Low Energy Measurements of RHIC Dipoles and Quadrupoles

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Introduction

- RHIC dipoles and quadrupoles are operated at very low currents (112-218 A for dipoles and 104-202 A for the quadrupoles) for low energy Au-Au studies.
- Indications of strong non-linearities have been seen at these low currents in RHIC.
- Field quality in superconducting magnets at such low excitations is strongly influenced by persistent current induced harmonics.
- Field quality at low excitations was measured in early 2010 in a spare D96 dipole (3 m long) and a spare arc quadrupole. The results of these measurements are reported here.

Low Energy Operating Parameters

Species	Z	A	mc^2 [GeV/u]				
Au	79	197	0.93113				
	2007 test	Au store	Au injection	2009-2010 Schedule From Vigdor			
sqrt(s) [AGeV]	9.183	201.870	19.600	18.000	11.500	7.700	5.000
Harmonic number	366	360	360	360	363	369	369
Beam E [AGeV]	4.592	100.935	9.800	9.000	5.750	3.850	2.500
Beam KE [AGeV]	3.660	100.004	8.869	8.069	4.819	2.919	1.569
gamma	4.931	108.401	10.525	9.666	6.175	4.135	2.685
beta	0.979	1.000	0.995	0.995	0.987	0.970	0.928
p [GeV/c]	4.496	100.931	9.756	8.952	5.674	3.736	2.320
Brho [T-m]	37.398	839.541	81.148	74.460	47.197	31.074	19.299
main dipole [A]	217.716	4887.394	472.401	433.471	274.759	180.895	112.348
main quad [A]	202.636	4548.873	439.681	403.447	255.728	168.366	104.567
Rev Freq [Hz]	76571.478	78192.963	77842.531	77776.668	77164.203	75874.890	72570.182

(*Parameter table from Todd Satagota*)

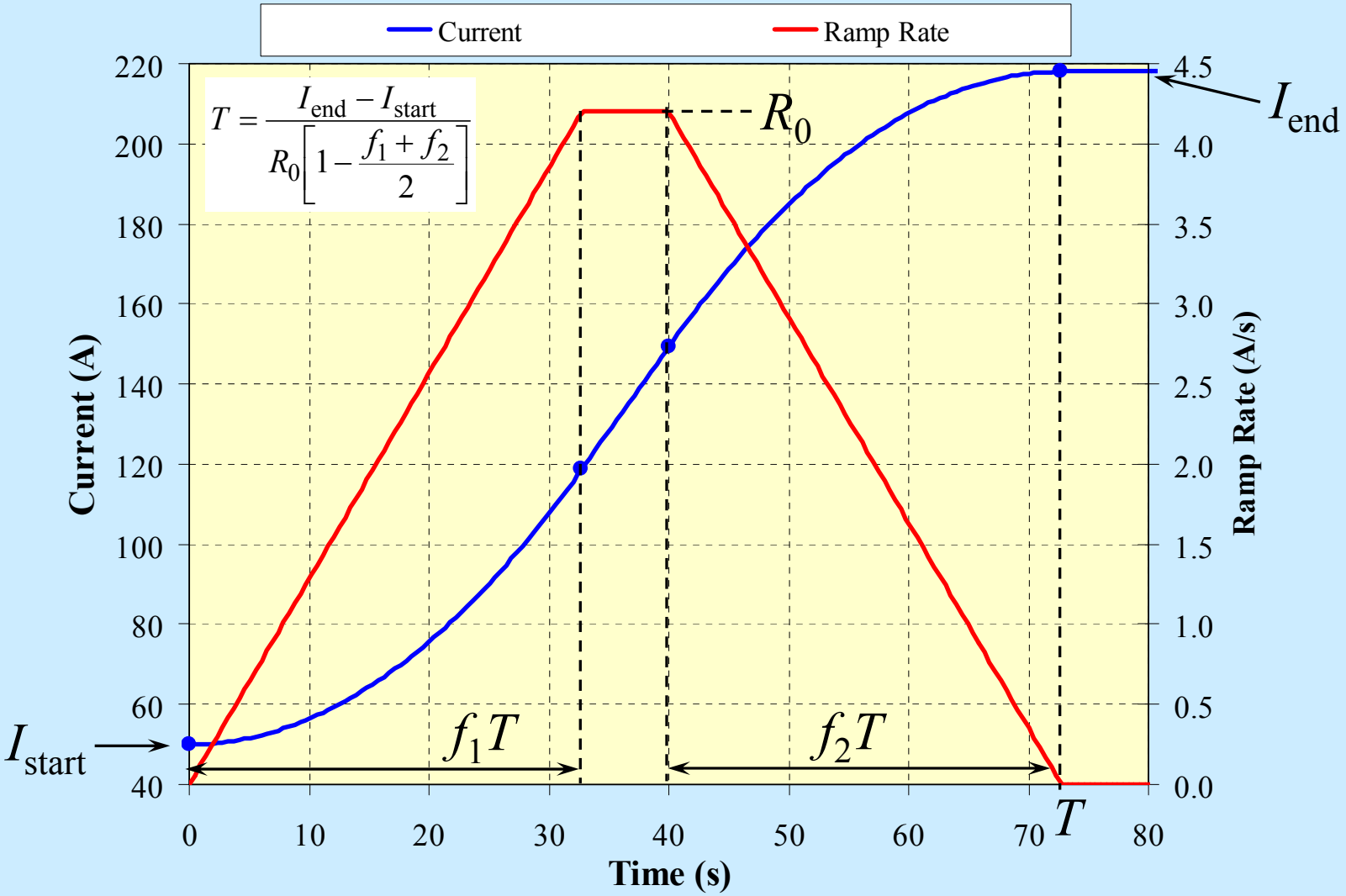
Measurements were made at currents corresponding to center of mass energies of 5.0, 7.7 and 9.2 Gev/u.

Maximum cycle current, I_{max}, for all three energies: 1948 A for the dipoles; 1833 A for the quadrupoles

Measurement Plan

- Magnet was cycled three times between 50 A (park current) and I_{max} as per ramp profile specified.
- Magnet was then ramped from 50 A to one of the operating currents, as per the specified ramp profile.
- Harmonics were measured with 1.32 s time resolution starting at the later half of this ramp, and continuing into the steady state for about 45 minutes, to study the time decay dynamics.
- Only one position covering 1 m in the body is measured. This length is not the best to use for the 1.1 m long quad.
- A full "DC Loop" was also measured from 50 A to I_{max} in order to compare results with the dynamic measurements.

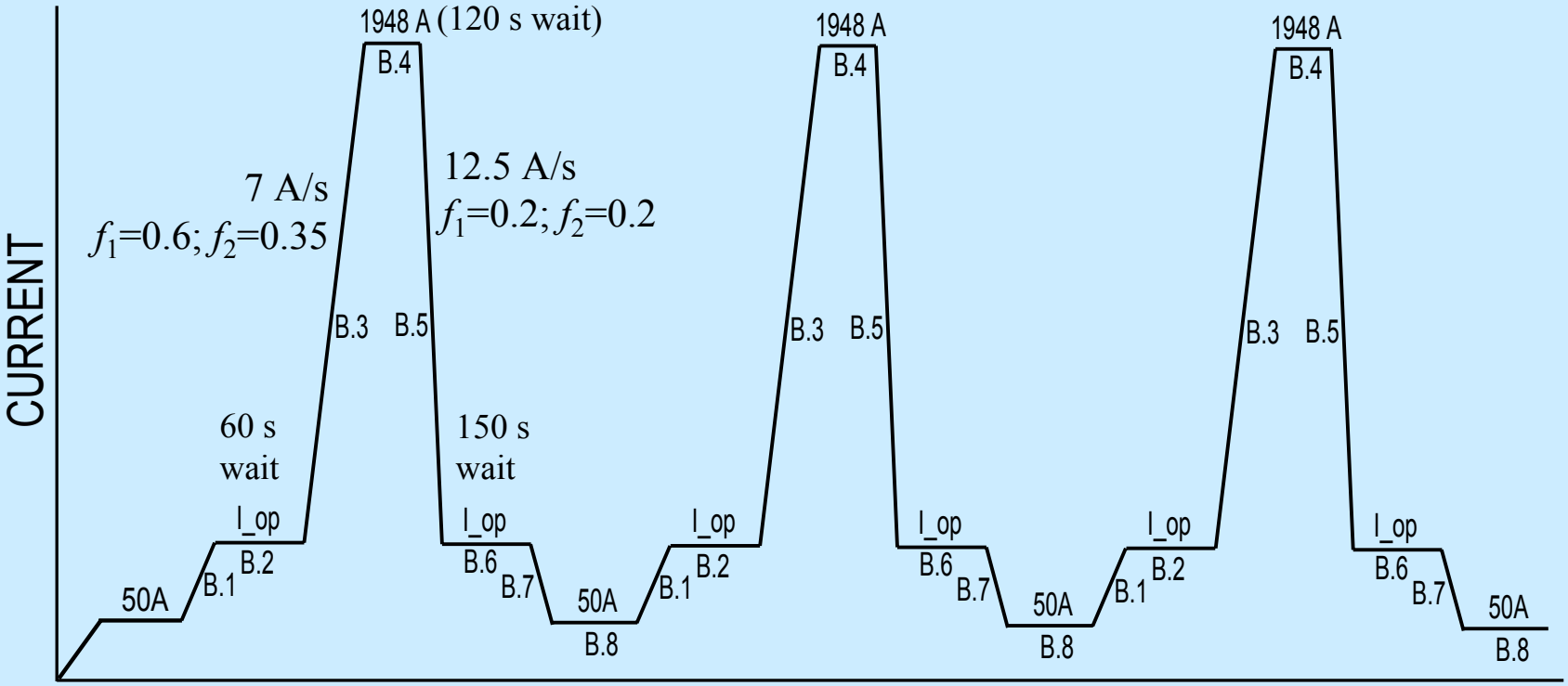
Ramp Parameterization



Parameters for all ramps were determined by examining actual ramp profiles used in RHIC provided by Todd Satogata.

Measurement Results in a D96 Dipole

Standardization Cycles for Dipole



Ramp B.1 details:

For I_{op} = 112 A: R_0 = 2.8 A/s; f_1 = 0.47; f_2 = 0.47, I_{start} = 50 A, I_{end} = 112 A

For I_{op} = 181 A: R_0 = 3.9 A/s; f_1 = 0.45; f_2 = 0.45, I_{start} = 50 A, I_{end} = 181 A.

For I_{op} = 218 A: R_0 = 4.2 A/s; f_1 = 0.45; f_2 = 0.45, I_{start} = 50 A, I_{end} = 218 A.

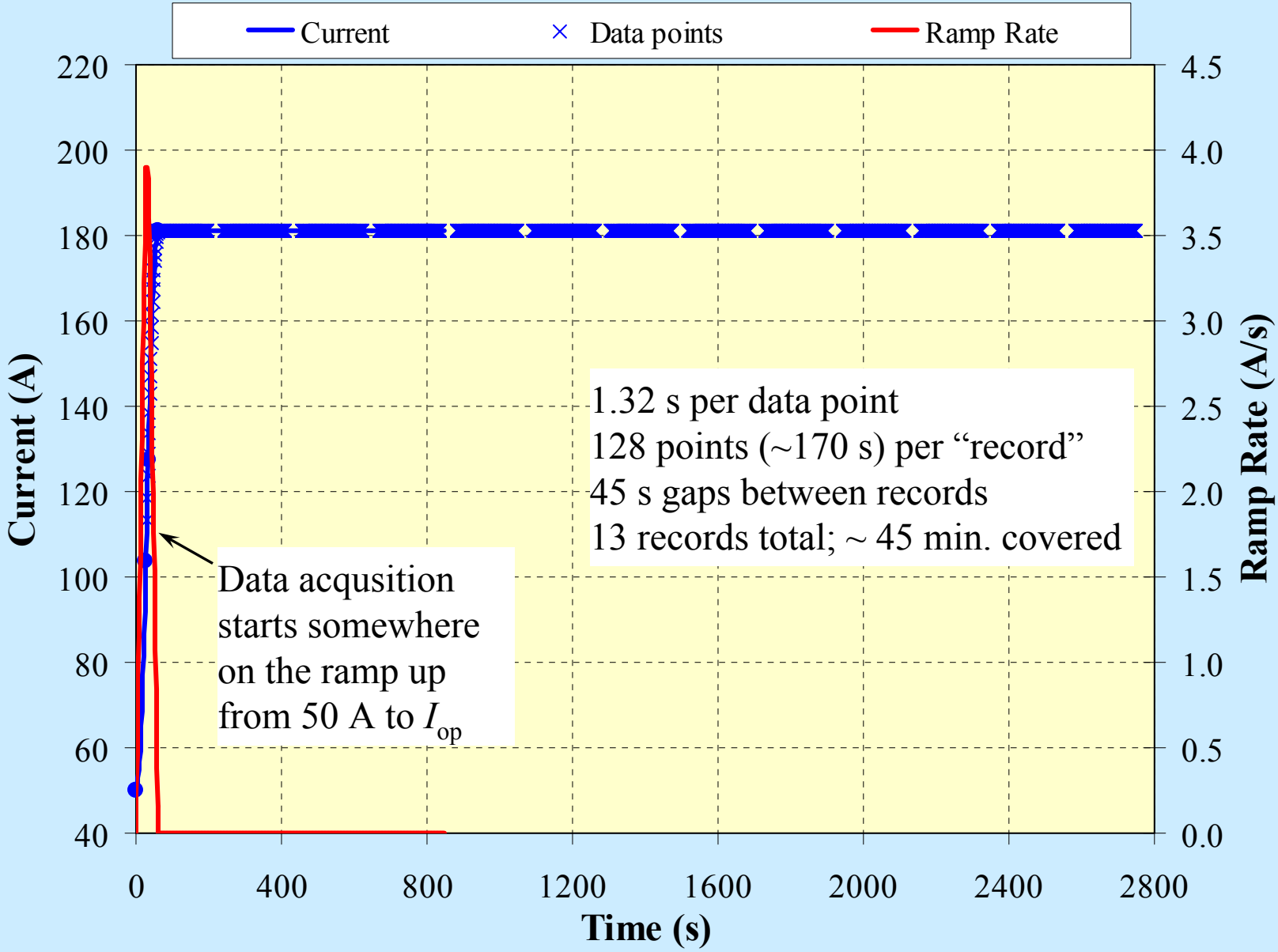
Ramp B.7 details:

For I_{op} = 112 A: R_0 = 2.8 A/s; f_1 = 0.47; f_2 = 0.47, I_{start} = 112 A, I_{end} = 50 A

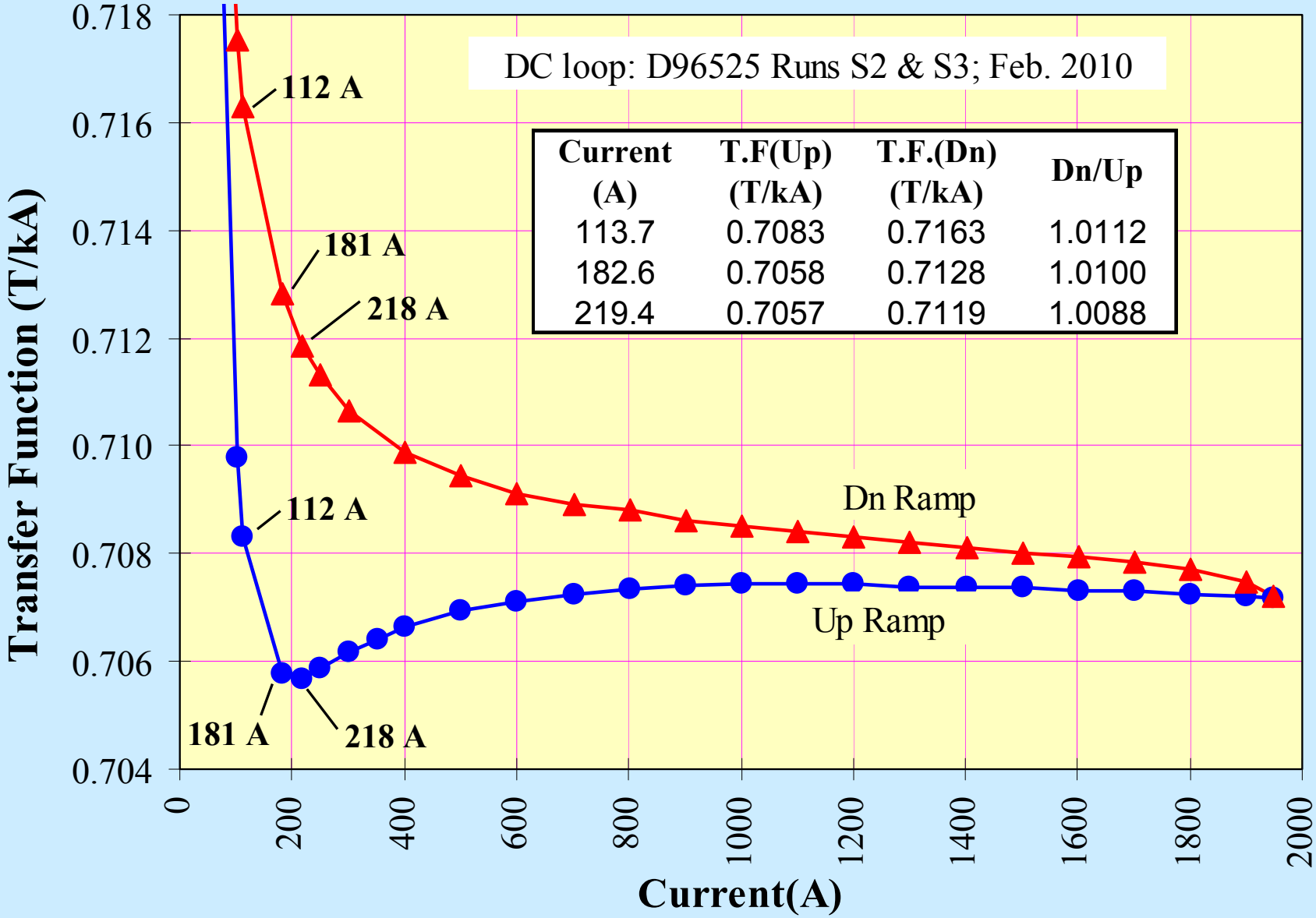
For I_{op} = 181 A: R_0 = 3.9 A/s; f_1 = 0.45; f_2 = 0.45, I_{start} = 181 A, I_{end} = 50 A.

For I_{op} = 218 A: R_0 = 4.6 A/s; f_1 = 0.47; f_2 = 0.47, I_{start} = 218 A, I_{end} = 50 A.

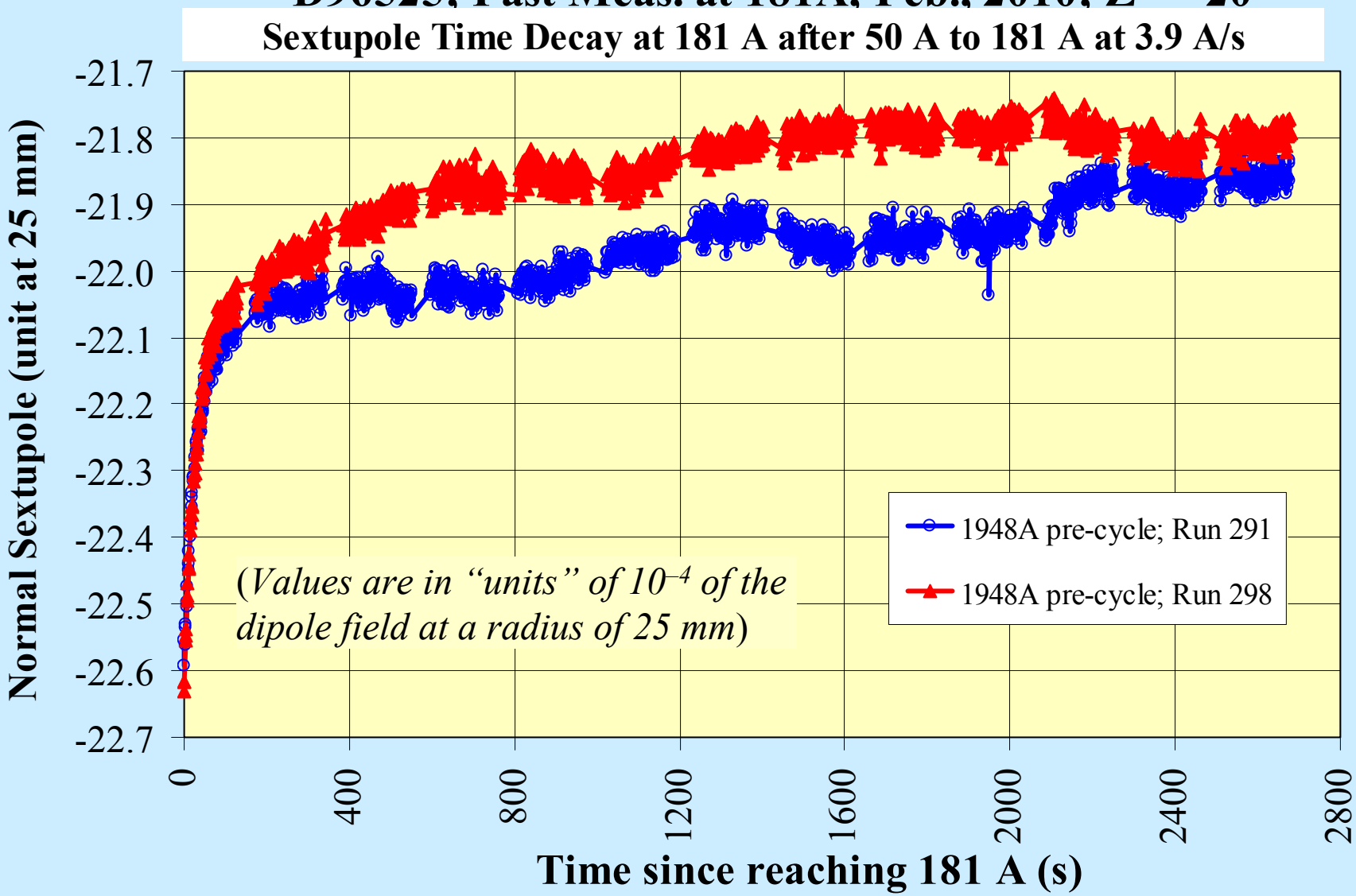
Time Decay Measurements



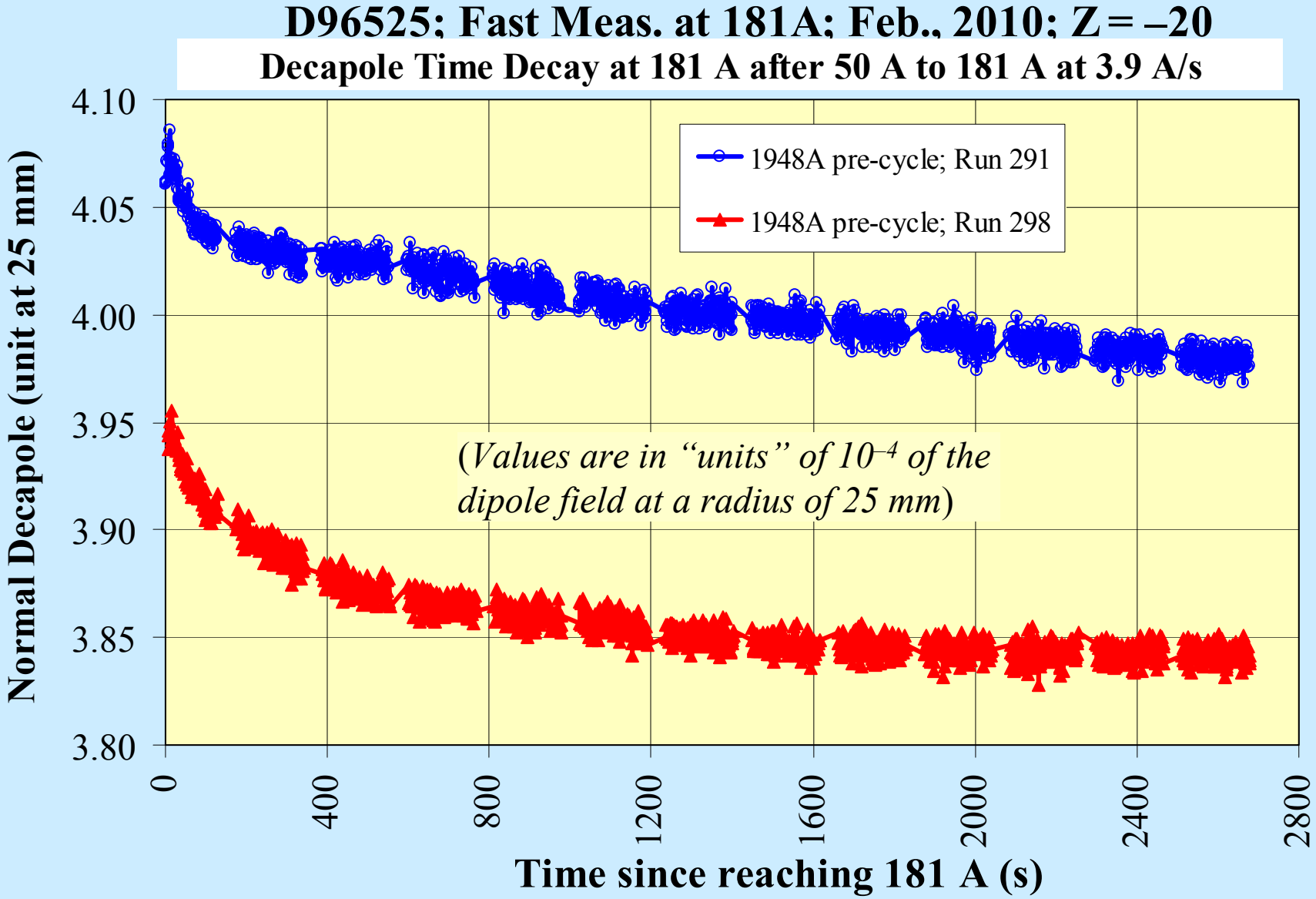
DC Loop: Transfer Function of Dipole



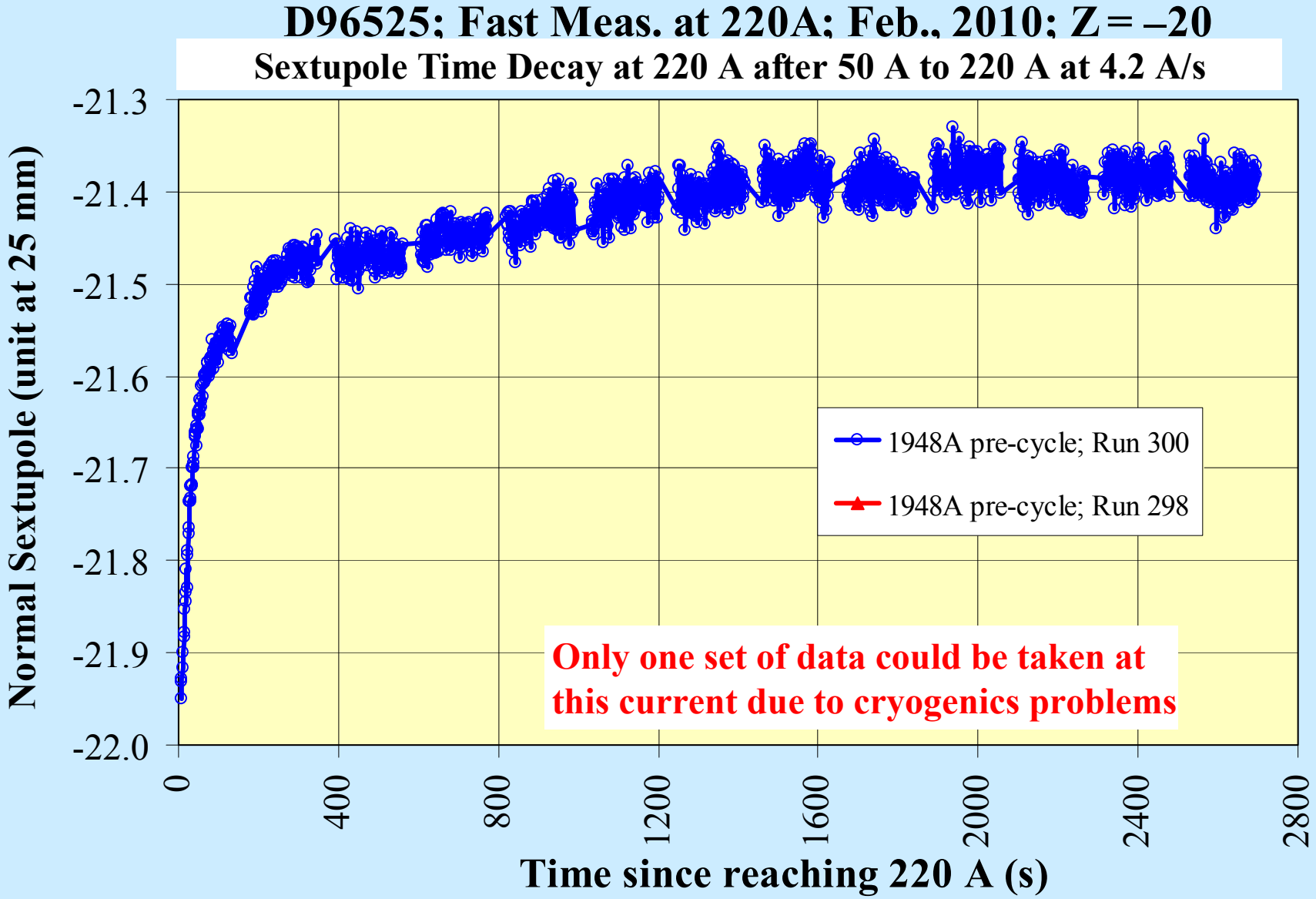
Time Decay at 181 A: Sextupole



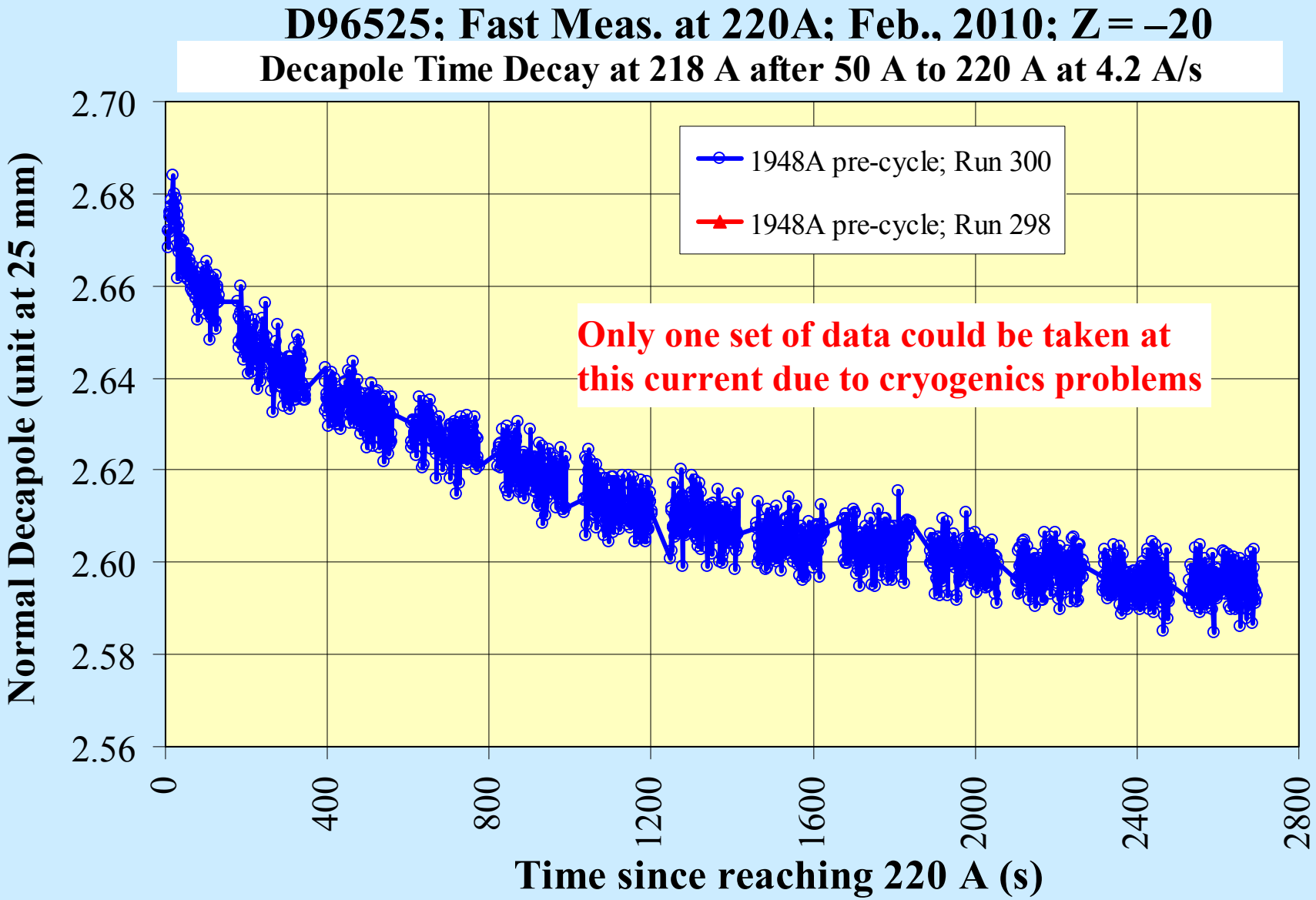
Time Decay at 181 A: Decapole in Dipole



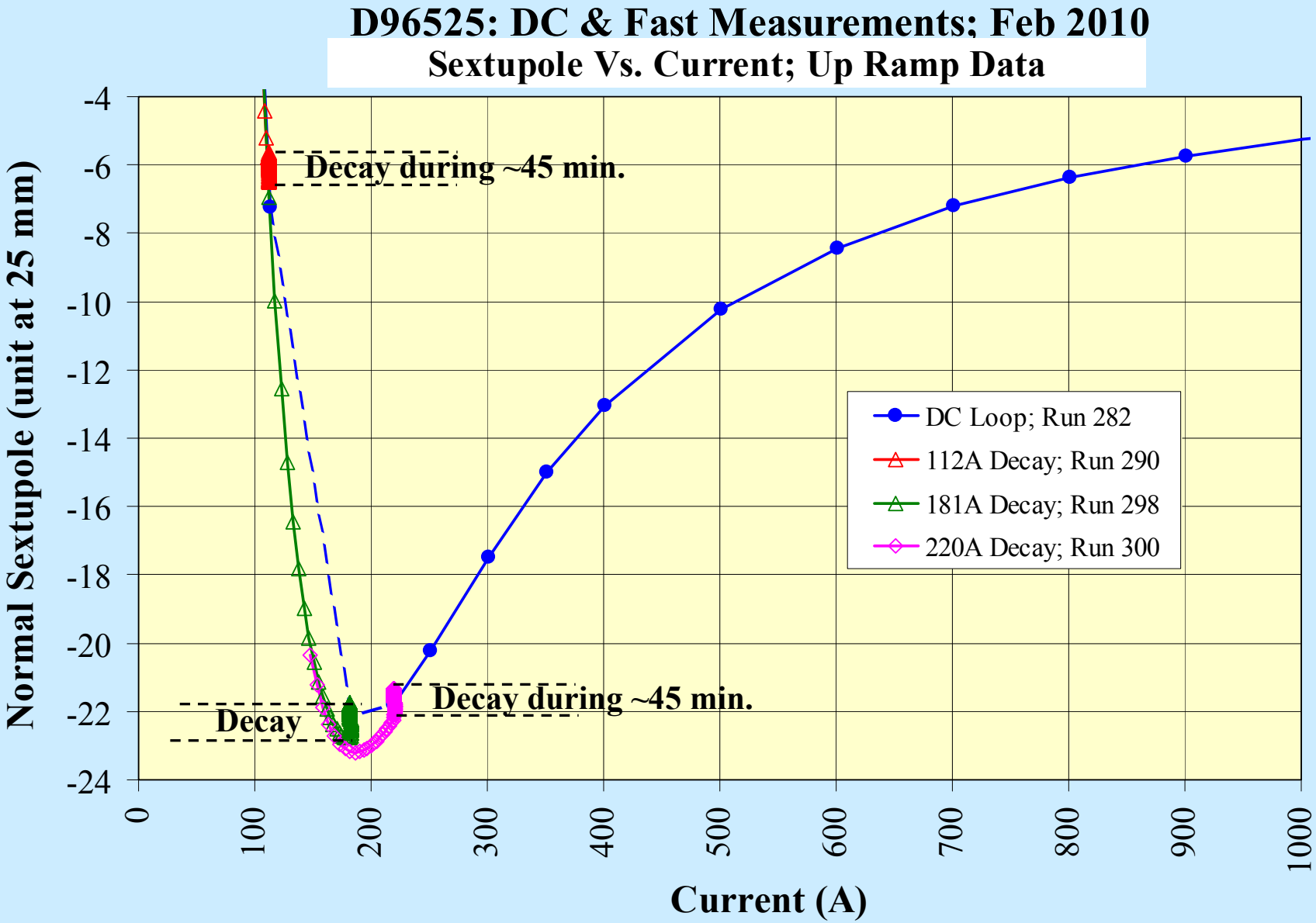
Time Decay at 220 A: Sextupole in Dipole



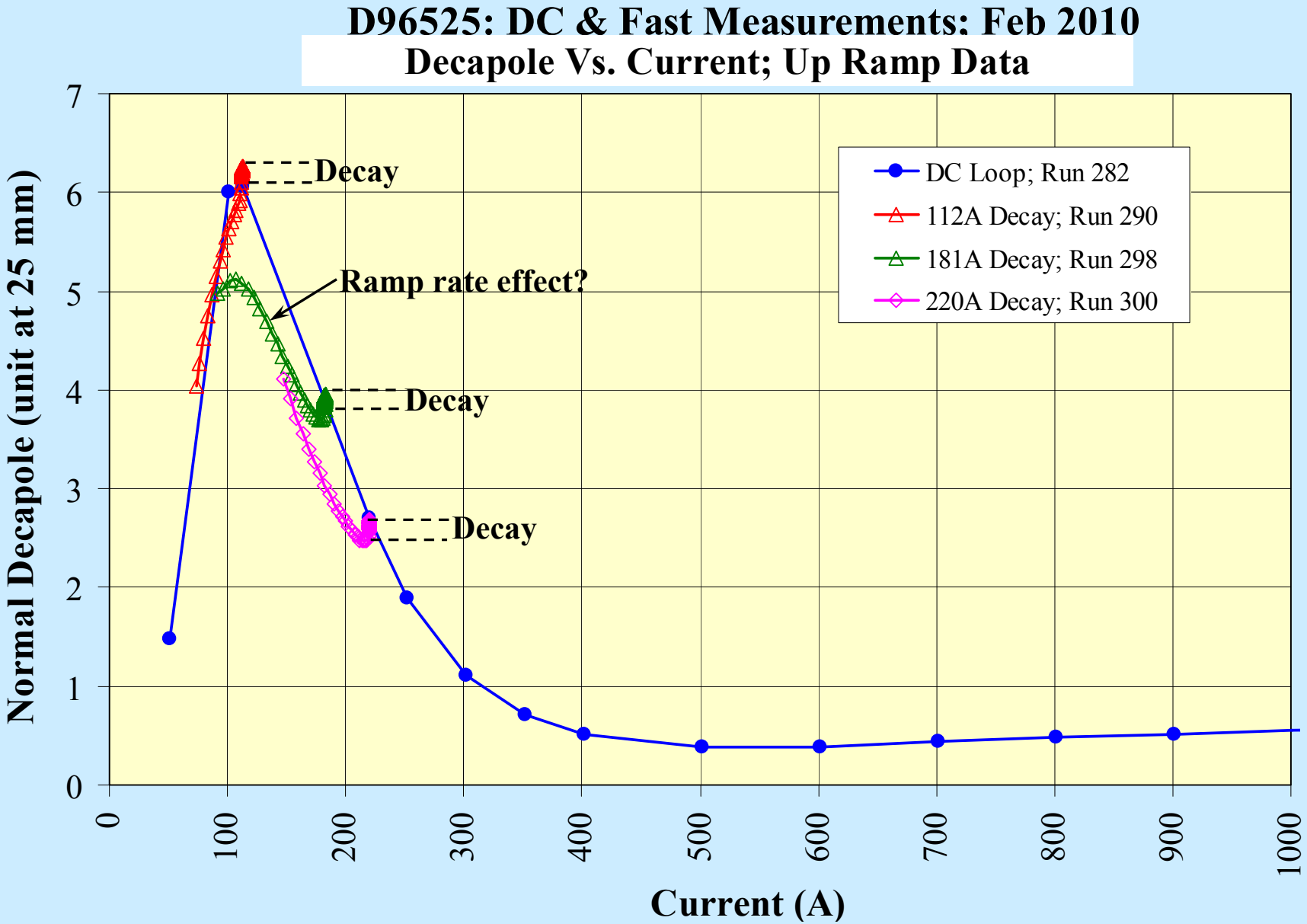
Time Decay at 220 A: Decapole in Dipole



Sextupole Term: Comparison with DC Data

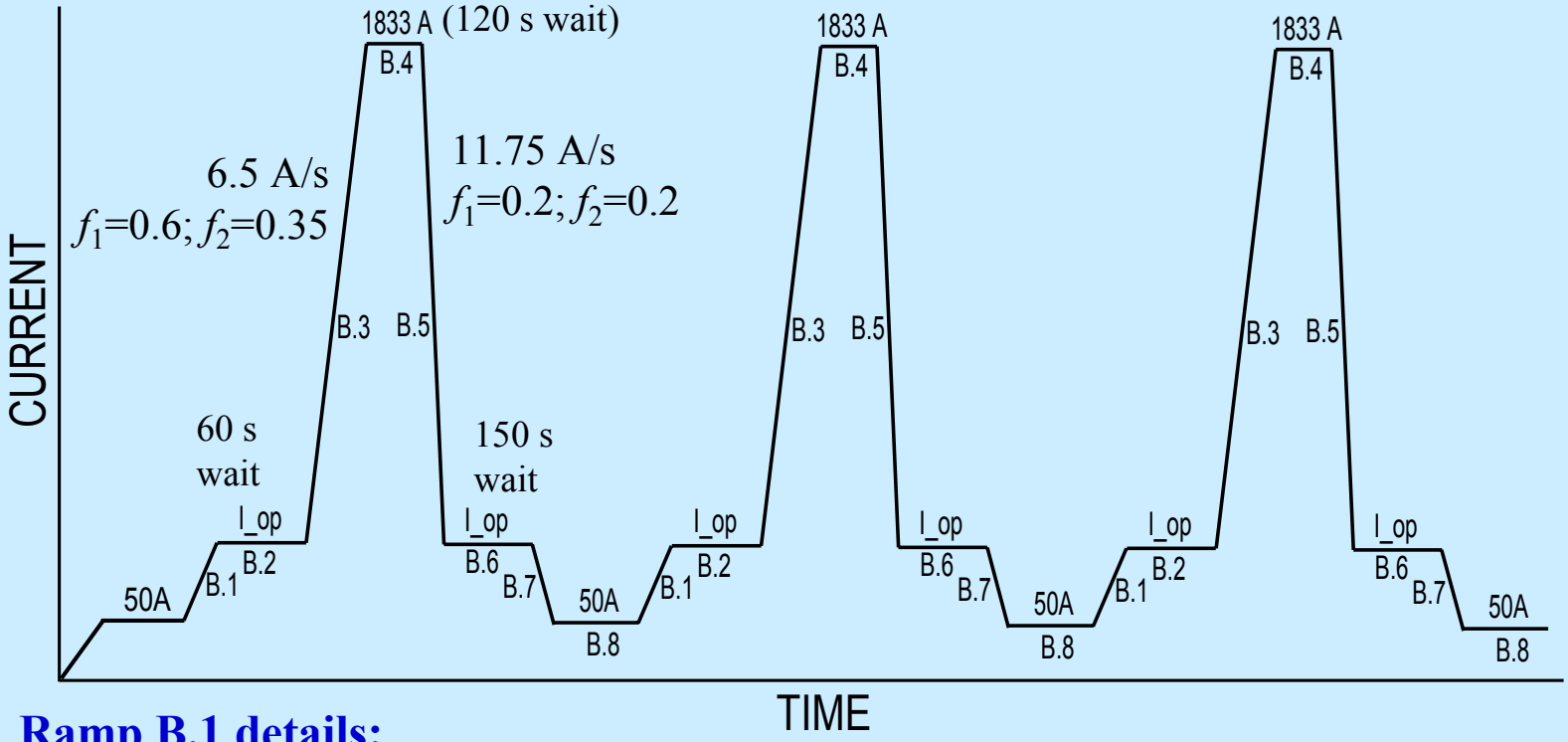


Decapole Term: Comparison with DC Data



Measurement Results in an Arc Quadrupole

Standardization Cycles



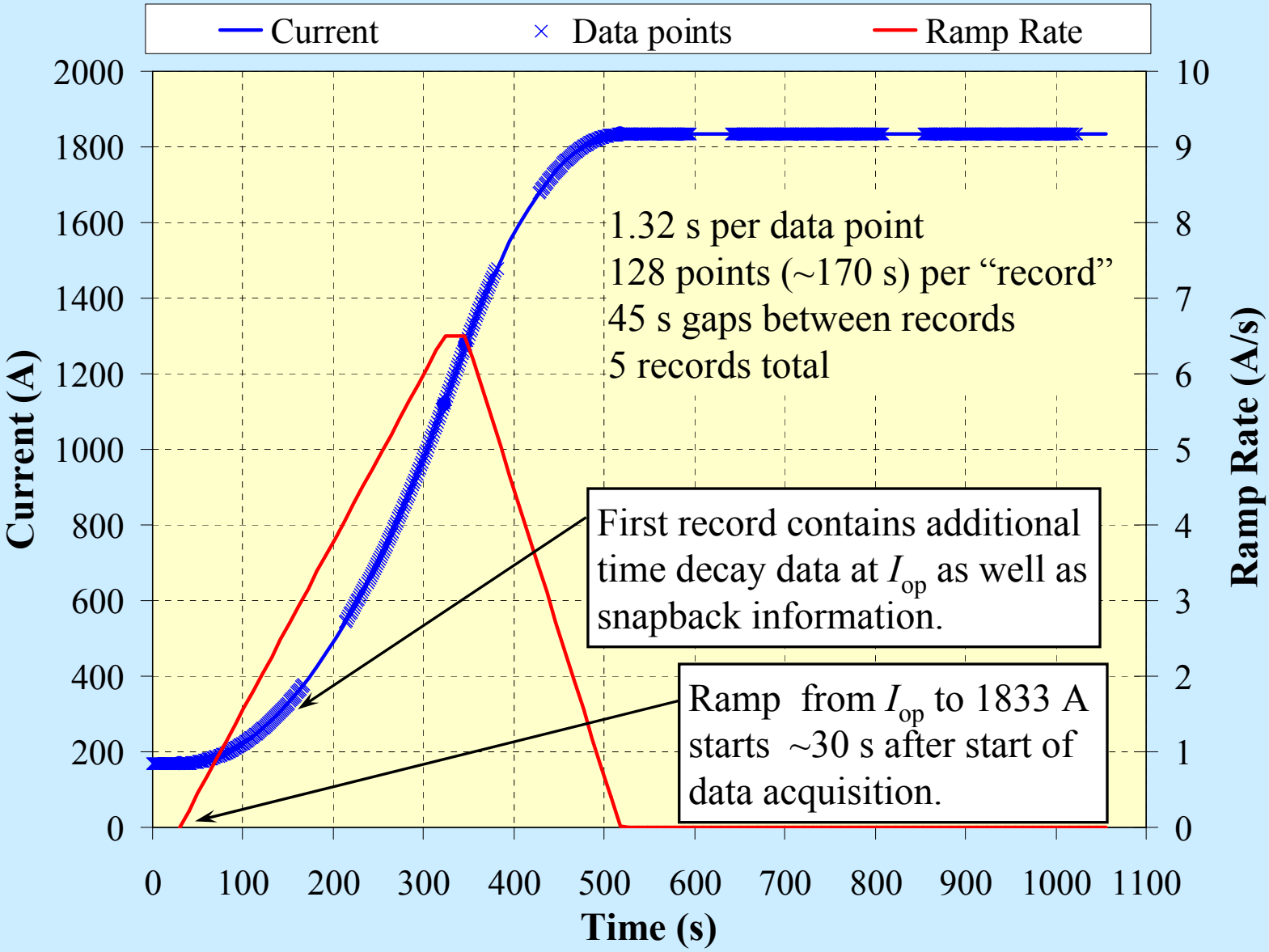
Ramp B.1 details:

For I_{op} = 104 A: R_0 = 2.5 A/s; f_1 = 0.47; f_2 = 0.47, I_{start} = 50 A, I_{end} = 104.5 A
For I_{op} = 168 A: R_0 = 3.5 A/s; f_1 = 0.45; f_2 = 0.45, I_{start} = 50 A, I_{end} = 168.4 A.
For I_{op} = 202 A: R_0 = 3.8 A/s; f_1 = 0.45; f_2 = 0.45, I_{start} = 50 A, I_{end} = 202.6 A.

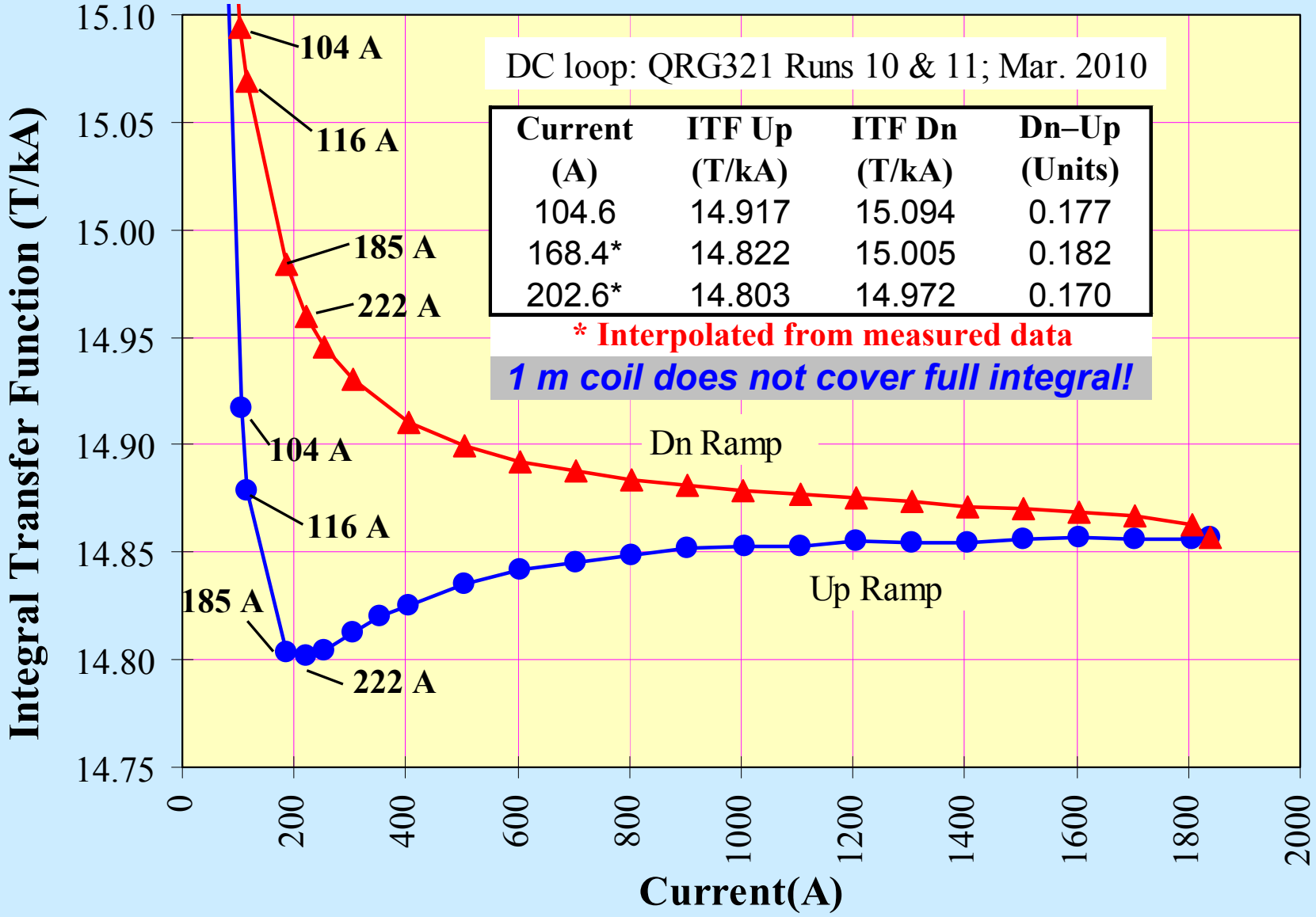
Ramp B.7 details:

For I_{op} = 104 A: R_0 = 2.5 A/s; f_1 = 0.47; f_2 = 0.47, I_{start} = 104.5 A, I_{end} = 50 A
For I_{op} = 168 A: R_0 = 3.6 A/s; f_1 = 0.45; f_2 = 0.45, I_{start} = 168.4 A, I_{end} = 50 A.
For I_{op} = 202 A: R_0 = 4.0 A/s; f_1 = 0.45; f_2 = 0.45, I_{start} = 202.6 A, I_{end} = 50 A.

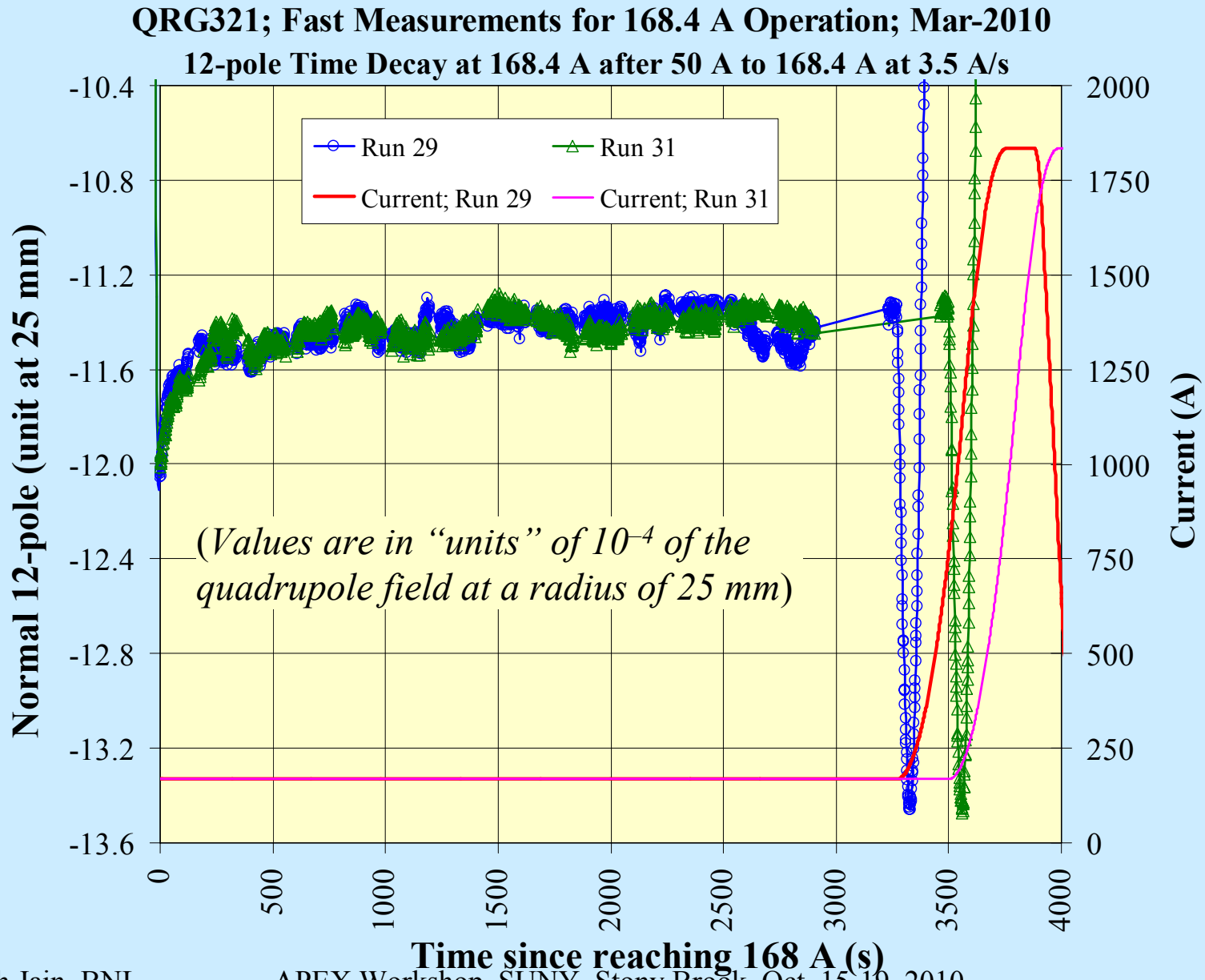
Snapback Measurements



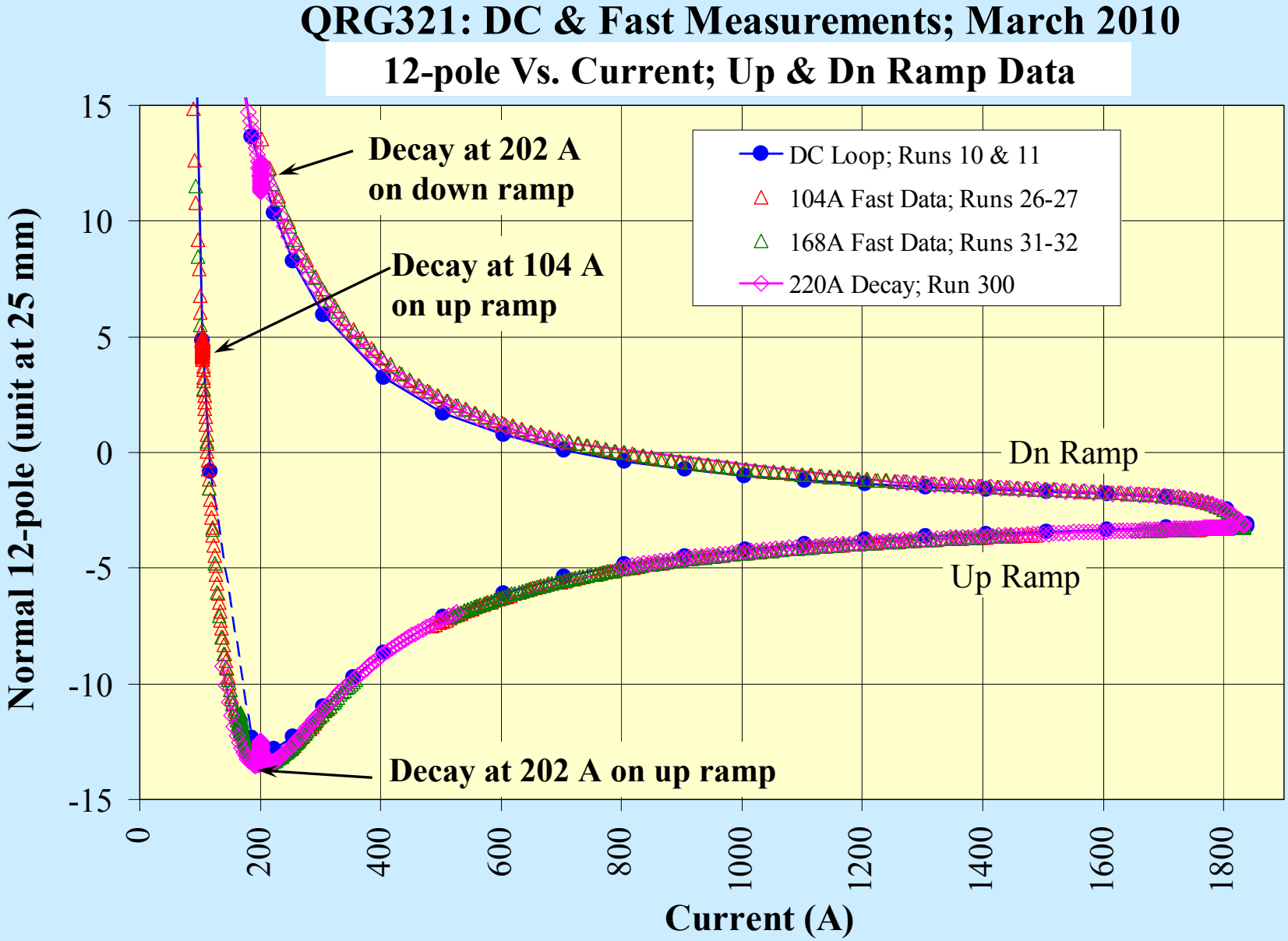
DC Loop: Transfer Function in Arc Quad



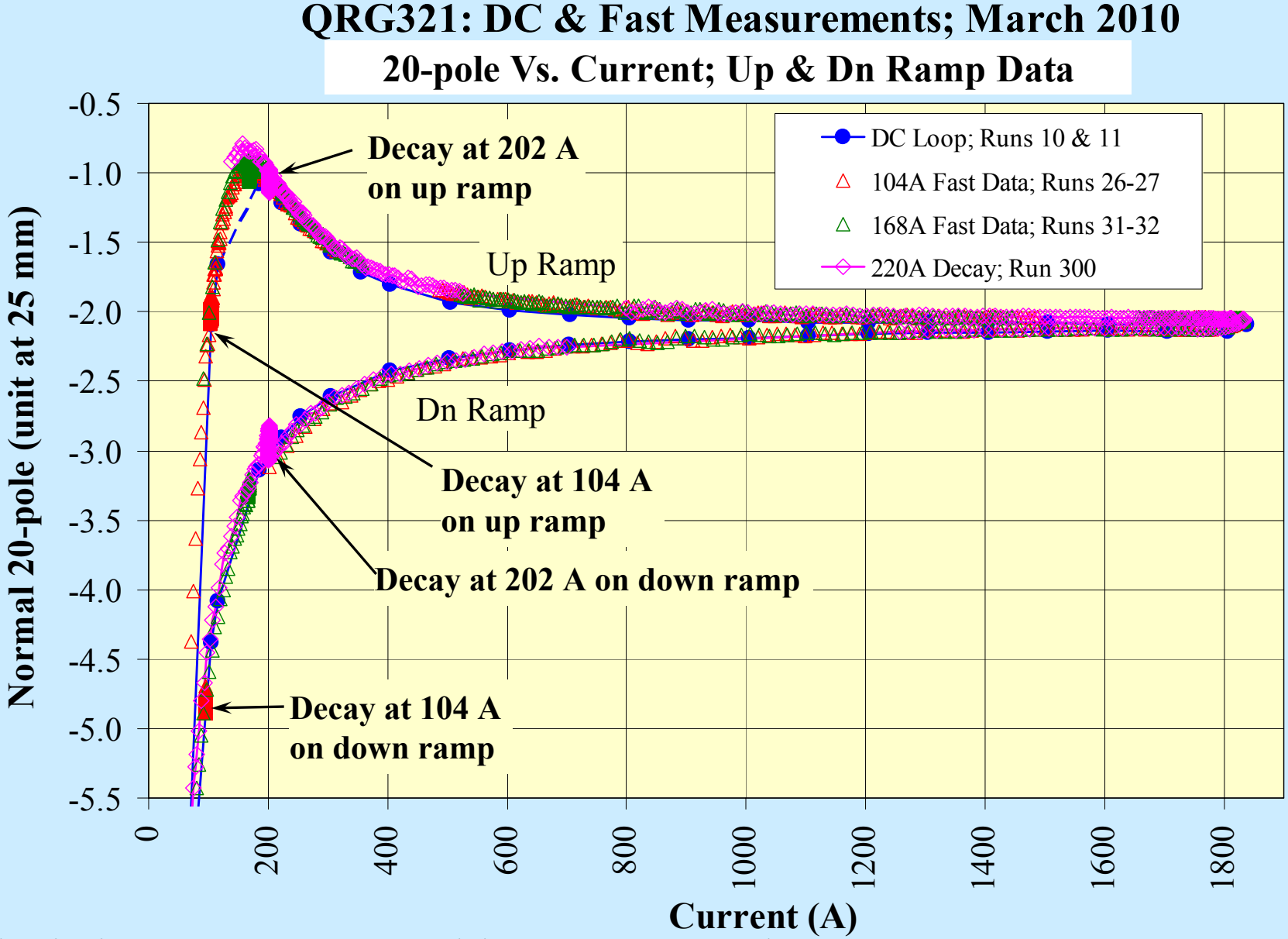
Time Decay & Snapback at 168 A: 12-pole



12-pole: Comparison with DC Data



20-pole: Comparison with DC Data

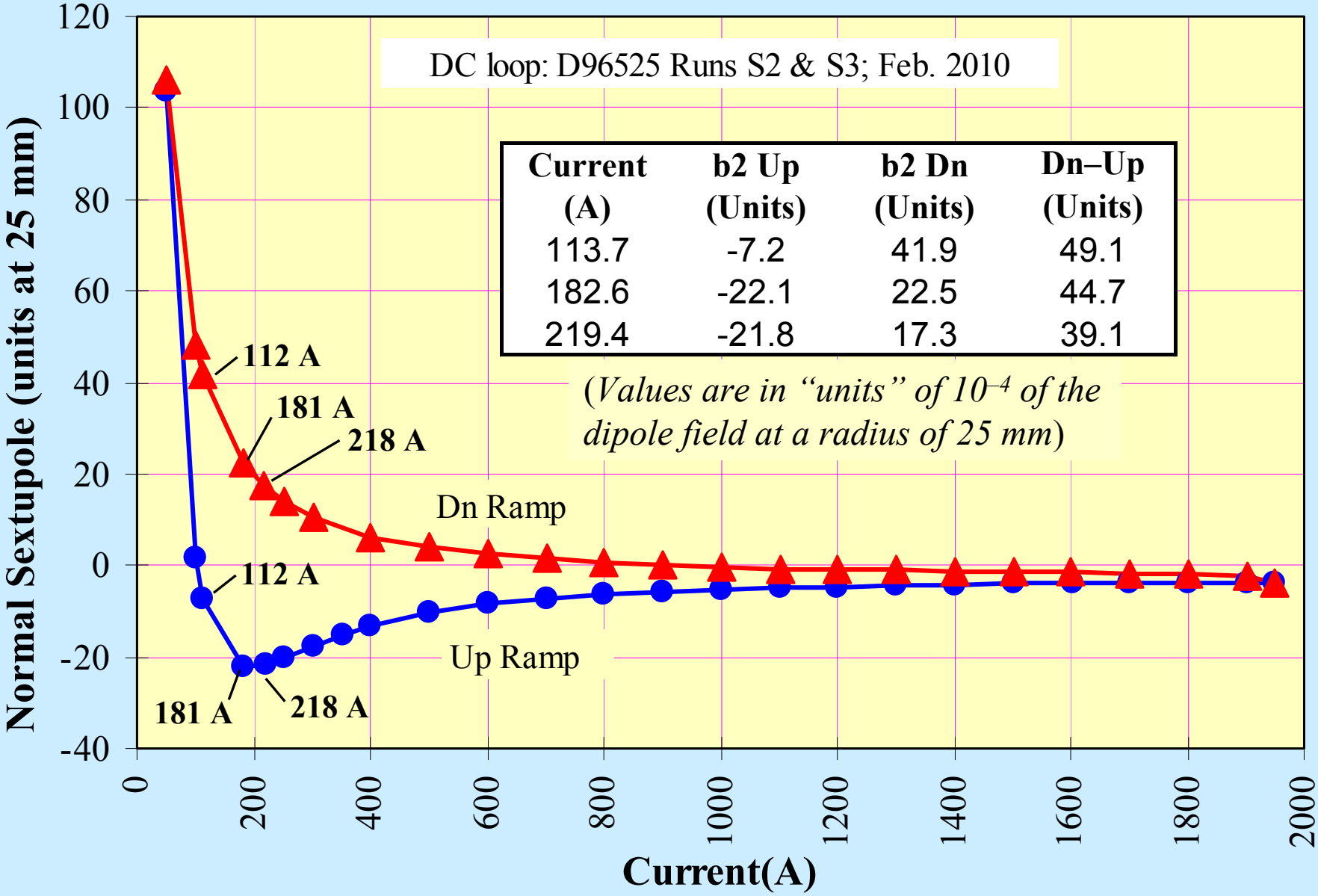


Summary

- Dynamic measurements of field quality at low current excitations corresponding to 5-9 Gev/u have been completed in a spare RHIC D96 dipole and a spare arc quadrupole.
- Sextupole decay of ~0.6 unit and decapole decay ~0.1 unit are seen in the dipole over a period of ~45 min.
- Large decapole term may be avoided by operating on the down ramp in the dipoles.
- 12-pole decay ~1 unit and 20-pole decay ~0.1 unit are seen in the quadrupole over a period of ~45 min.
- Snapback was measured in the quadrupole, and occurs over a span of only a few amperes of current.
- The harmonics at various currents are consistent with the DC loop data.

Supplementary Slides

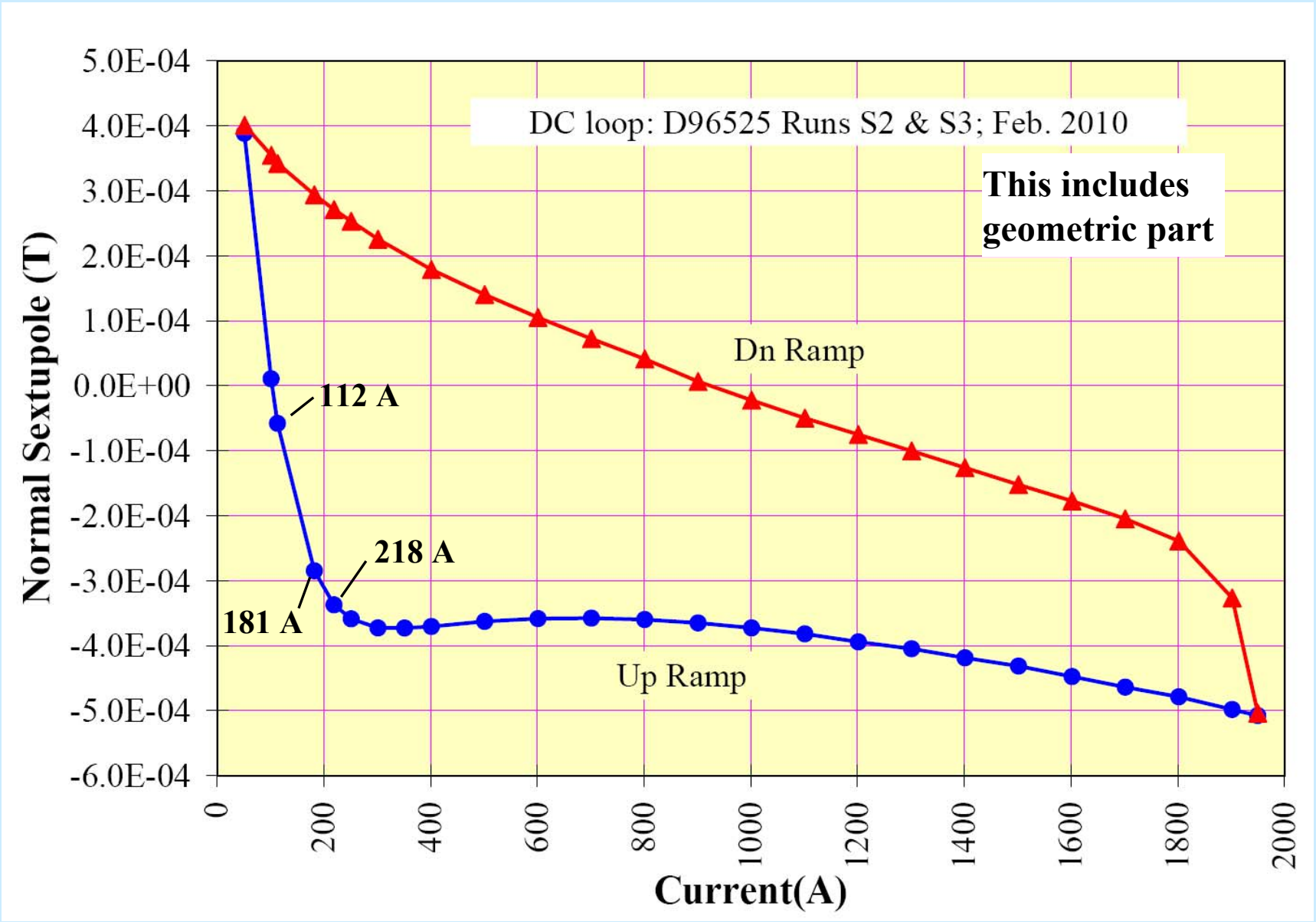
DC Loop: Sextupole Term in Dipole



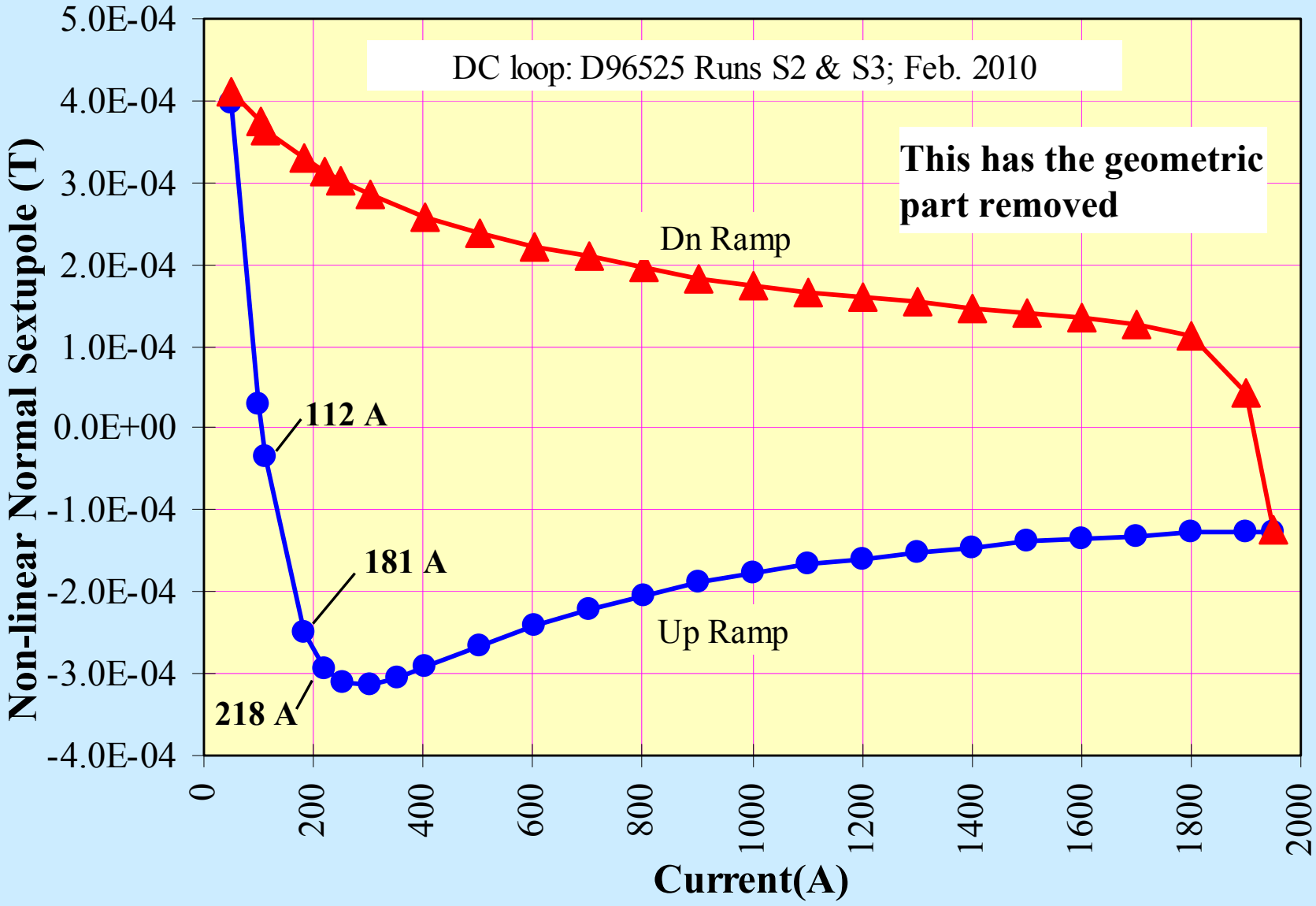
Current (A)	b2 Up (Units)	b2 Dn (Units)	Dn–Up (Units)
113.7	-7.2	41.9	49.1
182.6	-22.1	22.5	44.7
219.4	-21.8	17.3	39.1

(*Values are in "units" of 10^{-4} of the dipole field at a radius of 25 mm*)

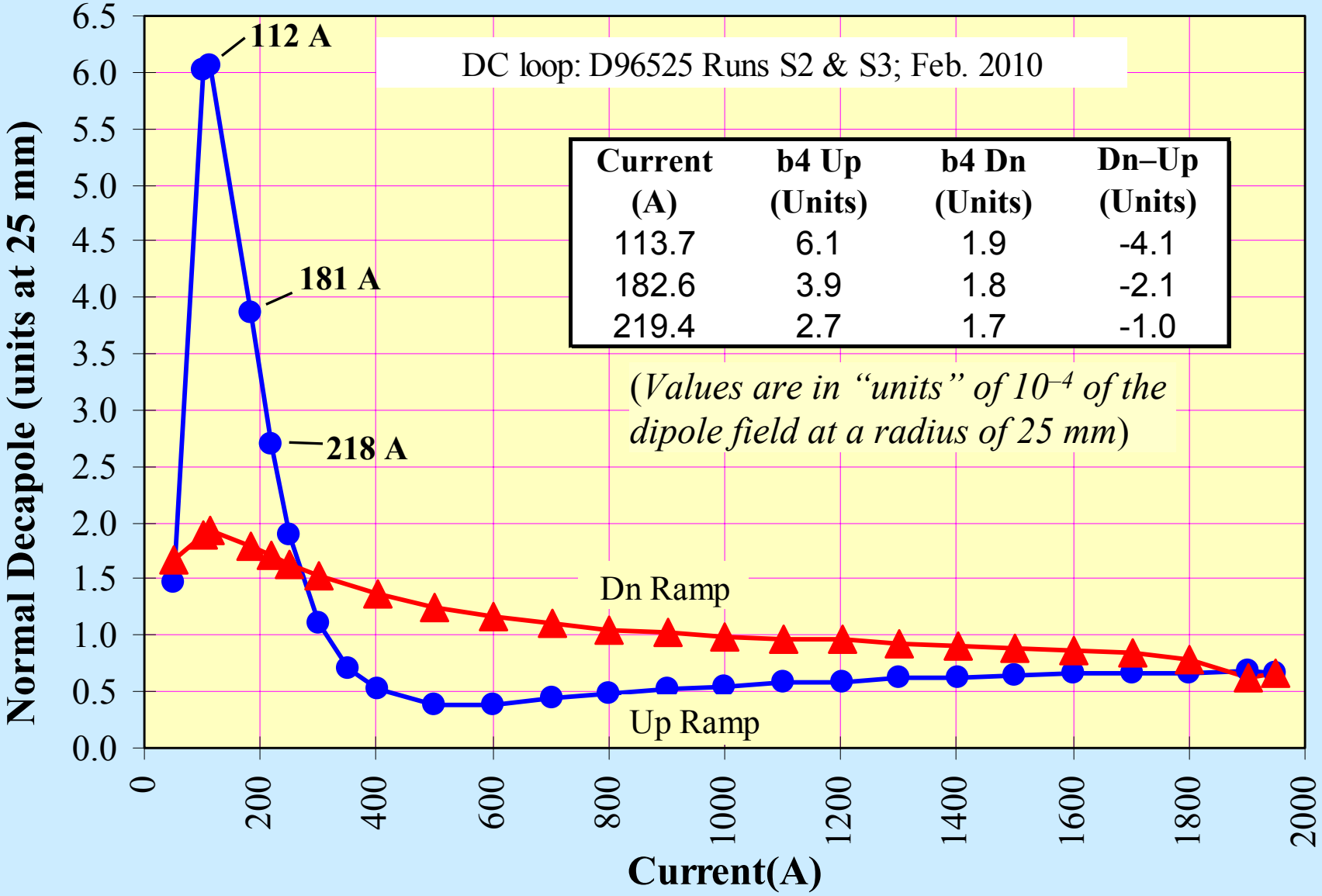
DC Loop Data: Sextupole in Tesla



DC Loop: Non-linear Part of Sextupole



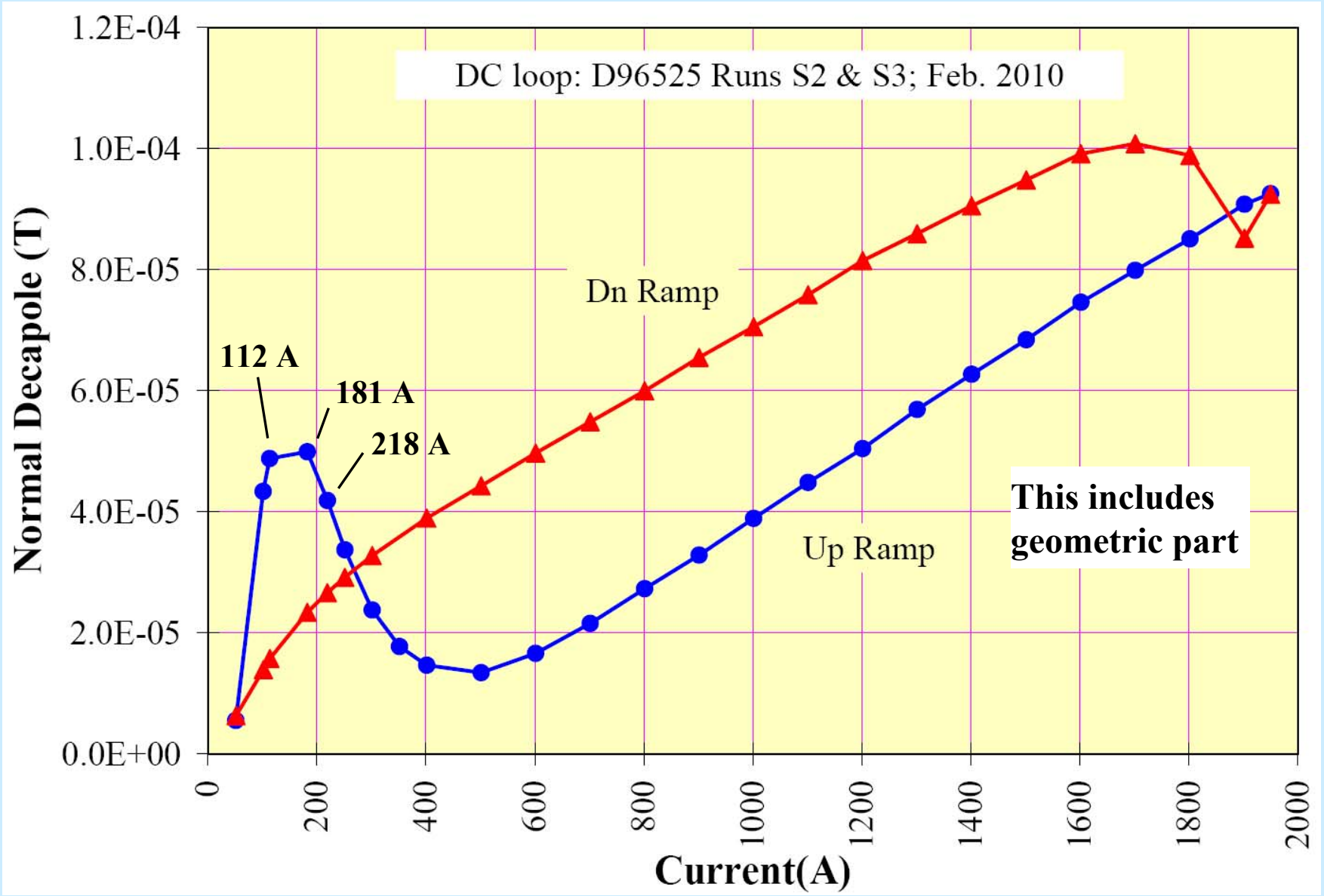
DC Loop: Decapole Term in Dipole



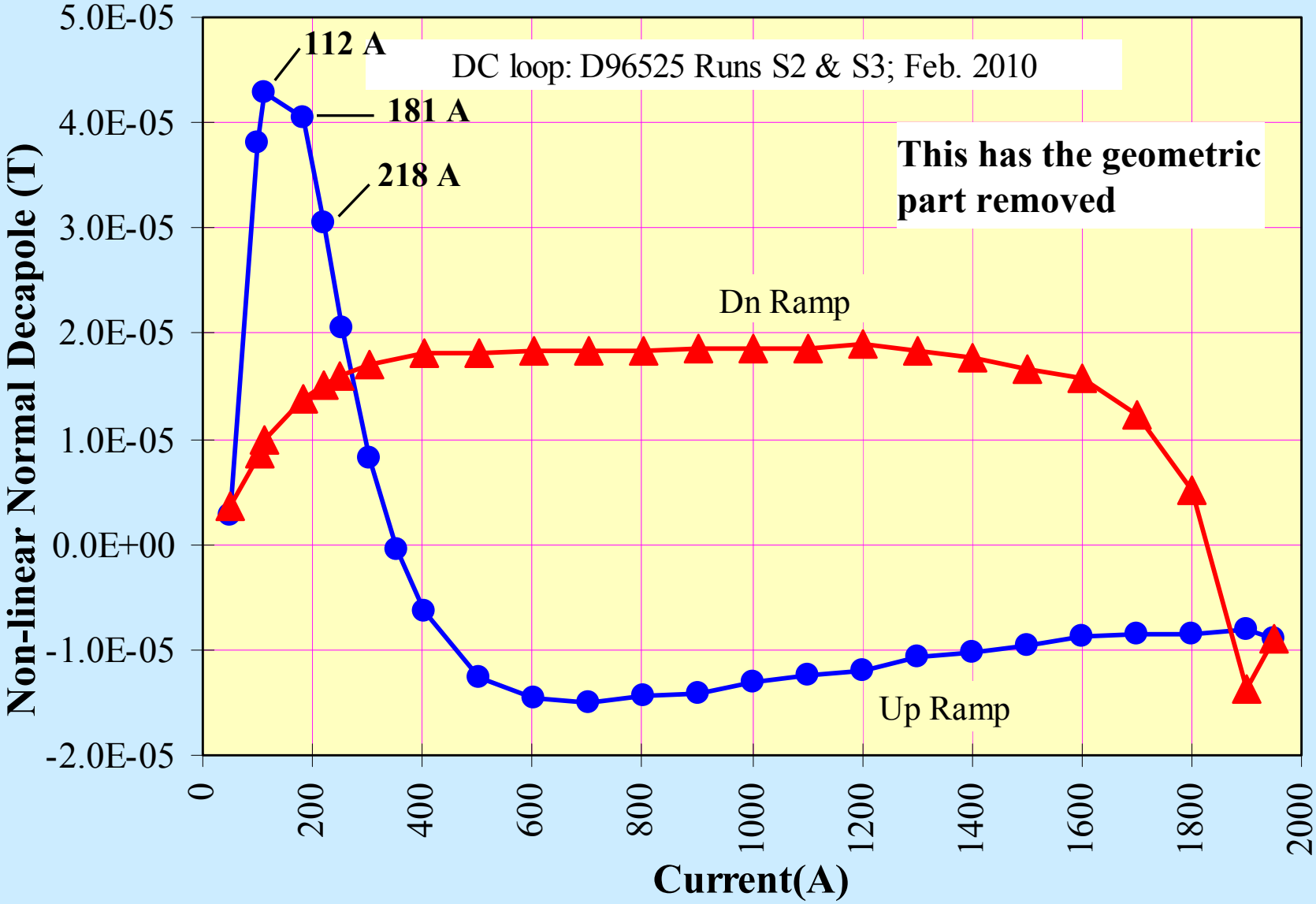
Current (A)	b4 Up (Units)	b4 Dn (Units)	Dn–Up (Units)
113.7	6.1	1.9	-4.1
182.6	3.9	1.8	-2.1
219.4	2.7	1.7	-1.0

(*Values are in "units" of 10^{-4} of the dipole field at a radius of 25 mm*)

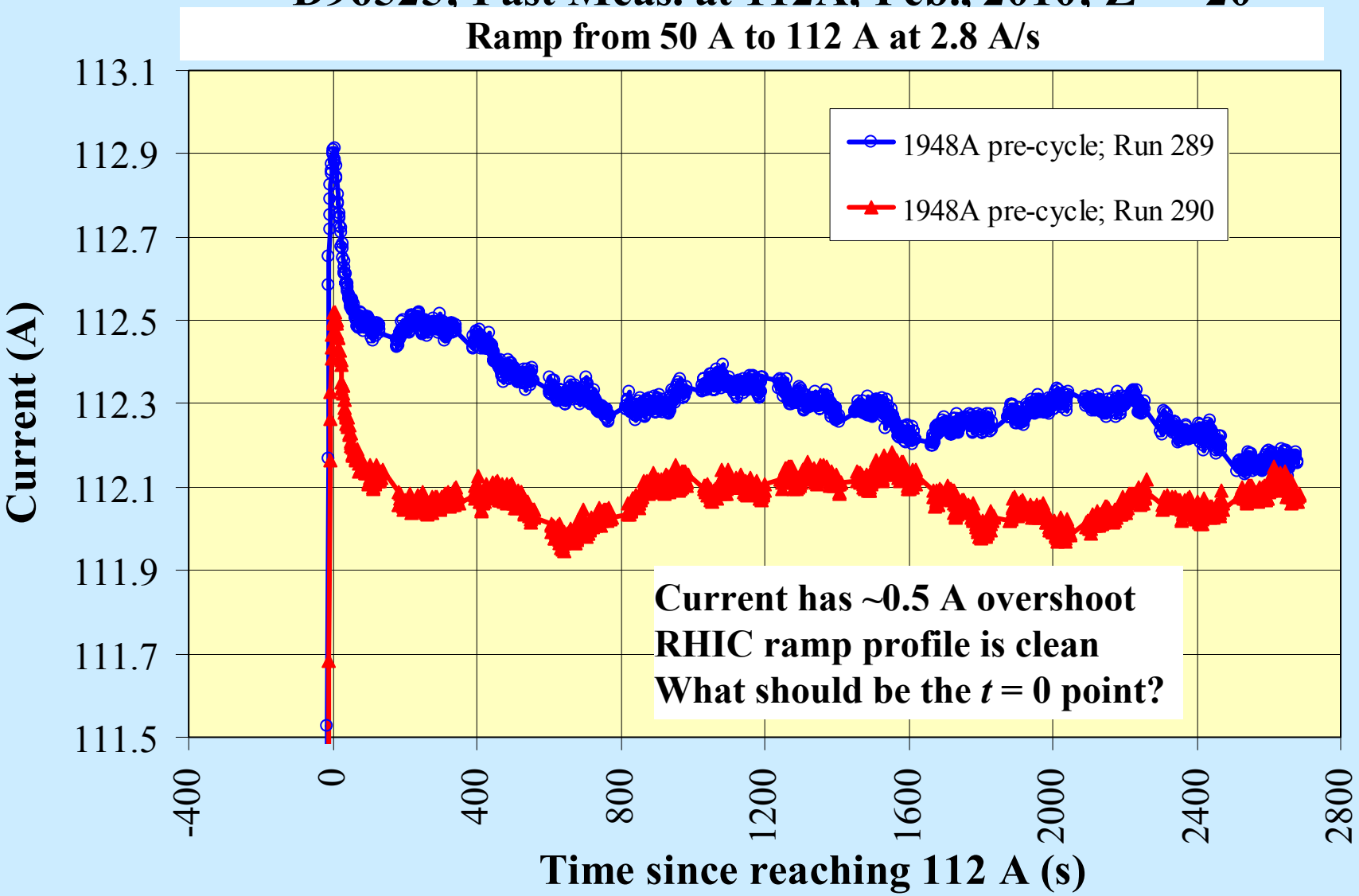
DC Loop Data: Decapole in Tesla



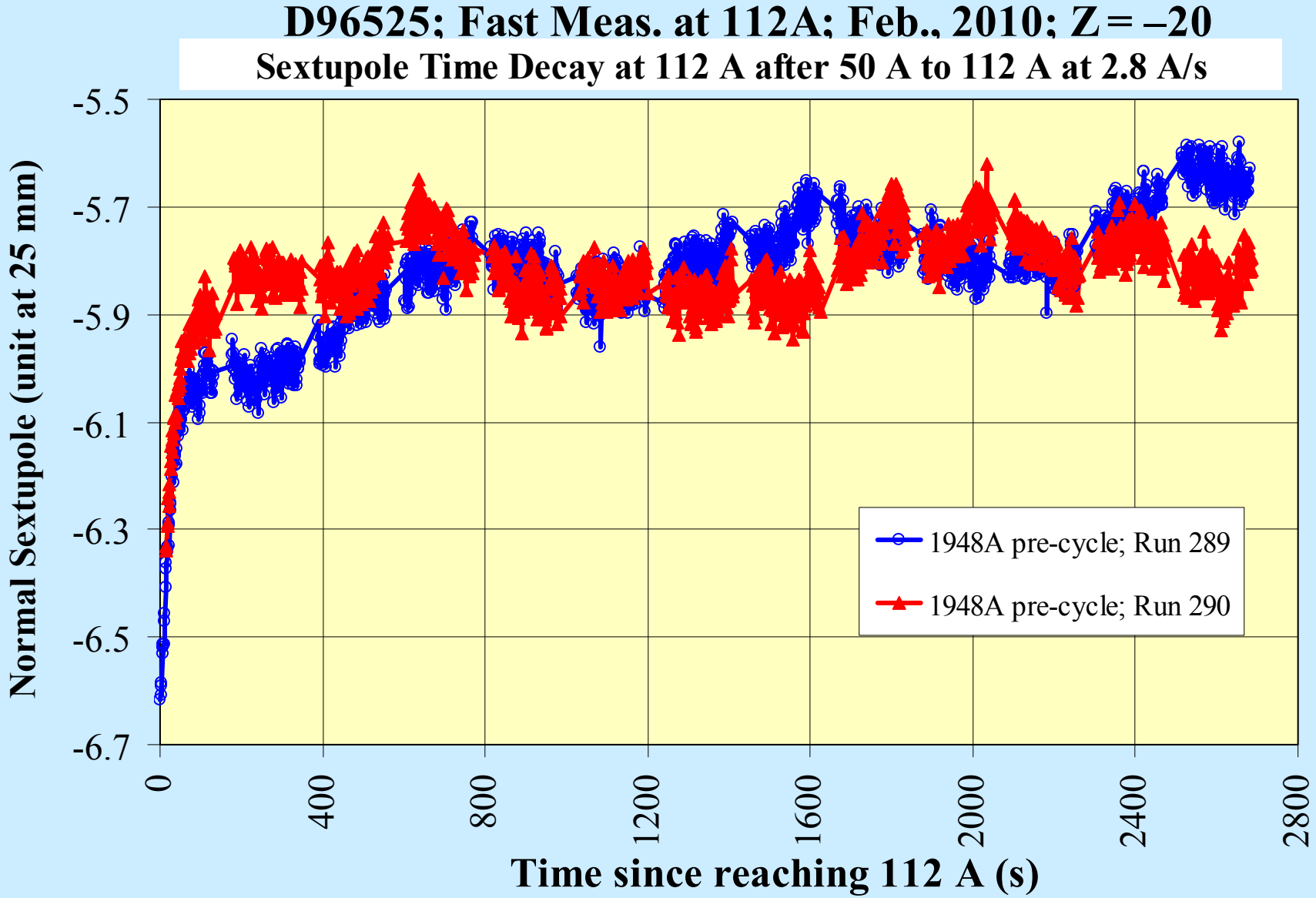
DC Loop: Non-linear Part of Decapole



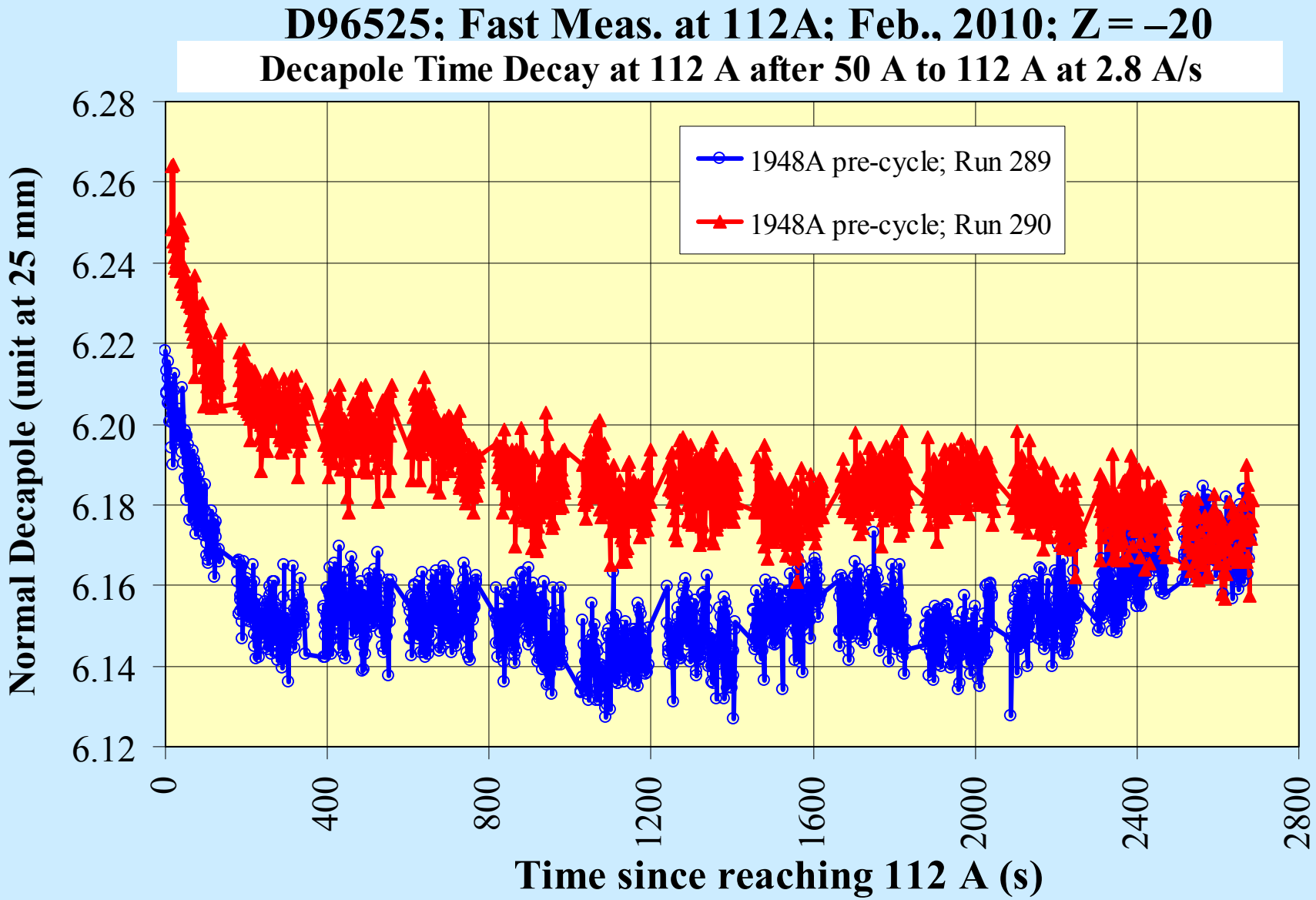
Time Decay at 112 A: Current Profile



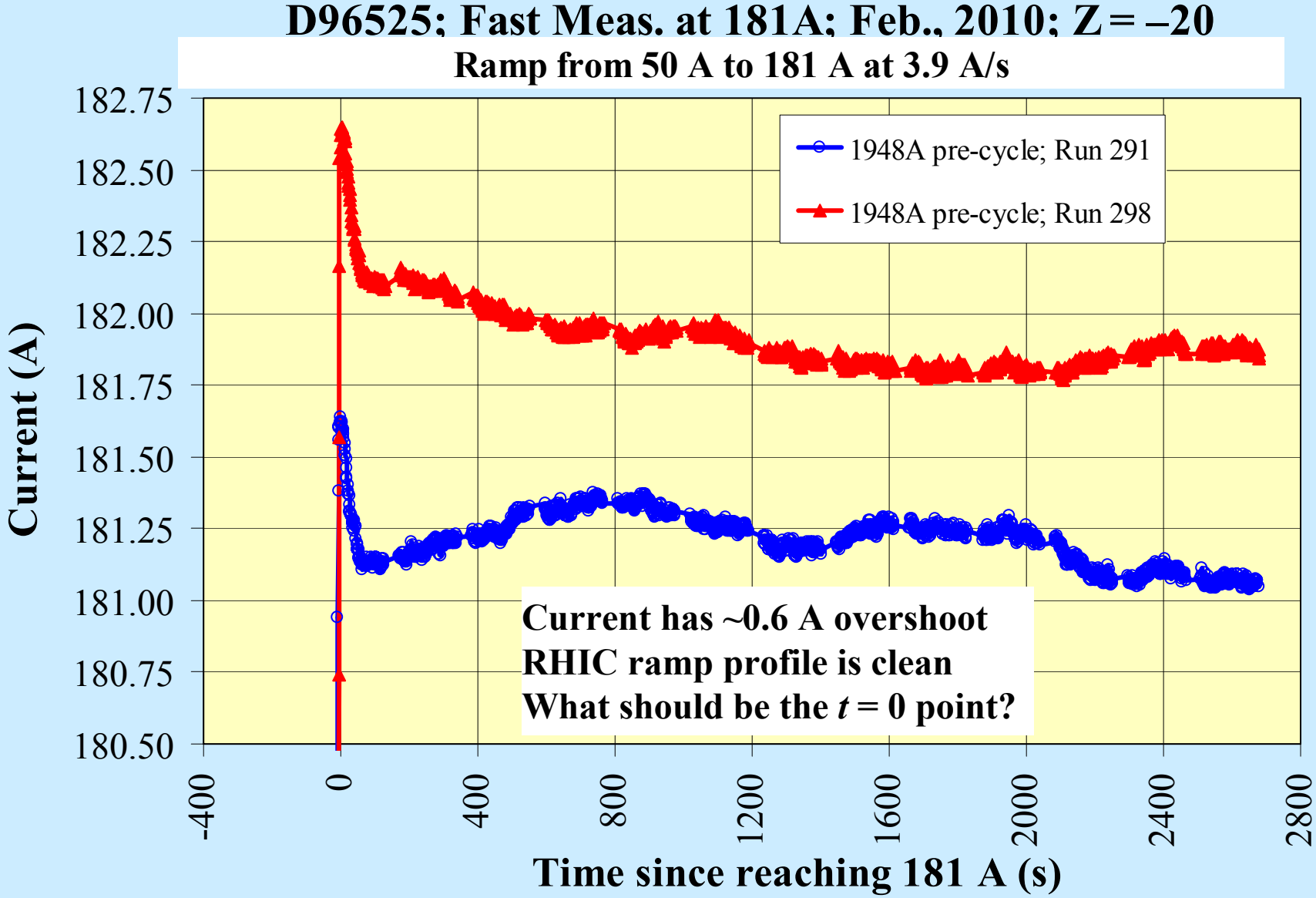
Time Decay at 112 A: Sextupole in Dipole



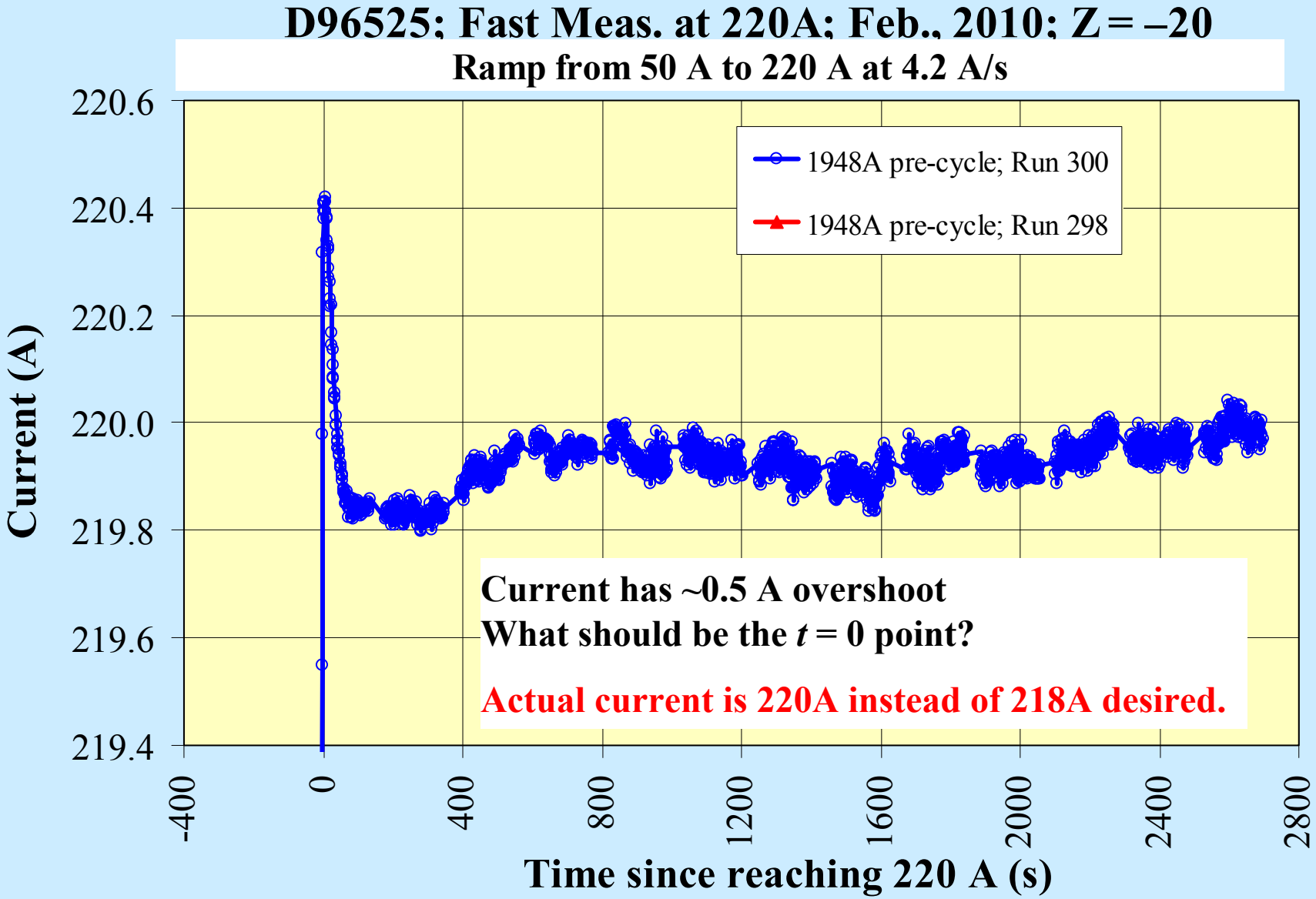
Time Decay at 112 A: Decapole in Dipole



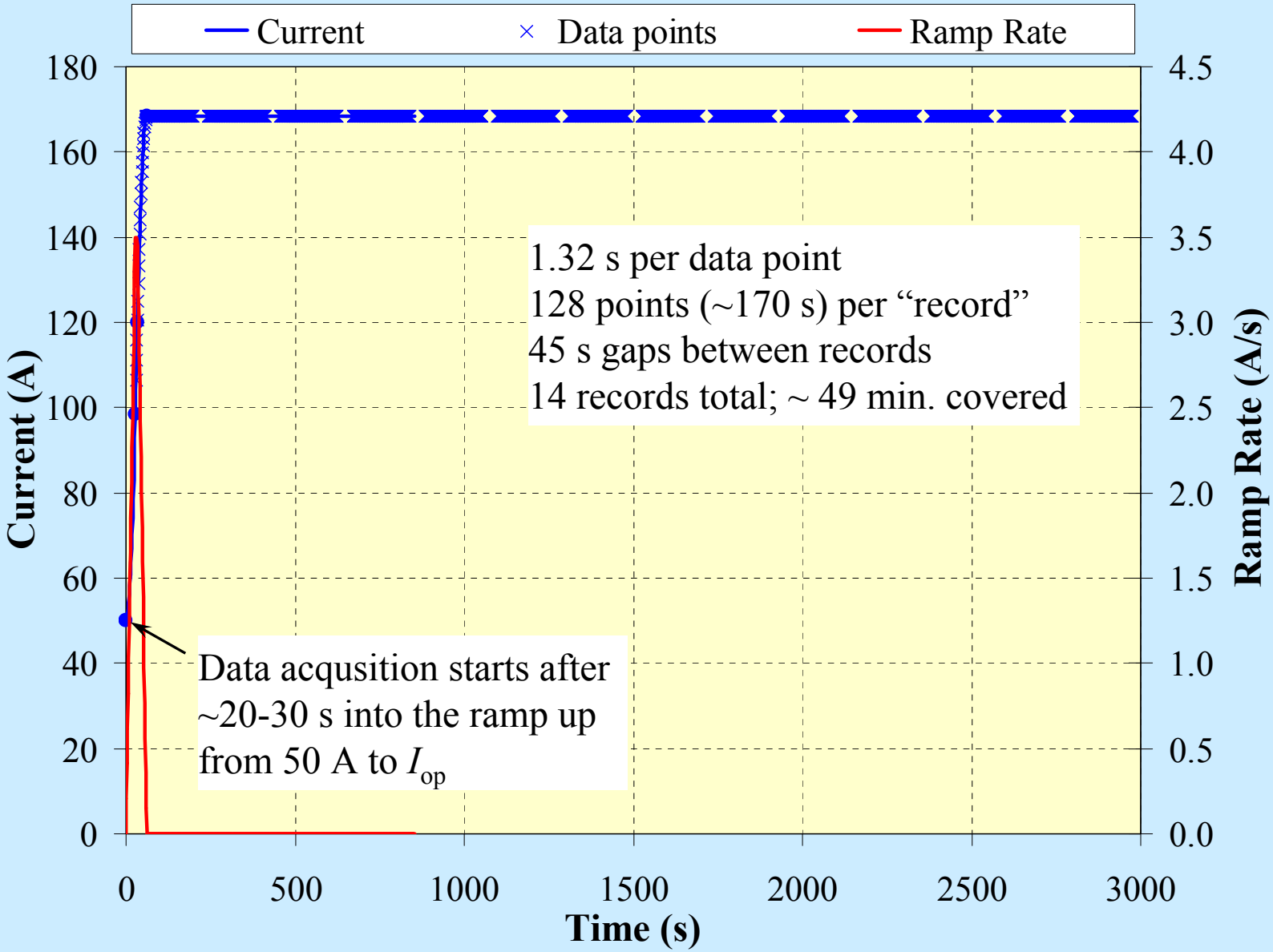
Time Decay at 181 A: Current Profile



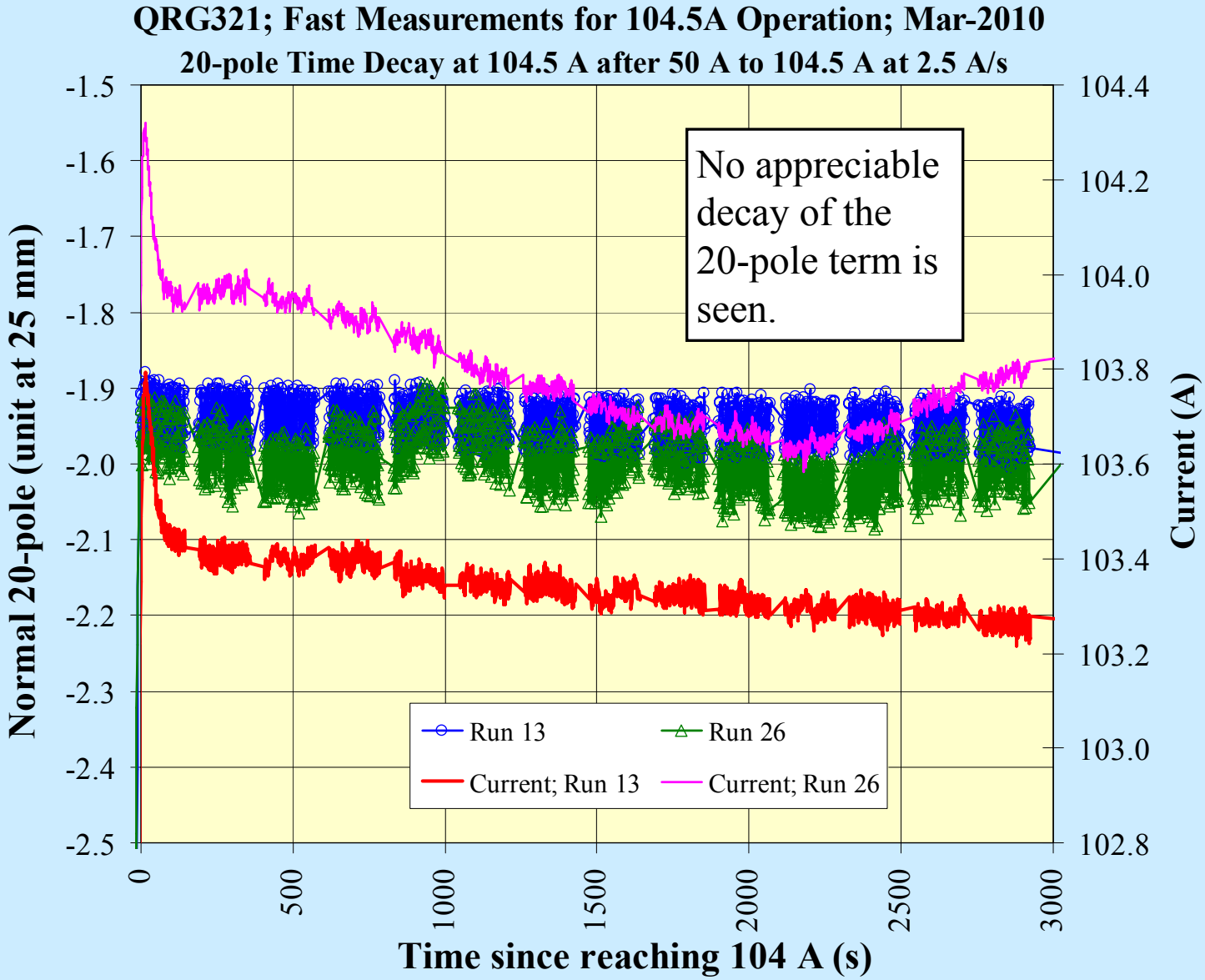
Time Decay at 220 A: Current Profile



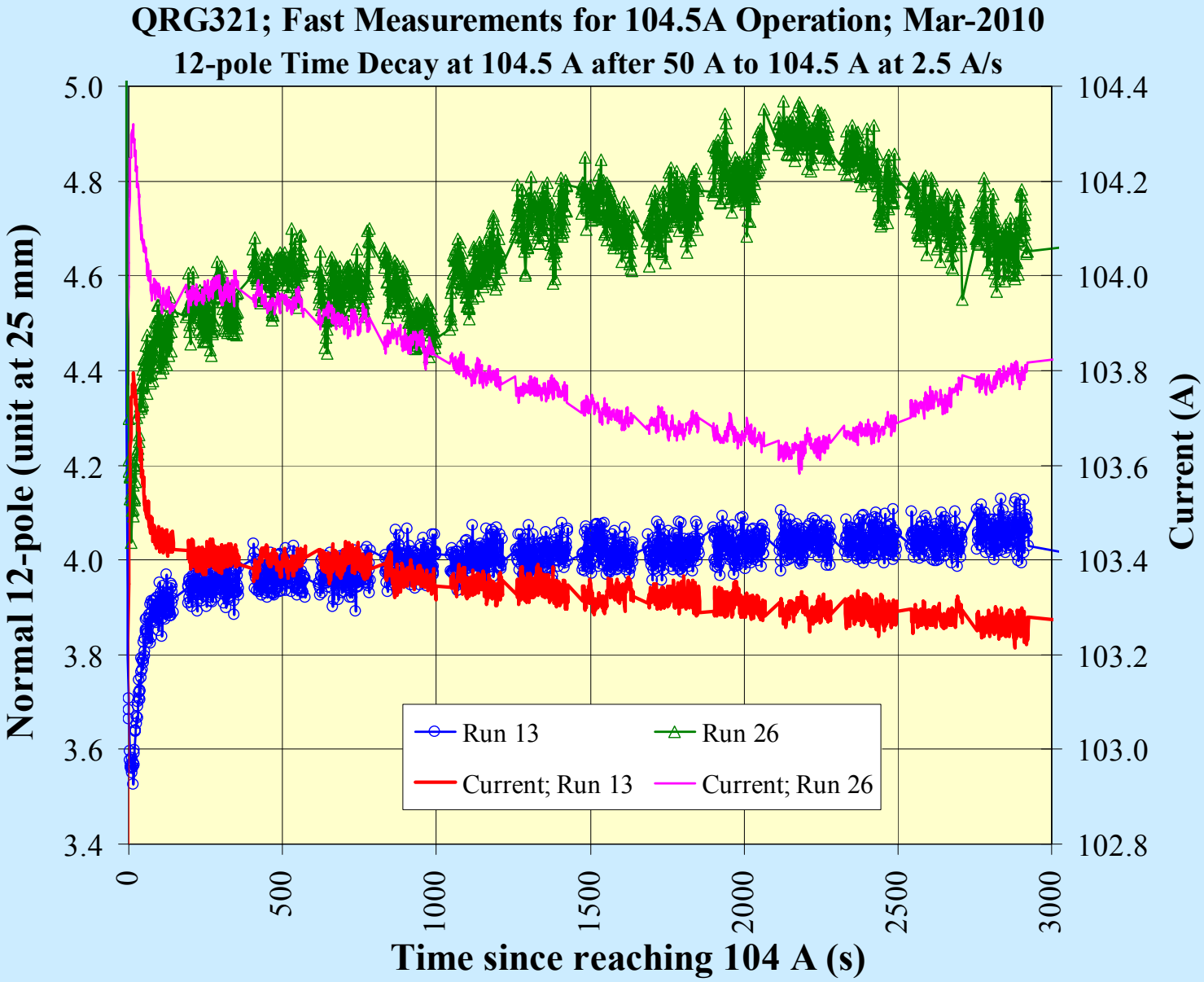
Time Decay Measurements



Time Decay at 104 A: 20-pole

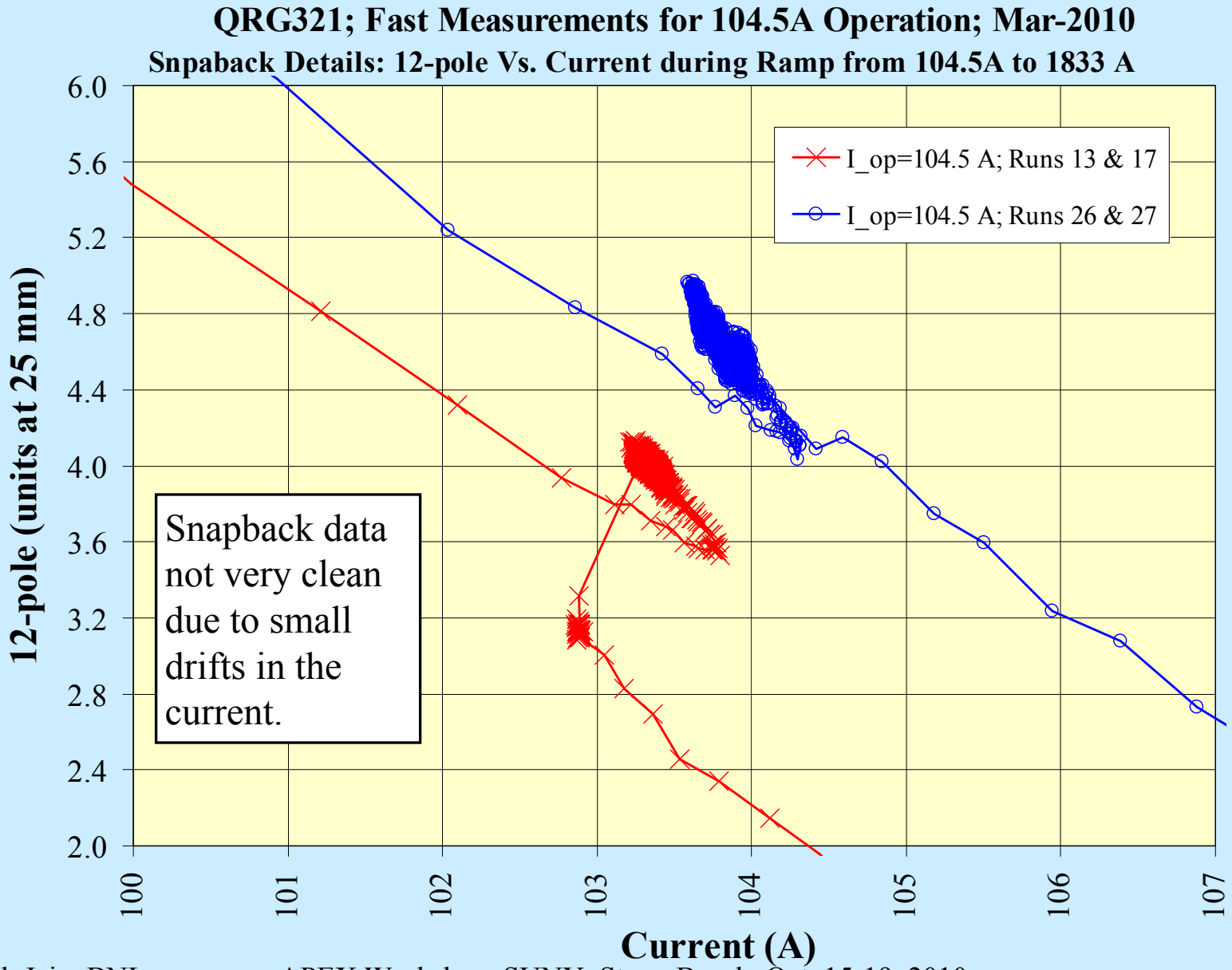


Time Decay at 104 A: 12-pole

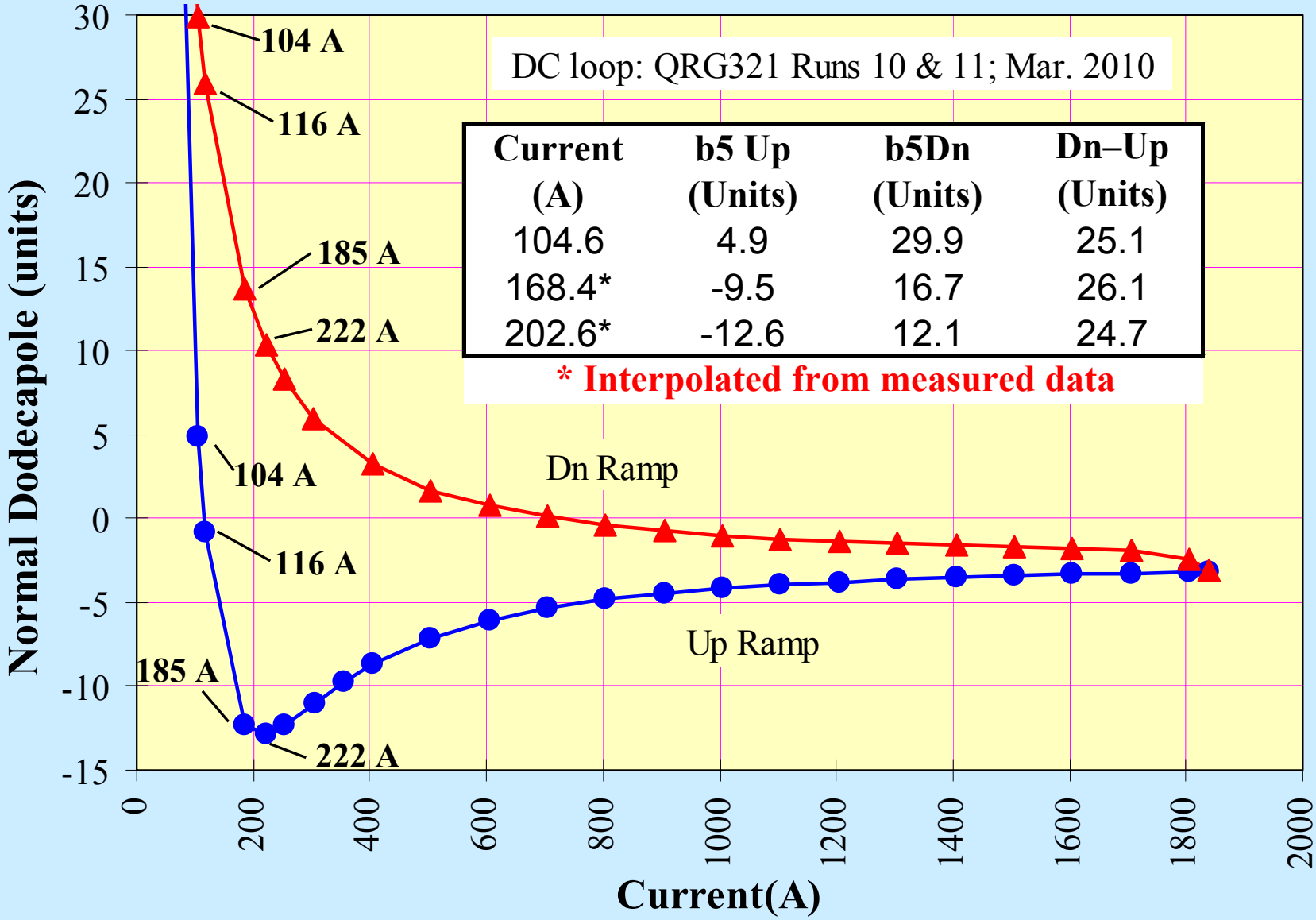


Variation of 12-pole after initial decay is correlated with changes in current, and may not represent true time decay.

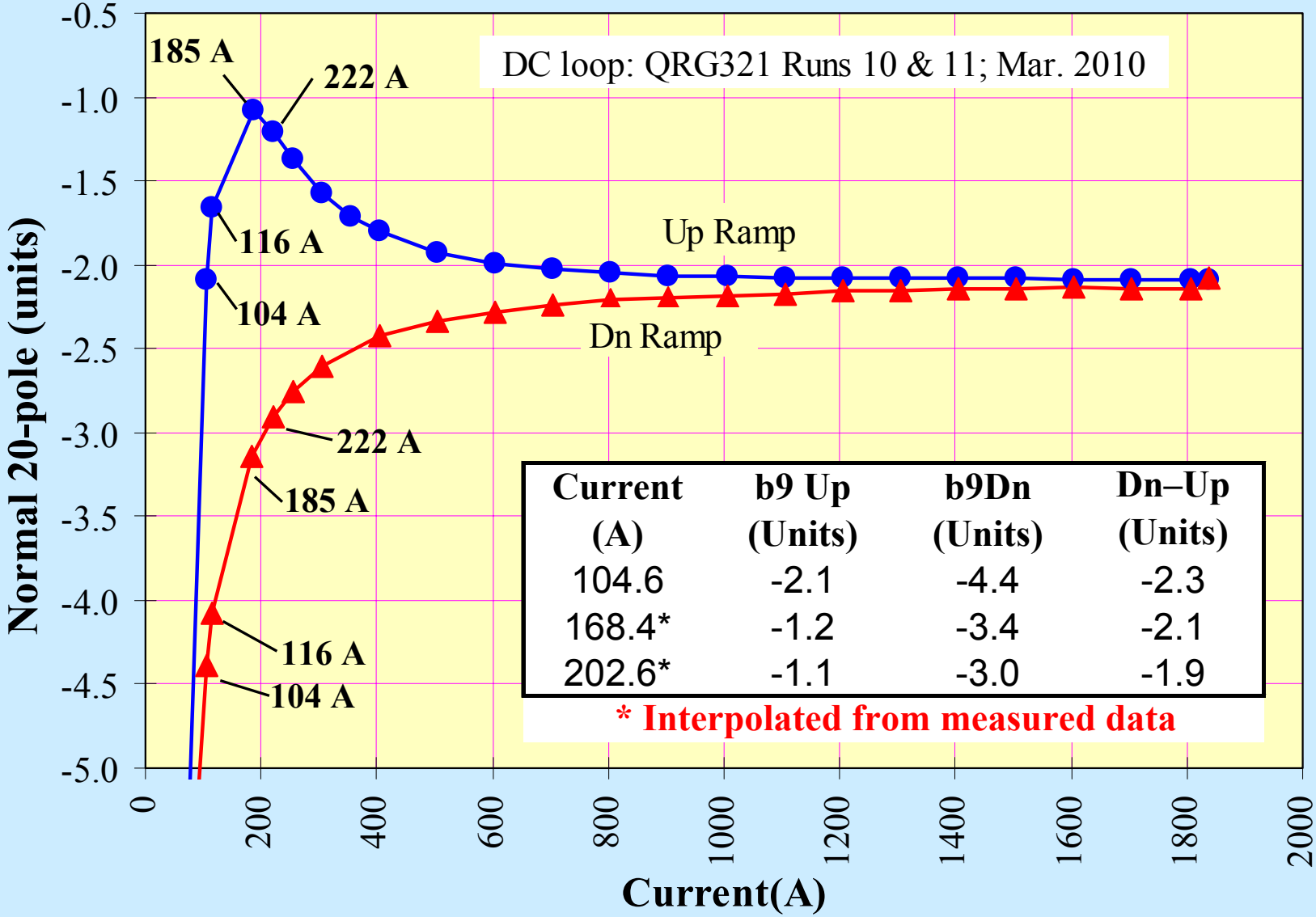
Snapback at 104 A: 12-pole



DC Loop: 12-pole Term in the Quadrupole



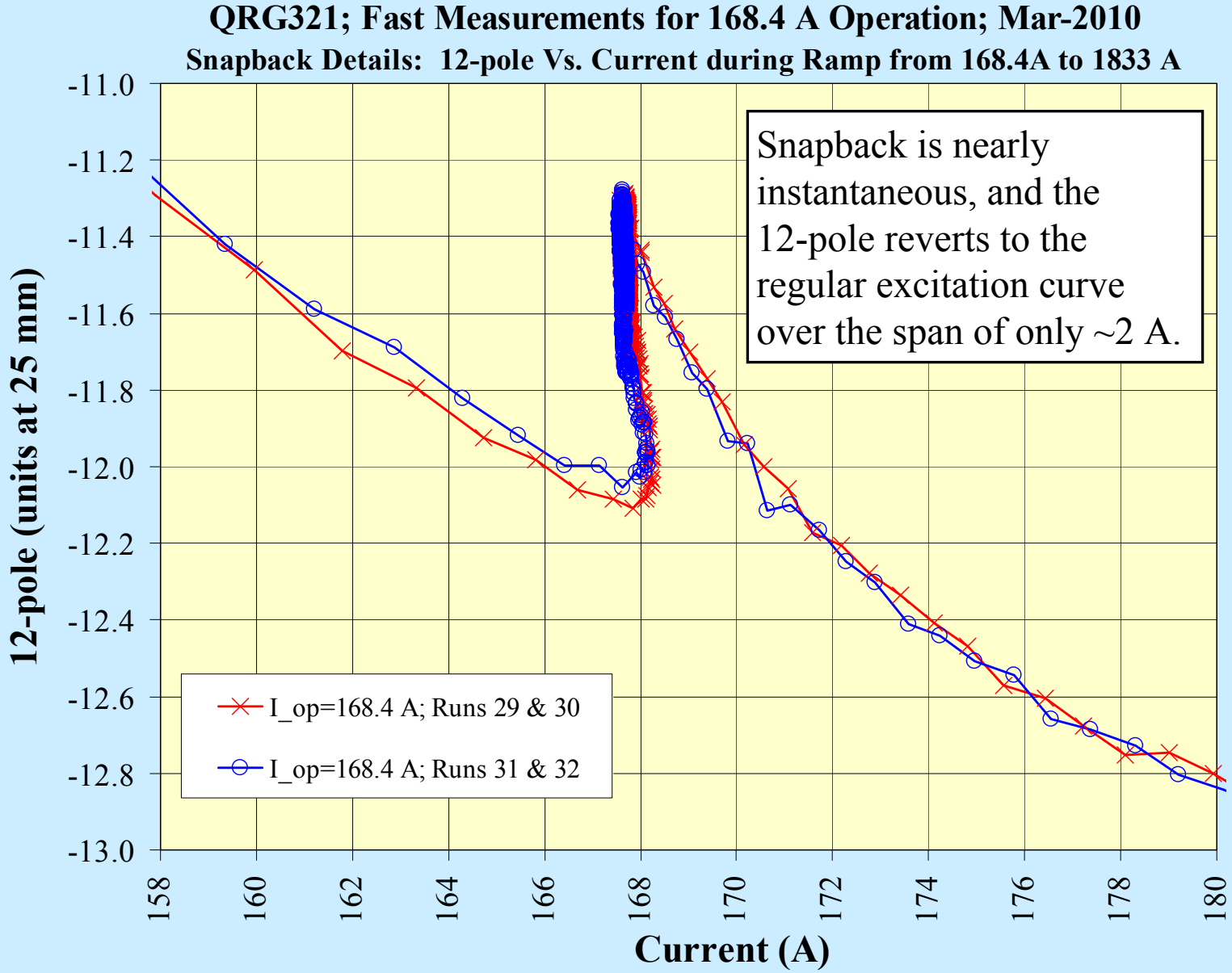
DC Loop: 20-pole Term in the Quadrupole



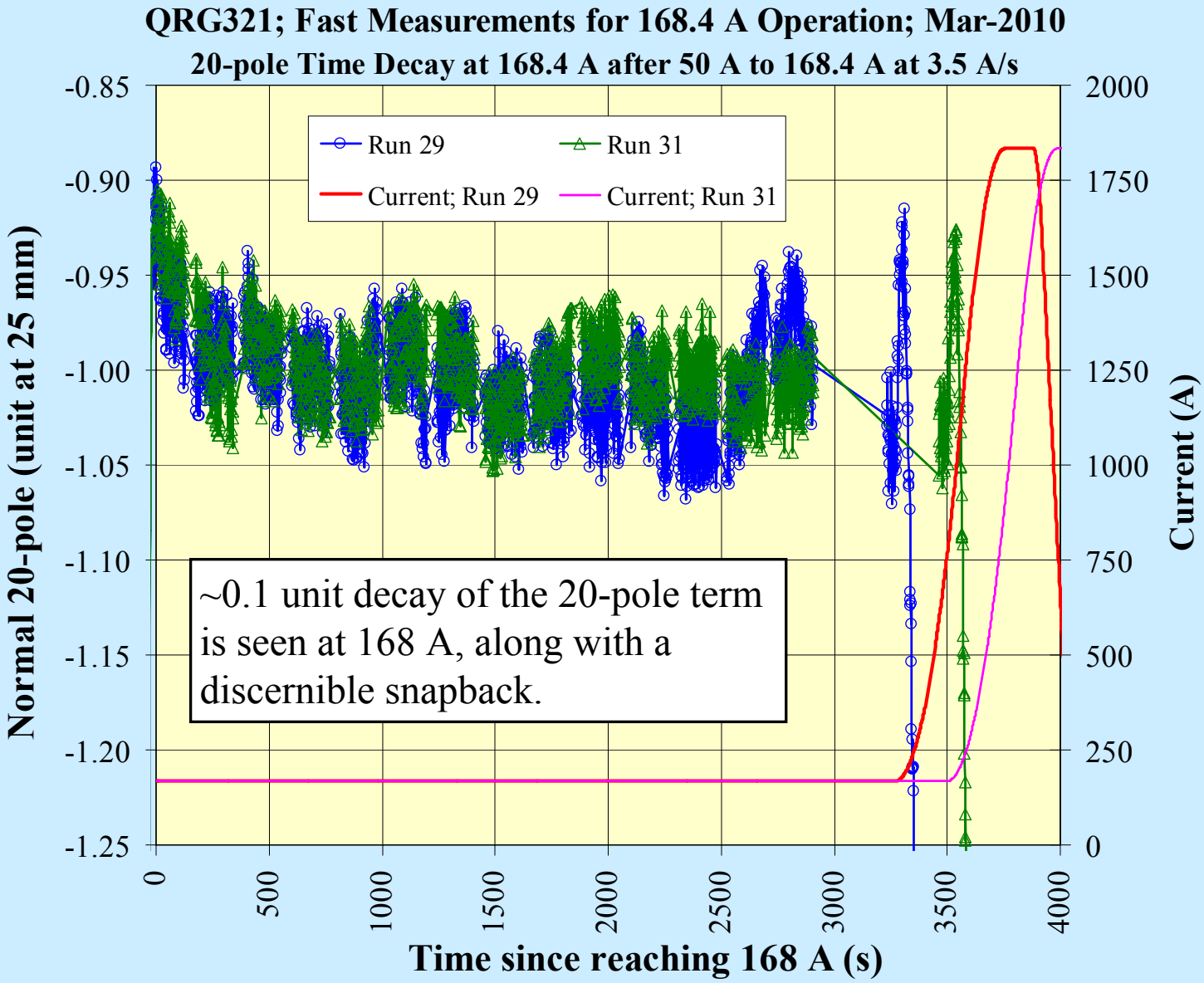
Current (A)	b9 Up (Units)	b9Dn (Units)	Dn–Up (Units)
104.6	-2.1	-4.4	-2.3
168.4*	-1.2	-3.4	-2.1
202.6*	-1.1	-3.0	-1.9

*** Interpolated from measured data**

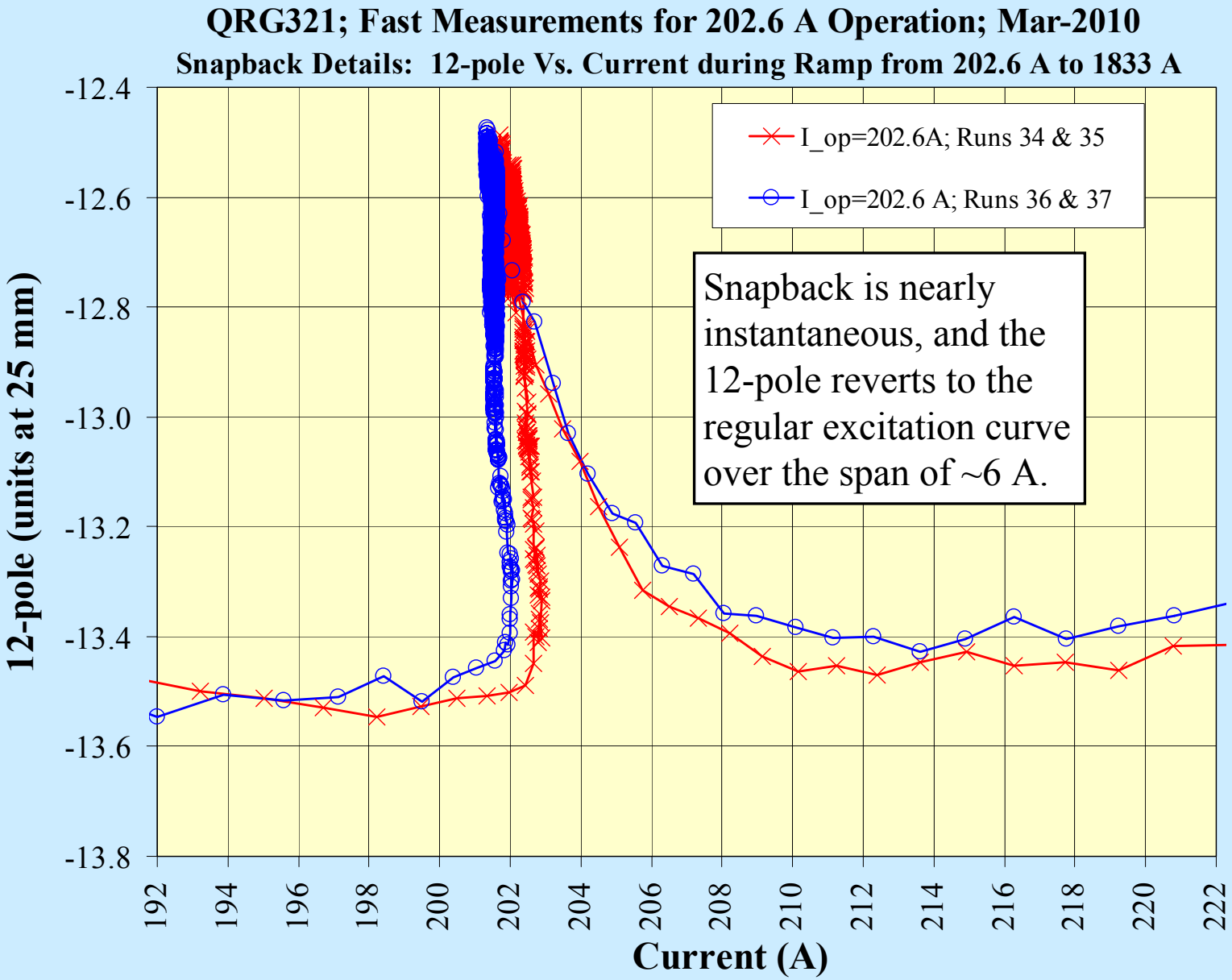
Snapback details at 168 A: 12-pole



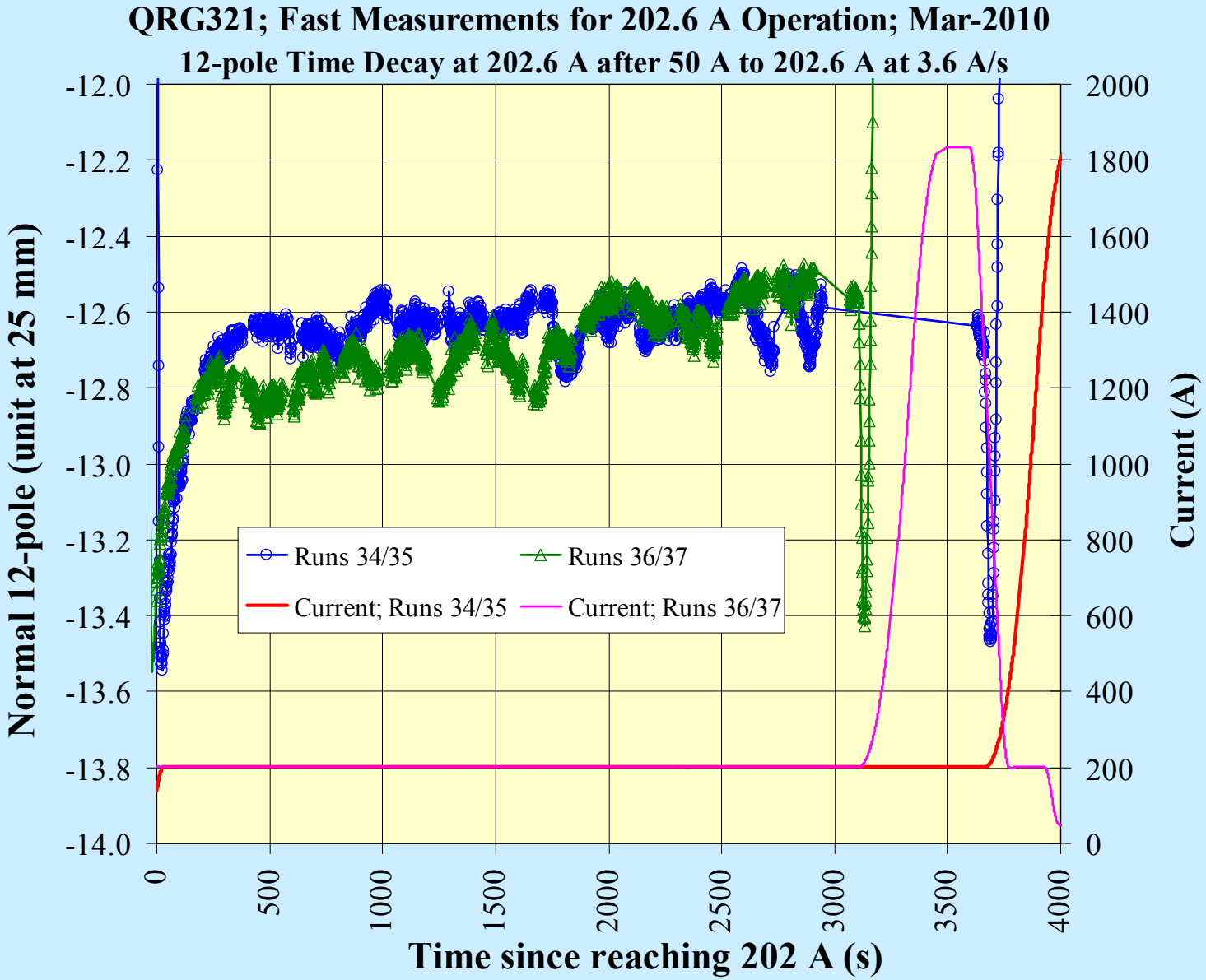
Time Decay at 168 A: 20-pole



Snapback details at 202 A: 12-pole



Time Decay & Snapback at 202 A: 12-pole



Time Decay at 202 A: 20-pole