Fermi National Accelerator Laboratory

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Beam-Beam Tuneshift During the TEVATRON Squeeze

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BEAM-BEAM TUNESHIFT DURING THE TEVATRON SQUEEZE

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We calculate the beam-beam tuneshift during the squeeze of the beam in the Tevatron from injection to mini-beta. We find that for the beam emittances typically used, there is little variation of the tuneshift, in either plane, during the squeeze.

1 Introduction and Basic Details

When proton and antiproton beams are injected into the Tevatron, the accelerator lattice is in the fixed-target configuration. This is then changed, in a process called the "squeeze," to a mini-beta configuration, where the beta functions at B0 (the CDF interaction point) are rdeuced to $\beta_x^* = 0.58$ m and $\beta_y^* = 0.6$ m. The squeeze is performed by changing the B0 quadrupole settings in a sequence of 35 steps. It is observed that particles are lost during the squeeze, and it is speculated that this may be because the beam-beam tuneshift increases at that point and causes a resonance to be encountered. An example of the data is shown in Fig. 1. The curve marked 1 shows the beam intensity (IBEAMB) as a function of time (or step number in the squeeze). The curve marked 2 shows the current in the Q1 quadrupoles at B0 (B0Q1) while the curves marked 3 and 4 show the luminosity as recorded at B0 (B0LUM and B0LUMH). We see a drop in intensity, indicating particle loss, at the arrowed point in curve 1. We therefore calculate the beam-beam tuneshift as a function of step number during the squeeze. We find that the tuneshift is almost constant during the squeeze.

2 Calculation

We calculate only the small-amplitude, or linear, beam-beam tuneshift below. The tuneshift for larger amplitudes is smaller than this value, so we are calculating an upper bound. We calculate the antiproton tuneshift below, assuming 6 proton bunches, each with 6×10^{10} particles. The tuneshift is linearly proportional to the number of particles, so we do not vary this parameter. The beam-beam tuneshift depends not only on the lattice but also on the beam emittances and the σ_p/p relative momentum spread. We perform the calculation for several values of the emittances, but assuming equal emittances $\epsilon_x = \epsilon_y = \epsilon$, say. All emittances are normalized 95% values in this report. We consider two values for σ_p/p, viz. zero and 1.5×10^{-4}. The latter number is appropriate for a beam at 900 GeV. For example, $\sigma_p/p = 1.49 \times 10^{-4}$ in the data shown in Fig. 1.

We use the SYNCH program to calculate the lattice functions, and calculate the tuneshift using another program called BBTS from D.E. Johnson.[1] We do *not* assume round beams. Only the B0 and correction quadrupole settings are changed (as a function of step number) in the calculations. The B0 quadrupole settings are taken from the T111 page, and are reproduced in Table 1 below. Note that the values of the correction quadrupole settings Qx and Qy in the last two columns are *not* used. Instead SYNCH is used to set their values by demanding that the tunes be equal to the values measured experimentally. The values of the tunes are given in Table 2.[2]

2.1 Special case

For the case where $\sigma_p/p = 0$, we can perform a simple analytical calculation of the linear beam-beam tuneshifts to derive the result that the sum $\Delta\nu_x + \Delta\nu_y$ is constant, provided that $\epsilon_x = \epsilon_y$. This result was actually first found numerically, in one of the graphs below, and provides a check on the numerical calculation. In this report, the

[1] D.E. Johnson, private communication.

[2] These values were obtained from D. Herrup (private communication).

formulas used for the tuneshifts are

$$\Delta\nu_{x,y} = \frac{Nr_p}{2\pi\gamma}\sum_{IP}\frac{\beta_{x,y}}{\sigma_{x,y}^2 + \sigma_x\sigma_y}\ . \tag{1}$$

Here N is the number of particles per bunch, r_p is the classical proton radius, $\beta_{x,y}$ is the {horizontal,vertical} beta function, and $\sigma_{x,y}$ is the {horizontal,vertical} r.m.s. beam size. For a planar horizontal ring, $\sigma_y^2 = \epsilon_y\beta_y$ and if $\sigma_p/p = 0$, then $\sigma_x^2 = \epsilon_x\beta_x$. Hence, defining $\lambda = \sqrt{\beta_x/\beta_y}$,

$$\begin{aligned}
\Delta\nu_x &= \frac{Nr_p}{2\pi\gamma}\sum\frac{\beta_x}{\epsilon_x\beta_x + \sqrt{\beta_x\beta_y\epsilon_x\epsilon_y}} \\
&= \frac{Nr_p}{2\pi\gamma}\sum\frac{1}{\epsilon_x + \lambda^{-1}\sqrt{\epsilon_x\epsilon_y}} \\
\Delta\nu_y &= \frac{Nr_p}{2\pi\gamma}\sum\frac{\beta_y}{\epsilon_y\beta_y + \sqrt{\beta_x\beta_y\epsilon_x\epsilon_y}} \\
&= \frac{Nr_p}{2\pi\gamma}\sum\frac{1}{\epsilon_y + \lambda\sqrt{\epsilon_x\epsilon_y}}\ .
\end{aligned} \tag{2}$$

Therefore, if $\epsilon_x = \epsilon_y$,

$$\begin{aligned}
\Delta\nu_x + \Delta\nu_y &= \frac{Nr_p}{2\pi\gamma}\sum\left\{\frac{1}{\epsilon_x(1+\lambda^{-1})} + \frac{1}{\epsilon_x(1+\lambda)}\right\} \\
&= \frac{Nr_p}{2\pi\gamma\epsilon_x}\sum\left\{\frac{\lambda}{1+\lambda} + \frac{1}{1+\lambda}\right\} \\
&= \frac{Nr_p}{2\pi\gamma\epsilon_x}\sum 1 \\
&= \frac{6Nr_p}{\pi\gamma\epsilon_x}\ .
\end{aligned} \tag{3}$$

Note that one must have equal emittances, else $\Delta\nu_x + \Delta\nu_y$ is not constant.

3 Results and Conclusions

The results are shown in Figs. 2 - 5. The order of the figures is

$$\begin{array}{ll}
\Delta\nu_x, & \sigma_p/p = 0 \\
\Delta\nu_x, & 1.5E-4 \\
\Delta\nu_y, & 0 \\
\Delta\nu_y, & 1.5E-4\,.
\end{array}$$

The individual graphs in each figure are for different values of the emittance. In the $\Delta\nu_x$ plots, we start from $\epsilon = 5\pi$ mm-mrad and increase in steps of 5π mm-mrad until 100π mm-mrad. Recall that we set $\epsilon_x = \epsilon_y = \epsilon$. In the $\Delta\nu_y$ plots, we start from $\epsilon = 10\pi$ mm-mrad instead because the 5π mm-mrad curve is off the scale, and it would compress the other graphs too much to change the scale to include this not very important case. We also plot $\Delta\nu_y$ vs. $\Delta\nu_x$ in Figs. 6 and 7 (with $\sigma_p/p = 0$ and $1.5E-4$ respectively).

We see that except for $\Delta\nu_x$ with $\sigma_p/p = 1.5E-4$, the tuneshifts stay almost constant during the squeeze. In the exception, the tuneshift increases slightly at the end of the squeeze, but not to a high value. We also see that $\Delta\nu_y > \Delta\nu_x$ always.

We conclude that the beam-beam tuneshift does not change significantly during the squeeze, at least on the present evidence, and is therefore not correlated with the particle losses during the squeeze.

Acknowledgements

The author thanks G. Jackson for bringing this problem to his attention, D.E. Johnson with SYNCH and the lattice datafiles, D. Herrup for information about the tunes, and especially D. Finley for critical comments and ideas on the manuscript, and help with the figures including teaching the author the use of TOPDRAWER. This work was supported by the Universities Research association Inc., under Contract DE-AC02-76CH03000 from the Department of Energy.

CONSOLE LOCATION 05; MCRLib   30-NOV-1988 11:26
Snapshot Plot

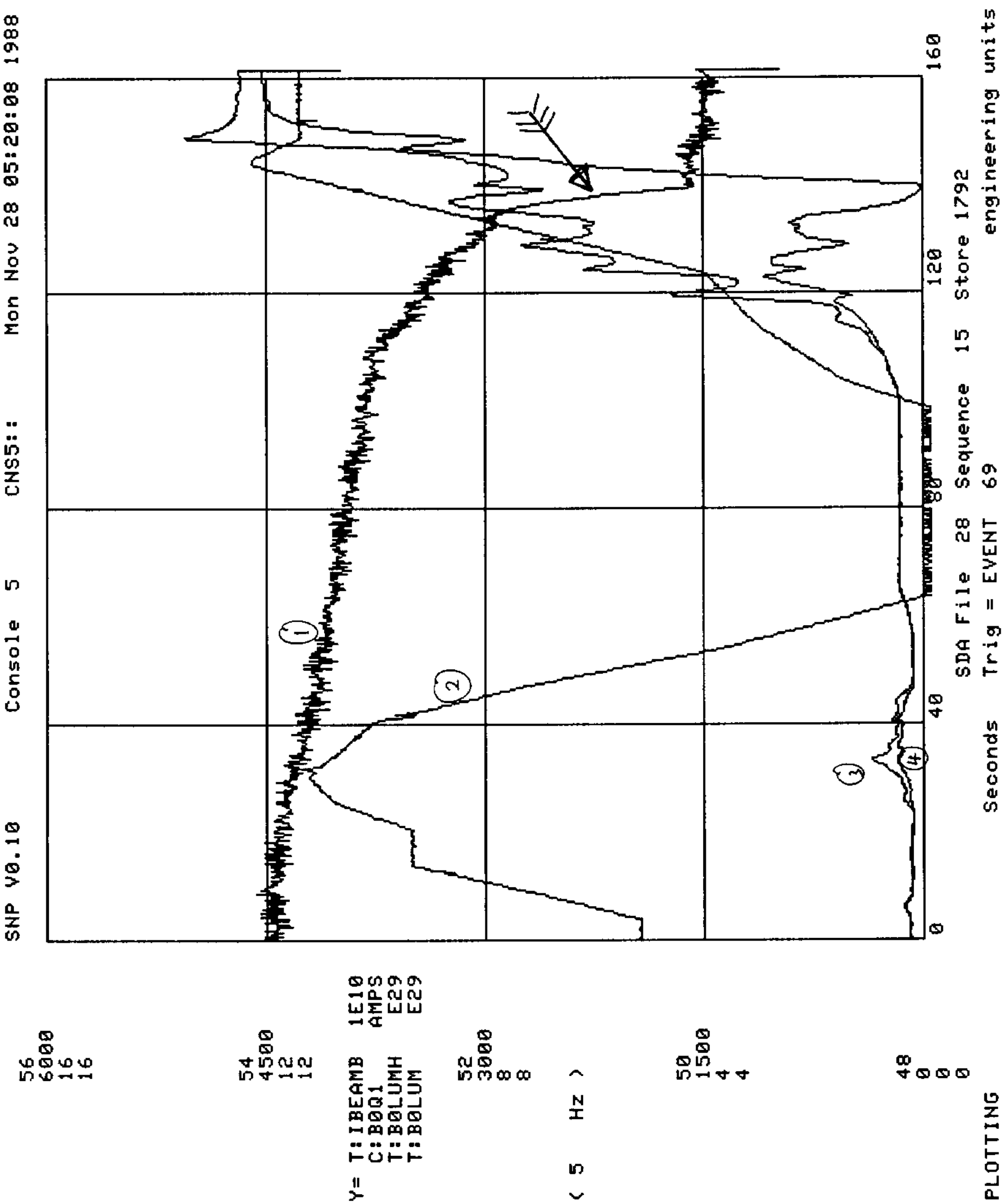

Fig. 1

TABLE 1

T111 MODIFYing file 7   1TO21 HALF TIME SQUEEZE, 29 SEP 1988   DAH
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*Help   CALC/PL   breakpoints as in rf/ramp
NORMAL

SEQ	TYPE	Dt	ENERGY	TIME	Q1	Q2	Q3	Q4	Qx	Qy
					------------values at end of sequence--------------					
1	LINEAR	0	900	4	369.6	0	0	0	0	0
2	LINEAR	0	900	9	510	0	50	0	-7.11	7.11
3	LINEAR	0	900	11.5	590	0	70	0	-10.86	10.86
4	LINEAR	0	900	14	670	0	78	26	-13.85	13.85
5	LINEAR	0	900	17.3	670	100	160	50	-14.7	14.7
6	LINEAR	0	900	20.6	670	200	240	75	-17.32	17.32
7	LINEAR	0	900	23.1	720	275	280	85	-17.88	17.88
8	LINEAR	0	900	25.6	770	350	320	100	-18.25	18.25
9	LINEAR	0	900	28.1	790	425	350	85	-18.65	18.65
10	LINEAR	0	900	30.6	805	500	380	70	-20.68	20.68
11	LINEAR	0	900	33.1	785	575	410	65	-20.71	20.71
12	LINEAR	0	900	35.6	760	650	440	55	-23.24	23.24
13	LINEAR	0	900	38.1	740	725	480	90	-23.24	23.24
14	LINEAR	0	900	40.6	720	800	520	130	-23.8	23.8
15	LINEAR	0	900	43.9	620	825	530	115	-25.02	25.02
16	LINEAR	0	900	47.2	520	850	545	100	-28.57	28.57
17	LINEAR	0	900	50.5	400	870	550	75	-29.23	29.23
18	LINEAR	0	900	53.8	275	890	560	50	-32.41	32.41
19	LINEAR	0	900	57.1	180	890	570	50	-33.33	33.33
20	LINEAR	0	900	60.4	90	890	580	50	-33.91	33.91
21	STOPLN	0	900	63.7	-2	908.5	640	176.9	-35.51	35.51

T111 MODIFYing file 8   21 TO MINI BETA, HALF TIME; ED15 P65   DF
*Return *ch-plot *ch-calc *ramp/rf *tune   *B0QUADS *timing *send
*Help   CALC/PL   breakpoints as in rf/ramp
NORMAL

SEQ	TYPE	Dt	ENERGY	TIME	Q1	Q2	Q3	Q4	Qx	Qy
					------------values at end of sequence--------------					
1	LINEAR	0	900	6	-2	908.5	640	176.9	-35.51	35.51
2	LINEAR	0	900	11	105	930	710	325	-37.37	37.37
3	LINEAR	0	900	16	160	942.5	765	467.5	-39.34	39.34
4	LINEAR	0	900	21	215	955	820	610	-41.3	41.3
5	LINEAR	0	900	26	250	950	872.5	775	-42.05	42.05
6	LINEAR	0	900	31	285	945	925	940	-42.79	42.79
7	LINEAR	0	900	36	433.5	960.3	936.5	954.8	-45	45
8	LINEAR	0	900	41	582	975.5	948	969.5	-47.3	47.3
9	LINEAR	0	900	46	730.5	991	959.5	984.3	-49.5	49.5
10	LINEAR	0	900	51	879	1006	971	999.2	-51.8	51.8
11	LINEAR	0	900	52	879	1006	971	999.2	-51.8	51.8
12	LINEAR	0	900	53	863.5	1007.3	973.3	993.7	-53.88	53.88
13	LINEAR	0	900	54	848	1009.1	975.6	988.2	-56.42	56.42
14	LINEAR	0	900	55	832.5	1010.8	977.8	982.7	-59	59
15	STOPLN	0	900	56	817	1012.6	980.1	977.2	-61.59	61.59

Table 2.

Only the fractional parts of the tunes are listed. The integer part is 19.

Step	Qx	Qy
1	4144	4071
2	4240	4062
3	4190	4048
4	4156	4034
5	4178	4067
6	4155	4044
7	4169	4042
8	4170	4042
9	4157	4034
10	4163	4036
11	4152	4038
12	4162	4039
13	4178	4031
14	4184	4071
15	4161	4047
16	4161	4037
17	4161	4034
18	4166	4044
19	4175	4078
20	4164	4078
21	4132	4056
22	4152	4074
23	4135	4100
24	4152	4081
25	4156	4038
26	4156	4037
27	4151	4025
28	4140	4048
29	4135	4071
30	4189	4098
31	4136	4067
32	4136	4054
33	4169	4047
34	4179	4051
35	4123	4021

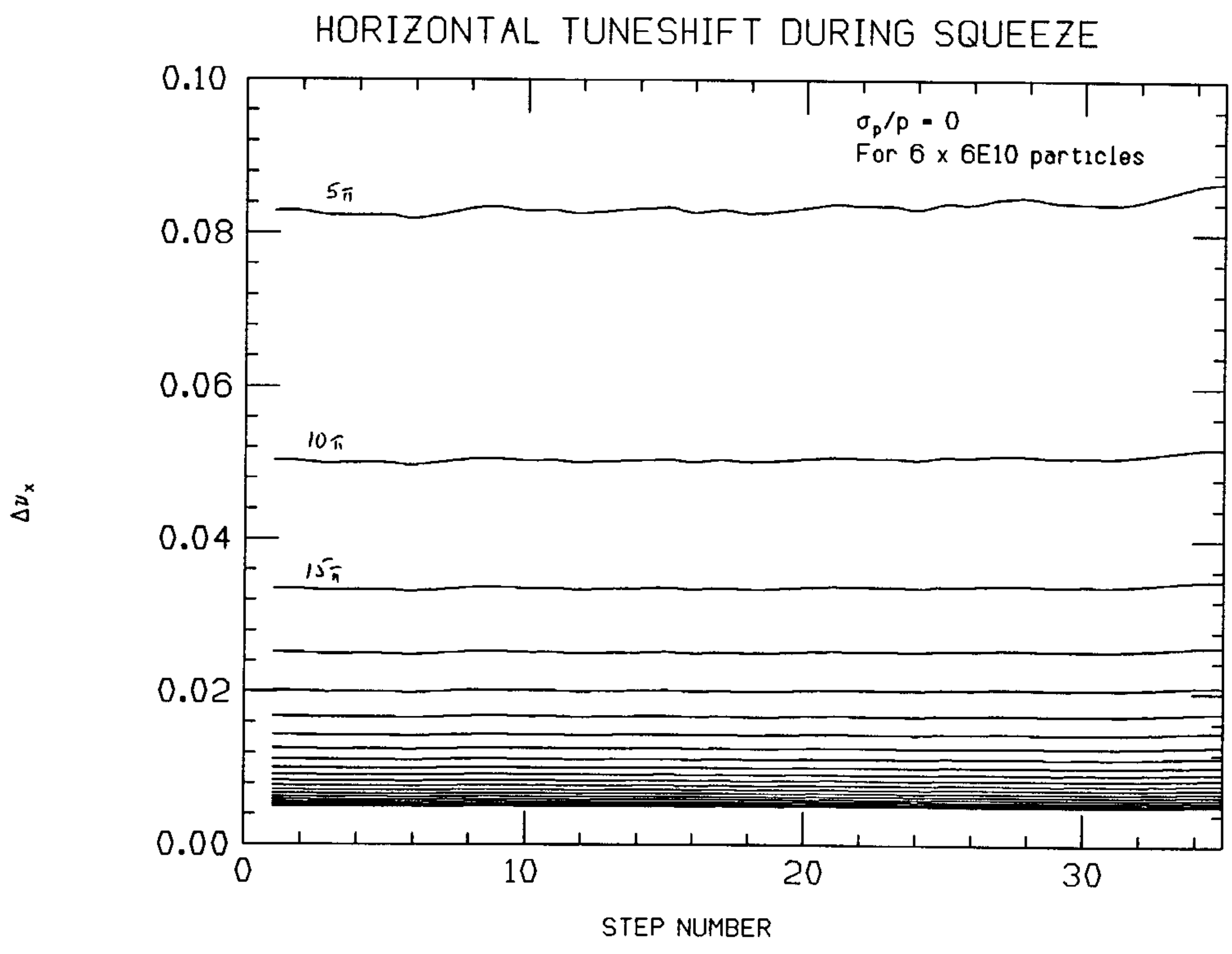

HORIZONTAL TUNESHIFT DURING SQUEEZE
$\sigma_p/p = 0$
For 6 x 6E10 particles
5π
10π
15π
0.10
0.08
0.06
0.04
0.02
0.00
0
10
20
30
STEP NUMBER
$\Delta\nu_x$

Fig. 2

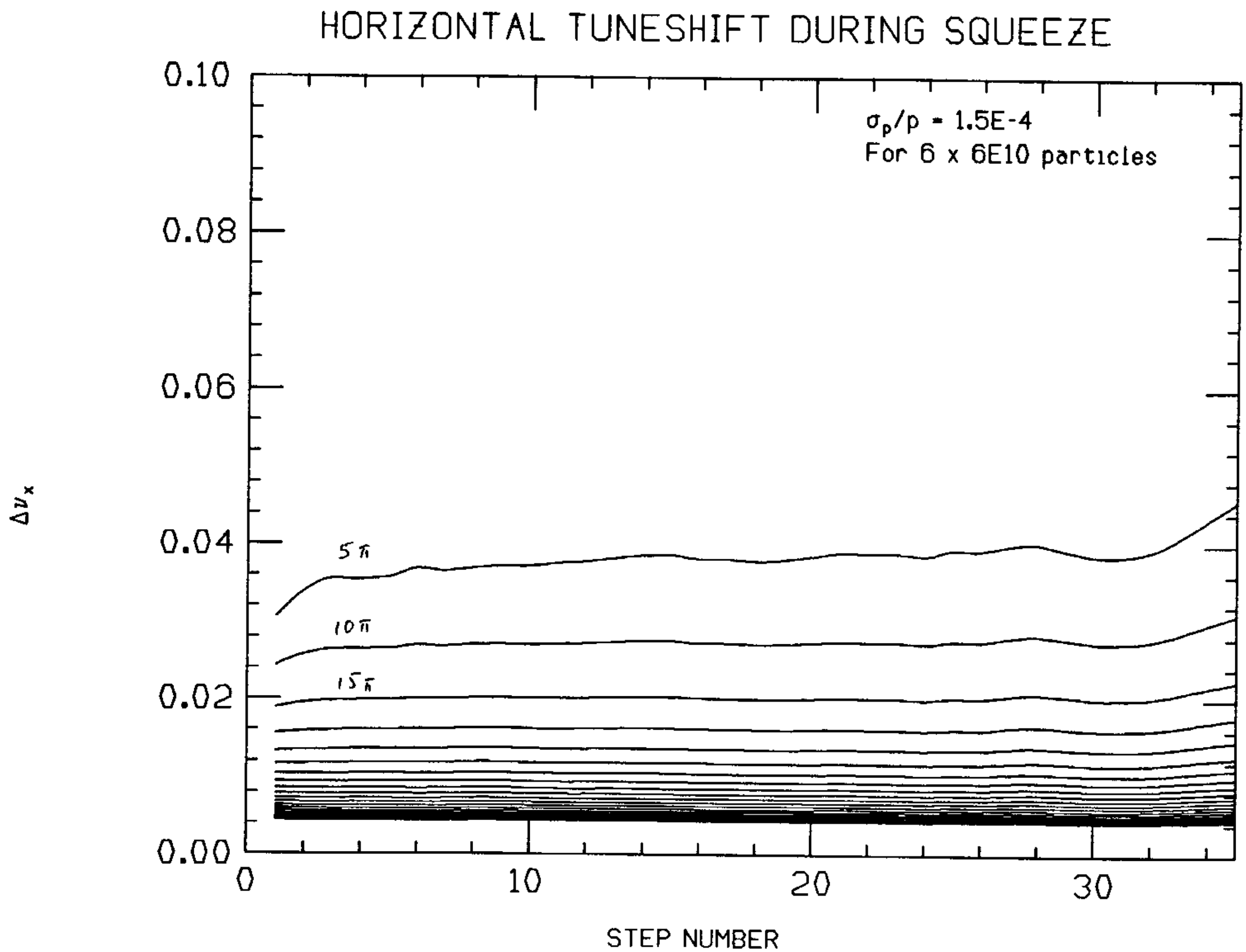
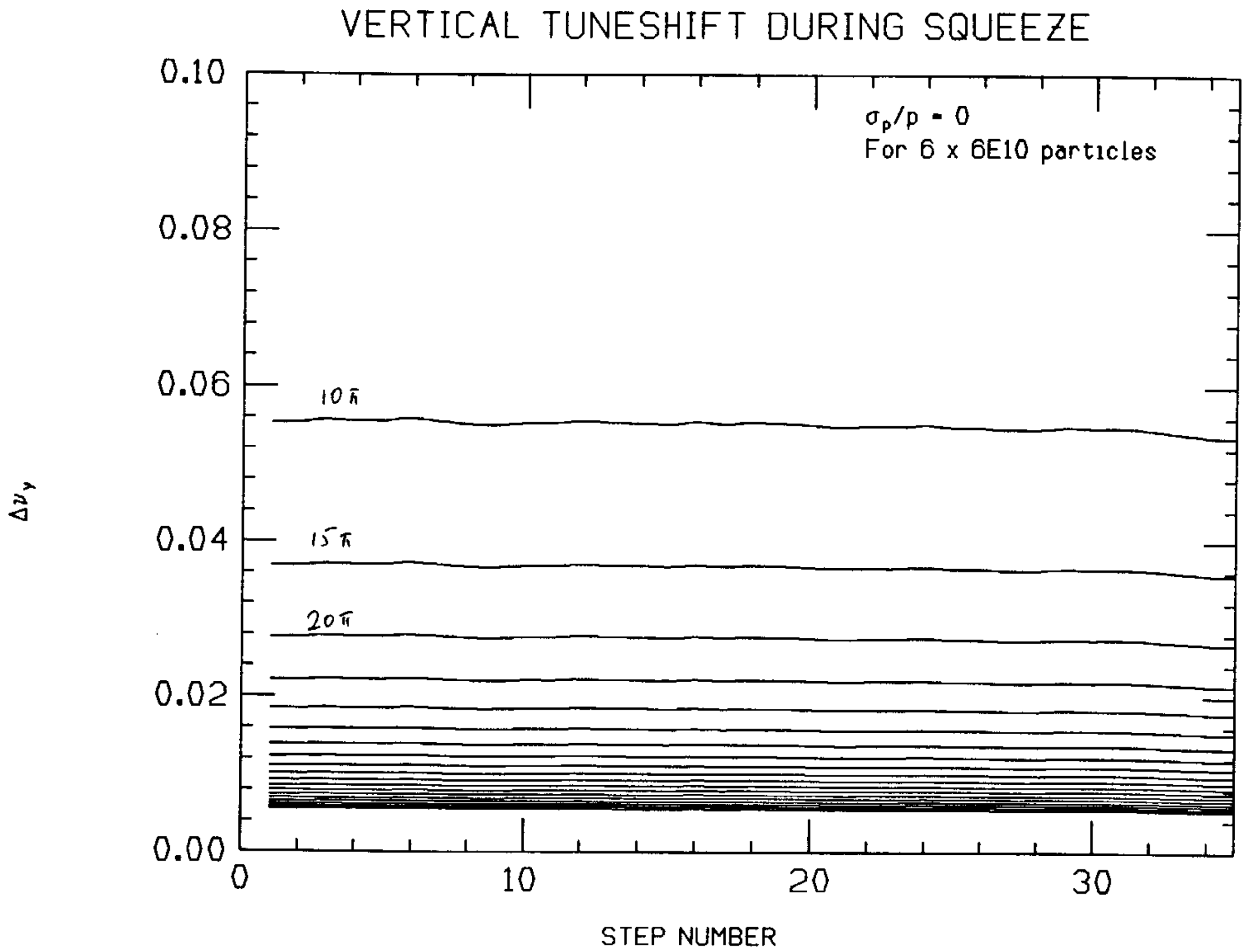

HORIZONTAL TUNESHIFT DURING SQUEEZE
σ_p/p = 1.5E-4
For 6 x 6E10 particles
$\Delta\nu_x$
0.10
0.08
0.06
0.04
0.02
0.00
0
10
20
30
STEP NUMBER
5π
10π
15π

Fig. 3



VERTICAL TUNESHIFT DURING SQUEEZE
$\sigma_p/p = 0$
For 6 x 6E10 particles
10π
15π
20π
0.10
0.08
0.06
0.04
0.02
0.00
0
10
20
30
$\Delta\nu_y$
STEP NUMBER

Fig. 4

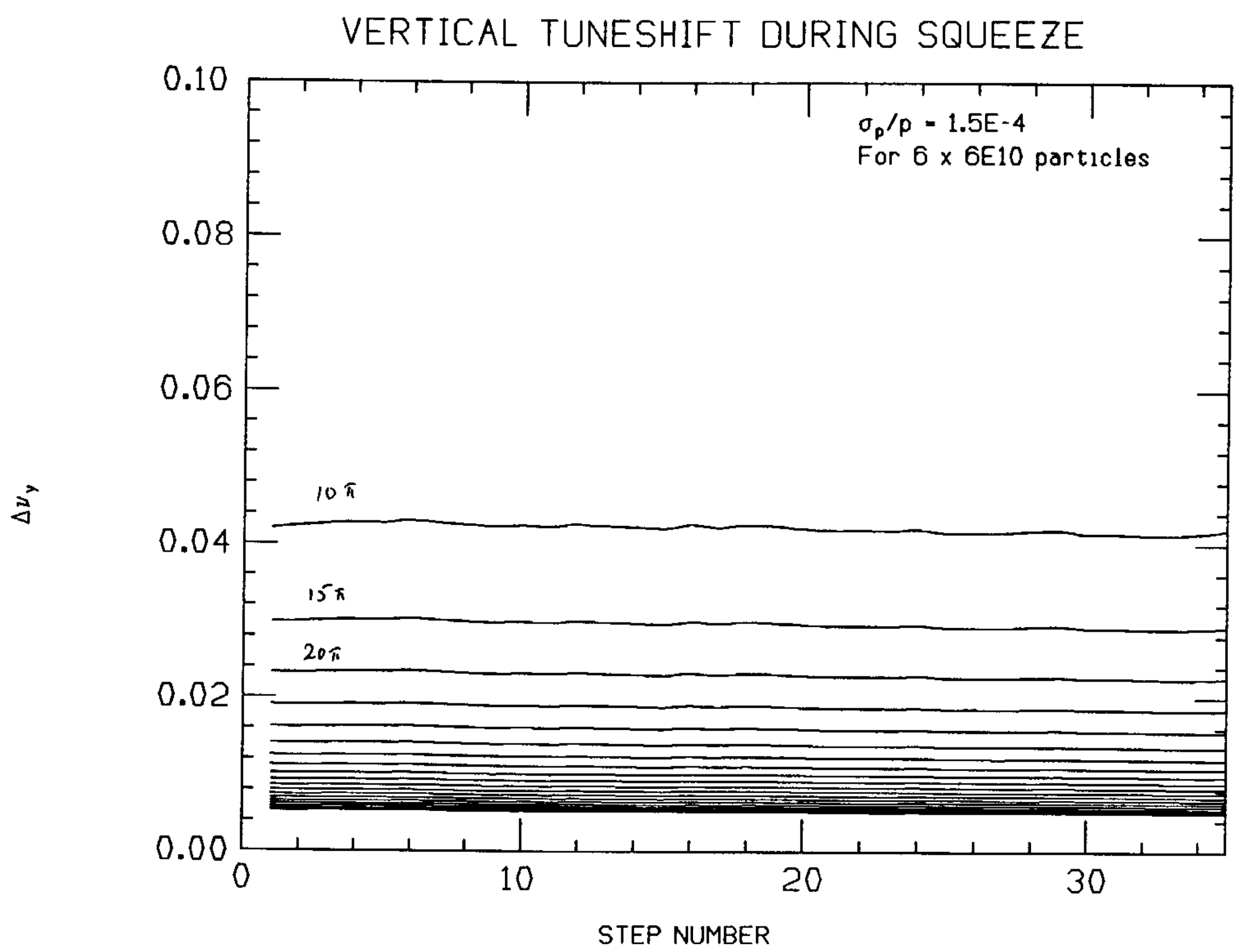

VERTICAL TUNESHIFT DURING SQUEEZE
σ_p/p = 1.5E-4
For 6 x 6E10 particles
10 π
15 π
20 π
0.10
0.08
0.06
0.04
0.02
0.00
$\Delta\nu_y$
0
10
20
30
STEP NUMBER

Fig. 5

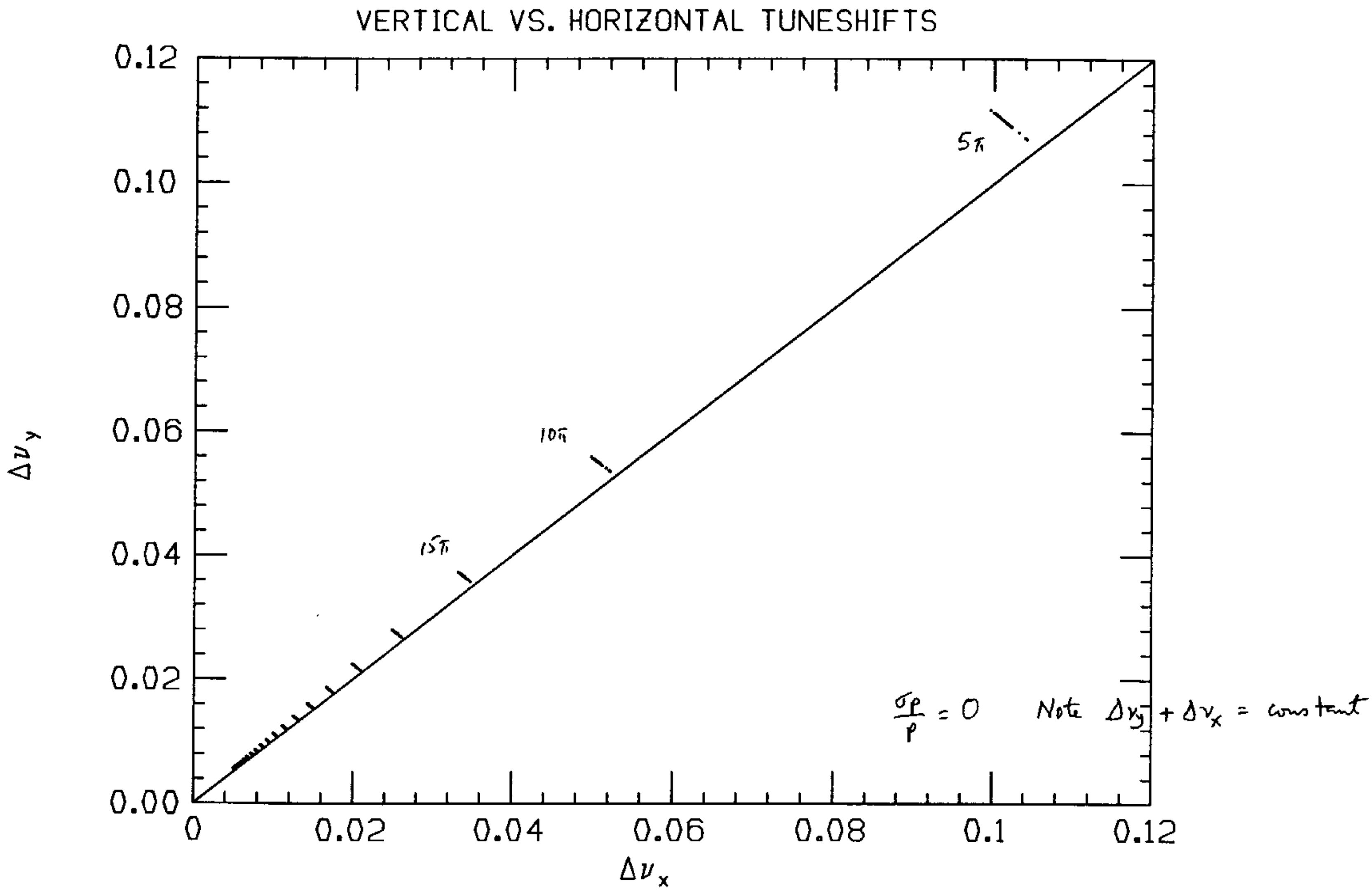

VERTICAL VS. HORIZONTAL TUNESHIFTS
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
0.02
0.04
0.06
0.08
0.1
0.12
$\Delta\nu_y$
$\Delta\nu_x$
5π
10π
15π
$\frac{\sigma_p}{p} = 0$
Note $\Delta\nu_y + \Delta\nu_x$ = constant

Fig. 6

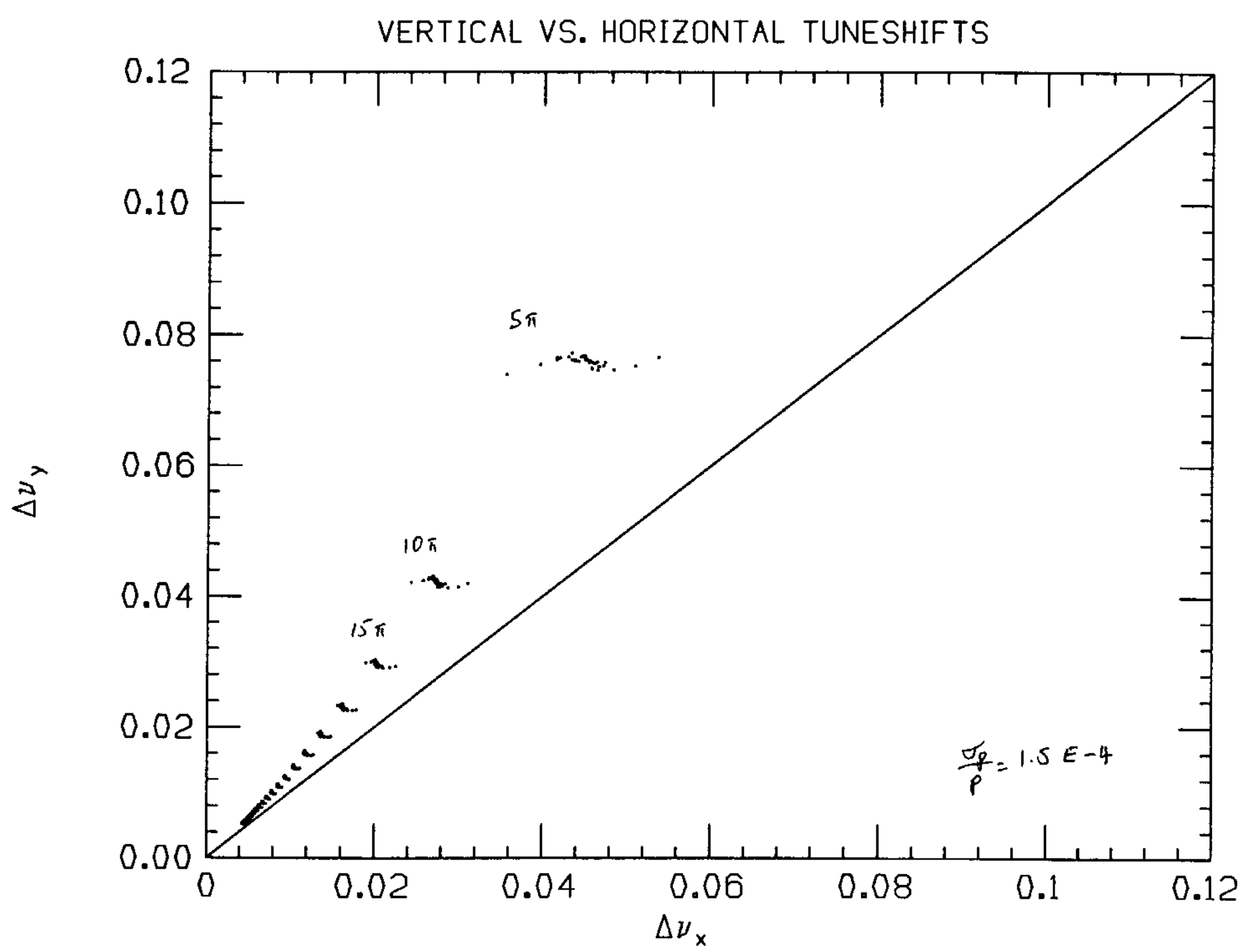

VERTICAL VS. HORIZONTAL TUNESHIFTS
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
0.02
0.04
0.06
0.08
0.1
0.12
$\Delta\nu_y$
$\Delta\nu_x$
5π
10π
15π
$\frac{\sigma_p}{p} = 1.5\ E-4$

Fig. 7