Diagnostic Investigation of Tune and Tune Shift in the IPNS RCS

J. C. Dooling, F. R. Brumwell, and
G. E. McMichael

Argonne National Laboratory

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Accelerator Operations Group

Diagnostic Motivations

Understand the nature of "pre-spill" and why phase-modulation* of the rf eliminates this ("scrambler").

Look for tune signatures in spectral data from detectors in the RCS

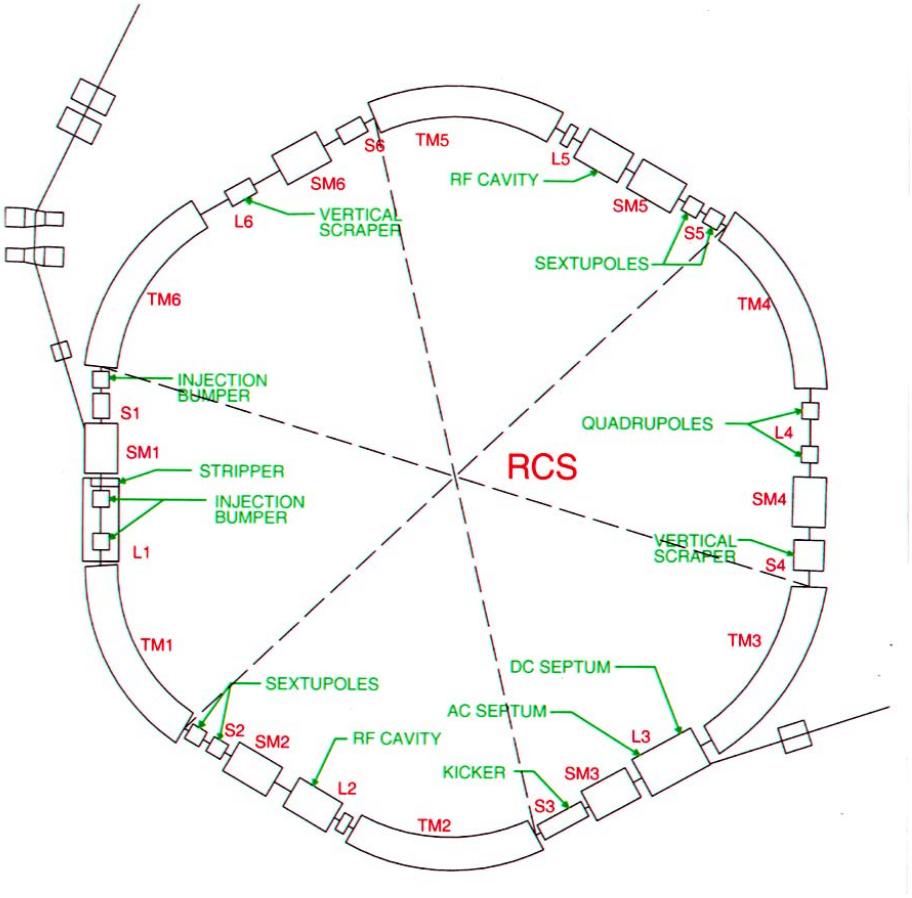
Anticipate instabilities that may arise with Second Harmonic (SH) rf

In all cases, reduce losses and downtime where possible and increase the current limit.

*Y. Mizumachi and K. Muto, IEEE Trans. Nuc. Sci., **28**(3), 2563(1981).

IPNS RCS Summary

Accelerate protons from 50 MeV to 450 MeV at 30 Hz.
Two rf cavities provide 21 kV, total of accelerating voltage
Bare tunes: Q_x~2.20 and Q_y~2.32, 6-sector, combined-func.
Inject up to 4.0x10^{12} ppp and extract up to 3.4x10^{12} ppp



Minimum bucket size: 0.33 eV-sec (7 ms). Minimum bucket size must exceed maximum longitudinal phase space of bunch (longitudinal emittance).

=> phase density~10 (x10^{12} p/eV-sec)

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RCS Diagnostics

Pie Electodes (transverse and longitudinal)

Position and Profile System (PAPS, transverse)

Resistive Wall Monitor (RWM, longitudinal)

Current Toroids
- Pearson
- Bergoz (new)

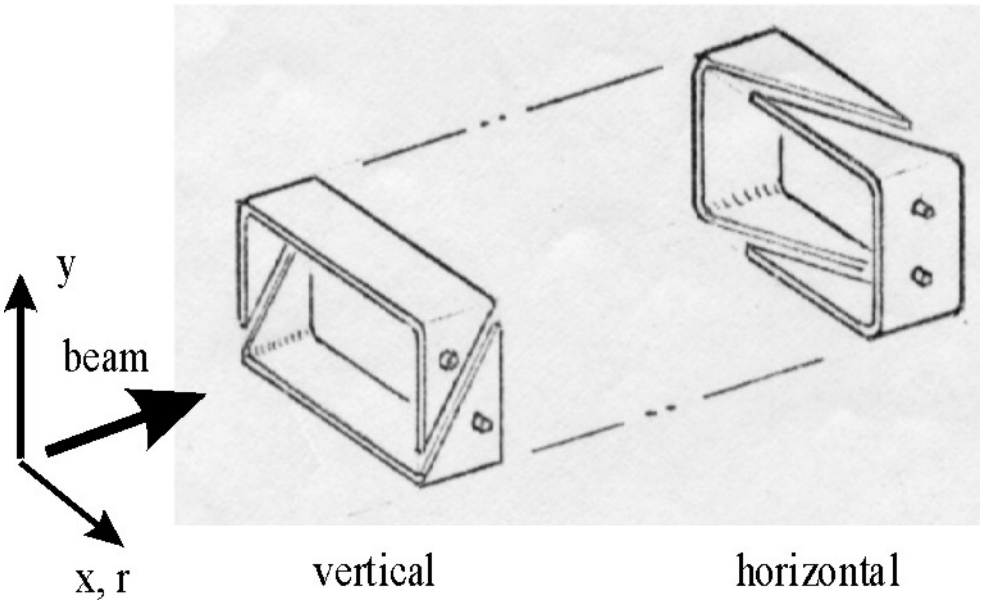
Retarding Field Analyzer (RFA, new, transverse and longitudinal)

Faraday Cup (injection, transverse)

This talk will concentrate mainly on data obtained with the Pie-electrode.

Pie Electrode

Four segments:



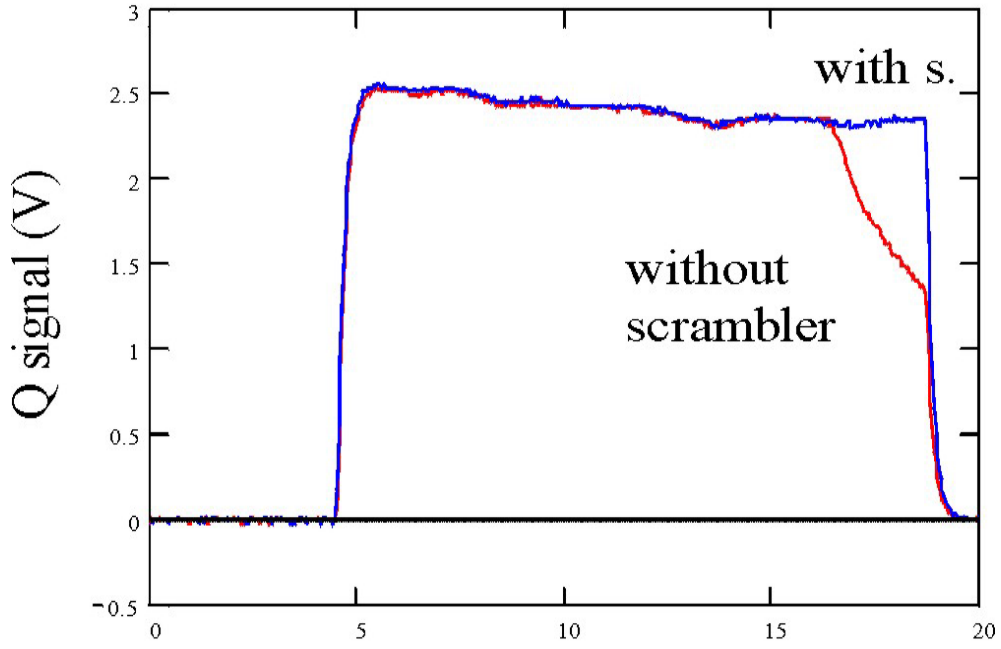
Located in “short” straight sections of the ring.

Provides fast-feedback for rf phase control (S2)

Frequency data recorded on HP4396B in SA mode or time data captured using TDS7254 oscilloscope with deep memory (4 MS per channel, 16 MS total)

Pre-spill

Slow Q signal in the IPNS RCS

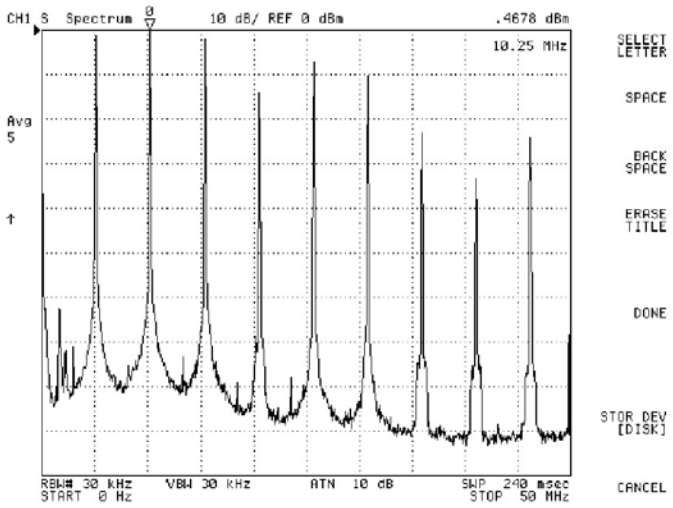


Note: the initial injected charge is 3.5×10^{12} protons

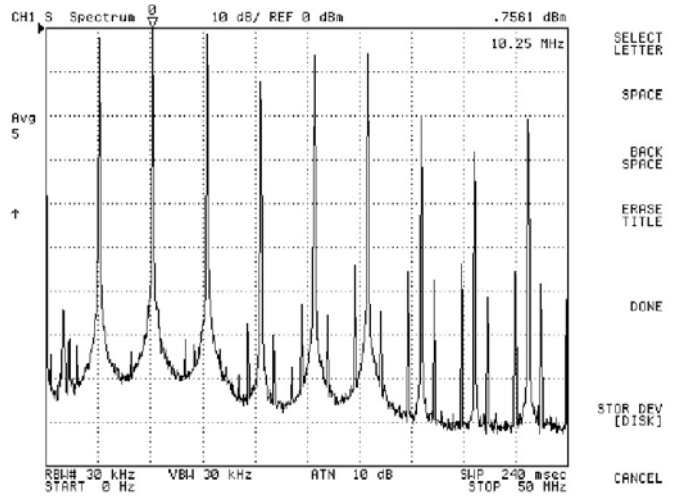
Pre-Spill, con't

Pie-electrode data revealed its nature:

0-50 MHz spectrum just prior to extraction with PM ("scrambler"):



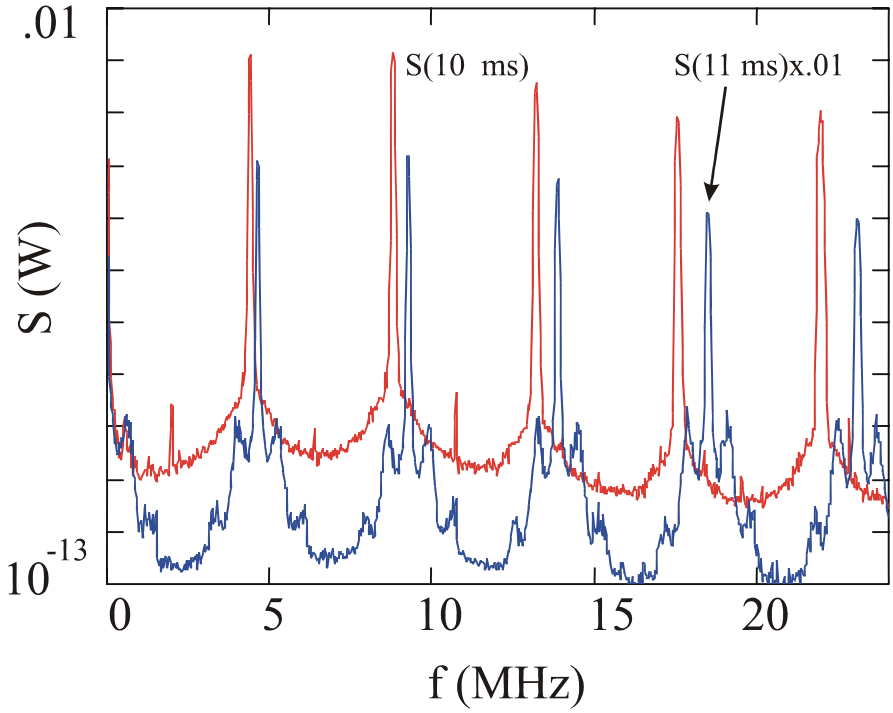
0-50 MHz spectrum just prior to extraction without the scrambler:



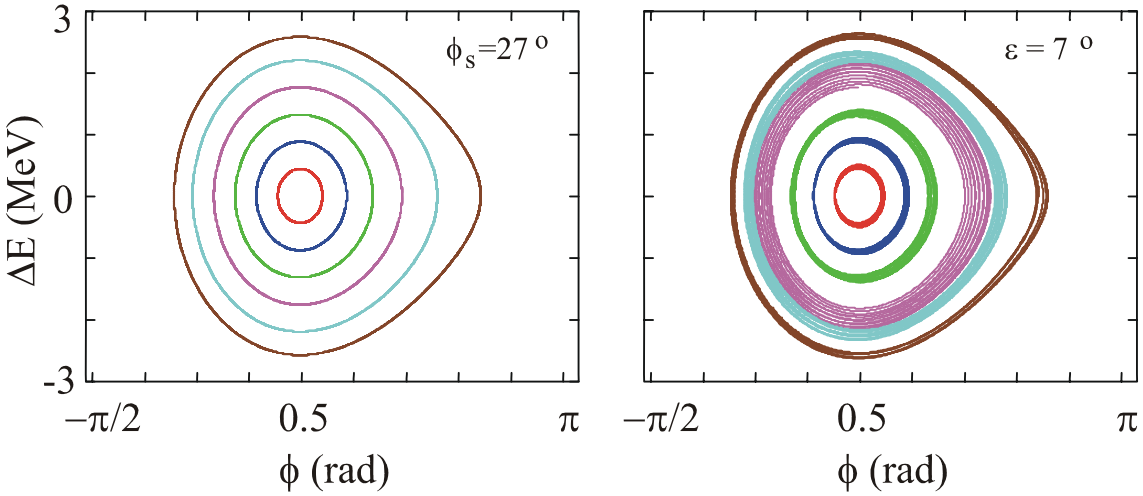
Culprit: A vertical, resistive-wall instability, just as predicted by Niel and Sessler: $(n \pm \nu_y) f_o$ for $n > Q_y$.

Scrambler Effects

The PM couples longitudinal energy transversely.



Longitudinal only picture:



Fast Acquisition of Pie Data

SA spectra typically take minutes to generate with averaging to reduce noise and reasonable VBWs. Moreover, to generate a spectrum every 100 μs over the entire accelerating cycle takes on the order of one day (approximately 150 frames).

Question: Using a fast oscilloscope with deep memory, could we observe the same features from a single accelerating cycle?

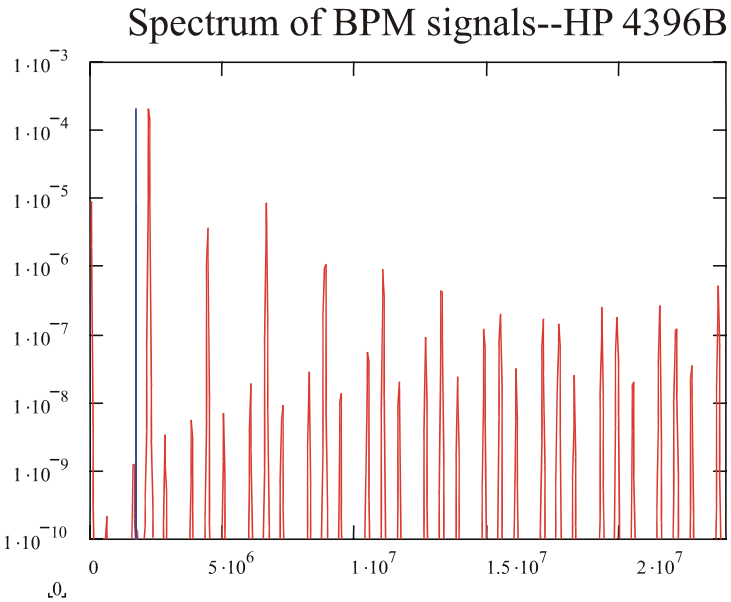
Answer: Yes, but…

With a Tektronix TDS7254-3M, sampling at 250 MS/s, can obtain the entire cycle from each of the four electrodes in the Pie set. This requires 4 MSamples (4 Mbytes) per channel for 16 ms of data.

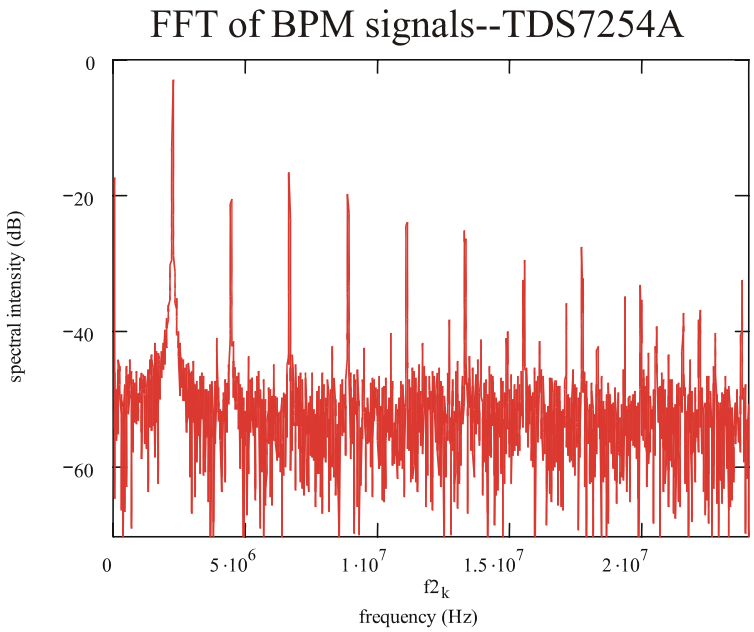
Strong spectral features are visible using the fast scope, but the noise floor is much higher (only have one pulse instead of say 10).

Still the ability to observe bunch dynamics in a single cycle is extremely attractive.

Comparison of SA (many cycles) and oscilloscope (single cycle) pie-electrode data



"008"



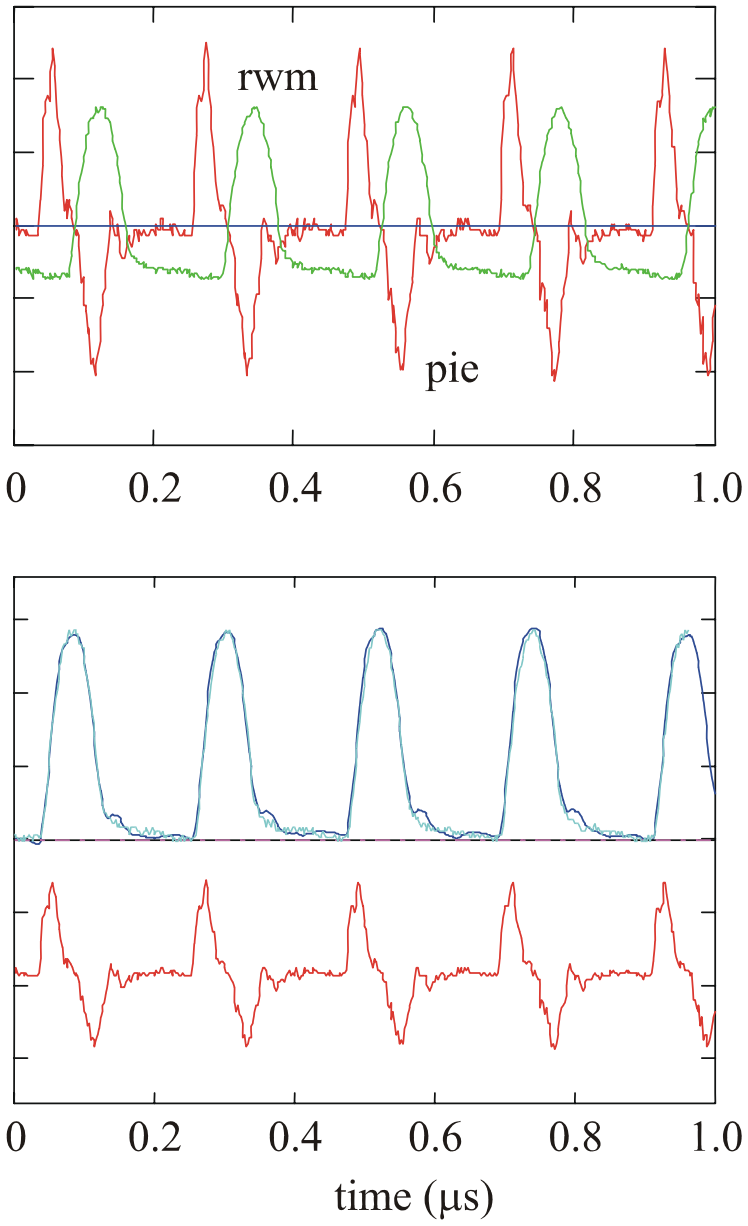
"030x-031x"

x: 0,1,..,4

Vertical oscillations 200 μs after injection (top: VBW= 30 kHz, 10 ave., 100 μs; bottom: 20 kS, 2^{15} FFT, 80 μs)

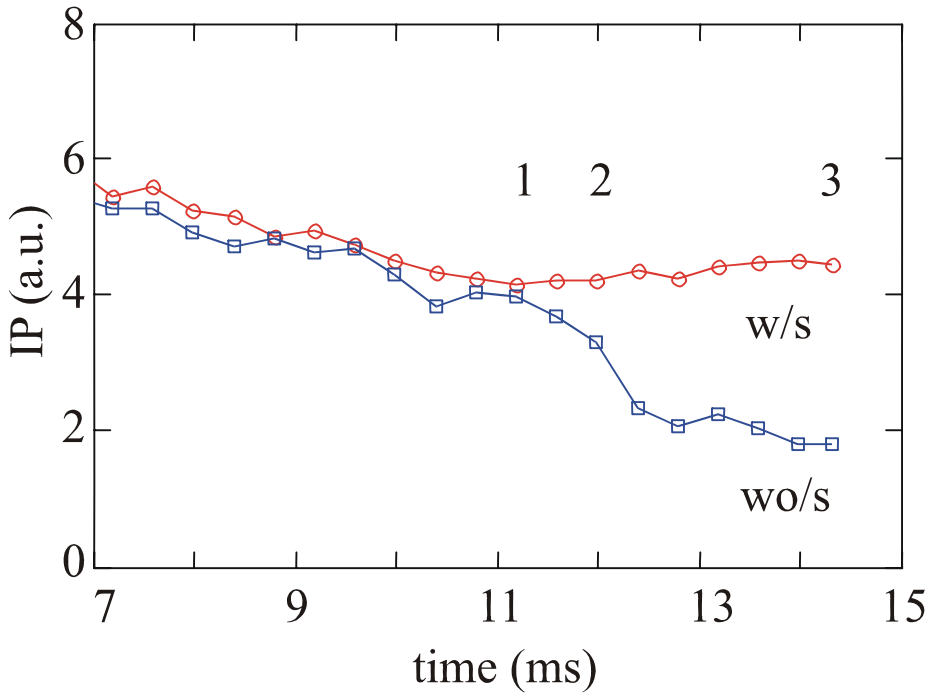
Pre-spill, revisited

If we integrate Pie signals should get pulse information. Can compare with RWM or CTs. The following compares Pie and RWM data at 8.2 ms (just prior to scrambler)



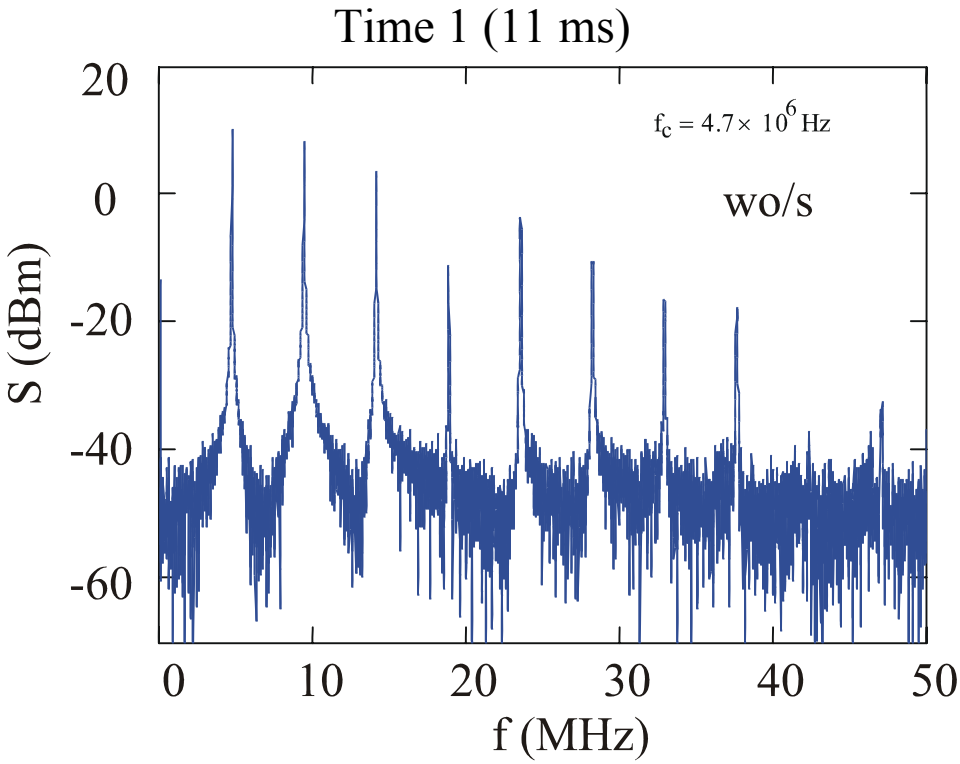
Pre-Spill, con't

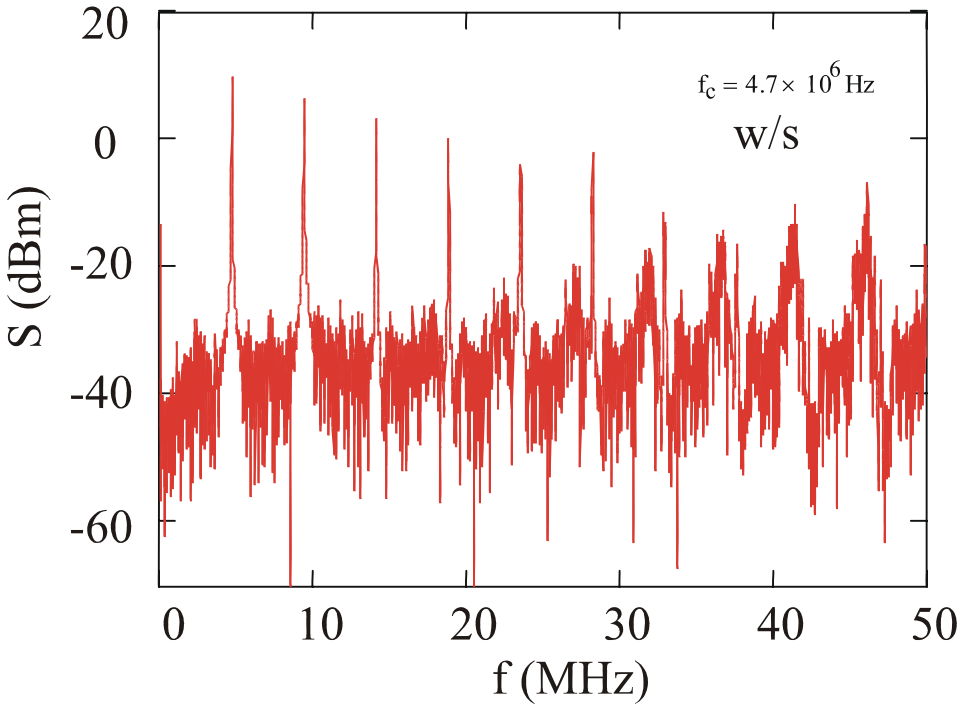
Integrating again, the pulse signal should yield the total charge in the bunch.



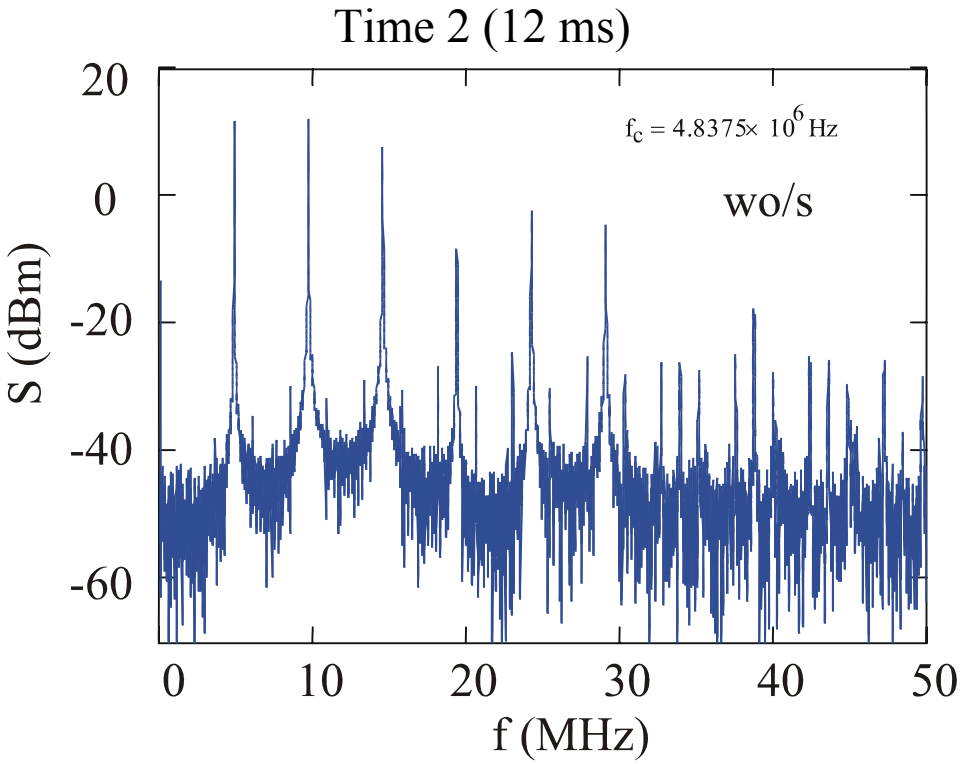
Will examine the spectra at times 1 and 2 and the pulse shapes at time 3

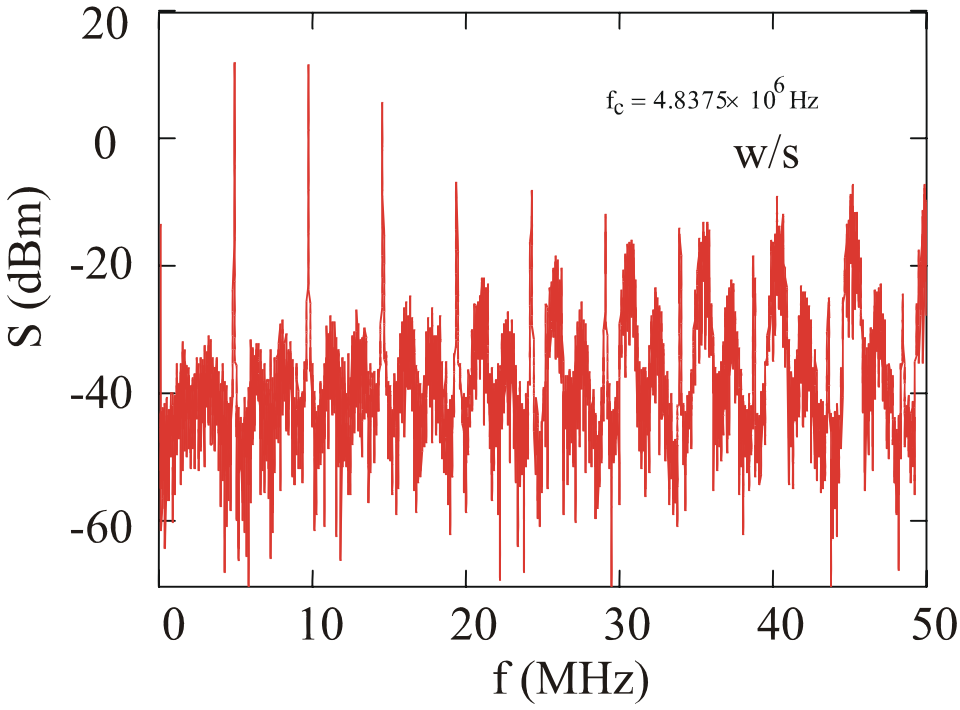
Pre-Spill, con't



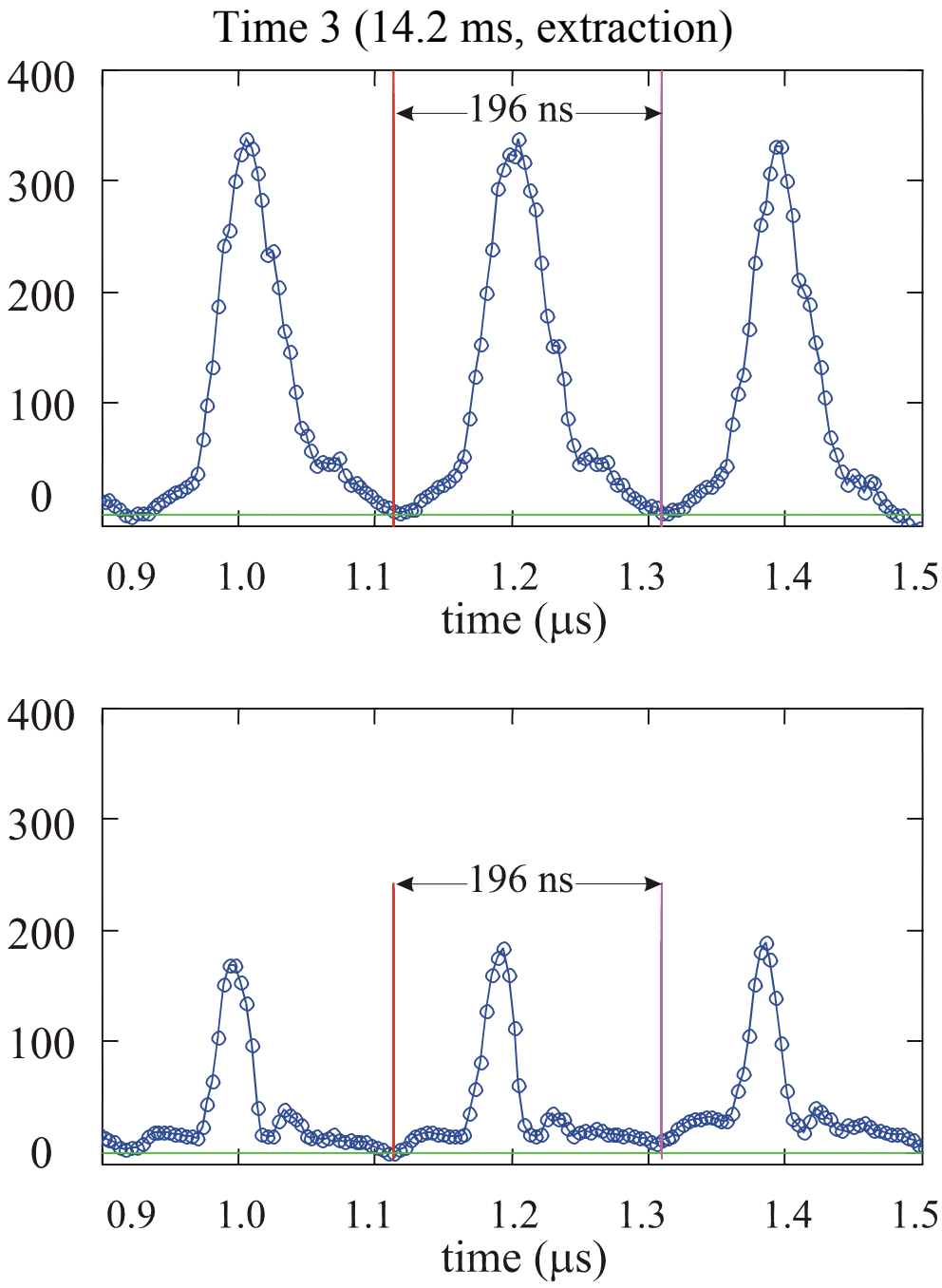


Pre-Spill, con't





Pre-Spill, con't

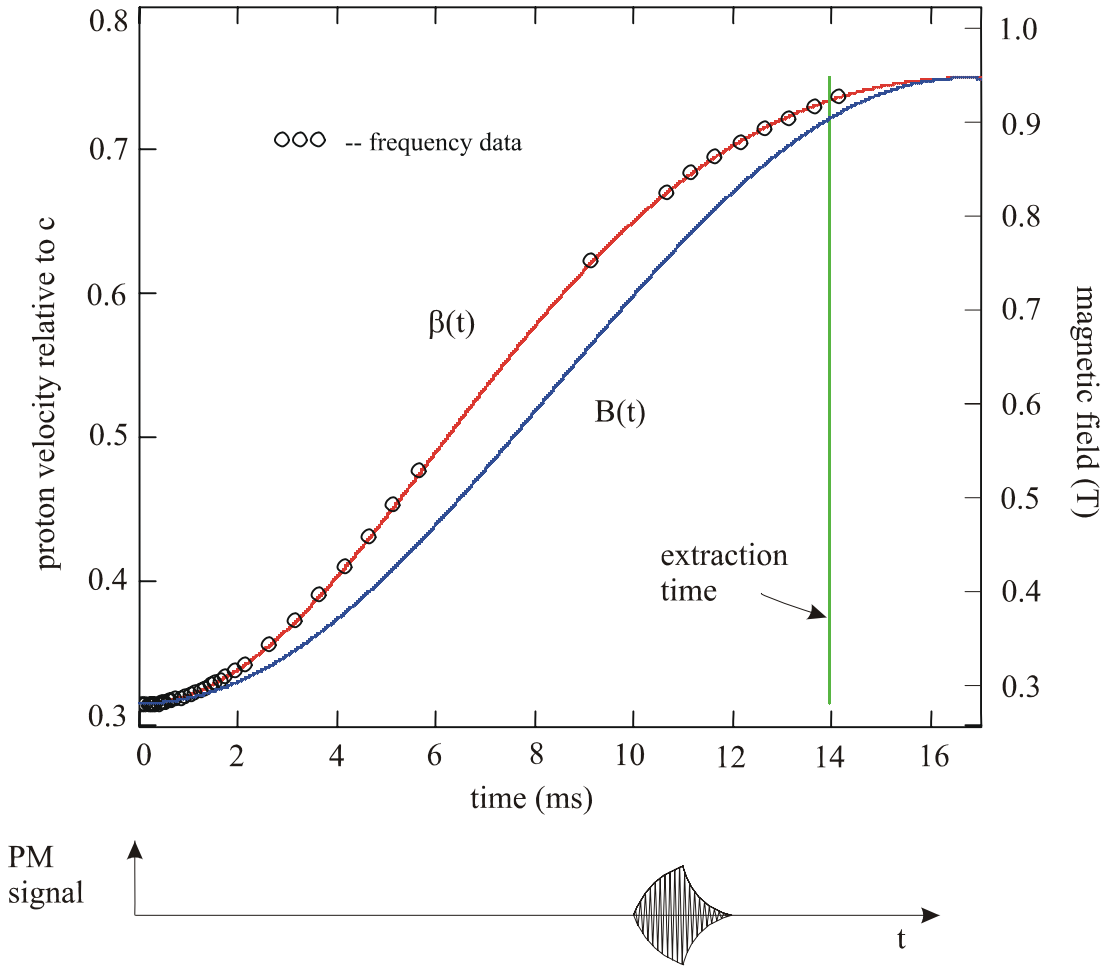


60 percent reduction in charge

Tune and Tune Shift

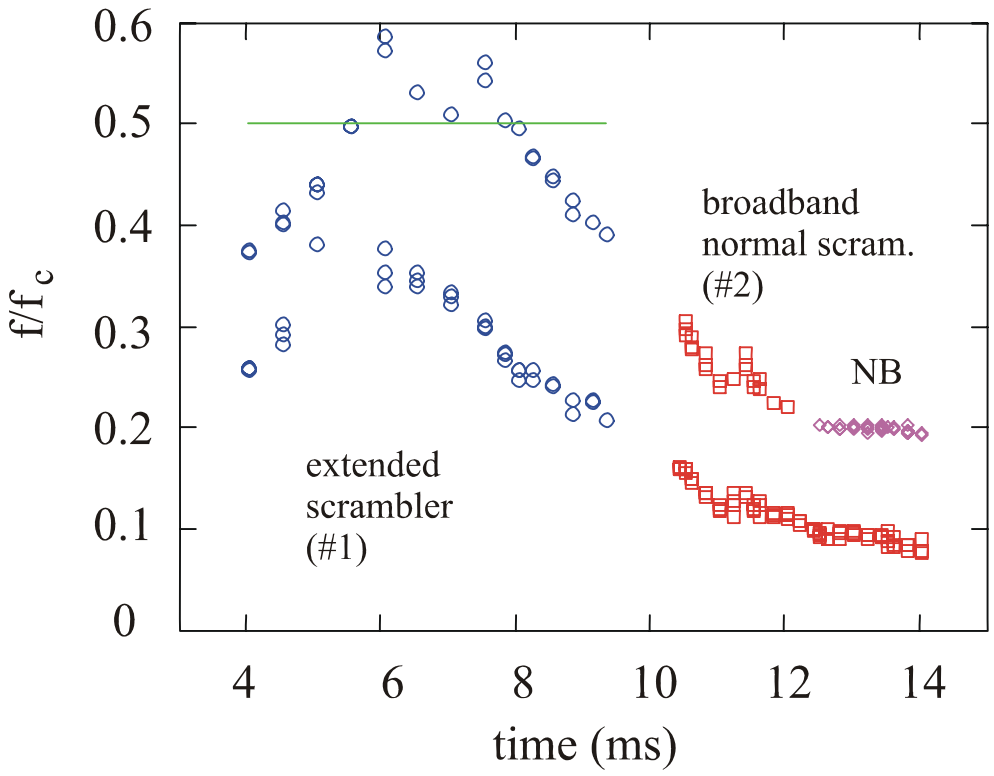
A second scrambler can be run during the same acceleration cycle. The original, as it stabilizes the beam against the vertical instability, brings out spectral features related to the tune; therefore, try to use the second scrambler to make tune measurements throughout the cycle.

First tried this during our 1999 December run.



Extended Scrambler Studies*

Fractional frequency measurements ‘99Dec



These results were puzzling.

*Note: all measurements made with HP 4396B SA

Tune Shift

Neutralization time at injection is approximately 600 μs (50 MeV, background gas pres. ~ 1 μTorr); this is to be compared with value of 20 ms on the PSR (800 MeV, 50 nTorr). The tune shift can be expressed as,

$$\Delta\nu(\tau) = -\frac{I_p R\left(1-\gamma^2 f_e(\tau)\right)}{I_0 \varepsilon_n \beta^2 \gamma^2}$$

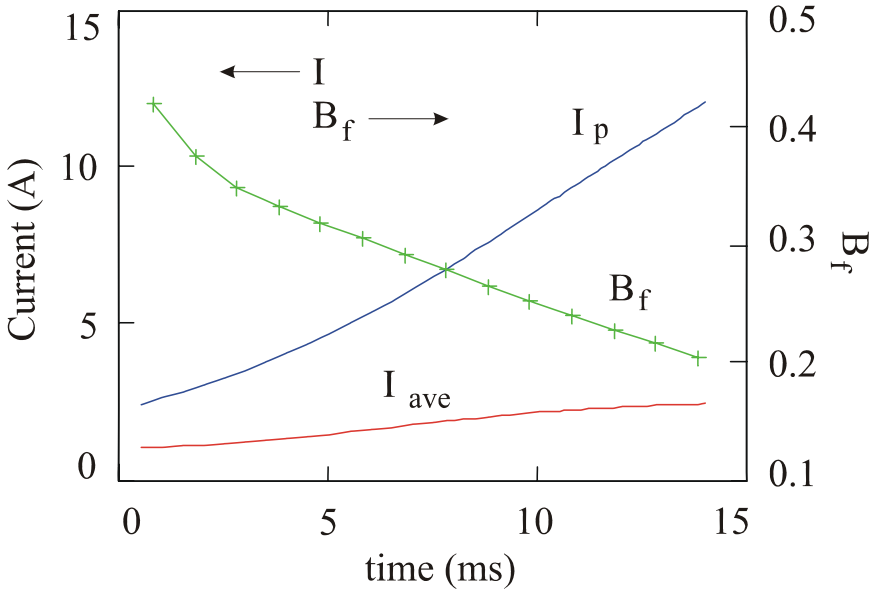
where f_e is the neutralization fraction. The total tune is then,

$$Q_\xi(t) = Q_{\xi o} + \Delta\nu_\xi(t)$$

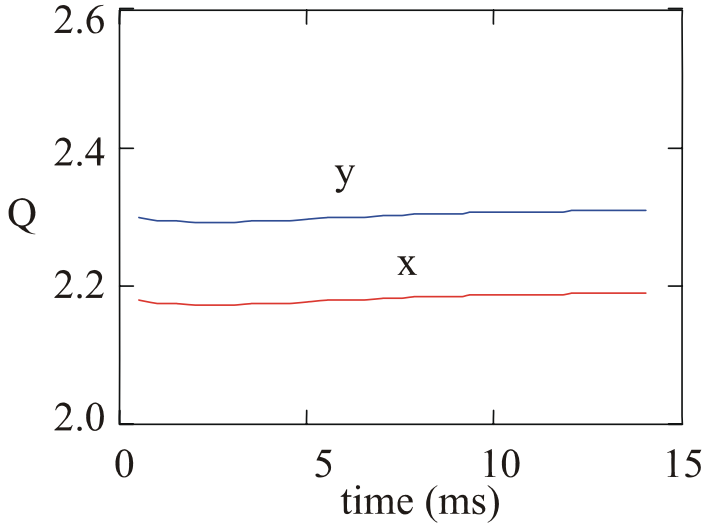
where the subscript represents the principal planes. It was initially assumed that since the RCS beam should be quickly neutralized, the value for f_e might be similar to the bunching factor, B_f.

Tune Shift, con't

Average and Peak Current/Bunching Factor:



However, substituting $B_f(t)$ for $f_e(t)$ in the expression for tune shift did not yield a satisfactory result:



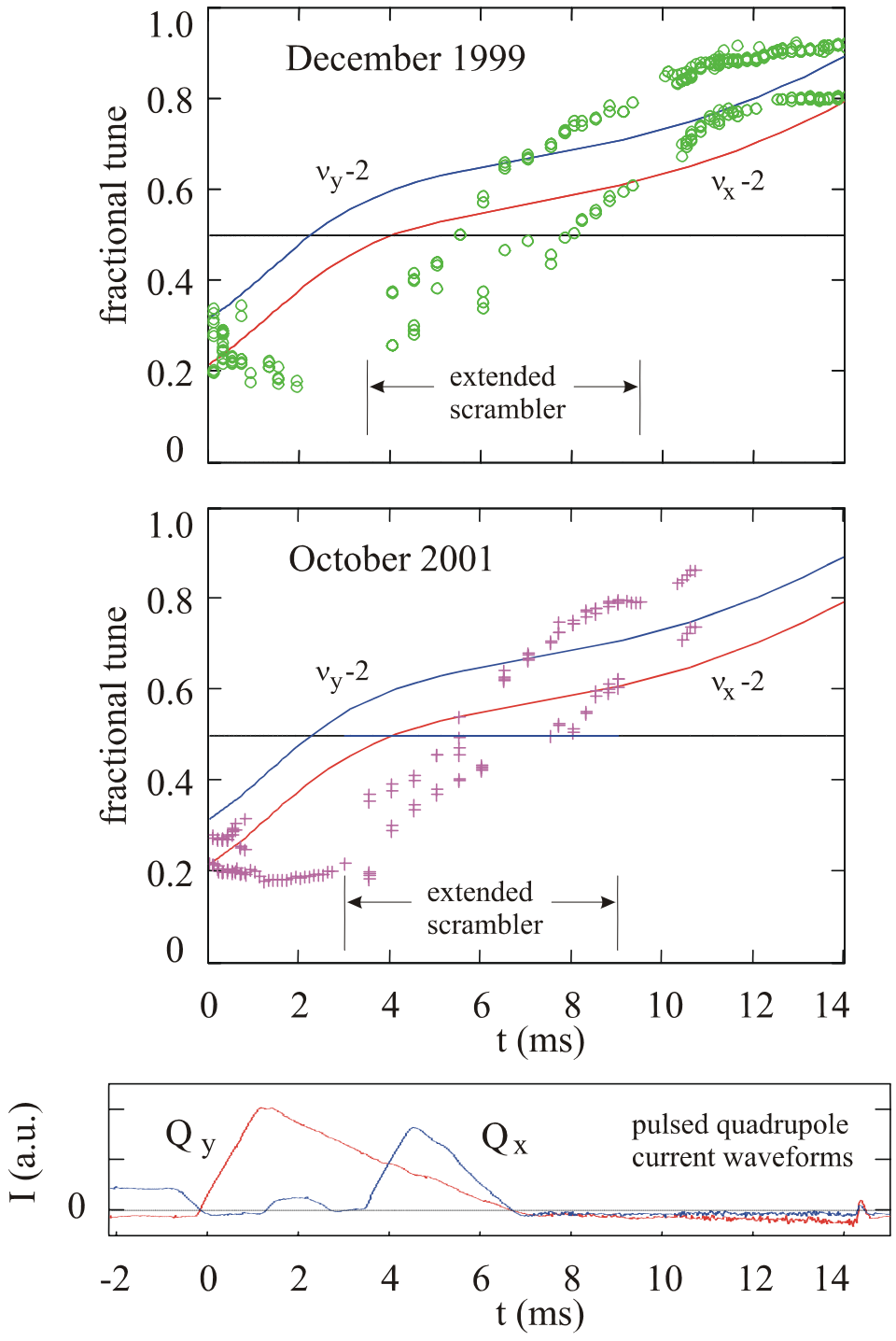
Tune Shift, con't

According to Reiser, it is possible that the beam may become over-neutralized. Instead of using the bunching factor, try simply the cycle time over the neutralization time:

$$\Delta\nu(t) = -\frac{I_p(t)R\left(1-\gamma^2\frac{t}{\tau_n(t)}\right)}{I_0\varepsilon_n\beta^2\gamma^2}$$

This gives the tune shift a different character. If we interpret the fractional frequencies as tunes and allow that some beyond a given time have crossed through the 1/2-integer value, obtain the following:

Tune Shifts, reinterpreted



Conclusions and Further Work

IPNS RCS is a high intensity proton machine

Fast spectral data shows consistency with SA data (slow)

Need to study tune shifts with fast data acquisition

Need to examine the effects of neutralization and plasma on the tune of the machine—have installed an RFA to examine electrons.

Electrons are observed with the Profile and Position system (not shown).

Large multi-pactoring effect is not in evidence

Acknowledgement

This presentation would not be possible without the dedication and hard work of the IPNS Operations staff

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