Fermi National Accelerator Laboratory

FERMILAB-TM-1916

Coupling in the Tevatron

Norman M. Gelfand

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

December 1994

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

Disclaimer

Coupling in the Tevatron

Norman M. Gelfand *
Fermi National Accelerator Laboratory

December 20, 1994

Introduction

The performance of the Fermilab Tevatron Collider at the commencement of run Ib was far below expectations. After a frustrating period of several months, a low-β quad downstream [1] of the interaction point at B0 was found to be rolled. This rolled quadrupole coupled the horizontal and vertical motion of the Tevatron beams. It also made matching the beam from the Main Ring to the Tevatron impossible, resulting in emittance blow up on injection. The net result of the roll was a significant reduction in the Tevatron luminosity. When the roll in the quadrupole was corrected the performance of the Tevatron improved dramatically. This note will discuss the experimental data indicating the presence of coupling and subsequent calculations which show how coupling can affect the luminosity. It is not intended to exhaust a discussion of coupling, which hopefully will be understood well enough to be discussed in a subsequent note.

*This work performed at the Fermi National Accelerator Laboratory, under contract DE-AC02-76CHO3000 with the U.S. Department of Energy

[1] Downstream and upstream in this note shall refer to the motion of the protons. Thus B11 is downstream of B0.

Coupling

Introduction

Two sets of measurements made with the Tevatron, the measurements of the change in the closed orbit when the strength of a dipole corrector is changed, and the variation in tune as the strength of a quadrupole is changed, both led to the conclusion that the Tevatron was coupled.

In the first case the evidence was the large change in the closed orbit in the crossed plane, the plane orthogonal to the plane of the dipole whose strength was varied. This is shown in figure 1 where the kick was generated using the correction dipole HE13. The rms size of the slope in the crossed plane is $\approx 40\%$ of the rms slope in the kick plane.

In the second case the evidence was anomalously small values of tune shift measured at locations outside of the interaction region. The small tune shifts imply values of β outside of the interaction region comparable to those expected at the interaction point (figure 2). This is clearly inconsistent with any of the usual models of the Tevatron. The values of β calculated from the measurements could not be understood as due to differences, from their nominal values, in the strengths of the lattice elements in the low-β insertion.

It is possible to understand both of these observations if we introduce coupling into the model we have of the Tevatron lattice.

β Measurements

Introduction

The primary source of information about the lattice in this run comes from a series of measurements, using a method pioneered here at Fermilab by Glenn Goderre. The fundamental idea is to apply to the beam a single, known dipole kick, either horizontal or vertical, at a specific location, and measure the resulting change in the closed orbit, at the locations of all the BPMs. To increase the precision of the resulting data, the measurements, of the changed closed orbit, are repeated with a number of different values for the dipole kicks and the slope of the closed orbit value with respect to the size of the dipole kick is calculated.

The correction dipoles located at HE11, HE13, VE11 and VE14 are used to produce the kicks and the closed orbits are measured in *both* planes for each dipole kick. These pairs of correctors are chosen because the phase advance between the locations is large ($\Delta\phi_x =\approx 69^0$) and ($\Delta\phi_y =\approx 95^0$) and yet is not near a multiple of 180°.

When the measurements are made, using the console program C91, the results appear in files [2] containing the slope of the variation in the closed orbit positions at the BPM as the dipole kick is varied.

The procedure just described was developed in order to measure the β function in the Tevatron. The change in the closed orbit at point k, Δu_k due to a dipole kick ($\delta u'_{ui}$) at point i, in the case of an *uncoupled* machine, can be written as:

$$\Delta u_k/\delta u'_{ui} = \sqrt{\beta_{ui}\cdot\beta_{uk}}\cdot\cos\left(\Psi_{ui}-\Psi_{uk}-\mu_u/2\right)/(2\cdot\sin\left(\mu_u/2\right)) \qquad (1)$$

where:
β_{ui} is the value of β_u at the point i;
Ψ_{ui} is the phase in the u plane at point i; and
μ_u is the tune in the u plane.
In the crossed plane, the plane orthogonal to u, there would not be any change in the closed orbit when a kick is applied in the u plane.

As was seen in Figure 1, that is not the case with the data. The slopes in the horizontal plane are comparable to those in the vertical plane when the vertical corrector is varied. Thus the Tevatron is coupled and the coupling is strong.

In a coupled machine the 4 x 4 transfer matrix, which transforms the initial phase space coordinates of a particle $(x, x', y, y')_i$ around the lattice back to the starting point in the lattice, is no longer just two 2 x 2 matrices along the diagonal, with zero for the off diagonal 2 x 2 matrices. As a consequence of this the usual representation of the motion of a particle in the lattice in terms of the horizontal and vertical β functions, viz. β_H and β_V, is not appropriate.

Despite the fact that calculating, and using, the normal β functions is not a correct way of describing the behavior of the beam, it can be helpful in trying to understand what is happening.

---

[2]I want to thank W. Marsh for providing a program which made it possible to access the data in the C91 files.

Consider a horizontal kick $\Delta x'$ at a location a, e.g. E13, and a lattice element with a skew quadrupole field at a location b. The amplitude of the horizontal closed orbit at b, x_b, given by equation (1) is:

$$x_b = \Delta x_i' \cdot \sqrt{\beta_{xa} \cdot \beta_{xb}} \cdot \cos\left(\Psi_{xa} - \Psi_{xb} - \mu_x/2\right)/(2 \cdot \sin\left(\mu_x/2\right)) \qquad (2)$$

A finite horizontal amplitude at the position of the coupling, b, results in a vertical kick, $\Delta y'$, equal to $x_b \cdot r_b$ where: r_b is the skew quadrupole strength of the coupling element.

This vertical kick will modify the vertical closed orbit whose amplitude, at a point c is again given by equation (1):

$$y_c = r_b \cdot x_b \cdot \sqrt{\beta_{yc} \cdot \beta_{yb}} \cdot \cos\left(\Psi_{yc} - \Psi_{yb} - \mu_y/2\right)/(2 \cdot \sin\left(\mu_y/2\right)) \qquad (3)$$

Combining equation (2) and equation (3) we see that the amplitude in the crossed plane is proportional to:

$$y_c \propto r_b \cdot \sqrt{\beta_{xb} \cdot \beta_{yb}}.$$

The effect in the crossed plane, due to a coupling element of a given magnitude, will be greatest if the element is located at a place in the lattice where the product

$$\sqrt{\beta_x \cdot \beta_y}$$

is large. [3]

We can compute the lattice functions for the design lattice of the Tevatron and compute $\sqrt{\beta_x \cdot \beta_y}$ for the different points in the lattice. The results, for a section of the lattice, are plotted in figure 3. It is clear that the largest values for $\sqrt{\beta_x \cdot \beta_y}$ occur in the low-β triplet, and in particular in the outside elements of the triplet, the Q2 magnets. It is therefore natural to look for the source of the coupling, observed in the cross plane orbit data taken in the Tevatron, in the quadrupoles of the low-β triplets.

[3] We see also the value, if not the necessity, of using more than one corrector in each plane. For a given choice of corrector the argument of the cosine function in equation (3) might be close to an odd multiple of $\pi/2$. In this case we would not see any effect in the cross plane. By choosing two correctors, with a large phase advance between them, we are able to see the effect of the coupling in at least one set of data.

These closed orbit data unfortunately do not allow the identification of which element is producing the coupling, or even on which side of the interaction region (IR) the coupling occurs. This can be seen by looking once again at equations (2) and (3) and noticing that the phase advance across the elements of the triplet are small (due to the large value of β in the triplet elements compared to their lengths) and that the phase advance across the low-β insertion is very close to 180°.

We can get the same vertical kick, $\Delta y'$, from different elements in the triplet, by adjusting the, unknown, strength of the coupling element to compensate for the different values of β in the different elements of the triplet. The value y_c will not change because the phase advance $\Psi_{yc} - \Psi_{yb}$ will not change significantly as I change the element in the triplet causing the coupling. Thus the triplet element causing the coupling can not be identified.

Across the IR the phase advance, in both planes, is $\approx 180°$. If the size of the closed orbit change due to the kick at a is δx on the upstream side of the IR it will be $-\delta x \cdot \sqrt{\beta_d/\beta_u}$ at the corresponding point on the down stream side. Adjusting the value of r_b the magnitude of vertical closed orbit at the point c will be the same, regardless of which side of the IR we have the coupling, because the phase advance in the y plane from point b to point c has also changed by 180°.

Measurements of the change in the closed orbit inside the IR can eliminate the ambiguities.

Analysis of the Data

The normal model of the Tevatron, whether in SYNCH, Tevlat, Tevconfig, MAD ..., contains no skew elements [4] except for the skew quadrupole and skew sextupole elements located in the Tevatron spool packages, and the high order skew moments in the Tevatron magnets. The high order skew elements are not strong enough to account for the magnitude of the observed closed orbits in the crossed planes. The values in the skew quadrupoles are adjusted to bring the tunes in the two planes together, i.e. to reduce the coupling, and therefore should not be the source of the coupling.

In order to study the source of the coupling we have to introduce into the description of the Tevatron lattice skew elements, whose strengths can

[4] Any of these models can, of course, be modified to include effects, such as rolls, that could produce coupling.

be varied. Zero length skew quadrupoles were inserted into the description of the lattice at the location of each of the quadrupoles in the lattice. These *pseudo* elements do not exist in the real machine but are used to reproduce effects, e.g. the change in the closed orbit in the cross plane, that are seen during Tevatron operation.

This modified lattice has been used with a version of the tracking code Tevlat [5] which allows fitting experimental data with MINUIT, varying the parameters of lattice elements in the course of the fit.

We begin with the closed orbit data, both for the kick plane and in the crossed plane, in C91 files # 18,19,20 and 21 taken on 3/15/94. The slopes of the original data have been converted into a closed orbit by assuming a kick of $30\mu r$ at the corrector. The results of fitting all four closed orbits, simultaneously with a single set of parameters are shown in figures 4a,4b,4c,4d. [6] Reasonable, though not totally satisfactory, solutions are found assuming skew quadrupole fields at the location of Q2 quadrupoles down stream of the IR at both B0 and D0.

It is possible, but not really meaningful, to convert the fitted values of these skew moments into a roll of the corresponding quadrupole. There is no reason to believe that the quad selected for the skew moment is the actual rolled quad. Nonetheless if we use the fitted skew moments and assume that the computed value is due to a roll in the appropriate quads in the B0 and D0 interaction region, we find that the roll would be of the order of a few mr.

Subsequent to the analysis described above, a survey was performed of the accessible low-β magnets at B0. A roll of $\approx 7mr$ was found in the downstream Q2. With the culprit identified it made sense to redo the fitting with the skew moment represented by a roll in the magnet. In this refitting the strengths of the skew correctors at A0(T:SQA0), B0(T:SQB0), and D0(T:SQD0) were fixed at values given by the currents in the spool elements used when the data were taken. The strength of the skew corrector circuit SQ was left as a parameter in the fitting, as were the strengths of the tuning quadrupoles and the rolls of the downstream Q2 quadrupoles at B0 and D0. The strengths of

[5] The original version of Tevlat was written by A. Russell

[6] The data in figures 4a,5a,6a and 7a are from the kick at HE11; in figures 4b,5b,6b and 7b are from the kick at HE13; in figures 4c,5c,6c and 7c are from the kick at VE13; in figures 4d,5d,6d and 7d are from the kick at VE14. The figures labeled as differences are the differences between the fitted closed orbit and the measured closed orbit.

the low-β quads were not varied and were set at the values given by C49.

The results of the fitting are shown in figure 5a,5b,5c, and 5d. The quality of the fits is similar to the fits done with the pseudo-quads. The fit gives a value of $+7.0mr$ for the roll in the downstream Q2 at B0 and -$1.4mr$ for the downstream Q2 at D0. I would estimate that the uncertainty in these values is $\approx 1mr$. The agreement with the survey result is striking, but should not be overemphasized. We have represented all the skew effects by the roll in a single magnet which is certainly not the case. We get the correct value in this instance because of the large roll in a single magnet. When the skew effects are distributed among several magnets we cannot expect to find the individual rolls using this technique for the reasons given earlier.

The roll of the downstream Q2 at B0 was corrected and the β measurements were repeated, again using C91, and the data was stored in files #201, 202, 203, 204 (the data were taken on 7/22/94). The crossed plane amplitudes have been reduced by approximately a factor of 2 from the earlier measurements. Even after correcting the roll in the upstream Q2 at B0 there is still a considerable amplitude in the crossed plane. Not all the coupling has been removed by unrolling the quad upstream Q2 at B0.

The data have been fit using the same procedures used to fit the earlier data. The results are shown in fig #6a, 6b, 6c and 6d. [7] The results show a reduction in the roll of the upstream Q2 at B0 to $\approx 0.3mr$. The fit now indicates a roll of the downstream Q2 at D0 of $\approx -1.5mr$ compared to the $\approx -1.4mr$ found earlier. It is reassuring that the same value for the roll at D0 is found here as in the earlier solution since no change was made to the magnets at D0.

During the long shutdown in Sept. 1994, the accessible triplet quads at B0 and D0 were surveyed and any measured rolls were removed. The β measurements were repeated. The results contained in files #250,251,252,and 253, (the data were taken on 9/30/94) show a further reduction in the slope of the closed orbit in the crossed plane. The data have been fit as before and here again the rolls of the upstream quad at D0 and at B0 were allowed to vary. The results of the fitting are shown in figure # 7a ,7b ,7c, and 7d. The fitted values for the roll in the Q2 at B0($\approx 0.5mr$) and D0($\approx 0.2mr$) are now very small and are consistent with zero.

Though the coupling from the interaction regions is considerably de-

[7]Please note that the vertical scale has been changed.

creased there is still a fair amount of coupling left in the Tevatron. Comparing the recent crossed plane data to the original data we find that the crossed plane amplitudes have been reduced by approximately a factor of 2. The fitting described above assumed that the coupling was in the low-β regions and so does not give a particularly good fit to the crossed plane closed orbit data because the coupling is not where I have assumed it to be. Further study will be needed to identify the source of this coupling.

A summary of the results is contained in table I.

Table I
Summary of Results from Fitting Closed Orbit Data

	Rolled B2	**Unroll B2**	**Unroll all**
C91 Files used in fit	18,19, 20,21	201,202, 203,204	251,252, 253,254
Variable	Fitted value	Fitted value	Fitted value
Tune quads ckt 1 ($/m$)	6.1E-04	6.5E-04	6.5E-04
Tune quads ckt 2 ($/m$)	-6.5E-04	-6.8E-04	-6.9E-04
Skew quad ckt SQ ($/m$)	-1.5E-05	-7.5E-05	-7.5E-05
Skew quad ckt SQA0 ($/m$)	-1.8E-03	-8.31E-04	-5.1E-04
Skew quad ckt SQB0 ($/m$)	-8.43E-04	1.75E-04	0
Skew quad ckt SQD0 ($/m$)	-1.6E-04	3.5E-04	0
Rotation, DS Q2 at B0 (mr)	7.0	0.29	0.49
Rotation, DS Q2 at D0 (mr)	-1.4	-1.5	0.20

Tune Shift

Introduction

The traditional method of measuring the value of β at a location in an accelerator is to vary the gradient of a quadrupole at that location and measure the resulting tune shift. In the *absence* of coupling the tune shift is related to the value of β, viz.

$$\delta\nu = (1/4\pi)\cdot\frac{\beta\cdot l\cdot\Delta B'}{[B\rho]} \tag{4}$$

where:
β is the value of the β function where the quadrupole is varied;

l is the length of the quadrupole;
$\Delta B'$ is the change of the gradient in the quadrupole;
$[B\rho]$ is the magnetic rigidity or momentum.

The data that I will analyze were taken on 4/24/94, before the unroll of the downstream Q2 at B0. The current in the different correction quadrupoles at B0 was varied and the tunes measured. Equation 4 was used to compute values of β from the data. The results were seen in figure 2.

In a coupled machine the simple relationship of equation 4 is no longer true. It is however possible to fit the measured tune shift as a function of quadrupole strength ($\Delta B'$ in the above equation) using a model of the Tevatron and MINUIT. The parameters used were the same as the ones used to fit the closed orbit data, viz. the strengths of the tuning quadrupoles, the strength of the skew quadrupole circuit T:SQ, and the rolls in the downstream quad at B0. The value of the roll in the downstream quad at D0 was fixed at -1.4mr from our fit to the closed orbit data. This was done because we have no tune shift data taken by varying the quads near the D0 interaction region.

For the original case, the only case for which we have data, the solution for the roll at B0(+6.5mr) agrees very well with the values found from fitting the closed orbit data. It is reassuring that two independent methods find the same roll for the quadrupole at B0. That they agree with the survey is even more astonishing.

Summary of Coupling Analysis

Measurements made with closed orbits and tune shifts both indicated that the Tevatron was coupled. A computed model was constructed in which it was assumed that the coupling was due to a roll in the downstream Q2 magnets at B0 and D0. The model was used with MINUIT to find the magnitudes of the rolls. Where both sets of measurements exist they give consistent values for the rolls and which furthermore agree with the survey data taken after the measurements were made.

Analysis of the data taken after surveys of the low-β quadrupoles, and correction of the observed rolls, indicate, as expected, sharply reduced rolls, and hence of the coupling. There is still significant coupling in the Tevatron.

Luminosity

Introduction

The objective for the Tevatron is to produce high luminosity at the interaction regions at B0 and D0. The luminosity is inversely related to the size of the p and $\overline{p}$ beams, when they collide. In an uncoupled accelerator (with no non-linear elements) the size of a beam at a given point in the lattice can be expressed in terms of the emittance (ϵ), which is invariant as one moves from point to point in the lattice, and the function $\beta(z)$, where the coordinate z identifies where in the lattice we are measuring β. The size, σ, of the beam is given, when either the dispersion η or the momentum spread dp/p is zero, by

$$\sigma_{rms} = \sqrt{\beta \cdot \epsilon_{rms}}.$$

The luminosity, $\mathcal{L}$ is then

$$\mathcal{L} \propto \frac{1}{\sqrt{\beta_x \cdot \epsilon_x(rms) \cdot \beta_y \cdot \epsilon_y(rms)}}$$

In the case where we have a coupled machine it is not possible to use the normal horizontal and vertical β functions to calculate the beam size. In order to see the effect of the coupling on the beam size, and hence on the luminosity Tevlat was used to track a distribution of 1000 particles for a thousand turns. The initial particle distribution was generated assuming the design lattice with no coupling. The values σ_x and σ_y for the distribution were chosen so that the particles had a 95% normalized emittance, $\epsilon_n(95\%) = 25\pi mmmr$.

In the tracking for each turn the value of σ for the particle distribution was calculated at D0 and B0 for both planes. The σs vary from turn to turn since the original distribution was not a stationary distribution. The values of σ were therefore averaged over 100 turns. The resulting average values for σ , which go into the calculation of $\mathcal{L}$ are very constant over the several thousand turns for which we have tracked.

Calculations and Results

The computed values of $\sqrt{\sigma_x \cdot \sigma_y}$ at B0 and D0 are plotted in figure 8 for four configurations of the Tevatron:

- The design lattice with $\beta^* \approx 0.35m$.
- The solution found for data taken with the downstream Q2 at B0 rolled.
- The solution found for data taken after the roll of the downstream Q2 at B0 was corrected.
- The solution found for data taken after the shut down in 9/94.

The calculated radius of the beam, $\propto (\sigma_x \cdot \sigma_y)^{1/2}$, at B0 after the roll of the Q2 was removed, $\approx 46\mu$ (see figure 8) is $\approx 74\%$ of the calculated radius using the fit to data where the Q2 was rolled. This decrease in radius should translate into an $\approx 80\%$ increase in the luminosity. [8] There is a much smaller change in the beam radius at D0 with the changes in the quad rolls, the unrolled value is $\approx 93\%$ of the value with the rolled Q2.

Figure 9 shows the equivalent beam size at the interaction point computed from the *measured* luminosity and beam intensities for a number of stores before and after the unroll of the downstream Q2 at B0.

The equivalent beam radius is

$$(\sigma_x \cdot \sigma_y)^{1/2} = \frac{N_p \cdot N_{\bar{p}}}{\mathcal{L}}$$

where:
$\mathcal{L}$ is the measured luminosity at the start of the store;
N_p is the measured proton intensity at the start of the store;
and $N_{\bar{p}}$ is the measured pbar intensity at the start of the store.

The effect of the unroll of the Q2 is clearly seen. The size of the beam at the interaction region at B0 clearly decreased when the quad was unrolled. Because of the variation in the beam emittances from one store to the next a simple comparison between the calculation described above and the measurements is not possible. We can however average the size of the beam calculated from the luminosity and the bunch intensities from stores before and after the correction of the roll. When we compare the averages we find that the beam size at the interaction region at B0 decreased by by $\approx 63 \pm 13\%$. The beam size at D0 did not change significantly. This is in

[8]The luminosity is $\propto 1/r^2$. I have not calculated the size of beam at other than the nominal interaction point and therefore have not calculated the luminosity by integrating over the bunch length

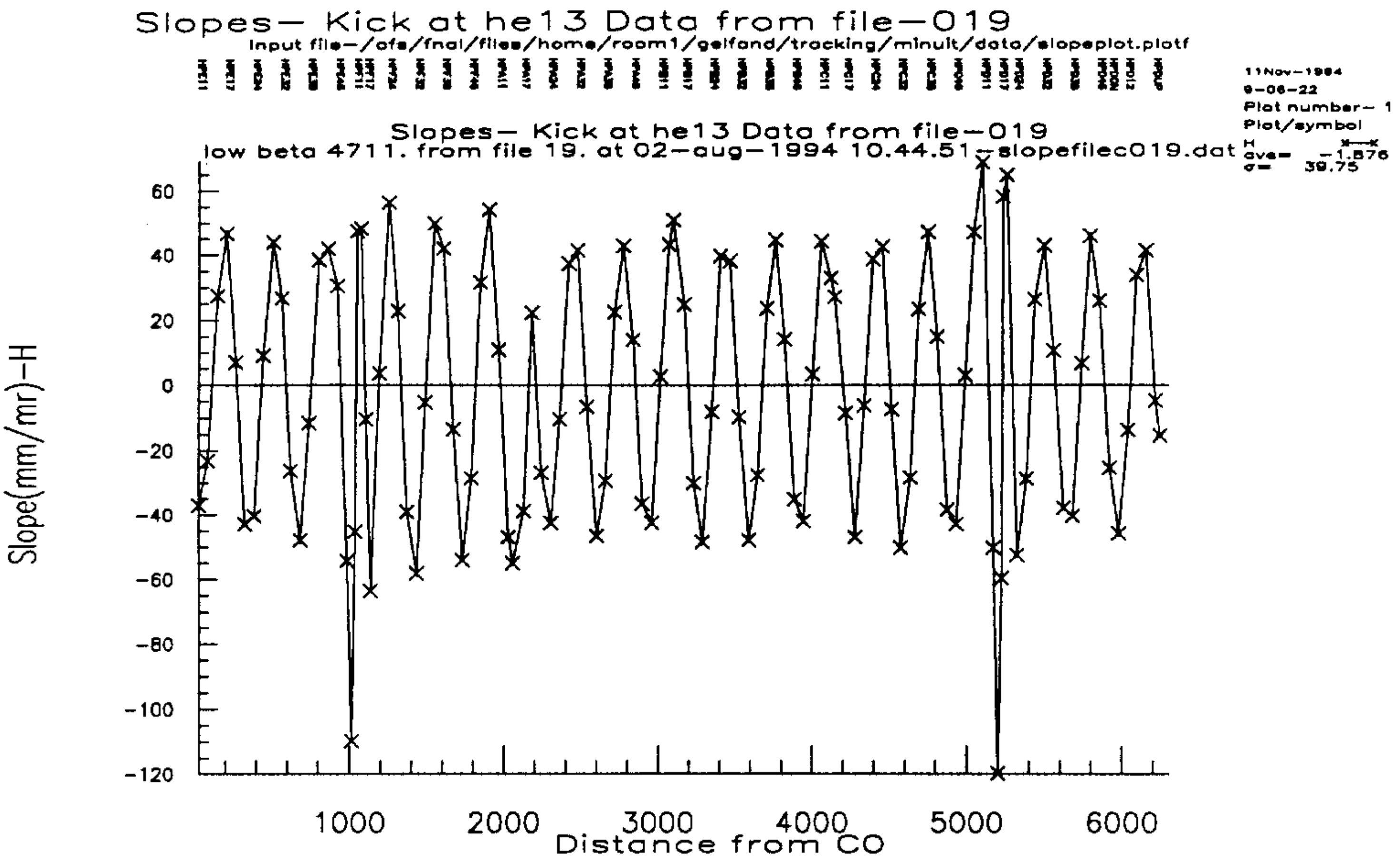
good agreement with the change predicted by the calculation in Tevlat of the beam size.

Conclusion

The data taken in the β measurements can be used to study coupling in the Tevatron. From the measurements it seems possible to construct a reasonable model of the Tevatron which, together with tracking can be used to calculate the Tevatron luminosity.

Acknowledgments

The data analyzed here were obtained by a number of members of the Accelerator Division as part of an extensive series of measurements performed to better understand and improve the Tevatron. Among those responsible for the data used in this note are G. Annala, S. Assadi, G. Goderre, G. Jackson and W. Marsh. I wish to express my gratitude to them first for taking the data with such care, and then for making it available in a form convenient for analysis.


Slopes— Kick at he13 Data from file—019
Input file—/afs/fnal/files/home/room1/gelfand/tracking/minuit/data/slopeplot.plotf
11Nov—1994
9-06-22
Plot number— 1
Plot/symbol
Slopes— Kick at he13 Data from file—019
low beta 4711. from file 19. at 02—aug—1994 10.44.51—slopefilec019.dat
H
ave= -1.576
σ= 39.75
Slope(mm/mr)-H
Distance from CO

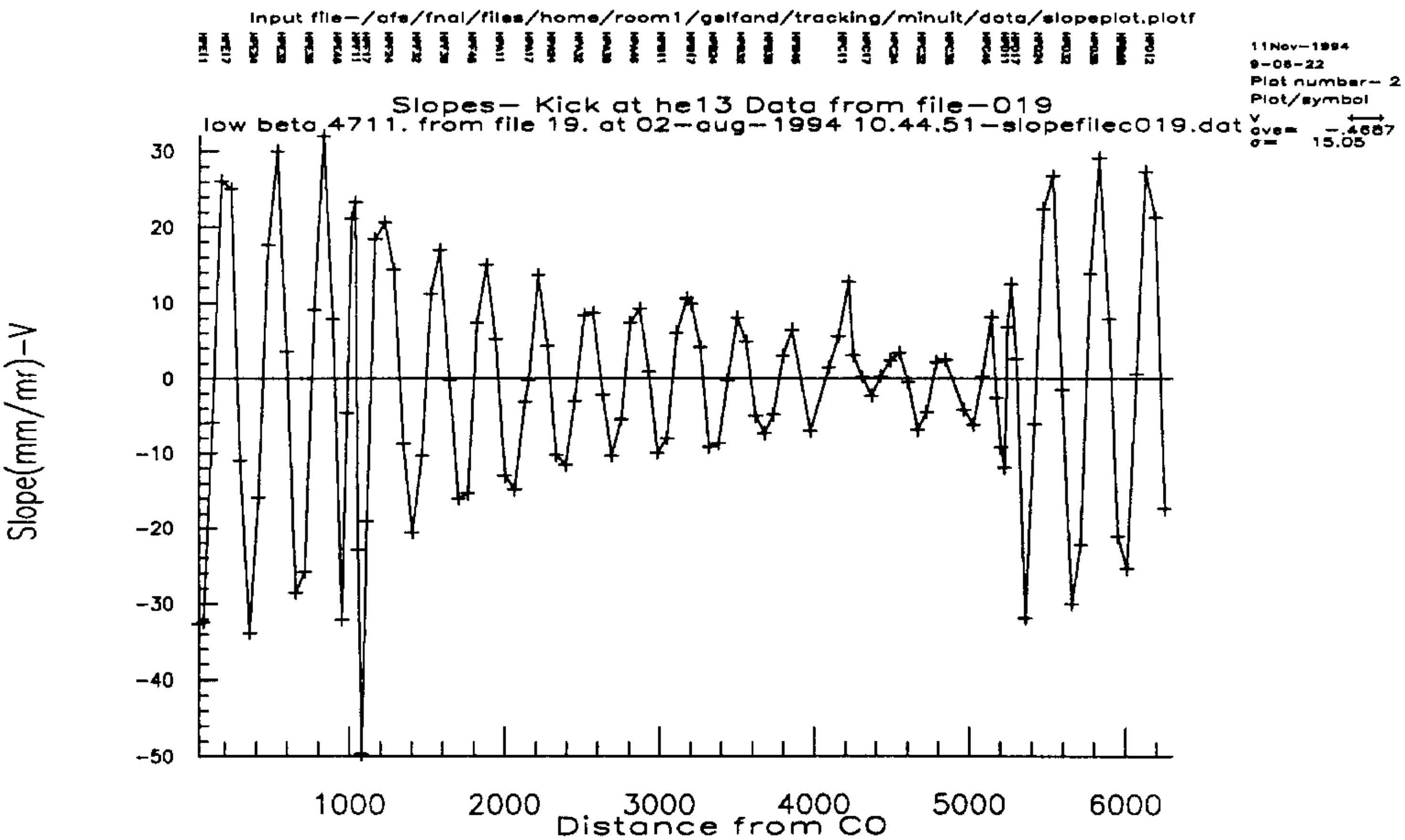
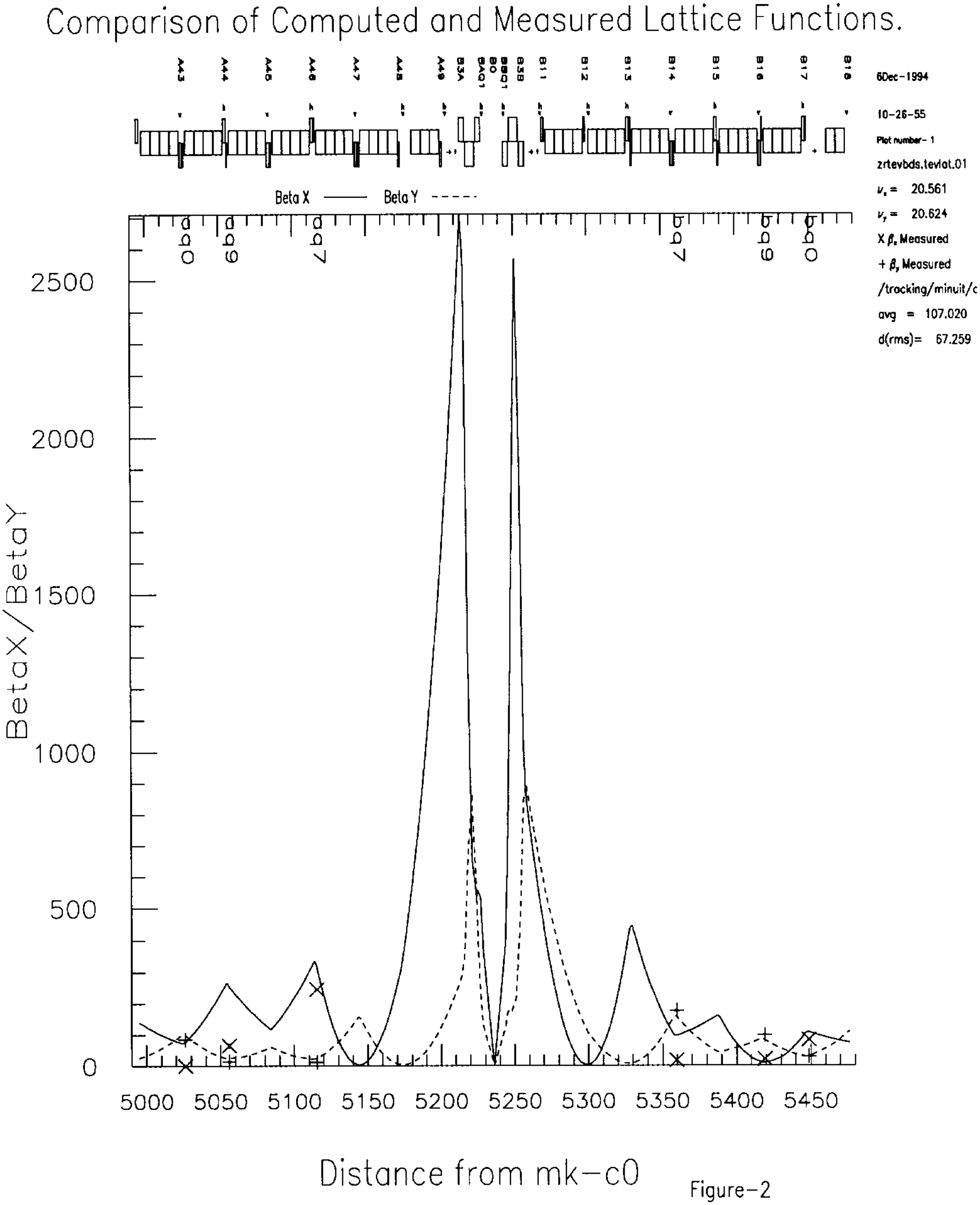
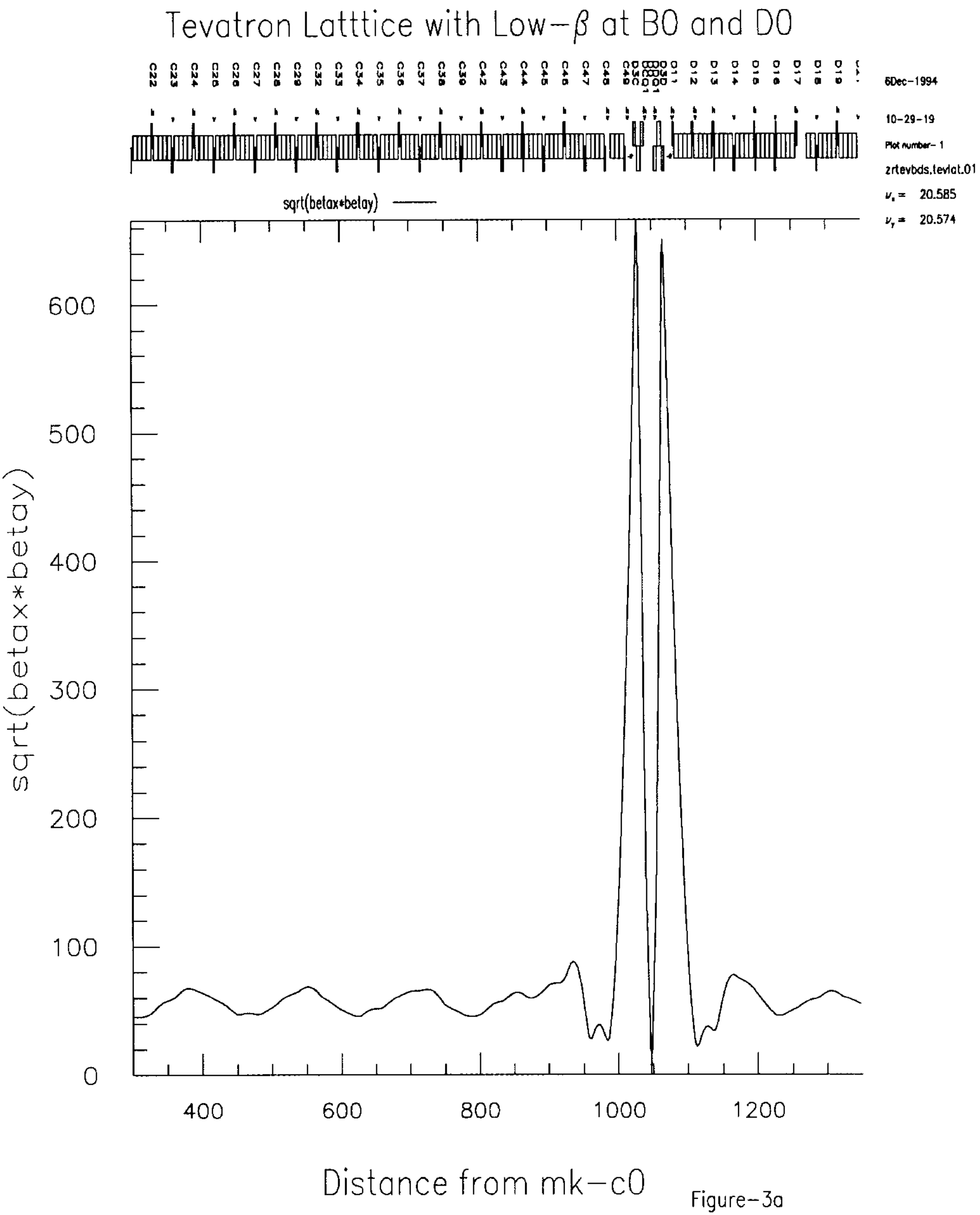

Input file—/afs/fnal/files/home/room1/gelfand/tracking/minuit/data/slopeplot.plotf
11Nov—1994
9-06-22
Plot number— 2
Plot/symbol
Slopes— Kick at he13 Data from file—019
low beta 4711. from file 19. at 02—aug—1994 10.44.51—slopefilec019.dat
V
ave= -.4687
σ= 15.05
Slope(mm/mr)-V
Distance from CO

Figure 1

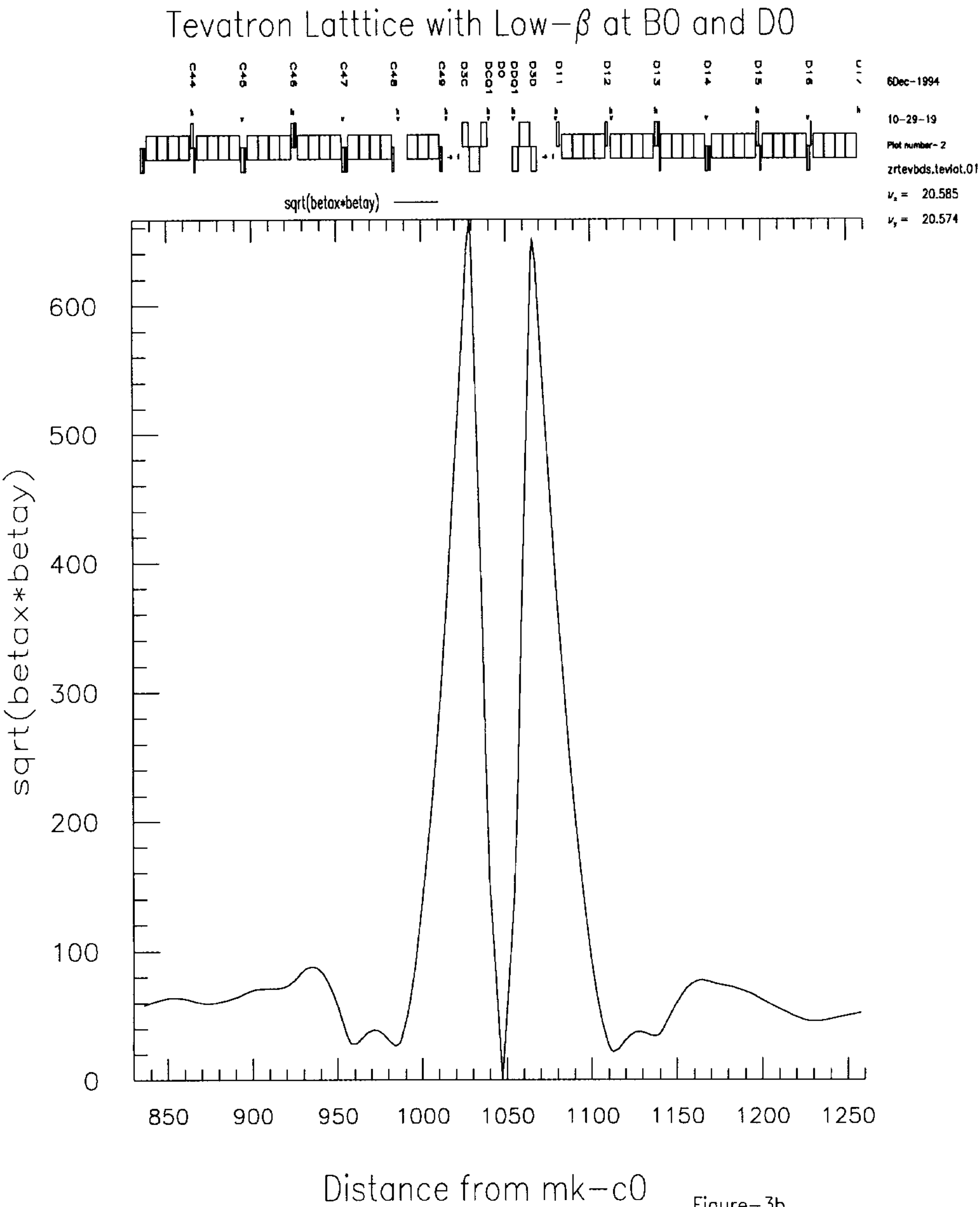


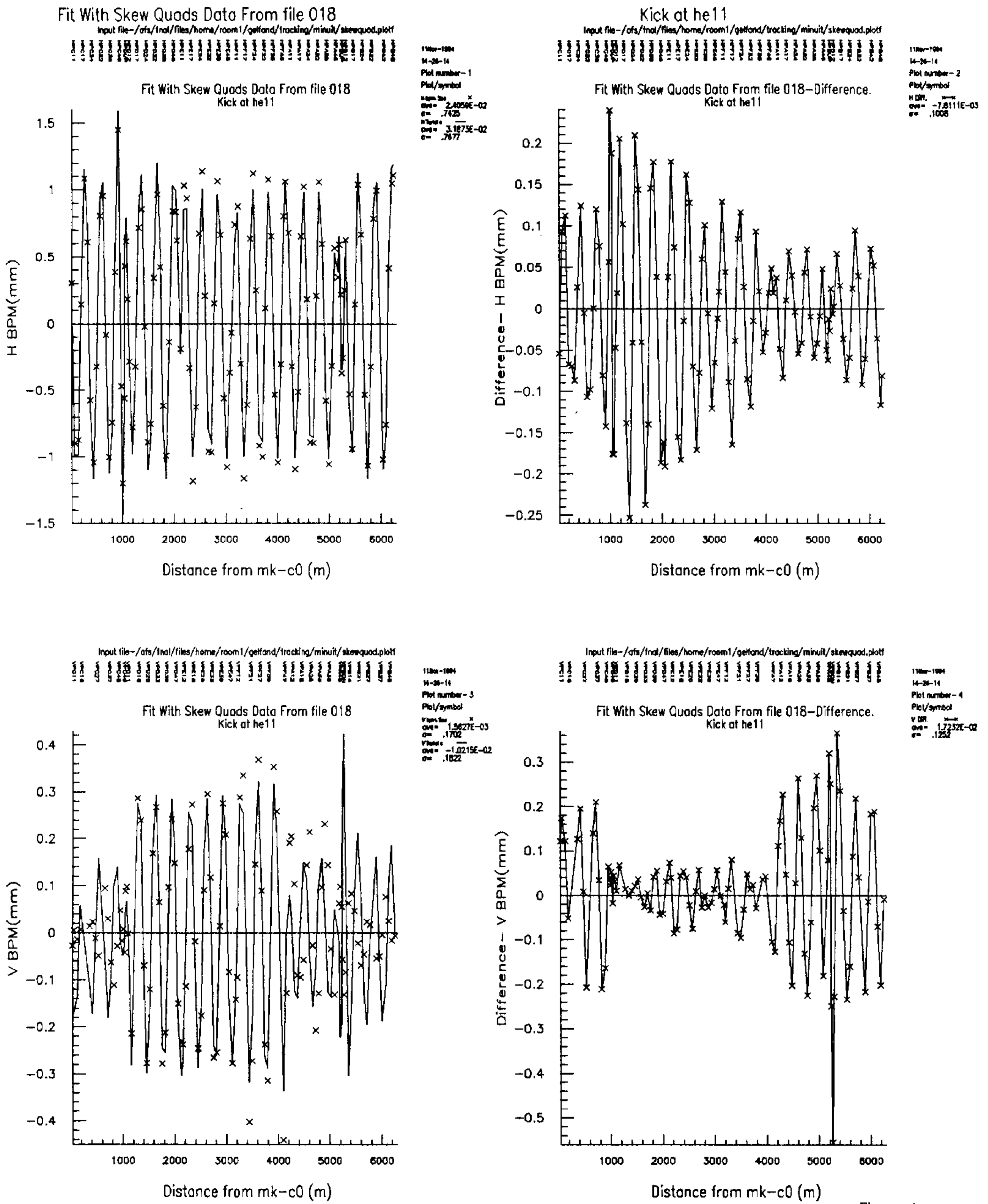
Comparison of Computed and Measured Lattice Functions.
A43
A44
A45
A46
A47
A48
A49
B3A
BAQ1
B0
BBQ1
B3B
B11
B12
B13
B14
B15
B16
B17
B18
6Dec-1994
10-26-55
Plot number- 1
zrtevbds.tevlat.01
ν_x = 20.561
ν_y = 20.624
X β_x Measured
+ β_y Measured
/tracking/minuit/c
avg = 107.020
d(rms)= 67.259
Beta X
Beta Y
BetaX/BetaY
0
500
1000
1500
2000
2500
5000
5050
5100
5150
5200
5250
5300
5350
5400
5450
Distance from mk-c0

Figure-2


Tevatron Latttice with Low−β at B0 and D0
6Dec−1994
10-29-19
Plot number- 1
zrtevbds.tevlat.01
ν_x = 20.585
ν_y = 20.574
sqrt(betax*betay)
sqrt(betax*betay)
Distance from mk−c0

Figure−3a


Tevatron Latttice with Low-β at B0 and D0
6Dec-1994
10-29-19
Plot number- 2
zrtevbds.tevlot.01
νx = 20.585
νy = 20.574
sqrt(betax*betay)
Distance from mk-c0
850
900
950
1000
1050
1100
1150
1200
1250
0
100
200
300
400
500
600
Figure-3b



Fit With Skew Quads Data From file 018
Kick at he11
Input file-/afs/fnal/files/home/room1/gelfand/tracking/minuit/skewquad.plotf
Plot number- 1
Plot/symbol
Fit With Skew Quads Data From file 018
Kick at he11
ave= 2.4059E-02
σ= .7625
ave= 3.1873E-02
σ= .7677
H BPM(mm)
Distance from mk-c0 (m)
Plot number- 2
Plot/symbol
Fit With Skew Quads Data From file 018-Difference.
Kick at he11
H Diff.
ave= -7.8111E-03
σ= .1006
Difference- H BPM(mm)
Distance from mk-c0 (m)
Plot number- 3
Plot/symbol
Fit With Skew Quads Data From file 018
Kick at he11
ave= 1.5627E-03
σ= .1702
ave= -1.0215E-02
σ= .1822
V BPM(mm)
Distance from mk-c0 (m)
Plot number- 4
Plot/symbol
Fit With Skew Quads Data From file 018-Difference.
Kick at he11
V Diff.
ave= 1.7232E-02
σ= .1252
Difference- V BPM(mm)
Distance from mk-c0 (m)

Figure 4a

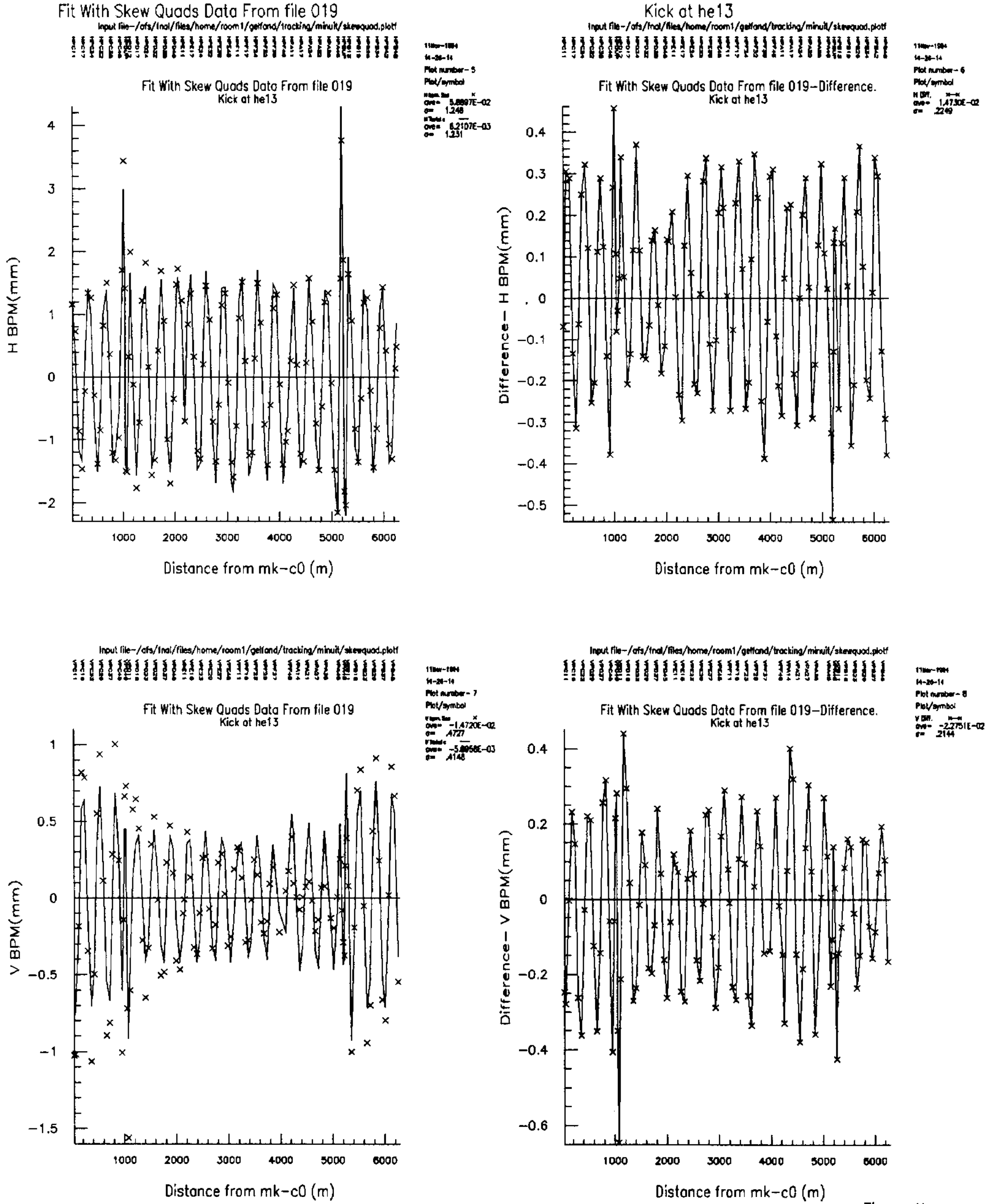
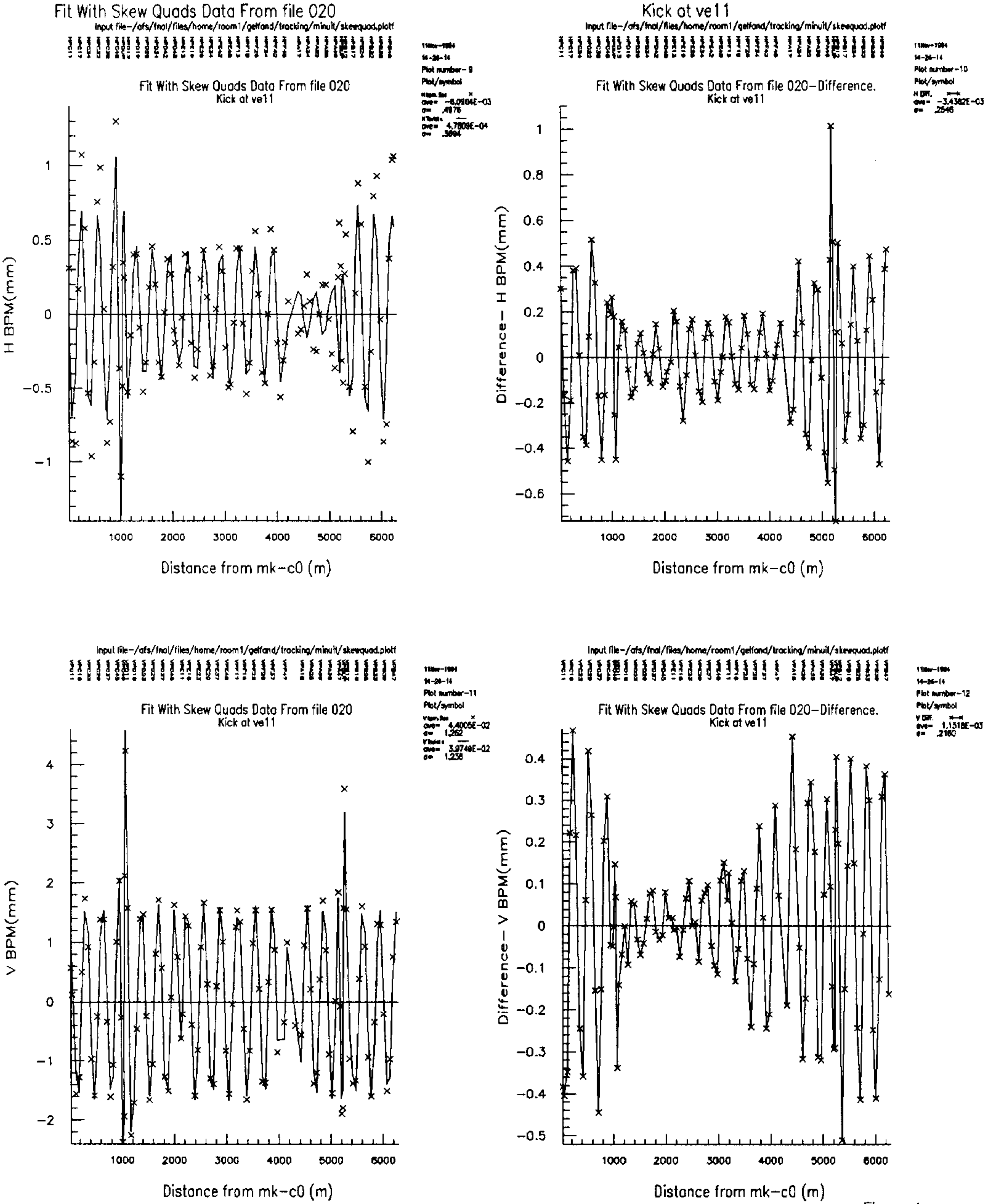

Fit With Skew Quads Data From file 019
Input file-/afs/fnal/files/home/room1/gelfand/tracking/minuit/skewquad.plotf
Plot number- 5
Plot/symbol
Fit With Skew Quads Data From file 019
Kick at he13
H BPM(mm)
Distance from mk-c0 (m)
Kick at he13
Input file-/afs/fnal/files/home/room1/gelfand/tracking/minuit/skewquad.plotf
Plot number- 6
Plot/symbol
Fit With Skew Quads Data From file 019-Difference.
Kick at he13
Difference- H BPM(mm)
Distance from mk-c0 (m)
Input file-/afs/fnal/files/home/room1/gelfand/tracking/minuit/skewquad.plotf
Plot number- 7
Plot/symbol
Fit With Skew Quads Data From file 019
Kick at he13
V BPM(mm)
Distance from mk-c0 (m)
Input file-/afs/fnal/files/home/room1/gelfand/tracking/minuit/skewquad.plotf
Plot number- 8
Plot/symbol
Fit With Skew Quads Data From file 019-Difference.
Kick at he13
Difference- V BPM(mm)
Distance from mk-c0 (m)

Figure 4b

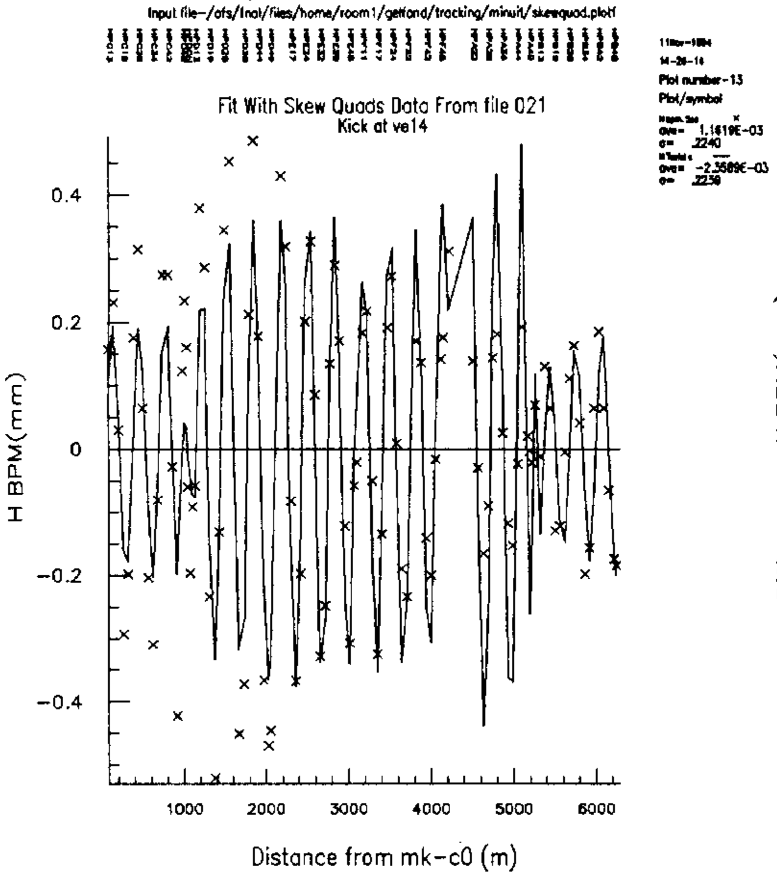


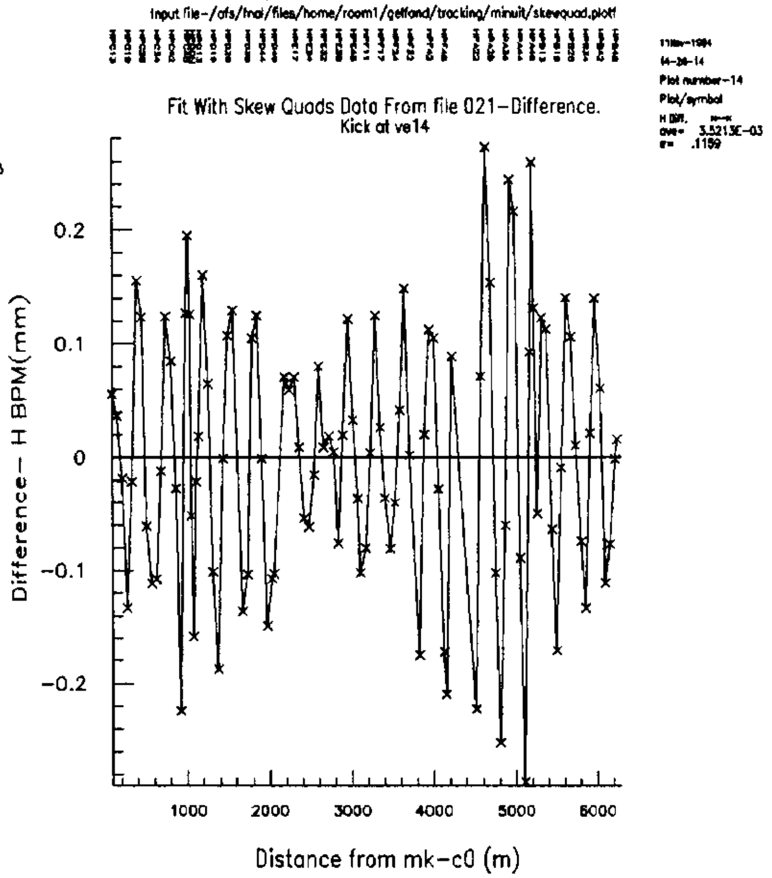
Fit With Skew Quads Data From file 020
Kick at ve11
Plot number-9
Plot/symbol
Fit With Skew Quads Data From file 020
Kick at ve11
H BPM(mm)
Distance from mk-c0 (m)
Plot number-10
Plot/symbol
Fit With Skew Quads Data From file 020-Difference.
Kick at ve11
Difference- H BPM(mm)
Distance from mk-c0 (m)
Plot number-11
Plot/symbol
Fit With Skew Quads Data From file 020
Kick at ve11
V BPM(mm)
Distance from mk-c0 (m)
Plot number-12
Plot/symbol
Fit With Skew Quads Data From file 020-Difference.
Kick at ve11
Difference- V BPM(mm)
Distance from mk-c0 (m)

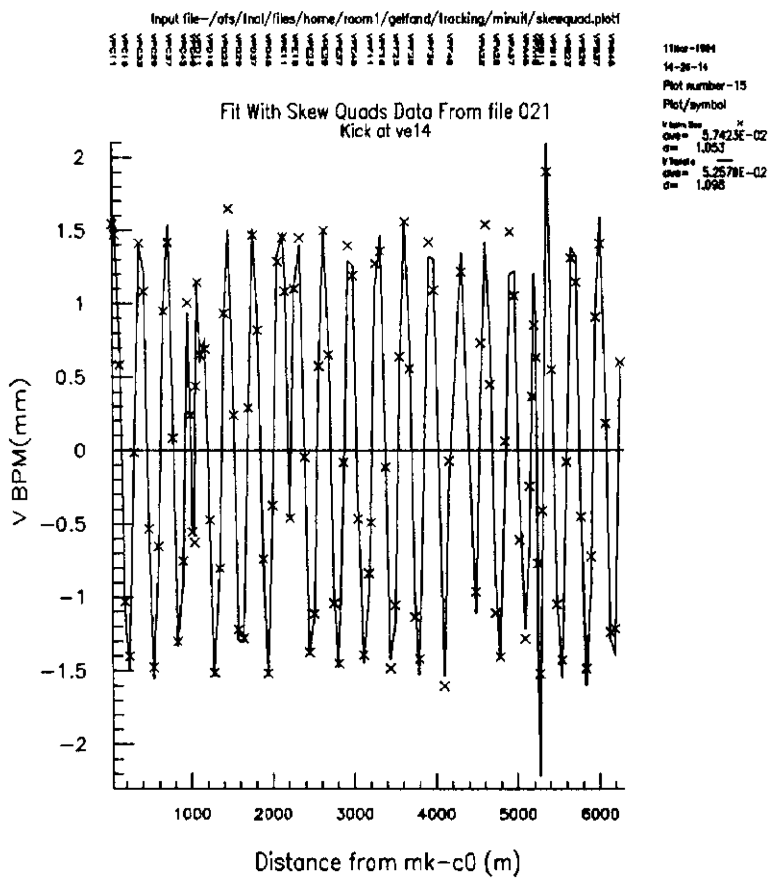
Figure 4c

Fit With Skew Quads Data From file 021

Kick at ve14







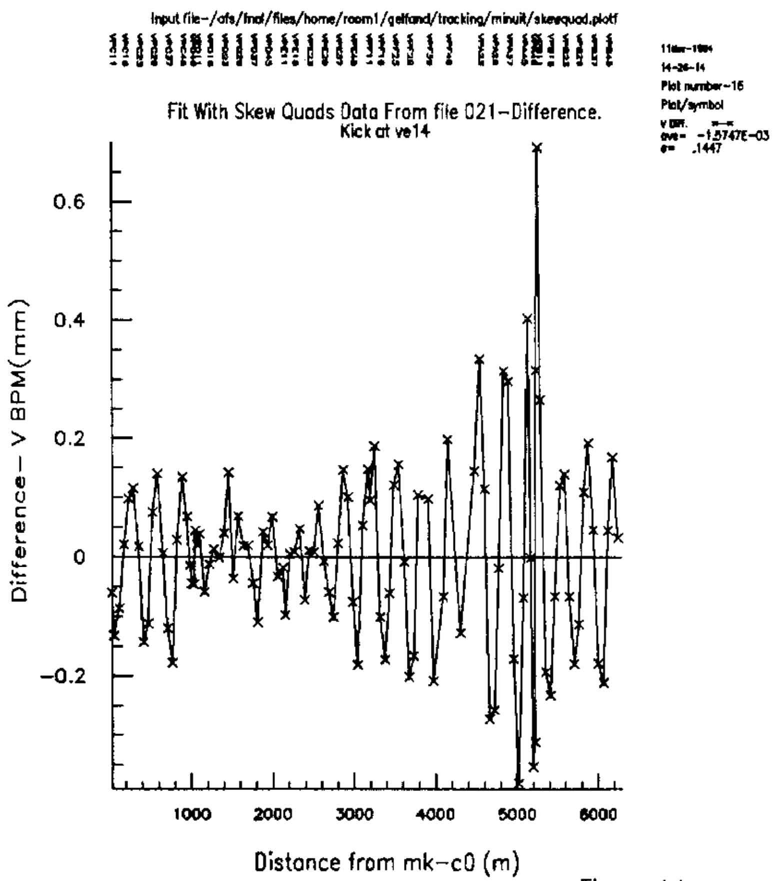


Figure 4d

Fit With Rolled Quads– Data from file 018

Kick at he11

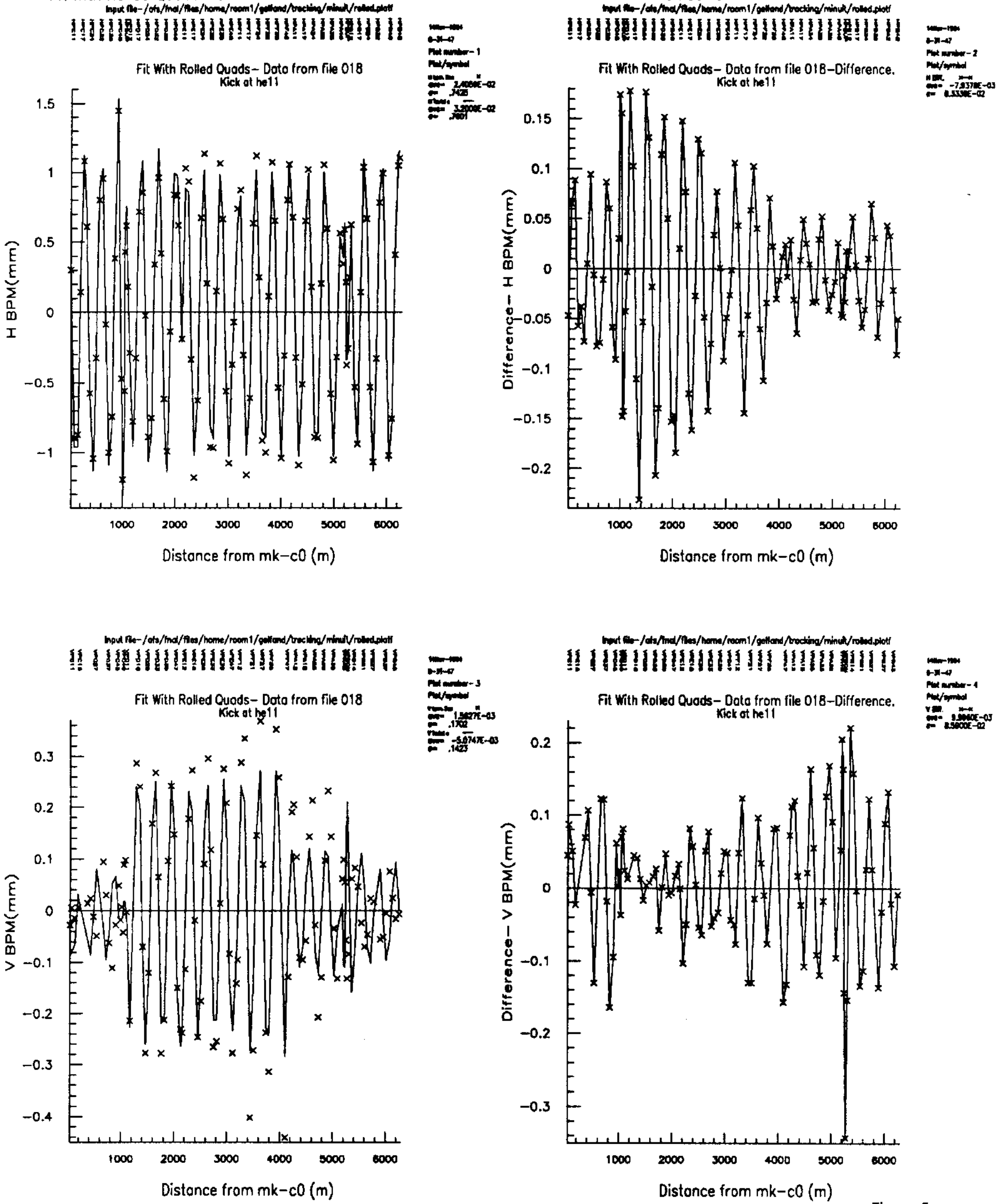
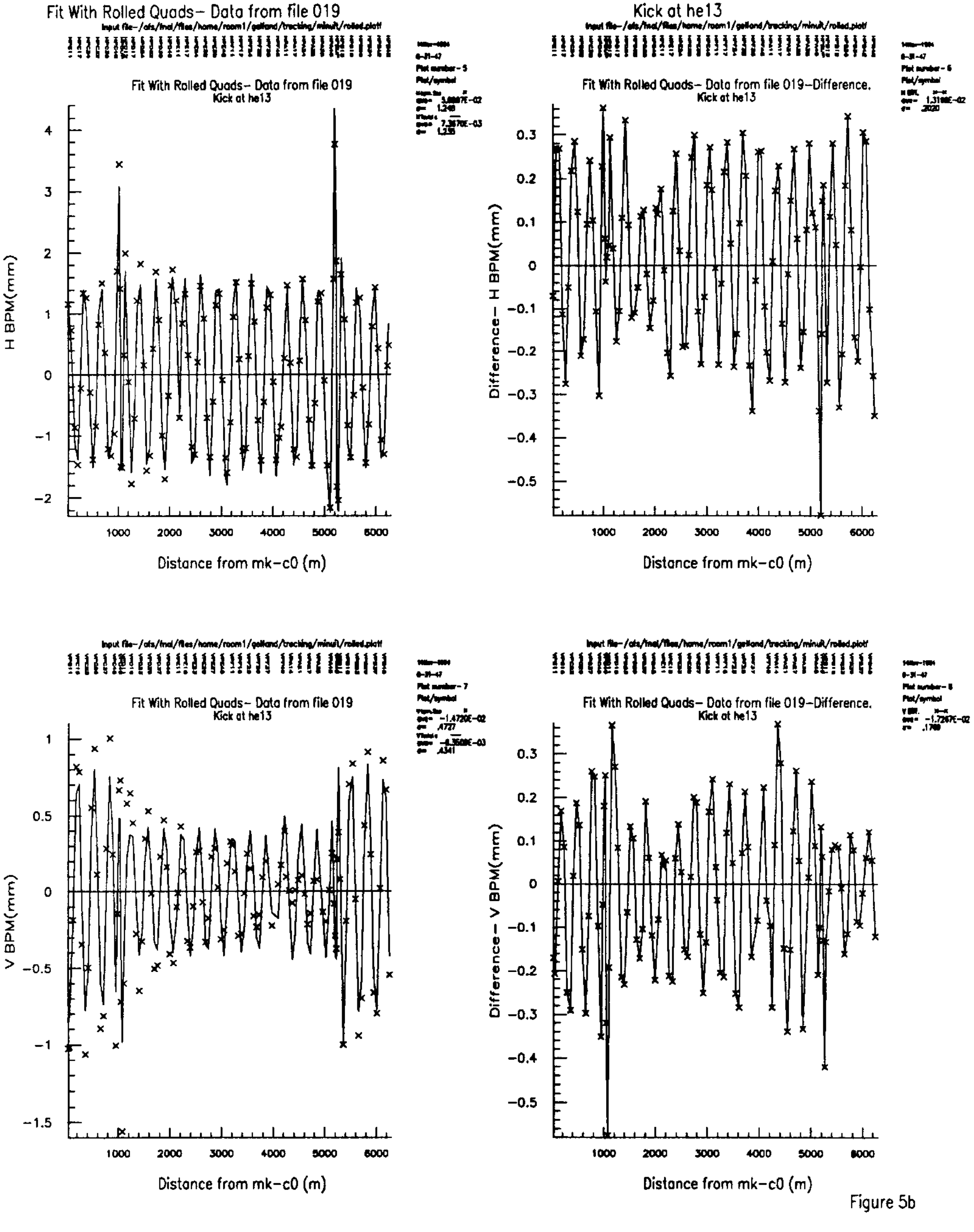


Figure 5a

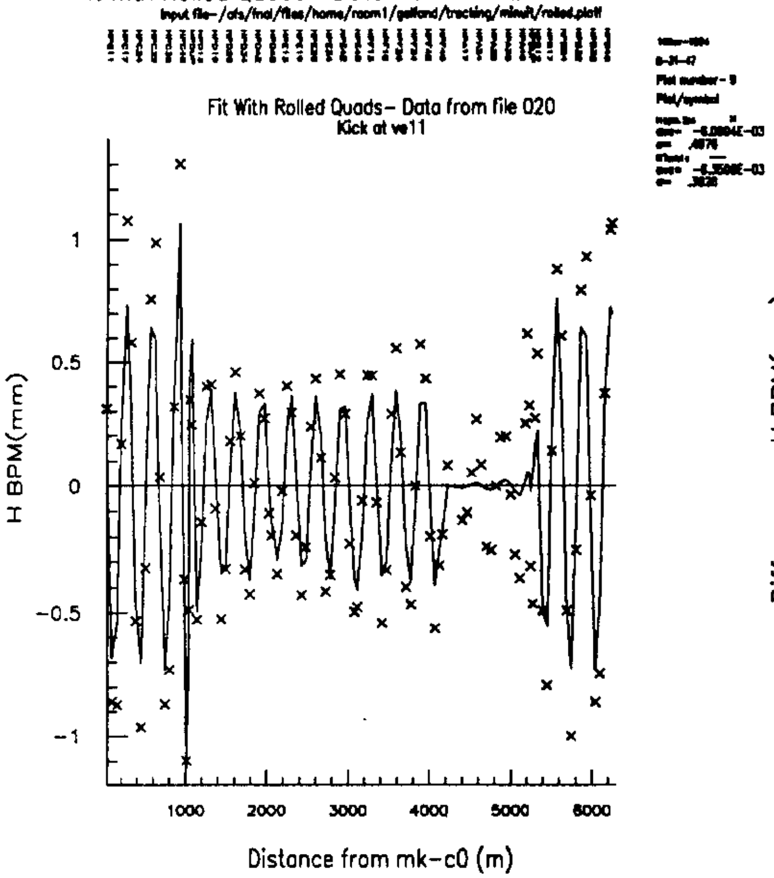


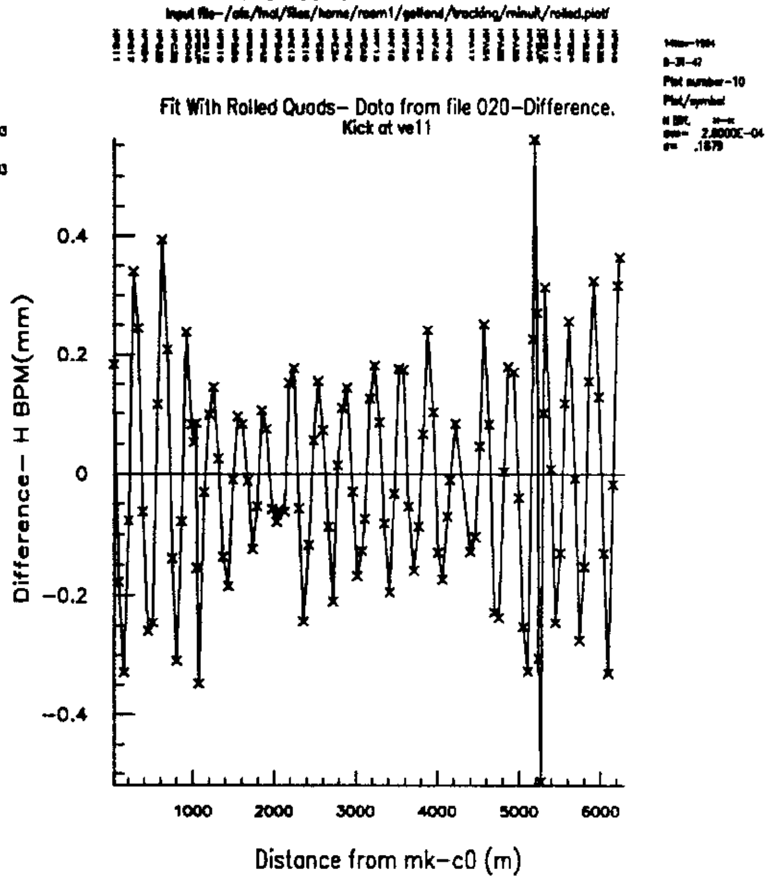
Fit With Rolled Quads- Data from file 019
Kick at he13
Fit With Rolled Quads- Data from file 019
Kick at he13
H BPM(mm)
Distance from mk-c0 (m)
Fit With Rolled Quads- Data from file 019-Difference.
Kick at he13
Difference- H BPM(mm)
Distance from mk-c0 (m)
Fit With Rolled Quads- Data from file 019
Kick at he13
V BPM(mm)
Distance from mk-c0 (m)
Fit With Rolled Quads- Data from file 019-Difference.
Kick at he13
Difference- V BPM(mm)
Distance from mk-c0 (m)

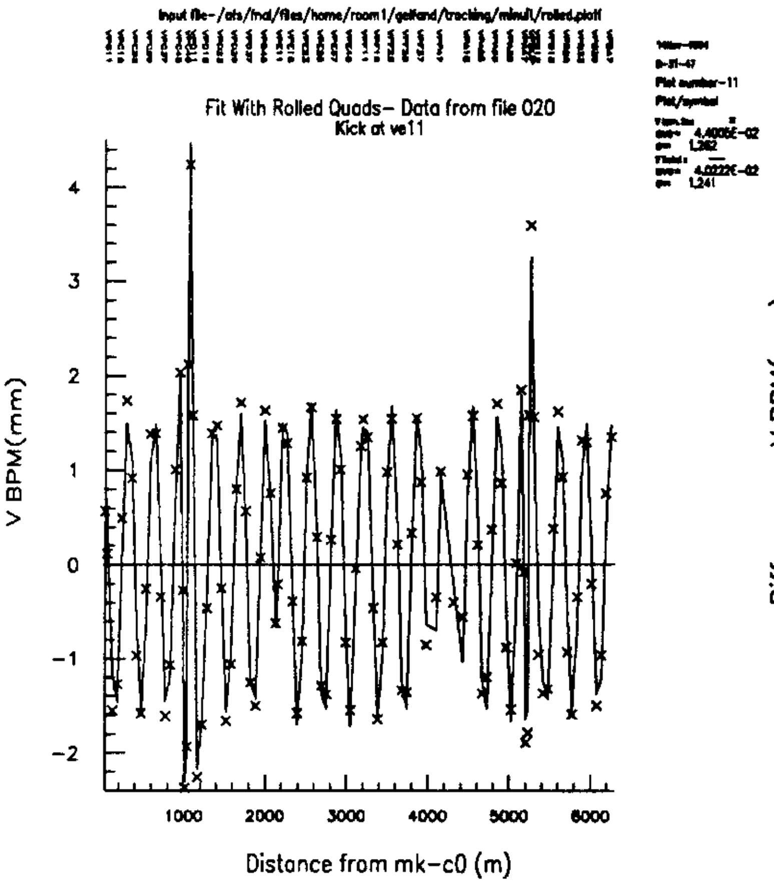
Figure 5b

Fit With Rolled Quads- Data from file 020

Kick at ve11







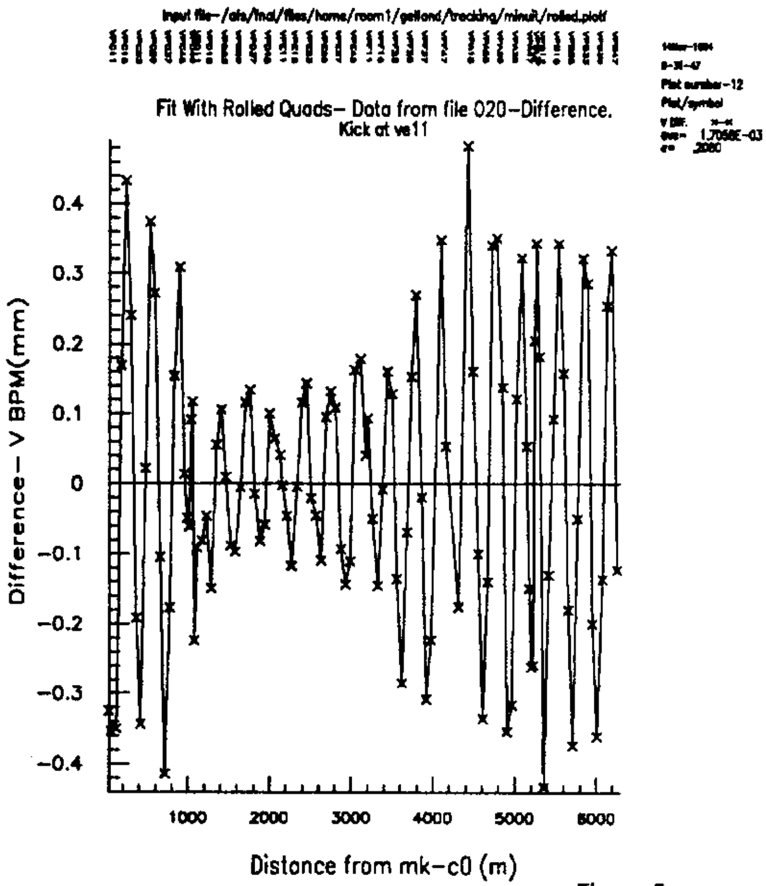
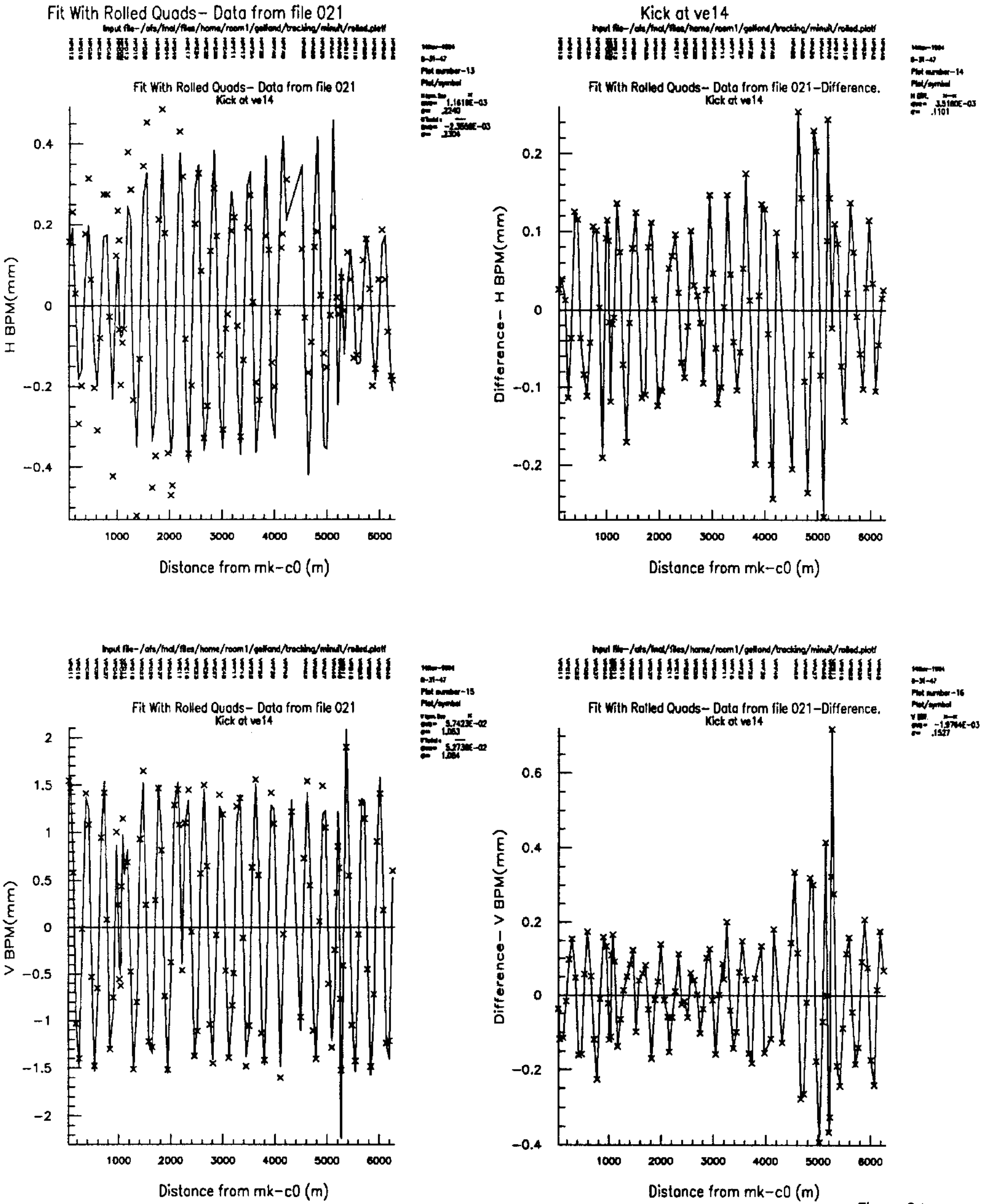
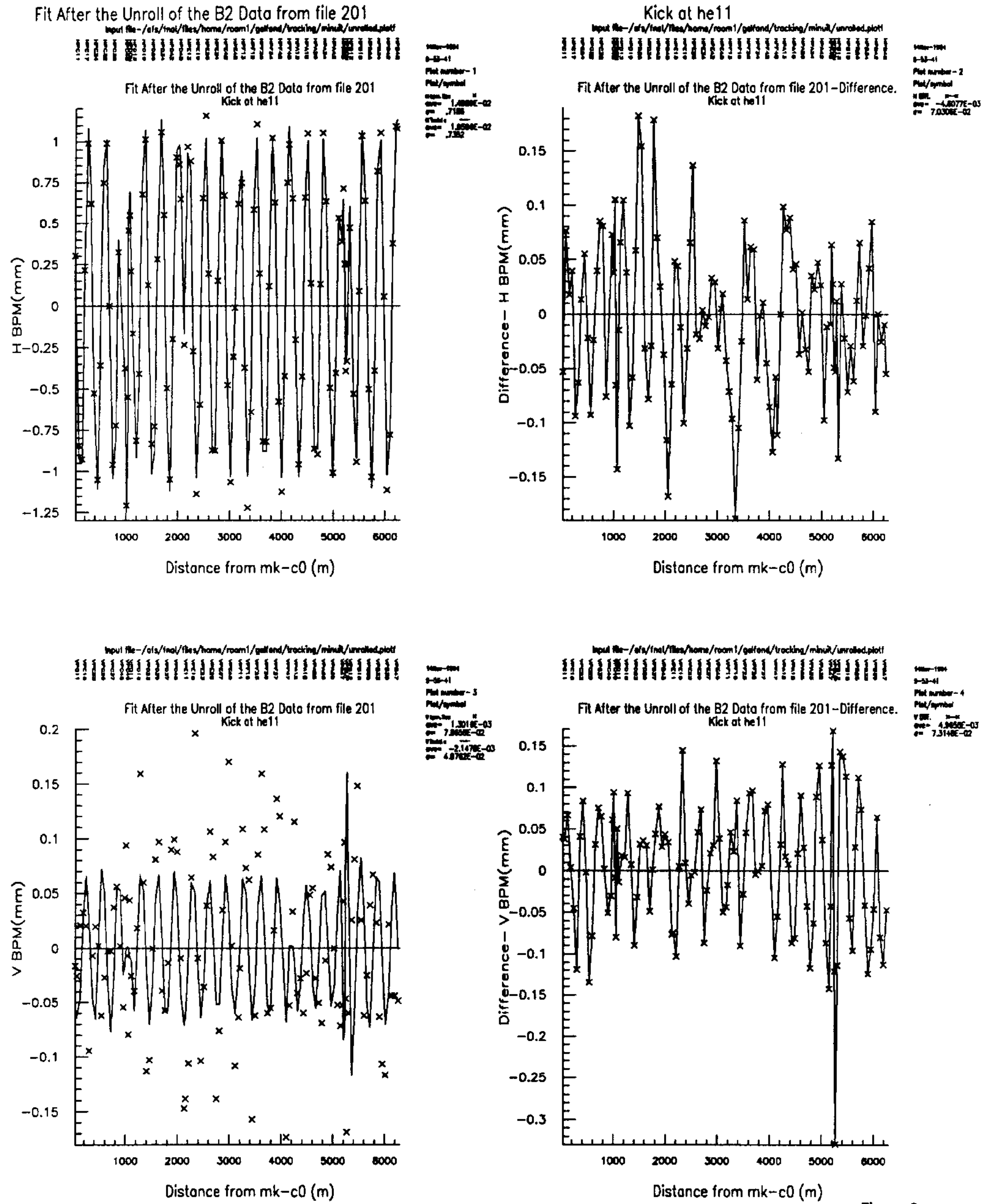


Figure 5c



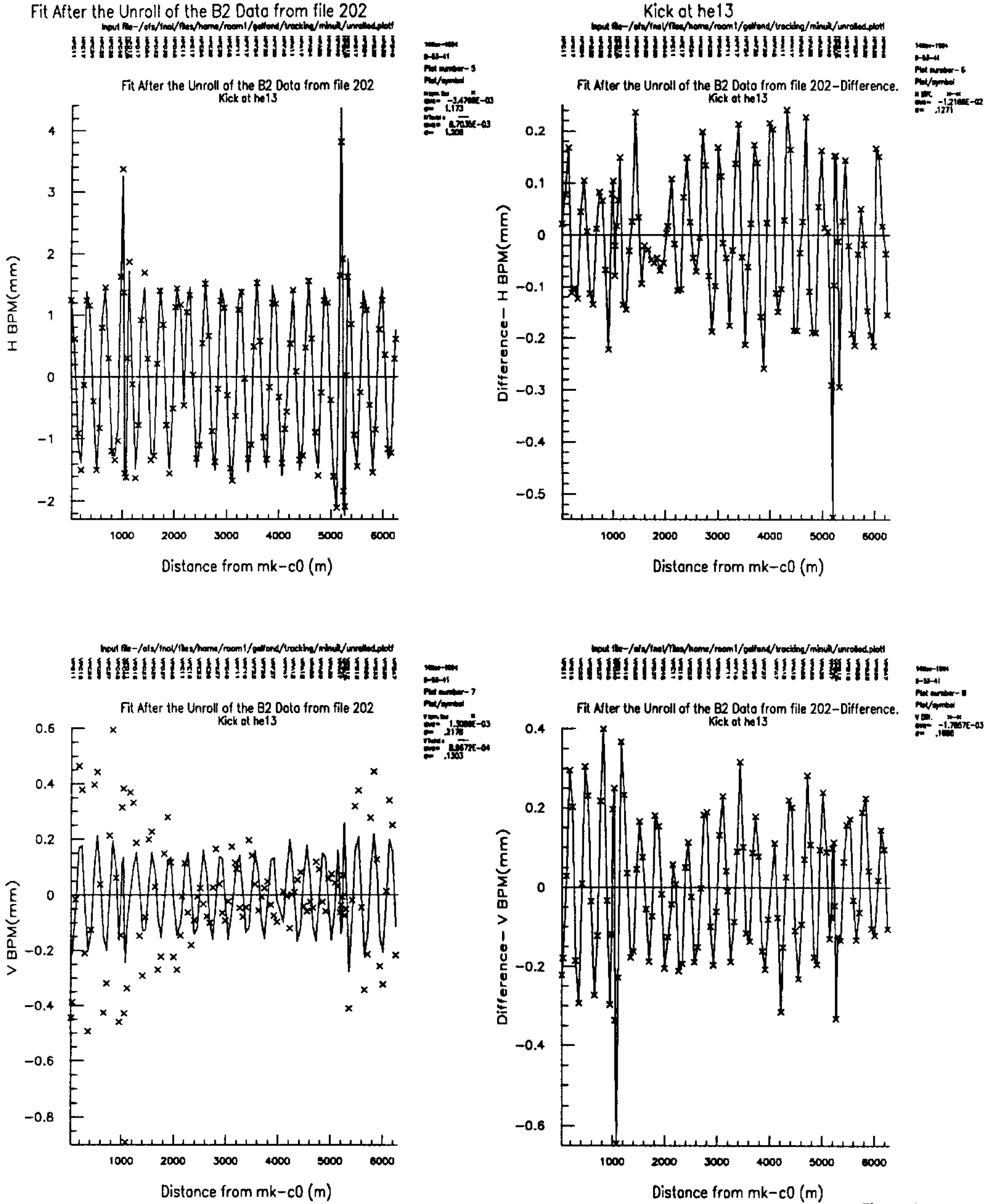
Fit With Rolled Quads- Data from file 021
Kick at ve14
Fit With Rolled Quads- Data from file 021
Kick at ve14
H BPM(mm)
Distance from mk-c0 (m)
Fit With Rolled Quads- Data from file 021-Difference.
Kick at ve14
Difference- H BPM(mm)
Distance from mk-c0 (m)
Fit With Rolled Quads- Data from file 021
Kick at ve14
V BPM(mm)
Distance from mk-c0 (m)
Fit With Rolled Quads- Data from file 021-Difference.
Kick at ve14
Difference- V BPM(mm)
Distance from mk-c0 (m)

Figure 5d



Fit After the Unroll of the B2 Data from file 201
Kick at he11
Fit After the Unroll of the B2 Data from file 201
Kick at he11
H BPM(mm)
Distance from mk-c0 (m)
Fit After the Unroll of the B2 Data from file 201-Difference.
Kick at he11
Difference- H BPM(mm)
Distance from mk-c0 (m)
Fit After the Unroll of the B2 Data from file 201
Kick at he11
V BPM(mm)
Distance from mk-c0 (m)
Fit After the Unroll of the B2 Data from file 201-Difference.
Kick at he11
Difference- V BPM(mm)
Distance from mk-c0 (m)

Figure 6a



Fit After the Unroll of the B2 Data from file 202
Kick at he13
Fit After the Unroll of the B2 Data from file 202
Kick at he13
H BPM(mm)
Distance from mk-c0 (m)
Fit After the Unroll of the B2 Data from file 202-Difference.
Kick at he13
Difference- H BPM(mm)
Distance from mk-c0 (m)
Fit After the Unroll of the B2 Data from file 202
Kick at he13
V BPM(mm)
Distance from mk-c0 (m)
Fit After the Unroll of the B2 Data from file 202-Difference.
Kick at he13
Difference- V BPM(mm)
Distance from mk-c0 (m)

Figure 6b

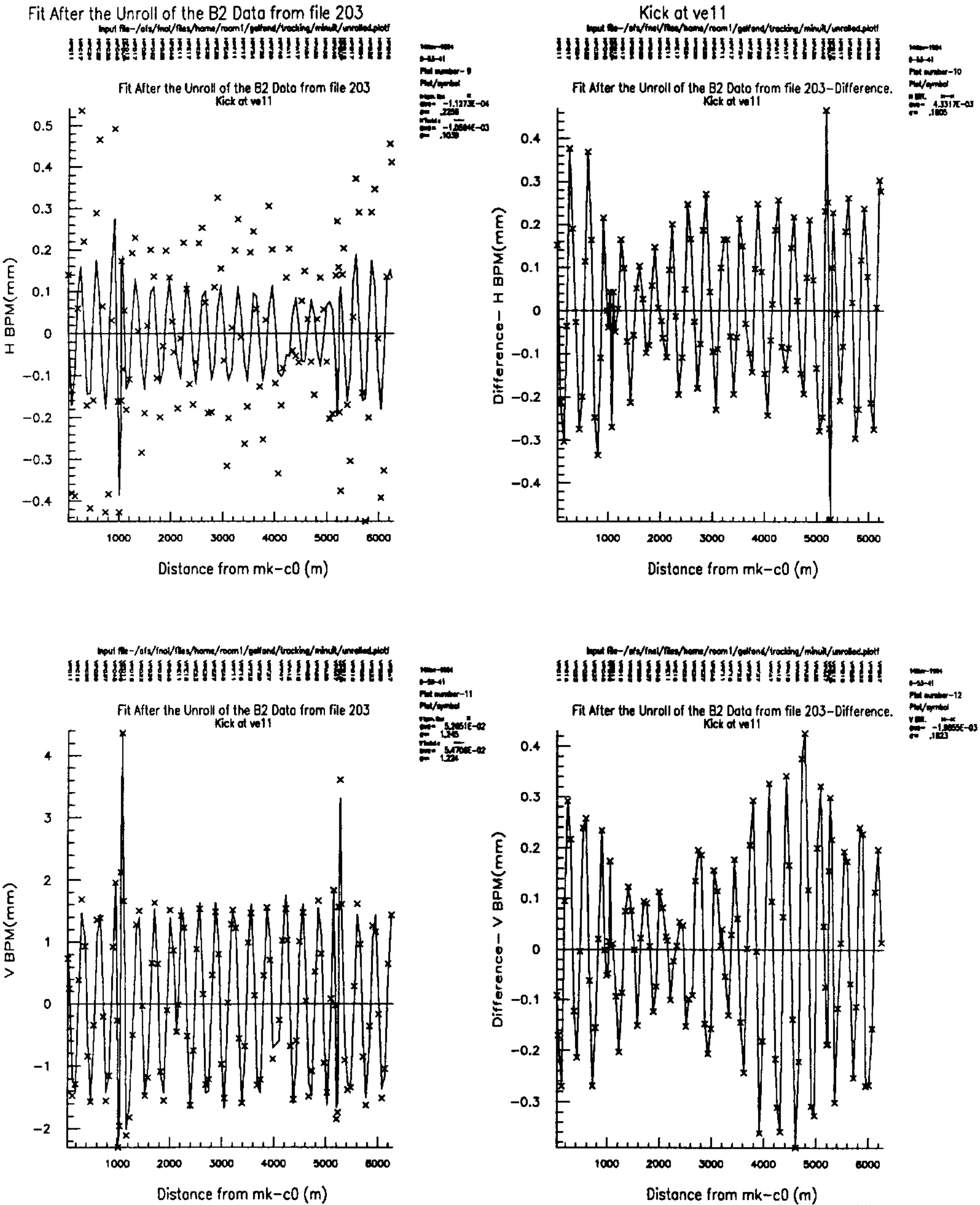

Fit After the Unroll of the B2 Data from file 203
Kick at ve11
Fit After the Unroll of the B2 Data from file 203
Kick at ve11
H BPM(mm)
Distance from mk-c0 (m)
Fit After the Unroll of the B2 Data from file 203-Difference.
Kick at ve11
Difference- H BPM(mm)
Distance from mk-c0 (m)
Fit After the Unroll of the B2 Data from file 203
Kick at ve11
V BPM(mm)
Distance from mk-c0 (m)
Fit After the Unroll of the B2 Data from file 203-Difference.
Kick at ve11
Difference- V BPM(mm)
Distance from mk-c0 (m)

Figure 6c

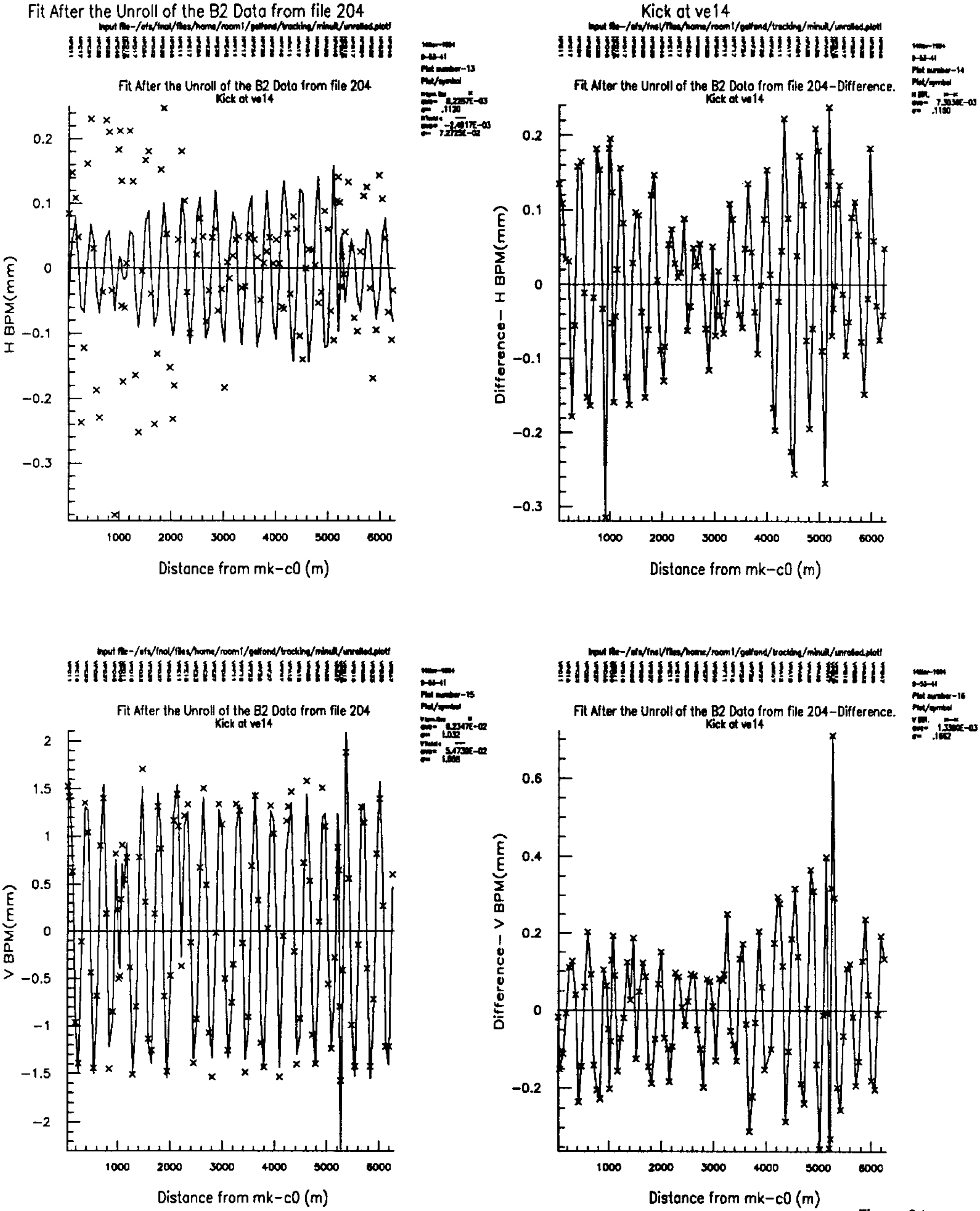

Fit After the Unroll of the B2 Data from file 204
Kick at ve14
Fit After the Unroll of the B2 Data from file 204
Kick at ve14
Fit After the Unroll of the B2 Data from file 204-Difference.
Kick at ve14
H BPM(mm)
Difference- H BPM(mm)
Fit After the Unroll of the B2 Data from file 204
Kick at ve14
Fit After the Unroll of the B2 Data from file 204-Difference.
Kick at ve14
V BPM(mm)
Difference- V BPM(mm)
Distance from mk-c0 (m)
Distance from mk-c0 (m)
Distance from mk-c0 (m)
Distance from mk-c0 (m)

Figure 6d

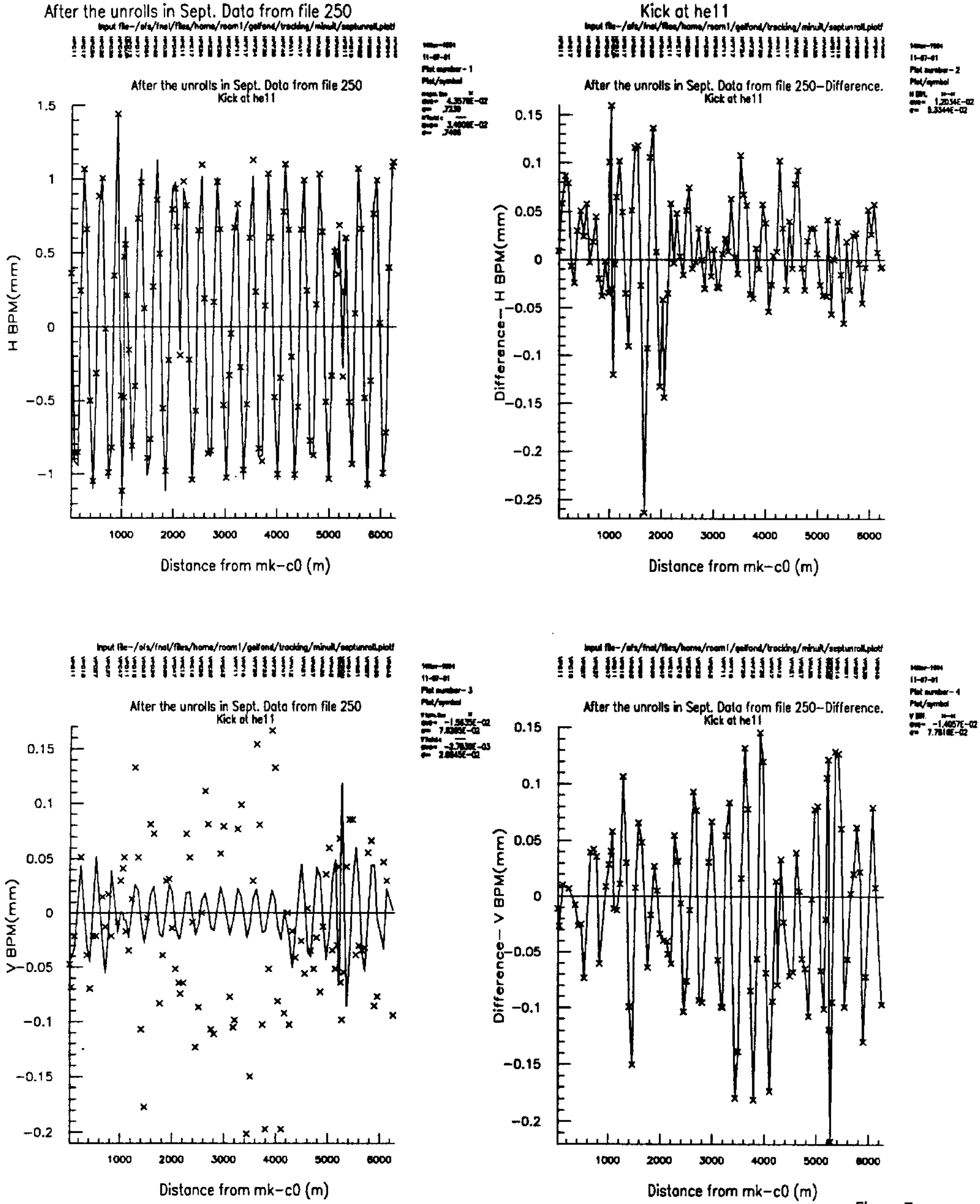

After the unrolls in Sept. Data from file 250
Kick at he11
After the unrolls in Sept. Data from file 250
Kick at he11
H BPM(mm)
Distance from mk-c0 (m)
After the unrolls in Sept. Data from file 250-Difference.
Kick at he11
Difference-- H BPM(mm)
Distance from mk-c0 (m)
After the unrolls in Sept. Data from file 250
Kick at he11
V BPM(mm)
Distance from mk-c0 (m)
After the unrolls in Sept. Data from file 250-Difference.
Kick at he11
Difference-- V BPM(mm)
Distance from mk-c0 (m)

Figure 7a

After the unrolls in Sept. Data from file 251

Kick at he13

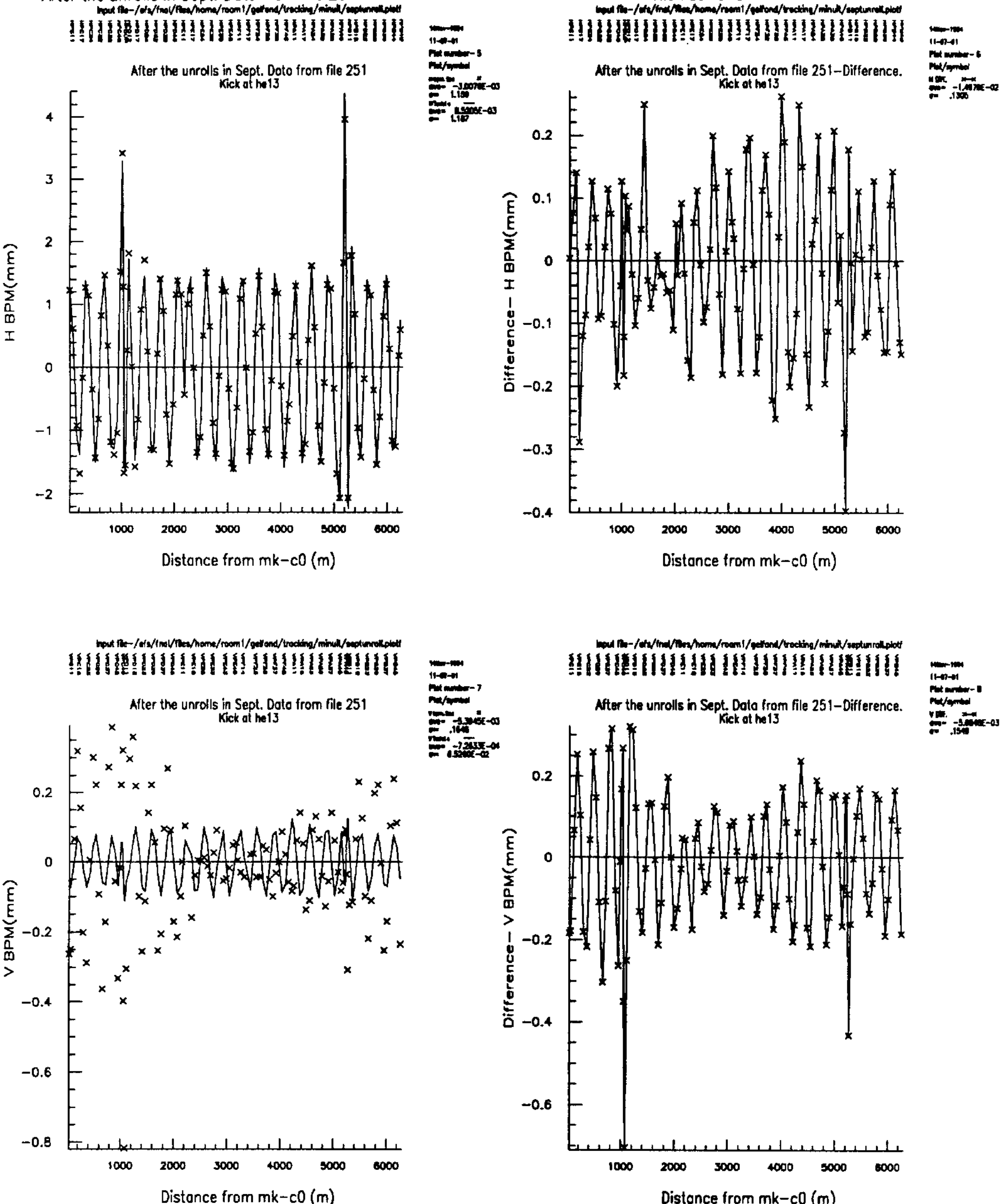


Figure 7b

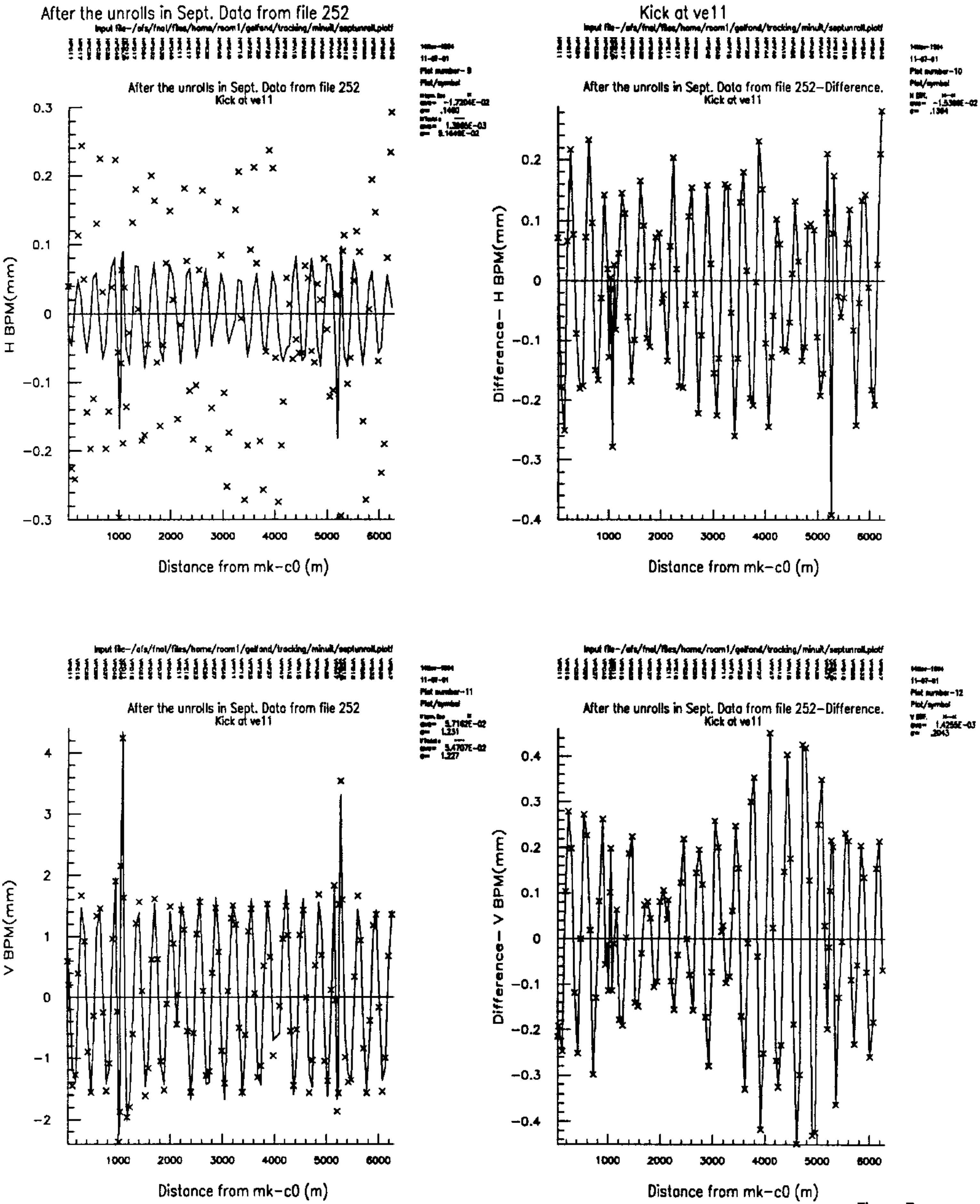

After the unrolls in Sept. Data from file 252
Kick at ve11
After the unrolls in Sept. Data from file 252
Kick at ve11
H BPM(mm)
Distance from mk-c0 (m)
After the unrolls in Sept. Data from file 252-Difference.
Kick at ve11
Difference- H BPM(mm)
Distance from mk-c0 (m)
After the unrolls in Sept. Data from file 252
Kick at ve11
V BPM(mm)
Distance from mk-c0 (m)
After the unrolls in Sept. Data from file 252-Difference.
Kick at ve11
Difference- V BPM(mm)
Distance from mk-c0 (m)

Figure 7c

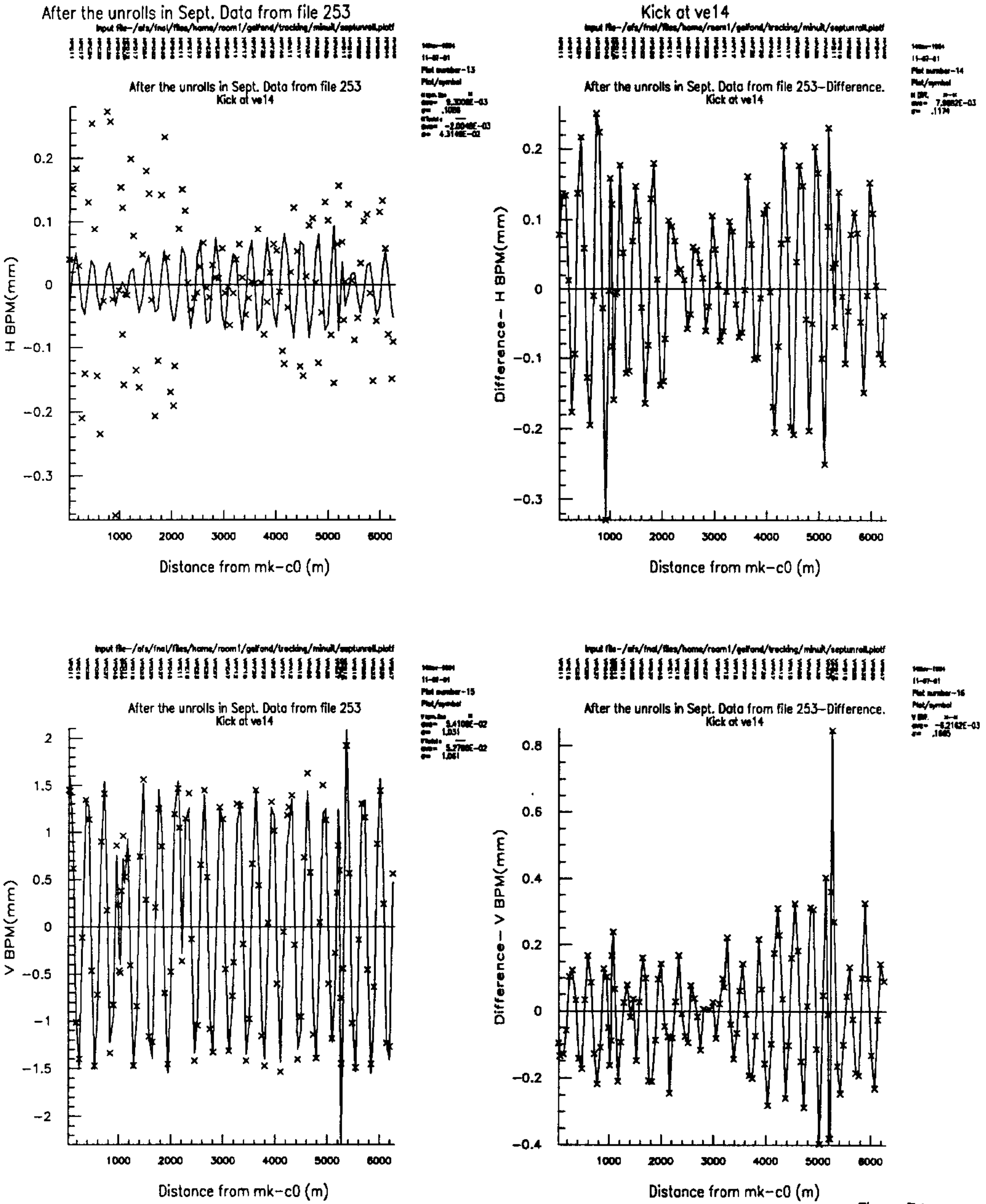

After the unrolls in Sept. Data from file 253
Kick at ve14
After the unrolls in Sept. Data from file 253
Kick at ve14
H BPM(mm)
Distance from mk-c0 (m)
After the unrolls in Sept. Data from file 253-Difference.
Kick at ve14
Difference- H BPM(mm)
Distance from mk-c0 (m)
After the unrolls in Sept. Data from file 253
Kick at ve14
V BPM(mm)
Distance from mk-c0 (m)
After the unrolls in Sept. Data from file 253-Difference.
Kick at ve14
Difference- V BPM(mm)
Distance from mk-c0 (m)

Figure 7d

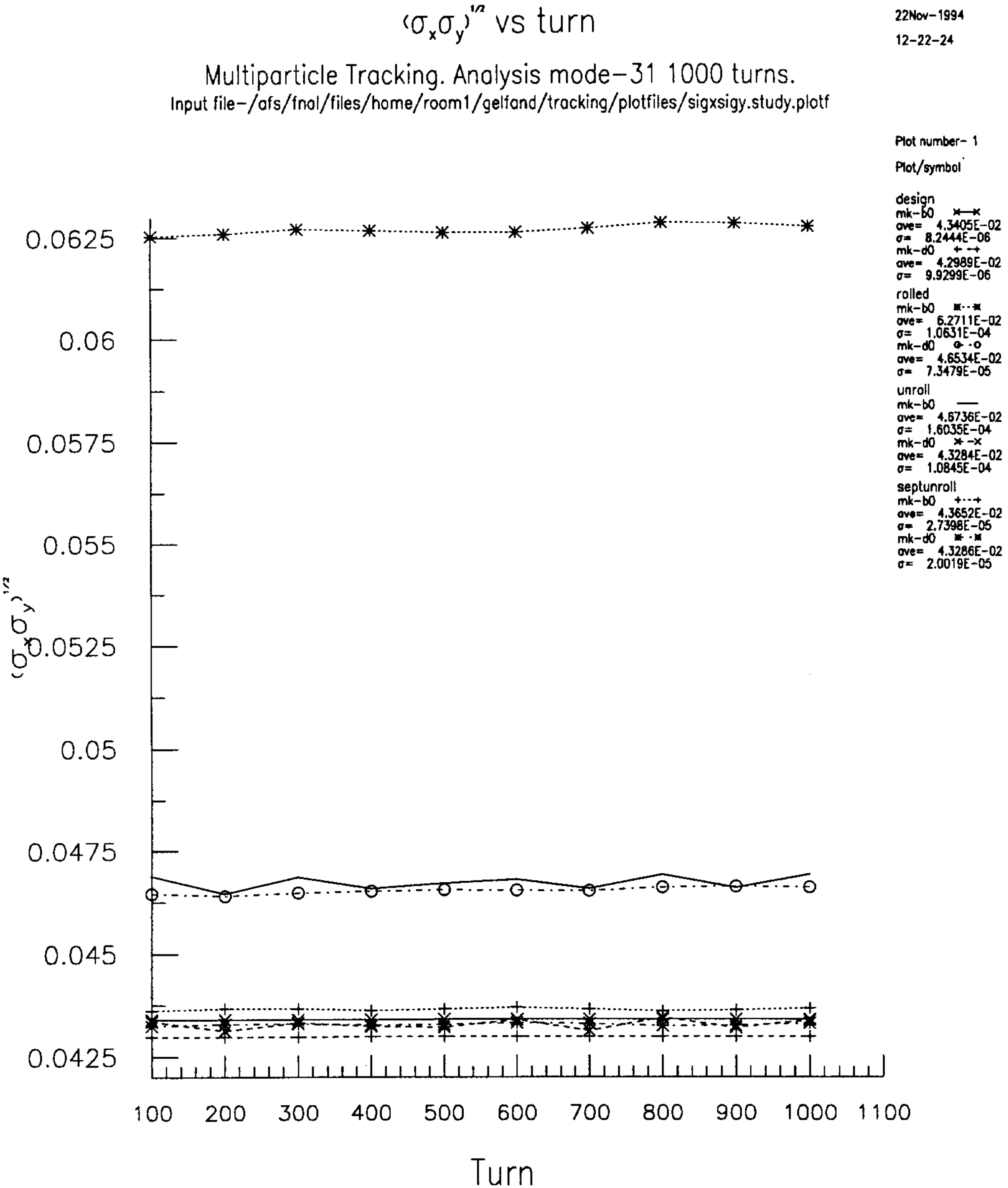
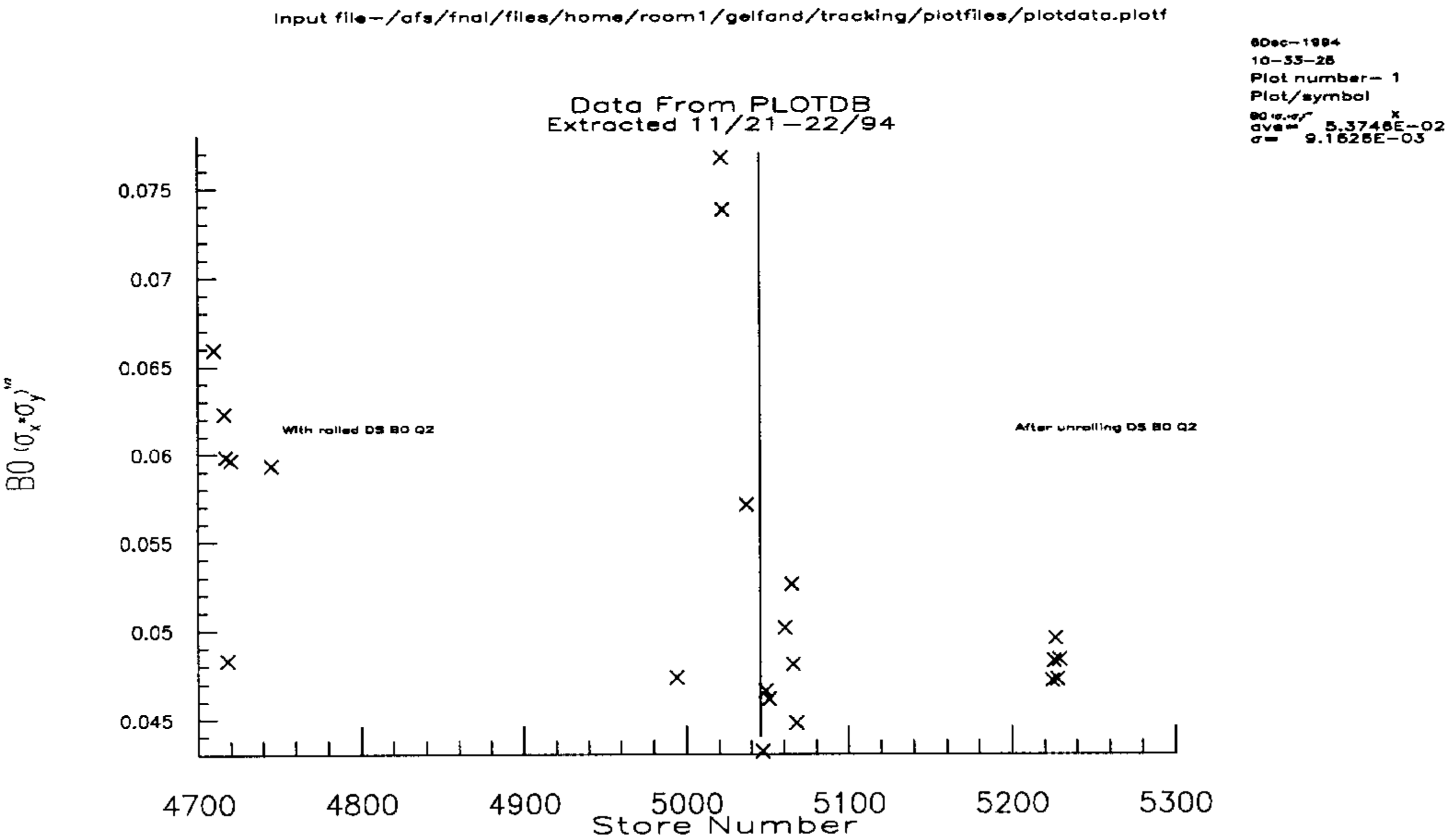

$(\sigma_x\sigma_y)^{1/2}$ vs turn
22Nov-1994
12-22-24
Multiparticle Tracking. Analysis mode-31 1000 turns.
Input file-/afs/fnal/files/home/room1/gelfand/tracking/plotfiles/sigxsigy.study.plotf
Plot number- 1
Plot/symbol
design
mk-b0
ave= 4.3405E-02
σ= 8.2444E-06
mk-d0
ave= 4.2989E-02
σ= 9.9299E-06
rolled
mk-b0
ave= 6.2711E-02
σ= 1.0631E-04
mk-d0
ave= 4.6534E-02
σ= 7.3479E-05
unroll
mk-b0
ave= 4.6736E-02
σ= 1.6035E-04
mk-d0
ave= 4.3284E-02
σ= 1.0845E-04
septunroll
mk-b0
ave= 4.3652E-02
σ= 2.7398E-05
mk-d0
ave= 4.3286E-02
σ= 2.0019E-05
0.0625
0.06
0.0575
0.055
0.0525
0.05
0.0475
0.045
0.0425
$(\sigma_x\sigma_y)^{1/2}$
100
200
300
400
500
600
700
800
900
1000
1100
Turn

Figure 8


Input file-/afs/fnal/files/home/room1/gelfand/tracking/plotfiles/plotdata.plotf
6Dec-1994
10-33-26
Plot number- 1
Plot/symbol
ave= 5.3746E-02
σ= 9.1626E-03
Data From PLOTDB
Extracted 11/21-22/94
0.075
0.07
0.065
0.06
0.055
0.05
0.045
B0 (σx*σy)^1/2
With rolled DS B0 Q2
After unrolling DS B0 Q2
4700
4800
4900
5000
5100
5200
5300
Store Number

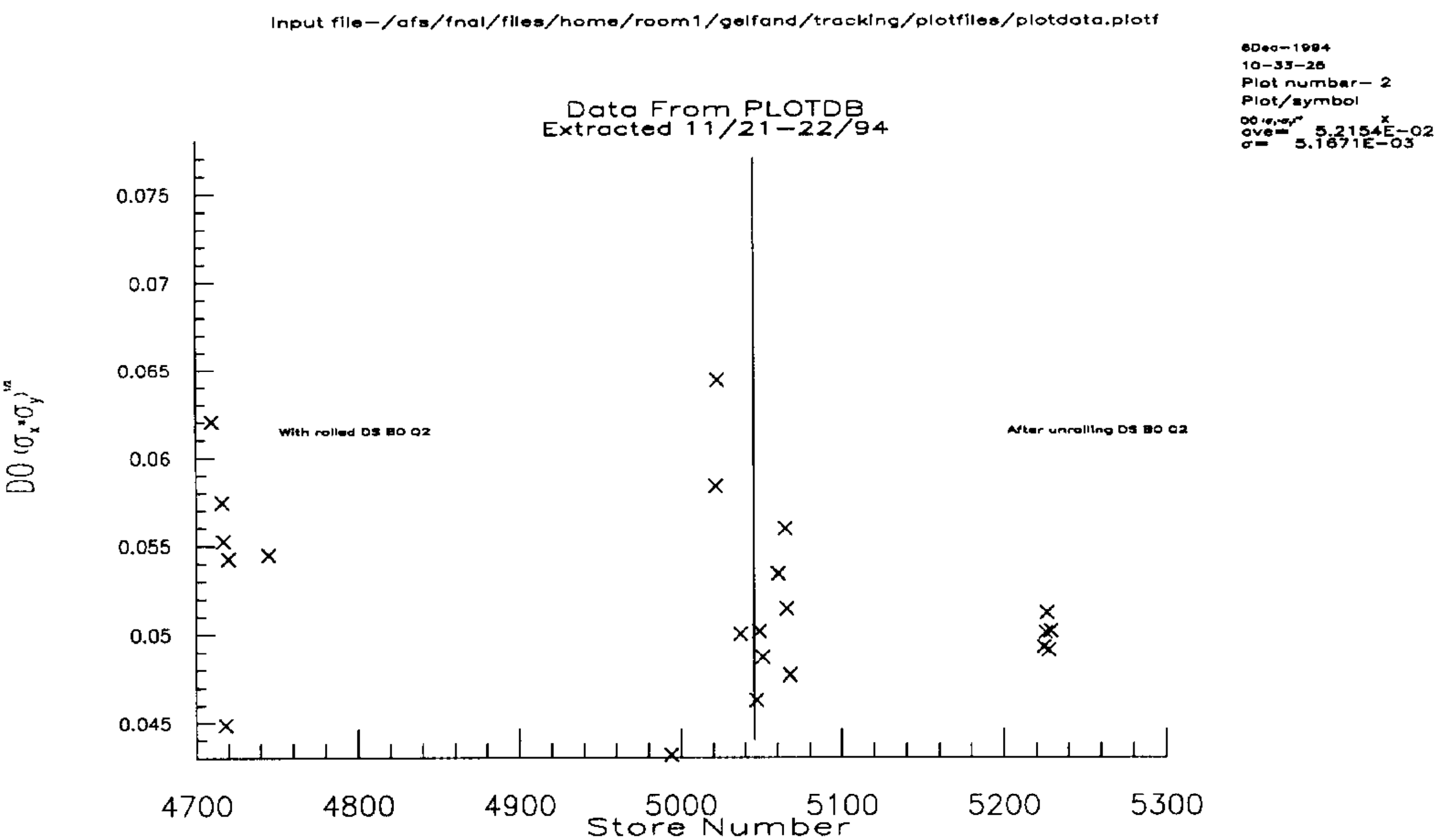

Input file-/afs/fnal/files/home/room1/gelfand/tracking/plotfiles/plotdata.plotf
6Dec-1994
10-33-26
Plot number- 2
Plot/symbol
ave= 5.2154E-02
σ= 5.1671E-03
Data From PLOTDB
Extracted 11/21-22/94
0.075
0.07
0.065
0.06
0.055
0.05
0.045
D0 (σx*σy)^1/2
With rolled DS B0 Q2
After unrolling DS B0 Q2
4700
4800
4900
5000
5100
5200
5300
Store Number

Figure 9