AP2 and Debuncher Acceptance Upgrades

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Overview

One exceedingly difficult problem that must be overcome in the accumulation of antiprotons is that of gathering the antiproton beam, which has been created in a very large phase space volume at the production target, into the relatively small admittance of the accelerator responsible for accumulation. Any endeavor to increase the yield of antiprotons will require either an increase in the overall acceptance of the Antiproton Source or improvements in the means by which a large reduction in the phase space volume occupied by the $\bar{p}$ beam is accomplished. The focus of this document is on the plans to increase the acceptance of Antiproton Source components immediately downstream of the production target – the AP2 beamline and the Debuncher ring.

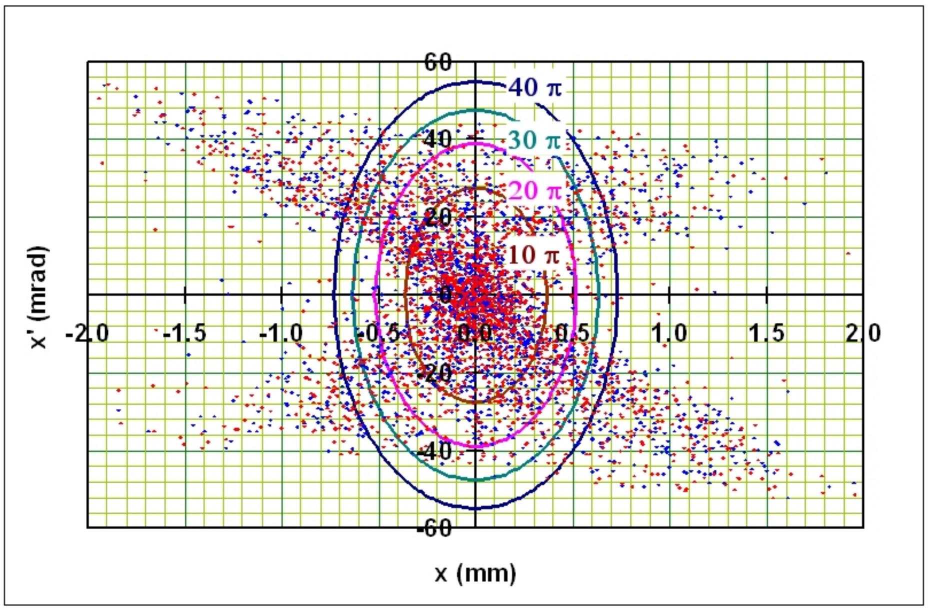

Figure 1 MARS model of $\bar{p}$ phase space distribution at the center of the target. The plot contains only $\bar{p}$'s that fall within the acceptance of Li Lens and with $\Delta p/p < 2.25\%$. The blue dots represent horizontal phase space coordinates (x, x') and the red dots represent vertical phase space (y, y') – there are two points for each $\bar{p}$ in the plot.

The first component significantly impacting the acceptance of the Antiproton Source is the lithium collection lens. The lithium lens matches the widely divergent $\bar{p}$ beam from the target into the AP2 beamline. In the present configuration, the number of antiprotons focused into the acceptance of the AP2 line increases nearly linearly with the magnetic field gradient of lithium lens. Therefore, a significant effort is presently underway to increase the operating gradient of the lens. This effort is described in [1].

An appreciable amount of $\bar{p}$ beam is produced at large amplitude in transverse phase space (see Figure 1). It is apparent that significant gains can be realized by increasing the acceptance of the Antiproton Source components downstream of the lens. Moreover, the fractional enhancement in $\bar{p}$ yield with increased lens gradient is greater with higher transverse acceptance (see Figure 2). Therefore, another significant effort has been launched to increase the acceptance of the AP2 line and the Debuncher. This effort is the AP2 and Debuncher Acceptance Upgrades project.

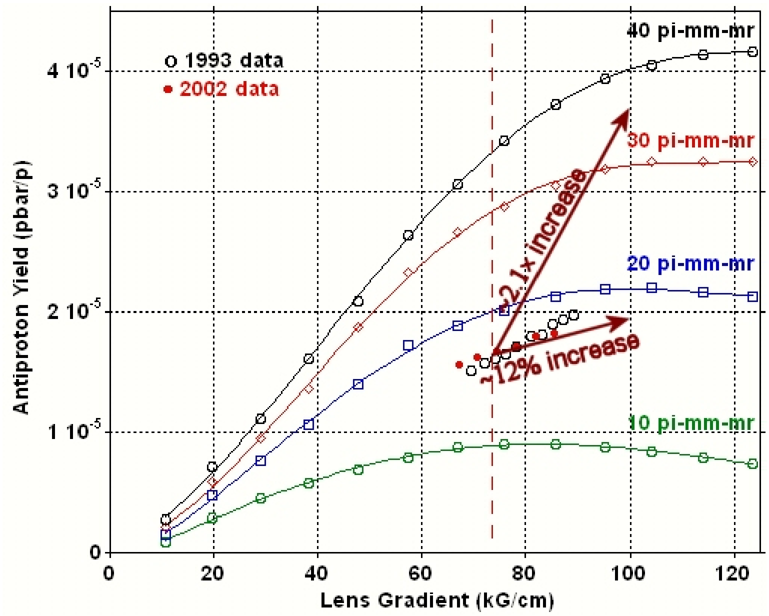

Figure 2 Antiproton yield into the Debuncher versus lithium lens gradient for various AP2/Debuncher transverse admittances. The family of colored solid curves is derived from a MARS model and particle tracking [2]. The open circles and the red dots are from beam-based measurements of yield vs. gradient. The vertical dashed line represents the present operating lens gradient. The expected gradient after completion of the lithium lens upgrade is 100 kG/cm. At the present AP2/Debuncher acceptance, the lithium lens upgrade gives an approximately 12% increase in $\bar{p}$ yield. If the AP2/Debuncher admittance is 35 π mm-mrad, an approximately 17% increase in $\bar{p}$ yield is realized when the gradient is increased from its present value to 100 kG/cm.

The goal of the AP2 and Debuncher Acceptance Upgrades project is to increase the combined acceptance of the AP2 beamline and Debuncher Ring to a value of 35 π mm-mrad (un-normalized). The AP2 beamline and Debuncher ring components and lattices were originally designed to have physical apertures in excess of 40 π mm-mrad. Historically, the actual acceptance has been measured to be significantly less than this value (see Table 1). The present antiproton yield into the Debuncher is approximately 16×10^{-6} $\bar{p}$/proton. At the present lens gradient (74.5 kG/cm), the yield is expected to increase to about 31×10^{-6} $\bar{p}$/proton if the AP2/Debuncher acceptance is increased to 35 π mm-mrad. The antiproton yield approaches 36×10^{-6} $\bar{p}$/proton if, at the same time, the lithium lens gradient is increased to 100 kG/cm. This would represent an approximately two-fold increase over the present performance.

Table 1 Design, measured, and projected admittances for the AP2 beam line and Debuncher Ring

	Design		Measured		Goal	
	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
AP2	40 π	40 π	26 π	20 π	35 π	35 π
Debuncher	40 π	40 π	20 π	12 π	35 π	35 π

Scope

The AP2 and Debuncher Acceptance Upgrades project consists of nine sub-projects that are summarized in Table 2.

Table 2 Summary of AP2 and Debuncher Acceptance Upgrades sub-projects

Sub-Project	Summary
Documentation & Drawings	1. Research documentation and drawings to determine the aperture anywhere the beam pipe changes and at the entrance, center and exit points of all accelerator components of the AP2 beamline and Debuncher ring. 2. Identify components having a physical aperture less than 40 π mm-mrad.
Optical Survey and Alignment	1. Determine the location and orientation of all beamline components of the AP2 beamline and the Debuncher. 2. Identify and correct alignment errors. 3. Determine alignment of AP2 beamline with respect to AP1 beamline, target, and lens.
Instrumentation	Facilitate monitoring and beam based alignment by: 1. Upgrading existing instrumentation 2. Adding additional instrumentation as necessary.
Beam Based Alignment	Develop and test beam based alignment software and procedures.
Redesign/Relocation of beamline components	1. Redesign and rebuild components identified as having a physical aperture less than 40 π mm-mrad. 2. Where possible, relocate aperture-limiting components to a more favorable location in the lattice.
Orbit Control	Build and install trim dipoles and motorized quadrupole magnet stands to improve orbit control.
Debuncher Injection Channel	1. Consider possible re-design of Debuncher injection channel 2. Develop procedures for beam based alignment of Debuncher injection channel
Beamline lattice model	Develop, calibrate, and test optics models of the AP2 beamline and the Debuncher.
Beam studies	1. Beam based determination of limiting apertures 2. Beam tests of software and procedures

A primary concern is to identify the location of all physical apertures that are less than 40π mm-mrad and take corrective action. The location of limiting physical apertures is accomplished through a study of existing drawings and documentation and through beam studies. The corrective actions consist of beamline element alignment, beam orbit control, optics adjustments, and possible relocation or redesign of beamline components.

Since the initial commissioning of the Antiproton Source, there have been several changes to the AP2 beamline and the Debuncher ring. A project has been initiated to collect, collate, and verify existing drawings and documentation of the AP2 beam line and the Debuncher ring. Beam studies are planed to measure the existing lattice. The combined information of physical apertures, component location, and optics will identify components that require redesign or relocation. It may also be possible to change the lattice to decrease the beam size at such physical apertures. The information gathered will also be used to determine the misalignment tolerance of all AP2 line and Debuncher components. Where the misalignment tolerance is small, both alignment and beam orbit control will be used to correct the situation.

During stacking beam orbit measurement in the AP2 line and for the first few turns in the Debuncher is greatly complicated by the fact that the beam consists predominantly of pions, muons, and their decay products. Consequently, orbit and optics measurements are primarily done with reverse 8 GeV proton beam (delivered from the Main Injector to the Accumulator and then transferred to the Debuncher). In any case, the Beam Position Monitoring systems of the AP2 beam line and Debuncher ring need to be upgraded to make the needed orbit measurements.

Status & Plans

Documentation & Drawings

Engineers and draftsmen from Fermilab Technical Division are in the process of researching existing documentation and drawings to determine the aperture everywhere in the AP2 beam line and Debuncher ring.

By summer 2003, the documentation research should result in table of the apertures throughout the AP2 beam line and Debuncher ring. In addition, the lattice model files will be completed and verified. The combined information will help identify possible limiting apertures. When the operations schedule permits, accesses to the Antiproton Source tunnels are planned to verify this research. It is expected that this work will be complete by the fall of 2003.

Optical Survey and Alignment

Surveys of portions of AP2 beam line and the Debuncher ring will be done whenever manpower is available and tunnel enclosure access is possible. Surveys will not only concentrate on the small alignment tolerance areas but also on areas where the tunnel enclosure may have moved: AP2 section that was removed and replaced for the construction of the MI8 beam line and where in the past tunnel movement has been measured. In addition, the overall alignment of the AP1 and AP2 beam lines will be checked.

Instrumentation

1. AP2 line instrumentation

The downstream AP2 BPMs are unusable for position measurement of reverse proton beam extracted from the Debuncher using the Debuncher injection kicker. The ground surge caused by firing the injection kicker completely overwhelms any signal from the beam that might be present on the BPMs. In addition, it is not known if the current procedures for transferring reverse proton into the AP2 line will provide enough beam intensity for the current beam line BPM system to work effectively.

Investigations into this problem have just begun. Since the downstream BPM electronics and the Debuncher injection kicker are housed in the same service building, a possible solution is to move the data acquisition electronics to another building. It may be possible to do the AP2 beam line optics measurements with BPMs at the upstream end of the beamline. Further study of the reverse proton beam intensity will be done. This could lead to a change of beam manipulation procedures and/or changes to the beam line BPM electronics and data acquisition.

2. Debuncher BPM upgrade

A new Debuncher BPM electronics prototype has been installed and tested under beam conditions. During the January 2003 shutdown, the new electronics was installed for all of the BPMs in one sector of the Debuncher. The one sector of new BPM electronics will be thoroughly tested in the near future.

The balance of the system will be completed and bench tested in the next few months with installation during opportune accesses. Data acquisition software is being developed and is expected to be ready by fall 2003.

Beam Based Alignment

The beam based alignment sub-project is an ongoing effort to develop procedures and software to optimize the acceptance of the AP2 beamline and the Debuncher using beam-based measurements. These procedures will be continuously adapted the other components of the AP2 and Debuncher Acceptance Upgrades project are completed.

Redesign/Relocation of Beamline Components

The plans for moving/modifying/redesigning suspected and known limiting apertures have not changed in the past year. The elements previously identified are the first Debuncher SQC quadrupole after injection (D4Q4), RF cavities (DRF3 and DRF2), and the band 4 cooling tanks. The proposed corrective actions are respectively to replace with a larger opening LQD quadrupole, move the RF cavities, and redesign the arrays and/or change the lattice through the cooling tanks.

Orbit Control

Previously, areas where it is believed that beam orbit control would be most useful were identified. One dipole trim per plane has been inserted in the upstream portion of the AP2 beam line during the past year. During the January 2003 shutdown, two vertical dipole trims have been added to the down stream portion of the AP2 beam line.

Due to the crowded Debuncher ring, orbit corrections will be done with remotely controlled movable quadrupole stands. The stands allow the quadrupole to be offset in the transverse planes producing a dipole kick to the intentionally off-centered beam. Ten stands have been manufactured and await installation.

The Debuncher movable quadrupole stands will await opportune accesses and availability of manpower for installation. The order of priority for the installation of the stands is four in the injection region, four in the extraction and cooling pickup region and then two in the kicker tank region. If these stands along with existing Debuncher correction elements are successful in providing local orbit control, then up to twenty-five more stands could be manufactured and installed for local orbit control throughout the Debuncher ring.

Debuncher Injection Channel

In March of 2003, physicists from Lawrence Berkeley National Laboratory agreed to undertake a critical re-examination of the design of the Debuncher injection channel. This project also includes the development of beam based alignment procedures specific to Debuncher injection. The end results of this project will include possible redesign of Debuncher injection and/or injection channel components as well as procedures to optimize the acceptance of the Debuncher injection channel.

Beamline Lattice Model

Working OptiM optics models of the AP2 line, the Debuncher injection channel, and the Debuncher ring presently exist. These models will be updated as physical aperture and alignment data become available. Beam studies will be conducted to verify and calibrate these models.

Beam Studies

In the first quarter of 2003 there was an effort to establish the procedures to reliably transport reverse 8GeV proton beam to the Debuncher as well as manipulating the beam in the Debuncher (RF to change beam momentum and to make BPM measurements with the existing partially working system) and sending beam through AP2 (verified with SEM grids and attempts to make beam line BPM measurements). The collimator scraper sets have been exercised and used to measure the current admittance during reverse protons studies in the Debuncher and during stacking to determine the current overall acceptance of the combined AP2 and Debuncher system. The measured admittances are shown in Table 1 above. In addition the total momentum acceptance of the AP2 and Debuncher system has been measured to be 4.6%.

A majority of the studies are to be preformed using the 8GeV reverse protons: beam delivered to the Debuncher from the Main Injector via the P1, P2, AP1 and AP3 beam lines to the accumulator and then transferred to the Debuncher through the connecting D2A beam line. Reverse proton can be kicked out of the Debuncher into AP2 for studies. There are some semi-parasitic studies that can be performed while the Fermilab complex is stacking. With the reversal of polarity of the magnet elements of the AP2 beam line and Debuncher, 8GeV forward protons can be used for studies when the production target and lithium lens are removed from the beam path (Main Injector, P1, P2, AP1, AP2 and then to the Debuncher).

<u>*Reverse Proton Studies*</u>

The accumulator shutter system can be closed to isolate any antiprotons circulating on the core orbit from kicker effects of the injection and extraction of reverse protons passing through to the Debuncher. These studies occur during dedicated studies periods.

I. Debuncher Studies
   A. BPM commissioning
      1. Single Sector: intensity versus result stability, local bump, front-end algorithm, data acquisition
      2. All Sectors: console application, polarity, scaling, archiving
   B. 1-Bump lattice measurements (after BPM system commissioned)

1. Nominal Orbit
2. Off momentum orbit

C. Determine quadrupole centers (after BPM system commissioned)

1. Vary shunt currents and see closed orbit changes
2. Determine if bumps can result in centered orbit

D. After installation of each set of remotely controlled motorized quadrupole stands:

1. Verify quadrupole movement
2. Determine dipole kick per unit of movement
3. Develop local bumps

E. Center orbit in aperture

1. Heat beam in transverse plane and watch Beam Loss Monitor (BLM) system signals
2. Determine which BLM counter shows first beam loss signal
3. See if local orbit bump removes loss signal on BLM counter

F. After every orbit change that is implemented:

1. Center appropriate motorized (non-steering) devices

G. At the end of most studies periods:

1. Measure closed orbit
2. Measure transverse admittances
3. Measure momentum aperture

II. AP2 Studies

A. BPM commissioning

1. Develop method for measuring orbit position reliably for upstream part of AP2
2. Commission downstream AP2 BPMs for solution that removes the kicker signal

B. 1-Bump lattice measurements (after BPM system commissioned; may be possible to do after upstream BPMs are commissioned)

1. Nominal orbit
2. Off momentum orbit

C. Commission newly installed dipole trims

D. Determine quadrupoles' centers (after BPM system commissioned)

1. Vary shunt currents and see orbit changes
2. Determine if bumps can result in centered orbit.

E. At the end of most studies periods:

1. Record nominal BPM orbit
2. Record nominal SEM orbit

III. Injection Region Studies

A. Center orbit in aperture

1. Blow-up/scrape beam to known emittance
2. Kick beam out of Debuncher into AP2
3. Measure surviving beam in AP2 varying closed orbit, kick strength, and septum voltage and position

Stacking Studies

These studies are semi-parasitic since antiprotons can still be stacked at a lower overall rate. The reduction of the stacking rate will be caused by increasing the stacking cycle time, scraping of the beam due to mis-steering of the beam, and/or particles are intercepted as part of the measurement.

I. AP2 Studies

A. Determine quadrupoles' centers (using SEMs)

B. Correct secondaries orbit to the reverse proton SEM orbit

II. AP2 & Debuncher Studies

A. After most studies periods:

1. Measure combined AP2+Debuncher transverse acceptance
2. Measure combined AP2+Debuncher momentum acceptance
3. Record beam orbit using SEMs

Forward Proton Studies

These studies are disruptive to the Collider program since antiprotons are not available from the Antiproton Source. Each reversal of polarity of the magnetic elements requires a few shifts. These studies require both the antiproton production target and lithium collection lens out of the beam path.

I. AP1 & AP2 studies

A. Make BPM, SEM and intensity monitors operate with the associated timing events to deliver forward proton beam

B. 1-Bump lattice measurements

C. Determine quadrupoles' centers

D. Record AP1 and AP2 BPM orbit

E. Record AP1 and AP2 SEM orbit

II. Injection Region Studies

A. Center orbit in aperture by measuring surviving beam after Debuncher injection kicker while varying different AP2 correction elements and injection elements (septum and kicker)

References

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