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Gold Beam Survival on a Magnetic Porch at Booster Injection

L. Ahrens

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Collider Accelerator Department

Brookhaven National Laboratory

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Gold Beam Survival on a Magnetic Porch at Booster Injection

Study Period: February 2, 1997

Participants: L. Ahrens and K. Zeno

Reported by: L. Ahrens

Machine: Booster

Beam: Au^{32+}

Tools: Booster Circulating Beam Transformer

Aim: To document and explore the dependence of the gold beam survival rate on past history in a simple situation.

Summary

A simple Booster machine configuration, with little time dependence in the magnetic parameters is established. Over short time intervals beam survival in this machine is adequately described as having an exponential time dependence. The coefficient in the exponential which is referred to here as the loss rate, (the "b" in $I=I_0e^{-bt}$), then gives a simple parameterization of the loss. We don't insist that b have no time dependence; however in that simple case and if the ions are lost by scattering from say residual gas ions in the Booster vacuum pipe; then b is proportional to the cross section for the interaction and to the number of scatters. For a fixed residual gas composition, the "b" would be proportional to the residual pressure.

First the setup is tuned to maximize survival, to minimize b. The best survival attained is reported; there is some indication that b decreases over times of order 100 ms. The shot to shot variability is noted. Next a measurable fraction of the beam is intentionally scraped off long (30 ms) after it is injected. The loss rate is measured after this scrape and is found to be increased in this situation. The extent to which the loss rate changes appears to depend on where the beam is scraped. Several loss geometries are explored. These results are suggestive that beam losses in the Booster may in some geometries, but not in all geometries, lead to increased loss rates ; some losses appear to be worse than others. From this an interesting leap is the conjecture that our decreased acceleration efficiency in the Booster as the injected current from Tandem is increased may be caused by the scraping of some of the beam at places in the Booster which are "bad". The study did not find any especially sensitive spot, but it did not systematically explore the entire Booster circumference either in the vertical or in the horizontal planes. The data of the study resides at the end of the AGS/Booster FY97 Iron/Gold Startup Book III.

The Booster Setup

The Booster main magnet cycle was modified from the normal acceleration cycle into a cycle that ramped up only about 13 Gauss from the dwell value to the value needed for injection. Injection itself was controlled by real time (pseudopeaker) set about 13 ms after T_0, rather than by a field trigger (peaker). The field was flattened from injection through at least 70 ms from T_0 to about 1 Gauss using the "up" and "down" Gauss counts. The function necessary to generate this flat field is given in figure 1. The reporter cannot comment on the reasonableness of this function. It requests an increase of 13 Gauss between 13 amd 89 ms in order to give what the Gauss clocks (and with less accuracy the beam) see as a flat field. In this tuning process it was noted that the effect from a differential change in the function was in agreement with that seen by the Gauss clocks. A field change of 1 Gauss, given the injection field of 600 Gauss would shift the beam radially by 5mm at a Booster dispersion max point (3 meters). With this magnetic function the intensity throughout the cycle showed little structure beyond a smooth modest loss - there were no step losses. The betatron tunes ($Q_x = 4.73$, $Q_y = 4.82$), chromaticity, and correction dipole functions were made flat in time. The rf was turned off before injection. The fast injection bump was not changed, except that its firing was now delayed from the injection real time trigger. The skew quad functions, which ramp down enthusiastically after affecting the coupling during injection, were not changed. The extraction (F3) kicker charging supply start charging signal was turned off. The resulting loss (associated with the presence of charging current flowing through the kicker to the PFN) was correctable by shifting the horizontal and vertical tunes slightly.

This setup was not quite as efficient as the normal acceleration cycle. Although it was essential to spend significant time getting the main magnet field "flat" similar time was not spent optimizing the injection itself, and at least one of the time dependent tricks invoked for higher intensity was intentionally left out. Highest intensity not essential for the main study effort, which was to measure changes in the loss rate, but the question of how the results would change at higher intensities cannot be answered. The initial intensity was typically 1×10^9 ions, whereas the highest levels achieved this year were more than twice this; of course that occurred with also the best Tandem beam.

Some Results

Figure 2a gives the Booster beam current during the 200 ms cycle as it typically existed during the study period. Reading off the current at 20 ms intervals, assuming a linearly decreasing background (which in any case was a small effect), and then taking the log of these values yields figure 2b. While a single straight line does not fit the data well, a line with gradually weakening slope does, provided we ignore the earliest and latest points. We don't mind excluding the first point (the circulating transformer has lots of transients at injection) and the last two points (the cycle stopped being time independent quite a while before 200 ms. as the main magnet was allowed to return to its dwell value). The fits to the three points around 60 ms. and to the three points around

120 ms. give loss rates of 6.1 sec^{-1} and 4.8 sec^{-1} respectively - which in the naive model would be interpreted as a 20% improvement in the ring pressure over this 60 ms.

Figure 3 gives another somewhat unfortunate, and rather important, feature of this setup, and quite probably of normal gold running. Here are shown three Booster cycles occurring nearly sequentially in time. Nothing is being changed but something is changing. 3a shows the three cycles with the same vertical offset, figure 3b shifts them vertically for clarity, 3c gives fits to a few points read off the plots. The loss rate varies from 4.7 sec^{-1} to 5.8 sec^{-1} to 6.8 sec^{-1}. Is there some correlation between this large change in loss rate and something else about the cycle - the initial intensity? the early losses? the position of the beam as it comes into the Booster?.... At any rate the other observations below suffer from the fact that shot-to-shot, things change anyway.

A major objective for the study (given the above conjecture) was to search for an aperture which when struck resulted in a greatly increased loss rate. The focus was on horizontal apertures. The means to hit the aperture were the Booster correction dipole "three bump" system with its associated application code. This code is calibrated for protons charge to mass and so under estimates the gold ions motion by a factor of 2.5. The current available (25A) in these dipoles allows the creation of bumps with amplitudes of about +/-30 mm given that some current is already used in the basic setup. The first observation was that at some azimuthal positions there was more available aperture than bump amplitude. Due to time constraints only about half of the available horizontal bumps were powered. Some scraping was visible for half of these. No huge change in loss rate was observed. An example is an outward 3 bump at F6 quad. Here the program allowed an "18mm" bump - which translates into 45mm of motion - and the trace in figure 4 resulted. The 20% loss at 40 ms seen in the lowest trace is rescaled using the digital scope (the highest trace) to overlay a bumpless reference trace late in the cycle. The rate of loss is seen to be slightly higher after the scrape. The lowest trace in the figure displays the current in one of the three correction dipoles contributing to the bump creating the scrape.

A vertical bump was tried at one location, the C3 quad, and easily found the aperture both up and down. The current traces with a +22.5mm ("-9mm") bump and a -15mm bump are shown in figures 5 a and b. The loss rate is higher after the scrape in 5a. Fitting the data, after 40 ms in the bump off and bump on traces after taking logs gives figure 5c. The "after" slope has increased up to 11 sec^{-1}. The significance of this increase in loss rate (assuming there is one) was not sufficient at the time of the study to cause more time to be spent in a further search for more sensitive vertical apertures.

Two further tests, for old times sake, were carried out during this study. A Faraday cup was inserted in TtB to inhibit the beam for several minutes to allow the Booster vacuum to return to some quiet state (to "cool"), and then beam was injected again. There was no significant change in the loss rate between "before" and "after", in fact the two traces overlaid nearly perfectly. The other study was to reduce the injected intensity by inserting three multiwires in TtB and record the Booster current trace. The result is shown in figure 6 a and b. No significant change in slope was observed. The "b" picture again uses the scope to magnify the smaller trace till it equals the larger trace. In this case the two overlay everywhere, within errors.

Some Conclusions and Comments

This machine setup, which was transparent to the HIP or RHIC program except to the extent that the Tandem foil usage rate increased, is especially clean and simple. Issues such as the variation of capture and stripping cross sections with beam energy do not come up since the beam energy is not changing. The capture of the beam into rf buckets does not enter. Nevertheless, variations in the observed beam survival behavior appear mysterious. To spend more time here (this study occurred over a single long shift, - though it built on work done over several shifts) could provide insight. As it stands, the study insists that much of the beam loss mystery is already present in this setup. There is clearly a hidden variable, even at this intensity, in the gold beam or the Booster at injection rigidity, where "hidden" means not measured. Some possibilities include: beam input trajectory, time dependence of the input trajectory during the pulse, input beam width or the transverse tails , time dependence of those tails, Booster orbit repeatability or more generally the repeatability of any Booster magnetic setting, The more likely contributors are those we don't measure - i.e. those associated with the incoming beam.

The scraping experiment would be cleaned if done farther from injection - say at 70 ms. This would allow a more certain characterization of the loss rate before the scrape, on that same shot. It also would be an improvement to maintain the flat machine for a longer time interval. This was not done only for lack of time. The (nonreproducing) wiggles on the current transformer make shot comparison more difficult. The program that builds the three bumps is not optimized for walking a bump around the machine. Each bump must be started afresh. This could be improved with a "walk" option. The Booster correction dipoles themselves are not in a very robust state. Alarms on the spread sheet page, and strange digital readbacks encourage a lack of confidence that the bump one asks for is indeed what one gets.

Figures

1. Booster Main Magnet function used to generate a flat magnetic field (from 13 to 70 ms)

2. Booster Circulating Beam Current monitor, typical trace. (20ms per "box")
    a. "Raw" data
    b. fit to a subset of the points

3. Beam survival on three arbitrary shots.
    a. display with overlaying base lines
    b. artificially separate baselines for clarity
    c. fits to a subset of points for the three traces

4. Beam survival with a horizontal bump at the F6 quadrupole

5. Beam survival with upward and downward bumps at the C3 quadrupole
    a. upward bump
    b. downward bump
    c. fit of the data with/without the upward bump after the bump scrape

6. Beam survival with/without reduction of input intensity from the Tandem

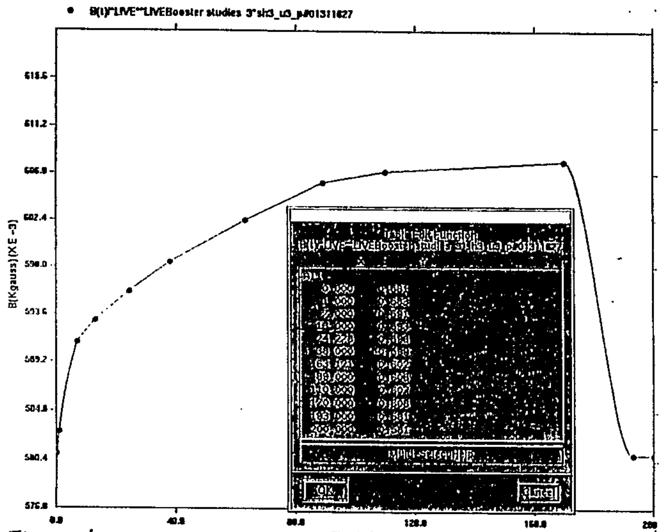


Figure 1

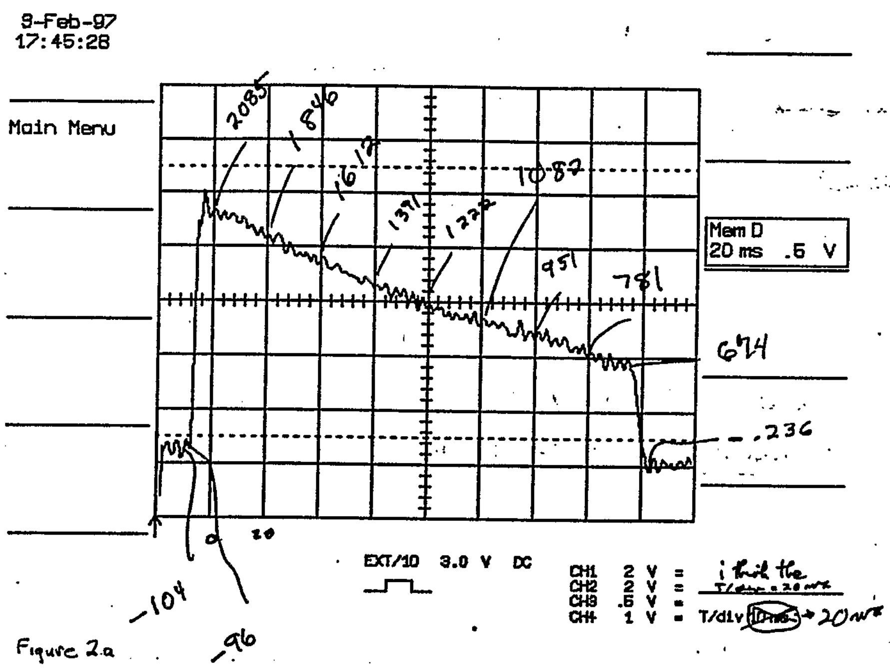
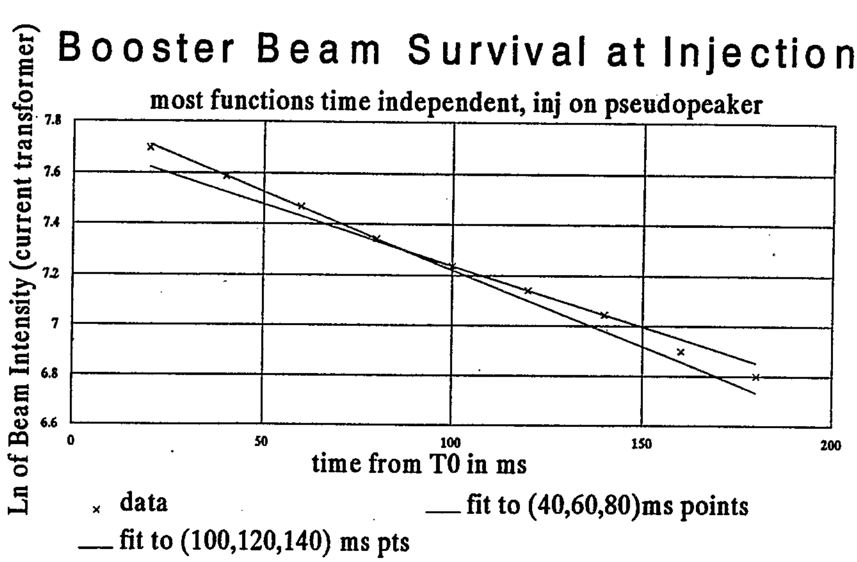


Figure 2.a



slope -.00611 for (40,60,80) fit
slope -.00482 for (100,120,140) fit

Figure 2b

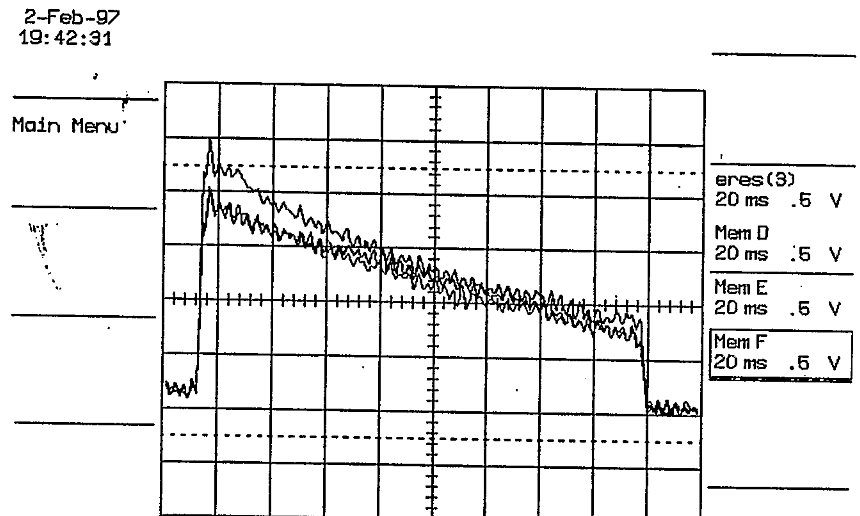


Figure 3a

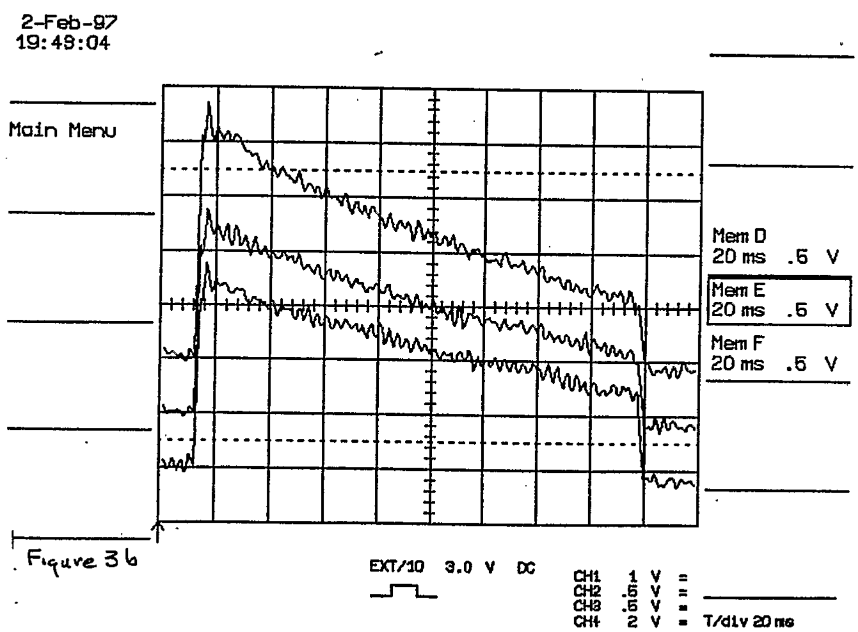


Figure 3b

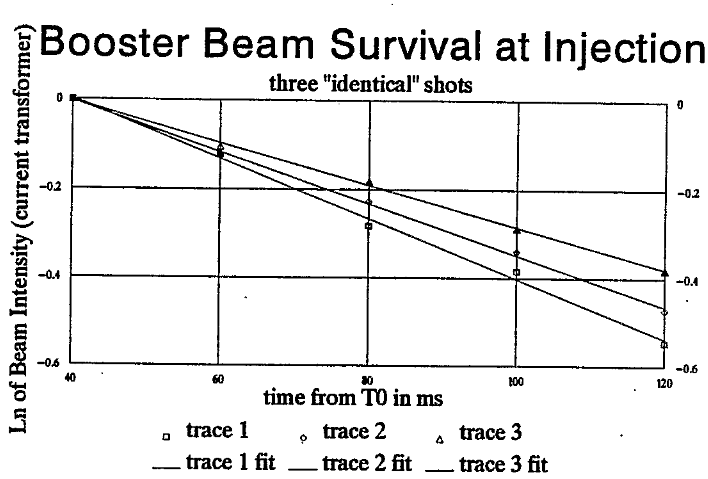


Figure 3c

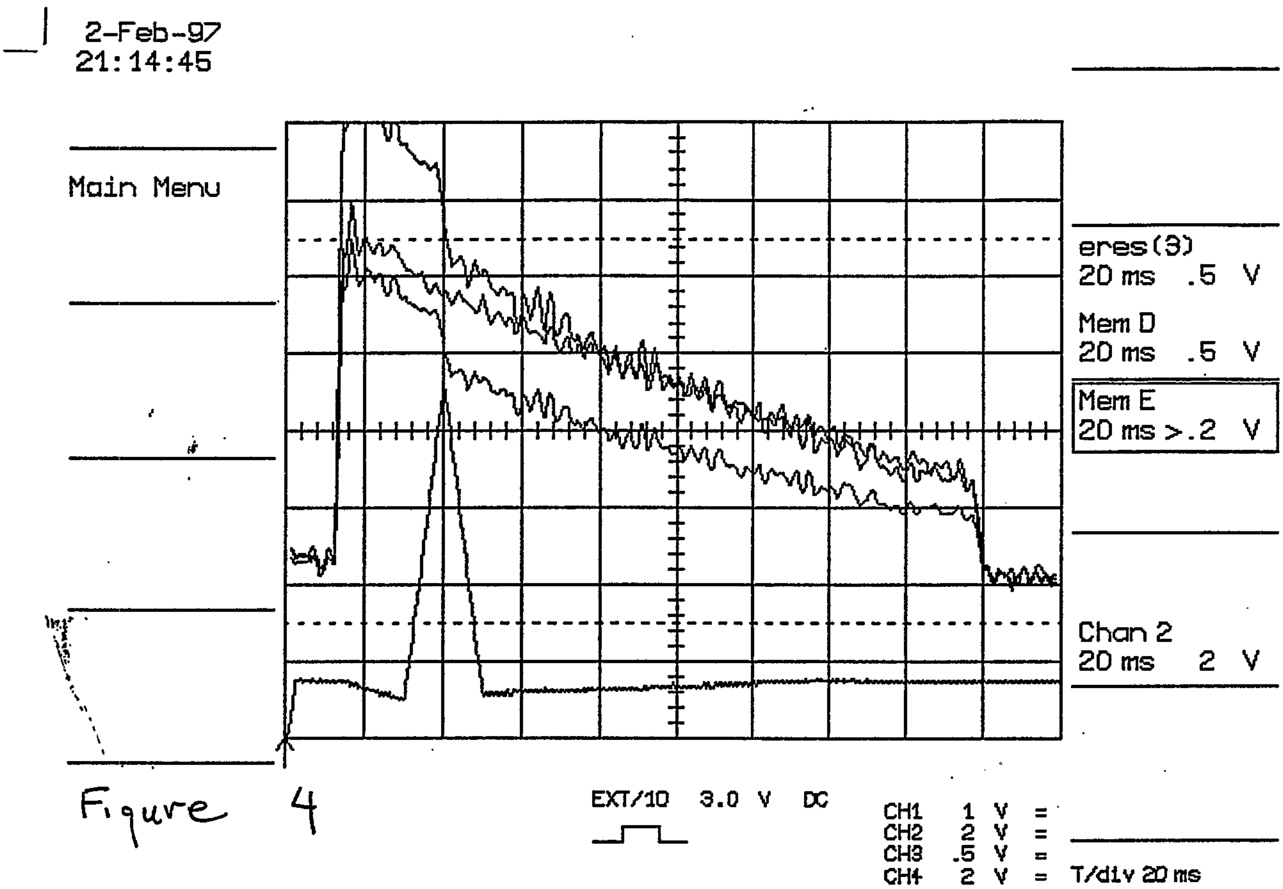


Figure 4

f6 -18

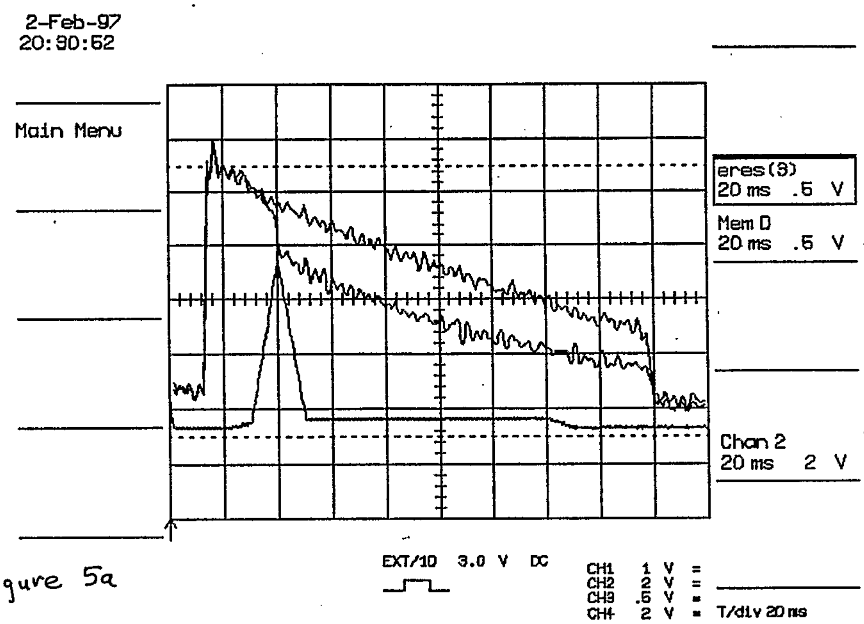


Figure 5a

c3-9mm

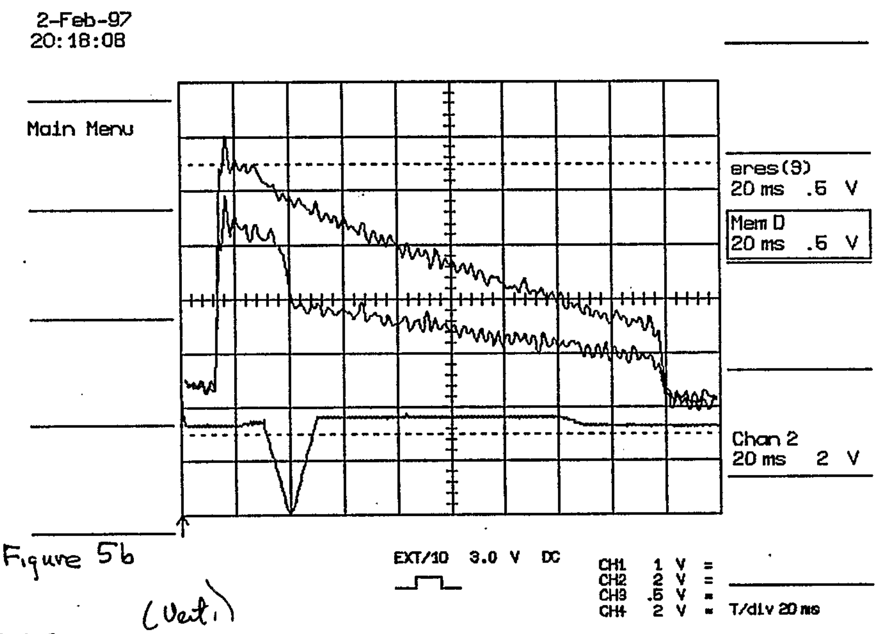


Figure 5b

(Vert.)

c3 @+6mm

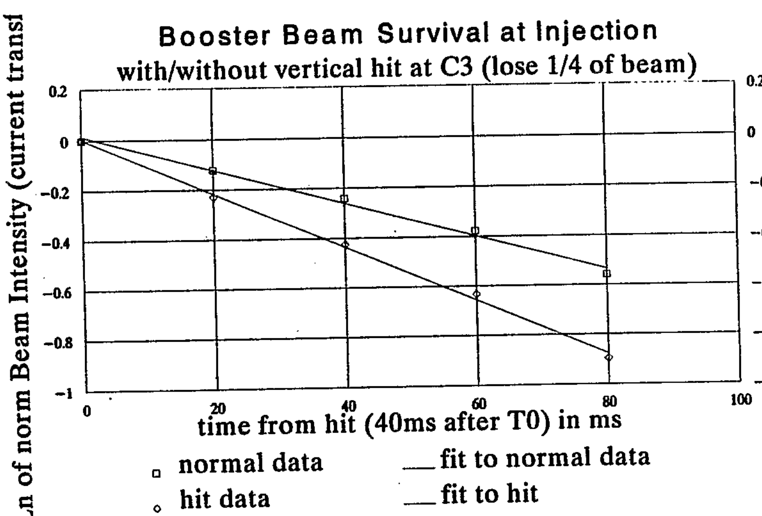


Figure 5c

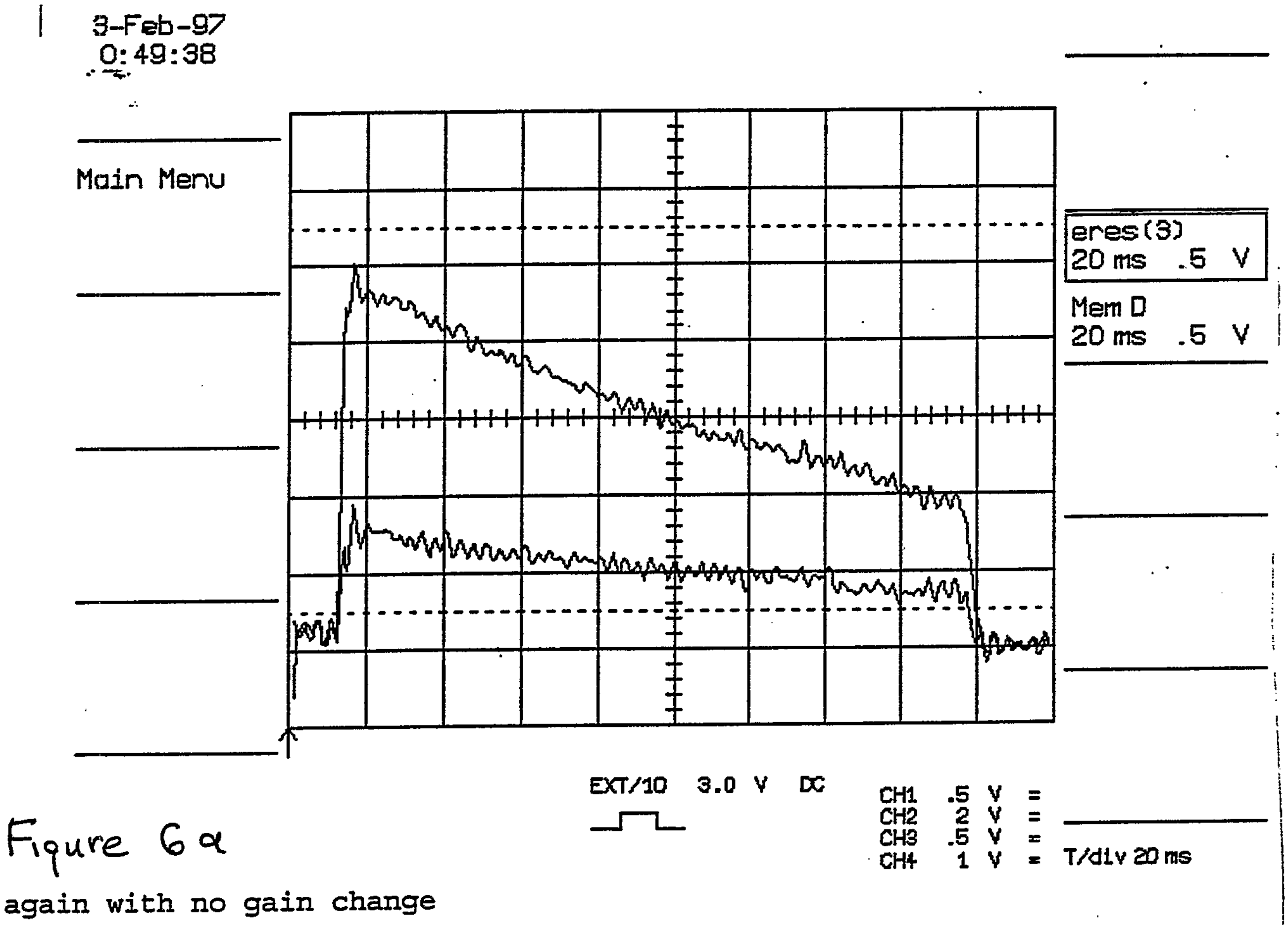


Figure 6a

again with no gain change

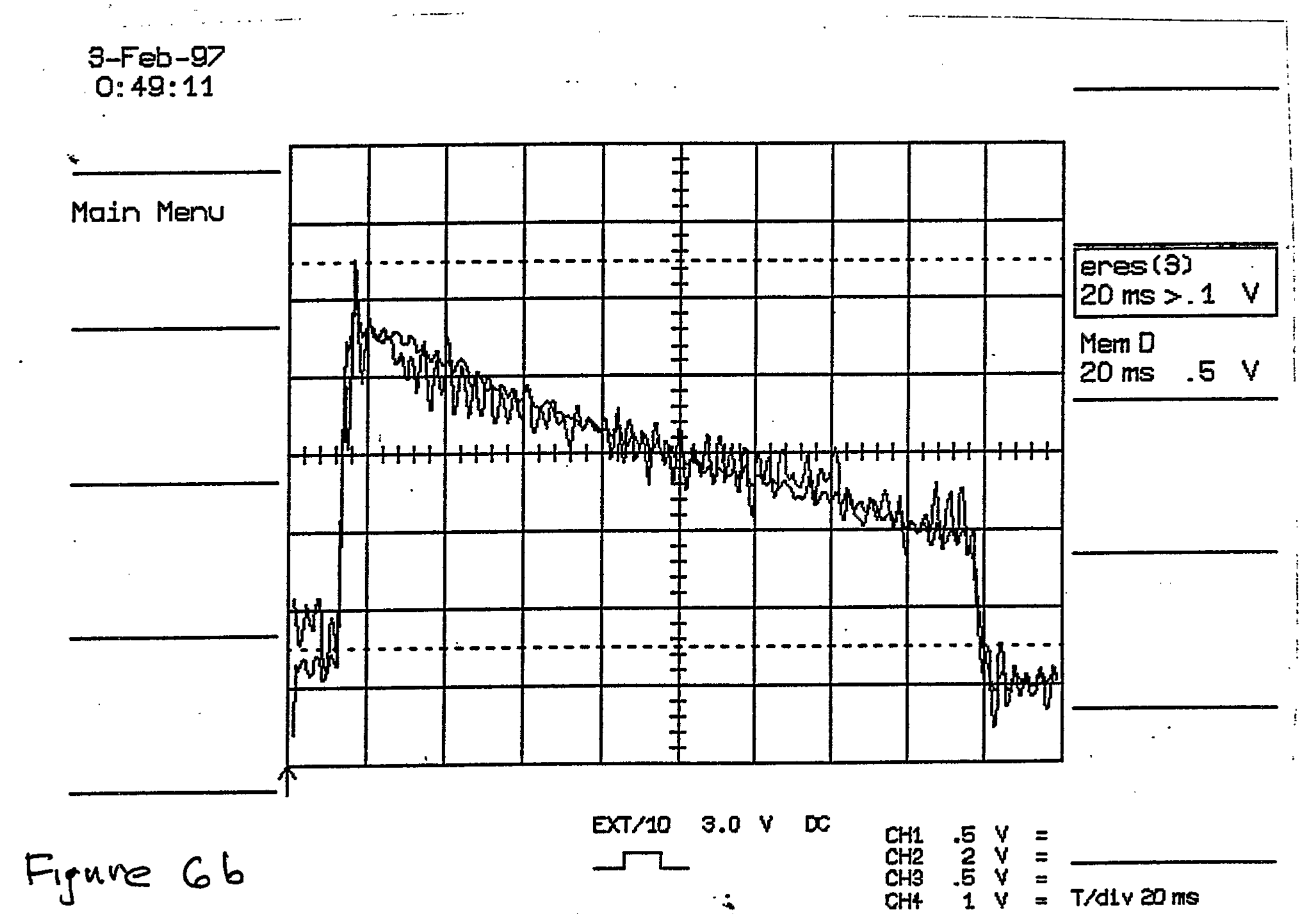


Figure 6b

3 multi wires in