BBTrack Simulations of the RHIC Long-range beam-beam experiments

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Contents

Chapter 1

Introduction

BBtrack (ver. 5.3 and higher) [?], a weak-strong tracking code, was used in order to simulate the RHIC long-range beam-beam interaction (LR-BBI) experiments [?].

In the RHIC LRBBI experiments both rings were filled by one bunch only causing a single LR-encounter at or close to IP6 (vertical seperation, opposite crossing seperated by more than 10 σ).

1.1 MAD-X inputfile generation

The Transfermatrices were obtained from MADX [?] using the inputfiles from [?]. The files were modified as following

- The rf-voltage was turned on: VINJECTION=-150V
- For calculations for the yellow beam, the rotation direction was altered using: rhic=(-yellow)
- Markers were introduced to get the transferematics for the required positions.
- In some files the makethin command was erased, as this canceled the Rf-vaoltage
- In some cases the tunes were adapted to match the experimental ones.
- In some cases the chromaticity was adapted to match the experimental ones.

1.2 some simulation details

- For the long-range beam-beam interaction (LRBBI) a round gaussian beam is assumed.

- The linear beam-beam tuneshift is calculated by (x-offset): (d given in σ)

$$\Delta Q_x = \frac{-2N_p r_p}{4\pi\gamma\epsilon_x d^2}\left(1 - e^{-\frac{d^2}{2}}(1+d^2)\right) \tag{1.1}$$

$$\Delta Q_y = \frac{-2N_p r_p}{4\pi\gamma\epsilon_y d^2}\left(1 - e^{-\frac{d^2}{2}}\right) \tag{1.2}$$

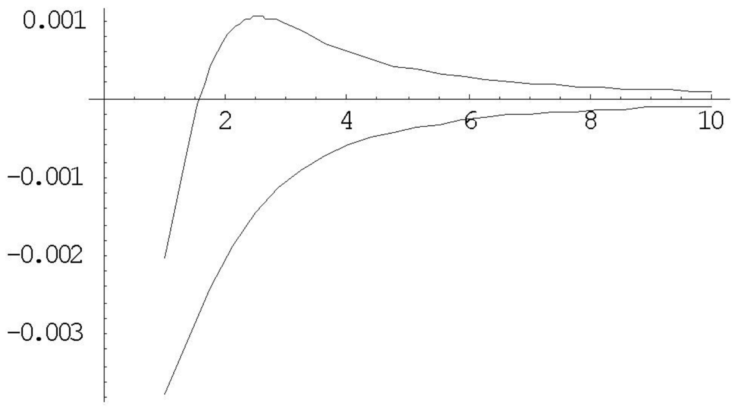


Figure 1.1: Tuneshift due to a round lr-interaction, x-axe: beam-beam seperation, y-axe: beam-beam tuneshift.

- The Liaponov-criterium was chosen as the main stability criterium. Two particels are launched next to each other and their distance in normalized phasespace is followed. A linear increasing function in time is not regarded as an indication of chaos, but only a sudden exponential one.

- All particles are launched with a momentum offset of 1σ

- In the simulations where Sextupoles are included, the sextupole strength was taken from MAD. As these strengths are set to compensate for the natural chromaticity (which is not reflected in the linear transfermaps) plus a small positive offset, a additional ”‘transfermap”’ was included to simulate the natural chromaticity. hte value of the natural chromaticity was take from a comparisson of a onmomentum and a offmomentum particle.

- Unless otherwies stated the particles were tracked for 300.000 turns

A short description for the different plottypes can be found here

Chapter 2

2005 Experiments

2.1 Beam parameter at injection - 2005 experiments

Most of the data are taken from http://www-ap.fnal.gov/~tsen/RHIC/05-Expts/fischer_IR2005.pdf

Proton energy E (GeV)	24.3
rel. gamma	26
magnet rigdity	82
Bunches per beam	1
Bunc hintensity	2×10^{11}
energy spread	$2.9 \times 10^{-}3$
bunch length [m]	1.35
lr-bb position [m]	0 or 10m
tune	varied
bb-seperation [vertical,σ]	0-11
norm. emittance $\epsilon_{n,x}$, $\epsilon_{n,y}$ 95%=2 σ, mm.mrad	20
$\epsilon_x = 0.25 * \epsilon_{x,n}/(\beta\gamma)$	1.925E-7
$\epsilon_y = 0.25 * \epsilon_{y,n}/(\beta\gamma)$	1.925E-7
RF (h=360 system, twice)	-150kV

2.2 2005 Experimental results s=0

The experimental results of the first 2005 experiment are given in http://www-ap.fnal.gov/~tsen/RHIC/05-Expts/fischer_IR2005.pdf by Wolfram Fischer and are summarized by figure 2.1.

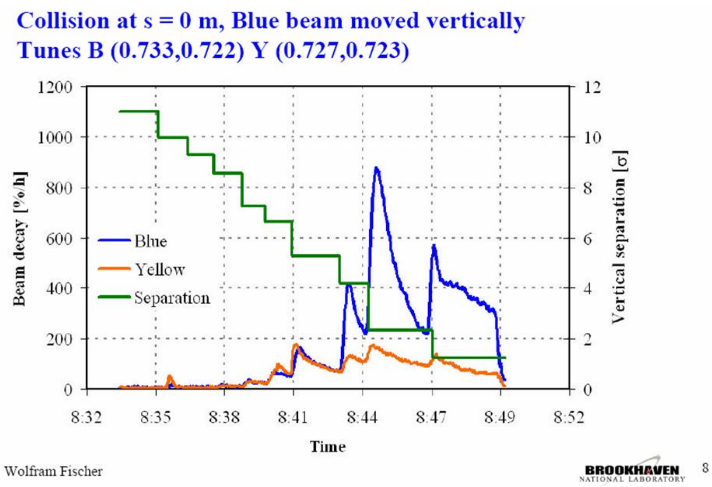


Figure 2.1: 2005 - Experiment 1. The blue beam shows a strong dependence on the beam-beam seperation while the yellow one is not that strong influenced.

2.3 2005 Simulation for exp 1

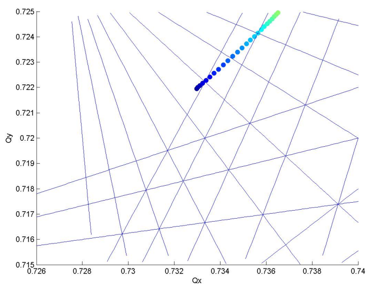
2.3.1 Blue beam

The chromaticty was found to be
offmomentum: $Q_x = 0.8656544307$, $Q_y = 0.8570675412$
onmomentum: $Q_x = 0.7329971583$, $Q_y = 0.7219972244$
The natural chromaticity is therfore $C_x = -42$, $C_y = -42$.

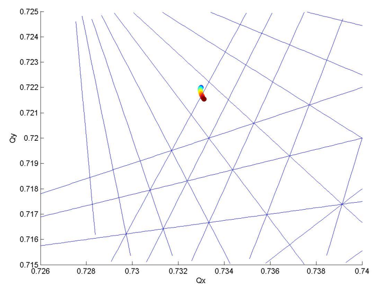
No sextupoles

- studied beam: blue
- LR-tunecompensation: yes
- sextupoles: no
- nat. chromat : no (no sextupoles)
- tunes: $Q_x = 28.733$ $Q_y = 29.722$
- initial distr: L45, 0-8σ

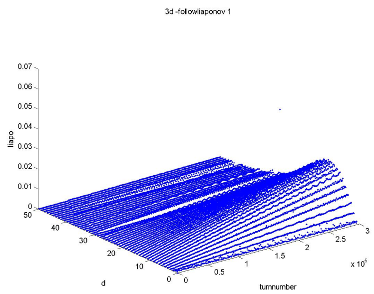
In this case no instability was found.



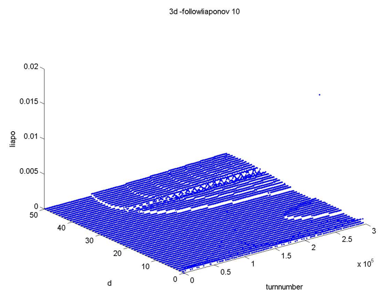
(a) The tunes of the particles in the d= 0.5σ case



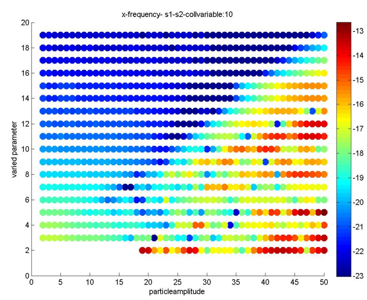
(b) The tunes of the particles in the d= 5σ case



(c) The distance of two initially close launched particles as a function of time ($d = 0.5\sigma$



(d) The distance of two initially close launched particles as a function of time ($d = 5\sigma$



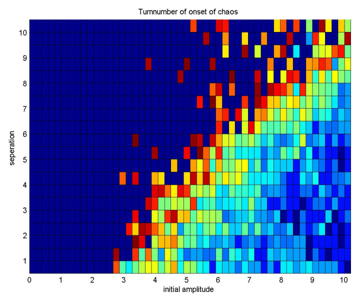
(e) The frequency diffusion as a function of inital amplitude and spacing. In all case the difference is below 10^{-13} and therefore seen as stable

The animated ”‘footprint”’ of these particles as a function of the beam-beam seperation can be found here It changes from the footprint due to the Lr to the one of a sextupole.

Sextupoles included

- studied beam: blue
- LR-tunecompensation: yes
- sextupoles: yes
- nat. chromat : -42
- tunes: $Q_x = 28.733$ $Q_y = 29.722$
- initial distr: L45, 0-8σ

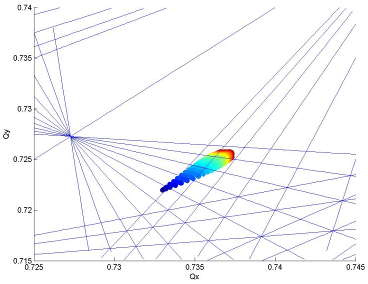
The additional sextupoles seem to be a major contribution to the stability.



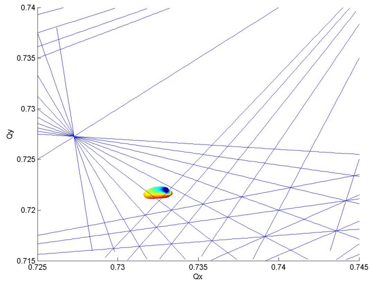
(f) The color encoded (dark blue =stabel) onset of chaos as a function of beam beam seperation and initial amplitude

The animated distance of initially closely launched particles as a function of the beam-beam seperation can be found here The animated footprint can be found here (only the stable particles as plotted!)

The footprint for particles launched on a (elliptic) grid (0-8σ) can be found here (500 turn sussix tunes)

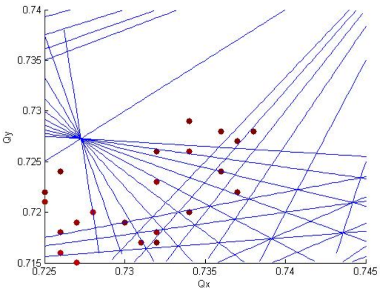


(g) The footprint of one close LR ($d = 0.5\sigma$), rather a HO one

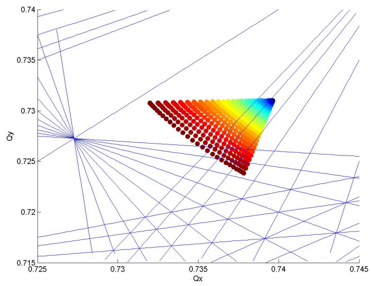


(h) The footprint of one close LR ($d = 5\sigma$)

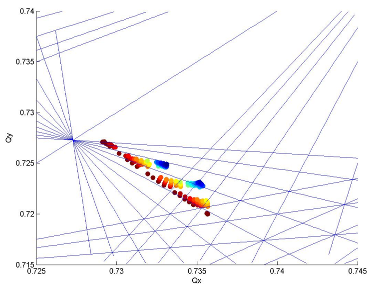
Figure 2.2:



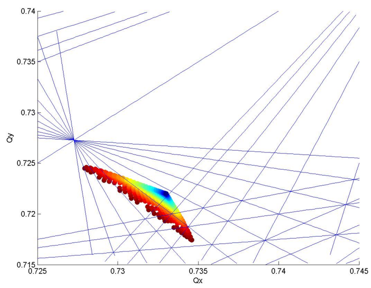
(a) offmomentum, no chroma correction, rf on



(b) offmomentum, no rf



(c) offmomentum, rf on



(d) onmomentum, rf on

Figure 2.3:

2.3.2 yellow beam

The natural chromaticity was determined (MAD-chromaticity=2),
onmomentum: $Q_x = 0.7269971463$, $Q_y = 0.7229972185$
offmomentum: $Q_x = 0.8597221456$, $Q_y = 0.8581506916$
The natural chrmaticity is therfore:-42 [0.7269971463-0.8597221456)/3E-3+2]

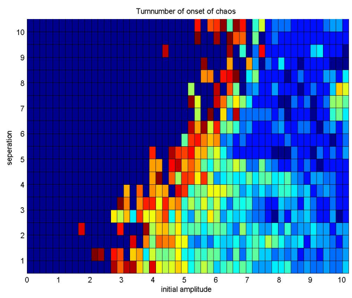


Figure 2.4: Instabilities are resolved.

2.4 2005 experiment s=10.6

For this experiment the LRBBI was shifted by 10.6m. The experimental results are given in http://www-ap.fnal.gov/~tsen/RHIC/05-Expts/fischer_IR2005.pdf by Wolfram Fischer and are there summarized by figure 2.5.

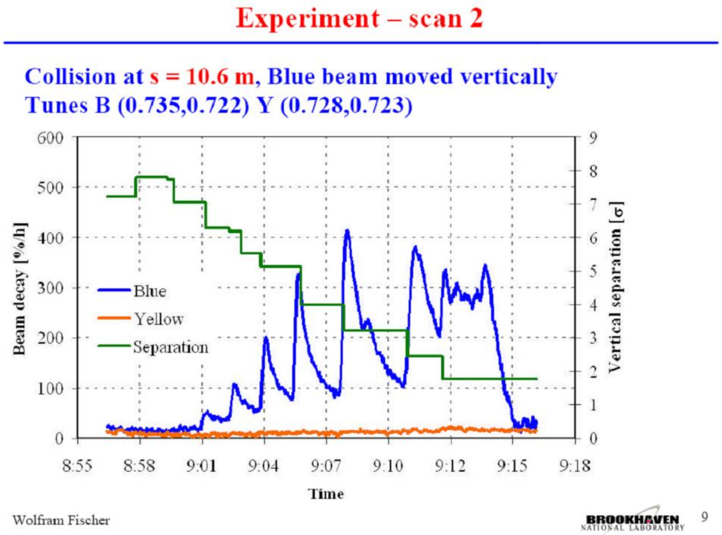
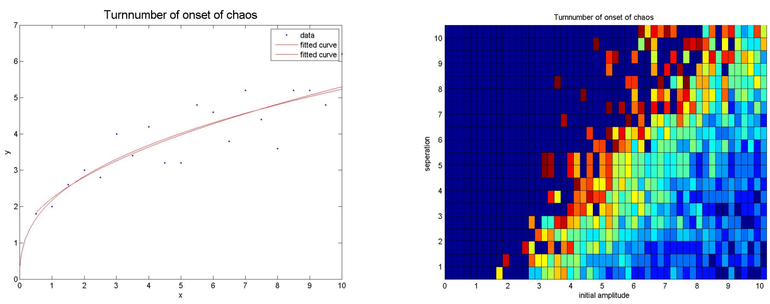


Figure 2.5: 2005 - Experiment 2

2.5 2005 Simulation for exp 2

2.5.1 Blue beam

Firstly the chromaticity was calculated. (MAD chromaticty :2)
offmomentum: $Q_x = 0.8689761268$ $_y = 0.8567370835$
onmomentum: $Q_x = 0.7383125$ $Q_y = 0.7253405961$
The natural chromaticity is again about -42.



(a) The amplitude of the first anstable particle

(b) color encoded onset of chaos, dark blue=stable

Chapter 3

2006 experiments

3.1 Beam parameter at collision - 2006 experiments

Most of the data are taken from http://www-ap.fnal.gov/~tsen/RHIC/parameters/parameters.html

Beam Energy [GeV]	100
rel. gamma	106.6
magnet rigidity	336
Bunch Intensity	1.5 $\times 10^{11}$
Value 1:norm. emittance $\sigma_{n,x}$,$\sigma_{n,y}$ 95%=2σ, mm.mrad	20
Value 1: $\epsilon_x = 0.25 * \epsilon_n/(\beta\gamma)$	3.5E-8
correct value :norm. emittance $\sigma_{n,x}$,$\sigma_{n,y}$ =2.45σ, mm.mrad	20
correct value: $\epsilon_x = \frac{1}{6} * \epsilon_n/(\beta\gamma)$	3.1E-8
RMS Energy Spread	0.3 $\times 10^{-3}$
Bunch length [m]	0.7
Beam-beam tune shift	9.8 $\times 10^{-3}$
RF (h=360 system, twice)	-150kV

In the experiments in 2006, carried out at store enegry, a the inpact of one single vertical LRBBI was studied.

3.2 RHIC 2006 experiment at s=0m

Lr-interaction at IP6

3.2.1 Experimental results

The experimental results are given in http://www-ap.fnal.gov/~tsen/RHIC/05-Expts/fischer_IR2005.pdf by Wolfram Fischer. According to W. Fischer no effect due to the LR was found.

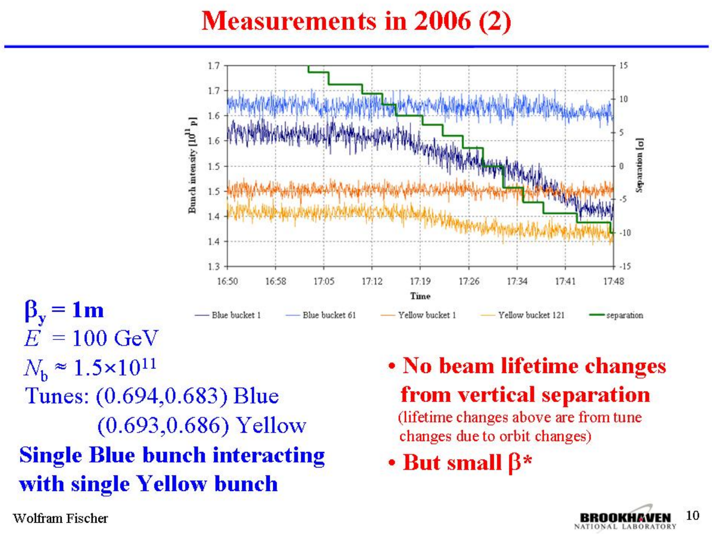
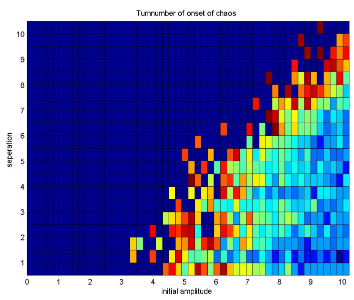
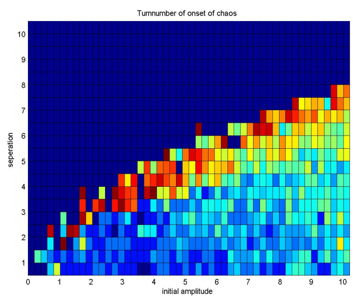


Figure 3.1: 2006 - s=0



(a) LR,sext,offmomentum



(b) LR only

3.3 2006 Simulation for s=0

3.3.1 Blue beam

Firstly the chromaticity was calculated. (MAD chromaticty :2)
onmomentum: $Q_x = 0.6939981029$ $Q_y = 0.6829982582$

offmomentum: $Q_x = 0.7167741127$ $Q_y = 0.7057664774$
The natural chromaticity is about -69.

The sextupoles alone are not causing instability.

3.4 RHIC 2006 experiment at s=9m

LRBBI at 9m upstream from IP6 (upstream for blue beam)

3.4.1 Experimental results

The experimental results are given in http://www-ap.fnal.gov/~tsen/RHIC/05-Expts/fischer_IR2005.pdf by Wolfram Fischer and are there summarized as in figure 3.2.

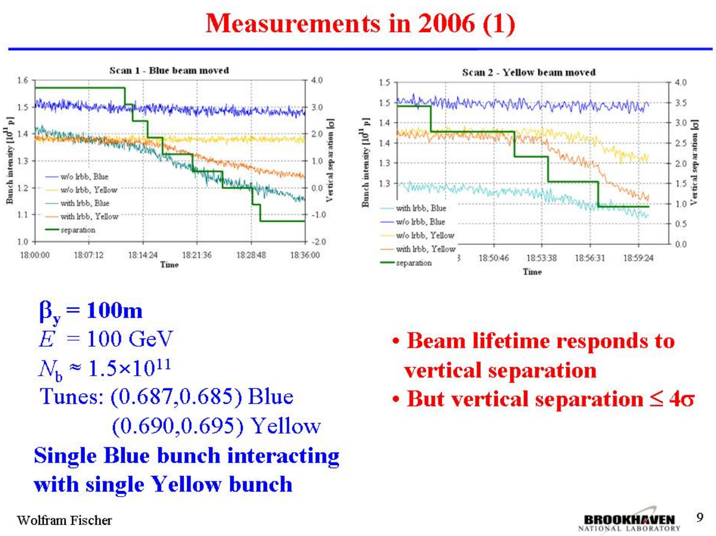


Figure 3.2: 2006 - s=9

3.5 2006 Simulation for s=9, $Q_x = 0.6600$ $Q_y = 0.6599998$

This is not the experimental tune, but was used last time as an extreme case

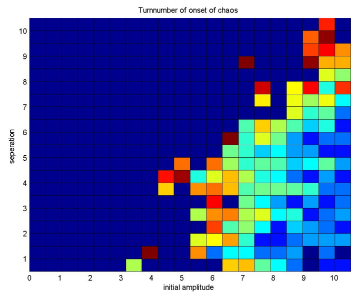
Firstly the chromaticity was calculated. (MAD chromaticty :2)
onmomentum: $Q_x = 0.6600$ $Q_y = 0.6599998$

offmomentum: $Q_x = 0.6825827863$ $Q_y = 0.6827509475$
natural chromaticity: -73

At this tune even with no LR most particles are unstable (6-poles at 0.66 tune!)

The footprint as a functiojn of the beam-beam seperation can be found here:

Therfore the **tune was sligthly changed** (to values of s=0 case0 Now the sextupoles themself are not stong enougth to cause instability.



Chapter 4

Wire compensation

The case of one LR interaction shifterd by 10m is studied. Beamparameter:

	LRIP (10m)	wire
s	3824.045181	3792.292119
β_x	102.0658362	1074.178848
α_x	10.35784959	-26.17915974
β_y	99.54250912	341.2388623
α_y	10.04909026	-13.12735024
μ_x	28.45306705	28.4407124
μ_y	29.45017092	29.43640497

The phaseadvance between LRBB and wire is given by 4.5° in x and 5.1° in y.

If the LR-seperation is d the ideal beam-wire distacen is given by $d_w = \sqrt{\beta_w/\beta_l}$ The ideal wire current is given by:

$$\frac{-4\pi B\rho N_b r_p n_p a r}{\mu_0 \gamma l_w} \tag{4.1}$$

In this case this is 7.28518 A.

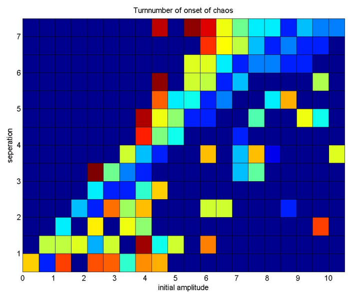


Figure 4.1: wirecompensated