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I. Introduction

In [1], it was reported that for the Booster harmonic 1 scheme, with the RF voltage of 45 KV at the injection, the bucket was smaller and the synchrotron frequency was lower than the harmonic 2 scheme, where the available RF voltage was 90 KV. As the result, the beam bunching factor was smaller, and the Booster efficiency was lower. Furthermore, the smaller equivalent beam longitudinal emittance defined during the multiturn injection was not favorable in improving the BTA transfer efficiency.

Several possible approaches for improvement were studied.

1. It was found in the simulation that given the lower synchrotron frequency, longer Linac pulse may improve the painting. However, the attempt to extend the Linac slow chopper beyond 500 μs failed as it caused sparking. In fact, later operation only used < 400 μs pulse, which was about 330 turns injection. On the other hand, a synchrotron period is about 430 μs pulse, or 360 turns injection.

2. One-side and two-side chopping of the fast chopper were studied. In the simulation, it has been shown that both can improve the painting, with even better result from the two-side chopping. Smooth particle distribution in phase space of one-side painting was in agreement with the operation experience, and it was used through the later part of operation. Difficulties were encountered in the two-side painting study. First, the program was not capable to provide the desired chopping. Second, attempt to bypass the difficulty in the program, i.e. shifting phase of the chopper by 180°, was not successful since the chopper phase jumped by about 100° as optimizing in progress.

3. Later in the g-2 run, a low $\dot{B}$ cycle was implemented. As expected, a longer bunch was obtained at the injection, and meanwhile the injection efficiency was improved. However, the bunch length was reduced in less than 10 ms after the injection. Two possibilities were considered. First, the bucket did not fill up at the injection. Second, the rising of $\dot{B}$ was too fast following the injection, and the available RF voltage could not accommodate with that. The limited running period did not allow for reaching a conclusion of this set-up.

In this note, the studies of injection painting and low $\dot{B}$ cycle are briefly summarized.

II. One-side Painting

In Fig.1, one-side painting at chopping rate of 0.3 is shown, in comparison with the full width painting of chopping rate 0.6. The simulation is under the condition of high $\dot{B}$ started at 3.4 T/s, with single RF of 45 KV, and 360 turns injection. Particle distribution of the one-side painting is smooth in phase space, and the peak current is reduced. Note that the chopping rate of the optimal one-side painting is small, at a little larger than 0.3, which will not provide enough beam current for the injection, given the Linac slow chopper at $< 400\ \mu s$.

With the second harmonic RF, the bucket size is larger. In Fig. 2, the one-side painting is shown for the low $\dot{B}$ cycle, started at 2.7 T/s at the beginning of the injection. The relative phase of the second RF is $-70°$ from the first harmonic. The optimal chopping rate is about 0.5, with 360 turns of injection.

The mountain range of the injection in operation is shown in Fig. 3. A simulation is also shown, which is quite similar to the observed one.

III. Two-side Painting

To improve the painting, a possible two-side chopping is shown in Fig. 4. The simulation is performed under the condition of $\dot{B} = 2\ T/s$, and the relative second RF phase of $-100°$. The beam peak current is below 4 A at the intensity of 15 TP. Also, the particle distribution in phase space is smooth, indicating that sharp peaks of beam line density is unlikely to present in the evolutions after the injection .

In the study, it was found that the optimization of width and distance of the two parts was not allowed by the chopper program. It was found, however, it might be possible if the chopper phase shifted by 180°, i.e. the two sides swapped. In approaching the optimization, another problem showed up. The chopper phase jumped about 100°. This problem was verified as agreeable with the similar observation made before in the machine tuning [2], and the effort did not go further.

IV. Low $\dot{B}$ Cycle

There are two potential benefits for a lower $\dot{B}$ cycle. First, for the single RF, the moving bucket length with the $\dot{B}$ of 3.4 T/s is 259°, which is increased to 281° at $\dot{B} = 2.7\ T/s$. The moving bucket area is increased from 3.94 eVs to 4.34 eVs. The larger bunching factor can help to reduce the loss. Second, larger beam emittance may help to increase the BTA transfer efficiency, since the strong space charge force as the beam entering the AGS ring contributes to the beam loss, and this force is smaller if the beam emittance is larger.

In Table 1, the comparison of relevant parameters in recent runs is shown. If the space charge effect is evaluated by $N_{bh}/\beta\gamma\sqrt{\epsilon_\ell}$, then the improvement of the BTA transfer efficiency of 1997 run vs. 1996 can be explained. The typical beam emittance in 1998 run, less than 3.0 eVs, is also in agreement with the observation that the BTA efficiency in 1998 was better than 1996, but a little worse than 1997.

Using the low $\dot{B}$ cycle, the beam emittance might be increased to 3.5 eVs, which could be beneficial for the BTA transfer.

	$\epsilon_{\ell,bh}$	$\beta\gamma$	N	N_{bh}	$\frac{N_{bh}}{\beta\gamma\sqrt{\epsilon_\ell}}$	
	Booster			AGS	SC effect	BTA Effi.
1996	1.86	2.46	90	11.25	3.35	74
1997	1.76	2.86	90	11.25	2.96	83
1998	<3.0	2.86	90	15	>3.03	81
Low $\dot{B}$	3.5	2.86	90	15	2.80	
	eVs		TP	TP		%

Table 1

In the 1999 g-2 run, a low $\dot{B}$ cycle with 2.7 T/s at injection was set-up, and later used for operation. It was observed that the bunch length was increased from 238° to 271° for the injection intensity of 11.7 TP, and increased from 249° to 281° for the injection intensity of 21.7 TP, measured at 2 ms after the stacking.

The bunch length was, however, reduced as the beam accelerated. For high $\dot{B}$ cycle, bunch length followed the line of the constant emittance 2.5 eVs. This is shown in Fig. 5.

For low $\dot{B}$ cycle, bunch length fits 3.4 eVs at 2 ms after the injection, and it is reduced to fit the line of 2.8 eVs in about 10 ms, and thereafter. This is shown in Fig. 6.

Possible reasons are considered as follows.

1. The injection pulse length was at typical 370 μs to 380 μs at that period. The synchrotron period was 430 μs, therefore, the bucket did not fill up, the emittance defined during the injection is less than the one calculated from the bunch length.

2. The $d\dot{B}/dt$ of the low $\dot{B}$ cycle right after the beam injected is higher than the one in high $\dot{B}$ cycle. In Fig. 7, it is shown that due to limited RF voltage rising rate, the bucket to bunch ratio of both height and area, is tight after the injection. This may contribute to the bunch length reduction.

V. References

1. S.Y. Zhang, AGS Tech. Note, No. 480, Aug. 1998.

2. L.A. Ahrens, private communication.

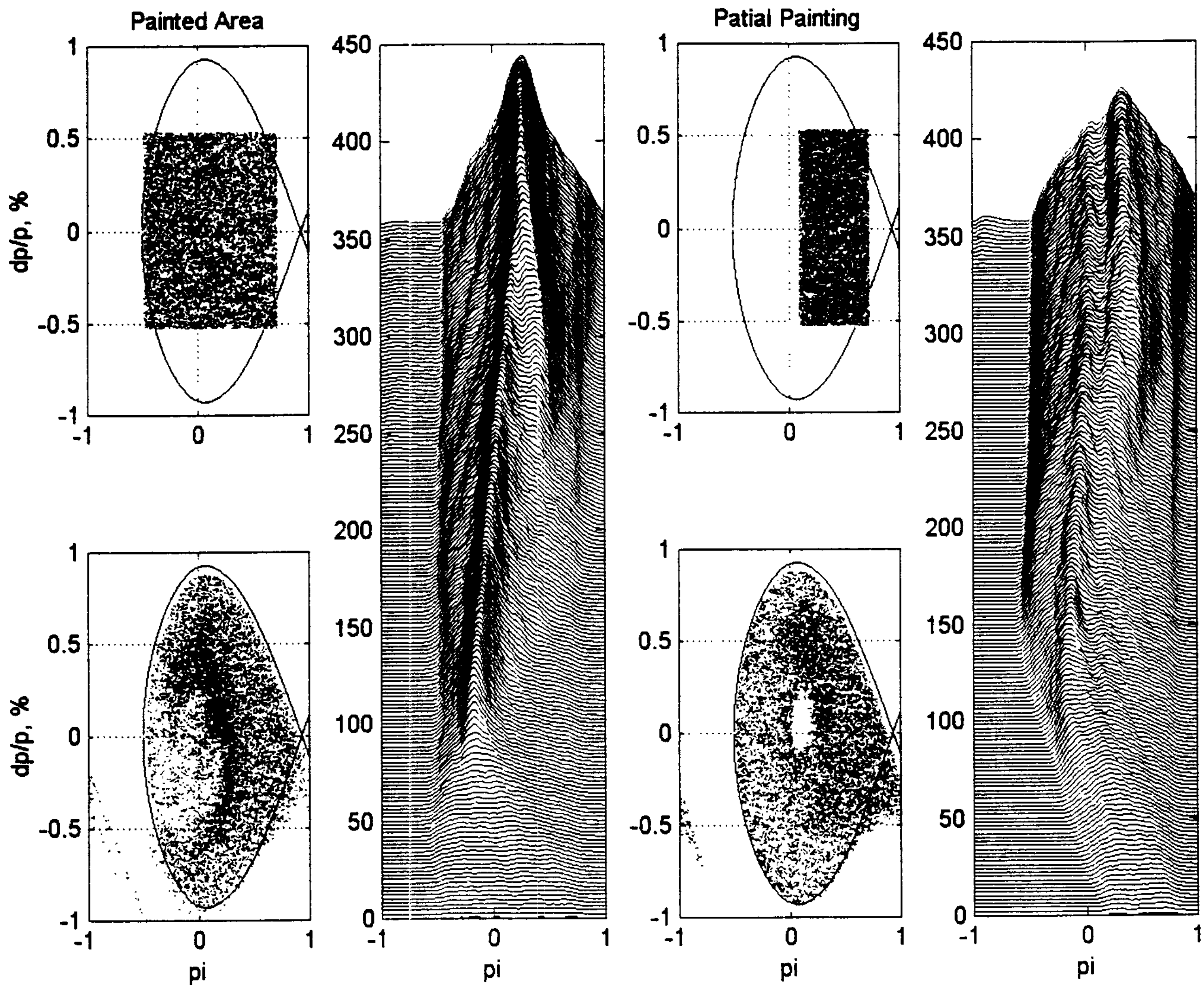

Fig. 1
One-side painting with chopping rate of 0.3, in comparison with the full width painting of chopping rate 0.6

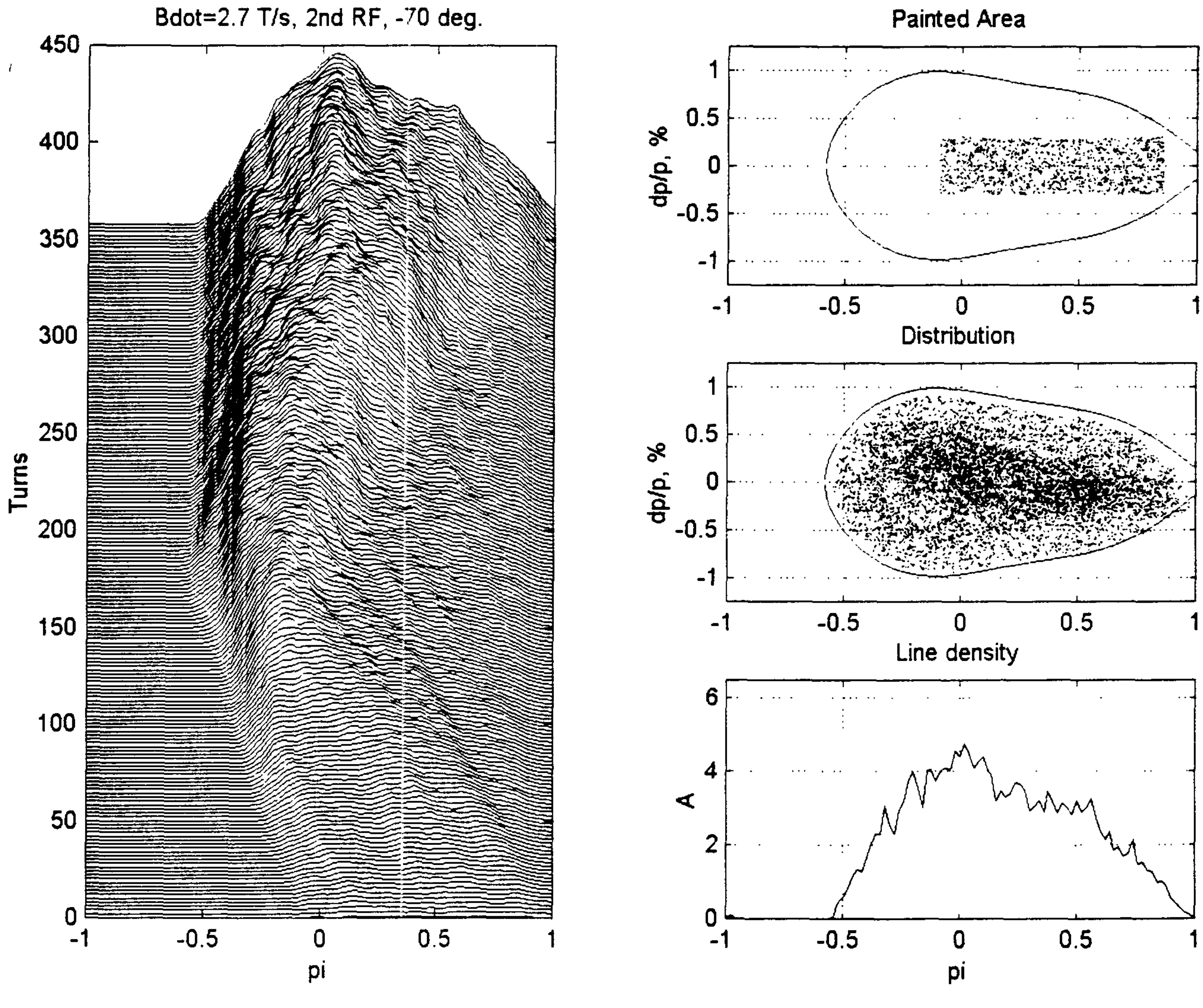

Fig. 2
One-side painting, with 2.7 T/s, 2nd RF $-70°$, 360 turns of injection

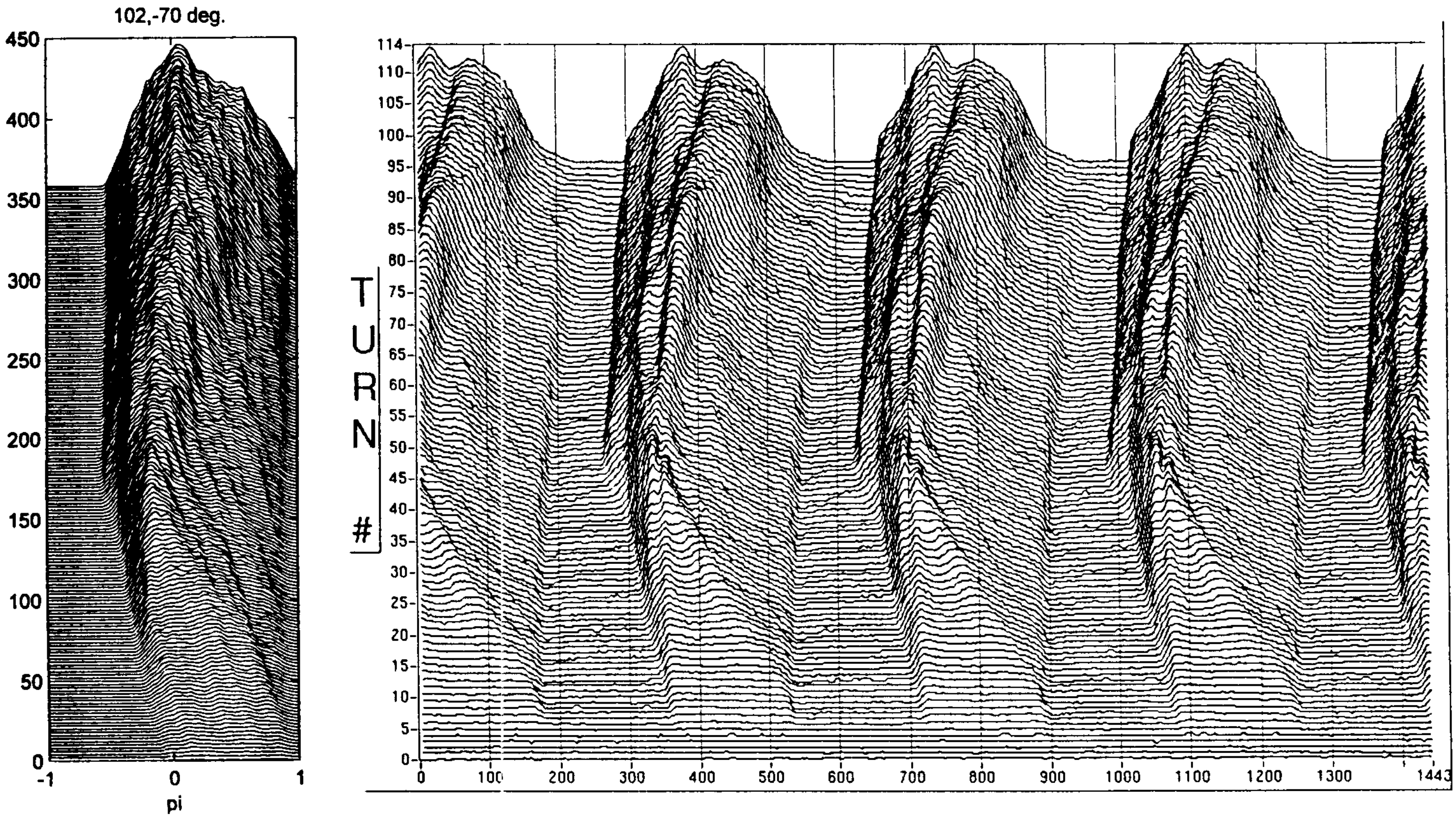

Fig. 3
Mountain range of the injection and the simulation, period is about 1 ms

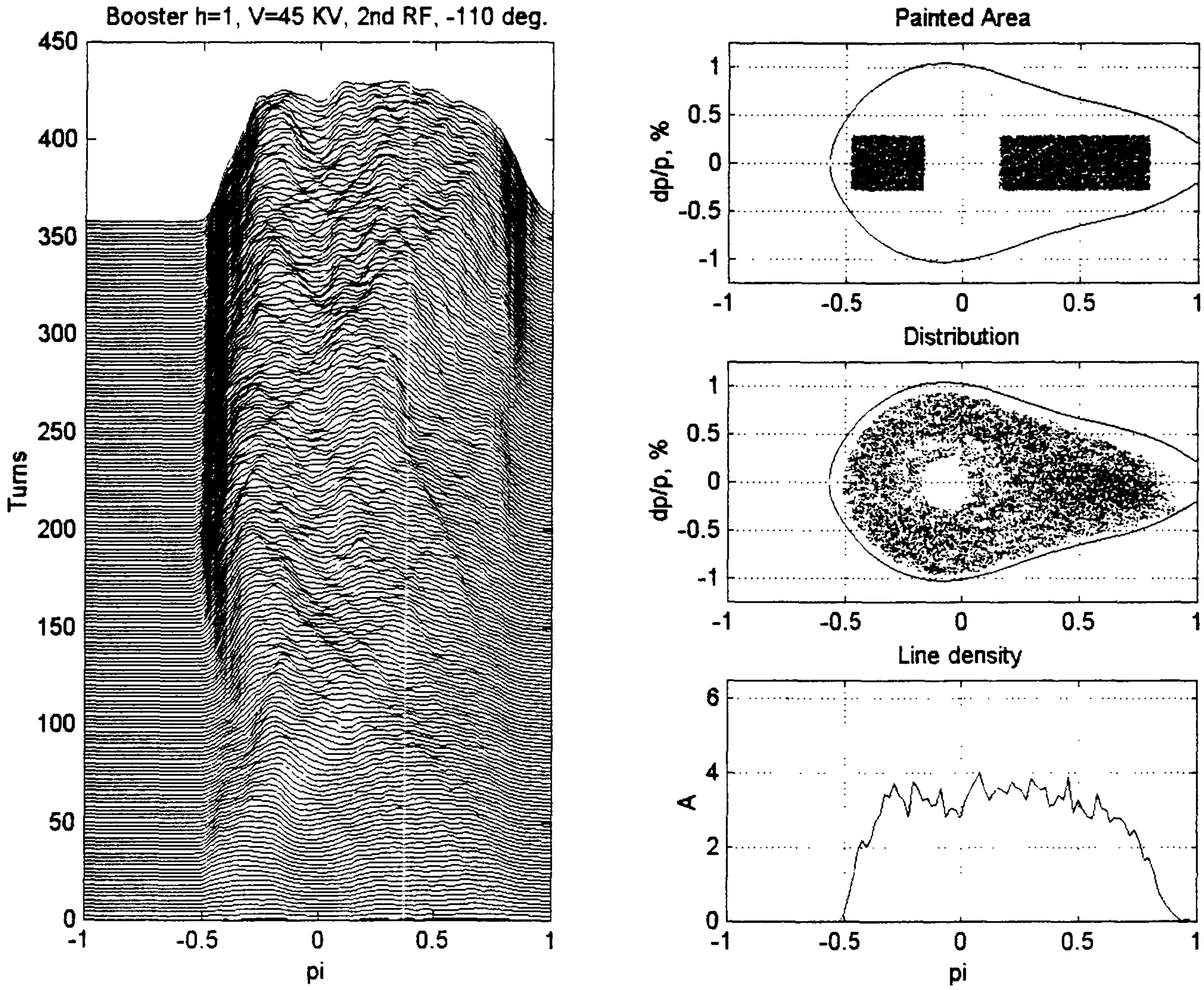

Fig. 4
Two-side painting with $\dot{B} = 2\ T/s$, and the relative second RF phase of $-100°$

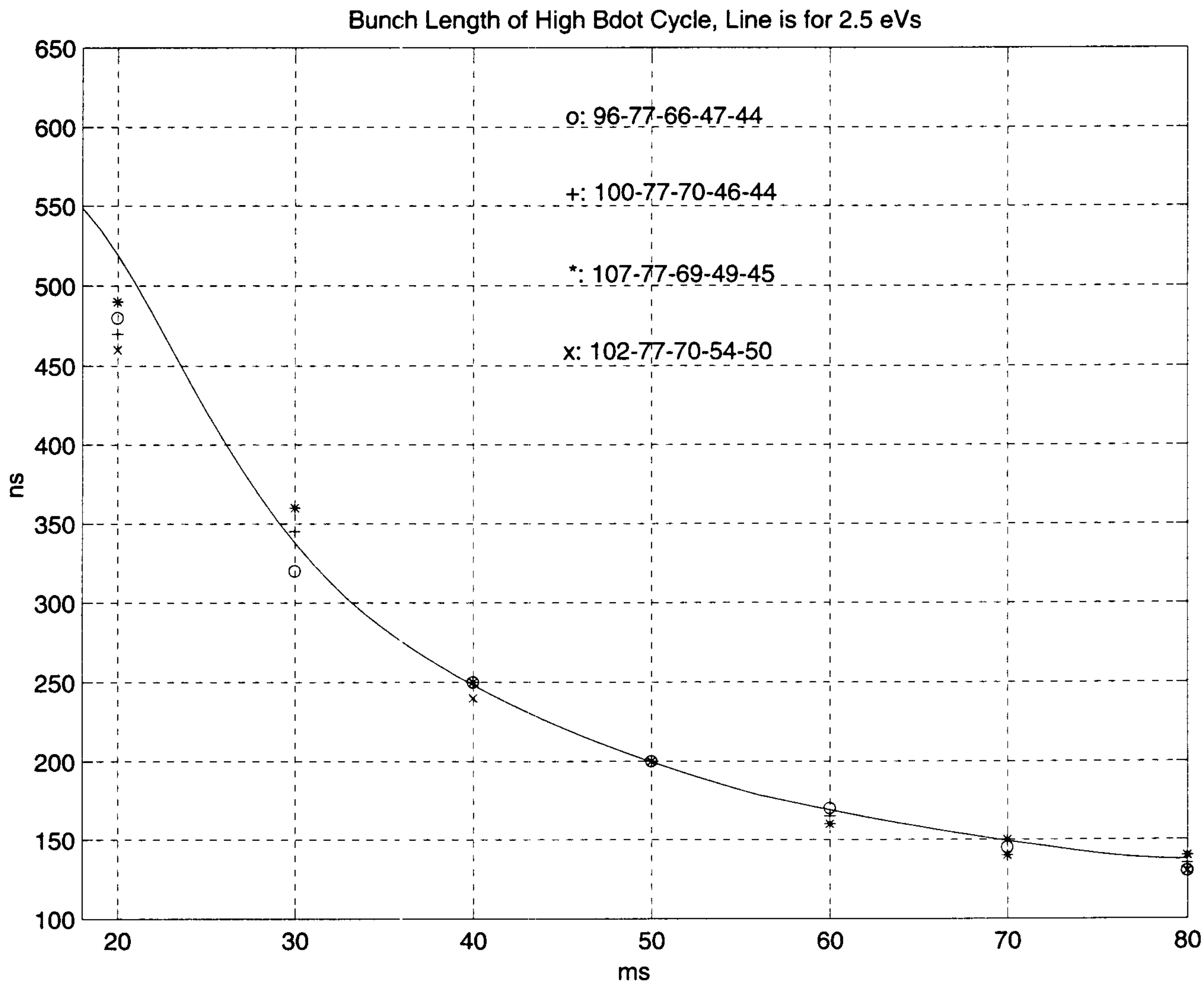

Fig. 5
High $\dot{B}$ cycle, bunch length followed the line of constant emittance 2.5 eVs

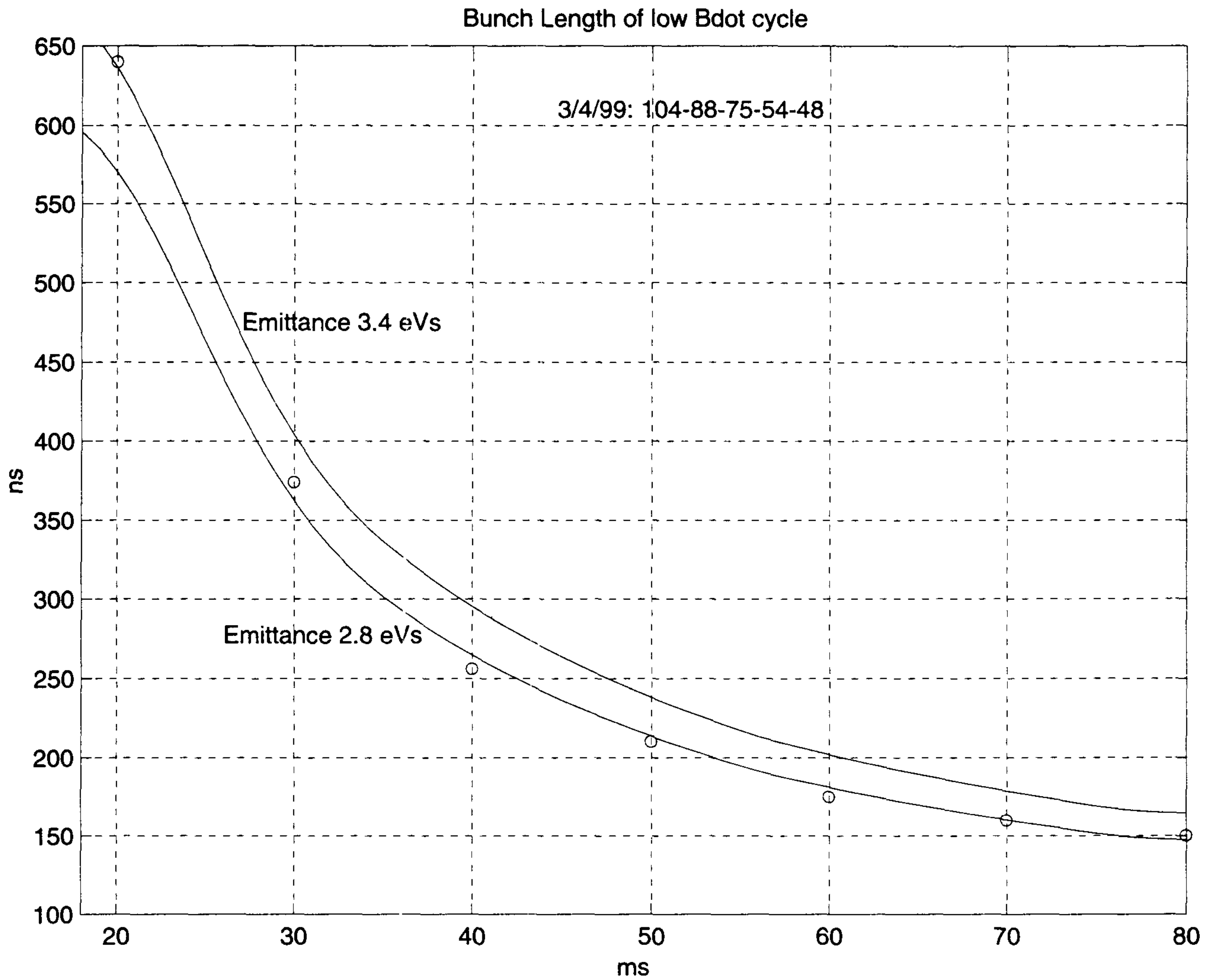

Fig. 6

Low $\dot{B}$ cycle. Bunch length fits 3.4 eVs at 2 ms after the injection, and it is reduced to fit the line of 2.8 eVs in about 10 ms

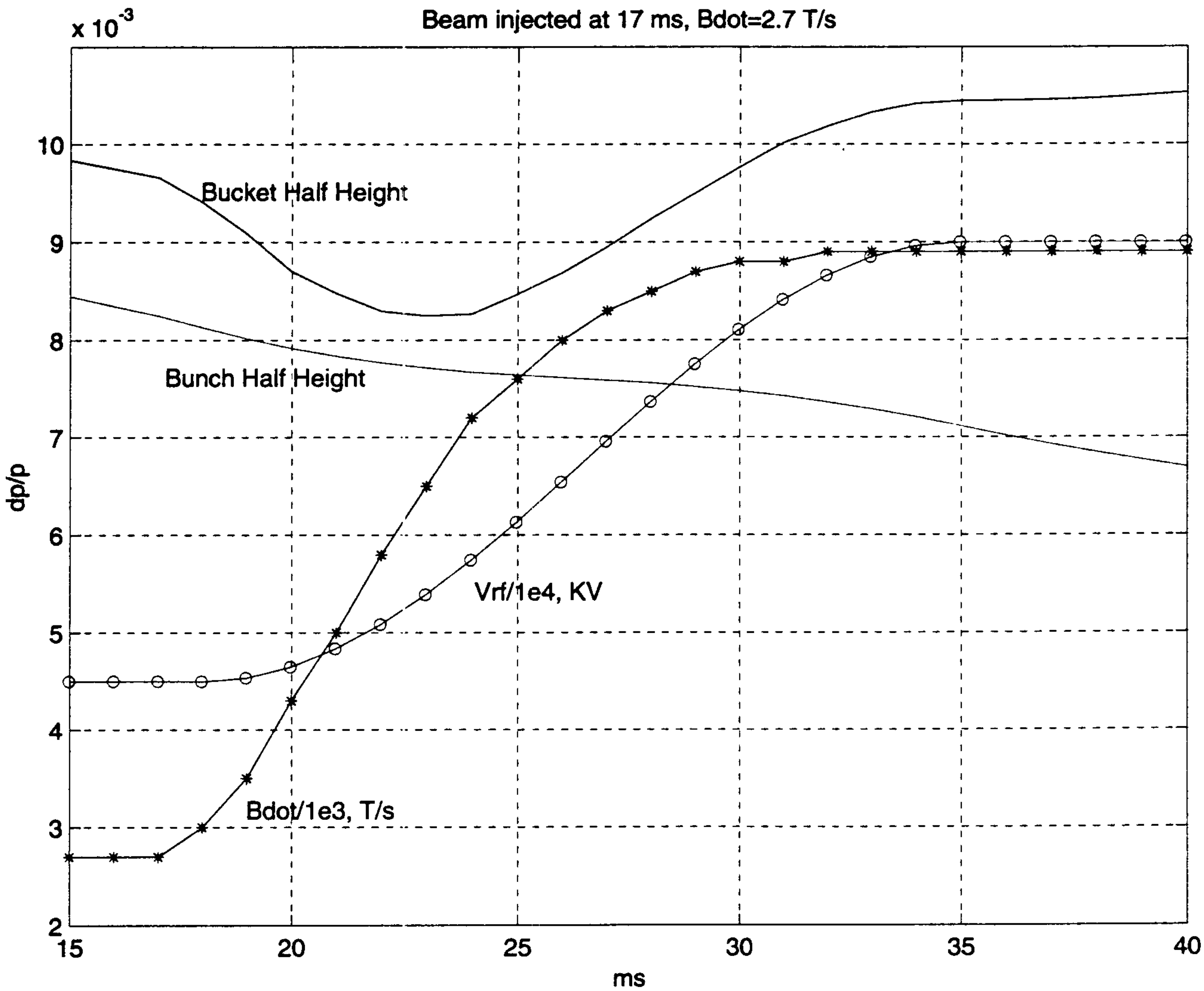

Fig. 7
Bucket to bunch ratio of height is tight after the injection for low $\dot{B}$ cycle