Study on IBS growth in presence of crab dispersion for flat beam

Motivation

- The EIC adopts flat beam to achieve highest luminosity. The vertical emittance is 10 times smaller than the horizontal one. The vertical emittance growth is what we care.
- Crab cavities are essential to recover geometry luminosity loss. However, crab cavities introduce synchro-betatron coupling, which is characterized in terms of crab dispersion.
- In the EIC-HSR design, there are 5 degrees off to the ideal value. The kick from the upstream crab cavity can't be cancelled by the downstream one. The crab dispersion leaks out of the IR.
- The leaked crab dispersion has little impact on the dynamic aperture. The beam-beam performance can be restored by adjusting crab cavity voltages. However, its impact on the vertical IBS time remains unknown.
- The existing IBS models are all 2.5D, taking the momentum dispersion into consideration.

The experiment is necessary to properly estimate the vertical IBS time.

Study on IBS growth in presence of crab dispersion for flat beam

Procedures

(1) Set the golden beam to flattop energy and activate the cooling system to generate a flat beam

(2) Adjust the dispersion bump around the RF cavity to observe crab dispersion effects

(3) Turn off cooling and measure emittance growth time for varying dispersion conditions

(4) Change beam flatness and repeat steps (2-3)

(5) Establish a 3D IBS model and benchmark with experiment results

The estimated time to assess the IBS time across four varying emittance ratios (1:1, 1:2, 1:3, 1:5) and three different dispersion values at RF (0 and ± 2 m with assuming $D' = 0$), is 12 hours.

Study on IBS growth in presence of crab dispersion for flat beam

Key components

- cooling to generate flat beam at store energy
- a **local** dispersion bump around RF cavity to generate and control crab dispersion in RHIC ring
- emittance measurement tools for capturing IBS growth time

Study on IBS growth in presence of crab dispersion for flat beam

Anticipated outcome

- Understand the dependence of the IBS time on beam flatness and crab dispersion
- Supply experimental data to assist in the development of a 3D IBS model
- In the end, the theoretical model should provide important input to the HSR lattice design and the Strong Hadron Cooling

Study on IBS growth in presence of crab dispersion for flat beam

Summary

Beam Experiment Title:	Study on IBS growth in presence of crab dispersion for flat beam
Spokesperson(s):	Derong Xu
Status:	Proposed
Team:	Derong Xu;Yun Luo;Guillaume Robert-Demolaize;Kevin Mernick;Travis C Shrey
Experiment Goal:	Measuring IBS growth rate for golden flat beam in presence of crab dispersion
Benefits:	We will gain a deeper comprehension understanding of the interplay between synchro-betatron coupling and IBS. It will offer crucial input for the HSR lattice design and provides guidance on determining the necessary vertical cooling rate.
Experiment Description:	The leakage of crab dispersion from the IR is adopted in the HSR lattice design. This leakage will lead to synchro-betatron coupling along the whole ring. However, existing IBS models exclusively consider 2.5D dynamics, incorporating betatron coupling and momentum dispersion. To accurately forecast the vertical IBS growth rate in the HSR, a comprehensive 3D IBS model becomes essential. This experiment holds significance for the EIC design as it contributes to a deeper comprehension of the interplay between synchro-betatron coupling and IBS. Furthermore, it offers crucial input for the HSR lattice design and provides guidance on determining the necessary vertical cooling rate. The general procedures includes: (1) Set the beam to flattop energy and activate the cooling system to generate a flat beam (2) Adjust the dispersion bump around the RF cavity to observe crab dispersion effects (3) Turn off cooling and measure emittance growth time for varying dispersion conditions (4) Change beam flatness and repeat steps (2-3)
Hazard Analysis:	None
Approved By:	
Date Approved:	
Resources:	
Instrumentation:	(1) cooling to generate flat beam at store energy (2) a dispersion bump around RF cavity to generate and control crab dispersion in RHIC ring (3) emittance measurement tools for capturing IBS growth time
Application:	Common operation application
Time:	12 hours (estimate)
Personnel:	Necessary operational support
Intentional Beam Loss?	No
Plan for Data Analysis:	Data analysis online and offline
Results:	To be reported in APEX bi-weekly meeting and probably in EIC Tech Note

Investigate beam-beam impact on hadron beam flatness

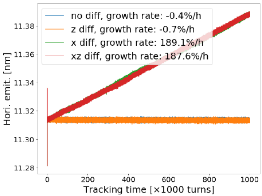
Motivation

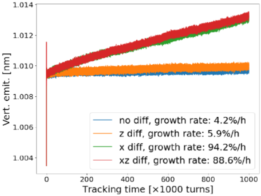
- The EIC adopts flat beam to achieve highest luminosity. The vertical emittance is 10 times smaller than the horizontal one. The vertical emittance growth is what we care.
- The resonance line $\nu_x - \nu_y + p\nu_z = 0$ goes across the hadron beam footprint. It doesn't drive observable vertical emittance growth in the beam-beam simulation.
- There are many random fluctuations in the real machine. When the random diffusion is included, a significant emittance transfer between horizontal and vertical plane is observed in beam-beam simulation.

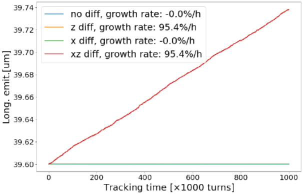
We must investigate whether the flat beam can survive random diffusion in presence of beam-beam interactions. If it cannot, we must explore mitigation strategies, except if Strong Hadron Cooling is capable of managing the issue.

IBS diffusion with beam-beam interaction

Set $\tau_x = 1$ h or ∞, $\tau_y = \infty$, and $\tau_z = 2$ h or ∞, where $\tau_{x,y,z}$ are IBS time in terms of beam size growth



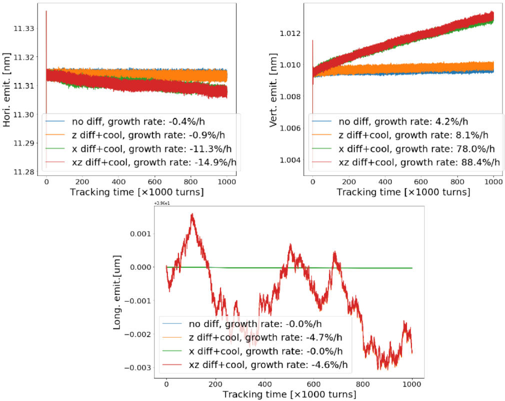




Significant vertical growth is observed when $\tau_x < \infty$. The required vertical cooling time may be as large as 1 h

IBS diffusion with beam-beam interaction and cooling

Set $\tau_x = 1$ h or ∞, $\tau_y = \infty$, and $\tau_z = 2$ h or ∞, where $\tau_{x,y,z}$ are IBS time (or cooling time) in terms of beam size growth



Unfortunately, the large cooling rate in hori. and long. planes can't cool the vert. plane

Investigate beam-beam impact on hadron beam flatness

We study around $\nu_x - \nu_y - 2\nu_z = 0$ for gold-gold collisions

- Based on prior runs, we select the working point as $(0.235, 0.225)$ and adjust the longitudinal tune to approximately 0.004.
- In the case of a round beam, the beam-beam parameters is chosen as $\xi_{x0} = \xi_{y0} = 0.005$.
- To avoid potential aperture issues, the $\beta^*_{x,y}$ are not squeezed for the flat beam.
- Assuming only the vertical emittance undergoes cooling, the horizontal emittance remains constant. The beam-beam parameters are scaled according to the beam flatness $\kappa \equiv \sigma_y/\sigma_x$ as follows:

  $$\xi_{x0} = \frac{0.01}{1+\kappa}, \qquad \xi_{y0} = \frac{0.01}{\kappa(1+\kappa)}$$

  To avoid large vertical beam-beam parameters, we only compare $\kappa = 1$ and $\kappa = 0.5$ in the experiments
- The crossing angle is also adjusted to enhance the resonance strength
- The random fluctuations are not artificially controlled

Investigate beam-beam impact on hadron beam flatness

Procedures:

(1) Set the cross angle $(0, 1.5$ mrad) and choose flatness $(1.0, 0.5)$

(2) Set the beam to flattop energy and activate the cooling system to generate desired flatness in both RHIC rings

(3) Bring two beams into collision with a small crossing angle, turn off cooling, and observe beam loss rate and/or emittance growth rate

(4) Perform the following scan: (a) scan ν_x while keeping ν_y unchanged (b) scan ν_y while keeping ν_x unchanged (c) scan ν_x and ν_y while keeping $\nu_x - \nu_y$ unchanged

(5) Choose a different crossing angle and beam flatness, and repeat steps (2-4)

The estimated time to is 24 hours.

Investigate beam-beam impact on hadron beam flatness

Key components

- cooling to generate flat beam at store energy
- hardware to adjust crossing angle (D0 and DX magnets?)
- hardware to set, adjust and measure the working point (BBQ?)
- emittance, beam loss and luminosity measurement tools

Investigate beam-beam impact on hadron beam flatness

Anticipated outcome

- Knowledge of the interplay between synchro-betatron resonance and random diffusion
- Confirm or refute our simulation findings our simulation results which will provide important input for the flat beam scheme in future EIC
- Hints for potential mitigation strategies

Summary

Beam Experiment Title:	Investigate beam-beam impact on hadron beam flatness
Spokesperson(s):	Derong Xu
Status:	Proposed
Team:	Derong Xu;Yun Luo;Guillaume Robert-Demolaize;Kevin Mernick;Travis C Shrey
Experiment Goal:	Demonstrate if flat beam can survive with synchro-betatron resonance in the beam-beam footprint
Benefits:	(1) Gain deep understanding about synchro-betatron resonance, (2) important input to achieve EIC flat hadron beam
Experiment Description:	The flat beam collision is adopted for future EIC to achieve high luminosity. The working point is chosen to avoid coupling resonance and its low-order synchro-betatron sidebands. However, the high-order synchro-betatron resonances are unavoidable due to the large beam-beam tune spread. There is a concern that the resonances 2*nux − 2*nuy + p*nuz = 0 will drive large vertical emittance growth, especially when the beam are subject to random fluctuations in real world, such as power supply ripple, IBS diffusion etc. This experiment aims to investigate beam-beam collisions with or without a small crossing angle (0 − 2 mrad), generating a flat beam through cooling. Parameters like emittance growth rate, beam lifetime, and beam loss will be measured at various working points and crossing angles, including scenarios simulating unexpected crab crossing behavior in the future EIC. We study around nux − nuy − 2*nuz = 0 for gold-gold collisions. Based on prior runs, we select the working point as (0.235, 0.225) and adjust the longitudinal tune to approximately 0.004. In the case of a round beam, we request beam-beam parameters ξx0 = ξy0 = 0.005. Assuming only the vertical emittance undergoes cooling, the horizontal emittance remains constant. To avoid potential aperture issues, the βx,y are not squzzed for the flat beam. The beam-beam parameters are scaled up according to the beam flatness. Procedures: (1) Set the cross angle to 0, 1, or 2 mrad and choose flatness 1.0 or 0.5 (2) Set the beam to flattop energy and activate the cooling system to generate desired flatness in both RHIC rings (3) Bring two beams into collision, and observe beam loss rate, emittance growth rate etc. (4) Perform the following scan: (a) scan nux while keeping nuy unchanged, (b) scan nuy while keeping nux unchanged, (c) scan nux and nuy while keeping nux − nuy unchanged (5) Choose a different crossing angle and beam flatness, and repeat steps (2-4)
Hazard Analysis:	None
Approved By:	
Date Approved:	
Resources:	
Instrumentation:	(1) Tune adjustment and measurement (2) Cooling to achieve flat hadron beams in both ring (3) Crossing angle within 2 mrad (4) Emittance growth and beam loss
Application:	(1) flat hadron beam in both rings
Time:	24 hours (estimate)
Personnel:	Necessary operational support
Intentional Beam Loss?	No
Plan for Data Analysis:	Data analysis online and offline
Results:	To be reported in APEX bi-weekly meeting and probably in EIC Tech Note.