Results of Magnetic Measurements in LEReC Solenoid #1 (Sl. No. 16046)

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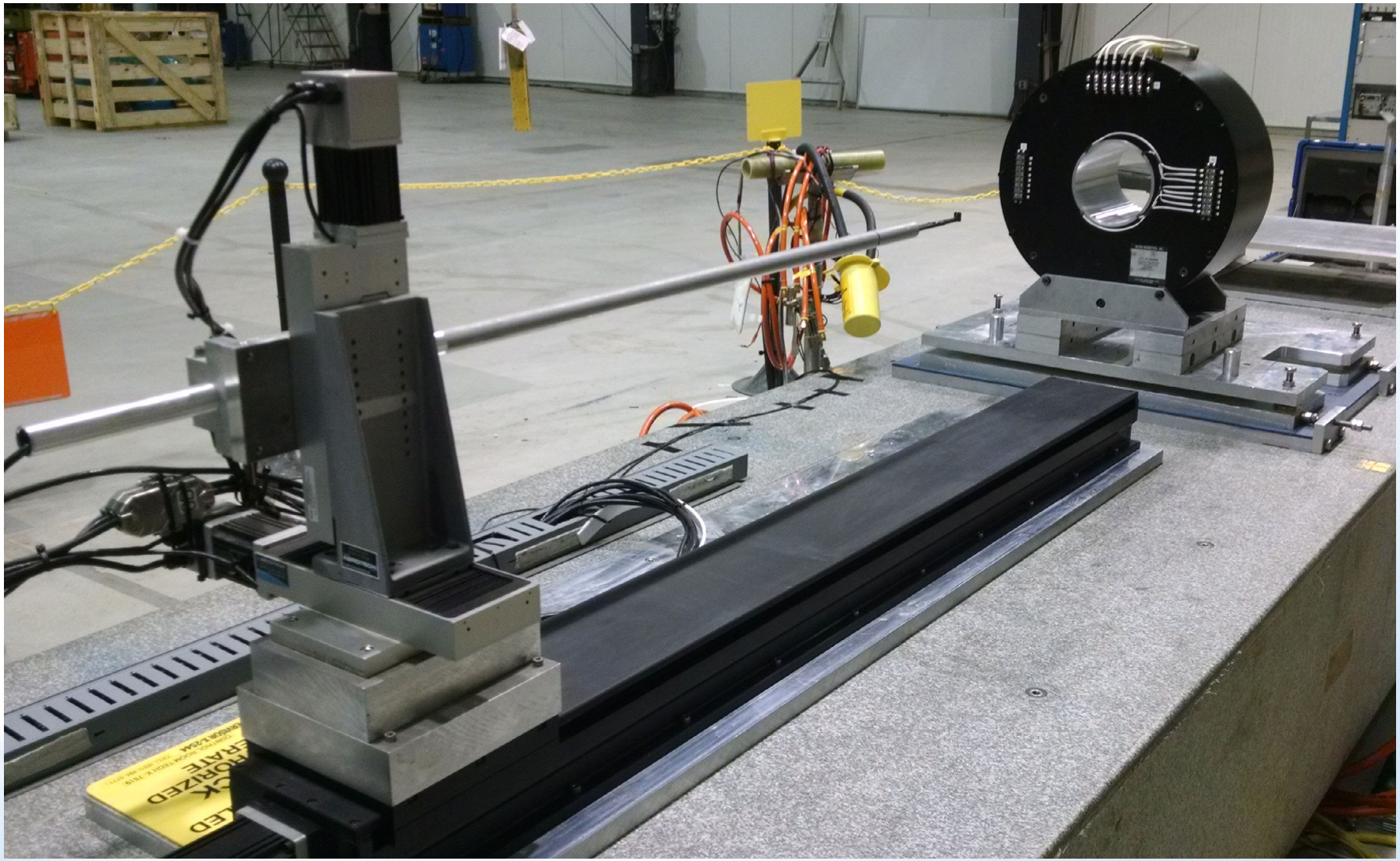
LEReC Solenoid Details

- 3 Solenoid coils – One *Main coil* and two *Bucking Coils:*
  - The Bucking Coils are expected to reduce the fringe field from the main solenoid to less than 1 Gauss at a distance of ~210 mm from the axial center.
  - Nominal operating current is < 15 A for all solenoid coils.
  - Goal is to get $\int [B_z(z)]^2 \, dz \geq 4 \times 10^{-5} \ \mathrm{T}^2 \cdot \mathrm{m}$
- Horizontal and vertical dipole correctors:
  - Operating current = 0.8 A (max.)
  - Expected dipole field integral ~ 10^{-5} T.m at 0.8 A.
  - Needed to correct transverse fields from any misalignment of the solenoid axis.
- 158.5 mm dia. clear aperture; 200.2 mm total length.

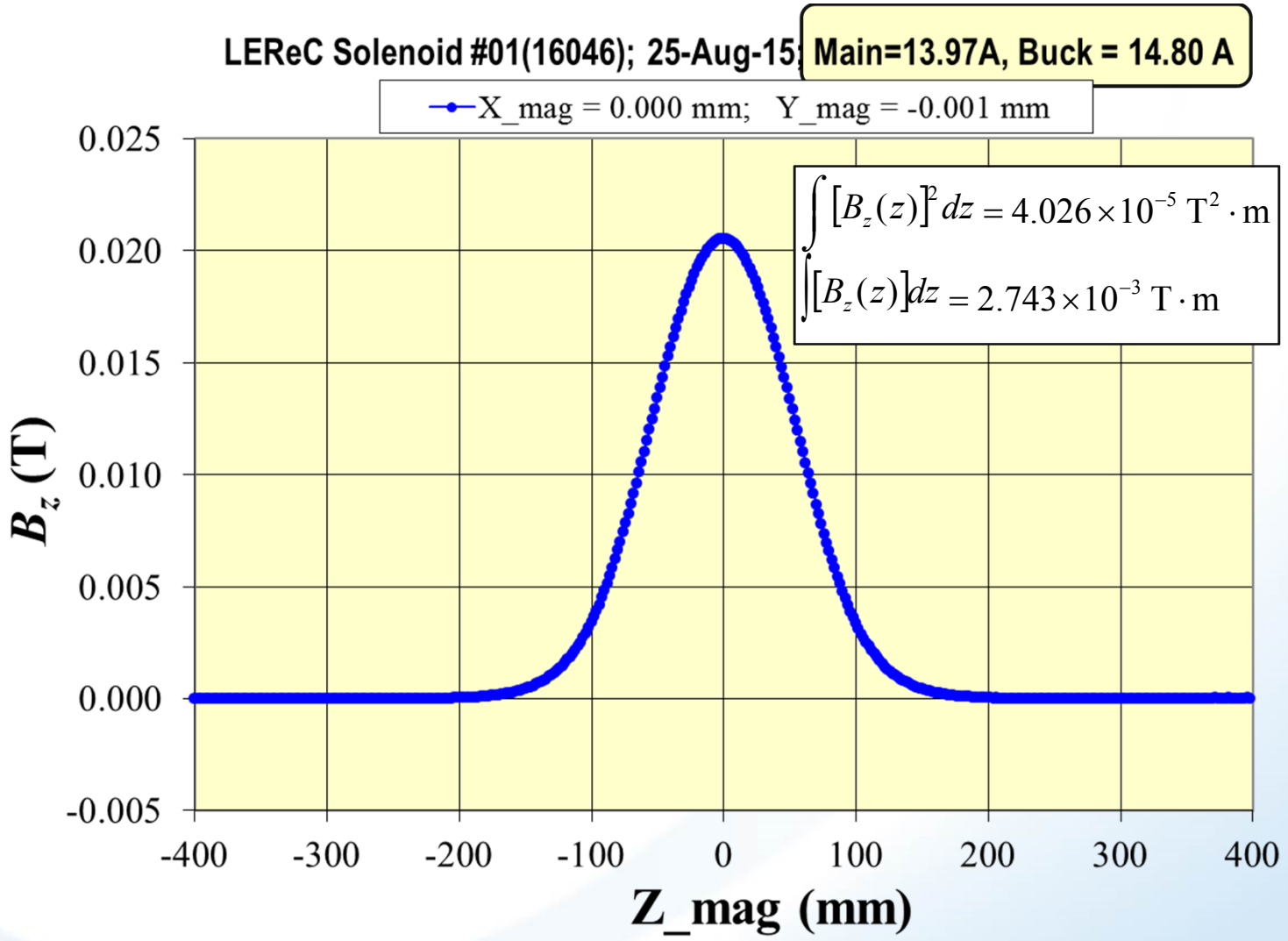
LEReC Solenoid Measurements

- Hall probe scans at a fixed current in the main and bucking solenoid coils:
  - Measured only axial component, B_z, with a single probe.
  - Currents of main and the bucking coils were determined to obtain the same fields at the axial center as in Wuzheng Meng's simulations.
    - Main current = 14.0 A, Bucking coil current = 14.8 A
  - Z-values from –400 mm to +400 mm in 2 mm steps
  - On-axis (r = 0) and every 45 deg. off-axis at r = 10 mm.
- Hall probe loop 0 A to 15 A at axial center, main solenoid only.
- Rotating coil measurements (integral coil, 0.914 m long):
  - Horizontal and vertical field correctors: full bipolar loops
  - Main & bucking solenoids separately, and all in series: loop from 0A to 15A.

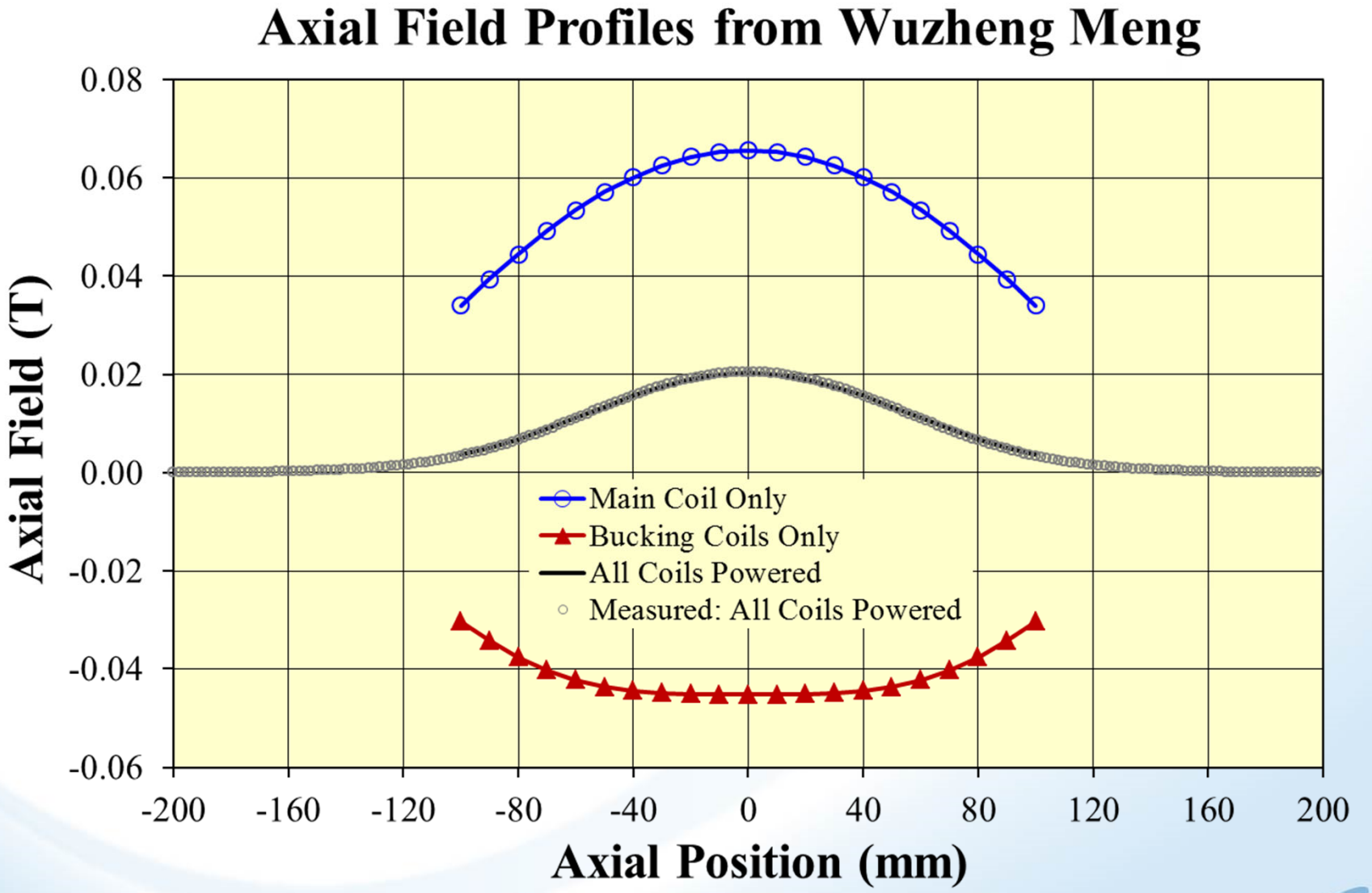
LEReC Solenoid: Hall Probe Setup



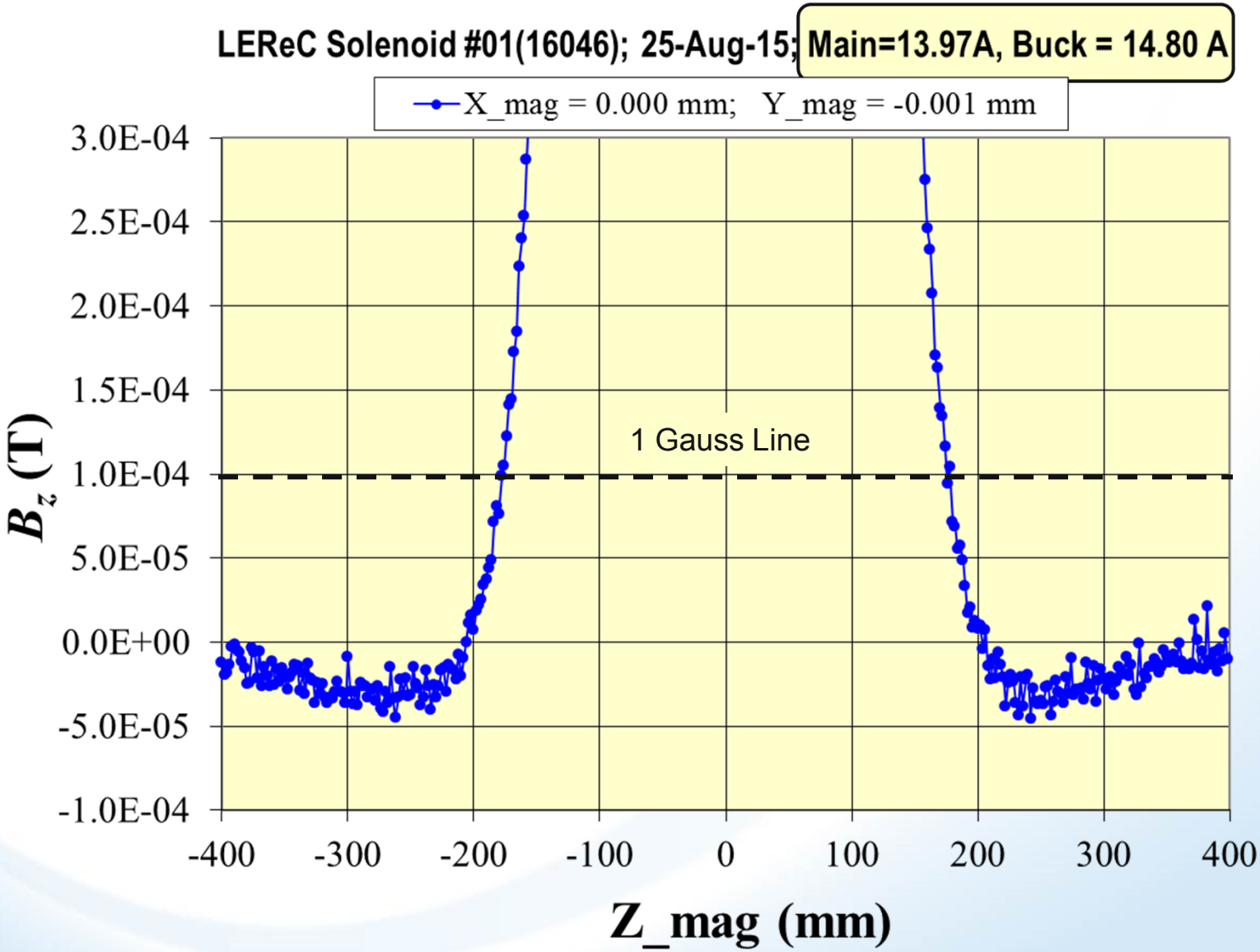
Solenoid Field Profile On-Axis (Main + Buck)



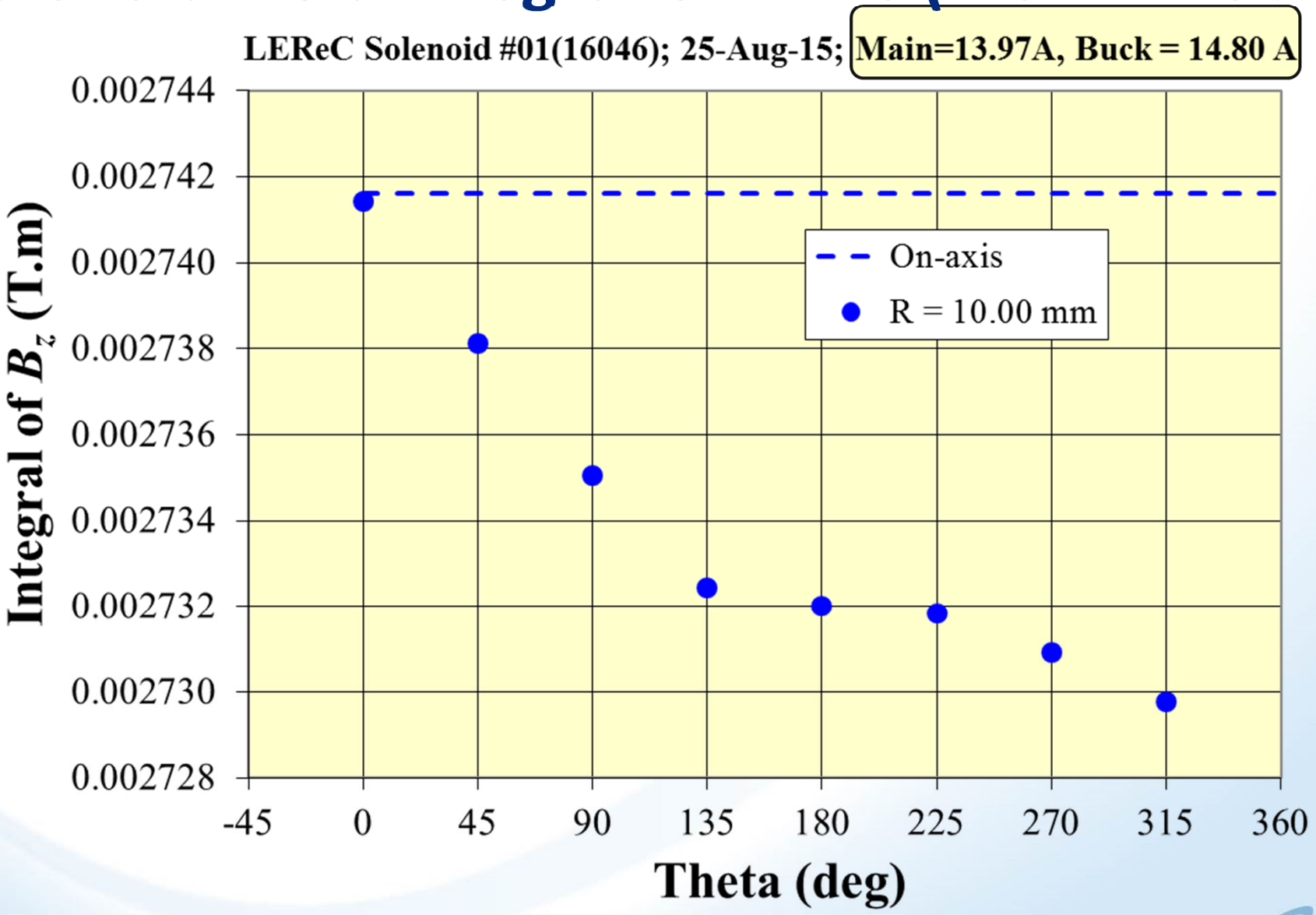
LEReC Solenoid: Computed Field Profiles



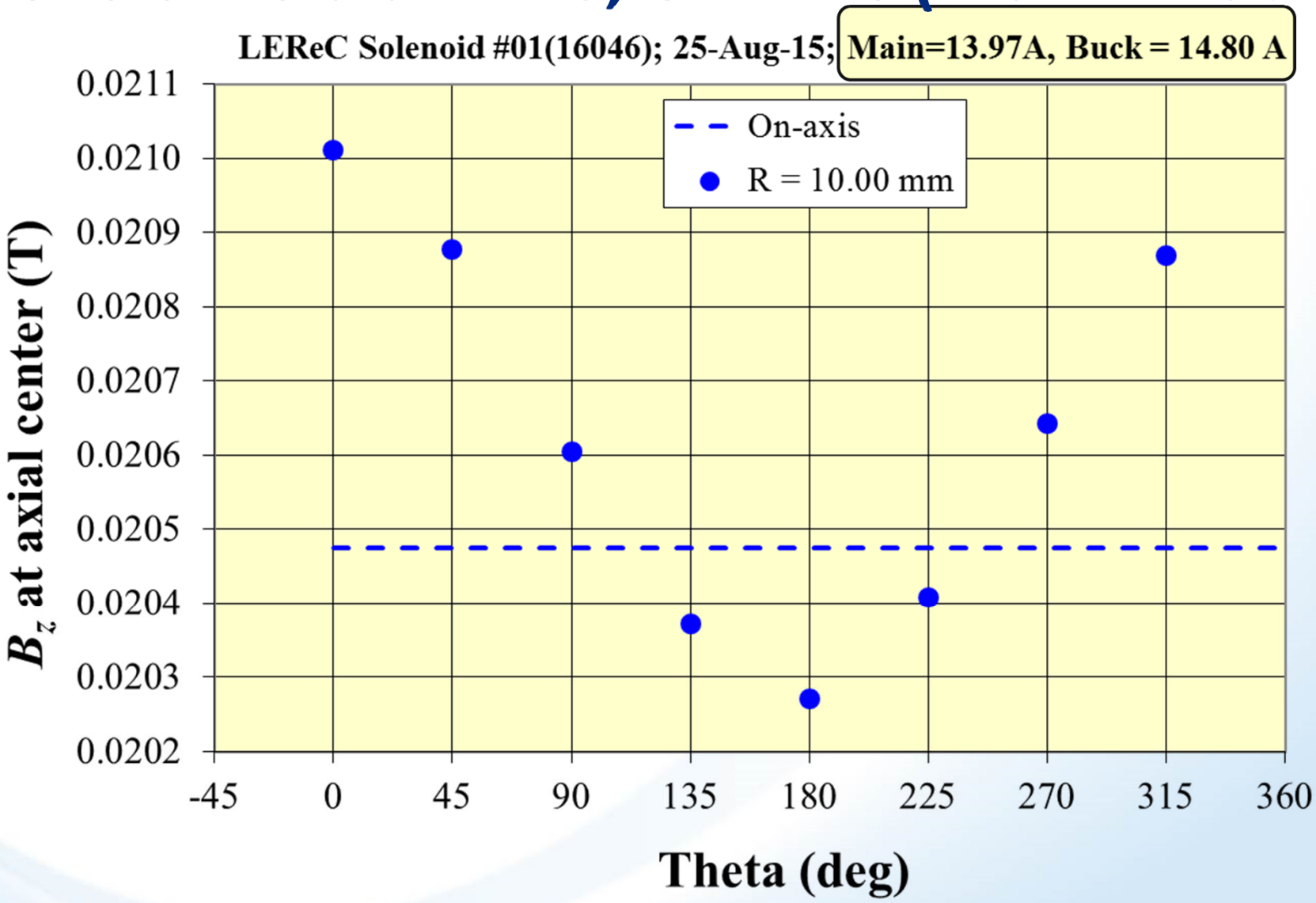
Solenoid Fringe Field On-Axis (Main + Buck)



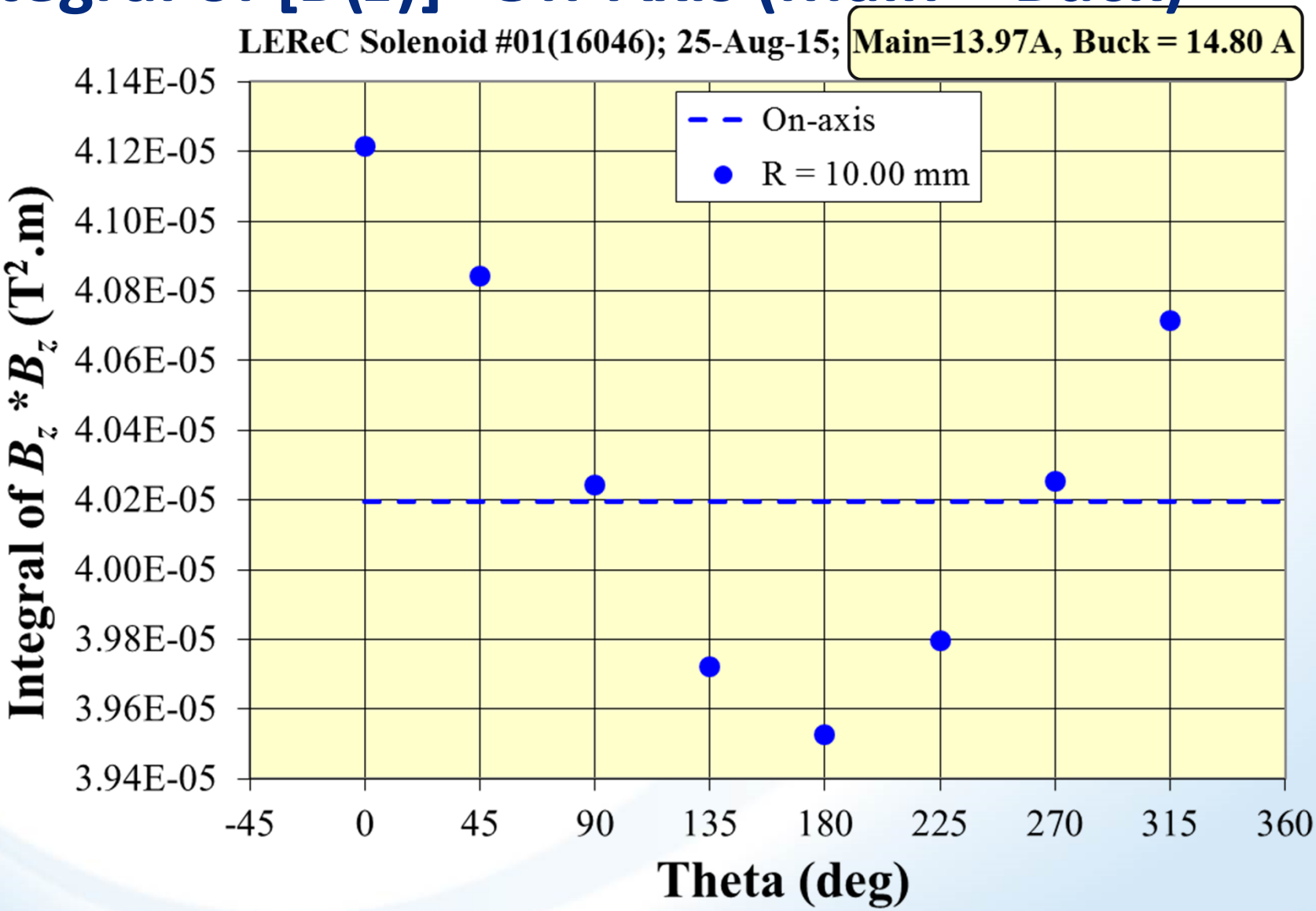
Solenoid Field Integral Off-Axis (Main + Buck)



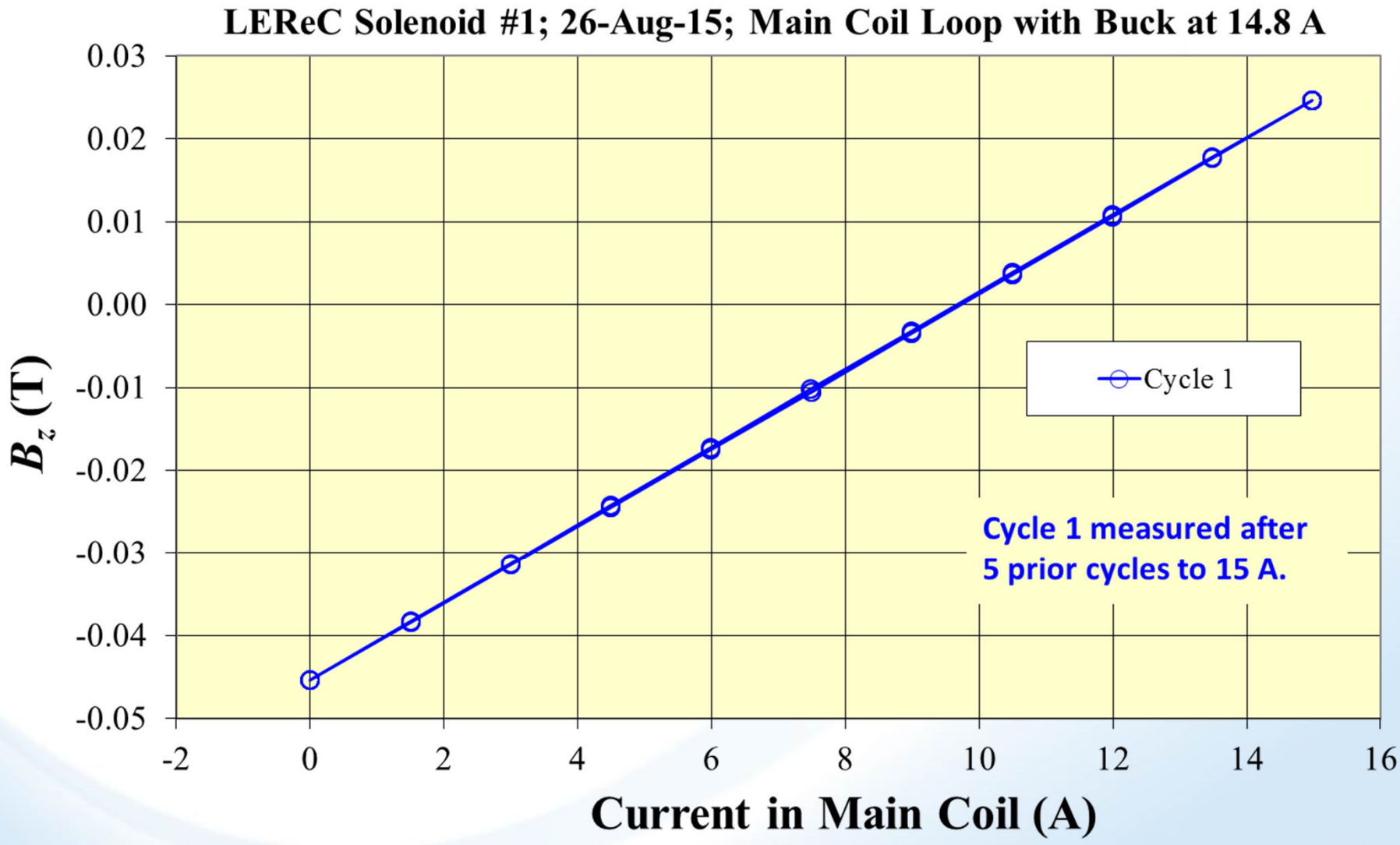
Solenoid Field at Z = 0, Off-Axis (Main + Buck)



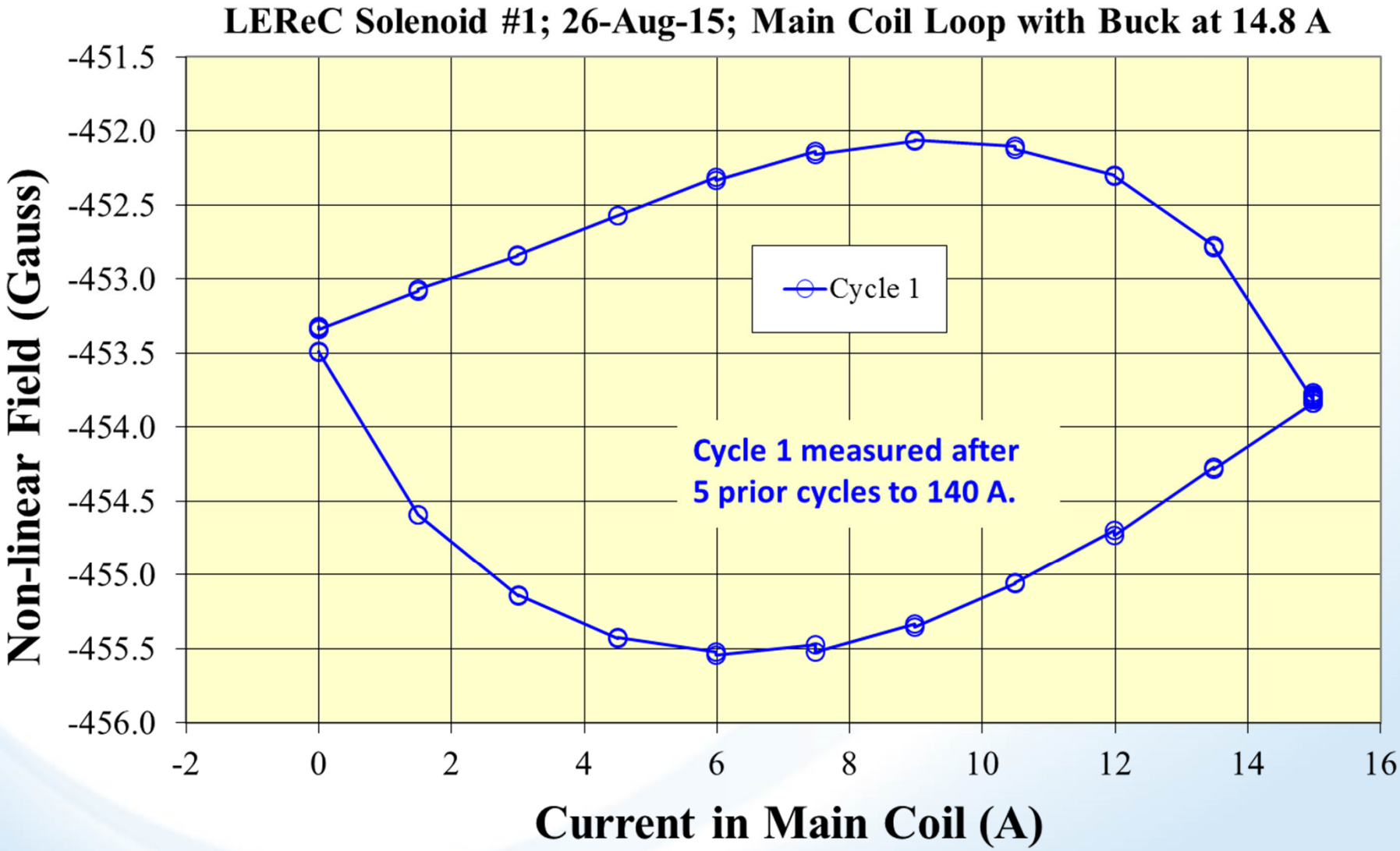
Integral of $[B(z)]^2$ Off-Axis (Main + Buck)



DC Loop in Main Coil at (*r*,*z*) = (0,0)



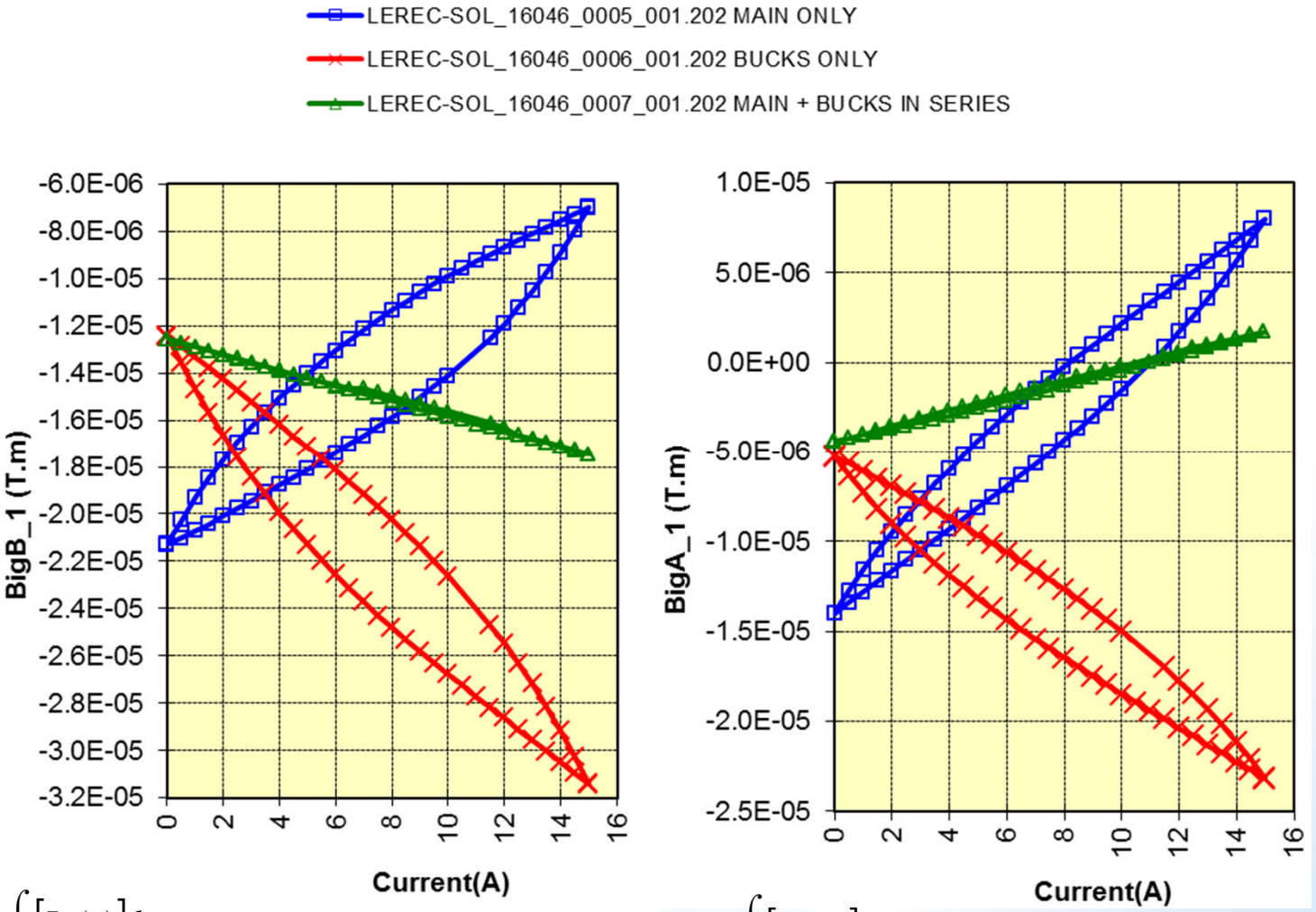
DC Loop in Main Coil at (*r*,*z*) = (0,0)



Rotating Coil Measurements

- Measuring coil is 0.914 m long, but the magnet is only 0.2 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 15 A for solenoids and +0.8A and –0.8 A for the correctors). 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 +15 A for solenoids and –0.8 A to +0.8 A for the correctors). 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.
  - Results from both methods are nearly identical.
  - Only the full excitation curve results are presented here.

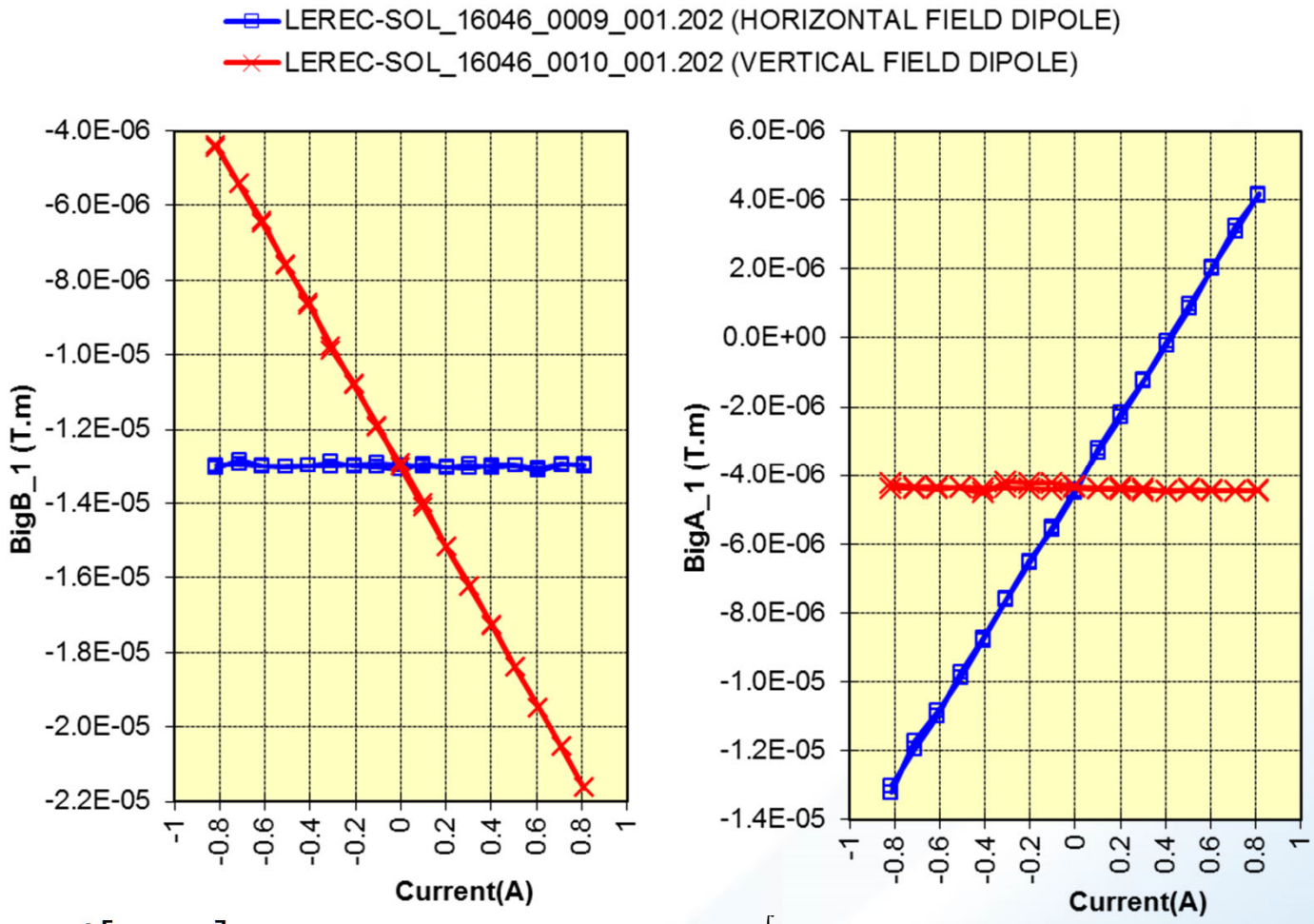
Solenoid Transverse Field Integrals



$$\int [B_y(z)]dz = 9.035\times10^{-7}\ \text{T}\cdot\text{m/A (Main)}$$
$$= -1.208\times10^{-6}\ \text{T}\cdot\text{m/A (Bucks)}$$
$$= -3.230\times10^{-7}\ \text{T}\cdot\text{m/A (Main + Bucks)}$$

$$\int [B_x(z)]dz = 1.411\times10^{-6}\ \text{T}\cdot\text{m/A (Main)}$$
$$= -1.151\times10^{-6}\ \text{T}\cdot\text{m/A (Bucks)}$$
$$= 4.111\times10^{-7}\ \text{T}\cdot\text{m/A (Main + Bucks)}$$

Corrector Field Integrals



$$\int [B_y(z)]dz = -1.061\times10^{-5}\ \mathrm{T\cdot m/A}$$

$$\sim 8.49\times10^{-6}\ \mathrm{T\cdot m\ at\ 0.8\ A}$$

$$\int [B_x(z)]dz = 1.058\times10^{-5}\ \mathrm{T\cdot m/A}$$

$$\sim 8.46\times10^{-6}\ \mathrm{T\cdot m\ at\ 0.8\ A}$$

Expected Transverse Field Integrals

- With main solenoid coil at 13.97 A and the bucking solenoid coils at 14.8 A, the expected transverse field integrals are:

$$\int [B_y(z)]dz = -5.257 \times 10^{-6}\ \mathrm{T \cdot m} \qquad \int [B_x(z)]dz = 2.677 \times 10^{-6}\ \mathrm{T \cdot m}$$

(neglecting any background fields)

- The axial field integral is $\int [B_z(z)]dz = 2.743 \times 10^{-3}\ \mathrm{T \cdot m}$
- This implies a misalignment of ~ 2 mr in pitch and ~ 1 mr in yaw. This could either be from misalignment of solenoid magnetic axis to the mechanical axis, or a misalignment of the measuring coil, or both.

Summary

- Hall probe scans were carried out to measure only the B_z component of the field – both on-axis, and at r = 10 mm.
- The magnet meets the focusing strength requirement.
- The fringe field drops to less than 1 Gauss well before the expected 210 mm from the center.
- There is a hysteresis of ~3.5 Gauss in the field from the main solenoid coil at the center of the magnet (with I_{buck} = 14.8 A)
- The corrector strengths are approx. 85% of the expected strengths, but are sufficient to compensate for the level of transverse fields seen in magnet #1 (serial #16046).
- The measured misalignment of magnetic and mechanical axes is ~2 mr in pitch and ~1 mr in yaw, but could be measurement error because of uncertainty in rotating coil placement.