# Operating Procedure Changes to Improve Antiproton Production at the Fermilab Tevatron Collider\*

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Abstract

Since the start of Fermilab Collider Run II in 2001, the average weekly antiproton accumulation rate has increased from 400E10 pbars/week to nearly 3,600E10 pbars/week. There are many factors contributing to this increase, one of which involves changes to our operational procedures that have streamlined and automated antiproton source production. Automation has been added to our beam line tuning, stochastic cooling power level management, and stabilizing RF.

## InTRODUCTION

The antiproton source creates antiprotons for Tevatron Run II operations as follows.

* Pulses of 120GeV proton beam from the Main Injector travel through the P1, P2 and AP1 beam lines, which total over 600m in length, every 2.2 seconds before striking a nickel alloy target.
* Downstream of the target, 8GeV negatively charged secondaries are collected and sent down the AP2 line, which is approximately 275m in length, before being injected into the Debuncher ring, where only antiprotons survive after the first hundred revolutions.
* The momentum spread and beam sizes are reduced by RF and stochastic cooling systems before the beam is transferred to the Accumulator via the D/A line just prior to the next stacking pulse.
* The Accumulator momentum stacks the 8 GeV Antiprotons while stochastic cooling systems further reduce the size of the beam.
* The collection of antiprotons in the Accumulator is called a stack.
* The rate at which antiprotons are accumulated decreases as the stack size increases, and the optimal settings for the stochastic cooling systems change with beam intensity.
* Once approximately 35x1010 antiprotons are accumulated in the stack, 8GeV antiprotons are transferred to the Recycler via the Main Injector., while we continue to stack in preparation for the next transfers.

## Increased Pbar Production

Antiproton production has increased steadily over the last three years. Figure 1 shows our weekly antiproton production over time [1]. Each data point represents the number of antiprotons produced in one week. We can see that in March 2006, the most antiprotons produced in a

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week was around 1,700E10, which is just under 250E10 per day. In March, 2009 we had weeks of just under 3,600E10 antiprotons, which is over 500E10 antiprotons per day. In effect, we have doubled the number of daily produced antiprotons in three years.

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| weeklypbars.png |
| Figure 1: Weekly pbar production over time [1]. |

An overview of the factors that contributed to the increase in antiproton production can be seen in {cite the main paper}[2]. One of these factors is the operational procedures that have streamlined and automated antiproton source production.

## Automation

Automation has been added to a number of operational tasks related to both stacking antiprotons well as transferring antiprotons to the Recycler. A significant portion of the automation is the implementation of Rapid Transfers, which is covered in detail in {cite Jim’s paper} [3]. Automation additions related to stacking antiprotons include a beam line tuner, stochastic cooling power manager and ion flusher.

### Beamline Tuner

With over 600m of 120GeV beam line between the Main Injector and target, and approximately 275m of 8GeV beam line between the target and the Debuncher, small changes in the upstream P1 line orbit can translate into changes in the downstream AP2 line orbit significant enough to reduced stacking rates. Prior to any automation, any beam line orbit drift was manually corrected by changing one horizontal and one vertical dipole trim in the AP1 line to maximize the beam intensity to the end of the AP2 line. This process, called “target tuning”, was performed a number of times each day.

Table 1: Automation Tools

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| **Tool** | **Implementation** | **Function** |
| Overthruster | Application | Maintains beamline orbit based on BPM readbacks. |
| Core Babysitter | Application | Maintains optimal Core momentum cooling powers |
| Debuncher Babysitter | Application | Monitors and resets tripped Debuncher cooling system power supplies |
| Stacktail monitor | ACL script | Maintains optimal stacktail momentum power based on stack size |
| Ion Flusher | ACL script | Maintains optimal stabilizing RF settings for larger stack sizes. |

The target tuning procedure has been replaced by an c++ application, called the Oscillation Overthruster. This application corrects drifts in the beam line orbits for 120GeV protons in the P1, P2 and AP1 lines, as well as the 8GeV secondaries in the AP2 line.

* On stacking pulses, the Oscillation Overthruster reads in beam line Beam Position Monitor (BPM) data and alternates making corrections between the 120GeV and 8GeV beam lines. An example of an 8 GeV correction is shown in Figure 2.
* Up to 36 trims in the P1, P2 and AP1 line are used to correct the 120GeV orbit and up to 27 trims in the AP1 and AP2 line are used to correct the 8GeV orbit.
* If the 120GeV BPM data is out of a specified range, the 8GeV correction reverts back to making corrections with only the two “target tune” trims until the 120GeV orbit is back under control.
* If the BPM data cannot be read, the BPM crates are reset to recover BPM functionality.
* If there are gaps between stacking pulses corrections are delayed by a number of pulses to allow the beam line elements to stabilize.

The implementation of the Oscillation Overthruster was made possible by improvements in instrumentation and controls.

The P1, P2, AP1 and AP3 lines all share the Echotek style Beam Position Monitor (BPM) electronics that were built as part of the “Rapid Transfers” Run II Upgrade. These BPMs are designed to detect seven to 84 consecutive 53MHz proton bunches in stacking mode and talk to the control system over Ethernet via VME crates located in five different service buildings [4].

The AP2 line BPMs also have been upgraded to allow beam orbit information during stacking cycles. Secondary particles in the AP2 line have the same 53MHz bunch structure as the targeted proton beam, providing the RF structure needed for the BPMs to function. One of the challenges is the small beam intensities in the line. When stacking, the number of antiprotons and other negative secondaries (mostly pions and electrons) in the AP2 line is on the order of 1E11 at the beginning of the line and 1E10 at the end of the line. In 2005, new BPM electronics were designed for use in the AP2 line. AP2 BPM electronics talk to the controls system over Ethernet via NIM downconverter modules in three service buildings [5].

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| Figure 2: The Overthruster maintains beam line positions. |

One unique problem that had impact on both the Echotek and AP2 BPM upgrades was the lack of Ethernet infrastructure in two service buildings. Due to lack of available network paths, a unique cost-effective solution was employed that involves connecting to the controls network via 802.11b wireless Ethernet [6].

Stochastic Cooling Power Management

Transverse and longitudinal beam cooling is provided by stochastic cooling systems in both the Debuncher and Accumulator. In the Debuncher the cooling systems are run near maximum amplitude to cool the beam as much as possible before sending it to the Accumulator. Accumulator stochastic cooling power levels are set based on both stack size and stacking conditions. Prior to any automation, the process of setting stochastic cooling power levels was manual and required constant attention. Three tools were developed to assist in stochastic cooling power management: the Debuncher babysitter, the Core Momentum babysitter and the Stacktail Monitor.

The Debuncher babysitter is a background application developed to monitor traveling wave tube (TWT) supplies and turn them back on if they trip. If there are three consecutive trips, the babysitter turns itself off to avoid damaging equipment. When this happens, power levels are manually adjusted and the babysitter turned back on.

The Accumulator Core Momentum babysitter is a background application that maintains power levels on both the Core 2-4GHz and 4-8GHz momentum systems at optimal levels. Optimal power level targets were determined over time and are set by the Stacktail Monitor.

The Stacktail Monitor is Accelerator Command Language (ACL) script that controls the Accumulator Stacktail Momentum system. The script

* Maintains optimal stacktail power based on stack size. The optimal settings have been determined by trial and error over time.
* Reduces the stacktail power if the core transverse emittances start to get too large.
* Provides the 2-4GHz and 4-8GHz target power levels used by the Core Momentum babysitter.
* Turns off the Core 4-8GHz momentum system when we are not stacking.
* Turns off some stacktail tanks to reduce heating if non-stacking events are in the timeline.

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| Figure 3: Stacktail Monitor maintains optimal stochastic cooling power levels. |

The creation of the Stacktail Monitor was made possible by the addition of Accelerator Command Languate (ACL) scripts [7]. ACL is an easy to use interpretive scripting language that provides access to Accelerator controls devices. ACL scripts can be launched from parameter pages or through sequencer applications that step users though all of the steps to complete common tasks.

### Ion Flusher

ARF2, also called the Stabilizing RF, is an h=2, 1.26MHz RF system that is used to dislodge trapped positive ions that can lead to emittance growth and stacking instabilities [8]. Prior to automating this system, the stabilizing RF was run at a fixed frequency and voltage. At larger stack sizes emittance instabilities would appear, resulting in periods of poor stacking performance. During these instabilities it was determined by trial and error that modulating the ARF2 frequency and changing the voltage based on stack size reduced the occurrences of instabilities. The ion flusher is an ACL script that is used at larger stack sizes to control the frequency modulation and voltage of ARF2. Figure 4 is plot showing the flusher being used to control ARF2 for a large stack on March 10, 2009.

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| Figure 4: The Flusher controls ARF2 for stacks > 90E10. |

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