BETA FUNCTION MEASUREMENT FOR THE AGS IPM*

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Abstract

Emittance control is important for polarization preservation of proton beam in the Alternative Gradient Synchrotron (AGS). For polarization preservation, two helical dipole partial Siberian snake magnets are inserted into the AGS lattice. In addition, the vertical tune has to run very high, in the vicinity of integer. These helical dipole magnets greatly distort the optics, especially near injection. The beta functions along the energy ramp have been modeled and measured at the locations of the Ion Profile Monitor (IPM). For the measurements to be valid, the betatron tune, dipole current and orbit responses have to be carefully measured. This paper summarize the experiment results and comparison with the model. These results will lead to understanding of emittance evolution in the AGS.

Introduction

Emittance control is important for high luminosity in colliders. For polarized proton operation in Relativistic Heavy Ion Collider (RHIC), emittance preservation is advantageous due to its link to polarization preservation. In general, larger emittance results in larger depolarizing resonance strength and consequently, larger polarization loss. Several techniques have been employed in the AGS to preserve polarization, such as dual partial snakes[1], horizontal tune jump quadrupoles [2] and harmonic orbit corrections. To further reduce polarization loss in the accelerator chain, it is necessary to control the emittance growth. As the first step, we need to measure emittance reliably.

The main device in the AGS to measure emittance is the ion collecting IPM[3], which has been put in use for more than 20 years. They are installed at β_{max} locations to measure both horizontal and vertical emittances. The device shows that vertical emittance increases four times in the AGS during polarized proton acceleration. However, some reported emittance growth is not real. First, two partial snake magnets (helical dipole magnets) with constant fields during the whole AGS cycle cause significant optical distortion. The expected beta beating may distort the reported emittance values at low energies. Second, the space charge of bunched beam is stronger at higher energy due to smaller beam size which causes larger reported emittance[4]. The profiles obtained from the AGS IPM has known effects from space charge of bunched beam, which can only be mitigated at a flattop by turning off the RF cavities.

Using the lattice model with the helical magnets included, the beta functions at the IPM locations can be calculated along the AGS magnet ramp. One example of measured emittance for polarized protons with the modeled beta functions in both vertical and horizontal in AGS magnet cycle is shown in Fig. 2. The drop of reported emittance at 1000ms indicates the effects of space charge. The distortion of beam profile due to space charge force is mitigated with RF off.

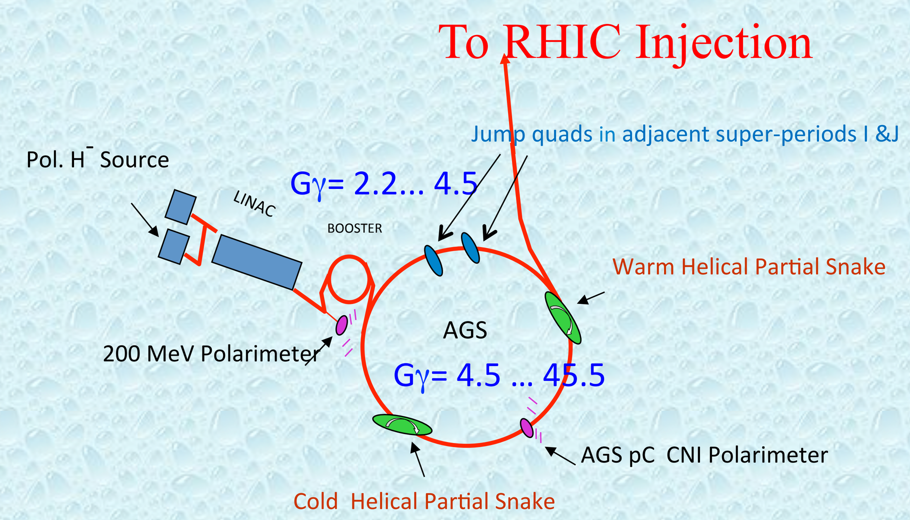


Figure 1: AGS polarized proton acceleration complex.

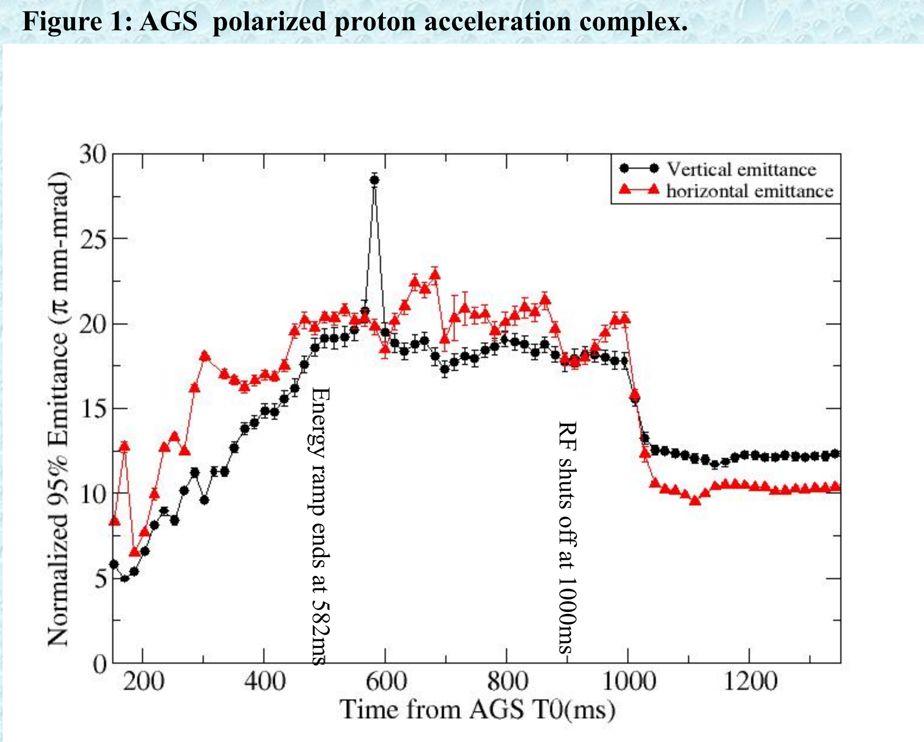
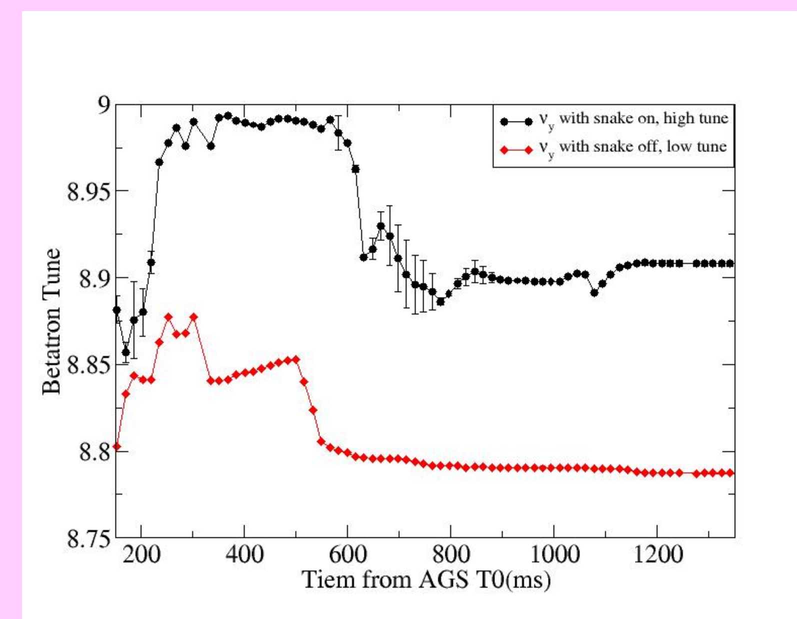


Figure 2: Measured normalized 95% emittance evolution in the AGS with IPM for both planes. The energy ramp finishes at 582ms. The RF cavities are shut off at 1000ms and the "true" emittance at flattop is reported after that.

Results

Proton beam is injected into AGS 150ms from AGS T0. The beam is then accelerated and reaches flattop energy of 25GeV at 582ms. There is a flattop of one second for extraction maneuvers. The transition is crossed around 315ms from AGS T0. To preserve beam polarization, the vertical tune has to be pushed high (above 8.98) on the acceleration part. Ideally, the vertical tune should be pushed high right at the beginning of acceleration. However, the significant optics distortion introduced by the partial Siberian snakes results in large beta function beating at lower energies. The vertical tune has to stay low for beam survival. After that, the vertical tune needs to be pushed high as soon as possible so that it is higher than 8.98 before the first major depolarizing resonance, which is located around 262ms from AGS T0.

The distorting current function needs to move the beam as far as possible without scraping - to improve signal to noise both for beam displacement and for dipole current. Given the tune variation this is a challenge. Big changes between minimum and maximum currents make the slopes less sensitive to small underlying machine drifts. For each point, the bipolar dipole was fired in both positive and negative directions to get several position changes. The measurement was repeated several times and the average was used in beta function calculation.



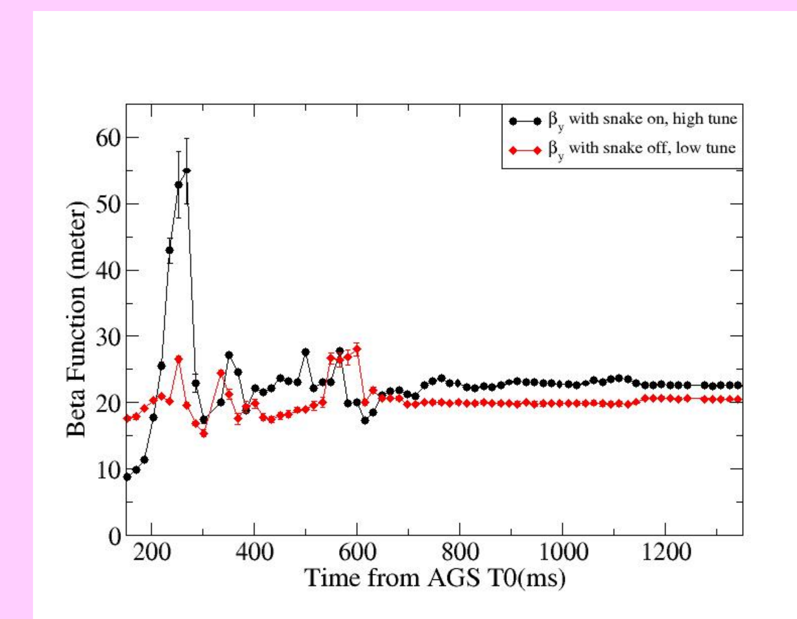


Figure 4: AGS vertical tunes for partial Siberian snakes on/off. Figure 5: The measured vertical beta functions for one AGS cycle.

The vertical tunes in the AGS for partial Siberian snakes on and off are shown in Fig. 4. The beta function measurements for partial Siberian snake on case were done several times over a few sessions. The tunes plotted are the average of the measured tune over several months. So it is not surprising for a few points the tune values have changed quite a bit, which resulted in larger error bars. As these large error bars are with tunes lower than 8.98, the impact on beta function measurement is not significant.

The measured beta functions with partial Siberian snakes on and off are shown in Fig. 5. For the optics without partial Siberian snakes, the beta functions at the IPM location is expected to be around 23m from model. The measured beta functions vary around 20m through the AGS cycle. There are some fluctuations which could be from systematic errors. For the optics with partial Siberian snakes, the beta functions at the IPM location is expected to be around 25m at flattop, when the partial Siberian snake effect is small (but still visible for slightly larger beta function). At injection, the model predicts that the beta function should be less than half of the value at flattop. The measurements confirmed that overall trend.

The horizontal beta function at the IPM can be measured with same procedure. However, the location of horizontal IPM is between the two BPMs used by RF system for radial loop. To measure beta function there, the RF system has to switch to phase loop so that the radius can be moved by dipole correctors. RF system has to be on radial loop around transition crossing (~300ms) but can be on phase loop during the rest period. The horizontal beta function measurement with RF system at phase loop has been tested but more beam time is needed to get this working.

Motivation for Beta Function Measurement

Vertical beta function near injection is less than half of the value at flattop in the model. It is clear that the vertical emittance seems doubled from injection to the flattop. Since the helical dipole partial snake magnets are hard to model, there is some doubt if the model gives the correct beta functions along the energy ramp. At higher energies, as the beam rigidity is higher, the effect from the helical dipoles are smaller. The model predicts that with helical dipoles inserted, the vertical beta function near injection is only half of the nominal beta function value. To check the model and to get true emittance evolution along the energy ramp, the beta functions have to be measured along the ramp.

Data Quality Control

To reach a benchmark error bar of 5%, we need to know following quantities well in the AGS magnet cycle: B field, betatron tune, beam centroid and readback current. It is necessary to estimate the errors for these calculated betas. From Eq.(3), taking partial derivatives, the dependence to each input can be calculated. For B field, taking the middle field 5kG on the ramp as example, 5% error means to know the B field down to 250G, which is easy to achieve. Polarized proton operation requires vertical tune near integer along the energy ramp (higher than 8.98)[1]. For betatron tune, the 5% error means that the betatron tune error needs to be less than 0.0005 for ν_y= 8.99, or 0.001 for ν_y= 8.98. These requirements can still be met for real measurement.

The dipole current readback at first was corrupted by beam noise. To alleviate this, filters were added to these signals on all dipole correctors associated with IPM. Once this was done, we were able to sufficiently determine that the functions were properly being followed and the current was known. The data was logged and they followed the set values within the 1%.

Beta Function Measurement

The beta function can be learned by distorting the equilibrium orbit of a functioning machine - by adding a dipole - and measuring the orbit motion at the dipole. This measurement is model-independent. One needs position-measuring capability at the dipole, and one only learns the beta function at the dipole. With a dipole magnet right at IPM, the centroid of the ion beam profile from the IPM provides the position measurement.

The beam position change due to a dipole kick is related to the local beta function, kick strength and the betatron tune. Beam position shift ΔY due to a known kick (with kick strength k) is given by

$$\Delta Y = \frac{1}{2} k\beta \cot(\pi Q) \qquad (1)$$

Where Q is betatron tune and β is the beta function in the corresponding plane.
The kick strength k is given as

$$k = \frac{Bdl}{B\rho} \qquad (2)$$

Where $Bdl= IT$ denotes the integrated magnetic fields of the dipole corrector, $B\rho$ is the magnetic rigidity of beam, I is the dipole corrector current and T is the transfer function of the dipole correctors.
The shift in measured position of the beam centroid at IPM ΔY_{IPM} and the known dipole kick (k) can be used to calculate the beta function:

$$\beta = \frac{2\Delta Y_{IPM}}{IT} B\rho \tan(\pi Q) \qquad (3)$$

In the above equation, betatron tune and beam position shift are measured with tune meter and IPM, respectively. The dipole corrector current is set to have maximum position shift without beam loss. The transfer function is known as 2.8×10^{-4} T-m/Amp.

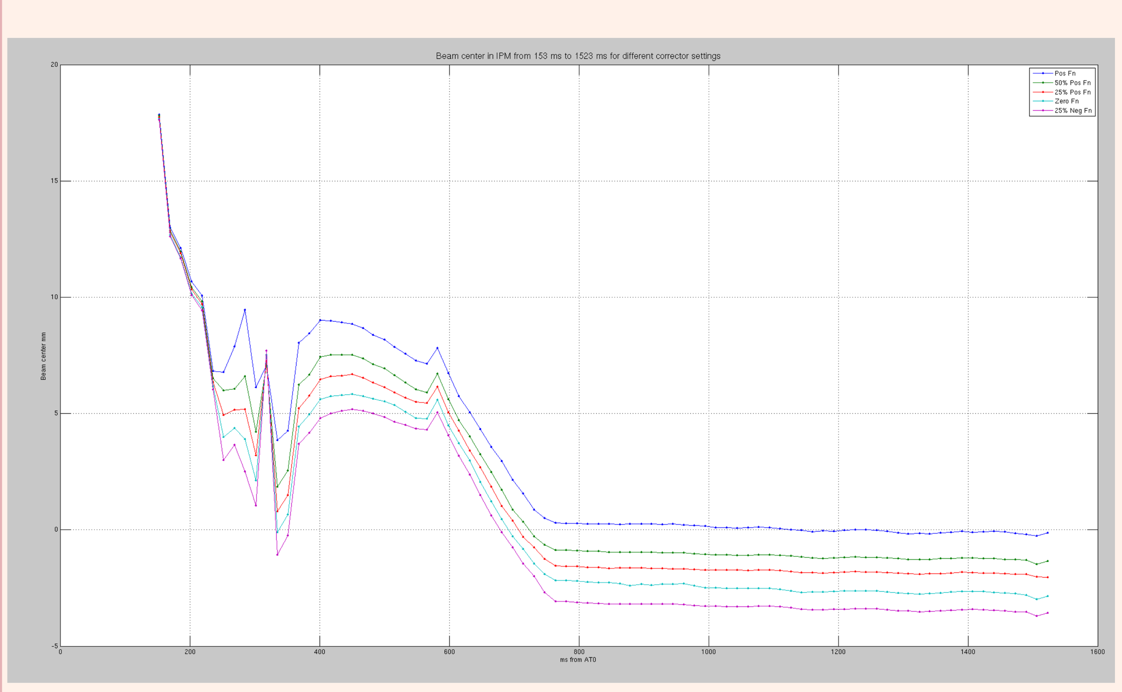


Figure 3: The vertical centroid measurements with different different dipole kicker strengths. Around 315ms is the transition crossing point where no displacement was recorded. No beta function was derived for that point.

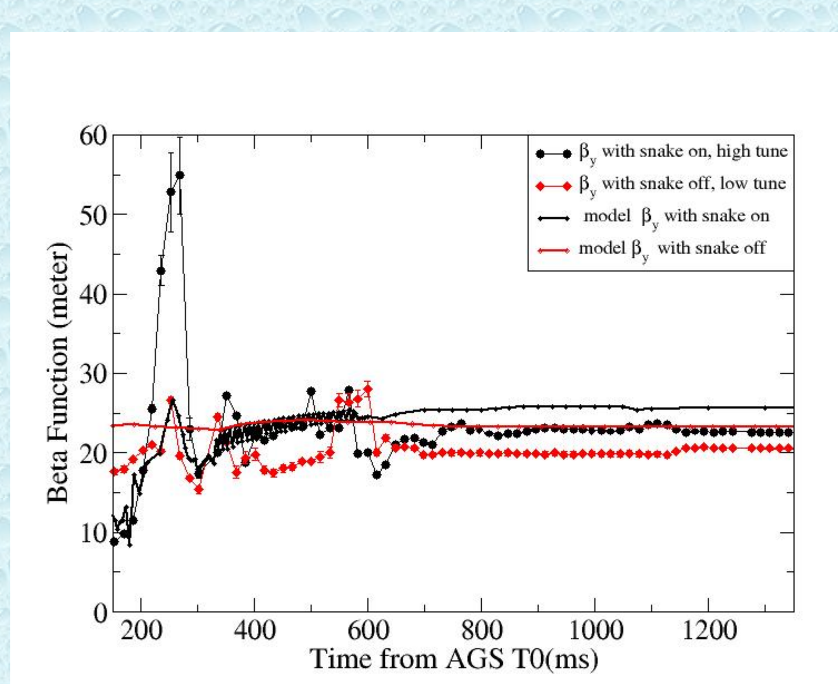


Figure 6: The comparison of model and measurement with old transfer function.

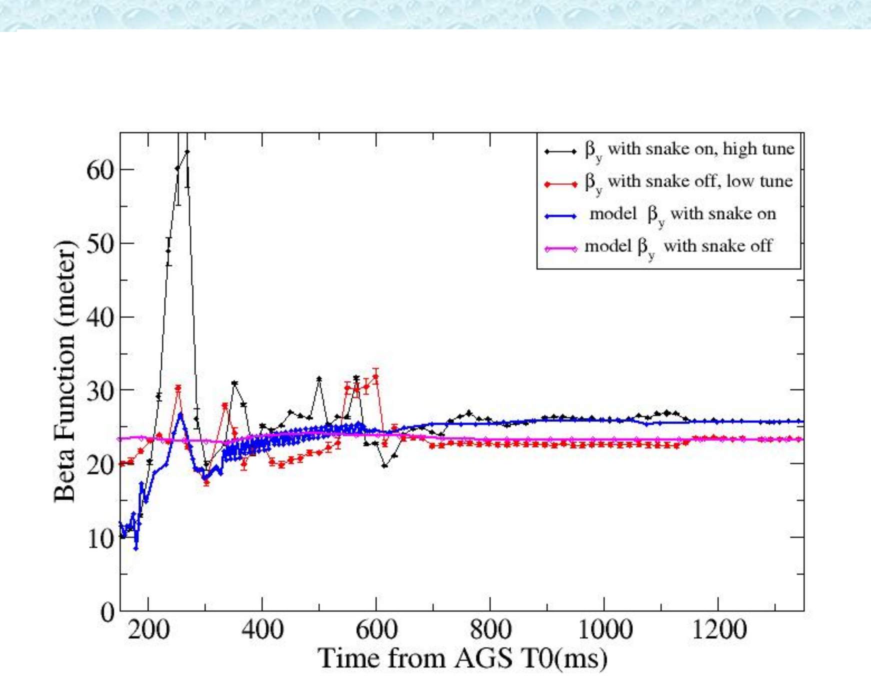


Figure 7: The comparison of model and measurement with transfer function multiplied by a factor of 1.137.

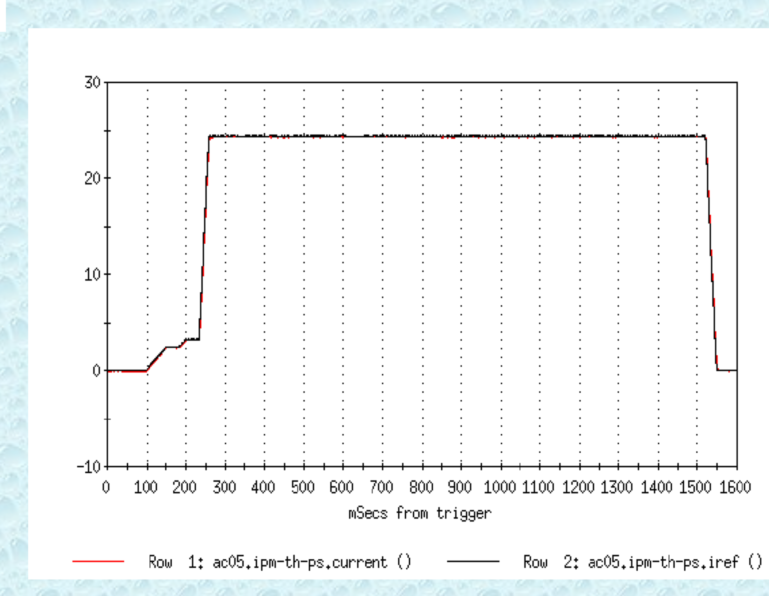


Figure 8: The set dipole corrector current and readback current for one AGS cycle. The agreement was very good.

Comparison of Model and Measurements

There is a systematic difference between the beta functions from measurements and model. The measurement results are smaller by about 14%. The transfer function was one we don't have much information about its accuracy. It is very possible that this number is off by 14%. The partial snake on and off data were taken on different years. However, the difference between model and measurements at flattop for both sets are the same. After multiplying the measurements with a factor 1.137, the beta functions from measurements and model are plotted in Fig.7. For the partial Siberian snake on case, the small fluctuations in the modeled beta function on the ramp is due to the jump quadrupoles on, which affect the beta function slightly. Besides the large deviations during the vertical tune swing (between 200-300ms), the agreement in other portion is fine, for both near injection and at flattop. This may imply that the fudge factor 1.137 is reasonable. The model beta function also shows a beta function swing between 200-300ms, but in a much smaller scale. It should be noted that the γ_{tr} quadrupoles were not in this model. For the partial Siberian snake off case, the model predicts a more or less flat beta function through AGS cycle. The measured beta functions has some fluctuations around that. Nevertheless, the modeled beta functions at flattop match the measurements after the fudge factor.

Summary

The Siberian partial snakes required for proton polarization preservation and near integer vertical tune(~8.98-8.99) complicate the optics in the AGS. To understand if the observed emittance growth is real and where is the growth, the vertical beta functions at IPM locations are needed. Careful attentions have been put into betatron tune, dipole current and orbit response measurements. With these quantities measured, the vertical beta functions have been measured along the AGS ramp with partial Siberian snakes on and off. The modeled and measured beta functions agreed with each other at AGS flattop and near injection for partial Siberian snakes on and off case. The measured big swing of beta functions between 200-300ms for partial Siberian snakes on case requires more modeling work. So far the model does not give the same level of beta function variation. However, the measured and modeled vertical beta function near injection and in the later part of the AGS cycle already suggest that some vertical emittance growth is real, as much as 100%, but the source is not fully understood. Emittances have also been measured with beam debunched at flattop to eliminate the space charge effect. The horizontal beta function measurement has been worked on and but more beam time is needed to get this working. The modeled horizontal beta function implies not much horizontal emittance growth. The horizontal beta function measurement will be taken in the future.

References

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