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Trimming Longitudinal Emittance of Au77+in the AGS

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Trimming Longitudinal Emittance of Au^{77+} in the AGS

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Reported by: D. -P. Deng
Machine: AGS
Beam: Gold 77+ Ions
Tools: LeCroy 7200A scope, LeCroy 9040 scope F20 wall current monitor.

1 Introduction

In FY93 gold run for SEB in AGS, the injected bunched beam from Booster was debunched into a ribbon beam and then adiabatically captured into 12 bunches.

In this report, we studied a method—bucket squeezing—to trim the longitudinal emittance during the acceleration cycle in at the expense of reduced beam intensity.

Longitudinal emittance is usually defined by the **macroscopic** area occupied by 95% of the particles in the longitudinal space. One pair of commonly used cannonical variables in the longitudinal space are the rf phase ϕ and $W = (E - E_s)/\omega_{rf}$ the energy difference from the synchronous energy divided by the angular rf frequency. Thus the longitudinal emittance takes the unit of the product of energy (electron volts) and time (seconds) or $eV\,s$. For heavy ions, a convenient unit is electron-volt-second per nucleon or $eV\,s/u$, the total emittance divided by the total number of nucleons. The longitudinal emittance is a conserved quantity under adiabatic and no beam loss conditions. Any non-adiabatic changes, such as transition crossing, can only increase the emittance.

In this report, we use the bunch size, bunch area and longitudinal emittance interchangeably.

2 A bunch in a bucket

A bunch is accelerated in a bucket provided by the rf system. The size of the bucket at certain energy is solely depended on the total rf voltage V_{rf} and the rate of change in the magnetic field $\dot{B}$.

$$\frac{1}{2}AW^2 = -B(\cos\phi - \cos(\pi-\phi_s) + (\phi - \pi + \phi_s)\sin\phi_s) \quad (1)$$

$$V_{rf}\sin\phi_s = 2\pi R_0 \rho \dot{B} \quad (2)$$

where

ϕ_s: the synchronous phase,

$A = \eta\omega_{rf}^2/Es\beta^2$,

$B = eV_{rf}/2\pi h$,

$\eta = 1/\gamma_{tr}^2 - 1/\gamma^2$,

Es: synchronous energy,

$\beta = v/c$: ratio of the speed of synchronous particle to that of light,

e: charge state of the particle,

V_{rf}: rf volts,

h: harmonic number, the ratio of the rf frequency to the revolution frequency of the synchronous particle,

R_0: the average radius of the orbit,

$\dot{B}$: rate of change in the magnetic field in the orbit,

ρ: the magnet bending radius.

These equations determine the shape of the bucket, see Figure 1. The size of the bucket critically depends on the synchronous phase ϕ_s, if $\phi_s = \pi/2$, the size of the bucket goes to zero. Usually the $\dot{B}$ is programmed a priori, then the gap volts is the only handle to change the size of the bucket.

It is obvious that the bucket has to be bigger than the bunch, otherwise beam is lost. This is also the basis to trim the longitudinal emittance by decreasing the size of the bucket below the size of the bunch non-adiabatically, see Figure 2. As long as the magnetic field is rising the beam outside the bucket will be driven to the beam catcher.

3 Experimental results

The experimental technique is very simple. When rf voltage is suddenly dropped down to sufficiently low, the bucket size will shrink below the size of the bunch. All the particles outside the smaller bucket are gone very quickly. The beam longitudinal emittance is essentially the area of the smaller bucket. As the rf voltage is adiabatically raised, the beam maintains its latter longitudinal emittance.

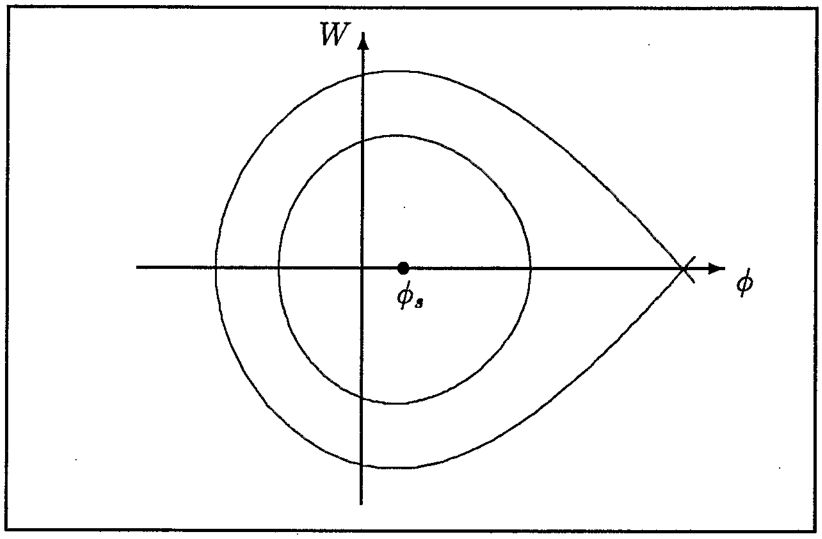

Figure 1: A bunch is inside a bucket

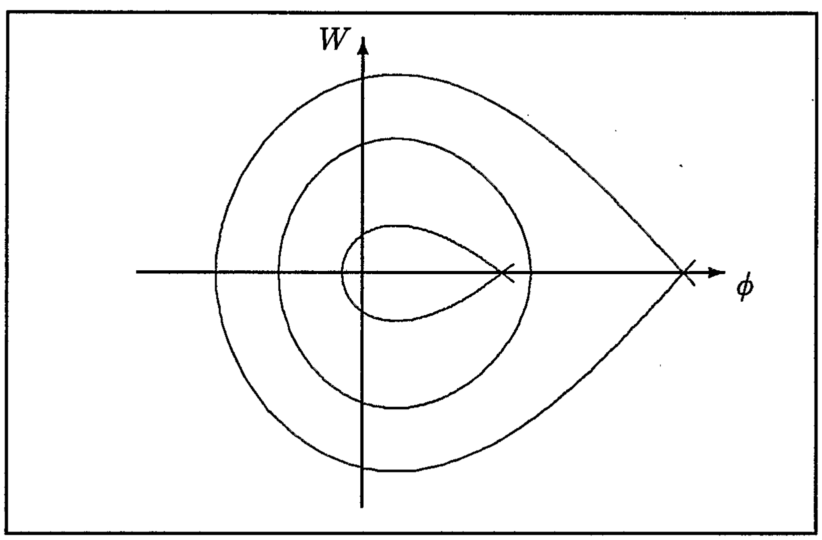

Figure 2: Bucket squeezing. The large bucket is suddenly shrunk to the small bucket.

3.1 Voltage program 1

The normal rf voltage during acceleration is kept constant at $200\,kV$. In our studies, we have designed two rf programs. In program 1, the rf voltage is dropped in the middle of acceleration from $200\,kV$ down to $100\,kV$ instantanously and then gradually raised to $200\,kV$ in $150\,ms$. Figure 3 shows

1. Voltage program.
2. F15 current transformer signal (beam intensity)
3. The rate of change of magnetic field $\dot{B}$.
4. F20 wall current monitor signal (bunch shape).

Figure 4 shows the bunch shape in the normal rf program, Figure 5 shows the bunch shape in the program 1. The bunch length has reduced from $55\,ns$ long to $29\,ns$ long. The measurement is made $478\,ms$ after T_0.

3.2 Voltage program 2

In program 2, the rf voltage is dropped from $200\,kV$ down to $100\,kV$ instantly, remained in there for $130\,ms$ and then gradually raised to $200\,kV$ in $100\,ms$.

Figure 7 shows the bunch shape in the normal rf program, Figure 8 shows the bunch shape in the program 2. The bunch length has reduced from $29\,ns$ long to $18\,ns$ long. The measurement is made $608\,ms$ after T_0.

4 Conclusions

We have successfully demonstrated the validity of bucket squeezing technique to trim longitudinal emittance. And in principle, this technique can produce beam with arbitrary value of longitudinal emittance, of course, provided that the intensity is not a big concern.

In the particular programs used the beam loss is roughly 50%. In the AGS Studies Report No. 310, the measurement of longitudinal emittance is illustrated. To extend the results there further, the emittance scales approximately as the square of the bunch length. So in program 1, the emittance reduction is $1 - (29/55)^2$ or 72%; in program 2, the emittance reduction is $1 - (18/29)^2$ or 60%.

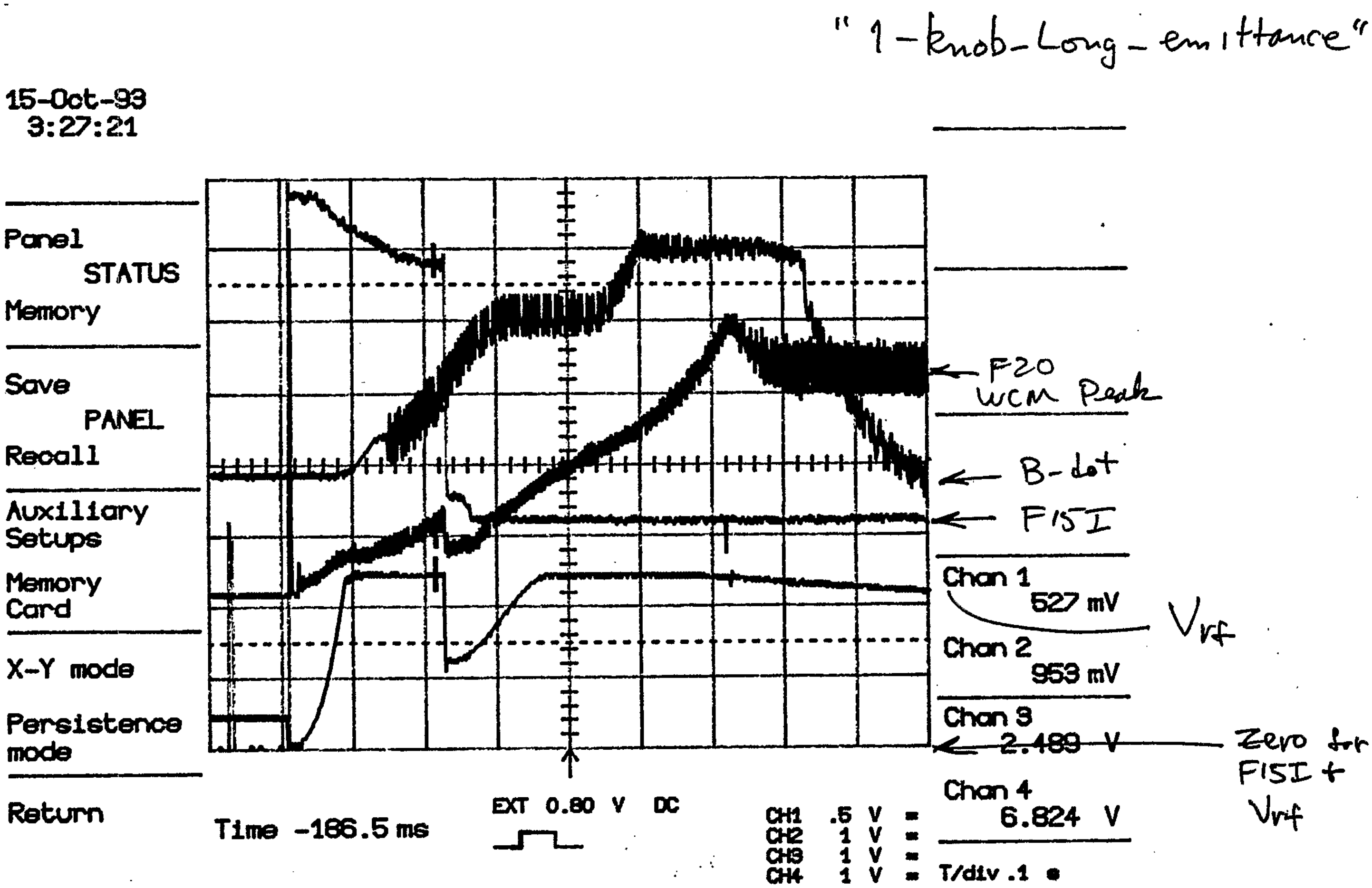

Figure 3: Voltage program 1. F15 current transformer signal (beam intensity). The rate of change of magnetic field $\dot{B}$. F20 wall current monitor signal (bunch shape).

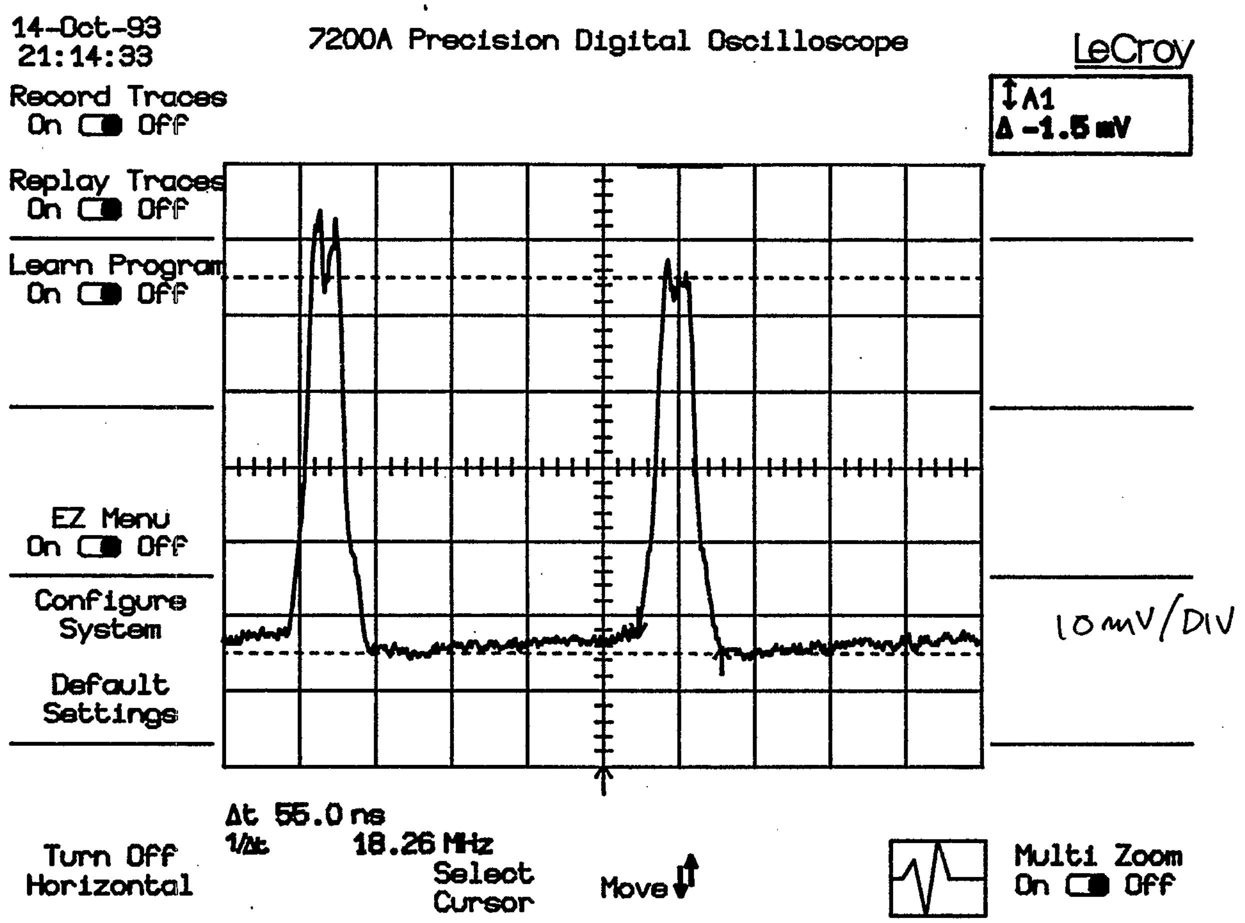

Figure 4: The bunch shape in the normal rf program.

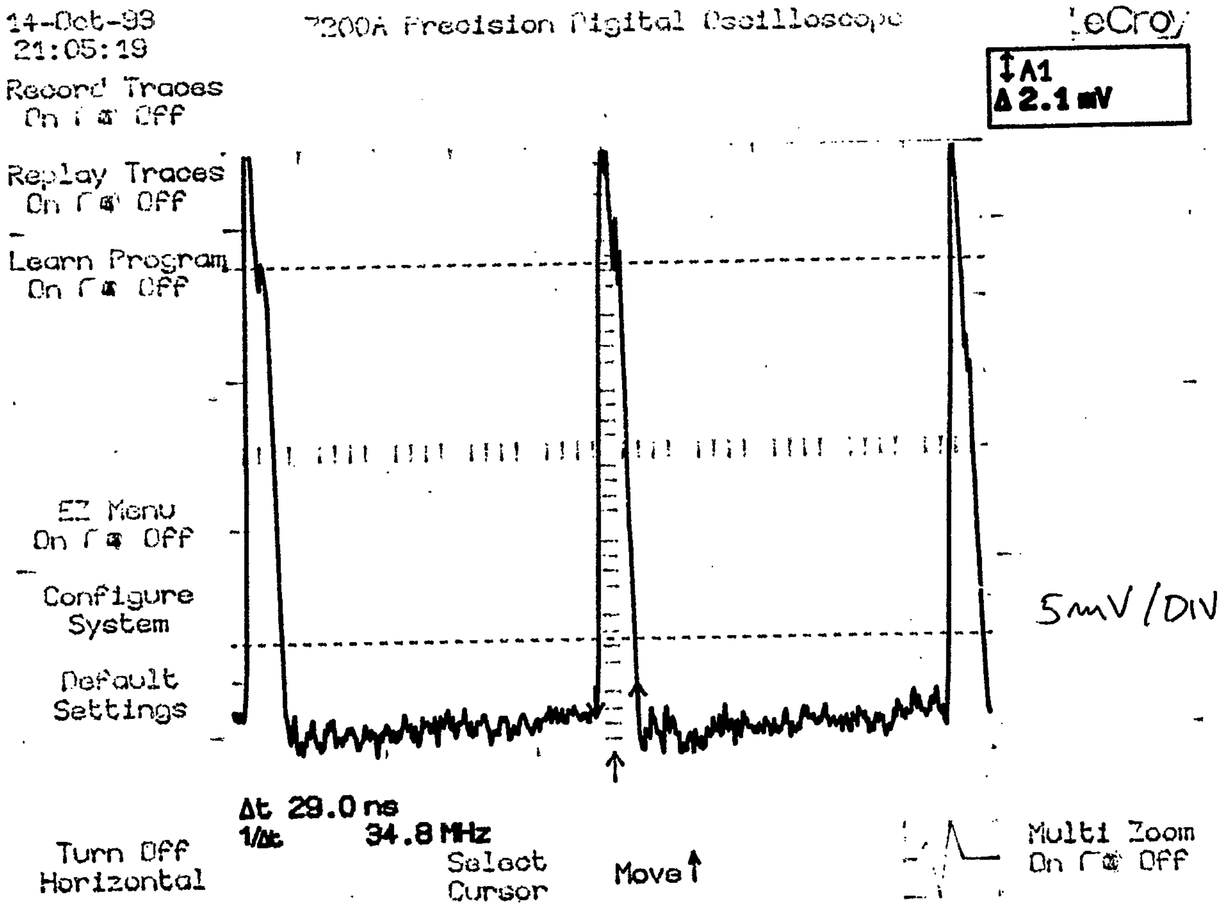

Figure 5: The bunch shape in the trimming program 1, shortened in comparison with previous figure, taken at the same point in the cycle.

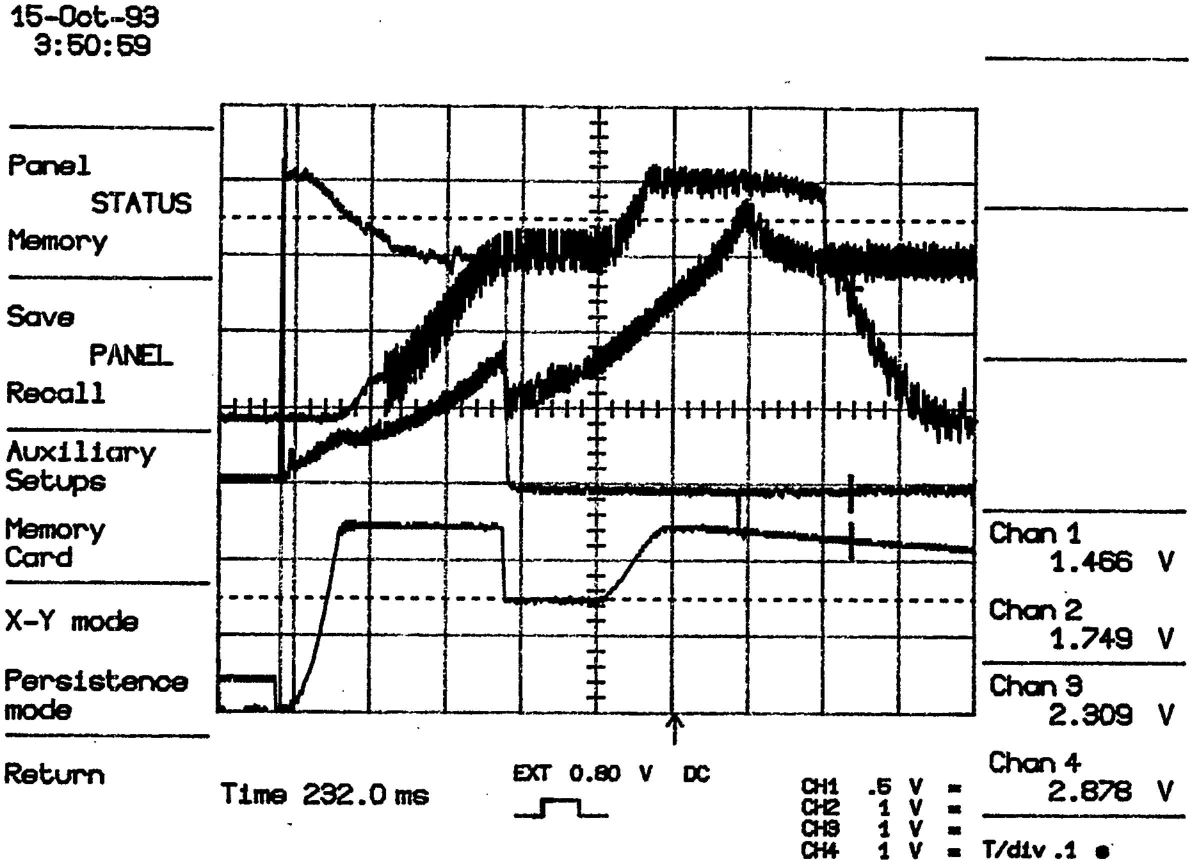

Figure 6: Voltage program 2. F15 current transformer signal (beam intensity). The rate of change of magnetic field $\dot{B}$. F20 wall current monitor signal (bunch shape).

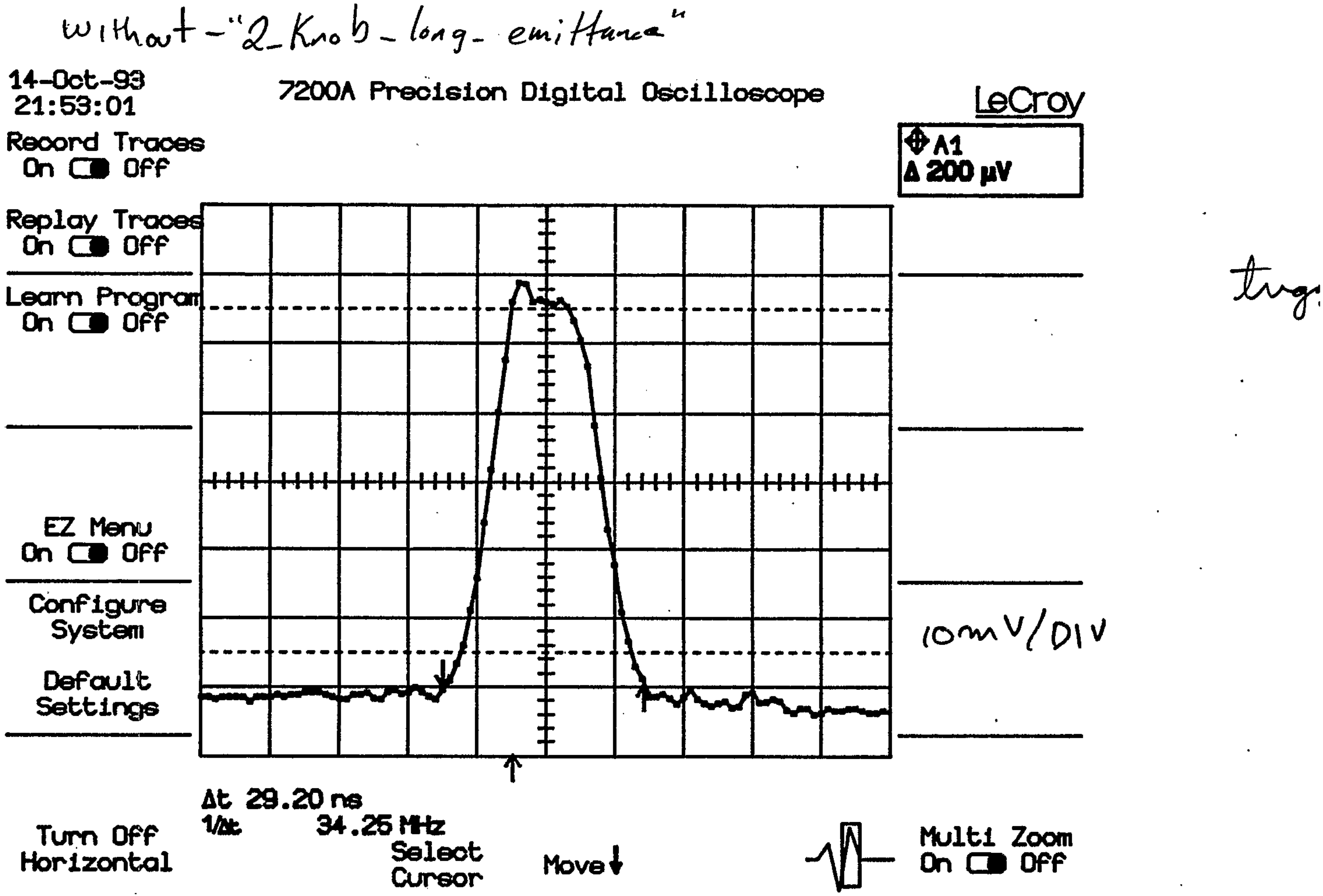

Figure 7: The bunch shape in the normal rf program.

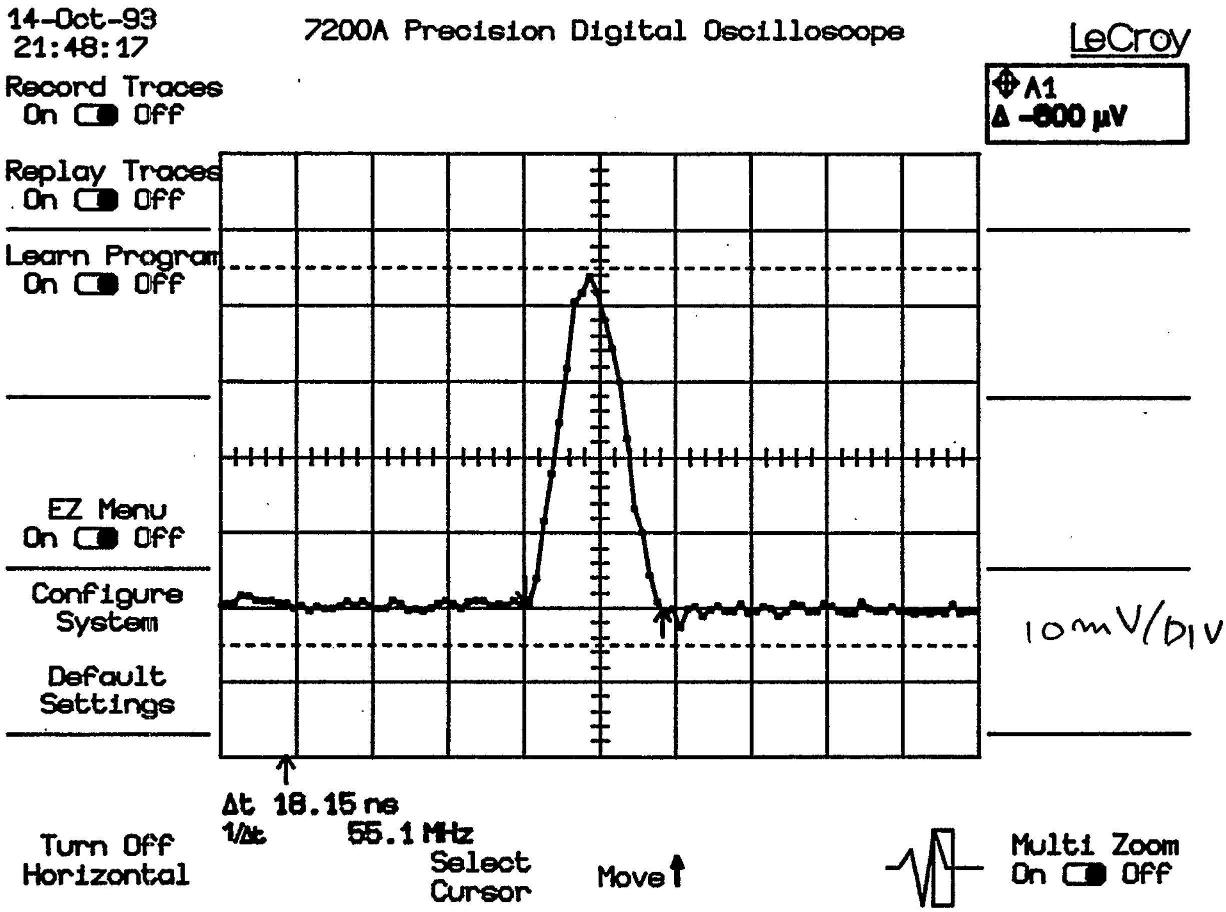

Figure 8: The bunch shape in the trimming program 2, shortened in comparison with previous figure, taken at the same point in the cycle.