U.S. MAGNET DEVELOPMENT PROGRAM

First field quality measurements of a 15 T Nb3Sn Dipole Demonstrator

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US Magnet Development Program

Outline

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  - Measurement System
  - Measurement sensitivity
  - Centering Corrections
- Measurement discussion
  - Transfer Function
  - Loop
  - Z-scan
  - Harmonics from Stair Step
  - Accelerator Profile
  - Comparison with Simulation
  - Decay and Snapback
- Summary

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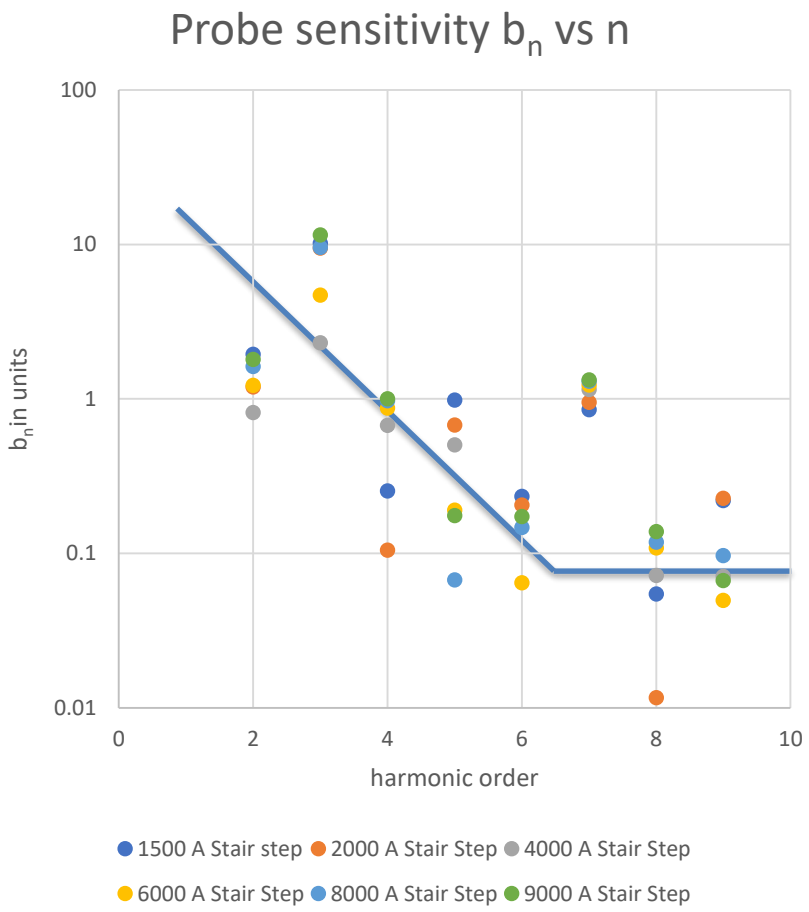
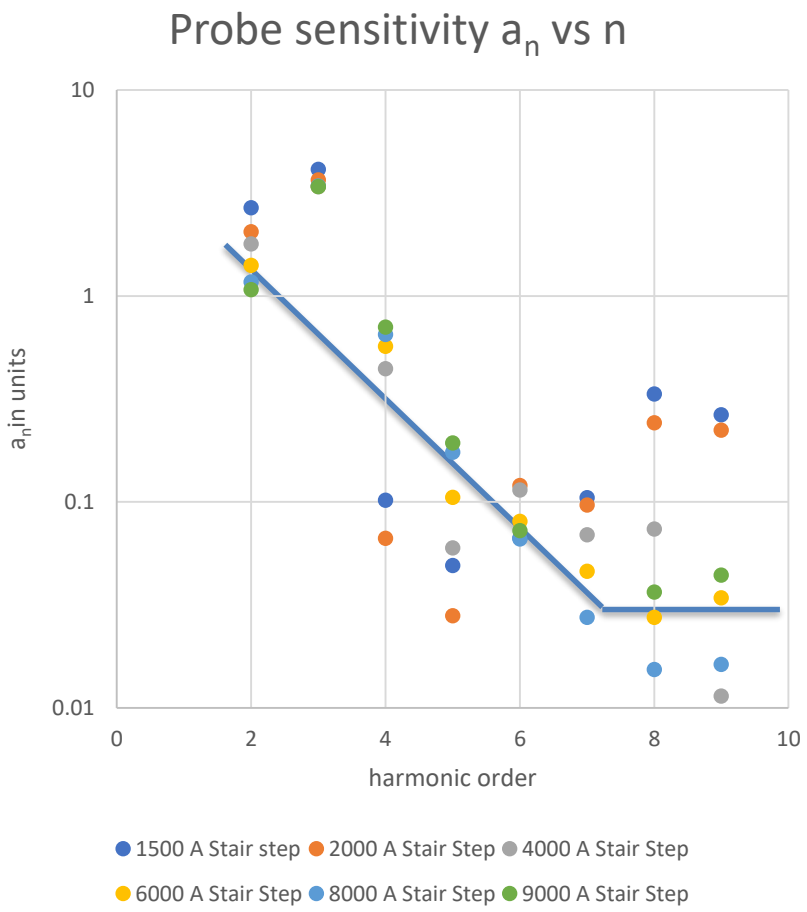
Measurement System

- Rotating Coil Measurement System at Fermilab Vertical Magnet Test Facility
  - 0.75 – 1 Hz rotation
  - Shaft with attached probe to scan ‘warm bore’ of the magnet, 3 m stroke
  - Two probes simultaneous in use, offset by 130 mm
    - 130 mm x 22.25 mm PCB probe (16 layers, 2 tracks, 13 Loops/track)
    - 26 mm x 22.25 mm PCB probe (16 layers, 2 tracks, 13 Loops/track)
    - Dipole bucked signal

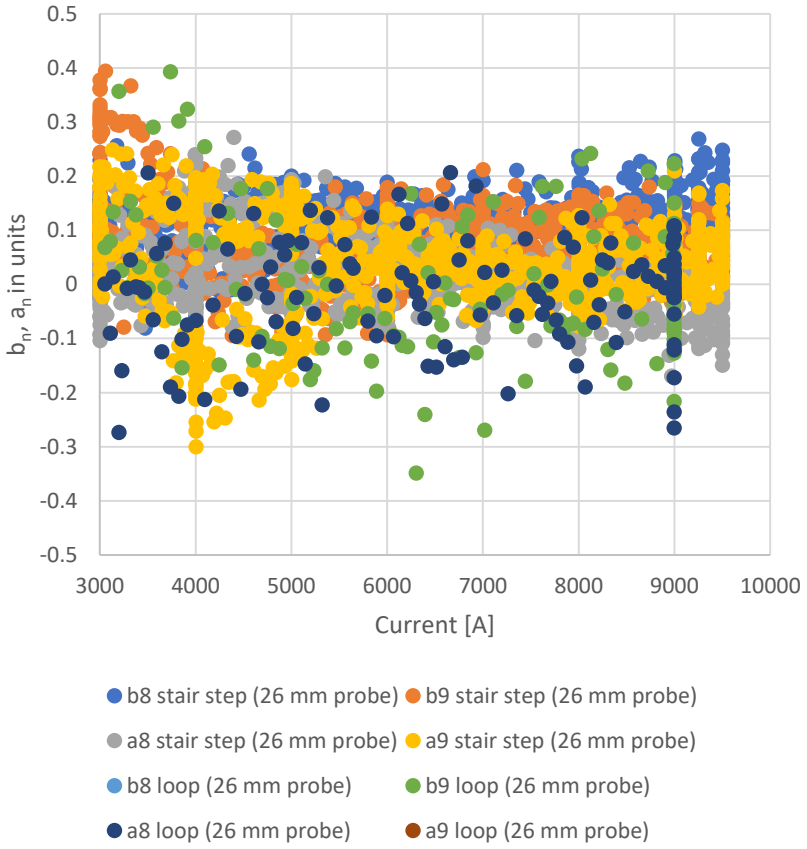
26 mm Probe sensitivity ~ 0.1 units



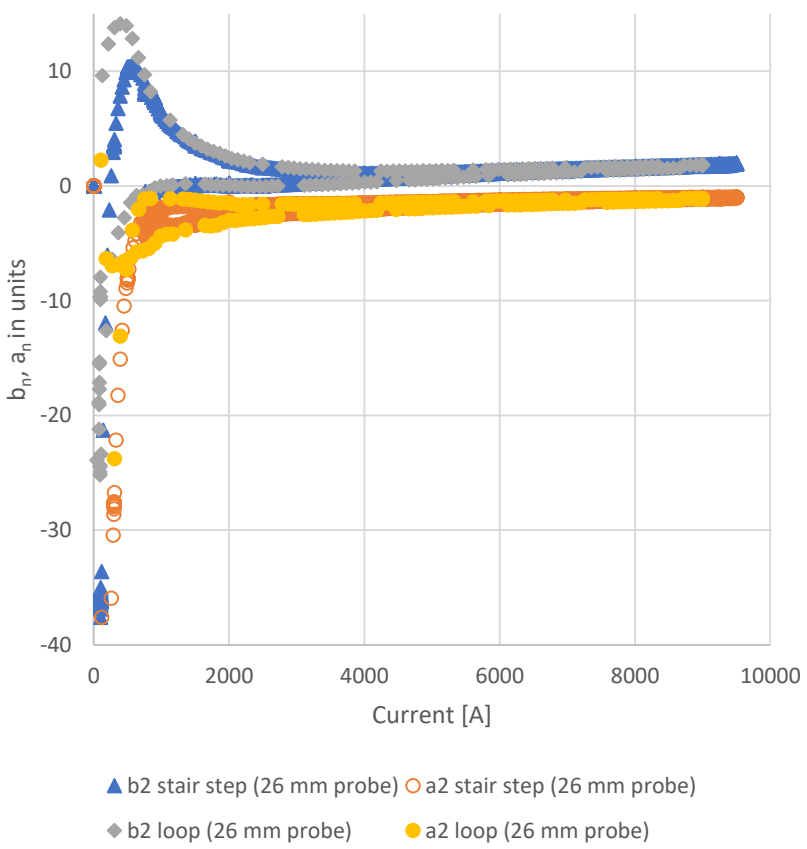


Centering Correction not required

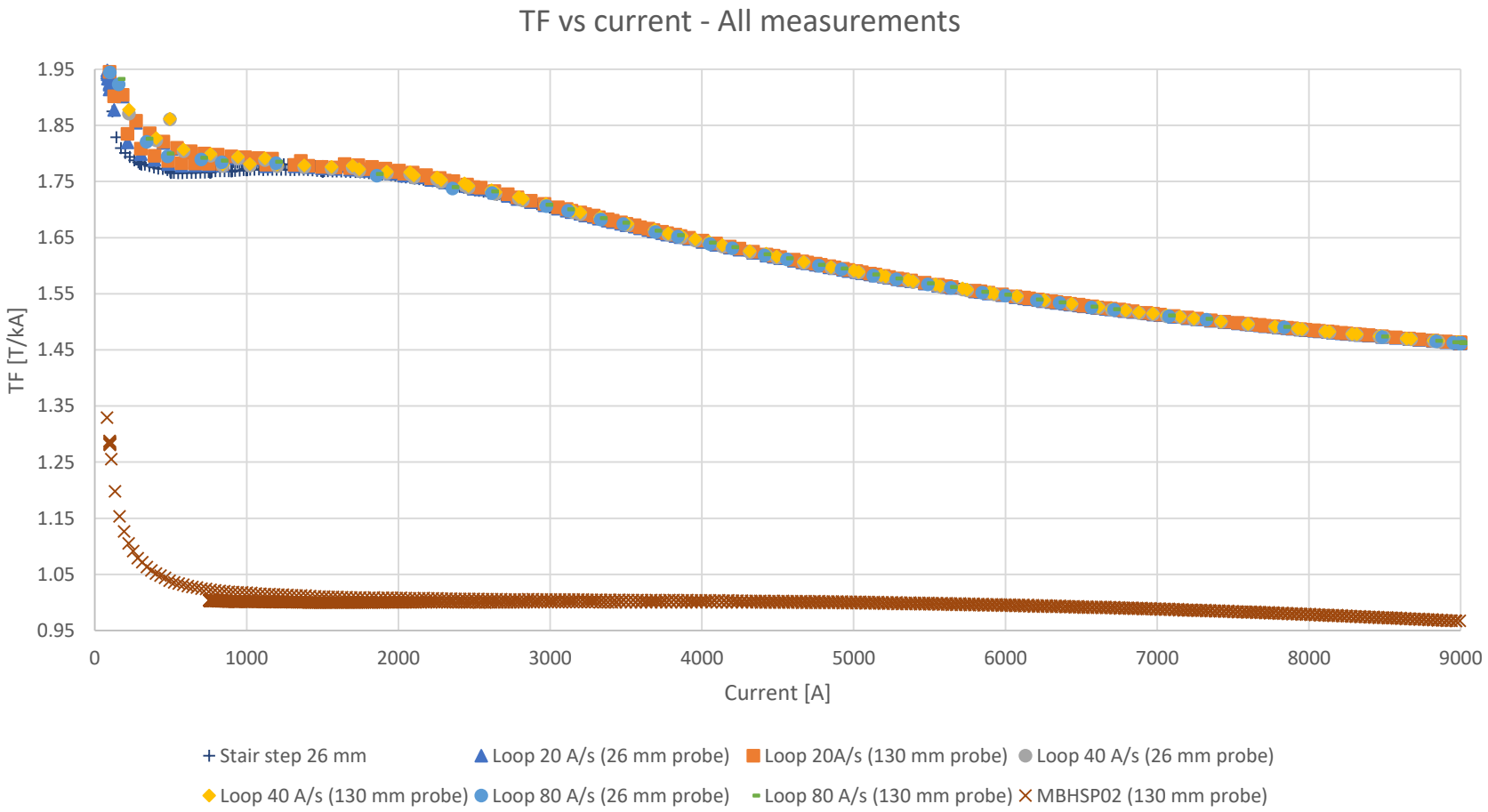
higher order units versus current



Hysteresis feed-down from b_3

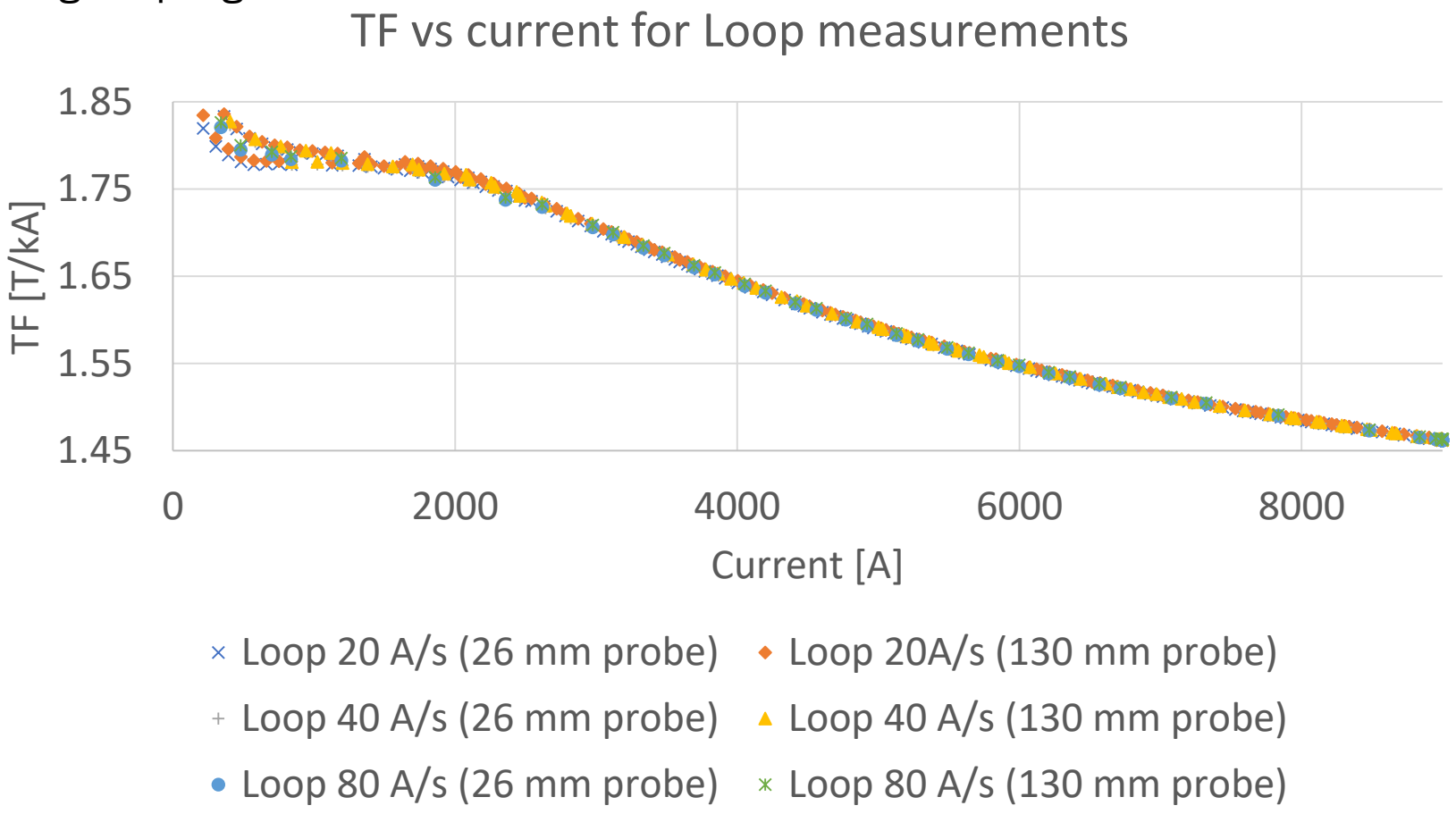


Transfer Function for multiple measurements

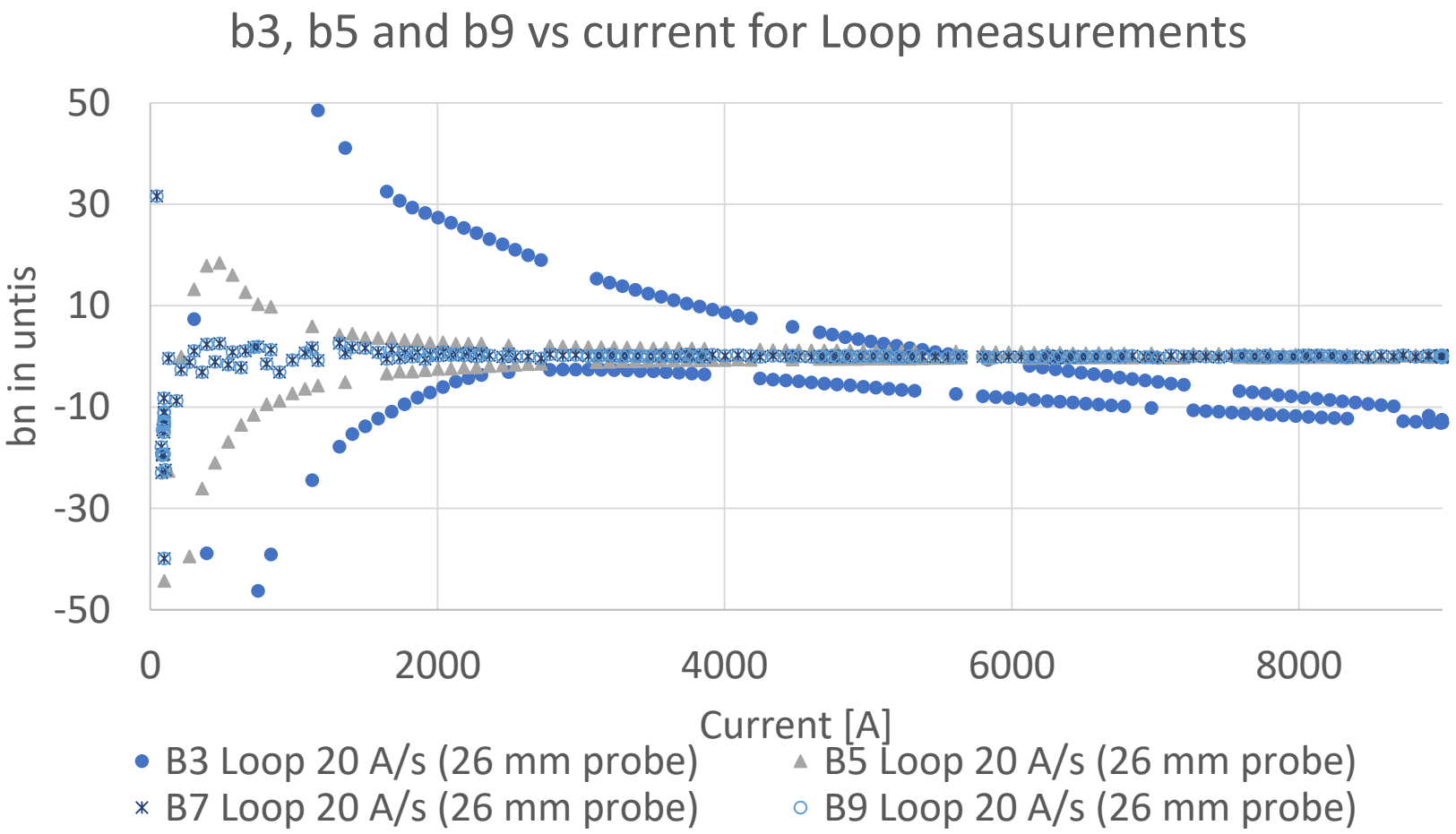


Loop measurements (20, 40, 80 A/s) Minimal dynamic effects

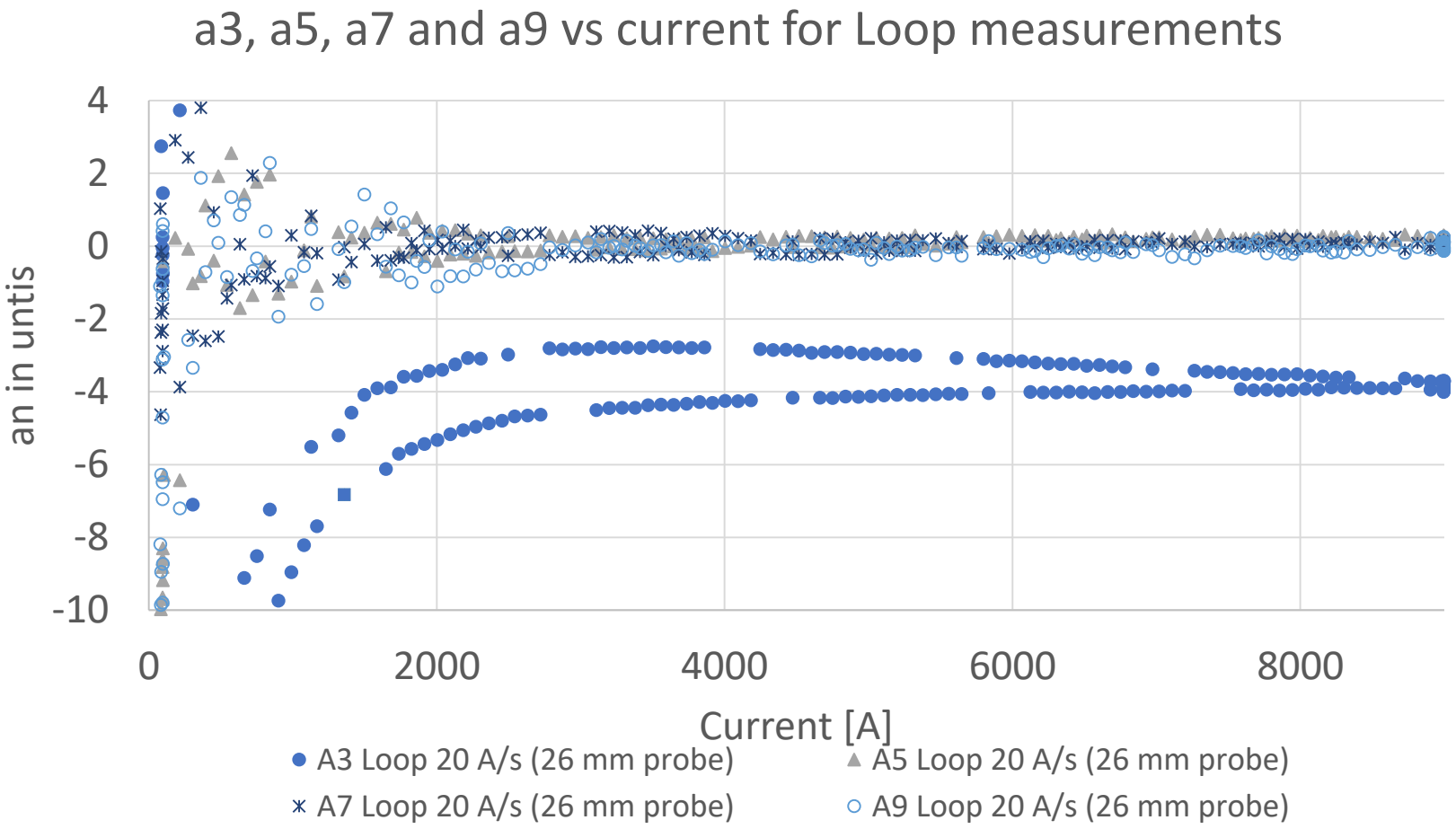
Conductor uses stainless core, reducing coupling currents



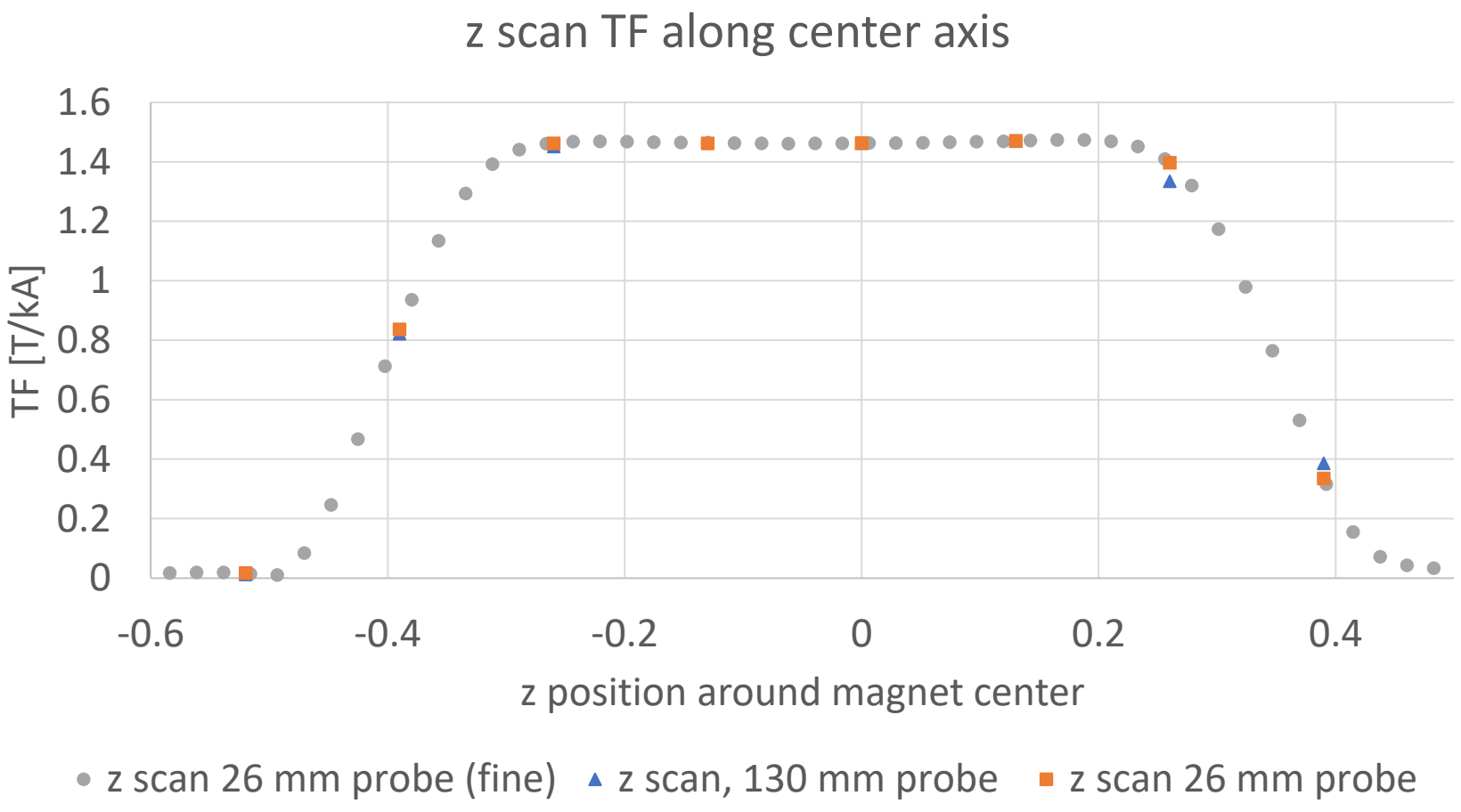
Loop measurement normal harmonics



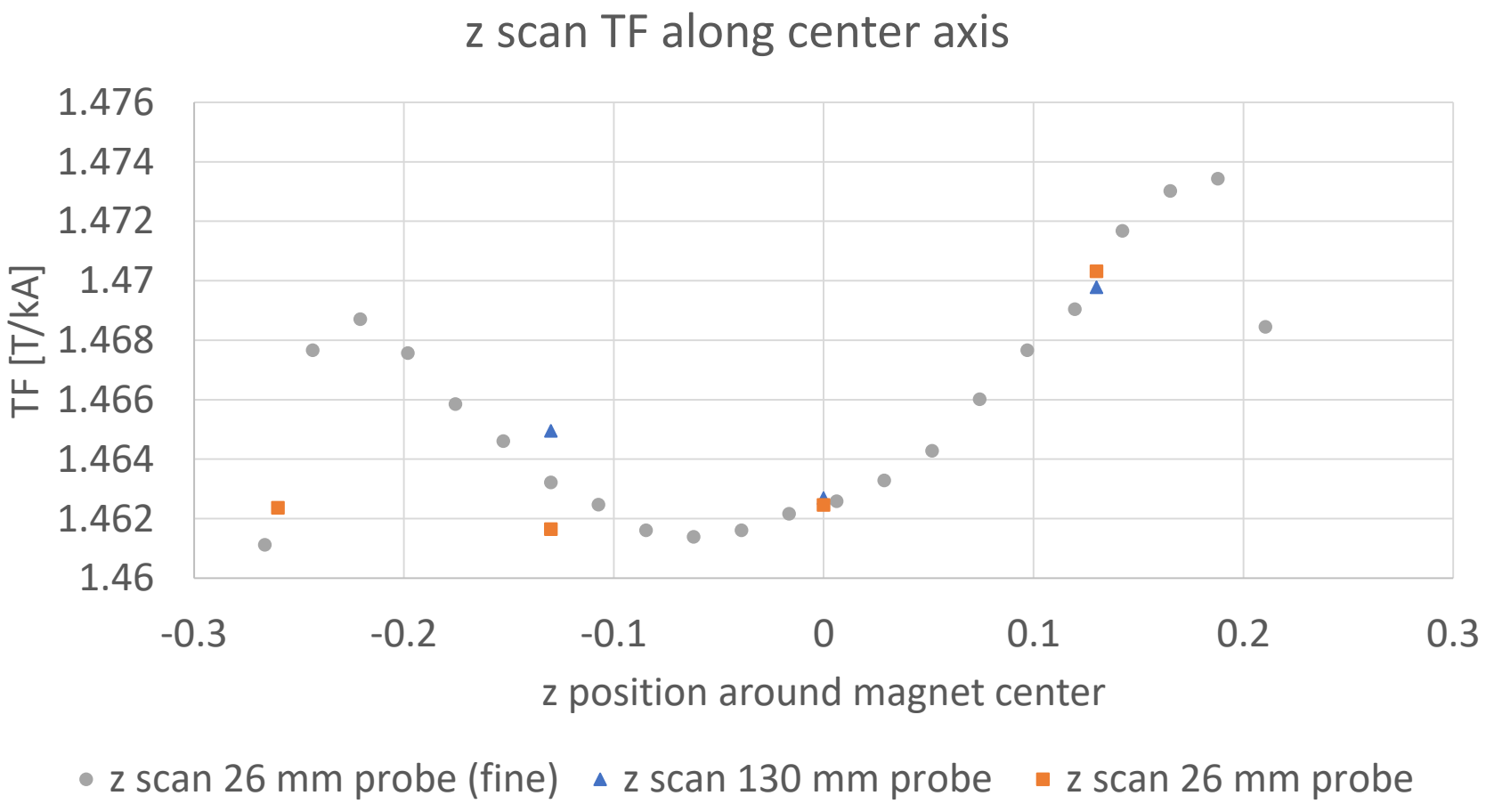
Loop measurements skewed harmonics



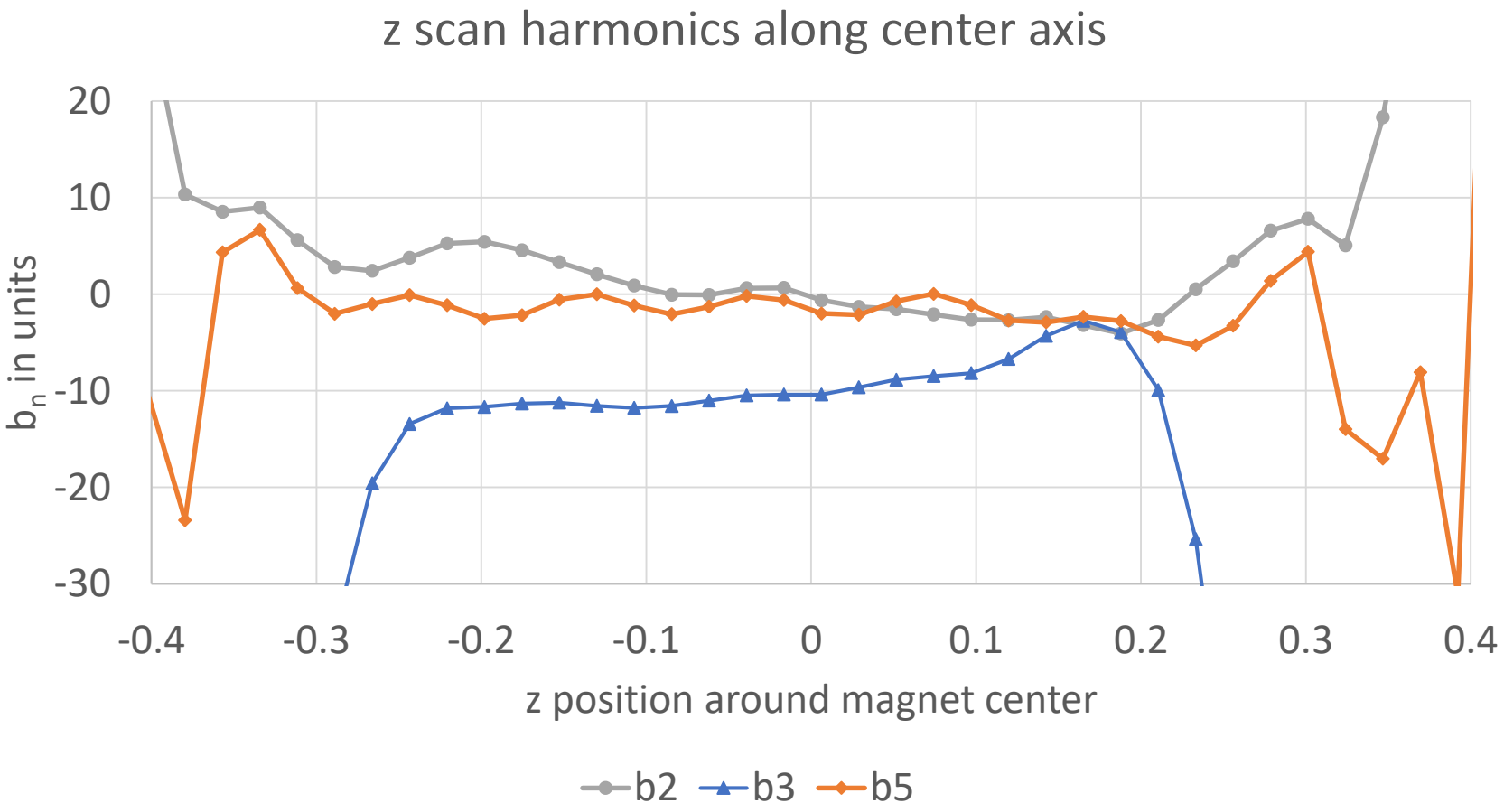
Z scan TF at 9 kA



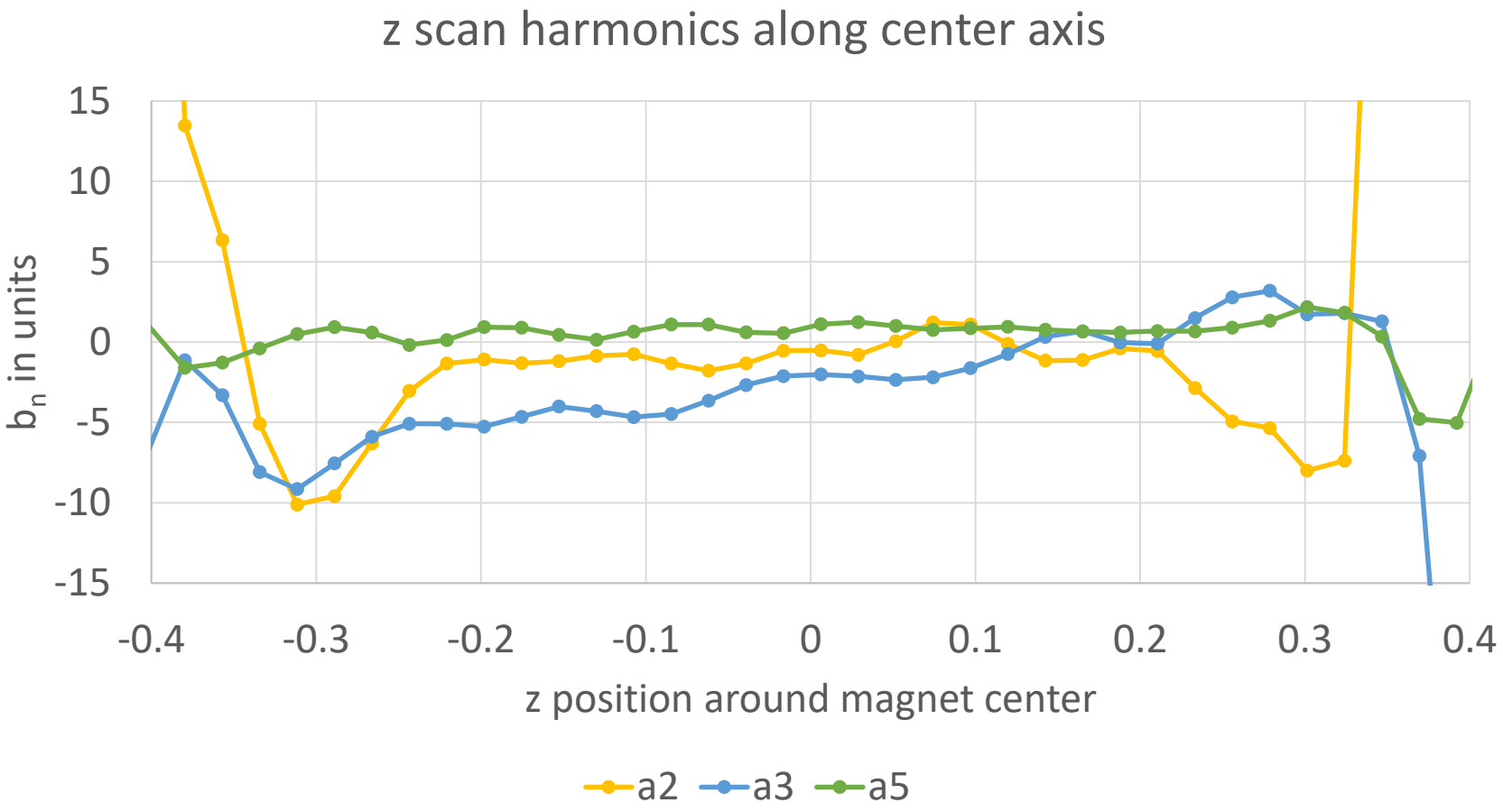
Z scan TF at 9kA, zoom



Z scan harmonics



Z scan harmonics



Geometrical Harmonics

- **Stair step, 26 mm probe**

Geometric harmonics nearly identical in stair step and loop, small except for a2,a3,b2, and b3

current	B main	TF	b2	b3	b4	b5	b6	b7	b8	b9		a2	a3	a4	a5	a6	a7	a8	a9
1001	1.779	1.778	3.0	13.0	1.1	1.4	0.4	0.6	-0.2	0.3		-3.0	-5.2	-0.6	-0.2	-0.3	-0.1	-0.2	0.5
1501	2.662	1.773	1.9	10.2	0.3	1.0	0.2	0.9	-0.1	0.2		-2.7	-4.1	-0.1	0.0	0.1	0.1	-0.3	0.3
2002	3.527	1.762	1.2	9.5	-0.1	0.7	0.2	1.0	0.0	0.2		-2.0	-3.7	0.1	0.0	0.1	0.1	-0.2	0.2
2502	4.346	1.737	0.8	8.8	-0.4	0.7	0.1	1.0	0.0	0.2		-2.2	-3.5	0.3	0.1	0.1	0.1	-0.1	0.2
3002	5.117	1.705	0.8	6.5	-0.5	0.6	0.1	1.1	0.1	0.2		-2.0	-3.5	0.4	0.1	0.1	0.0	0.0	0.1
3496	5.849	1.673	0.8	4.4	-0.6	0.6	0.1	1.1	0.0	0.1		-1.9	-3.4	0.4	0.0	0.2	0.0	0.0	0.1
4002	6.576	1.643	0.8	2.3	-0.7	0.5	0.0	1.2	0.1	0.1		-1.8	-3.4	0.4	0.1	0.1	-0.1	0.1	0.0
5002	7.953	1.590	1.0	-1.5	-0.8	0.3	0.0	1.2	0.1	0.0		-1.6	-3.4	0.5	0.1	0.1	0.0	0.0	0.0
6002	9.289	1.548	1.2	-4.7	-0.9	0.2	-0.1	1.2	0.1	0.0		-1.4	-3.4	0.6	0.1	0.1	0.0	0.0	0.0
7003	10.599	1.514	1.4	-7.4	-0.9	0.1	-0.1	1.3	0.1	0.1		-1.3	-3.4	0.6	0.1	0.1	0.0	0.0	0.0
8003	11.894	1.486	1.6	-9.6	-1.0	-0.1	-0.1	1.3	0.1	0.1		-1.2	-3.4	0.6	0.2	0.1	0.0	0.0	0.0
9002	13.174	1.463	1.8	-11.5	-1.0	-0.2	-0.2	1.3	0.1	0.1		-1.1	-3.4	0.7	0.2	0.1	0.0	0.0	0.0
9502	13.810	1.453	2.0	-13.2	-1.0	-0.2	-0.2	1.3	0.2	0.1		-1.0	-3.4	0.7	0.2	0.1	0.0	-0.1	0.1

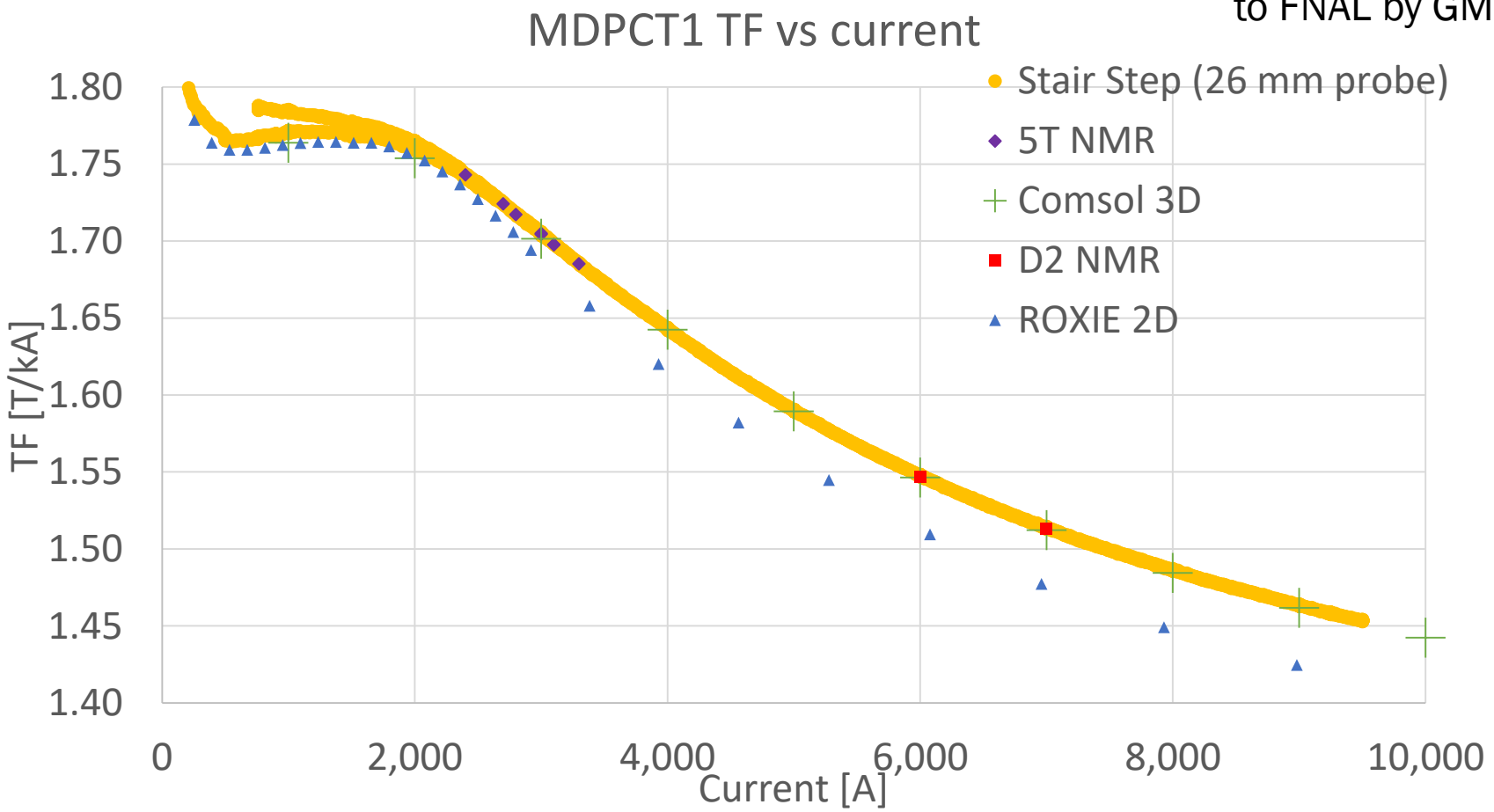
- **Loop, 20 A/s, both probes, 130 mm offset in between**

Loop 20 A/s 26 mm																			
1427		1.779	2.0	13.6	1.0	-0.7	-0.1	0.3	-0.5	1.1		-2.5	-5.5	0.6	-0.2	-0.1	0.0	-1.0	0.2
3530		1.671	0.8	4.4	-0.6	0.4	0.0	1.0	0.0	0.1		-2.0	-3.6	0.7	0.1	0.2	0.1	0.1	0.0
4992		1.590	1.0	-1.5	-0.8	0.3	-0.2	1.1	0.1	0.0		-1.7	-3.5	0.7	0.1	0.2	0.0	0.0	-0.2
6996		1.512	1.4	-7.6	-1.0	0.2	-0.2	1.4	0.1	-0.2		-1.4	-3.7	0.8	0.2	0.2	0.1	0.0	0.0
8996		1.462	1.8	-12.8	-1.0	0.0	-0.2	1.4	0.1	0.0		-1.1	-3.9	0.8	0.2	0.2	0.1	0.0	0.0
Loop 20 A/s 130 mm																			
1426.754		1.782	-3.1	11.7	-1.4	-1.9	-0.1	0.5	0.2	0.9		-2.5	-2.3	2.8	0.8	0.0	-0.2	-0.6	0.0
3530.193		1.673	-2.6	6.4	-1.6	-1.1	0.0	0.6	0.1	0.1		-2.3	-2.1	2.2	1.1	0.1	0.0	0.0	0.0
4991.803		1.591	-2.0	-0.1	-1.8	-1.1	-0.1	0.7	0.1	0.0		-1.9	-2.5	2.3	1.2	0.1	0.0	-0.1	0.0
6996.030		1.514	-1.2	-7.2	-1.8	-1.3	-0.1	0.7	0.2	0.0		-1.5	-3.0	2.4	1.2	0.1	0.1	-0.1	0.0
8995.939		1.463	-0.6	-13.6	-1.9	-1.4	-0.1	0.8	0.2	0.0		-1.0	-3.4	2.4	1.3	0.2	0.0	-0.1	0.0

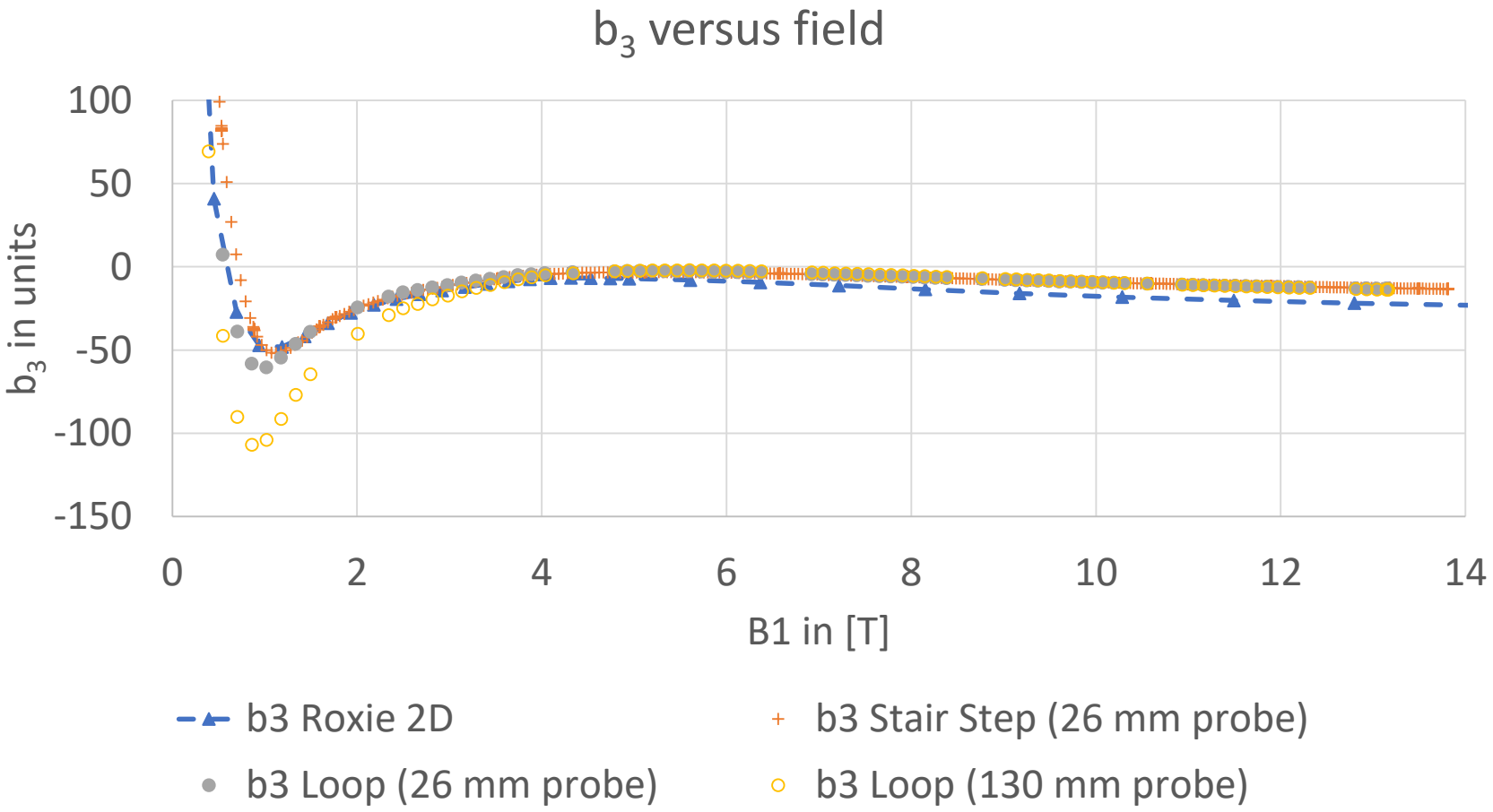
Transfer Function

Vadim Kashikhin: 2% difference between the 2D Roxie and 3D COMSOL transfer functions at high field

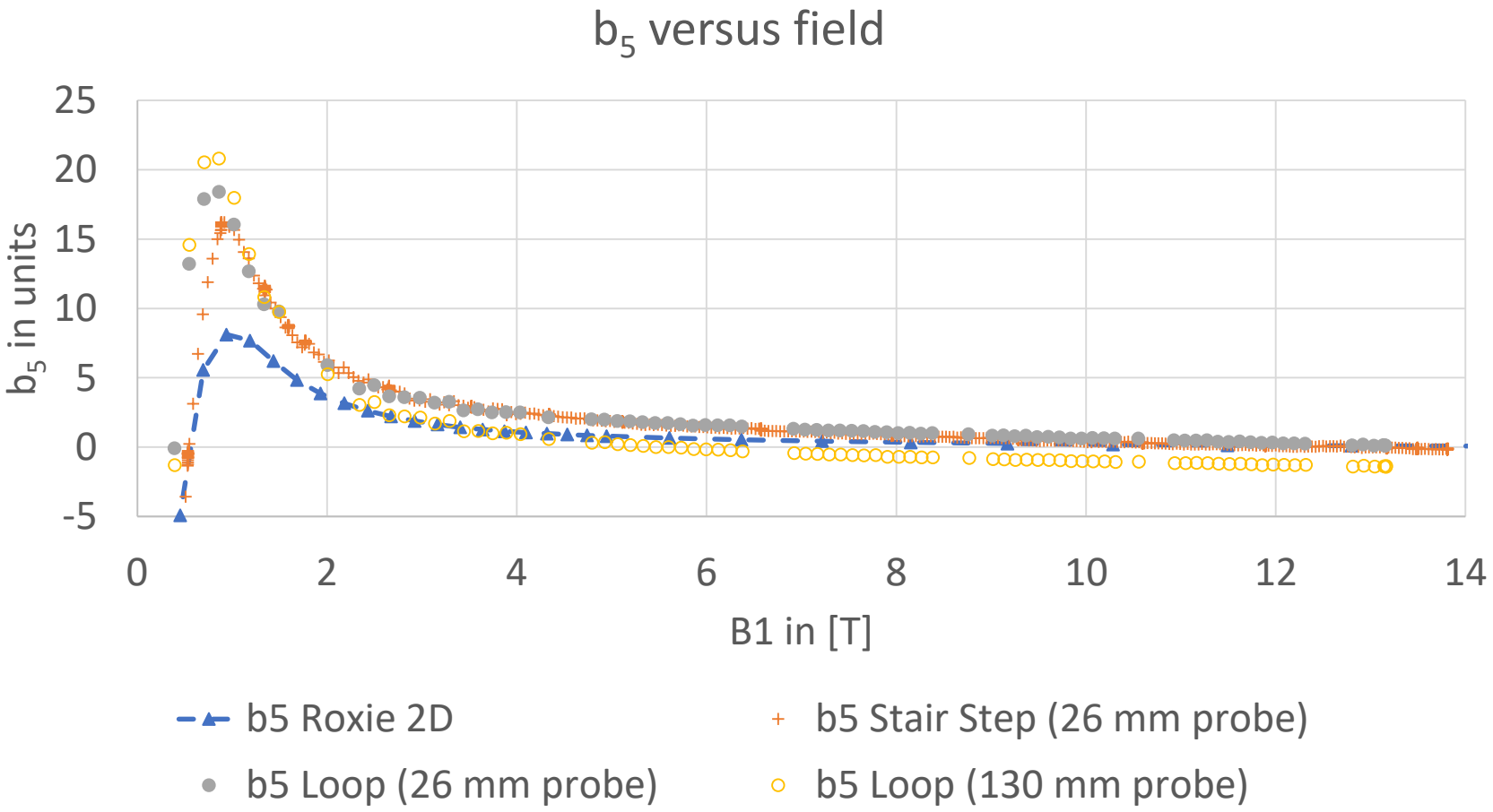
D2 probe was loaned to FNAL by GMW



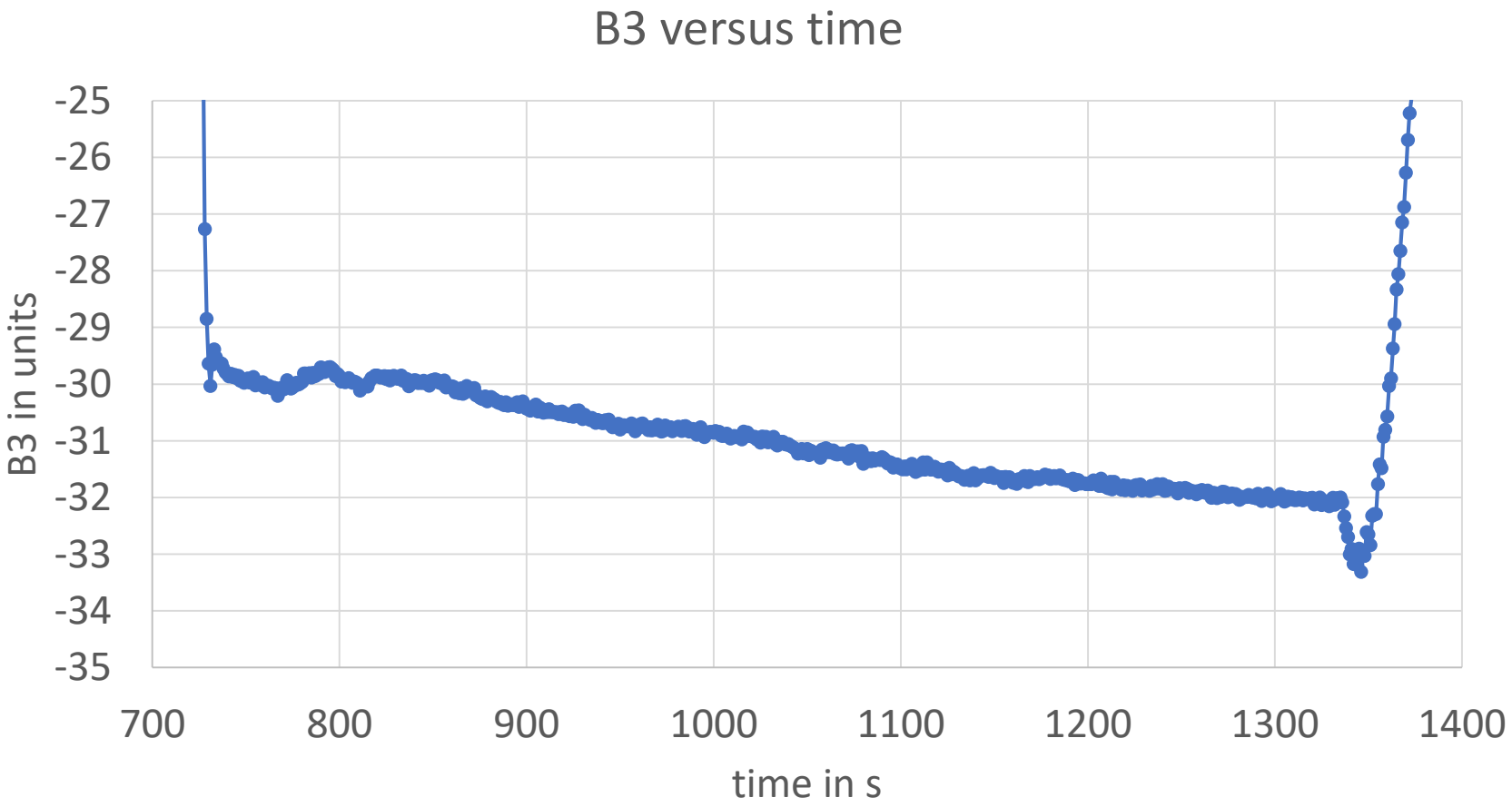
b_3 versus dipole field



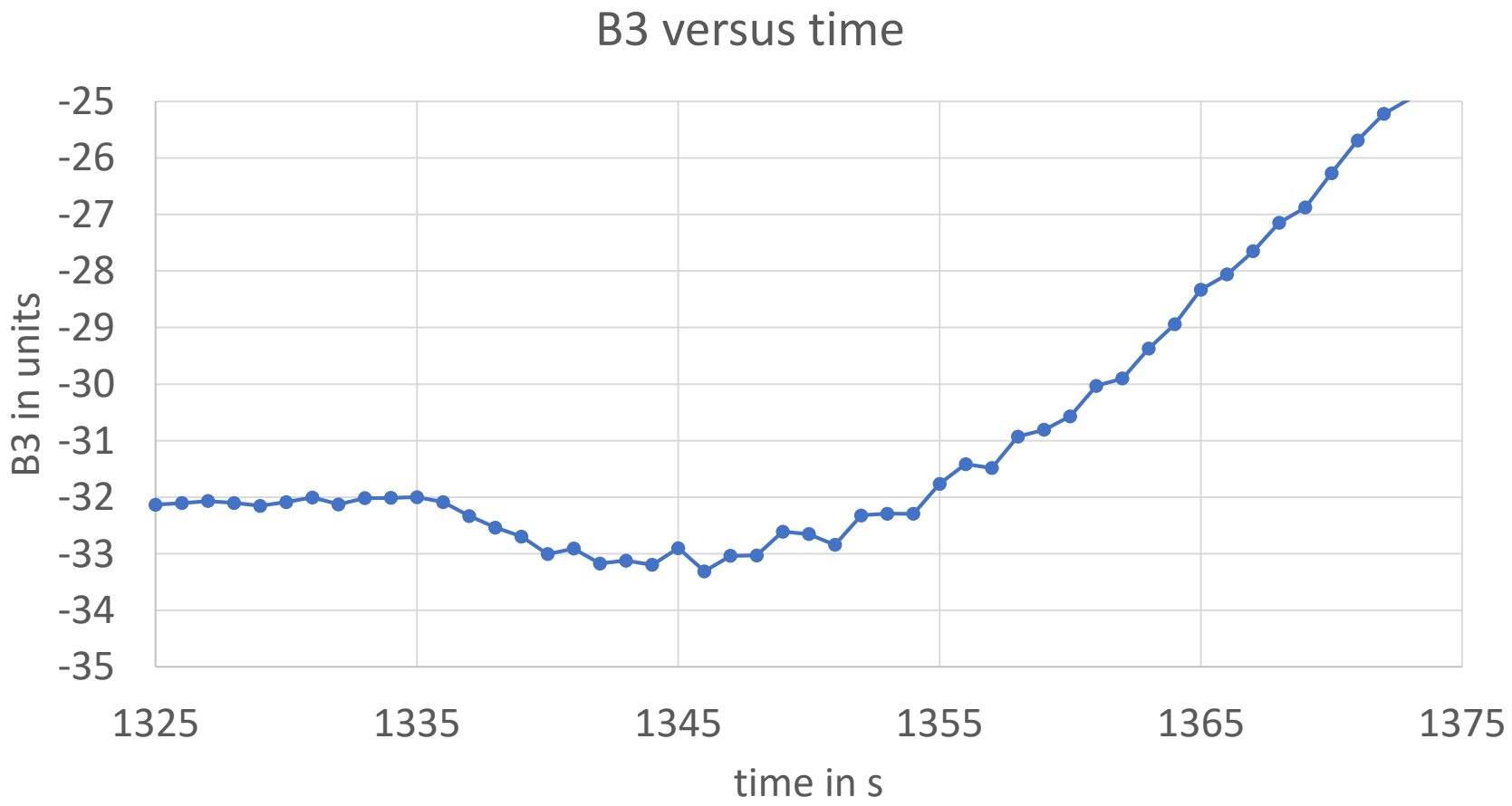
b_5 versus dipole field



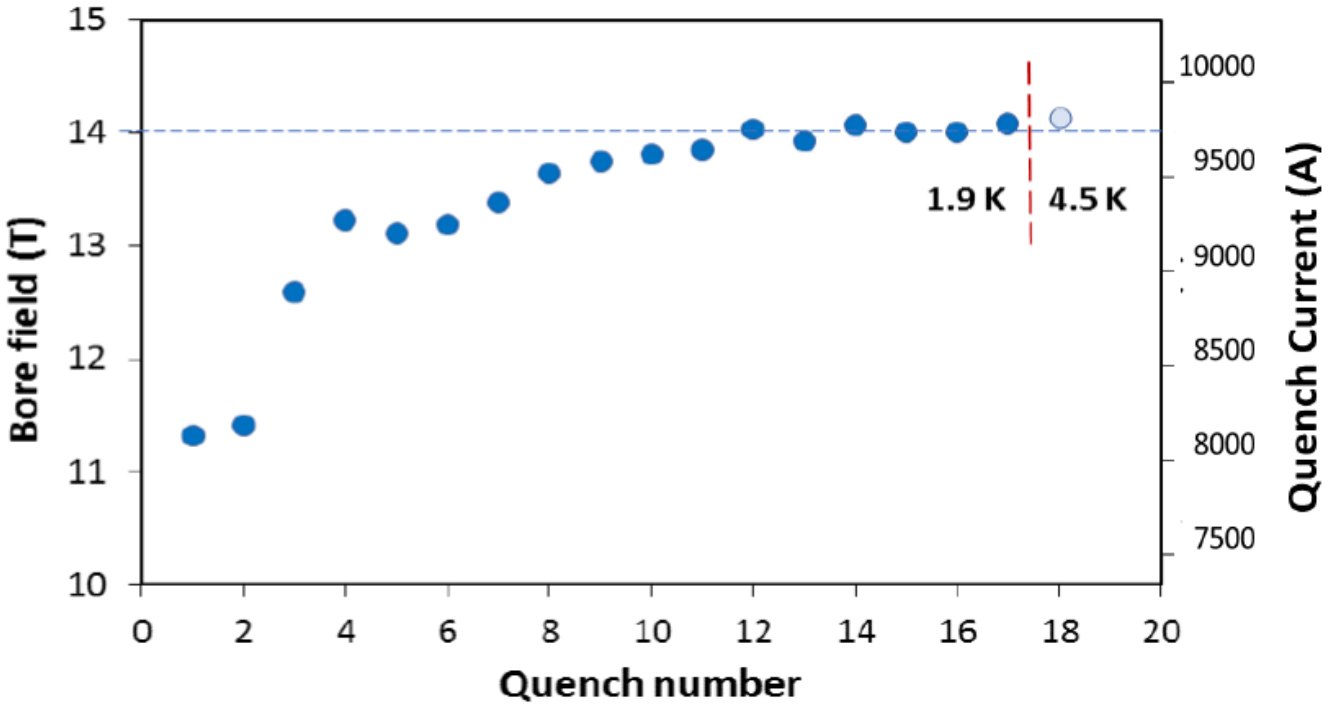
Decay and Snapback



Snapback


B3 versus time
B3 in units
-25
-26
-27
-28
-29
-30
-31
-32
-33
-34
-35
1325
1335
1345
1355
1365
1375
time in s

Maximum Field Achieved



First quenches above 11 T

Maximum bore field at 4.5K
measured 14.10±0.04 T
calculated 14.112 T

Summary

- Magnet *TF* and low-order field harmonics were measured using 26 mm and 130 mm long rotating coils in the field range up to ~14 T.
- The measurements included geometrical components and contributions from the coil magnetization and iron yoke saturation effects.
- All the measured geometrical harmonics, except for a_2, a_3, b_2, b_3, are small, on the level of 1 unit or less at R_{ref}=17 mm.
- The coil magnetization effect in MDPCT1 at low fields is large due to the high critical current density and relatively large sub-element size in the contemporary Nb_3Sn strands.
- The iron yoke saturation effect in MDPCT1 starts at fields above 2.5 T and is also large.
- Both coil magnetization and iron saturation effects are in good agreement with theoretical predictions for TF and b3
- The eddy current effect in the cable on the *TF* and field harmonics in MDPCT1 was suppressed by using a stainless-steel core inside the cables.

Acknowledgment

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- We thank GMW (www.gmw.com) for providing us with a Metrolab 1226 8-22T NMR probe for our PT2026 Teslameter

GMW Associates