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AP-Note-90-008

ACCELERATOR PHYSICS DEPARTMENT

AP Note 90-008

TITLE: E778: Preliminary Analysis of Chirped Persistent Signals

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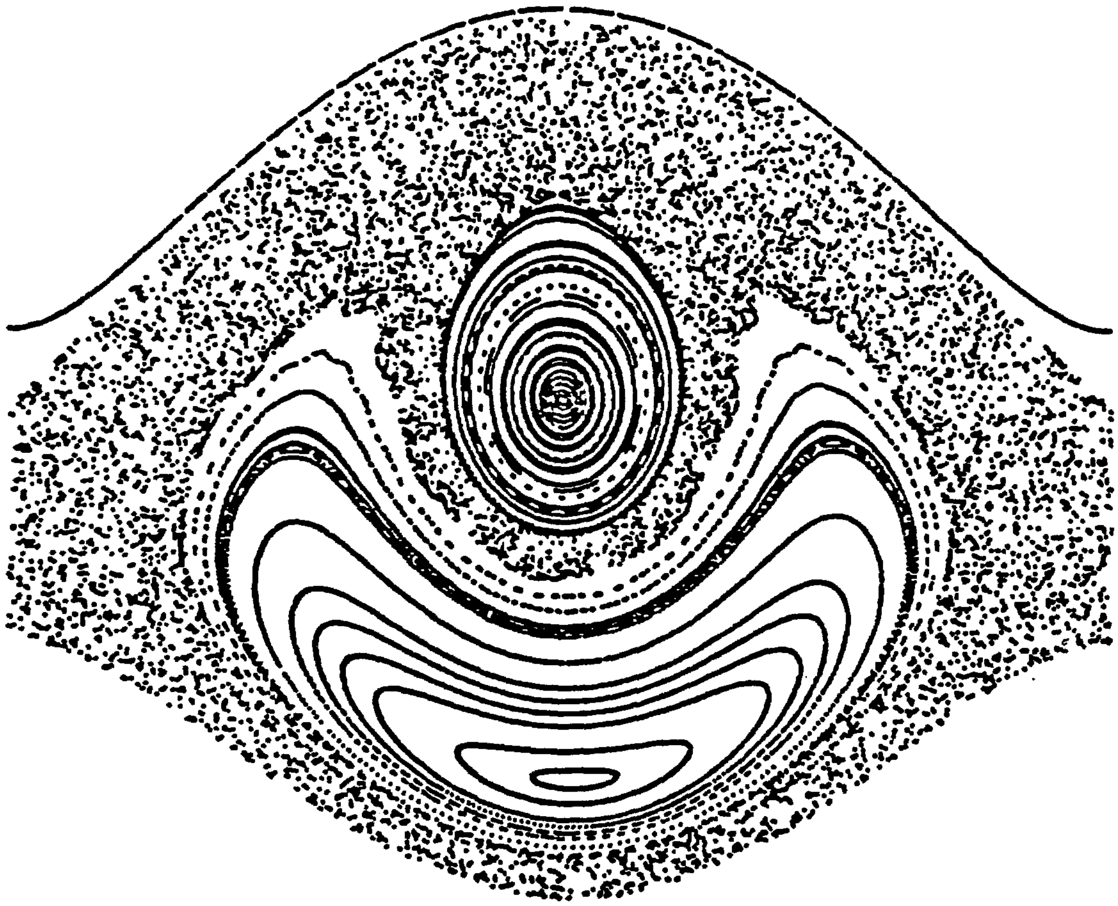
April 27, 1990



E778: Preliminary analysis of chirped persistent signals

Tong Chen, Steve Peggs, George Tsironis

Introduction

This is a very abbreviated and preliminary version of a more complete paper which is being submitted to the 1990 European Particle Accelerator Conference.

During this phase of the June 1989 run of the E778 experiment, the small amplitude tune of the Tevatron was set just above the $Q_{H0} = 19 + 2/5$ resonance, with a negative quadratic detuning with amplitude. Consequently, when a bunch was kicked in a single turn, some fraction of the total charge was trapped in a fifth order resonance island. This phase locked charge caused a "persistent signal", which was recorded on the turn-by-turn data taken from Beam Position Monitors. After the rapid filamentation of the untrapped charge, this signal appears in that data as a solitary narrow Fourier peak. Typically, data was taken for about 250,000 turns, or about 6 seconds, out of the two minute periodic cycle of the Tevatron. The response of the persistent signal to a chirped tune modulation provided a diagnostic tool with which the resonance strength was measured.

Tune modulation was introduced into the Tevatron by using fast response quadrupoles. It is conveniently parameterized through the control parameters q and Q_M, where

$$Q_{H0} = Q_{H00} + q\cos(2\pi Q_M t) \qquad 1$$

and where t is the turn number. The amplitude and tune of the tune modulation were themselves a function of time, ramped or chirped linearly according to

$$q = q_0 \frac{t}{T}$$

$$2$$

$$Q_M = Q_{M0} \frac{t}{T}$$

When the modulation tune Q_M was much smaller than the island tune Q_I - the tune for small oscillations around the center of an island - then the condition for resonance island instability was

$$q\,Q_M > \frac{Q_I^2}{5} \qquad 3$$

At the time of the kick $t = 0$ and, through equation 2, $q = Q_M = 0$, so that condition 3 was not satisfied and the island was stable. Usually, however, this condition was satisfied at times greater than a critical value, t_C, that depends on q_0 and Q_{M0}, the maximum tune modulation parameters. When the islands became unstable, the persistent signal rapidly decayed away.

Table 1 summarizes the experimental conditions relevant to the sample of persistent signal datasets that is discussed below, and is presented in Figures 1 through 5. The values q_C and Q_{MC} are measured from the tune modulation drive signal, which was digitized along with beam position monitor and current data.

Figure number	Data number	q_0	Q_{M0}	T (secs)	q_C	Q_{MC}	Comment
1	1	.0017	.0006	5.0	-	-	little decay
2	2	.0017	.0063	5.0	.0005	.0046	
3	9	.0083	.0063	5.0	.0026	.0022	
4	5	.0083	.0063	0.1	?	?	fast ramp

Table 1. Conditions for persistent signal results shown in Figures 1 through 5.

Response of four sample datasets

Figure 1 shows the standard set of four pictures which summarize the experimental analysis of the persistent signal behavior. It shows the least dramatic behavior of the four datasets. The top left picture shows the raw data, taken from one of the two horizontal and two vertical beam position monitors, over approximately 250,000 turns. The initial filamentation of the untrapped beam is so fast on this time scale, approximately 100 turns, that the initial decoherence of the signal cannot be seen. The top right picture shows a mountain range display of a multiple discrete Fourier transforms of this signal, over a narrow range around a tune of $Q = 0.4$, the persistent signal tune.

The bottom left picture plots the amplitude of this Fourier component as a function of time. For the first 150,000 turns or so, the persistent signal decays away at the nominal background rate, with an e-folding time of approximately 64,000 turns, or 1.34 seconds. In the last 100,000 turns or so, the rate of decay increases noticeably, due to the tune modulation. The bottom right picture show the phase of the persistent signal, as a function of time. The fact that it is so constant and steady across the data sample implies that the signal is indeed phase locked, at a tune which is not measurably different from 0.4, with an accuracy of perhaps 10^{-7}.

The second figure, with a maximum modulation tune Q_{M0} ten times higher than in Figure 1, shows a clear loss of persistent signal at about 150,000 turns. The minimum e-folding time, at about $t = 170{,}000$ turns, is approximately 7,000 turns, corresponding to a rate which is nearly ten times faster than the background. The phase picture, bottom right, shows the expected loss of coherency at about 160,000 turns.

Figure 3 shows the even more dramatic behavior that results when the maximum tune modulation amplitude q_0 is increased by a factor of five, over the value used in the two previous cases. In this case the persistent signal is lost at about 80,000 turns, as shown very clearly in the phase plot, bottom right. The shortest e-folding time here is even smaller, about 2,700 turns, or 57 milliseconds.

Figure 4 shows the same conditions as Figure 3, except that the tune modulation ramp rate is 50 times faster, achieving full modulation in only 0.1 seconds, or 4,800 turns. It is not surprising that the persistent signal has completely disappeared after 5,000 turns.

Nor is it surprising, considering that this ramp time is commensurate with the 2,700 turn e-folding time in Figure 3, that it is essentially impossible to derive q_C and Q_{MC} values from these data.

Preliminary summary

Equation 3 is appropriate in the adiabatic (slow) modulation limit that is represented by the diagonal line at −45 degrees in Figure 5. This figure summarizes the critical values derived from the 10 such shots taken on June 9 1989, and shows that the adiabatic limit was not always applicable. The data span more than an order of magnitude in both q_C and Q_{MC} variables. They are well fitted by the solid theoretical curves after adjustment of the single parameter available, $Q_I = 0.006$, which is within a factor of two of the value predicted by tracking.

Finally, it should be emphasized again that the analysis of this data is preliminary. Several questions remain to be answered - such as:

What is the natural decay time of the persistent signal, when it goes metastable, as a function of the speed of crossing the unstable boundary?

Can the signal punch through from the "amplitude modulation" zone to the "phase modulation" zone (see "Signal phase" in Figure 2 ??).

How important is the parametric modulation, or betatron modulation, which is also caused by the modulated quadrupoles?

What is the true accuracy, and the fundamental accuracy, of these measurements?

And many more.

Nonetheless, since the simplest complete theoretical description of a one dimensional resonance consists of its island tune, Q_I, and the local slope of the tune with amplitude, dQ/da, this method appears to hold the promise of rapid measurement of proton accelerator resonances. More studies will be performed in later E778 runs.

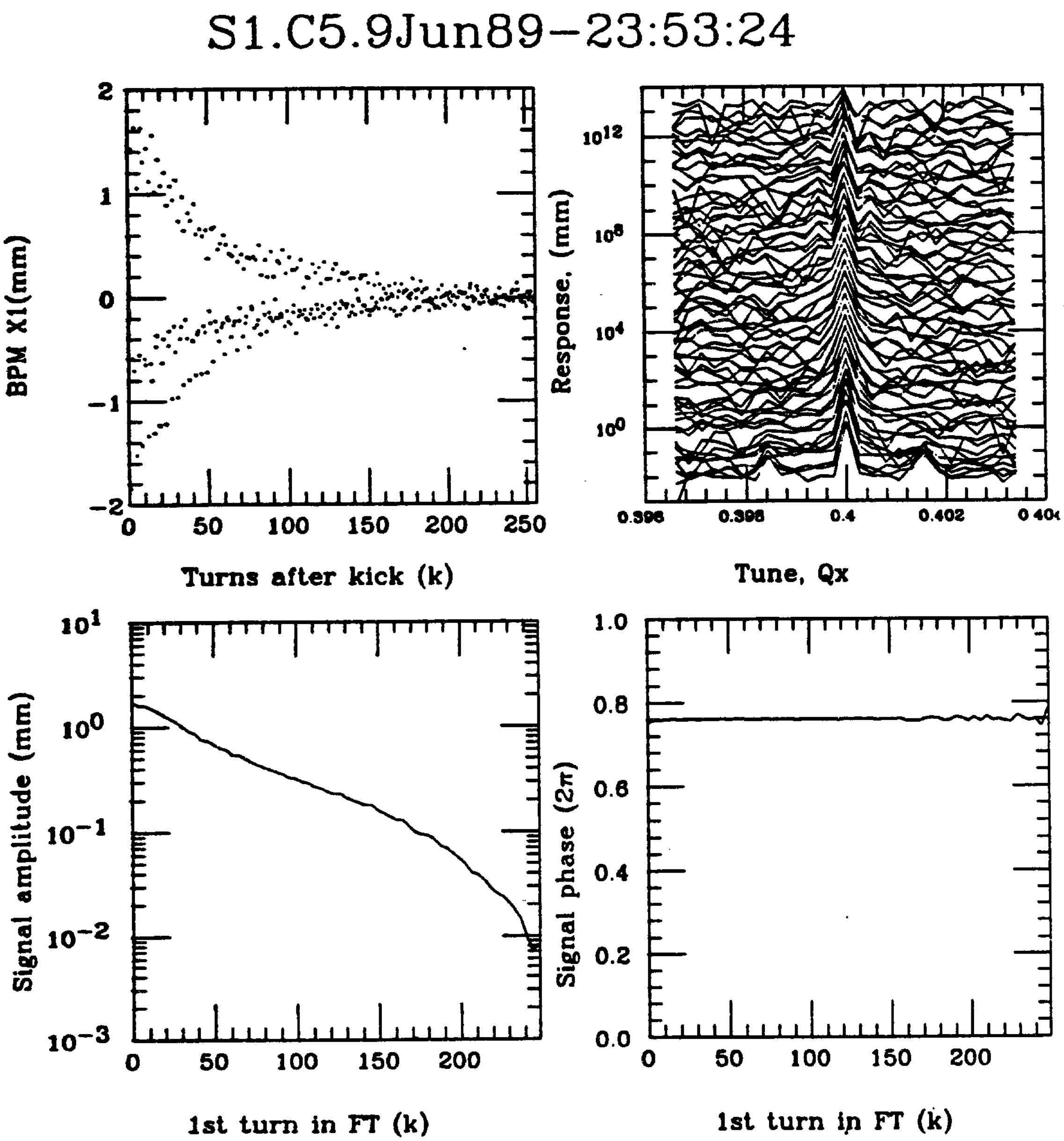


Figure 1 Little persistent signal loss, with maximum tune modulation (q_0, Q_{M0}) = (.0017,.0006) after 5 seconds.

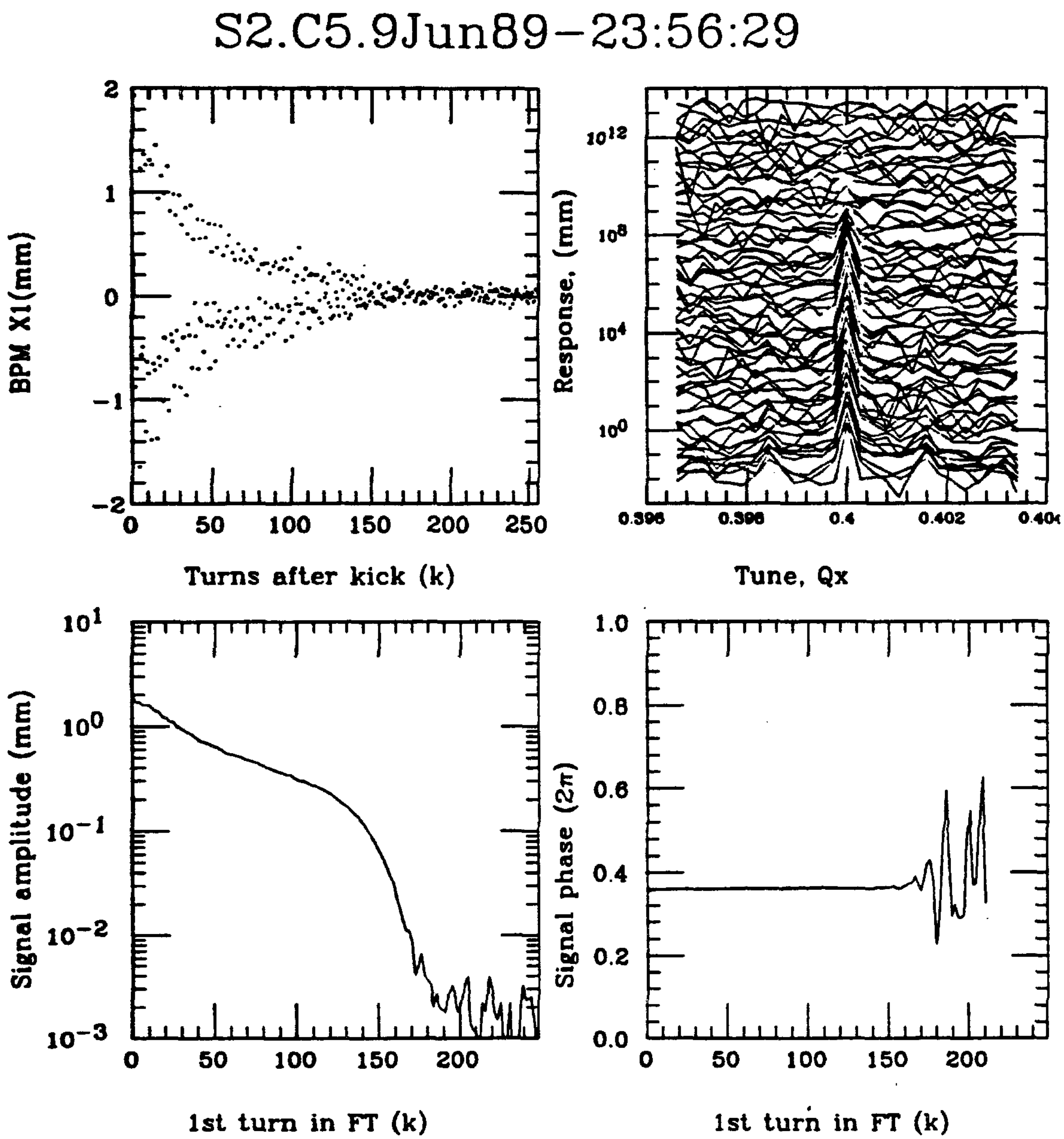


Figure 2 Strong persistent signal loss, with more rapid maximum tune modulation $(q_0, Q_{M0}) = (.0017,.0063)$ after 5 seconds.

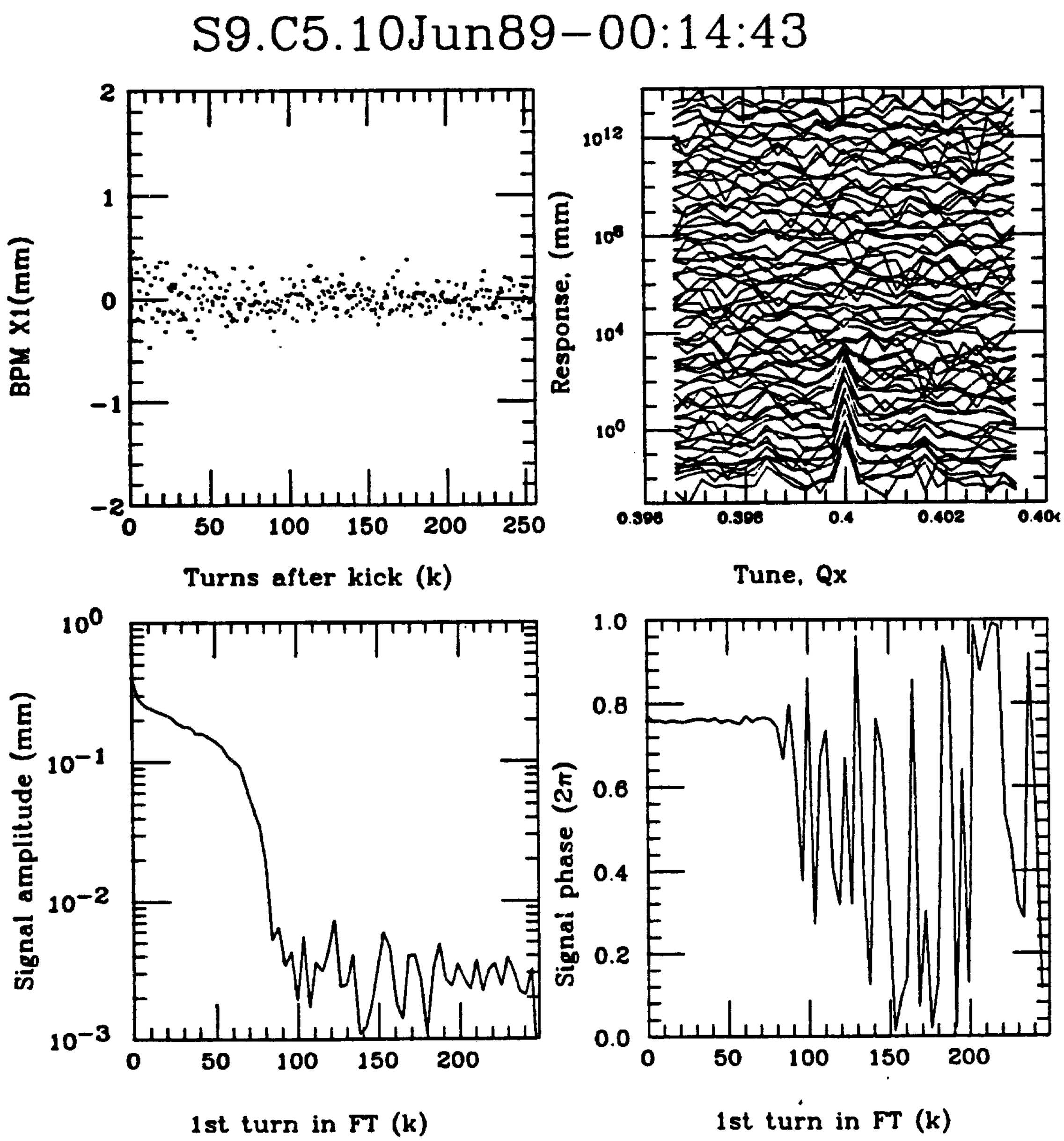


Figure 3 Dramatic persistent signal loss, with strongest and fastest maximum tune modulation parameters $(q_0, Q_{M0}) = (.0083,.0063)$ after 5 seconds.

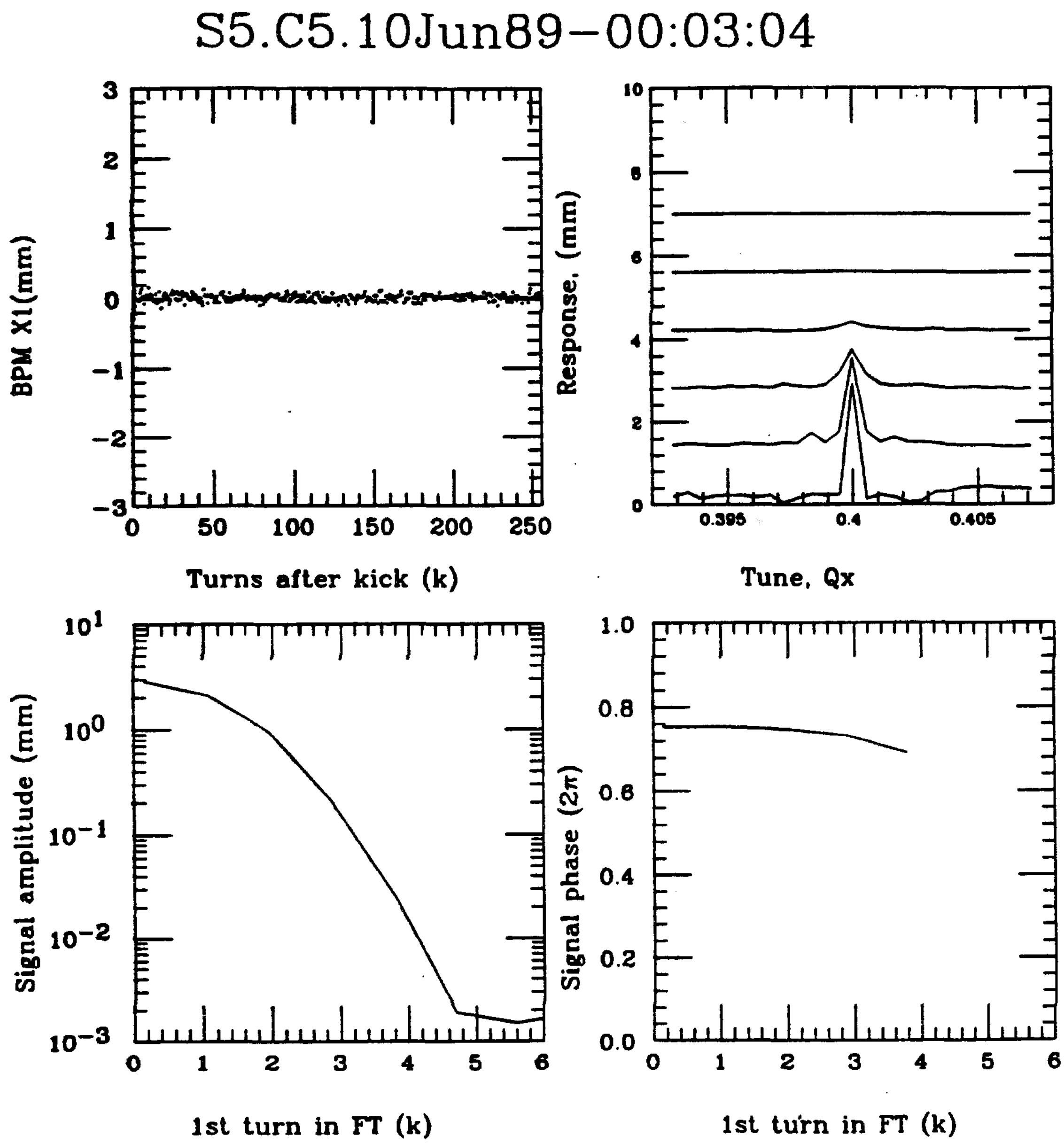


Figure 4 Very rapid and dramatic persistent signal loss, with strong maximum tune modulation parameters $(q_0, Q_{M0}) = (.0083, .0063)$ after 0.1 seconds.

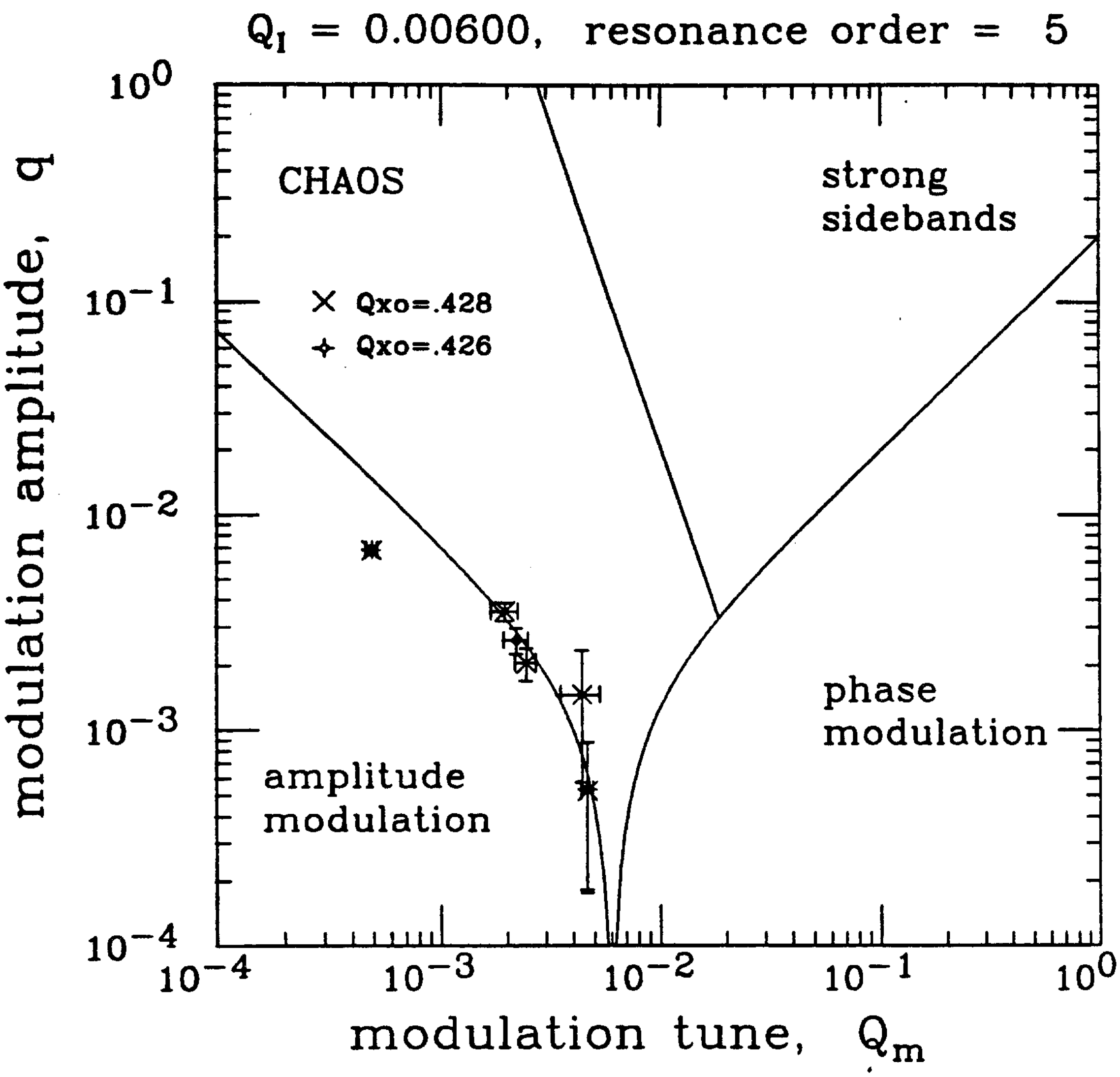


Figure 5 Fit of the experimental data to theoretically predicted behavior, with one free variable, Q_I, set equal to 0.006 .