HEP Lab A Hardware Documentation

Varian v-4004 Electromagnet

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Synopsis:

The following documentation refers specifically to the current electronic configuration and the magnetic field strength mapping of the Varian v-4004 electromagnet.

Thanks to Chris Bracci for helping with the many field measurements and to Aiwu Zhang for a concise introduction to ROOT and script formalities.

1. Electronic Configuration

1.1 Specific Setup and Settings

To see the general setup of the electromagnet and circuit information, please refer to the hardware report (entitled and authored similarly) written in Fall 2013. This section will briefly describe the updates that have been made to produce the current configuration.

Figure 1 shows a summary of the current circuit setup. Resistances are based directly on the values given for the coils. The voltages were read from the screens of the power supplies. Current was then calculated as the quotient of voltage and resistance. The availability column gives the remaining values that could be added to the circuitry to maximize the electromagnet's field. The final column shows which coils would need additional power supplies in order to further increase the field. Refer to section **4.2** of the **Appendix** for a picture of the current power supply setup.

Element (Drum/Coil)	Resistance (Ω)	Voltage (V)	Current (A)	Available to Add (V / A)	Supply Maxed?
1/A	25.0	50.0	2.00	0.0 / 0.00	No
1/C	42.0	65.0	1.55	19.0 / 0.45	Yes
1/B & 1/D	81.0	115.0	1.42	47.0 / 0.58	Yes
2/A	25.0	50.0	2.00	0.0 / 0.00	No
2/B	32.0	0.0	0.0	64.0 / 2.0	No
2/C & 2/D	91.0	123.5	1.36	58.5 / 0.64	Yes

Figure 1: *circuit configuration and important quantities*

2. Magnetic Field Strength Mapping

2.1 Geometry

With the setup described in the previous section, the electromagnet's magnetic field was subjected to extensive mapping. Before presenting the results it is important to introduce the geometry of the map.

Mapping in 3 dimensions was achieved by mapping individual planes between the pole caps. The z-axis was set to be along the axis of the pole caps. Therefore, measurements were taken in the xy-plane at specific values of z. A single xy-plane consisted of a 20 cm^2 area with a point at every 0.5 cm value of z. This yielded 41 coordinates in both x and y for a total of 1,681 points in a given *xy*-plane. The mapping was repeated for 5 values of *z* (0.0, 0.625, 1.25, 1.875, and 2.5 cm). Conceptually, these values of *z* allowed for symmetric measurements: the two pole caps, the center, and the two mid-points between the pole caps and the center. A visualization of the coordinate system and the measurement planes is presented in ***Figure 2***.

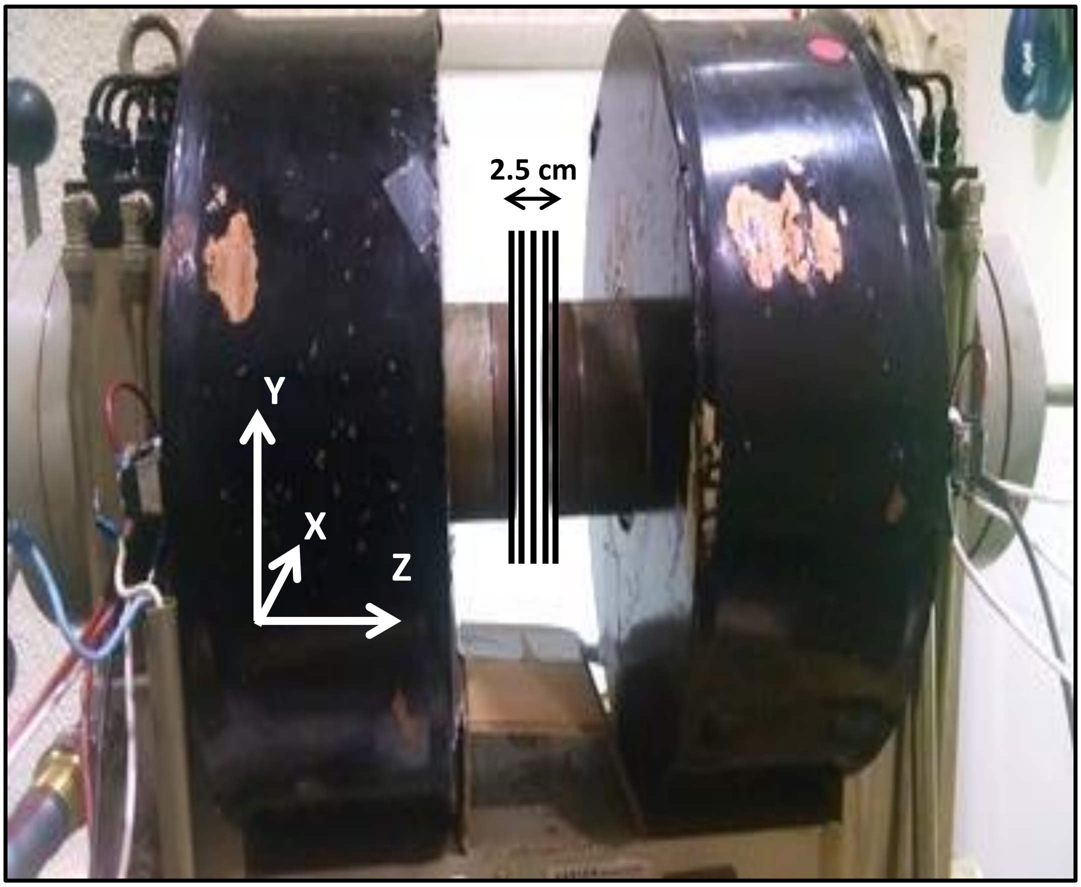


Figure 2: *3-dimensional spatial coordinate system and measurement planes*

To see further pictures pertaining to the specific pattern used or the positioning of the Hall probe during measurements please refer to section **4.1** of the **Appendix**.

2.2 Mapping Results

The following are 2-dimensional histograms which contain color scaling for the magnetic field strength. **All magnetic field values were measured in Tesla**. Please note the specific color scale for each plot carefully. Colors between plots may be slightly offset due to varying maximum values present in the data sets.

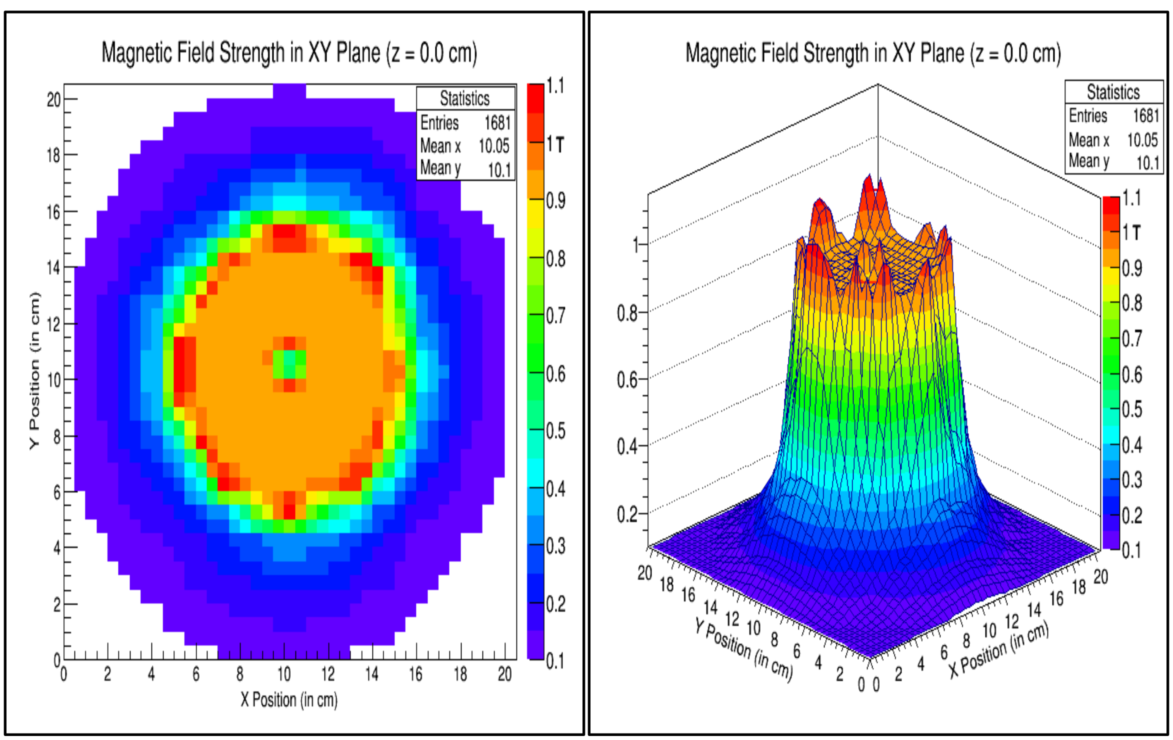
2.2.1 Plots of *XY*-Planes

The plots in various *xy*-planes consist of the maps as measured in the electromagnet. The *xy*-planes at each value of *z* are parallel to the faces of the pole caps (***Figure 2***).

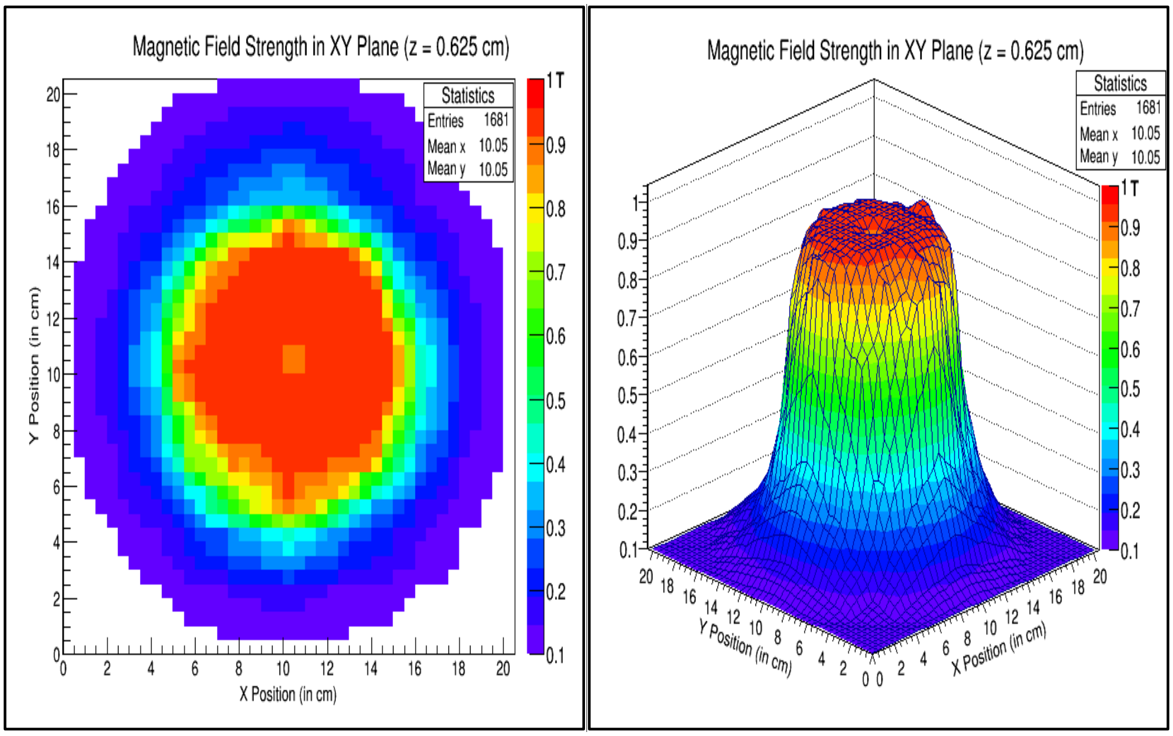
The main feature to notice is the region of uniformity present in the central part of all the histograms. It was found to range from 0.90 – 0.95 T in a region of approximately 8 cm^2. The uniform region appears to decrease in radius as the distance from the pole caps increases.

Another interesting feature is the appearance of spikes in the field strength around the edges of the pole caps (***Figures 3a & 3b*** and ***Figures 7a & 7b***). An explanation for this occurrence is not known in full certainty, but it is likely due to fringing. A test particle placed at the edge of one pole cap would most likely follow a curved trajectory to the other. This could potentially cause an increase in the density of field lines near the edges of the pole caps as compared to the central uniform region. Consequently, the magnetic field strength measured would be greater.

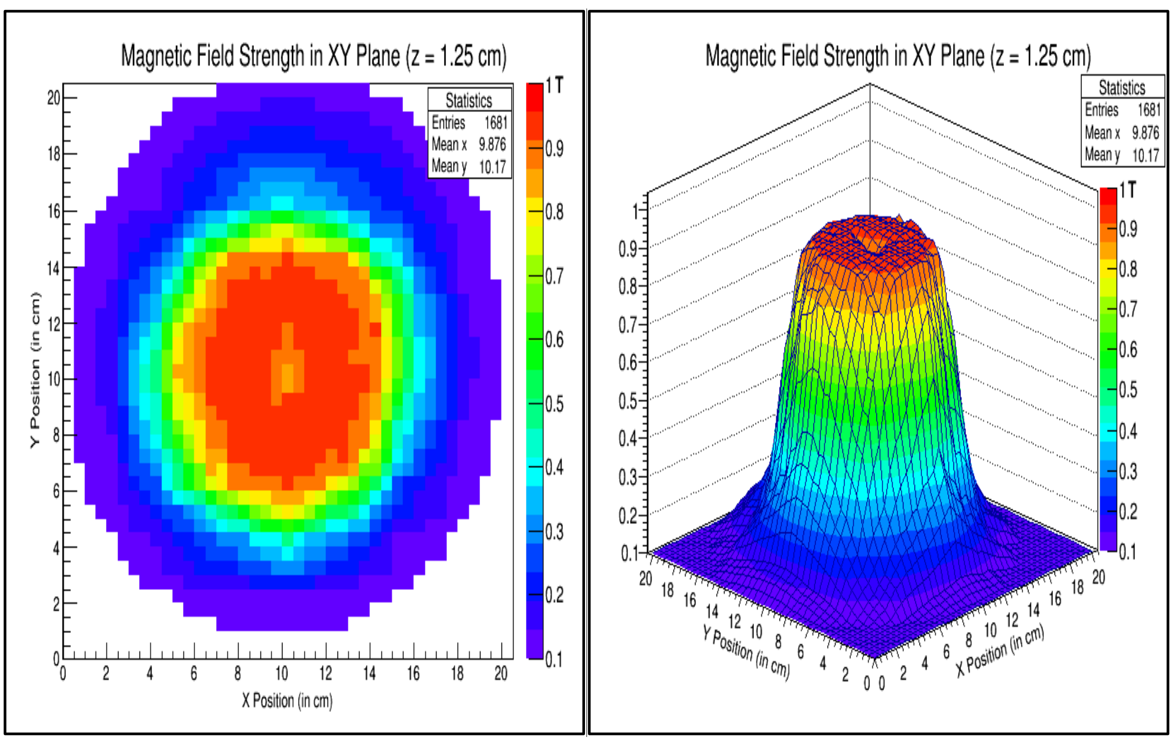
Plots of the *xz* and *yz*-planes are displayed in the following section (**2.2.2**).



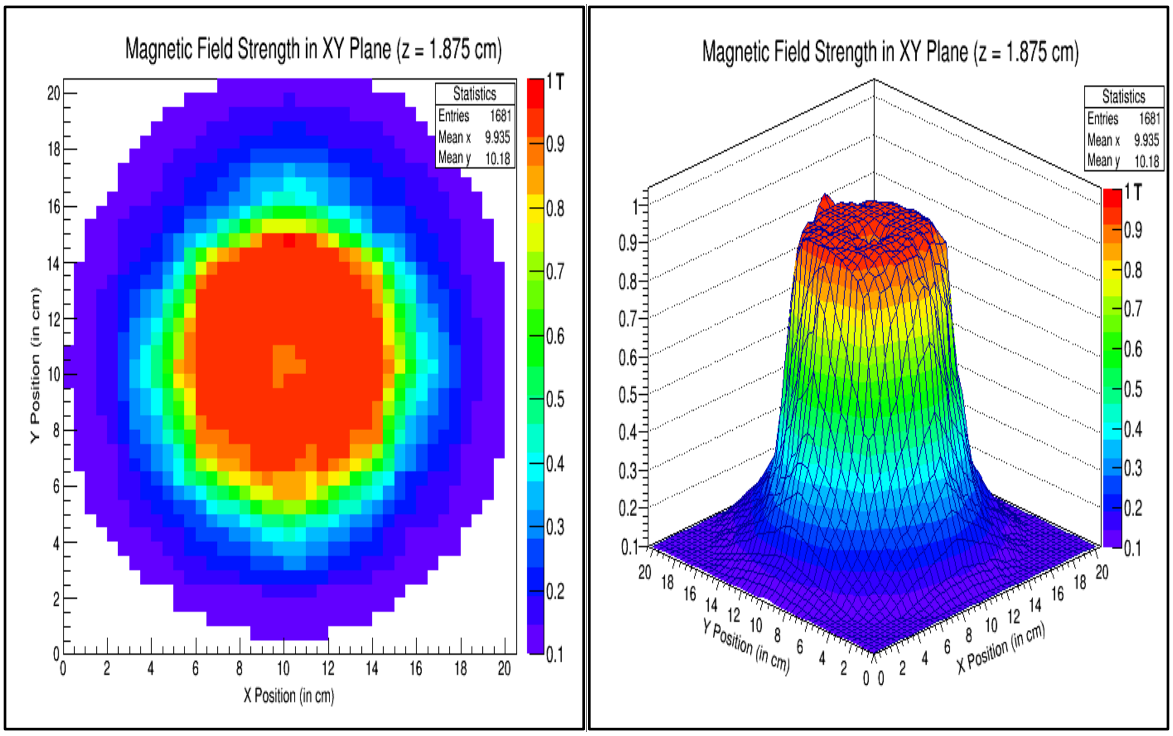
Figures 3a & 3b: *2d & 3d histograms of magnetic field strength in XY-plane at z = 0.0 cm*



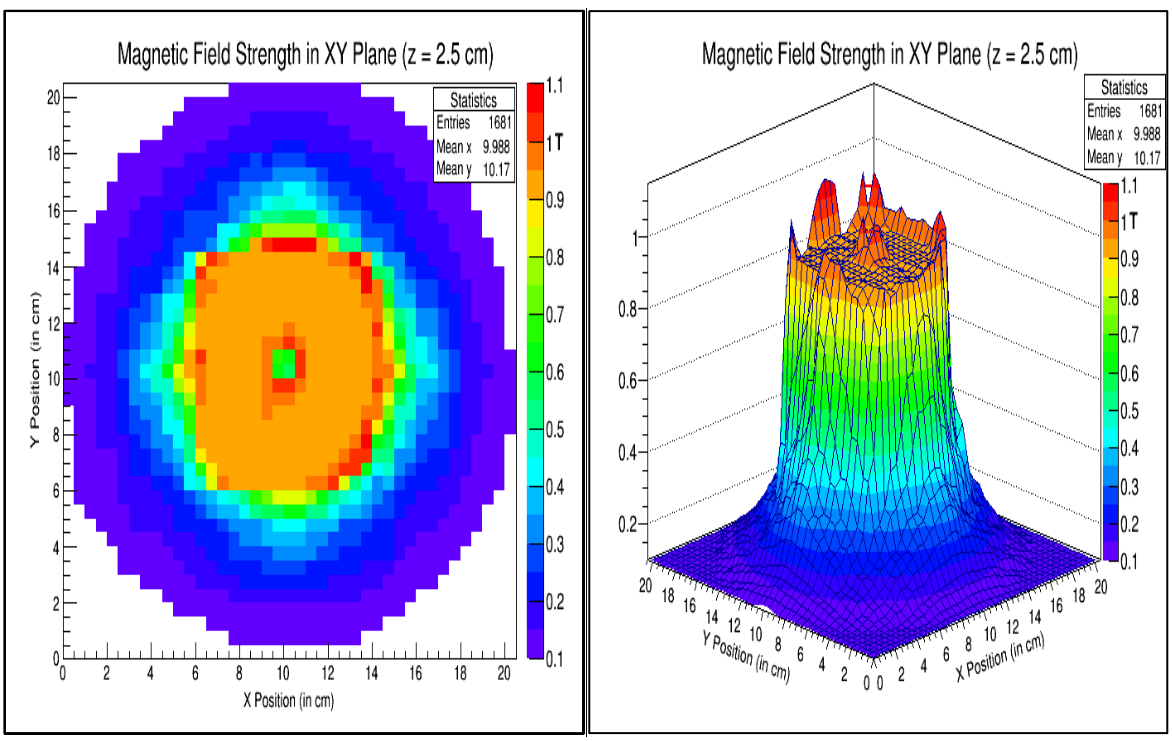
Figures 4a & 4b: *2d & 3d histograms of magnetic field strength in XY-plane at z = 0.625 cm*



Figures 5a & 5b: *2d & 3d histograms of magnetic field strength in XY-plane at z = 1.25 cm*

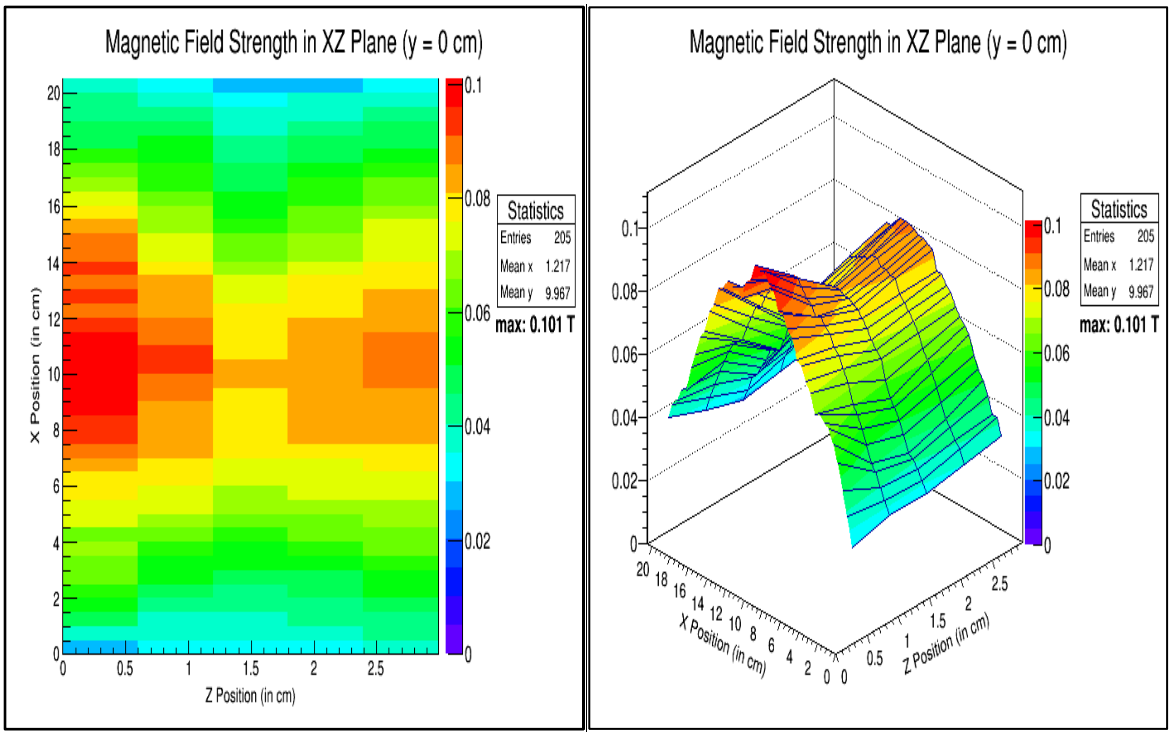


Figures 6a & 6b: *2d & 3d histograms of magnetic field strength in XY-plane at z = 1.875 cm*

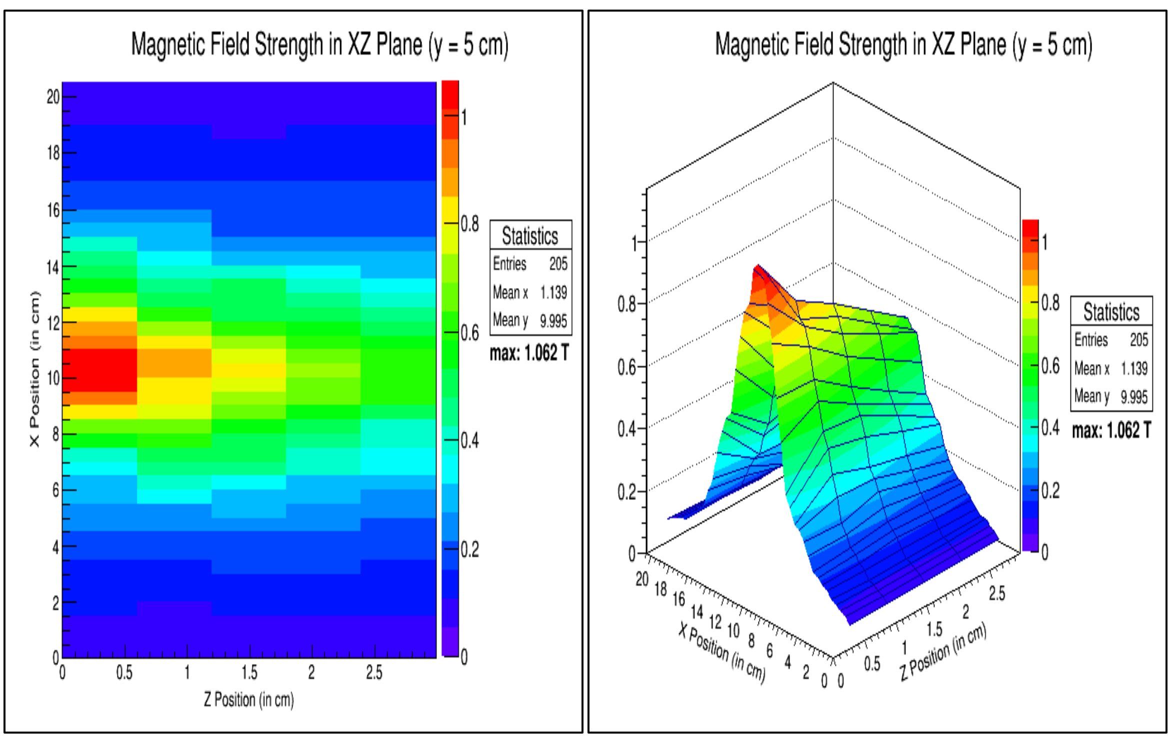


Figures 7a & 7b: *2d & 3d histograms of magnetic field strength in XY-plane at z = 2.5 cm*

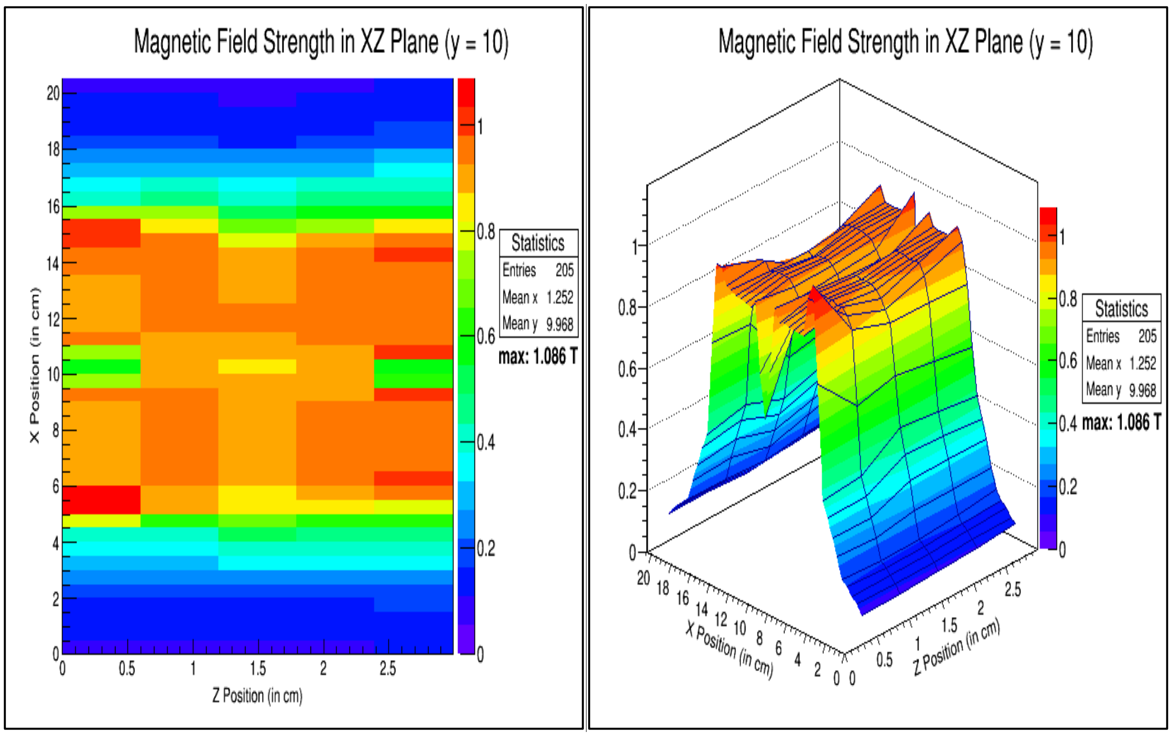
2.2.2 Plots of *XZ*-Planes and *YZ*-Planes



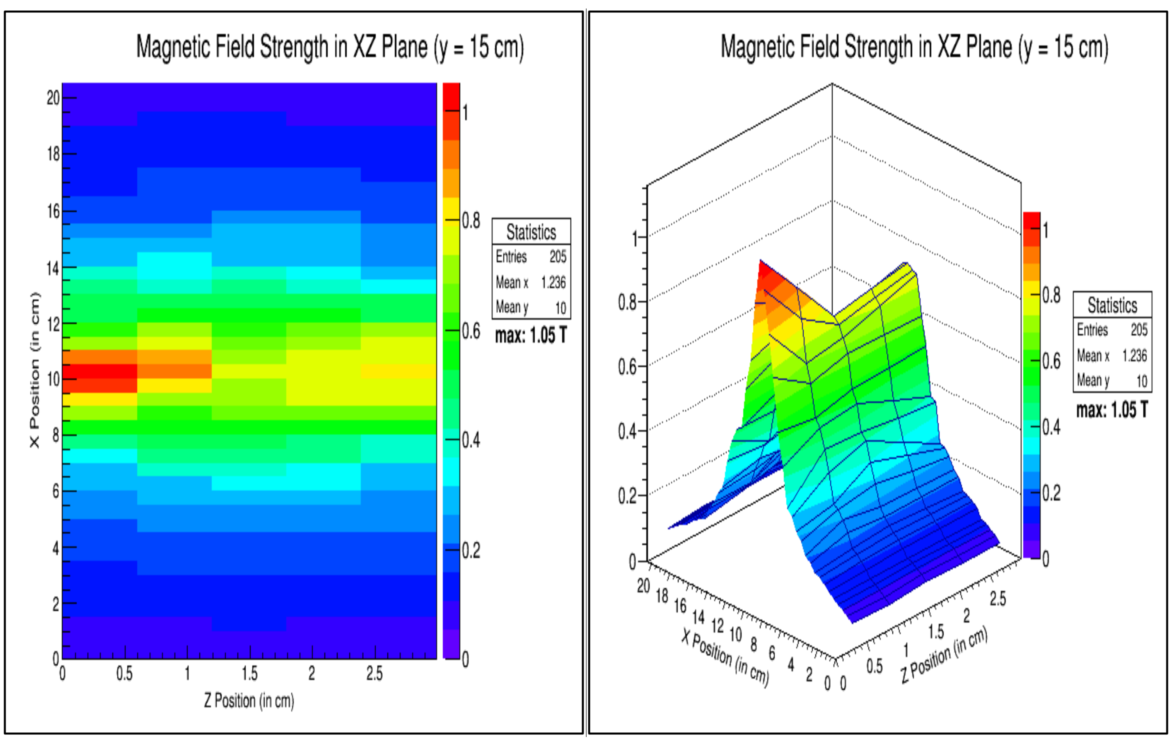
***Figures 8a & 8b:** 2d & 3d histograms of magnetic field strength in XZ-plane at y = 0 cm*



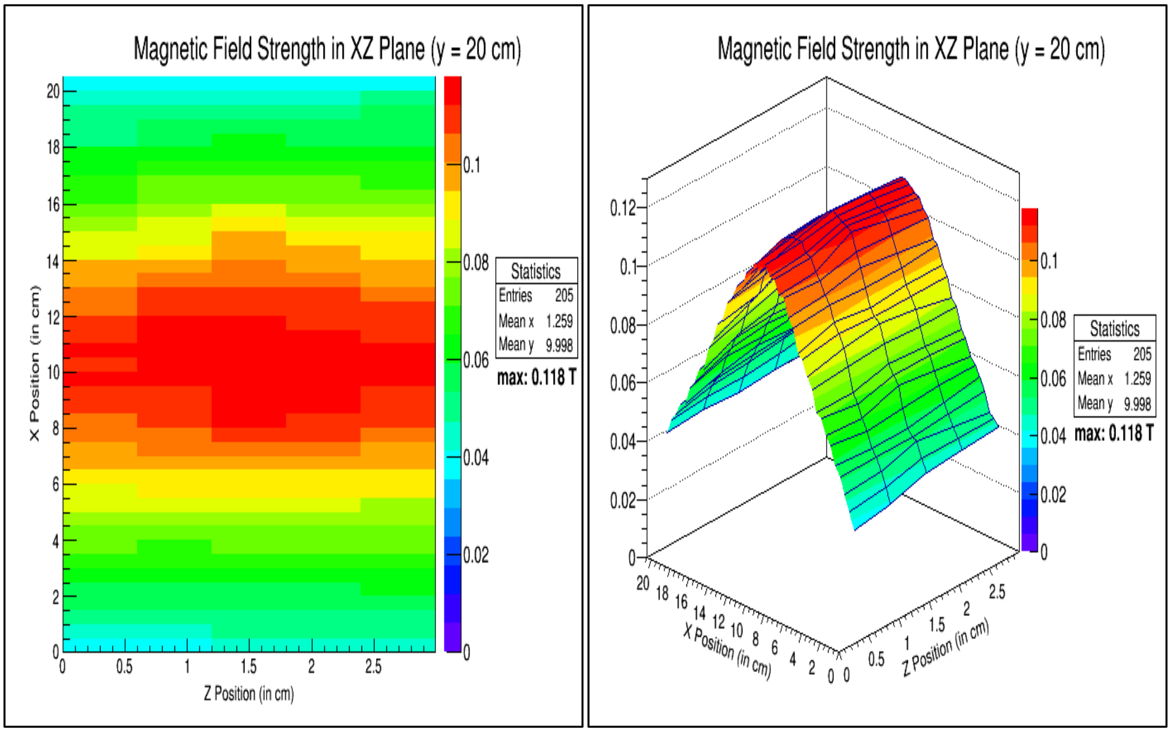
***Figures 9a & 9b:** 2d & 3d histograms of magnetic field strength in XZ-plane at y = 5 cm*



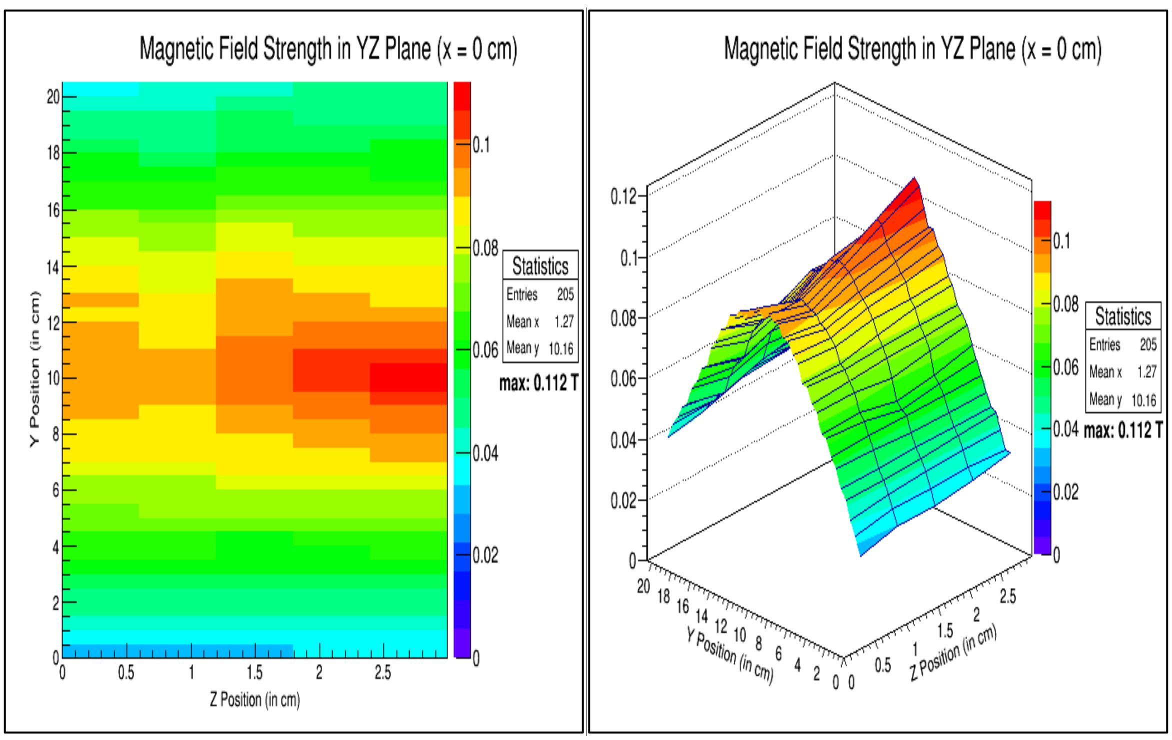
Figures 10a & 10b: *2d & 3d histograms of magnetic field strength in XZ-plane at y = 10 cm*



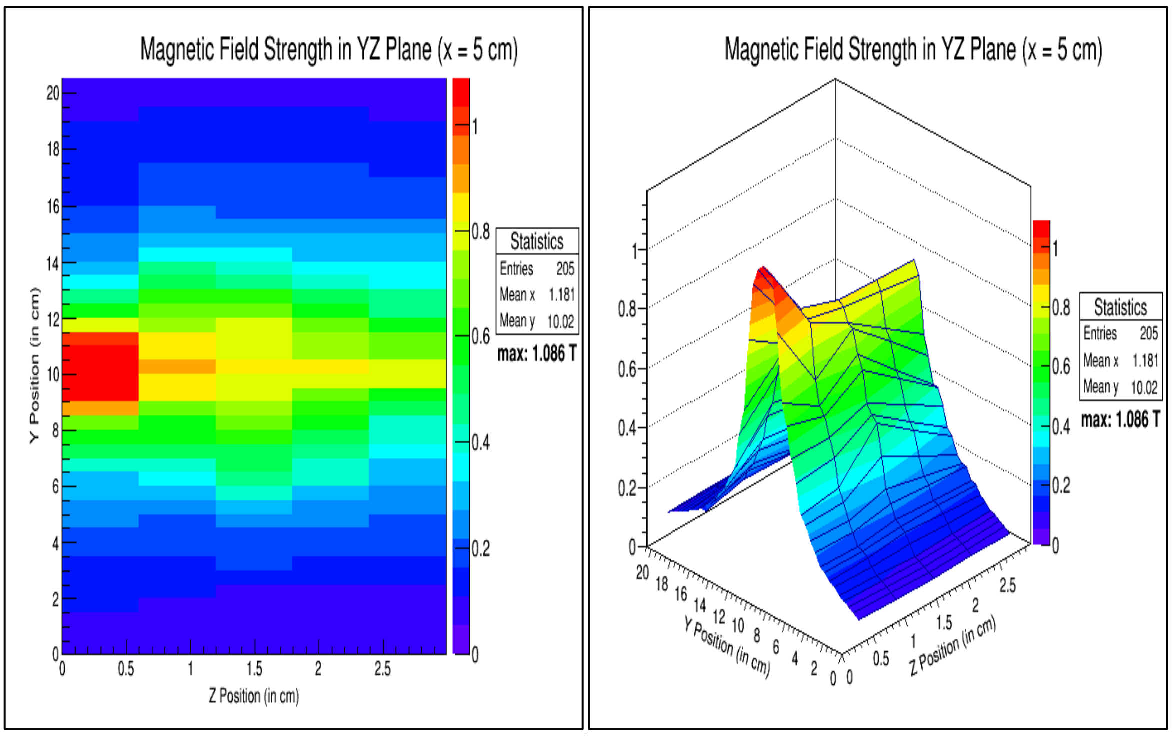
Figures 11a & 11b: *2d & 3d histograms of magnetic field strength in XZ-plane at y = 15 cm*



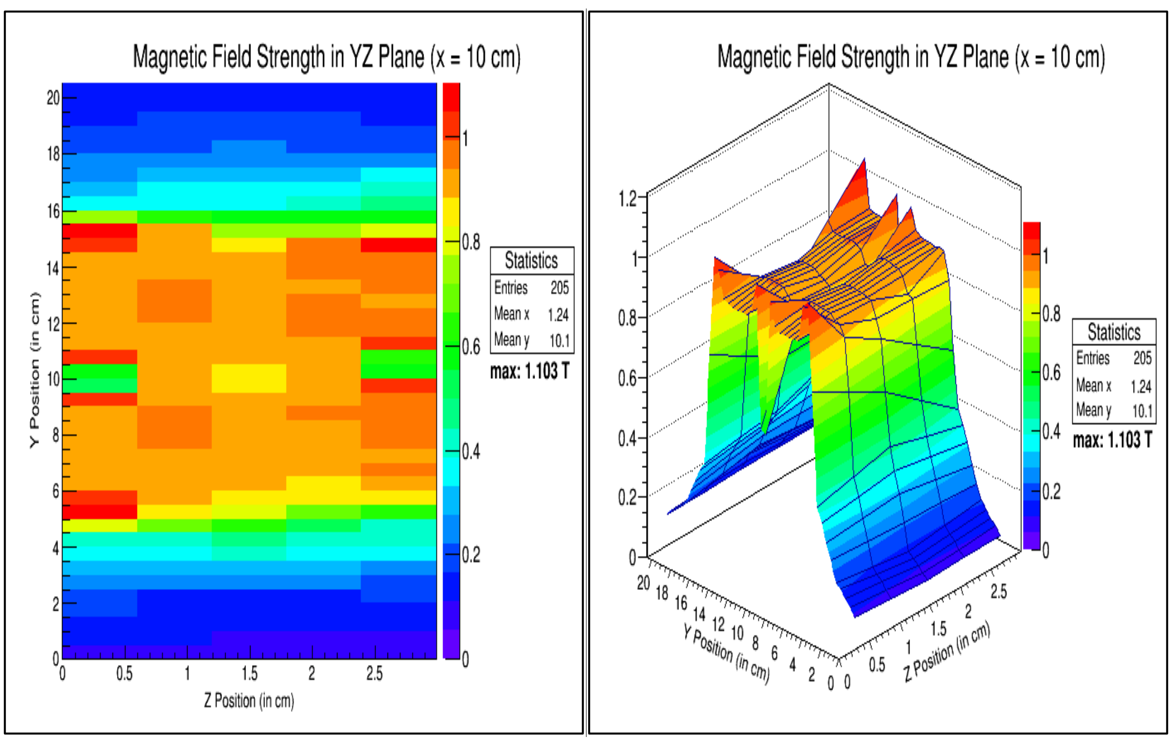
Figures 12a & 12b: *2d & 3d histograms of magnetic field strength in XZ-plane at y = 20 cm*



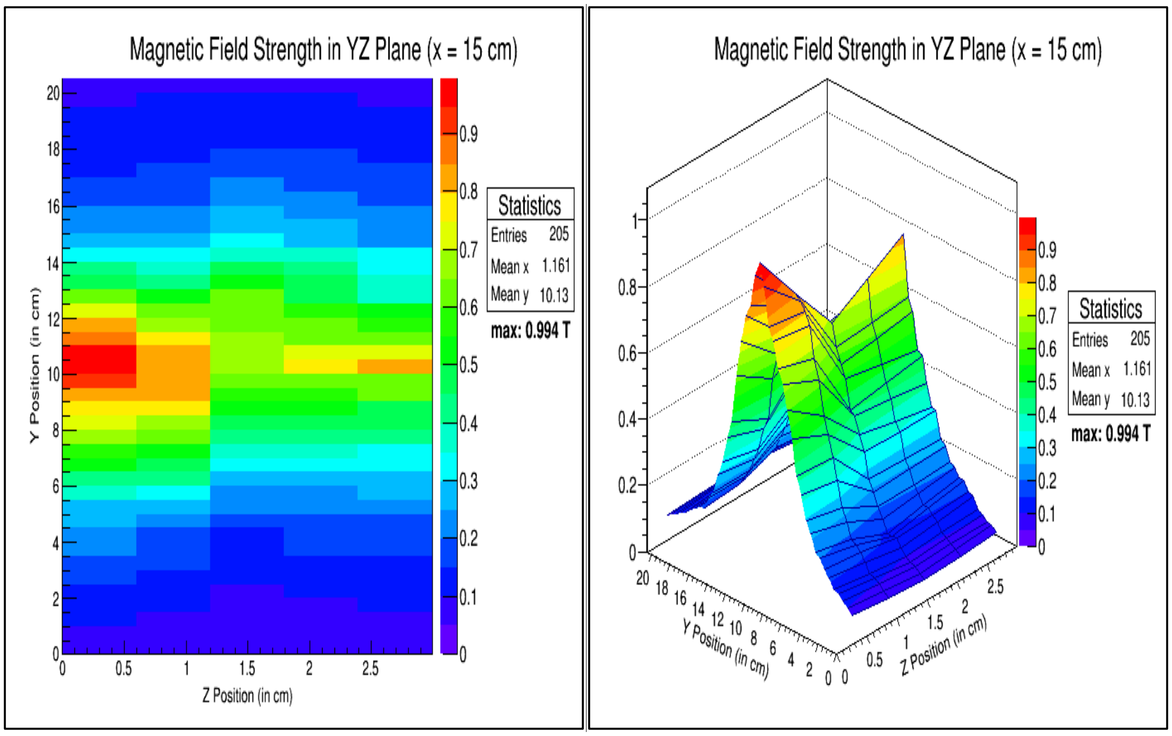
Figures 13a & 13b: *2d & 3d histograms of magnetic field strength in YZ-plane at x = 0 cm*



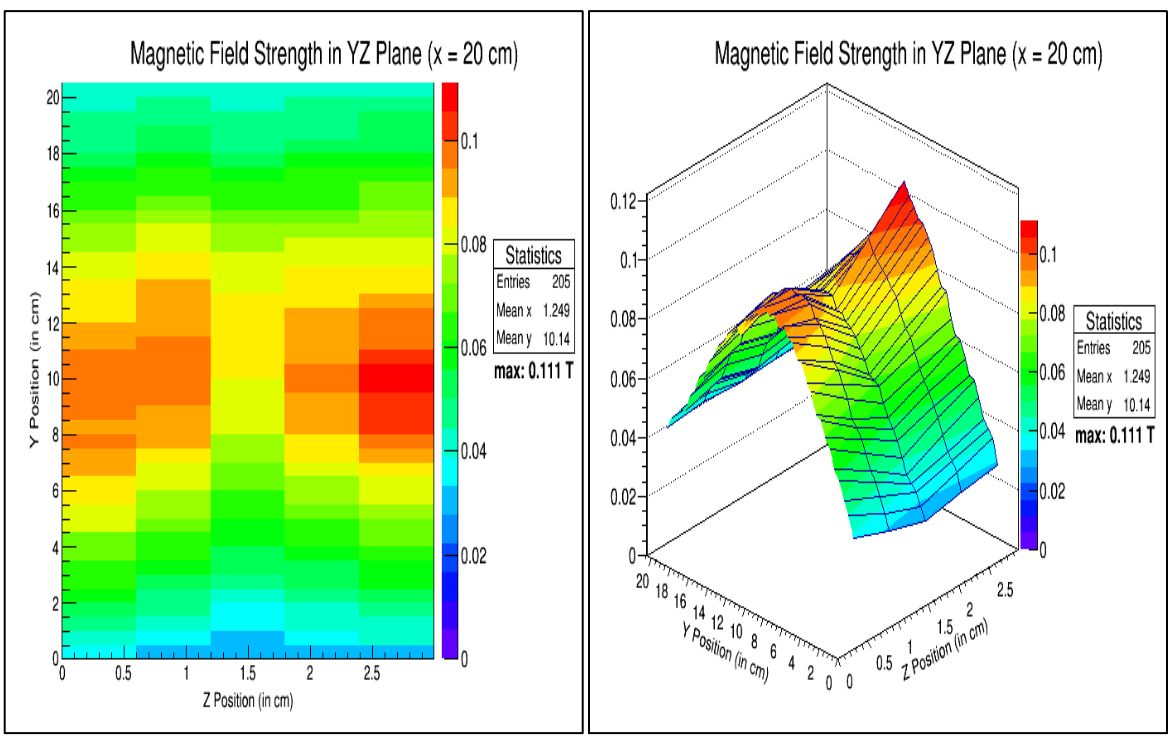
Figures 14a & 14b: *2d & 3d histograms of magnetic field strength in YZ-plane at x = 5 cm*



Figures 15a & 15b: *2d & 3d histograms of magnetic field strength in YZ-plane at x = 10 cm*



Figures 16a & 16b: *2d & 3d histograms of magnetic field strength in YZ-plane at x = 15 cm*



Figures 17a & 17b: *2d & 3d histograms of magnetic field strength in YZ-plane at x = 20 cm*

2.2.3 Uniformity of the Field

A major concern that arises is how to accurately describe what is meant by the term "uniform" in regard to the magnetic field strength.

From section **2.2.1**, it is easily discernable that there is a central region containing a relatively constant field. However, the *xy* plots only show how that consistent field strength is orientated in 2 dimensions. Moreover, it can be difficult to see this uniformity in the *xz* and *yz* plots due to much lower statistics. Therefore, the *z*-axis should be explored a bit further to determine uniformity.

The following plots show the variation in field strength along the *z*-axis. All plots were made **relative to the central plane z = 1.25 cm**. Furthermore a color with a positive value would indicate that the bin in the plane of comparison has a stronger field than the same bin located in the central plane, while a color with a negative value would indicate the opposite.

There is no plot comparing the central plane relative to itself, as such a display is trivial.

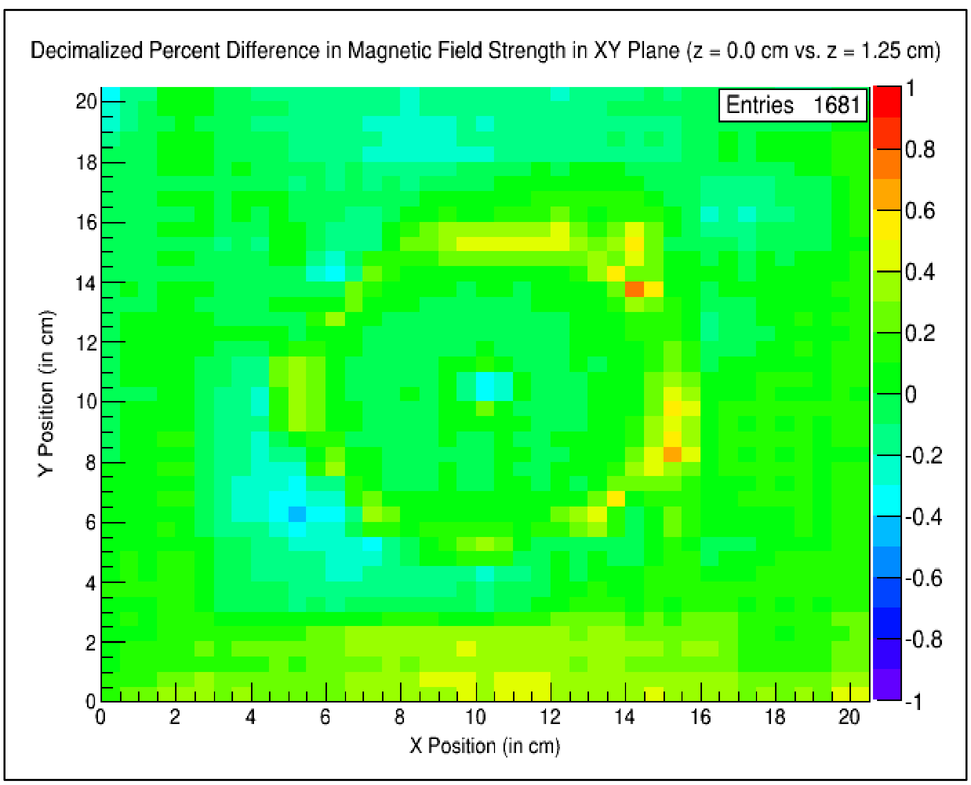


Figure 18: *magnetic field strength difference between z = 0.0 cm & z = 1.25 cm*

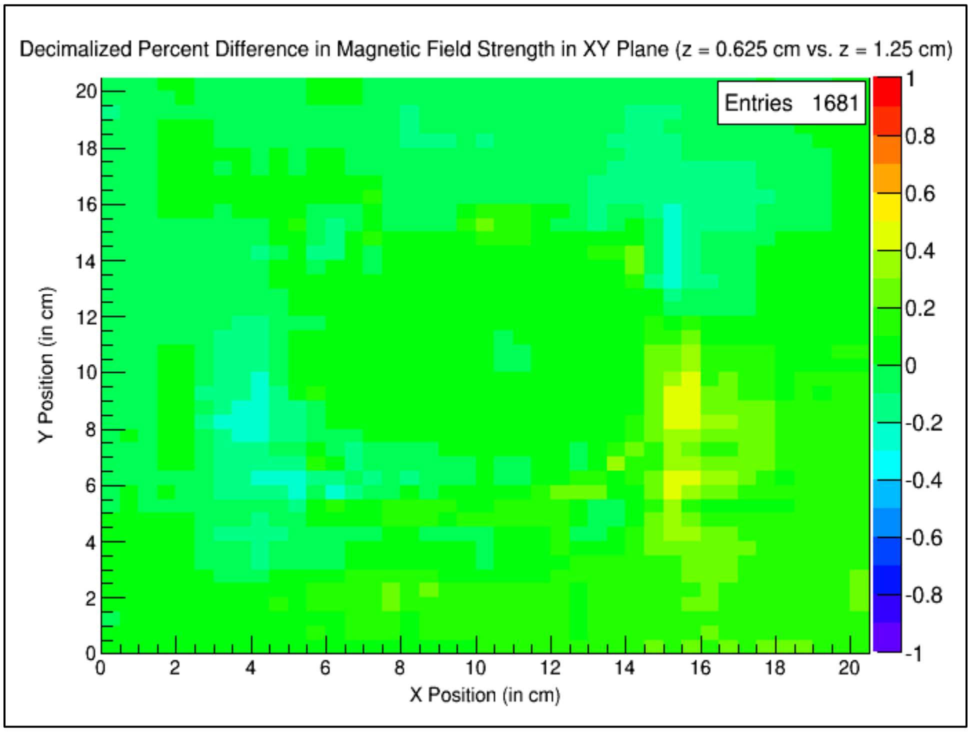


Figure 19: *magnetic field strength difference between z = 0.625 cm & z = 1.25 cm*

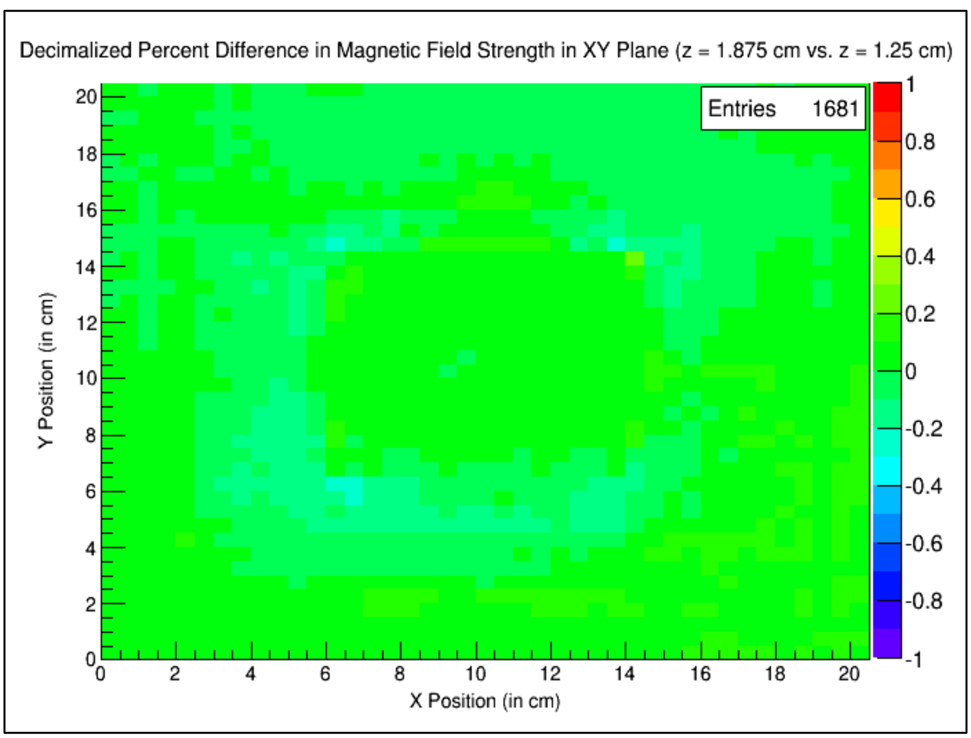


Figure 20: *magnetic field strength difference between z = 1.875 cm & z = 1.25 cm*

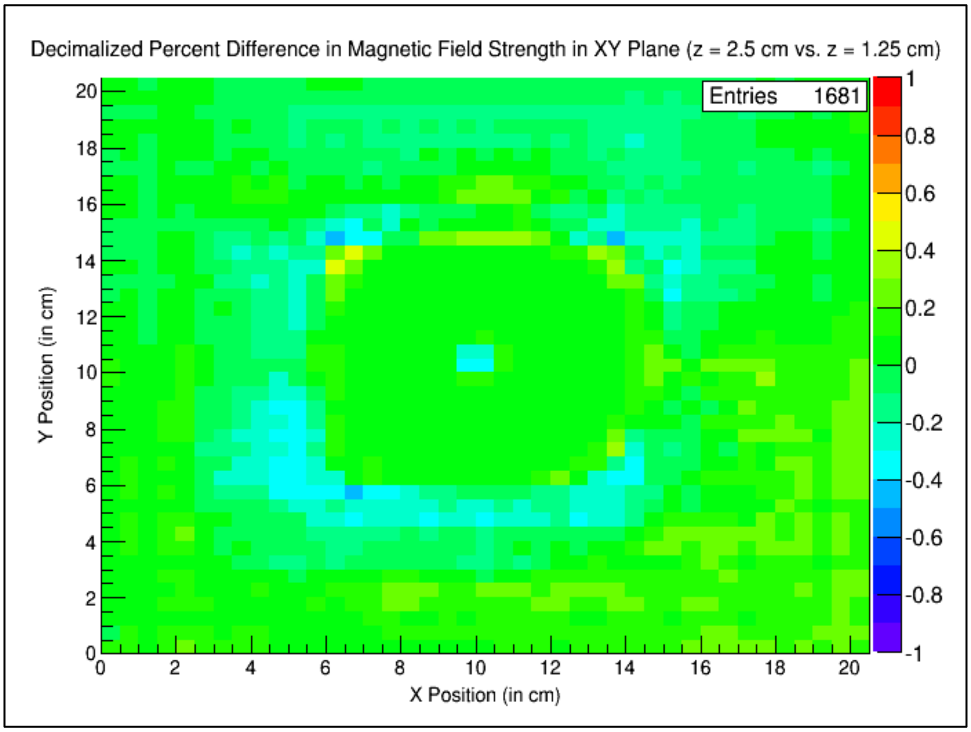


Figure 21: *magnetic field strength difference between z = 2.5 cm & z = 1.25 cm*

The plots comparing the pole caps to the central plane (***Figure 18*** and ***Figure 21***) have the most inconsistencies. This has already been discussed at the beginning of section **2.2.1** as a possible consequence of fringing at the edges of the pole caps. Applicable to a discussion on uniformity, this region forms a fairly distinct boundary where the field will begin to decrease rapidly shortly thereafter.

After moving to the mid-point between a pole cap plane and the central plane (***Figure 19*** and ***Figure 20***) the field becomes much more consistent with the field that is present in the central plane. As given by the color scale in the plots, there is no significantly noticeable variation in the central region that is under consideration (even at the pole caps). Thus, the *z*-axis contributes approximately 2.0 cm of uniformity.

To summarize the uniform region of the electromagnet's field:

(1) The magnetic field strength ranges from **0.90 – 0.95 T**.

(2) The volume is approximately: 8 cm x 8 cm x 2.0 cm = **128 cm^3**

2.2.4 Stability of the Field

Although the magnetic field strength has consistency within the spatial coordinates it is important to understand how that consistency behaves over time. The plots for both stability tests can be seen in ***Figure 22*** and ***Figure 23***.

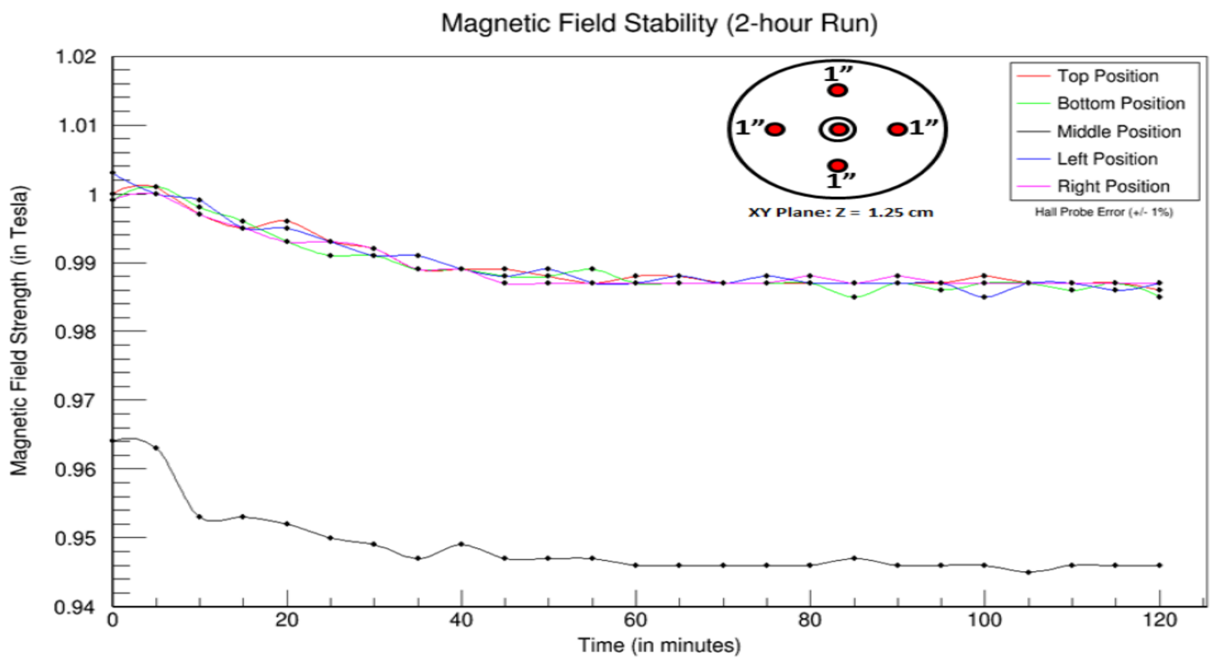


Figure 22: *magnetic field stability of five points in uniform region at z = 1.25 cm (2-hour run)*

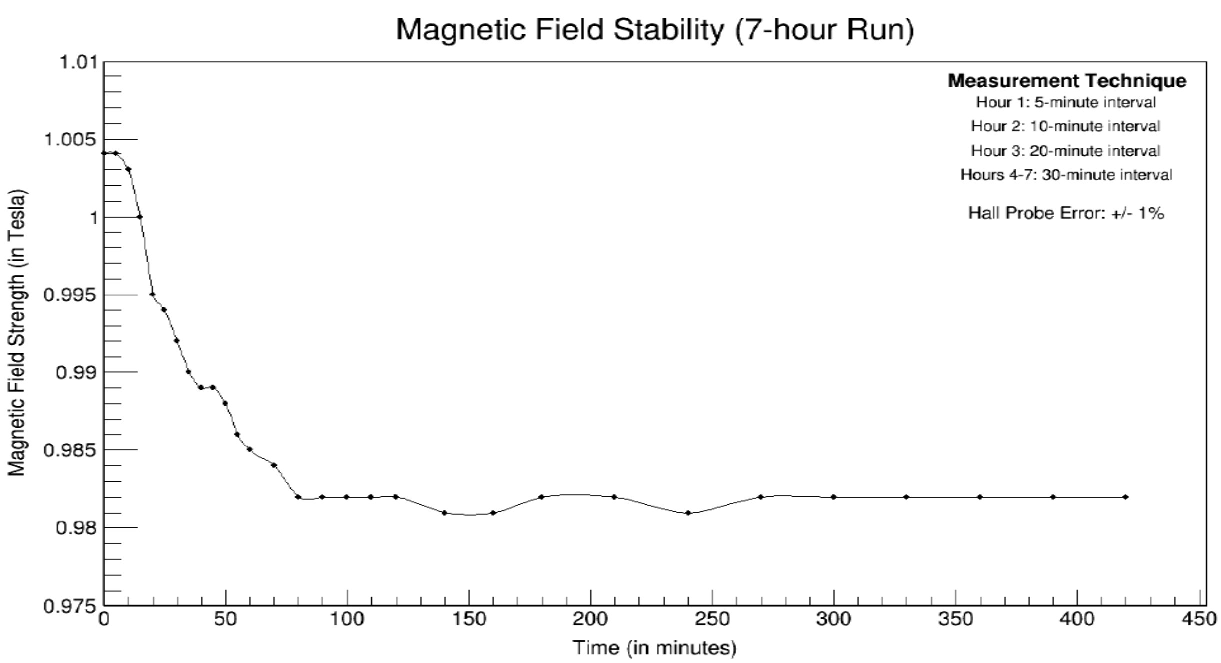


Figure 23: *magnetic field stability of one point in uniform region at z = 1.25 cm (7-hour run)*

3. Future Plans

3.1 Increasing Field Strength

The key component of increasing the field strength is still to add power supplies. After performing the experiment some improvements were already made towards enhancing the field further.

It was noticed through closer examination that one of the power supplies was not supplying a coil. Measurement through a multimeter suggested it was functioning properly, but further analysis of the magnetic field strength showed it was not. This problem was quickly remedied and when added to the current setup, the uniform field increased to approximately 1 T. Although this already makes the data presented outdated, but the general shape of the field seems to have been unchanged.

In addition, a new power supply capable of supplying 36 V has been obtained. Some further analysis of the current circuitry will have to be done to find the most efficient location to add the supply. However, in order to reach a maximized field more supplies will be needed. Specific voltages required to complete all of the coils is located in section **1.1** in ***Figure 1***.

The Varian v-4004 manual has a plot which shows the theoretical magnetic field strengths at various air gaps. The point of interest has been labeled on the plot included in the **Appendix**. The air gap used in this investigation was 2.5 cm which is very nearly 1 inch. The plot shows that when the magnet is at maximum power, the highest field achievable is about 12,000 Gauss, or 1.2 T. With this in mind, it would be expected that completing the current circuitry to maximize the field would produce a field near this value.

3.2 Testing of 10x10 GEM Detector

The ultimate goal with the electromagnet is to be able to test the effects of a magnetic field on the functionality of a 10x10 GEM detector. The current pole cap separation of 2.5 cm is near the minimum distance required to fit the detector. The addition of a small, radioactive source would necessitate another 5 mm, which would negatively impact the strength of field. More precise planning will need to be done when this experiment is ready to be conducted. A picture showing the relative size of the detector and the electromagnet is included in section **4.3** of the **Appendix**.

4. Appendix

4.1 Technique

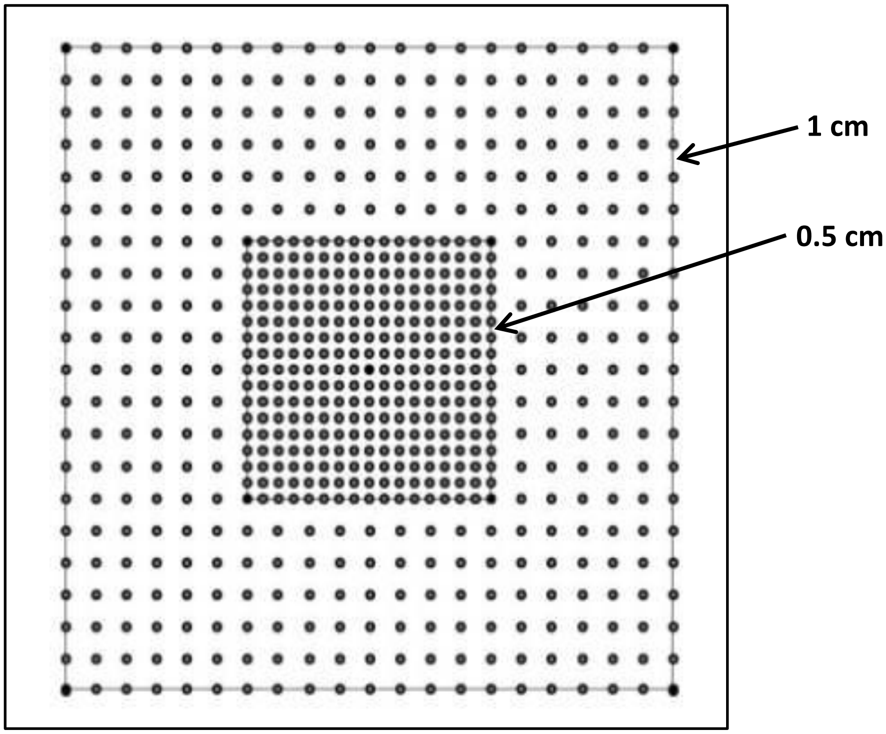


Figure 24: *grid pattern used during measurements*

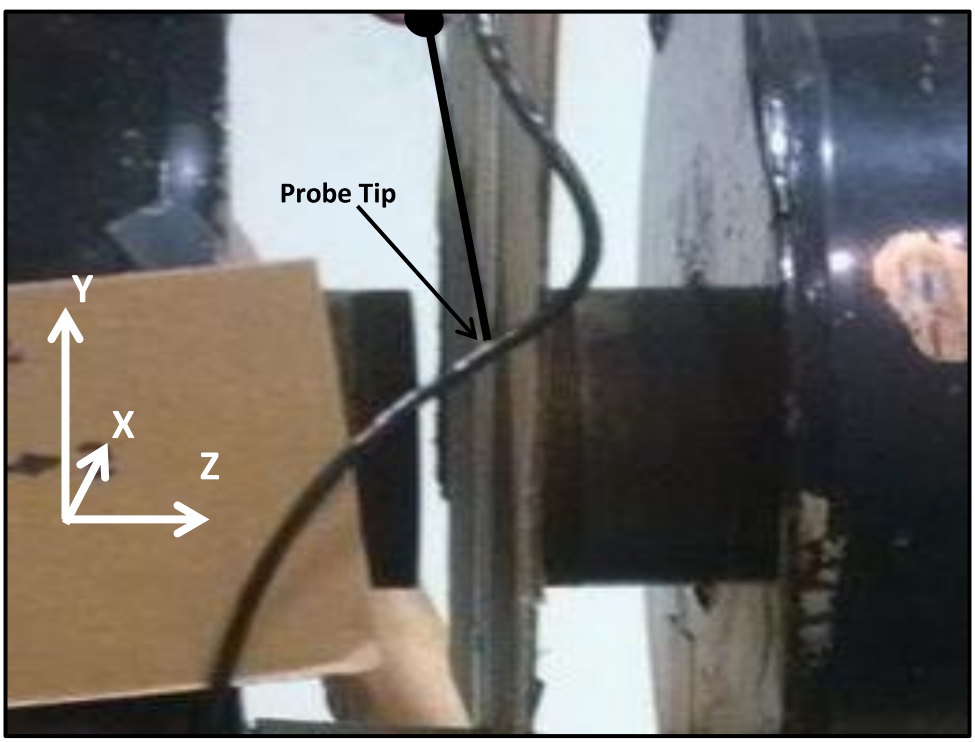


Figure 25: *using the Hall probe to find the magnetic field strength at a point*

4.2 Electromagnet Setup

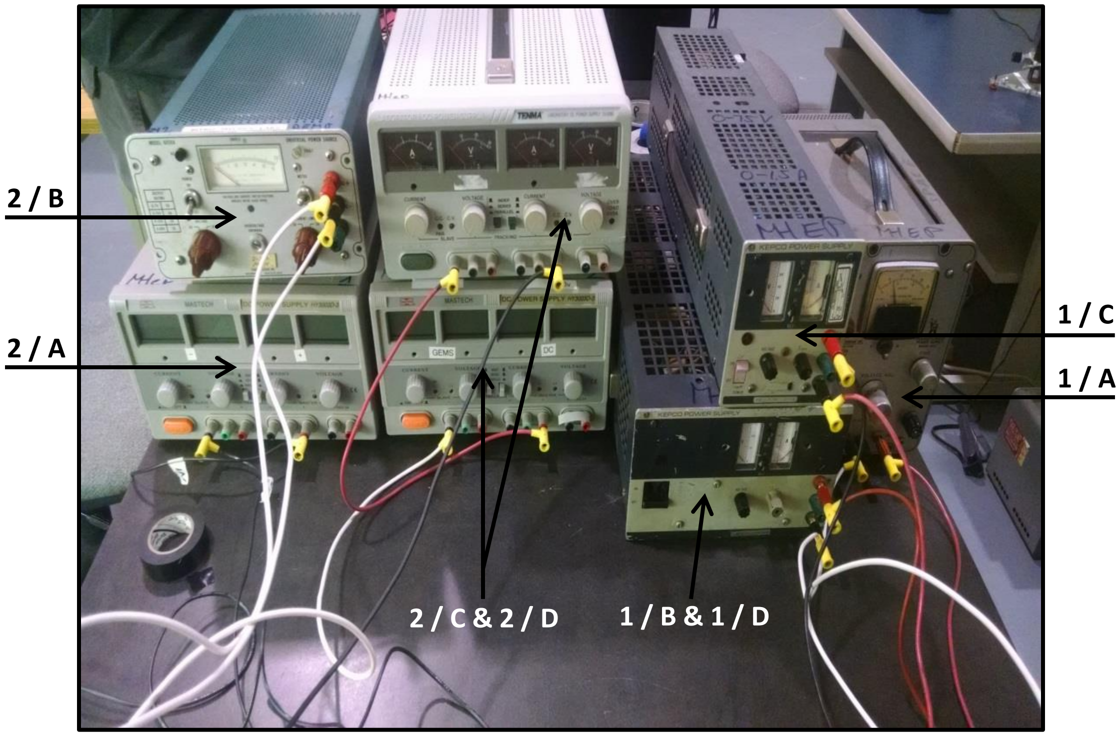


Figure 26: *power supply setup*

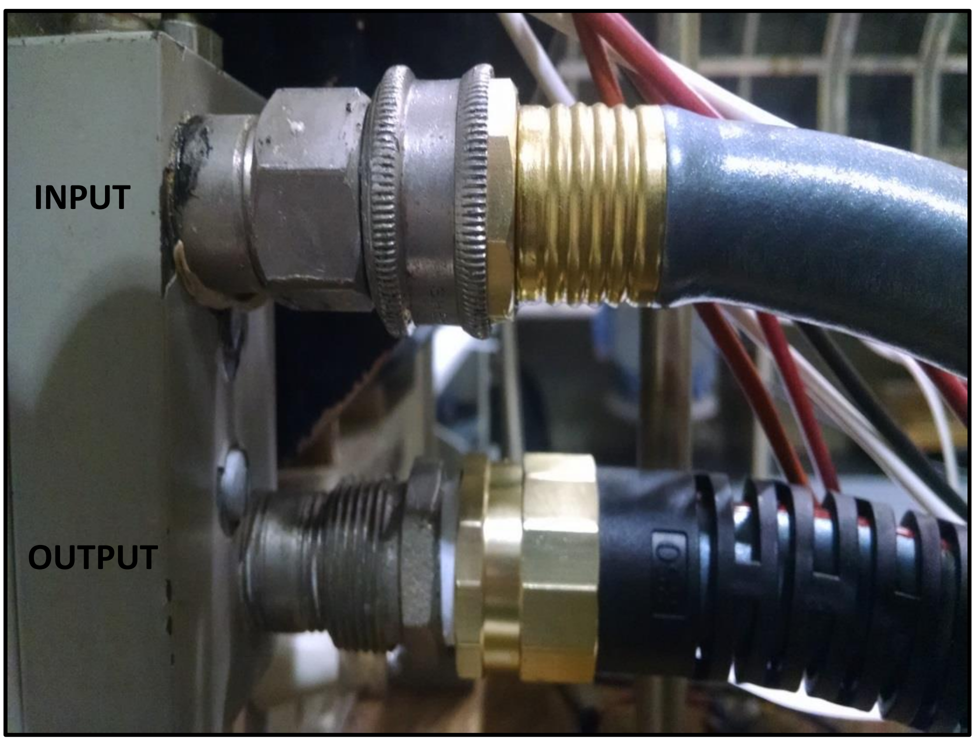


Figure 27: *water cooling- electromagnet connection*

4.3 Future Experimentation

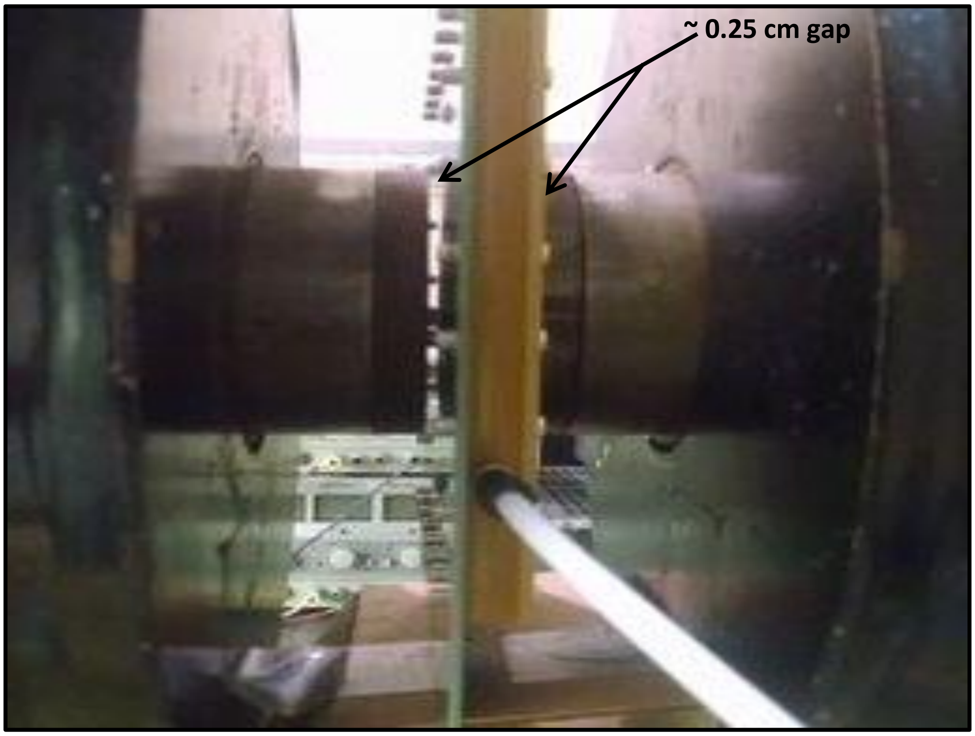


Figure 28: *10x10 GEM detector between pole caps of electromagnet*