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Space charge efffects in the AGS Booster

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USDOE Office of Science (SC)

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SPACE CHARGE EFFECTS IN THE AGS BOOSTER

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ACCELERATOR DEVELOPMENT DEPARTMENT

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Introduction

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

Simulation Program

Using a tracking program, space charge ~~effects~~ forces are entered as a Kick at each element in the lattice. Kick ~ E_x 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 ε_x ε_y
but different x, x', y, y'
One group of 4 starts at ε_x ε_y at edge of beam, other groups start at smaller ε_x ε_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 inconsistant results, or results that appear unacceptable. Increasing the number of parameters and the complexity of the model may eliminate many of thes 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 ones 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).

Simulation Program Difficulties

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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 or 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 magnetic field 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, whic can generate nearbye resonances.

This prentation will give only results for the intrinsic limit. Studies of the resonance limit are being done at present. Results so far indicate that the space charge limit is dominated by the intrinsic limit. Results for the intrinsic limit for the AGS 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) AGS
2) Fermilab Booster.

AGS Results

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

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

Aperture Limits, ± 32 mm Vertical

± 35 mm Horizontal

$\varepsilon_x, \varepsilon_y = 56, 46$

Is the AGS space charge limited?

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

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

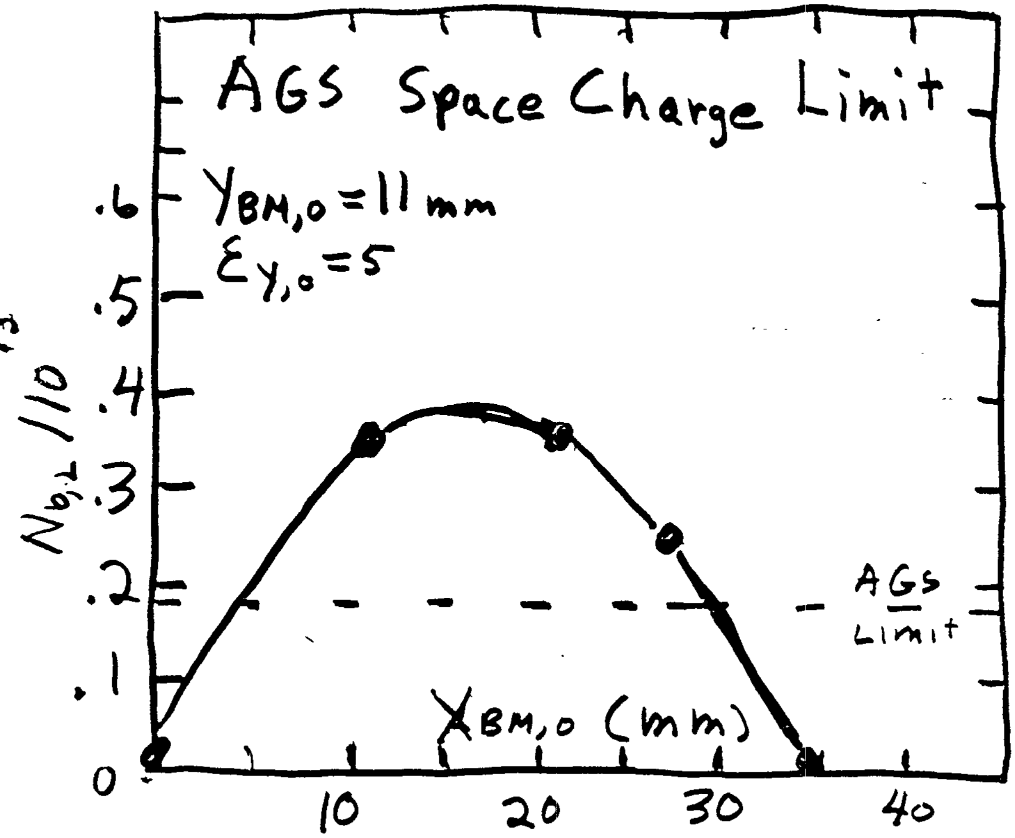

AGS Space Charge Limit
$Y_{BM,0}$ = 11 mm
$\mathcal{E}_{y,0}$ = 5
$N_{b,\perp}/10^{13}$
.6
.5
.4
.3
.2
.1
0
AGS Limit
$X_{BM,0}$ (mm)
10
20
30
40

Fig 6

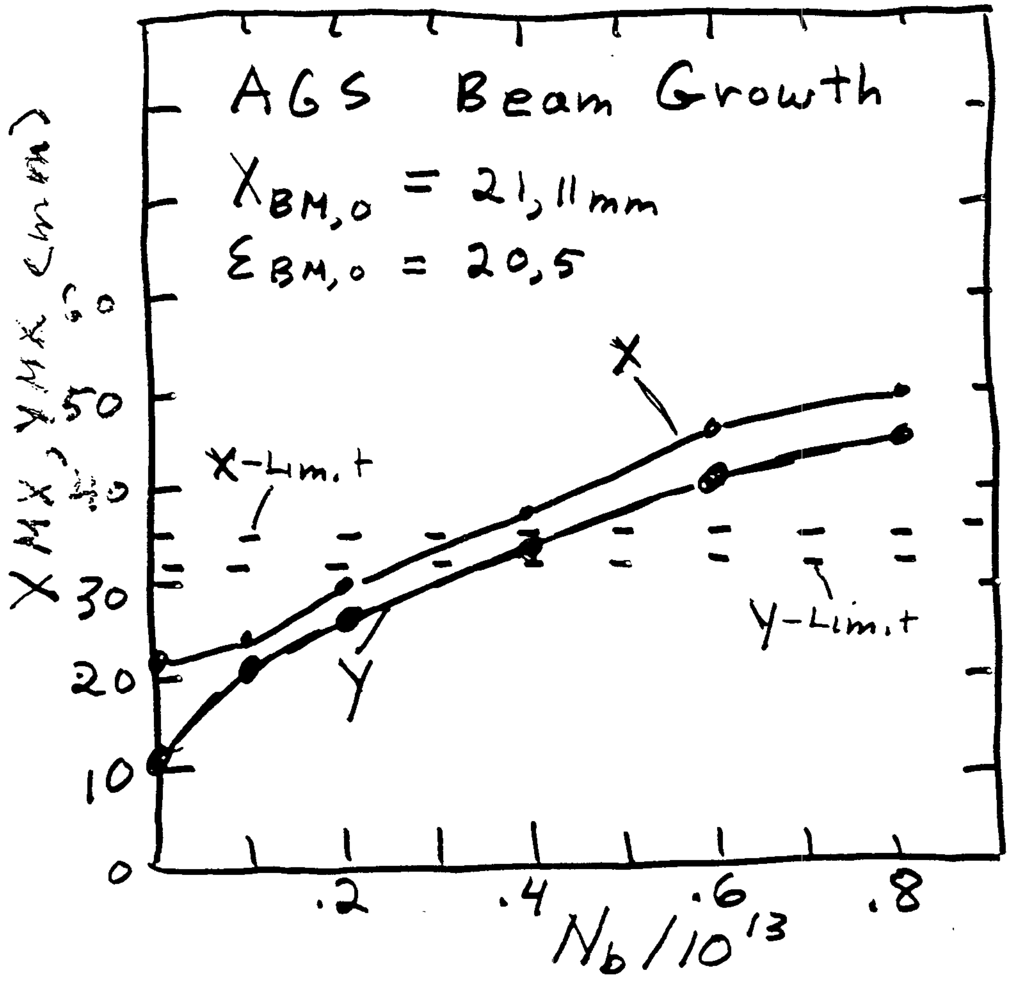

AGS Beam Growth
$X_{BM,0}$ = 21, 11 mm
$\mathcal{E}_{BM,0}$ = 20, 5
XMX, YMX (mm)
50
30
20
10
0
X-Limit
X
Y
Y-Limit
.2
.4
.6
.8
$N_b/10^{13}$

Fig. 5

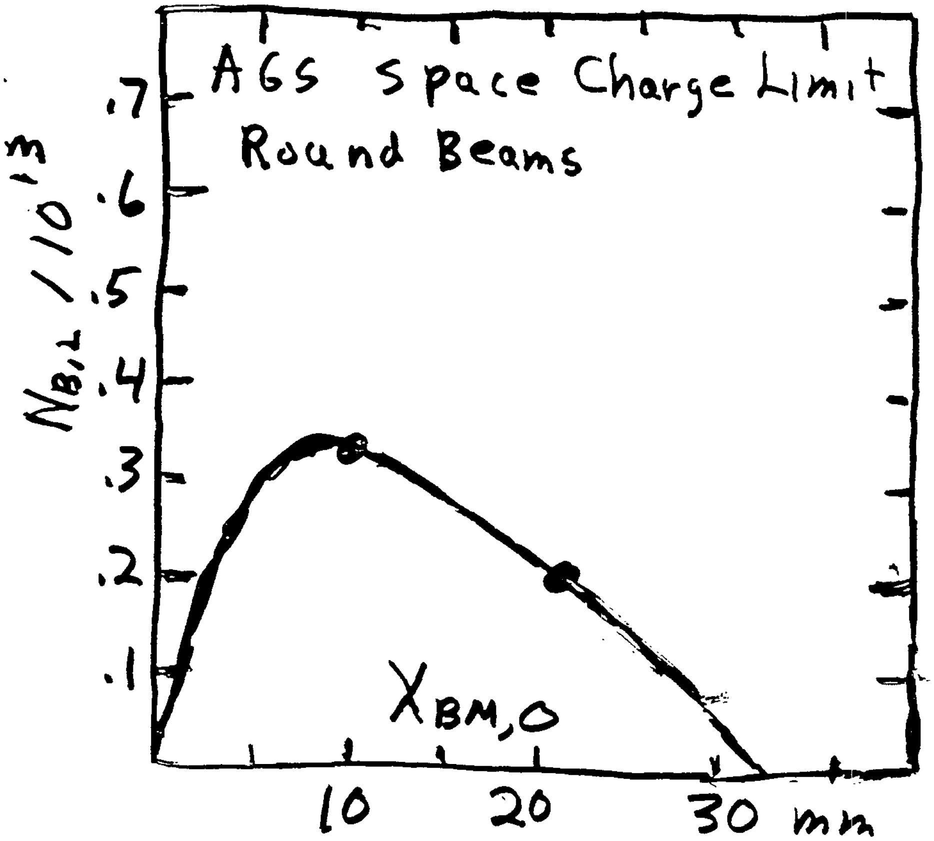
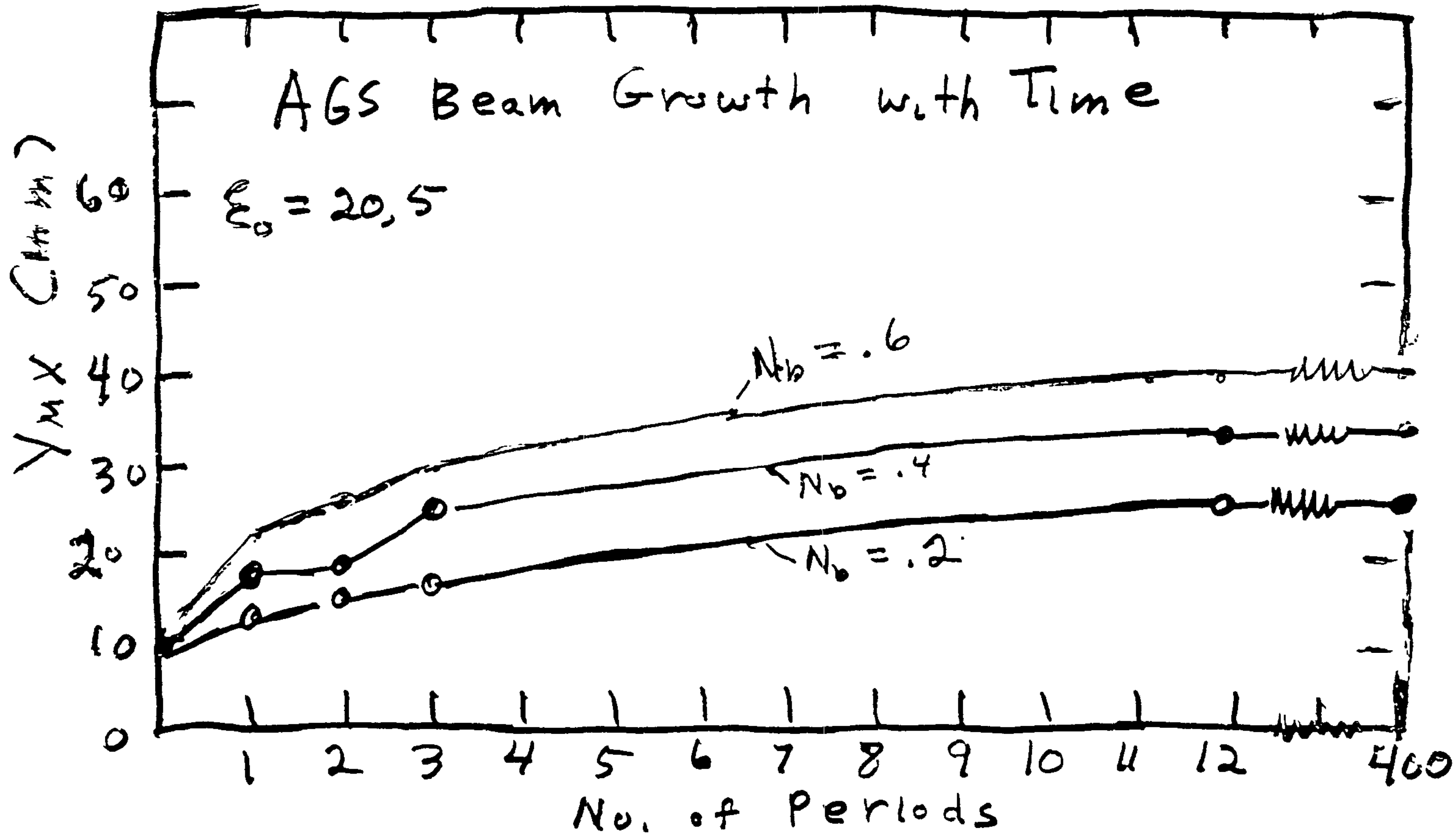

AGS Space Charge Limit
Round Beams
$N_{B,L}/10^{13}$
.7
.6
.5
.4
.3
.2
.1
$X_{BM,O}$
10
20
30 mm

Fig 7

Fig 8


AGS Beam Growth with Time
$\mathcal{E}_o = 20.5$
Y_{MX} (mm)
60
50
40
30
20
10
0
$N_b = .6$
$N_b = .4$
$N_b = .2$
1
2
3
4
5
6
7
8
9
10
11
12
400
No. of Periods

FermiLab Booster Results

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

$\beta_x = 34 \rightarrow 6$, $\beta_y = 20 \rightarrow 5.3$, $X_p = 3.2 \rightarrow 1.8$ m

$\nu = 6.7, 6.8$

Aperture Limits $\pm$ 24 mm Vertical

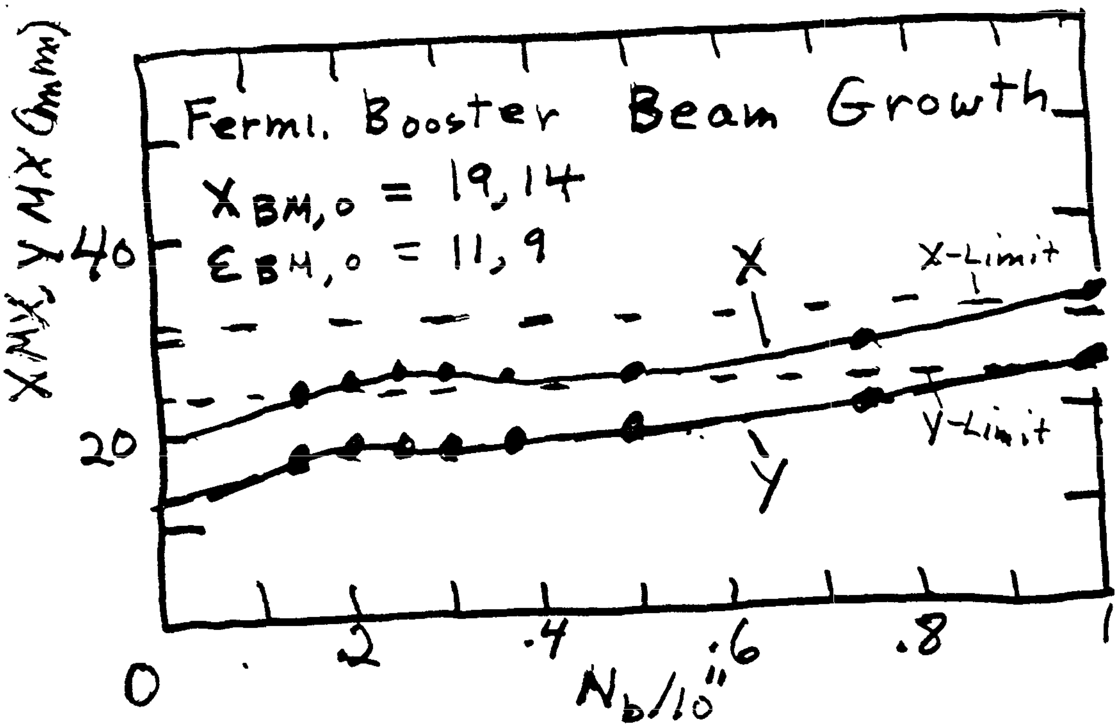
$\pm$ 31 mm

$\varepsilon_x, \varepsilon_y = 29$

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

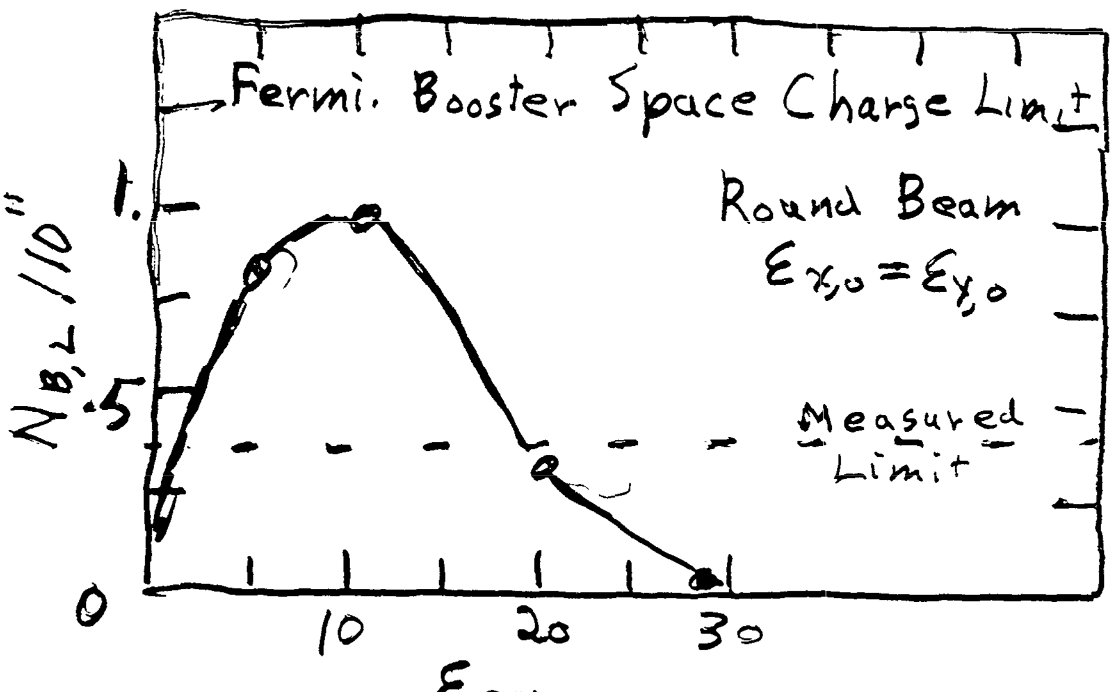
$N_b = 3.6 \times 10^{10}$ protons / bunch

Bunching Factor = 4 was assumed



Fermi. Booster Beam Growth
X BM,0 = 19, 14
ε BM,0 = 11, 9
X
Y
X-Limit
Y-Limit
40
20
0
.2
.4
.6
.8
1
N b/10 11
XMX, YMX (mm)

Fig 10



Fermi. Booster Space Charge Limit
Round Beam
ε x,0 = ε y,0
Measured
Limit
1.
.5
0
10
20
30
N B,L /10 11
ε BM,0

Fig 11

Booster Results

$E_{inj} = 200$ MEV, $R = 32m$, $h = 3$

$\beta_x = 13.9 \rightarrow 3.6$, $\beta_y = 13.6 \rightarrow 3.7$, $\chi_p = 2.8 \rightarrow .5$

$\nu = 4.82, 4.83$

Aperture Limits ± 32 mm Vertical

± 48 mm Horizontal

$\varepsilon_x, \varepsilon_y = 162, 74$

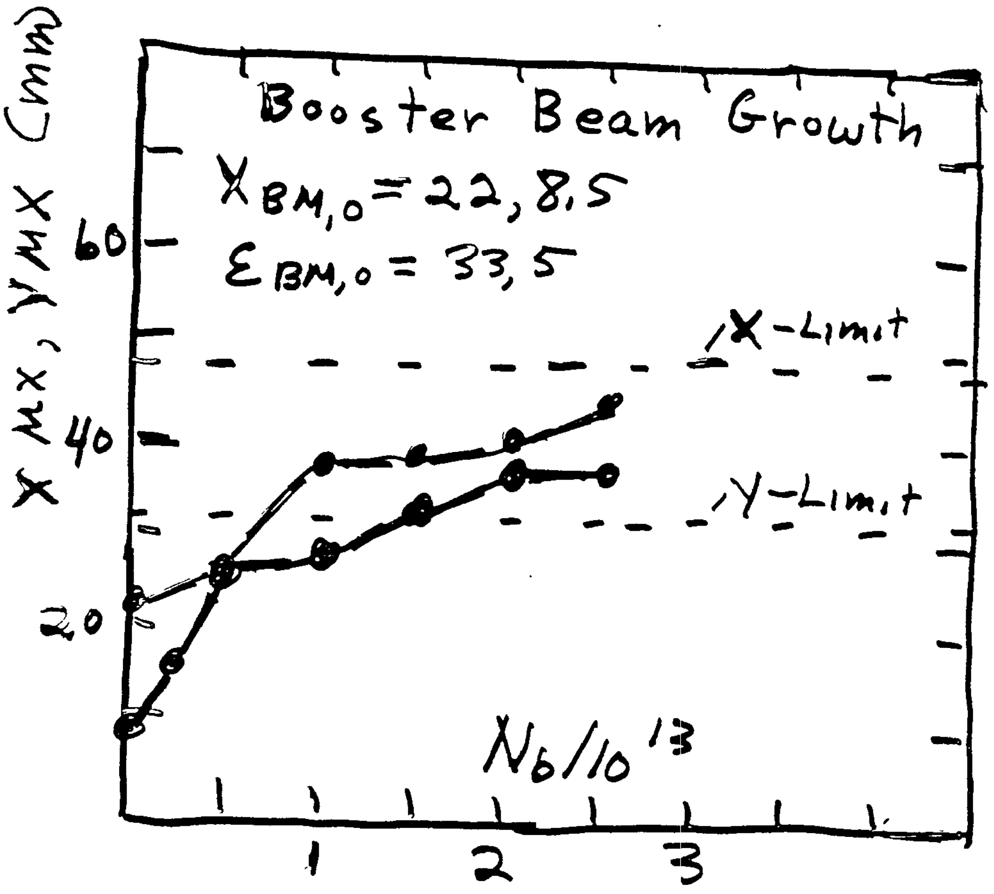

Booster Beam Growth
$X_{BM,0} = 22, 8.5$
$\varepsilon_{BM,0} = 33, 5$
X-Limit
Y-Limit
$N_b/10^{13}$
XMX, YMX (mm)
20
40
60
1
2
3

Fig 13

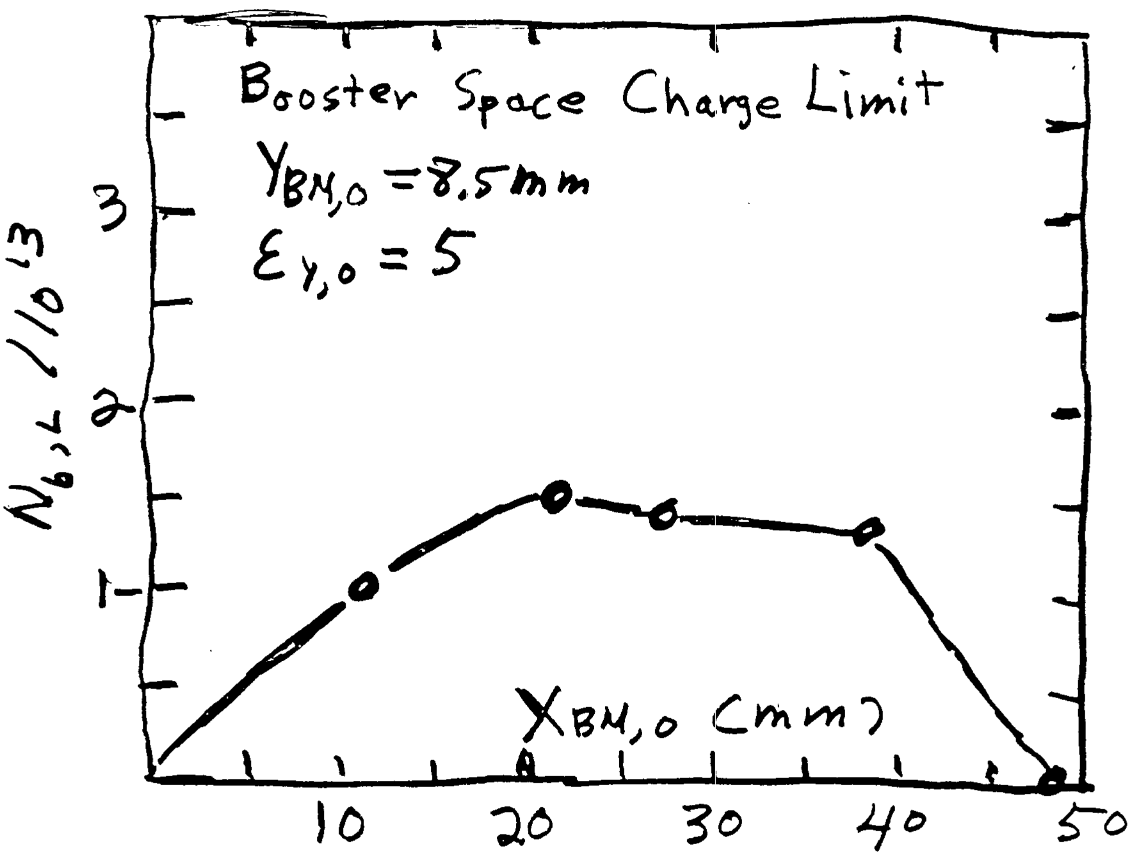

Booster Space Charge Limit
$Y_{BM,0} = 8.5$ mm
$\varepsilon_{y,0} = 5$
$N_{b,L}/10^{13}$
$X_{BM,0}$ (mm)
1
2
3
10
20
30
40
50

Fig. 14

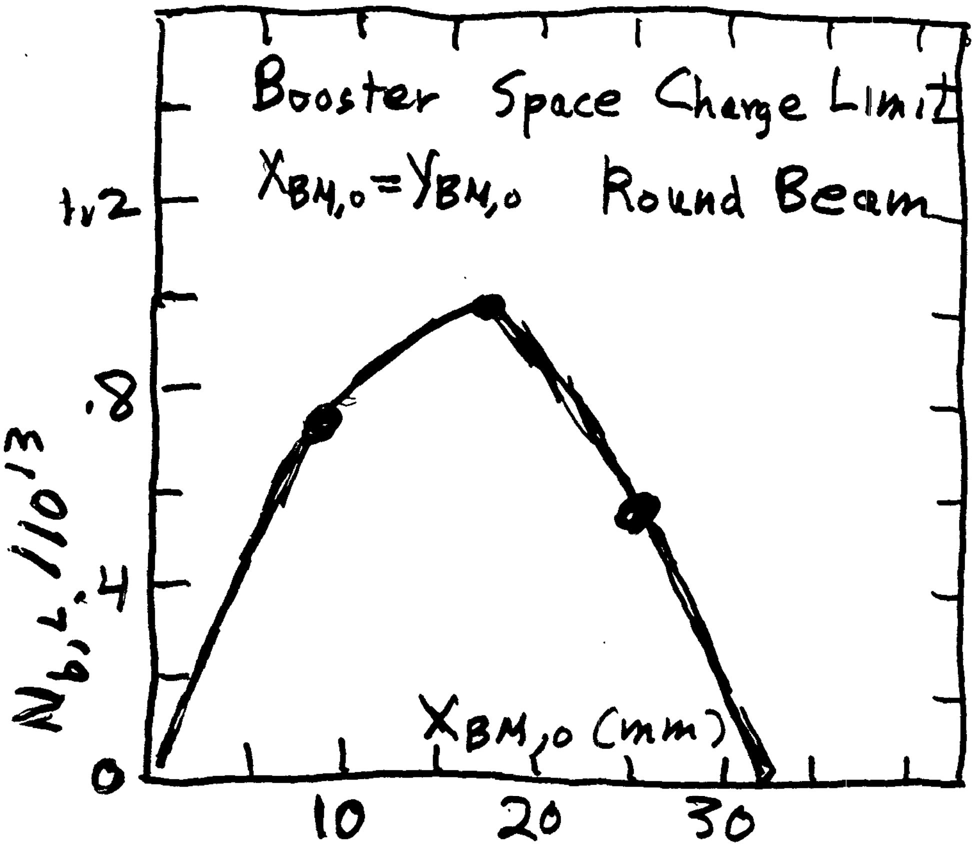
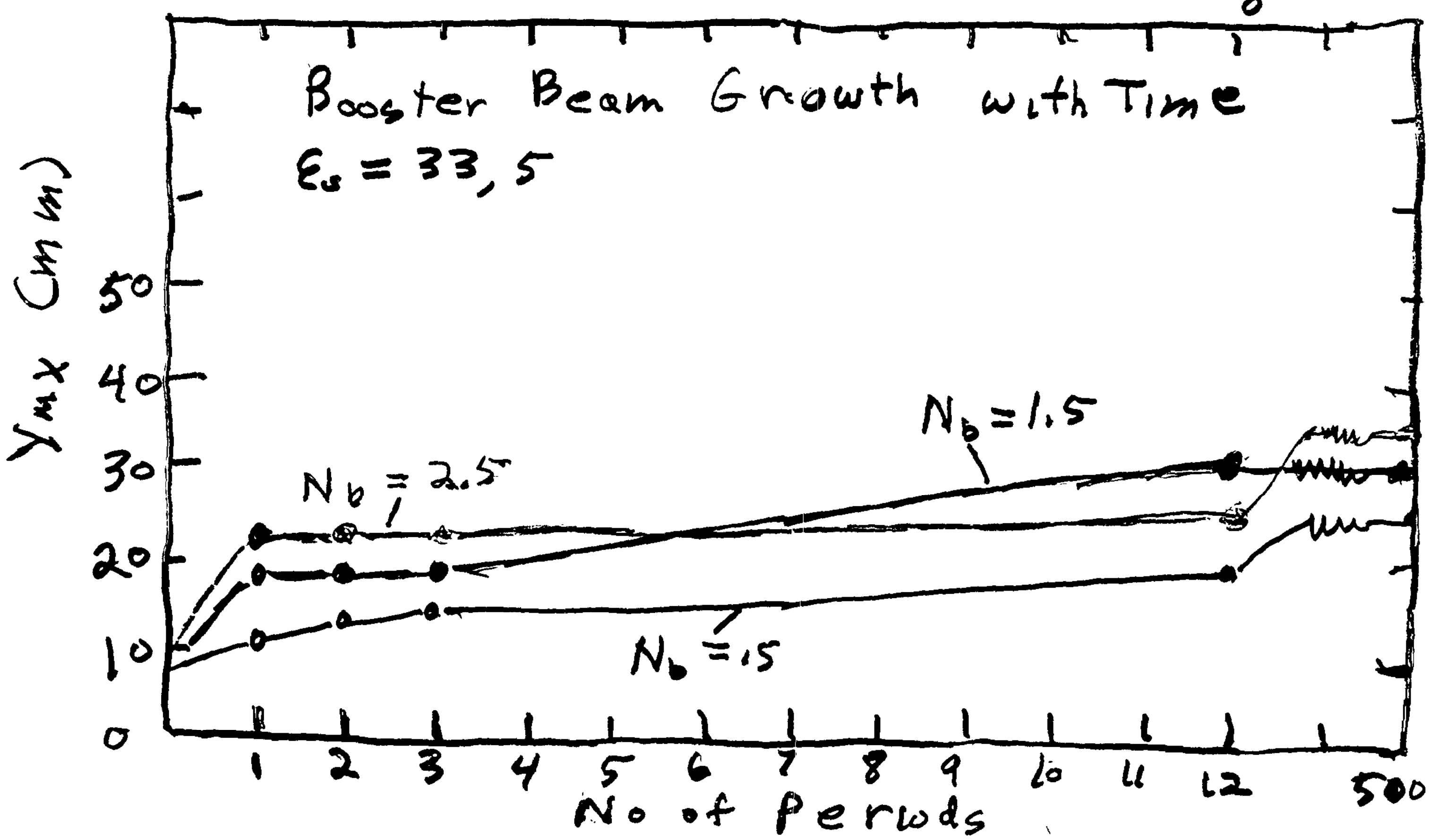

Booster Space Charge Limit
$X_{BM,0} = Y_{BM,0}$ Round Beam
$N_{b,L}/10^{13}$
1.2
.8
.4
0
$X_{BM,0}$ (mm)
10
20
30

Fig 15

Fig 16


Booster Beam Growth with Time
$\epsilon_s = 33.5$
Y_{mx} (mm)
50
40
30
20
10
0
$N_b = 1.5$
$N_b = 2.5$
$N_b = .5$
1
2
3
4
5
6
7
8
9
10
11
12
500
No of Periods

Booster Performance — Extrapolation from the AGS and the Fermilab Booster

Extrapolation from the AGS

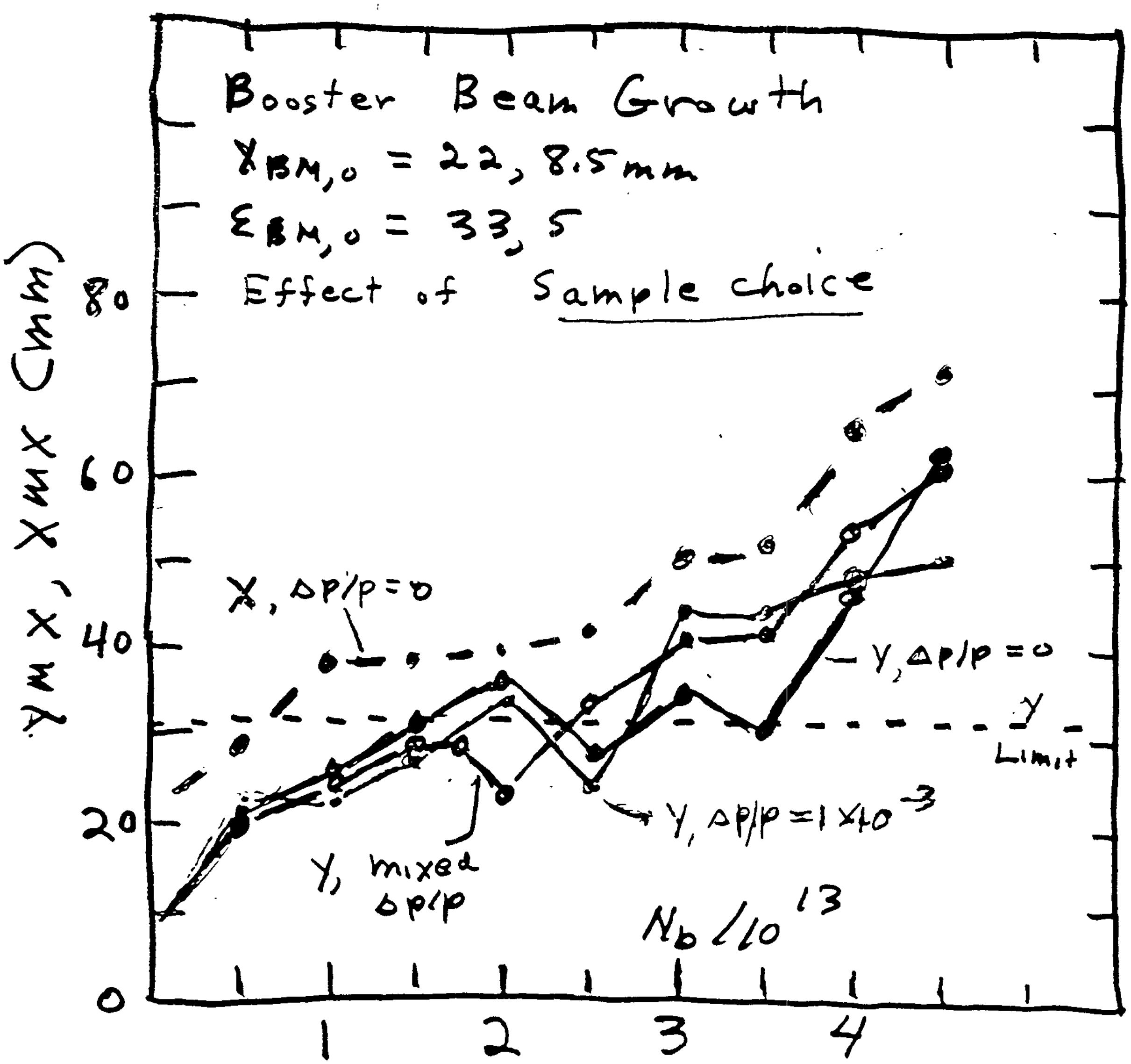
$$N_b = .18 \times 10^{13} \times \frac{1.5 \times 10^{13}}{.37 \times 10^{13}}$$

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

Extrapolation from the Fermilab Booster

$$N_b = .36 \times 10^{11} \times \frac{1.5 \times 10^{13}}{.9 \times 10^{11}}$$

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


Booster Beam Growth
X BM,0 = 22, 8.5 mm
ε BM,0 = 33, 5
Effect of Sample choice
YMX, XMX (mm)
80
60
40
20
0
X, Δp/p = 0
Y, Δp/p = 0
Y Limit
Y, Δp/p = 1×10^-3
Y, mixed Δp/p
Nb / 10^13
1
2
3
4

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.