Computational Challenges for Beam-beam Simulation for RHIC

Y. Luo, W. Fischer

(Brookhaven National Laboratory, Upton, NY 11973, USA)

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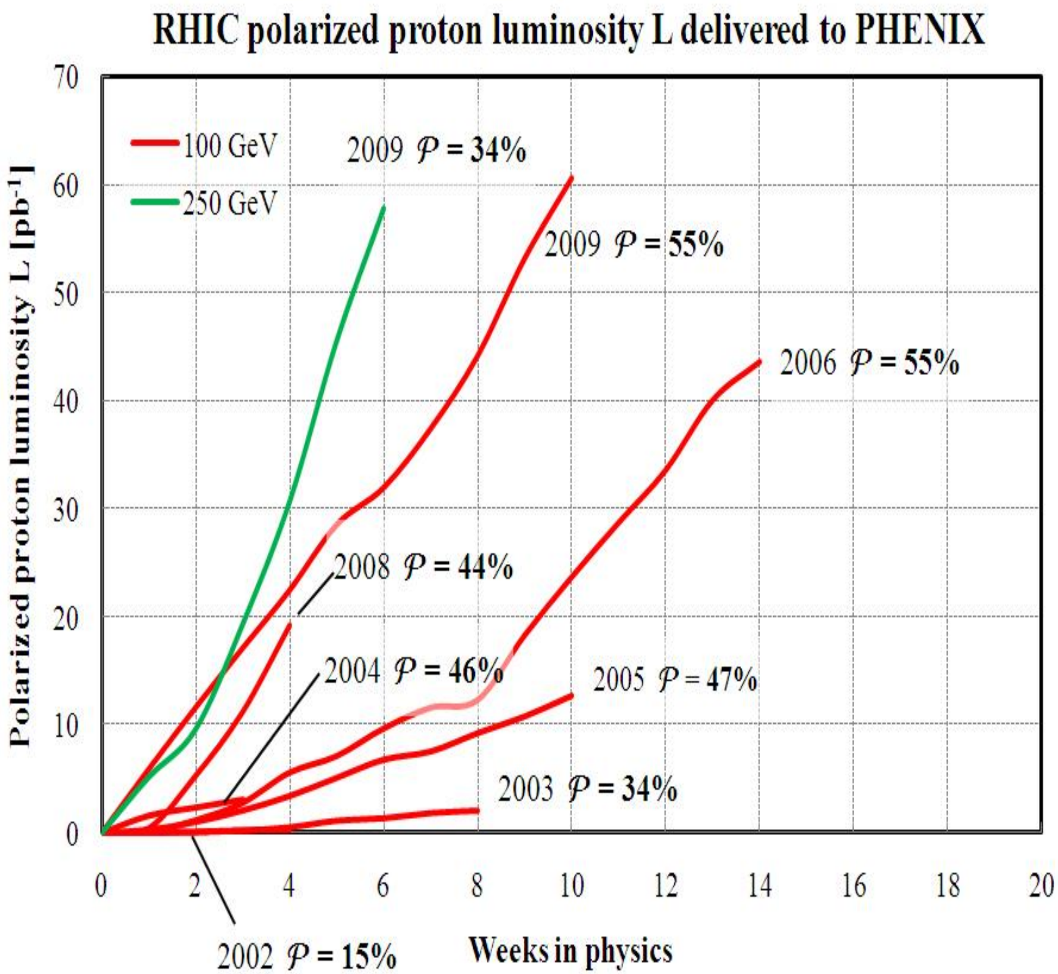
RHIC Luminosity Upgrade



- Luminosity in the 100 GeV polarized proton run has increased an order since its first run in 2003.

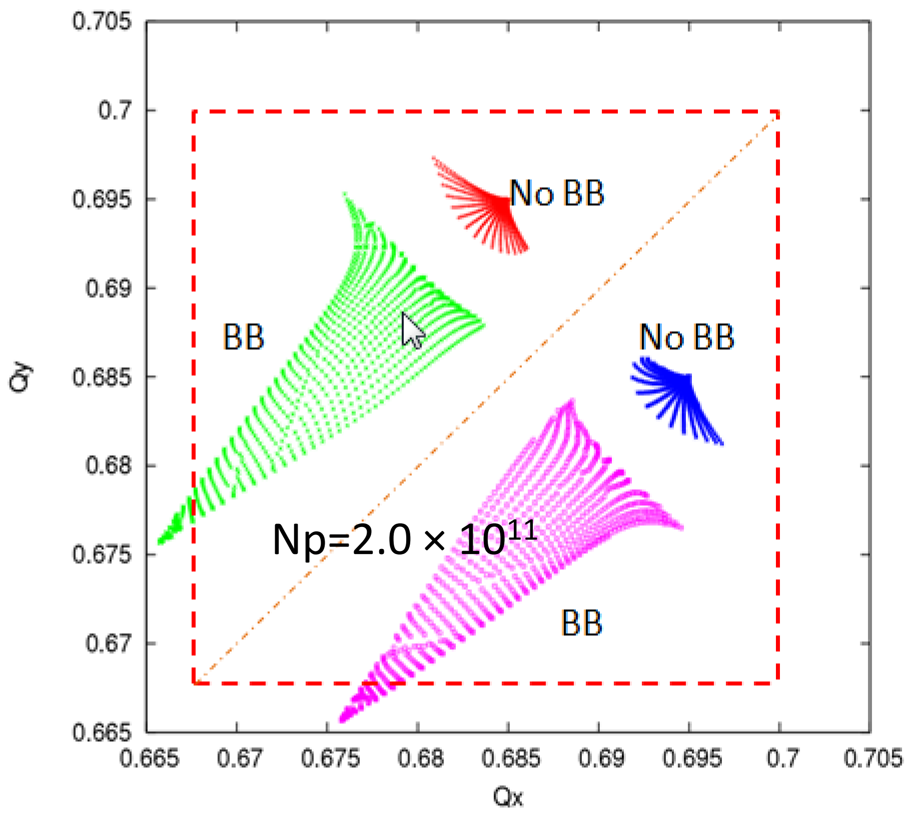
- Luminosity upgrade at 250 GeV run:

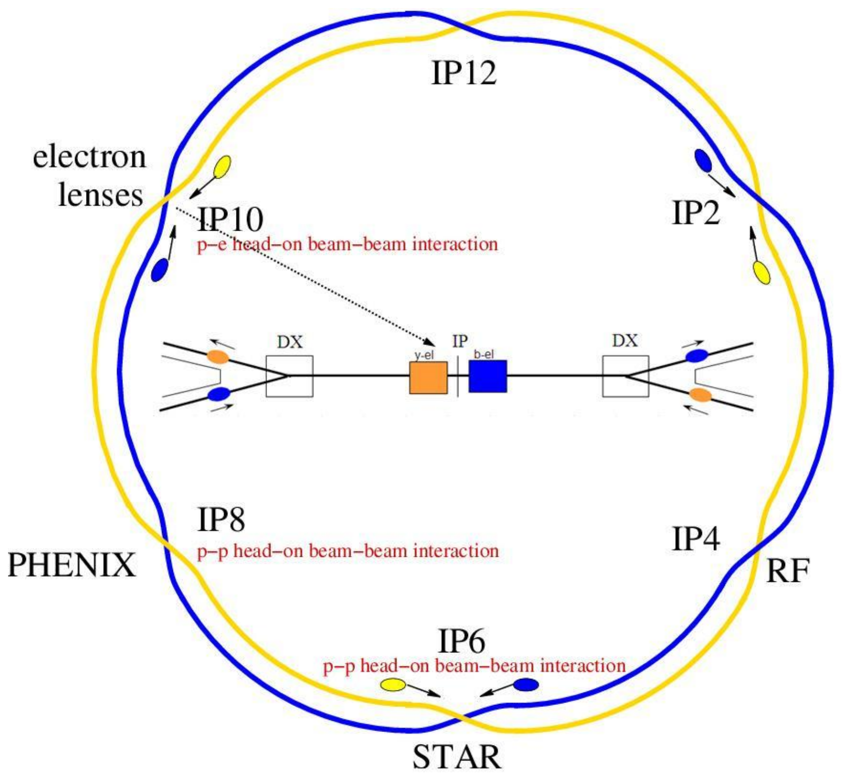
  - β* squeezing from 0.7m to 0.5m.

  - increase bunch intensity from 1.5×10^{11} to 2.0×10^{11} and beyond.

  (proton source upgrade is under way to double the current)

Head-on Beam-beam Compensation





To compensate the large beam-beam tune spread, a low energy electron beam is introduced into the ring to collider head-on with the proton beam. Such a device is called electron lens.

Beam-beam Simulation for RHIC

- Beam-beam study tools
  - single particle tracking:
    tune/amplitude diffusion, dynamic aperture (DA), etc.
  - multi-particle tracking:
    beam decay / lifetime, emttance growth
- Dynamic aperture versus lifetime
  - DA doesn’t give information about emittance
  - DA is not direct connected beam lifetime
  - online measurement of DA is tedious
  - beam decay, emittances, luminosity are measured online

Computational Challenges (I)

- Reduce statistic error
  - Good Gaussian generator
  - Enough number of macro-particles
  - How to define particle loss
  - How to calculate emittance
- Limit from CPU time
  - Our computing capacity

    track 10^4 macro particles up 10^7 turns

    mostly we only track 5000 particles to 2×10^6 turns

    which costs 400 nodes ×4 hours = 1,600 hours* 1 node

Computational Challenges (II)

- High resolution in simulation is needed

  - RHIC beam decay measurement(DCCT)

    typical store beam decay: a few %/hour

    resolution: 1%/ hour => 0.007% loss in 2×10^6 turns !

  - RHIC emittance measurement (IPM, polarimeter, WCM)

    bunch length measurement with higher resolution

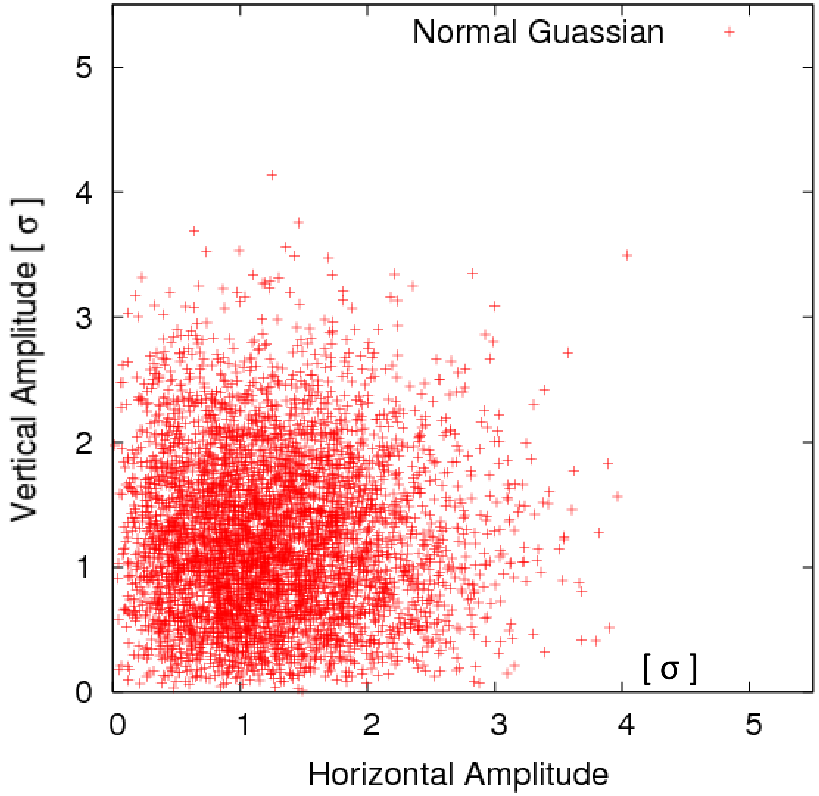
    typical store emittance growth:

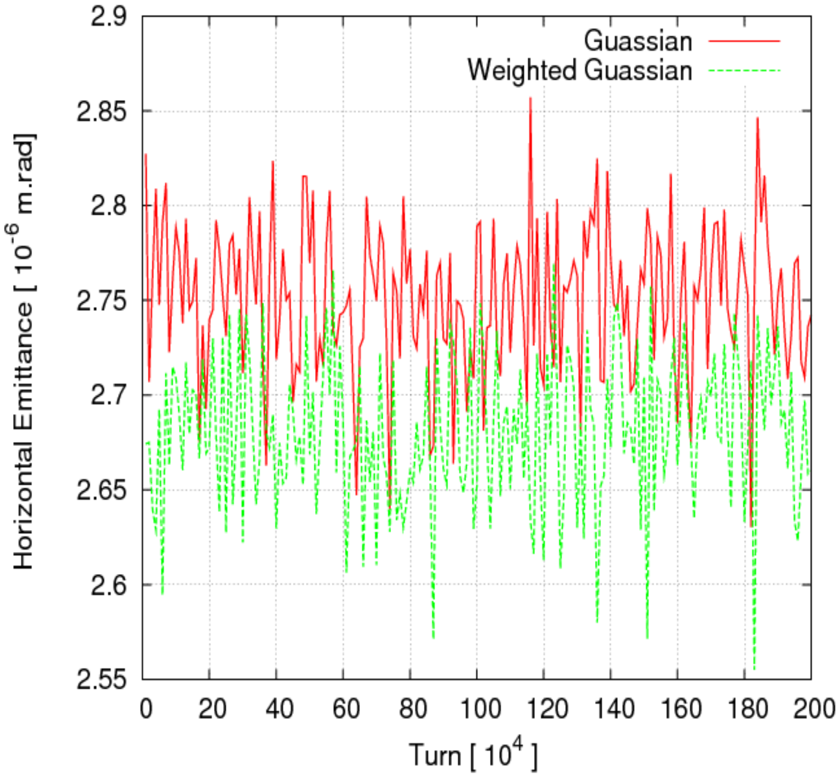
    30 % increase over 10 hours

    => emittance growth percentage is 0.02% in 2×10^6 turns !

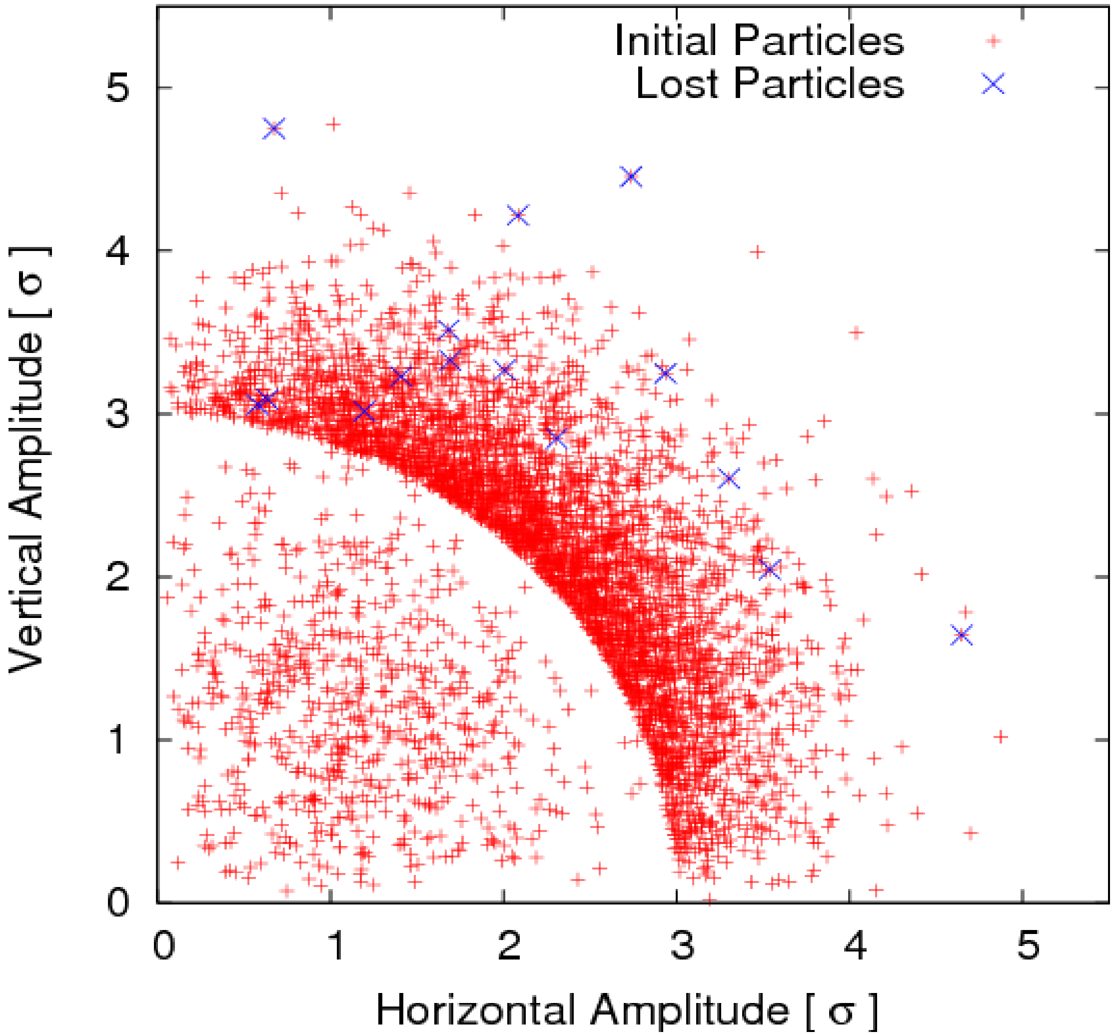
One Example (track a Gaussian distribution)

- Tracking condition: Np=2.5 × 10^{11}, BB at IP6 and IP8. Track 4800 macro-particles up to 2 × 10^6 turns. CPU time: 400 nodes ×4 hours.
- Tracking result: Just 1 macro-particle lost. The fluctuation of calculated emittance is about 2% of the average value.





Hollow Gaussian Distribution

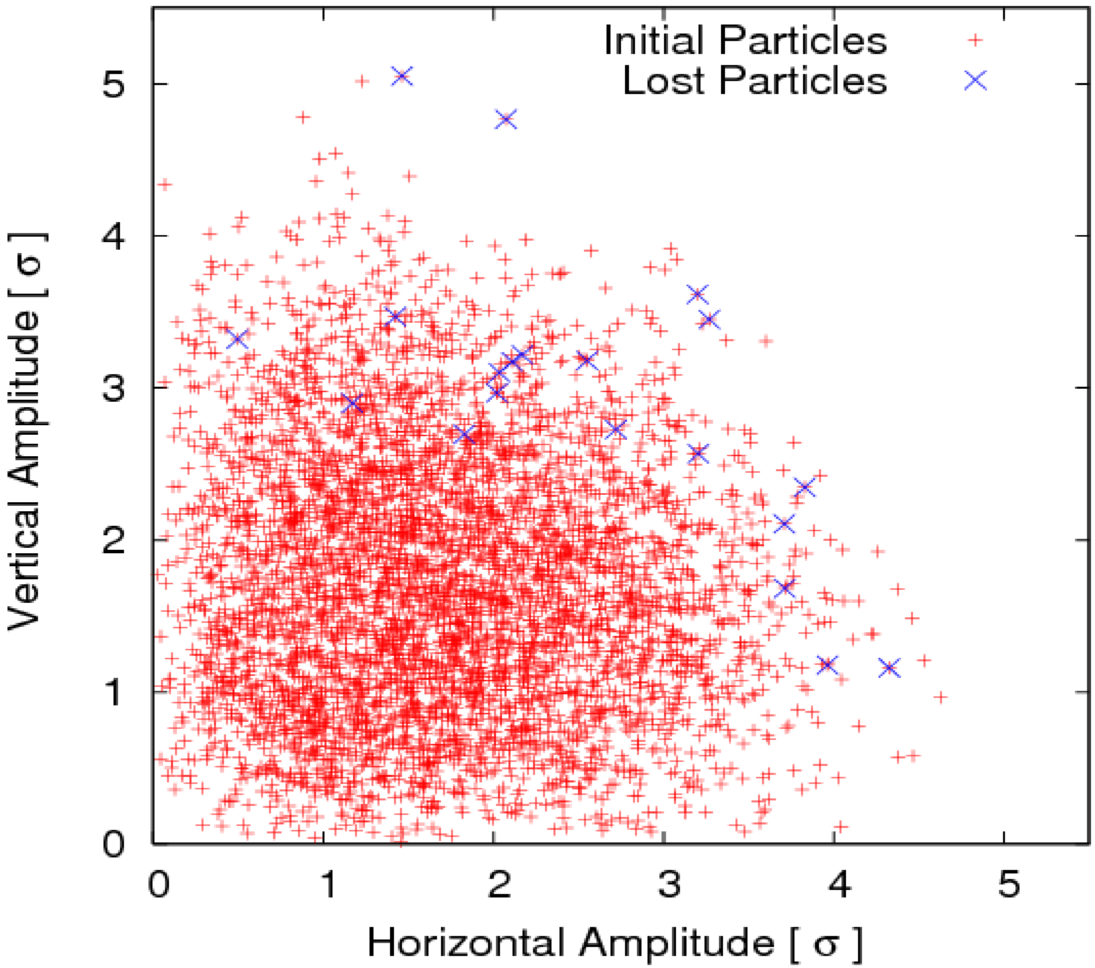


•Only track particles initially with a hollow Gaussian distribution. The boundary should be chosen carefully.

•Left plot shows the tracking results for the above example. We only tracked macro-particles whose $N_t > 3$ and $N_l > 3$.

•Same with 4800 macro-particles, there are 16 macro-particle lost.

Weighted Gaussian Distribution



- Another solution is to track particles initially with a weighted Gaussian distribution like LIFETRAC.

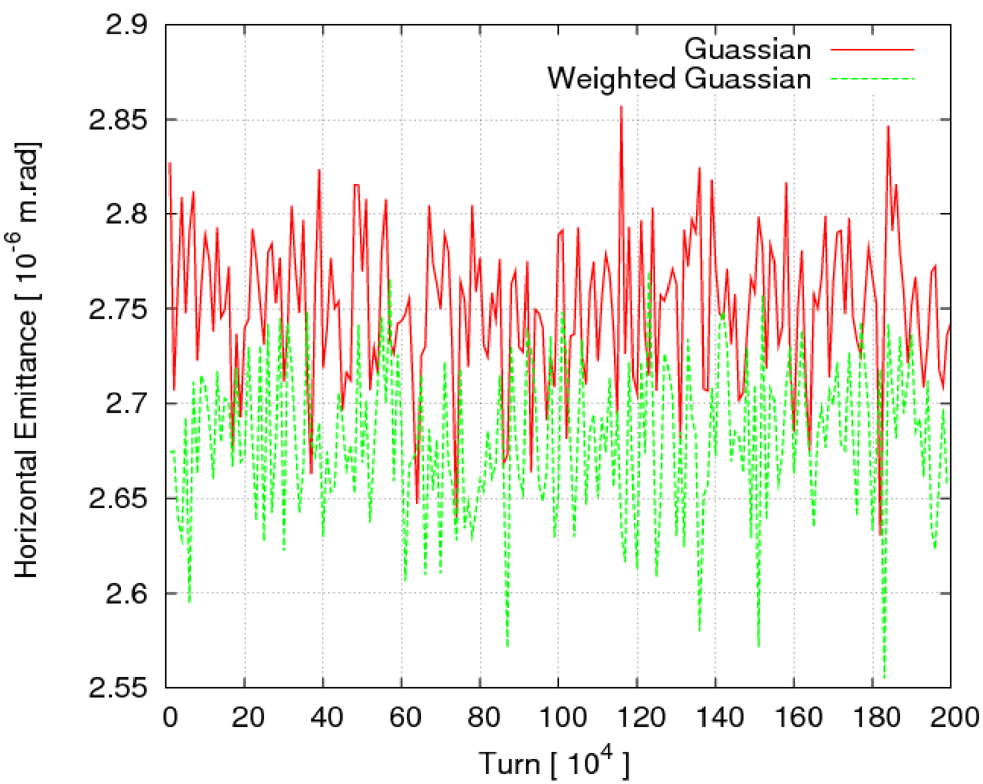
- Left plot shows the tracking results for the above example.

- Same with 4800 macro-particles, there are 20 macro-particle lost.

Compare the above approaches

Table 1: Particle Losses with Different Initial Distributions

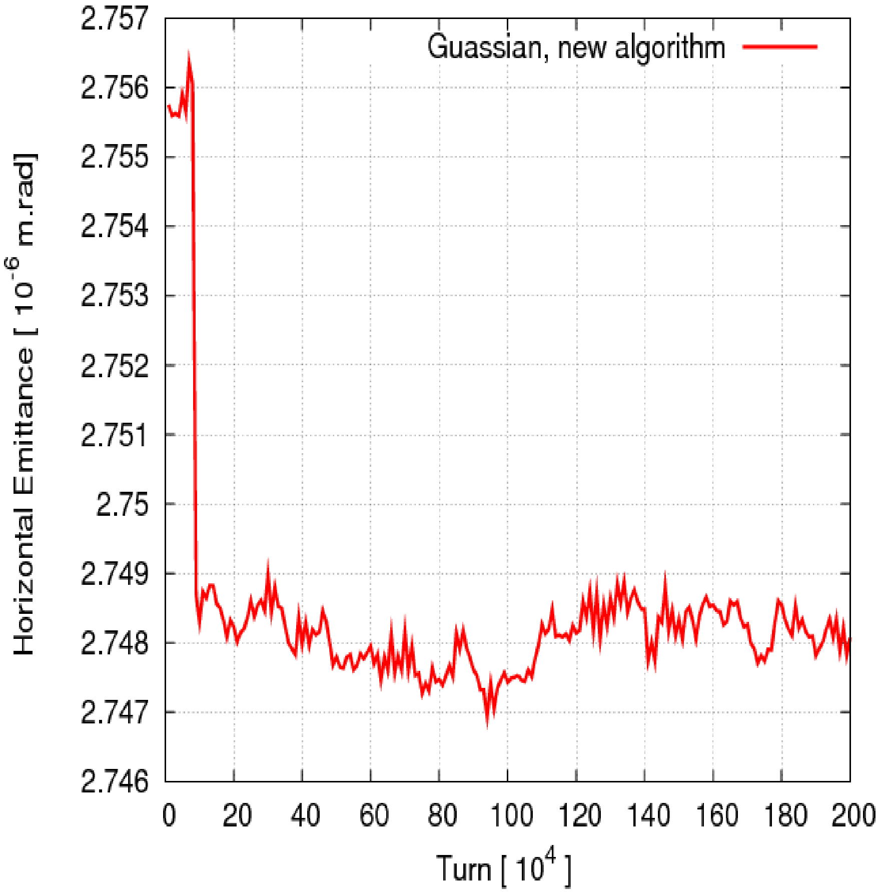
Case	$N_{represent}$	N_{lost}	beam decay
Plain Gaussian	4800	1	2.9%/hr
Hollow Gaussian	66269	16	3.4%/hr
Weighted Gaussian	70108	20	4.0%/hr

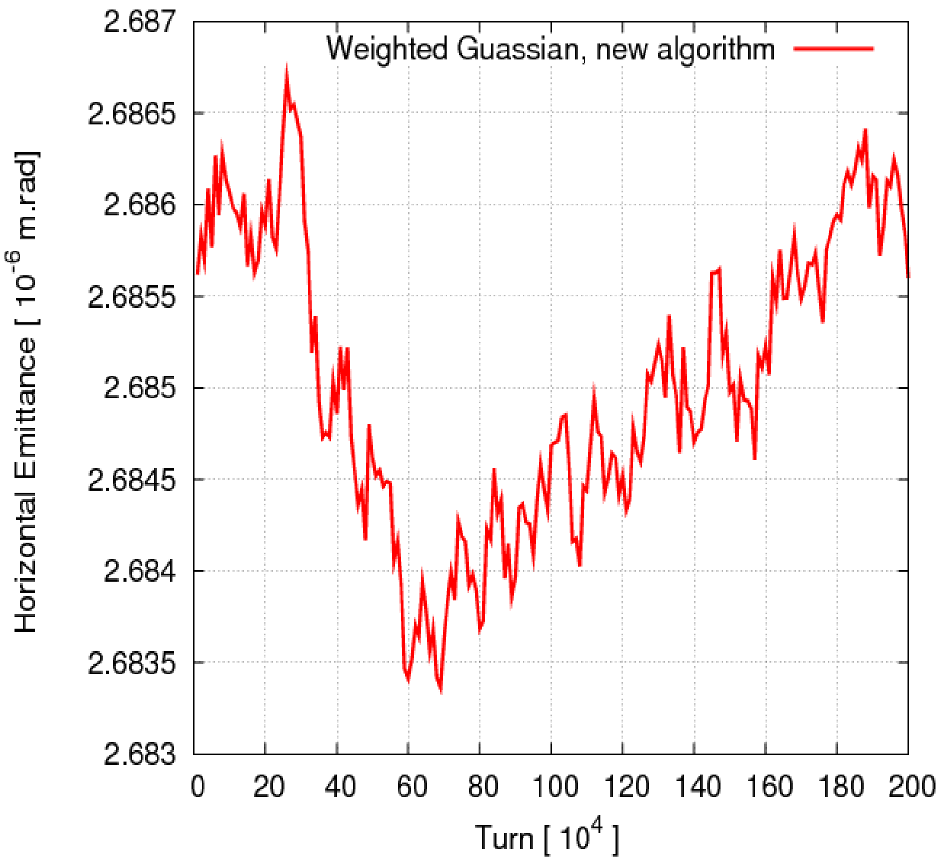


- All three approaches tracked 4800 macro-particles. Therefore, they used similar CPU time.
- Tracking with hollow and weighted Gaussian distribution have smaller statistic errors than that with plain Gaussian distribution.
- The weighted Gaussion tracking method doesn't reduce the fluctuation in calculated emittance .

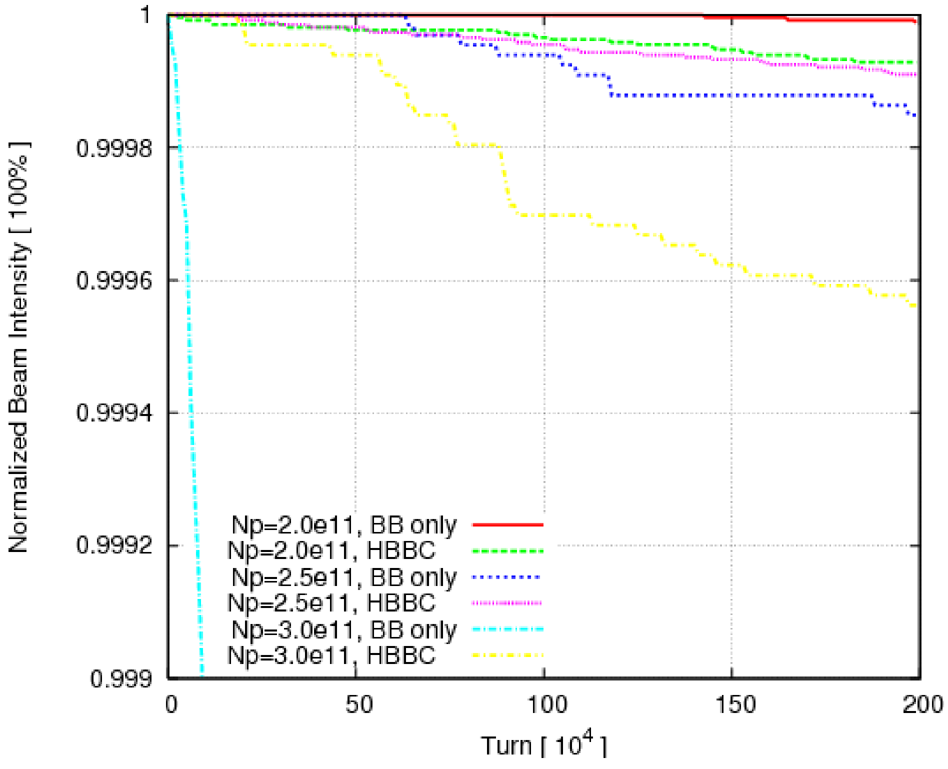
Enhanced Emittance Calculation

•To reduce the fluctuation in calculated emittance, LIFETRAC calculates emittance with all coordinates of all live macro-particles in each 10,000 turns. This approach reduces the fluctuation in calculated emittance to 0.03% of the averaged value.

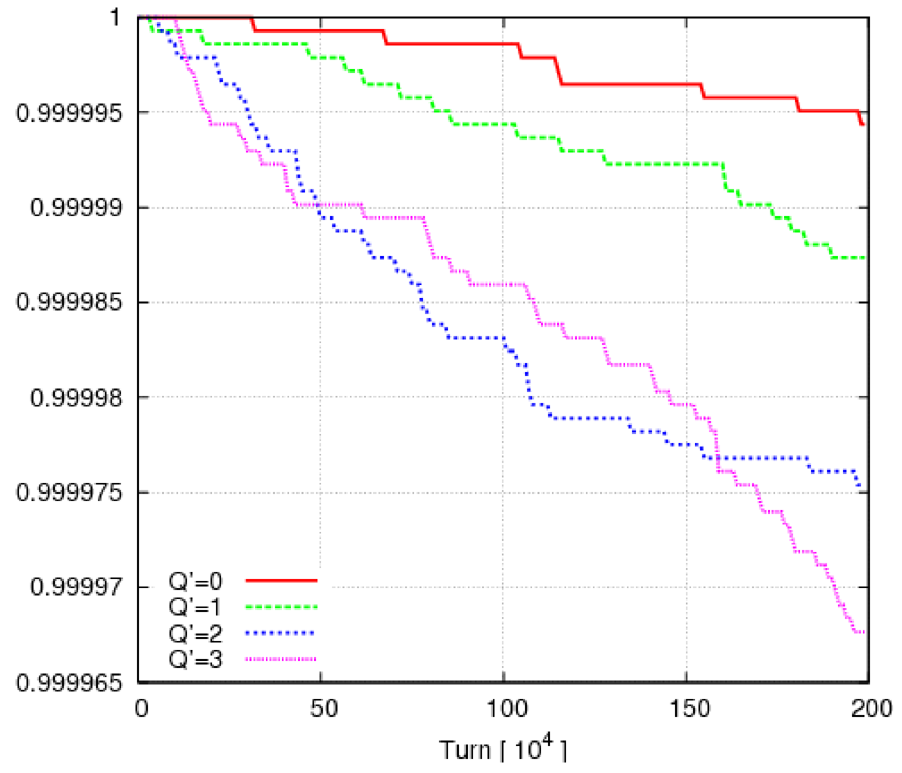




Head-on Beam-beam Compensation



Particle loss rate without and with half head-on beam-beam compensation.



Particle loss with different first order chromaticity. Half BBC is included.

Benchmark RHIC Beam Lifetime

- Our ultimate goal is to reproduce the current RHIC observations and to predict the luminosity gain with head-on beam-beam compensation.

- Benchmarked our simulation code (SimTrack by Y. Luo) with other codes like SIXTRACK, LIFETRAC, BBSIM.

- Benchmarking the lifetime, emittance growth and luminosity for the current RHIC operation. Smaller lifetime from simulation was seen. Tracking lattice model is being improved.

- Effects of other diffusions and noises is under evaluation.
  - Intra-beam scattering
  - Beam-gas scattering
  - Luminosity burning-off
  - Parameter modulation, etc.

Summary

- The computational challenge for RHIC beam-beam simulation is to get meaningful physics results with limited computing resources and computing time.
- Some approaches to calculate the proton particle loss rate and emittance growth were tested and used for head-on beam-beam compensation studies.
- Benchmarking the real RHIC beam lifetime is in progress. More realistic tracking lattice model was built. The effect of diffusion and errors in the machine is under investigation.