

# PBAR NOTE NO. 629

## DEBUNCHER ENERGY MISMATCH

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### The Problem

During the December 1999 startup of antiproton stacking, a quick measurement of the Debuncher momentum aperture was made. The measurement was done by turning off and de-tuning the Debuncher bunch rotation cavities and observing the Debuncher 75 MHz longitudinal schottky signal of the circulating antiprotons as shown in Figure 1. The frequency at the center of the plot corresponds to the rotation frequency of the Debuncher RF cavities. (The schottky signal and the bunch rotation frequency occur at the 127<sup>th</sup> and 90<sup>th</sup> harmonics of the revolution frequency, respectively.) Figure 1 shows that the Debuncher bunch rotation energy is offset from the middle of the Debuncher momentum aperture by about 0.7% (57 MeV). The measured value of momentum aperture using the width of the base of the signal shown in Figure 1 ( $\eta=0.006$ ) is 3.9% (346 MeV). This is close to the design value of 4%, so the offset is probably not due to any asymmetric momentum aperture restrictions.

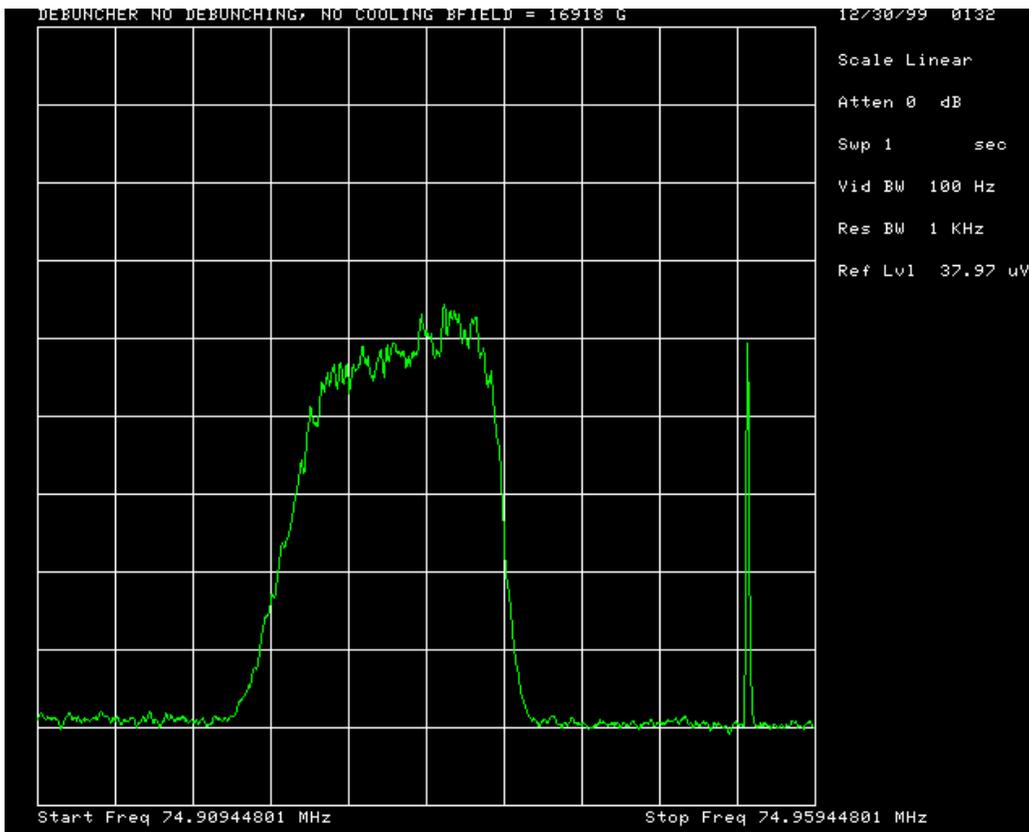


Figure 1. Longitudinal Schottky scan (127<sup>th</sup> harmonic) of antiprotons with the Debuncher bunch rotation cavities off and mis-tuned. The center of the plot corresponds to the frequency of bunch rotation.

## The Constraints

At this point in time, it was unclear that the energies of the Debuncher and the Accumulator were matched. To match the energies between the two machines, the following constraints must be fulfilled:

1. The RF frequency of the Debuncher bunch rotation equals the RF frequency of the Main Injector at 120 GeV.
2. The revolution frequency of the beam in the Debuncher after bunch rotation is  $1/90^{\text{th}}$  of the bunch rotation RF frequency.
3. The energy of the beam in the Accumulator on the injection orbit equals the energy of the beam in the Debuncher after bunch rotation.
4. The energy of the beam on the extraction orbit of the Accumulator equals the "8 GeV" energy of the Main Injector.
5. The energy of the Accumulator extraction orbit is approximately equal to the energy of the Accumulator injection orbit. (See Figure 2)

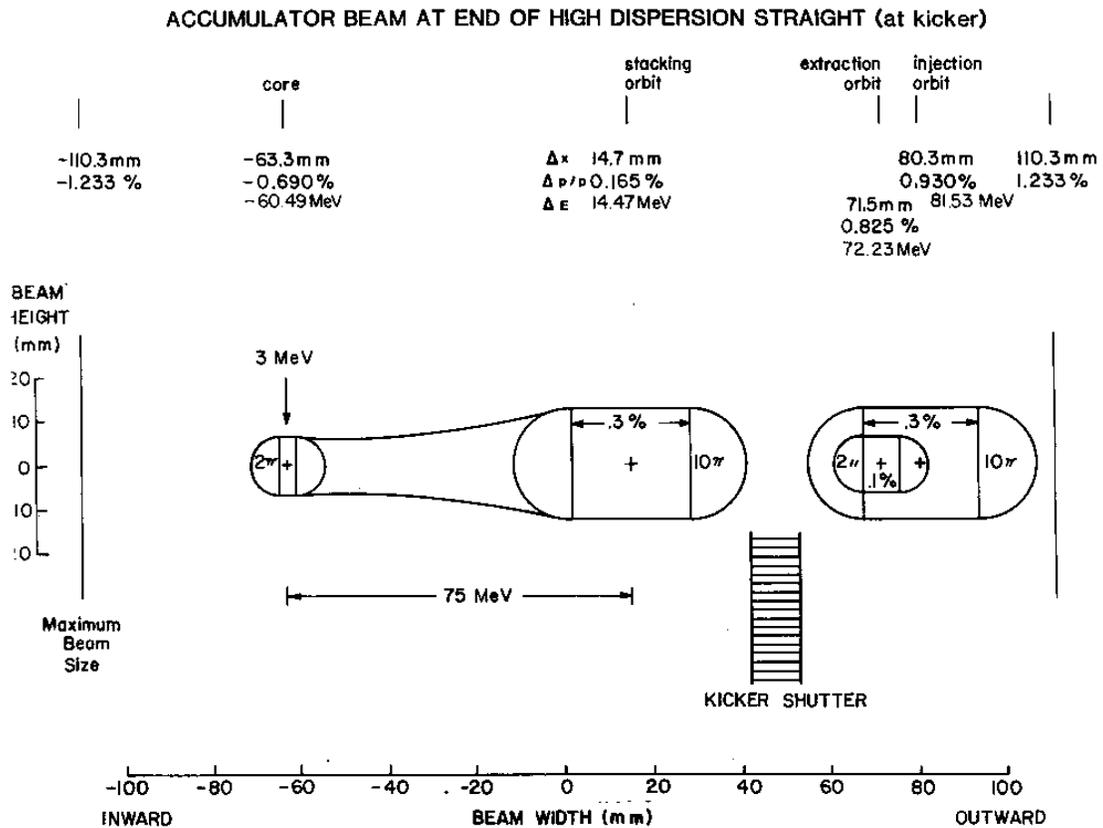


Figure 2.

## The Experiment

To determine the size of the energy offset between the center of the Debuncher momentum aperture and the Debuncher beam after bunch rotation when the energies between the Debuncher, Accumulator, and the Main Injector are matched, a set of studies were performed in the Antiproton Source during the early part of January, 2000. The following steps were performed during the studies:

1. The Accumulator bend bus (A:IB) was adjusted so that when the reverse "8 GeV" proton beam from the Main Injector was asynchronously injected into the accumulator, the beam landed in the middle of the Accumulator extraction aperture.
  - a. The Accumulator extraction aperture is measured by RF displacing the beam in the Accumulator (via ARF3) all over the momentum aperture (the green trace in Figure 3) and closing the extraction shutter (the red trace in Figure 3). The high energy edge of the aperture (low frequency edge in Figure 3) is due to the betatron tunes crossing the  $2/3$  integer.
  - b. The momentum aperture for a zero betatron amplitude particle was measured to be 0.7%.
  - c. This step was initially done in May, 1999 when the Antiproton Source was first turned on after the Main Injector commissioning (See Entry #123 Pbar Electronic Logbook 1999). The value of A:IB had to drop by about 0.5% from its Run I value. This measurement was done many times over the 1999 Pbar commissioning period without need of adjusting the Accumulator bend field.
2. The energy of the reverse 8 GeV beam was not changed in the Accumulator and the beam was extracted from the Accumulator and injected into the Debuncher. The A/D line was adjusted for good efficiency.
3. With the Debuncher bunch rotation cavities off and de-tuned, the Debuncher bend bus was adjusted until the revolution frequency of the 8 GeV reverse protons was 590035 Hz which is  $1/90^{\text{th}}$  of the bunch rotation frequency for forward antiprotons.(53.10315 MHz)
4. The Debuncher momentum aperture was measured by RF displacing the beam in the Debuncher via DRF3 and is shown in Figure 4. The center of the spectrum plot corresponds to the bunch rotation frequency. The momentum aperture is 4%. The center of the momentum aperture is +0.66% (+59 MeV) away from the bunch rotation frequency.

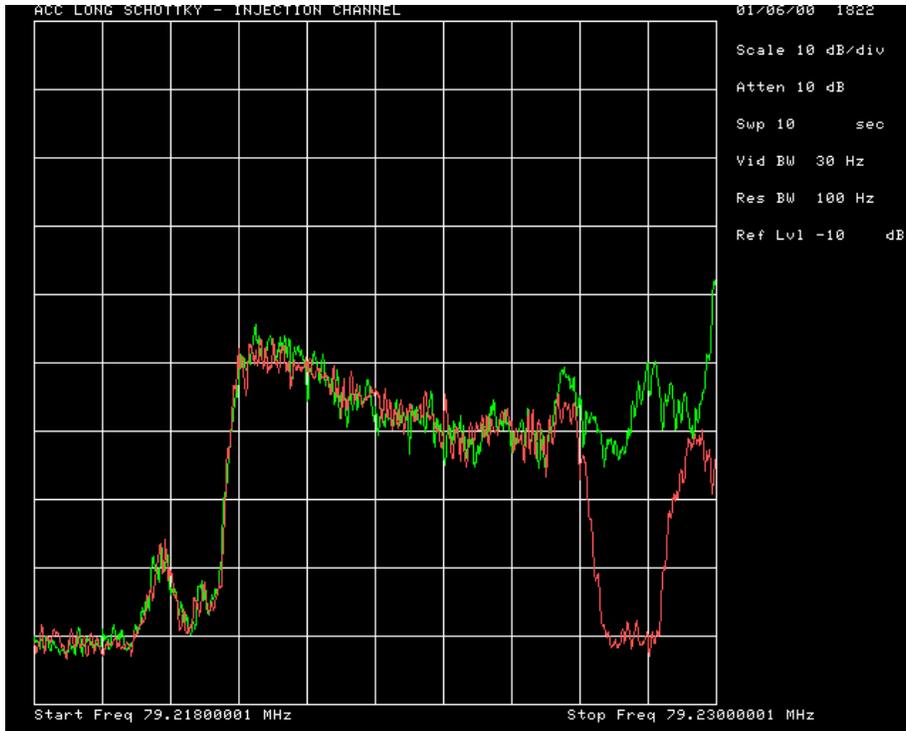


Figure 3. Accumulator longitudinal schottky spectrum ( $126^{\text{th}}$  harmonic) of RF phased displaced reverse 8 GeV protons in the extraction channel. The green trace is before the shutters were closed. The red trace was after the shutters were closed.

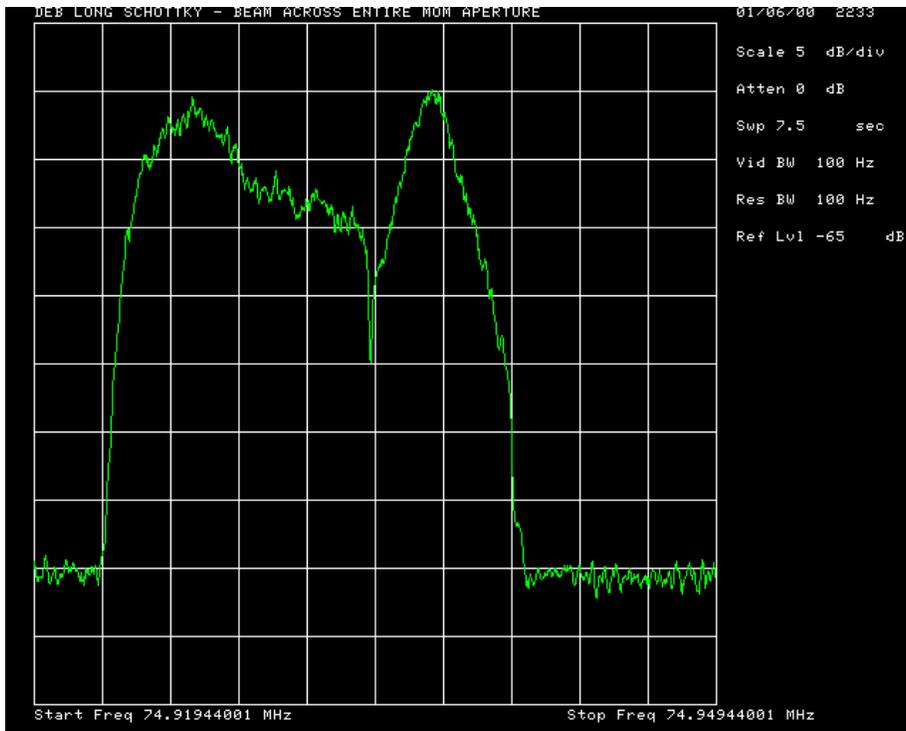


Figure 4. Longitudinal Schottky scan ( $127^{\text{th}}$  harmonic) of RF phased displaced reverse 8 GeV protons with the Debuncher bunch rotation cavities off and mis-tuned. The center of the plot corresponds to the frequency of bunch rotation.

## Solutions

The following section will discuss three possible solutions to make the center of the Debuncher momentum aperture to be equal to the bunch rotation energy.

### Solution 1

The first solution is to not change anything and suffer the reduction in antiproton production efficiency.

To calculate the reduction production efficiency, a number of ESME simulations of Debuncher bunch rotation was done by Steve Werkema. The goal of the simulations was to determine the final momentum distribution of the beam in the Debuncher after bunch rotation as a function of offset between the center of the momentum aperture and the bunch rotation energy. It was assumed that any beam that fell outside the Debuncher momentum cooling aperture at 8 GHz (0.6% at the 45 degree points) would not be cooled and transferred to the Accumulator. Figure 5 shows the result of the simulations for a number of different proton bunch lengths on target. The x-axis is the difference in energy between the bunch rotation energy and the center of the Debuncher momentum aperture. The y-axis is the amount of particles that would not be transferred to the Accumulator. It should be noted that for energy differences less than 70 MeV, most of the "lost" particles are not lost in the Debuncher but are not captured by the Debuncher bunch rotation. For an energy difference of the measured 60 MeV, the production efficiency would drop by 14% if the proton bunch length on target is 1 nS and the efficiency would be reduced by 19% if the proton bunch length on target is 2 nS.

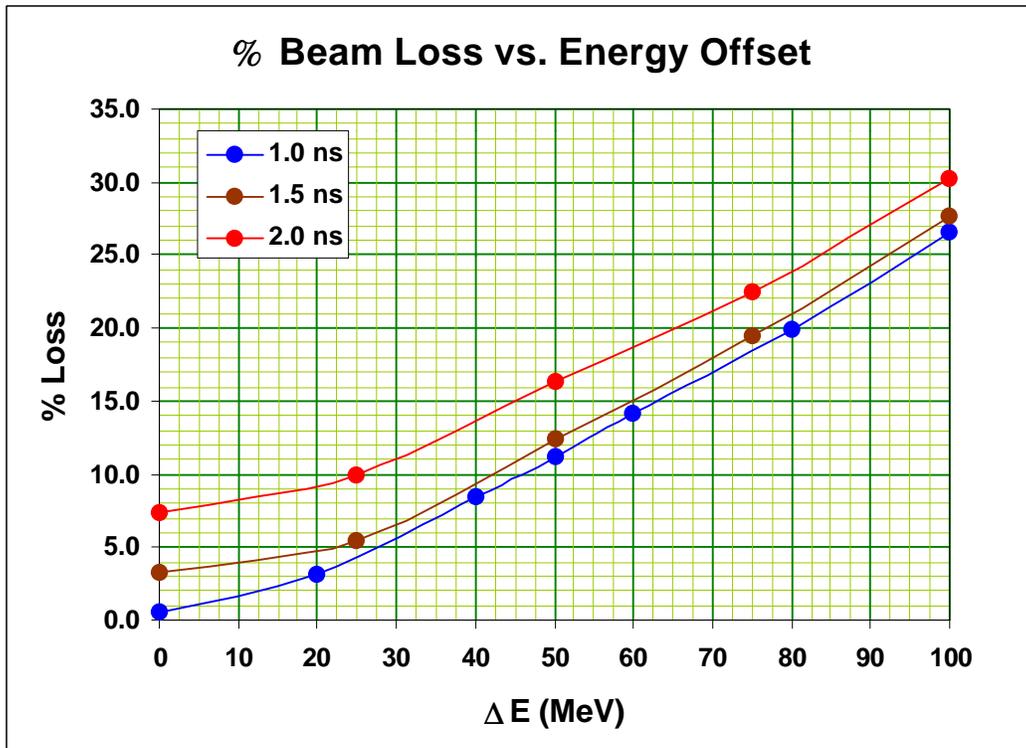


Figure 5. ESME simulation results of reduction in antiproton production efficiency vs. energy error between the bunch rotation energy and the center of the Debuncher momentum aperture. (Steve Werkema)

### Solution 2

The second solution would be to adjust the circumference of the Debuncher by moving magnets.

The Debuncher bend field would be adjusted so that the revolution frequency of the center of the Debuncher Momentum aperture increases by 23 Hz to the Debuncher bunch rotation revolution frequency (590035 Hz) and that the momentum of the center of the aperture decreases by 60 MeV. The governing equation is:

$$\frac{dp}{p} = \gamma^2 \frac{df}{f} + \gamma^2 \frac{dL}{L} \quad (1)$$

where:

$$\frac{dp}{p} = \frac{-60\text{MeV}}{8873\text{MeV}} \quad (2)$$

$$\frac{df}{f} = \frac{23\text{Hz}}{590035\text{Hz}} \quad (3)$$

The Lorentz factor  $\gamma$  at 8 GeV is 9.52 so that the change in circumference is:

$$\frac{dL}{L} = -113.6 \times 10^{-6} \quad (4)$$

or shorten the circumference of the Debuncher by 57mm. The change in bend field is calculated from:

$$\frac{dp}{p} = \frac{dB}{B} + \gamma_t^2 \frac{dL}{L} \quad (5)$$

The transition  $\gamma$  in the Debuncher is 7.59 so that the bend field would decrease by 0.02% (-3.87 Gauss)

While were moving magnets in the Antiproton Source, it would be interesting to see what change in circumference of the Accumulator is needed (while keeping the "8 GeV" extraction energy constant) to line up the extraction frequency of the Accumulator with the equivalent "8 GeV" frequency of the Main Injector. The present "8 GeV" RF frequency (harmonic 588) of the Main Injector is 52.8114 MHz. This corresponds to a revolution frequency of 628,707 Hz in the Accumulator (harmonic 84). The present revolution frequency of the beam on the extraction orbit is 628,767 Hz. Using Eqn. 1 but setting  $dp/p=0$ , the change in circumference is  $dL/L = 95.0 \times 10^{-6}$  or the circumference must be increased by 45 mm. From Eqn. 5, the bend field would be reduced by 0.54% (-91 Gauss)

### Solution 3

The third solution would be to keep the circumference of the center of the Debuncher momentum aperture constant but increase the Main Injector "8 GeV" energy until the bunch rotation energy is in the center of the Debuncher momentum aperture. The bend field in the Accumulator would have to increase to keep the extraction and

injection energy in the Accumulator centered in the extraction channel. The Debuncher bend field would also have to increase.

Using Eqns. 1-3, the difference in circumference between the present bunch rotation energy and the present center of the momentum aperture is 0.01136%. If the bunch rotation frequency is held constant, then (from Eqn. 1) the amount of change in momentum to increase the circumference by 0.01136% is 1.0% or +88 MeV.

Using Eqn. 5, with a 1% increase in momentum and a 0.01136% increase in circumference, the increase in the Debuncher bend field is 0.375% or +63 Gauss. For the Accumulator, the radial position in the extraction channel cannot change so the 1% increase in momentum must be accompanied by a 1% change in bend field (167 Gauss). This huge change in momentum in the Accumulator momentum can be offset somewhat due to the energy difference between the extraction orbit and the injection orbit (0.1% from Figure 2). This would allow the bend field in the Accumulator and the "8 GeV" Main Injector energy to change by 0.9% and the Debuncher momentum to change by 1.0%.