Measurement of Ion Bombardment Heat Load Distributions on the Central Grid of an IEC Fusion Device

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Oct 2, 2014

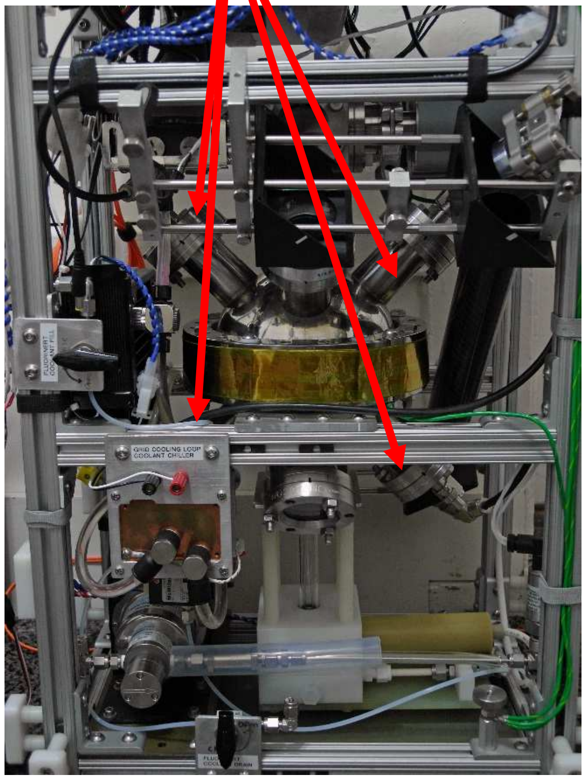
Motivation

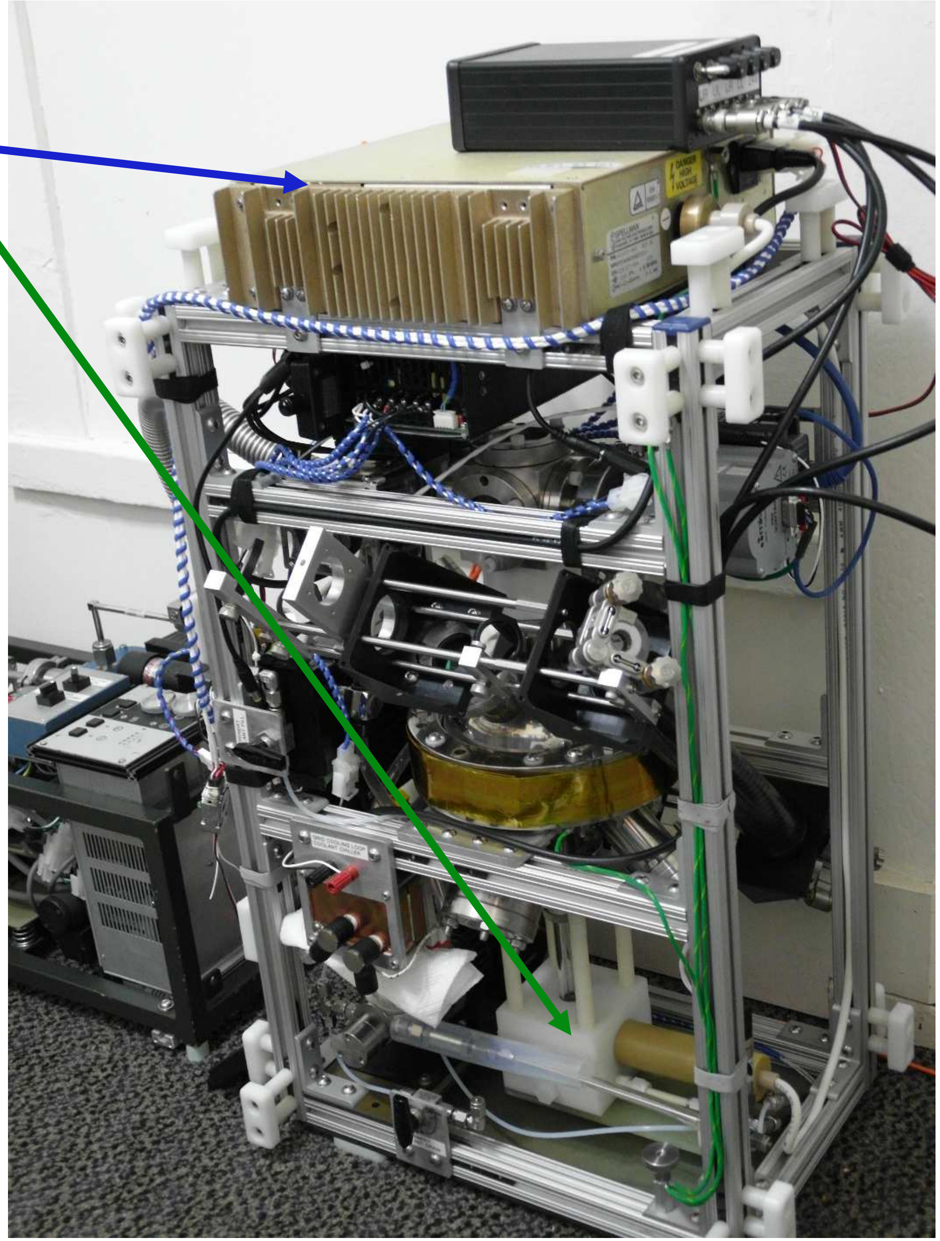
- Ion-grid collisions lead to:
  - Loss of circulating ions
  - Sputtering and erosion of grid material
  - Thermionic and secondary electron emission increasing power draw from HV supply

- Measurements of ion-grid collisions may be used to optimize the design of the grid and device configuration.
- Experimental validation of PIC simulations

IEC System Overview

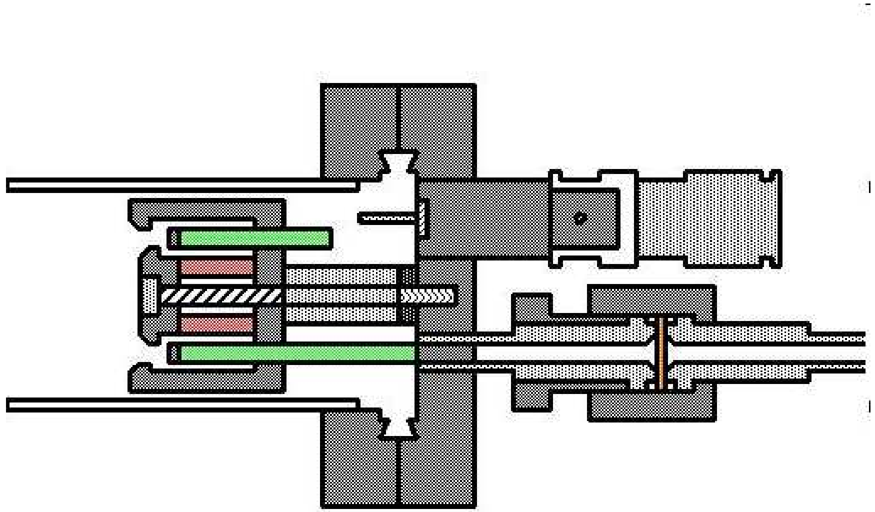
- 6”(150mm) vacuum chamber
- -40kV, 5mA power supply
- 1” (25mm) liquid cooled central grid
- 4 independently controllable anode layer ion sources

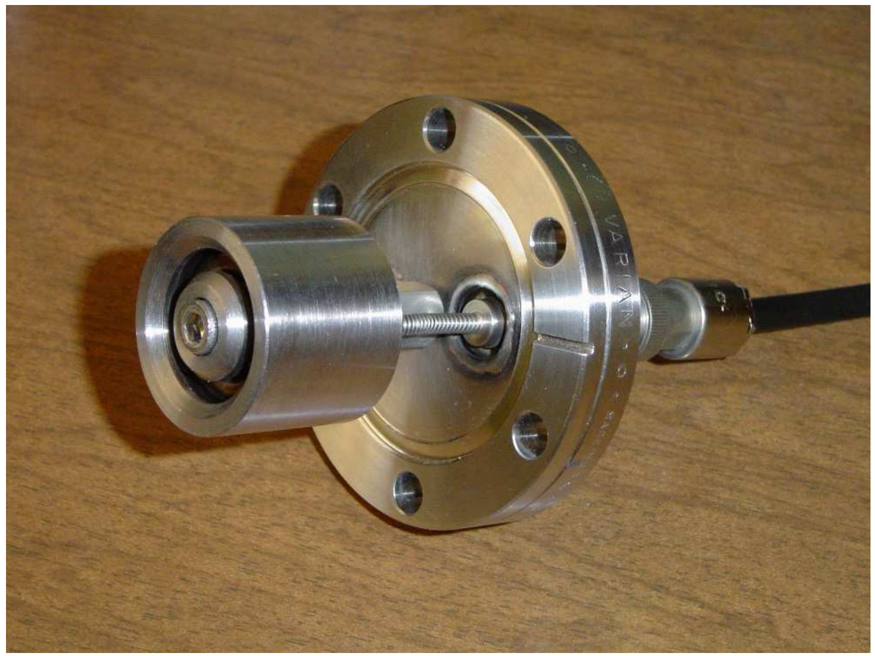




Ion Source System

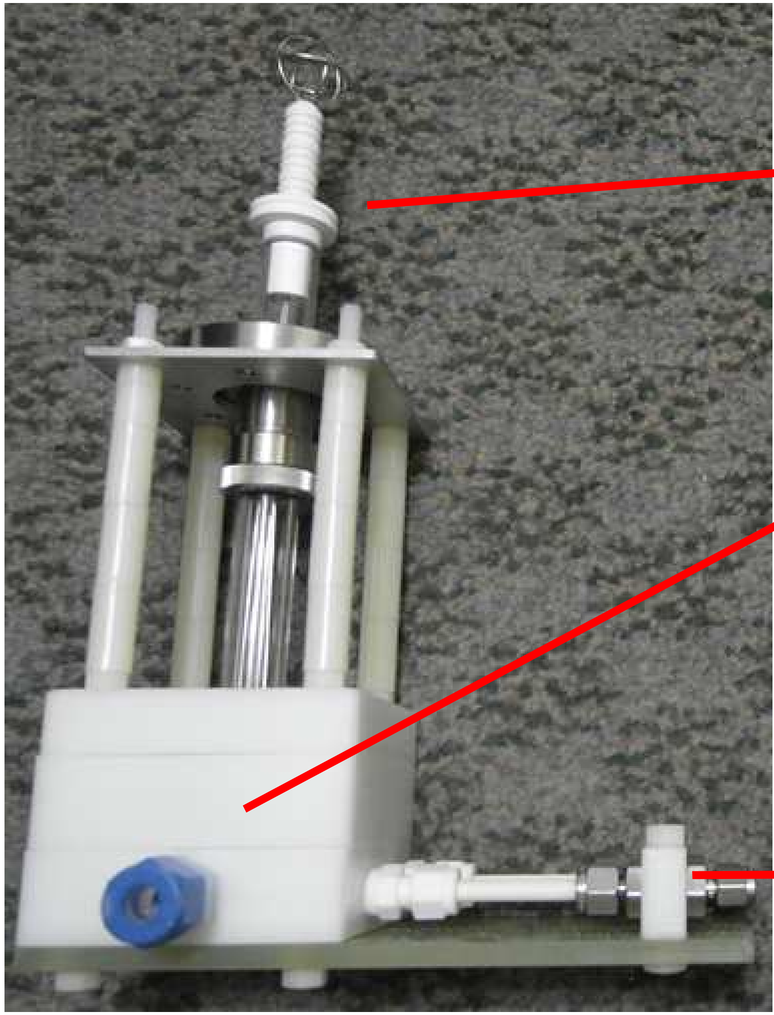
- Up to 2.5mA anode current (limited by power supply)
  - ~50% into ion beam

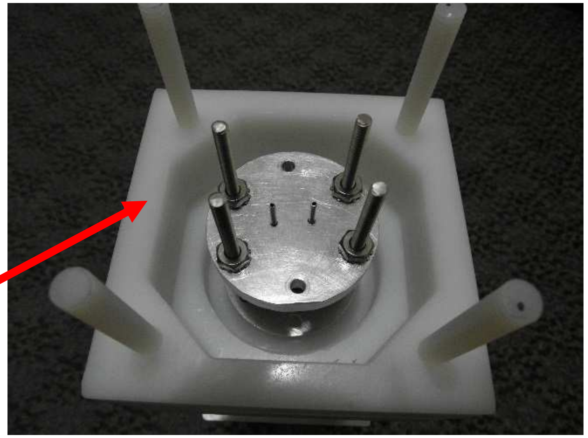




Liquid Cooled Grid Design

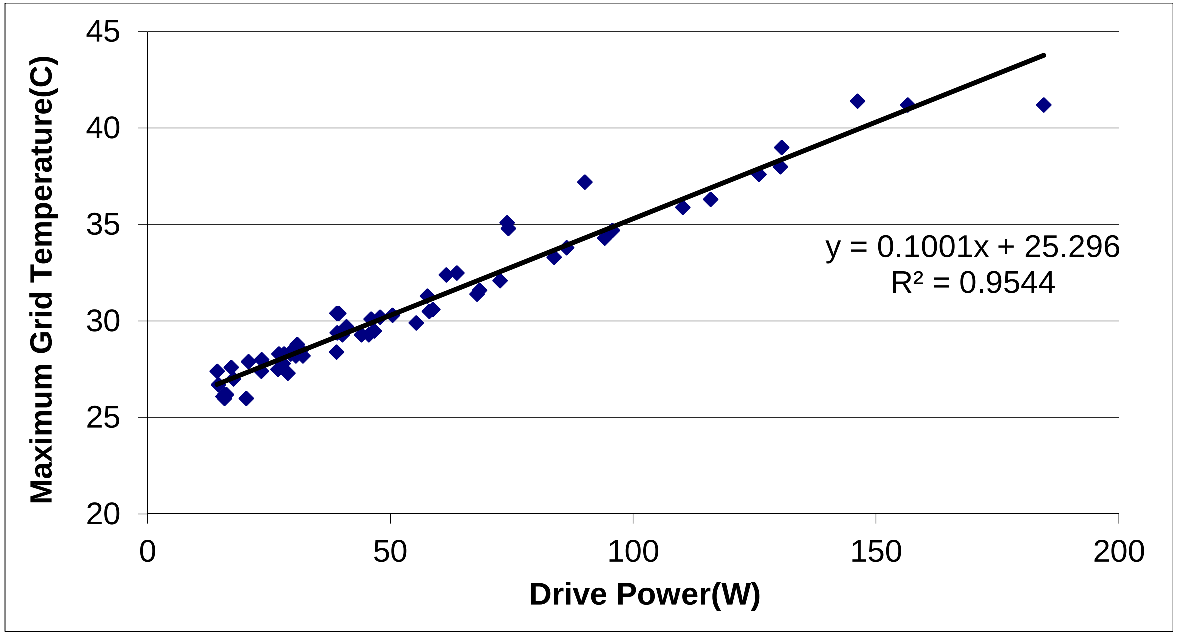
- Nonconductive 3M Fluorinert coolant flow maintains grid at low(<45C) temperature at up to 200w input power
- Heat removed from grid may be measured

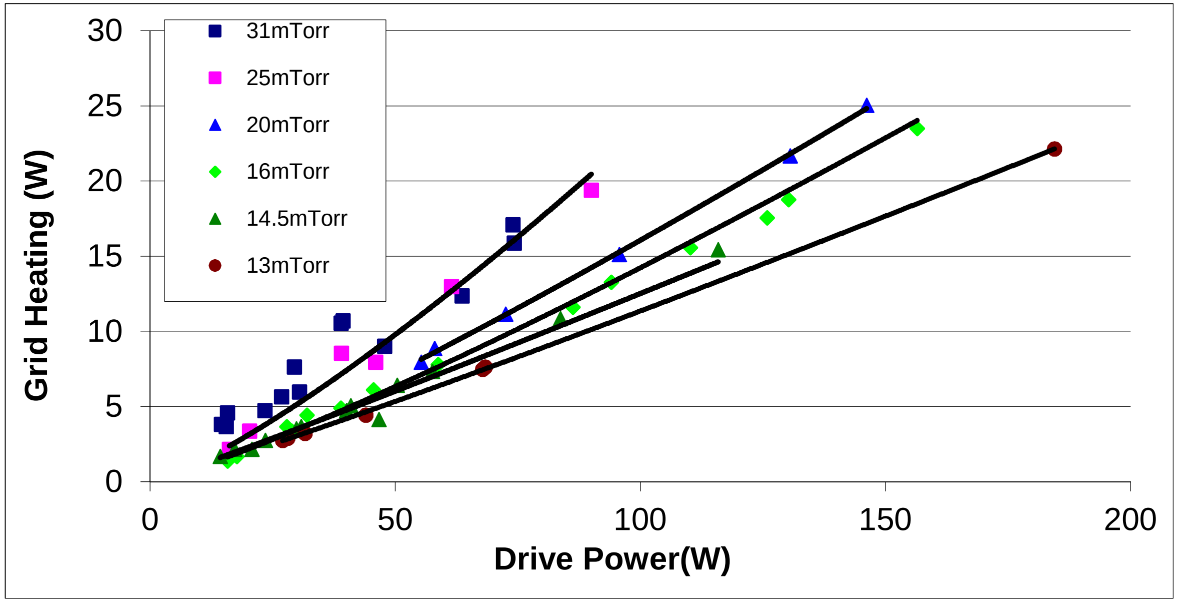




Liquid Cooled Grid Data

- Previous data from liquid cooled grid:
- Knowing:
  - coolant input and output temperature
  - flow rate
  - specific heat
- Total power absorbed by grid may be calculated
- This provides no information on **where** the ions are hitting the grid
- An ion collector is designed to mount on grid and measure distribution on ion bombardment

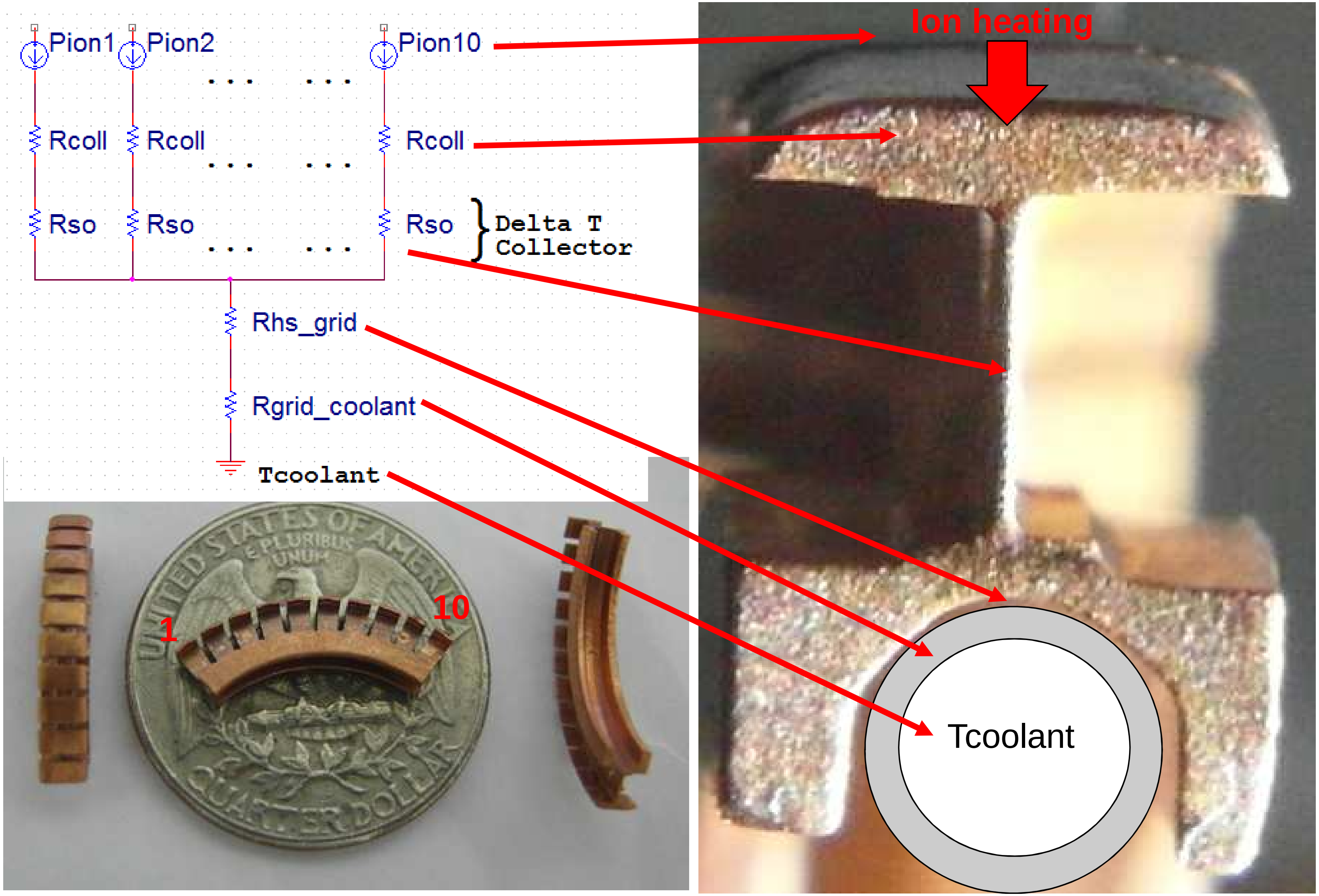




Ion Collector Array Design

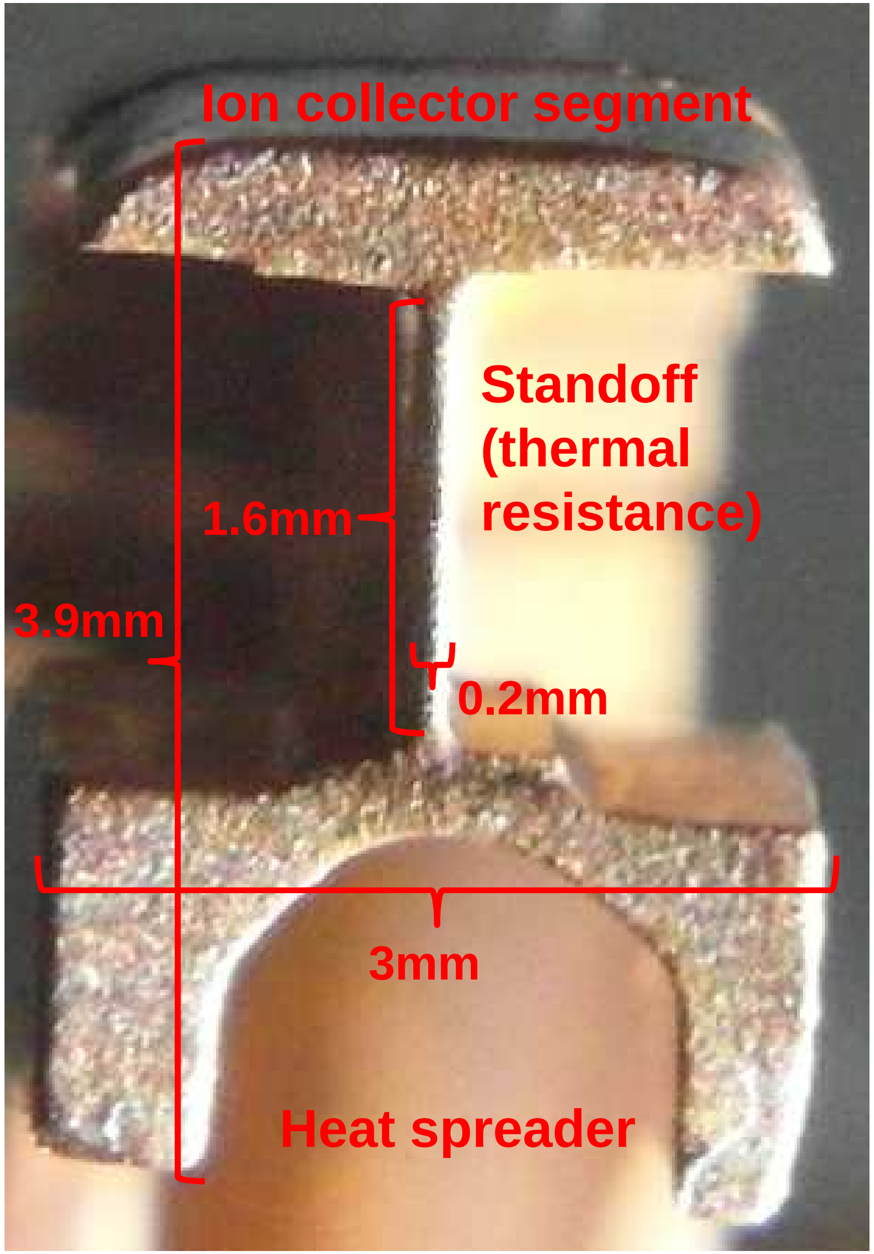
- Requirements:
  - Ion collector array mounts on grid surface and collector segments heat up when struck with ions
    - Hot enough to get good resolution with thermal imager, 10C-20C increase in temperature required
  - Low radiative losses
    - Low temperature so conductive heat transfer to grid is dominant
  - Anisotropic thermal conductivity:
    - Radial conductivity>>conductivity along length
    - Prevents thermal transfer from segment to segment

Ion Collector Array Design



Ion Collector Array Design

- Assume 100% power into grid surface, 13kV 5mA =>65W
- 3 ring grid => 12 segments =>5.4W/segment => 0.54W/collector
- For copper K=400 wm^{-1}C^{-1}
- For 0.2mm thickness, standoff resistance ~12.5 C/w



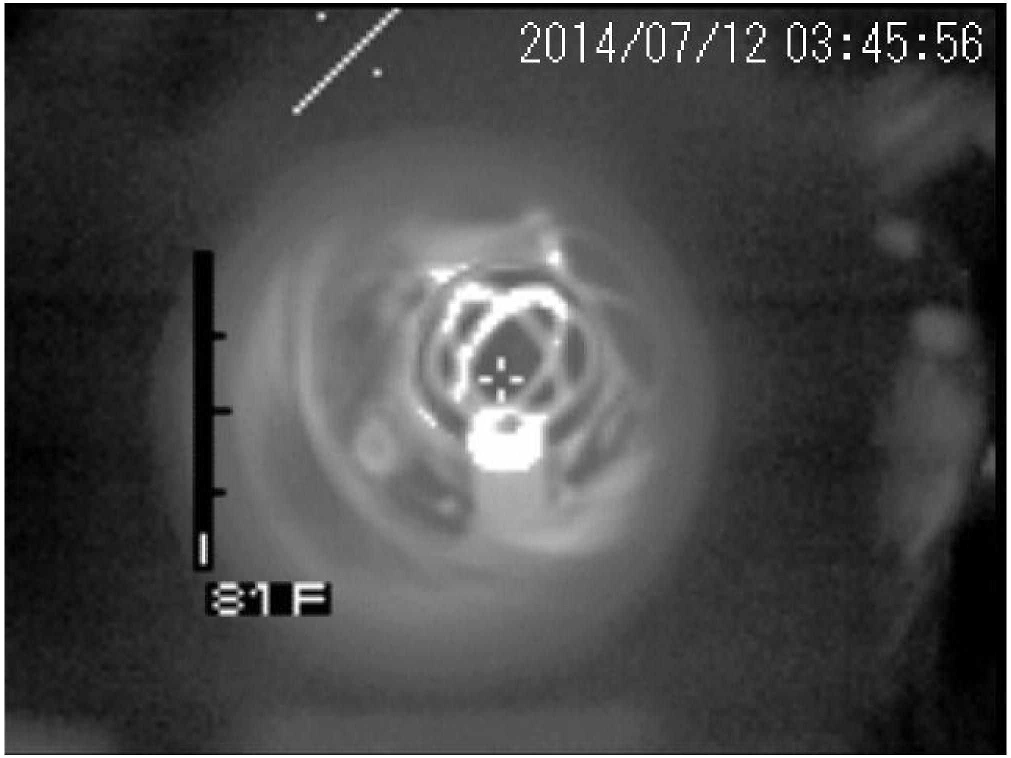
Ion Collector Mounted on Grid

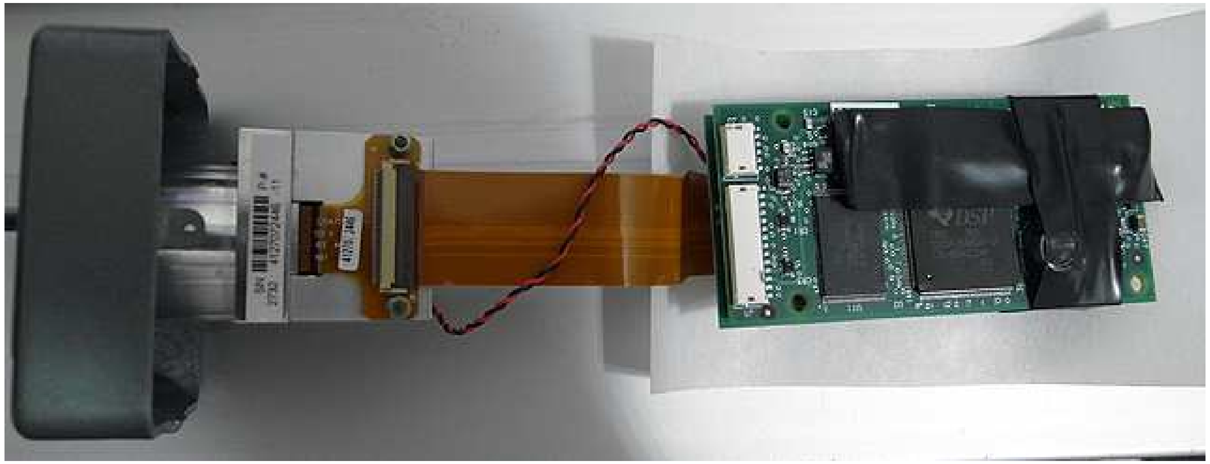
- Additional holes drilled in standoff surface to increase thermal resistance

- Copper heat spreader is compression fit onto grid tube

Thermal Imager

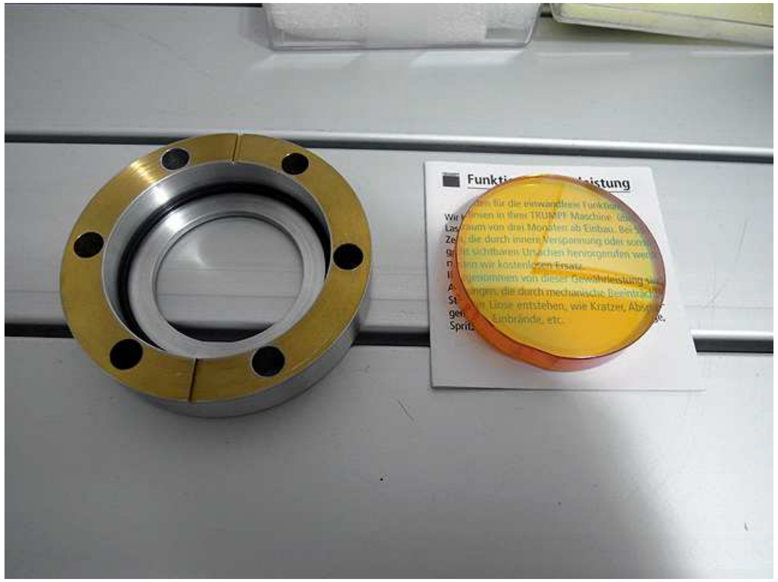
- L3 thermal eye 2500AS
- 160x120 resolution
- 7-14um wavelength
- 10ms thermal time constant



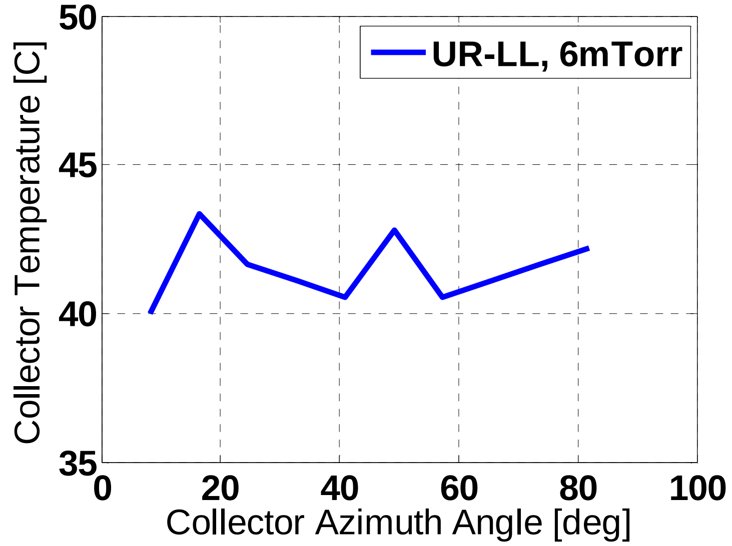


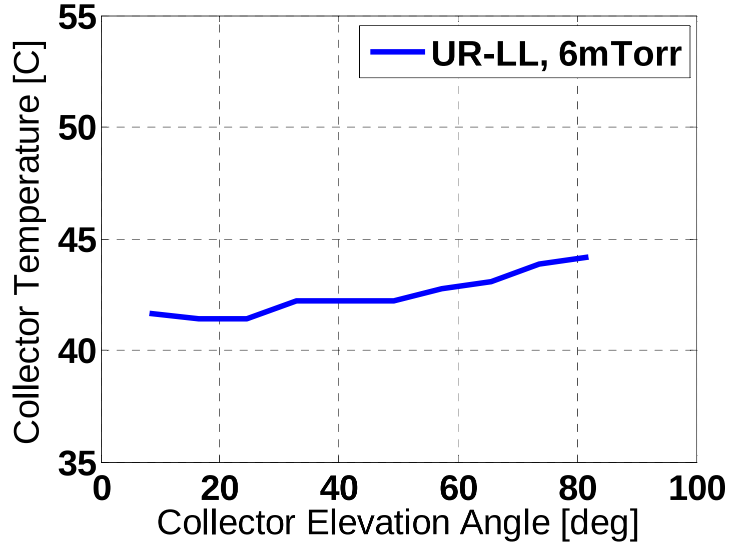
Infrared Viewport Assembly

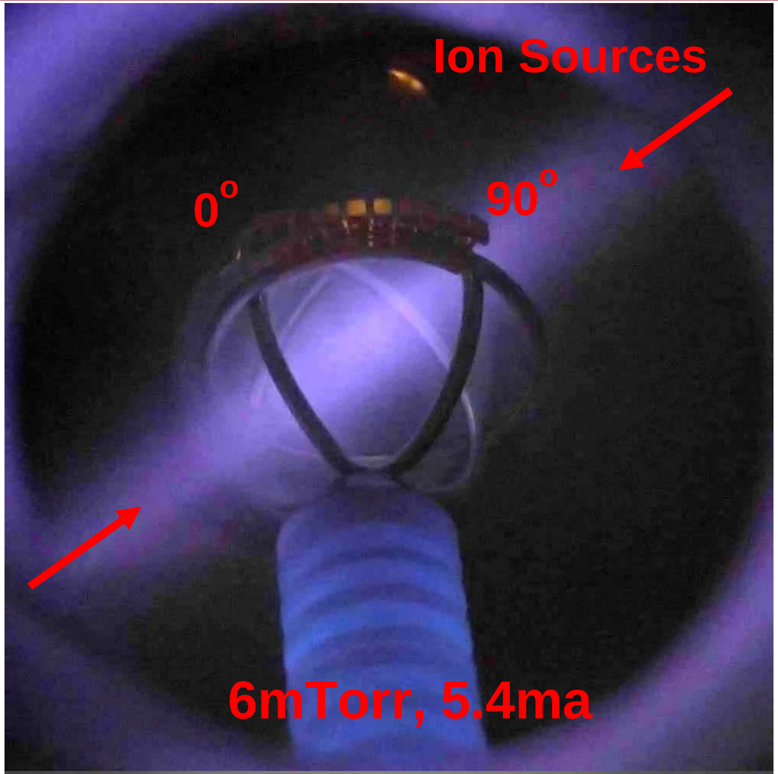
- Thermal imager requires a 7-14um transparent viewport
- Zinc Selenide (ZnSe) laser cutter lens (10.6um AR)
- Viton o-ring sealed
- Fits in bored out 2.75” CF rotating ring
- 50mm OD, 250mm FL

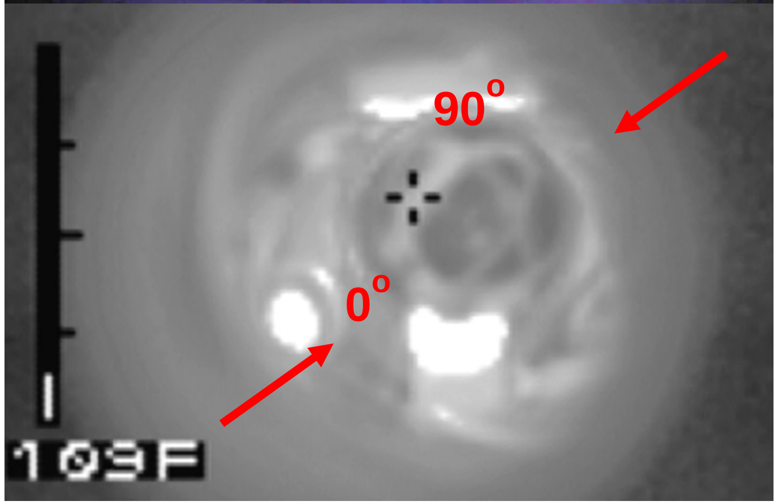


Upper Right, Lower Left Sources









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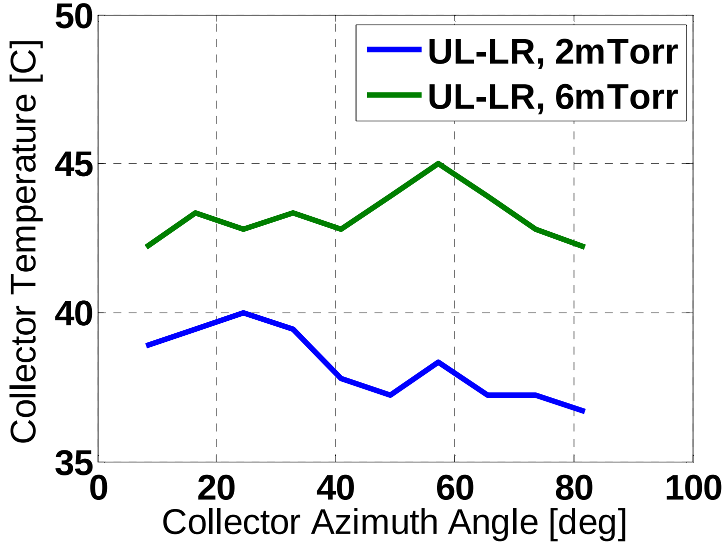
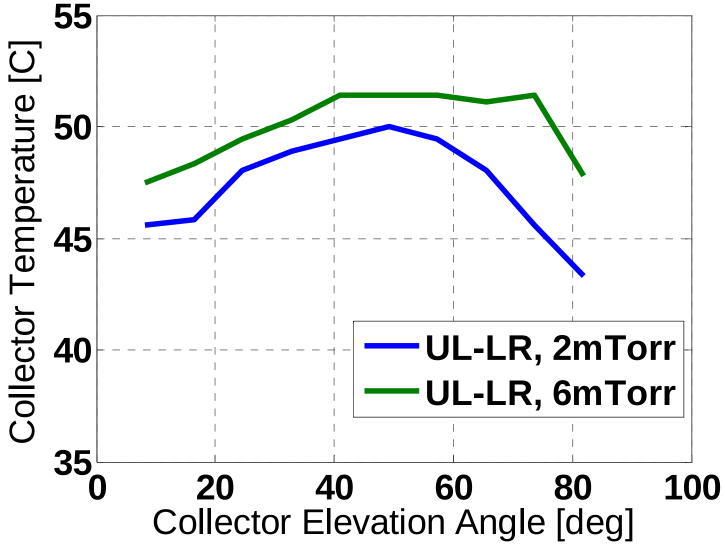
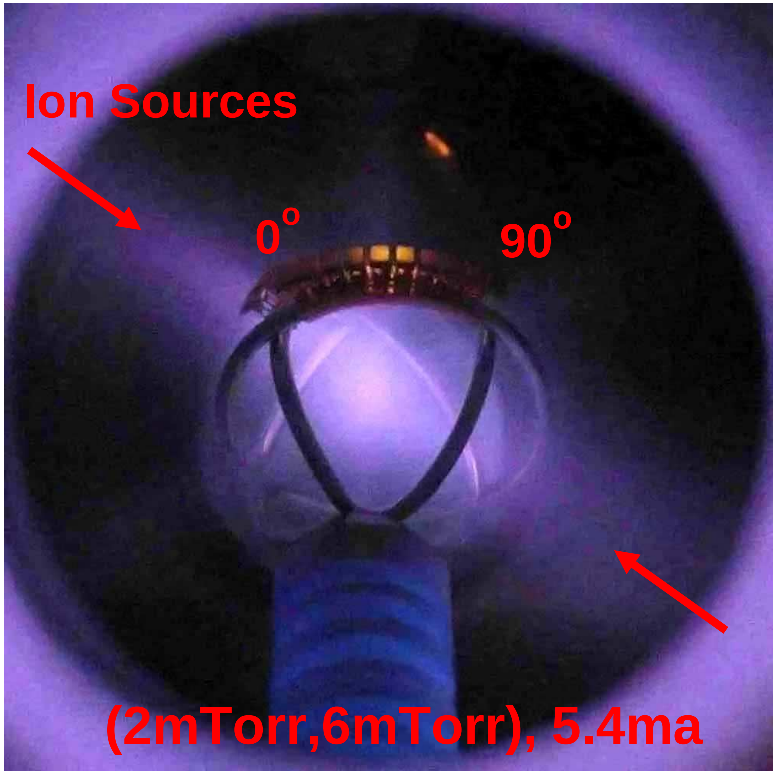
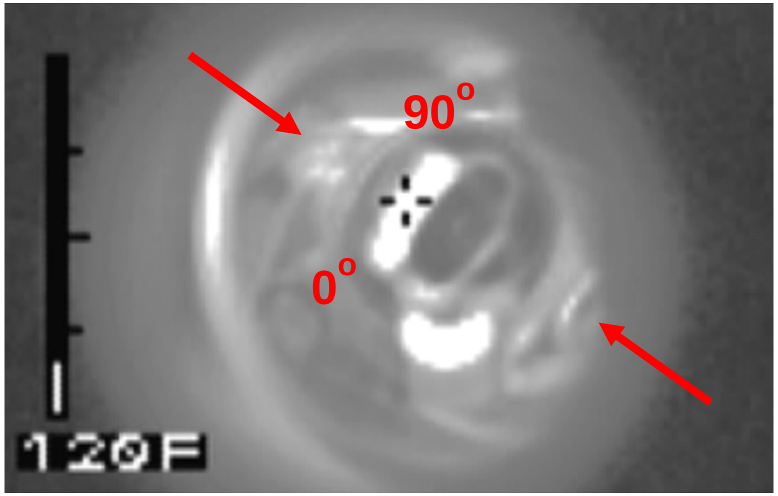
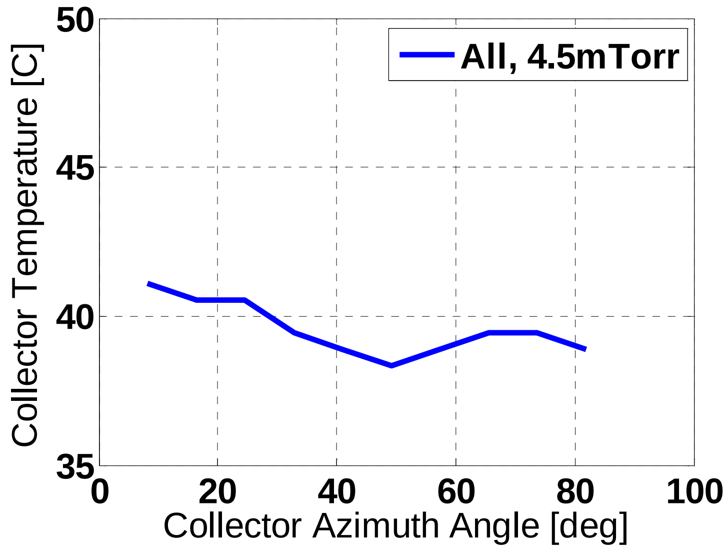


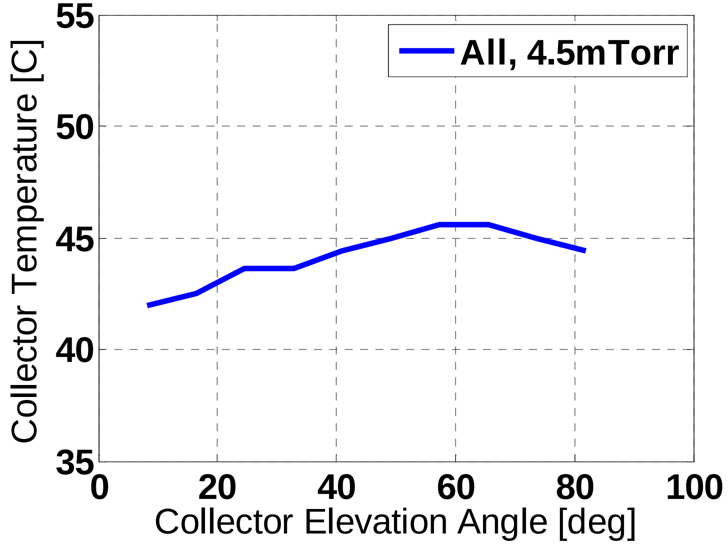


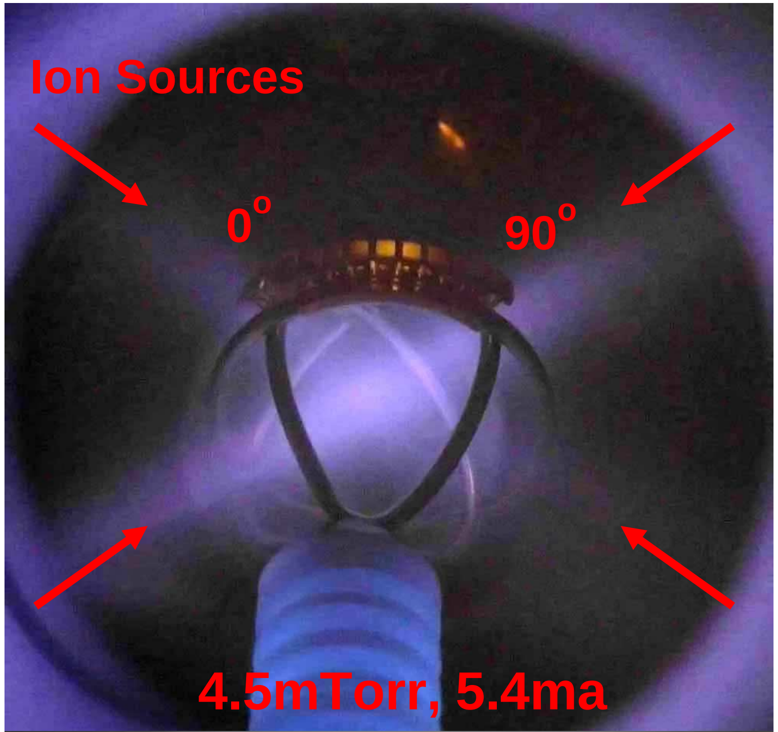


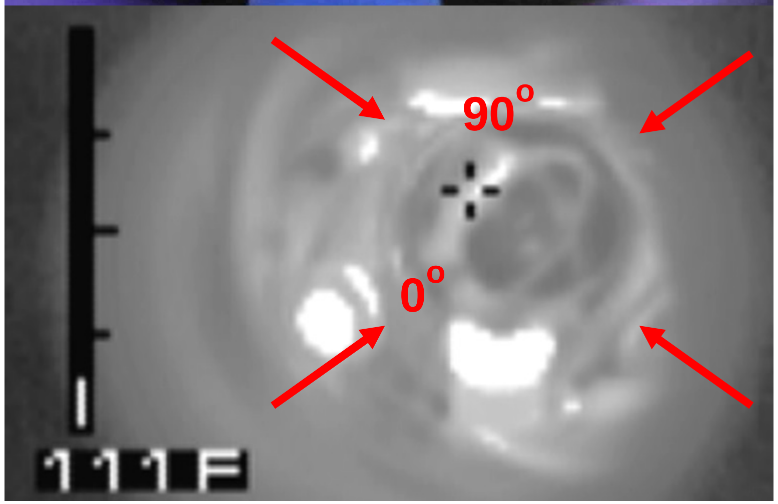


All Ion Sources

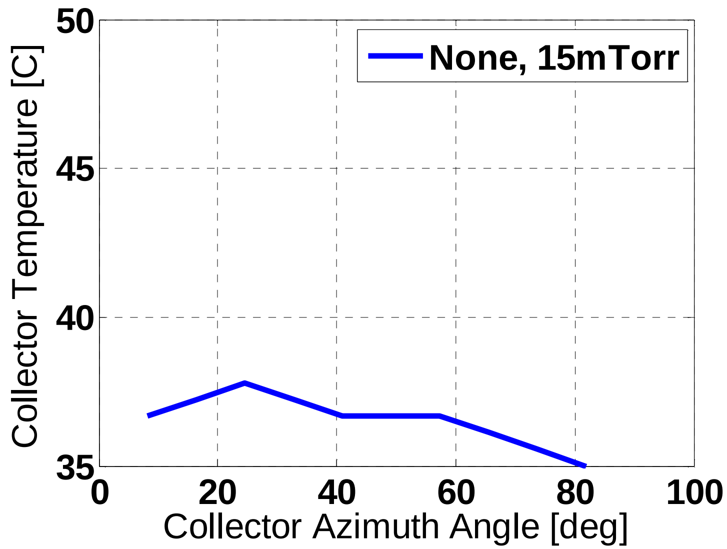


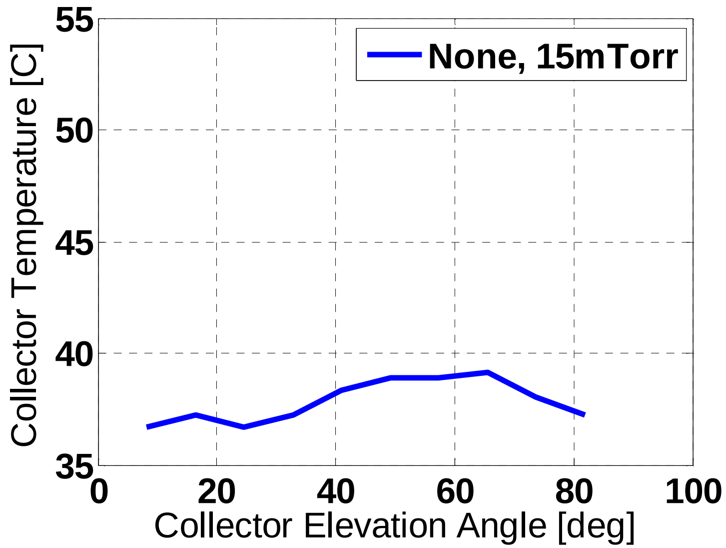


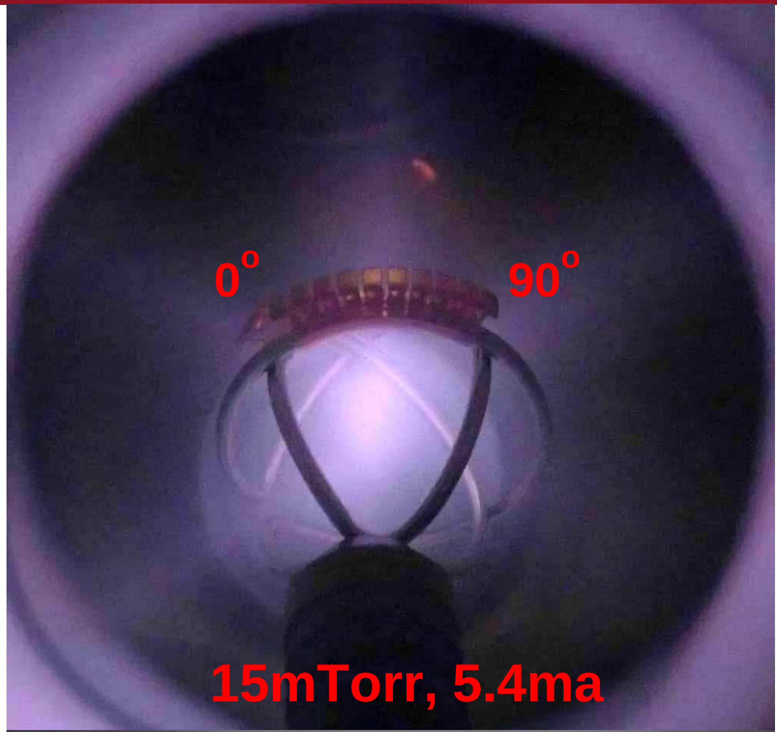


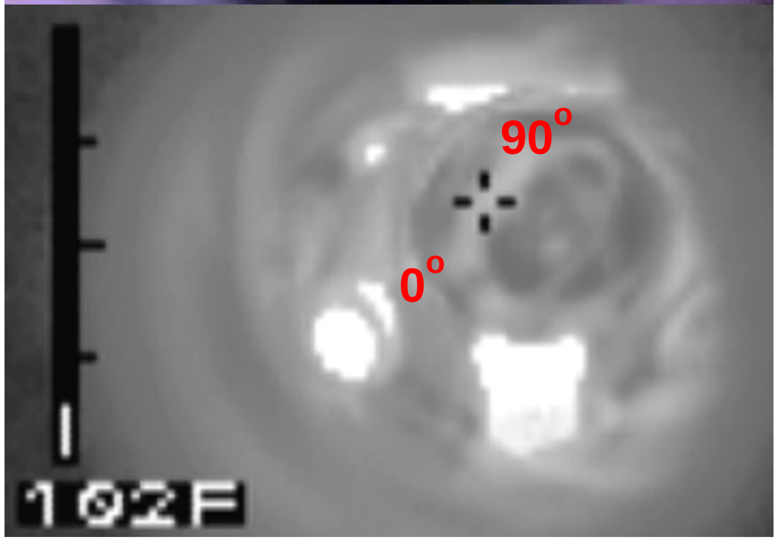


No Ion Sources



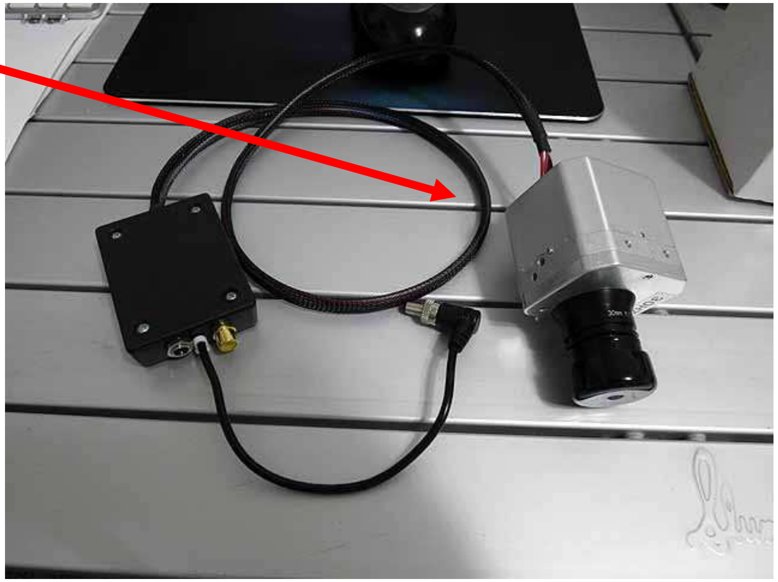


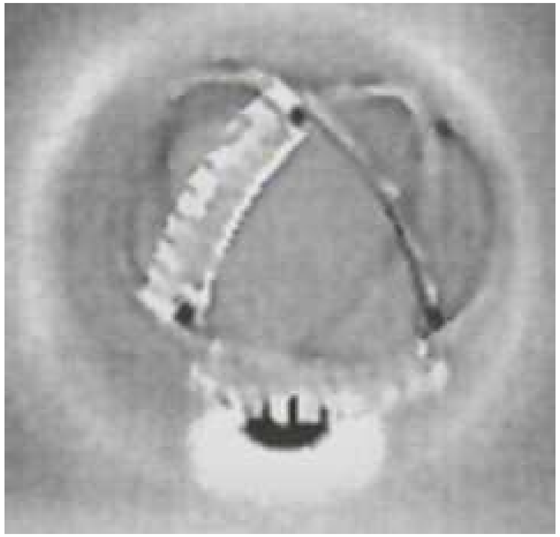


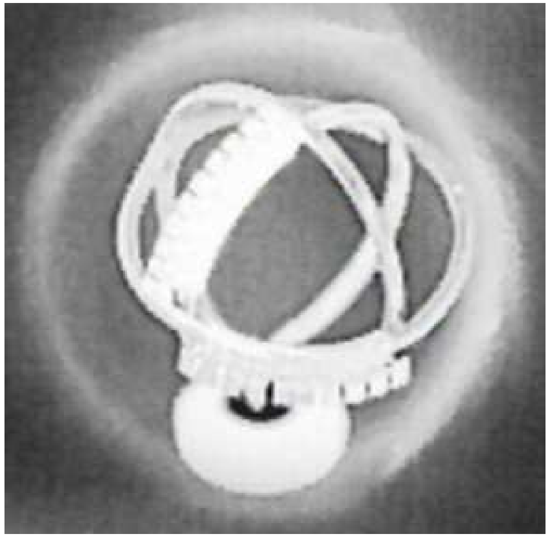


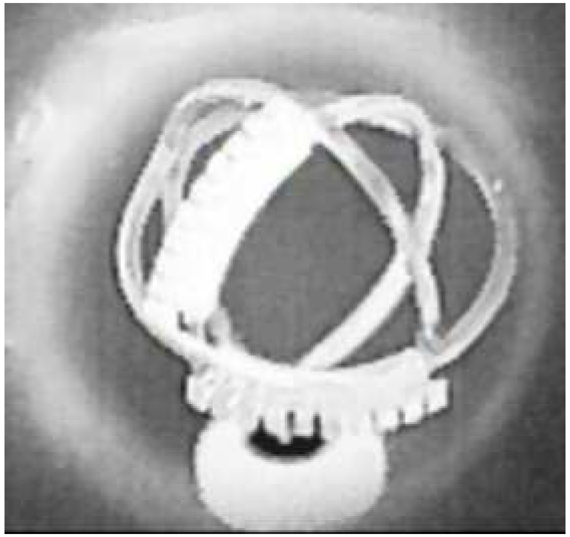
High Resolution Thermal Imager

- FLIR Photon 320
  - 320x240 resolution
  - More detailed images of the ion collector, but no temperature readout







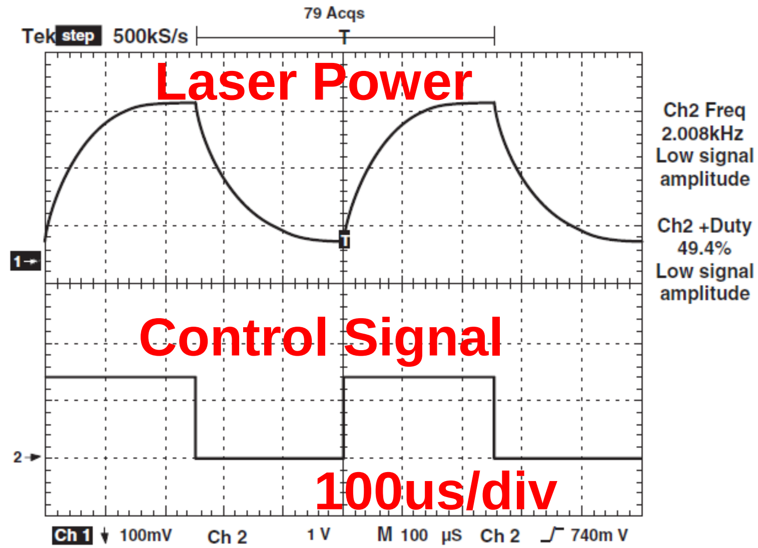


Laser Interferometer Feasibility

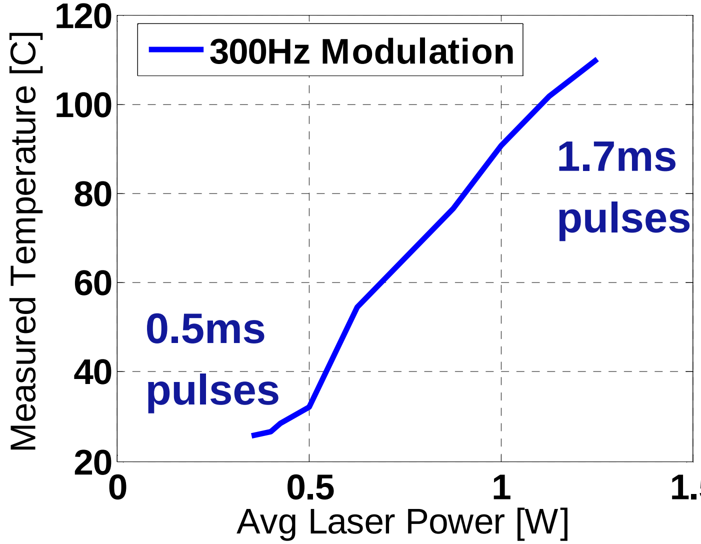
- ZnSe viewports provide optical access for use with a 10.6um CO_2 laser
- Long wavelength more sensitive to plasma density then visible wavelength laser
- Thermal imager can be used to provide spatially resolved information of plasma density structure at focal points
- Requires high enough plasma density for multiple fringe shifts (near cutoff)
- Beyond capability of continuous power supply and thermal dissipation of grid, but within range of pulsed systems
- A very fast, high current pulse would be required
- Ex 40kV, 50A pulse for 500us is 1000J, 100J into grid, 2.5 gram grid, 500J/(kg*K) yields 64C temperature rise

Laser Interferometer Feasibility

- Synrad 48-1 10W CO2 laser (10.6um)
  - 100us power rise/fall time
- L3 thermal eye 2500AS
  - 46.8um pixels, 160x120 resolution
  - 7.5mmx5.6mm detector
  - Beam on detector reduced to 5.3mm diameter
  - 10ms thermal time constant
  - 200x power attenuation added
- For 300Hz laser modulation
  - ~2.5W peak pulse power
  - 3 pulses per detector time constant
    - Detectable at 0.5ms pulses
    - Saturation at 1.7ms pulses

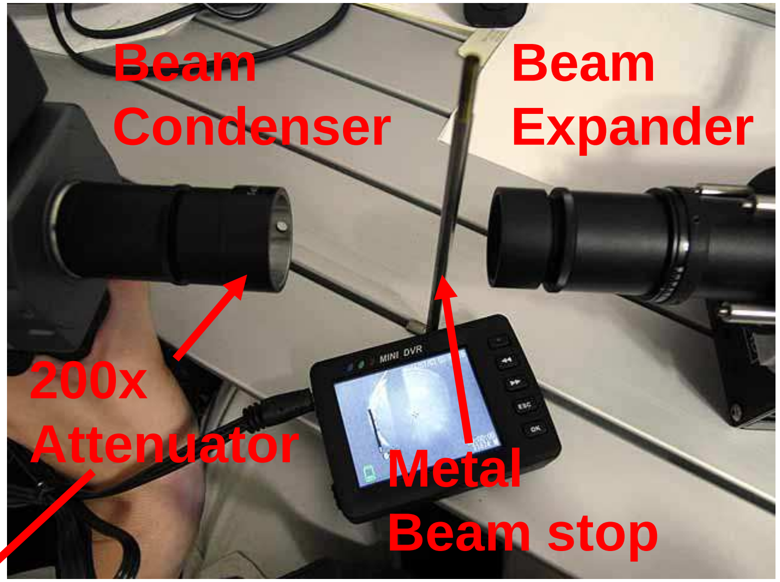


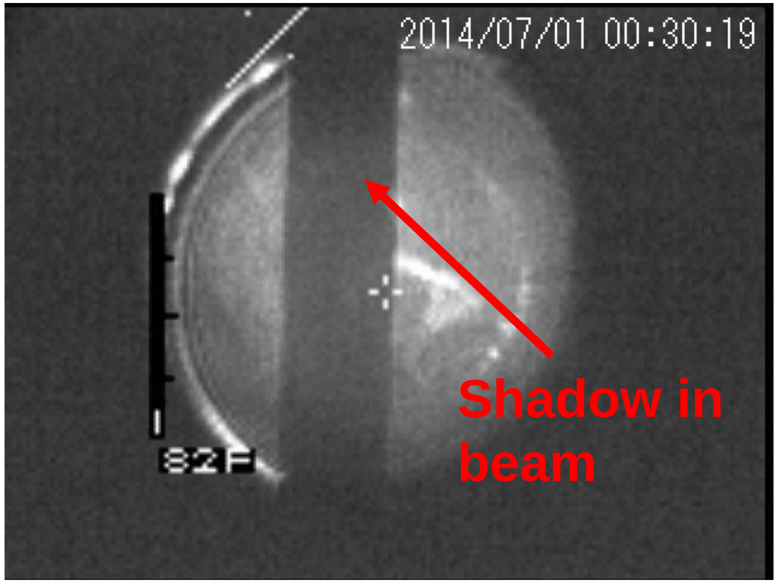
2 kHz Modulation



Preliminary Tests

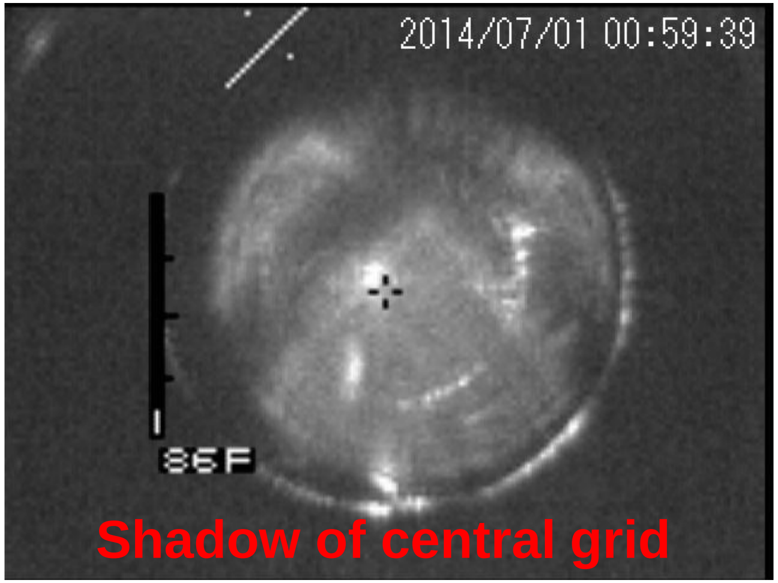
- Laser: Synrad 48-1
- Laser run at ~25% power (2.5W pk)
- 300Hz pulses (1/3 thermal time constant)
- 16% duty cycle
- Germanium rear coupler provides 200x attenuation of beam (99.5% reflection)
- Shadow of metal tube imaged on detector

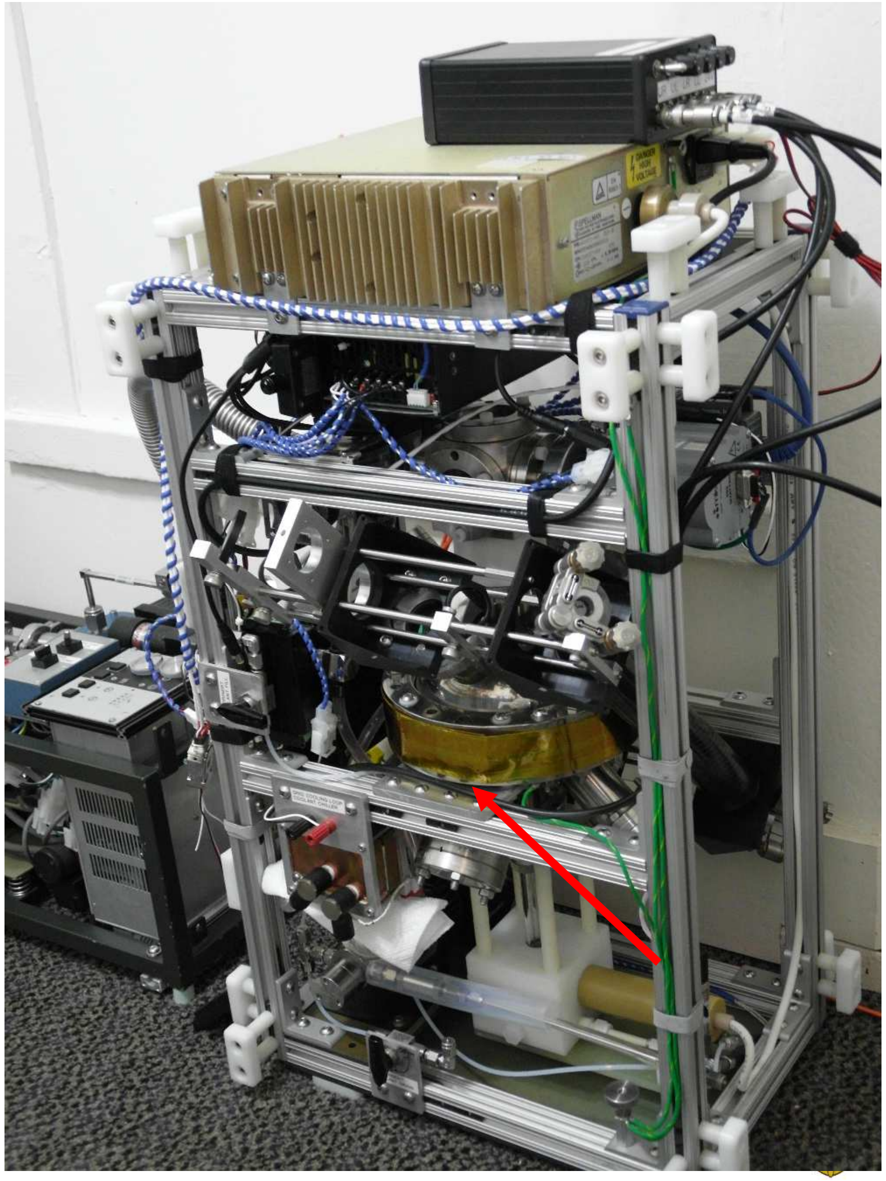




Preliminary Tests

- Imaging beam directed through vacuum chamber, w/o reference beam
- Thermal imager captures shadow of central grid
- Mach Zehnder interferometer construction in progress





Conclusions

- Use of a cooled grid with a segmented ion collector can provide measure spatially resolved distribution of ion bombardment on the grid
- Higher resolution thermal imagers will allow construction of ion collectors with more segments
- Laser power of 500mW avg. with 200x attenuation (2.5mW) sufficient to provide detectable power to the thermal imager without causing damage to the detector
- Grid has required thermal capacity and laser can generate sufficiently short pulses for use with a pulsed power system driving the grid

Questions?

More documentation on this IEC device:
www.rtftechnologies.org