

# Scientific Note for Magnetic Field Measurement of Detector Components for Muon g-2 Experiment

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## Abstract

This scientific note describes the details of the magnetic field measurement for the muon g-2 experiment. The magnetization of some samples, including a standard tungsten sample, components of the detector for the muon g-2 experiment and the DC-DC convertors, is measured in two perpendicular direction. The results of this study can be used as a reference in the calculation of the total effect caused by the detector.

## 1 Introduction

A uniform magnetic field with 3.0T and a local uniformity of <1ppm is required in muon g-2 experiment. However, any components employed in the magnetic field shows magnetization, which affect the uniformity of the magnetic field. A practical approach is to measure the magnetization of each components and consider their effects in the final calculation.

In this study, the magnetic field difference caused by the sample is measured. A standard cylinder tungsten sample is measured as a reference. Components of the detector are measured at a similar setup as the formal run, which can be used in the calculation of the total magnetic field difference caused by the detector.

## 2 Methods

### 2.1 Magnetization of a Point-like Object in the Magnetic Field

A simple way to calculate the magnetic susceptibility of the component is to treat it as a point-like object. Magnetic field ( $\Delta B$ ) created by a magnetic dipole is

$$\Delta B = \frac{\mu_0}{4\pi} \left[ \frac{3\hat{r}(\mathbf{m} \cdot \hat{r}) - \mathbf{m}}{r^3} \right]$$

So, the B-field distribution along the direction of the dipole is

$$\Delta B = \frac{\mu_0 m}{2\pi r^3}$$

While the B-field distribution along the perpendicular direction is half. The magnetization  $m$  can be expressed as

$$m = \frac{\chi_V V B}{\mu_0}$$

, where  $\chi_V$  is the magnetic susceptibility per unit volume.

Therefore, the fitting function for the direction along the dipole can be

$$\frac{\Delta B}{B} = \frac{p_0}{(r - p_1)^3} + p_2$$

, where  $\chi_V = \frac{2\pi p_0}{V}$ ,  $p_1$  refers to the position error, and  $p_2$  refers to the error of the magnetic field due to the inhomogeneous distribution caused by time shift.

## 2.2 Samples for Measurement

Samples listed are measured:

1. Standard tungsten sample in cylinder shape (49 mm in height and 30 mm in diameter, Figure 1)
2. DC-DC converter of two versions (Figure 2)
3. Chip TPS53319 (used for the DC-DC converter)
4. Copper coil (used for the DC-DC converter, Figure 3)
5. Silicon strip sensor  $\times 5$  (Figure 4)
6. Flexible printed circuit board (PFC)  $\times 18$  (Figure 5, 6)
7. Heat pipe of pure copper  $\times 5$  (Figure 7)
8. ASIC (SliT128B) ( $5 \times 5$ , 25 in total, Figure 8)
9. Conductive adhesive (CW2400, Figure 9)
10. Connector  $\times$  (5 with board + 1 without board, Figure 10 to 11)
  - 1) USLS00-30, with board
  - 2) XSLS00-30, with board

- 3) SSL0X-30L3-XXXX, with board
- 4) XSL00-48L, with board
- 5) USL00-40L-X, with board
- 6) Unnamed, without board

Illustration of each sample and measuring position is shown in the figures below.



Figure 12: Standard Tungsten Sample

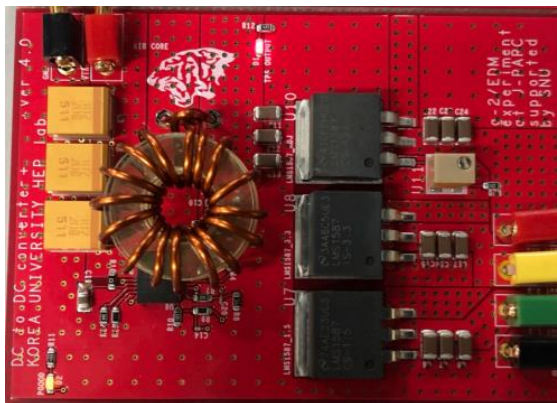


Figure 13: DC-DC Converter with chips and coil on it

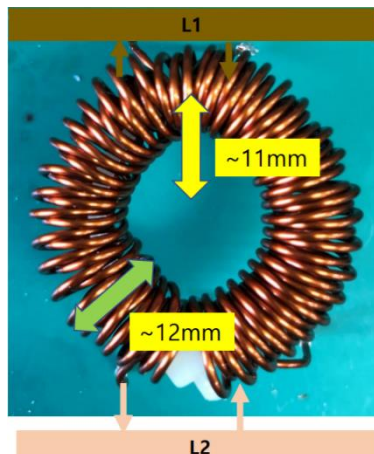


Figure 14 Copper Coil

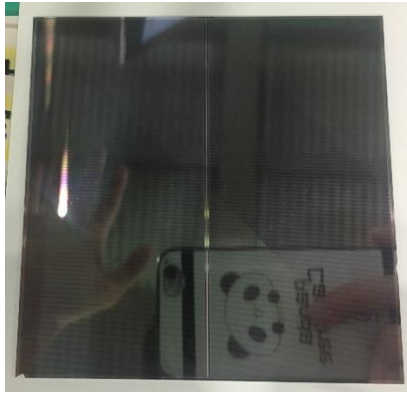


Figure 15: Silicon Sensor



Figure 16: FPC Board. There are two different measuring position “edge” and “head” in the second measurement.



Figure 17: FPC Board. There are two different measuring position “P1” and “P2” in the third measurement.



Figure 18: Heat Pipe

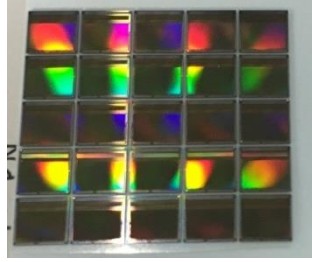


Figure 19: ASIC



Figure 20: Adhesive (2.753g)

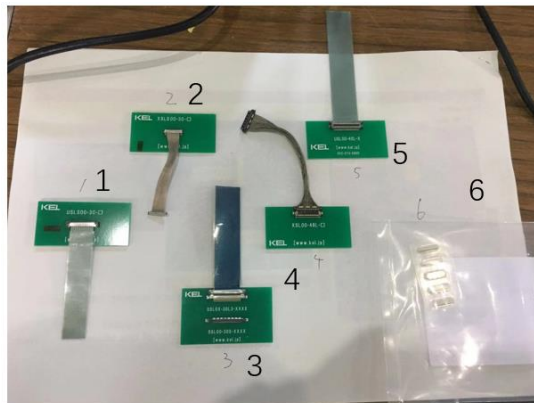


Figure 21: Connectors

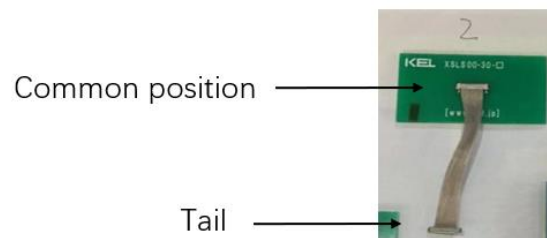


Figure 22: Illustration of Measuring Position of Connector #2 and #4

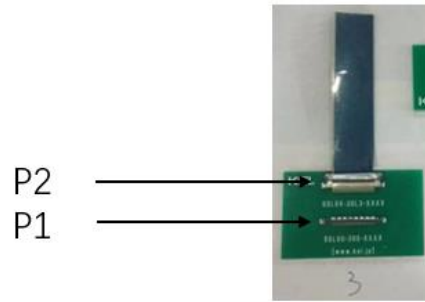


Figure 23: Illustration of Measuring Position of Connector #3

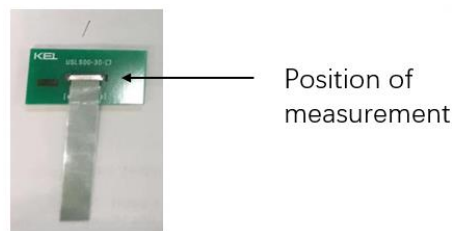


Figure 24: Illustration of Measuring Position of Connector #1 and #5

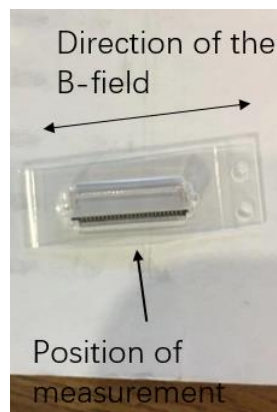


Figure 25: The connector without circuit board

## 2.3 Experiment Setup

There are three different measurements in total, while the first measurement is mainly operated by Yamanaka-san, Sato-san, and Yamaguchi-san.

In order to measure the magnetization of each sample, there are two measurements for a certain sample, with sample and without sample. By subtraction, the magnetization of each sample can be calculated. Nuclear magnetic resonance (NMR) tube is employed to measure the magnetic field at a certain position, which is supported by a 3D moving service controlled by computer. In each measurement, sample is fixed inside the magnetic field, while NMR tube moves along a certain direction. In the first and third measurement, NMR tube moves in a parallel direction (z direction) to the magnetic field, while in the second measurement, NMR tube moves perpendicular (x direction) to the magnetic field.

The layout of the components of the detector in the second measurement is the same as the formal run, with the magnetization measured along the radius direction. Therefore, the result of this measurement can be a direct reference in the calculation of the total effect of the detectors.

The distance between the NMR tube and the edge of the stage is about 3 mm at zero position in the second measurement while this distance is about 1.3 mm in the third measurement. We try to parallel the edge of each sample is with the edge of the stage.

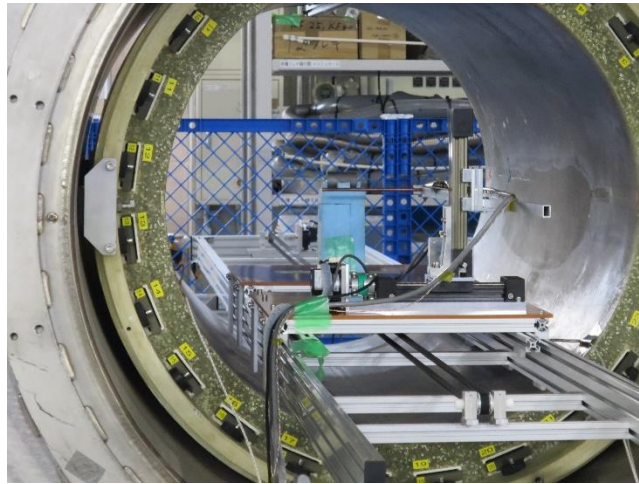


Figure 26: Setup of the First Measurement

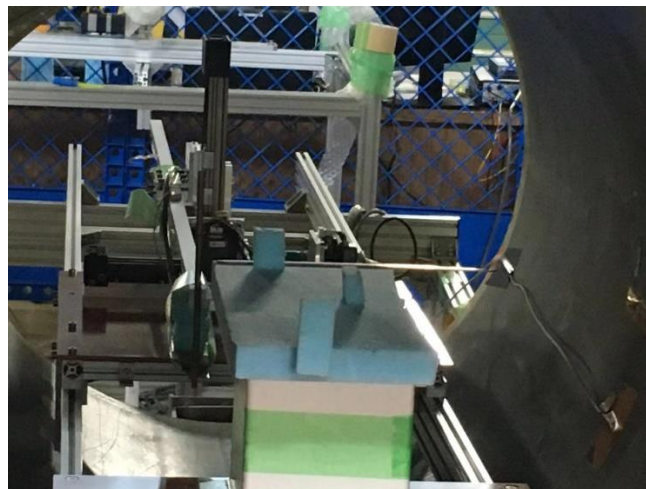


Figure 27: Setup of the Second Measurement



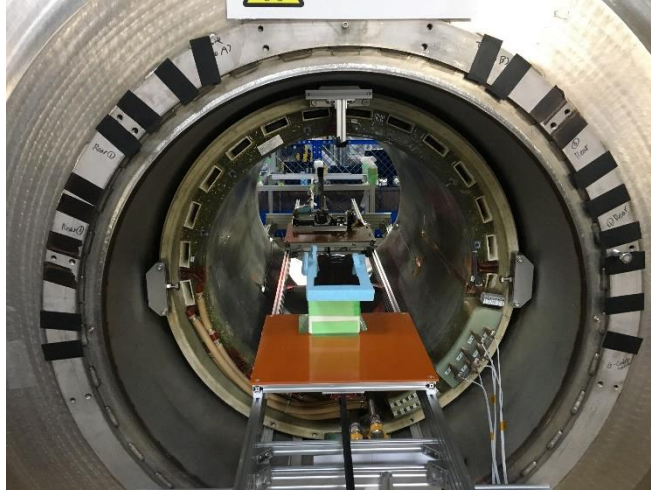


Figure 28: Setup of the Third Measurement

### 3 Measuring Results

#### 3.1 Measuring Results for Standard Tungsten Sample

The results of tungsten act as a reference of the measurement.

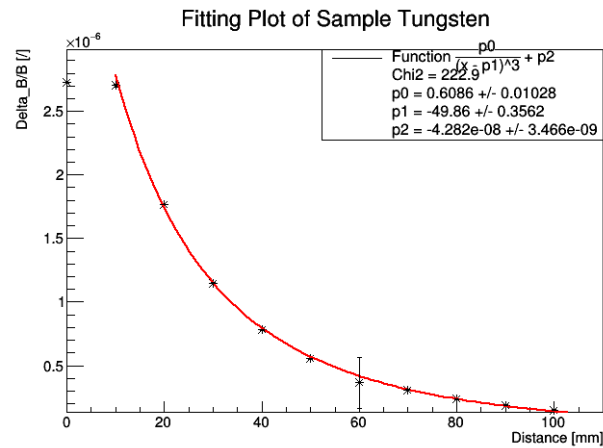


Figure 29: Fitting Plot of Tungsten Measured along z Direction

According to the fitting result,  $p_0 = 0.6086 \text{ mm}^3 = 6.086 \times 10^{-10} \text{ m}^3$ .

As the volume of tungsten sample is

$$V = 1.10\pi \times 10^{-5} \text{ m}^3$$

The magnetic susceptibility per unit volume measured is

$$\chi_{V_{mea}} = \frac{2\pi p_0}{V} = 1.082 \times 10^{-4} \pm 1.828 \times 10^{-6}$$



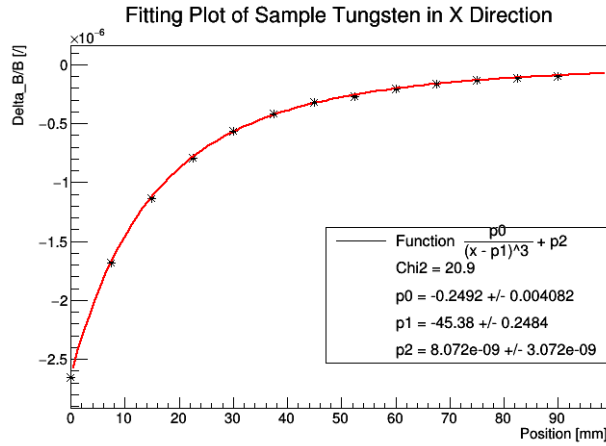


Figure 30: Fitting Plot of Tungsten Measured along x Direction

According to the fitting result,  $p_0 = 0.2492 \text{ mm}^3 = 2.492 \times 10^{-10} \text{ m}^3$ .

As the volume of tungsten sample is

$$V = 1.10\pi \times 10^{-5} \text{ m}^3$$

The measured value of the magnetic susceptibility per unit volume is

$$\chi_{V_{mea}} = \frac{4\pi p_0}{V} = 9.062 \times 10^{-5} \pm 1.484 \times 10^{-6}$$

While the standard value of the magnetic susceptibility per unit volume is

$$\chi_{V_{sta}} = 7.8 \times 10^{-5}$$

Both results of the measured value of the magnetic susceptibility per unit volume are differed from the standard value by about 25%. The reason for the difference may be that the point-like model is employed in the fitting process.

### 3.2 Further Discussion on Measuring Results for Standard Tungsten

#### Sample

In order to figure out better calculation of the magnetization of the standard tungsten sample, simple integral method considering the size of the tungsten is employed. In the calculation, the lay-out of the tungsten sample and the measuring direction are the same as that of the second measurement. The distribution of magnetic field is calculated. The result is shown in the figure below.

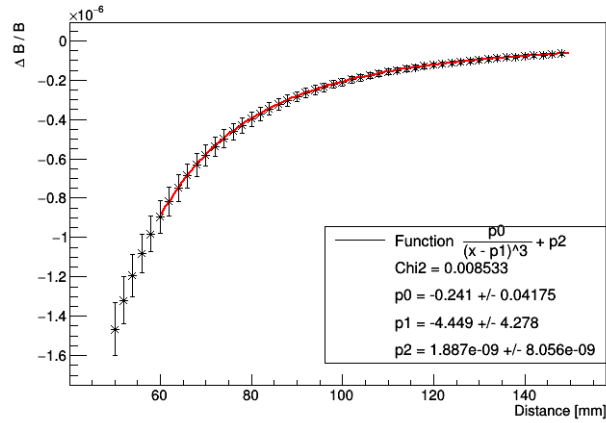


Figure 31: Fitting Result Using Integral Method Considering the Size of Tungsten

The result given by this method is  $p_0 = 0.241 \text{ mm}^3$ . Compared with the result of the second measurement, which is  $p_0 = 0.2492 \text{ mm}^3$ , there is a difference of about 3%. This is within the range of the error of the measurement itself.

### 3.3 Measuring Results for the DC-DC Convertors and their Components

The results of magnetic field measurement of DC-DC convertors, chip and copper coil in z direction are shown in the figures below.

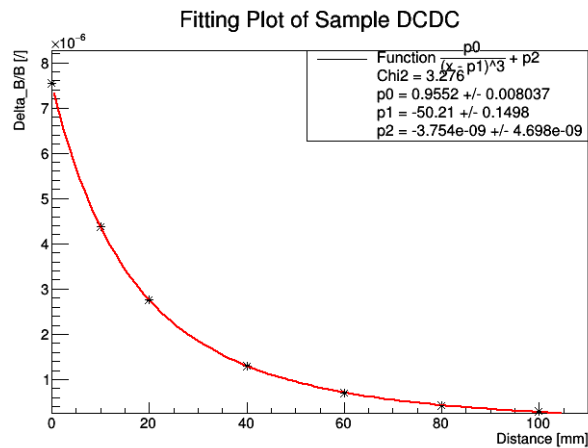


Figure 32: Fitting Plot of Sample DC-DC Convertor in z Direction

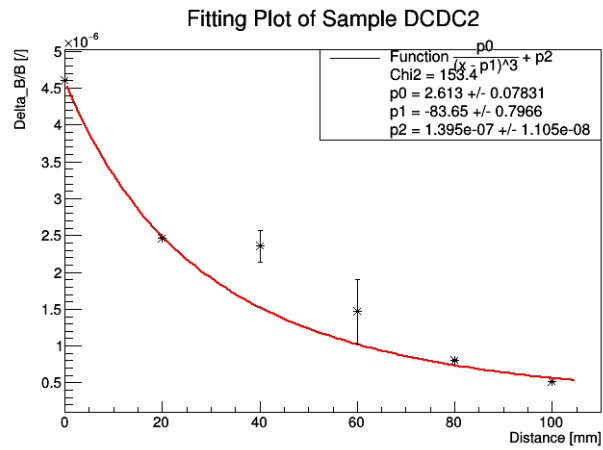


Figure 33: Fitting Plot of Sample DC-DC Converter 2 in z Direction

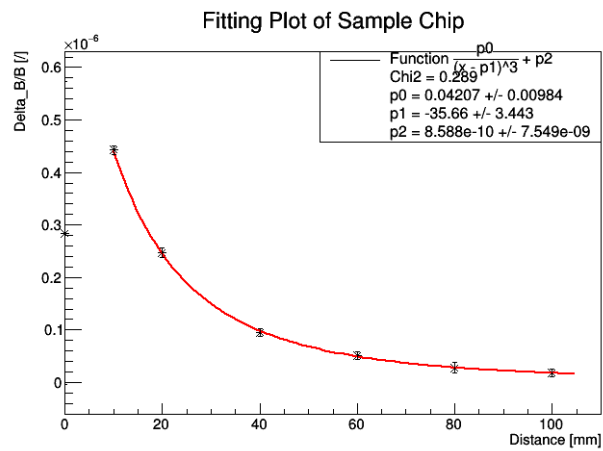


Figure 34: Fitting Plot of Sample Chip in z Direction

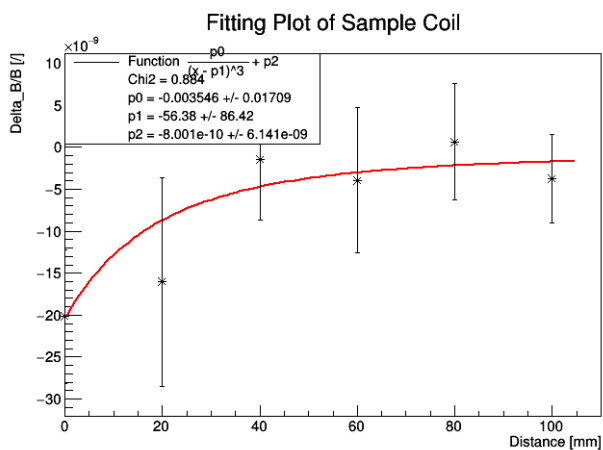


Figure 35: Fitting Plot of Sample Copper Coil in z Direction

### 3.4 Measuring Results for the Silicon Sensor

The results of magnetic field measurement of one silicon sensor and five silicon sensors in both x and z direction are shown in the figures below.

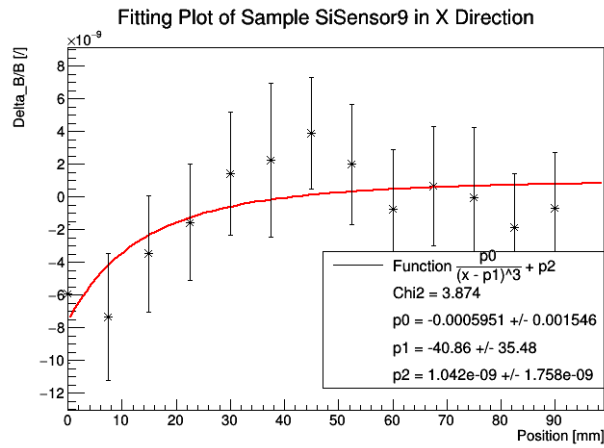


Figure 36: Fitting Plot of Sample Silicon Sensor No.9 in x Direction

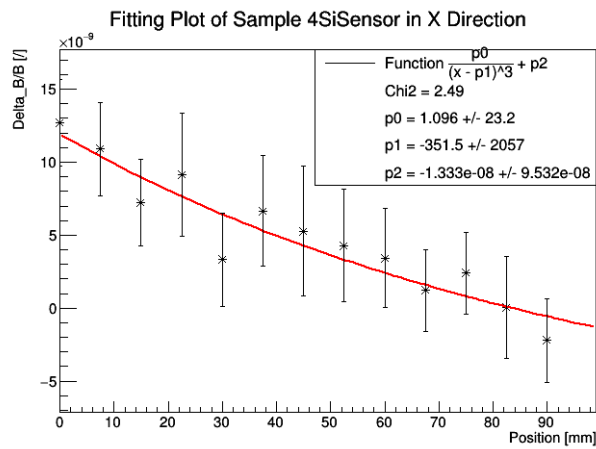


Figure 37: Fitting Plot of Four Silicon Sensor in x Direction

### 3.5 Measuring Results for the FPC Board

The results of magnetic field measurement of one FPC board and five FPC board at different measuring position in both x and z direction are shown in the figures below.

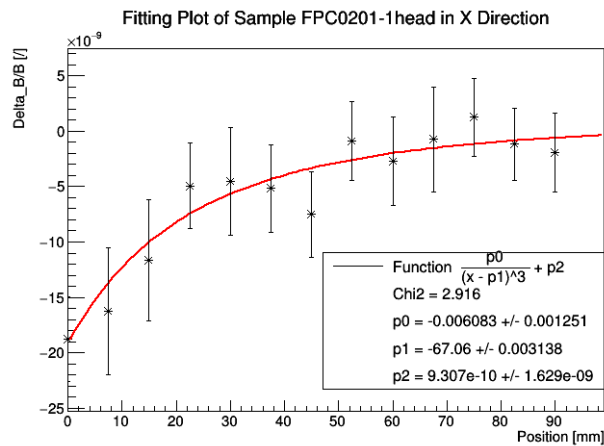


Figure 38: Fitting Plot of Sample FPC 0201-1 at Position Head in x Direction

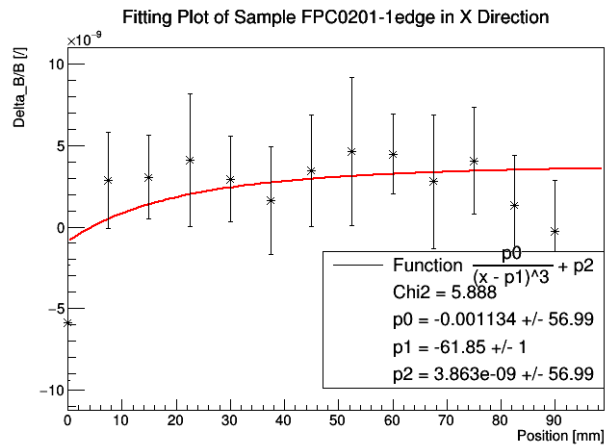


Figure 39: Fitting Plot of Sample FPC 0201-1 at Position Edge in x Direction

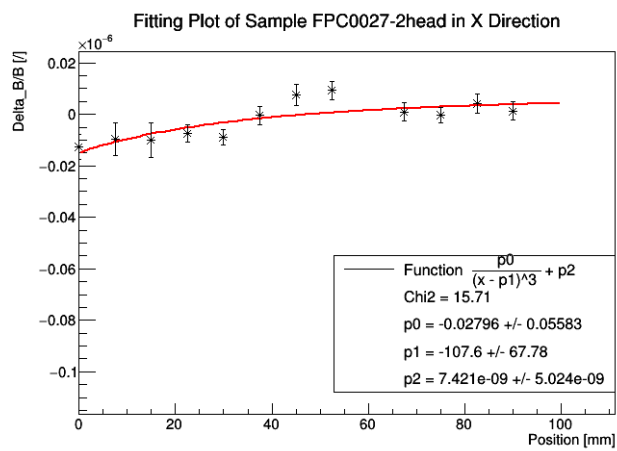


Figure 40: Fitting Plot of Sample FPC 0027-2 at Position Head in x Direction. There is a wrong point at x = 60 mm.

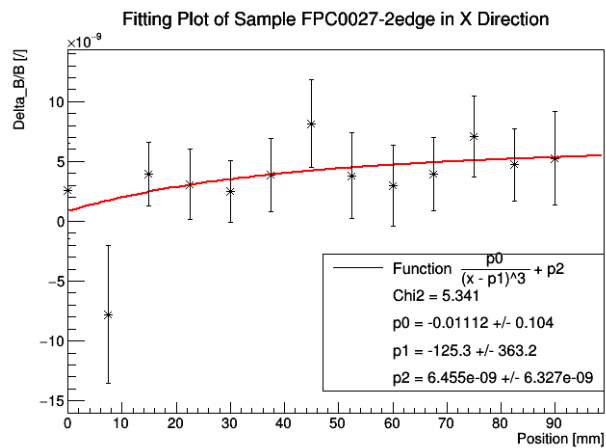


Figure 41: Fitting Plot of Sample FPC 0027-2 at Position Edge in x Direction.

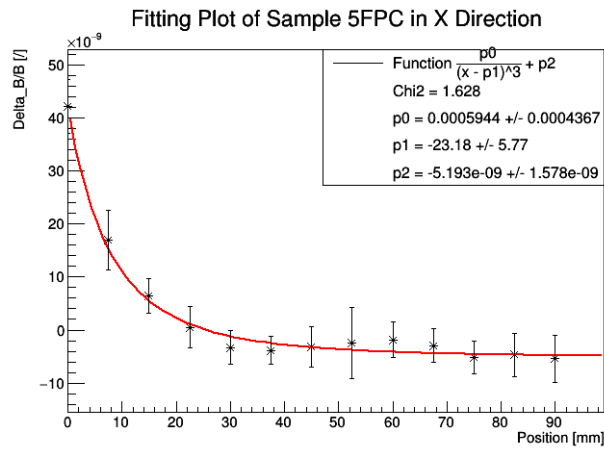


Figure 42: Fitting Plot of Five FPC Board at Position Head in x Direction

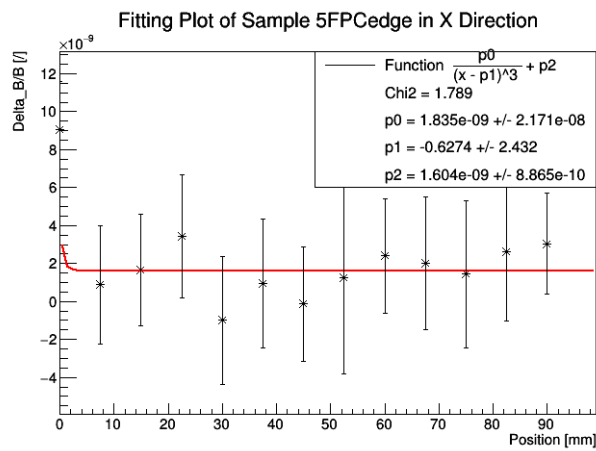


Figure 43: Fitting Plot of Five FPC Board at Position Edge in x Direction

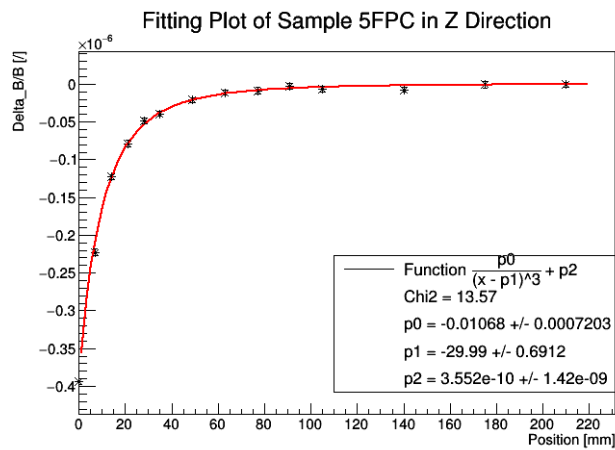


Figure 44: Fitting Plot of Five FPC Board at Position P1 in z Direction

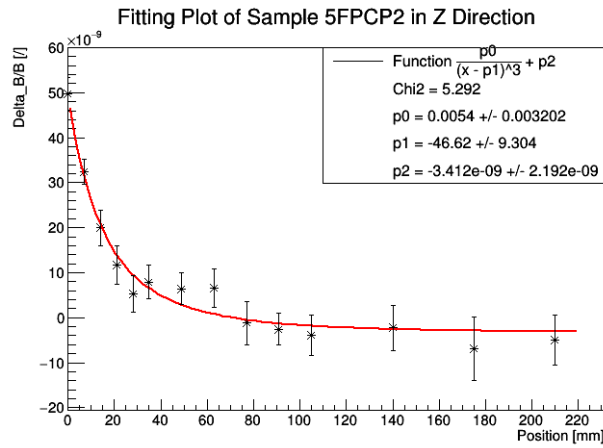


Figure 45: Fitting Plot of Five FPC Board at Position P2 in z Direction

### 3.6 Measuring Results for the Heat Pipe

The results of magnetic field measurement of one heat pipe and five heat pipes in both x and z direction are shown in the figures below.

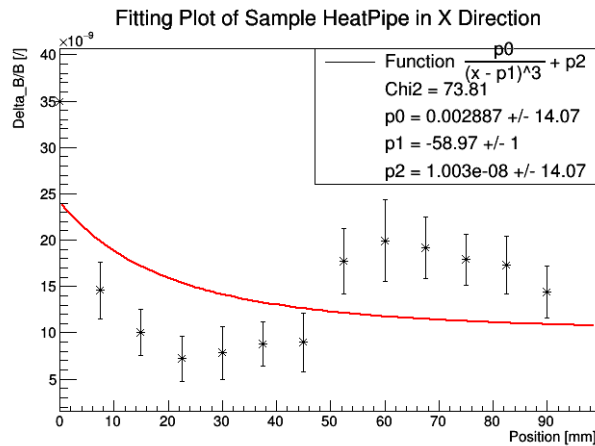


Figure 46: Fitting Plot of One Heat Pipe in x Direction

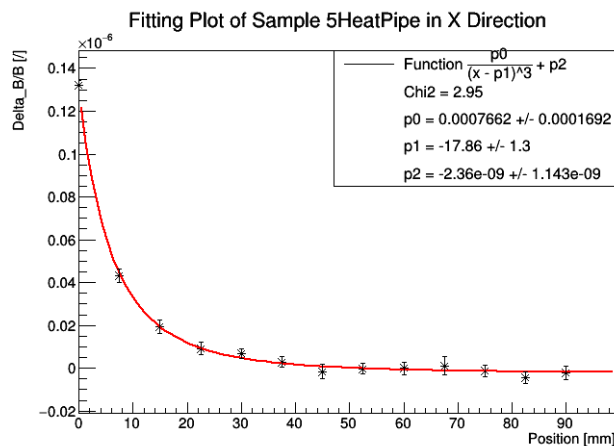


Figure 47: Fitting Plot of Five Heat Pipe in x Direction



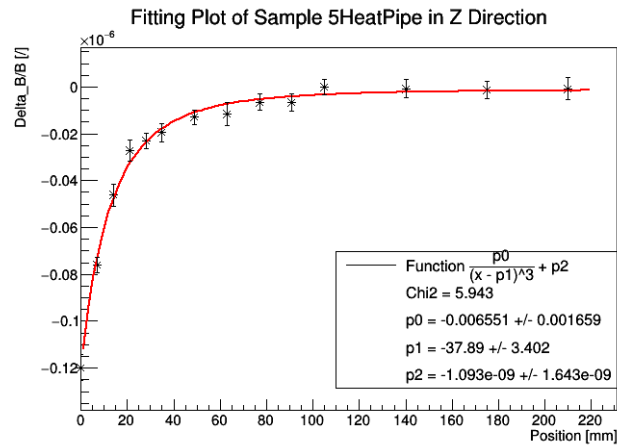


Figure 48: Fitting Plot of Five Heat Pipe in z Direction

### 3.7 Measuring Results for the ASIC

The results of magnetic field measurement of 25 ASIC in both x and z direction are shown in the figures below.

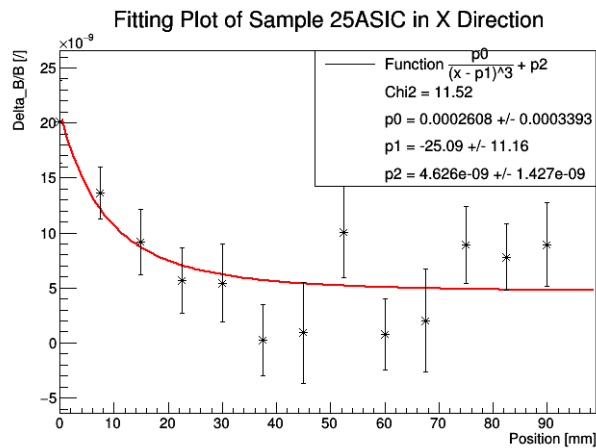


Figure 49: Fitting Plot of 25(5x5) ASIC in x Direction

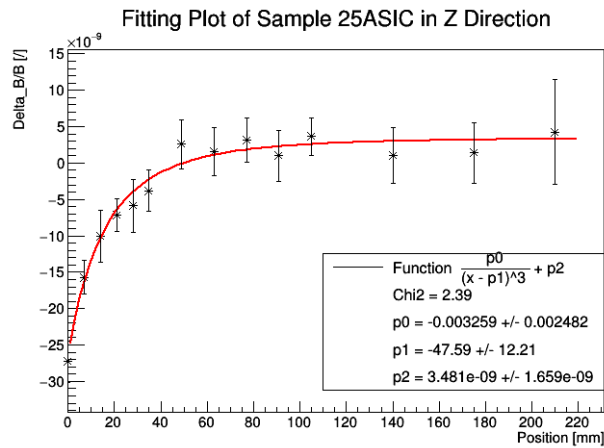


Figure 50: Fitting Plot of 25(5×5) ASIC in z Direction

### 3.8 Measuring Results for the Adhesive

The results of magnetic field measurement of adhesive of 2.753g in both x and z direction are shown in the figures below.

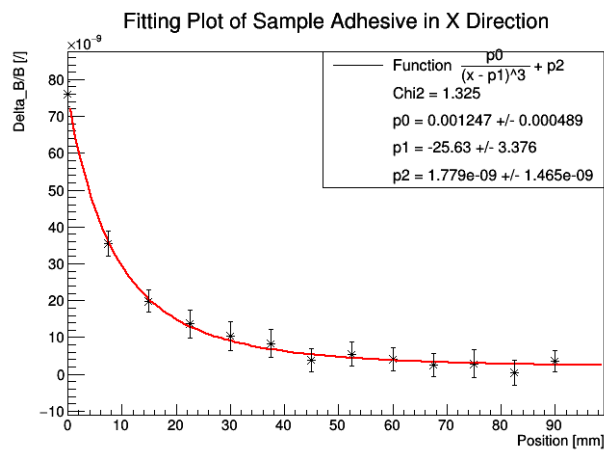


Figure 51: Fitting Plot of Adhesive in x Direction

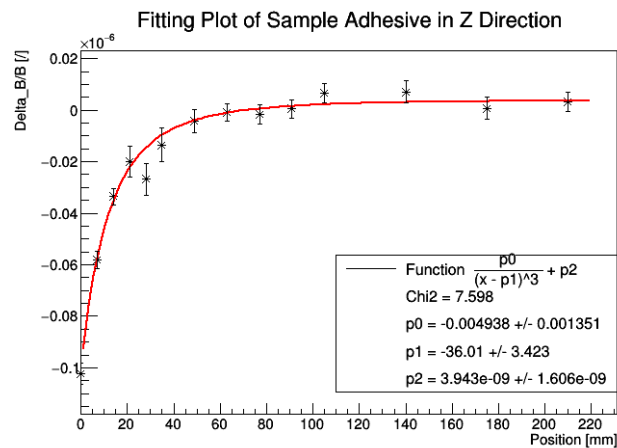


Figure 52: Fitting Plot of Adhesive in z Direction

### 3.9 Measuring Results for the Connectors

The results of magnetic field measurement of the connectors at different measuring position are shown in the figures below.

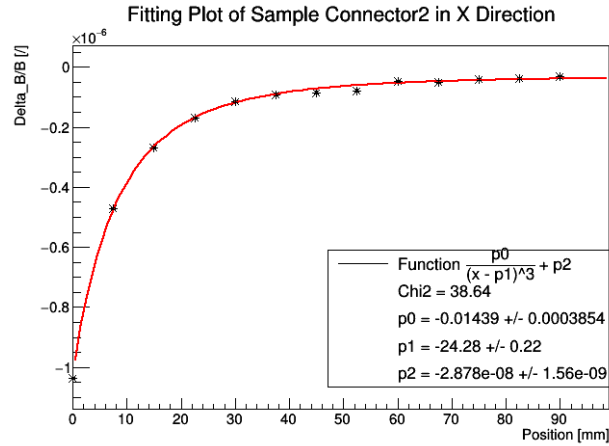


Figure 53: Fitting Plot of Connector XLS00-30 at Position Common in x Direction

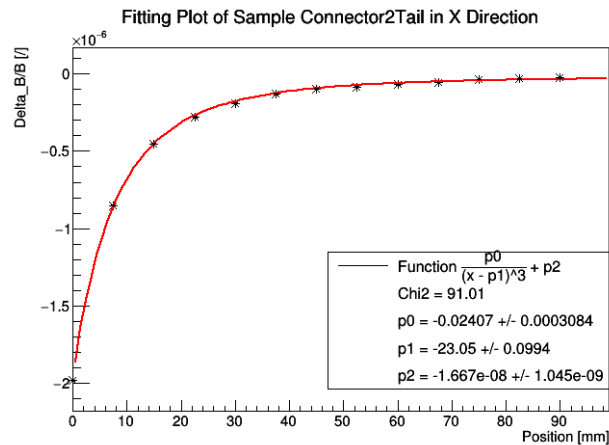


Figure 54: Fitting Plot of Connector XLS00-30 at Position Tail in x Direction

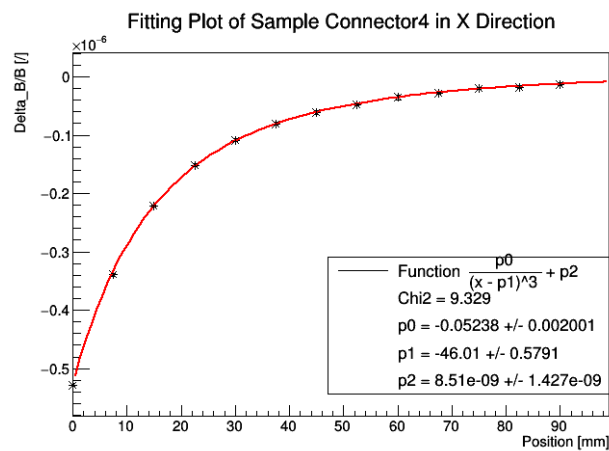


Figure 55: Fitting Plot of Connector XSL00-48L at Position Common in x Direction

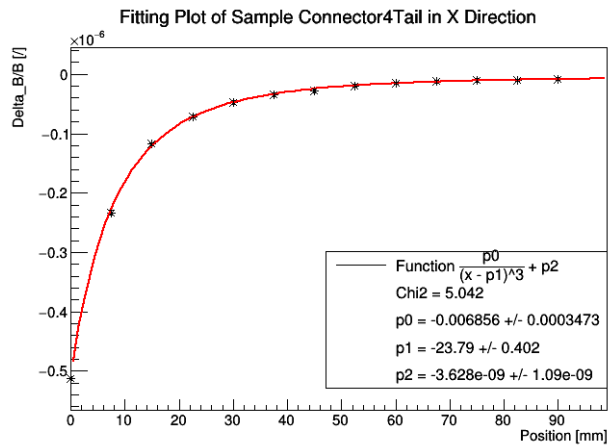


Figure 56: Fitting Plot of Connector XSL00-48L at Position Tail in x Direction

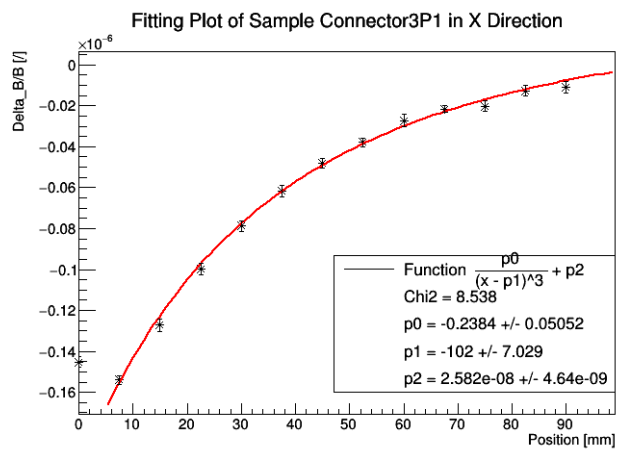


Figure 57: Fitting Plot of Connector SL0X-30L3-XXXX at Position P1 in x Direction

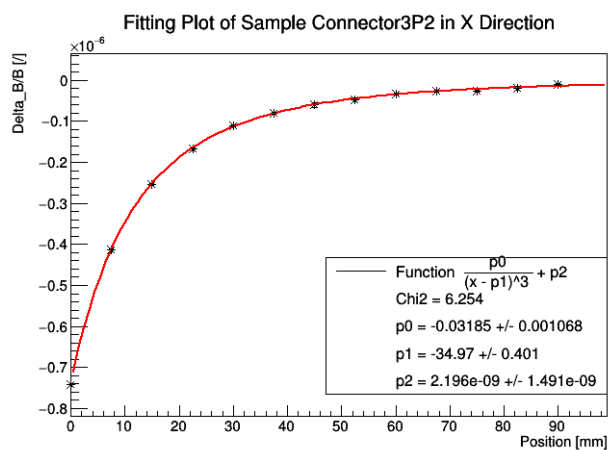


Figure 58: Fitting Plot of Connector SL0X-30L3-XXXX at Position P2 in x Direction

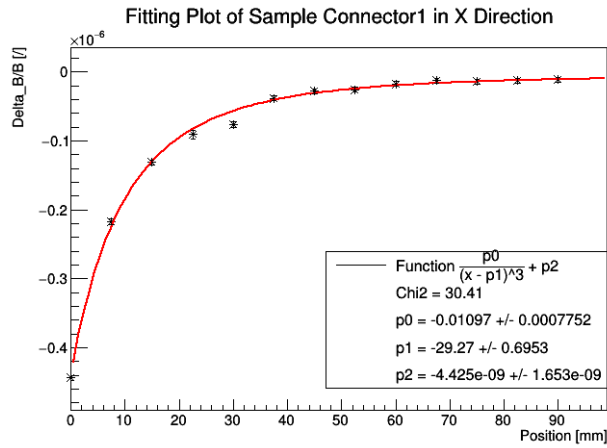


Figure 59: Fitting Plot of Connector USLS00-30 in x Direction

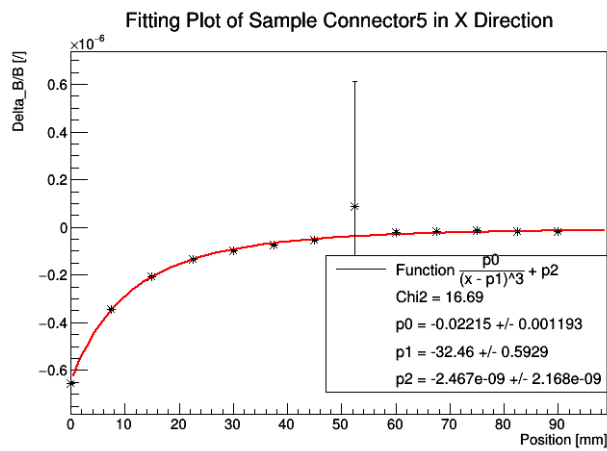


Figure 60: Fitting Plot of Connector USL00-40L-X in x Direction

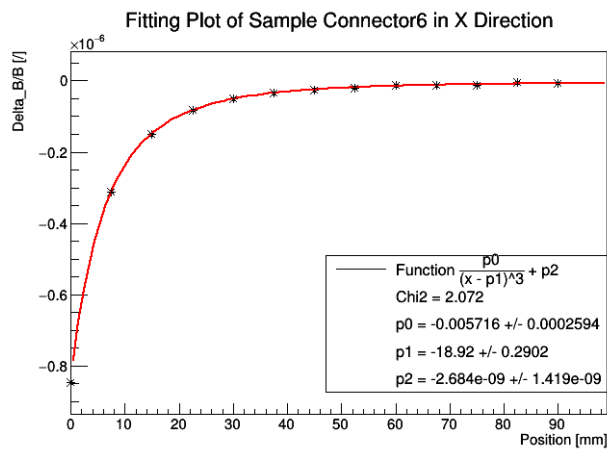


Figure 61: Fitting Plot of The Connector without Circuit Board in x Direction

## 4 Discussion

The results in this study is mainly raw data from the measurement. Further study is necessary in order to estimate the total effect of the detector.

As the deviation of the magnetic field is around several ten ppb, there is relatively poor accuracy of the points far from the sample. However, the effect of the close points to a certain component is dominant in the final calculation.

## **Acknowledgement**

The author would like to show his gratitude to Sasaki-san for the guidance and the support of the experiment, Yamanaka-san, Sato-san, Yamaguchi-san and Woodo for the help through the experiment and everyone in the muon g-2 experiment for the support at any needed time.

## **Reference**

Temporarily, there is no reference for this note.