Magnetized Dusty Plasma Experiment (MDPX) Facility

Magnetized Plasma Research Laboratory
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Technical Summary Document

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Revision history:
Version 1.0 – Draft – July, 2014 (internal)
Version 1.1 – Draft – August, 2014 (internal)
Version 1.2 – Draft – August, 2014 (internal)

Version 1.3 – Release document – September 5, 2014 – internal use only
Version 1.4 – Release document – January 28, 2015 – posted online
- Primary MDPX operations document

Version 2.0 – Release document – October 31, 2021
- Revised MDPX operations document
- Added new mode descriptions
- Added revision history list and reference documents
- Updated figure descriptions and added new Fig. 14.

Reference documents:
The following publications may also be used to reference the design and operation of the MDPX device:
[1] E. Thomas, U. Konopka, D. Artis, B. Lynch, S. Leblanc, S. Adams, R. L. Merlino, M. Rosenberg "The magnetized dusty plasma experiment (MDPX)," *J Plasma Phys*, vol. 81, no. 2, p. 345810206, 2015, doi: 10.1017/s0022377815000148.

[2] E. Thomas, A. M. DuBois, B. Lynch, S. Adams, R. Fisher, D. Artis, S. LeBlanc, U. Konopka, R. L. Merlino, M. Rosenberg, "Preliminary characteristics of magnetic field and plasma performance in the Magnetized Dusty Plasma Experiment (MDPX)," *J. Plasma Phys.*, vol. 80, no. 6, pp. 803–808, Jun. 2014, doi: 10.1017/s0022377814000270.

Summary:

The purpose of this document is to provide a technical description of the Magnetized Dusty Plasma Experiment (MDPX) device for potential users and collaborators. While we have attempted to provide an overview of technical capabilities of the MDPX device, this document will likely never contain every detail of the experimental facility. Therefore, we strongly encourage any persons seeking to develop an experiment for MDPX to contact us to get the most up-to-date information.

The MDPX device consists of two integrated components: a superconducting magnet system and a plasma chamber.

<ins>Magnet:</ins>
The MDPX magnet is a "split-bore" superconducting magnet assembled from 4 electromagnet coils and a surrounding cryostat. The coils are cooled within the cryostat to a nominal temperature of 4.5 to 5 K to maintain a superconducting state. The magnet has a 50 cm diameter, 157 cm long (19.68" dia. x 62.0" long) cylindrical "warm bore" where the strongest magnetic field is generated. The open, split-bore design of the magnet (to be shown in the upcoming pages) means that items placed in the magnet can be accessed both from the ends of the magnet as well as radially – allowing substantially greater diagnostic access to the regions with high magnetic field.

The MDPX device is designed to achieve a central, uniform magnetic field of up to 4 T. However, unlike MRI magnets, the magnetic field of the MDPX device is designed to be reconfigurable from uniform to gradient conditions over a range of magnetic field settings. The capability to produce a variety of magnetic geometries "on demand" is a unique feature of the facility.

<ins>Vacuum chamber:</ins>
The primary vacuum chamber used on the MDPX device for dusty plasma experiments is an octagonal chamber with height of 17.78 cm and an inner diameter of 35.56 cm (7" tall x 14" inner dia.). The eight chamber sides have large 5" tall x 4" thru ports that accommodate windows or adapt to ISO-vacuum standard KF63, KF40, and KF25 vacuum ports. The top and bottom covers of the vacuum chamber have a large, 6" diameter port that can accommodate 36" long extensions tubes that expand the overall length of the plasma chamber to over 6 feet long. The top and bottom covers also have several KF25 ports for diagnostics.

<ins>Integration:</ins>
The two components are connected to each other using four aluminum brackets. There four mounting points are easily accessible through the split-bore and can rapidly be disconnected. This means that it is relatively easy (say within 1 to 2 days – depending upon the number of additional diagnostic system that have to be moved) to remove the vacuum chamber from the bore of the magnet and "swap" it with an alternate vacuum chamber or other structure that is to be placed in the bore – provided that the new device uses the same mounting points.

We believe that this flexibility of design will enable the MDPX device to serve as a research instrument for a variety of plasma physics and dusty plasma physics experiments. Moreover, this flexibility means that the device can be easily reconfigured to perform a variety of different scientific studies beyond plasma science where the need for a **long duration (days to weeks), steady-state, high magnetic field (B > 1 T)** is required.

Experimental hardware and diagnostics:

The development of diagnostic systems for the MDPX device is ongoing. As of the writing of this document, the current experimental hardware and diagnostic systems are available:

- Plasma generation systems:
  - Parallel plate, capacitively coupled rf configuration with a powered lower electrode and an upper electrode that can either be electrically floating, grounded, or have a dc bias.
  - The primary MDPX electrodes are 11 inches (279 mm) in diameter with a nominal separation of 62 mm (see Fig. 10). This separation can be adjusted with the use of isolated spacer to a gap size from ~40 to 80 mm.
  - 13.56 MHz rf generator with autotuning matching network (primary plasma generation). Power levels up to 100 W are nominally available.
  - 5 kV, 25 mA dc power supply that is used as a secondary plasma source – connected to the upper electrode.

- Available diagnostic systems.
  - Radially scanning probes for measuring electron temperature, plasma density, and floating/plasma potential profiles along the experiment mid-plane.
  - 300 mW, 532 nm laser for particle illumination
  - Cameras – We have USB3 based (up to 90 fps) cameras that can be mounted on the top and sides of the MDPX device for plasma and dust particle imaging. Typical spatial resolution is ~20 – 30 μm/pixel
  - Spectrometers – A high resolution (≤ 0.1 nm) Princeton Instruments spectrometer for OES measurements; also available are USB-based StellarNet survey spectrometers for plasma process monitoring

- Dust particles
  - Solid silica microspheres with mass density 2200 kg/m^3.
  - Size range (diameter): 0.1 micron to 8 micron

Collaborative studies using MDPX:

- Collaborative experiments could either be one-time, stand-alone experiments or be used to obtain preliminary data for more extensive studies. For the latter case, if the preliminary studies are successful, we would provide letters of support and commitments of future run-time for funding proposals that seek to use MDPX.

At the present time, five modes of collaborative experiments have been used. See Fig. 14 for some examples of various modes:

Mode 0: Complementary studies using previous MPRL data – theoretical, computational, or analytical projects

- A proposed experiment would use previous data obtained in experimental runs and no new experiments are requested.
- Data will be provided to a user – including calibration information. Data must be outside of the 1 year "embargo" period established by the MPRL data management plan.
- Example: A collaborator wishes to use previous measurements of particle transport in the MDPX device to perform a complementary study of diffusive processes in dusty plasmas.

Mode 1: Measurements on MDPX using existing capabilities

- In this mode, a proposed experiment would use the existing hardware and diagnostics of the facility to perform an experiment. This could be to investigate a particular phenomenon or characterize a type of particle or plasma behavior at high magnetic field.
- A typical visit of this type could be 5 to 7 days – with a half-day for setup and a half-day for shut down and 3 to 5 days of experimental operations.
- Example: A collaborator wishes to operate the device in a low pressure regime to see how particle transport is affected by laser manipulation.

Mode 2: Measurements on MDPX using non-invasive tools

- Here, a proposed experiment would use the plasma and dusty plasma generation systems of the MDPX device, but a collaborator would provide some additional diagnostic system.
- A visit of this type could be between 8 to 14 days depending upon complexity of the diagnostic system. The goal would be to install and test the hardware at the end of one week (or over a weekend), and to perform 4 to 5 days of experiments the following week.
- The extra days would be needed to ensure the compatibility and safe operation of the external hardware with the magnetic field.
- Example: A collaborator wishes to add a high frame rate microscope system to perform high resolution studies of particle motion in the magnetic field.

Mode 3: Measurements on MDPX requiring changes in the experiment configuration

- Here, a proposed experiment would require changing something on the interior of the MDPX vacuum chamber – e.g., adding electrodes for particle manipulation, changing particle sizes, adding a probe, etc.
- A visit of this type could be between 8 to 14 days depending upon complexity of the changes and time required to establish a good vacuum. The goal would be to install and test the hardware at the end of one week (or over a weekend), and to perform 4 to 5 days of experiments the following week.
- The extra days would be needed to ensure the compatibility and safe operation of the external hardware with the magnetic field.

- Example: A collaborator wishes to change particles and add additional confinement rings to the MDPX electrode to create multiple trapping regions for dust particles.

Mode 4: Measurements using the MDPX magnet system, but using a different vacuum chamber

- Here, the "standard" MDPX vacuum chamber would be exchanged for a collaborator-provided system.
- This type of experiment would likely require an extended stay of 2 to 3 weeks with significant planning beforehand.
- This has become one of the more highly used methods for collaborative experiments and the MPRL has extensive experience in supporting these types of studies.
- Example 1 ($B = 0$ vs. $B \neq 0$ studies): Often, collaborators have performed extensive studies in their systems without a magnetic field and are seeking to perform complementary studies in the presence of a magnetic field.
- Example 2 (Calibration of fusion diagnostics): We have also supported studies where a collaborator seeks to calibrate an instrument / diagnostic for use in a high magnetic field environment (e.g., fusion experiments), where the magnetic field is pulsed. The MDPX facility provides a steady-state, uniform, high magnetic field environment for detailed testing of diagnostic performance.

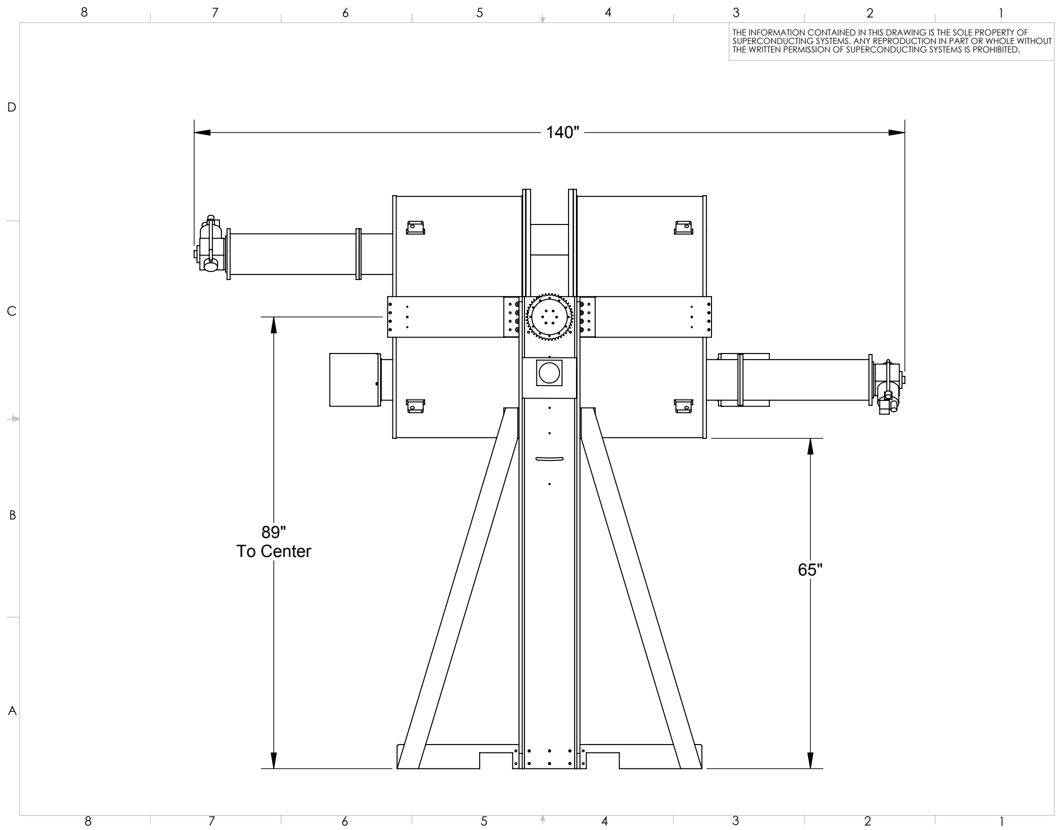
Collaboration logistics:

- Runtime proposal submissions:
    - Users may submit requests for operational time using the MDPX device (or any of the MPRL facilities, including the linear experiment ALEXIS) at any time. Users are strongly encouraged to participate in the MagNetUS call (http://MagNetUs.net) or submit proposals directly to us via the website (http://aub.ie/mprl).
    - User requests are reviewed internally and externally in order to make decisions about awarding operational time.
    - The MPRL has a strong history of welcoming and support junior scientists (graduate student and post-doc) as well as collaborative users from predominantly undergraduate institutions (PUIs). We particularly seek to work with researchers from institutions with smaller plasma physics programs to give faculty and students opportunities to expand their research opportunities.
    - https://docs.google.com/spreadsheets/d/1XXnLGeFFSBT4n7XQG4KAmnPR4v3uTWtZ-Wwli1u5xlE/ (Collaborative User List)

- Operational logistics:
    - A typical plan for an experiment will include:
        - A 1 or 2 day "pre-visit", a minimum 6 to 8 weeks prior to the experiment to become familiar with the laboratory and to discuss operational logistics with the local team
        - We recommend users plan on a 7 to 10 day run schedule for Mode 1 or 2 projects. A minimum 10 day run schedule (up to 21 days) for Mode 3 or 4 experiments.
    - Please contact the Auburn team about practical logistics such support for travel and lodging.
    - We also work with collaborative users to help them develop requests to funding agencies for support for projects at the MPRL.

List of Figures: Page

Figure 1: Overall dimensions - courtesy Superconducting Systems, Inc. [SSI]



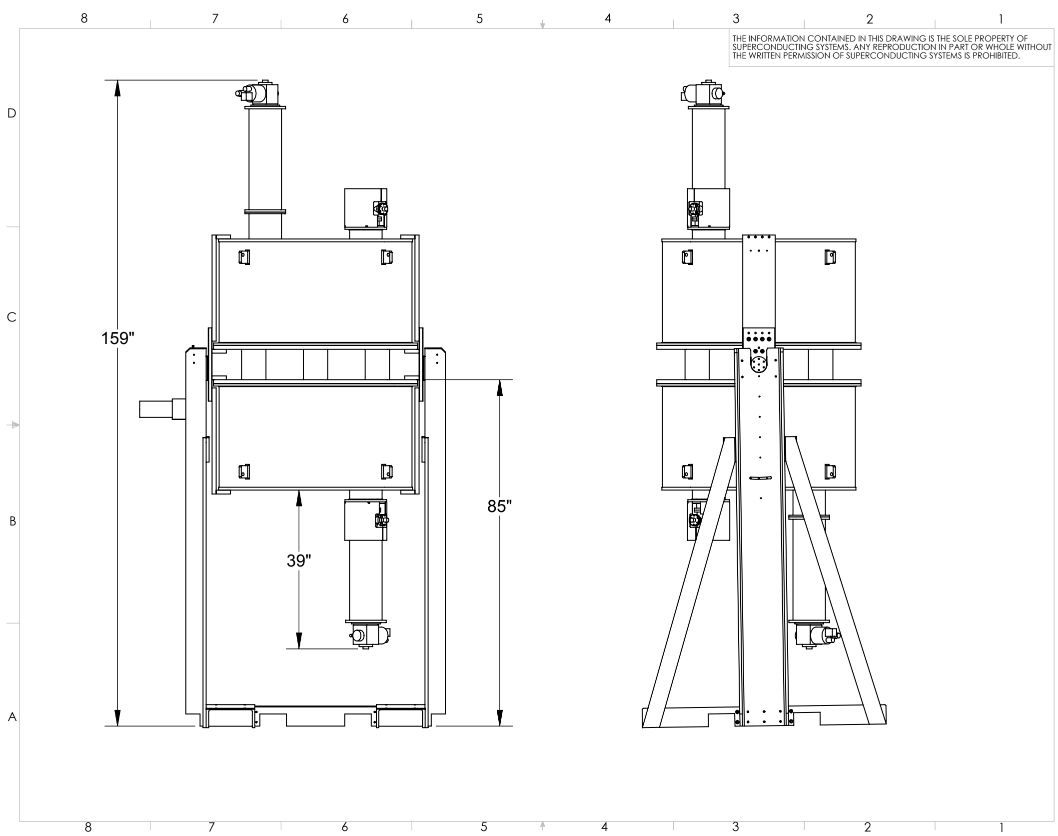
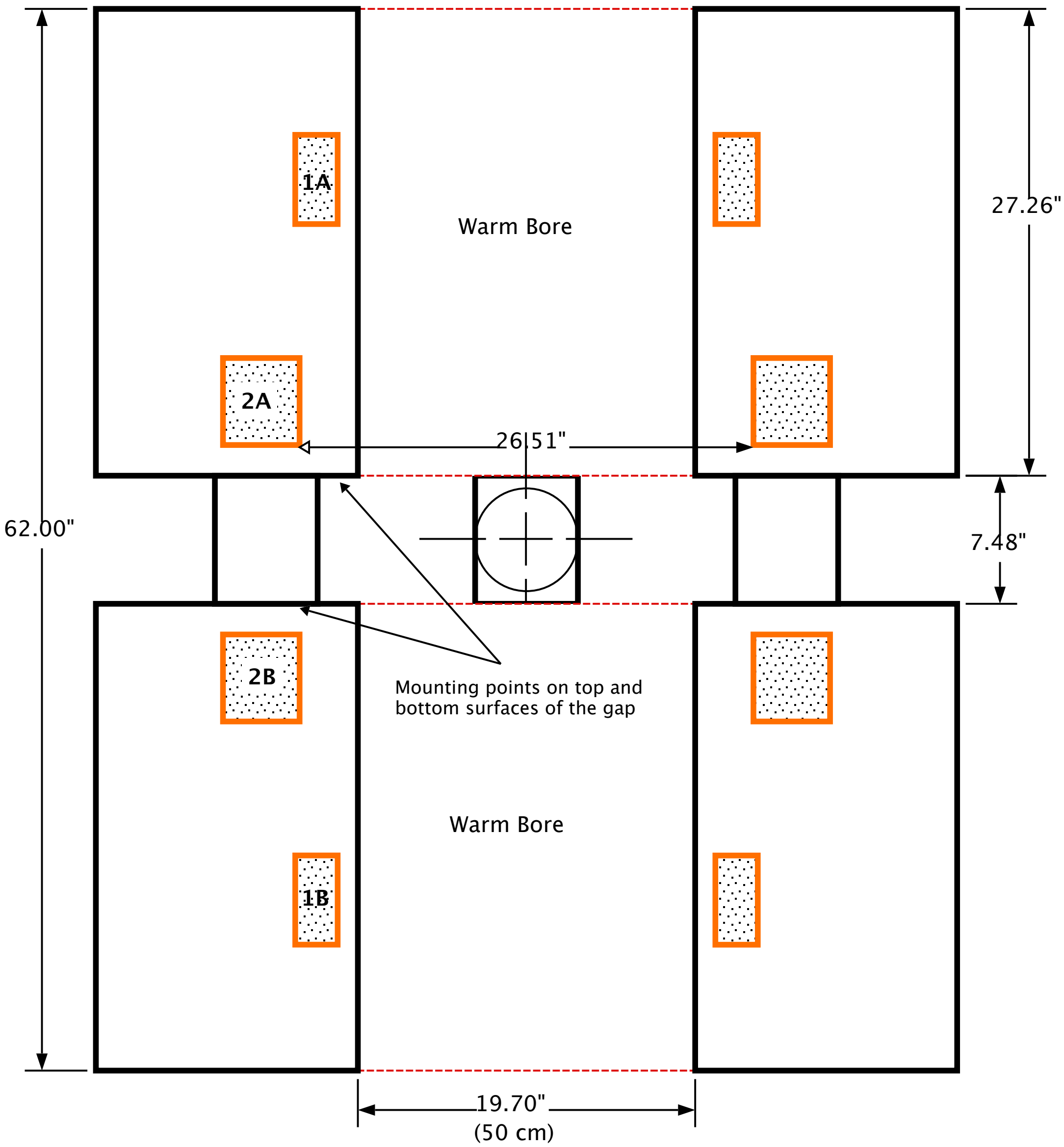


Figure 2: Schematic drawing of the magnet cryostat



Drawing: MDPX – Magnet Cryostat
By: E. Thomas, Jr.

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Auburn University, Auburn, AL

Figure 3: Cryostat mounting points

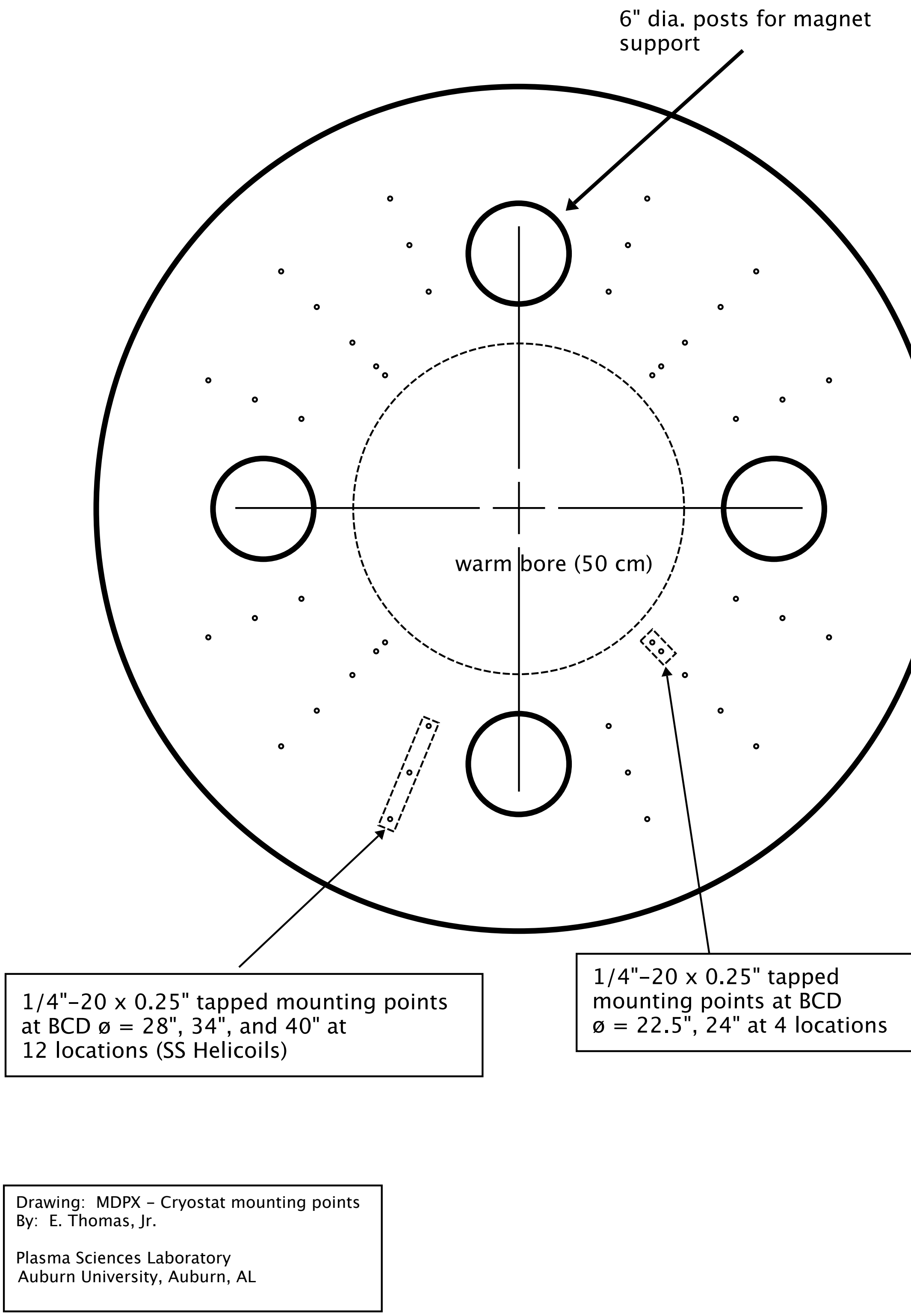
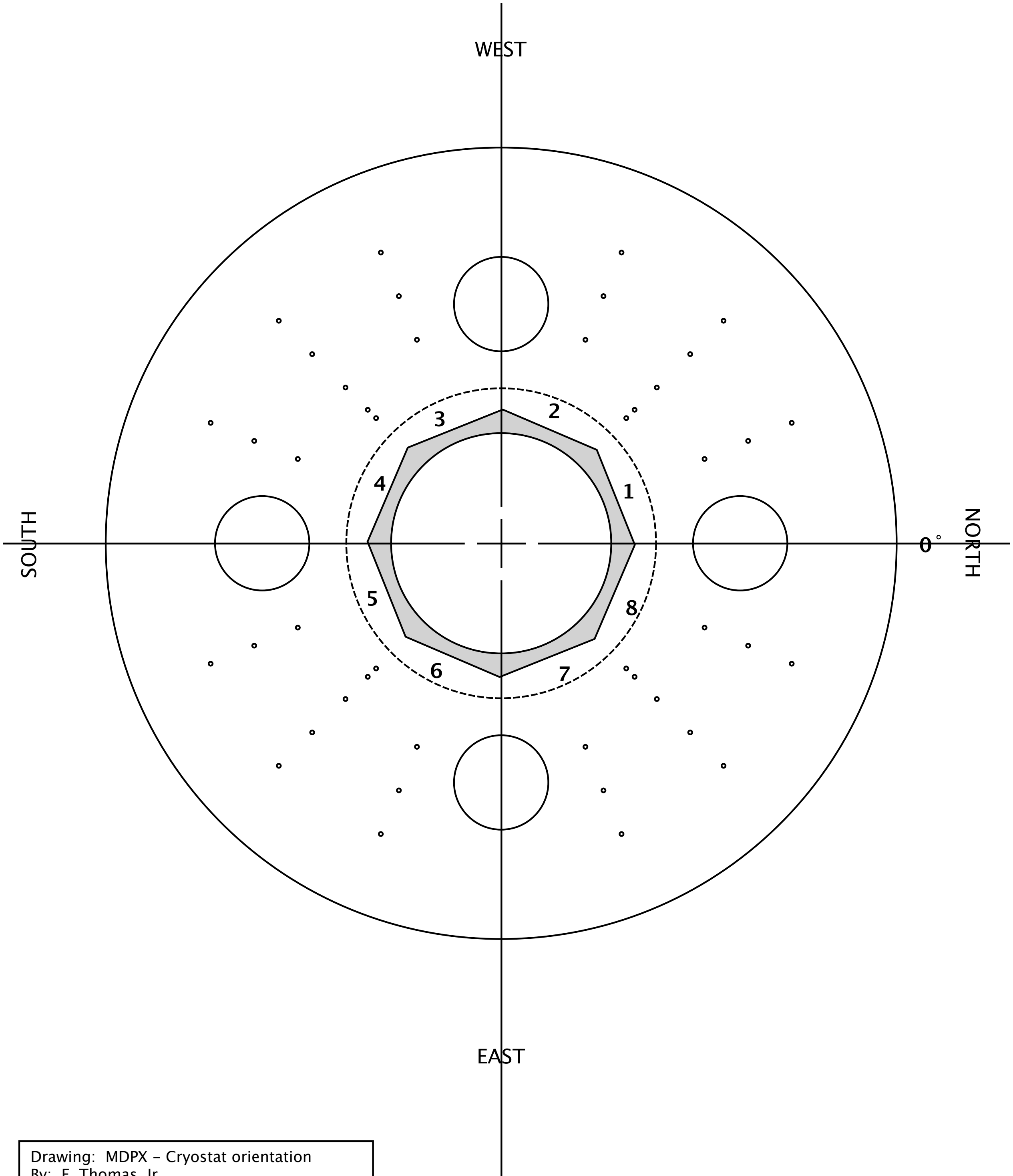


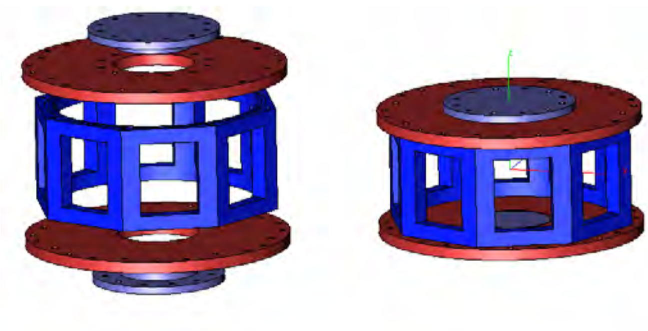
Figure 4: MDPX cryostat and octagon vacuum chamber orientations (number indicate port designation)



Drawing: MDPX – Cryostat orientation
By: E. Thomas, Jr.

Plasma Sciences Laboratory
Auburn University, Auburn, AL

Figure 5: MDPX vacuum chamber – design and photographs (before integration into magnet)



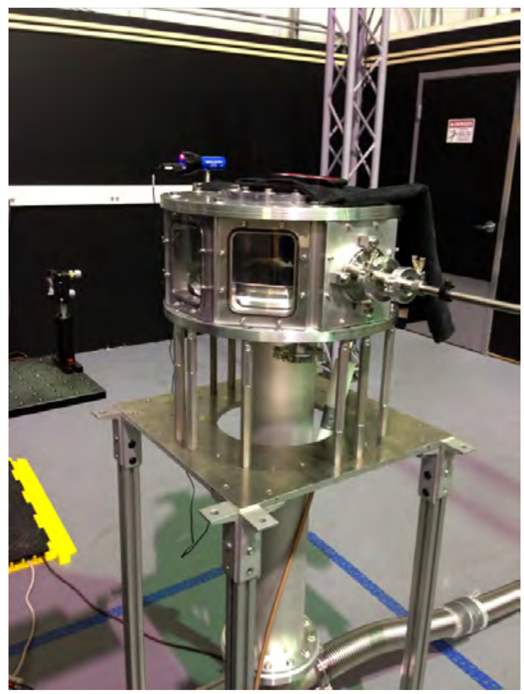


Figure 6: Overview photograph and design of the Magnet Lab. The control room for the Magnet Lab is behind the East wall. The Utility Room containing the power supplies and DAQ system is to the West.

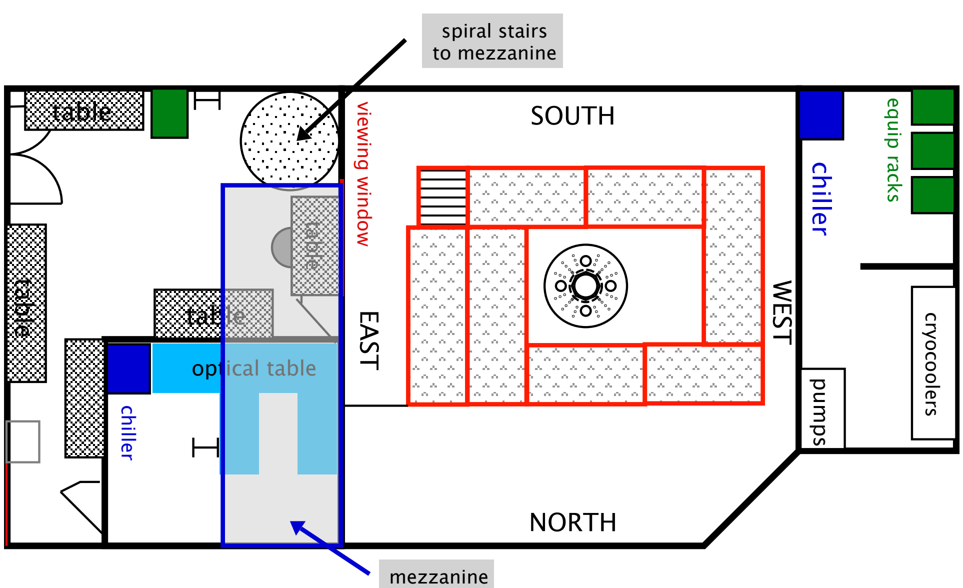


Figure 7: Photograph of magnet cryostat showing split bore design

Figure 8: Photograph of mounting bracket

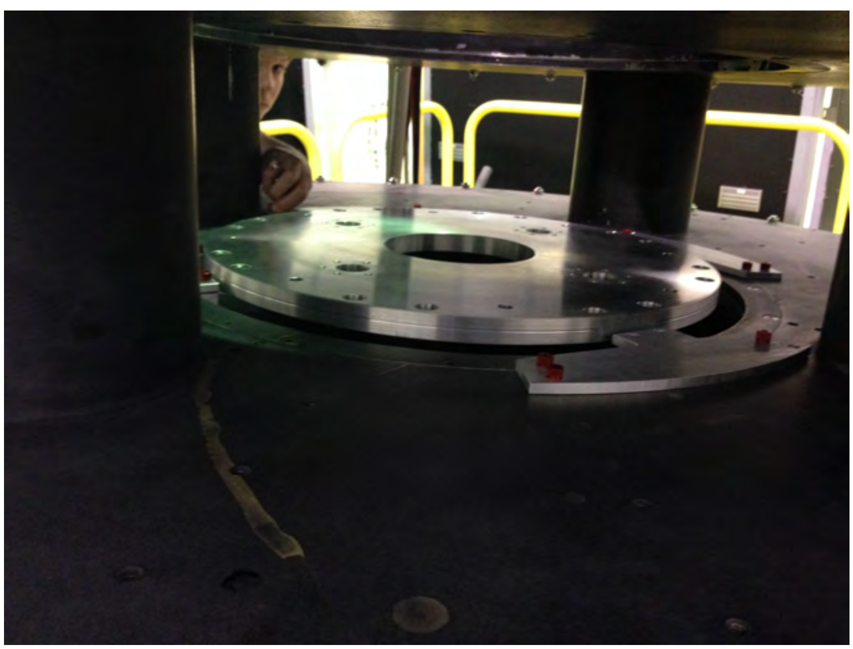


Figure 9: Photograph of plasma glow in MDPX plasma chamber

Figure 10: Preliminary diagnostics for dusty plasmas experiments (July, 2014)

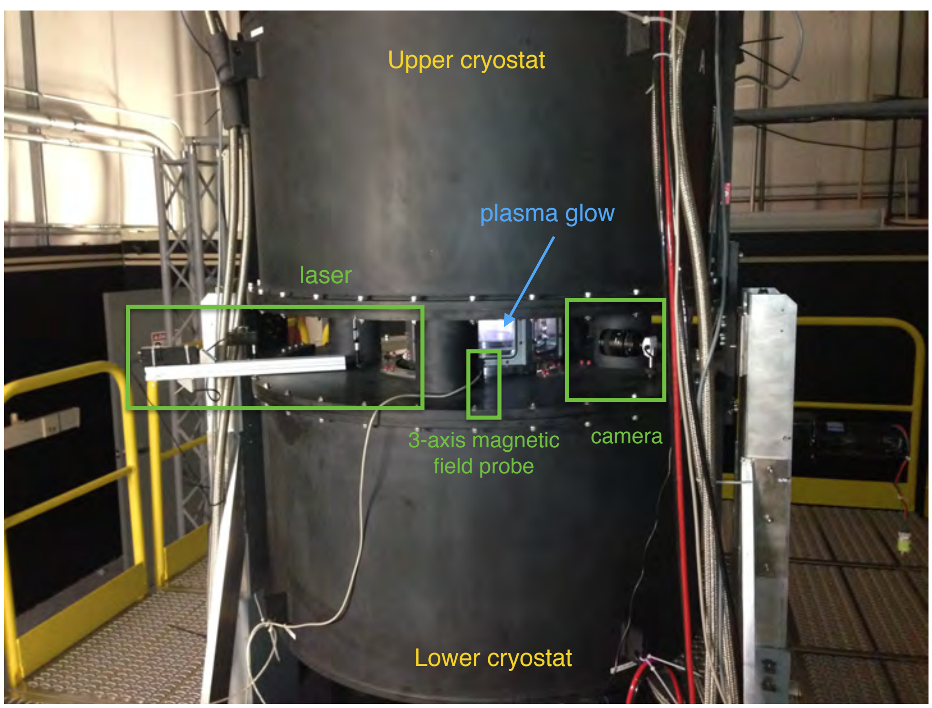


Figure 11: Nominal configuration of rf and dc electrodes for plasma generation

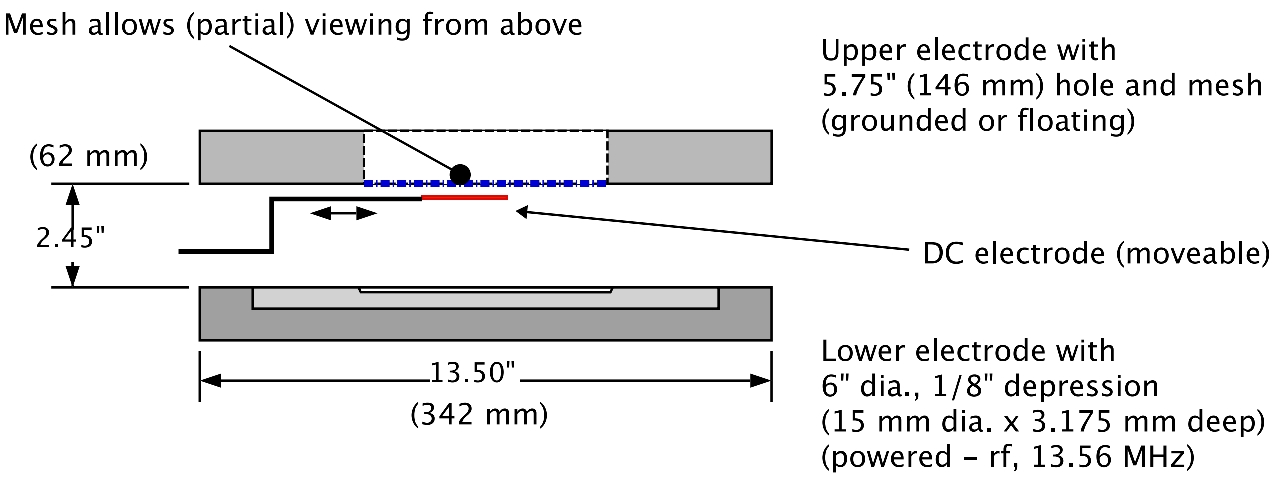
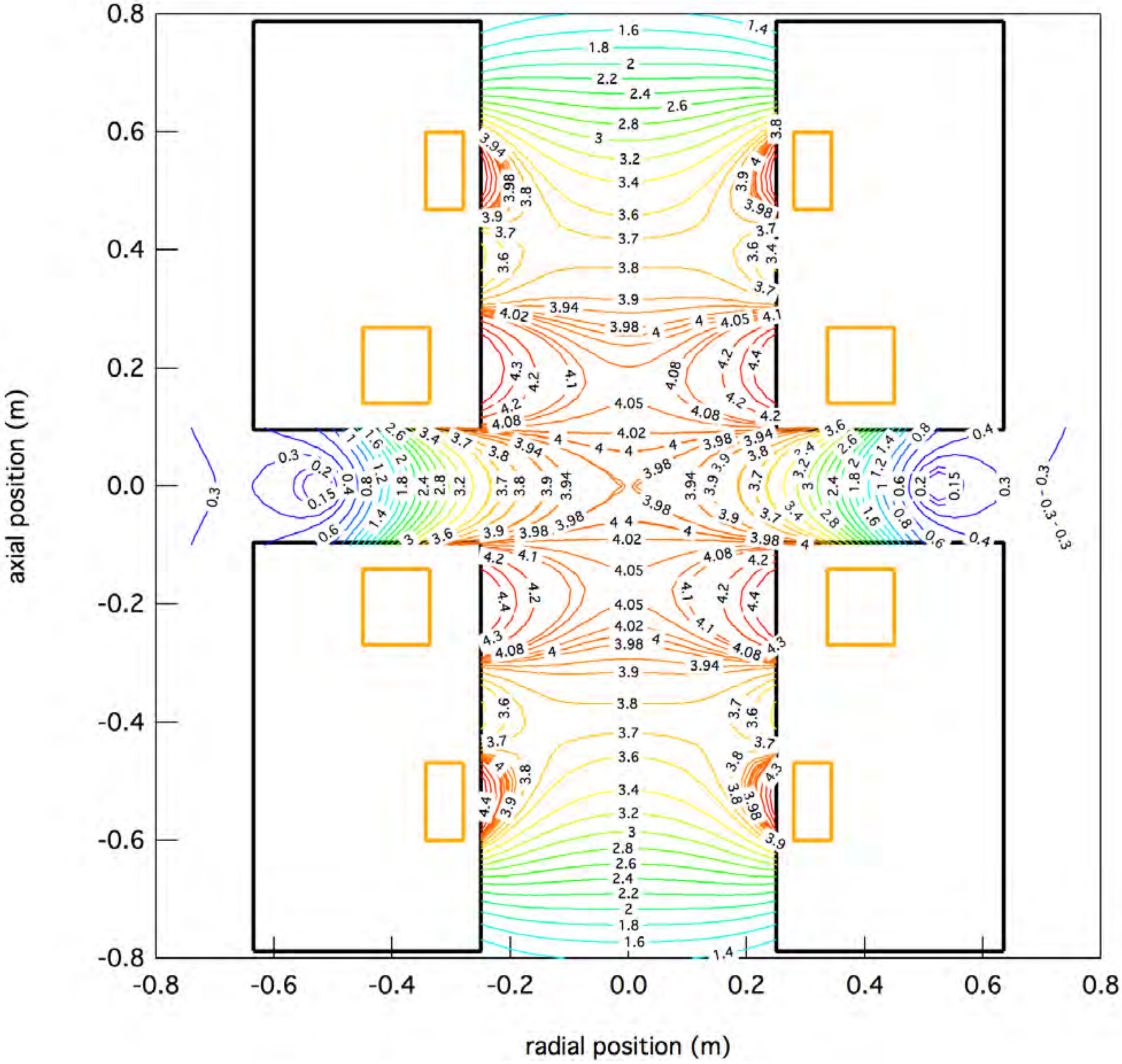


Figure 12: Magnetic field contour calculations – uniform field
[Based upon calibrated field model 7-31-14 for a central field of B = 4 T]

(a) Whole device magnetic field contour



(b) Central bore magnetic field contour

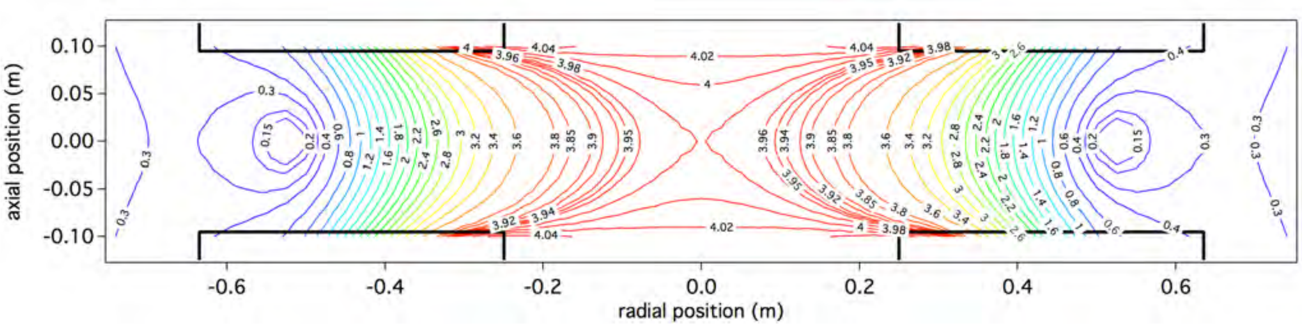
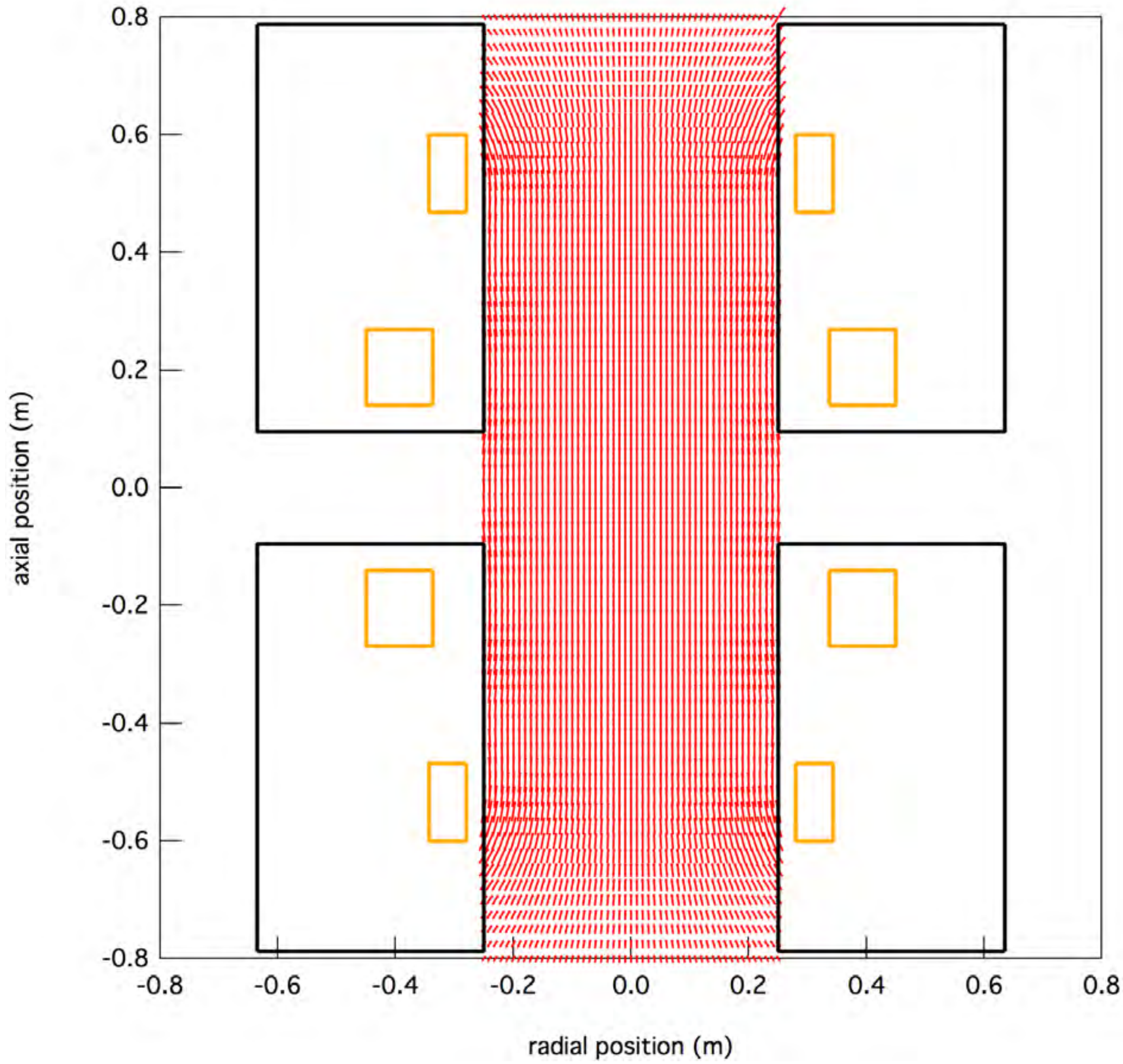


Figure 13: Magnetic field vector calculations – uniform field

(a) Whole device magnetic field vectors



(b) Central bore magnetic field vectors

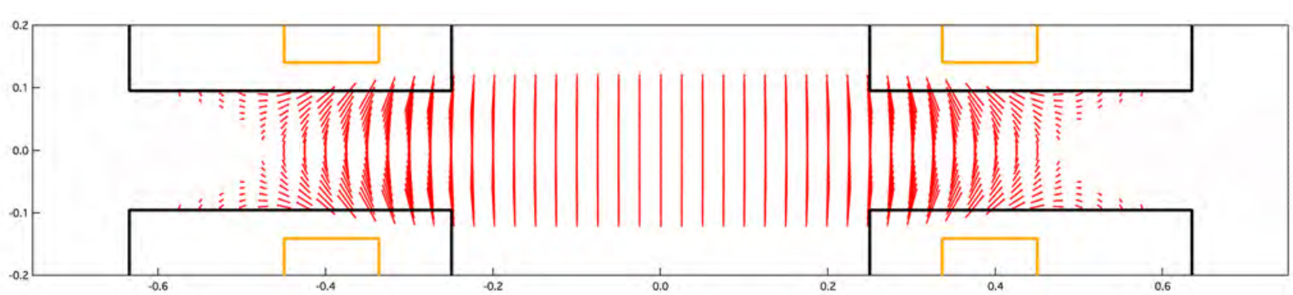
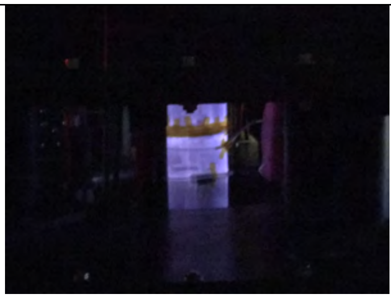
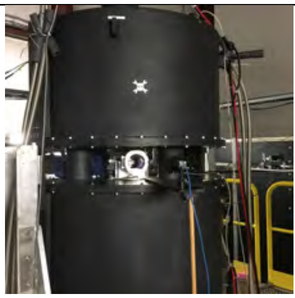
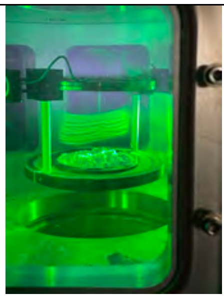


Figure 14: Examples of collaborative experiments and operational modes in the MDPX device.

	DC glow discharge plasma in a cylindrical glass chamber. Mode 4 experiment – Univ. of Maryland – Baltimore County (UMBC)
	Dust particle growth chamber using reactive gases. Mode 4 experiment – Univ. of Saskatchewan (Canada)
	Influence of magnetic fields on dusty plasma waves. Mode 3 experiment – Wittenberg University
	Horizontal experimental configuration for MDPX – Mode 1 experiment – Auburn University
	Performing Laser Induced Fluorescence in the MDPX device. Mode 2 experiment – West Virginia University