Results of Magnetic Measurements in LEReC 20-deg Dipoles

Animesh Jain

December 22, 2015

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LEReC 20-deg Dipole Details (W. Meng)

- Central field:
  - 0.02512 T at 7.8 A for 5 MeV operation
  - 0.00937 T at 2.91 A for 1.6 MeV operation

- Field integrated along a straight line at x =0, y = 0:

$$\int \left[B_y(z) \right] dz = 6.414 \times 10^{-3}\ \mathrm{T \cdot m\ for\ 5\ MeV\ (7.8\ A)}$$

- Field integrated along a curved path:

$$\int \left[B_y(s) \right] ds = 6.396 \times 10^{-3}\ \mathrm{T \cdot m\ for\ 5\ MeV\ (7.8\ A)}$$

$$= 2.386 \times 10^{-3}\ \mathrm{T \cdot m\ for\ 1.6\ MeV\ (2.91\ A)}$$

- 104 mm clear gap; 255 mm magnetic length

Hall Probe Measurements

- Magnets were measured with a 3-axis Hall probe. All axes were calibrated against NMR.

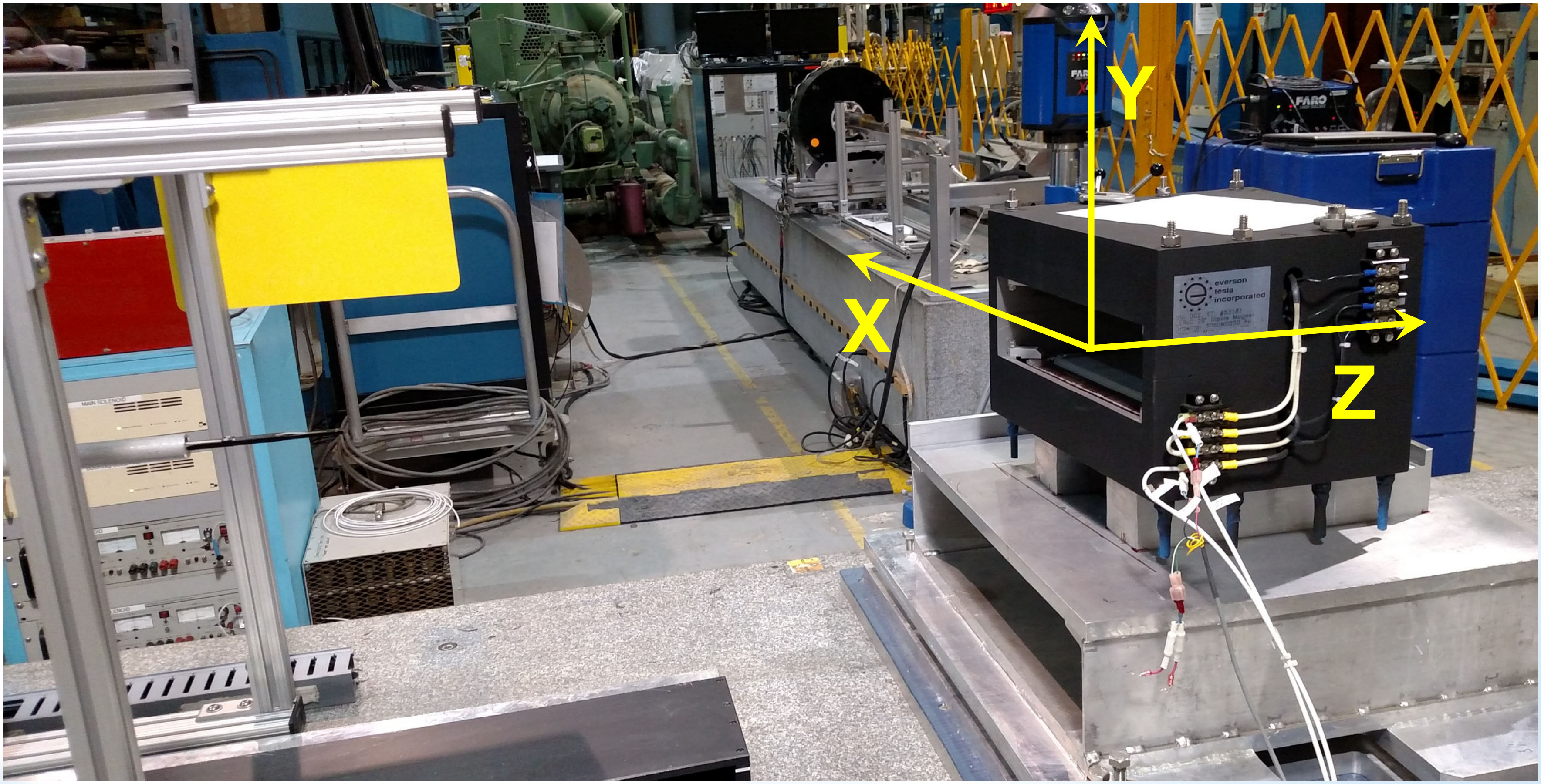
- Hall probe scans at a fixed current:
  - ➢ Magnet current = 7.8 A (5 MeV) and 2.91 A (1.6 MeV)
  - ➢ Z-values from –300 mm to +300 mm in 5 mm steps
  - ➢ X-values from –20 mm to +20 mm in 2 mm steps (21 lines)
  - ➢ Y-value = 0 for all scans (magnet midplane)

- Hall probe DC loop 0 A to 10 A, and back to 0A:
  - at axial and transverse center of the magnet (x=0, y=0, z=0)
  - Data taken in 1 A steps.

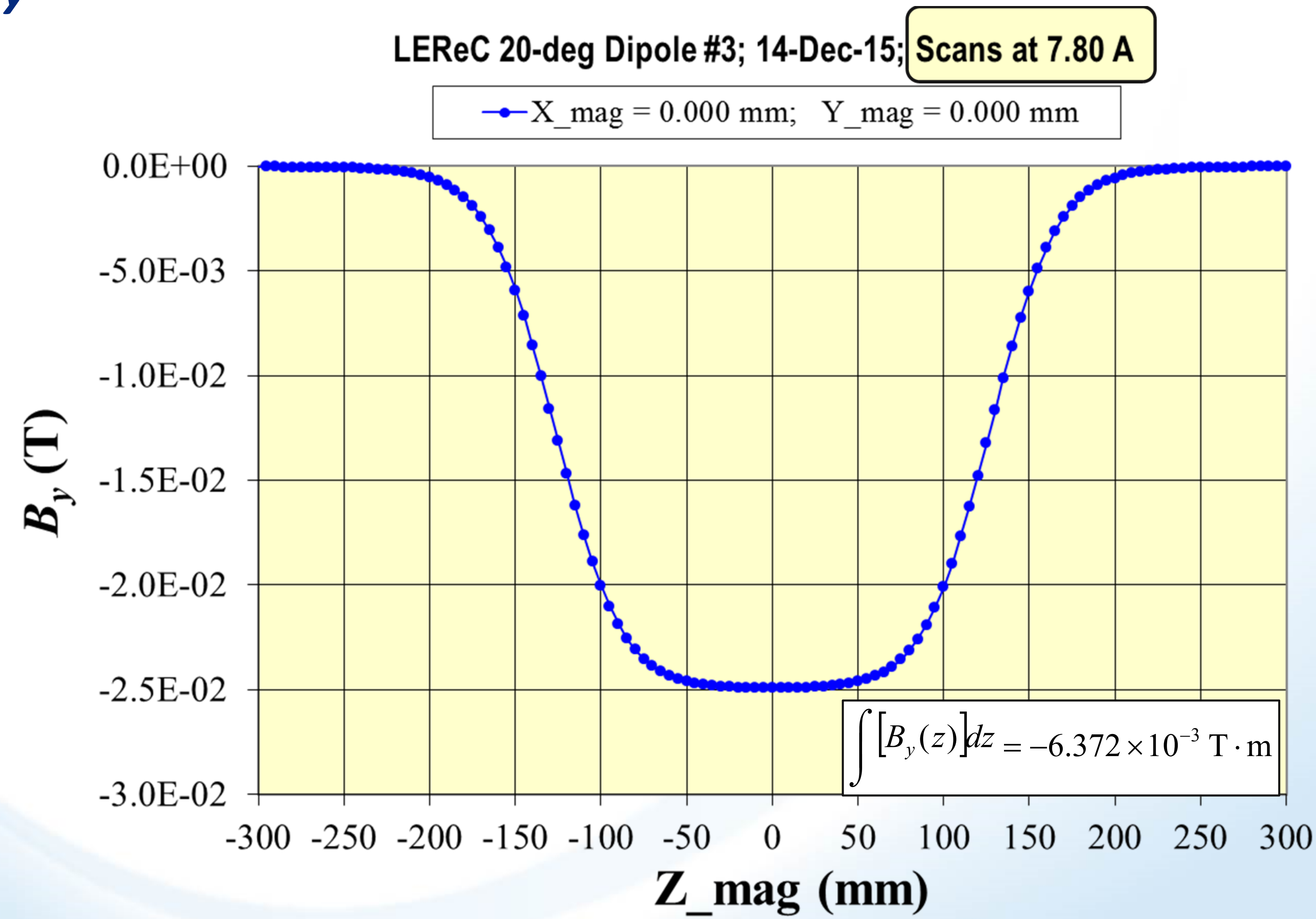
Hall Probe Measurement Limitations

- Probe calibration is sensitive to temperature. Probe temperature varies with the ambient.
  - Offset is corrected to some extent by measuring in a mu metal shield just prior to each measurement.
  - Gain errors are unknown.
- Measurement of minor field components is not reliable (error could be up to 1% of the main field component):
  - Non-orthogonality of the 3 probe axes
  - Misalignment of the probe axes with respect to the magnet coordinate system.
  - Imperfect motion of stages causing slight angular tilts as a function of position.
  - We do not have means to characterize or reduce these errors.

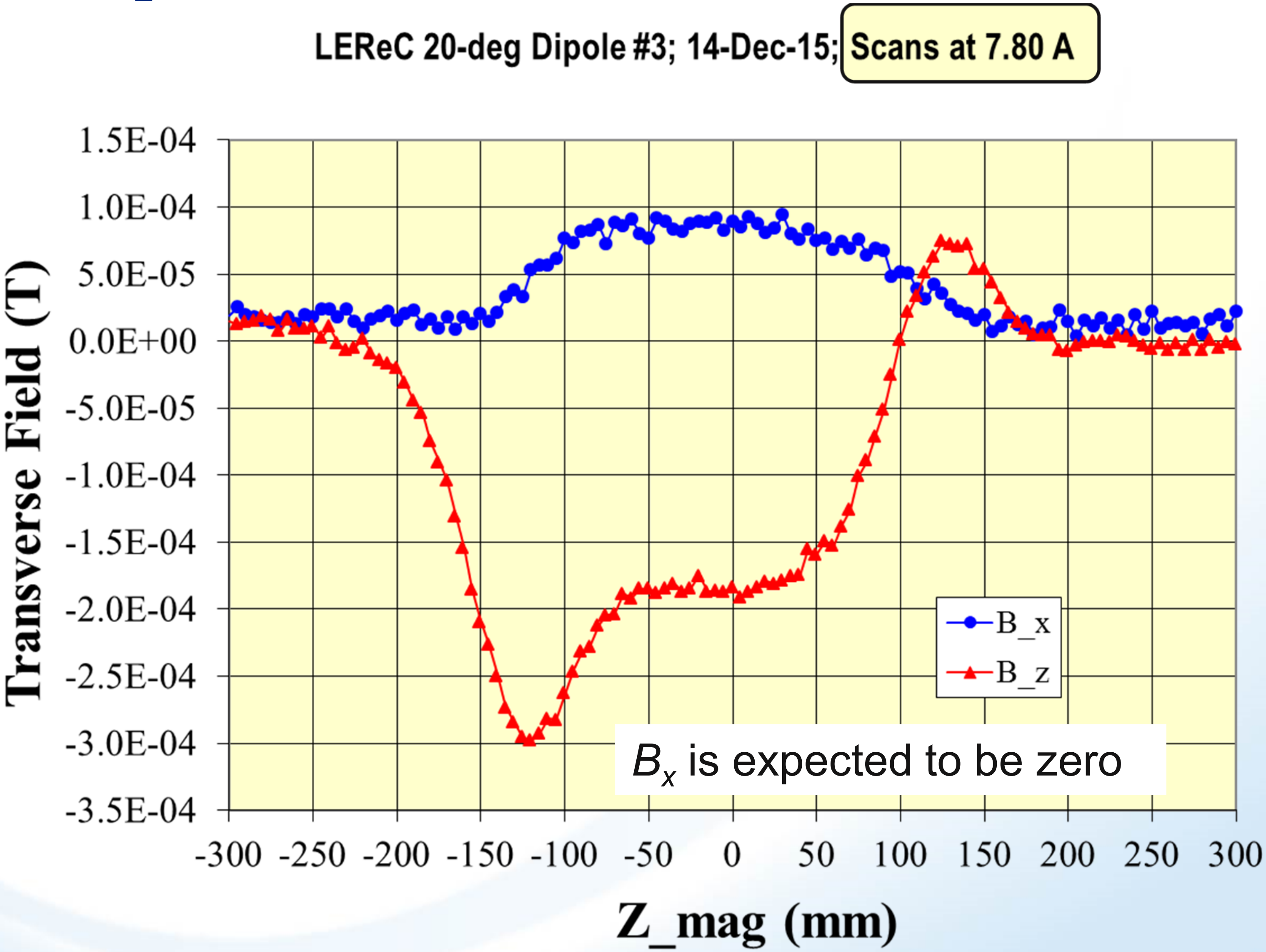
LEReC 20-deg Dipoles: Hall Probe Setup



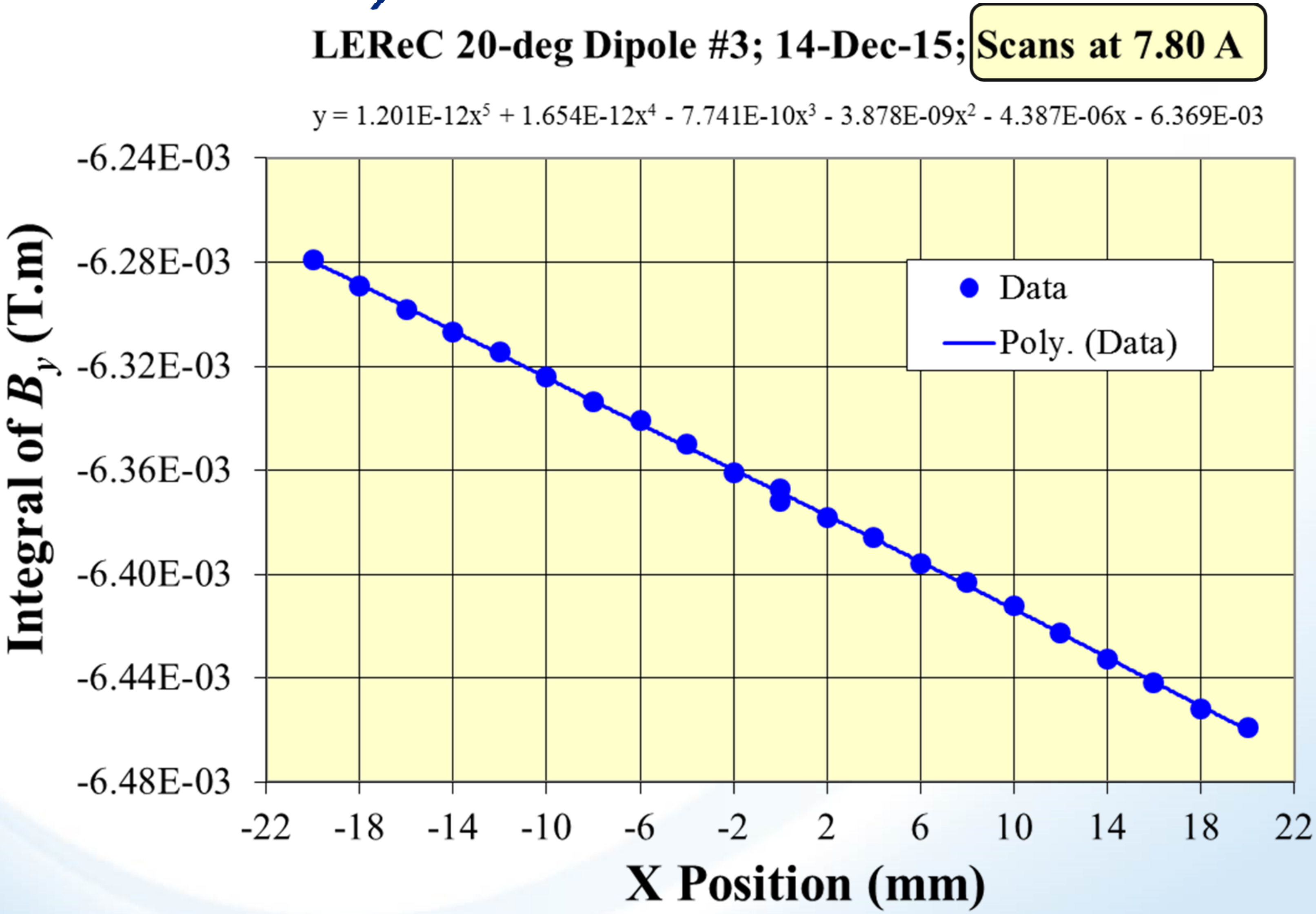
B_y Field Profile On-Axis at 7.8 A



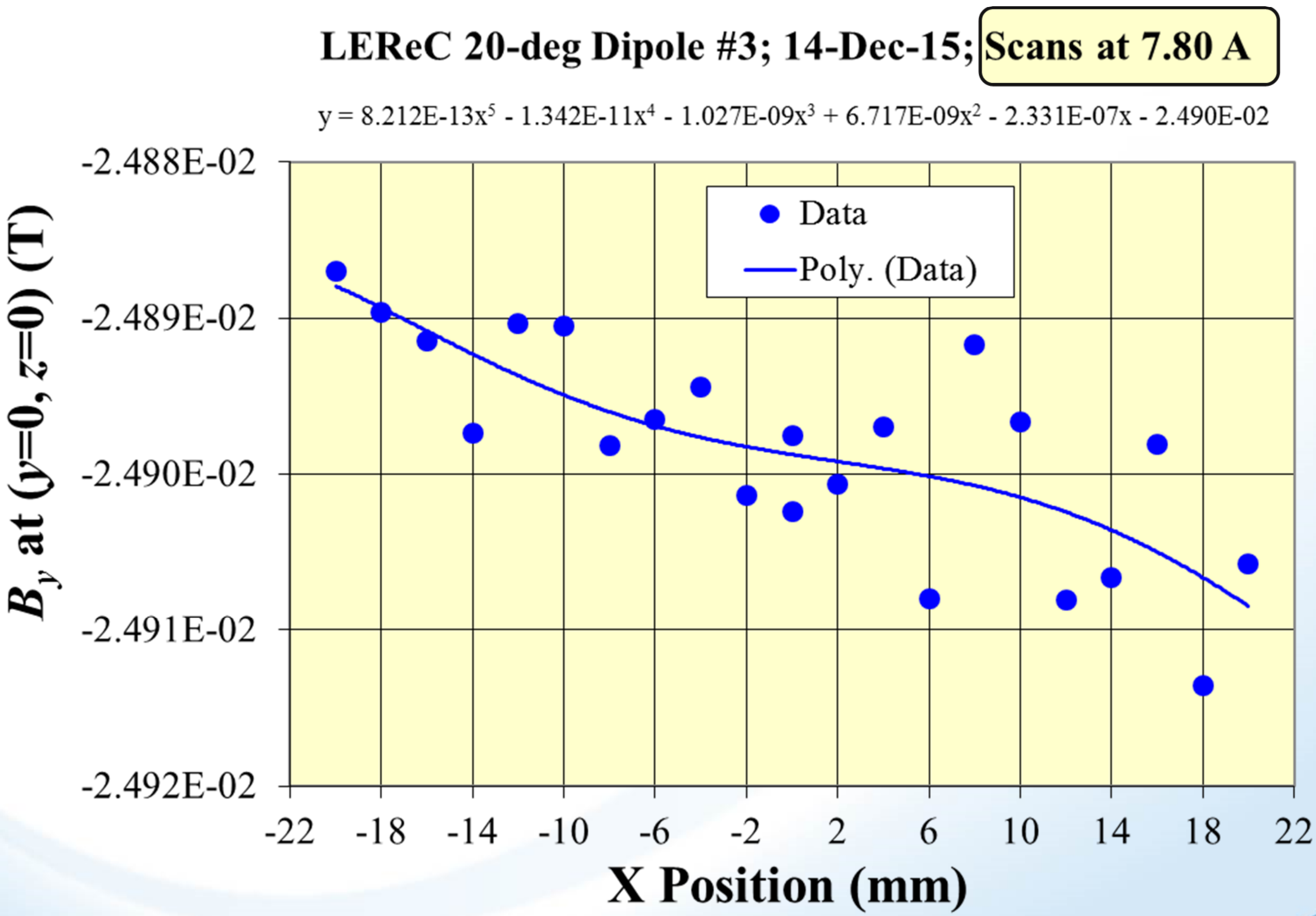
B_x and B_z Field Profiles On-Axis at 7.8 A



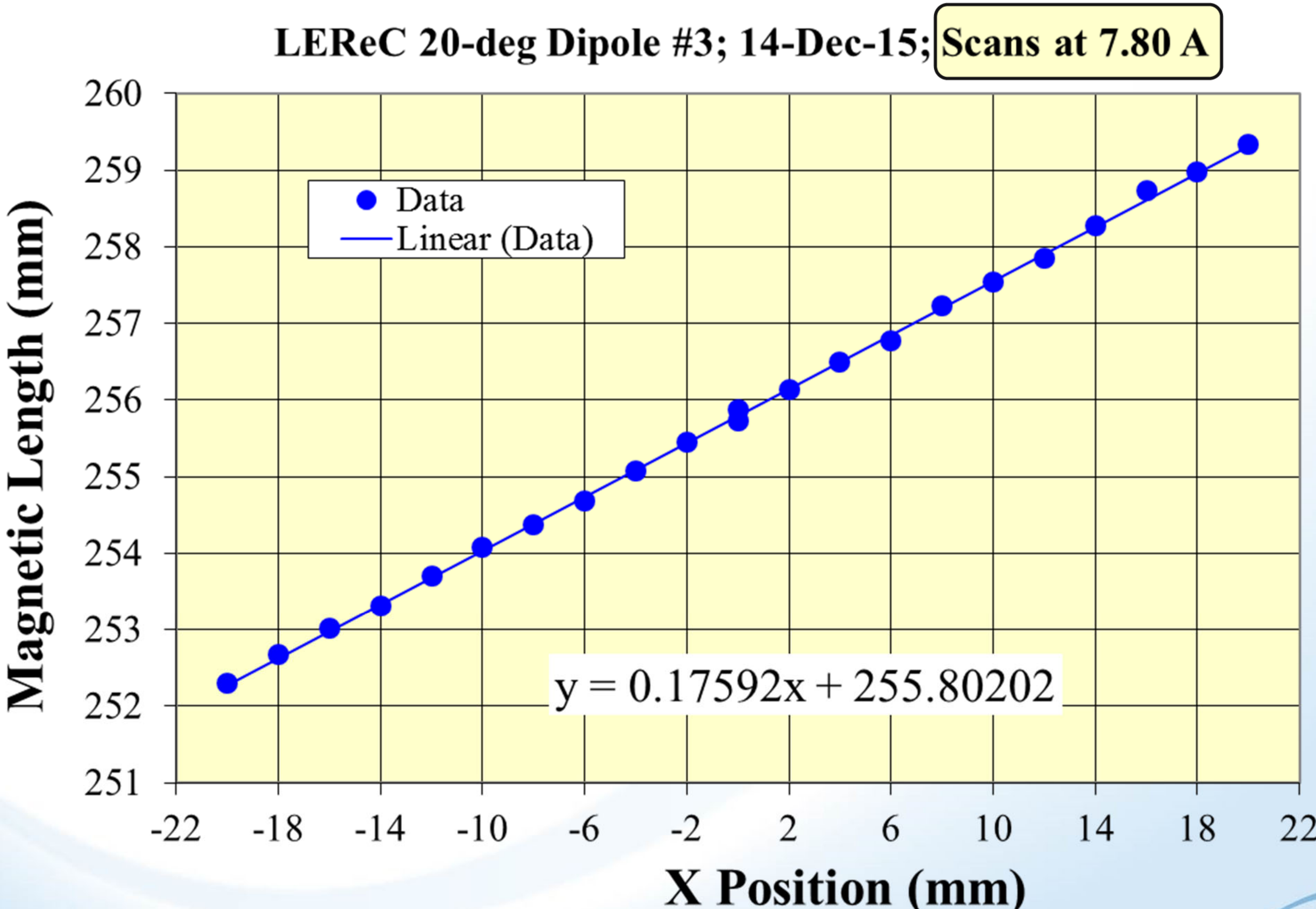
Integral of B_y Vs. X at 7.8 A



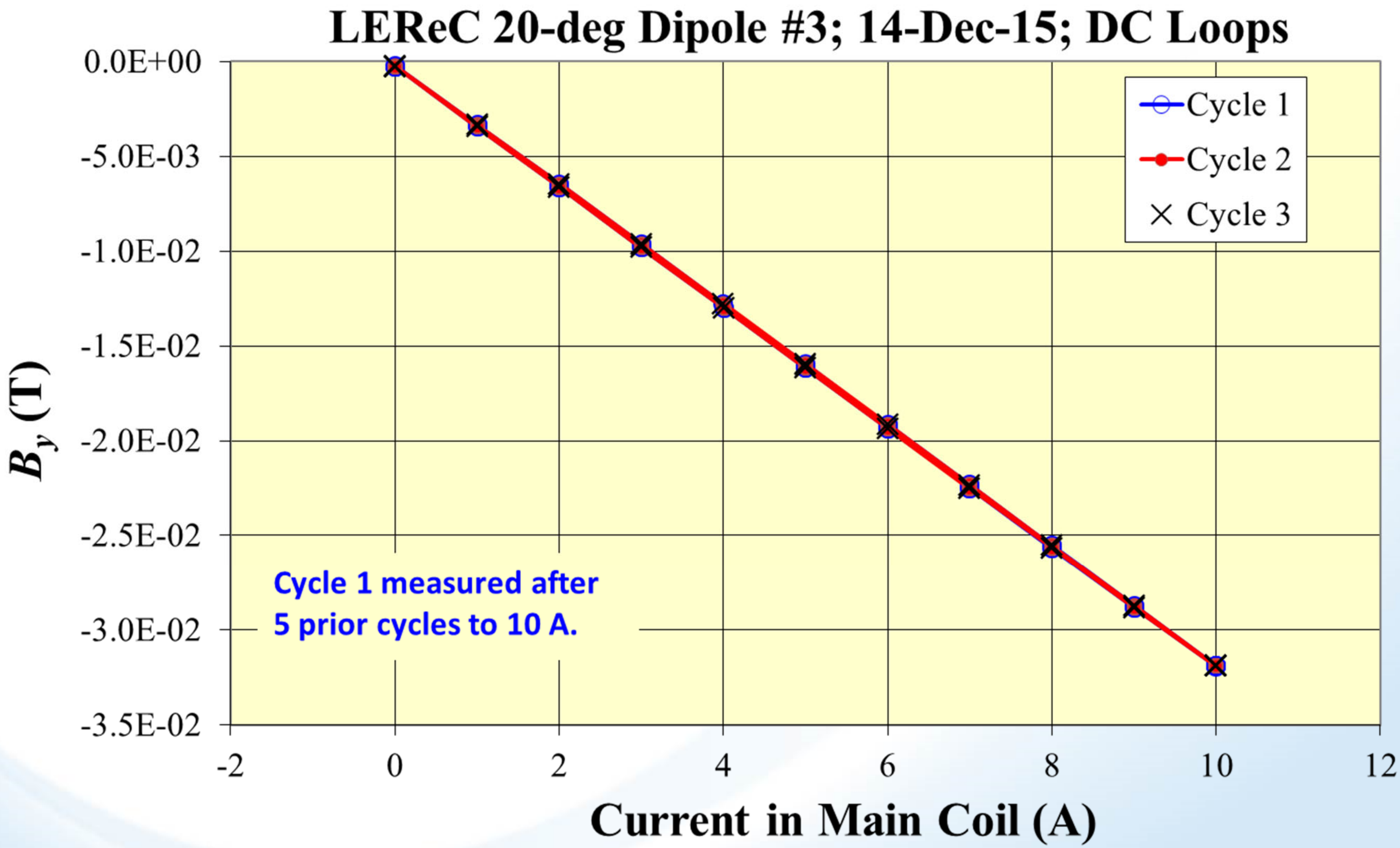
$B_y(0,0,0)$ Vs. *X* at 7.8 A



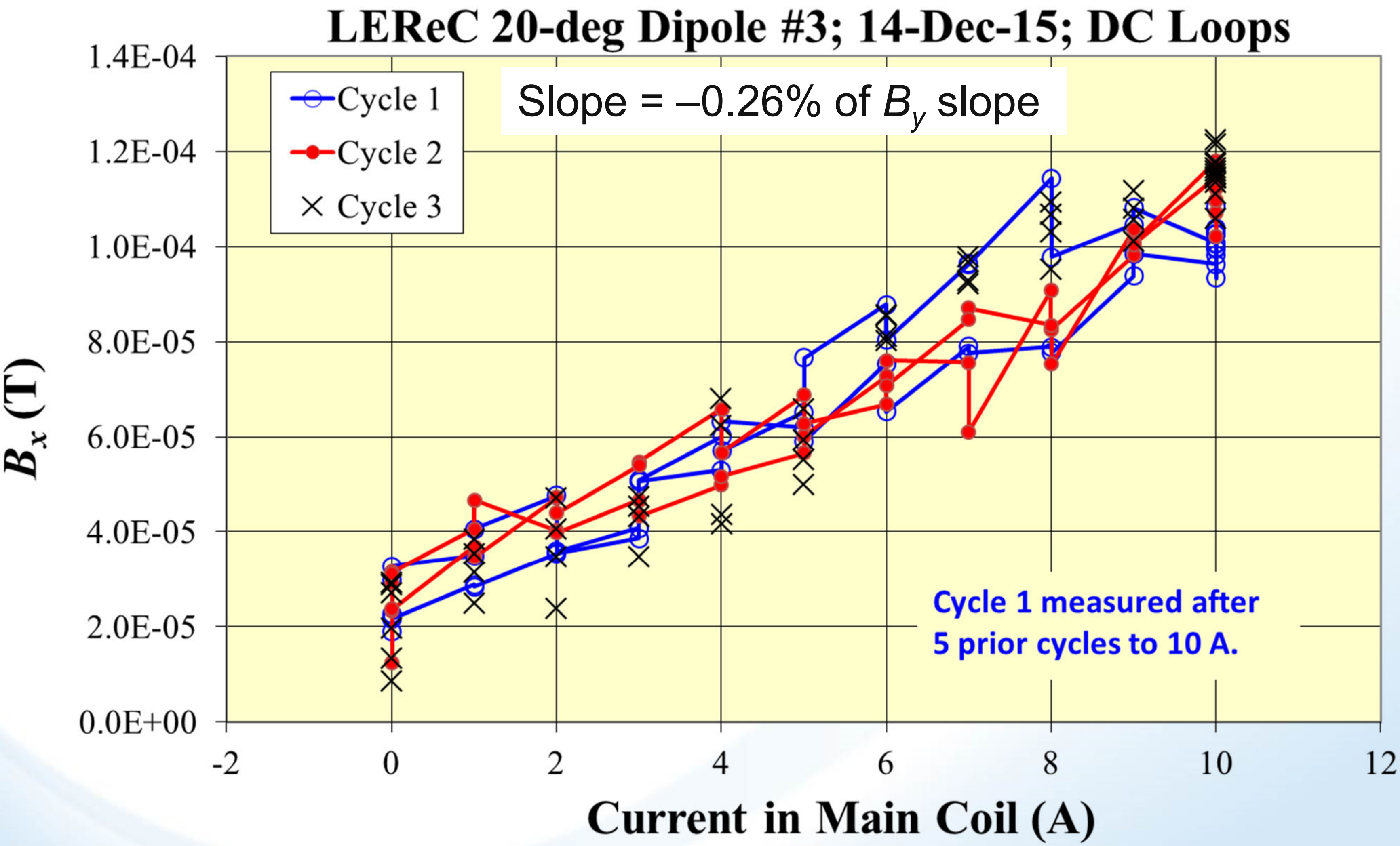
Magnetic Length Vs. *X* at 7.8 A



DC Loop at (*x,y,z*) = (0,0,0)



DC Loop at (*x*,*y*,*z*) = (0,0,0)



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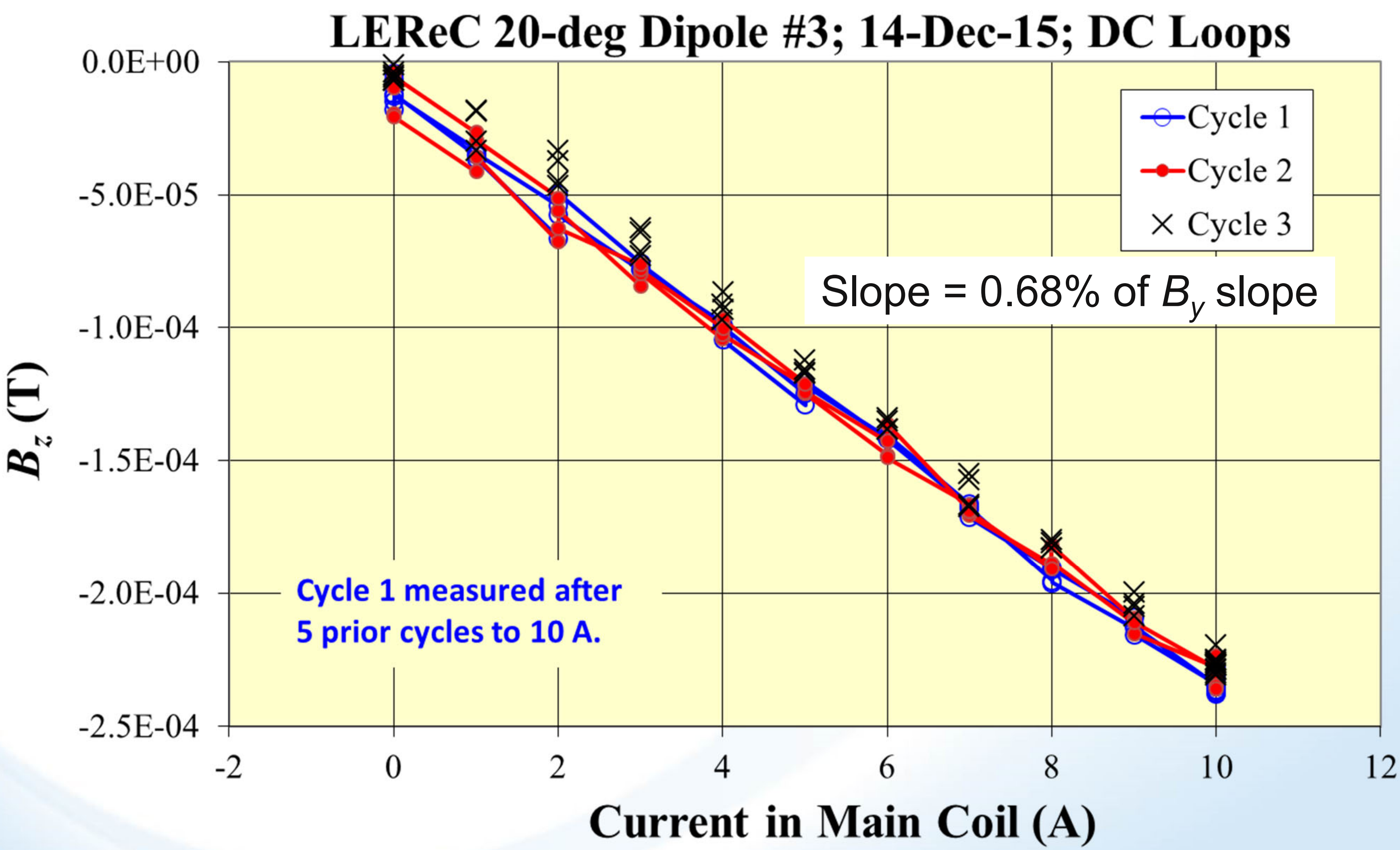
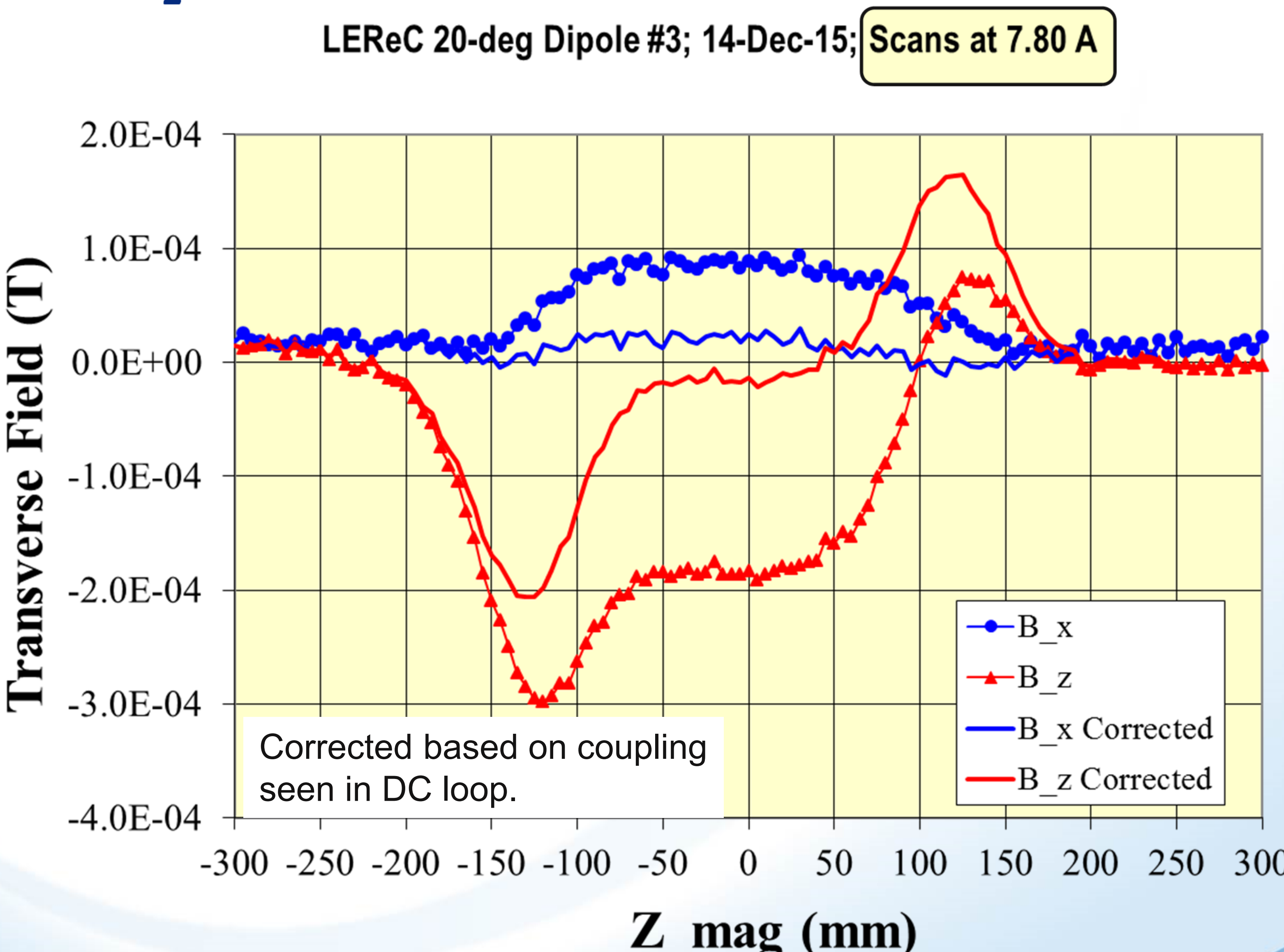


B_x and B_z Field Profiles On-Axis at 7.8 A



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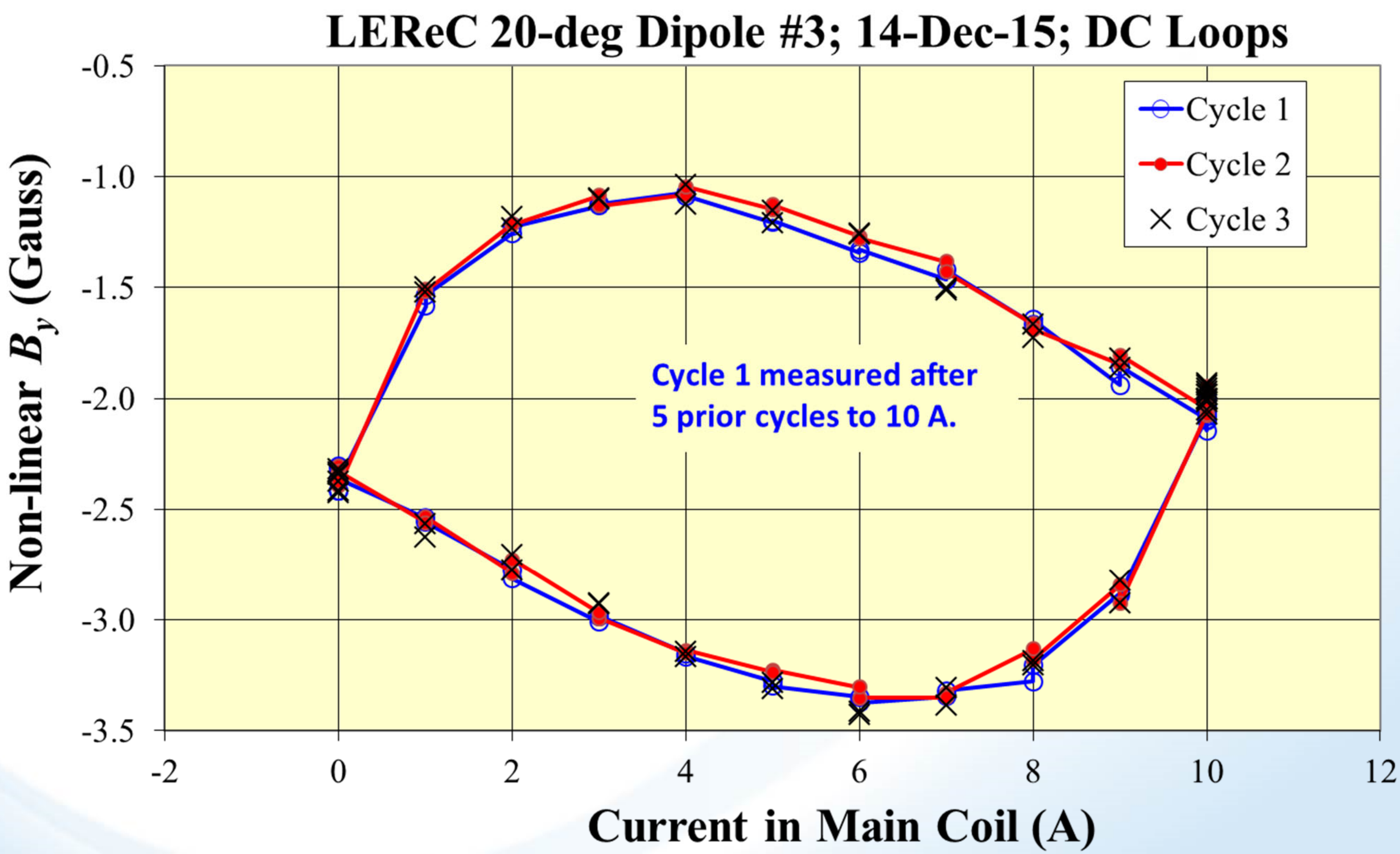

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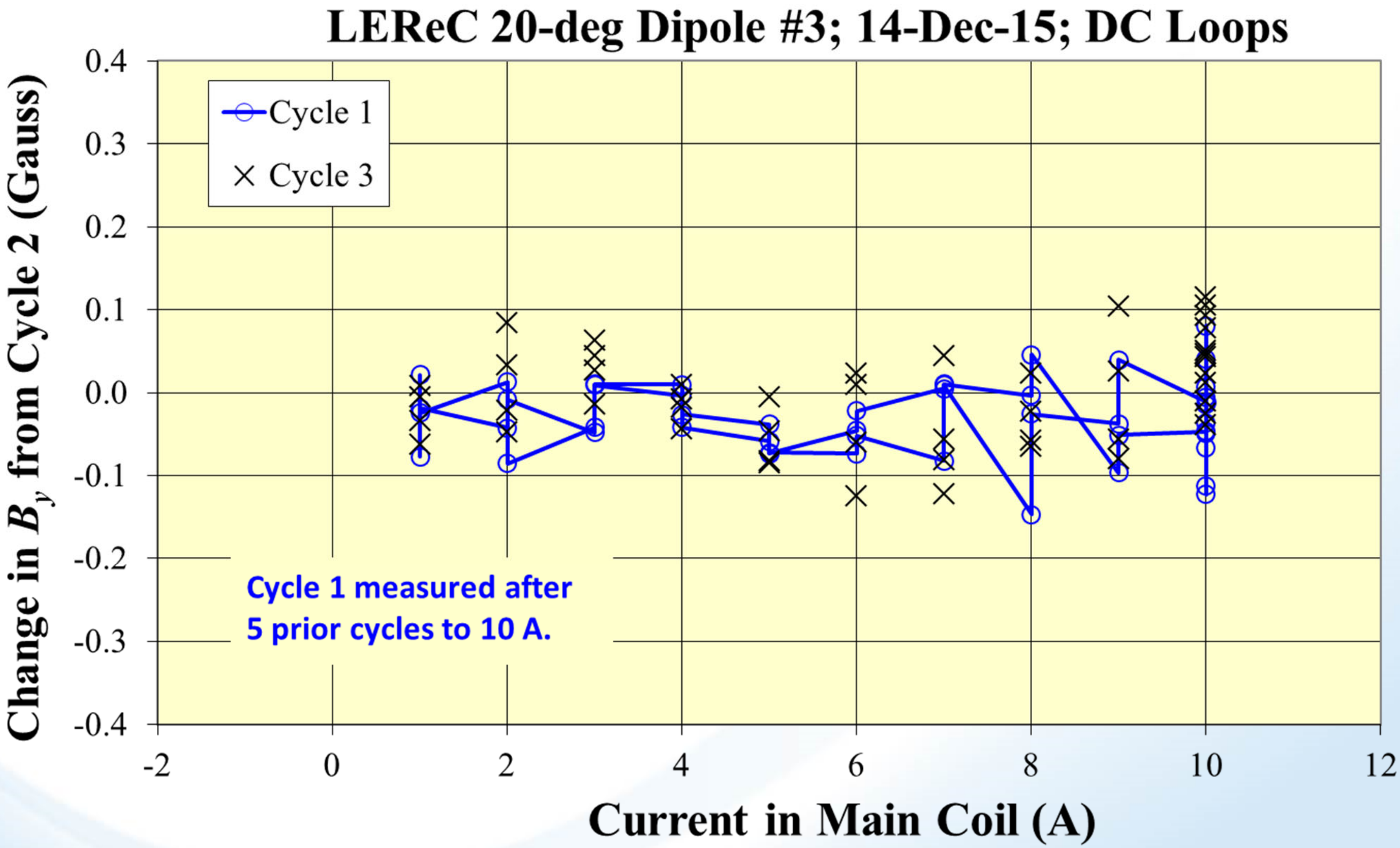

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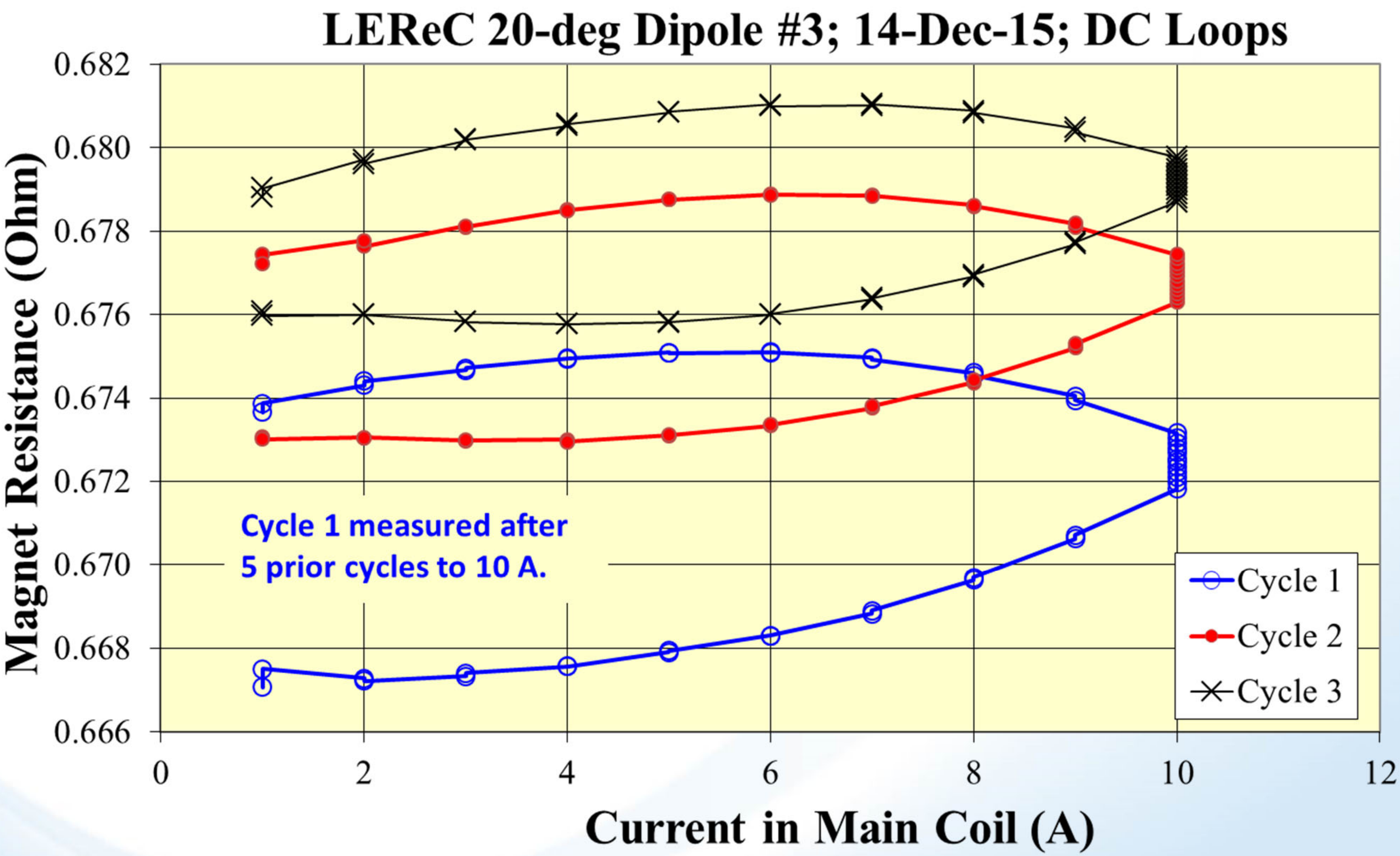
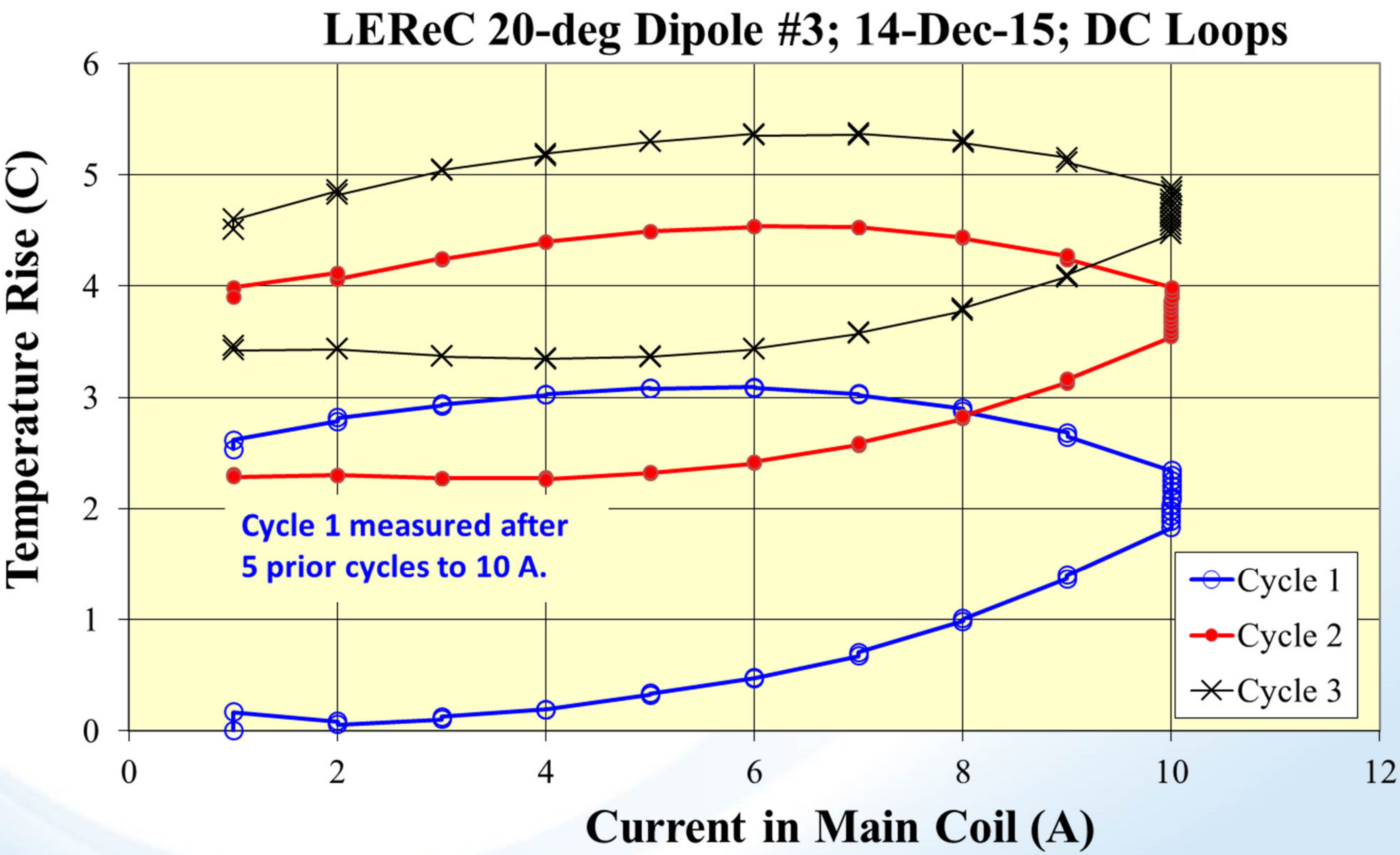


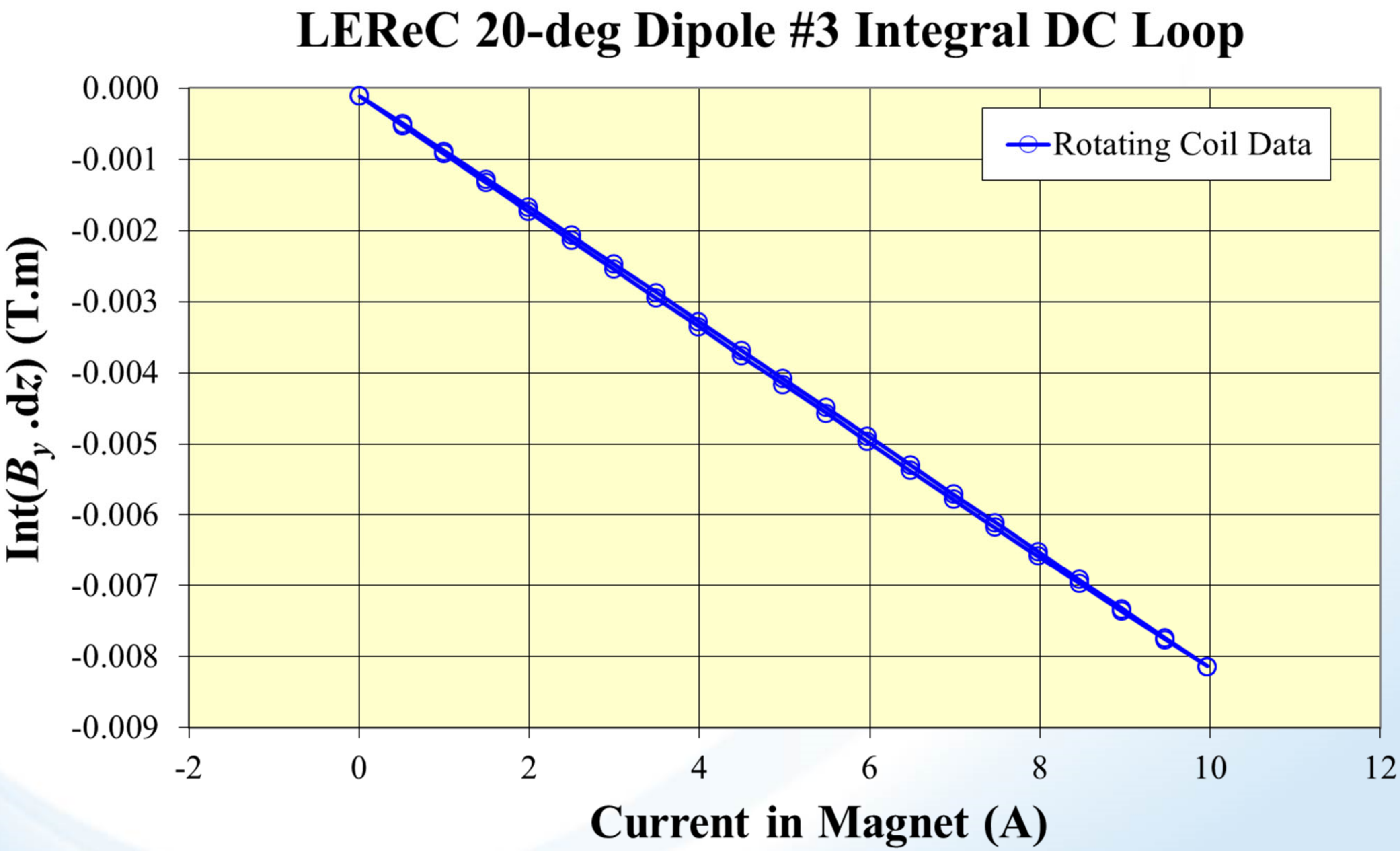
DC Loop at (*x*,*y*,*z*) = (0,0,0)



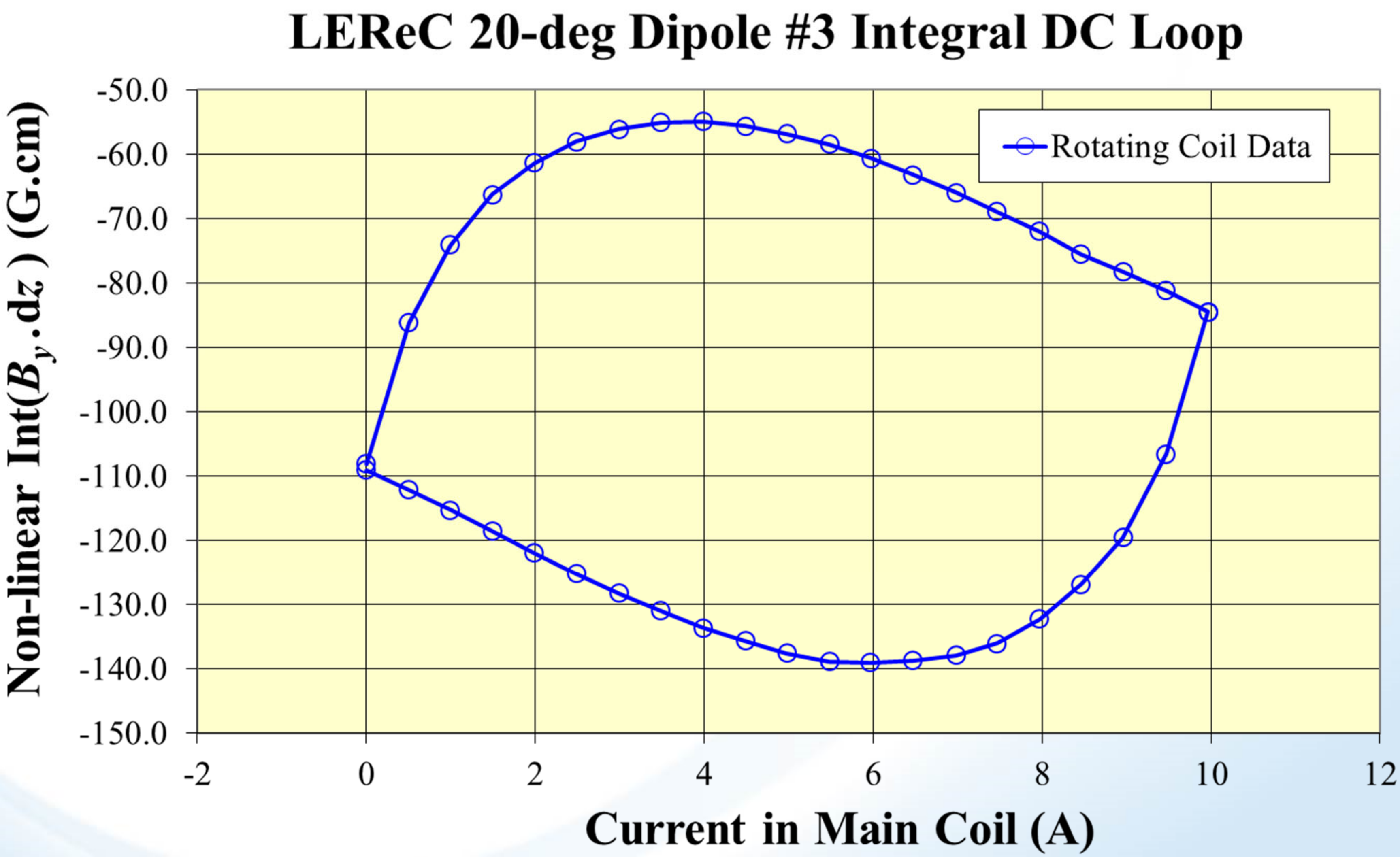
Rotating Coil Measurements

- Measuring coil is 0.914 m long, but the magnet is only ~0.26 m
  - Good for capturing all the fringe field, but sees a lot of extra transverse field from earth's field.
  - Need to subtract background fields to get true contribution from the magnet
- Measurements were carried out in two ways:
  - Several measurements at two different currents (0 A and 10 A). True fields obtained by the slope of a straight line fit to two currents.
  - Full excitation curves measured from I_{min} to I_{max} (0 A to +10 A). True fields obtained by the slope of a straight line fit to both the up ramp and down ramp data.
    - This also gives non-linearity such as hysteresis.
  - Harmonics from both methods are very similar.
- Plots from the full excitation curve results are presented here.
- Results of 0A/10A measurements are presented as a table.

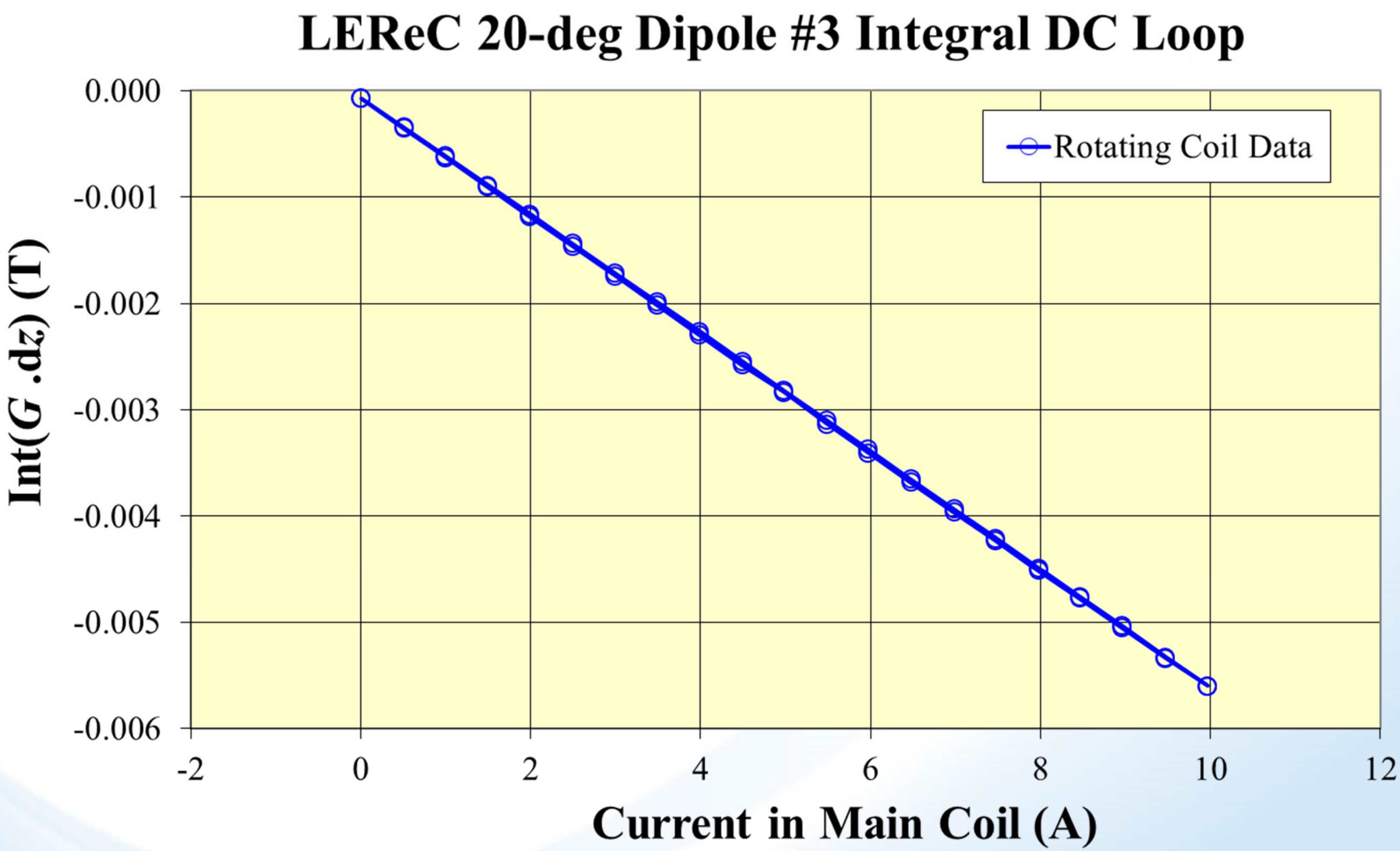
Rotating Coil Data: Integral of B_y



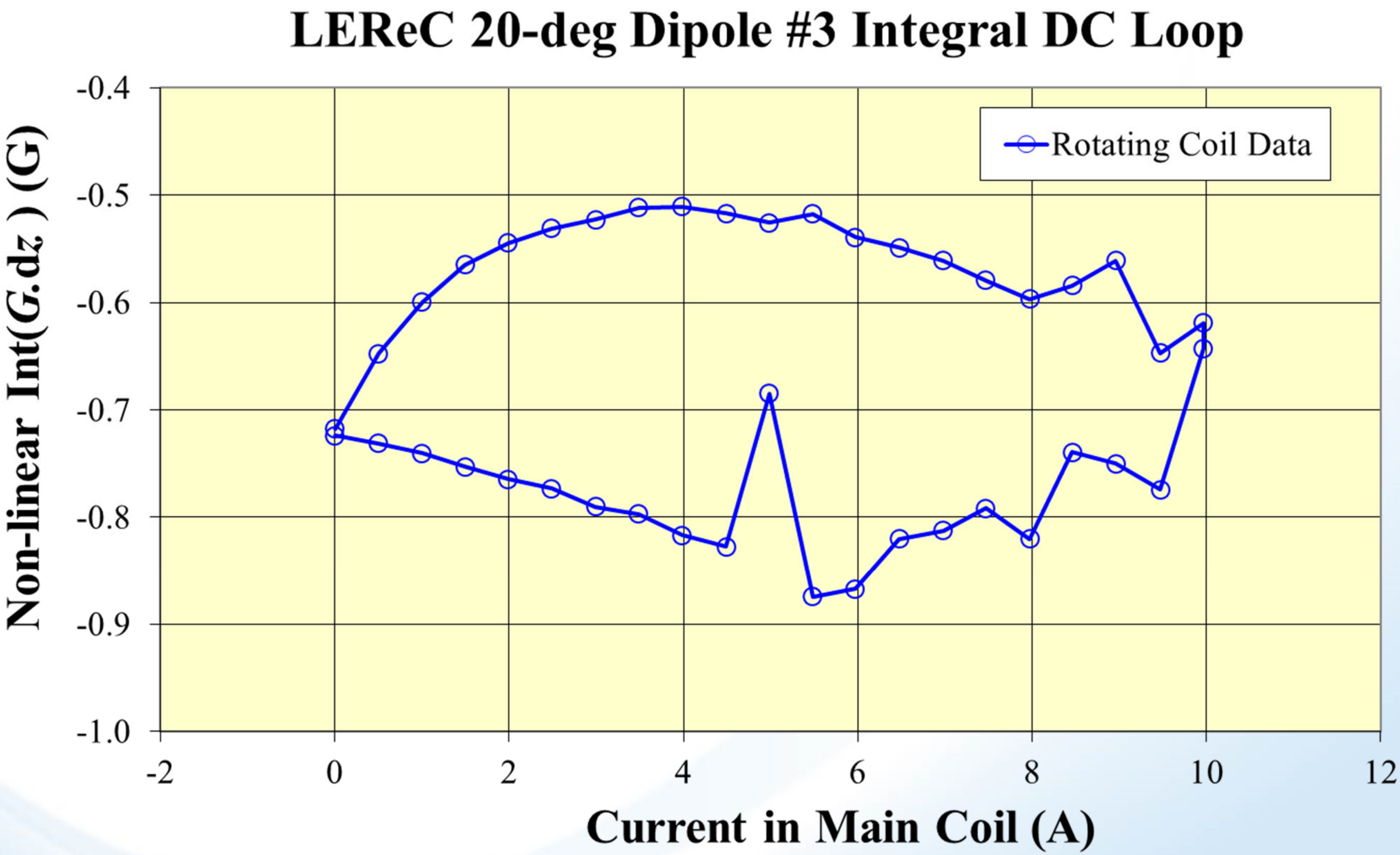
Rotating Coil Data: Hysteresis in Integral of B_y



Rotating Coil Data: Integral of $G = dB_y/dx$



Rotating Coil Data: Hysteresis in Integral of *G*



Summary of Hall Probe Measurements

Summary of Hall Probe Measurements in LEReC 20-deg Dipoles

Quantity	Dipole #1	Dipole #2	Dipole #3	Dipole #4	Mean	Std.Dev
Int(By.dz)/*I* @ 2.91 A (T.m/A)	-8.261E-04	-8.244E-04	-8.248E-04	-8.247E-04	-8.250E-04	0.09%
By(0,0,0) at 2.91 A (T)	-9.360E-03	-9.348E-03	-9.348E-03	-9.354E-03	-9.352E-03	0.06%
L_mag at 2.91 A (mm)	256.84	256.64	256.75	256.57	256.70	0.12
dL_mag/dx at 2.91 A	0.1713	0.1686	0.1797	0.1776	0.1743	0.0052
Int(By.dz)/*I* @ 7.8 A (T.m/A)	-8.180E-04	-8.171E-04	-8.166E-04	-8.173E-04	-8.172E-04	0.07%
By(0,0,0) at 7.8 A (T)	-2.494E-02	-2.492E-02	-2.490E-02	-2.493E-02	-2.492E-02	0.07%
L_mag at 7.8 A (mm)	255.81	255.74	255.80	255.73	255.77	0.04
dL_mag/dx at 7.8 A	0.1739	0.1729	0.1759	0.1731	0.1740	0.0014
Hysteresis (Up – Dn) at 5 A (Gauss)	2.07	1.96	2.14	1.98	2.04	0.08

Summary of Rotating Coil Measurements

Summary of Rotating Coil Measurements in LEReC 20-deg Dipoles

Harmonics at 25 mm radius (at 10 A, background subtracted)

Quantity	Dipole #1	Dipole #2	Dipole #3	Dipole #4	Mean	Std.Dev
Int(By.dz)/*I* (T.m/A)	8.084E-04	8.078E-04	8.061E-04	8.080E-04	8.076E-04	0.13%
Roll Angle (mrad)	-1.08	-0.88	-0.92	-0.96	-0.96	0.09
Normal Quadrupole (units)	-172.600	-173.346	-172.009	-172.150	-172.526	0.602
Normal Sextupole (units)	2.793	2.715	2.475	2.706	2.672	0.137
Normal Octupole (units)	0.218	0.239	0.195	0.207	0.215	0.019
Normal Decapole (units)	0.667	0.672	0.672	0.671	0.671	0.002
Normal 12-pole (units)	0.018	0.019	0.024	0.019	0.020	0.003
Normal 14-pole (units)	0.050	0.050	0.052	0.050	0.051	0.001
Normal 16-pole (units)	0.002	0.002	0.001	0.001	0.001	0.000
Normal 18-pole (units)	-0.001	-0.001	-0.001	-0.001	-0.001	0.000
Skew Quadrupole (units)	0.752	-0.448	0.978	0.425	0.427	0.626
Skew Sextupole (units)	-0.088	0.080	0.033	0.053	0.019	0.074
Skew Octupole (units)	0.099	0.103	0.152	0.113	0.117	0.024
Skew Decapole (units)	0.000	-0.003	0.003	0.005	0.001	0.003
Skew 12-pole (units)	0.012	0.011	0.015	0.013	0.013	0.001
Skew 14-pole (units)	0.002	0.002	0.000	0.001	0.001	0.001
Skew 16-pole (units)	0.000	0.000	-0.001	0.000	0.000	0.000
Skew 18-pole (units)	0.000	0.000	0.000	0.000	0.000	0.000

Summary

- Measurements of all four LEReC 20-deg dipoles are completed.
- Issues exist for measuring the minor field components using the 3-axis Hall probe. An extensive calibration of the system is required for reliable measurements of the minor components.
- It is desirable to have temperature stabilization for the probe to further improve resolution and stability of calibration.
- Integral field measured by the Hall probe and the rotating coil agree within ~ 0.1% .
- The integrated field strength is slightly lower than the computed strength (< 1% difference)
- Integral field measurements using rotating coil do not show any significant higher order harmonics, except for the quadrupole term due to the geometry of the magnet.