

Space charge effects in the AGS Booster

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SPACE CHARGE EFFECTS IN THE AGS BOOSTER

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Booster Technical Note

No. 108

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Introduction

Space Charge effects are an important limitation on the performance of the A GS Booster

Simulation Program

Using a tracking program, space charge ~~effects~~ forces are entered as a Kick at each element in the lattice. $\text{Kick} \sim E_x \text{ or } E_y$, and the length of the element.

To compute the electric field of the beam, E_x, E_y , the beam shape in x, y space is assumed to be gaussian with the two parameters σ_x, σ_y , which are different at each element in the lattice.

The parameters σ_x, σ_y are determined by tracking a sample of about 16 to 24 particles. The growth of this sample determines the growth in σ_x, σ_y .

Particle Sample

Sample may have 16 particles, 4 groups of 4
 Each group of 4 starts at same E_x, E_y
 but different x, x', y, y'

One group of 4 starts at E_x, E_y at edge
 of beam, other groups start at smaller E_x, E_y .

Groups can have $\Delta p/p \neq 0$

Initial State of the Beam

The beam is assumed to exist
 in the accelerator in the shape it would
 have in the absence of space charge
 forces. This beam shape depends on
 the injection procedure. The space
 charge forces are then turned on, and
 the subsequent growth of the beam
 is studied.

Simulation Program Difficulties

The model used may have relatively few parameters. This may lead to inconsistent results, or results that appear unacceptable.

Increasing the number of parameters and the complexity of the model may eliminate many of these unwanted results.

However, to some extent inconsistent results may remain. In the space charge model, the results may depend, to a certain extent, on the choice of the sample. This introduces an uncertainty in the results. At some point, one may be inclined to use one's judgement as to which results to emphasize.

For the Booster, there appears to be some dependence of the answer for the space charge limit on the choice of the sample. This may be reduced by improving the sample and the algorithm relating the beam size with the growth of the sample. (~~partly the size of the uncertainty~~) The uncertainty in the answer at this time could be about 50% for the Booster (on the optimistic side).

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Increasing the number of parameters and the complexity of the model may eliminate many of these unwanted results. However, to some extent inconsistent results may remain. In the space charge model, the results may depend, to a certain extent, on the choice of the sample. This introduces an uncertainty in the results.

For the Booster, this not very large uncertainty in the beam growth can cause a fairly large uncertainty in the space charge limit, of about 50%, for ^{the} case where the injected beam is flat.

This will be shown later on below.

This does not happen for round beams in the Booster, nor for the AGS in the Fermilab Booster.

One might prefer the more pessimistic result.

On the plus side, the uncertainty in the results for the AGS and the Fermilab Booster are considerably smaller. The overall shape of the growth curves are similar for different samples. The agreement with experimental results is reasonable for the AGS and the Fermilab Booster

Intrinsic Limit and the Resonance Limit

The intrinsic limit is the space charge limit in the absence of ~~any~~ magnetic field ~~errors~~ errors. This limit is due to the forces generated by the beam itself.

The Resonance limit is the space charge limit due to presence of random field errors, which can generate nearby resonances.

This presentation will give only results for the intrinsic limit, studies of the resonance limit are being done at present. Results so far indicate that the ~~the~~ space charge limit is dominated by the intrinsic limit. Results for the intrinsic limit for the A6S and the Fermilab Booster are fairly close to the experimental results. Tentative results for ^{the} resonance limit indicate that external resonances may only become important near the intrinsic limit.

Experimental Tests of Simulation Program

The validity of the simulation program can be tested by comparing its ^{results} with experimental results found in existing accelerators.

So far, comparisons have been made with two existing accelerators

- 1) A65
- 2) Fermilab Booster.

AGS Results

$$E_{\text{inj}} = 200 \text{ MEV}, \quad R = 128 \text{ m}, \quad h = 12$$

$$\beta_x = 22.17 \rightarrow 10.2, \quad \beta_y = 22 \rightarrow 10, \quad \alpha_p = 2.2$$

$$\text{Aperture Limits}, \quad \pm 32 \text{ mm Vertical}$$

$$\pm 35 \text{ mm Horizontal}$$

$$\epsilon_x, \epsilon_y = 56, 46$$

Is the AGS space charge limited?

$$N = 2 \times 10^{13} \text{ achieved/pulse}$$

$$N_b = .18 \times 10^{13} \text{ protons/bunch}$$

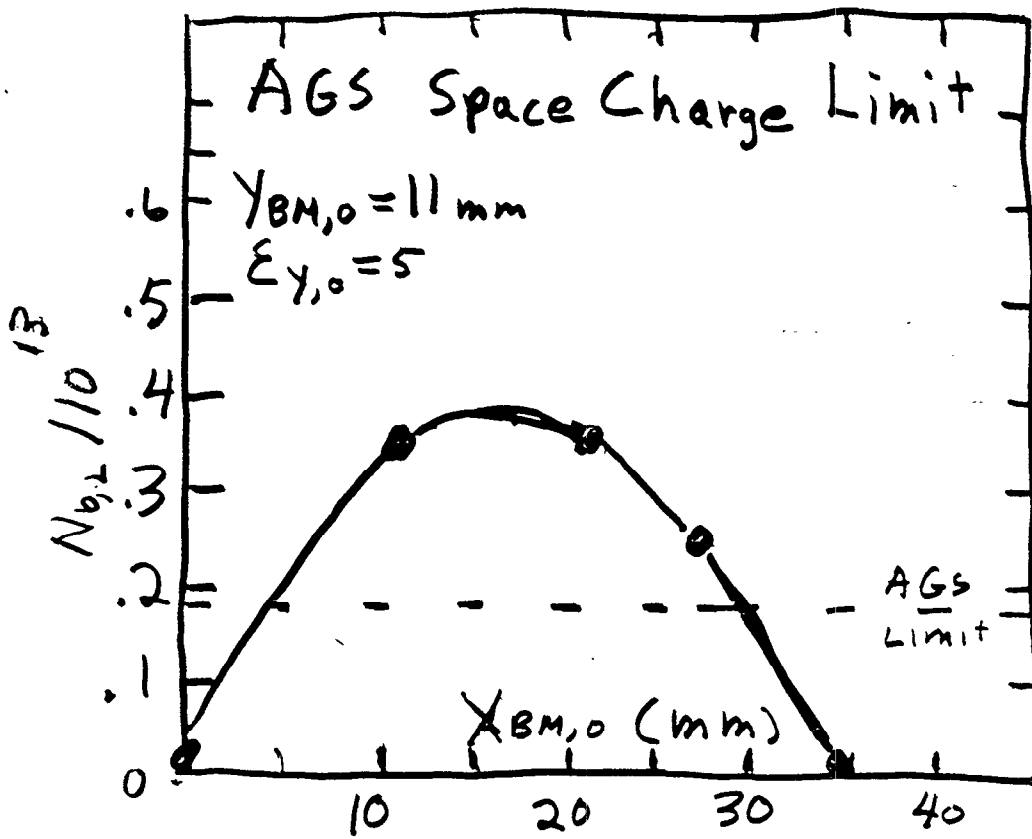


Fig 6

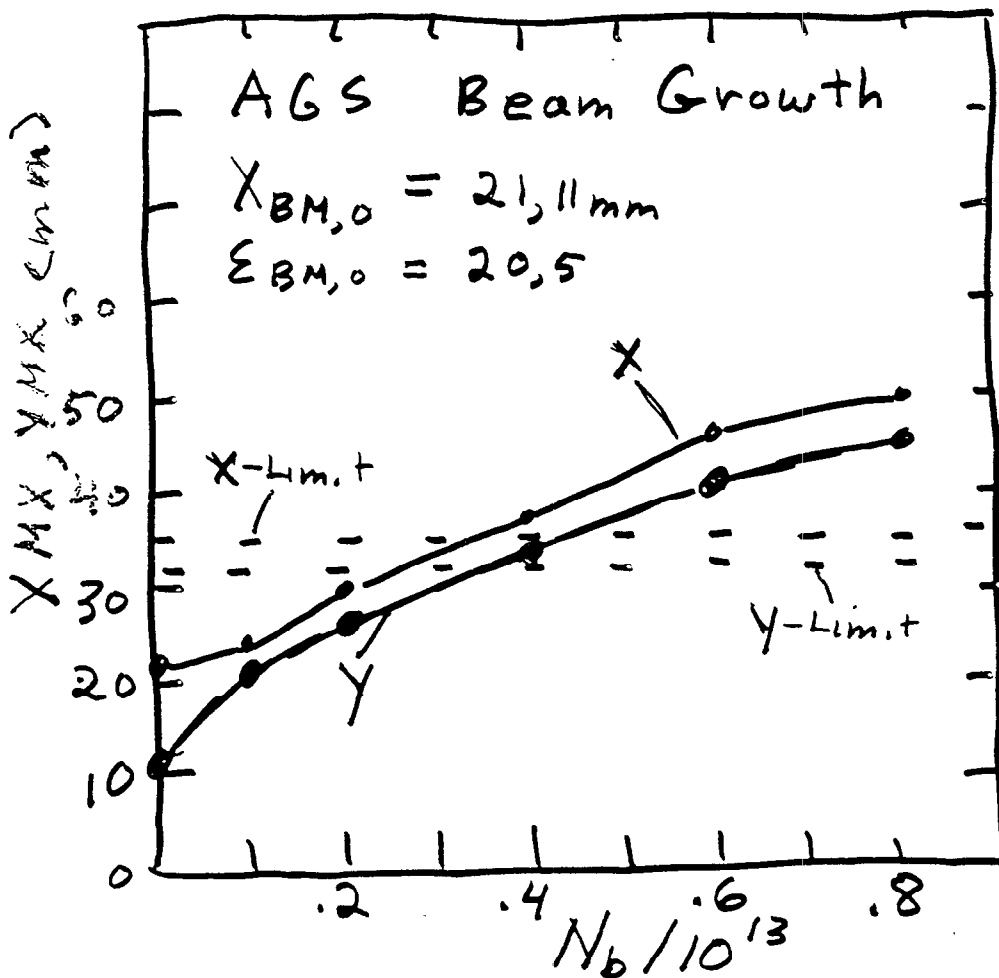


Fig. 5

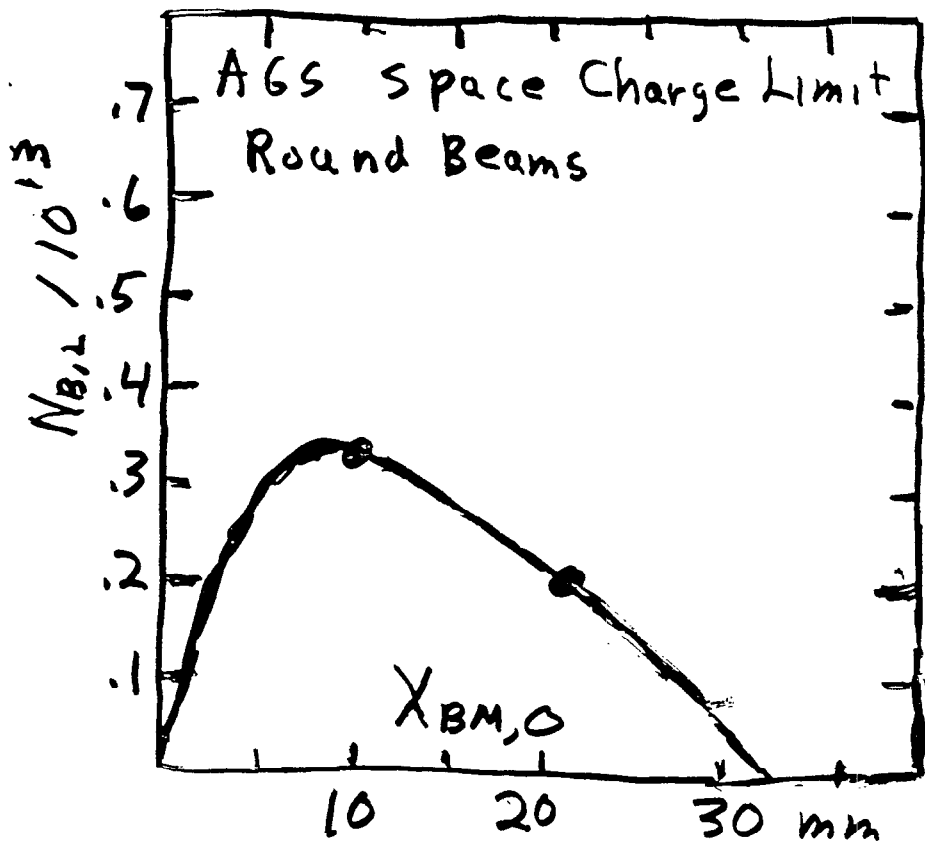


Fig 7

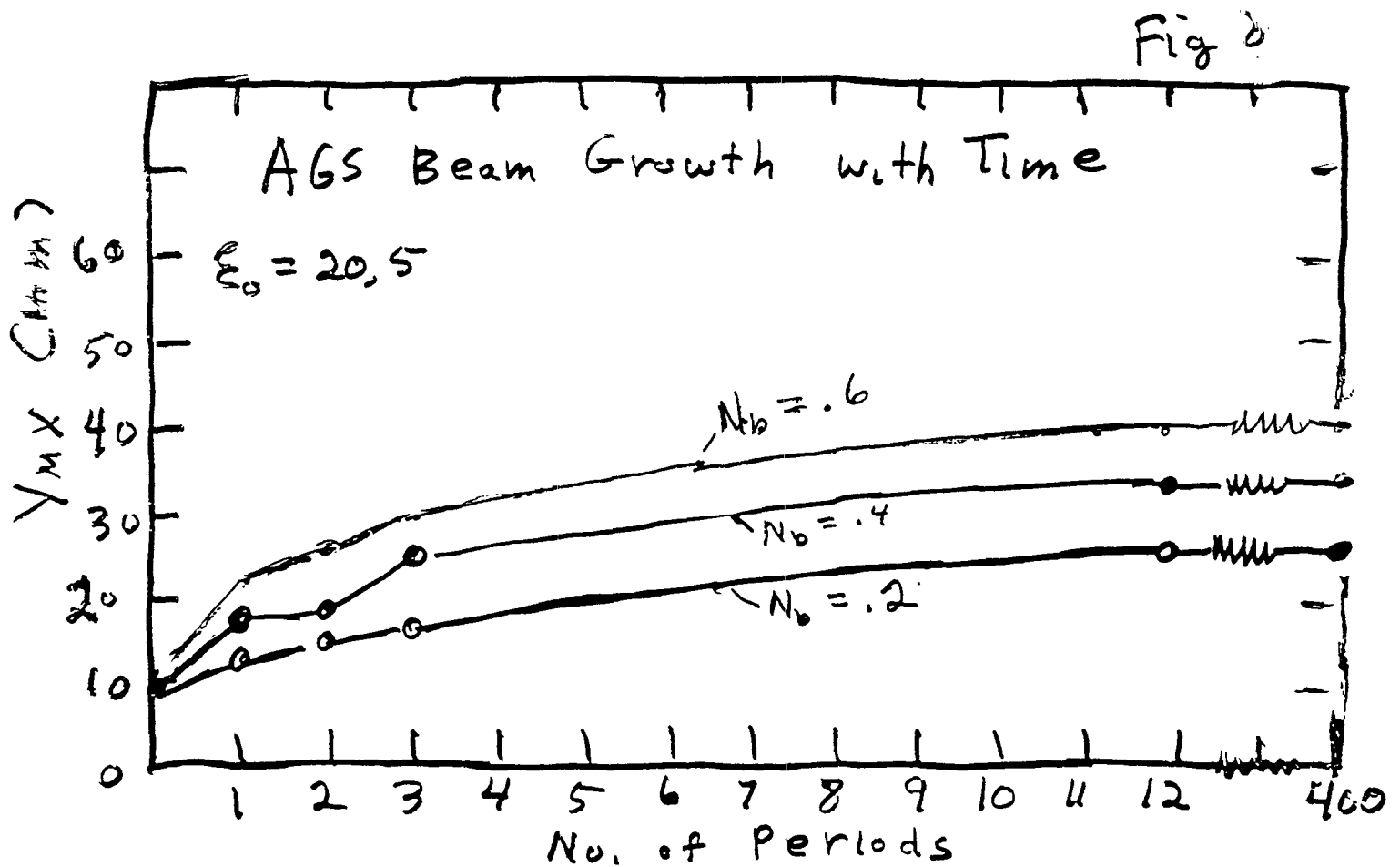


Fig 8

Fermi Lab Booster Results

$$E_{\text{inj}} = 200 \text{ MEV}, \quad R = 75.5 \text{ m}, \quad h = 84$$

$$\beta_x = 34 \rightarrow 6, \quad \beta_y = 20 \rightarrow 5.3, \quad X_p = 3.2 \rightarrow 1.8 \text{ m}$$

$$\nu = 6.7, 6.8$$

$$\text{Aperture Limits} \quad \pm 24 \text{ mm Vertical}$$

$$\pm 31 \text{ mm}$$

$$\epsilon_x, \epsilon_y = 29$$

$$N = 3 \times 10^{12} \text{ achieved}$$

$$N_b = 3.6 \times 10^{10} \text{ protons / bunch}$$

Bunching Factor = 4 was assumed

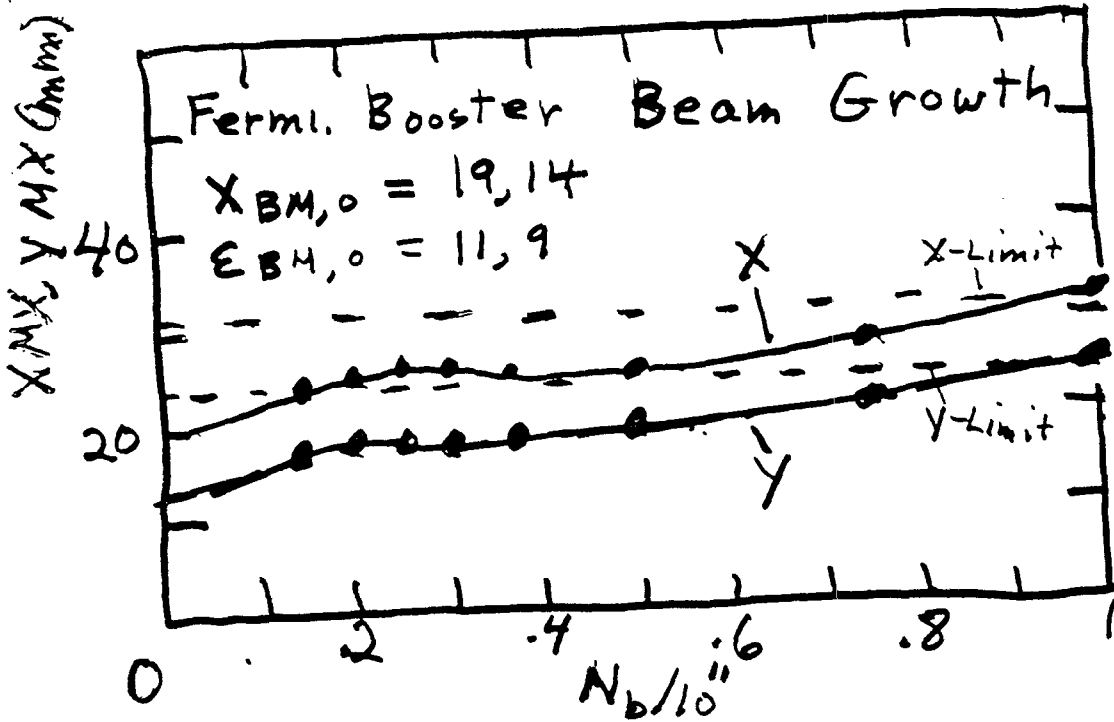


Fig 10

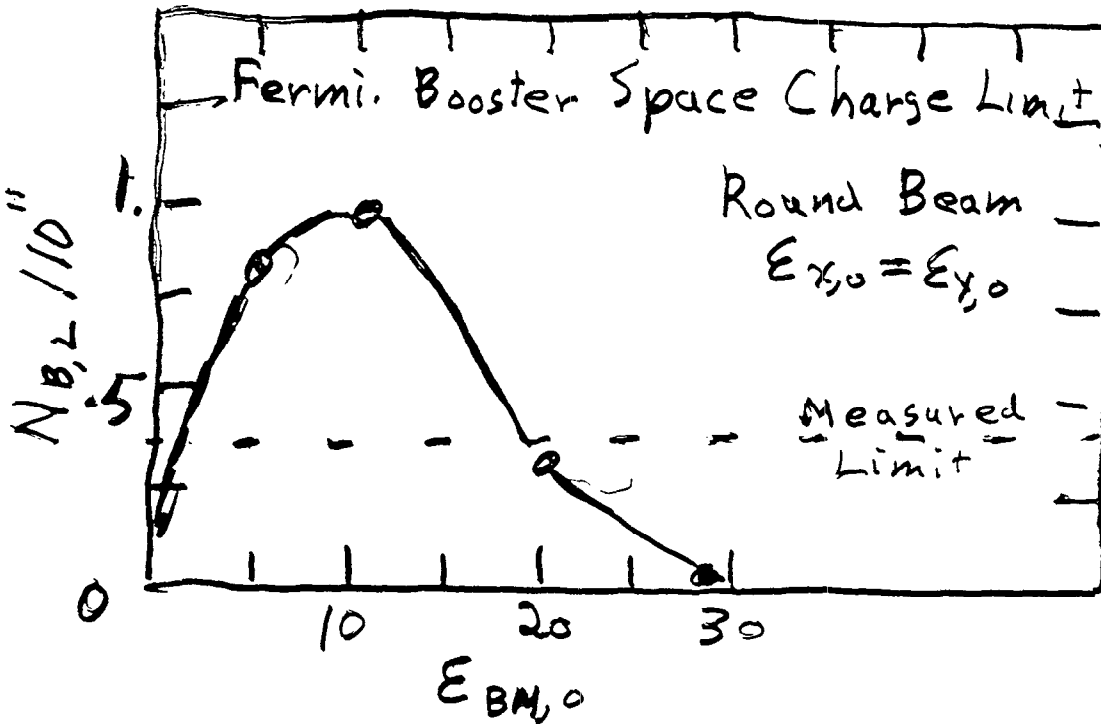


Fig 11

Booster Results

$$E_{in} = 200 \text{ MEV}, \quad R = 32 \text{ m}, \quad h = 3$$

$$\beta_x = 13.9 \rightarrow 3.6, \quad \beta_y = 13.6 \rightarrow 3.7, \quad \chi_p = 2.8 \rightarrow 0.5$$

$$\gamma = 4.82, 4.83$$

$$\text{Aperture Limits} \quad \pm 32 \text{ mm} \quad \text{Vertical}$$

$$\pm 48 \text{ mm} \quad \text{Horizontal}$$

$$\epsilon_x, \epsilon_y = 167, 74$$

1. 12

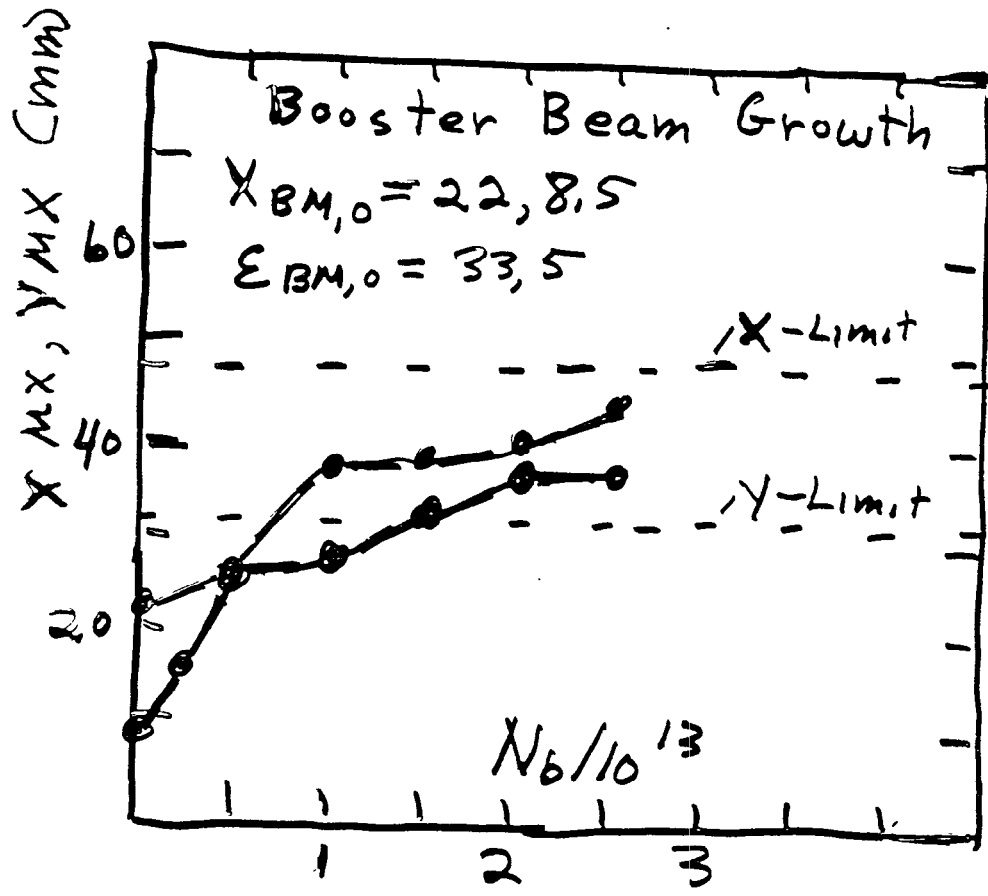


Fig. 13

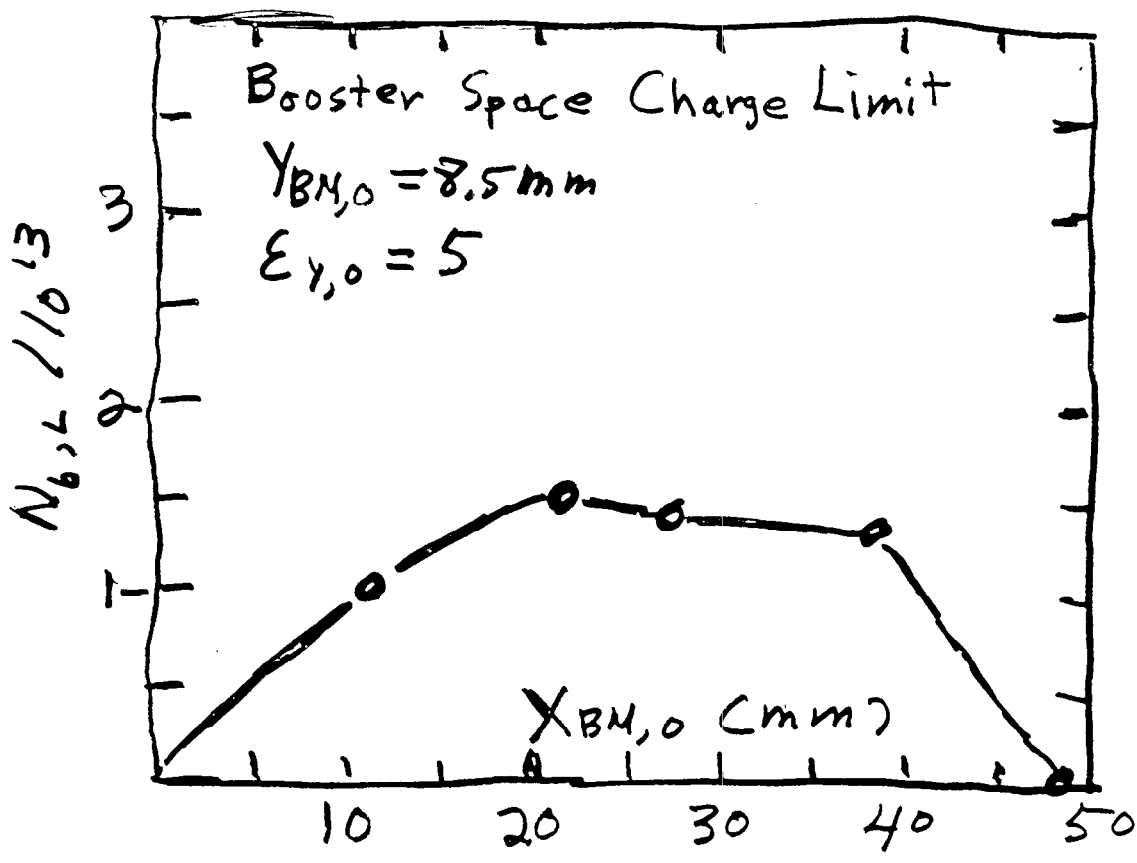


Fig. 14

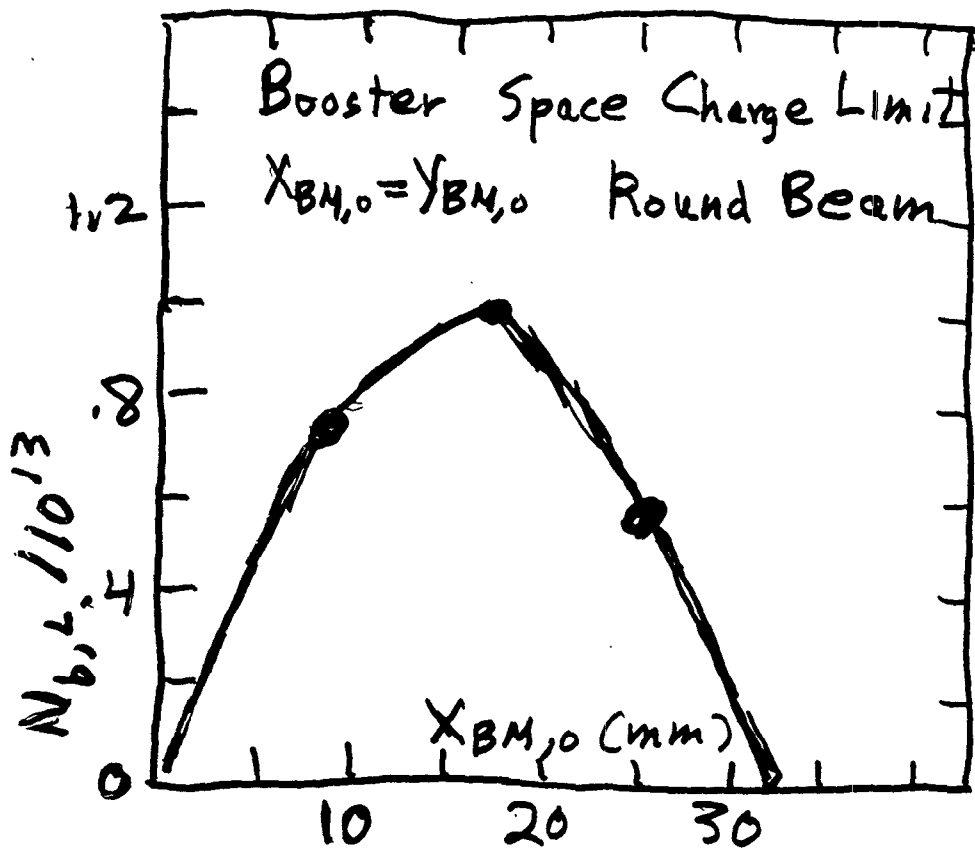


Fig 15

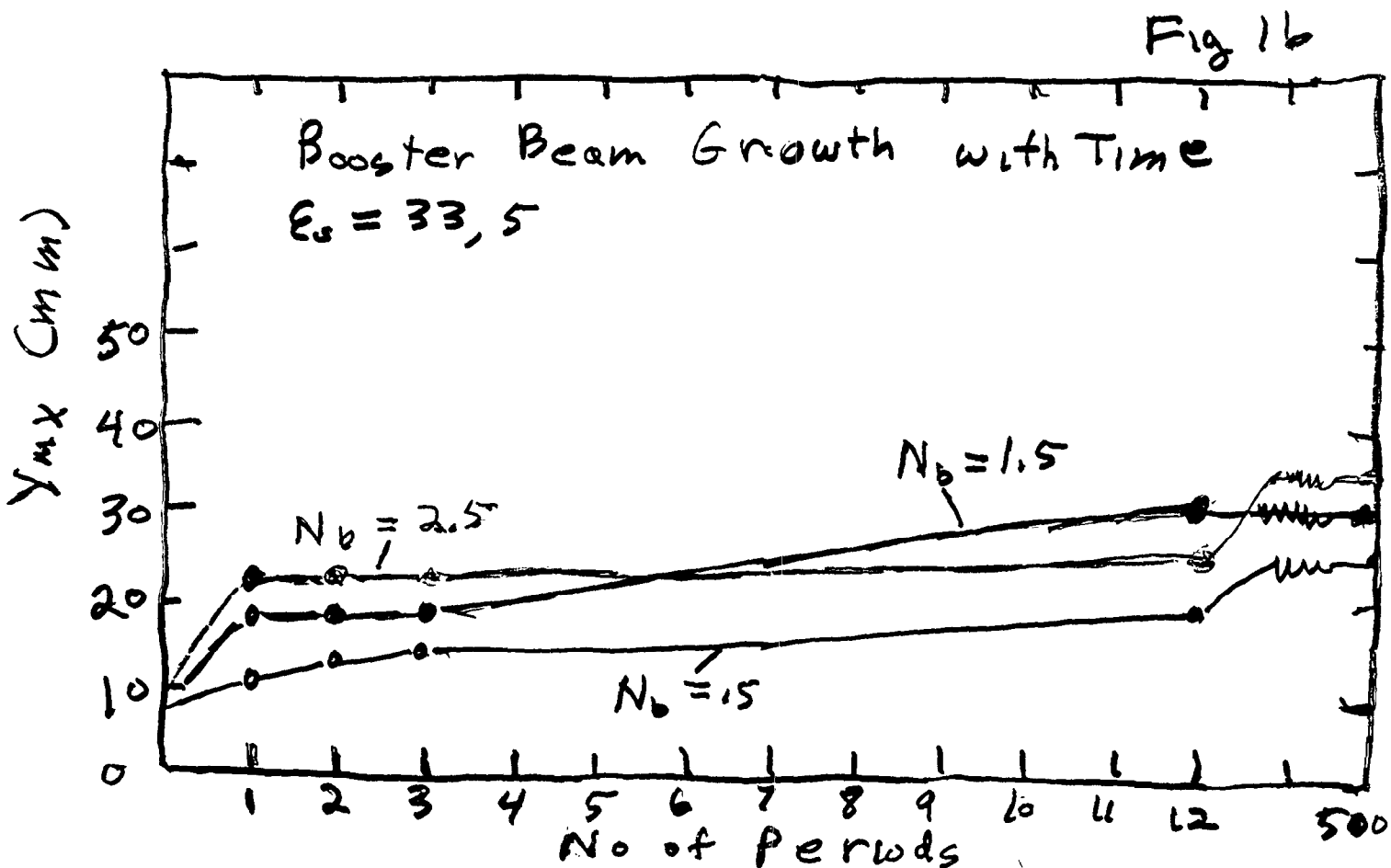


Fig 16

Booster Performance — Extrapolation
from the AGS and the Fermilab Booster

Extrapolation from the AGS

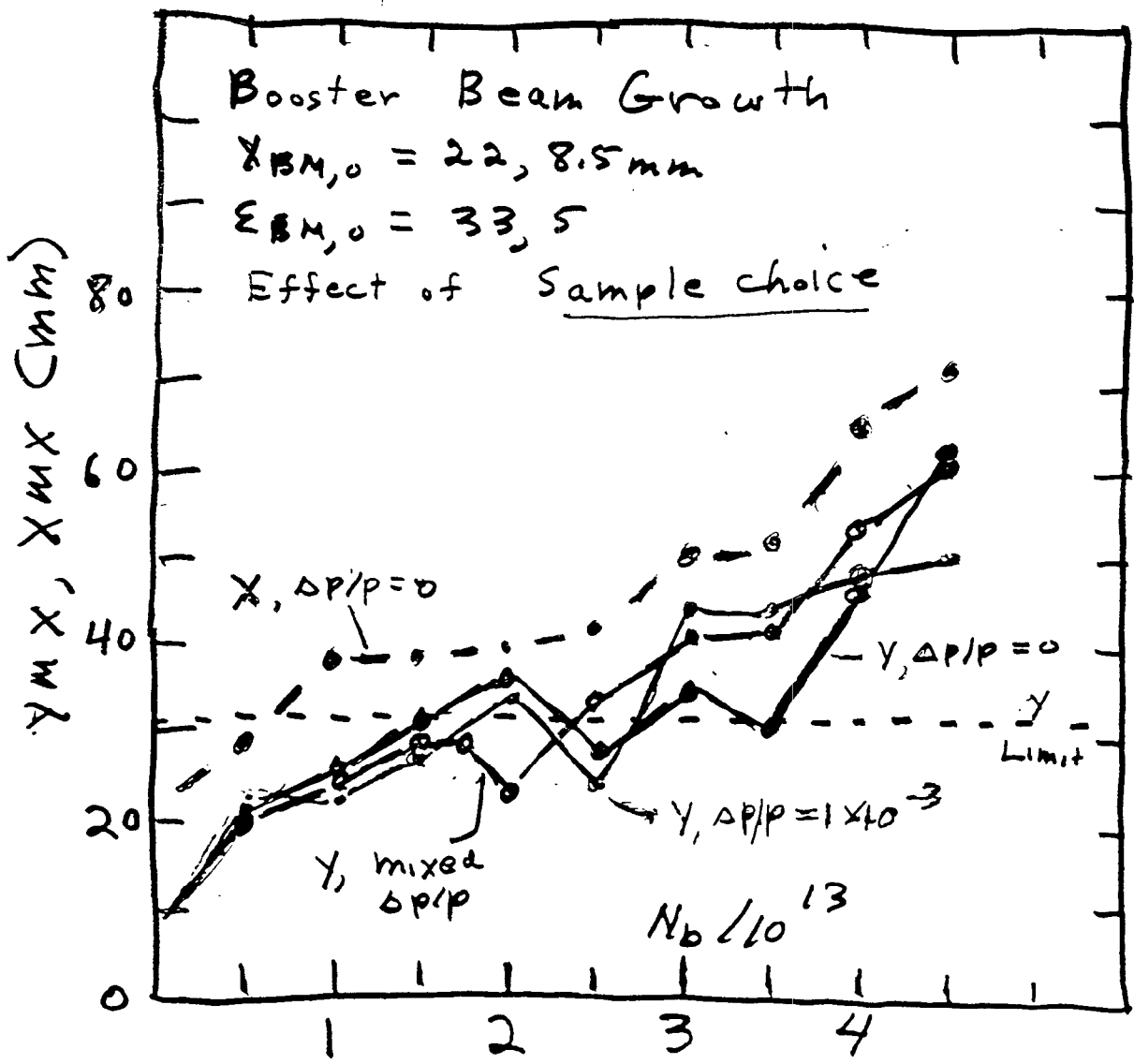
$$N_b = \frac{.18 \times 10^{13} \times 1.5 \times 10^{13}}{.37 \times 10^{13}}$$

$$N_b = .7 \times 10^{13} \quad \text{Booster Space Charge Limit}$$

Extrapolation from the Fermilab Booster

$$N_b = \frac{.36 \times 10^{14} \times 1.5 \times 10^{13}}{.9 \times 10^{14}}$$

$$N_b = .6 \times 10^{13} \quad \text{Booster Space Charge Limit}$$



Why is the Space Charge Limit

Higher in The Booster than in the AGS?

Considerations of the Intrinsic Space Charge indicate that the Space Charge limit in the Booster is about 4 times higher than in the AGS. If the Resonance limit is ~~is not very important~~ less important than the intrinsic Limit, what is ^{the} factor 4 due to?

It appears to be due to the choice of Lattice, and the effect of the lattice choice on the coupling between the horizontal and vertical motions.