WBS 26.4.8 Tevatron Alignment

Ray Stefanski

February 25, 2004

Jim Morgan

"I believe we are seeing a payoff from the efforts of many people during the Fall shutdown," says Jim Morgan, Run Coordinator and head of operations in the Beams Division Integrations Department. "In particular, the magnet alignment seems to have contributed to making the Tevatron operate with better reproducibility."

FermiNews February 6, 2004

Roles and Responsibilities of the Tevatron Alignment Task Force

Roles and Responsibilities of the Tevatron Alignment Task Force

We report to Roger Dixon, head of the Accelerator Division.	Recommendations are reviewed and approved by Peter Garbincius, Craig Moore, and Vladimir Shiltsev.
The task force leader is Ray Stefanski	The shutdown coordinator is Jim Volk.
The Run II project leader is Jeff Spalding	Mike Syphers represents the Accelerator Integration Department.
PPD and TD Management is represented by John Cooper and Bob Kephardt.	Bob Bernstein, John Greenwood, Terry Sager, and George Wojcik represent the AMG
The Technical Division Representatives are Ray Hanft, Dave Harding, Jamie Blowers, Fred Nobrega, and John Tompkins.	The Accelerator Division representatives are Keith Gollwitzer, Norm Gelgand, Bruce Hanna, Todd Johnson, Mike McGee, Duane Plant, and Aimin Xiao
The PPD representatives are Alvin Tollestrup, Hans Jostlein and Jesse Guerra.	Consultants are Gerry Annala, Don Edwards, Al Russell, and Jean Slaughter
Rob Roser and Rich Smith represent CDF and D0.	Outside Consultants are: Andrei Seryi (SLAC) and Andrey Chupyra (BINP)

Tevatron Alignment Review Committee
Peter Garbincius, Chair

Alvin Tollestrup
Bruce Hanna
Craig Moore
Dave Augustine
Doug Allen
Helen Edwards
John Carson
Peter Garbincius
Vladimir Shiltsev
Wes Smart
William Cooper

Goals for the Summer/Fall shutdown - 2003

There were four main tasks in the Tevatron that involved magnet survey and alignment during the last shutdown:

1. Installation of Real Time Motion Sensors

a. BINP devices in B sector, (BINP, SLAC, Fermilab)
b. Tilt Monitors, (AD)
c. Homemade Devices; (PPD, AD)

2.Physical Alignment of the Tevatron

a. Network Installation, and Measuring Horizontal and Vertical Magnet Positions, (PPD)
b. Roll Measurements, (CDF, DZero)
c. MTF tests (Impact of roll and position changes in warm and cold magnets) (TD),
d. Roll and Position Corrections; (PPD, AD)

Magnet Stand Replacement (AD)

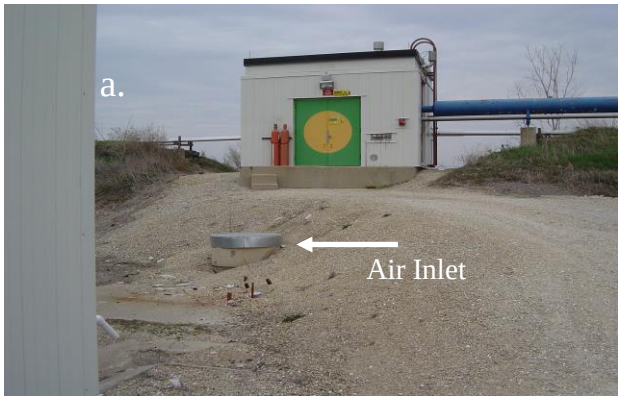
3. Smart Bolt Corrections

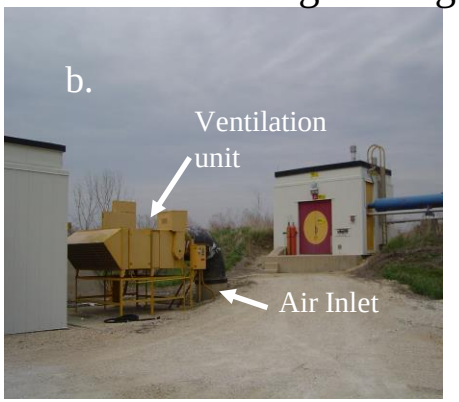
a. MTF Tests (Impact of Shim Changes in Cold Tevatron Magnets—TD-03-045.doc.) (AD, TD)
b. Shim Corrections in 106 Tevatron Magnets; (AD, TD)

Reviewed by Garbincius Committee

Additional Work done during in 2003

- Vertical Alignment of LBQ at CDF
- Horizontal Alignment of LBQ at D0
- Alignment of Lambertson Magnets at F0
- Alignment of Kicker Magnet at A0





a) A photograph of an air duct that is not in use. These are found at all of the 2 and 3 numbered houses around the ring.

b) A photograph of a ventilation unit sitting atop an air-duct. These are seen at the 1 and 4 numbered houses around the ring.

c) At the bottom of each of the 24 air ducts sits a cable tray that obstruct a clear view into the alcove. A special device was designed by Mike McGee to bring the line-of-sight around the cable tray.

d) A photo of the alcove at the bottom of the air ducts, showing also a cable tray. The AMG used twelve air ducts for the installation of TevNet. Those used were located at the 1 and 3 houses.

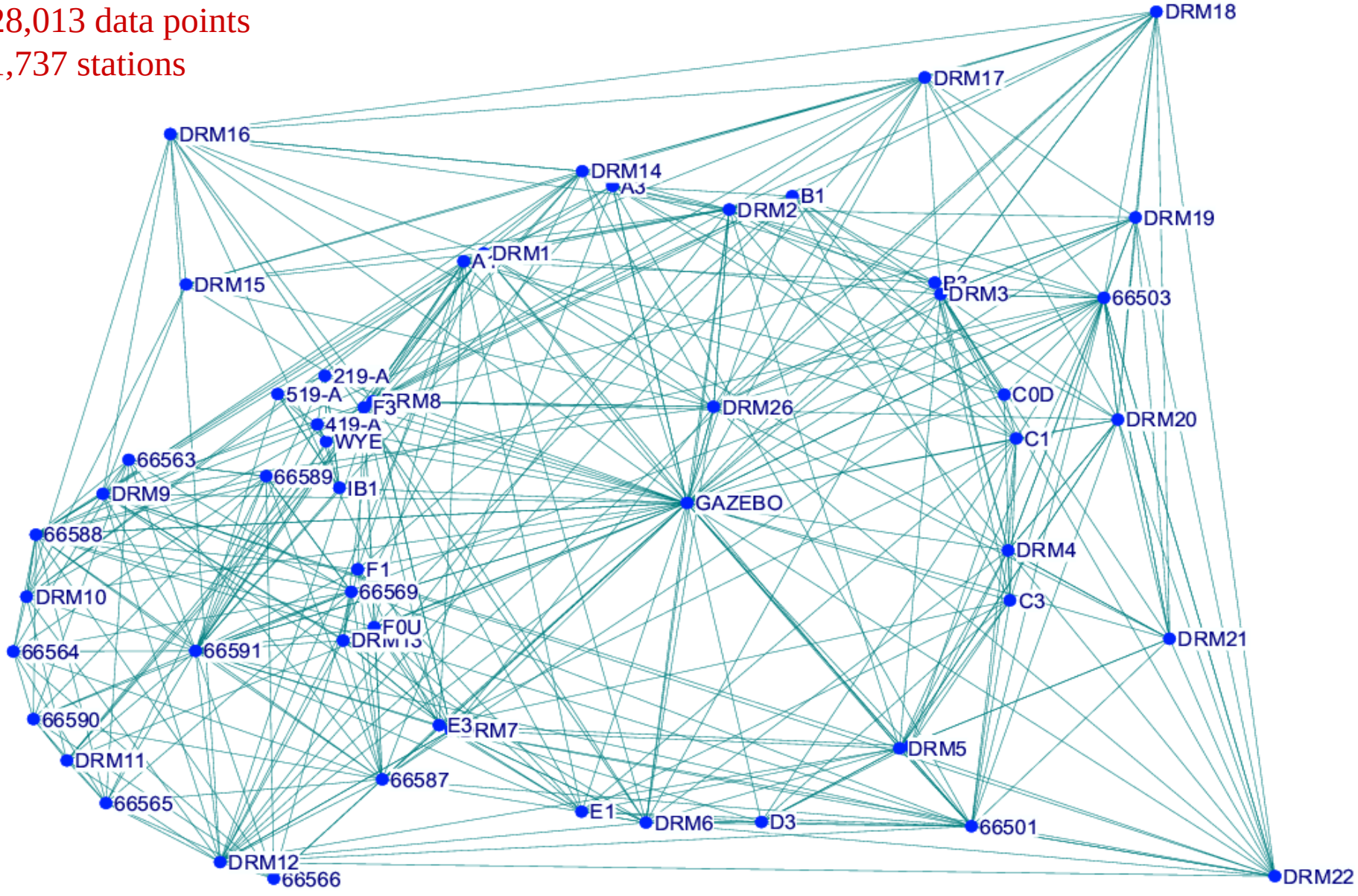
e) A photograph of one of twelve towers constructed above the air-shafts, this one at C3. From the top of the tower, which extends above the surrounding structures, readings taken at the surface can be transmitted down the sight-riser, nee air-duct.

Magnet Alignment

TevNet

28,013 data points

1,737 stations



Where to from here?

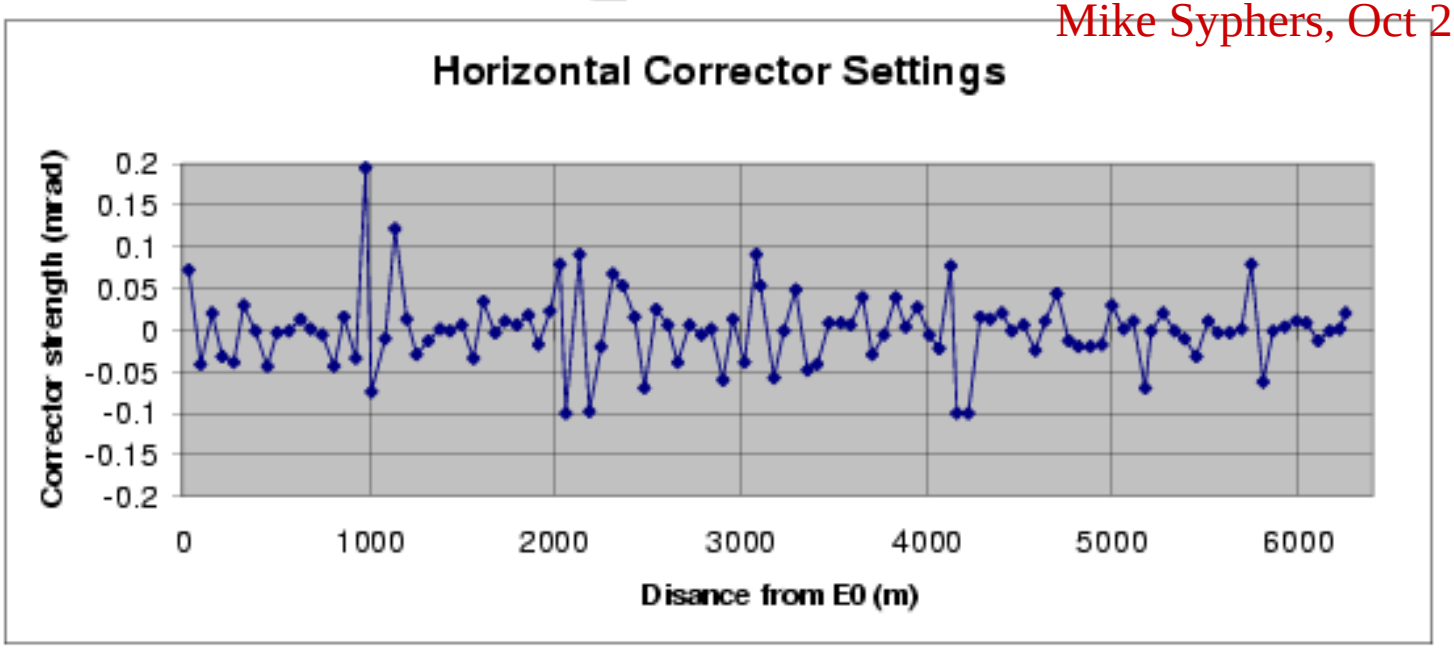
The original alignment spec was 10 mils for quads and 30 mils for dipoles with respect to the monument system. This was both horizontally and vertically.

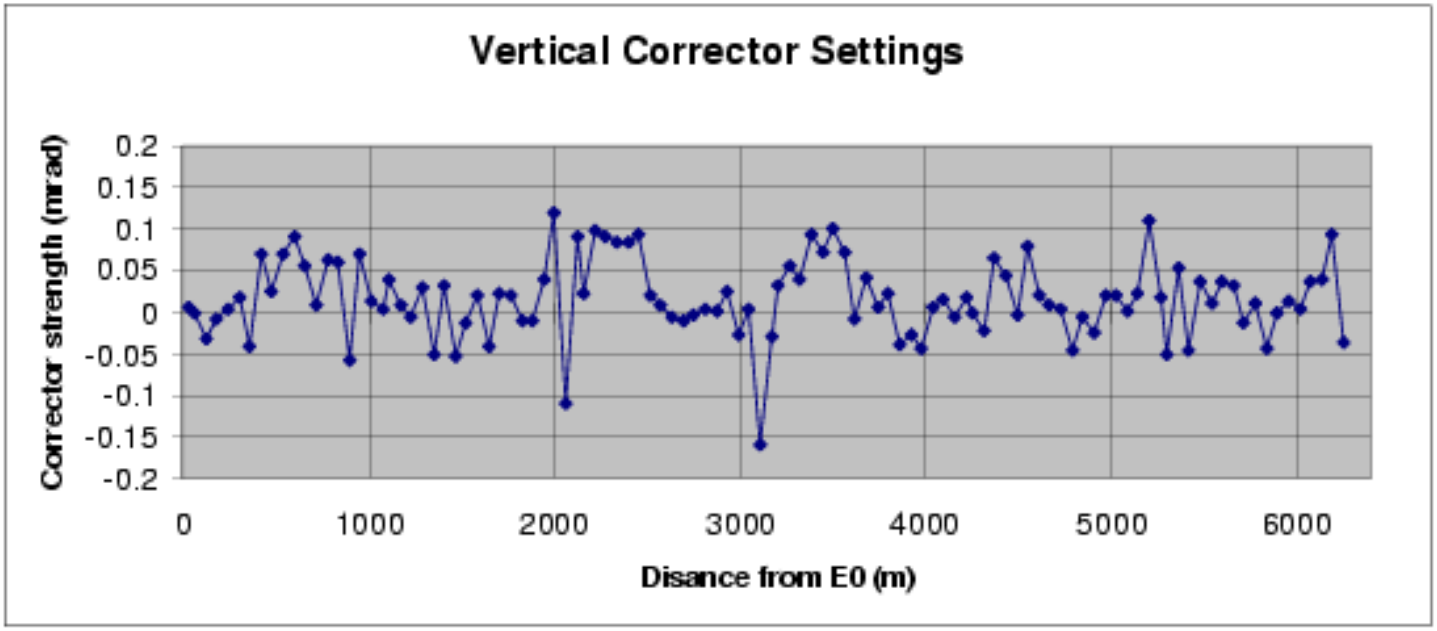
The total error budget also included measuring the magnetic center of the elements, setting the reference lugs on the outside wrt the magnetic center, and the error on analyzing and installing the monument system.

We will shoot for nothing less 20 years later, especially since TevNet is supposed to give us better information about the monument system.

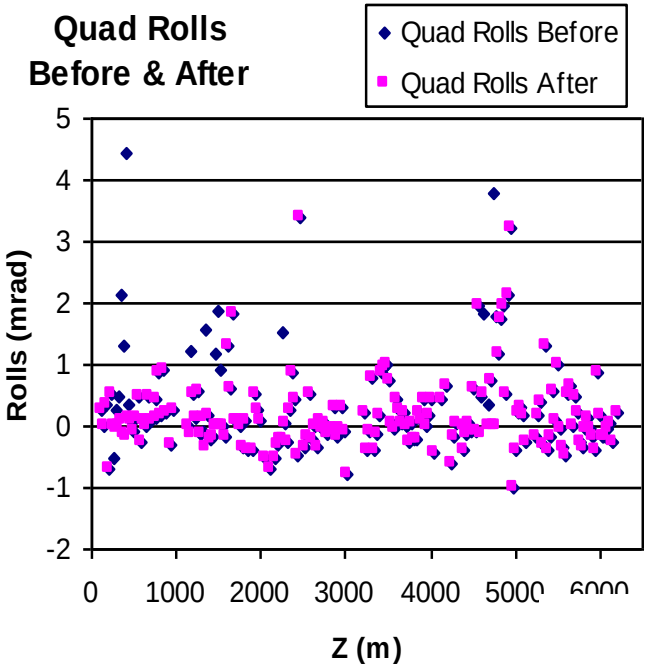
Quote from Craig Moore

Mike Syphers, Oct 2002

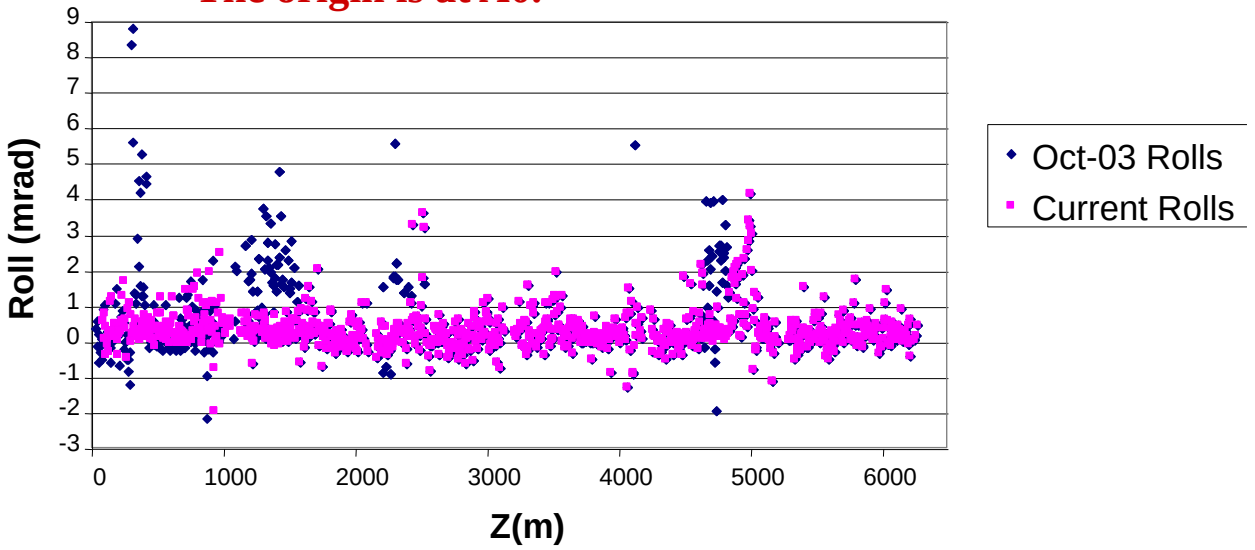


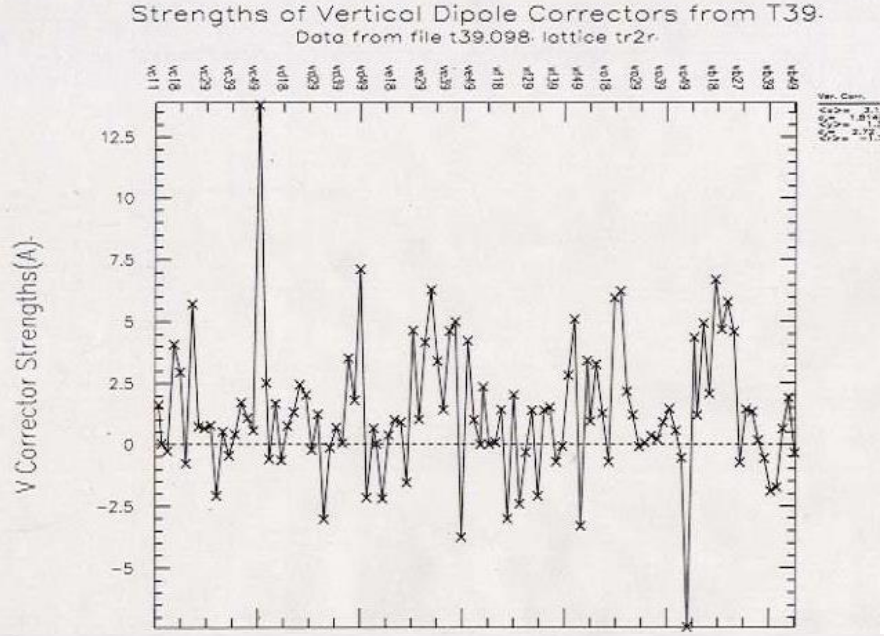


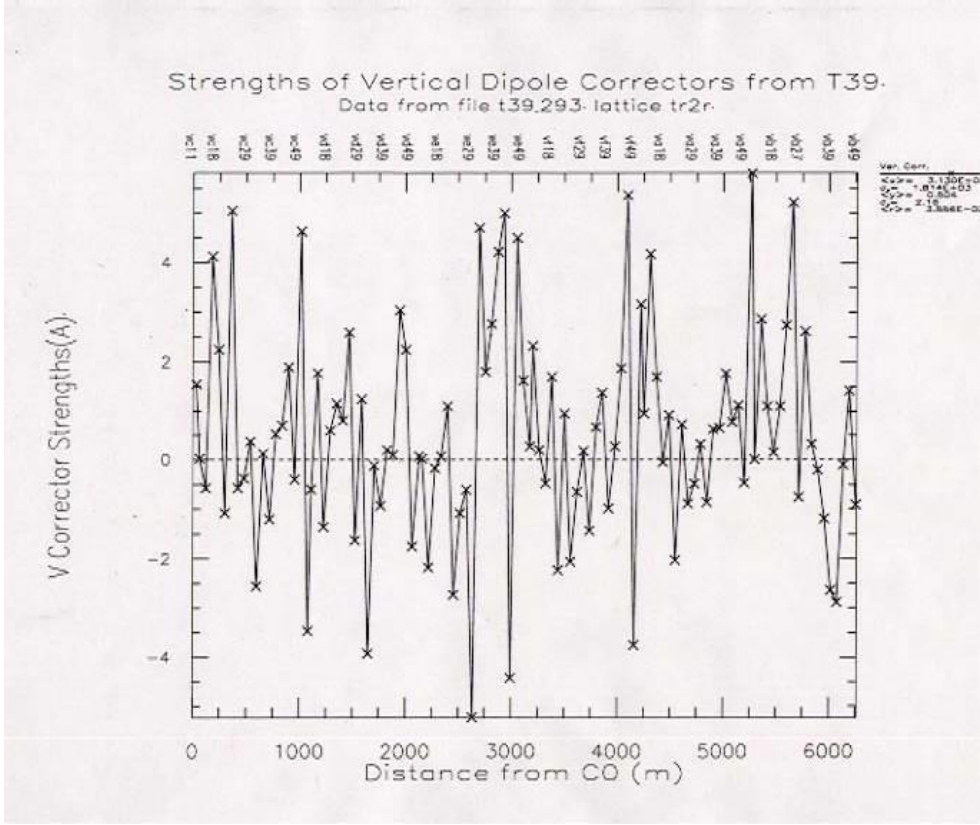
Correction in Rolls

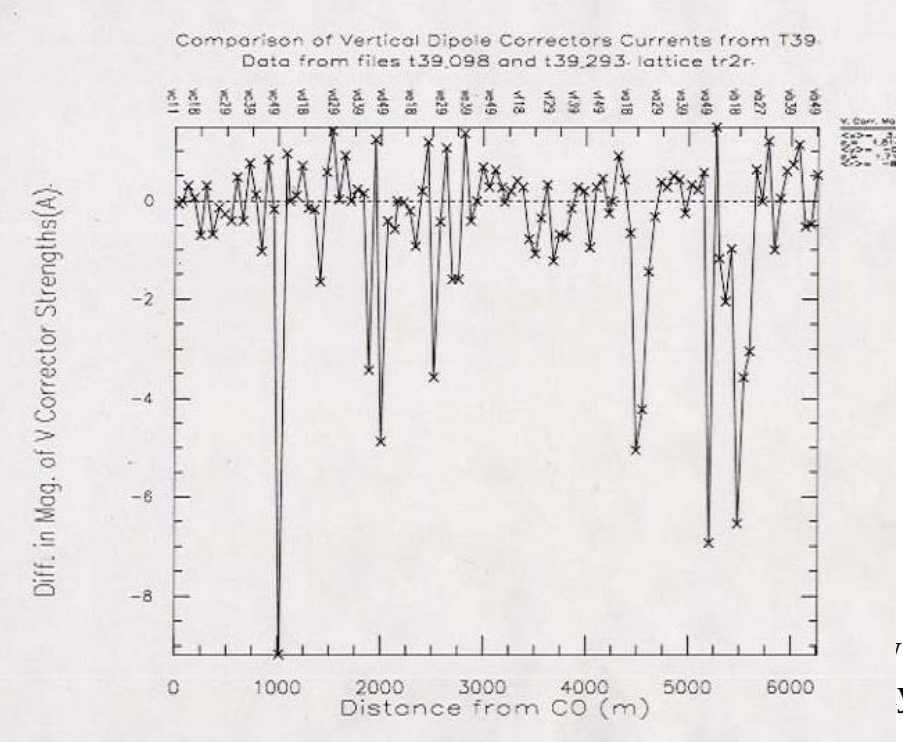


Comparison of magnet rolls (Dipoles and Quadrupoles) around the entire Tevatron before and after the summer shutdown and the two December shutdowns. Current rolls are in purple, the corrected Oct-03 rolls are in dark blue. The origin is at A0.

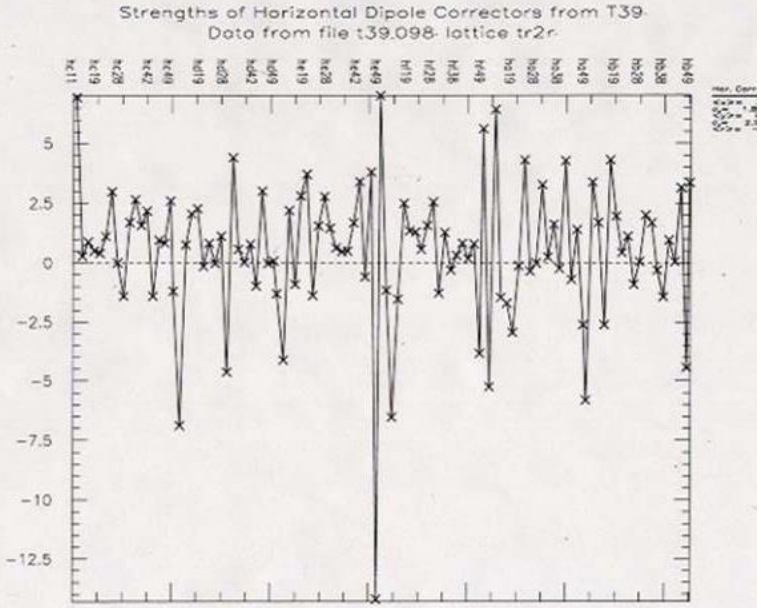


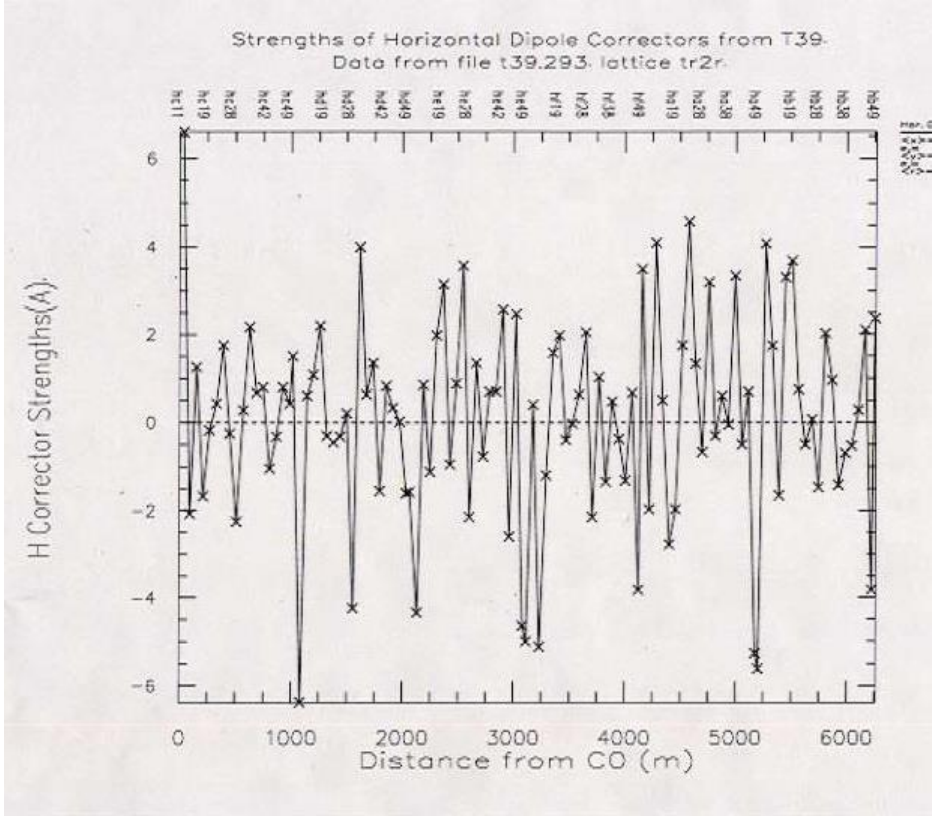


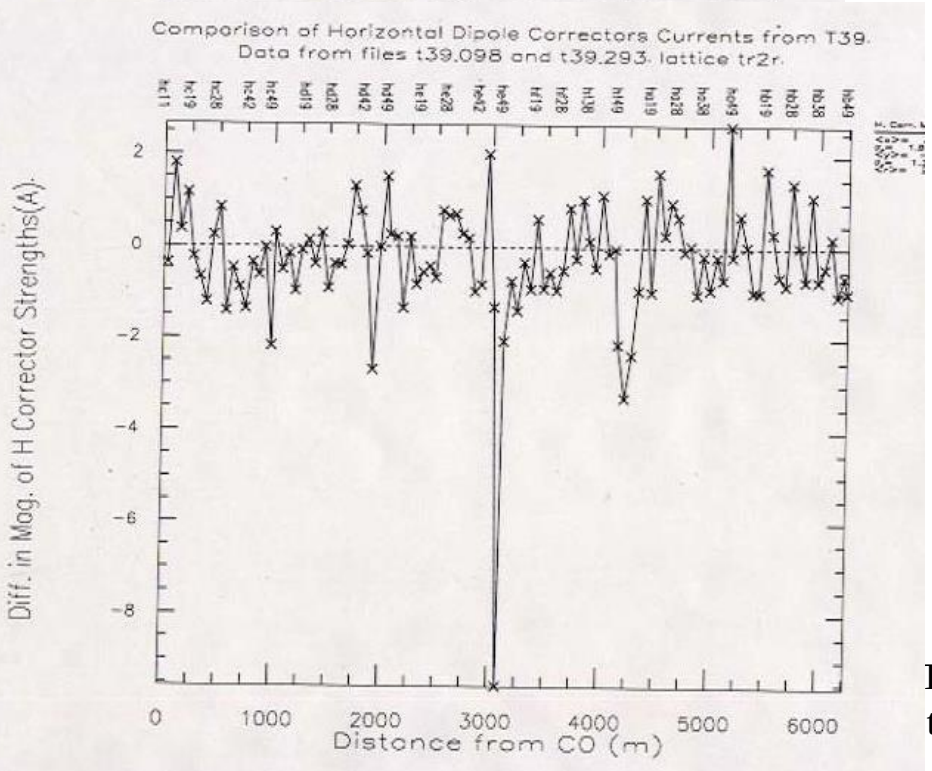




Vertical Corrector Settings



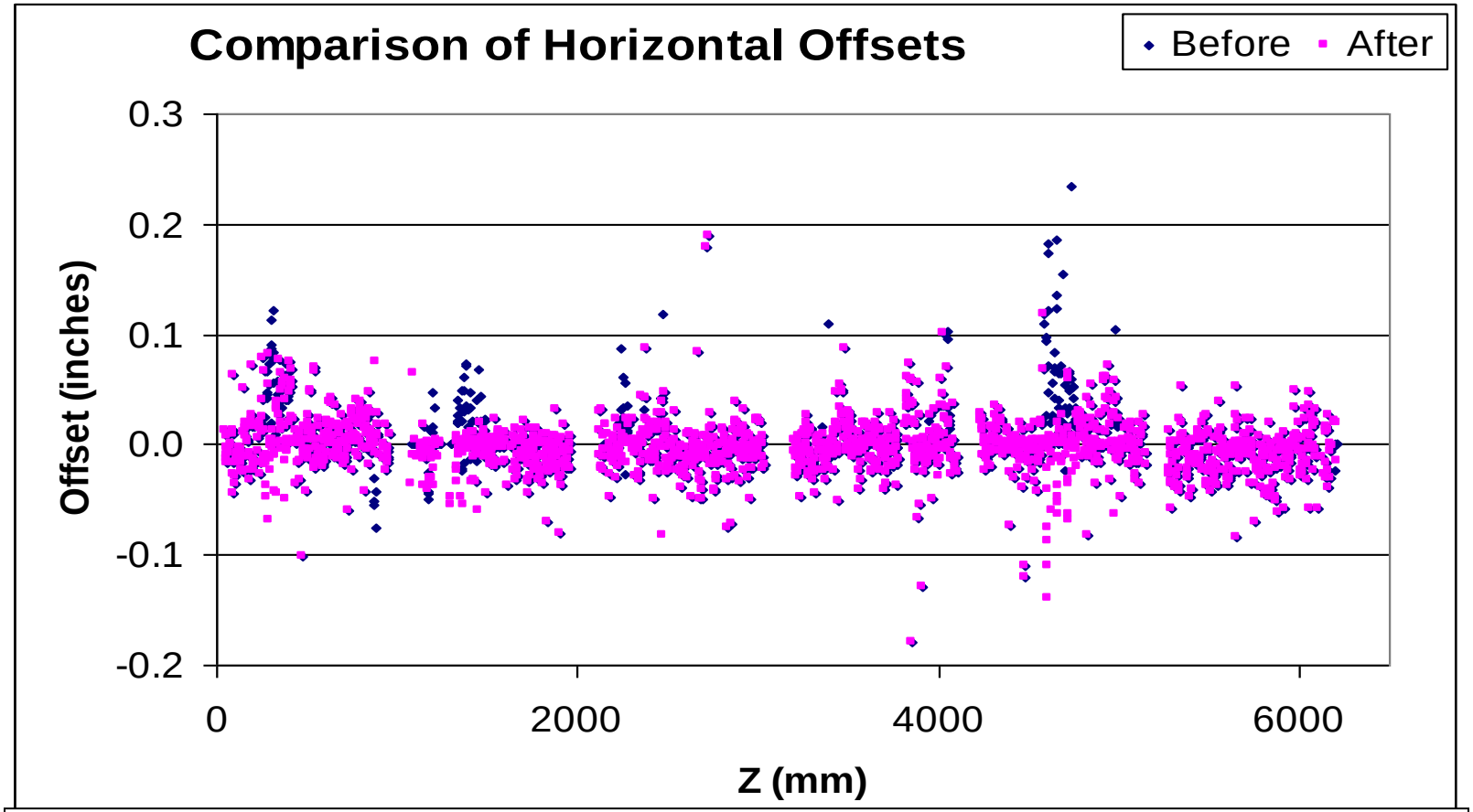




Horizontal Corrector Settings

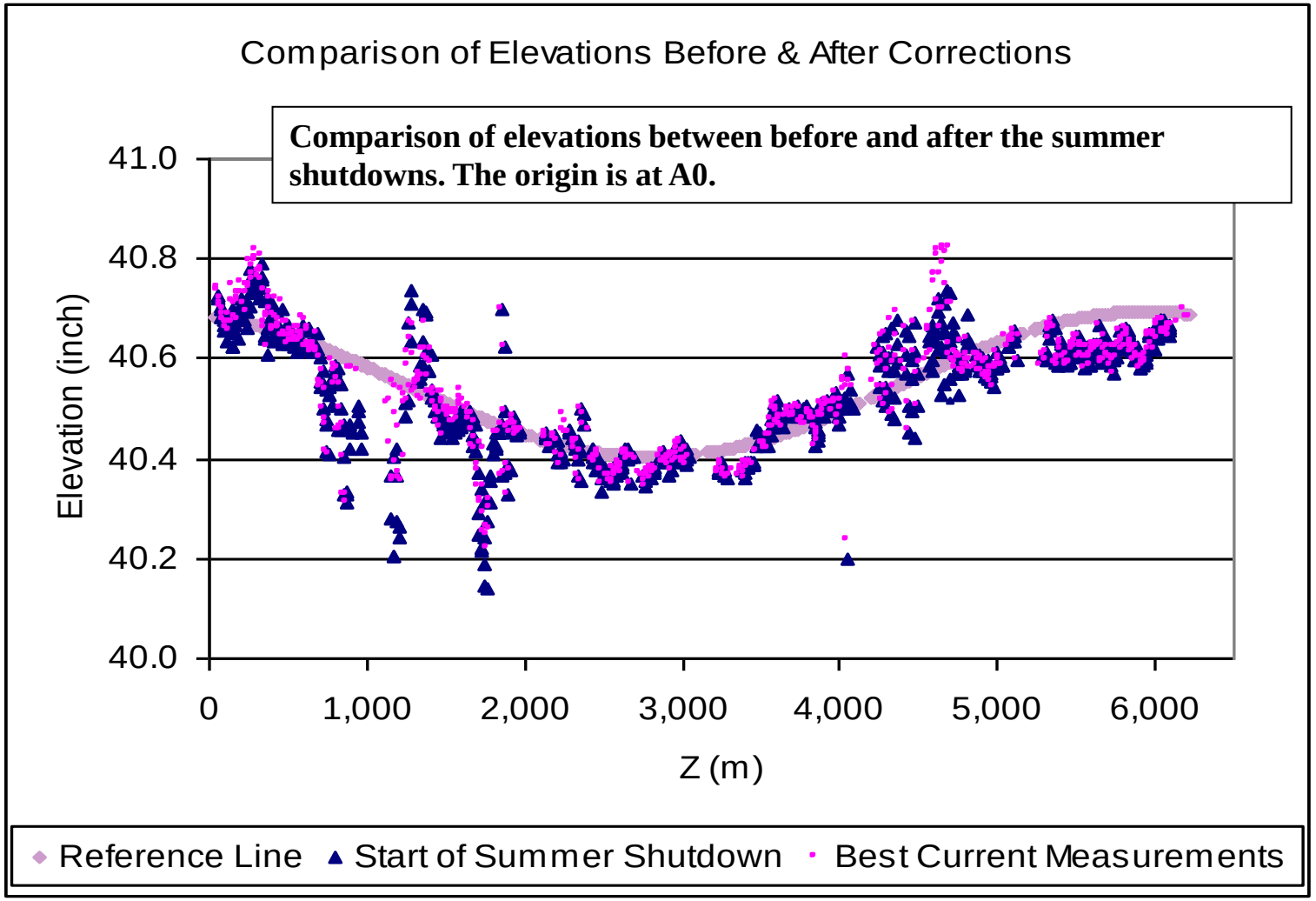
Comparison of magnet rolls before and after the summer shutdown. (#before, #after)

House	Roll Angle	>N mrad					
	>1	>2	>3	>4	>5	>6	>7
A-1	(3,3)						
A-2	(20,2)	(10,0)	(8,0)	(8,0)	(4,0)	(2,0)	(2,0)
A-3	(4,4)						
A-4	(2,2)	(1,1)					
B-1	(20,0)	(9,0)	(3,0)				
B-2	(19,0)	(7,0)	(2,0)	(1,0)			
B-3	(2,2)						
B-4							
C-1	(11,0)	(1,0)	(1,0)	(1,0)	(1,0)		
C-2	(5,4)	(3,3)	(2,2)				
C-3							
C-4							
D-1	(1,1)						
D-2	(4,4)						
D-3							
D-4	(2,1)	(1,0)	(1,0)	(1,0)	(1,0)		
E-1	(1,1)						
E-2	(17,4)	(10,0)	(3,0)				
E-3	(23,17)	(13,8)	(5,3)				
E-4	(2,2)						
F-1	(1,1)						
F-2	(2,2)						
F-3	(1,1)						
F-4							
Total>N	(141,51)	(55,12)	(25,5)	(11,0)	(6,0)	(2,0)	(2,0)

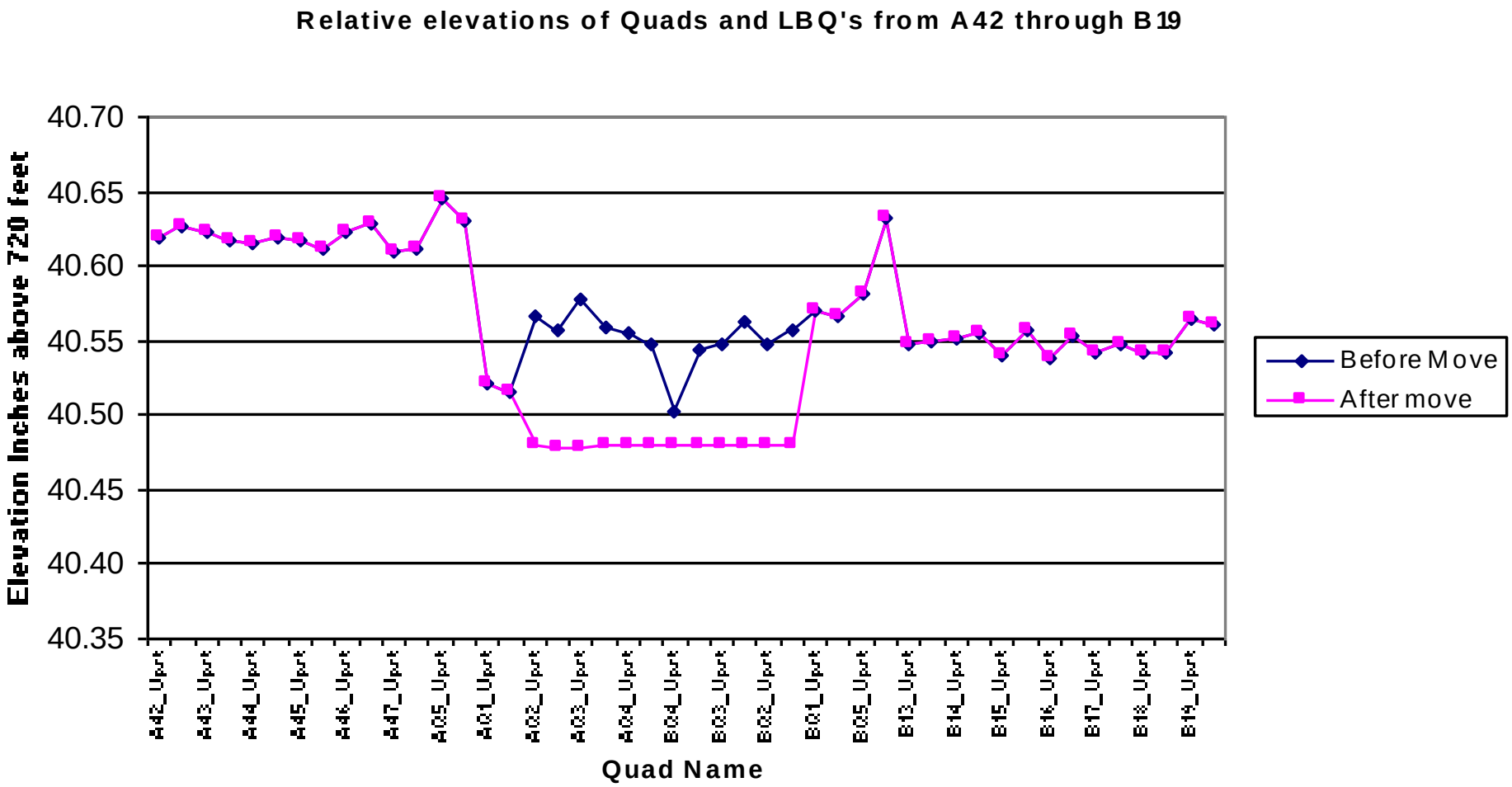


A comparison of horizontal offsets relative to the Murphy line. The blue points are measured offsets at the start of the shutdown, later corrected. The purple points are current offsets, including those corrected during the shutdown. The origin is at A0.

Compatison of Horizontal Offsets

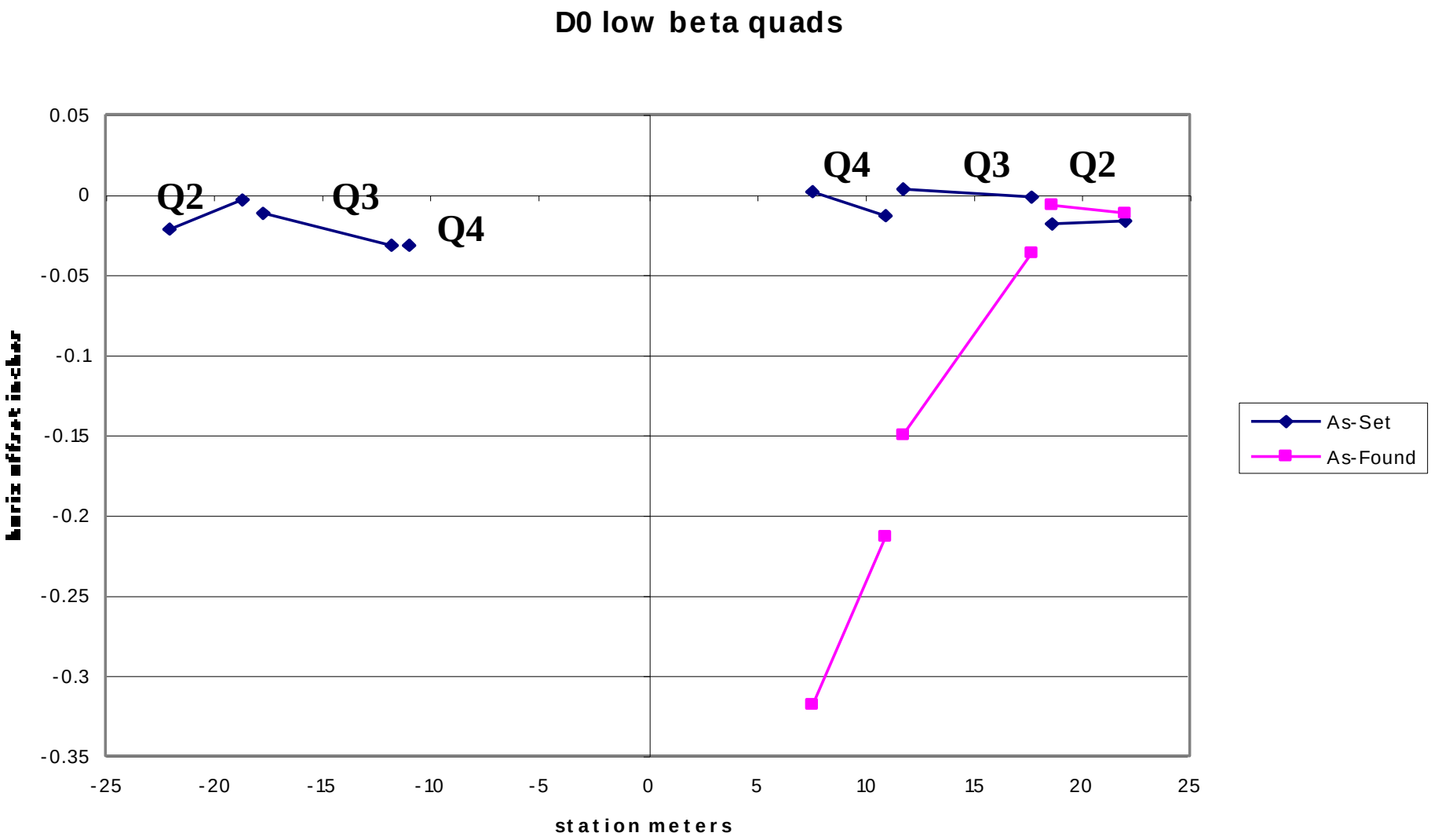

Comparison of Elevations Before & After Corrections
Comparison of elevations between before and after the summer shutdowns. The origin is at A0.
41.0
40.8
40.6
40.4
40.2
40.0
Elevation (inch)
0
1,000
2,000
3,000
4,000
5,000
6,000
Z (m)
Reference Line
Start of Summer Shutdown
Best Current Measurements

CDF LBQ corrections

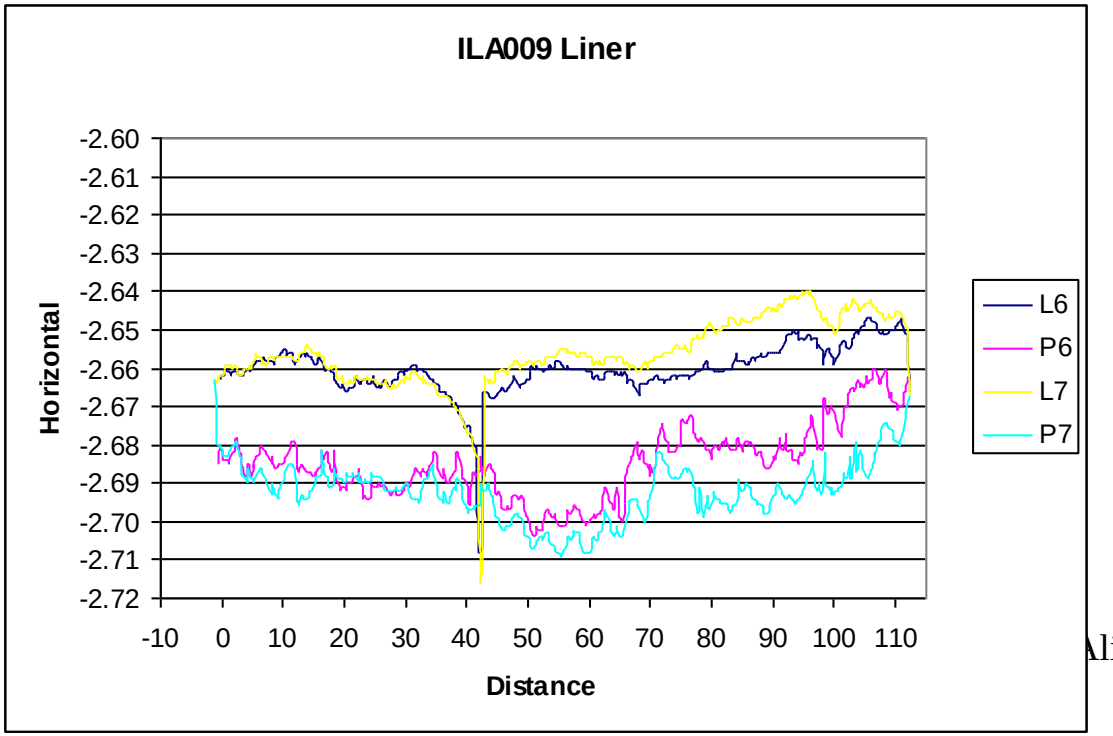


D0 LBQ Corrections

Corrections were in the horizontal plane.

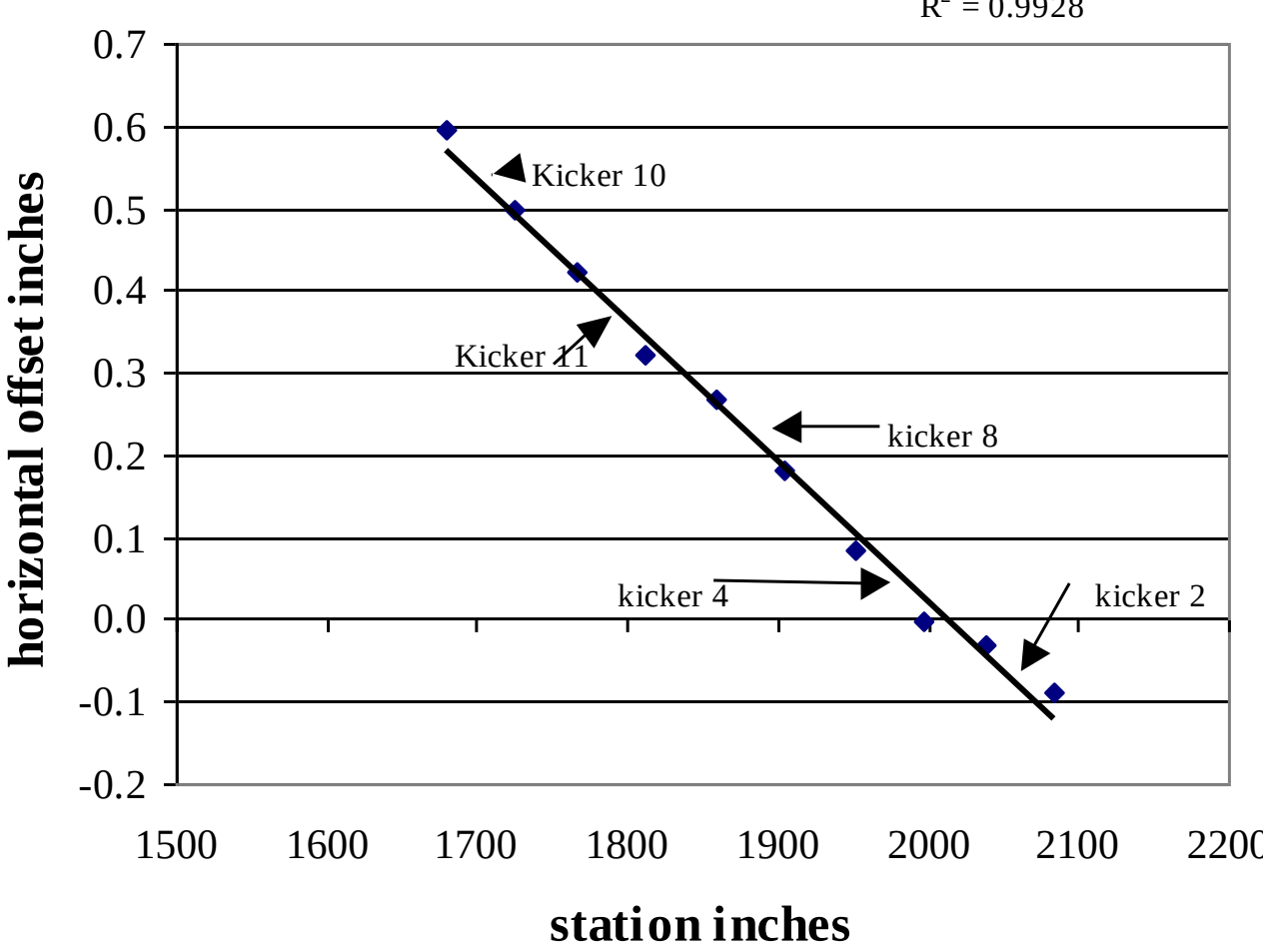


In the process of reassembly a mismatch or misalignment of about 6mm (0.25 inch) was discovered between the Tevatron and Main Injector. Given the size of the beam pipe, the aperture of the magnets and that the history of successful beam transport in this part of the Tevatron, no attempt was made to correct this misalignment during the summer shutdown. More work will be needed to understand the source of the misalignment, further beam studies will be done, with the goal of correcting this problem during the next shutdown.



Installation of F0 Lambertson Liner

All five kickers were mounted on a bedplate that was designed to move during the change from 800 GeV fixed target to colliding beam operations. Adjacent and to the radial inside were the bedplates for the fixed target extraction Lambertsons. Both systems were designed for easy movement during change over between these two running modes.



Pbar Kicker misalignment

It appears that sometime between March 2001 and October 2003 the bedplates for the Lambertsons were pushed into the bedplate for the kickers causing the offset.

Magnet Stand Replacement

A-1	2	D-1	0
A-2	15	D-2	0
A-3	0	D-3	0
A-4	0	D-4	2
A-Sector	17	D-Sector	2
B-1	15	E-1	0
B-2	5	E-2	12
B-3	0	E-3	5
B-4	0	E-4	1
B-Sector	20	E-Sector	18
C-1	1	F-1	0
C-2	1	F-2	0
C-3	2	F-3	0
C-4	0	F-4	0
C-Sector	4	F-Sector	0
		All	61

Hans Jostlein's measurements with tilt meters at D0, 1990

Readback from Two Tiltmeters on a Common Support Over a 38 Day Period.

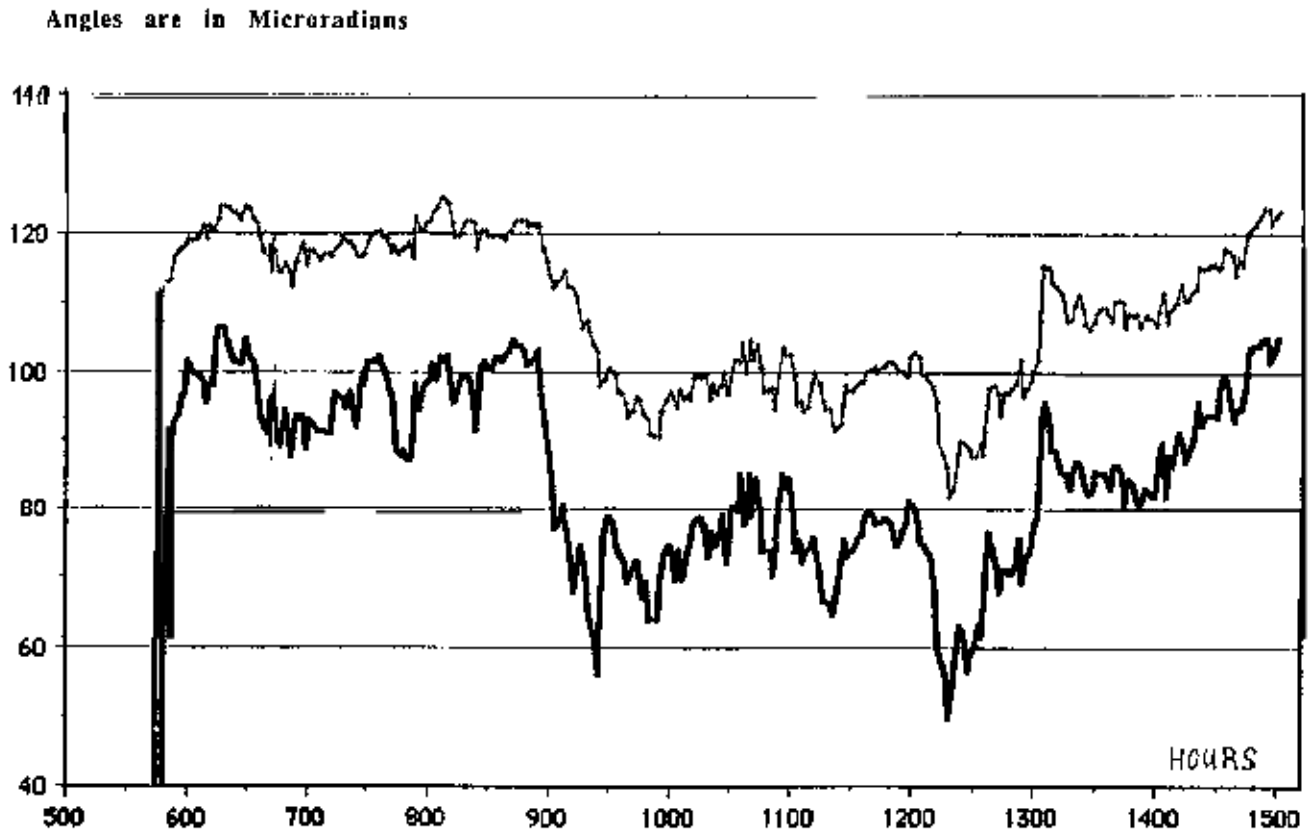


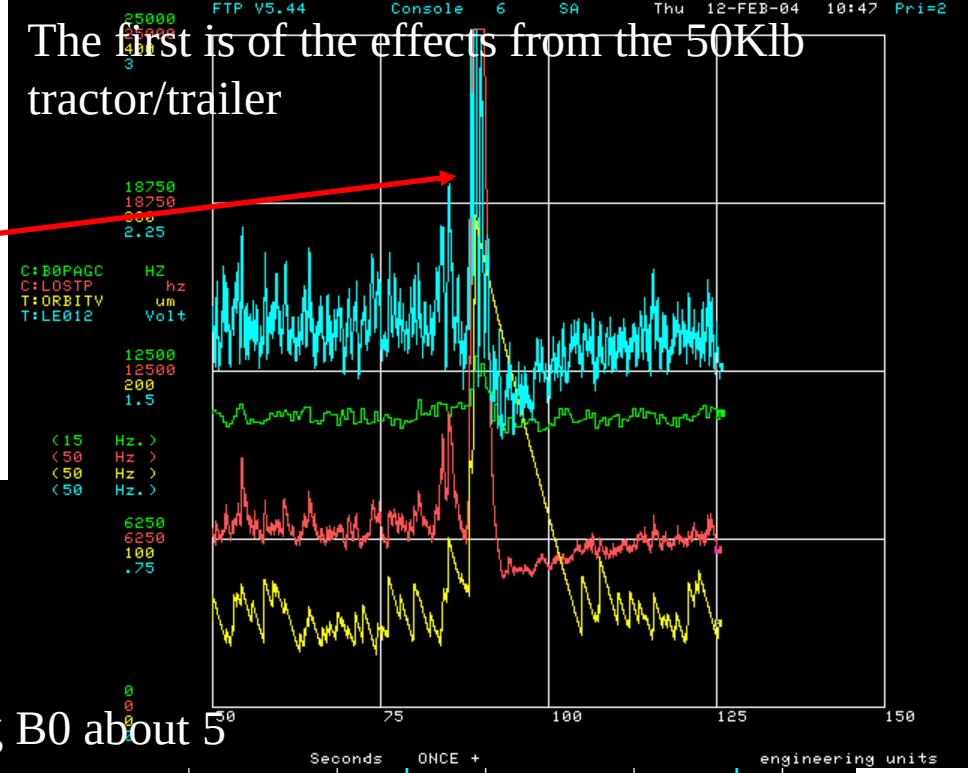
Fig. 10 Response of two Tiltmeters during a 38 Day Run

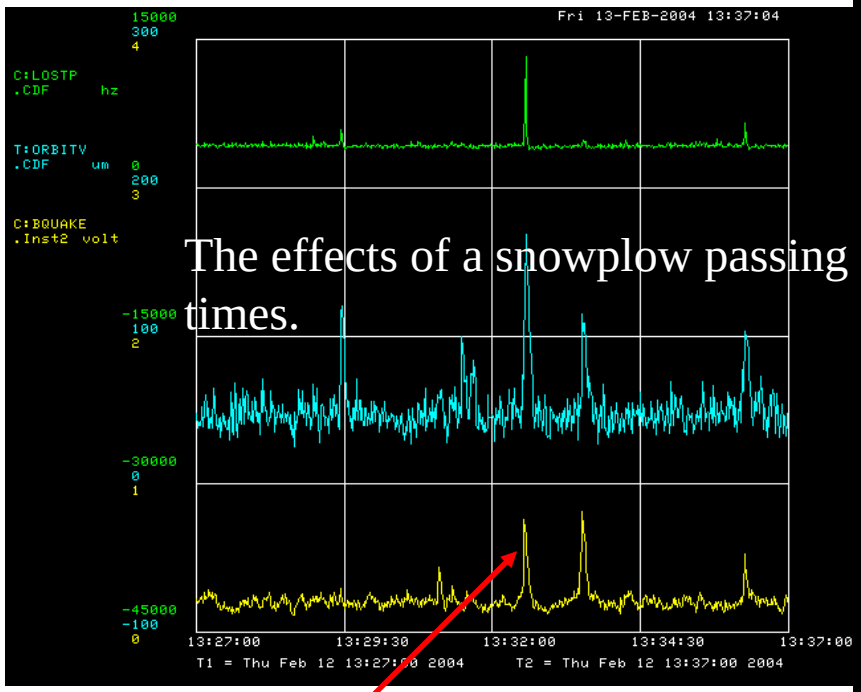
TeV Level System

Accelerometer Measurements at B0

Measured by
Todd Joihnson
And Duane Plant

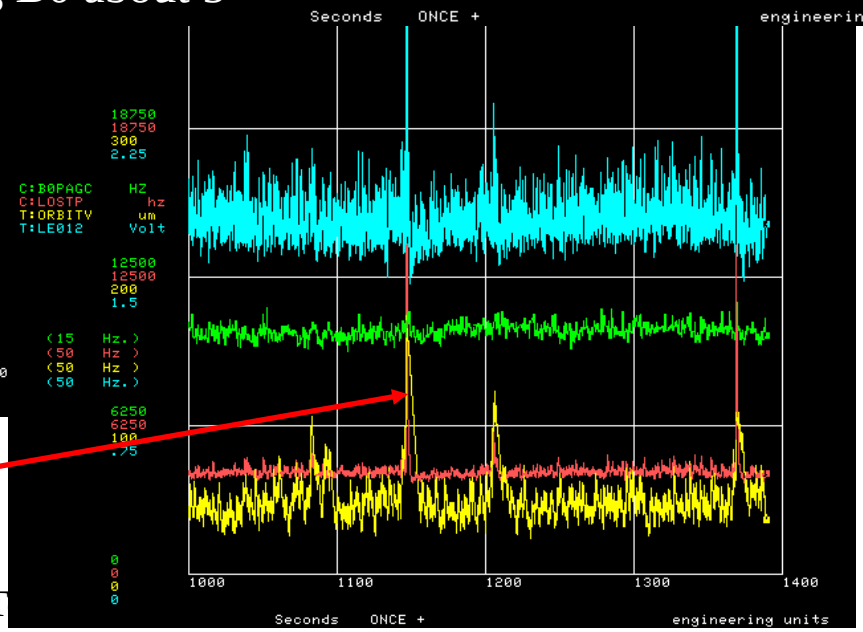
This would cause the collimators to stop during beam halo scraping!





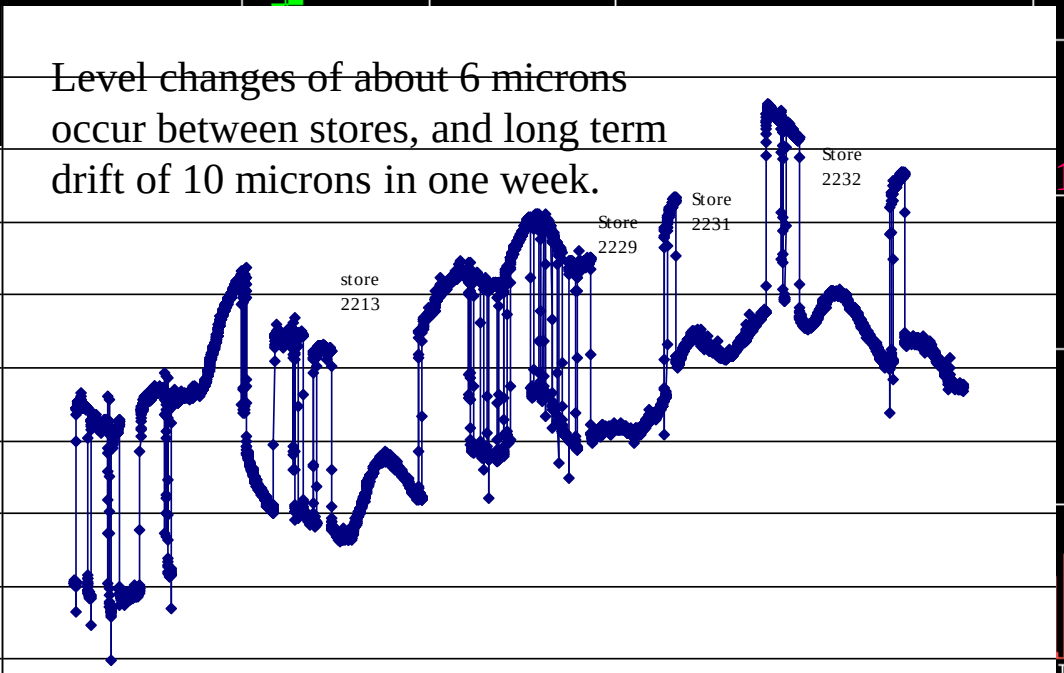
The effects of a snowplow passing B0 about 5 times.

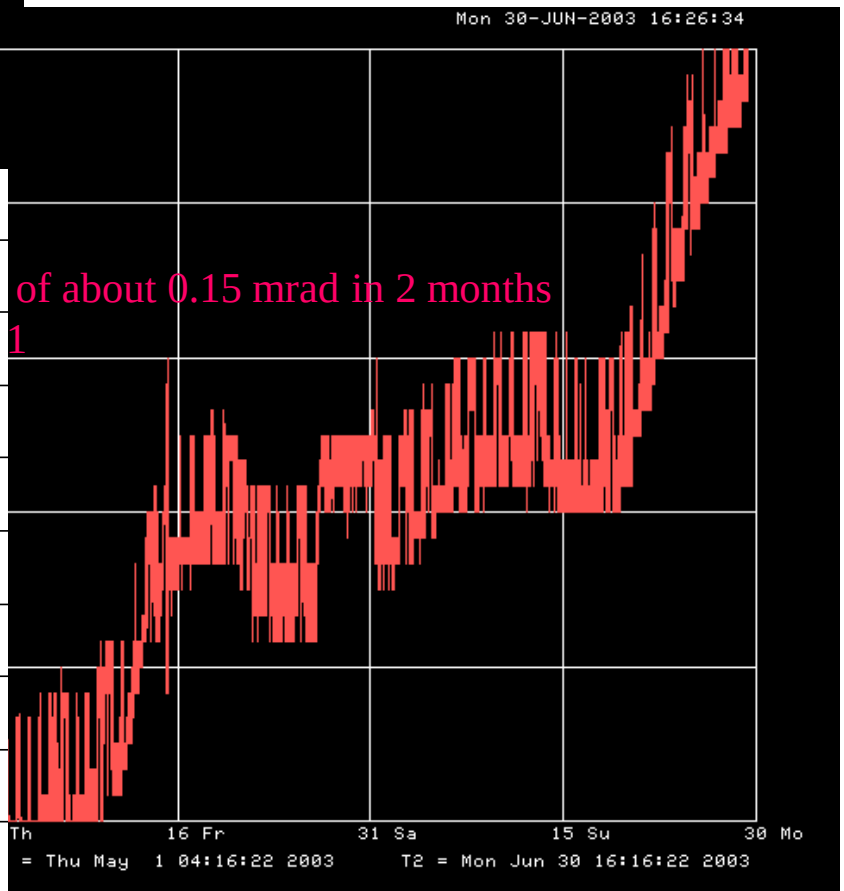
Explains the source of spikes on the BLMs



TeV Level System

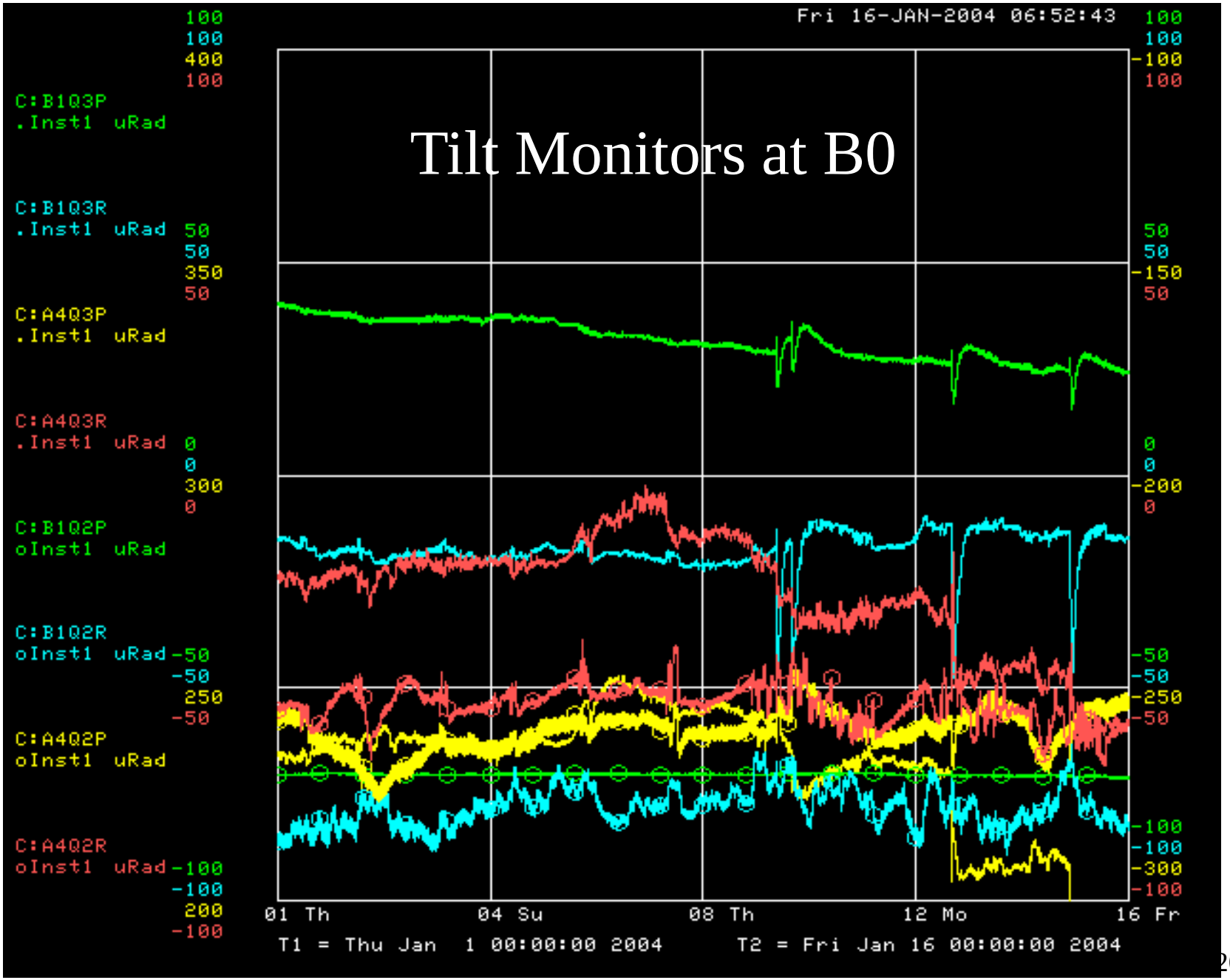
Tilt Monitors located in the Tev tunnel indicate that long term changes do occur. Discrete short term motion can also be seen.



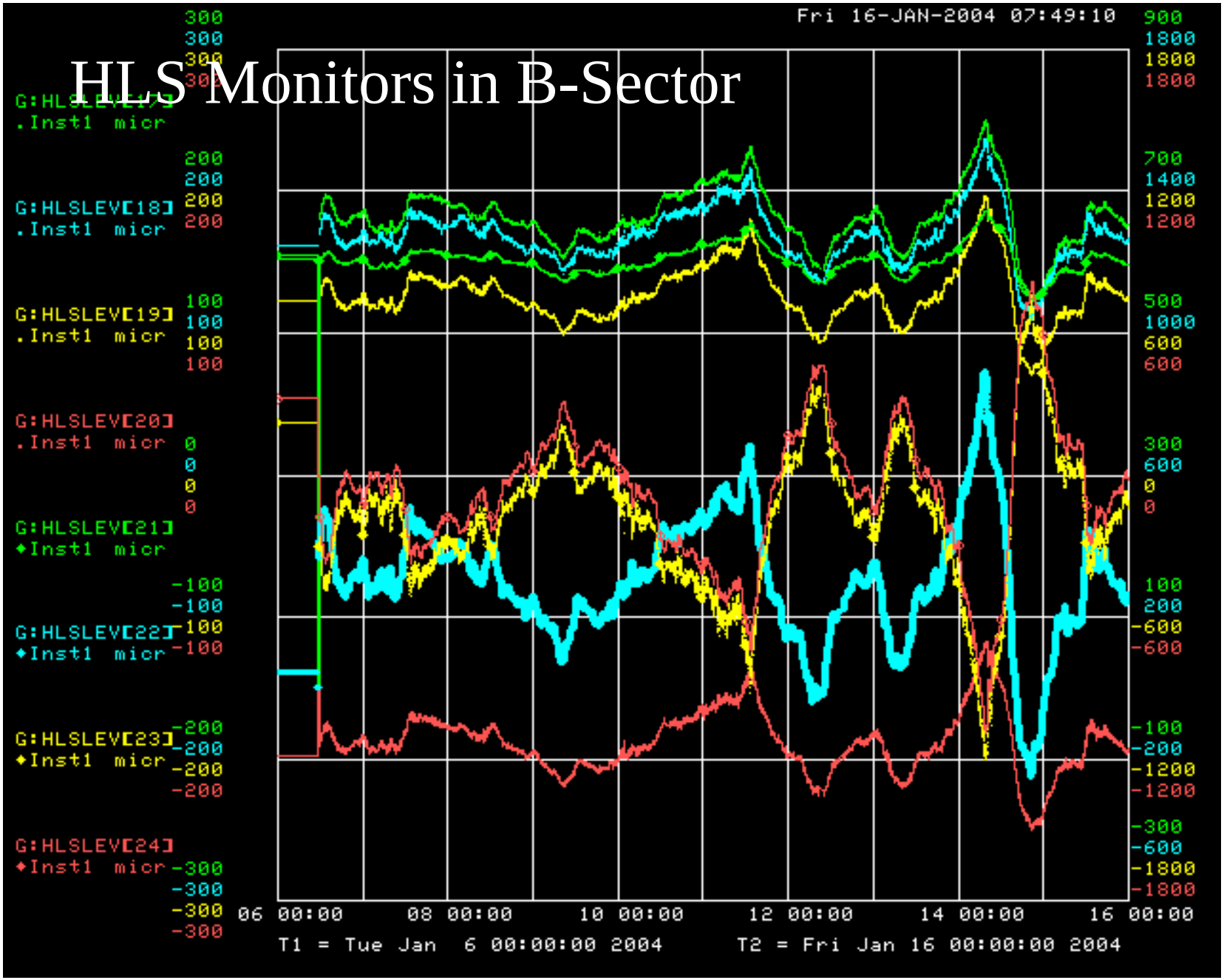


Tilt Monitor Data Detectors

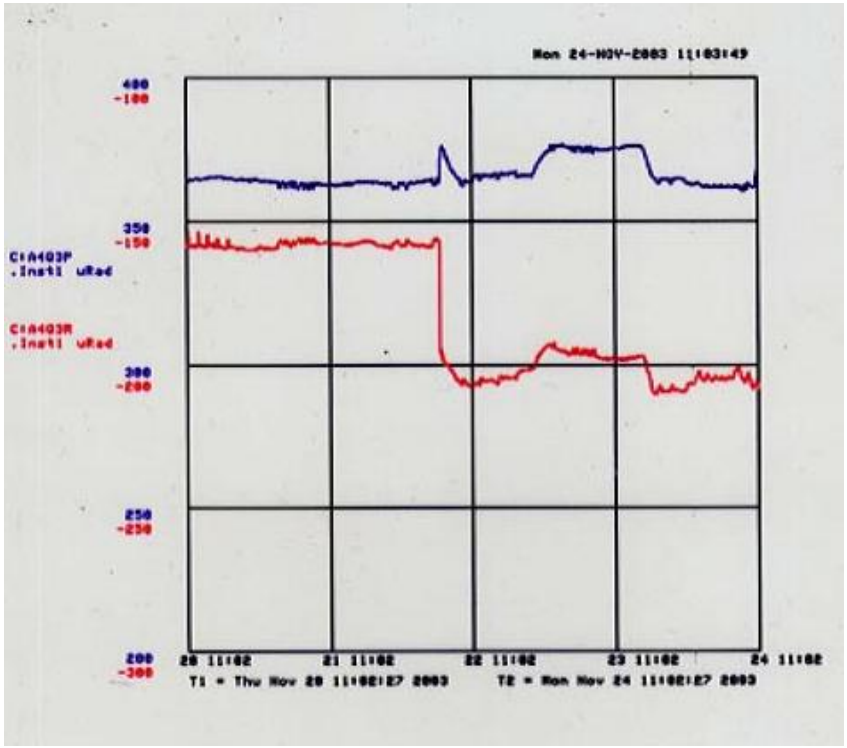
Location	Average Roll/Time	Estimated Annual Roll
	μrad/day	μrad/year
A15-1 Quad	1.10	400
A16-3 Dipole	0.58	210
A21-1 Quad	0.21	77
B17-5 Dipole	1.52	555
B24-1 Quad	0.22	80
C24-1 Quad	1.30	474
E29-1 Quad	1.07	-390
E32-1 Quad	1.77	538
E39-1 Quad	1.18	430


Tilt Monitors at B0
Fri 16-JAN-2004 06:52:43
C:B1Q3P
.Inst1 uRad
C:B1Q3R
.Inst1 uRad
C:A4Q3P
.Inst1 uRad
C:A4Q3R
.Inst1 uRad
C:B1Q2P
oInst1 uRad
C:B1Q2R
oInst1 uRad
C:A4Q2P
oInst1 uRad
C:A4Q2R
oInst1 uRad
01 Th
04 Su
08 Th
12 Mo
16 Fr
T1 = Thu Jan 1 00:00:00 2004
T2 = Fri Jan 16 00:00:00 2004

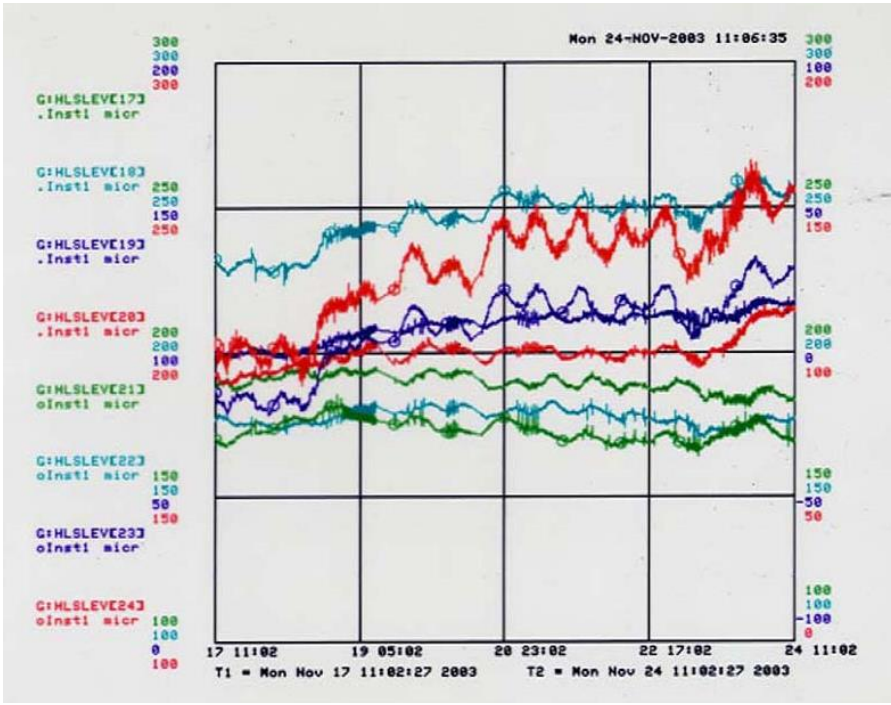
HLS Monitors in B-Sector



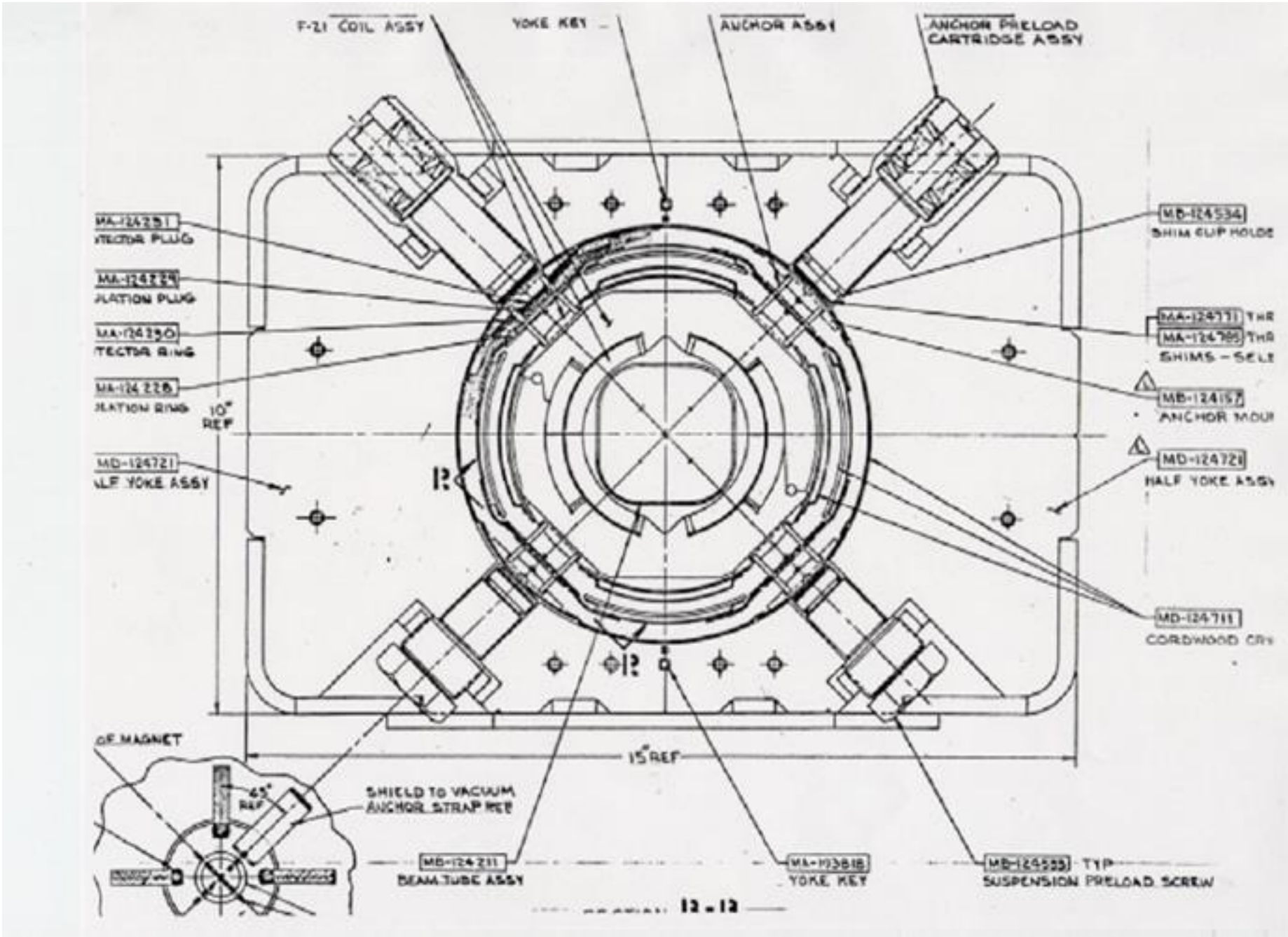
Example of a magnet quench



HLS response in B-Sector

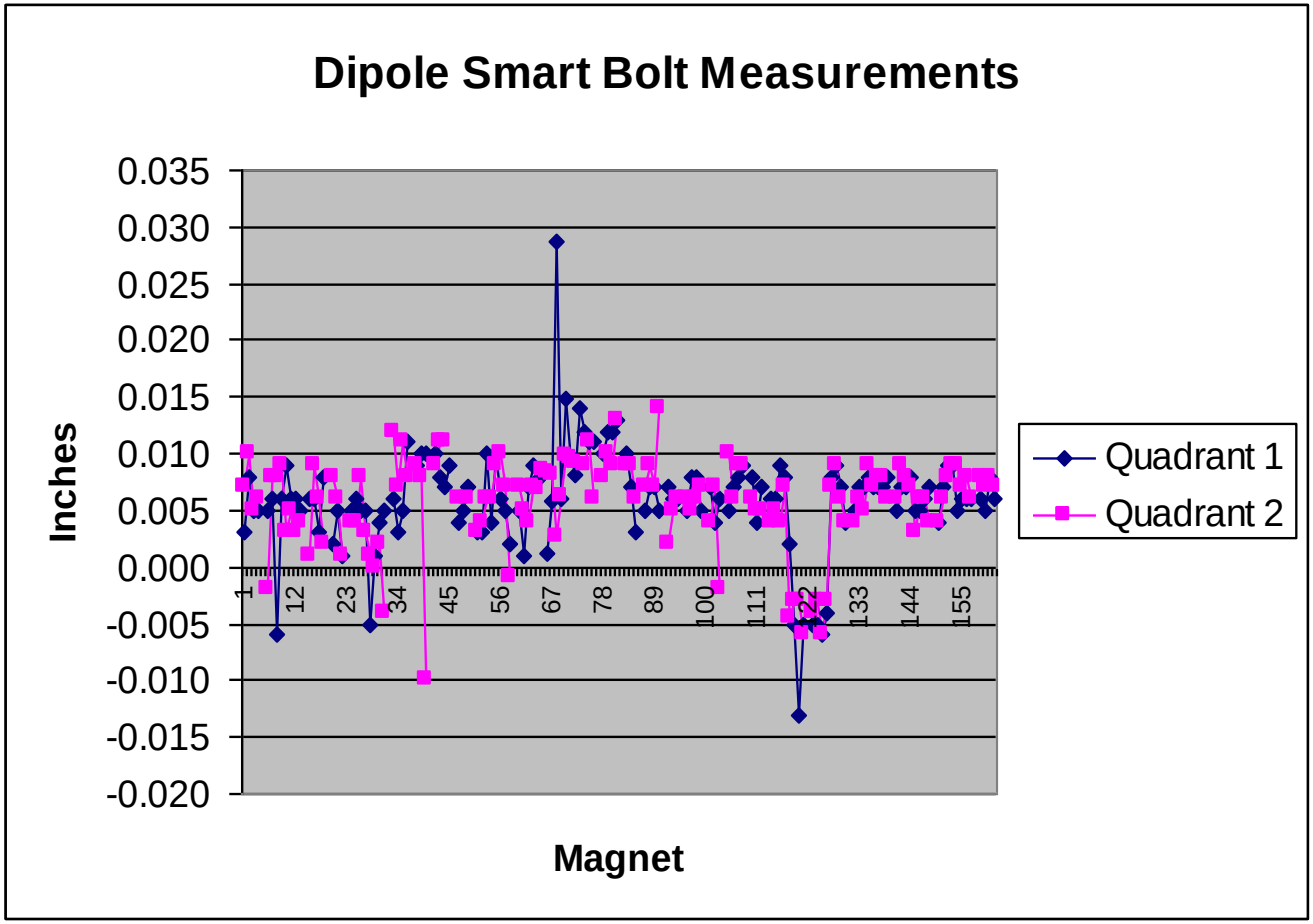


Tev Magnet cross section



106 dipole magnets near the low beta regions were modified for cryostat movement. By concentrating on the magnets that have no nearby skew-quad correctors, the coupling can be reduced by 75 %. Virtually all dipoles were measured in the Tevatron to establish a baseline: to detect future movement if it occurs. Some dipoles show unusual behavior, as if the anchor bolt is broken.

Suspicious magnets are being studied to develop an understanding of this phenomenon.



Summary from Mike Syphers

The skew quadrupole circuits haven't been studied in depth since the shutdown due to lack of proper study time.
The circuits were generally brought up with the same currents used before the shutdown, and then adjusted empirically to be able to bring the two tunes together. We can probably do a better job at this With a little dedicated study time.
Thus, only a few general comments can be made:

1) The currents used in the skew quad circuits are lower than they were. The main circuit is lower by about the expected amount.
2) The auxiliary circuits, SQA0 in particular, have not been optimized in any systematic way
3) The vertical dispersion is slightly smaller, but this is present predominately due to the SQA0 quads
4) Study time is required to further optimize the system.

Database and Beam Sheets

Once the TevNet data is processed and the position of the machine and its components are documented, a statement of the current machine definition can be made - a beam-sheet, if you will. As the requests to move various components are submitted, a new 'beamsheet' evolves. Whether the request says "move this dipole 50 mils right and set the roll at 0.1 milliradians“ or it says "set the magnetic center at these coordinates with this roll, pitch, yaw set", doesn't change this at all.

The only correct way to put the position of a magnet into a database is to use absolute global coordinates. The reference trajectory changes often, so measurements relative to local coordinates would be difficult to maintain. (The reference orbit has changed five times since the summer shutdown.) However, beam diagnostic and design software operate in local coordinates. (Magnet roll plus vertical and horizontal offset relative to a reference orbit.) For survey measurements to be useful for machine studies, an absolute definition of a beam trajectory must be made.

Work Plan for 2004 Shutdown

- **Align the Tevatron**
  - **Eliminate rolls**
  - **Fix Murphy Line if Needed.**
  - **Identify and Implement Optimized Elevations**
- **Replace More Magnet Stands**
  - **Spool Stands, especially Bartelson Quads**
  - **Replace Quadrupole Stands**
  - **Replace more Dipole Stands**
- **Complete Installation of Motion Detectors**
  - **Verify that data is useful!**
  - **Choose HLS system, Complete the ring**
- **Implement Electronic Database**
- **Possible Work Needed for Dipoles with Broken Anchors**
- **Develop Better Understanding of Long Straights.**

Summary

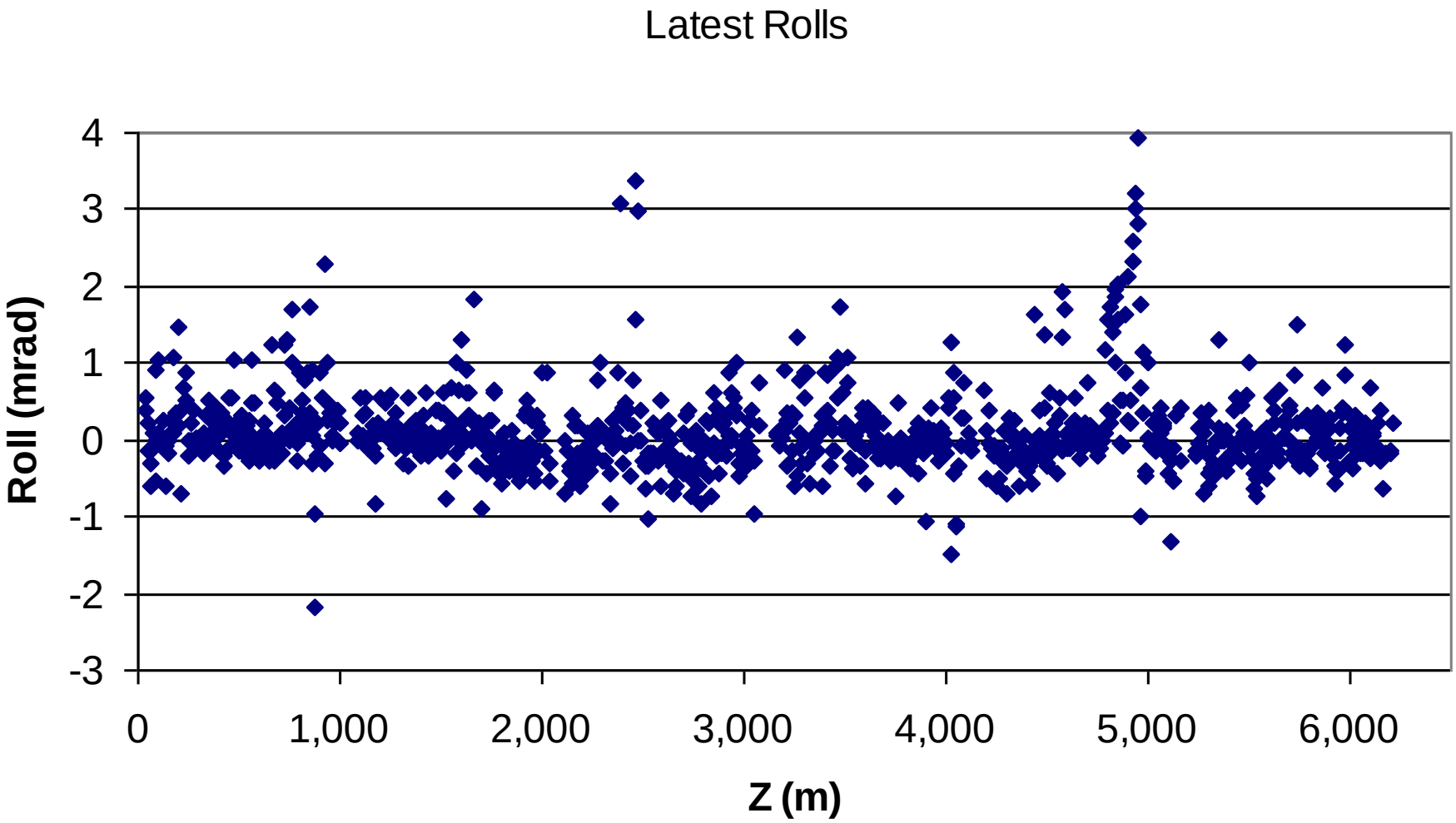
We feel that much has been accomplished, but much more remains to be done.

Backup Transparencies

WBS

WBS	26.4	26.4.8
Title	Tevatron High Luminosity	Tevatron Alignment
Leader	Vladimir Shiltsev	Ray Stefanski
Base SWF ($FY03)	$8,059,865	$898,492
Base M&S ($FY03)	$5,577,968	$281,000
Start	1/1/03	1/1/03
Finish	5/10/07	2/2/06
Milestone	Review Tevatron Alignment Plans	8/1/03

Latest Rolls



Summary

Goals – Configuration Management; Keep Tev Magnets aligned; Reduce corrector currents from saturation.

Status/Plans for Summer/Fall 2003

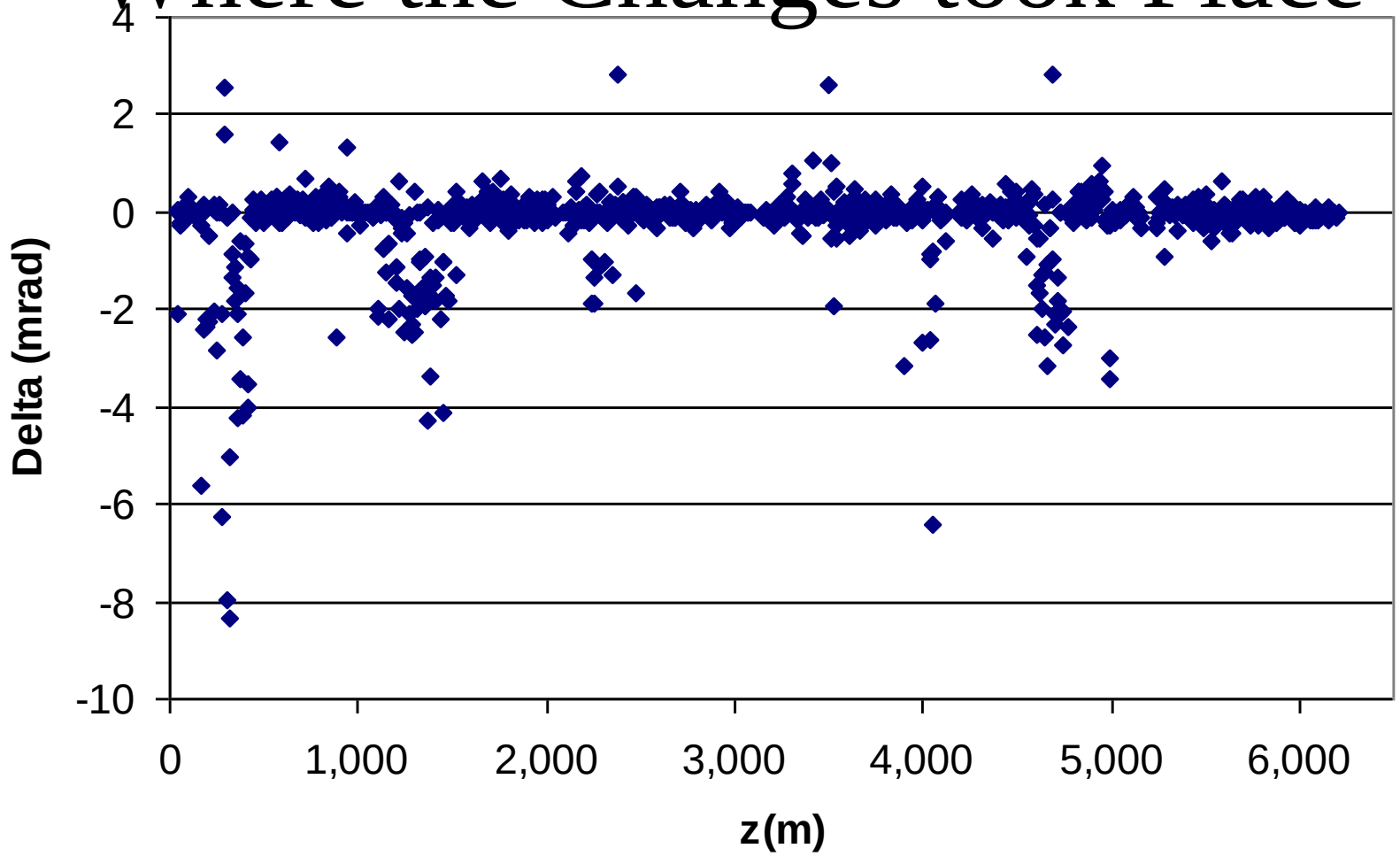
- Install 10 tilt meters to report on-line
- Install 26 HLS in B-sector in '03, ring wide in 2004.
- Upgrade survey system to TevNet (Reviewed recommended.)
- Fix Smart Bolts to limit coupling (Review recommended.)
- Align the magnet; correct rolls and misalignments.

Requires Analysis Resources. (Norm Gelfand, Aimin Xiao)
Depends a great deal on PPD and TD for people and support.
Requires access to the Tevatron tunnel.

Summary of Run II Tevatron Alignment WBS:

WBS 1.3.4.8 Magnet Alignment	R. Stefanski	$280K through July 2005.
WBS 1.3.4.8.1 Orbit/Aperture Optimization	G. Annala	$0
WBS 1.3.4.8.2 TeV On-line Level System	J. Volk	$180K Contingency = $100K
WBS 1.3.4.8.3 Magnet Alignment	R. Stefanski	$100K Contingency = $60K
WBS 1.3.4.8.4 SC coil realignment/smart bolts	D. Harding	$0

Where the Changes took Place



WBS 1.3.4.8.3 Magnet Alignment Roll and Position Corrections

								% magnets	Number of
House	Roll Angle > N mrad							> 1 mrad	Magnets
								roll	Measured
	>1	>2	>3	>4	>5	>6	>7		in house.
A-1	1	1						0.66%	42
A-2	18	11	8	5	2	2	1	11.92%	45
A-3	5							3.31%	41
A-4	3	1						1.99%	35
B-1	20	10						13.25%	42
B-2	19	6	3	1				12.58%	43
B-3	2							1.32%	40
B-4								0.00%	36
C-1	10	2	1	1				6.62%	43
C-2	4	2	1					2.65%	45
C-3								0.00%	40
C-4								0.00%	26
D-1	1							0.66%	41
D-2	6	1						3.97%	44
D-3	1	1						0.66%	38
D-4	8	3	1	1	1			5.30%	33
E-1	1	0						0.66%	43
E-2	17	6						11.26%	44
E-3	23	10						15.23%	40
E-4	6	2						3.97%	36
F-1	1							0.66%	39
F-2	3							1.99%	45
F-3	2							1.32%	40
F-4								0.00%	32
Total > N	151	56	14	8	3	2	1	100.00%	953

The table gives the distribution of rolls among the 16 houses In the Tevatron before the shutdown.

These measurements were redone at the start of the Shutdown. CDF and D0 Experimenters did these measurements. We then Made corrections to as many Magnets as we could, given Other constraints on resources During the shutdown.

Many elevations and horizontal offsets were also be corrected, During the shutdown. However, data from the TevNet installation will not be available until the alalysis is done, perhaps before the Lehman review.

108 magnets had significant Realignment in this period.

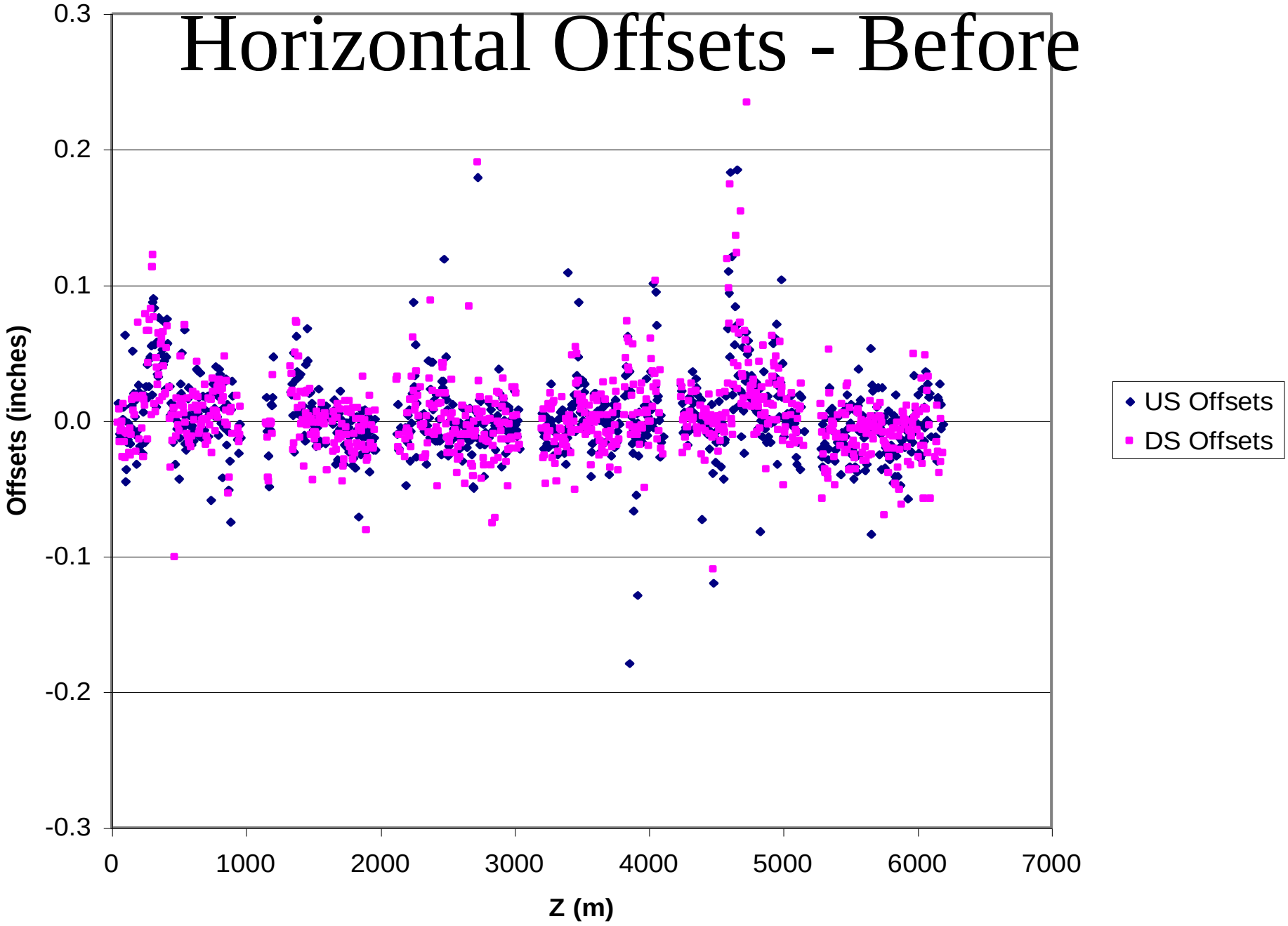
Latest Rolls

	>1	>2	>3
All	58	13	5
A Sector	12	2	0
B Sector	2	0	0
C Sector	5	3	2
D Sector	10	0	0
E Sector	25	8	3
F Sector	4	0	0

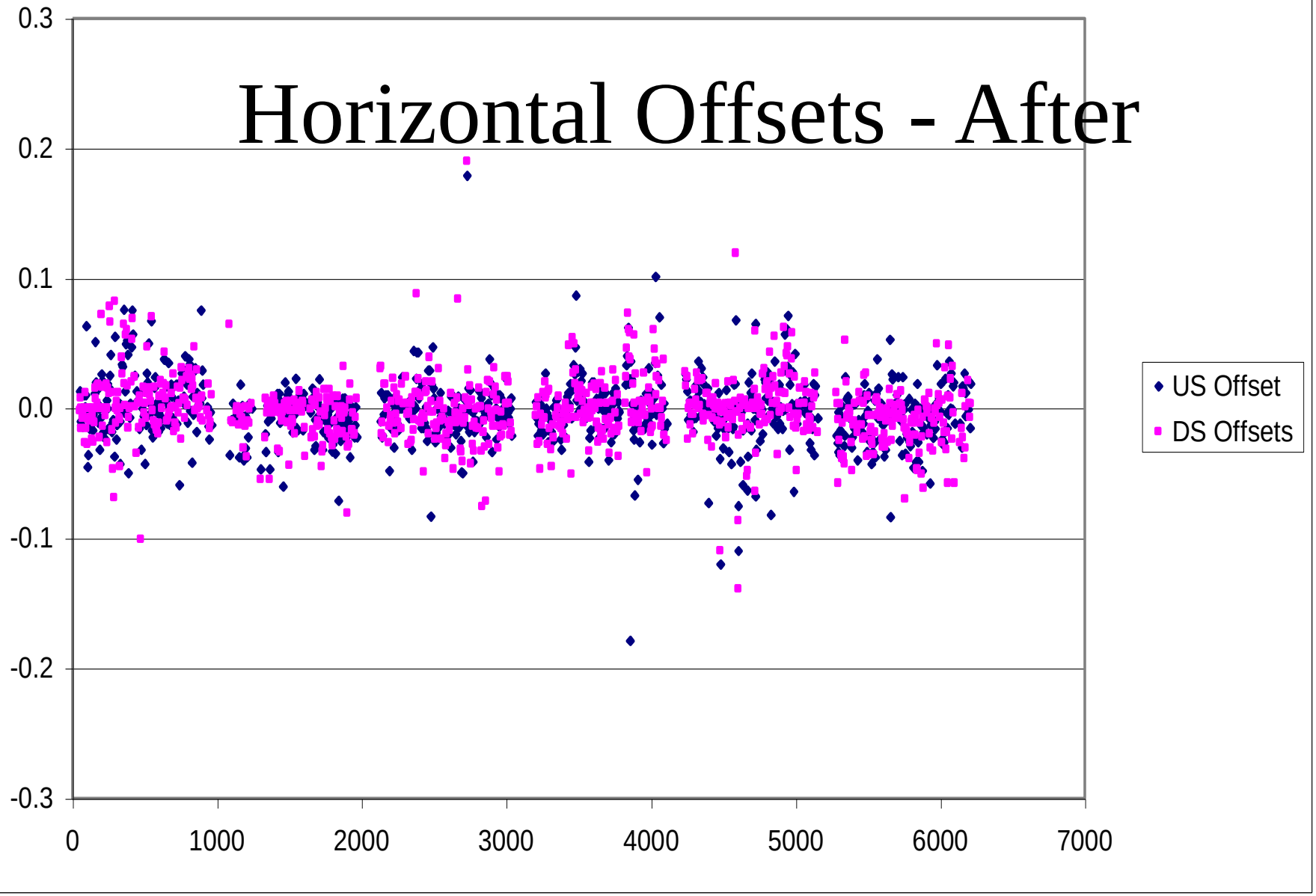
	>1	**>2**	**>3**
A-1	**3**	**0**	**0**
A-2	**2**	**0**	**0**
A-3	**4**	**0**	**0**
A-4	**3**	**2**	**0**
B-1	**0**	**0**	**0**
B-2	**0**	**0**	**0**
B-3	**2**	**0**	**0**
B-4	**0**	**0**	**0**
C-1	**0**	**0**	**0**
C-2	**5**	**3**	**2**
C-3	**0**	**0**	**0**
C-4	**0**	**0**	**0**

	>1	**>2**	**>3**
D-1	1	0	0
D-2	4	0	0
D-3	1	0	0
D-4	4	0	0
E-1	1	0	0
E-2	4	0	0
E-3	17	8	3
E-4	3	0	0
F-1	1	0	0
F-2	2	0	0
F-3	1	0	0
F-4	0	0	0
All	58	13	5

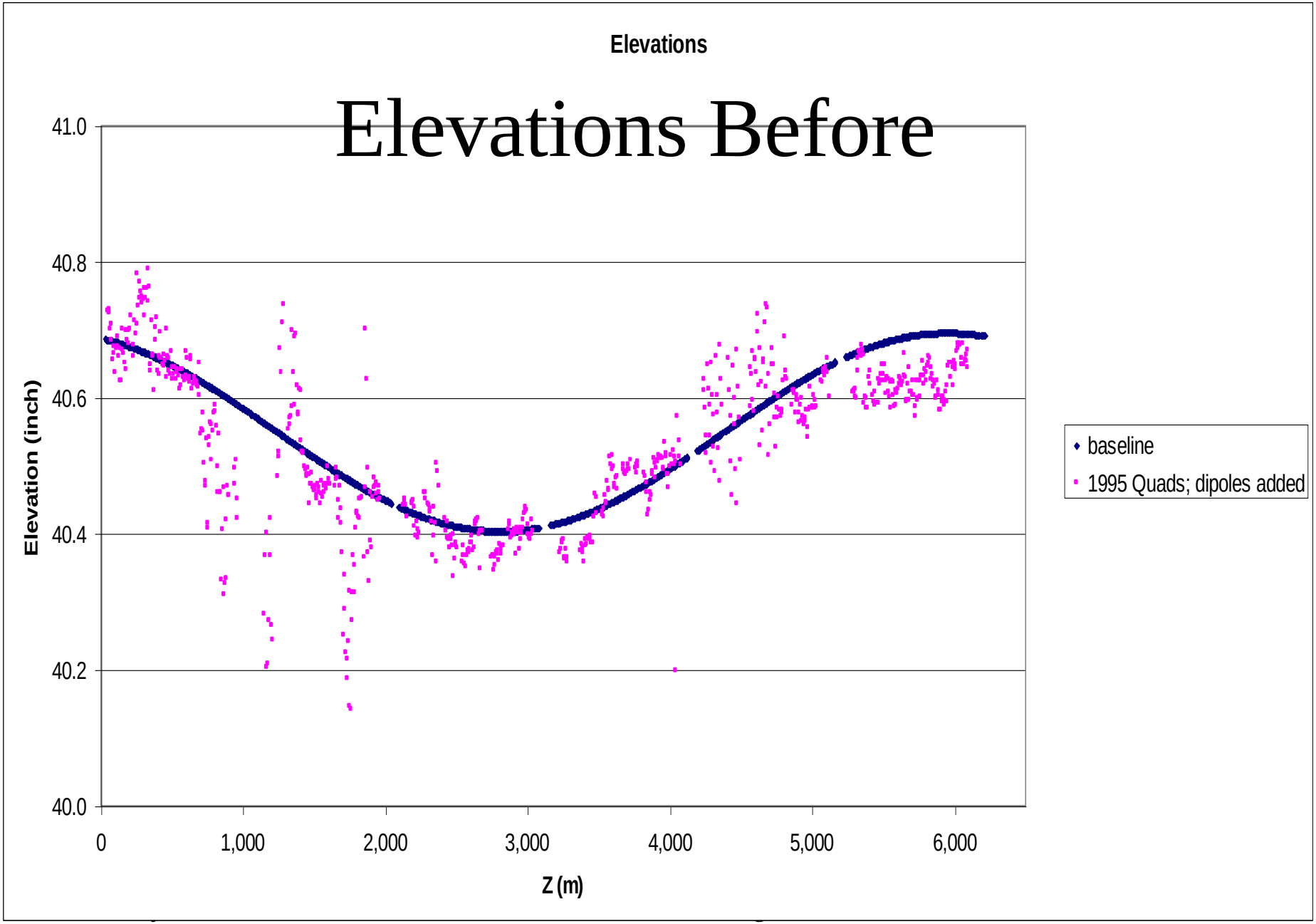
Horizontal Offsets - Before



Horizontal Offsets - After



Elevations Before



Y=40.5485*COS((Z-5953)/1000