# 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 maximum 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 orbit control, stochastic cooling power level management, and RF settings. In addition, daily tuning efforts have been streamlined by implementing sequencer driven aggregates.

## 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 every 2.2 seconds before striking a nickel alloy target.
* Downstream of the target, 8GeV negatively charged secondaries are focused and sent down the AP2 line. They are then injected into the Debuncher ring, where only antiprotons survive after the first hundred revolutions.
* The momentum spread and transverse size are reduced by RF and stochastic cooling systems before the beam is transferred to the Accumulator via the D/A line.
* The 8 GeV antiprotons are momentum cooled in the Accumulator and are collected into a region known as the stack.
* The optimal settings for the stochastic cooling systems change as the stack grows.
* When approximately 35x1010 antiprotons are accumulated, antiprotons are transferred to the Recycler via the Main Injector.

## 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 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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| Figure 1: Weekly Pbar production over time [1]. |

There are many factors that have contributed to the increase in antiproton production [2], some of which are 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 [3]. Automation additions related to stacking antiprotons are summarized in Table 1.

Table 1: Automation Tools

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|  **Tool** | **Implementation** |  **Function** |
| Overthruster | Application | Active beamline steering control using BPM’s. |
| Core Babysitter | Application | Core momentum cooling power regulation |
| Debuncher Babysitter | Application | Automatic recovery of tripped Debuncher TWT’s. |
| Stacktail monitor | ACL script | Regulates stacktail momentum cooling power  |
| Ion Flusher | ACL script | Regulates stabilizing RF settings for larger stacks.  |

### 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.

The target tuning procedure has been replaced by a 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.

* During stacking, the Oscillation Overthruster reads in beam line Beam Position Monitor (BPM) data and alternates making corrections between the 120GeV and 8GeV beam lines.
* Trim magnets are used to correct both the 120GeV proton and 8GeV pbar orbits.
* If the 120GeV BPM data is out of range, the 8GeV correction reverts back to only using the two “target tune” trims until it has been corrected.
* If the BPM data cannot be read, the BPM crates are reset to recover BPM functionality.
* During beam interruptions, corrections are temporarily delayed 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.

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 C application developed to monitor traveling wave tube (TWT) supplies and turn them back on if they trip. If there are six 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 Core Momentum babysitter is an application that regulates power levels on the Core 2-4GHz and 4-8GHz momentum systems. Regulation power levels have been determined empirically 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

* Regulates stacktail power based on stack size based on operational experience.
* Reduces stacktail power, if necessary, to control core transverse emittances.
* 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 not stacking.
* Sequentially turns off stacktail amplifiers to reduce heating if transverse emittances become excessive.

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| Figure 2: Stacktail Monitor regulates stochastic cooling power levels. |

 The creation of the Stacktail Monitor was made possible by the addition of Accelerator Command Language (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 has been used to improve beam stability for large stacks. Prior to automating this system, the stabilizing RF was run at a fixed frequency and voltage, which proved inadequate in maintaining good beam lifetime. Studies demonstrated that modulating the ARF2 frequency and increasing the voltage based on stack size greatly reduced the problem. The ion flusher is an ACL script that is used at larger stack sizes to control the frequency modulation and voltage of ARF2. Figure 3 is a plot showing the flusher being used to control ARF2 for a large stack.

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| Figure 3: The Flusher controls ARF2 for stacks > 80E10.  |

## Tuning

Daily tuning efforts have been streamlined by the implementation of sequencer driven procedures that take non-experts step by step through each tuning procedure. These procedures are divided into stacking and standby (meaning not stacking) sections and are executed in a specific order to maximize efficiency. Prior to the implementation of the sequencer driven tuning aggregates there was no standard to when and how each procedure was executed.

Figure 4 shows the portion of the Pbar Sequencer that covers tuning procedures. The individual aggregates that represent each tuning procedure are listed in the left column. The individual commands for the aggregate selected in the left column are listed in the right column. The individual sequencer commands can include ACL scripts which add functionality, flexibility and performance gains to the procedures.

Table 2 lists the most commonly used tuning procedures,

 Table 2: Daily Tuning

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| **Procedure** | **Mode** | **When task is completed** |
| Accumulator tunes | Stacking or standby | Sets operating point in tune space.  |
| Core Signal Suppression | Stacking or standby | Optimize trombone delays for core cooling systems |
| Kicker Timing | Stacking | Optimize kicker timing |
| Debuncher momentum notch filters | Stacking or standby | Ensures beam leaving the Debuncher is centered on 59,0018 Hz |
| Debuncher transverse notch filters | Standby | Centers notches to ensure optimal Debuncher transverse cooling. |
| Debuncher Cooling power | Stacking | Maximizes Debuncher stochastic cooling powers |
| Energy Alignment | Stacking | Match Accumulator and Debuncher energies. |
| Center Core pick-ups | Standby | Minimizes excessive power due to misaligned tanks. |

## Conclusion

Operational procedure changes which include automation and streamlining of common tasks have contributed to the increased performance of the Antiproton Source. A number of common operational tasks have been automated including beam line orbit control, stochastic cooling power management and stabilizing RF settings. In addition, daily tuning efforts have been streamlined by implementing sequencer driven aggregates that take non-experts step by step through each tuning procedure.

## References

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