HEP Lab A Hardware Documentation

Mini HV Divider & Electromagnet

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PHY 3901

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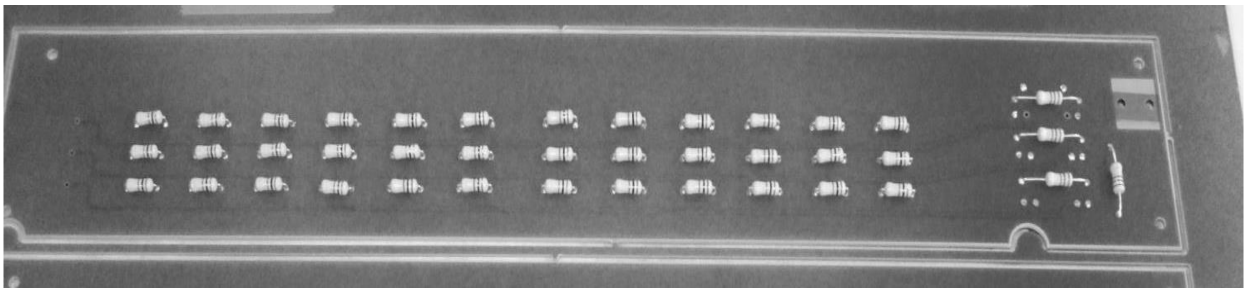
Synopsis:

The following documentation refers specifically to the design and construction of mini high-voltage dividers with 10x10 GEM detectors, as well as preliminary results and work with the Varian v-4004 electromagnet.

[1] Mini HV Divider (MHVD)

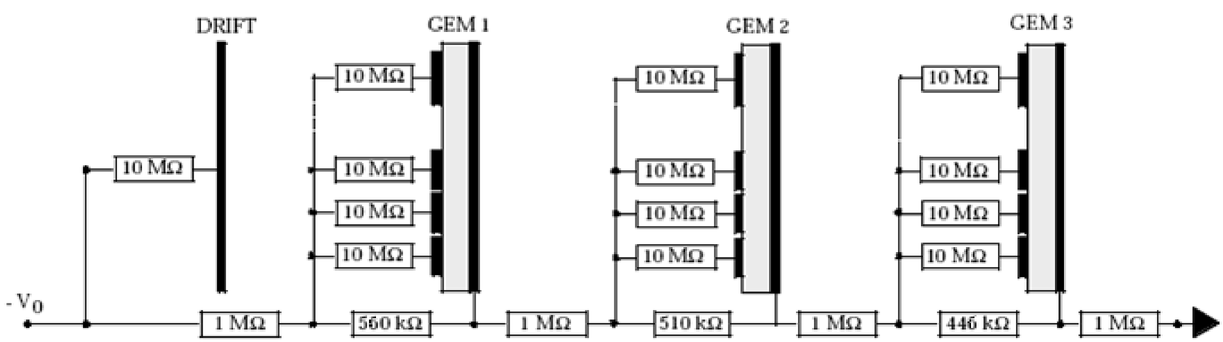
1.1 Design

The MHVD acts as improvement to the traditional class of voltage divider, displayed in *Figure[1.1.1]*. This section will provide the detailed specifications for the MHVD.



Figure[1.1.1] *Underside of original HV divider*

Circuitry for the MHVD remains consistent with the original concept shown in *Figure[1.1.2]*. The finalized design is electronically described by Quintero[1].

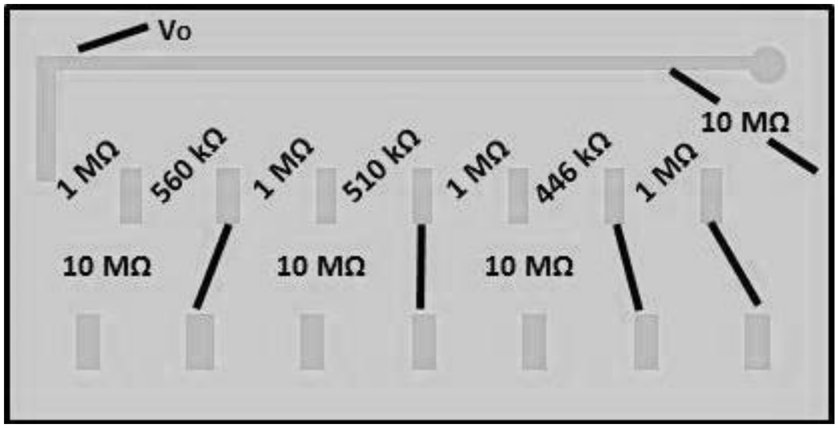


Figure[1.1.2] *Electronic diagram for HV divider*

A GEM detector is connected to a voltage divider at both the top and bottom of each individual foil. Specific potential differences between junctions are required for proper functionality. The MHVD board is sizably efficient at approximately an inch and a half by two inches in dimensions. This allows the MHVD to be mounted directly to the detector it is wired to.

1. Quintero, Amilkar (2010).
http://research.fit.edu/hep_labA/documents/Amilkar_Thesis_submitted_July9_2010.doc

Figure[1.1.3] displays a synonymous circuitry with that shown in *Figure[1.1.2]* in the format of the MHVD.



Figure[1.1.3] *Electronic diagram for MHVD*

Wired connections shown in *Figure[1.1.3]* are detailed using thick black lines. Labels are present to specify the values of resistors between junctions. All MHVDs constructed to date have used a single consolidated resistor card for the continuous row of seven resistors as depicted in *Figure[1.2.1]*.

1.2 Construction

The final assembled MHVD is displayed in *Figure[1.2.1]*. This section will offer suggestions for approaching the creation of a new MHVD.

Figure[1.2.1] *Fully-constructed MHVD*

Construction should proceed outwards from the center row of resistors. This helps to ensure that there is plenty of accessibility for soldering as well as to deter damage to progress. The first task is to solder the eight connections required to mount the resistor card to the board. There are small holes contained within the MHVD which should facilitate this process. **Note: be sure to confirm the pattern of resistances across the card to ensure it is attached in the proper configuration.** The resistances that vary within the card should progressively decrease moving left-to-right as shown in *Figure[1.1.3]*).

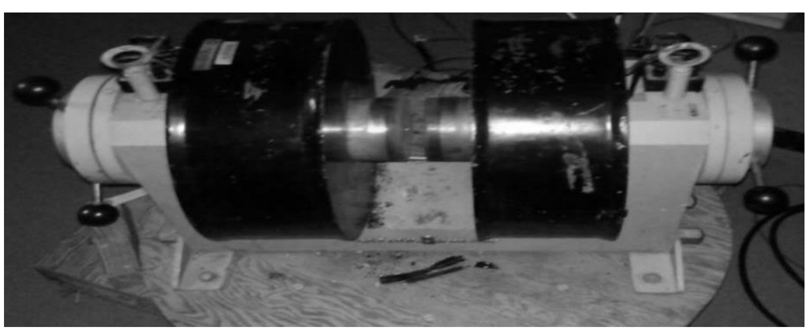
The second task is to create short resistor and wire connections between the resistor card and the metal junctions along the front edge of the MHVD. These connections act as the beginning circuit elements which run to individual GEM faces. Proceeding left-to-right, again as in *Figure[1.1.3]*, the seven metallic junctions ultimately connect by wire (approximately 6-8 inches in length) to the top of GEM1, the bottom of GEM1, the top of GEM2, the bottom of GEM2, the top of GEM3, the bottom of GEM3, and the ground. This connection sequence can also be visualized in *Figure[1.1.2]*.

The final task is to implement the MHVD. Current procedure uses Velcro® (or possibly no attachment at all) to hold and mount the MHVD directly on one corner of the 10x10 GEM detectors. Future detector design will most likely incorporate a more permanent accommodation for making more stable MHVD connections.

[2] Varian v-4004 Electromagnet

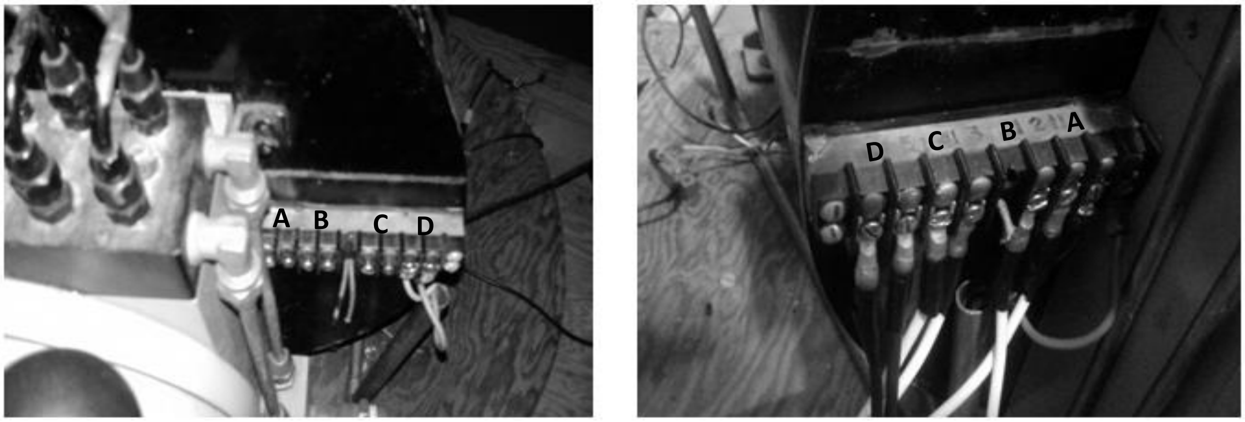
2.1 General Configuration

The entirety of the electromagnet is displayed in *Figure[2.1.1]*. This section will present an overview of the major components of the electromagnet.



Figure[2.1.1] *Varian v-4004 Electromagnet*

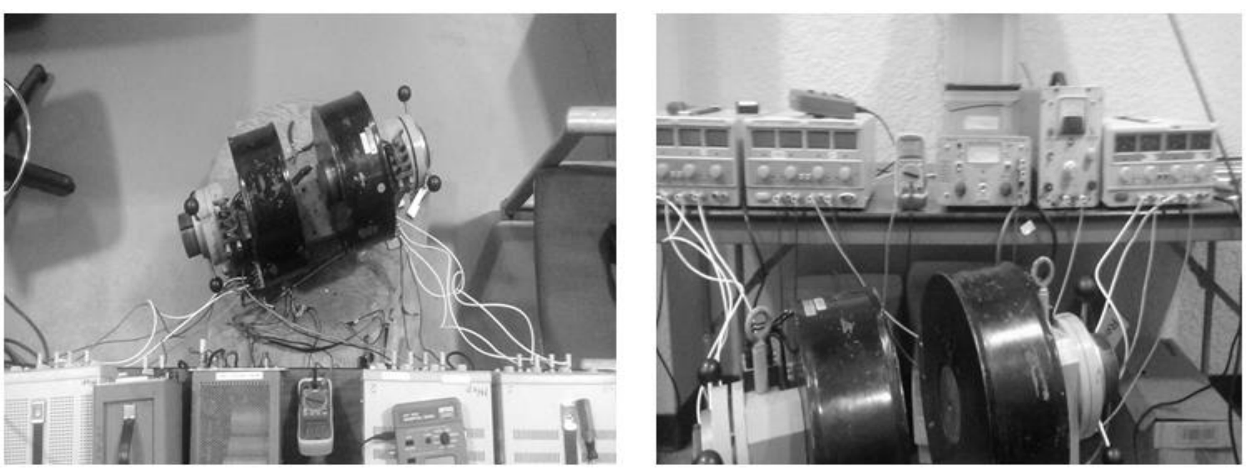
The electromagnet consists of two black drums, each containing four coils. Between the drums there are two pole caps, which are magnetized by the field produced by the coils within the drums. This allows constant field production directly between the pole caps, which are 10.0 cm in diameter. A single drum has an external set of eight nodes which allow connections to both ends of each coil, as shown in *Figure[2.1.2]*.



Figure[2.1.2] *Coil Junction Terminal (with and without wiring)*

These nodes are numbered and allow for wired connections simply by screwing the junction tight. Due to the convenience of having all input and output connections to individual coils accessible externally, all coils can be powered separately using power supplies configured in parallel. **Note: it is worthwhile to run supplies in parallel, as this eliminates the need to wire the electromagnet coils in series and prevents an increase to the overall resistance of the circuit.**

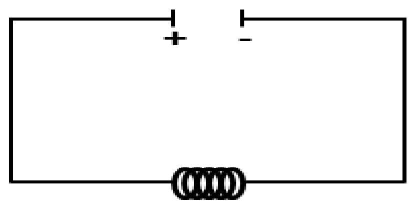
The general setup (organized chaos) can be seen below in *Figure[2.1.3]*. The most important check before running is to make sure the field is augmented by every coil.



Figure[2.1.3] *General Experimental Setup*

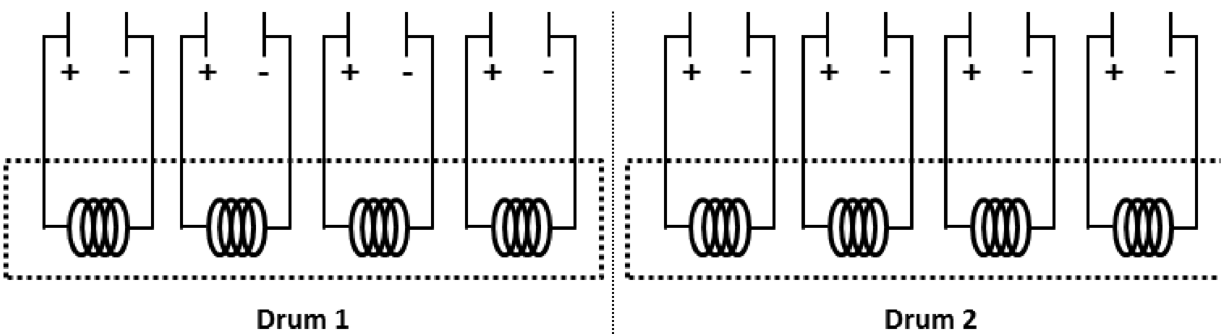
2.2 Circuit Configuration

The electronic diagram in *Figure[2.2.1]* depicts the experimental setup for single-coil magnetic field production. This section will describe the specific circuit configurations used during experimentation.



Figure[2.1.1] *Electronic Diagram for Single-coil Field Production*

All coils follow the simple circuit shown in *Figure[2.2.1]*. Scaling this circuit produces the electronic diagram for the entire electromagnet, as depicted in *Figure[2.2.2]*.



Figure[2.2.2] *Electronic Diagram for Electromagnet Field Production*

All coils contain 2500 turns; however, the coils contain varying resistances. Specific values can be seen in *Figure[2.2.3]*.

Coil	Resistance (Ω)
A	25
B	32
C	42
D	49

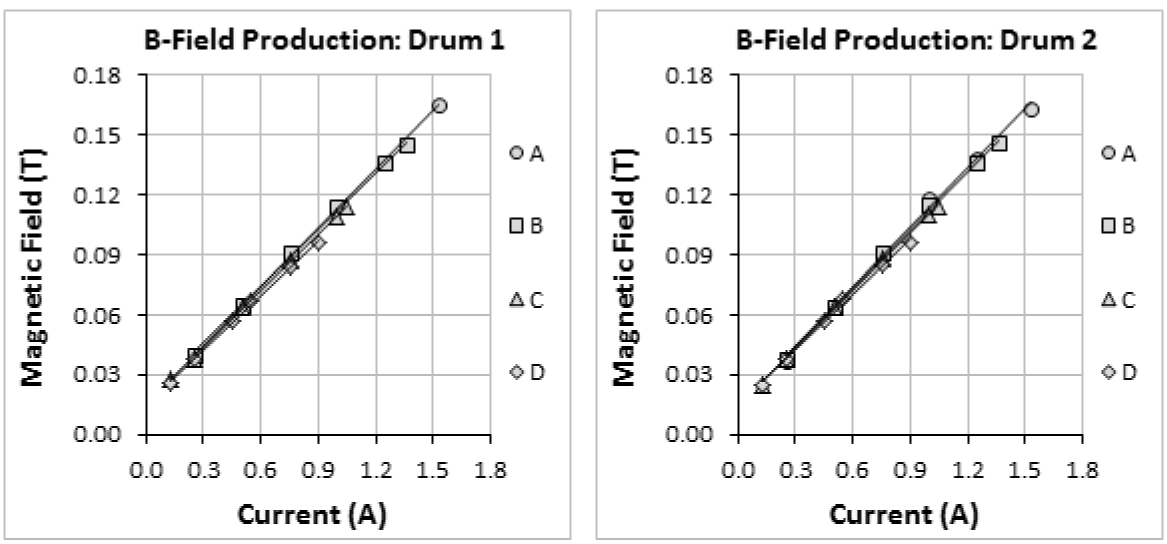
Figure[2.2.3] *Coil Resistances*

An explicit configuration of the coils within the drums is not known. The general mechanism of magnetic field production seems to rely on the general Helmholtz pair (created by the two drums), but it is thought that the Helmholtz design may also generally depicts the coils within the drums.

2.3 Preliminary Results

Present experimentation has yielded basic confirmations regarding the functionality of the electromagnet. This section will present the measurements taken while attempting to maximize the field production of the electromagnet.

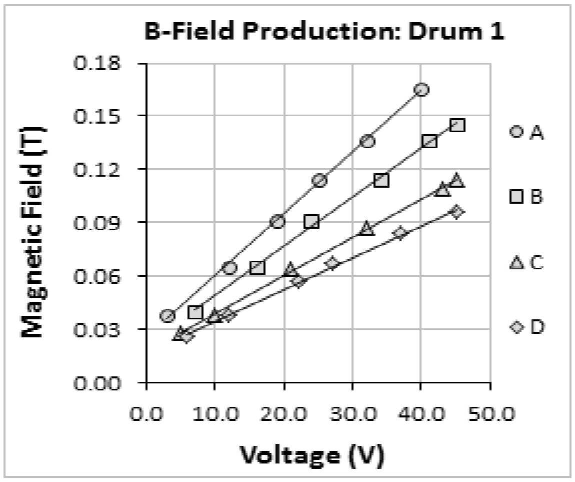
Measurements were taken across all coils individually using a Uniply® Model 6050A power source (60V/6A) at 2.0 cm pole cap separation in order to determine the capabilities of the electromagnets subunits. *Figure[2.3.1]* shows a comparison of both drums and the field production for individual coils at varying currents.

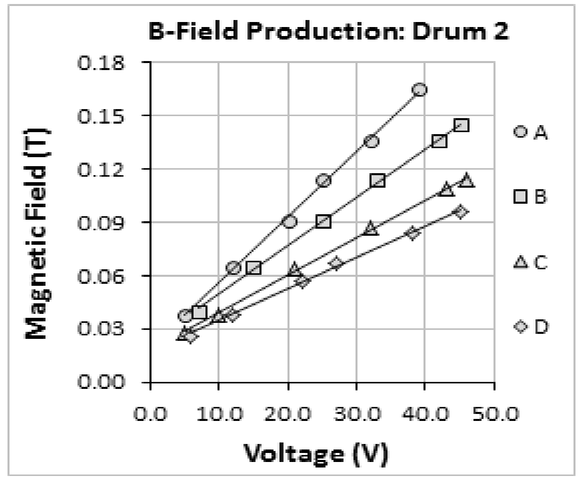


Figure[2.3.1] *Single-Coil Field Production (as a function of current)*

The plots in *Figure[2.3.1]* show magnetic field production versus current. Linear fits were generated for each coil. *Figure[2.3.1]* gives confirmation that the coils are all functioning at a reasonable level and are in accordance with one another.

Figure[2.3.2] shows a comparison of both drums and the field production for individual coils at varying voltages. These voltages were recorded in direct conjunction with the currents in *Figure[2.3.1]*.





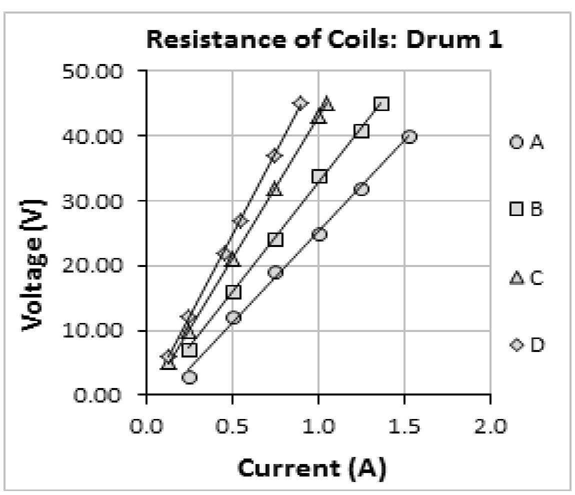
Figure[2.3.2] *Single-Coil Field Production (as a function of voltage)*

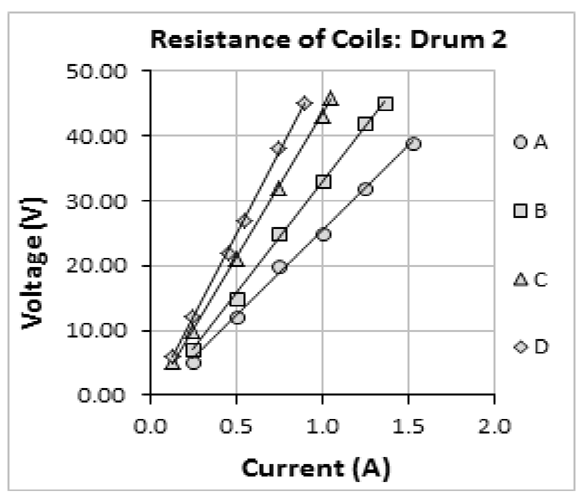
The plots in *Figure[2.3.2]* show magnetic field production versus voltage. Linear fits were generated for each coil. The plots display expected results since the coils are different resistances. As resistance increases the voltage required to produce equivalent currents increases proportionally as a consequence of Ohm's Law shown in *Figure[2.3.3]*.

$$V = I\ R$$

Figure[2.3.3] *Ohm's Law*

The plots in *Figure[2.3.4]* show voltage as a function of current. Linear fits were generated for each coil where the gradient was equal to the resistance of the single-coil circuit.





Figure[2.3.4] *Single-Coil Circuit Resistances*

The resistance found for each coil was averaged across both drums. The table below in *Figure[2.3.5]* displays the results.

Coil	Exp. Resistance (Ω)	Th. Resistance (Ω)
A	27.3	25.0
B	34.3	32.0
C	43.9	42.0
D	50.8	49.0

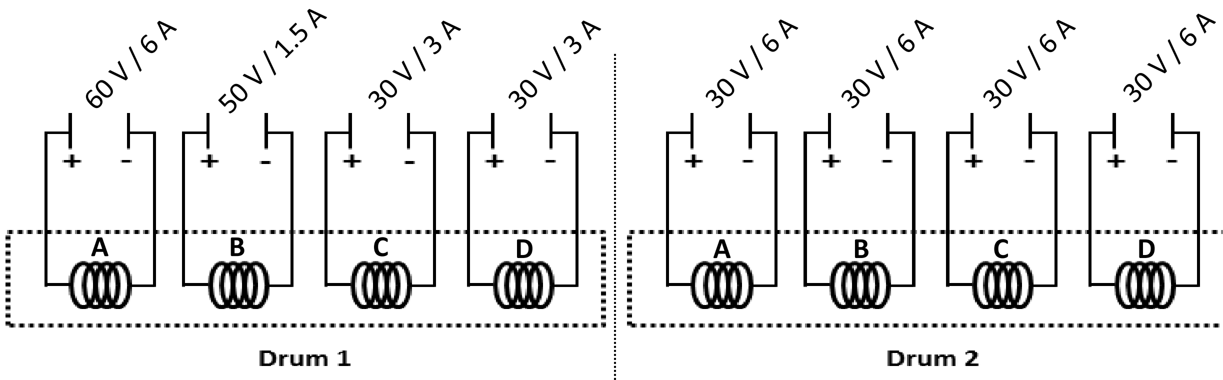
Figure[2.3.5] *Resistances of Single-Coil Circuits*

Comparing the values of *Figure[2.3.5]* with those in *Figure[2.2.3]*, all experimental resistances were slightly higher than the manufacturer-provided values for the coils; however, this was expected due to the additional wires required to connect the power supply and warm environmental conditions. Therefore, these numbers are in agreement with theoretical resistances. Included below in *Figure[2.3.6]* are the tables of the data set plotted in this section.

DRUM 1				DRUM 2			
Coil ("Z")	Current (A)	B-Field (T)	Voltage (V)	Coil ("Z")	Current (A)	B-Field (T)	Voltage (V)
A	0.25	0.038	3.0	A	0.25	0.037	5.0
(R = 25Ω)	0.50	0.065	12.0	(R = 25Ω)	0.50	0.064	12.0
	0.75	0.091	19.0		0.75	0.091	20.0
	1.00	0.114	25.0		1.00	0.118	25.0
	1.25	0.136	32.0		1.25	0.138	32.0
(max)	1.53	0.165	40.0	(max)	1.53	0.163	39.0
B	0.25	0.040	7.0	B	0.25	0.038	7.0
(R = 32Ω)	0.50	0.065	16.0	(R = 32Ω)	0.50	0.064	15.0
	0.75	0.091	24.0		0.75	0.091	25.0
	1.00	0.114	34.0		1.00	0.115	33.0
	1.25	0.136	41.0		1.25	0.136	42.0
(max)	1.36	0.145	45.0	(max)	1.36	0.146	45.0
C	0.13	0.028	5.0	C	0.13	0.025	5.0
(R = 42Ω)	0.25	0.038	10.0	(R = 42Ω)	0.25	0.038	10.0
	0.50	0.064	21.0		0.50	0.064	21.0
	0.75	0.087	32.0		0.75	0.088	32.0
	1.00	0.109	43.0		1.00	0.110	43.0
(max)	1.05	0.114	45.0	(max)	1.05	0.114	46.0
D	0.13	0.026	6.0	D	0.13	0.025	6.0
(R = 49Ω)	0.25	0.038	12.0	(R = 49Ω)	0.25	0.038	12.0
	0.45	0.057	22.0		0.45	0.057	22.0
	0.55	0.067	27.0		0.55	0.068	27.0
	0.75	0.084	37.0		0.75	0.085	38.0
(max)	0.90	0.096	45.0	(max)	0.90	0.096	45.0

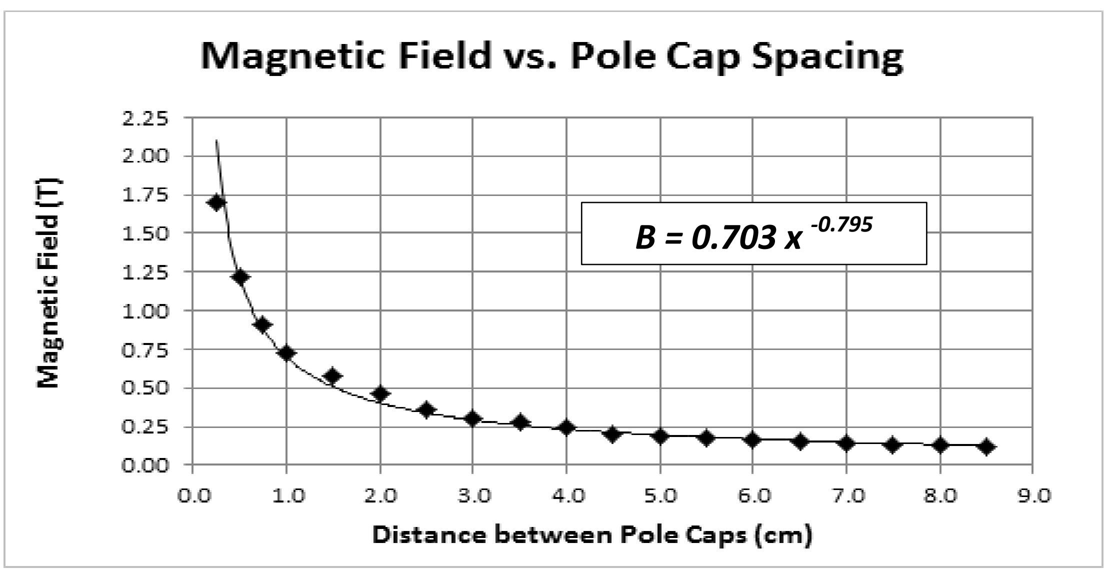
Figure[2.3.6] *Drum 1 and Drum 2 Data Sets*

Ultimately, the goal is to maximize the magnetic field produced by the electromagnet. *Figure[2.3.7]* presents the same circuit as introduced in *Figure[2.2.2]*, this time indicating the exact power supply capacities available at each of the terminals.



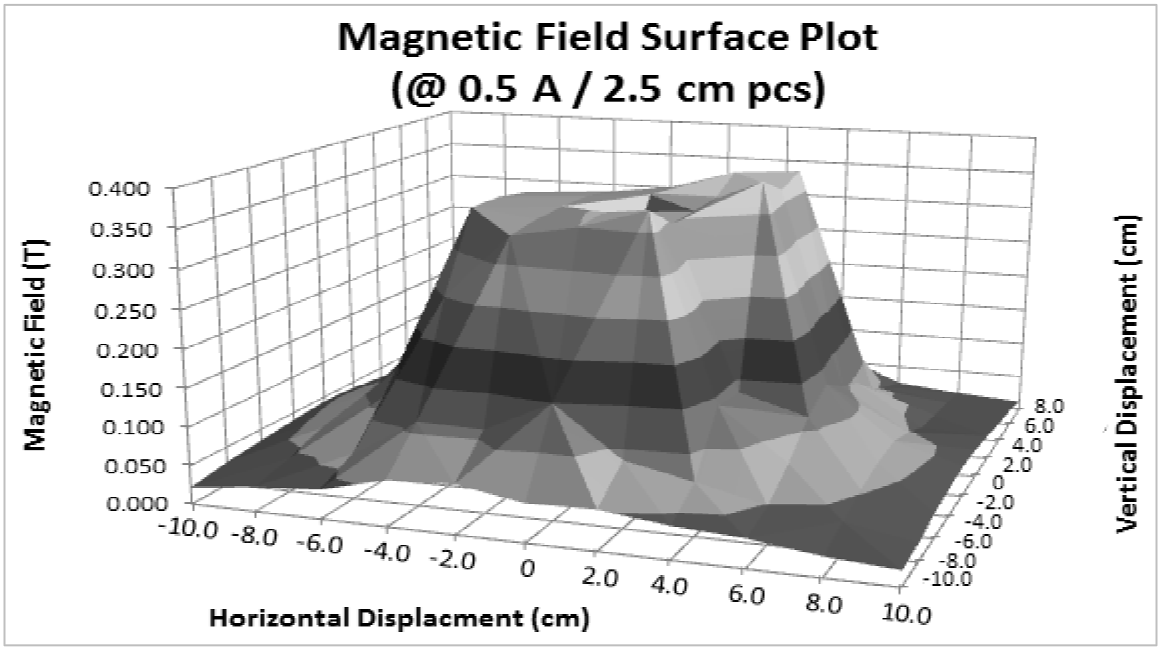
Figure[2.3.7] *Experimental Circuit Configuration*

Figure[2.3.8] shows the relationship between the strength of the magnetic field as a function of the distance between the pole caps. All coils were run with a current of 0.5 A. The smallest separation achievable with the teslameter probe was 0.15 cm. The probe was mounted on the face of one pole cap and remained stationary while the second pole cap was adjusted accordingly.



Figure[2.3.8] *Magnetic Field Strength vs. Pole Cap Separation*

Figure[2.3.9] shows a three-dimensional surface plot of the field produced by the configuration in *Figure[2.3.7]*. Again, all coils were set at a current of 0.5 A while the pole cap separation was kept at 2.5 cm (separation required to house a single 10x10 detector).



Figure[2.3.9] *Magnetic Field Surface Plot*

The plot in *Figure[2.3.9]* depicts a field which is relatively strong and constant in an area of approximately 100 cm^2 surrounding the center of the pole caps. There were 110 samplings across an 11x10 grid, with each vertex spaced 2.0 cm apart. Omitting the dip in the center of the pole caps, the maximum region contains a range of strengths from 0.334 T – 0.376 T, which is a variation of approximately 11%. As mentioned, the pole cap diameter is 10.0 cm. This plot certainly agrees with the region immediately between the pole caps having the largest, most constant field.

The final test that was done was a maximization test (without water-cooling). This involved maxing out all supplies as shown in *Figure[2.3.7]* for a very short period of time. Such a test gave a maximum magnetic field strength of 0.645 T. **Note: only the maximum magnetic field was measured since the recording of specific currents and voltages would have been time consuming and put the electromagnet in danger of damage.** It is from here that any improvements to this field can only be made through more powerful supplies.

2.4 Future Experimentation

As of the present time, the electromagnet field has been mapped and the functionality of all coils and components has been confirmed. This section will suggest the next stage of experimentation.

According to the Varian v-4004 electromagnet manual, the coils require water-cooling in order to function at higher currents for longer periods of time. In order to maximize the magnetic field, the maximum current must be present in all coils. When current within all coils exceeds 0.5 A, water-cooling is said to be required by the manufacturer. Testing will then need to be done to confirm steady flow through the intake and outtake pipes.

The most beneficial power source currently used is the Uniply® Model 6050A power source (60V/6A). Observing that the lowest resistance coil held a maximum of 1.53 A during experimentation at approximately 40 V, more powerful supplies will be needed to obtain similar figures with the higher resistance coils.

Finally, experimentation will be done to observe the effect of an external magnetic field on the functionality of the 10x10 GEM detector. Specific tests have not yet been determined.