Effect of a DC wire on the RHIC Au beams *

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Abstract

This report discusses experiments with the two DC wires installed in RHIC before Run 2007. Experiments were performed at two fixed currents, 5 A and 50 A in both the Blue and the Yellow ring. The effect of the wire on orbit, tune, and beam loss rate at two working points as a function of varying distance were measured. In addition, the effect of varying wire current at a fixed location, and with varying chromaticity was also measured. The data are intended for comparison with analytical formulas and benchmarking simulations.

INTRODUCTION

To test a long-range beam-beam compensator in RHIC, two DC wires have been installed in 6 'o clock region (IR6). Fig 2 shows a graphic of the wire locations in IR6 region for both the Blue and the Yellow rings. The wires were installed in 2006 and experiments with beam at top energy (100 GeV) during Run 2007 were carried out with gold beams with different configurations of beam and wire parameters.

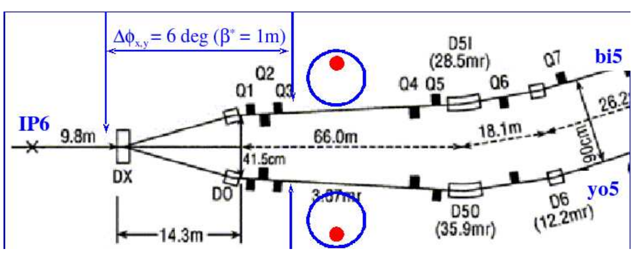

Figure 1: DC wire location with respect to IP6 in the RHIC rings.

The plans layed out in Refs. [1, 2] were followed during the experiments to observe the wire's effect on a stored beam. The experimental program was developed together with CERN [3].

Without beam, an attempt was made to measure the current ripple. At any current, the ripple could not be determined since it was below the noise threshold of the measurement system. This gives an upper limit for the current ripple of $\Delta I/I < 1.7 \times 10^{-4}$ at 50 A [4].

The β-functions in Tab. 1 are the best estimate of the real β-functions in the machine. The design lattice has $\beta^* = 0.8$ m at IP6, but measurements indicate that the actual value may be as high as 1.0 m [5]. To calculate the β-functions at the wire location we use $\beta^* = 0.9$ m, and assume a 10% error.

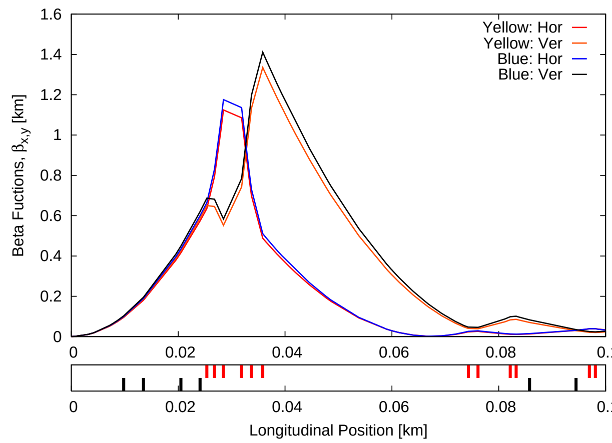

Figure 2: The beta functions from MAD lattice for both rings as a function of logitudinal position.

The initial beam sizes were determined with the ionization profile monitor (IPM) just before the wire was turned on.

Different configurations of wire position and current were explored to observe the long range effects at top energy (100 GeV). The available instruments and observables during the experiments were:

- Wire current and position readback
- Beam position monitors (BPMs) near the wire to record the vertical separation
  Blue: bi5-b1, bi5-b3 (closest to wire), bi5-b4
  Yellow: yo5-b1, yo5-b3 (closest to wire), yo5-b4
- DCCT for beam decay rate
- Tune meter and base-band tune meter for tune measurements
- Beam transfer function to measure tunes and tune distributions
- Emittances from ionization profile monitors (IPM)

The vertical dipole kick $\Delta y'$ and vertical tune change ΔQ_y due to the wire are given by ($d_x = 0$)

$$\Delta y' = \frac{K}{d} \quad \text{and} \quad \Delta Q_{x,y} = \pm \frac{K\beta_{x,y}}{4\pi}\frac{1}{d_y^2} \tag{1}$$

with

$$K = \frac{\mu_0 (IL)}{2\pi (B\rho)}. \tag{2}$$

* This work was performed under the auspices of the US Department of Energy

Table 1: RHIC parameters for experiments with Au beams (100 GeV).

quantity	unit	Blue	Yellow
beam energy E	GeV/n	100	
rigidity $(B\rho)$	Tm	831.8	
number of bunches	...	23	
max. wire current I_{max}	A	50	
distance IP6 to wire center	m	40.92	
parameter K (at 50 A)	nm	-30.1	
wire length L	m	2.5	
position range d	mm	0...65	-65...0
β_x at wire location	m	1091	350
β_y at wire location	m	378	1067
curr ripple $\Delta I/I$ (at 50 A)	10^{-4}	< 1.7	

Table 2: Experiment I, Fill 8609, April 25, 2007.

Quantity	unit	Blue	Yellow
Init avg. bunch intensity	10^9	1.00	1.08
Beam loss rate w/o wire	%/h	1.0	1.6
Init. ver. emittance ϵ_n	mm.mrad	23	38
Ver. rms beam size at wire	mm	3.7	7.9
Horizontal tune Q_x	...	28.234	28.228
Vertical tune Q_y	...	28.226	29.235
Chromaticities (ξ_x, ξ_y)	...	$(+2, +2)$	
Harmonic number h	...	2520	
Gap voltage V_{gap}	MV	3.5	

d is the distance between wire and the beam, μ_0 the permeability of the vacuum, (IL) the integrated wire strength, and $(B\rho)$ the beam rigidity.

Note that we take a positive sign for d for a wire above the beam, and a negative sign below the beam. We also assume that $y = 0$ for the wire current off. The sign of K depends on the direction of the wire relative to the beam direction, and the charge of the beam particles. In our case the wire current has the opposite direction to the beam, the Blue wire is above and the Yellow wire below the beam, and the beam particles have positive charges. In this case the sign of K is negative in Blue, and positive in Yellow. The orbit change Δy at the location of the wire due to the dipole kick $\Delta y'$, for $\Delta y \ll d$, is then

$$\Delta y = \frac{K\beta_y}{2d} \frac{\cos(\pi Q_y)}{|\sin(\pi Q_y)|}. \quad (3)$$

If the wire comes close to the beam Eq. (3) becomes inaccurate and needs to be replaced by

$$\Delta y = \frac{d}{2} - \sqrt{\frac{d^2}{4} - \frac{1}{2} K\beta_y \cot(\pi Q_y)} \quad (4)$$

where now d is the distance between the wire and the beam position at zero wire current.

Table 3: Experiment II, Fill 8727, May 9, 2007.

Quantity	unit	Blue	Yellow
Init avg. bunch intensity	10^9	0.75	0.78
beam loss rate w/o wire	%/h	2.5	1.5
Init ver. emittance ϵ_n	mm.mrad	18	29
Ver rms beam size at wire	mm	3.3	6.9
Horizontal tune Q_x	...	28.220	28.232
Vertical tune Q_y	...	29.231	29.228
Chromaticities (ξ_x, ξ_y)	...	$(+2, +2)$	
Harmonic number h	...	360	
Gap voltage V_{gap}	MV	0.3	

BEAM MEASUREMENTS

Two experimental session were used. The main beam parameters are listed in Tab. 2 and 3. An overview of the beam intensity, beam decay rate, wire position is shown in Figs. 4 and 6. The loss rates the Blue and the Yellow rings are show different patterns. A comparison of the loss pattern to the experiments done using two proton bunches during Run 2006 show qualitative agreement with the Blue beam as shown in Fig 3.

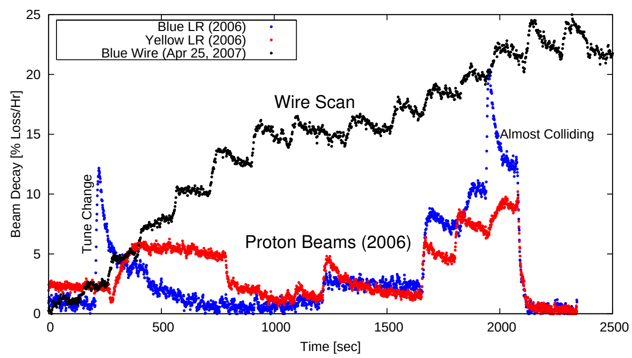

Figure 3: A qualitative comparison between the loss pattern between single long-range beam-beam interaction with two proton bunches (2006) and losses induced by the wire in the Blue ring (2007).

Data taken are listed below. The loss rates are fitted with power law curves. For orbit and tune deviation, analytical estimates are plotted along with the data, and fitted using an initial offset as a free variable.

- Orbit vs. vertical separation (Fig. 8 & 9) and orbit vs. wire current (Fig. 10)
- Tune vs. vertical separation (Fig. 11 & 12) and tune vs. wire current (Fig. 13)
- Beam loss rate vs. vertical separation (Fig. 14 & 15)
- Tune and beam loss rate vs. wire current (Fig. 16)
- Fitted exponential beam decay rates vs. vertical separation (Fig: 17 & 18)

- Beam loss rate vs. chromaticity, and beam loss rate vs. wire current at the highest chromaticity (Fig. 19)

ACKNOWLEDGEMENTS

We would like to thank the instrumentation and pulsed power group for their support, in particular J. Adessi, D. Lehn, T. Russo, D. Gassner, and W. Eng. U. Dorda, J.-P. Koutchouk and F. Zimmermann were helpful in discussing our experimental program, and A. Della Penna and P. Cameron supported the beam experiments.

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[3] U. Dorda, J.P. Koutchouk, G. Sterbini, F. Zimmermann, “Proposal for investigations on the LHC long-range beam-beam effect with an application to a wire compensation and an early separation scheme at RHIC”, private communication (2007).

[4] J. Addessi and W. Eng, private communication.

[5] T. Satogata and M. Bai, private communication.

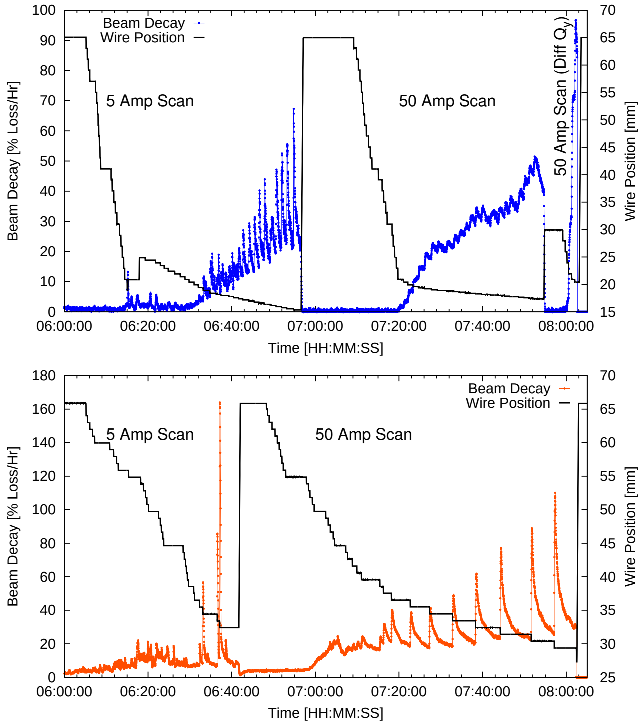

Figure 4: Overview of experiment 1 (April 24, 2007) in Blue (top) and Yellow (middle) ring. Shown are the beam loss rate and vertical wire position with respect to the beam pipe center. The current set point is labeled on the plot during the position scan.

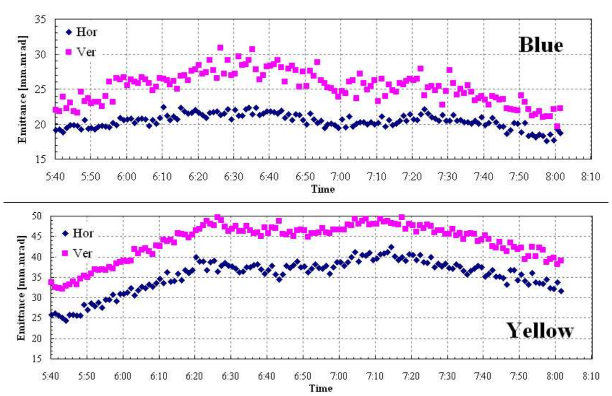

Figure 5: Normalized emittances during experiment 1, measured with the IPM (single bunch) in Blue (top) and Yellow (bottom).

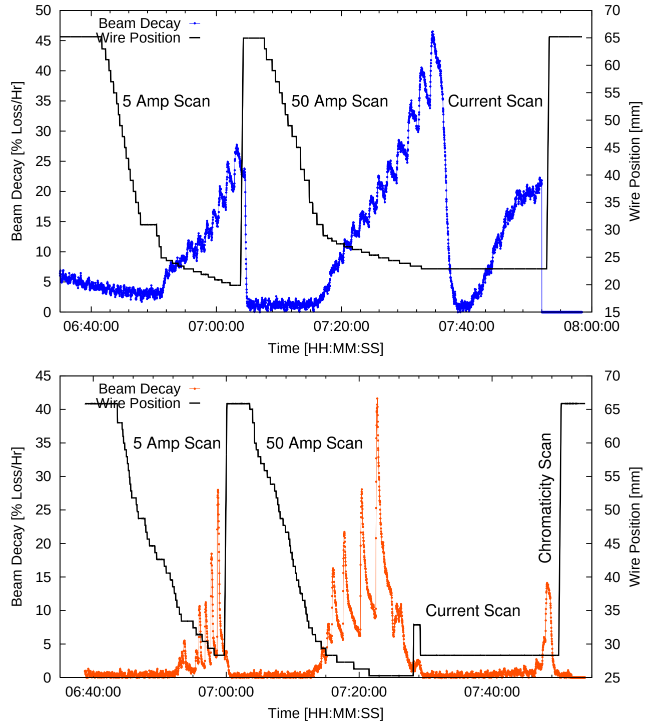

Figure 6: Overview of experiment 2 (May 9, 2007) in Blue (top) and Yellow (middle) rings. Shown are the beam loss rate and vertical wire position with respect to the beam pipe center. The current set point is labeled on the plot during the position scan.

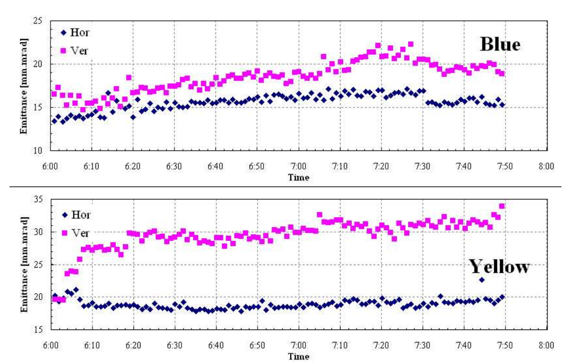

Figure 7: Normalized emittances during experiment 2, measured with the IPM (averaged over 3 or 4 bunches) in Blue (top) and Yellow (bottom).

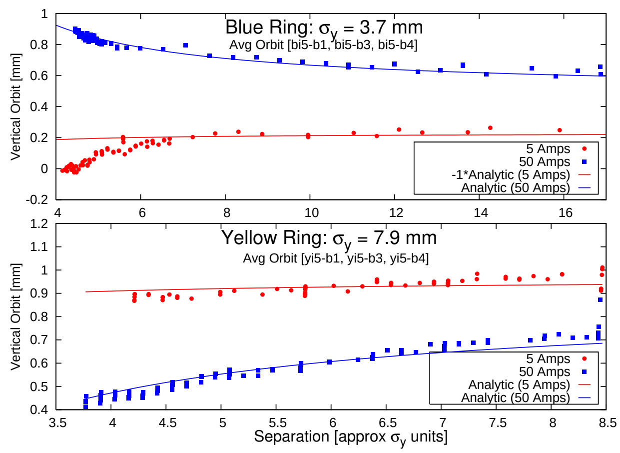

Figure 8: Vertical orbit change (average of 3 BPMs near wire) as a function of vertical distance, in Blue and Yellow ring for experiment 1 (Apr 24, 2007).

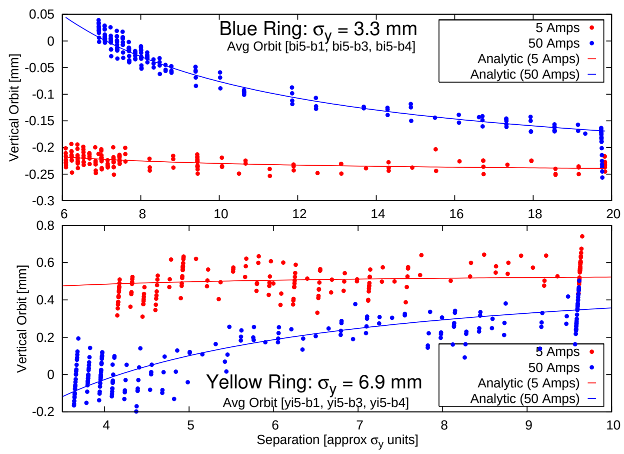

Figure 9: Vertical orbit change (average of 3 BPMs near wire) as a function of vertical distance, in Blue and Yellow ring for experiment 2 (May 9, 2007).

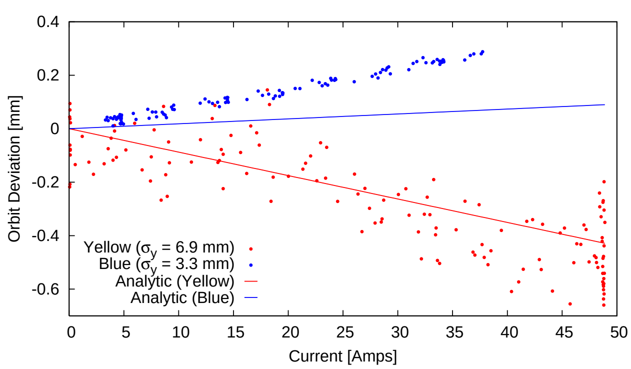

Figure 10: Blue and Yellow orbit at the wire location as a function of wire current. The Blue wire is fixed at +23 mm, the Yellow wire at -29 mm. All data are taken during experiment 2 (May 09, 2007).

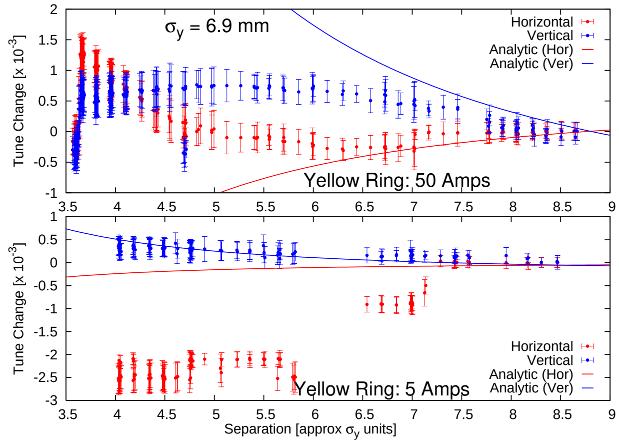

Figure 11: Horizontal and vertical tune change for 50 A and 5 A wire current, for the Yellow ring. All data are taken during experiment 2 (May 09, 2007).

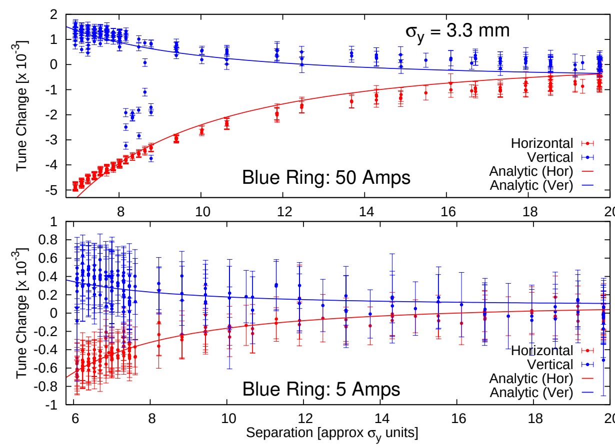

Figure 12: Horizontal and vertical tune change for 50 A and 5 A wire current, for the Blue ring. All data are taken during experiment 2 (May 09, 2007).

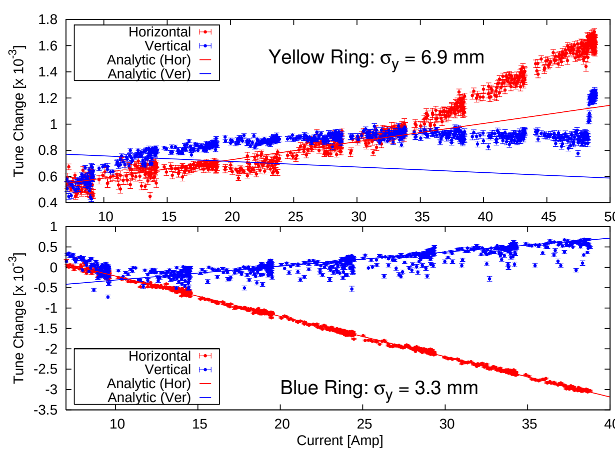

Figure 13: Blue and Yellow tunes as a function of wire current. The Blue wire is fixed at +23 mm, the Yellow wire at -29 mm. All data are taken during experiment 2 (May 09, 2007).

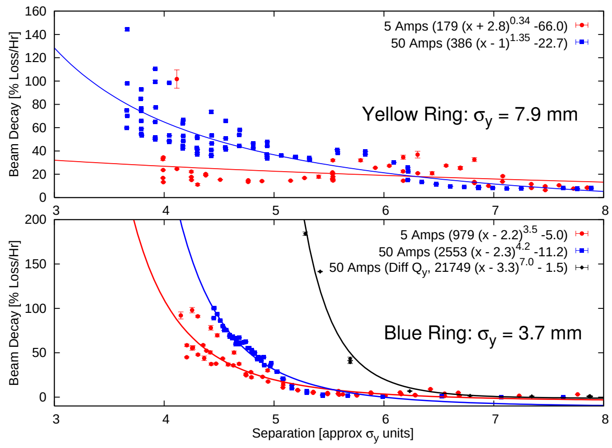

Figure 14: Beam loss rate as a function of vertical distance, in Yellow and Blue ring for experiment 1 (Apr 24, 2007). The solid lines are power law fits to the respective data.

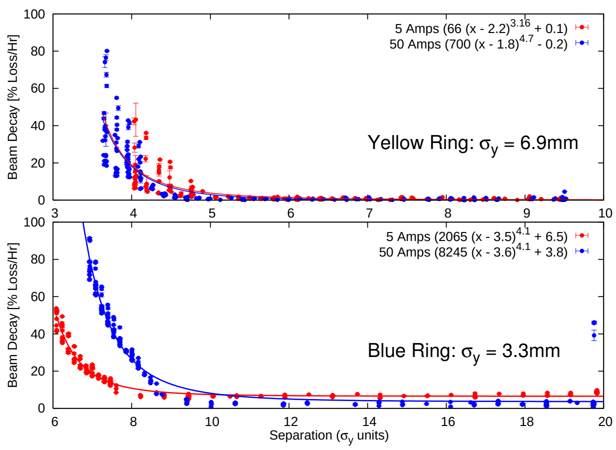

Figure 15: Beam loss rate as a function of vertical distance, in Yellow and Blue ring for experiment 2 (May 09, 2007). The solid lines are power law fits to the respective data.

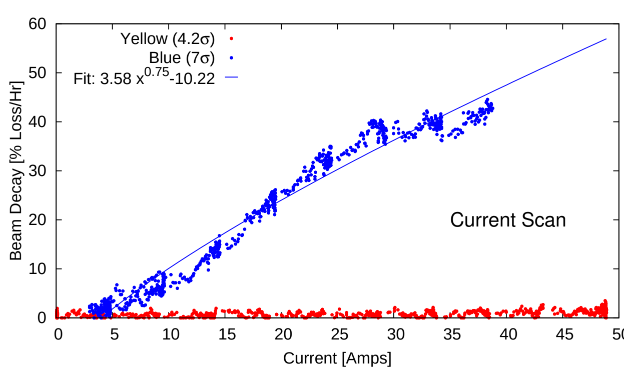

Figure 16: Blue and Yellow beam loss rates as a function of wire current during experiment 2. The Blue wire is fixed at +23 mm, the Yellow wire at −29 mm. All data are taken during experiment 2 (May 09, 2007).

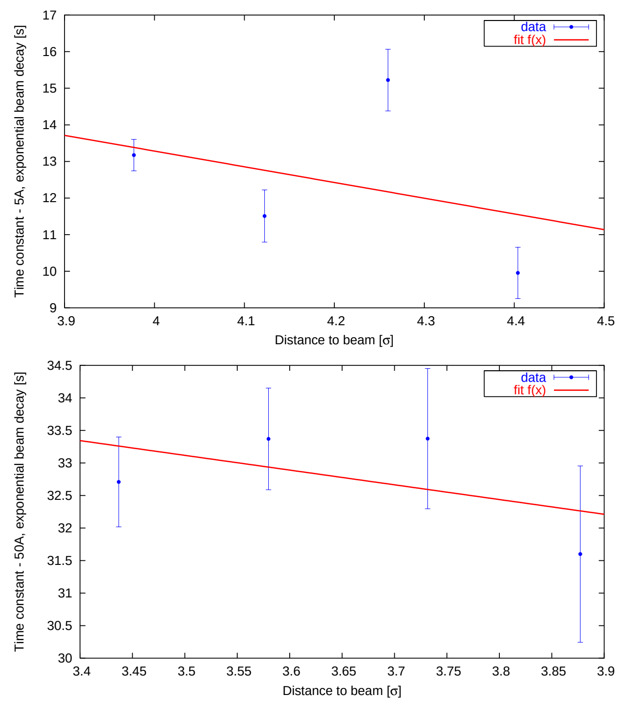

Figure 17: Fitted exponential decay constants after a distance step was made in Yellow ring.All data are taken during experiment 2 (May 09, 2007).

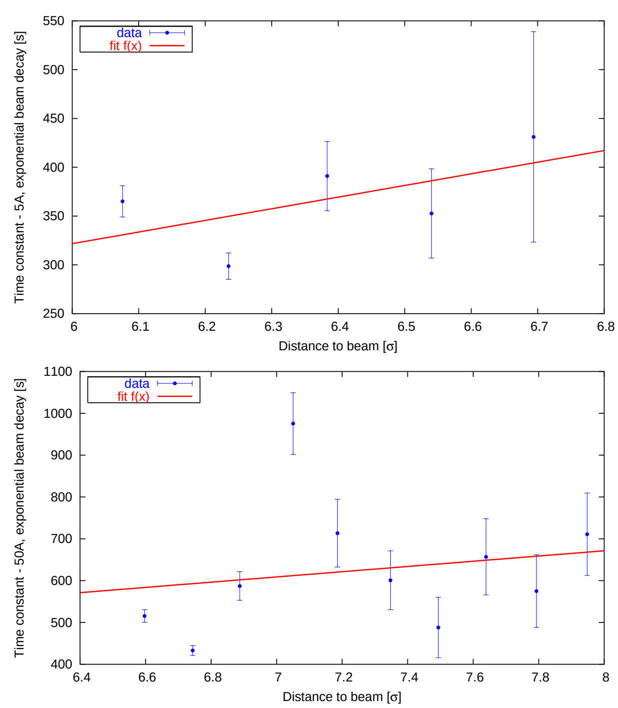

Figure 18: Fitted exponential decay constants after a distance step was made in Blue ring. All data are taken during experiment 2 (May 09, 2007).

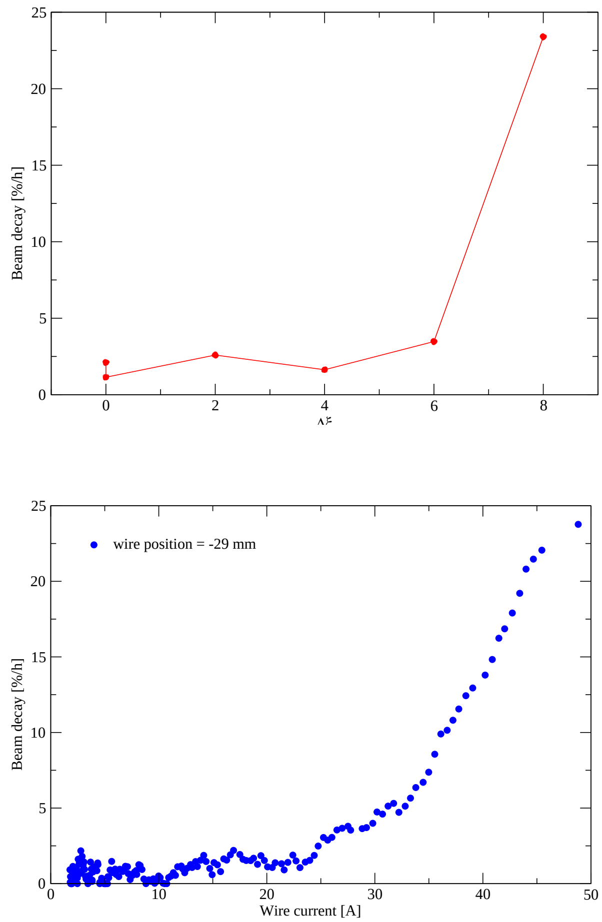

Figure 19: Yellow beam loss rate as a function of vertical chromaticity change (top) with the wire at fixed position -29 mm, and Yellow beam loss rate as a function of wire current at the maximum chromaticity setting (bottom). For the data in the latter plot the wire current was turned off.