RHIC
Beam-beam Effects

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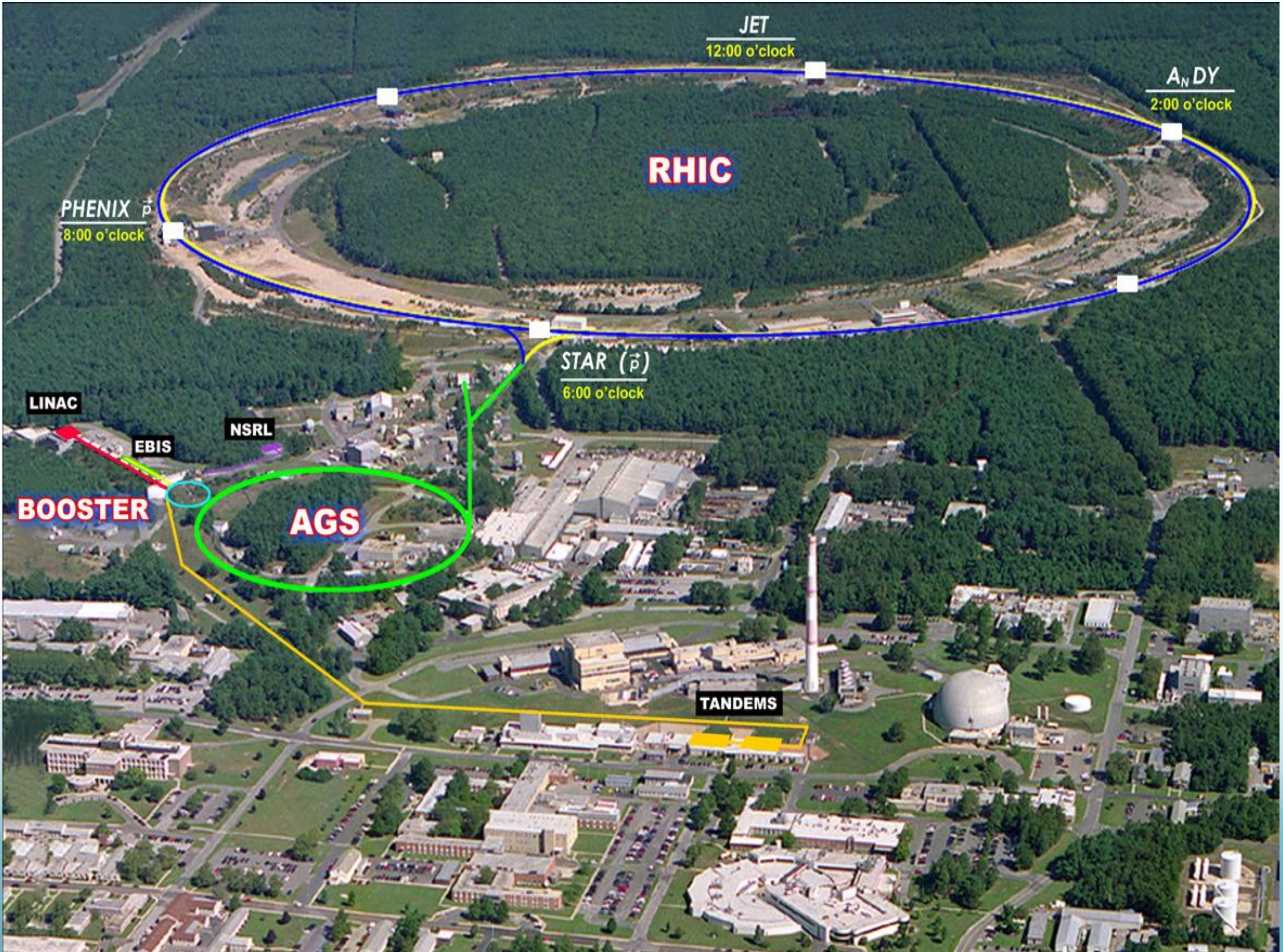
JET
12:00 o'clock
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BOOSTER
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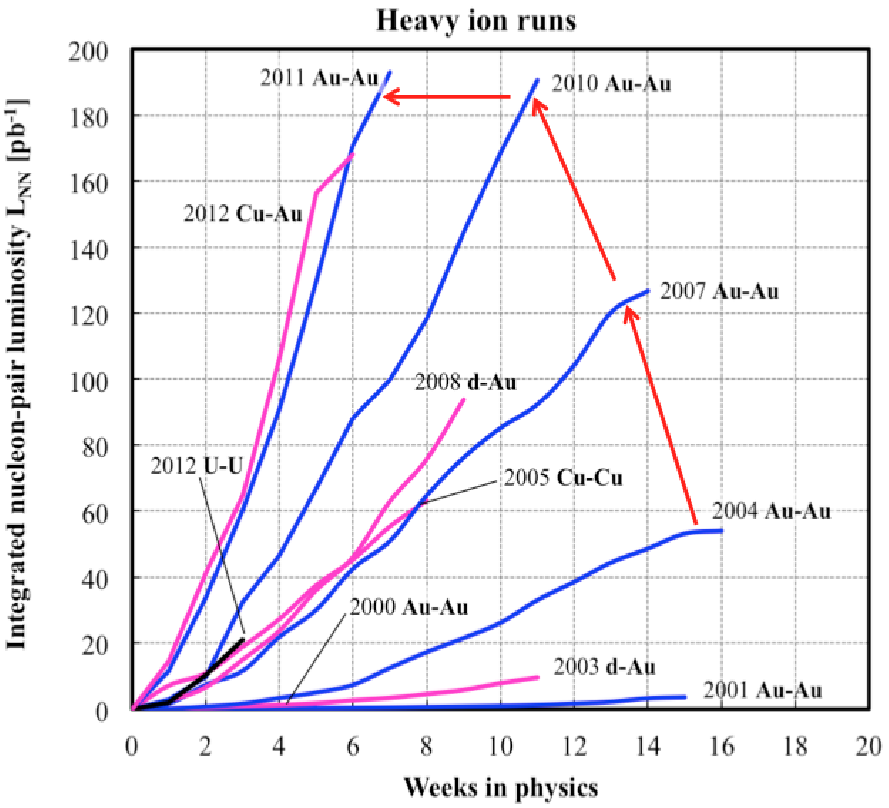
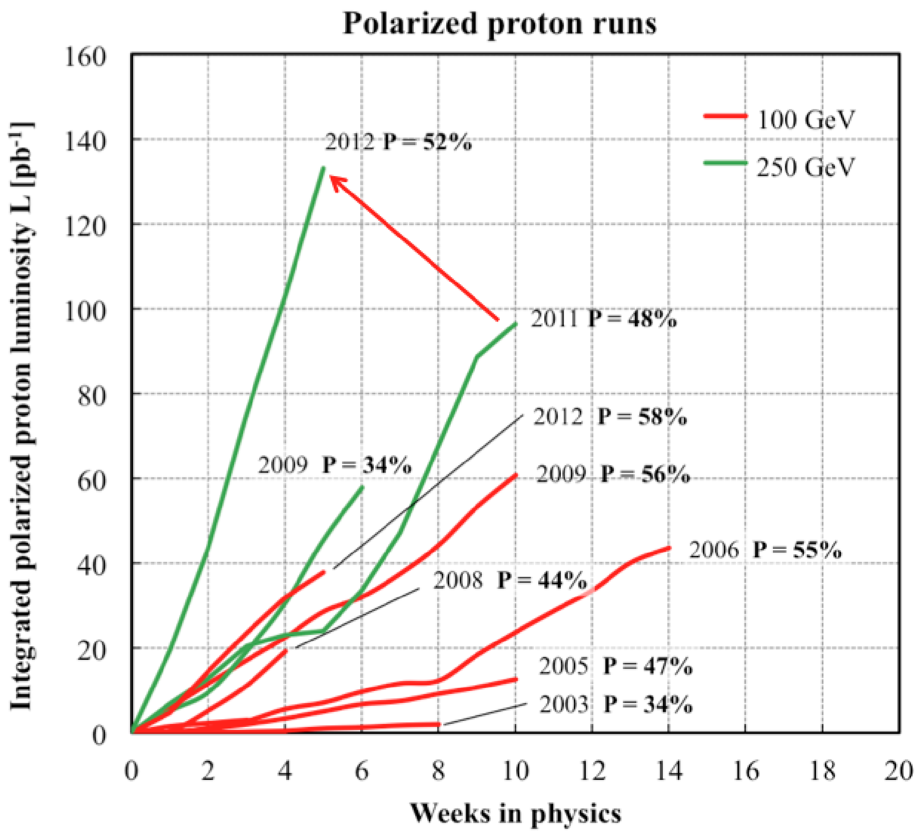
TANDEMS

Previous RHIC Runs





Maximum beam-beam parameter in Au-Au runs is 0.003 with Nau=1.3e9.
Maximum beam-beam parameter in p-p run is 0.017 with Np=1.7e11.

Tune Space

- ❑ Working point in p-p run is determined by the beam lifetime with BB and the polarization preservation on ramp and at store.
- ❑ Current nominal working point (28.695, 29.685) is constrained between 2/3 and 7/10. 7/10 is 10th order betatron resonance but also a spin depolarization resonance.
- ❑ Simulation and experiment effects have been carried out to explore new working points.

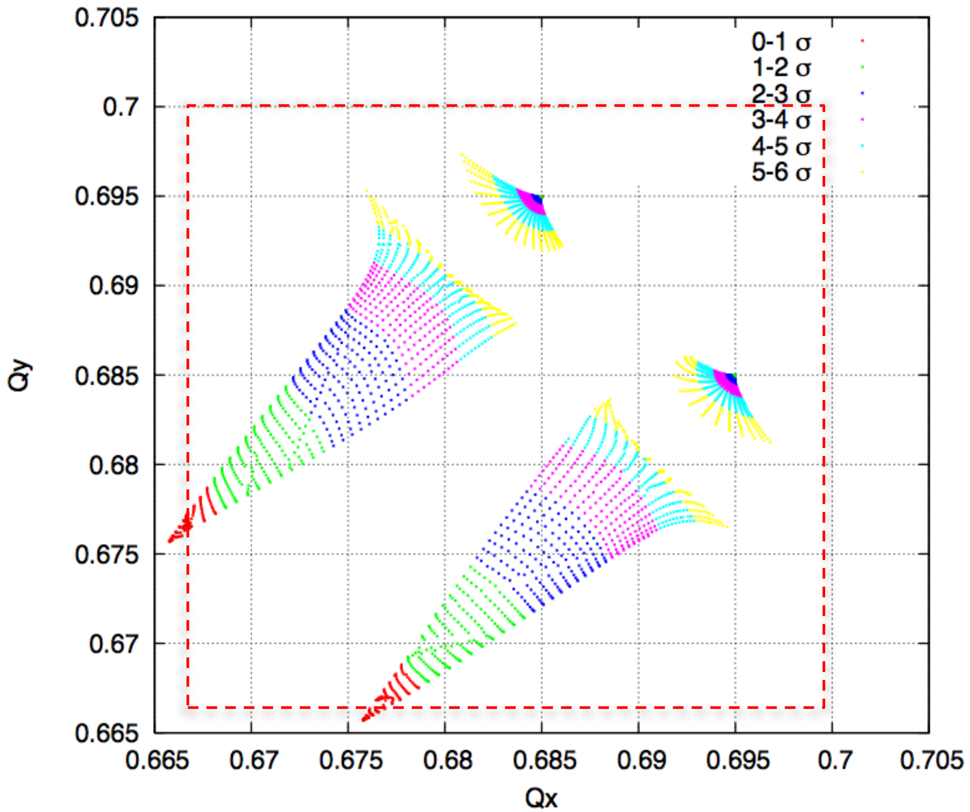
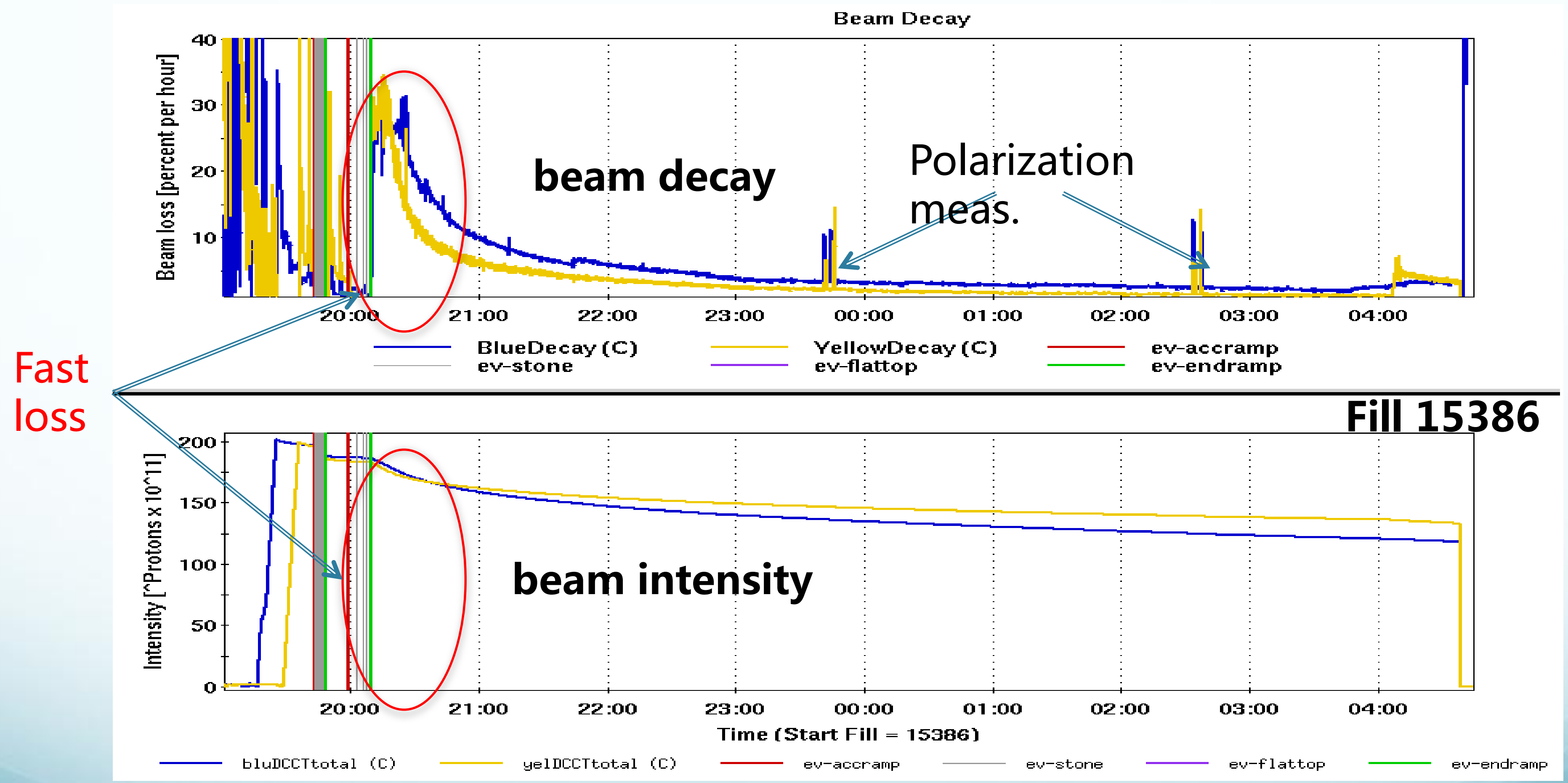


Figure 2: Tune footprint with beam-beam. In this calculation, the bunch intensity is 2.0×10^{11}.

Beam Lifetime at Store



When the beams were brought into collision, we observed a fast beam loss in the first 1-2 hours and a small loss in the rest of store. The mechanism for the fast loss in the beginning is being investigated.

Beam Lifetime with BB

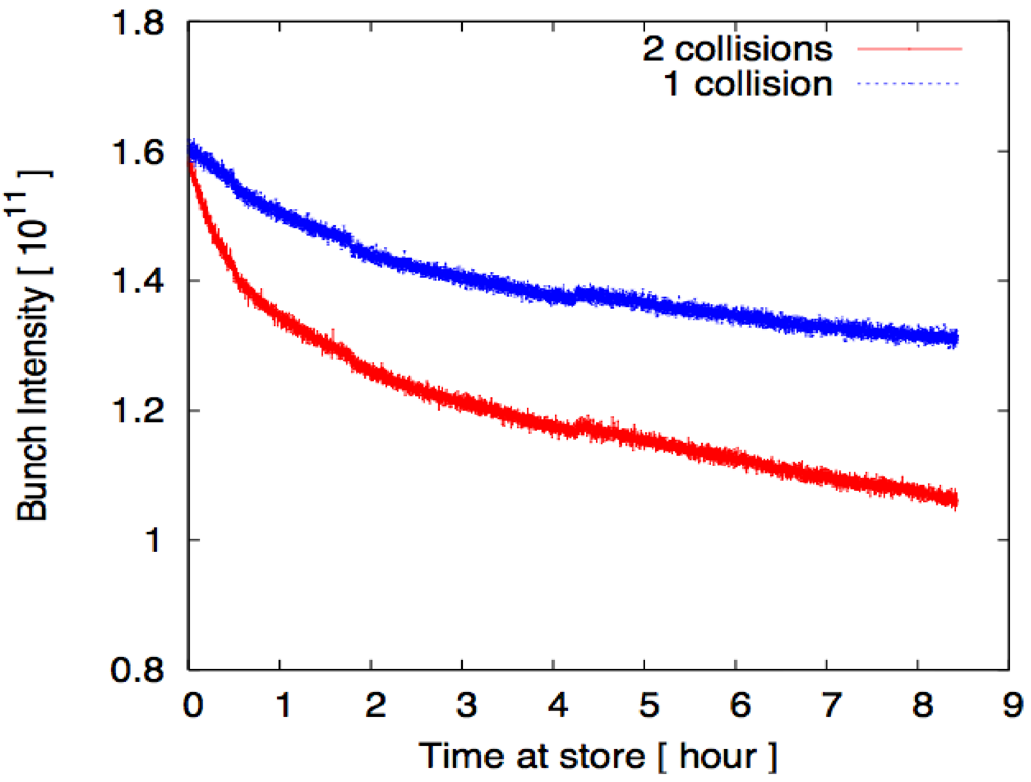


Figure 3: Typical evolutions of bunch intensities with 1 and 2 collisions at store in 2011 250 GeV p-p run. The fill number is 15386.

- Bunch intensity can be empirically fitted with double exponentials.

$$N_p(t) = A_1 \exp(-t/\tau_1) + A_2 \exp(-t/\tau_2)$$

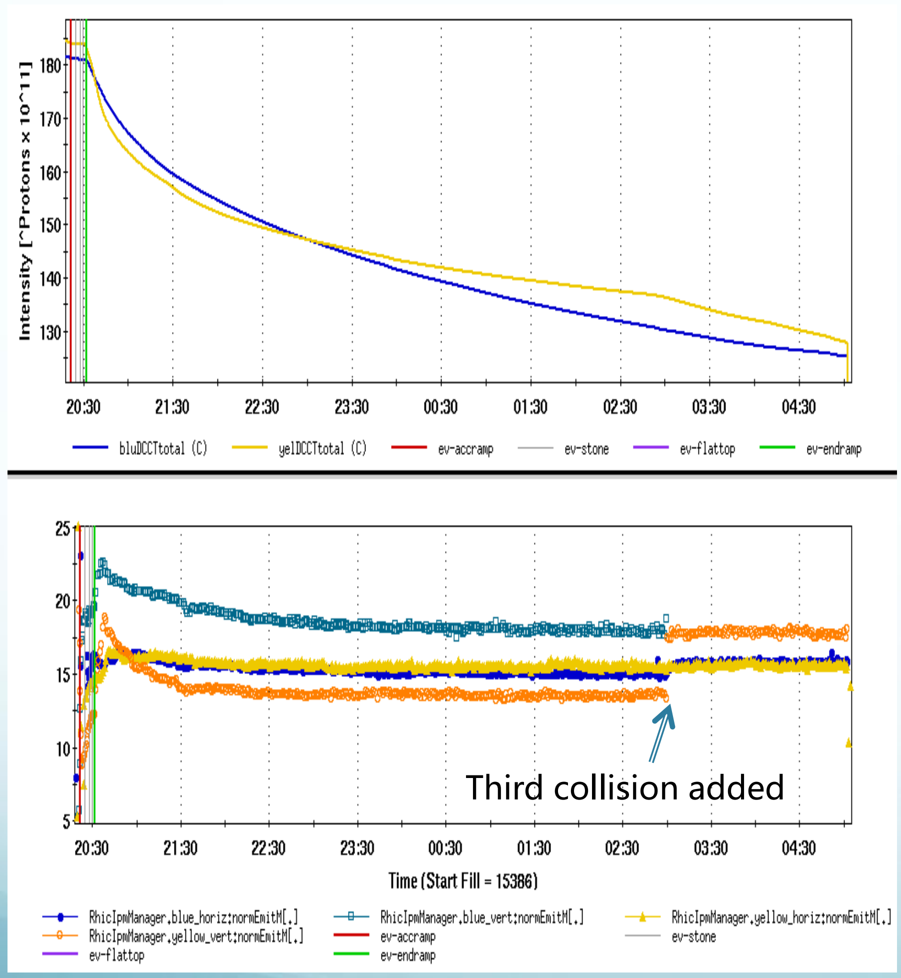
- (τ_1, τ_2)=(0.8, 30) hours for bunches with 2 collisions. (τ_1, τ_2)=(1.5, 100) hours for bunches with 1 collisions.

- We conclude that BB is the dominant factor for beam lifetime with collision.

Transverse Emittance at Store

Intensity

Emittance

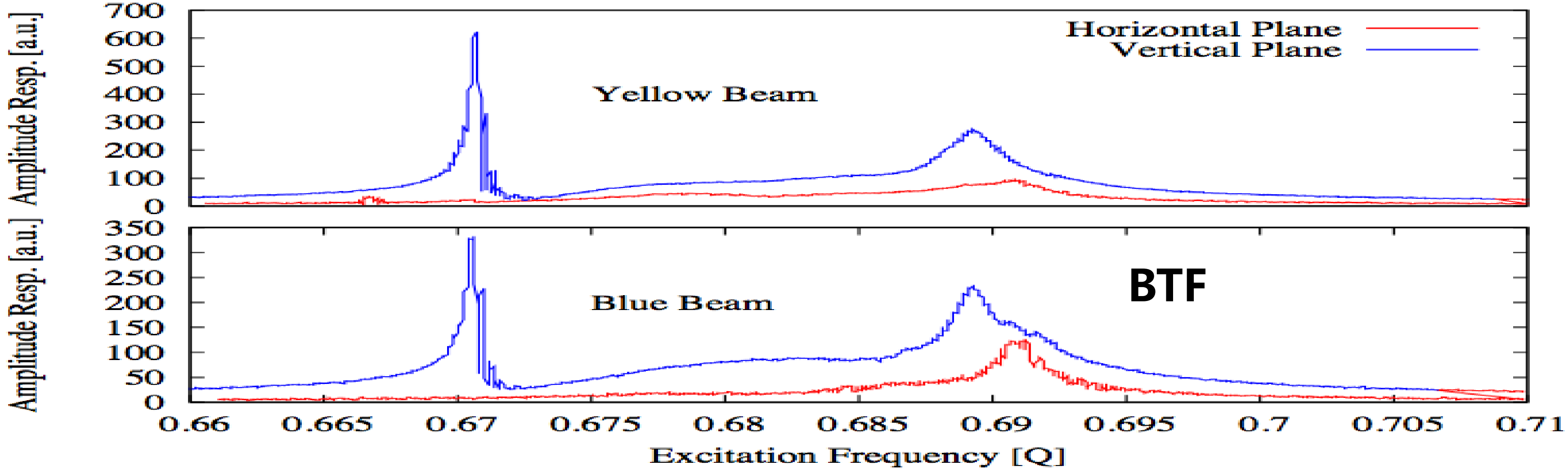


- Emittance can be measured with ionization profile monitor (IPM) or derived from luminosity.
- In the 2011 & 2012 p-p runs, the initial transverse emittance was about 15 π mm.mrad.
- No clear transverse emittance growth observed in the store. Therefore, particles lose in the transverse plane due to limited dynamic aperture.

Bunch Length at Store

- Bunch length is measured with a Wall Current Monitor (WCM).
- To minimize transverse and longitudinal emittance blow-up on the energy ramp, we used a 9 MHz cavity to produce a long bunch to avoid the electron cloud effects. After beams reach the store, we re-bucket with 28 MHz to shorten the bunch length.
- In the 2011 & 2012 p-p runs, we measured ~20% bunch lengthening in the typical 8 hour store. Analytical calculation shows that IBS contributes half of measured bunch lengthening.
- Dipole mode oscillation in the longitudinal plane was observed at store. We had to use 200~KV Landau cavity to overcome it.

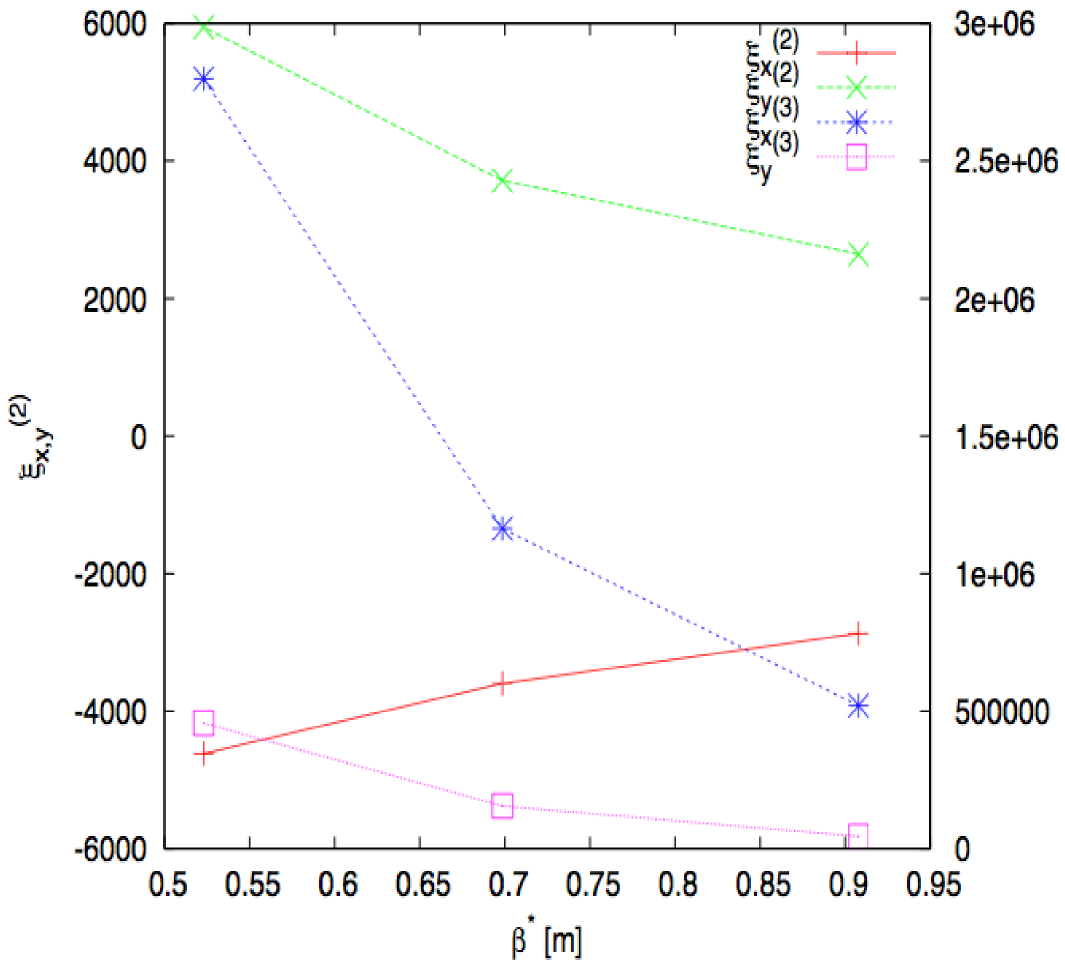
Coherent Beam-beam Modes



- Beam-beam coherent mode was routinely measured with a phase-lock-loop tune meter kickers. We scan the excitation frequency to measure BTF. Pi-mode only can be seen in the vertical plane.

- In a dedicated beam experiment, we moved the tunes of Blue ring towards Qy=2/3. We observed a large beam loss ONLY in the Blue ring when the Pi-mode was at 0.669. We concluded that the loss was due to 3Qy resonance instead of beam-beam coherent mode.

Low beta* Lattices



- 100 GeV run: in 2009 we used beta*=0.7m, we observed a poor beam lifetime. In 2012 we released beta* to 0.85m which gave 16 hour beam lifetime.
- In the 250 GeV run: we achieved beta*=0.65m with a good store lifetime.
- Low beta* lattices reduce dynamic aperture due to IR nonlinear field errors and nonlinear chromatic effects. Considering that RMS bunch length~0.5m. Further beta* will not yield a big gain in luminosity.

3Qx,y Resonances

- We would like to mirror the working points on both side of diagonal in tune space. However, 3Qx prevented working point above diagonal.
- We observed 3Qy caused beam loss in the 2011 100GeV p-p run when the bunch intensity is higher than 1.7e11 at 100 GeV run.
- 3Qx,y resonances are locally corrected with IR bump method.

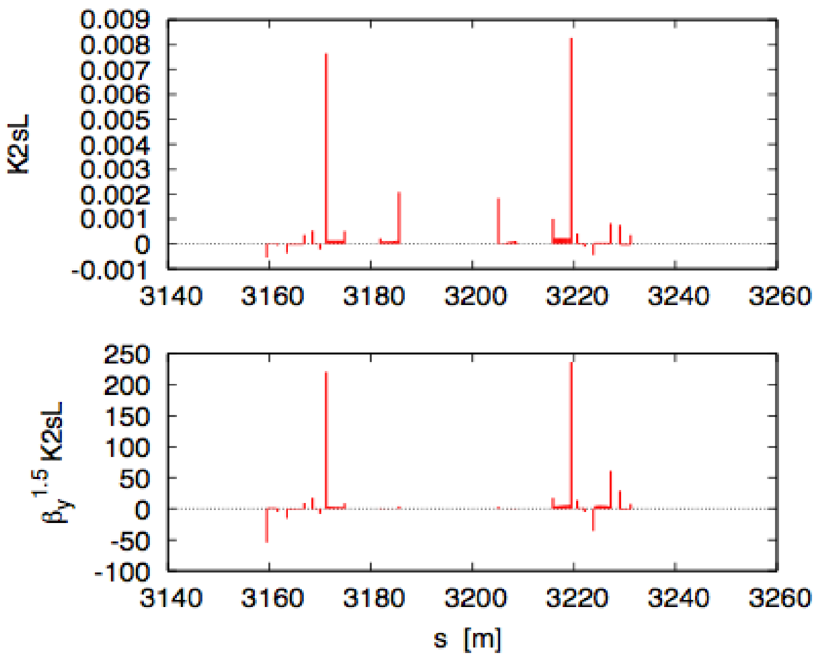


Figure 2: $K_{2s}L$ and $\beta_y^{1.5}K_{2s}L$ in IR8 in Yellow ring.

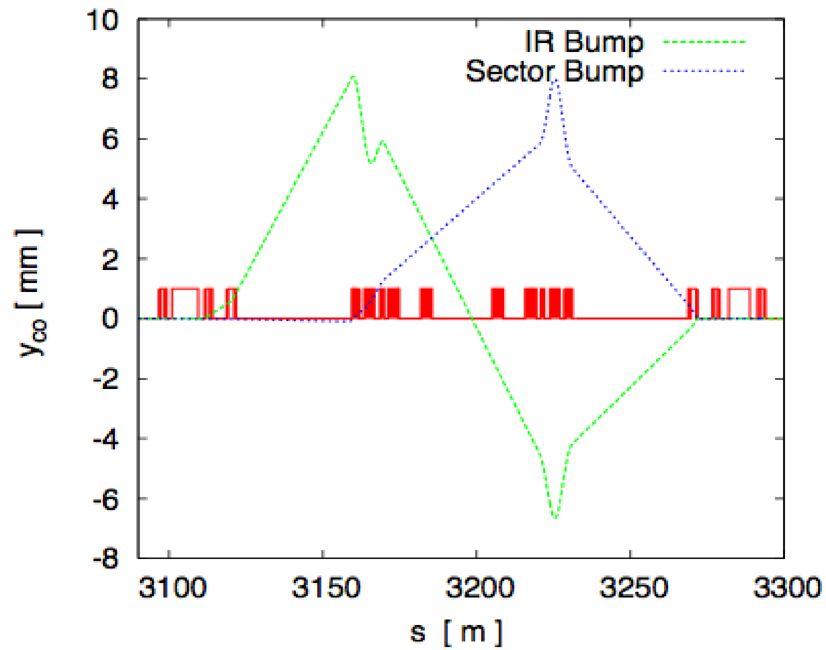


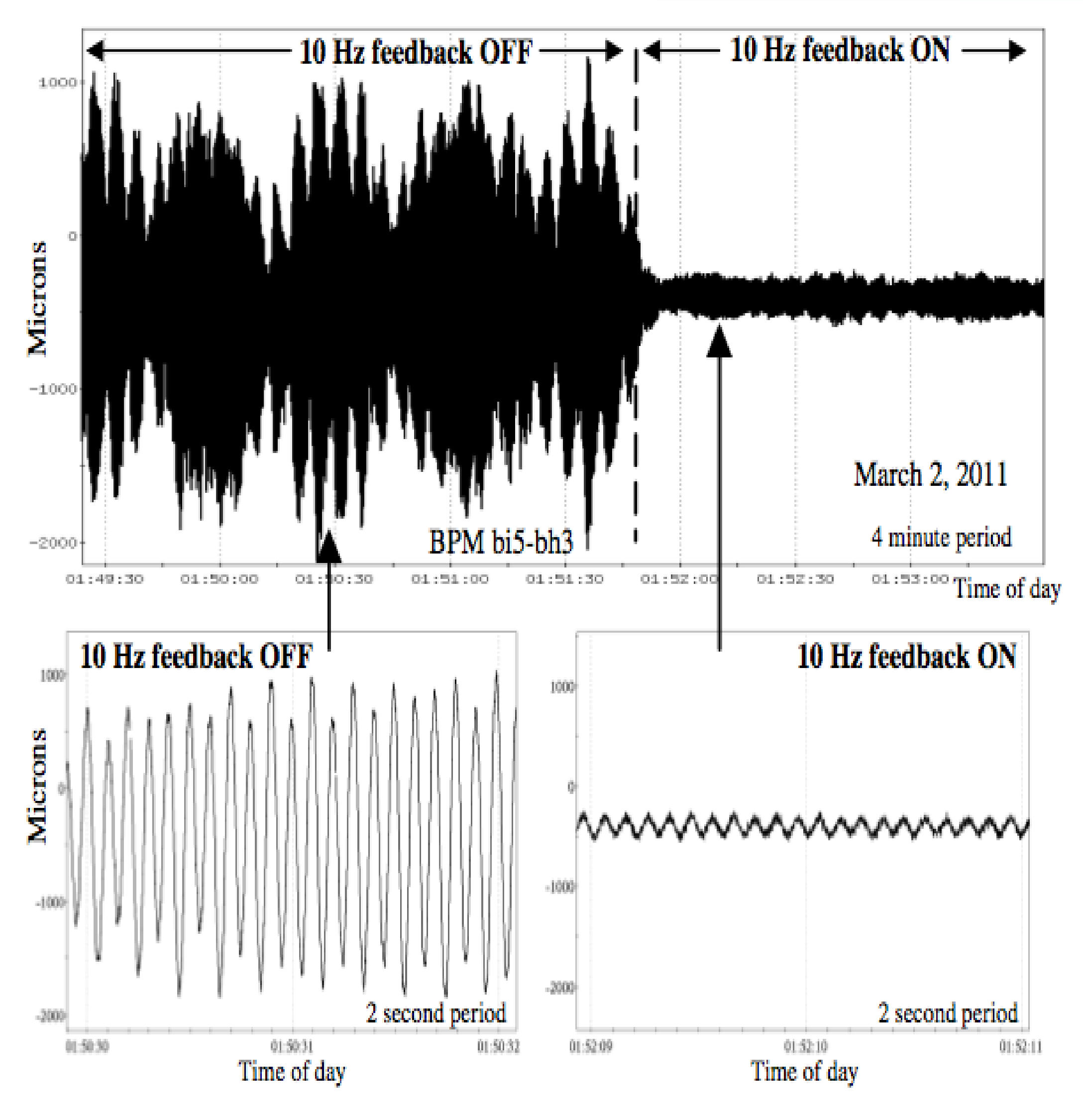
Figure 4: IR bump and sector bump in IR8 in Yellow ring.

10 Hz Orbit Oscillation

- In 2008 we tested a near-integer working point (0.96, 0.95) which was abandoned due to the horizontal 10 Hz orbit oscillation originated from cryogenic follows.

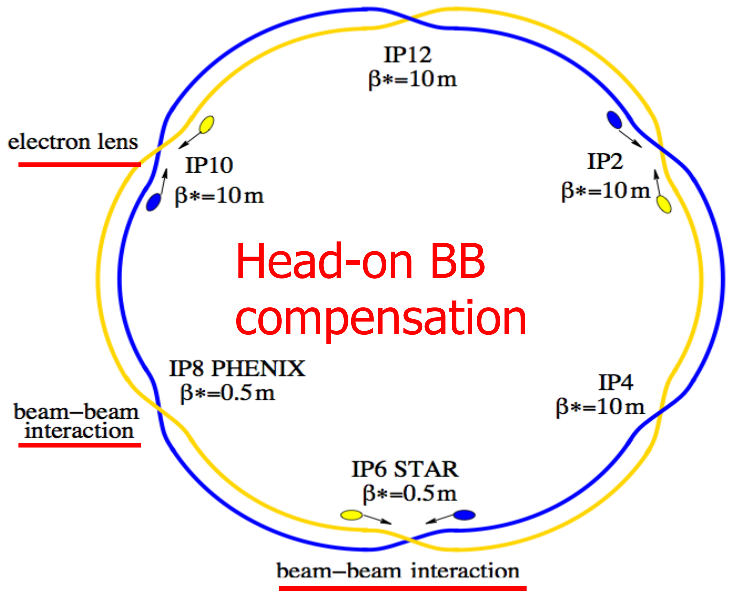
- A 10 Hz feedback was developed and the peak-to-peak amplitude of 10 Hz orbit oscillation was reduced from 3000 microns down to 250 microns in triplets.

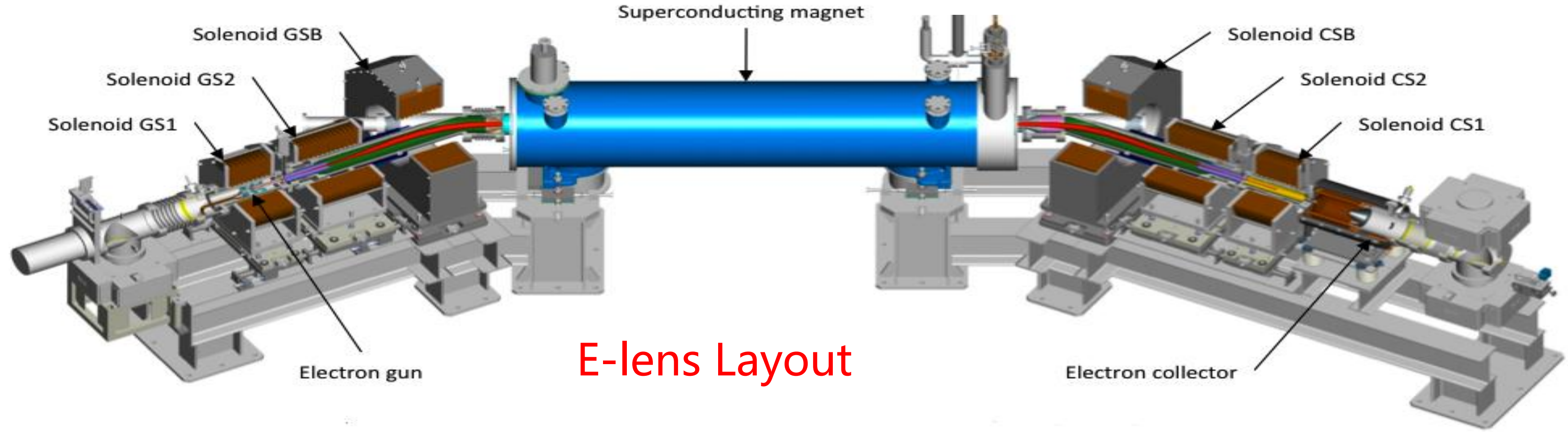
- We plan to revisit the tunes in the future beam experiments.



Electron Lens Project

10 times current from the upgraded gun





E-lens Layout

Head-on Beam-beam Compensation

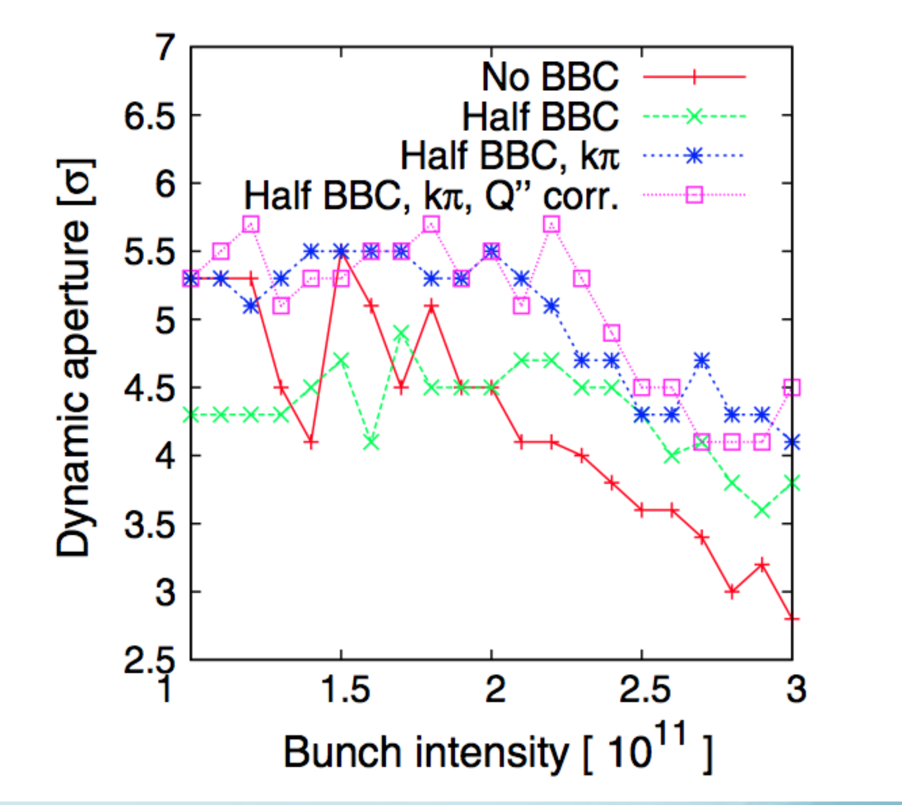
❑ **Basic idea:**

- 2 beam-beam collisions with **positively** charged beam
- Add collision with a **negatively** charged beam – with matched intensity and same amplitude dependence

❑ **Compensation of nonlinear effects:**

- e-beam current and shape
  => reduces tune spread
- $\Delta\psi_{x,y} = k\pi$ between p-p and p-e collision
  => reduces resonance driving terms

Started installation in 2012
Expect up to 2x more luminosity



Summary

- We reviewed the beam-beam effects in the RHIC polarized proton runs. The limitations from tune space, low beta* lattices, 3Qx,y resonances, 10Hz orbit oscillation, coherent beam-beam mode are presented and discussed.

- The next luminosity goal is to double current luminosity by increasing the proton bunch intensity from 1.7e11 up to 3.0e11 with an upgraded polarized proton source.

- To accommodate the large beam-beam tune spread and to compensate the nonlinear beam-beam resonance driving terms, we plan to install two electron lenses in RHIC rings for head-on beam-beam compensation.