EIC ACCELERATOR COLLABORATION MEETING 2018

# HIGH-BANDWIDTH FEEDBACK SYSTEMS FOR JLEIC

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# ACKNOWLEDGEMENTS

## People who deserve more credit than they receive.

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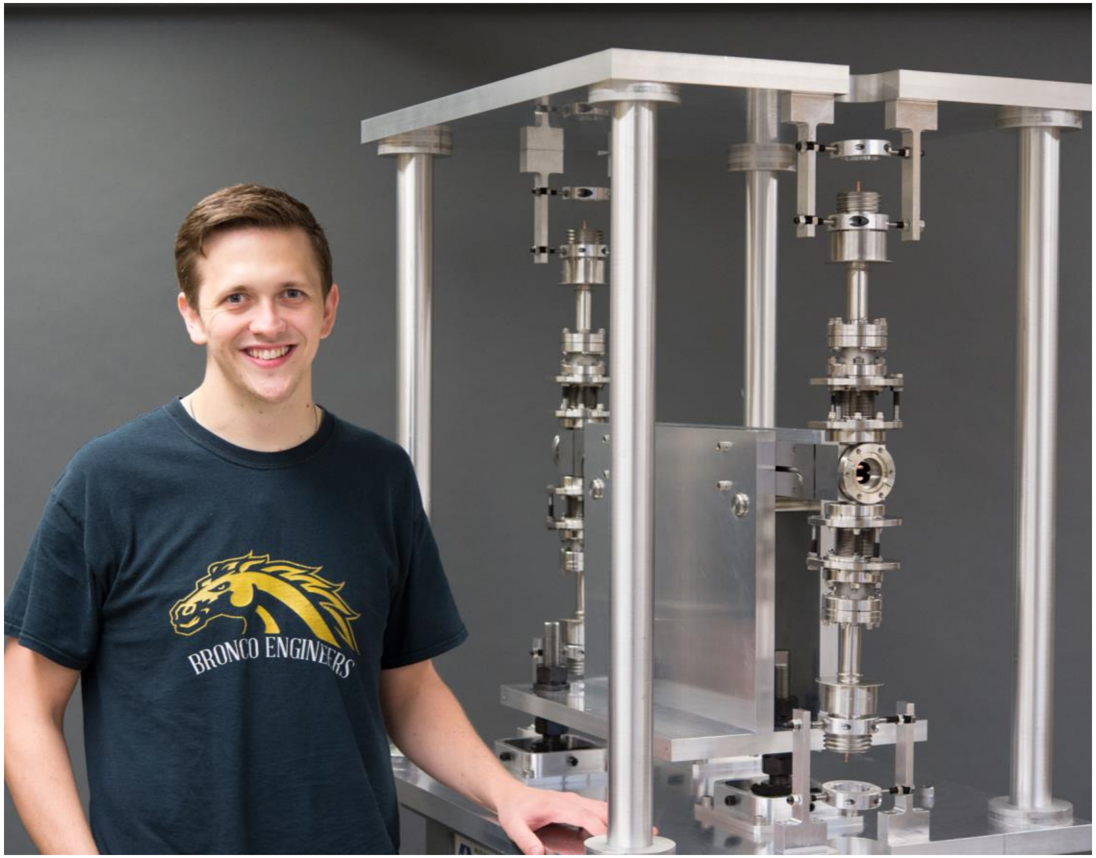
- **Sang-hoon Kim (MSU-FRIB)**
- **Chris Hopper (ITW)**

**ANL-APS/PHY 30 kV, 22 ns, Fast Kicker**



# MOTIVATION

## Jones Report

- **2017 Jones Report:**

| Row No. | Proponent | Concept / Proponent Identifier | Title of R&D Element | Panel Priority | Panel Sub-Priority |
|---|---|---|---|---|---|
| 18 | PANEL | JLEIC | Develop a high current magnetized electron injector | High | B |
| 19 | PANEL | JLEIC | High power fast kickers for high bandwidth (2ns bunch spacing) feedback | High | B |
| 20 | PANEL | JLEIC | Complete the design of the gear change synchronizations and assess its impact on beam dynamics | High | B |

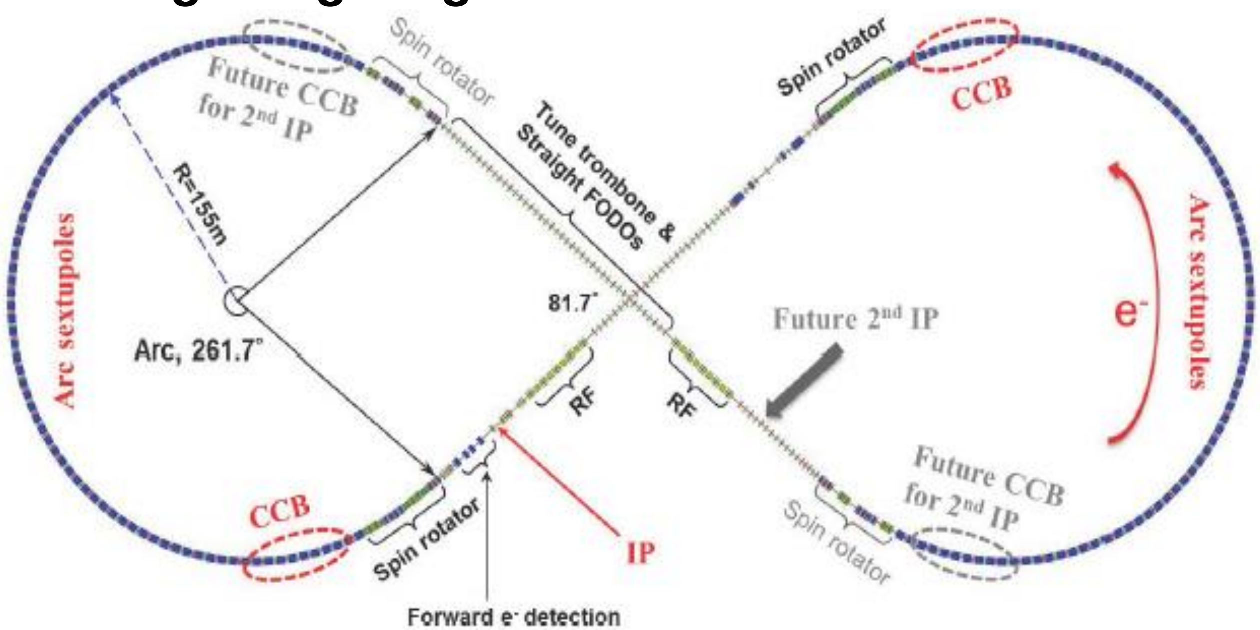
- **JLEIC luminosity requires the storage of high-current electron beam distributed over many bunches spaced at ~500 MHz (PEP-II = 476 MHz).**
- **The interaction of these bunches with the accelerator hardware can give rise to collective effects called coupled-bunch instabilities.**
- **JLEIC plans on using PEP-II hardware: RF cavities, vacuum chambers, magnets, etc.**

# APPROACH

## FY2018 NP EIC Accelerator FOA

- **Collaboration with JLAB and ANL.**
- **Apply recent ANL developments in transverse and longitudinal kicker hardware to the JLEIC.**
- **JLEIC electron storage ring plans to use the PEP-II RF cavities, magnets, vacuum chambers and other hardware.**
  - **Electron storage ring = figure 8.**

**2017 JLEIC Electron Ring (Figure 8)**




**"Update on the JLEIC Electron Collider Ring Design," Y. Nosochkov et al., IPAC2017, WEPIK041, Pg. 3018, 2017**

# JLEIC TO PEP-II COMPARISON

## Commonalities between the 3 rings

- **PEP-II operation experience = electron beam is unstable without feedback.**
- **The PEP-II experience is informative. We need detailed studies of the JLEIC to account for:**
  - **Longer JLEIC relative to the PEP-II low- or high-energy rings,**
  - **More and different types of RF cavities (e.g., crab cavities),**
  - **modified RF cavity tuner positions, and**
  - **different beam current, synchrotron frequency, etc.**
- **There is enough information to start.**

| | PEP-II LER | PEP-II HER | JLEIC |
|---|---|---|---|
| Energy | 3.1 GeV | 9 GeV | 3-12 GeV |
| Current | 3.2 A | 2 A | ≤ 3 A |
| Bunch Spacing | 238 MHz | 238 MHz | 476 MHz |

J.T. Seeman, EPAC’08, TUXG01, Pg. 946
F.C. Pilat, IPAC’18, TUXGBD3, Pg. 590

# PROPOSAL WORK OVERVIEW

## What are we doing?

- **A broad spectrum of coupled bunch modes will be excited, predominantly, by the HOMs of the PEP-II RF cavities and the resistive wall impedance.**

- **To do: simulate and estimate the driving terms for coupled bunch instabilities; estimate required feedback bandwidth, damping time and voltage; design transverse and longitudinal feedback kickers; and prototype transverse feedback kicker.**

- **Digital feedback systems capable of operating with 500 MHz bandwidths are commercially available from Dimtel (San Jose, CA) and Instrumentation Technologies (La Jolla, CA).**
  - **PEP-II digital feedback systems were designed to operate at bandwidths greater than where they were operated.**
  - **ALS, BESSY, KEKB, PLS, etc already operate @ 500 MHz, 2 ns.**

# OPERATING BANDWIDTH

## Bounding the task

- **# of bunches = # of modes, $m$.**
- **Each multi-bunch mode has associated frequencies:**

$$f_{MB} = l * f_{bunch} \pm (m + \nu) * f_{rev}$$

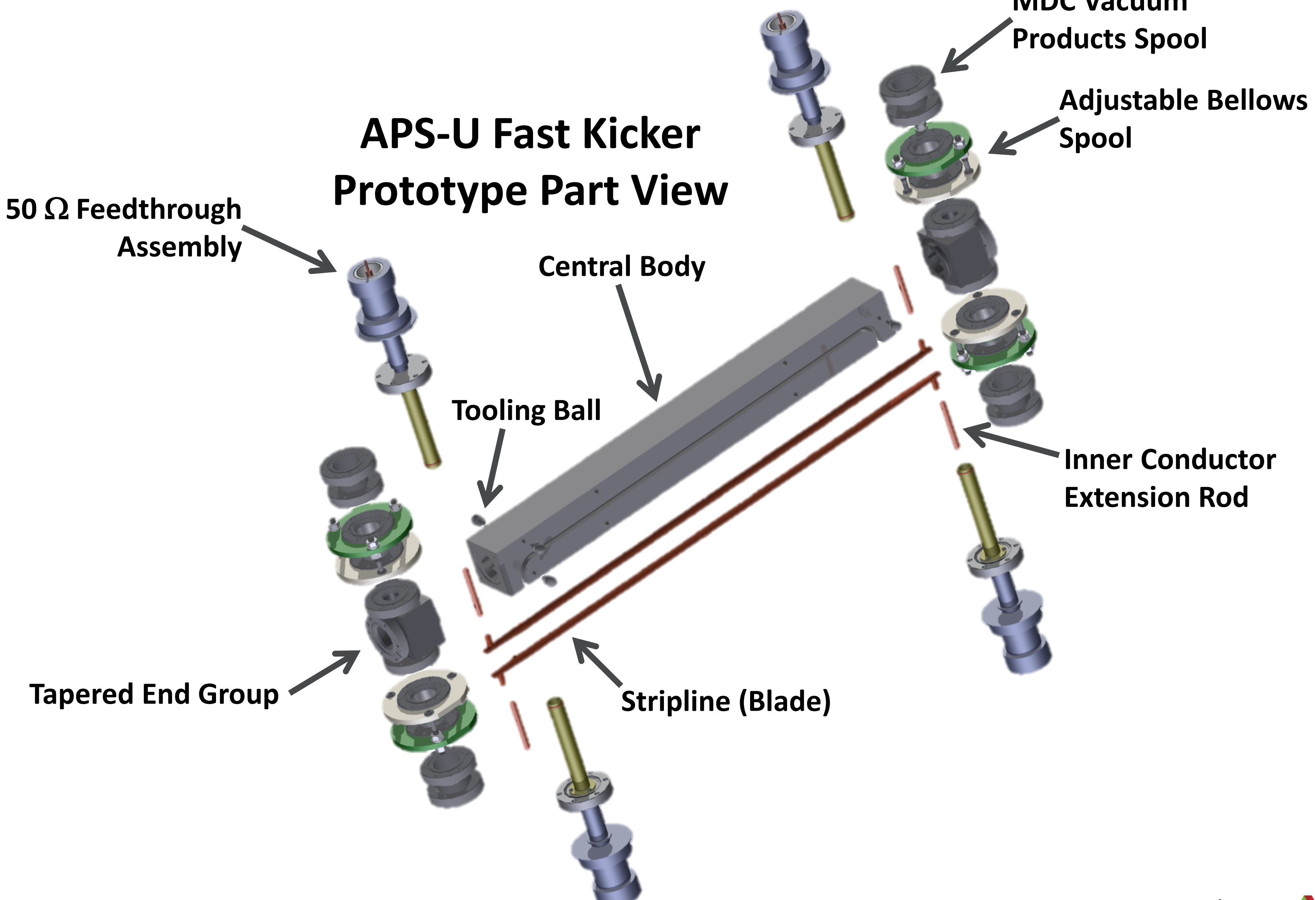
- **Feedback Frequency ($f_{RF} = 476\ MHz$):**

$$Transverse\ Feedback: \sim DC\ to\ {f_{rf}}/{2} = \sim DC - 238\ MHz$$

$$Longitudinal\ Feedback: n * f_{RF} - {f_{bunch}}/{4} = 1,547\ MHz$$

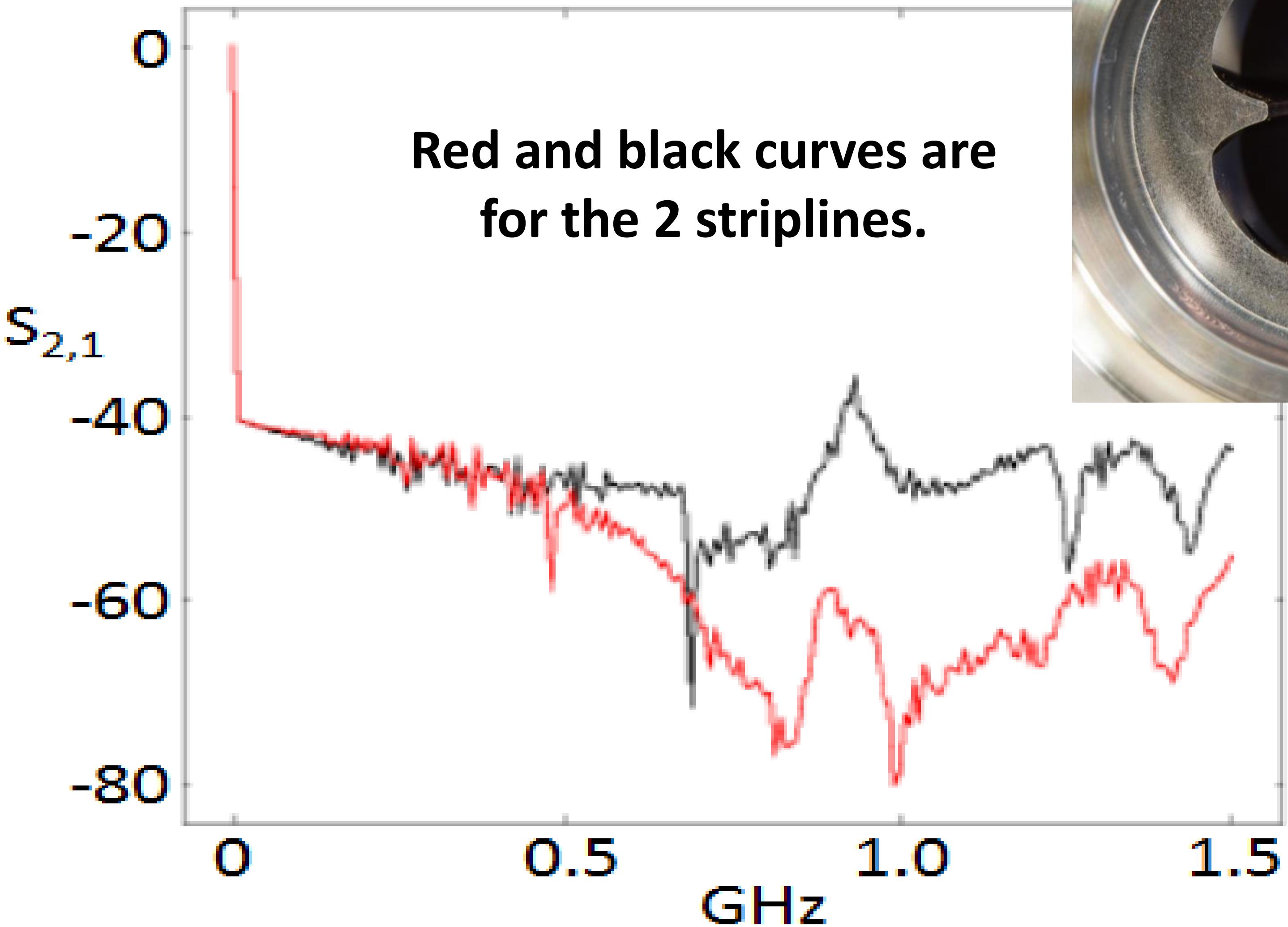
- **PEP-II:**
  - **Transverse kickers ~ 3.4 kV per kicker.**
    - **W. Barry et al, PAC'95 (based on ALS design) .**
  - **Longitudinal kickers**
    - **P. McIntosh et al, PAC'03, 1.071 GHz with BW = 238 MHz (based on DAFNE design)**

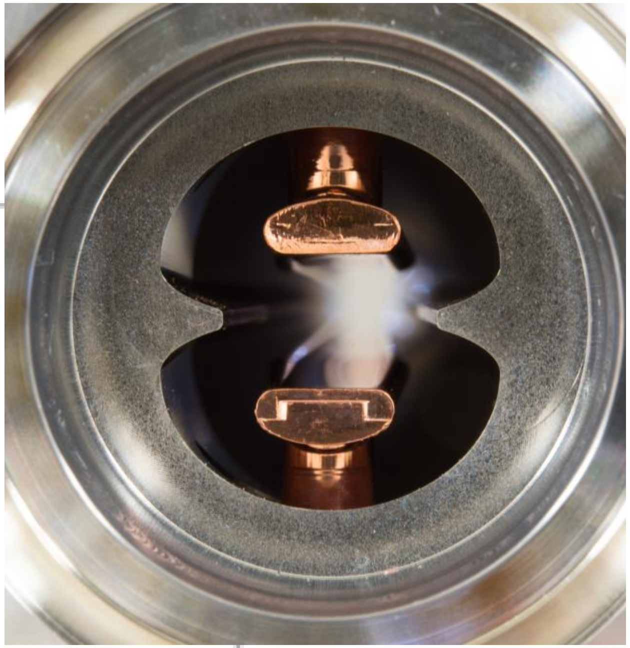
# TRANSVERSE KICKER GEOMETRY



# TRANSVERSE KICKER TRANSMISSION PROPERTIES

## Measured with network analyzer.

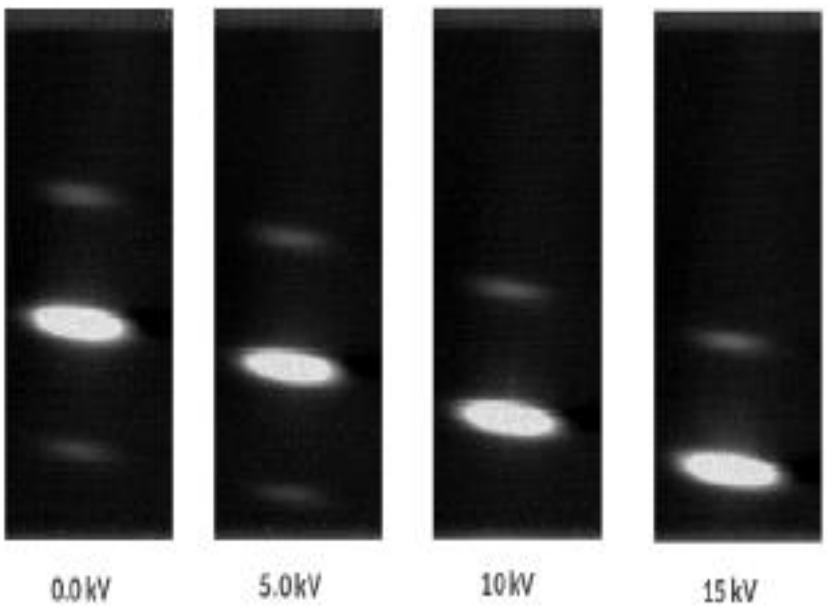


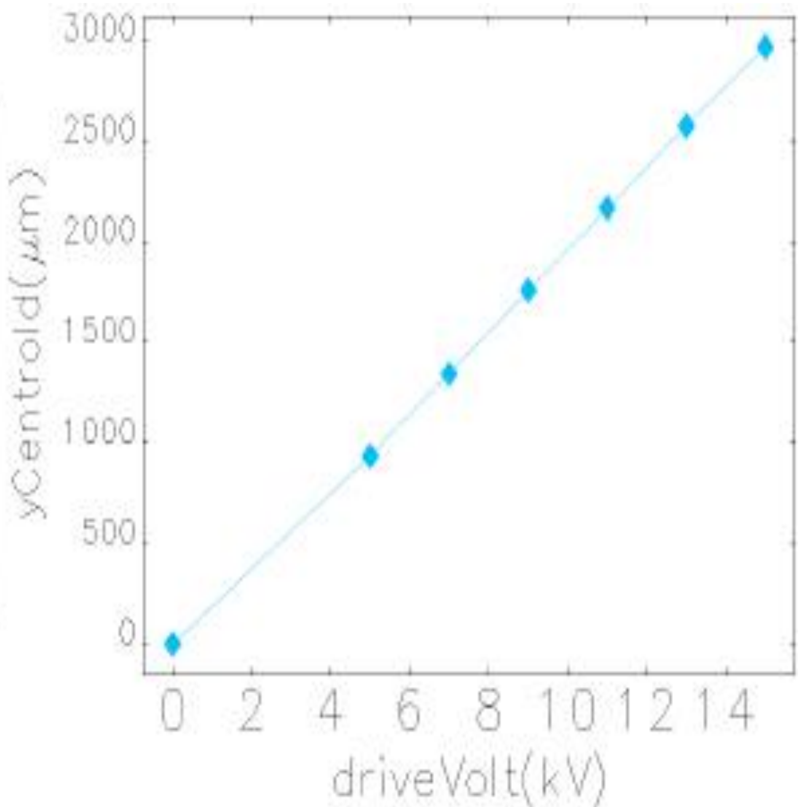



# TRANSVERSE KICKER TESTED WITH BEAM

## APS Injector Test Beam Line.

**Striplines, 720 mm**




**C.Y. Yao et al.,** **NA-PAC2016, WEPOB24, Pg. 950.**

# TRANSVERSE KICKER TO DO

## Future Work.

- **APS-U kicker to operate with a 6 GeV, 200 mA, electron beam.**
- **Not the LJLEIC electron storage ring beam. Work to do.**
- **Optimize length.**
- **Evaluate HOM interactions up to 6 GHz.**
  - **Kicker strip-lines strongly coupled to the RF transmission lines.**
  - **Expect good HOM damping and power removal.**
- **Evaluate kicker thermal properties.**
- **Add vacuum pumping and diagnostics.**

**Feedthroughs**

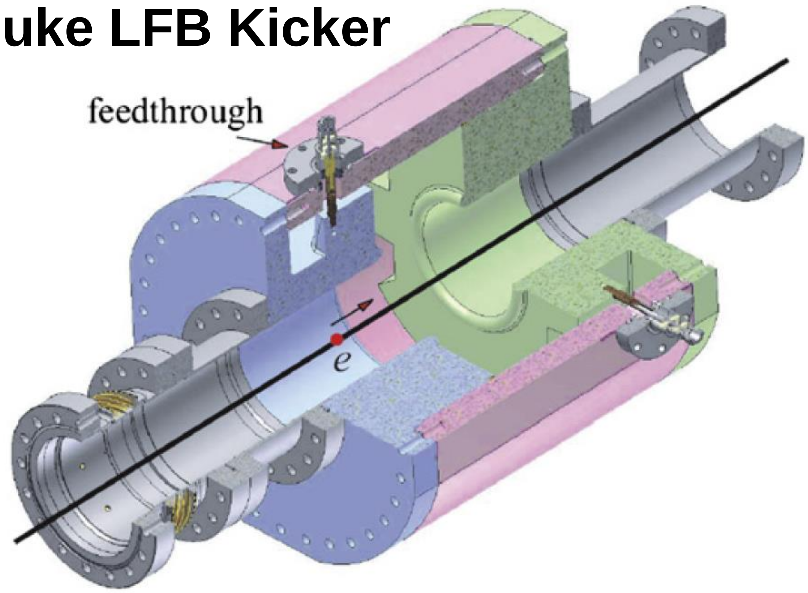
# LFB KICKER CONCEPT

## Background

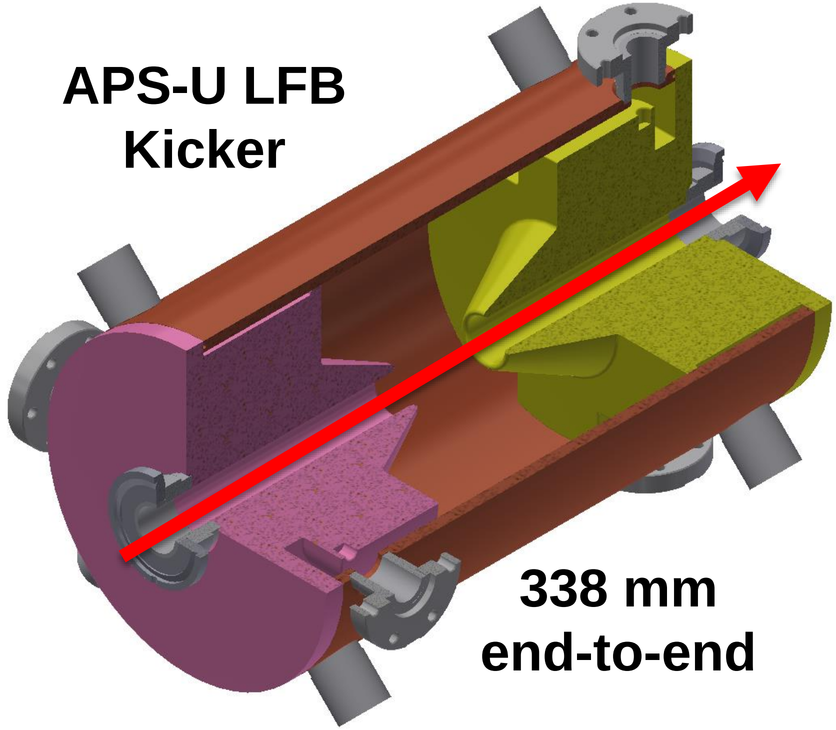
- **Chose a waveguide over-damped resonator for the APS-U longitudinal feedback (LFB) kicker:**
  - **Used at ALS, BESSY-II, DIAMOND, Duke, DAΦNE, HIGS, HLS-II, KEK-B, PEP-II, etc,**
  - **High shunt impedance,**
  - **Low HOM shunt impedances,**
  - **High power handling, and**
  - **Straightforward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

**Duke LFB Kicker**




**APS-U LFB Kicker**



**338 mm end-to-end**

# ELECTROMAGNETIC DESIGN

## APS-U LFB Performance Parameters

| Parameter | Value |
|---|---|
| Frequency, $f_0$ | 1.027 GHz ± 18 MHz |
| Bandwidth | 59 MHz (+0/-5) MHz |
| Beam Pipe Radius | 11 mm |
| Total $Q_{ext}$ | 17.5 (17.4 with $f_0$ = 1.027 GHz) |
| $Q_{ext}$ per port | 70.0 (69.6 with $f_0$ = 1.027 GHz) |
| $Q_0$ | 1.31x10$^4$ (OFHC Copper) |
| $R_{shunt,a}/Q$ | 320 |
| Required Voltage per LFB Kicker | 2,000 V |
| Voltage with 2 500 W Amplifiers | 4,710 V |

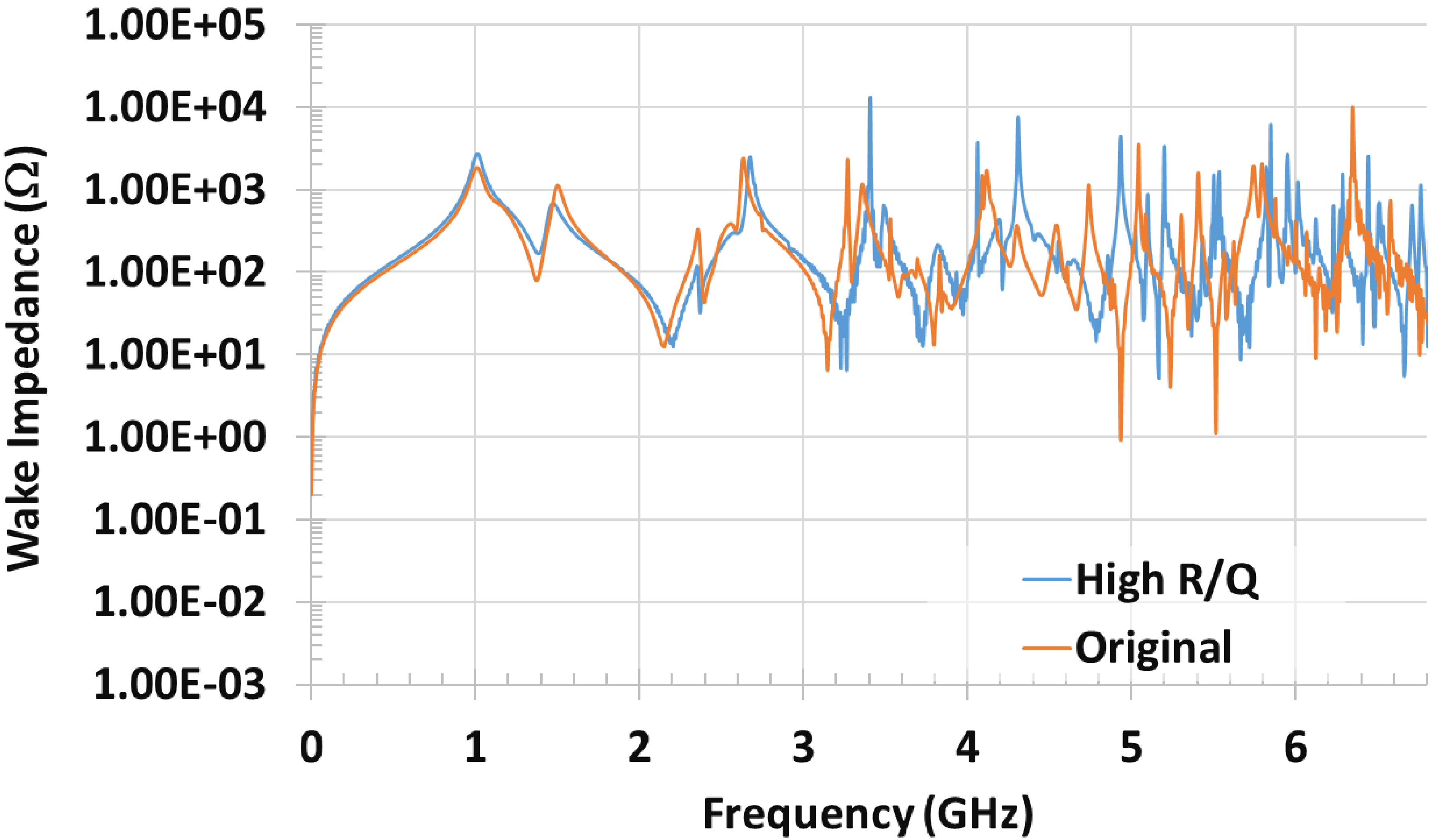
$$\frac{R_{shunt,a}}{Q} = \frac{{V_a}^2}{\omega_0 U_0}$$

$$Voltage = V_a = \sqrt{R_{Shunt} * Power}$$

$$P = \frac{4P_{for} / (Q_{ext,1} Q_{ext,2})}{\left(\frac{1}{Q_0} + \frac{1}{Q_{ext,1}} + \frac{1}{Q_{ext,2}}\right)^2 + \left(\frac{f}{f_0} - \frac{f_0}{f}\right)^2}$$

# LONGITUDINAL WAKE FIELD IMPEDANCE

## Monopole Modes Only



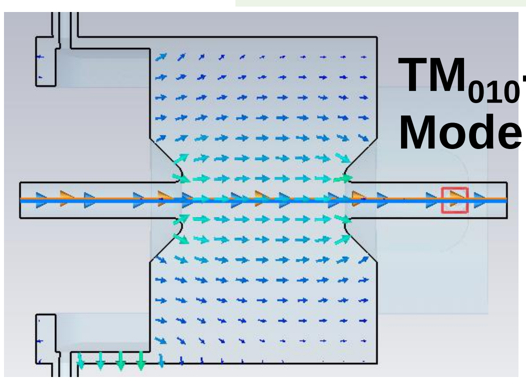
# LFB KICKER EIGENMODE SHUNT IMPEDANCES

## Eigenmodes from 1.027 through 1.8 GHz
## Before the Reentrant Nose Optimization

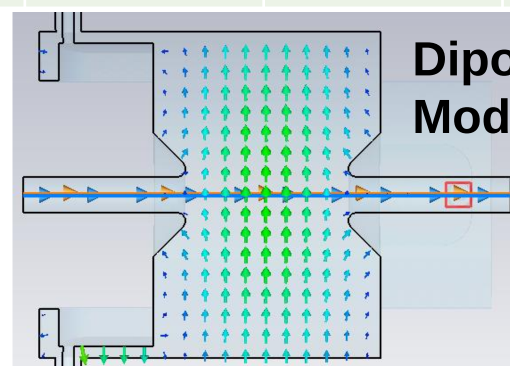
$$\frac{R_{sh,a}}{Q} = \frac{V_a^2}{\omega * U}$$

$$\left(\frac{R_{sh,\perp}}{Q}\right)_{\perp} = \frac{V_\perp^2}{\omega * U}$$

| Frequency (GHz) | $R_{\perp,z}/Q$ (Ω) | $R_{\perp,x}/Q$ (Ω) | $R_{\perp,y}/Q$ (Ω) | $Q_{loaded}$ |
|---|---|---|---|---|
| 1.027 | 251.8 | 0.0 | 0.0 | 17.4 |
| 1.079 | 0 | 1.9 | 1.9 | 4.5 |
| 1.0897 | 0 | 6.0 | 6.0 | 4.3 |
| 1.0898 | 5.1 | 1.9 | 1.9 | 4.3 |
| 1.191 | 75.5 | 0 | 0.0 | 5.85 |
| 1.430 | 0 | 52.7 | 119.9 | 64.3 |
| 1.430 | 0 | 119.9 | 52.7 | 64.3 |
| 1.484 | 72.5 | 0 | 0 | 28.1 |
| 1.786 | 0.3 | 0 | 0 | 94.6 |
| 1.796 | 0 | 27.4 | 0.1 | 119.8 |



$TM_{010}$-like Mode

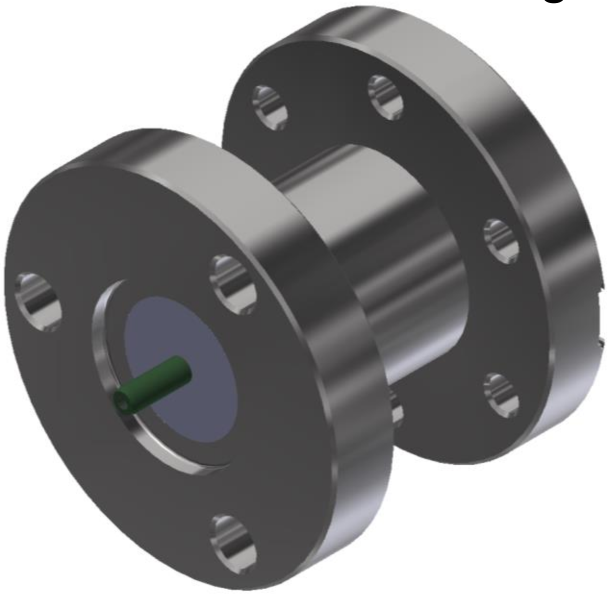


Dipole Mode

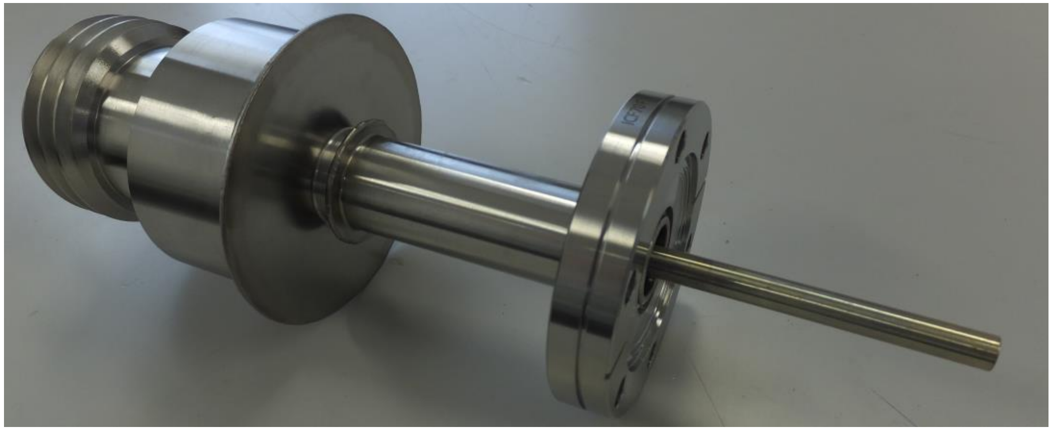
# LFB KICKER 50 Ω FEEDTHROUGHS

## 1.033 GHz High Power Feedthroughs

**SLAC PEP-II Feedthrough**



**Kyocera/Cosmotec Custom Feedthrough**



- **Top Left: SLAC PEP-II LFB Kicker Feedthrough. Used now.**
- **Top Right: Cosmotec 9 kV feedthrough tested to 30 kV with 6 ns pulses.**
- **Bottom, Right: 20 kV Kyocera feedthrough. Based on 15 kV CLIC feedthrough.**

**CLIC/Kyocera 20 kV Feedthrough**

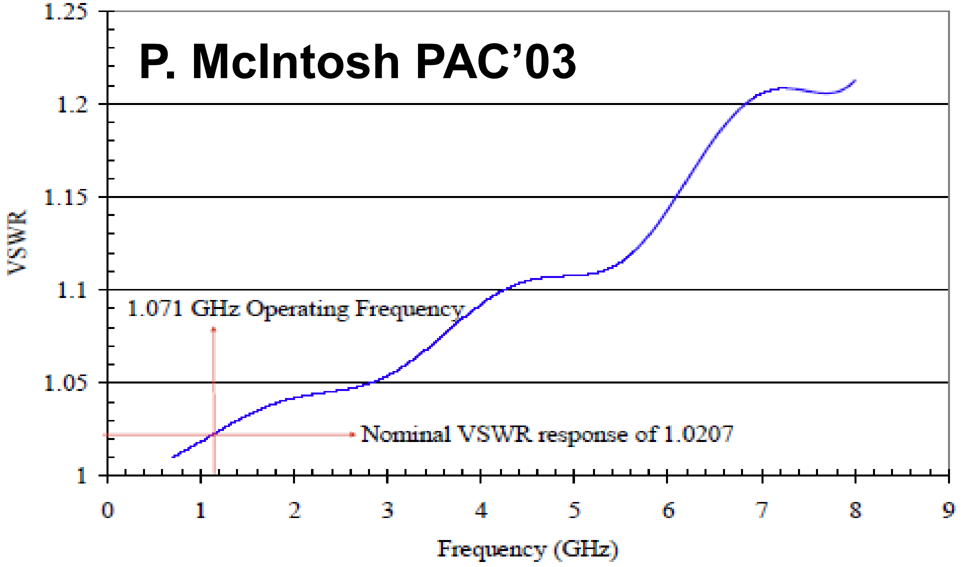
**Feedthroughs from the APS-U Injection Kickers**

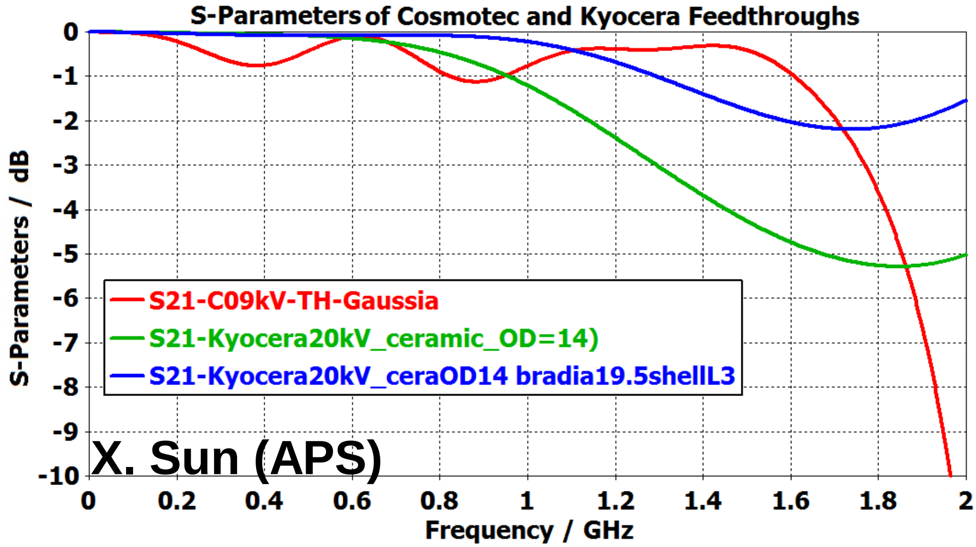
# LFB KICKER 50 Ω FEEDTHROUGHS

## Feed Through RF Response

- SLAC PEP-II LER LFB kicker feedthrough pass band characteristics look good for our application.
- Need to modify the dimensions of the feedthrough or the LFB kicker inner conductor diameter.
- Other options considered:
  - Use existing feedthrough from APSU injection/extraction kickers.
    - Questionable power handling and passband characteristics.
  - Use existing feedthrough from CLIC transverse kickers.
    - Hard to get desired passband.
  - Design new.

**SLAC LFB Kicker Feedthrough**



# CLOSING REMARKS

## Almost Done

- **Developing hardware for JLEIC transverse and longitudinal feedback kickers.**
- **Working on preliminary design concepts until JLEIC requirements are clarified.**
- **Build prototype transverse kicker and test.**