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February 1992

Collider Accelerator Department

**Brookhaven National Laboratory**

**U.S. Department of Energy**

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G. Parzen

February 1992

**RHIC PROJECT**

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# The Dependence of the Dynamic Aperture on the Tune in RHIC

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## 1. Introduction

This note studies the dependence of the dynamic aperture on the choice of the operating tune $\nu_x, \nu_y$ in RHIC. Tracking studies for 1000 turns were done over the tune range $\nu_x \simeq \nu_y = 28$ to $\nu_x \simeq \nu_y = 29.5$. It was found that in each tune interval of length $\Delta\nu = 0.5$, e.g. $\nu = 28.5$ to $\nu = 29$, the dynamic aperture as a function of the tune has 5 peaks, each of which is a possible operating point. Each of these possible operating points is in a tune region free of imperfection resonances of tenth order or less, and the width of this tune region ranges from $\Delta\nu = 0.022$ to $\Delta\nu = 0.036$.

Operating tunes near integer values of $\nu$, which appear desirable because of the relatively large tune interval free of imperfection resonances of 10th order or less, may not be desirable because of the lower dynamic aperture in this region. Operating near integer tunes may not be desirable for heavy ions like Au, but may be desirable for the lighter ions which do not experience a large transverse growth due to intrabeam scattering.

If a loss in dynamic aperture of 2 mm is regarded as significant, then the tune range of $\nu = 28$ to $\nu = 28.5$ does not appear as attractive as the tune range $\nu = 28.5$ to $\nu = 29.5$.

## 2. Tracking Results

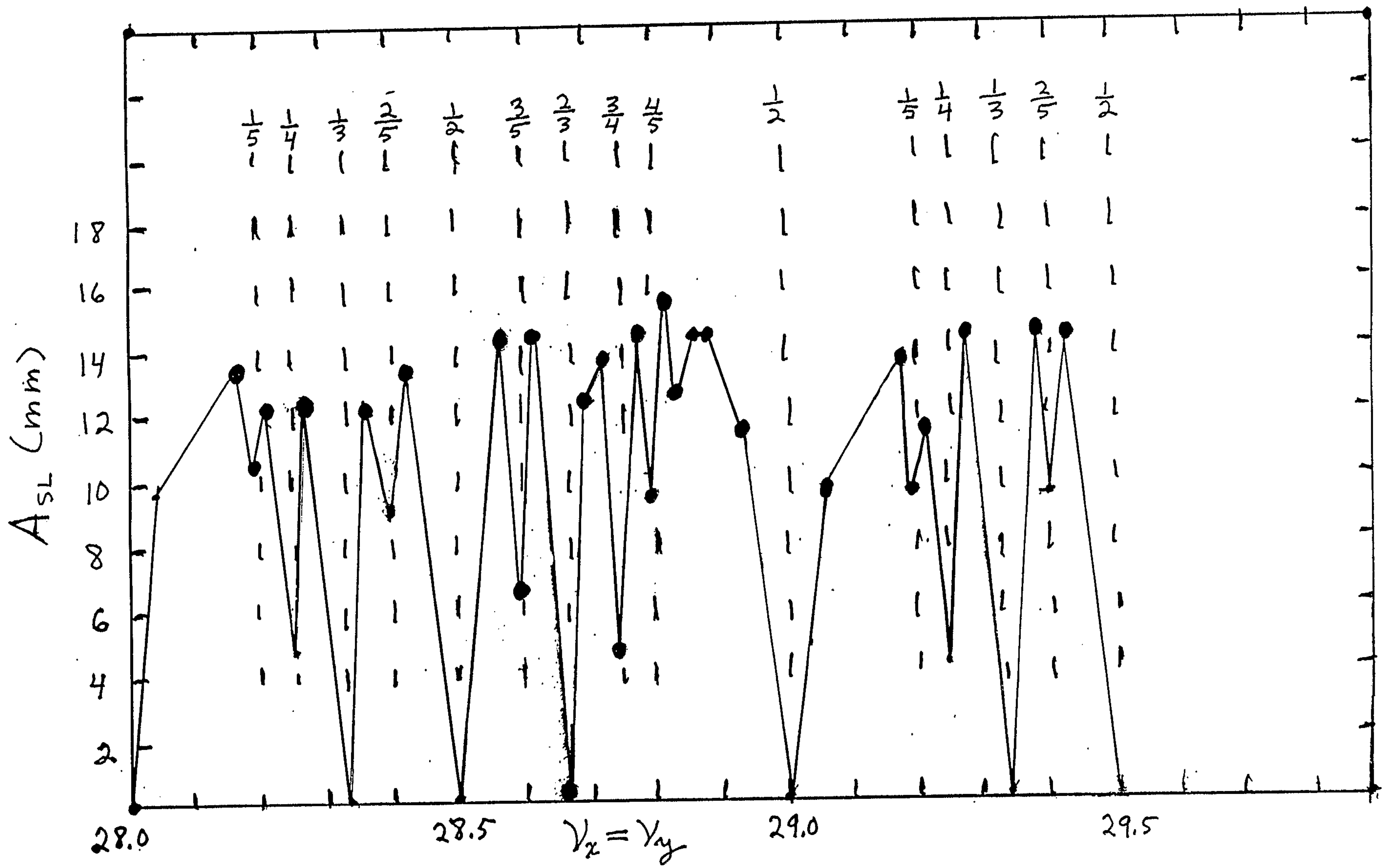
In order to study the dependence of the dynamic aperture on the tune $\nu_x, \nu_y$, the tune was varied using the QF and QD quadrupoles in the normal cells in the arcs. The insertions were not rematched to the arcs as the tune was varied. It was found that the mismatch introduced was not large in RHIC over the tune range of $\nu \cong \nu_y = 28$ to $\nu_x \cong \nu_y = 29.5$.

The lattice used in this tracking study has 6 $\beta^* = 6$ insertions that were matched to the arcs at a tune close to $\nu_x = 28.826$, $\nu_y = 28.821$. At the matched tune, the $\beta_x$ at the QF quadrupole is almost constant at $\beta_x = 50$, the maximum $x_p$ at QF is 1.6 m, the $\beta_x \simeq \beta_y$ at the crossing points is $\beta^* = 6$ m, and the maximum $\beta$ in the insertions is $\beta_{\max} = 225$ m. At $\nu_x = \nu_y = 29.2$, the corresponding quantities without rematching the insertions, are $\beta_x$ varies from 50 to 49 m, $x_p = 1.64$, $\beta^* = 6.01$ and $\beta_{\max} = 223$ m. At the $\nu_x = \nu_y = 28.2$, the corresponding quantities are, $\beta_x$ varies from 55 to 45 m, $x_p = 1.7$, $\beta^* = 6.16$, and $\beta_{\max} = 210$ m. Thus over the entire range of tune studied, $\nu_x = \nu_y = 28$ to $\nu_x = \nu_y = 29.5$, there was at most a 10% variation in the orbit parameters from the matched values.

In the tracking study the tune was varied from $\nu = 28$ to $\nu = 29.5$ with $\nu = \nu_x = \nu_y$. Tracking runs were done with the ORBIT program for 1000 turns to determine the dynamic aperture at $\Delta p/p = 0$. The dynamic aperture was measured by $A_{SL}$ which is the largest initial $x$ that is stable for 1000 turns, when the initial $x' = y' = 0$ and $\epsilon_y = \epsilon_x$. $A_{SL}$ is plotted against $\nu$ in Fig. 1. The general shape of this curve can be understood by considering $A_{SL}$ at the low order resonances, the 1/2, 1/3, 1/4, and 1/5 resonances. The curve has low values for $A_{SL}$ when $\nu$ lies on these low order resonances (see Section 3). In between these low points at the low order resonances, $A_{SL}$ reaches a peak value, and each of these peaks may be considered as a possible operating point. In Fig. 1, the dots are points found from tracking runs; the curve between the dots is an extrapolated curve assuming that $A_{SL}$ at the low order resonances is about the same at corresponding low order resonances.

Thus between the half integer values of $\nu$, there are 5 peaks in $A_{SL}$ which may be considered as 5 possible operating points, as they have reasonable values of $A_{SL}$. There may be other considerations than the size of $A_{SL}$ that may make some of these possible operating points undesirable. This indicates that for RHIC there are 5 possible operating

Fig.1 $A_{SL}$ versus $\nu_x = \nu_y$



points between $\nu = 28.5$ and $\nu = 29$, and 5 more between $\nu = 28$ and $\nu = 28.5$ and 5 more between $\nu = 29$ and $\nu = 29.5$.

There is also a slight dip in $A_{SL}$ at the 1/6 resonances; which was largely omitted in Fig. 1. The small dips at the 1/6 resonance would split some of the 5 peaks into 2 peaks, and to keep the picture simple these 2 peaks are being regarded here as one peak.

In order to see whether the peak $A_{SL}$ in Fig. 1 are at $\nu$-values which are possible operating points, one needs to examine where the $\nu$-values are relative to imperfection resonances; especially imperfection resonances of order 10 or less. It would be desirable that for possible operating points, there should be a $\nu$ interval, $\Delta\nu$, which is free of resonances of order 10 or less. One might aim for a $\Delta\nu \simeq 0.02$ or more. Table 1 lists all the peaks found in Fig. 1, and lists the nearby imperfection resonances and the $\Delta\nu$ available.

**Table 1:** A listing of the peaks, possible operating points, from Fig. 1, showing the corresponding $\nu$-values, dynamic aperture $A_{SL}$, the nearby low order resonances, and nearby imperfection resonances. $\nu_x = \nu_y = \nu$.

| $\nu - 28$ | $A_{SL}$ | Low Order Resonances | Imperfection Resonance | $\Delta\nu$ |
|---|---|---|---|---|
| 0.190 | 13.5 | 1/2=0.000, 1/5=0.200 | 1/6=0.167, 1/5=0.200 | 0.033 |
| 0.21 | 12.5 | 1/5=0.200, 1/4=0.250 | 1/5=0.200, 2/9=0.222 | 0.022 |
| 0.27 | 12.5 | 1/4=0.250, 1/3=0.333 | 1/4=0.250, 2/7=0.286 | 0.036 |
| 0.38 | 12.5 | 1/3=0.333, 2/5=0.400 | 3/8=0.375, 2/5=0.400 | 0.025 |
| 0.424 | 13.5 | 2/5=0.400, 1/2=0.500 | 2/5=0.400, 3/7=0.429 | 0.029 |
| | | | | |
| 0.575 | 14.5 | 1/2=0.5 , 3/5=0.6 | 4/7=0.571, 3/5=0.60 | 0.029 |
| 0.620 | 14.5 | 3/5=0.6 , 2/3=0.667 | 3/5=0.6 , 5/8=0.625 | 0.025 |
| 0.720 | 13.5 | 2/3=0.667, 3/4=0.750 | 5/7=0.714, 3/4=0.750 | 0.036 |
| 0.780 | 14.5 | 3/4=0.750, 4/5=0.800 | 7/9=0.778, 4/5=0.800 | 0.022 |
| 0.824 | 15.5 | 4/5=0.800, 2/2=1.00 | 4/5=0.800, 5/6=0.833 | 0.033 |
| | | | | |
| 1.190 | 13.5 | 2/2=1.000, 1/5=0.2 | 1/6=0.167, 1/5=0.200 | 0.033 |
| 1.21 | 11.5 | 1/5=0.200, 1/4=0.25 | 1/5=0.200, 2/9=0.222 | 0.022 |
| 1.27 | 14.5 | 1/4=0.250, 1/3=0.333 | 1/4=0.250, 2/7=0.286 | 0.036 |
| 1.39 | 14.5 | 1/3=0.333, 2/5=0.400 | 3/8=0.375, 2/5=0.400 | 0.025 |
| 1.424 | 14.5 | 2/5=0.400, 1/2=0.5 | 2/5=0.400, 3/7=0.429 | 0.029 |

## 3. The Dynamic Aperture at the Low Order Resonance

The plot of the dynamic aperture versus the tune has low points at $\nu$-values that correspond to the low order resonances $\nu = 1/2, 1/3, 1/4, 1/5$. In Table 2, the dynamic aperture $A_{SL}$ is listed as found from tracking runs for 1000 turns for the low order resonances that lie between $\nu = 28.5$ to $\nu = 29.0$ in RHIC. Also listed are the $A_{SL}$ for the 1/6, 1/7, 1/8 and 1/9 resonance in this region of $\nu$. The error in $A_{SL}$ is about $\pm 0.5$ mm.

**Table 2:** A listing of the dynamic aperture for some of the resonances between $\nu = 28.5$ and $\nu = 29$ in RHIC. $\nu_x = \nu_y = \nu$.

| $\nu - 28$ | $A_{SL}$ (mm) |
|---|---|
| 1/2=0.5 | ~0 |
| 2/3=0.667 | ~0 |
| 3/4=0.750 | 4.5 |
| 4/5=0.800 | 9.5 |
| 5/6=0.833 | 12.5 |
| 6/7=0.857 | 14.5 |
| 7/8=0.875 | 14.5 |
| 8/9=0.889 | 14.5 |