Magnetized Dusty Plasma Experiment (MDPX) Facility

Plasma Sciences Laboratory
Physics Department
Auburn University
Auburn, AL

Technical Summary Document

Current Version: 1.4
Date: January 28, 2015

Contact:
Prof. Edward Thomas, Jr., Physics Department, Auburn University
334-844-4126 (office) – 334-844-8508 (magnet lab)
etjr@auburn.edu

Prof. Uwe Konopka, Physics Department, Auburn University
334-844-4248 (office)
uzk0003@auburn.edu

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.

Magnet:
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.

Vacuum chamber:
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.

Integration:
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 3 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 (which is its primary mission). Moreover, this flexibility means that the device can be easily reconfigured to perform a variety of different scientific studies beyond plasma science.

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. Plates are 11 inches (279 mm) in diameter with a separation of 62 mm (see Fig. 10).
  - Secondary anode, 2 inches (50.8 mm) in diameter, movable from center to edge of vacuum chamber.
  - 13.56 MHz rf generator with autotuning matching network (primary plasma generation)
  - 5 kV, 25 mA dc power supply that is used as a secondary plasma source – connected to the upper electrode.

- Diagnostic systems.
  - Radially scanning triple probe for measuring electron temperature, plasma density, and floating/plasma potential profiles along the experiment mid-plane.
  - 300 mW, 532 nm laser for particle illumination
  - Camera 1: 0.4 Mpixel, 80 frame/second (fps) USB 2.0 camera that can operate up to 2 T (grayscale) – side view camera [IDS imaging]
  - Camera 2: 4 Mpixel, 90 fps, USB 3.0 camera – has some image distortion above 1 Tesla, otherwise works reasonably well (grayscale) – top view camera [Ximea].
  - Camera – 1.4 MPixel, 150 fps, USB 3.0 grayscale camera – side view camera [PointGrey]
  - Camera – 1.3 Mpixel, 60 fps, USB 3.0 color camera (to be tested in magnet)
  - Spectrometer – USB-based Ocean Optics spectrometer (to be tested in magnet)

- Dust particles
  - Solid silica microspheres with mass density 2200 kg/m^3.
  - Size range (diameter): 0.5 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, four levels of collaborative experiments are envisioned:

Level 1: Measurements on MDPX using existing capabilities

- At this level, 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.

Level 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.

Level 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.

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

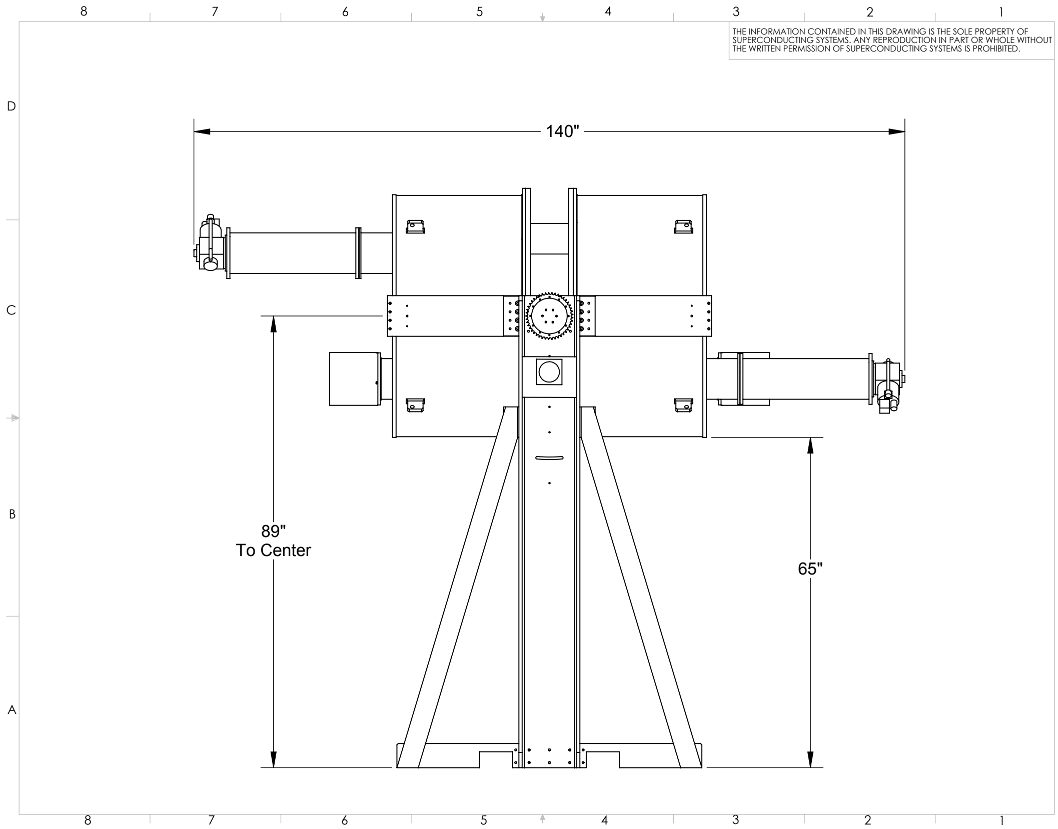
- Here, the "standard" MDPX vacuum chamber would be exchanged for a collaborator-provided system.
- This type of experiment would likely require an extended stay of 10 to 14 days and significant planning beforehand.

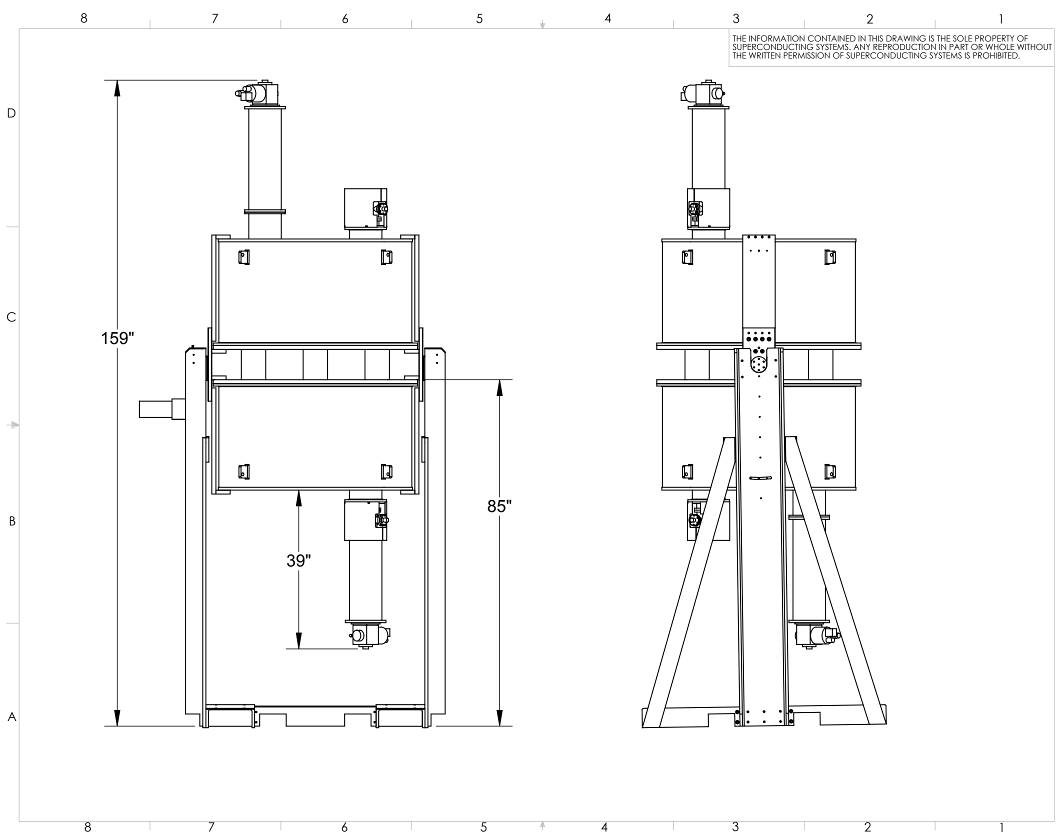
Collaboration logistics:

- The MDPX project was awarded some funds to support collaborations.
- At the present time, we believe that we could support between 4 to 8 visitors per year (each visit being nominally 7 days) over the next two years – starting sometime in early 2015.
- Funds provided by the Auburn group would cover lodging, meals, and partial travel support. Some limited funding is available for supporting hardware development for collaborative experiments. This would need to be discussed on a case-by-case basis.
- We would strongly welcome, encourage and support junior scientists (graduate student and post-doc) participation in these collaborations.

List of Figures for MDPX: Page

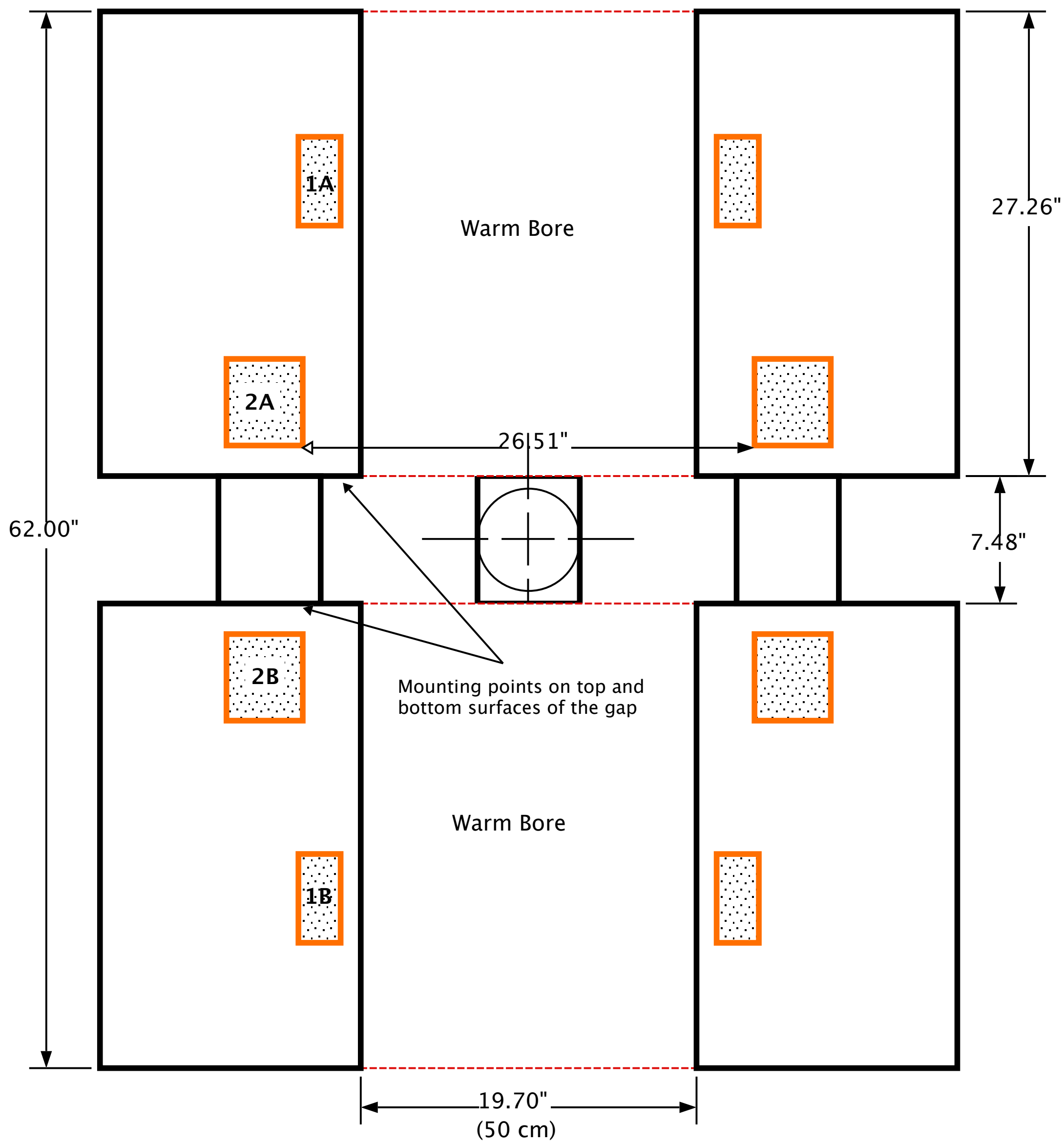
Figure 1: Overall dimensions - courtesy Superconducting Systems, Inc. [SSI]





DRAFT – 28 January 2015

Figure 2: Schematic drawing of the magnet cryostat

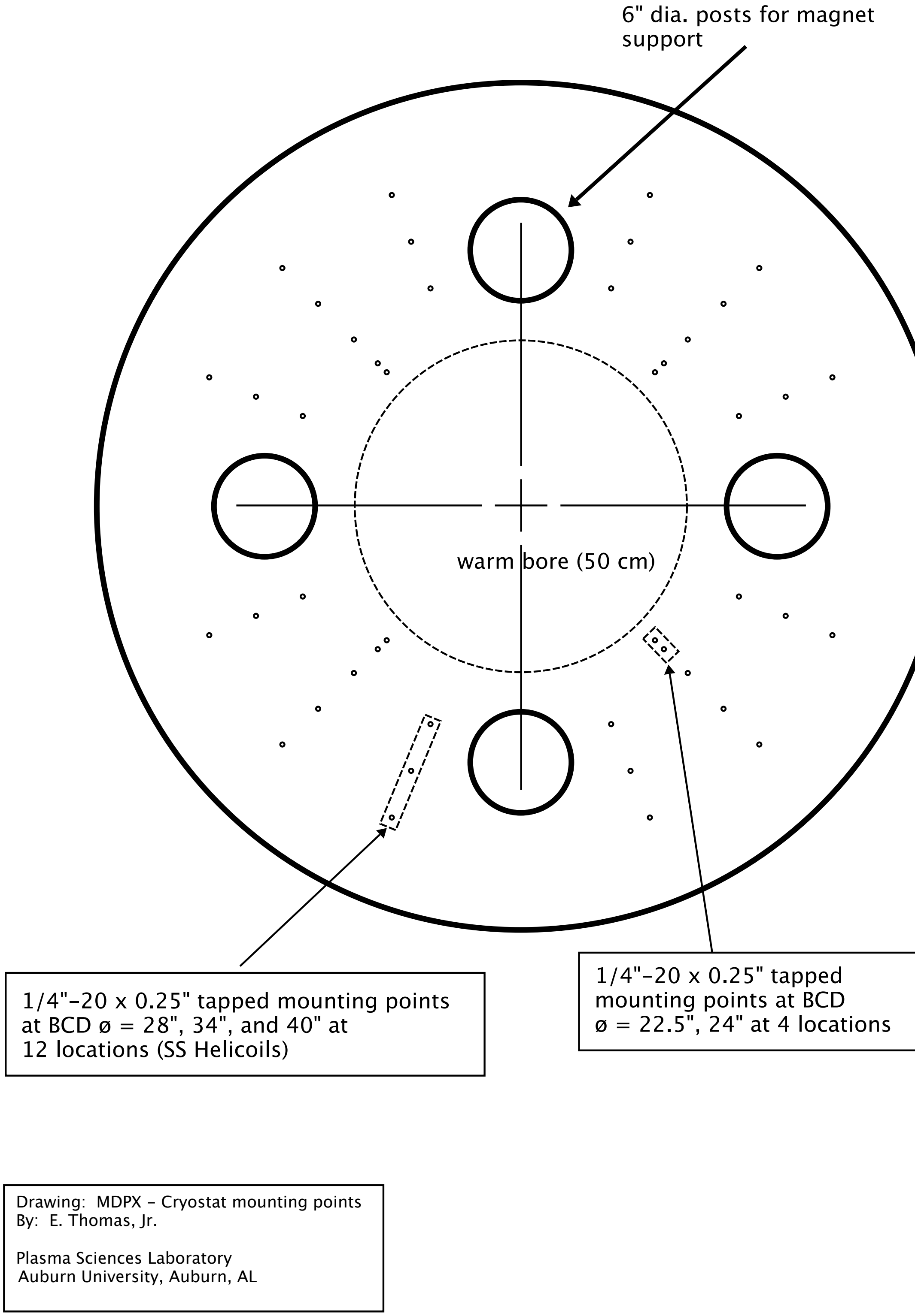


Drawing: MDPX – Magnet Cryostat
By: E. Thomas, Jr.

Plasma Sciences Laboratory
Auburn University, Auburn, AL

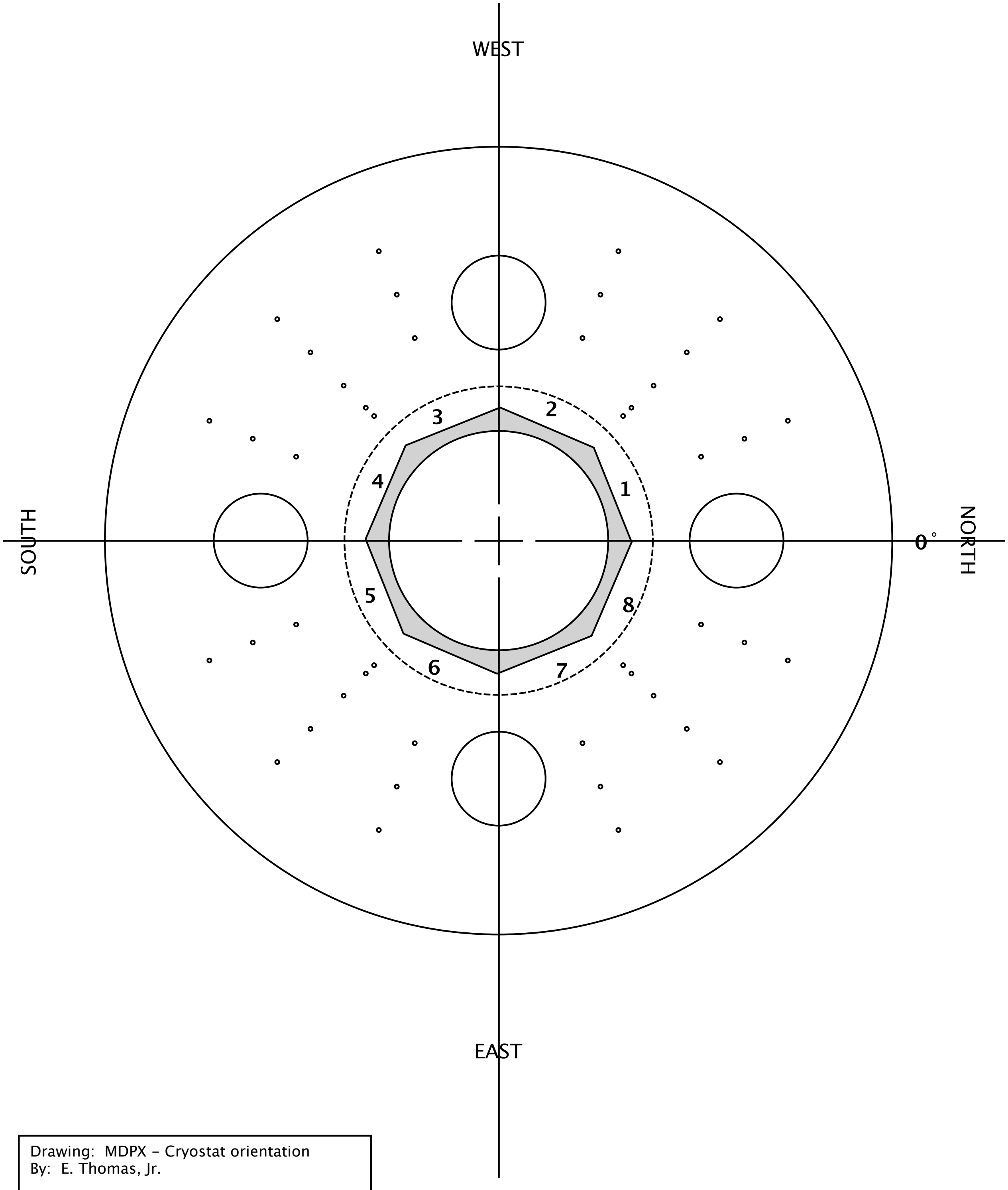
DRAFT – 28 January 2015

Figure 3: Cryostat mounting points



DRAFT – 28 January 2015

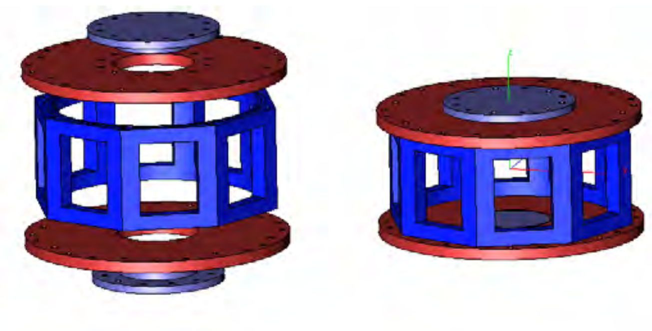
Figure 4: Cryostat and vacuum chamber orientation (number indicate port designation)



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)



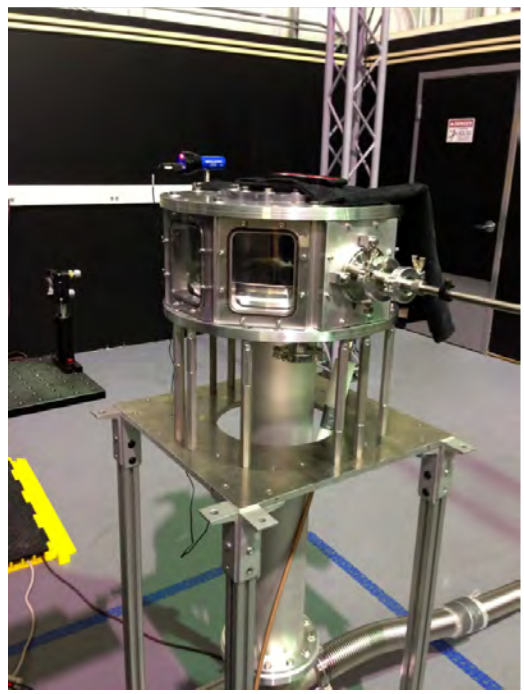


Figure 6: Overview photograph and design of the Magnet Lab

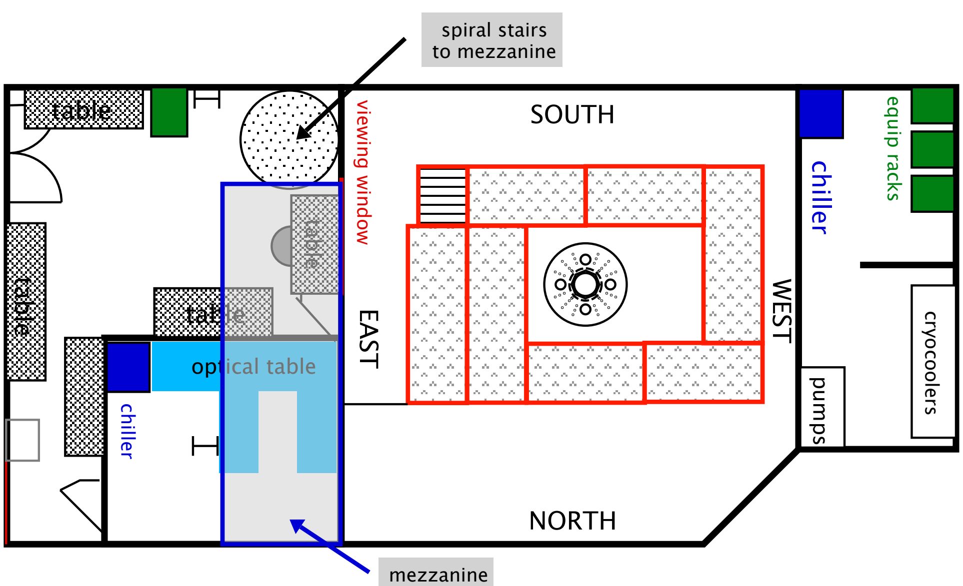


Figure 7: Photograph of magnet cryostat showing split bore design

Figure 8: Photograph of mounting bracket

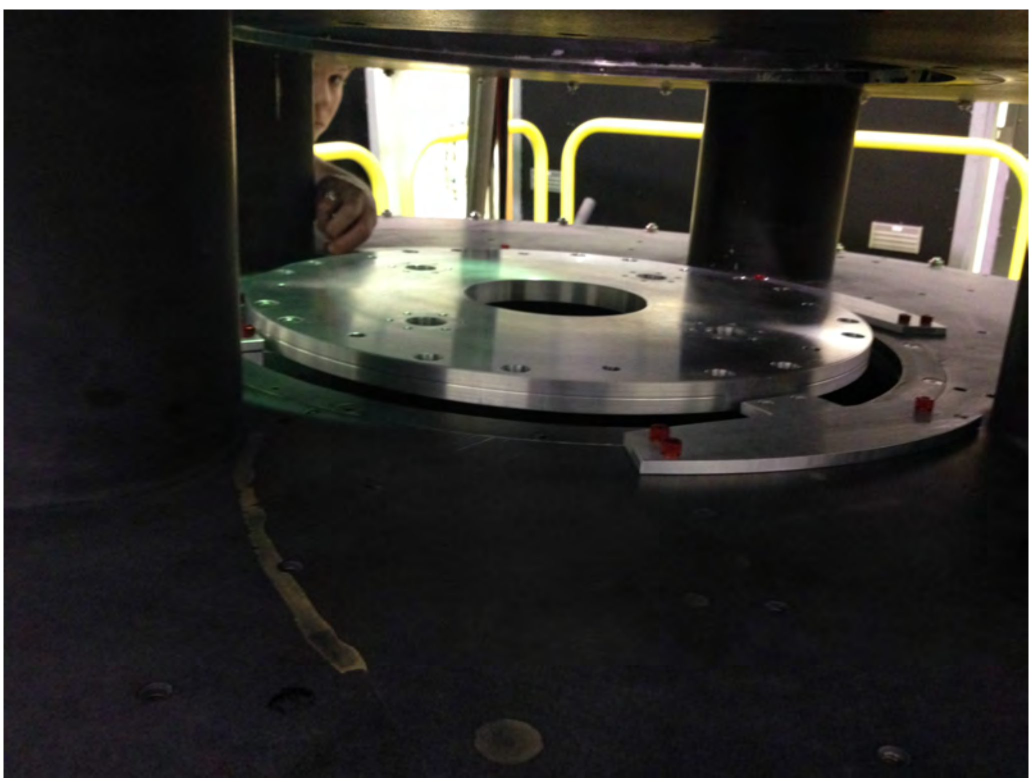


Figure 9: Photograph of plasma glow in MDPX plasma chamber

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

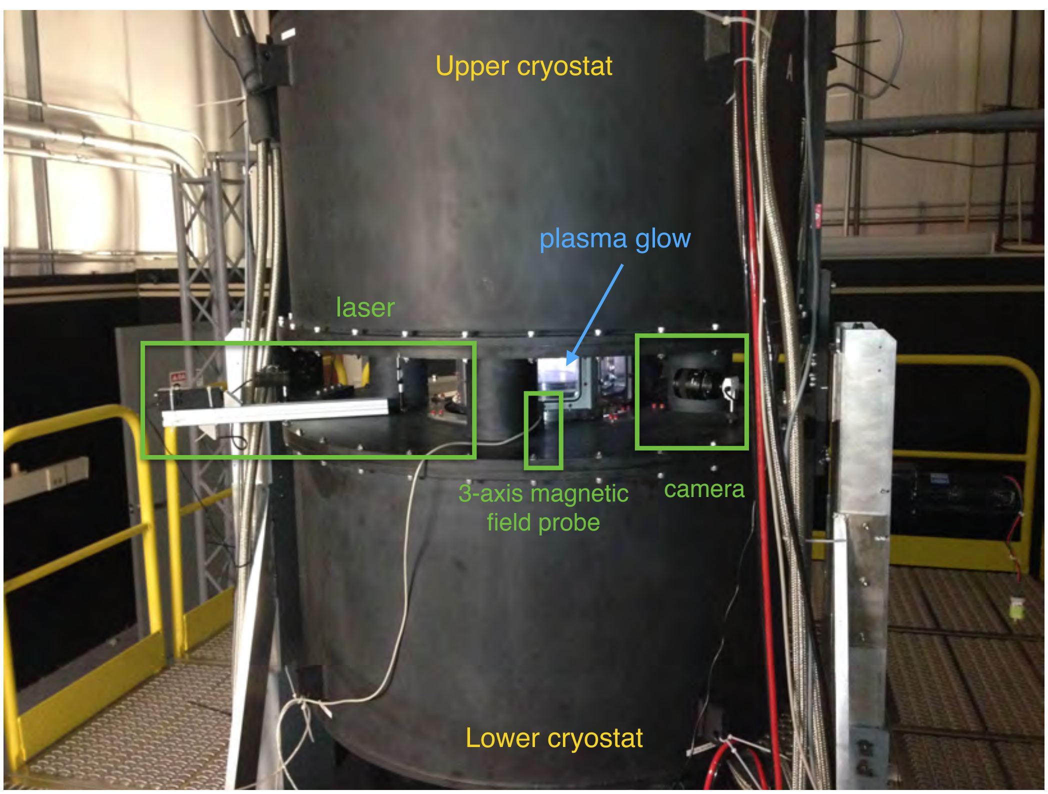


Figure 11: Configuration of rf and dc electrodes for plasma generation

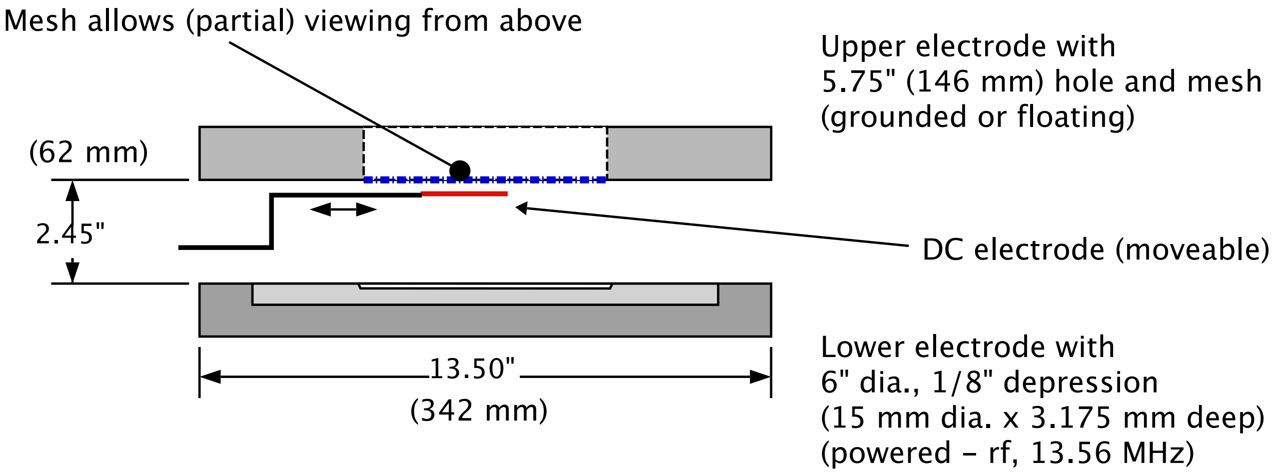
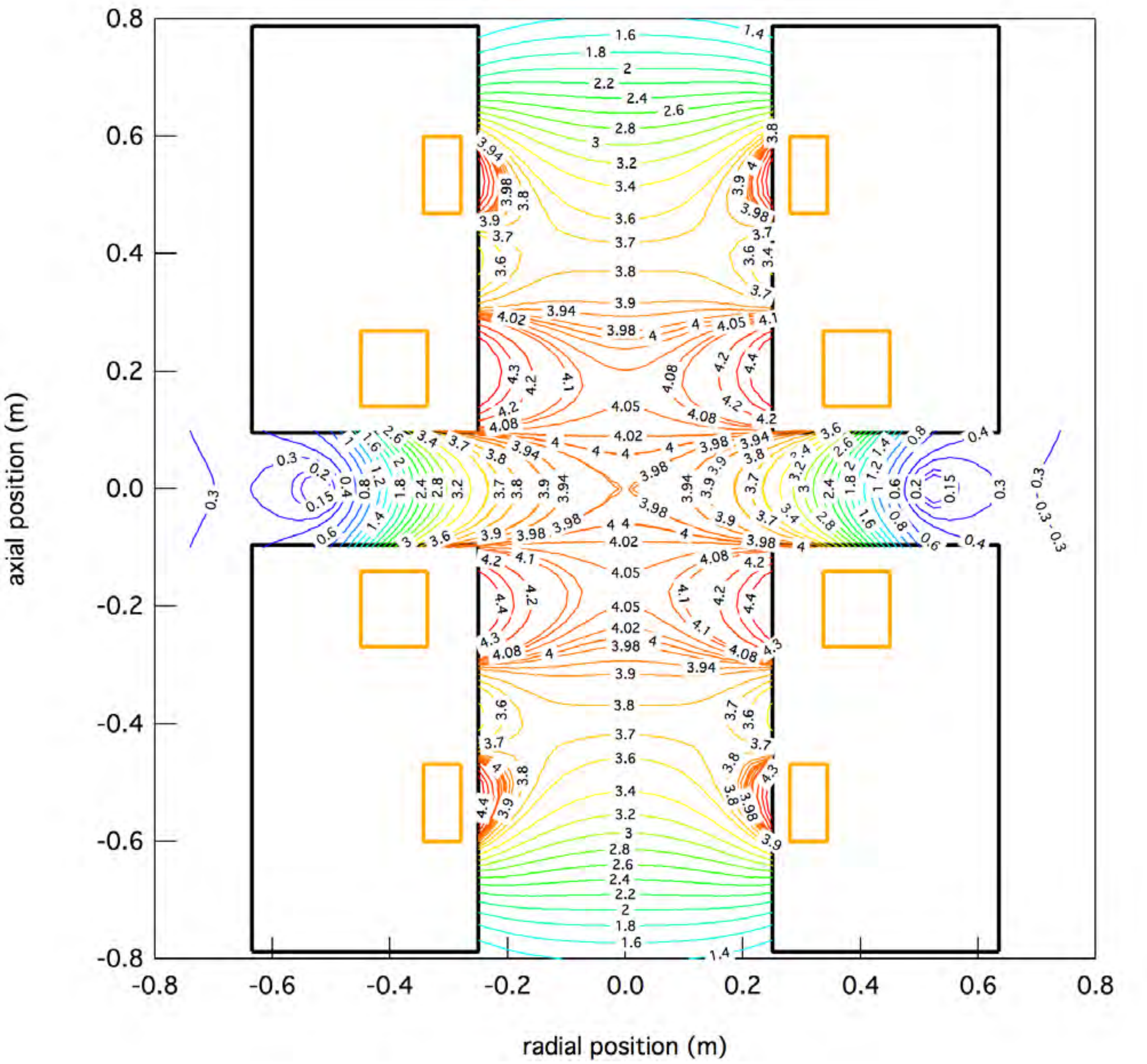


Figure 12: Magnetic field contour calculations – uniform field
[Based upon calibrated field model 7-31-14 for a central field of B = 4 T]

(a) Whole device magnetic field contour



(b) Central bore magnetic field contour

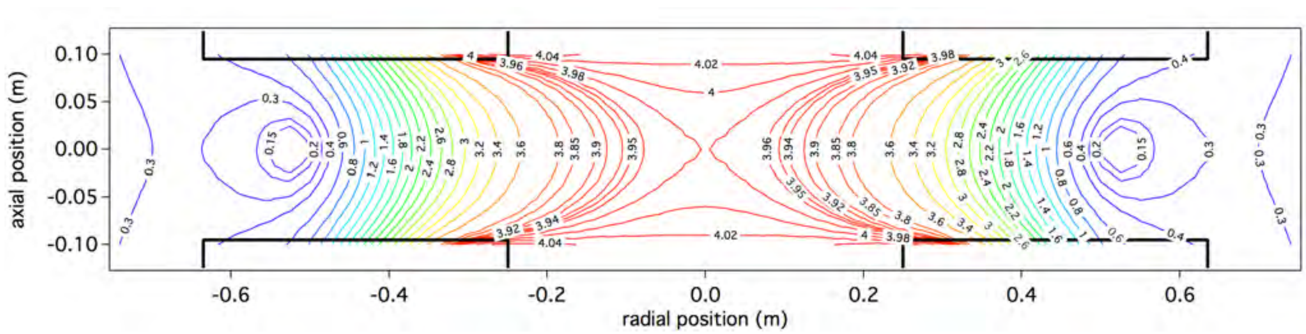
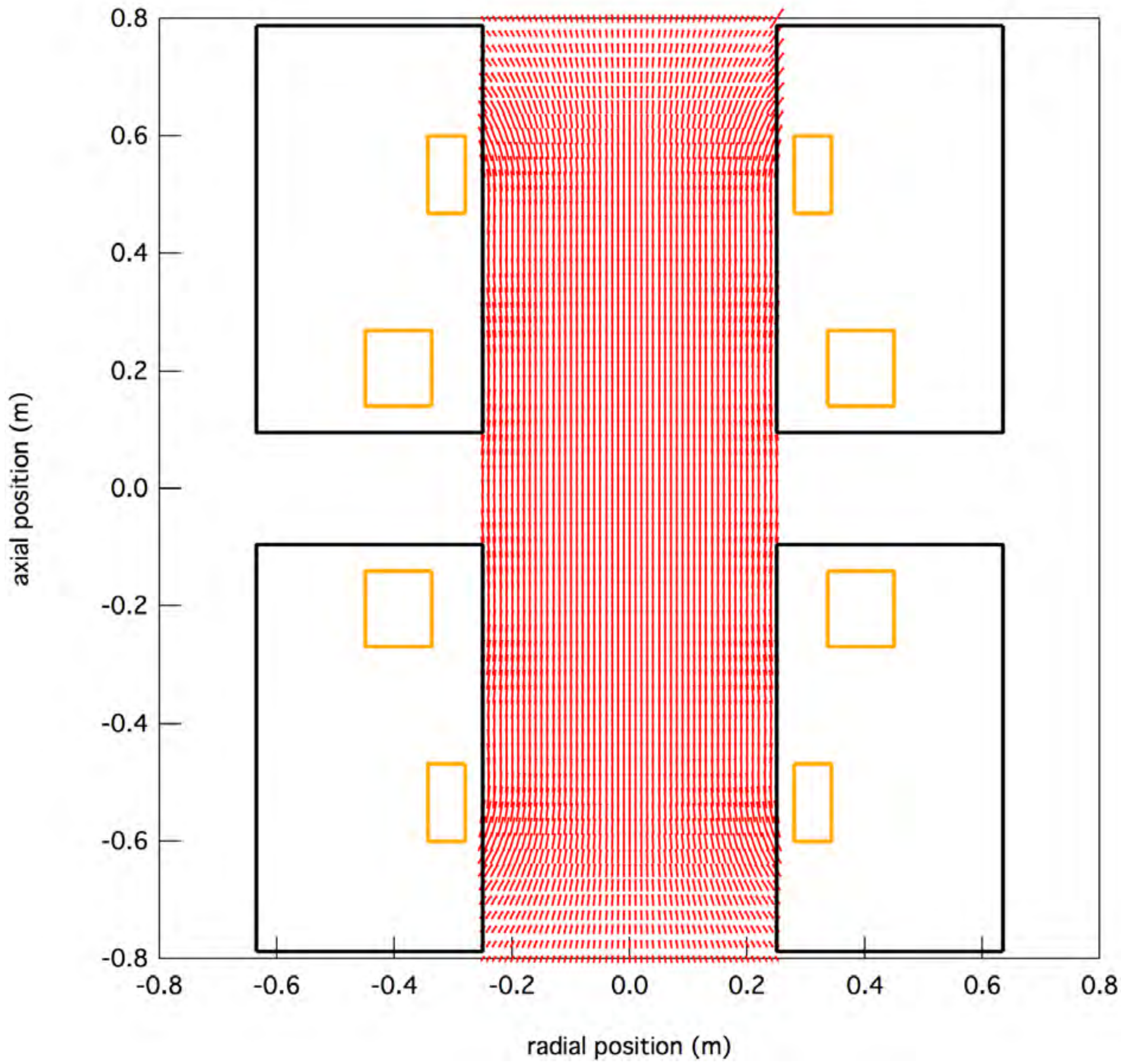


Figure 13: Magnetic field vector calculations – uniform field

(a) Whole device magnetic field vectors



(b) Central bore magnetic field vectors