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Asymmetric Antiproton Debuncher: No Bad Mixing, More Good Mixing

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Abstract

An asymmetric lattice for the Fermilab Antiproton Debuncher is designed. The lattice has zero mixing between the pickups and the kickers (bad mixing) while the mixing in the rest of the machine (good mixing) can be varied (even during the operation of the machine) in order to optimize the stochastic cooling. As an example, a lattice with zero bad mixing and twice the good mixing is presented. The betatron cooling rate in this lattice is twice its present value.

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1 Introduction

In this Letter I present a method for the local control of the beam mixing in an accelerator. This is of particular importance for machines with stochastic cooling [1], as it allows one to eliminate the so-called bad mixing while at the same time enhance the good mixing. The method is based on the use of the Local Dispersion Insert [2] and thus causes no tune shift. Therefore it can be used *during* the cooling cycle in such a way that the cooling process is continuously optimized.

Machines with different values of η in different segments were discussed in the literature (see *e.g.* [3]), however, the method presented here is the first one which (*i*) can be applied in an existing machine (as opposed to designing an asymmetric lattice from the start) and (2) can be used during the operation of the accelarator in order to continuously optimize the cooling in various regimes of the machine cycle. As an example, I present the design for the Fermilab Antiproton Debuncher, where by modifying a total of 18 quadrupoles the bad mixing is completely eliminated, while the good mixing is enhanced by a factor of two.

In a stochastic cooling system, Fig. 1, the pickup basically takes a snapshot of a sample of the beam and a corrective voltage is applied to the same sample when it arrives at the kicker. The efficiency of this procedure hinges on the word "same"– it is maximal if the sample at the kicker is indeed the same one that passed by the pickup. This picture gives rise to the notions of *good* and *bad* mixing. Ideally, one would have no randomization between the pickup and the kicker (bad mixing) and the maximal randomization between the kicker and the pickup (good mixing). The first requirement means that the sample arriving at the kicker is the same one that passed the pickup, thus the corrective voltage is maximally efficient. The second means that between two consecutive passings of the pickup the beam will be maximally randomized, which again means the maximal cooling efficiency. By using the method described in this paper, *this ideal situation can indeed be achieved.*

2 The Lattice with no Bad Mixing

The mixing between the points s_1 and s_2 of an accelerator is determined by the time of flight dispersion for particles of different momenta,

$$\frac{\Delta\tau(s_1,s_2)}{\tau_0(s_1,s_2)} = -\eta(s_1,s_2)\frac{\Delta p}{p_0}, \tag{1}$$

where $\tau_0(s_1, s_2)$ is the time of flight of an on-momentum particle, *i.e.* one with momentum p_0 between the points s_1 and s_2. $\eta(s_1, s_2)$ depends on the dispersion function $D_x(s)$, the local radius of curvature $\rho(s)$ of the beam trajectory, and the Lorentz parameter γ of the beam:

$$\eta(s_1, s_2) = \frac{1}{L_{s_1 s_2}} \int_{s_1}^{s_2} \frac{D_x(s)}{\rho(s)} ds - \frac{1}{\gamma^2}, \tag{2}$$

where $L_{s_1 s_2}$ is the arc length between the points s_1 and s_2. For the entire ring η becomes the closed loop integral:

$$\eta = \frac{1}{C} \oint_C \frac{D_x(s)}{\rho(s)} ds - \frac{1}{\gamma^2}. \tag{3}$$

The optimal efficiency of the stochastic cooling system is thus achieved if the following conditions can be satisfied:

$$\eta(PU, K) = \frac{1}{L_{PU-K}} \int_{PU}^{K} \frac{D_x(s)}{\rho(s)} ds - \frac{1}{\gamma^2} = 0$$

$$\eta(K, PU) = \frac{1}{L_{K-PU}} \int_{K}^{PU} \frac{D_x(s)}{\rho(s)} ds - \frac{1}{\gamma^2} = \text{maximum.}$$

These conditions can indeed be satisfied by using the recently invented Local Dispersion Insert [2], an accelerator cell which produces local dispersion and beta waves (and thus a local η wave) while keeping the other properties of the machine unchanged. In order for it to be used in an accelerator, the latter must have the phase advance per cell π/integer and a point or a region of zero dispersion. The Antiproton Debuncher at Fermilab is a perfect candidate: the phase advance per cell is $\pi/3$, it has zero dispersion sections and is used for stochastic cooling of the beam. The layout of the Debuncher is shown in Fig. 2. The positions of the pickups and kickers are marked in the picture.

The superperiodicity of the machine is three, each superperiod consisting of two mirror-image halves. The lattice functions of one sextant are shown in Fig. 3. The nominal η of the machine is 0.006. In order to achieve $\eta(PU, K) = 0$, we need a *negative* dispersion wave in the two sextants between the pickup and the kicker. This can be achieved by putting one Local Dispersion Insert in each of these two sextants. The strength of the Local Dispersion Insert needed to make $\eta(PU, K)$ exactly zero is about

$(+16, +16, -32)$ per cent of the regular quadrupole strength. The lattice functions of one sextant with $\eta = 0$ are shown in Fig. 4.

In order to increase $\eta(K, PU)$ we need a *positive* dispersion wave in the four sextants between the kicker and the pickup. This can be achieved by putting one Local Dispersion Insert in each of these four sextants. The strength of the Local Dispersion Insert needed to achieve the desired value of $\eta(K, PU)$ is about $(-8, -8, +16)$ per cent of the regular quadrupole strength. The lattice functions of one sextant with $\eta = 0.009$ are shown in Fig. 5.

Notice that, since the changes of the lattice functions are strictly local, the lattice functions and their derivatives at the ends of the sextants do not change and the sextants can be smoothly joined as desired. In other words, there will be no beta or dispersion waves caused by joining the sextants with different values of η. A complete Debuncher lattice with the same η as present, but with $\eta(PU, K) = 0$ is obtained by putting the zero-eta sextants between the pickups and the kickers and the $\eta = 0.009$ sextants in the rest of machine. This lattice and the corresponding lattice functions are shown in Fig. 6.

For stochastic cooling η should be maximized. As an example, a sextant with the threefold increase in η leading to doubling of the good mixing compared with the nominal lattice is shown in Fig. 7. The gradients of the Local Dispersion Inserts needed are $(-30, -30, +60)$ per cent, relative to the regular quadrupole strength. The complete Debuncher lattice with η twice the present value *and* $\eta(PU, K) = 0$ is shown in Fig. 8.

3 The Stochastic Cooling

The instantaneous betatron cooling rate is

$$\frac{1}{\tau} = g\frac{W}{N}\left(2(1-B) - g(M+U)\right)$$

where $W = f_{max} - f_{min}$ is the amplifier bandwidth, N is the number of particles in the beam, g is the system gain, B is the bad mixing, M is the mixing factor, and U is the noise to signal ratio. The mixing factor, the bad mixing, and the noise to signal ratio are all functions of the emittance, therefore the cooling rate changes during the cycle. A detailed analysis of the Debuncher betatron cooling system including the time dependence of various parameters can be found in Ref. [4]. Here I present only the calculation of the initial cooling rate with the present and with the new lattice with η doubled and $\eta(PU, K) = 0$, shown in Fig. 8.

The optimal gain is

$$g_{opt} = \frac{1-B}{M+U}$$

and the fastest cooling rate

$$\left(\frac{1}{\tau}\right)_{max} = \frac{W}{N}\frac{(1-B)^2}{M+U}$$

For the nominal values of the parameters, the initial cooling rate is about 1/0.2s.

In the new lattice, Fig. 8, there is no bad mixing, *i.e.* $B = 0$, and the good mixing is increased by a factor of two. Compared to the nominal lattice, the optimal gain is increased and the cooling rate is higher by a factor of two.

4 Conclusions

The possibility to adjust the local η in an accelerator such that the mixing in a certain region is either decreased or enhanced is potentially a useful tool for improvement of the stochastic cooling rates. By virtue of the Local Dispersion Insert as a zero-tune-shift device, η can be continuously adjusted during the operation of the machine in a desired way.

As a concrete example I have presented a Debuncher lattice with twice the mixing of the present lattice whose (initial) cooling rate is approximately twice the present rate.

There is no apparent reason for not aiming for even higher values of η. The maximal value of the (horizontal) beta function increases with η, but quite substantial increases can be tolerated. For the lattice of Fig. 8 the maximal value of the beta function is about 90m – 5 times larger than for the nominal lattice. This leads to an increase of the transverse beam size by a factor of $\sqrt{5}$. However, with the initial beam emittance of about 20π mm mrad, this beam size is still only one half of the beam size before the bunch rotation ($\Delta p/p \approx 0.04$, maximal dispersion about 2m.)

I would like to thank C. Ankenbrandt and S. Holmes for useful comments.

References

[1] D. Möhl, G. Petrucci, L. Thorndahl, S. van der Meer, Phys. Reports **58** 1979, pp. 73–119.

[2] V. Visnjic, Fermilab Report TM-1888, May 1994.

[3] D. Möhl in CERN Report 87-03, 1987.

[4] V. Visnjic, Fermilab Report TM-1845, July 1993.

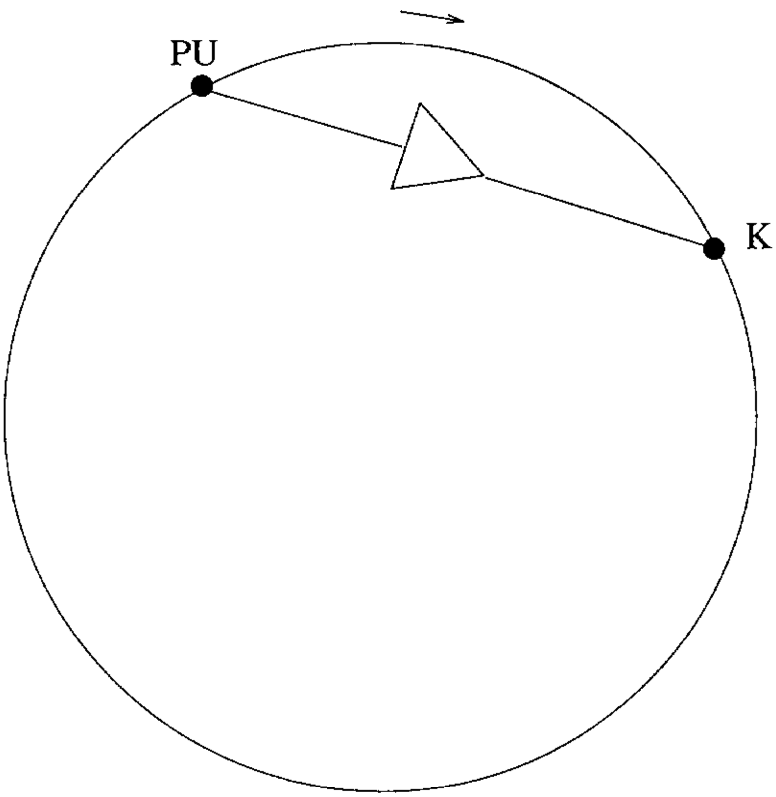

FIGURE 1 Schematic drawing of a stochastic cooling system.

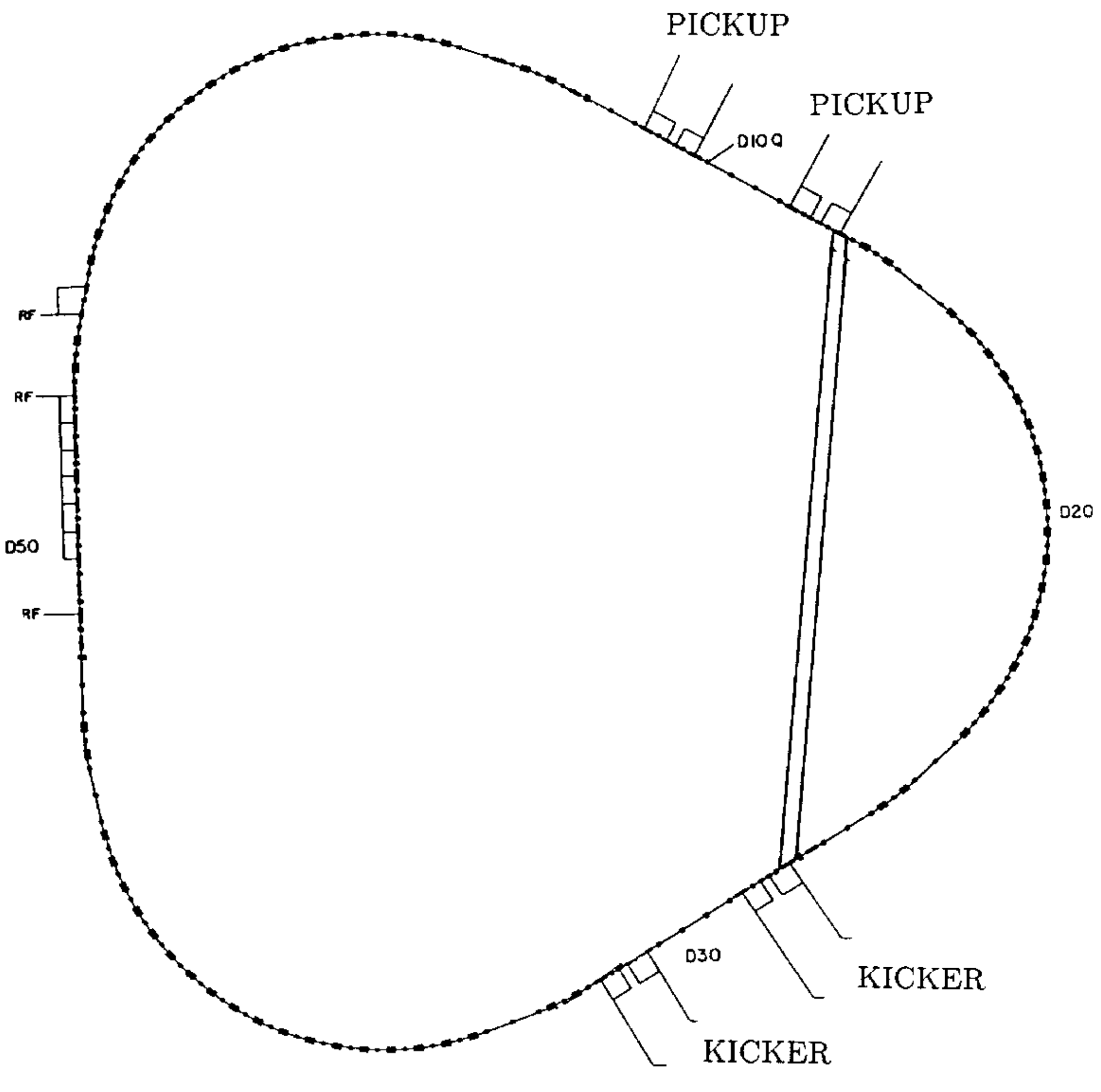

FIGURE 2 The layout of the Antiproton Debuncher at Fermi National Accelerator Laboratory. Note the positions of the pickups and kickers.

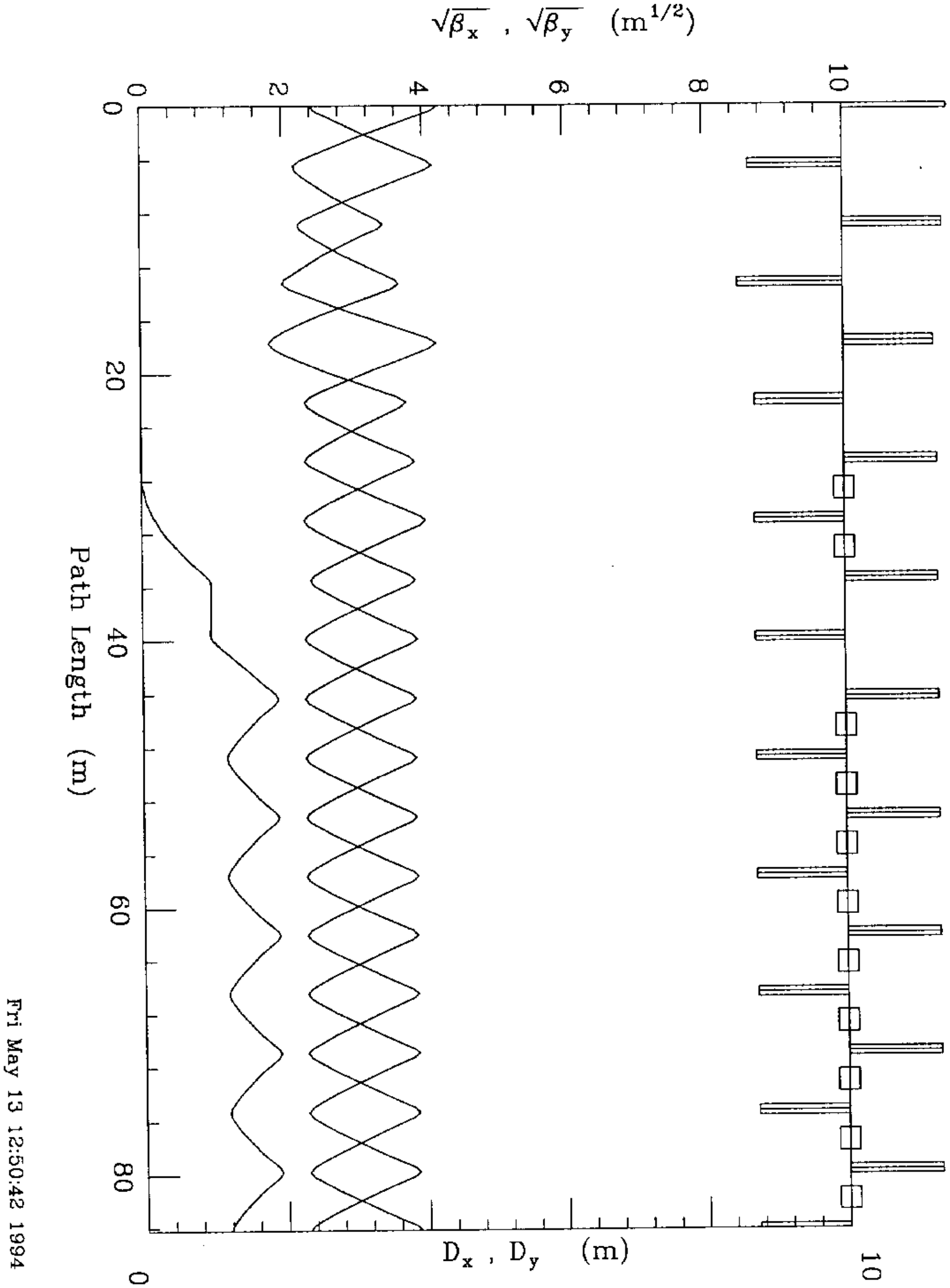

FIGURE 3 The lattice functions in one superperiod of the Antiproton Debuncher at Fermi National Accelerator Laboratory.

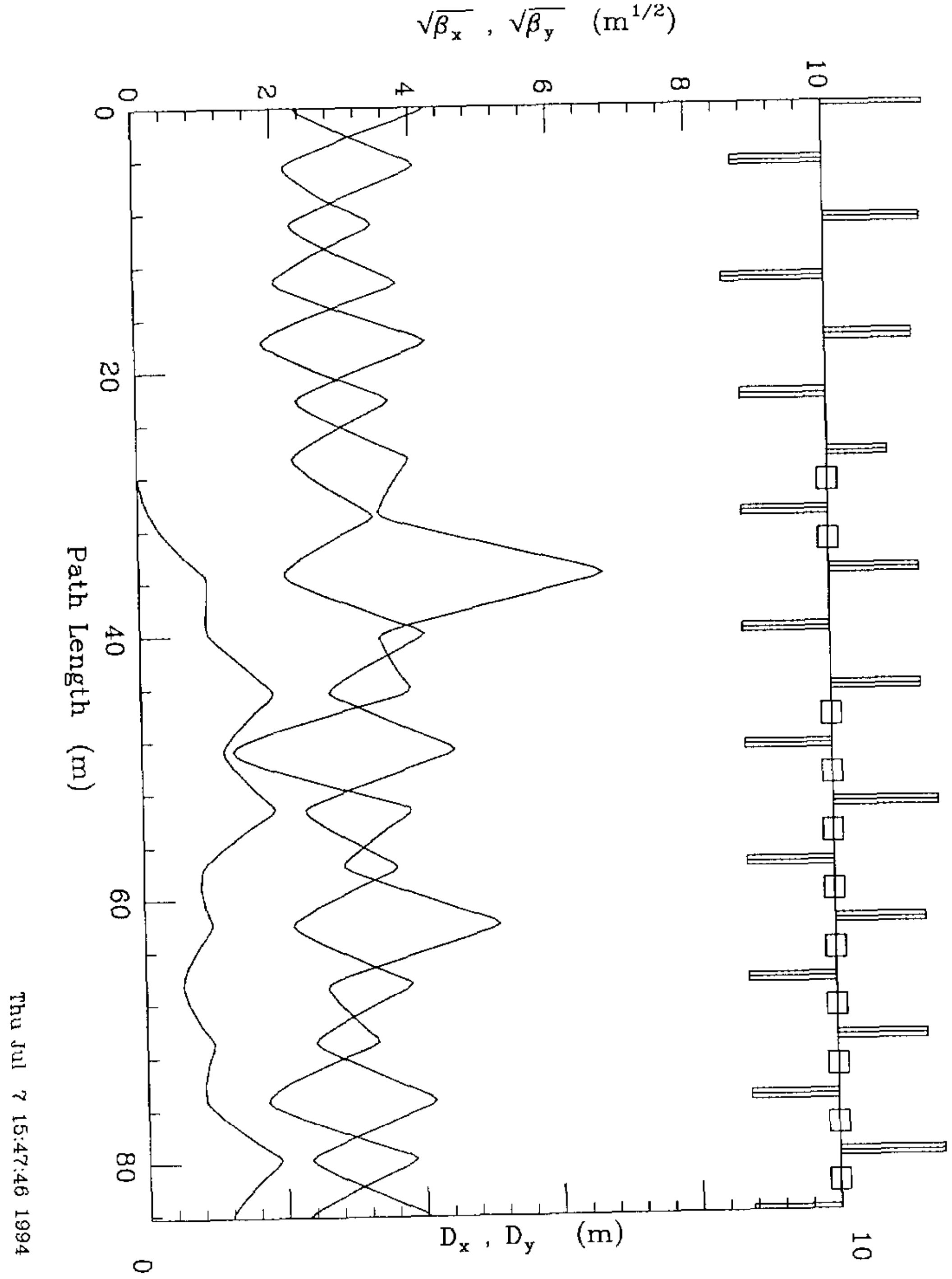

FIGURE 4 A Debuncher sextant with $\eta = 0$.

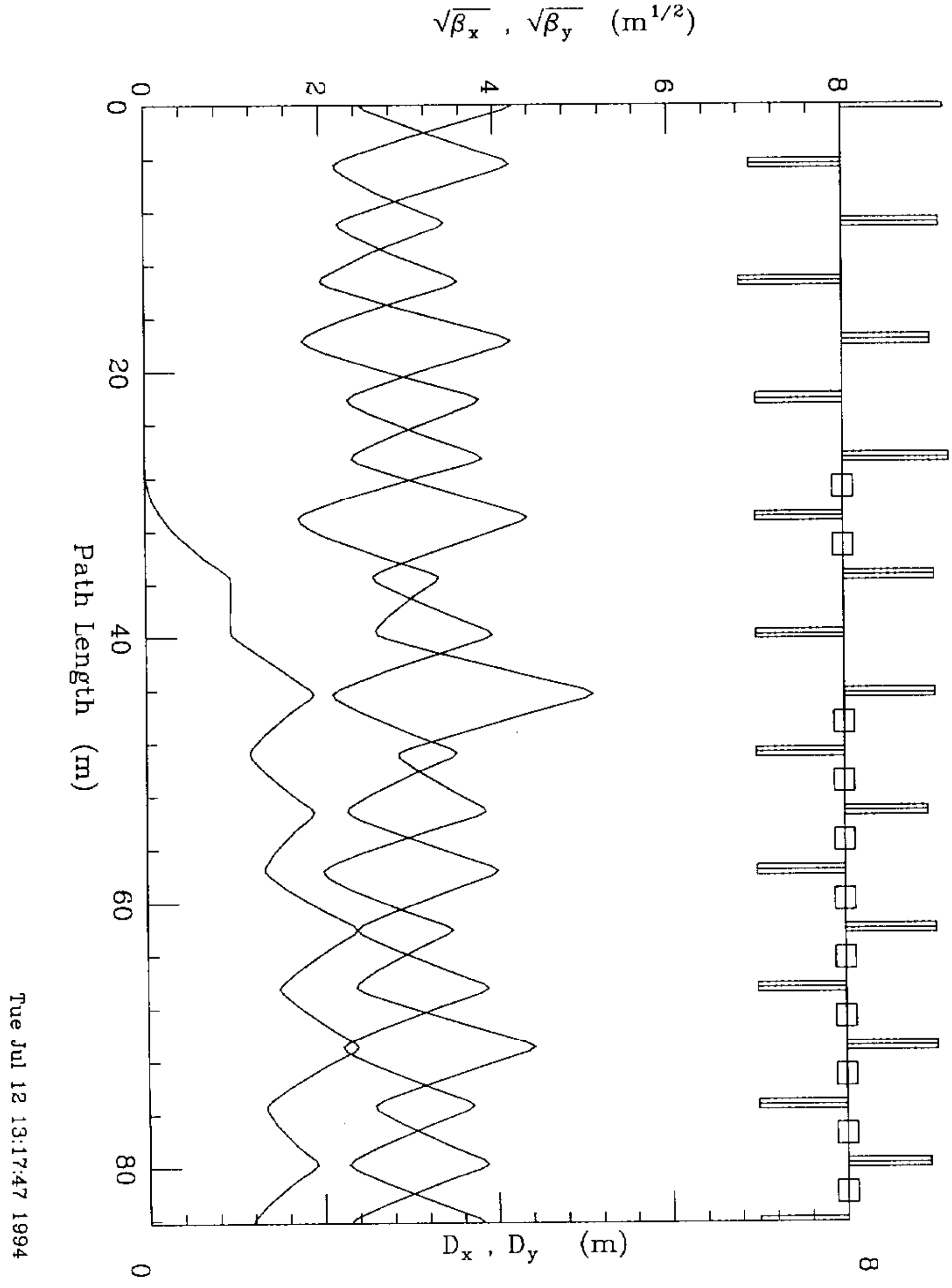

FIGURE 5 A Debuncher sextant with $\eta = 0.009$.

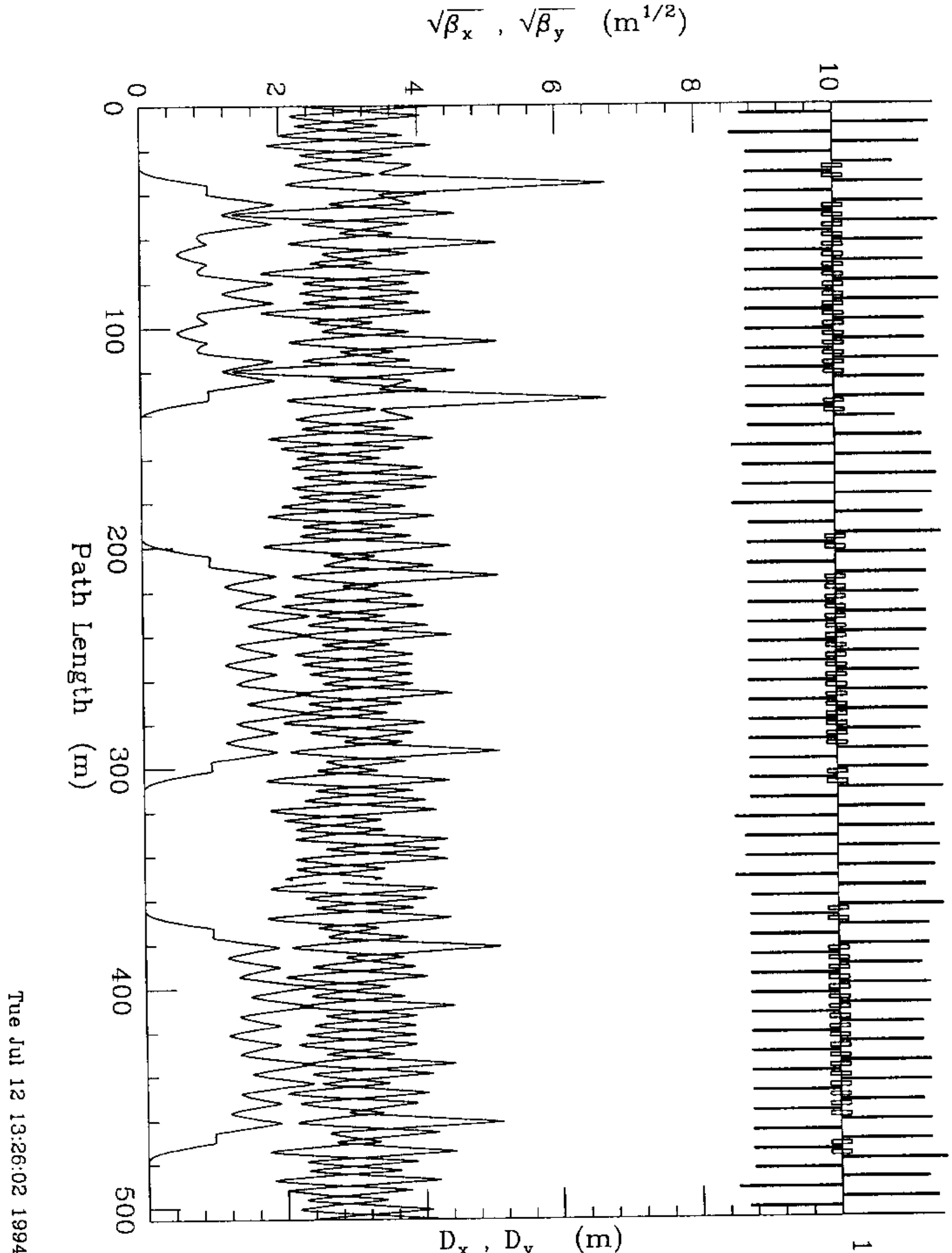

FIGURE 6 Asymmetric Debuncher: $\eta = 0.006$, no bad mixing.

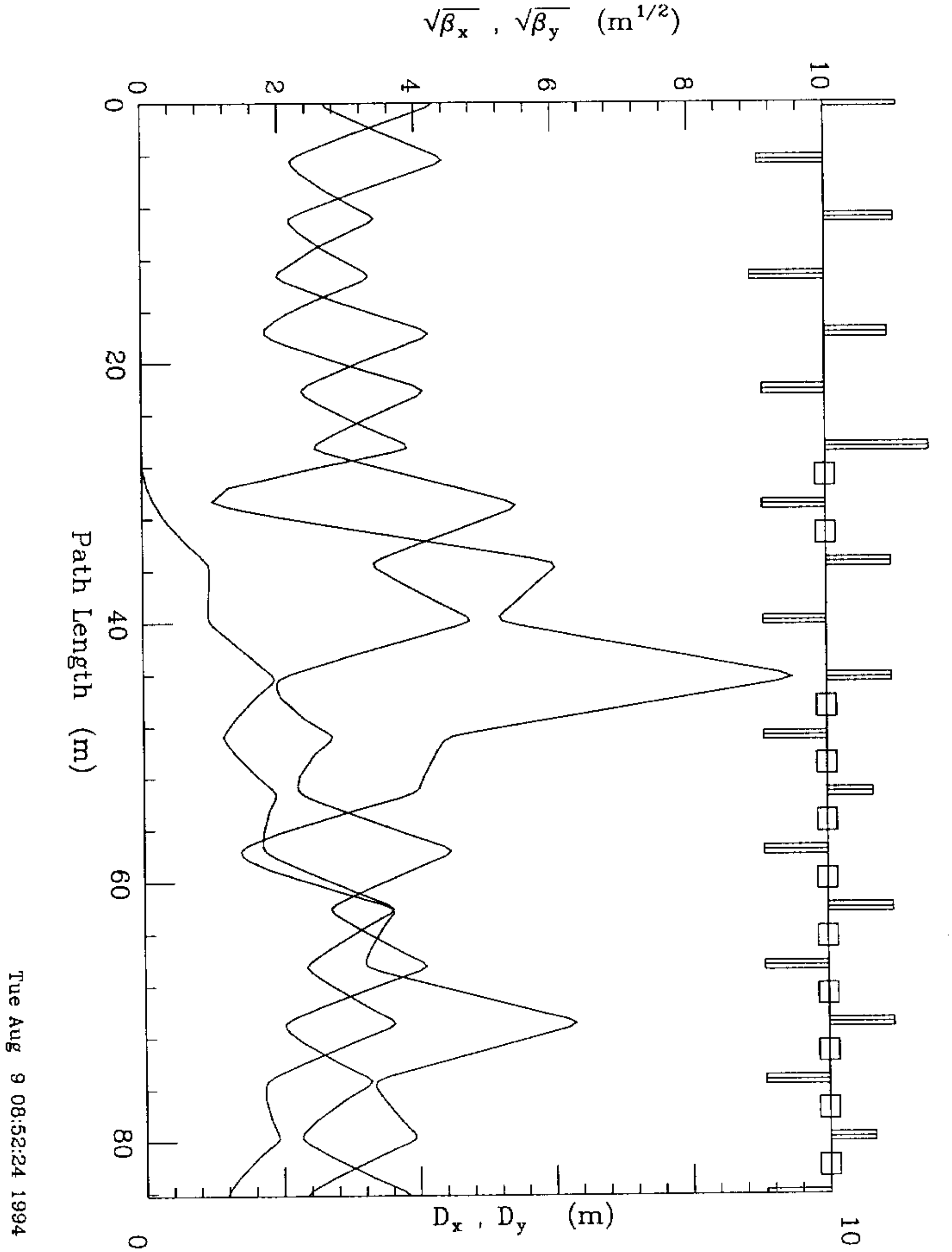

FIGURE 7 A Debuncher sextant with $\eta = 0.018$. The complete lattice has $\eta = 0.012$, twice the value of the nominal lattice and np]bad mixing.

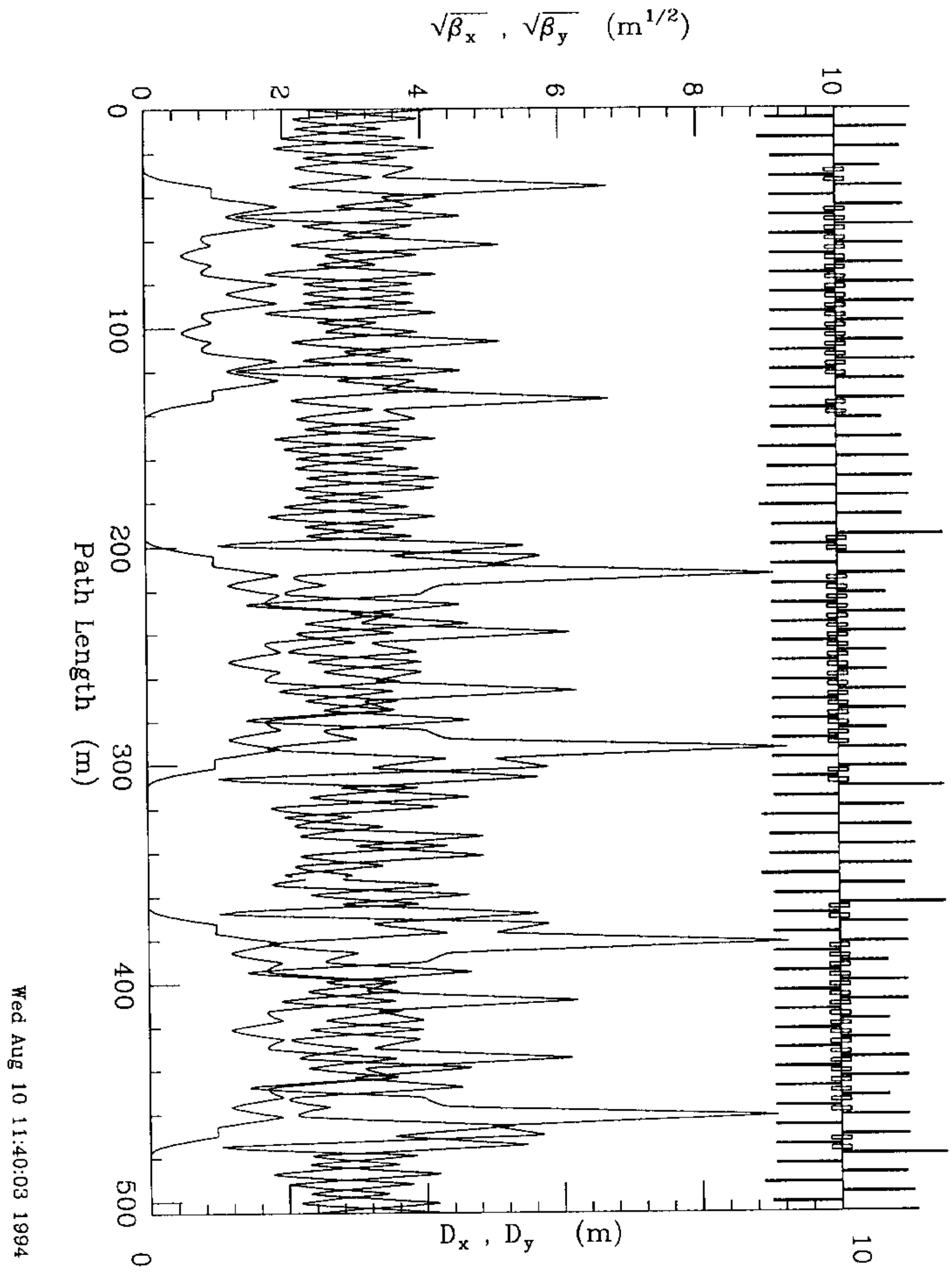

FIGURE 8 The complete Debuncher lattice with zero bad mixing and η twice the value of the nominal lattice.