High Bandwidth Feedback Systems for a High Luminosity EIC

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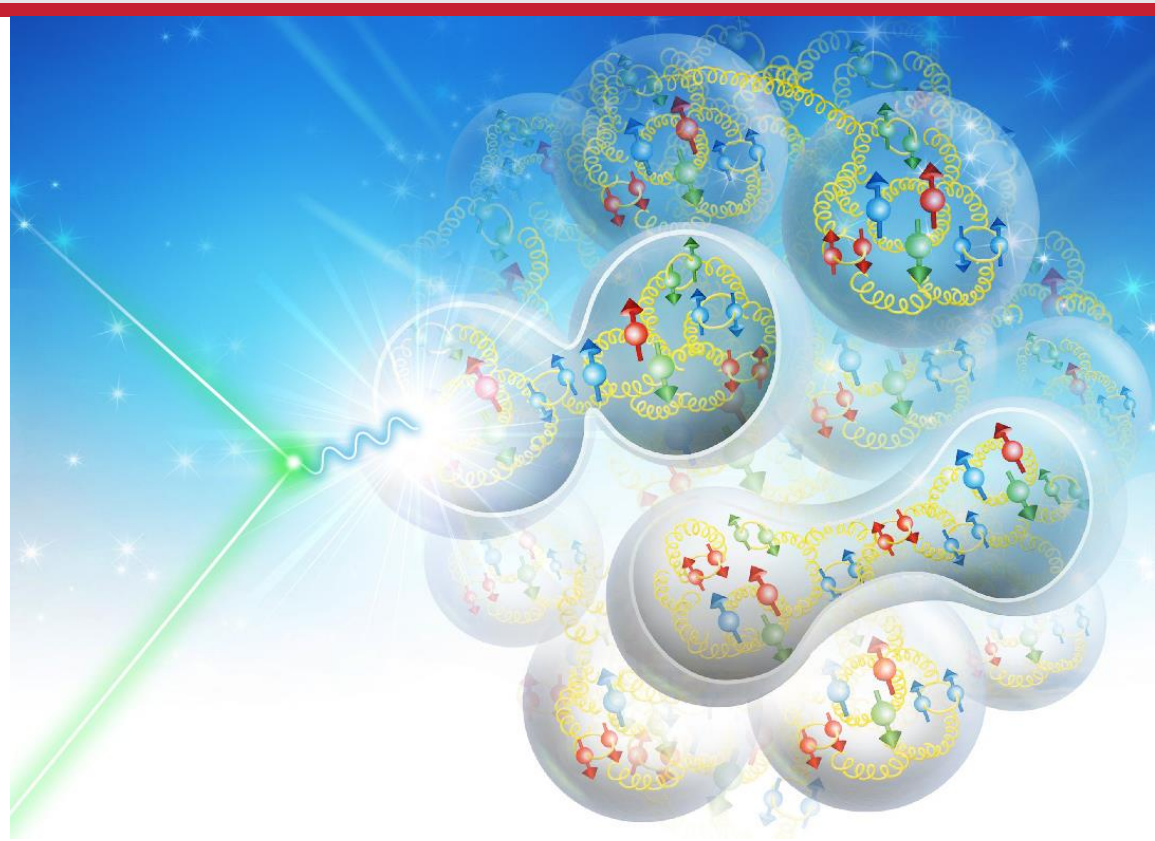


Supported by FY 2018-19 DoE NP FOA JLab and BNL Base R&D Funding

2020 NP Accelerator R&D PI Exchange Meeting
December 2, 2020

U.S. DEPARTMENT OF ENERGY | Office of Science

High Bandwidth Beam Feedback Systems for a High Luminosity Electron Ion Collider

- Project description
  - This proposal is to perform the key research and development required to make practical the production of transverse and longitudinal feedback systems capable of providing the high-bandwidth high-voltage feedback signals required for the future 3 A 12 GeV electron collider ring at the JLAB EIC (JLEIC). Having a large operating bandwidth, lower HOM impedance and better power handling will be the focus of these developments. This will create a robust solution which can be easily adapted to future JLEIC accelerator parameter changes and make developments here adaptable to different accelerators, like the Brookhaven National Laboratory (BNL) electron Relativistic Heavy-ion Collider (eRHiC).
- Project status
  - Closed
- Main goal
  - Develop transverse feedback system and kickers for an EIC
- Supported by FY 2018-19 DoE NP FOA JLab and BNL Base R&D Funding

Progress report

- Prior FY17 project completed
  - (including a subcontract to DimTel to do high level system architecture)
- JLEIC impedance budget progressed up to pre-CDR-100
- Concept for longitudinal kicker
- Initial EM model of transverse kicker (based on ANL stripline)
- Half-time postdoc started
- Resource issues at ANL, PI moved to BNL

R&D Highlights: JLEIC Impedance analysis

R. Li

- Ongoing refinement as designs matured
- High-count small impedances (e.g. bellows), and one-off high impedances (e.g. IR)
- Scale from other machines where undefined

e-ring

- Component Counts (Courtesy to T. Michalski)

Elements	e-Ring
Flanges (pairs)	1215
BPMs	405
Vacuum ports	480
Bellows	480
Vacuum Valves	23
Tapers	6
Collimators	16
DIP screen slots	470
Crab cavities	2
RF cavities	32
RF valves	68
Feedback kickers	2
IR chamber	1

- Impedance Estimation (Courtesy to K. Deitrick)

Broadband Impedance	Reference: PEP-II	Reference: SUPERKEKB	
L [nH]	99.2	28.6	
$\lvert Z_{\parallel}/n \rvert$ [Ω]	0.09	0.02	$\leq 0.1\ \Omega$
$k_{\parallel}$ [V/pC]	7.7	19	
$\lvert Z_{\perp} \rvert$ [kΩ/m]	60	13	$\leq 0.1\ \mathrm{M\Omega}/m$

- JLEIC plans to use PEP-II vacuum systems
- Effective impedance is bunch length dependent

i-ring

- Component Counts (Courtesy to T. Michalski)

Elements	p-Ring
Flanges (pairs)	234
BPMs	214
Vacuum ports	92
Bellows	559
Vacuum Valves	14
Tapers	6
Collimators	16
DIP screen slots	-
Crab cavities	8
RF cavities	40
RF cavity bellows	40
RF valves	24
Feedback kickers	2
Roman Pot	2
IR chamber	1

- Impedance Estimation (Courtesy to K. Deitrick)

Broadband Impedance	Reference: PEP-II	
L [nH]	97.6	
$\lvert Z_{\parallel}/n \rvert$ [Ω]	0.08	$\leq 0.1\ \Omega$
$k_{\parallel}$ [V/pC]	8.6	
$\lvert Z_{\perp} \rvert$ [kΩ/m]	80	$\leq 0.1\ \mathrm{M\Omega}/m$

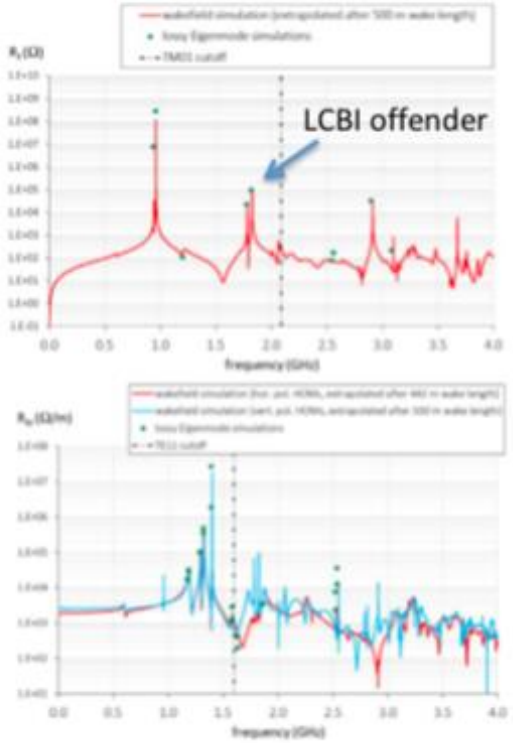
- The short bunch length (1.0cm) at collision is unprecedented for the ion beams in existing ion rings
- Bunch length varies through the whole bunch formation process

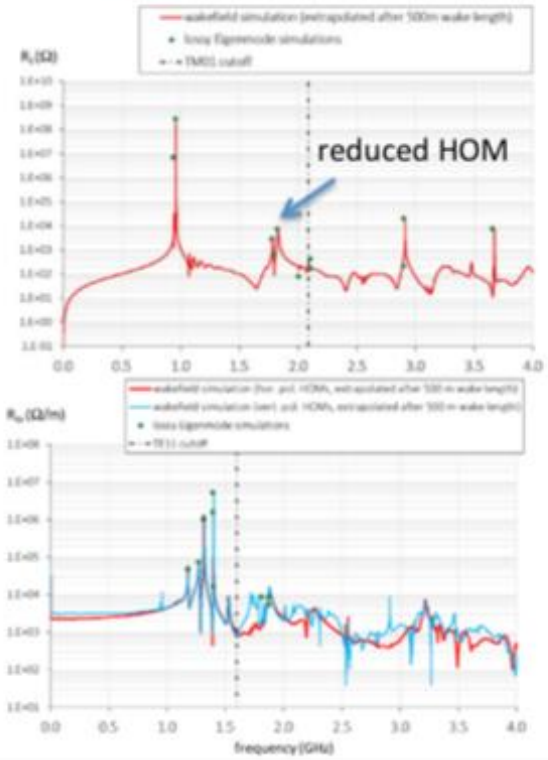
Narrowband Impedance optimization: JLEIC ion-Ring cavity and IR (F. Marhauser)

- 956 MHz 2-cell Cavity

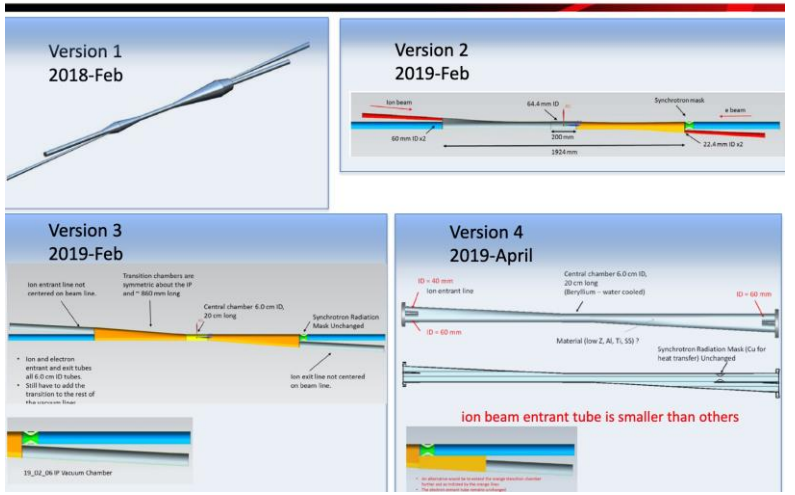
Coaxial couplers

Waveguide couplers

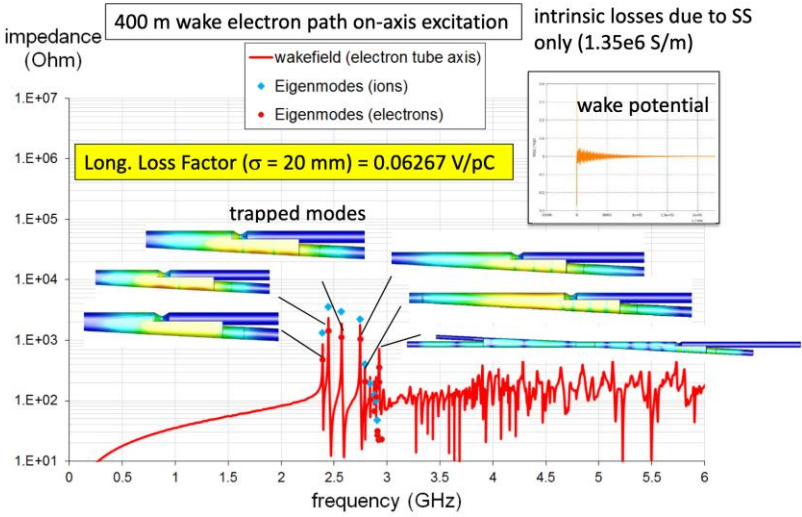




JLEIC IR Chamber Version History

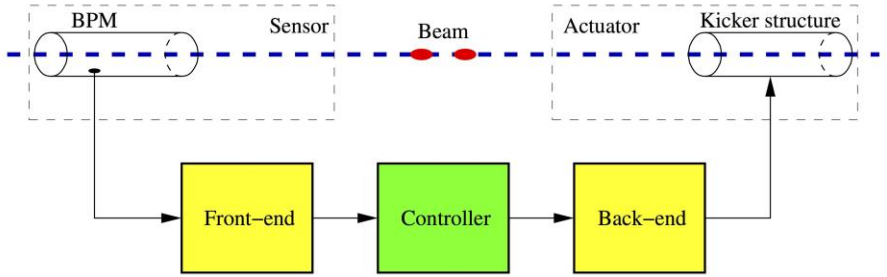


Version 4

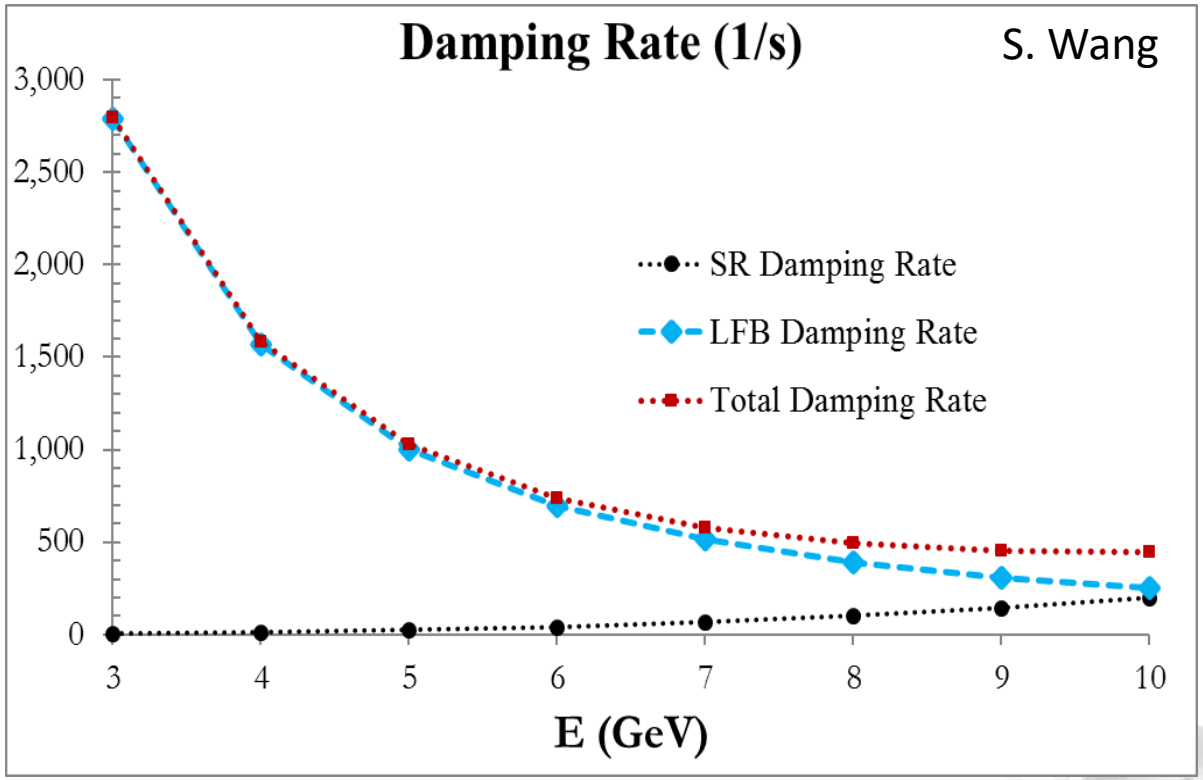


R&D Highlights: Feedback System architecture*

- Maximum bunch frequency =F_{RF} = 476.3 MHz
- Transverse feedback (baseband)
  - —**~DC to F_{RF}/2 = ~DC to 238 MHz**
- Longitudinal Feedback (damped cavity)
  - —Center frequency = n*F_{RF} – F_{bunch}/4,
  - —e.g. **1547 MHz, bandwidth ≥ 238 MHz**



Parameter description	Value
Optimal closed-loop damping time	1.6 ms (205 turns)
Fastest achievable damping time	29 µs (3.7 turns)
Residual dipole motion at optimal damping	28 µm
Feedback gain for optimal damping	1.5 µrad mm^{-1}
Power requirement with 0.5 mm excitation, 10 kΩ kicker $R_\perp$	250 W
Power requirement at 5 GeV	700 W



LFB: Longitudinal Feedback

LFB Kicker Total Voltage: 7kV

LFB phase resolution: 0.02 rad

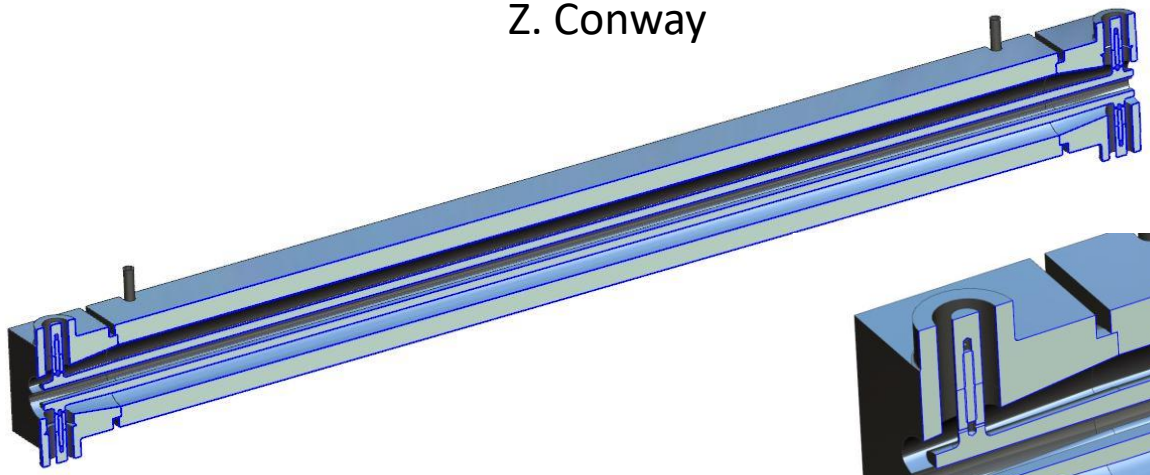
Max LFB Gain: 3.5e5

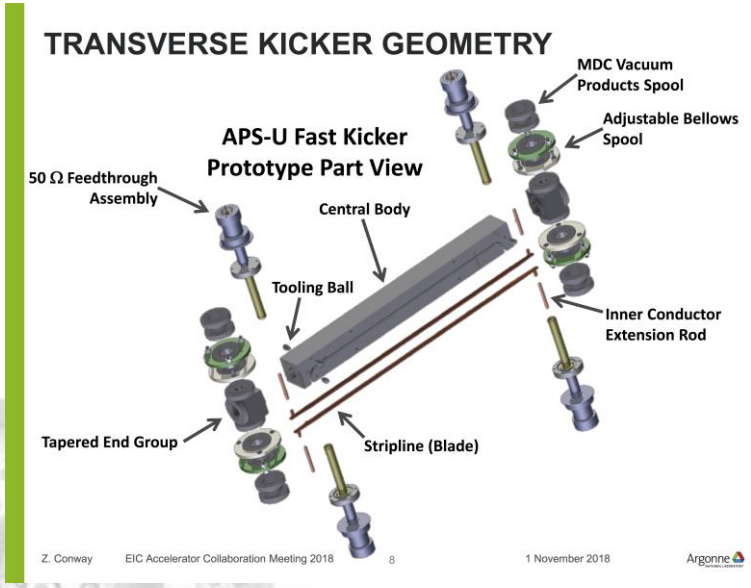
*"Transverse bunch-by-bunch options for JLEIC electron ring", report, Dmitry Teytelman, 2019

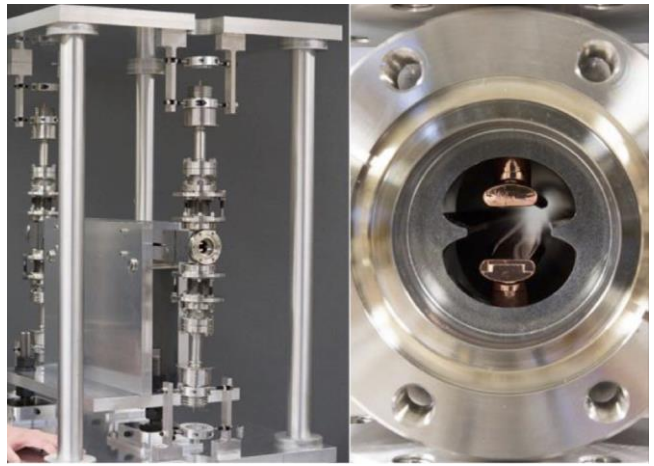
R&D Highlights: Transverse kicker

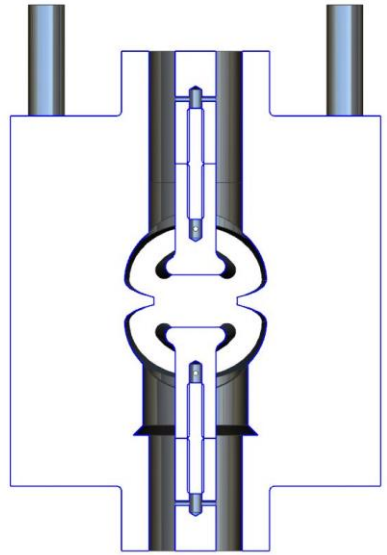
Z. Conway

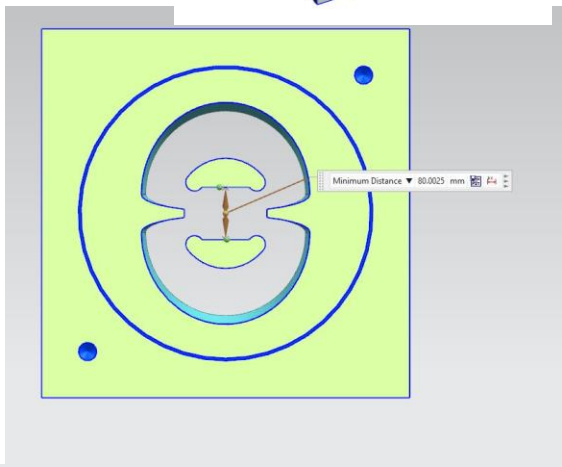
- Based on APS-U injector stripline design
  - Better thermal properties compared to PEP-II style
  - More efficient, more robust feedthroughs
  - Tested with beam at ANL and NSLS-II
- Scaled to JLEIC frequency/aperture
- Feedthrough matching needed optimization







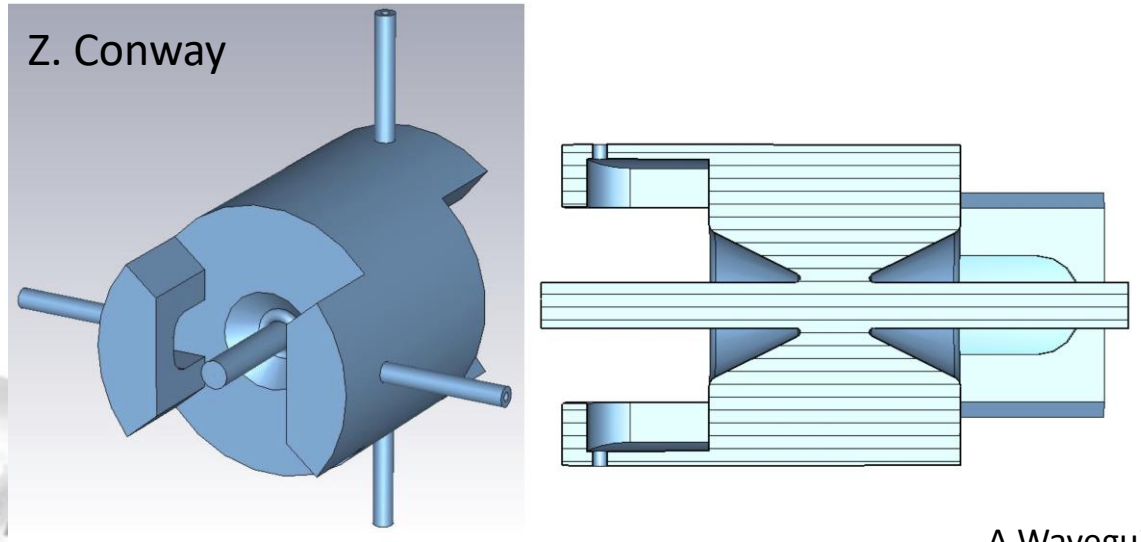




"Preliminary Test Results of a Prototype Fast Kicker for APS MBA Upgrade," C. Yao et al., NA-PAC2016, WEPOB24, Pg. 950 (2016)

R&D Highlights: Longitudinal Feedback Kickers

- ANL has developed a 1.027 GHz, 59 MHz bandwidth, R/Q = $V^2/2P$ = 160 Ω, longitudinal feedback kicker for the APS-U electron storage ring. The APS-U longitudinal feedback system is designed to deliver > 4 kV kick distributed over two longitudinal feedback kickers.
- The APS-U storage ring will operate with a 200 mA 6 GeV electron beam. This beam current is much less than the expected JLEIC electron storage ring operating level of 3 A.



LFB KICKER CONCEPT

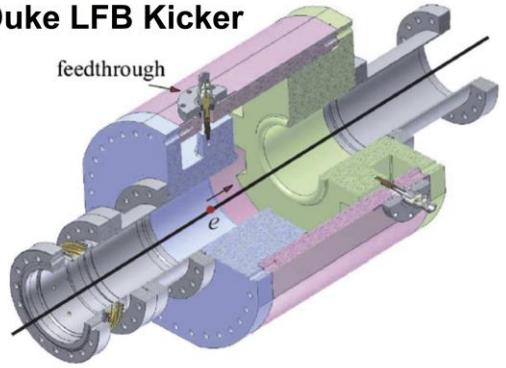
Background

- Chose a waveguide over-damped resonator for the APS-U longitudinal feedback (LFB) kicker:
  - Used at ALS, BESSY-II, DIAMOND, Duke, DAΦNE, HIGS, HLS-II, KEK-B, PEP-II, etc,
  - High shunt impedance,
  - Low HOM shunt impedances,
  - High power handling, and
  - Straightforward fabrication.
- APS-U LFB kicker is much more reentrant for high shunt impedance.

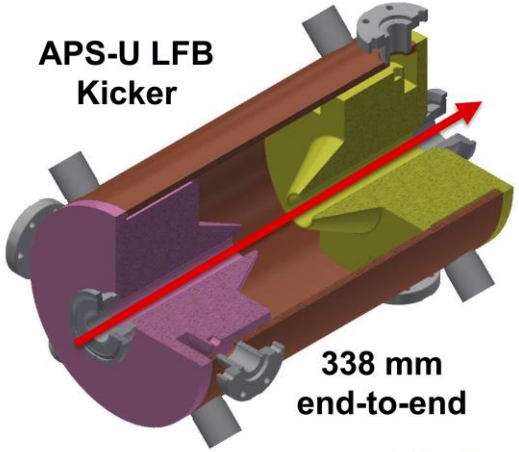
W.Z. Wu et al., NIMA, Vol. 632, # 1, 11 March 2011, Pg. 32-42

Z. Conway EIC Accelerator Collaboration Meeting 2018 12

Duke LFB Kicker



APS-U LFB Kicker



1 November 2018

A Waveguide Overloaded Cavity as Longitudinal Kicker for the DAFNE Bunch-by-bunch Feedback System," A. Gallo et al., International Workshop on Collective Effects and Impedance for B-Factories, Tsukuba, Japan, June 1995.

Present status:

- After 2019 PI meeting attempted to restructure the work with PI at BNL but…
- After 2020 EIC site selection agreed to terminate the project
- JLab funds reprogrammed for EIC*
- ANL funds returned to DOE

- Lessons learned will be useful for EIC
- Actual systems will be developed as/when needed on project

*Continued to support 50% of postdoc to end of FY20

Total expenditures (FY18-19 funds)

ID #	Item/Task	Baseline Total Cost	Costed & Committed	Estimate To Complete	Estimated Total Cost
		(AY$)	(AY$)	(AY$)	(AY$)
JLCFF2	Fast Feedback Sys&Kicker2	$8,000	$7,834	$0	$7,834
JLECFF	Fast Feedback Sys&Kickers	$448,000	$89,846	$0	$89,846
	Totals:	$456,000	$97,680	$0	$97,680*

*half post-doc for FY19 and 20

	Item/Task	Baseline Total Cost	Costed & Committed	Estimate To Complete	Estimated Total Cost
		(AY$)	(AY$)	(AY$)	(AY$)
ANL	Fast Feedback Sys&Kickers	$200,000	$300	$0	$300

Deliverables and Schedule

- Experimental deliverables were shifted by more than a year due to delay in system parameter definition* and EM/ mechanical design

Task	FY'18				FY'19				FY'20			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
JLab: Provide e-ring parameters			→	✓	✓	✓	✓	✓				
ANL: Preliminary model of transverse kicker			→	✓	→	→	→	✓				
JLab: Impedance and instability studies				✓	✓	✓	✓	✓				
ANL: Mechanical design of transverse kicker				→	→	→	→	→	X			
ANL: preliminary design of longitudinal kicker				→	✓	→	→	→	X			
JLab: Survey of industrially available digital electronics					✓	✓	✓	✓				
ANL: Drawings of transverse kicker/impedance estimates					→	→	→	→	X			
JLab: Ring impedances, instabilities and requirements						→	✓	✓	X			
ANL: Tolerance study trans.; Preliminary model of long. kicker						→	→	✓				
JLab: Calculate current limit with feedback							✓	✓				
ANL: HOM calcs. Parts ordered for transverse kicker prototype							→	→	X			
JLab: study effect of FB on polarization lifetime								→	X			
ANL: Assembly of kicker, measure, ship to JLab								→	X			

*Prior FY17 project "Fast Feedback System and Kicker Design" just ended in Q4 FY19 (incl. subcontract to DimiTel).

Back up

Original FOA proposal

Title:

- High Bandwidth Beam Feedback Systems for a High Luminosity EIC

Institution:

- Argonne National Laboratory

Lead Principal Investigator (PI):

- Dr. Zachary Conway

JLab Co-PI

- Bob Rimmer

Other personnel:

- Dr. H.-Ulrich Wienands

Collaborative Proposal Information						
	Names	**Institution**	**Year 1 Budget**	**Year 2 Budget**	**Year 3 Budget**	
Lead PI	Zachary Conway	Argonne national Lab	$400,000	$400,000		Funded $200k
Co-PI	Robert Rimmer	Jefferson Lab	$227,464	$228,079		$218k
Total			$627,464	$628,079		$418

requested

2018 milestones (funded)

- **Q3 FY2018 Milestones:**
- (JLAB) Table of JLEIC electron storage ring parameters; and
- (ANL) Preliminary model of the transverse kicker for single axis beam deflection.
- **Q4 FY2018 Milestones:**
- (JLAB) JLEIC storage ring preliminary impedance estimate;
- (JLAB) JLEIC electron storage ring collective instability feedback requirements;
- (ANL) Mechanical tolerance study for the transverse fast kicker; and
- (ANL) Preliminary model of the longitudinal kicker.

2019 milestones (funded)

- **Q1 FY2019 Milestones:**
- (ANL) Drawings suitable for fabrication of the transverse kicker;
- (JLAB) Initial results from the survey of industrially available digital electronics; and
- (ANL) First order estimates of the monopole impedance spectrum for the transverse and longitudinal kickers
- **Q2 FY2019 Milestones:**
- (JLAB) JLEIC storage ring impedance;
- (JLAB) JLEIC electron storage ring collective instability feedback requirements;
- (ANL) Mechanical tolerance study for the transverse fast kicker; and
- (ANL) Preliminary model of the longitudinal kicker.
- **Q3 FY2019 Milestones:**
- (ANL) All parts required for the transverse fast kicker ordered and first parts received;
- (JLAB) Calculation of the JLEIC beam current limit with transverse and longitudinal feedback; and
- (ANL) Calculation results for the dipole mode shunt impedance and loaded quality factors for the transverse and longitudinal kickers up to 3 GHz.
- **Q4 FY2019 Milestones:**
- (JLAB) Calculation of the effects of transverse and longitudinal feedback systems on the lifetime of the electron beam polarization;
- (ANL) Final assembly of the transverse kicker;
- (ANL) Measurement of the transverse kicker impedance with a network analyzer;
- (ANL) Leak check of the transverse fast kicker; and
- (ANL) Shipment of the longitudinal fast kicker components to JLAB.