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STUDY OF THE INJECTION TO THE AGS ACCUMULATOR BOOSTER RING

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H^- ion injection to a synchrotron enables one to circumvent the restrictions imposed by the Louisville theorem and one can inject into the same phase space occupied by circulating protons in the synchrotron. In other words, if there are no other restrictions, one can inject arbitrarily long or many linac pulses. This is particularly useful for the proposed "Accumulator-Booster"[1] for the AGS since only multiple scattering and space charge would eventually limit the length of the injection process. In conventional H^- ion injection scheme, both incoming ions and circulating protons go through the stripping foil every time they come around to the injection point, and the stripping foil is the major contributor to multiple scattering. The gas scattering in the synchrotron can be controlled by means of a better vacuum but the growth of the emittance eventually causes loss of the protons out of the admittance of the machine. For polarized protons, the problem is even more serious because the depolarizing resonance depends on the vertical emittance of the circulating protons.

A new scheme to inject H^- ions into a synchroton was examined.[2] The scheme attempts to minimize the vertical emittance growth and preserve the protons inside the horizontal admittance of the machine. A Monte Carlo simulation was made to compare the scheme with conventional injection. The calculation indicates that up to twenty-five linac pulses can be injected without excessive loss or vertical emittance blow-up.

Conventional H^- ion injection schemes[3] used at the AGS and Fermilab utilizes the stripper foil arranged as shown in Figure 1a. The orientation of both vertical and horizontal phase space is matched to minimize the dilution of the phase space density. The foil covers one side of the phase space. In this arrangement more than half of the circulating beam goes through the foil every time it comes around to the injection point.

An obvious improvement to this is shown in Figure 1b, where the stripper is only wide enough to cover the incoming linac beam. The circulating beam has less chance to hit the stripper and the growth of the emittance is reduced.

The scheme we are going to examine is a variation of the latter. One can recognize the fact that there are two competing processes in the phase space density dilution. One is from the multiple scattering and the other is caused by the phase space orientation mismatch.

The injection point we examined has the following properties. In order to minimize vertical emittance increase, we chose a location where the vertical β-function is as small as practical. In a regular synchrotron lattice, the vertical condition imposed makes the horizontal β-function large. Since the emittance of the linac is much smaller than the synchrotron admittance, one can choose from a variety of phase space orientations. We choose one such that vertical orientations of phase space match with circulating beams and form a horizontal waist at the stripping foil (Figure 1).

Figure 2 shows the stacking inefficiency as a function of horizontal β-function of the linac and number of injected turns. Stacking inefficiency is defined as the fraction of the particles lost during injection out of the synchrotron admittance of:

$A_H = 120\ \pi \times 10^{-6}$ meter-radian
$A_V = 40\ \pi \times 10^{-6}$ " "

Injected linac emittance is assumed to be:

$E_H = E_V = 5\ \pi \times 10^{-6}$ meter-radian

The Twiss parameters at the stripper foil are:

$\alpha_H = -2.14$ $\quad\alpha_V = 0.89$
$\beta_H = 9.6$ m $\quad\beta_V = 2.93$ m
$\gamma_H = 0.58$ $\quad\gamma_V = 0.61$

which are the actual parameters of the proposed A/B ring for the AGS.

As can be seen in Figure 2 there is a minimum at β linac of .8 meters and a stacking efficiency of 99% even after 12,500 turns (25 linac pulses). Below that point particles are lost because of the phase space dilution by mismatch and above the point beams are lost because of multiple scattering. Several other lattices were also examined and an empirical relationship was found. When the emittances and β-function of the linac have the relation:

$$\frac{\varepsilon_{acc}}{\beta_{acc}} = 2\,\frac{\varepsilon_{inj}}{\beta_{inj}}$$

the best stacking efficiency was obtained. In other words, when angular spread of the linac is $\frac{1}{\sqrt{2}}$ of the angular spread at $x = o$, the stacking efficiency is highest.

We also examined the growth of both horizontal and vertical emittance as a function of β inj. and number of turns injected. The results are shown in Figures 3 and 4; again, the best compromise between both horizontal and vertical emittance is found around β injection of 0.8. The emittances are calculated for 97% of the surviving protons.

The case of β inj. = .8 m is compared with conventional methods used at the AGS and Fermi labs. Also included in the comparison is the method which is a simple improvement over conventional schemes. Figure 5 shows stacking inefficiencies vs. number of stacking turns. Figures 6 and 7 show the growth of horizontal and vertical emittances vs. number of turns. Apparent flattening of the emittance growth is due to the particle loss out of the admittance of the accumulator synchrotron. The error bars indicate systematic error mainly caused by uncertainty of the foil thickness.

Acknowledgements

I would like to acknowledge L.W Smith and L.G. Ratner for valuable discussions.

References

1. AGS Accumulator Booster Proposal, 1983.
2. A similar scheme was suggested by L.G. Ratner.
3. D.S. Barton and R.L. Witkover, BNL 26732, 1982.
   C. Hojfat, et al., IEEE NS-26, 3149 (1979).

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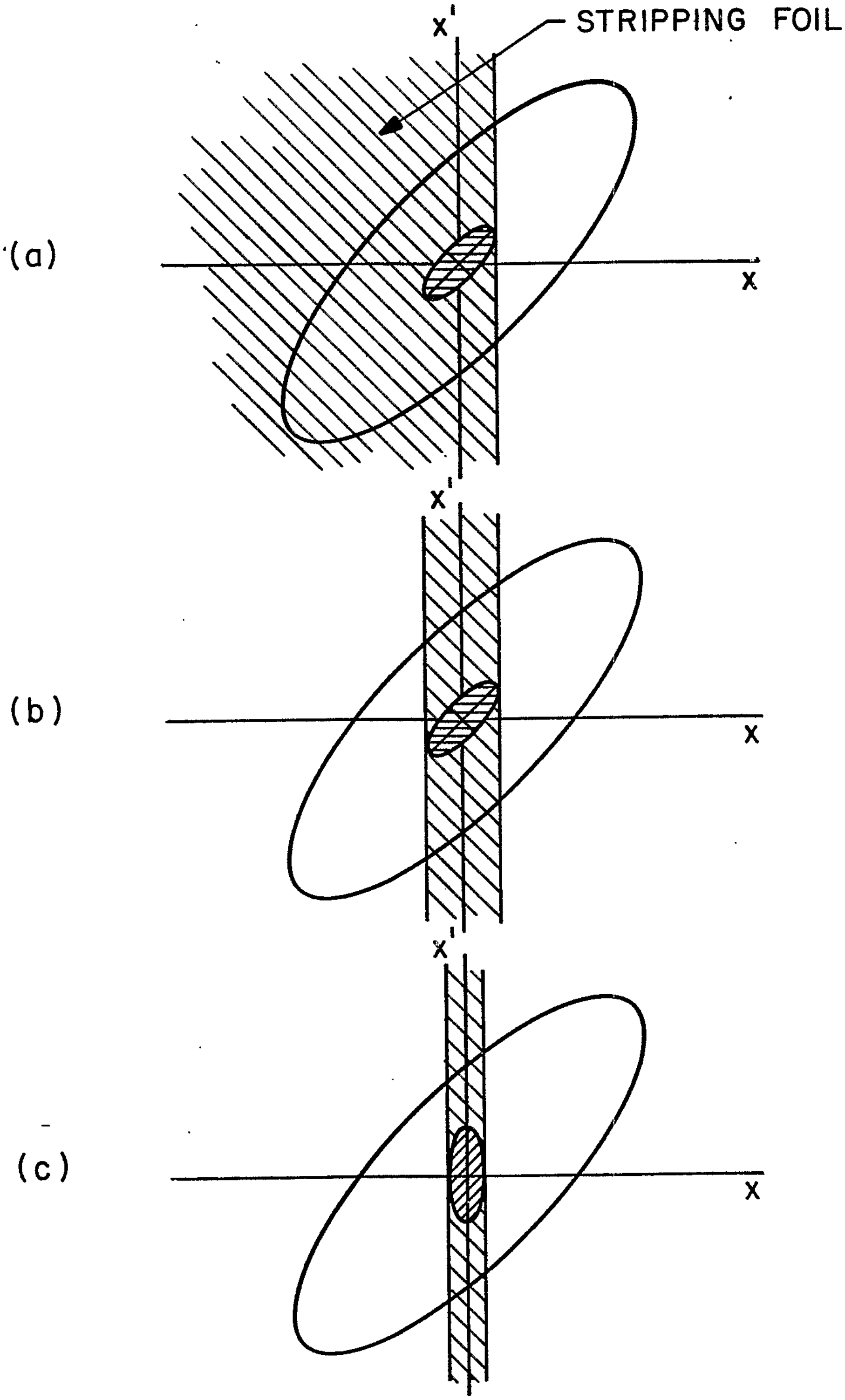


Figure 1

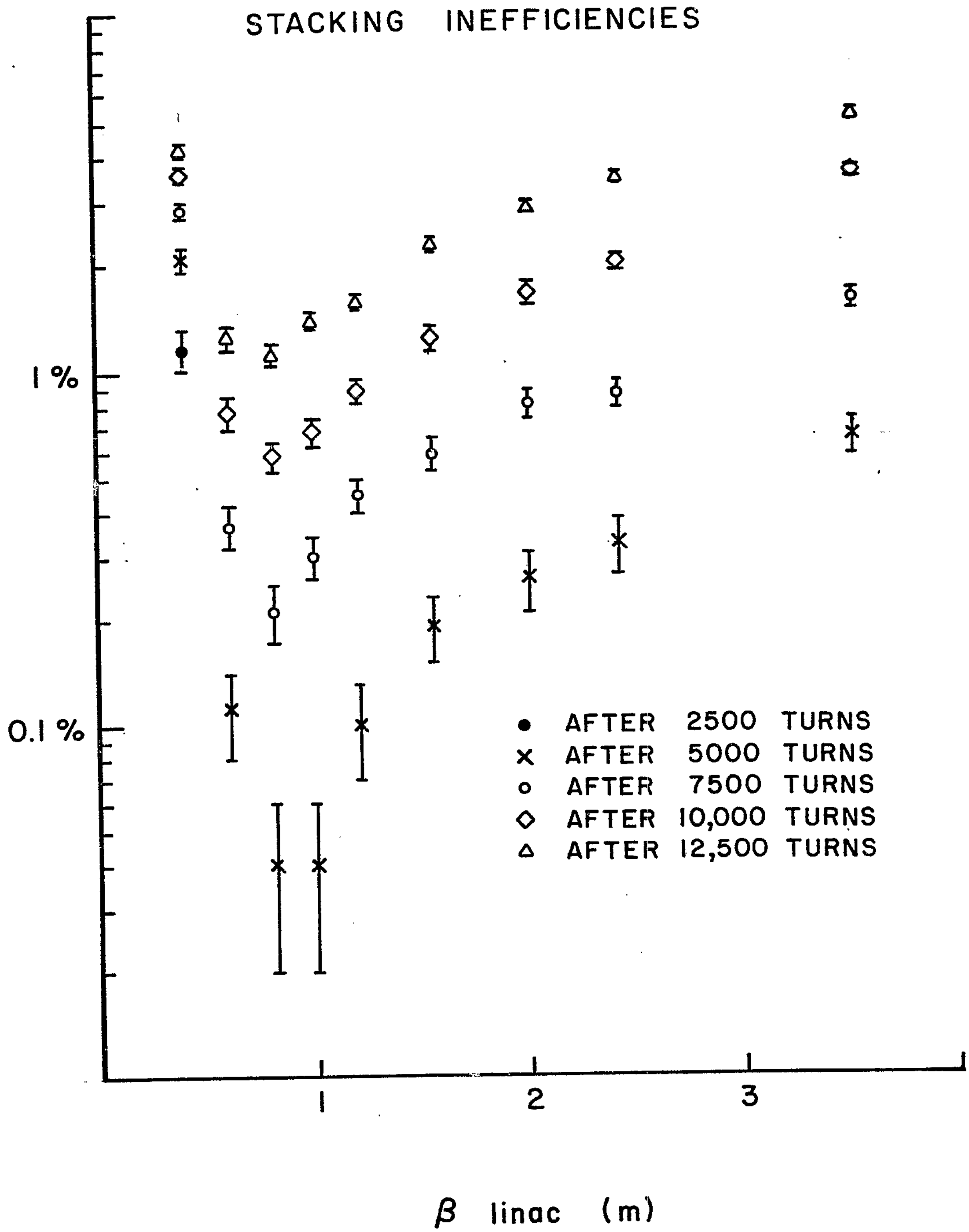

STACKING INEFFICIENCIES
1 %
0.1 %
AFTER 2500 TURNS
AFTER 5000 TURNS
AFTER 7500 TURNS
AFTER 10,000 TURNS
AFTER 12,500 TURNS
1
2
3
β linac (m)

Figure 2

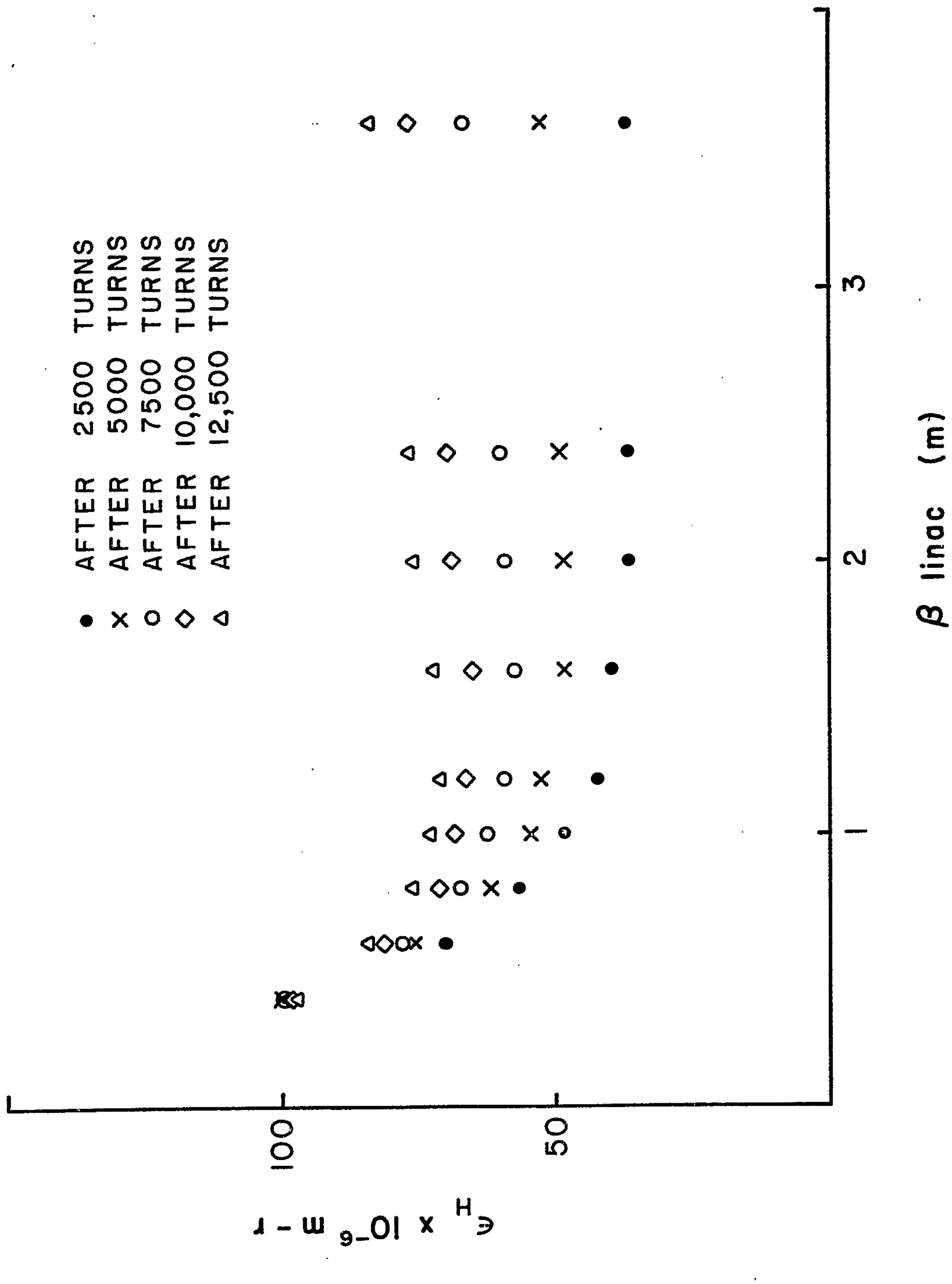
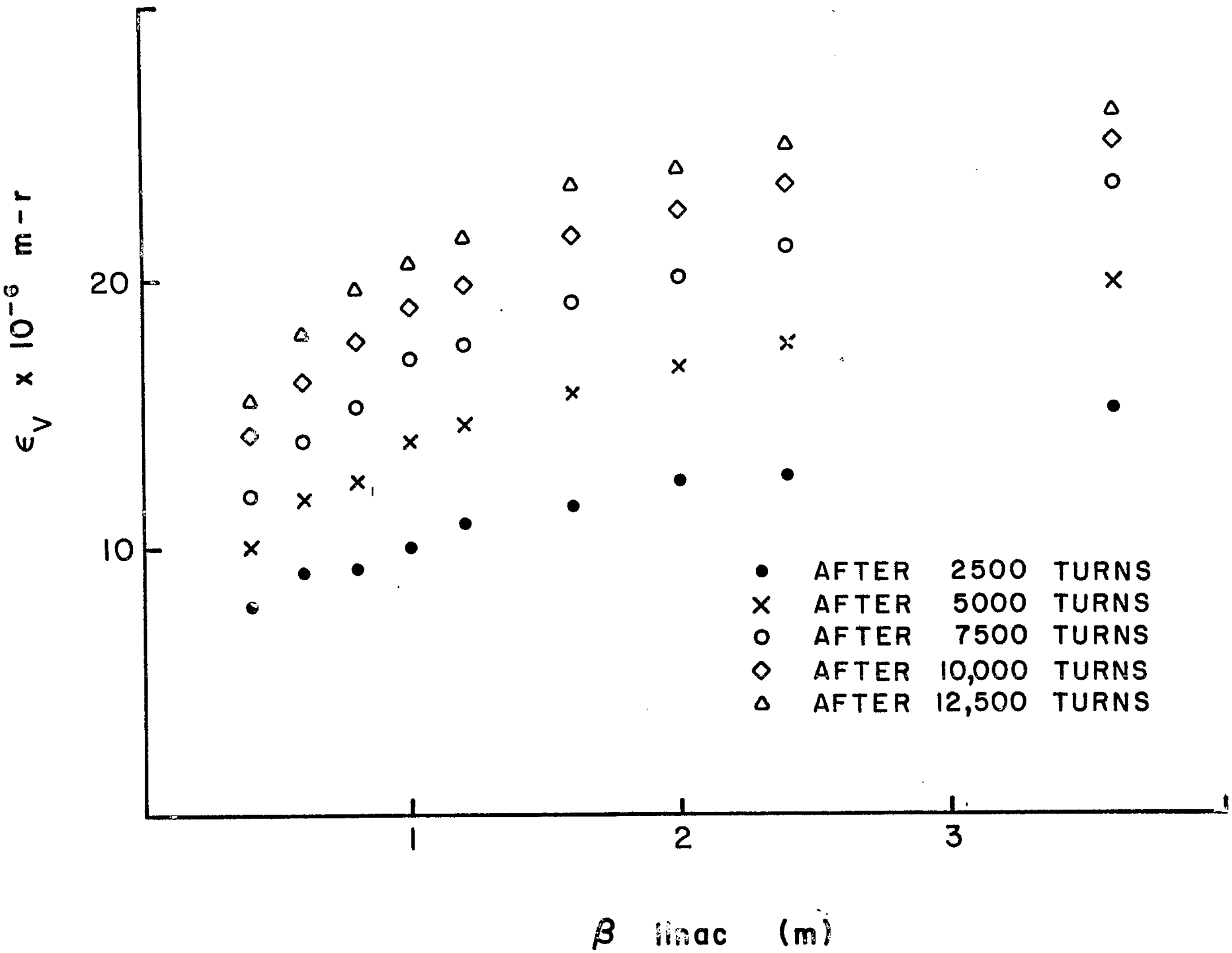

AFTER 2500 TURNS
AFTER 5000 TURNS
AFTER 7500 TURNS
AFTER 10,000 TURNS
AFTER 12,500 TURNS
1
2
3
β linac (m)
100
50
ε_H x 10^-6 m-r

Figure 3



$\epsilon_V \times 10^{-6}$ m-r
20
10
1
2
3
β linac (m)
AFTER 2500 TURNS
AFTER 5000 TURNS
AFTER 7500 TURNS
AFTER 10,000 TURNS
AFTER 12,500 TURNS

Figure 4

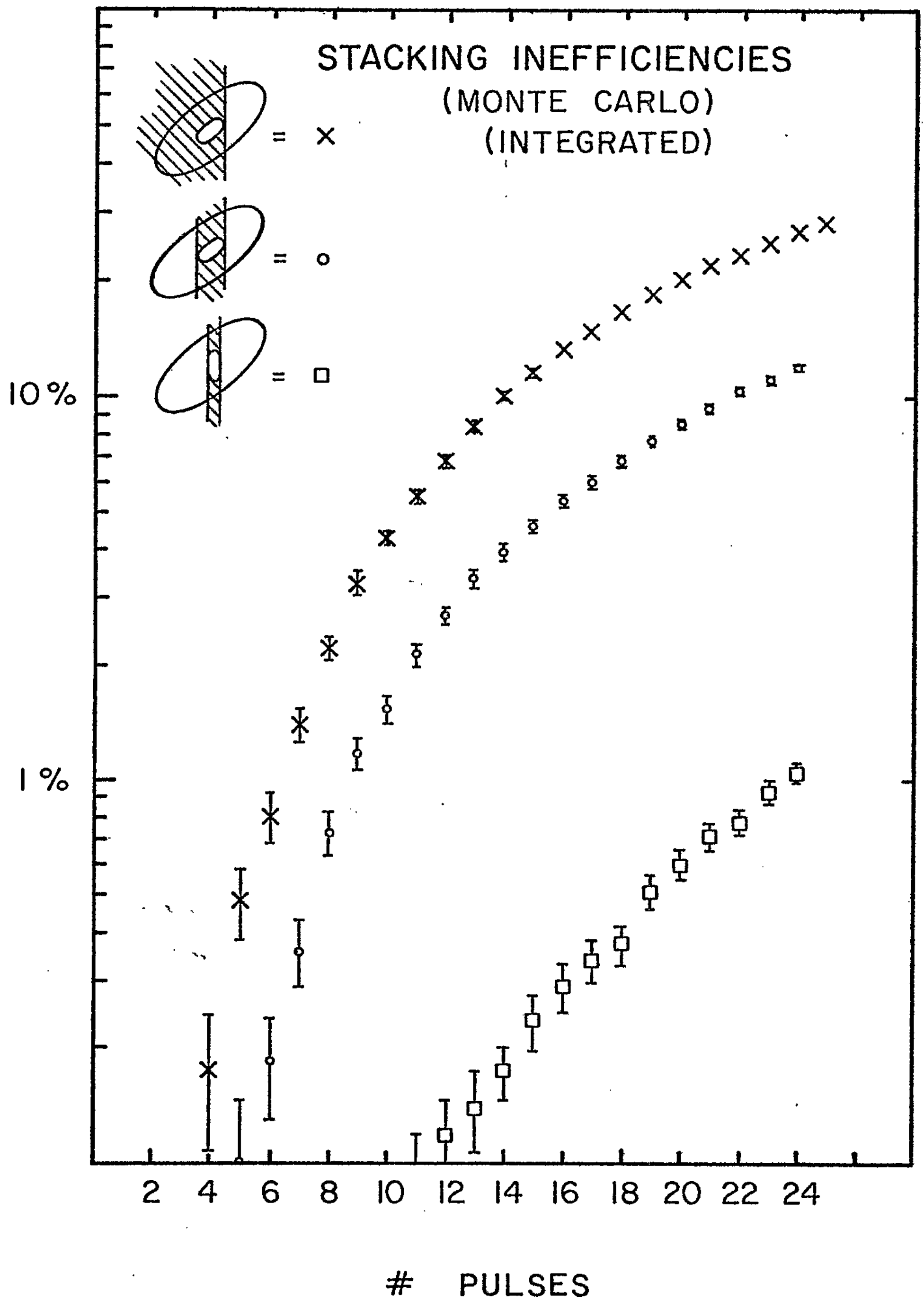

STACKING INEFFICIENCIES
(MONTE CARLO)
(INTEGRATED)
= ×
= o
= □
10%
1%
2
4
6
8
10
12
14
16
18
20
22
24
PULSES

Figure 5

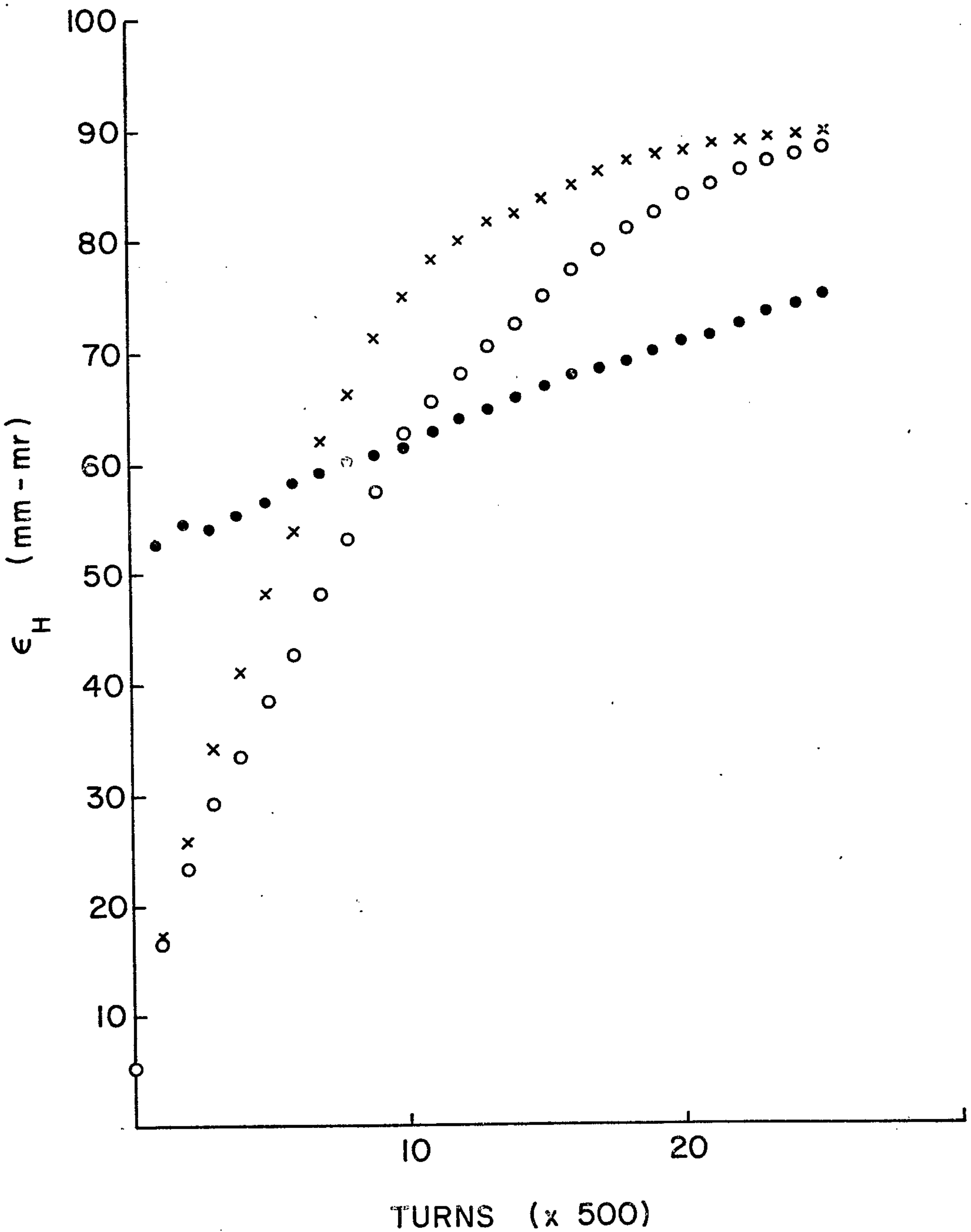


Figure 6

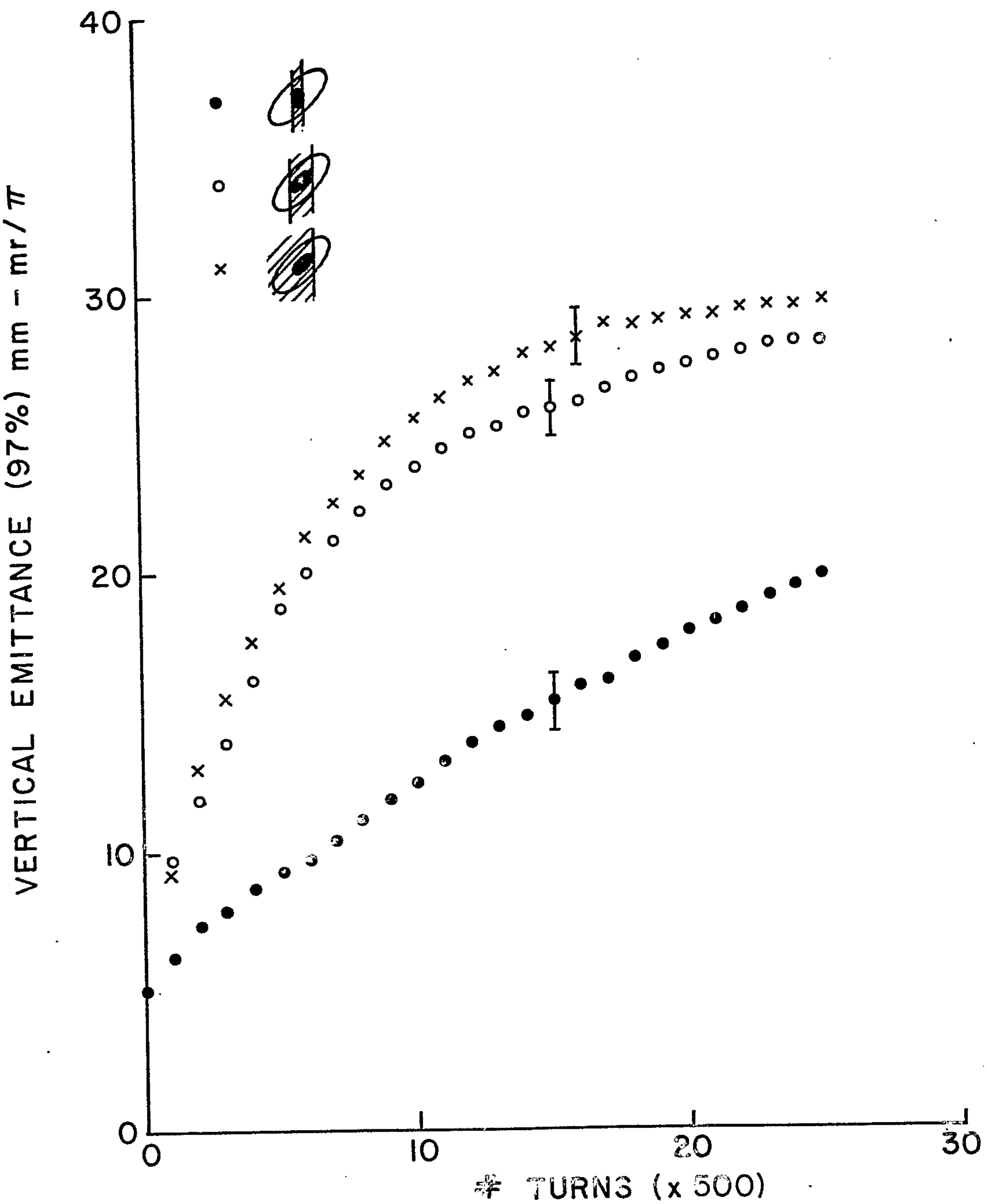


Figure 7