Computational Challenges for Beam-beam Simulation for RHIC

Y. Luo, W. Fischer

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

HB2010, Sept 27- Oct 1, 2010, Morschach, Switzerland
Content

• RHIC Beam-beam studies
• Computational challenges
• Example and approaches
• Benchmarking RHIC beam lifetime
• Summary
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:
  - $\beta^*$ squeezing from 0.7m to 0.5m.
  - Increase bunch intensity from $1.5 \times 10^{11}$ to $2.0 \times 10^{11}$ and beyond.

(Proton source upgrade is under way to double the current)
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, emittance 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 $2 \times 10^6$ turns
    which costs 400 nodes $\times$ 4 hours $= 1,600$ hours $\times$ 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 ×10⁶ 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 ×10⁶ turns!
One Example (track a Gaussian distribution)

• Tracking condition: \( N_p = 2.5 \times 10^{11} \), BB at IP6 and IP8. Track 4800 macro-particles up to \( 2 \times 10^6 \) turns. CPU time: 400 nodes \( \times 4 \) 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.
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

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 Gaussian tracking method doesn’t reduce the fluctuation in calculated emittance.

Table 1: Particle Losses with Different Initial Distributions

<table>
<thead>
<tr>
<th>Case</th>
<th>$N_{represent}$</th>
<th>$N_{lost}$</th>
<th>beam decay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain Gaussian</td>
<td>4800</td>
<td>1</td>
<td>2.9%/hr</td>
</tr>
<tr>
<td>Hollow Gaussian</td>
<td>66269</td>
<td>16</td>
<td>3.4%/hr</td>
</tr>
<tr>
<td>Weighted Gaussian</td>
<td>70108</td>
<td>20</td>
<td>4.0%/hr</td>
</tr>
</tbody>
</table>
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.