Progress in E-lens work for RHIC

Presented by Yun Luo

(N. Abreu, W. Fischer, Y. Luo, C. Montag,

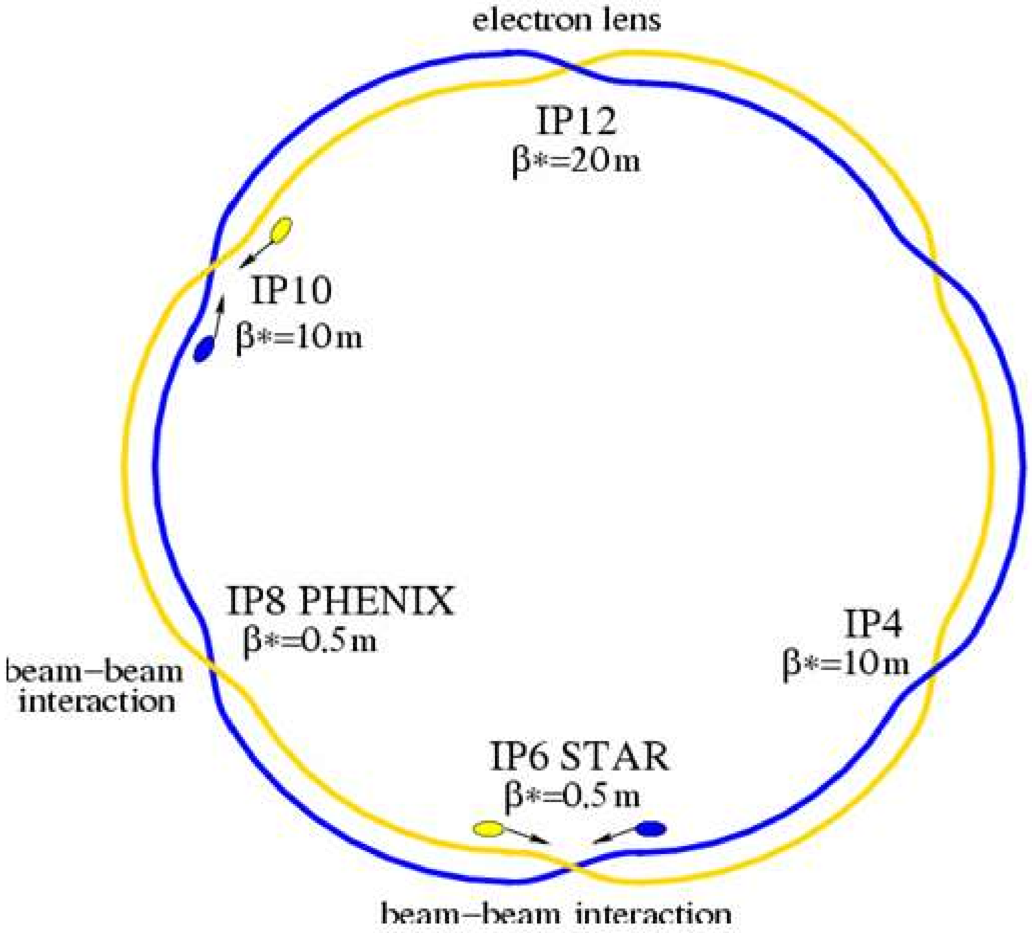
G. Robert-Demolaize, E. Beebe, A. Pikin)

1. General Description
2. Some Simulation Results
3. Plans

(2007 RHIC APEX workshop, Nov. 1-2, 2007, BNL)

General Description

Electron lens (e-lens) for head-on beam-beam compensation



- P-p bunch interaction:

$$\begin{pmatrix} \Delta x' \\ \Delta y' \end{pmatrix}_{p-pbunch} = \frac{2N_p r_0}{\gamma r^2}(1 - e^{-\frac{r^2}{2\sigma_p^2}}) \begin{pmatrix} x \\ y \end{pmatrix}$$

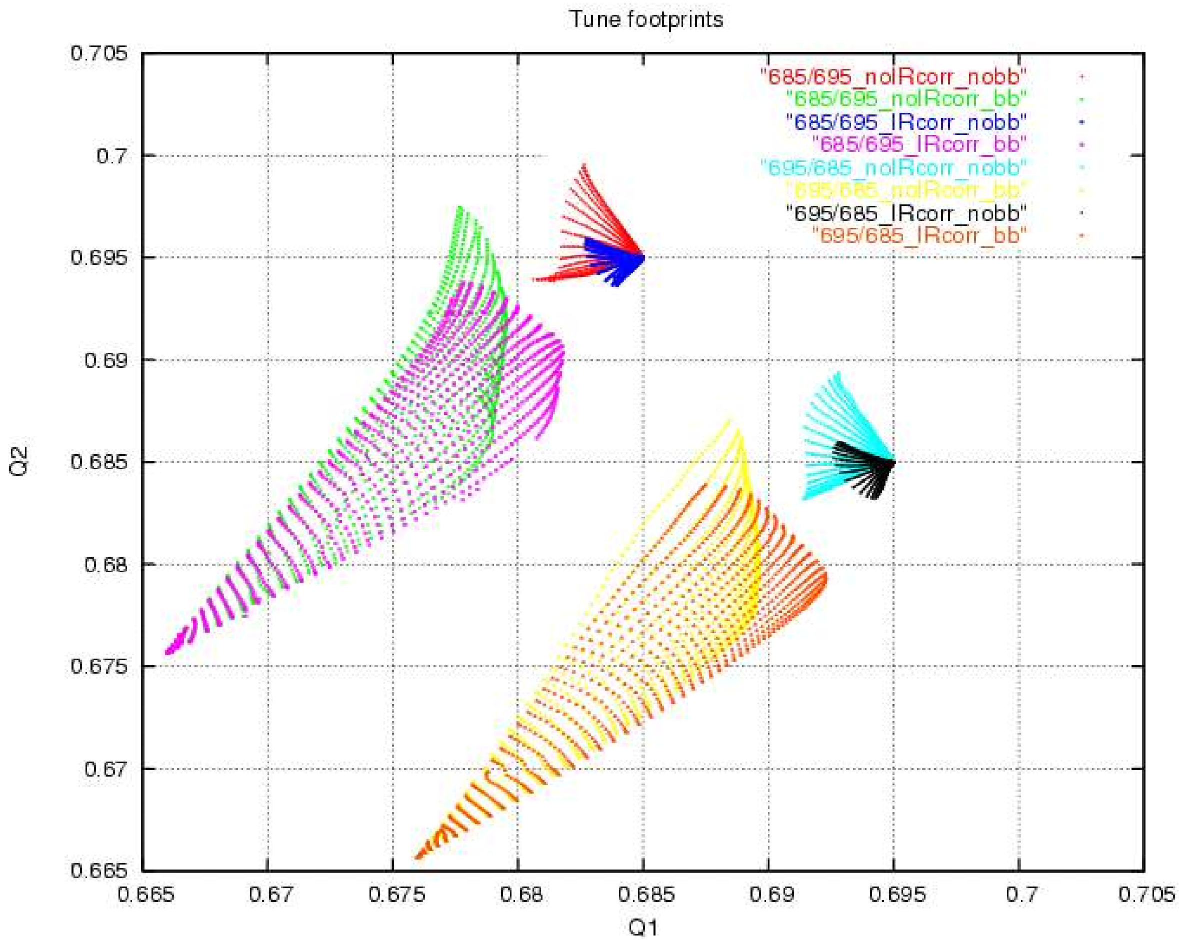
$$\Delta Q_{x,y}|_{p-pbunch} = -\frac{N_p r_0 \beta^*}{4\pi\gamma\sigma_p^2} = -\frac{N_p r_0}{4\pi\gamma\varepsilon_p}$$

- p-elens interaction:

$$\begin{pmatrix} \Delta x' \\ \Delta y' \end{pmatrix}_{p-ebeam} = -\frac{2N_e r_0}{\gamma r^2}(1 - e^{-\frac{r^2}{2\sigma_e^2}})(1+\beta_e) \begin{pmatrix} x \\ y \end{pmatrix}$$

$$\Delta Q_{x,y}|_{p-elens} = \frac{N_e r_0 \beta_{elens}}{4\pi\gamma\sigma_e^2}(1+\beta_e) = \frac{N_e r_0}{4\pi\gamma\varepsilon_e}(1+\beta_e)$$

Why e-lenses for RHIC



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

Solutions to mitigate the tight beam-beam tune space
1) new working points; 2) BBC compensation with e-lens

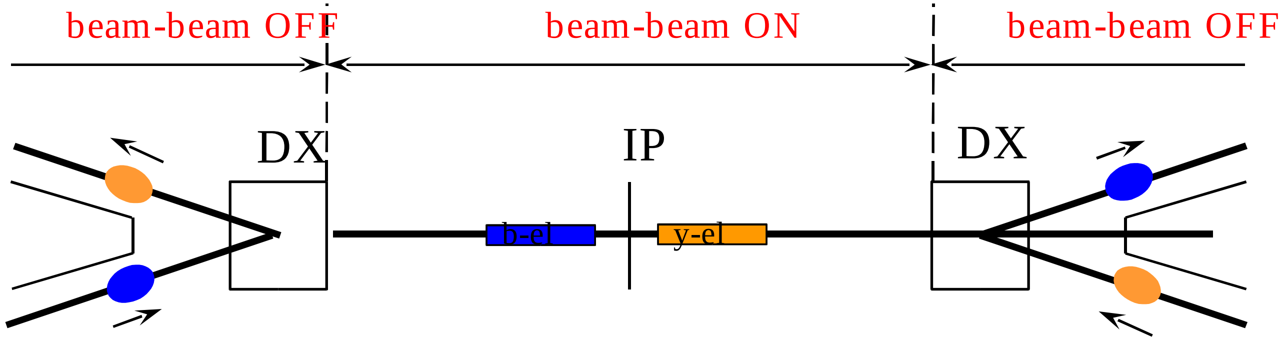
Possible benefits expected from RHIC e-lens

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

Attraction:

If we don't deteriorate the collisional lifetime while increasing the bunch intensity by 50% with the head-on beam-beam compensation, the luminosity will be doubled.

Accommodation of two RHIC e-lenses



Input parameters		
Location:	…	IP10
envelope function at IP β*, injection	m	10.0
envelope function at IP β*, store	m	10.0
beginning of solenoid	m	1.5
length of solenoid	m	2.0
relativistic γ, injection	…	25.4
relativistic γ, store	…	106.6
bunch intensity	10^{11}	2.0
normalized emittance	mm.mrad	25
vertical beam separation	mm	10.0
orbit error tolerance	mm	2.0
e-beam radius / p-beam radius	…	1.5
aperture requirement, e-beam	σ	6.0
vertical half-heigh IP4	mm	19.0
β-function at IP4	m	10.0
vertical half-heigh IP6 and IP8 (new beam pipes)	mm	20.0
e-lens current	A	1.2

Output parameters		
aperture requirement from IP4, injection	σ	14.8
aperture requirement from IP4, store	σ	9.6
β-function at beginning of solenoid, injection	m	10.2
β-function at beginning of solenoid, store	m	10.2
β-function at end of solenoid, injection	m	11.2
β-function at end of solenoid, store	m	11.2
beam size at end of solenoid, injection	mm	1.36
beam size at end of solenoid, store	mm	0.66
vertical separation, end of solenoid, injection	$\sigma_{p\text{-beam}}$	7.4
vertical separation, end of solenoid, store	$\sigma_{p\text{-beam}}$	15.1
vertical separation, end of solenoid, injection	$\sigma_{e\text{-beam}}$	4.9
vertical separation, end of solenoid, store	$\sigma_{e\text{-beam}}$	10.1
solenoid pipe radius requirement p-beam, injection	mm	27.1
solenoid pipe radius requirement p-beam, store	mm	11.0
solenoid pipe radius requirement e-beam, injection	mm	19.2
solenoid pipe radius requirement e-beam, store	mm	13.0
solenoid pipe radius requirement, min (from all above)	**mm**	**27**
design radius	mm	55

Two proton beam vertically separated by 6 sigmas.

Proton and electron beam parameters (subject to change)

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	-	266
harmonic number	-	360
rf cavity voltage, accelerating system $h = 360$	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)	-	$(28.695, 29.685)$
chromaticities (ξ_x, ξ_y)	-	$(1,1)$
beam-beam parameter per IP $\xi_{\mathrm{p}\to\mathrm{p}}$	-	-0.01

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Table 2: Nominal RHIC e-lens parameters. For full compensation

quantity	symbol	unit	value
electron kinetic energy	K_e	keV	5
electron speed	$\beta_e c$	...	0.14c
electron transverse rms size	σ_e	mm	0.433
effective e-lens length	L_{elens}	m	2.0
total electron particles in e-lens	N_e	-	3.5×10^{11}
electron beam current	I_e	A	1.2

Some Simulation Results

Tune footprint

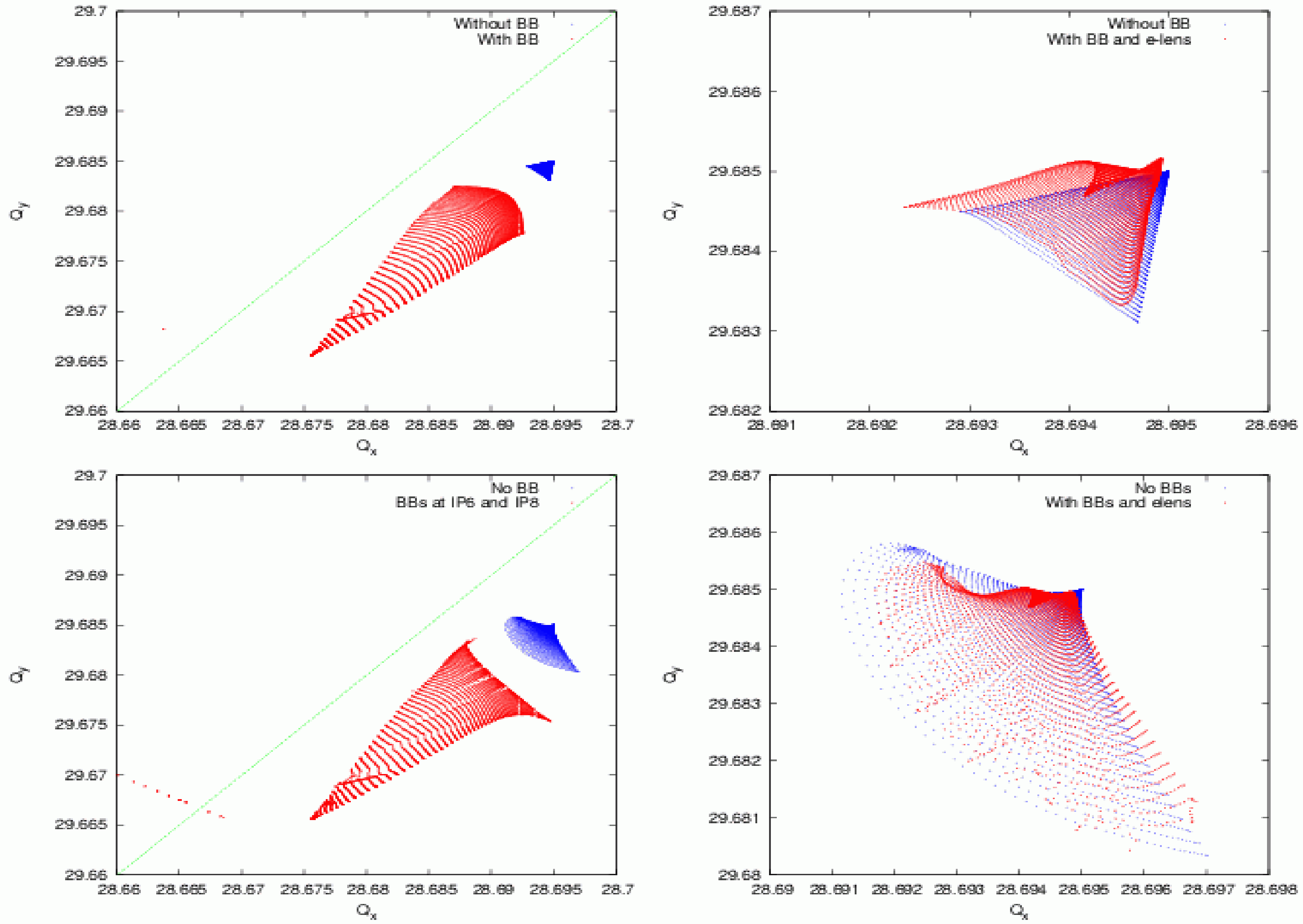


Figure 2: Tune footprints without and with the head-on beam-beam compensation.

Frequency map analysis

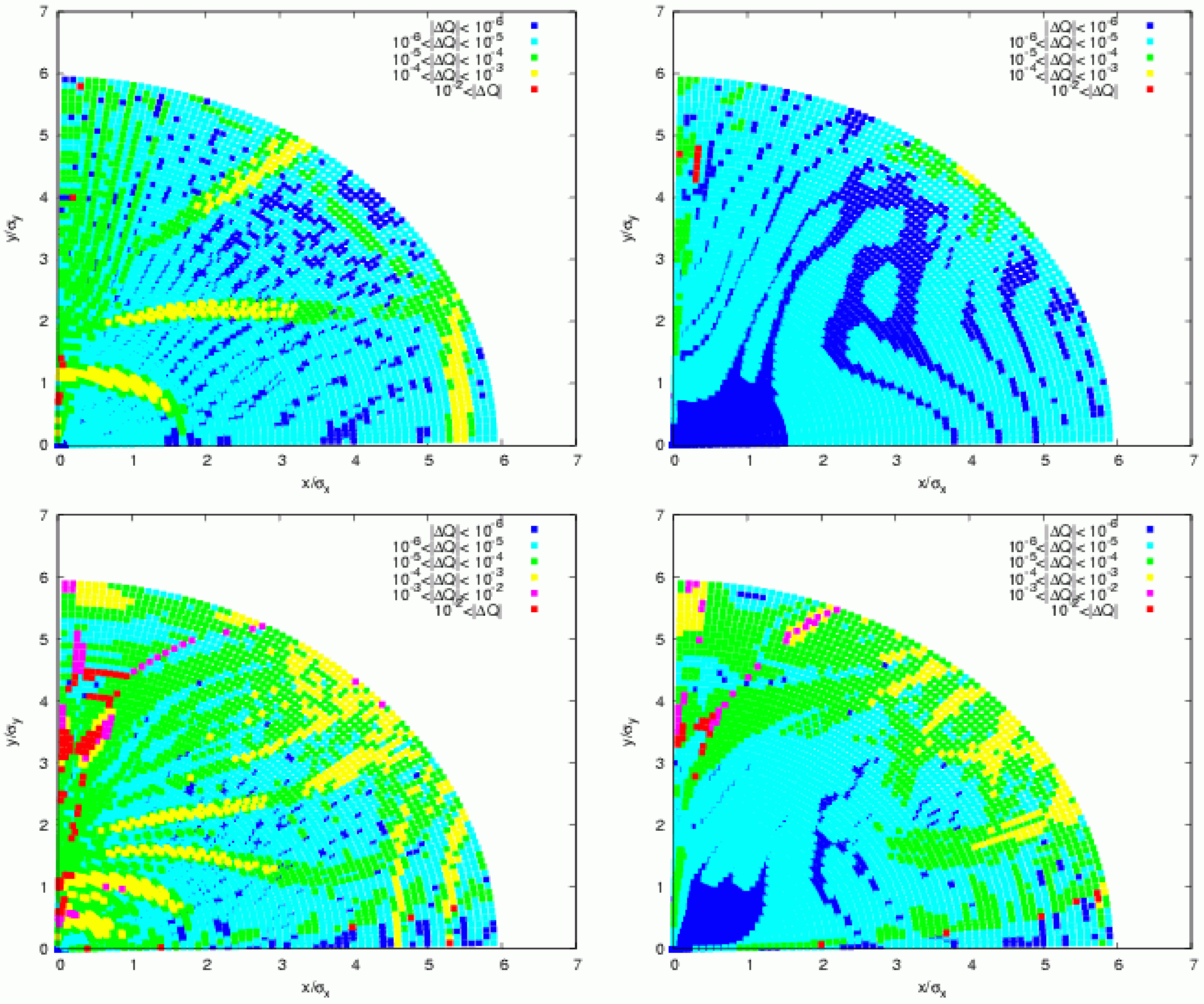


Figure 3: Frequency maps without and with the head-on beam-beam compensation.

Dynamic aperture calculation

Table 2: Dynamic apertures with and without full head-on beam-beam compensation

IRerrcorr	δ	N_p [$\times 10^{11}$]	N_e [$\times 10^{11}$]	Dynamic Apertures [σ] 15°	30°	45°	60°	75°	Min.
No	0	2.0	0	12.0	8.4	9.6	10.7	10.7	8.4
No	0	2.0	4.0	12.3	9.9	8.8	9.2	12.0	8.8
No	0.0007	2.0	0	4.3	4.7	6.2	6.4	6.9	4.3
No	0.0007	2.0	4.0	5.2	3.9	4.3	5.1	5.9	3.9
Yes	0	2.0	0	6.2	5.9	4.8	5.6	5.9	4.8
Yes	0	2.0	4.0	6.4	5.5	5.4	5.8	6.6	5.5
Yes	0.0007	2.0	0	3.6	4.2	4.6	4.8	4.9	4.2
Yes	0.0007	2.0	4.0	4.2	3.6	3.6	4.5	4.5	3.6

DAs were systematically calculated:

- full/partial compensation
- different beta at e-lens location
- different proton bunch intensity
- variations in electron beam current,...

It turned out that dynamic aperture is not sufficient to check the effects from the beam-beam compensation.

Multi-particle simulation (I)

Code choosing:

SixTrack code is chosen for the weak-strong beam-beam simulation

SixTrack optics tracking: 6-D, simplectic, element-by-element tracking

Two modifications:

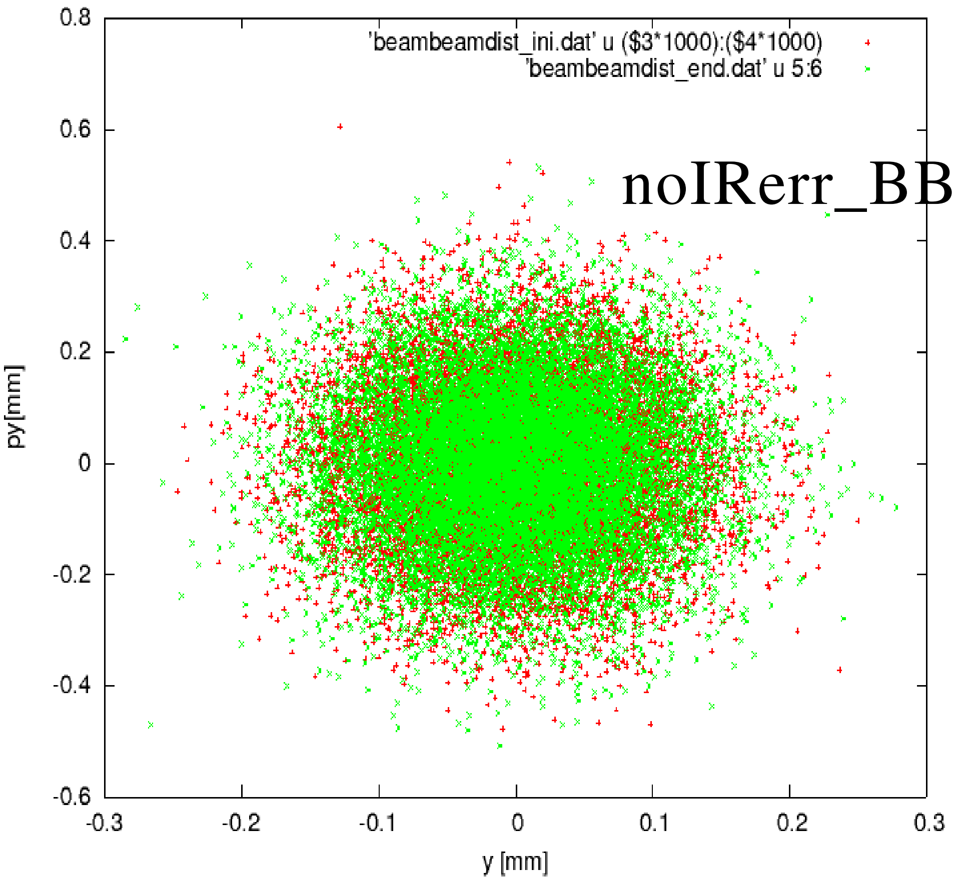
1) multi-particle tracking, instead of 64 particles

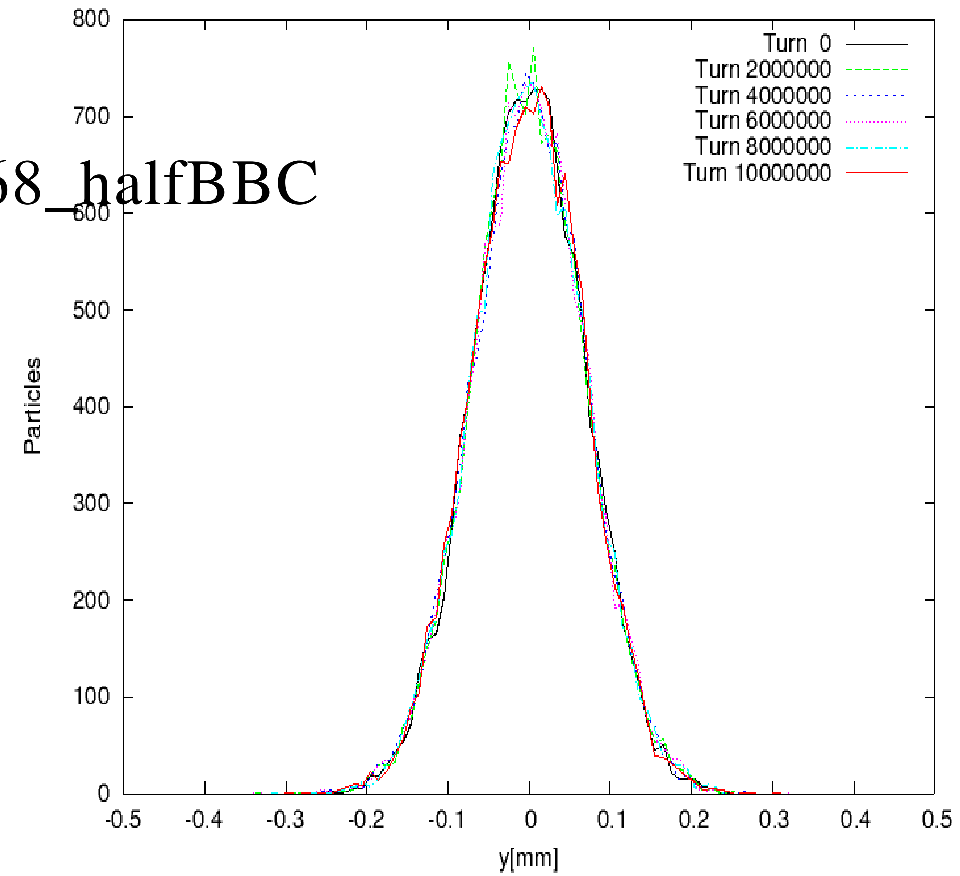
2) modifying beam-beam interaction on turn-by-turn basis

Both were done by G. Robert-Demolaize.

Multi-particle simulation (II)

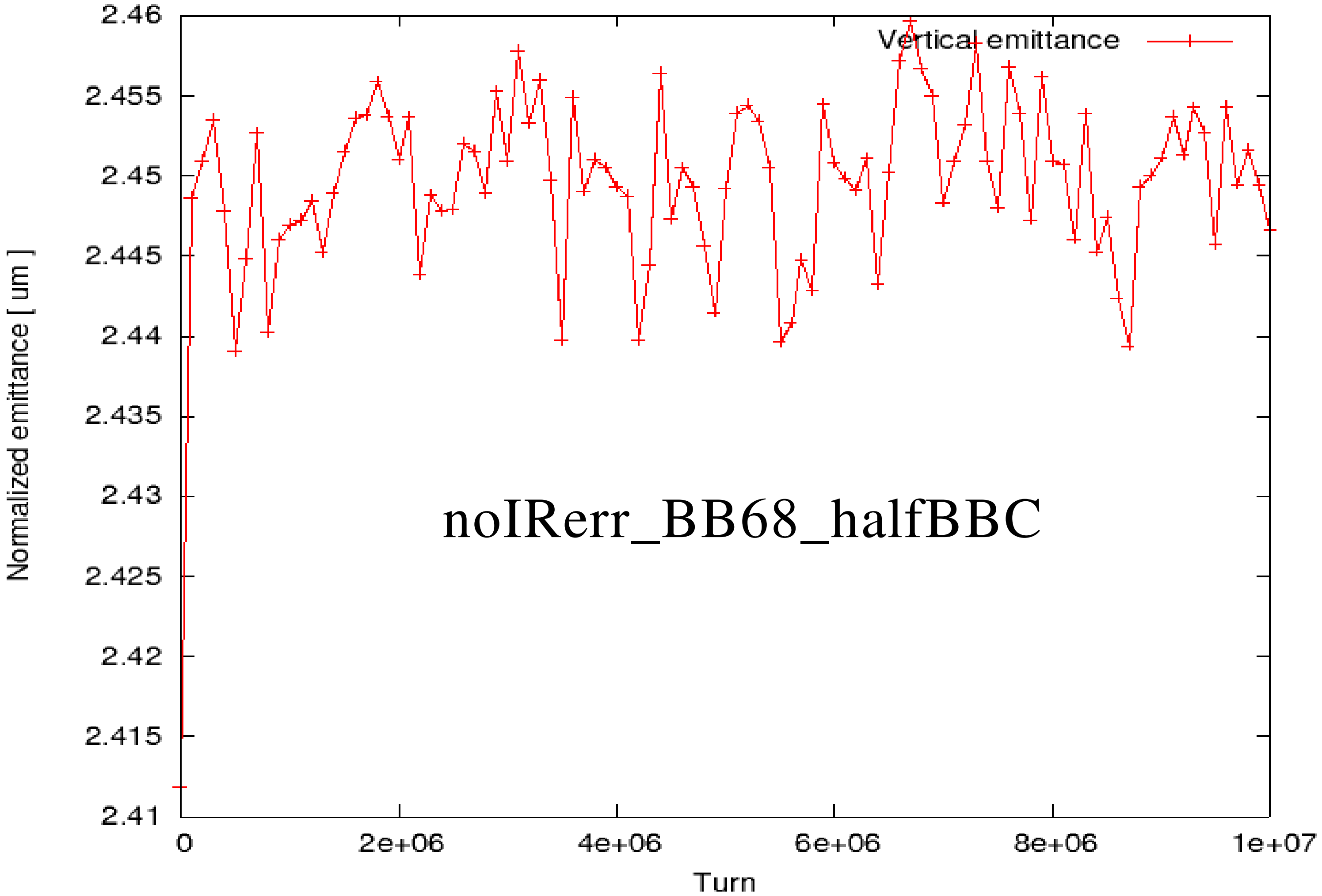
noIRerr_BB68_halfBBC





12800 particles, tracking up to 10^7 turns, or 120 seconds of real operation.

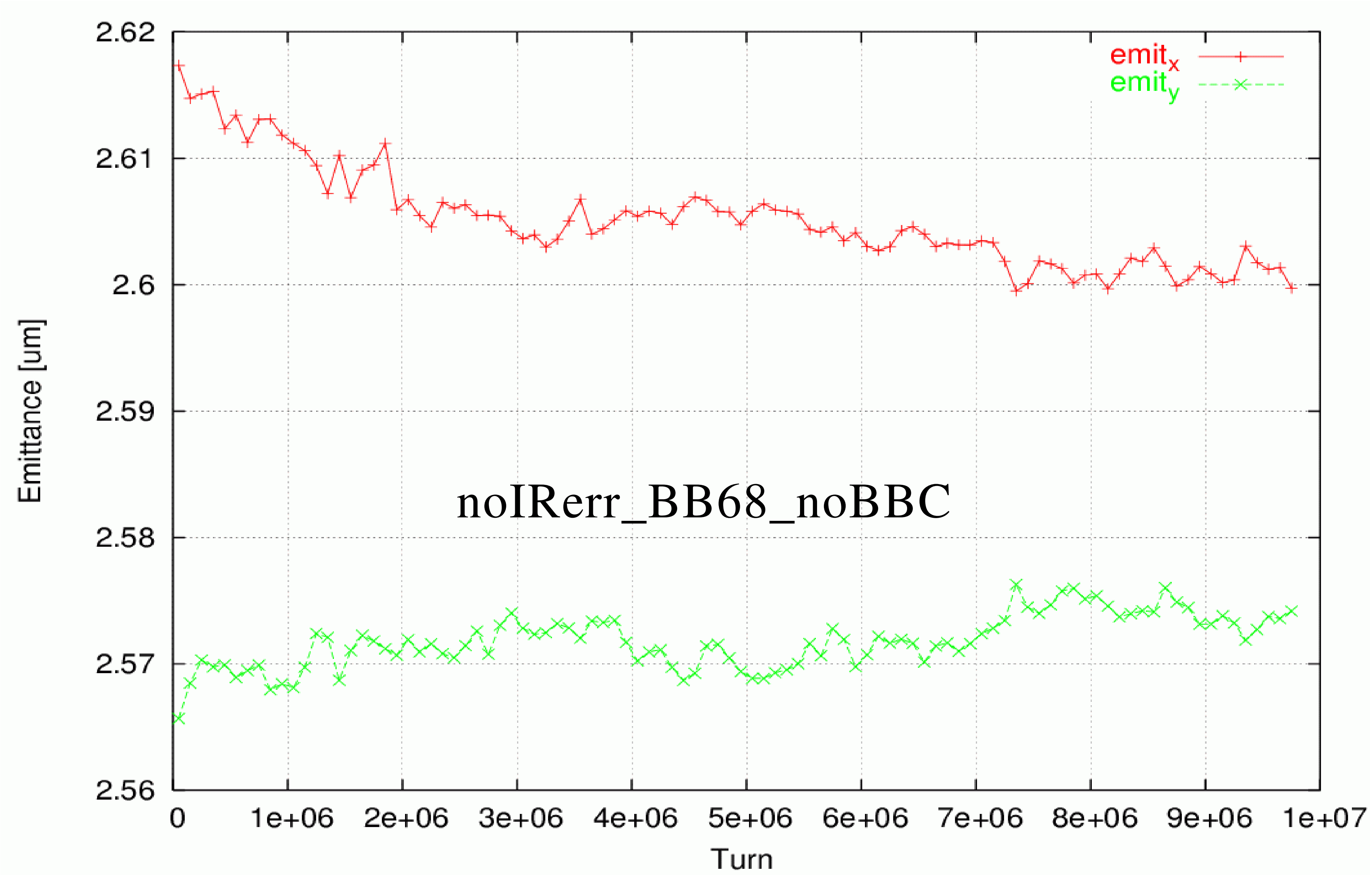
Multi-particle simulation (III)



12800 particles, tracking up to 10^7 turns, or 120 seconds of real operation.

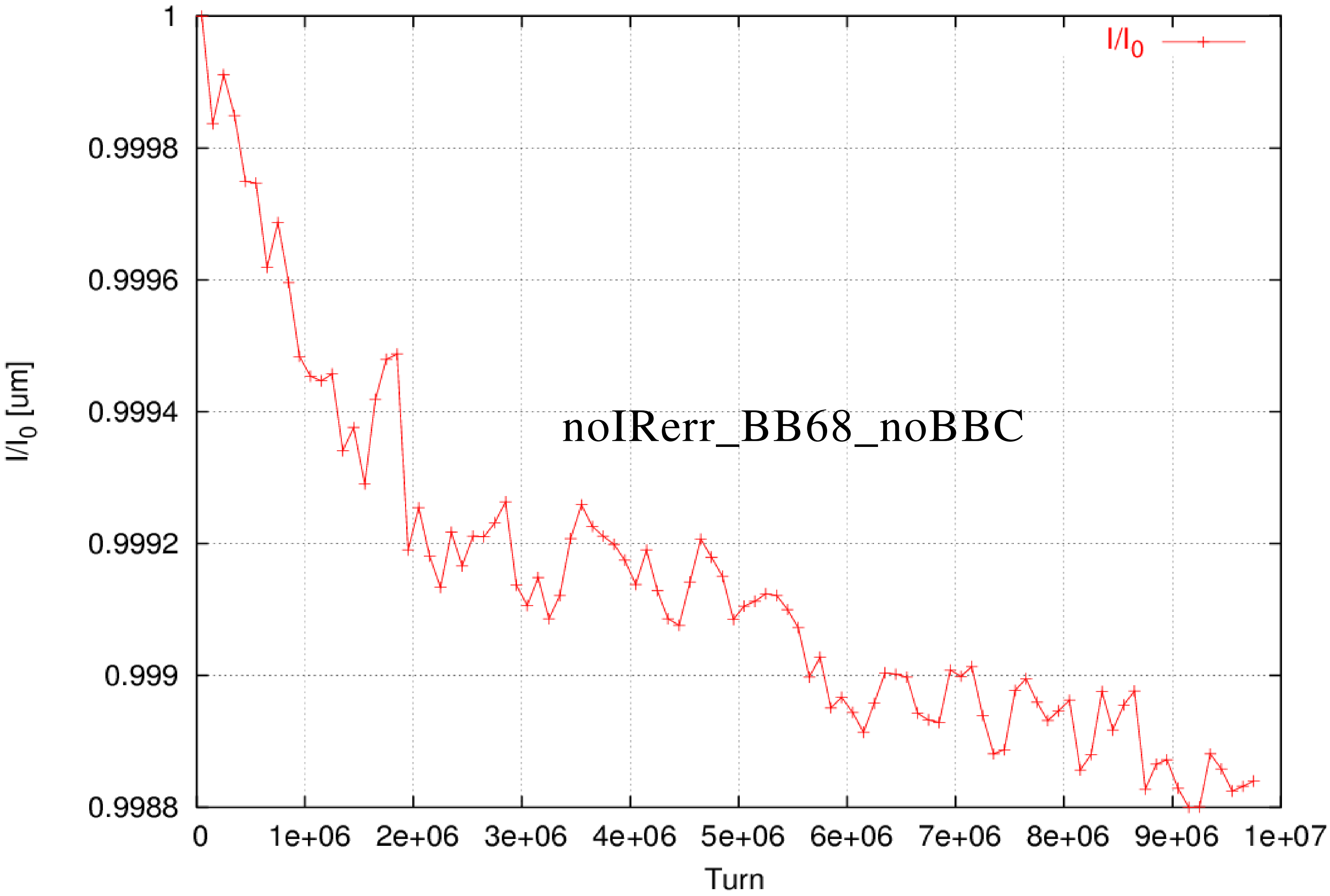
Statistics noise has to be reduced from 0.05% to 0.005%!

New way to calculate emittances (I)

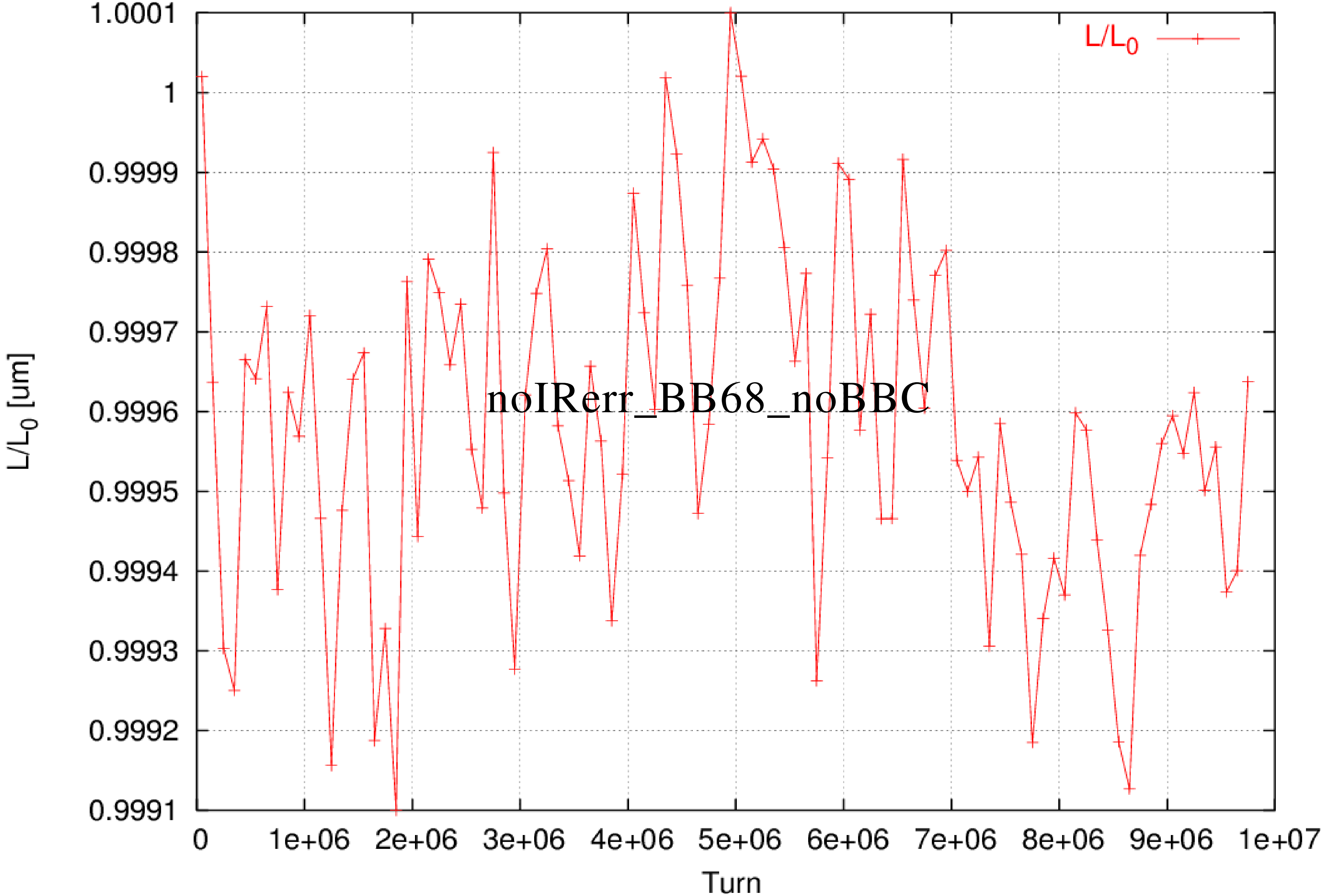


Calculate the emittances with all coordinates of 12800 particles in continuous 100 turns. And use cut=5 sigmas.

New way to calculate emittances (II)



New way to calculate emittances (III)



Planes

1. Multi-particle tracking

   Reduce the noise level in calculated emittance
   Benchmarking with RHIC current runs
   Tracking with e-lenses
   Parameter scans

   Most concern : need a lot of CPU Time

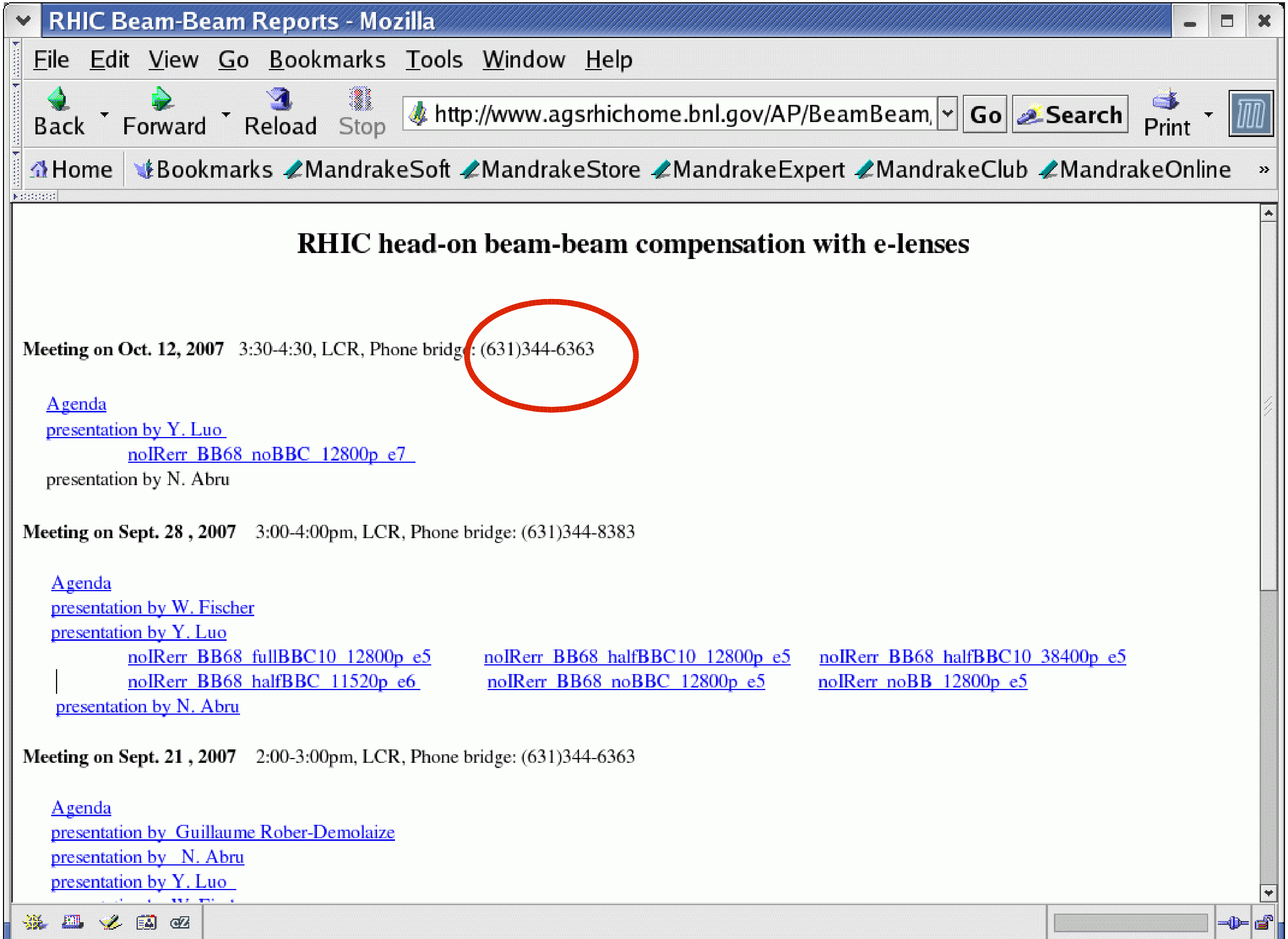
2. Single particle stability

   migrations of particles in the bunch core,
   searching the chaotic boundary or stable boundary,...

3. Design of the e-lens system

   should put more efforts here

Discussions, suggestions, corrections are all welcome.



http://www.agsrhichome.bnl.gov/AP/BeamBeam/2007_elens_meeting.html