Antiproton Extraction in the Fermilab Antiproton Accumulator*

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Abstract

The RF and other manipulations required to extract antiprotons from the Accumulator core for Collider operation are described. ESME simulations of the motion in longitudinal phase space are shown. Measurements of the emittances of the extracted antiprotons are presented. The effect of the unstacking process on the core longitudinal and transverse emittances is examined and recent performance is also presented.

I. INTRODUCTION

In order to maximize the initial luminosity of proton-antiproton collisions in the Tevatron, as many antiprotons as possible must be extracted from the Accumulator core in a phase space volume small enough to be efficiently transferred to the Main Ring and there accelerated from 8.9 Gev/c to 150 Gev/c before injection into the Tevatron. The process of transferring antiprotons from the Accumulator core to the Fermilab Main Ring has been previously described [1]. However, increased antiproton stack (core) sizes, upgrades to the Accumulator stochastic cooling systems, and additional operational experience in the current Collider run have all led to refinements in this process. The increase in antiproton stack size by approximately a factor of two over the 1988 Collider run has led to beam loading in one of the rf cavities and beam instabilities due to trapped positive ions [2] [3]. Improvements to the Accumulator stochastic cooling systems have led to much denser antiproton cores, which in turn contributes to the two problems mentioned above, but also allows for a much greater fraction of the antiproton core to be transferred to the Main Ring.

II. PROCEDURE

Antiprotons are rf unstacked from the core by an H=2, 1.26 MHz suppressed bucket rf system (ARF2). 10-15% of the antiproton core is (pseudo)adiabatically captured in a single bucket of size 1.25 ev-sec which is 12 volts on the cavity. This bunch is then accelerated across the Accumulator momentum aperture by about 140 Mev/c in an rf bucket of constant size. On the extraction orbit a second H=2 rf system (ARF3) is then turned on to 810 volts to narrow the single bunch to 210 nsec. This is followed by adiabatic bunching by an H=84, 53 MHz rf system (ARF1) which produces 11 bunches, separated by 19 nsec, under a parabolic envelope. At this point the 11 bunches are simultaneously extracted from the Accumulator by a kicker magnet. After acceleration to 150 Gev/c these 11 bunches are coalesced into one bunch in the Main Ring [4]. This entire process is repeated 6 times to produce the 6 antiproton bunches in the Tevatron. The voltage and frequency curves of the 3 rf systems are shown in Figure 1. Figure 2 shows the phase space distribution of particles in the rf buckets just before extraction as generated by ESME [5] using the rf curves in Figure 1.

Since the ARF2 bucket is entirely full with an almost uniform density of antiprotons, and since the synchrotron frequency at the center of the bucket is only a few hertz, it was found that slowing the entire process down as much as possible minimized the amount of beam that fell out of the bucket on its trip from the core to the extraction orbit. It was also found that by varying the precise location in the core from which beam is unstacked, the fraction of the core unstacked over the 6 shots could be maximized. This is due to phase displacement by the moving rf bucket which displaces the centroid of the remaining antiproton core.

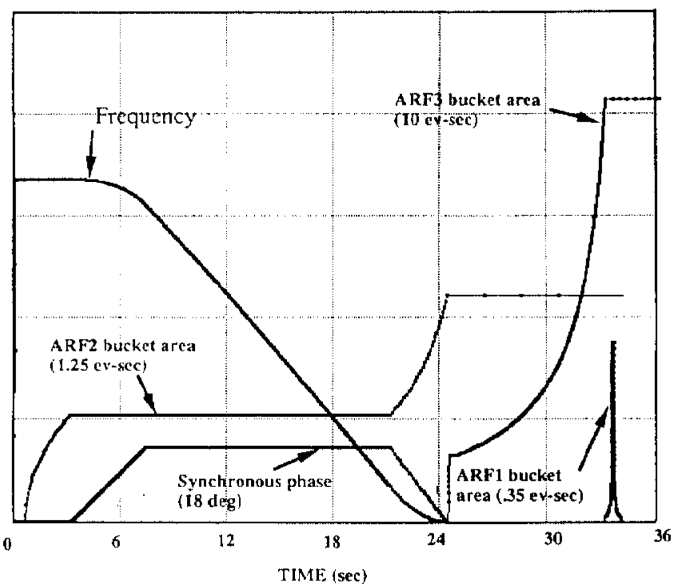

Figure 1. Frequency, synchronous phase, and bucket area for the 3 rf cavities as a function of time during the unstacking process.

III. ANTIPROTON CORE

The Accumulator core cooling systems have recently been upgraded from 2-4 GHz bandwidth cooling to 4-8 GHz bandwidth cooling [6]. This has allowed much larger stacks to be cooled to much smaller emittances. Typical horizontal and vertical emittances are .9 π mm-mrad and .6 π mm-mrad respectively. A typical momentum width is 2.5 Mev/c (σ). For an antiproton stack size of 100 mA (10^{12} particles) this corresponds to a peak density of .12 x 10^{12} particles per 1.25

*Operated by Universities Research Association Inc. under contract with the United States Department of Energy.

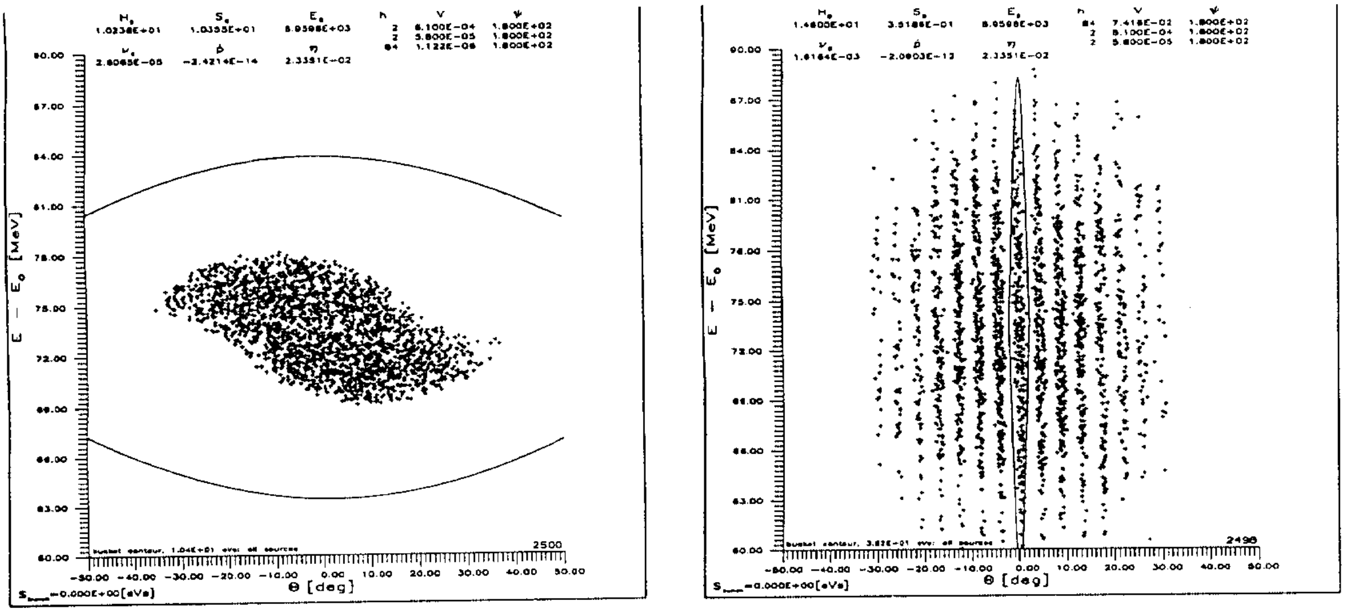

Figure 2. Longitudinal phase space distribution of particles after complete bunching with ARF3 (H=2) but before bunching with ARF1 (H=84); and after complete bunching with ARF1.

ev-sec. Figure 3 shows a typical core longitudinal density measurement just before antiproton extraction. The largest stack obtained to date is 155 mA.

Instability due to trapped positive ions in these large stacks was initially effectively eliminated by increasing the clearing electrode voltage from 100 V to 1kV. However, for stacks over about 110 mA it has become necessary to slightly bunch the antiproton core with ARF2 at about 5 V to stabilize the beam prior to extraction. This technique for beam stabilization is well known in electron storage rings [7] and it has been found to be effective here also.

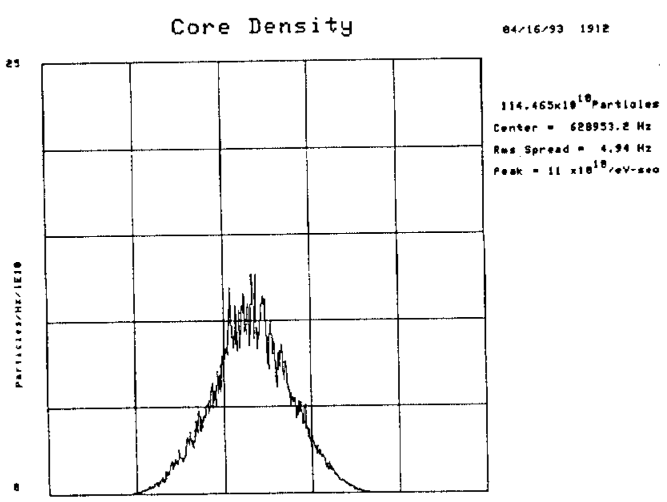

Figure 3. Antiproton core frequency spectrum. Momentum is given by $\eta * dP/P = dF/F$ where η is -.023.

The procedure for extracting the 6 antiproton bunches has been tailored to match the increased core cooling power. The 4-8 GHz cooling systems have a fast enough cooling rate such that a short wait (40-120 seconds) between antiproton extractions is enough to allow the core to cool down to smaller emittances in all 3 dimensions after each extraction. The transverse emittance of the 6th extraction is typically 10% smaller than for the 1st extraction.

IV. BEAM LOADING

Increased antiproton core densities have also produced a deleterious beam loading [8] effect in ARF3. The ARF3 cavity has a shunt impedance of about 1000Ω. If 10 mA is unstacked from the core, this will produce a voltage of .01 x 1000 / 2 = 5V which is 90° out of phase with the 12V being driven by the generator on ARF2. In practice this causes large dipole oscillations within the rf bucket during unstacking, which in turn causes much of the beam to fall out of the bucket before reaching the extraction orbit. Without some remedy, the maximum amount of beam that could be extracted in a single shot was about 7 mA. The solution used involved shorting the ARF3 cavity during the extraction process until the beam reached the extraction orbit, and then quickly unshorting the cavity. This appears to cause some quadrupole oscillations within the bucket, causing some longitudinal emittance growth. However as much as 14 mA has been extracted in a single shot using this technique. Figure 4 shows the longitudinal bunch structure with ARF3 shorted and unshorted.

V. RECENT PERFORMANCE

The transverse emittances of the extracted beam, as measured from a SEM profile in the beam transfer line between the Accumulator and Main Ring, range from .5 π mm-mrad to 1 π mm-mrad depending on stack size. The longitudinal profile is measured from a Schottky pickup in the Accumulator. Figure 5 shows the stack profile before and after extracting 6 bunches. Note that the core is displaced slightly after the extractions, and that about 10% of the beam that is unstacked from the core is scattered along the momentum aperture. ESME simulations also predict that 10% of the beam should fall out of the bucket during acceleration to the extraction orbit. The transfer efficiency from Accumulator to Main Ring is typically 95% if the transverse emittances are less than 1 π mm-mrad. Above this, the transfer efficiency drops rapidly due to aperture restrictions in the Main Ring and transfer line. Typically about 50% of the antiproton core can be extracted in 6 shots.

1.38 ev-sec rf buckets were tried but found to be inefficient in acceleration in the Main Ring. The longitudinal emittance of the extracted beam is measured with a resistive wall monitor and bunch length monitor in the Main Ring. These show that there is about a 35% longitudinal emittance blowup in the extraction process. Simulations with ESME also predict an emittance growth of 35%, primarily due to the ARF3 non-adiabatic bunching previously mentioned.

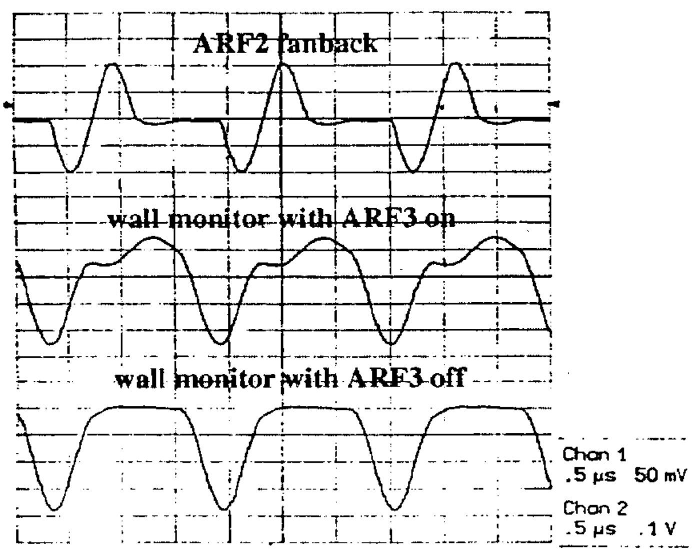

Figure 4. Top trace is ARF2 voltage waveform. Bottom two traces show the effect of beam loading on bunch structure.

VI. CONCLUSIONS

Antiproton extraction from the Accumulator has improved dramatically during the present Collider run. Figure 6 is a plot of the number of antiprotons per bunch in the Tevatron at 900 Gev/c as a function of stack size. Although the curve is beginning to flatten at large stack sizes, we expect that larger antiproton stacks will continue to contribute to greater luminosities in the Tevatron.

VII. REFERENCES

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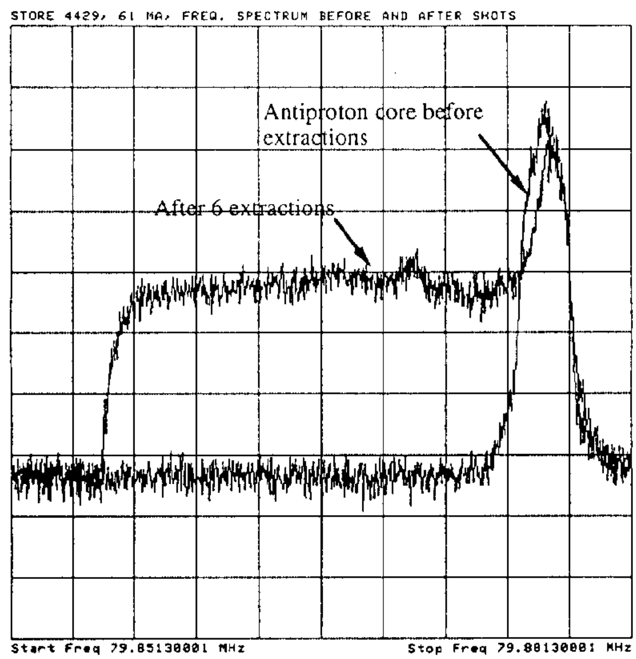

Figure 5. Antiproton frequency spectrum before and after 6 extractions.

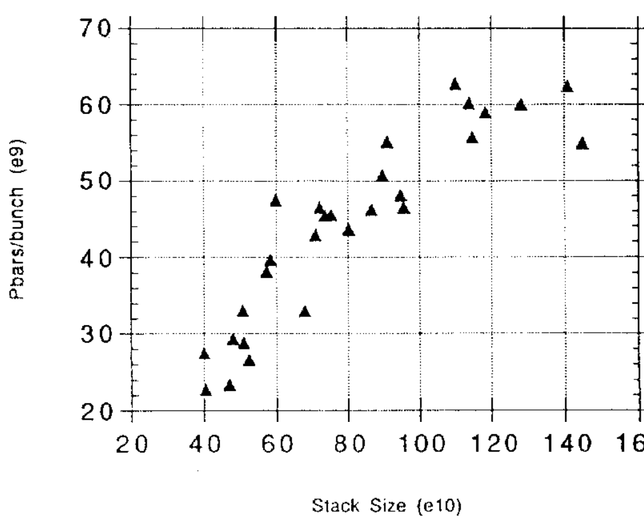

Figure 6. Number of antiprotons/bunch at 900 Gev/c in the Tevatron as a function of antiproton stack size.