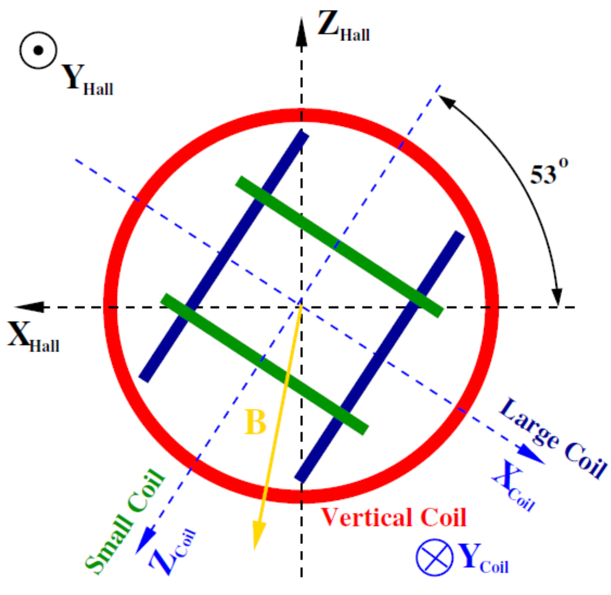
Compass calibration on He3 target

The He3 target is placed in the center of three sets of Helmholtz coils, which regulate the magnetic field direction and intensity on the target. Two sets, the big and small coils are used to manipulate horizontal components and the largest, vertical coil to manipulate the vertical component of the magnetic field.

The problem is that in addition to the field the coils produce, there are also the Earth magnetic field and the fringe field of the Big Bite spectrometer which are non-negligible. To solve this, a compass was placed on the target, to show the direction of the field. What remained was to calibrate the compass.

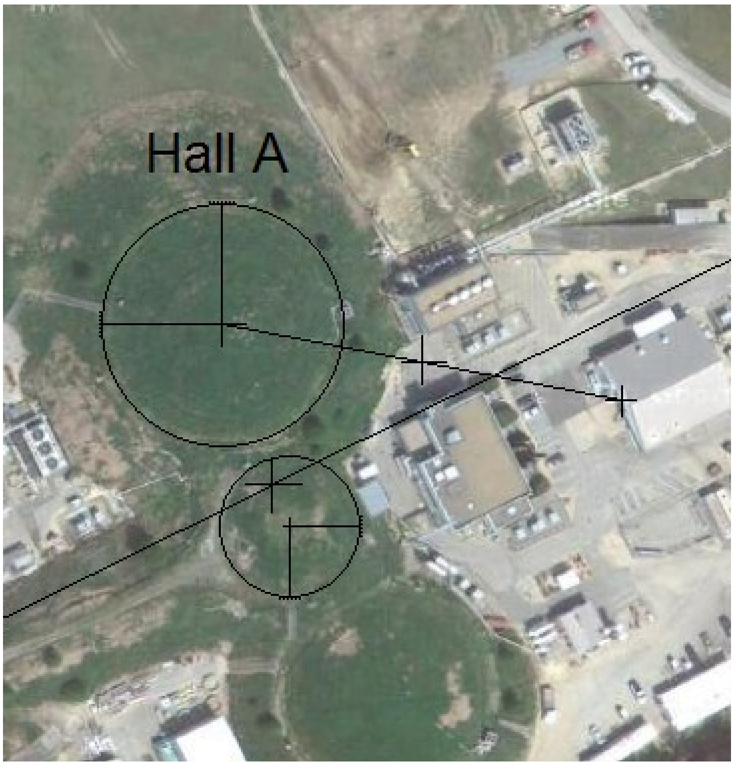
As mentioned there are two contributions to the magnetic field apart from the Helmholtz coils. And while the Earth field is constant for all purposes of the experiment, the Big Bite field is not, for it is dependent of the current in the spectrometer.

To measure the nett field at target location, a mirror placed on the compass and a laser were used. There were essentially two sets of data, the first being horizontal and the second vertical measurements. They were both gathered by sampling the angle at which the laser reflected from the mirror back to the laser, while changing the current through Big Bite. With two such angles (corresponding to two different currents) and the direction and magnitude of Earths magnetic field[1], one is able to calculate the direction and magnitude of the Big Bite field. Used in the calculation was an assumption, that Big Bite's field is linearly dependent on the current, which may not be the case. If not, this assumption may be one of contributors to the overall error of magnetic field calculation.



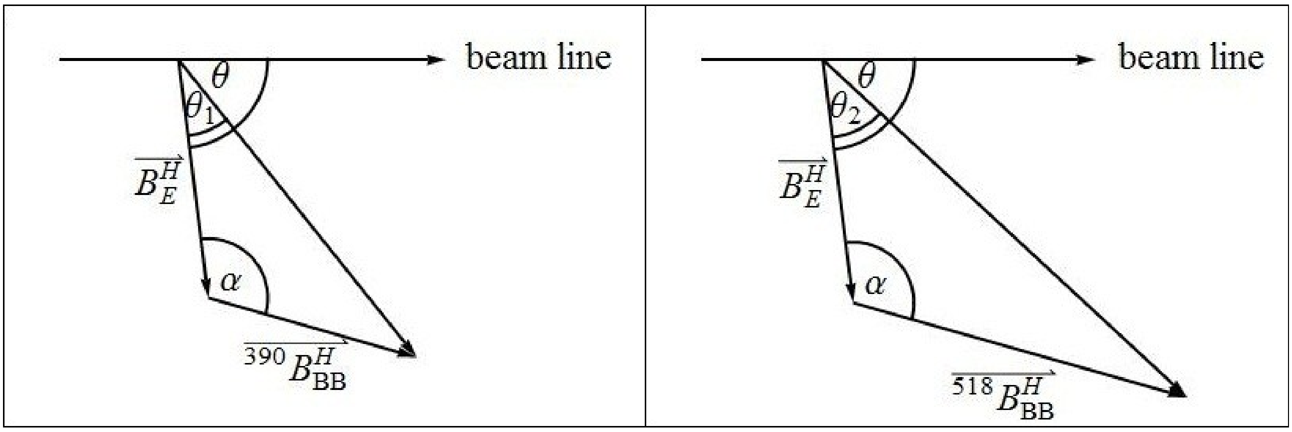
Picture 1: The orientation of the Helmholtz coils and the hall coordinate system. The hall Z axis is alined with the electron beam.

The first step in the data analysis was to specify Earth's magnetic field intensity and inclination relative to the beam (hall coordinate system). A reference[1] (date 4/25/2009) was used to determine the magnitude and its components along the North-South, East-West and vertical axes. To put that in the perspective of the hall coordinate system, a satellite picture of Jefferson Lab Hall A was used (picture 2).



Picture 2: The beam through the center of Hall A arcs away of the primary beam at an angle of about 37 Degrees. This picture is a representation of the angle, not the beam line placement.

Once the Earth magnetic field was known, the rest was more or less geometry, as picture 3 shows.



Picture 3: As the Big Bite current changes from 390A to 518A, the magnetic field density changes it's magnitude and the angle θ1 changes into θ2, but α remains the same. The picture is in the horizontal plane. The same principle applies to the vertical plane.

With this, all contributions to the magnetic field were determined. To calculate the currents through the Helmholtz coils, the equation

$$B=\left(\frac{4}{5}\right)^{\frac{3}{2}}\frac{\mu_0 N I}{R}$$

Equation 1

was used. N and R are the number of windings of the coil and the coil radius respectively. A slight adjustment had to be made, because the coil coordinate system is at an angle α to the hall system, so the final expressions for the currents are

$$I_{Small}=\left(\frac{5}{4}\right)^{\frac{3}{2}}\frac{R_{Small}}{\mu_0 N_{Small}}(-\sin(\alpha)B_1-\cos(\alpha)B_3)$$

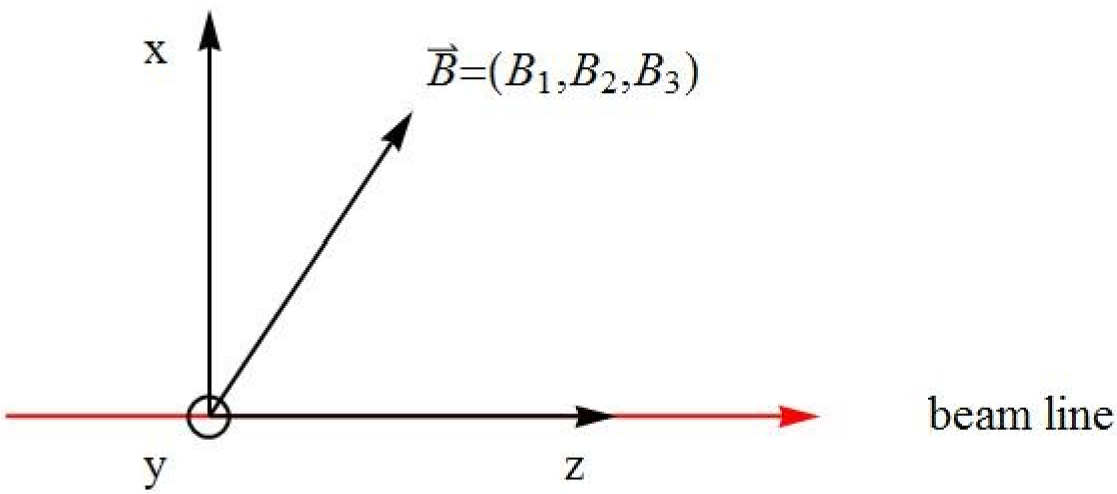
$$I_{Big}=\left(\frac{5}{4}\right)^{\frac{3}{2}}\frac{R_{Big}}{\mu_0 N_{Big}}(\cos(\alpha)B_1-\sin(\alpha)B_3)\quad,$$

$$I_{Vertical}=\left(\frac{5}{4}\right)^{\frac{3}{2}}\frac{R_{Vertical}B_3}{\mu_0 N_{Vertical}}$$

Equation 2: The calculation of the currents through the coils to compensate for the magnetic field.

$$\begin{gathered}\alpha=37^o\pm1^o\\ R_{Small}=0.635\,m\\ R_{Big}=0.725\,m\\ R_{Vertical}=0.915\mathrm{m}\\ N_{Small}=256\\ N_{Big}=272\\ N_{Vertical}=355\\ \mu_o=4\pi\cdot10^{-7}\frac{V\,s}{A\,m}\end{gathered}\quad,$$

where B_i are components of the magnetic field vector in the hall coordinate system, as shown in picture 4.



Picture 4: The hall coordinate system z axis is alined with the beam line, while the y axis is vertical and the x axis is horizontal.

In this coordinate system the Big Bite and Earth magnetic fields can be written as

$$\vec{B}_{BB}^{390}=(-16193.4,50860.8,5414.3)\,nT\pm(50,0.3,17)\,nT$$

$$\vec{B}_{BB}^{518}=(-21508.2,67553.6,7191.3)\pm(50,0.3,17)\,nT\quad.$$

$$\vec{B}_E=(-19996,46939,7667)\,nT\pm(1,1,1)\,nT$$

$\vec{B}_{BB}^{390}$ and $\vec{B}_{BB}^{518}$ are Big Bite fields with currents through the spectrometer at 390A and

518A respectively and $\vec{B}_E$ is the Earth's magnetic field.

Using equation 1, the currents, corresponding the magnetic fields can be calculated.

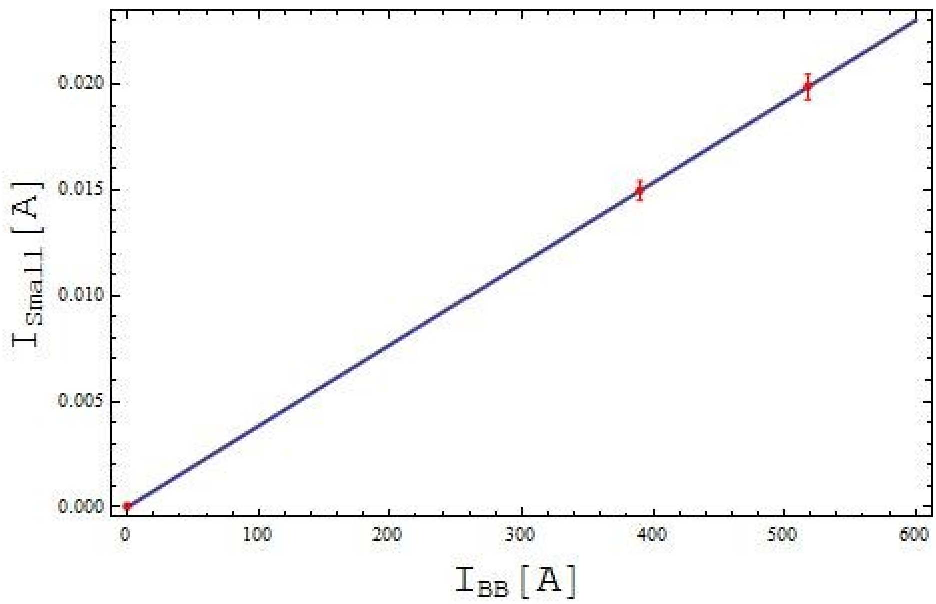
Table 1: Currents through the small , big and vertical coils to compensate for the Earth's magnetic field.

$I_{Small}(\Delta I_{Small})[A]$	$I_{Big}(\Delta I_{Big})[A]$	$I_{Vertical}(\Delta I_{Vertical})[A]$
0.0163(0.00044)	-0.0610(0.00165)	-0.1345(0.00364)

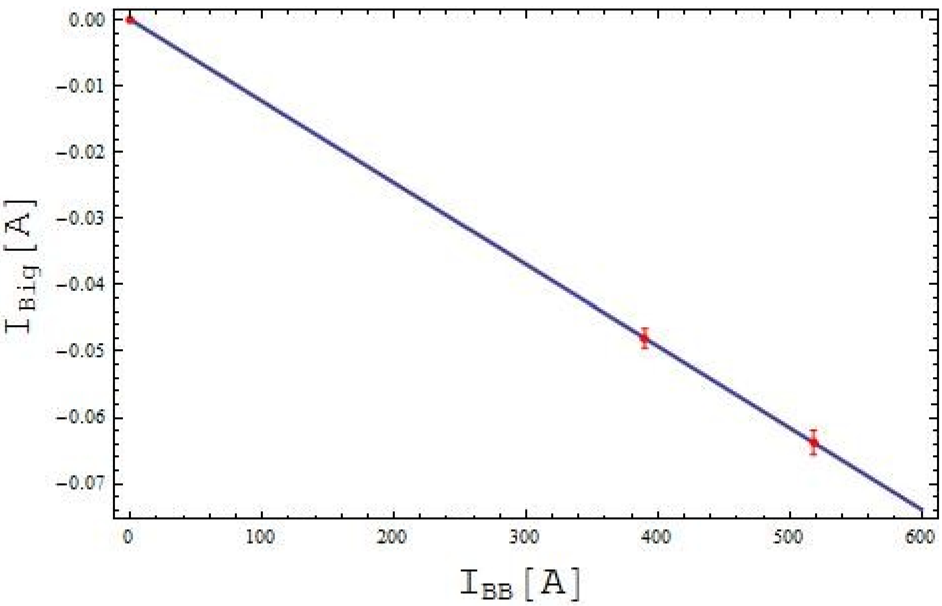
Table 2: Currents through the small, big and vertical coils to compensate for the Big Bite magnetic field at different Big Bite currents.

$I_{BB}[A]$	$I_{Small}(\Delta I_{Small})[A]$	$I_{Big}(\Delta I_{Big})[A]$	$I_{Vertical}(\Delta I_{Vertical})[A]$
0	0	0	0
390	0.01496(0.00046)	-0.04800(0.00144)	-0.14579(0.00394)
518	0.01986(0.00058)	-0.06375(0.00187)	-0.19364(0.00523)

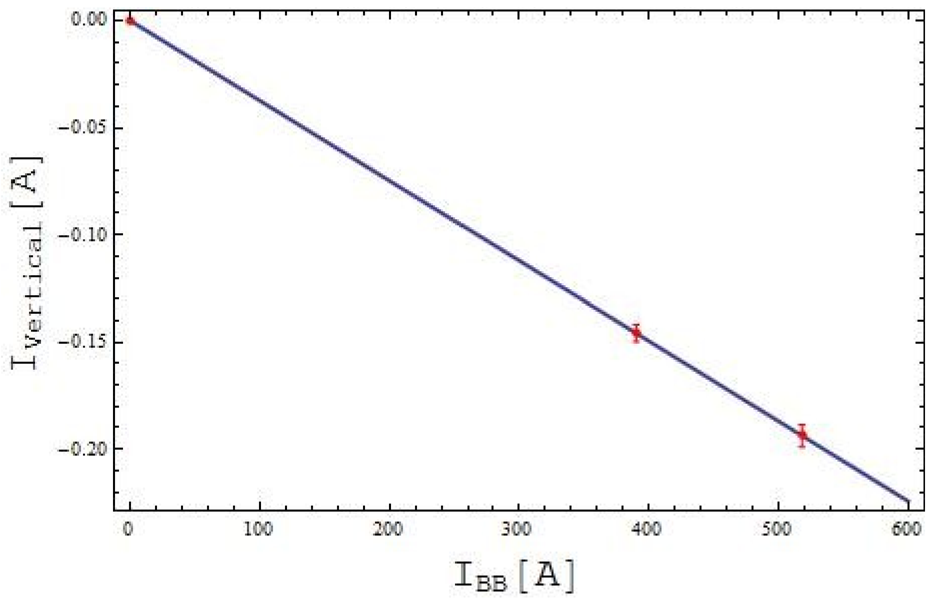
Graphic representation:



Plot 1: Small coil current in relation to the current through the Big Bite spectrometer.

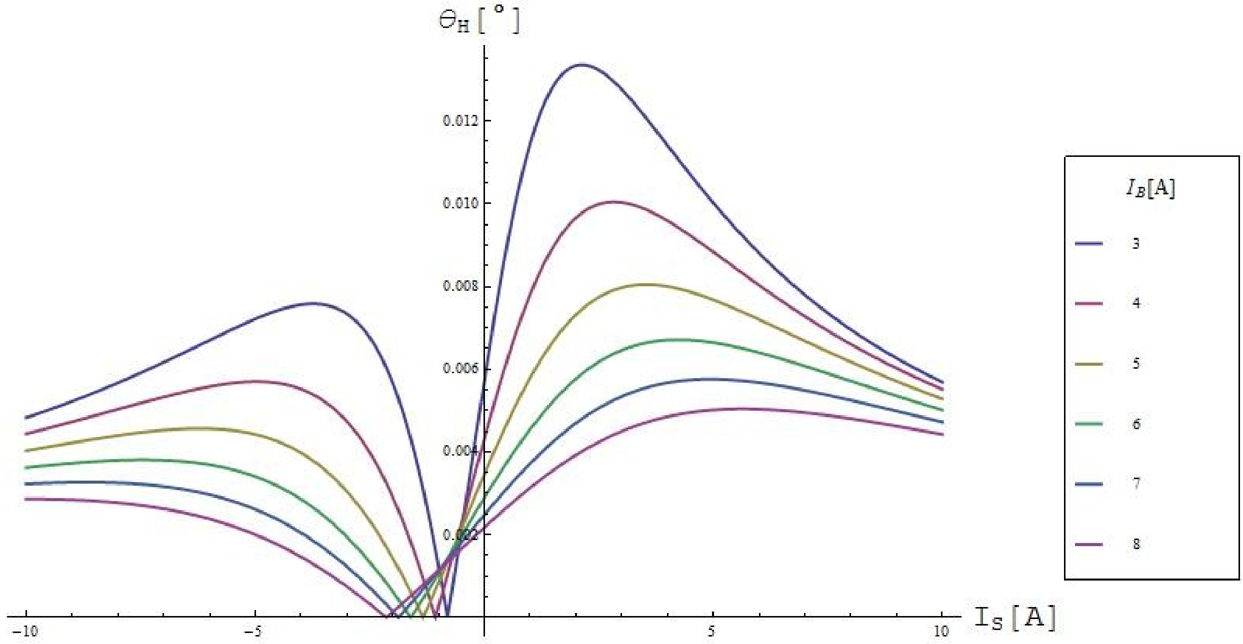


Plot 2: Big coil current in relation to the current through the Big Bite spectrometer.

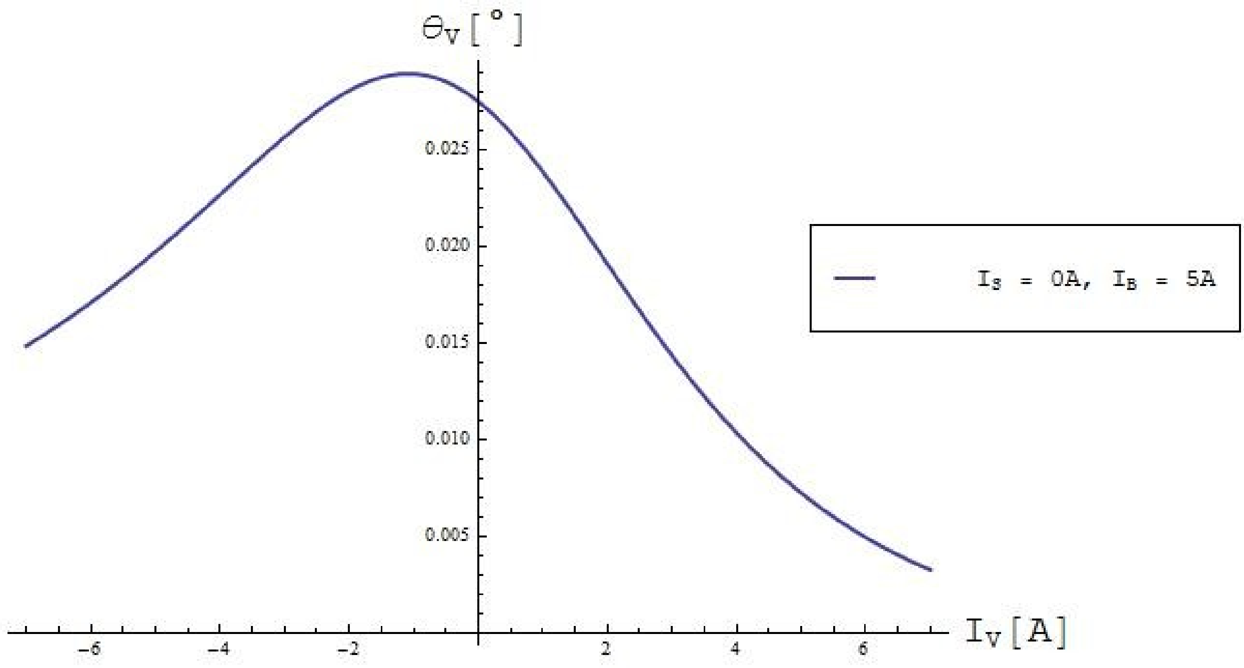


Plot 3: Vertical coil current in relation to the current through the Big Bite spectrometer.

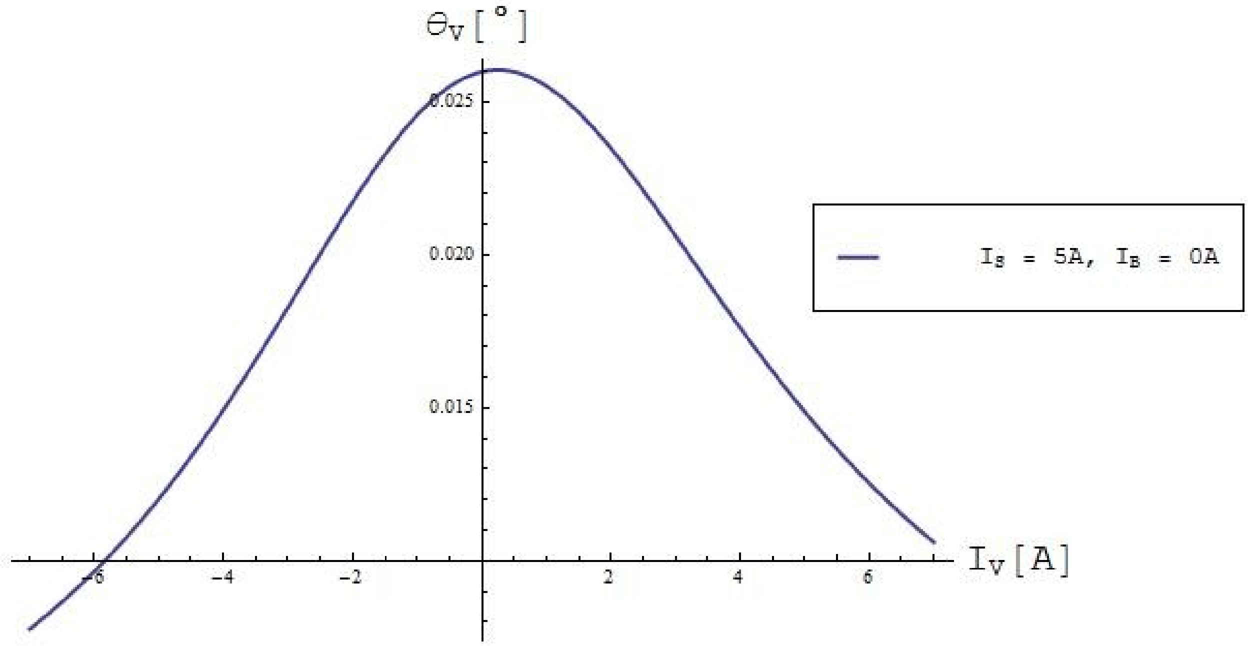
The consequence of the non-zero fringe field at the target is ultimately a deviation of the direction of the nett magnetic field. Without the Earth magnetic field, the expected direction of the target polarization would coincide with the known magnetic field of the Helmholtz coils. Since the Earth magnetic field is present, the actual magnetic field on the target points in a different direction, with the angle being dependent on the current through the coils, as shown in the following plots.



Plot 4: Horizontal angle of deviation from the expected field direction at various currents through the big coil.



Plot 5: Vertical angle of deviation from the expected field direction with two currents through the big and small coils.



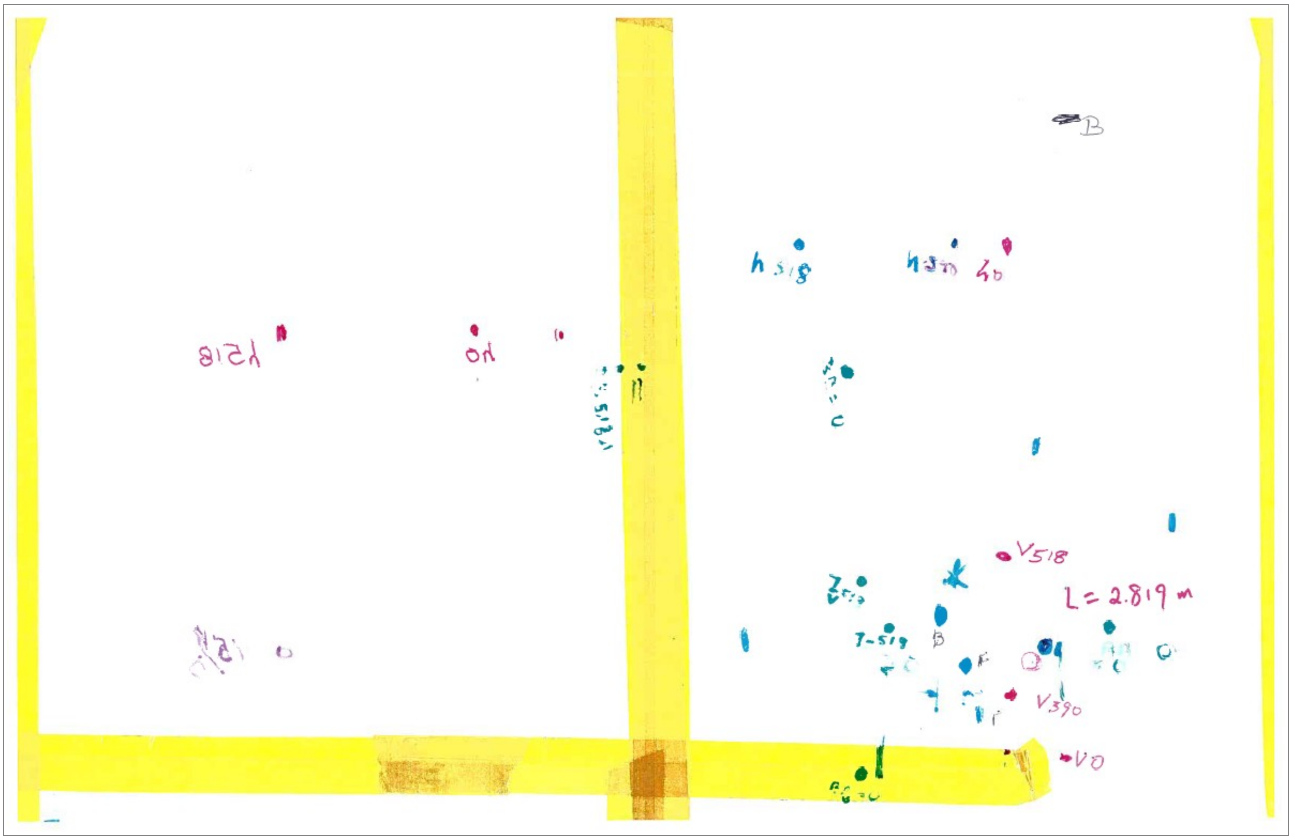
Plot 6: Vertical angle of deviation from the expected field direction with two currents through the big and small coils.

The results are quite good, but there are still some possible causes of error. One, already stated, is that the BB field may not be linearly proportional to to the BB current. Also the equation 1 is valid only in the center point of the Helmholtz coils, and with the compass having a finitely large magnetic needle, the overall field may not be as calculated.

Added are the scans of the actual measurements of the laser refraction on the compass mirror. Some (but not all) of the circles represent where the laser originated and the corresponding dots where it refracted back. The numbers next to the dots are the current through the Big Bite in Amperes. V and H stand for vertical and horizontal measurements.

References:

[1] http://ngdc.noaa.gov/geomagmodels/IGRFWMM.jsp, 7/31/2012.



Picture 5: Measurements.

Picture 6: Measurements.