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Position scan of Tev VPA33 BPM with upgraded electronics.

M. Martens
Fermilab, Accelerator Division

Updates

This is the first version of this memo.

Abstract

The BPMs in the A3 house of the Tevatron are outfitted with the Tev BPM upgrade electronics. As a test we measured the response of the BPM system to changes in the closed orbit. The results are presented and compared to a rudimentary model of the Tev stripline BPMs. The upgraded BPM electronics performed as expected and, with minimal beam intensity, provided closed orbit measurements with about 0.04 mm rms resolution. The results of the measurement are in qualitative agreement with the simple model of the BPMs, but differ in magnitude. Compared to the model the BPM response (defined as the change in reported position divided by the actual position change) is 25% less than expected. The measured change in intensity as a function of beam intensity is also less than predicted by the simple model. (Probably the model is too simple to accurately predict the actual response of the stripline pickups.)

Introduction

The study took place using uncoalesced beam from 16:45 till 17:00 on 12/19/04. During this time the beam position in the VPA33 BPM was moved horizontally and vertically using the Tevatron dipole corrector magnets. The position was held constant at each location for 4 seconds while position measurements were collected at a 15 Hz rate using the ACNET data logger.

The horizontal and vertical positions changes were made in 2 mm increments to cover an approximately ±8 mm vertical × ±6 mm horizontal grid. The position changes were made using a vertical 3-bump and a horizontal 4-bump with the Tevatron dipole correctors with excitation currents predicted by MAD calculations using the design Tevatron lattice. The vertical 3-bump (using VA29, VA33, and VA35 correctors) also gives a 0.024 mrad vertical angle for each 1mm of vertical position change. The horizontal 4-bump (using HA28, HA32, HA34, and HA36 correctors) is designed to give a pure horizontal position change without any horizontal angle change. The calculated orbit changes are plotted in Figure 1.

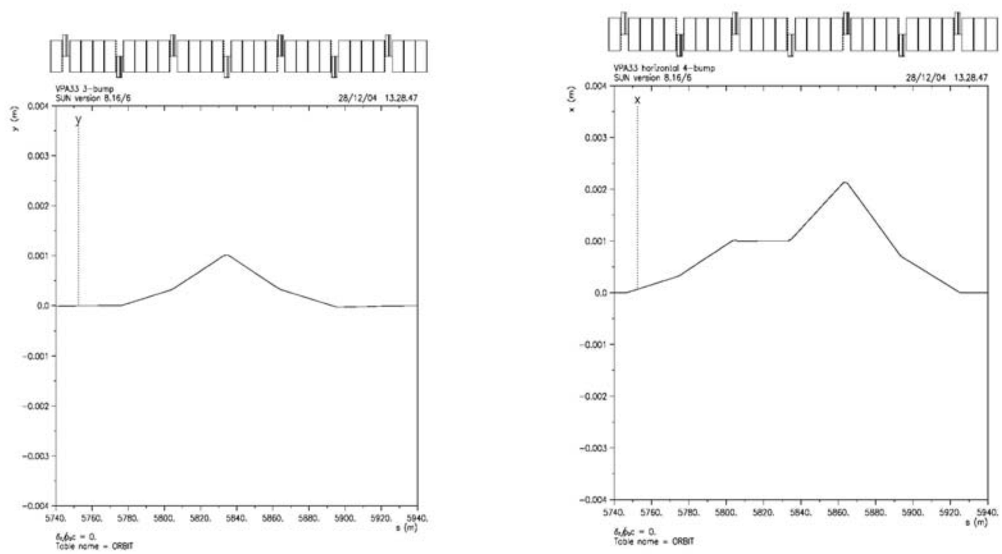

Figure 1 Calculated position changes from the vertical 3-bump and horizontal 4-bump at VPA33. For a 1mm vertical orbit bump the beam position also changes by +0.024 mrad at the VPA33 BPM. For a 1mm horizontal orbit bump a VPA33, the position at HPA32 changes by 1mm and the angle changes by +0.024 mm and the position at HPA34 changes by 2.12 mm and the angle changes by +0.039 mrad.

During the position scan, a ring wide measurement of BPM positions was made without any bumps in place, with only a +4mm vertical 3-bump, and with only a -4mm horizontal 4-bump. The difference orbits with and without the bumps are shown in Figure 2 and Figure 3. In each case the position of the orbits responds as expected although there is a slight amount of orbit motion in the orthogonal plane.

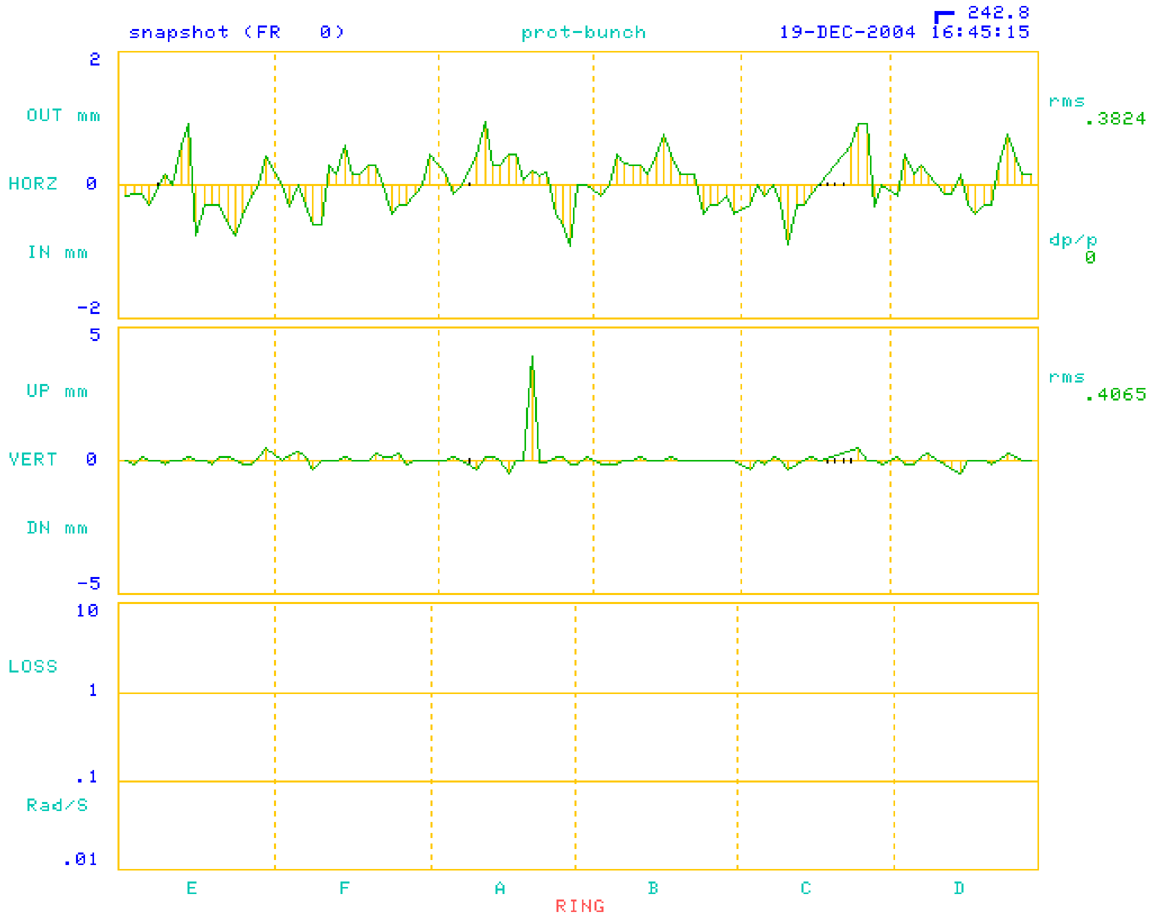

Figure 2 Orbit difference with and without a +4mm vertical 3-bump at VPA33.

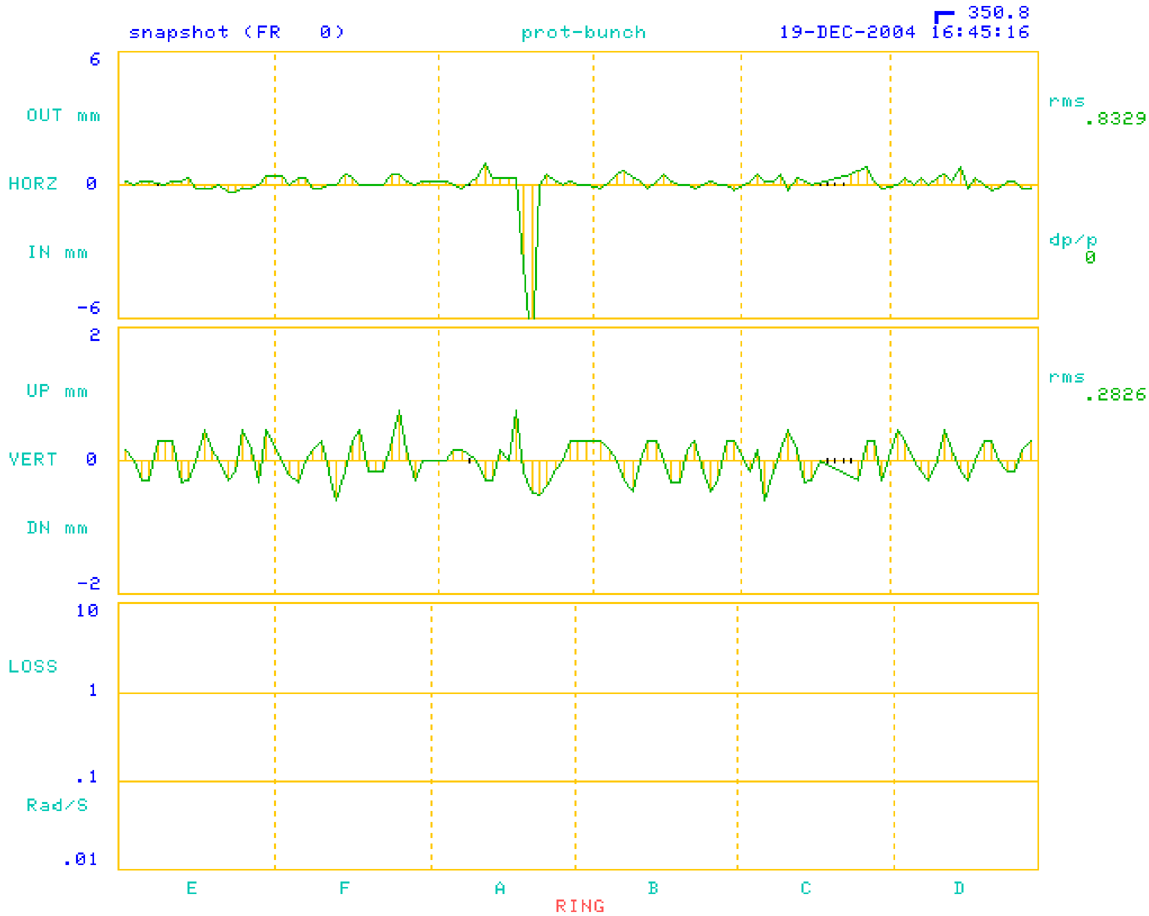

Figure 3 Orbit difference with and without a -4mm horizontal 4-bump at VPA33.

Using these calculated orbit bumps, the position of the beam within the VPA33 BPM was moved in 2mm steps for form a grid of position in the x and y plane. The beam was held for 4 seconds at each position on the grid in order to collect several measurements. After collecting the data, 40 separate closed orbit measurements were used to determine the average position at each grid location. These position values along with the standard deviation of the 40 measurements are listed in Table 1. The same procedure was used to determine the intensity as recorded by the BPM position. These are listed in Table 1 as well.

Table 1 Measured position at VPA33 as reported by the upgraded electronics during the position scan. For each predicted change in the orbit (given by the values of T:BUMPV and T:BUMPH) the average position listed in the table is from 40 measurements of the closed orbit. The standard deviation of the 40 measurements is also listed. The intensity of the beam as reported by the upgraded electronics is also given. It is also the average of 40 measurements and the standard deviation is given.

Time (Seconds)	T:BUMPV (calc. mm)	T:BUMPH (calc. mm)	Average T:VPA33 (mm)	Std. Dev. T:VPA33 (mm)	Average T:VPA33[1] (units)	Std. Dev. T:VPA33[1] (units)
52.311	0	0	-1.27268	0.0432	277.9878	1.6438
61.252	2	0	0.686275	0.0510	278.004	1.7319
70.258	2	2	0.945939	0.0461	277.6985	1.9464
78.997	0	2	-0.97476	0.0526	276.2242	1.8992
87.936	-2	2	-2.89265	0.0492	277.5987	1.5004
96.942	-2	0	-3.10118	0.0506	277.8646	1.7116
105.881	-2	-2	-3.34978	0.0474	278.7937	1.5934
115.021	0	-2	-1.45321	0.0474	277.3674	1.6708
123.894	2	-2	0.484471	0.0488	276.9436	1.2550
132.765	4	-2	2.443734	0.0568	277.1477	1.6490
141.971	4	0	2.691908	0.0367	277.6261	1.9655
151.177	4	2	2.910428	0.0600	277.0047	1.9556
160.117	4	4	3.174253	0.0592	276.2644	1.6683
168.923	2	4	1.264376	0.0454	275.3083	1.2723
177.862	0	4	-0.68749	0.0465	274.4337	2.0266
186.802	-2	4	-2.62904	0.0347	274.7886	1.6026
195.676	-4	4	-4.56108	0.0445	275.2664	1.4953
204.749	-4	2	-4.7496	0.0512	277.1692	1.6134
213.754	-4	0	-4.96473	0.0403	277.0838	1.8093
222.561	-4	-2	-5.2035	0.0419	277.5013	1.7674
231.632	-4	-4	-5.45778	0.0332	277.2509	1.3697
240.507	-2	-4	-3.58967	0.0398	275.4013	1.6392
249.777	0	-4	-1.6843	0.0508	273.5864	1.9347
258.648	2	-4	0.268716	0.0496	272.5043	1.6667
267.587	4	-4	2.221437	0.0535	273.3923	1.9218
276.525	6	-4	4.193798	0.0483	274.0075	2.0695
285.531	6	-2	4.40471	0.0638	274.687	1.6384
294.669	6	0	4.626394	0.0523	274.4711	1.9595
303.673	6	2	4.869417	0.0512	274.8721	2.1431
312.678	6	4	5.137273	0.0509	272.9266	2.5425
321.682	6	6	5.414874	0.0585	271.3394	1.4963
330.62	4	6	3.529863	0.0573	268.4836	2.5657
339.091	2	6	1.596484	0.0548	266.7604	2.2634
348.362	0	6	-0.38073	0.0555	265.9106	1.9562
357.037	-2	6	-2.36919	0.0509	265.9339	2.4772
365.838	-4	6	-4.35159	0.0437	266.5956	2.5297
374.642	-6	6	-6.30882	0.0392	268.6956	2.6216
383.646	-6	4	-6.46705	0.0418	270.1627	2.2047
392.45	-6	2	-6.63429	0.0352	271.5296	2.3042
401.454	-6	0	-6.82856	0.0464	271.8091	2.6631
410.392	-6	-2	-7.08075	0.0445	272.265	2.6539

419.463	-6	-4	-7.32843	0.0467	272.0845	2.3327
428.6	-6	-6	-7.63325	0.0460	270.7485	3.0300
437.405	-4	-6	-5.78874	0.0414	268.3815	2.5274
446.275	-2	-6	-3.90797	0.0405	266.1501	2.4004
455.146	0	-6	-1.94978	0.0449	265.0046	2.3974
464.084	2	-6	0.018438	0.0488	264.3373	2.8677
472.888	4	-6	2.018954	0.0550	263.0904	2.2310
481.958	6	-6	4.008398	0.0509	265.1536	2.9519
490.961	8	-6	5.957632	0.0654	266.4579	2.7555
499.897	8	-4	6.122814	0.0595	267.753	2.7863
508.901	8	-2	6.3284	0.0607	268.5493	2.8752
517.974	8	0	6.543618	0.0568	268.5487	2.5683
527.113	8	2	6.767992	0.0566	268.4256	3.0167
535.985	8	4	7.067543	0.0659	267.8267	3.0176
544.925	8	6	7.37568	0.0463	266.4999	2.7782
553.998	8	8	7.680208	0.0646	264.657	2.9466
562.871	6	8	5.817823	0.0523	261.3577	2.9766
571.746	4	8	3.904988	0.0565	258.4923	2.6858
580.685	2	8	1.928519	0.0474	256.9065	2.2623
589.425	0	8	-0.1049	0.0513	255.4376	2.6475
598.431	-2	8	-2.12906	0.0476	255.2015	2.4701
607.171	-4	8	-4.14719	0.0449	256.5357	2.2399
616.178	-6	8	-6.14824	0.0463	257.7665	2.6500
625.185	-8	8	-8.10581	0.0466	260.1086	2.8922
634.259	-8	6	-8.2066	0.0383	261.9201	2.5804
643.199	-8	4	-8.34795	0.0387	264.0559	3.1659
652.007	-8	2	-8.50301	0.0432	265.5785	3.3798
661.014	-8	0	-8.69042	0.0462	267.1311	2.3405
669.955	-8	-2	-8.93353	0.0434	267.4581	3.1253
679.03	-8	-4	-9.19543	0.0518	267.1982	3.0529
688.037	-8	-6	-9.49507	0.0436	266.2633	2.3548
720.929	0	0	-1.27444	0.0484	260.7032	3.0157

For this study uncoalesced beam of 30 bunches and a total intensity of 0.29E12 particles was used. During the 12 minutes of the grid study the intensity of the beam in the Tevatron as recorded by T:IBEAM and by T:FBIPWG changed by less than 1%. However, the intensity as reported by the BPM system decreased by 7% from 278 units to 260 units. Some of this drop may have been related to the increase in bunch length during the scan. As reported by the SBD the bunch length increased from about 1 nsec at the start of the scan to about 1.15 nsec at the end of the scan. This is shown in Figure 4.

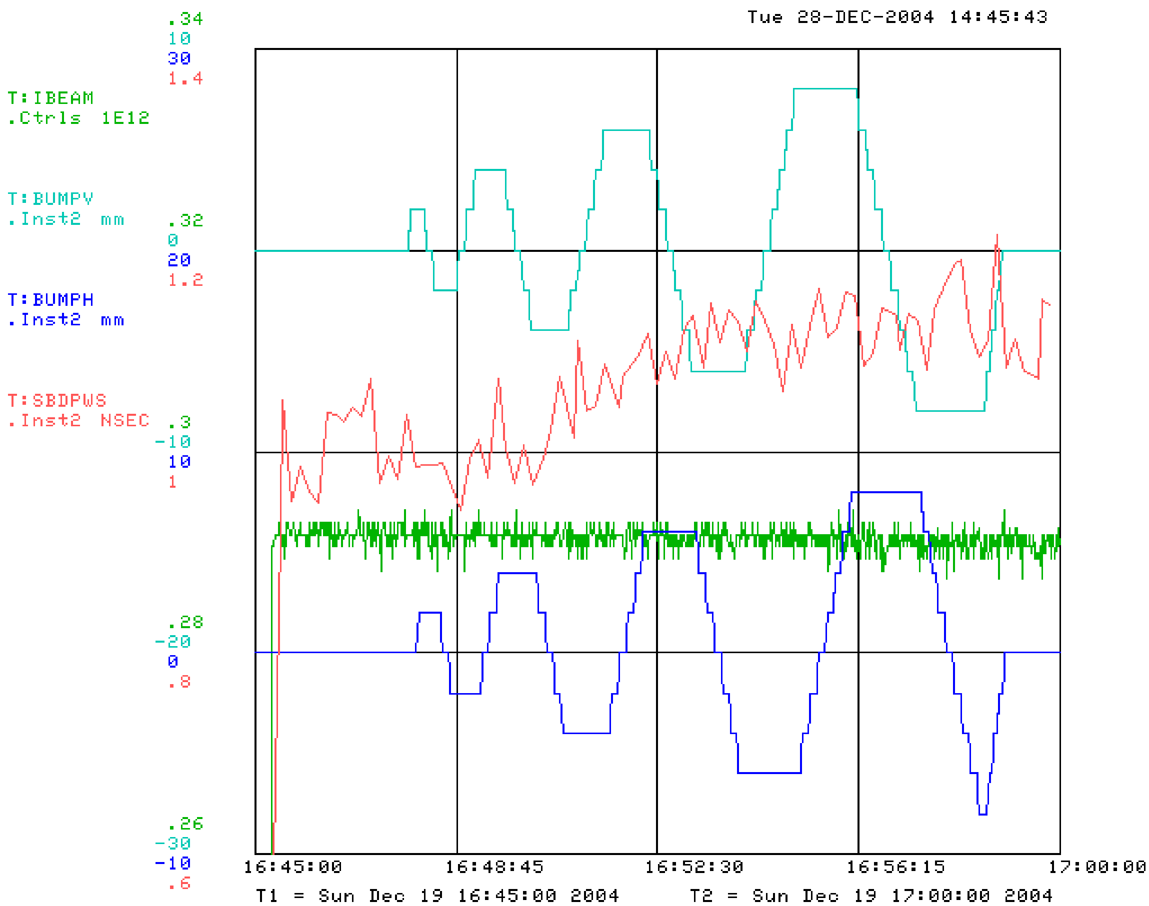

Figure 4 Plot of the beam intensity (T:IBEAM) and longitudinal beam width (T:SBDPWS) during the VPA33 position scan. The values of T:BUMPV and T:BUMPH are the predicted amount of orbit motion during the scan.

In Figure 5 and Figure 6 the data from Table 1 is plotted. Note that the horizontal position changes have an effect on both the reported vertical position and the reported intensity. Also note that the reported intensity at the end of the scan is 7% lower than at the start even though the position of the beam was returned to its starting value.

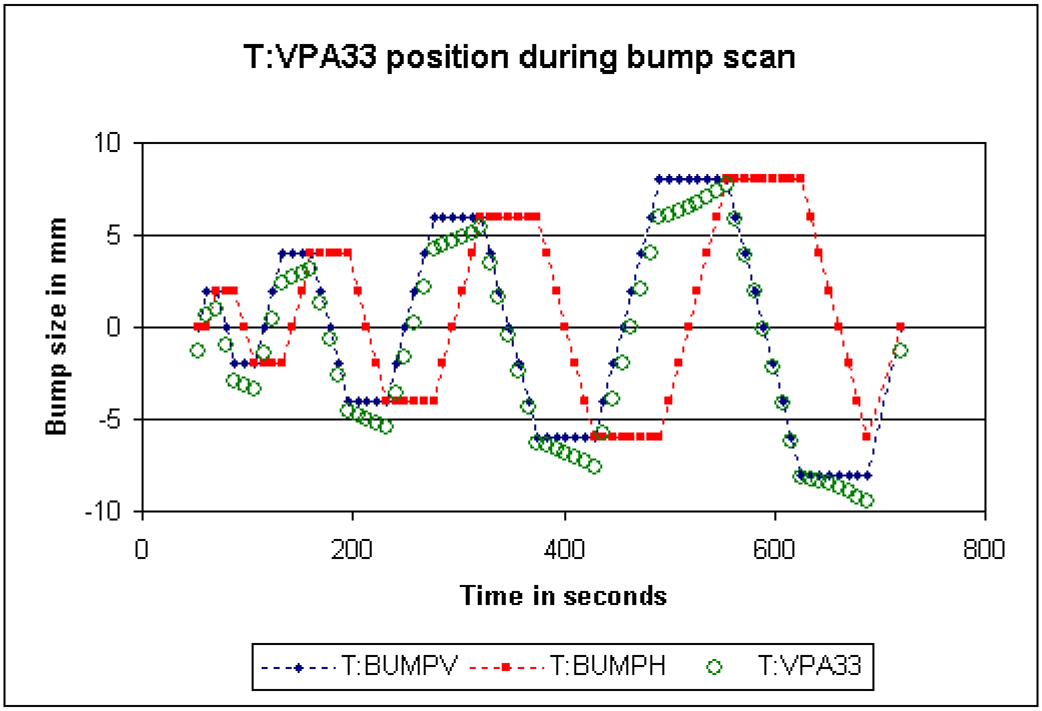

Figure 5 Measured position at VPA33 during the grid study. The plotted data is taken from **Table 1**. Note that the horizontal position changes have an effect on the reported vertical position.

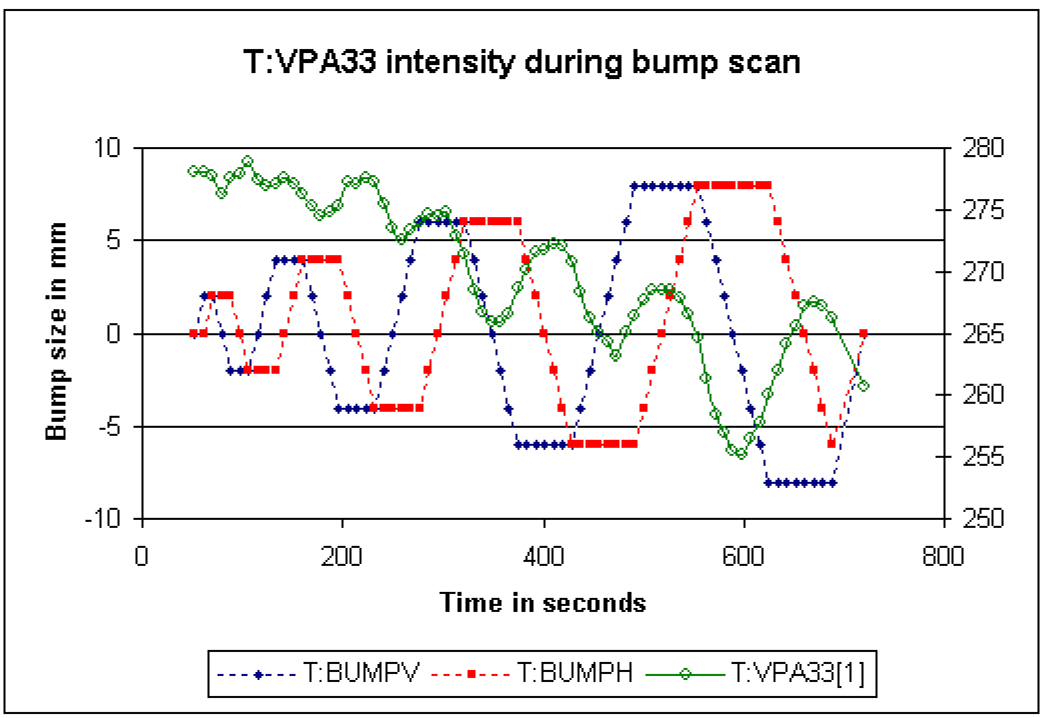

Figure 6 Measured intensity using VPA33 during the grid study. The plotted data is taken from **Table 1**. Note that the horizontal intensity changes as a function of both the horizontal and vertical position changes. Also note that the intensity at the end of the scan is 7% lower than at the start even though the position of the beam was returned to its starting value.

In Figure 7 the rms value of the position measurement is plotted during the grid scan. Interestingly there appears to be a correlation between the rms and the vertical position of the beam (see Figure 8) but no correlation between the rms and the horizontal position of the beam (see Figure 9).

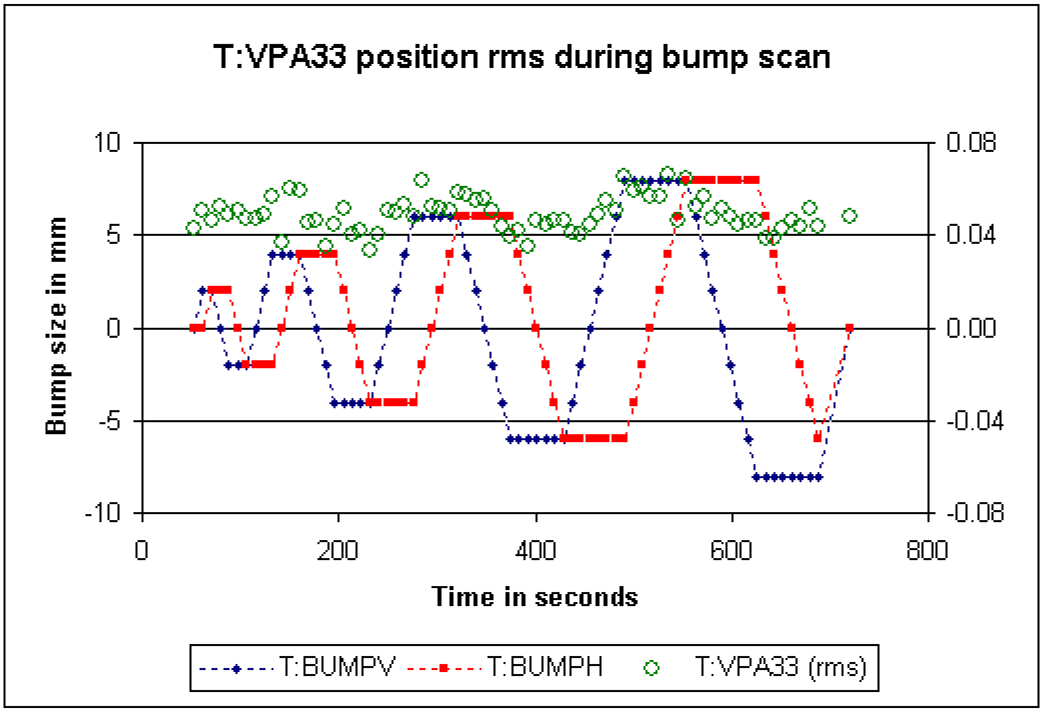

Figure 7 Standard deviation (rms) of the position measurements during the grid scan. Each value of the plotted rms values is from 40 closed orbit measurements.

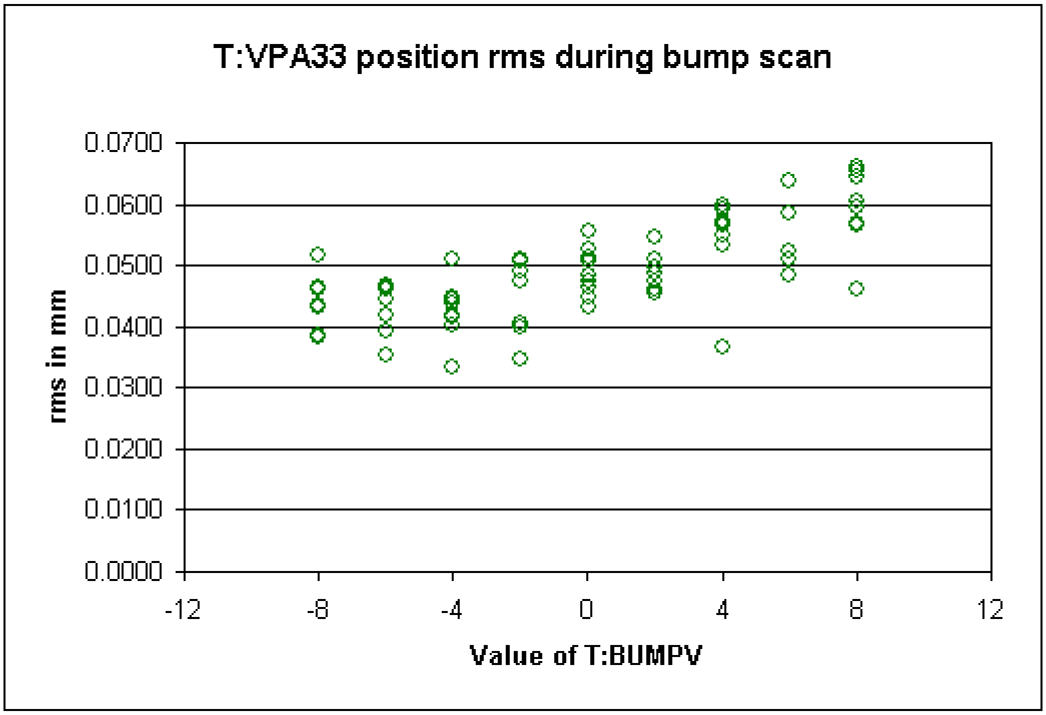

Figure 8 Plot of the rms value of 40 position measurements versus the vertical position change.

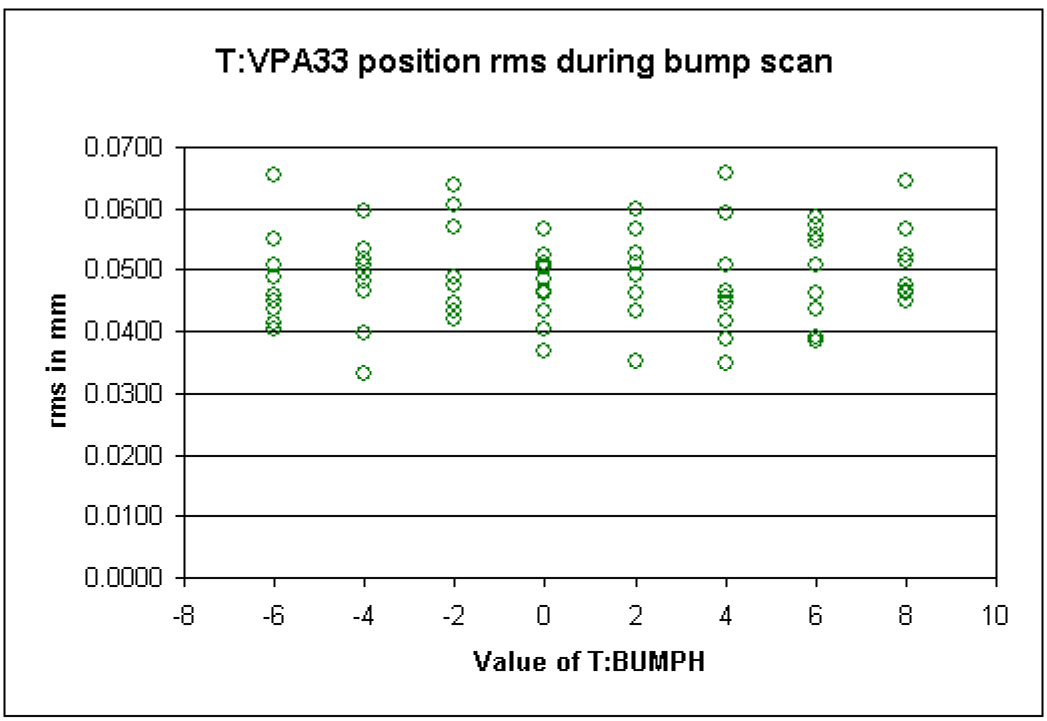

Figure 9 Plot of the rms value of 40 position measurements versus the horizontal position change.

Next we consider the response of the BPM to vertical orbit motion. We define the response as the slope reported BPM position versus the calculated change in vertical position. The response (slope) is determined at each of the horizontal positions in the scan by fitting a line to the measured position versus the size of the vertical bump T:BUMPV. The results are shown in Figure 10. The solid line in Figure 10 is a fit to the BPM response and is given in Equation 1 below.

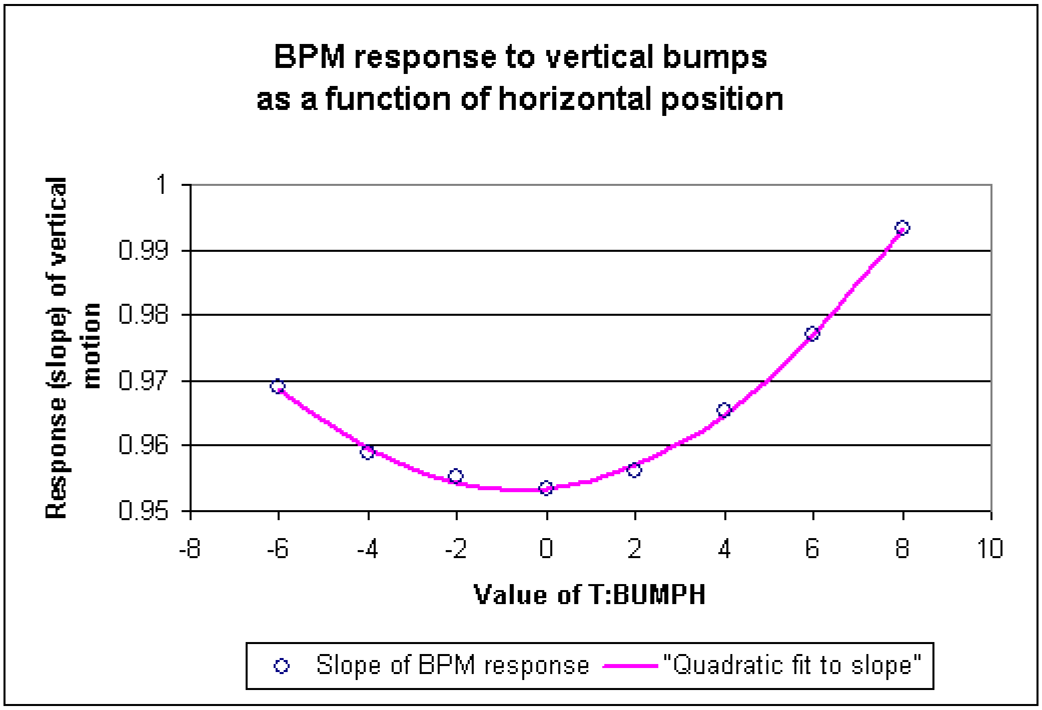

Figure 10 Response of T:VPA33 to vertical orbit bumps as a function of the horizontal orbit position change.

Equation 1

$$\frac{\Delta \mathrm{T:VPA33}}{\Delta \mathrm{T:BUMPV}}(\mathrm{x}) = 0.953 + 5.39\times10^{-4}\times(\mathrm{x}+0.625)^2$$

The theoretical response of the BPM slope versus the horizontal position x is given by

Equation 2

$$\frac{\Delta \mathrm{T:VPA33}}{\Delta \mathrm{T:BUMPV}}(\mathrm{x}) = 1.27 + 6.77\times10^{-4}\times(\mathrm{x})^2$$

This is derived from notes by Jim Crisp (see Beams-doc-812) giving the response of a stripline pickup based on the formula in Equation 3

Equation 3

$$I_A = \frac{\varphi}{2\pi}\left[1 + \sum_{n=1} \frac{4}{n\varphi}\left(\frac{r}{b}\right)^n \cos(n\theta)\sin\left(\frac{n\varphi}{2}\right)\right]$$

$$I_B = \frac{\varphi}{2\pi}\left[1 + \sum_{n=1} \frac{4}{n\varphi}\left(\frac{r}{b}\right)^n \cos(n\theta)\sin\left(n\left(\pi + \frac{\varphi}{2}\right)\right)\right]$$

$$\text{Position} = 26\frac{I_A - I_B}{I_A + I_B}(\text{ in mm })$$

where ϕ is the angle subtended by the stripline (= 110 degrees), b is the radius of the stripline (= 35 mm), and r and θ is the angular coordinate of the beam. A plot of the theoretical position is shown in Figure 11.

If we multiply the theoretical response by a value of 0.751 and add an offset of 0.625 mm then we get

Equation 4

$$\frac{\Delta T : \text{VPA33}}{\Delta T : \text{BUMPV}}(x) = 0.953 + 5.09 \times 10^{-4} \times (x + 0.625)^2$$

There is pretty good agreement between the measured response and the predicted response except for a scale factor of 0.75. It seems that either the vertical bumps that are used in the Tevatron are really smaller than expected, or the BPM response is smaller than expected. In Figure 12 we plot both the measured response and the predicted response multiplied by a factor of 0.751 and then the two show excellent agreement.

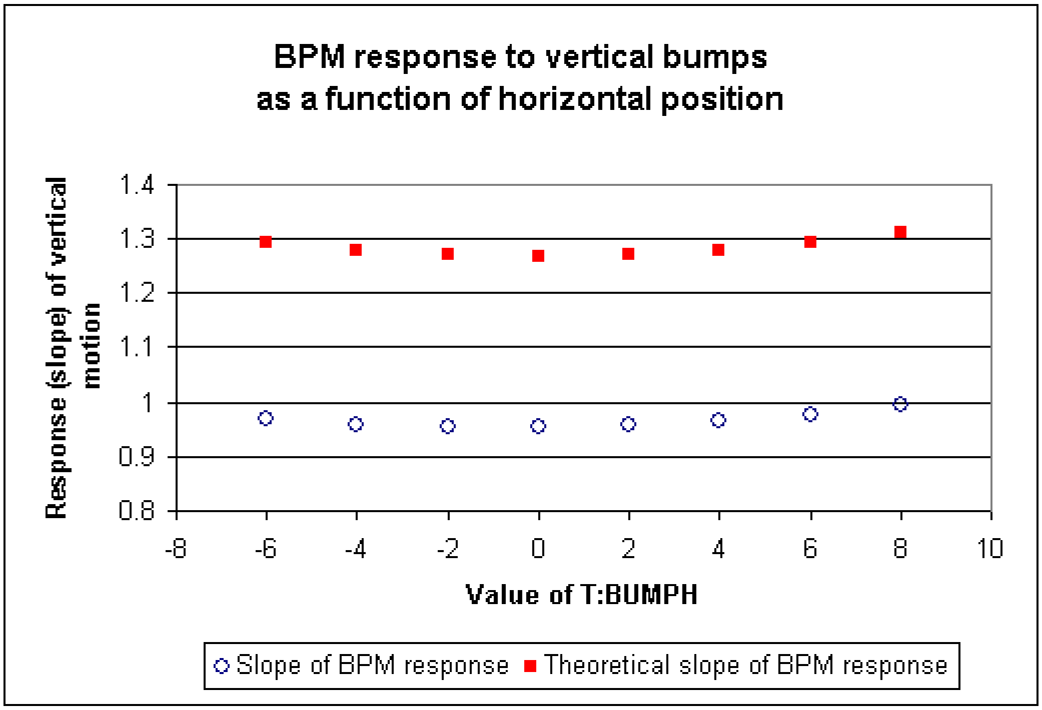

Figure 11 Plot of measured BPM response versus horizontal position against the "theoretical response" explained in the text.

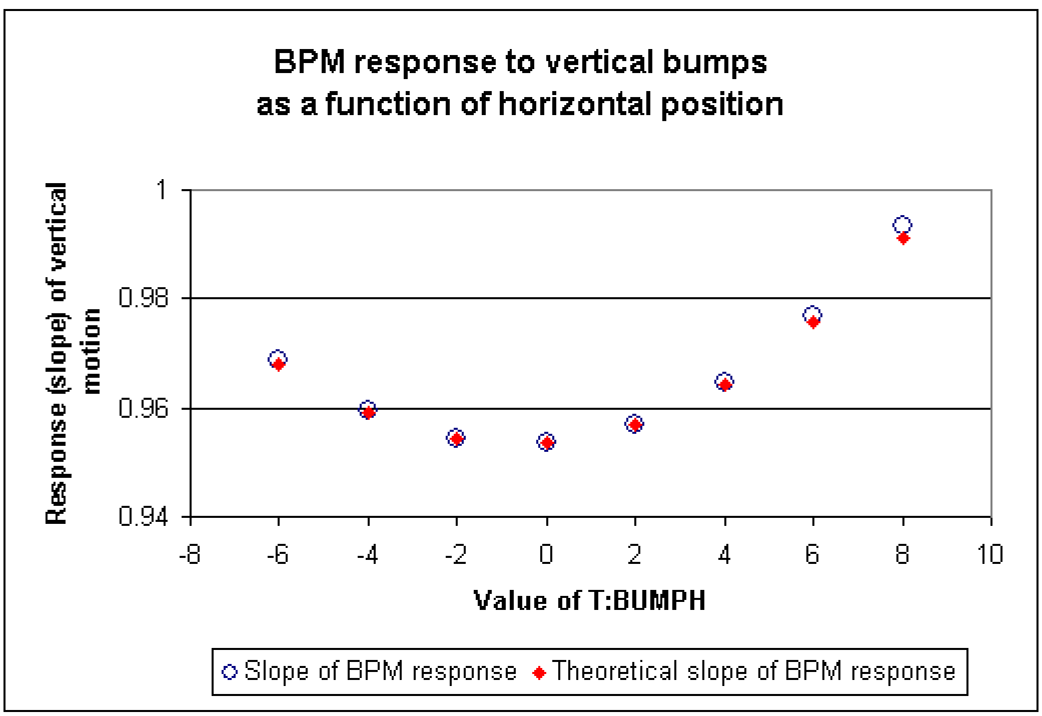

Figure 12 Measured slope of the BPM response and the theoretical slope multiplied by a factor of 0.751.

Next we turn to the intensity response of the BPM. The intensity of the beam as measured by the DCCT and FBI did not decrease significantly during the BPM scan. However the intensity of the BPM did change over the course of the position scan. Part of this reported decrease may be due to a lengthening of the bunch during the scan and therefore a reduction in the 53 MHz component of the beam. Another part of the change in intensity is clearly related to the change in beam position. To help sort this out, I have linearly scaled the intensity as a function of time so that the starting and ending values of the intensity remain the same as shown in Figure 13.

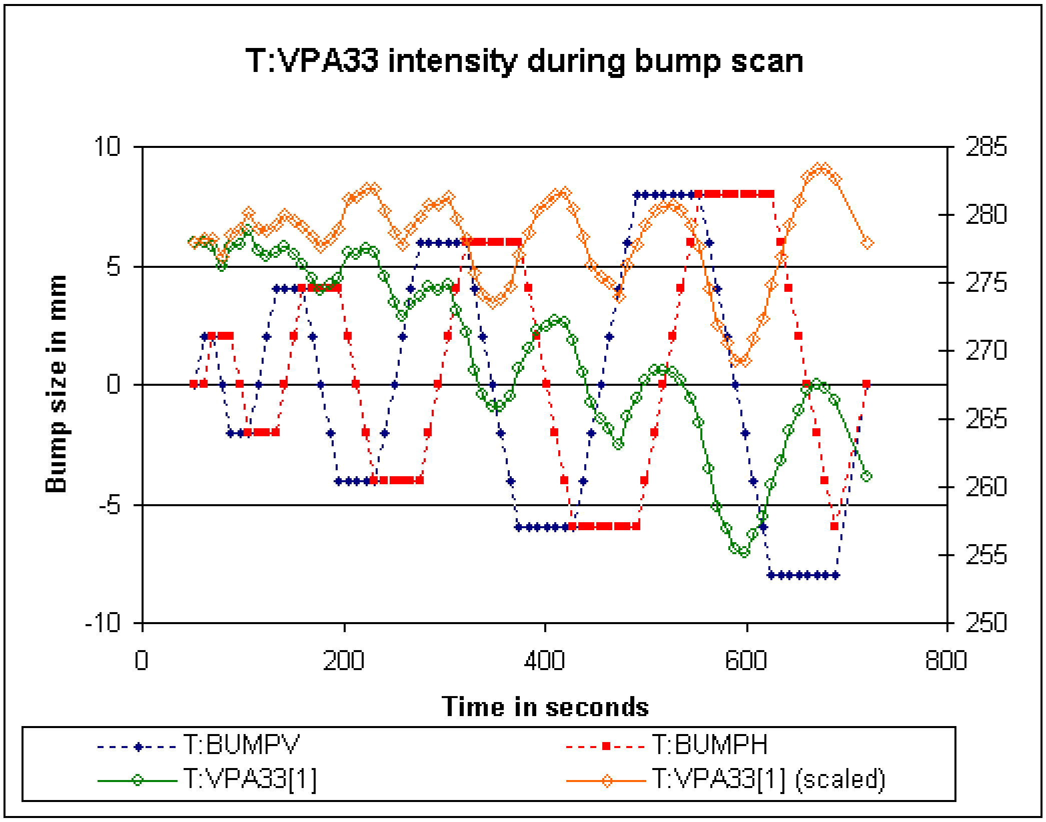

Figure 13 Intensity reported by the BPMs during the scan (green line) and the intensity scaled as a function of time (orange line.)

Using the scaled intensity Figure 14 and Figure 15 plot the intensity as a function of the vertical orbit motion and the horizontal orbit motion. Using the simple BPM model the same plots are made in Figure 16 and Figure 17. Qualitatively the measured intensity and predicted intensity agree, but the data predicted with the model shows larger changes in intensity with orbit motion.

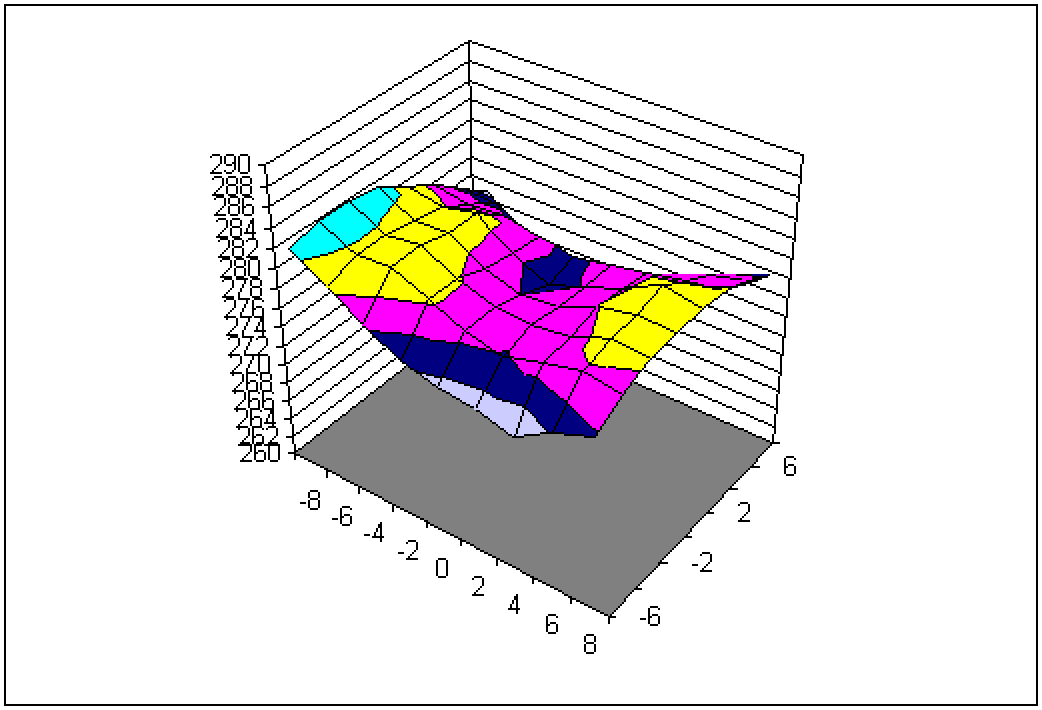

Figure 14 Scaled intensity report by T:VPA33 as a function of T:BUMPV (front axis) and T:BUMPH (right axis).

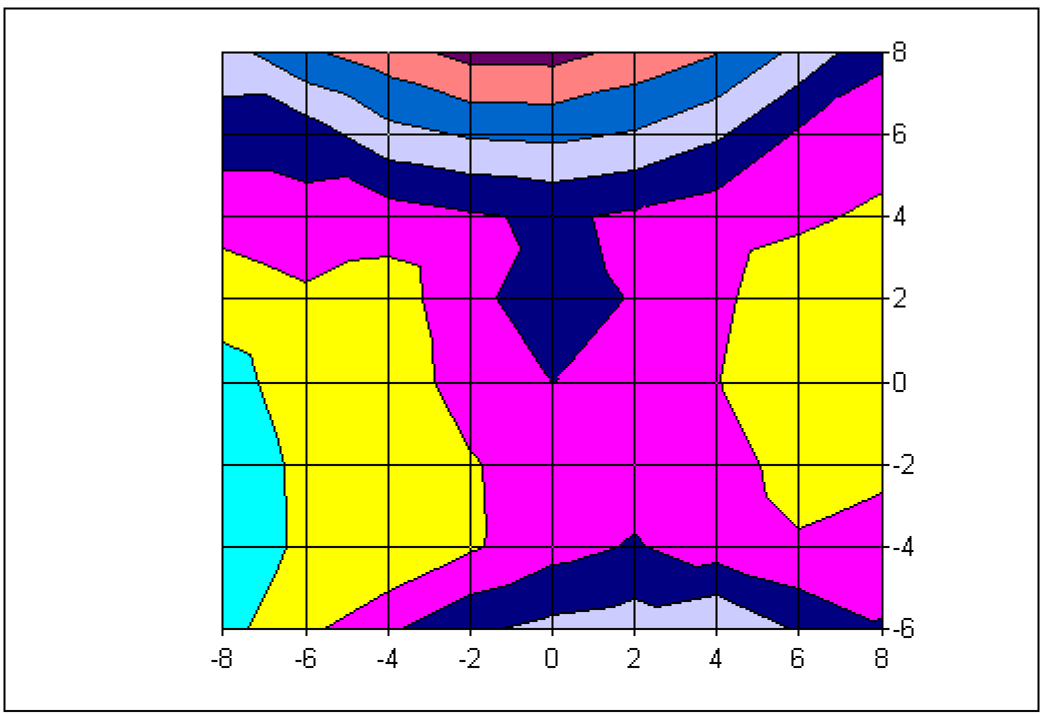

Figure 15 Scaled intensity report by T:VPA33 as a function of T:BUMPV (front axis) and T:BUMPH (right axis).

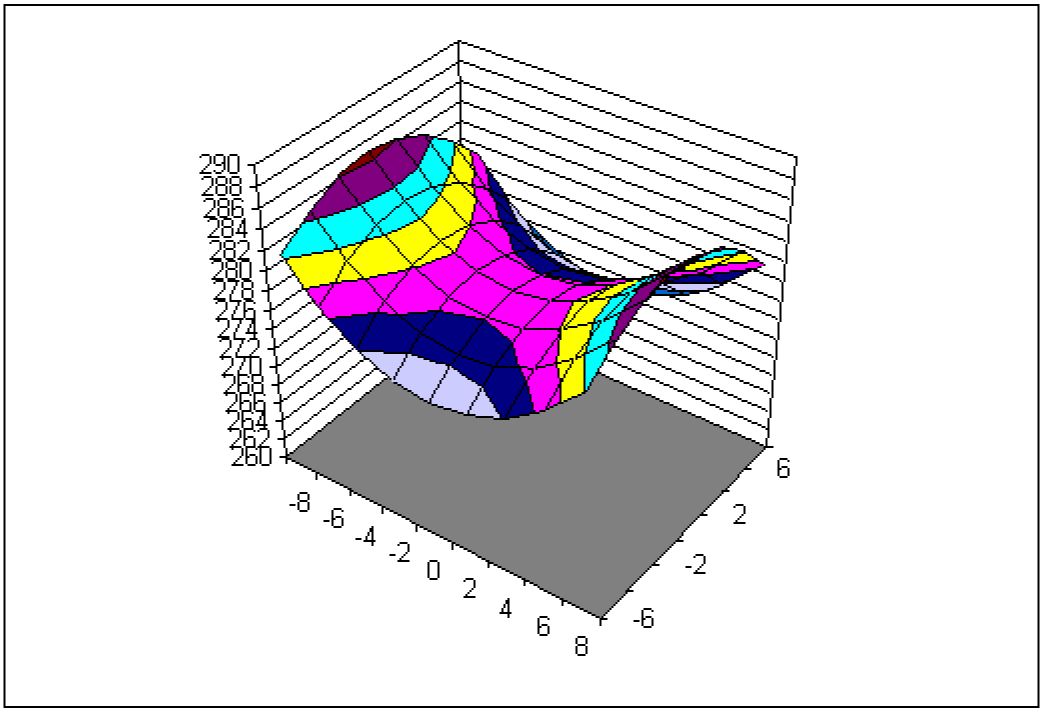

Figure 16 Predicted intensity versus vertical and horizontal orbit changes using the simple BPM model.

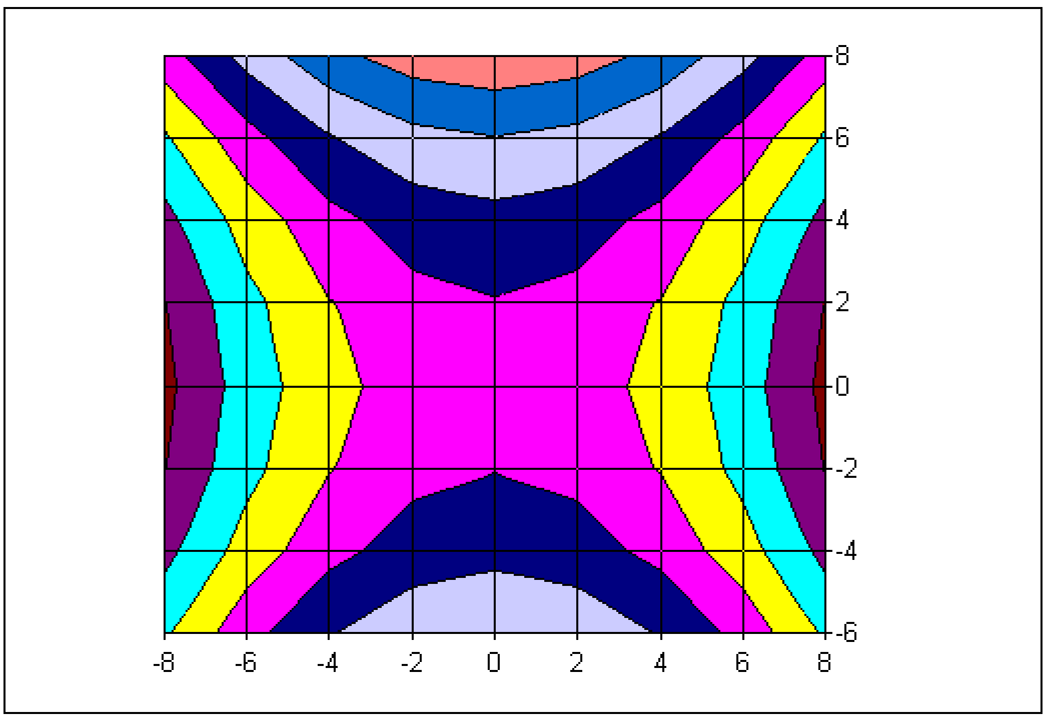

Figure 17 Predicted intensity versus vertical and horizontal orbit changes using the simple BPM model.

Appendix A: Study Plan

BPM upgrade: Position Scan of VPA33

Title: Position scan at VPA33 with upgraded BPM electronics

Author: M. Martens, J. Steimel, R. Kutschke, R. Webber

Date: December 9, 2004

Category: Tevatron BPM upgrade.

Goal: Use and test the latest version of the BPM upgrade electronics installed at the A3 house in the Tevatron. Perform a set of BPM measurements by scanning the horizontal and vertical positions at VPA33.

Machine States
Main Injector: Need occasional injections of uncoalesced protons.

TEV: Stored uncoalesced proton beam at 150 Gev.
Time Needed: 30 minutes of beam.

Prerequisites: A3 BPM upgrade system working.
ACL study scripts to implement bumps.
BPM ACNET devices entered in the data logger.

Setup:

Setup the Tev A3 house BPMs. (The default mode is the correct mode.)

Make a save of the DFG settings in a C50 save file.

Inject 1 uncoalesced batch of protons in the Tevatron at 150 GeV.
(The usual 0.3E12 total beam intensity.)

Verify that the A3 house BPMs are running properly.

Verify that the BPM ACNET variables are being data logged correctly.
The devices are T:BUMPH, T:BUMPV, T:HPA34[], T:VPA33[], and T:VA33IQ [] and they are in the 15 Hz list of the Tev datalogger.
Select Node=martens and recall plot “VPA33 study” on D44 for canned data logger plots of these devices at 15 Hz. If the data logger is not collecting data it may be necessary to restart the Tev, 15Hz list containing these devices. Use page D43 for this.

Measurements:

Use the STUDIES Sequencer (T48) and the “BPM Testing” aggregate to run the ACL script making the orbit bumps. There are several FTP commands to run also. These are all at the top of the “BPM Testing” aggregate. If it becomes necessary to modify the ACL script, it exists in CBS_FILE:[SEQUENCER.ACL]MARTENS_BPM_STUDY.ACL

Monitor the beam current, T:IBEAM and the beam position T:VPA33 and T:HPA34 Collect orbits at several of the measurement points to verify that the orbit bumps are indeed local.

The script will make a set of vertical and horizontal position bumps at VPA33. The position of the beam should “spiral” outward and each step is 2 mm. In the end a 8x9 grid of positions will be mapped out.

When the aggregate is complete check to make sure that the DFGs are back to their original settings by doing a C50 DFG compare to the file made previously.

Save Data:

Mail the data from the data logger to the interested party. Note that the data logger list at 15 Hz will start to wrap-around after about 2 days.

Appendix B: ACL script used during study

```
! Script to scan horizontal and vertical positions
! for BPM study at VPA33
! Writen by M. Martens 12/10/04
! Version 1.0
! Makes horizontal and vertical position bumps at VPA33

output mail:martens

print "Scanning horizontal and vertical position at VPA33"
print " "
print "Today's date"
print date
print "Present time"
print time
print "Store number"
read T_STORE
print " "
!
print "Original settings of correctors"
read T_VA29[2]
read T_VA33[2]
read T_VA35[2]
read T_HA28[2]
read T_HA32[2]
read T_HA34[2]
read T_HA36[2]


!Set bump position counters to zero
set T:BUMPH 0
set T:BUMPV 0

!dwell time for measurement
$dwell = 4
!pause for corrector sets
$wait_corrector = 1

! Ratios for the orbit bumps

! +1 mm vertical 3-bump at VPA33
! $VA29_3 =  0.0110
! $VA33_3 = -0.0086
! $VA35_3 =  0.0116
$VA29_3 = 0.0110
$VA33_3 = 0.0086
$VA35_3 = 0.0116

! +1 mm horizontal 4-bump at VPA33
! $HA28_4 = -0.0114
! $HA32_4 = -0.0154
! $HA34_4 =  0.0061
! $HA36_4 = -0.0239
$HA28_4 = 0.0114
```

```
$HA32_4 = 0.0154
$HA34_4 = 0.0061
$HA36_4 = 0.0239

! size of the steps for the bumps
! enter an integer number
$horizontal_bump_size = 2
$vertical_bump_size = 2

print "dwell"
print $dwell
print "wait_corrector"
print $wait_corrector
print "VA29_3"
print "VA33_3"
print "VA35_3"
print $VA29_3
print $VA33_3
print $VA35_3
print "HA28_4"
print "HA32_4"
print "HA34_4"
print "HA36_4"
print $HA28_4
print $HA32_4
print $HA34_4
print $HA36_4


print "horizontal_bump_size"
print $horizontal_bump_size
print "vertical_bump_size"
print $vertical_bump_size

! Spiral outward

gosub collect_data


$num_vertical_positions 1
loop $num_vertical_positions
  gosub positive_vertical_bump
  gosub collect_data
endloop

$num_horizontal_positions 1
loop $num_horizontal_positions
  gosub positive_horizontal_bump
  gosub collect_data
endloop

$num_vertical_positions 2
loop $num_vertical_positions
  gosub negative_vertical_bump
  gosub collect_data
endloop
```

```
$num_horizontal_positions 2
loop $num_horizontal_positions
  gosub negative_horizontal_bump
  gosub collect_data
endloop

$num_vertical_positions 3
loop $num_vertical_positions
  gosub positive_vertical_bump
  gosub collect_data
endloop

$num_horizontal_positions 3
loop $num_horizontal_positions
  gosub positive_horizontal_bump
  gosub collect_data
endloop

$num_vertical_positions 4
loop $num_vertical_positions
  gosub negative_vertical_bump
  gosub collect_data
endloop

$num_horizontal_positions 4
loop $num_horizontal_positions
  gosub negative_horizontal_bump
  gosub collect_data
endloop

$num_vertical_positions 5
loop $num_vertical_positions
  gosub positive_vertical_bump
  gosub collect_data
endloop

$num_horizontal_positions 5
loop $num_horizontal_positions
  gosub positive_horizontal_bump
  gosub collect_data
endloop

$num_vertical_positions 6
loop $num_vertical_positions
  gosub negative_vertical_bump
  gosub collect_data
endloop

$num_horizontal_positions 6
loop $num_horizontal_positions
  gosub negative_horizontal_bump
  gosub collect_data
endloop

$num_vertical_positions 7
loop $num_vertical_positions
  gosub positive_vertical_bump
```

```
  gosub collect_data
endloop

$num_horizontal_positions 7
loop $num_horizontal_positions
  gosub positive_horizontal_bump
  gosub collect_data
endloop

$num_vertical_positions 8
loop $num_vertical_positions
  gosub negative_vertical_bump
  gosub collect_data
endloop

$num_horizontal_positions 8
loop $num_horizontal_positions
  gosub negative_horizontal_bump
  gosub collect_data
endloop

$num_vertical_positions 4
loop $num_vertical_positions
  gosub positive_vertical_bump
  gosub positive_horizontal_bump
endloop

gosub collect_data

print "Final settings of correctors"
read T_VA29[2]
read T_VA33[2]
read T_VA35[2]
read T_HA28[2]
read T_HA32[2]
read T_HA34[2]
read T_HA36[2]

exit



positive_horizontal_bump:

  loop $horizontal_bump_size
    increment T:BUMPH  1
    decrement T:HA28[2] $HA28_4
    decrement T:HA32[2] $HA32_4
    increment T:HA34[2] $HA34_4
    decrement T:HA36[2] $HA36_4
    wait/sec $wait_corrector
  endloop
return


negative_horizontal_bump:
```

```
  loop $horizontal_bump_size
    decrement T:BUMPH  1
    increment T:HA28[2] $HA28_4
    increment T:HA32[2] $HA32_4
    decrement T:HA34[2] $HA34_4
    increment T:HA36[2] $HA36_4
    wait/sec $wait_corrector
  endloop

return


positive_vertical_bump:

  loop $vertical_bump_size
    increment T:BUMPV  1.0
    increment T:VA29[2] $VA29_3
    decrement T:VA33[2] $VA33_3
    increment T:VA35[2] $VA35_3
    wait/sec $wait_corrector
  endloop

return


negative_vertical_bump:

  loop $vertical_bump_size
    decrement T:BUMPV  1.0
    decrement T:VA29[2] $VA29_3
    increment T:VA33[2] $VA33_3
    decrement T:VA35[2] $VA35_3
    wait/sec $wait_corrector
  endloop

return


collect_data:
  wait/sec $dwell
  print " "
  print "*******************"
  print "Collecting Data"
  print "*******************"
  print " "
  print "Present time"
  print time
  read T:IBEAM
  read T:BUMPH
  read T:BUMPV
  read T:VPA33
  read T:VPA35
  read T:VPA37
  read T:VPA39
  read T:HPA32
  read T:HPA34
  read T:HPA36
```

```
  read T:HPA38
  print " "
  read T:VA33IQ[0:7]
  print "********************"

return
```