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Field Measurements of the CANREB Nier Dipole

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1 Introduction

The CANREB NIer-Spectrometer (NIS) consists of a magnetic and electric dipole. It is designed for an achromatic mode of operation that allows for high resolution mass spectroscopy of beams with high energy dispersion[1]. For design note see reference [2].

In preparation for the instalment of the NIS in the new ARIEL building, some preliminary measurements were performed. This report includes measurements of the deviation from linearity of the magnetic field, the electric resistance of the instrument, and the field stability at 140 A.

1.1 Abbreviations

- **ARIEL:** Advanced Rare IsotopE Laboratory
- **CANREB:** CANadian Rare isotope facility with Electron Beam ion source
- **EBIS:** Electron Beam Ion Source
- **NIS:** NIer-Spectrometer

2 Measurements

Measurements of the magnetic field and temperature were performed with a hall probe instrument (figure 9). The hall probe is located in the mid plane of the dipole, 438.809 mm from the centre of curvature of the beam. The hall probe arm is 75.346 mm in length. See figures 10 and 11 for hall probe position inside the magnet. Data was recorded using epics control software.

DANFYSIK Dipole Magnet (figure 8) specifications are shown in table 1.

2.1 Magnetic Field

In order to determine the magnetic field's non-linearity, measurements of the field were taken at step intervals of 5 A-10 A starting from 0 A and going up to 140 A and 70 A. These measurements were only recorded after the field stabilized on a value. When time was not given to stabilize the field, the deviation from linearity was found to be much higher, sometimes above the specified 2 % for certain rate of current settings in the epics software.

The remanence field measured by the hall probe after cycling to 140 A was measured to be around 17 G. Comparatively, after degaussing the magnet, the remanence field was measured to be around -2.5 G.

Magnet No.	16503
Deflection angle	90°
Bending Radius	360 mm
Induction	0.57 T
Entrance Angle	22.5°
Exit Angle	22.5°
Effective length	565.5 mm
Pole Gap	60 mm
Nominal Voltage	35 V
Nominal current	147 A
Coil circuit resistance	0.230 Ω
Water flow rate	$10\,\mathrm{L\,s^{-1}}$
Pressure drop	4 bar
Temperature rise	7.5 °C
Total weight	1470 kg
Manufacturing year	2017

Table 1: Dipole magnet specifications

Plots of the magnetic field as a function of current are shown in figures 1 (140 A) and 3 (70 A). The parameters of the line of best fit of these two graphs are shown in table 2.

	slope	y-intercept
140A	39.82	1.91
70A	39.90	0.45

Table 2: Best fit line parameters

In both experimental measurements, the deviation from linearity at the maximum field remained below the specified value of 2 %[2], at 0.5 % for 140 A (figure 2) and 0.3 % for 70 A (figure 4).

2.2 Electrical Resistance

The design electric resistance of the circuit is expected to be from 0.2293 Ω to 0.2408 Ω.

With the exception of a couple of outliers, the electric resistance of the circuit is in well within the design parameters. It is noticeable, however, that the current reversal mechanism adds some extra resistance to the circuit. Plots of the electrical resistance as a function of current as shown in figures 5 (140 A) and 6 (70 A).

2.3 Field Stability

The magnetic field was recorded for one and half hours after current reached 140 A (figure 7)[1]. After reaching the desired current intensity, the largest variation from the average field was of around 0.1 G, or 0.002 %, well below the required stability of 2 G [2]. The field was even less variant from 15:24 to 16:00, varying by around 0.05 G, or 0.0009 % of the average.

At 16:14, air was forced to circulate through the space between the magnet dipoles in order to determine if changes in the temperature of the air around the magnet affected the magnetic field. A change of around 1 °C as measured by the hall probe, resulted in a negligible change in the magnetic field.

From 16:00 to 16:13, several people came in and out of the experimental area with steel toe shoes, which may explain some fluctuations in the magnetic field at this time. Further measurements are required to take any definitive conclusions.

3 Summary

The NIS magnet non-linear effects were determined to be around 0.5 % at 140 A, well below the design requirement 2 %. The electric resistance of the circuit was measured to be within the expected range of 0.2292 Ω-0.2408 Ω. It was noticed that the reversed current had an increase in resistance, but still within the acceptable range. The magnetic field was measured to vary by around 0.003 % at 140 A.

[1]Note that on graph no. 3, the magnetic field is measured by adding 5549 G to the value read off the y-axis. The magnetic field is not at 0.1 G to 0.4 G, but at 5549.1 G to 5549.4 G

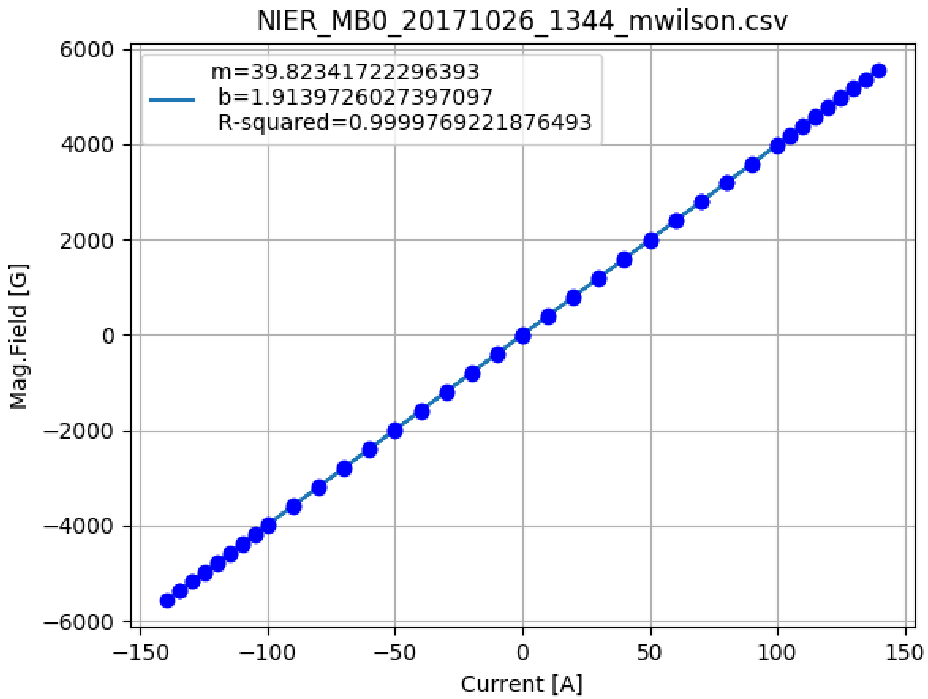

Figure 1: Magnetic field as a function of current up to 140 A

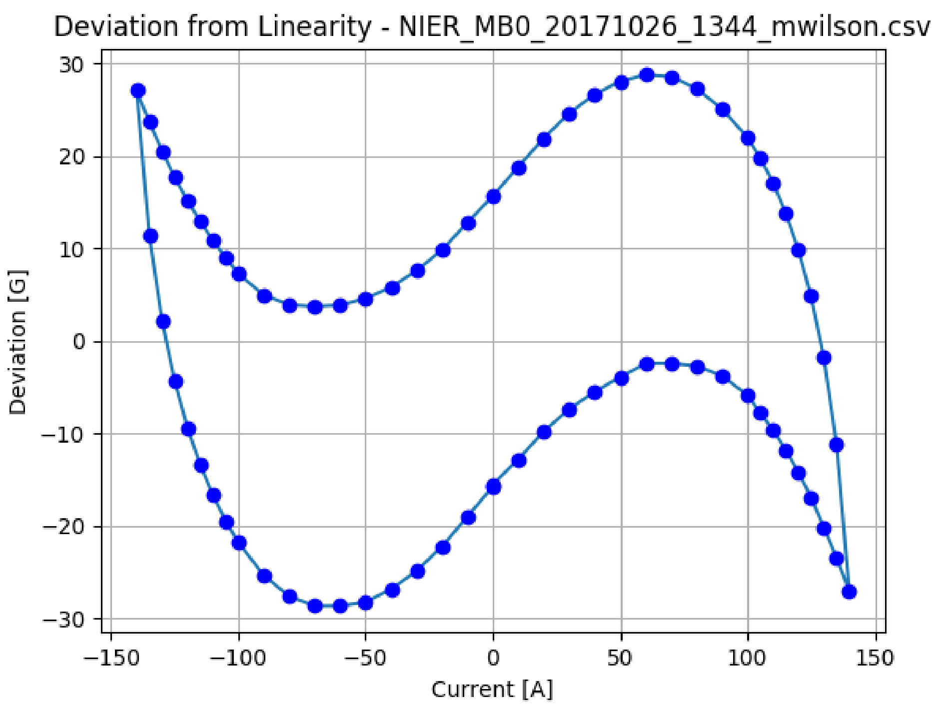

Figure 2: Deviation from linearity of magnetic field as a function of current up to 140 A

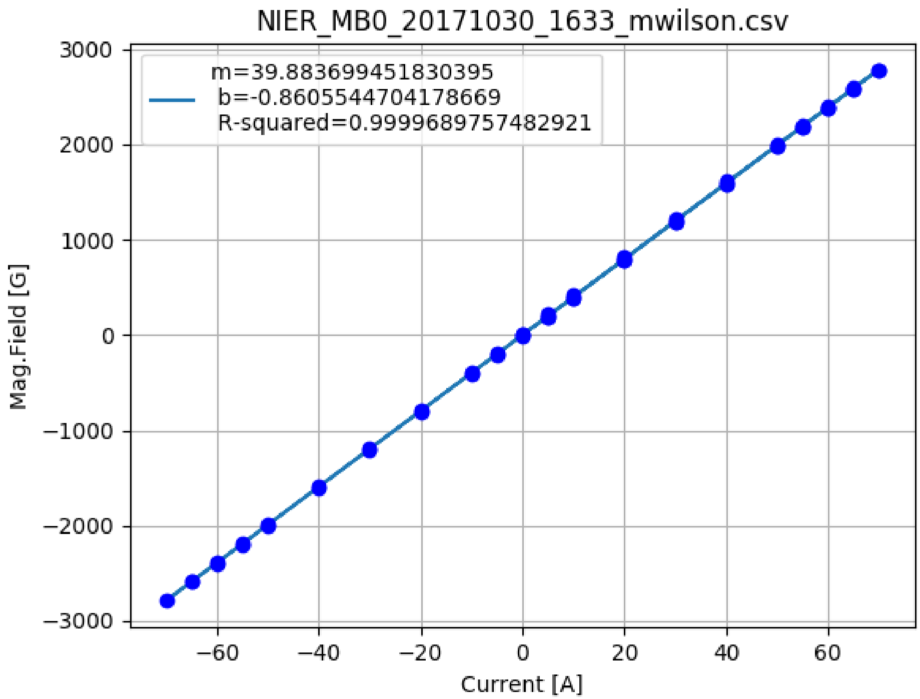

Figure 3: Magnetic field as a function of current up to 70 A

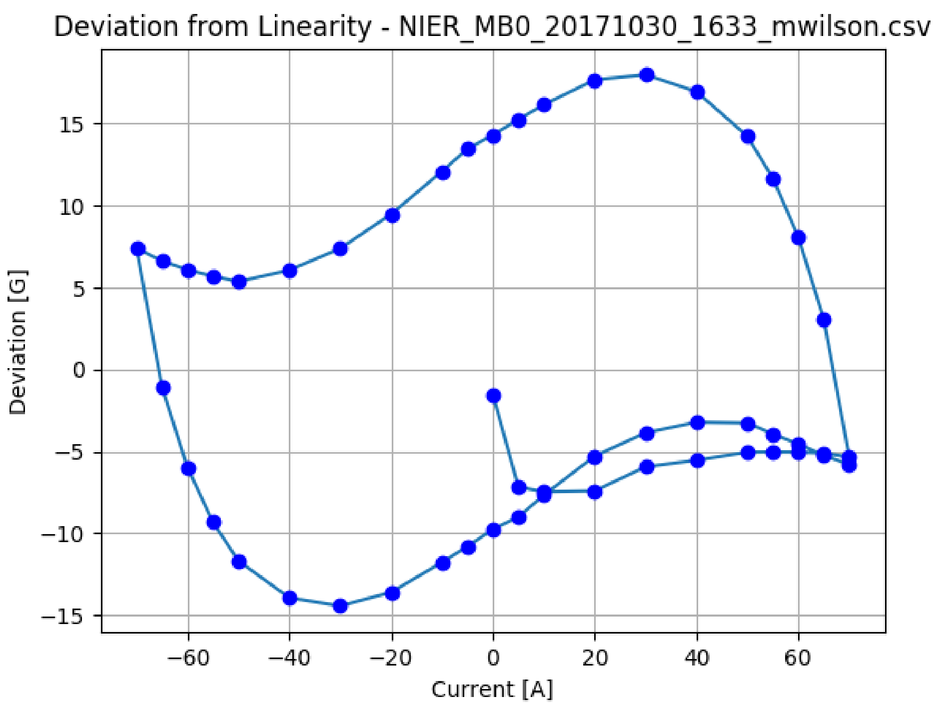

Figure 4: Deviation from linearity of magnetic field as a function of current up to 70 A

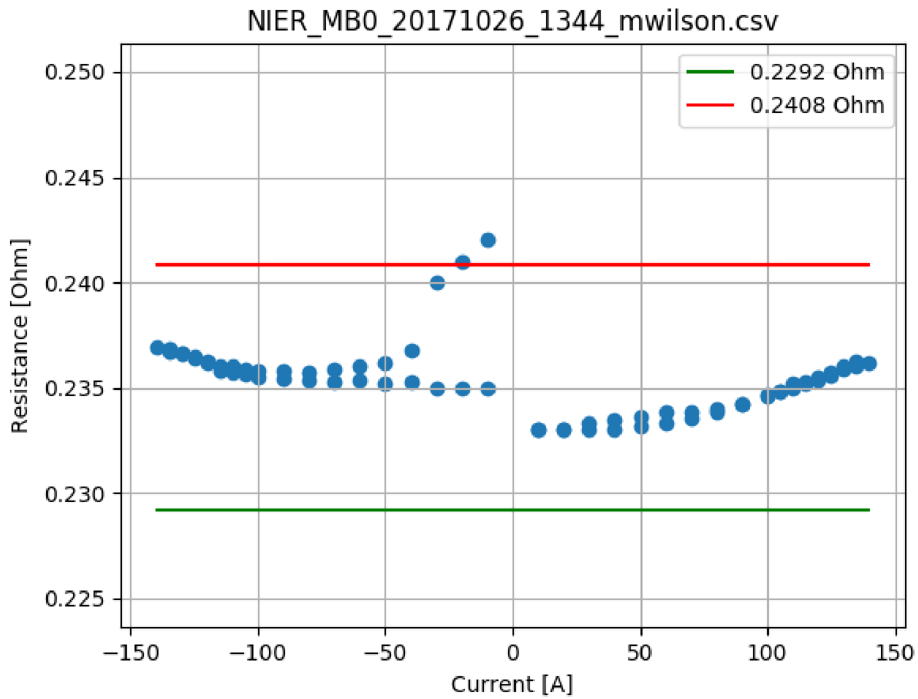

Figure 5: Electric resistance as a function of current up to 140 A

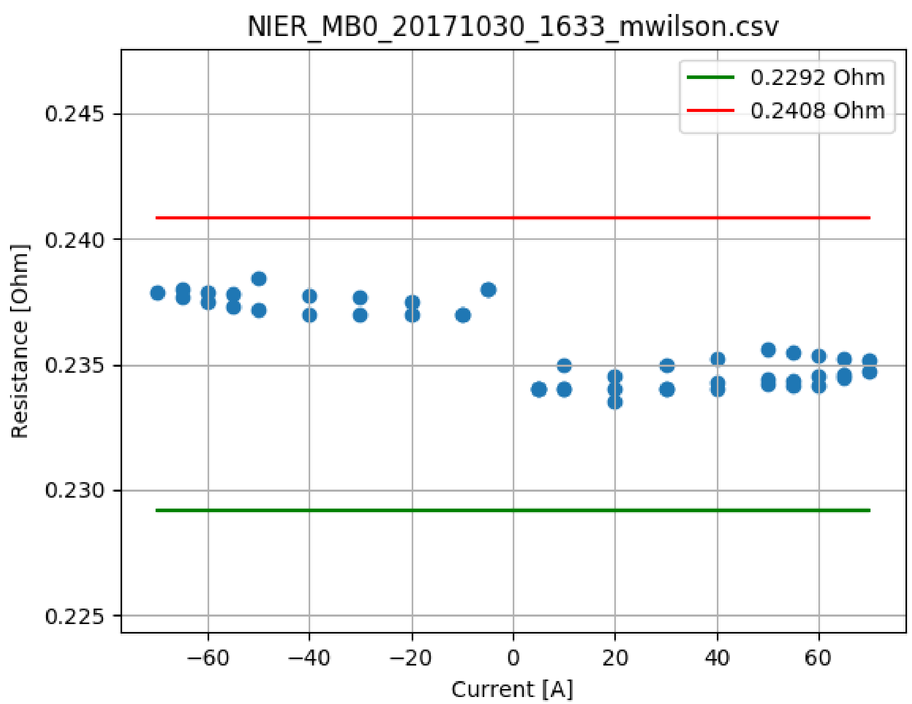

Figure 6: Electric resistance as a function of current up to 70 A

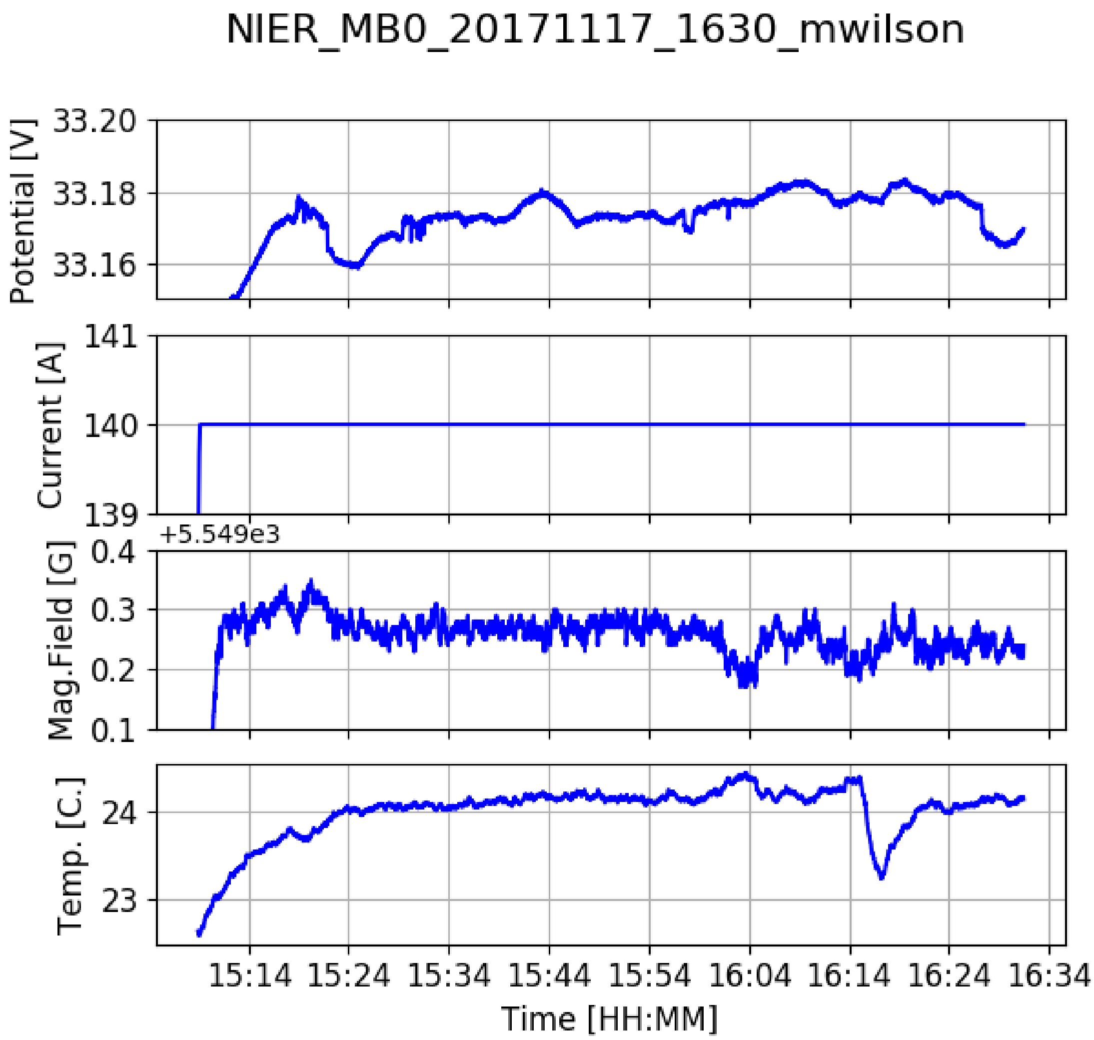

Figure 7: Magnetic Field Oscillations at 140 A

4 Appendix A - Images

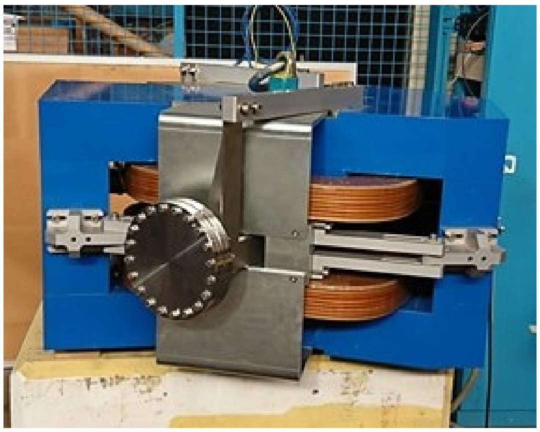

Figure 8: Nier dipole

Figure 9: Hall probe instrument with holder

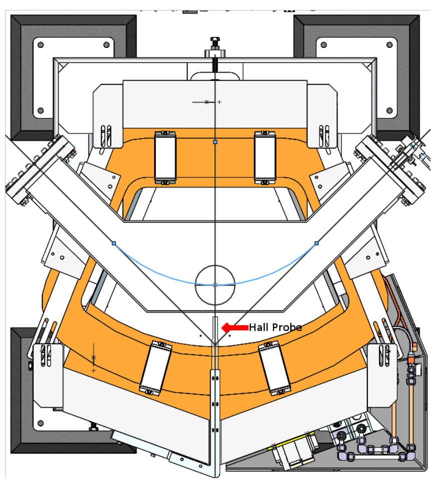

Figure 10: Hall probe position inside the dipole magnet (top view)

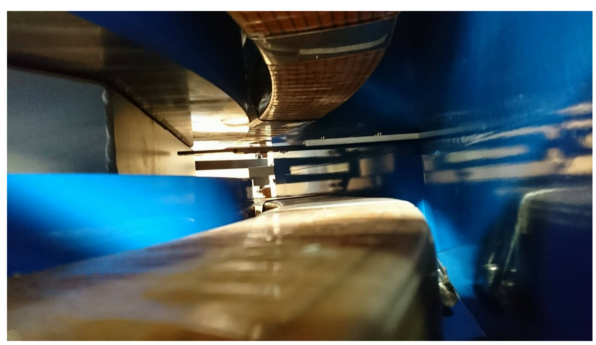

Figure 11: Hall probe positioning inside the dipole magnet (mid plane)

5 Appendix B - Data Files

All experiments are recorded with the following naming scheme:
NIER_MB0_YYYYMMDD_HHMM_signature

The table below presents all the experimental data recorded at the time of this report, with the initial purpose for the data acquisition and a file name.

File Name	Purpose/Notes
NIER_DIPOLE_MEASURE	Settings used for data collection
NIER_MB0_20171023_1606_mwilson	Test the power source. First recorded power up of NIS.
NIER_MB0_20171024_1507_mwilson	Power source and magnet response testing. Measure field non-linearity at 50 A and 100 A.
NIER_MB0_20171024_1623_mwilson	Measure field non-linearity at 140 A. Power source would not reach desired 140 A current.
NIER_MB0_20171025_1653_mwilson	Measure field non-linearity at 100 A.
NIER_MB0_20171026_1206_mwilson	140 A cycle up and down. Measurements for field non-linearity up to 140 A (incomplete).
NIER_MB0_20171026_1348_mwilson	140 A cycle up and down. Measurements for field non-linearity up to 140 A (complete)[2].
NIER_MB0_20171026_1440_mwilson	50 A measurements for field non-linearity. Smallest possible rate of current ($0.1\,\mathrm{A\,s^{-1}}$).
NIER_MB0_20171026_1515_mwilson	Testing resolution of hall probe and power-supply.
NIER_MB0_20171027_1140_mwilson	Degauss of magnet. Max 140 A, $1.0\,\mathrm{A\,s^{-1}}$ rate of current.
NIER_MB0_20171027_1224_mwilson	70 A measurements for field non-linearity. $0.2\,\mathrm{A\,s^{-1}}$ rate of current. Hall probe scan frequency changed to 5 Hz[3].
NIER_MB0_20171027_1403_mwilson	30 min stability test at 140 A.
NIER_MB0_20171027_1611_mwilson	Magnet degaussing. 70 A measurements for field non-linearity[4].
NIER_MB0_20171030_1633_mwilson	Magnet degaussing. 70 A measurements for field non-linearity[5].
NIER_MB0_20171117_1630_mwilson	Field stability measurements at 140 A

References

[1] S. Saminathan, and R. Baartman, *Low Energy Beam Transport line for the CANREB Charge State Breeder* TRI-DN-15-06, Internal report, TRIUMF, Apr., 2017

[2] S. Saminathan, *Dipole magnet requirements for Nier-spectrometer* TRI-DN-15-09, Internal report, TRIUMF, Jan., 2015

[2]Measurements taken after the field stabilized. Unless specified, this was not the case.
[3]All previous data was recorded with hall probe scan frequency at 0.2 Hz.
[4]Measurements taken after the field stabilized.
[5]Measurements taken after the field stabilized.