Hall Probe Studies in Solenoids and High Field Dipole Magnets

@ Fermilab

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For Magnet Systems & Technical Division / Fermilab

Focusing Solenoids for HINS

(High Intensity Neutrino Source)

Project to build the front end (β<1) of a high intensity (40mA) H^- linac (Meson area)

Magnet considerations began ~spring 2005

Magnet Designs Constrained by

Available Slot Length, Field Integral

Low B-Field on nearby RF cavities (<1 μT)

~5 T(+30%) Sc Solenoids w/ Bucking Coils

solution for several RF sections (DTL, SS-1, 2)

r ~25 mm, L~120 mm

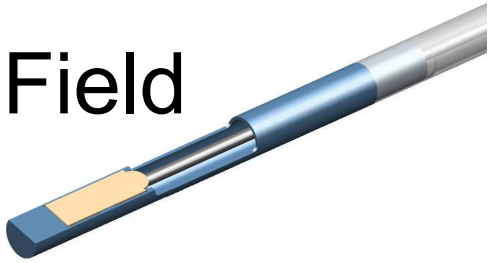
(Variations on the requirements, design details)

New: Embed {H,V} Dipole Steering Corrector Coils

R&D solenoid Field mapping interests

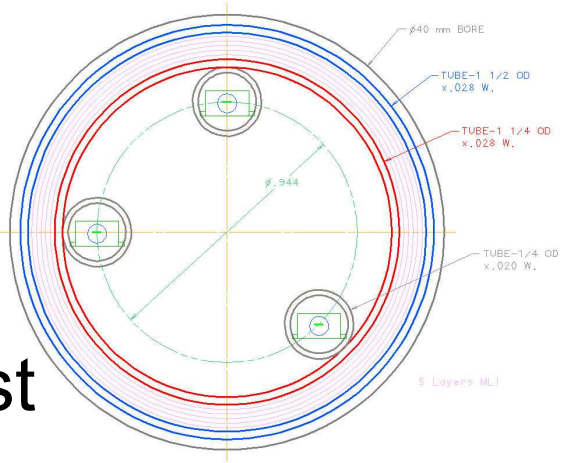
- Validate 2D Model (as-built)
- Investigate other effects for design choices
  - Axial Field profiles and integrals
    - Main Coil, Bucking Coils, Combination
    - Dipole corrector coils
  - Radial Field profiles and solenoid alignment
  - Peak Field, transfer function
    - Main Coil, Bucking Coils
  - Stray Field levels
    - Bucking Coil effectiveness (Versus distance from solenoid)
    - Hysteresis from Iron Yoke
    - Hysteresis from superconductor(d_{eff})
- *Reality:* Second to Quench Performance Studies
  - 500 Liter LHe dewars ➔ { $, *time* } limited

Initial Design Concepts (2005) for Field Mapping studies in R&D test dewar:



3-axis Hall Probe (and fluxgate magnetometer)

vertical support, {r, θ, z} motion



This Motion System *Not Built*:

- shortage of designer resources
- concerns: vibration, coverage, cost
- time for measurements, analysis

Hall Probes Acquired/Used:

3D, 10 T (Senis / GMW)

1D, 3 T axial & transverse (Group3)

Simple Probe Positioning System Evolved:

Vertical Drive with "z" position encoder (0.1mm)

Shafts with close fit to warm bore inner diameter

bore conveniently matched to VMTF HFM bore

centering probe holders, adapted to shafts

stainless shaft, alum. holder for axial 1D

watch out for "stainless" screws, holder

G10 shaft w/bearings, G10 mount for 3D

Visual angle marks, manual rotation

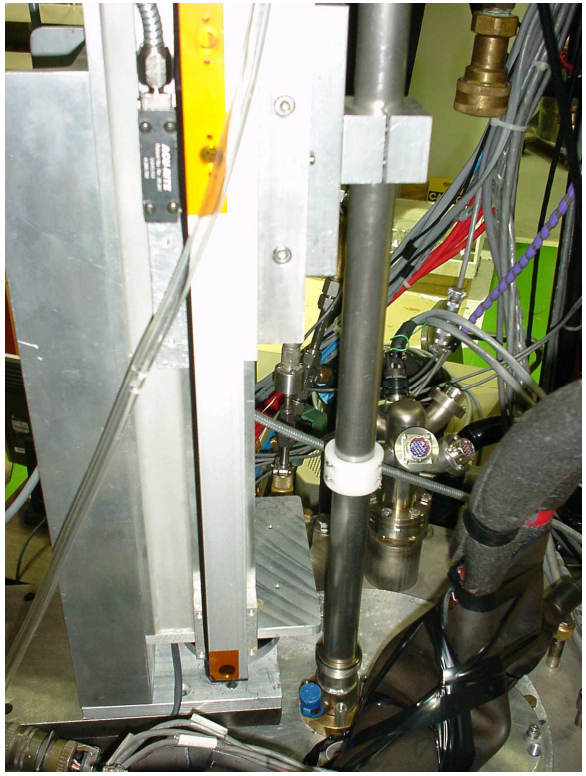
Still in R&D phase –

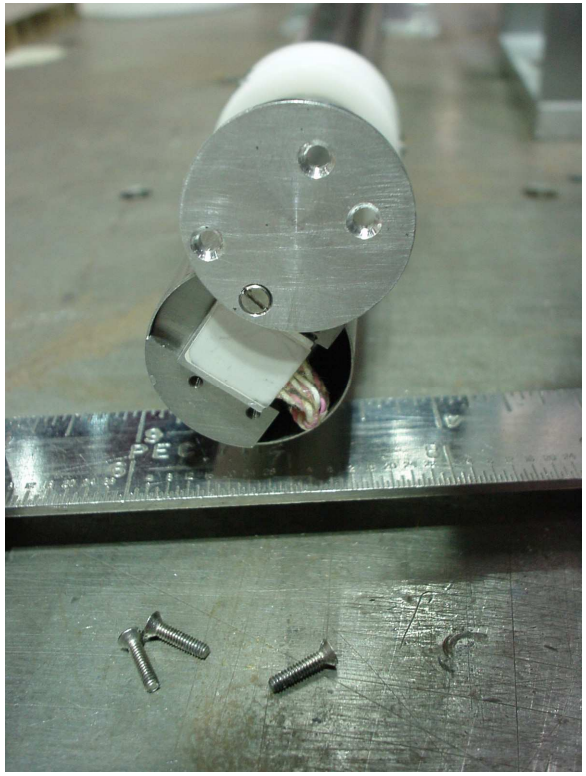
Learning how to make both magnets and measurements

requirements still somewhat "vague"

not particularly "challenging" (?)

Stand 3 Probe positioning hardware



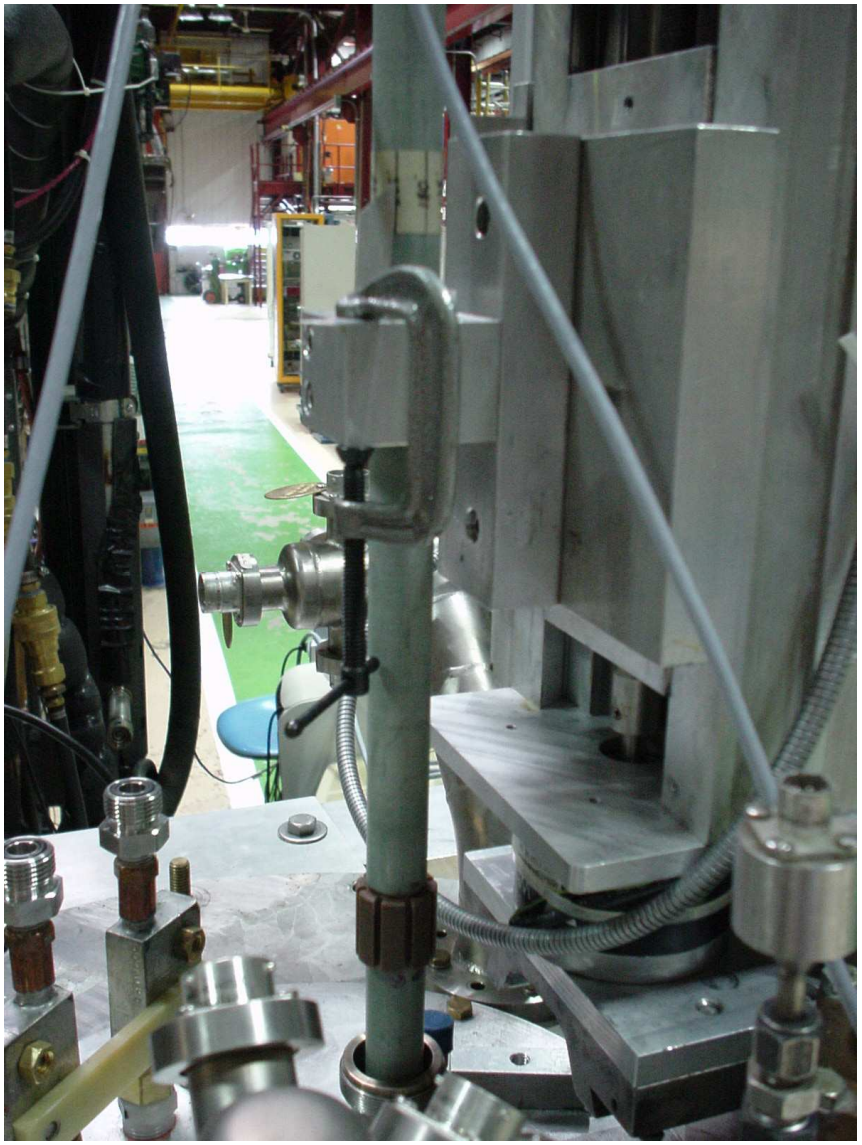


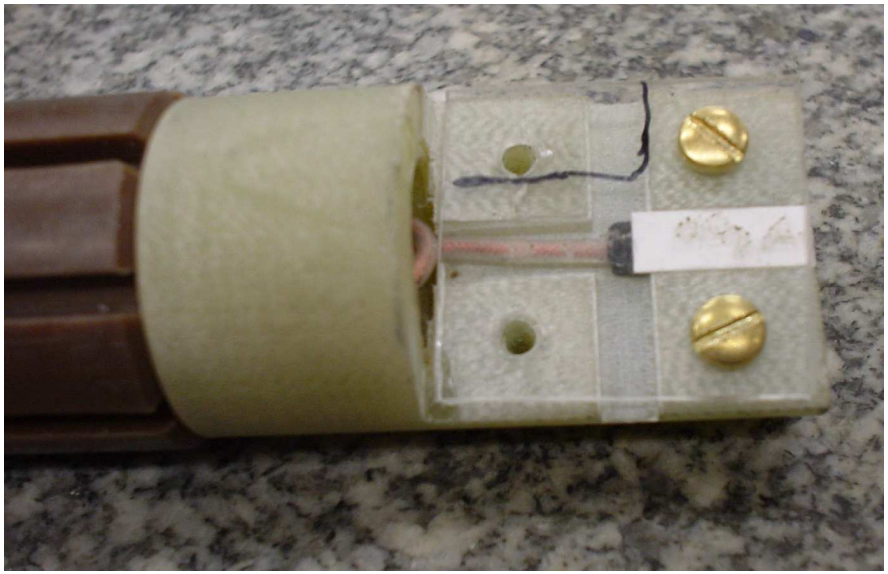
Test Assembly with solenoid mounted

z-drive and stainless shaft entering bore

1D axial Hall probe configuration

Stand 3 Probe positioning hardware





3D (and 1D transverse) Hall probe positioning holder

orientation options:

r=0 on, >0 off axis

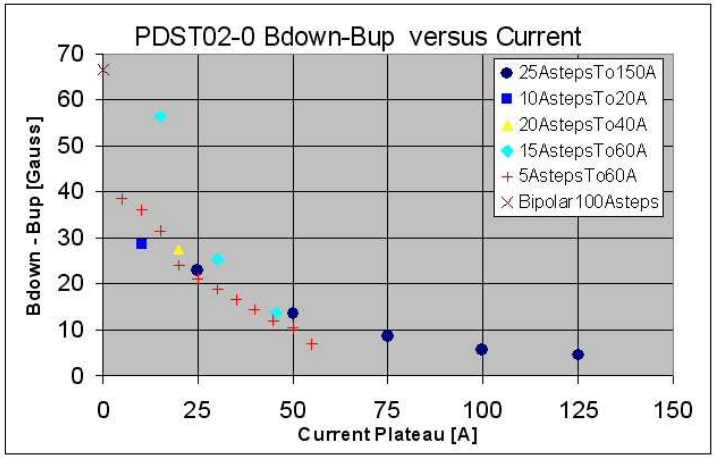
G10 shaft and bearings with visual angle marks

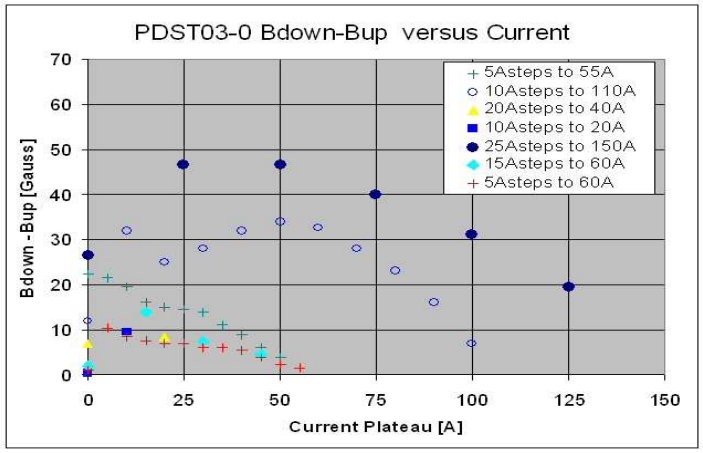
Current and Data Acquisition

- Kepko Trim PS (0.5A) for warm measurements
  - precision shunt Resistor
- Lakeshore 4 x 125A Sc magnet PS (SSC)
  - Danfysik transductor current signal
    - Cross checked with precision shunt resistor (~.1%)
  - MTF Precision vme/unix readout (HP3458)
  - 3 pairs of power leads for flexibility in coils powered
- 1D Probe Digitization: DTM-141
- 3D Probe Digitization: Keithley 2700 DMM
  - some readout instability: instrument ground issues ?
    - Have not had time to systematically study this
- Visual and Labview readout of { B, I, z }
  - *Synchronization not easy …*
    - Measure on current plateaus, steps in z

3 Test Solenoid Data Sets

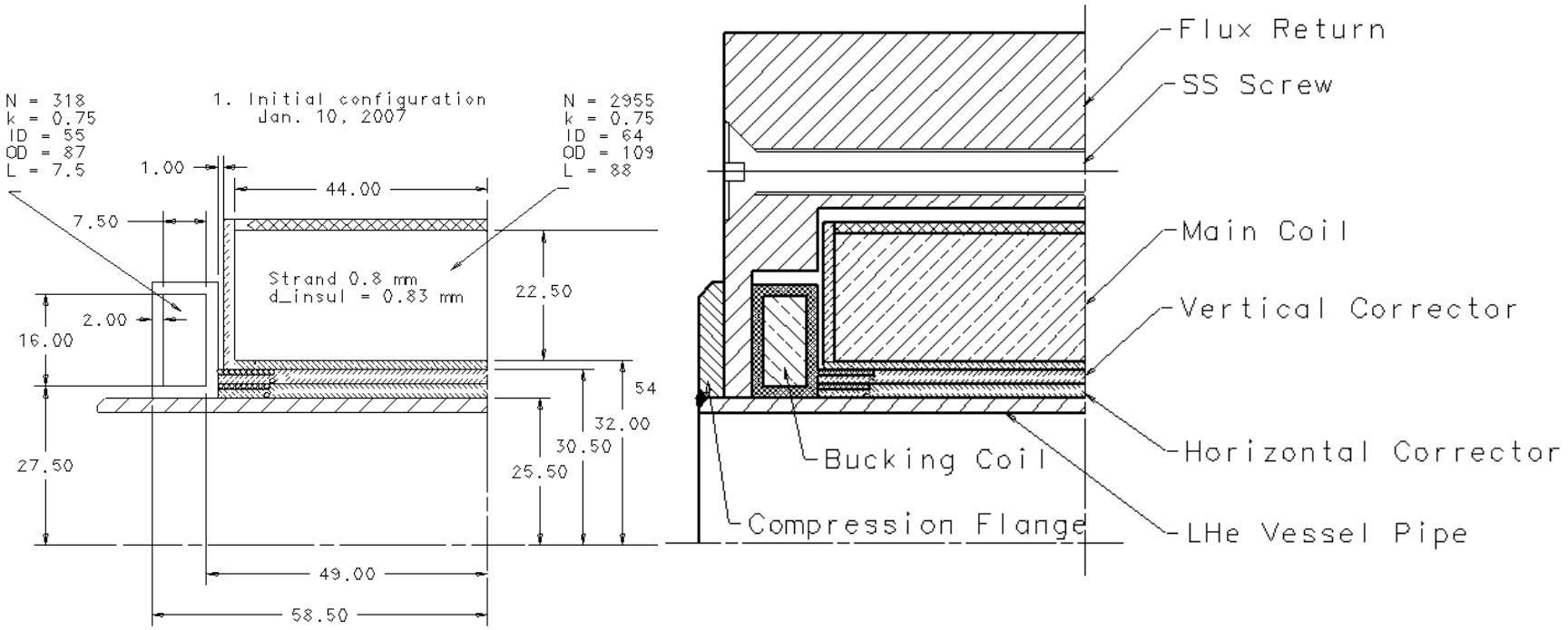
- PDST01-3 (ASC, Sept. 2006) Main Coils only; 1 w/Fe yoke
  - B vs Z on axis w/ 1D, 3T probe (not at I_{nom})
    - nice agreement with 2D model (strength to ~1%)
  - Hysteresis Studies vs $SCond^{r}$ (d_{eff}) for *bare* coil (at r=z=0)
    - Soft iron yoke hyst. not seen (magnetic screw problem)
    - complicated by Phase difference in B, I digitiz^{n}
    - [$B_{up\ ramp}(I) - B_{dn\ ramp}(I)$] is clean meas. of width
    - complex (& history dependent); interesting, but…need to model
    - flux return will change it, and magnetic shielding needed anyway
      - » So, no further study made of this.





3 Bucked Coil Solenoid Data Sets

- HINS_CH_SOL_01 to _03 (_04 test not yet completed)

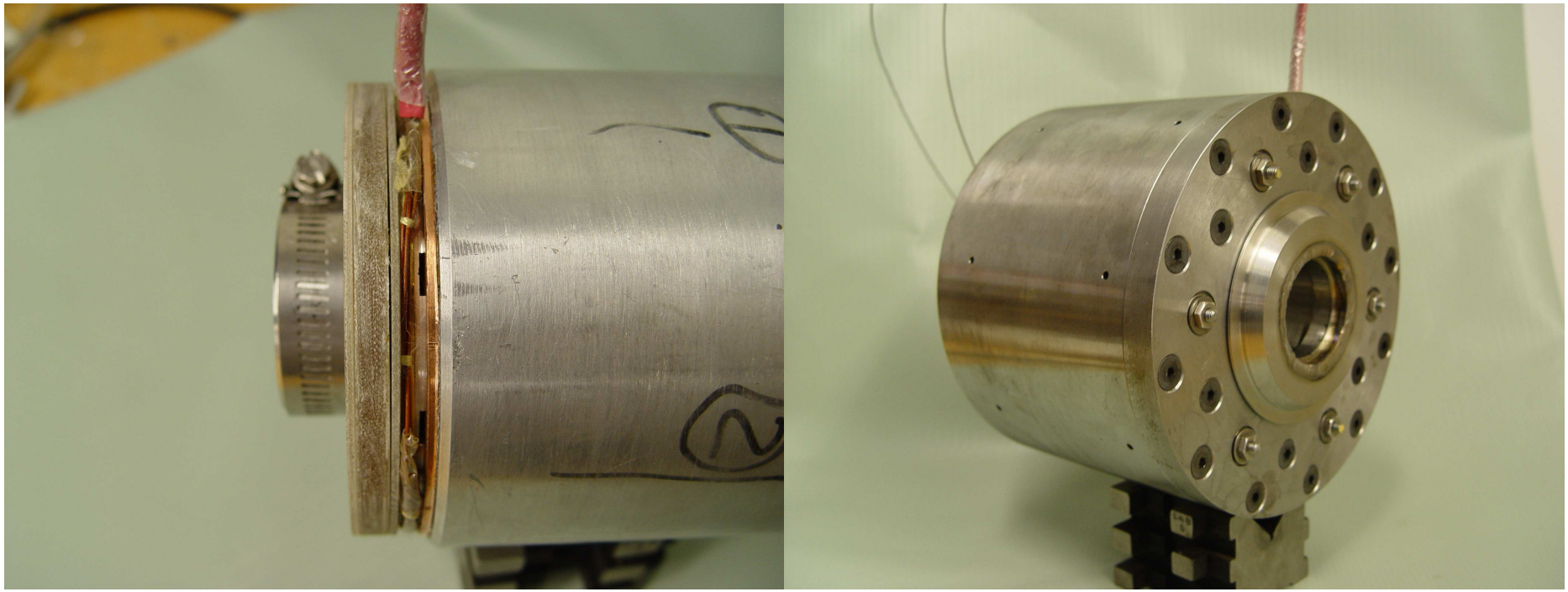


Nominal Coil Dimensions Packaged with Iron Yoke

"type 2" with Dipole coils ("type 1" is without them)

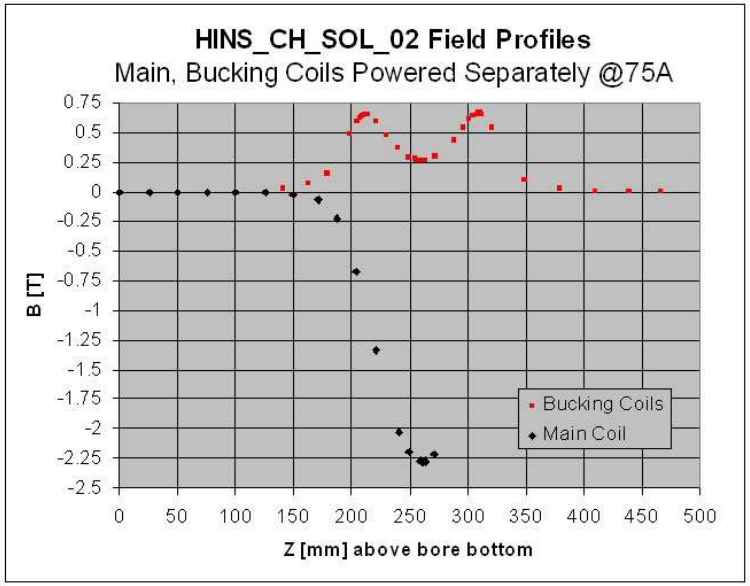
I_{nom} ~ 180 A, (I_{quench} ~ 230 A) B_{peak} ~ 5.5 T (B_q ~ 7 T)

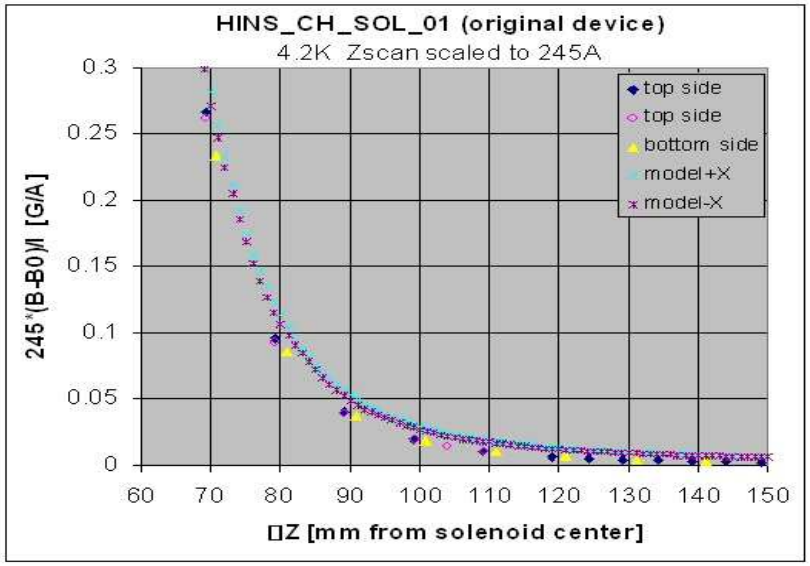
Bucked Coil Solenoid

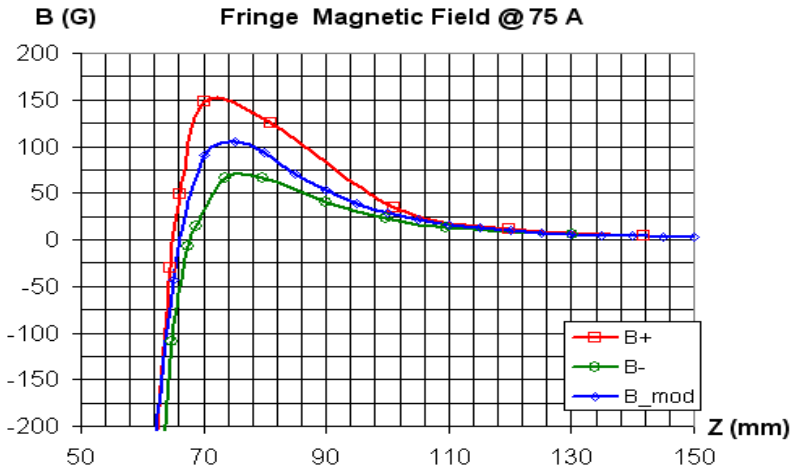


Bucked Solenoid Axial Profiles

- Bucking coil effectiveness
  - Asymmetry easily seen (coils not always nominal winding parameters)
  - Fringe field has been ~ as expected
  - Somewhat better than the 2D model in some cases (although the bucking coil design has evolved somewhat)







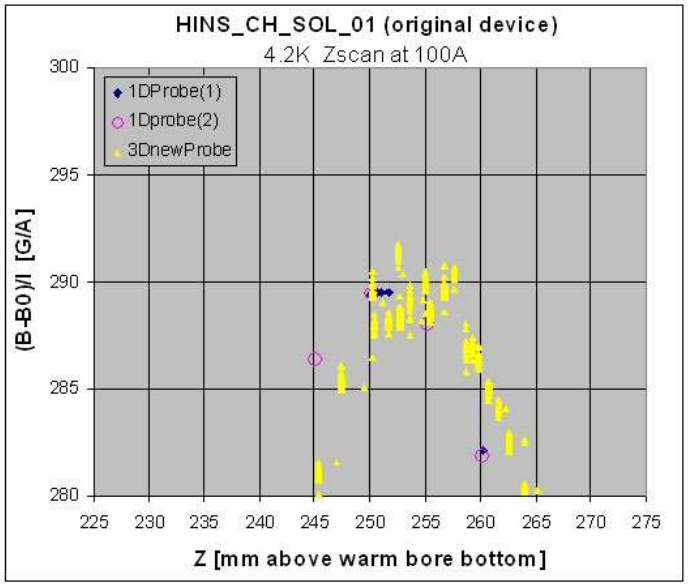
See PAC 2007 paper

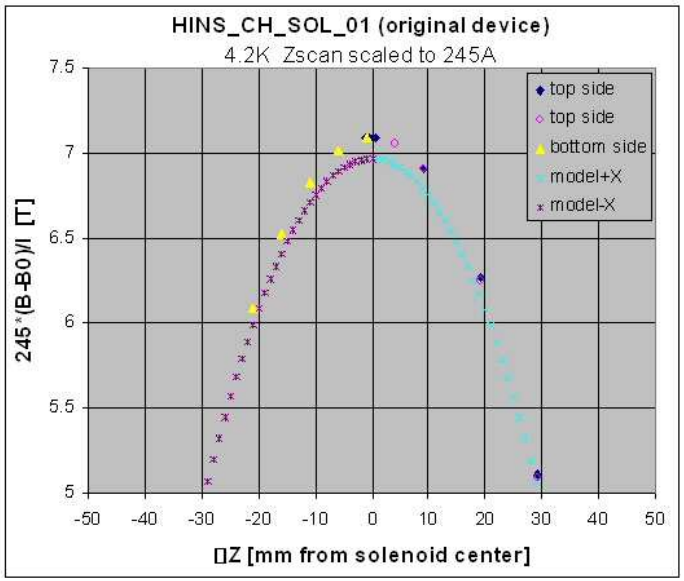
Bucked Solenoid Axial Profiles

- Model shape agrees well in all regions
- Peak B/I (100A) good to 1-2%
- Have yet to measure B(*I*~*I*q)

3D probe readout was not as consistent at the same level as 1D; seen with two separate probes in several magnets.

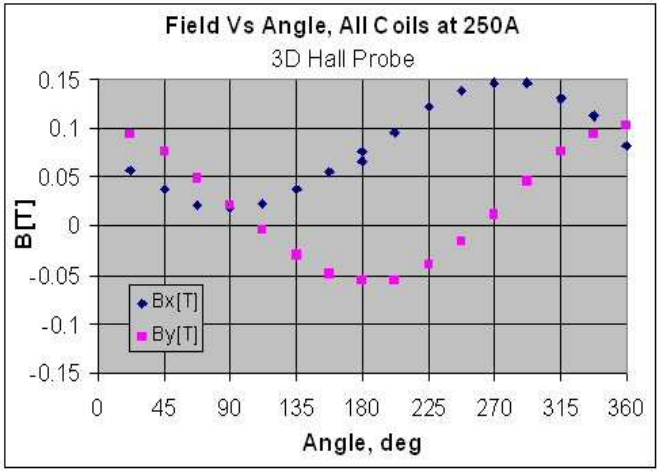
Not systematically investigated for lack of time, but more careful attention to cable shield and instrument grounding setup is needed.

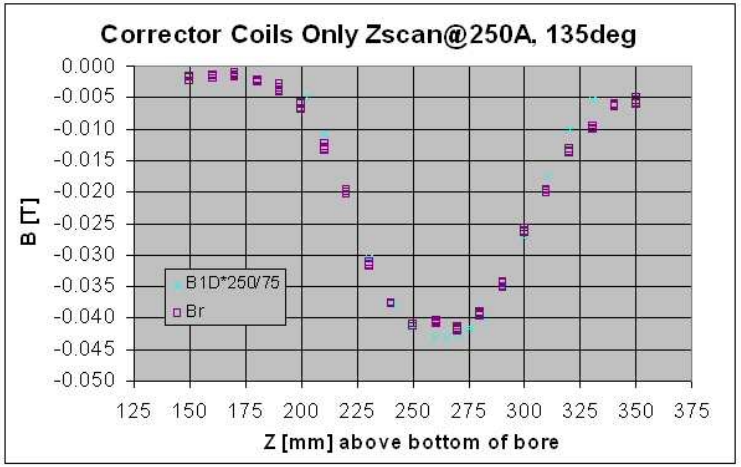


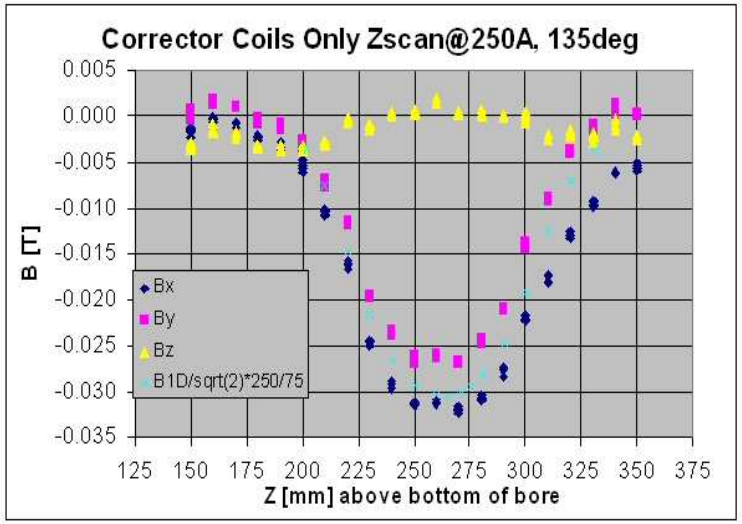


Solenoid Angle and Axis Determination

- Angle scans Using 3D probe (on axis in holder; off-axis not yet studied for lack of time)
  - Power coils separately to disentangle contributions
  - Find corrector dipole angles (rel to external features)
  - agrees with expected angle
  - Profile agrees with 1D /sqrt(2)

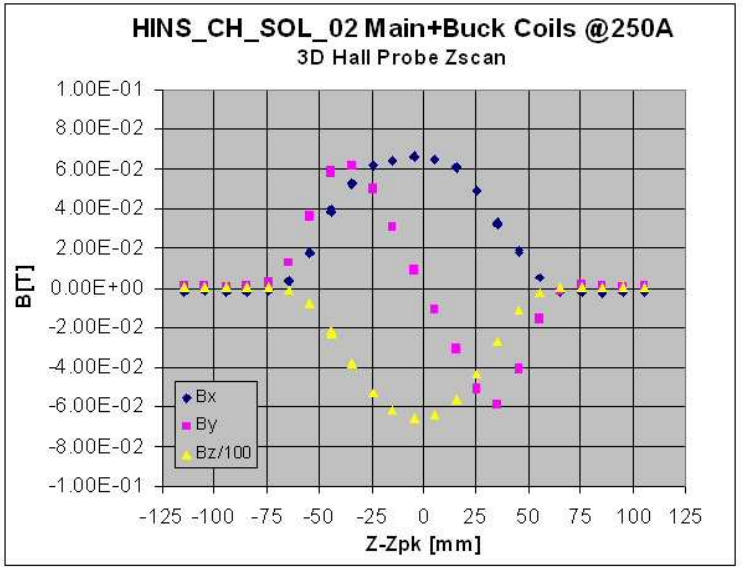


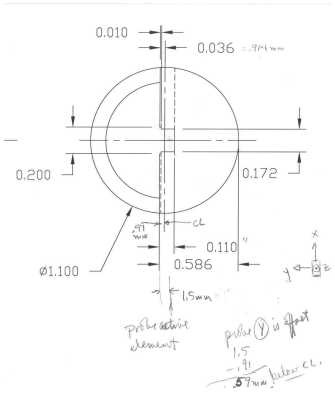


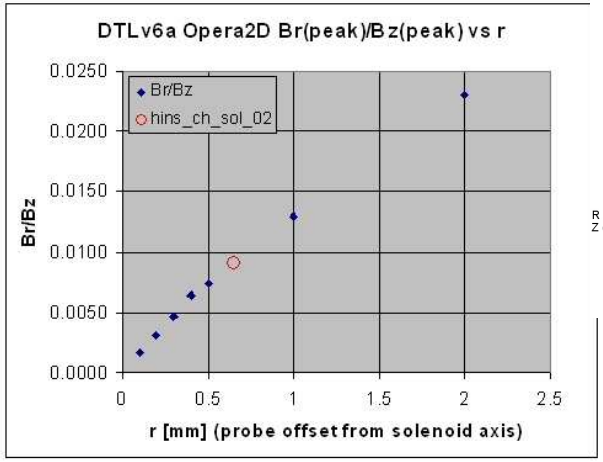


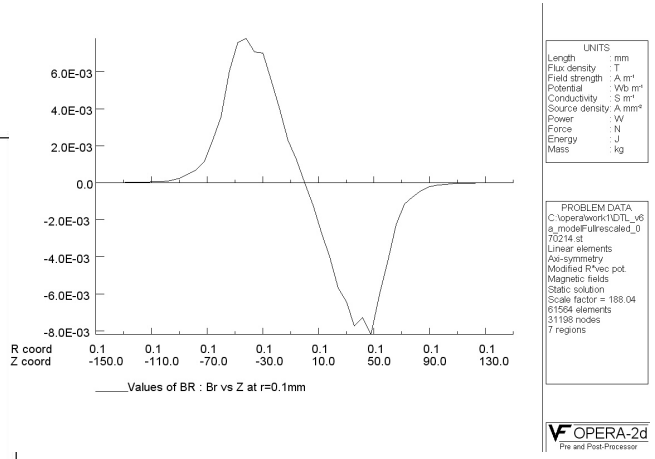
Solenoid Angle and Axis Determination

- Z scans at fixed angle
  - Solenoid is very well centered around the warm bore
  - Bx Contributions probably from probe tilt and slight axis offset
  - By Contributions from axis offset
    - Use 2D model to predict sensitivity
    - Agrees with actual offset in probe support: estimate is 0.065 mm
    - Drawings show Hall element is offset in r by -0.059 mm







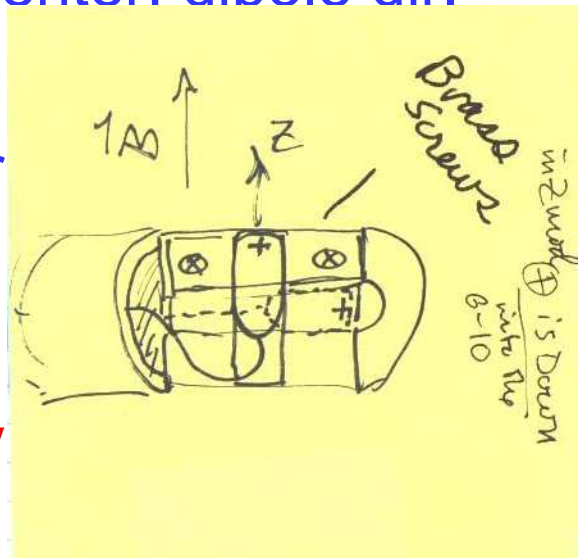


Solenoid Summary

- Time constraints have limited our progress
- Axial measurements w/1D probe
  - Nice agreement with model in shape (integral)
  - Peak transfer fn agrees to 1-2%
    - Measured well below the operating current
- 3D probe axial and angle studies
  - Still some signal stability issues to figure out at 1-2% level
  - Still “on axis”; will expand these in near future
  - Evidence we can get Br, axis information

3D 10 T Dipole Measurement

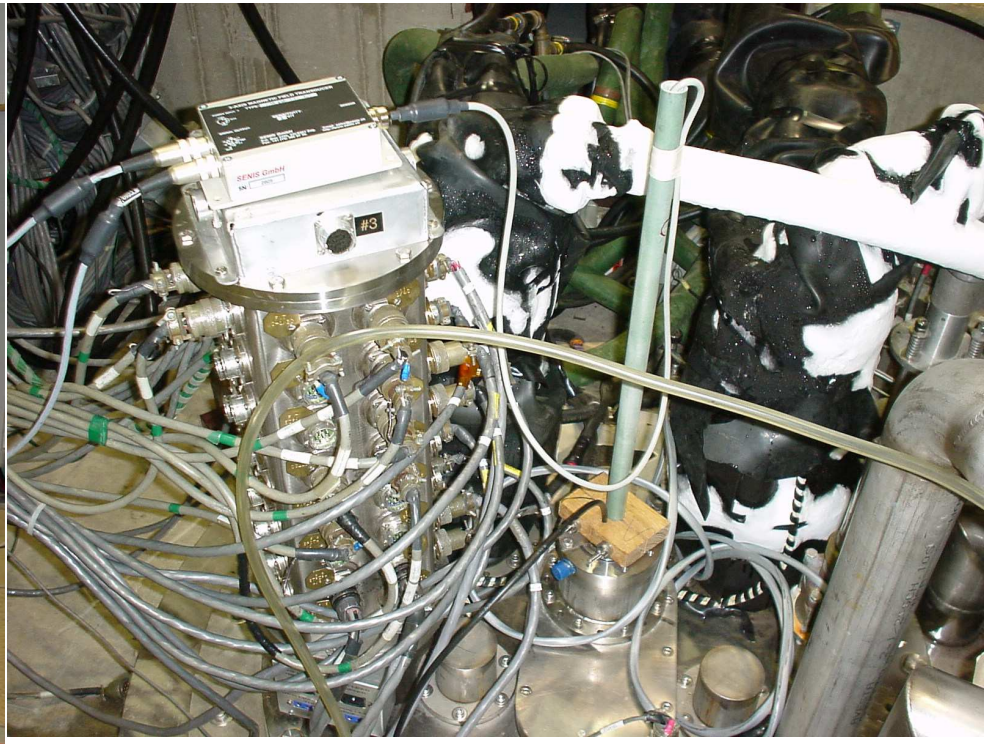
- HFDA07 10 T dipole tested at VMTF (6/06)
  - A rare window of opportunity !
- Standard Harmonics data L= 10cm rotating coil
  - Stairstep ramps to 9 T at magnet center position (GV)
- Independent 3D 10 T Hall probe measurements
  - Probe in holder on-axis; scan to find center, dipole dir.
  - Stair step to 10 T
  - Probe in holder off-axis; find dipole dir
  - Stair step down to 0 T
  - Rotate 90 deg; stair step up to 10 T
    - **Gives two independent measures of By**



Summary: 3D Hall at high field

- Hope to do more soon…(when ??)
  - 5 T Tevatron dipole (recent NMR calibration)
  - Additional High Field Dipole Tests
  - More solenoid studies in test dewar
    - Pre-production, production of DTL design
    - On and off-axis
    - R&D for SSR-1,2 designs

3D 10 T Dipole Result



Hall probe shaft in HFM warm bore

Keithley 2700 Mux/DMM, PC with Labview readout

3D 10 T Dipole Result