**LS Note 279**

# Retuning the APS Storage Ring for Better Chromaticity Correction

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***Summary***

When the APS storage ring was retuned to provide smaller $\beta_y$ values in the insertion straight sections, it was necessary to increase the vertical tune by at least two units. Since the design values for the horizontal and vertical tunes are 35.22 and 16.30, respectively, this put the tunes dangerously close to the sextupole $2\nu_y$-$\nu_x$ coupling resonance. The large injection horizontal oscillations could couple to the vertical plane and exceed the 5-mm vertical apertures that exist in some of the insertion straight sections.

To avoid this resonance, the vertical tune was raised beyond the resonance to 19.30. The result was a reduction in the ability of the chromaticity sextupoles to correct the chromaticity.

Recent investigation has shown that the chromaticity correction capability of the sextupoles can be greatly increased by a modest increase in the horizontal tune. Increasing the horizontal tune by one unit and reducing the vertical tune by three units produces a lattice with better chromaticity control while maintaining an acceptable dynamic aperture.

## I. Effects of Tune Changes

The APS storage ring normally runs with the chromaticity sextupoles S3 and S4 (see Figure 1) set at the $K_2L$ values of 5.244 $m^{-2}$ and 4.310 $m^{-2}$, respectively. The tunes are $\nu_x$=35.22 and $\nu_y$=19.30 and the corrected chromaticities are $\xi_x$=1.42 and $\xi_y$=6.94. The horizontal chromaticity $\xi_x$ can be increased by increasing S4. However, in order not to decrease $\xi_y$, it would be necessary to increase S3. But the S3 strength is already near its magnetic saturation limit (see Figure 2).

Figure 3 shows the effect on the chromaticities of increasing the horizontal tune. The chromaticity sextupoles were not changed. There is a sizable increase in $\xi_x$ with very little change in $\xi_y$. This happens in spite of the more negative natural chromaticities shown in Figure 4. If the vertical tune is reduced to 16.30, still further gains are achieved as shown in Figure 5. Figure 6 shows that the natural emittance is also reduced by increasing the horizontal tune.

Of course, increasing the horizontal tune brings the lattice closer to the $\nu_x$=40 fundamental resonance. Investigation shows that this resonance causes a large decrease in dynamic aperture for $\nu_x$=38.22 (see Figure 7). In this figure the outer curve represents the size of the limiting vacuum chamber. The limiting effects of the chamber on the dynamic aperture are more fully discussed in the next section.

Although it may prove possible to operate the storage ring at $\nu_x$=37.22, adequate gains in chromaticity correction are achieved with the more modest change to $\nu_x$=36.22 together with a decrease of $\nu_y$ to 16.30. Figure 8 shows the beta and dispersion functions for this condition.

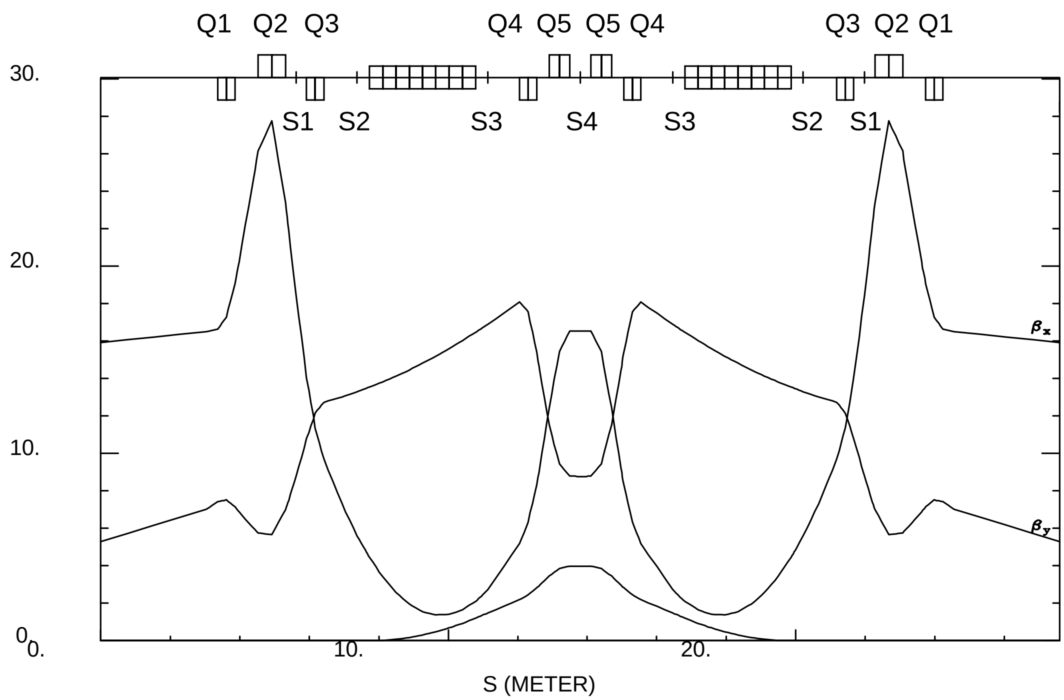


**Figure 1: Normal Low $\beta_y$ Lattice Tuned to $\nu_x$=35.22, $\nu_y$=19.30.**

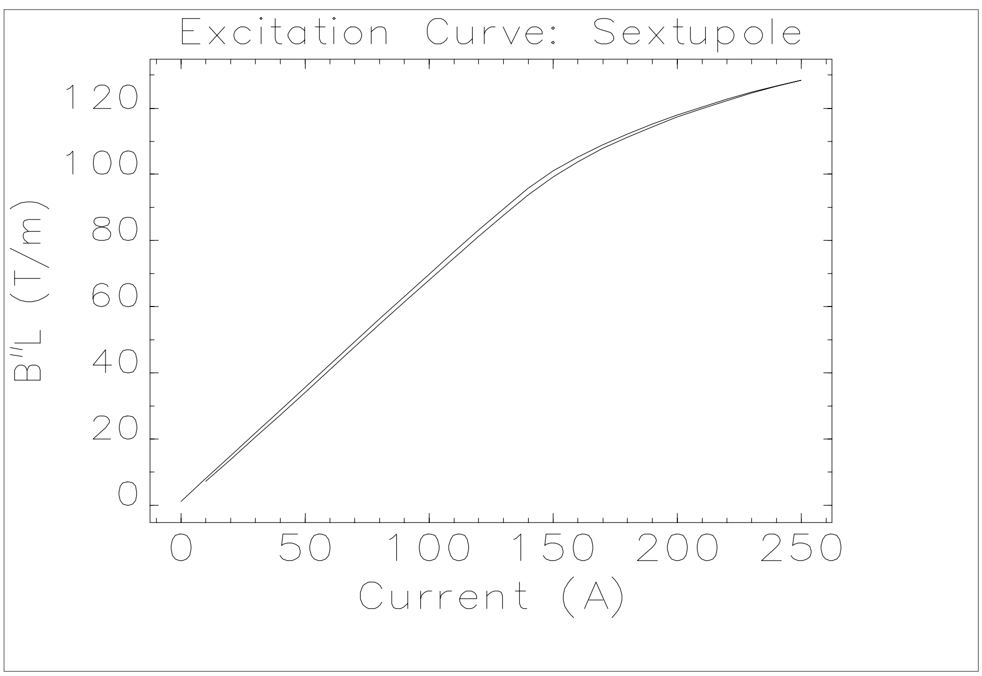


**Figure 2: Sextupole Magnet Excitation Curve.**

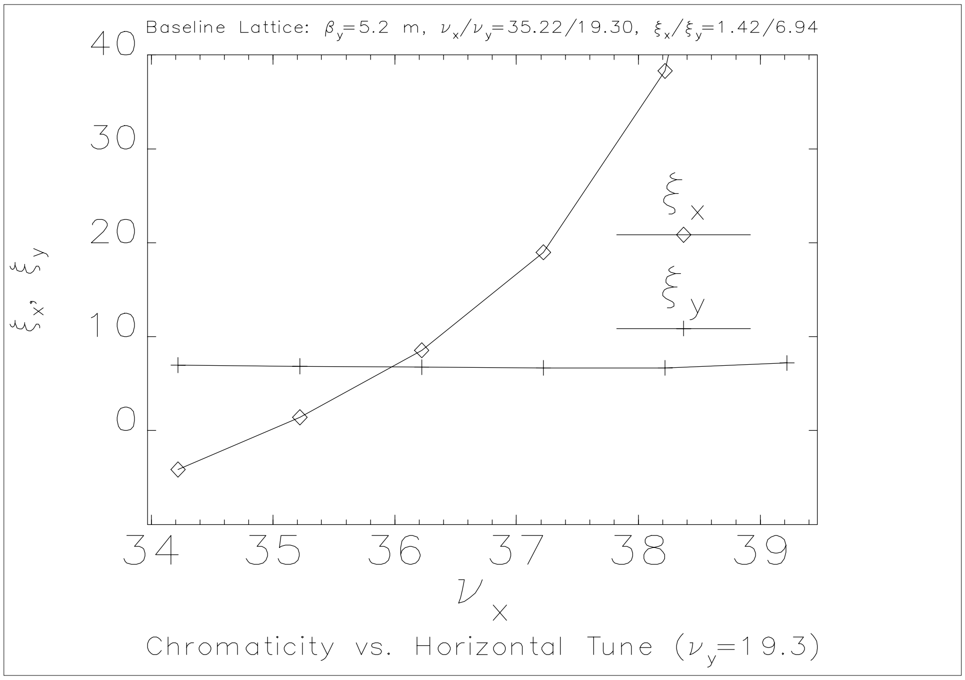


**Figure 3: Chromaticity Variation as a Function of Horizontal Tune (Vertical Tune is 19.3).**

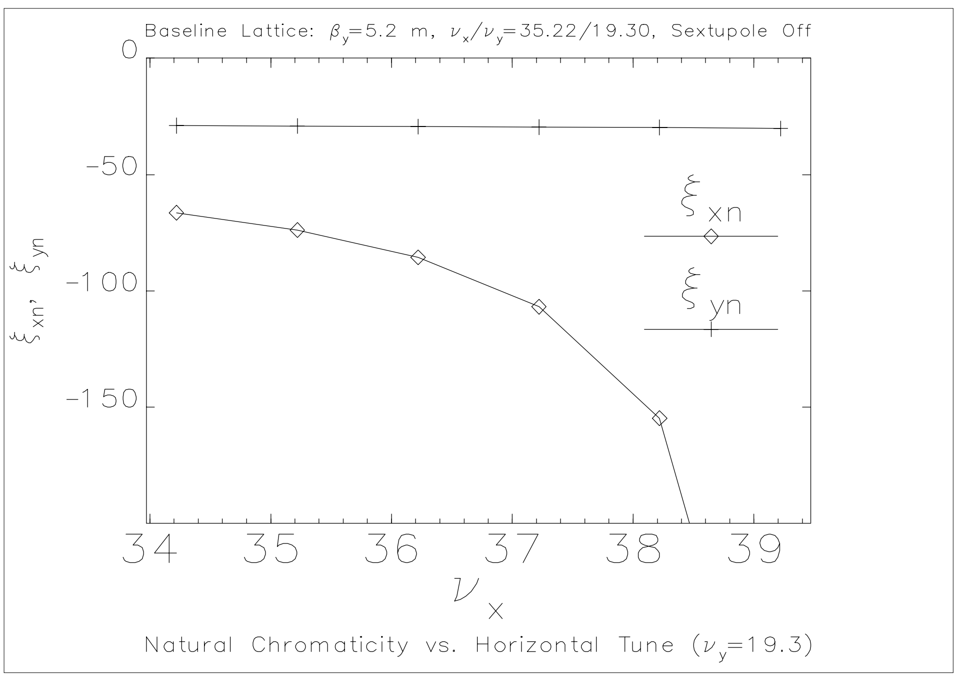


**Figure 4: Natural Chromaticity Variation as a Function of Horizontal Tune (Vertical Tune is 19.3).**

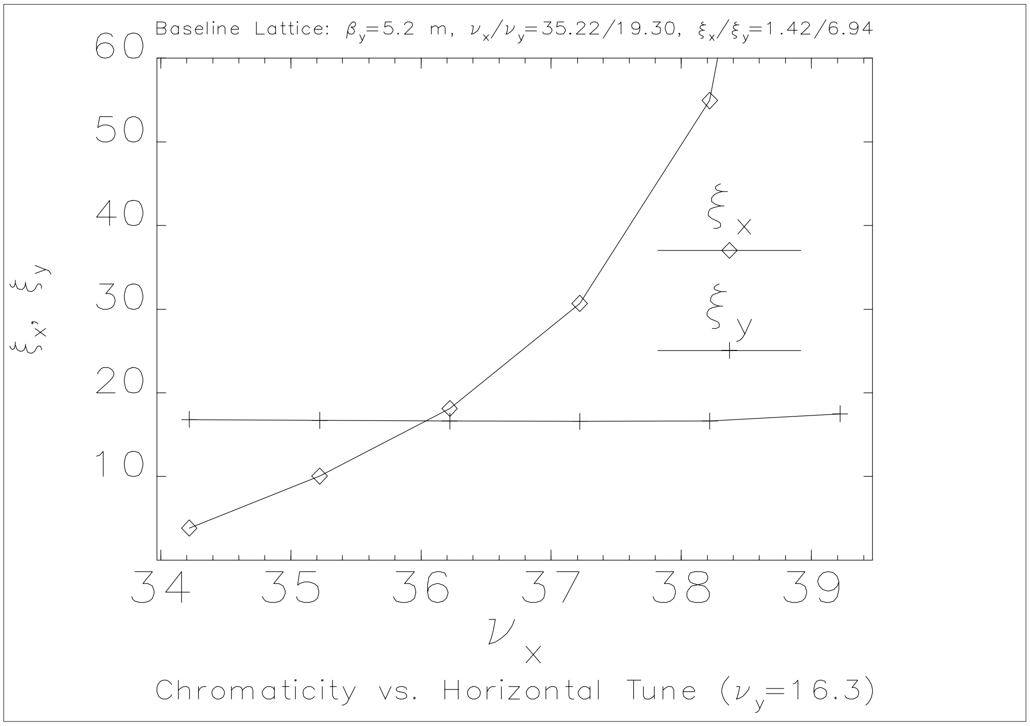


**Figure 5: Chromaticity Variation as a Function of Horizontal Tune (Vertical Tune is 16.3).**

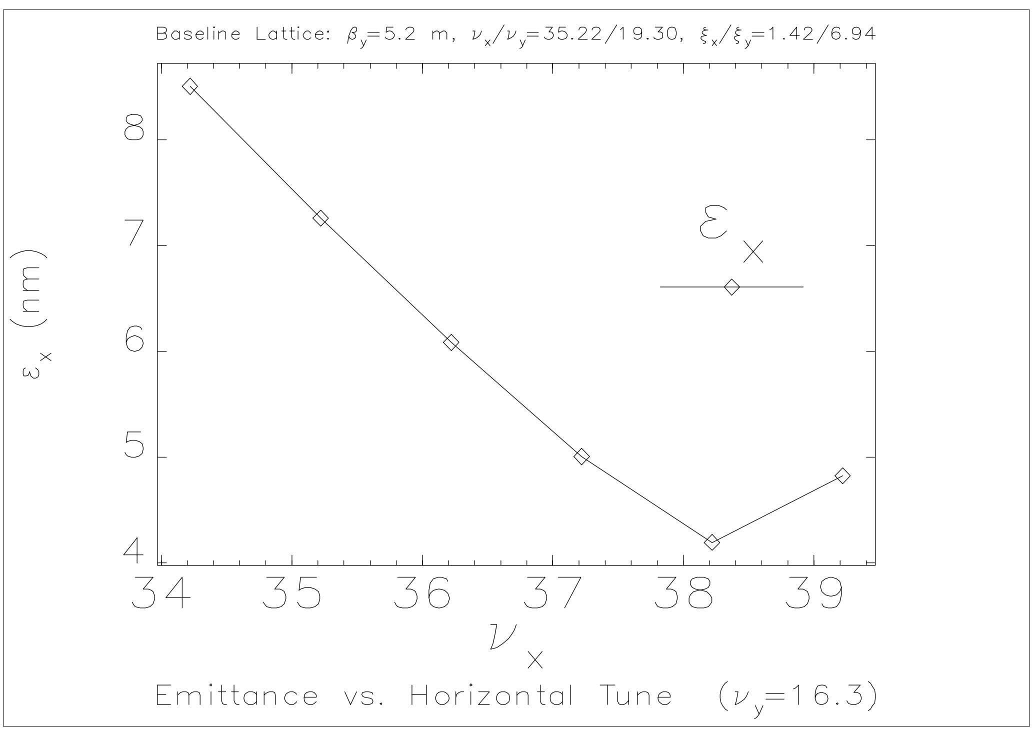


**Figure 6: Emittance Variation as a Function of Horizontal Tune (Vertical Tune is 16.3).**

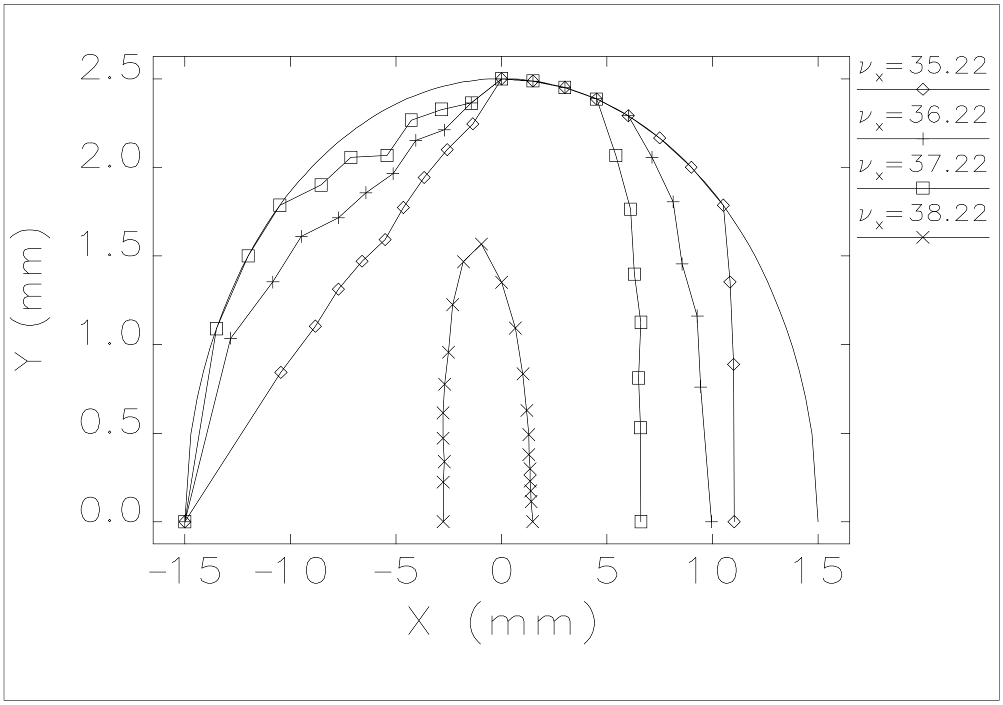


**Figure 7: Vacuum Chamber Limited Dynamic Aperture for Various Horizontal Tunes Showing Collapse of Dynamic Aperture at $\nu_x$=38.22 (Vertical Tune is 16.3).**

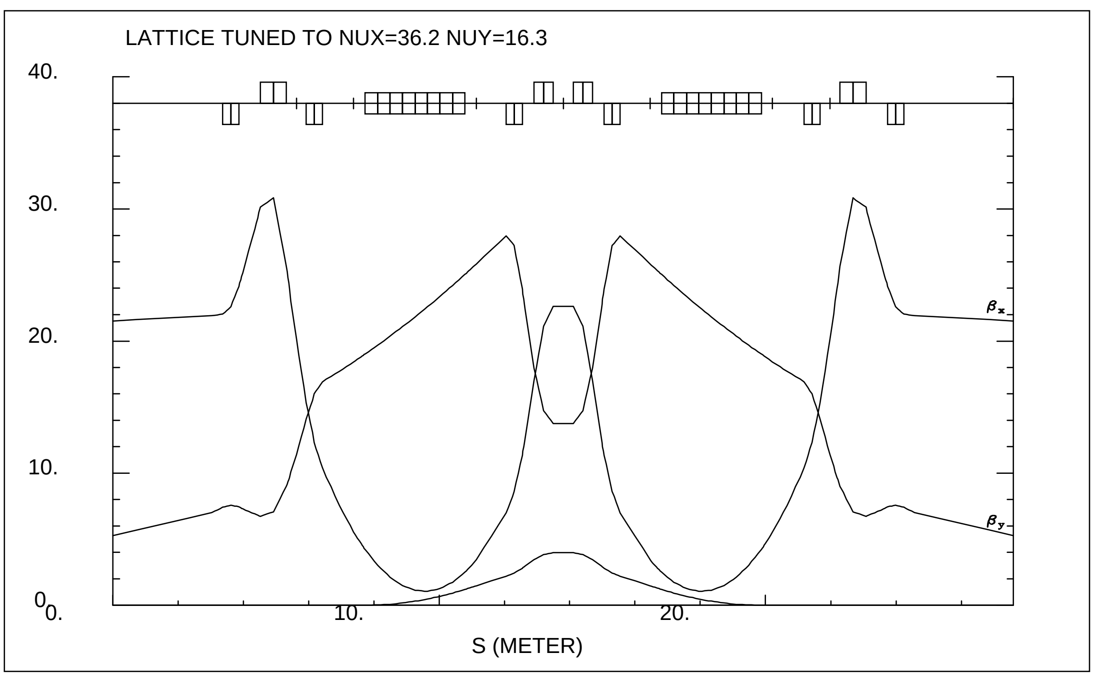


**Figure 8: Low $\beta_y$ Lattice Tuned to $\nu_x$=36.22, $\nu_y$=16.30.**

## II. Vacuum Chamber-Limited Dynamic Apertures

It is of some interest to show the effect of the $2\nu_y$-$\nu_x$ coupling resonance on the 30mm x 5mm vacuum chamber-limited dynamic aperture. Figures 9 and 10 tell the story. The 35.22,19.30 tune result clearly shows that the aperture is limited only by the chamber. The apparent less than chamber aperture for positive x values is caused by the distortion in the horizontal phase-space contour due to the $\nu_x$=40 resonance (Figure 11). The limiting curve for positive x values is caused by electrons hitting the inner wall of the chamber. Note that injection into the storage ring is from the inside.

As the vertical tune is decreased, one approaches the coupling resonance, and limiting horizontal amplitudes exist that couple to the vertical plane. The beam is lost on the vertical aperture. At $\nu_y$=16.3 one is far enough below the resonance so that there is no limiting horizontal coupling amplitude within the limits of the chamber. There does exist a small amount of horizontal-to-vertical coupling for nonzero vertical amplitudes. This effect is less for $\nu_x$=36.22 than for $\nu_x$=35.22 because the former is further from the resonance. Note also that the distortion shown for the 36.22,19.30 tune condition is more pronounced than for the 35.22,19.30 condition because the former is closer to the $\nu_x$=40 resonance.

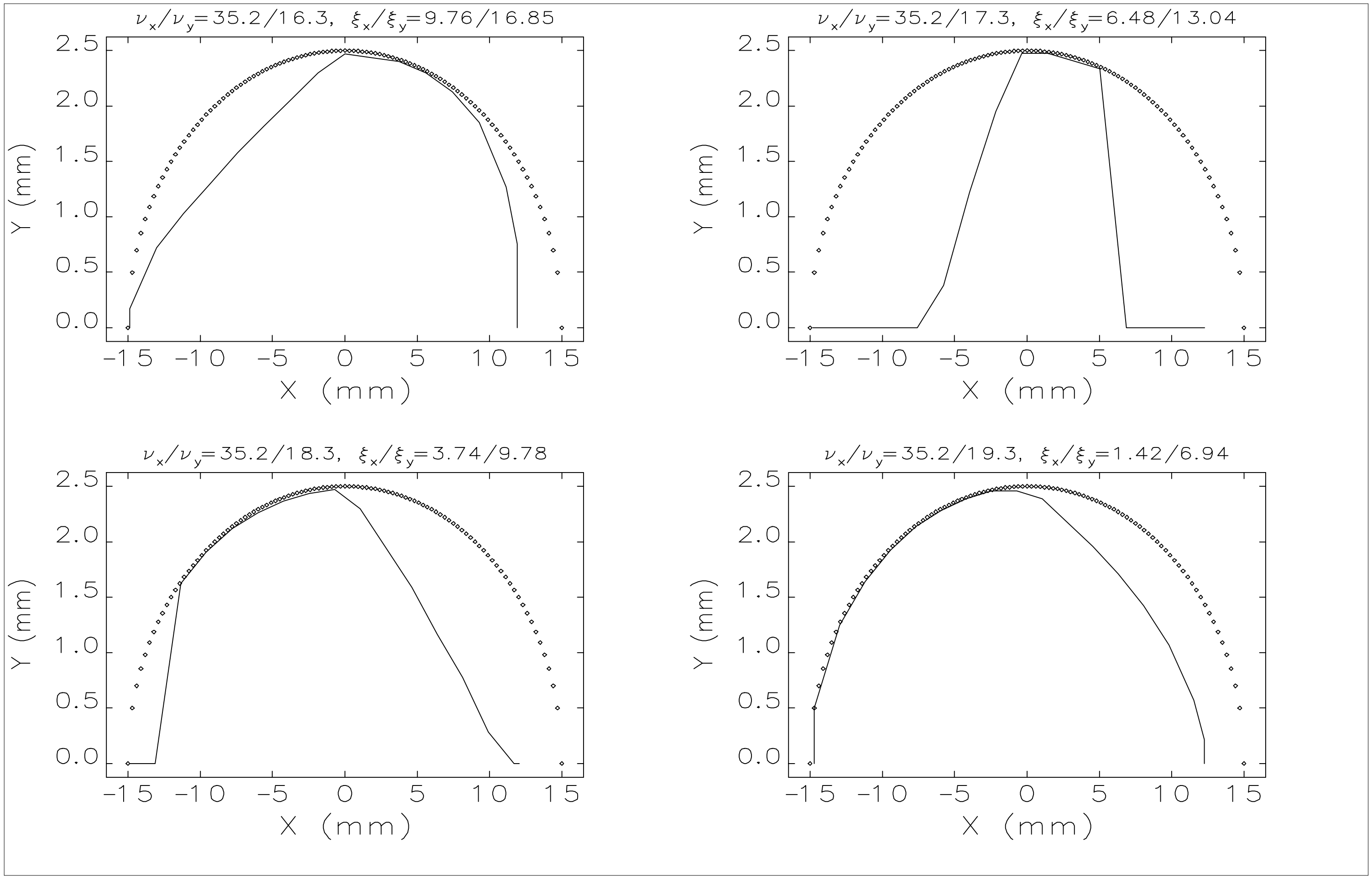


**Figure 9: Vacuum Chamber Limited Dynamic Aperture for Various $\nu_y$ at $\nu_x$=35.22.**

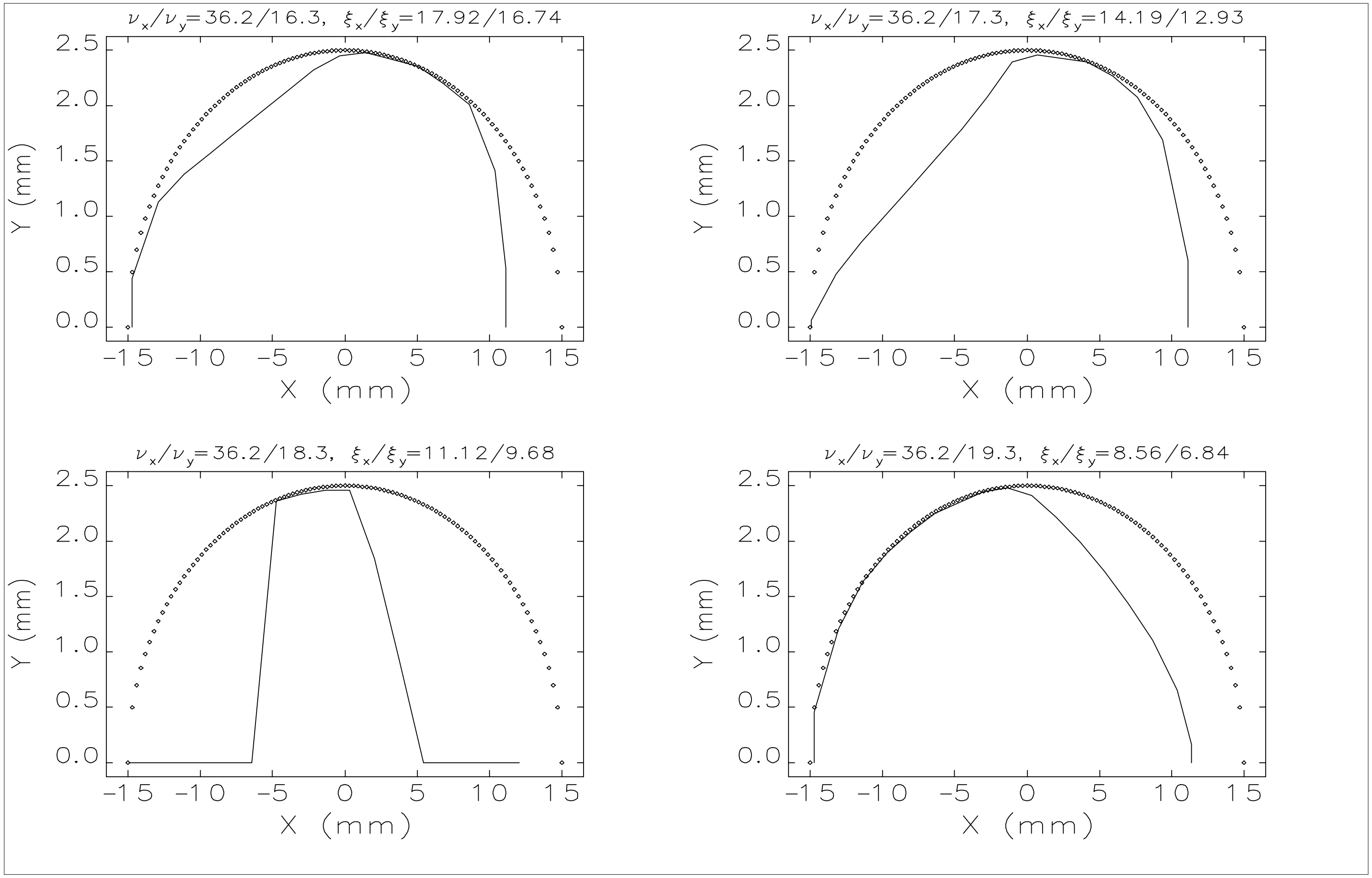


**Figure 10: Vacuum Chamber Limited Dynamic Aperture for Various $\nu_y$ at $\nu_x$=36.22.**

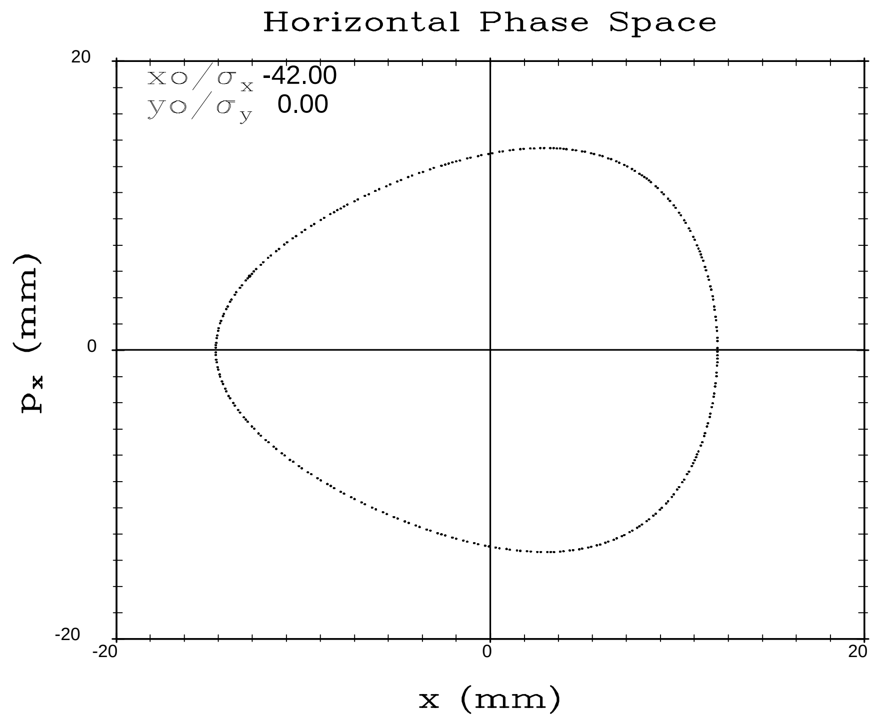


**Figure 11: Distortion of Horizontal Phase Space due to $\nu_x$=40 resonance.**

## III. Conclusion

We have shown that sizable increases in chromaticity correction capability can be achieved by changing the horizontal and vertical tunes from the present values of 35.22,19.30 to 36.22,16.30. It should be possible to achieve this tune condition without affecting the injection efficiency.

Tables I and II summarize the results. Table I shows the corrected chromaticities with the chromaticity sextupoles fixed at their normal operating strengths. Table II shows (in amperes) the sextupole currents required to produce the present storage ring horizontal and vertical chromaticities.

**Table I Chromaticities Keeping S3 and S4 Fixed**

| | **Horizontal Chromaticity** | | **Vertical Chromaticity** | |
|---|---|---|---|---|
| $\nu_y \backslash \nu_x$ | **35.22** | **36.22** | **35.22** | **36.22** |
| **19.30** | 1.42 | 8.56 | 6.94 | 6.84 |
| **16.30** | 9.76 | 17.92 | 16.85 | 16.74 |

**Table II Sextupole Currents for Fixed Chromaticity (Amps)**

| | **S3 (Amps)** | | **S4 (Amps)** | |
|---|---|---|---|---|
| $\nu_y \backslash \nu_x$ | **35.22** | **36.22** | **35.22** | **36.22** |
| **19.30** | 219 | 200 | 154 | 140 |
| **16.30** | 165 | 157 | 134 | 126 |