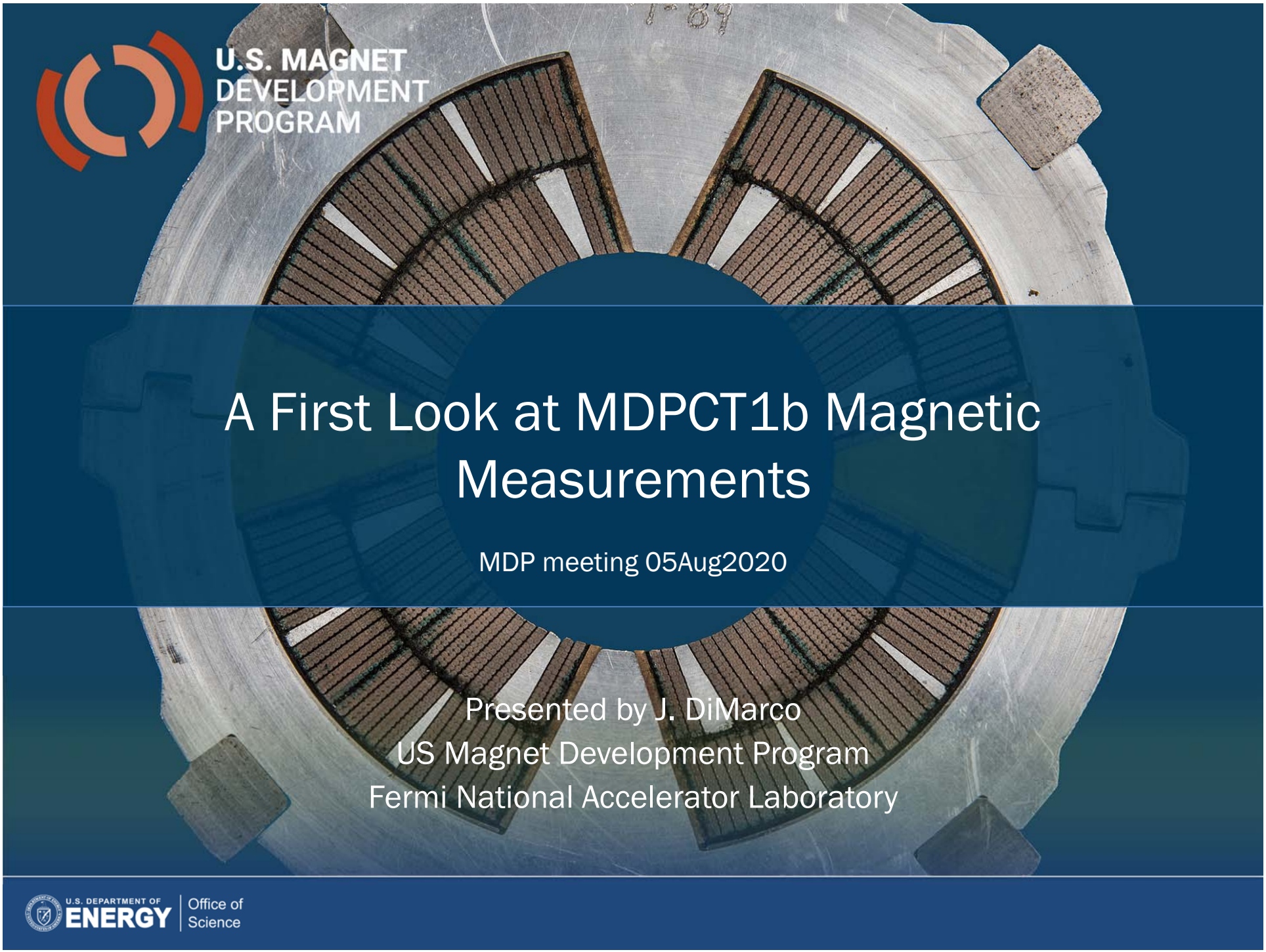


U.S. MAGNET DEVELOPMENT PROGRAM

A First Look at MDPCT1b Magnetic Measurements

MDP meeting 05Aug2020

Presented by J. DiMarco
US Magnet Development Program
Fermi National Accelerator Laboratory

U.S. DEPARTMENT OF ENERGY | Office of Science

MDPCT1b magMeas tests

- Magnetic Measurements Performed :
  - Warm zscan before cooldown (19Mar2020)
  - Loops to 7kA (10Jul2020) – 20A/s and 40A/s
  - Zscan at 5kA (10Jul2020)
  - Zscan at 5kA (10Jul2020) repeat in reverse direction
  - Zscan at 9kA (10Jul2020)
  - Zscan at 9kA (10Jul2020) repeat in reverse direction
  - Accelerator Cycle (13Jul2020)
  - Accelerator Cycle shifted -6cm (13Jul2020)
  - Stairstep to 9kA (15Jul2020)

- Measurements repeated with new prototype data acquisition:
  - Zscan at 9kA (15Jul2020)
  - Stairstep to 9kA (15Jul2020)

Probe used was the same as for MDPCT1

3D-printed support structure with carbon-fiber rods

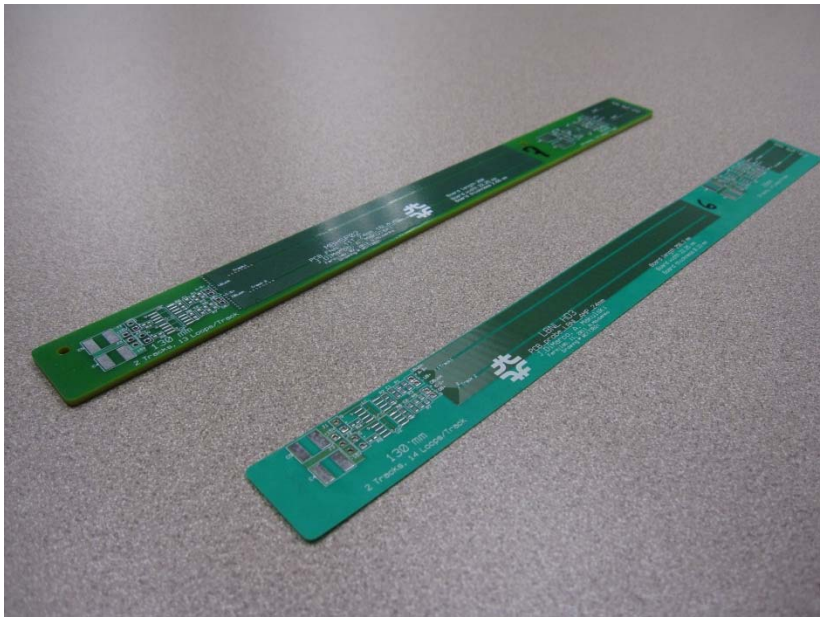
Printed Circuit Board (PCB) probe

UnBucked (UB) and DipoleBucked (DB) windings

- **16-Layer, 13 turns/layer/track with outer trace at 14mm radius**

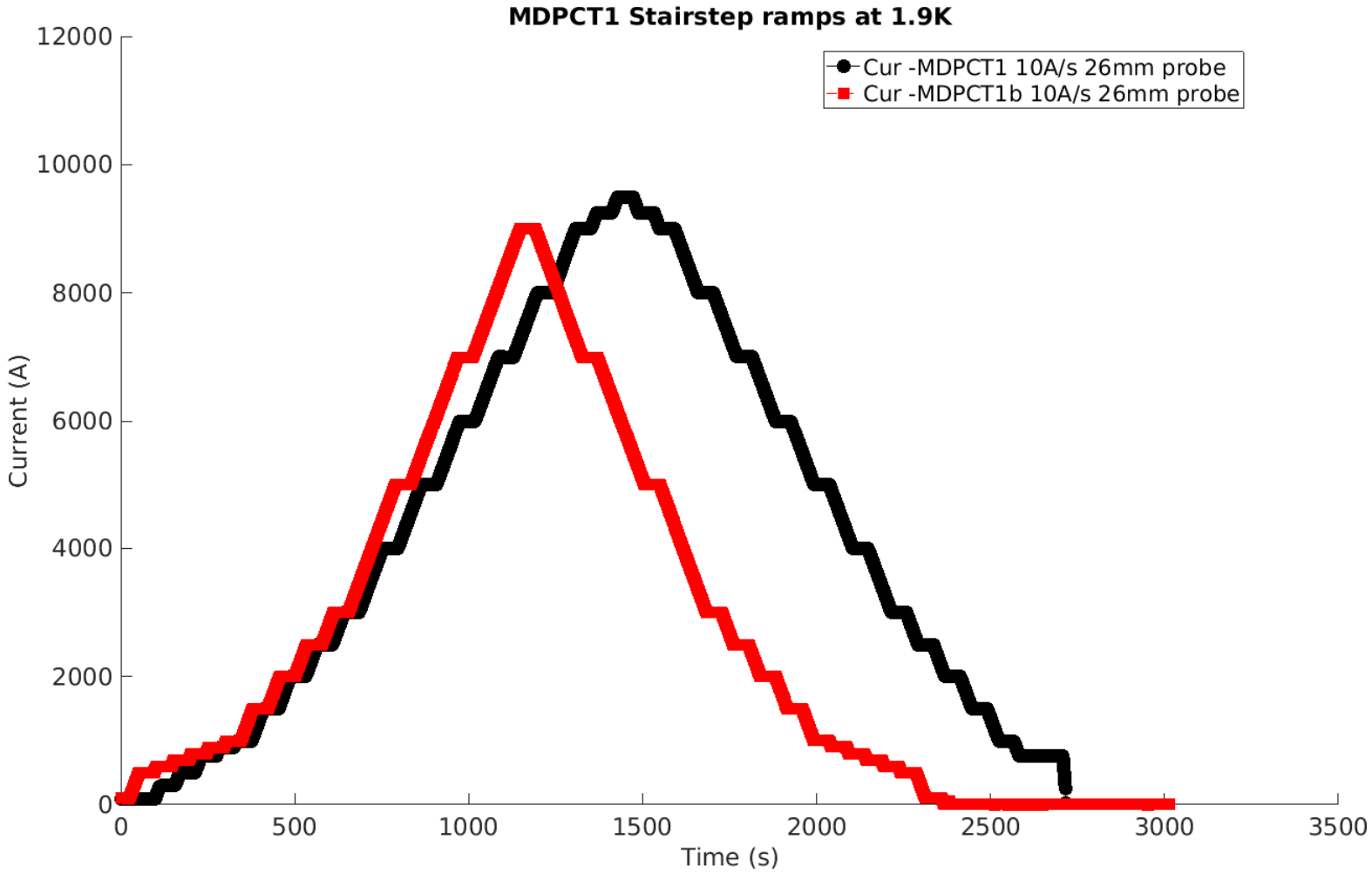
Probe has two different length circuits

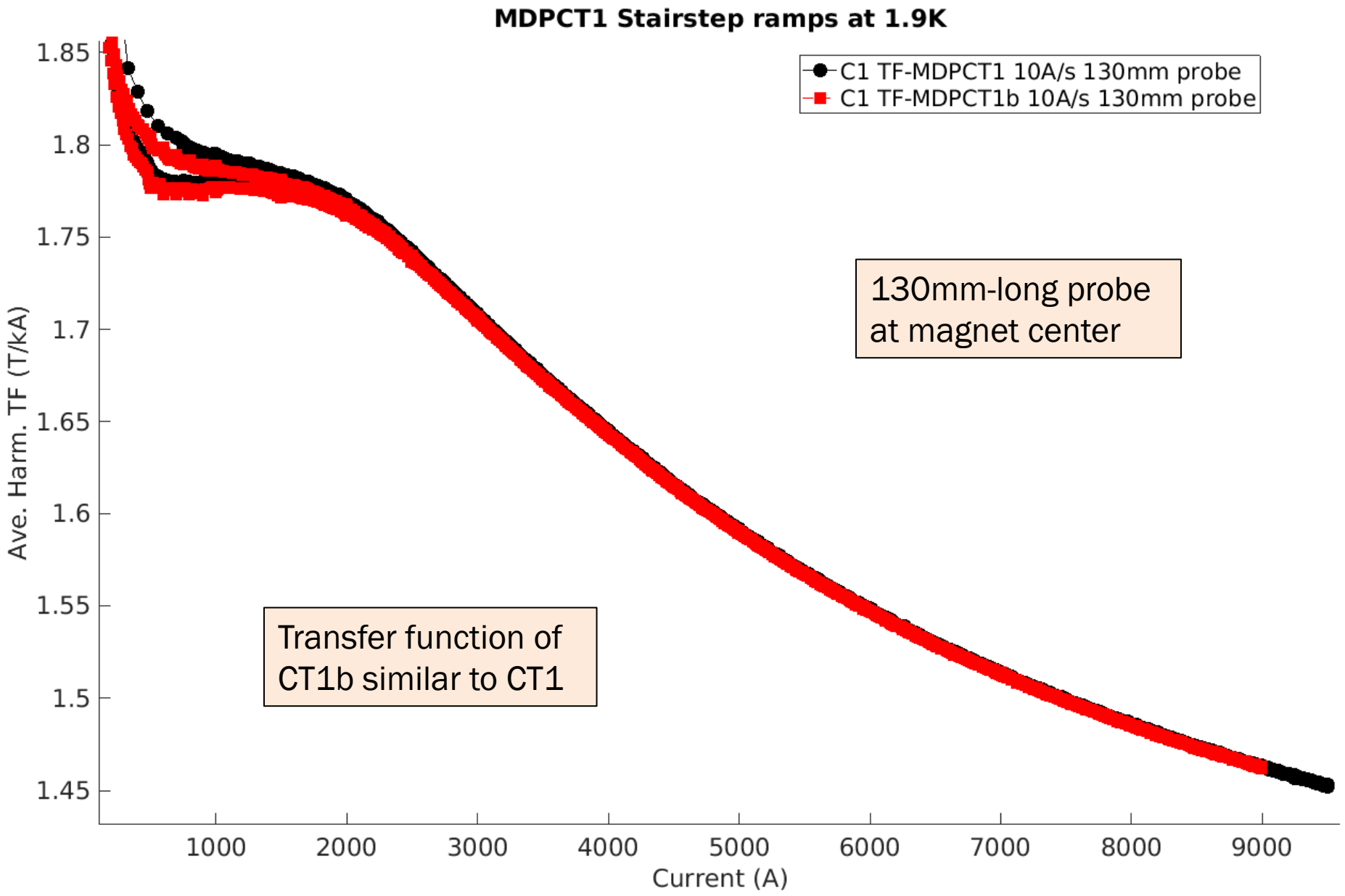
- **130mm (close to twist pitch)**
- **26mm (1/5) for fine structure measurements**
- **Data acquired with both probes for all measurements**

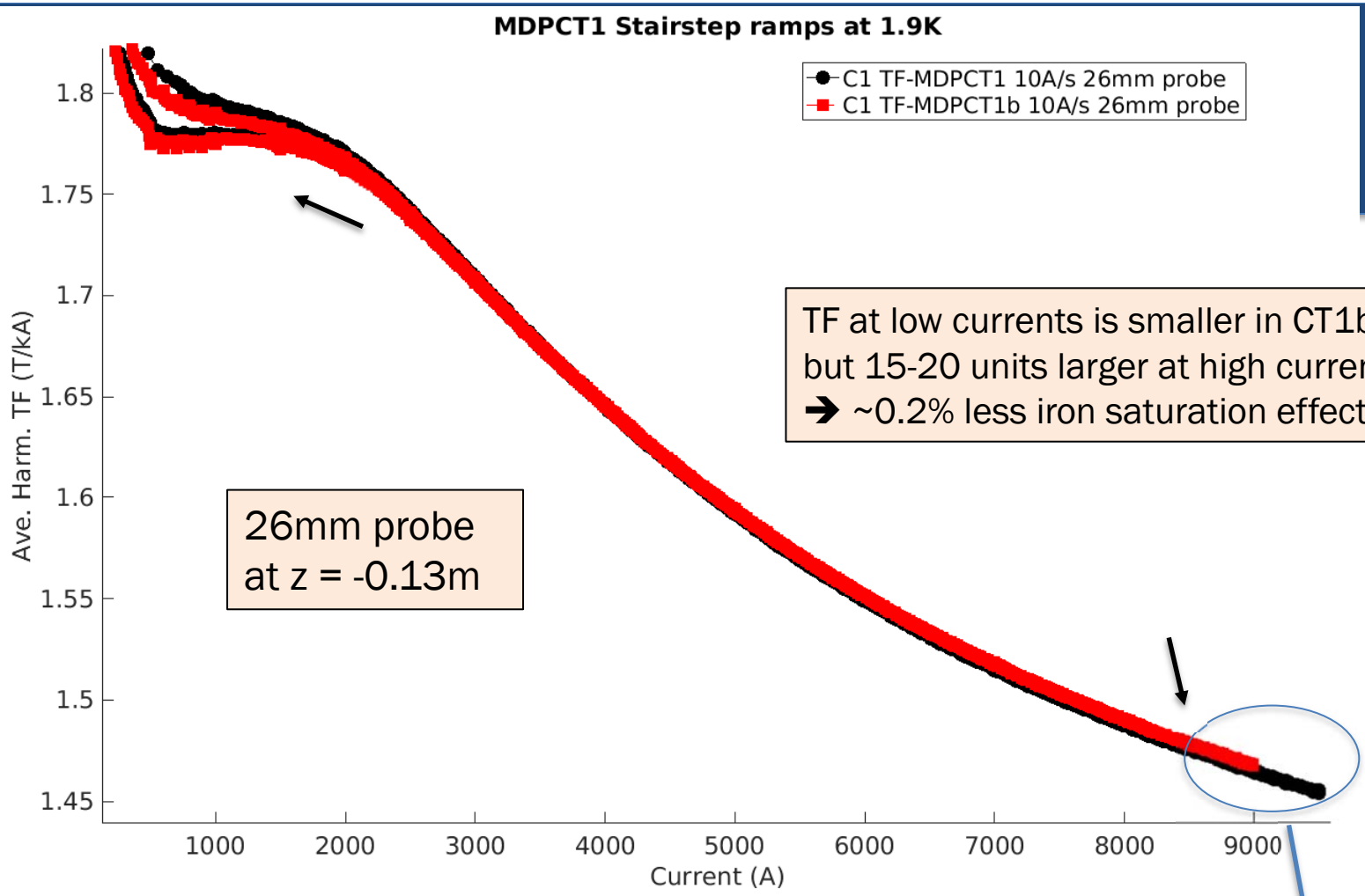


- Reference radius 17mm.
- Z=0 is magnet center, with +Z towards leads.
- Pre-cycle to 5kA and back to 100A before each measurement.
- No centering correction applied (except hysteresis-based centering during ramping measurements)

Stairstep measurement

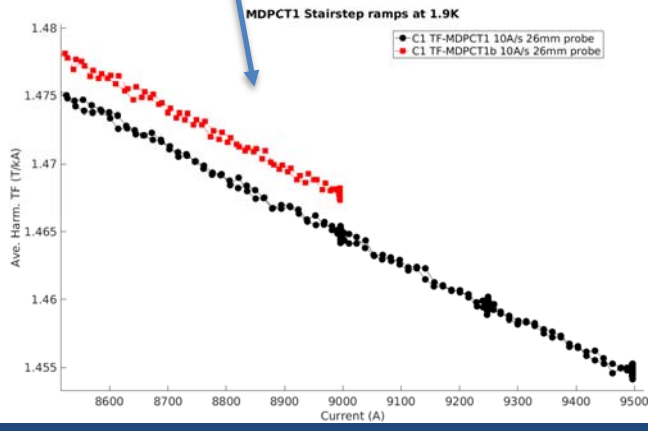



MDPCT1 Stairstep ramps at 1.9K
C1 TF-MDPCT1 10A/s 130mm probe
C1 TF-MDPCT1b 10A/s 130mm probe
130mm-long probe at magnet center
Transfer function of CT1b similar to CT1
Ave. Harm. TF (T/kA)
Current (A)
1.85
1.8
1.75
1.7
1.65
1.6
1.55
1.5
1.45
1000
2000
3000
4000
5000
6000
7000
8000
9000

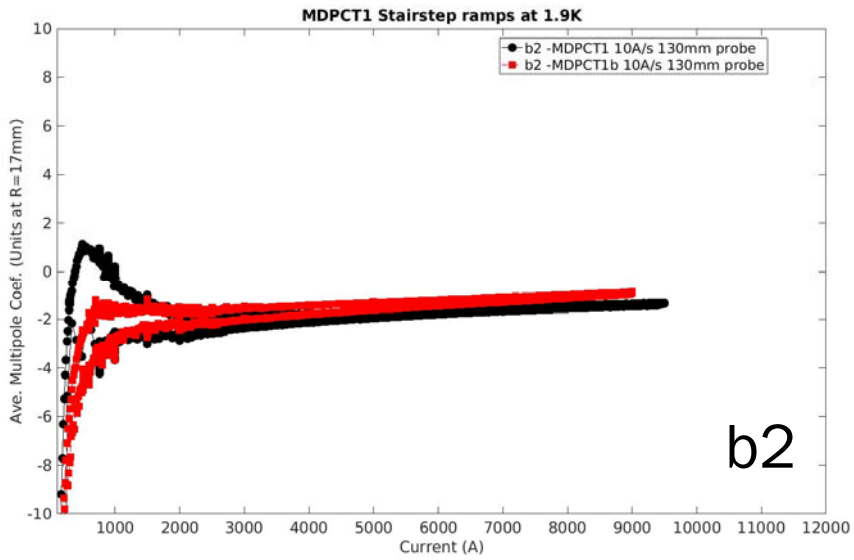


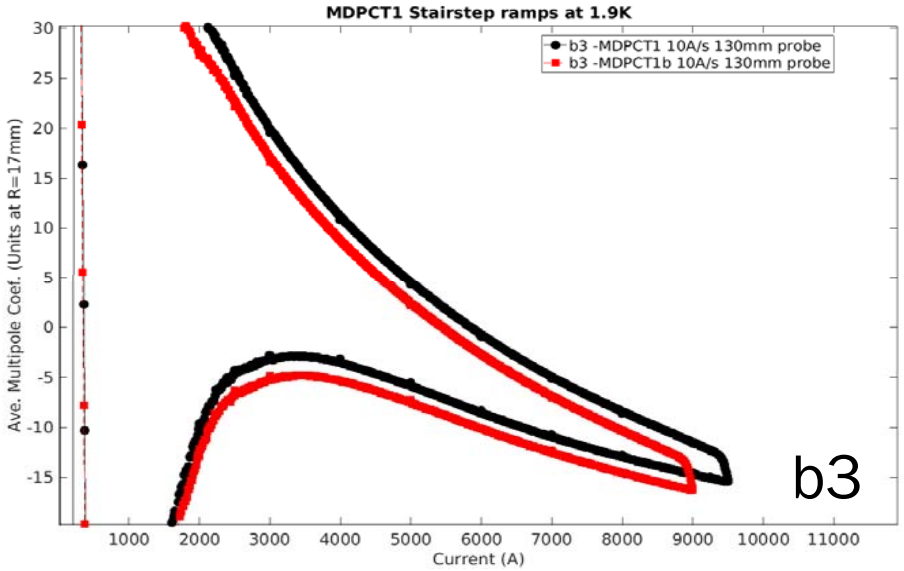
TF at low currents is smaller in CT1b, but 15-20 units larger at high currents
➔ ~0.2% less iron saturation effects

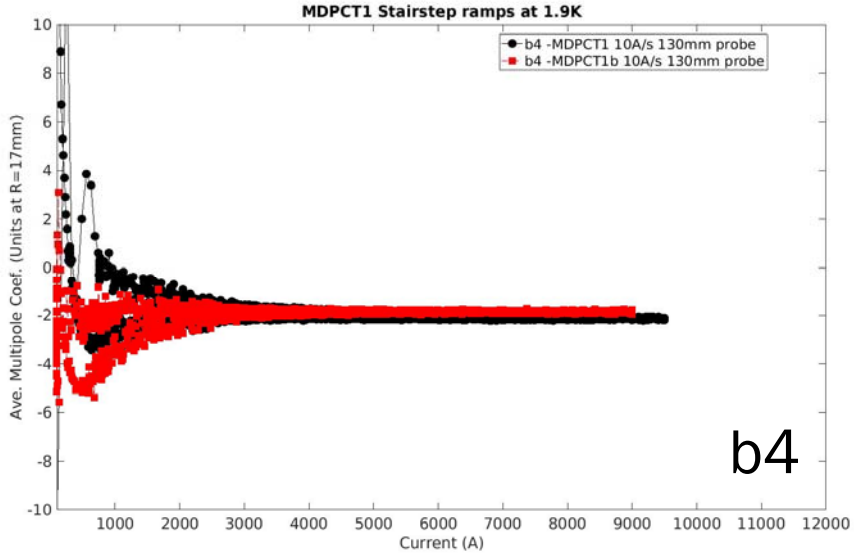
26mm probe
at z = -0.13m

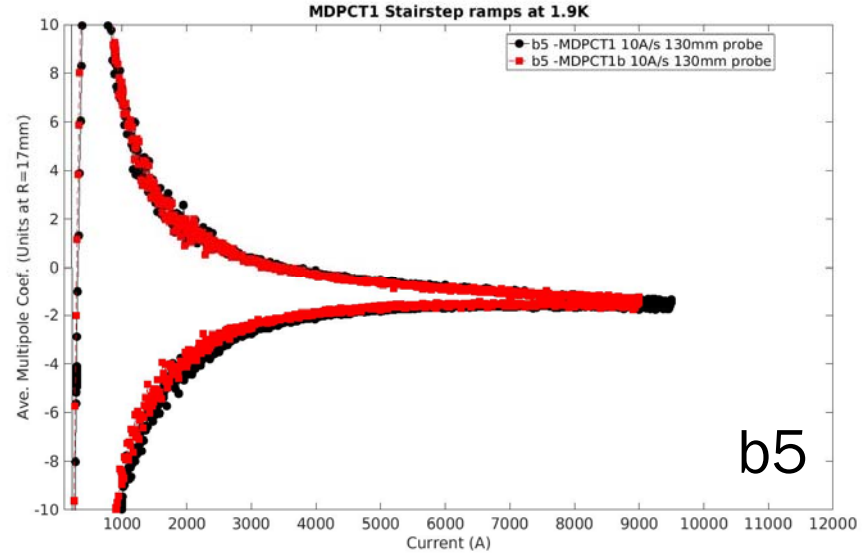


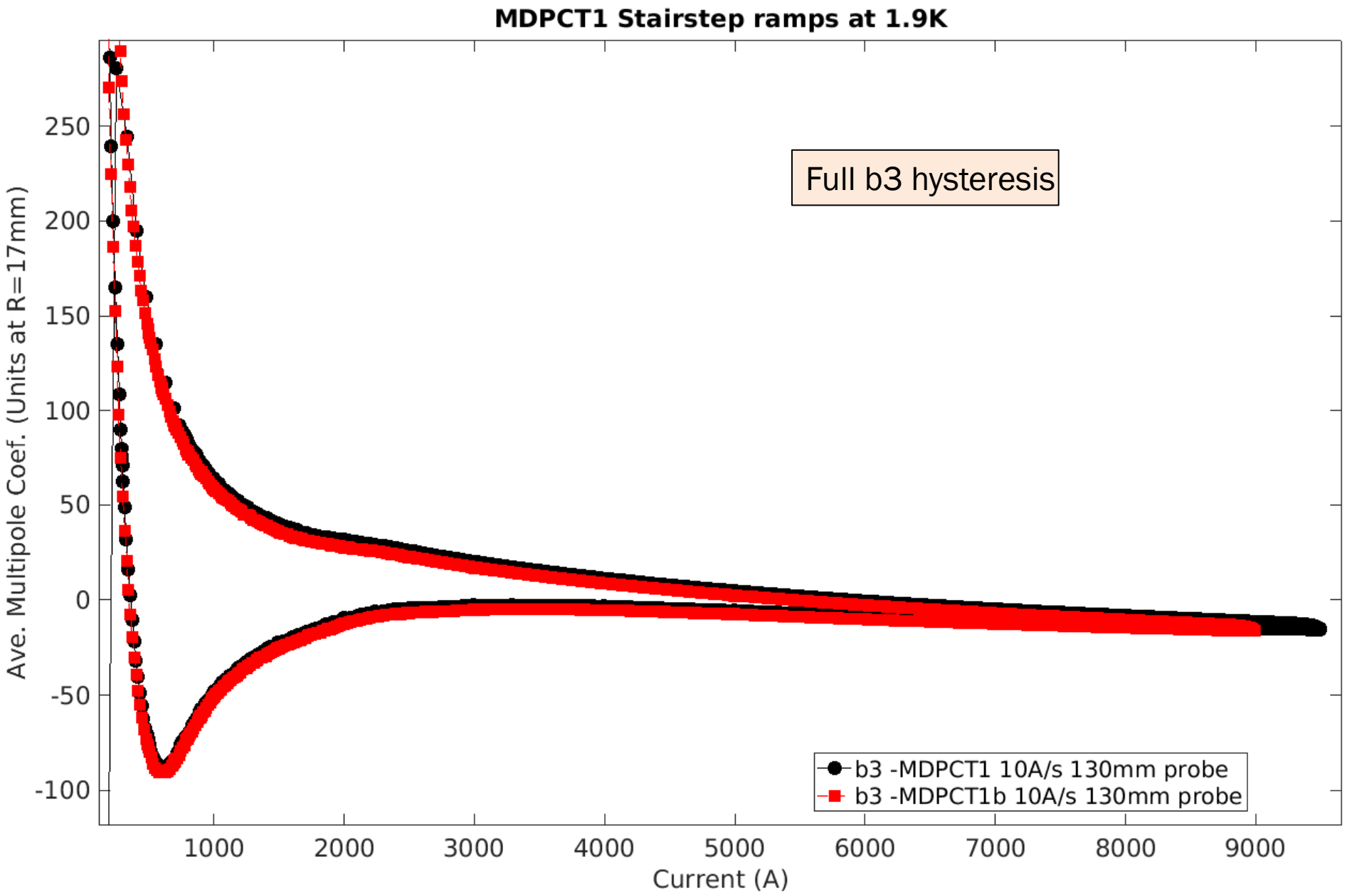
Calc. of quench fields for the two builds should be ~same within the 0.2% difference

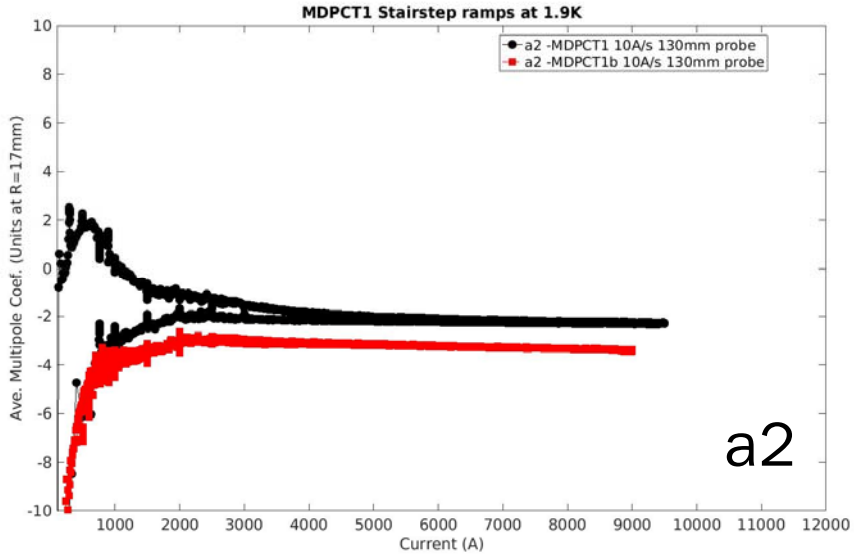

MDPCT1 Stairstep ramps at 1.9K
b2 -MDPCT1 10A/s 130mm probe
b2 -MDPCT1b 10A/s 130mm probe
Ave. Multipole Coef. (Units at R=17mm)
Current (A)
b2

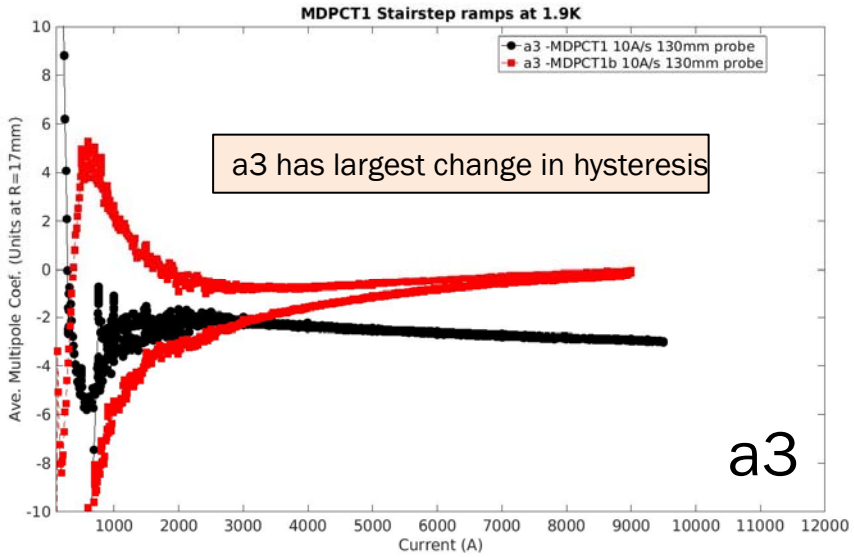

MDPCT1 Stairstep ramps at 1.9K
b3 -MDPCT1 10A/s 130mm probe
b3 -MDPCT1b 10A/s 130mm probe
Ave. Multipole Coef. (Units at R=17mm)
Current (A)
b3

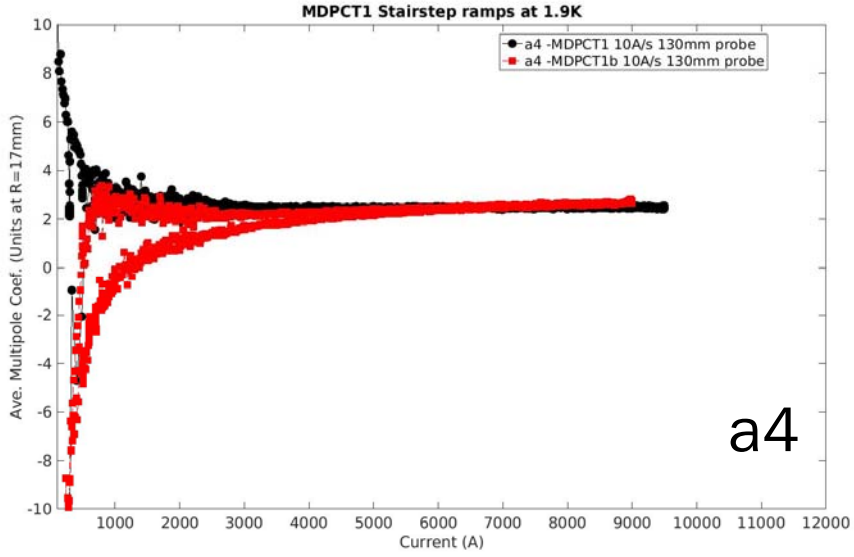

MDPCT1 Stairstep ramps at 1.9K
b4 -MDPCT1 10A/s 130mm probe
b4 -MDPCT1b 10A/s 130mm probe
Ave. Multipole Coef. (Units at R=17mm)
Current (A)
b4

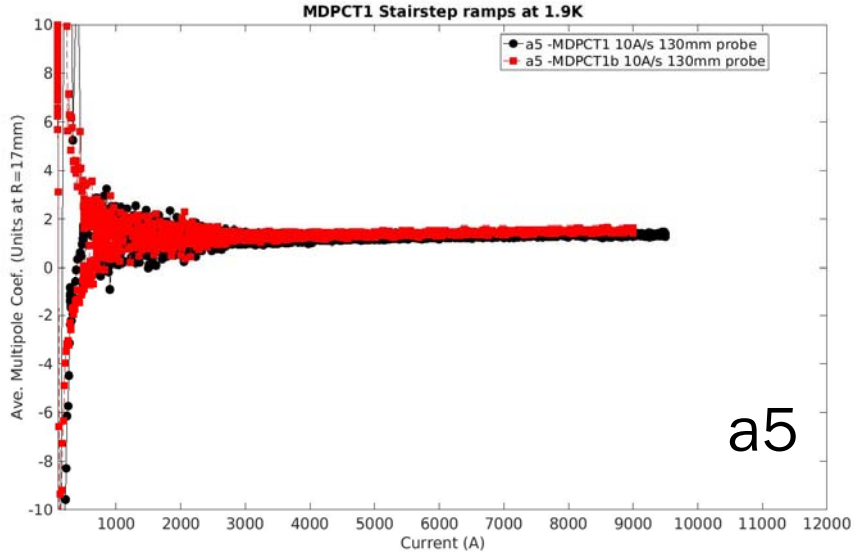

MDPCT1 Stairstep ramps at 1.9K
b5 -MDPCT1 10A/s 130mm probe
b5 -MDPCT1b 10A/s 130mm probe
Ave. Multipole Coef. (Units at R=17mm)
Current (A)
b5


MDPCT1 Stairstep ramps at 1.9K
Full b3 hysteresis
Ave. Multipole Coef. (Units at R=17mm)
Current (A)
250
200
150
100
50
0
-50
-100
1000
2000
3000
4000
5000
6000
7000
8000
9000
b3 -MDPCT1 10A/s 130mm probe
b3 -MDPCT1b 10A/s 130mm probe


MDPCT1 Stairstep ramps at 1.9K
a2 -MDPCT1 10A/s 130mm probe
a2 -MDPCT1b 10A/s 130mm probe
Ave. Multipole Coef. (Units at R=17mm)
Current (A)
a2

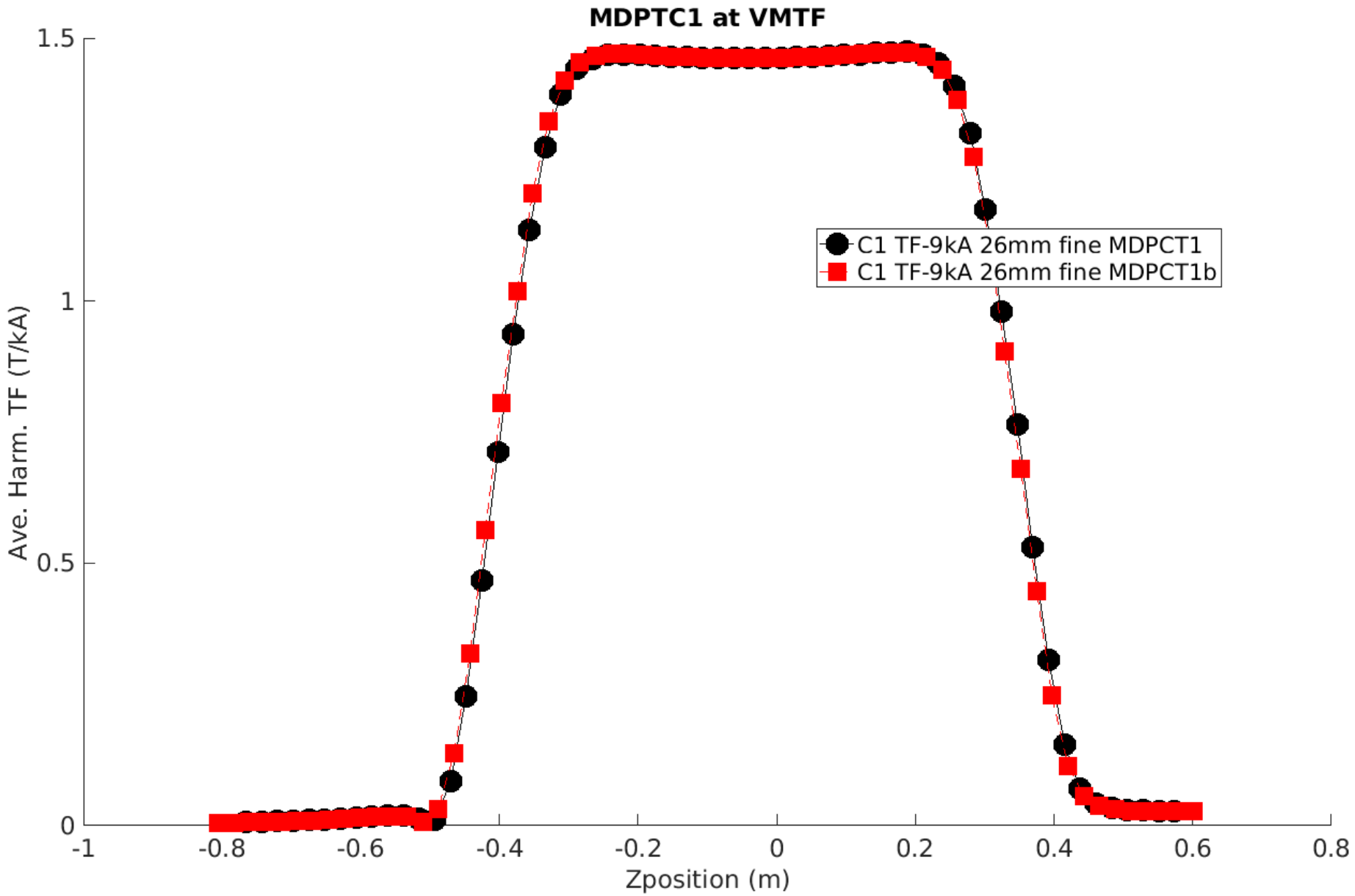

MDPCT1 Stairstep ramps at 1.9K
a3 -MDPCT1 10A/s 130mm probe
a3 -MDPCT1b 10A/s 130mm probe
a3 has largest change in hysteresis
Ave. Multipole Coef. (Units at R=17mm)
Current (A)
a3

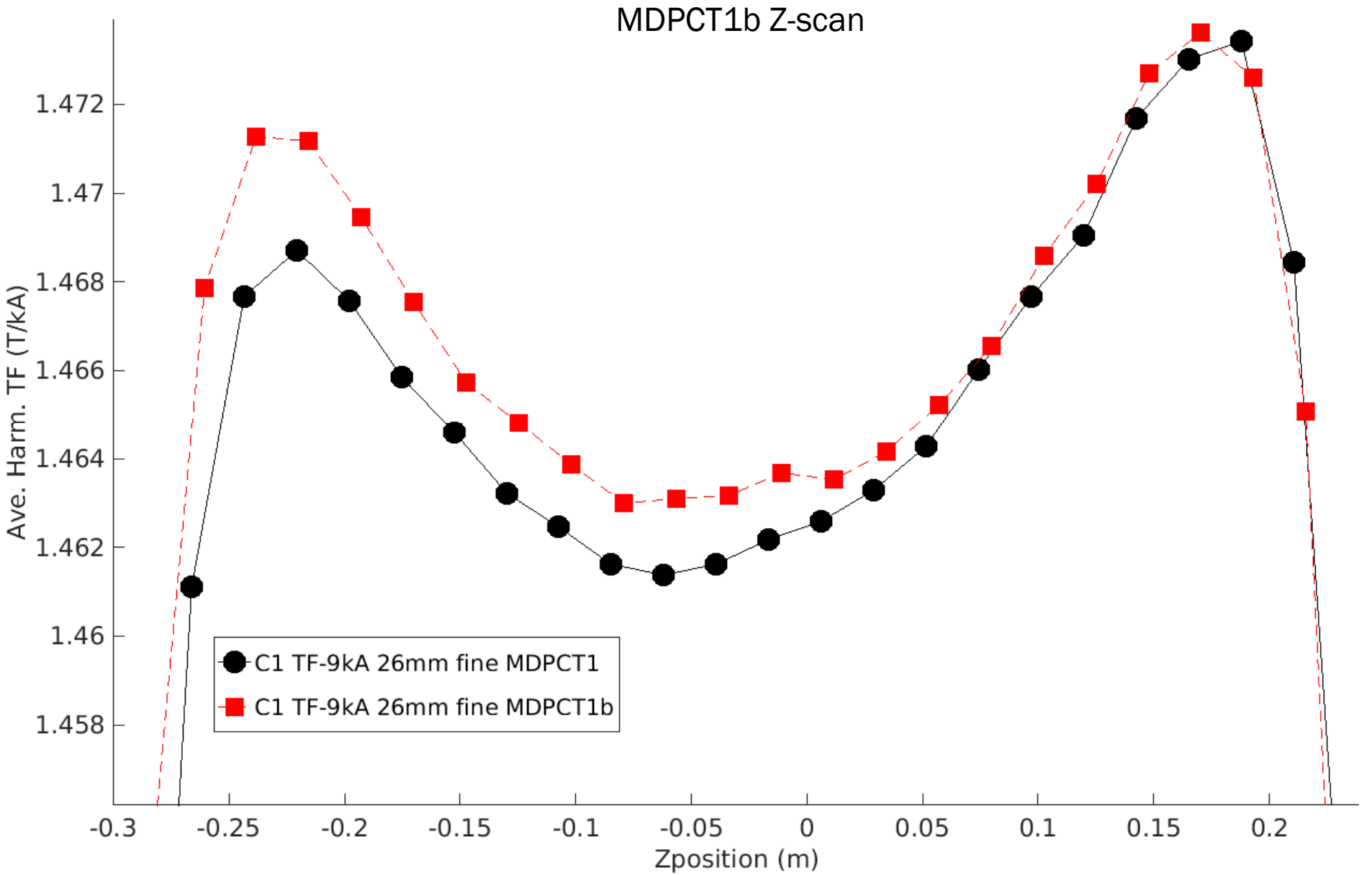

MDPCT1 Stairstep ramps at 1.9K
a4 -MDPCT1 10A/s 130mm probe
a4 -MDPCT1b 10A/s 130mm probe
Ave. Multipole Coef. (Units at R=17mm)
Current (A)
a4


MDPCT1 Stairstep ramps at 1.9K
a5 -MDPCT1 10A/s 130mm probe
a5 -MDPCT1b 10A/s 130mm probe
Ave. Multipole Coef. (Units at R=17mm)
Current (A)
a5

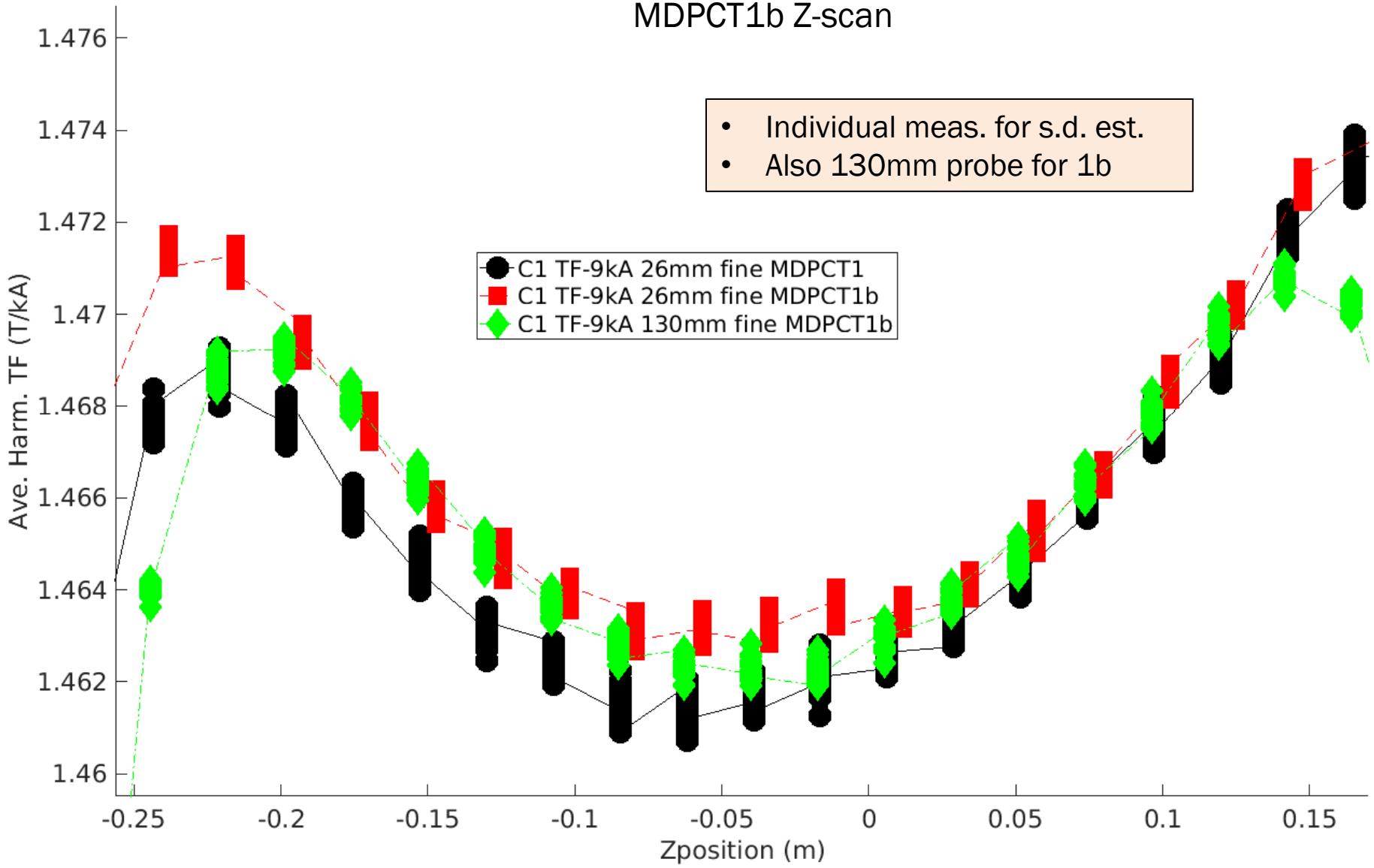
U.S. MAGNET DEVELOPMENT PROGRAM

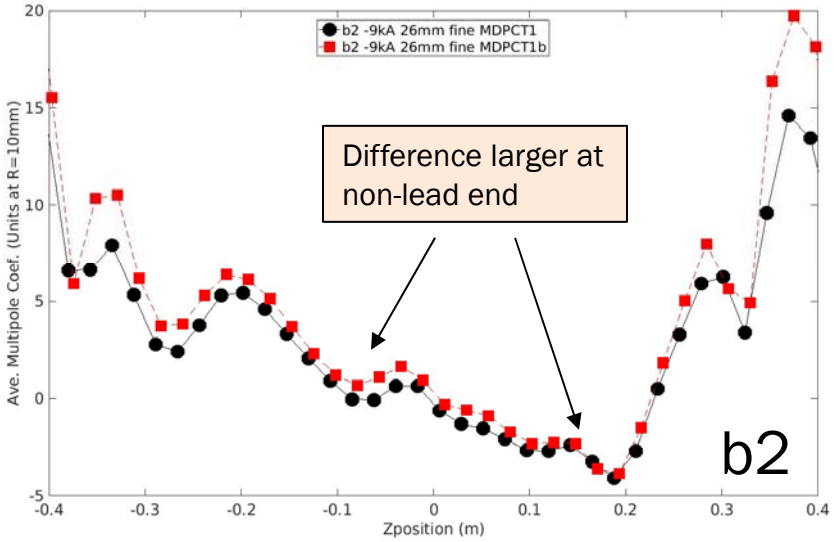
Zscans

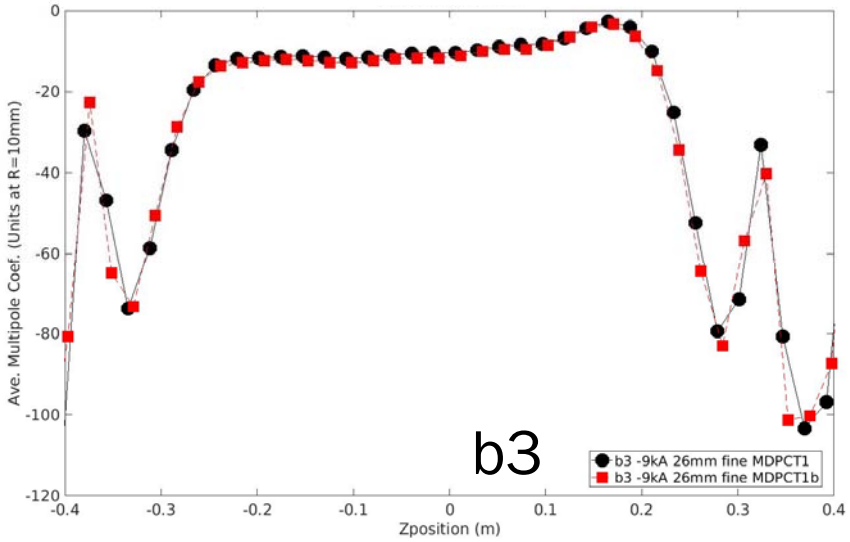


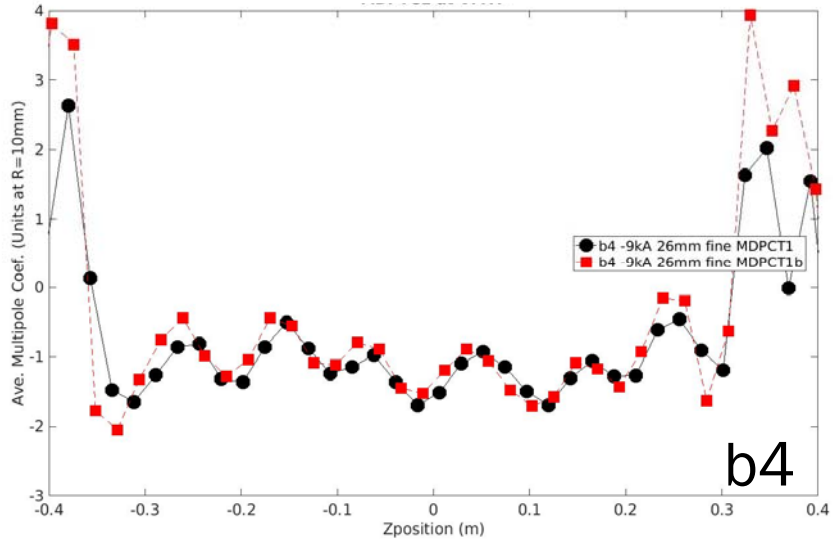

MDPCT1b Z-scan
Ave. Harm. TF (T/kA)
1.472
1.47
1.468
1.466
1.464
1.462
1.46
1.458
-0.3
-0.25
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Zposition (m)
C1 TF-9kA 26mm fine MDPCT1
C1 TF-9kA 26mm fine MDPCT1b

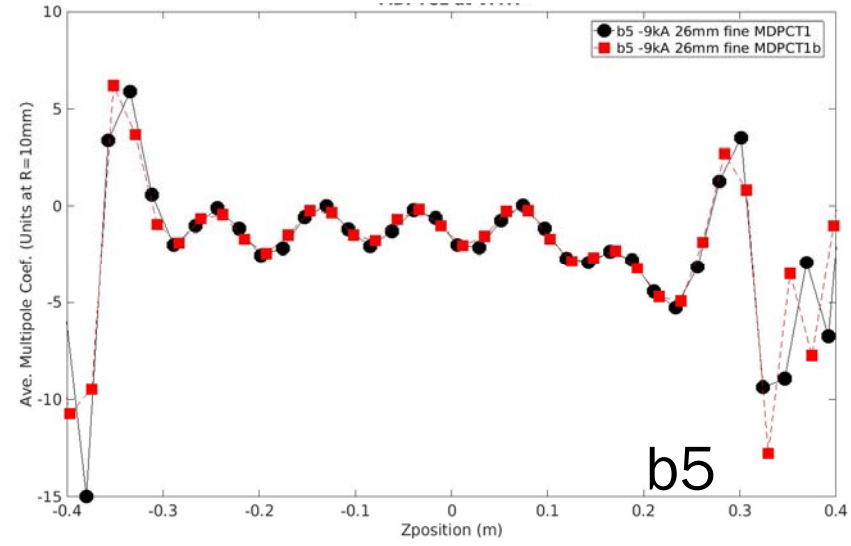
MDPCT1b Z-scan



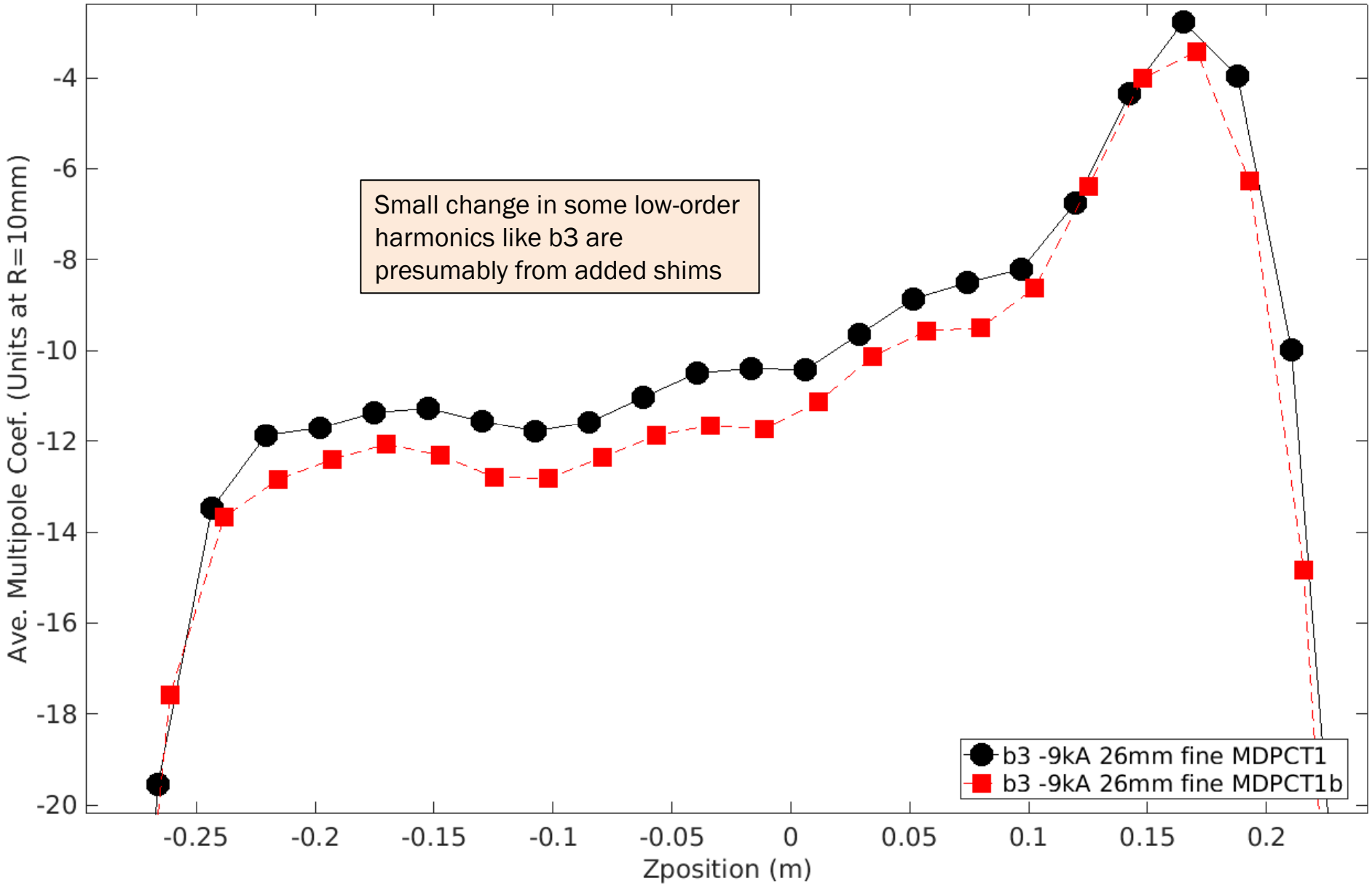

b2 -9kA 26mm fine MDPCT1
b2 -9kA 26mm fine MDPCT1b
Difference larger at non-lead end
b2
Ave. Multipole Coef. (Units at R=10mm)
Zposition (m)

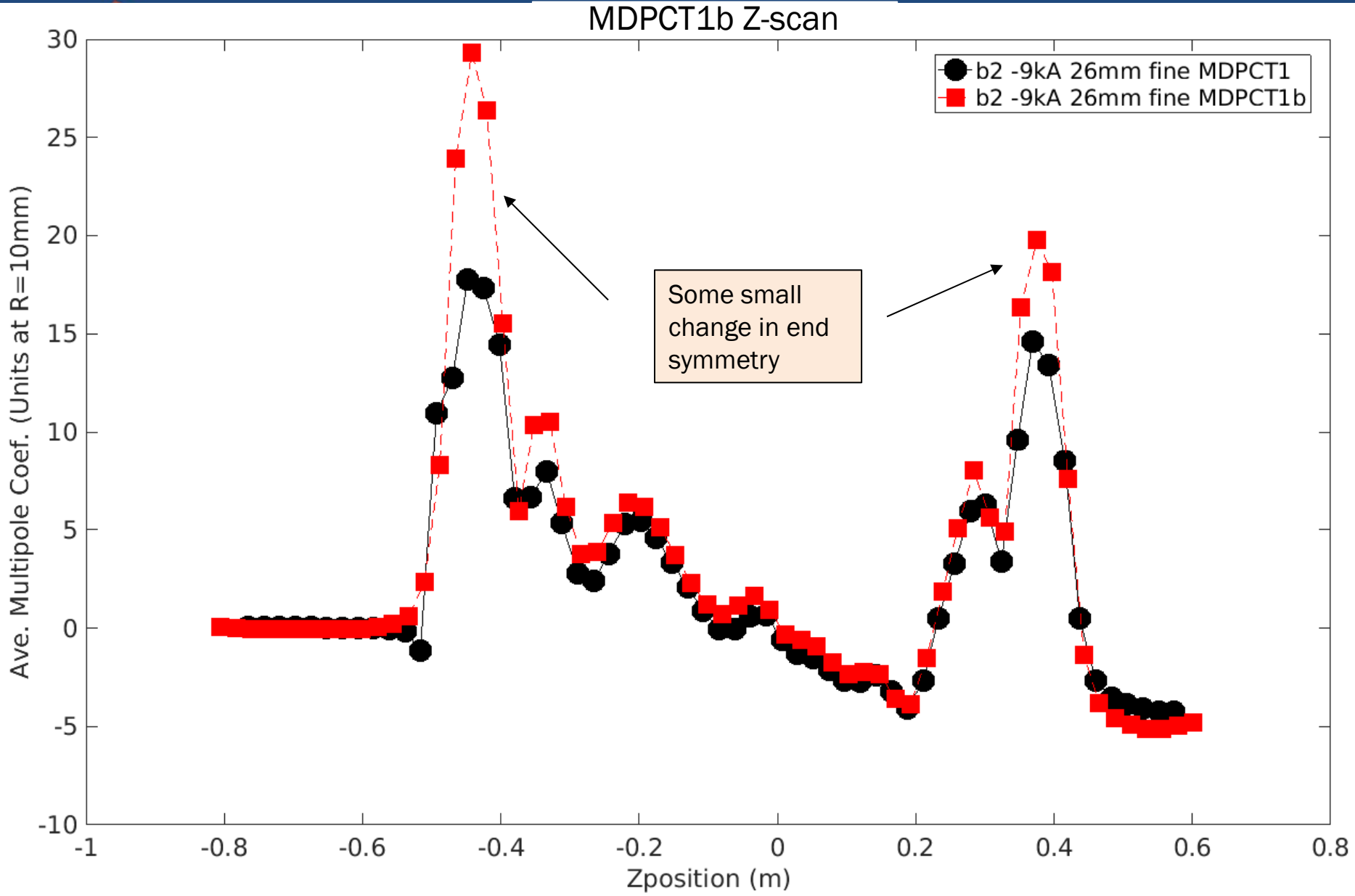

b3
b3 -9kA 26mm fine MDPCT1
b3 -9kA 26mm fine MDPCT1b
Ave. Multipole Coef. (Units at R=10mm)
Zposition (m)

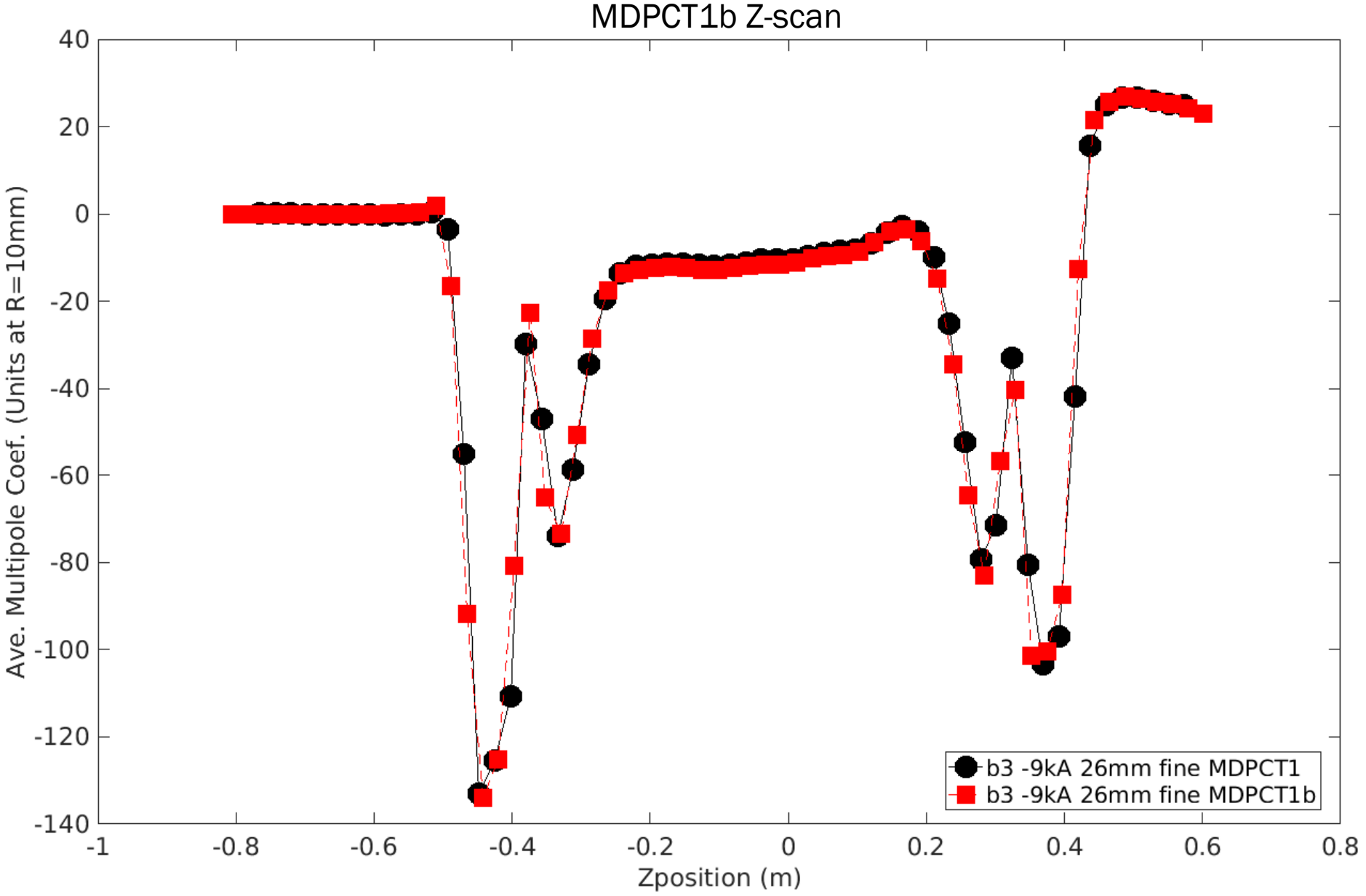

b4
b4 -9kA 26mm fine MDPCT1
b4 -9kA 26mm fine MDPCT1b
Ave. Multipole Coef. (Units at R=10mm)
Zposition (m)

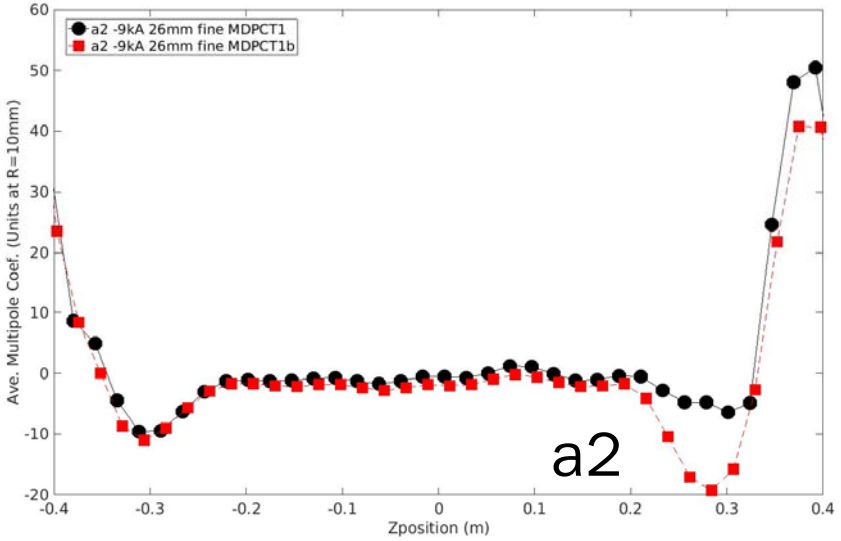

b5
b5 -9kA 26mm fine MDPCT1
b5 -9kA 26mm fine MDPCT1b
Ave. Multipole Coef. (Units at R=10mm)
Zposition (m)

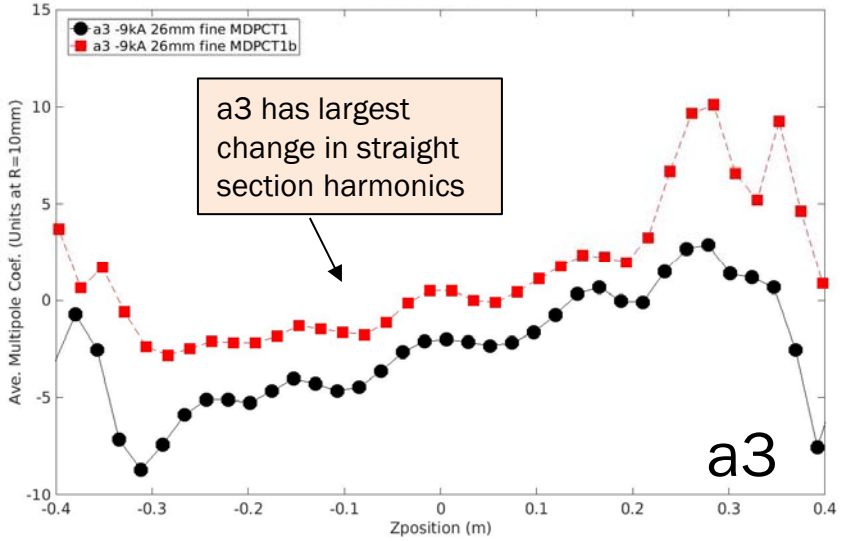
MDPCT1b Z-scan



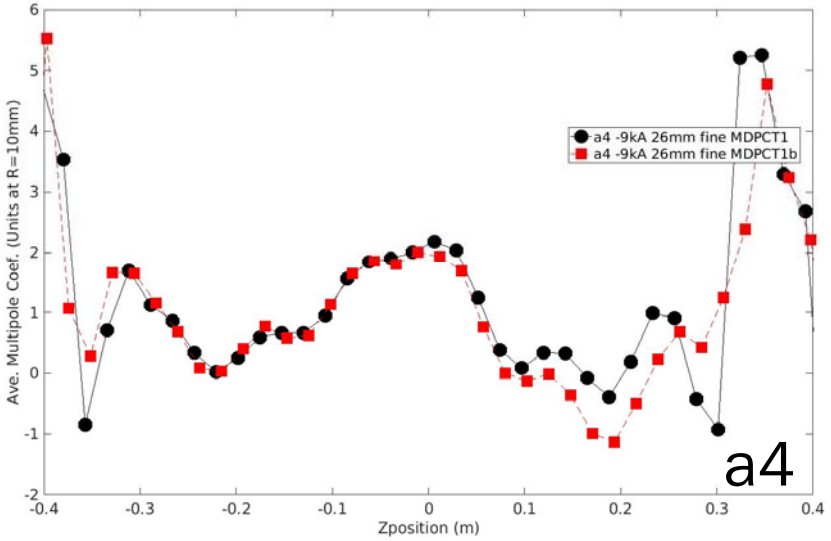

MDPCT1b Z-scan
b2 -9kA 26mm fine MDPCT1
b2 -9kA 26mm fine MDPCT1b
Some small change in end symmetry
Ave. Multipole Coef. (Units at R=10mm)
Zposition (m)
30
25
20
15
10
5
0
-5
-10
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8

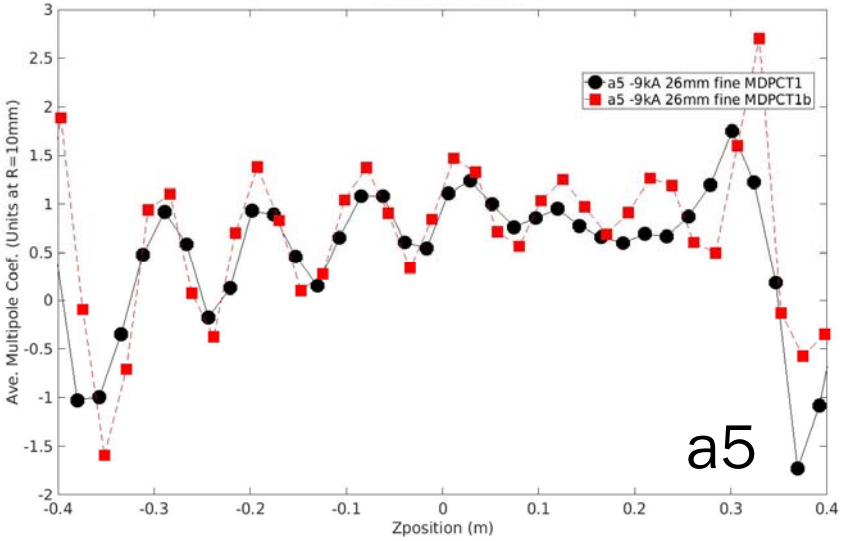

MDPCT1b Z-scan
Ave. Multipole Coef. (Units at R=10mm)
Zposition (m)
40
20
0
-20
-40
-60
-80
-100
-120
-140
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
b3 -9kA 26mm fine MDPCT1
b3 -9kA 26mm fine MDPCT1b



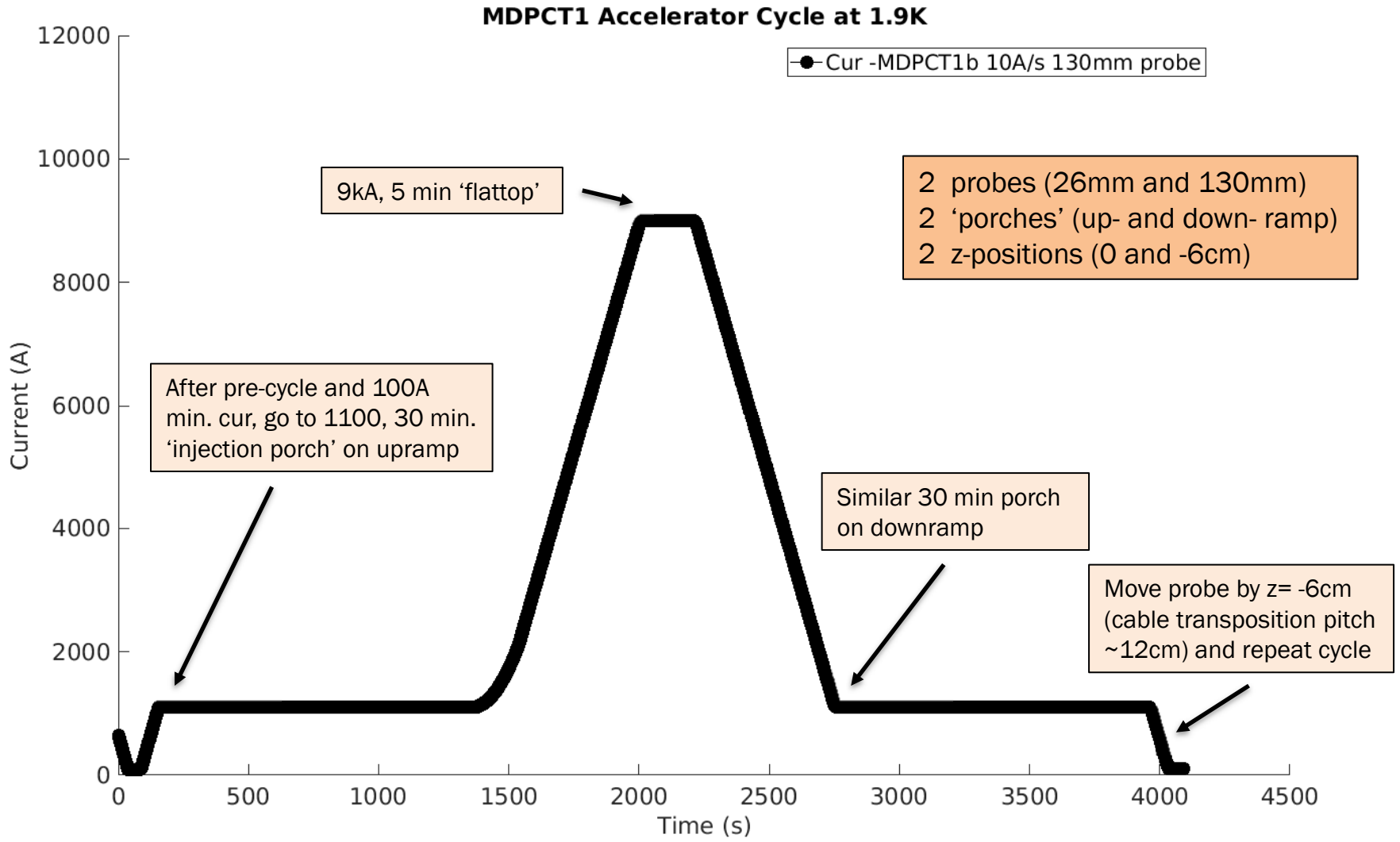


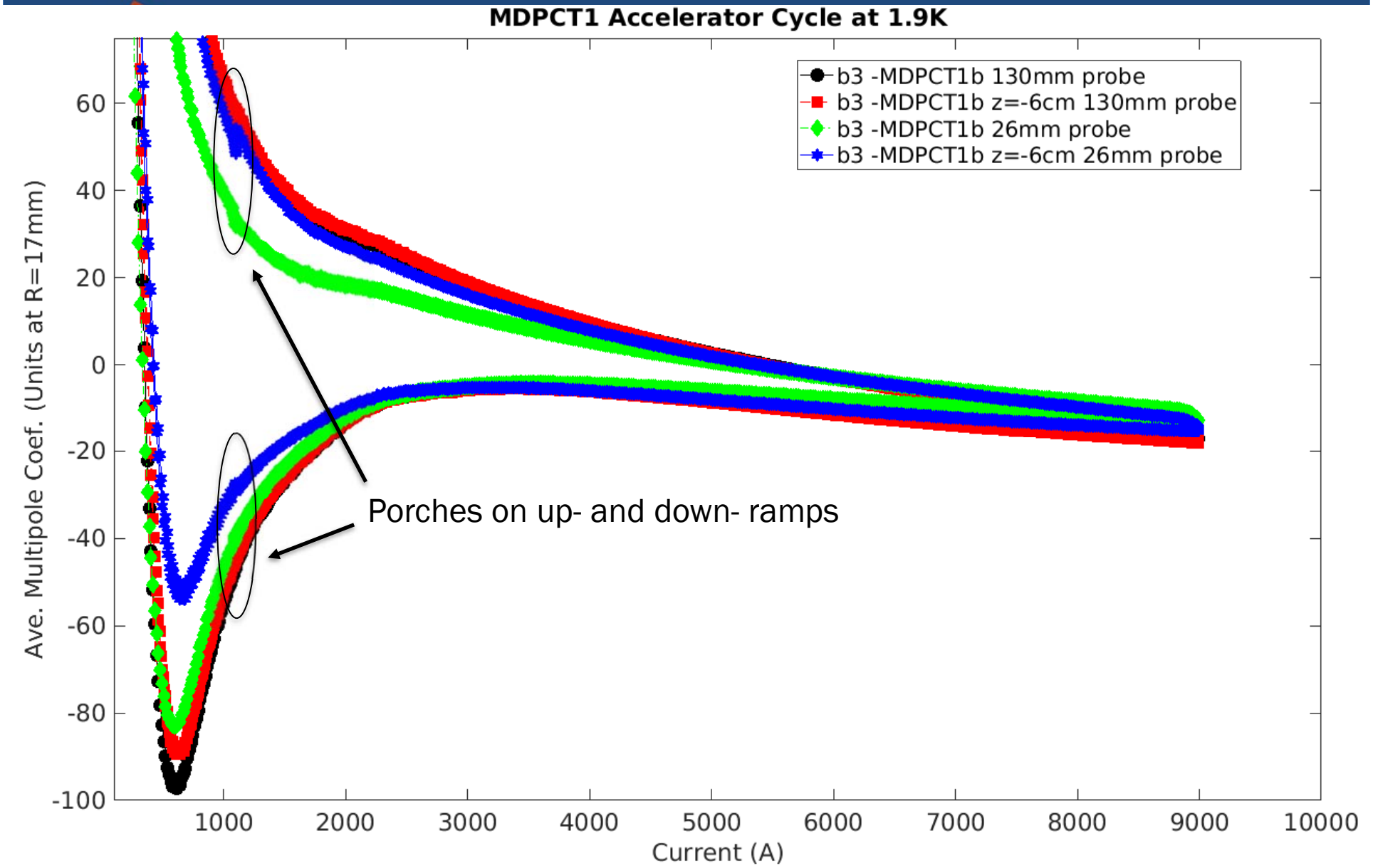
Skew harmonics have some changes especially at lead end

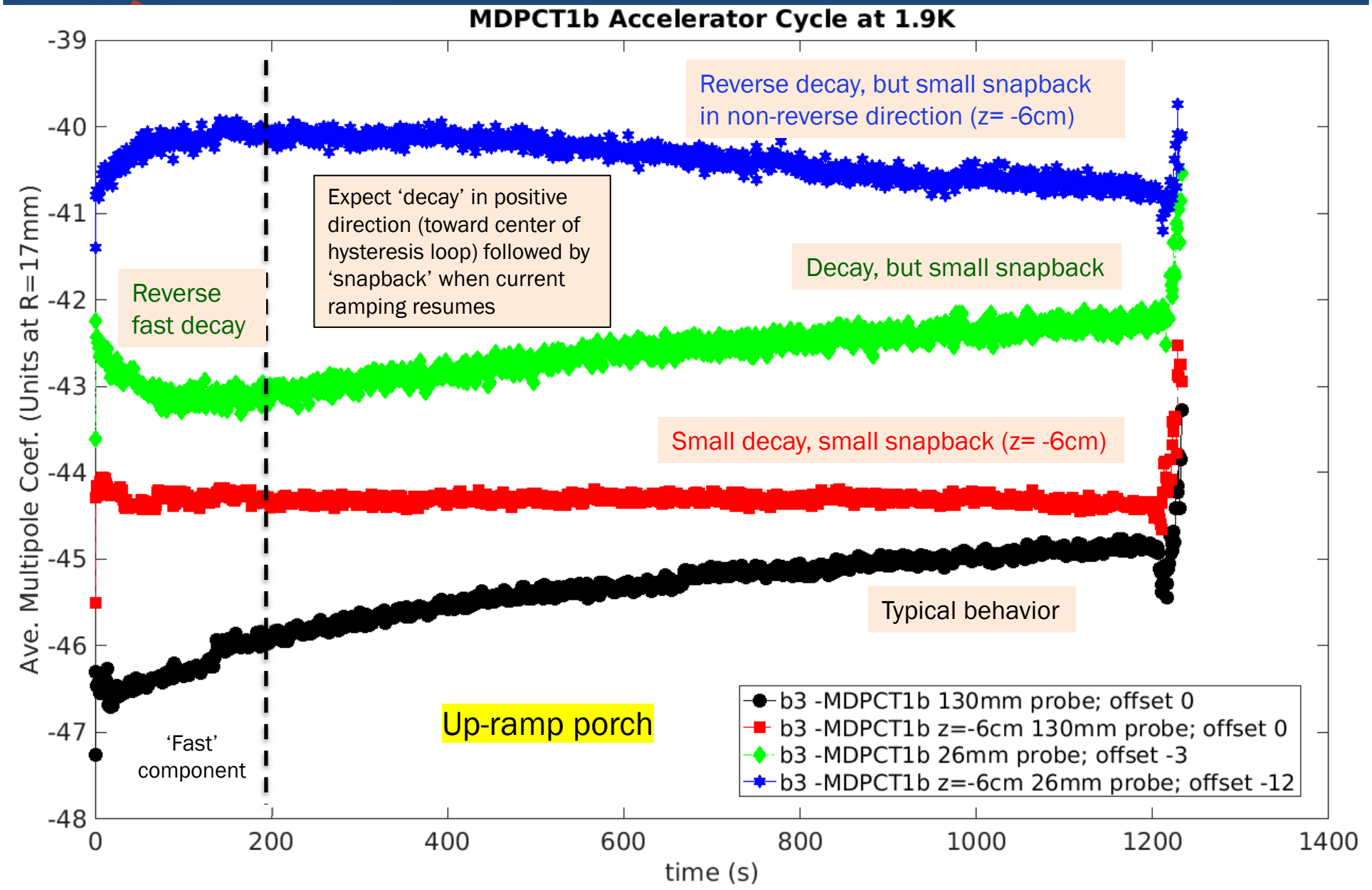


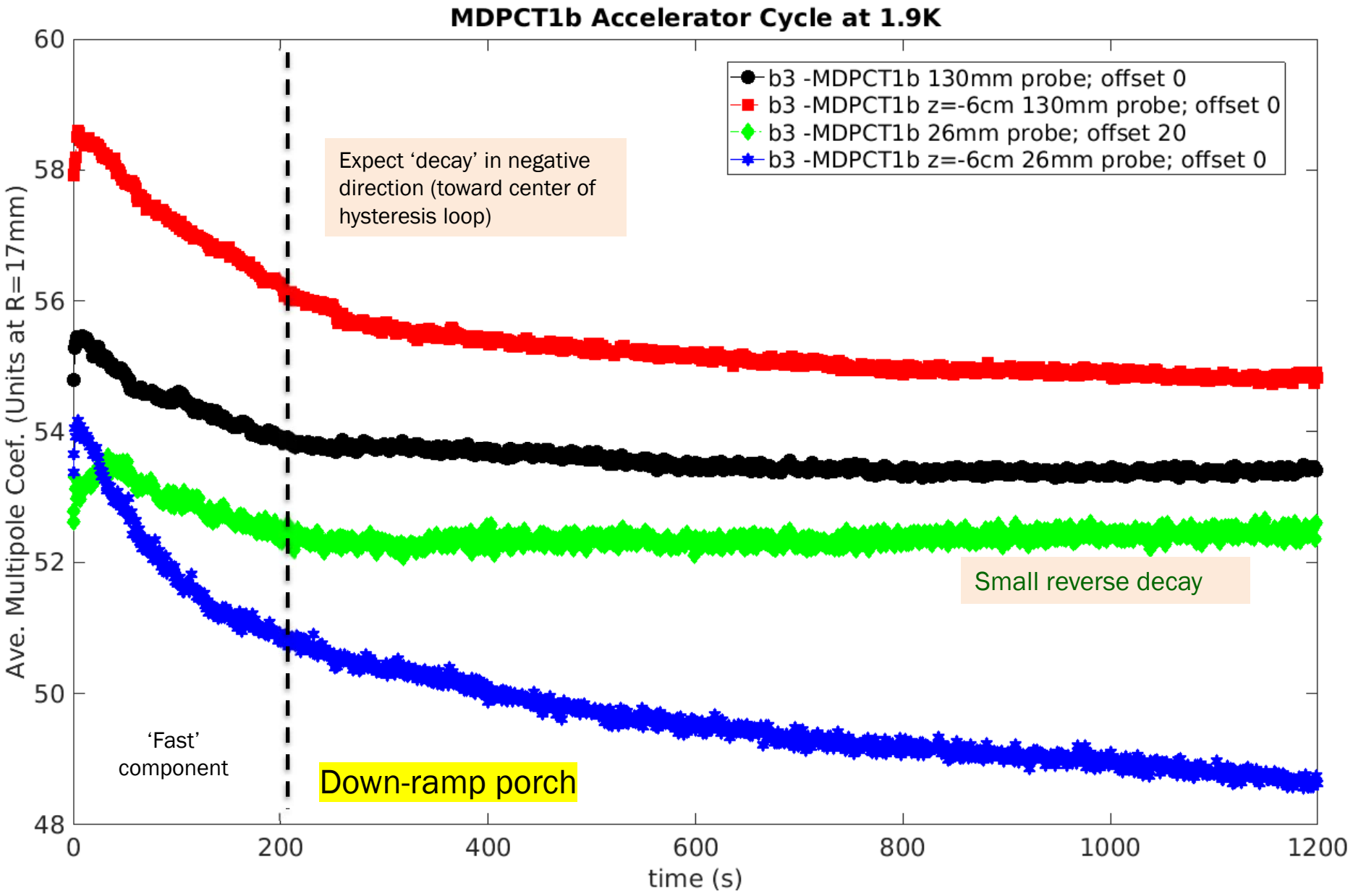


Accelerator Cycle




MDPCT1 Accelerator Cycle at 1.9K
b3 -MDPCT1b 130mm probe
b3 -MDPCT1b z=-6cm 130mm probe
b3 -MDPCT1b 26mm probe
b3 -MDPCT1b z=-6cm 26mm probe
Ave. Multipole Coef. (Units at R=17mm)
Current (A)
Porches on up- and down- ramps
60
40
20
0
-20
-40
-60
-80
-100
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000


MDPCT1b Accelerator Cycle at 1.9K
Ave. Multipole Coef. (Units at R=17mm)
time (s)
-39
-40
-41
-42
-43
-44
-45
-46
-47
-48
0
200
400
600
800
1000
1200
1400
Reverse decay, but small snapback in non-reverse direction (z= -6cm)
Expect 'decay' in positive direction (toward center of hysteresis loop) followed by 'snapback' when current ramping resumes
Decay, but small snapback
Reverse fast decay
Small decay, small snapback (z= -6cm)
Typical behavior
'Fast' component
Up-ramp porch
b3 -MDPCT1b 130mm probe; offset 0
b3 -MDPCT1b z=-6cm 130mm probe; offset 0
b3 -MDPCT1b 26mm probe; offset -3
b3 -MDPCT1b z=-6cm 26mm probe; offset -12


MDPCT1b Accelerator Cycle at 1.9K
b3 -MDPCT1b 130mm probe; offset 0
b3 -MDPCT1b z=-6cm 130mm probe; offset 0
b3 -MDPCT1b 26mm probe; offset 20
b3 -MDPCT1b z=-6cm 26mm probe; offset 0
Expect 'decay' in negative direction (toward center of hysteresis loop)
Small reverse decay
'Fast' component
Down-ramp porch
Ave. Multipole Coef. (Units at R=17mm)
time (s)
60
58
56
54
52
50
48
0
200
400
600
800
1000
1200

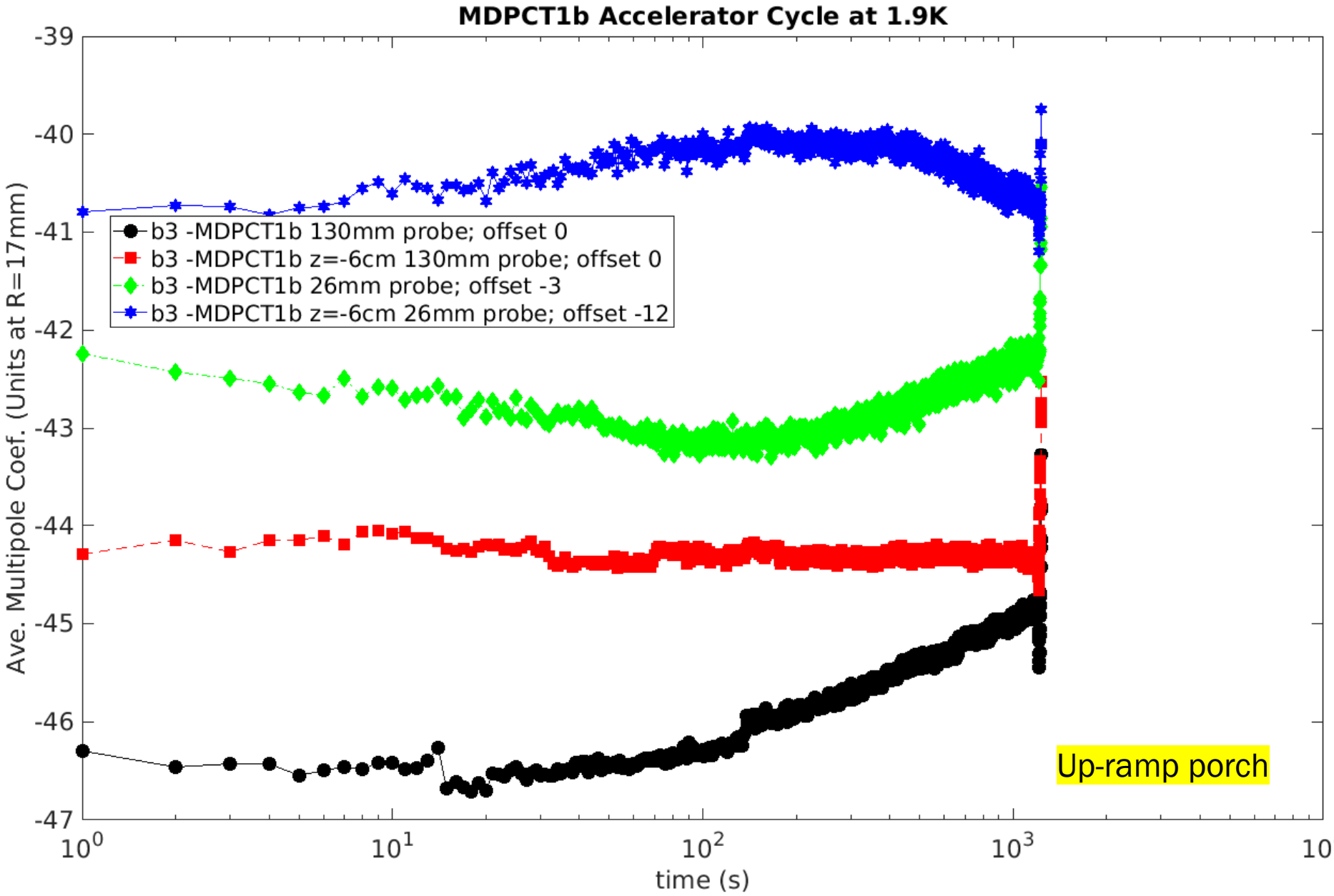
Summary/Discussion

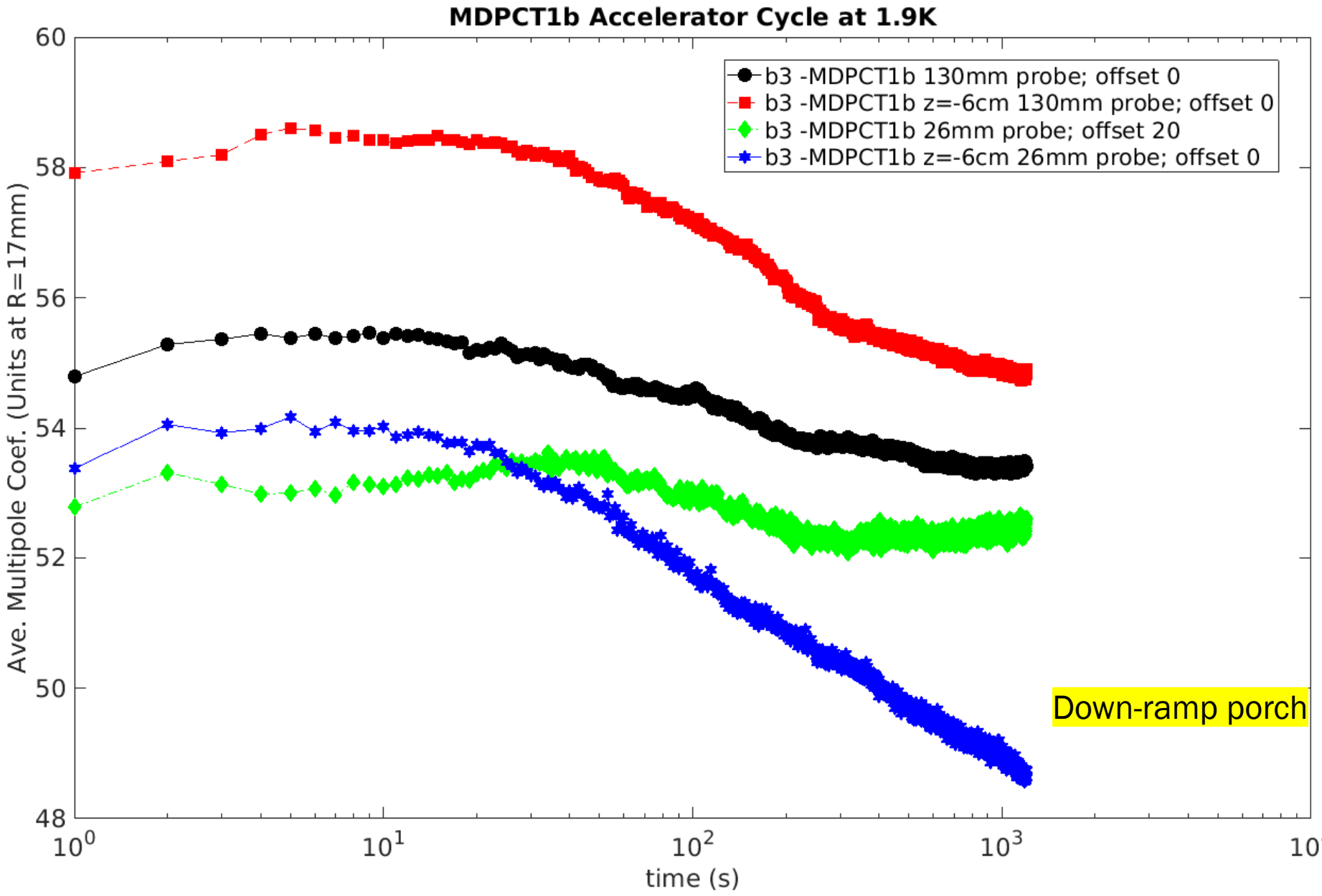
Transfer function in CT1b is similar to MDPCT1 except that the non-lead 'half' is slightly stronger by about 15-20 units, seeming to stem from smaller saturation effects. Only a few unit increase is expected from coil compression, so this difference may be related to difference in gap closure of the two halves between the builds. This is being looked into.

CT1b harmonics in the straight section are at the level of few units (largest being b3 at about -13 units) and besides small changes which likely stem from shims, very close to those in MDPCT1. Largest change seen was in skew sextupole (a3). The b2 and a3 also seem to show some small difference between non-lead end and lead-end halves.

Skew sextupole also had largest change in hysteresis (effectively slight rotation of normal b3 wrt main dipole field). Hysteresis of other harmonics were comparable.

Decay and snapback studies were taken during Accelerator Cycle ramping. These show some dependence on position and coverage of cable transposition pitch and will be further examined. Additional tests will be performed in next cooldown.


MDPCT1b Accelerator Cycle at 1.9K
Ave. Multipole Coef. (Units at R=17mm)
time (s)
b3 -MDPCT1b 130mm probe; offset 0
b3 -MDPCT1b z=-6cm 130mm probe; offset 0
b3 -MDPCT1b 26mm probe; offset -3
b3 -MDPCT1b z=-6cm 26mm probe; offset -12
Up-ramp porch


MDPCT1b Accelerator Cycle at 1.9K
b3 -MDPCT1b 130mm probe; offset 0
b3 -MDPCT1b z=-6cm 130mm probe; offset 0
b3 -MDPCT1b 26mm probe; offset 20
b3 -MDPCT1b z=-6cm 26mm probe; offset 0
Ave. Multipole Coef. (Units at R=17mm)
time (s)
60
58
56
54
52
50
48
10^0
10^1
10^2
10^3
10^4
Down-ramp porch