IPNS Linac Beam Injection into the RCS

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1:30 PM Huddle

Question:

How long do linac microbunches persist after injection into the IPNS RCS?

IPNS Linac Parameters (H^-)

f_{linac}=200.07 MHz

W_o=50.8 MeV, (β=0.316, γ=1.054)

IPNS RCS Parameters

$N_{inj}=3.5\text{x}10^{12}$ protons

τ_{inj}= 70 μs

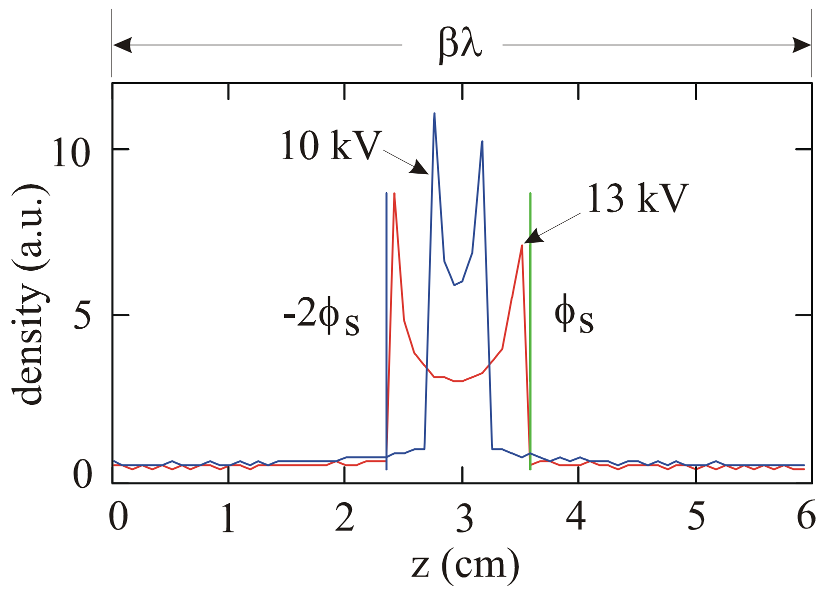
f_o=2.2 MHz

$n_t=\tau_{inj} f_o$

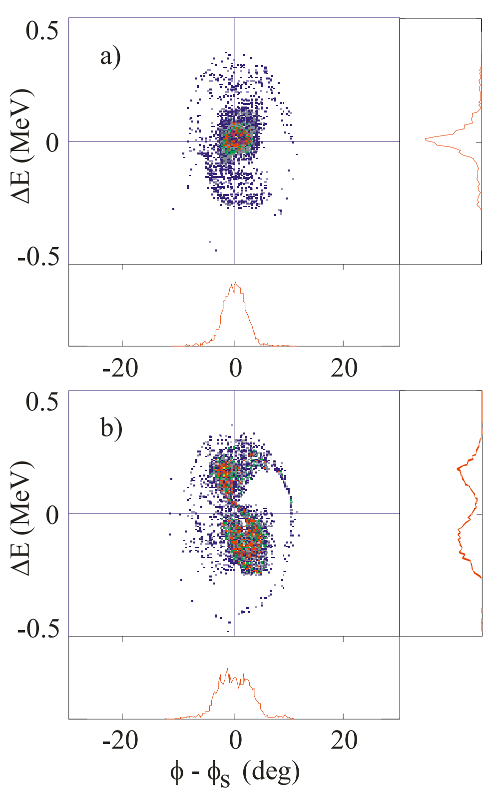
$\frac{\Delta p}{p}$~0.3–0.4% (ΔW~0.3-0.4 MeV)

PARMILA modeling can be a helpful guide

Buncher cavity studies with PARMILA



simple buncher density model



PARMILA Linac output for buncher voltage of a) 10 kV and b) 13 kV

Linac Energy/Momentum Spread

We believe our linac output is somewhere between these two extremes. The ESEM diagnostic[1], indicates our 50-MeV linac output energy spread is 0.3-0.4 MeV or $\Delta p/p \sim 0.3$-0.4 percent.

Estimate the time for 200 MHz bunch structure to wash out using the linac output energy spread. Calculate the time for a (stripped) proton to travel from the center of one bunch to the center of the next (either forward or backward). May also want to consider half this time when a fast proton from a trailing bunch catches up to a slow proton from the adjacent leading bunch. The bunch spacing is $\beta\lambda$ where λ is the free-space wavelength of the 200 MHz.

$\beta\lambda = 0.474$ m

$$v = \beta c$$
$$x = \int v\,dt$$
$$x + \Delta x = \int (\beta + \Delta\beta) c\,dt$$

Let's assume that β and $\Delta\beta$ are constant, then write:

$$\begin{aligned}\Delta x &= \Delta\beta c \int dt \\ &= \frac{\Delta W}{W}\frac{(\gamma - 1)}{\beta\gamma^3} ct \\ &= \beta\lambda\end{aligned}$$

or

$$\begin{aligned}t &= \frac{\beta^2\gamma^3}{(\gamma-1)}\frac{\lambda}{c}\frac{W}{\Delta W} \\ &= \frac{\beta^2\gamma^3}{(\gamma-1)} T_{lin}\frac{W}{\Delta W} \\ &= 1.57\ \mu s\end{aligned}$$

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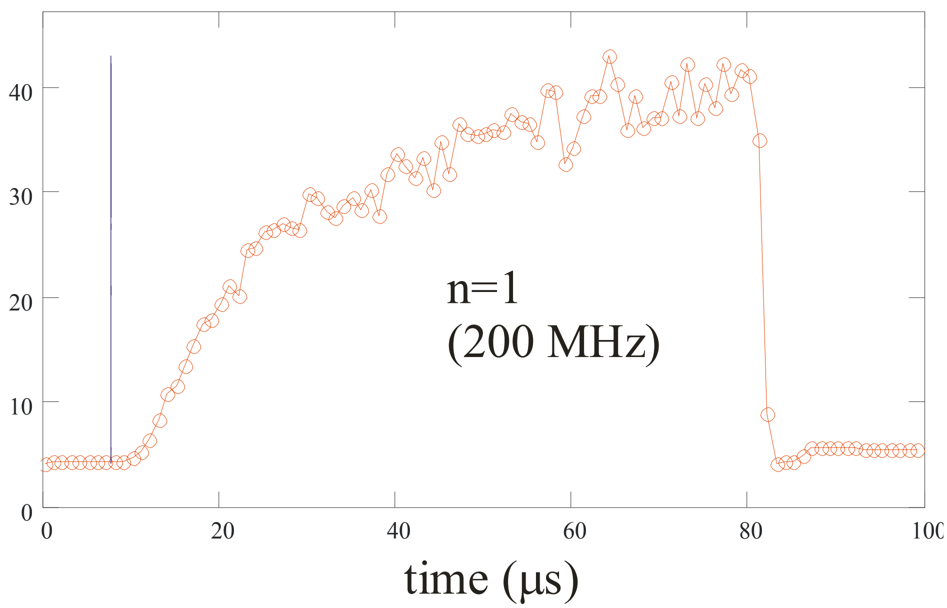
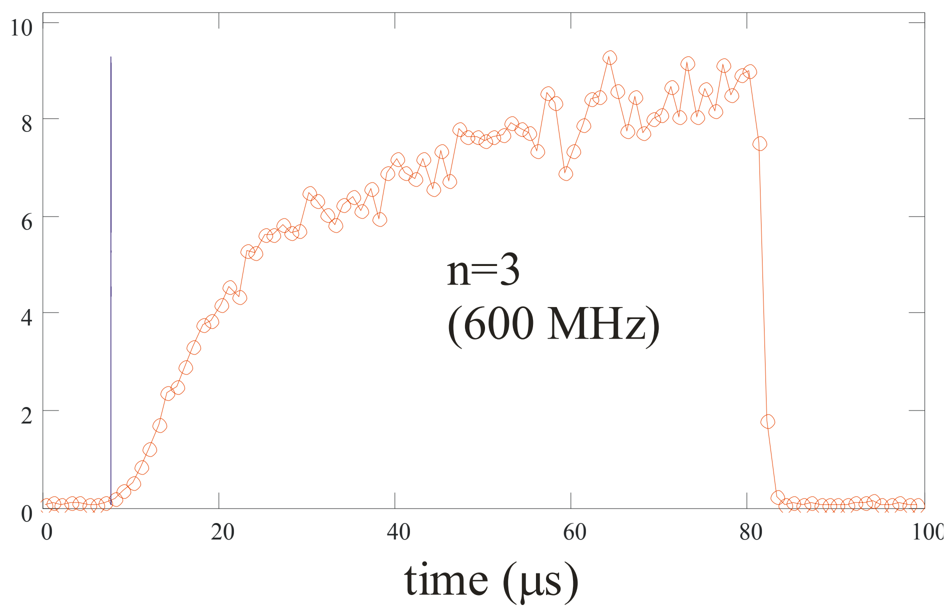
[1] J. C. Dooling, et al., Proc. 20th Int. Linac Conf., Monterey, CA, August 21-25, 2000, SLAC-R-561.

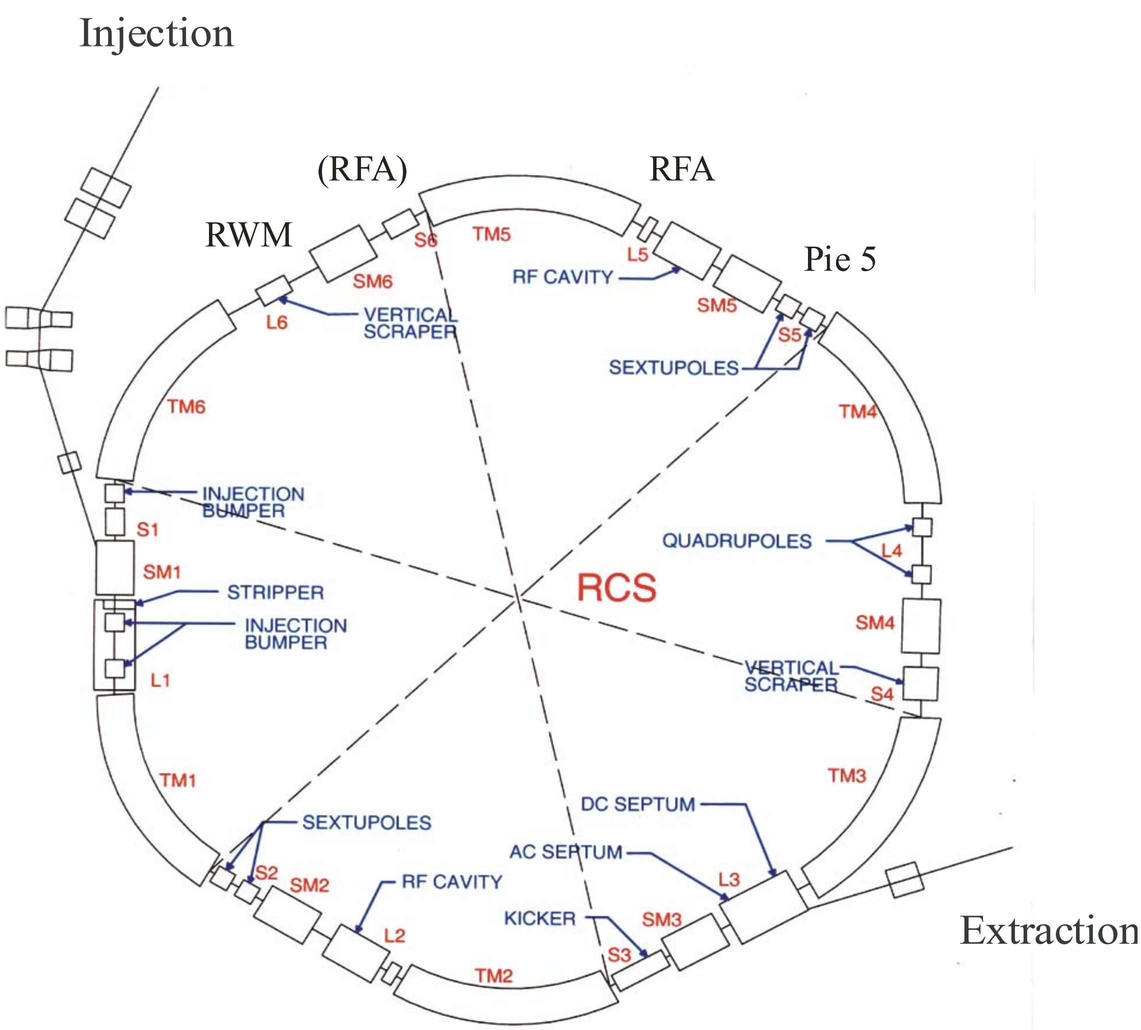
Diagnostic Indications

We observe microbunch structure for the ESEM diagnostic mentioned above using terminated strip-line BPMs. The first and third harmonics of the microbunch train are shown below from BPM 1, closest to the linac output. Because of linac noise, the 3rd harmonic gives a better indication of current. The data is recorded at 5 GS/s for 100 µs. Each point represents data from a 2 kS FFT (400 ns/pt).



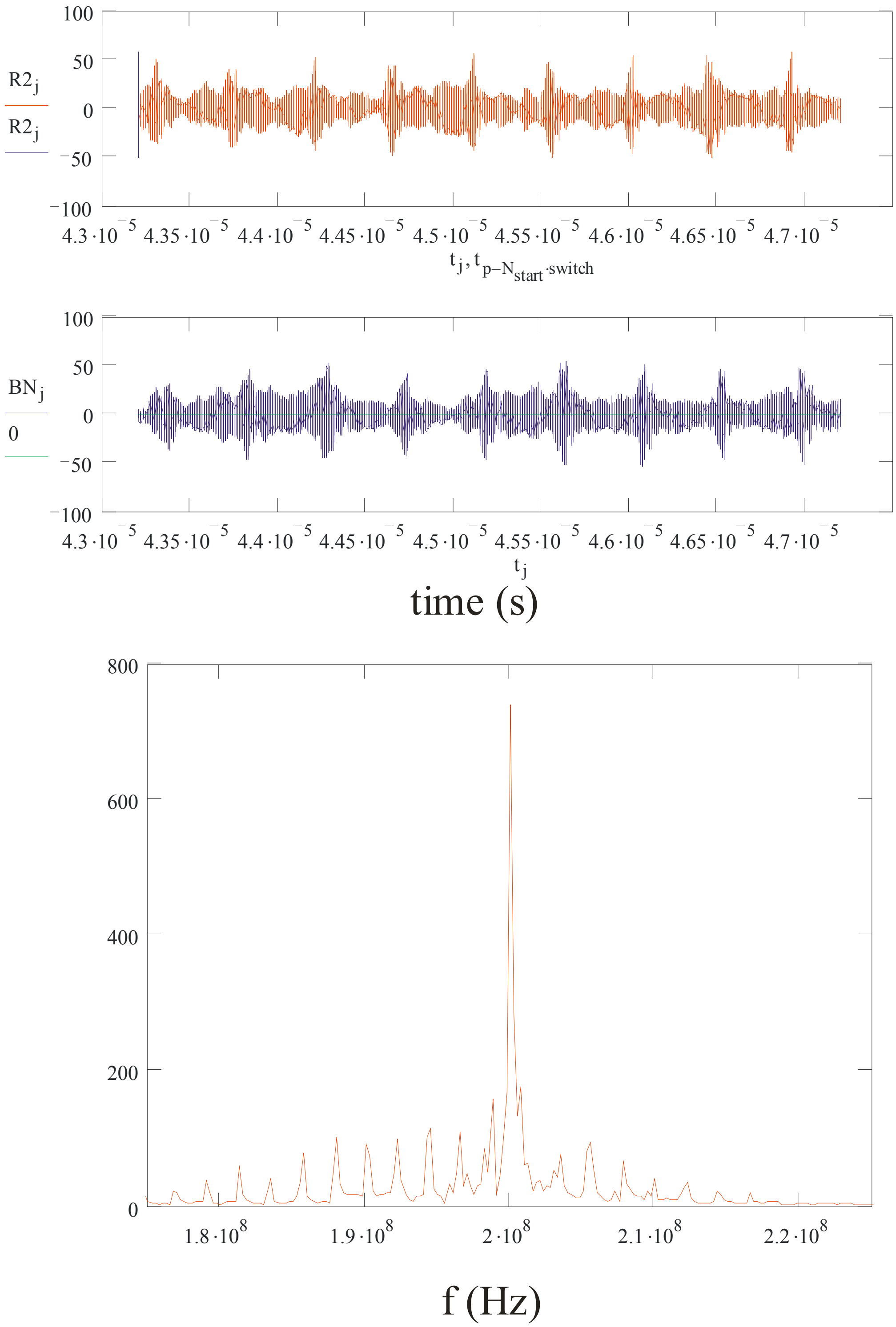


First noticed microbunch coalescing when Retarding Field Analyzer (RFA) was placed into the RCS ring in early in 2002. Data was recorded adjacent to the ring before signals passed near linac. Other diagnostics used here are the Resistive Wall Monitor (RWM) and the Pie electrodes (sextant 5); the locations of which are indicated in the RCS diagram below. The RFA has been moved from its position in a vertical port in S6 to a horizontal location in L5. This signal is now monitored in the Main Control Room. The RFA now sees much more linac noise than it did in its former location.



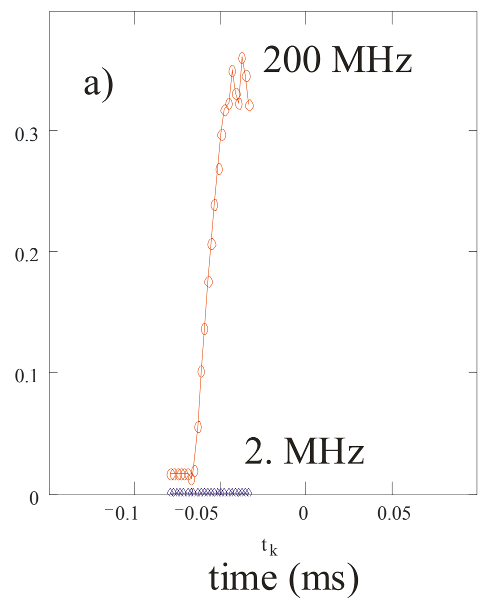
Bunch “birdies” appeared during injection. These pulses are spaced at the RCS injection frequency, but little energy appears in the FFT at this frequency; instead, modulation of the 200 MHz signal at the RCS injection frequency were observed.

Bunch birdies

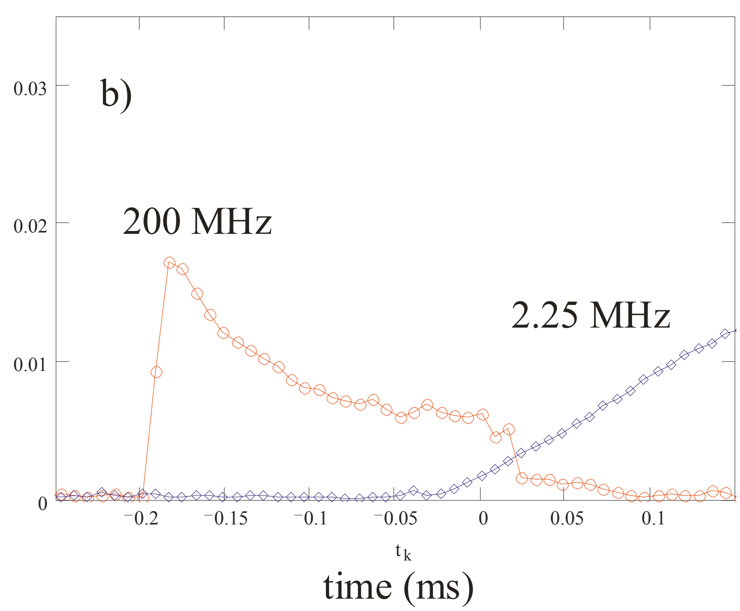


RFA data

Early RFA data near injection (rec. 15 Mar 02)
120 kS, 2.5 GS/s, 5 kS per point (2 μs / point)

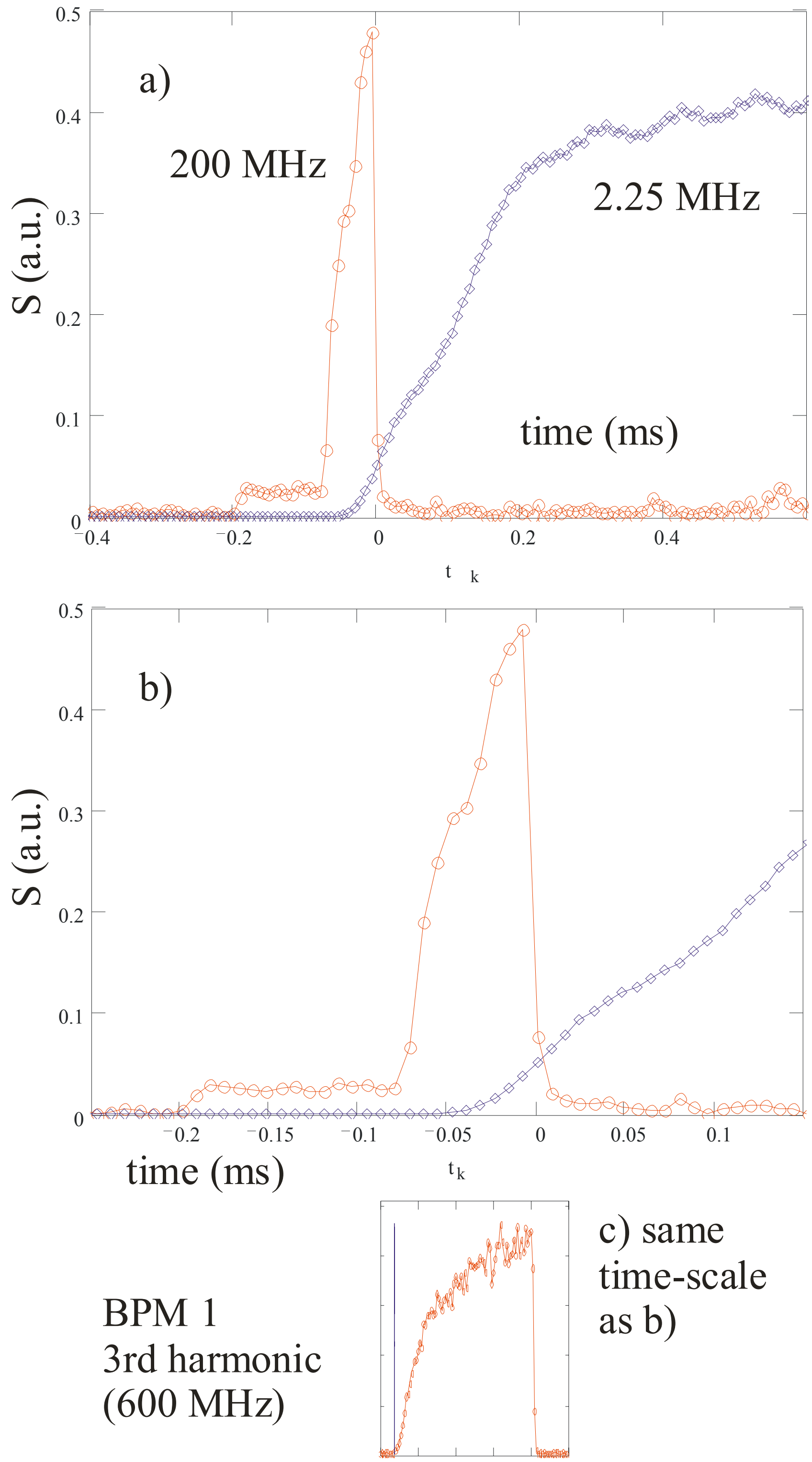


Recent RFA data near injection (rec. 24 Sep 03)
4 MS, 1.25 GS/s, 10 kS per point (8 μs / point)



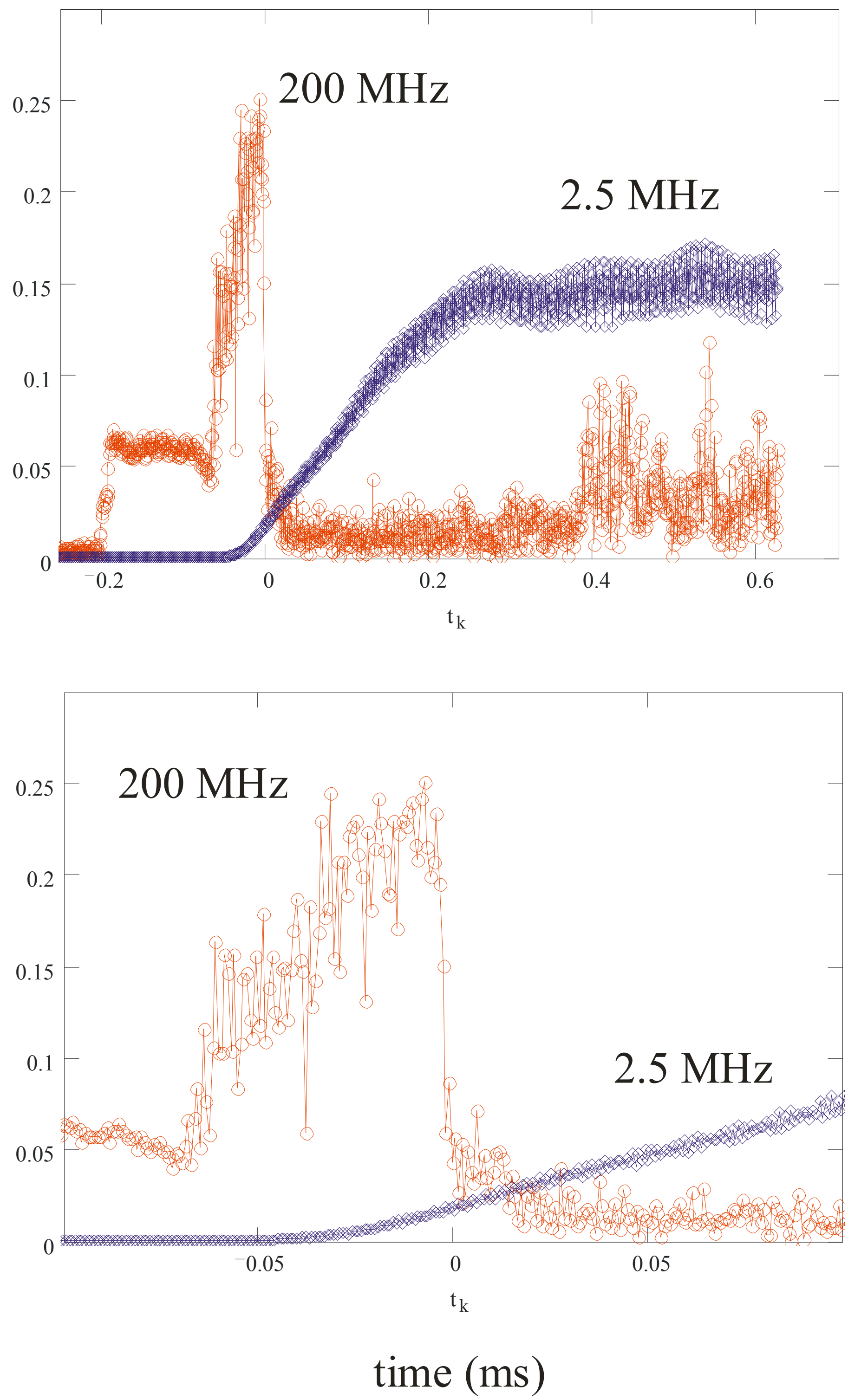
RFA a) vertical port (birdie data), b) horizontal port

Pie Electrode Data--2.25 and 200 MHz



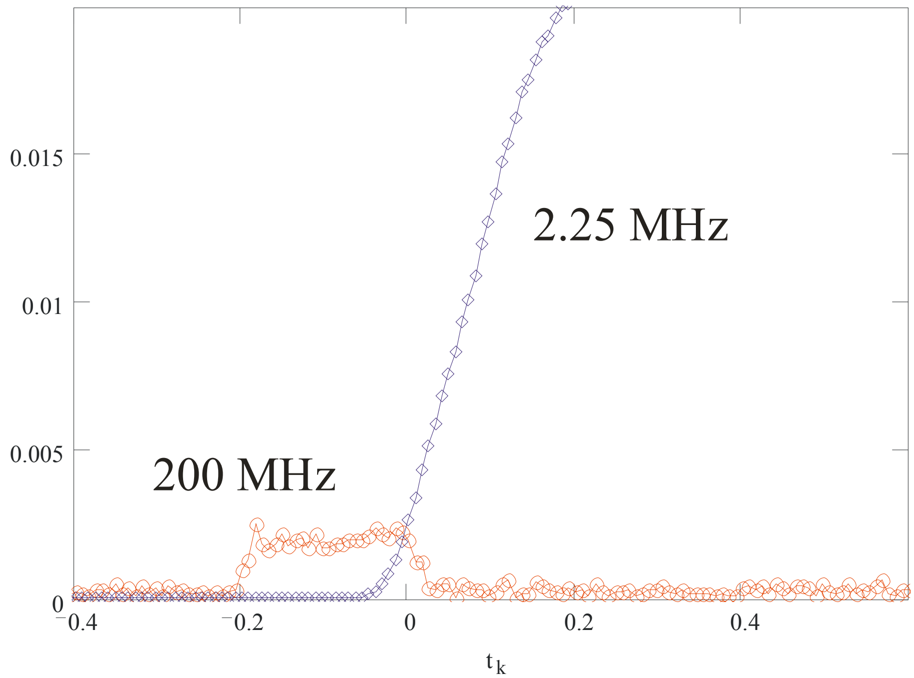
Pie data: 10 kS/pt at 1.25 GS/s or 8 μs/pt, data interpolated to 2^{14} for FFT

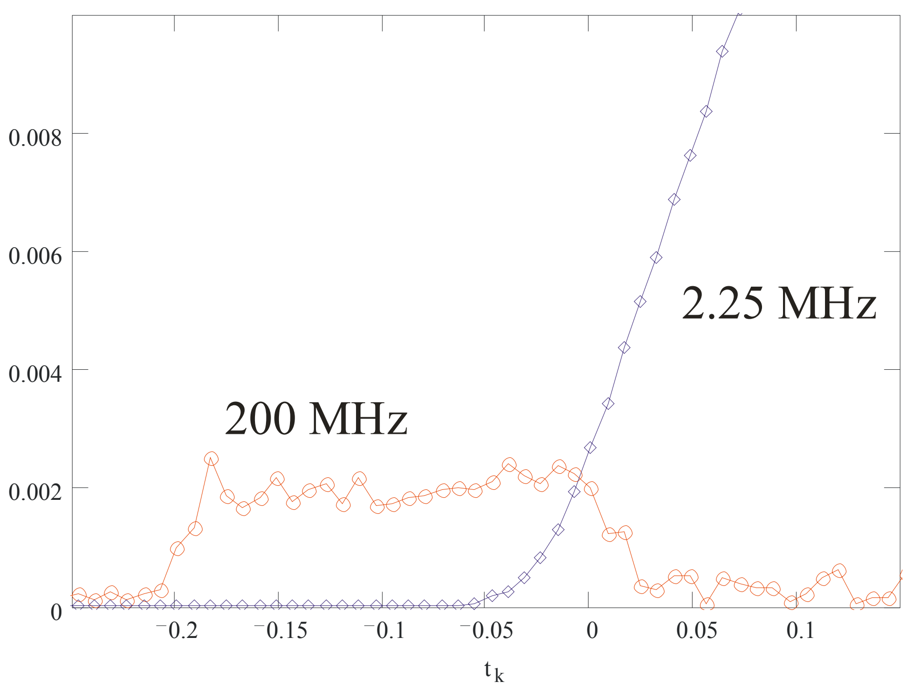
Pie data sampled at a faster rate



Pie data: 2 kS/pt at 2.5 GS/s or 0.8 μs/pt, data interpolated to 2^{11} for FFT

RWM data near injection





time (ms)

RWM data: 10 kS/pt at 1.25 GS/s or 8 μs/pt, data interpolated to 2^{14} for FFT

Comments on observations

In all cases above, the RCS bunch frequency signal is reduced by a factor of 20 with respect to the 200 MHz component.

Pie electrode data give the clearest indication of injected 200 MHz microbunches into the RCS ring. Pie output signal strength is proportional to dI/dt; therefore, within its bandwidth, the Pie electrode has an advantage over the RWM (signal proportional to I) for higher frequency data.

Pie data show an initial noise pedestal coincident with the introduction of linac rf into the DTL tank, this starts approximately 130 μs before the beam is injected into the linac.

Pie data show a rapid decrease in the 200 MHz signal immediately after injection. The second set of Pie data graphs indicate the 200 bunch signal drops into the noise in about 2 time increments or 1.6 μs, in good agreement with the calculated value above.

RWM data also show the noise pedestal associated with 200 MHz rf power being switched into the linac tank; however it responds very weakly to the injected beam from linac.

While the RFA was initially sensitive to 200 MHz beam, this no longer appears to be the case. Two possibilities for the change are 1) a relocation from a top port to a horizontal port, and 2) signal cable passing near a linac noise source.