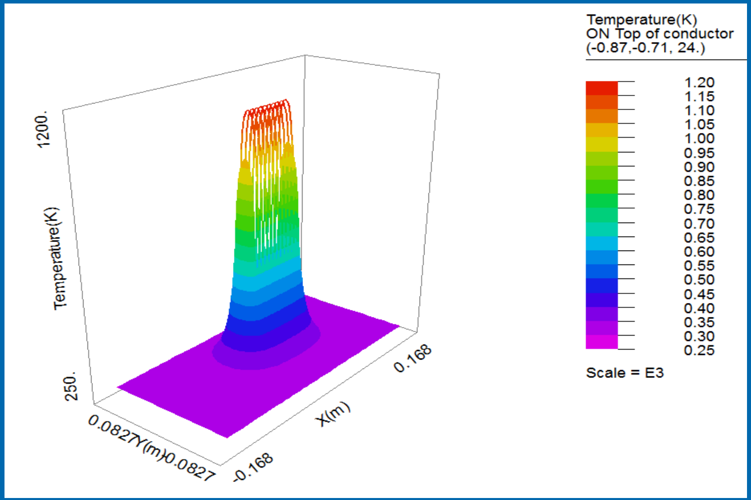
Comparison of Actual L-MPG Current Density Distribution to Simulated

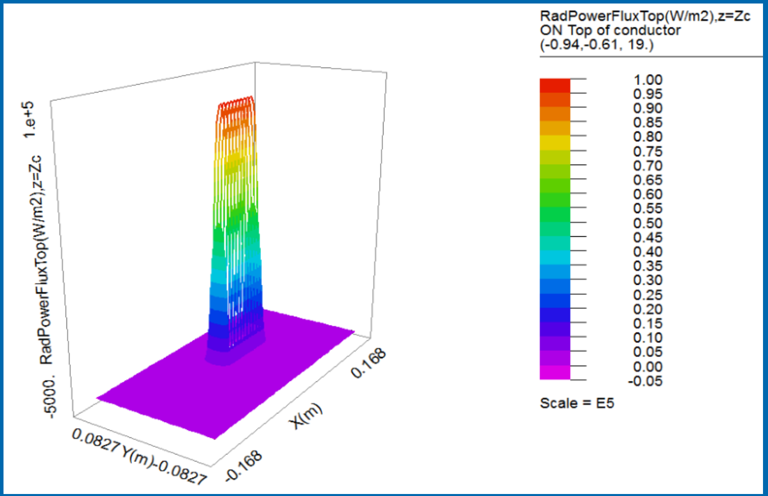


L-MPG Beam Heating of Anode Grid

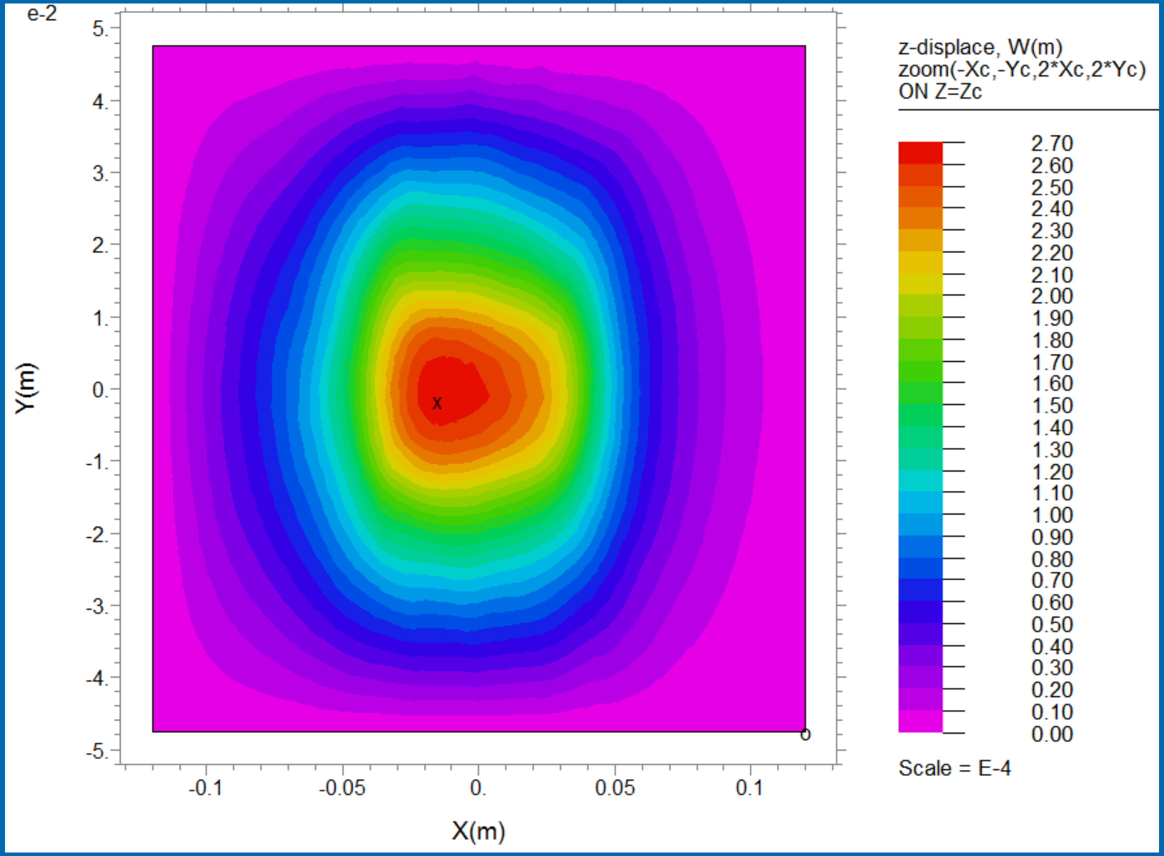




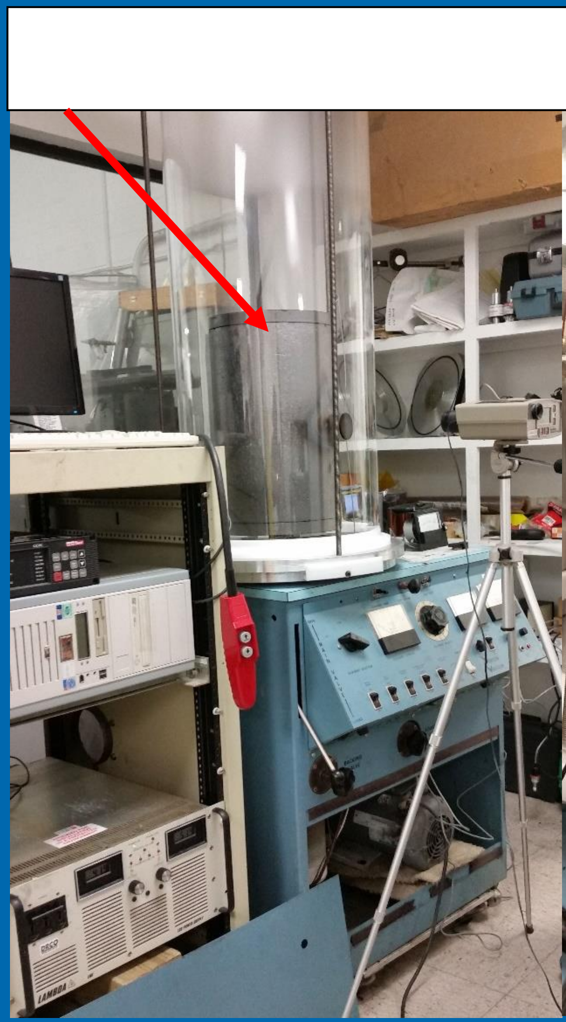




Displacement of Anode Towards Cathode Due to Beam Heating



Upgrading Furnace for Joining



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Summary and Status

- L-MPG built, operational and expected performance in agreement with design, except for “bump” in current density distribution.

- Localized current density distribution will need to be flattened by redesigning and rebuilding existing L-MPG anode.

- Choices for redesigning the L-MPG anode include:
  - In planar geometry, the anode thermal conductivity will need to be increased.
  - A cylindrical Anode-Cathode geometry has the effect of producing uniform expansion under beam heating, which enables compensation for grid spacing.

- Simultaneously, the joining furnace chamber has been successfully expanded in volume by 10x to accommodate the joining required for the high-power RF load and cavity and other joining.