RHIC head-on beam-beam compensation with e-lens

N. Abreu, W. Fischer, Y. Luo, C. Montag, G. Robert-Demolaize

J. Alessi, E. Beebe, A. Pikin

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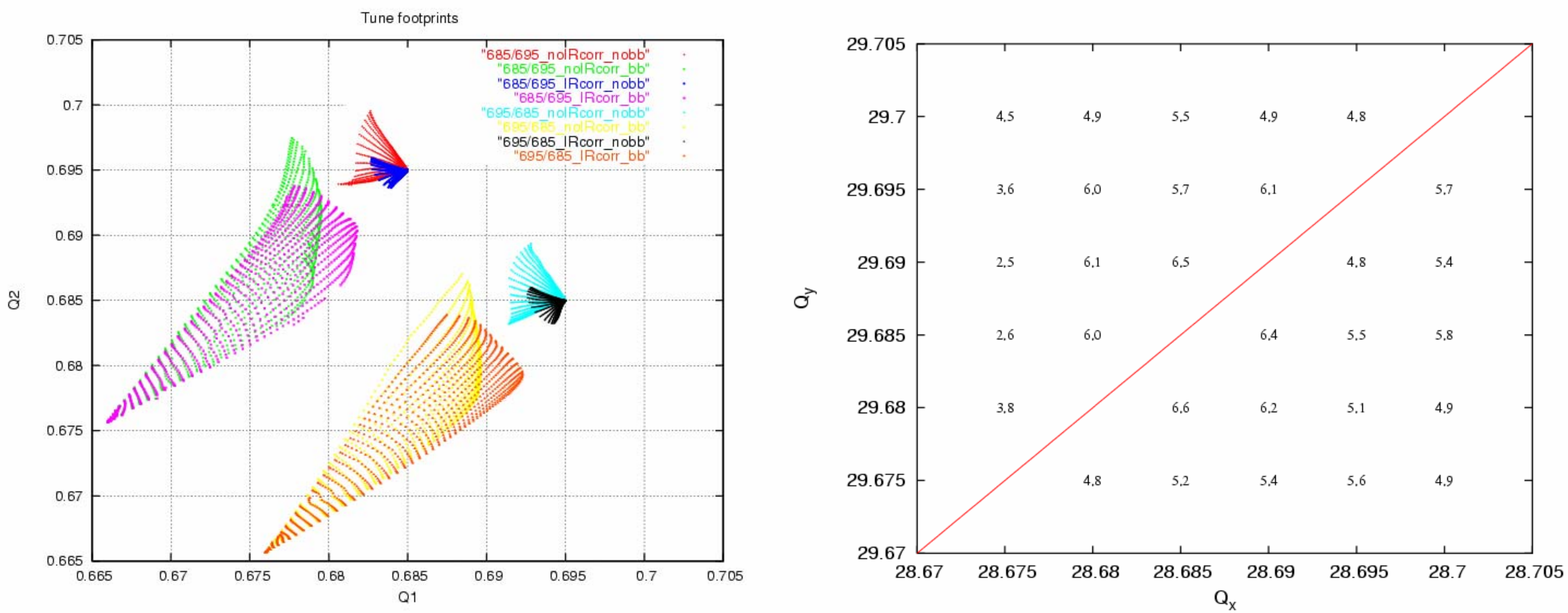
Introduction

- The idea to use electron lens for RHIC head-on beam-beam compensation can be dated back to 2005. E-lens had been proposed for SSC and installed in Tevatron.
- However, the simulation work for RHIC was stopped due to other higher priority jobs and lack of manpower.

- Recently, exactly about 20 days ago, a small team including 8 physicists from AP and EBIS groups was set up formally.
- The goal of this team is to check the possibility of using electron lens for the RHIC head-on beam-beam compensation. This work may take 1 – 1.5 years.

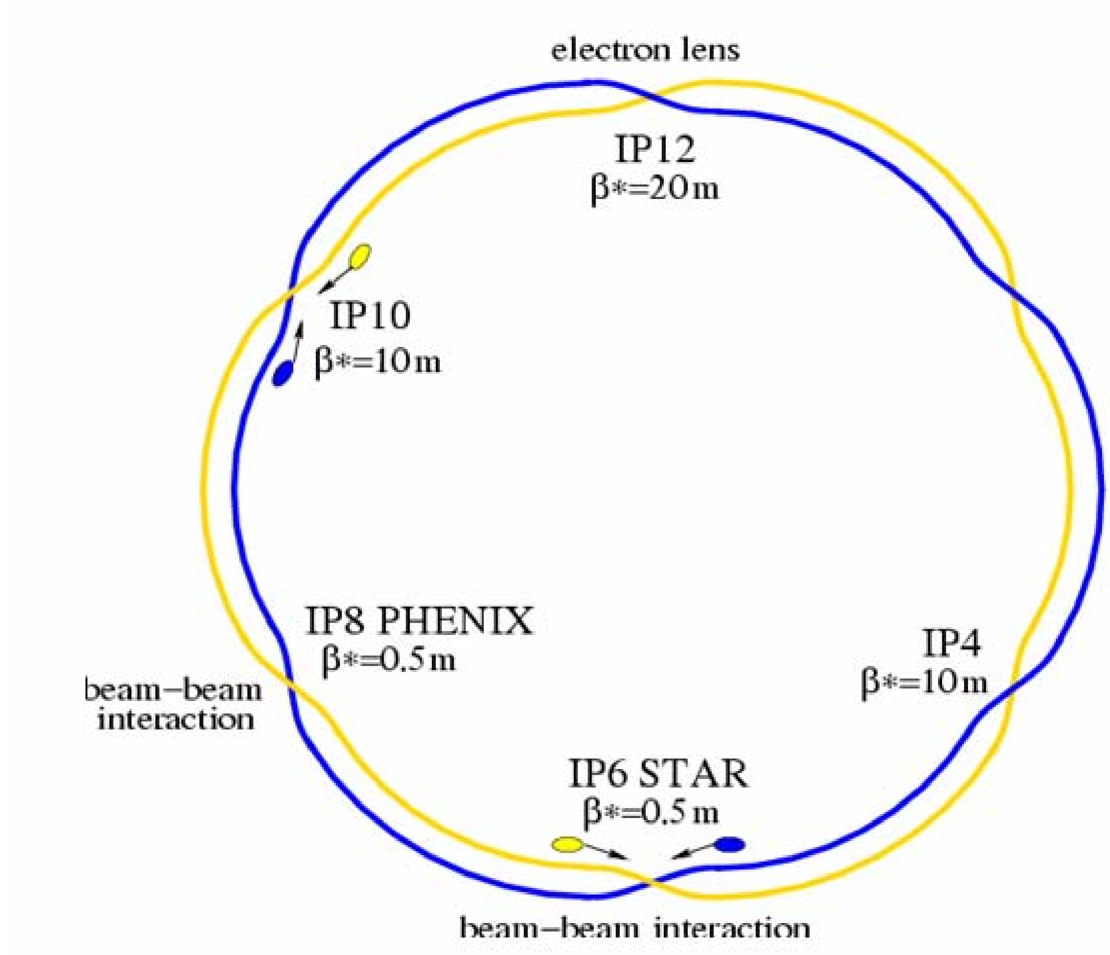
Why e-lens



Tunefoot prints with Nb=2.0e11, beta*=0.5m at IP6 and IP8

At current polarized proton run working point, no enough tune space to accommodate the beam-beam induced tune spread.

Layout with e-lens



Bunch intensity will be 2.0e11 protons,

Beta* at IP6 and IP8 will be 0.5m.

Parameters for simulation

Table 1: RHIC parameters used in the simulations.

quantity	unit	value
lattice		
beam-beam collision points	-	IP6, IP8
envelop function at beam-beam collision points $\beta^*_{x,y}$	m	0.5
e-lens location	-	IP12
envelop function at e-lens location $\beta^e_{x,y}$	m	20
envelop function at all other IPs $\beta^*_{x,y}$	m	10
proton beam		
ring circumference	m	3833.8451
energy	GeV	250
relativistic γ	-	270
harmonic number	-	360
rf cavity voltage	KV	300
particles per bunch N_p	-	2×10^{11}
normalized transverse rms emittance $\epsilon_{x,y}$	mm mrad	2.5
transverse rms beam size at collision points $\sigma^*_{x,y}$	mm	0.068
transverse rms beam size at e-lens $\sigma^e_{x,y}$	mm	0.430
transverse tunes (Q_x, Q_y)	-	$(28.695, 29.685)$ and $(28.685, 29.695)$
chromaticities (ξ_x, ξ_y)	-	$(1, 1)$
beam-beam parameter per IP $\xi_{\mathrm{p}\to\mathrm{p}}$	-	-0.01
electron beam		
number of electrons per bunch passage N_e	-	4×10^{11}
transverse rms beam size at interction point	mm	0.430
beam-beam parameter per e-lens $\xi_{\mathrm{e}\to\mathrm{p}}$	-	$+0.02$

Benefits from e-lens

- Reduce beam-beam tune spread ?
- Increase collision beam lifetime?
- Reduce emittance growth rate?
- Increase beam-beam parameter?

Reducing tune spread ONLY couldn't justify

using e-lens for head-on beam-beam compensation.

Challenges with e-lens

- Challenges in the e-lens design and manufacture

- **Tolerances** for e-lens compensation

  electron beam intensity variation
  electron beam size variation
  centering both beams
  combining other known orbit/tune fluctuations

- E-lens installation and RHIC ring/optics modification

Preliminary Simulation Results

- Tune footprints
- Tune diffusion calculation
- Action diffusion calculation
- Dynamic aperture calculation

Tune footprints (I)

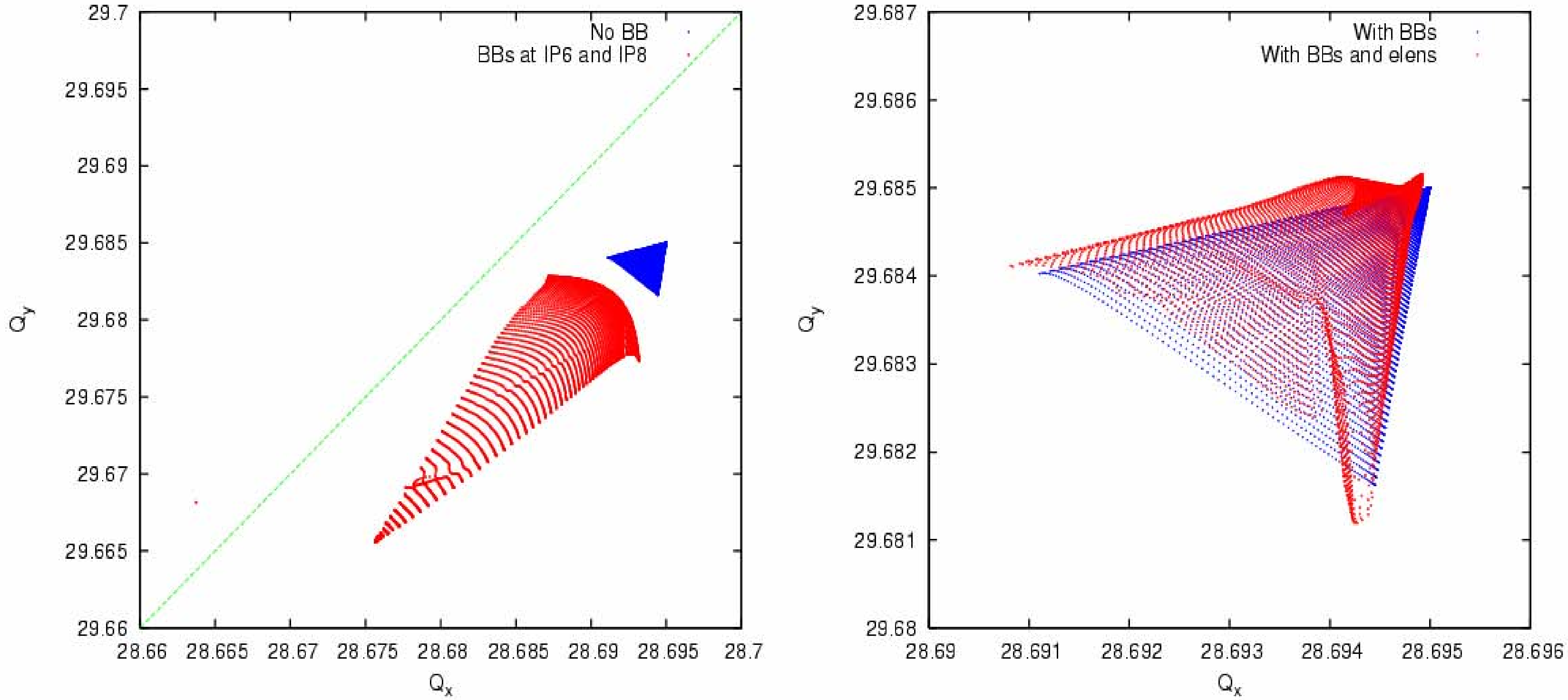


Figure 2: Tune footprints up to 8σ without the IR multipole errors. The left plot shows two footprints: one without beam-beam interactions at all, the other with beam-beam interactions in IP6 and IP8. The right plot shows two footprints: one without beam-beam interaction and without the e-lens, the other with beam-beam interactions and with the e-lens.

Tune footprint (II)

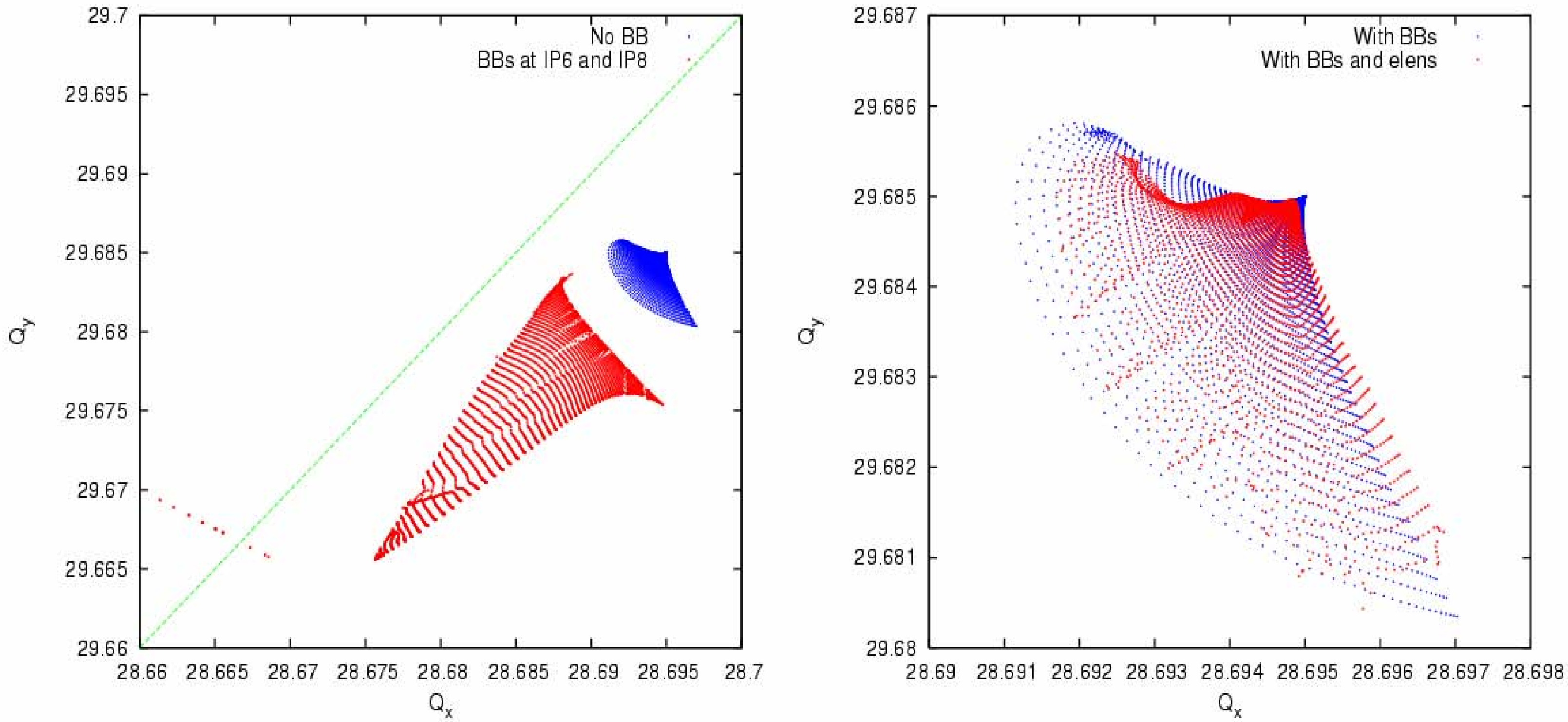


Figure 3: Tune footprints up to 6σ with the IR multipole errors and their corrections. The left plot shows two footprints: one without beam-beam interactions at all, the other with beam-beam interactions in IP6 and IP8. The right plot shows two footprints: one without beam-beam interaction and without the e-lens, the other with beam-beam interactions and with the e-lens.

Tune diffusion (I)

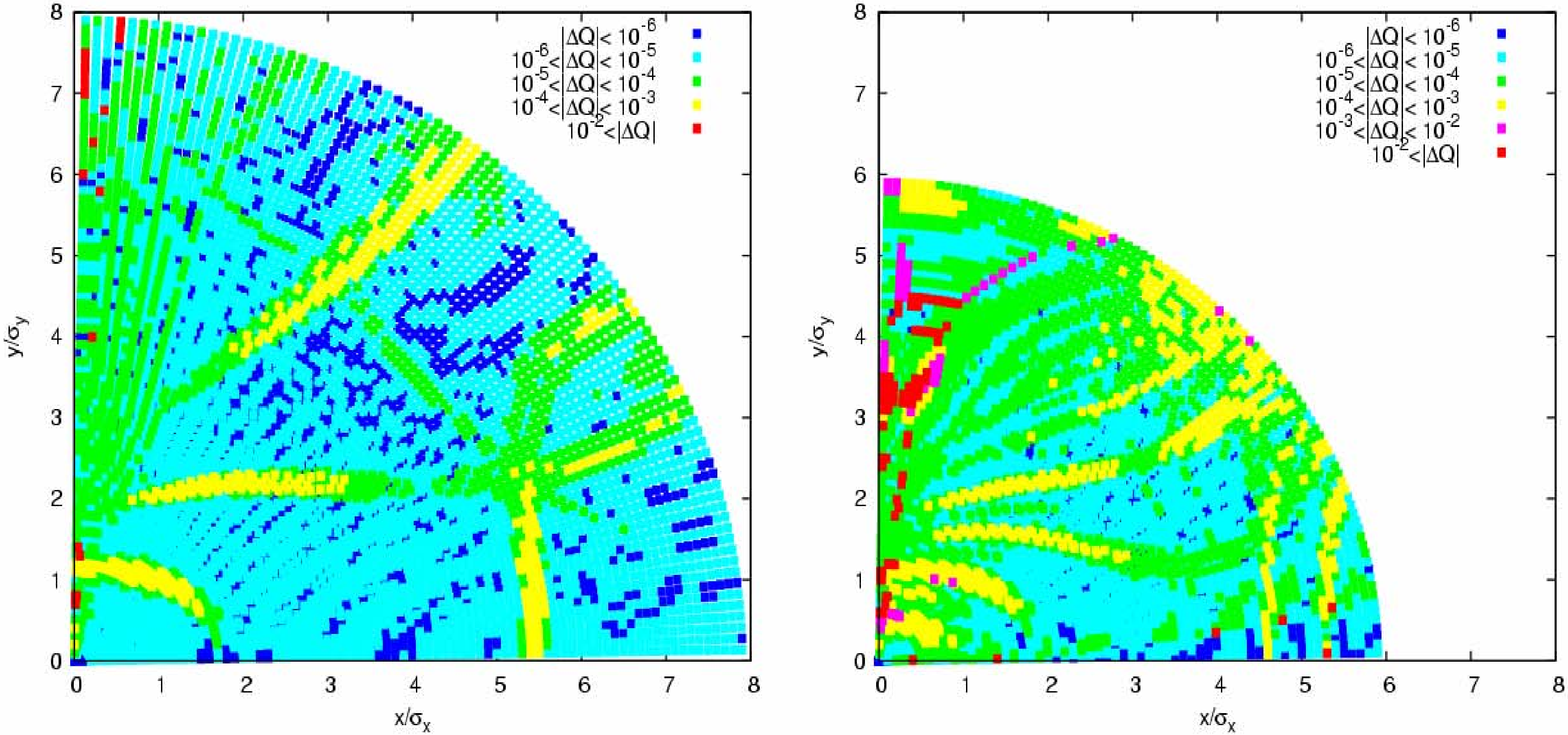


Figure 5: Tune diffusions with beam-beam interactions: the left one without IR multipole errors, while the right one with.

Tune Diffusion (II)

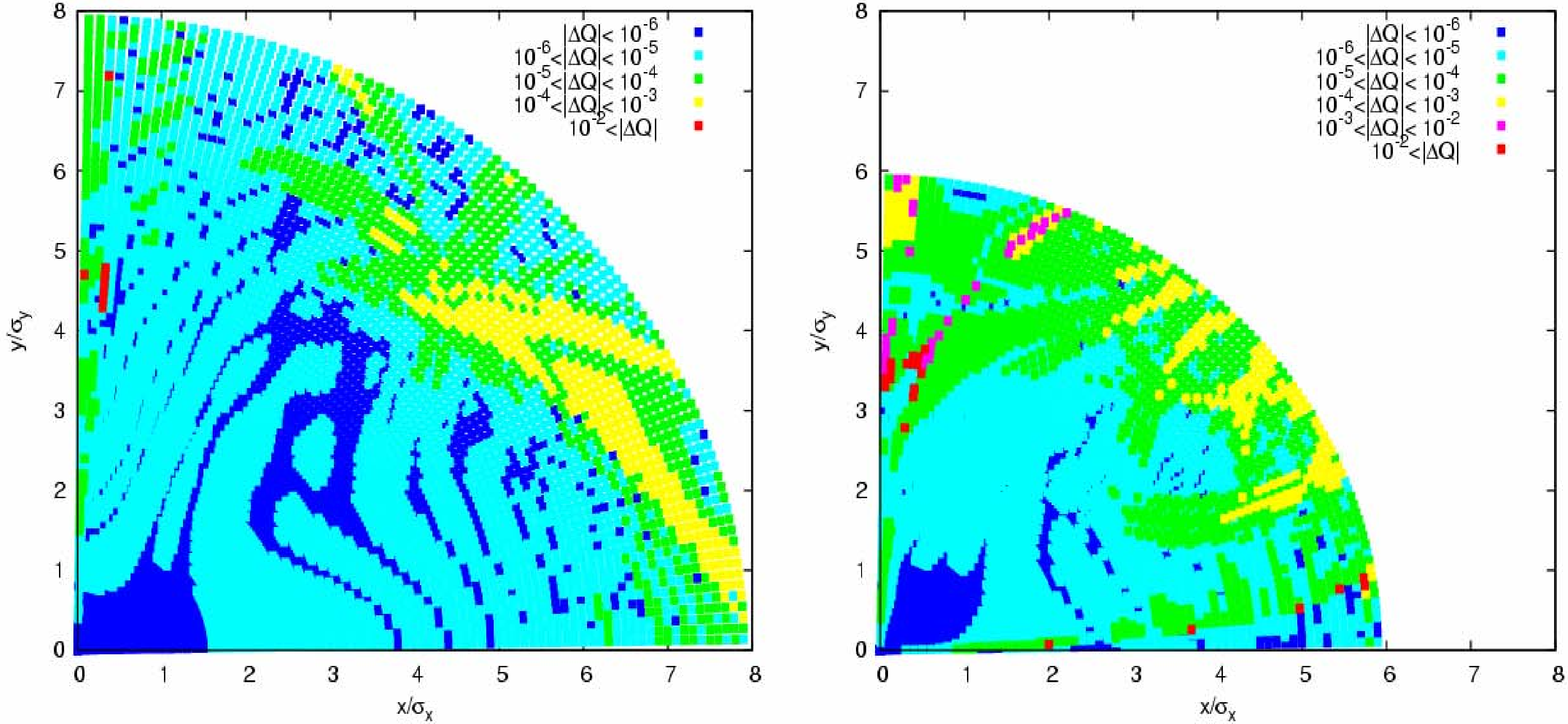
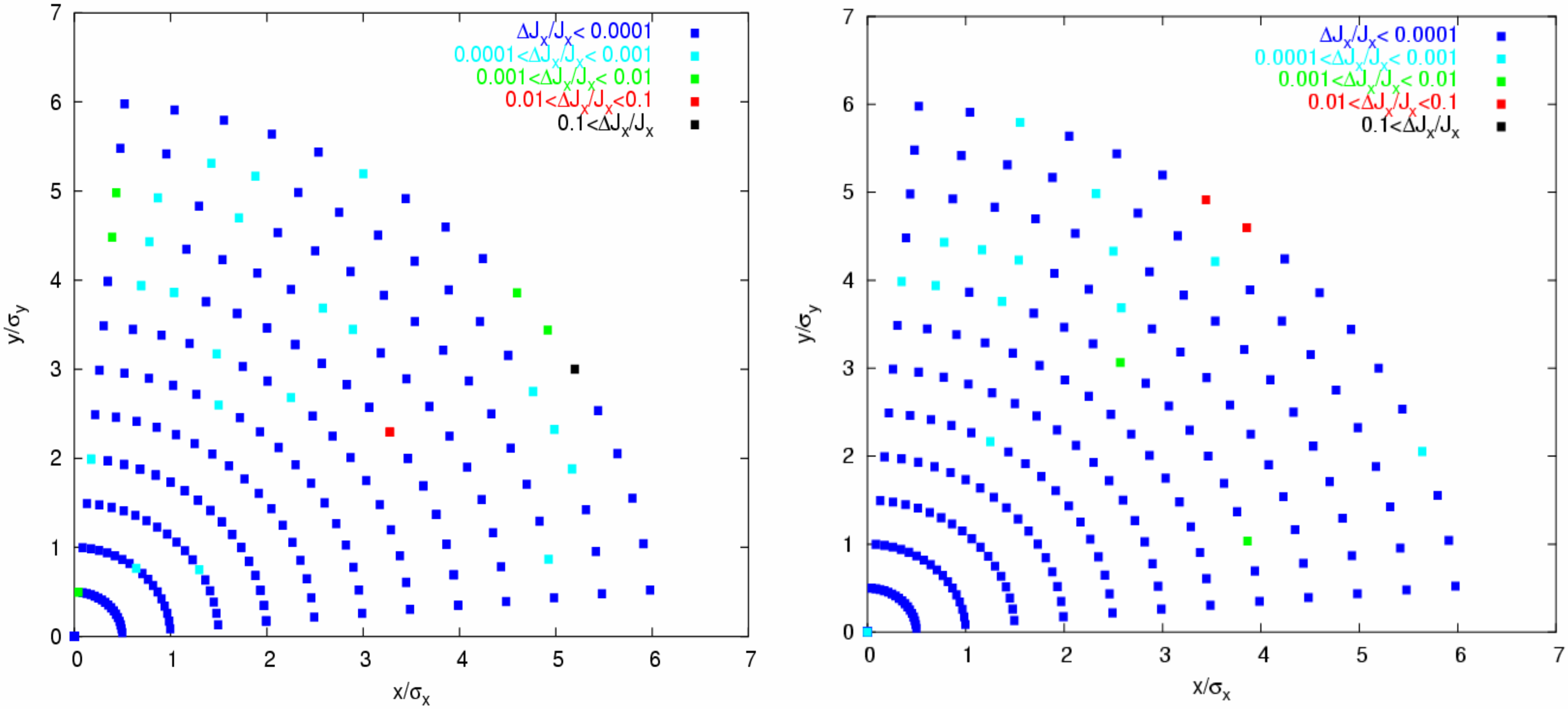


Figure 6: Tune diffusions with beam-beam interactions and e-lens: the left one without IR multipole errors, while the right one with.

Action Diffusion (I)

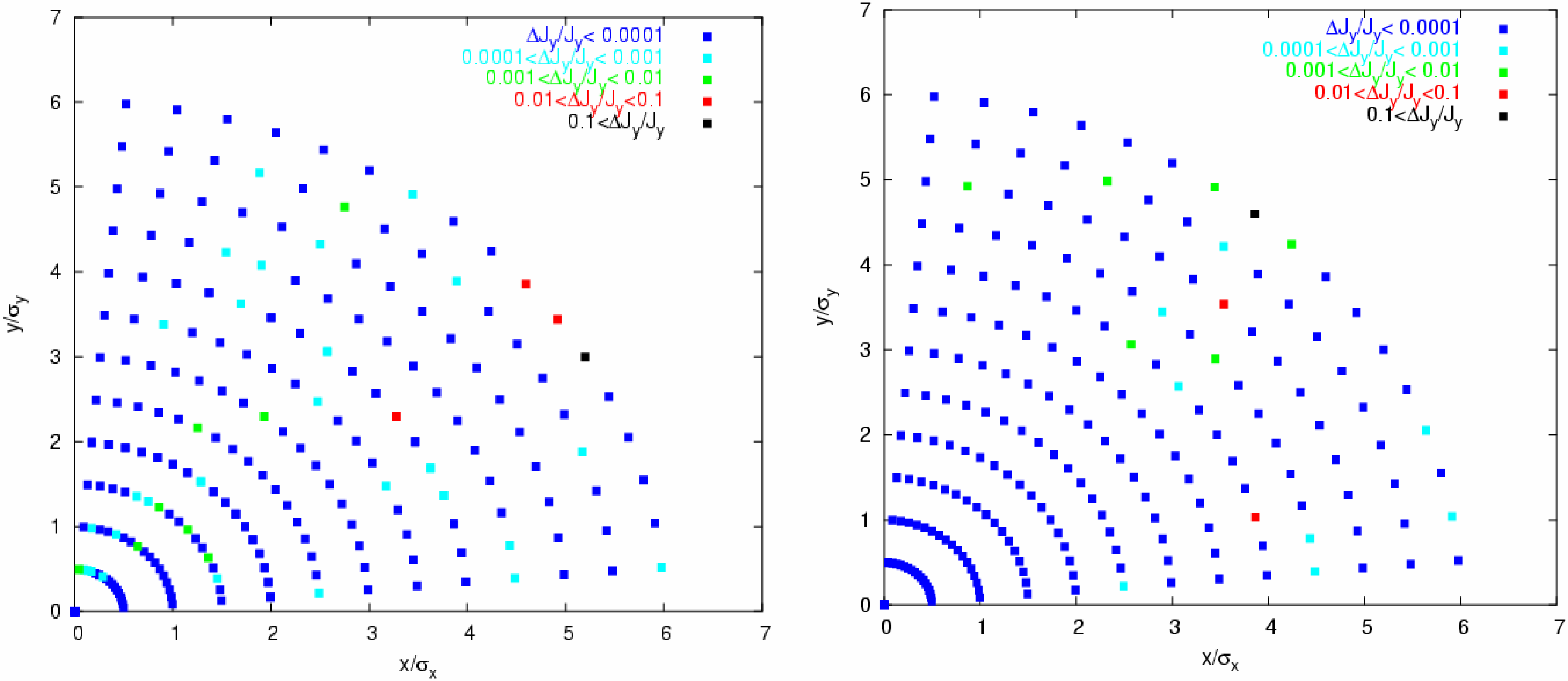


Left: with BB at IP6 and IP8, Right: with BB and e-lens

Horizontal action change in the first and the last 10^3 turns during 10^5 turn tracking.

(calculated with beta*=1.0m at IP6 and IP8)

Action diffusion (II)



Left: with BB at IP6 and IP8, Right: with BB and e-lens

Vertical action change in the first and the last 10^3 turns during 10^5 turn tracking.

(calculated with beta*=1.0m at IP6 and IP8)

Dynamic apertures (I)

10^5 turn DA searching

DA, β^* = 0.5 m in IP6 and IP8, e-lens in IP12, 10^5 turns, $N_b = 2\times10^{11}$ dp/p=0.0007										
Angle (deg)	10	20	30	40	50	60	70	80	min	avg
NoIRerrCorr+BB	7.4	7.6	7.5	8.8	9.8	10.5	11.0	10.3	7.4	9.1
NoIRerrCorr+BB+elens	6.9	6.0	5.8	5.4	6.6	9.0	8.4	8.4	5.4	7.1
IRerrCorr+BB	4.9	4.5	4.8	5.4	5.7	5.9	5.7	5.6	4.5	5.3
IRerrCorr+BB+elens	5.8	4.5	5.2	5.8	5.5	5.8	5.7	5.7	4.5	5.5

No clear DA increase with e-lens in 10^5 turn tracking.

Dynamic Apertures (II)

10^6 turn DA searching

DA, β* = 0.5 m in IP6 and IP8, e-lens in IP12, 10^6 turns				dp/p=0.0007			
Angle (deg)	15	30	45	60	75	min	avg
NoIRerr	14.5	12.3	12.4	12.7	13	12.3	13.0
NoIRerr+BB	4.6	4.5	5.7	6.5	7.2	4.5	5.7
NoIRerr+BB+elens	5.1	4.2	4.2	4.9	6.2	4.2	4.9
Angle (deg)	15	30	45	60	75	min	avg
IRerrCorr	4.6	3.9	3.9	4.2	4.1	3.9	4.1
IRerrCorr+BB	3.1	3.1	3.3	3.4	3.5	3.1	3.3
IRerrCorr+BB+elens	4.1	3.3	3.1	3.8	3.8	3.1	3.6

No clear DA increase with e-lens in 10^6 turn tracking.

DAs are mainly decided by IR multipole errors.

Dynamic apertures (III)

DA, β^* = 0.5 m in IP6 and IP8, e-lens in IP12, DA vs. N_p, N_e (both scaled up)					dp/p=0.0	10^5 turns		
	N_p	15	30	45	60	75	min	avg
IRerrCorr+BB	2.0E+11	6.2	6	6	6.1	6.1	6.0	6.1
IRerrCorr+BB+elens	2.0E+11	6.4	5.7	5.7	5.9	6.7	5.7	6.1
IRerrCorr+BB	2.5E+11	7.4	5.7	5.8	6.3	6.3	6.3	6.3
IRerrCorr+BB+elens	2.5E+11	6.4	5.5	5.6	5.7	7.1	5.5	6.1
IRerrCorr+BB	3.0E+11	6.7	5.8	5.7	6.4	6.1	5.7	6.1
IRerrCorr+BB+elens	3.0E+11	6.2	4.8	5.5	6.1	6.8	4.8	5.9
IRerrCorr+BB	4.0E+11	7.1	5.1	5.7	6	6.1	5.1	6.0
IRerrCorr+BB+elens	4.0E+11	5.6	4.7	5.1	5.9	6.9	4.7	5.6

DA versus bunch intensity

DA, β^* = 0.5 m in IP6 and IP8, e-lens in IP12, DA vs. N_p, N_e (both scaled up)					dp/p=0.0	10^5 turns		
	N_p	15	30	45	60	75	min	avg
NoIRerr+BB	2.0E+11	12	11.6	11.4	11.7	11.8	11.4	11.7
NoIRerr+BB+elens	2.0E+11	13.2	10.1	10.8	11	12	10.1	11.4
NoIRerr+BB	2.5E+11	11.4	8.7	11.4	10.8	11.8	8.7	10.8
NoIRerr+BB+elens	2.5E+11	13.3	10.1	9	10.8	12.3	9.0	11.1
NoIRerr+BB	3.0E+11	10.7	10.8	11.3	10.8	11.4	10.7	11.0
NoIRerr+BB+elens	3.0E+11	11.6	9.3	8.4	9.9	12.4	8.4	10.3
NoIRerr+BB	4.0E+11	9.5	10.3	10.5	10.8	10.7	9.5	10.4
NoIRerr+BB+elens	4.0E+11	11.4	9.1	8.4	9.5	12.4	8.4	10.2

DA is not sensitive to bunch intensity.

The Plan

- Set up first version of beam/e-lens parameters for RHIC head-on beam-beam collision compensation.

- Continuing simulations to check **benefits** and **challenges** with e-lens head-on beam-beam compensation. Find out various **tolerances** for its practical usage.

- Preliminary design of e-lens gun and possible modification of the RHIC ring/optics.

Timeline

- July 2007, first version of beam/e-lens parameters.

- July 2007-August 2008 feasibility study
  physics simulation / hardware design
  to answer **Benefits** and **Challenges**

- August 2008, Decision-making
  Go ahead with it or not ?

Next simulation jobs

- Long-term particle stability
- Emittance growth rates
- Possibility to increase bunch intensity

- Various tolerances in the compensation
- Combination with tune ripple/orbit vibration

- Slicing e-lens compensation

Conclusion

- Feasibility study of using e-lens for RHIC head-on beam-beam compensation is in action.

- By August 2008, we should be able to answer the Benefits and Challenges with this technique.

- RHIC is a good test bed for the head-on beam-beam compensation. Collaborations and contributions among labs are needed and very welcome.