Experimental Physics: Magnetic Field Measurements & Maps

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Summer 2011

Overview

- Presenter Bio
- Motivation & Goals
- GMW Calibration Magnet Field Mapping
- Hall Probe Calibrations
- Tevatron Dipole Field Map

Presenter Bio

Toni Aubrecht – Age 22 – Hometown: Los Angeles, CA

Recent graduate of the **University of Southern California**

Bachelor of Science in Astronautical Engineering with an emphasis in physics

Member of both the Society of Physics Students and the American Institute of Aeronautics and Astronautics

Became interested in particle physics while taking two semesters of quantum physics.

No current graduate school plans, but wish to obtain a Ph.D. in experimental particle physics in the future (begin ~2 years from now)

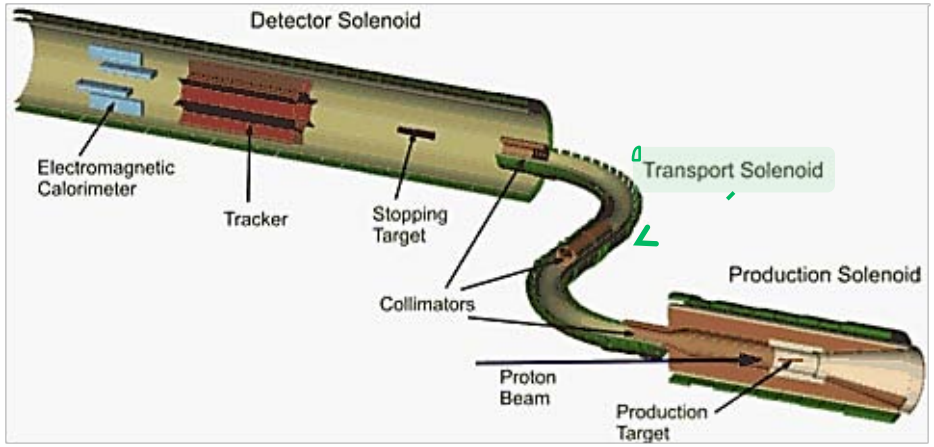
Other interests include:
Snowboarding, reading, street art, marching band, USC football, piano, sketching, exploring Los Angeles, my cat Alia

Mu2e

Experimental Motivation

Project Motivation

Muon-to-Electron Conversion Experiment (Mu2e)



Direct conversion of a muon to an electron with no neutrinos

Transport Solenoid:

Transport the muons created in the production solenoid to the detector solenoid.
Has specific magnetic field requirements to reduce backgrounds and ensure the experiment runs as proposed.

- How do you measure the actual magnetic fields and how accurate & precise do you have to be?

CMS Fieldmapper Description

Fieldmapper is designed and fabricated at Fermilab.

Slide from: https://edms.cern.ch/document/879493/1

- Nonmetallic/nonmagnetic materials
- Linear Bearings on Al Rails
- Pneumatic (N_2 cylinder) Power
- Gas flow controlled with 24-V piezoelectric valves
- Rotary Air Motors and Gas Cylinders
- ΔZ-steps (= 5 cm) fixed by tensioned toothed Kevlar belt
- ΔR = 408 mm (starts @ R = 92, ends @ R = 1724 mm)
- NIKHEF Hall Sensors, CERN calibrated to 4.5 T
- Commercial NMR sensors @ R = 0, R = 1724
- Remote operation via PLC and operator's LabVIEW console
- Laser ranger for absolute Z reference after unscheduled stop

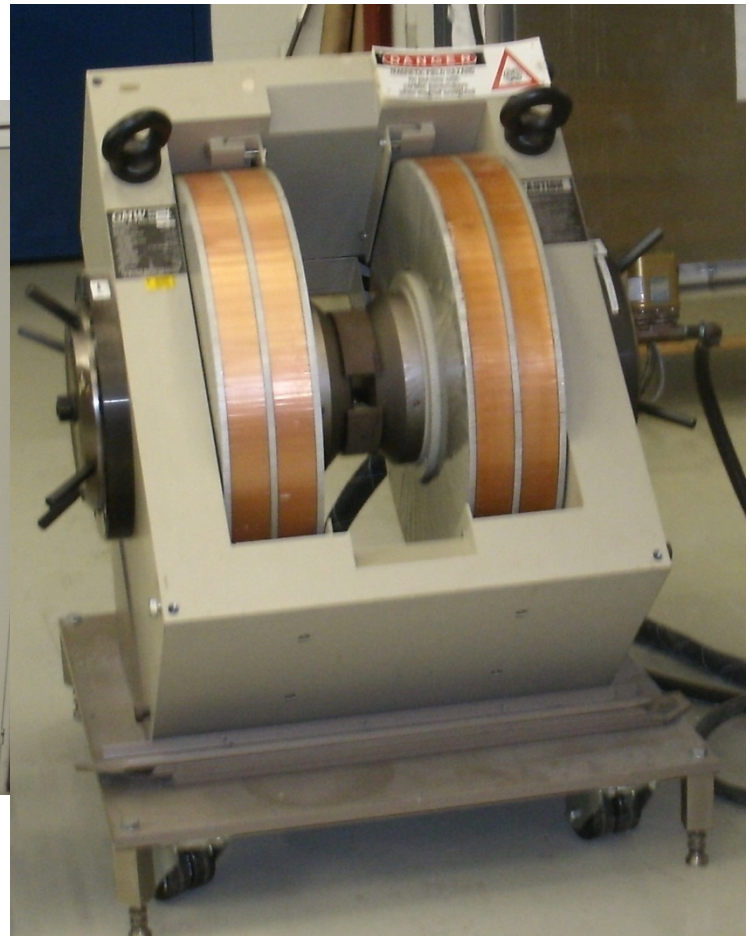
Summer Project Goals

- Research/understand the proposed magnet system design for the Mu2e project and the proposed plan to map its field.
- Map the field of the GMW calibration magnet.
- Create LabVIEW programs to automate procedures and allow computer control of all instruments & devices.
- Test the calibrations and performance of various Hall probes, both 1D and 3D.
- Check the sensitivity of the 3D Hall probes that may be used for Mu2e by using a Tevatron dipole magnet.
- Map the field of a helical solenoid magnet.

MAGNETIC FIELD MAPPING

Improving our understanding of the magnet

GMW Dipole Calibration Magnet

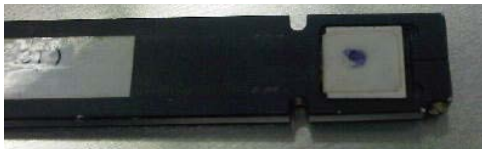


Location: IB1
Last Field Map: 1993 (but coils changed since then)
Field Range: 0–2.5 T

Mapping the Field

Probe Choice: 1D Hall, 0–3 T range (#001047)

- Allowed us to ramp the magnet up to 200 A (max of 2.5 T) without having to change the probe during testing.
- 3D probes had not yet been calibrated.



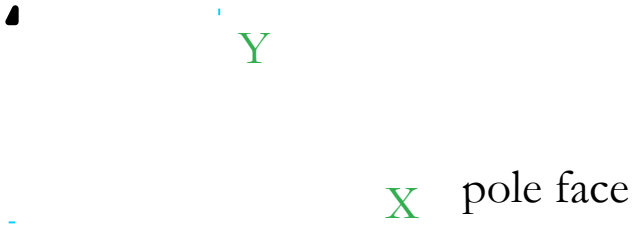
Magnet Current: 0–200 A, every 40 A

- Only took data while ramping up to avoid hysteresis

Map Diagram: ±75 mm, every 5 mm in both x and y

- Measured in the center of the gap.
- Allowed for a fine enough resolution of the field without exceeding the limit of the probe.

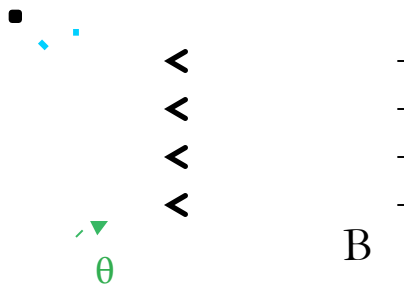
Gap Distances: 20, 30, 40, 50, 60, 80, 100, 150 mm



Possible Errors/Uncertainties

Magnet Current:

- Readout resolution is 1 amp.
- Sometimes fluctuated even when the setting wasn't change
- Wouldn't always "lock on" to certain values.



Center Position:

- Tried to center the probe every morning and afternoon by using assumed symmetry of the field.
- Most likely uncertainty: ± 2 mm

Probe Alignment

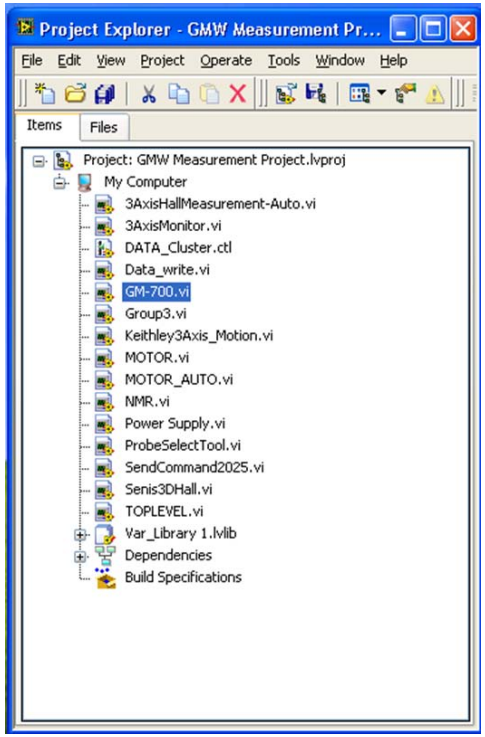
- Set magnet at an arbitrary field and turned the probe until it read at maximum.
- Assumed this position to be vertical.
- Whereas it was easy to adjust the "roll" of our probe, the side-to-side angle was difficult to adjust because the probe was attached to the heavy motor control system.
- However, later it was confirmed by the 3-axis probe that this small loss was not significant.

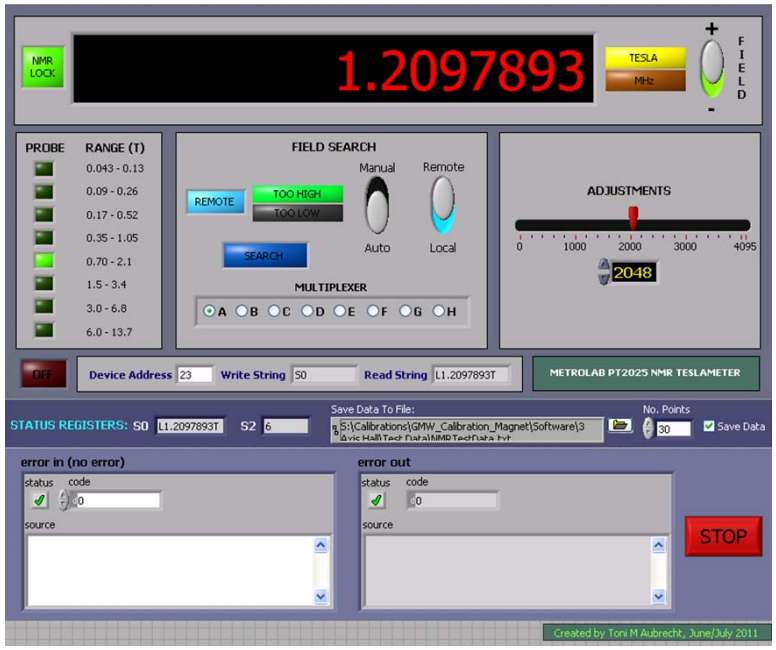
LabVIEW

Operated from the computer via LabVIEW 10:

- 2-axis motor control
- Magnet power supply
- ALL probe readouts (NMR, Hall, Cryo)

Data was then saved in the form of XML or TXT files.





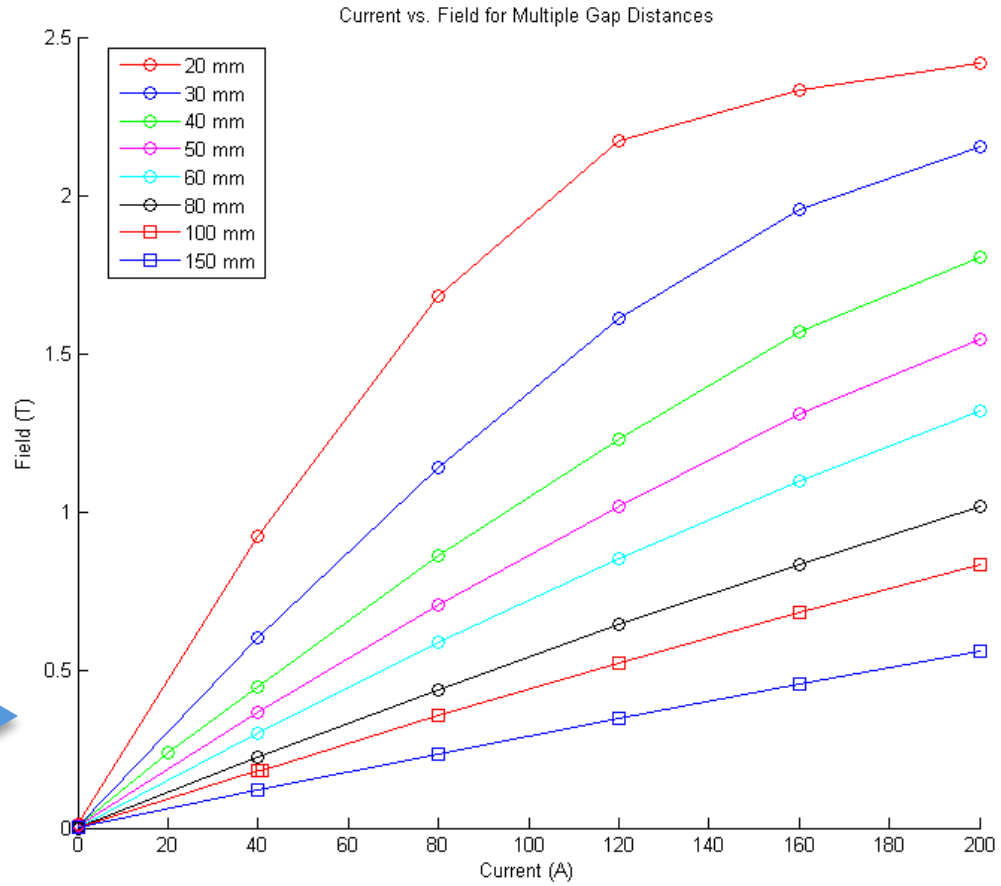
Example LabVIEW VI:
NMR - MetroLab PT 2025

Results

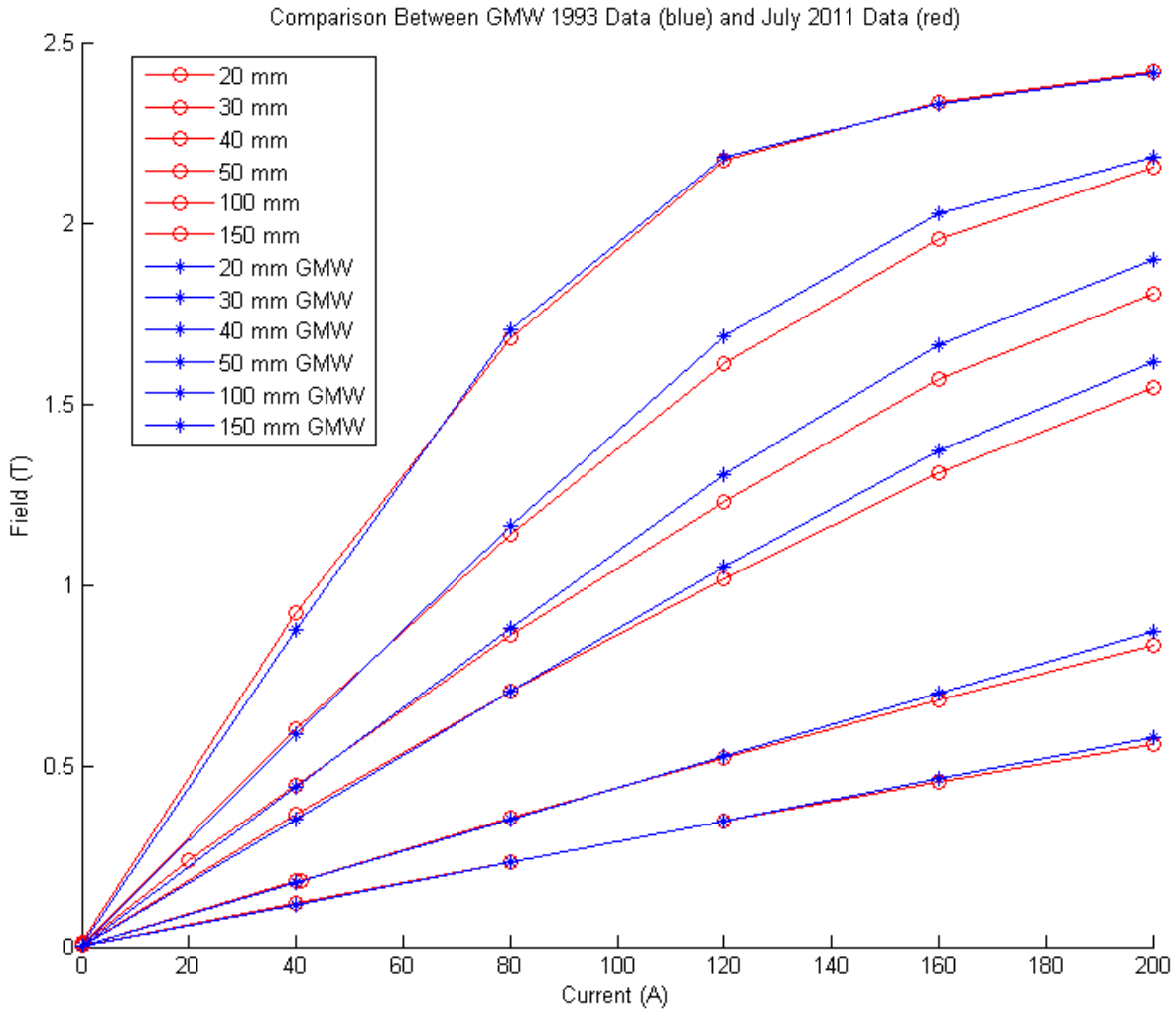
S:\Calibrations\GMW_Calibration_Magnet\Software\GMW Mapping Data

- XML Data Files
- MATLAB script (for plotting and future analysis)
- Imported data sets in *.mat files (for use in MATLAB or easy export to Excel).

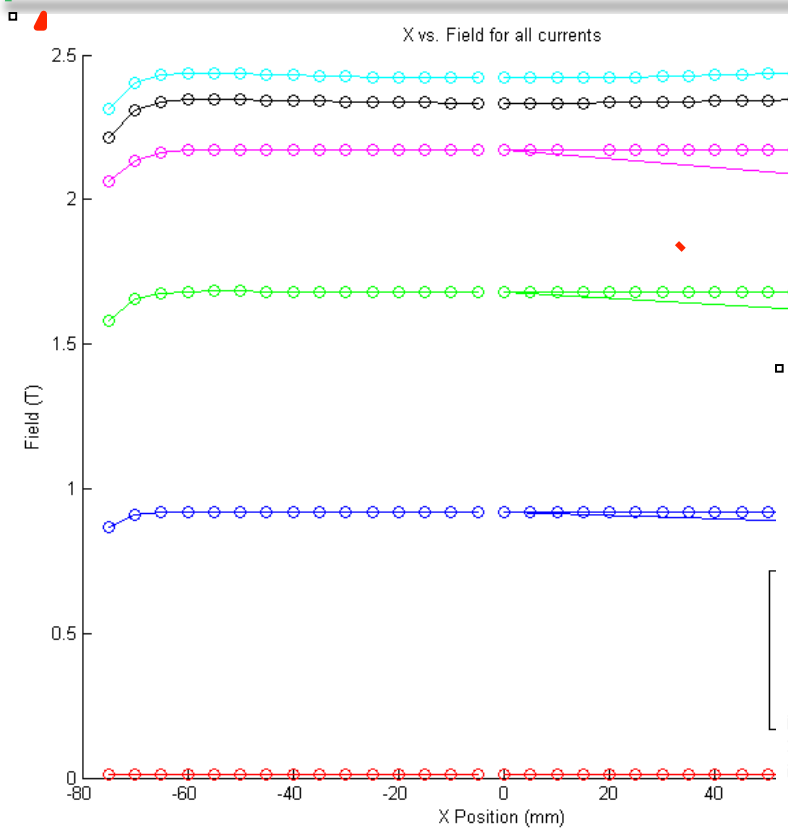
Data shown at (x,y) = (0,0) only!



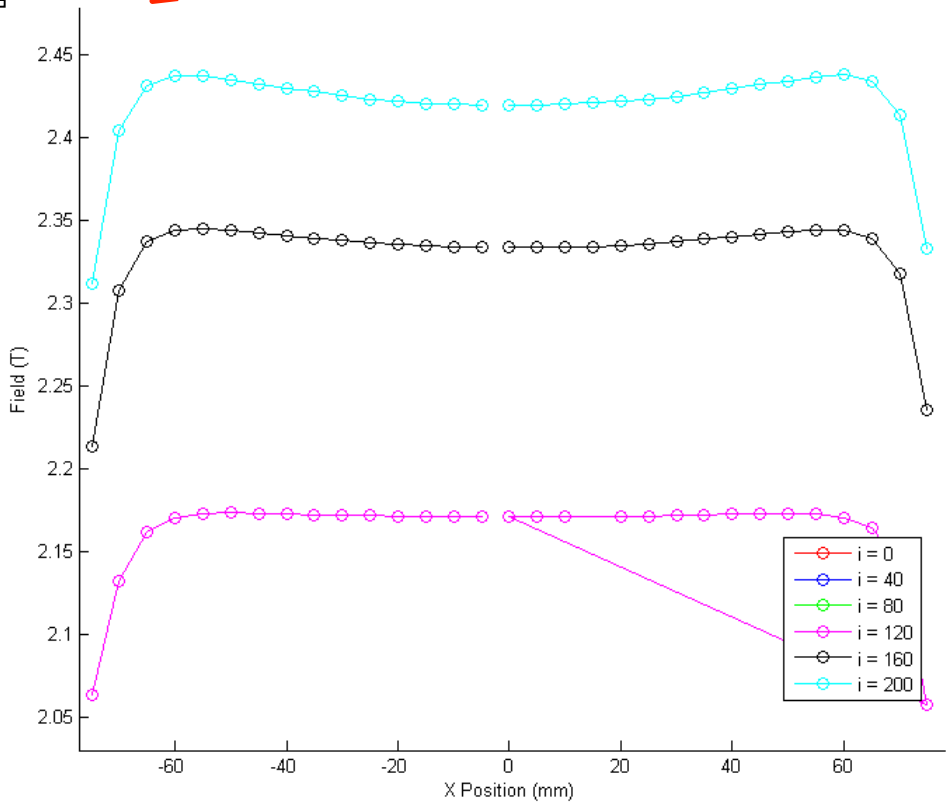
Results


Comparison Between GMW 1993 Data (blue) and July 2011 Data (red)
20 mm
30 mm
40 mm
50 mm
100 mm
150 mm
20 mm GMW
30 mm GMW
40 mm GMW
50 mm GMW
100 mm GMW
150 mm GMW
Field (T)
Current (A)
0
0.5
1
1.5
2
2.5
0
20
40
60
80
100
120
140
160
180
200

Anomalies



20 mm gap



HALL PROBE CALIBRATIONS

Verifying the accuracy of our measurement tools

Calibrations

Goal: Check the readings of various Hall probes to ensure they match the field measured by the NMR probe (assumed to be correct).

All Data:
S:\Calibrations\GMW_Calibration_Magnet\Software\3 Axis Hall

All LabVIEW programs:
S:\Calibrations\GMW_Calibration_Magnet\Software\3 Axis Hall\TEMPLATE

- All calibrations performed at a gap distance of 40 mm. This ensured the field was uniform within a circle of radius = 20 mm, allowing a higher tolerance in probe placement.

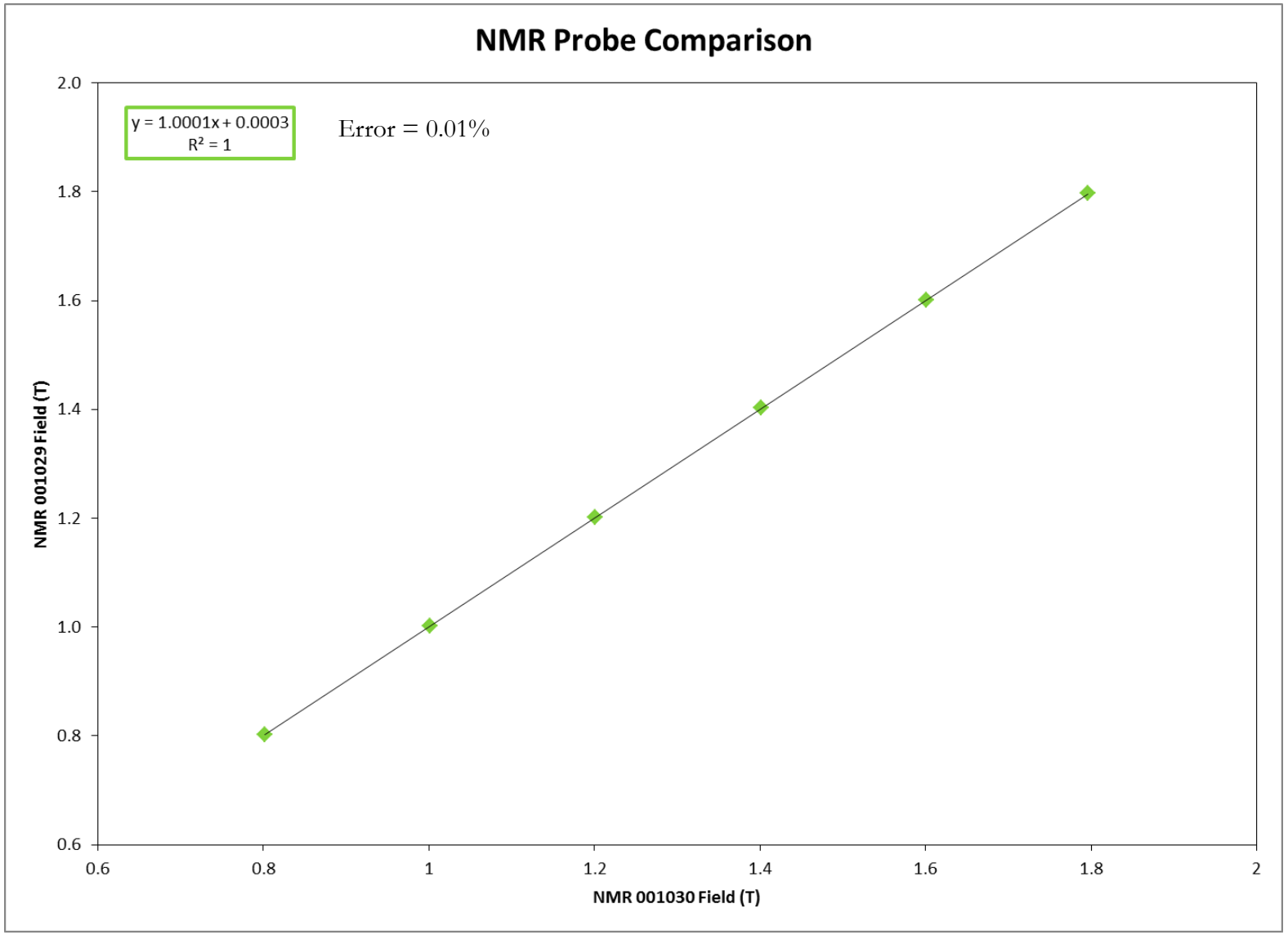
Probes

- 3- 1D Hall
  - Barcode #: 001047, 000829, 000808
  - 0–3 T range
  - DTM-151
- 1- Cryogenic Hall
  - GM 700
- 2- NMR
  - Barcode #: 001030, 001029
  - 0.7–2.1 T range (5)
  - PT 2025
- 2- 3D Hall (Senis GmbH)
  - Serial #: 5406, 058-11(new)
  - 0–10 T range
  - DSA card, Keithley 2700 multiplexer

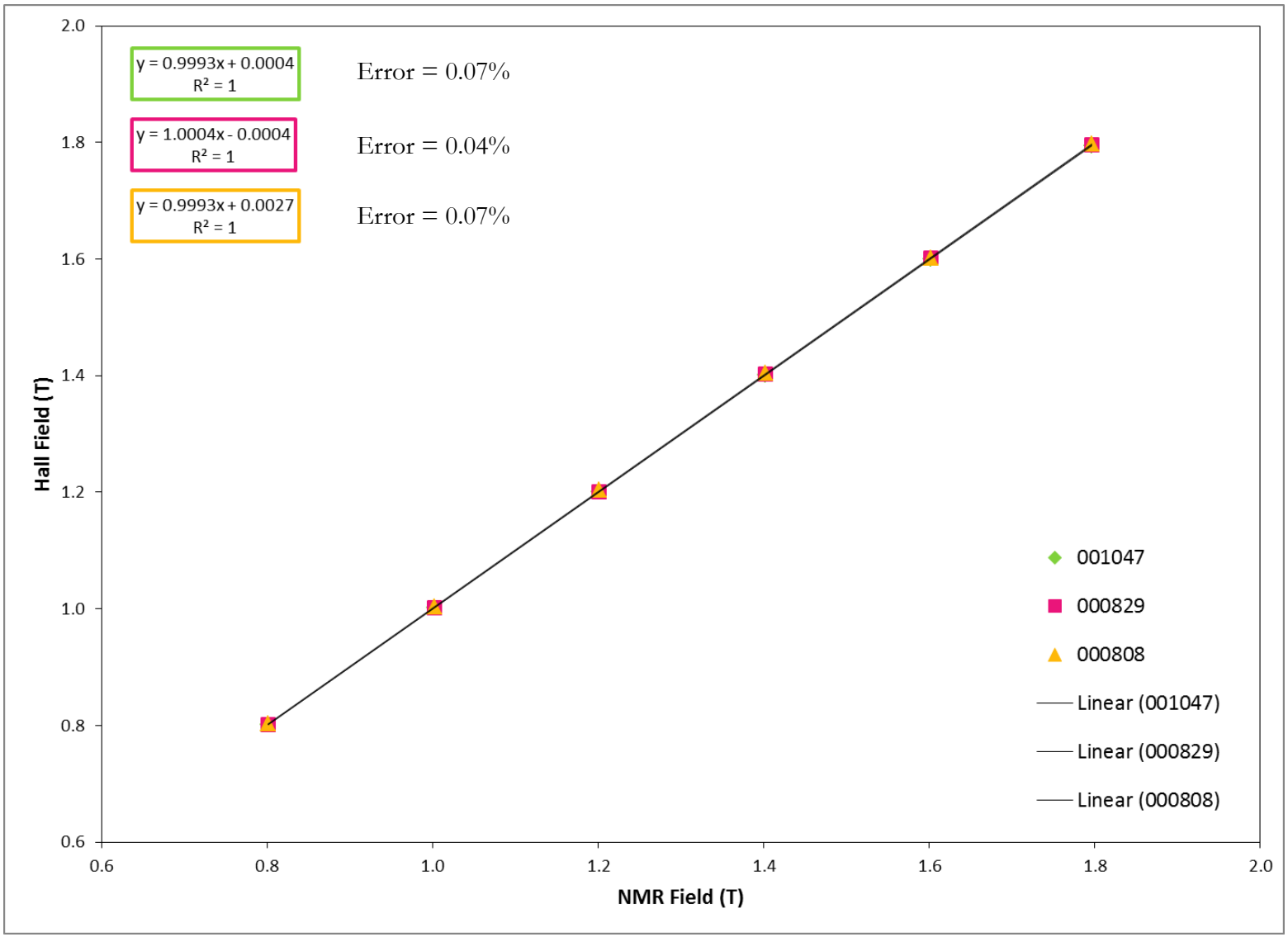
Basic Experiment

- Took data on multiple days with the NMR to provide a standard baseline at fields near 0.8, 1.0, 1.2, 1.4, 1.6, and 1.8 T.
- GMW magnet was controlled through a LabVIEW VI and set at the same number of "counts" each time.
- Data always taken on the ramp upwards to avoid hysteresis
- Raised current, waited for the field to "settle," took 15+ data points, averaged over the points, and compared to the NMR.
- Two full run-throughs of range to ensure repeatability and create a better average
- Always used a field around 1 T to align probe perpendicular to field by turning until maximum readout achieved.

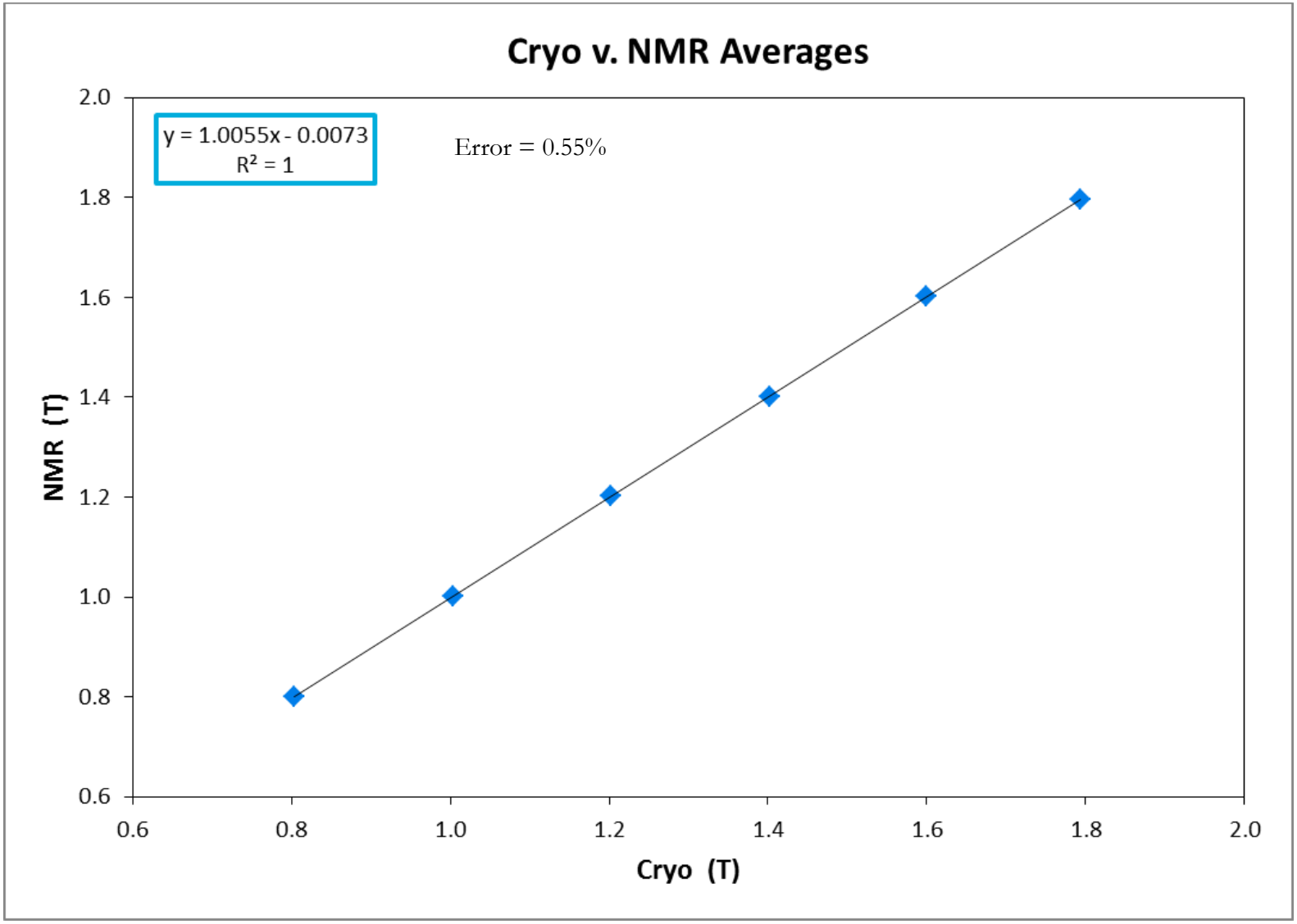
NMR Results


NMR Probe Comparison
y = 1.0001x + 0.0003
R² = 1
Error = 0.01%
NMR 001029 Field (T)
NMR 001030 Field (T)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.6
0.8
1
1.2
1.4
1.6
1.8
2

1D Hall Results



Cryogenic Hall Results



3D Hall Probe

- Only looked at Bx, By
- DSA card v. Keithley multiplexing noltmeter
- 3 m cable splice
- Different power sources
- Temperature dependence
- Two probes: Senis 5406 & 058-11(new)

3D Hall Probe Test Order

DSA Card:

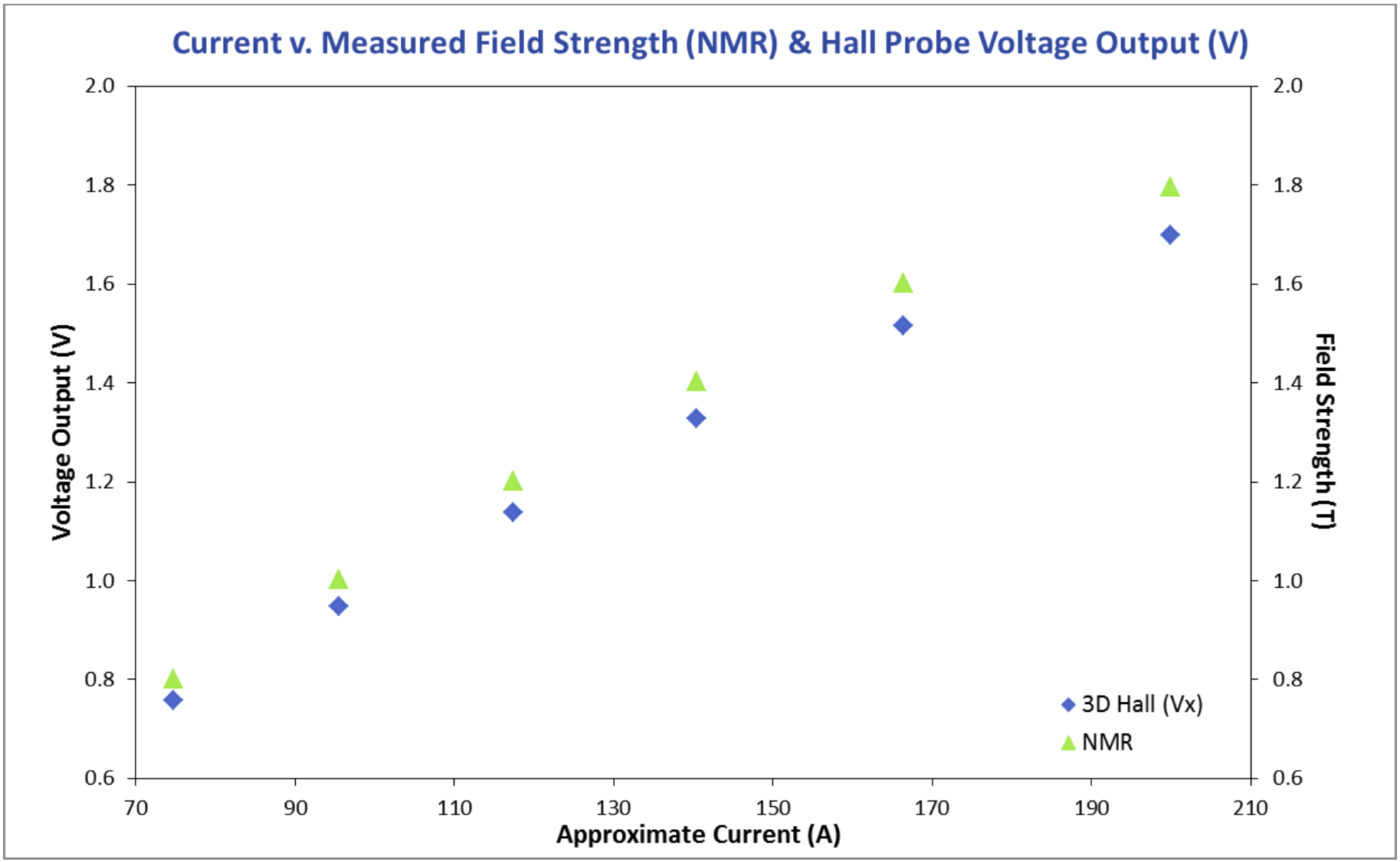
1. Bx/By with 'makeshift' power source
2. By with manufacturer's power source
3. Bx/By after 3 m cable spliced in
4. Bx/By after splice is redone

Keithley 2700 Multiplexing Voltmeter:

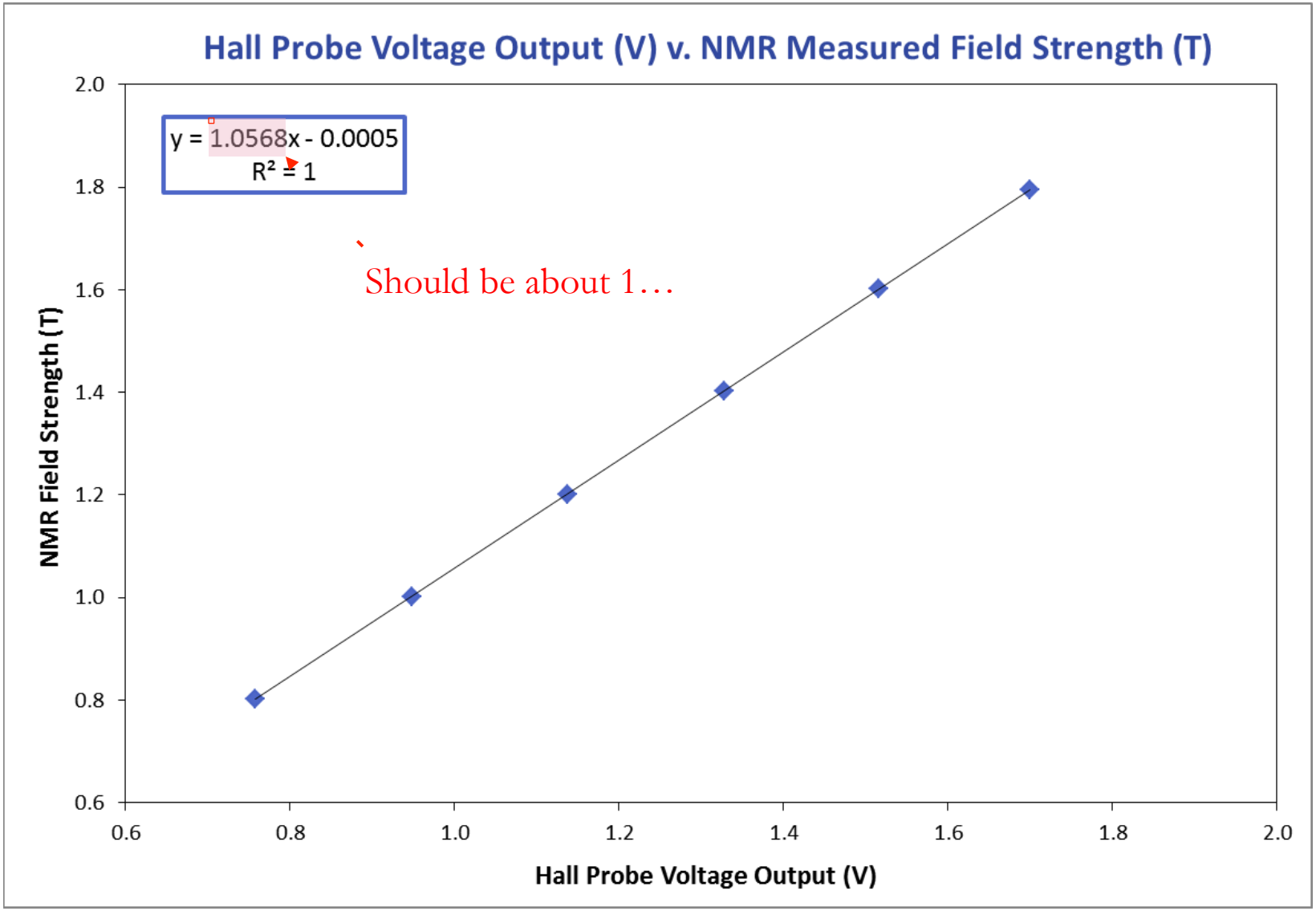
5. Bx/By (twice) to see the effect of a different method of digitally obtaining the readout
6. By temperature dependence
7. Bx/By for 2nd Hall probe (S/N 058-11)

Expect 1-1 relationship for 1st probe (5406) and 5-1 relationship for 2nd probe (058-11).

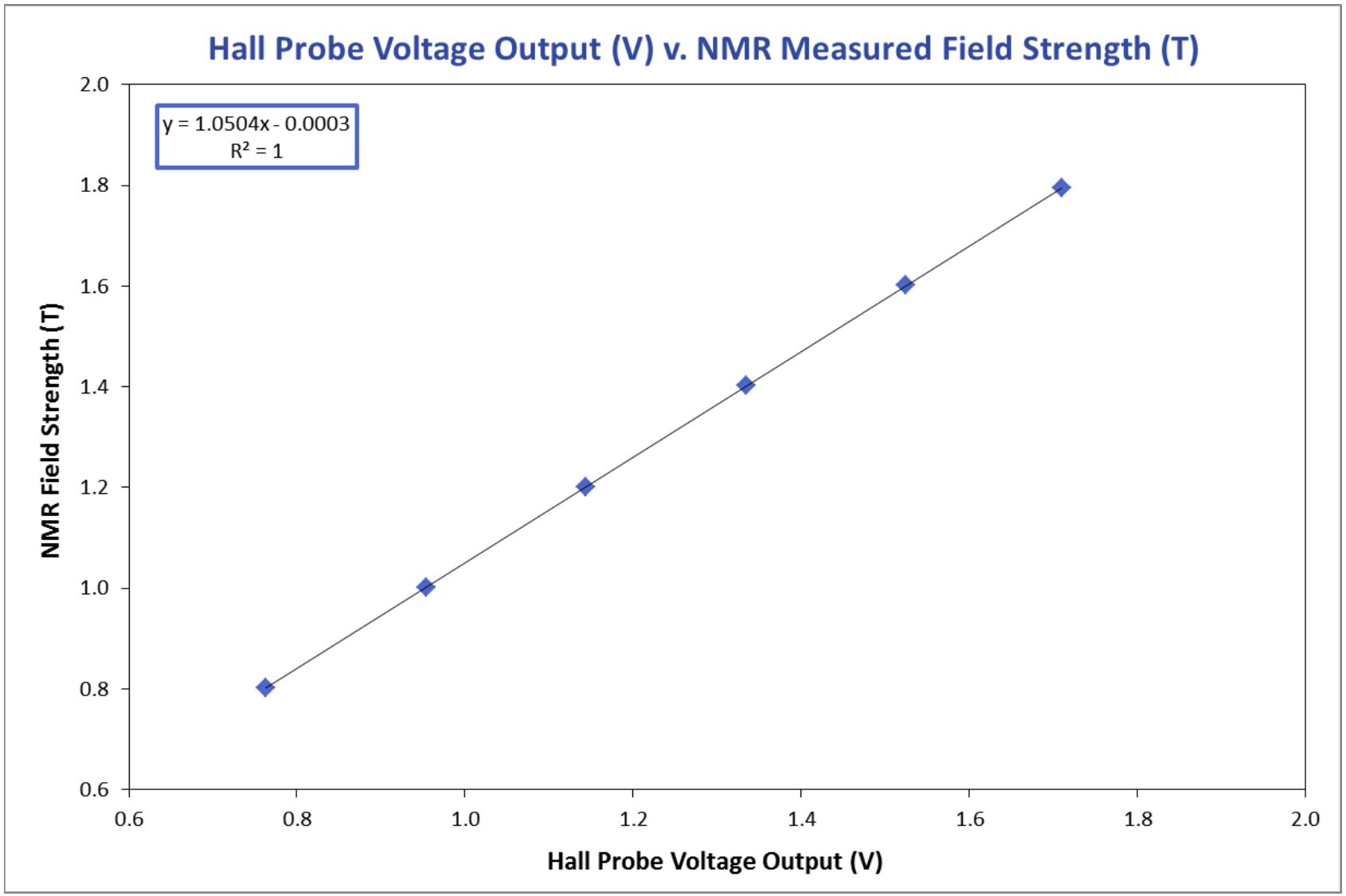
Test 1


Current v. Measured Field Strength (NMR) & Hall Probe Voltage Output (V)
Voltage Output (V)
Field Strength (T)
Approximate Current (A)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
70
90
110
130
150
170
190
210
3D Hall (Vx)
NMR

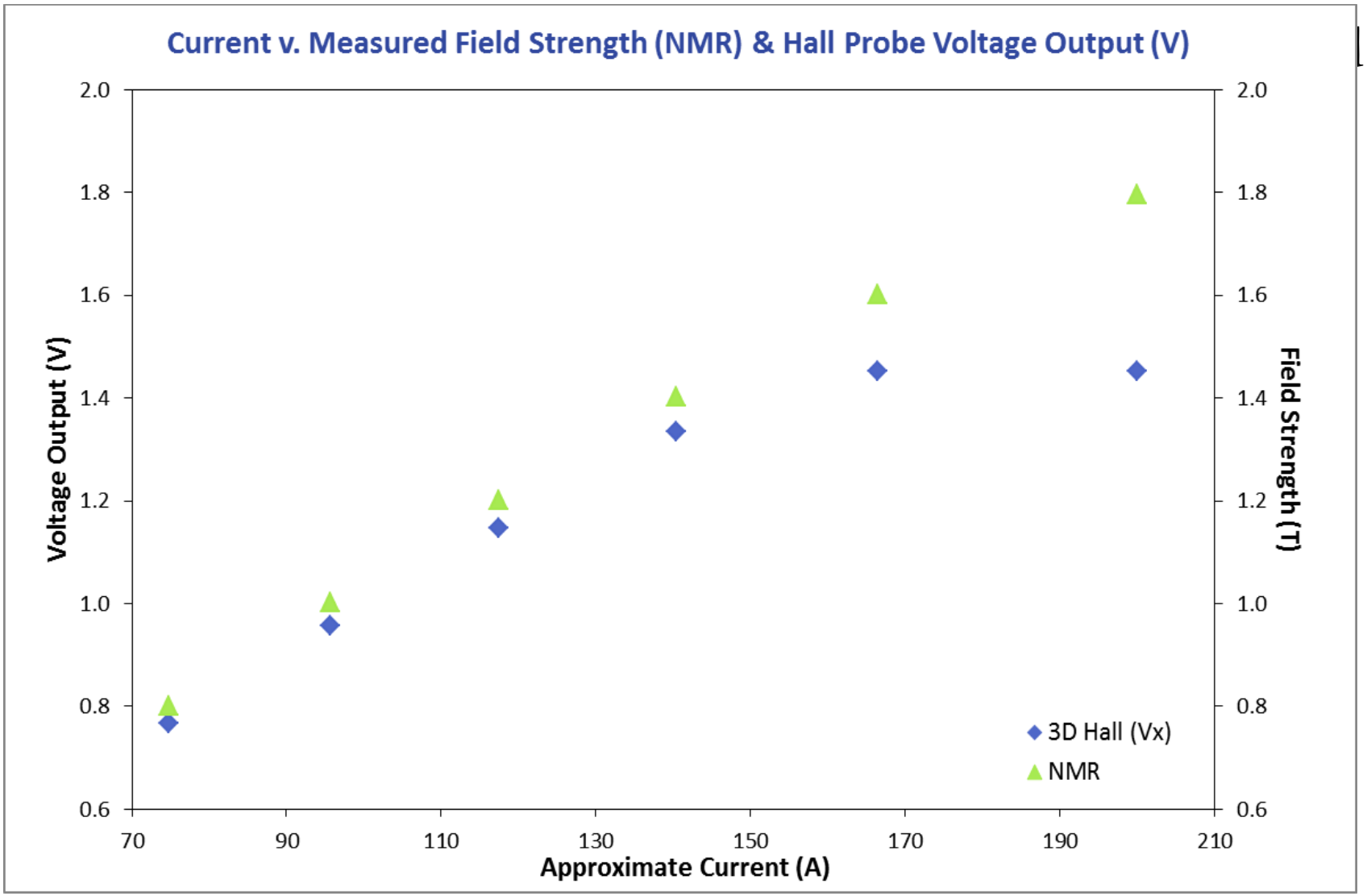
Test 1


Hall Probe Voltage Output (V) v. NMR Measured Field Strength (T)
y = 1.0568x - 0.0005
R² = 1
Should be about 1…
NMR Field Strength (T)
Hall Probe Voltage Output (V)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0

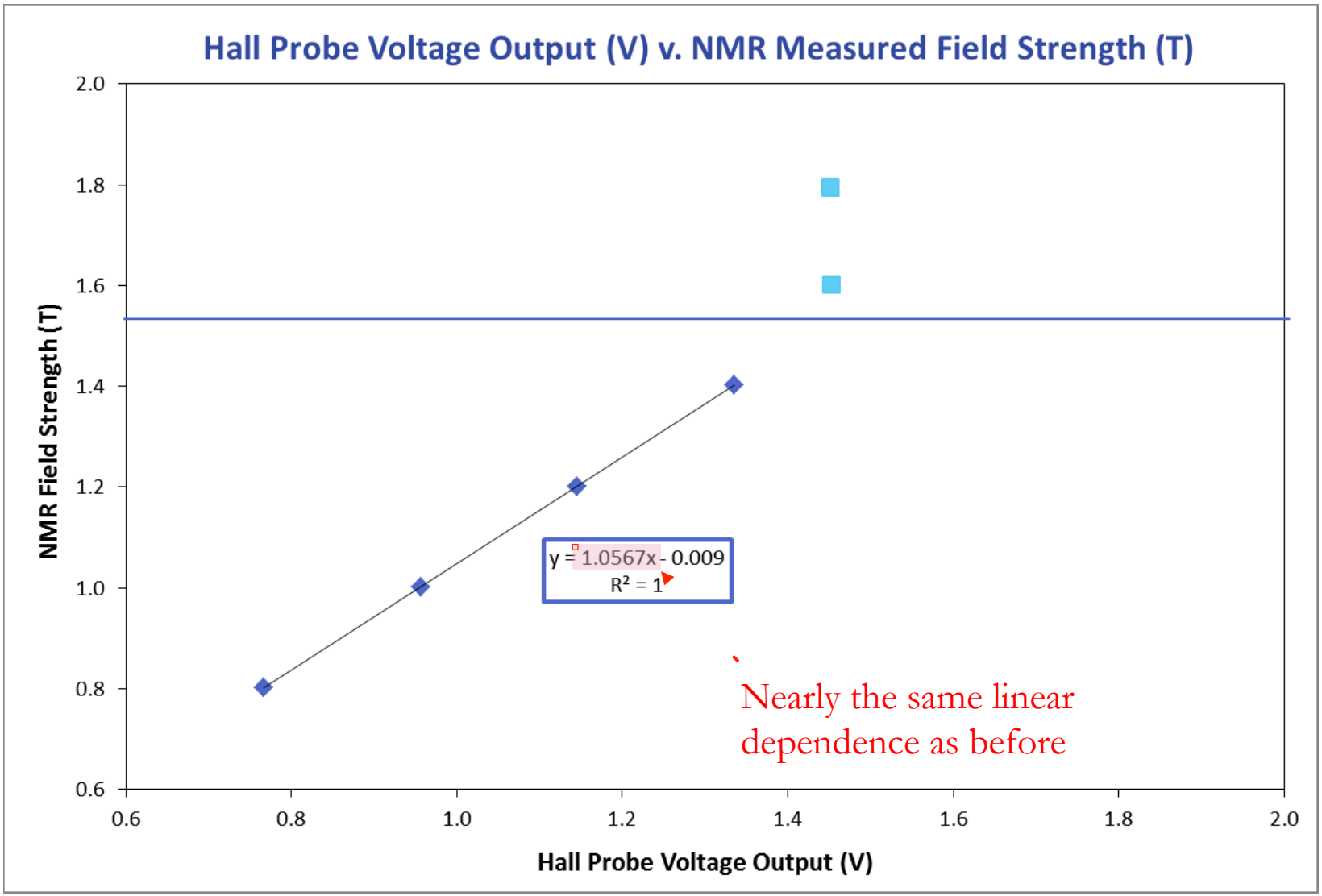
Test 2


Hall Probe Voltage Output (V) v. NMR Measured Field Strength (T)
y = 1.0504x - 0.0003
R² = 1
NMR Field Strength (T)
Hall Probe Voltage Output (V)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0

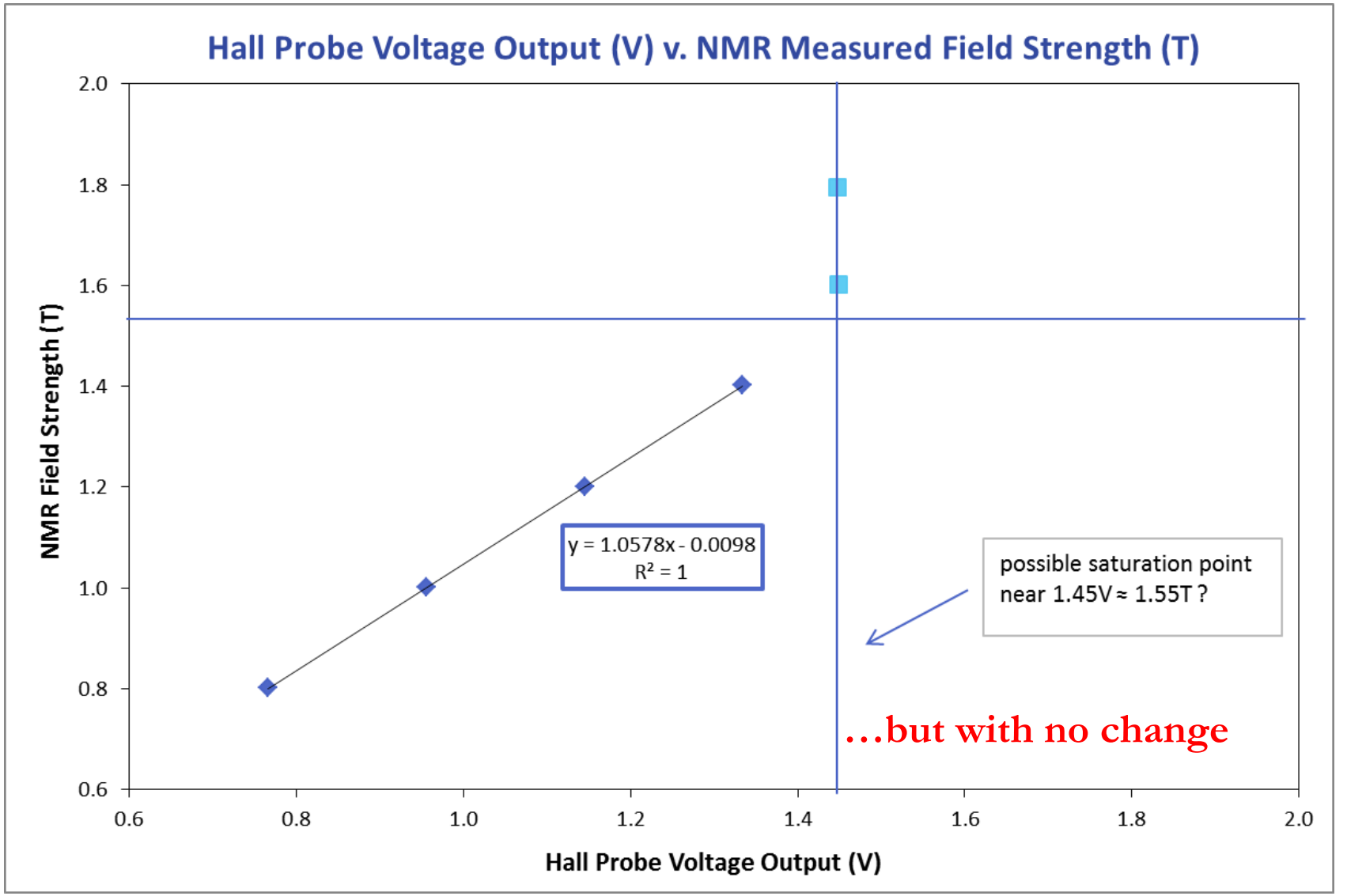
Test 3


Current v. Measured Field Strength (NMR) & Hall Probe Voltage Output (V)
Voltage Output (V)
Field Strength (T)
Approximate Current (A)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
70
90
110
130
150
170
190
210
3D Hall (Vx)
NMR

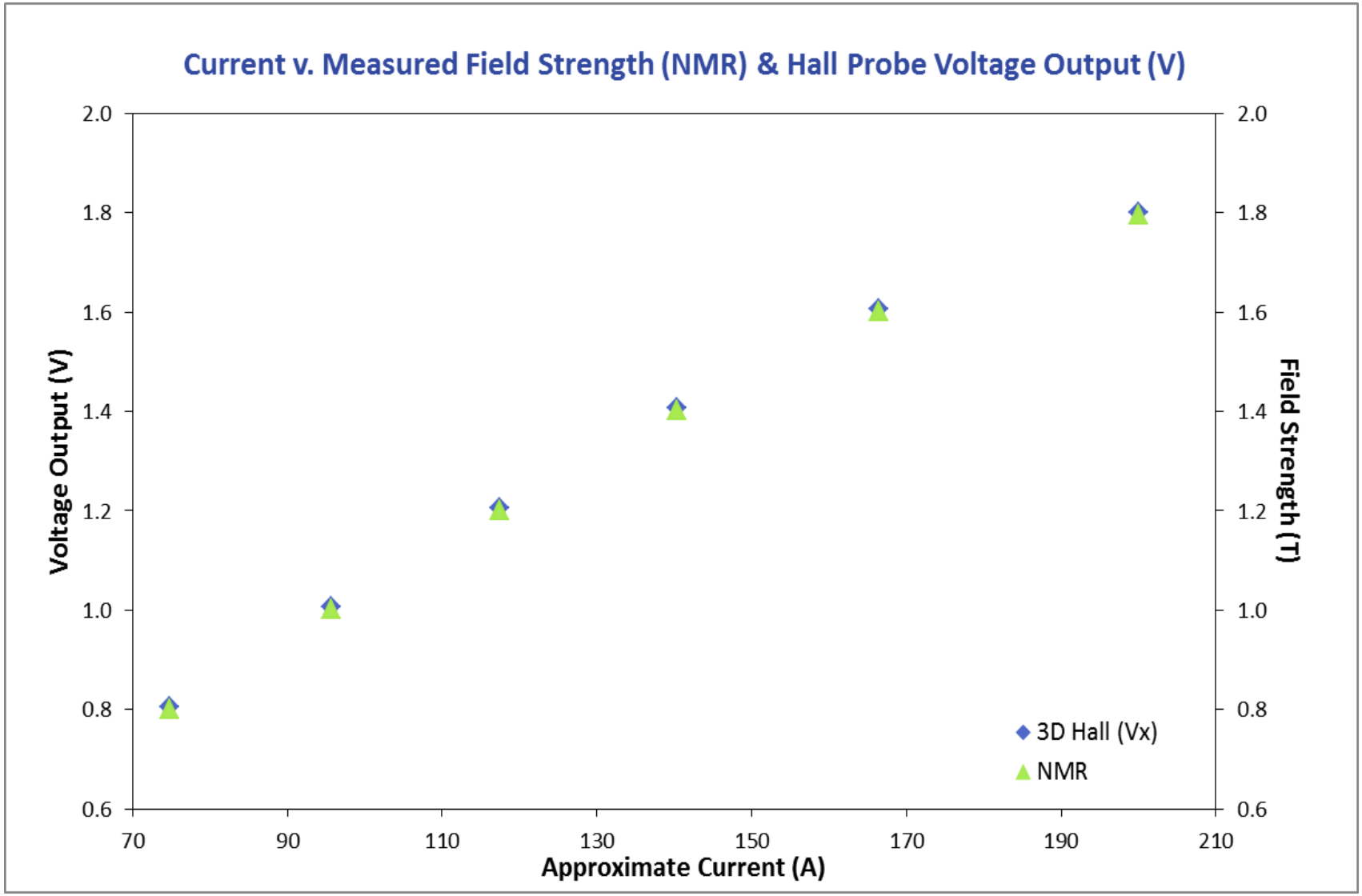
Test 3


Hall Probe Voltage Output (V) v. NMR Measured Field Strength (T)
NMR Field Strength (T)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Hall Probe Voltage Output (V)
y = 1.0567x - 0.009
R² = 1
Nearly the same linear dependence as before

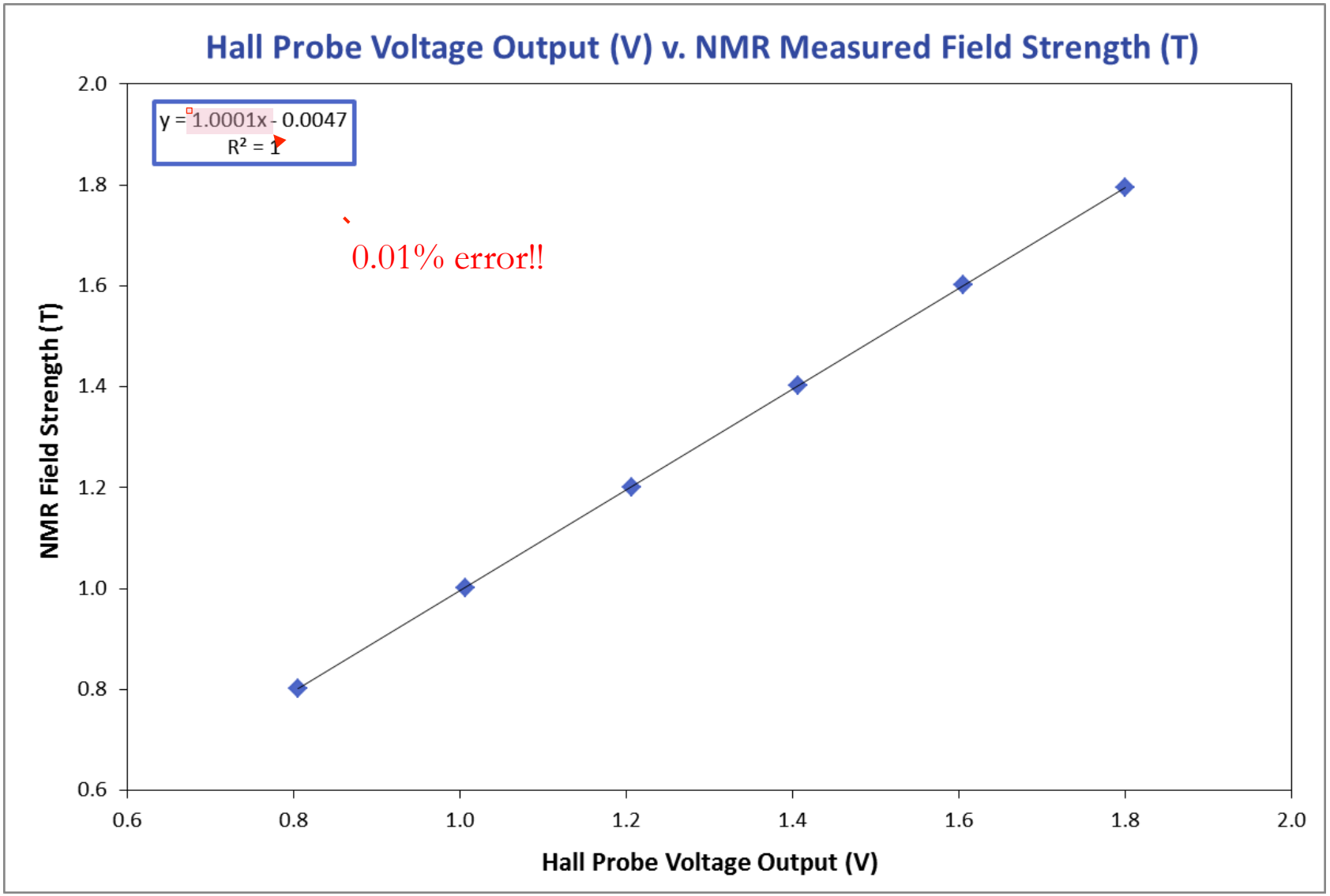
Test 4


Hall Probe Voltage Output (V) v. NMR Measured Field Strength (T)
NMR Field Strength (T)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Hall Probe Voltage Output (V)
y = 1.0578x - 0.0098
R² = 1
possible saturation point
near 1.45V ≈ 1.55T ?
…but with no change

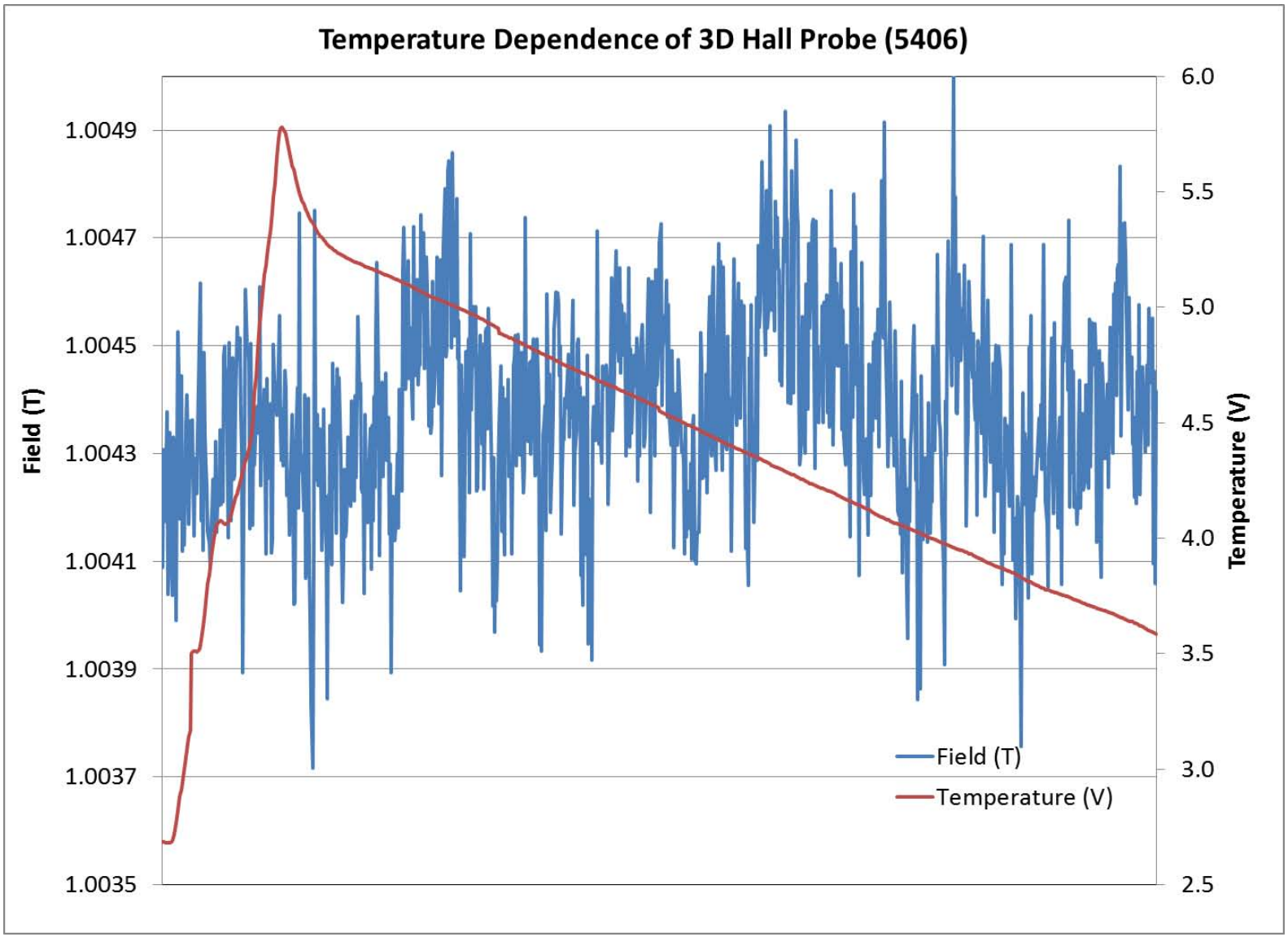
Test 5


Current v. Measured Field Strength (NMR) & Hall Probe Voltage Output (V)
Voltage Output (V)
Field Strength (T)
Approximate Current (A)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
70
90
110
130
150
170
190
210
3D Hall (Vx)
NMR

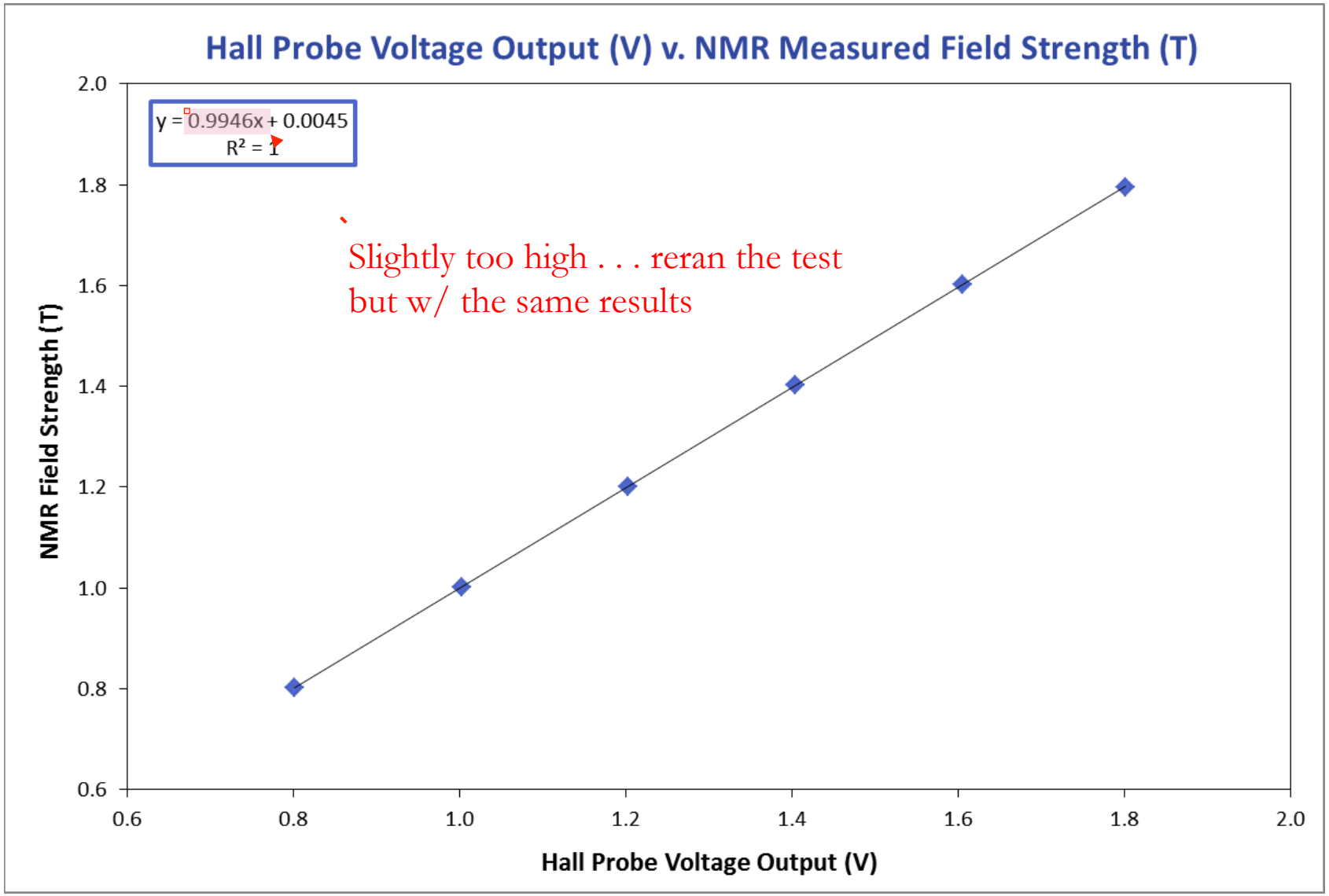
Test 5


Hall Probe Voltage Output (V) v. NMR Measured Field Strength (T)
y = 1.0001x - 0.0047
R² = 1
0.01% error!!
NMR Field Strength (T)
Hall Probe Voltage Output (V)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0

Test 6


Temperature Dependence of 3D Hall Probe (5406)
Field (T)
1.0049
1.0047
1.0045
1.0043
1.0041
1.0039
1.0037
1.0035
Temperature (V)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
Field (T)
Temperature (V)

Test 7


Hall Probe Voltage Output (V) v. NMR Measured Field Strength (T)
y = 0.9946x + 0.0045
R² = 1
Slightly too high . . . reran the test
but w/ the same results
NMR Field Strength (T)
Hall Probe Voltage Output (V)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0

TEVATRON DIPOLE MAGNET

Checking the uniformity of a standard Tevatron dipole & using the small field fluctuations (0.01%) to check the sensitivity of a Senis 3D Hall probe

Tevatron Dipole (TC1206)

Probe: NMR range 5, barcode *#001029*

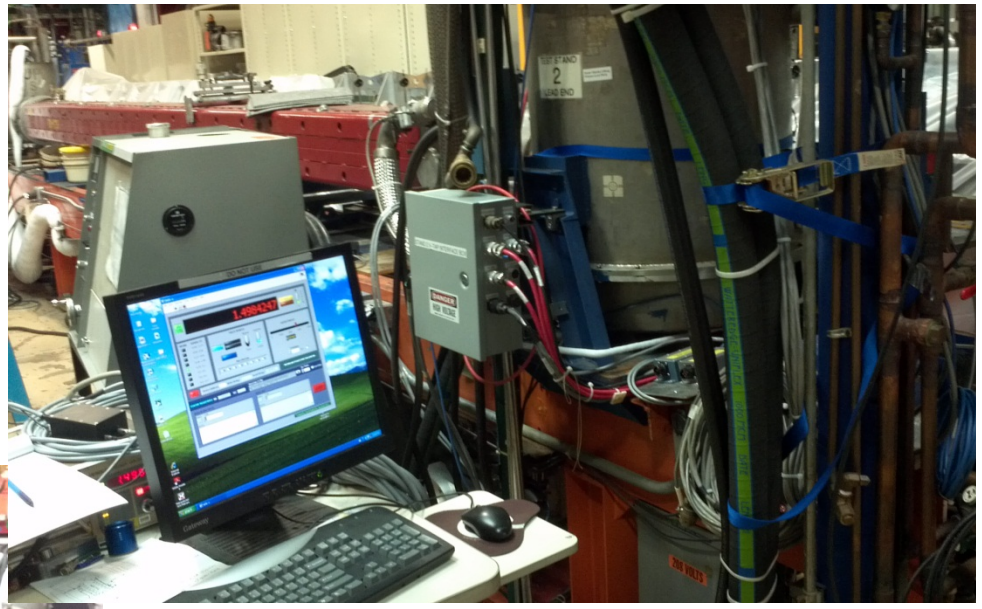
Current: 1000 A, 1500 A, 2000 A

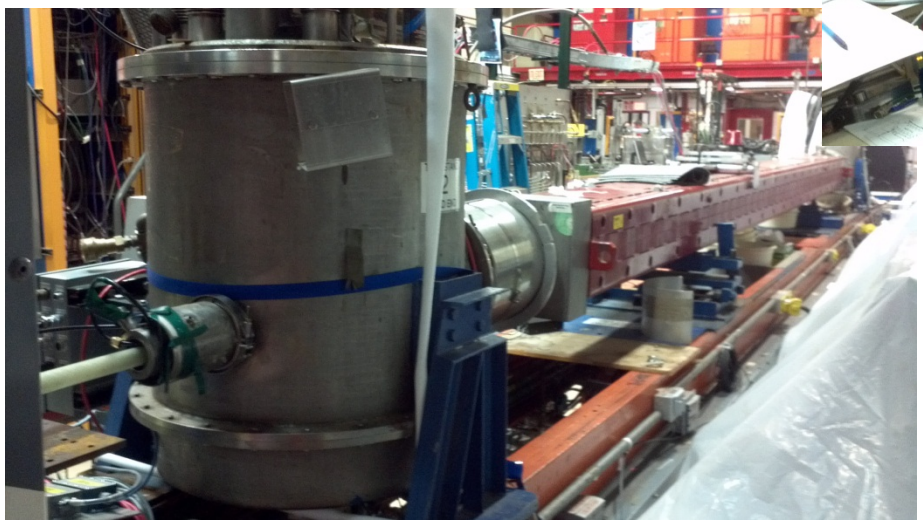
Dates: 8/2/2011 – 8/3/2011

End of Magnet: Lead

Motion Control: Manual

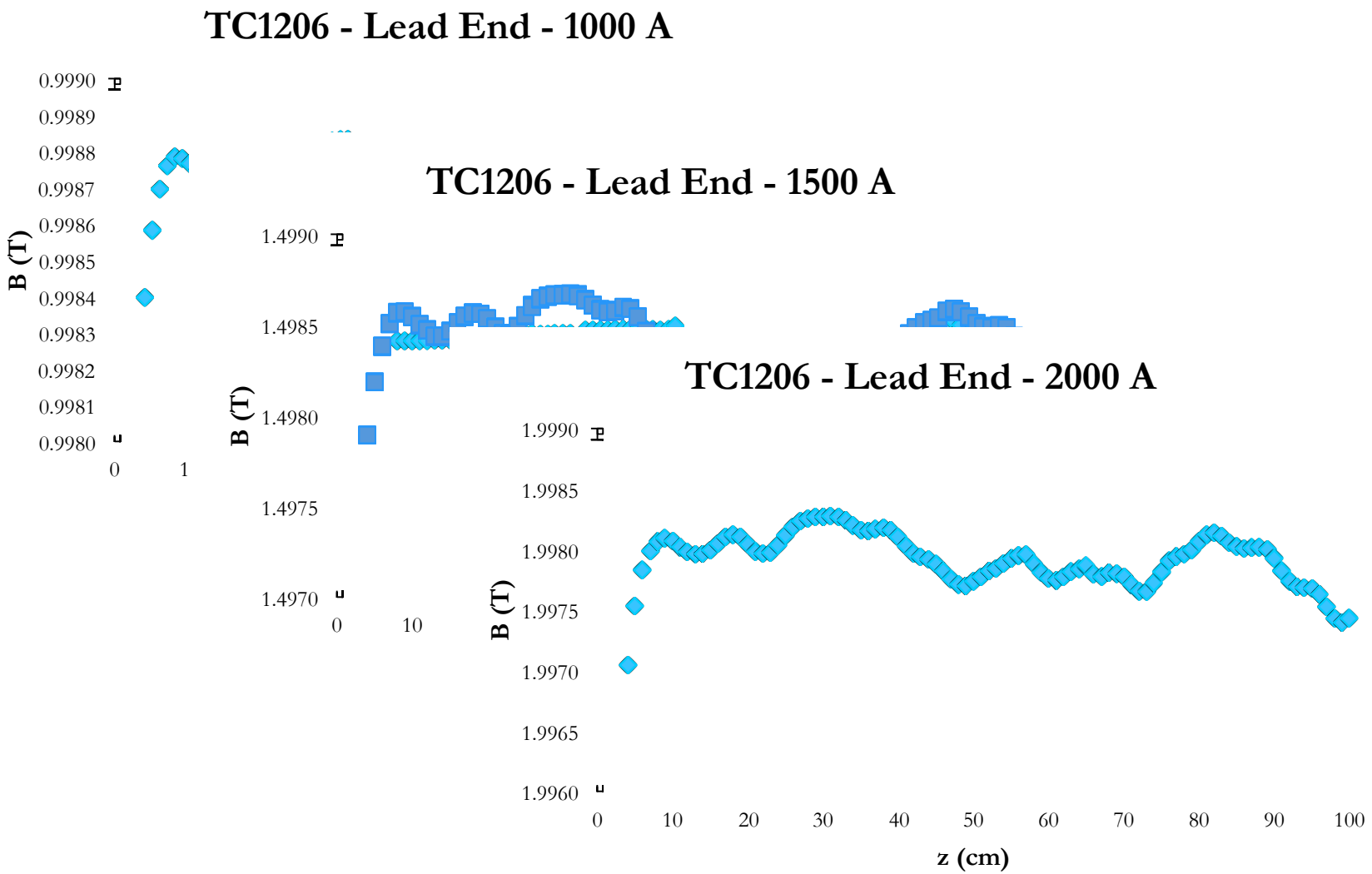
Scan Range: 96 cm



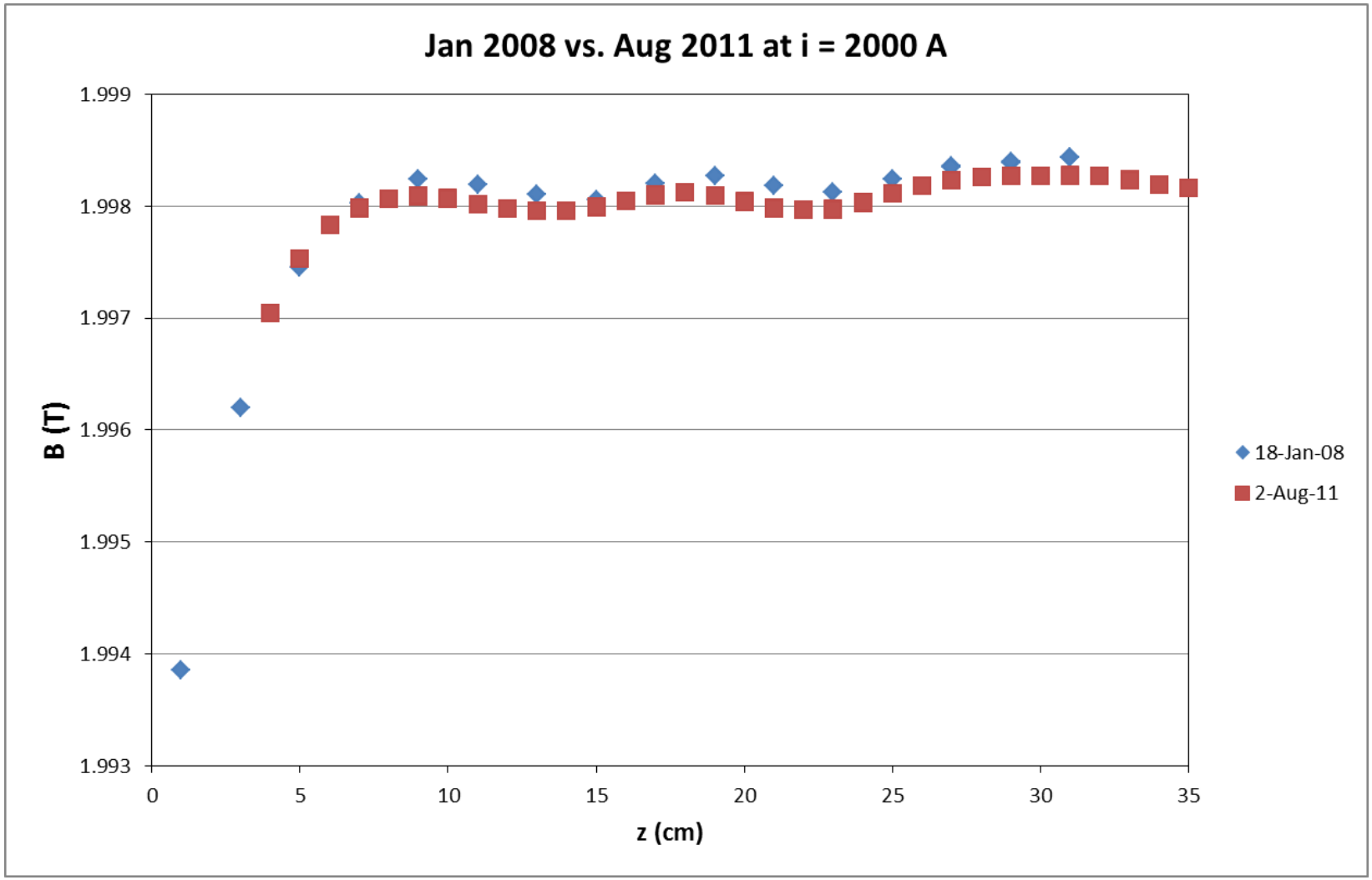


S:\Run Support\TestData\Calibrations\HallProbeNMRCalibrations\July 2011\TC1206_NMRRange5_110802.xlsx

Results


TC1206 - Lead End - 1000 A
B (T)
0.9990
0.9989
0.9988
0.9987
0.9986
0.9985
0.9984
0.9983
0.9982
0.9981
0.9980
0
1
TC1206 - Lead End - 1500 A
B (T)
1.4990
1.4985
1.4980
1.4975
1.4970
0
10
TC1206 - Lead End - 2000 A
B (T)
1.9990
1.9985
1.9980
1.9975
1.9970
1.9965
1.9960
0
10
20
30
40
50
60
70
80
90
100
z (cm)

Comparison with Previous Data



Next Step – 3D Hall Probe

A scan of the Tevatron dipole using the Senis 3D Hall probe is scheduled for August 4, 2011.

We want to see if these results are as sensitive as the results produced by the NMR.

Results to follow!

Questions??