Feedback Scheme for Kink Instability in ERL Based Electron Ion Collider

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OUTLINES

- Revisit, Beam-Beam notation.
- Kink Instability Formation
  - Beam-Beam wake field
  - Strong Head-Tail Threshold
- Feedback Schemes
  - Principles
  - Compare with Landau Damping
  - Flexibilities
  - Limitations

Revisit, Beam-Beam Notations in ERL based EIC

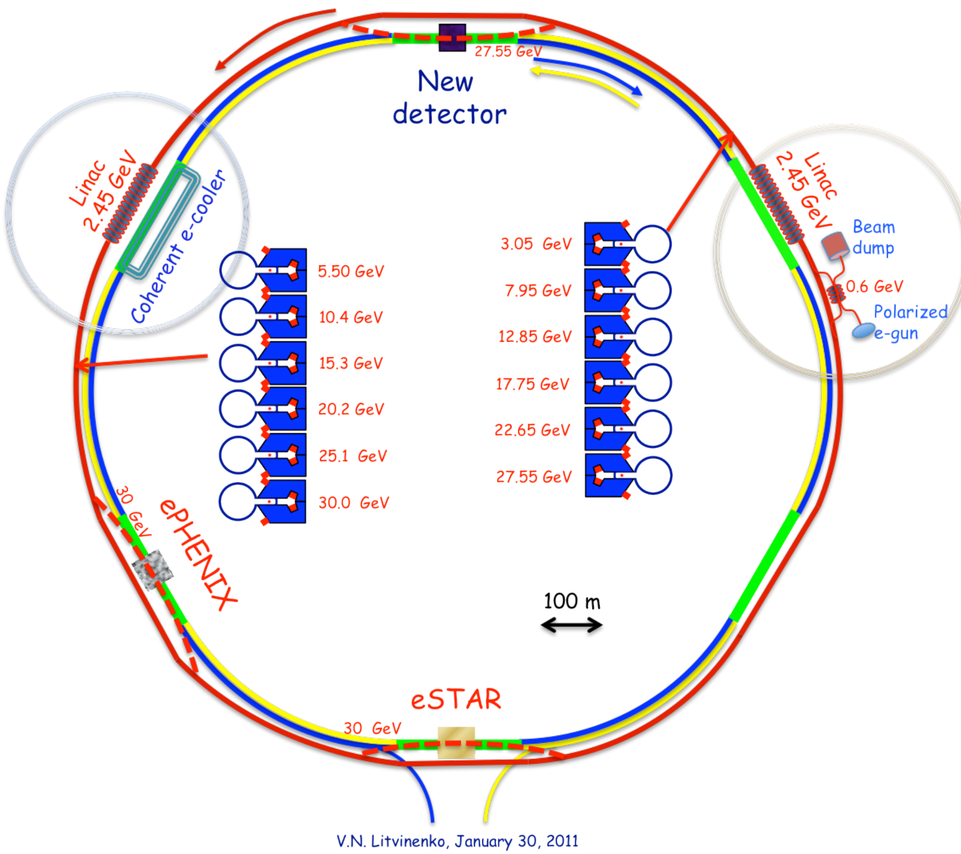
- The beam-beam parameter is the linear tune shift of the beam-beam force.

$$\xi_p = \frac{1}{4\pi}\frac{\beta^*}{f_p} = \frac{\beta^* N_e r_p}{4\pi\gamma_p\sigma_e^2}$$

- The disruption parameter

$$d_e = \frac{l_p}{f_e} = \frac{l_p N_p r_e}{\gamma_e \sigma_p^2}$$

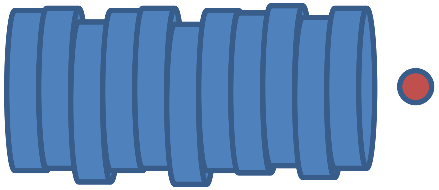
Is important parameter since the electron finishes $\sqrt{d_e}/4$ oscillations.[1]



eRHIC, a proposed ERL based EIC

Kink Instability

- The instability arise from the beam-beam interaction between the ion/proton beam and the electron beam.
- The proton beam experiencing a wake field. The longitudinal mode 1 dominate for the snap shot in simulation.



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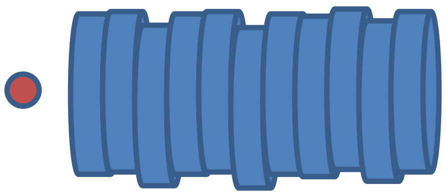
$$x_e'' + k^2(s)\left[x_e - \bar{x}_p(s, z = 2s)\right] = 0$$



$$k^2(s) = \frac{2N_p r_e}{\sigma_{px}^2 \gamma_e}\lambda(z = 2s)$$
$$= \frac{2\lambda(z = 2s)}{f_e} = \frac{2d_e\lambda(z = 2s)}{\sigma_{pz}}$$

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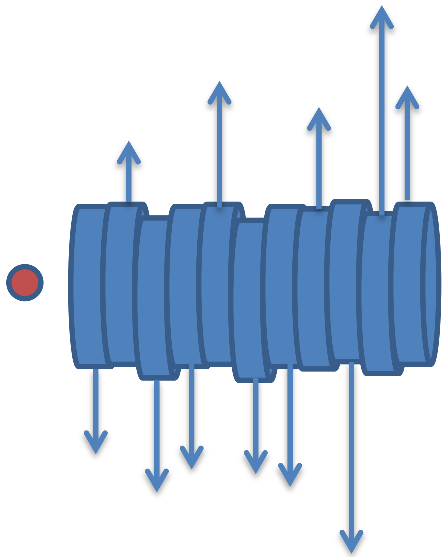

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$$x_p''(s, z) + K_\beta^2 x_p = \delta\left(s - \frac{z}{2}\right)\frac{x_p - \bar{x}_e(s)}{f_p}$$

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Wake Fields

If we make assumptions

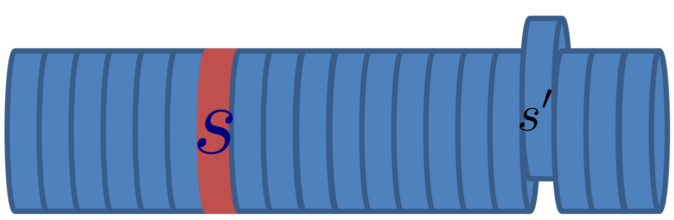
- Infinite short electron beam
- Offsets are small to use linear beam-beam approximation
- No hourglass effect
- Both beams are rigid
- Longitudinal distribution of Proton beam is uniform

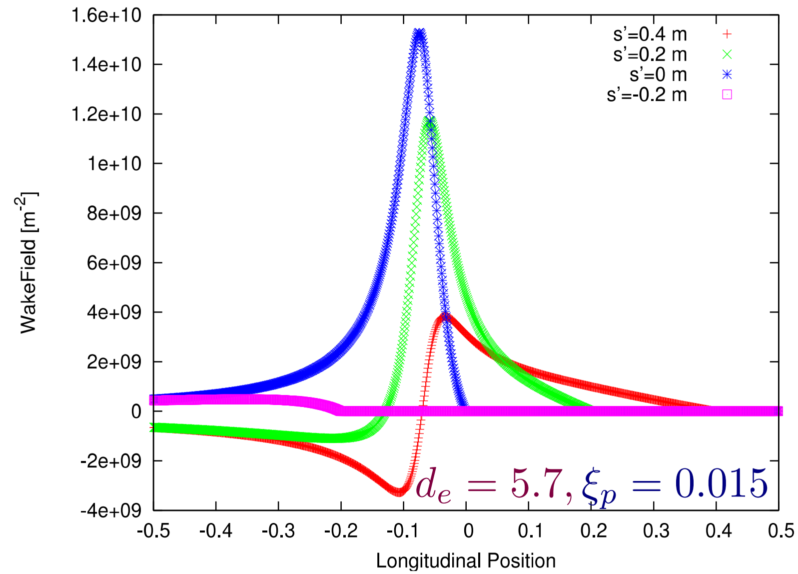
The wake field has analytical form

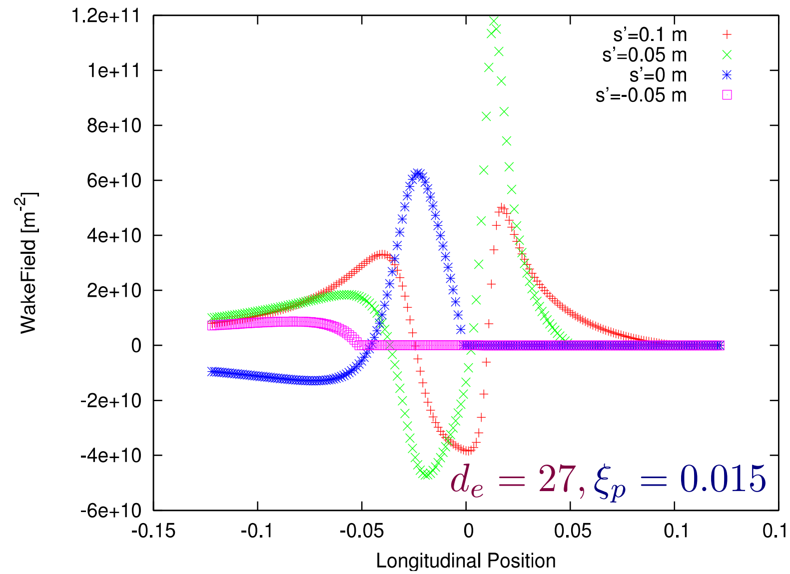
$$W(s,s') \sim k \sin k(s-s')H(s'-s)$$

Alternatively:

$$W(s,s') = \frac{\gamma_p}{N_{pb} r_0} \frac{\Delta x'(s)}{\Delta x(s')}$$





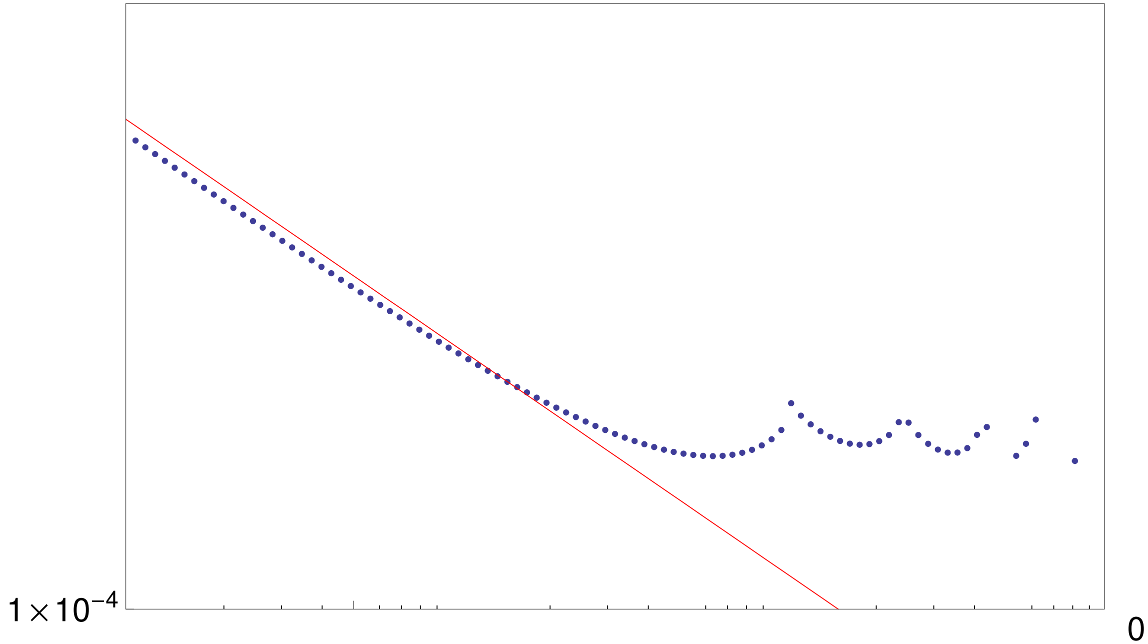


SHT Threshold

A simplest two-proton (with one electron) model can be used to estimate the strong head-tail instability threshold.

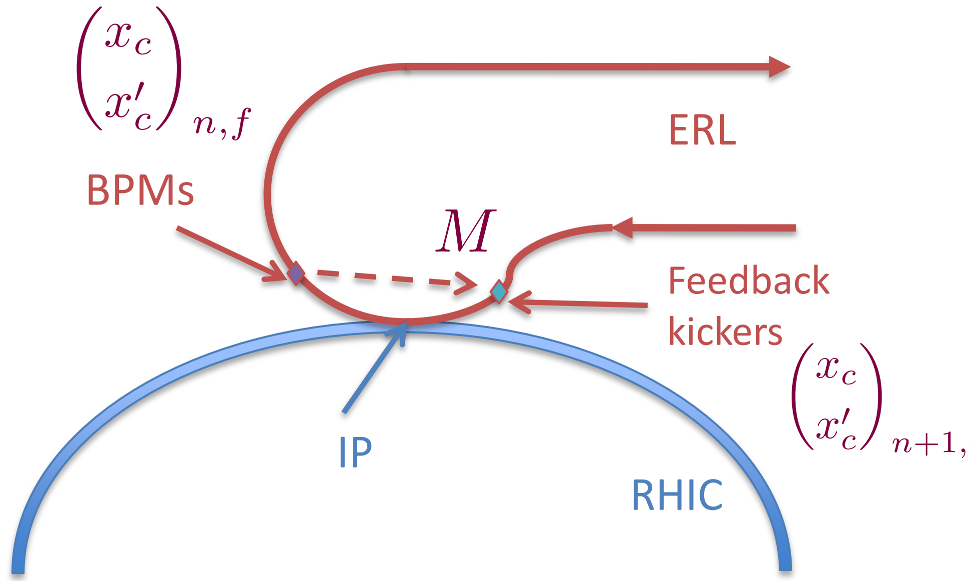
$$\xi_p d_e < 4\nu_s/\pi$$

Multi-particle model can be achieved with circulant matrix [3], which demonstrates the high disruption parameter d_e case.



The Feedback Scheme

- Motivation: avoid unwanted nonlinearity
  - Chromaticity
  - Nonlinear field magnets
- Advantages
  - No changes on existing RHIC
- Challenges
  - Accurate BPMs
  - Fast kickers

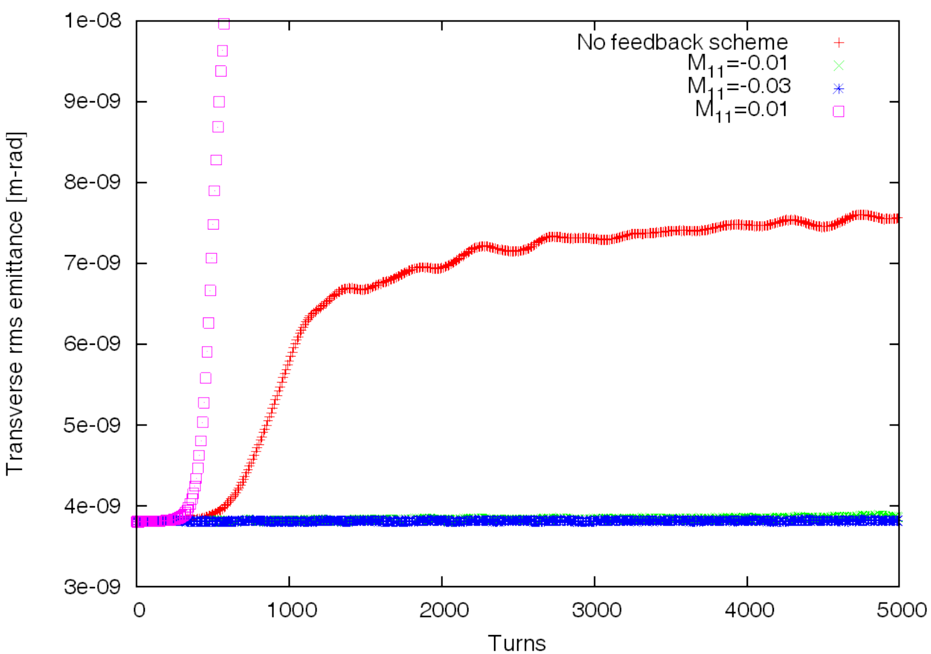


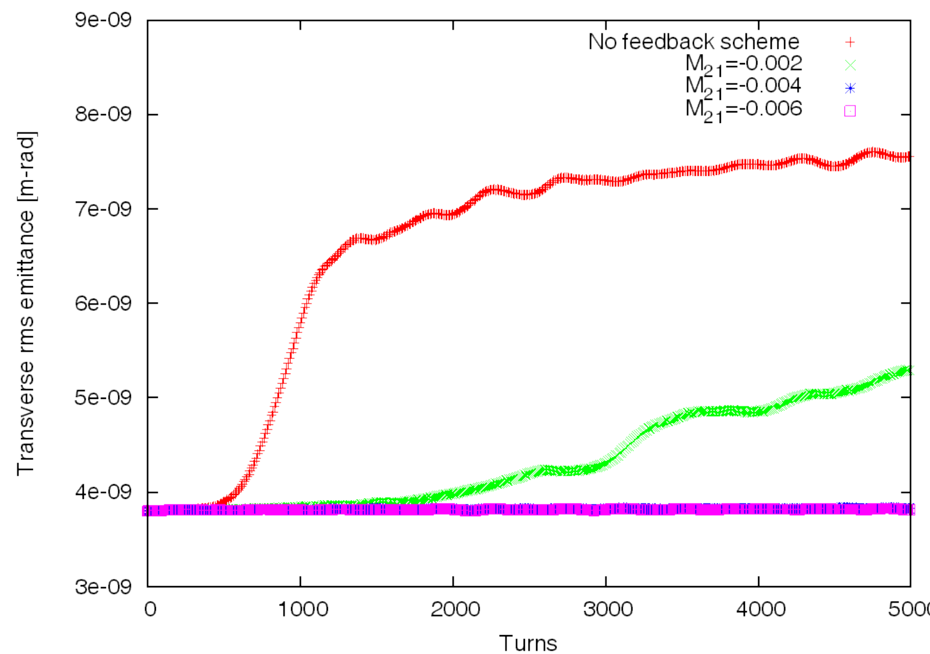
$$\begin{pmatrix} x_c \\ x'_c \end{pmatrix}_{n+1,i} = M \begin{pmatrix} x_c \\ x'_c \end{pmatrix}_{n,f}$$

$$M = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix}$$

Feedback Scheme Effects

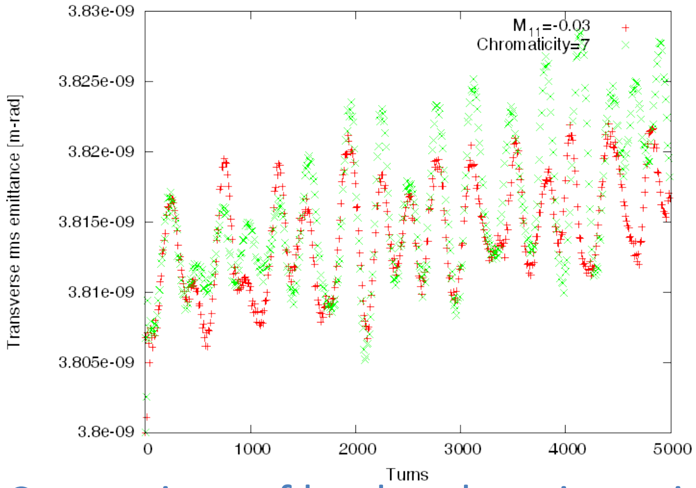
Beam-Beam Parameters: $d_e = 5.7, \xi_p = 0.015$



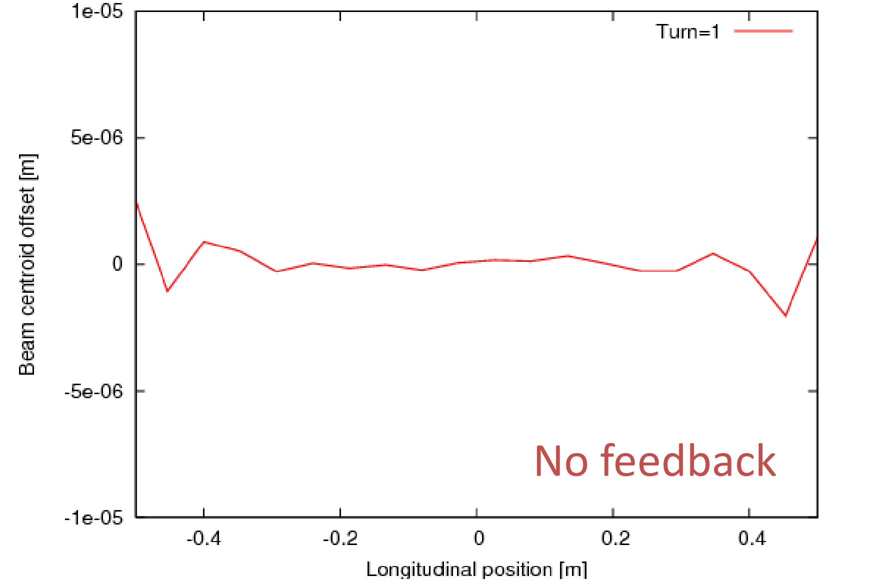


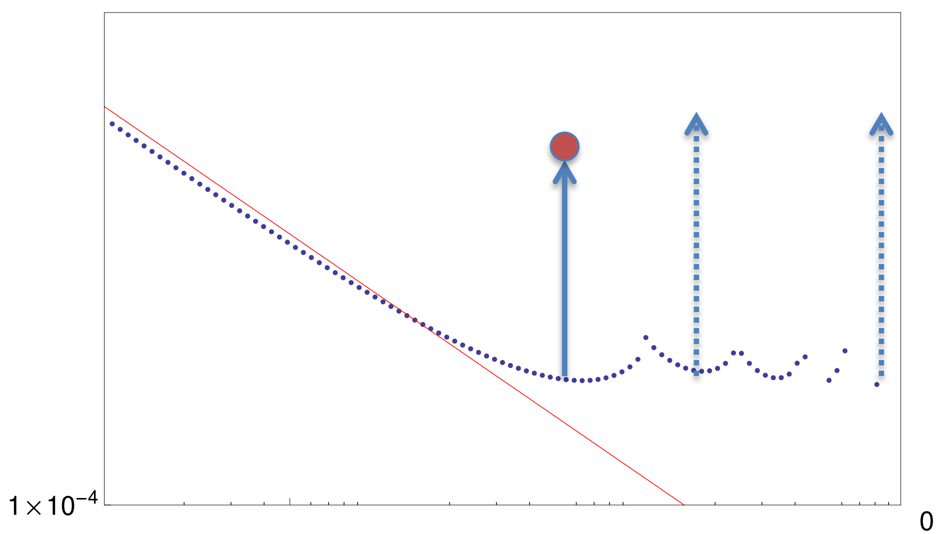
The working schemes are not unique. The feedback amplitude must be controlled to the minimum effective value to prevent luminosity loss.

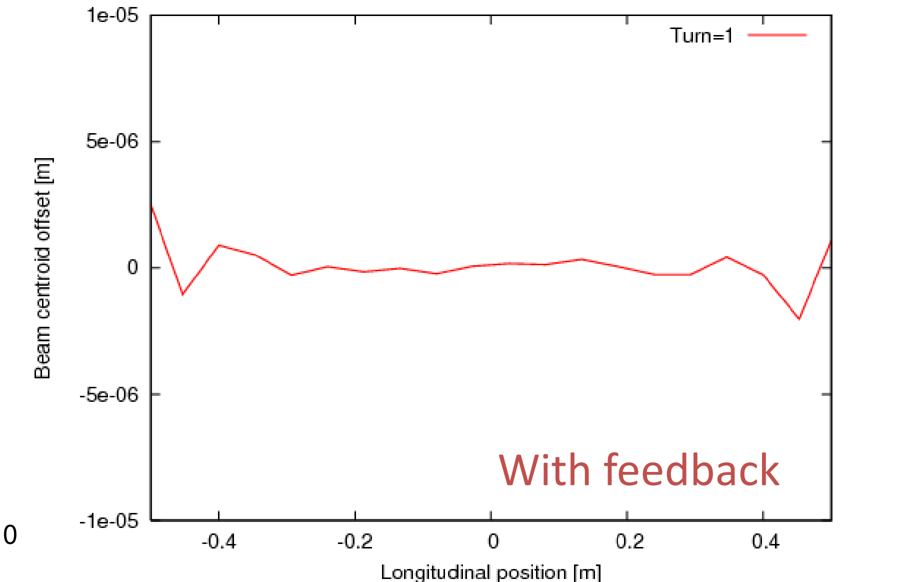
A Closer Look



Comparison of landau damping using chromaticity and feedback scheme.

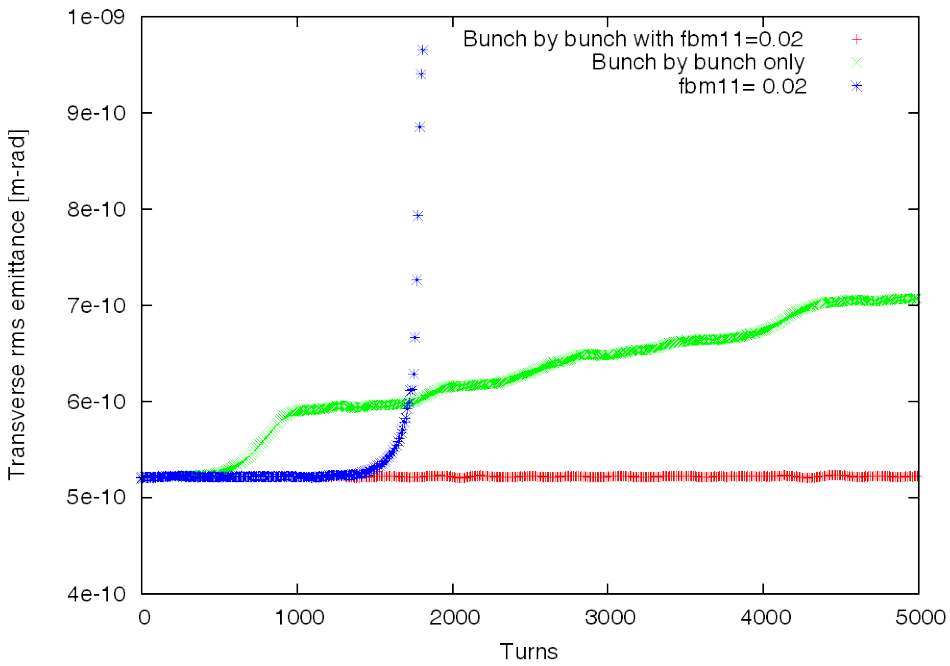






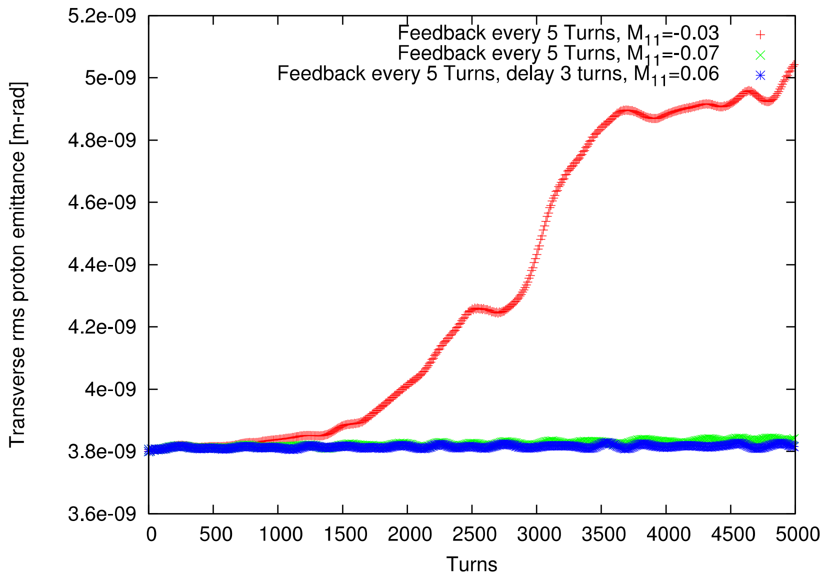
Large Disruption Parameter Cases

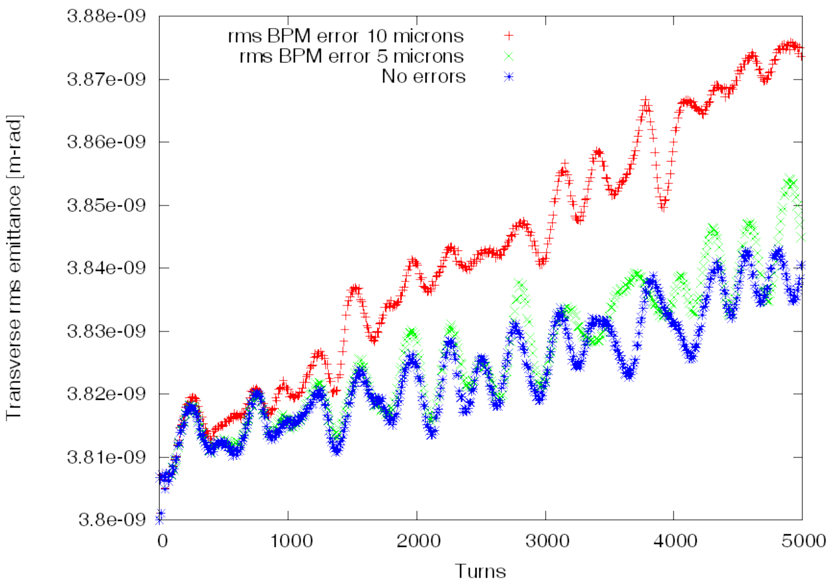
- At large disruption parameters (d>10), simulation shows the feedback system damps higher mode while excites the mode zero, which damages the luminosity.
- An addition regular bunch by bunch feedback in RHIC is a necessary add-on to damp the beam.
- More studies are undergoing to make the system work at even higher disruption parameter up to 150.



$$d_e = 14, \xi_p = 0.015$$

Tolerance on Slower, Less Frequent and Noisy Situation





The feedback scheme is enabled every 5 turns (Red and Green). Larger feedback strength is needed. Blue curve shows the information is delayed by 3 turns. The feedback strength need to change according to the different betatron tune.

The random error of BPMs are included. To reduce 'statistical heating' on the proton beam, the rms error should be in micron-range. And the pickup should be installed at high beta locations.

Summary

- The feedback system to cure kink instability can stabilize the beam beyond SHT threshold without introducing additional unwanted tune spread.
- For large disruption parameter, the bunch by bunch transverse feedback system is needed in the ion/proton ring.
- The efforts to extend the method to meet the entire design parameter range of eRHIC are undergoing.

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References

[1] Y. Hao and V. Ptitsyn, Phys. Rev. ST Accel. Beams 13, 071003 (2010)

[2] R.Li, et.al. p.2014-2016 Proceeding of PAC 2001

[3] V. V. Danilov and E. A. Perevedentsev, Nucl. Instrum. Methods Phys. Res., Sect. A 391, 77 (1997)