EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE

CERN - PS DIVISION

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# INVESTIGATION OF CLEARING SWEEPS FOR PS BOOSTER BY MEANS OF SCHOTTKY SCANS

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## Abstract

The main purpose of the 17th November and 22nd November 1999 a.m. MDs was to investigate the effect of a clearing sweep scheme by means of the Schottky scan. The scheme is a sawtooth modulation of the high harmonic cavity frequency to pass empty RF buckets to and fro across the coasting beam frequency spread. A subsidiary purpose was to evaluate these scans as a means of finding the momentum distribution.
The purpose of the p.m. 17th November MD was, based on the archived MDPSB cycle, to fine tune the flat beams in all four rings ready for neutron TOF beam experiments by Roberto Cappi on Thursday 18th November.

Geneva, Switzerland
14 June 2000

# 1 Introduction

“Linac bubbles” are small voids in the injected beam phase space; they do not necessarily have 200 MHz time structure. Empirically it is found that sweeping C16 empty buckets through the coasting beam reduces the prominence of these bubbles. The precise mechanism by which this occurs is unknown, and investigations are under way to find/understand this mechanism. Earlier in the week, the HP 89410A had been instituted as a means of performing Schottky scans. This scan gives the incoherent frequency spectrum proportional to $\sqrt{N}$. However, if there are coherent signals present in the beam, the Schottky signal is swamped because the coherent signals scale as N, the number of particles involved. Ideally, the clearing sweep should leave no coherent signal. In practice, because it is a non-adiabatic procedure there are residual modulations. Moreover, the linac bubbles are themselves a source of coherent signals. Consequently, interpretation of the Schottky spectra is not necessarily straightforward. Nevertheless, because the BTFM was not operational at this time, the method of Schottky scans was the only one available to attempt to find the effect of cleaning sweeps.

# 2 C16 Off –17$^{th}$ Nov.

Measurements were made on ring #2 using the MEFLAT cycle at 50 MeV. Injection ocurs at 275 ms of the C-train. As a reference case, the high harmonic cavity was turned off, and the beam data collected as below. Most of the structure appearing in the waterfall plot of beam density versus time, Figure 1, is h=1. Injection of a partial turn accounts for the strong black and white band appearing at the base of the waterfall plot.

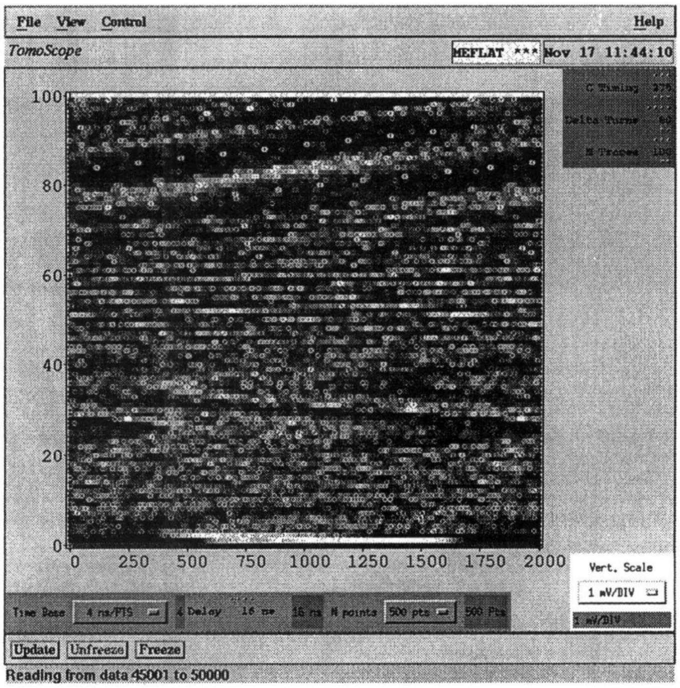



**Figure 1: C16 OFF, 3.3 turns injected, start @ injection, 80 turns/trace, 100 profiles, span 13.3 ms**

## 2.1 Momentum spread versus intensity

ΔT(keV)=192.8(eV/Hz)×Δf(kHz) @ h=1 @ 50MeV. The span of the Schottky scan is 60 kHz at h=6 and takes 4 ms to perform. The full width frequency spread in Figure 2 is ≈15 kHz, leading to a width of 480 keV.

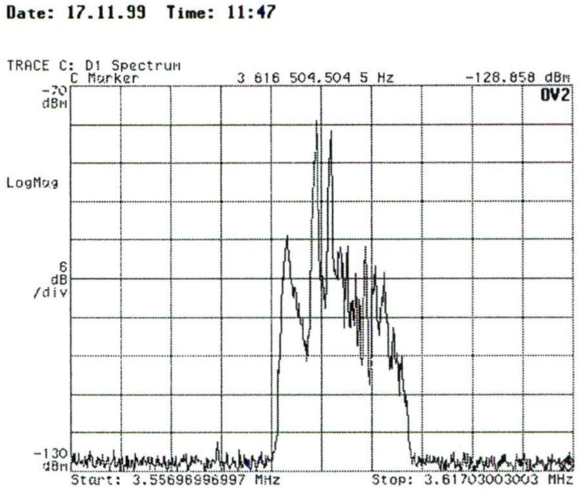



**Figure 2: C16 OFF, 1 turn injected, Schottky scan @ h=6, start @ C-train 300 ms .**

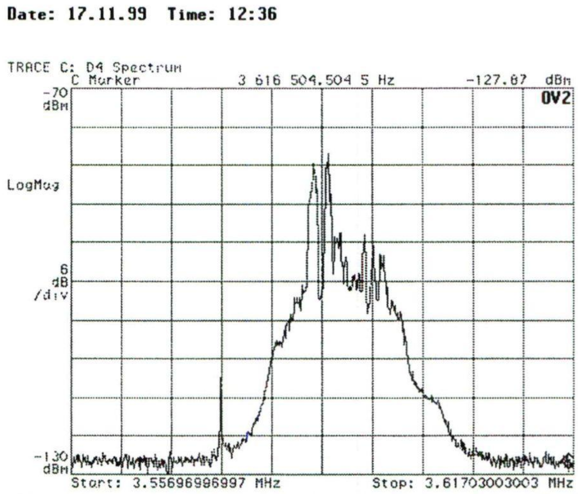



**Figure 3: C16 OFF, 3.3 turns injected, Schottky scan, start @ C-train 276 ms .**

The full width frequency spread in Figure 3 is ≈21 kHz, leading to a beam energy width of 670 keV. However, signals at the base are 42dB down from the peak. Since the spectral density is plotted on a log scale, the peaks are enormous and very narrow. It is more likely that they pertain to coherent signals than to truly enormous particle densities.

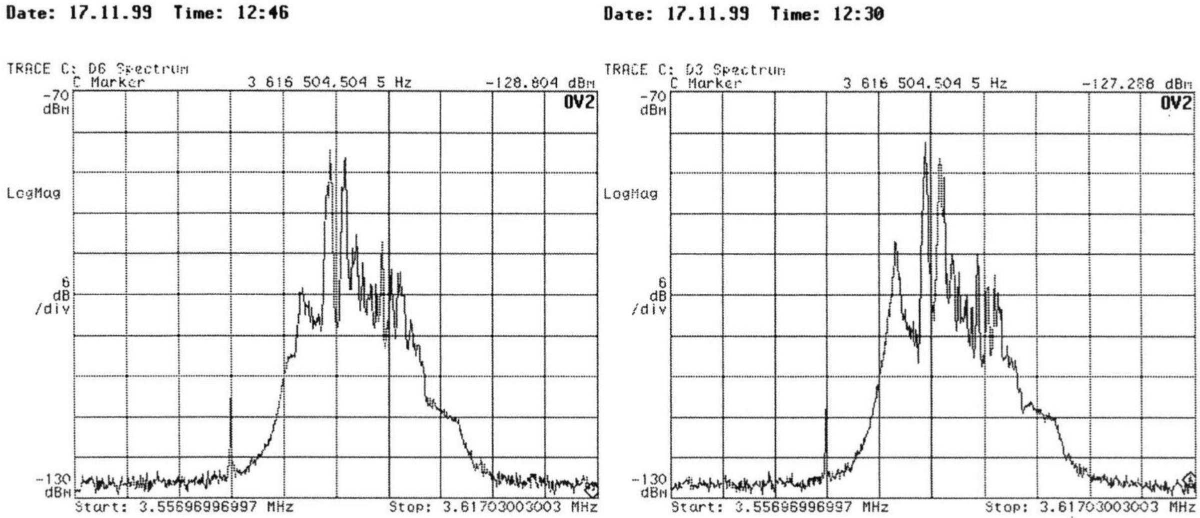



**Figure 4: C16 OFF, 3.3 turns injected; left => start @ C-train 283 ms; right=> start @ C-train 300 ms .**

Figure 3 and Figure 4 are sufficiently similar that differences between them can be attributed to "shot-to-shot" variations, rather than any evolution of the frequency distribution with time.

# 3 C16 Off – 22$^{nd}$ Nov.

Measurements were performed on ring #2 with an MEFLAT cycle at 50 MeV with the C02 and C04 cavities turned off. Beam injection occurs at 275 ms of the C-train.

## 3.1 Schottky scans versus beam intensity

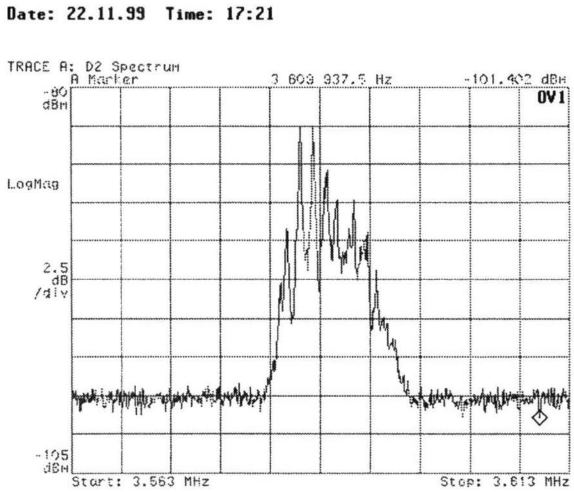



**Figure 5: C16 Off, 2 turns injected, Schottky scan, start @ 276 ms, span 60 kHz .**

The small forest of spikes appearing in Figure 5 may signal coherent perturbations such as "linac bubbles" rather than true spires of high particle density. Two turns were injected giving 1.6E12ppp.

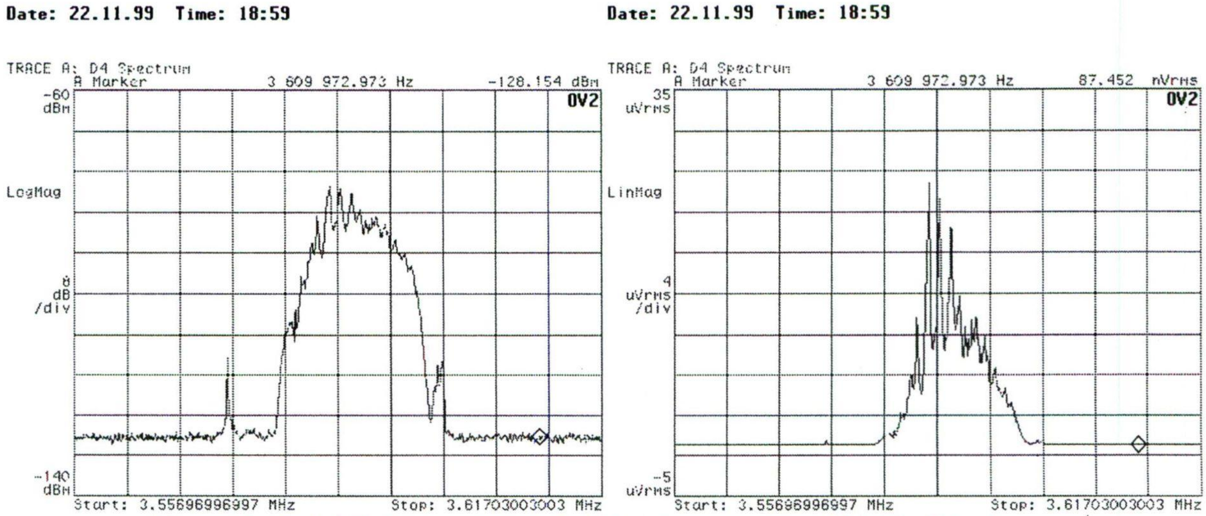



**Figure 6: C16 Off, 2 turns injected, Schottky scan, span 60 kHz @ h=6 .**

Apart from the change of vertical scales between figures 5 and 6, there are a host of potential reasons why these figures might differ, but it is hard to point to a particular one excepting that these data were acquired at different times. Figures 6 and 7 show more common spectra.

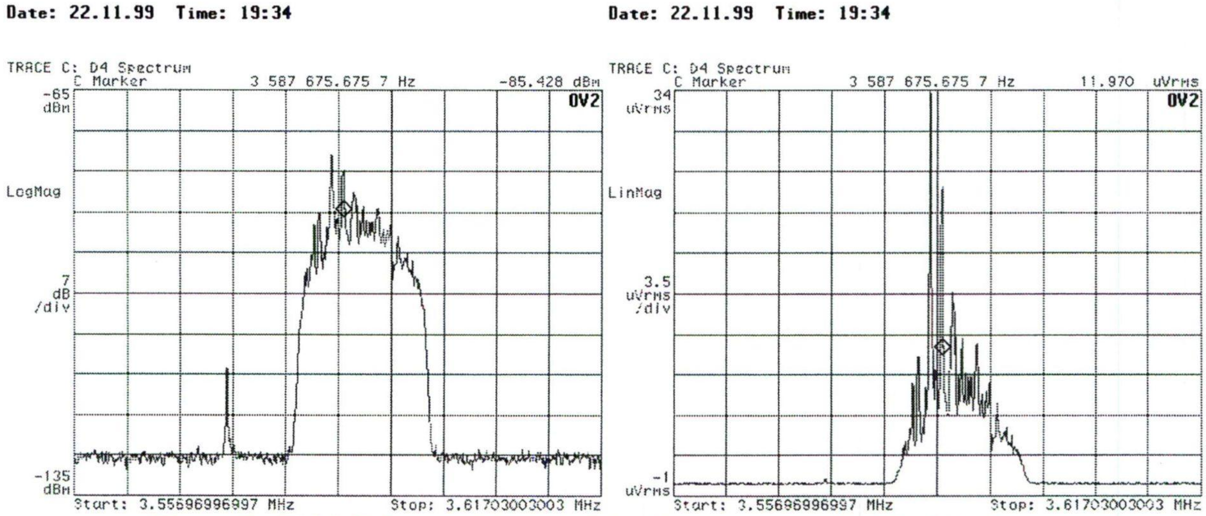



**Figure 7: C16 Off, 2 turns injected, Schottky scan, span 60 kHz @ h=6 .**

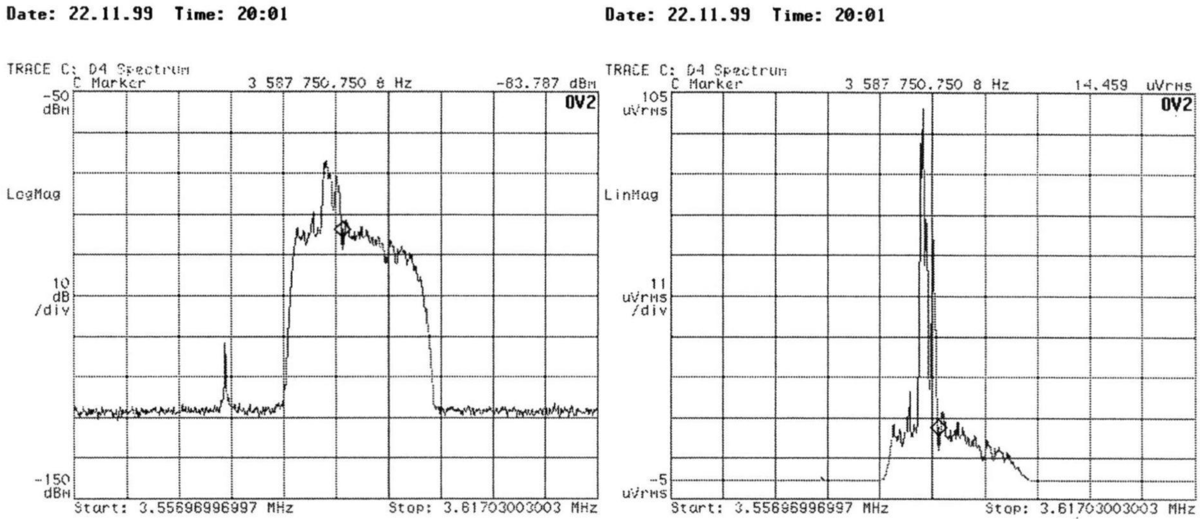



**Figure 8: C16 Off, 4 turns injected, Schottky scan, start @ 276 ms, span 60 kHz @ h=6 .**

Five injected turns seems to correspond to some kind of instability threshold, as the Schottky scans show large qualitative shot-to-shot variations; some of these spectra look like Figure 8 (4 turns) while many others are similar to Figure 9 (6 turns injected).

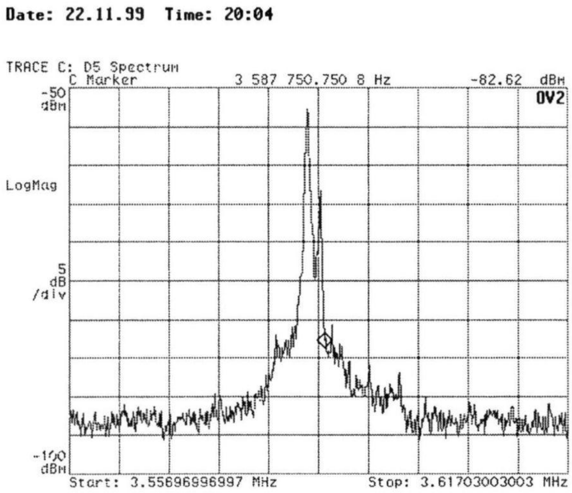



**Figure 9: C16 Off, 6 turns injected, Schottky scan, start @ 276 ms, span 60 kHz @ h=6 .**

The spectrum of Figure 9 was very repeatable and reproducible.

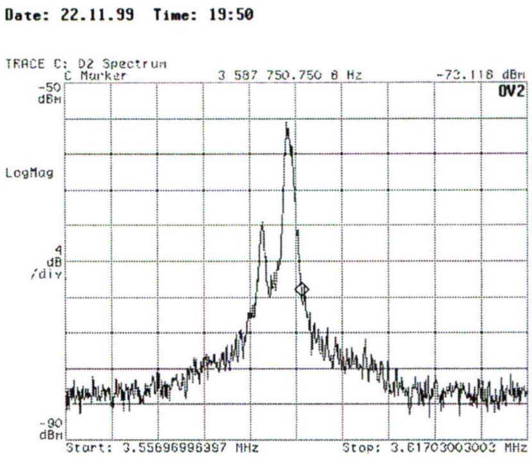



**Figure 10: C16Off, 10 turns injected, Schottky scan, start @ 276 ms .**

Because of the difficulty in differentiating between incoherent and coherent signals, it is not possible to say whether the twin peaks in Figure 10 and Figure 11 are due to a redistribution of particle density or to the presence of 2 coherent frequencies.

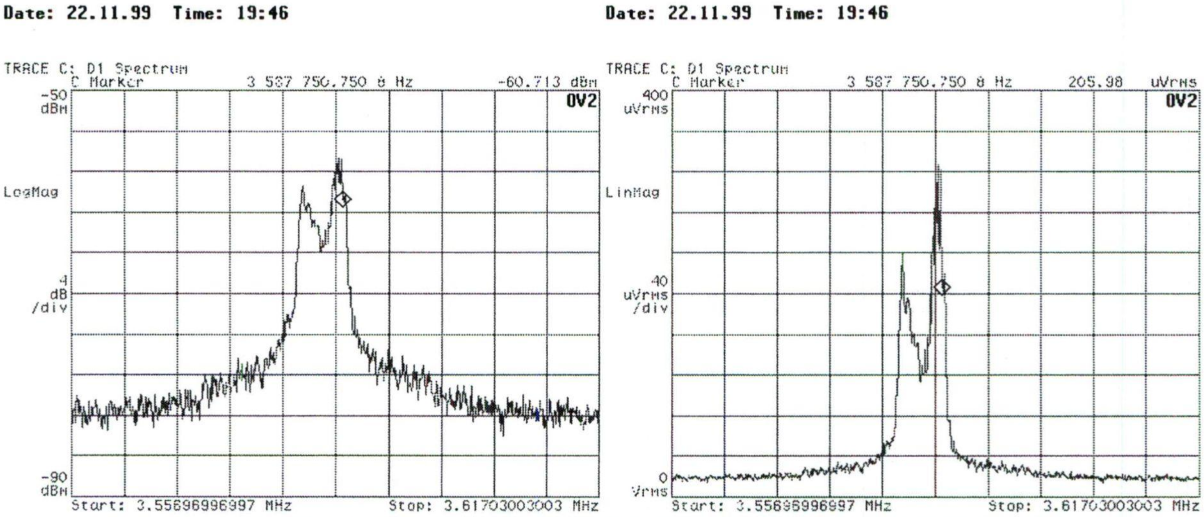



**Figure 11: C16 Off, 10 turns injected, Schottky scan, start @ 284 ms, span 60 kHz .**

# 4 C16 On, clearing sweep but no deposition – 17th Nov.

The clearing sweep is performed by the C16 cavity which can produce a wide range of harmonic numbers at the injection energy. Harmonic number 24 was chosen for the empty buckets, but because the abscissa of Figure 12 spans 1.2 turns there are 29 black and white stripes appearing. Quite a complicated sweep program was used. The radial position GFA (GSRPOS) is offset by –4 volts at injection, ramps up to +4 volts in 1.5ms, ramps down to –4 volts in 2.5 ms and ramps up to +4 volts in 1.5 ms, for a total of 5.5 ms. Because the C02 and C04 cavities are turned off, the GSRPOS offset could, in principle, remain at +4 V, but it is ramped down to zero after the C16 cavity voltage is reduced to zero so that it may be used as a reference frequency for the "tomoscope". The C16 voltage is maintained at 3 kV for 6 ms

starting at injection and then brought to zero. Hence, the C16 program is similar to Figure 23 but the voltage is turned off prematurely so that there is no empty bucket deposition.
The empty buckets sweep three times through the beam momentum distribution, and their effect is clearly seen in the 3 bands of tight black-and-white stripes in the lower portion of Figure 12. The grey bands between the stripes occur when the RF buckets are outside the beam frequency spectrum. The Schottky scans below commence at least 2 ms after the C16 cavity voltage tends to zero.

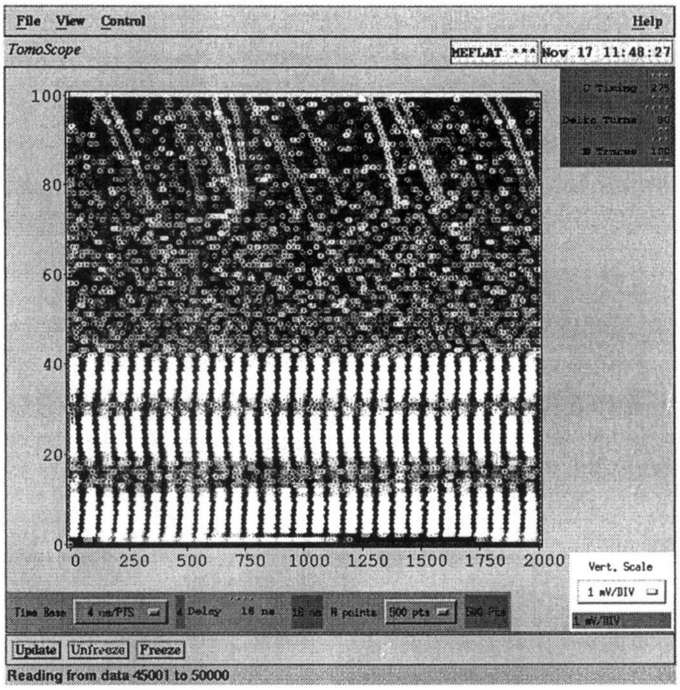
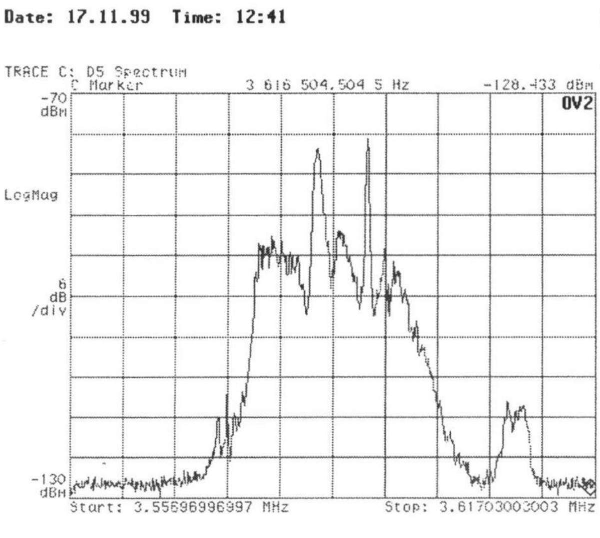



**Figure 12: C16 ON, 3.3 turns injected, 2.5E12 ppp .**



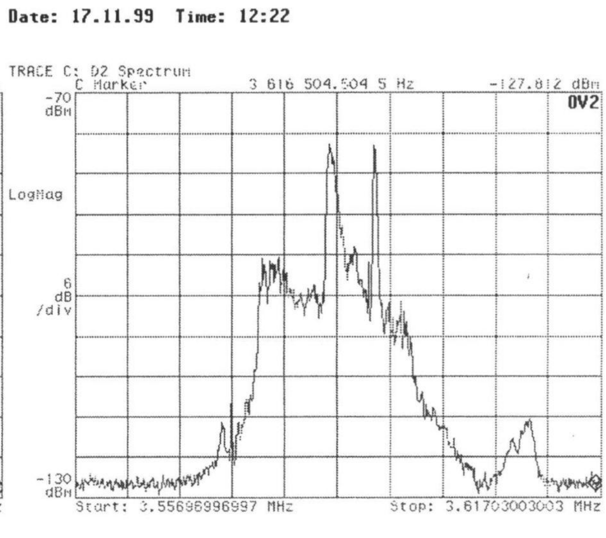



**Figure 13: C16 ON=3kV (GFA=3volt), Schottky scan; left => start @ C-train 283 ms; right => start @ C-train 300 ms .**

If one compares Figure 4 and Figure 13, it is clear that the sweeping significantly broadens the beam frequency distribution. The sub-peak at the right hand side of the main peak in Figure 13 (and absent from Figure 4) is evidence that the empty buckets are in fact not completely empty, but rather that their energy span is great enough to dip into the beam and redistribute particles. The left and right members of Figure 13 are sufficiently similar that we can infer no beam evolution during the 7 ms that separates them.

# 5 Various clearing sweep and bucket deposition schemes – 22nd Nov.

In chronological order, we began with a complicated scheme of three clearing sweeps followed by an empty bucket deposition, and end with a simple scheme involving only a bucket deposition. However, for clarity of exposition it is perhaps better to reverse the order and proceed from simple to complicated cases.

## 5.1 Empty bucket deposition only

The C16 cavity is excited at 24th harmonic (h=24) with the following program (similar to Figure 14). The gap voltage is maintained at 3 kV for 8 ms following injection and then turned down to zero. Using the radial position GFA (GSRPOS), the frequency is offset. The GFA starts at negative 4.5V and ramps linearly to 0.0V in 7 ms after which time it remains constant.

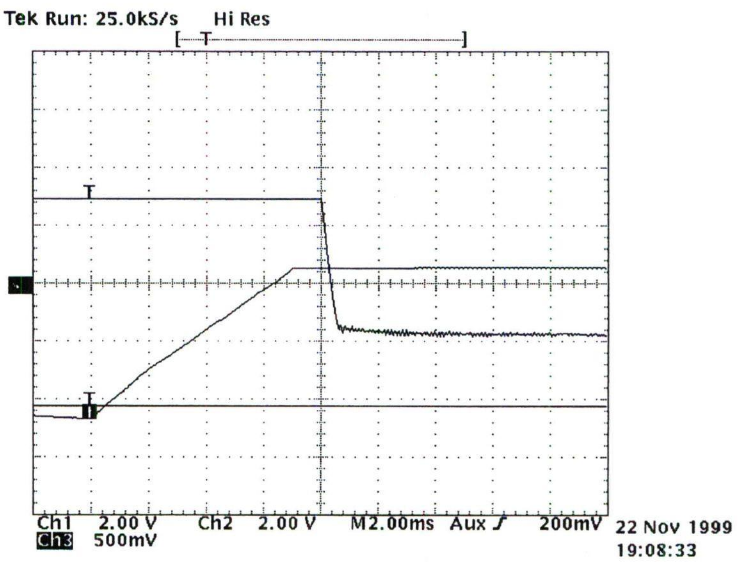



**Figure 14: C16 cavity voltage and frequency (channel #1) laws .**

The effect of the bucket deposition is clear in figure 15: a notch is introduced into the beam frequency spectrum. However, coherent signals remain giving rise to spikes which cannot be proportional to • N. Two turns were injected giving 1.6E12 ppp.

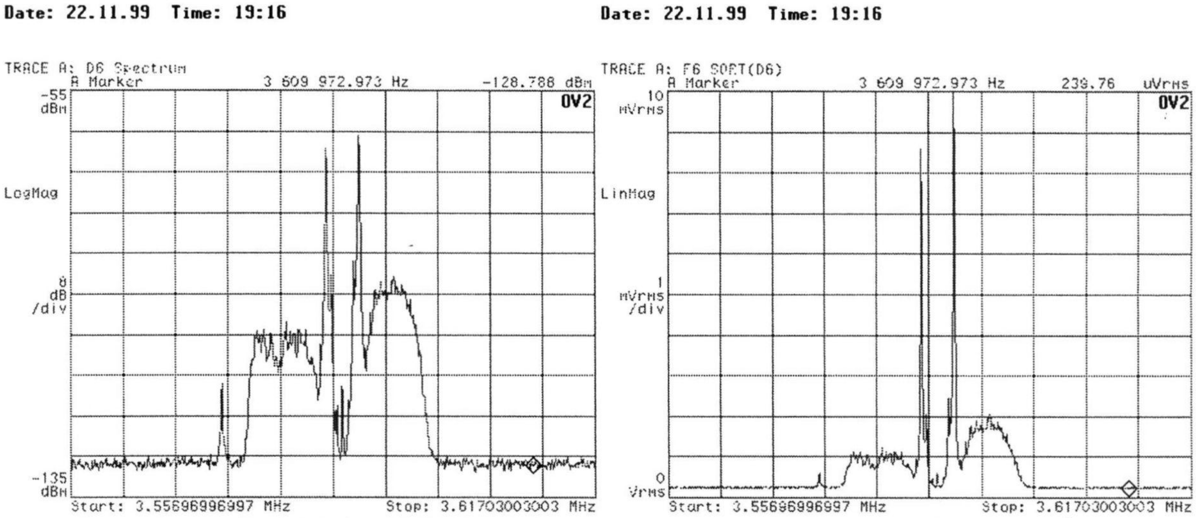



**Figure 15: C16 On, Δf GFA=0.0V at end, Schottky scan, start @ 284 ms .**

The final frequency at which the buckets are deposited was raised by increasing the final GFA offset to 0.2V, as in Figure 14, and the result appears in Figure 16. The notch does appear to move upward in frequency, Figure 15 versus 16, but it is difficult to argue this case with confidence.

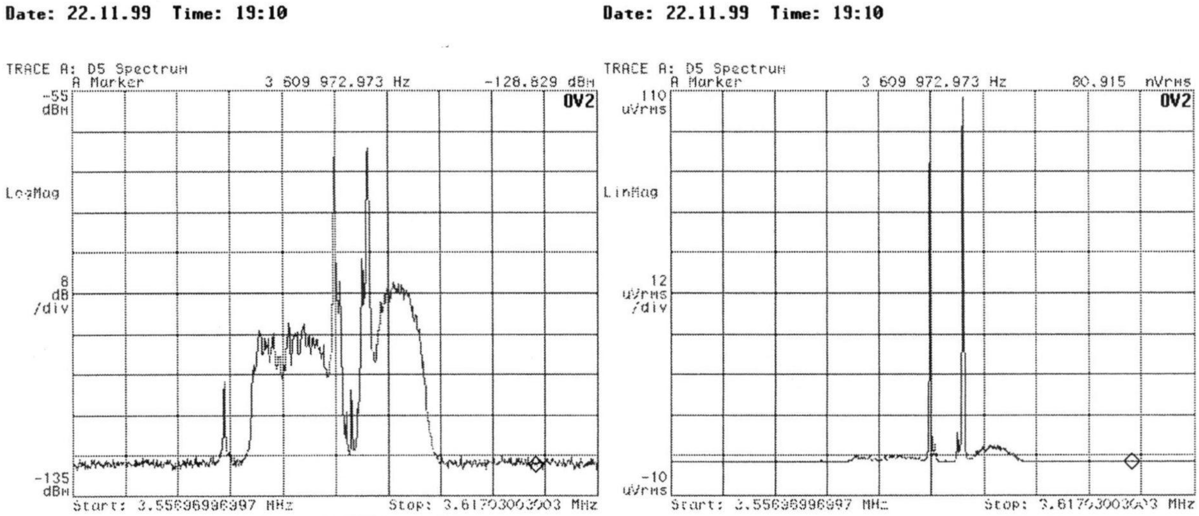



**Figure 16: C16 On, Δf GFA=0.2V at end, Schottky scan, start @ 284 ms, span 60 kHz .**

## 5.2 Single sweep and deposition

The C16 frequency program was modified as shown in Figure 17 the GSRPOS GFA rises from –4.5 to +4.5V in 4 ms and then ramps down to zero in 2 ms. The cavity voltage remains at 3 kV for 8 ms and then goes to zero. The final setting of the GSRPOS GFA was progressively reduced to see if, as anticipated, the notch in the frequency spectrum would move to lower frequency. Measurements were made with two injected turns (1.6E12ppp).

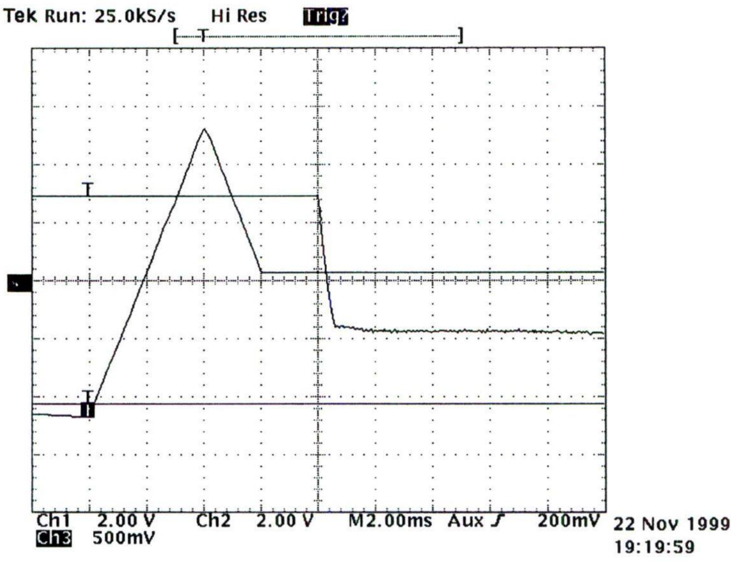



**Figure 17: C16 cavity voltage and frequency (channel #1) programs .**

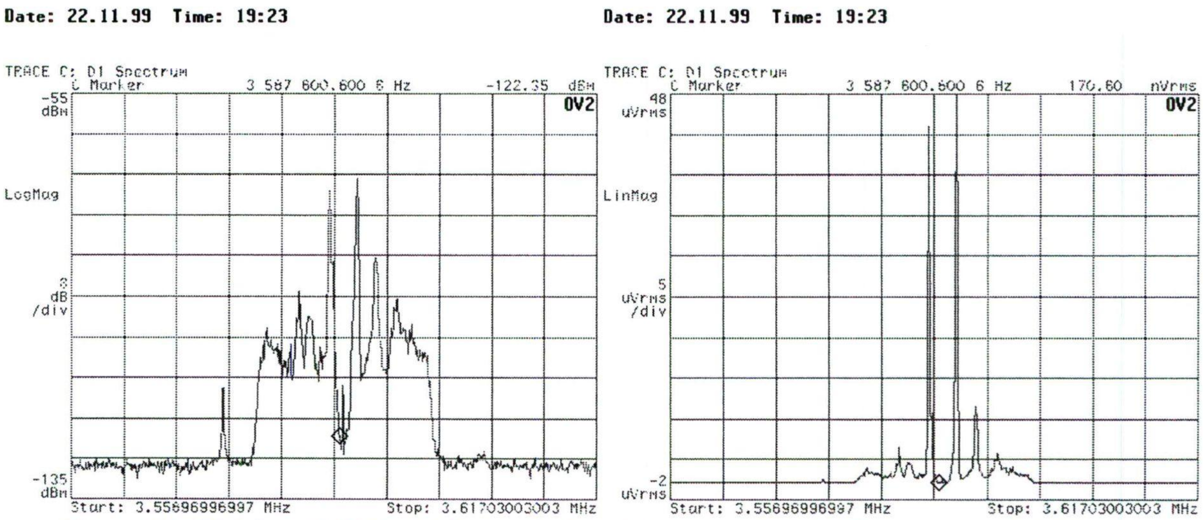



**Figure 18: C16 On, Δf GFA=0.0V at end, Schottky scan, start @ 284 ms, span 60 kHz .**

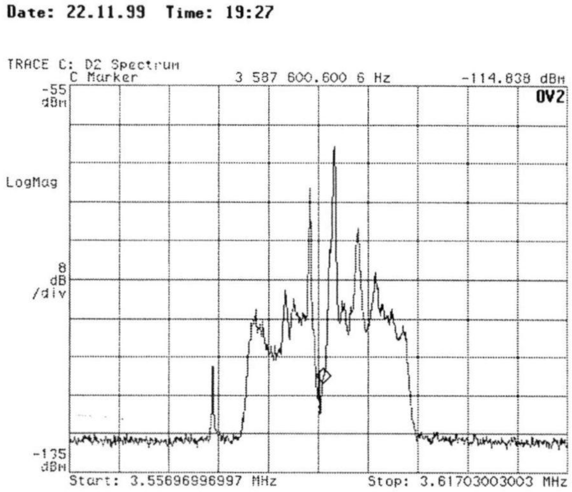



**Figure 19: C16 On, Δf GFA=--0.3V at end, Schottky scan, 2 turns injected .**

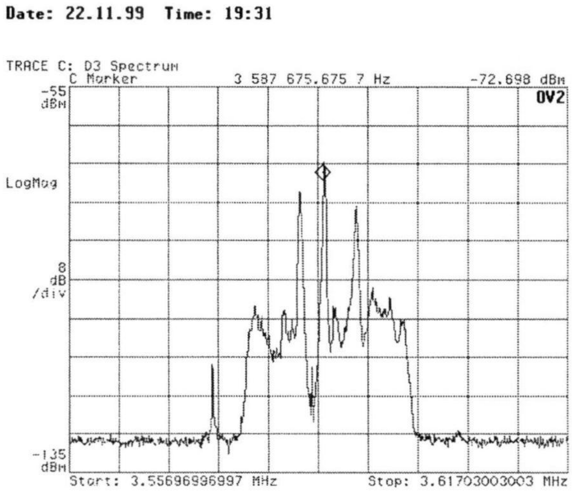



**Figure 20: C16 On, Δf GFA= --0.6V at end, Schottky scan, 2 turns injected .**

As anticipated, the notch in the spectra does move to lower frequency as the final value of the C16 frequency offset is reduced. What is also evident, if one compares figures 18, 19, and Figure 20 against figures 15 and 16, is that there are 3 rather 2 spikes in the spectra indicating that the clearing sweep has introduced additional coherent structure into the beam.

### 5.3 Dual clearing sweep, and deposition

The C16 cavity frequency law was modified yet again, as shown in Figure 21. Measurements were made with two injected turns (1.6E12ppp).

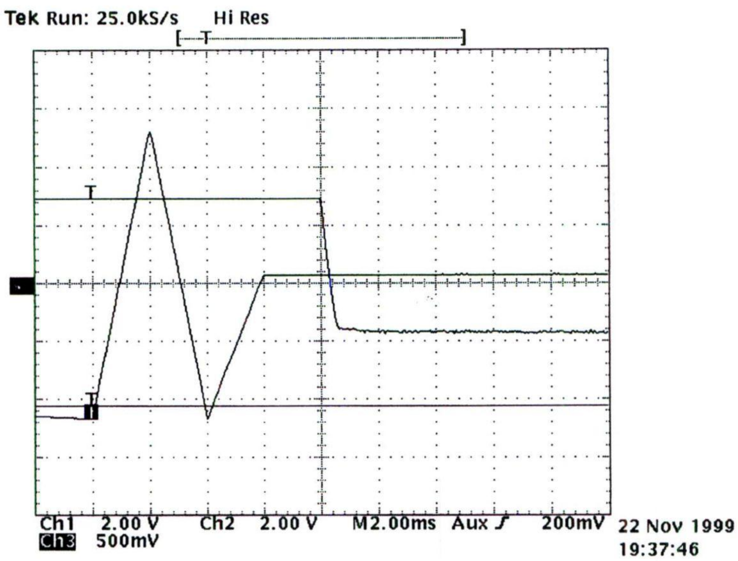



**Figure 21: C16 cavity voltage and frequency (channel #1) laws .**

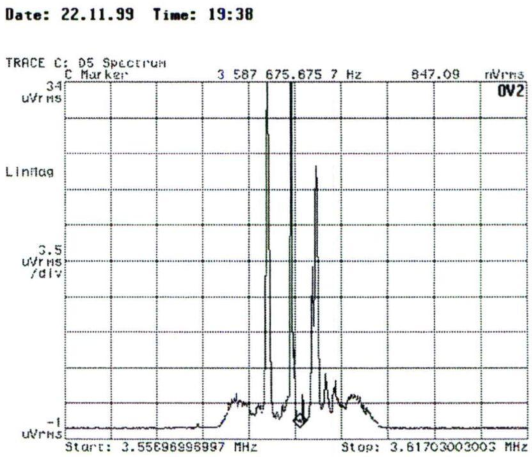



**Figure 22: C16 On, • f GFA =0.0V at end, Schottky scan .**

## 5.4 Triple clearing sweep, and deposition

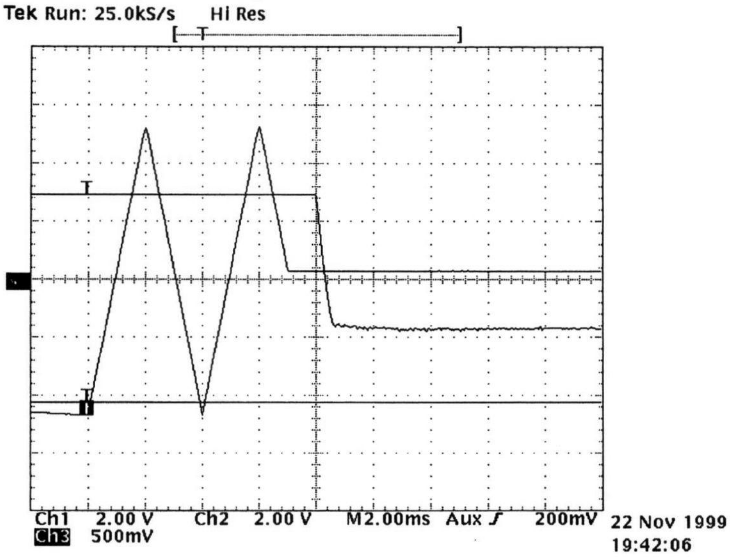



**Figure 23: C16 cavity voltage (3kV) and frequency (channel #1) laws .**

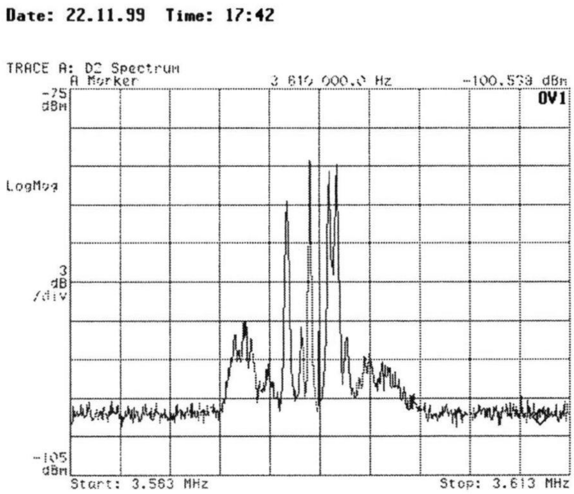



**Figure 24: C16 On, 3kV, Δf GFA=0.0V at end, Schottky scan, start @ 283 ms, span 60 kHz .**

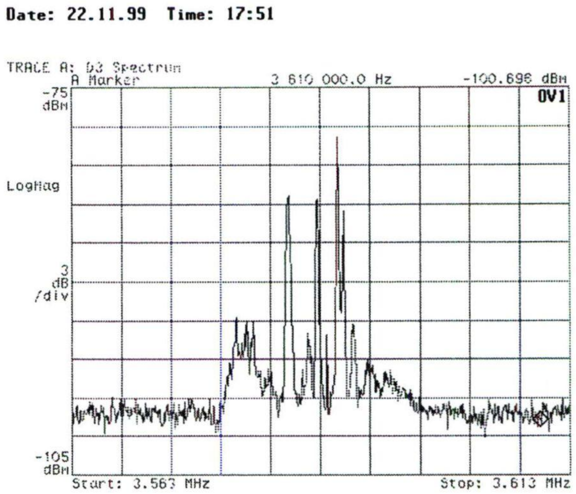



**Figure 25: C16 On, 3kV, Δf GFA=0.2V at end, Schottky scan, start @ 283 ms, span 60 kHz .**

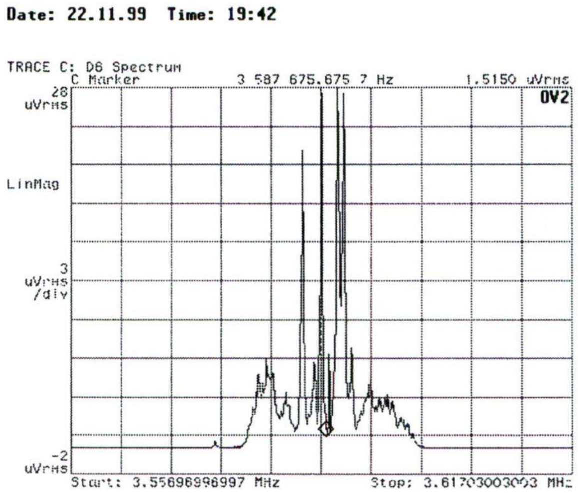



**Figure 26: C16 On, 2 turns injected, Δf GFA=0.0 at end, Schottky scan, start @ 284 ms .**

The instability that causes a redistribution of the beam phase-space occupancy with C16 Off, also occurs when the beam has been manipulated with empty bucket sweeps. Compare Figure 26 and 27, two versus ten injected turns, and note that no coherent structure from the sweeps survives the instability.

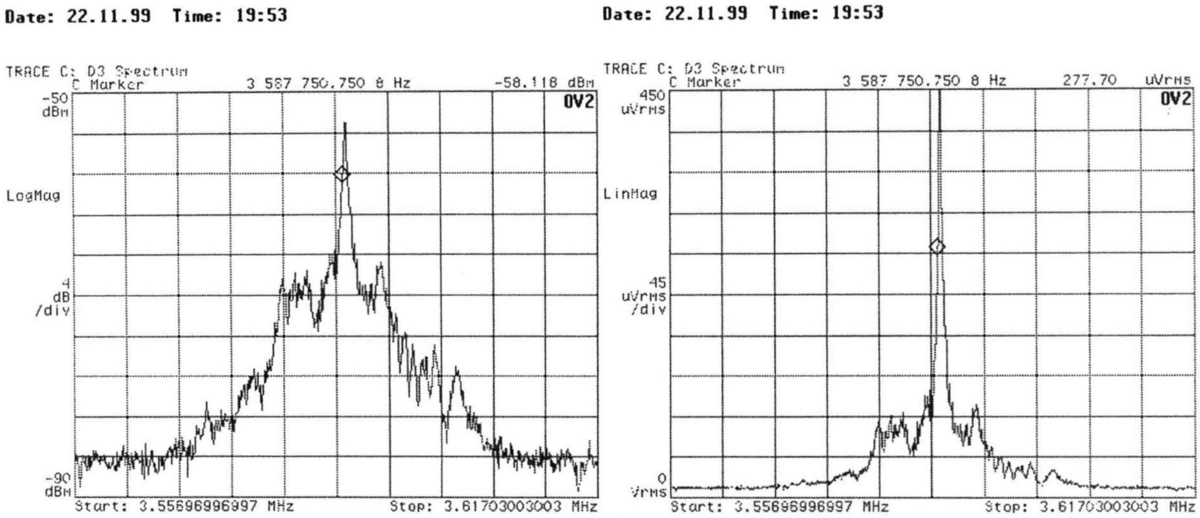



**Figure 27: C16 On, 10 turns injected, Δf GFA=0.0 at end, Schottky scan, start @ 284 ms .**

# 6 Set up for MDPSB – 17th Nov.

Capture of a beam into which high harmonic holes have been deposited leads to a hollow phase space distribution, the projection of which gives a flat bunch. During the 17th November p.m. MD, we fine tuned the "flat beams" in all four rings ready for measurements on the TOF beam by Robert Cappi on the 18th. This went quite smoothly, and it was given a final adjustment on Thursday 18th November as shown in Figure 28.

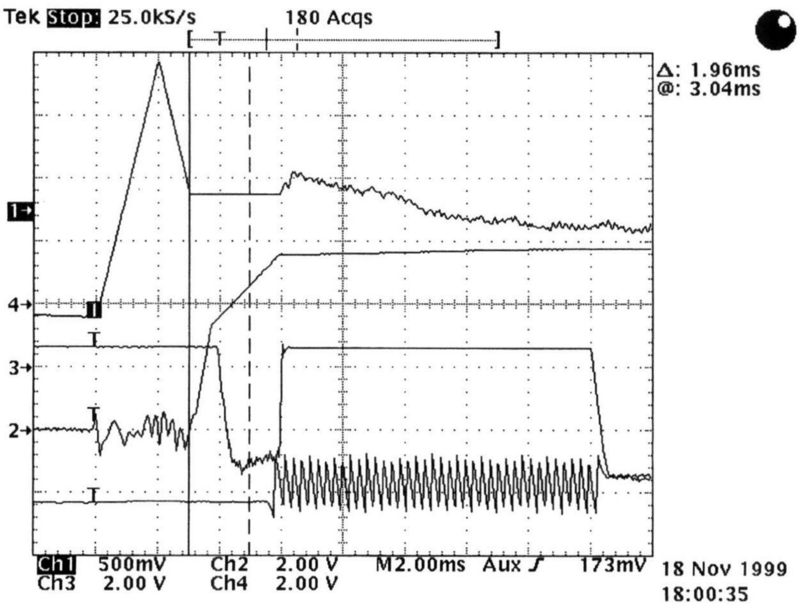



**Figure 28: Δ-f program (trace 4), the C02 gap detect (trace 2),the C16 gap detect (trace 3), and a signal indicative of the RF burst used for the blow up (trace 1).**

Notice that only a single cleaning sweep is used before the bucket deposition. The frequency offset for the blow up is accomplished by an additional GFA set to 6 volt which yields an

11.76 kHz offset. The flattened bunch, at a time shortly before extraction, is shown in Figure 29.

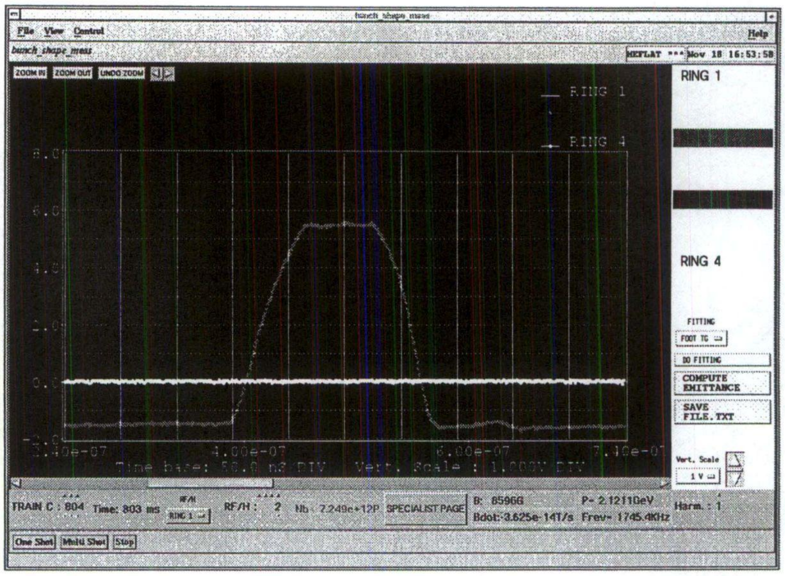



**Figure 29: bunch shape as monitored by capacitive pick-up at 801 ms of the C-train .**