EIC Crab Cavity Low-Level RF Design

APS Far West Section, 2023

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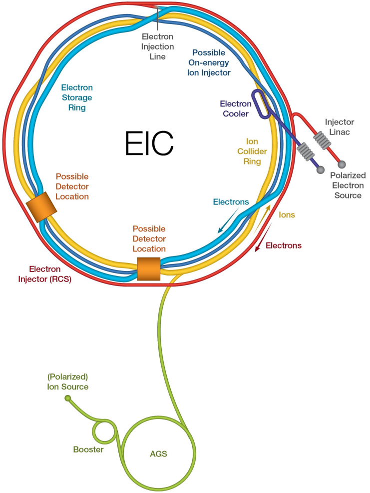
October 7th 2023

The Electron Ion Collider

- The next big US accelerator, the Electron-Ion Collider (EIC), at Brookhaven National Lab, NY (within the 2030s)
- 3.8 km circumference ring
- 8 crab cavities operating at 197 MHz, and 4 operating at 394 MHz
- Crab cavities will significantly increase the collision rate [4]



A Crab Cavity

- An electromagnetic resonator that will rotate the particle cloud (bunch) around its center, so that it moves sideways (transversely), like a crab
- After crabbing the beam, it must be uncrabbed
- Why would we want to do this?
  - More collisions → more data

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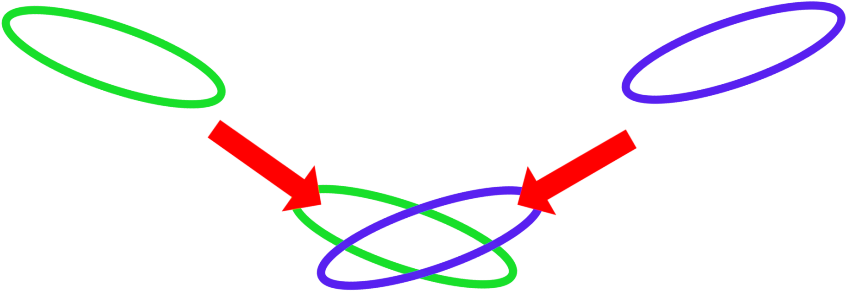

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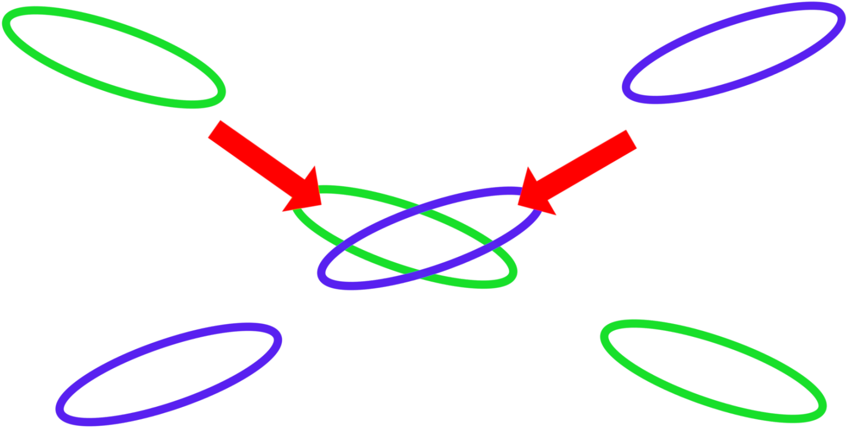

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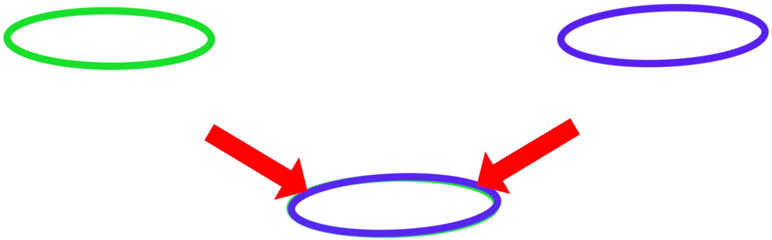

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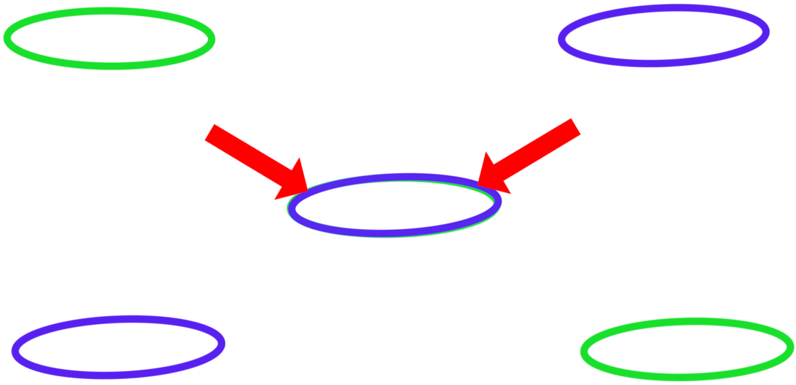
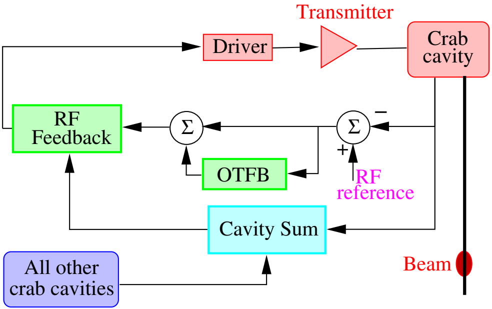


The LLRF

- The Low Level Radio Frequency (LLRF) Controller
  - RF feedback (proportional and integral controller)
  - One-turn Feedback
- Makes corrections on the order of kV
- Acts on each cavity individually



The 3 Main Challenges

- Transient beam loading
  - Passing beam induces voltage on cavity
  - Cavity voltage magnitude → beam tilt
  - Cavity voltage phase → beam position
- RF Noise
  - Analog and digital RF devices give off RF noise
  - Noise leads to transverse beam size growth
- Transverse Coupled-Bunch Instabilities
  - Interaction with cavity impedance couples bunch transverse motion
  - Could lead to transverse oscillation growth (instability)
- Our research defines system requirements to achieve these objectives and studies potential trade-offs

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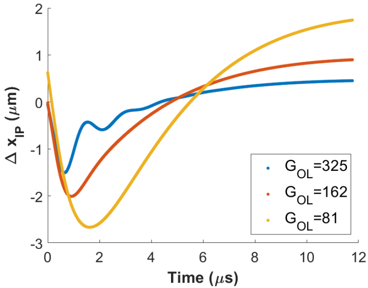
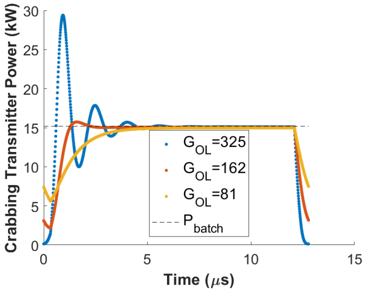
1. Crab Cavity Overview
2. **Transient Beam Loading**
3. RF Noise
4. Transverse Instabilities
5. Conclusions

Summary of Transient Beam Loading studies

- Work presented in BNL-224087-2023-TECH [2]
- Insignificant effect on beam position
- Insignificant effect on cavity voltage
- Peak power can be double depending on controller parameters





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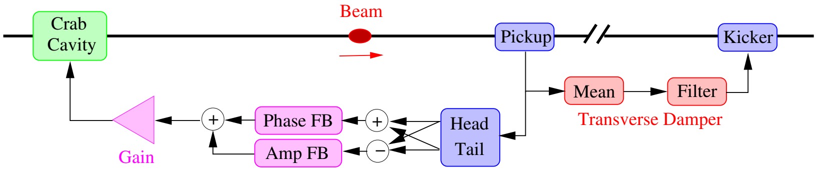
Summary of RF Noise studies

- Work presented in EIC-ADD-TN-026 [3]
- The transverse beam size would grow rapidly with expected RF noise levels and is much higher than the specifications
- We need to reduce the RF noise *and* design a dedicated feedback system to counteract it

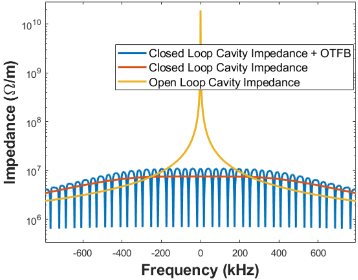


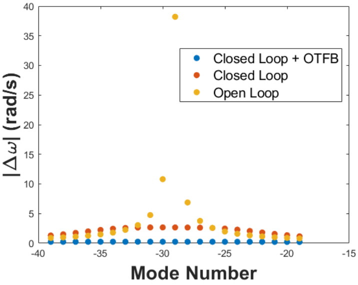
Objective

- We want to determine the max stable beam current as a function of LLRF parameters and architecture
    - Beam-cavity interaction is approximately proportional to impedance and I_{beam}
- We calculate the system's impedance for a certain configuration
- We estimate the resulting maximum I_{beam}

Results

- The very high Q-factor resonance is significantly reduced by the RF FB and OTFB (at frequencies of interest)
- Most unstable mode -29 (center)
- Stable currents are 0.3 A (open-loop), 1.4 A (closed-loop), and 10.0 A (OTFB)





Effect on LLRF Design

- We have completed the necessary studies to define LLRF specifications
    - RF noise is the most concerning effect
- We now need to explore trade-offs
    - For example, incorporate a low-pass filter on the RF FB to reduce RF noise while maintaining instability control

Acknowledgements

- This work was conducted under Dr. Themis Mastoridis in the physics department
- Thank you to the other students I worked with: Trevor Hidalgo, Matti Toivola, and Paul Mahvi
- Thank you to Mike Blaskiewicz of Brookhaven National Lab

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[2] T. Mastoridis, K. Smith, T. Hidalgo, T. Loe, and M. Toivola.
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[4] F. Willeke and J. Beebe-Wang.
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Image Sources

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