Fermi National Accelerator Laboratory

FERMILAB RECYCLER STOCHASTIC COOLING FOR LUMINOSITY PRODUCTION

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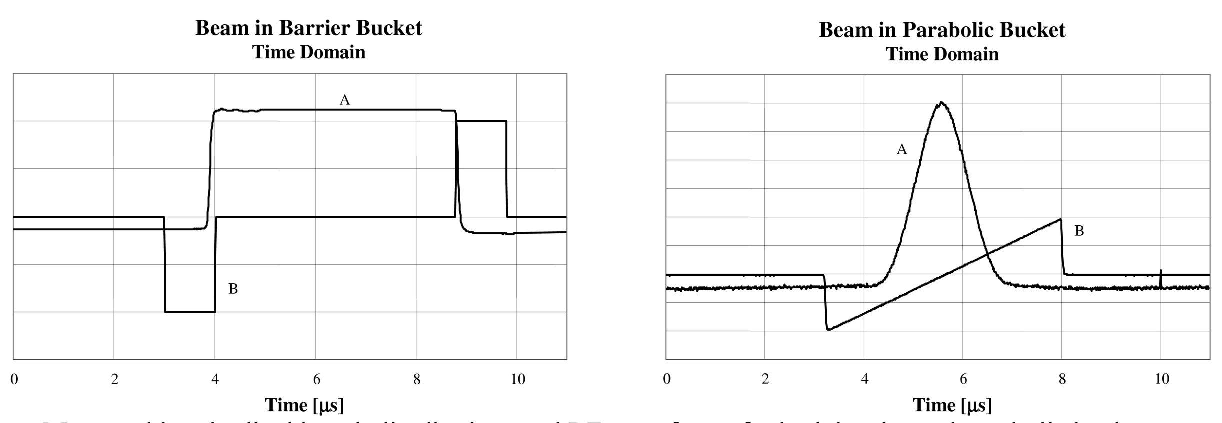
ABSTRACT

The Fermilab Recycler began regularly delivering antiprotons for Tevatron luminosity operations in 2005. Methods for tuning the Recycler stochastic cooling systems are presented. The unique conditions and resulting procedures for minimizing the longitudinal phase space density of the Recycler antiproton beam are outlined.

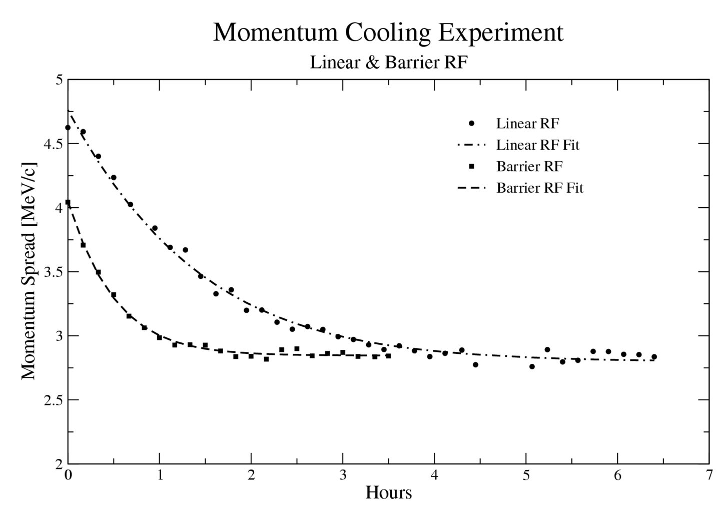
INTRODUCTION

Recycler ring			
Circumference	C	3320	m
Momentum	p	8.9	GeV/c
Slippage factor	η	-0.0086	
Emittance (n, 95%)	ε_n	~3-5	μm
Average β-function	β_{ave}	30	m

Bunched beam stochastic cooling at the Recycler is being used to support Tevatron Collider operations. Experiments have shown that for fixed bunch lengths and stochastic cooling system gain, the asymptotic momentum spread is approximately the same.



Measured longitudinal bunch distributions and RF waveforms for both barrier and parabolic buckets.

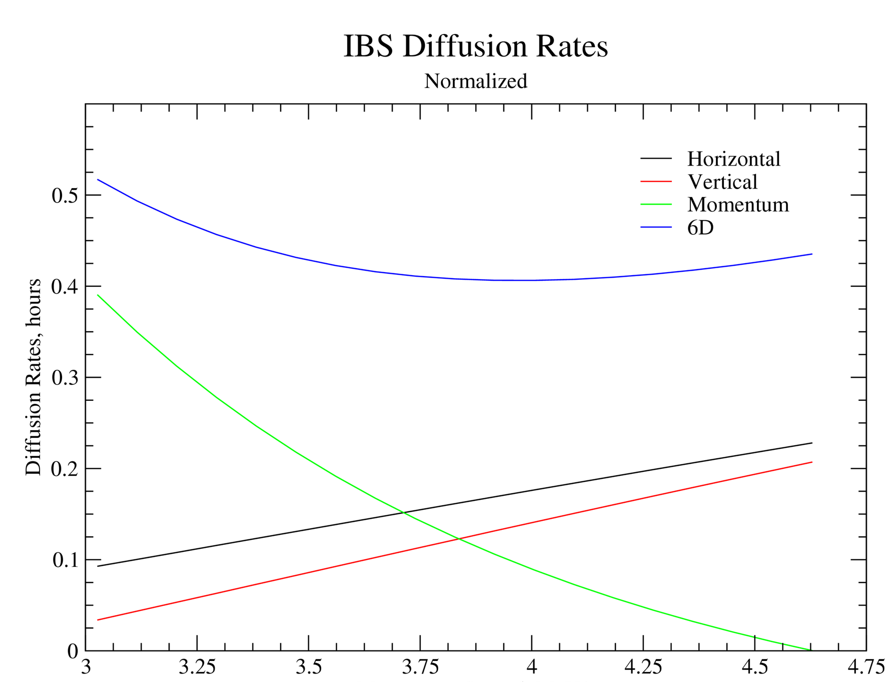


Evolution of the beam rms momentum spread for the parabolic and barrier RF buckets. Points are data, lines are the fits.

INTRA-BEAM SCATTERING

Intra-Beam Scattering is expected to be the dominant diffusion mechanism for the intense antiproton beams in the Recycler. A detailed IBS model using the measured Recycler lattice functions predicts a momentum spread that minimizes the 6-dimensional IBS diffusion rate. Because there is a small non-zero dispersion, there is no point at which the 6-d diffusion rate is zero.

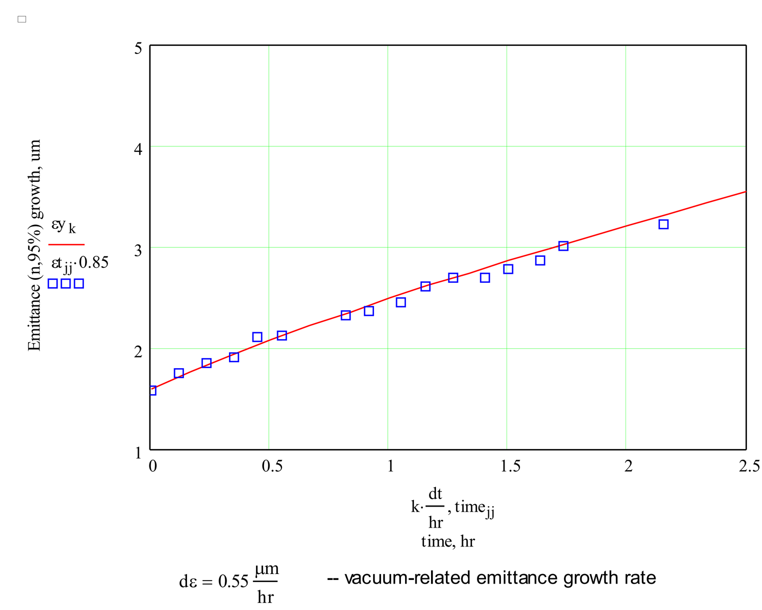
IBS Model



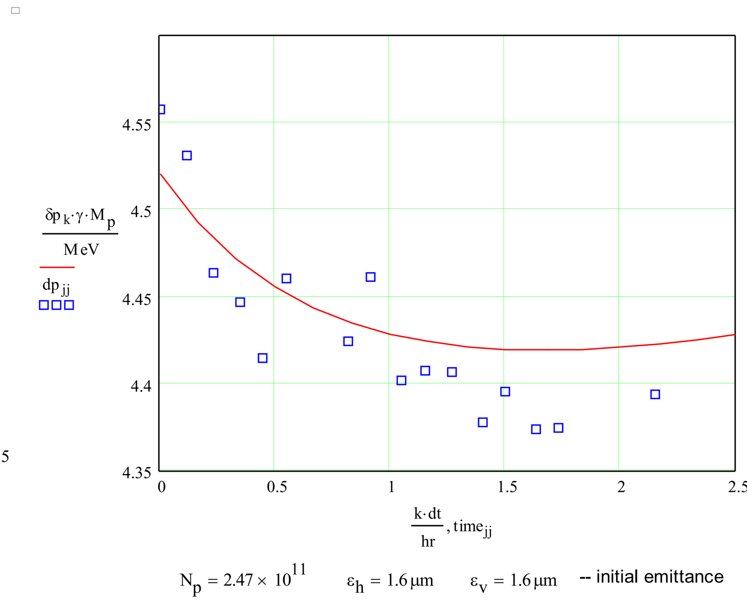
Model calculation for 40×10^{10} particles with fixed transverse emittance of 3.2π mm-mrad.

IBS Experiment

Sympathetic IBS cooling has been demonstrated at the Recycler. The measurements were conducted with a bunched antiproton beam of 25×10^{10} particles which was initially cooled transversely to a very small emittance (< 2 π mm-mrad). The momentum spread was increased to above 4.5 MeV/c by increasing the amplitude of the rf voltage and thus compressing the beam. The figures below show the measured transverse emittance and longitudinal rms momentum spread evolutions. Also shown is the IBS model. The only adjustable parameter in this model is the vacuum-related emittance growth rate.



The transverse emittance evolution for a bunched antiproton beam (25×10^{10}).

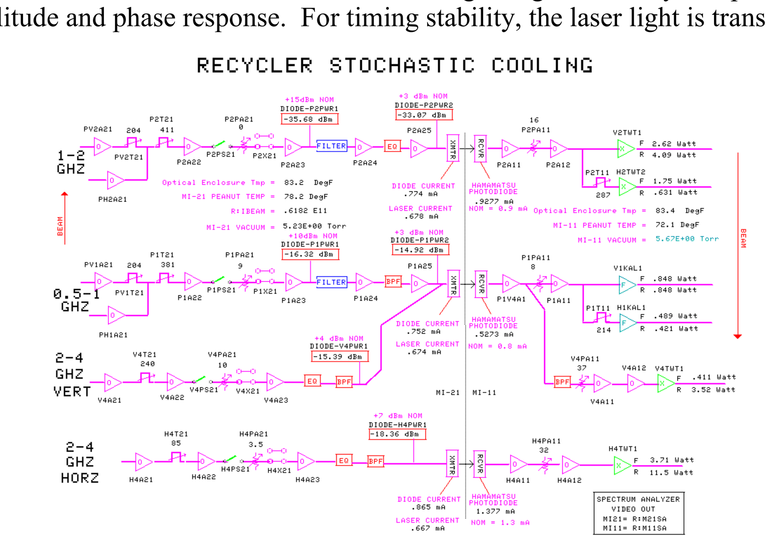


The longitudinal rms momentum spread (MeV/c) as a function of time (hours). The IBS model (solid line) has only one adjustable parameter – the vacuum-related transverse emittance growth rate.

STOCHASTIC COOLING

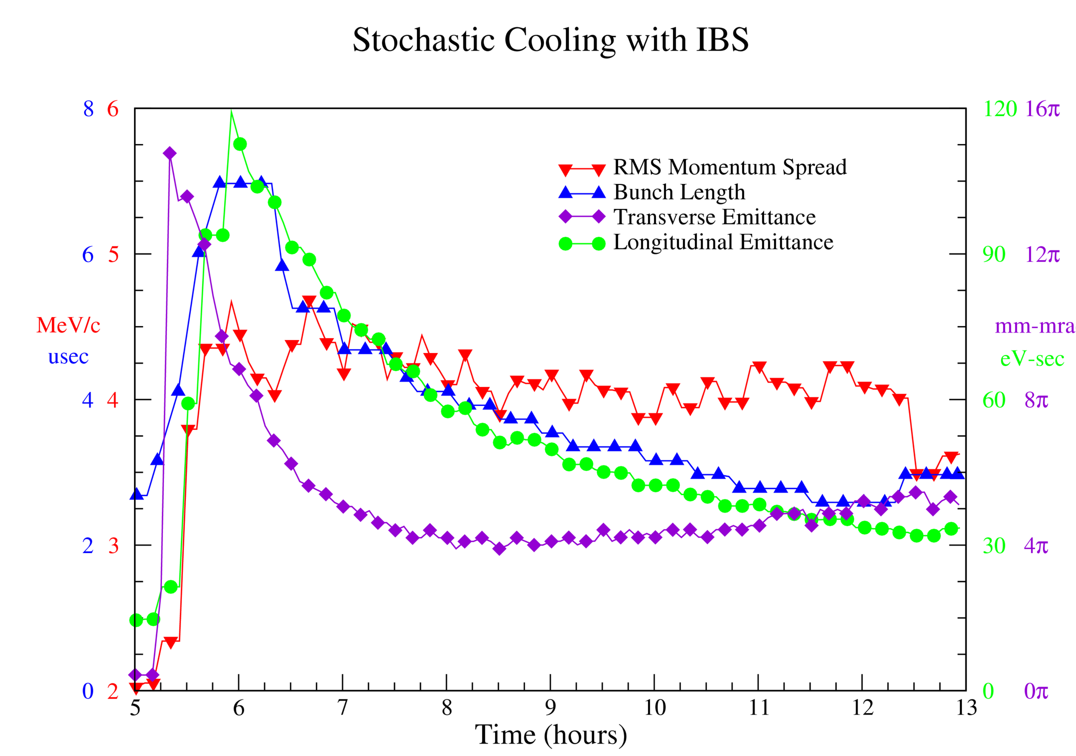
Room temperature phased planar loop array electrode technology was chosen for the Recycler stochastic cooling pickups and kickers.

Amplitude modulated infrared lasers are used to transmit the error signals generated by the pickups to the kickers. These optical links provide flat amplitude and phase response. For timing stability, the laser light is transmitted through a vacuum.



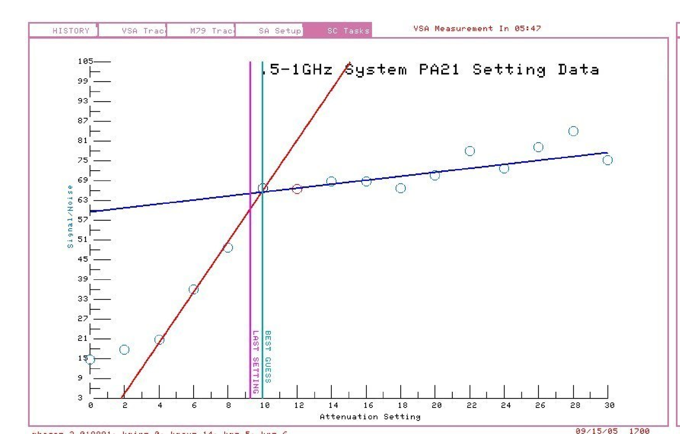
Overview diagram of all the stochastic cooling systems.

Parameter Summary				
	Betatron		Momentum	
	H2-4 GHz	V2-4 GHz	0.5-1 GHz	1-2 GHz
W (MHz)	495	715	260	674
τ (s)	516	644	615	
N	$7\cdot10^{10}$		$4\cdot10^{10}$	

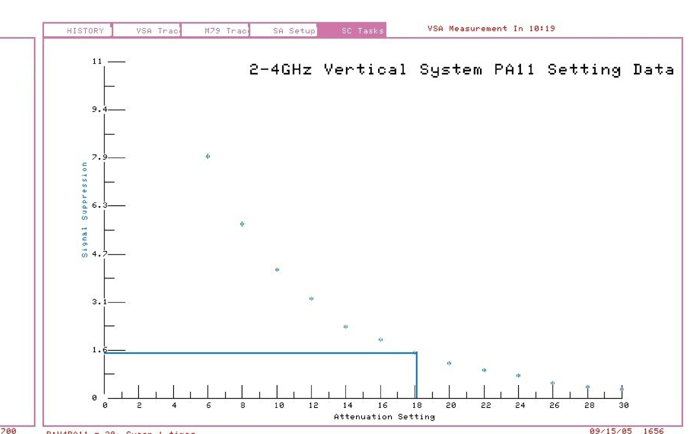


Antiprotons are transferred into the Recycler and are cooled stochastically. The rms momentum spread is kept constant by decreasing the bunch length. Since the beam is confined inside a barrier-bucket, bunch length is decreased by decreasing the separation of the barrier voltages.

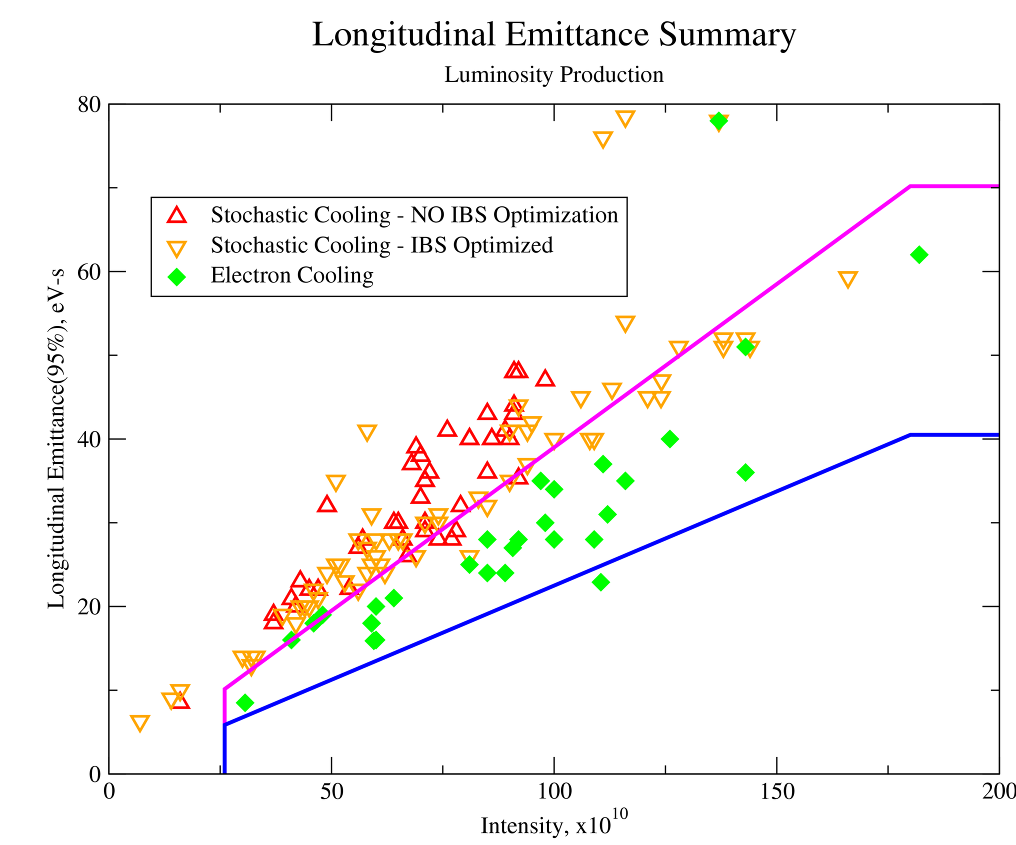
Since the RF is constantly being adjusted to compensate for the IBS diffusion rate, the stochastic cooling systems also need to be constantly adjusted. As the duty cycle and peak voltages are changing, consistent and appropriate methods for quickly tuning the stochastic cooling systems are needed to keep optimal performance. Because of the arbitrary nature of the beam conditions in the Recycler, a simple table of settings becomes cumbersome.



Avoiding amplifier compression is critical for optimal performance in the Recycler stochastic cooling systems.



A zero span signal suppression measurement normalized to the resolution bandwidth used, gives a low noise result proportional to the peak signal suppression found at a single side-band.



Attained longitudinal emittance of antiproton beams before extraction from the Recycler for collider luminosity production.

SUMMARY

Stochastic cooling in the Recycler has been shown to be limited by diffusion processes. A precise IBS model has been developed for the Recycler. This model has been verified with beam measurements made during storage and cooling of the antiprotons before extraction to the Tevatron. Longitudinal IBS heating and cooling effects have been demonstrated by designing the beam parameters based on the IBS model. Minimization of IBS-diffusion has been incorporated in the storage and cooling procedures for antiproton beam for Tevatron collider luminosity generation. Operational data analysis and tuning procedures have been developed for the stochastic cooling systems. The Recycler has successfully increased the number of antiproton available for Tevatron collider operations for the past year.

Bibliography

[1] J.P. Marriner, Fermilab MI Note 168 & 169, April, 1996.
[2] "Novel Stochastic Cooling Pickups and Kickers," J. Petter, D. McGinnis and J. Marriner, Proceedings of the 1989 IEEE Particle Accelerator Conference, Vol. 1, 636, March 1989.
[3] R. Pasquinelli, "Wide Band Free Space Transmission Link Utilizing a Modulated Infrared Laser," PAC'99, New York, March 1999, p. 7984.
[4] J.E. Dey and D.W. Wildman, Proc. Part. Acc. Conf., New Your, p. 869 (1999).
[5] S. Nagaitsev, "Intrabeam scattering formulas for fast numerical evaluation," Phys. Rev. ST Accel. Beams 8, 064403 (2005).
[6] D. Broemmelsiek, R.J. Pasquinelli, "Fermilab Recycler Stochastic Cooling Commissioning and Performance," PAC'03, Portland, Oregon, May 2003, p. 3431.
[7] Martin Hu, Sergei Nagaitsev, "Observation of Longitudinal Diffusion and Cooling Due to Intrabeam Scattering at the Fermilab Recycler Ring," PAC'05, Knoxville, Tennessee, May 2005, FPAE017.