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Long storage of short single bunches
Transverse Schottky scans of continuous beams

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Summary

The lifetime dependence of stored single bunches on the noise level and the synchrotron frequency spread has been investigated systematically. The lifetime is inversely proportional to the noise level and to the square of the synchrotron relative frequency spread. With the smallest bunches and higher RF voltage available at present, instantaneous lifetimes of 30 hours have been achieved (measured after 2 hours of storage).

An experimental transverse Schottky set-up has been tested with continuous beams. Signals obtained with debunched beams are very clean. It was possible to see the narrow betatron lines of a bunched beam.

1. Single bunch storage

Up to now the behaviour of intense bunches of 10^{11} p (the design proton-antiproton intensity) had been studied. This intensity can be achieved only by injecting the beam at 15.8 GeV, the SPS transition energy being lowered from the usual 22.2 to 13.4 GeV[1]. This unfortunately also lowers the available bucket area at high energy. As we wanted to study the behaviour of short bunches in larger buckets, we had to abandon momentarily this scheme and inject below transition. The intensity which can be accelerated in one bunch is then limited to 3.5 10^{10} p.

With our maximum RF voltage of 4.7 MV, bunches of 450 mrad emittance can be stored at high energy with lengths down to 1.5 ns (we store now systematically at 270 GeV/c). The behaviour of these short bunches is quite different from the behaviour of the 2.5 - 3 ns long bunches studied up to now. With long bunches, the instantaneous lifetime (logarithmic decay time measured in, say 10 to 15 minutes) settles rather rapidly to a steady value, and the bunch length does not change much. With short bunches, on the contrary, the initial lifetime is large (50 hours, comparable to what is measured with continuous debunched beams) but the bunch length slowly increases, the lifetime decreasing accordingly. This is closer to the behaviour displayed by ISR bunches [2]. To make comparison, we always measure a characteristic lifetime τ_L after two hours of storage.

On Fig. 1 the τ_L values measured under widely differing conditions of energy, intensity, RF voltage and transition energy, are plotted against the inverse square of synchrotron frequency spread calculated from the bunch length. An empirical law is found: the lifetime is proportional to the inverse square of the relative spread. (Note that according to available theory 2), the absolute spread $\Delta\Omega s$ should be considered.)

For a constant beam emittance, the synchrotron spread varies as the square root of the RF voltage. So under the conditions now prevailing in the SPS (RF loops, noise level) the lifetime is proportional to the RF voltage, and to reach the 30 hours lifetime of 1.5 ns bunches with the nominal antiproton emittance of 880 mrad 3) an RF voltage of 18 MV would be needed.

More refined measurements of the beam noise level have been made. Fig. 2 shows an example of the spectral analysis of the peak detected signal from a wide-band sum pick-up. The spread of the synchrotron frequencies is visualized, in good agreement with the value calculated from the bunch length. Moreover, the order of magnitude of the 2 Ωs spectral line corresponds to what can be calculated from the Schottky noise theory. Any disturbance to the beam should therefore show up as an increase of the signal level. Such spectra have been recorded for different settings of the radial loop bandwidth: the height of the signal goes down when the bandwidth of the loop is reduced below the synchrotron frequency, as was expected, showing that the RF noise level is reduced, giving longer lifetimes.

It is thought that more information can be gained from such measurements, and also by measurements of the noise levels in the low level system, and this line of work will be pursued.

A specific experiment has been made to see if the noise of the RF amplifiers themselves was important: cavity 1 was disconnected from the phase loop and the lifetime recorded. No change could be seen, so the conclusion is that the noise of the amplifiers proper is not important under present conditions.

2. Betatron Schottky bands of a continuous beam

The principle of the set-up used had been described previously 3). To increase the signal to noise ratio, a special 3 m long horizontal pick-up has been built 4). Both plates are movable radially, so that one can, once the beam is stored at high energy, match the electrodes gap to the beam width. For a given resonating coil, a series of gap widths can be used, each corresponding to a given observation frequency range between two successive harmonics of the revolution frequency. The coil used in these measurements had been matched for a frequency around 5.6 MHz, the corresponding P.U. gap width being 10 mm. The bandwidth covered is 40 kHz.

Fig. 3 shows the vertical betatron lines obtained on a debunched beam of about 10^{12} particles. The working point being near to the diagonal, vertical lines are visible as well on the horizontal plates. The slow wave signal has been reversed and superimposed on to the fast one.

Fig. 4 shows the longitudinal line at 5.6 MHz which gives the momentum distribution in the beam. The vertical Q distribution of the beam straddles a systematic 7th order resonance, to which the marked asymmetry of the lines can be attributed. (The momentum distribution shows no such asymmetry, so it has to come from betatron amplitudes.)

Fig. 5 shows the horizontal line. The Q_H distribution straddles a 5th order resonance, which probably gives the observed structure. From the width of these lines, one concludes that $\Delta p/p = 7.7\ 10^{-4}$, horizontal chromaticity $\xi_H = .47$ and $\xi_V = .37$ (values measured with radial bumps and Q kicker on the flat top before storing the beam were respectively + .44 and + .38).

Fig. 6 shows how the horizontal Schottky line evolved when the beam was scraped horizontally by 25%. Much of the structure disappeared, and during the following almost two hours the amplitude increased, probably a signature of a beam size growth.

An attempt was made at observing the betatron Schottky lines of a bunched beam. First the plates were centred carefully around the debunched beam, to an accuracy of 0.05 mm. The best common mode rejection achieved was such that the longitudinal line was 13 dB below the betatron lines. Under these conditions a bunched beam was stored, and the spectrum observed.

Around each coherent line at harmonics of the revolution frequency one saw a wealth of 50 Hz sidebands almost masking the synchrotron frequency satellites. After a careful search and knowing where they ought to be, the betatron lines were finally uncovered from the background. Fig. 7 shows how they appeared to move when Q changes were asked for from the main quadrupole power supplies.

It should be noted that in this experiment we benefitted from the fact that the structural beam lines at 5.6 MHz are much reduced compared to the 200 MHz lines (continuous bunched beam). Observing the betatron bands of a single bunch will be much more difficult, and very sharp filters will have to be used.

3. Conclusion

The already known dependence of the single bunch lifetime on the noise level and the frequency spread has been confirmed over a wider range of parameters. No progress has been made on reducing the noise level, but observation tools are being sharpened.

The observation of transverse Schottky bands of a debunched beam is at hand although not yet in a very convenient form. Much effort has still to be devoted to the observation of betatron bands of single bunches.

References

1) SPS Improvement Report No. 154.
2) S. Hansen et al., Particle Accelerator Conference 1977,Chicago, p. 1452-54
3) SPS Improvement Report No. 163.
4) W. Scandale, SPS/AC/Tech.Note/79-3.

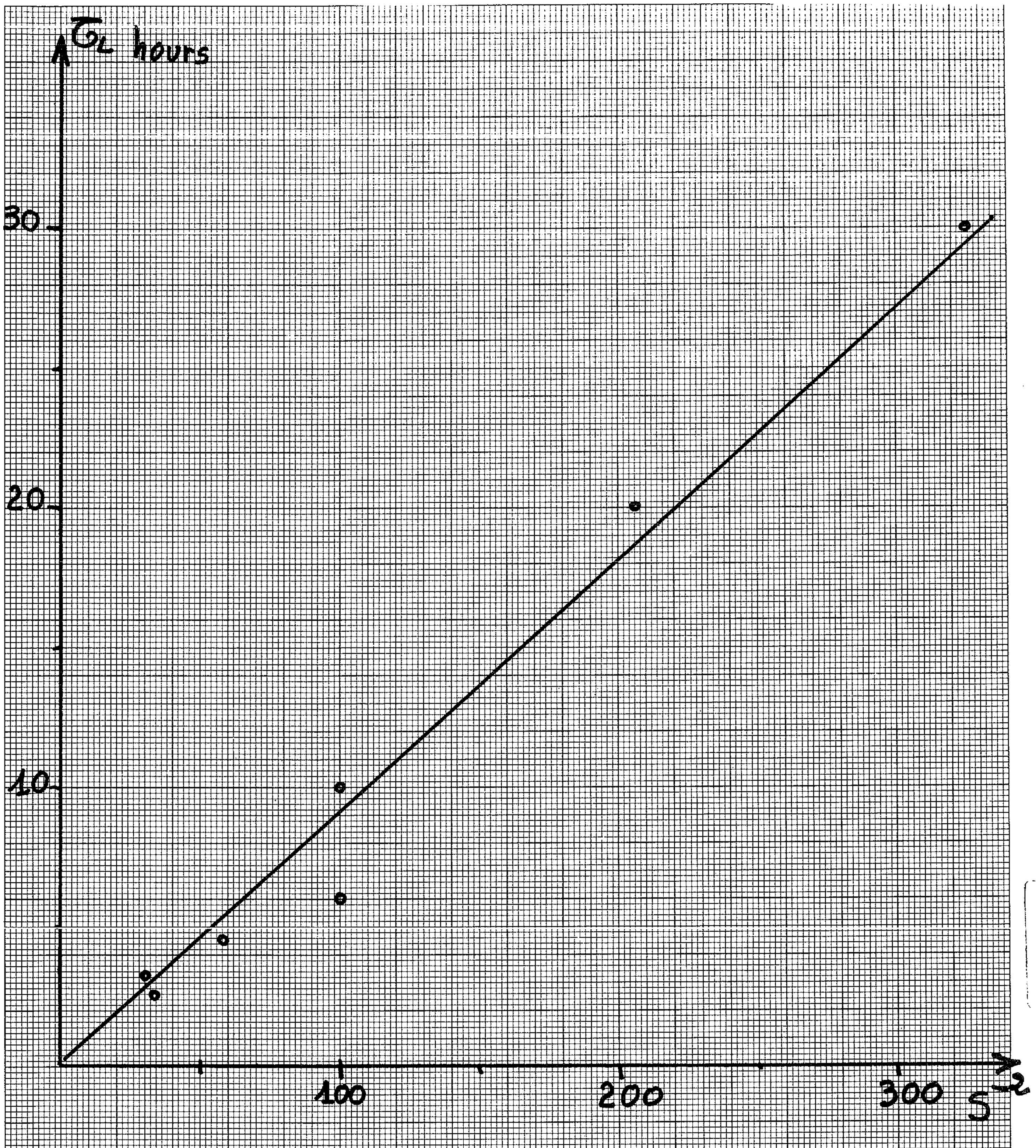

Fig. 1 : Lifetime variation with frequency spread

$$S = \frac{\Omega - \Omega_0}{\Omega}$$

Radial loop bandwidth: 10 Hz

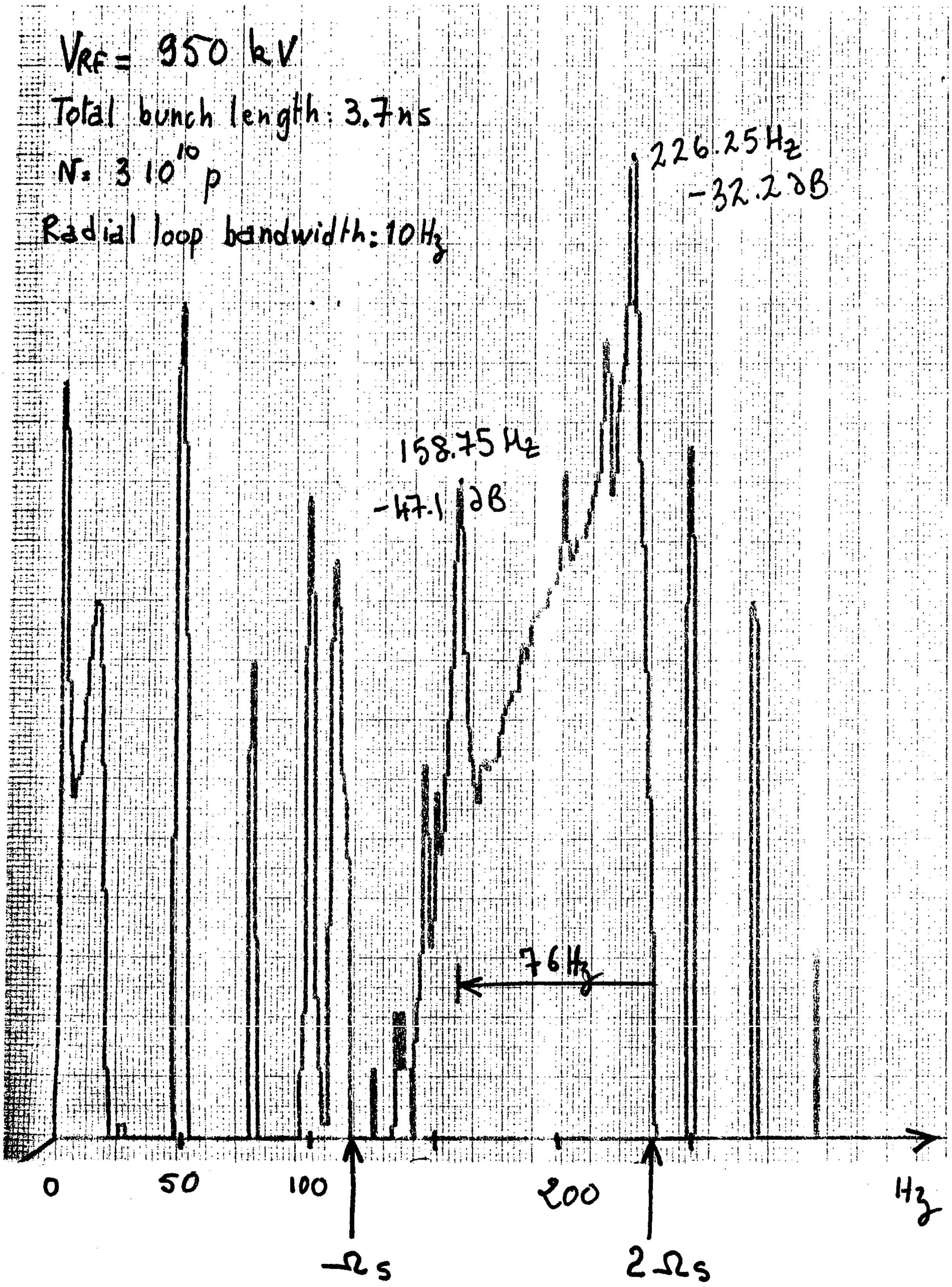

Fig. 2 : Synchrotron frequency spread revealed by Schottky spectrum of peak detected wide band P.U signal. Spread calculated from bunch length: 76 Hz

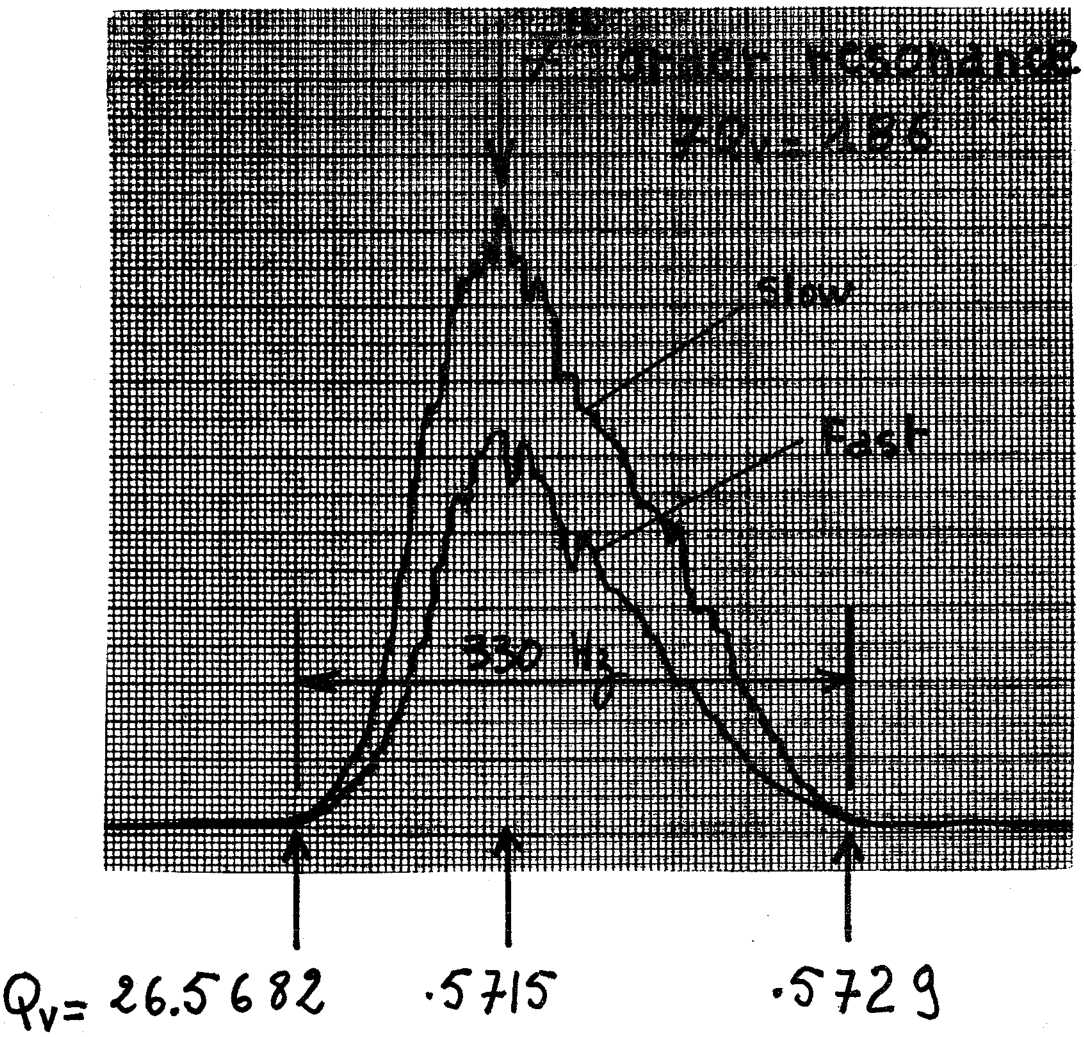

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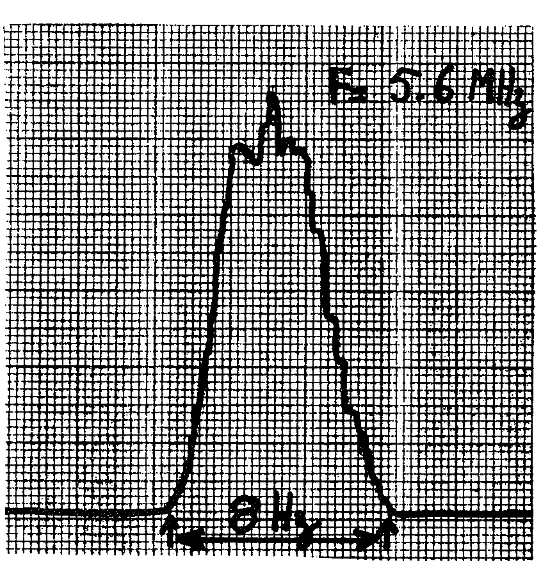
Fig. 3:

Fast and slow vertical Schottky Lines superimposed (the slow is reversed).

Fig. 4 : Longitudinal Schottky line $\frac{\Delta p}{p} = 7.7\ 10^{-4}$



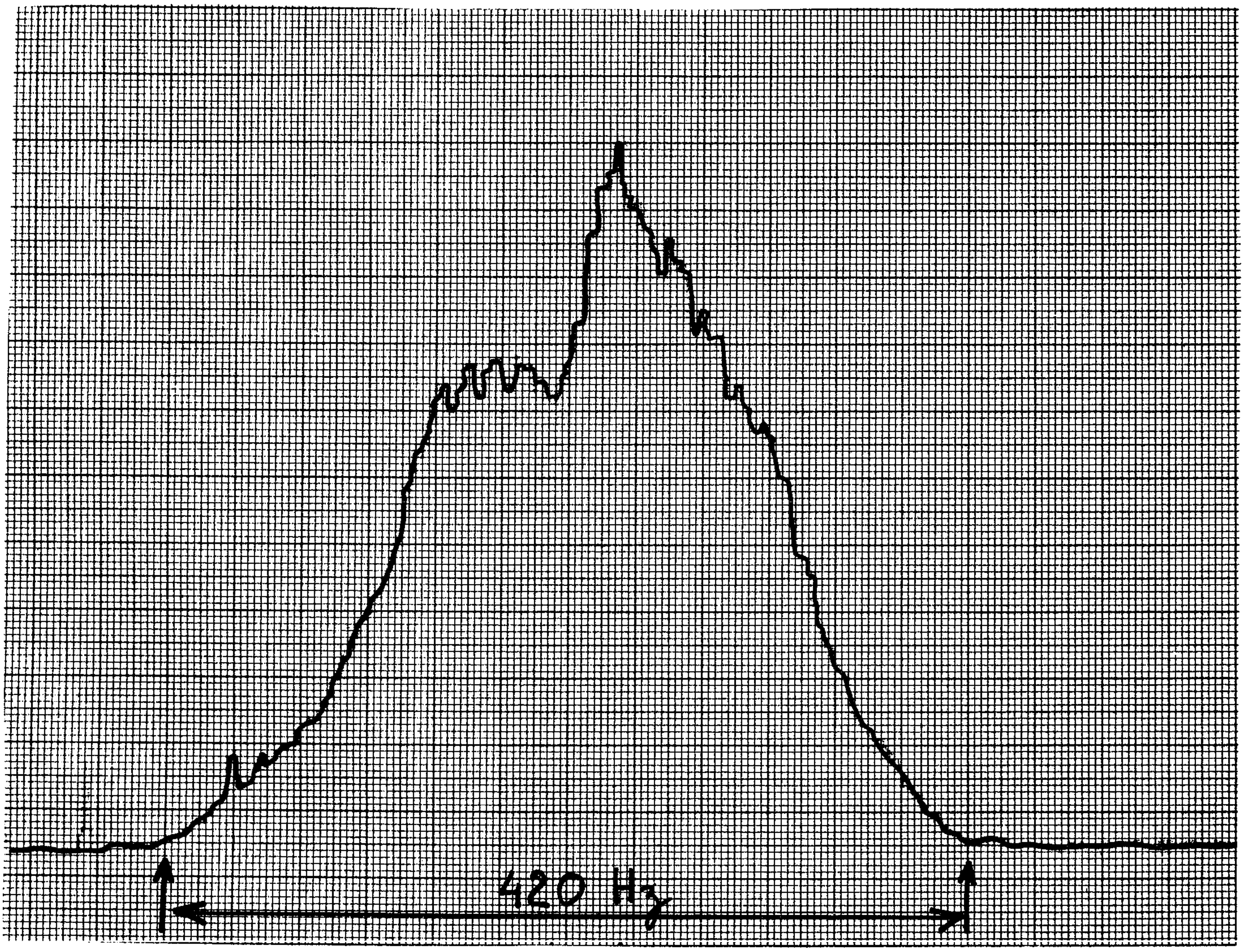


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Fig. 5 : Horizontal slow Schottky line
The beam overlaps a 5th order resonance ($5Q_H = 133$)
$\xi_H = +.47$

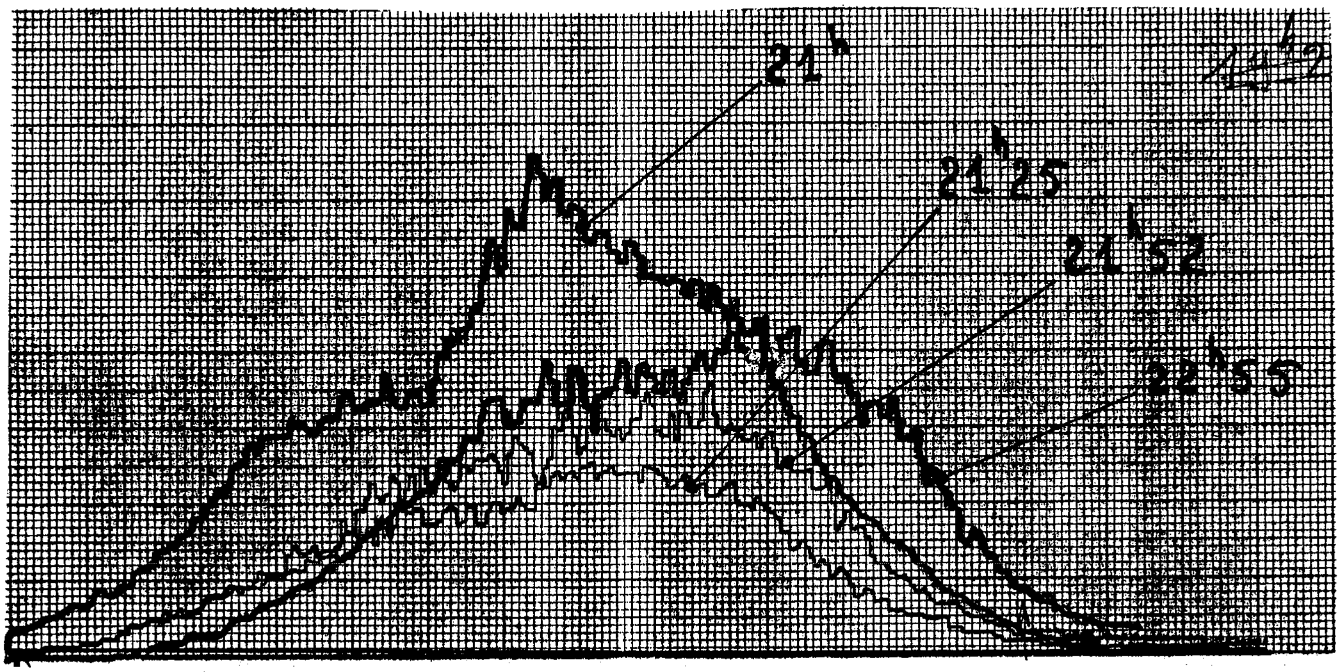

Fig: 6: Horizontal line before and after scraping 25% of the beam

(scraping occured at 21^h05)

$\Delta Q_H \sim .009$. The beam straddles a 5th order resonance

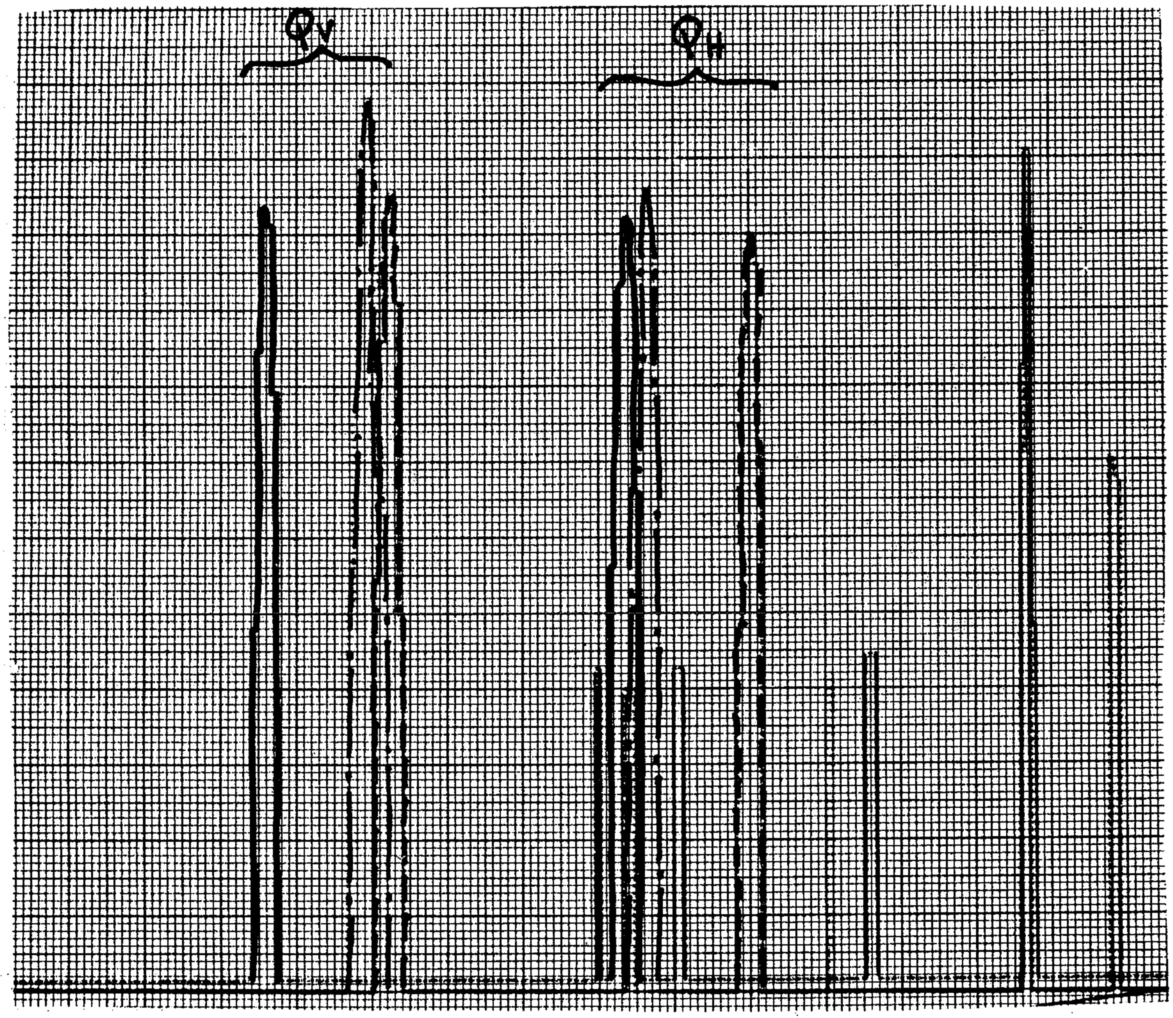

Fig 7 : Betatron Schottky lines of a bunched beam

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\- - - - - initial positions

—.——.— Q change asked for: $\Delta Q_H = -.01$
$\Delta Q_V = 0.$

——————— Q change asked for: $\Delta Q_H = 0.$
$\Delta Q_V = -.01$

Spurious lines on the right do not move.
Q modulation amplitude due to chromaticity $\sim .005$