PROGRESS REPORT ON TECHNICAL DIVISION TEVATRON MAGNET TEST ACTIVITIES IN SUPPORT OF RUN II

P. Bauer for

G. Ambrosio, G. Annala, R. Berggreen, J. Blowers, R. Cargagno, J. Carson, J. DiMarco, N. Gelfand, H. Glass, R. Hanft, D. Harding, R. Kephart, M. Lamm, A. Makulski, M. Martens, T. Peterson, P. Schlabach, D. Still, C. Sylvester, M. Syphers, M. Tartaglia, J. Tompkins, G. Velev

& the MTF operations & maintenance team

Also thanks to L. Bottura, M. Haverkamp, S. Russenschuck, GL. Sabbi, V. Shiltsev, A. Tollestrup

Overview

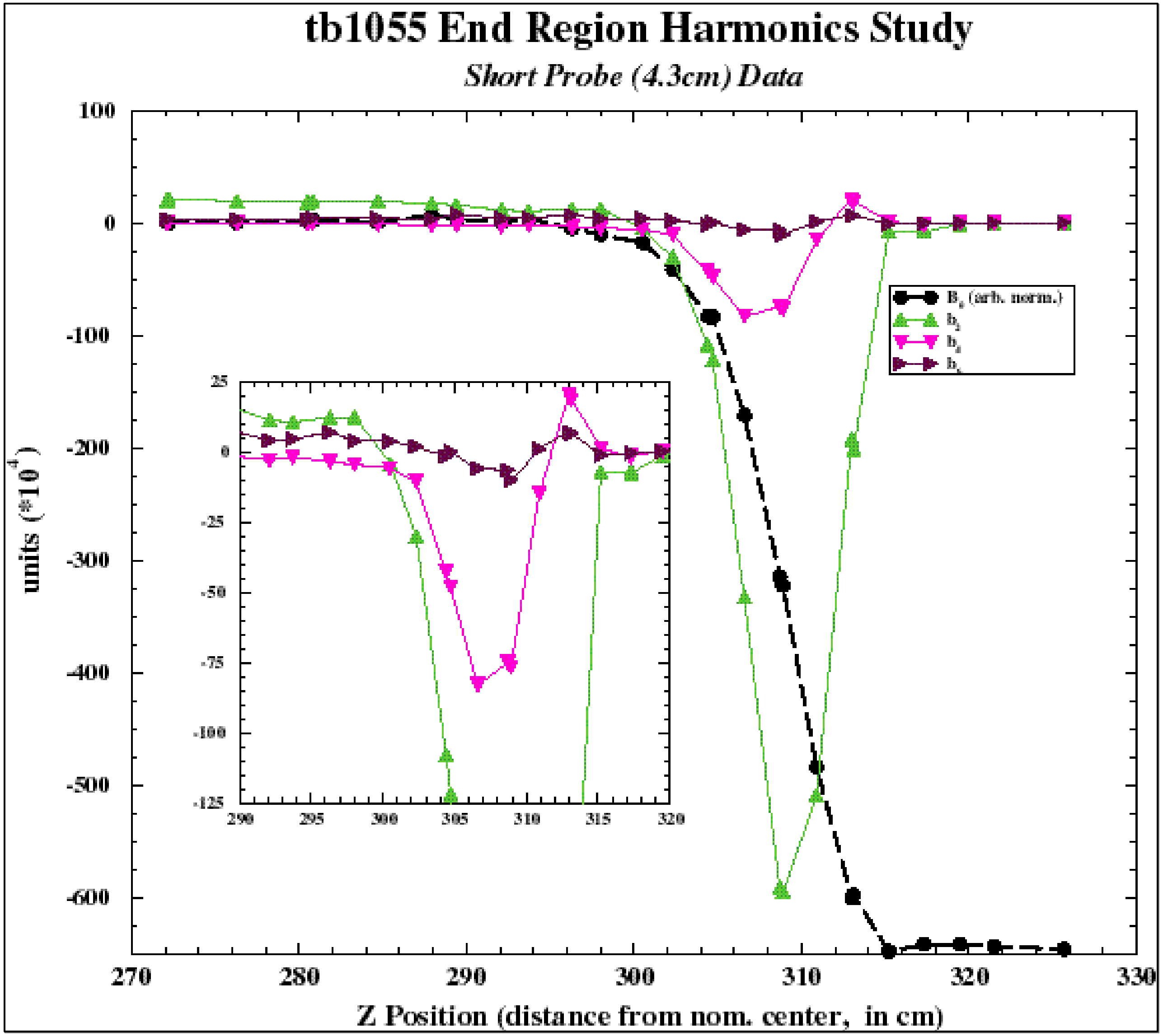
- Recapitulation of Feb. 20th talk
- Some News regarding Geometric and Hysteretic b2
- Results of Recent Measurements of b2 Drift and Snapback in Tevatron Dipoles
- Proposal for Improvements of the b2 drift/SB compensation
- a1 Measurements in Support of Re-shimming Effort
- Progress in other Multipoles
- Summary

Recapitulation of Feb. 20th talk

- **Discovery of “dynamic” effects in Tevatron, summary of past studies of dynamic effects in Tevatron dipole magnets;**
- **Geometric multipoles in Tevatron dipoles – archive data vs. magnetic model calculations;**
- **Current explanation of “dynamic effects” in superconducting magnets;**
- **Discussion of possible magnet issues in Tevatron: temperature variations, tune and coupling drift, main field drift, analysis of the b2-compensation in the Tevatron**
- **Summary of b2 beam studies – “chromaticities up the ramp”;**
- **Discussion of possible improvements of b2 compensation in Tevatron;**

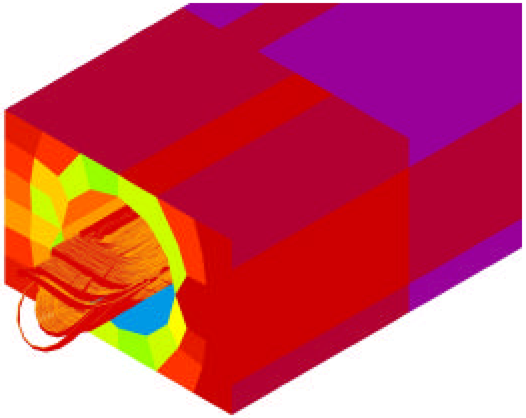
New z-scan measurements in 1055

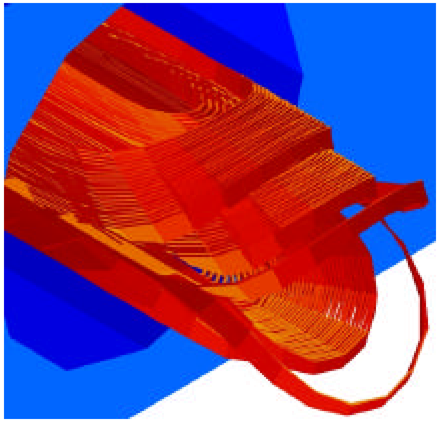
Geometric Multipoles in Tevatron dipole end measured with short probe in two separate z-scan measurements Data were used to refine 3D model of Tevatron dipole;

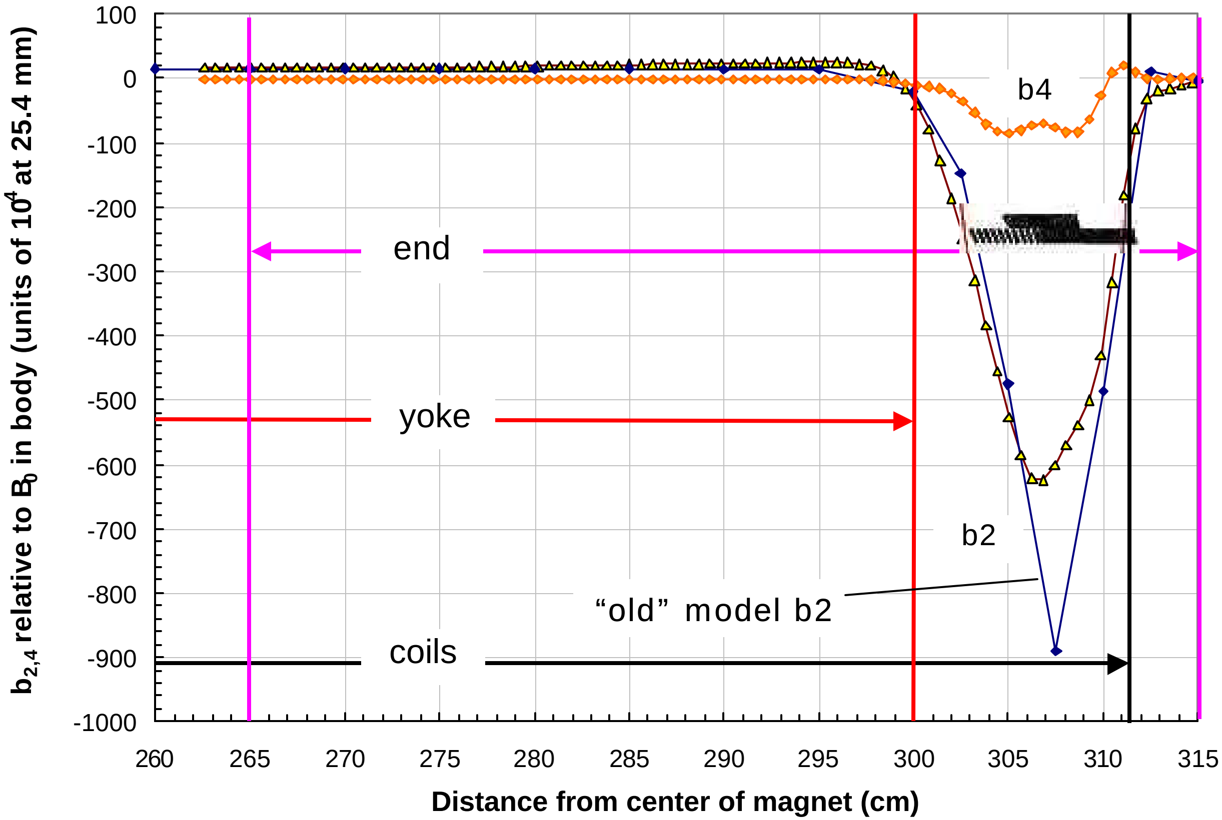


Improved Tevatron dipole 3D model

Improved 3D model of Tevatron dipole – on the basis of new z-scan data from TB1055;



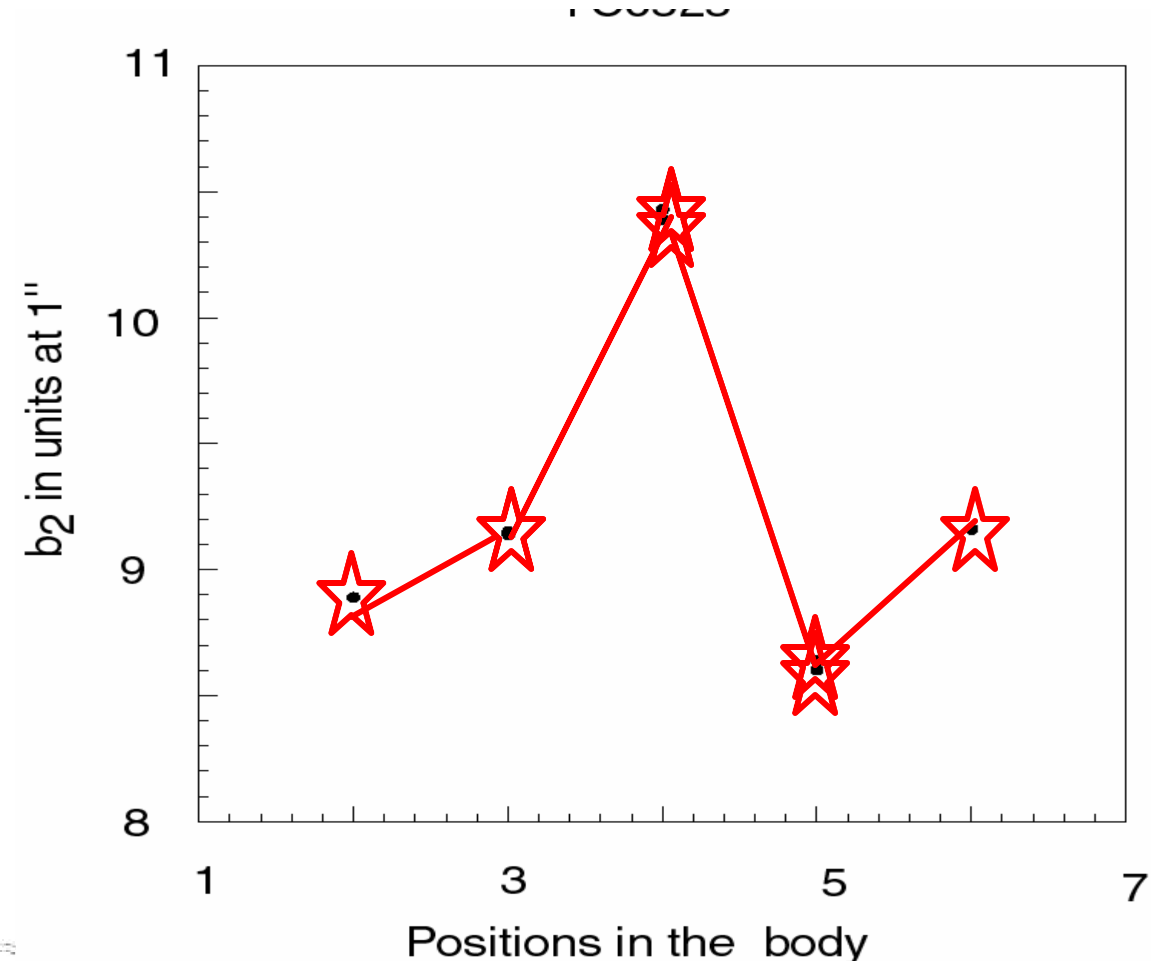




Longitudinal variations of b2 in TB0525

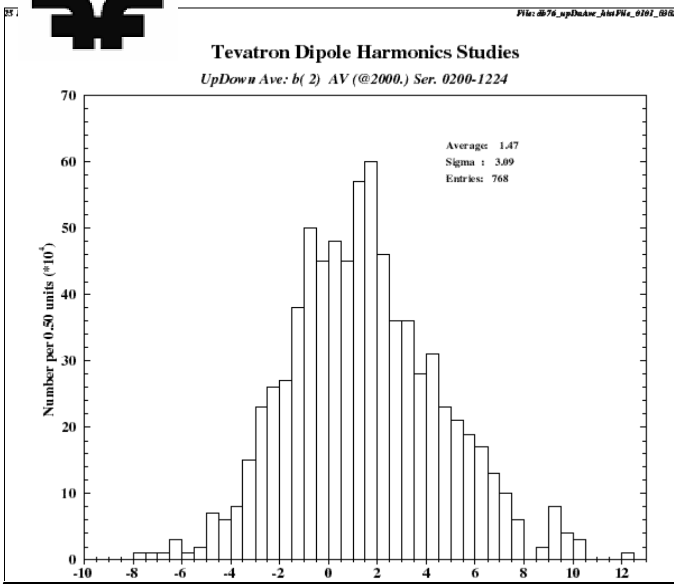
Possible cause:

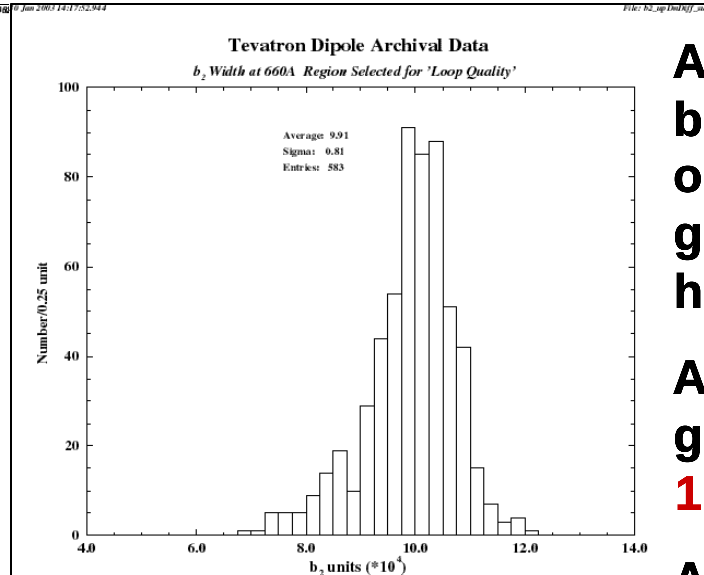
Variations of pole angle and mid-plane coil angles;

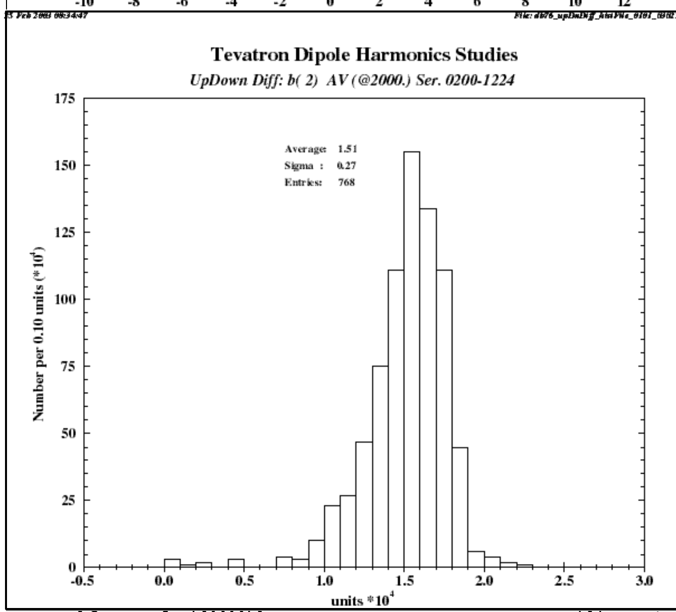


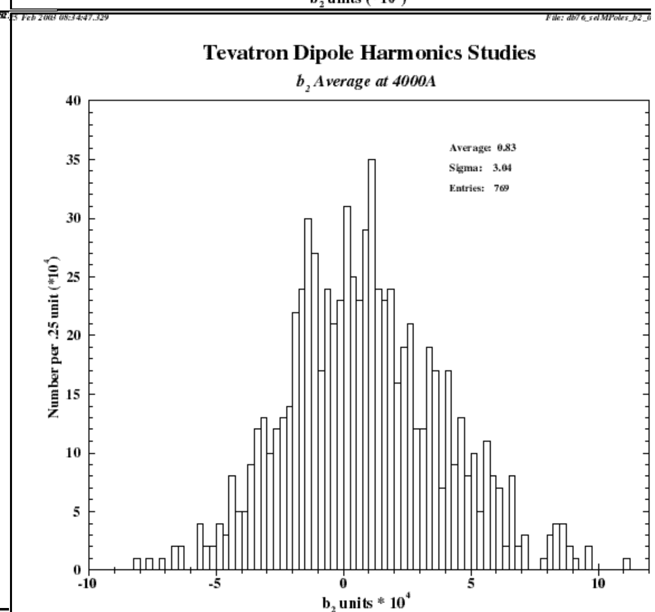
Plot of geometric a1 along axis of magnet 0525

Geometric and hysteretic b2 from archive









Archive data based estimate of average geometric & hysteretic b2:

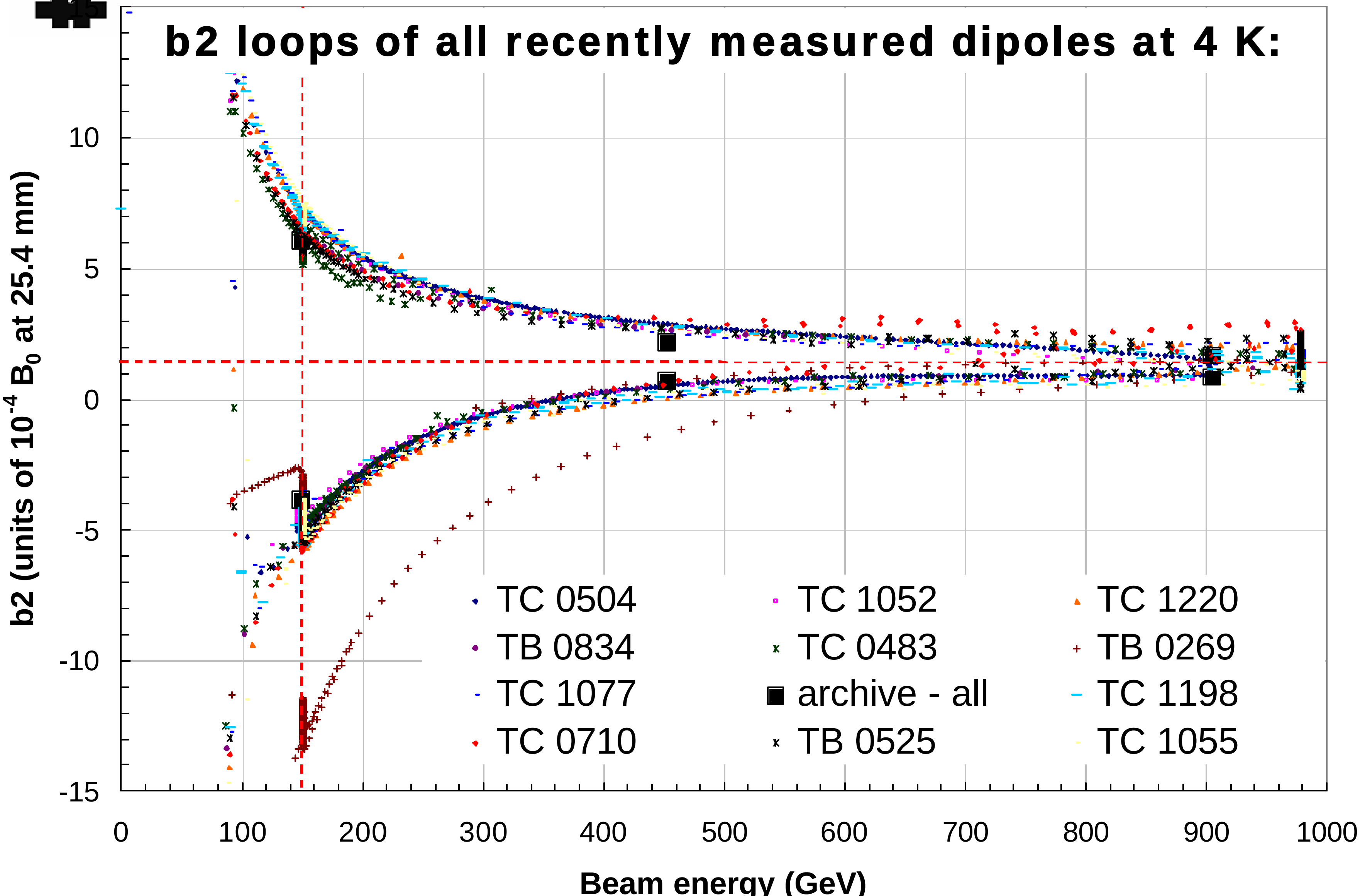
Average geometric (s): 1.47 u (3.09u)

Average width (s) @ ~150GeV: 9.9 u (0.82u)

Average width (s) @ ~450GeV: 1.5 u (0.27u)

Average width (s) @ ~900GeV: 0.83 u (3.04u)

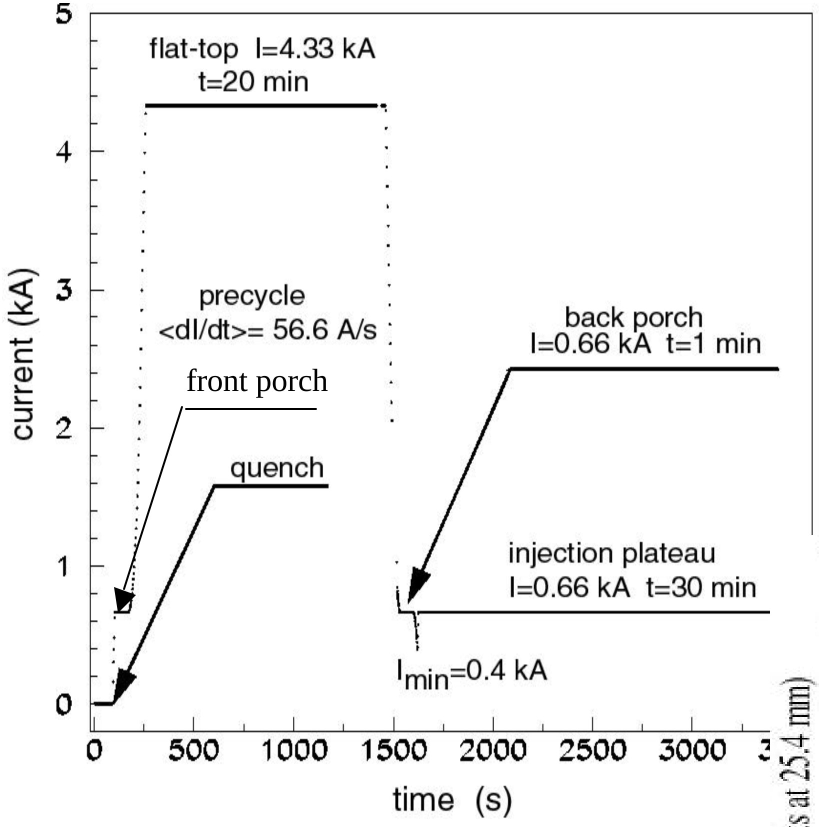
More new hysteretic b2 - loops



Summary: b2 in Tevatron dipoles

- geometric b2 in body: ~ 14 u, in end:~-600 u over 10 cm, body end average b2 of all installed dipoles is ~1.45 u.
- geometric b2 z-variation: 1-2 u (averaged over in above numbers).
- b2 periodic pattern, ~10 u ampl, 2.5” period, (not relevant for beam).
- hysteretic b2 loop width: ~10 u at inject. (drift in archival data!) width increase by ~15% / 1 K (otherwise invariant).
- dynamic b2: 1-2 u drift in 30 mins at inject., log dependence; magnet-to-magnet spread; dependence on powering “history”;
- b2 drift and snapback vary with pattern along body, no particular end effect, no temperature effect.

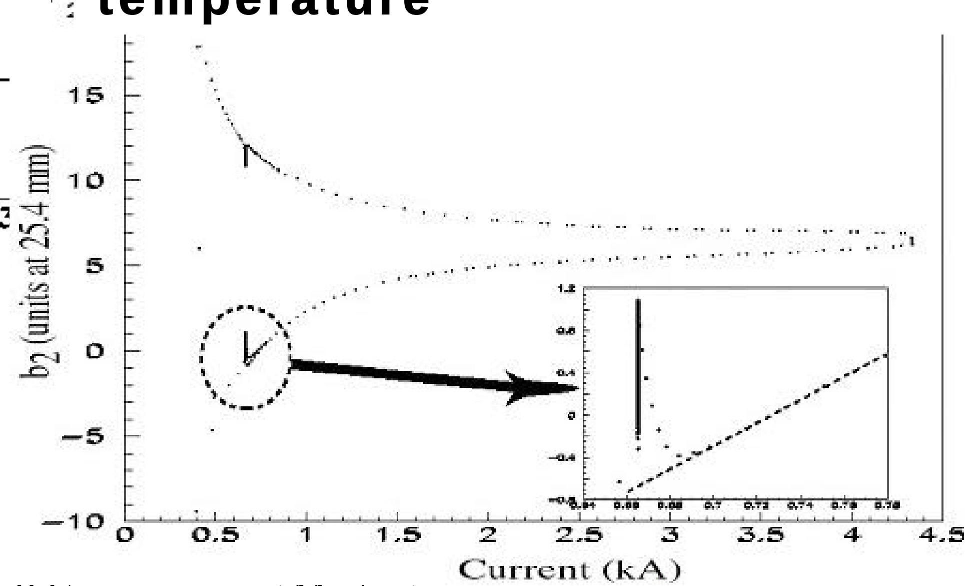
b2 measurements – dynamic effects



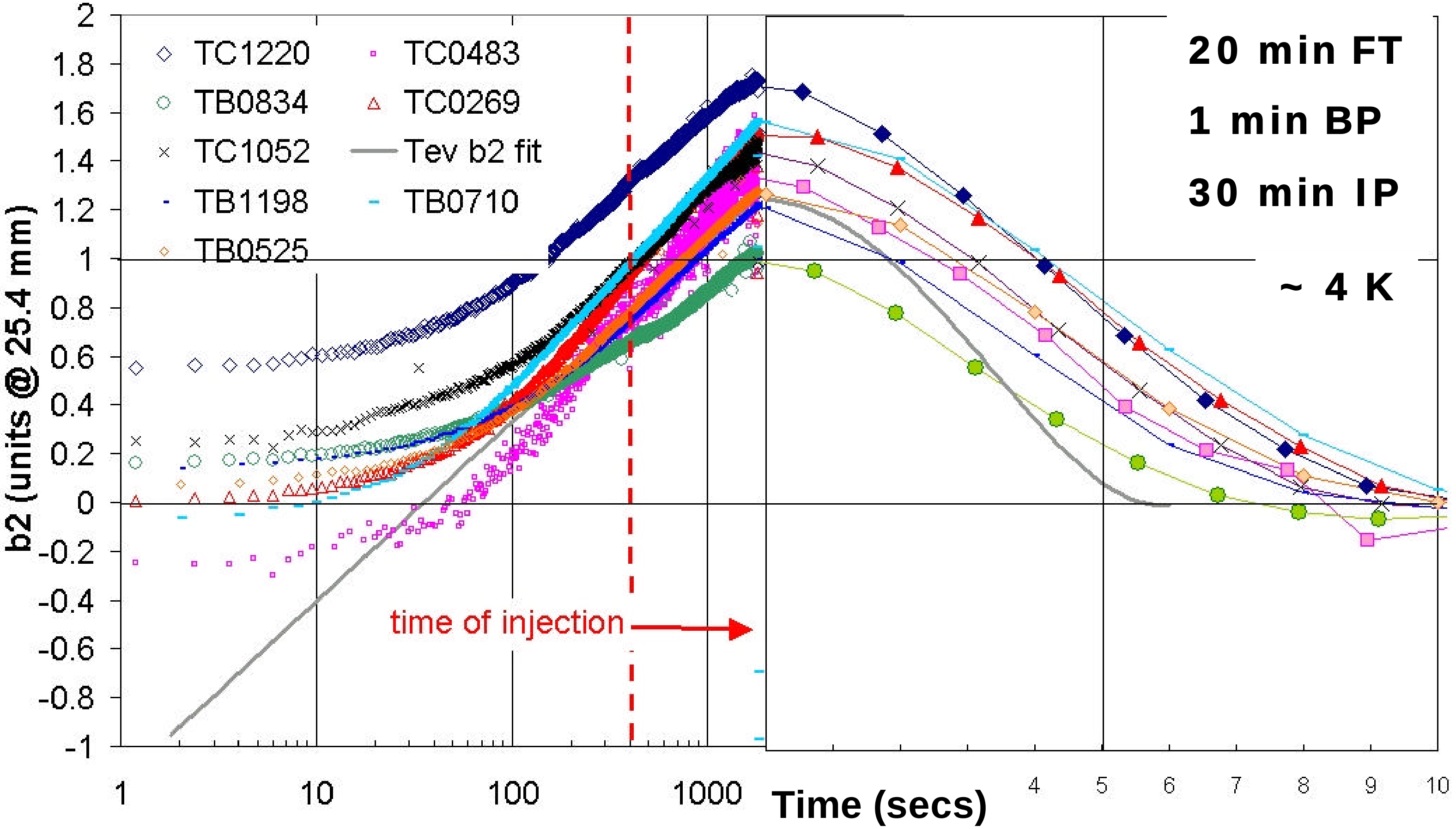
Measurement ramping cycle = current Tevatron operation cycle and variations (of the pre-cycle parameters).

Parameters varied: front-porch, flat -top, back-porch, injection porch, flattop energy, # of pre-cycles, probe position, magnet temperature

b2 loop & b2 drift/SB after a 30 min injection porch



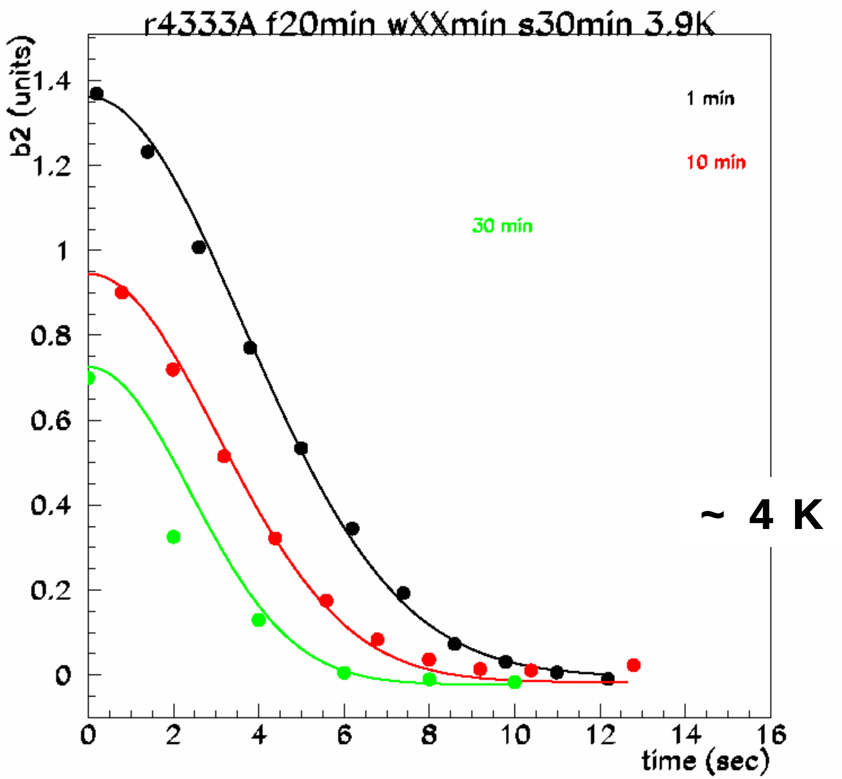
Dynamic b2 in Tevatron dipoles



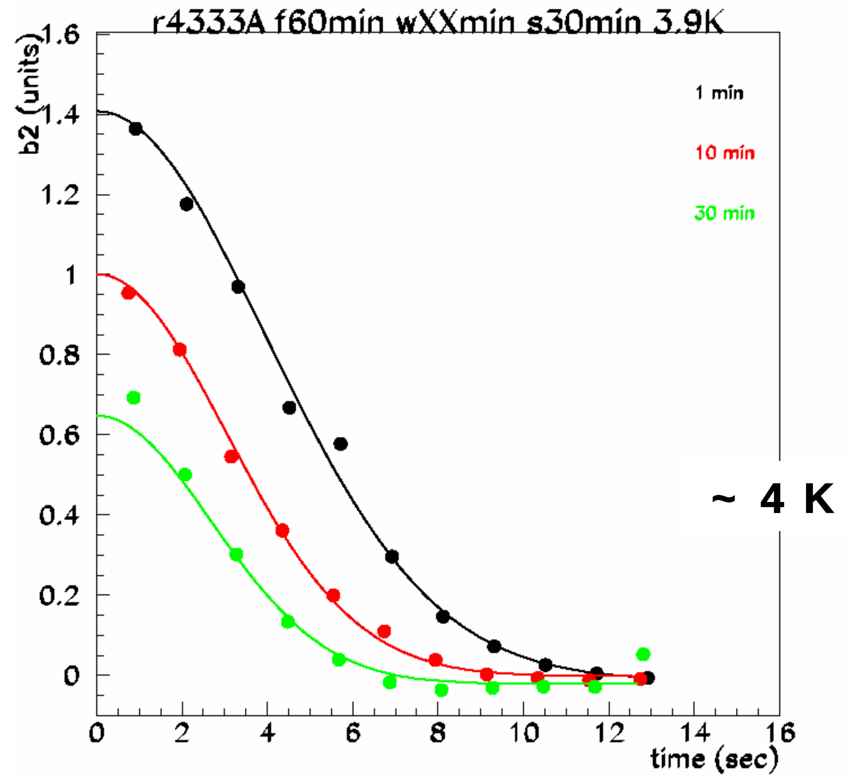
b2 D&SB after 30 min IP for *standard* pre-cycle in 8 Tev dips – geometric and hysteretic b2 were removed to show the dynamic effects only; Comparison to current Tev fit!

b2 measurement example TC1052: snapback vs. back-porch duration

20 min FT



60 min FT

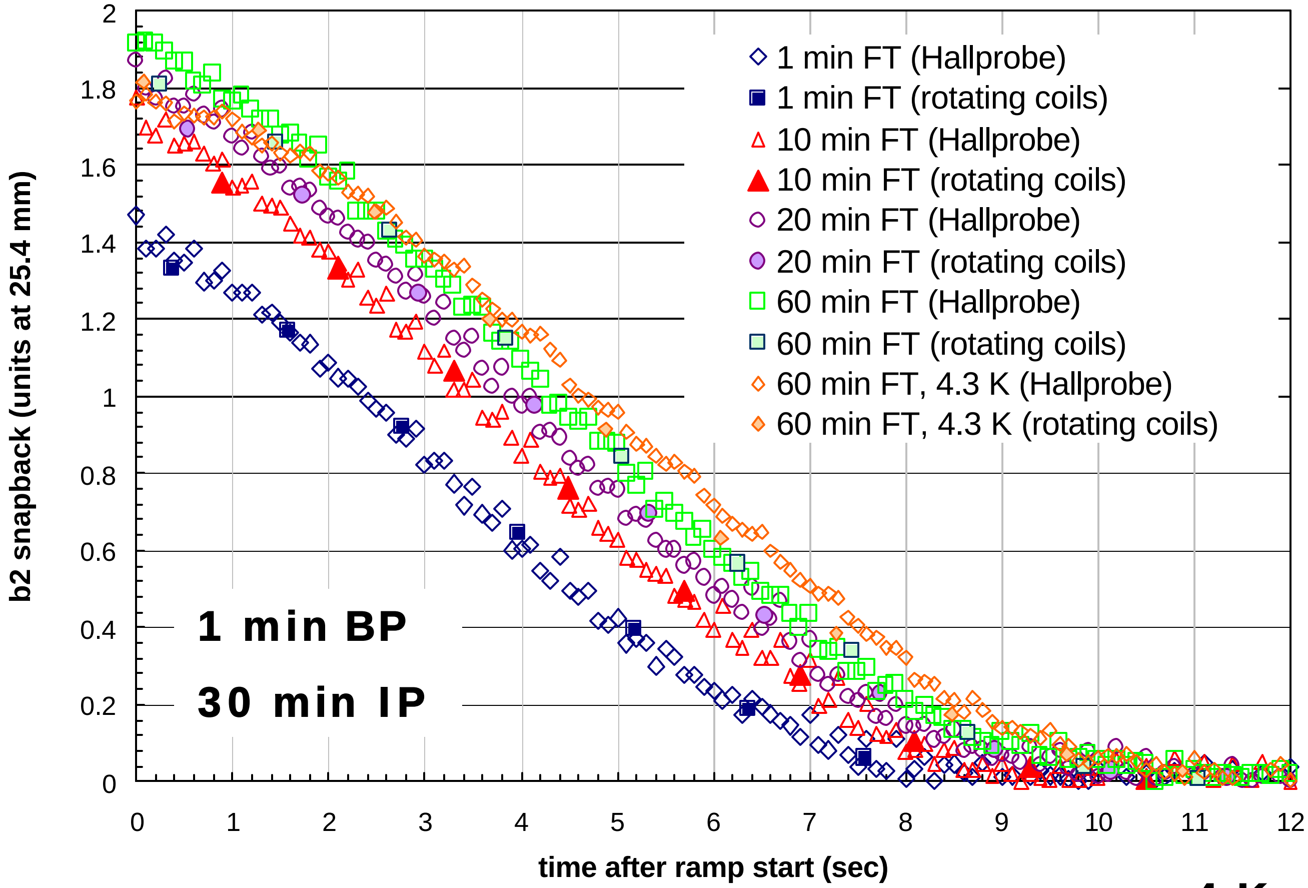


Example of SBs after 30 min at IP in magnet TC1052 for different pre-cycle BP and FT times. Data clearly show that the back-porch affects the drift amplitude more than the flat-top duration!

b2 Hallprobe measurement example:

Cern sextupole Hall-probe array;

Example of comparison of SBs measured with rotating coils and Hall-probe-array in TC1220 (body) after 30 min at IP for varying FT times (BP=1 min);



~ 4 K

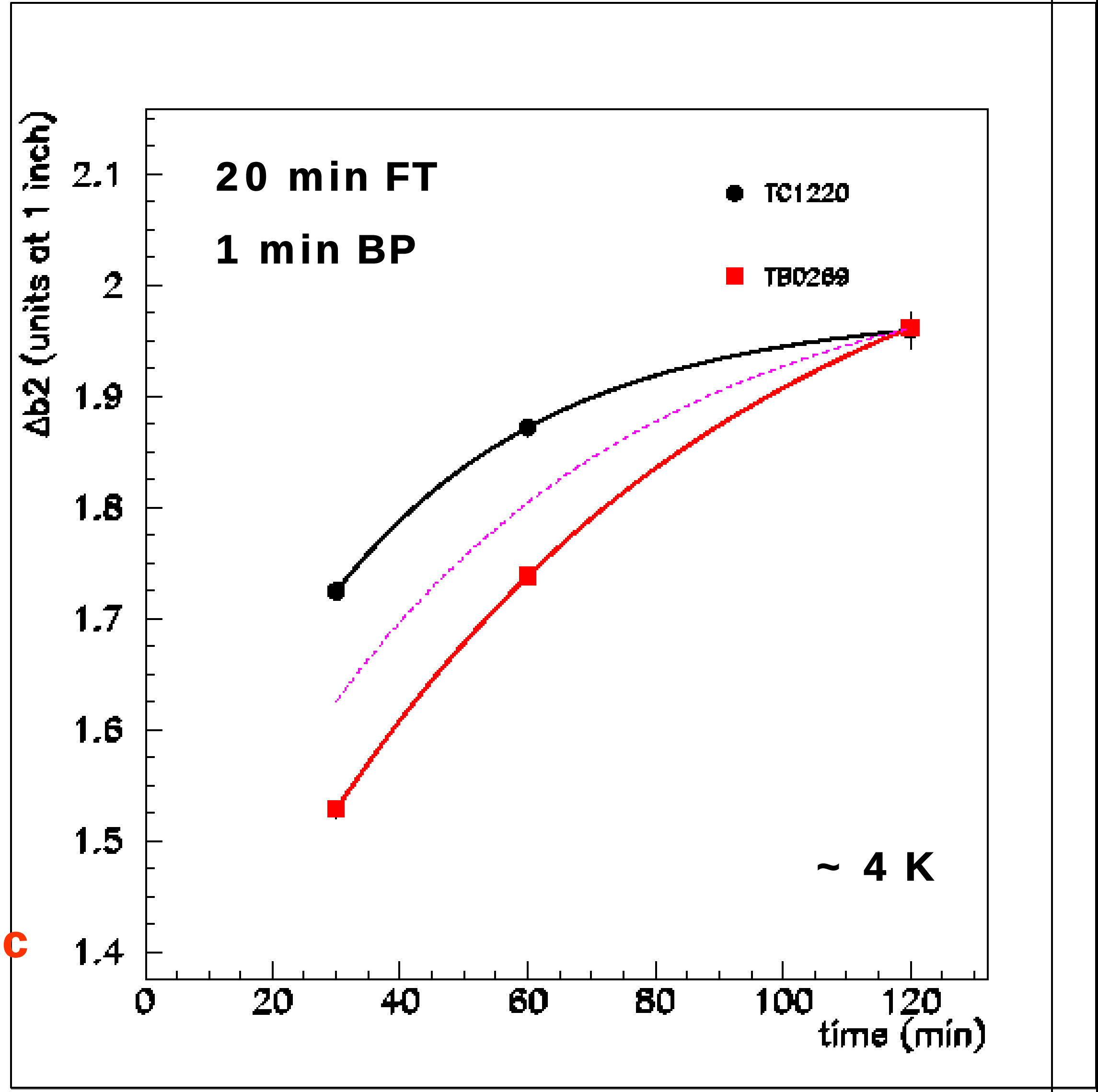
Effect of injection-porch duration

If the decay is parameterized for one injection porch duration (fixed BP, FT) one can calculate b2 for every IP using the formula

b2= a*ln(t+tshift) + c

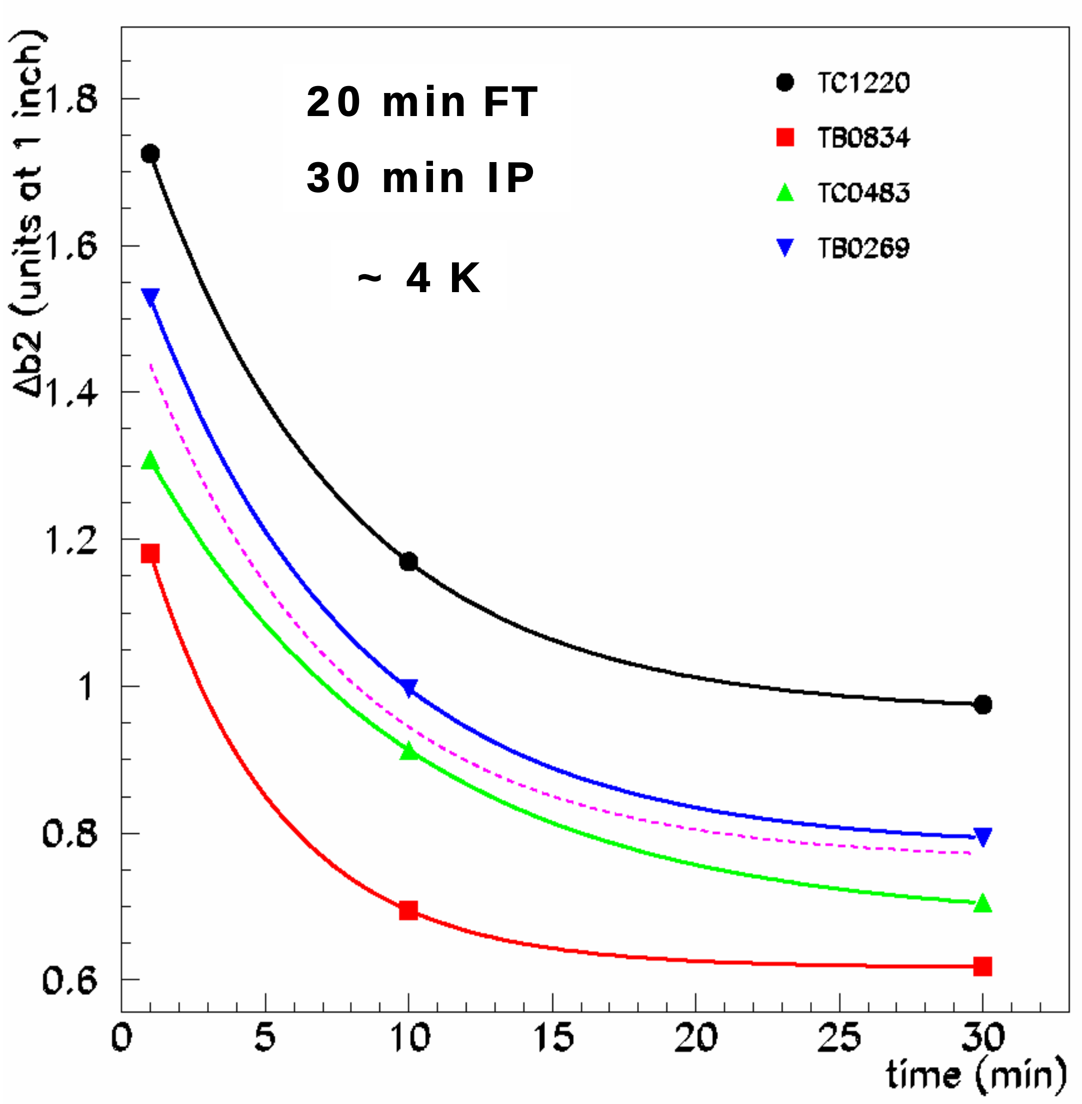
Another option is:

$$b_2 = a_1*(1-\exp(-t/t_1)) + a_2*(1-\exp(-t/t_2)) + c$$



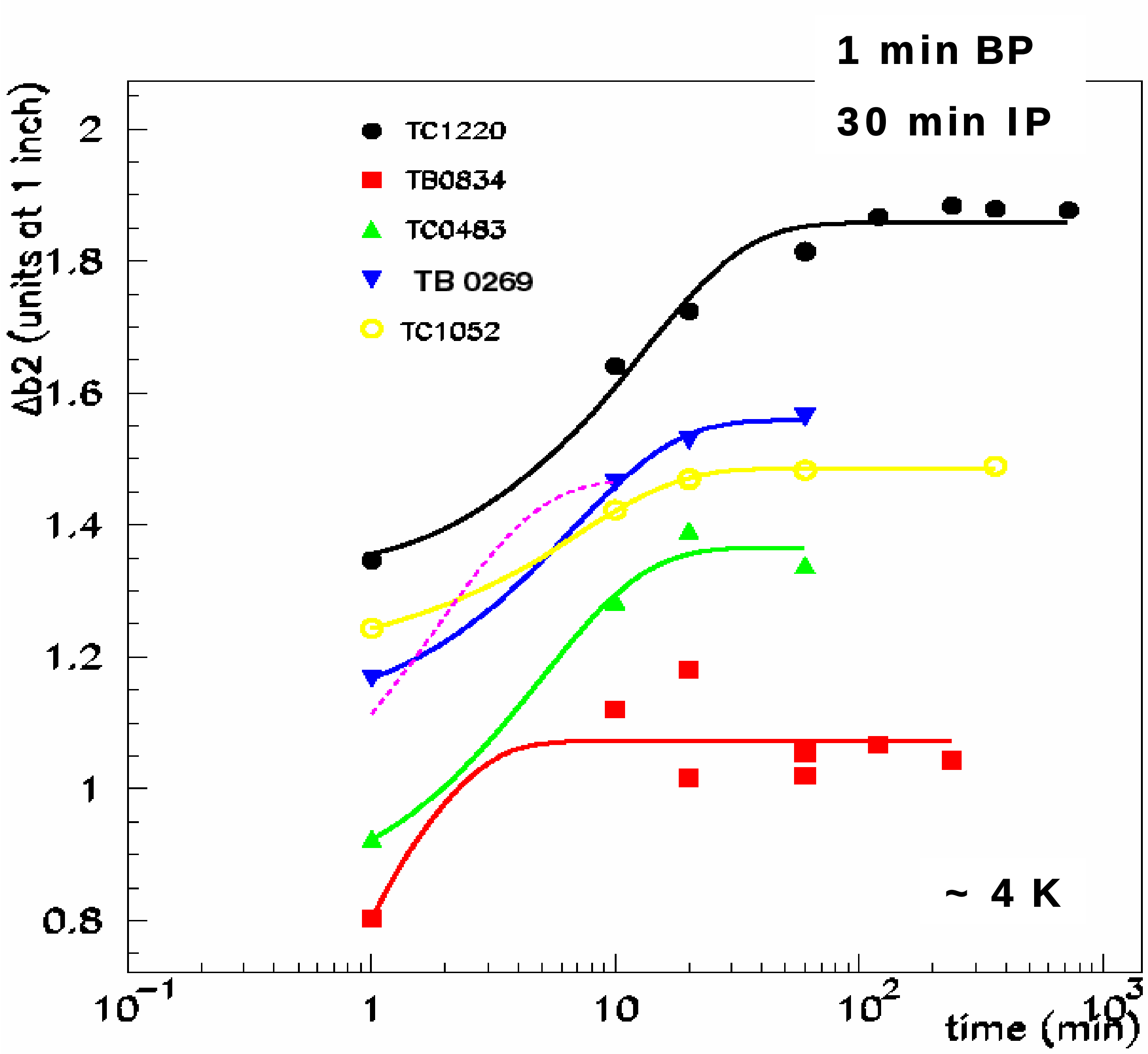
Effect of back-porch duration

The back-porch is clearly the pre-cycle parameter with the strongest impact on the drift amplitude. The longer the back-porch, the less drift.



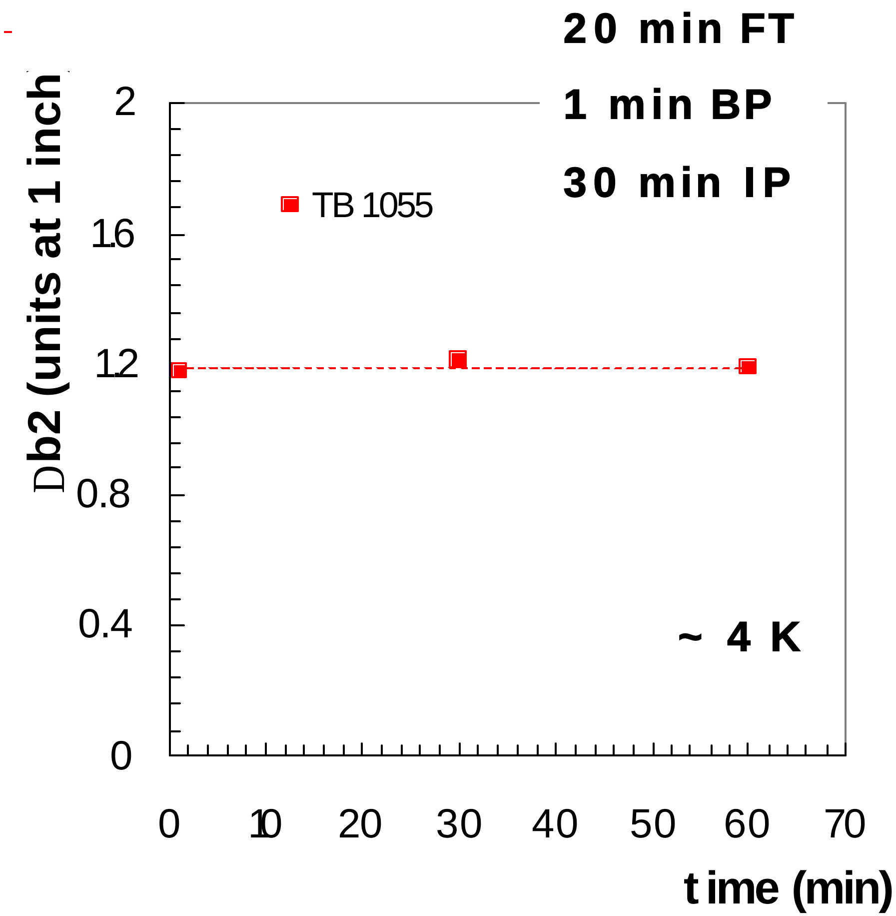
Effect of flattop duration

Saturation of the b2 drift with long flat-tops (measured in 4 magnets for FTs up to 12 hrs) makes it an interesting option to eliminate the beam-less precycle and thus use the last shot as the “pre-cycle” to the next shot.



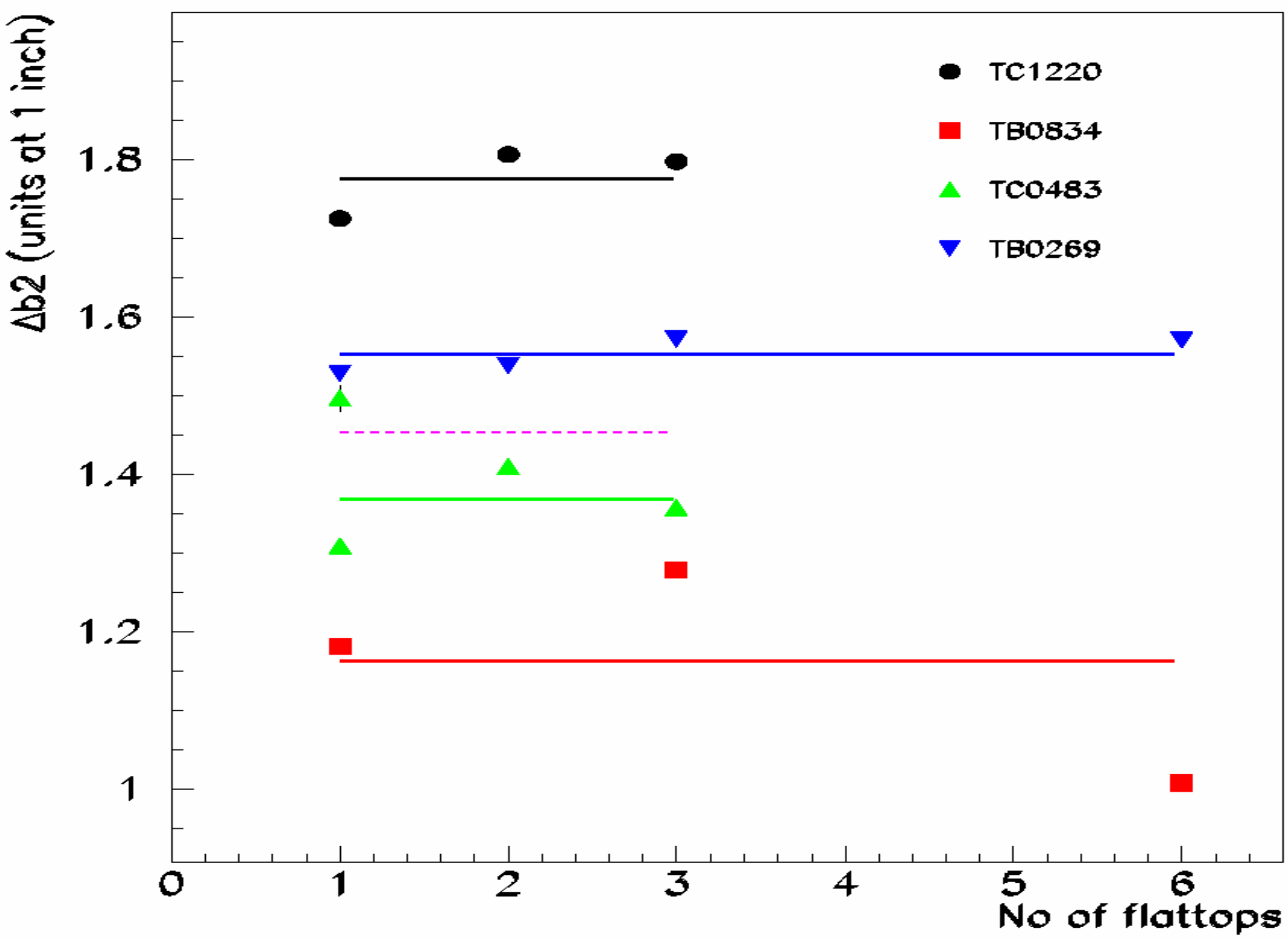
Effect of front porch duration

The measurement (so-far only on TB1055) of the effect of the front-porch (1,5,30 and 60 min) has shown no effect whatsoever on the b2 drift.



Number of pre-ramps after quench

No effect beyond 1 pre-cycle! A pre-cycle takes ~ 25 mins (20 min FT).



20 min FT

1 min BP

30 min IP

~ 4 K

Effect of flat-top energy

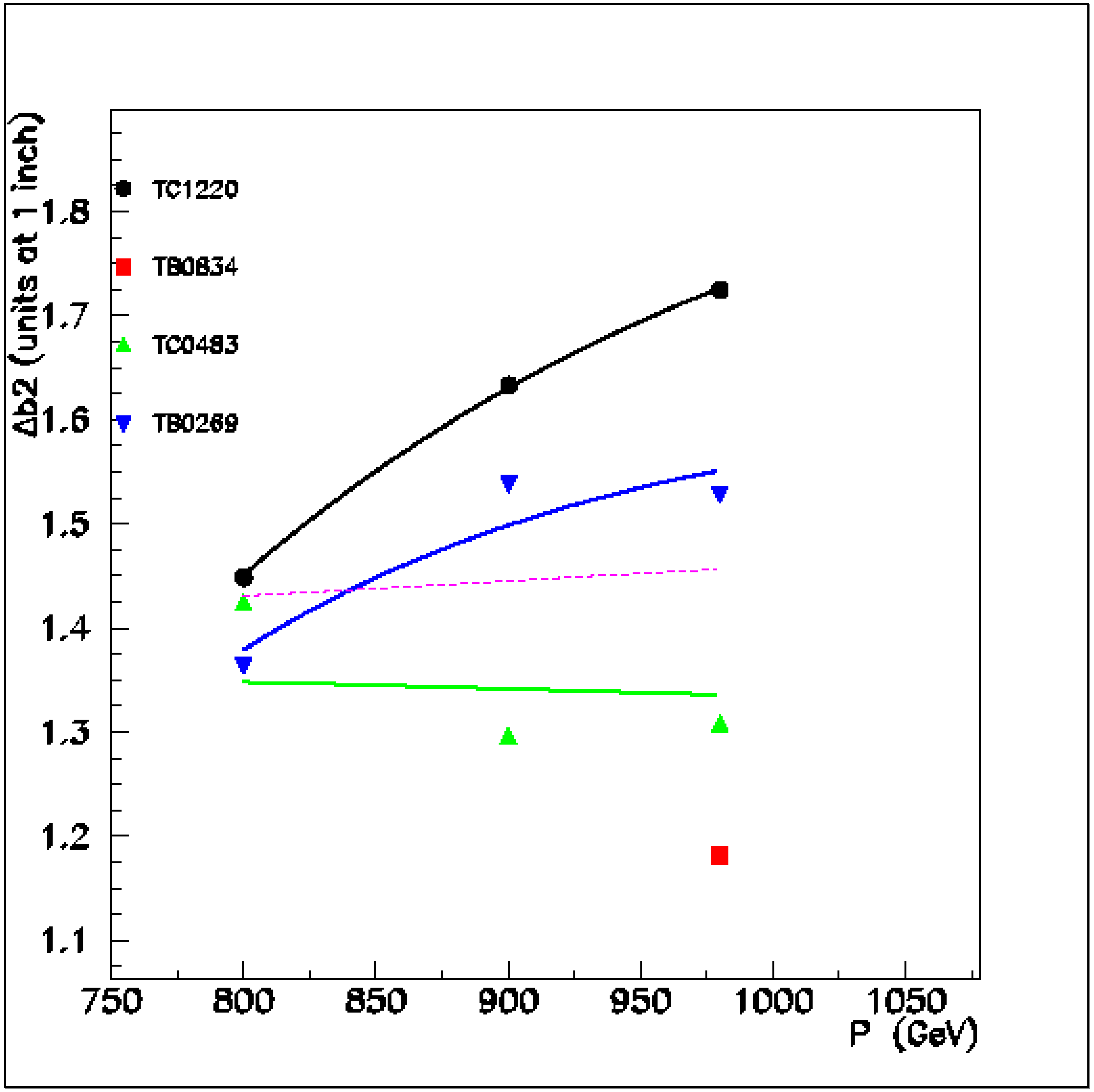
Strong effect, but probably not important..

20 min FT

1 min BP

30 min IP

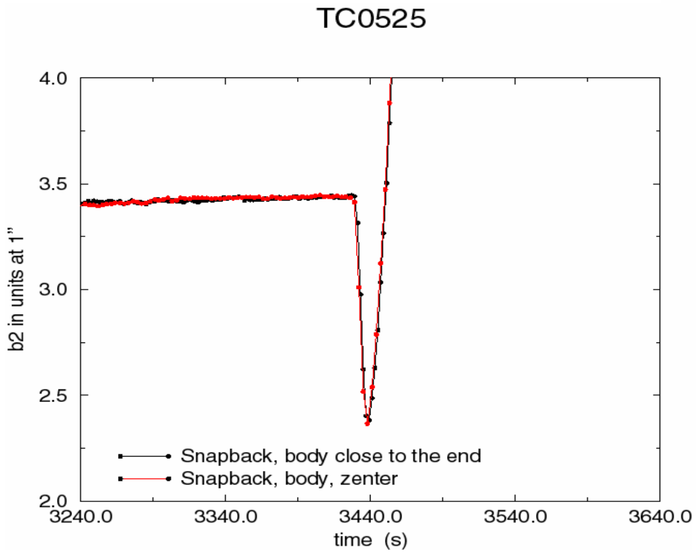
~ 4 K

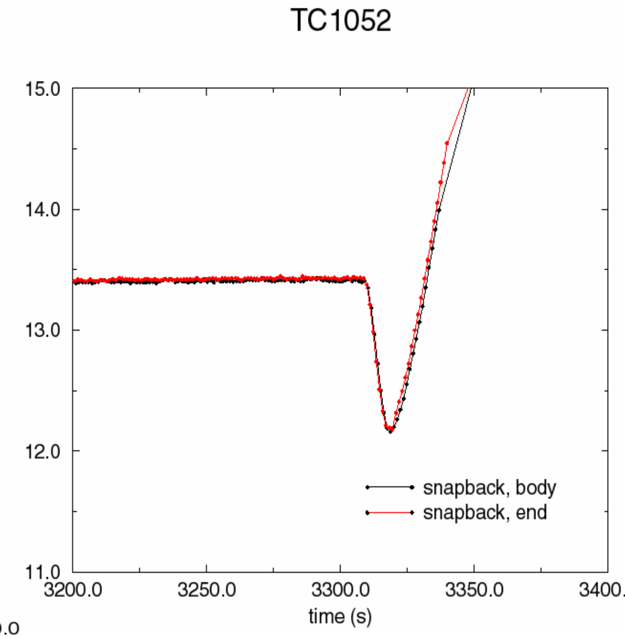


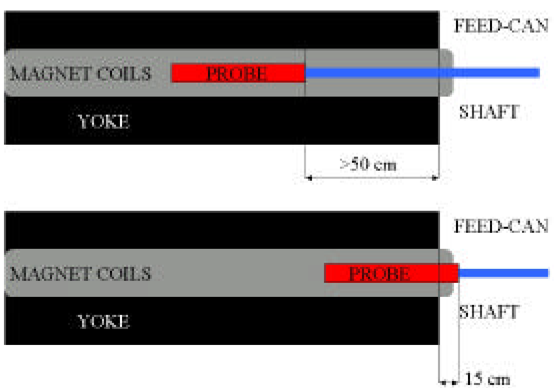
Body-end differences

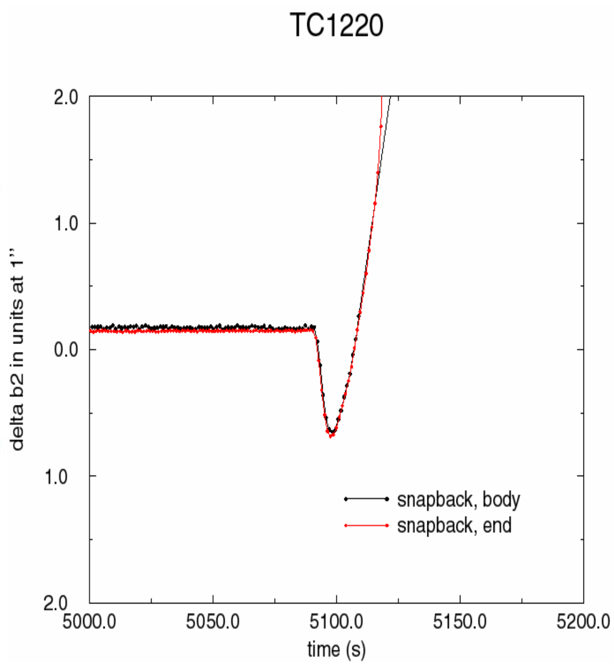
Not detectable ..

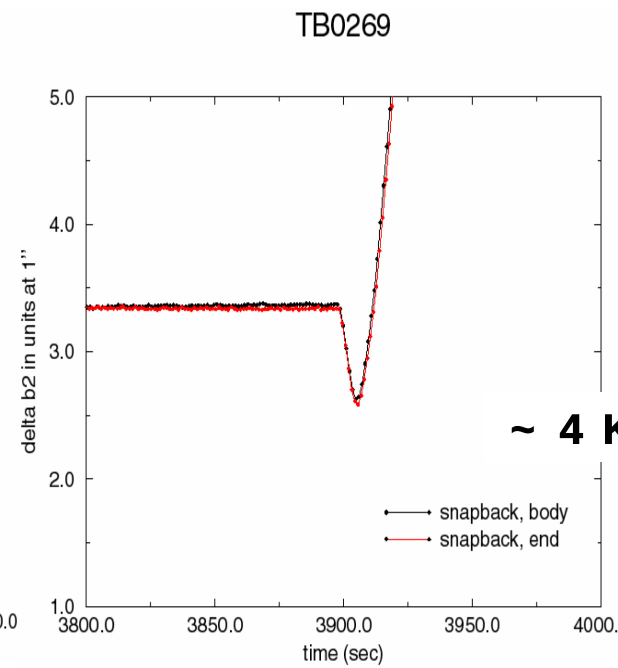
B2 SB amplitude "winds" down in end as B0;











~ 4 K

Functional shape of snapback correction

❖ **Polynomial snapback (currently used in Tevatron):**

$$b_2(t) = Db_{2,0}\,(1-t^2/t_0{}^2)^2$$

❖ **Exponential form:**

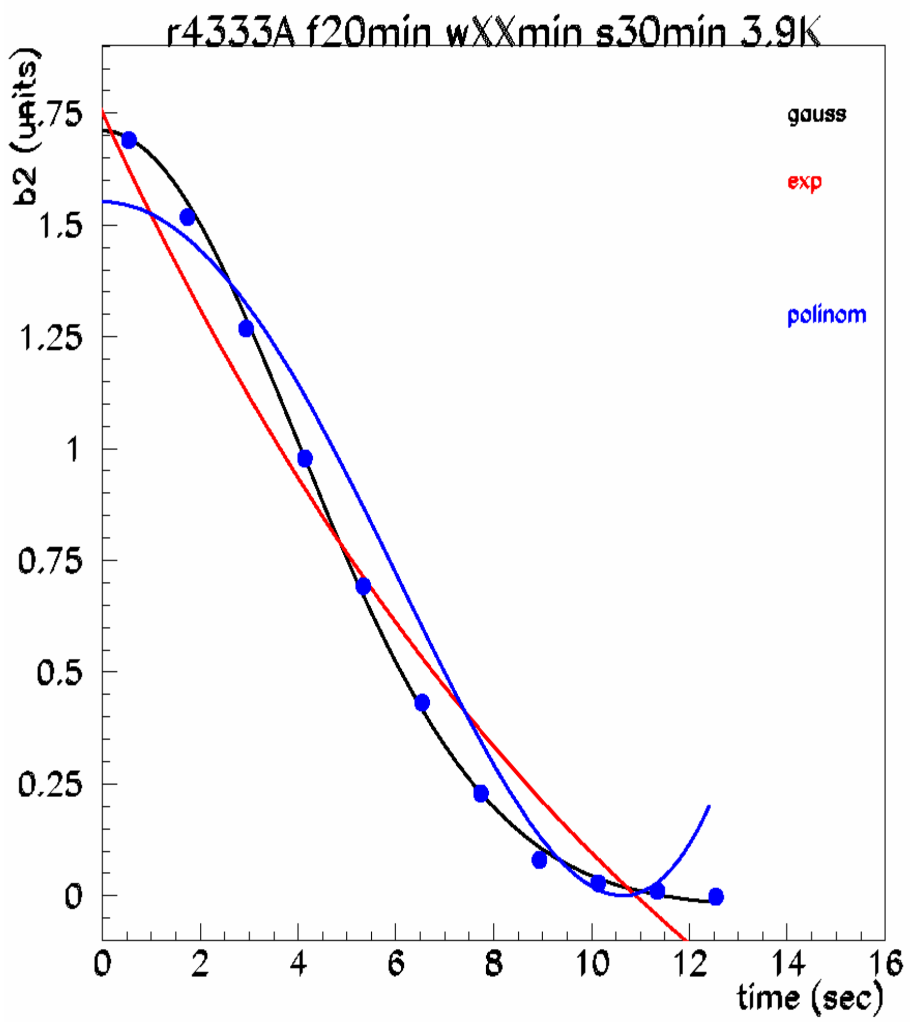
$$b_2(t) = Db_{2,0}\,\exp(-t/t_0)$$

❖ **Proposed parameterization:**

$$b_2(t) = Db_{2,0}\,\exp(-(t/t_0)^2)$$

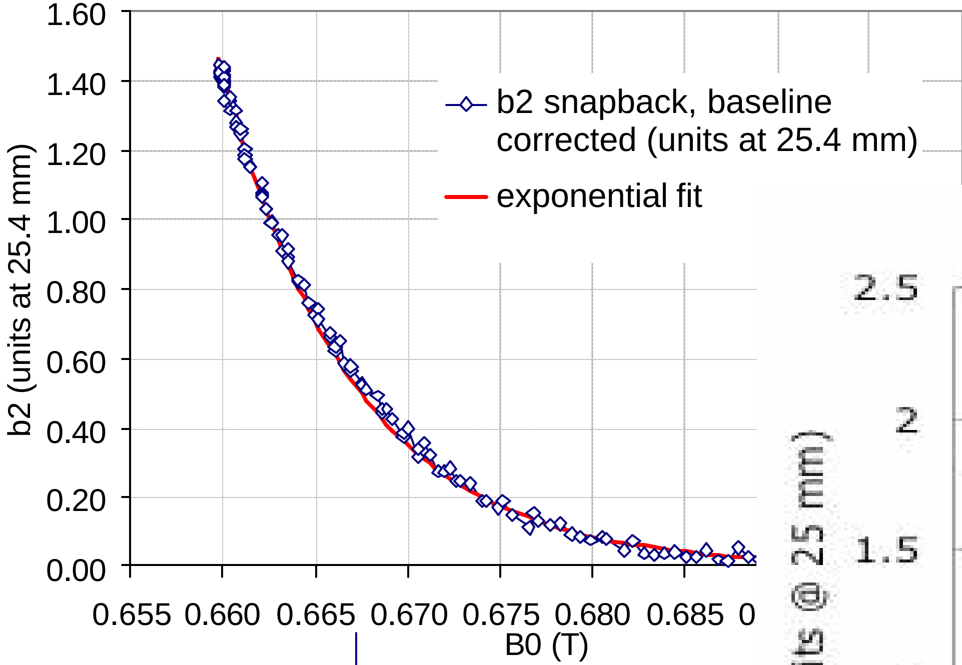
❖ **In addition we parameterize the drift amplitude Db_{20} and the SB time t_0 as a function of the durations of the pre-cycle parameters (IP,BP,FT)**

$$Db_{2,0}{}^*, t_0{}^* = p_1\,\exp(-t/p_2) + p_3$$

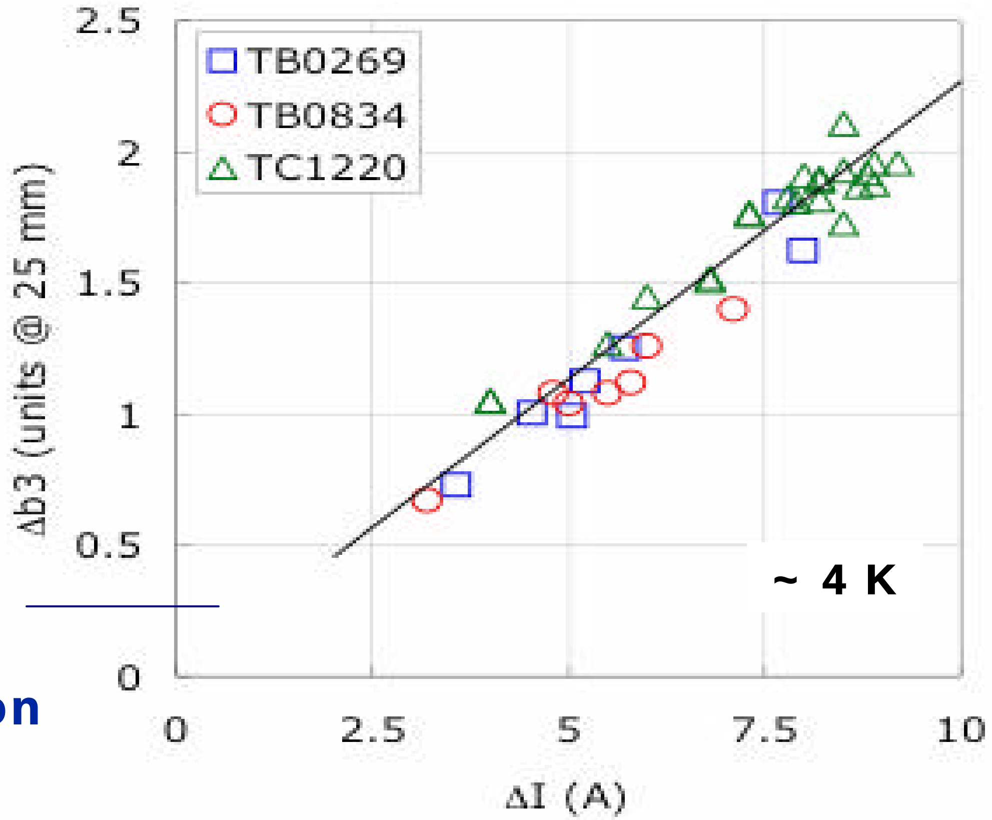


* **These parameters are in fact correlated $t_0 = t_0(Db_{20})$!**

Correlation between SB amplitude and time



Scatter plot of the SB fit parameters that correspond to sets of different powering cycles in 3 Tevatron dipoles.



Fit of Hall-probe-measurement with exponential – exponential current (field) constant is on x-axis of correlation plot.

Functional shape of drift correction

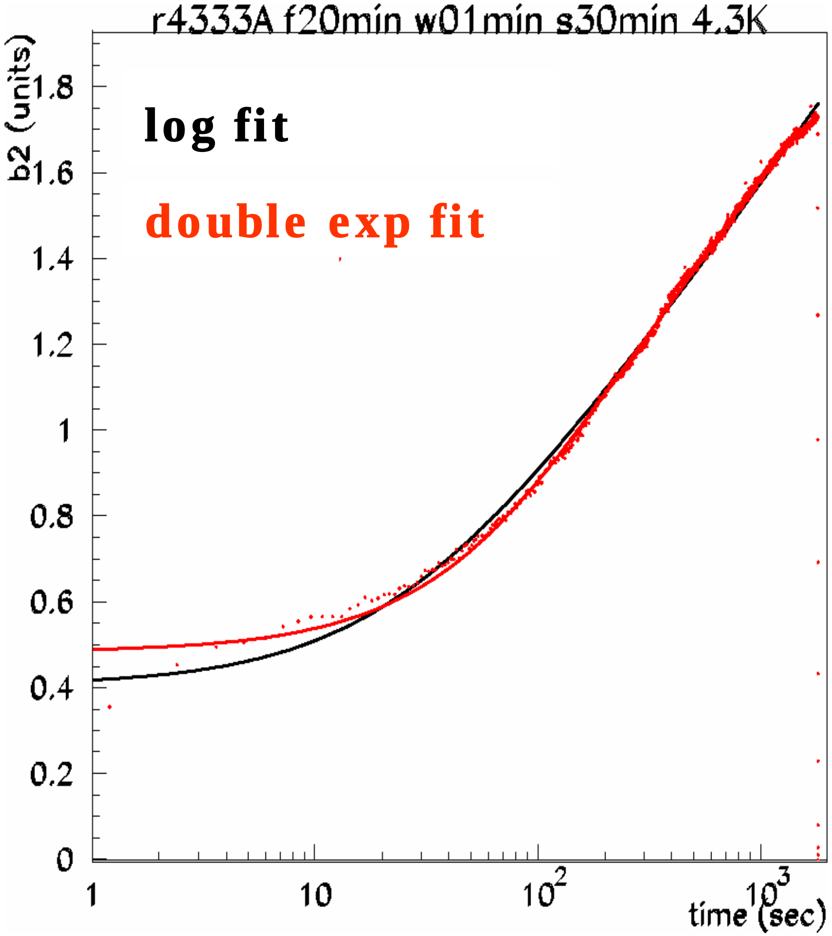
- There are two standard forms to parameterize the magnet decay. HERA and Tevatron use the log form:

  $b_2 = a*\ln(t+t_{shift}) + c$

- RHIC uses double exp form (adopted for LHC):

  $b_2 = a_1*(1-\exp(-t/t_1)) + a_2*(1-\exp(-t/t_2)) + c$

- It was found that double exp form works better in 3/4 of the cases, especially in the first 100 s region



While revisiting the Tev drift compensation one might also want to remove the “history” dependence of the so-called b2ini parameter.

Proposals for improved b2 fit

1) Fix (and extend) back-porch time (resolve “20-sec” issue)

2) Reduce # of beam-less pre-cycles following a Tevatron quench from 6 to 1 (~40 min flat-top);

3) Change b2 SB fit® Gaussian

4) saturation of flat-top duration effect on drift amplitude and absence of effect of front-porch duration ® foundation for elimination of pre-cycle

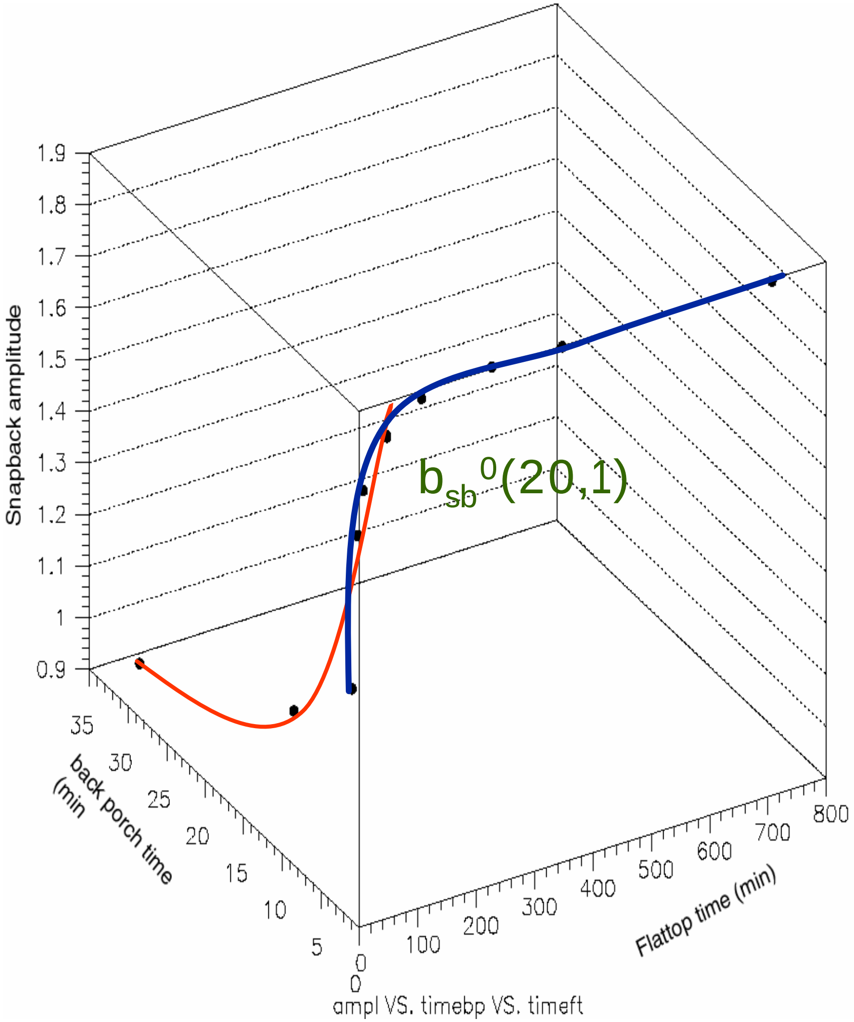
5) Improve drift fit – a parameter in the old fit is history dependent although it shouldn’t be, a double exponential appears to be slightly better than the log fit.

Proposals for improved b2 fit

To improve the b2 drift fit we need to explore better the parametric space..

There are discussions whether we should explore the "practical" parameter space or a more fundamental parameter space..

This represents a lot of work that we have just started!

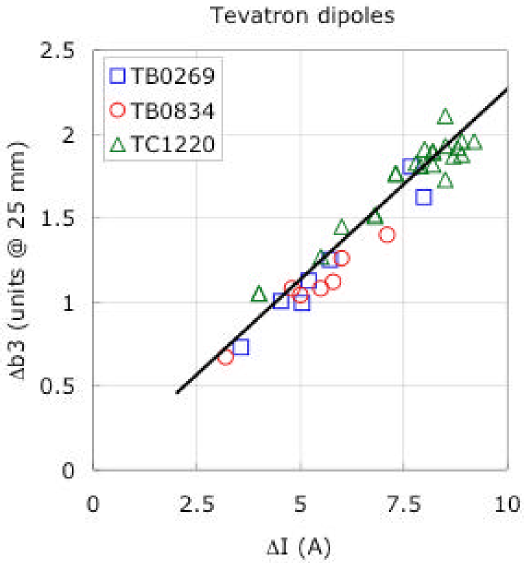


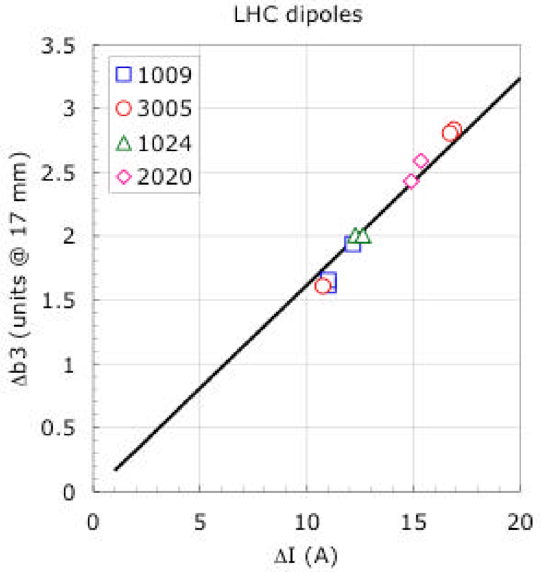
Cern-Fnal proposal for new b2 approach

Correlation of SB amplitude and magnetic field to completely resolve SB is the same in Tevatron and LHC dipoles!

® **If b2 amplitude can be measured "on-line" the SB fit can be predicted w/out use of "multi-parameter" algorithm!**

Testing / implementation of the new "Gaussian" SB fit will also be in the interest of the LHC.





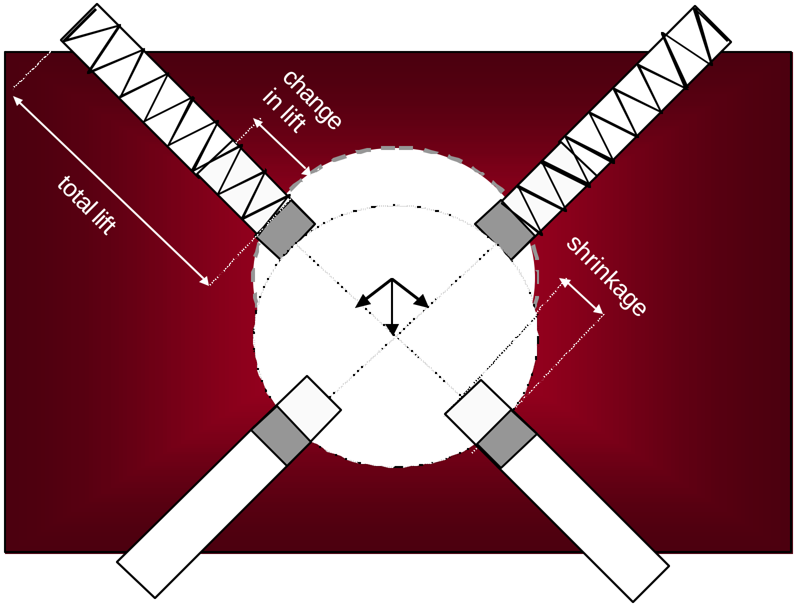
~ 4 K

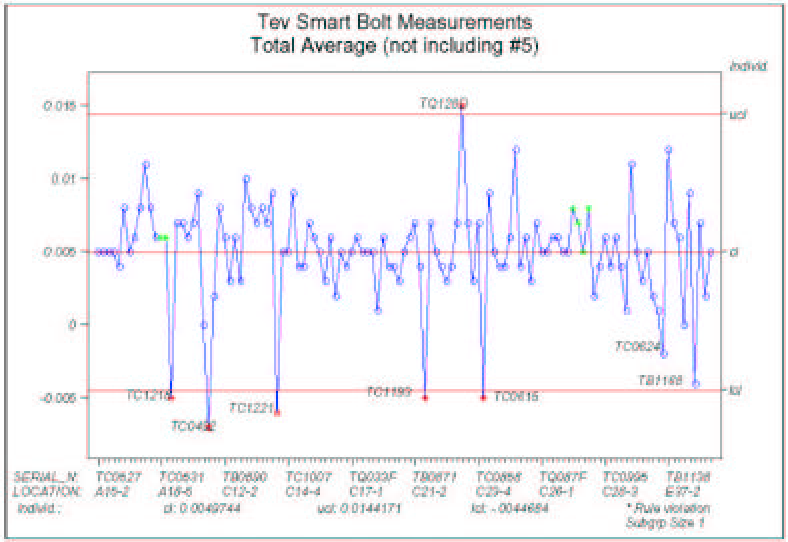
a1 issue

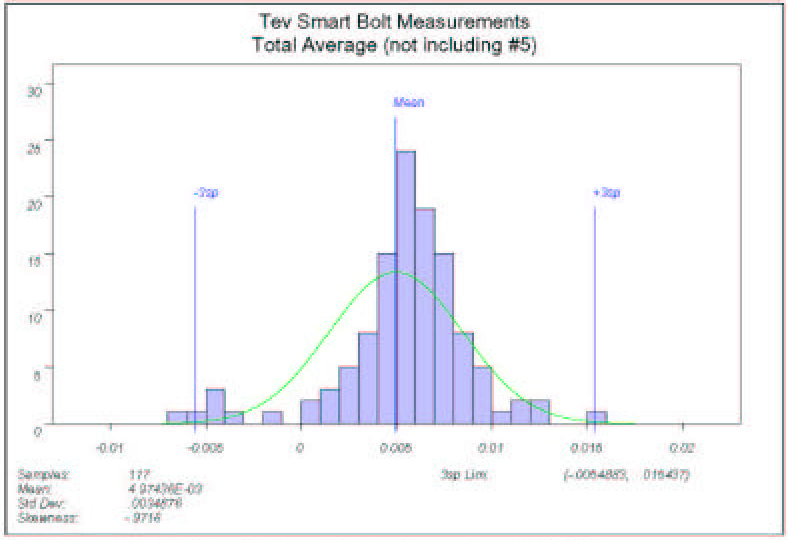
Creep in G11 suspensions;

Cold lift difference 1980s and last January shutdown:

More by Dave Harding!





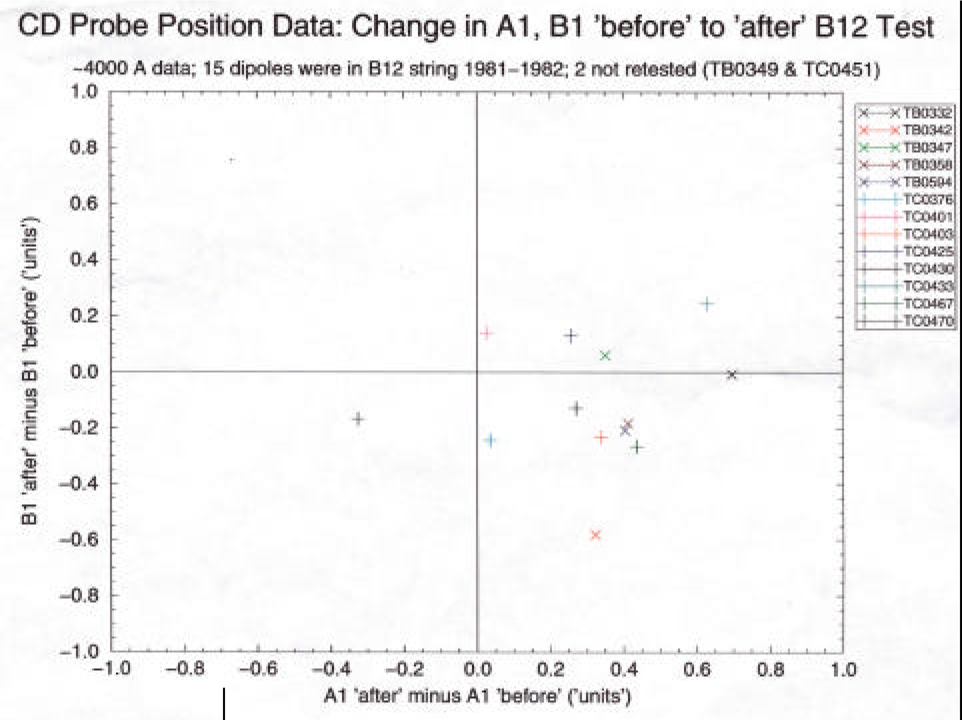


http://tdserver1.fnal.gov/users/me/blowers/projects/tevatron/smart_bolt3.pdf
03-Jun-2003

TM-1182
1630.000
March 1983

MAGNETIC FIELD PROPERTIES OF FERMILAB ENERGY SAVER DIPOLES

R. Hanft, B. C. Brown, W. E. Cooper, D. A. Gross†, L. Michelotti, E. E. Schmidt, F. Turkot
Fermi National Accelerator Laboratory*
P. O. Box 500
Batavia, Illinois 60510



center-line of the yoke by adjusting the thickness of the shim packs on the preload screw ends. The iron yoke contributes about 18% of the total dipole field within the magnet bore. When the collared coil is off center with respect to the yoke, the iron can also modify the field harmonics. However since the iron is far away relative to 1 inch, it is only the quadrupole coefficients a_1 and b_1 that can be materially affected

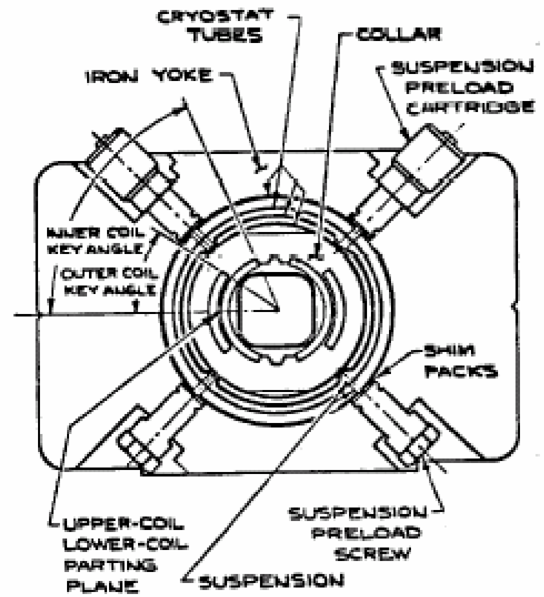


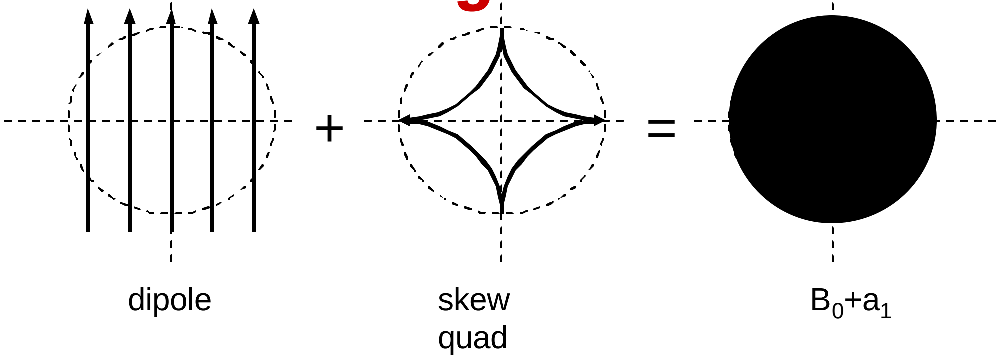
Fig. 1. Schematic cross section of dipole

in the region of interest for circulating beam. Moving the coil 0.0037 inches in the + x direction increases b_1 by 1 unit, while moving it 0.0037 inches in the + y direction decreases a_1 by 1 unit.

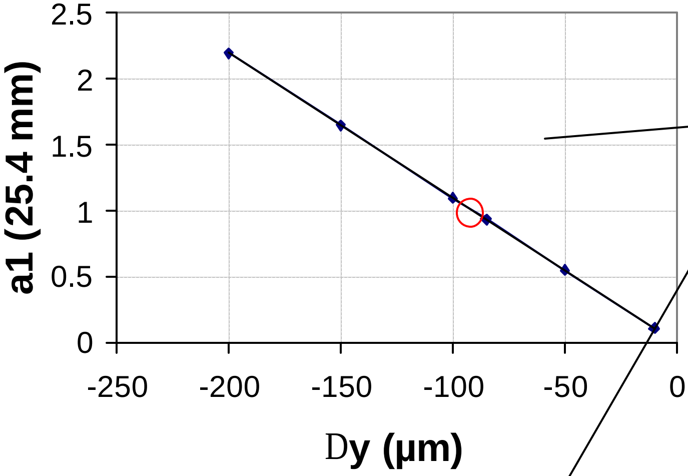
B12 test: early evidence of a1 problem

"It's all said… "

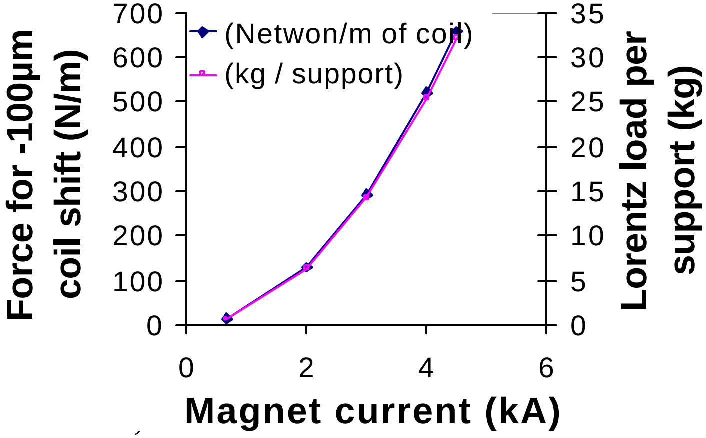
Effect of coil – yoke shift on geometric a1:



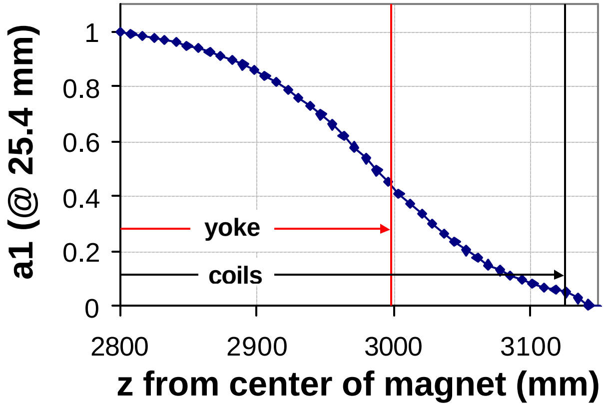
Up-down asymmetry in iron contribution to field "gives" a1:

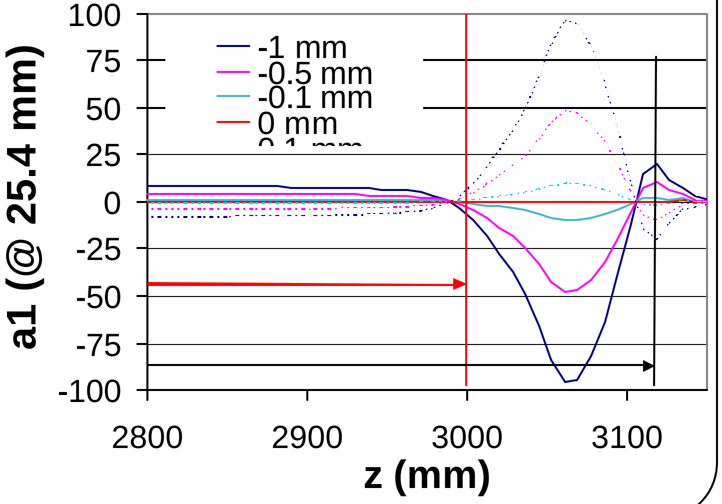


Body effects



End effects

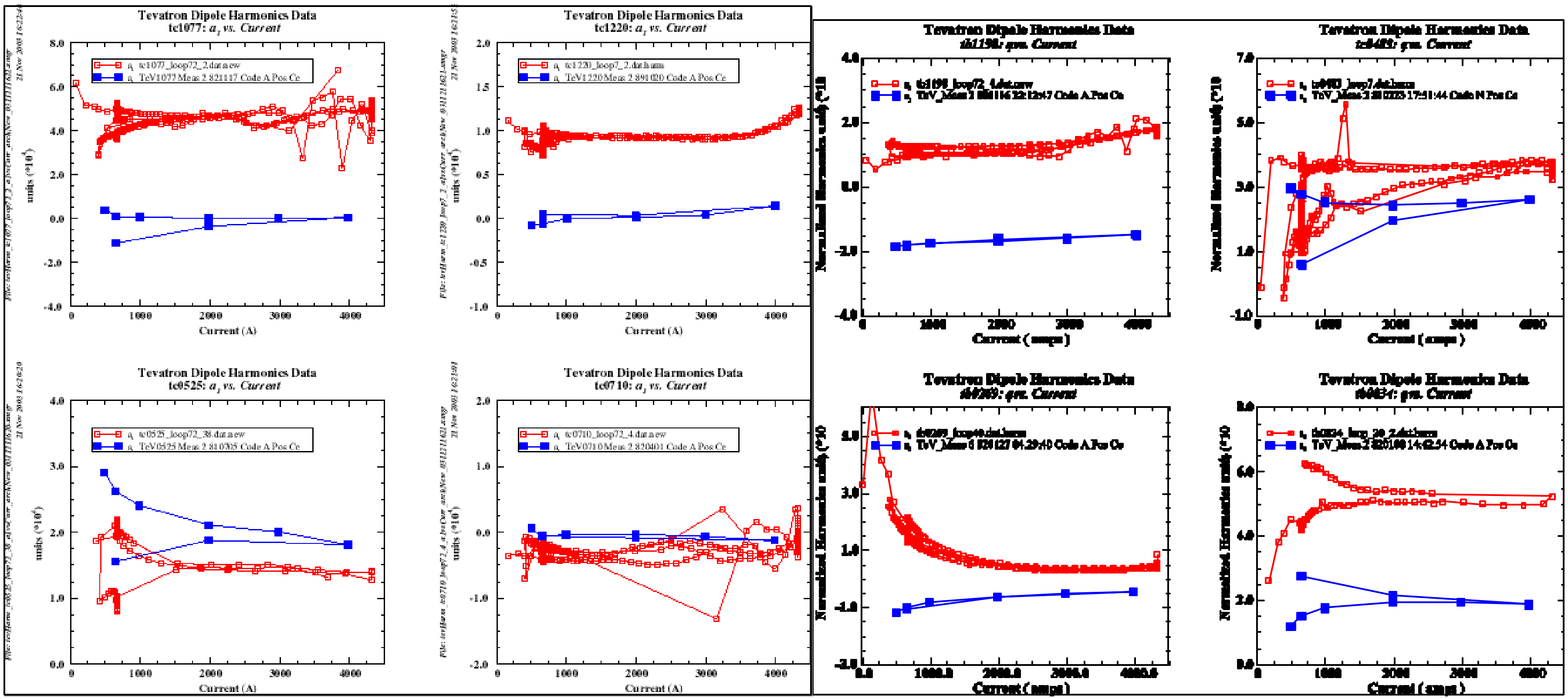




ı II C

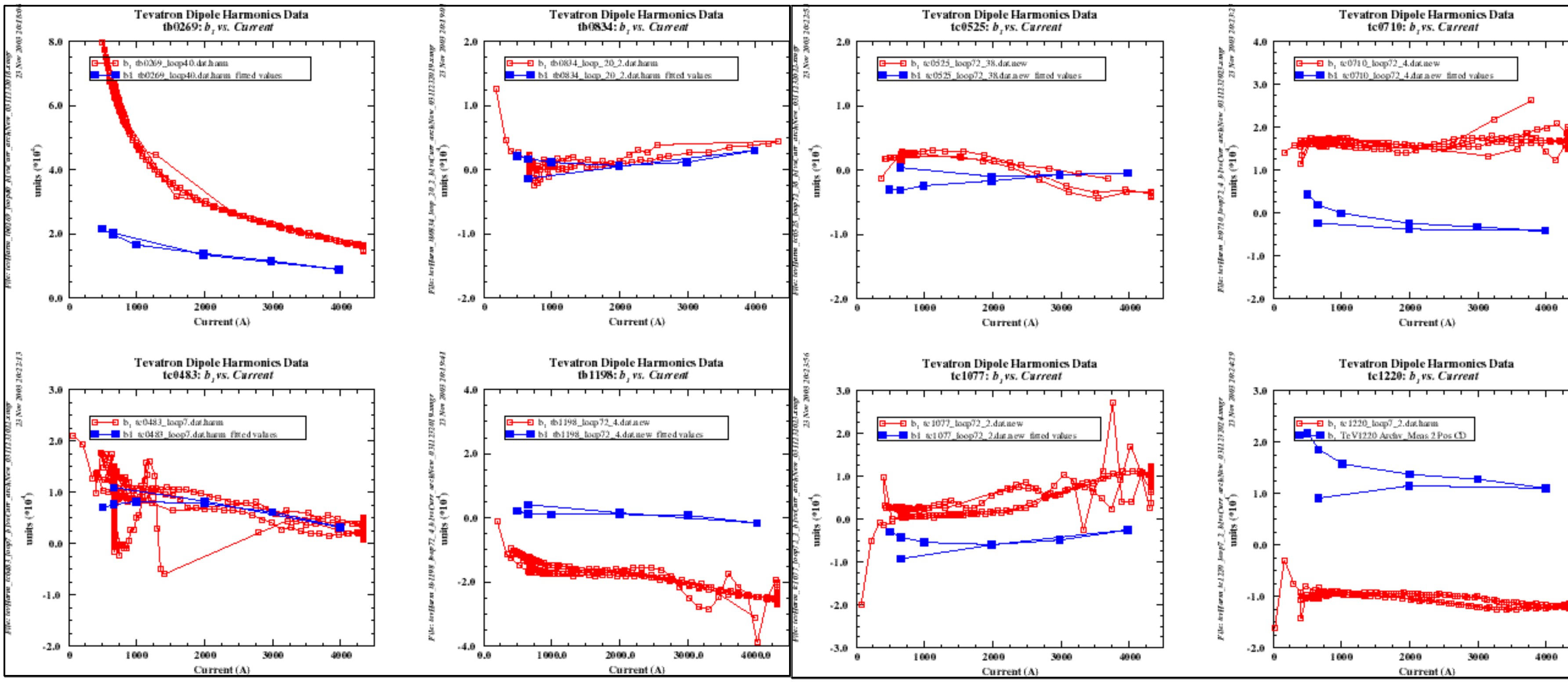
a1 magnetic measurement comparison then & now in 269, 1220, 834, 483, 525, 710, 1198, 1077

	269	1220	834	483	525	710	1198	1077	Mean diff / s
1980	-0.5	0.1	1.8	2.6	1.8	-0.1	-1.5	0.0	1.7
02/03	0.4	1.1	5.0	3.8	1.4	-0.3	1.7	4.9	1.9



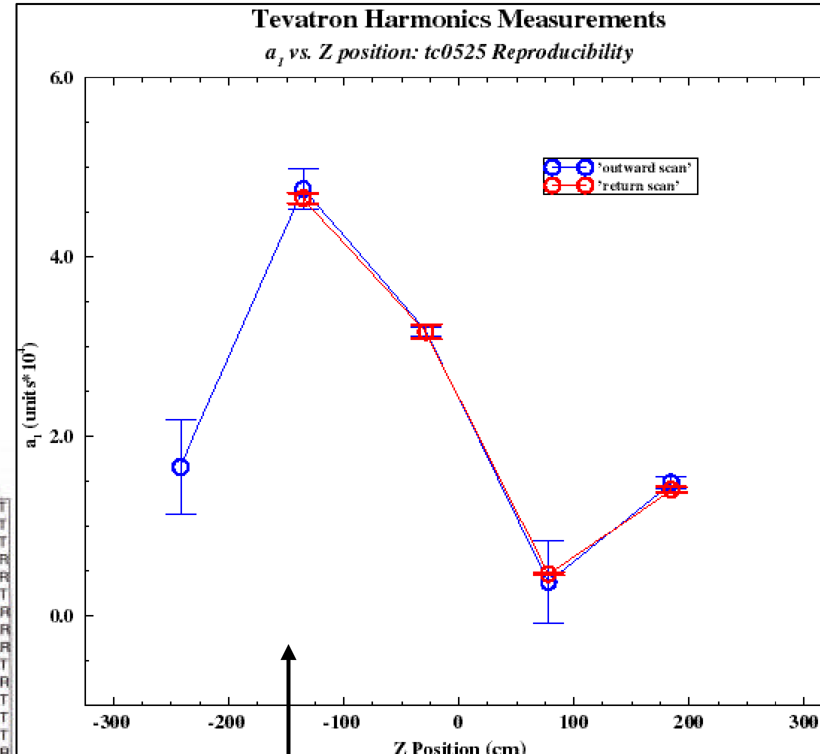
b1 magnetic measurement comparison then & now in 269, 1220, 834, 483, 525, 710, 1198, 1077

	269	1220	834	483	525	710	1198	1077	Mean diff / s
1980	1.0	1.8	0.6	-0.2	-0.4	0.5	0.3	0.3	-0.3
02/03	1.7	-1.1	0.4	0.4	-0.3	1.7	-2.5	1.1	1.6

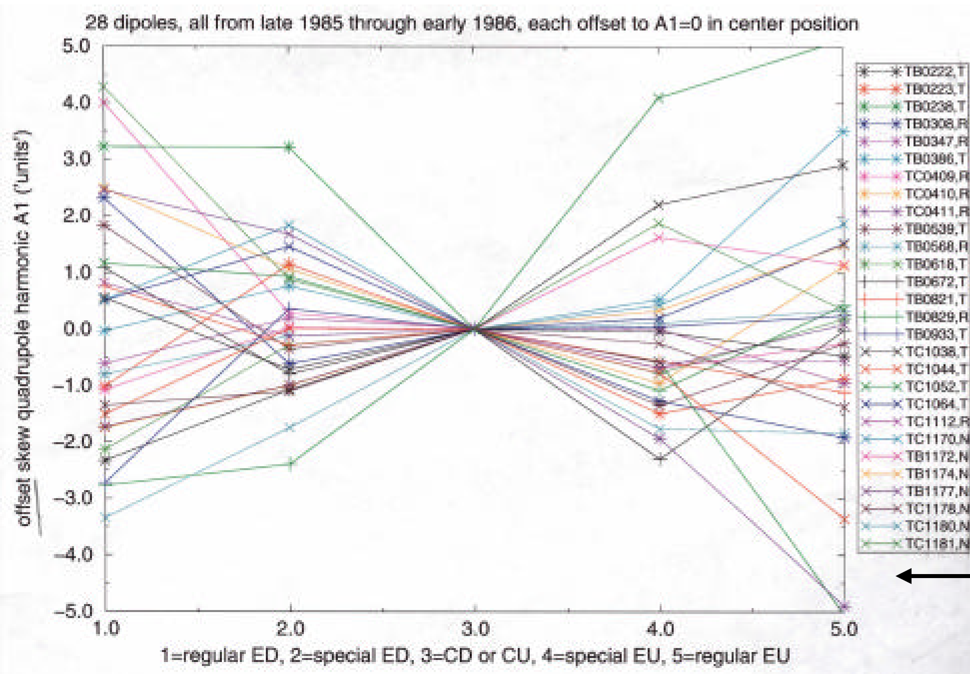


Issue: a1 variations along magnets

Length variations of a1 have to be taken into account when comparing a1 measurements taken in different magnet positions!

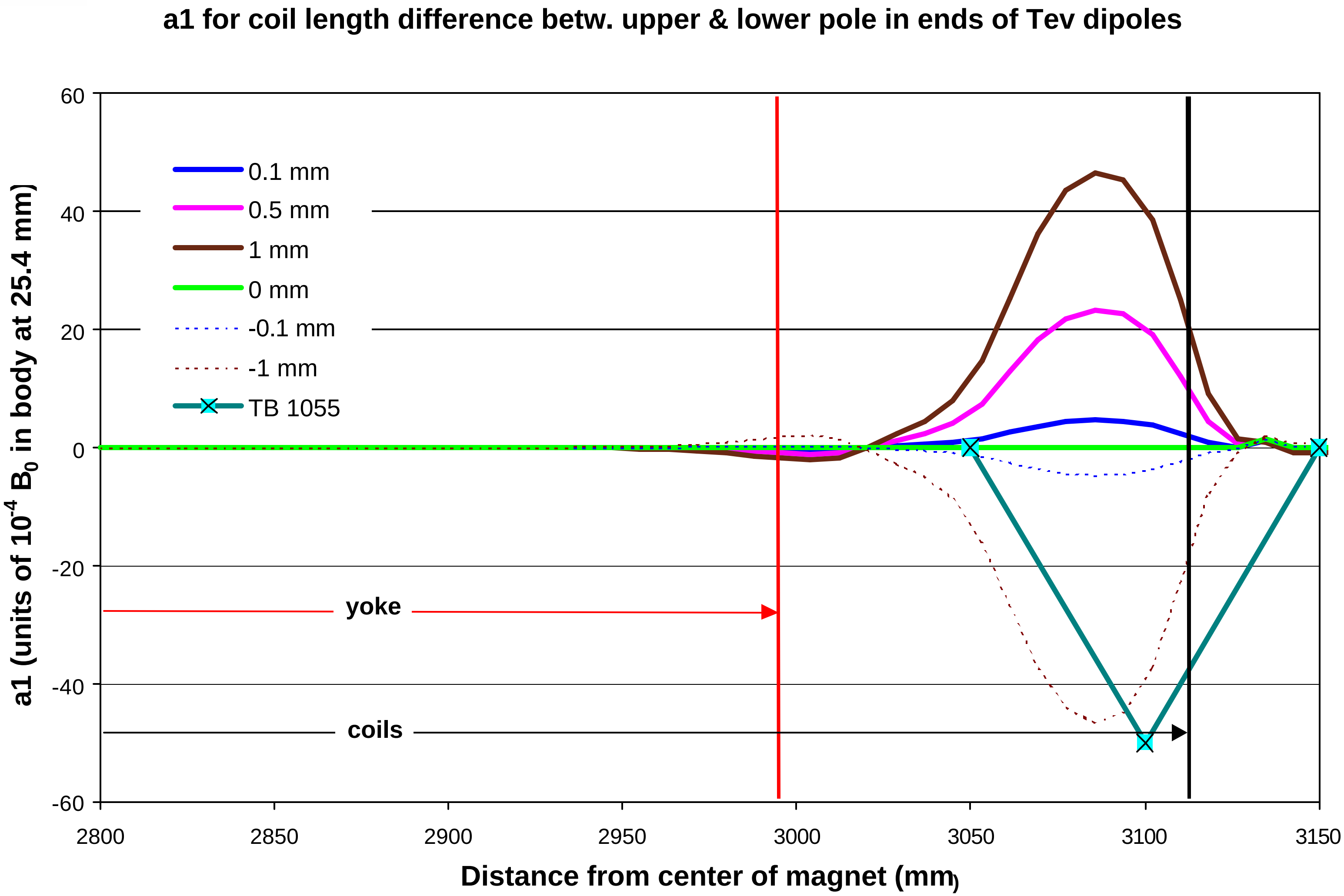


Length variation in TB0525



"Special probe position" measurements in 28 Tev dipoles in 1985/86;

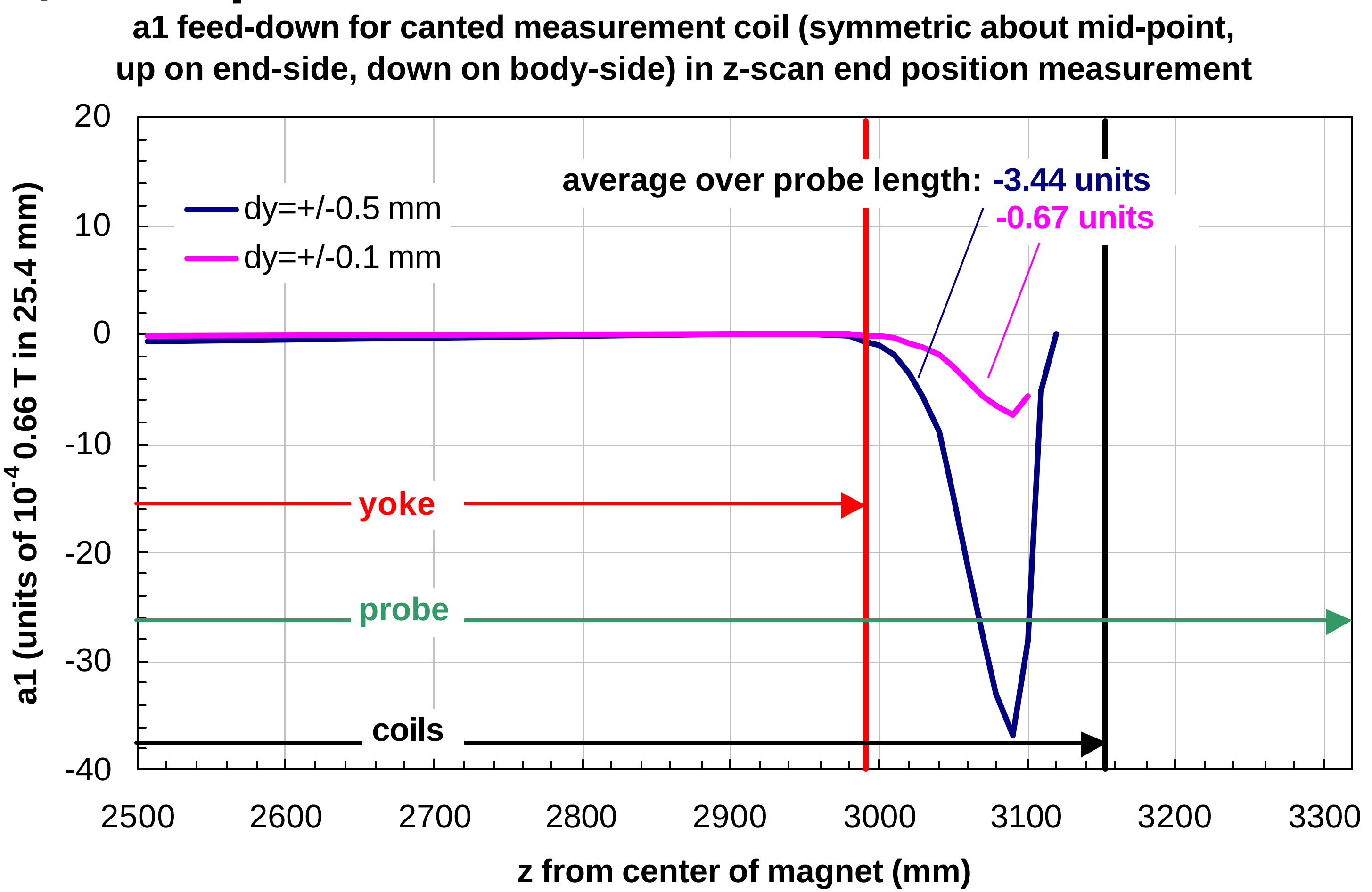
a1 in ends due to difference in coil length



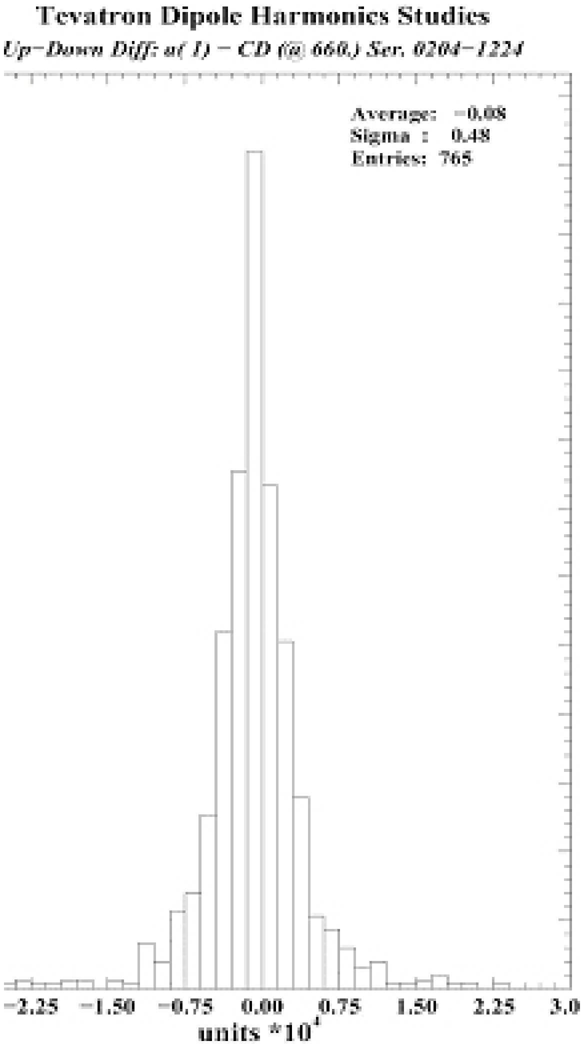
TB1055

Issue: feed-down effect in ends

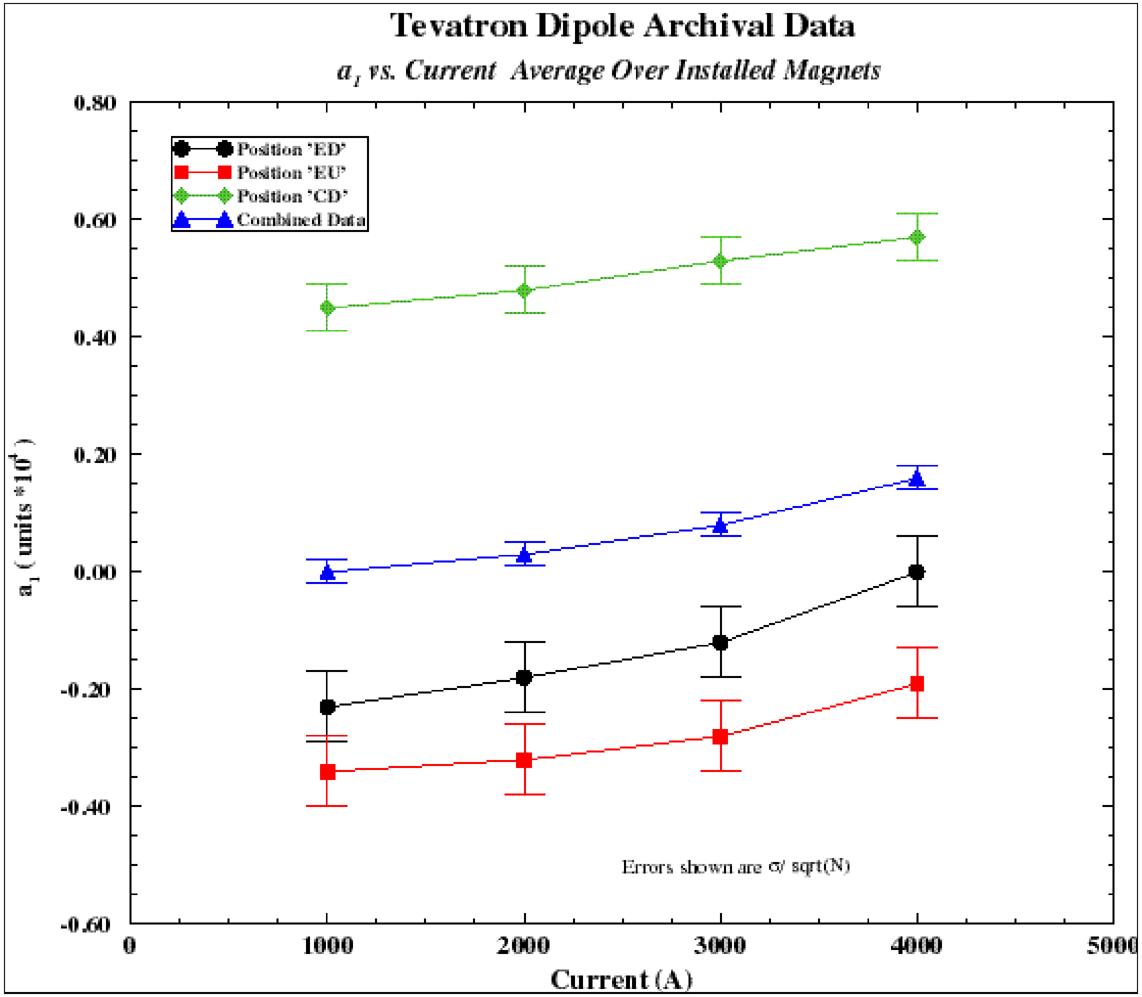
Large b2 spike in ends can easily lead to a1 due to feed-down; Example: canted measurement coil



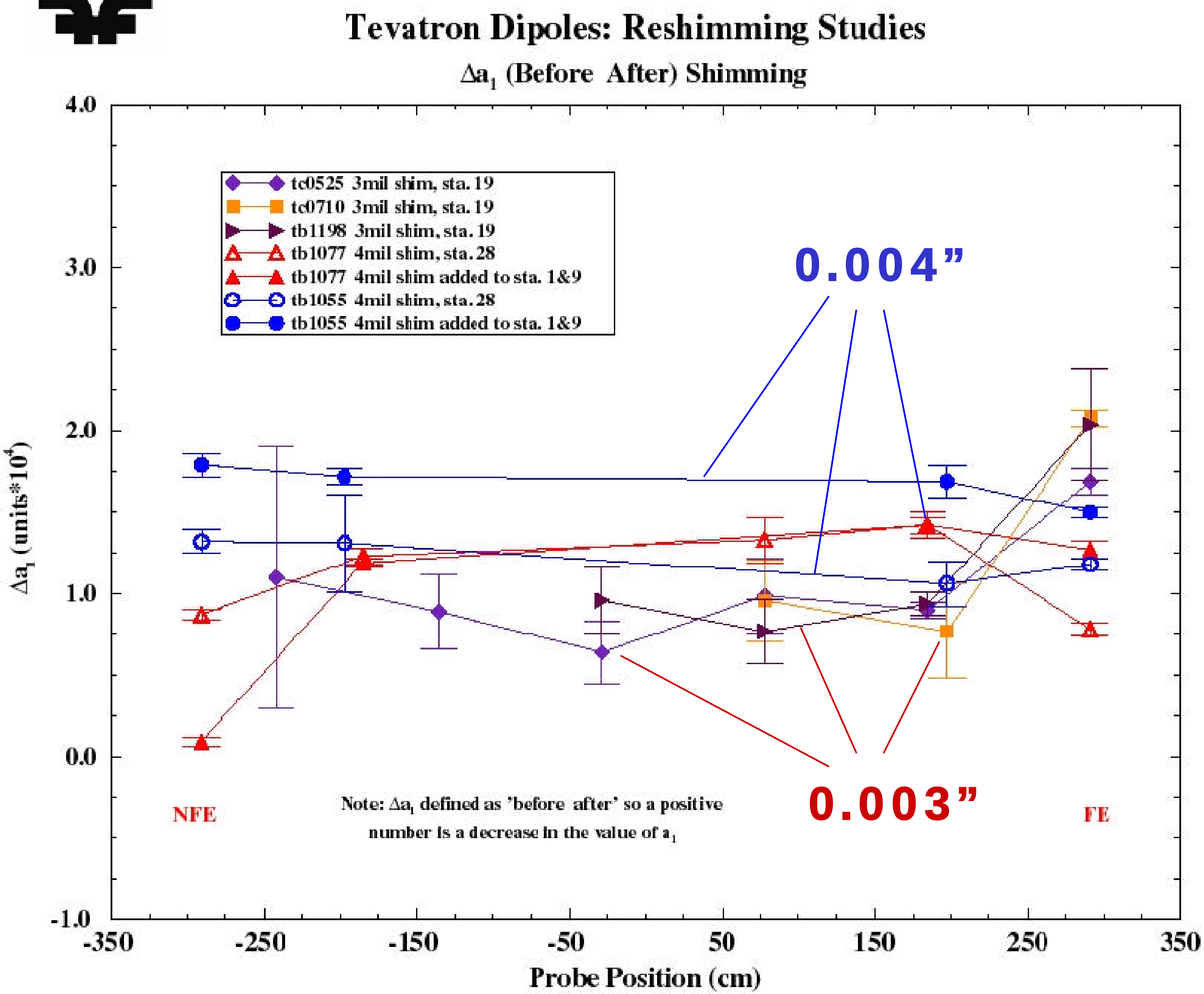
Archive a1 data



I dependence of archive a1 – hyst?, decentering-forces?



Reshimming demonstration experiment:



5 magnets re-shimmed at MTF with 3 or 4 mils;

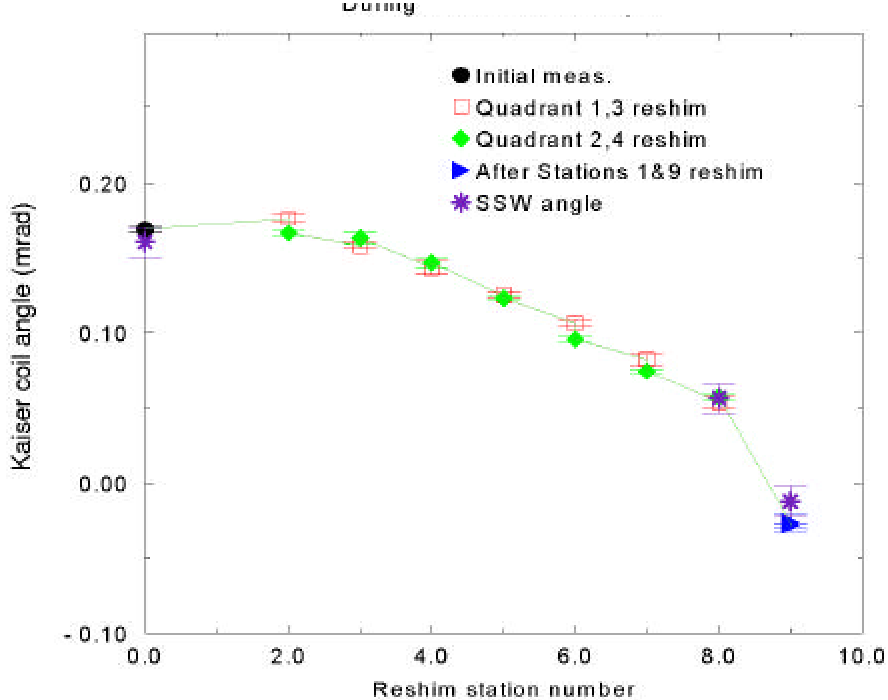
Plot shows difference old-new a1;

In some cases stations 2-8 were shimmed first and 1,9 later;

Reshimming demo - roll:

Magnet	D Field Angle	Roll Change	Coil Angle Change (Kaiser coil)	Coil Angle Change D(Field Angle - Mech. Roll)
TC0525	-0.29	NA	NA	NA
TC0710	0.06	0.00	NA	0.06
TB1198	0.25	+0.09*	NA	0.16
TC1077(st. 2-8)	0.18	+0.05*	0.11	0.13
TC1077(+st. 1,9)	0.18	0.05	0.12	0.13
1055(st. 2-8)	-0.10	0.00	-0.11	-0.10
1055(+st. 1,9)	-0.17	0.00	-0.20	-0.17

Example TB1055



Roll measured with Kaiser coil, level-probe and stretched wire:

very small overall roll change; roll appears to occur almost entirely between coil and yoke (Kaiser coil and stretched wire measurements agree)

Reshimming demonstration – extreme:

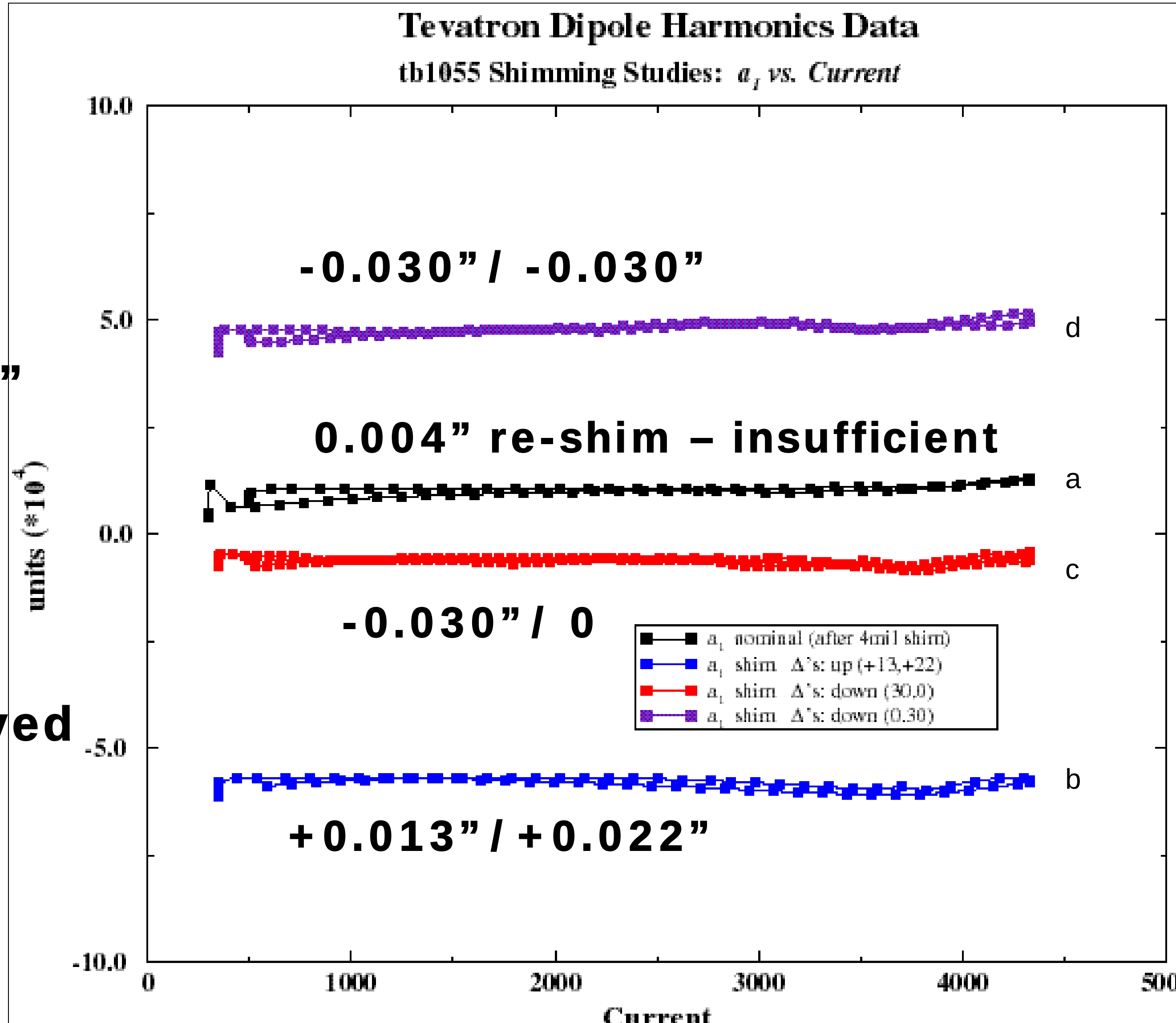
Extreme shimming in TB1055 (0.015"), measurement coil "between" stations,

Breakage expected at ~0.030";

TB1055 behaved as expected:

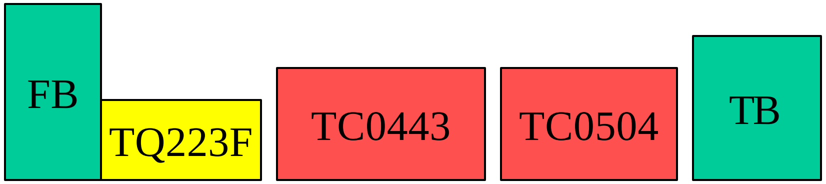
~6 units for 0.015";

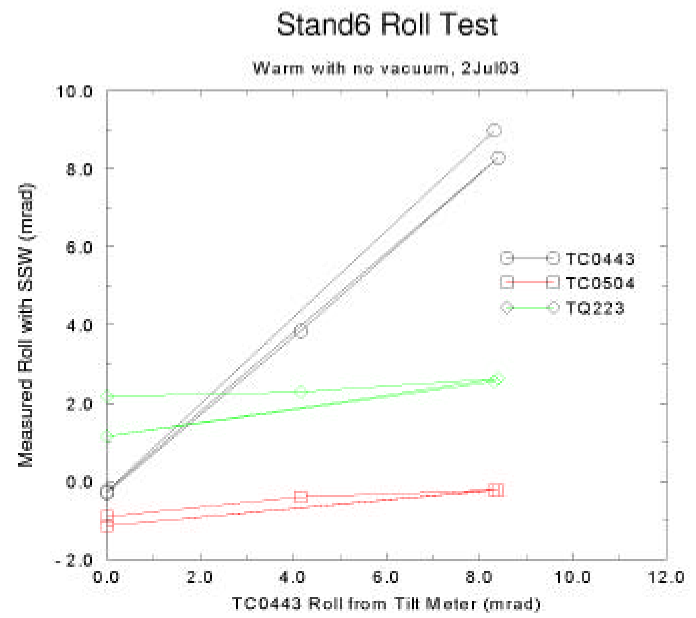
No LF effect?

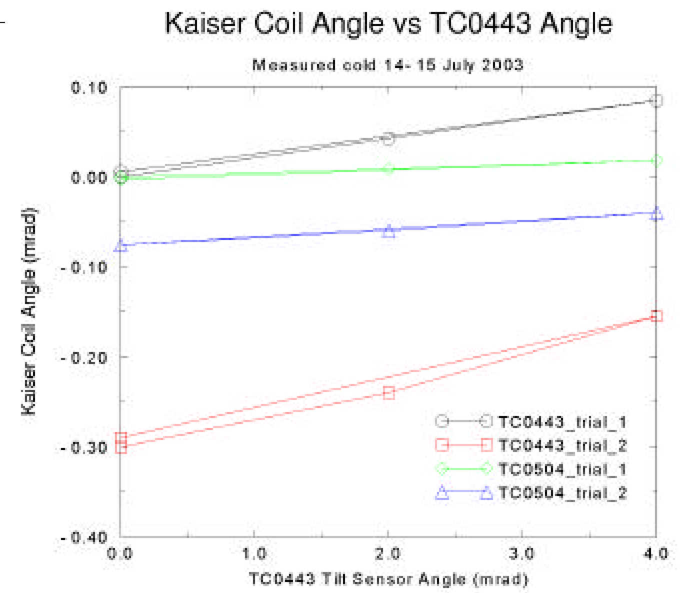


Re-rolling experiments

Rolling of dipole in string to verify if roll correction can be performed in tunnel without damaging the magnet vacuum. Dipole TC0443 was rolled both warm (up to 8 mr) and then cold (up to 4 mr) while completely connected to the adjacent quad and dipole.







Status of other issues:

1) **Tune drift during injection**

feed-down from b2 drift due to differential horizontal beam orbit between dipoles and b2 correctors

difference in drift amplitude in main dipoles and quads

main field decay in low beta quads

2) **Coupling drift**

feed-down from b2 drift due to differential vertical beam orbit between dipoles and b2 correctors (e.g. as a result of scallops due to dipole rolls or as a result of “dipole-sag”)

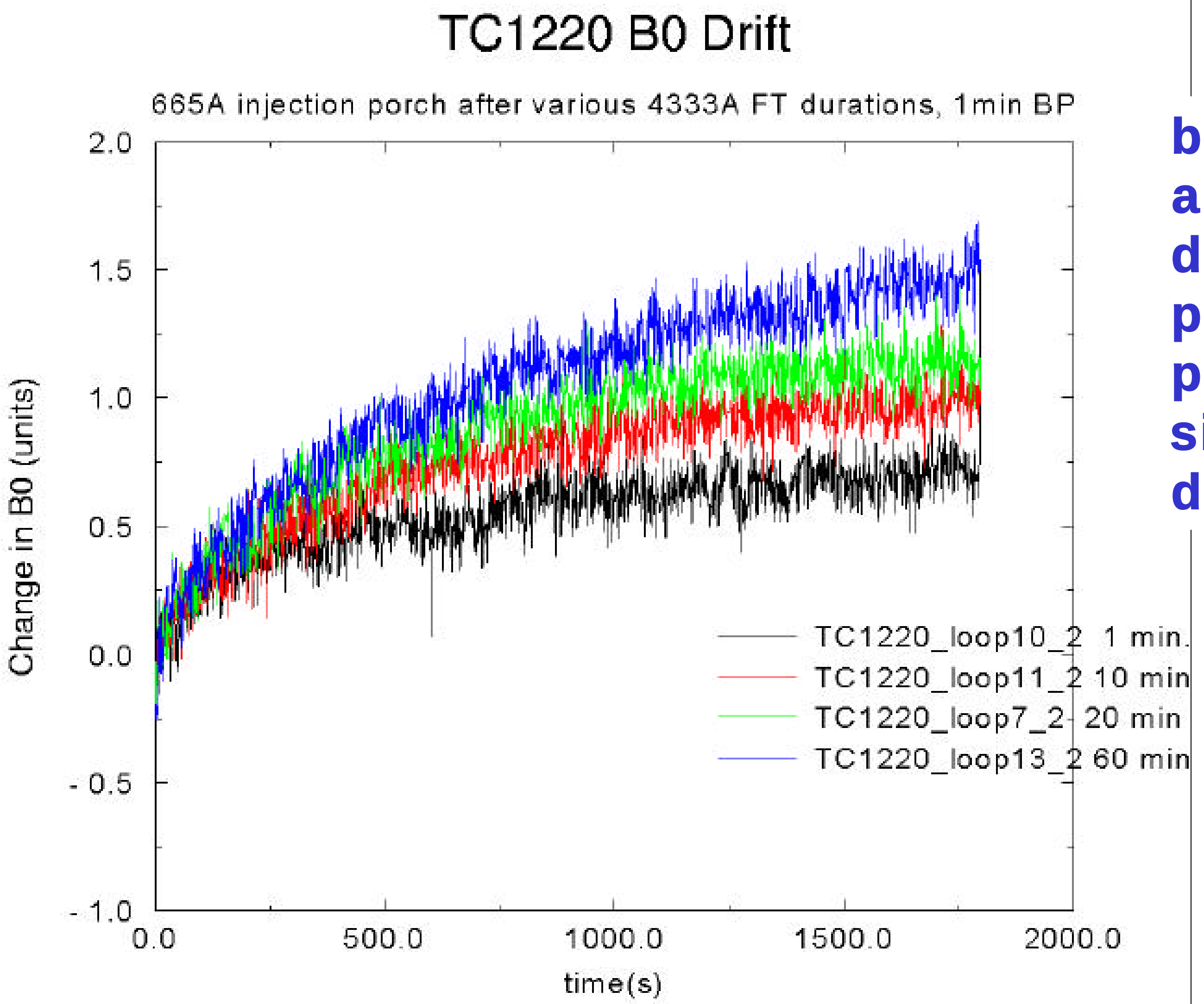
a1 drift in dipoles

3) **Change of coupling during ramp**

hysteresis in a1?, Decentering-forces?

Main field drift

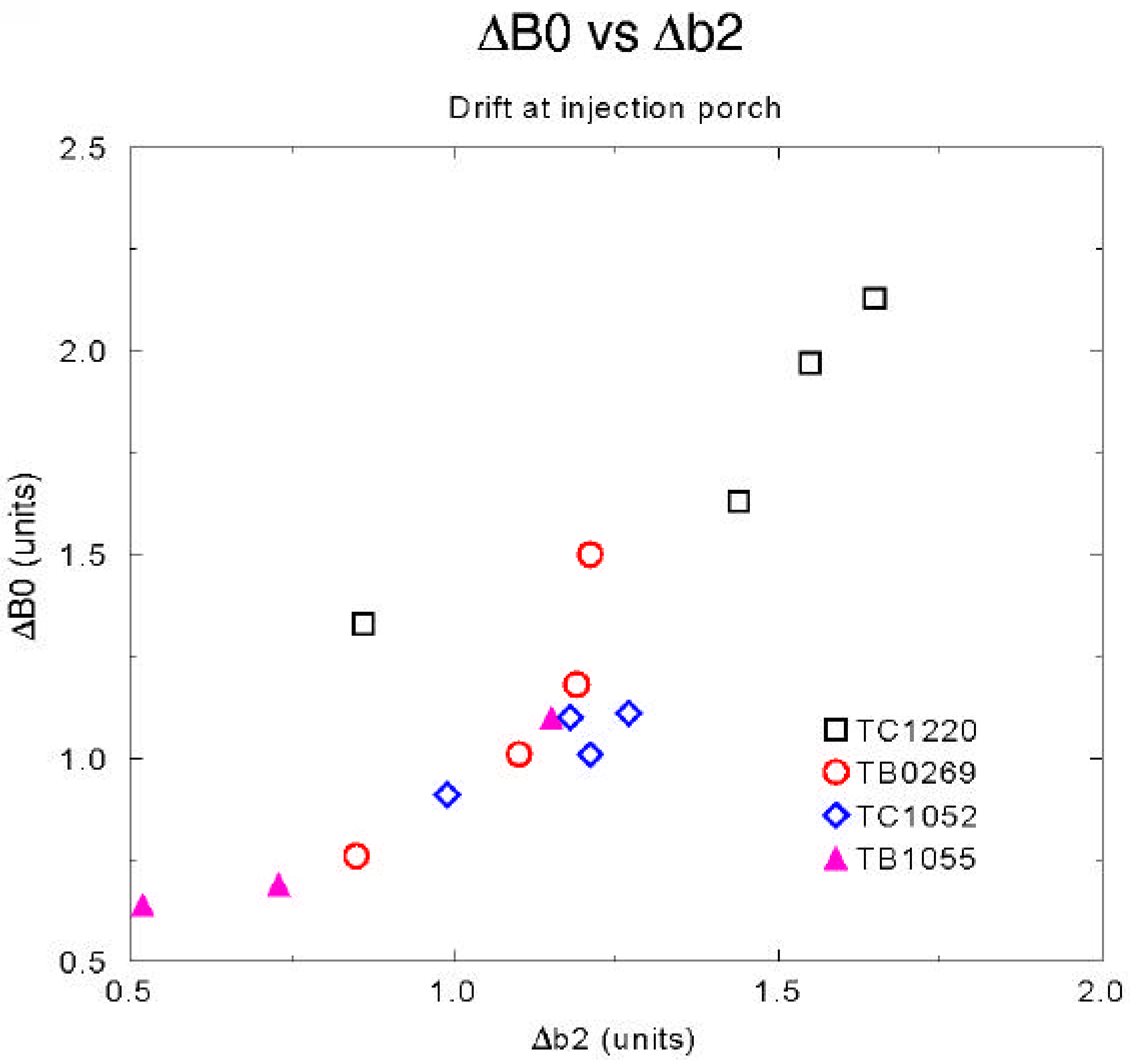
First evidence of main field drift in Tev dipoles:



b0 drift amplitude dependence on pre-cycle parameters similar to b2 drift

B0 drift at injection in TC 1220 after pre-cycle with 4 different FT durations.

Main field drift

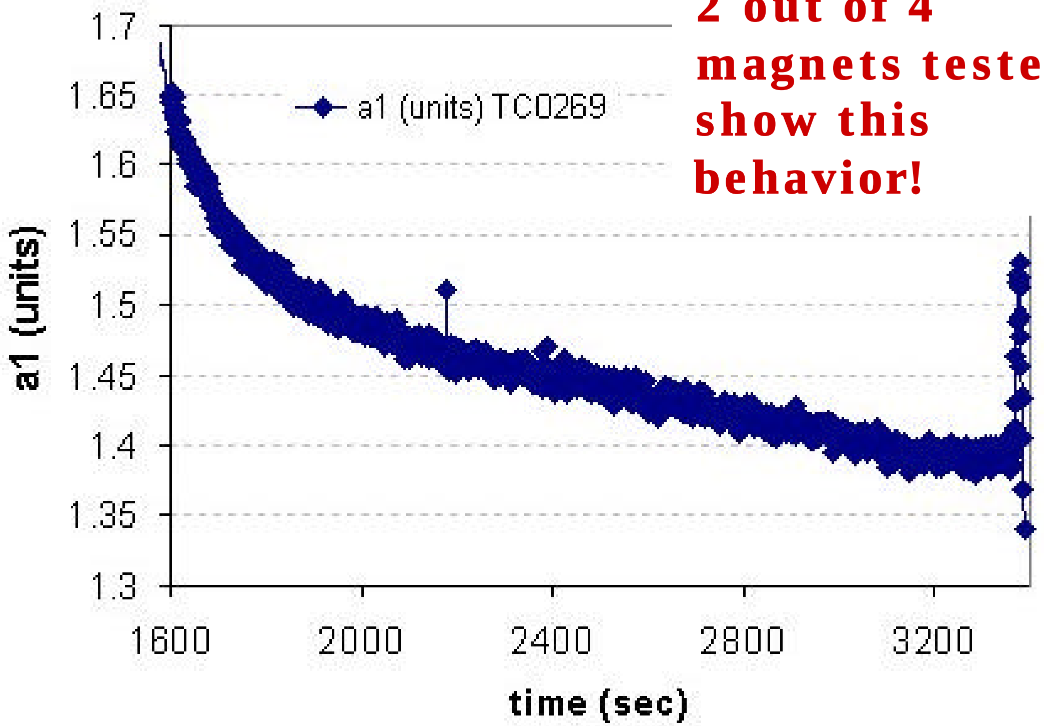


b0 drift amplitude correlated with b2 drift amplitude (as expected)

B0 drift at injection in 4 dipoles after pre-cycle with diff. pre-cycle parameters.

Dynamic a1/b1

Possible magnet borne causes of tune/coupling drift: 0.1 units of a1, b1 drift in all dipoles would explain 100% of tune/coupling drift;



2 out of 4 magnets tested show this behavior!

® **Progress on characterization of a1 drift...**

a1 drift in Tevatron dipole 269 during the injection porch following a standard pre-cycle

Summary

- Lots of new b2 data (geometric, hysteretic, dynamic) giving us confidence in our ability to understand b2 issues – still outstanding: pattern measurement
- On the basis of detailed dynamic b2 measurements on 5 spare dipoles we can now propose 5 improvements to the b2 correction in the Tevatron
- Re-shimming demonstration experiments were conducted in support of the ongoing re-shimming operation in the tunnel; Expected behavior was found, rolls during re-shimming are minimal (and with random sign), Re-rolling of magnets was tested on the bench;
- Some progress also in other multipoles: main field drift found in all magnets tested; a1 drift found in some;

Outlook

- More magnetic measurements

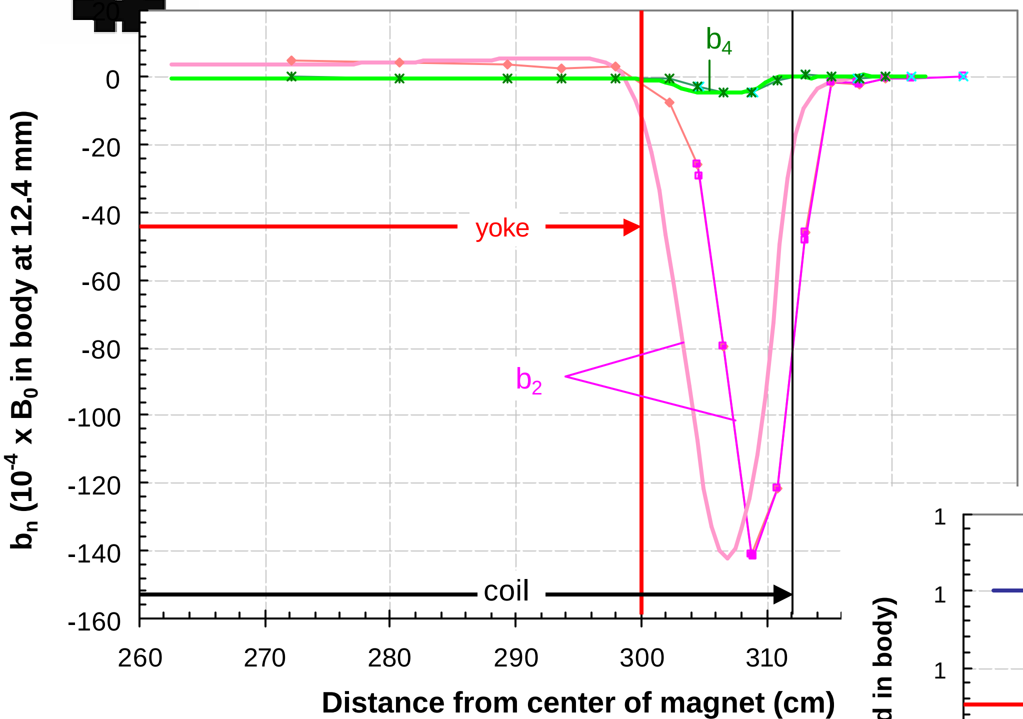
(Broken anchor study, b2 pattern,..., dynamic b2 fit parameter space, a1 drift, quadrupole, ...)

- Participation and support of beam studies and implementation of b2 improvements

(Cern proposal of new b2 SB)

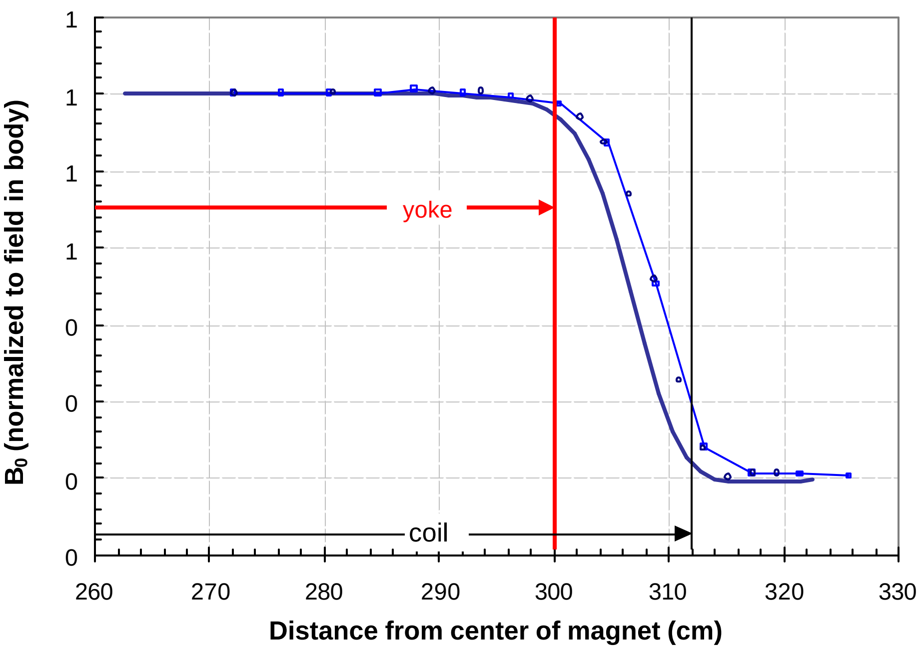
- reference magnet system

New z-scan measurements in 1055



Opportunity to refine end-model to get agreement with TB1055 data; Quantitative agreement is OK;

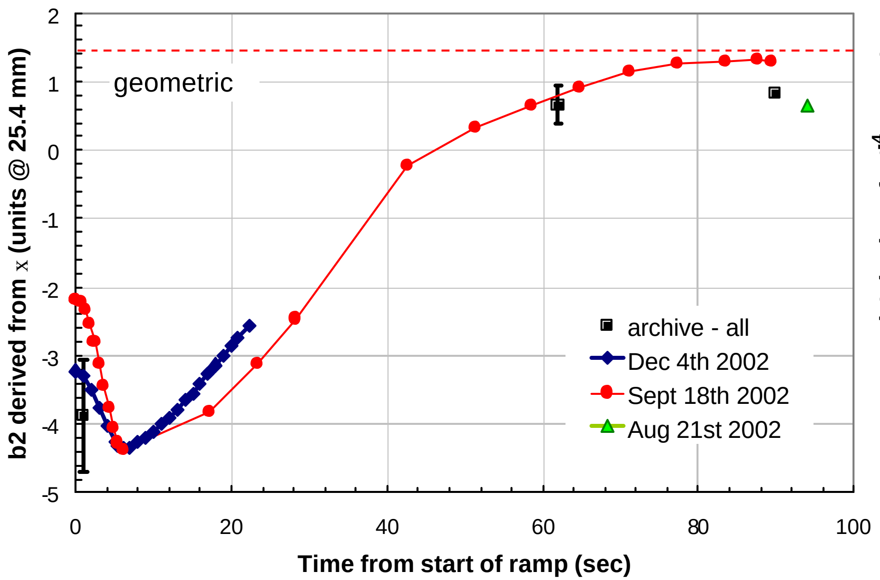
Slight disagreement in magnetic length; Published Tevatron dipole magnetic length: 6.116 m !

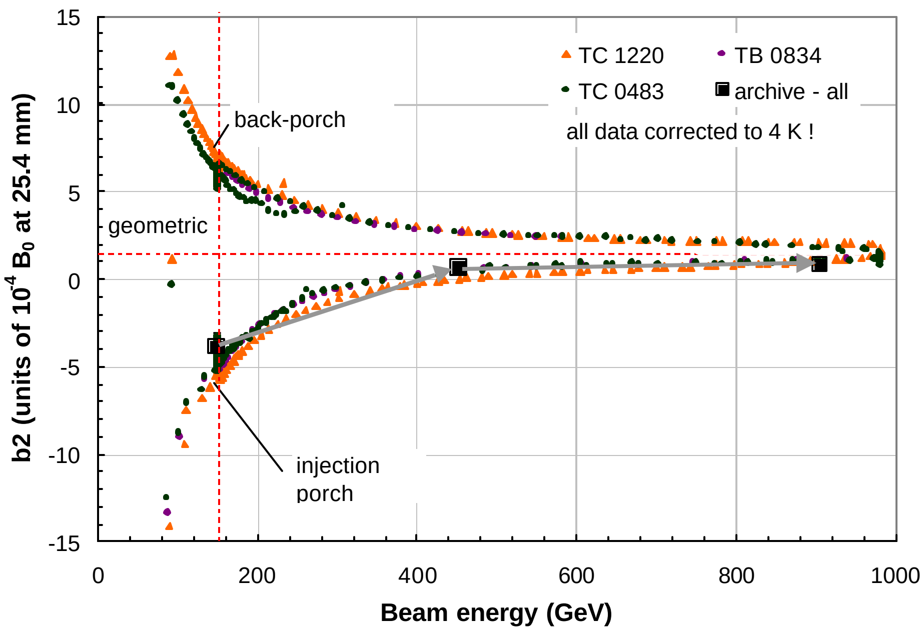


Reason for terminating store	**# of stores terminated**	**Store hours**
Intentional	285	5036.48
Controls	8	68.38
Correction Magnet Systems	3	7.21
Cryogenics	22	233.11
Experimental areas	3	65.76
Glitches/Lightning	17	187.98
Human Error	3	57.78
Kickers	8	64.41
Low Beta Quadrupoles	6	42.27
Magnet Failure	2	26.55
Miscellaneous	4	25.99
Quench	11	104.36
Quench Protection System	22	175.24
Separators	3	8.31
Tevatron Power Supplies	7	41.99
Tevatron RF	6	39.80
Vacuum	1	7.58
Sum	**411**	**6193.4**

Measurement of the hysteretic b2:

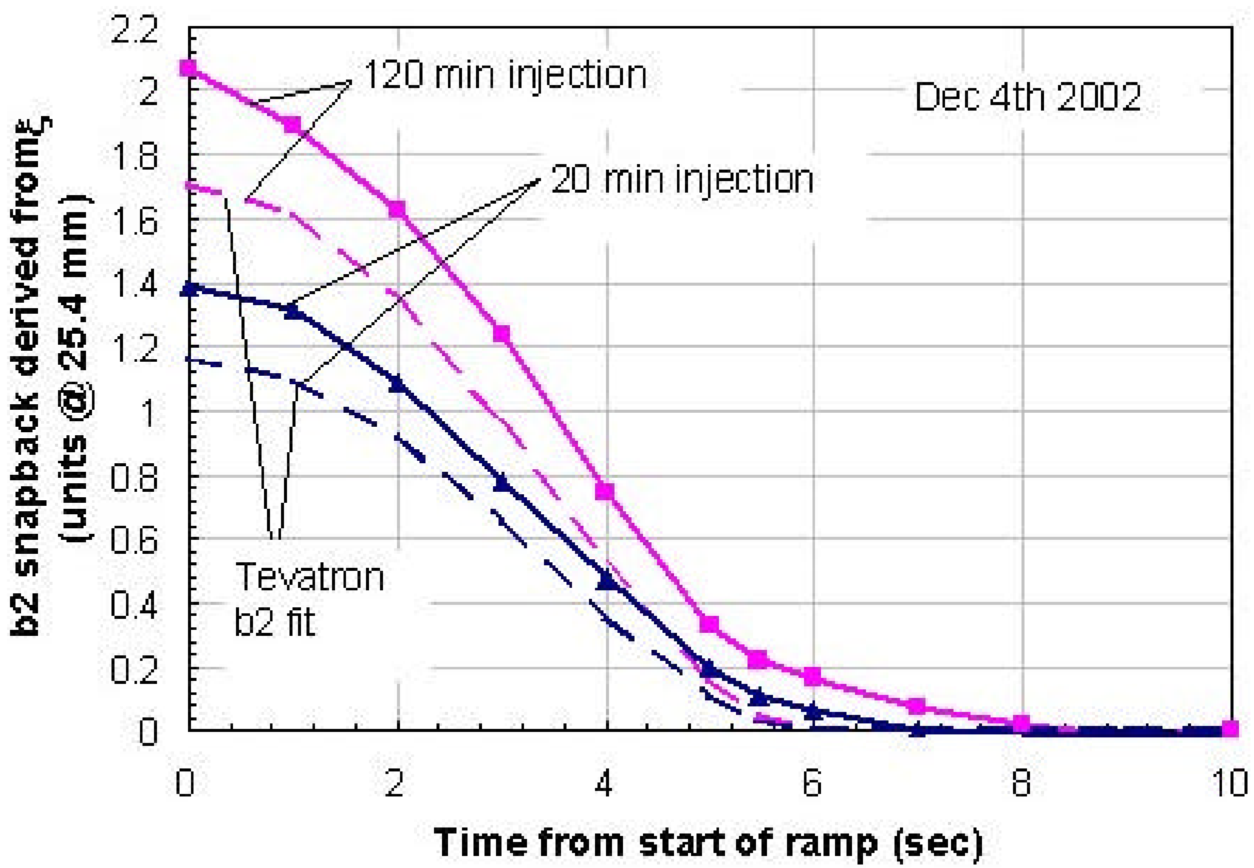
Beam based and magnetic measurement based data indicate that hysteretic and geometric b2 are as expected





Derivation of average magnet b2 up the ramp from beam chromaticity measurements and expected b2 derived from magn. measmnt archive.

Beam based measurements – dynamic b2



- **Measured SB longer than predicted by fit**
- **drift amplitude larger than predicted by fit**

Average Tevatron dipole b2 SB after 20 & 120 min injection porch, derived from measured beam chromaticity (dashed: b2 compensation)

Tev b2 drift and SB compensation

Currently used b2 drift&SB correction:

drift:

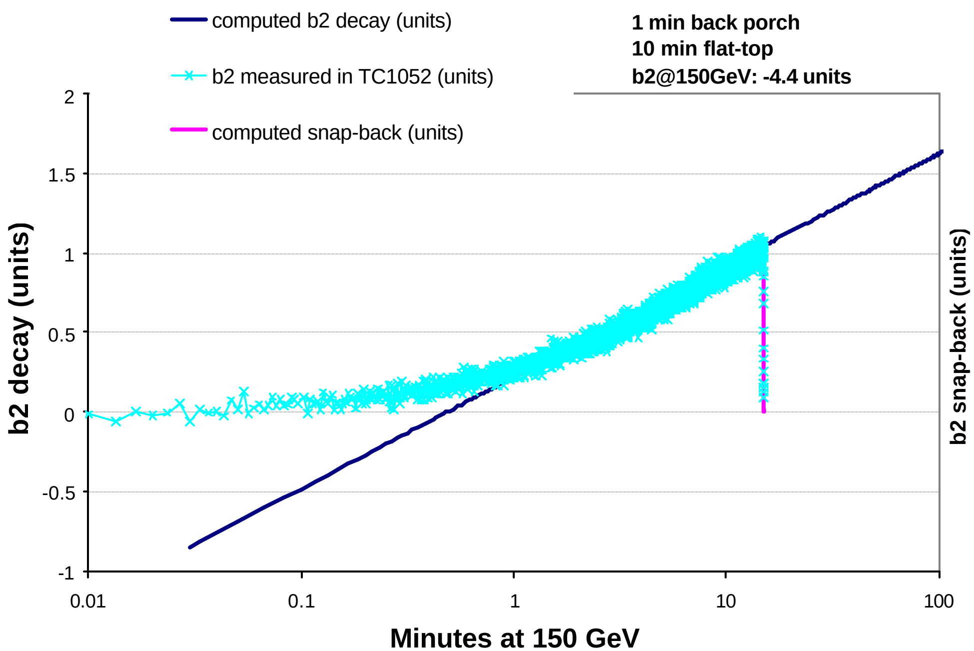
$$b_2^{drift}(t_{ext},t_{ft},t) = b_2^{ini}(t_{ext},t_{ft}) + \left(m(t_{ext},t_{ft})\ln(t)\right)$$

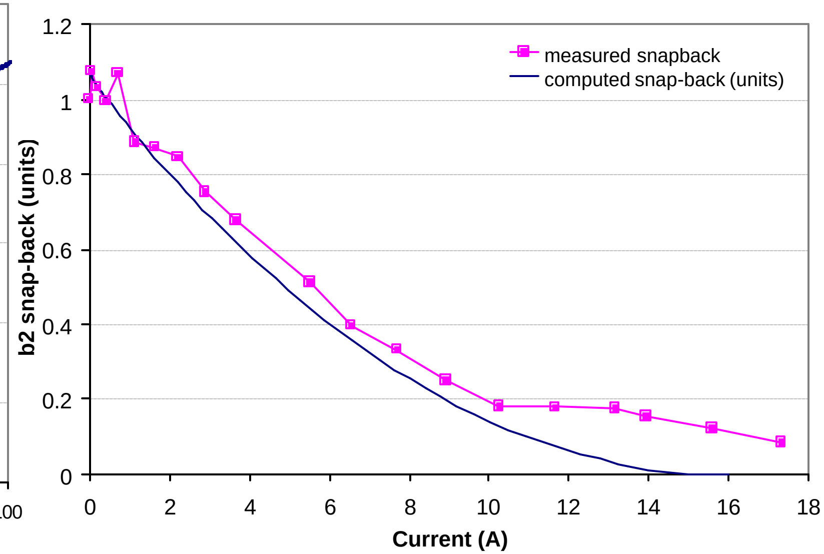
$$m(t_{ext},t_{ft}) = D - E\cdot\left[2\ln(t_{ext}) - \ln(t_{ft})\right]$$

$$b_2^{ini}(t_{ext},t_{ft}) = -A\ln\left(\frac{t_{ext}}{60}\right) - \left[B - C\ln\left(\frac{t_{ext}}{60}\right)\right]\ln(t_{ft})$$

snapback:

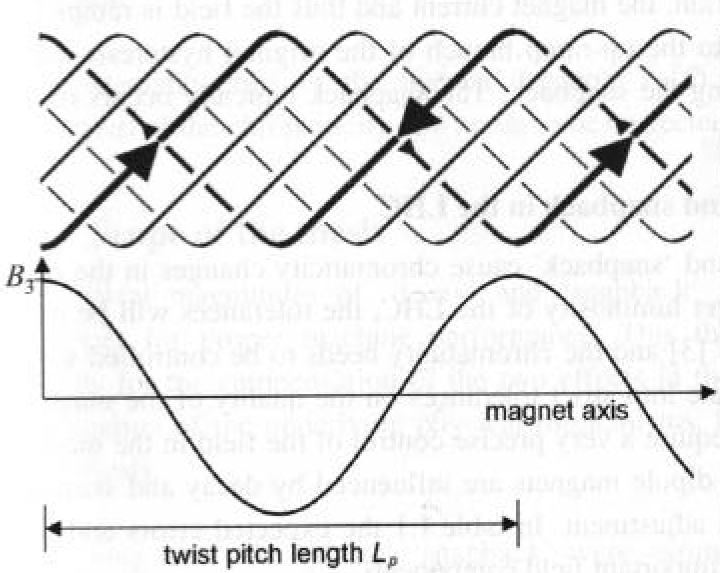
$$b_2^{snap}(t_{ext},t_{ft},t_{inj},t_{SB},t) = b_2^{drift}(t_{ext},t_{ft},t_{inj})\left[1-\left(\frac{t}{t_{SB}}\right)^2\right]$$

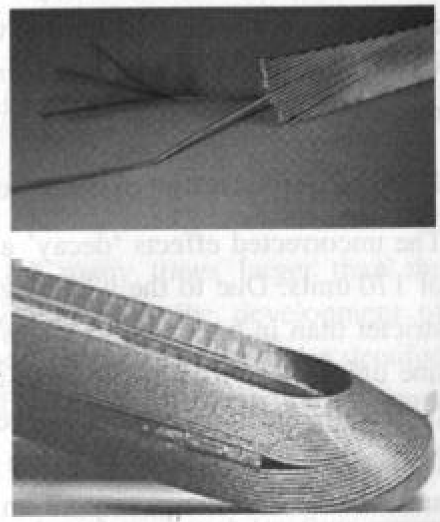




b2 drift and SB compensation as compared to dipole TC 1052.

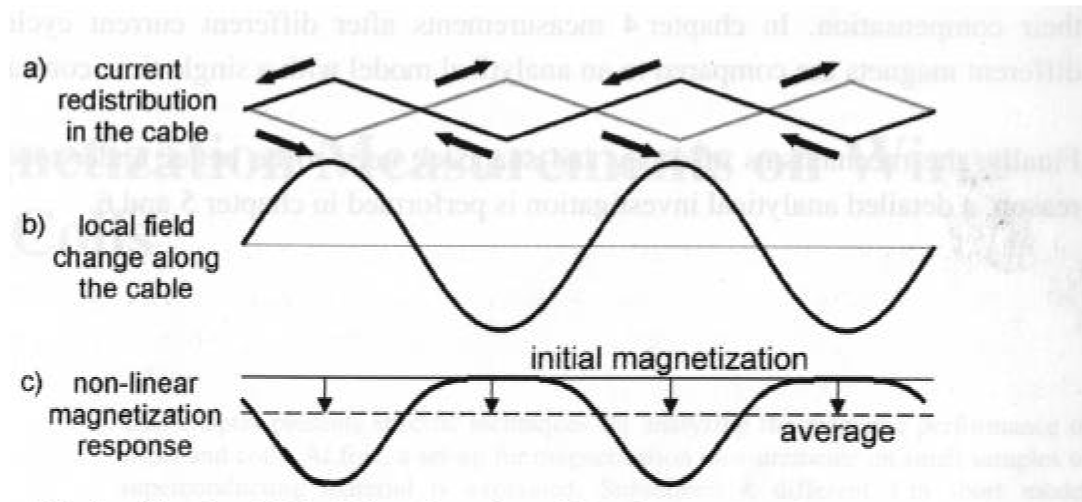
Causes of dynamic effects





Non-uniform current distribution in cable (flat braid) due to varying splice to strand resistances and spatial dB/dt variations in ends – current imbalances vary in time with t~1000 secs..

Produces time varying "pattern" – longitudinal variation of field (B0, b2,..) along magnet axis). At constant excitation in magnet it brings out non-linear magnetization effects.



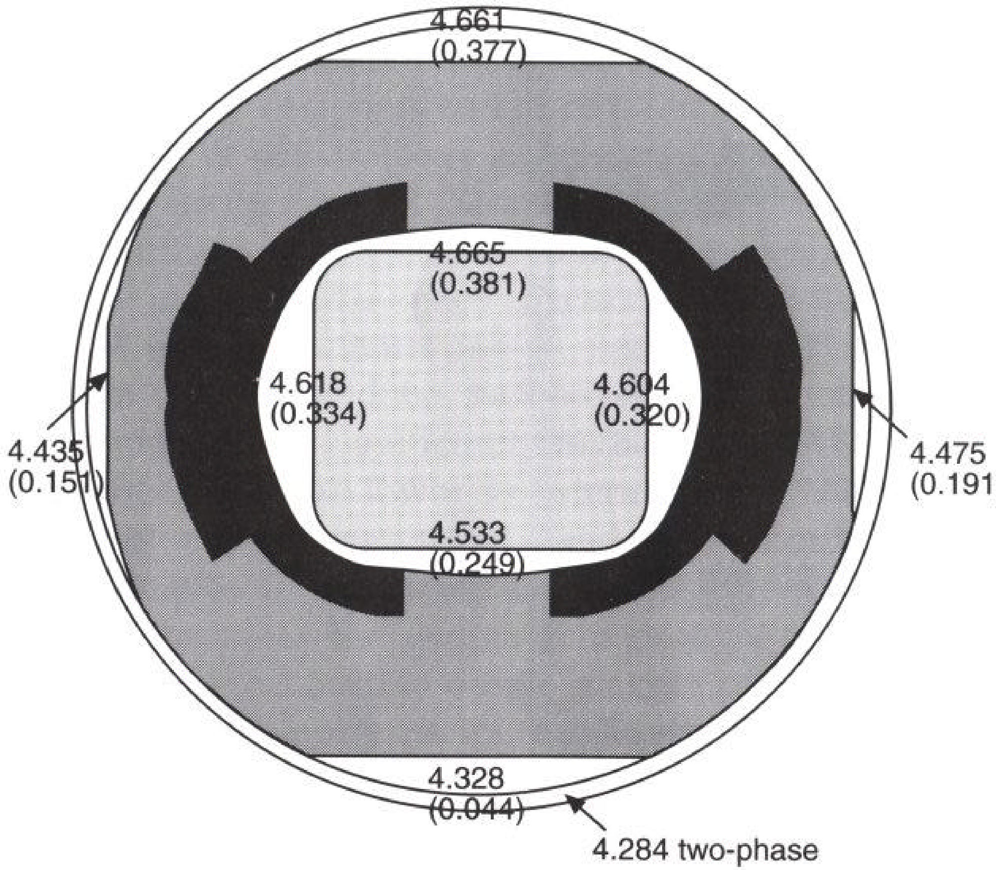
Temperature profile in Tev dipoles

Issues:

1) stratification of two-phase

2) poor heat exchange betw. in/out single-phase flow

® ~ 100 mK DT across coil bottom/top

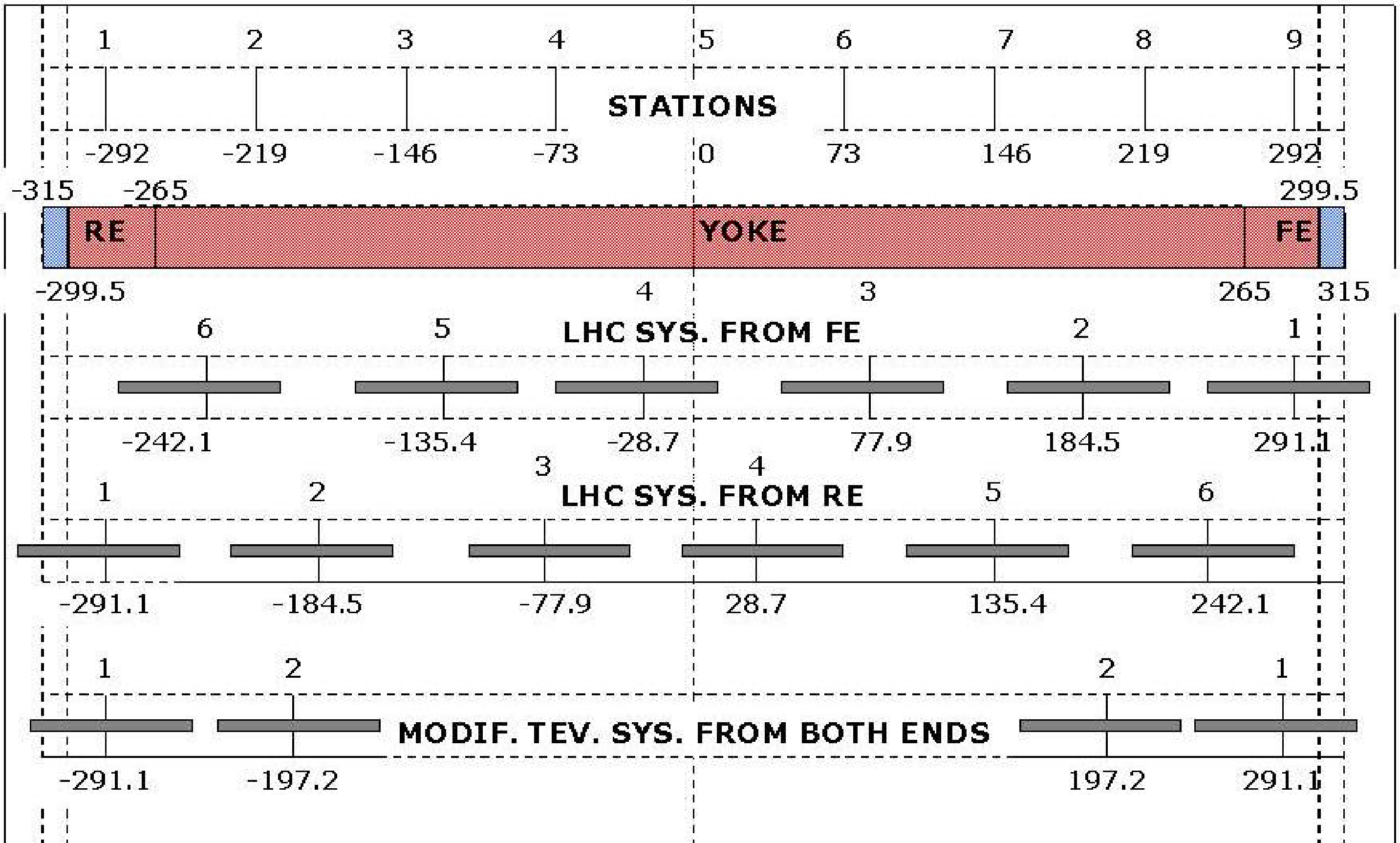


Linear heat load: ~10 W/dipole →
~**25 mK** / longitudinal magnet DT

T. Peterson et al. 1997

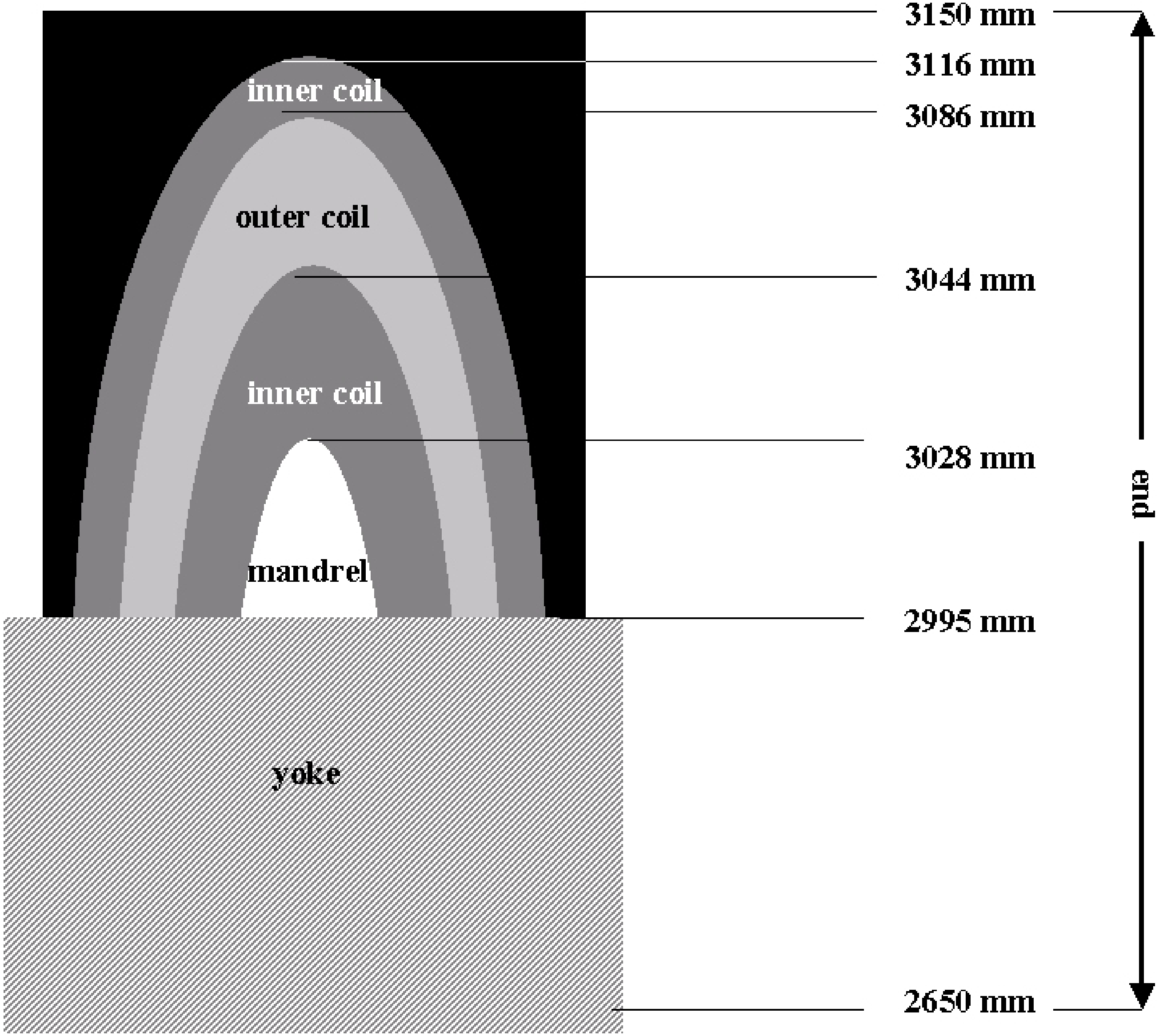
Total length of iron yoke: 599 cm
Total length of coils: 630 cm
Length of end (arbitrary): 50 cm

Length of rot. coil probe (active): 81.7 cm
Distance betw. coil support stations: 73 cm
All measures in cm!



Tevatron dipole mag measurements: z-scan probe positions

PB, 08/20/03


inner coil
outer coil
inner coil
mandrel
yoke
3150 mm
3116 mm
3086 mm
3044 mm
3028 mm
2995 mm
2650 mm
end