STUDIES TO INCREASE THE ANTI-PROTON TRANSMISSION FROM THE TARGET TO THE DEBUNCHER RING*

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Abstract

The AP2 beamline at Fermilab transports anti-protons from the production target to the Debuncher ring. The measured admittance of the Debuncher ring and the theoretical aperture of the line are larger than the size of the transmitted beam. Extensive tracking studies were done using the Accelerator Toolbox (AT) to understand the sources of the difference. As simulations pointed to chromatic effects being a source of problems, measurements were done to study this. Several possible remedies were studied including adding sextupoles to the line to reduce the chromatic effects.

INTRODUCTION

After the production target the anti-protons are focused by a lithium lens, which is not part of the studies presented here, into the AP2 line. The AP2 line consists mainly of a FODO lattice and a left bend section with matching sections at the beginning and a vertical bending section at the end to inject the beam into the Debuncher ring. The lattice is shown in Fig. 1.

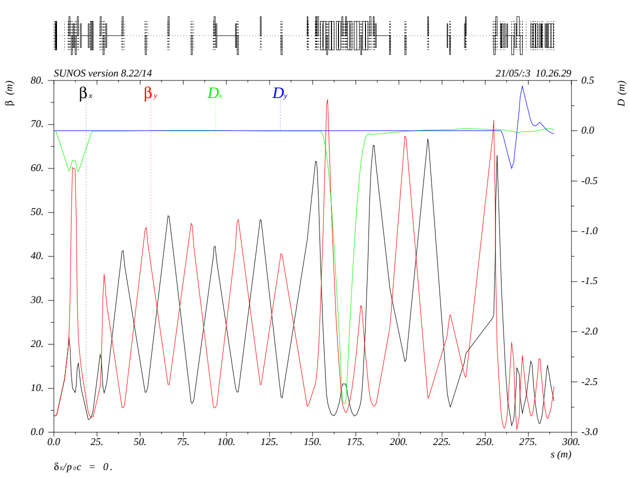

Figure 1: Lattice of the AP2 beamline.

The Debuncher will eventually have an acceptance of 35π mm mrad after removal of some aperture restrictions. It is therefore desirable that the AP2 line has at least the same aperture in order to maximize the number of anti-protons transferred. Just comparing envelopes and apertures shows that the aperture in the line should be sufficient (see Fig. 2), although for years the measured acceptance of the injected beam has been significantly smaller than the acceptance of the Debuncher. As the beam from the target has a very large beam size and nearly flat distribution, an increase in the transmitted beam size would translate into a higher number of anti-protons stored, resulting in the possibility to refill the Tevatron more often and therefore run it at a higher average luminosity.

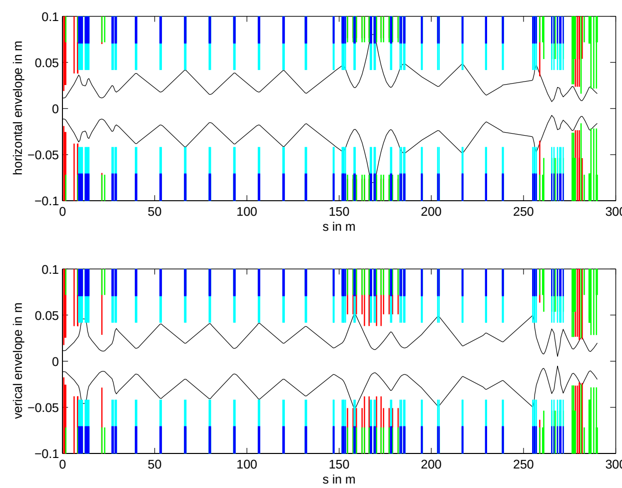

Figure 2: Beam envelopes for 35π mm mrad emittances and 4.5 % full width energy spread based on the β-functions and dispersions shown in Fig. 1. Aperture restrictions, where known, are indicated (rectangular apertures are in red, circular ones in green and the star shaped chambers are in blue (outer radius) and cyan (inner radius)). Betatron and dispersion contributions are added linearly as all distributions are (to first order) flat.

Some initial studies have focused on identifying possible sources of the aperture restriction [1]. We are now presenting suggestions on increasing the transmission rates.

MEASUREMENTS

As chromatic effects were suspected, slicing measurements were performed: A collimator in the bending section, where the dispersion dominates the transverse position of the particles, was used. The two jaws of the collimator can be moved independently and can be moved all the way across the beam pipe to the other jaw. This allows

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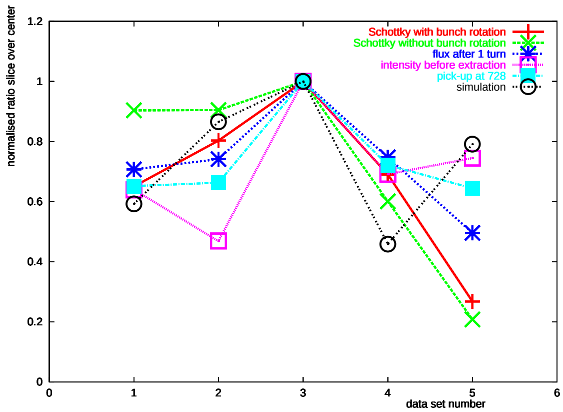

Figure 3: Results from slicing measurements.

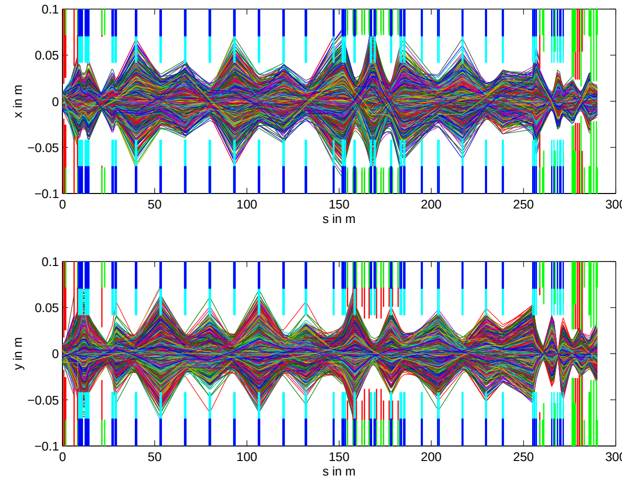

Figure 4: Trajectories and apertures in AP2.

the selection of momentum slices.

We did two measurements under slightly different conditions and with different slices. Each time we used about five slices, in one case they were constrained to have about the same aperture, and in the other case about the same transmission. The transmission was measured by a number of instruments including Schottky spectra. It was also measured with and without bunch rotation. Figure 3 shows the results from one of the measurements. Simulation and measurement agree that there are fewer particles transmitted near the edges of the momentum distribution confirming that chromatic effects are limiting the transmission.

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TRACKING STUDIES

In order to understand where particle losses might occur, a large number of tracking studies have been performed with MAD [2] and AT [3]. A set of particles corresponding to the anti-proton distribution after the lithium lens was created with MARS [4]. The set contains 1429 particles which are all inside the momentum acceptance of the Debuncher ($\pm$2.25%) but some of the particles are outside the transverse acceptance (1082 particles are within 40π mm mrad).

The lattice used in the tracking for the line and the Debuncher corresponds to the one used in 2004. All known apertures are included in the tracking. Figure 4 shows the tracking results through the line. We find that 1070 particles of the sample reach the end of AP2.

The particles are then tracked through the Debuncher for 50 turns. As the bunch rotation takes only slightly longer than that, a simple approximation of the momentum change was implemented as the energy spread of the beam shrinks by almost a factor of ten during this time. After 50 turns only 814 particles are left, i.e. only about 75% of the particles in the desired aperture.

One of the first things studied in more detail were the chromatic lattice functions, as they are fairly large in the line and not matched well into the Debuncher. It was suspected that this, together with the large energy spread of the beam, could lead to significant losses. Figure 5 shows that the energy distribution is slightly depleted at the edges. Setting the energy deviation of all particles to zero increases the transmission but still more than 15% of the particles inside 40π mm mrad are lost. This is partially due to the on-energy mismatch and partially due to the aperture in the Debuncher being less than 40π mm mrad in the version that was used for these studies. It also shows that the vertical aperture in the Debuncher is only about 30π mm mrad, reducing the particles in the initial sample by another 10%. Thus, about 15% of the particles are lost despite having a sufficiently small initial amplitude.

Tracking studies were also done with increased apertures at the tightest places in the AP2 line. Although the transmission right after the line was increased by about 10%, after fifty turns in the Debuncher the transmission was exactly the same as with the nominal apertures. We therefore conclude that increasing the aperture anywhere in the line will not have an impact on the overall transmission.

SUGGESTED REMEDIES

We found two things that each increase the transmission by about 5%: Matching the on-energy lattice functions into the Debuncher and adding sextupoles to decrease chromatic effects.

Rematching

Even the on-energy lattice functions are not very well matched into the Debuncher. Simulations have shown that a better match increases the transmission by about 5%. Ideally one would like to measure the lattice functions at the injection point in the Debuncher and then match the ones of the line. This is difficult, as the strength of the quadrupoles in the line is only known to about 1%. Creating linear knobs to change individual lattice functions is also difficult, if not impossible.

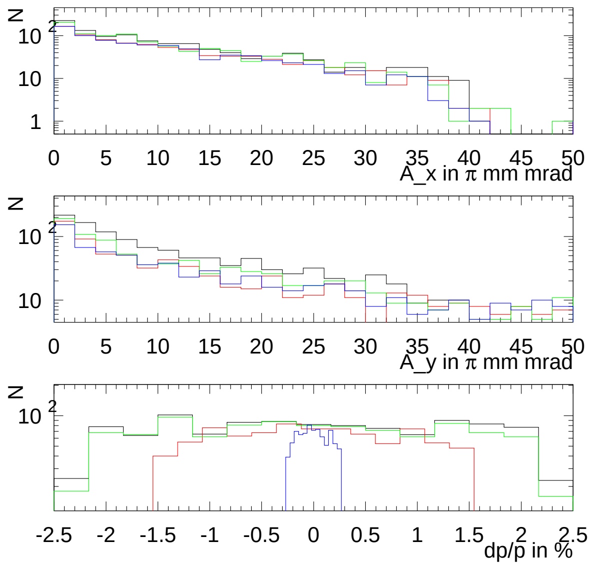

Figure 5: Particle distribution in normalized coordinates after AP2 (green), ten turns (red) and fifty turns (blue) using only particles with initial amplitudes smaller than 40π mm mrad.

We therefore tried a different approach: One quadrupole strength at a time was varied to find the strength where the transmission is highest. This was done with six quadrupoles at the end of the line, including the three that are inside the vertical bending section.

In simulations, the transmission with the lattice obtained this way was equal to the one obtained with a matched lattice. It was also found that not more than one or two iterations are necessary.

This method can be applied parasitically to normal running, but it requires the beam to be very well centered in the quadrupoles to avoid steering (as this could more than eat up the gain from the better optics). Centering the beam in the quads will soon be possible after the BPMs in the line have been upgraded.

Chromatic Correction

Optimizing the chromatic properties of the line requires sextupole magnets in areas with dispersion. The only area with significant dispersion is the bending section. In this area there is no room at all for additional magnets. We therefore considered powering the top coils of quadrupole magnets differently than the bottom ones thus creating a sextupole term. The dipole term created by this can be corrected using conventional orbit correctors.

This method was tried with a quadrupole on a test stand to measure what kind of sextupole term could be obtained and what higher multipoles are also present. Some higher multipoles were indeed observed (mainly b_5). Simulations have shown that these multipoles do not decrease the transmission of the line.

Finding the optimal strength of the sextupole terms is tedious: Ideally one would like pairs of sextupoles π apart with equal β-functions, one of them with and one without dispersion. This way one could get the largest impact on the chromatic functions and reduce the geometric effects introduced by the sextupoles. As this is not possible here, we choose quadrupoles that are roughly π apart at least.

Usually we used eight sextupoles at a time. Just minimizing chromatic functions does not increase the transmission as the geometric effects decrease the transmission of on-energy, large amplitude particles. One therefore has to optimize the settings using tracking.

Using the fitting algorithms provided by MATLAB and optimizing the number of transmitted particles, we have found sextupole settings that increase the transmission by up to 5%.

CONCLUSION

We have found two solutions which each should increase the anti-proton yield by about 5%. Rematching the lattice should be implemented first. This solution requires no additional hardware and only some hours of beam time to steer the beam. The rematching itself can be done parasitically to normal running.

After that, we suggest implementing the hardware to add sextupole terms to a number of quadrupole magnets. Adding the sextupole term should increase the transmission by another 5%.

Acknowledgments

We would like to thank Christoph Steier for converting the lattice files into AT and for implementing both a circular and a star-shaped collimator in AT.

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